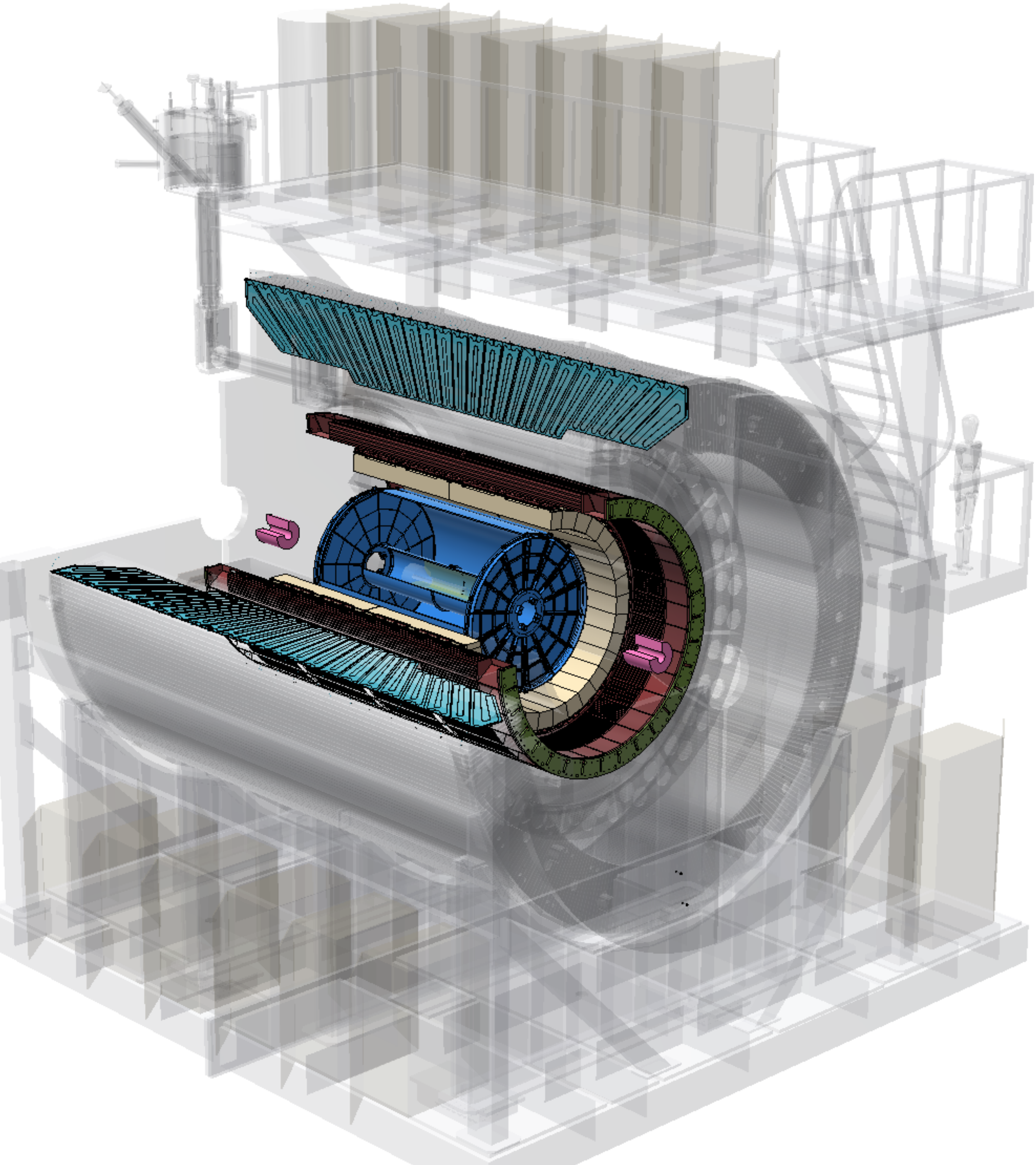
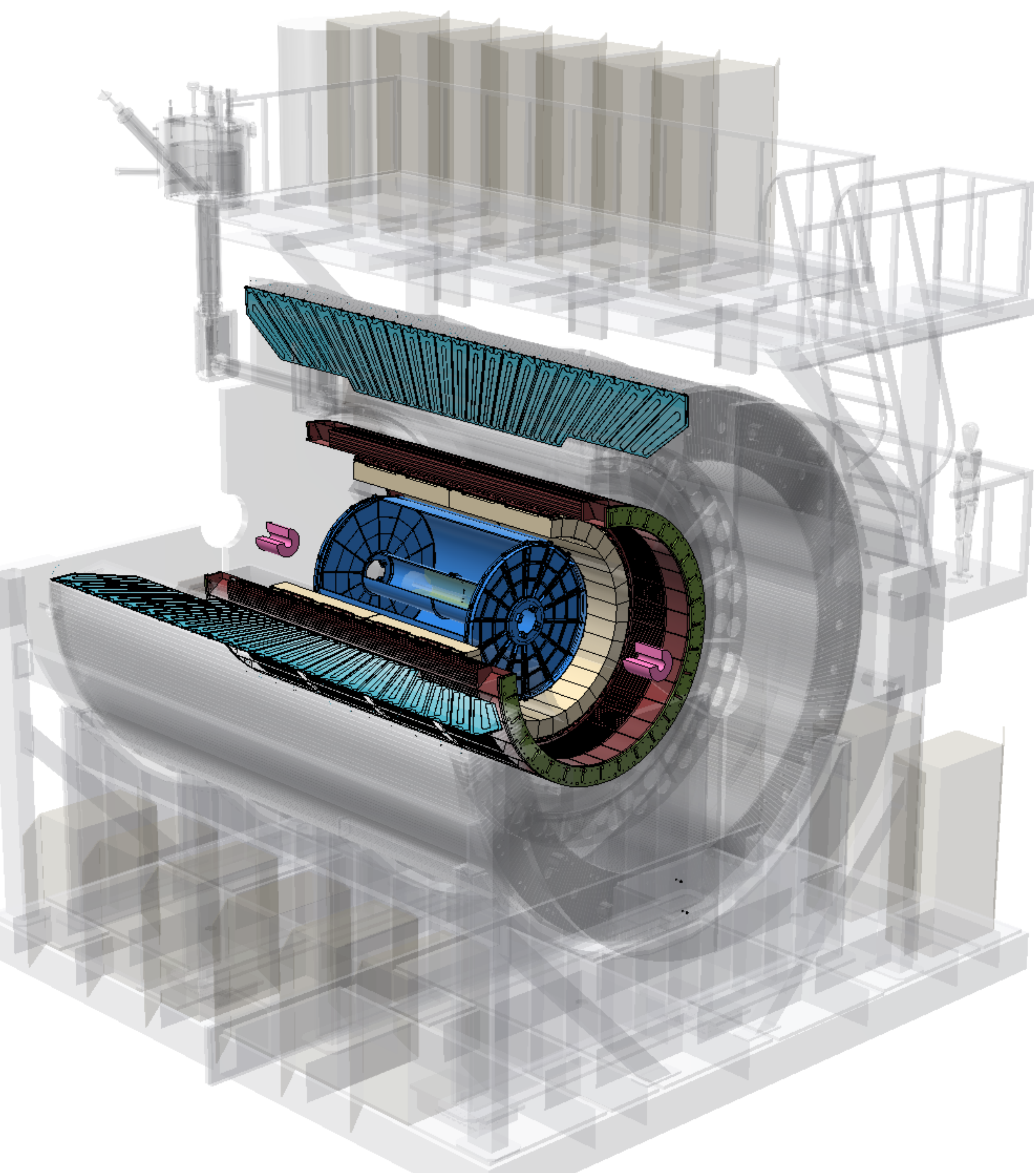


sPHENIX at RHIC

Dave Morrison (BNL)
Gunther Roland (MIT)
} co-spokespeople

JETSCAPE workshop
3/20/2020



sPHENIX at RHIC

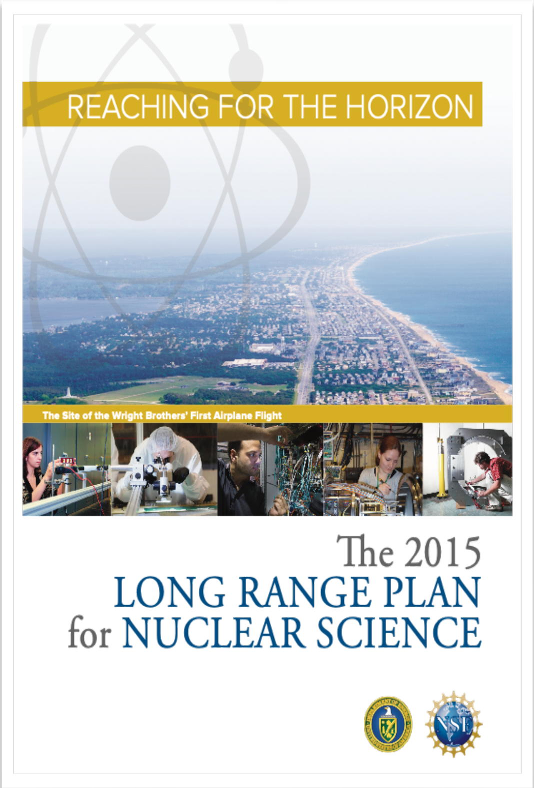
Dave Morrison (BNL)
Gunther Roland (MIT)
} co-spokespeople

1. Science Mission
2. Detector, schedule, construction status
3. Science Mission and JETSCAPE

JETSCAPE workshop
3/20/2020

sPHENIX science mission

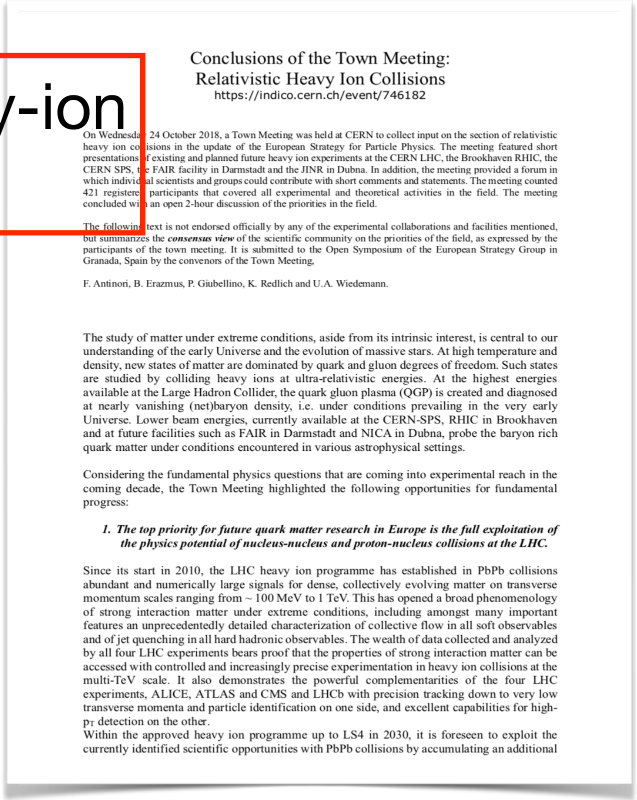
2015 US NP LRP



"Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of [RHIC and the LHC] is essential to this goal, as is a state-of-the-art jet detector at RHIC, called **sPHENIX**."

WG5 for 2019 ECFA process

Reaffirmed in ECFA heavy-ion (WG5) discussion



Conclusions of the Town Meeting:
Relativistic Heavy Ion Collisions
https://indico.cern.ch/event/746182

On Wednesday 24 October 2018, a Town Meeting was held at CERN to collect input on the section of relativistic heavy ion collisions in the update of the European Strategy for Particle Physics. The meeting featured short presentations of existing and planned future heavy ion experiments at the CERN LHC, the Brookhaven RHIC, the CERN SPS, the FAIR facility in Darmstadt and the JINR in Dubna. In addition, the meeting provided a forum in which individual scientists and groups could contribute with short comments and statements. The meeting counted 421 registered participants that covered all experimental and theoretical activities in the field. The meeting concluded with an open 2-hour discussion of the priorities in the field.

The following text is not endorsed officially by any of the experimental collaborations and facilities mentioned, but summarizes the ***consensus view*** of the scientific community on the priorities of the field, as expressed by the participants of the town meeting. It is submitted to the Open Symposium of the European Strategy Group in Granada, Spain by the convenors of the Town Meeting,

F. Antinori, B. Erazmus, P. Giubellino, K. Redlich and U.A. Wiedemann.

The study of matter under extreme conditions, aside from its intrinsic interest, is central to our understanding of the early Universe and the evolution of massive stars. At high temperature and density, new states of matter are dominated by quark and gluon degrees of freedom. Such states are studied by colliding heavy ions at ultra-relativistic energies. At the highest energies available at the Large Hadron Collider, the quark gluon plasma (QGP) is created and diagnosed at nearly vanishing (net)baryon density, i.e. under conditions prevailing in the very early Universe. Lower beam energies, currently available at the CERN-SPS, RHIC in Brookhaven and at future facilities such as FAIR in Darmstadt and NICA in Dubna, probe the baryon rich quark matter under conditions encountered in various astrophysical settings.

Considering the fundamental physics questions that are coming into experimental reach in the coming decade, the Town Meeting highlighted the following opportunities for fundamental progress:

1. ***The top priority for future quark matter research in Europe is the full exploitation of the physics potential of nucleus-nucleus and proton-nucleus collisions at the LHC.***

Since its start in 2010, the LHC heavy ion programme has established in PbPb collisions abundant and numerically large signals for dense, collectively evolving matter on transverse momentum scales ranging from ~ 100 MeV to 1 TeV. This has opened a broad phenomenology of strong interaction matter under extreme conditions, including amongst many important features an unprecedentedly detailed characterization of collective flow in all soft observables and of jet quenching in all hard hadronic observables. The wealth of data collected and analyzed by all four LHC experiments bears proof that the properties of strong interaction matter can be accessed with controlled and increasingly precise experimentation in heavy ion collisions at the multi-TeV scale. It also demonstrates the powerful complementarities of the four LHC experiments, ALICE, ATLAS and CMS and LHCb with precision tracking down to very low transverse momenta and particle identification on one side, and excellent capabilities for high-p_T detection on the other.
Within the approved heavy ion programme up to LS4 in 2030, it is foreseen to exploit the currently identified scientific opportunities with PbPb collisions by accumulating an additional

"The Town Meeting observes that the recently approved sPHENIX proposal targets these opportunities by bringing greatly extended capabilities to RHIC …"

Physics goals → Detector performance

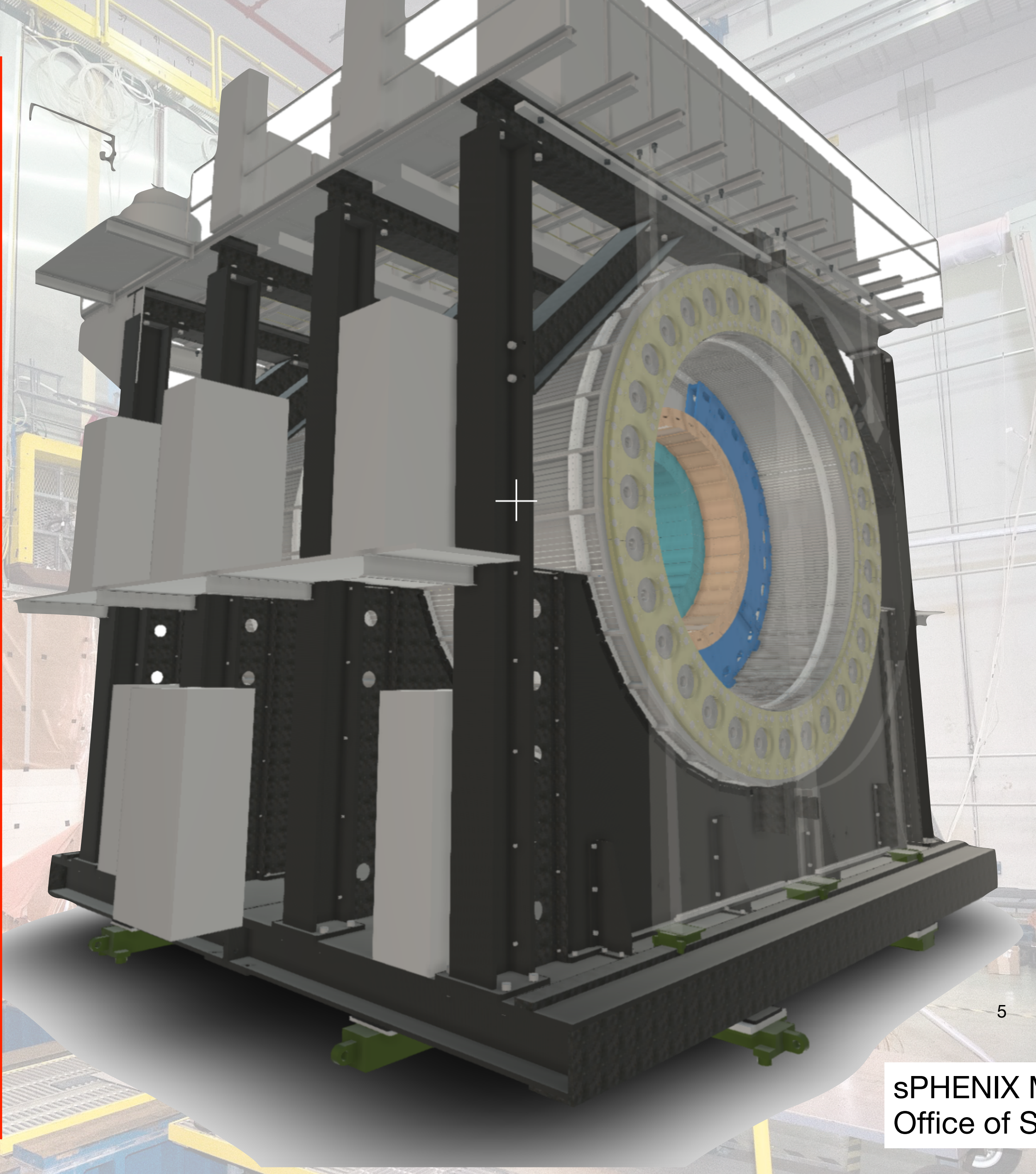
sPHENIX

Physics Goal	Analysis Requirement	Performance Goal
Maximize statistics for rare probes	Accept/sample full delivered luminosity	**Data taking rate of 15kHz for Au+Au**
Precision Upsilon spectroscopy	Resolve Y(1s), Y(2s), (Y3s) states	**Y(1s) mass resolution ≤ 125MeV in central Au+Au**
High jet efficiency and resolution	Full hadron and EM calorimetry Jet resolution dominated by irreducible background fluctuations	**$\sigma/\mu \leq 150\%/\sqrt{p_{Tjet}}$ in central Au+Au for R=0.2 jets**
Full characterization of jet final state	High efficiency tracking for $0.2 < p_T < 40$GeV	**Tracking efficiency ≥ 90% in central Au+Au** **Momentum resolution ≤ 10% for p_T = 40 GeV**
Control over initial parton p_T	Photon tagging with energy resolution dominated by irreducible higher order	**Single photon resolution ≤ 8% for p_T = 15 GeV in central Au+Au**
Control over initial parton p_T	Topological identification of heavy flavor hadron decays	**High resolution secondary vertex identification (DCA < 30μm @ 1GeV)**

Success of LHC multi-purpose experiments in HI physics demonstrates importance of large acceptance, high resolution tracking, high collision rates and full EM+Hadronic calorimetry

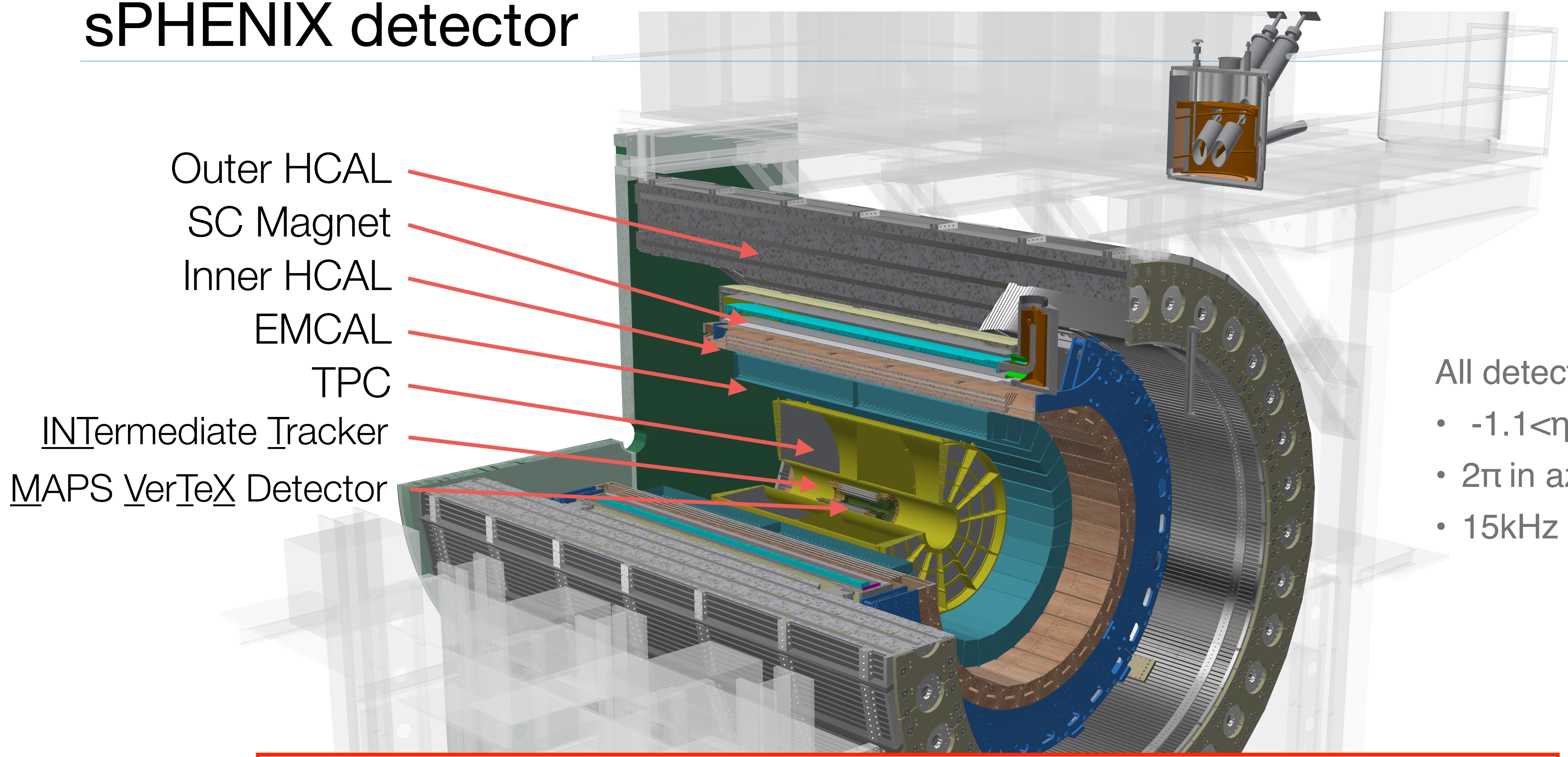
sPHENIX is a major upgrade to the PHENIX detector. It is a large-acceptance, high-rate detector for Heavy Ion physics that repurposes **>$20M** in existing PHENIX equipment, infrastructure and support facilities.

The detector is optimized for a **focussed physics program** employing using jet and heavy flavor observables



sPHENIX MIE supported by US DOE Office of Science - Office of NP

sPHENIX detector



All detectors:

- -1.1<η<1.1
- 2π in azimuth
- 15kHz readout rate

Qualitative improvement on 20 years of studies at RHIC through higher statistics (x10+), full calorimetry and higher precision tracking

Employ proven and cost-effective detector technology

sPHENIX collaboration

- Steady growth after CD-0
  - 18 new institutions (80 total)
  - about 25% non-US institutions
  - ≈ 300 participants (➔ 400-500 by 2023)
- CERN recognized experiment (April ’19)
- Steady evolution of collaboration organization

2016 2017 2018 2019

Berkeley University of California
Temple University
Berkeley Lab
Purdue University
cea
U. Sao Paolo
NCU, Taiwan
Sejong University
Florida AMU
Peking University
IMP
SINAP
UNC Greensboro

List of Recognized Experiments

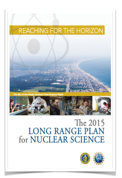
RE status at CERN

Ref.	Experiment	since	until
RE 33	LIGO	2016	31-MAR-2022
RE 34	JUNO	2017	31-MAR-2020
RE 35	SNO+	2017	31-MAR-2020
RE 36	Mu3e	2018	31-MAR-2021
RE 37	DarkSide 20k	2018	31-MAR-2021
RE 38	DAMIC-M	2019	31-MAR-2022
RE 39	sPHENIX	2019	31-MAR-2022

sPHENIX timeline

sPHENIX

2015 2016 2017 2018 2019 2020 2021 2022 2023



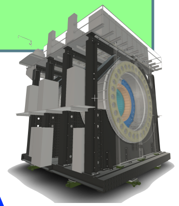
sPHENIX science collaboration

DOE CD-0
"Mission need" approval

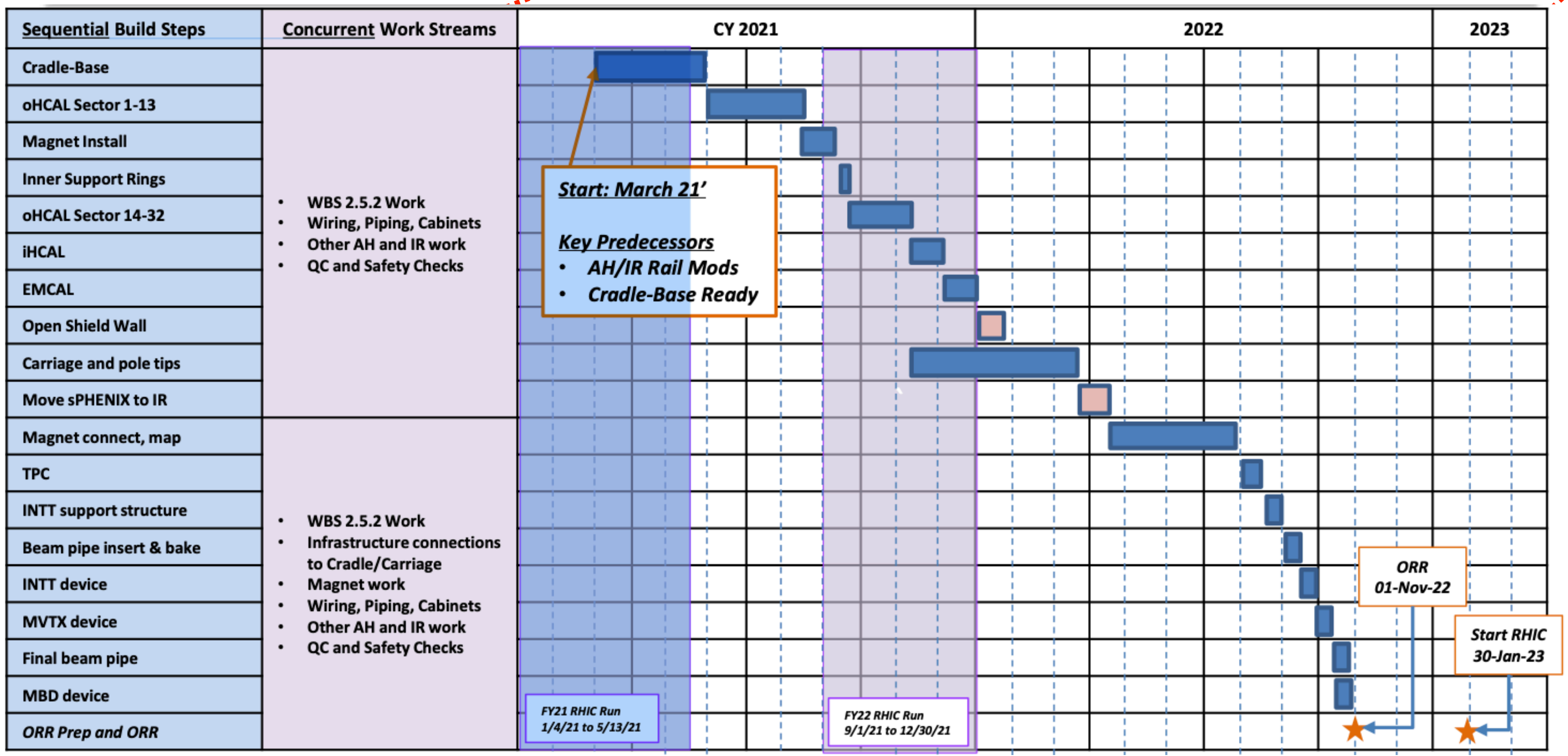
DOE CD-1/3A
Cost, schedule, advance purchase approval

BNL PD-2/3
Final project design approval, authorization to execute

Installation & commissioning



Start physics data taking



https://indico.bnl.gov/event/4788/attachments/19066/24594/sph-trg-000_06142018.pdf

sPHENIX multi-year run plan

https://indico.bnl.gov/event/4788/attachments/19066/24594/sph-trg-000_06142018.pdf

Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}

- Main Au+Au running mode: 15kHz min bias for $|z_{vtx}| < 10$cm
- Year-1 (commissioning) + Year-2,3 (high statistics production): **145 billion** Au+Au collisions
  - cf. more than 20x STAR 2016 data set of 6.5 billion events

- Collaboration sees strong science case for additional running, if opportunity arises
- Improve uncertainties and respond to discoveries in first years

Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

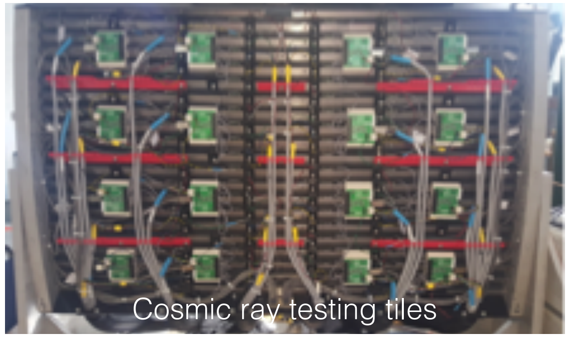
sPHENIX magnet

- Former BaBar magnet
- 1.4T superconducting solenoid
- tested at full field
- will be integrated in RHIC cryo infrastructure

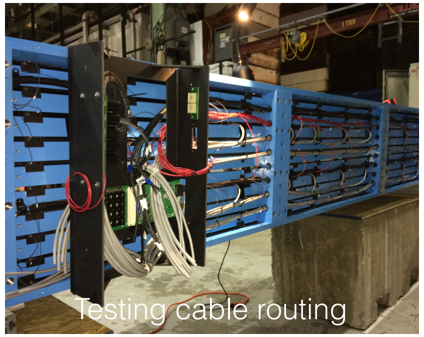
HCAL hadronic calorimeter

- Provides energy resolution for hadrons and jets
- Scintillating tiles interleaved in steel magnetic flux return
- Analog SiPM signals from 5 tiles combined into one tower
- 48 towers ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) per sector
- 32 azimuthal sectors 6.3m x 0.7m, 13.5 tons each

Testing support assembly

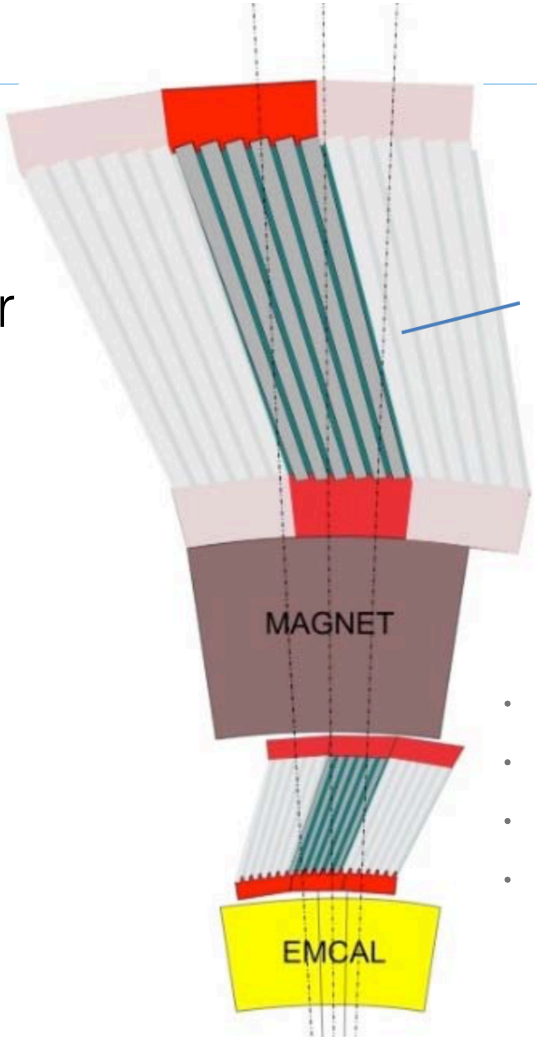


Cosmic ray testing tiles



Testing cable routing

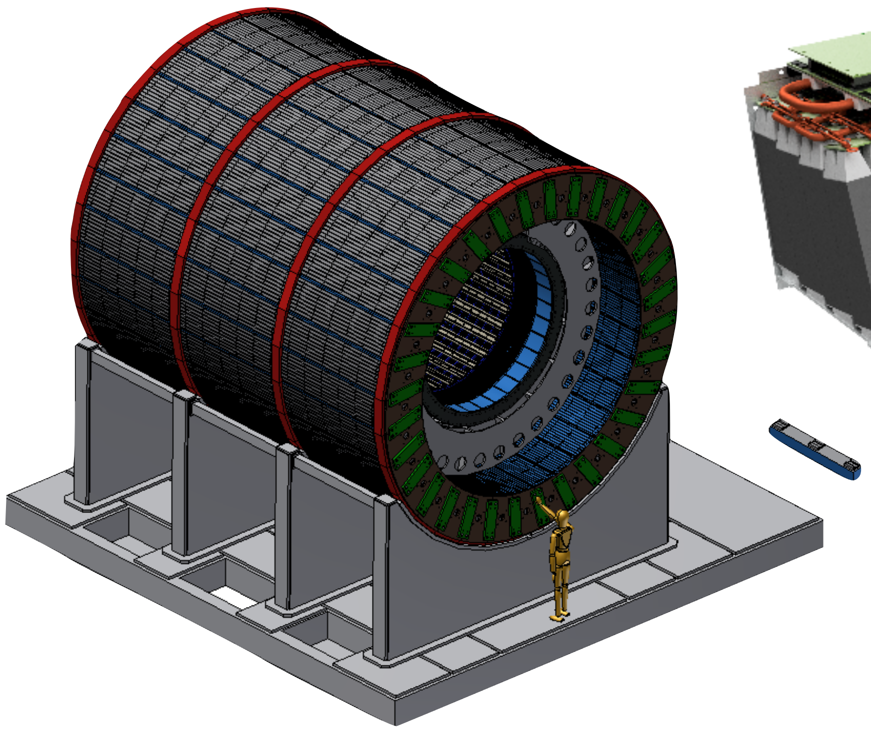
all 32 sectors at

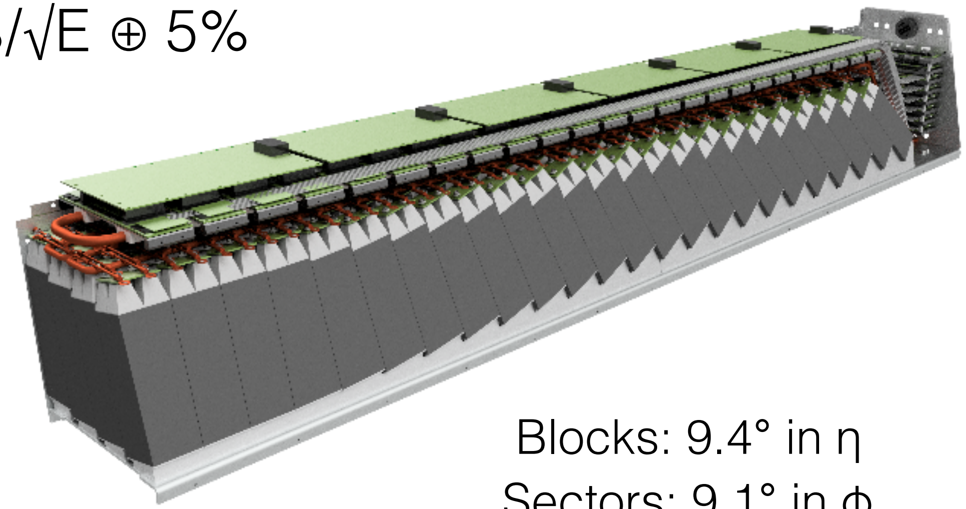


- Outer HCAL ~$3.5\lambda_I$
- Magnet ~$1.4X_0$
- Frame ~$0.25\lambda_I$
- EMCAL ~$18X_0 \approx 0.7\lambda_I$

EMCAL electromagnetic calorimeter

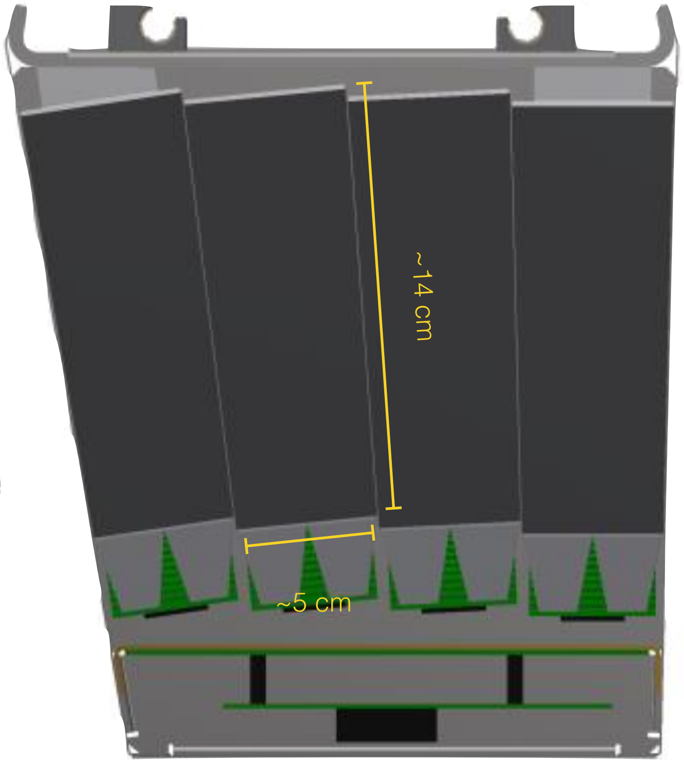
- Provides energy resolution for EM particles and jets
- W/SciFi SPACAL design for compactness
- Segmentation: $\Delta\eta \times \Delta\phi \approx 0.025 \times 0.025$
- Channels: 96 x 256 = 24576 2-D projective towers
- Energy resolution: $< 16\%/\sqrt{E} \oplus 5\%$



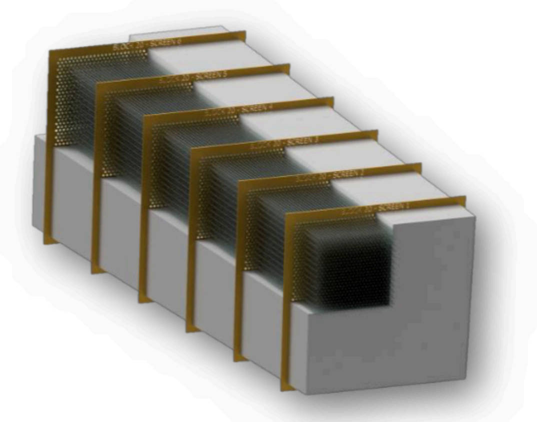


Blocks: 9.4° in η

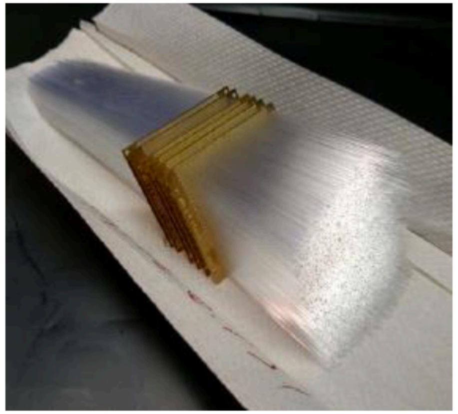
Sectors: 9.1° in ϕ



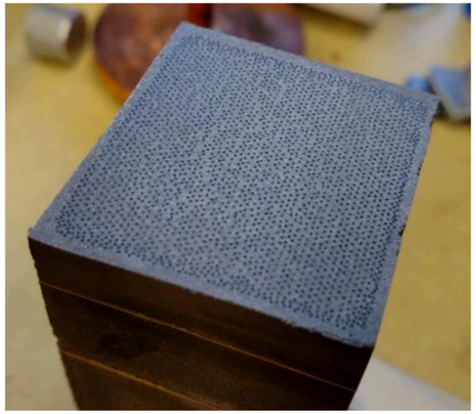
EMCAL in real life



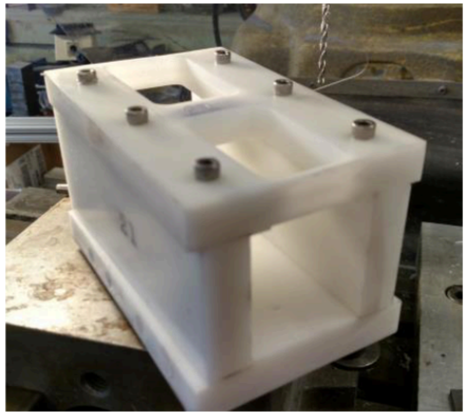
2D Projective Block with Screens



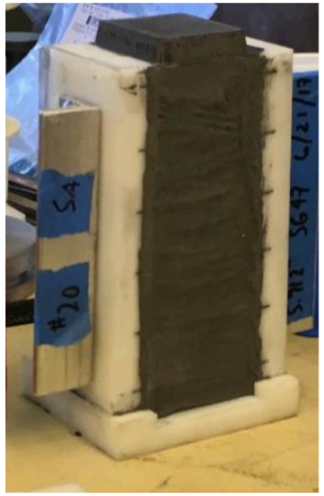
Fiber Assembly



Fibers are tapered inward at readout end to improve light collection



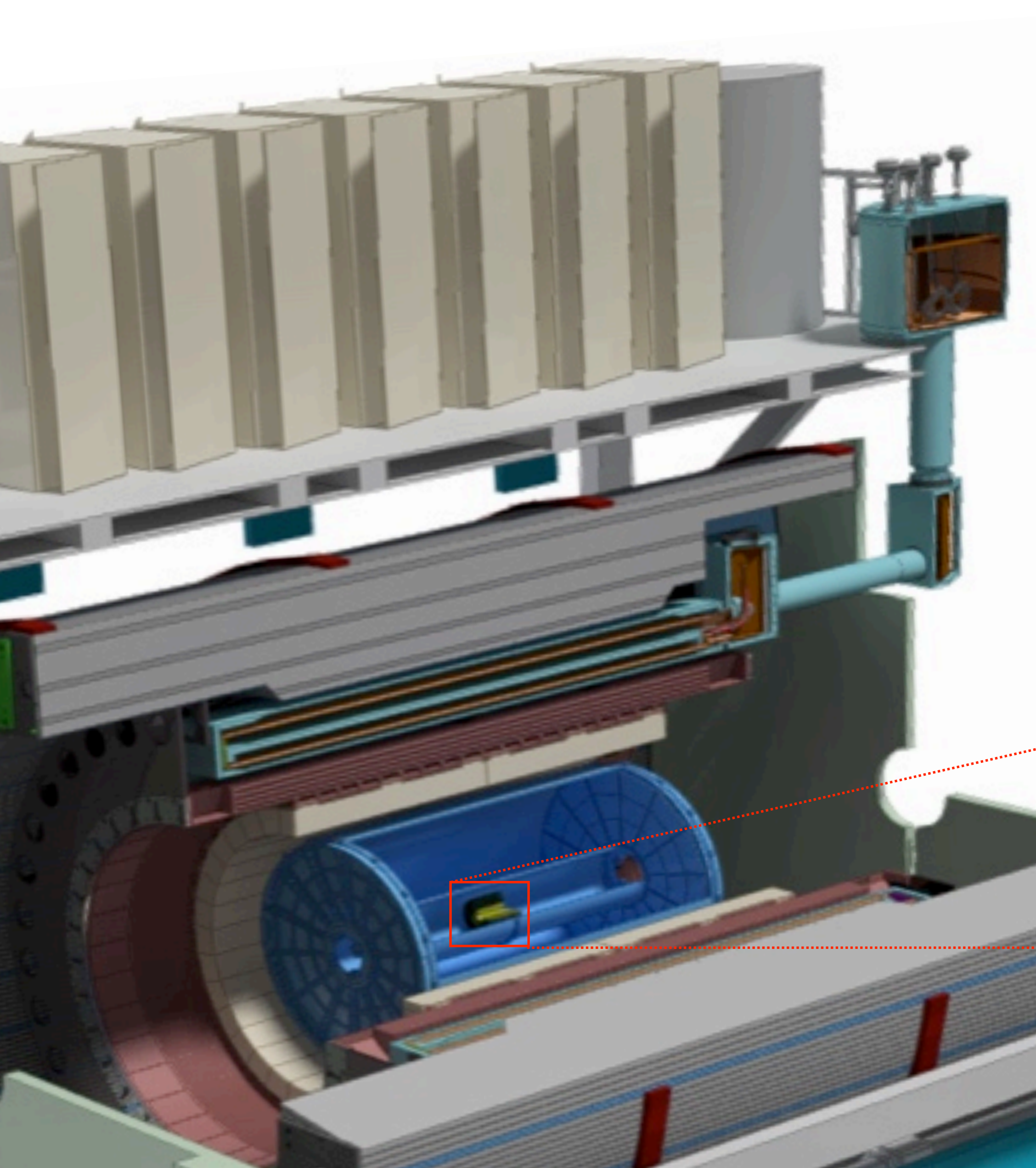
Mold for casting blocks

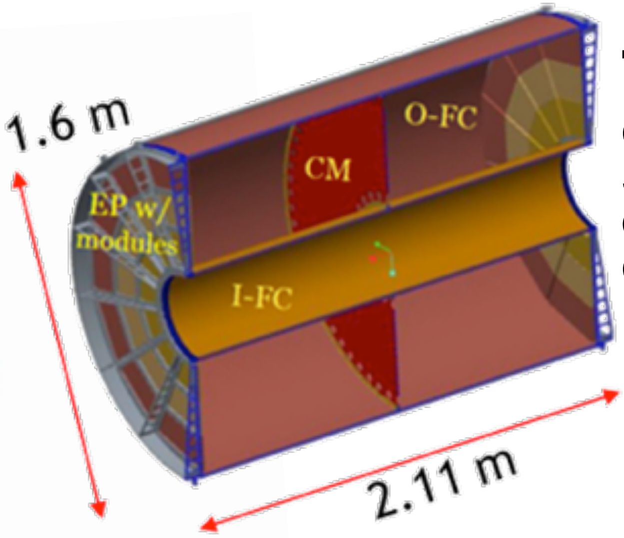


Finished 2D projective block

Full size "sector 0" prototype completed August 2019

sPHENIX tracking subdetectors



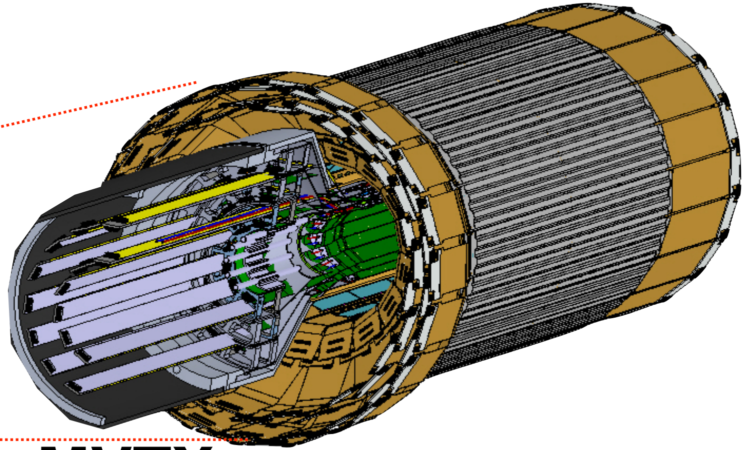


TPC

Continuous readout TPC
SAMPA based front-end card
Quad-GEM readout chambers
Close relation to ALICE TPC

INTT

Silicon strips, 2 layers
re-use of PHENIX FVTX electronics

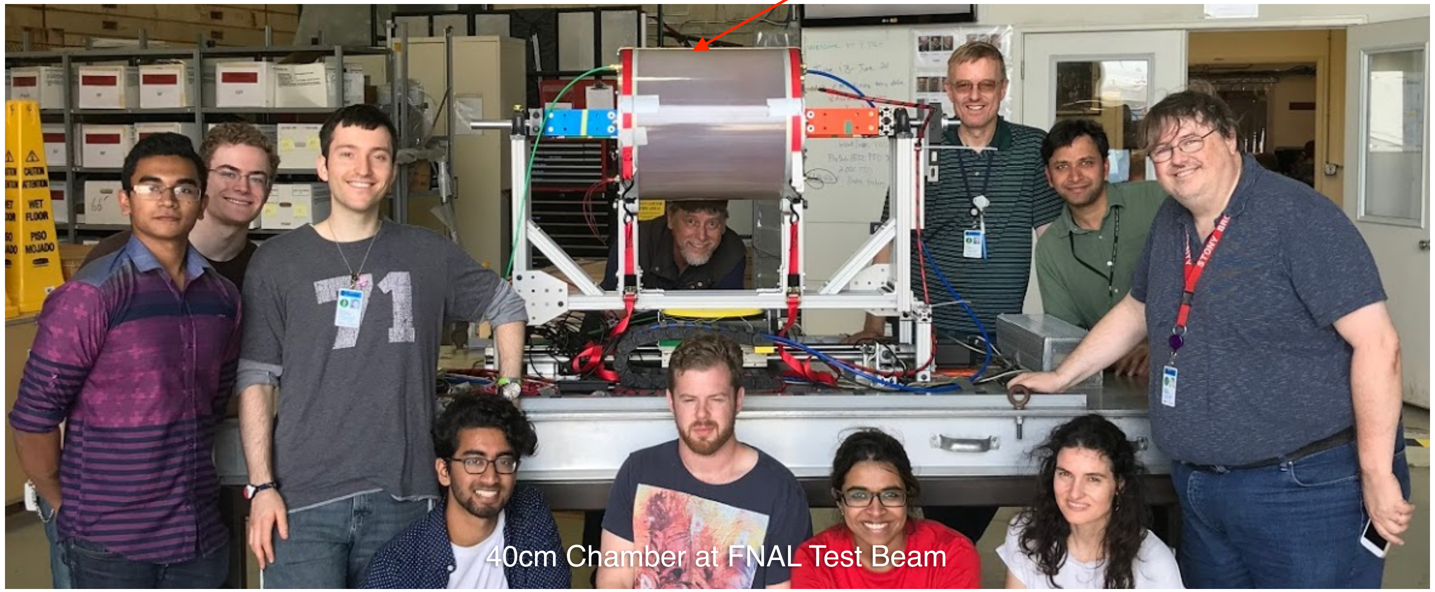


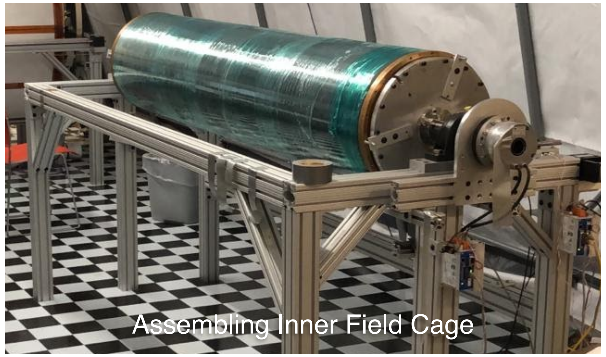
MVTX

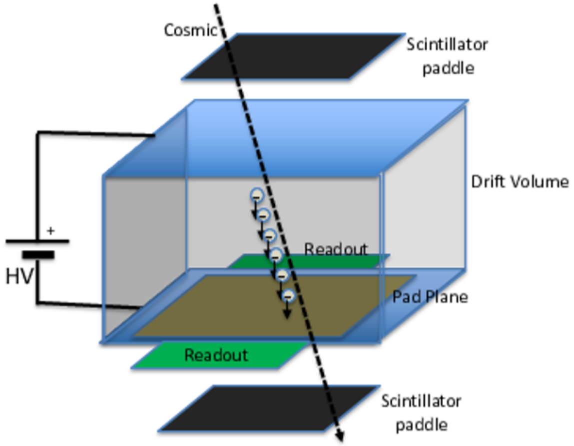
Monolithic Active Pixel Sensors (MAPS),
3 layers, based on ALICE ITS IB detector

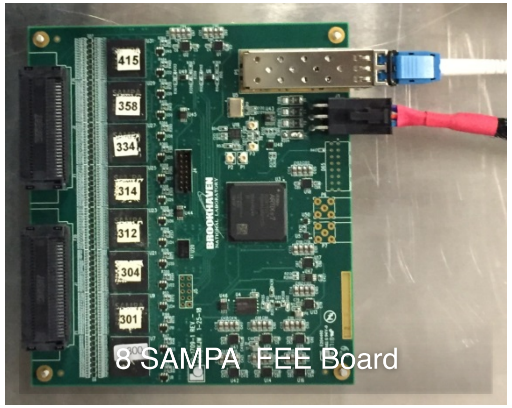
TPC in real life

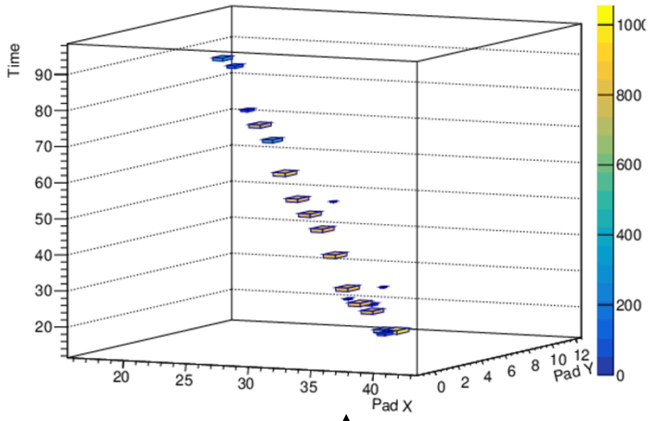
test beam prototype chamber









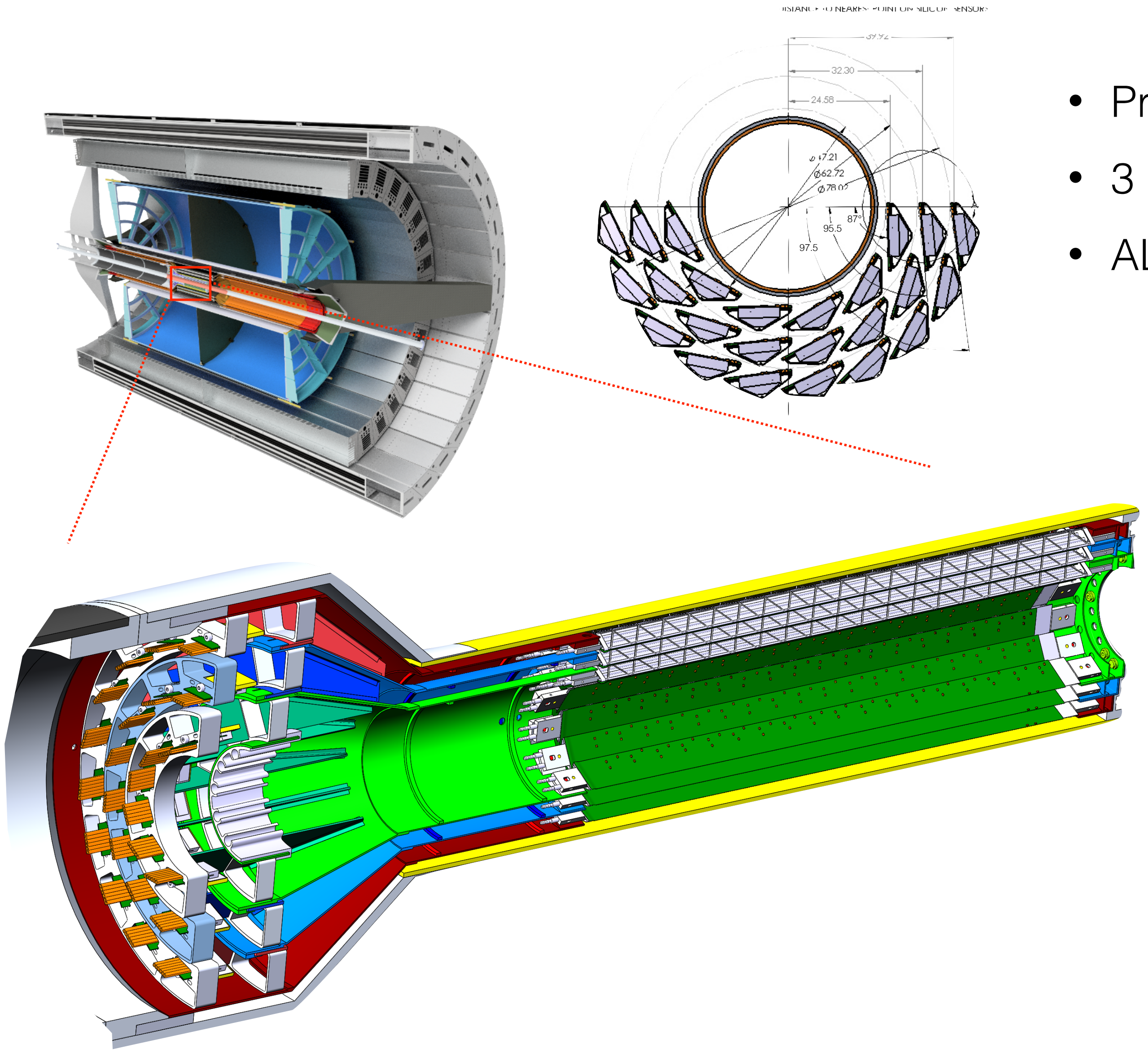


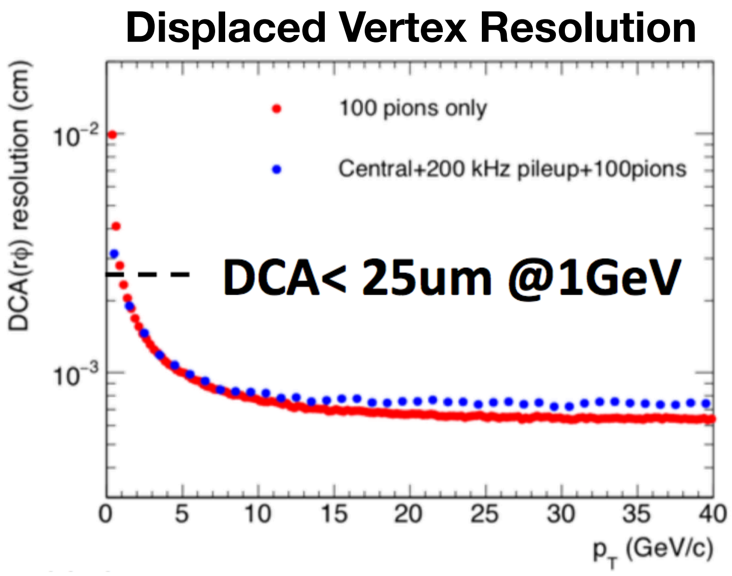
Full chain readout

Microvertex detector (MVTX)

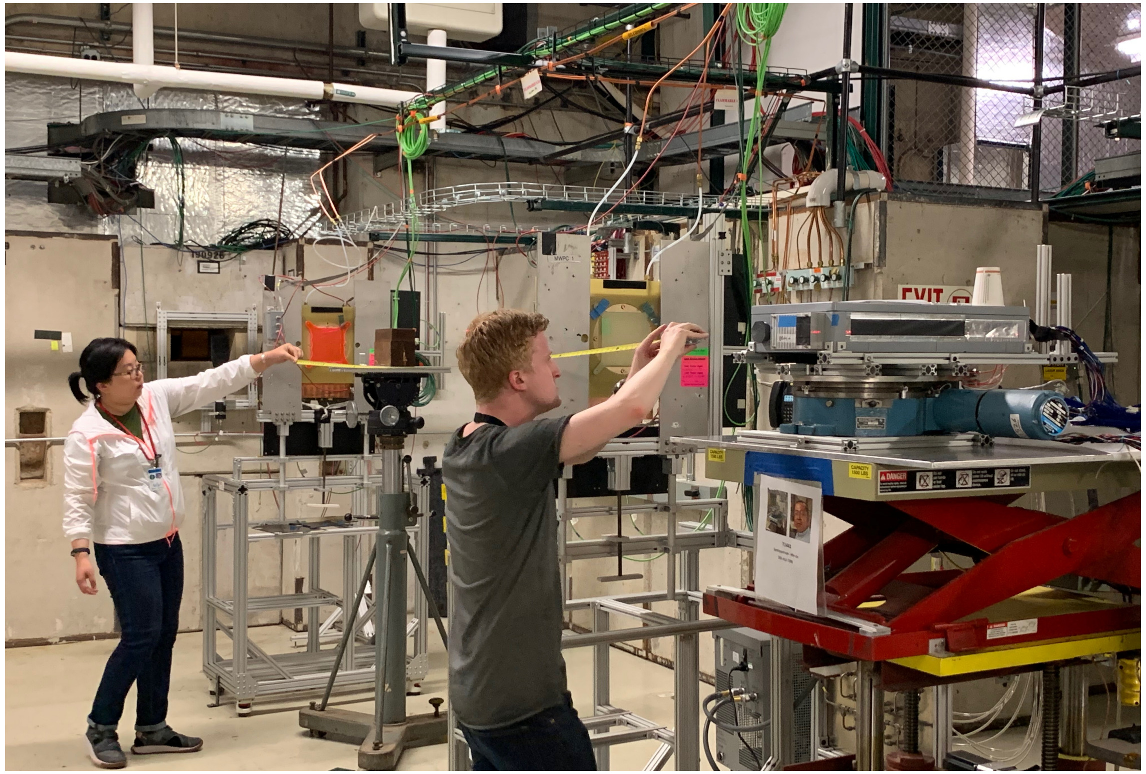
sPHENIX

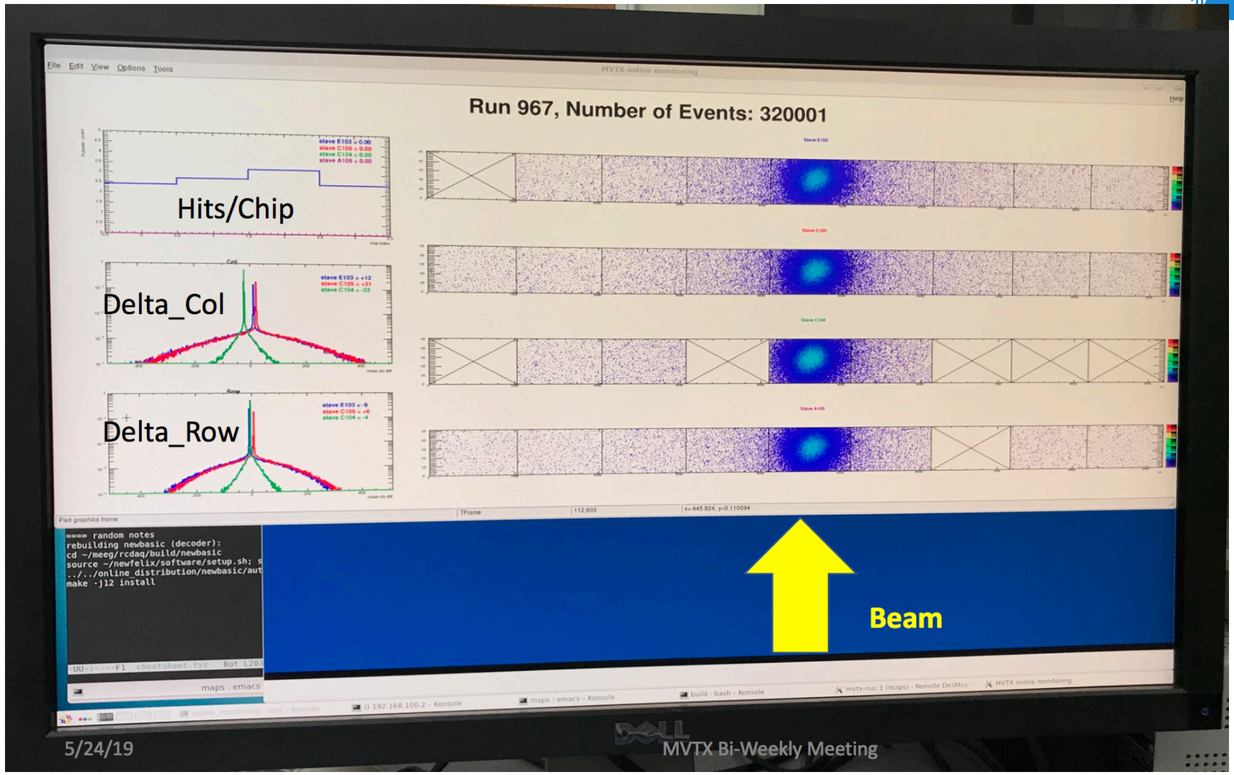
- Provides spatial resolution for displaced vertices
- 3 layers of hermetic Monolithic Active Pixel sensors
- ALICE ITS design modified to fit sPHENIX envelope





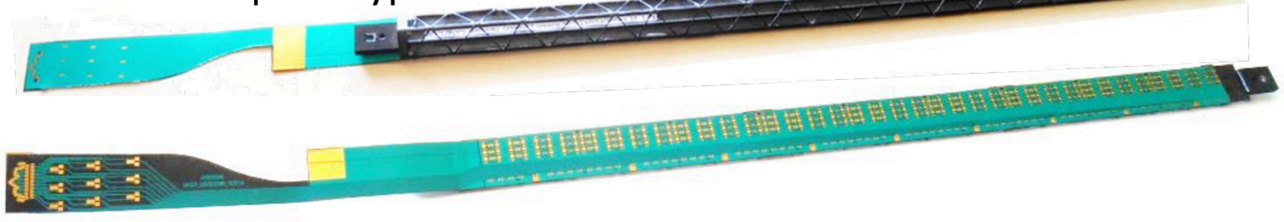
MVTX test beam



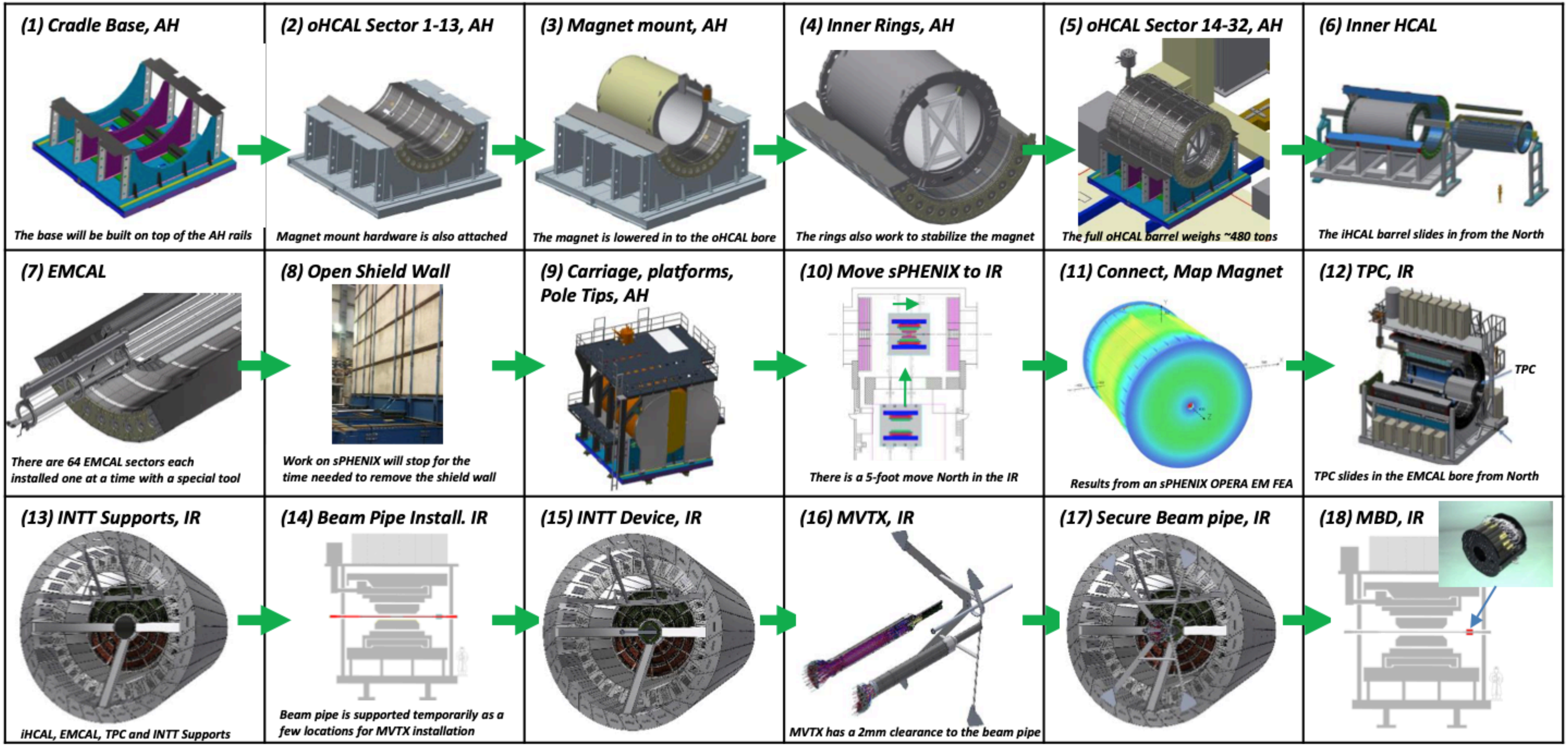


- 2019 test of telescope with full readout and cables just completed (May 25)
- Readout tested up to 300kHz with p beam and p-on-Pb sprays (sPHENIX requirement 15kHz)
- Expected hit resolution verified
- Stave production underway in CERN ALICE ITS facility

Stave prototype



sPHENIX installation (3/21 to 11/22)

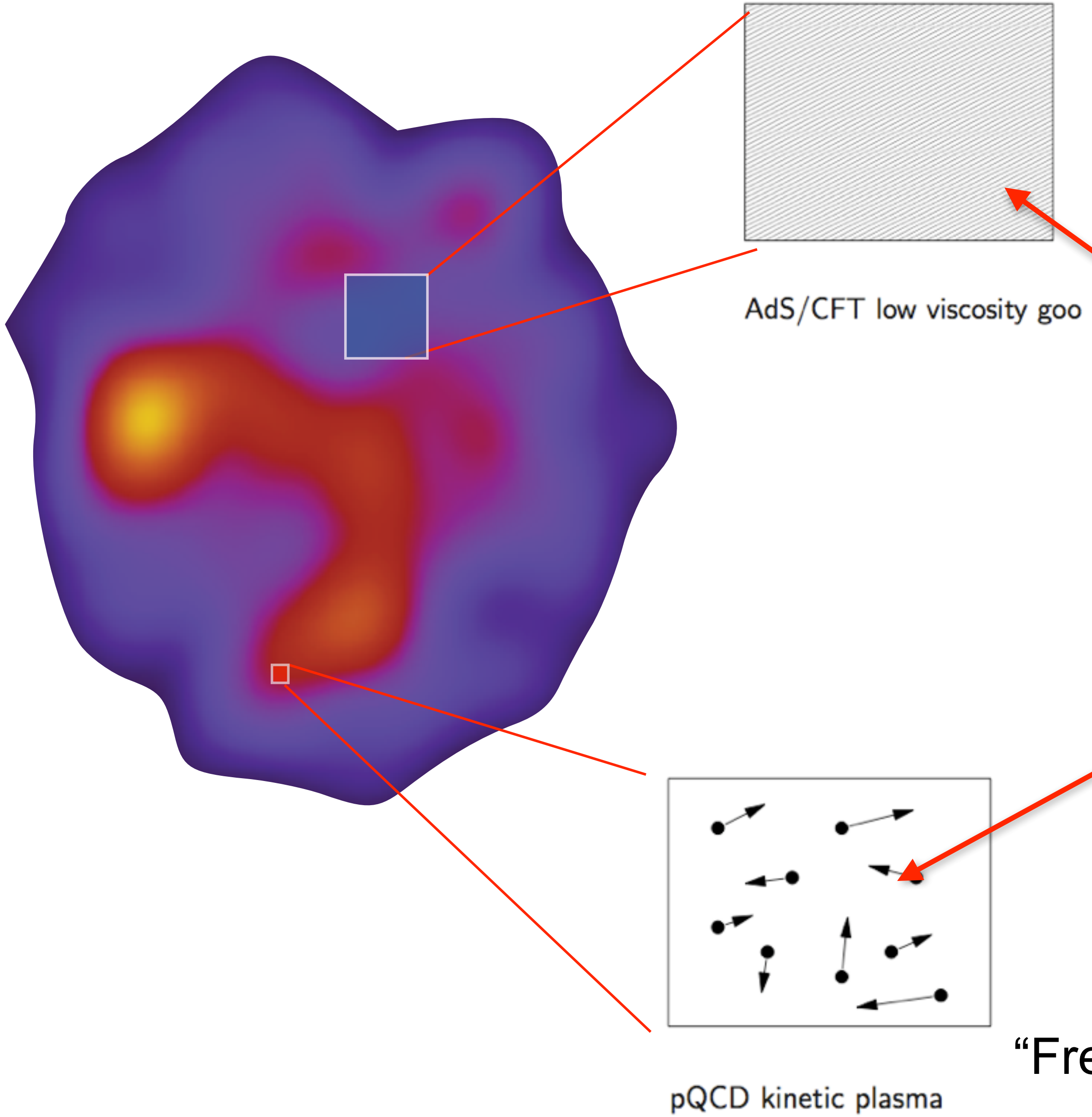


Department of Energy
FY 2021 Congressional
Budget Request

Page 51:

- Continuing support for R&D and design activities for the Electron Ion Collider at BNL.
- Continuing design and long-lead activities for the SIPRC to mitigate U.S. dependence on foreign sources of enriched stable isotopes for research and applications.
- Support for fabrication of new NP scientific equipment: the Gamma-Ray Energy Tracking Array Major Item of Equipment (MIE), which will enable the provisioning of advanced, high resolution gamma ray detection capabilities for FRIB and the sPHENIX MIE, which will have enhanced capabilities that will further RHIC's scientific mission by studying high rate jet production; the High Resolution Spectrometer (HRS) to study fast neutron beams at FRIB, the Ton-scale Neutrinoless Double Beta Decay MIE experiment to determine whether the neutrino is its own antiparticle; and the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER), which will measure the parity-violating asymmetry in electron-electron scattering with the 12 GeV CEBAF machine.

How does the QGP work?



$\Delta x \approx 1\text{fm}$
$\Delta p \lessapprox 200\text{MeV}$

“Perfect Liquid”

How does the nearly-perfect liquid emerge from the underlying, asymptotically weakly coupled gauge theory?

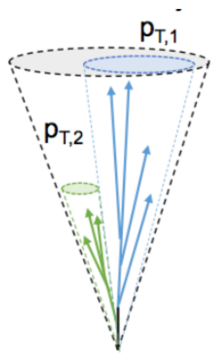
What is the scale-dependent microscopic structure of QGP?

What is its quasi-particle nature at intermediate scales?

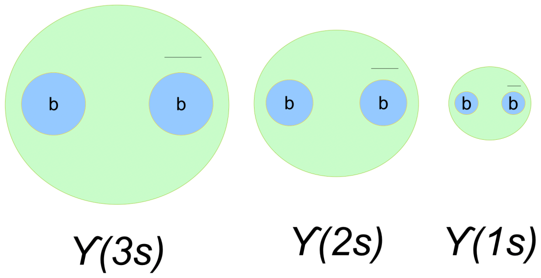
$\Delta x \ll 1\text{fm}$
$\Delta p >> 1\text{GeV}$

“Free quarks and gluons”

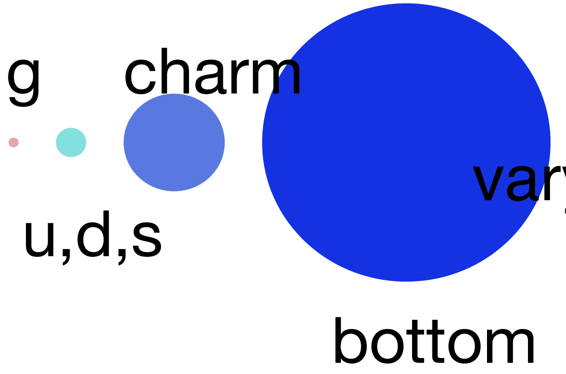
Hard Probes: sPHENIX ⊕ LHC



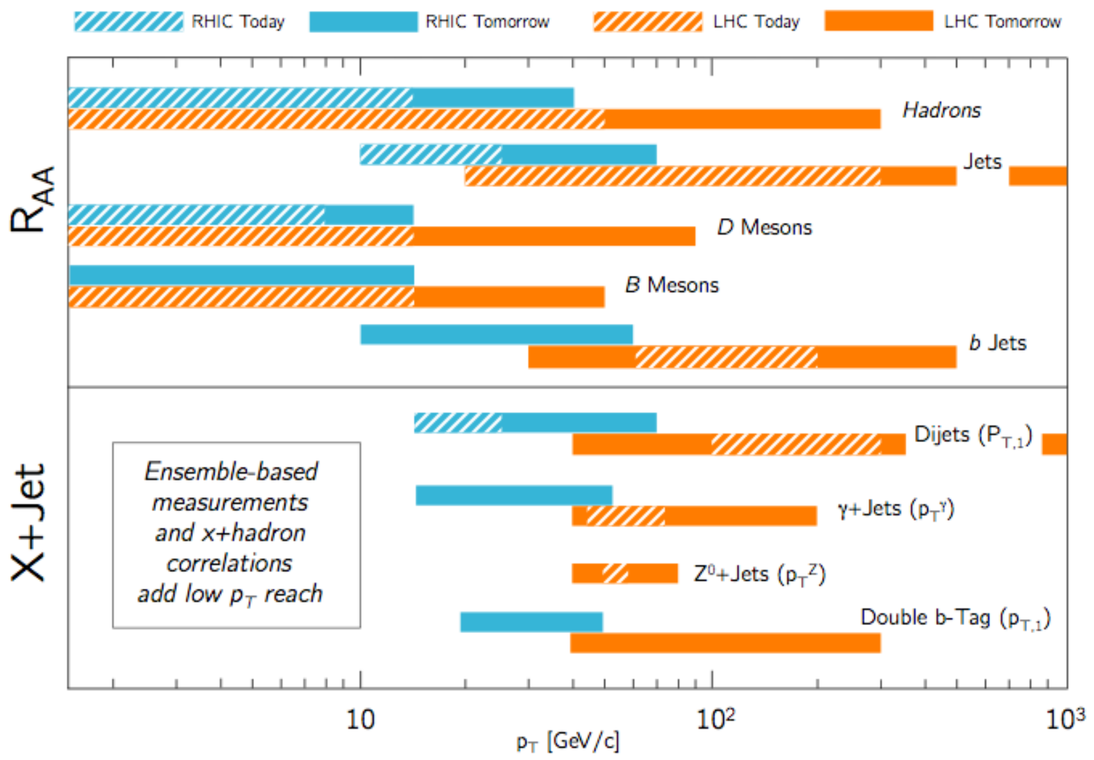
Jet structure
vary momentum/ angular scale of probe



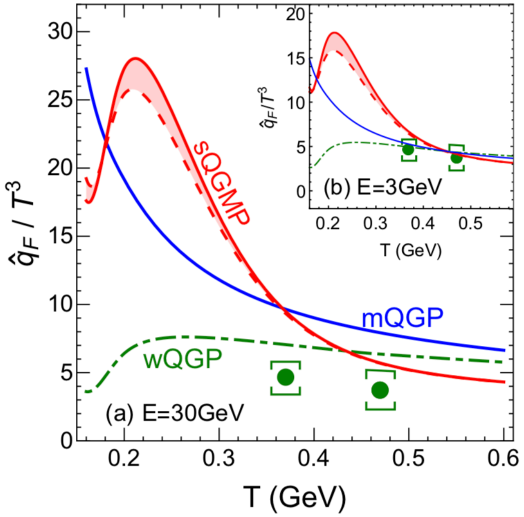
Quarkonium spectroscopy
vary size of probe

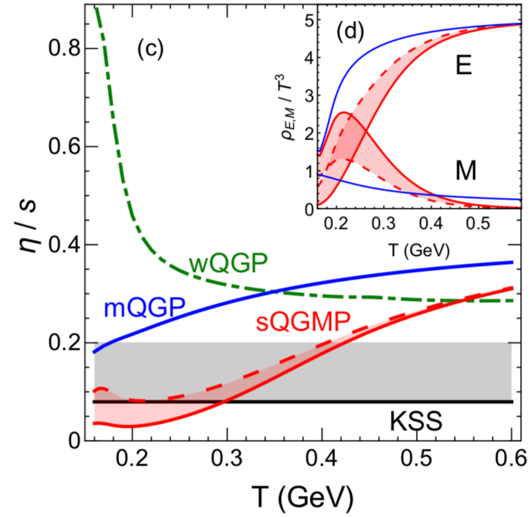


Parton energy loss
vary mass/momentum of probe

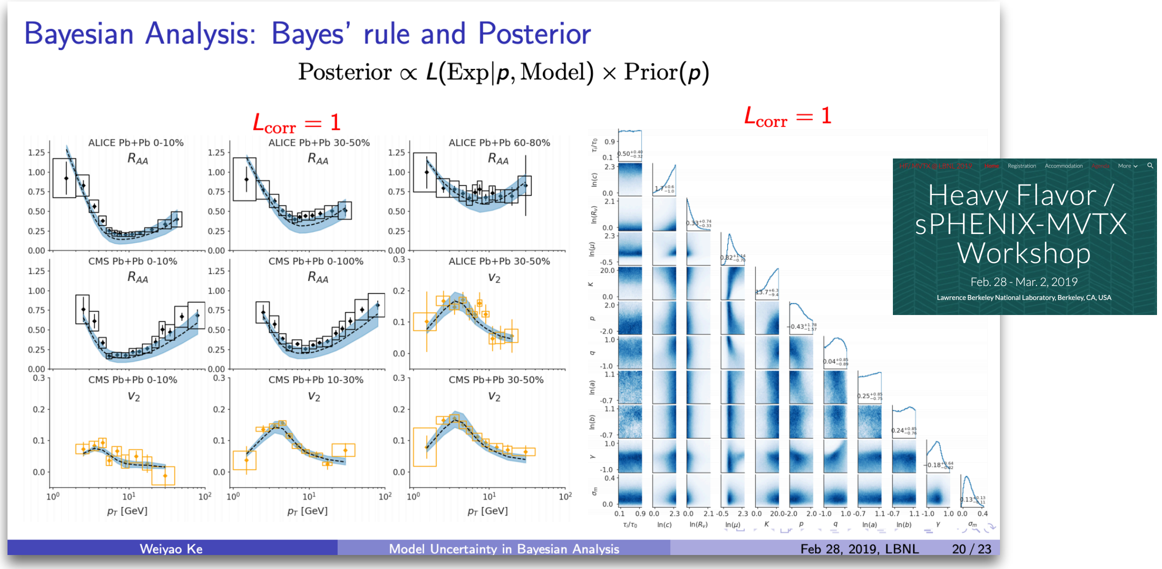


Key approach: Transport coefficients vs T





T-dependence of QGP structure, as reflected e.g. in transport coefficients has been sPHENIX focus since beginning



Bayesian inference key approach for both HF and jet sector (started in soft sector)

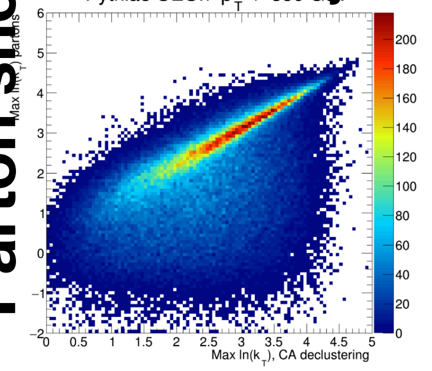
Data from two energy regimes, RHIC & LHC, essential to constrain T dependence

Many points of contact between sPHENIX and theory/LHC communities (e.g., LBNL HF workshop, work with Duke group, JETSCAPE collaboration).

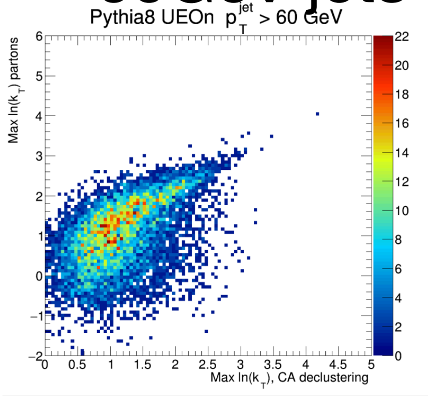
Key approach: Parton shower modification in QGP

Parton shower

350GeV jets



60GeV jets



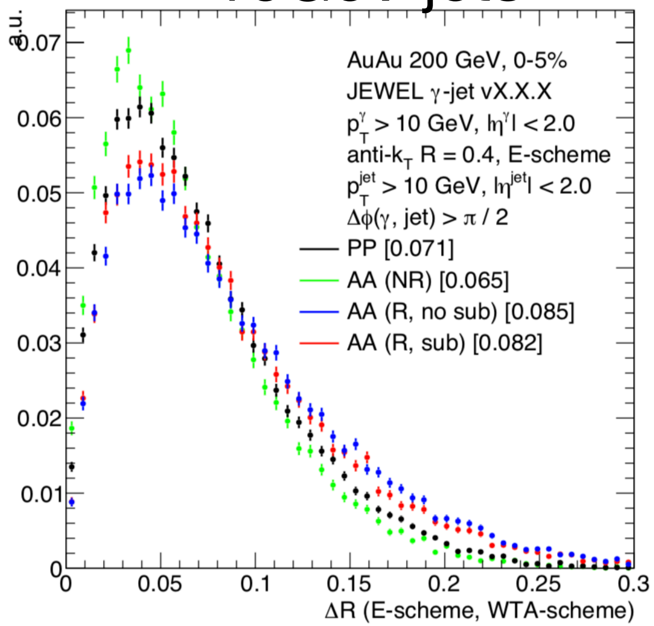
Q: To which extent is parton level structure of jet evolution accessible in final state?

Hadron level C-A declustering

Increasing interest and significant progress regarding jet substructure modifications, employing tools developed for pp discovery physics

Distinct strengths and challenges in different energy regimes

10GeV jets

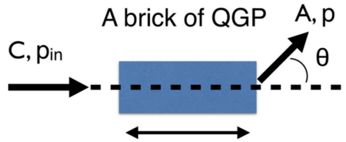


Decorrelation of jet axes in QGP for low p_T jets

“Moliere scattering”

Molière Scattering in Quark-Gluon Plasma: Finding Point-Like Scatterers in a Liquid

Francesco D'Eramo,[a,b] Krishna Rajagopal,[c] Yi Yin[c]



Physics case studies

6 examples to illustrate role of sPHENIX in context of LHC and previous RHIC studies

Same probe at sPHENIX and LHC: photon-jet balance

CERN Yellow Report projections for Runs 3, 4

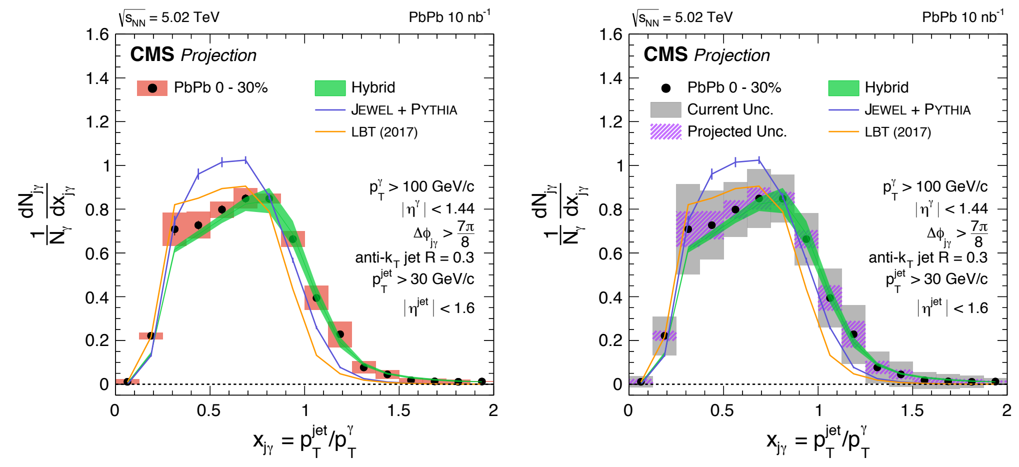
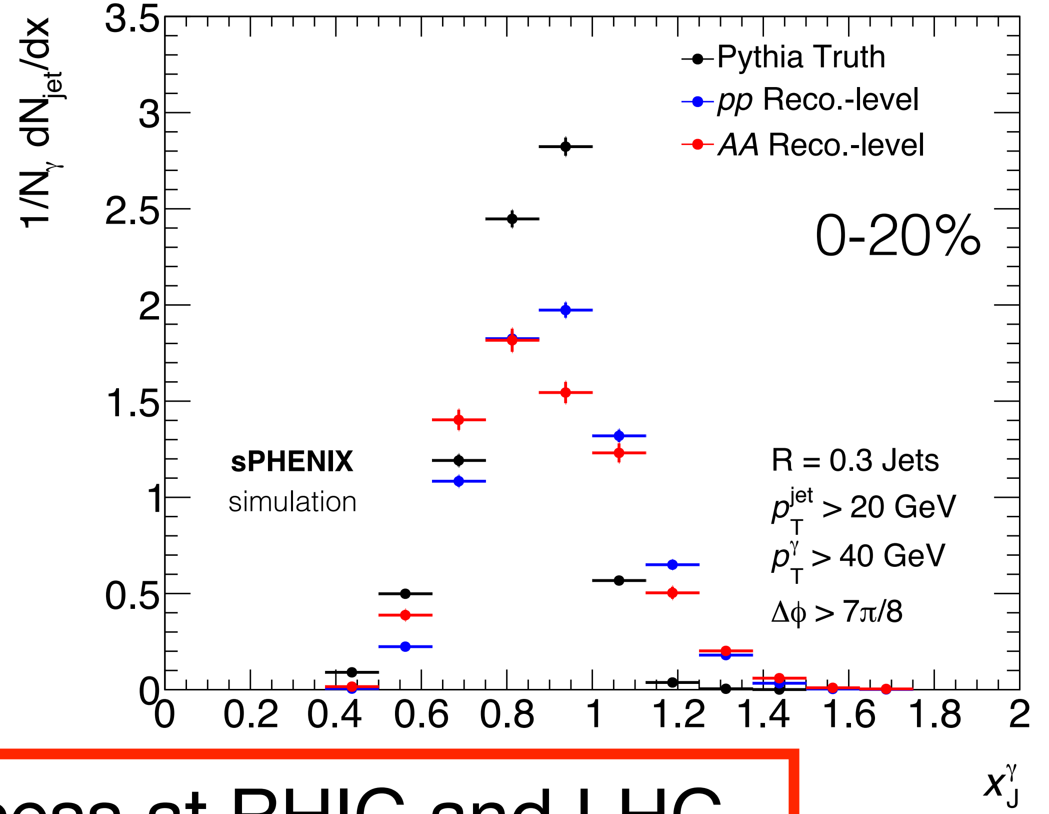
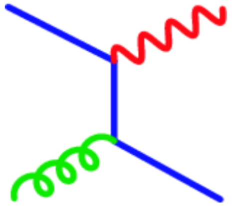


Fig. 29: (Left Panel) Photon-jet momentum balance $x_{j\gamma}$ distribution for isolated-photon+jets of $p_\gamma > 100$ GeV/c and $|\eta_\gamma| < 1.44$, $p_{jet} > 30$ GeV/c and $|\eta_{jet}| < 1.6$ in the HL-LHC data (Right Panel). Comparison between the current performance with 0.4 nb^{-1} of Pb–Pb data collected in 2015 and with HL-LHC data [8].

Photon-tagged jets in sPHENIX

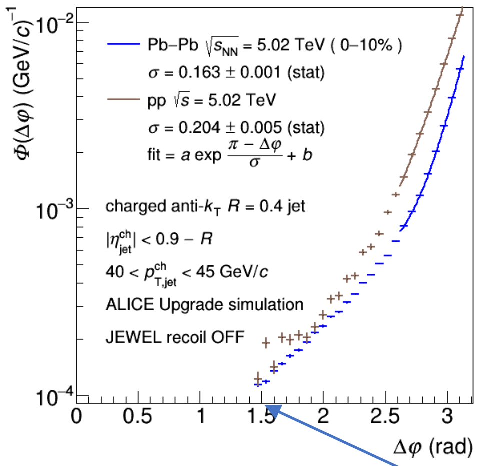




Same hard scattering process at RHIC and LHC

Direct comparison of QGP effects for different QGP temperature evolution

Same probe, different sensitivity: Jet angular correlations

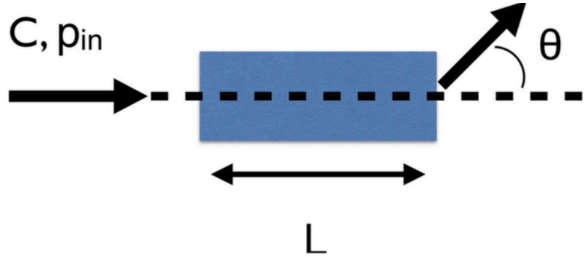


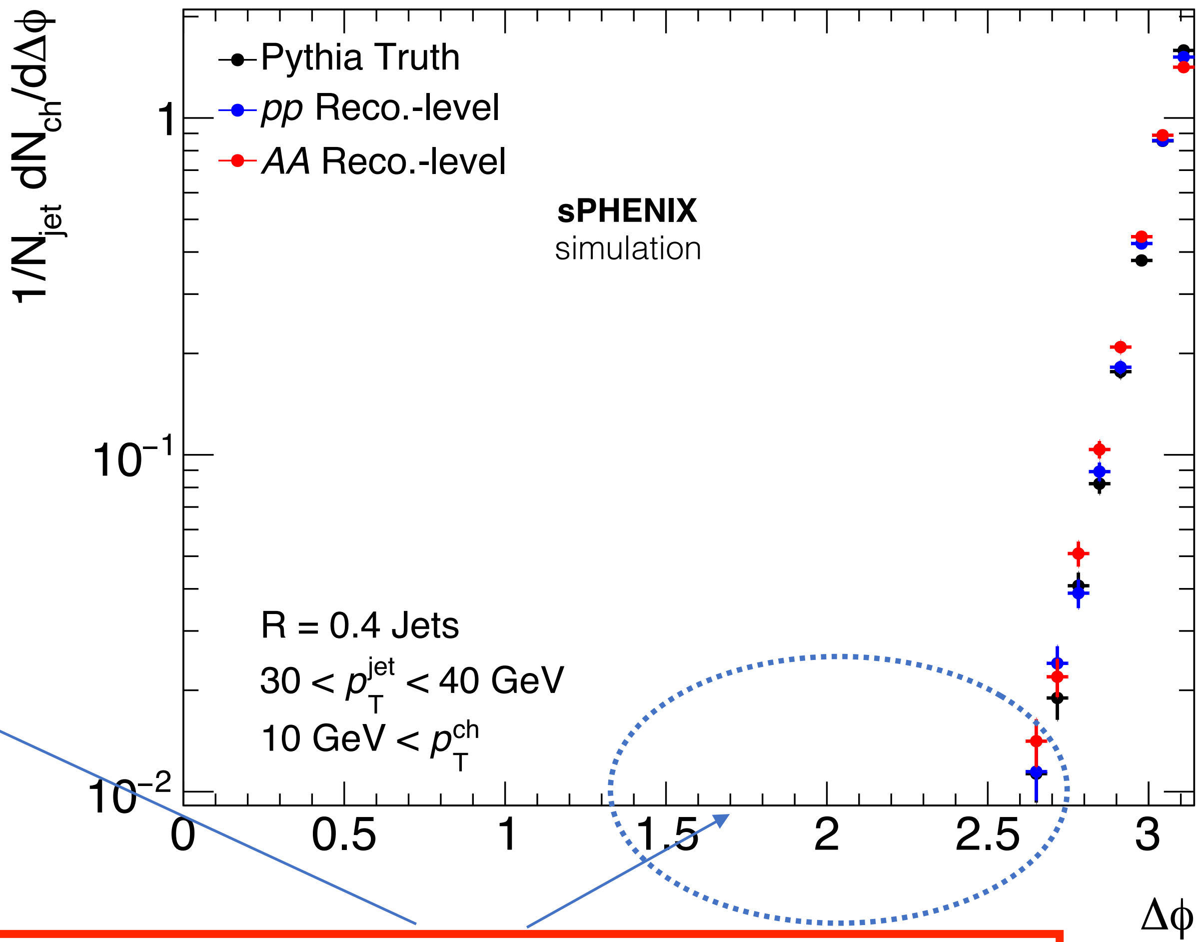
CERN Yellow Report projections for Runs 3, 4

Fig. 31: JEWEL simulation of the angular distribution of charged jet yield in the ALICE acceptance for $40 < p^{ch}_{T,jet} < 45$ GeV/c and $R = 0.4$ recoiling from a high-p_T reference hadron ($20 < p_{T,trig} < 50$ GeV/c), for central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with 10 nb^{-1} int. luminosity, and pp collisions at $\sqrt{s} = 5.02$ TeV with 6 pb^{-1} int. luminosity. The recoil jet azimuthal angle $\Delta\varphi$ is defined with respect to the reference axis. The observable shown is $\Phi(\Delta\varphi)$ which incorporates statistical suppression of uncorrelated background. Figure from Ref. [1].

Molière Scattering in Quark-Gluon Plasma: Finding Point-Like Scatterers in a Liquid

Francesco D'Eramo,[a,b] Krishna Rajagopal,[c] Yi Yin[c]

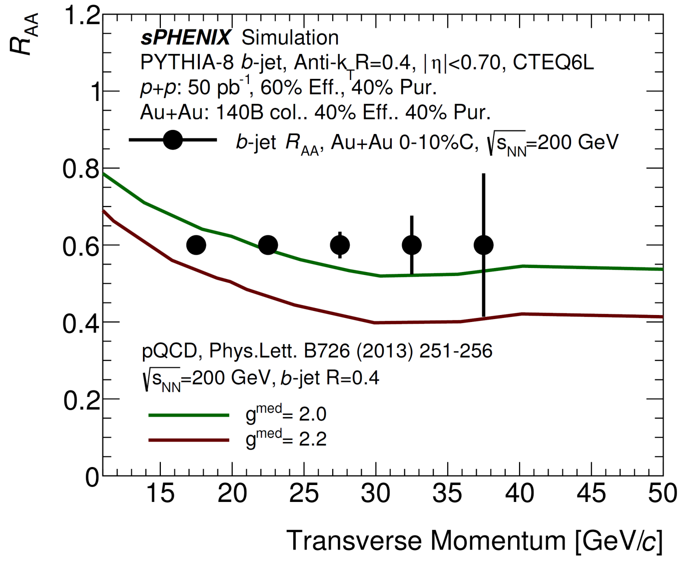




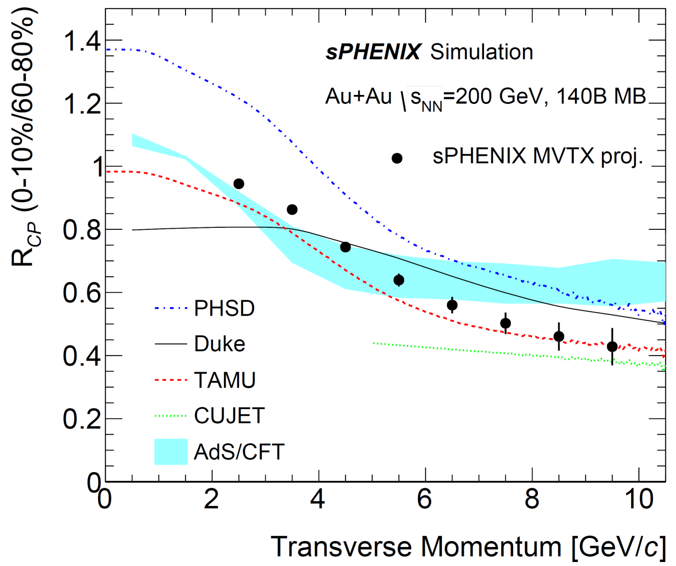
At comparable jet energies, much smaller contribution from ISR/FSR at RHIC, as well as smaller smearing from UE fluctuations

New capabilities at RHIC: b-tagged jets, B mesons

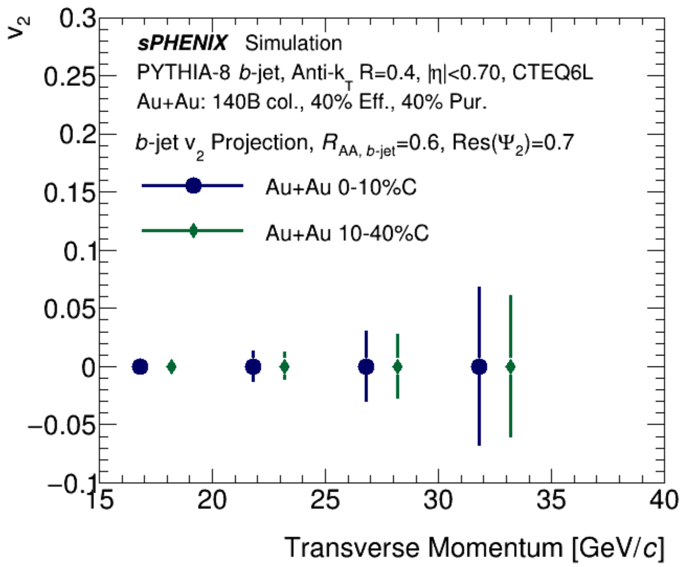
b-tagged jet R_{AA}



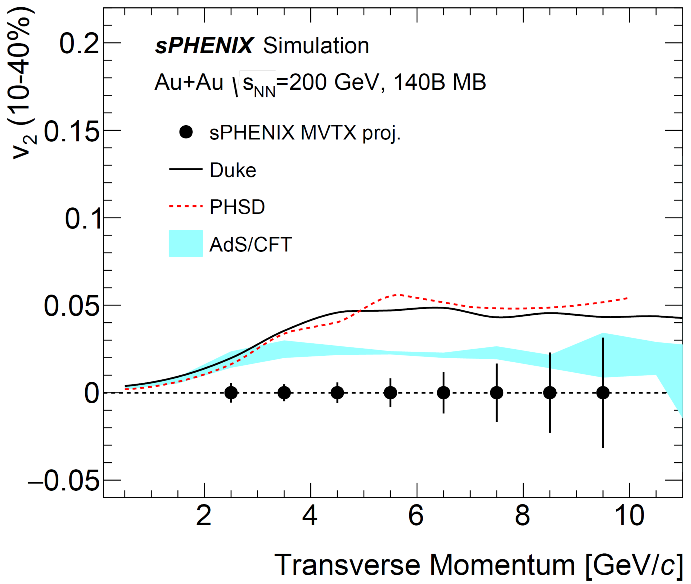
B-meson R_{CP}



b-tagged jet v_2



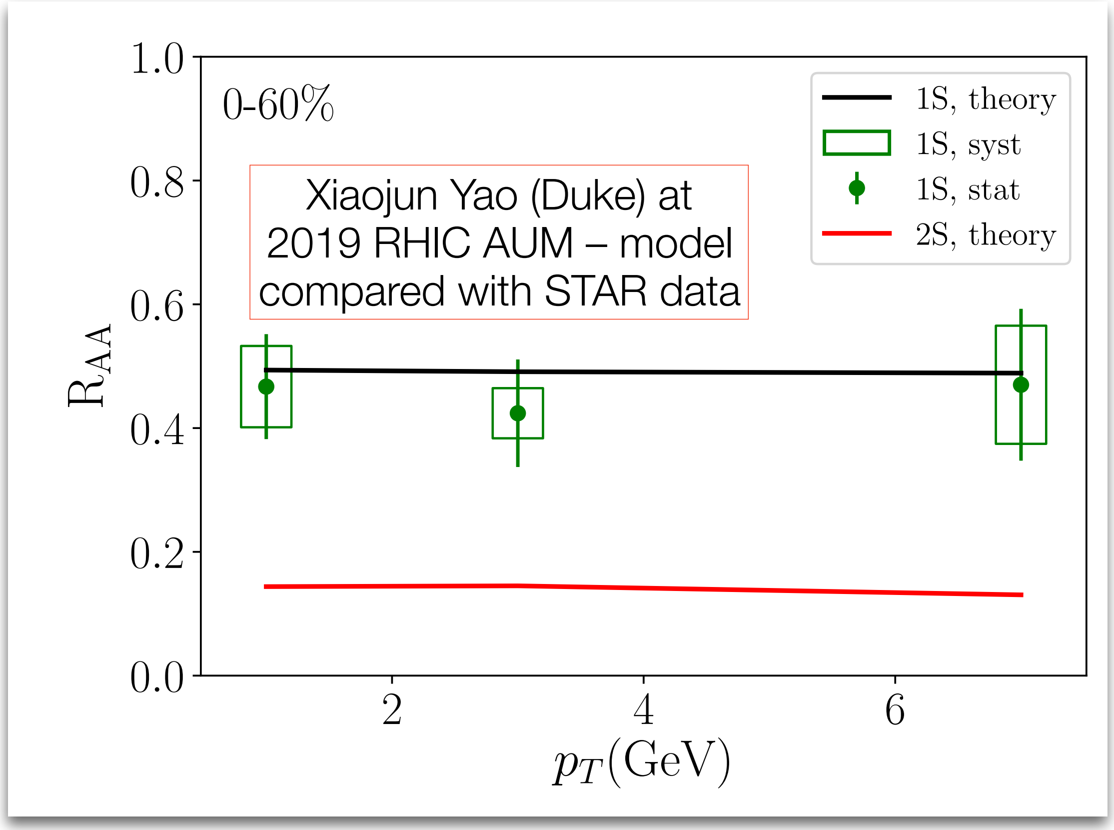
B-meson v_2

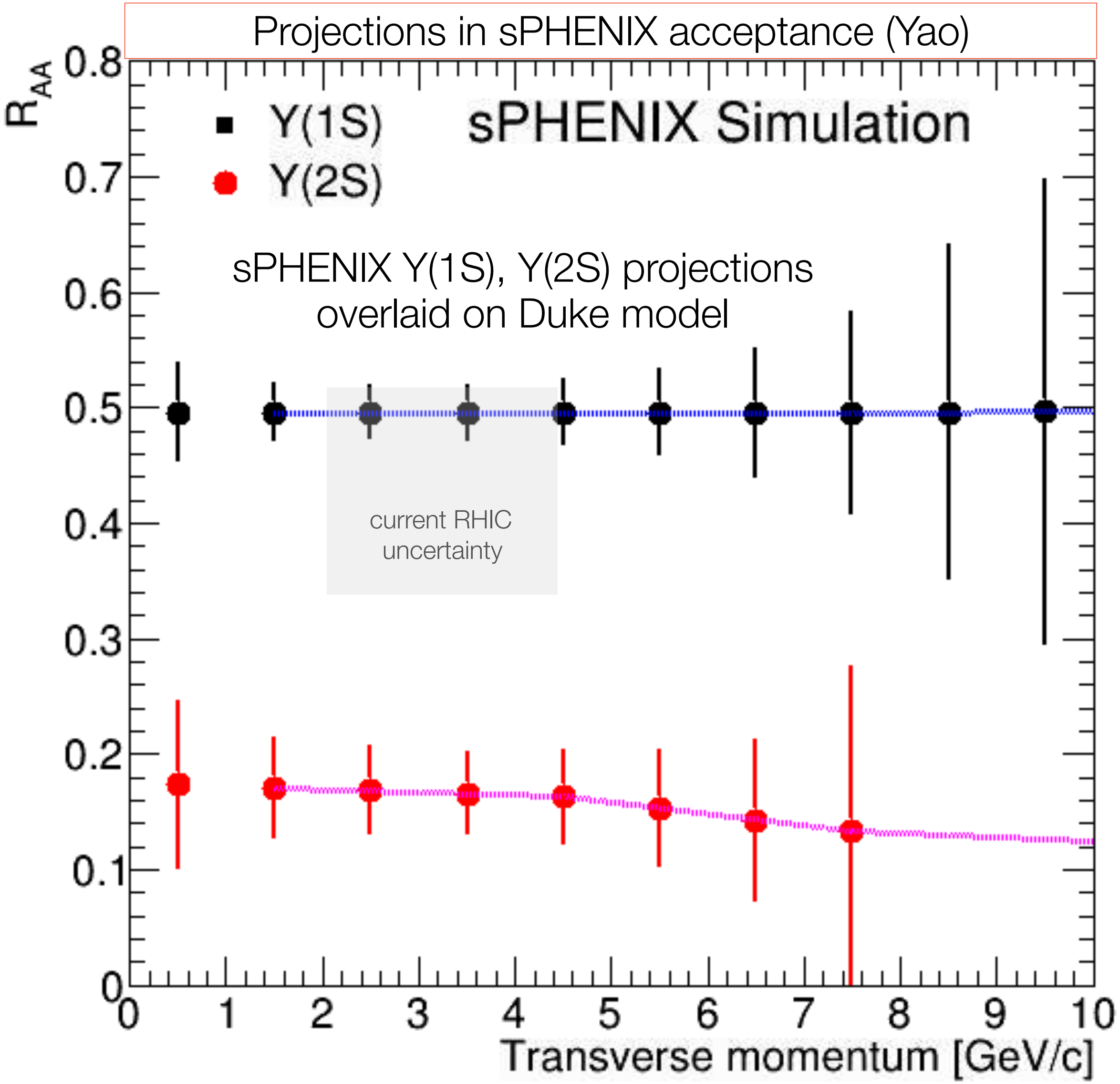


sPHENIX vs current RHIC results: Υ(nS) family

Detailed balance affected by dissociation, strong energy loss of bare HQ, recombination

See X. Yao, B. Mueller, arXiv:1811.09644





sPHENIX and the Big Picture

- A new NP long-range planning process is expected to start within a year
- Major initiatives in all NP subfields (JLab 12GeV, FRIB, 0νββ, nEDM,EIC,…)
- RHIC operations (~30% of NP budget) will attract significant attention
    - “Knives will be out”
- Barring a surprise, unambiguous breakthrough, continued RHIC operations (until ~2026) after BES-II hinges on sPHENIX science case
    - Field of Hot QCD needs to present a coherent plan: sPHENIX, LHC, STAR
- What can sPHENIX do for you? What can you do for sPHENIX?

Summary

- Key goal of 2015 LRP: Understand microscopic structure of QGP and the emergence of its unique long-wavelength properties
  - New state-of-the-art detector for hard probes: sPHENIX @ RHIC
  - Exploit complementarity with LHC
  - Combination of high precision tracking, full calorimetry, large acceptance and high rate
  - sPHENIX relies on proven, cost-effective technology to bring qualitatively new capabilities to RHIC
- Project entered construction phase in 2019
- Preparing for first physics data in 2023

Backup

Comparison of projected FF uncertainties

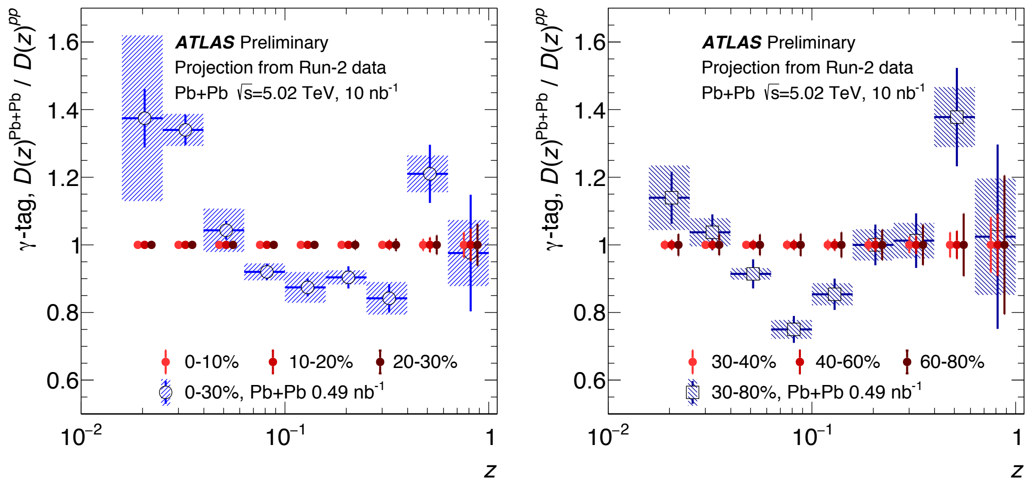


Fig. 35: Projection of the statistical precision that can be reached for the ratio of jet fragmentation functions in Pb–Pb and pp collisions, $R_{D(z)}$, of jets recoiling from a photon. The left panel shows the projection for the most central collisions while the right panel for the more peripheral events [5].

CERN Yellow Report projections for Runs 3, 4

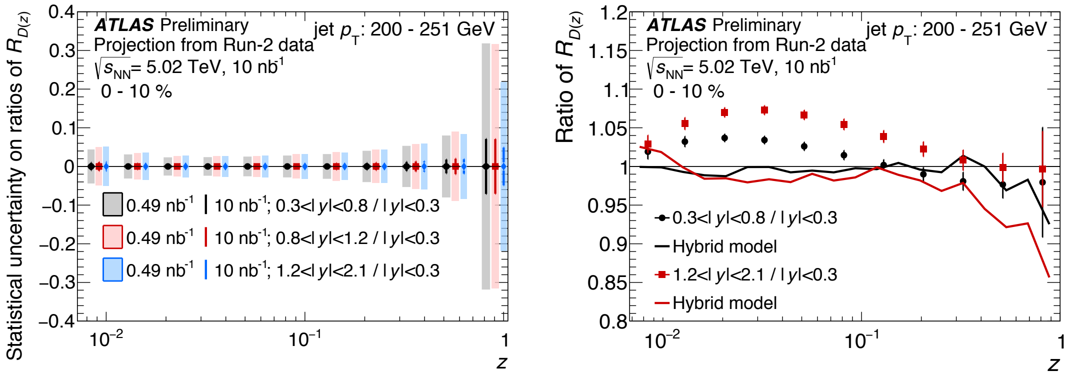
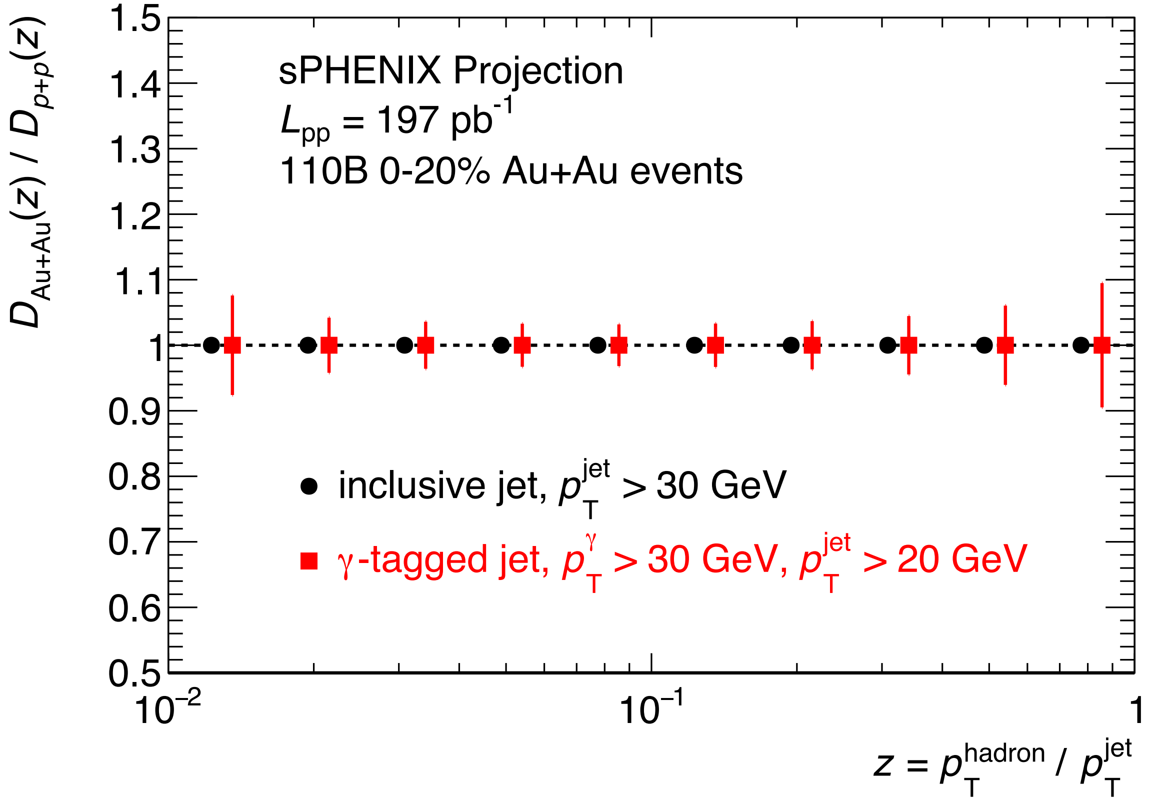


Fig. 33: Projection of the precision that can be reached for the modification of jet fragmentation function, $R_{D(z)}$, measured in jet p_{T} interval $200 - 251$ GeV/c. In the left panel the statistical uncertainty on the measurement with the shaded boxes corresponding to $0.49\ \mathrm{nb}^{-1}$ while the vertical bars are for $10\ \mathrm{nb}^{-1}$. The right panel shows a comparison of $R_{D(z)}$ with a theory model (see text for more details) [5].



- different min. hadron & jet p_{T} at LHC (>1 GeV, ~100's of GeV) vs. RHIC (>0.4 GeV, ~30-40 GeV), but coincidentally similar low-z reach
- matched x-axis range & binning, jet cone size, etc

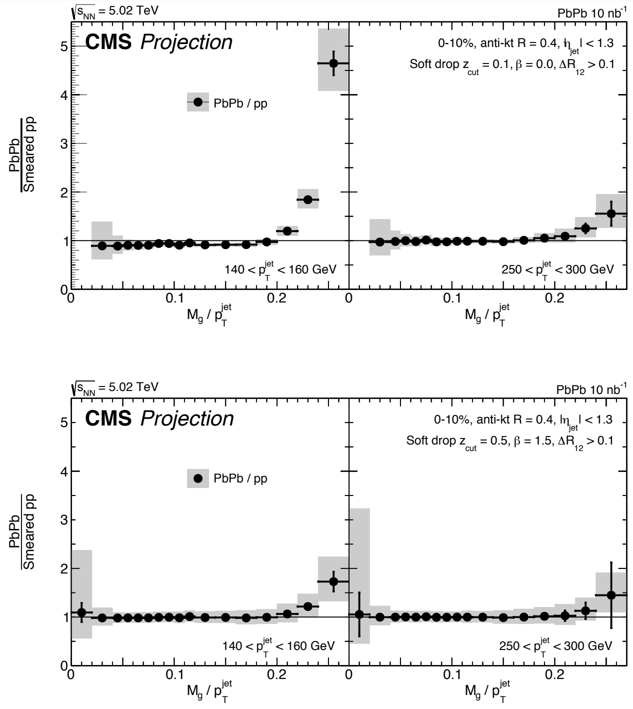
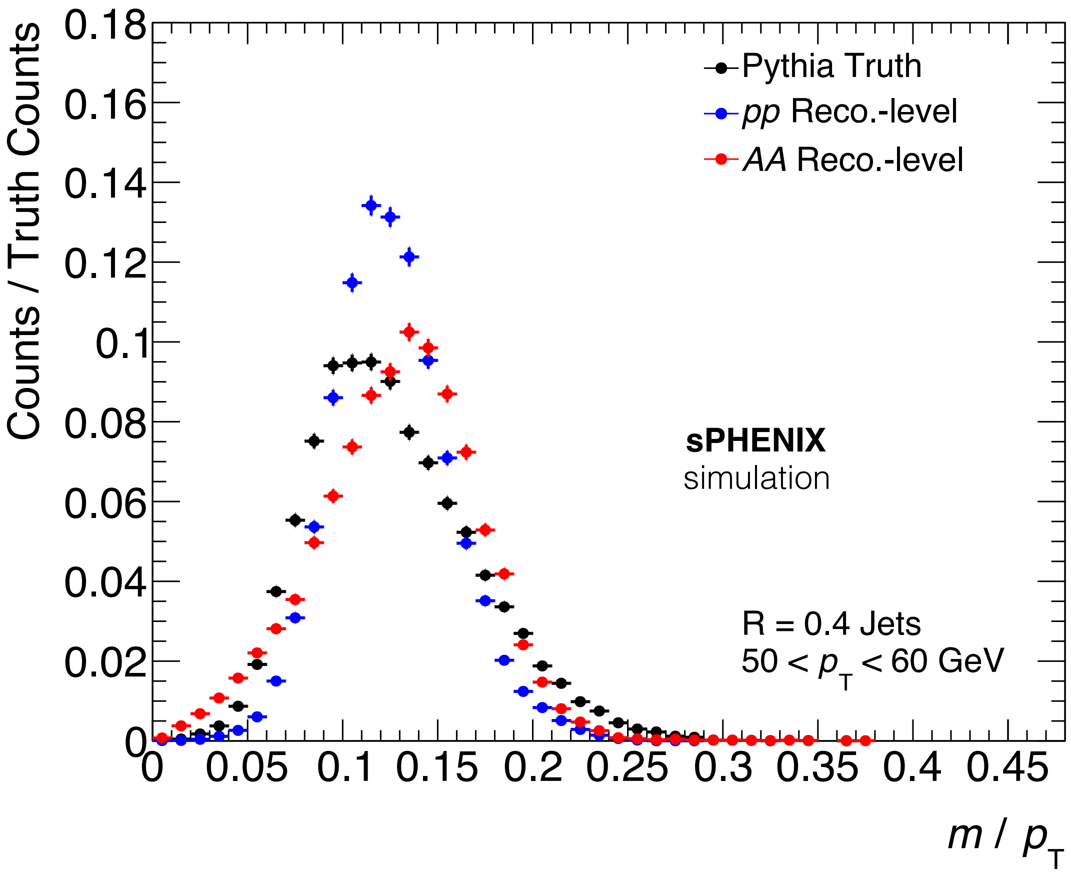


Fig. 37: Jet mass distribution with grooming setting $(z_{cut}, \beta) = (0.1, 0.0)$ (Upper panels) and $(z_{cut}, \beta) = (0.5, 1.5)$ (Lower panels). [8]

CERN Yellow Report projections for Runs 3, 4



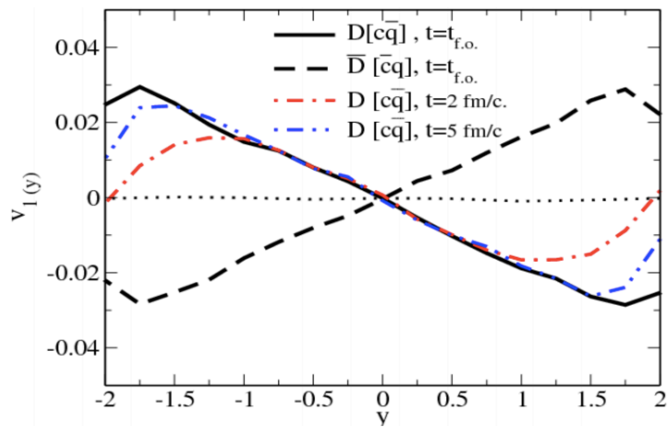
CMS groomed mass / p_T (left) — c.f. sPHENIX version w/ <u>ungroomed</u> mass (right)

➡ new observable enabled by constituent mass subtraction

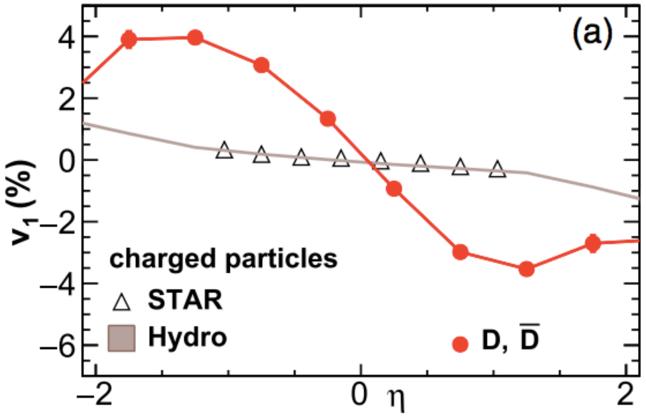
➡ general conclusion: can pick kinematic regions where UE effects are small

D^0 v_1 - Direct Access to Initial B Field

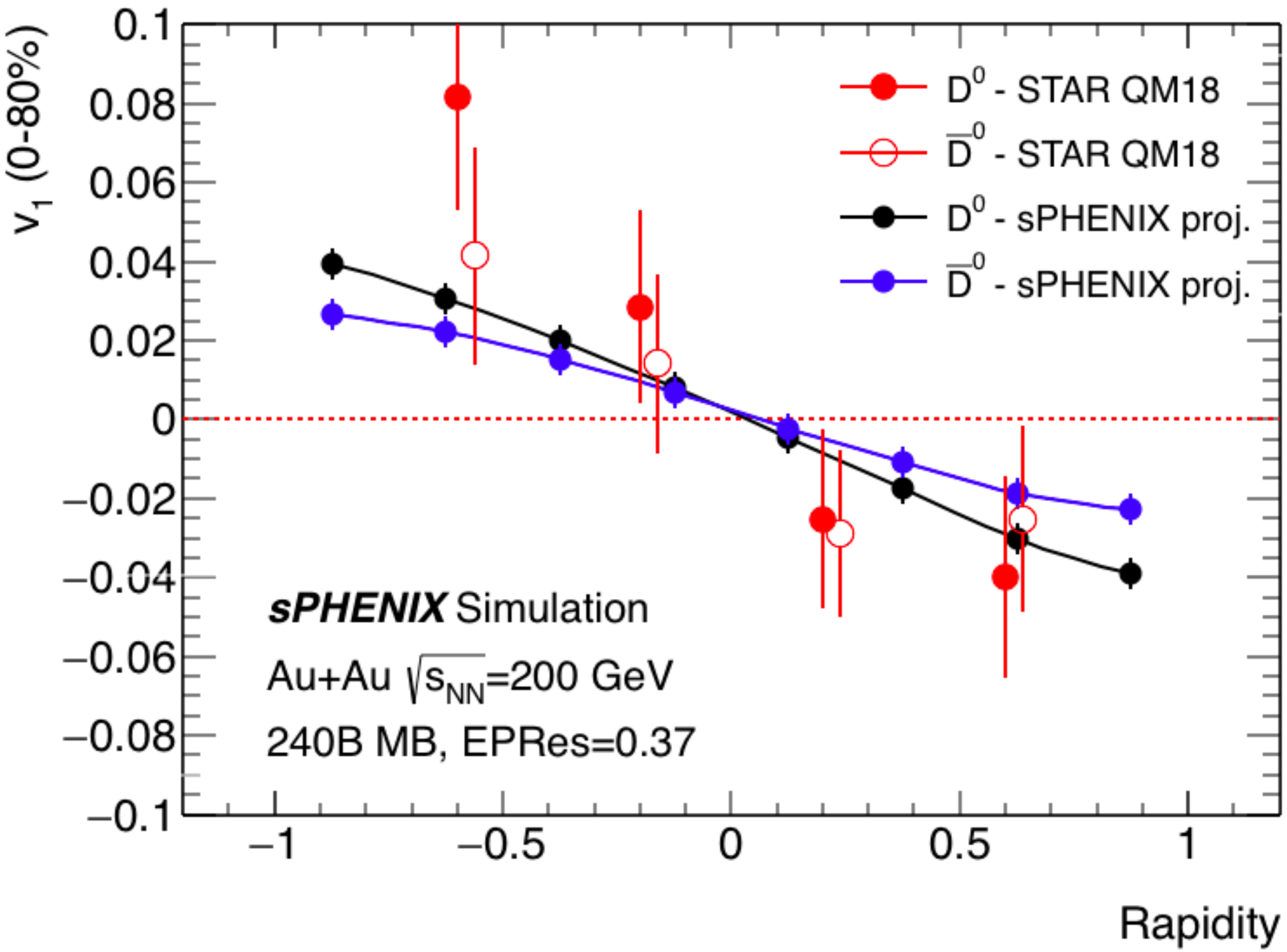
init. B -> v1(D) = -v1(Dbar)



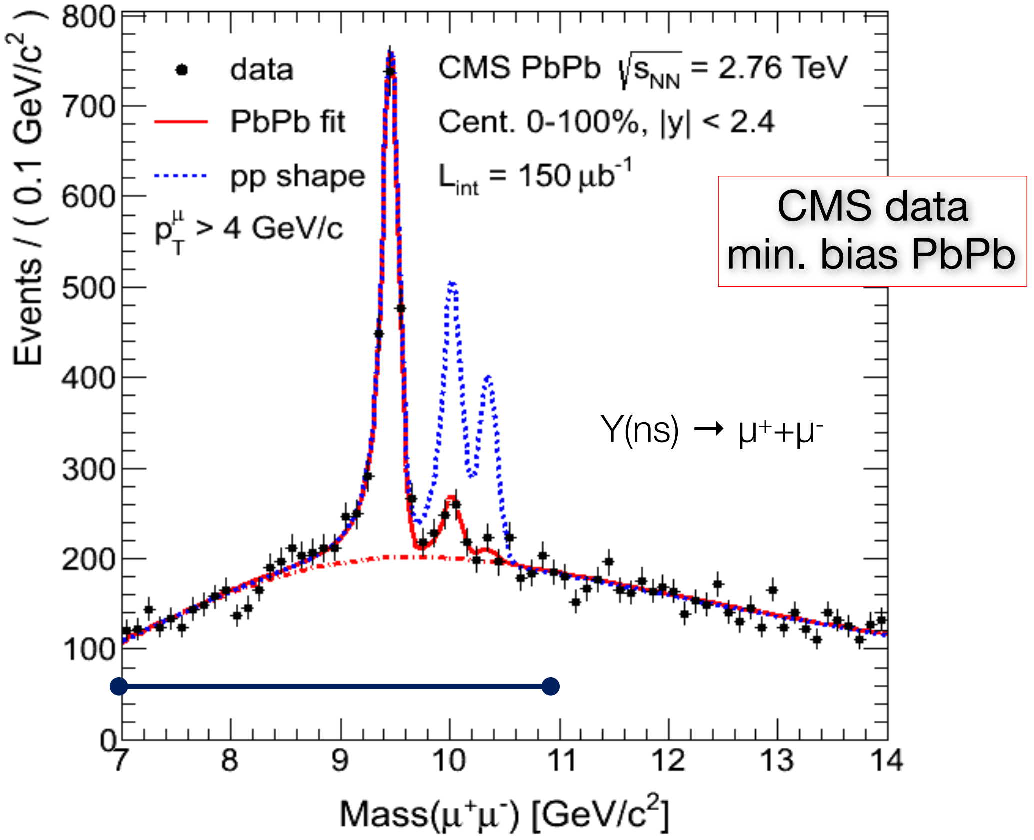
tilt QGP -> v1(D) = v1(Dbar) >> v1(h)

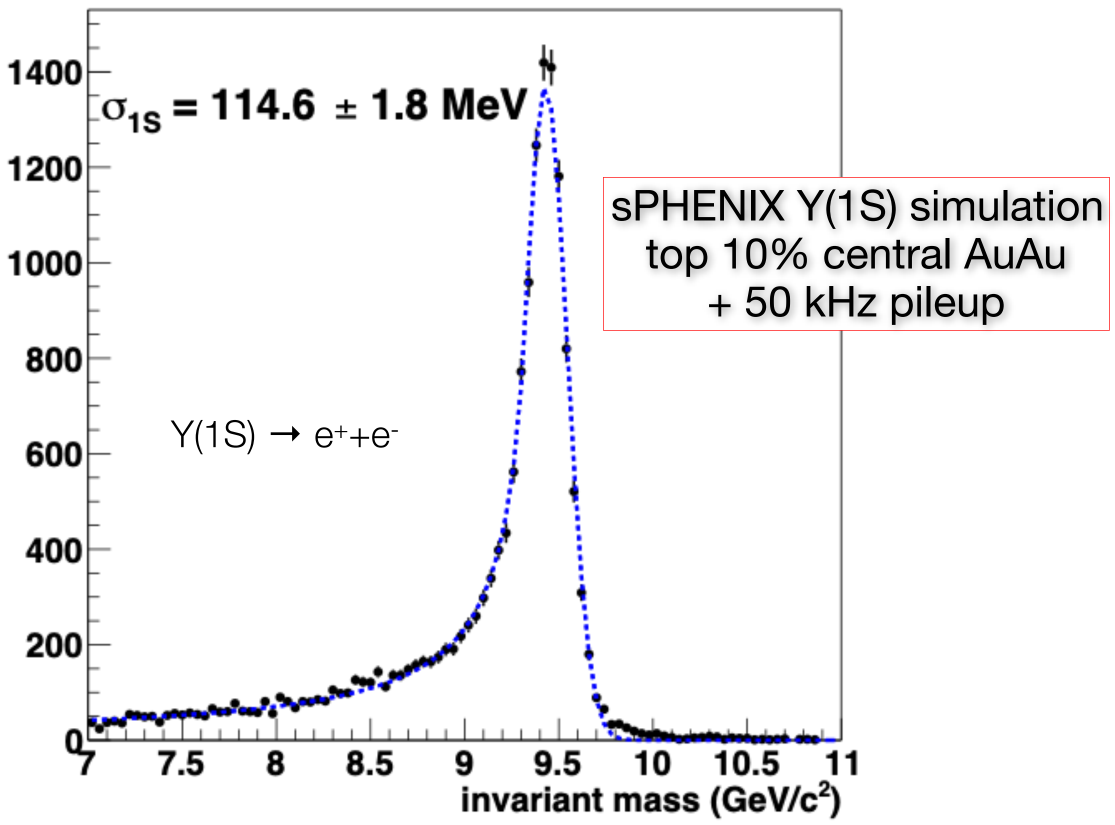


Need: Good ZDC-SMD detector to improve 1st EP resolution



Upsilons at sPHENIX and LHC

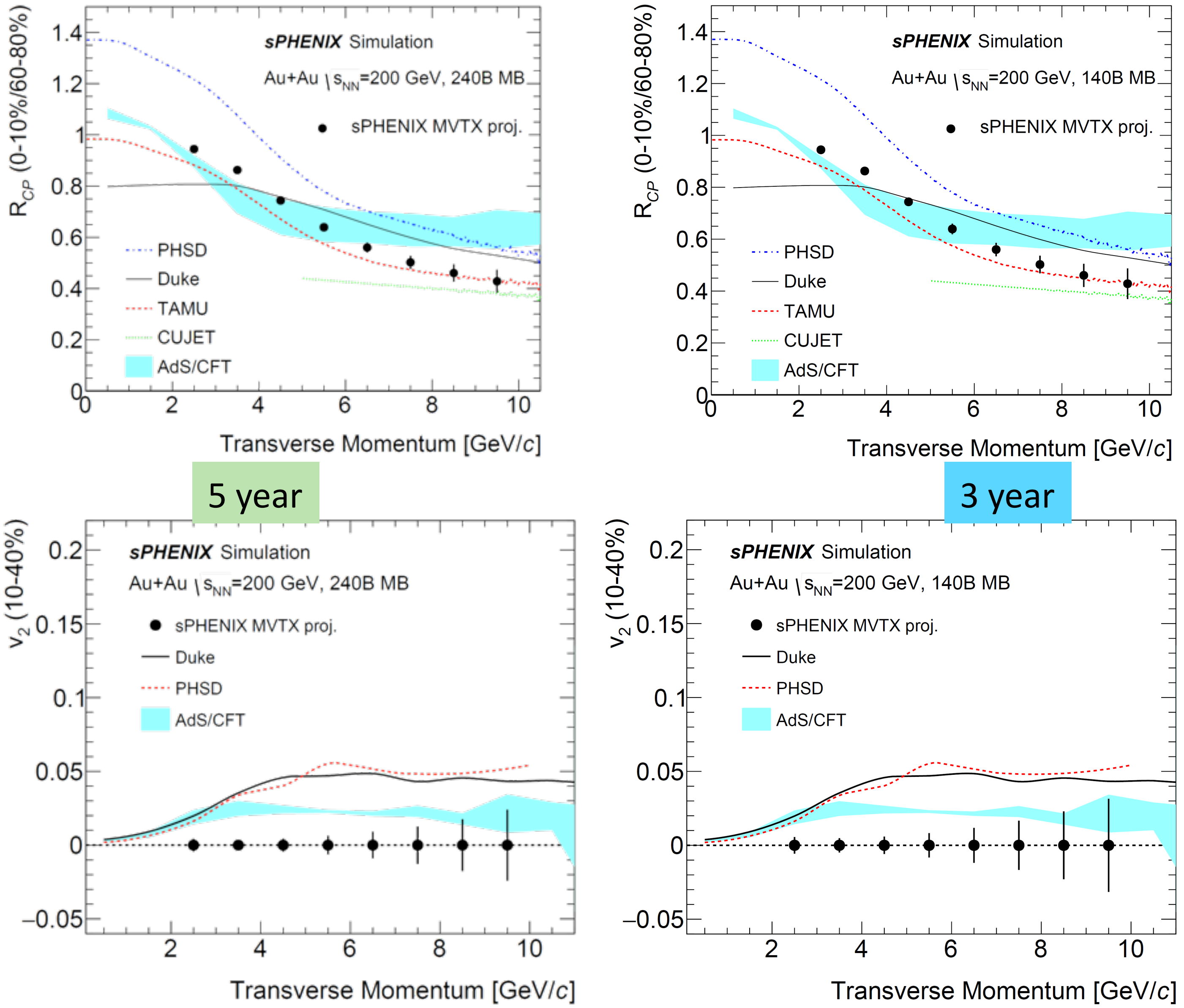




Differential suppression of Υ(nS), temperature dependence of QGP Debye screening length

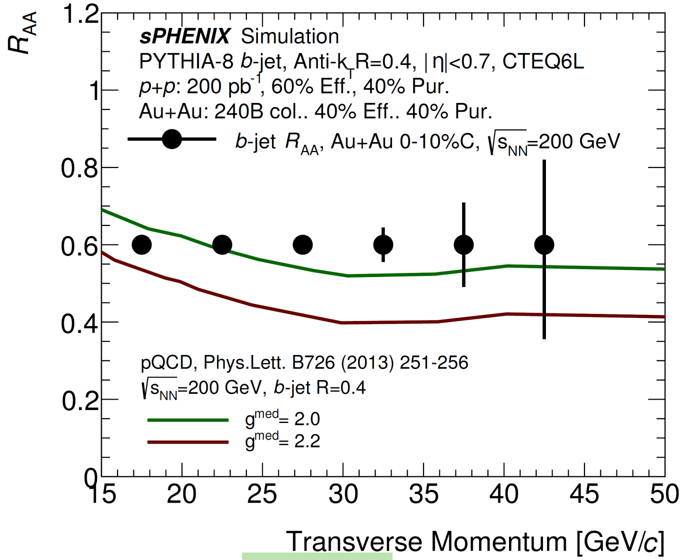
Υ(1S) width key f.o.m. in work of Inner Detector Optimization Task Force – deciding INTT configuration (pattern recognition vs. radiative tails and conversions)

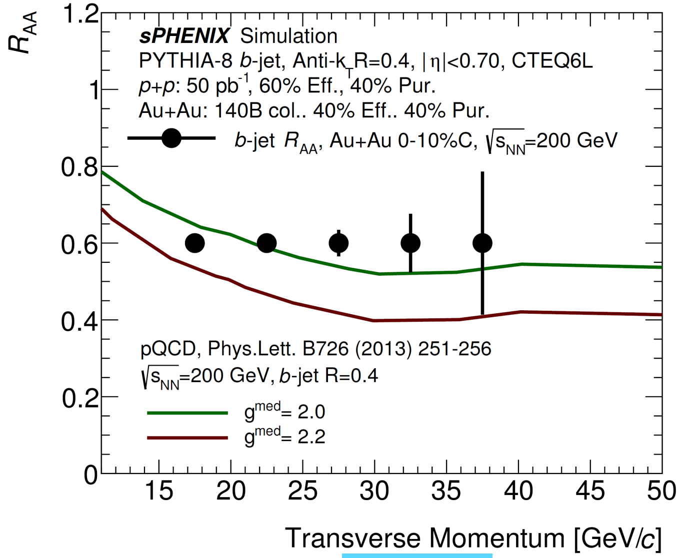
5-yr vs. 3-yr



sPHENIX Simulation
Au+Au √sNN=200 GeV, 240B MB
sPHENIX MVTX proj.
PHSD
Duke
TAMU
CUJET
AdS/CFT
RCP (0-10%/60-80%)
Transverse Momentum [GeV/c]
sPHENIX Simulation
Au+Au √sNN=200 GeV, 140B MB
sPHENIX MVTX proj.
PHSD
Duke
TAMU
CUJET
AdS/CFT
RCP (0-10%/60-80%)
Transverse Momentum [GeV/c]
5 year
3 year
sPHENIX Simulation
Au+Au √sNN=200 GeV, 240B MB
sPHENIX MVTX proj.
Duke
PHSD
AdS/CFT
v2 (10-40%)
Transverse Momentum [GeV/c]
sPHENIX Simulation
Au+Au √sNN=200 GeV, 140B MB
sPHENIX MVTX proj.
Duke
PHSD
AdS/CFT
v2 (10-40%)
Transverse Momentum [GeV/c]

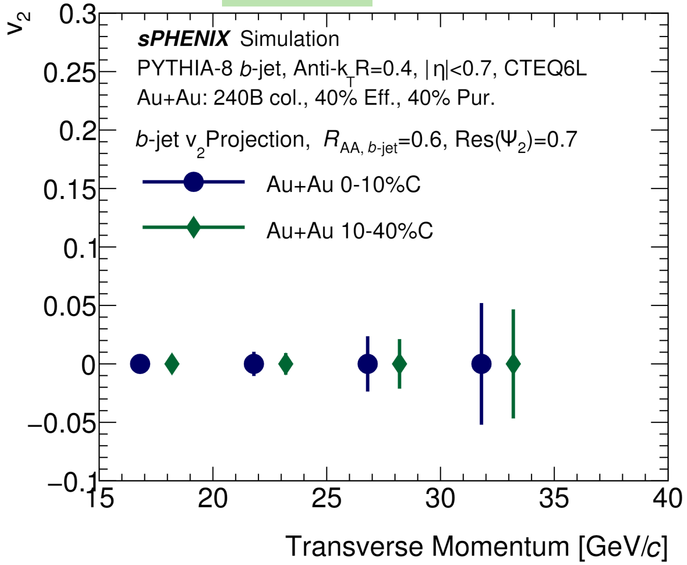
5-yr vs. 3-yr

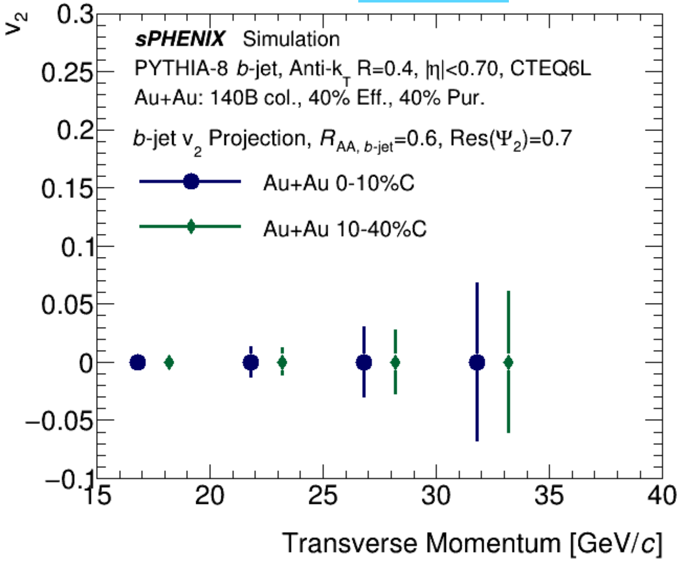




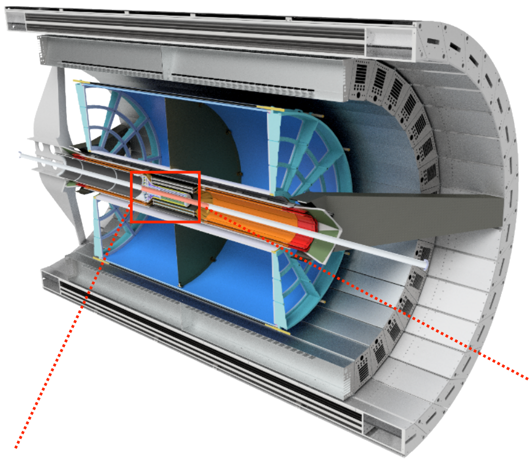
5 year

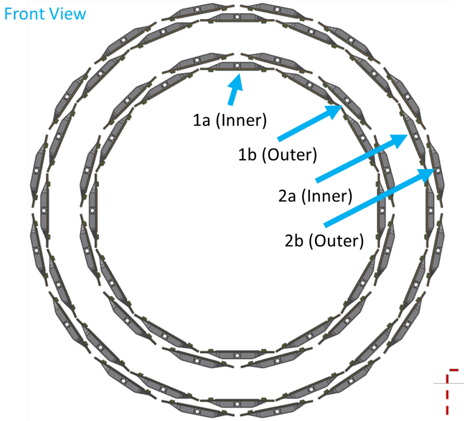
3 year

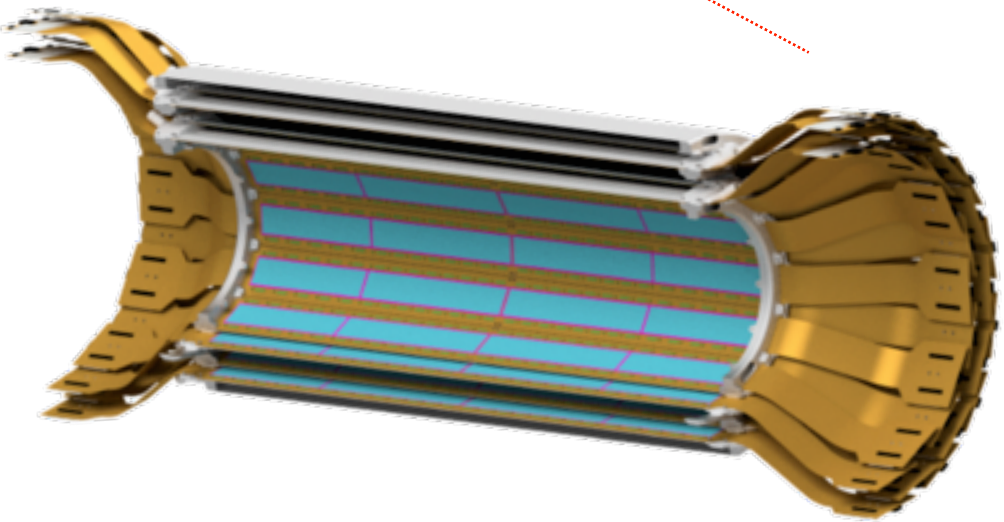


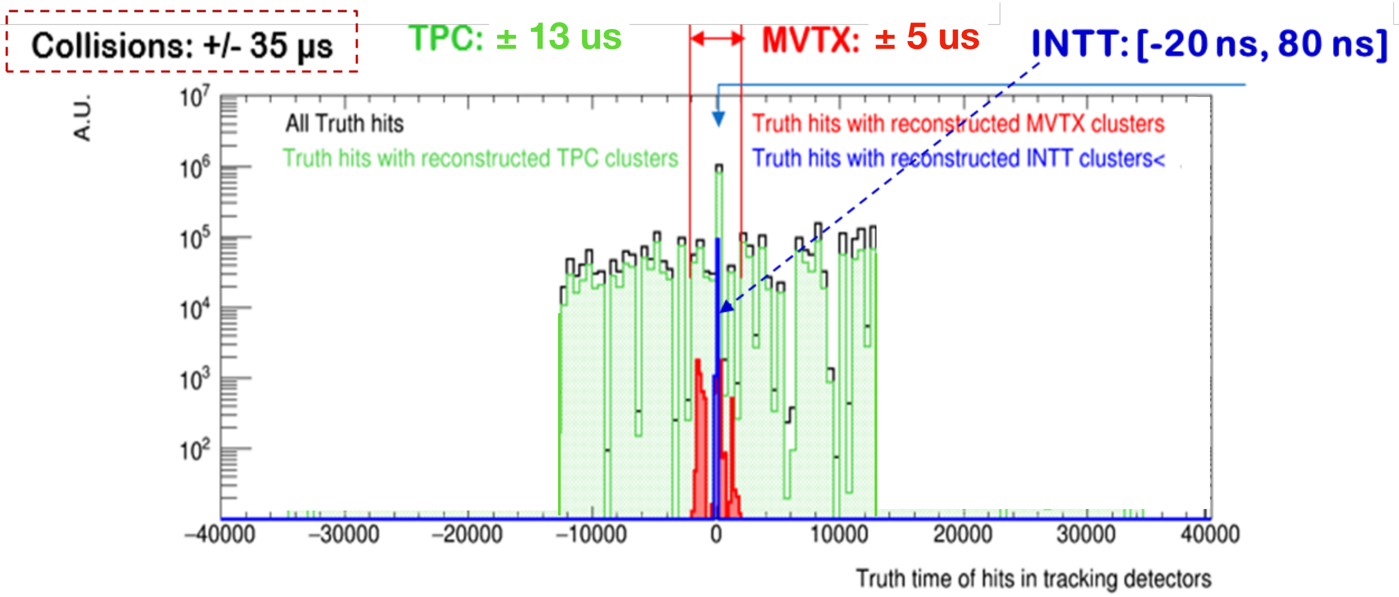


INTT



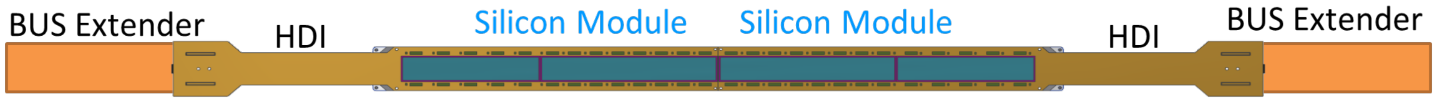

Front View
1a (Inner)
1b (Outer)
2a (Inner)
2b (Outer)

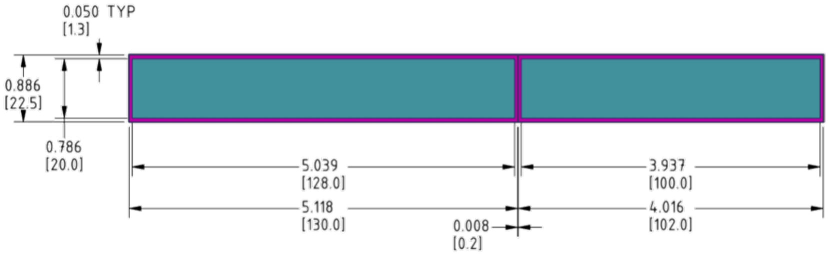


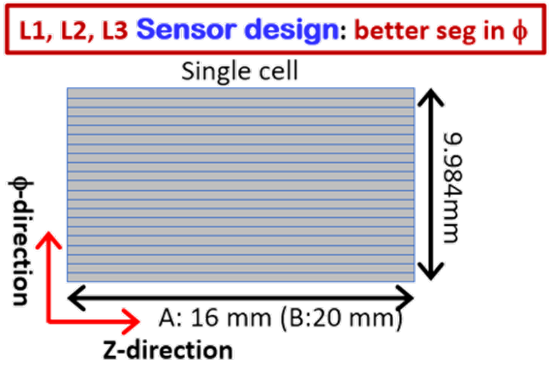

Collisions: +/- 35 μs
TPC: ± 13 us
MVTX: ± 5 us
INTT: [-20 ns, 80 ns]
A.U.
All Truth hits
Truth hits with reconstructed TPC clusters
Truth hits with reconstructed MVTX clusters
Truth hits with reconstructed INTT clusters
Truth time of hits in tracking detectors

INTT

- Sensors from HPK
  - **78 μ pitch**
  - **single-sided**
  - **AC coupled**
  - **320 μ thick**
- Two sizes of sensors
  - **128x20 mm**
  - **100x20 mm**
- FPHX ASIC (developed for PHENIX)
  - **128 channels**
  - **3 bit ADC**
  - **64 mW/chip**
  - **200 MHz data port**
- Near detector Readout Cards (ROC's) from PHENIX FVTX
- Data acquisition by FVTX FEM + DCM II/JSEB II
  - **Alternative under consideration**







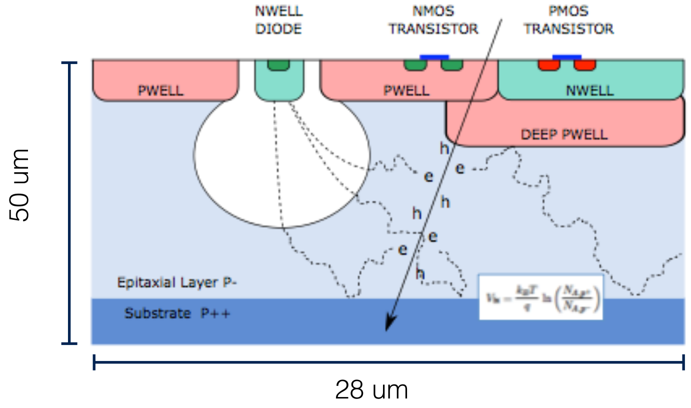
Type A: Single sensor = 8 x 2 cells
Type B: Single sensor = 5 x 2 cells

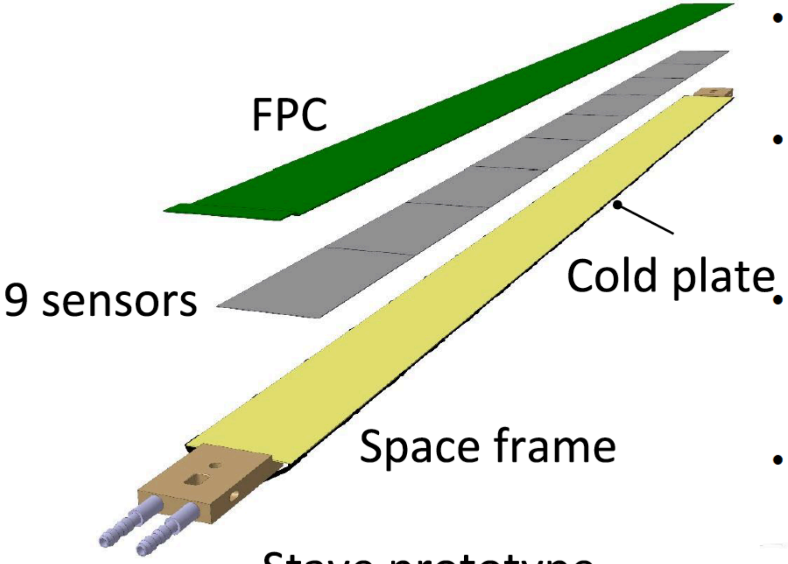
Thickness: 320 um
Pitch: 9.984 mm/128 = 78 um
Φ-length (single sensor) = 22.5 mm
F-length (active area) = 20.0 mm
Z-length type-A (single sensor) = 130.0 mm
Z-length type-A (active area) = 128.0 mm
Z-length type-B (single sensor) = 102.0 mm
Z-length type-B (active area) = 100.0 mm

MVTX

ALICE Pixel Detector

- Very fine pitch (27µm x 29µm), for superb spatial resolution
- High efficiency (>99%) and low noise ($<10^{-6}$), for excellent tracking
- Time resolution, as low as ~5 µs, for less pileup
- Ultra-thin/low mass, 50µm (~0.3% X_0), for less multiple scattering
- 0.5M channels with on-pixel digitization, for zero-suppression and fast readout
- Low power dissipation, 40mW/cm², for minimal service materials





- **Staves:** detector modules consisting of a Hybrid Integrated Circuit (HIC) mounted on carbon fiber mechanical support structure
- **HIC:** a row of 9 ALPIDE sensors wire-bonded to a Flexible Printed Circuit (FPC). Area covered by the chips: 15x271.2 mm², including a gap of 150 µm between adjacent chips.
- **Mechanical support:** single light structure composed of a Space Frame, providing the required stiffness, and a Cold Plate, high-thermal conductivity carbon fiber sheet with embedded polyamide cooling pipes.
- **Heat Dissipation** – The ALPIDE sensors dissipate only 40 mW/cm².

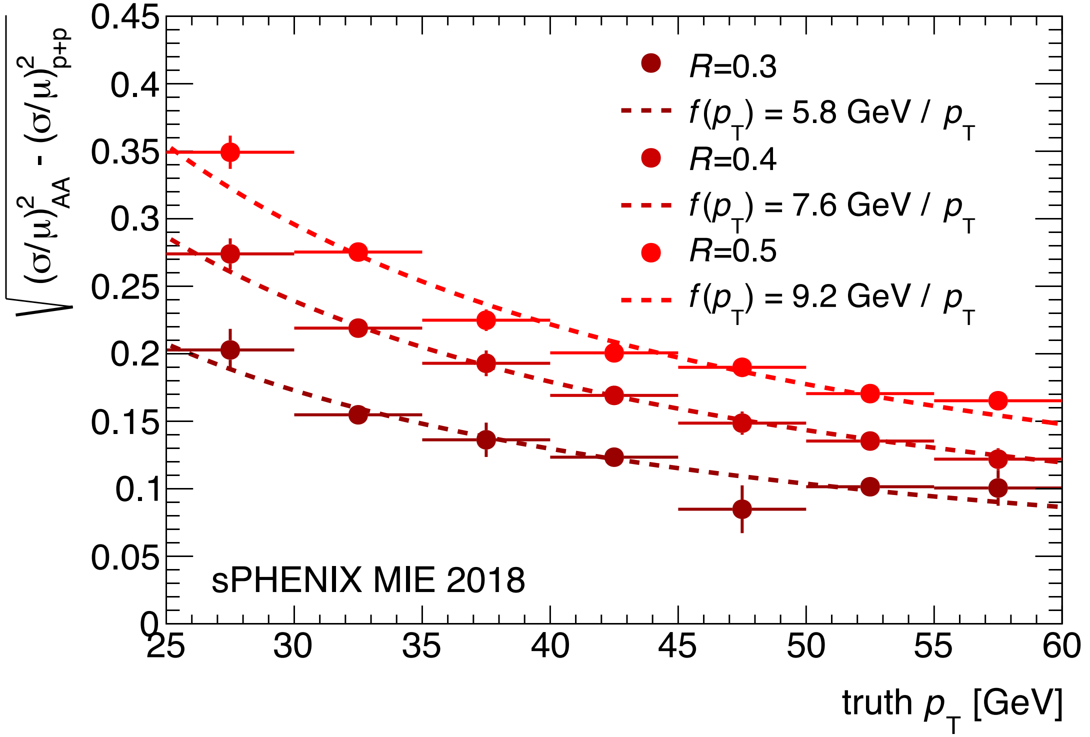
Stave prototype

Jet performance

Deconvolution of UE term in Au+Au response

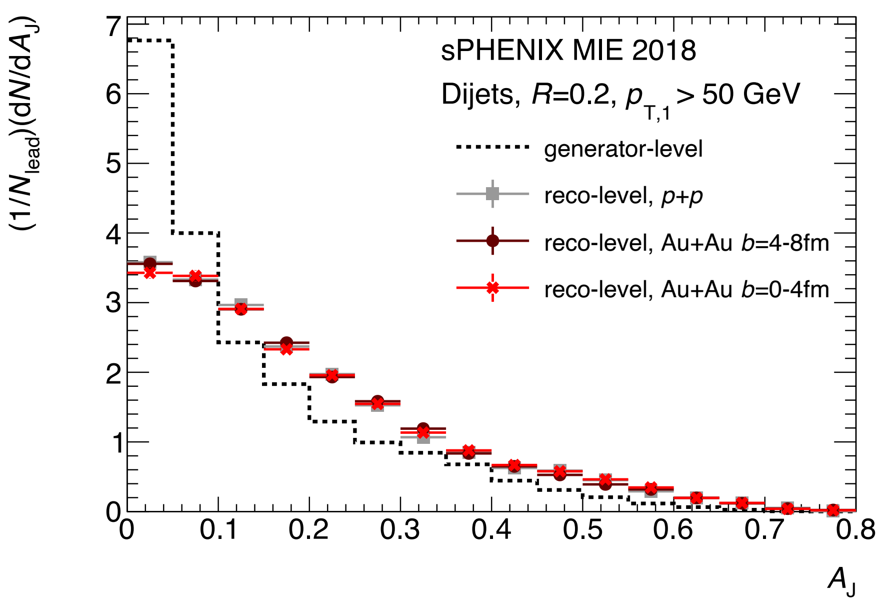
$$\frac{\sigma_{p_\mathrm{T}}}{p_\mathrm{T}} = \frac{n}{p_\mathrm{T}} \oplus \frac{s}{\sqrt{p_\mathrm{T}}} \oplus c$$

Noise Stochastic Constant

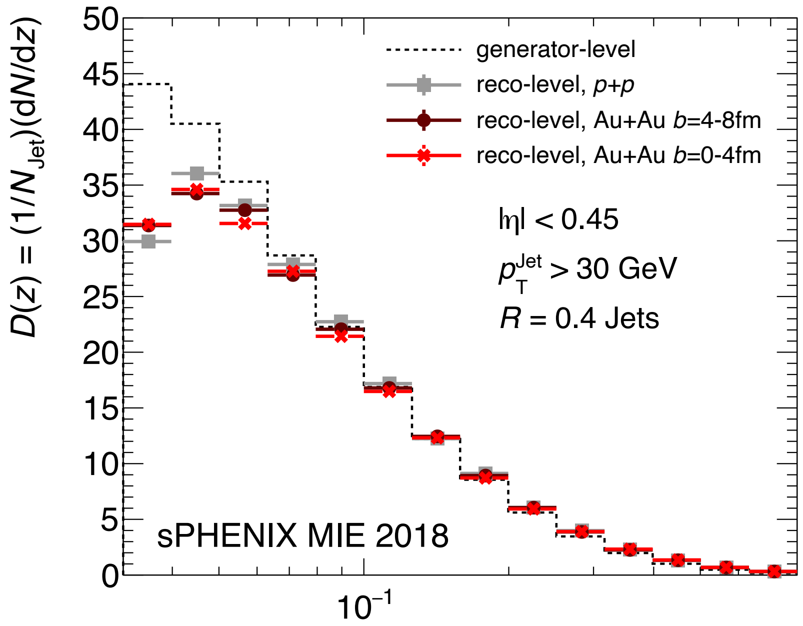


- One advantage of purely calorimetric measurement: reconstruction proceeds identically in *pp* and Au+Au
  - ➡ can understand Au+Au response as *pp* response ⊗ UE
  - ➡ identical, i.e. sensitivity of response to fragmentation, in both systems

Jet performance summary



di-jet p_T balance

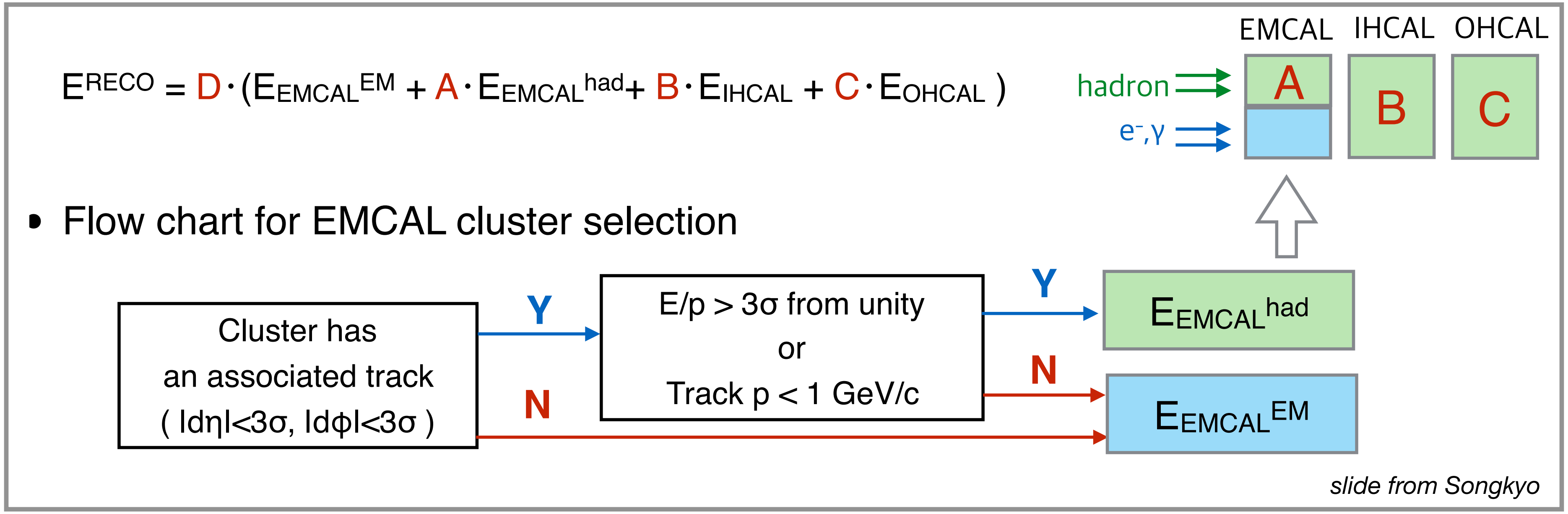


inclusive jet FF

Good news: kinematic regions where p+p ~ Au+Au

➡ but want to make measurements in difficult regions too (detector corrections via unfolding, etc.…)

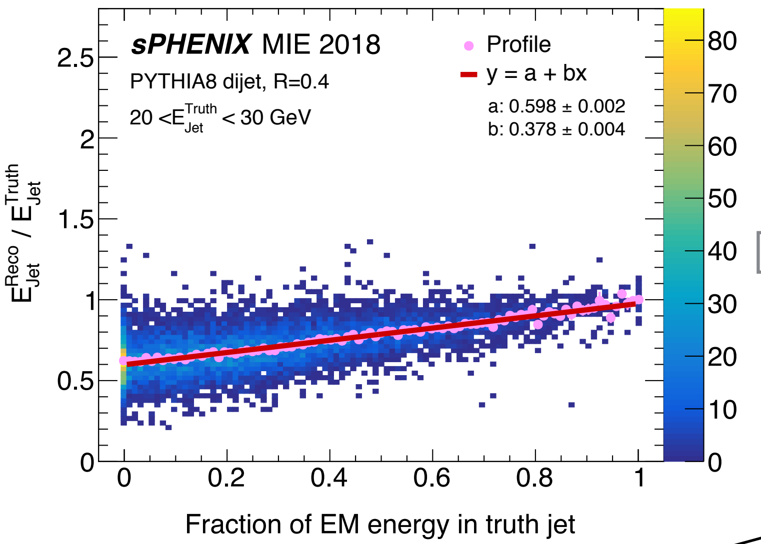
Jet energy calibration

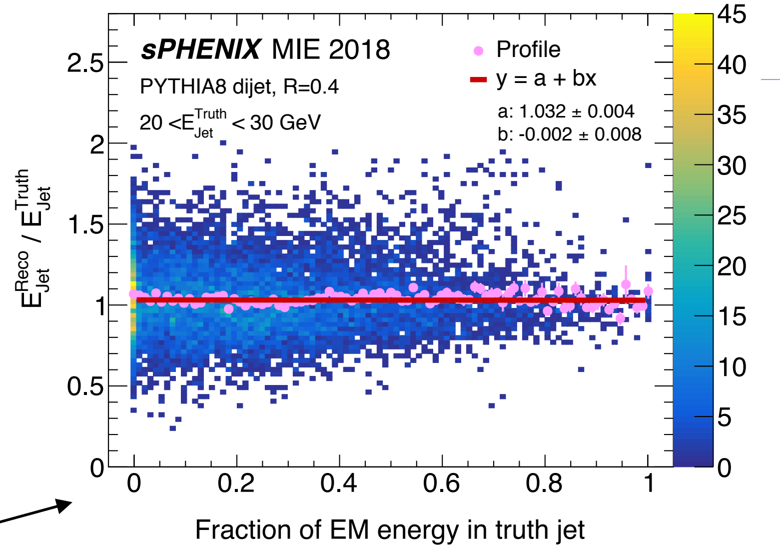


Exploring calibration schemes based on multiplicative scale factors for each calorimeter layer

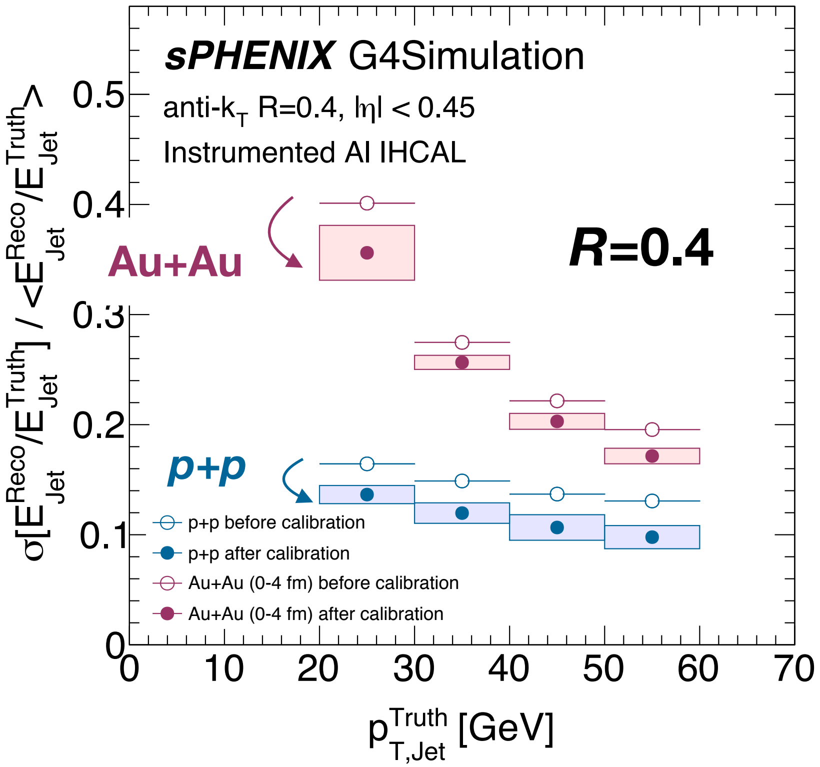
- separation of EMCal energy into e/γ (no track or E/p ~ 1 track) and hadronic (track with $E^{EM}/p < 1$)
- discussion of *in situ* validation with γ+jet events in *p+p*

Jet calib





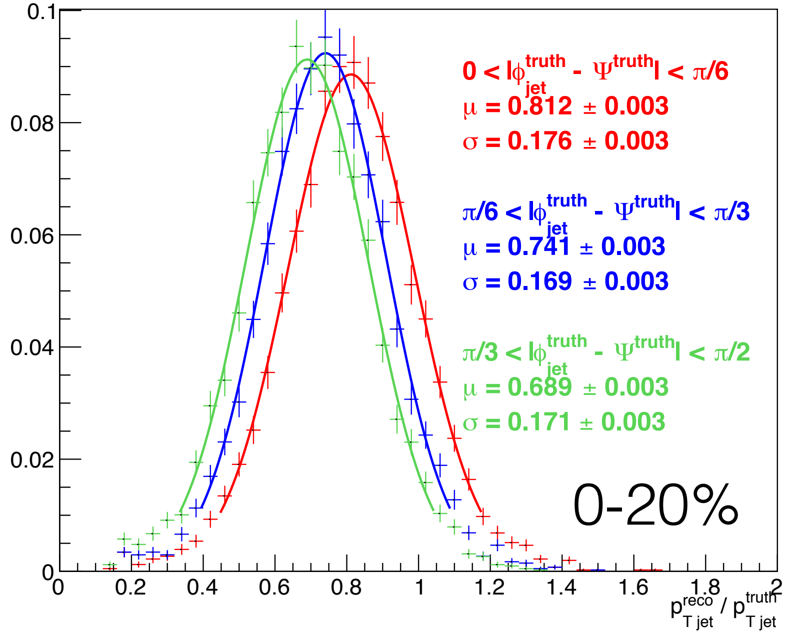
Response nearly independent of truth-EM fraction (i.e. fragmentation) in p+p



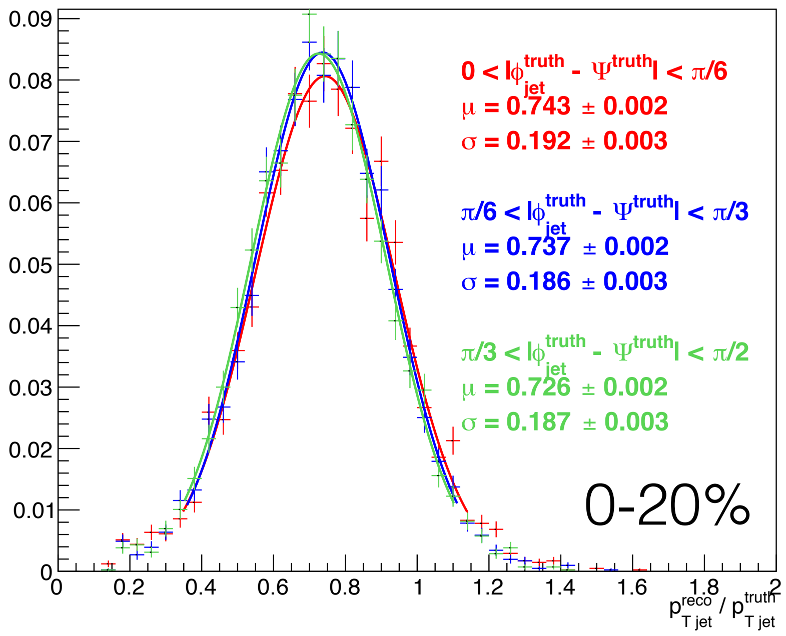
ϕ-dependent jet performance

sPHENIX

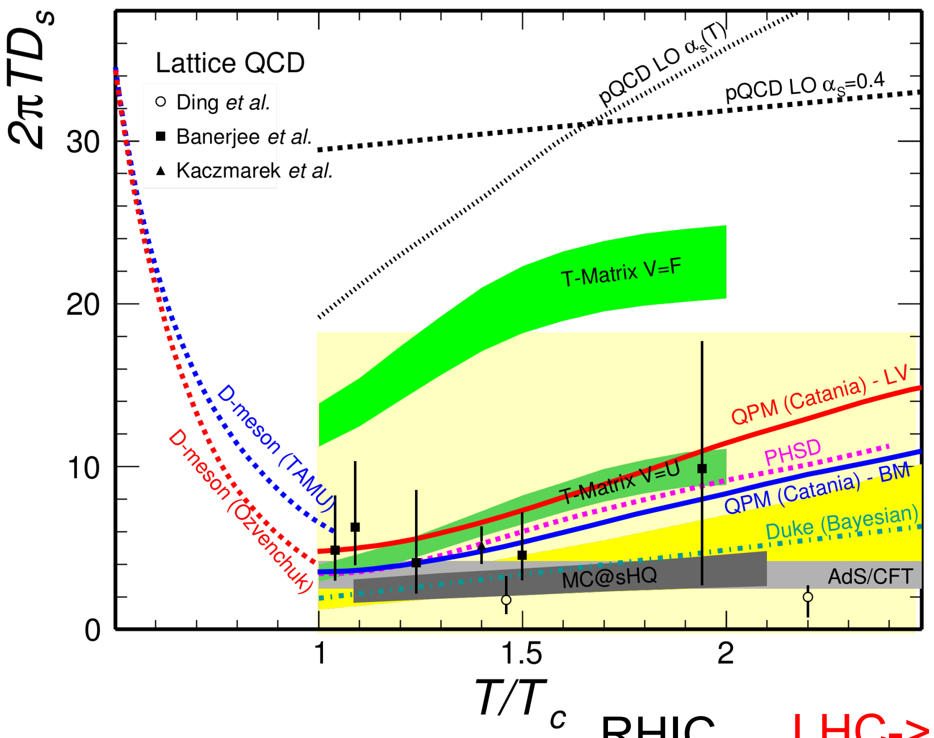
HI jet reco w/o flow determination…



HI jet reco **WITH** flow determination

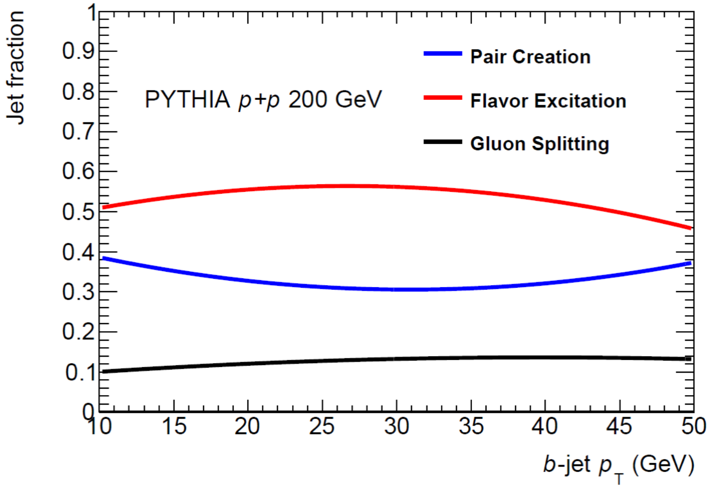


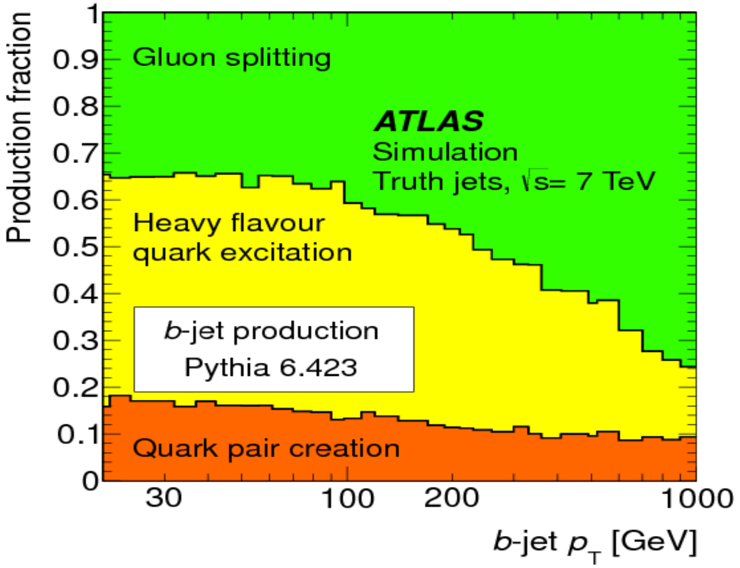
RHIC vs. LHC



RHIC LHC->

A. Adare et al., 1501.06197

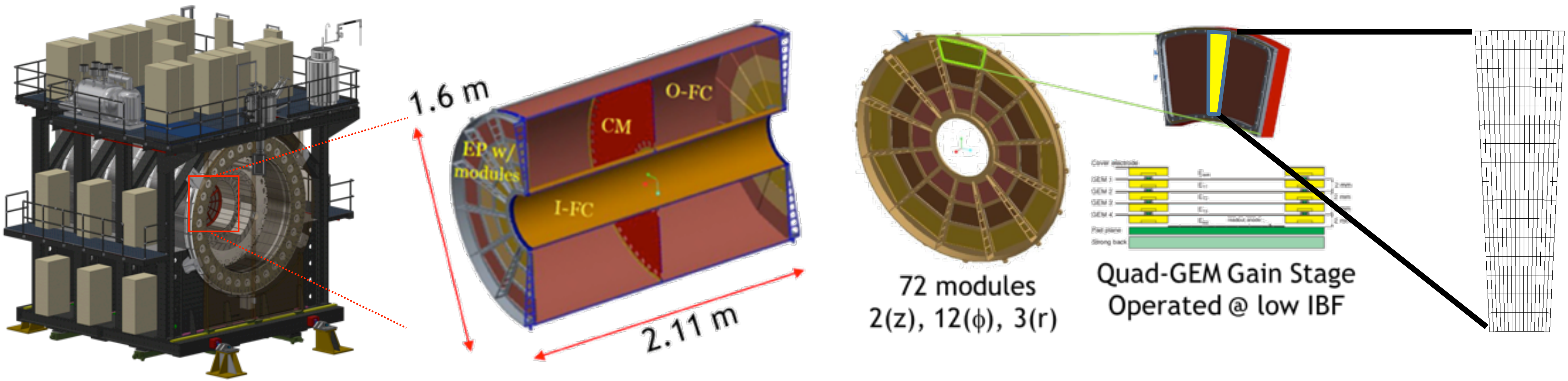




Complementarity: RHIC vs. LHC
- Sensitive to different temperature regions

Uniqueness at RHIC (vs. LHC)
- Gluon splitting contribution is much less (~10%)

Time projection chamber



- Provides momentum reconstruction
- Operates in continuous readout mode
- Gas-Electron Multiplier (GEM) avalanche for low Ion Back Flow (IBF)
- FEE, Data Aggregation from ALICE and ATLAS

Threshold & Objective KPP's

- The individual L2 components of sPHENIX are the MIE deliverables.
- KPP's are determined using bench tests, LED/Pulser/laser tests, and cosmics. Beam collisions are not needed to satisfy the KPP's.

System	Demonstration or Measurement	Threshold KPP's	Objective KPP's
Time Projection Chamber	Preinstall, Bench Test	$\geq$ 90% live channels based on laser, pulser, cosmics	$\geq$ 95% live channels based on laser, pulser, cosmics
Time Projection Chamber	Preinstall, Bench Test	Ion Back Flow $\leq$ 2% per GEM Module averaged over the active area of ea. GEM Module	Same
Time Projection Chamber	Preinstall, Bench Test w/cosmics	$\geq$ 90% single hit efficiency / mip track, averaged over the active TPC volume	$\geq$ 95% single hit efficiency / mip track
Time Projection Chamber Front End Electronics	Preinstall, FEE Stand-alone Bench Test	Cross talk $\leq$ 2% per channel, averaged over all channels	Same
EM Calorimeter	Preinstall, Bench Test	$\geq$ 90% live channels based on LED, cosmics	$\geq$ 95% live channels based on LED, cosmics
Hadronic Calorimeter	Preinstall, Bench Test	$\geq$ 90% live channels based on LED, cosmics	$\geq$ 95% live channels based on LED, cosmics
EM Calorimeter	Preinstall, Bench Test	Each sector with an absolute energy pre-calibration to a precision of $\leq$ 35% RMS	Same
Hadronic Calorimeter	Preinstall, Bench Test	Each sector with an absolute energy pre-calibration to a precision of $\leq$ 20% RMS	Same
Min Bias Trigger Detector	Preinstall, Bench Test	$\geq$ 90% live channels based on laser. 120 ps/channels timing resolution w/ Bench Test	$\geq$ 95% live channels based on laser. 100 ps/channels timing resolution w/ Bench Test
DAQ/Trigger	Event rate	10 kHz with random pulser	15 kHz with random pulser
DAQ/Trigger	Data Logging Rate	10 GBit/s with pulser	Same