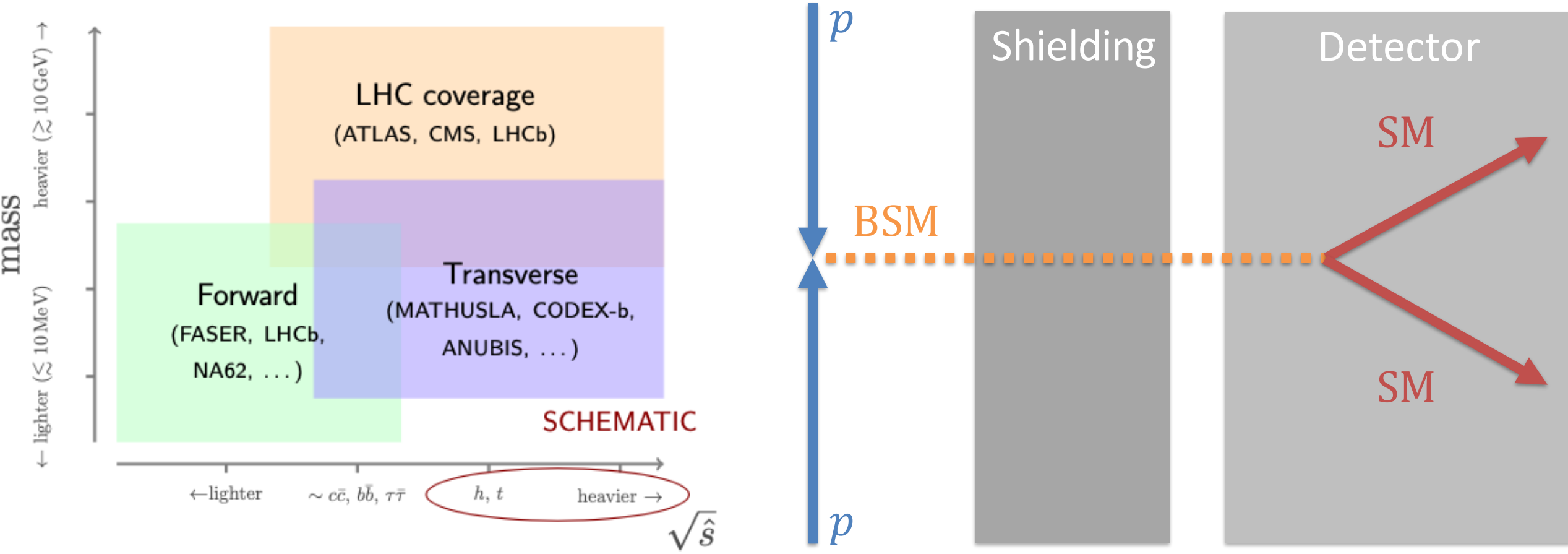


MICHAEL K. WILKINSON

University of Cincinnati

**“The importance of shielded
transverse detectors for
BSM physics with long-
lived particles”**

The need for a shielded, transverse detector for LLPs



Long-lived particles (LLPs) are ubiquitous in **Beyond Standard-Model (BSM)** physics, and dedicated **transverse detectors** are needed at the LHC to search for their couplings to, *e.g.*, **the Higgs**

$\mathcal{B}(h \rightarrow \text{invisible}) < 19\%$ (PDG)
invisible New Physics...?

ANUBIS proposal: [arXiv:1909.13022](https://arxiv.org/abs/1909.13022)
CODEX-b proposal: [arXiv:1708.09395](https://arxiv.org/abs/1708.09395)
CODEX-b expression of interest: [arXiv:1911.00481](https://arxiv.org/abs/1911.00481)
CODEX-b Snowmass whitepaper: [arXiv:2203.07316](https://arxiv.org/abs/2203.07316)

ROBERT SZAFRON

Brookhaven National Laboratory

“Precision theory for energy and intensity frontiers”

PRECISION THEORY FOR ENERGY AND INTENSITY FRONTIERS

ROBERT SZAFRON, BROOKHAVEN NATIONAL LABORATORY, RSZAFRON@BNL.GOV

☀️ *Precise Standard Model predictions are required to discover the unknown at the LHC, DUNE, mu2e, muon g-2, dark matter searches,...*

☀️ *Experiments are only as good as the theory behind them — being limited by the accuracy of the theory is a missed opportunity*

☀️ *Even “clean” signals of New Physics require precision computations to find and interpret the signal*

New Physics may be hidden in deviations from SM

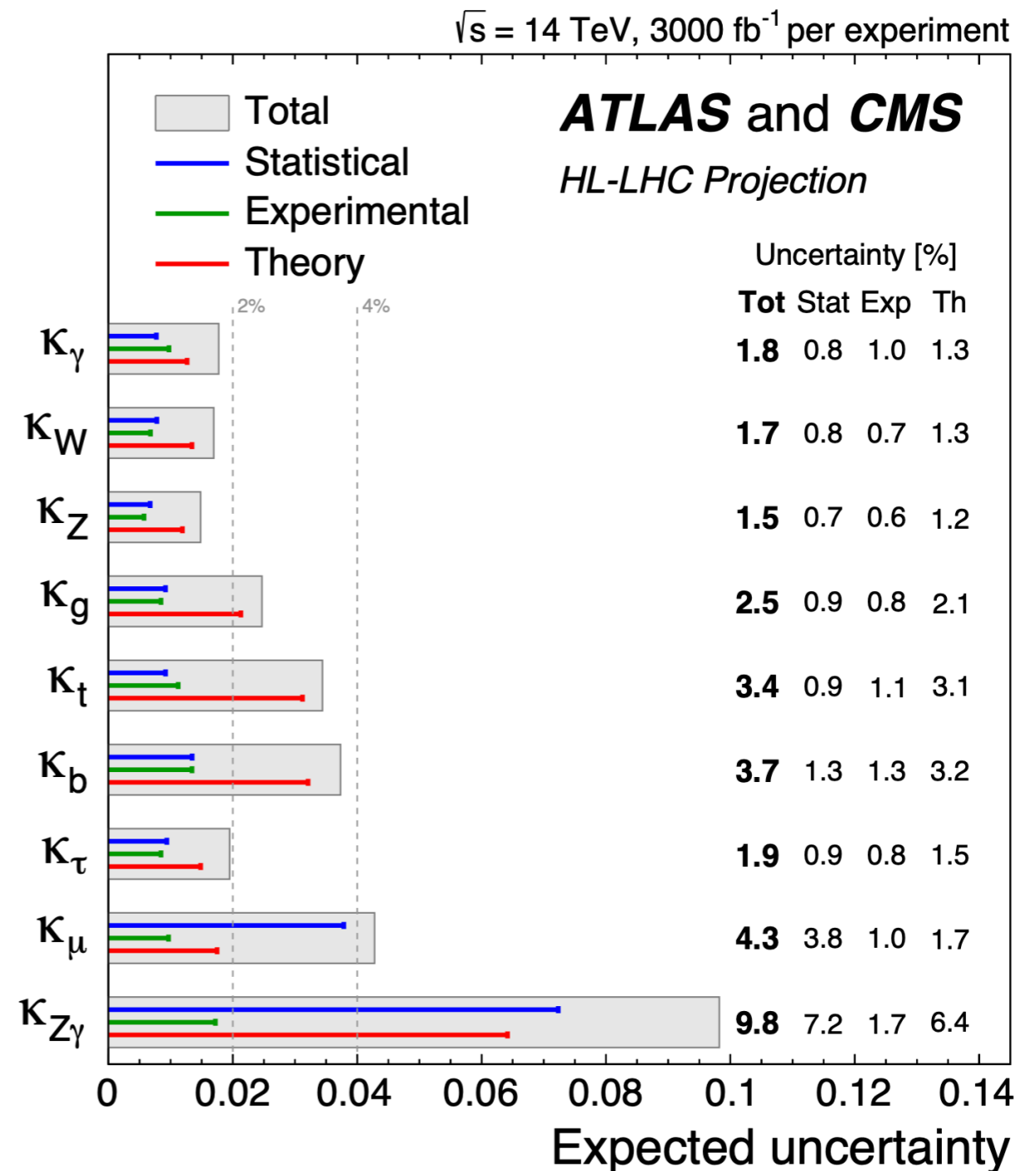


Figure from arXiv:1902.00134

PRECISION THEORY FOR ENERGY AND INTENSITY FRONTIERS

ROBERT SZAFRON, BROOKHAVEN NATIONAL LABORATORY, RSZAFRON@BNL.GOV

- ✻ *Physicists in the US performed many pioneering computations that allowed to establish the Standard Model*
- ✻ *During the LEP era US started losing leadership in the precision computations*
- ✻ *Precision collider physics is now dominated by European groups*
- ✻ *There is insufficient theory support for low energy experiments*
- ✻ *Even US based experiments at the intensity frontier receive insufficient effort from the theory community: large emphasis on novel signatures of beyond the Standard Model physics, insufficient effort to improve theory input to the accuracy of current and future experiments*

Lattice computations are notable exceptions, partially thanks to SciDAC scheme

PRECISION THEORY FOR ENERGY AND INTENSITY FRONTIERS

ROBERT SZAFRON, BROOKHAVEN NATIONAL LABORATORY, RSZAFRON@BNL.GOV

We see faculty members working on precision computations move from the US to Europe — **we need to reverse the direction of the flow**

Main reason: European funding model allows for creating larger focused research groups — these are needed to perform increasingly challenging computations

- *Encourage collaboration between institutions (Topical Collaborations like in NP)*
- *Lab theory groups should provide core support for experiments and collaborate strongly with University based PIs*
- *Increase funding for theory: PI + postdoc + student is the critical mass for typical precision computations: even more needed to compete with leading European groups*
(consolidation better than fragmentation)
- *Strengthen ties between experimental and theory communities, create theory initiatives dedicated to experiments (example: muon g-2 Theory Initiative)*

SAVANNAH SHIVELY

University of California, Irvine

**“Compact Experiments &
Early-Career Opportunities with
FASER, FPF, and FLArE (FPF)”**

Compact Experiments & Early-Career Opportunities

with FASER, FPF, and FLArE (FPF)

Smaller experiments with shorter development periods allow greater impact
and more variety of experimental physics-related activities

Jianming Bian, Savannah Shively, Wenjie Wu



University of California, Irvine

April 13, 2023, P5 Town Hall @ BNL

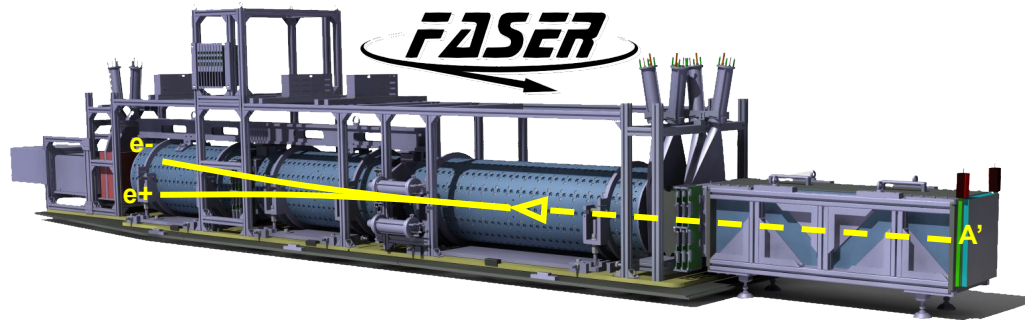
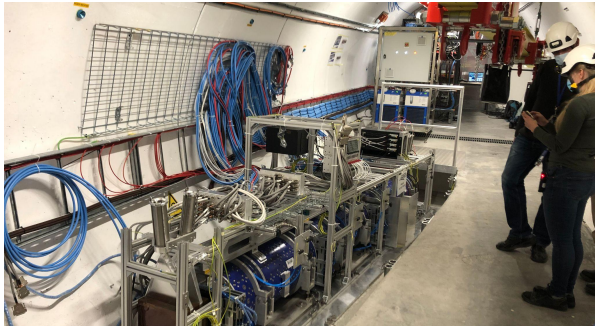


Opportunities with FASER

- ForwArd SeaRch ExpeRiment - installed and collecting data in Run 3 from collisions in ATLAS interaction point
- Driven by early-career researchers, guided by experienced PI
- **2023 Results:** Collider neutrino detection, dark photon exclusion
- FASER Timeline (2017-Present) < PhD student tenure (4-6 years)
- Many students participated in commissioning, monitoring, collecting data, and analysis.



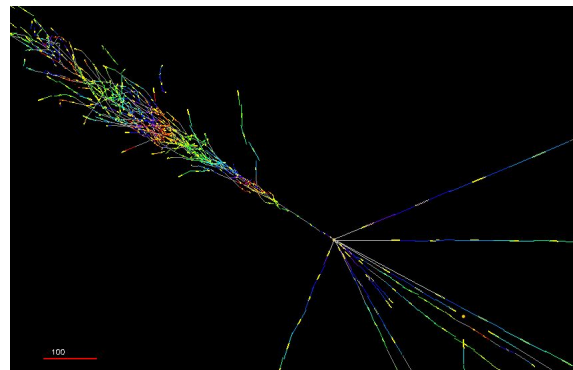
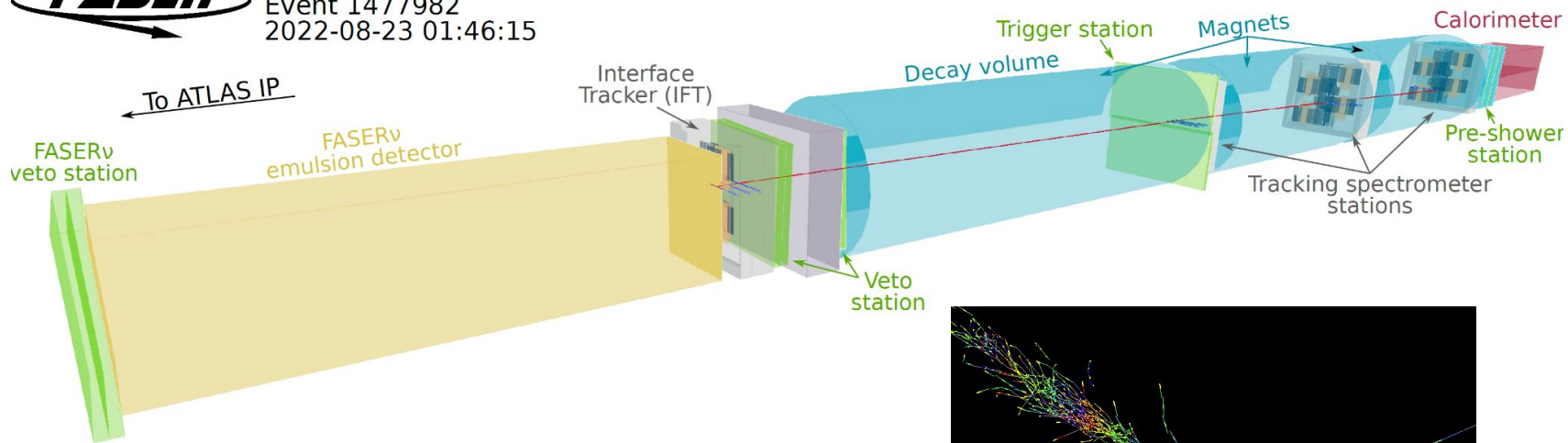
Commissioning set up (top left) and part of the test beam team, including early career members (top right). FASER installed in T112 (bottom left) and 3D model with yellow dark photon signal (bottom right)



Opportunities with FASER



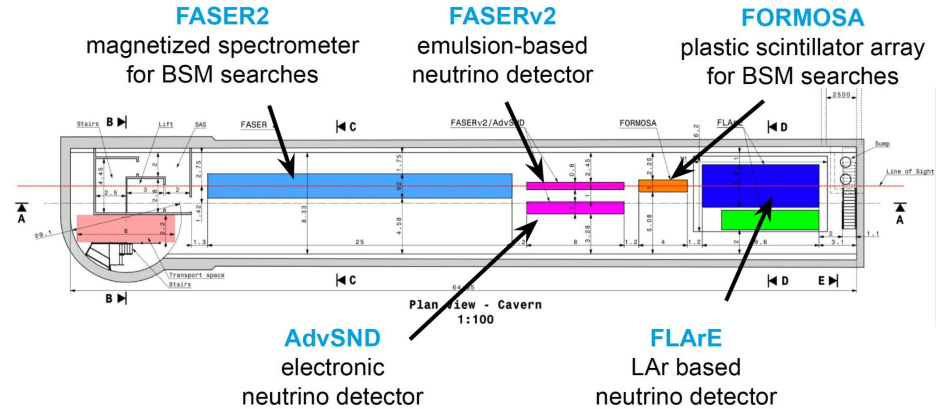
Run 8336
Event 1477982
2022-08-23 01:46:15



Opportunities with FPF



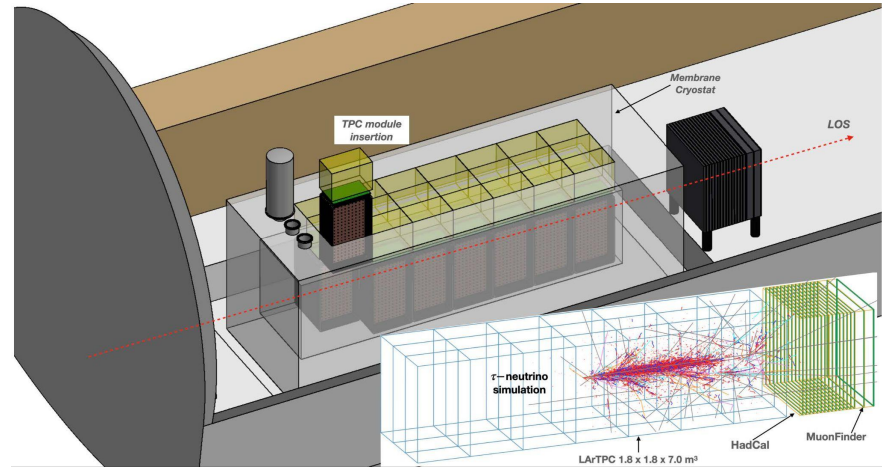
- The **F**orward **P**hysics **F**acility (FPF) is a proposed scientific facility hosts a suite of detectors in the forward region of the ATLAS interaction point
 - Guaranteed SM progress from \sim a million neutrinos at \sim TeV energies
 - Rich program of BSM physics searches
- A possible timeline (With the experience from the pathfinder experiments like FASER)
 - Build FPF during long shutdown 3 from 2026-2028
 - Install detectors in 2029
 - Start data taking soon after the beginning of of Run 4
- It provides good opportunities for junior researchers in a relative short timescale



FLArE at FPF



- Segmented liquid argon TPC
 - 10 tons fiducial mass
- Neutrino detection, light dark matter searches
- Wide dynamic range: ~ 10 MeV to hundreds of GeV
- R&D is helped by the considerable investment in the field (ICARUS, MicroBooNE, SBND, DUNE, ...)
 - High spatial and kinematic resolution
 - Effective trigger in the presence of large muon backgrounds



Promising yet also challenging
Rich physics program with “free” particle sources
Perfect platform for early career scientists

CRISTINEL DIACONU

**CPPM, Aix-Marseille Université,
CNRS/IN2P3 (FR)**

**“Data Preservation in
High Energy Physics”**

Data Preservation in High Energy Physics

Cristinel DIACONU
CPPM/CNRS/Aix-Marseille University



- What is “data”?
 - not (only) : “files”
 - but : “every digitally encoded information that was created as a result of planning, running and exploiting an experiment”
- What is “preservation”?
 - not: a freezer, a herbarium, a museum, an album, a cellar
 - but: the **process** of transforming a "high intensity/ rapidly changing " computing system into a "low intensity / slowly evolving" computing system with conserving the capacity of extracting new science from the "data".
 - Requires clear plans and a long term organization
 - Within each collaboration and at international level (DPHEP)

DPHEP Collaboration/ICFA Panel



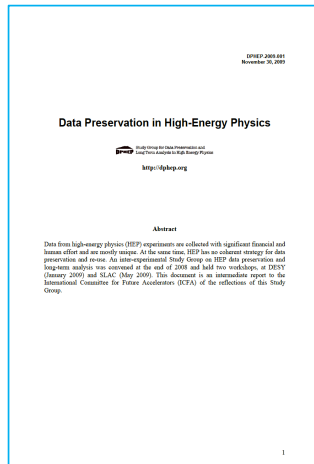
DPHEP Data Preservation in High Energy Physics
@DPHEPColl

<http://dphep.org>

2009

Lol

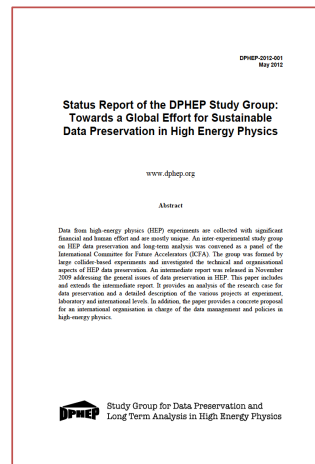
[arXiv:0912.0255](https://arxiv.org/abs/0912.0255)



2012

Blueprint

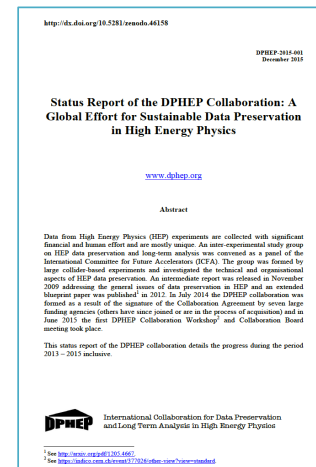
[arXiv:1205.4667](https://arxiv.org/abs/1205.4667)



2015

Collaboration MoU

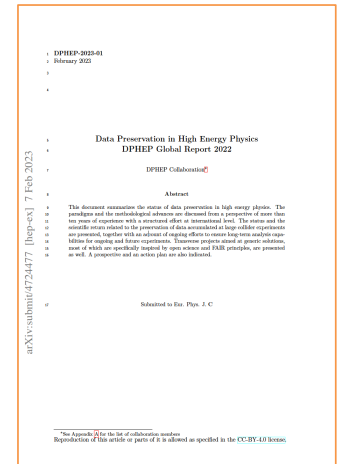
[arXiv: 1512.02019](https://arxiv.org/abs/1512.02019)



2023

Decade report

[arXiv: 2302.03583](https://arxiv.org/abs/2302.03583)

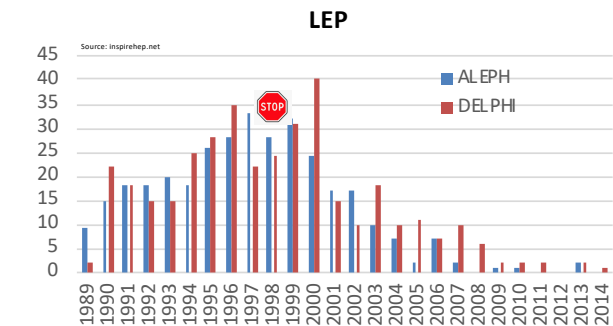
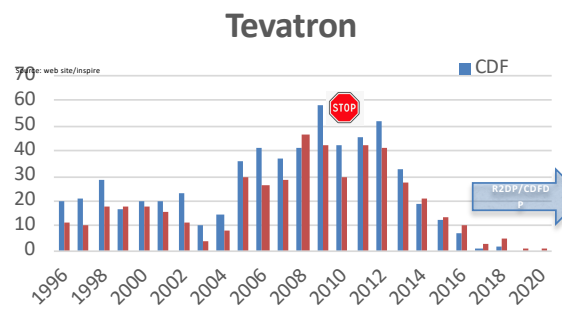
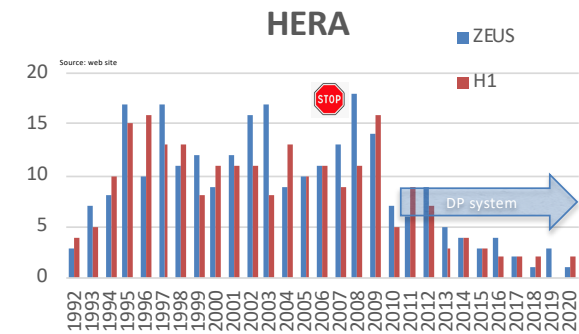
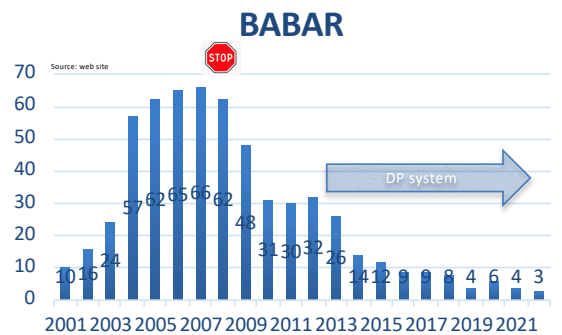


Data Preservation (DP) is a mandatory specification for any present and future experimental facility

Enhancing the scientific output

DP is a **cost-effective way of doing fundamental research** by exploiting unique data sets in the light of the increasing theoretical understanding.

- DP leads to
 - a **significant increase in the scientific output** (10% typically)
 - for a minimal investment overhead (0.1%).



	Data taking stopped	Publications before 2012	Publications after 2012	Scientific return increase %
Babar	2008	471	154	33%
H1+ZEUS	2007	436	62	14%

Preserved and Open Data

- Planning for preserved data improves the design of running and future experiments
- DP relies on and stimulates cutting-edge technology developments
- DP is strongly linked to **Open Science and FAIR** data paradigms
- Examples:
 - CERN Open Data Portal, Analysis Preservation (CAP), Reusable Analyses (ReAna), cernvm, key4hep etc.

Boosting the future experiments

Preserved data can be used to transfer knowledge, training/teaching, outreach or boosting new research programs

- **HERA → EIC**
 - “Scientists today have a **renewed interest in HERA’s particle experiments**, as they hope to use the data – and more precise computer simulations informed by tools like OmniFold – to aid in the analysis of results from future electron-proton experiments, such as at the Department of Energy’s next-generation **Electron-Ion Collider (EIC)**. “
- **Possibly**
 - LHC → FCChh
 - LEP → FCCee

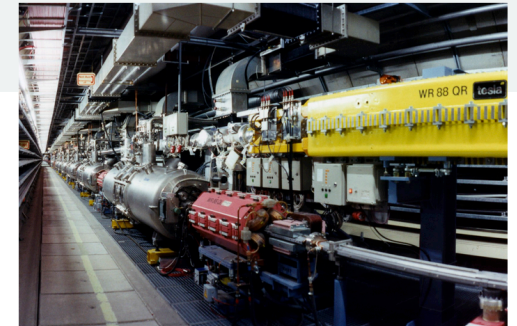
ARTICLE • MYSTERIES OF MATTER

How Do You Solve a Problem Like a Proton? You Smash It to Smithereens – Then Build It Back Together With Machine Learning

By Theresa Duque
October 25, 2022

New tool decodes proton snapshots captured by history-making particle detector in record time

CONTACT MEDIA@LBL.GOV →



Looking into the HERA tunnel: Berkeley Lab scientists have developed new machine learning algorithms to accelerate the analysis of data collected decades ago by HERA, the world’s most powerful electron-proton collider that ran at the DESY national research center in Germany from 1992 to 2007. (Credit: DESY)

<https://newscenter.lbl.gov/2022/10/25/solving-the-proton-puzzle/>

MATTHEW SZYDAGIS

The University at Albany, SUNY

“How to Accelerate Future Innovation in the Instrumentation and Computational Frontiers, and Everywhere”



How to Accelerate Future Innovation in the **Instrumentation** and **Computational** Frontiers (and Everywhere Else) *for the 21st century*

Matthew Szydagus, UAlbany SUNY

(DISCLAIMER: fully funded, LZ: Cosmic Frontier. Not complaining. Advocating for others, offering solutions)



UNIVERSITY^{AT}ALBANY
STATE UNIVERSITY OF NEW YORK

(not representing LZ, NEST, Snowball, or any other collaboration today. All opinions my own)

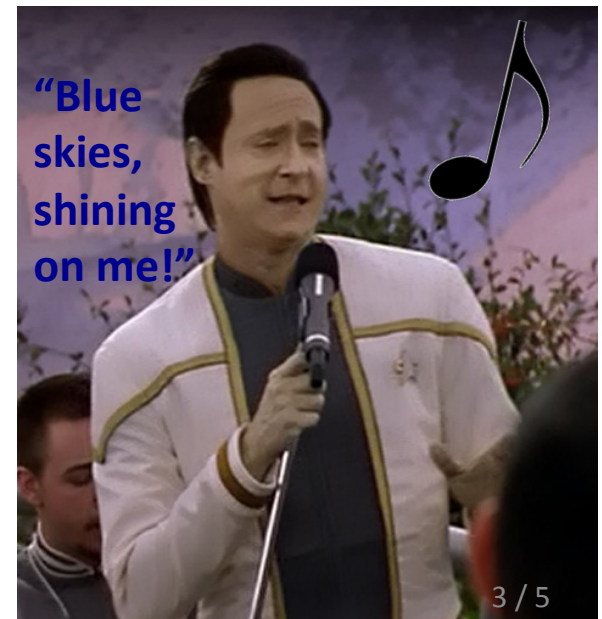
Proposal Reviews

- Double-blind review for concepts being proposed by individual PIs and/or by small consortia instead of by large collaborations (which are not always “hypothesis driven”)
 - Will help with DEI, not just in terms of non-old-white-males but also smaller institutions
 - Imperfect of course due to arXiv and Google, but it can work: <https://arxiv.org/abs/1807.01408>
- Institution of a rebuttal round (just one)
 - This is especially key when the following happens: “You never addressed X,” except that X is in bold on page 4 or in Figure 3. Only counter argument is that extra work. UK already has this
- Continuity: because panels and mail-in reviewers change every year, this can lead to repeated 180-degree changes and changes back
 - Hard to find (same) reviewers in general, too much work
 - Solution: have section “Addressing Past Reviews” (NIH does it)
- Consolation prizes for hard work: e.g. 1 student to try out

Specific to Instrumentation

Snowball chamber:
only one example

- Budget: for the DOE R&D program specifically, need clearer guidance
 - Cannot just say “there is very little \$,” as then when you only ask for a little money you get told by the reviewers “not enough for scope” Too fine a line to walk
 - De-scope -> “not interesting enough”
 - Consortia encouraged, except that costs more \$\$\$ and then you’re told too much money or too little for scope
- CPAD etc: Allow for a truly “misc” category for new ideas which don’t fit in any pre-determined box
- Allow truly interdisciplinary ideas. At least allow HEP and nuclear \$ to merge
 - Increased cooperation: DOE and NSF,...
 - Real high-risk, high OR low-return (not just for early career programs)



Final Thoughts on Proposals & Projects

- Community engagement should not be just an afterthought (discussed at length at Snowmass)
 - DOE could become better aligned with NSF in this respect
- Less multiplication of regulations and appendices, which are getting out of hand
 - Proposal is now only ~5% research narrative, the rest of it is required appendices (and budgets)
- Data management plan, new DEI mentorship plan,... => These are important. But, conserve work time
 - To make room for them, drop/reduce the other appendices
- Broader impacts suggestion seems contradictory, but that can be woven into narrative, even 1 paragraph
 - Not just in wider community: more support for tools used by scientific communities (G4, NEST)
- Be less risk averse: e.g. allow DOE projects to fail. Risk aversion also affects smaller schools

Machine Learning Example

- I put in proposals 9-10 years ago myself to do AI/ML for dark matter. Colleagues did too
- Reviewers said (more than 1, and more than once) that that was “silly” and it would “never work” (I have saved the review PDFs)
- Now, DOE has official AI/ML programs and can't get enough of it, and QIS (Note: UAlbany has new AI institute)
- There is something wrong with this picture

YU-DAI TSAI

University of California, Irvine

**“Strong and Robust Searches for
Millicharged Particles at the Energy
Frontier with LHC FPF and FORMOSA”**

FASER2

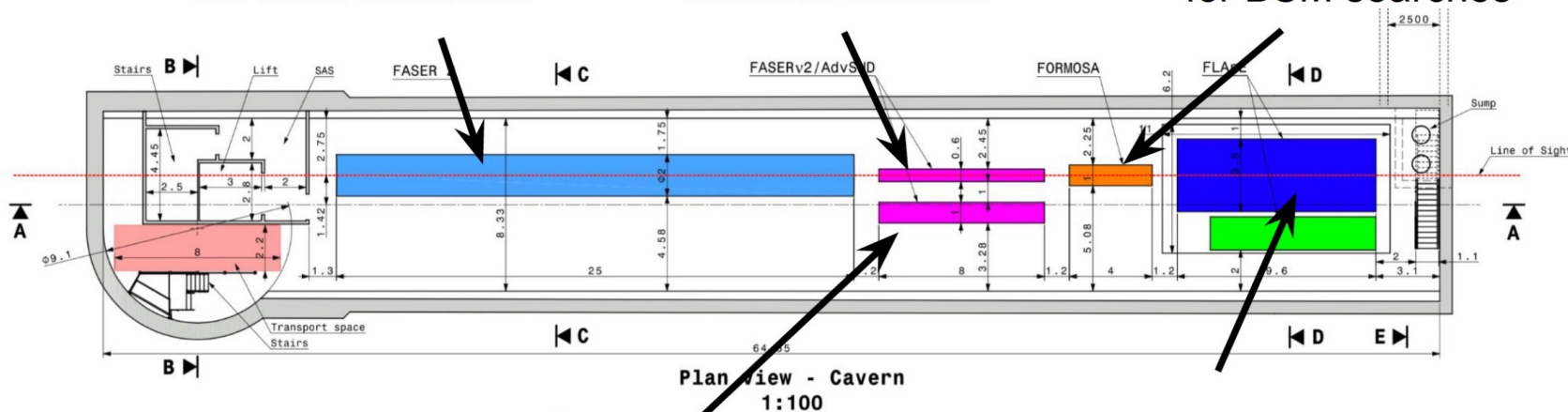
magnetized spectrometer
for BSM searches

FASERv2

emulsion-based
neutrino detector

FORMOSA

plastic scintillator array
for BSM searches



AdvSND
electronic
neutrino detector

FLArE
LAr based
neutrino detector

Strong & Robust Searches for Millicharged Particles (mCP) with LHC FPF & FORMOSA

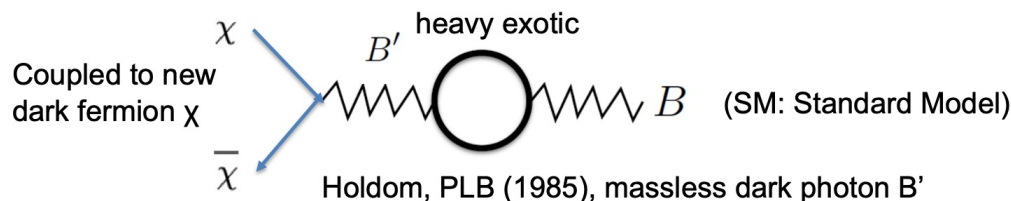
Yu-Dai Tsai, University of California, Irvine

Contact: yudait1@uci.edu or yt444@cornell.edu



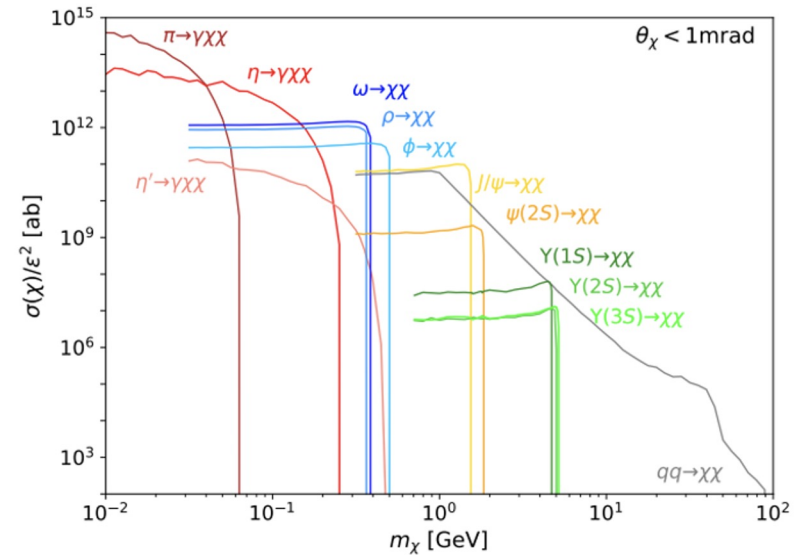
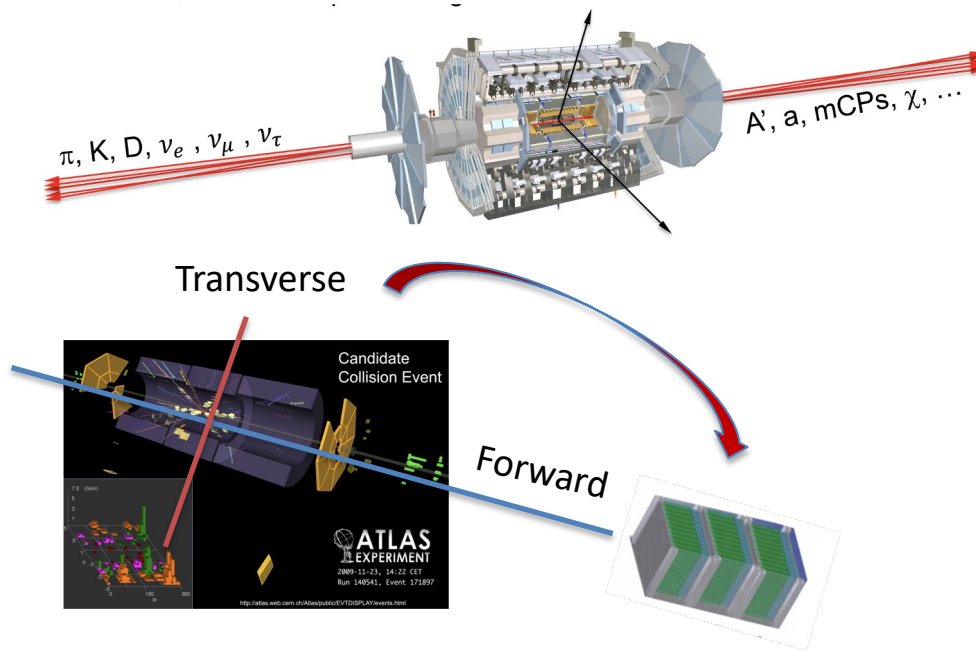
Theoretical Motivations

- **Is electric charge quantized and why?** A long-standing question!
- Motivates **Dirac quantization, Grand Unified Theories (GUTs)**
- **Fractionally charged particles (not confined)** is predicted by some **Superstring theories**: Wen, Witten, NPB (1985)
- Link to **string compactification, quantum gravity, and reheating in Cosmology**, Shiu, Soler, Ye, PRL (2013), **Gan, Shiu, Tsai, in progress**
- **Conservatively, testing if $e/3$ is the minimal charge**
- Simply a search for particles with **{mass, electric charge} = $\{m_\chi, \epsilon e\}$** , $\epsilon = Q_\chi/e$
- **Massless dark photon yields millicharged particles**



FORMOSA: A “New” Way to Study mCP

FORward MicrOcharge SeArch (FORMOSA),
 Foroughi-Abari, Kling, Tsai, *PRD* (2021), [2010.07941](https://arxiv.org/abs/2010.07941)

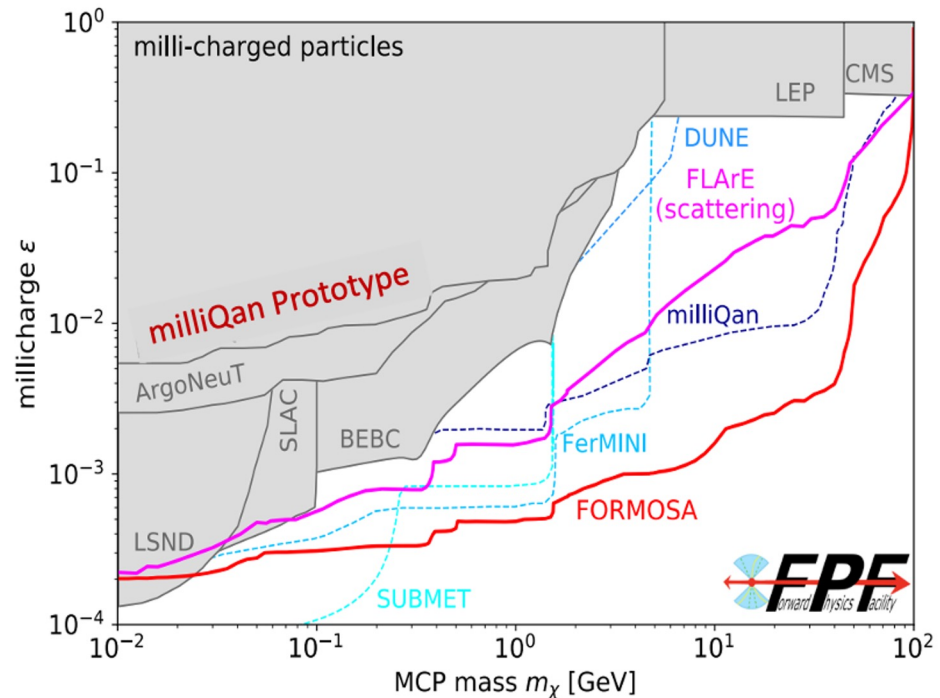


$$\mathcal{L}_{\text{MCP}} = i\bar{\chi}(\not{\partial} - i\epsilon'e\beta + M_{\text{MCP}})\chi$$

- milliQan Col., *PRD* (2021), Haas et al, *PLB* (2015)
- milliQan detector: **long scintillator bars to detector**
small ionization from mCP
- milliQan run with great success in the transverse region of CMS
- FORMOSA ([2010.07941](https://arxiv.org/abs/2010.07941))
- The flux increases by $\sim 10^3$ to 10^4 from the **transverse** to the **forward region**
- This increases the sensitivity of $\epsilon = Q_x/e$ by roughly 1 order of magnitude.

Projection and Timelines

- **milliQan prototype** ran successfully and has set new limits
- **Full milliQan operating now ('22 - '26)**
- **FORMOSA prototype installation (end of 2023)**
- New scintillator study & R&D ongoing;
- Collaborating with **Matthew Citron (UC Davis)** to design and install prototype to reach even better sensitivity
- **FPF/Full FORMOSA construction (~ 2032)**



Foroughi-Abari, Kling, Tsai, 2010.07941

Solid/colored: FPF experiments

Dotted/dashed: other near-future experiments

Thank you!

Yu-Dai Tsai, UC Irvine, 2023

Contact: yudait1@uci.edu or yt444@cornell.edu

Millicharged Particles (mCP) is an important benchmark model

Snowmass RF06 Classification; PBC Benchmark

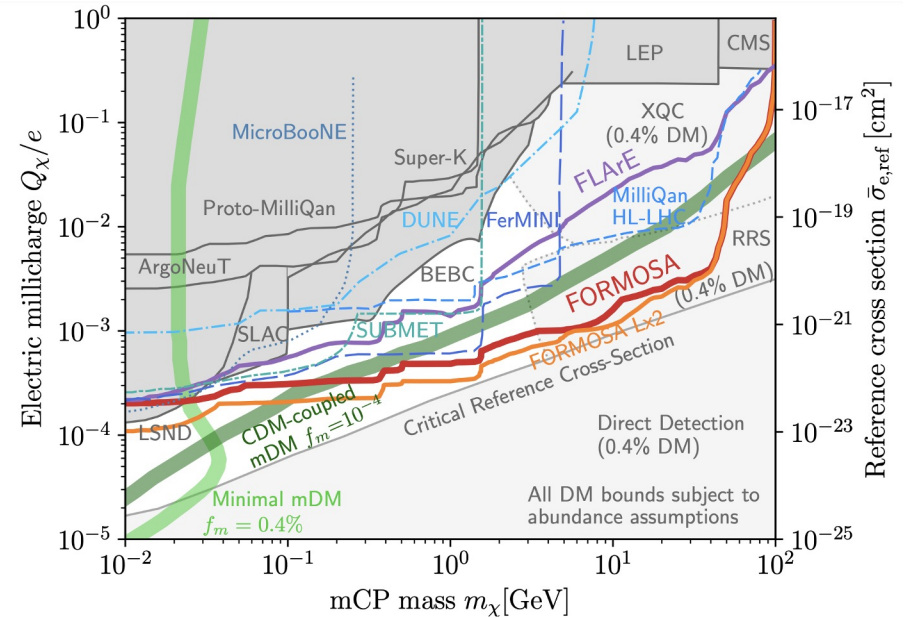
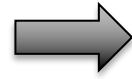
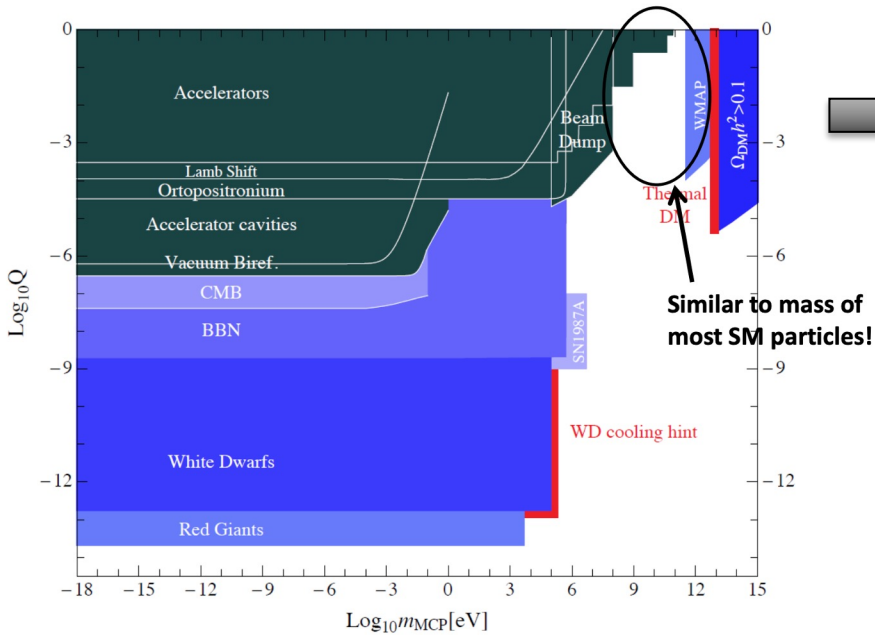
Benchmarks in Final State x Portal Organization

	DM Production	Mediator Decay Via Portal	Structure of Dark Sector
Vector	m_χ vs. y [$m_A/m_\chi=3, \alpha_D=.5$] $m_{A'}$ vs. y [$\alpha_D=0.5, 3 m_\chi$ values] m_χ vs. α_D [$m_A/m_\chi=3, y=y_{iso}$] m_γ vs. m_A [$\alpha_D=0.5, y=y_{iso}$] <i>Millicharge m vs. q</i>	$m_{A'}$ vs. ϵ [<u>decay-mode agnostic</u>] $m_{A'}$ vs. ϵ [<i>decays</i>]	iDM m_χ vs. y [$m_A/m_\chi=3, \alpha_D=.5$] (anom connection) SIMP-motivated cascades [slices TBD] $U(1)_{B-L/\mu-\tau/B-3\tau}$ (DM or SM decays)
Scalar	m_χ vs. $\sin\theta$ [$\lambda=0$, fix $m_s/m_\chi, g_D$] (thermal target excluded 1512.04119, should still include) Note secluded DM relevance of $S \rightarrow SM$ of mediator searches	m_S vs. $\sin\theta$ [$\lambda=0$] m_S vs. $\sin\theta$ [$\lambda=s.t. Br(H \rightarrow ss) \sim 10^{-2}$]	Dark Higgsstrahlung (w/vector) scalar SIMP models Leptophilic/leptophobic dark Higgs
Neutrino	$e/\mu/\tau$ a la 1709.07001	m_N vs. U_c m_N vs. U_μ m_N vs. U_τ Think more about reasonable flavor structures	Sterile neutrinos with new forces
ALP	m_χ vs. f_q/l [$\lambda=0$, fix $m_s/m_\chi, g_D$] (thermal target excluded) What about f_γ, f_G ?	m_a vs. f_γ m_a vs. f_G m_a vs. $f = f_1$ m_a vs. f_w^q	FV axion couplings

Bold = BRN benchmark, italic=PBC benchmark. others are new suggestions. Underline=CV benchmarks that were not used in BRN

PBC: The Physics Beyond Colliders initiative at CERN

Tremendous Progress in Millicharge Studies: Both mCP and Millicharge Dark Matter



Andy Haas, Fermilab, 2017

- Both **experimental & theoretical** advances
- Led by **milliQan**, followed by neutrino experiments, **FerMINI**, **SUBMET**, **FORMOSA**, **FLArE**, etc

Yu-Dai Tsai, UC Irvine, 2023

Contact: yudait1@uci.edu or yt444@cornell.edu

WILLIAM MCCORMACK

Massachusetts Institute of Technology

**“DarkQuest: A dark sector upgrade to
SpinQuest at the 120 GeV
Fermilab Main Injector”**

DarkQuest: A dark sector upgrade to SpinQuest at the 120 GeV Fermilab Main Injector



Patrick McCormack (MIT)
For the DarkQuest Working Group
BNL P5 Town Hall meeting
April 13, 2023



DarkQuest: Motivating a dark photon

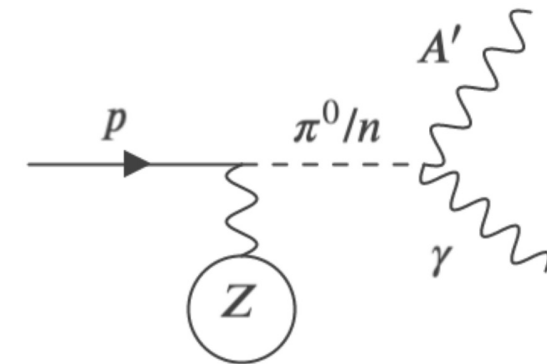
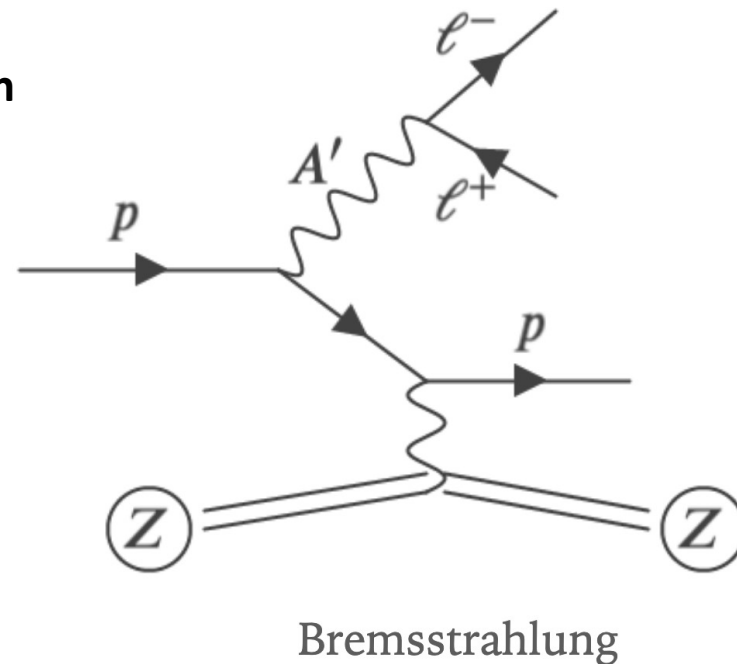
Theory papers inspiring this idea:

Dark forces at SQ: [[1509.00050](#)]

Dark Sectors at SQ: [[1804.00661](#)]

- As [highlighted yesterday](#), a **dark sector** can give us thermal dark matter with mass below the Lee-Weinberg bound

A minimal **dark photon production** scenario:



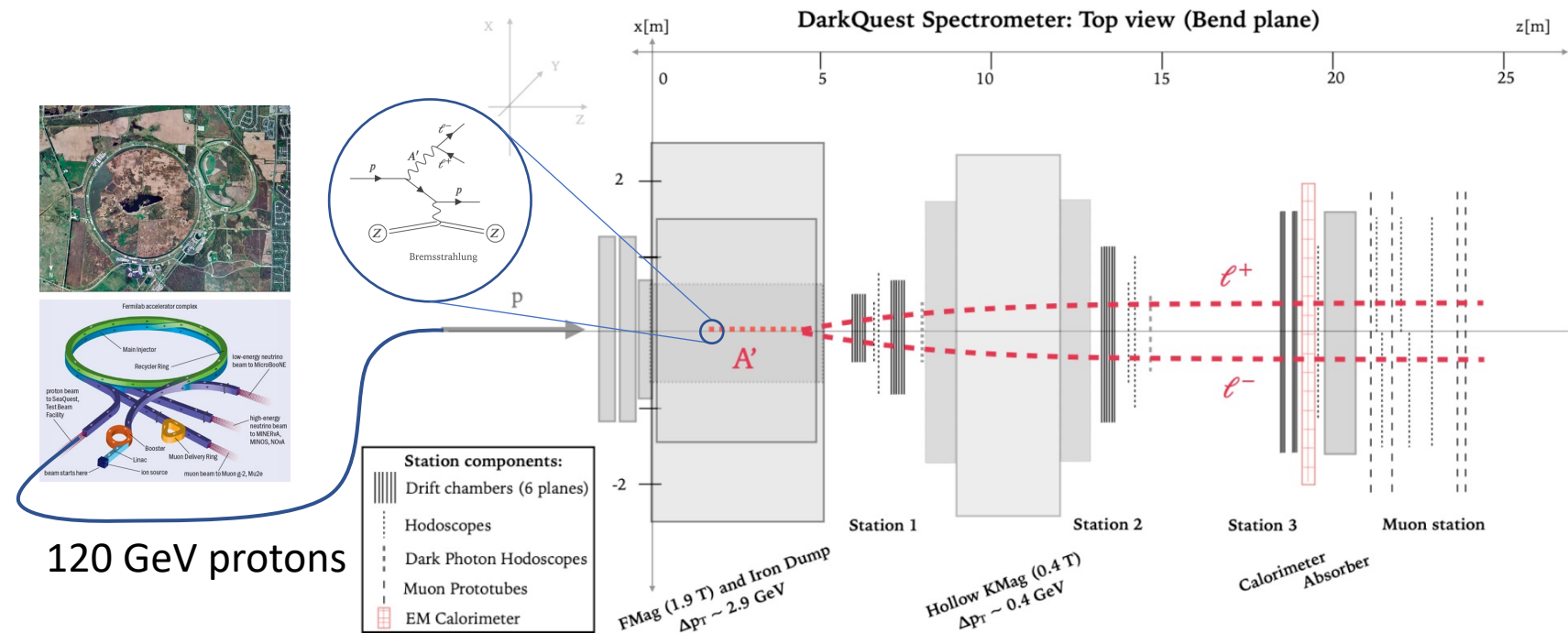
Meson production

Another production mechanism:
Meson decay

DarkQuest: An A' production facility

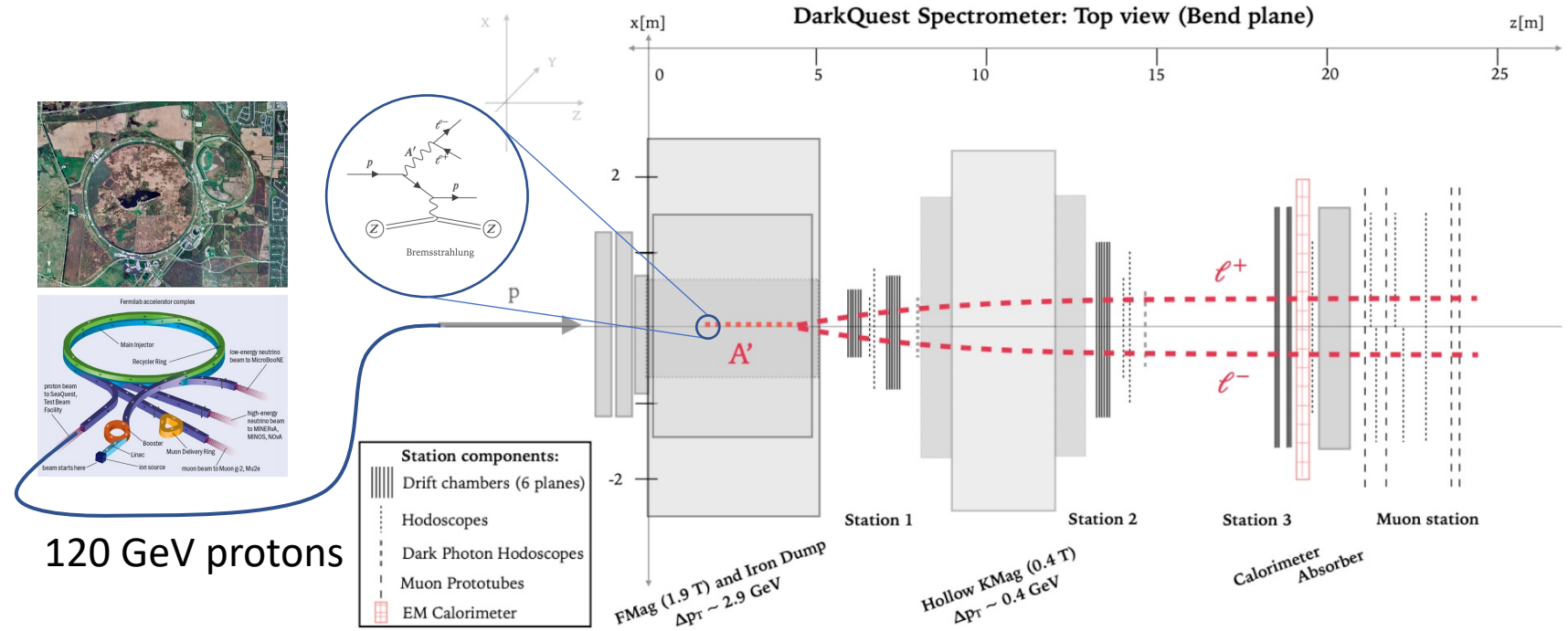
We can work *with* SpinQuest

- For this minimal scenario, **we need:**
 - High energy **proton beam**
 - Dense target/**shielding** that's several meters thick
 - Lepton **spectrometer**



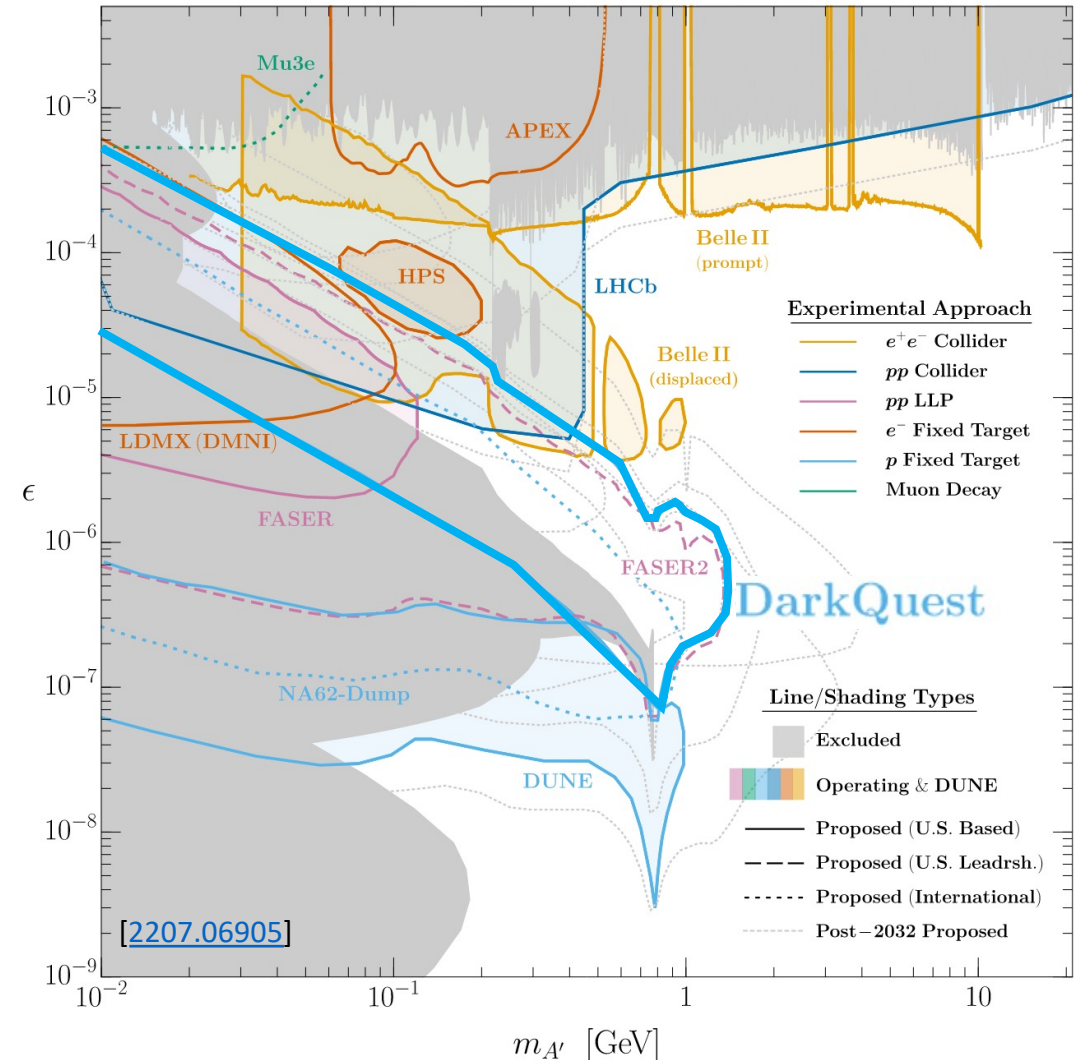
DarkQuest: A unique opportunity

- DarkQuest (DQ) Unique Features:
 - **Highest intensity** proton beam **in US** (with energy > 10 GeV)– we can reach $m_{A'} \sim \mathcal{O}(10)$ GeV
 - Uniquely **short baseline** with good shielding – can probe lifetimes $\mathcal{O}(1 - 1)$ m
 - Could reach **10^{18} POT by 2026**
 - Maintains SpinQuest's complimentary nuclear physics program



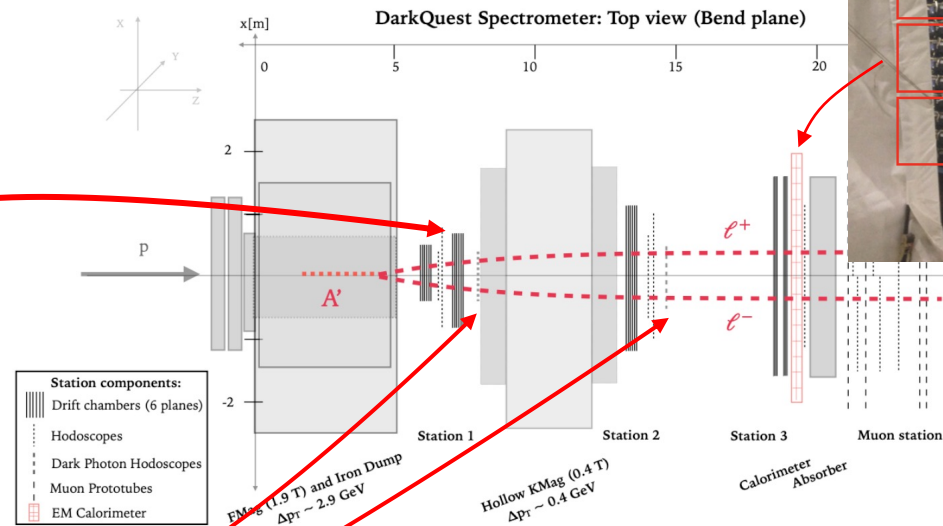
DarkQuest: Breadth for less

- See [Stefania's talk](#) from yesterday for more detail on physics goals of DQ and expected limits. We expect sensitivity to
 - **Dark photon visible portal benchmarks**
 - **SIMP benchmarks**
 - Muon-philic **scalars that modify g-2**
 - Different portals: scalar, vector, axion-like (by using different flavor pairs)
 - Electrons, muons, charged pions, photons, etc.



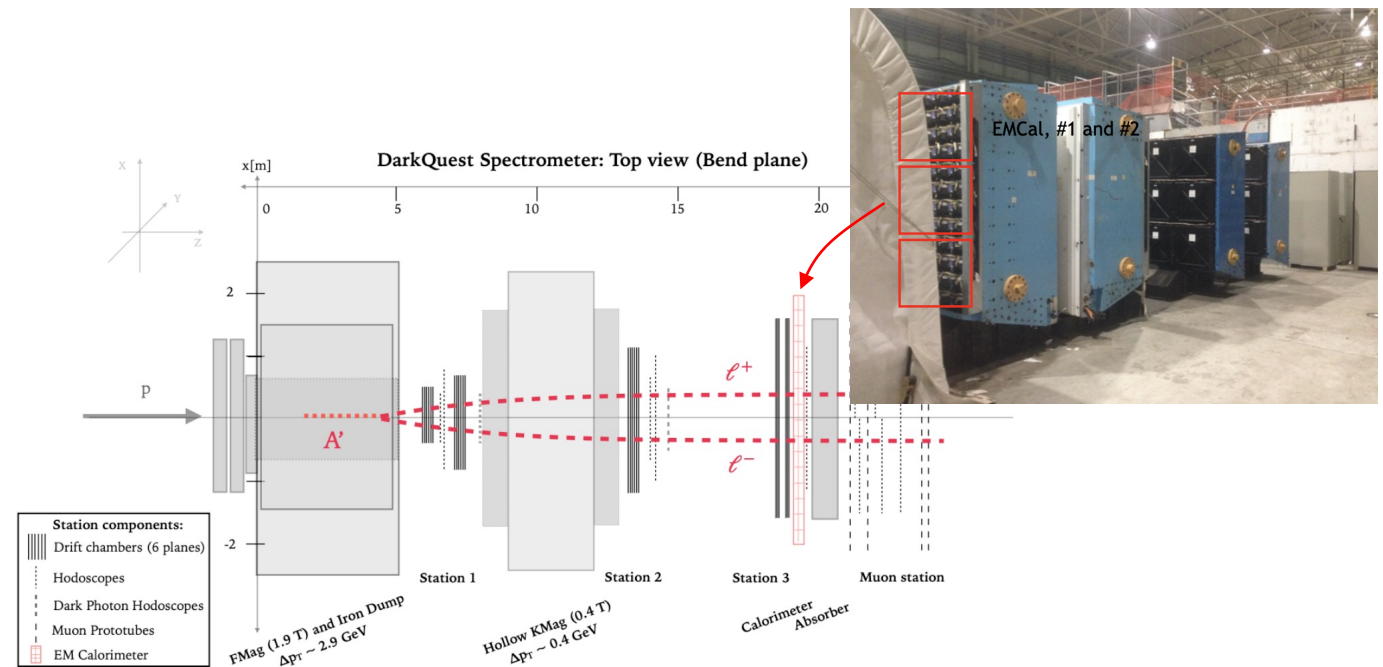
DarkQuest: The hardware

- Goals for DQ:
 - Add **decommissioned PHENIX EMCAL** to **enable sensitivity to electrons** (+other visible signatures)
 - Add prop. chambers from finished experiment (HyperCP) to **increase detection baseline**
 - Use hodoscopes for **dark-sector-specific triggers**



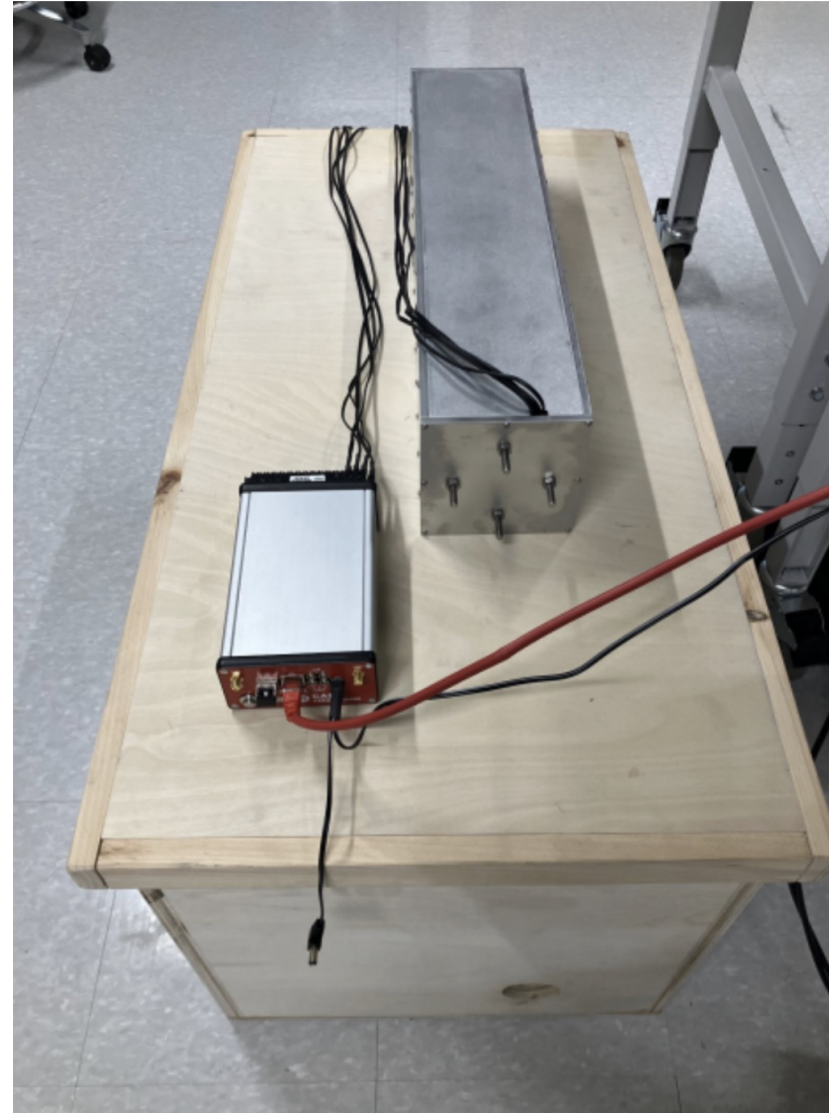
DarkQuest: Experimental Status

- **Core idea** of DQ: work with **existing experiment and detector components** to achieve **affordable experiment**. Have access to **new** dark sector parameter space **quickly** (~few year timescale)
 - E.g. should have a batch of new di-muon data later this year
 - Aiming to add EMCal soon
- This is a **US-based experiment!**
- Experimental to-do list:
 - Develop **EMCal readout and triggering** scheme
 - Create **reconstruction algorithms** for highly displaced vertices and for particle flavor tagging



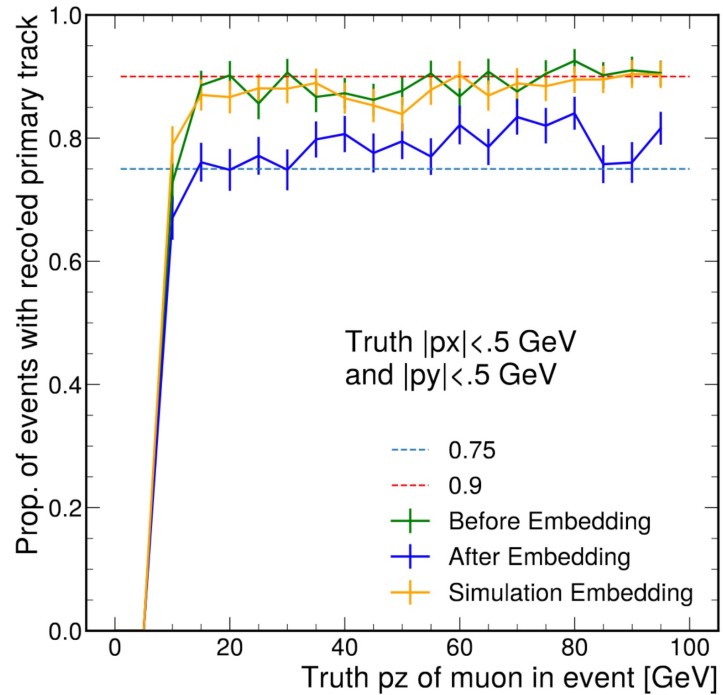
DarkQuest: Adding an EMCal

- We currently have a few calorimeter cells (lead tungstate+iron sampling calorimeter)
 - EMCal **test stand has been assembled** to test readout electronics
- Target: **install test stand** in experiment hall this year for testing and to measure background rates

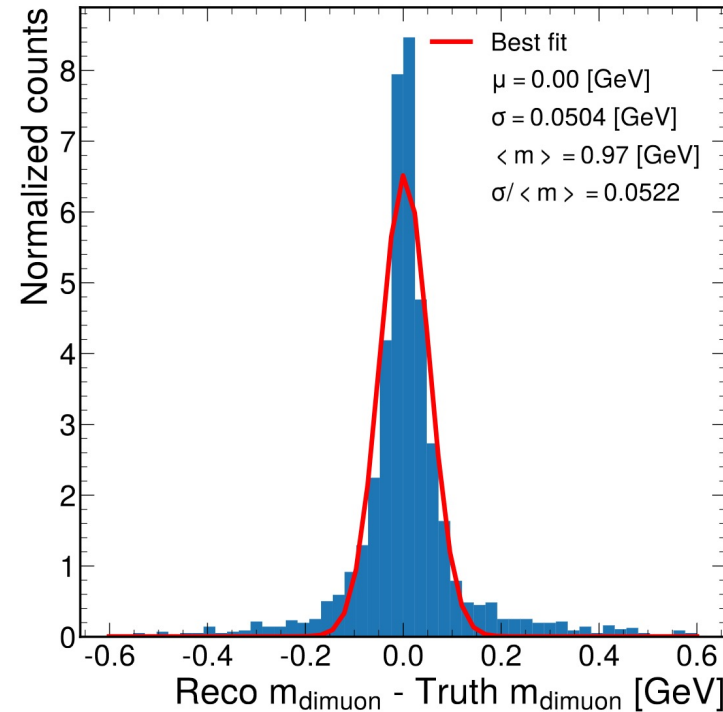


DarkQuest: New algorithms

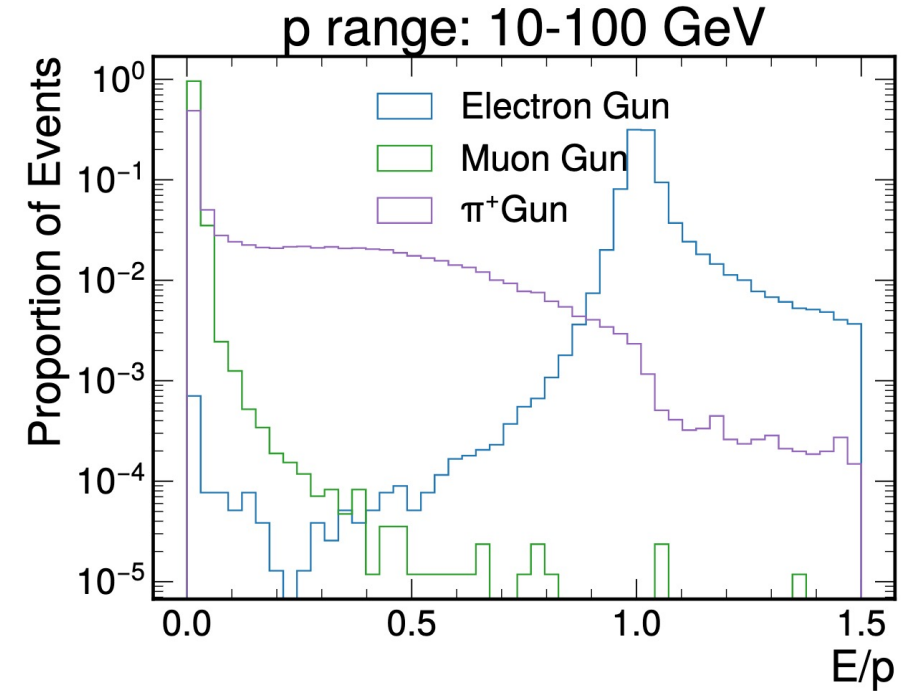
- Original SQ reconstruction software only designed to find di-muon events produced before iron block (DQ's target)
 - Significant rewrites of code!



Rewritten code can **find charged particles** created after iron block **with high efficiency**



We achieve **good di-muon mass resolution** (~ 0.05 GeV resolution)



Flavor tagging algorithm uses **EMCal cluster energy & width information** and **tracking information**

DarkQuest: Snowmass paper

- Please check out our Snowmass paper for more details!
 - <https://arxiv.org/pdf/2203.08322.pdf>
- We are a strong team of experimentalists and theorists
 - Has been a unique chance for early career scientists to gain experience on a small scale experiment
 - Please let us know if you have questions or are interested in contributing



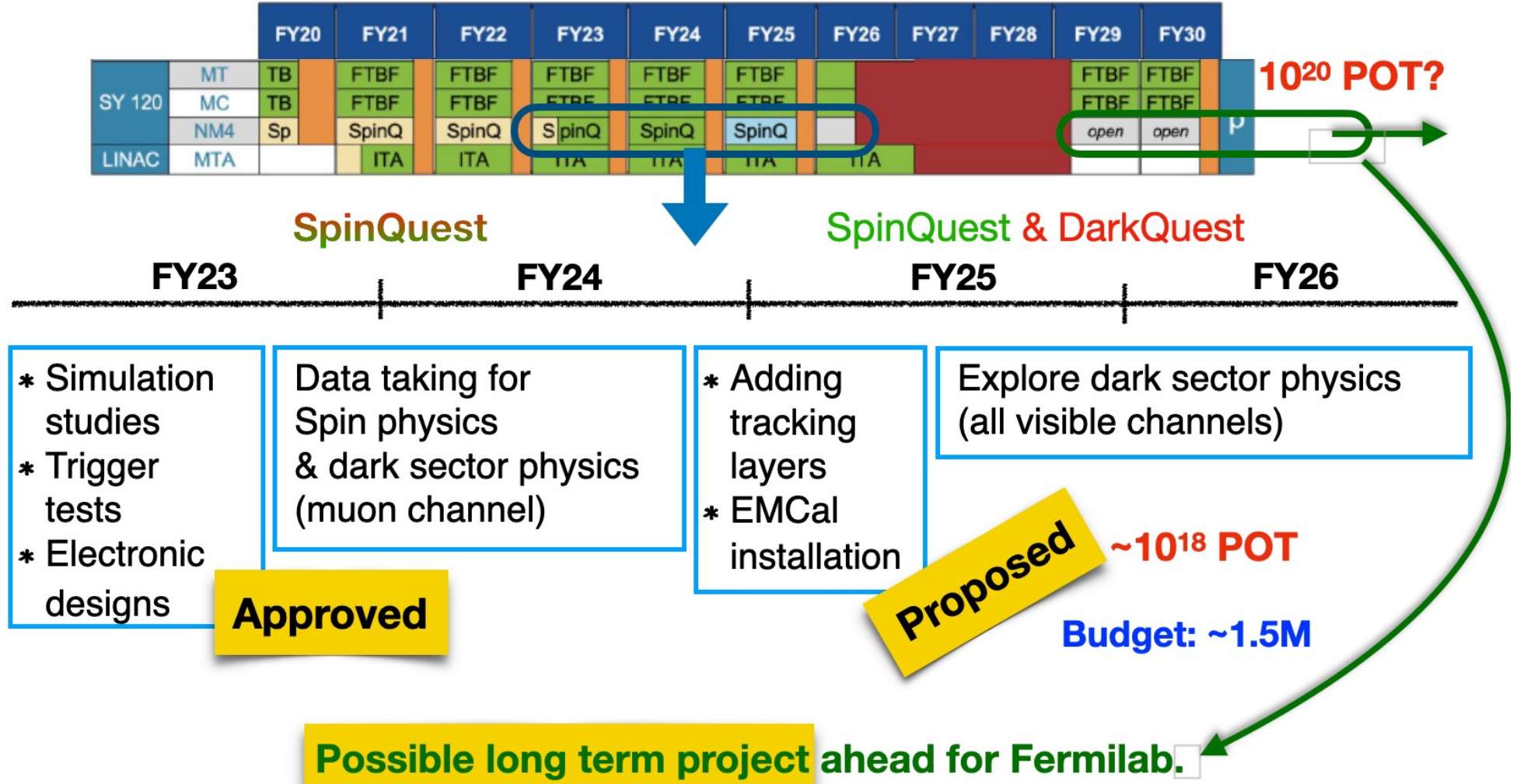
DarkQuest: A dark sector upgrade to SpinQuest at the 120 GeV Fermilab Main Injector

Aram Apyan¹, Brian Batell², Asher Berlin³, Nikita Blinov⁴, Caspian Chaharom⁵, Sergio Cuadra⁶, Zeynep Demiragli⁵, Adam Duran⁷, Yongbin Feng³, I.P. Fernando⁸, Stefania Gori⁹, Philip Harris⁶, Duc Hoang⁶, Dustin Keller⁸, Elizabeth Kowalczyk¹⁰, Monica Leys², Kun Liu¹¹, Ming Liu¹¹, Wolfgang Lorenzon¹², Petar Maksimovic¹³, Cristina Mantilla Suarez², Hrachya Marukyan¹⁴, Amitav Mitra¹³, Yoshiyuki Miyachi¹⁵, Patrick McCormack⁶, Eric A. Moreno⁵, Yasser Corrales Morales¹¹, Noah Paladino⁶, Mudrit Rai¹², Sebastian Rotella⁶, Luke Saunders³, Shinaya Sawada²¹, Carli Smith¹⁷, David Sperka³, Rick Tesarek³, Nhan Tran³, Yu-Dai Tsai¹⁸, Zijie Wan⁵, and Margaret Wynne¹²

¹Brandeis University, Waltham, MA 02453, USA
²University of Pittsburgh, Pittsburgh, PA 15260, USA
³Fermi National Accelerator Laboratory, Batavia, IL 60510, USA
⁴University of Victoria, Victoria, BC V8P 5C2, Canada
⁵Boston University, Boston, MA 02215, USA
⁶Massachusetts Institute of Technology, Cambridge, MA 02139, USA
⁷San Francisco State University, San Francisco, CA 94132, USA
⁸University of Virginia, Charlottesville, VA 22904, USA
⁹University of California Santa Cruz, Santa Cruz, CA 95064, USA
¹⁰Michigan State University, East Lansing, Michigan 48824, USA
¹¹Los Alamos National Laboratory, Los Alamos, NM 87545, USA
¹²University of Michigan, Ann Arbor, MI 48109, USA
¹³Johns Hopkins University, Baltimore, MD 21218, USA
¹⁴Yamagata University, Yamagata, 990-8560, Japan
¹⁵KEK Tsukuba, Tsukuba, Ibaraki 305-0801 Japan
¹⁶Yerevan Physics Institute, Yerevan, 0036, Republic of Armenia
¹⁷Penn State University, State College, PA 16801, USA
¹⁸University of California Irvine, Irvine, CA 92697, USA

Backup

Proposed timeline*



"A Booster replacement will enable the capability of the complex to serve precision experiments and searches for new physics with beams from 1-120 GeV"

CARI CESAROTTI

Massachusetts Institute of Technology

“Physics On the way to 10 TeV”

Physics on the Way to 10 TeV

Energy Frontier Report: 2211.11084

For the five year period starting in 2025:

1. Prioritize the HL-LHC physics program, including auxiliary experiments,
2. Establish a targeted e^+e^- Higgs factory detector R&D program,
3. Develop an initial design for a first stage TeV-scale Muon Collider in the US,
4. Support critical detector R&D towards EF multi-TeV colliders.

BIG QUESTIONS

Early Universe?

Flavor?

New Physics?

BAU?

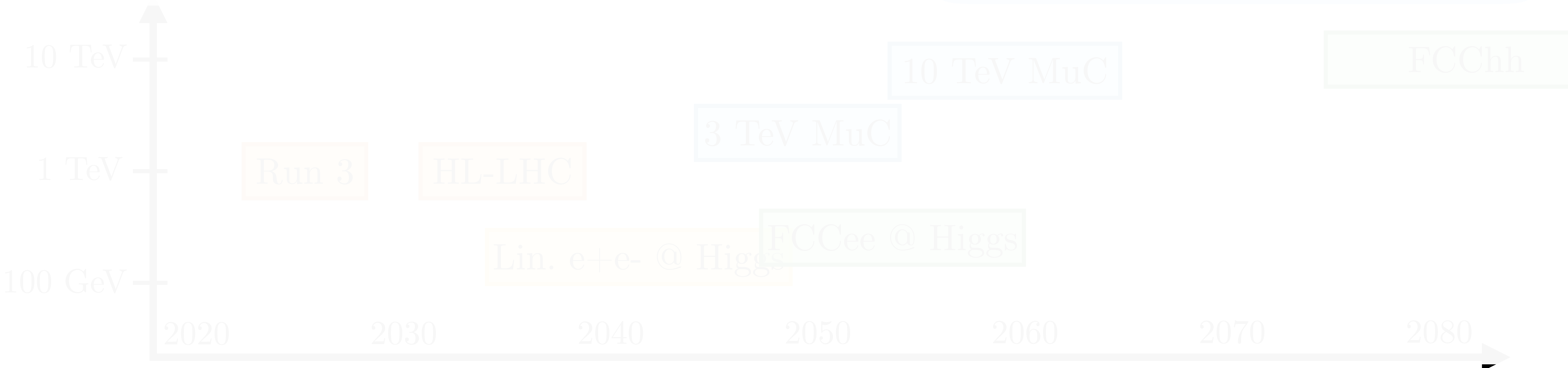
Neutrino Mass?

Nature of DM?

EW Scale?

AT HIGH ENERGY

Future Collider Time Scales



Physics on the Way to 10 TeV

Energy Frontier Report: 2211.11084

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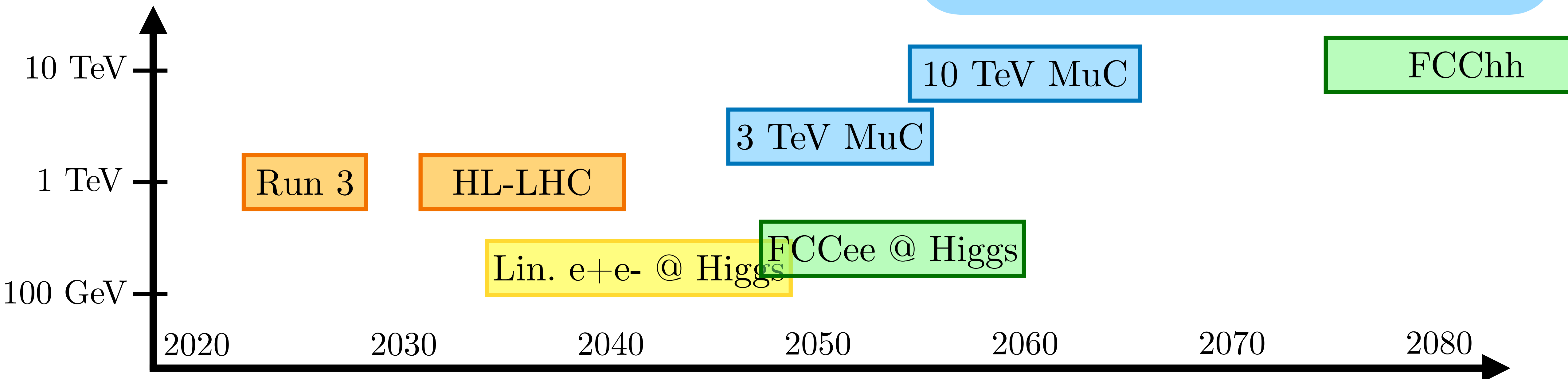
Early Universe? Flavor?

New Physics? BAU? Neutrino Mass?

Nature of DM? EW Scale?

AT HIGH ENERGY

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BIG QUESTIONS

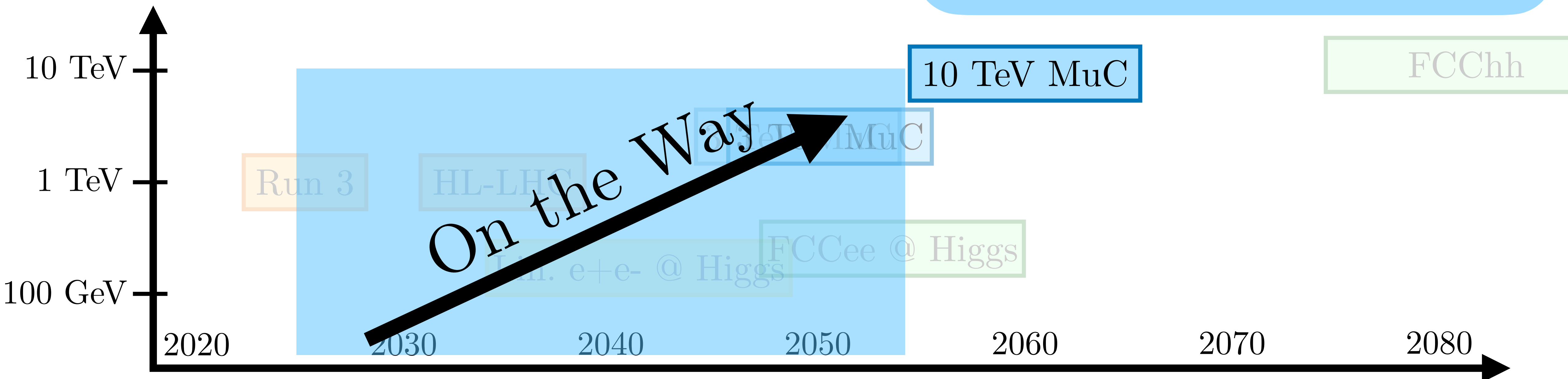
Early Universe? Flavor?

New Physics? BAU? Neutrino Mass?

Nature of DM? EW Scale?

AT HIGH ENERGY

Future Collider Time Scales



Physics at Muon Collider Demonstrator Facilities



Facilities needed for MuC R&D can:

Utilize existing experiments' infrastructure (like DUNE)

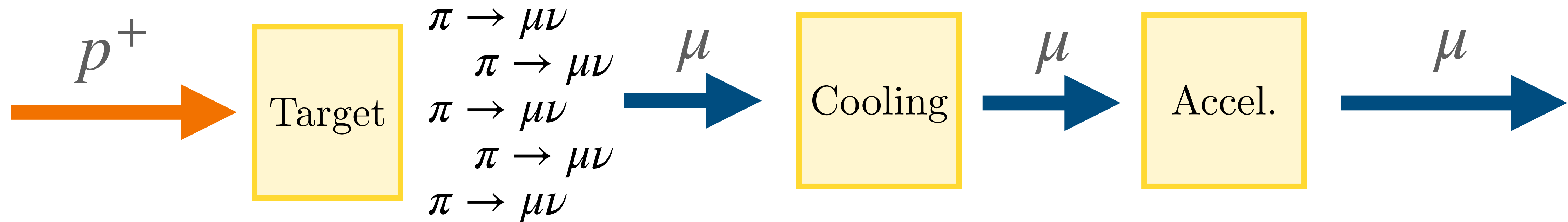
Probe rare or suppressed physics processes

Physics at Muon Collider Demonstrator Facilities

Facilities needed for MuC R&D can:

Utilize existing experiments' infrastructure (like DUNE)

Probe rare or suppressed physics processes

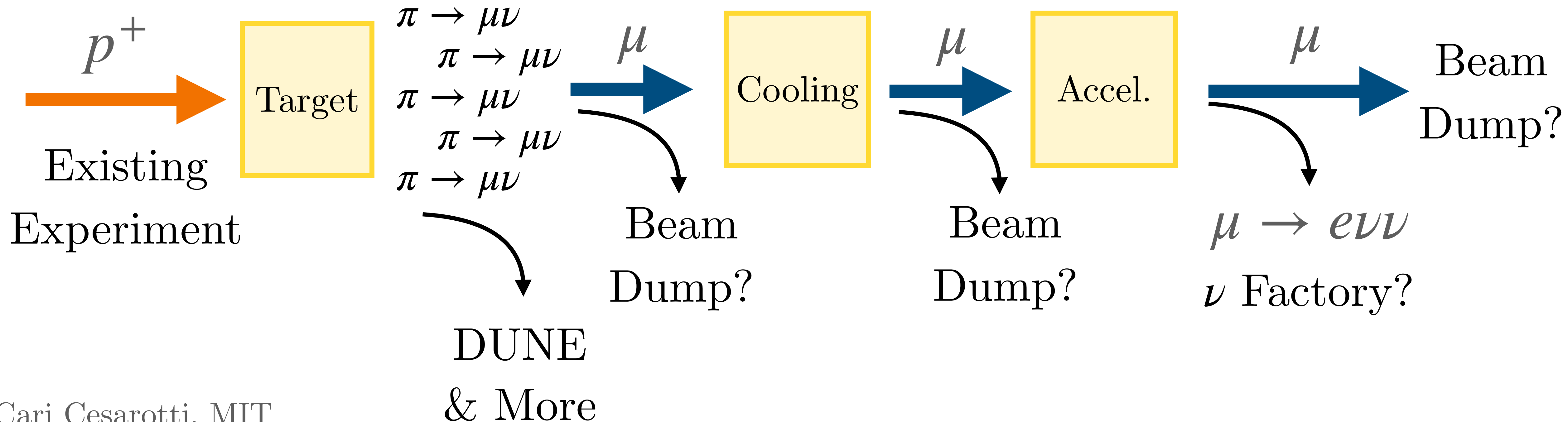


Physics at Muon Collider Demonstrator Facilities

Facilities needed for MuC R&D can:

Utilize existing experiments' infrastructure (like DUNE)

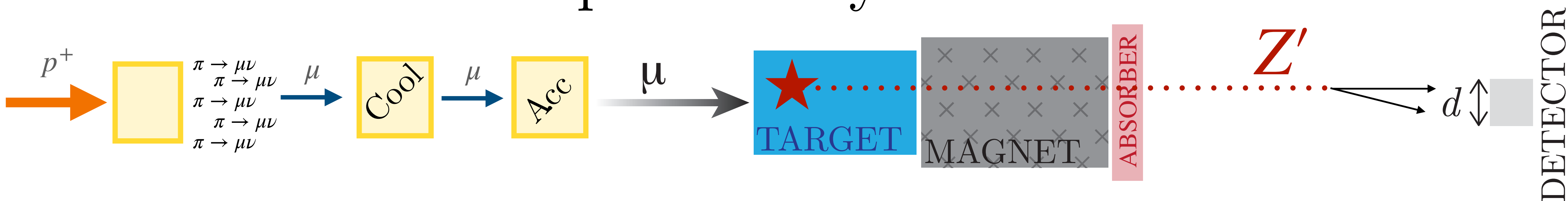
Probe rare or suppressed physics processes



Beam Dumps at Demonstrator Facilities

2202.12302

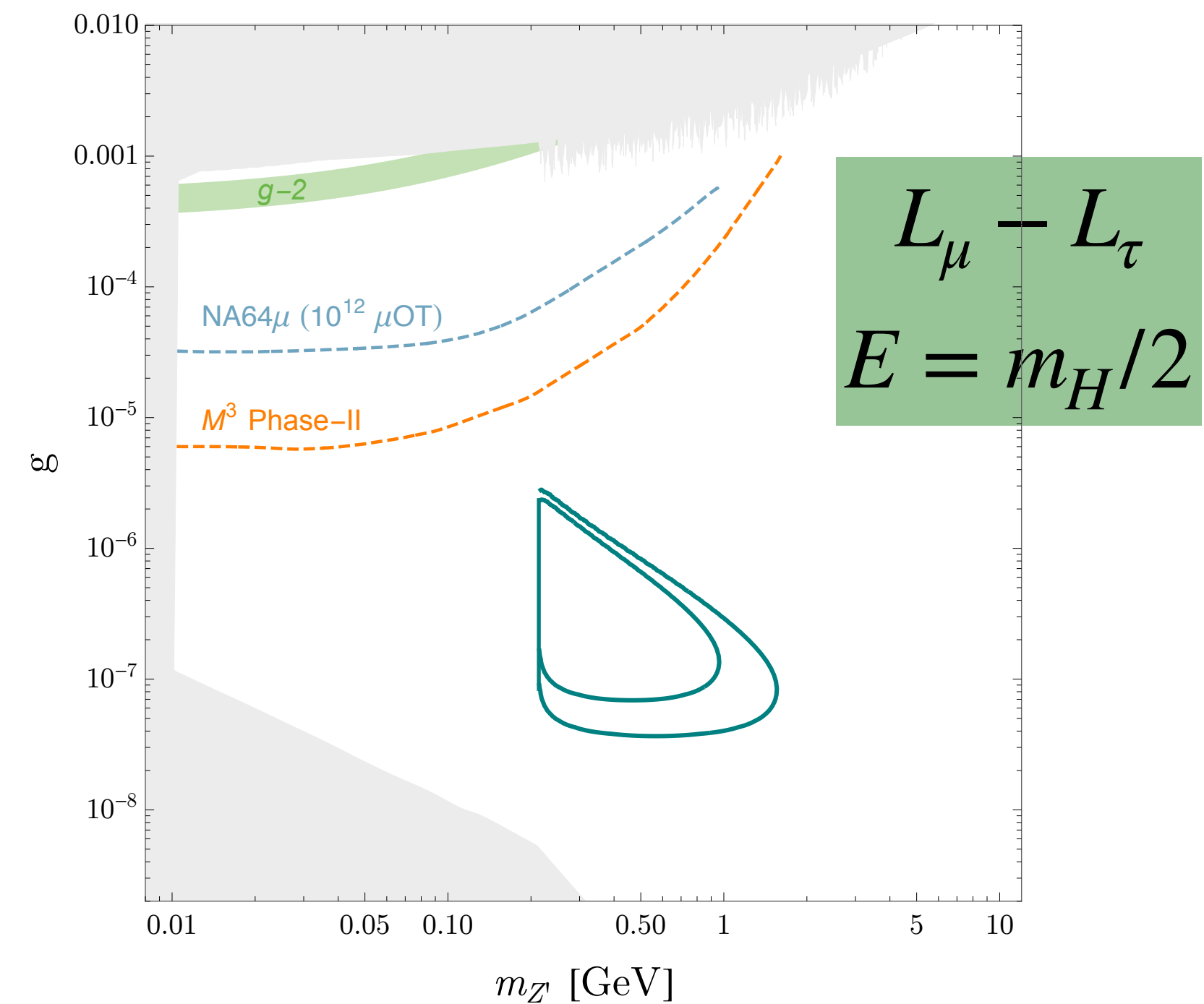
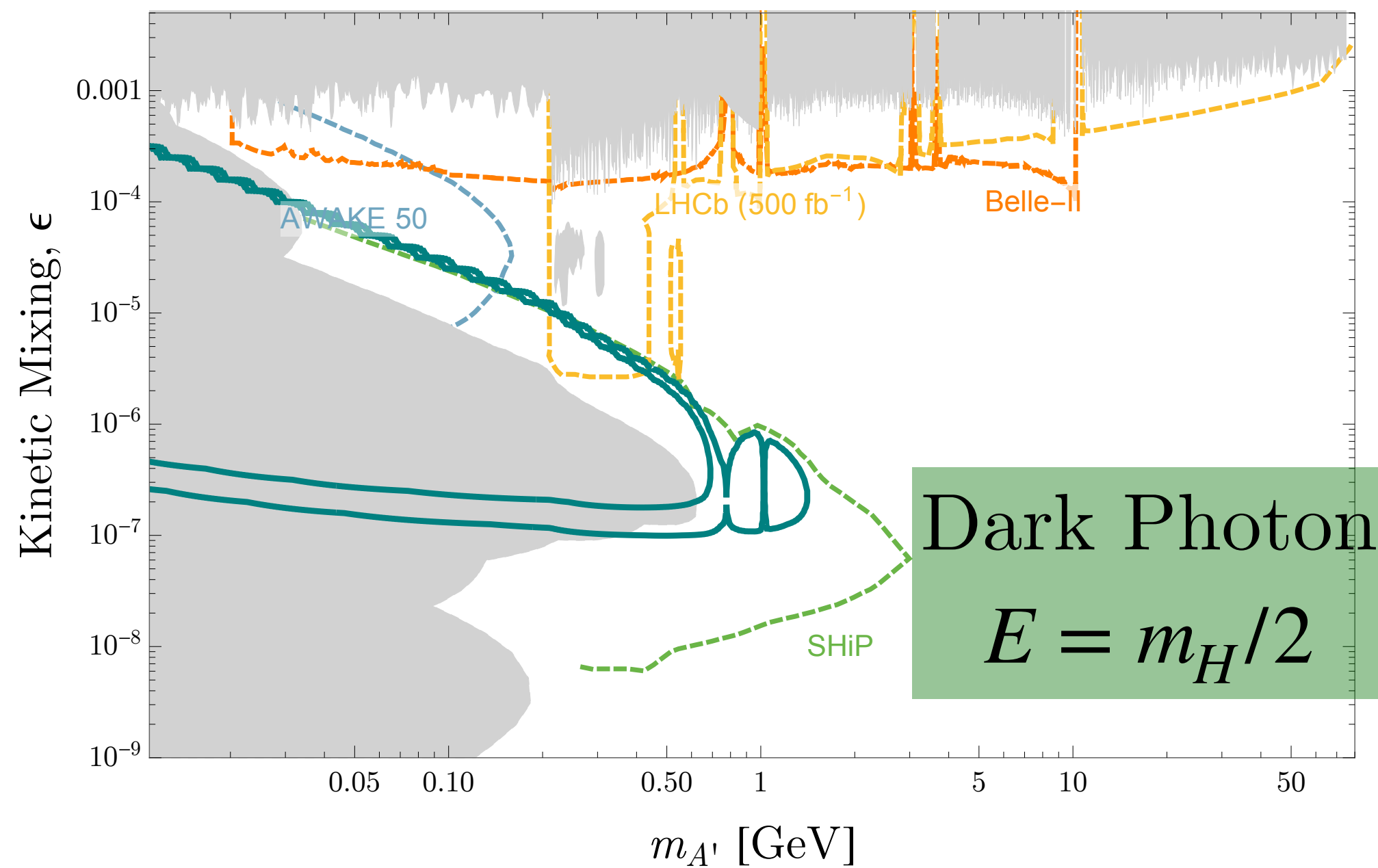
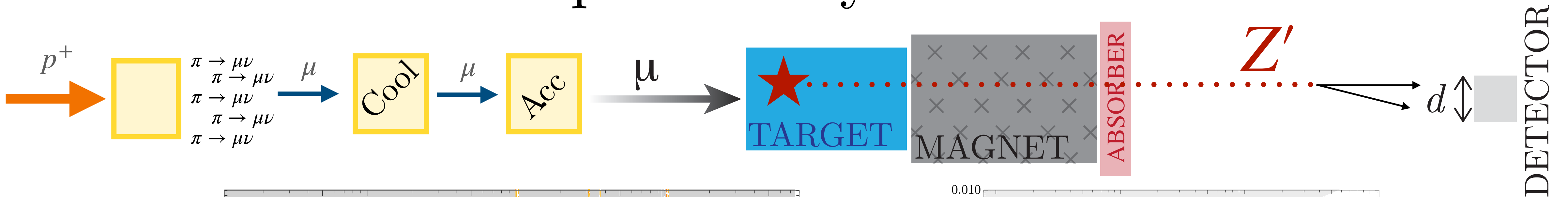
Beam dumps are low-cost auxiliary experiments with complementary reach to main collider



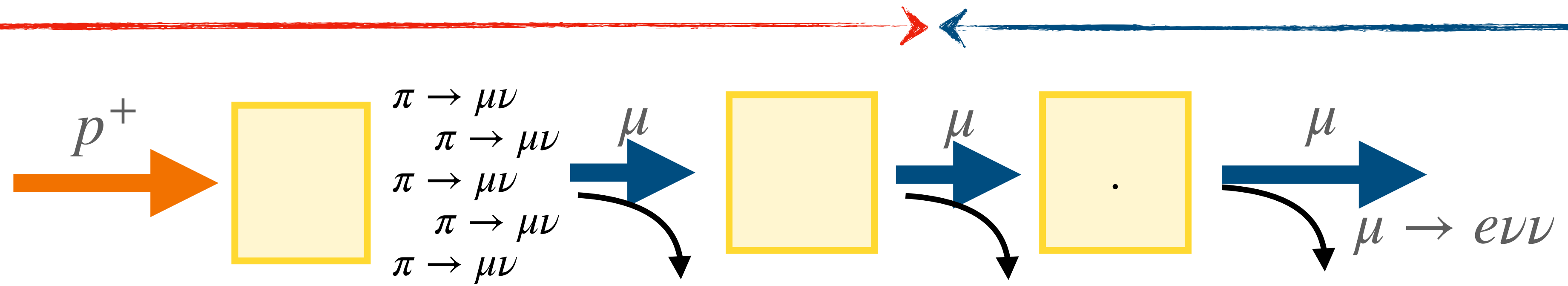
Beam Dumps at Demonstrator Facilities

2202.12302

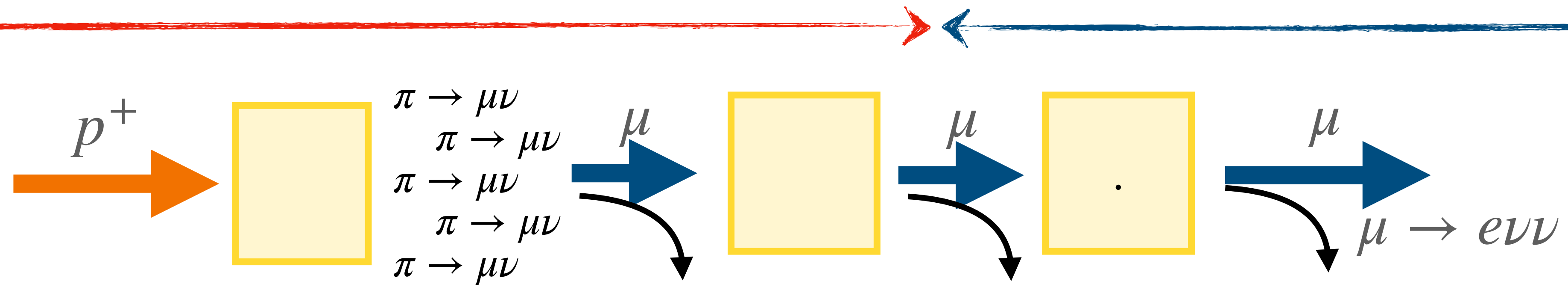
Beam dumps are low-cost auxiliary experiments with complementary reach to main collider



Physics at Muon Collider Demonstrator Facilities



Physics at Muon Collider Demonstrator Facilities

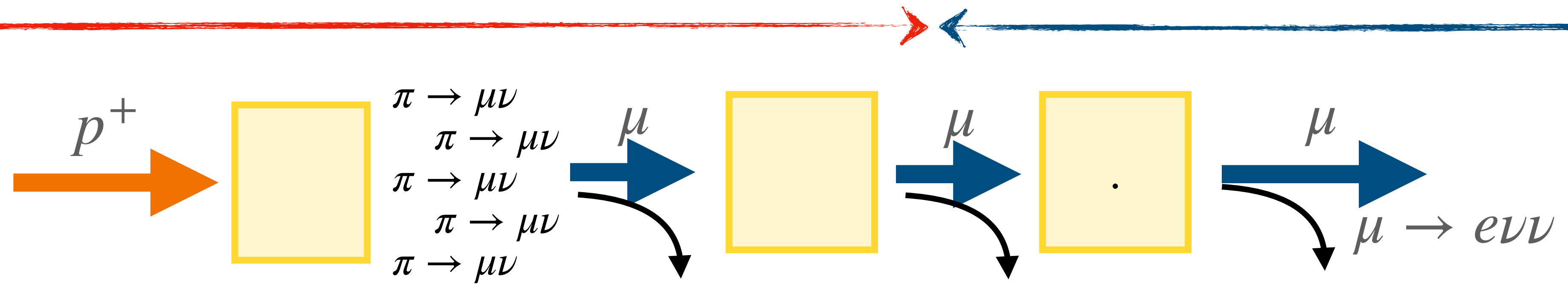


DUNE ACE Upgrade

ESS ν SB 2107.07585

LHC TT10

Physics at Muon Collider Demonstrator Facilities



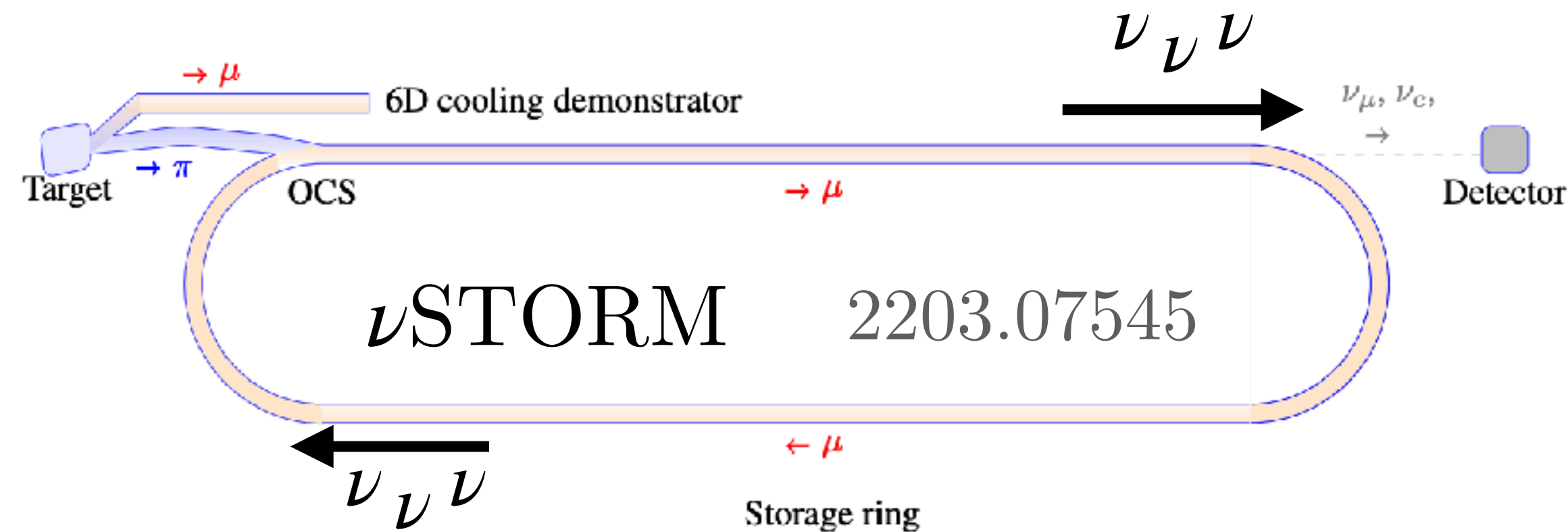
DUNE ACE Upgrade

ESS ν SB 2107.07585

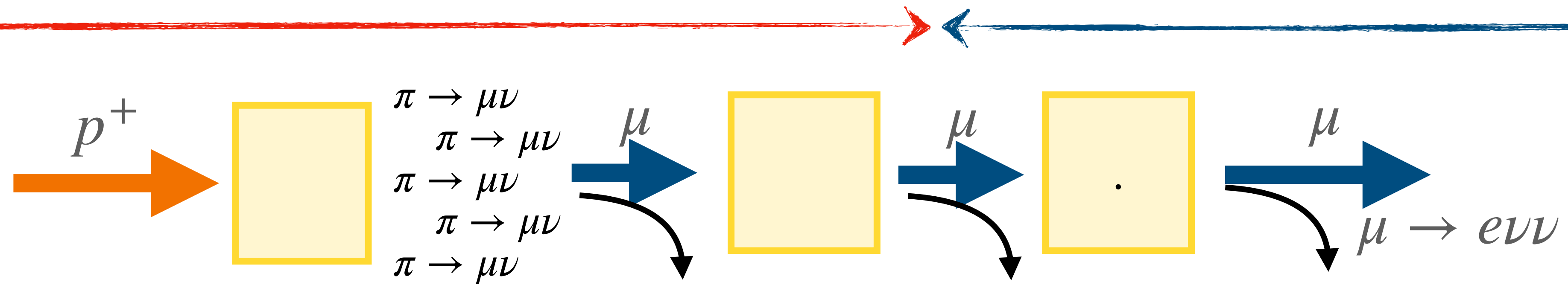
LHC TT10

Muon Beam Dump

Neutrino Physics (e.g. ν STORM)



Physics at Muon Collider Demonstrator Facilities



DUNE ACE Upgrade

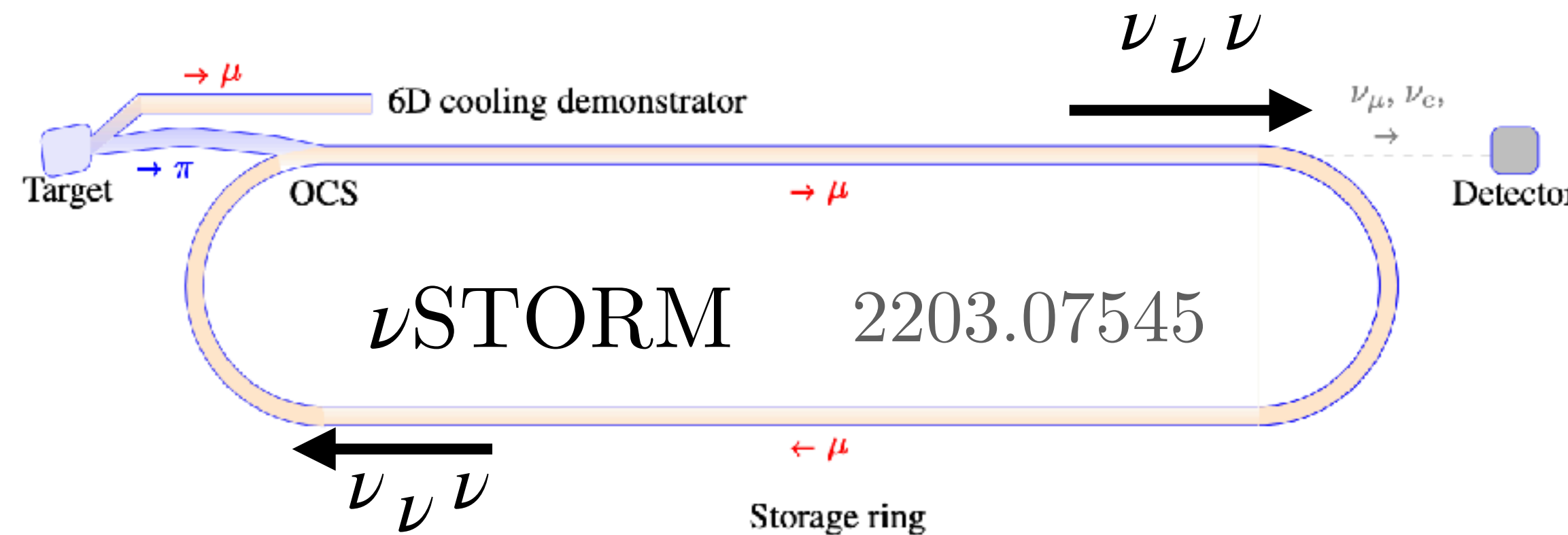
ESS ν SB 2107.07585

LHC TT10

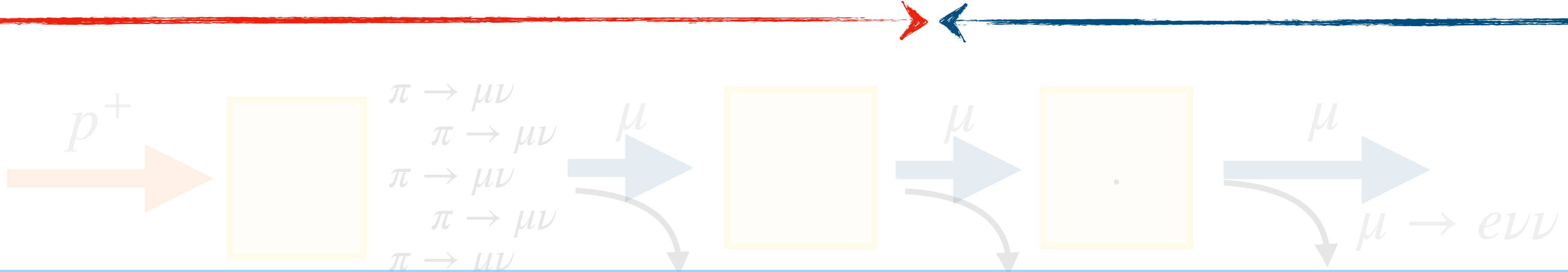
Muon Beam Dump

Neutrino Physics (e.g. ν STORM)

And more?



Physics at Muon Collider Demonstrator Facilities



What we need:

Funding for R&D for proof-of-concept demonstrator facilities and funding for theorists to explore physics possibilities along the way



KRZYSZTOF GENSER

Fermilab

“On Sustaining Geant4”

Geant4 - a focal HEP simulation tool

- While HEP experiments use variety of tools to perform detector simulations, [Geant4](#) is a toolkit used by most, if not all of them. It has become a **de-facto standard for many aspects of HEP detector simulations**
 - It is **used** not only in **detector and facility design**, but also in the **extraction of physics results and estimation of systematic uncertainties**
 - While being **widely and successfully used** in various contexts, it **also has its limitations**, in part, because of the **lack of a sufficient number of people** working on it.
 - Quoting from the [Snowmass2021 Book](#) Rare Processes and Precision Measurements Frontier (RPF) p538-539:

The RPF wants to send a strong and emphatic message, also discussed in the Computing Frontier report: **GEANT4 is not sufficiently supported in the U.S.** The physics models of some crucial processes, including but not limited to their cross-sections, rates, and spectra, are in disrepair [...] Many experiments in RPF rely on low-energy phenomena whose simulations are not kept up to date; when bugs and errors are found, they are **not fixed because there is no one to fix them**. GEANT is infrastructure akin to "roads and bridges"; ***the current trajectory endangers progress across particle physics.*** [emphasis/abbreviation by KLG]

Sustaining Geant4 Physics Models

- Geant4 **physics models** have a **similar impact** on the simulation of experiments, extraction of physics results and estimation of systematic uncertainties as **physics event generators**
- Ensuring that there are **people who can maintain and develop Geant4**, including its physics models, is **critical to Geant4 usability**
 - The most widely used **models** [have been shown](#) to **require more work** to fully describe the existing data
 - Unfortunately, one of these models **has not been actively developed** over the last few years due to the **lack of people**
- Establishing **strong partnerships** and collaboration among **theorists, developers of event generators, and Geant4 physics model developers** would be **beneficial** for the entire HEP community
- **To benefit US experiments the most, the people working on the physics models relied on by these experiments should be specifically funded to do so.** Just a best effort of people having other priorities has not been sufficient
- Geant4 is a very complex toolkit; **its all elements**, not only its physics models, **need to function well and run efficiently and fast** on modern (super)computers; **it all requires constant human attention and work**

Sustaining Geant4 and Geant4 Collaboration

- The people of the (international) Geant4 Collaboration are aging
- Many Geant4 developers have retired over the last few years, and many are approaching retirement (specific data can be provided upon request)
- **Scarcity of dedicated permanent HEP positions** is a negative and discouraging factor; There are many job opportunities outside of HEP for people with the skills needed to develop Geant4; Some **Geant4 developers** decided to, or **had to, leave** when their **contracts ended**
- Experience shows that **it takes several years of learning and knowledge transfer for a new person to be able to contribute to Geant4 development at an expert level**; If new people are not hired in a timely manner, a significant loss in productivity occurs
- Given the prevalent use of Geant4, the **impact of investing in it is large (and so is the *impact of insufficient funding*)**
- As the needs of experiments and computing environments evolve the Geant4 toolkit requires **constant *development, maintenance, and user support*. All that requires an adequate number of people and stable funding**
- Also see: [SnowmassCompF2DetSim20220718](https://arxiv.org/abs/2203.07614) and <https://arxiv.org/abs/2203.07614>, <https://arxiv.org/abs/2203.07645>

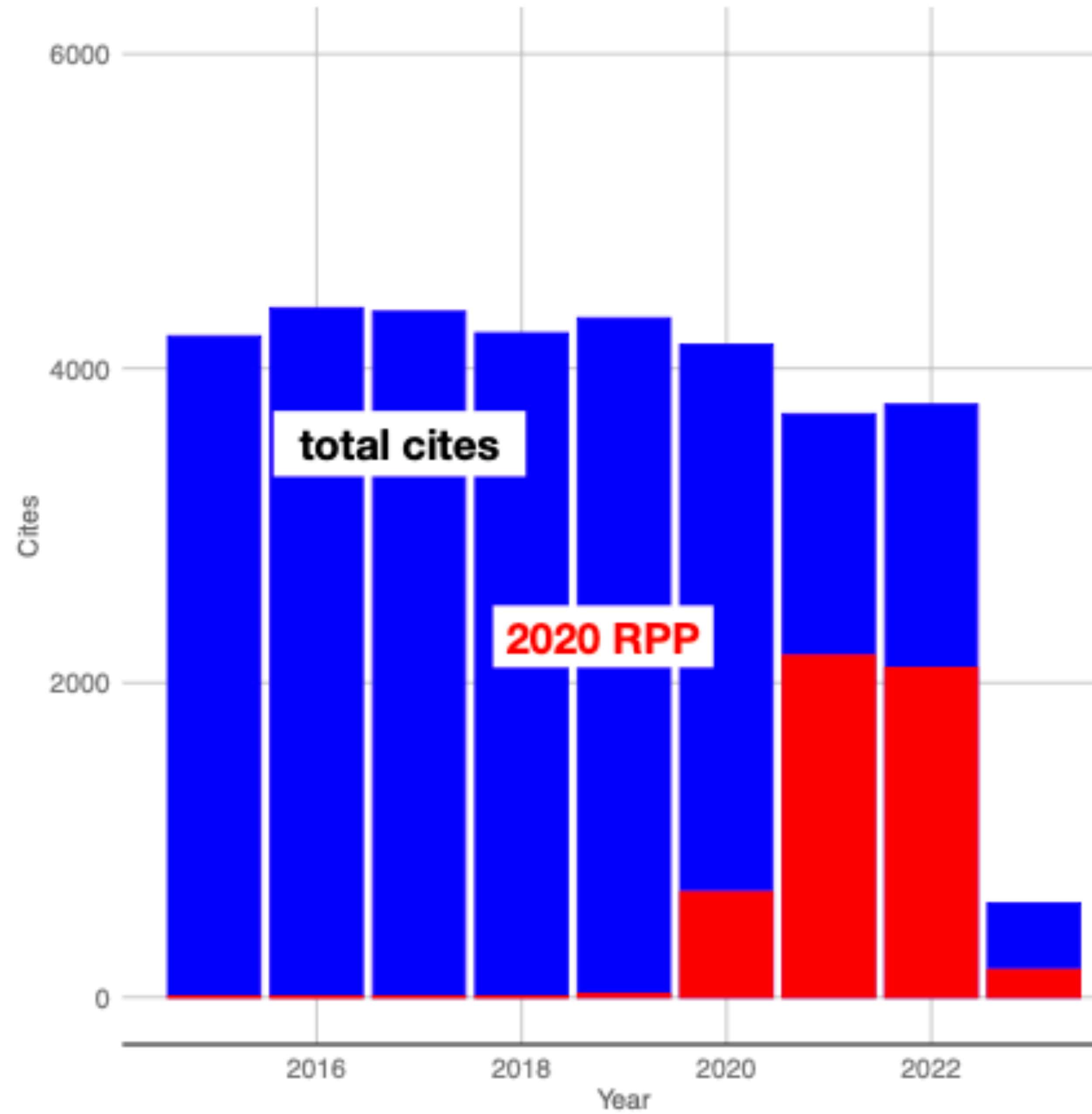
MICHAEL PESKIN

SLAC National Accelerator Laboratory

**“Importance of the particle physics
information services”**

Importance of the Particle Physics Information Services

**M. E. Peskin
Brookhaven P5 meeting
April 2023**





Year	CERN	DESY	Fermilab	IHEP	IN2P3	SLAC	total
2012	5.5	5.3	2.2	0	0	6.0	19.0
2016	12.0	4.5	4.0	2.5	1	3.3	27.3
2019	9.5	3.4	2.5	2.5	1	1.5	20.4
2023	6.0	3.2	3.25	2.5	1	0	15.95

Table 1: INSPIRE personnel at each member laboratory, in FTE. Staffing varies from year to year with the arrival and departure of students and other part-time workers. The higher counts for CERN in the intermediate years reflect additional software developers for the new INSPIRE format and backend.

SIMONE MAZZA

University of California, Santa Cruz

**“Long-term development of 4/5D
detectors for future colliders and
blue-sky R&D”**

4D/5D technology for future trackers – Simone Mazza (UCSC)

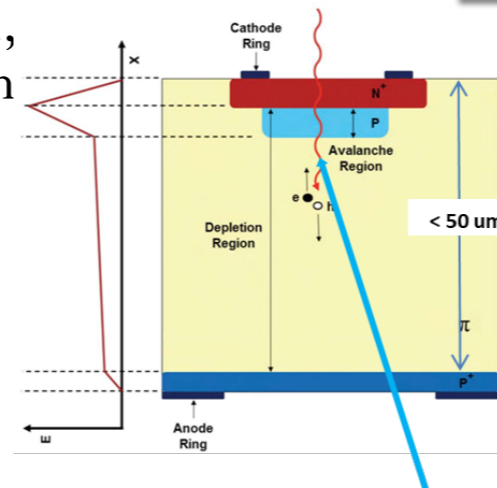
Need very small pixels:
(e.g. 50k pixels/cm²)

Thin sensors are required for
very good time resolution
Thin sensors need gain!

- **Basic research need (BRN) requirements for future trackers**
- Spatial resolution $\sim 5 \mu\text{m}$
- Temporal resolution $\sim 10 \text{ ps}$
- Very low material budget (sensor + elect. $< 100 \text{ mm}$ of silicon)
- Very low power consumption (air cooling $< 0.2 \text{ W/cm}^2$)

- Low-Gain avalanche detectors (**LGADs**)
 - **Example of blue-sky R&D** within RD50, AIDA, supported by the US DoE (UCSC), now also within US-Japan collaboration
- **Started in 2012**
 - In 2019/2020 **ATLAS** and **CMS** submitted TDRs for **large-scale timing upgrades** to suppress backgrounds using **LGADs** with area of $\sim 10 \text{ m}^2$
 - Now produced by >10 companies/labs
- **Issues:** granularity, radiation hardness, power dissipation

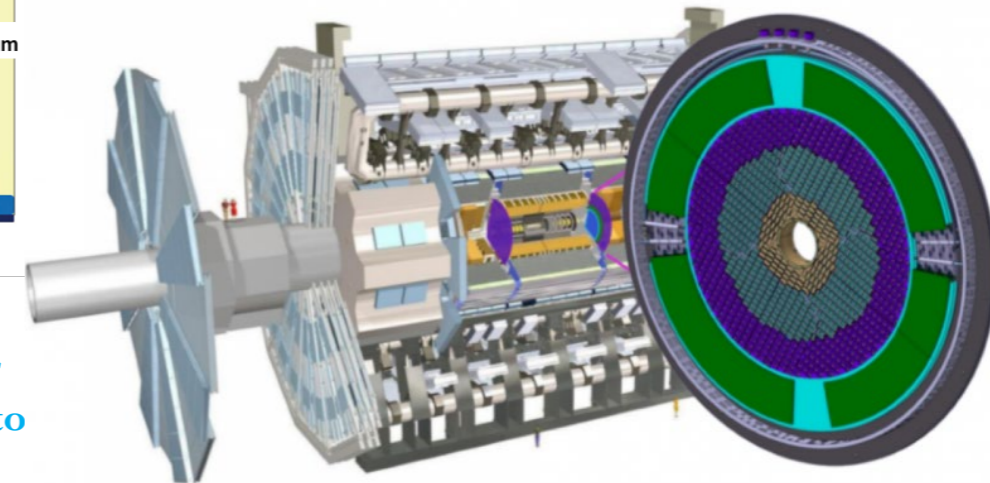
Good temporal resolution requires a lot of
power per pixel: minimize # of channels!



LGAD, Silicon sensor
with thin gain layer to
boost S/N

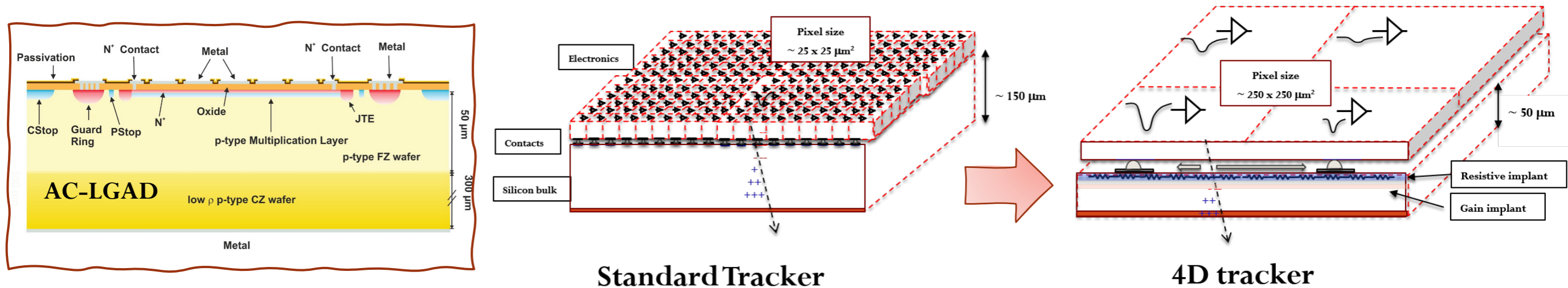
ATLAS HGTD

CMS ETL



4D devices – AC Low-gain avalanche detectors (AC-LGADs)

- Issues to solve: **low granularity** of traditional LGADs and **power dissipation**
 - Solution for both: **AC-coupled LGADs (AC-LGADs)**
- Continuous sheets of multiplication layer and resistive N⁺ layer, **AC-coupled readout**
 - **Collected charge is shared** between electrodes (**position resolution \ll pitch**)
- New concept: **sparse readout, high precision and low power**
 - Great time resolution from thin LGADs
 - Works in low occupancy environment, good for lepton colliders
- Upcoming AC-LGAD applications: the ePIC (@ EIC) and PIONEER (small-scale) experiments
 - **Next: Higgs factories**, technology optimization needed!



Long-term development of 4/5D LGAD detectors

- **New technology** needs to be developed for future colliders with **high radiation hardness requirements** (10^{16-17} Neq/cm²) and **high occupancy** (e.g.: FCC-hh)
 - **x10 improvement in LGADs radiation hardness**, up to $2.5E15$ Neq/cm², with R&D effort in ATLAS/CMS in **~6 years**
 - Need for **order of magnitude increase in radiation hardness and higher granularity**
- **Critical need to continue developing LGAD sensor technology** for far future applications
 - Why **5D**? Think of **extra information on Angle or Energy**
- **Lower power electronics and advanced integration** needs to be developed together with sensor R&D
- At the same time **pursue pure technology advancement: blue sky R&D**
 - **Applications in other fields** (X-ray detection, imaging, medical science, space, ...)

DJ-LGAD

TI-LGAD

High granularity

iLGAD

DS-LGAD

Buried-LGAD

Carbon implantation

FBK UFSD2, High Carbon

Compensated gain layer

Inactive Boron, Low diffusion...

Radiation hard

3D trenches

LGAD CMOS

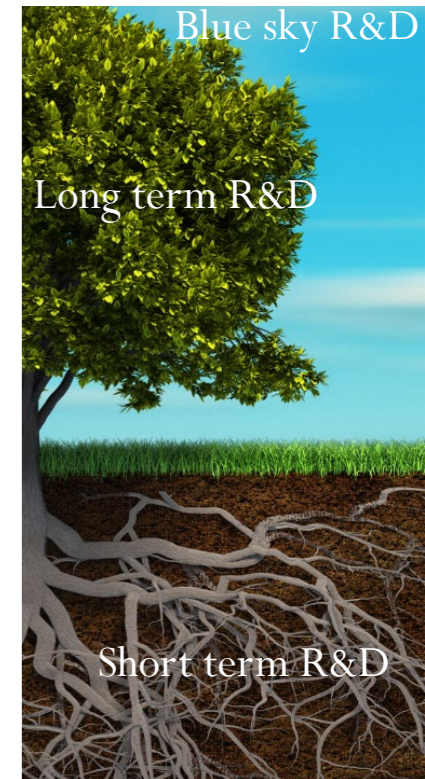
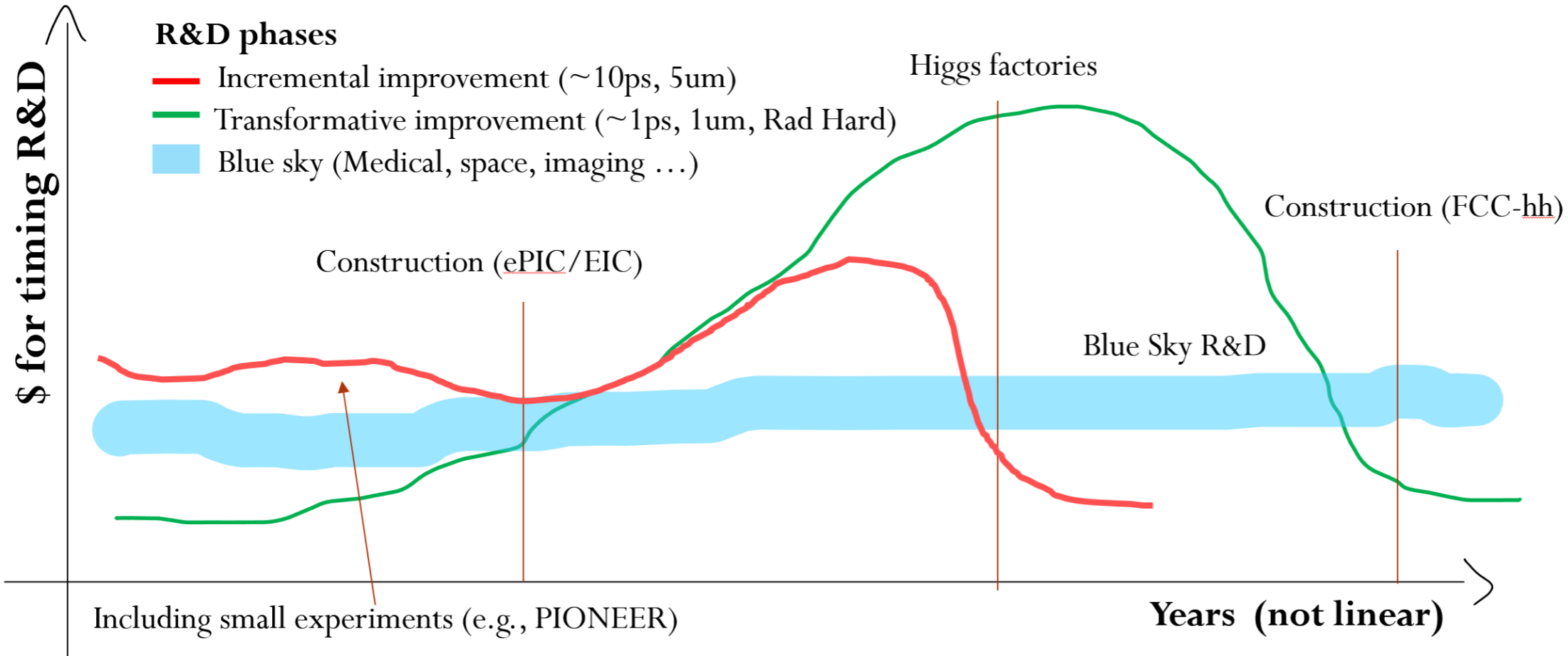
?

Snowmass papers: [4D tracking paper](#), [CMOS](#), [Electronics](#), [SiC](#), [3D integr.](#)

Conclusions and R&D cost profile



- For **near-future applications AC-LGADs** seem to solve **granularity and power issue**
 - However, **many challenges lie ahead** in terms of high radiation damage and large occupancy
- There has been **great and fast development on 4/5-D detectors based on the LGAD technology** that makes it a **viable technology for short, medium and long term applications**
 - But **to fully meet the BRN goals** continuing funding for R&D is critical
 - Cost increment: **new technologies are progressively more complicated**



ISABEL OJALVO

Princeton University

**“Beyond the Energy Frontier: Advancing
Precision Measurements and
Exploring the Unknown”**

Beyond the Energy Frontier

Advancing Precision Measurements
and Exploring the Unknown

Isobel Ojalvo
Assistant Professor, Princeton University



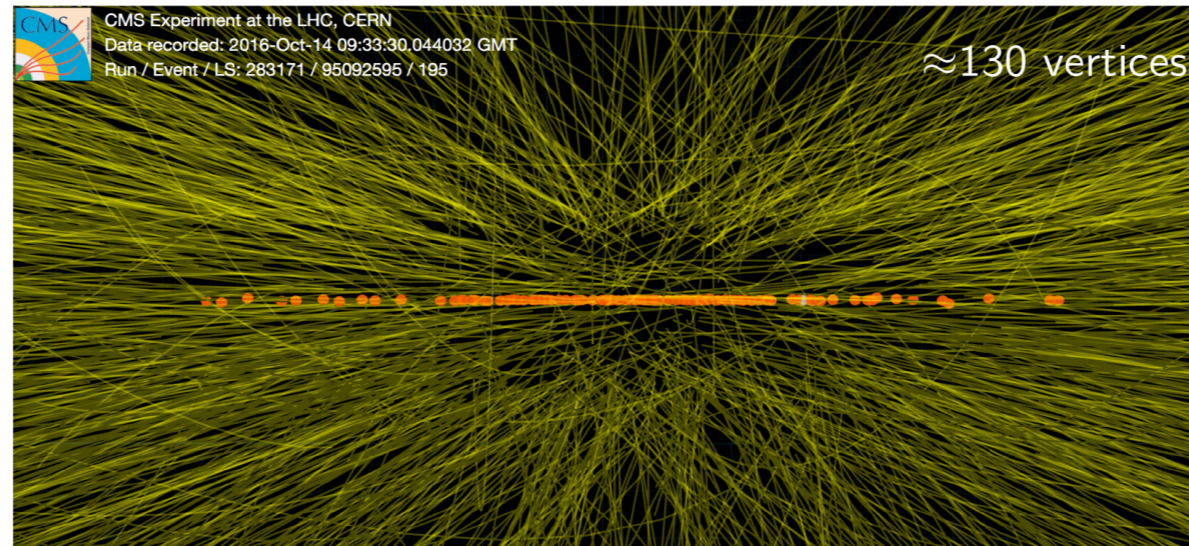
Particle Physics

You are Here

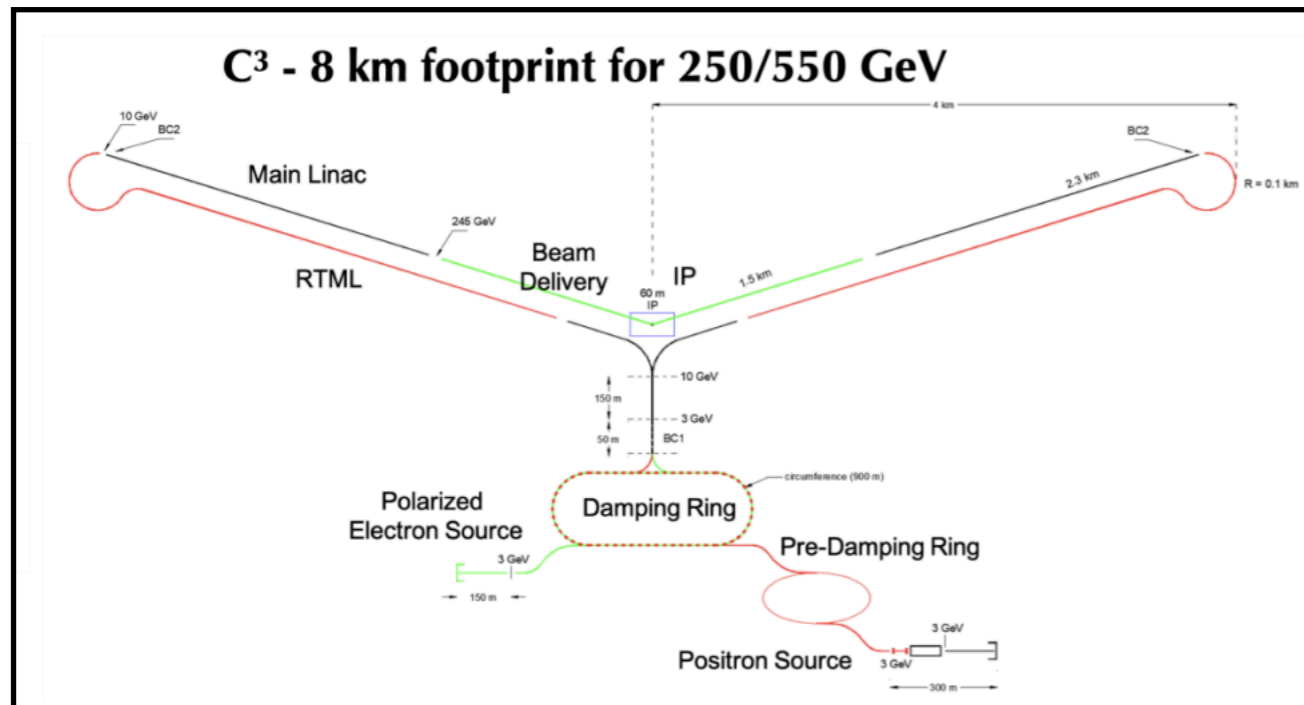
Astrophysics

Graphic by Wikimedia

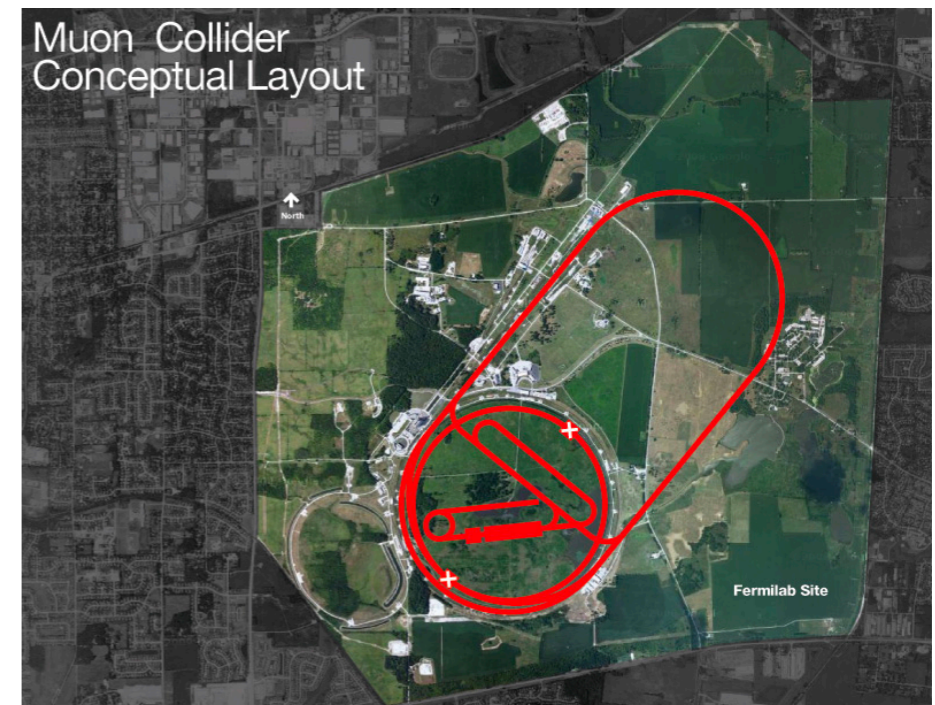
The Energy Frontier Recommendations



HL-LHC



Higgs Factory



Multi-TeV Facility

Energy Frontier: Physics Reach

This is a sampling of a spectacular program worth 1000s of PhDs in particle physics

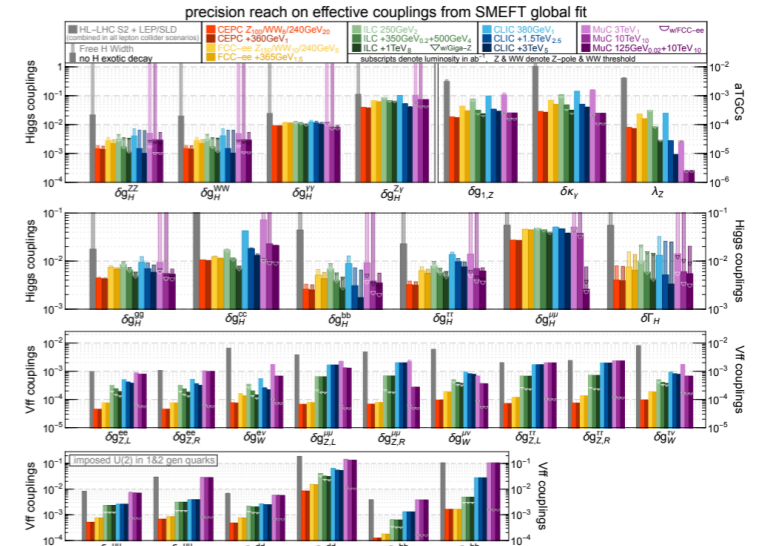
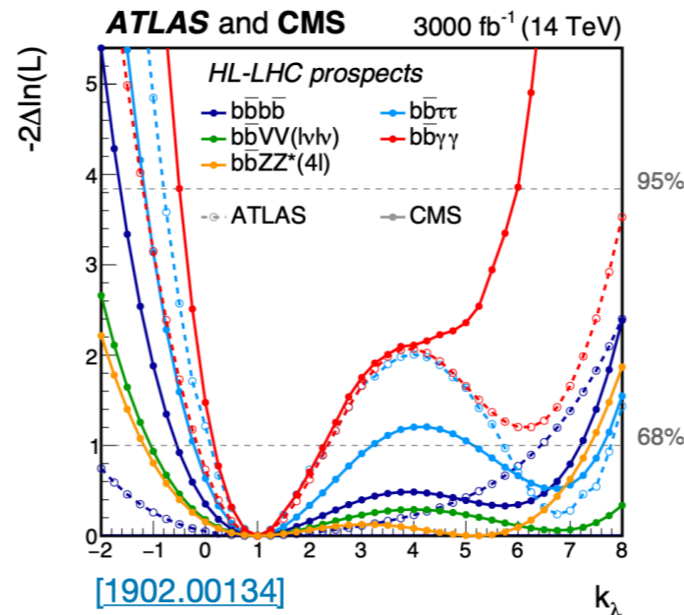
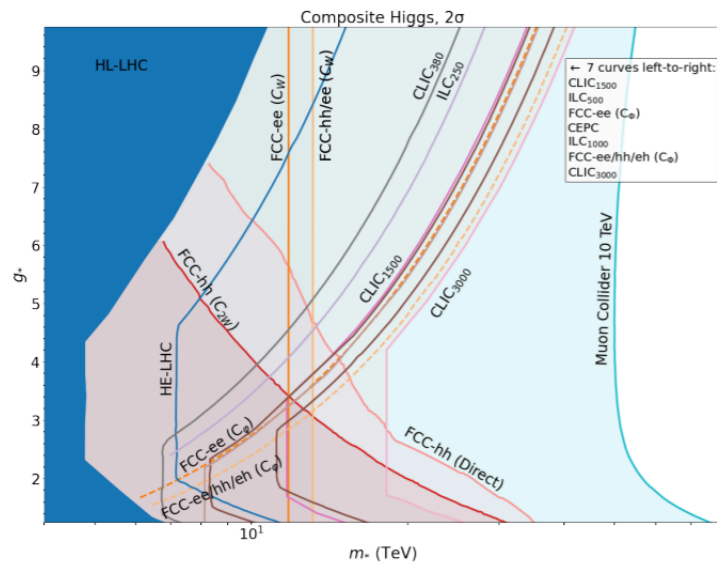


Figure 1-21. Precision reach on Higgs and electroweak effective couplings from a SMEFT global analysis of the Higgs and EW measurements at various future colliders. The wide (narrow) bars correspond to the results from the constrained- Γ_H (free- Γ_H) fit. The HL-LHC and LEP/SLD measurements are combined with all future lepton collider scenarios. For e^+e^- colliders, the high-energy runs are always combined with the low energy ones. For the ILC, the (upper edge of the) triangle mark shows the results for which a Giga-Z run is also included. For the Muon Collider, three separate scenarios are considered. The subscripts in the collider scenarios denote the corresponding integrated luminosity of the run in ab^{-1} .

Figure 1-30. Exclusion ($2\text{-}\sigma$) sensitivity projections for future colliders. Plot based on Refs. [81, 411].

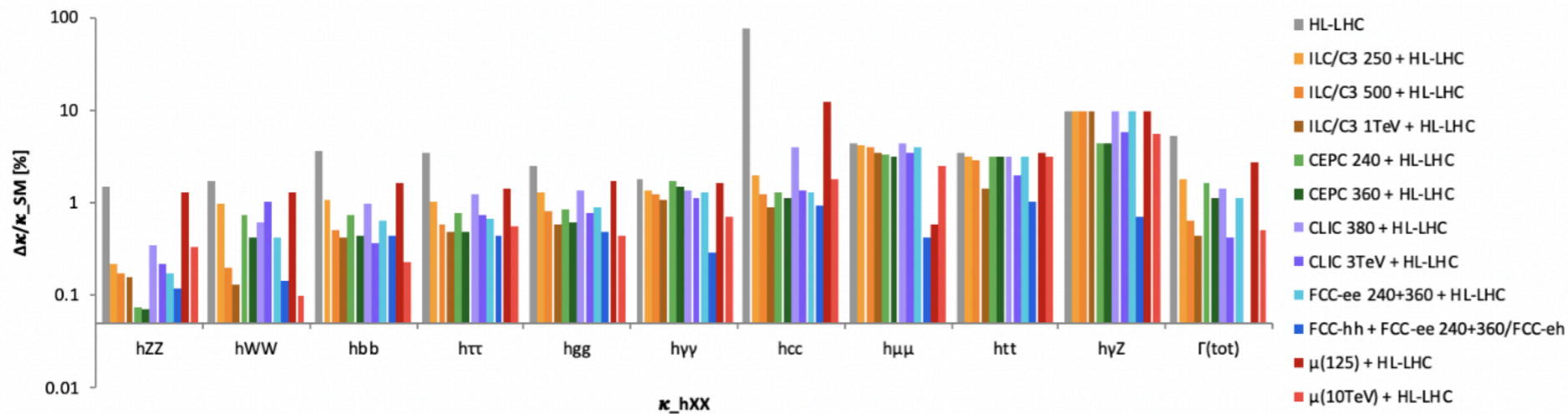
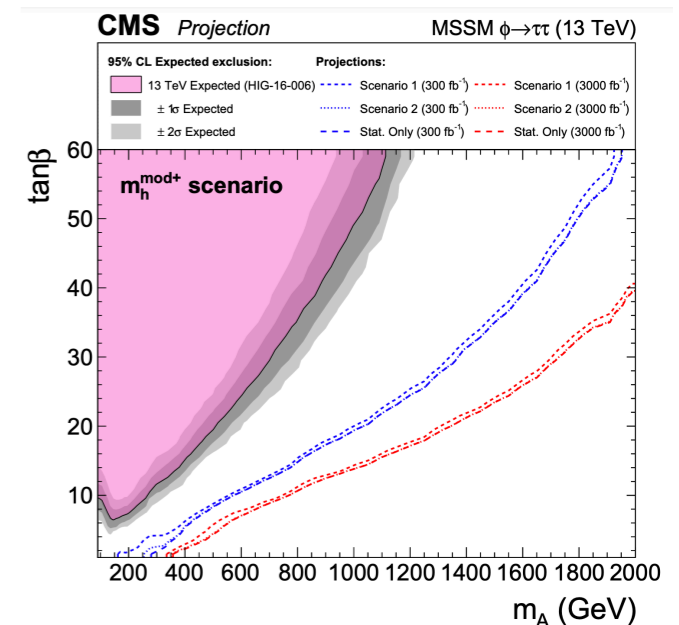


FIG. 20: Relative Higgs coupling measurements in % when combined with HL-LHC results. All values assume no beyond the Standard Model decay modes of the Higgs boson. The energies and luminosities are those defined in Table IV A.



Energy Frontier: Physics Reach

This is a sampling of a spectacular program worth 1000s of PhDs in particle physics

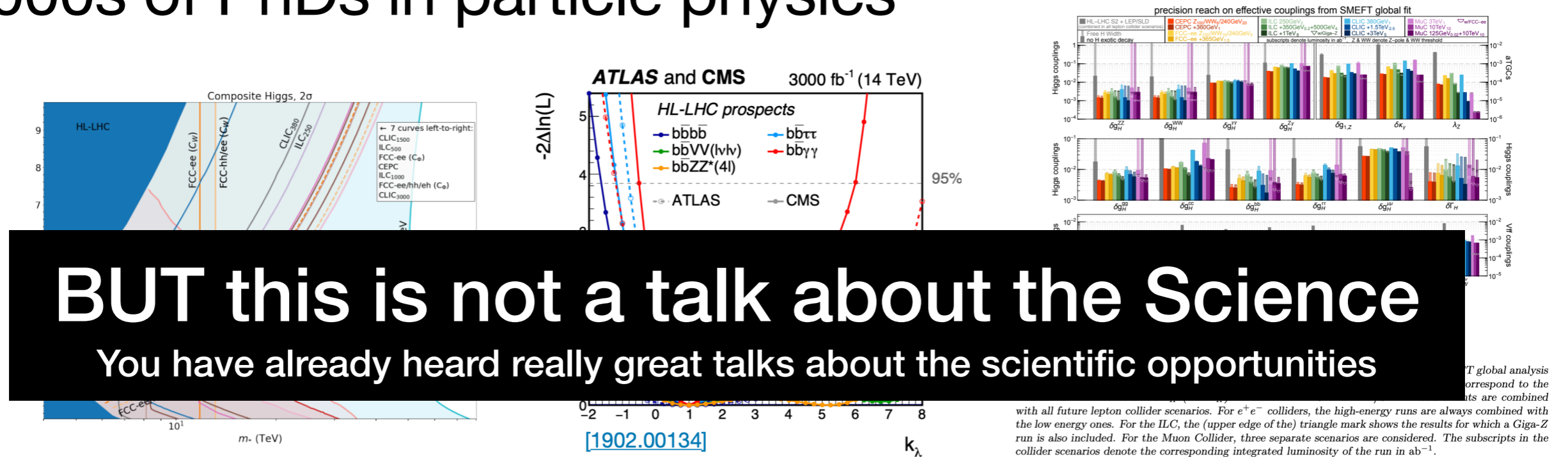


Figure 1-30. Exclusion ($2\text{-}\sigma$) sensitivity projections for future colliders. Plot based on Refs. [81, 411].

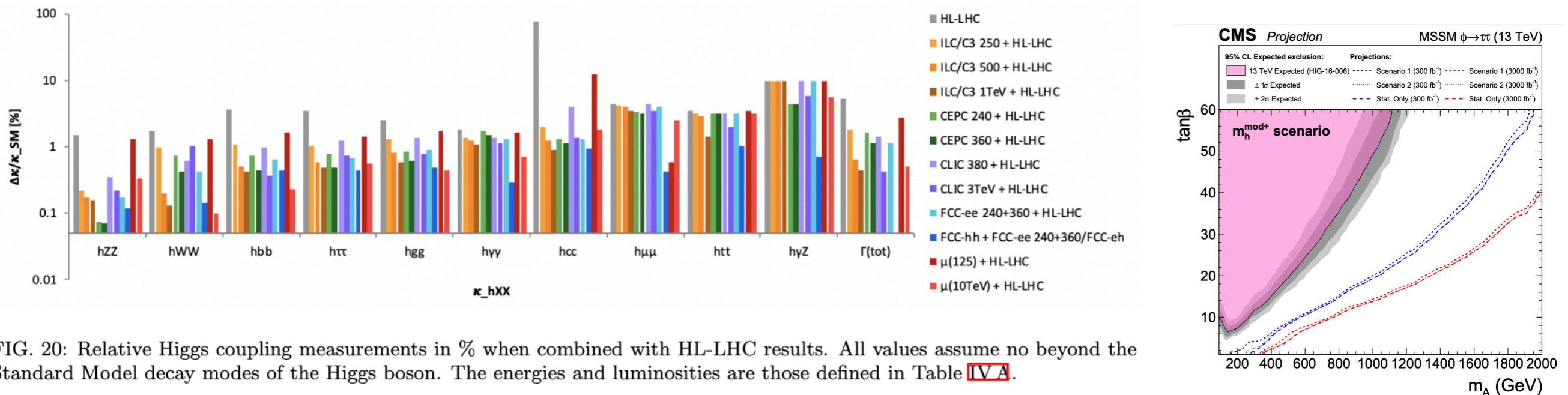


FIG. 20: Relative Higgs coupling measurements in % when combined with HL-LHC results. All values assume no beyond the Standard Model decay modes of the Higgs boson. The energies and luminosities are those defined in Table IV A.

Message to Leadership:

Be kinder to yourself about the SSC

Many esteemed colleagues maintain that the cancellation of the Superconducting Super Collider (SSC) marked the conclusion of new HEP EF Colliders in the United States

We have two options before us, either:

1.) **Acknowledge defeat:** stop the next generation from making the same mistakes

-OR-

2.) **Contemplate what might have been and learn:** had we succeeded in building the SSC, the discovery of the Higgs boson could have been achieved a decade earlier, and we would be 20 years further along on the quest to study multi-TeV phenomena

Right (log scale) : JWST, ISS, Hubble, LHC, SSC, ITER

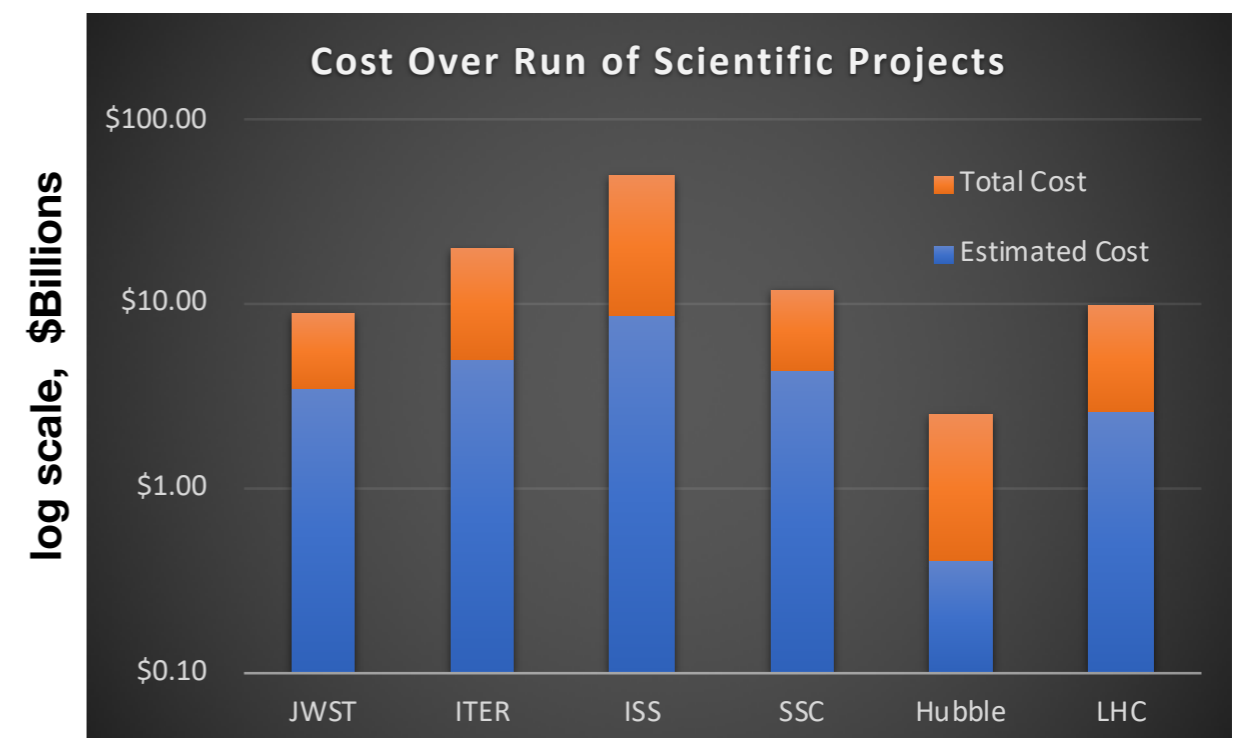
- ALL with **significant cost overruns**

Completed projects: JWST, ISS, Hubble, LHC

- ALL considered **great successes**

- ALL **inspired the next generation** to participate in STEM

We need to think of how to manage the optics of cost overruns before they happen & advocate for the scientific opportunities



Message to Leadership: **Enable the Next Generation**

The P5 Charge:

The panel's report should identify priorities and make recommendations for an optimized particle physics program over 10 years, FY 2024–FY 2033, under the following budget scenarios:

- 1) Increases of 2.0 percent per year during fiscal years 2024 to 2033 with the FY 2024 level calculated from the FY 2023 President's Budget Request for HEP.
- 2) Budget levels for HEP for fiscal years 2023 to 2027 specified in the Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022, followed by increases of 3.0 percent per year from fiscal years 2028 to 2033.

The particle physics community is more diverse than ever - full of intelligent, creative thinkers, people who are passionate and driven!

Where is the opportunity to propose exciting new large-scale projects to engage this group?!



**P5 should also propose a budget to enable the science -
- not reduce the Science to fit the Budget**

Message to Leadership: **Think Outside the Box (or at least allow us to)**

Enabling EF Collider Projects:

The US community has a longstanding history of achieving great discoveries in science - **We must continue to propose big projects and inspire the next generation STEM workforce**

- 1.) **Collaboration AND competition with other countries (Europe, China) is good! Be prepared with exciting projects when budget opportunities arise.**
- 2.) **Make Outreach and Engagement a real mission of the office (NASA has ~\$150 million budget for STEM Engagement)**
- 3.) **Encourage experiment/accelerator/theory to collaborate - through co-supervision of students, joint appointments, encouraging PIs to work on multiple projects**
- 4.) **Pay for the best project managers/legal teams but also admit there will inevitably be cost overruns**

Early Career faculty are ready to organize and take on the job of advocacy for a future Higgs Factory and a Multi-TeV project that could go online in <30 years

We are excited to **advocate for bold new ideas! We are ready to advocate to congress and the public!!**

Please do not make US EF compete with US NF - Choosing between DUNE and an EF future is not good for the field!! We should be working together as a community.

The Asks:

- 1.) We need a **method to propose and advocate for US collider projects on the 15-year timeline** that are outside the range of current DOE budgets (**Higgs Factory!**)
- 2.) We need to **increase funding for accelerator and experiment R&D** to enable a faster realization of a multi-TeV experiment (**Muon Collider!**) on the **25-year timeline**
- 3.) **We need P5 to support scientific goals and enable grass roots organizational efforts to accomplish our scientific goals:** A coordinating panel for future US-based colliders?

PRITHWISH TRIBEDY

Brookhaven National Laboratory

**“A Framework for Interdisciplinary
Research in High-Energy and
Nuclear Physics”**

A Framework for Interdisciplinary Research in High-Energy and Nuclear Physics



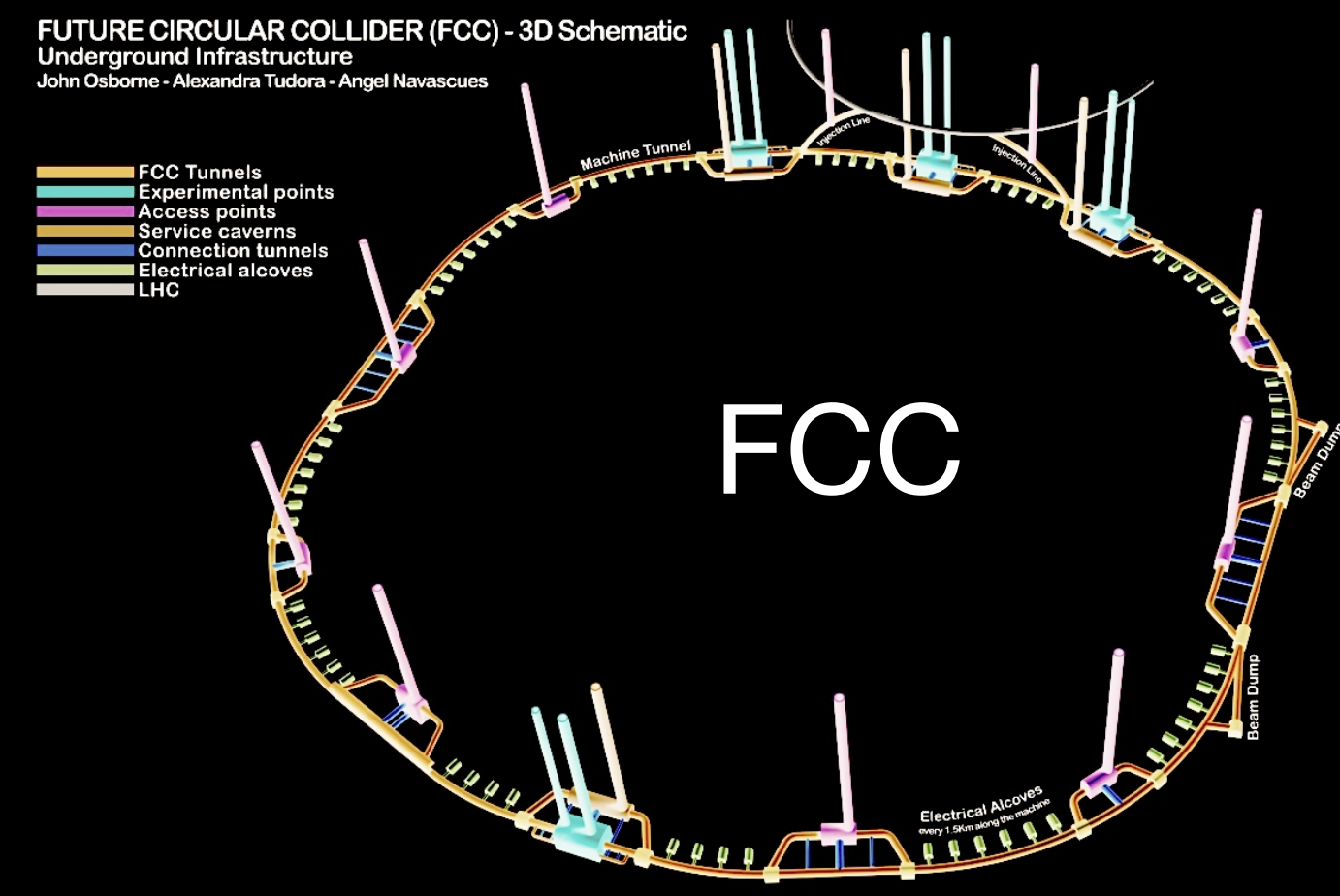
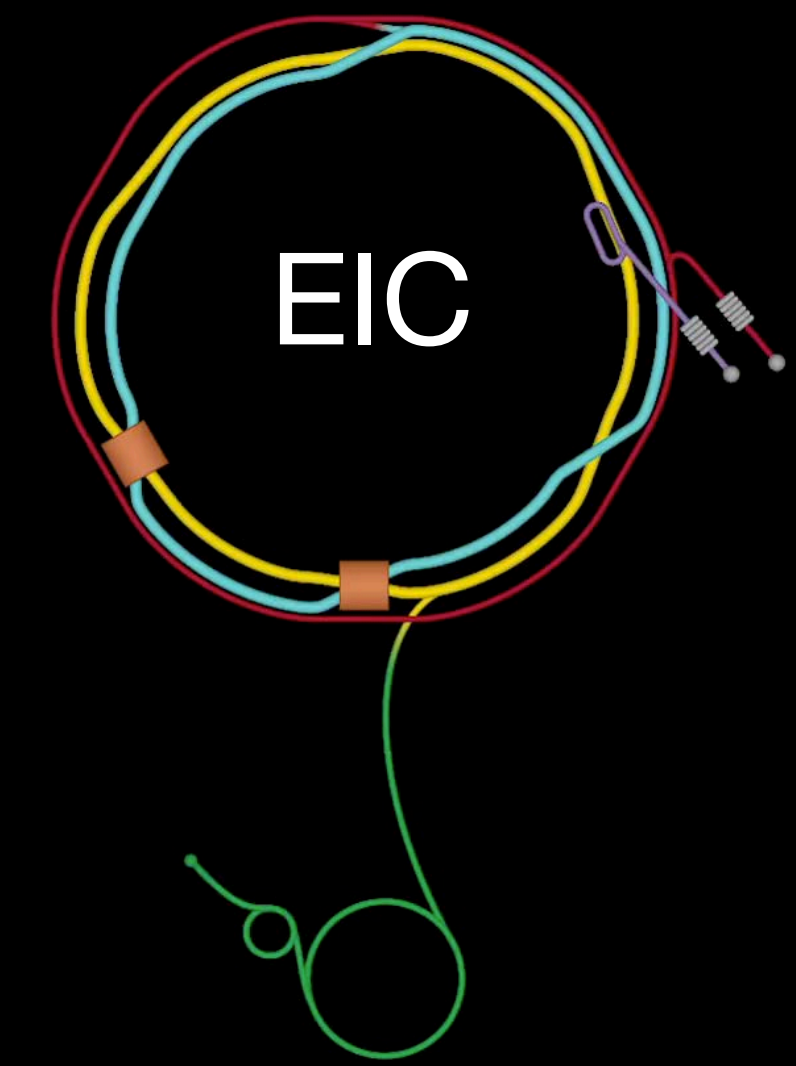
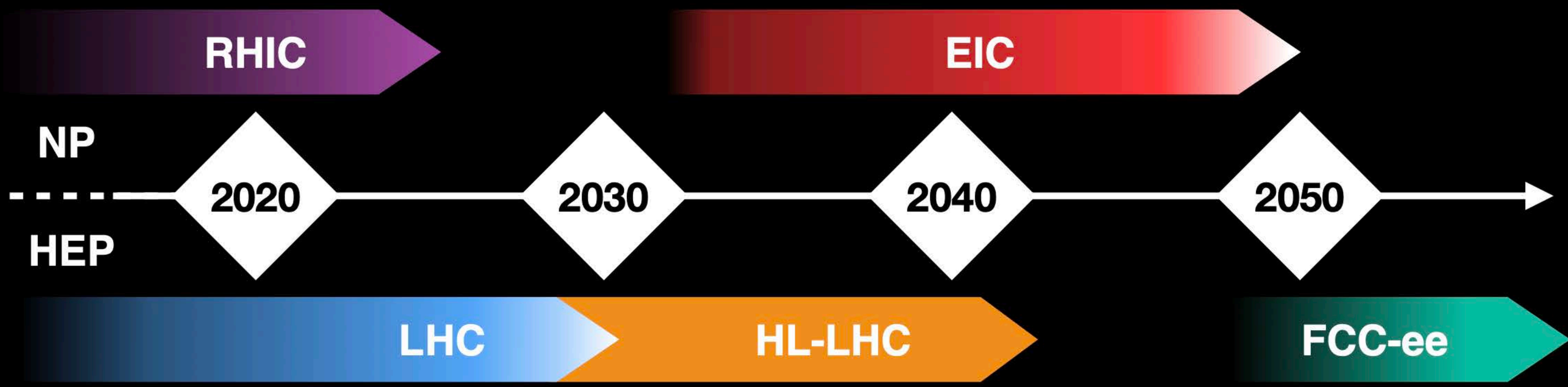
**Prithwish Tribedy (ptribedy@bnl.gov)
(Brookhaven National Laboratory)**

P5 Town Hall Meeting, 12-14 Apr, 2023

TEASER: Join forces to advance High-Energy and Nuclear Physics by establishing an official framework of R&D for early career scientists

Opportunities as (an early-career) high-energy physicists

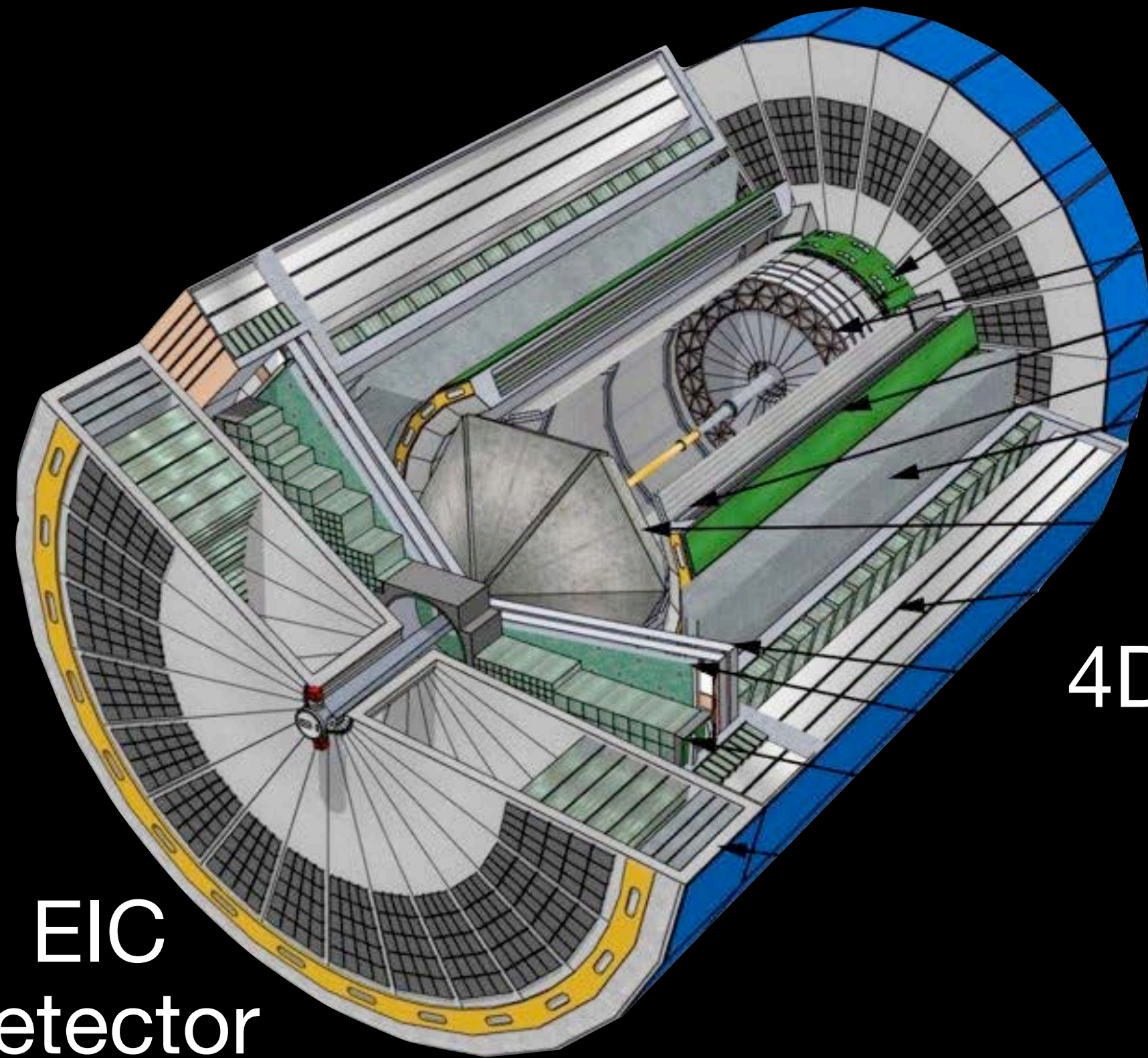
The US-based electron-ion collider is the next major nuclear physics collider is an opportunity



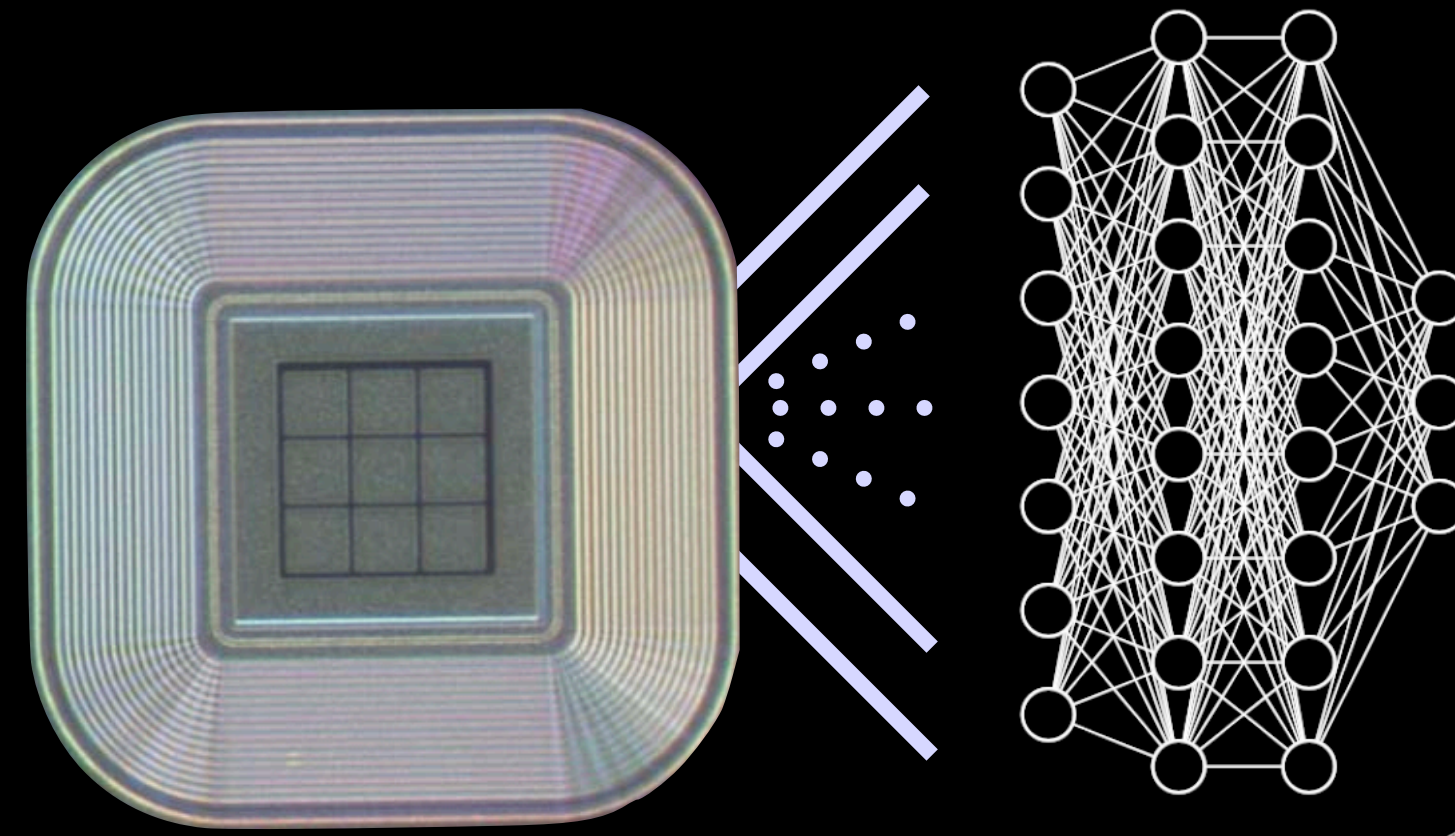
- Detectors: Leapfrogging technologies (MAPS, AC-LGAD) at the EIC for future FCC-ee
- Readout: Testing ground for Edge-AI and advanced streaming systems
- Physics: High precision PDF for QCD background in HL-LHC data

Opportunities as (an early-career) nuclear physicists

EIC experiments can leverage High-Energy Physics technologies and technique

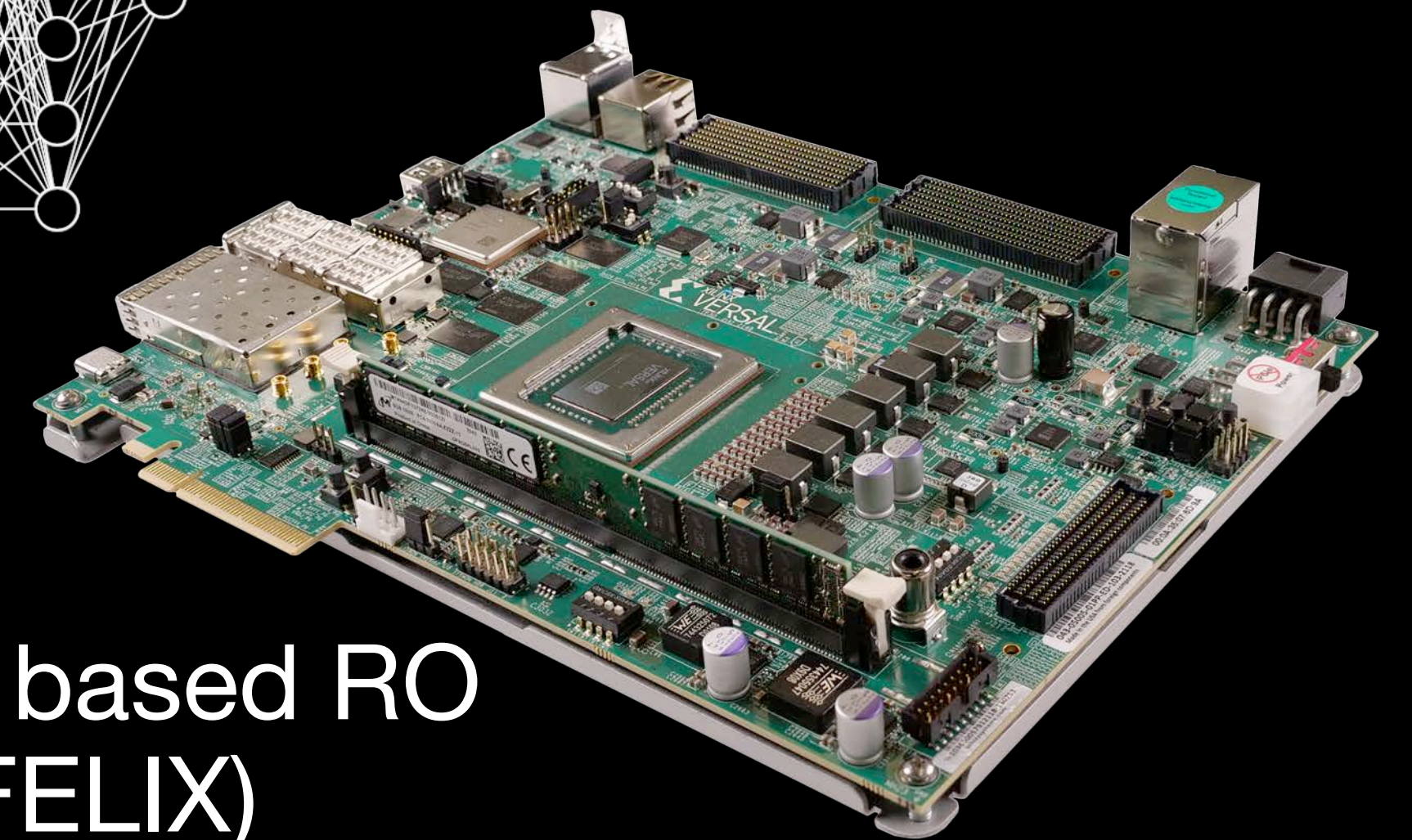


EIC detector



4D sensor (AC-Low Gain Avalanche Diode)

Edge-AI The logo for hls4mi, featuring the text 'hls' in purple, '4' in a white box with a purple border, and 'mi' in blue, all connected by lines to a central square chip icon.



FPGA based RO (FELIX)

- Fast-time pixel/strip sensors, front-end electronics: candidates for EIC detectors
- Edge-AI enhance readout and FGPA : candidate for reduce data throughput
- Machine learning techniques (Jet-substructure): improve measurement precision

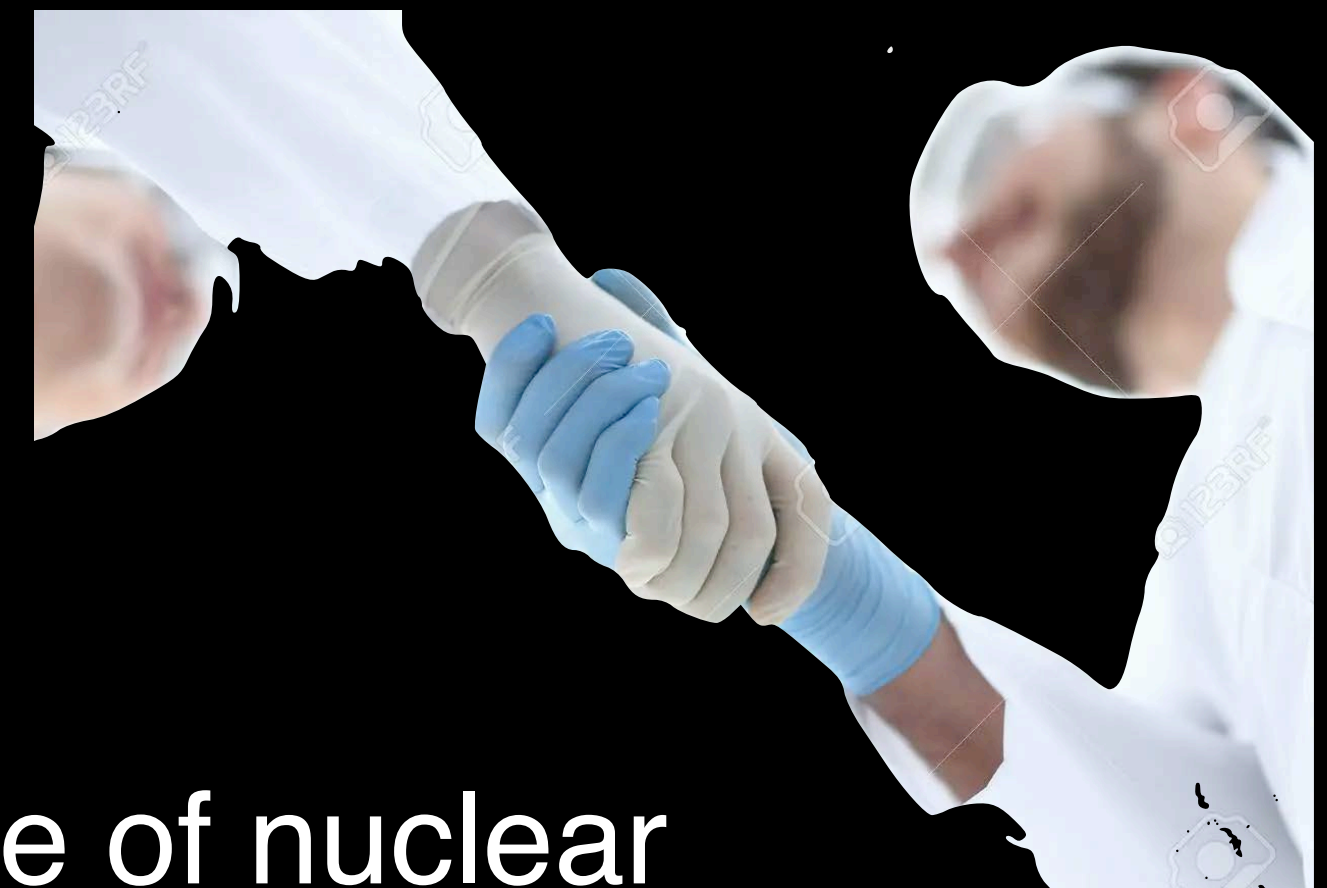
Summary

Recommendations:

- Establish an official framework to foster collaboration and leverage synergy between early career high-energy and nuclear physicists
- Transfer technologies and techniques between the two fields
- Exploit the timeline of mega-facilities to leapfrog advancements in both fields

Action Items:

- Organize joint conferences and workshops
- Fund interdisciplinary research
- Develop joint training programs & workforce development
- Encourage more dialogue and collaboration between the "office of nuclear physics" and the "office of high energy physics"



Potential example of success:

- AC-LGAD/MAPS detector + AI-enhanced readout at EIC, informative for FCC-ee

SOUBHIK KUMAR

University of California, Berkeley

**“Broad impact of the Energy Frontier
towards BSM searches in synergy with
the other frontiers:
Axion and ALP example”**

Broad impact of the Energy Frontier towards BSM searches in synergy with the other frontiers: Axion and ALP example

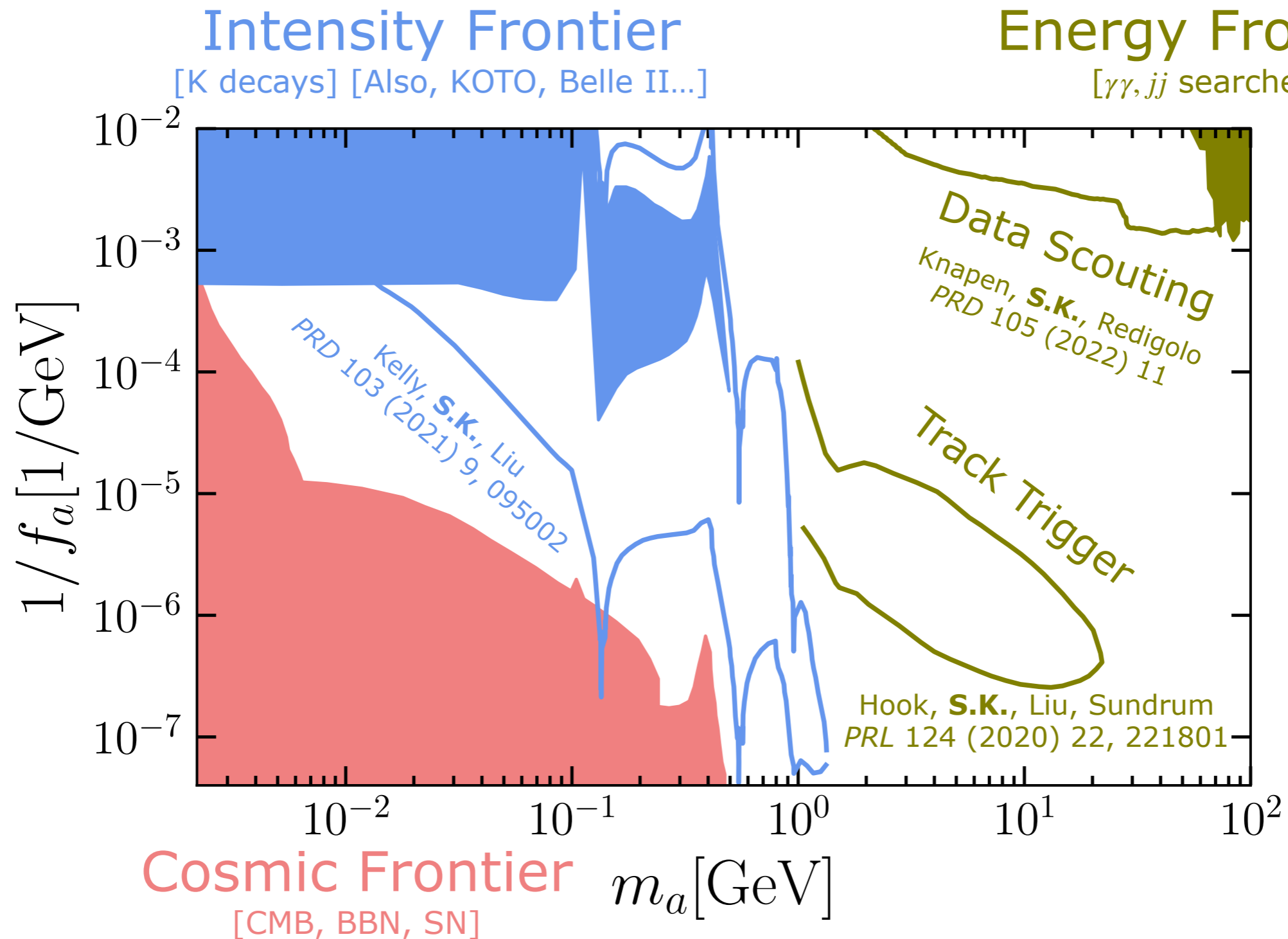
Soubhik Kumar
UC Berkeley and LBL

P5 Town Hall Meeting
Brookhaven National Laboratory

Hidden Sectors

- ▶ Very well motivated: Dark Matter, Strong CP Problem...
- ▶ Cosmic Frontier and Intensity Frontier provide excellent probes, especially for MeV-GeV scale masses [e.g., CMB, BBN, rare meson decay]
- ▶ Energy Frontier can play a complementary and powerful role: lots of room for progress!
 - ▶ Theory predictions and model building
 - ▶ Detection strategy and upgrades

Energy Frontier Probes of Axion/ALP



Back-up Slides

Low-Mass Diphotons

Knapen, **S.K.**, Redigolo: *PRD* 105 (2022) 11

$$m_{\gamma\gamma} \simeq \sqrt{p_{T_1}^\gamma p_{T_2}^\gamma \Delta R_{\gamma\gamma}}$$

Addressing
trigger threshold

Use "data scouting"

allows for **smaller** p_T

event rate increases, but **event
size is smaller**

so can still write data on tape
at $\ll 1$ GB/s

Addressing
photon isolation

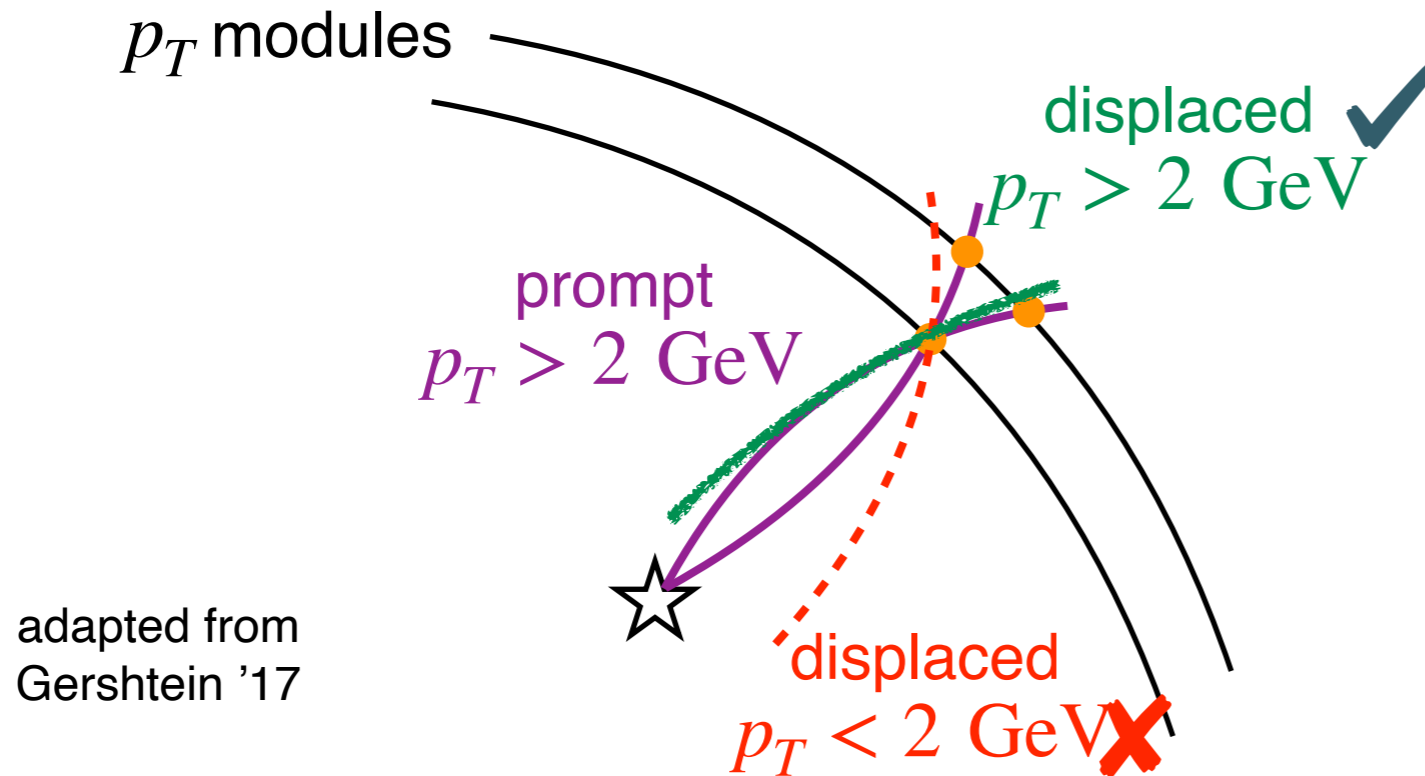
Use "modified isolation"

Light resonance: **boosted** &
the photons overlap with each other

Subtract the subleading photon

Track Trigger

Hook, **S.K.**, Liu, Sundrum:
PRL 124 (2020) 22, 221801



proposal to trigger on
displaced tracks

Gershtein '17
CMS-PAS-FTR-18-018
Gershtein, Knapen '19

Vertex selection

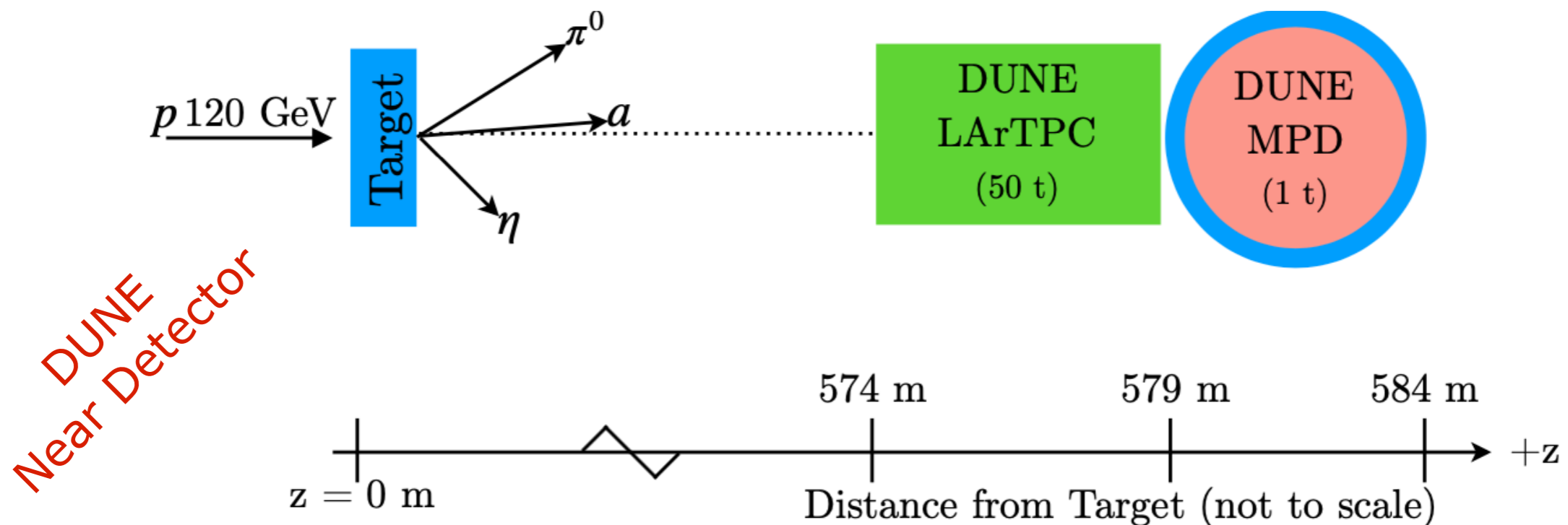
1. The 2D tracks fit a common vertex with standard deviation $\Delta d_T < 1 \text{ cm}$;
2. The 2D common vertex has a minimal distance to the interaction point of 0.5 cm and maximal distance of 35 cm, $0.5 \text{ cm} < d_T < 35 \text{ cm}$;
3. The 2D common vertex is significantly displaced away from the interaction point, $d_T/\Delta d_T > 5$;
4. The corresponding 4D vertex has a standard deviation in z direction $\Delta d_z < 5 \text{ cm}$;
5. The corresponding 4D vertex has a z -direction location $d_z < 20 \text{ cm}$;
6. The corresponding 4D vertex has a standard deviation in time $\Delta d_t < 500 \text{ ps}$;
7. The corresponding 4D vertex has a time $d_t < 1000 \text{ ps}$;
8. The tracks are within 0.4 in pseudorapidity of the reconstructed displaced jet direction $|\eta_i - \eta_V| < 0.4$ for all the three tracks;
9. The tracks are within 0.4 in azimuthal angle of the reconstructed displaced jet direction $|\phi_i - \phi_V| < 0.4$ for all the three tracks,

Axions at DUNE

Kelly, S.K., Liu: *PRD* 103 (2021) 9, 095002

$$\mathcal{L}_{\text{gauge}} \supset c_3 \frac{\alpha_s}{8\pi f_a} a G \tilde{G} + c_2 \frac{\alpha_2}{8\pi f_a} a W \tilde{W} + c_1 \frac{\alpha_1}{8\pi f_a} a B \tilde{B}$$

need a **large distance** between production and detector:
beam dump experiments



RAZA SUFIAN

Brookhaven National Laboratory

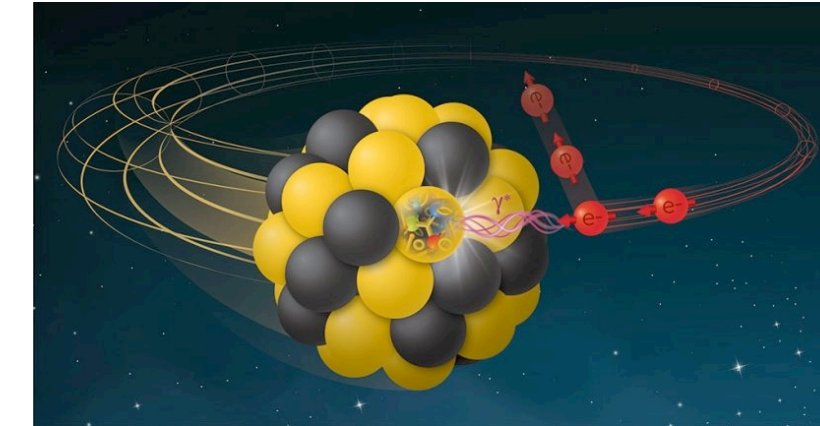
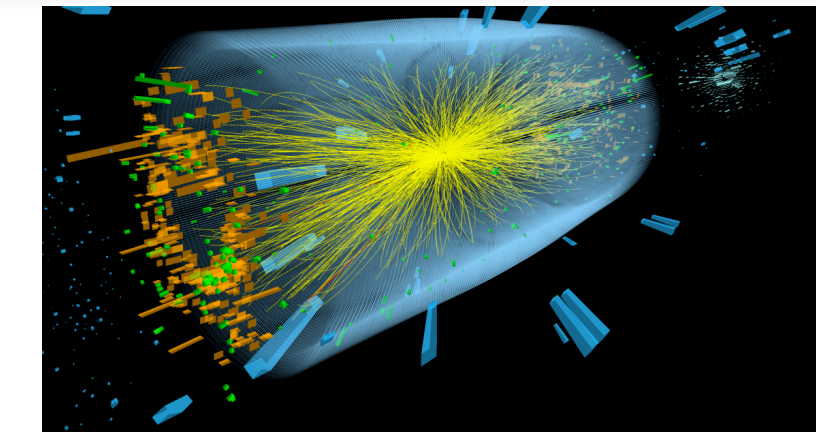
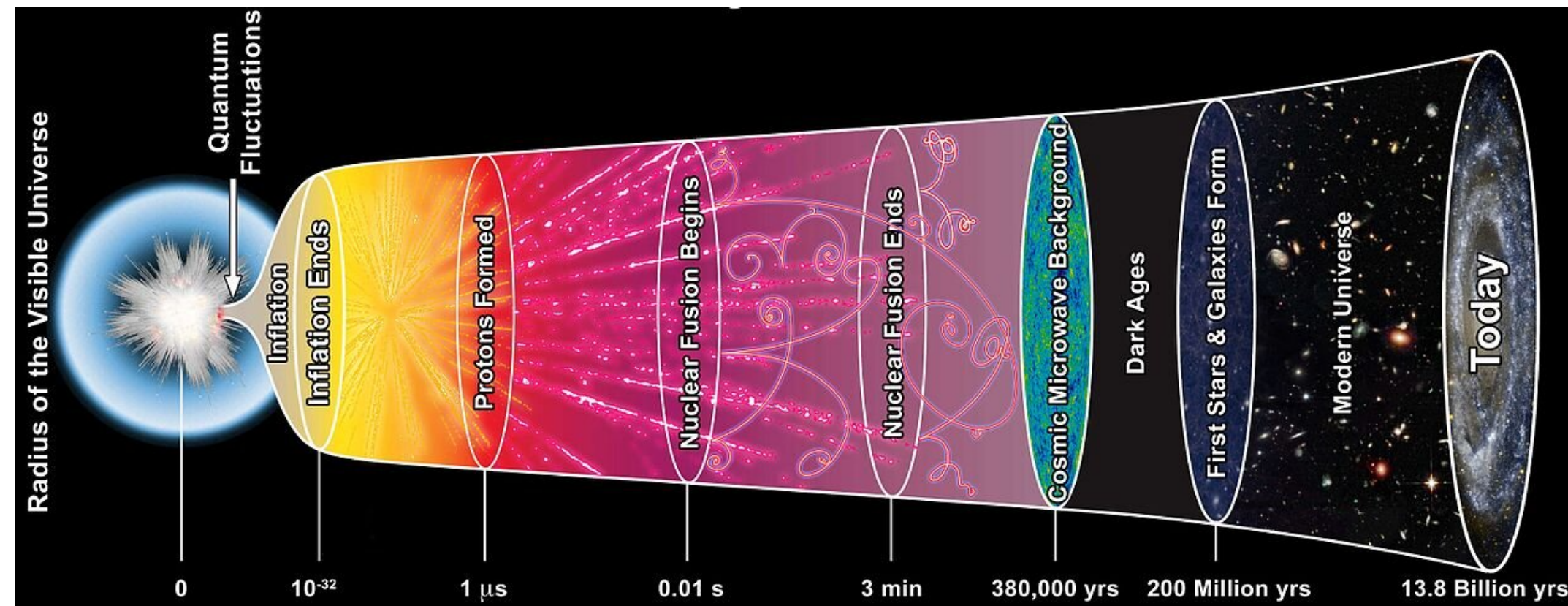
“Elucidating the quark and gluon distributions in the nucleon, pion, and kaon from lattice QCD”

Elucidating the quark & gluon distributions in the nucleon, pion and kaon from Lattice QCD

Raza Sabbir Sufian

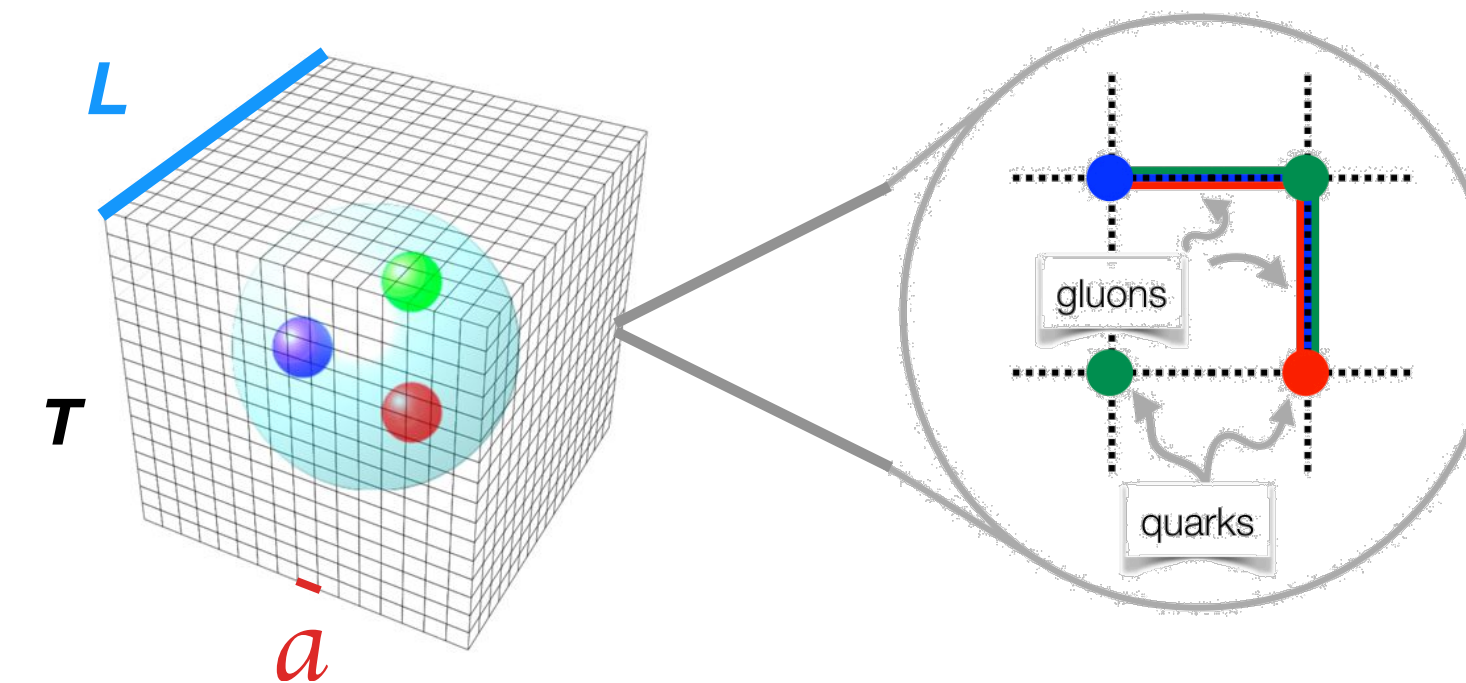
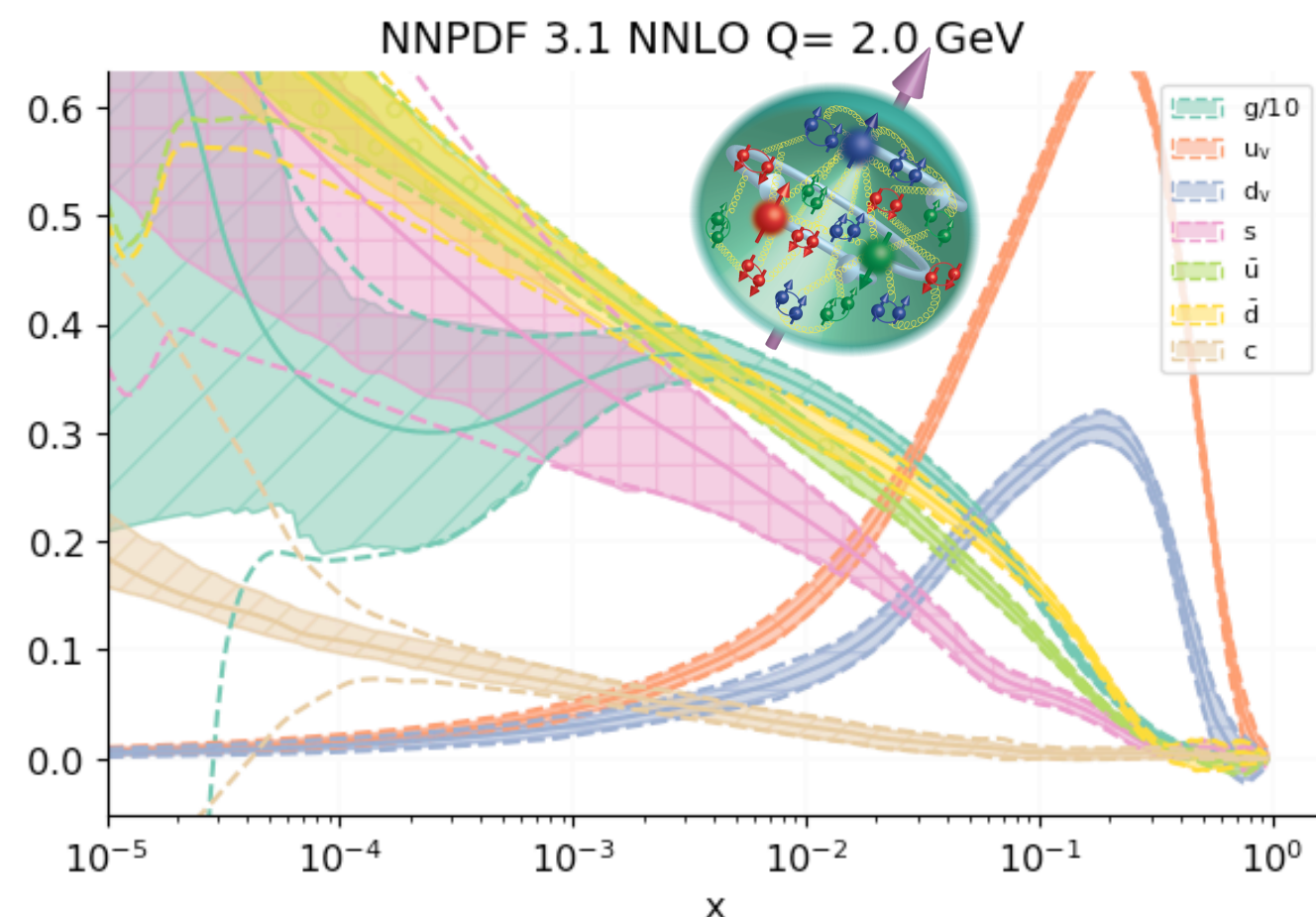


Frontiers of QCD and how Lattice QCD can contribute



● Nonperturbative quark/gluon distributions are essential for

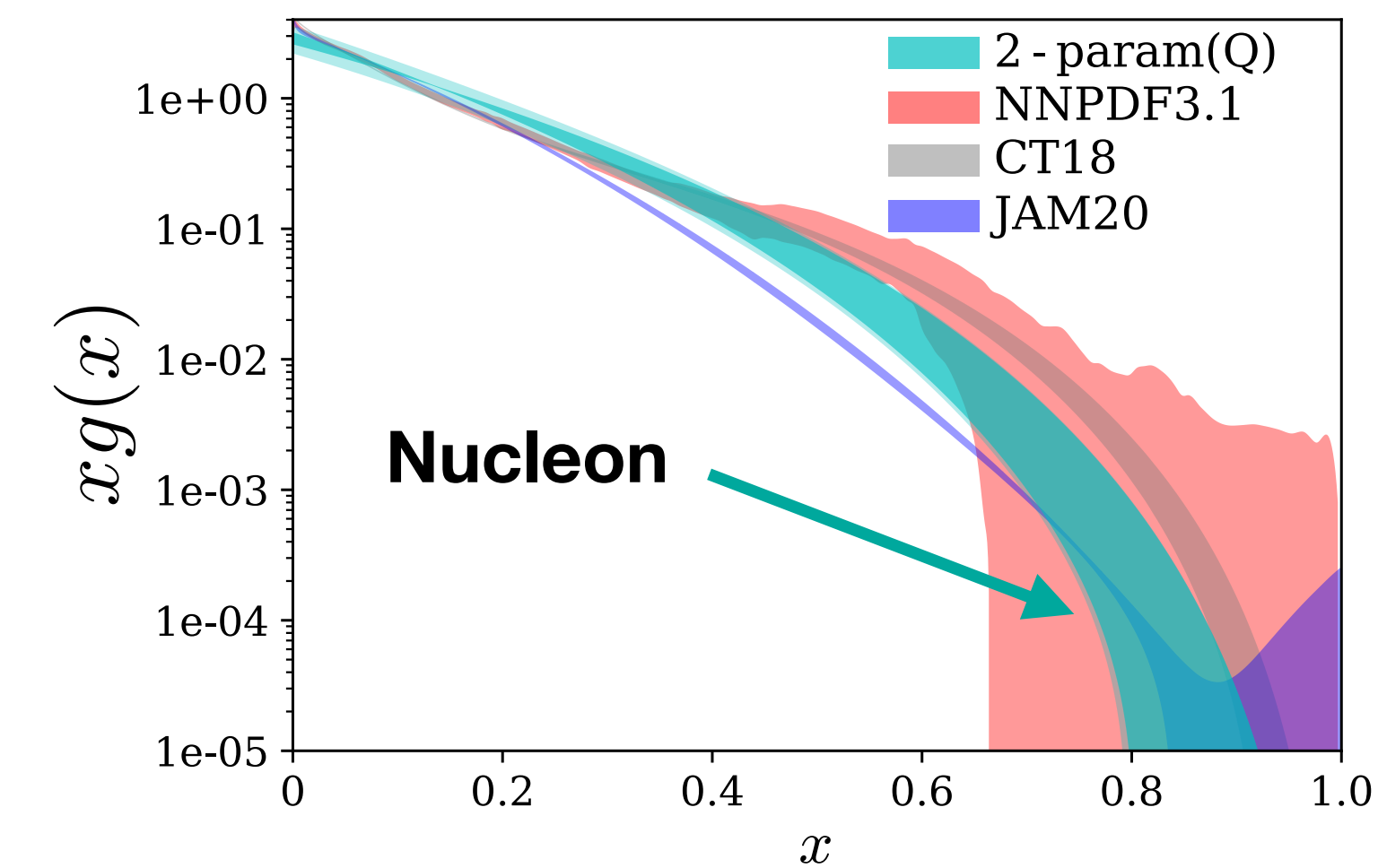
- ▶ predicting/describing outcomes from collider experiments
- ▶ understanding the role of gluon that binds us all



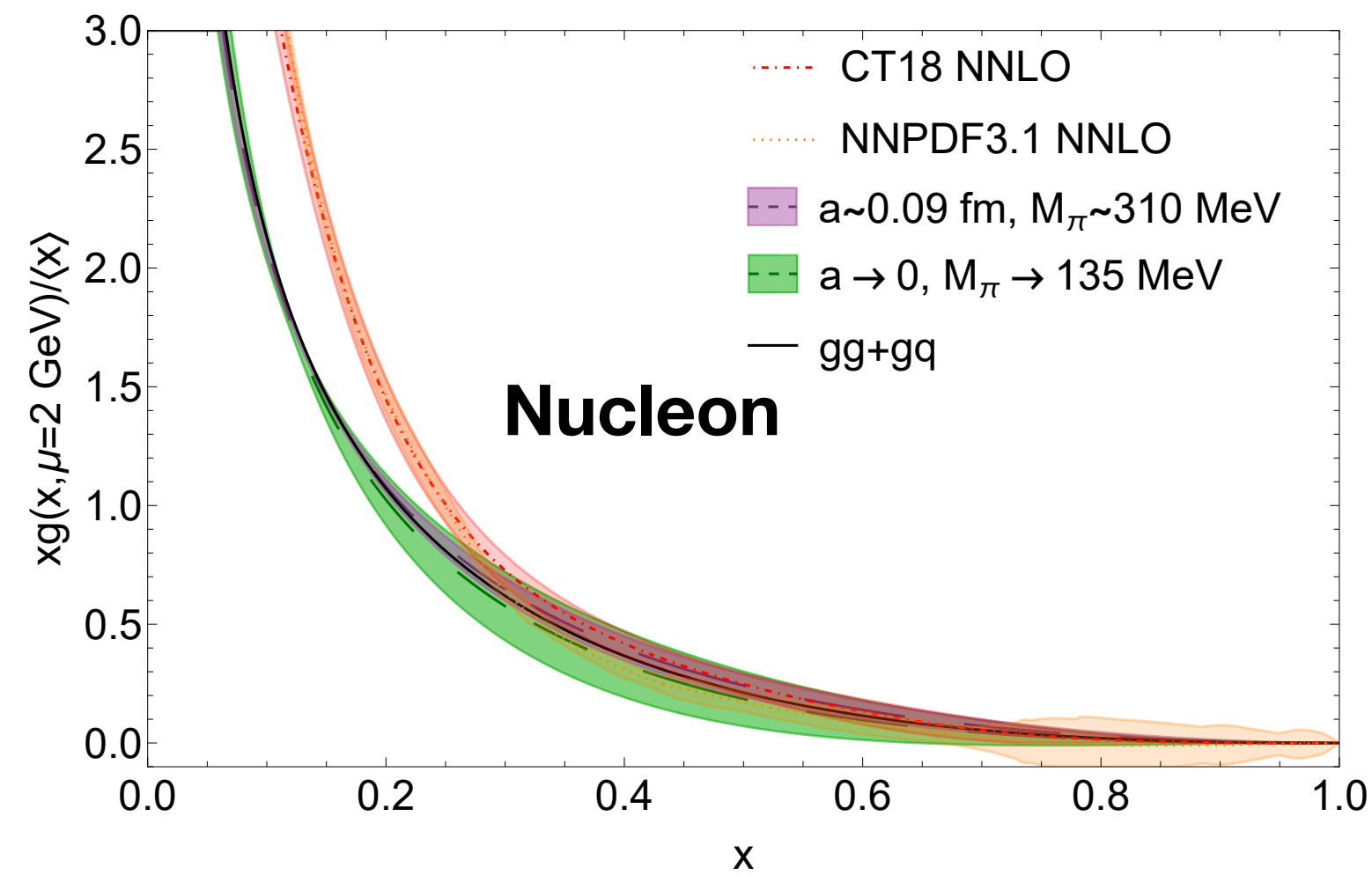
Lattice QCD

Potential impacts of Lattice QCD (e.g. gluon distributions)

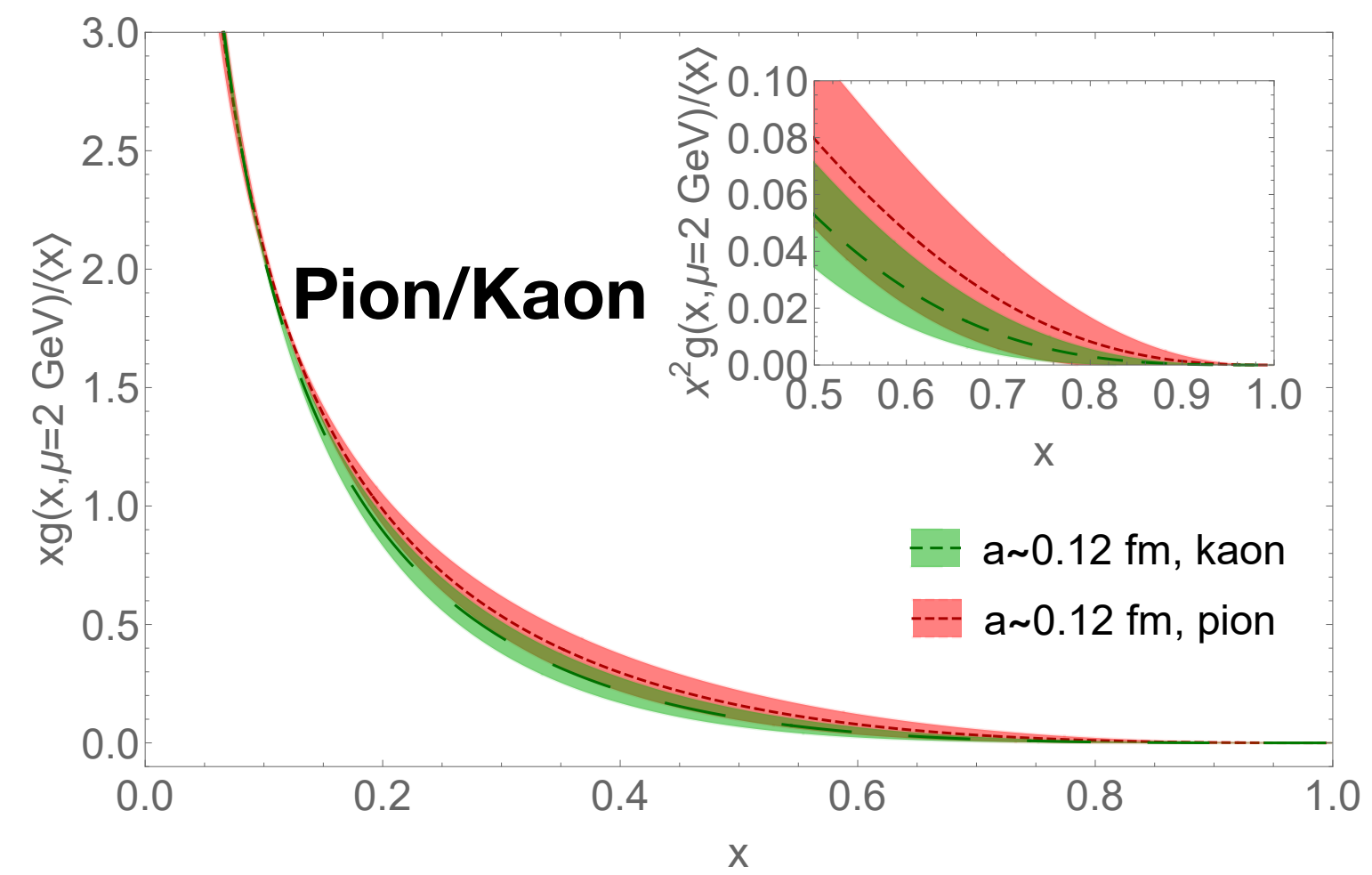
Unpolarized gluon PDF



Khan, RSS, et al (HadStruc)(2021)

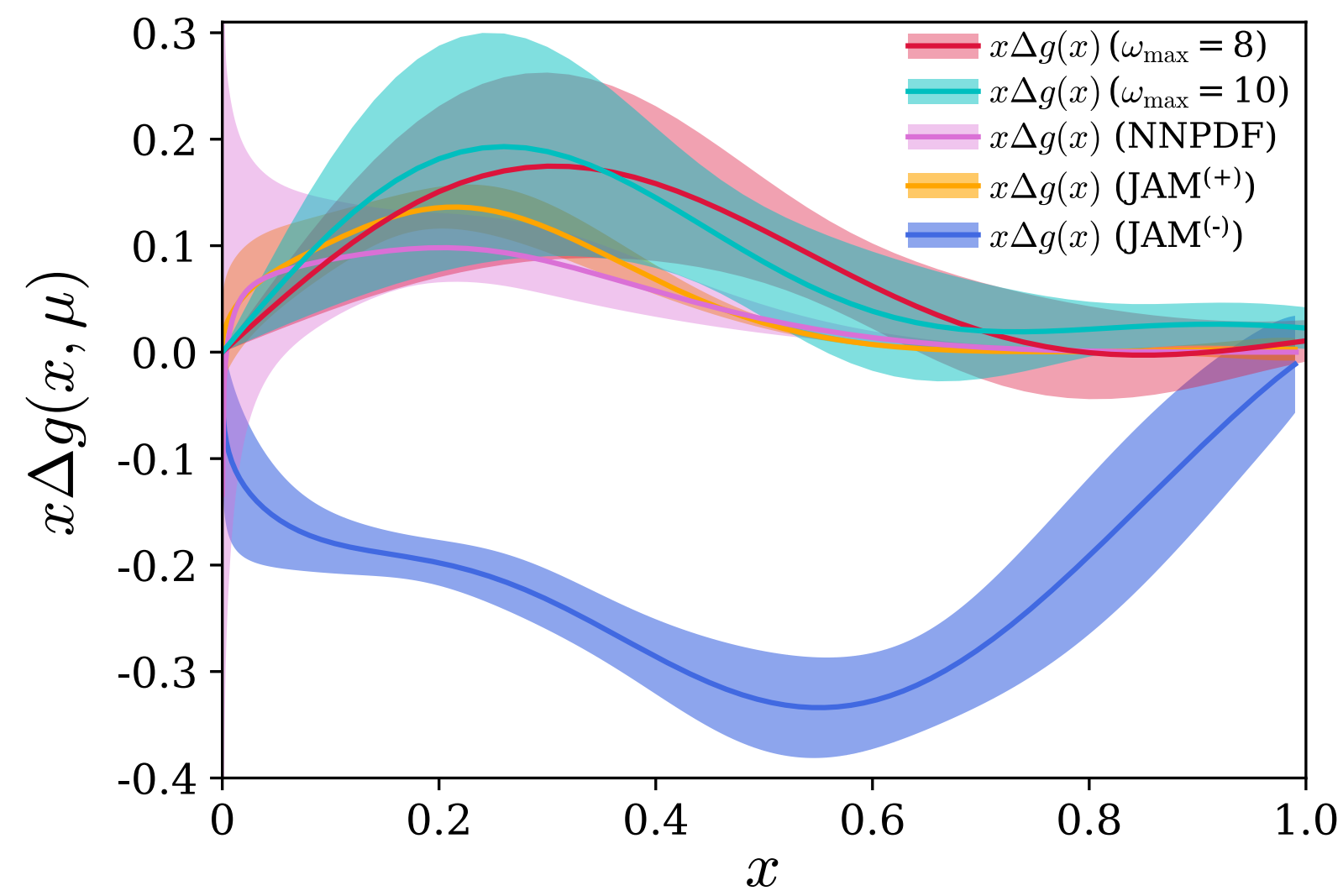


Fan, Lin, et al (MSU Latt)(2022)



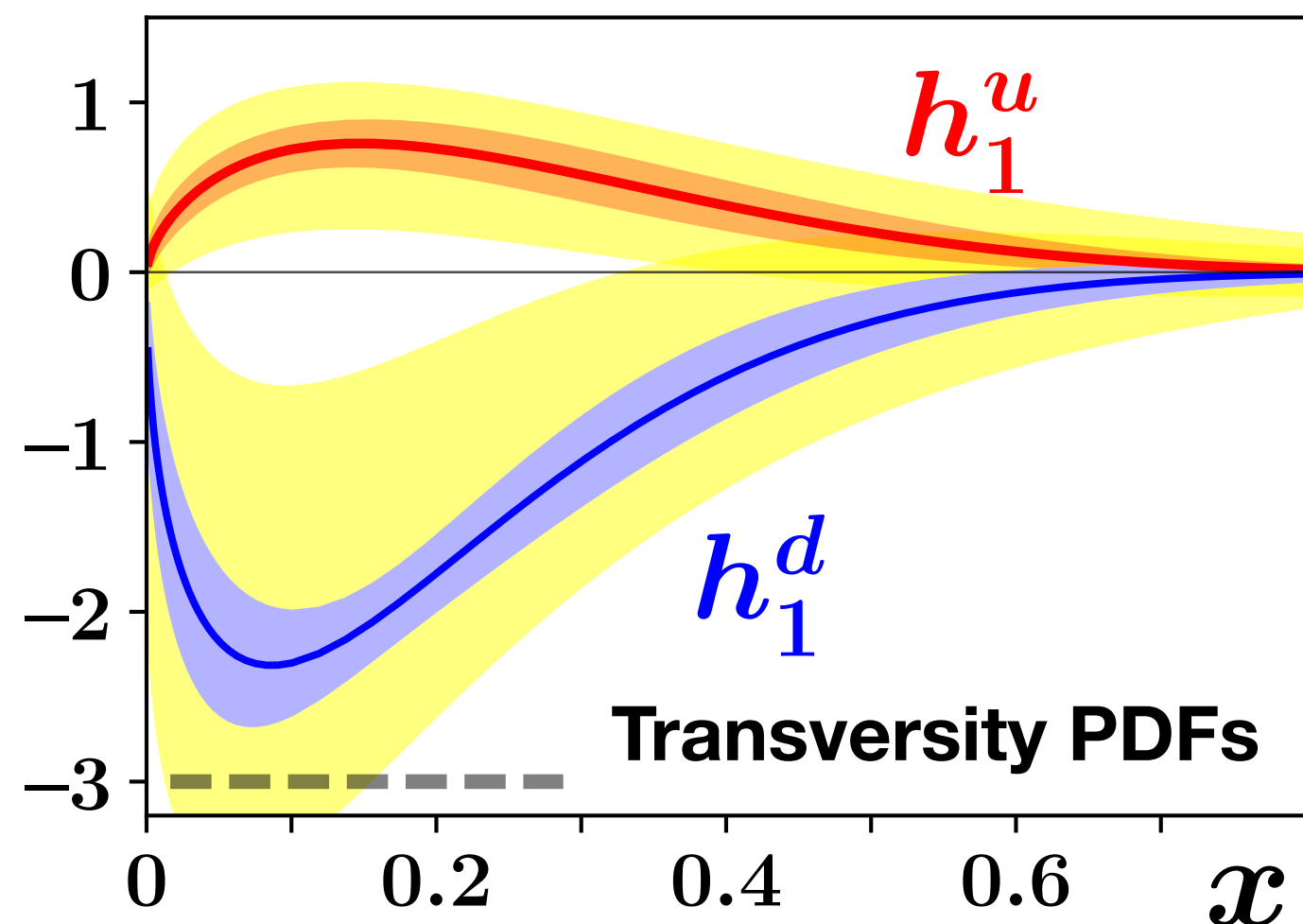
Fan, Lin, et al (2022)

Gluon helicity PDF (Lattice QCD + ML)

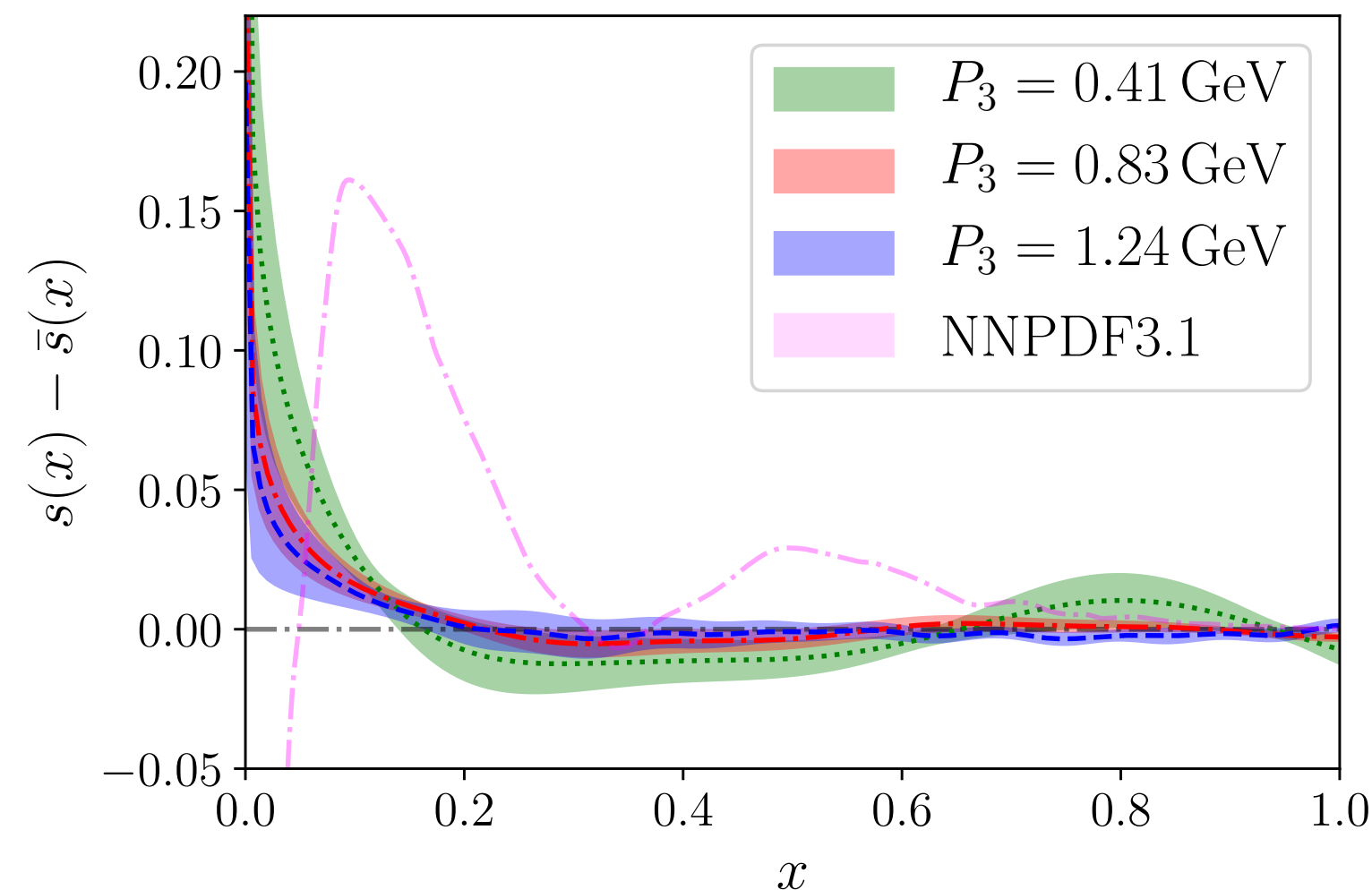


Khan, Liu, RSS (2022)

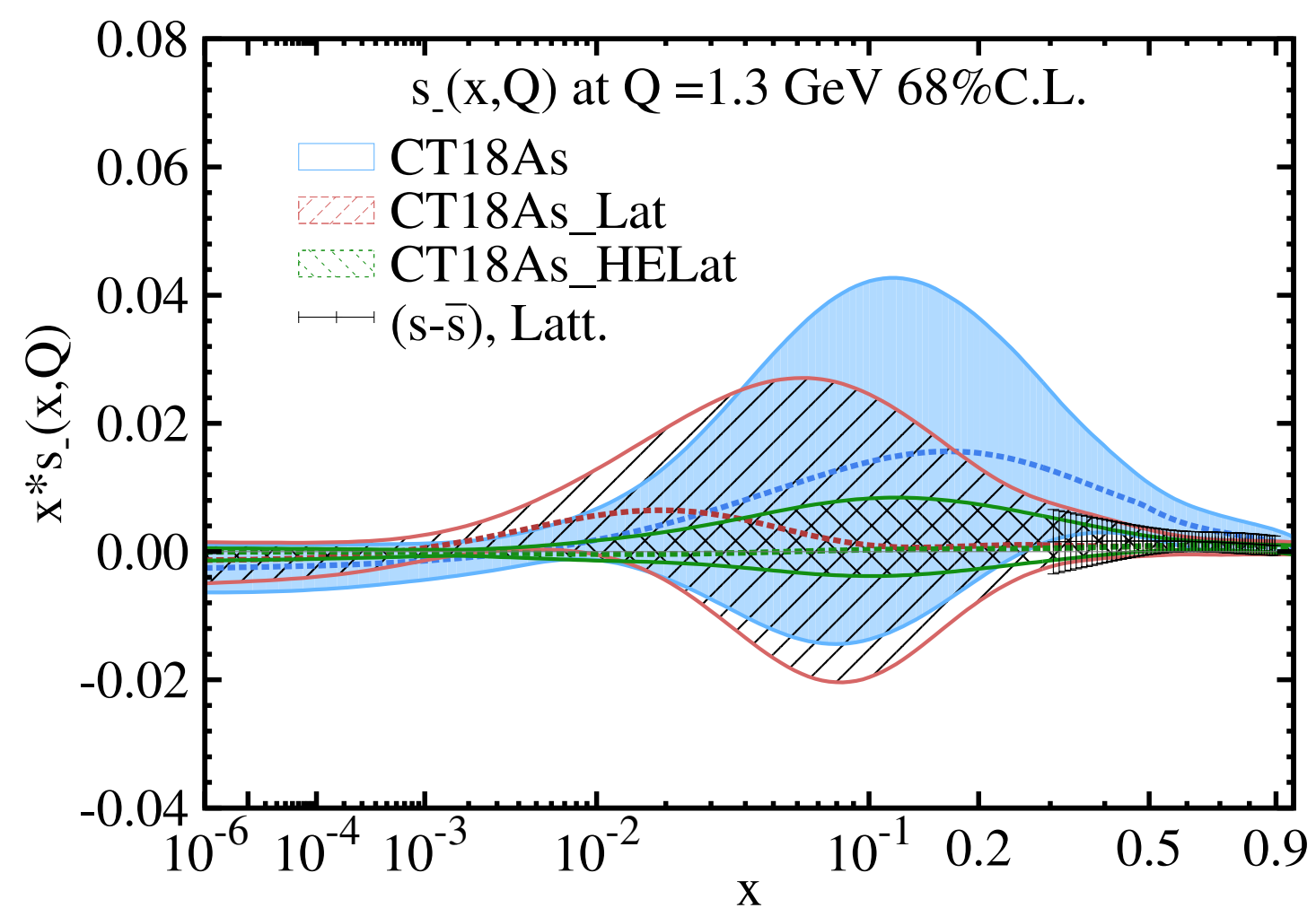
Potential impacts of Lattice QCD on global fits of PDFs



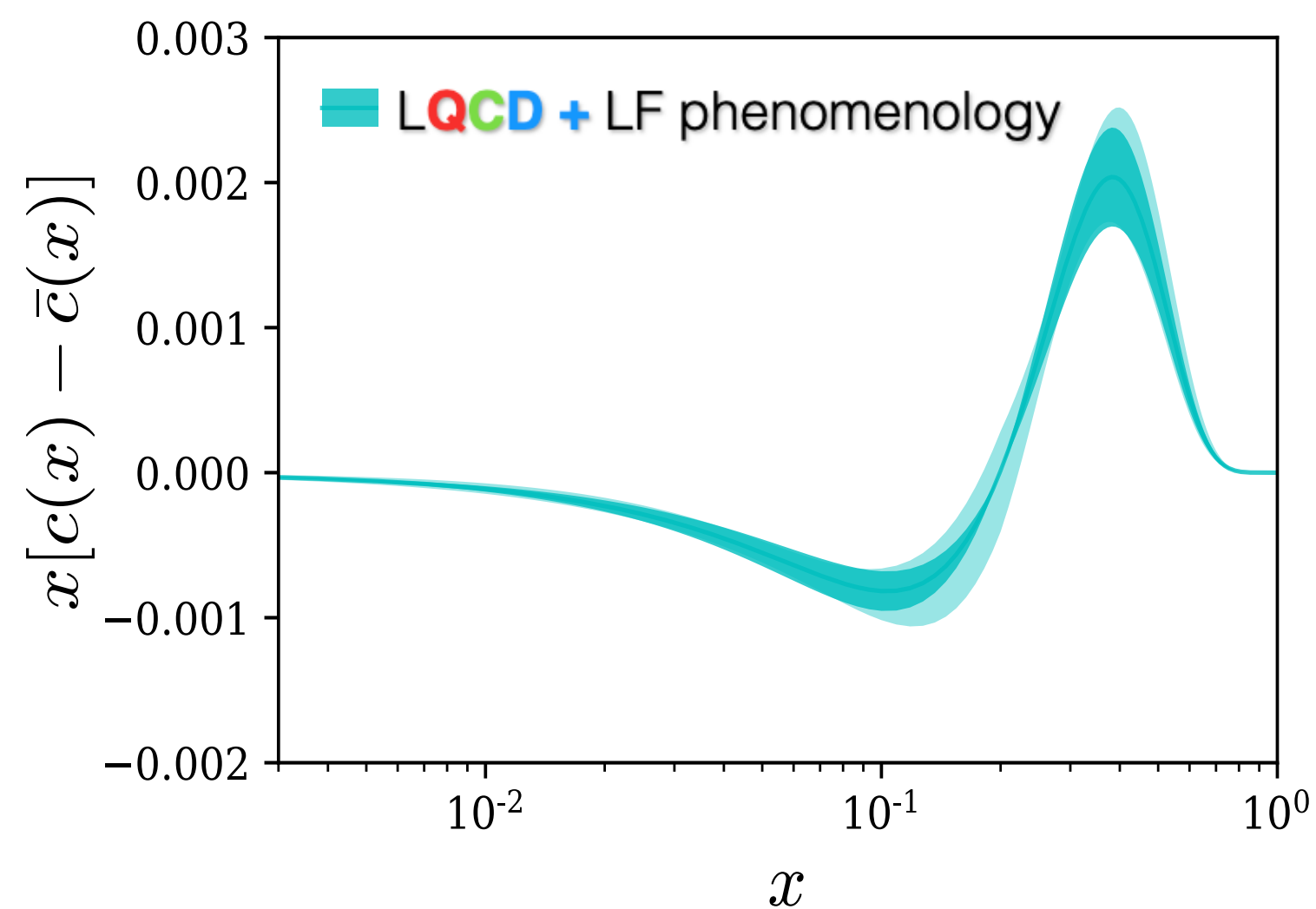
Lin, et al (2018)



Alexandrou, et al (ETMC)(2021)



LQCD + CTEQ-TEA global analysis
[Hou, Lin, et al (2022)]



RSS, Liu, Brodsky et al (2021)

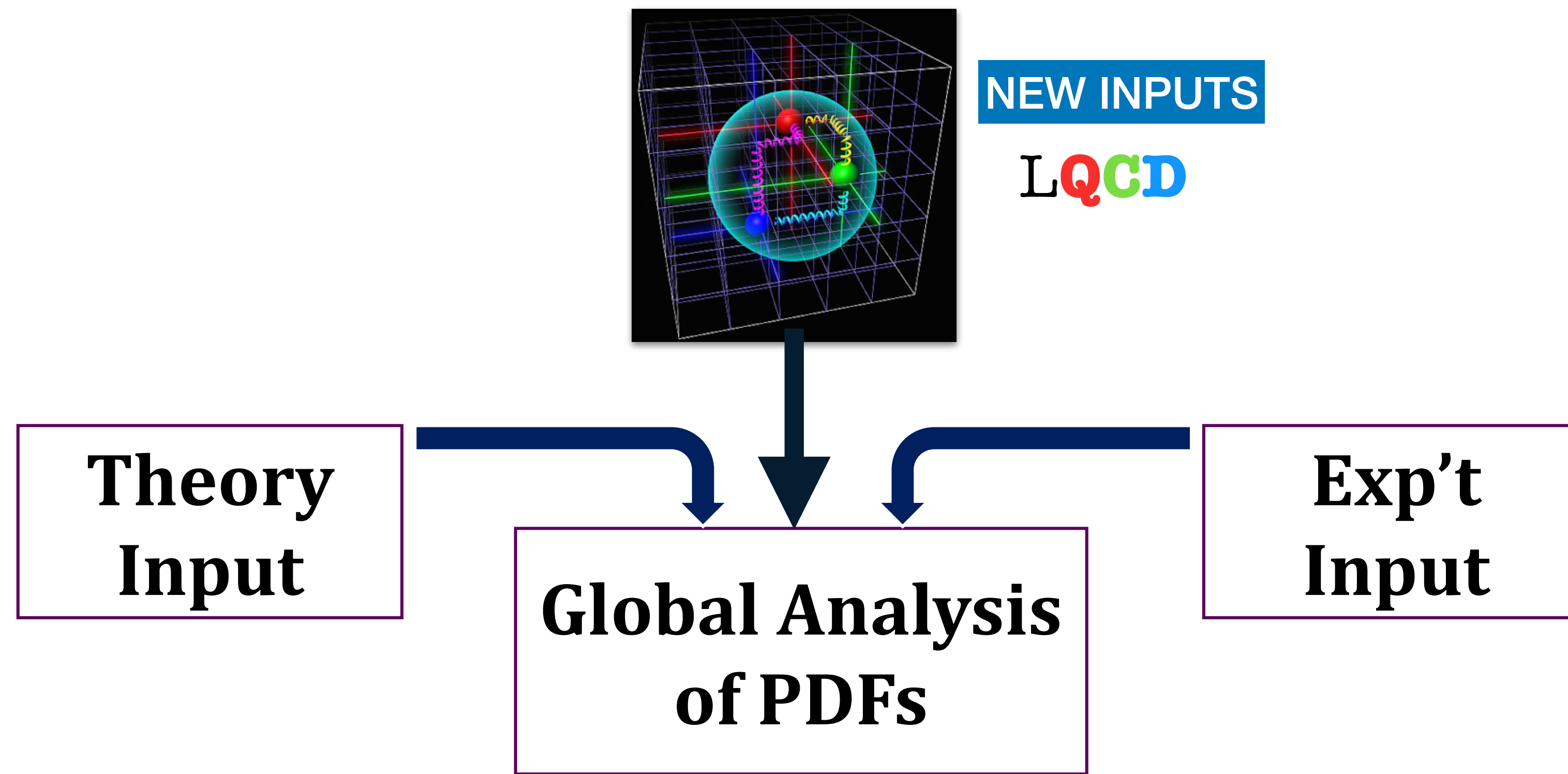
Supported by subsequent LHCb experiment (PRL 2022)

Challenges + Resources



New opportunities + impactful physics insights

- Precision calculation and study of systematics are planned for near future
- ▶ Precision and progress are limited on resources (computing resources, human resources, etc)



- Exciting time for LQCD to study PDFs

For more : Snowmass 2021 whitepaper: Proton structure at the precision frontier

Thank you

DEBORAH PINNA

University of Wisconsin

**“Can future colliders be the light
to see dark matter?”**

Can future colliders be the light to see dark matter?

Deborah Pinna
(University of Wisconsin, LPC)

P5 Town Hall Meeting, *Short remarks*

BNL, 12-14 April



Why and where to look for Dark matter?

DM evidence



- ▶ Many empirical evidences of DM from astrophysical observations
 - interacts gravitationally, long lived and neutral
 - no information about its nature
- * most studied class of theories: DM is a weakly interacting massive particle

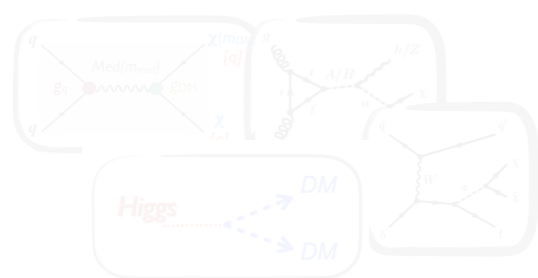
DM production



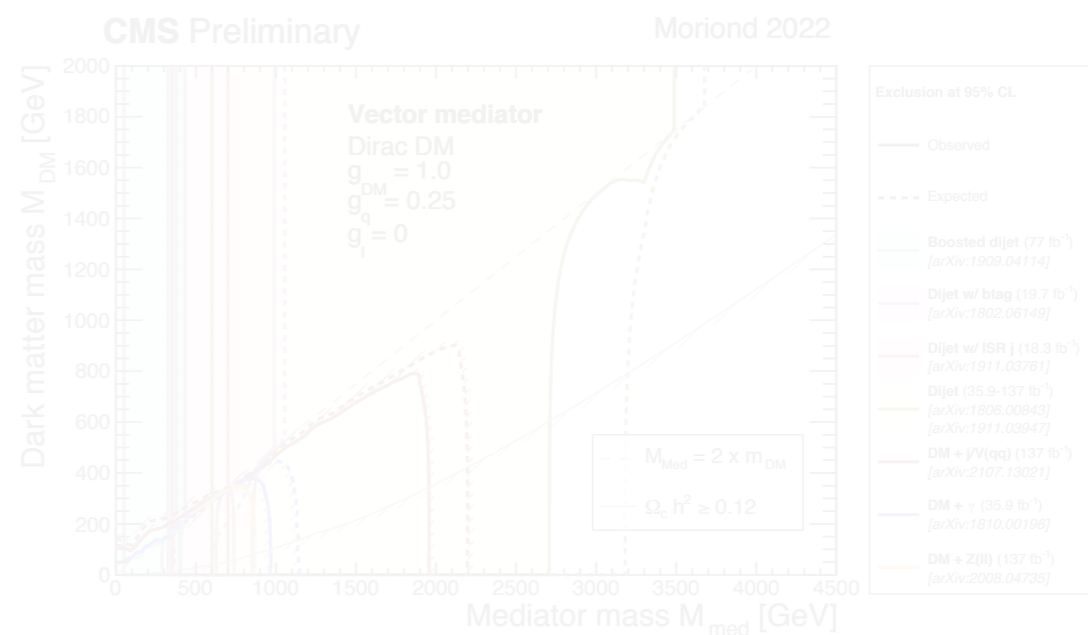
- ▶ DM could be produced at colliders (rare process)
 - no direct trace in the detector, but could create a p_T imbalance (**MET**)
 - need visible particle X for DM particle to recoils against (*mono-X searches*)

DM signature

investigate specific interactions/final states



- ▶ Very rich phenomenology studied at LHC
 - simplified models
 - DM Higgs portal
 - 2HDM, ...
- * not only mono-X ...
 - dijet
 - resonances



WHAT IF DM HIDES AT HIGHER ENERGIES?

Why and where to look for Dark matter?

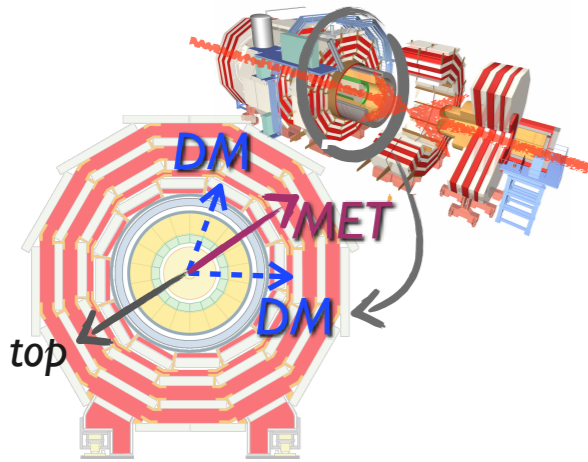
DM evidence



assume weak interactions with SM



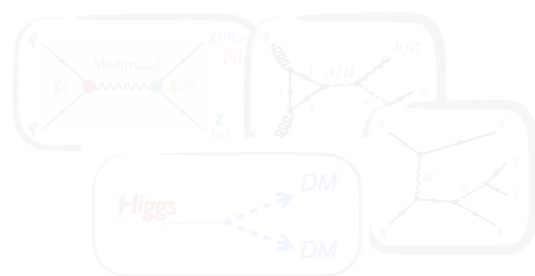
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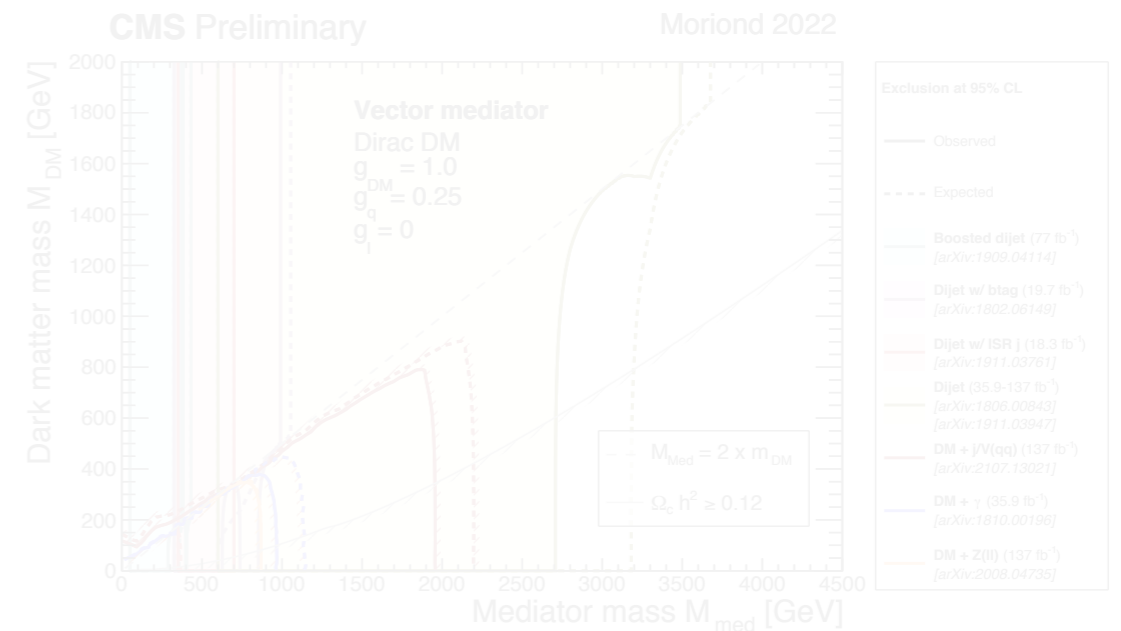
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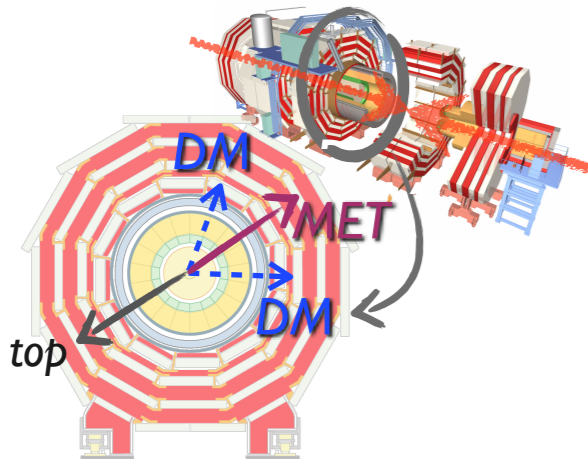
Why and where to look for Dark matter?

DM evidence



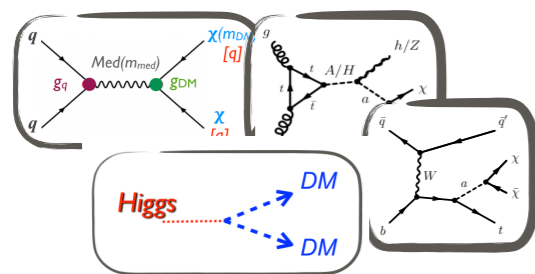
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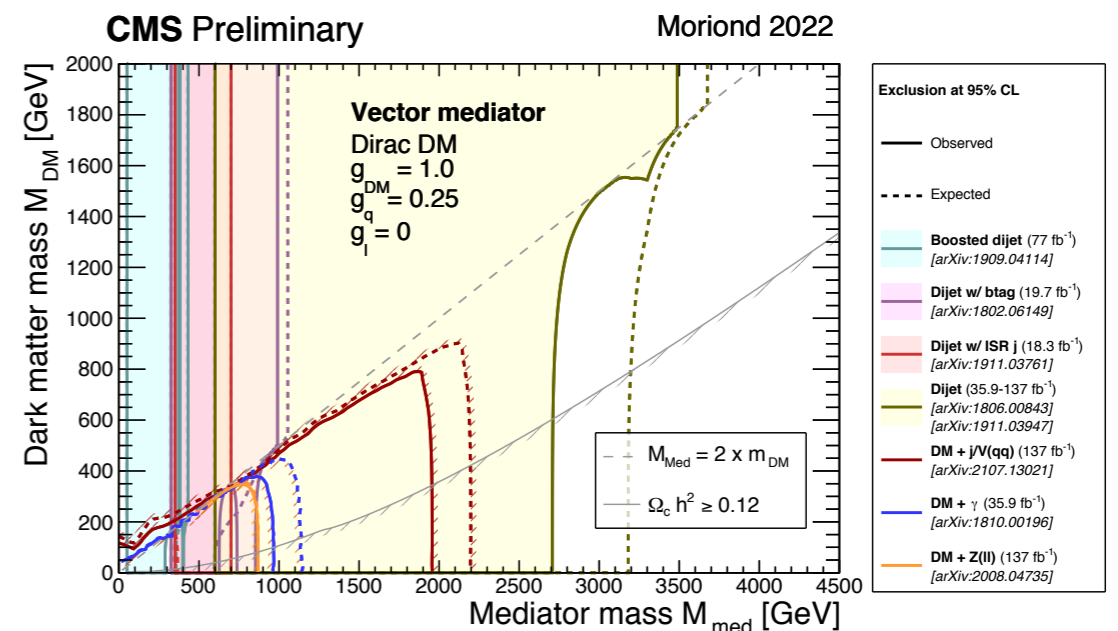
- DM Higgs portal

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* *not only mono-X ...*

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- resonances



WHAT IF DM HIDES AT HIGHER ENERGIES?

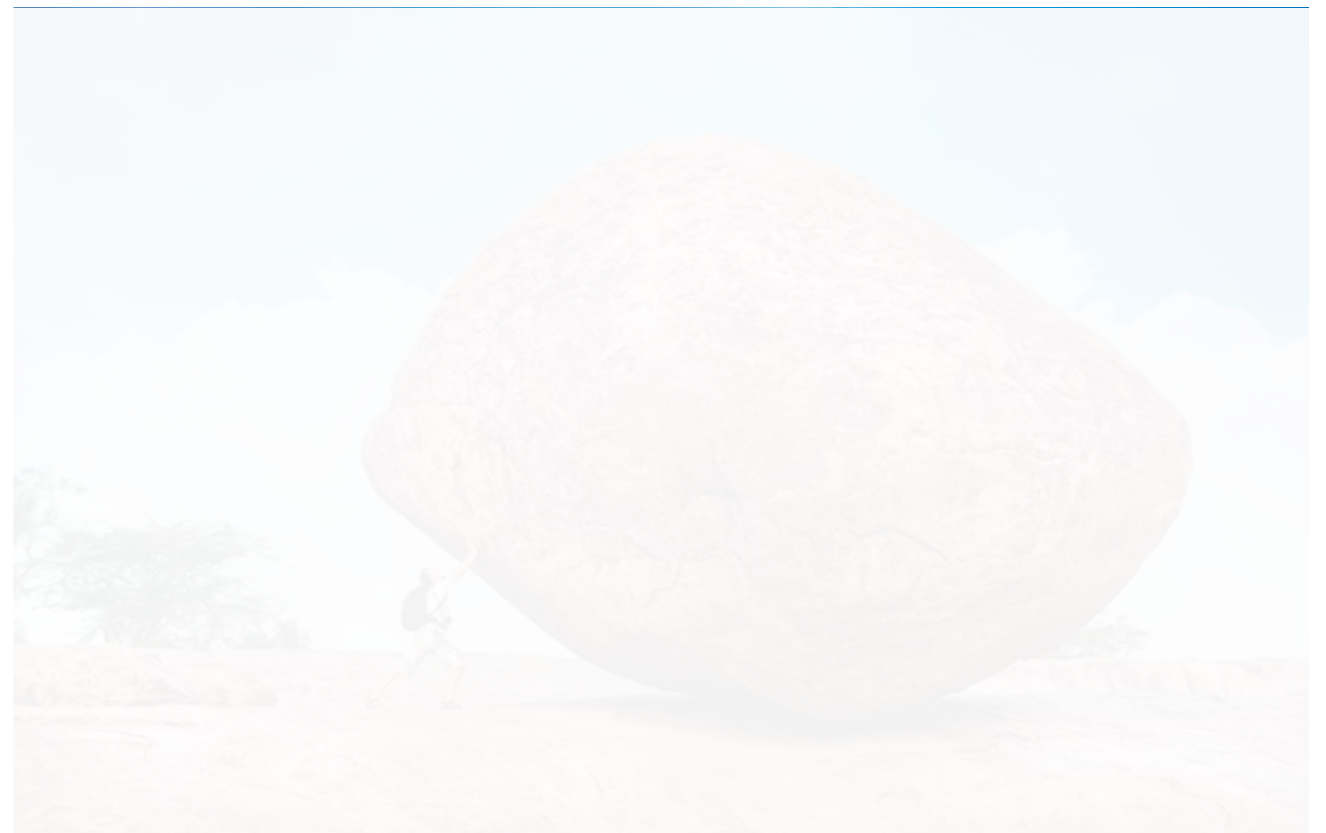
Leaving no stone unturned ...

► *DM could be the lightest member of an EW multiplet*

[arXiv:2009.11287](https://arxiv.org/abs/2009.11287), [arXiv:1805.00015](https://arxiv.org/abs/1805.00015)

- *near mass degeneracy extremely challenging*
- *very high mass scale, DM mass $\sim 1\text{-}23$ TeV*
- *Higher dark matter/mediator mass parameter space will remain unexplored after HL-LHC*
- *challenging to probe in direct detection experiments due to loop-suppressed cross-sections*

HOW CAN WE TURN THIS
"HEAVIER STONE"?



Leaving no stone unturned ...

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HOW CAN WE TURN THIS
"HEAVIER STONE"?



How can we turn this “heavier stone”?

► FUTURE COLLIDERS ARE THE ANSWER!

- MUON COLLIDER:

[arXiv:2205.10404v1](https://arxiv.org/abs/2205.10404v1), [arXiv:2206.03456](https://arxiv.org/abs/2206.03456),
[arXiv:2009.11287](https://arxiv.org/abs/2009.11287)

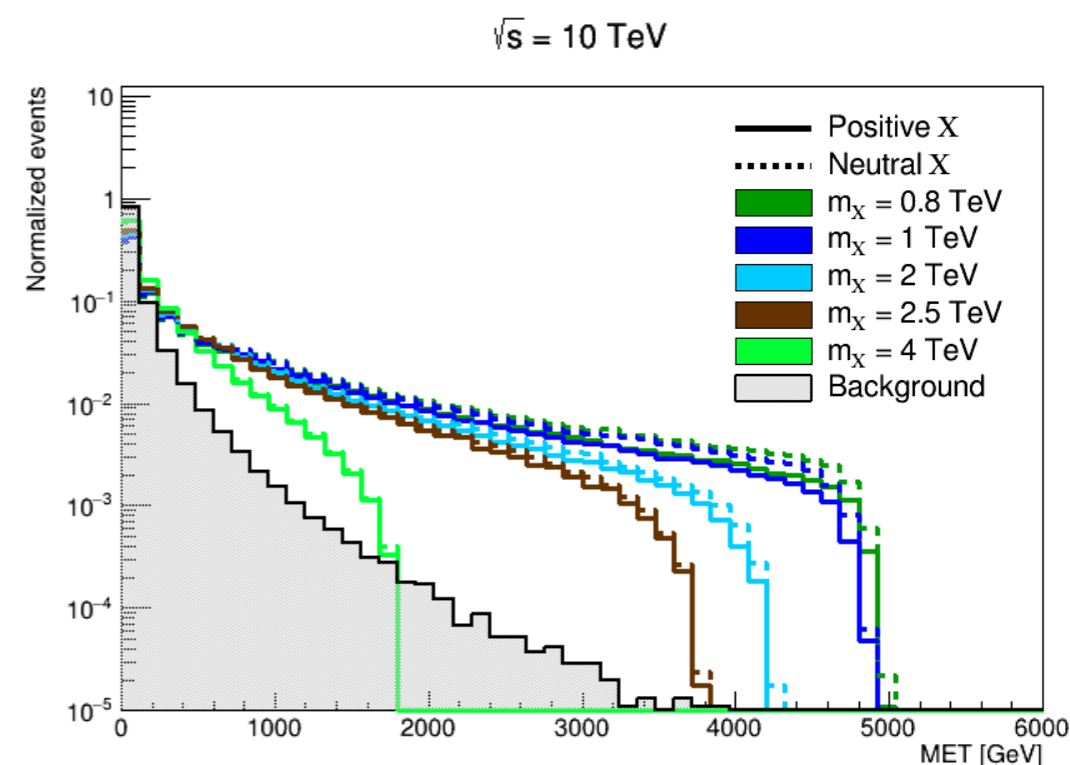
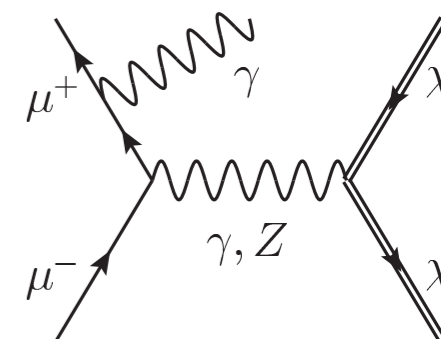
- could explore well beyond current energies, (complementary mass ranges wrt to ee colliders)
- fixed \sqrt{s} , full event reconstruction
- *direct search* through mono-X for eg mono-photon
- *indirect searches* model-independent probe of new EW states through precision measurements

- HADRON COLLIDER:

[arXiv:1810.10993v2](https://arxiv.org/abs/1810.10993v2)

- potential higher \sqrt{s} , variable collision energy due to pdfs
- *direct search* through mono-X or disappearing tracks
- *indirect searches* model-independent probe of new EW states through precision measurements

MUON COLLIDER:
mono-photon
signature

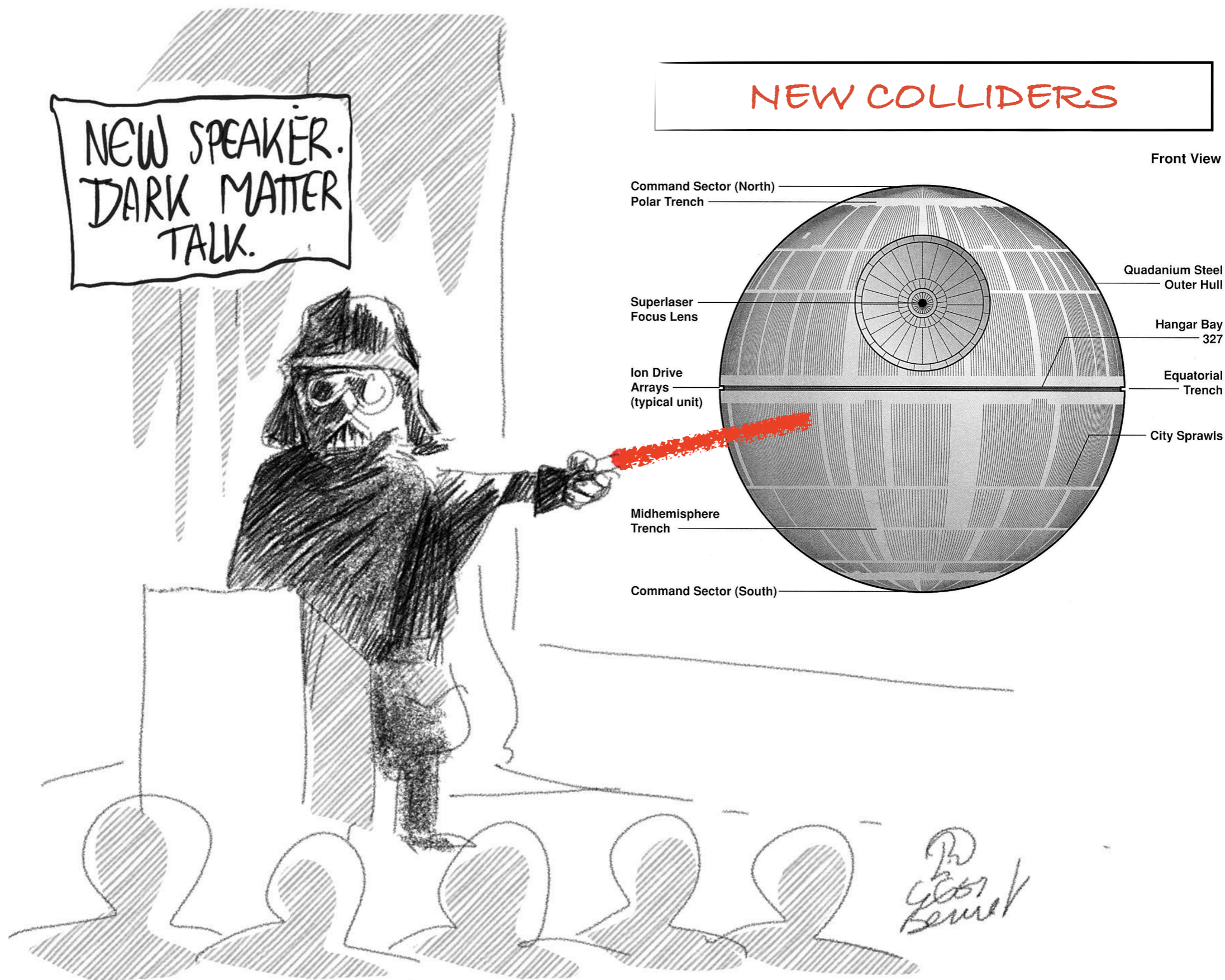


COMPLEMENTARITY WILL BE ESSENTIAL FOR DARK MATTER DISCOVERY

Can future colliders be the light to see dark matter? YES!



Can future colliders be the light to see dark matter? YES!

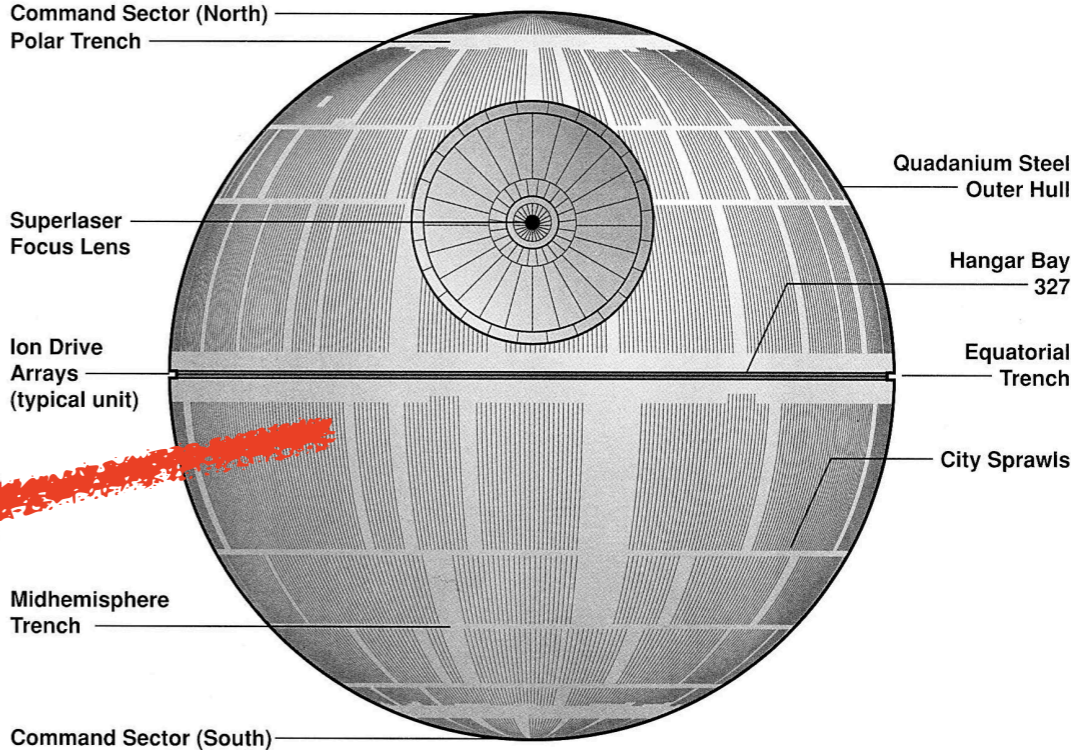


Can future colliders be the light to see dark matter? YES!

NEW SPEAKER.
DARK MATTER
TALK.

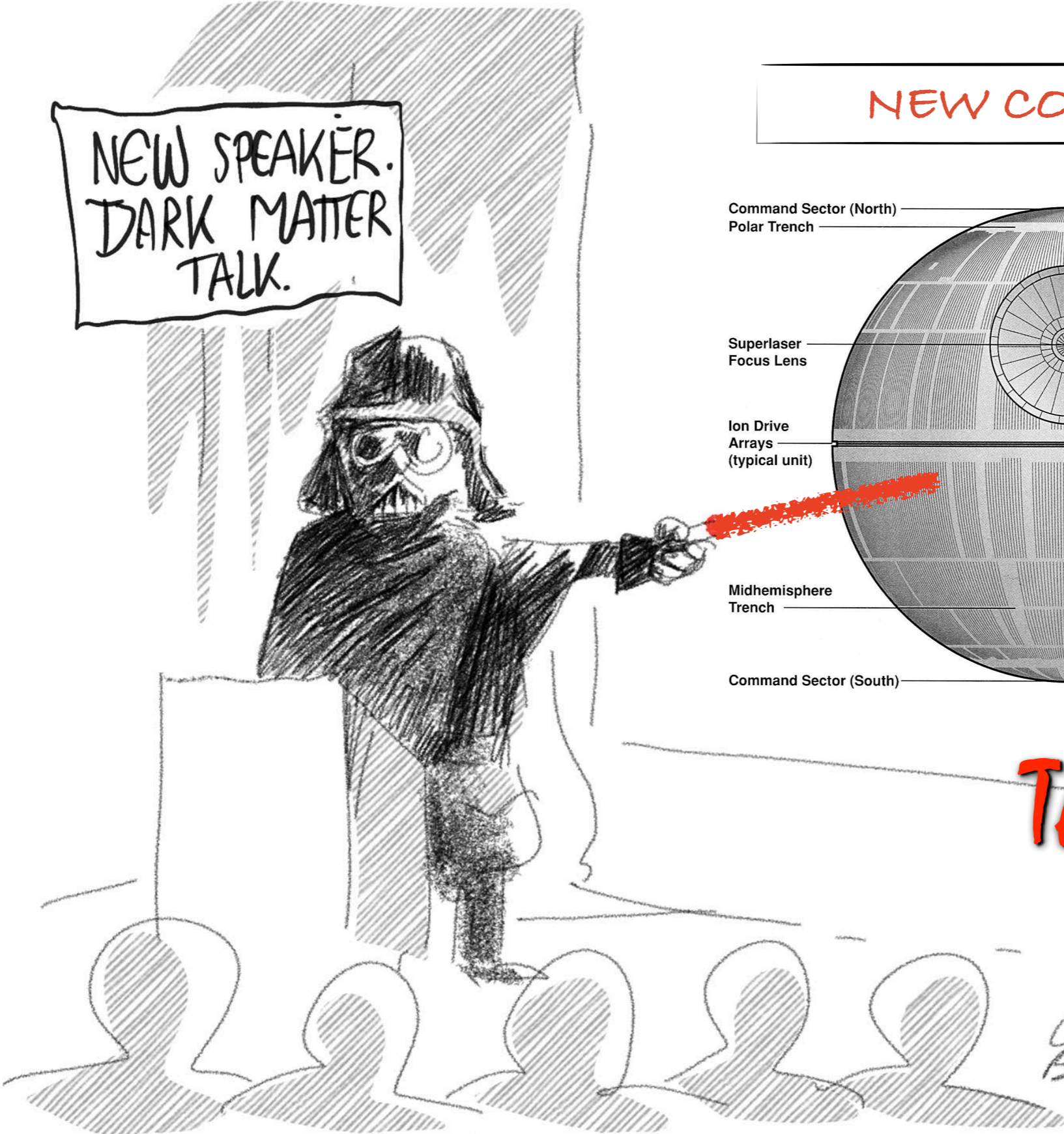
NEW COLLIDERS

Front View



Thank you!

Dr. G. Bennett



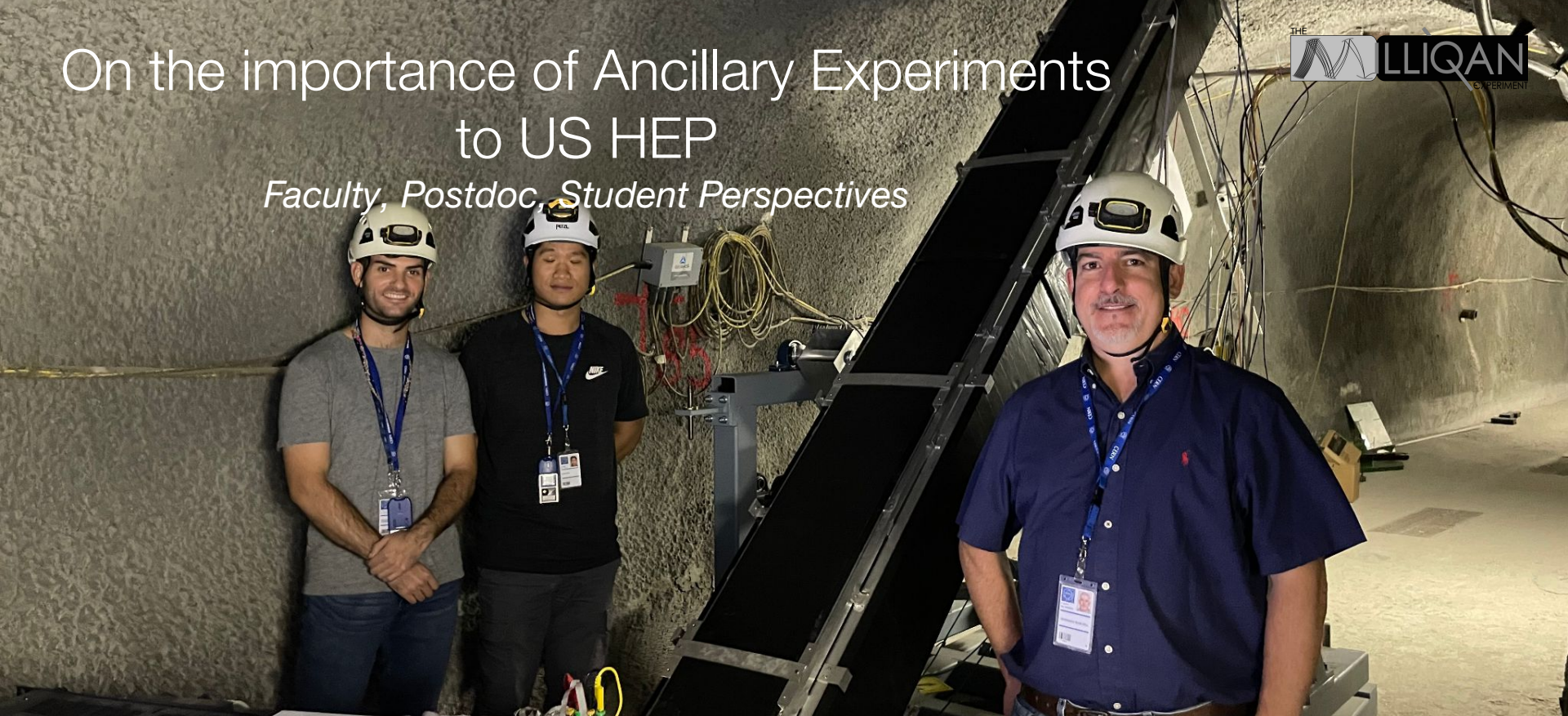
TIANJIA DU

University of Chicago

**“milliQan and future
ancillary experiments”**

On the importance of Ancillary Experiments to US HEP

Faculty, Postdoc, Student Perspectives



Open Mic Contribution BNL P5 Townhall

Mike Carrigan (OSU), Teresa Du (Chicago),
Chris Hill (OSU), Neha Santpur (UCSB)
April 2023

“Cheap” Extension(s) of HEP Program

- milliQan was formed in 2014 from a small group of interested collider physicists as a low-cost way to extend LHC physics reach ... it is currently recording Run 3 data!
- “Simple” experiment to “quickly” address interesting developments in the field (e.g. dark sectors)
- Since then other ancillary LHC experiments proposed by many, some realized already e.g. FASER
 - *For HL-LHC and any future collider experiments, planning to include these from the start of program makes good scientific (and economic) sense*



Prof. Chris Hill
(milliQan co-spokesperson)

Science was my original goal ... but the opportunities afforded students/postdocs maybe the most enduring legacy

These projects are great for students

- Training on all aspects of HEP experiments from design to commissioning to operation and analysis
- Being able to take runs and work on the detector provides great context for any simulation or analysis work

It's so rewarding to go from drafting and machining to testing and installation



Tianjia (Teresa) Du
(Chicago grad student)



Mike Carrigan
(OSU grad student)

I have gotten more hands on experience with every part of running the experiment

Possible to work on many parts of an experiment and fully understand them

- Learn about complex subsystems like triggering/DAQ in a simpler context
- New ideas can be implemented immediately without large bureaucracy

Also very attractive for postdocs

- Provides ability to have critically significant impacts on experiments (and shape direction of sub-field)
 - *“Easy” visibility - relatively good faculty job prospects compared to larger HEP experiments*
 - *Large impact on detector design, implementation, data acquisition and data analysis*
 - *I will be spending summer 2023 at CERN building MilliQan slab detector*
 - *Provides a better work satisfaction by complimenting my work on the CMS experiment*



Neha Santpur
(UCSB postdoc)

MilliQan provides a unique opportunity to do exciting particle research with a small-scale detector

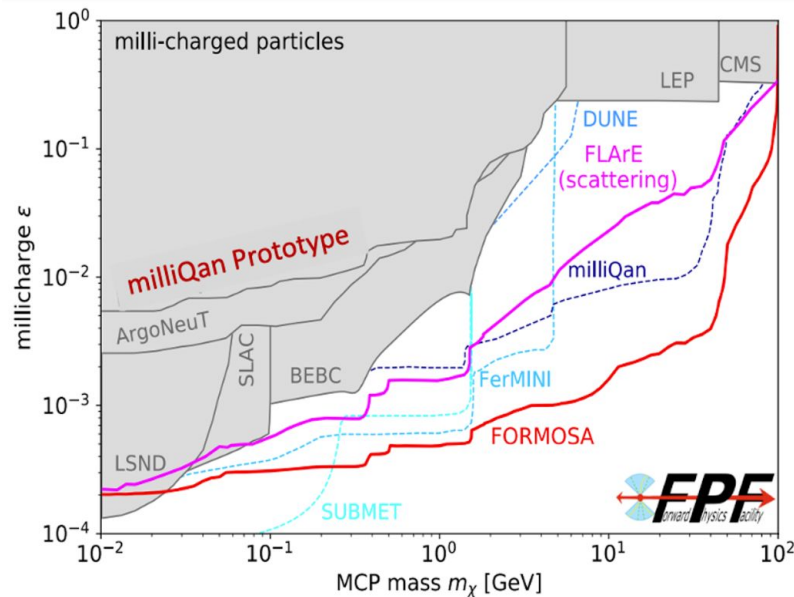
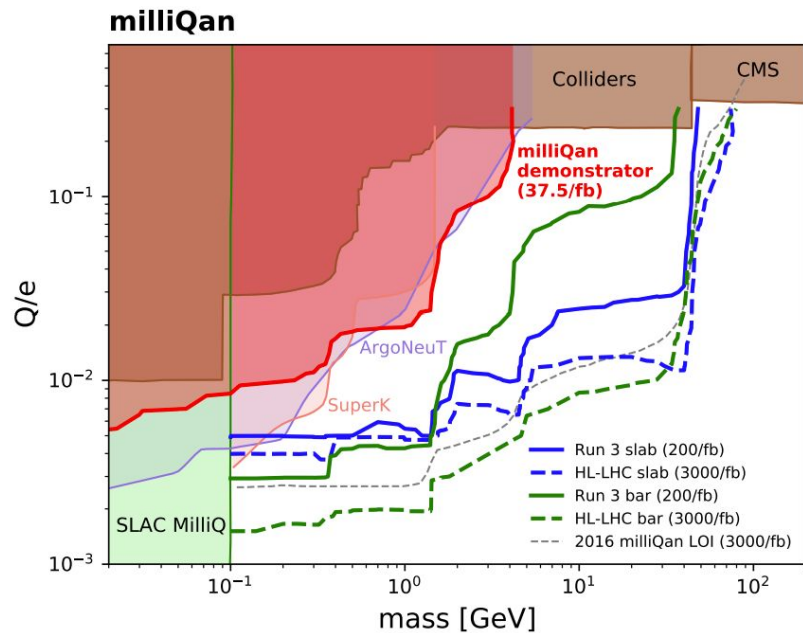
Summary of main points

- Small scale experiments such as MilliQan provide a unique opportunity to conduct particle physics research in smaller collaborations
- We urge P5 committee to prioritize increased funding and support for small-scale yet high impact particle detectors (e.x. FPF)
- Continued and increased funding for these experiments in addition to the support for future detector R&D will help retain critical expertise in the field while decisions on future colliders is being made
- Design for future large facilities should leave designated room in anticipation of ancillary experiments



Backup





Foroughi-Abari, Kling, Tsai, 2010.07941

<https://arxiv.org/pdf/2104.07151.pdf>

TOBIAS NEUMANN

Brookhaven National Laboratory

**“Maximizing the Return on
US Investment in the LHC:
Time to Take Action”**

U.S. investment in the LHC program: time to take action

Tobias Neumann, BNL

supported by abstract submissions from

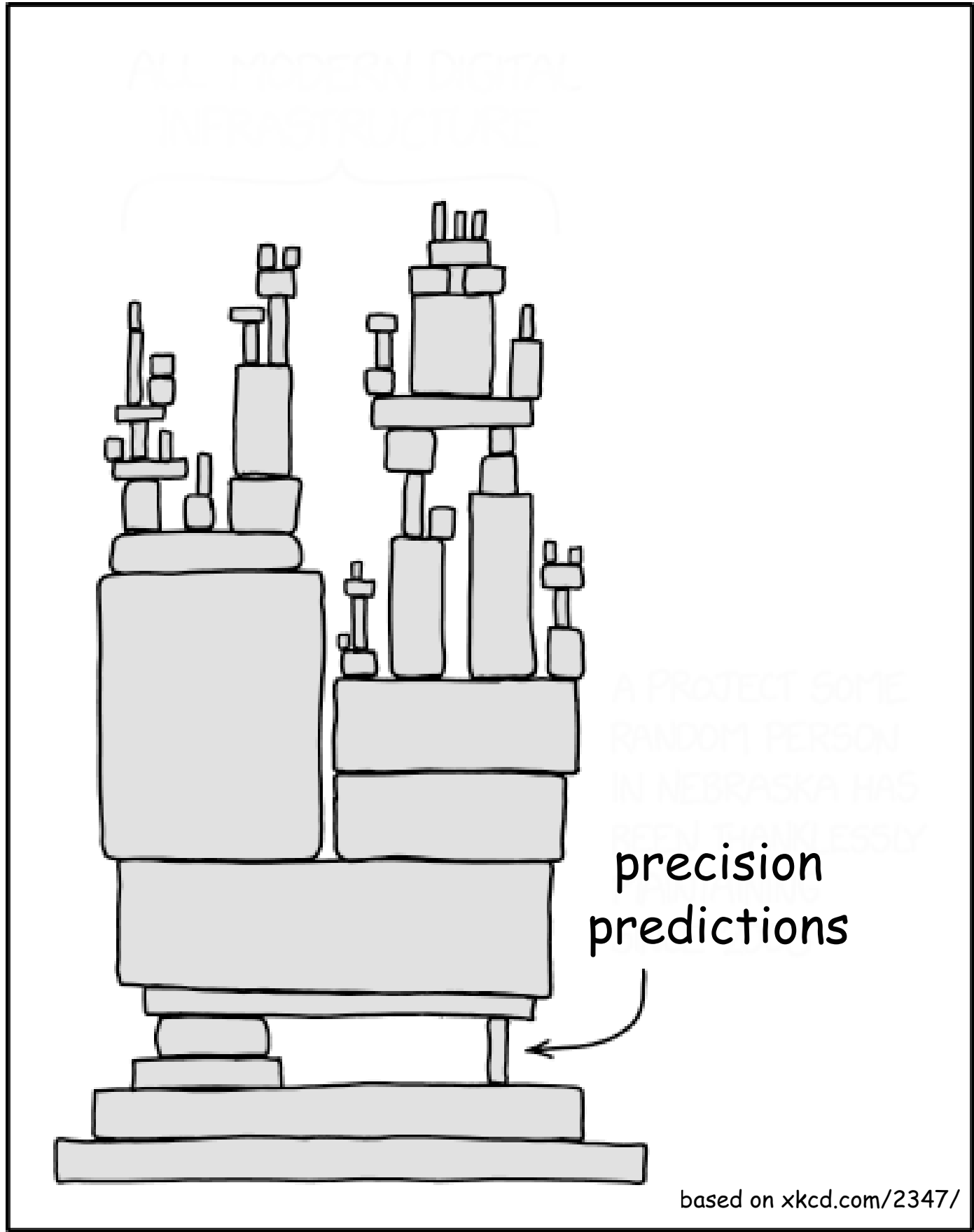
Jennifer Roloff (BNL)

Philip Ilten (Cincinnati) on event generators

Maarten Boonekamp (DAPNIA, Saclay) and Stefano Camarda (CERN) on PDFs

The nightmare scenario of particle physics?





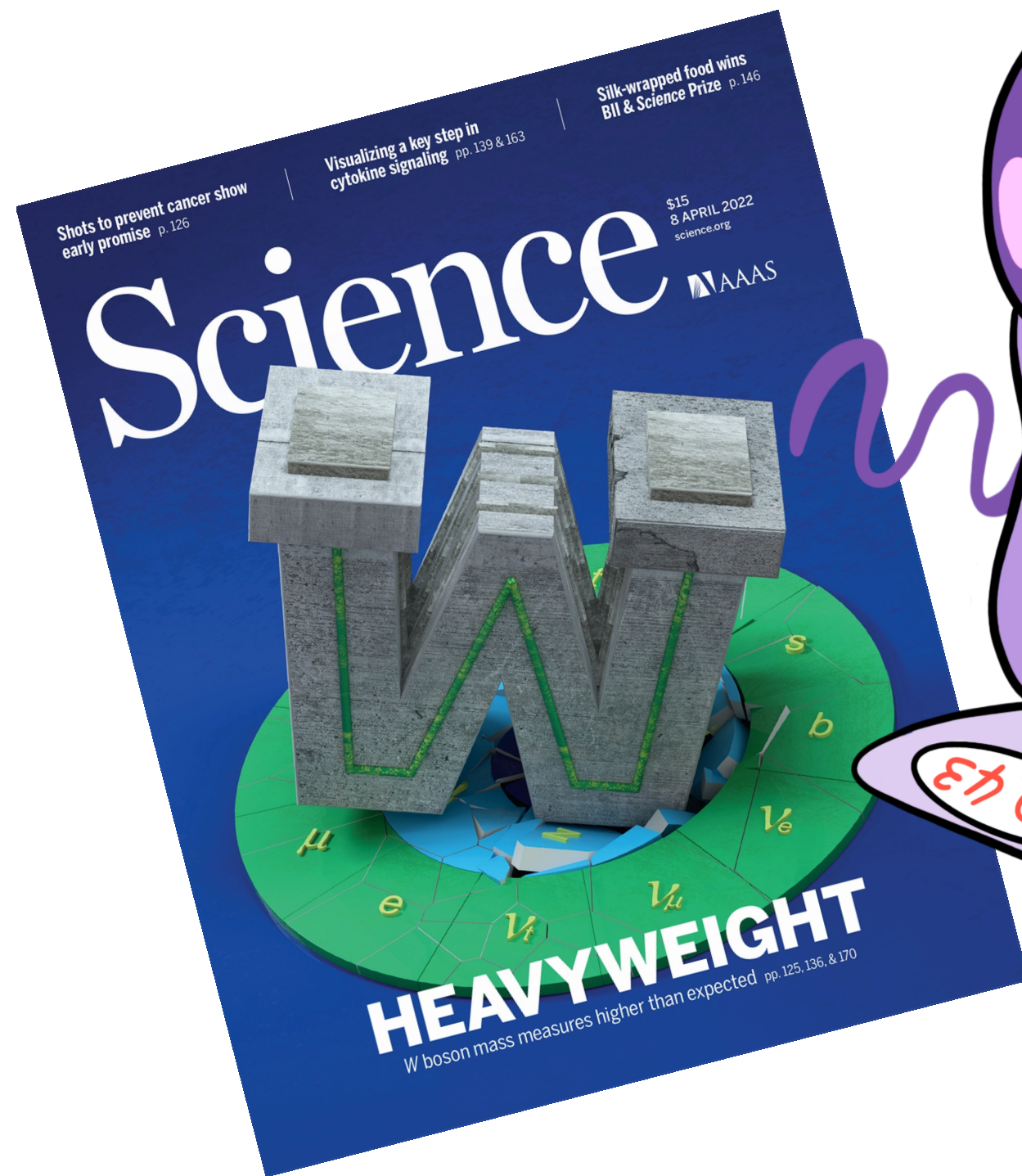
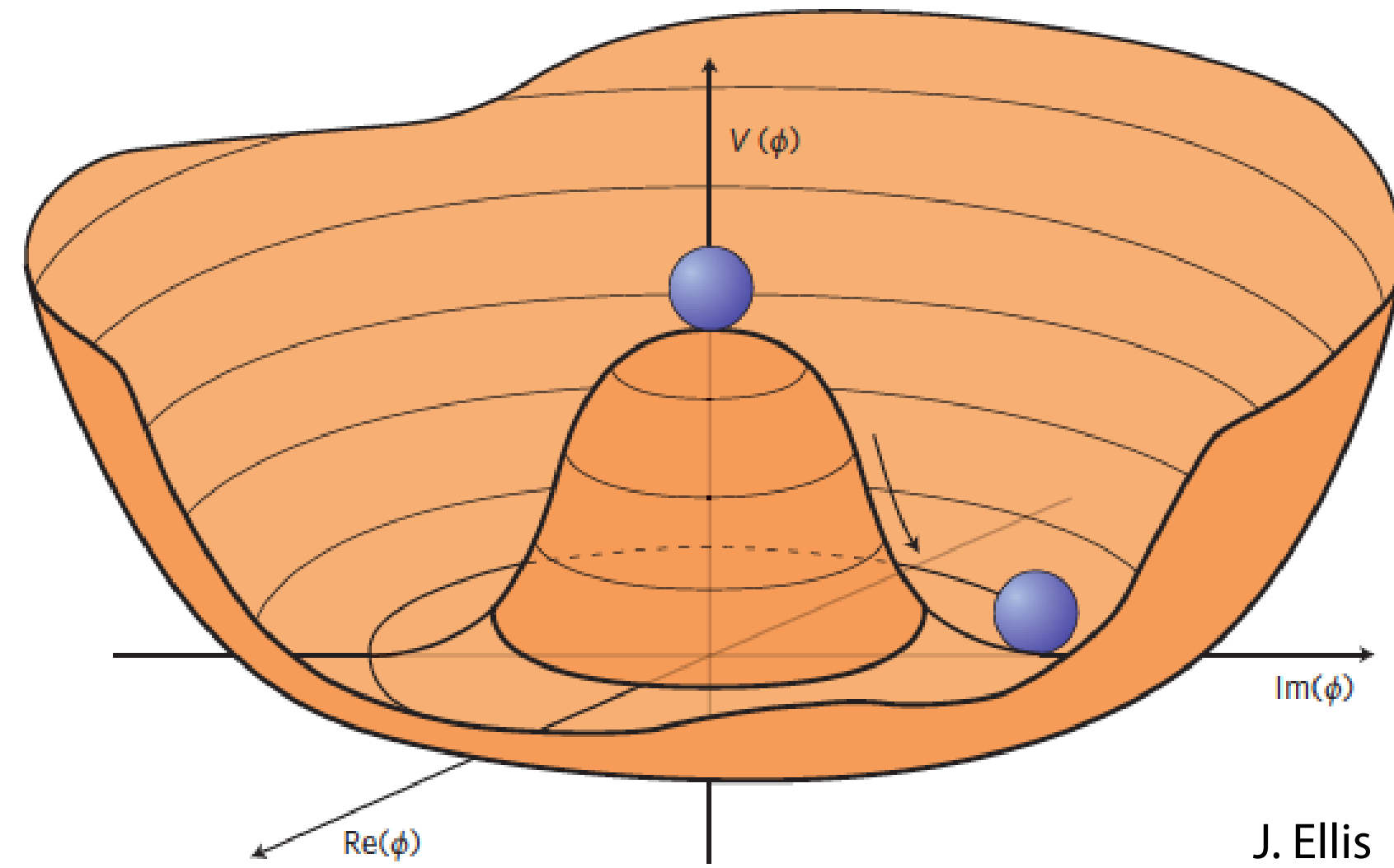


Illustration: Gaia Fontana



Theory uncertainties

- Fixed-order expansions in QCD and EW
- Higher-order resummation
- Parton showers, event generators
- Non-perturbative effects, PDFs, TMDs, ..
- Higher power/twist terms in factorization
- Understanding universality of tuning
- Numerical precision
- ...

1997: DOE/NSF/CERN treaty

**U.S. to contribute \$531 million to
CERN's Large Hadron Collider project**

8 DECEMBER, 1997

2015: +\$350M provisioned for HL-LHC

**Protocol II Between the
UNITED STATES OF AMERICA
and the EUROPEAN ORGANIZATION FOR
NUCLEAR RESEARCH**

To Agreement of May 7, 2015

+ annual upkeep (e.g. \$20M/y NSF)



LHC continues to be key for fundamental particle physics

Precision *is* discovery

Precision theory and experiment are interdependent

The U.S. investment is > \$1 BN

We need to aim to maximize the scientific benefit that taxpayers get from their investment

For this, we need strong support for precision theory

CHRISTIAN WEBER

Brookhaven National Laboratory

**“Large Language Models for
Particle Physics Experiments”**

Large Language Models for Particle Physics Experiments

Christian Weber, Elena Zhivun

April 13th, 2013



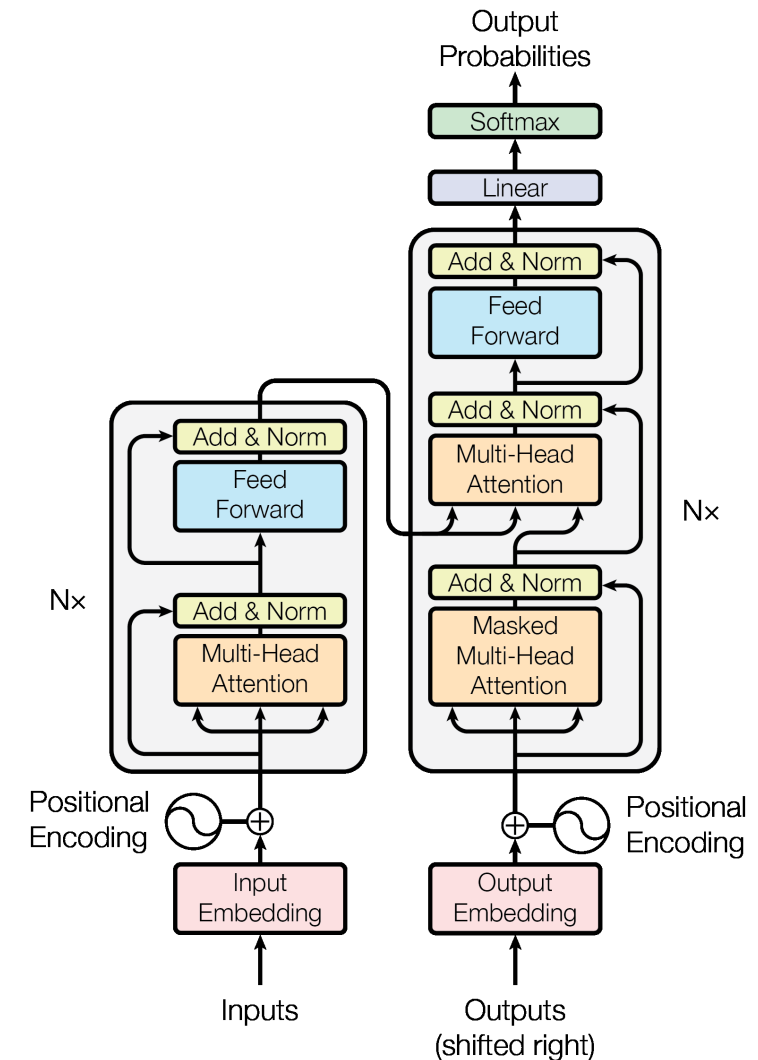
@BrookhavenLab

Large Language Models

- Large Language Models (LLMs) are a type of neural network trained on large amounts of unlabeled text using self-supervised learning.
- 100+ billion parameters in a transformer network – deep learning model for the processing of sequential input data
- Operates on sequences of ‘tokens’:
 - words, characters, or sub-words, depending on implementation
 - represented as vectors in an n-dimensional space
- Model learns representation of language
 - Stored as model parameters
 - Concepts and meaning are represented in the relevant phase space, related concepts are closer aligned therein
- Many different LLMs available: ChatGPT, LaMDA, BLOOM, ...



The Transformer – model architecture



Source: [Attention Is All You Need](#)

Already useful in HEP I

Generate algorithm to match reconstructed jets to quarks.

Prompt and response:

ZH

I do have two c++ objects, quark1 and quark2, and a c++ vector called myJets, whose elements are called jet. For each element of myJets and quark1 or quark2 I can calculate a metric deltaR: deltaR(quark1, jet) and deltaR(quark2, jet). How can I find the two jets that minimize the metric deltaR for each, quark1 and quark2.



You can find the two jets in the `myJets` vector that minimize the metric deltaR for each `quark1` and `quark2` by iterating over each element in `myJets` and computing the deltaR for each `quark`. Here is an example code snippet that demonstrates how you can do this:

c++

Copy code

```
#include <iostream>
#include <vector>
```

c++

```
#include <iostream>
#include <vector>
#include <algorithm>
#include <cmath>

using namespace std;

// Define a struct to hold the jet and its corresponding deltaR
struct JetDeltaR {
    double deltaR;
    int jetIndex;
};

// Define a function to calculate the deltaR between two objects
double calculateDeltaR(double eta1, double phi1, double eta2, double phi2) {
    double dEta = eta1 - eta2;
    double dPhi = abs(phi1 - phi2);
    if (dPhi > M_PI) {
        dPhi = 2 * M_PI - dPhi;
    }
    return sqrt(dEta * dEta + dPhi * dPhi);
}

int main() {
    // Define the quarks and jets
    double quark1Eta = 1.0;
    double quark1Phi = 2.0;
    double quark2Eta = -1.0;
    double quark2Phi = 3.0;
```

Already useful in HEP II

Explain what 'RECAST' is
(analysis reinterpretation tool)

Find reference for RECAST

ZH What is RECAST in the context of the ATLAS experiment



In the context of the ATLAS experiment at CERN, RECAST (REanalysis of Cms and ATlas data) is a tool developed to facilitate the reinterpretation of experimental results. It allows researchers to quickly and easily test new theoretical models against existing ATLAS data, without the need for access to the original data or Monte Carlo simulations.

RECAST works by providing a standardized interface for submitting requests to the ATLAS collaboration to reanalyze existing data using different theoretical models. The tool then compares the results of the original analysis with those obtained using the new models, allowing researchers to quickly assess the compatibility of their theories with the data.

ZH

Point me to a reference for RECAST



Sure, here is a reference to a paper describing RECAST:

"RECAST: Extending the Impact of Existing Analyses" by B. Nachman et al., Eur. Phys. J. C 74 (2014) 3076.


The paper describes the development and implementation of RECAST in the context of the ATLAS experiment at the Large Hadron Collider (LHC), and provides examples of how the tool can be used to reinterpret existing ATLAS data in the search for new physics.



Already useful in HEP III

Process ROOT TTree data format in Python

ZH Write me a Python code that processes a TTree with two Branches, 'Branch1' and 'Branch2'

 Sure, here is an example Python code that uses ROOT to process a TTree with two branches, 'Branch1' and 'Branch2':

```
python Copy code
import ROOT

# Open the input file
file = ROOT.TFile.Open("input.root")

# Get the input tree
tree = file.Get("tree")

# Define variables to hold the branch values
branch1_val = ROOT.Double()
branch2_val = ROOT.Int()

# Set the branch addresses
tree.SetBranchAddress("Branch1", branch1_val)
tree.SetBranchAddress("Branch2", branch2_val)
```

Output continued:

```
# Loop over the tree entries
for i in range(tree.GetEntries()):

    # Get the current entry
    tree.GetEntry(i)

    # Do something with the branch values
    print("Entry", i, "- Branch1:", branch1_val, "Branch2:", branch2_val)

# Close the input file
file.Close()
```

This code opens an input file, retrieves a TTree named "tree", and sets the branch addresses for "Branch1" and "Branch2" using the `SetBranchAddress()` function.

The code then loops over the entries in the tree using a for loop, and gets the values of the "Branch1" and "Branch2" branches for each entry using the `GetEntry()` function. The values are then printed to the console using the Python `print()` function.

Finally, the code closes the input file using the `Close()` function.

Note that this is just a basic example, and you would likely want to perform some actual analysis or processing on the branch values instead of just printing them to the console. Additionally, you may need to import additional ROOT libraries or modules depending on your specific needs.

Already useful in HEP IV

Generate ATLAS analysis template

```
ZH Write me a template for an AthAnalysis based ATLAS analysis

Sure! Here's a basic template for an AthAnalysis-based ATLAS analysis:

c++ Copy code

#include "xAODRootAccess/Init.h"
#include "xAODRootAccess/TEvent.h"
#include "xAODRootAccess/TStore.h"
#include "xAODEventInfo/EventInfo.h"
#include "xAODJet/JetContainer.h"

#include <EventLoop/Job.h>
#include <EventLoop/StatusCode.h>
#include <EventLoop/Worker.h>

class MyAnalysis : public EL::AnaAlgorithm {
public:
    MyAnalysis() {}
};
```

```
private:
    xAOD::TEvent* m_event; //!
    xAOD::TStore* m_store; //!

    // Add any other member variables or functions as needed
};

EL::StatusCode MyAnalysis::initialize()
{
    // Initialize xAOD access
    xAOD::Init("MyAnalysis").ignore();

    // Get the input TEvent object
    m_event = wk()->xaodEvent();
    m_store = wk()->xaodStore();

    return EL::StatusCode::SUCCESS;
}

EL::StatusCode MyAnalysis::execute()
{
    // Get the event information
    const xAOD::EventInfo* evtInfo = 0;
    m_event->retrieve(evtInfo, "EventInfo").ignore();

    // Get the jets from the event
    const xAOD::JetContainer* jets = 0;
    m_event->retrieve(jets, "AntiKt4EMTopoJets").ignore();

    // Loop over the jets and do something
    for (const xAOD::Jet* jet : *jets) {
        double pt = jet->pt();
        double eta = jet->eta();
        double phi = jet->phi();
    }
}
```

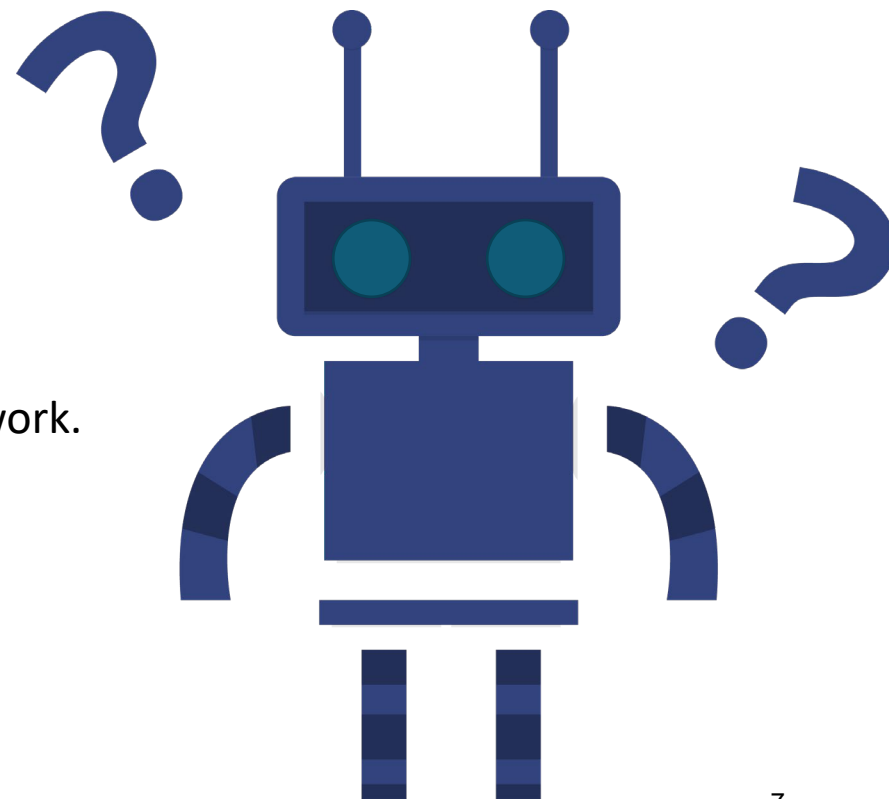
What we would like: ChatHEP

Large Language Models like ChatGPT can already provide utility for work in High Energy Physics. Particularly for less experienced collaborators.

We think however that LLMs utility in HEP can be improved.

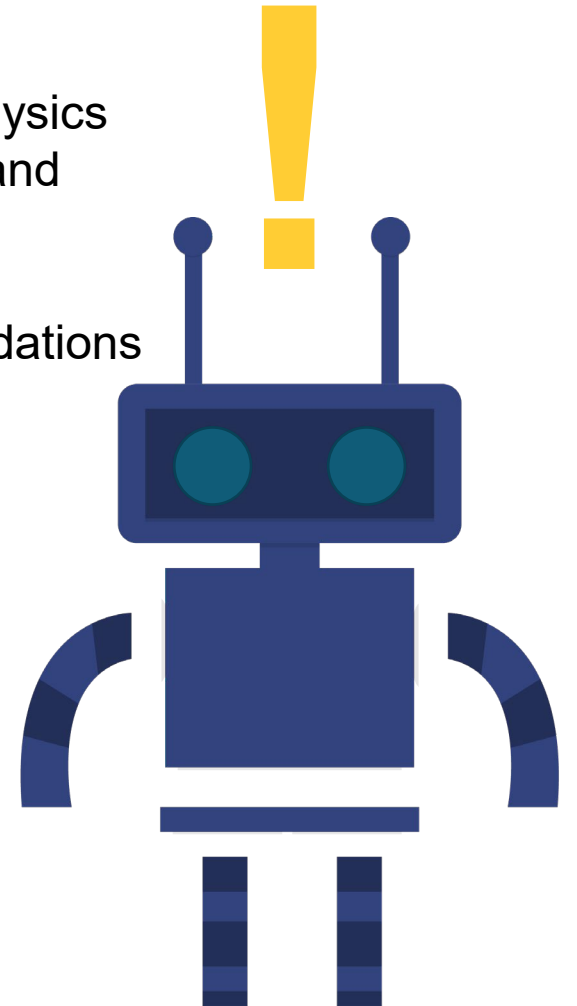
What we would like them to be able to do

- Inform us about the current jet recommendations for ATLAS analyses
- Generate Monte Carlo Event Generator configuration files for specific Beyond Standard Model physics process
- Tell me how electrons are calibrated in my very specific analysis framework.
- Give me an example of running my exotic active learning tool
- Expertise in VHDL
- Reading and understanding electronic components datasheets

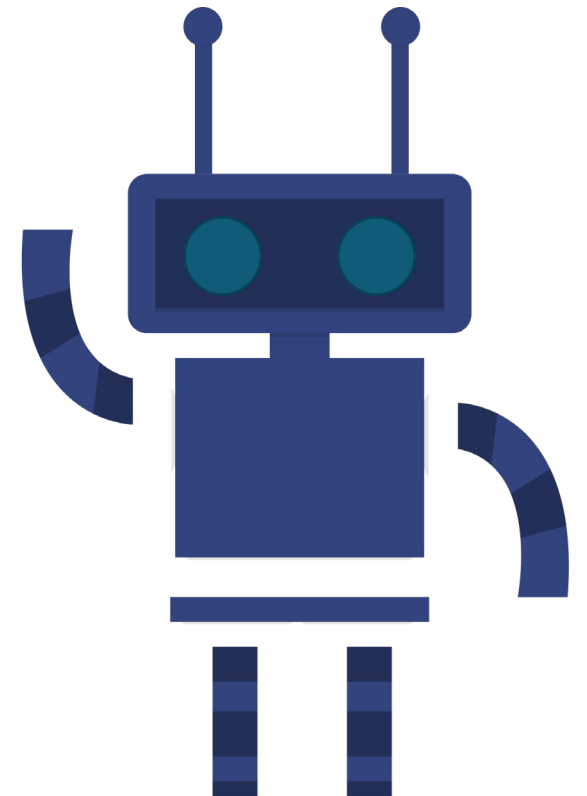


Conclusion

- We expect LLMs to become a useful and common tool to help in computing and navigate information.
- We should make sure that we can take advantage of LLMs for particle physics efforts - by having a platform for training language models on our codes and other information.
- We propose to the P5 to include a LLM training platform in its recommendations that either leverages our existing computational infrastructure or is done in cooperation with the private sector.
- Expect the cost training such a model to be around 10 million USD, depending on model size and particularities of the training.



Thank you!

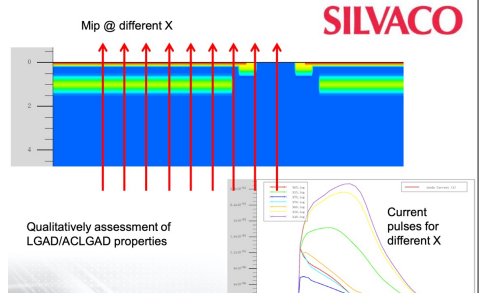
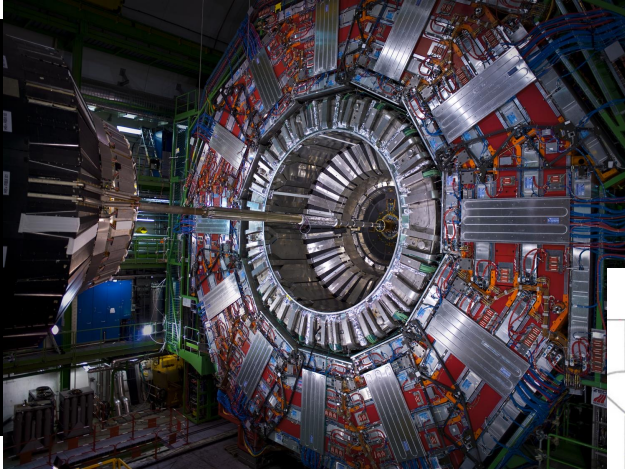
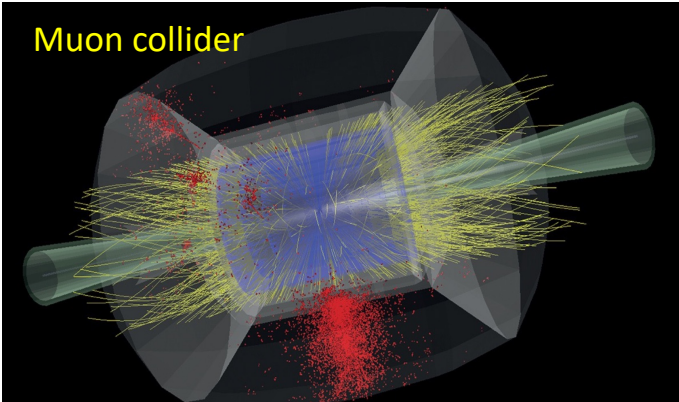


ARTUR APRESYAN

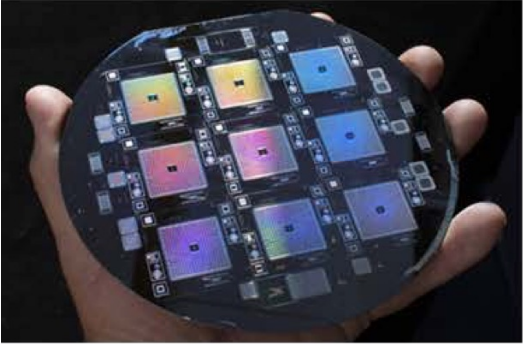
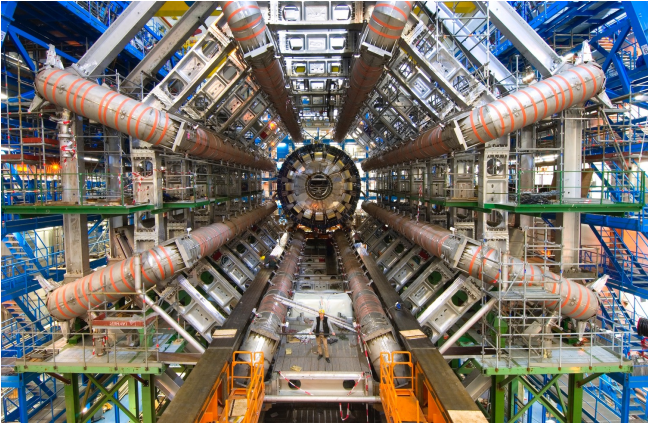
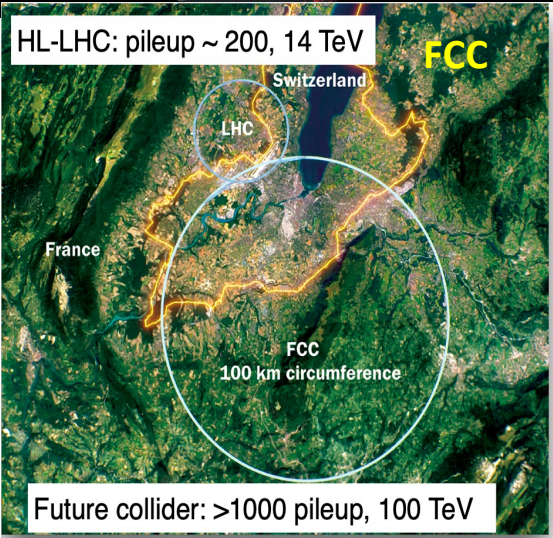
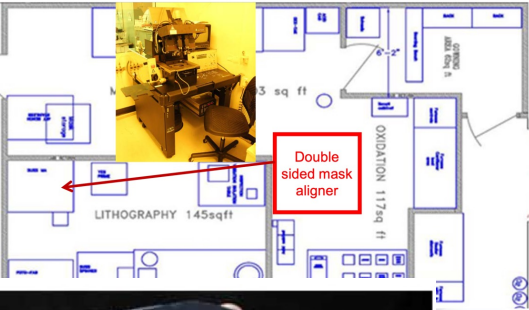
Fermilab

“Detector R&D future colliders”

Detector and Accelerator R&D are consilient and co-dependent



Class 100 Cleanroom



Detector and Accelerator R&D are consilient and co-dependent

- Collaborative efforts are key !
- Many of my detector peers want to engage and contribute **materially** to accelerator R&D (or vice versa)
 - **Barriers of entry**: need a **funding framework** for inter- and cross-boundary research
- Establish consortia and common schemes for R&D on detectors and accelerators
- Strengthen **lab -- university** connection: joint appointments, student co-supervision
 - Encourage consilient PhD research programs in LHC physics and accelerator R&D

CATERINA VERNIERI

SLAC National Accelerator Laboratory

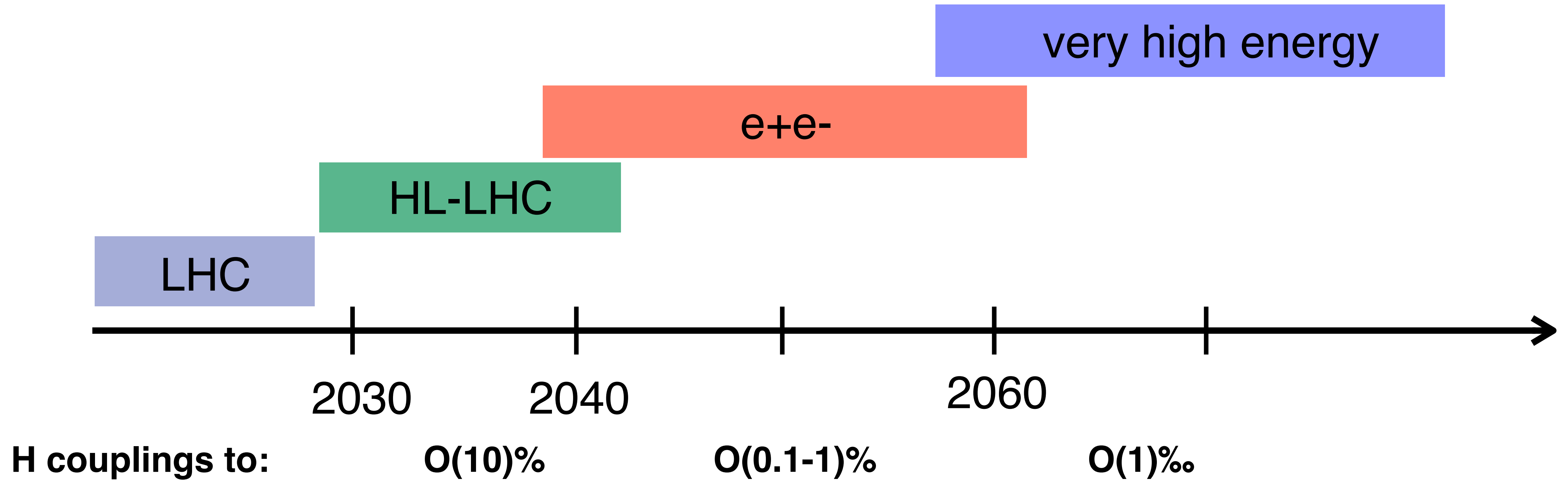
“A US-based future collider initiative for physics prospects and detector R&D ”

A US-based future collider initiative for physics prospects and detector R&D

P5 Town Hall Meeting · BNL · April 13, 2023

Caterina Vernieri

What's next?



Physics goals beyond HL-LHC:

1. Establish Yukawa couplings to light flavor \Rightarrow precision & lumi
2. Search for invisible/exotic decays and new Higgs \Rightarrow precision & lumi
3. Establish self-coupling \Rightarrow high energy

A strong US-based initiative mitigates Global Uncertainty

The Snowmass Energy Frontier discussions have unequivocally highlighted the following theme:

1.7.4 Opportunity for US as a site for a future Energy Frontier Collider

Our vision for the EF can only be realized as a worldwide program, and CERN as host of the LHC has been the focus of EF activities for the past couple of decades. In order for scientists from all over the world to buy into the program, the program has to consider siting future accelerators anywhere in the world. The US community has to continue to work with the international community on detector designs and develop extensive R&D programs, and the funding agencies (DOE and NSF) should vigorously fund such programs (as currently the US is severely lagging behind).

The US community has expressed a renewed ambition to bring back EF collider physics to the US soil, while maintaining its international collaborative partnerships and obligations, for example with CERN. The international community also realizes that a vibrant and concurrent program in the US in EF collider physics is beneficial for the whole field, as it was when Tevatron was operated simultaneously as LEP.

The US EF community proposes to develop plans to site an e^+e^- collider in the US. A Muon Collider remains a highly appealing option for the US, and is complementary to a Higgs factory. For example, some options which are considered as attractive opportunities for building a domestic EF collider program are:

- A US-sited linear e^+e^- (ILC/CCC) Collider
- Hosting a 10 TeV range Muon Collider
- Exploring other e^+e^- collider options to fully utilize the Fermilab site

[ArXiv:2211.11084](https://arxiv.org/abs/2211.11084)

Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	290	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	20.5 km	I	I
CLIC (0.38 TeV)	110	11.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	91 km	II	I
ReLiC (0.24 TeV)	315	20 km	II	I
ERLC (0.24 TeV)	250	30 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	0.3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	50.2 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km (linac)	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA (15 TeV)	~1030	6.6 km	III	I
PWFA (15 TeV)	~620	14 km	III	II
SWFA (15 TeV)	~450	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	100 km	II	III

ArXiv:2208.06030

A strong US-based initiative mitigates Global Uncertainty

The Snowmass Energy Frontier discussions have unequivocally highlighted the following theme:

- The US community advocates for an active role in planning for future colliders
 - Investigate the possibility of an Higgs factory and the R&D for a future muon collider in the US
 - Given global uncertainties, consideration should be given to the timely realization of a domestic Higgs factory, in case none of the currently proposed options will be realized.
- Future colliders will set unique challenges in detector design to achieve our ambitious physics goals

The investment in detector and collider R&D for lepton facilities in the US should start now

- A parallel effort with the LHC to enable a future e^+e^- precision electroweak program and a high-energy machine
- **Such a domestic R&D program would grow the US accelerator & detector workforce and strengthen the international community, regardless of where the next big project will be realized**

The opportunity to work on fundamental problems and technological challenges is a key element to motivate students and early career scientists

- A US-based future collider R&D program will give the impetus to make particle physics program attractive to the young and future generations of scientists in the US.

GRACE CUMMINGS

Fermilab

**“Dual readout crystal calorimetry for
precision measurements at
future colliders”**



Dual Readout crystal calorimetry for precision measurements at future colliders

Grace Cummings

BNL P5 Town hall, 12-14 April, 2023

Demands of Future Colliders

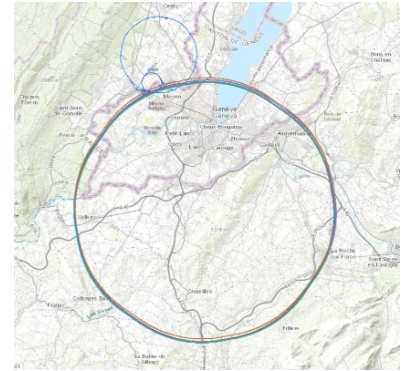
- Precision Machines!
- We need the detectors to match them
 - And we do not have them (in most cases)
- We need the research supported
 - [Jinlong's Talk](#)
 - [Marina's Talk](#)

Priority Research Direction (PRD)

PRD 1: Enhance calorimetry energy resolution for precision electroweak mass and missing-energy measurements

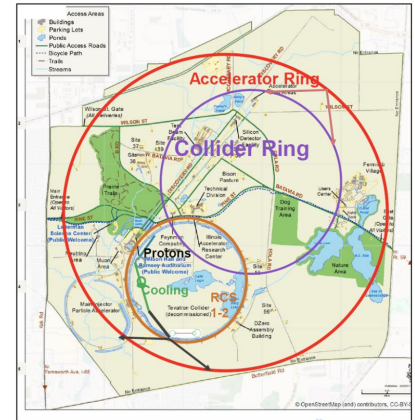
PRD 2: Advance calorimetry with spatial and timing resolution and radiation hardness to master high-rate environments

PRD 3: Develop ultrafast media to improve background rejection in calorimeters and improve particle identification



[arXiv:2203.08310](#)

These slides touch on two points, but **support is needed across all of the proposed detector R&D collaborations**



[2209.01318](#)

[arXiv:2208.12861v2](#), <https://doi.org/10.2172/1659761>

Electromagnetic Calorimetry in Crystals

- Full shower capture
 - good energy resolution
- Scintillation light a proxy for energy
- Poor e/h response
 - 2.4 e/h for CMS ECAL
 - degrades hadronic energy resolution

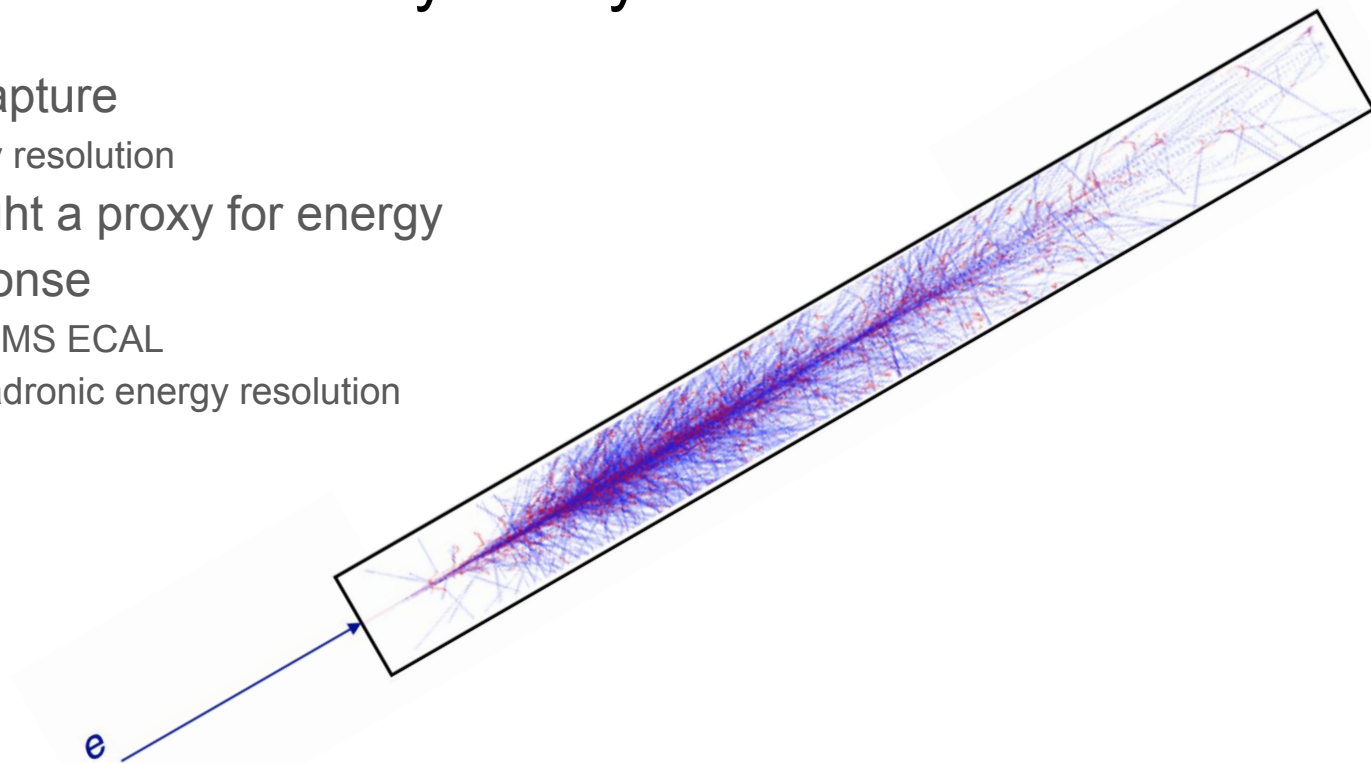
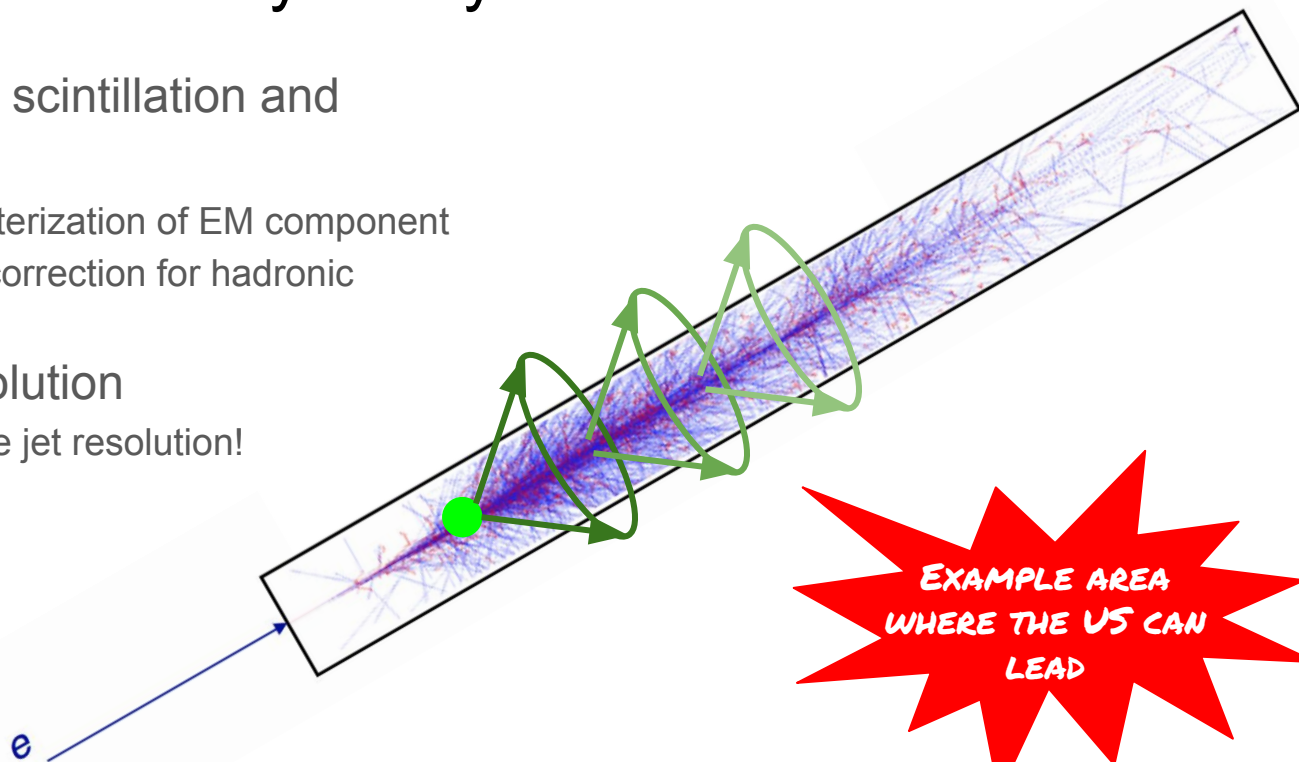


image credit:

https://www.physi.uni-heidelberg.de/~sma/teaching/ParticleDetectors2/sma_ElectromagneticCalorimeters.pdf

Dual Readout Calorimetry in Crystals

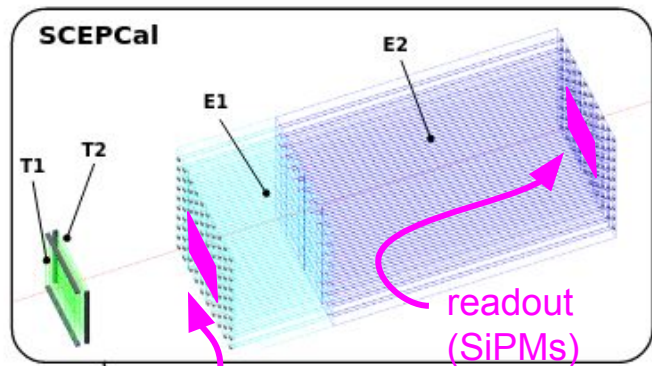
- Measure both the scintillation and Cerenkov light
 - complete characterization of EM component
 - Event-by-event correction for hadronic component
- Preserve EM resolution
 - does not degrade jet resolution!



DREAM Paper
[arXiv:1712.05494](https://arxiv.org/abs/1712.05494)

image credit:
https://www.physi.uni-heidelberg.de/~sma/teaching/ParticleDetectors2/sma_ElectromagneticCalorimeters.pdf

Other potential features



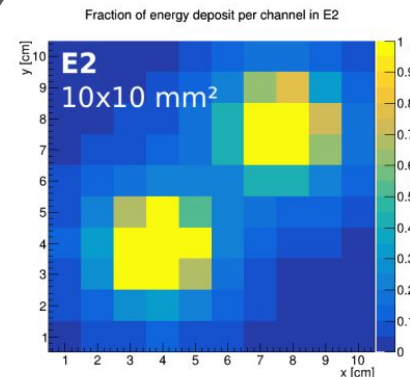
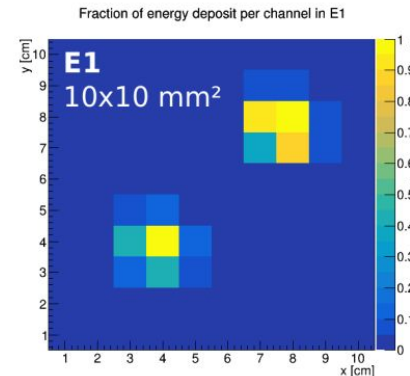
readout (SiPMs)

SiPMs open new space!

Moderately high granularity

Particle ID w/
minimal segmentation

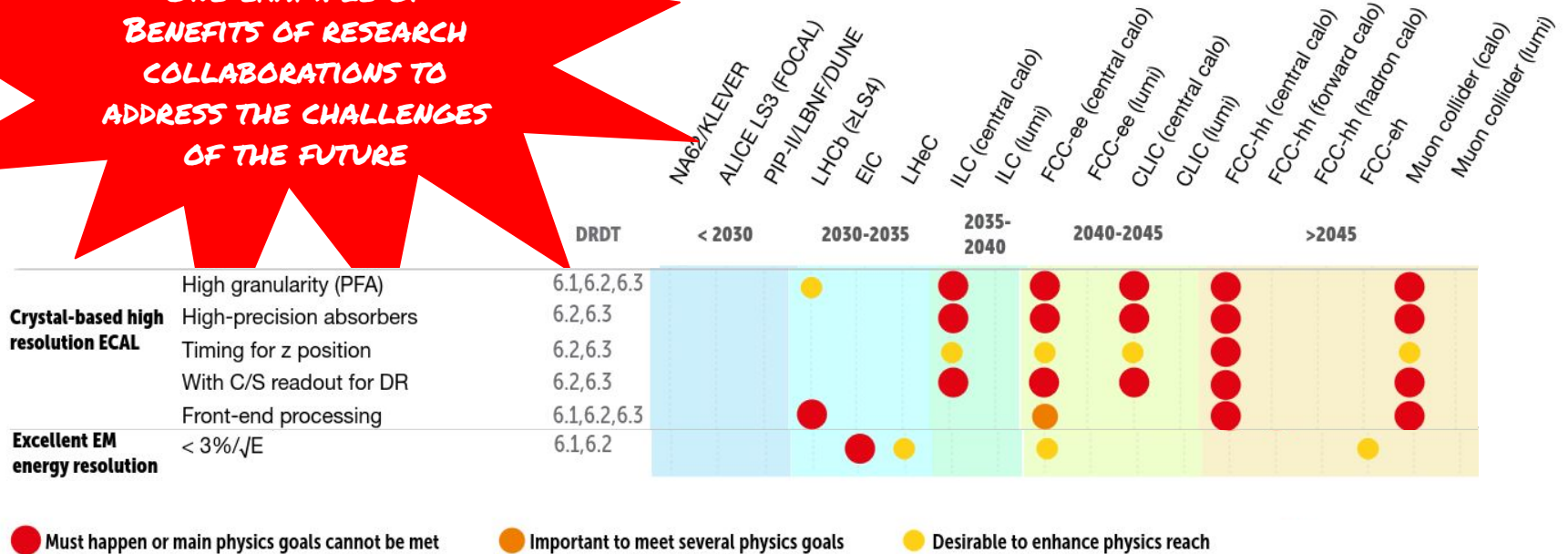
incorporating timing



More research is needed!

WE HAVE INITIATIVES LIKE **CALVISION** THAT CAN FUNDAMENTALLY CHANGE CALORIMETRY, BUT THIS CAN ONLY HAPPEN BY FUNDING THIS R+D

ONE EXAMPLE OF BENEFITS OF RESEARCH COLLABORATIONS TO ADDRESS THE CHALLENGES OF THE FUTURE



10.17181/CERN.XDPL.W2EX - 2021 ECFA Roadmap

CHRISTIAN HERWIG JENNET DICKINSON

**Brookhaven National Laboratory
Fermilab**

**“On-chip intelligence and
real-time data-processing”**

Accelerating scientific discovery with Intelligent Detectors

Detectors probe ever-shorter distances+timescales, producing data at PB/sec rates.

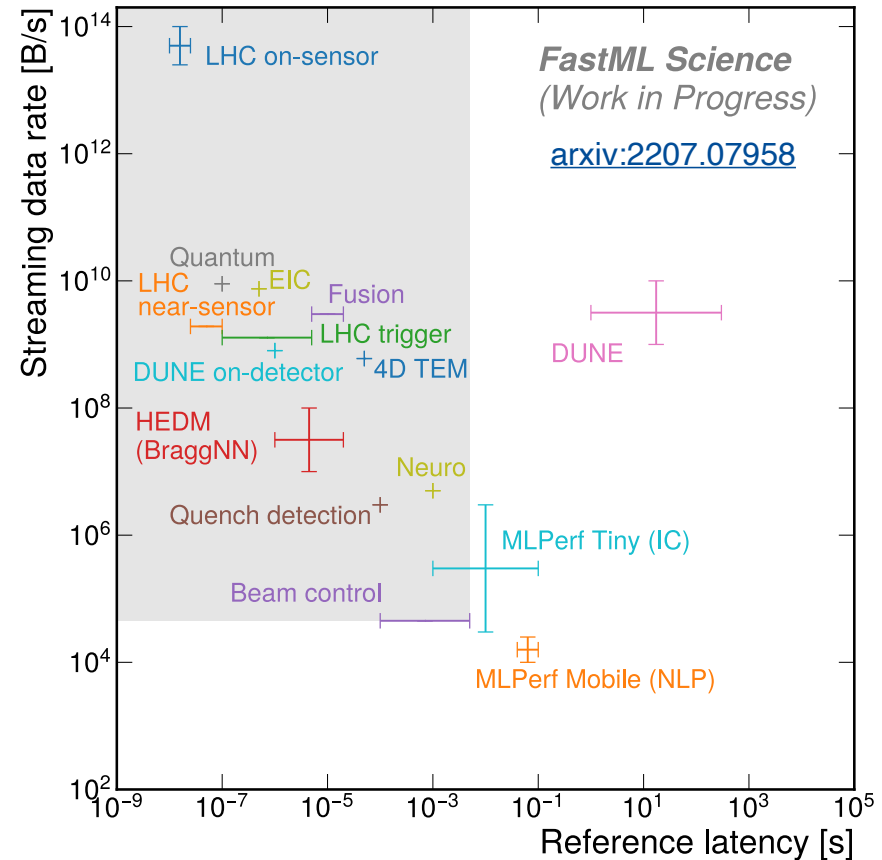
- Common challenges *across scientific domains!* → Driven by technology & science goals.

Intelligent, real-time analysis is key.

- Data distillation without information loss.
- Modern tools: FPGA, HLS, optical links,...
- AI/ML plays an increasing role.

Ongoing efforts are building new capabilities

- Open tools for **hardware co-design**
 - Automate translation of models → circuits.
 - Find minimal resources, latency for the task.
- **Ecosystem of open data sets** and **benchmark tasks** to study deep questions.
 - Spur on new algorithms, tools, and hardware.
 - Robustness? Generalizability? Interpretability?



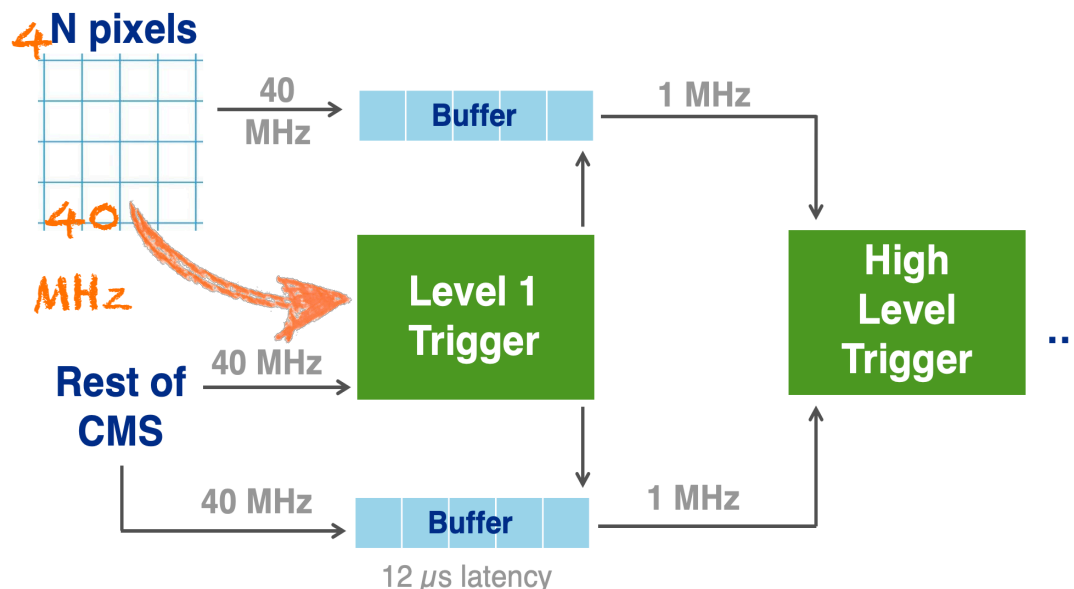
Case study: Smart Pixel sensors for collider detectors

Pixel detectors have the **largest data rates in HEP!**

- Measure charged particle tracks and vertices
- At the LHC, can only read out for triggered events

Next-gen detectors will provide

- Better resolution (position, angle)
- Precise timing information



What would we gain if we could analyze it all? Some aspirational targets:

- **Higgs self-coupling:** 5x increase in the low- m_{hh} spectrum from b-jet triggers.
- **WIMP dark matter:** 50x rate for low- p_T / disappearing tracks / long-lived particles.
- **New capabilities for high-rate, soft objects:** e.g. dark sector BSM, B-physics, and more!

Smart Pixel sensors for data reduction at source

More details:
[CPAD 2022](#)

AI analysis of charge cluster shape on-ASIC, within the pixelated area

Filtering: read out only clusters that come from interesting tracks, e.g. high p_T

- Reject tracks with $p_T < 2$ GeV (corresponds to 95% of tracks)
- On-chip algorithm achieves $\sim 3x$ reduction with 90% efficiency
- Investigating spiking neural network for energy-efficient implementation

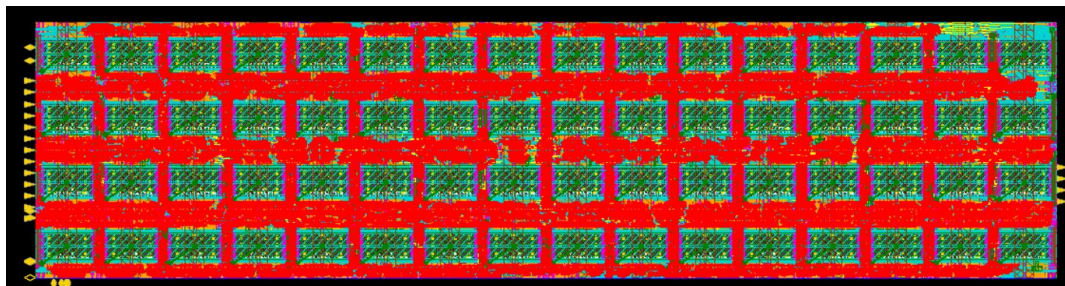


Fig. Prototype with 256 pixels. Classifier algorithm is highlighted in red.

Featurization: extract and read out particle properties instead of raw data

- Position, incident angle
- Mixture Density Network provides **prediction** and **meaningful error**
- Initial estimates show 1σ angular uncertainties $\sim 10^\circ$ with full precision. Potential for large reduction in track seeds!

Achieving this within power constraints requires leveraging new techniques in sensors, circuits, algorithms

Our simulated dataset
is [public!](#)

Final messages to the community and P5

These activities stretch from **front of detector** to **cutting-edge CompSci & ML**.

- E.g. Smart Pixels bridge solid-state detectors (IF3) + readout (IF6) + trigger/DAQ (IF4) + ML (CompF03) + community engagement (Applications/Industry, CommF1).
- **Coherent efforts** are essential. Difficult when components are split across funding structures.

Open pathways to **enhance near-term experiments** with intelligent detectors.

- E.g. a “first wave” at the High-Lumi LHC will:
 - Add **unique physics reach** to the experiments.
 - **Commission new technologies** in a complete system.
 - **Train the next generation** with exciting, impactful upgrades.

Invest in Grand Challenges with the promise of **great scientific leaps**.

- Futuristic collider detectors, a ‘self-driving’ accelerator complex, ...
- Galvanize cross-cutting efforts “under one roof” to render the impossible possible!

ULASCAN SARICA

University of California, Santa Barbara

“Shifting trends in the research involvement of a younger and more global generation of scientists”

Shifting trends in the research involvement of a younger and more global generation of scientists

Ulascan Sarica
University of California, Santa Barbara

BNL P5 Townhall
Apr. 13, 2023

Needs for collaboration resonate across boundaries in Snowmass

“The current standard for S&C training is project-specific on-the-job training. These **training activities** can be very effective, especially with formalized curricula and documentation. However, these activities are often **inaccessible beyond a particular experiment or other organization** and due to **limited person-power**, these events often do **not cover as deep or as broad as is needed** to be maximally effective with S&C.” ([Computational Frontier Report](#))

“In addition to slowing advancement, it makes it **difficult to maintain a viable R&D portfolio** and threatens **student training and work-force development** in US accelerator science. **Integrated efforts are needed to mitigate** this situation and maintain at adequate levels the Beam Physics and Accelerator Science & Engineering (AS&E) education and outreach programs in the US.” ([Accelerator Frontier Report](#))

“Adapting successfully to the move to specialized computing architectures will require significant new software development since we are only in the earliest days of making use of these facilities in many neutrino experiments, as highlighted by Critical Challenge 3 in the Computing Frontier report. **Achieving this adaptation will require support for the development of both shared software solutions (Critical Challenge 2) where they are possible as well as in experiment-specific contexts.** DUNE provides examples of both: it is **already making use of some LHC-developed tools** for data movement and workflow management, which shows the possibility for sharing solutions. However, DUNE will also have specialized needs which differ from colliders” ([Neutrino Frontier Report](#))

“**Presently US funding** for advanced detector R&D is **institute-based rather than collaboration-based.** Yet collaborations are more essential than ever to leadership in detector R&D technology. To a significant extent, **funding constraints have limited the opportunity to establish significant collaborative detector R&D programs.**” ([Instrumentation Frontier Report](#))

Perspectives on career success in physics

Based on the [statistics](#) collected by the AIP for success in career ten years after PhD, “[f]lexibility and adaptability seemed to be important traits for success in PhD physicists’ careers and enabled them to take advantage of more career opportunities. Physicists stated that they were more successful when they were **willing to work in a different scientific field, research area, location, or type of position...** Flexibility also meant **broadening and diversifying their skills and interests**, rather than focusing on narrow and technical tasks.”

“Flexibility about the kind of research I am willing to do.”

“Willingness to expand into new areas of expertise, such as statistical analysis and simulation.”

“Seek (and make known that I am seeking) growth opportunities, including ones that increase my professional breadth rather than depth.”

Funding seems to be a **major organizational support mechanism**, together with **social support** and immersion in **diversity of mentors**:

“Basic research support by US government.”

“Support and collaboration with intelligent and generous colleagues.”

“Links to senior scientists that I have formed during my research career. They have taught me not only how to hone my scientific skills, but also how to promote my science and formulate clear ideas for proposals.”

Toward a more synergistic culture

Challenges in workforce development and retention that span different particle physics frontiers are also **opportunities for cross-pollination** to flourish:

- **Young researchers are willing** to participate in different projects that can benefit our community and **share the expertise they develop**.
- Such participation can help them gain a **broader perspective of our field** and make **more informed choices** about the developments of their skills and their future careers.
 - Importance felt for students in **large collaborations** where it is **easy to lose sight of the big picture** and general trends in our field
- We have the **opportunity to enable synergistic collaborative efforts** and help our future workforce gain the expertise our particle physics community needs.

Different particle physics **frontiers have common themes for needs**, and extending existing (and creating new) funding opportunities for **cross-frontier research to group these themes together** seem to be gaining more importance.

- For the **long-term sustainability** of our field, it would be vital to continue to
 - **Support training needs of our workforce** either through **dedicated schools** or enhanced **internship partnerships**, and
 - **Create funding paths that can enable academic hiring** of experts who plan to interact with **multiple frontiers**.
- **Flexibility to share** our **human power** could **lower costs** in the long term.
- We have the opportunity **today** to **start transforming how our workforce looks** in the next ten years.

Physics in the US is international.

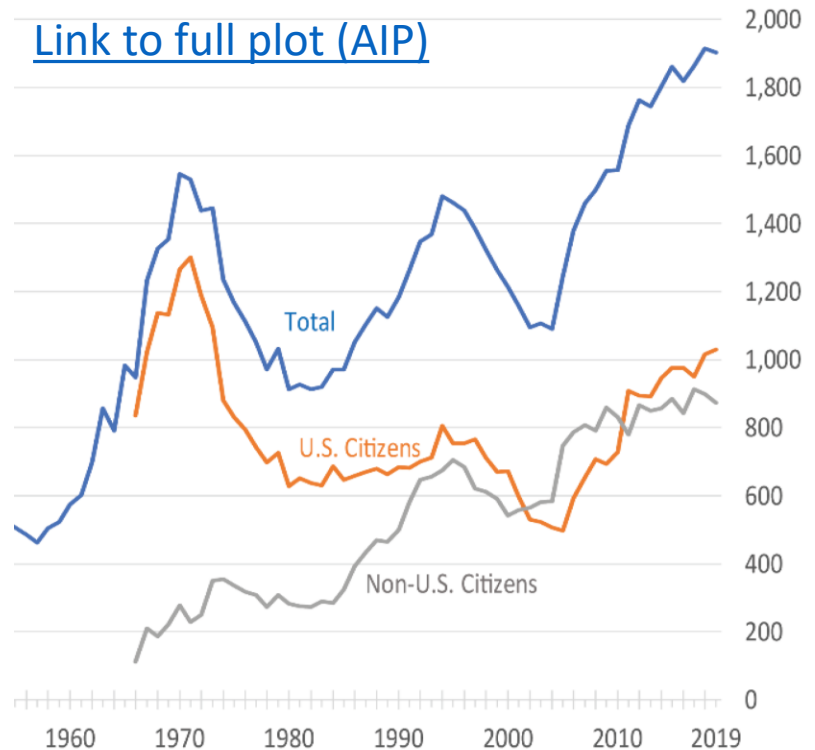
The number of **PhD recipients in the US** who are **non-US citizens** has been **almost equal** to that of **US citizens** for **more than twenty years**.

- The proportions typically exceed 50% for postdoctoral researchers.
- We keep **high retention rates**, and **workforce** considerations remain **highly international**.

In providing opportunities, we need to **keep in mind** that **international students and scholars** in the US may have **different needs** than non-US citizens:

- **Funding opportunities are not equally available to international researchers.**
- This includes **funding for training**.
- **Even when they are**, there are **non-academic concerns** that can influence their acquisition.

Number of PhD recipients in the US



Visas and immigration issues

According to the Fall '21 NSF [survey](#) of graduate students and postdocs in S&E, roughly **31% of doctoral or master's students** and **52% of postdocs** in sciences hold **temporary visa status**, and these rates have remained **stable over a decade**.

→ The typical **visa path available for postdocs** imposes **restrictions** over their **subsequent employability** in the US and **increases risks** in the **retention of their expertise**.

→ **Temporary visa** requirements can **place a barrier** in acquisition of **governmental funds**.

→ The **immigration process** also features **indeterminate delays**, and places **more financial burden** that are **not necessarily all covered by hiring institutions**.

“Postdocs also are affected more by visa restrictions compared to graduate students, and some Postdocs applying for jobs reported that immigration issues were an important concern for them. **Our results indicate that immigration issues disproportionately affect early career scientists in other racial groups, while White early career scientists remain largely unaffected. Current U.S. visa policies are largely inadequate to support Postdocs' transitions into non-academic job sectors [29].** Immigration concerns should always be taken into account while training Postdocs on how to navigate various job markets, and institutions should support their Postdocs' struggles with U.S. visas and immigration policies by advocating for updated policies and a streamlined application process.”

([Snowmass '21 Community Survey Report](#))

The **US visa and immigration policies need to adapt** for the sustainability of our increasingly international collaborative environment:

→ Even if policies cannot be changed in the short-term, **passing the message** could prevent implementations with potentially harmful consequences to our field.

→ In the meantime, it remains important to develop **alternative pathways to continue to support our international colleagues**.

Thank you!