The Large Hadron-Electron Collider at CERN: Status and Plans

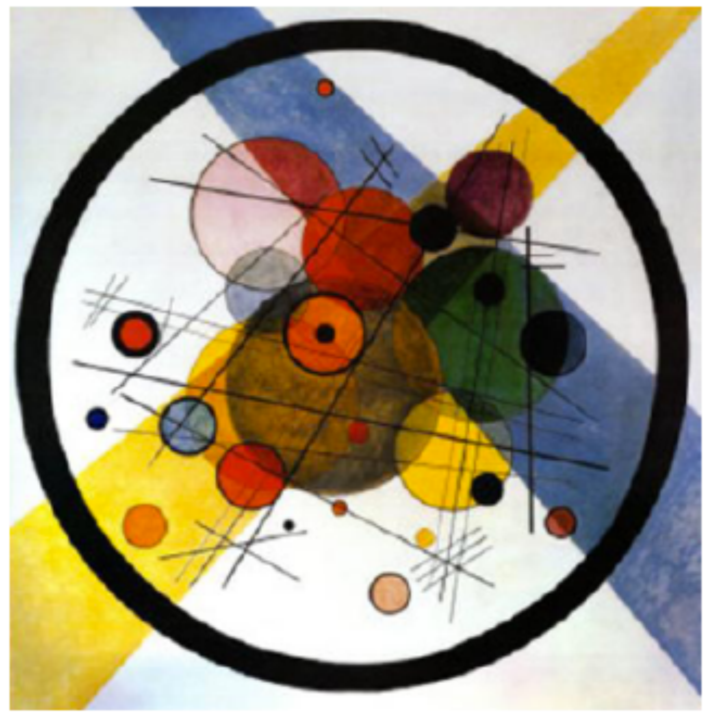
Christian Schwanenberger

Deutsches Elektronensynchrotron (DESY)

XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects

Stony Brook, NY (Virtual)

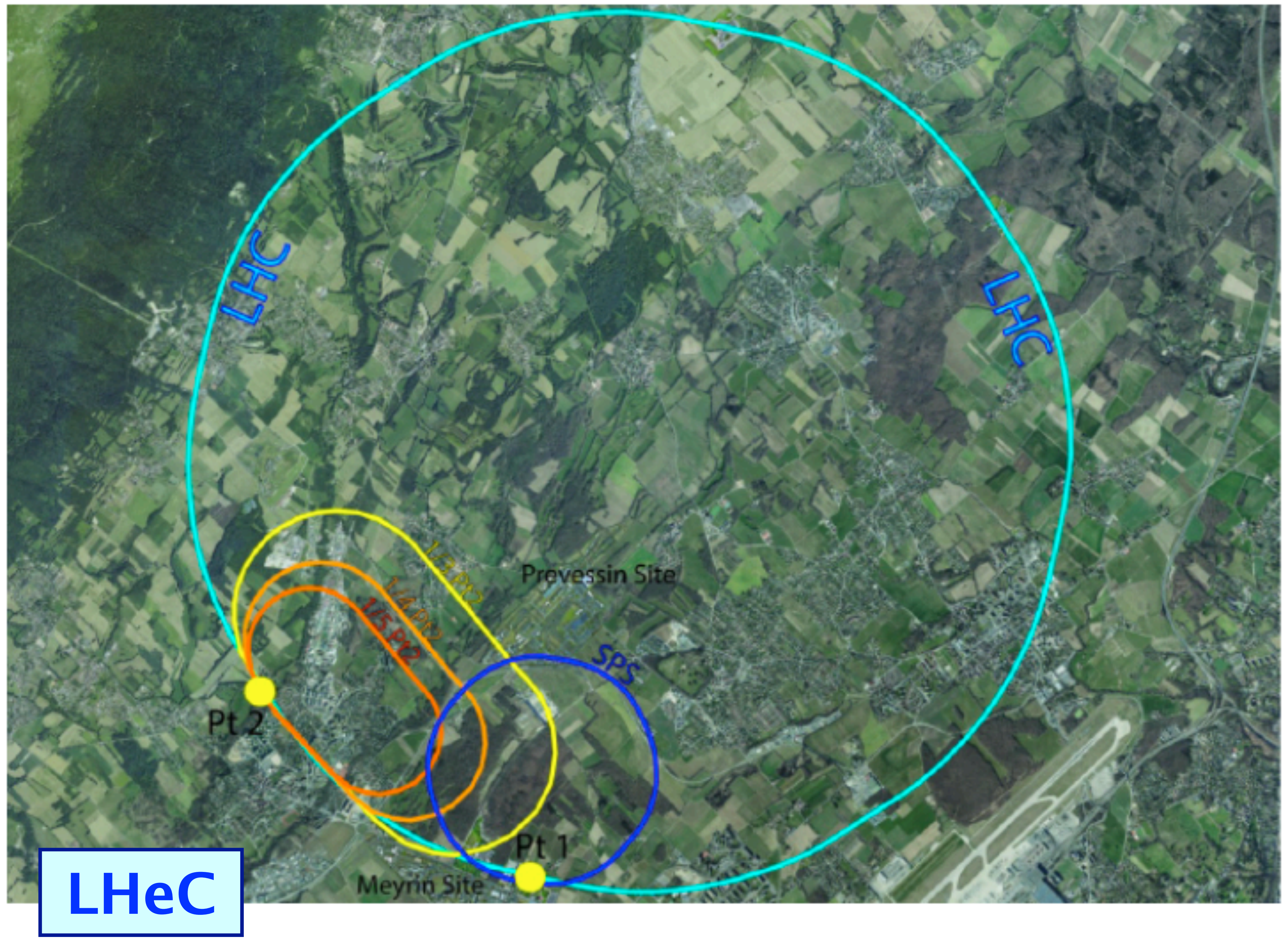
11 November 2020



Circles in a circle
W Kandinsky

Special thanks to M. Klein

Linac-Ring Collider, LHeC and FCC-eh

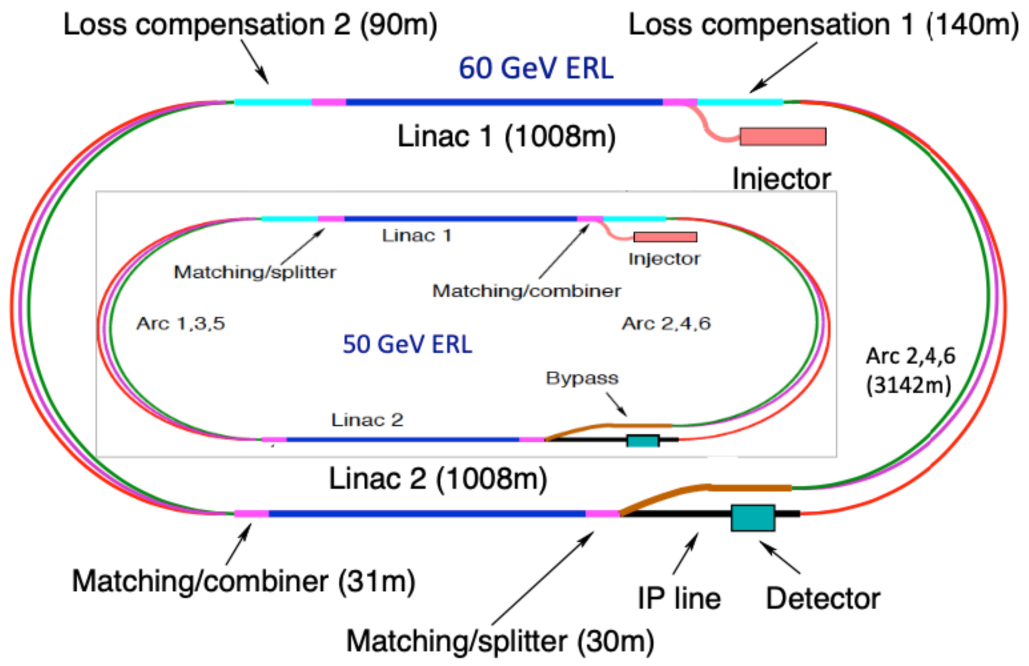


- operated synchronously with HL-LHC:
  e beam: 50 GeV × p beam: 7 TeV:
  $\sqrt{s}$=1.2 TeV
- operation: 2035+
- cost: O(1) BCHF
- luminosity of 10^{34} cm^{-2}s^{-1}

- **The LHeC as Part of the HL-LHC Programme**, Ludovica Aperio Bella, Apr 15, 2021, 8:50 AM
- **DIS (EIC & LHeC) physics and connections to LHC**, Tim Hobbs, Friday, Apr 16, 10:15 AM

Energy Recovering Linac

e beam: 50, 60 GeV

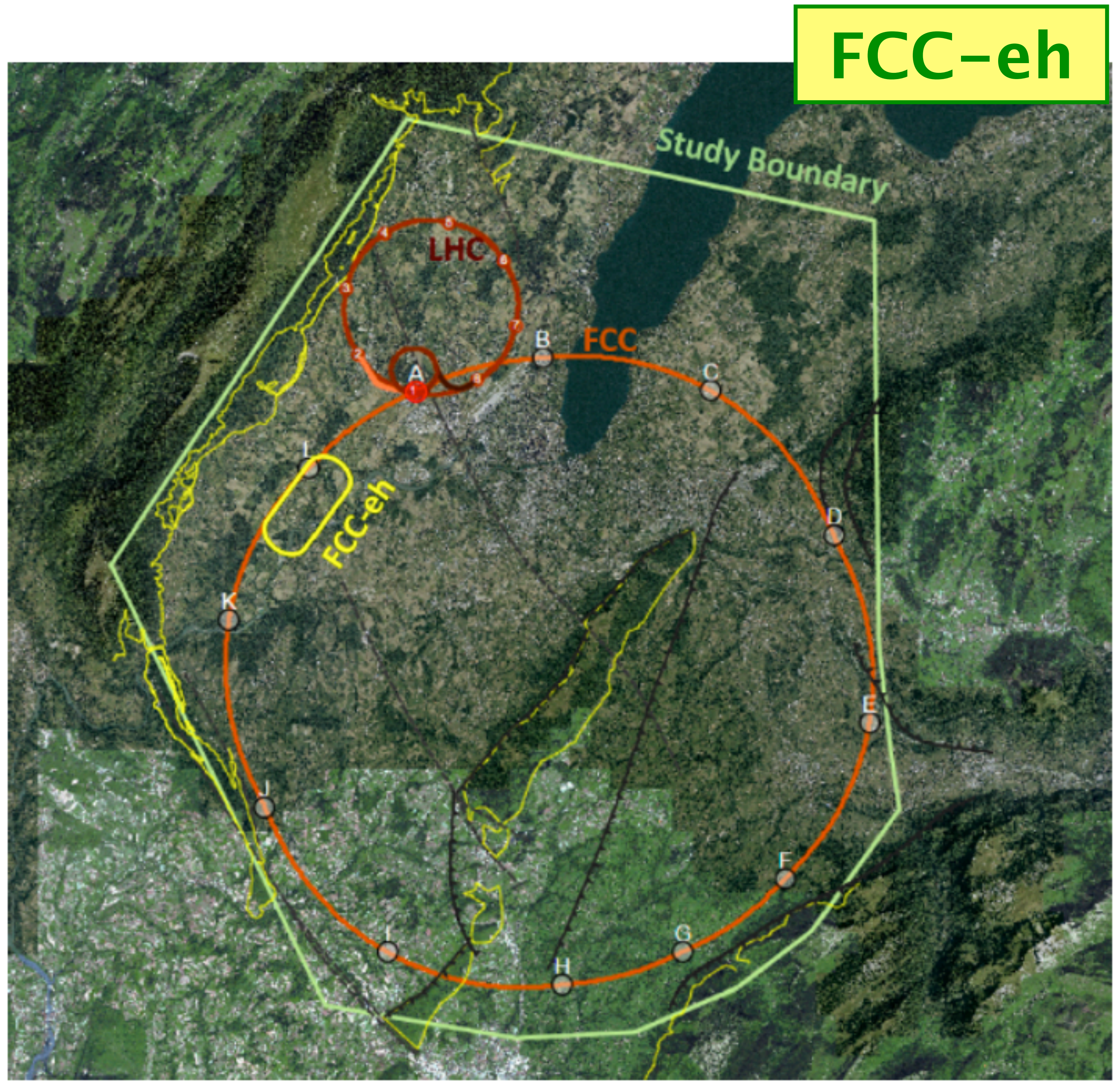


L_{int} = 1-2 ab^{-1} (1000×HERA!)

LHeC CDRs:
arXiv:1206.2913, J. Phys. G 39 075001 (2012)
arXiv:2007.14491 (accepted in J. Phys. G)

- operated synchronously with FCC-hh:
  e beam: 60 GeV × p beam: 50 TeV:
  $\sqrt{s}$=3.5 TeV
- operation: 2050+
- cost: O(1-2) BCHF

FCC CDR:
Eur. Phys. J. C 79, no. 6, 474 (2019) - Physics
Eur. Phys. J. ST 228, no. 4, 755 (2019) - FCC-hh/eh



The Large Hadron-Electron Collider at the HL-LHC

CERN-ACC-Note-2020-0002
Geneva, July 28, 2020

CERN

LHeC

The Large Hadron-Electron Collider at the HL-LHC

LHeC and FCC-he Study Group

arXiv:2007:14491 (400 pages, 300 authors)

To be submitted to J. Phys. G

accepted

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Marhauser[30], C. Marquet[105], A. Martens[39], R. Martin[9], S. Marzani[106,107], J. McFayden[9], P. Mcintosh[10], B. Mellado[92], F. Meot[57], A. Milanese[9], J. G. Milhano[14], B. Militsyn[10,11], M. Mitra[108], S. Moch[24], M. Mohammadi Najafabadi[76], S. Mondal[104], S. Moretti[109], T. Morgan[46], A. Morreale[26], P. Nadolsky[77], F. Navarra[110], Z. Nergiz[111], P. Newman[6], J. Niehues[46], E. W. Nissen[9], M. Nowakowski[112], N. Okada[113], G. Olivier[39], F. Olness[77], G. Olry[39], J. A. Osborne[9], A. Ozansoy[17], R. Pan[95,96], B. Parker[25], M. Patra[114], H. Paukkunen[3], Y. Peinaud[39], D. Pellegrini[9], G. Perez-Segurana[15,11], D. Perini[9], L. Perrot[39], N. Pietralla[115], E. Pilicer[87], B. Pire[105], J. Pires[14], R. Placakyte[116], M. Poelker[30], R. Polifka[117], A. Polini[118], P. Poulose[23], G. Pownall[22], Y. A. Pupkov[91], F. S. Queiroz[119], K. Rabbertz[120], V. Radescu[121], R. Rahaman[122], S. K. Rai[108], N. Raicevic[123], P. Ratoff[15,11], A. 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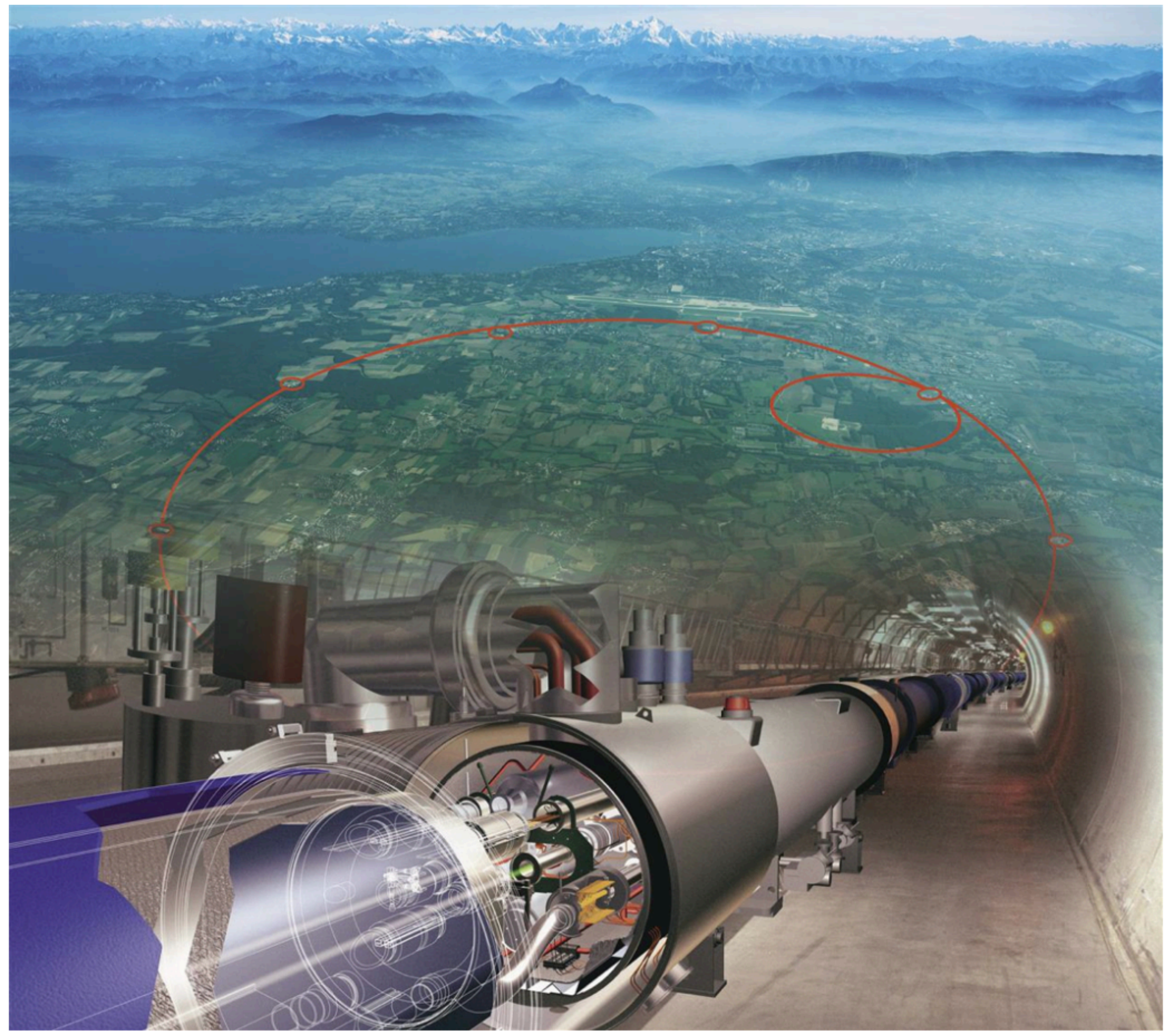
156 institutions involved

5 pages summary:

ECFA
European Committee for Future Accelerators

ECFA Newsletter #5



Following the Plenary ECFA meeting, 13 July 2020
https://indico.cern.ch/event/933318/
Summer 2020

https://cds.cern.ch/record/2729018/files/ECFA-Newsletter-5-Summer2020.pdf

O. Brüning, M. Klein

Colliders in Europe at the energy & precision frontier

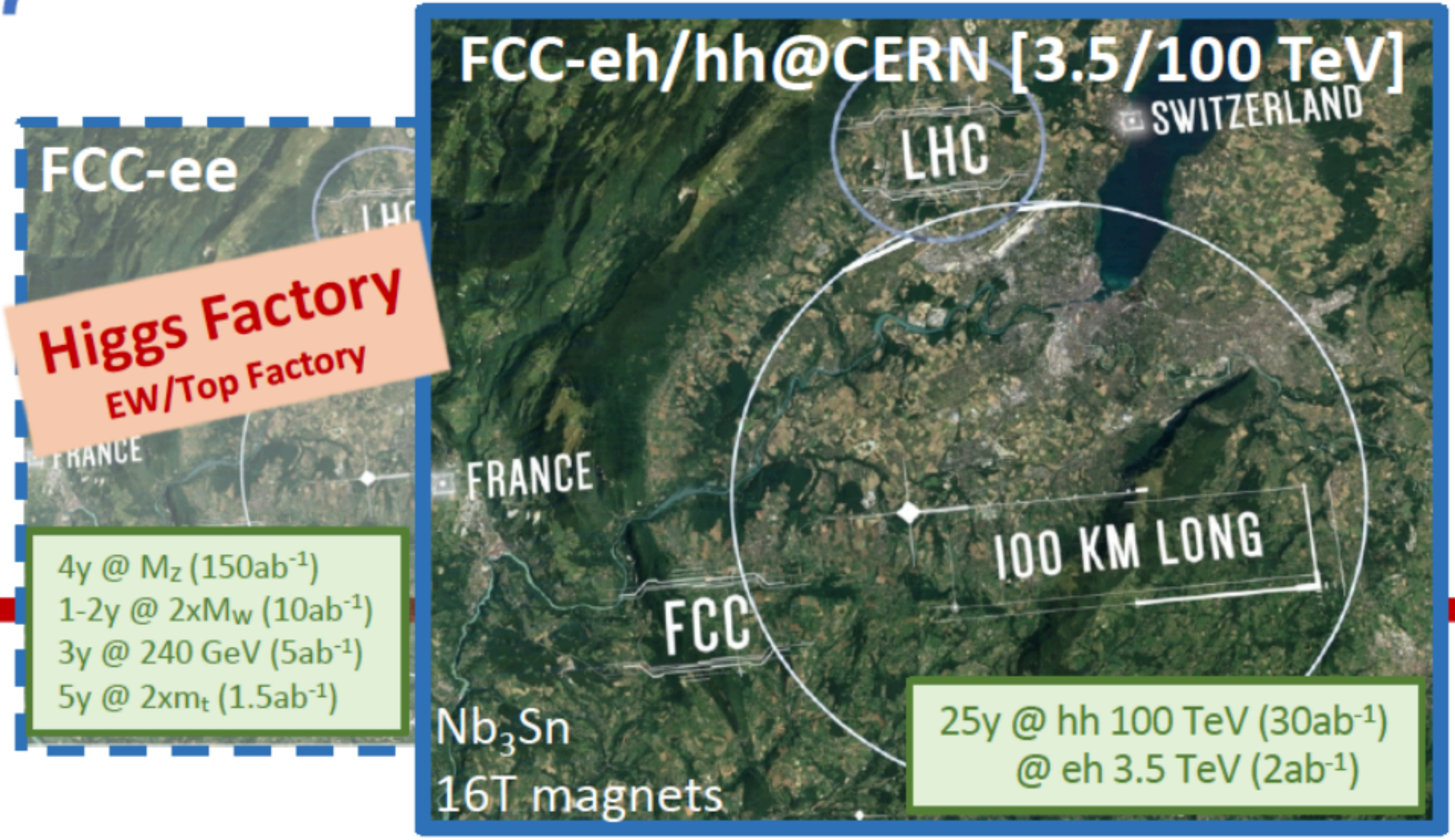
Current flagship (27km)

impressive programme up to 2040

Big sister future ambition (100km), beyond 2040

attractive combination of precision & energy frontier

ep-option with HL-LHC: LHeC



numbers assume 2 IPs for each collider (only one for FCC-eh)

by around 2026, verify if it is feasible to plan for success (techn. & adm. & financially & global governance)

potential alternatives pursued @ CERN: CLIC & muon collider

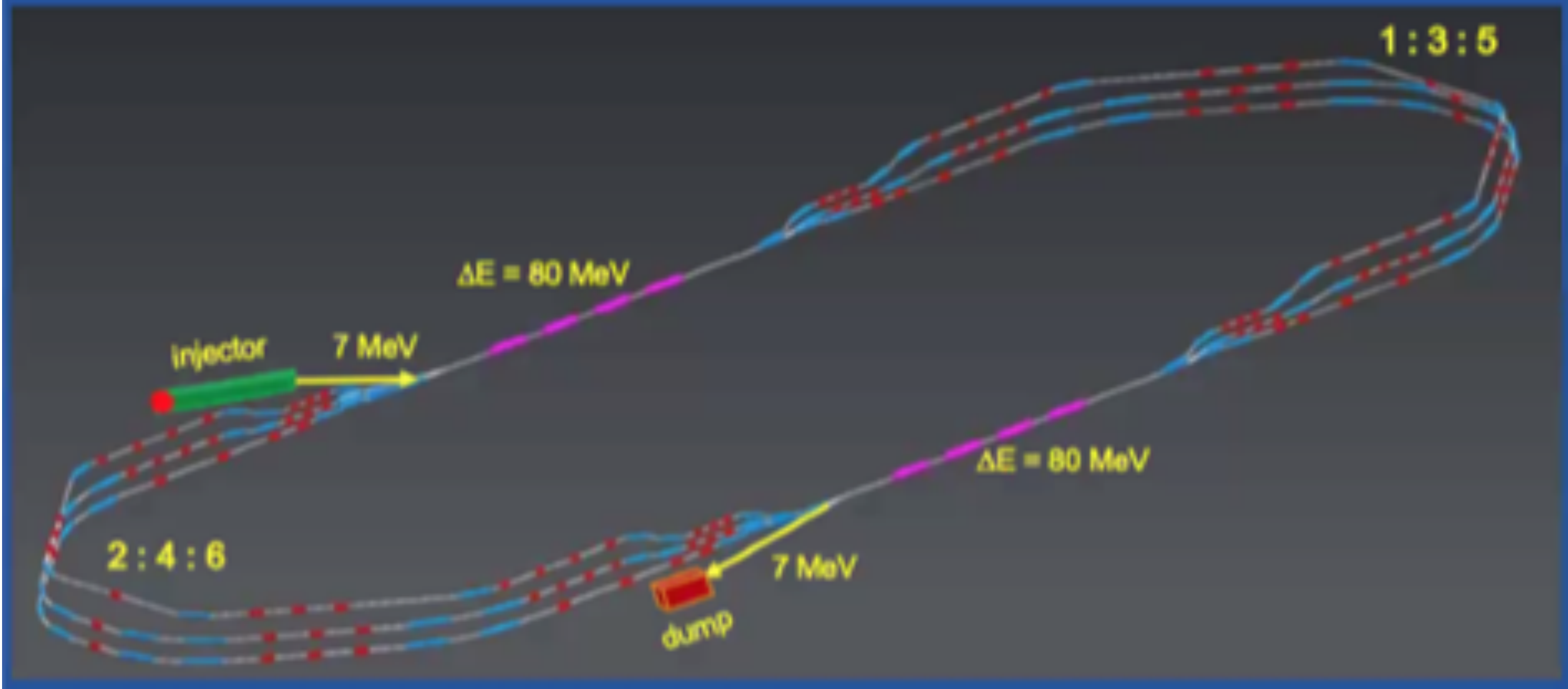
J de Hondt (5.10.20 to Snowmass)

17

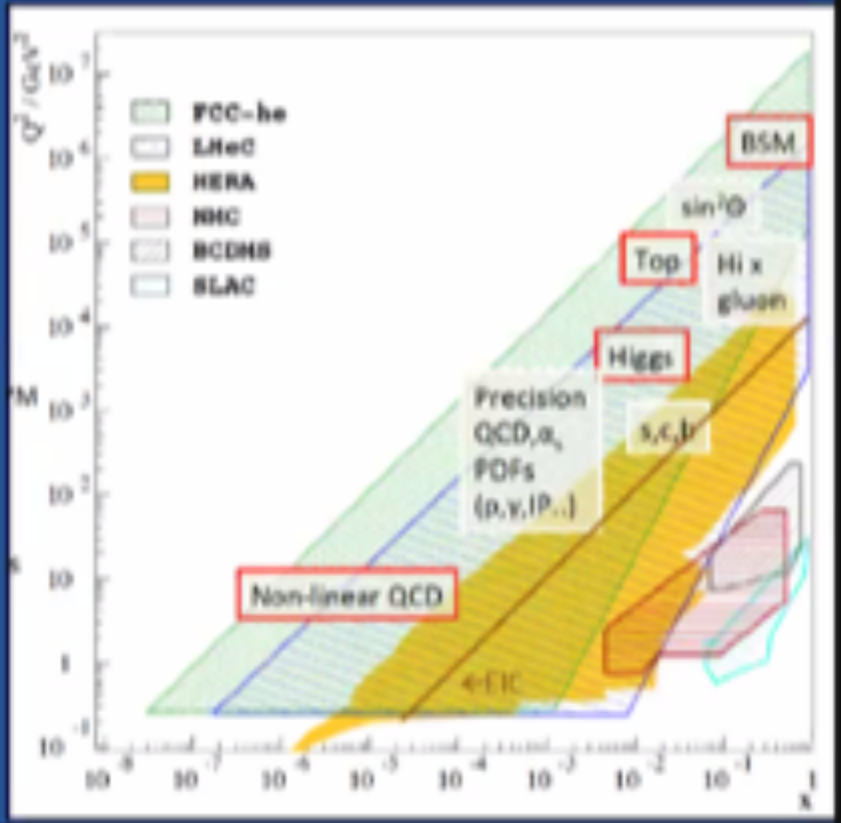
Energy recovery Linac: ep-collider

Concept:
accelerate electrons to high energy → use the beam → decelerate
→ recover beam energy for machine operation → Energy Saving

Worldwide developments :
p.ex BINP (Novosibirsk) CERL (KEK), CBETA-Cornell
projects: bERLinPro (light source), MESA…
HEP: PERLE superconductive multipass demonstrator in Orsay (≈25M€)
TDR expected by 2022

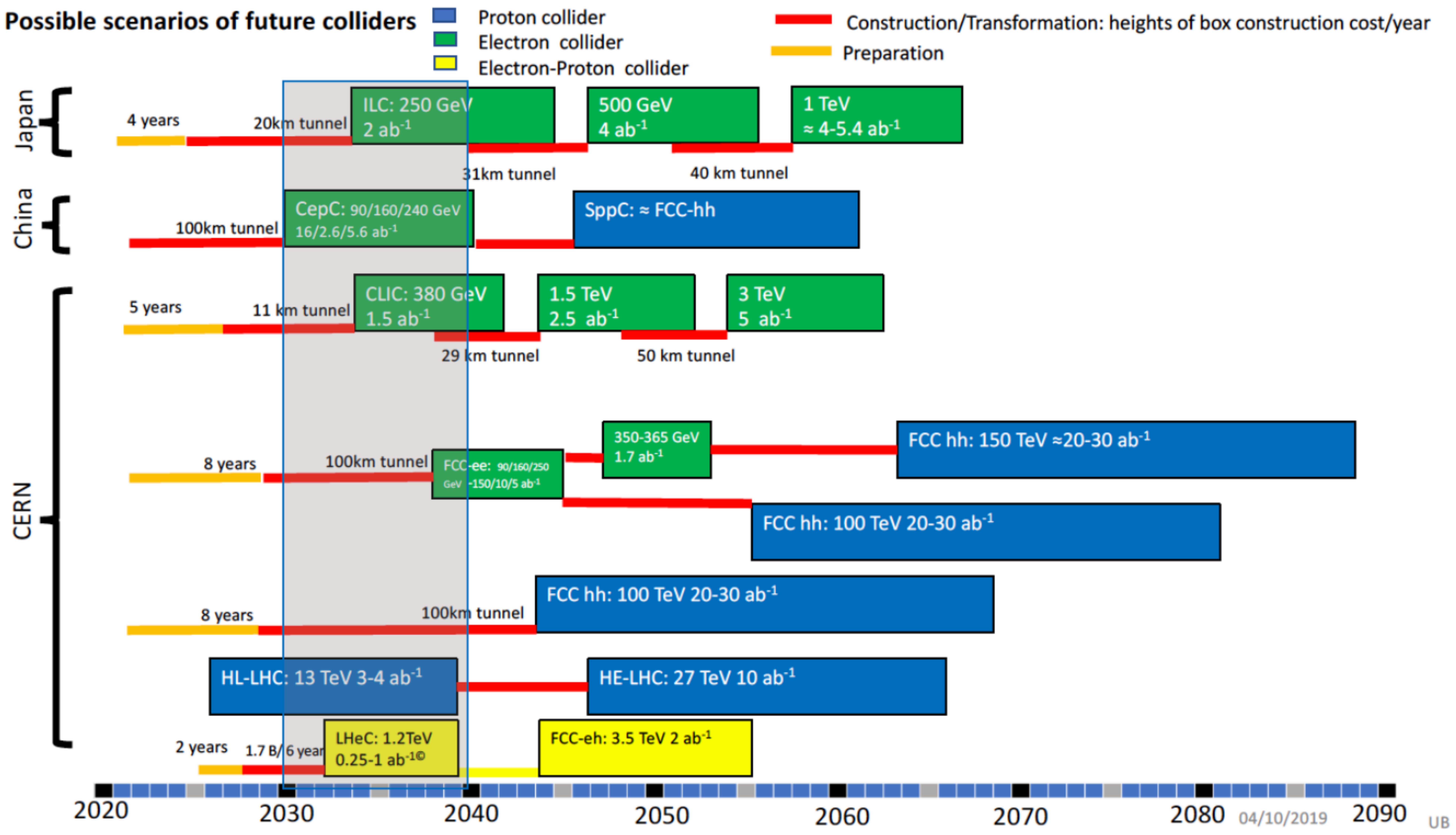


High energy ep-collider:
- Independent proton-structure function measurements
- Higgs physics measurements
- Complementary to EIC



Ursula Bassler (Chair of CERN Council), Talk about "European Strategy for Particle Physics: towards the next collider at CERN", given at the German Physics Society Spring Conference, March 2021

Timeline of Future Colliders in European Strategy



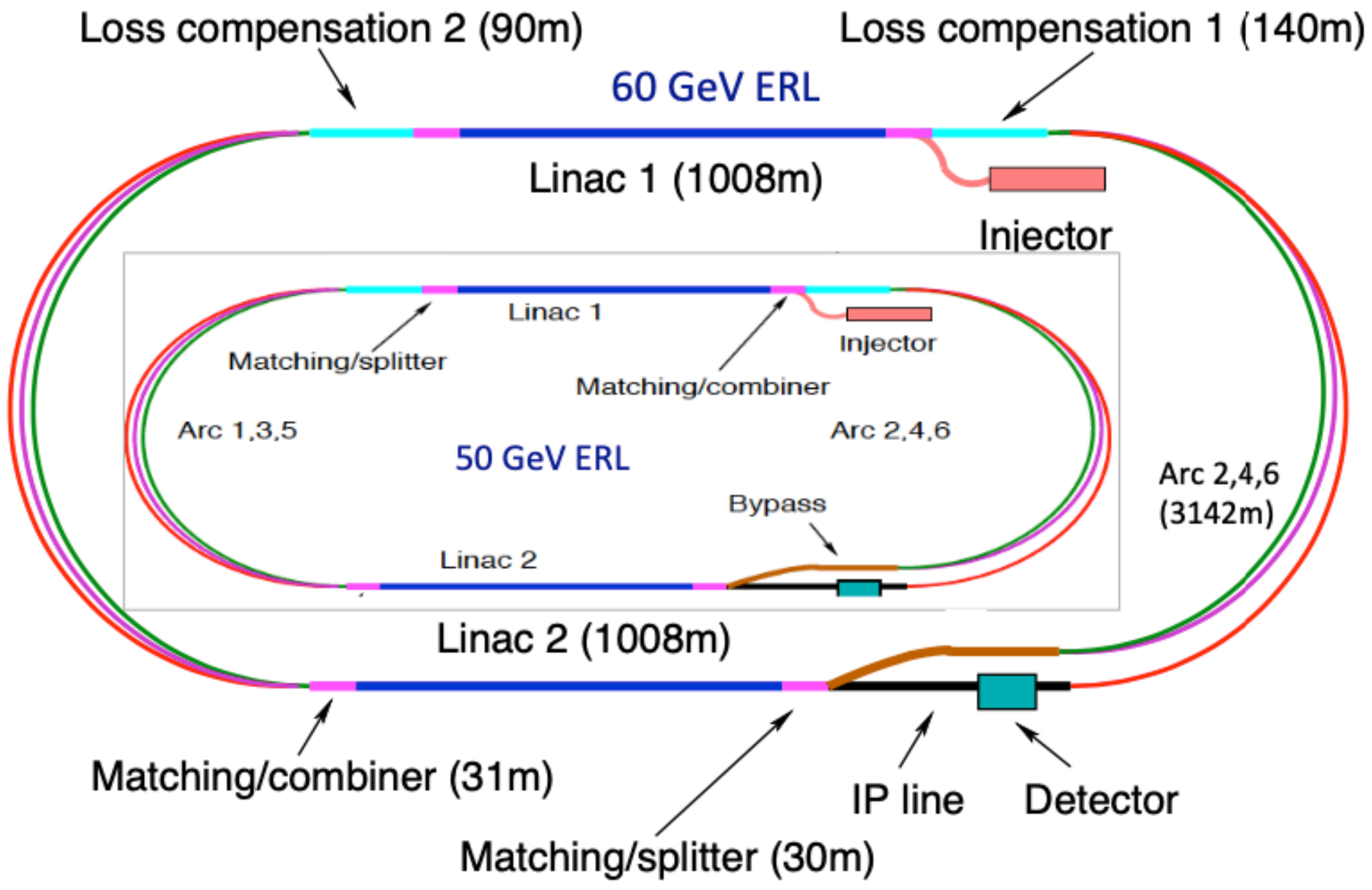
CERN/ESG/05b

extracted from submitted inputs by U. Bassler

Energy Recovering Linac (ERL)

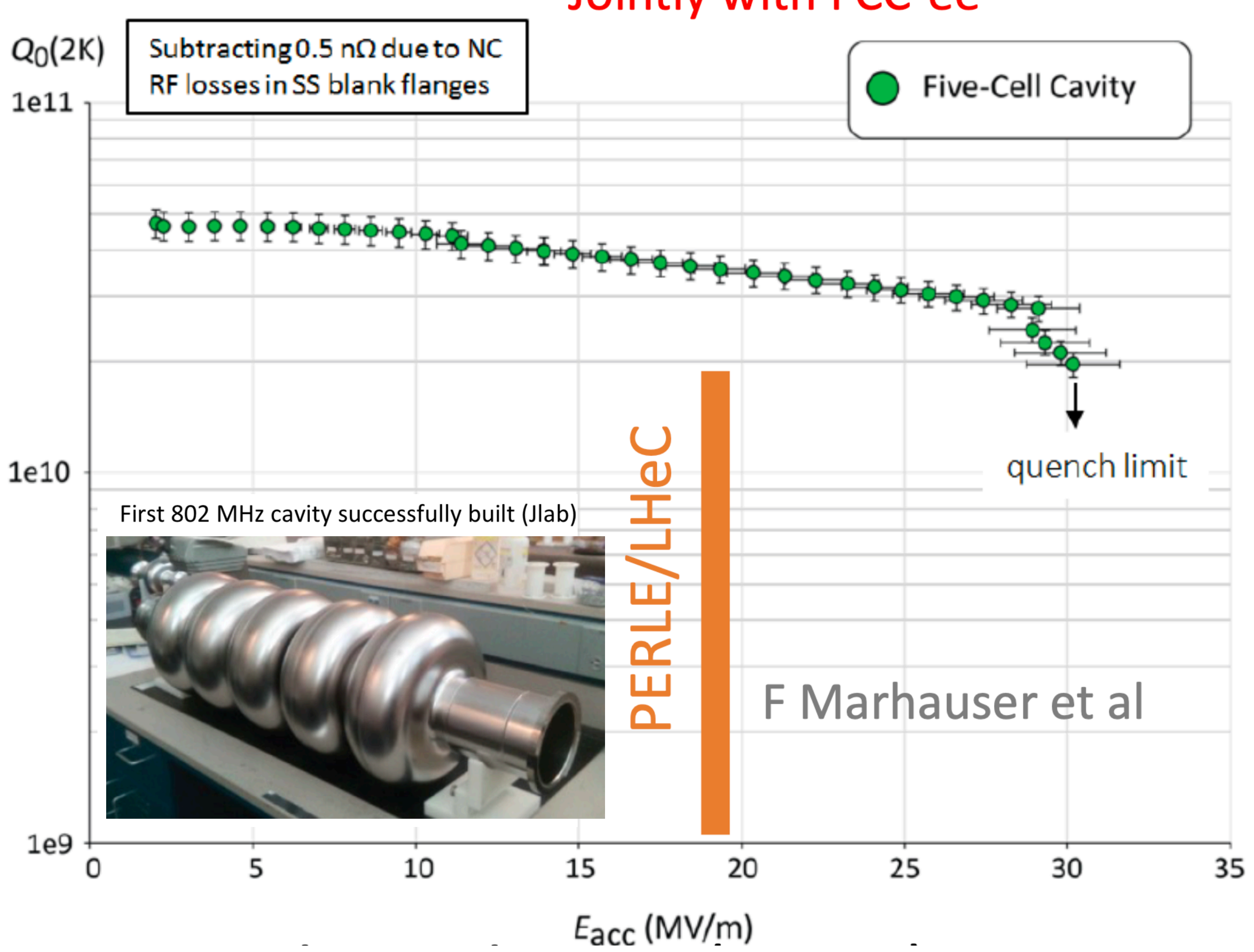
LHeC/FCC-eh: needs high luminosity, high energy:

High ERL power facility $P=I_e E_e$



- high quality Superconducting Radio Frequency ($Q_0 > 10^{10}$)

Jointly with FCC-ee



- LHeC Configuration reduced from 60 to 50 GeV
- LINAC: 112 cryomodules with 4 cavities each
  → total number of cavities: 896 [ILC: $O(10^4)$]
- configuration may be staged with less RF
- tunnel is small part of cost and better not reduced further, synchrotron loss, upgrades…
- ERL reduces power to ≪ GW and dumps at < GeV

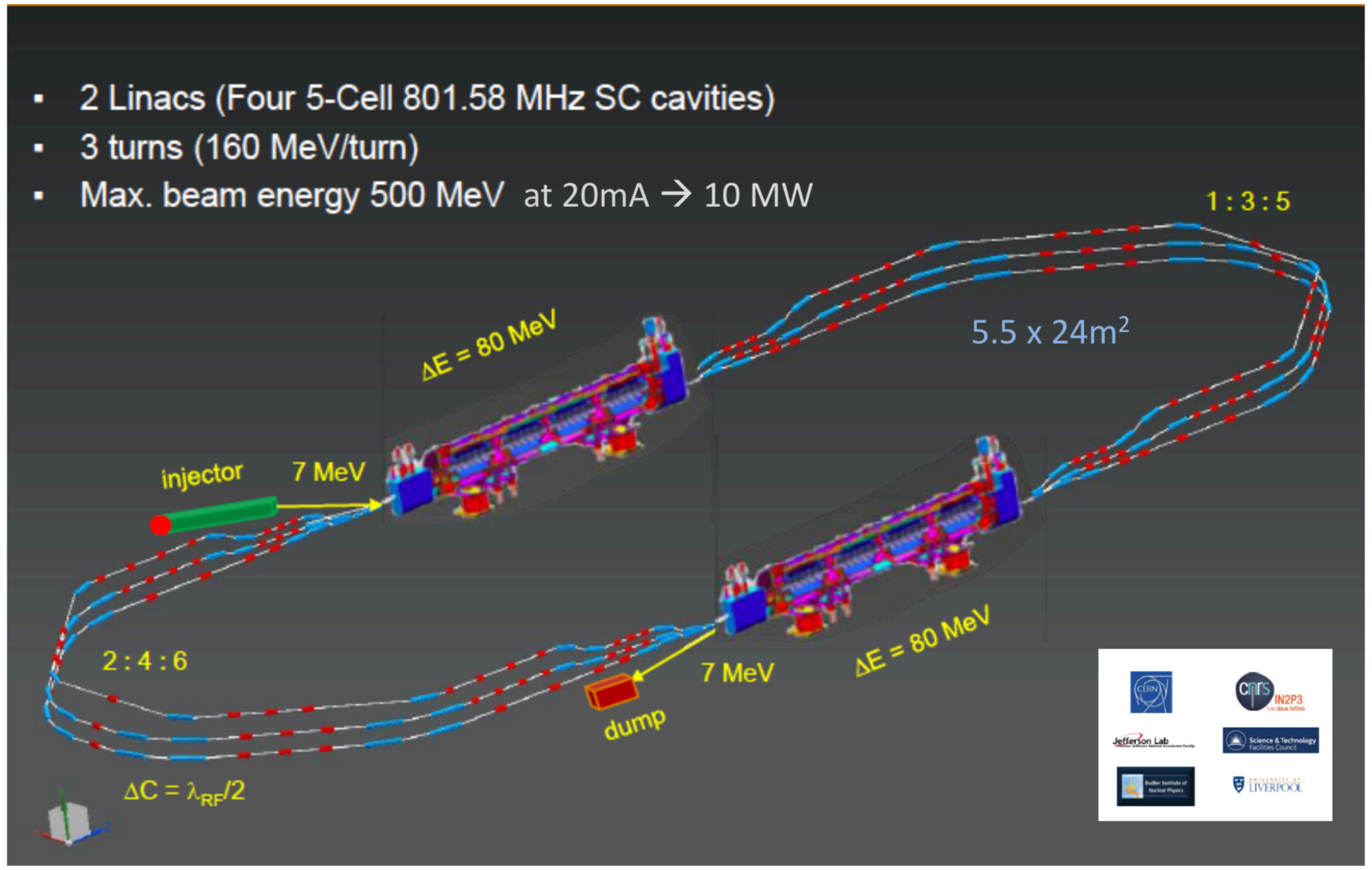
→ novel, "green" accelerator technology and save energy

- high current sources
- multiturn to reach high E_e

Technical Synergies of LHeC with other applications

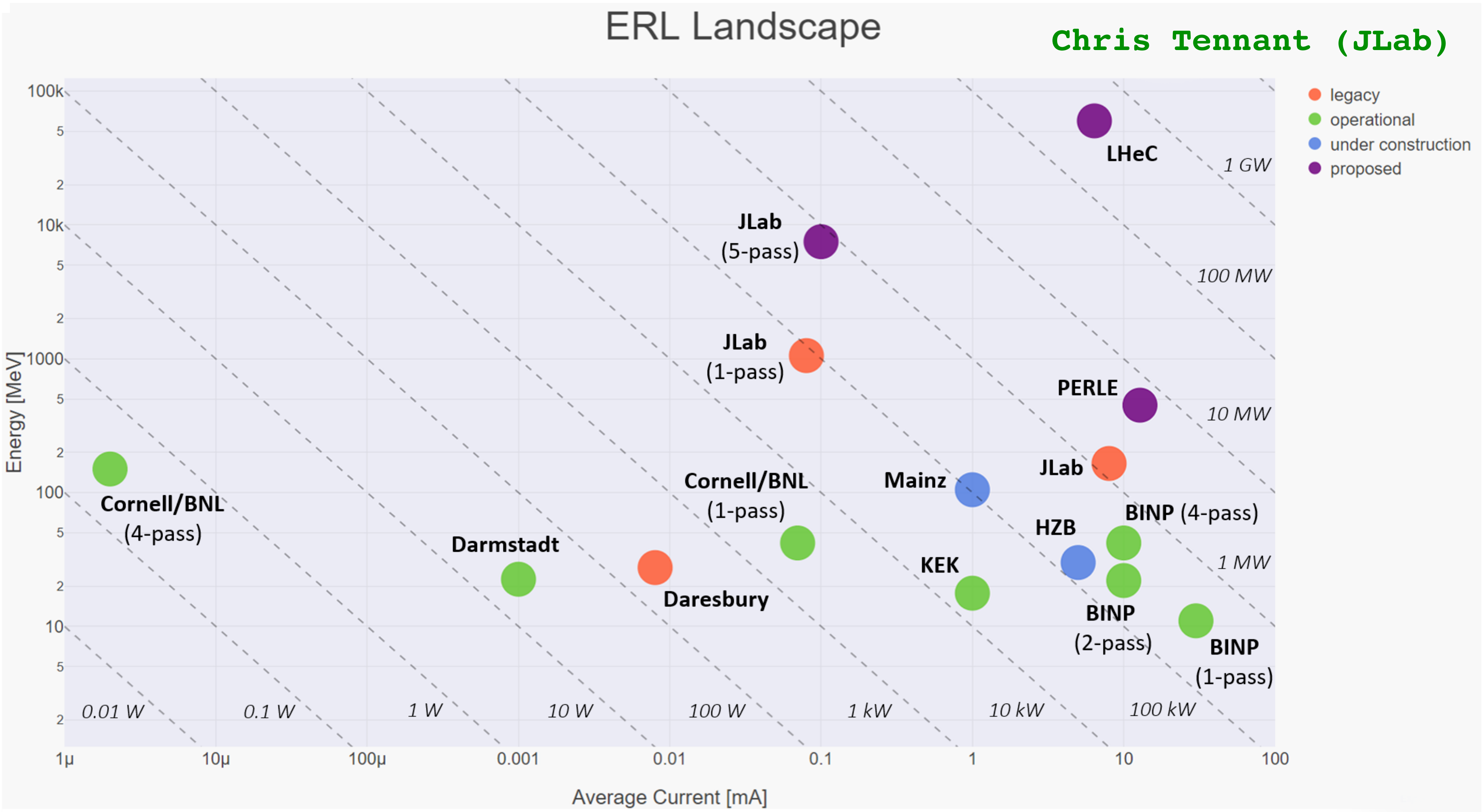
- **operate the ILC as an ERL**: boost luminosity to 10^{36} $cm^{-2}s^{-1}$
  Vladimir Telnov at the March 21 LCWS
- SAPPHIRE: a γγ collider : Higgs, EWK and QCD machine
  F. Zimmermann et al., arXiv:1208.2827
- Racetrack as an injector into FCC-ee [direct into Z]
  O. Bruening, Y. Papaphilippou
- HeC-FEL
  F. Zimmermann et al., work in progress
- Injector into FCC-hh
  R. Calaga
- Proposal of ERL Version of FCC-ee for high Lumi at high E_e
  V Litvinenko, T Roser, M Chamizo-Llatas arXiv: 1909.04437
- 802 MHz technology: PERLE, FCC-ee, eSPS
  F Marhauser, B Rimmer et al.
- 704 MHz SPL Cryomodule (CERN) modified for PERLE
  F Gerigk, E Jensen et al.
- ALICE (Daresbury) Gun delivered to Orsay for PERLE
  D Angal-Kalinin, B Militsyn et al.
- JLEIC Booster (Jlab) likely to be used in PERLE
  F Hannon, B Rimmer et al.
- Forward Calorimetry: FCC-hh and ee colliders / CALICE…
- Inner Tracker/CMOS: ee colliders, new HI detector at IP2
- …

Powerful ERL for Experiments (PERLE) @ Orsay



PERLE

CDR: 1705.08783, J. Phys. G
CERN-ACC-Note-2018-0086 (ESSP)



PERLE Collaboration (2021): CERN, Cornell, Daresbury, JLab, Liverpool, Novosibirsk (BINP), Orsay (IJC)

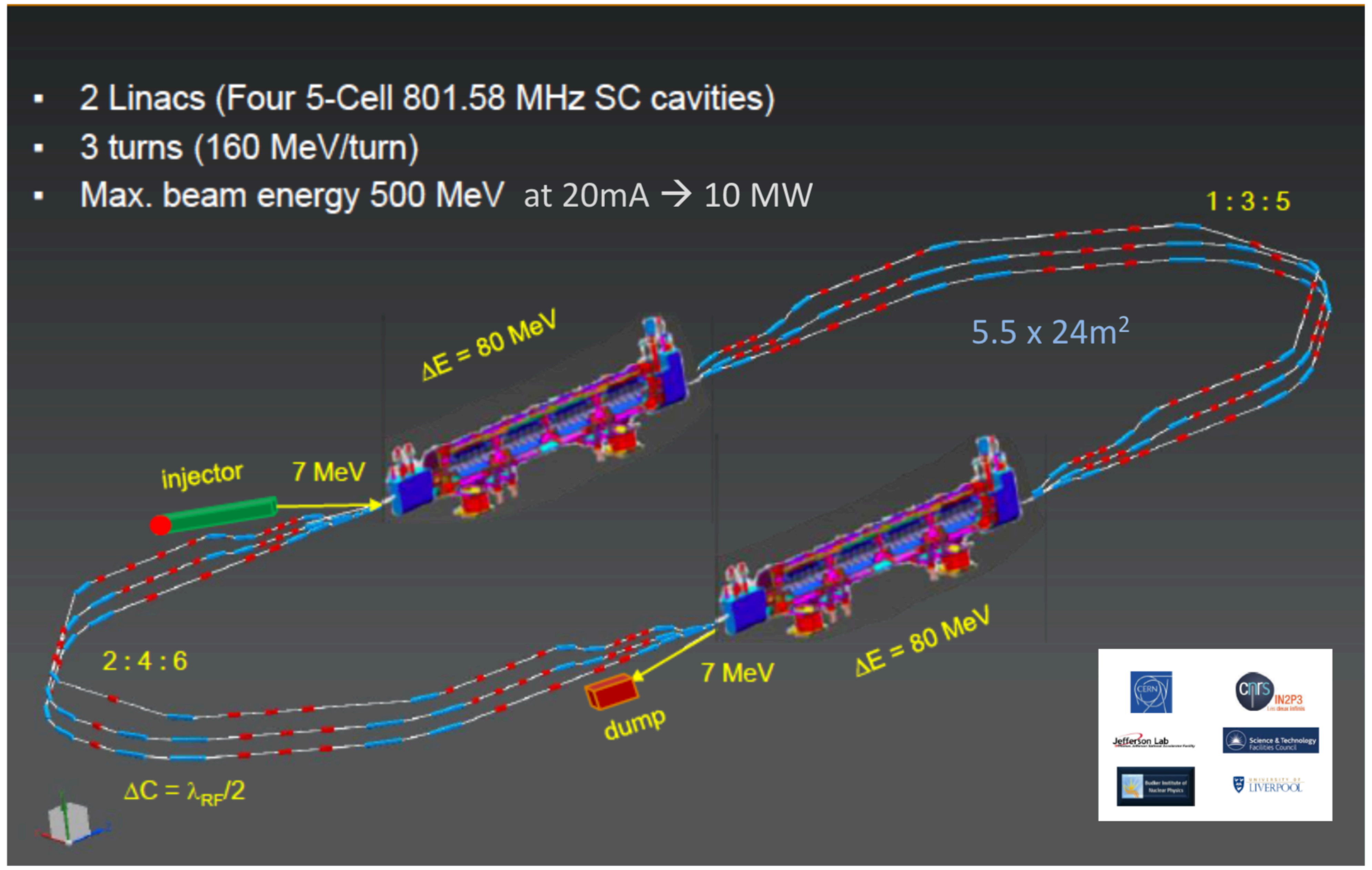
- **LHeC Technology Development Facility**
- **high luminosity particle and nuclear physics experiments**

- **part of global ERL Developments (Roadmap end of 2021)**
- **synergies: ERL Concepts for FCC-ee and ILC**

→ **high precision elastic ep scattering, photo-nuclear reactions, …**

- **The ERL Facility PERLE at Orsay**, Alex Bogacz, Apr 13, 10:15 AM

Powerful ERL for Experiments (PERLE) @ Orsay



PERLE

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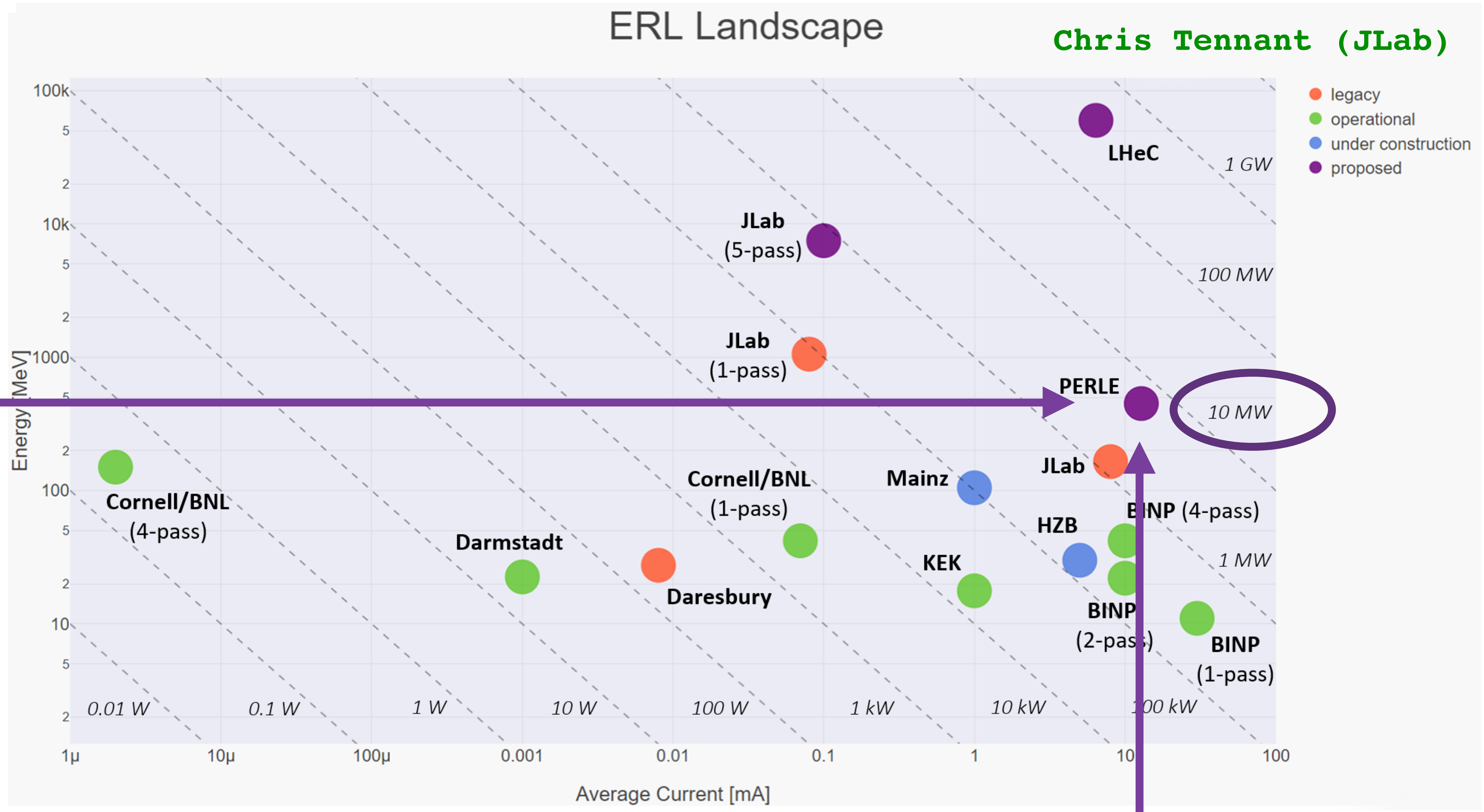


E_e=500 MeV

I_e=20mA

802 MHz SRF

3 turns

- LHeC Technology Development Facility
- high luminosity particle and nuclear physics experiments

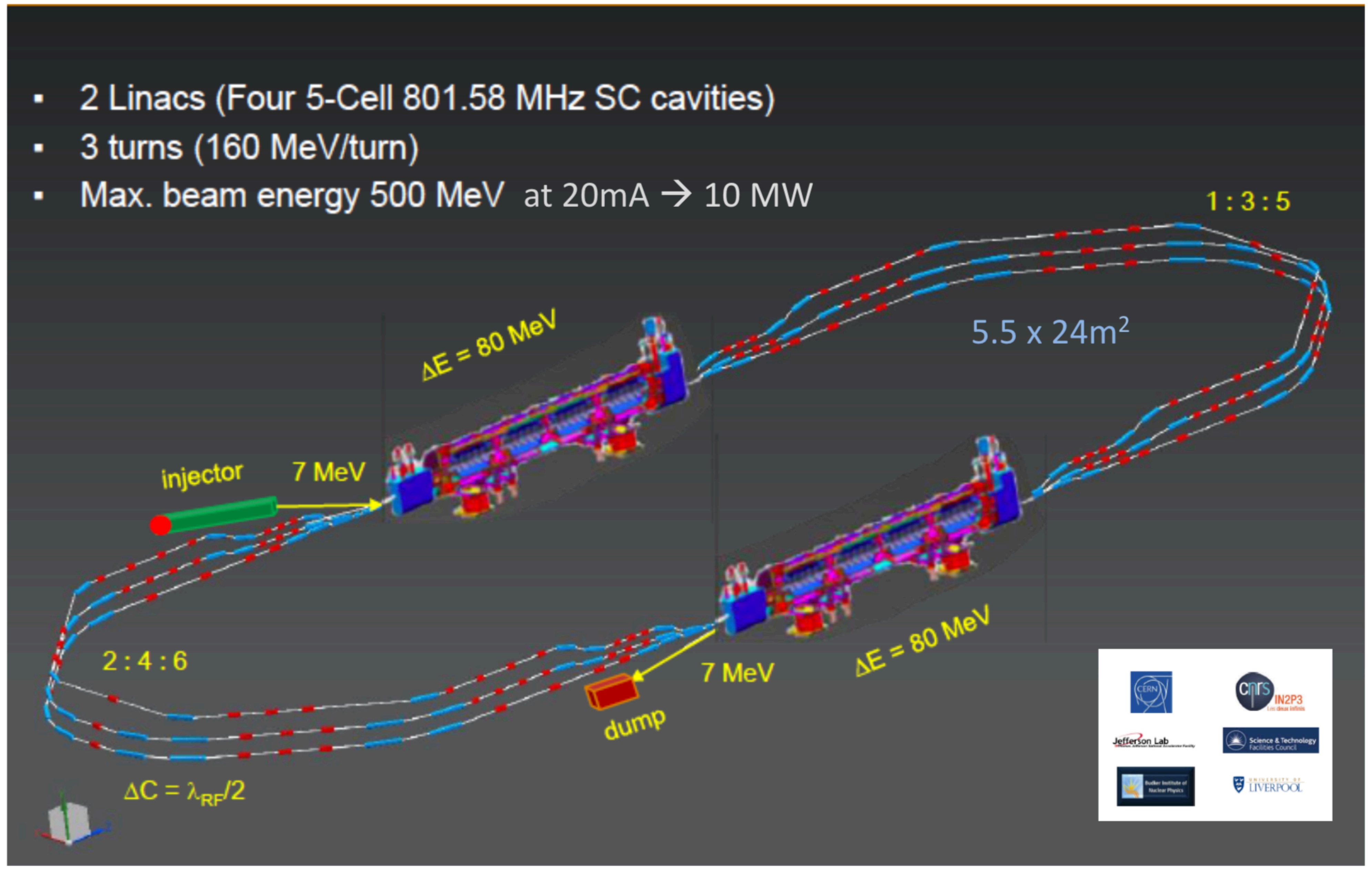
- part of global ERL Developments (Roadmap end of 2021)
- synergies: ERL Concepts for FCC-ee and ILC

→ high precision elastic ep scattering, photo-nuclear reactions, …

→ first 10 MW ERL facility

Powerful ERL for Experiments (PERLE) @ Orsay

CDR: 1705.08783, J. Phys. G
CERN-ACC-Note-2018-0086 (ESSP)



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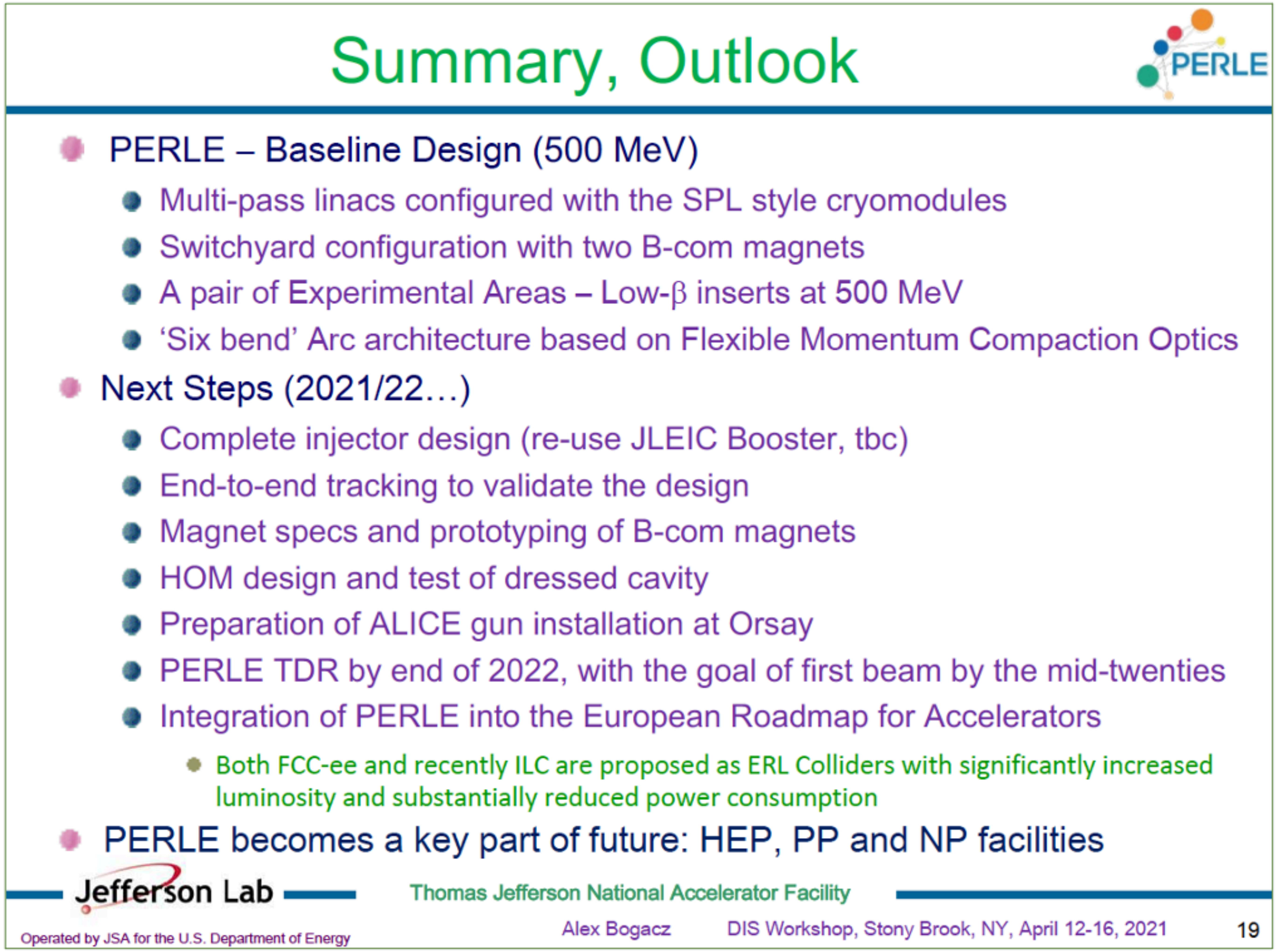


LHeC Detector Design

L=13.2 m [FCCeh:19.3 about CMS size]

R=4.8 m
[6.2 FCCeh]

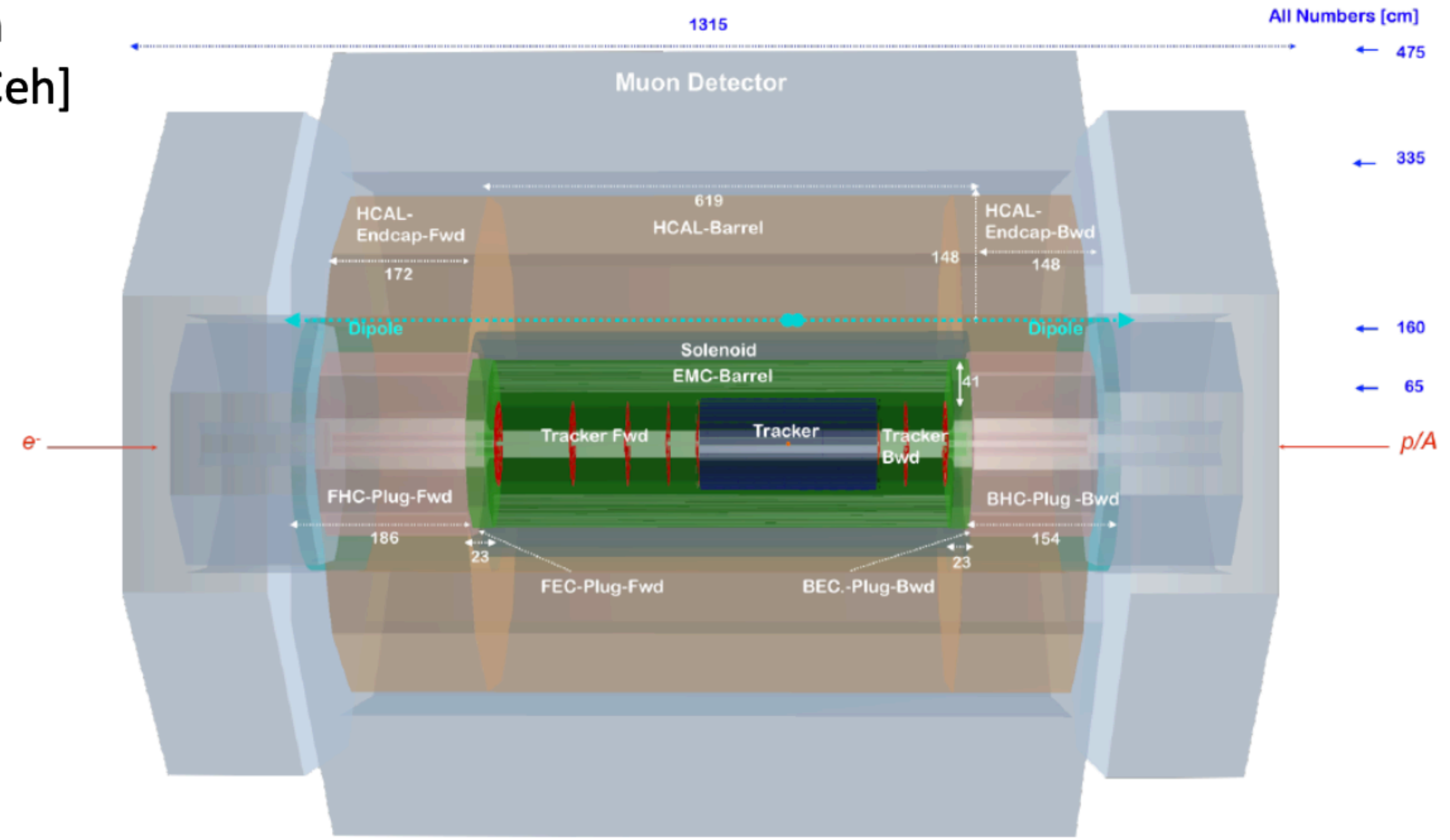
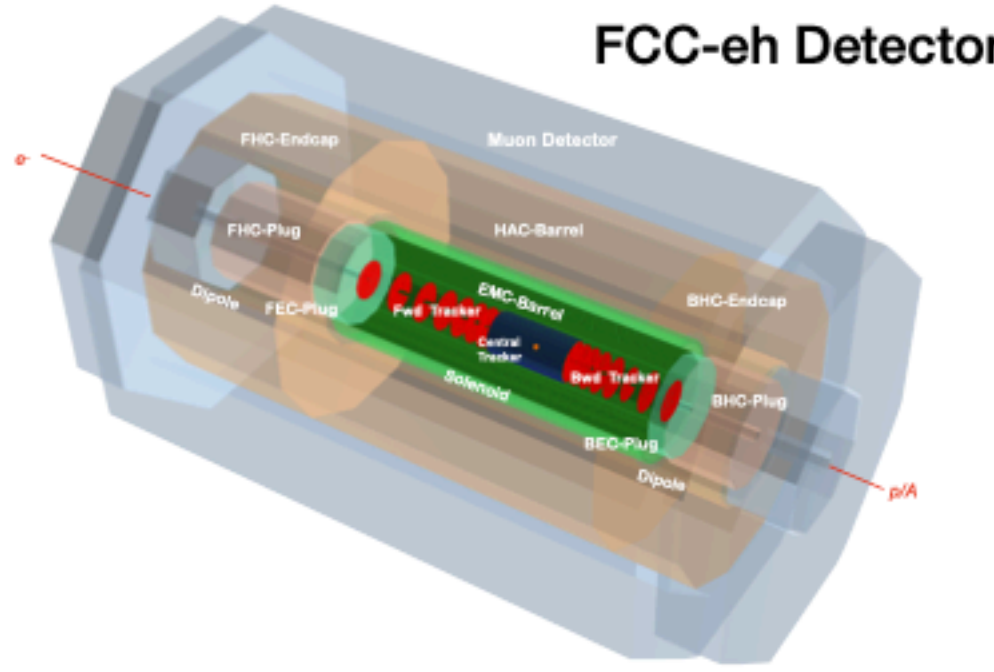
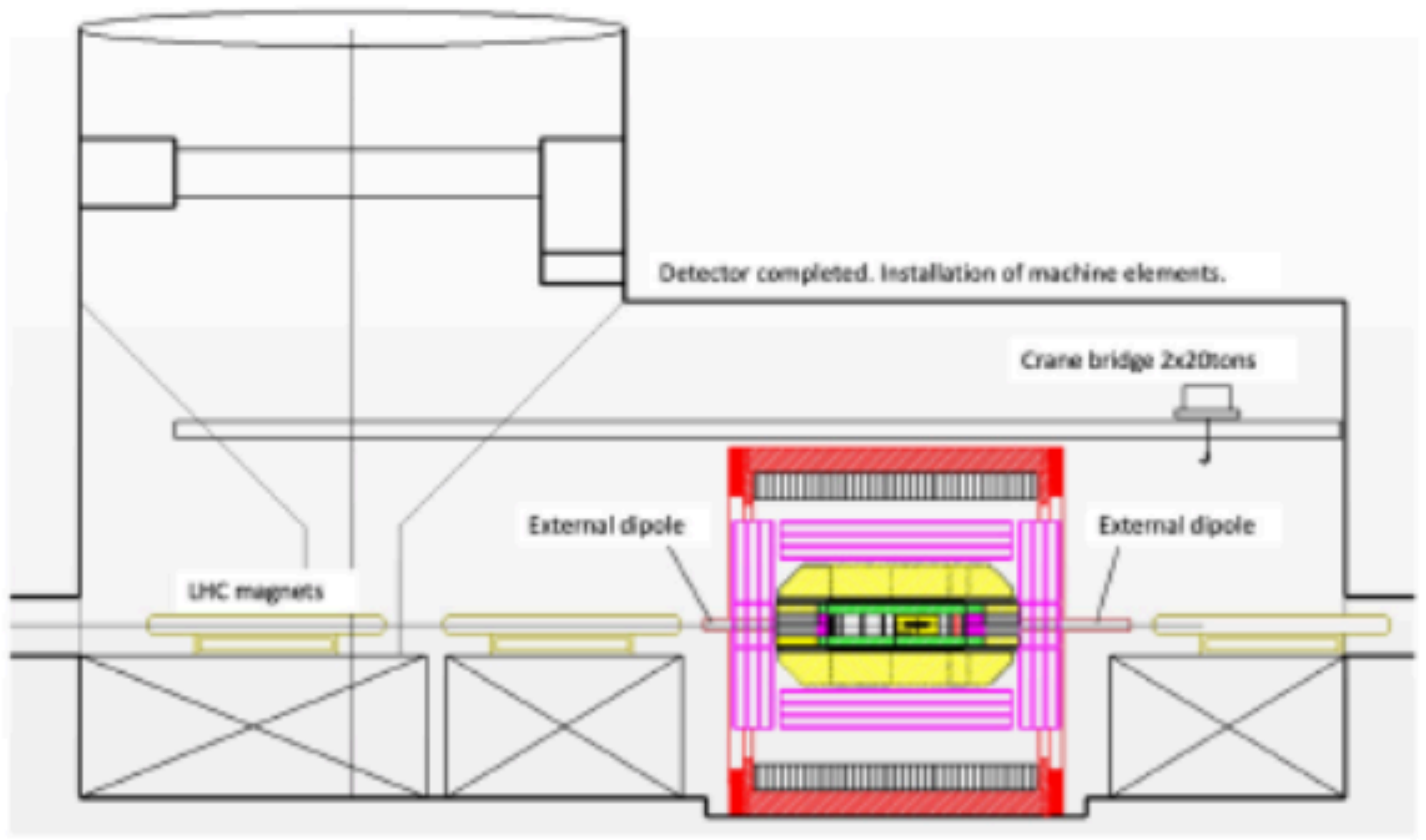


Figure 12.1: Side view of the updated baseline LHeC detector concept, providing an overview of the main detector components and their locations. The detector dimensions are about 13 m length and 9 m diameter. The central detector is complemented with forward (p, n) and backward (e, γ) spectrometers mainly for diffractive physics and for photo-production and luminosity measurements, respectively. See text for details.

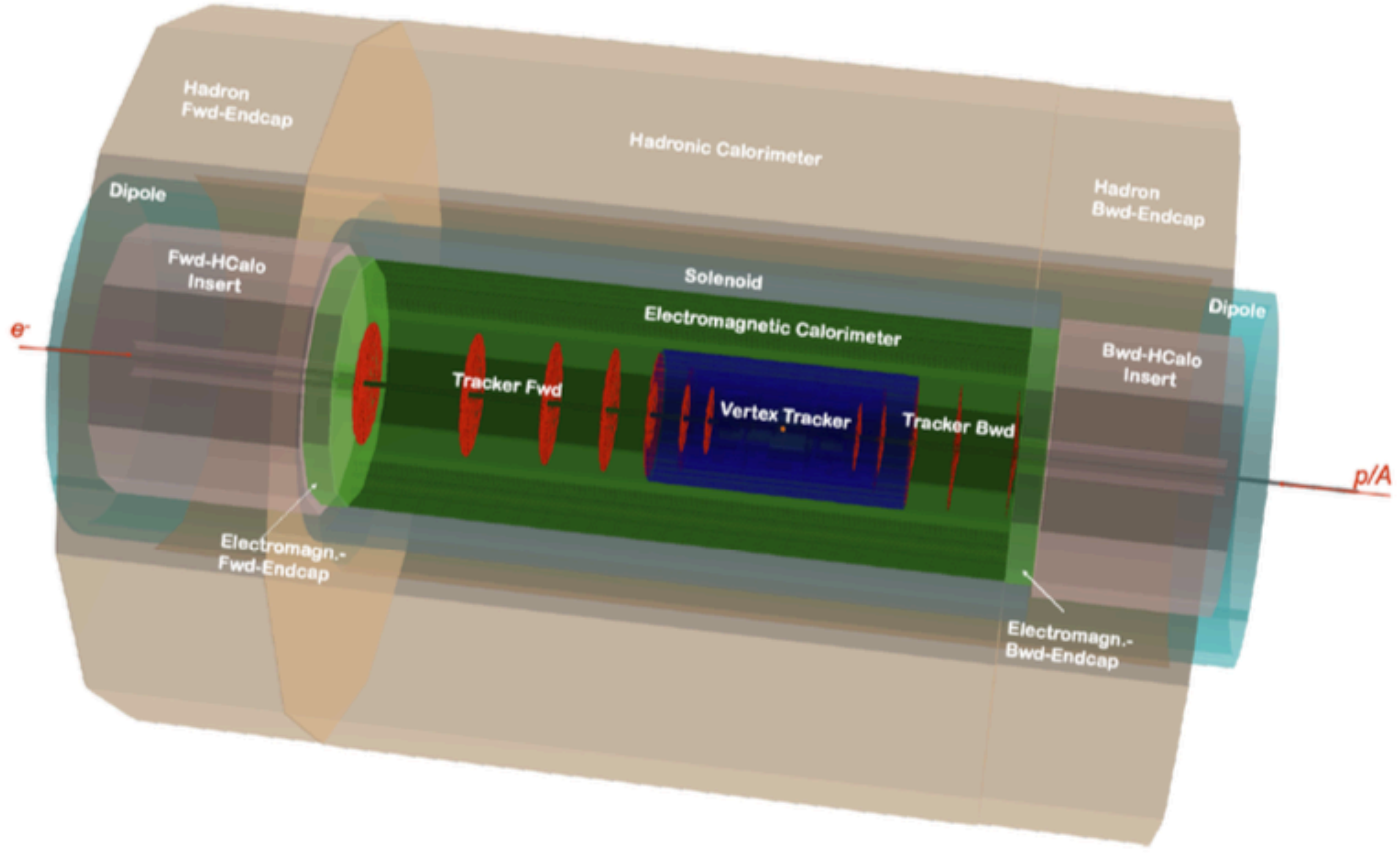
FCC-eh Detector



Study of installation (sequence)
of LHeC detector in IP2 cavern
using L3 magnet support structure
[commensurate with 2 year shutdown]



LHeC Calorimeter Design



LHeC Calorimeters

Complete coverage to +- 5 in (pseudo)rapidity

Central Region: 2012: LAr, 2020 Sci/Fe option.

Forward Region: dense, high energy jets of few TeV

H → bb and other reactions demand resolution of HFS

Backward Region: in DIS only deposits of $E < E_e$

Barrel Calorimeters

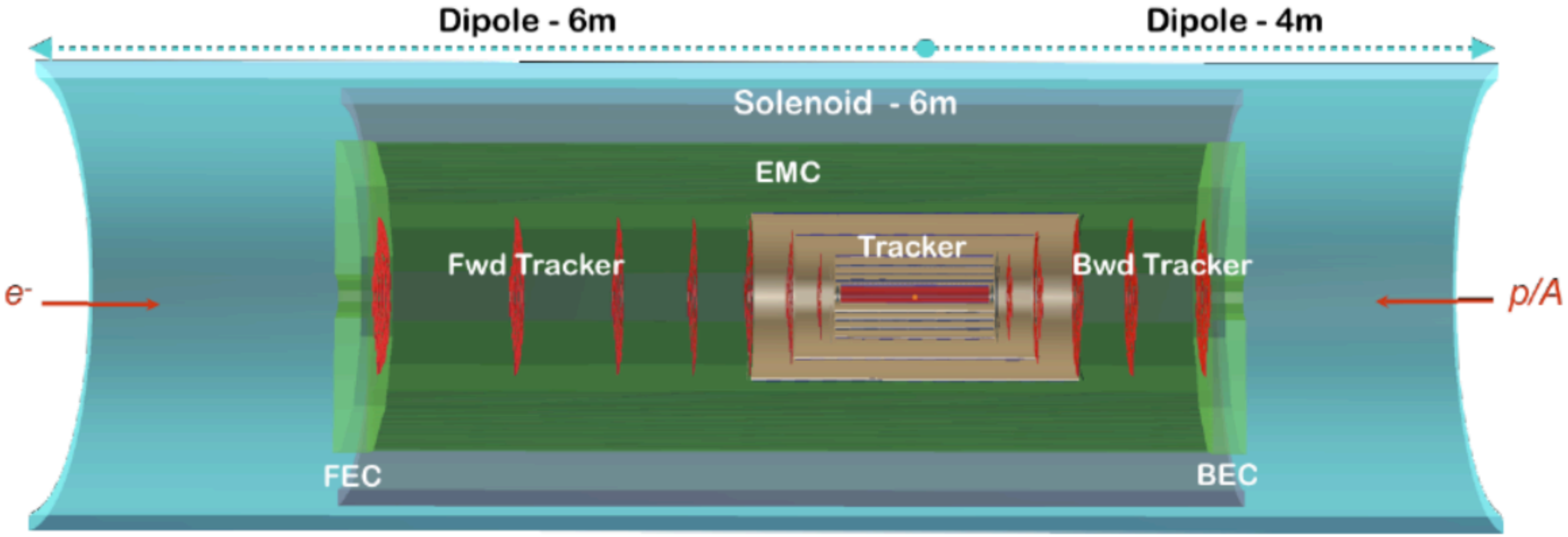
Calo (LHeC)	EMC	HCAL		
	Barrel	Ecap Fwd	Barrel	Ecap Bwd
Readout, Absorber	Sci,Pb	Sci,Fe	Sci,Fe	Sci,Fe
Layers	38	58	45	50
Integral Absorber Thickness [cm]	16.7	134.0	119.0	115.5
η_{max}, η_{min}	2.4, −1.9	1.9, 1.0	1.6, −1.1	−1.5, −0.6
$\sigma_E/E = a/\sqrt{E} \oplus b$ [%]	12.4/1.9	46.5/3.8	48.23/5.6	51.7/4.3
Λ_I / X_0	$X_0 = 30.2$	$\Lambda_I = 8.2$	$\Lambda_I = 8.3$	$\Lambda_I = 7.1$
Total area Sci [m^2]	1174	1403	3853	1209

Forward/Backward Calorimeters

Calo (LHeC)	FHC Plug Fwd	FEC Plug Fwd	BEC Plug Bwd	BHC Plug Bwd
Readout, Absorber	Si,W	Si,W	Si,Pb	Si,Cu
Layers	300	49	49	165
Integral Absorber Thickness [cm]	156.0	17.0	17.1	137.5
η_{max}, η_{min}	5.5, 1.9	5.1, 2.0	−1.4, −4.5	−1.4, −5.0
$\sigma_E/E = a/\sqrt{E} \oplus b$ [%]	51.8/5.4	17.8/1.4	14.4/2.8	49.5/7.9
Λ_I / X_0	$\Lambda_I = 9.6$	$X_0 = 48.8$	$X_0 = 30.9$	$\Lambda_I = 9.2$
Total area Si [m^2]	1354	187	187	745

arXiv:2007.14491

LHeC Tracker Design



Inner Tracker

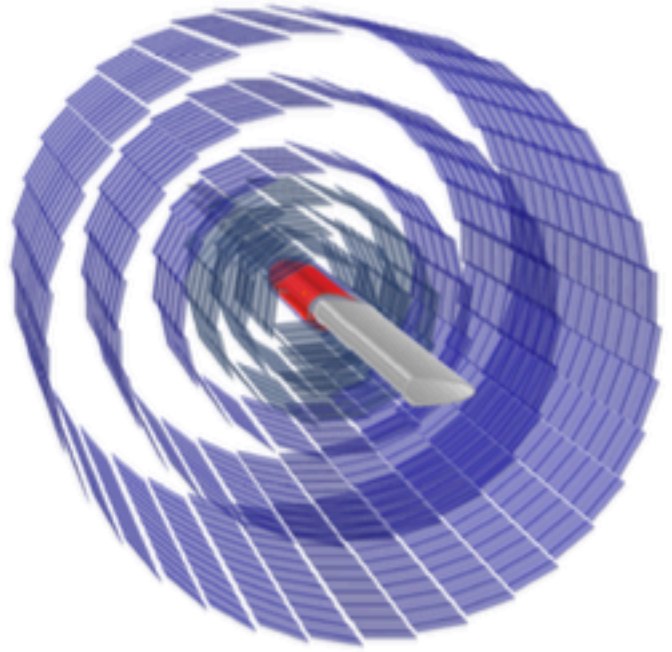
Rapidity to ~5

r_O = 60 cm

impact resolution 5-10 µm

40.7 m² Si

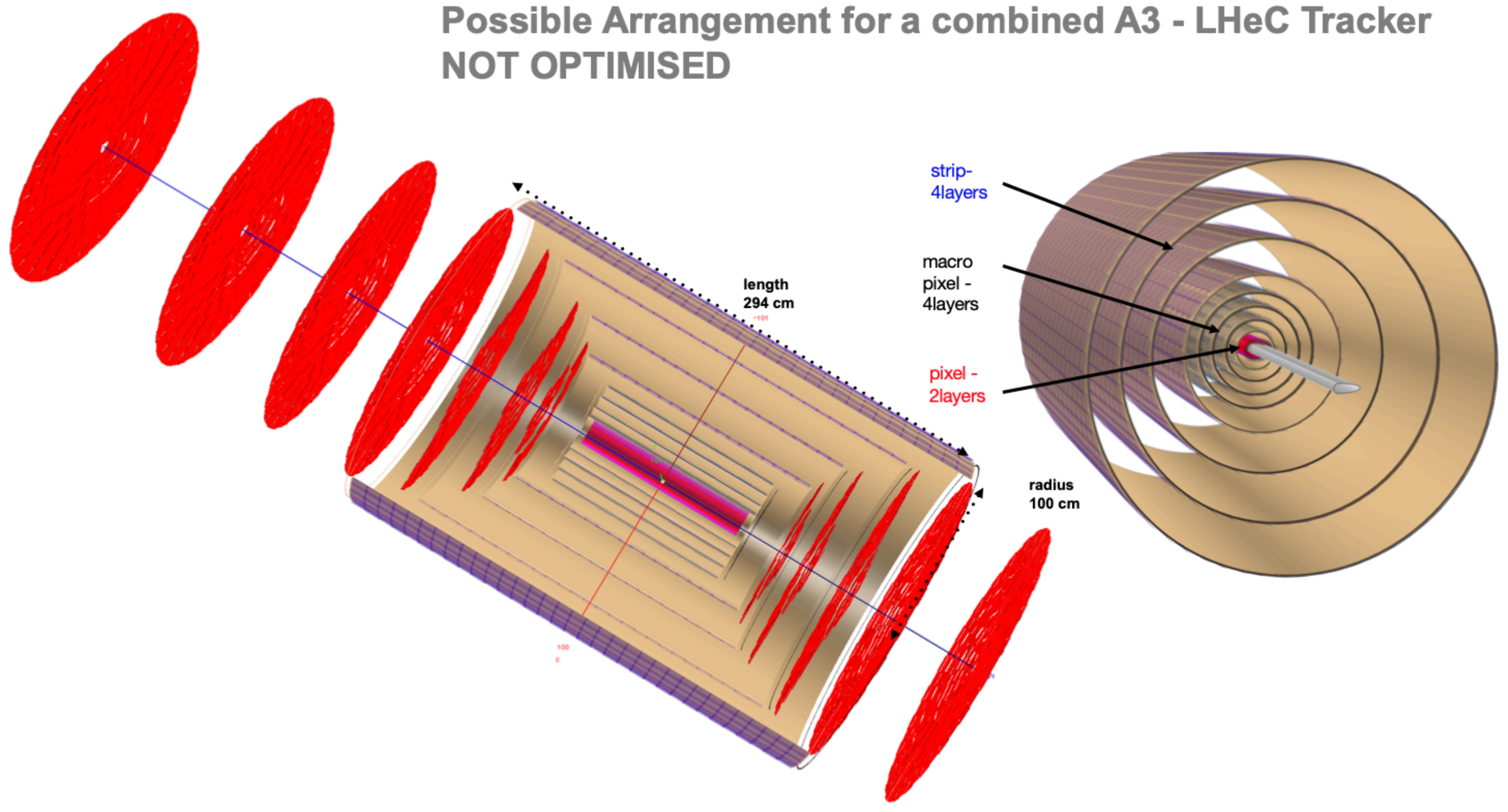
Tracker (LHeC)		Fwd Tracker			Bwd Tracker		Total
		pix	$\text{pix}_{\text{macro}}$	strip	$\text{pix}_{\text{macro}}$	strip	(incl. Tab. 12.1)
η_{max}, η_{min}		5.3,2.6	3.5,2.2	3.1,1.6	−4.6, −2.5	−2.9, −1.6	5.3,−4.6
Wheels		2	1	3	2	4	
Modules/Sensors		180	180	860	72	416	10736
Total Si area	$[m^2]$	0.8	0.9	4.6	0.4	1.8	40.7
Read-out-Channels	$[10^6]$	404.9	68.9	26.4	27.6	10.6	2934.2
$\text{pitch}^{r-\phi}$	[µm]	25	100	100	100	100	
pitch^{z}	[µm]	50	400	50k 2)	400	10k 1)	
Average X_0/Λ_I	[%]	6.7 / 2.1			6.1 / 1.9		
incl. beam pipe	[%]						40 / 25



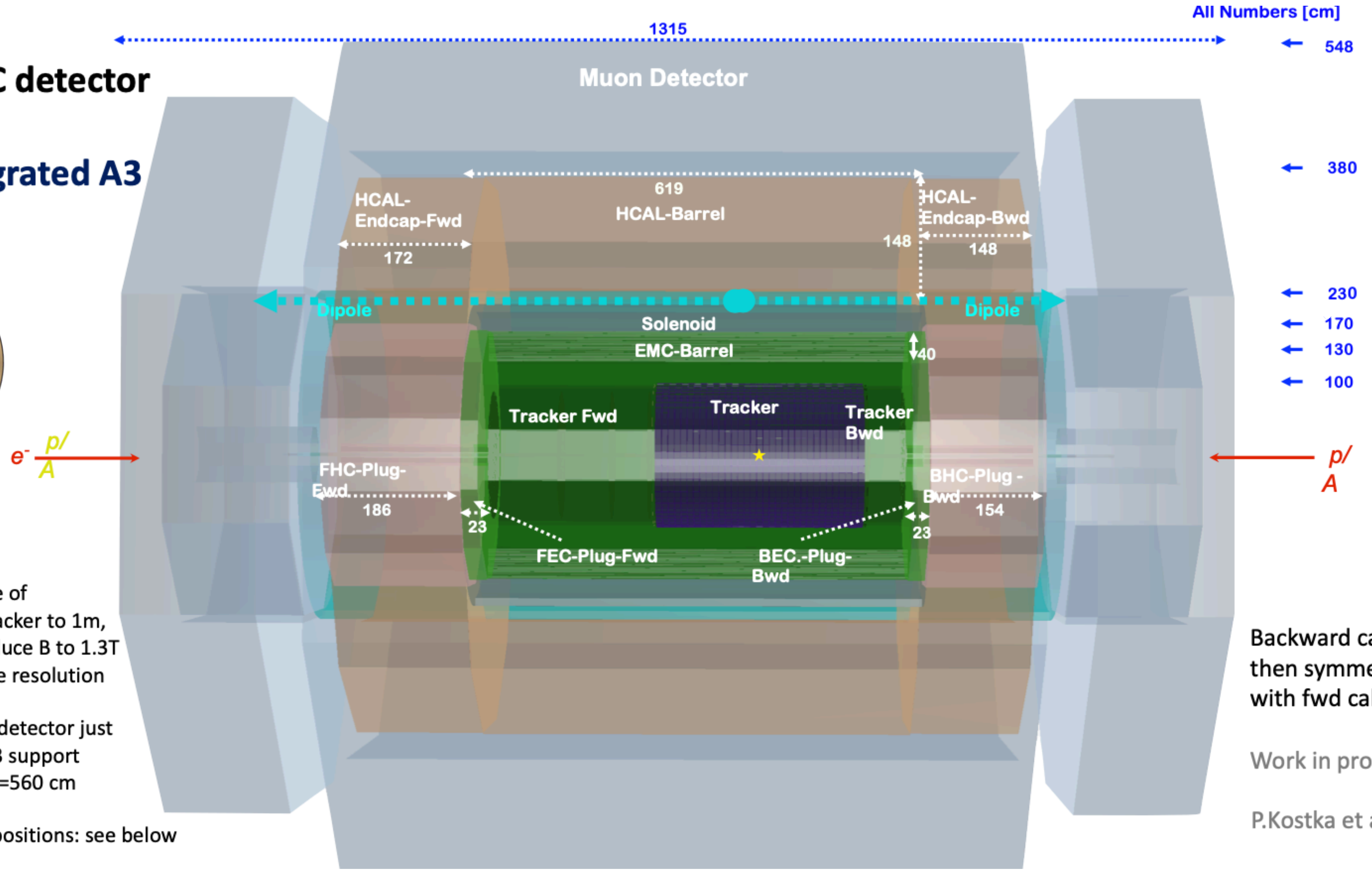
New idea to combine LHeC and A3

LHeC detector
with
integrated A3

Possible Arrangement for a combined A3 - LHeC Tracker
NOT OPTIMISED



arXiv:1902.01211



Increase of
radii, tracker to 1m,
may reduce B to 1.3T
for same resolution

Overall detector just
fits in L3 support
R_{free}(L3)=560 cm

Vertex positions: see below

Backward calos
then symmetric
with fwd calos

Work in progress

P.Kostka et al.

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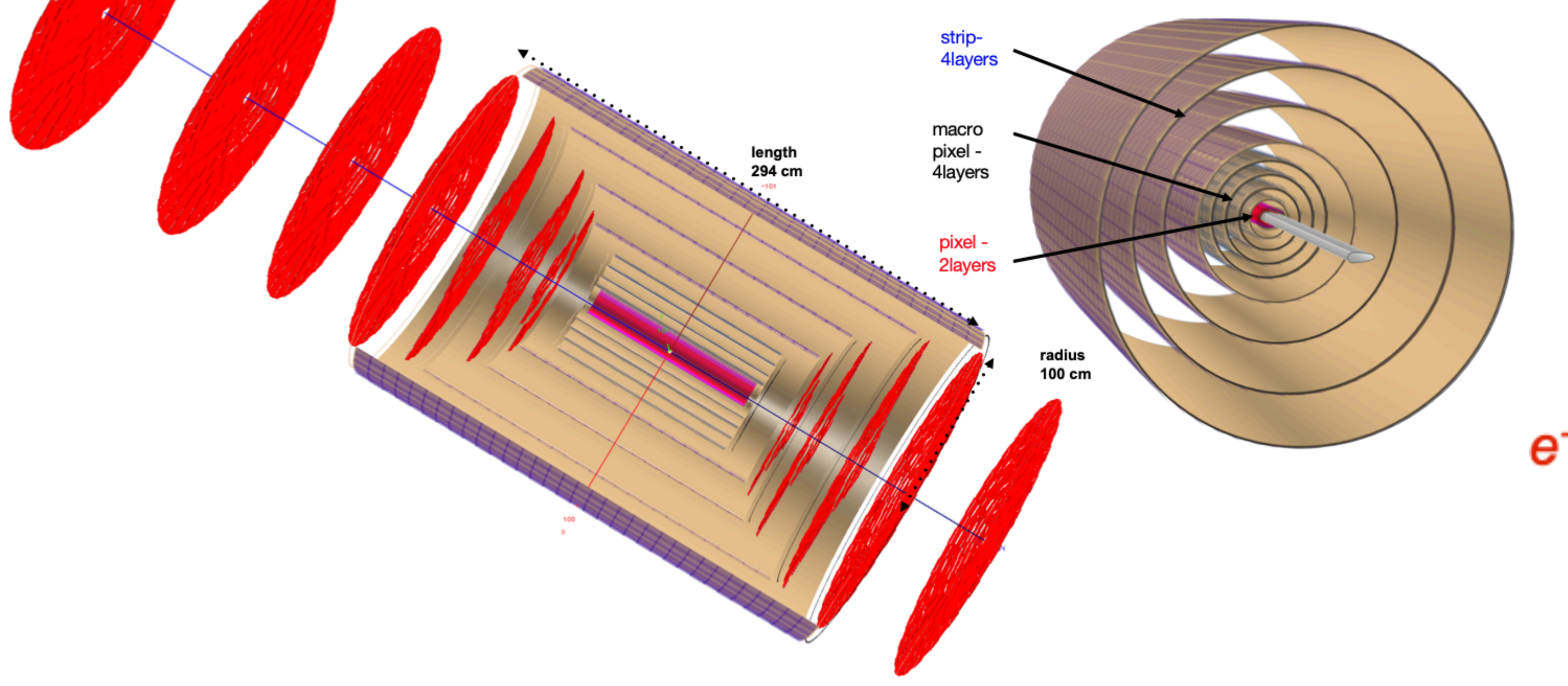
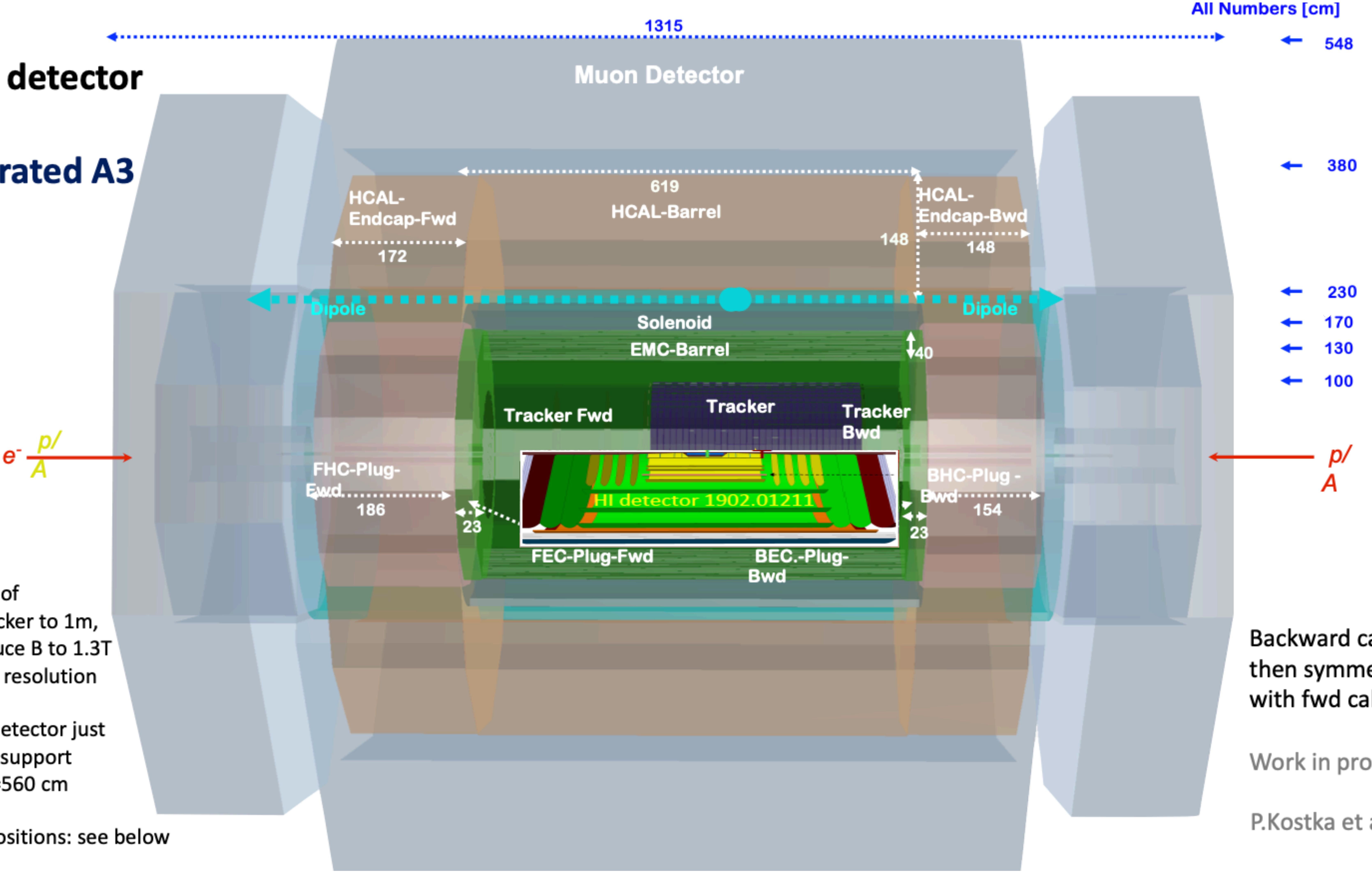


arXiv:1902.01211



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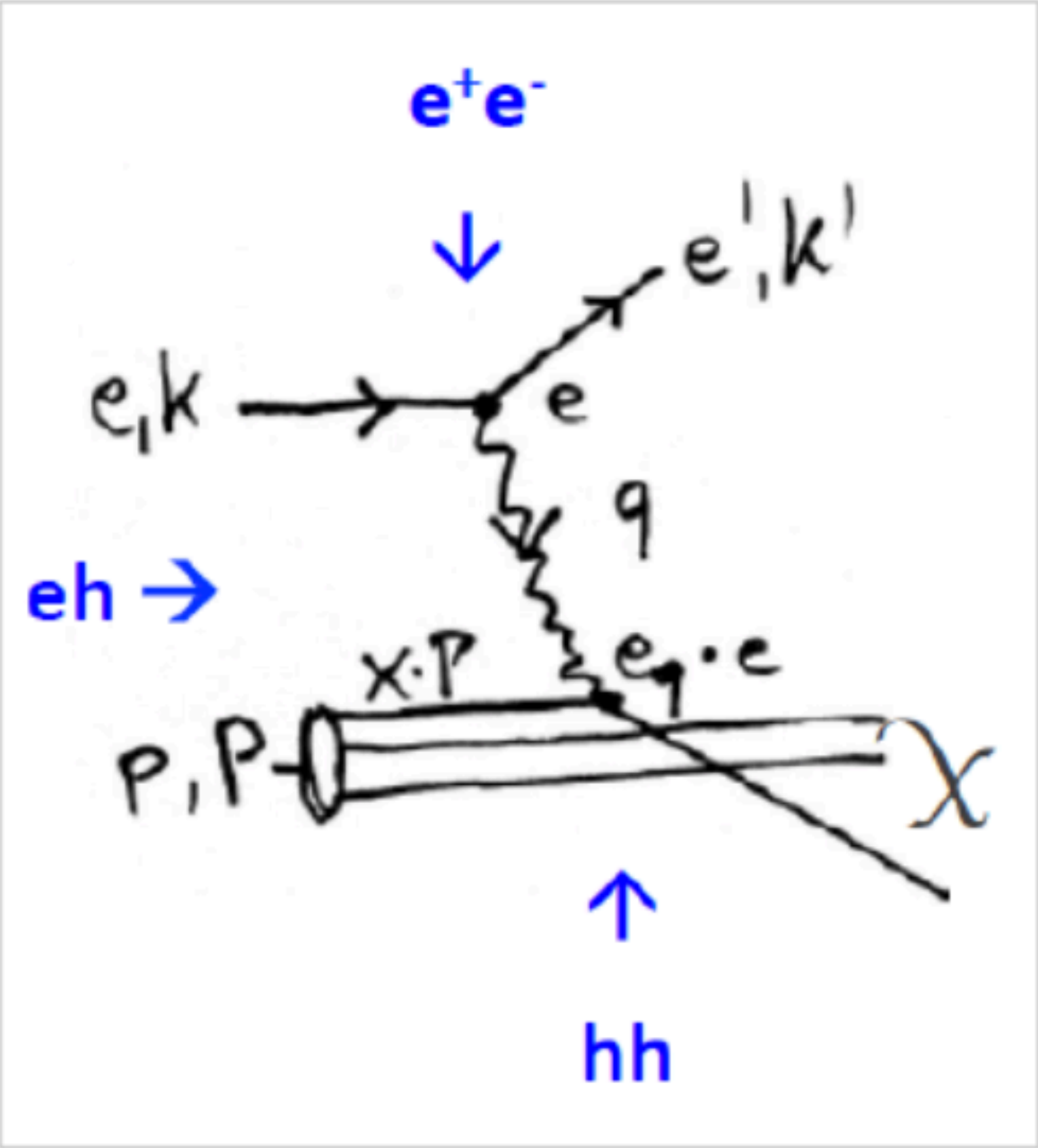
Vertex positions: see below

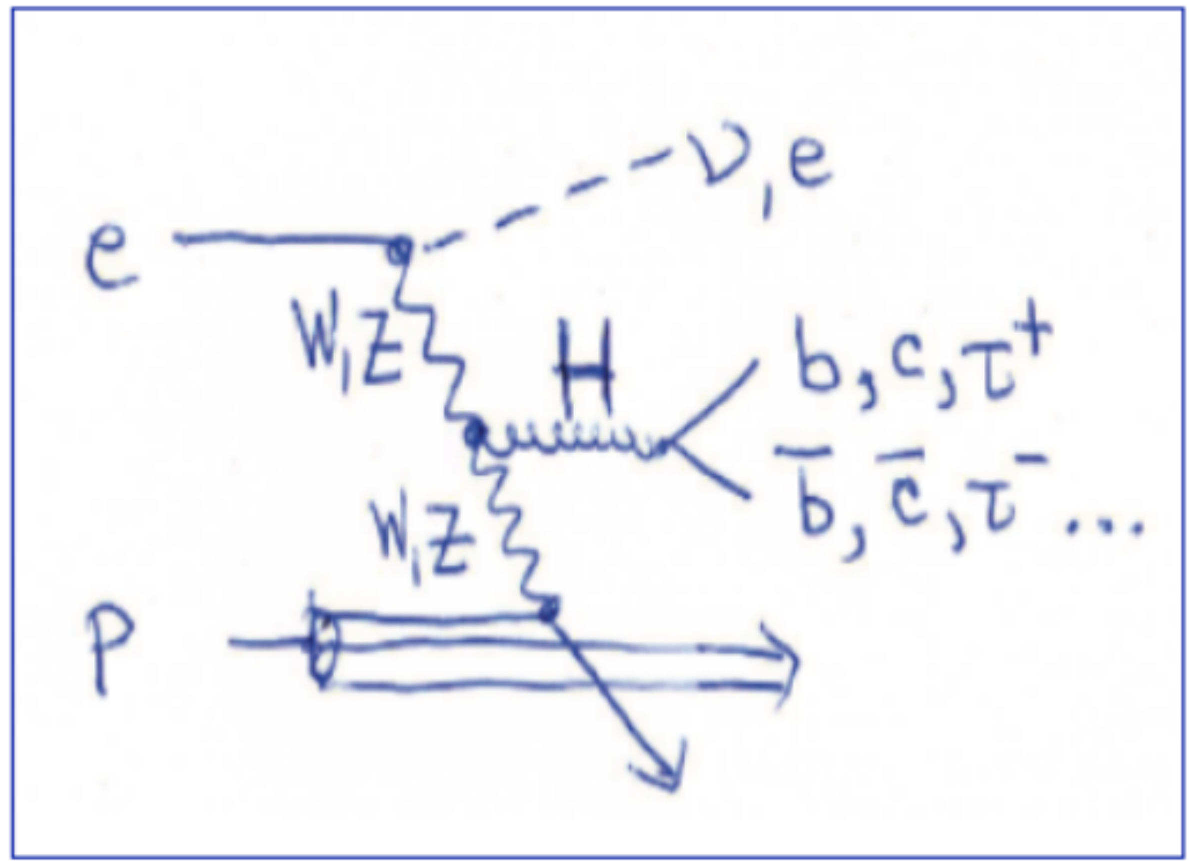
Backward calos then symmetric with fwd calos

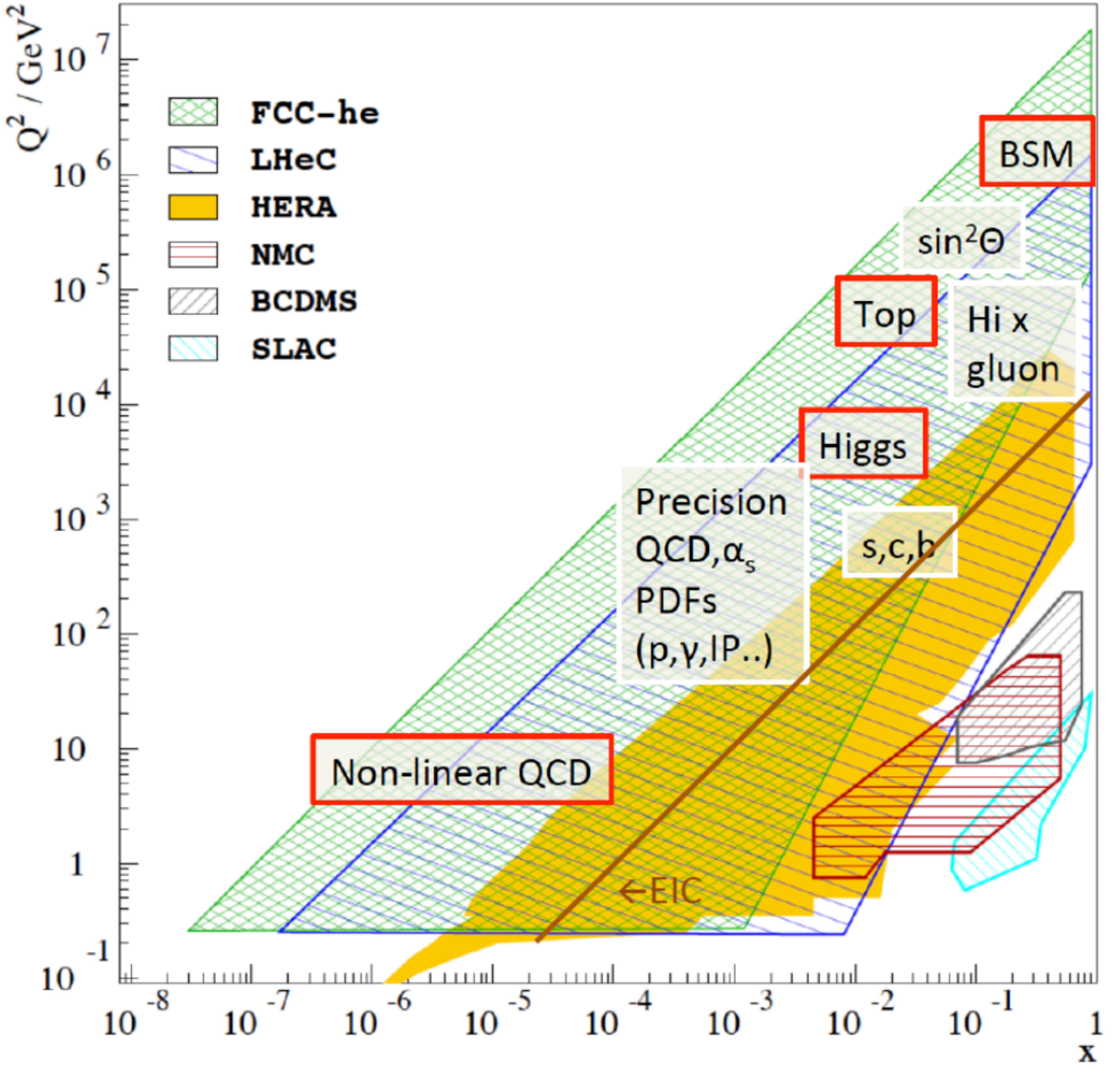
Work in progress

P.Kostka et al.

Deep Inelastic Scattering at the Energy Frontier







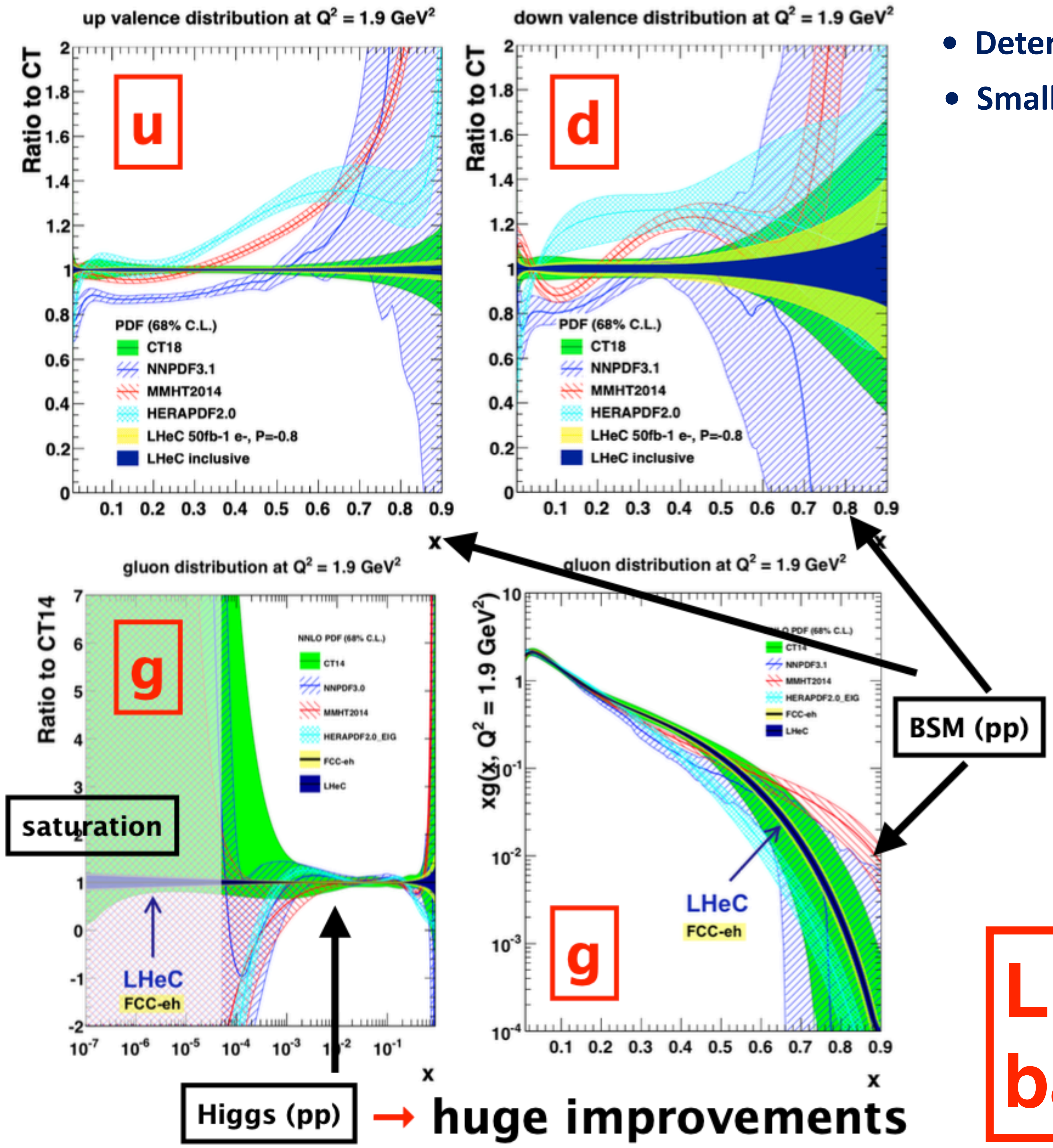
deliveries of ep/eA at the energy frontier

- cleanest high resolution microscope: QCD discovery
- empowering the LHC/FCC search program
- precision Higgs facility together with LHC/FCC-hh
- precision and discovery facility (top, EWK, BSM)
- unique nuclear physics facility

→ **diversity**

PDF

Parton Density Functions



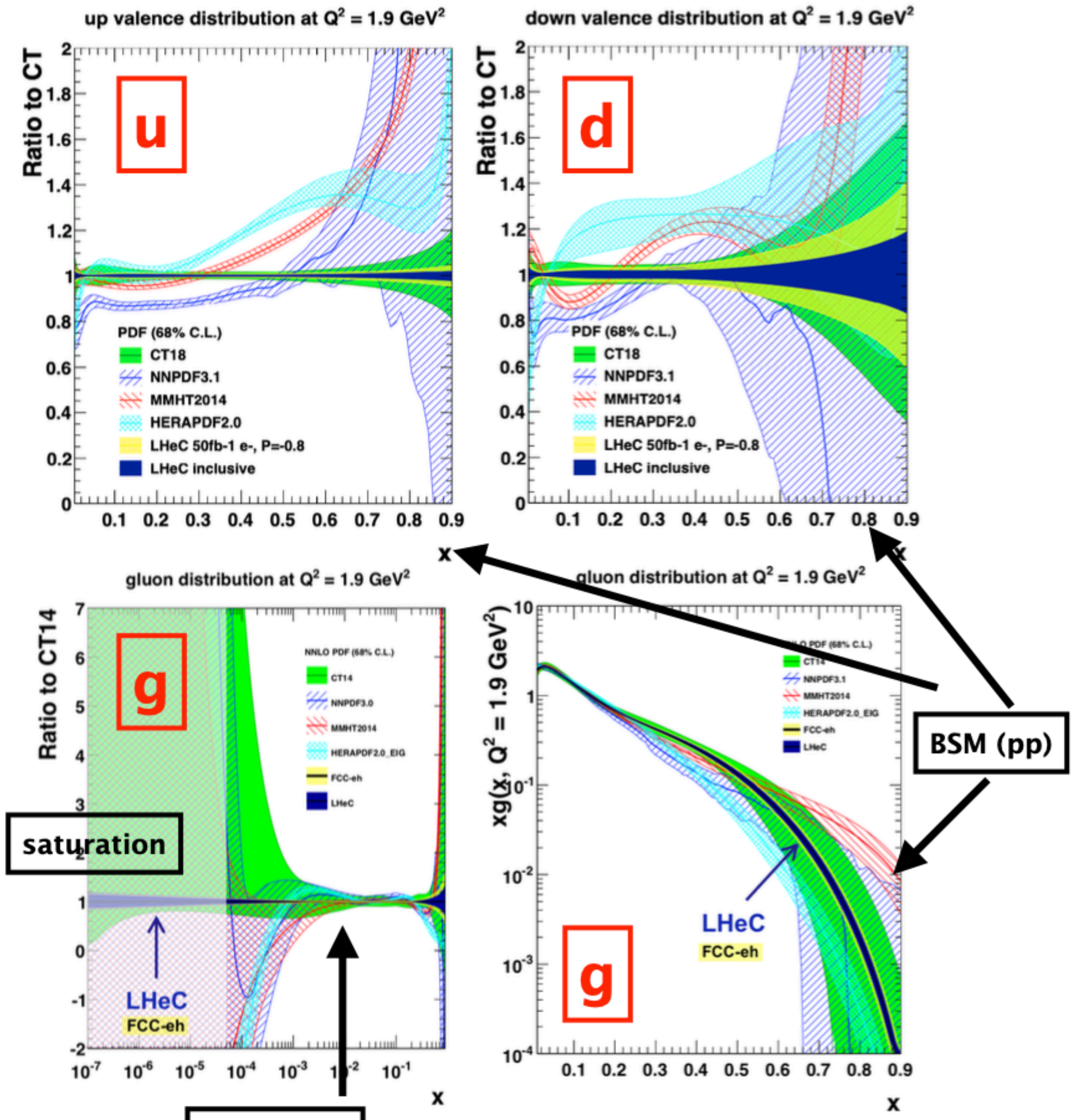
- **Determination of the Parton Densities in the Proton at the LHeC**, Claire Gwenlan, Apr 14, 10:50 AM
- **Small-x Physics at the LHeC and FCC-eh**, Anna Stasto, Apr 15, 2021, 1:27 PM

LHeC provides a single, coherent base for PDF determination to N3LO

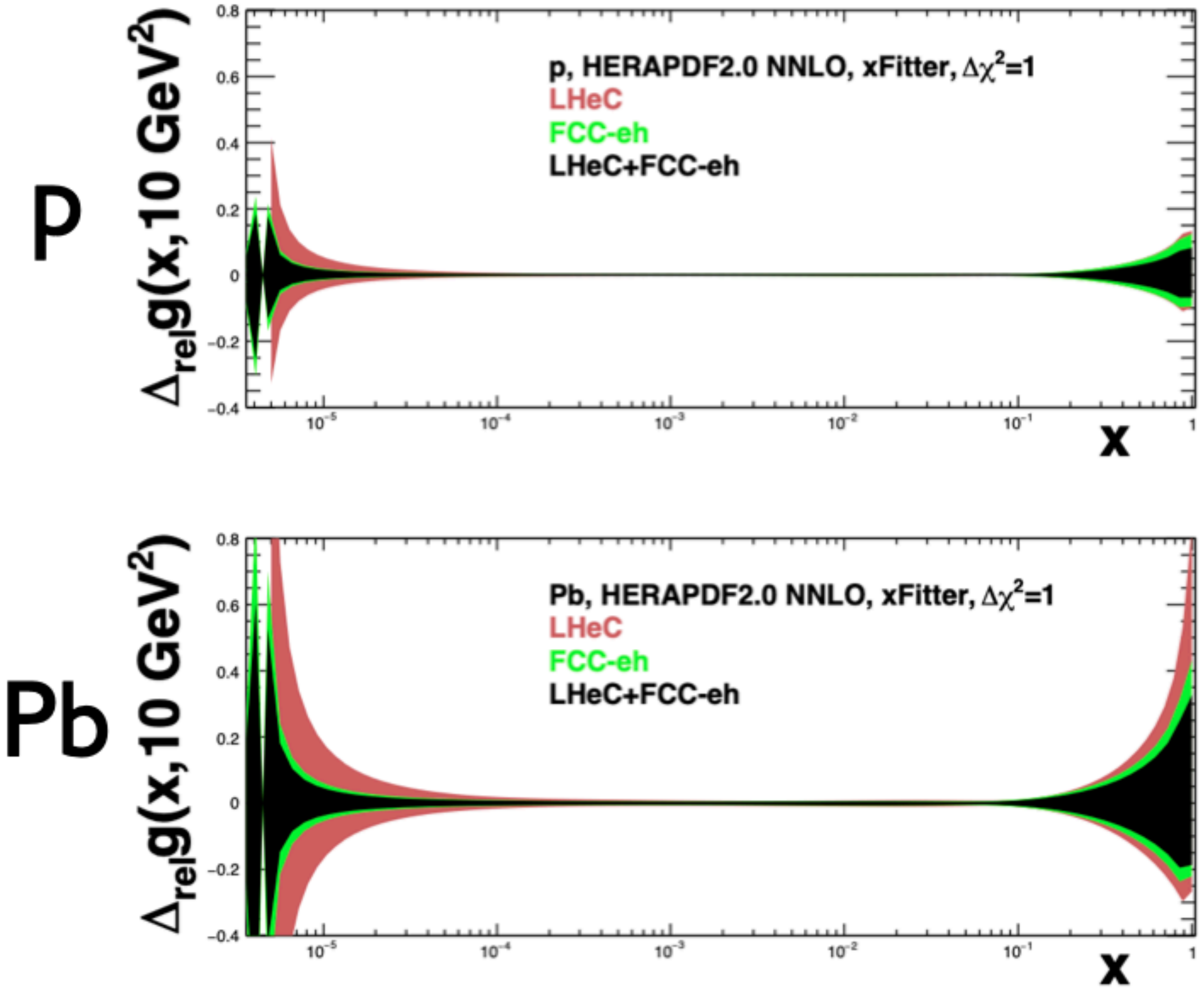
PDF

Parton Density Functions

QGP

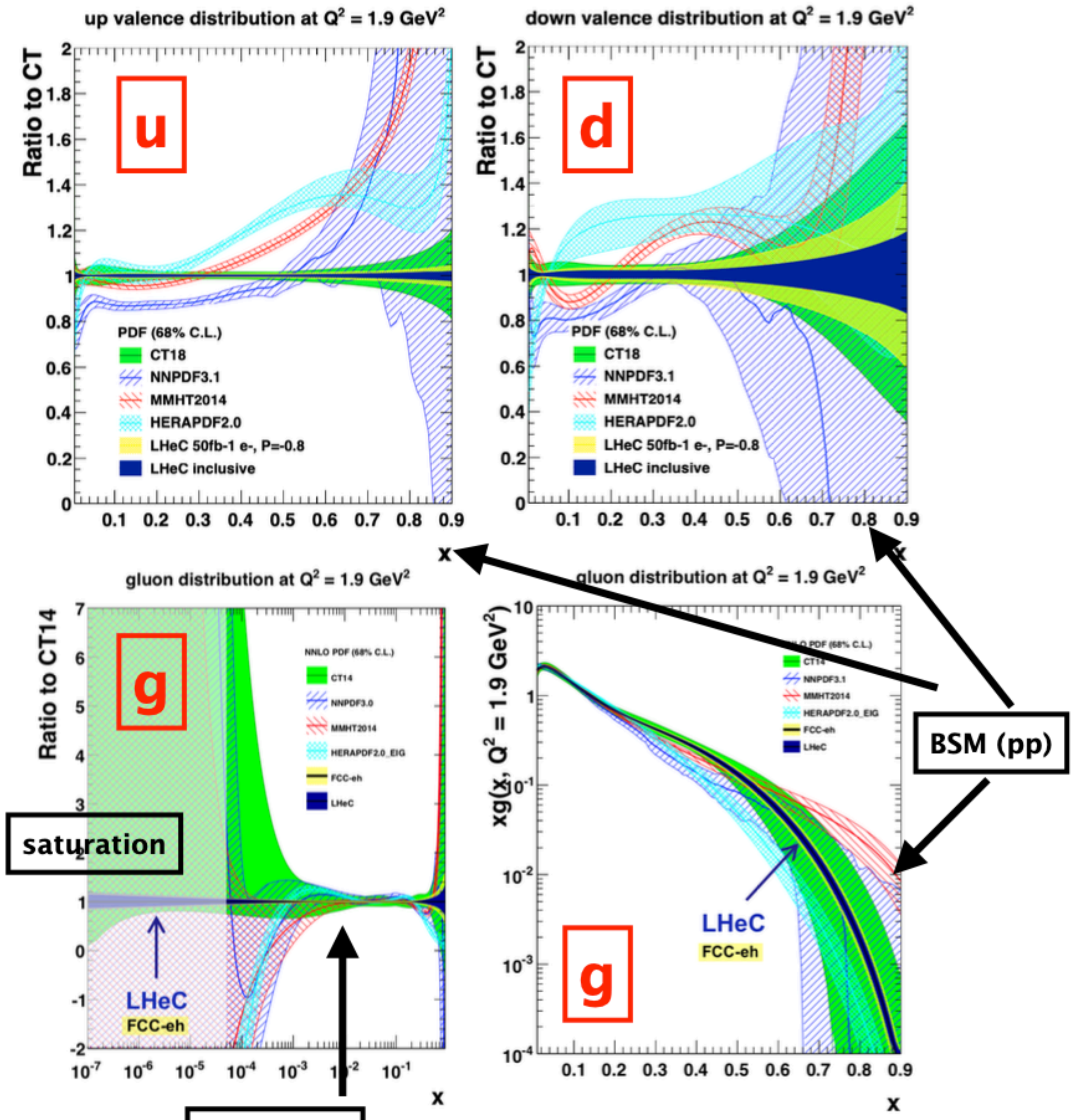


→ **huge improvements**

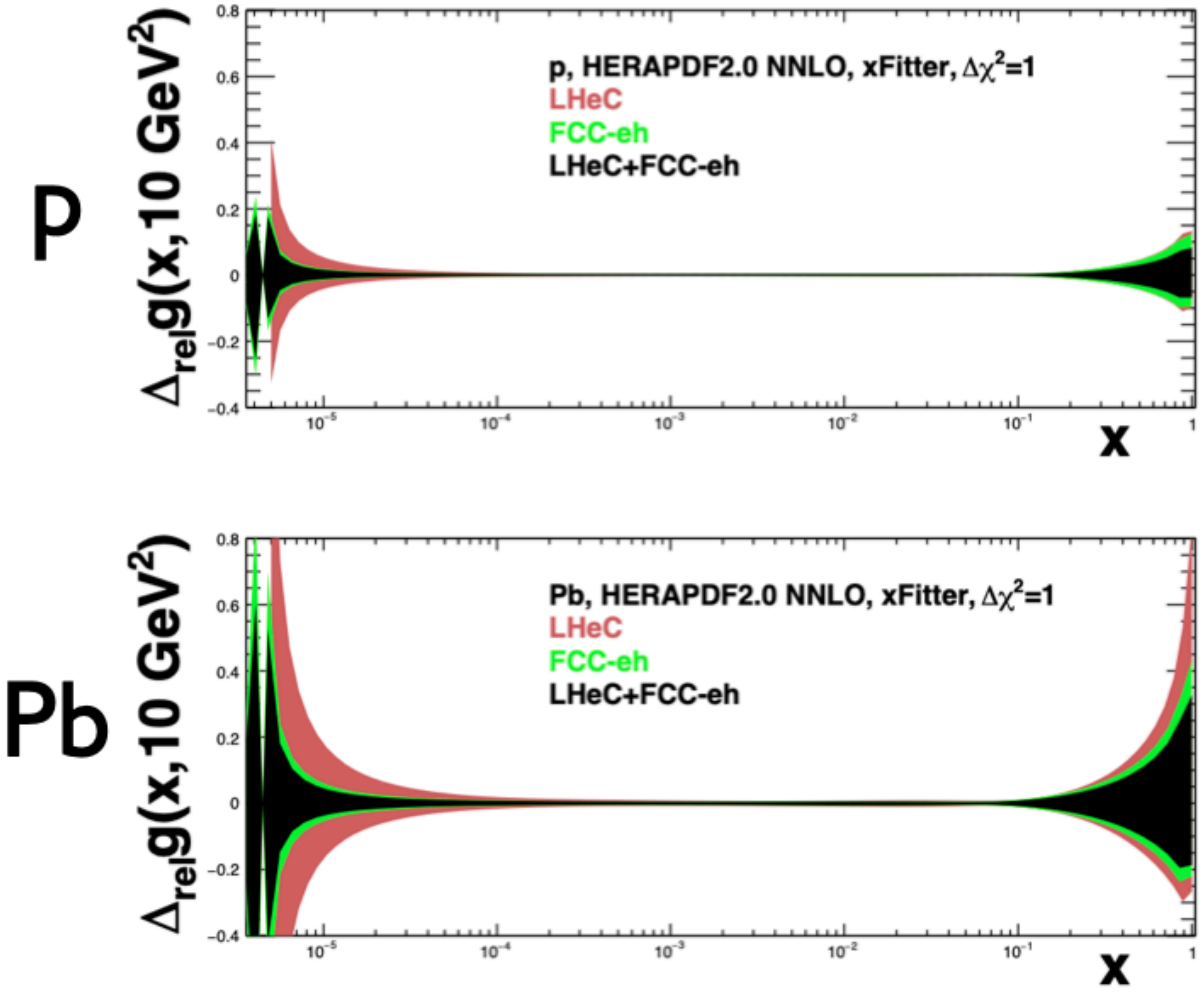


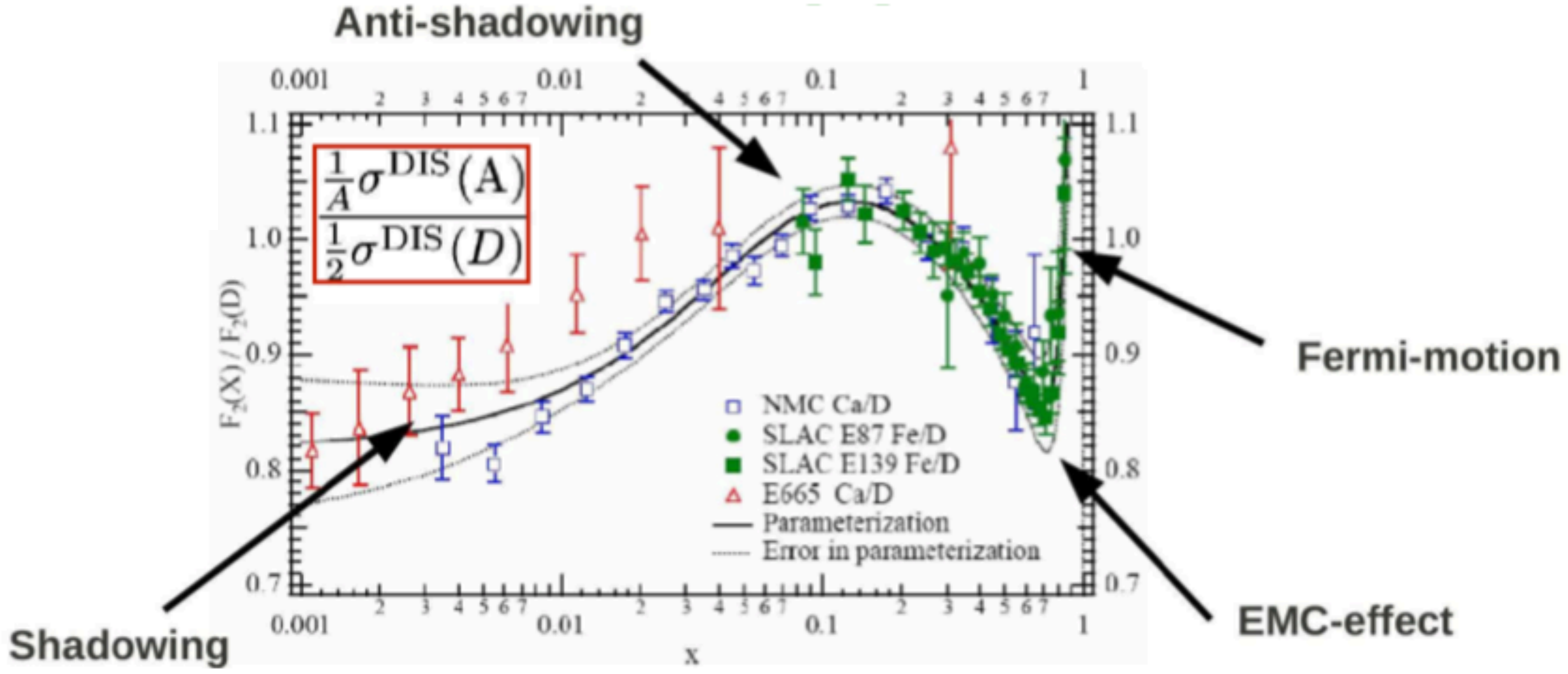
- **Electron-Ion Collisions at the LHeC and FCC-eh**, Heikki Mäntysaari, Apr 13, 1:08 PM

PDF Parton Density Functions QGP



Higgs (pp) → huge improvements

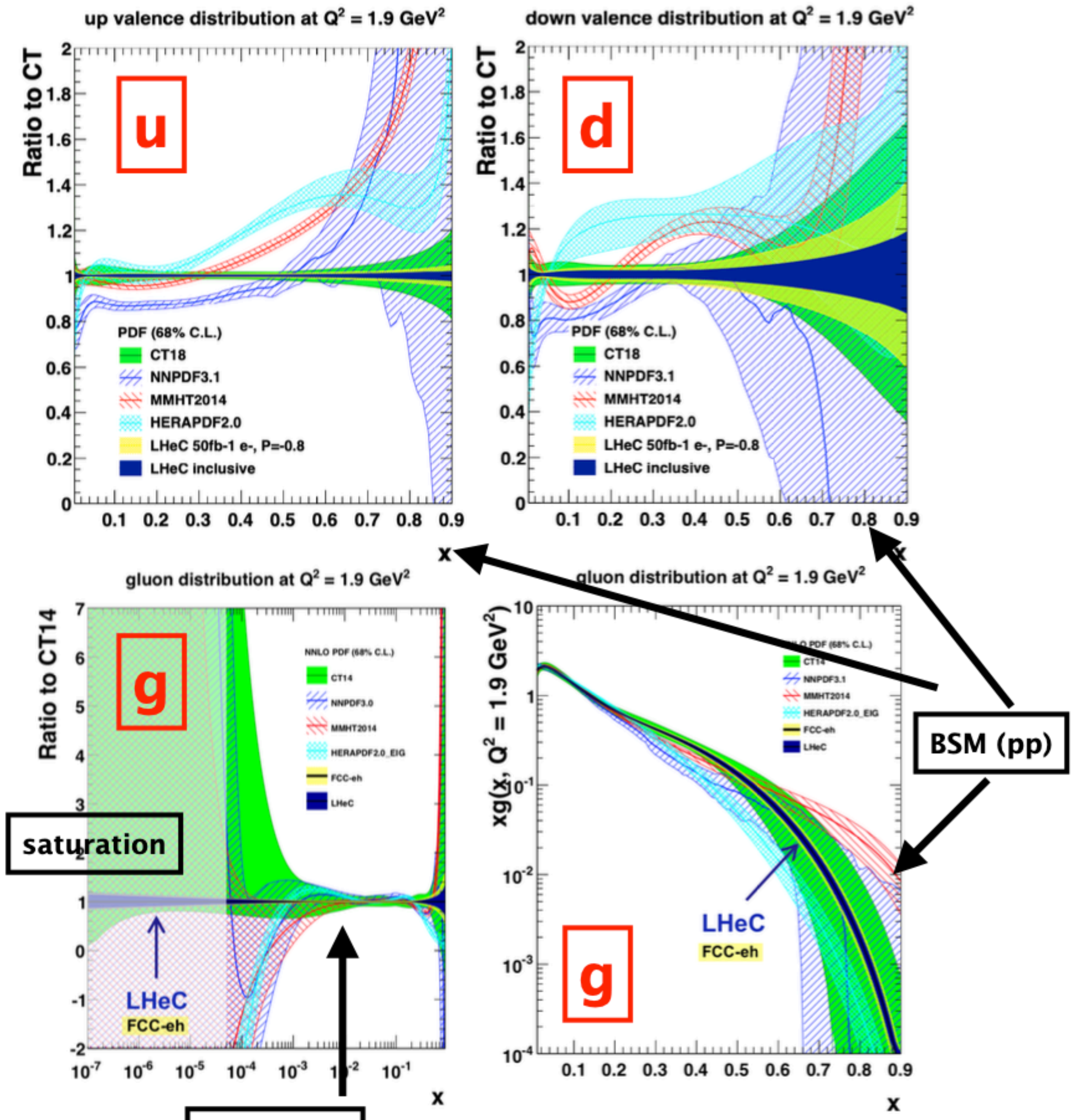




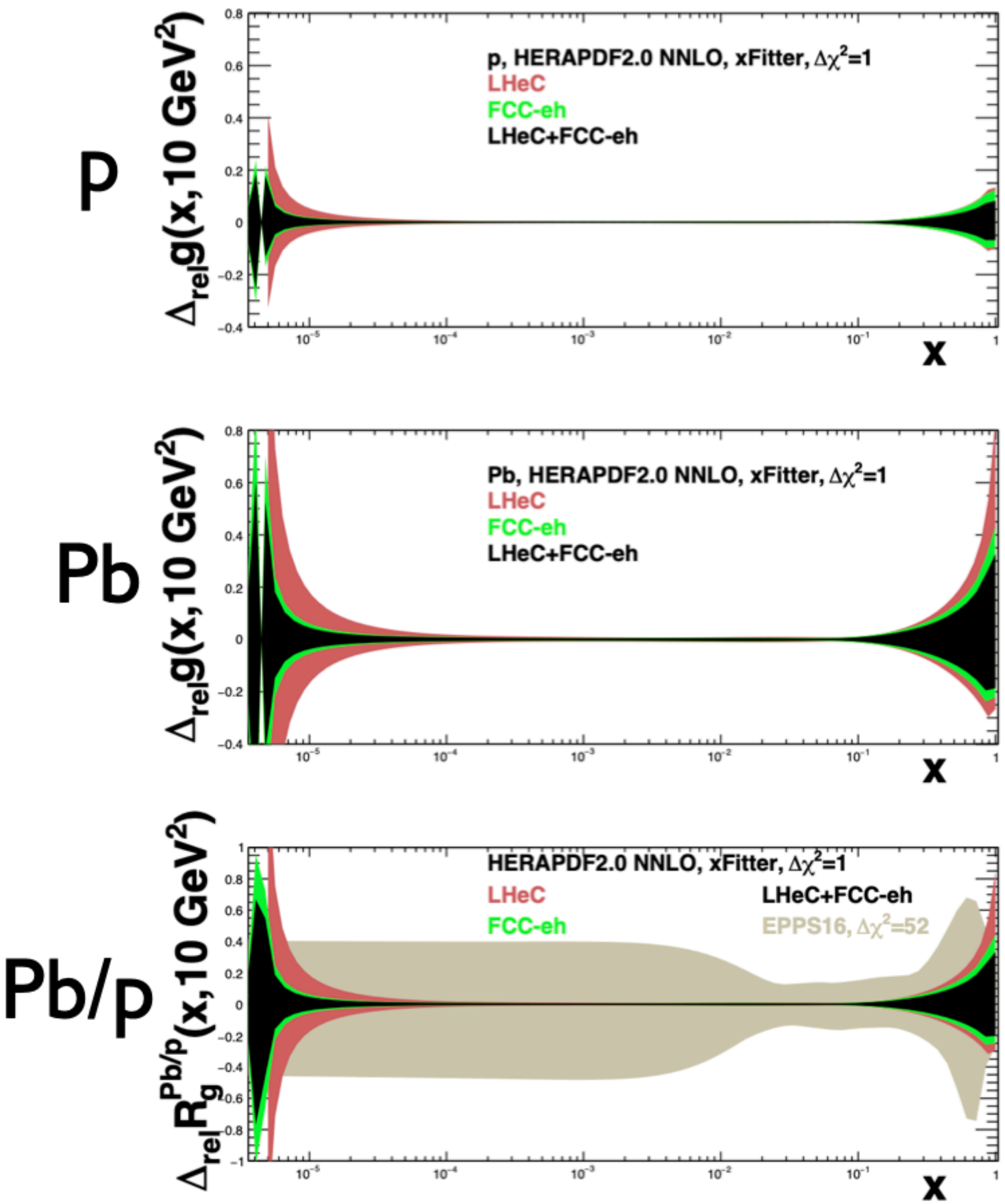
Parton Density Functions

PDF

QGP

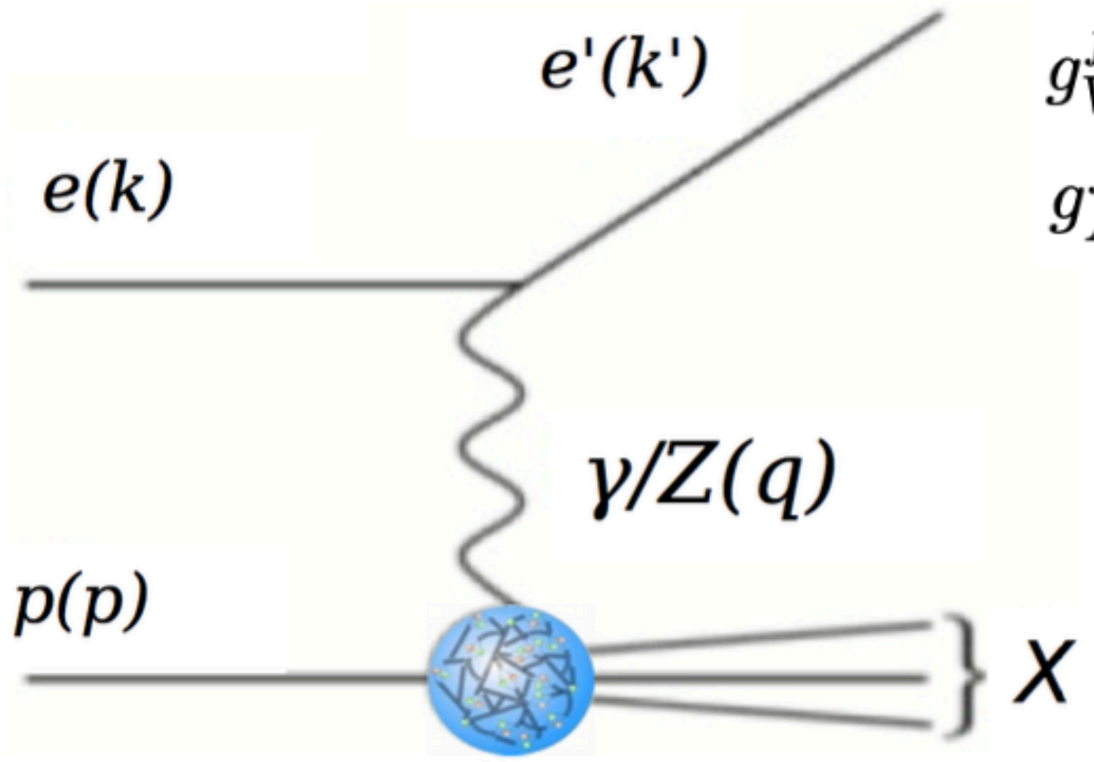


Higgs (pp) → huge improvements



EWK Precision: Electroweak and top quark physics

- **Precision electroweak measurements at the LHeC and the FCC-eh**, Daniel Britzger, Apr 15, 1:27PM



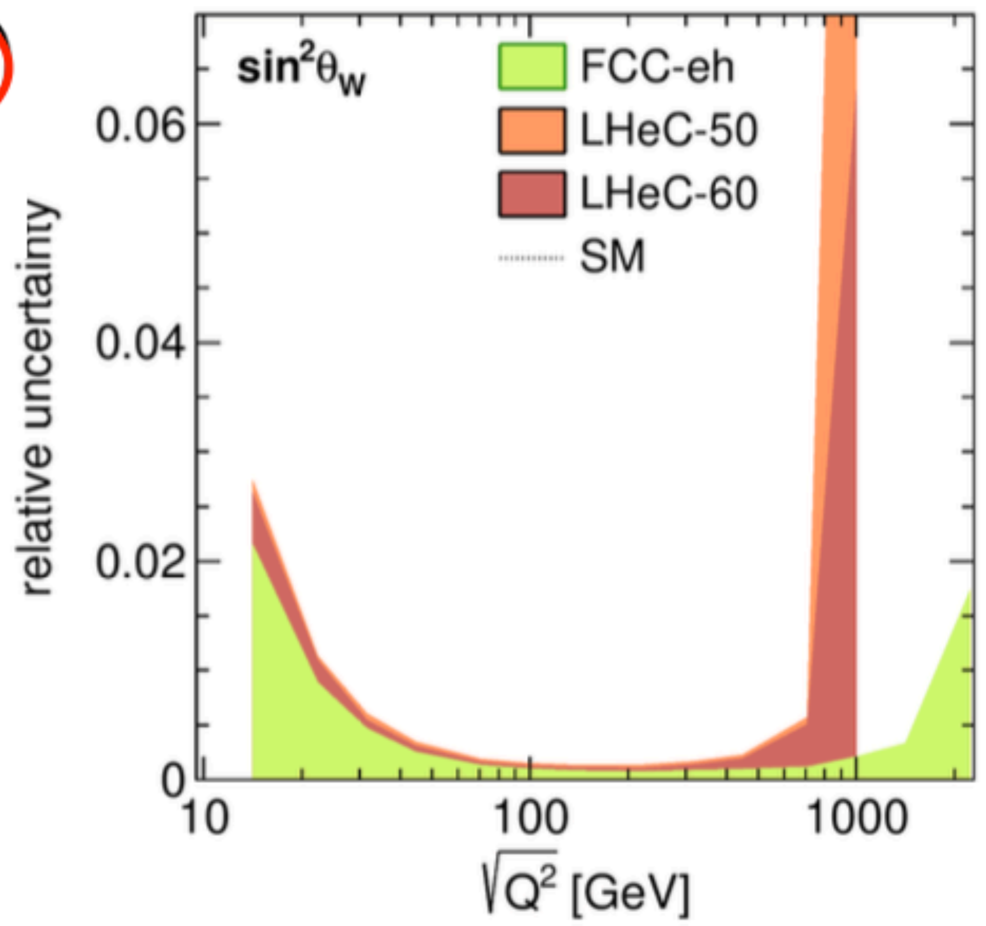
$$g_V^f = \sqrt{\rho_{\mathrm{NC},f}}\left(I^3_{\mathrm{L},f} - 2Q_f\kappa_{\mathrm{NC},f}\sin^2\theta_{\mathrm{W}}\right)$$

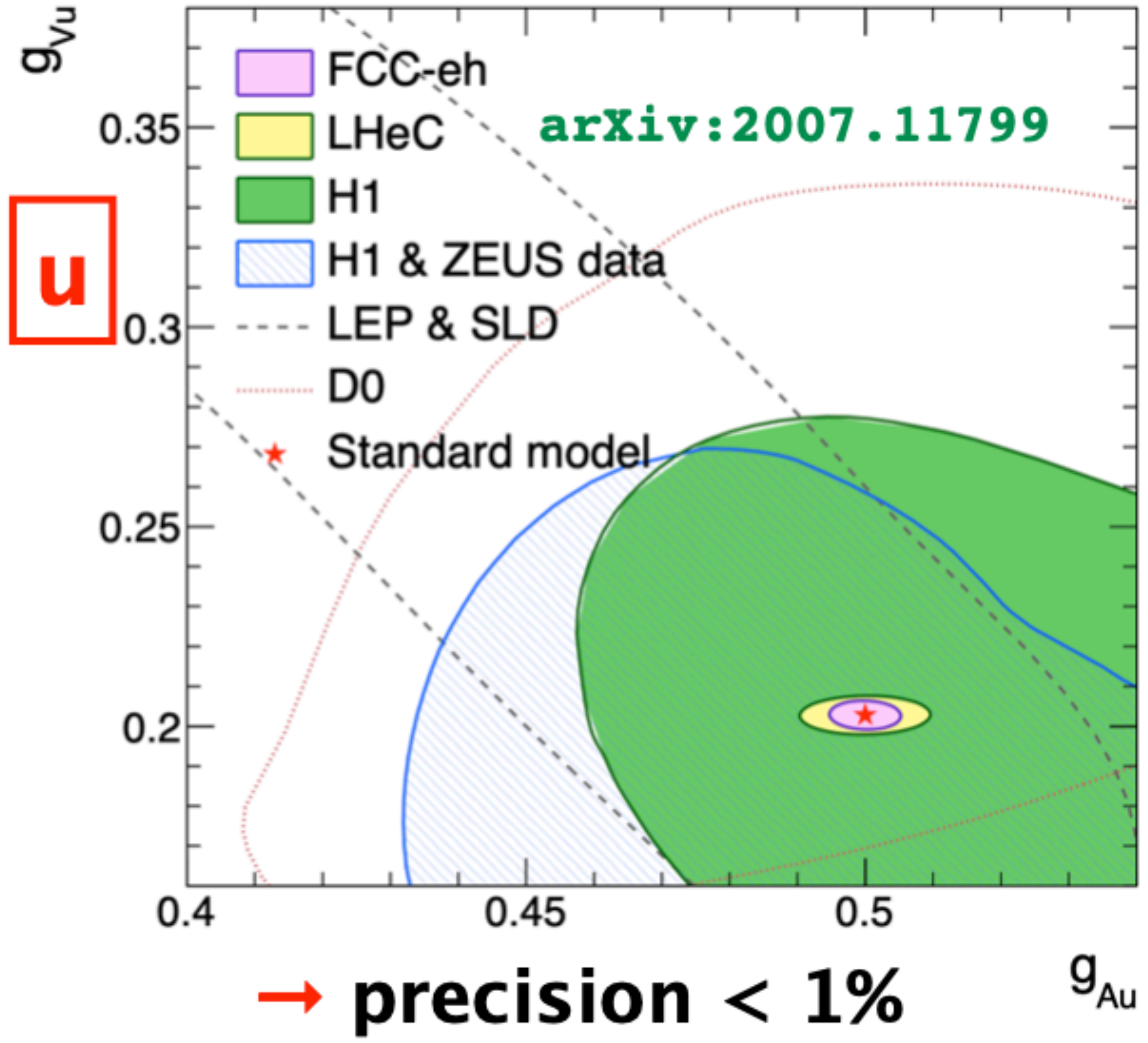
$$g_A^f = \sqrt{\rho_{\mathrm{NC},f}}\, I^3_{\mathrm{L},f}$$

→ **precision per mille level**
→ **scale dependence**

$\Delta\sin^2\theta_w$ (FCC-eh) = ±0.00011
= ±0.00010$_{(exp)}$ ±0.00004$_{(PDF)}$

FCC-eh with L ~ 1ab^{-1} $\Delta m_W = \pm 4.5$ MeV
(includes PDF uncertainty of about ±3.6 MeV)

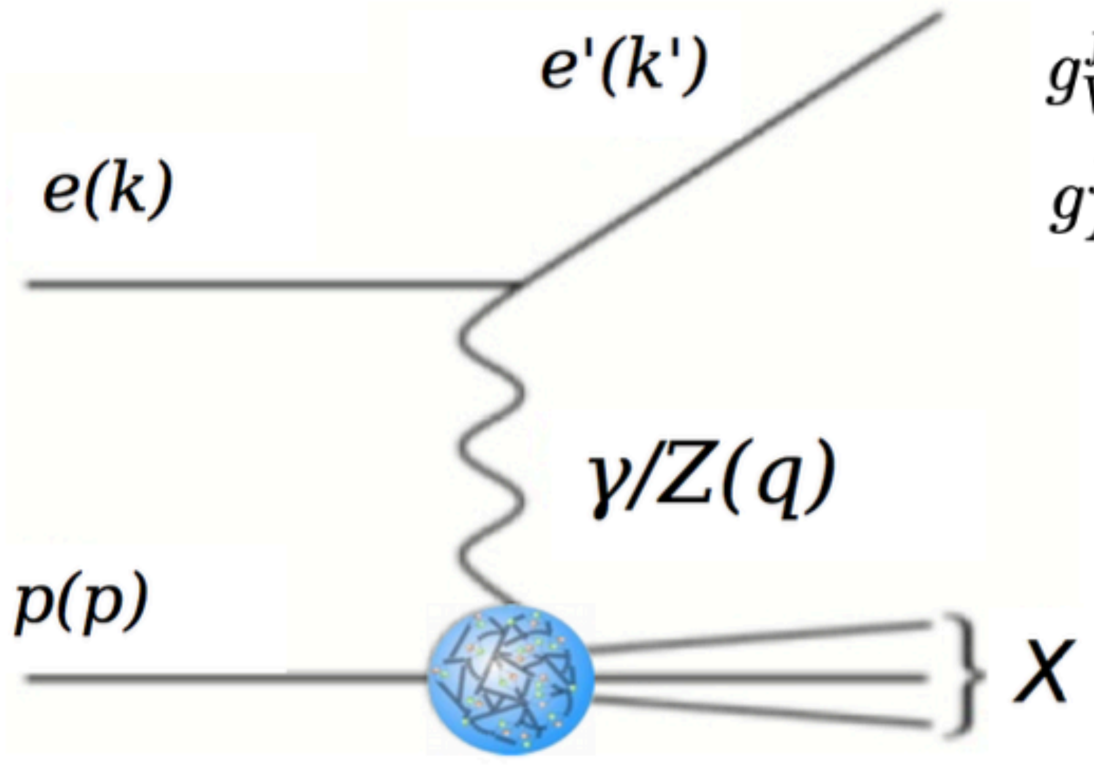




→ **precision < 1%**

Precision: Electroweak and top quark physics

- **Precision electroweak measurements at the LHeC and the FCC-eh**, Daniel Britzger, Apr 15, 1:27PM



$$g_V^f = \sqrt{\rho_{\mathrm{NC},f}}\,(I_{\mathrm{L},f}^3 - 2Q_f\kappa_{\mathrm{NC},f}\sin^2\theta_{\mathrm{W}})$$

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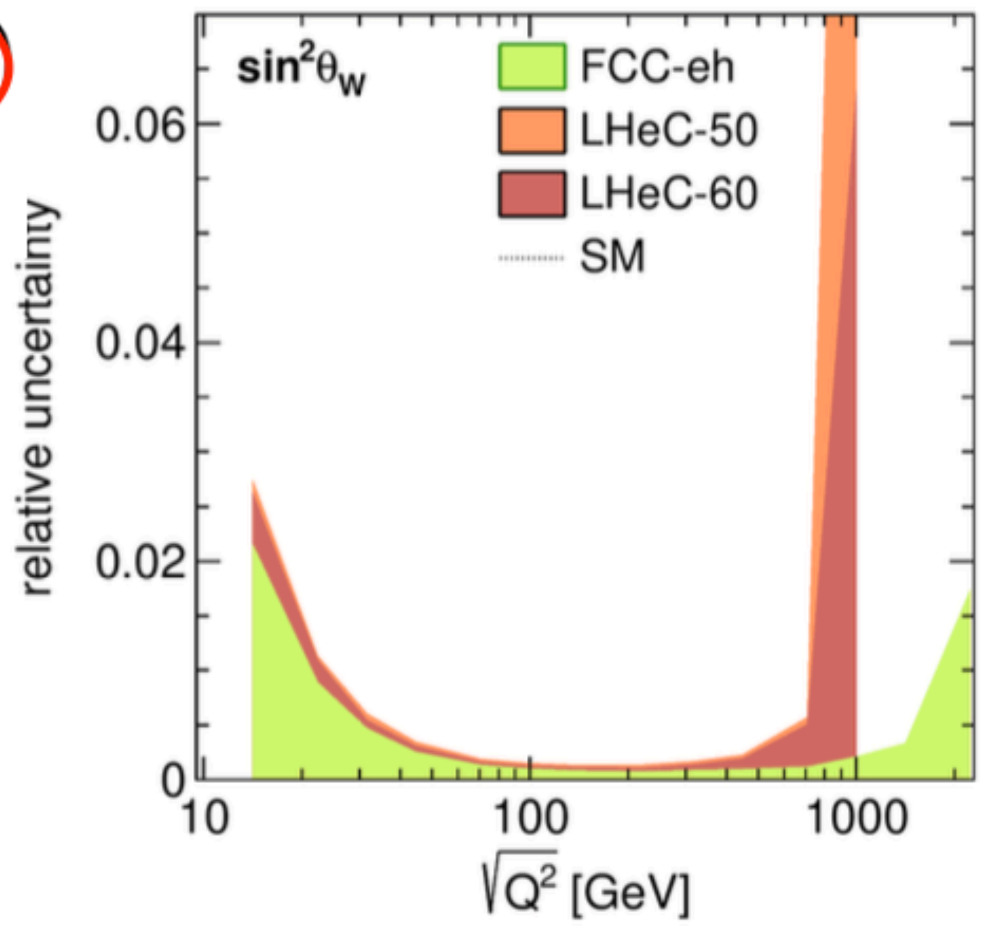
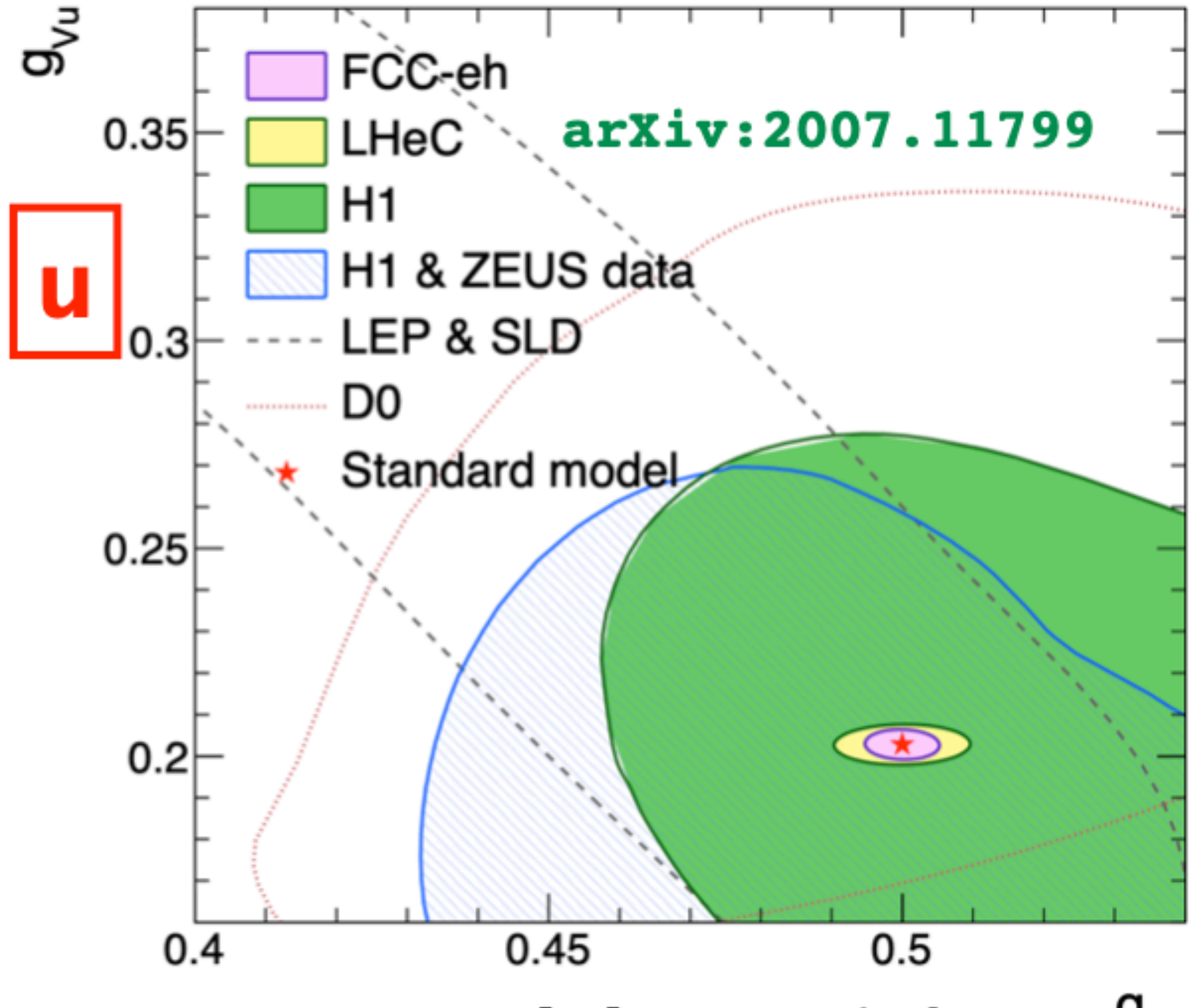
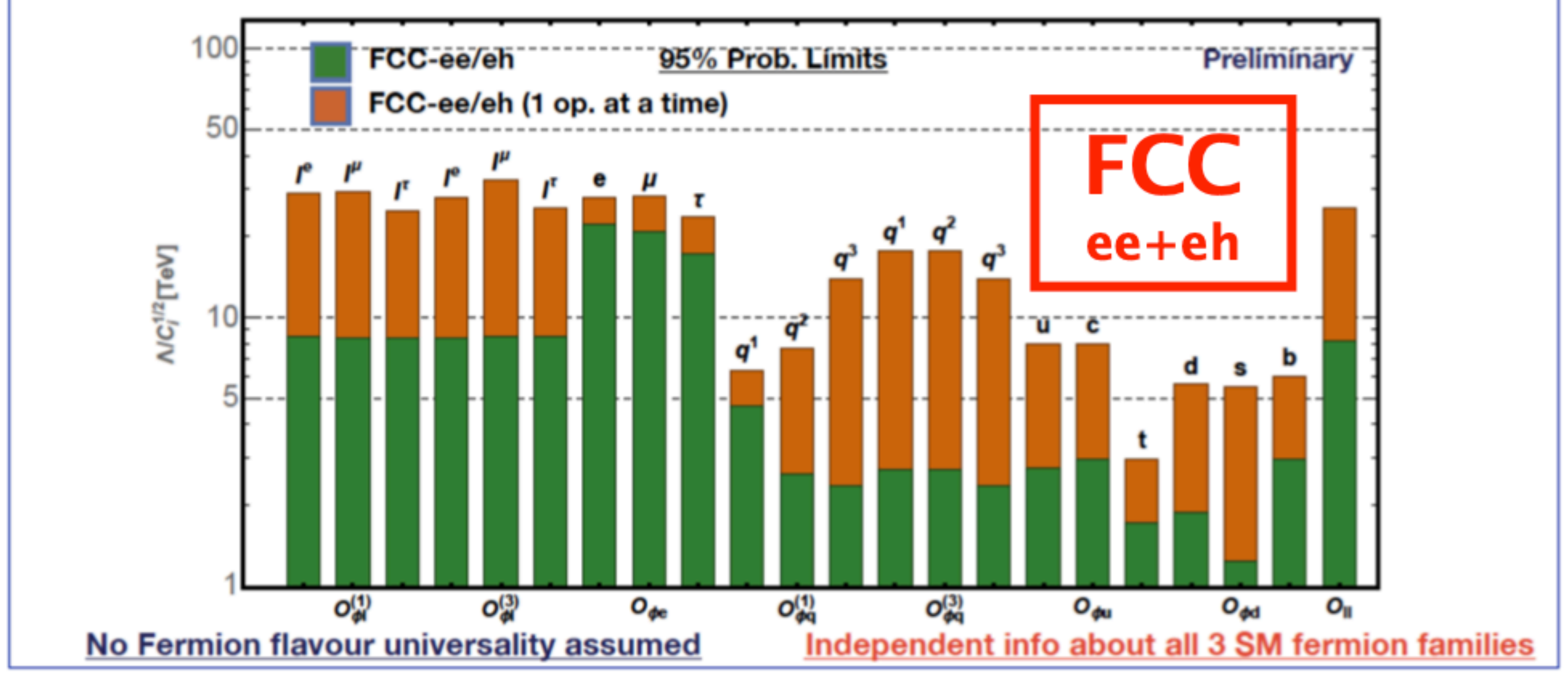




→ **precision < 1%**

→ **high sensitivity to NP**

- **Global fit to electroweak precision measurements at FCC-ee + FCC-eh**

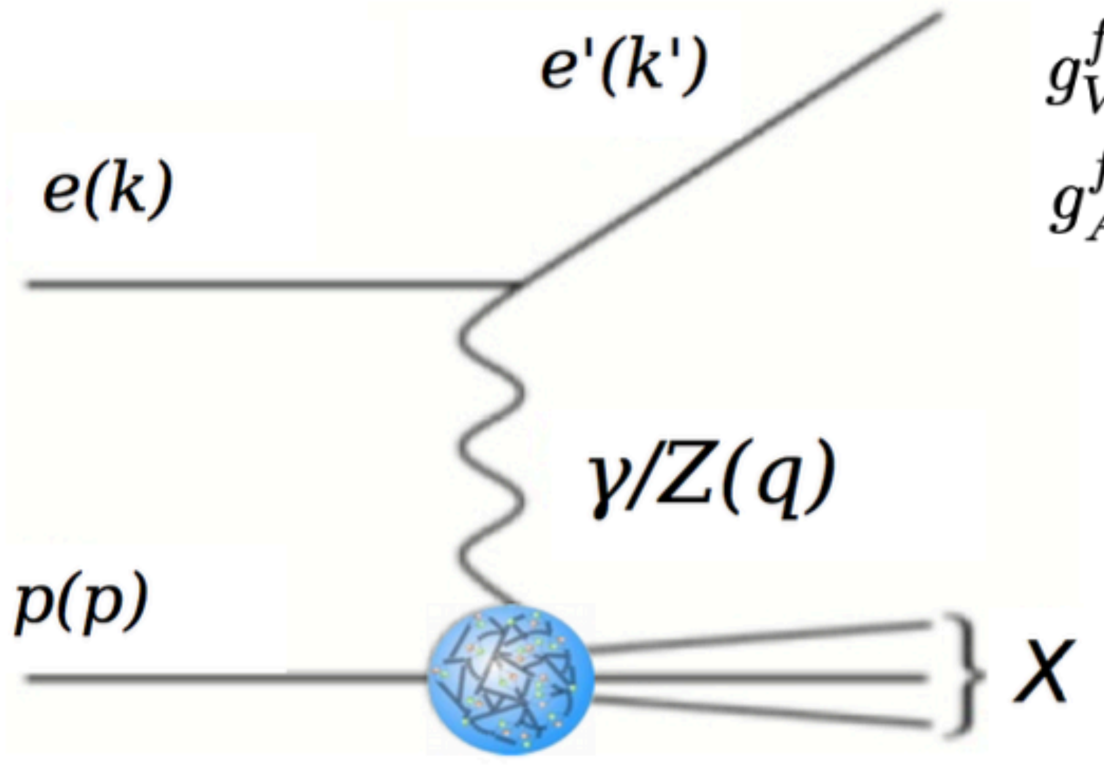


EWK

Precision: Electroweak and top quark physics

Top

- **Precision electroweak measurements at the LHeC and the FCC-eh**, Daniel Britzger, Apr 15, 1:27PM



$$g_V^f = \sqrt{\rho_{\mathrm{NC},f}}\left(I^3_{\mathrm{L},f} - 2Q_f\kappa_{\mathrm{NC},f}\sin^2\theta_W\right)$$
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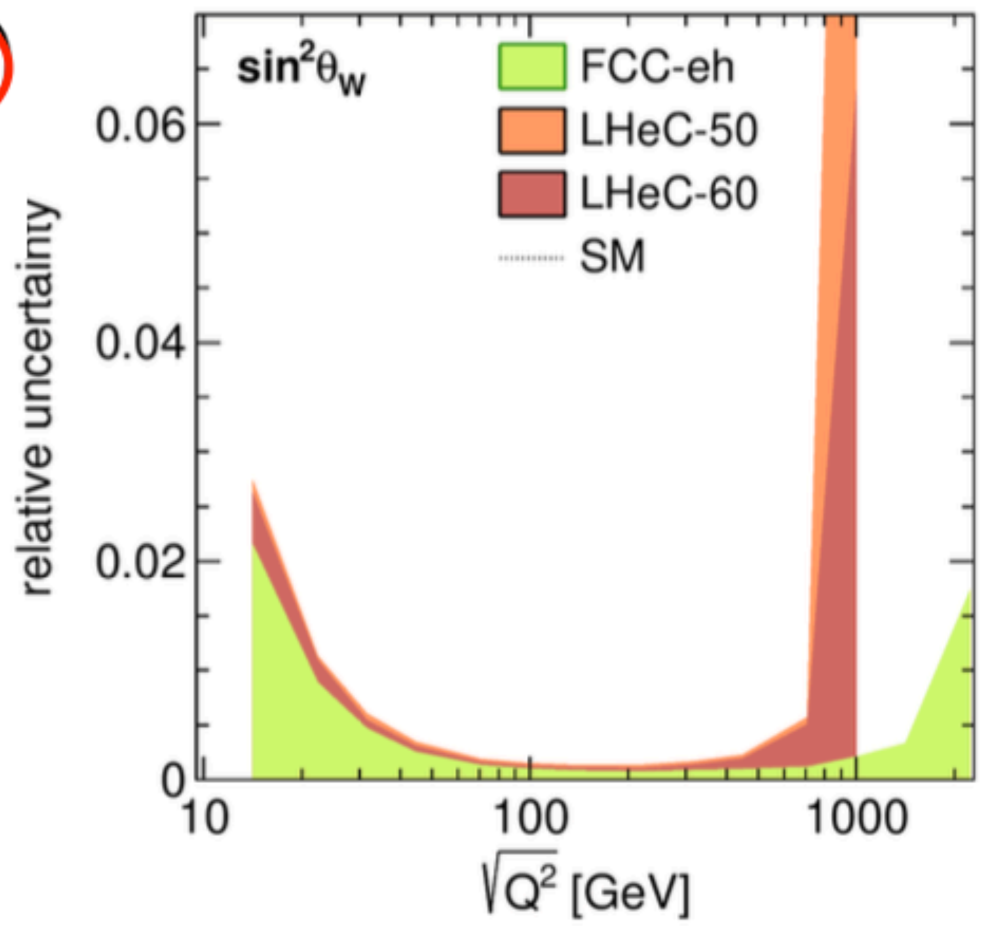
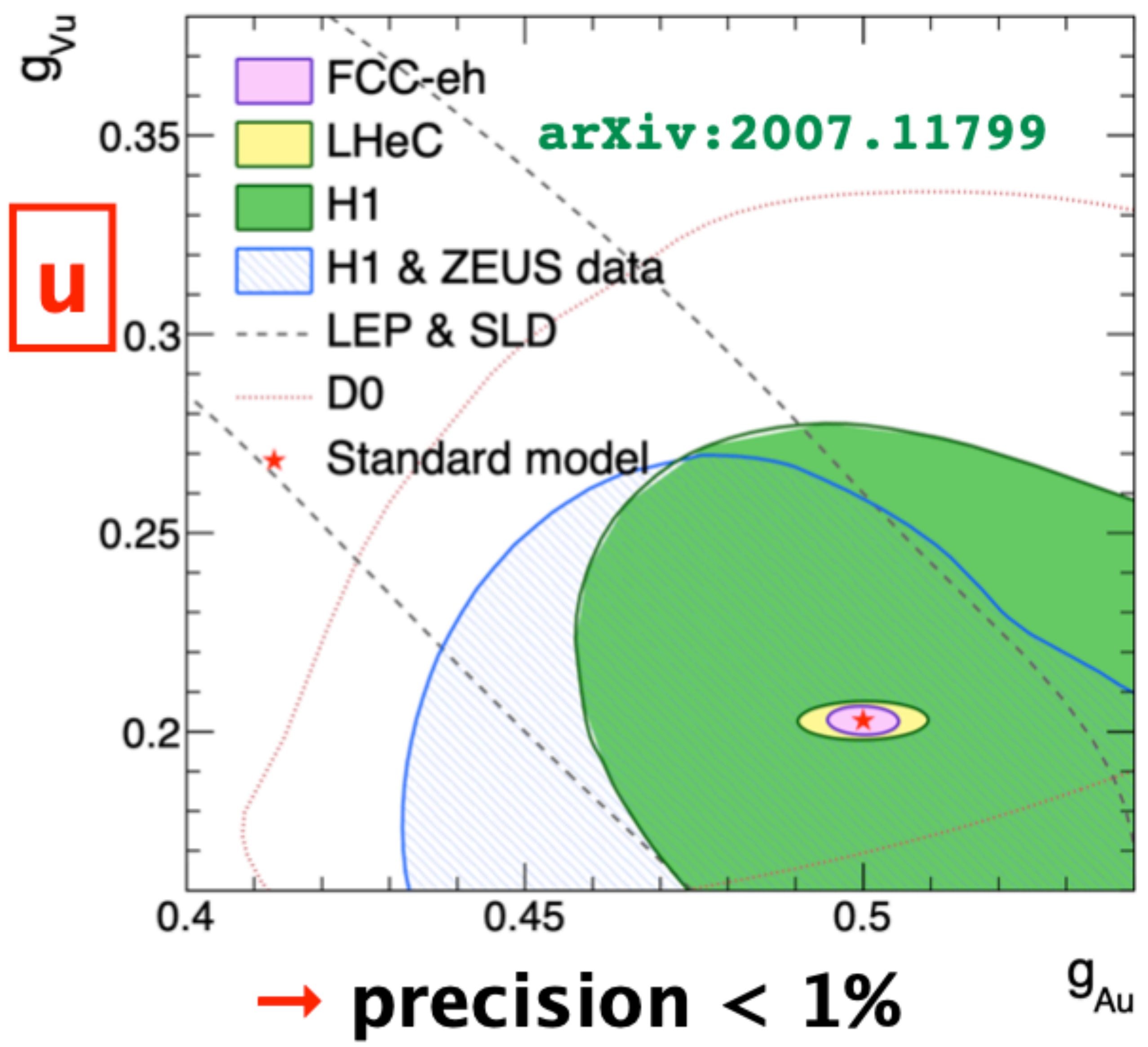
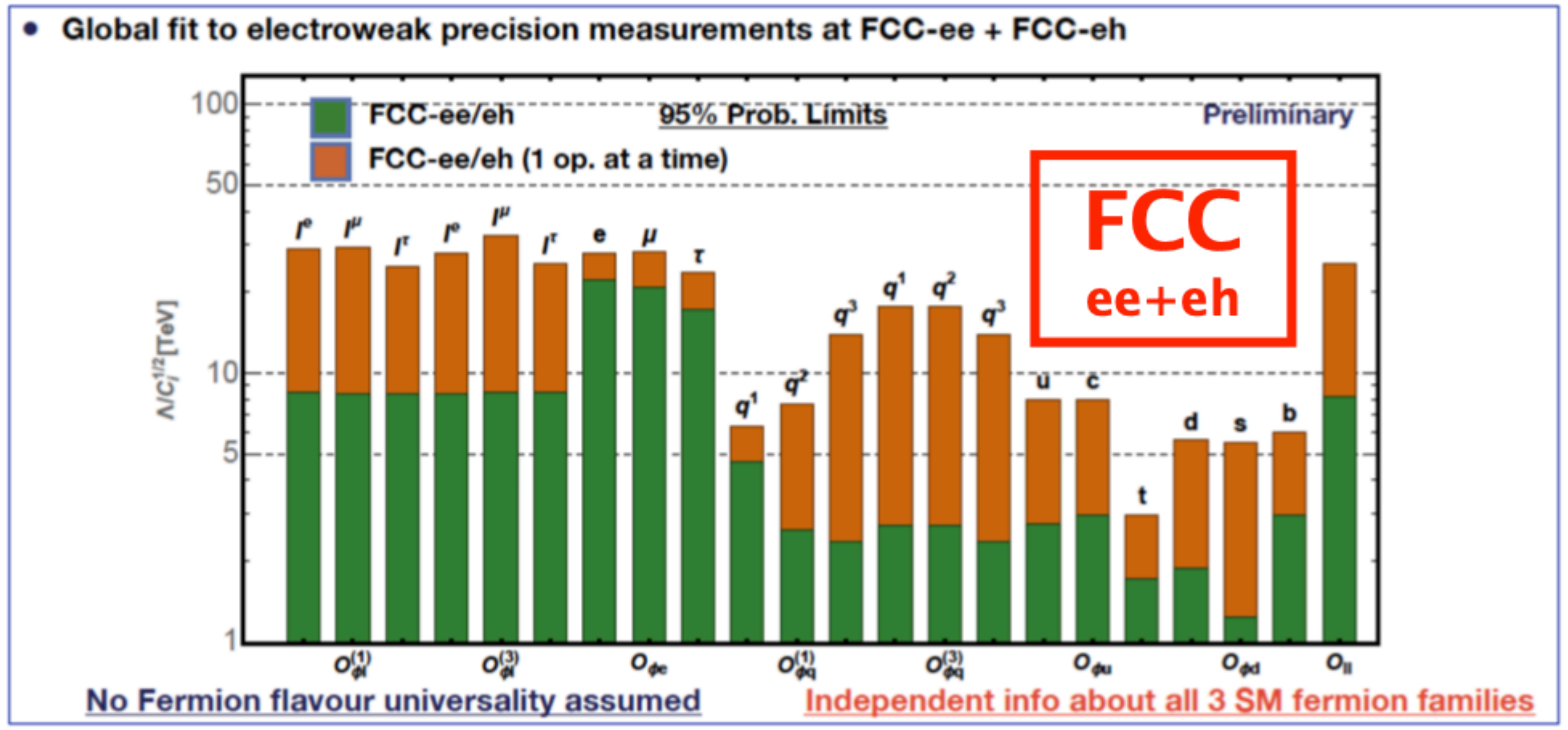
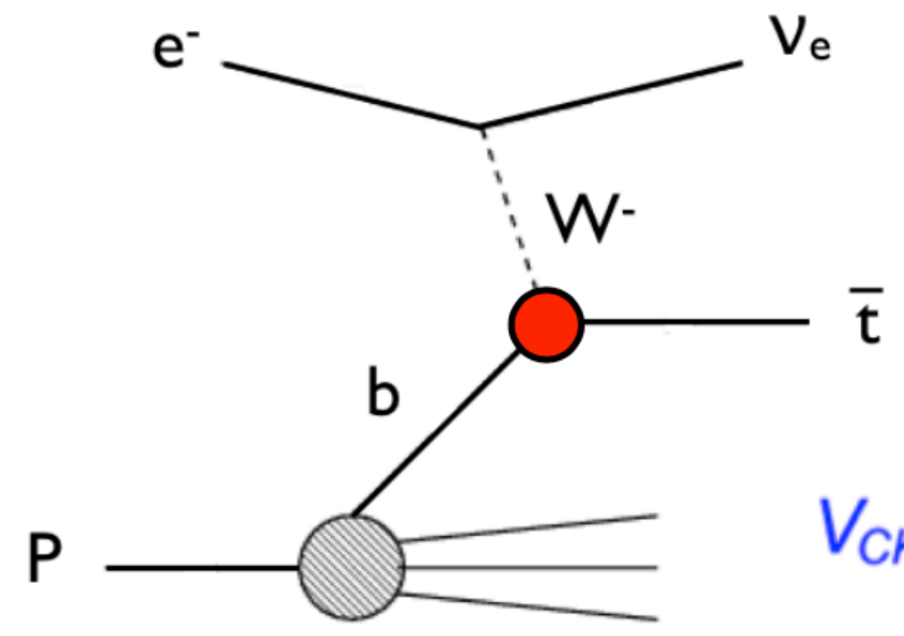




→ **precision < 1%**

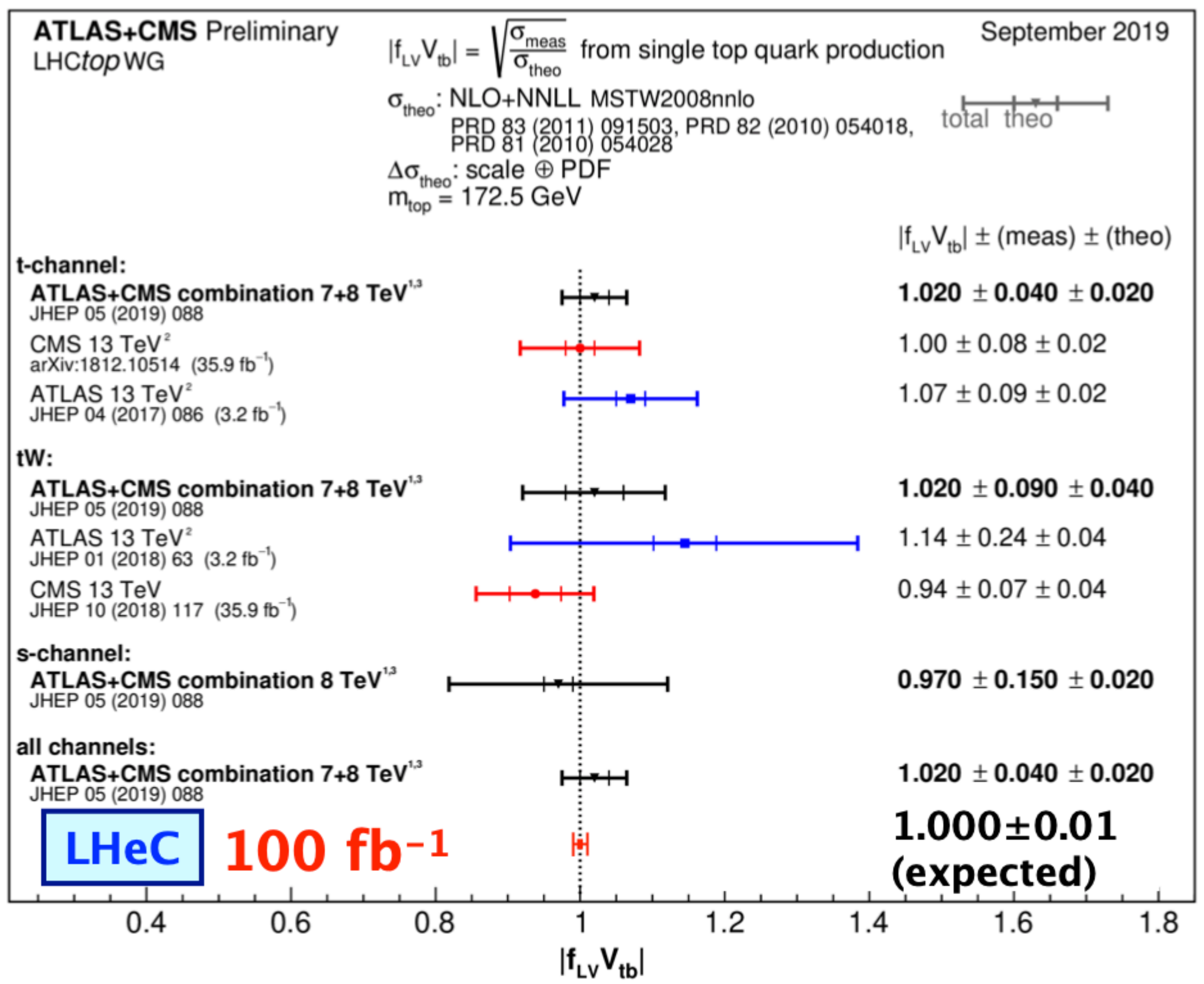
→ **high sensitivity to NP**





- **Top physics at the LHeC and the FCC-eh**, Mukesh Kumar, Apr 15, 12:51 PM

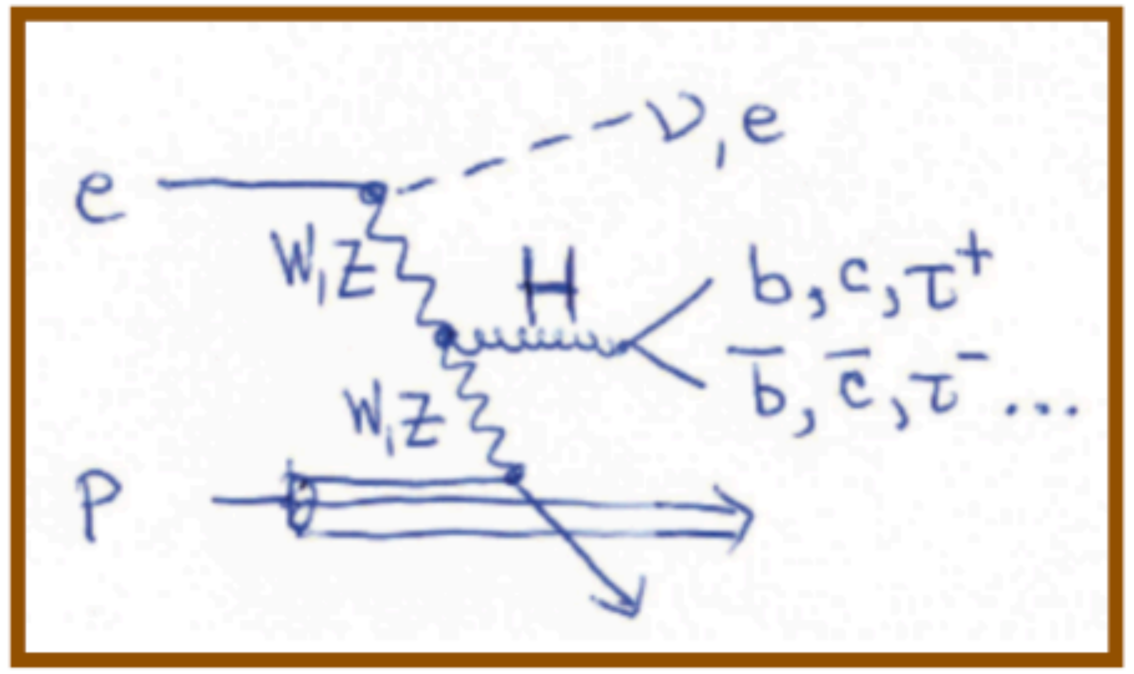
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

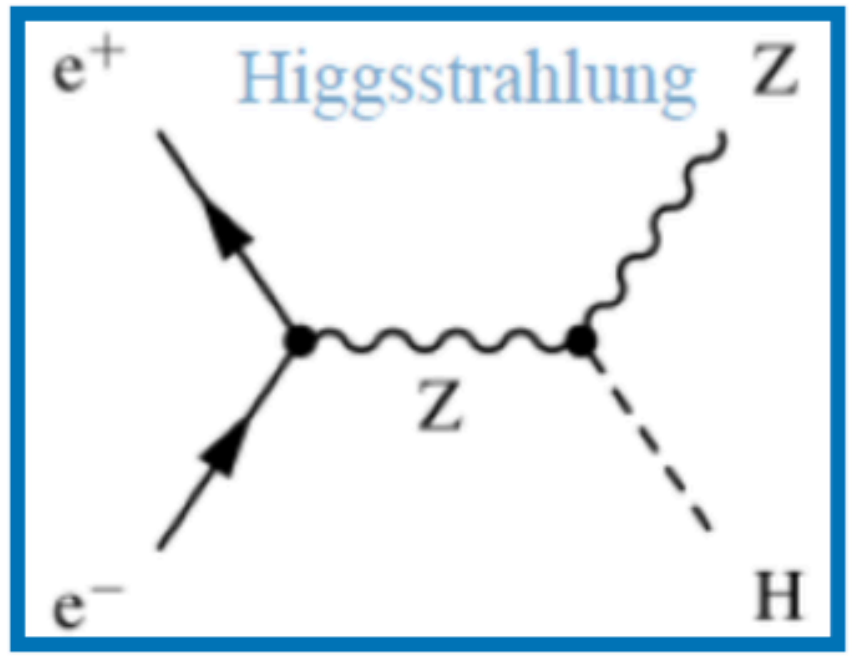


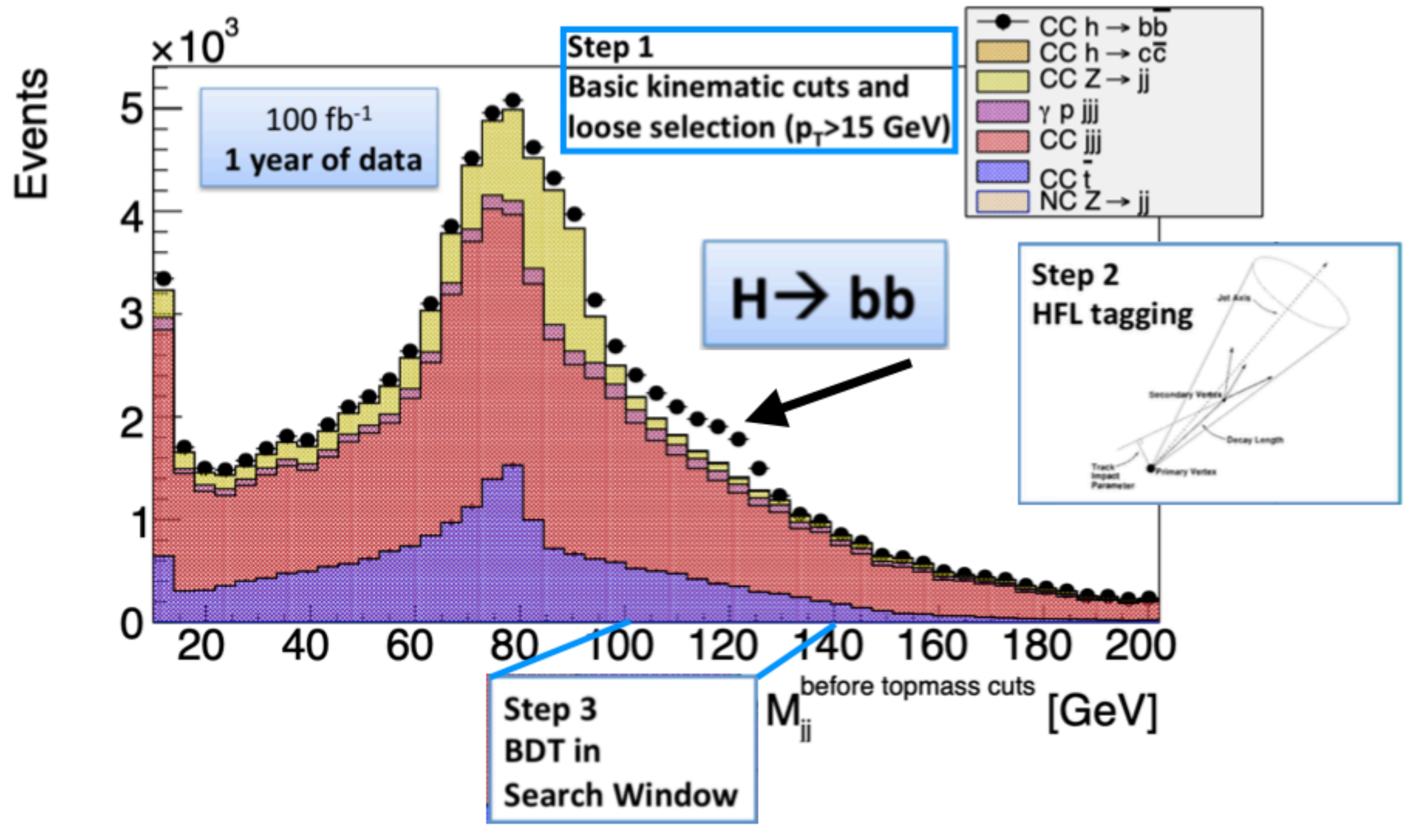
→ **high precision**

Higgs Couplings (κ-framework)

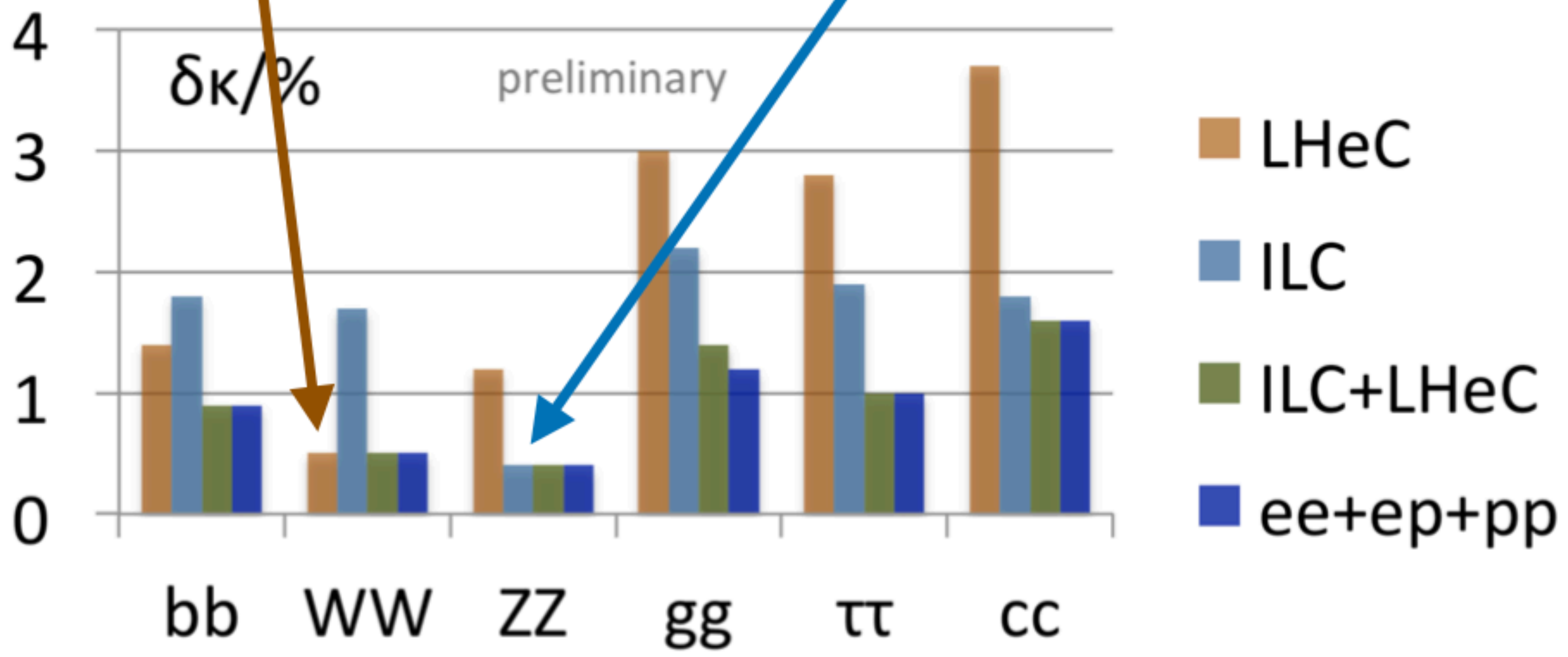
Higgs







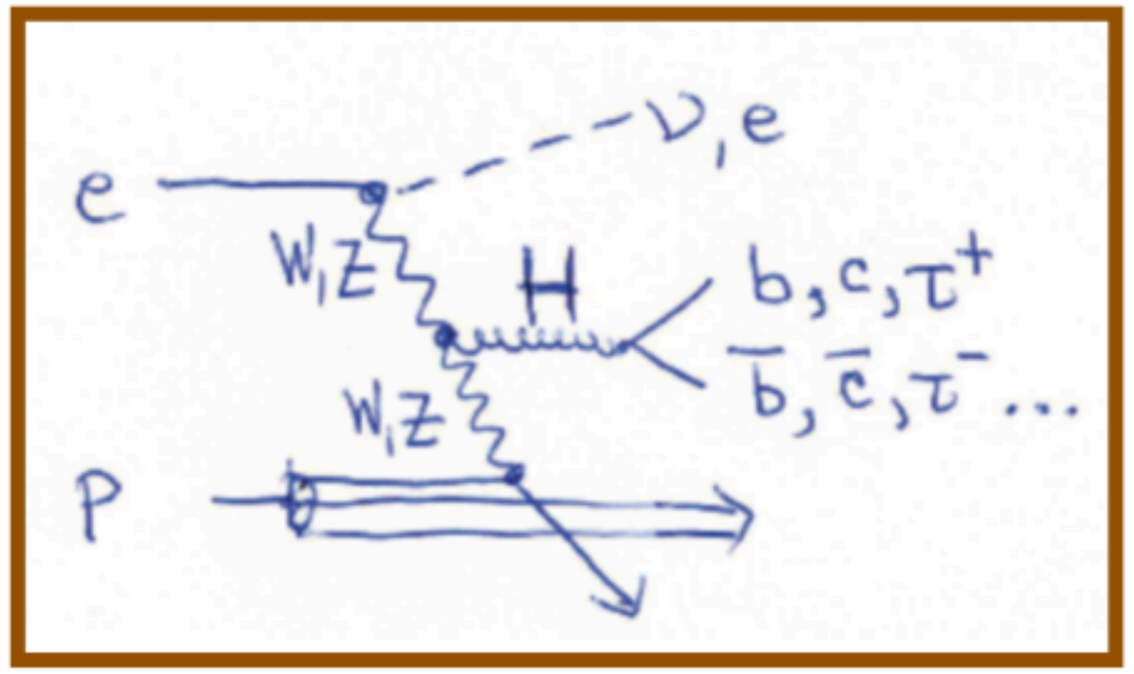
Most abundant SM Higgs decays

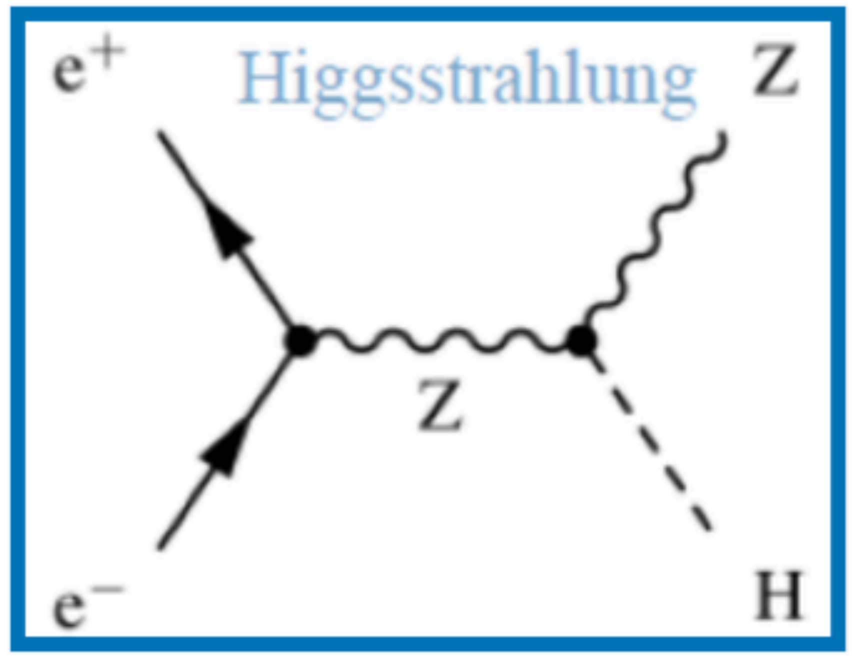


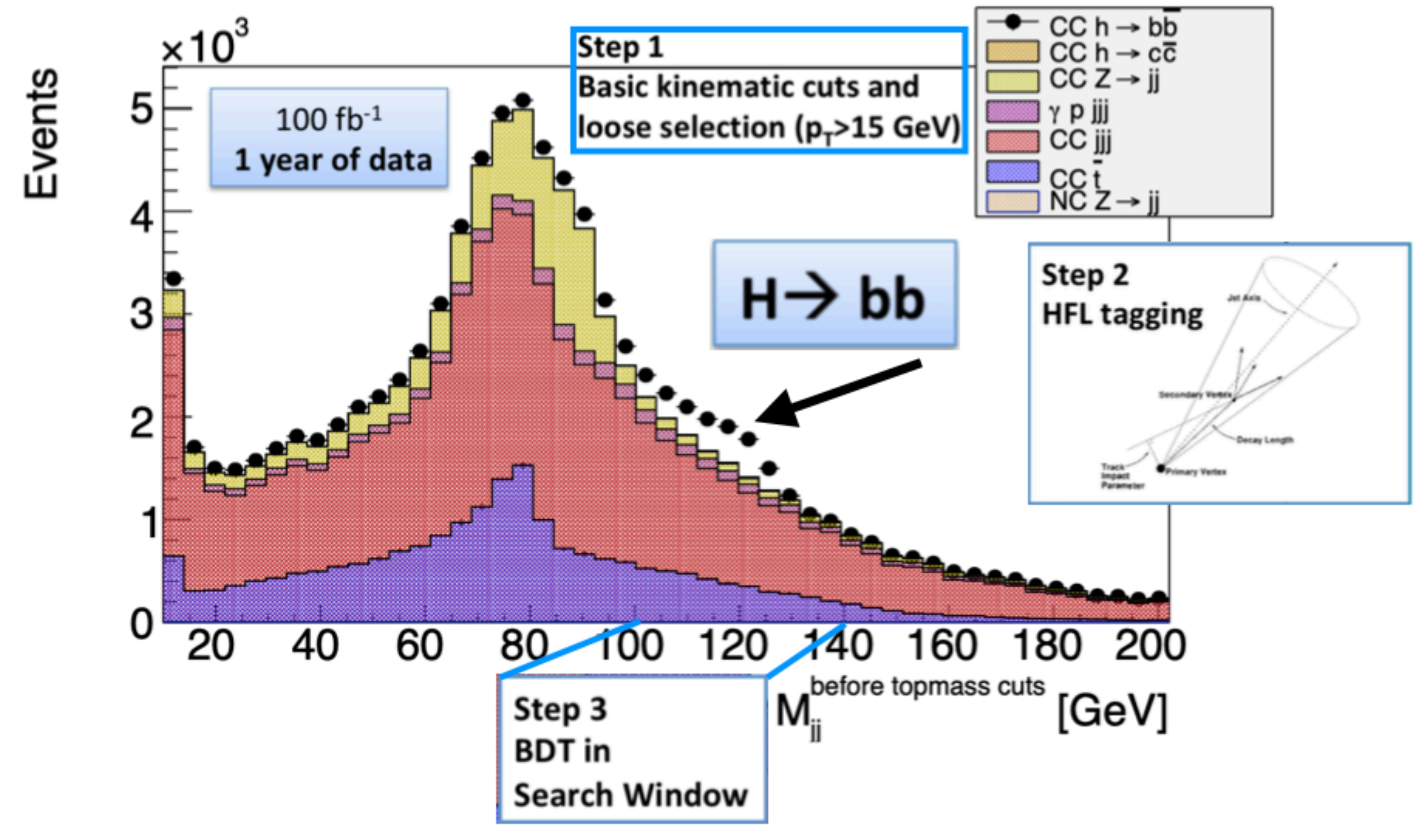
→ **complementarity of colliders**

Higgs Couplings (κ–framework)

Higgs







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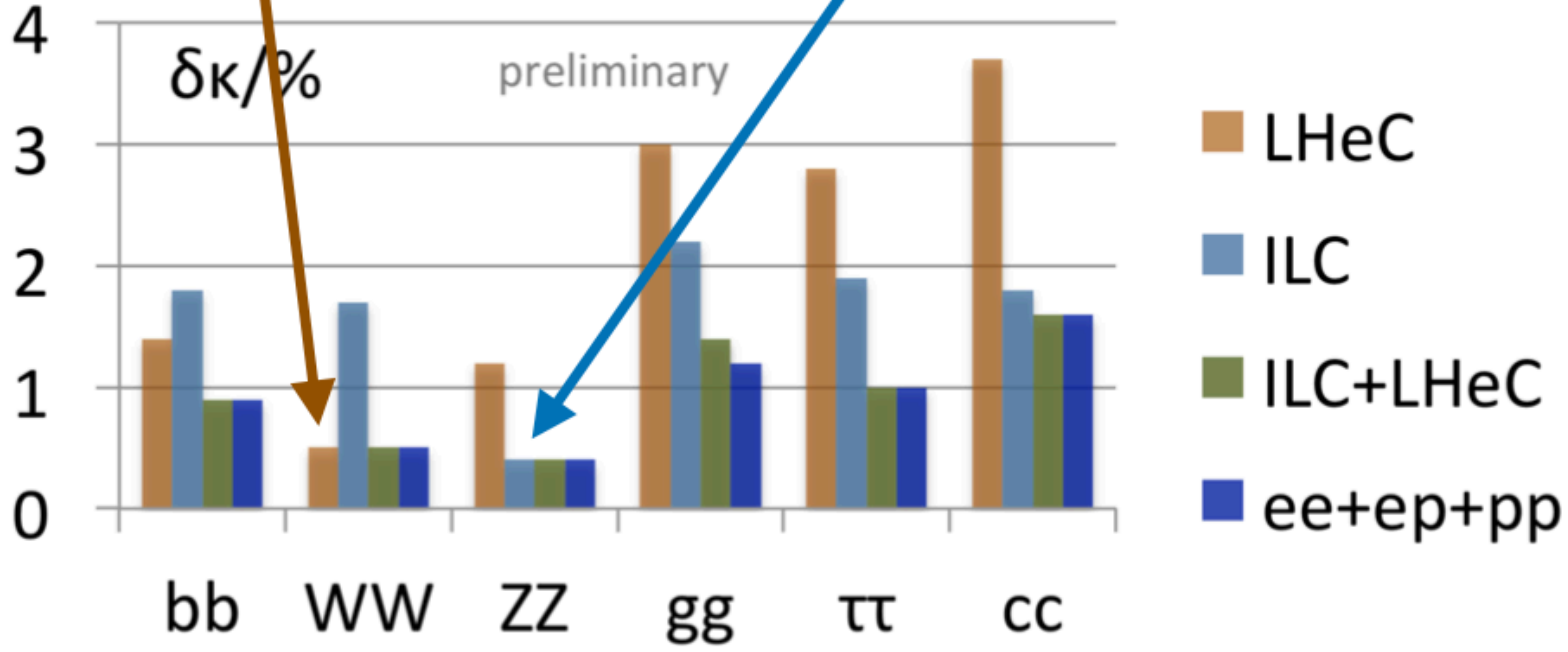

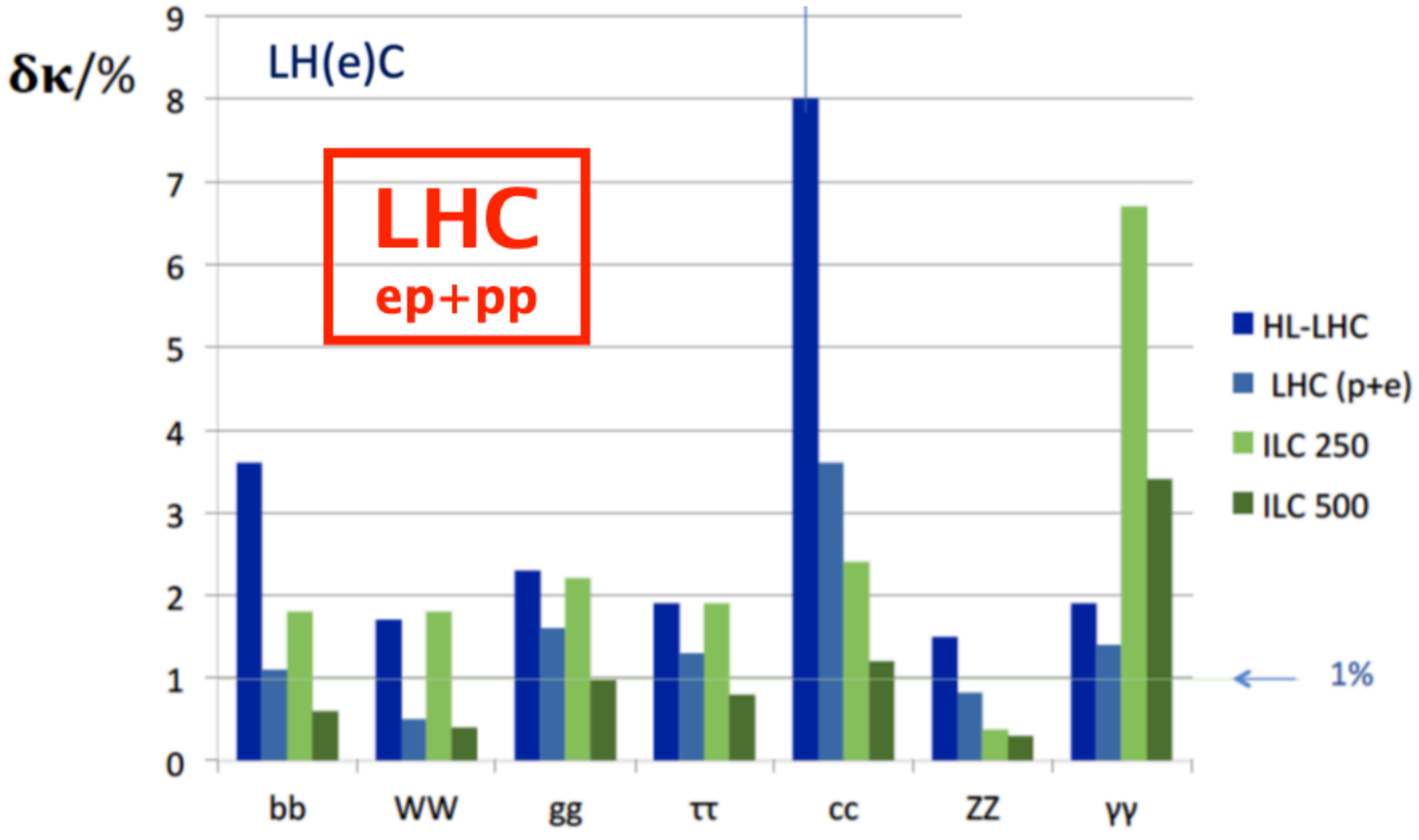

→ complementarity of colliders

→ adding electrons makes the LHC a Higgs precision facility

Search for New Phenomena

BSM

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  - 8.2.1 Modifications of the Top-Higgs interaction . . . 189
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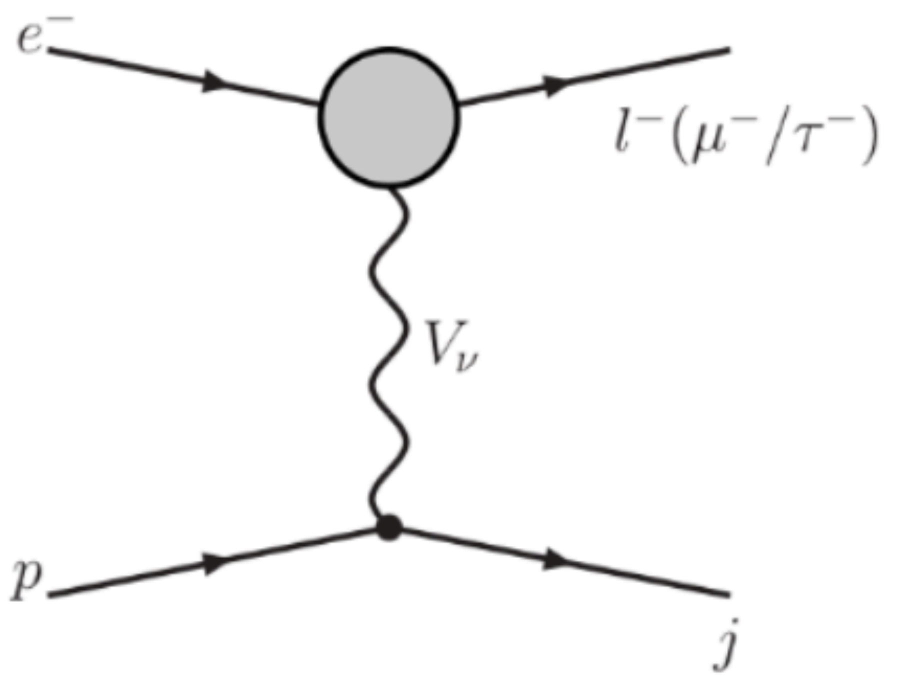
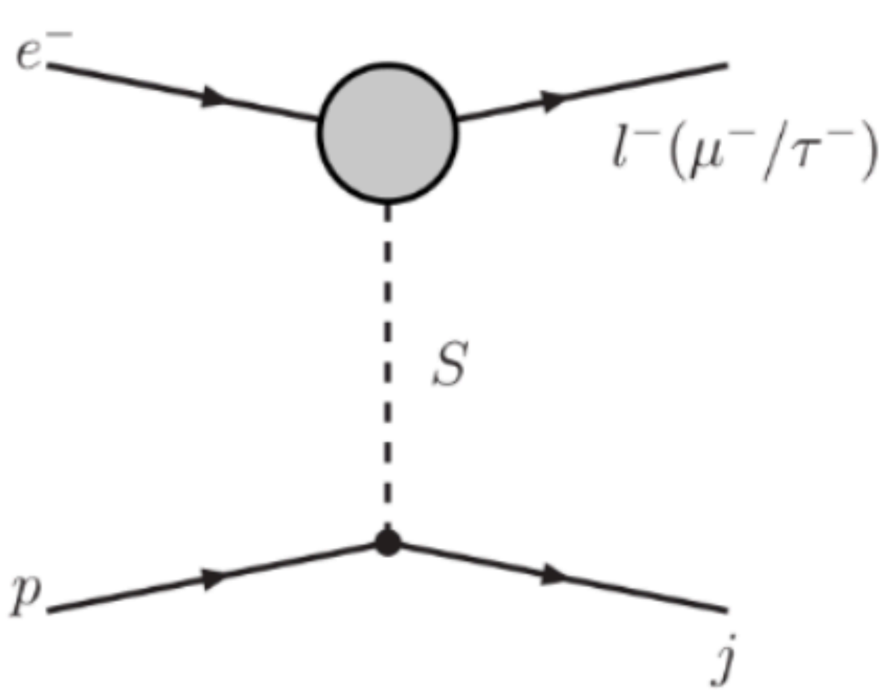
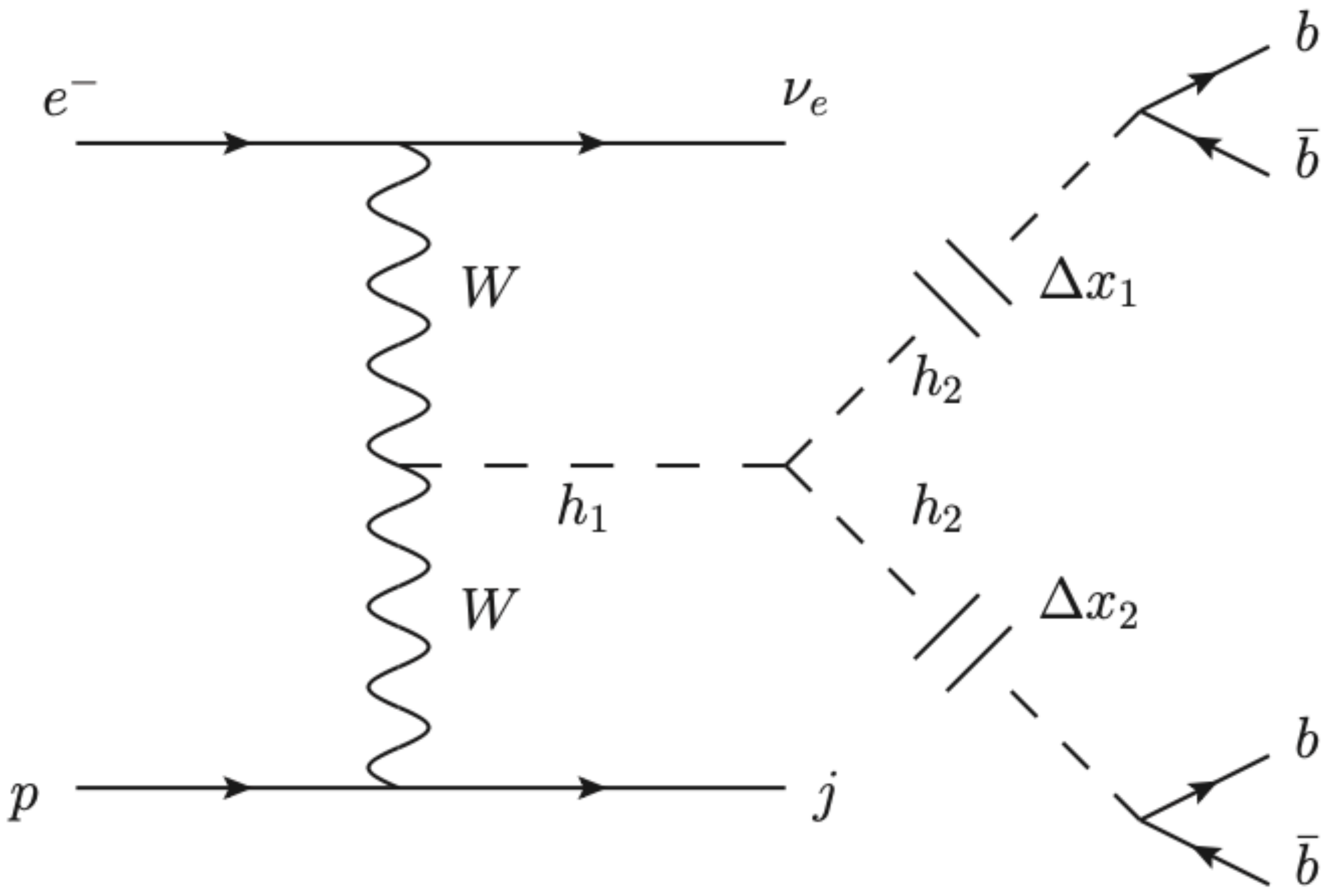




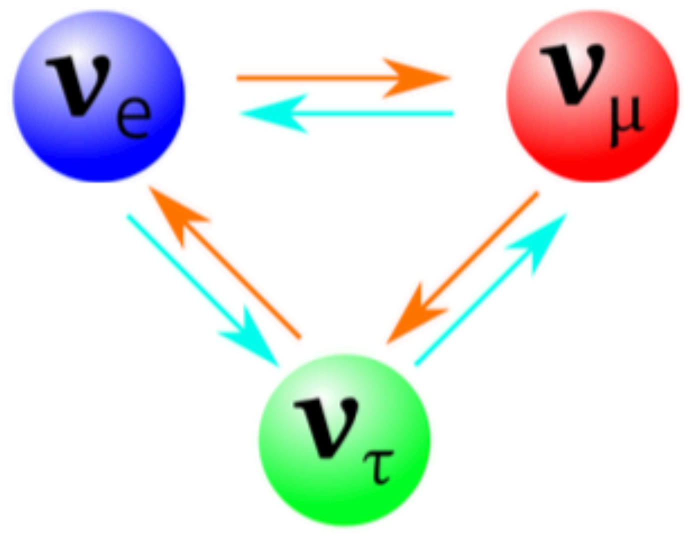


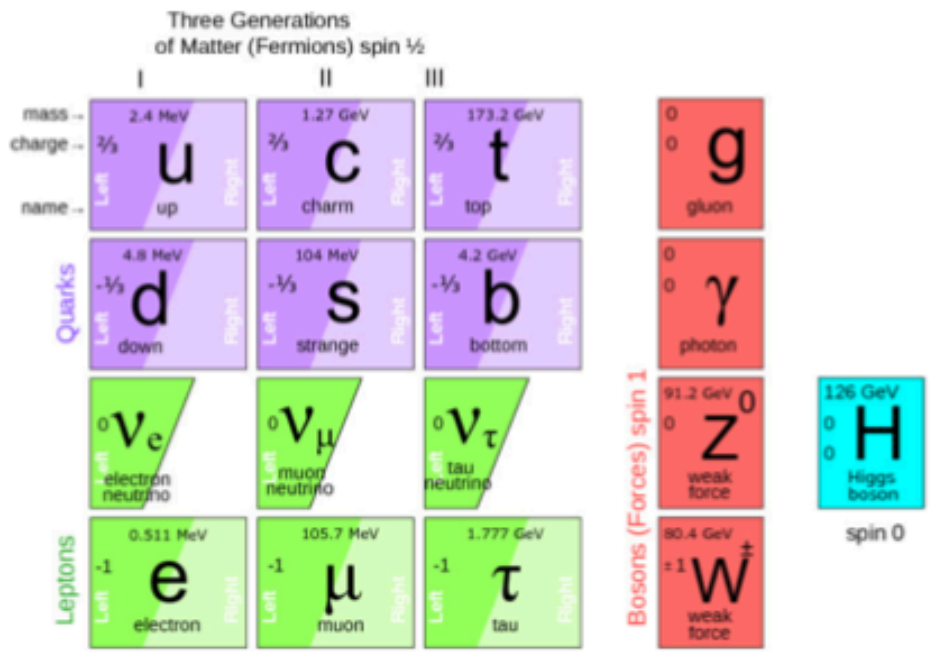
… and much more

- **BSM Physics at the LHeC and the FCC-eh**, Oliver Fischer, Apr 13, 11:09 AM

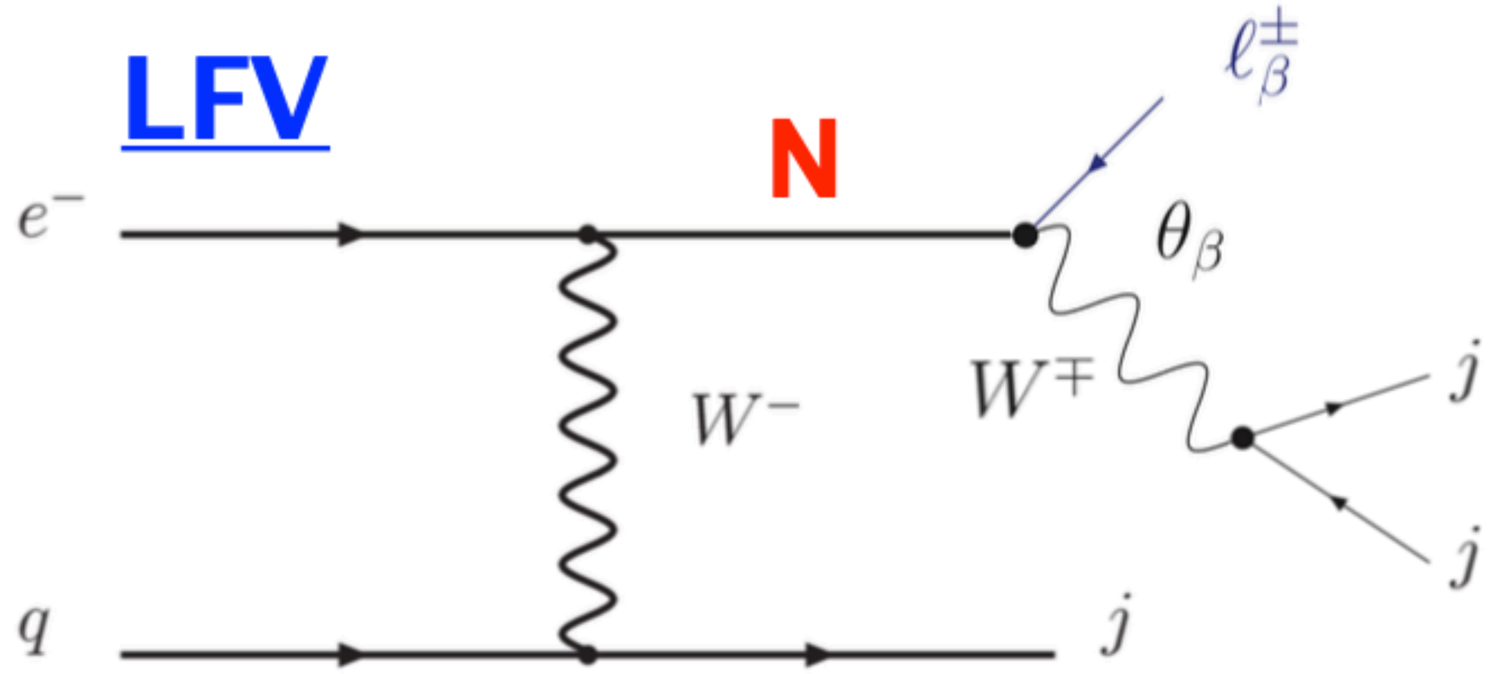
Search for heavy sterile neutrinos

BSM

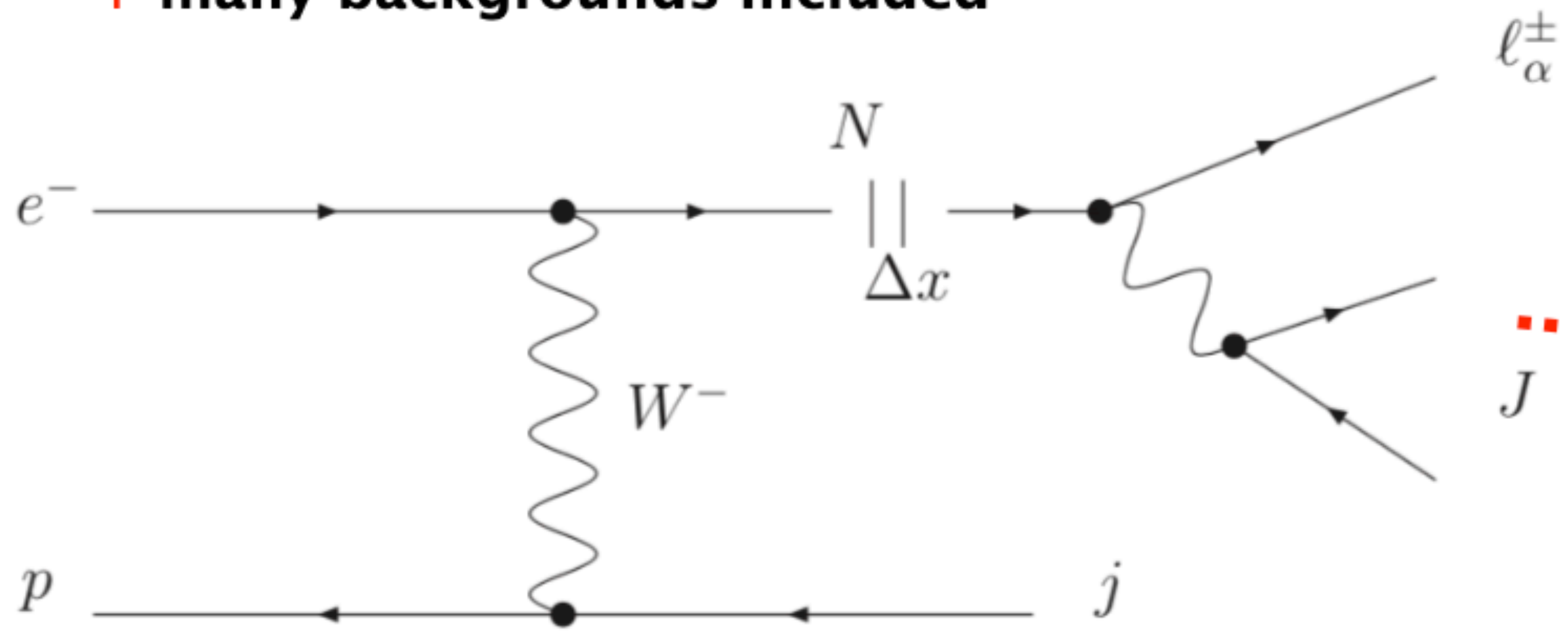




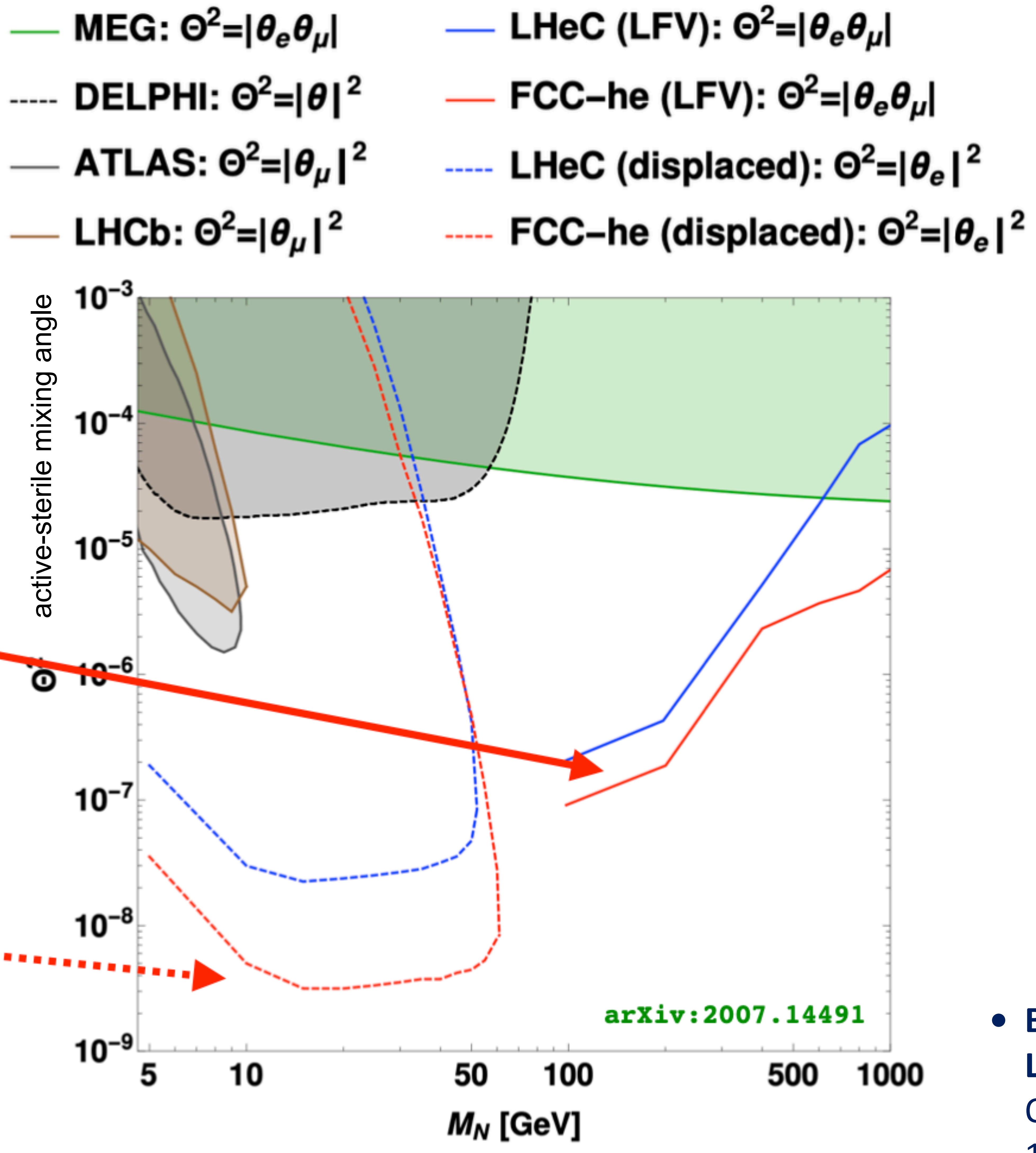
LFV



+ many backgrounds included



arXiv:1908.02852

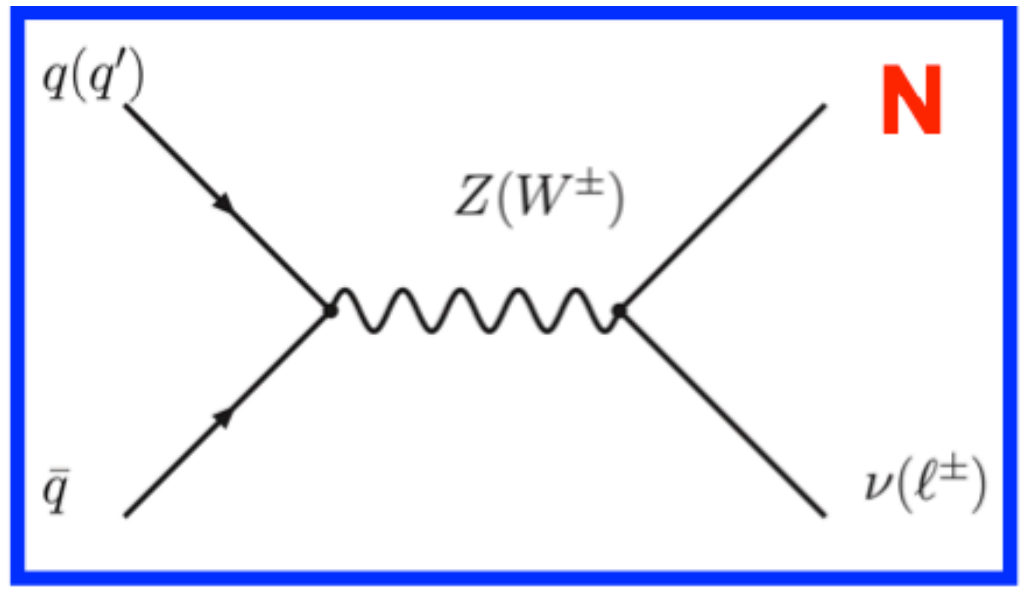


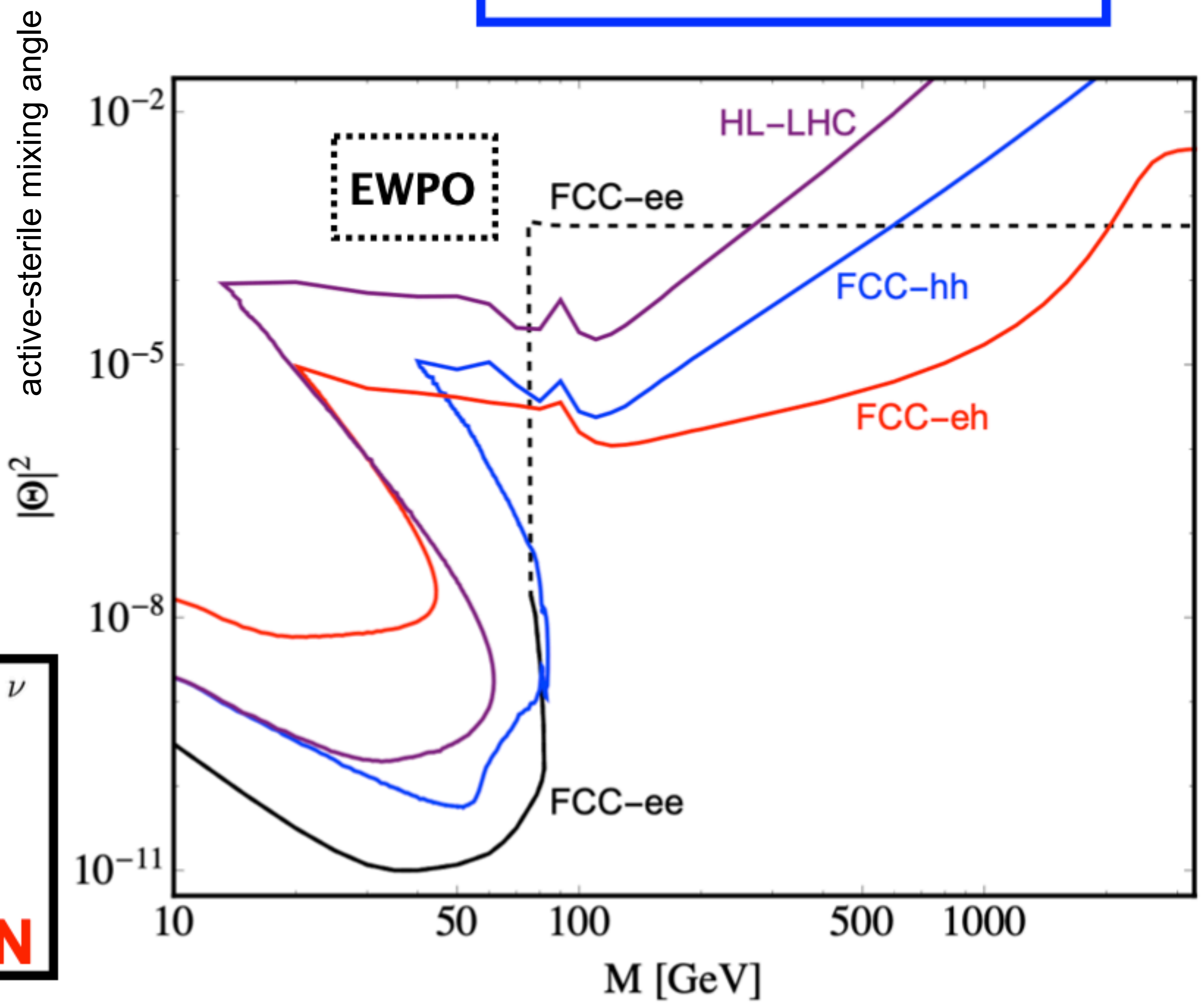
- **BSM Physics at the LHeC and the FCC-eh**, Oliver Fischer, Apr 13, 11:09 AM

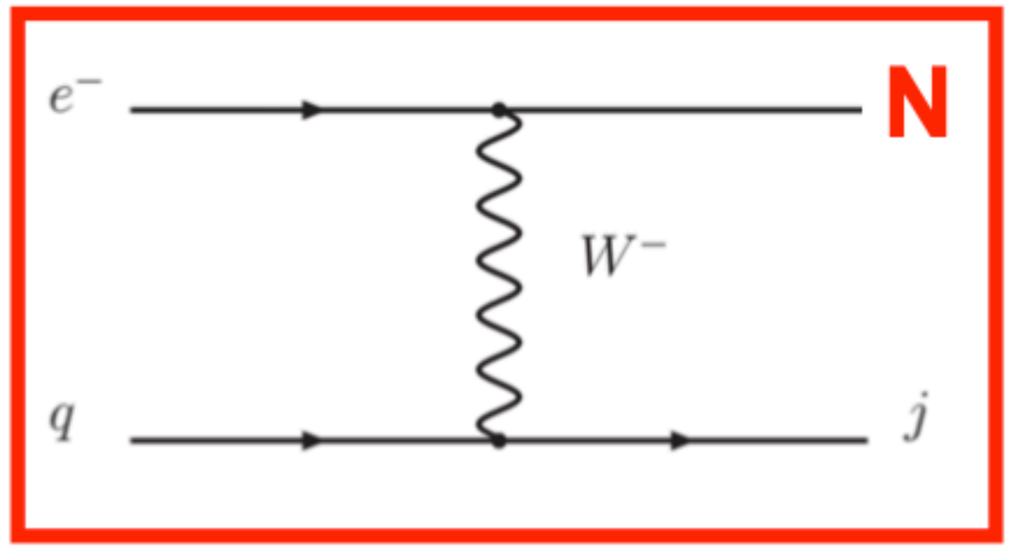
Search for heavy sterile neutrinos

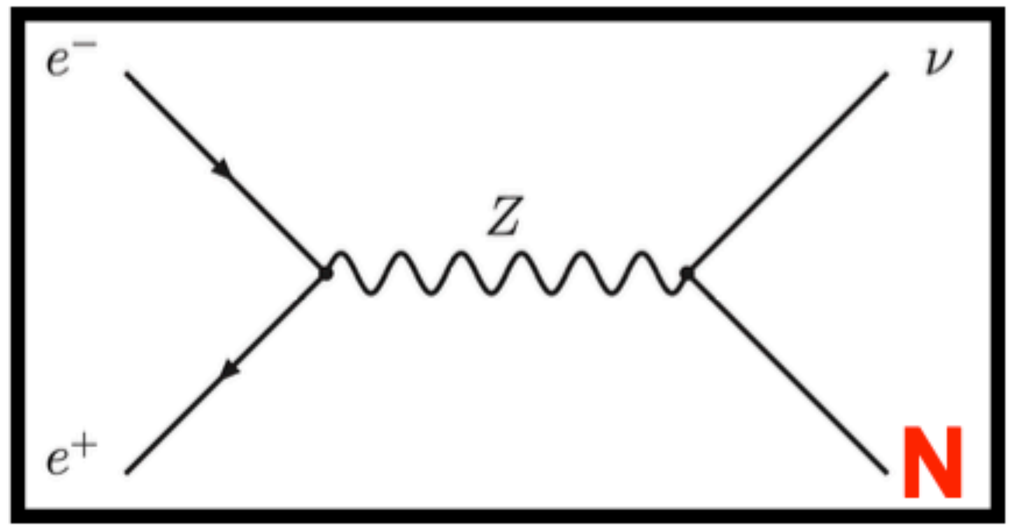
BSM

FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019)
arXiv:1612.02728 [hep-ph]









→ **complementary prospects for discovery in ee, ep and pp**

Conclusions: Statement of the IAC to DG

published in arXiv:2007.14491

In conclusion it may be stated

- The installation and operation of the LHeC has been demonstrated to be commensurate with the currently projected HL-LHC program, while the FCC-eh has been integrated into the FCC vision;
- The feasibility of the project as far as accelerator issues and detectors are concerned has been shown. It can only be realised at CERN and would fully exploit the massive LHC and HL-LHC investments;
- The sensitivity for discoveries of new physics is comparable, and in some cases superior, to the other projects envisaged;
- The addition of an ep/A experiment to the LHC substantially reinforces the physics program of the facility, especially in the areas of QCD, precision Higgs and electroweak as well as heavy ion physics;
- The operation of LHeC and FCC-eh is compatible with simultaneous pp operation; for LHeC the interaction point 2 would be the appropriate choice, which is currently used by ALICE;
- The development of the ERL technology needs to be intensified in Europe, in national laboratories but with the collaboration of CERN;
- A preparatory phase is still necessary to work out some time-sensitive key elements, especially the high power ERL technology (PERLE) and the prototyping of Intersection Region magnets.

Recommendations

i) It is recommended to further develop the ERL based ep/A scattering plans, both at LHC and FCC, as attractive options for the mid and long term programme of CERN, resp. Before a decision on such a project can be taken, further development work is necessary, and should be supported, possibly within existing CERN frameworks (e.g. development of SC cavities and high field IR magnets).

ii) The development of the promising high-power beam-recovery technology ERL should be intensified in Europe. This could be done mainly in national laboratories, in particular with the PERLE project at Orsay. To facilitate such a collaboration, CERN should express its interest and continue to take part.

iii) It is recommended to keep the LHeC option open until further decisions have been taken. An investigation should be started on the compatibility between the LHeC and a new heavy ion experiment in Interaction Point 2, which is currently under discussion.

After the final results of the European Strategy Process will be made known, the IAC considers its task to be completed. A new decision will then have to be taken for how to continue these activities.

Herwig Schopper, Chair of the Committee, Geneva, November 4, 2019

→ **exciting programme for the coming years which is established and for us to shape**

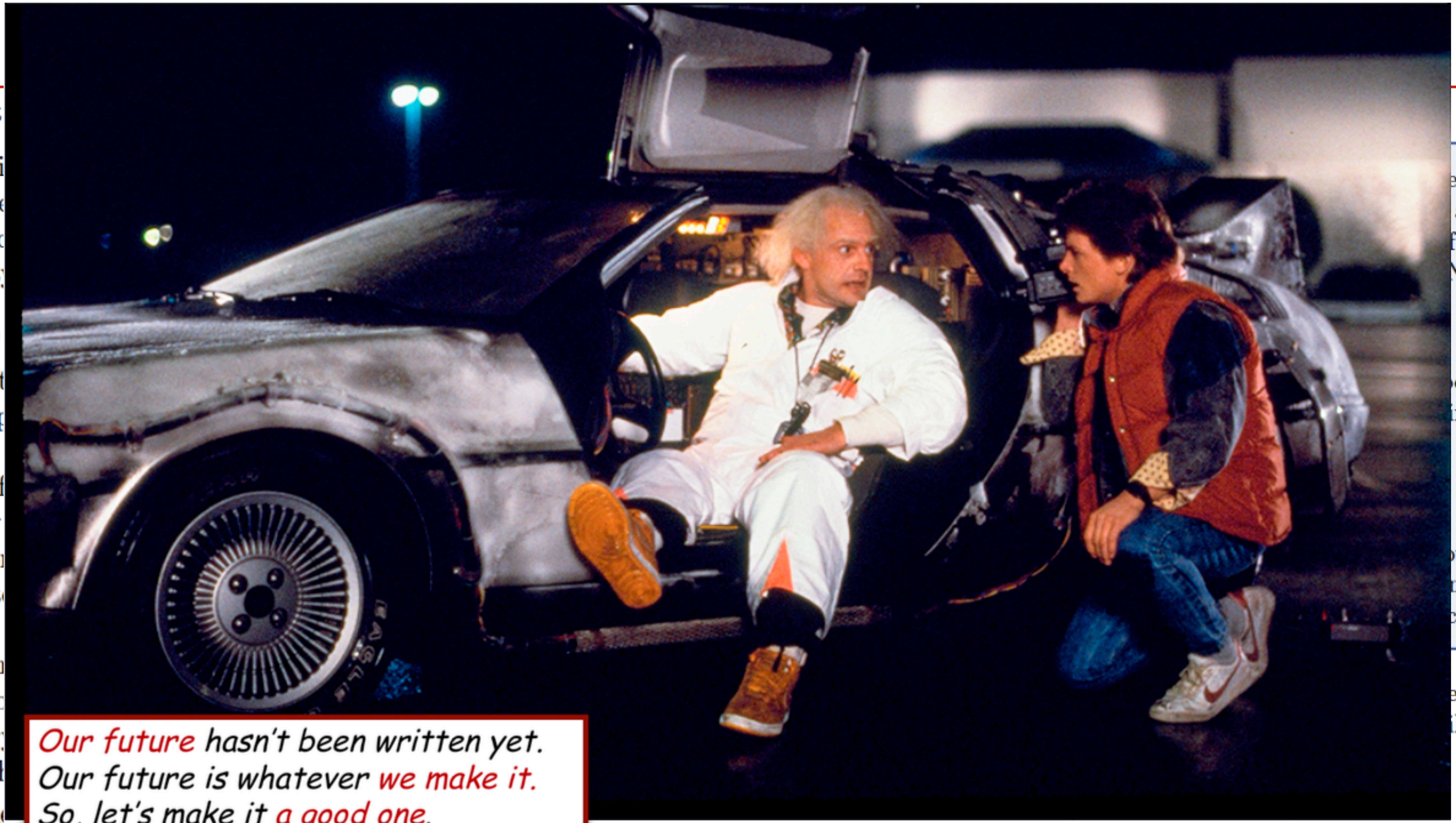
https://lhec.web.cern.ch/

Conclusions: Statement of the IAC to DG

published in arXiv:2007.14491

In conclusion it

- The installati with the curr the FCC visio
- The feasibility been shown. and HL-LHC
- The sensitivit to the other p
- The addition gram of the f well as heavy
- The operatio LHeC the int ALICE;
- The developm laboratories b
- A preparatory pecially the I Region magn



Our future hasn't been written yet.
Our future is whatever we make it.
So, let's make it a good one.
(Doc Brown)

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Geneva, November 4, 2019

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https://lhec.web.cern.ch/

Backup

LINAC at Stanford

Three Messages from the 2m LINAC at Stanford

-- **you do NOT need to promise to discover dark matter or know what new to expect when you increase the energy range** (we yet may have to readjust our perception about nature, its richness and as well our ability to predict and understand it. 'we like to see the field to be driven by experiment' – Burt Richter 2009)

-- **you can build a 2 mile electron linac in 3 years time, if you really want it**
we surely could build LHeC and FCC-eh in short time when decided to do so

-- **electron-proton scattering is the best means to explore the substructure of matter**
a crucial complement to the LHC/FCC and moreover, now a unique Higgs facility

50 years since the discovery of quarks by the SLAC-MIT ep scattering experiment

W.K.H. PANOFSKY Vienna 8/1968 SLAC-PUB-502

Therefore theoretical speculations are focused on the possibility that these data might give evidence on the behaviour of point-like, charged structures within the nucleon.

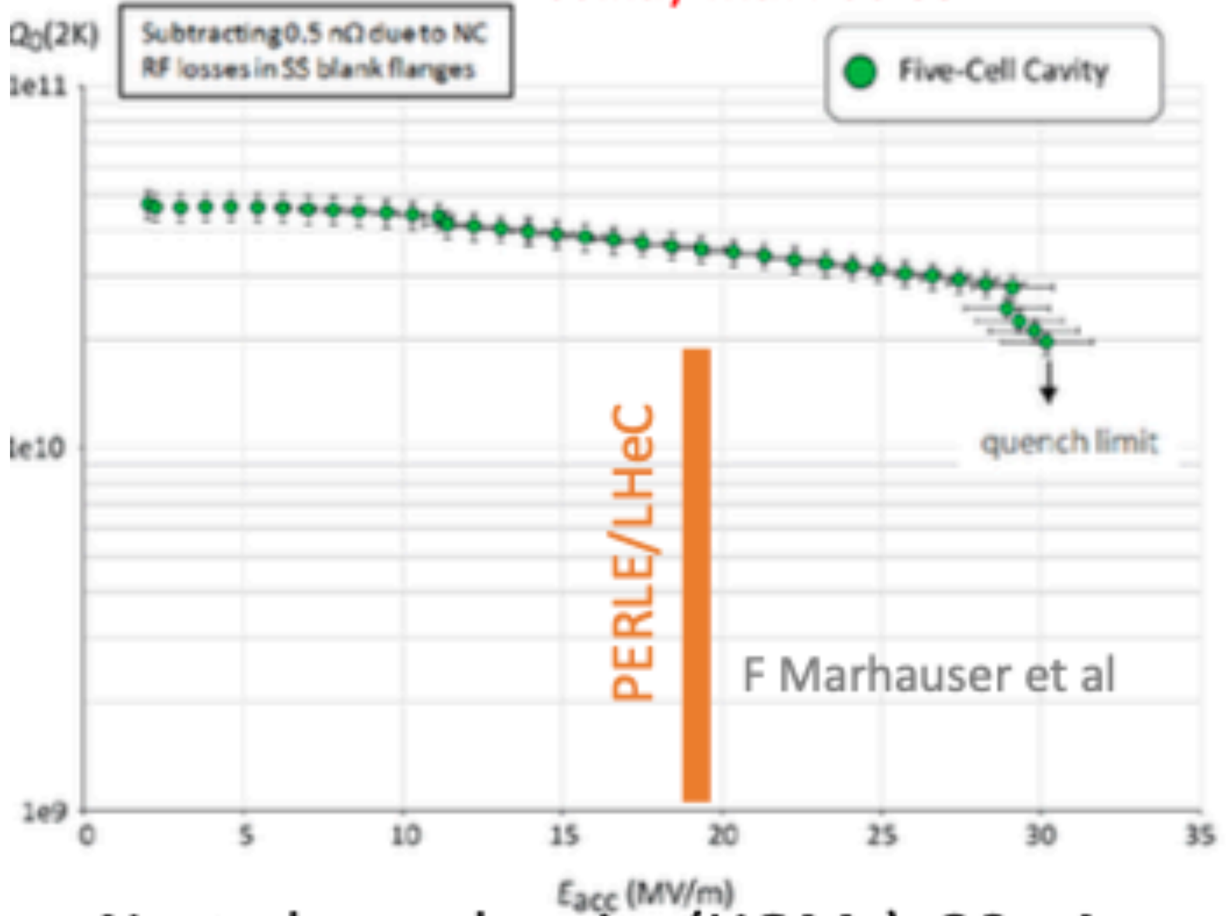
Max Klein

Further developments

Developments +Partners

SCRF: High Q_0, complete Cryomodule

Jointly with FCC-ee

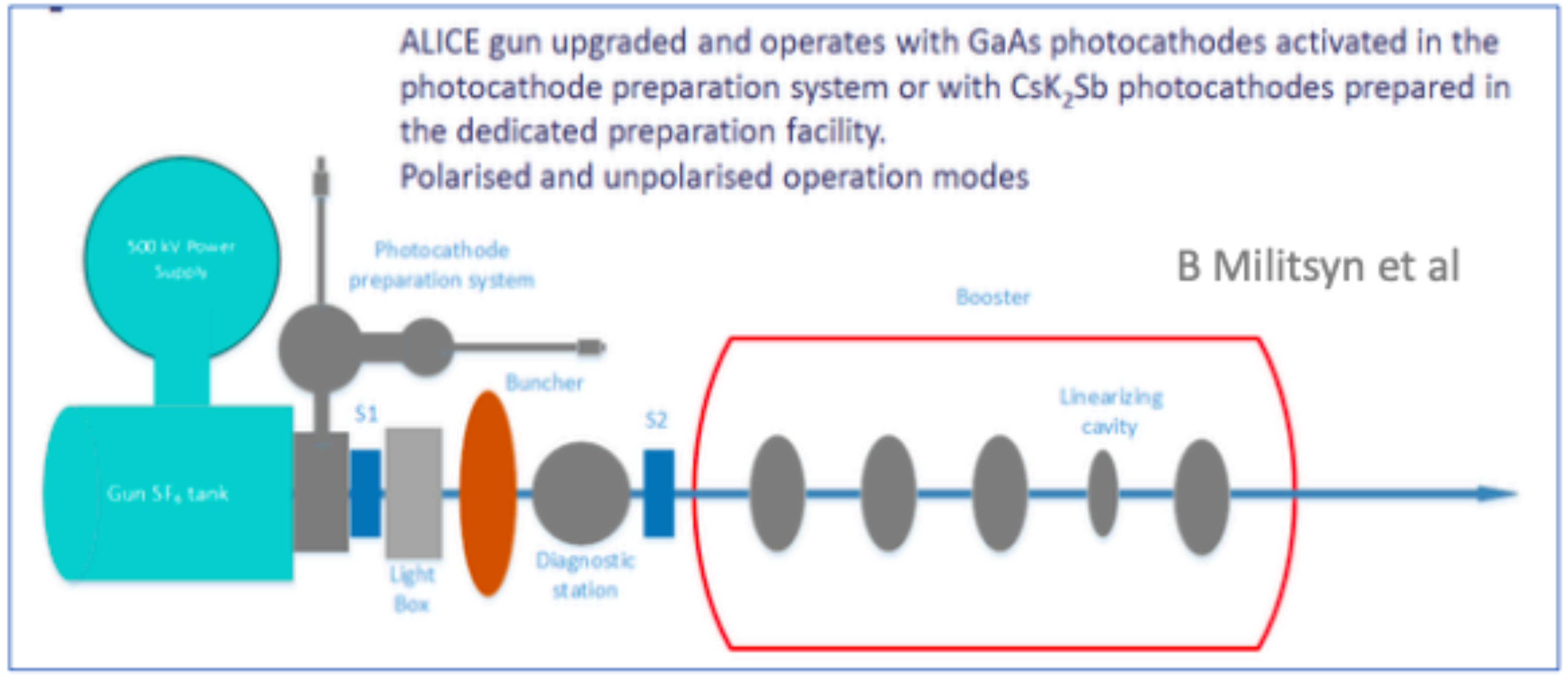


Next: dressed cavity (HOMs), 20mA
Adapt SPL Cryomodule for PERLE

CERN, Jlab, Orsay +

Cf recent meeting: https://indico.cern.ch/event/923021/

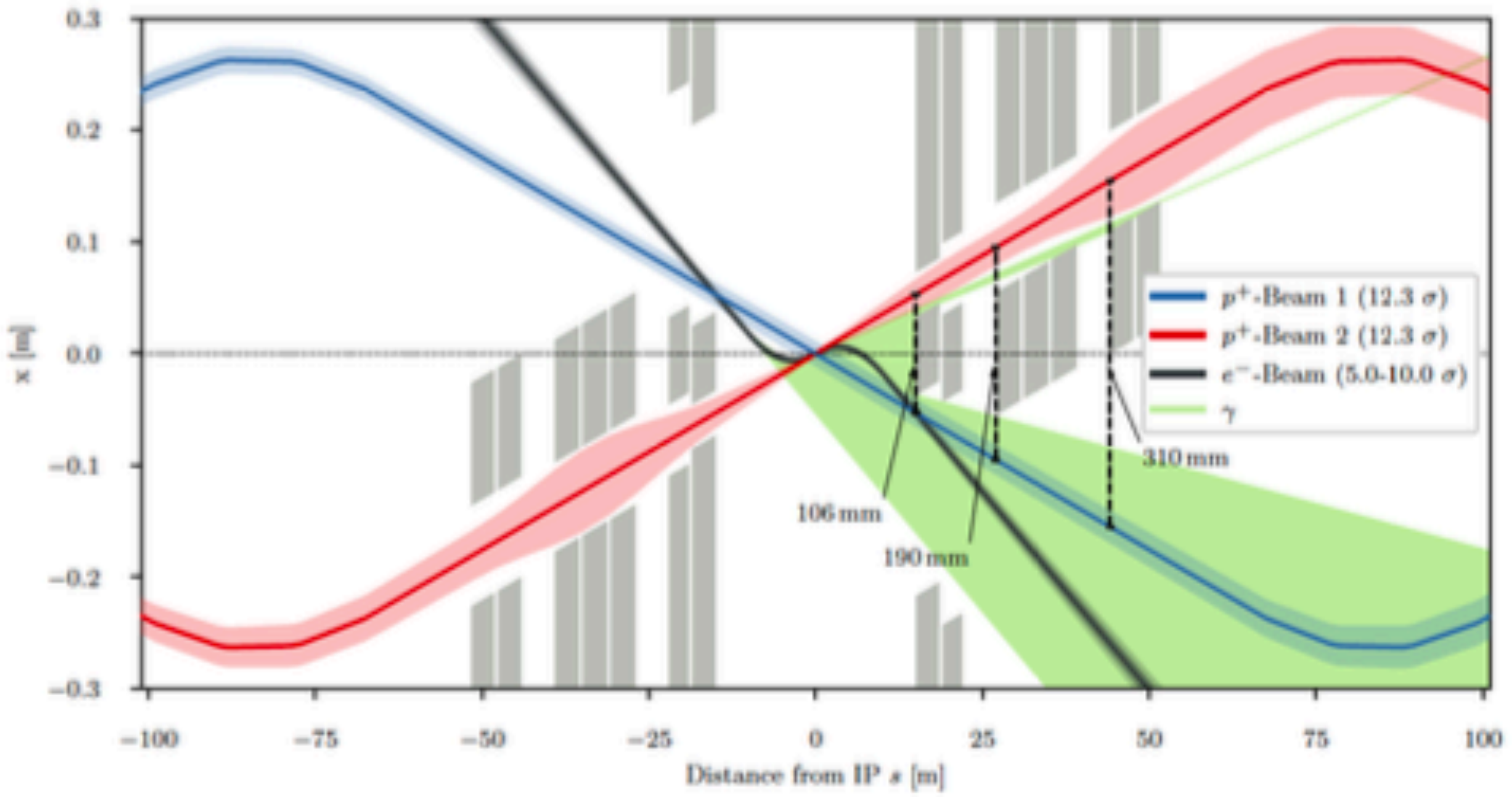
High Current Source (e^-, P, e^+)

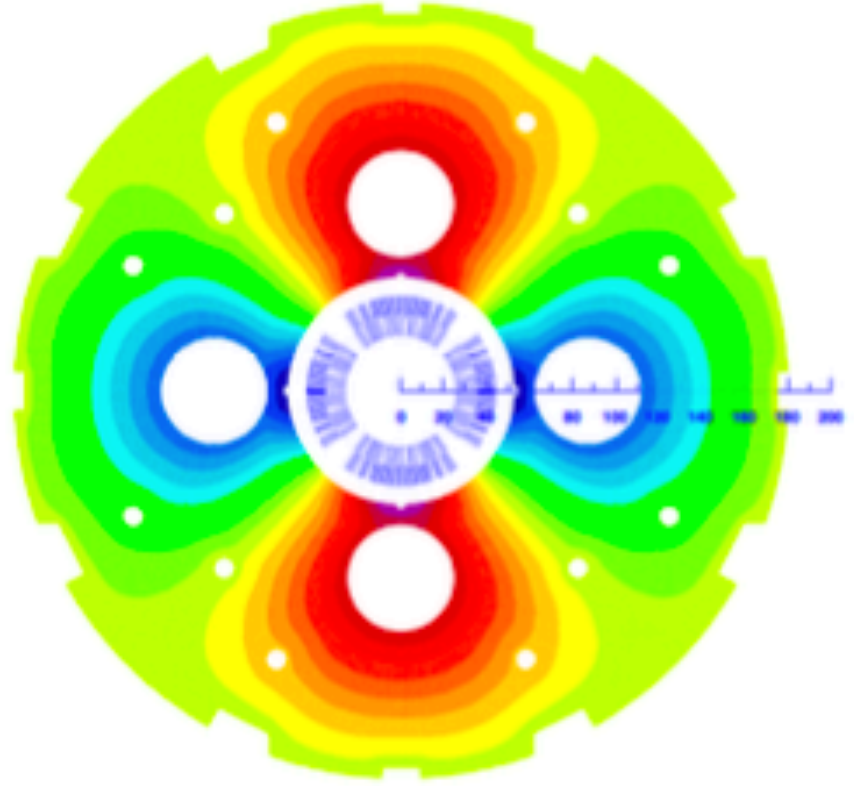


PERLE will begin with 5mA ALICE source, which has been transferred from Daresbury to Orsay while UK was in EU..

BINP, BNL/Cornell (cBETA), Daresbury, IJC, Jlab, +

Interaction Region Design and Q_1 Prototype: B Holzer, B Parker, S Russenschuck et al

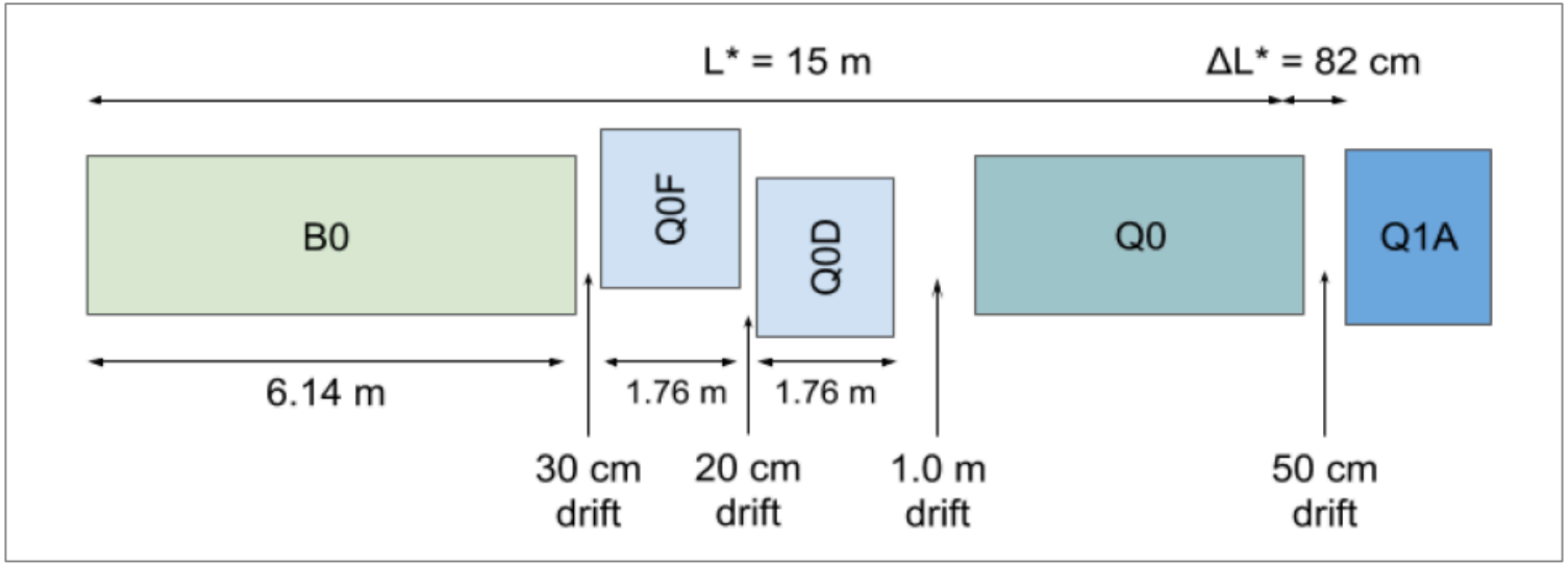




BNL, CERN, +

Max Klein

LHeC IR modified for dual purpose



Optimisation of synchrotron radiation (power and E_{crit})

		LHeC	HERA
E_{crit}	keV	270	150
Synrad Power	kW	30	28

Detector dipole — Staggered quads — Half-quad (NC) — First of triplet qaudrupoles

For ep/A: synchronous with pp/AA in GPDs and LHCb – keep non-colliding beam apart
with option of pp/AA the non-colliding beam needs to be kept inside pipe:
then: shift transversely (as in regular injection mode) and possibly in time
For pp/AA in IP2: no electron beam in. Collisions at nominal IP (or shifted by 25/4ns)

Max Klein

Technical synergy

LHeC-FEL

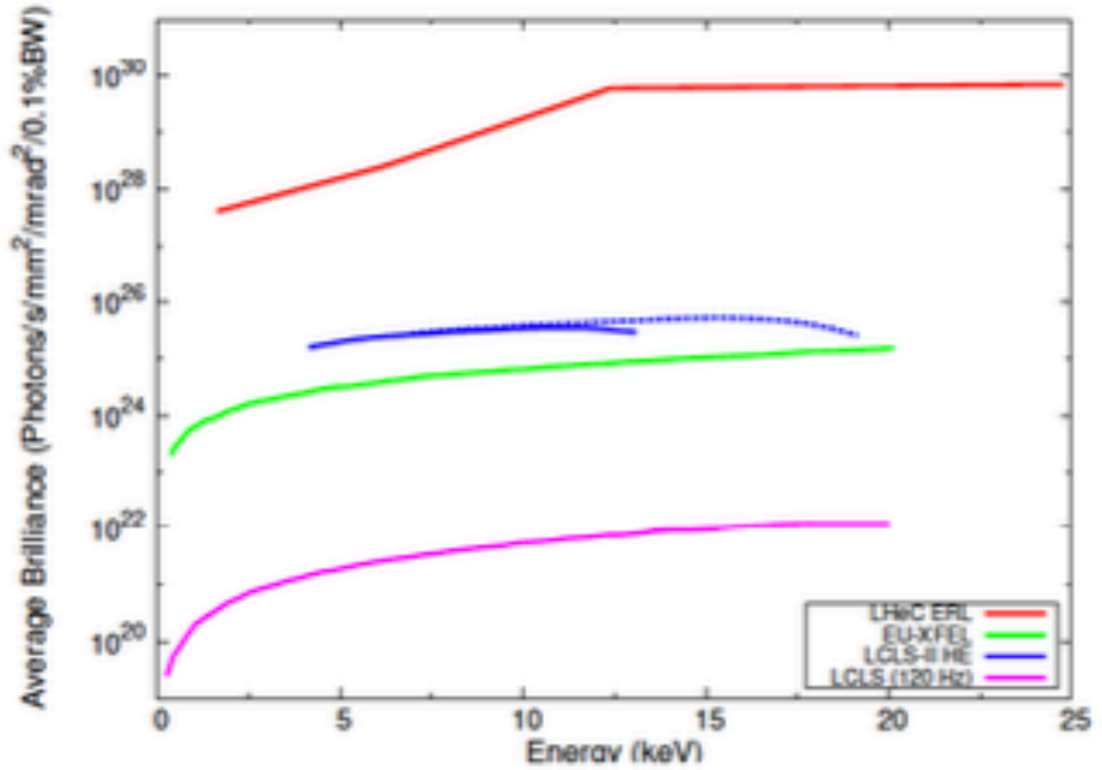


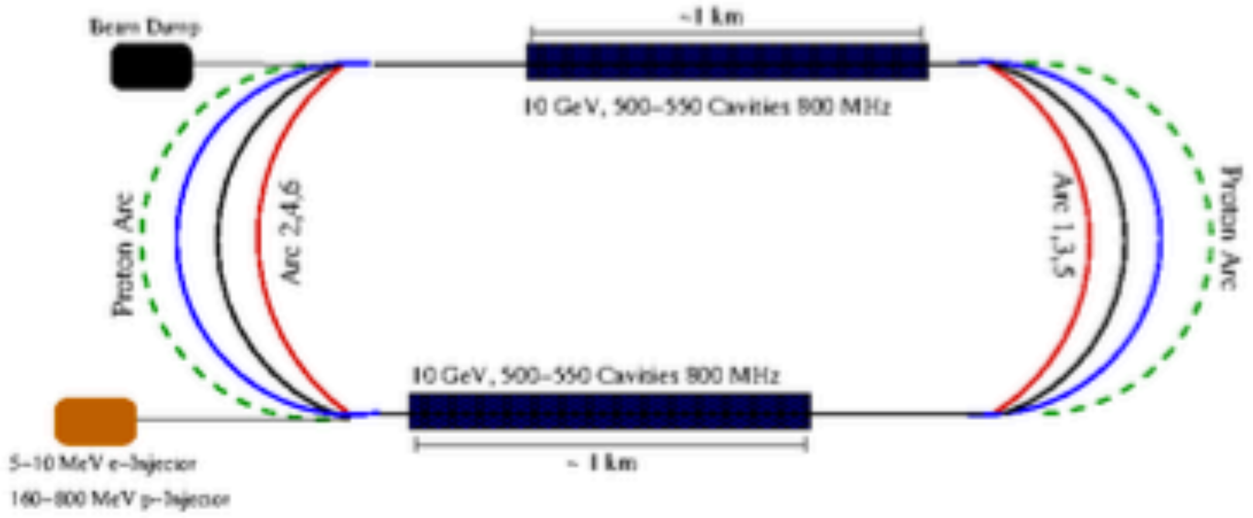
Figure 9: Comparison of FEL average brilliance for the LHeC-FEL with existing and planned world-leading hard X-ray FEL sources.

Work in progress, F Zimmermann et al. [in between LHeC and FCC-hh potentially]

e-ERL for Proton Injection

Recall: "SPL+PS2" as a new high brightness injector was already considered and abandoned for LHC

Proposal to use a single recirculating linac to directly inject to SPS (26 GeV) or SPS+ (~50 GeV), especially for 5ns bunch spacing.



Presented by R Calaga, 2017 [worth reconsidering]

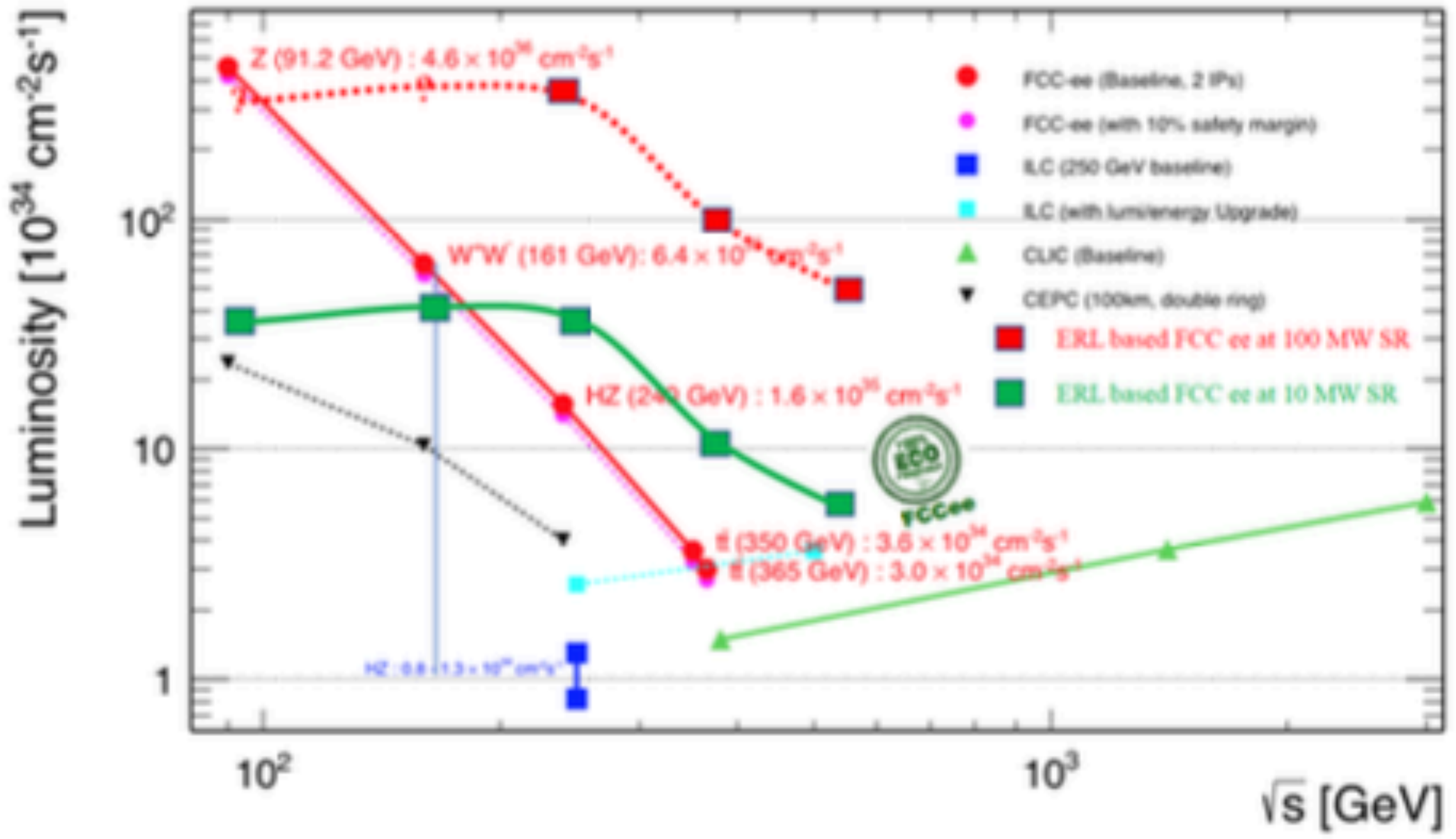
FCC-ee Injector Complex

Applications/ Synergy - examples

- FCC-ee Baseline Injector Plan: e^+/e^-
  - Linac with 6 GeV followed by 20GeV pre-booster ring [SPS] or 20GeV linac
  - 2.0 10^{10} N_b with 2 bunches per pulse and 200Hz rep-rate → < 2μA average current
  - Requires transfer lines from SPS or linac to FCC → ca. 10km tunnel structures?
- Using LHeC type Recirculating Linac as injector: e^+/e^-
  - Common hardware and infrastructure: one could use the FCC-ee pre-series SRF
    - -Either using a 5km long racetrack suitable for 50GeV upgrade for FCC-eh and / or direct injection into the FCC-ee for Z production mode
    - -Dedicated smaller tunnel optimized for FCC-ee injector at 6 GeV or 20 GeV
  - In both cases I assume installation near point 'L' to minimize transfer line length
  - In all cases the machine would be used as re-circulating linac and not in ERL mode

Presented by O Bruening, March 2019 [being rediscussed. Note PSI FEL concept]

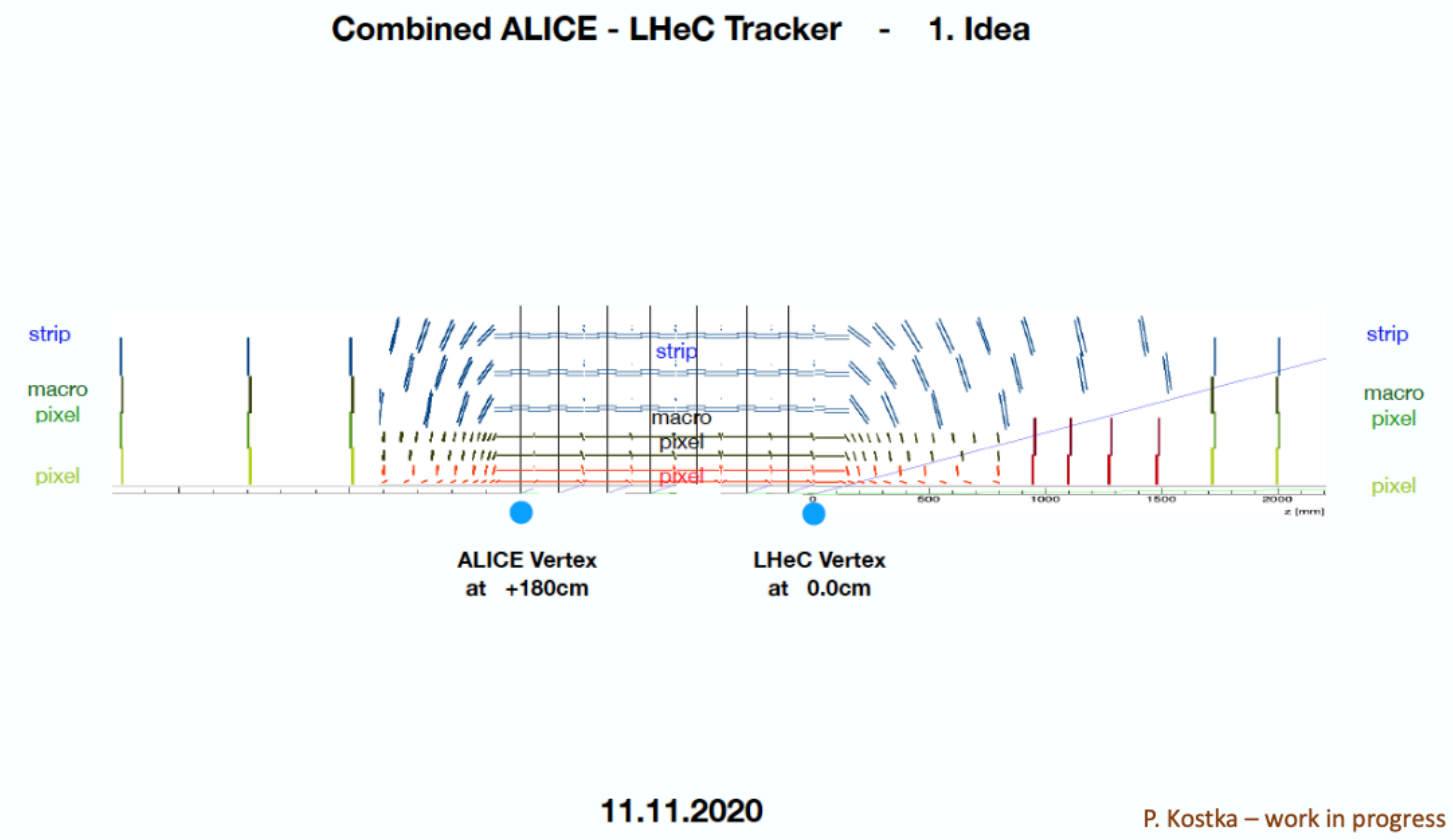
Energy recovery configuration of FCC-ee



V Litvinenko, T Roser, M Chamizo-Llatas arXiv: 1909.04437, [ongoing study]

Max Klein

Combined A3 – LHeC Tracker



Various Questions:

- Low or HV CMOS
- Thickness, radiation hardness
  (note ep: below 10^{15}cm^{2}n eq.
  no pile-up in ep, .. → maybe low)
- Detectors in Vacuum? Elliptic ep pipe ☹
- Bent wafers?
- Same vertex or 1.87 apart? Cost
- ...

P. Kostka