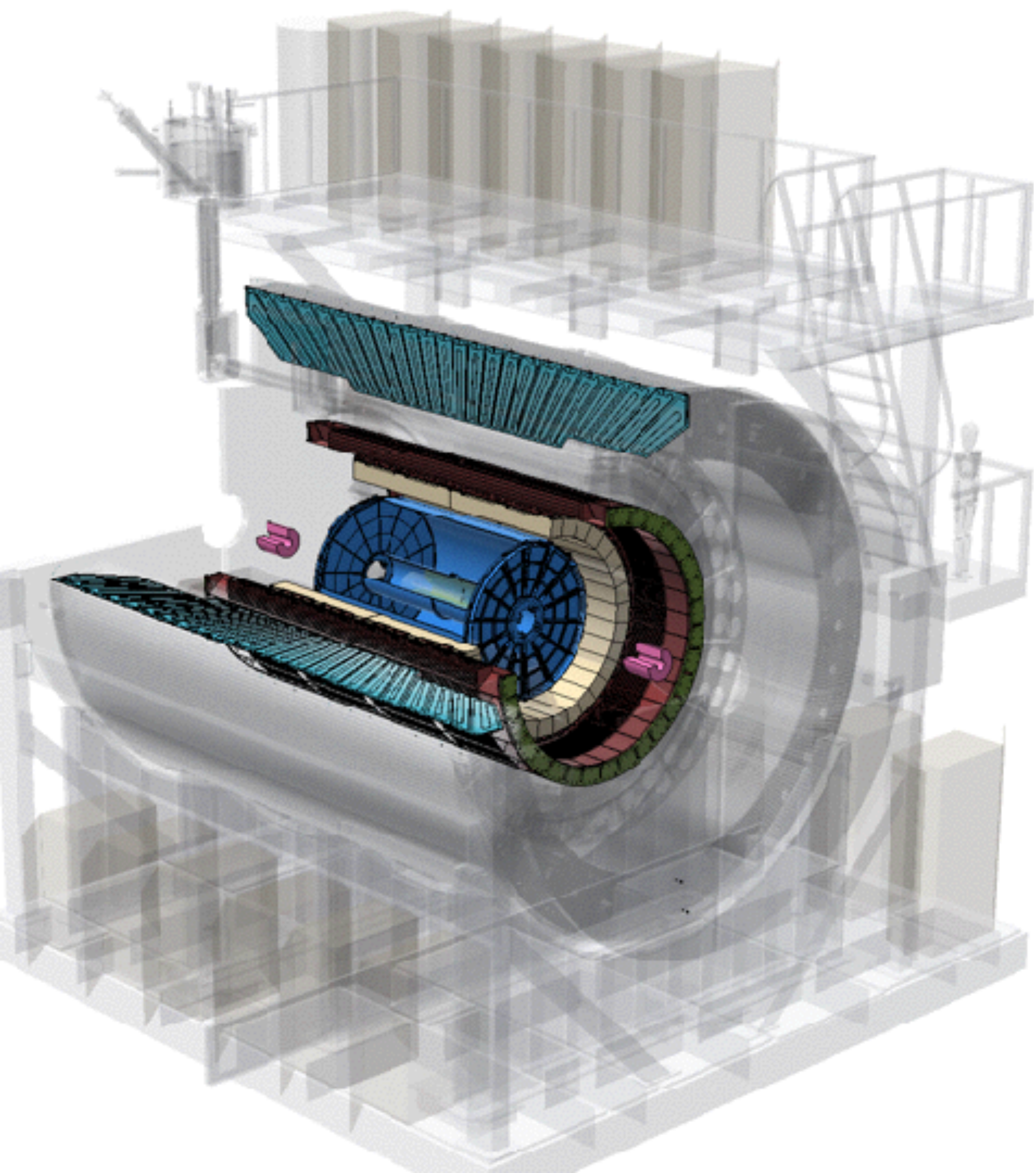


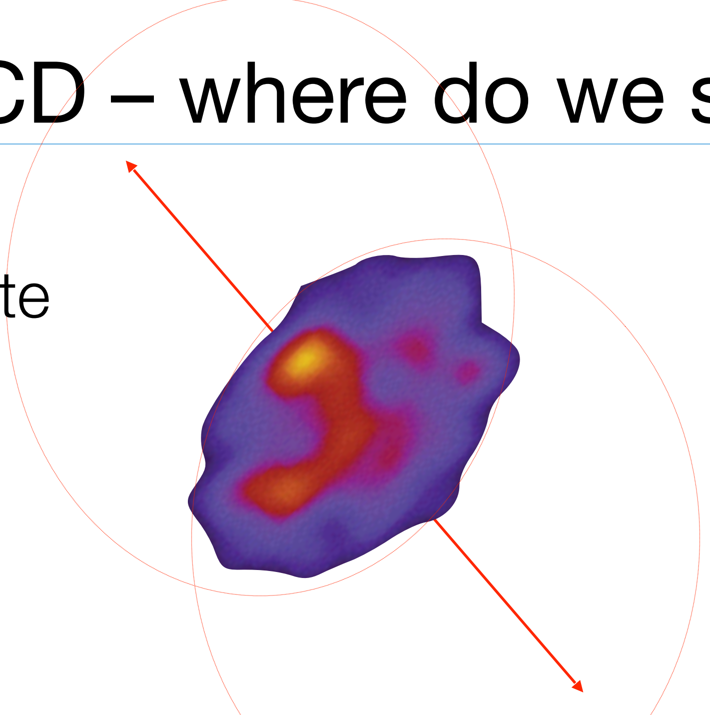
sPHENIX update

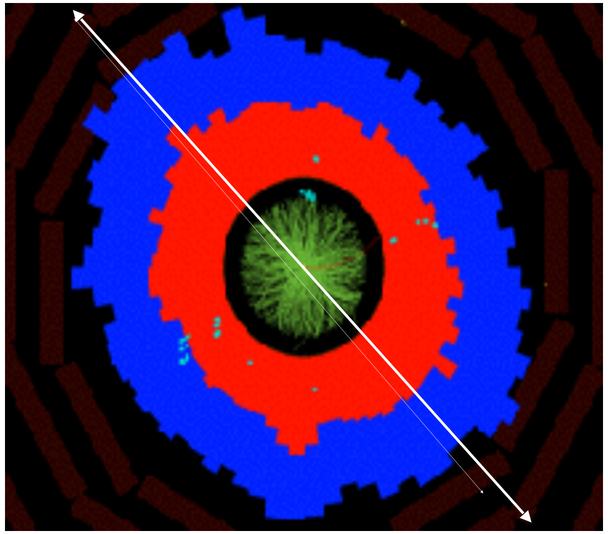
Dave Morrison (BNL)
Gunther Roland (MIT)
for the collaboration

Invitation to "present an update on sPHENIX, emphasizing its physics program and technical achievement to date"

Hot QCD – where do we stand

Initial state

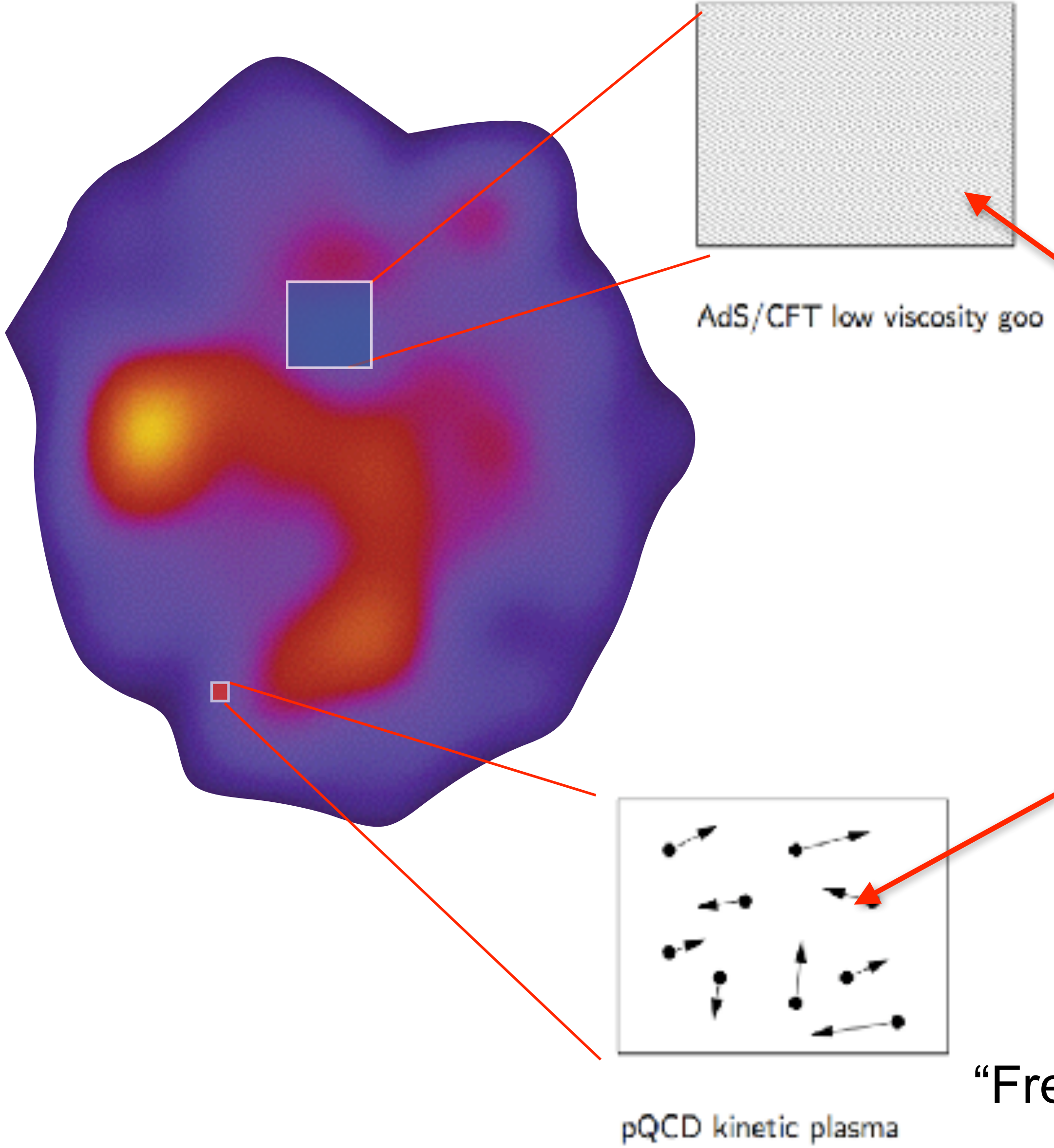




Experiment

- First RHIC results demonstrated surprising properties of **Quark-Gluon Plasma** created in heavy-ion collisions: near perfect fluidity and extreme opacity
- Precision studies at RHIC and LHC showed that many aspects of final state structure can be understood via relativistic viscous hydrodynamics applied to QGP evolution
- 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
- Coming decade: **Improved instrumentation at RHIC and LHC to understand emergence of QGP properties from underlying (asymptotically) weakly coupled interactions**

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?

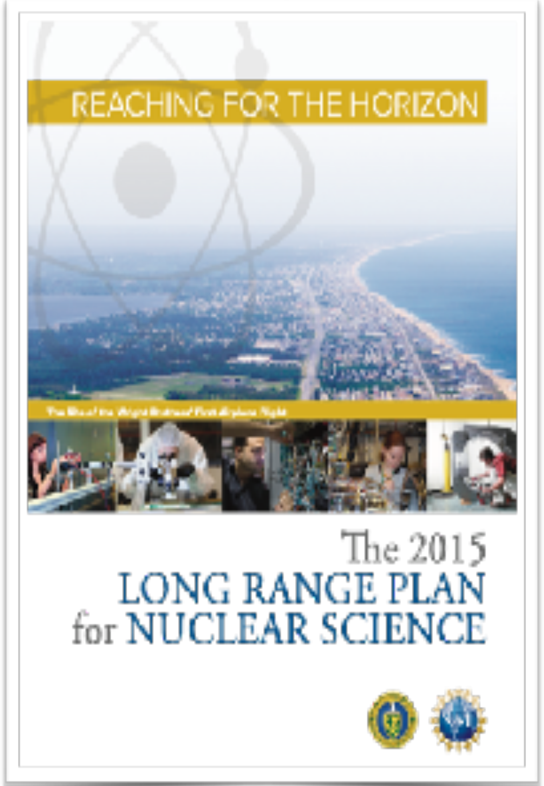
What is it's quasi-particle nature at intermediate scales?

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

"Free quarks and gluons"

sPHENIX science mission

2015 US NP LRP



Reaffirmed in ECFA heavy-ion (WG5) discussion

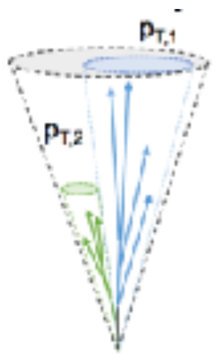
“Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of [RHIC and the LHC] is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX.”

WG5 for 2019 ECFA process

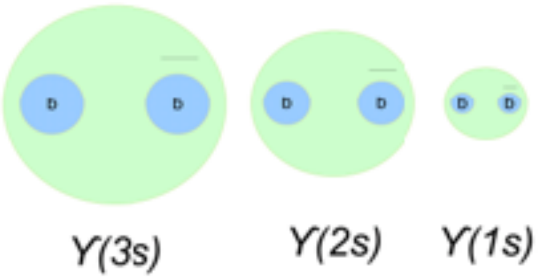

Conclusions of the Town Meeting
Relativistic Heavy Ion Collisions

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

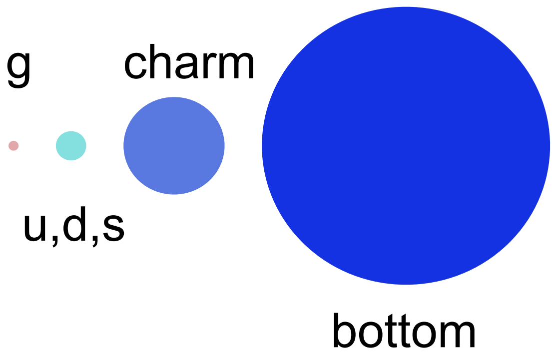
Hard Probes: sPHENIX ⊕ LHC



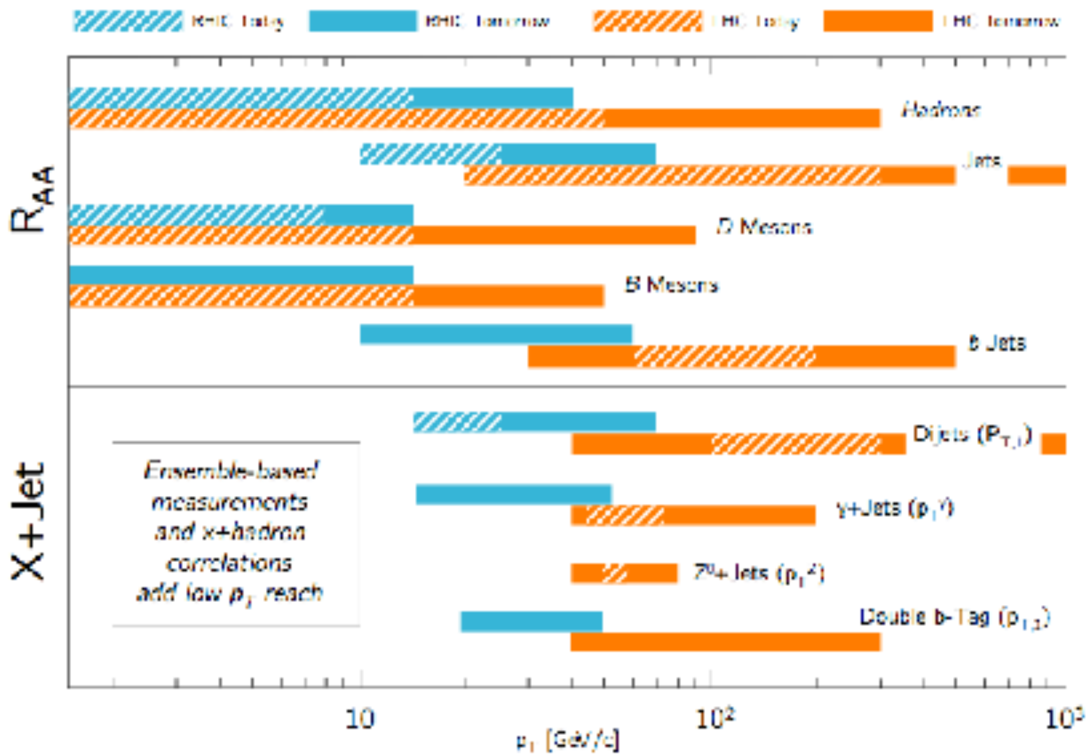
Jet structure
vary momentum/
angular scale of probe



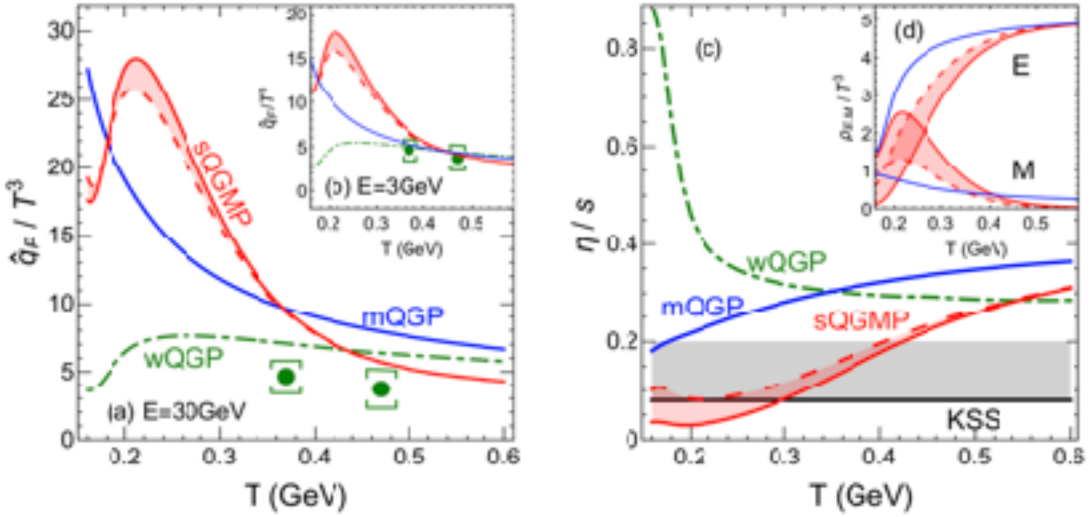
Quarkonium spectroscopy
vary size of probe



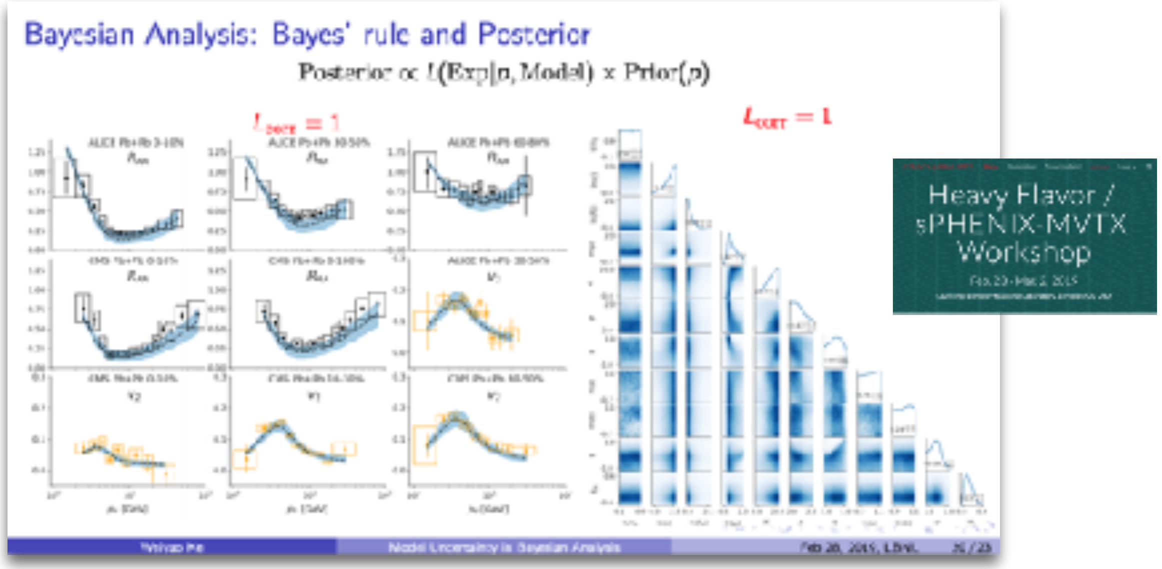
Parton energy loss
vary mass/momentum of probe



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).

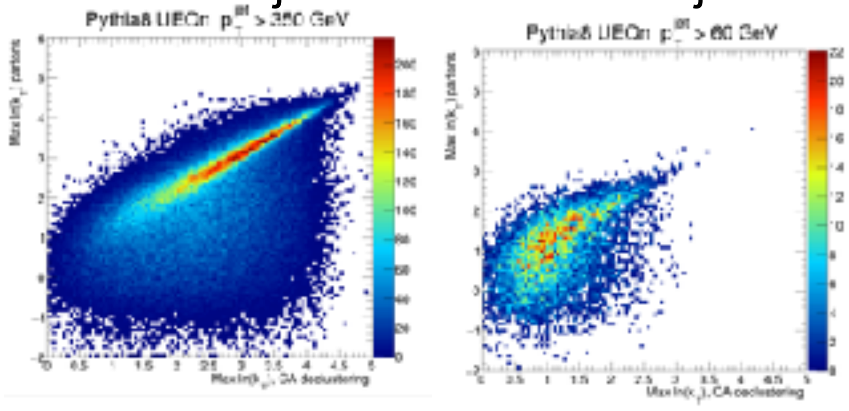
Key approach: Parton shower modification in QGP

sPHENIX

Parton shower

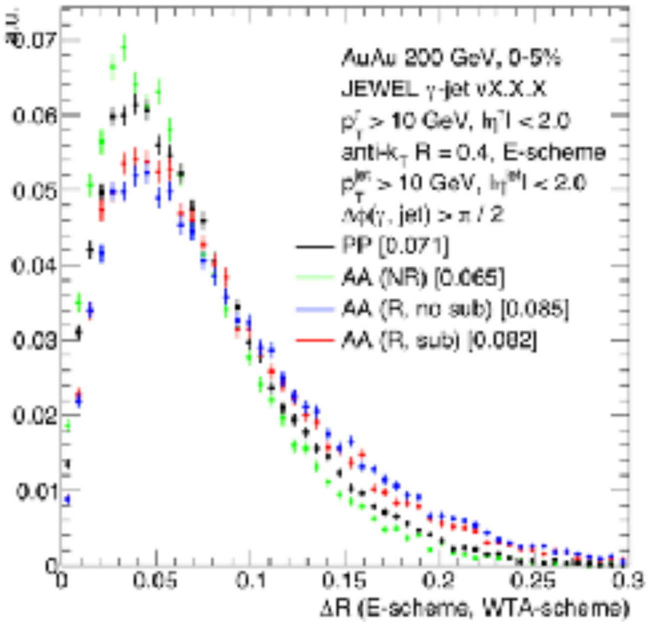
350GeV jets

60GeV jets



Hadron level C-A declustering

10GeV jets



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

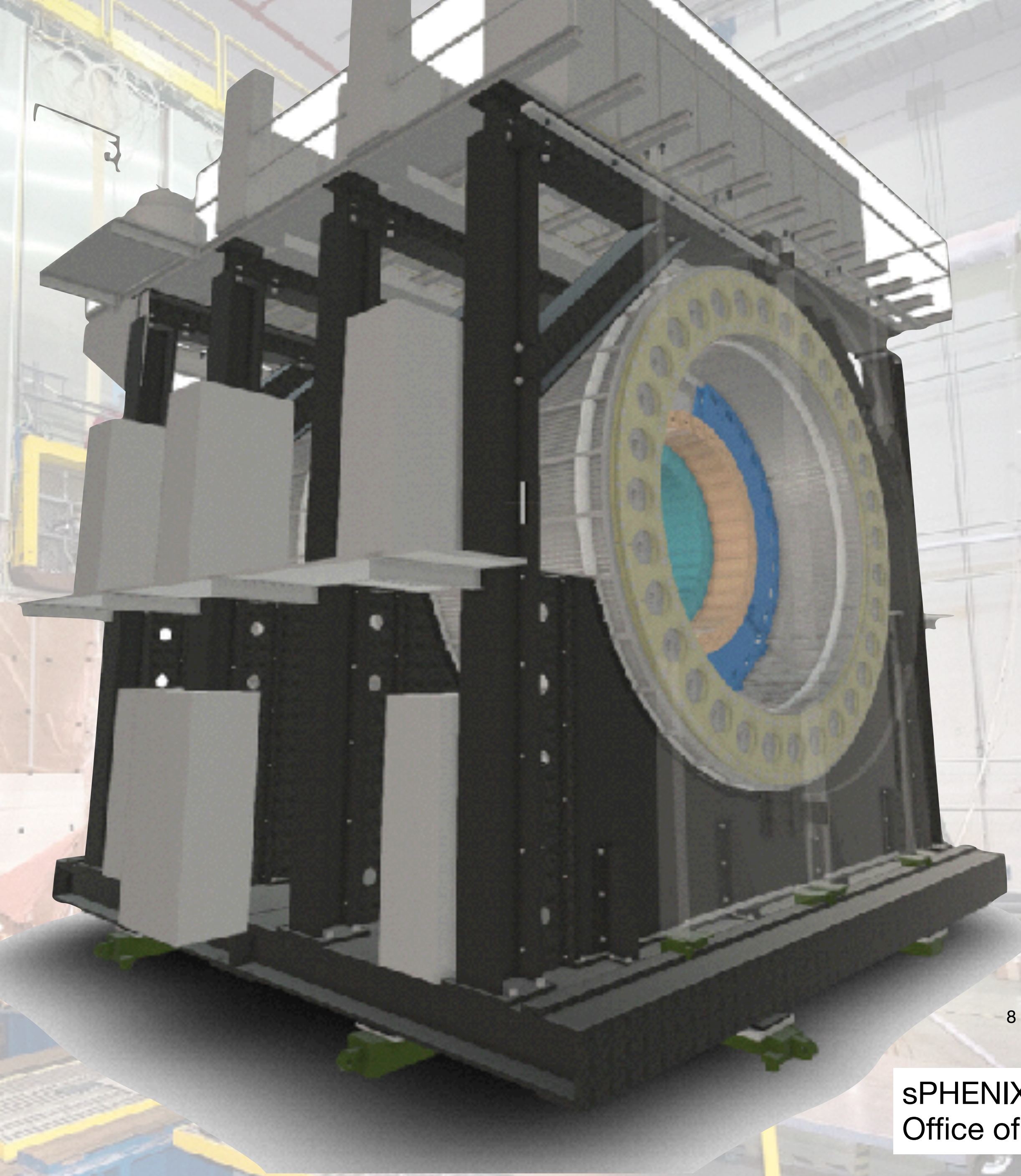
Increasing interest and significant progress regarding jet substructure modifications, e.g., JetTools workshops at CERN, Bergen, EMMI RRTF in Aug ’19

Decorrelation of jet axes in QGP for low p_T jets
“Moliere scattering”

Distinct strengths and drawbacks in different energy regimes

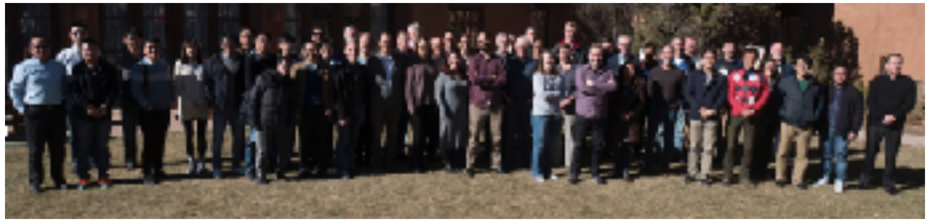
<u>sPHENIX is a major upgrade to the PHENIX detector</u>. It is a large-acceptance, high-rate detector for Heavy Ion physics that repurposes **>$20M** in existing PHENIX equipment, infrastructure and support facilities.

The detector is optimized to measure jet and heavy quark physics by incorporating a Time Projection Chamber, Electromagnetic and Hadronic Calorimeter with a high rate DAQ/Trigger and a **1.4 T solenoidal magnetic field**.



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

sPHENIX collaboration

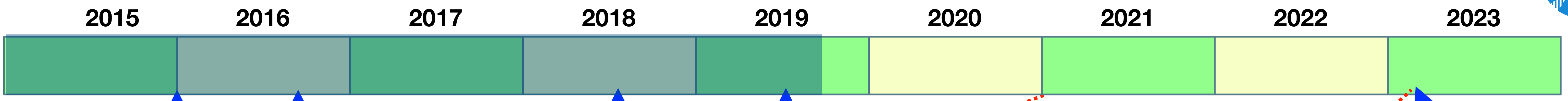


- Steady growth after CD-0
  - 18 new institutions (77 total)
  - about 25% non-US institutions
- CERN recognized experiment (April ’19)
- Steady evolution of collaboration organization

List of Recognized Experiments

Ref.	Experiment	RE status at CERN 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 science collaboration

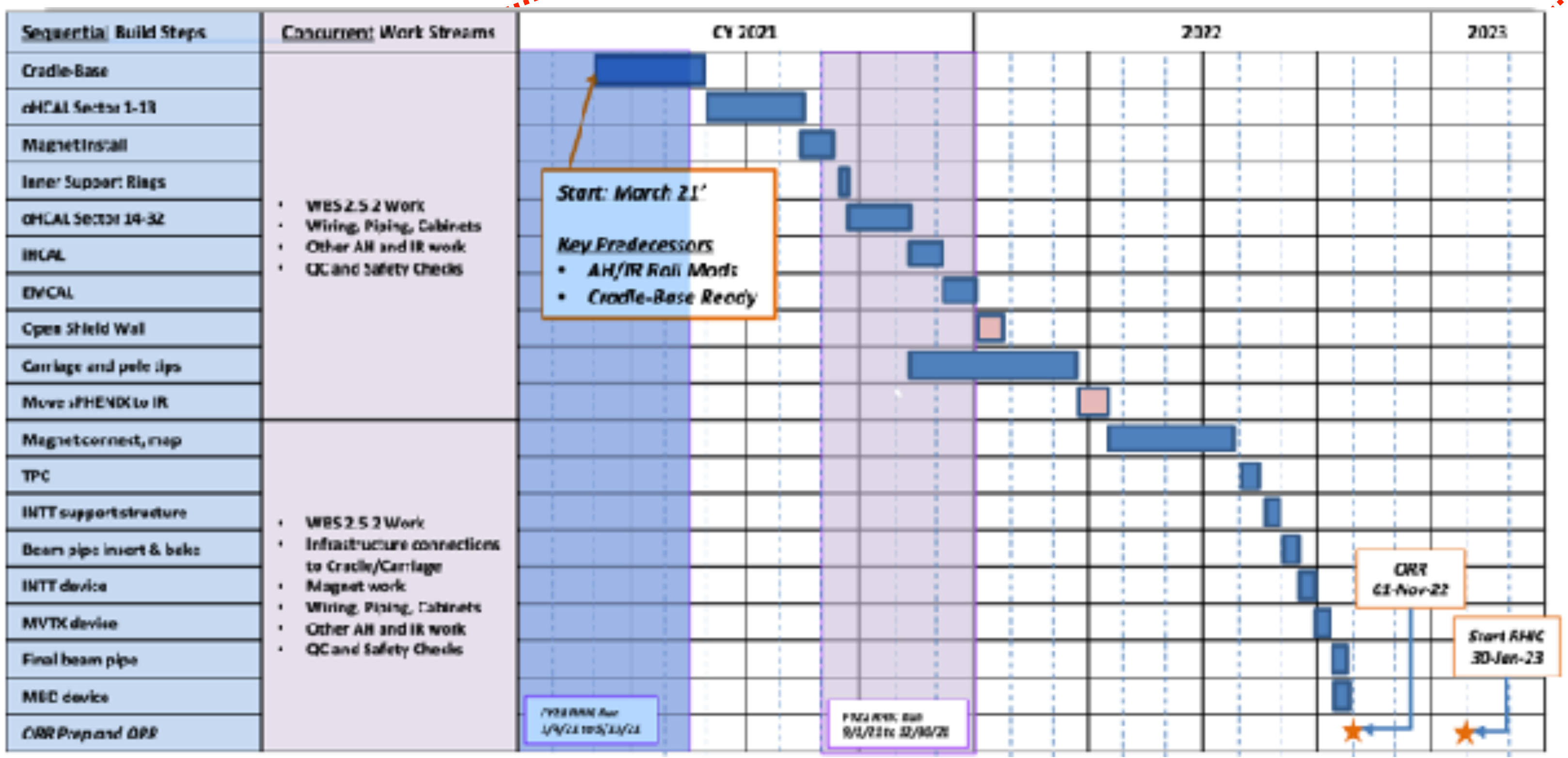
DOE CD-0
"Mission need" approval

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

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

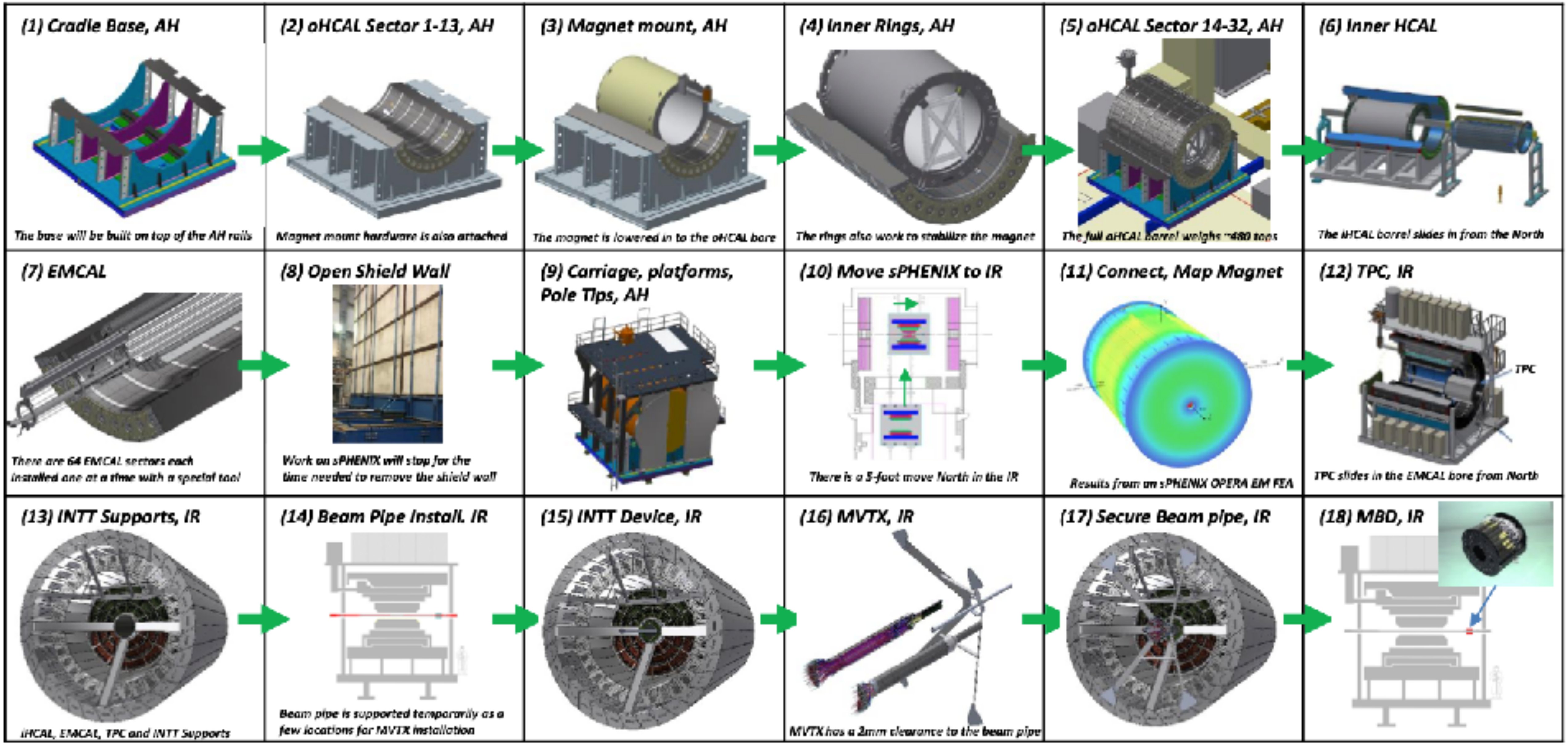
Installation & commissioning

Start physics data taking



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

sPHENIX installation



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

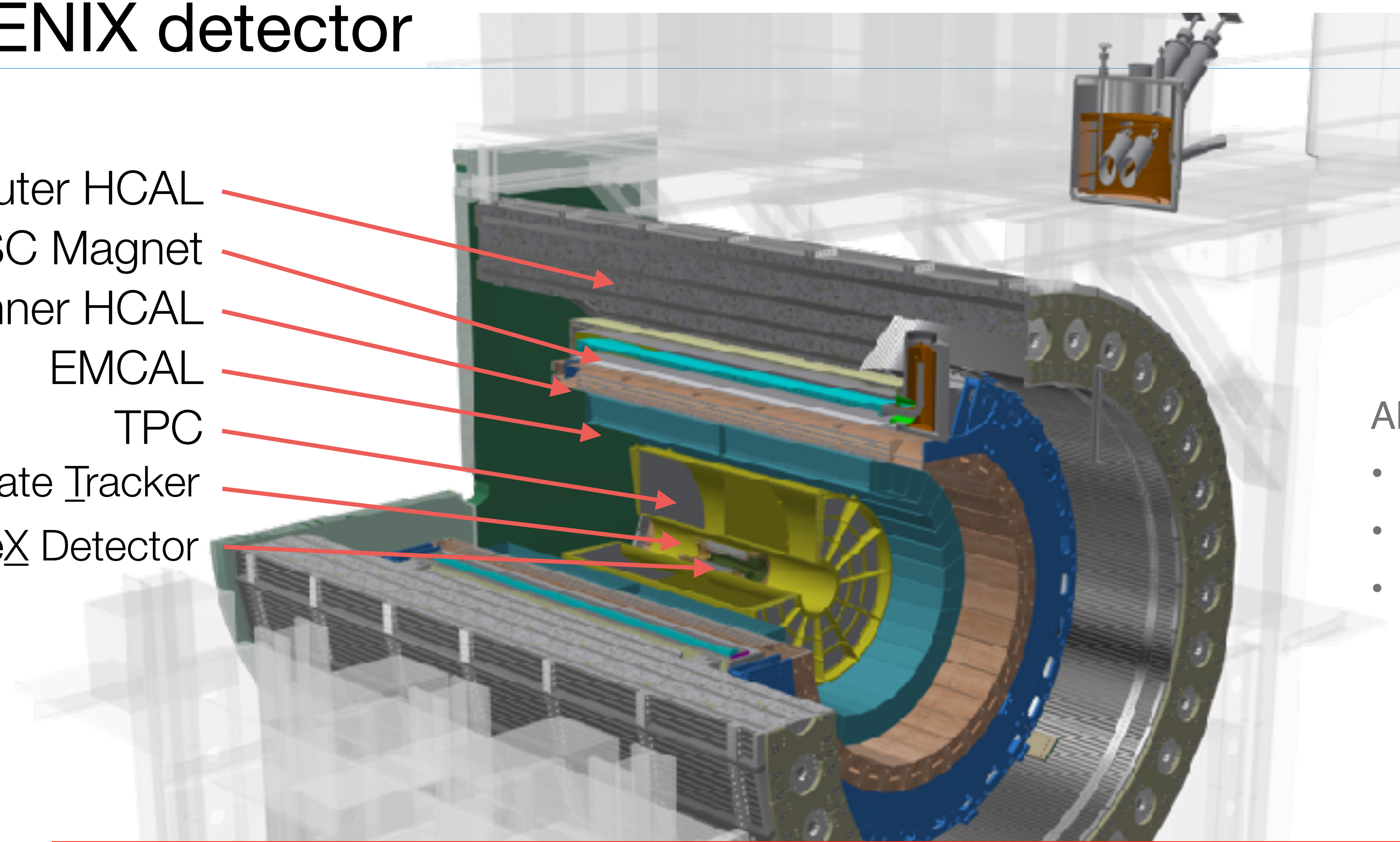
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

Physics goals → Detector performance

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 Υ(1s), Υ(2s), (Υ3s) states	**Υ(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 detector



All detectors:

- $-1.1<\eta<1.1$
- 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

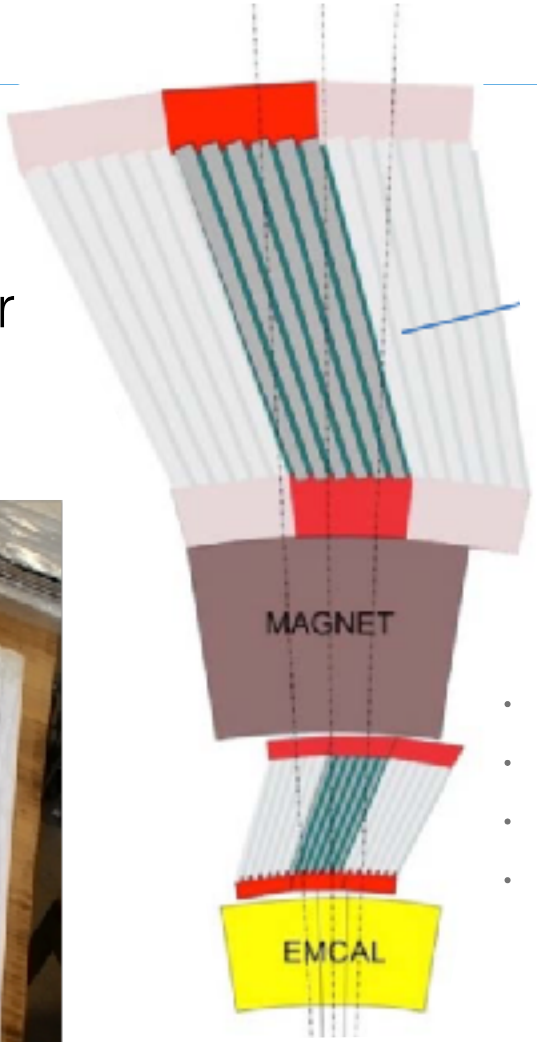
Employ proven and cost-effective detector technology

sPHENIX magnet

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

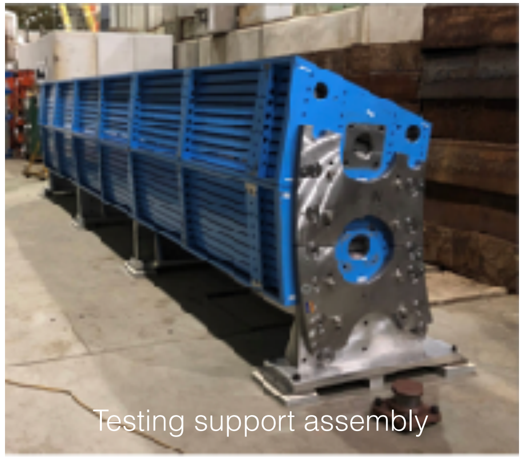
HCAL

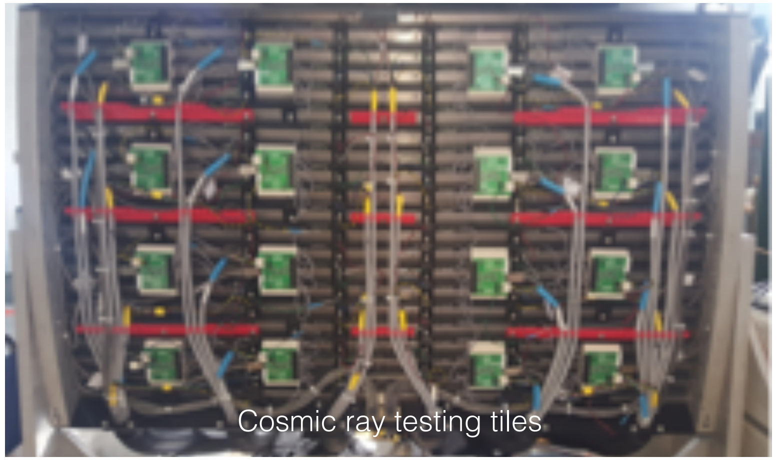
- Provides energy resolution for hadrons and jets
- Scintillating tiles interleaved in steel magnetic flux return
- Analog SiPM signals from 5 tiles combined into one tower
- 48 towers ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$) per sector
- 32 azimuthal sectors 6.3m x 0.7m, 13.5 tons each



- Outer HCAL ~3.5λ_I
- Magnet ~1.4X_0
- Frame ~0.25λ_I
- EMCAL ~18X_0 ≈ 0.7λ_I

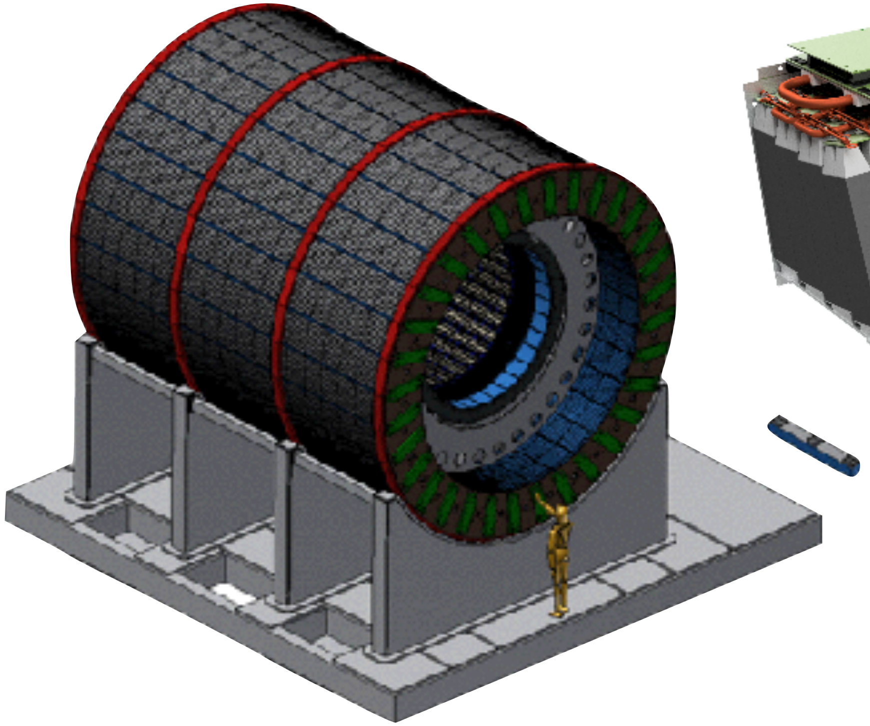
HCAL in real life

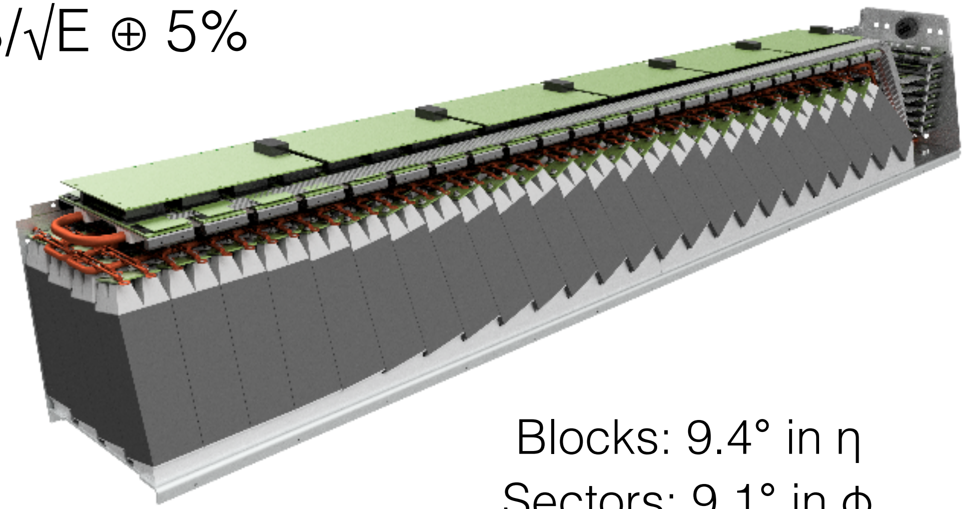


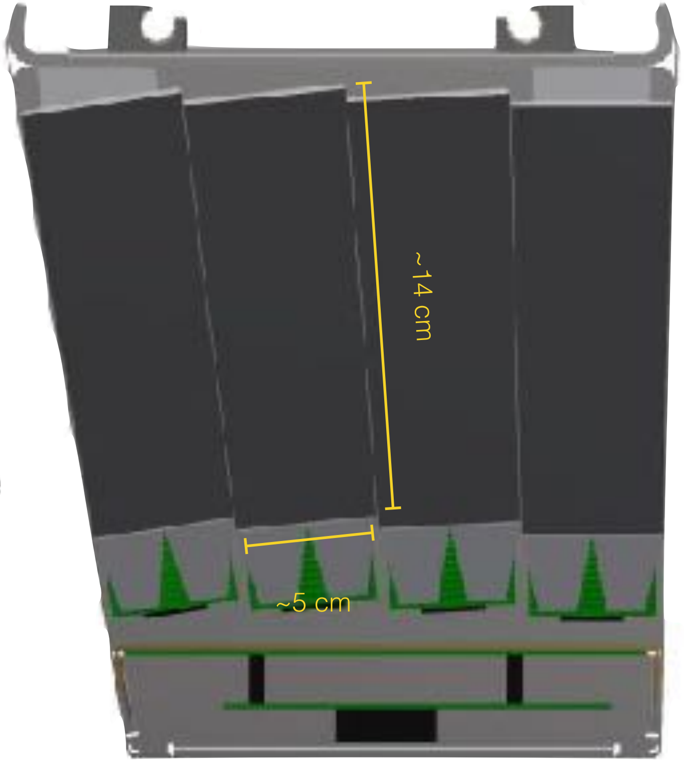


EMCAL

- 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: $< 16\%/\sqrt{E} \oplus 5\%$

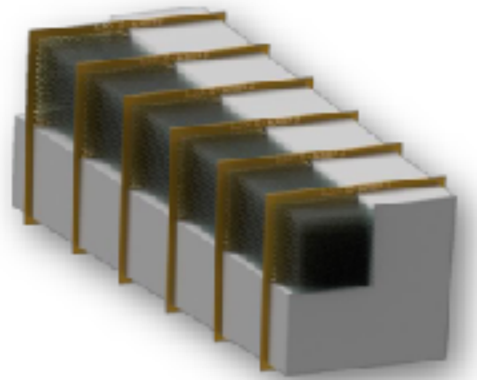




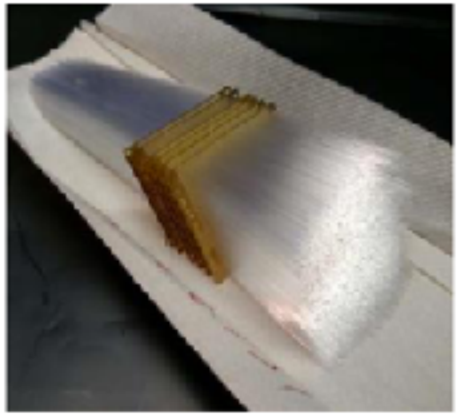


Blocks: 9.4° in η
Sectors: 9.1° in ϕ

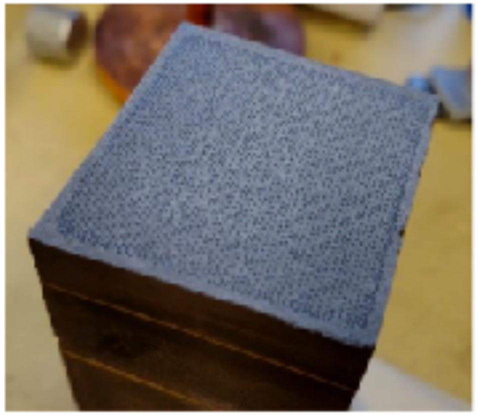
EMCAL in real life



2D Projective Block with Screens

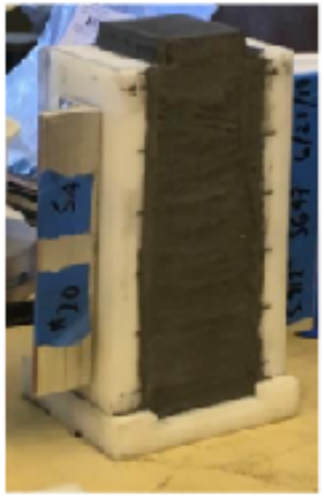


Fiber Assembly



Fibers are tapered inward at readout end to improve light collection

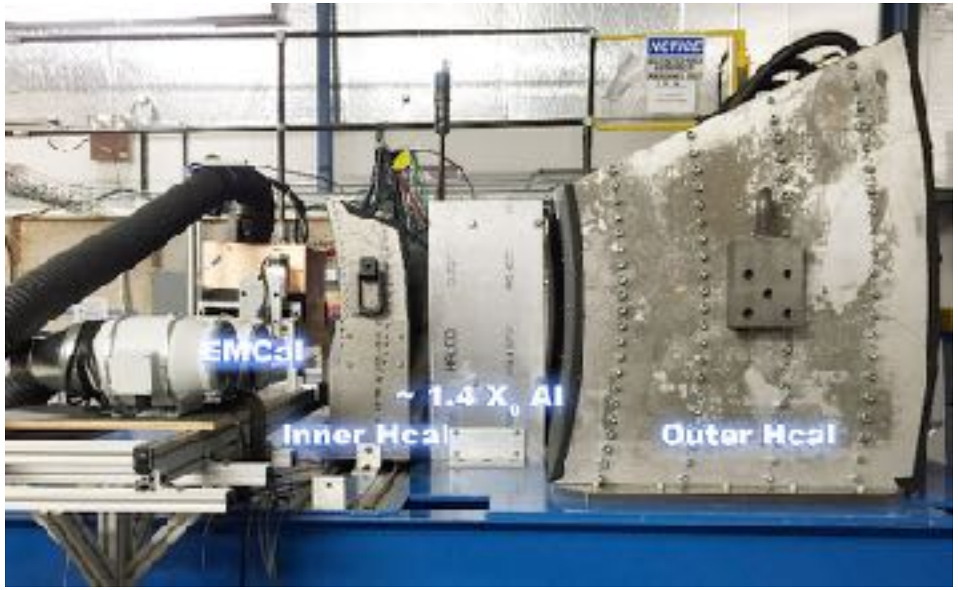
Mold for casting blocks

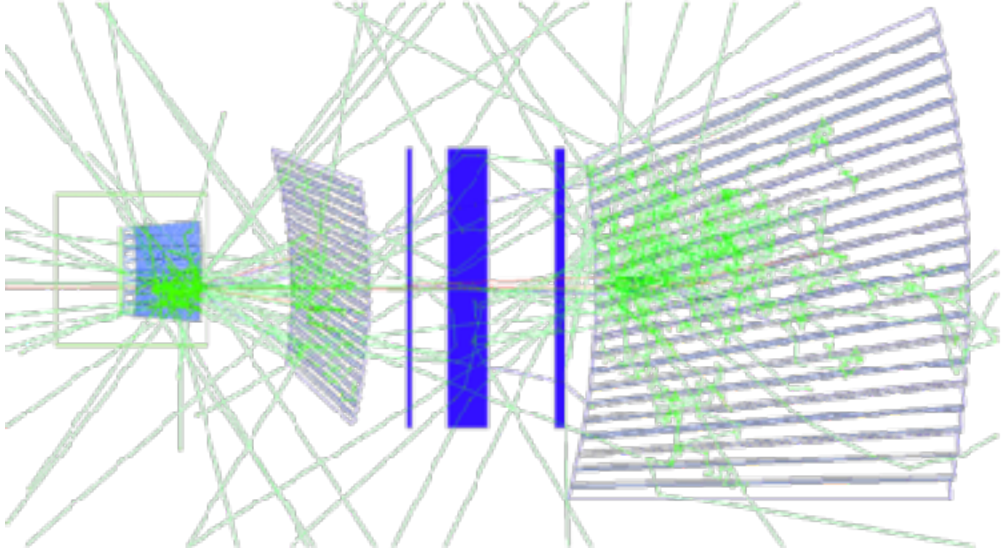


Finished 2D projective block

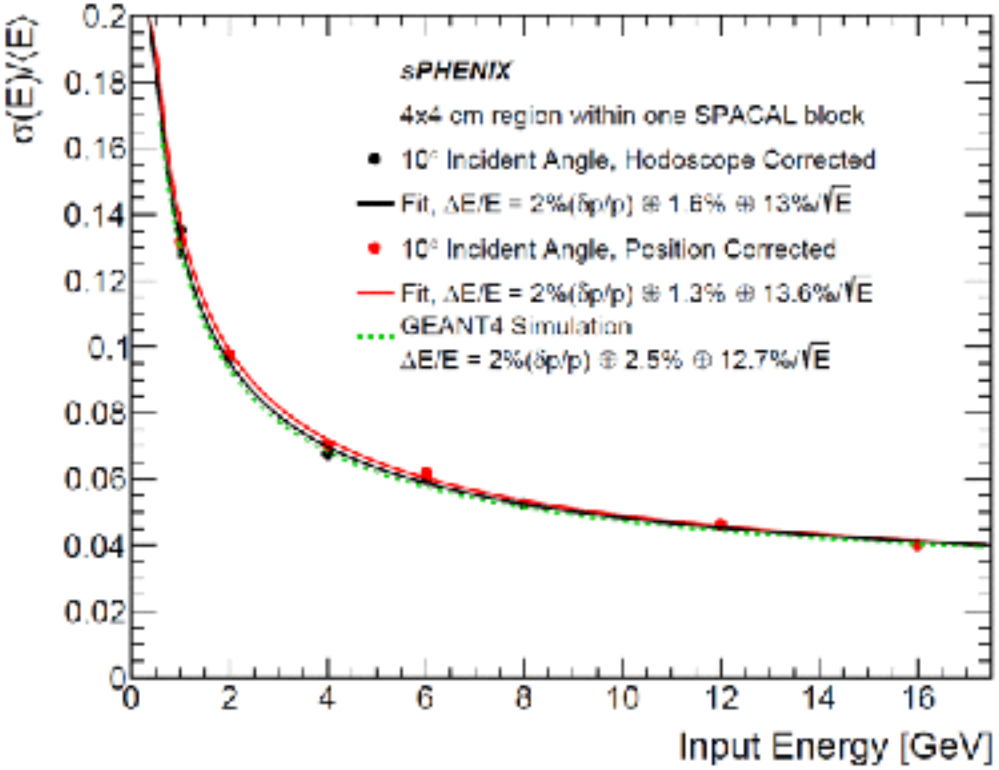
Full size “sector 0” prototype completed August 2019

Calorimeter stack beam test



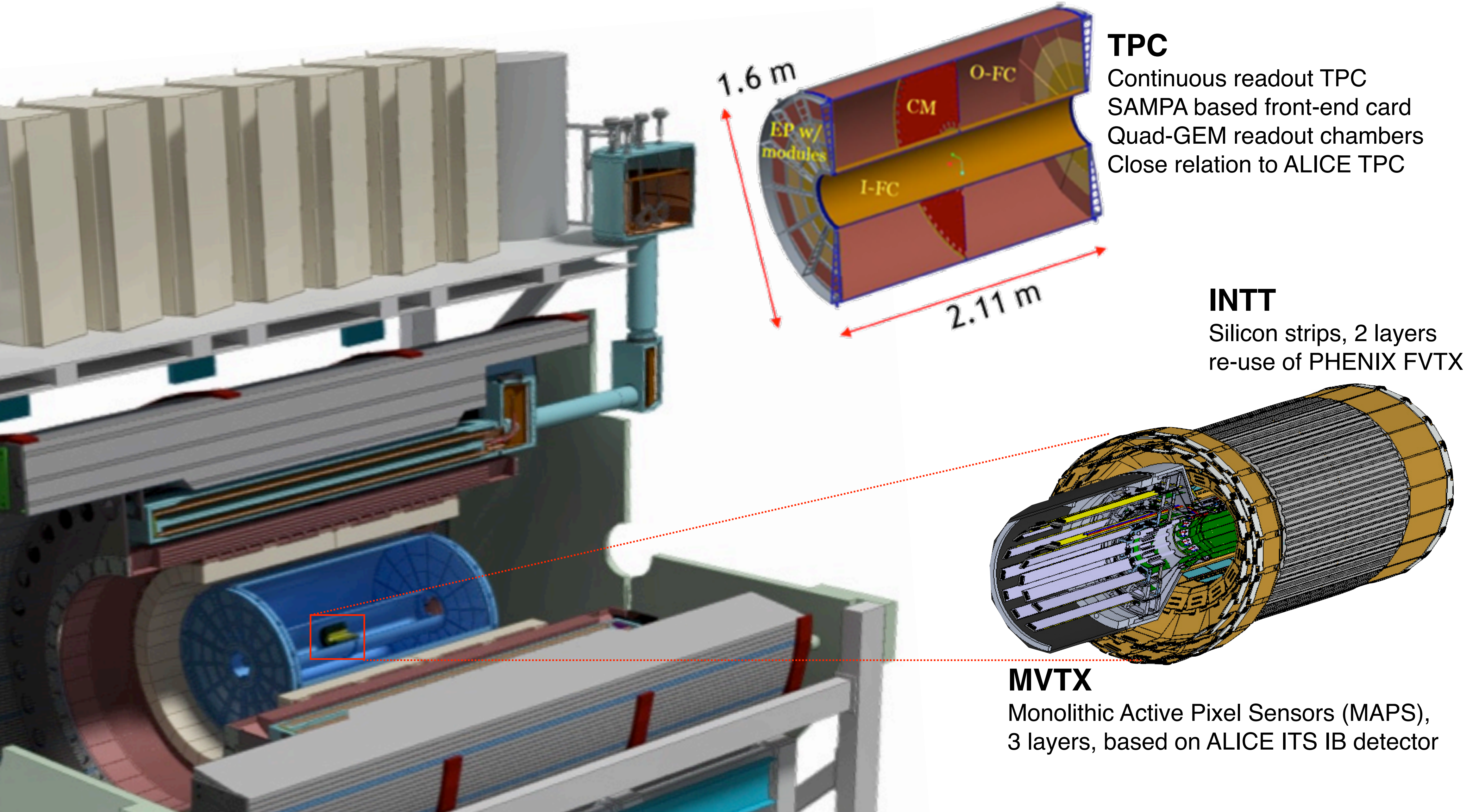


Calorimeter energy resolution



Measured performance matches simulations and meets (exceeds) performance goals

sPHENIX tracking subdetectors



TPC

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

INTT

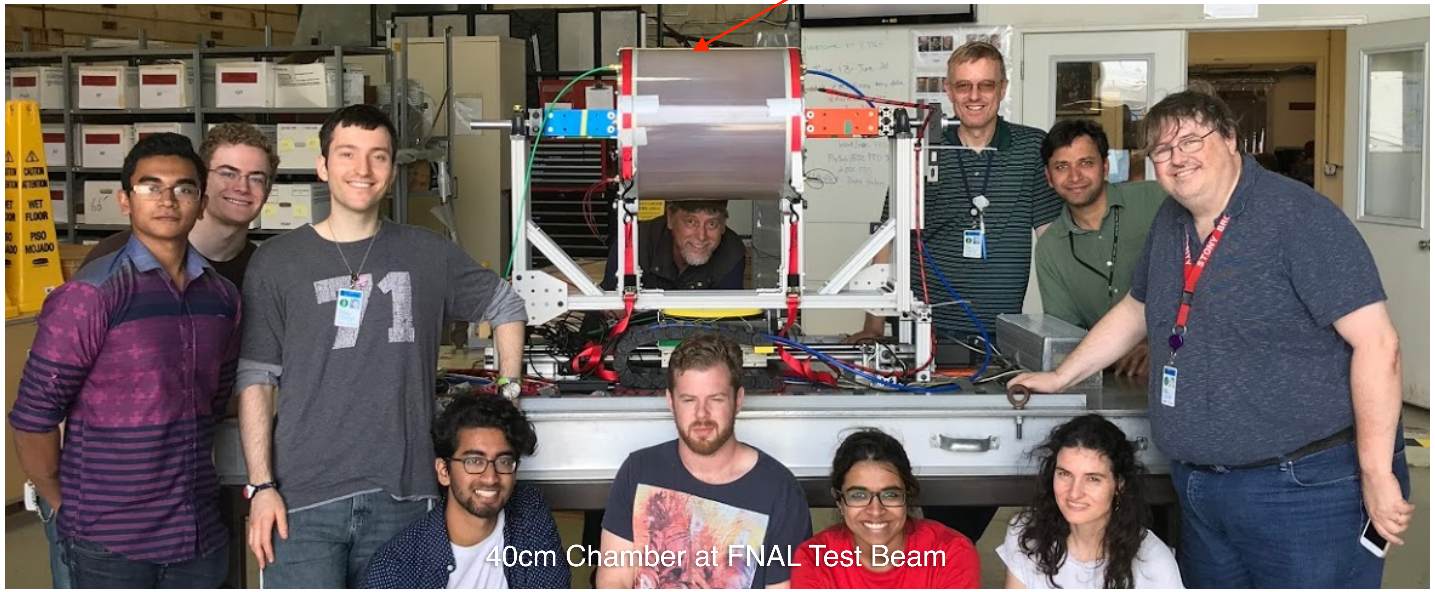
Silicon strips, 2 layers
re-use of PHENIX FVTX electronics

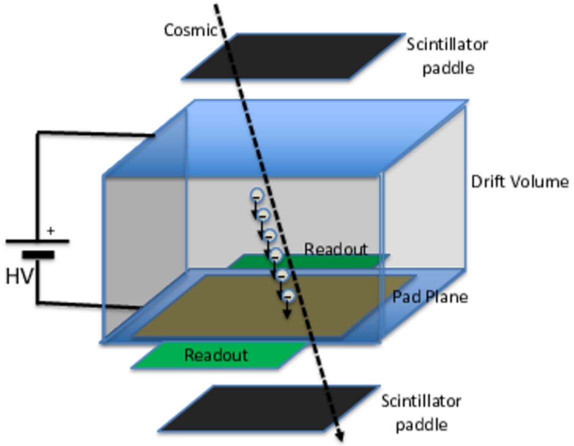
MVTX

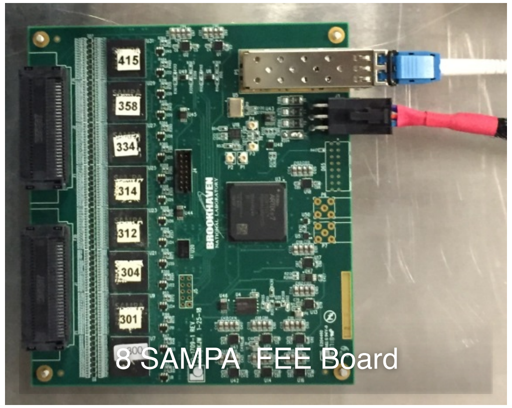
Monolithic Active Pixel Sensors (MAPS),
3 layers, based on ALICE ITS IB detector

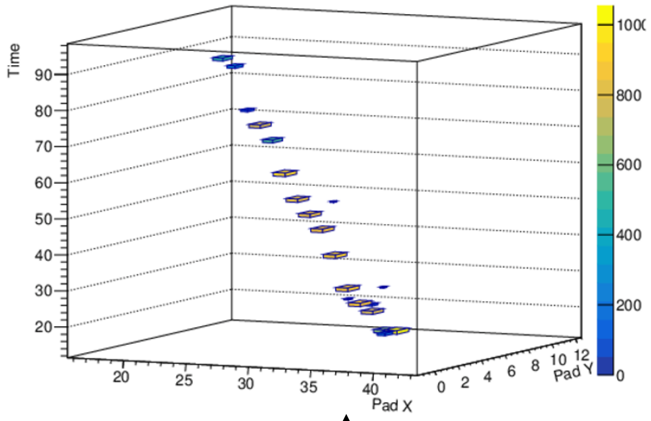
TPC in real life

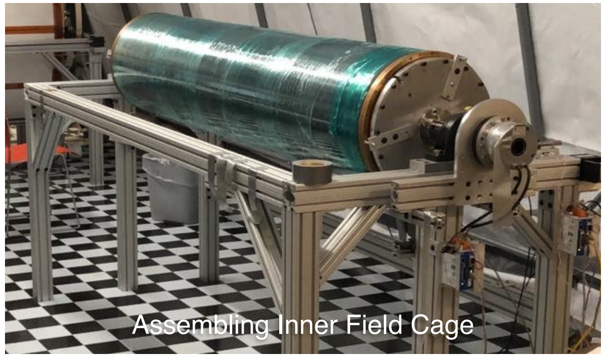
test beam prototype chamber







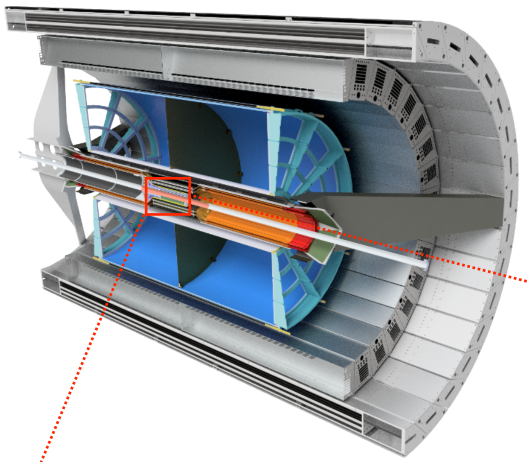


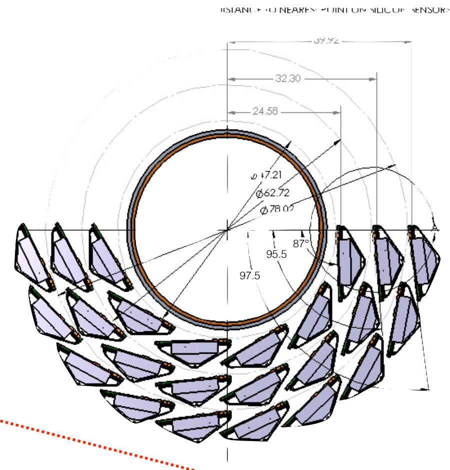


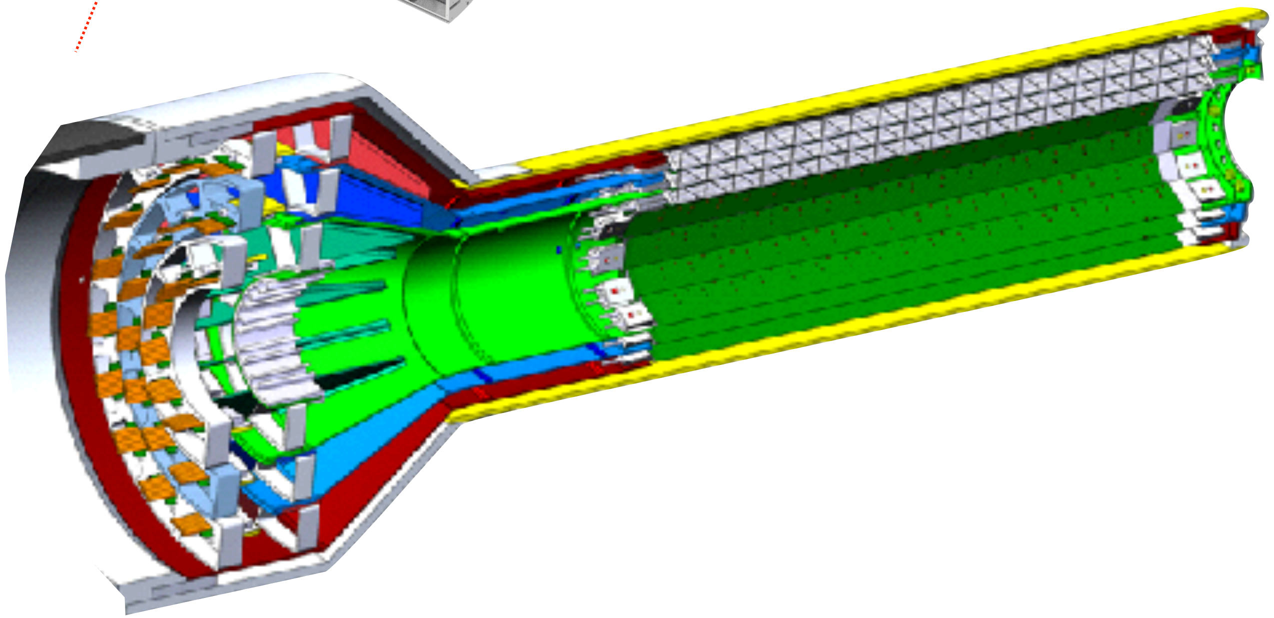
Full chain readout

Microvertex detector (MVTX)

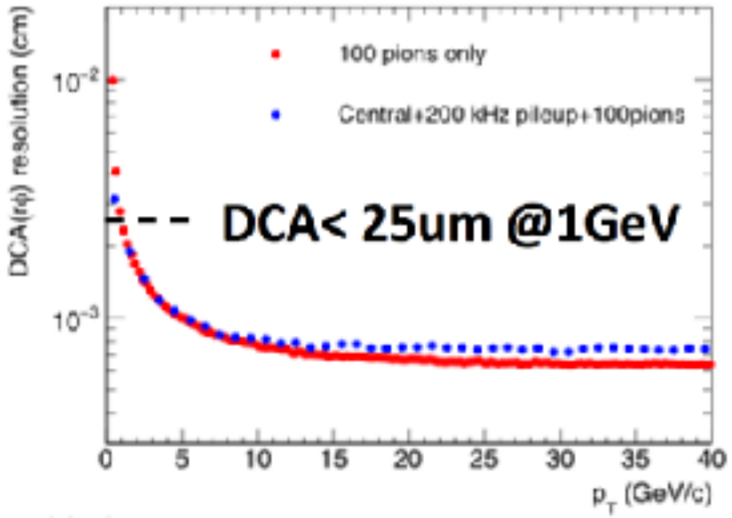
- Provides spatial resolution for displaced vertices
- 3 layers of hermetic Monolithic Active Pixel sensors
- ALICE ITS design modified to fit sPHENIX envelope



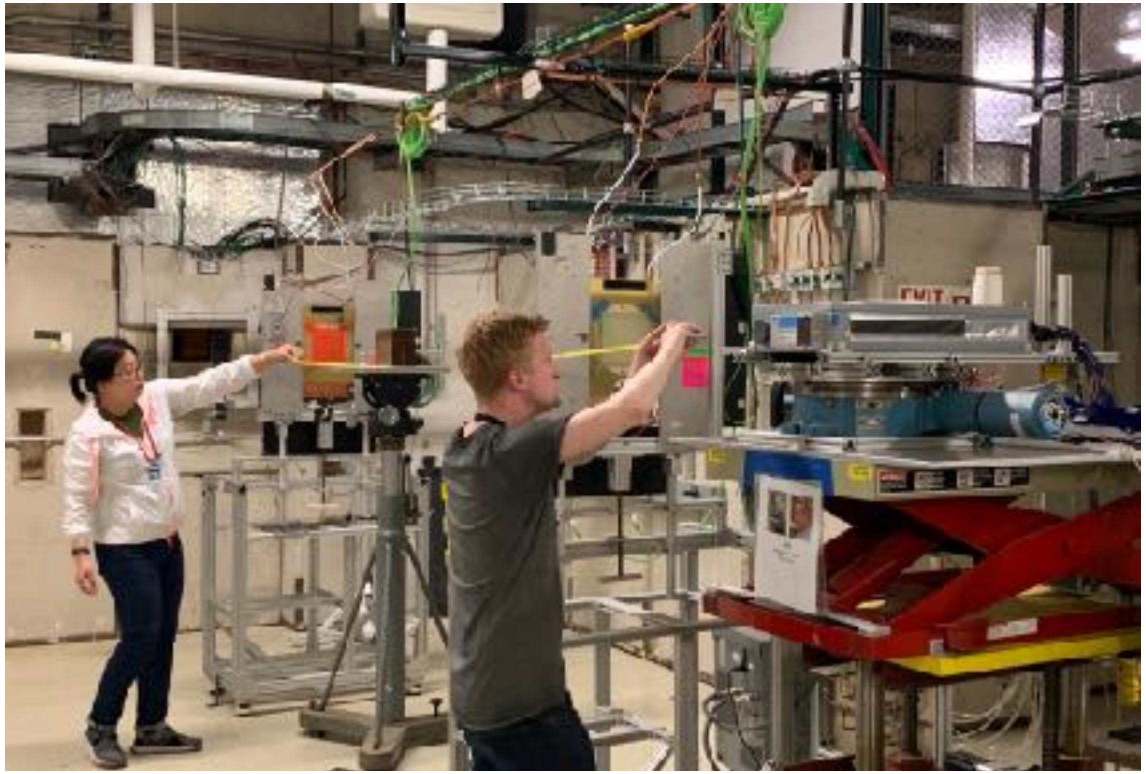


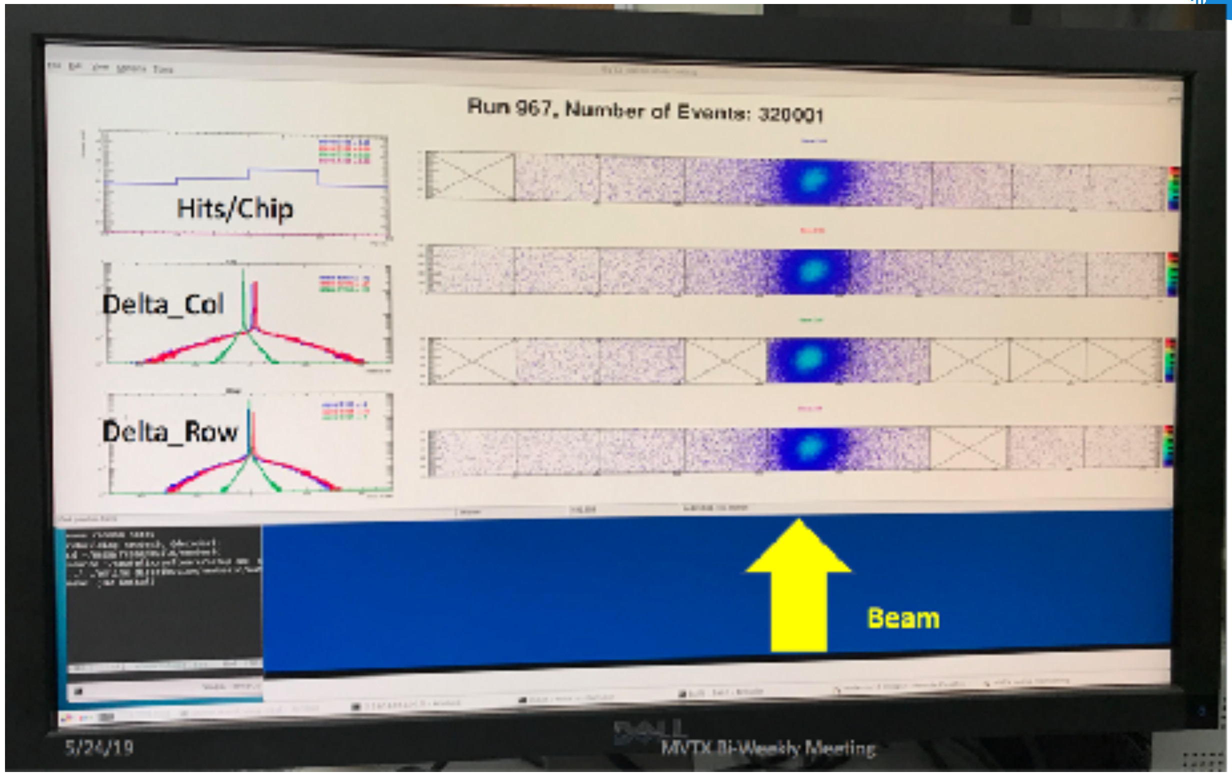


Displaced Vertex Resolution



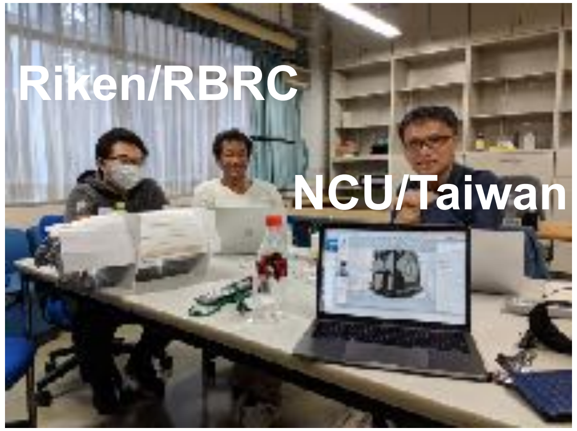
MVTX test beam



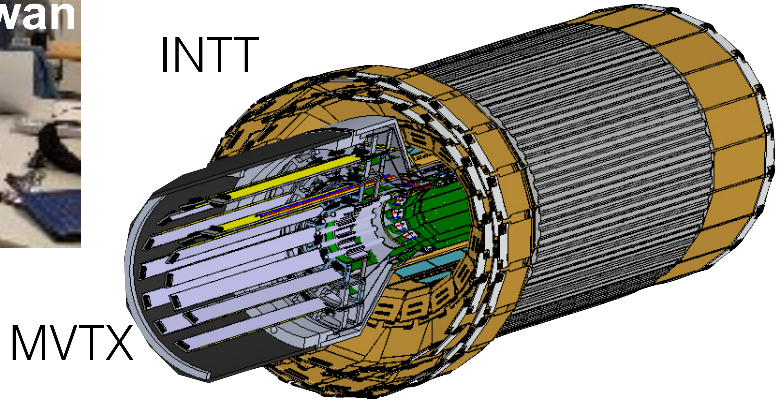


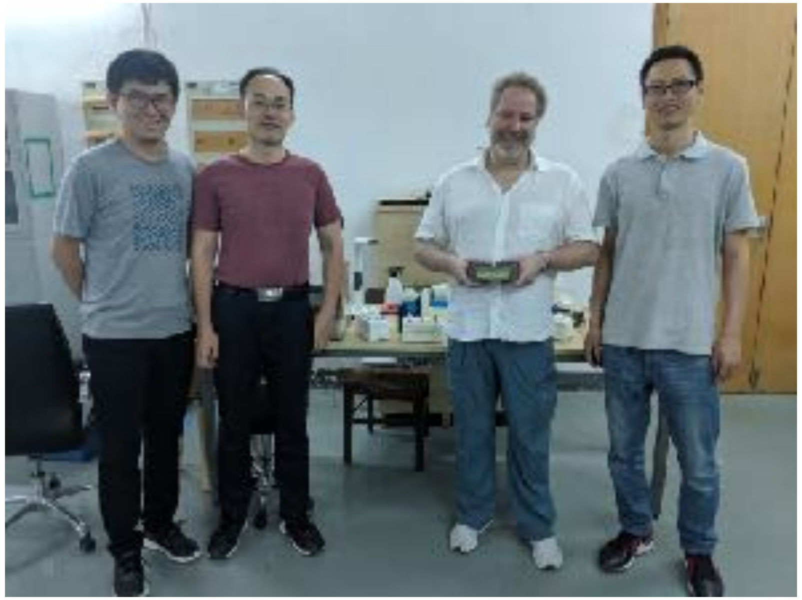
- 2019 test of telescope with full readout and cables just completed (May 25)
- Readout tested up to 300kHz with p beam and p-on-Pb sprays (sPHENIX requirement 15kHz)
- Expected hit resolution verified
- Stave production underway in CERN ALICE ITS facility

Contributions from non-US institutions



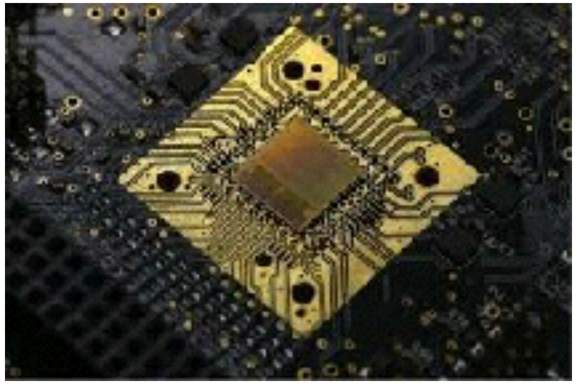
INTT contributed by Riken
assembly/testing at NCU/Taiwan





EMCal prototype blocks at
Fudan University

Block production to extend
EMCAL acceptance to |η| < 1.1
by Chinese consortium



Sampa TPC FE chip
sPHENIX specific v5
U. Sao Paulo

PHENIX MBD
Hiroshima U.

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

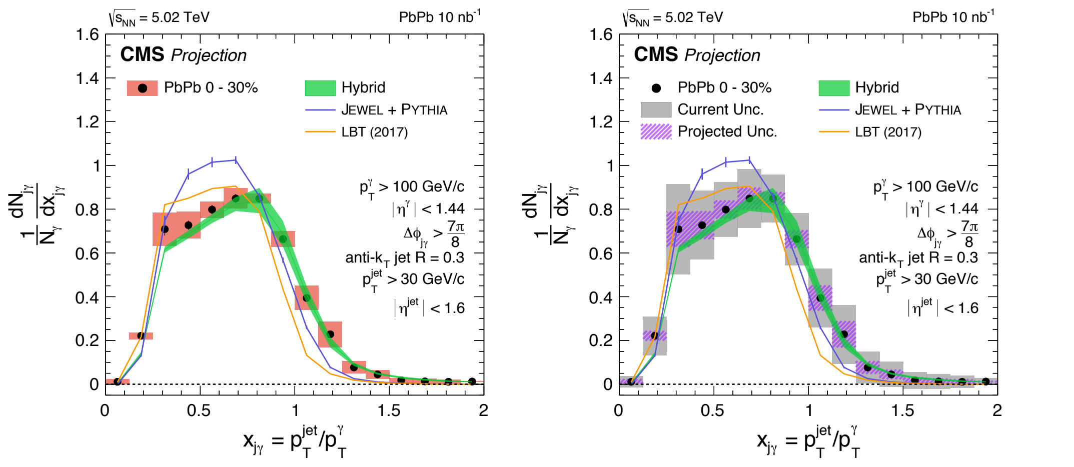
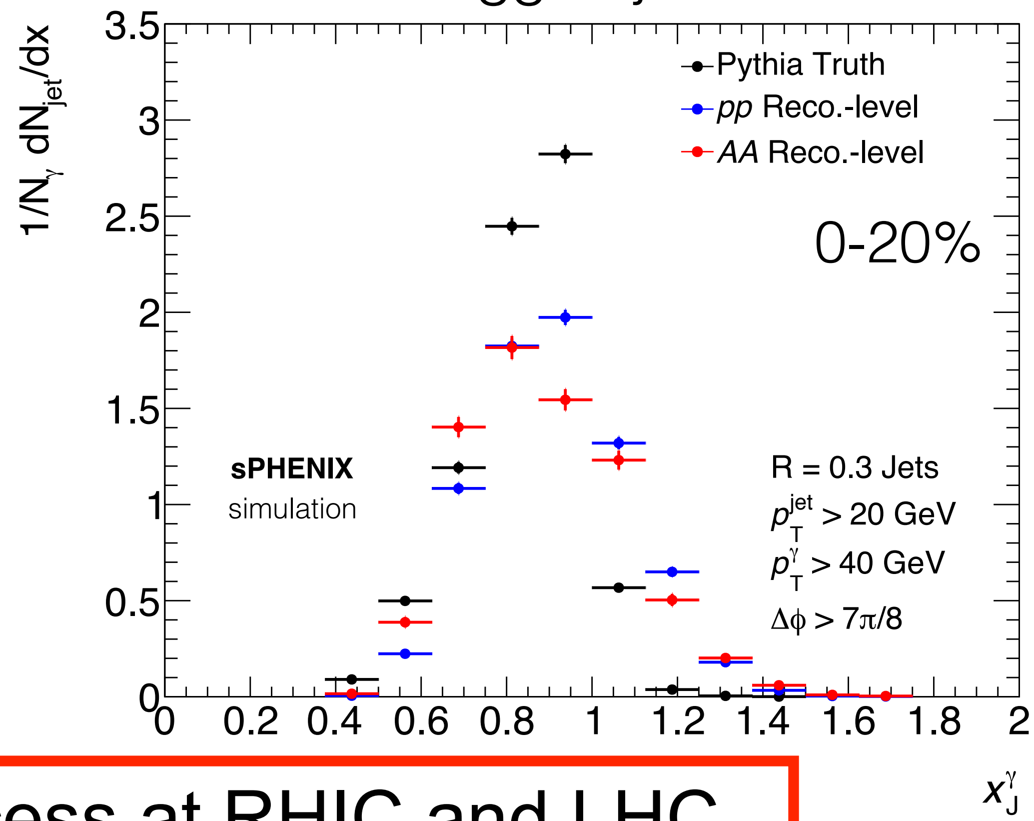


Fig. 29: (Left Panel) Photon-jet momentum balance $x_{j\gamma}$ distribution for isolated-photon+jets of $p_\gamma >$ 100 GeV/c and $|\eta_\gamma| < 1.44$, $p_{\text{jet}} > 30$ GeV/c and $|\eta_{\text{jet}}| < 1.6$ in the HL-LHC data (Right Panel). Comparison between the current performance with 0.4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

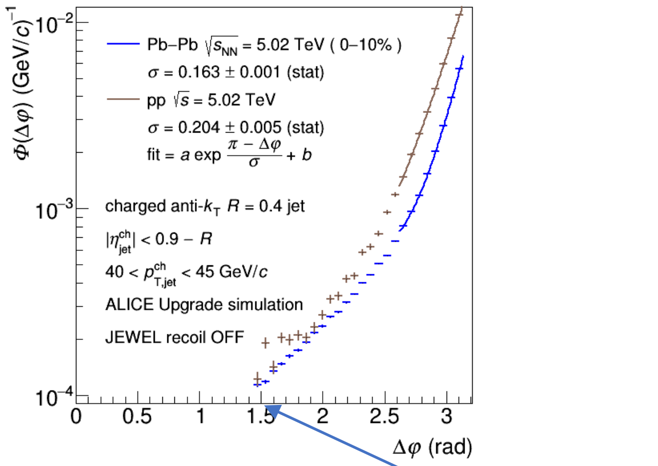
Photon-tagged jets in sPHENIX



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

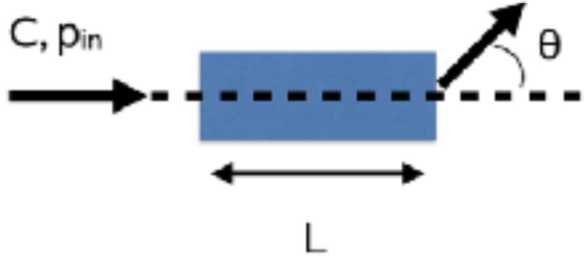


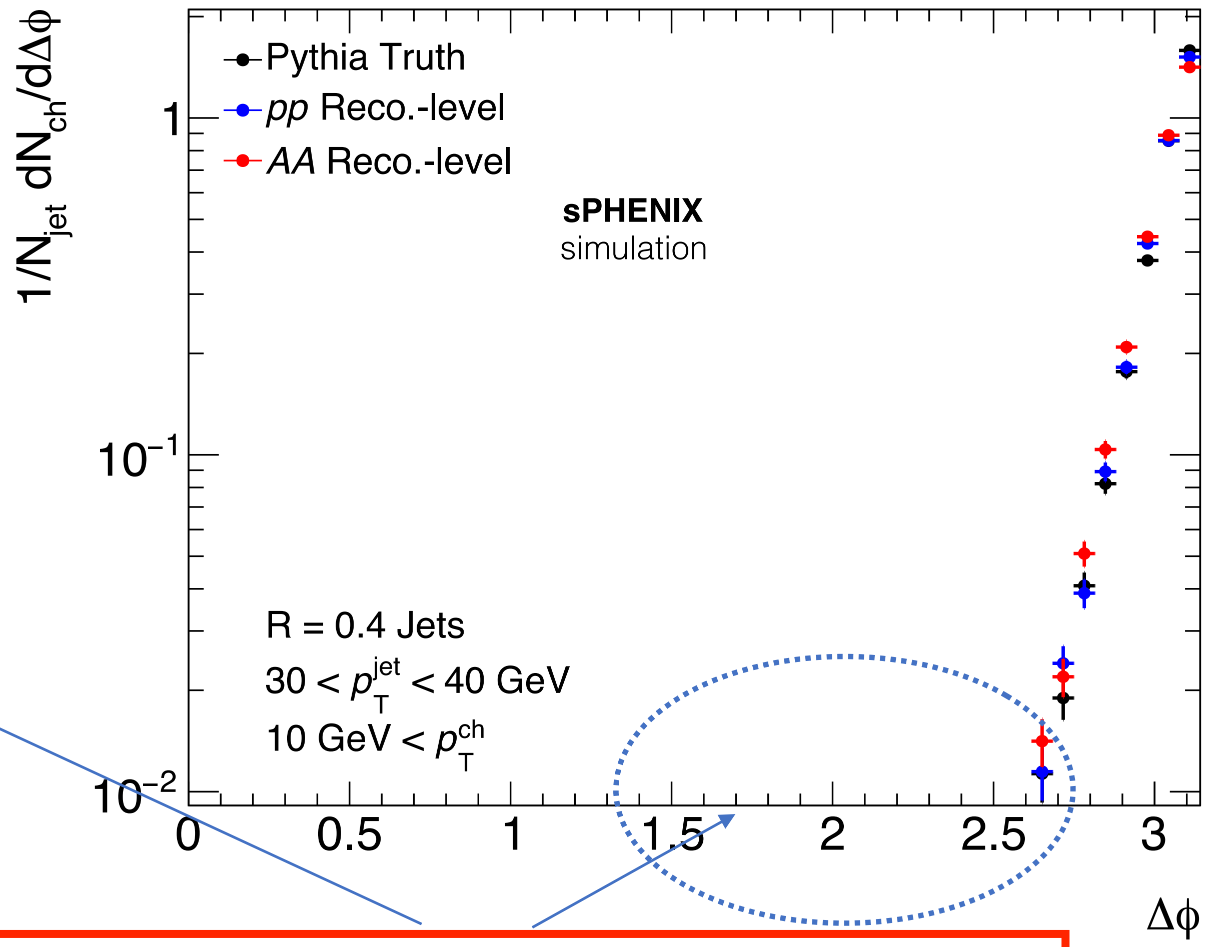
CERN Yellow Report projections for Runs 3, 4

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]

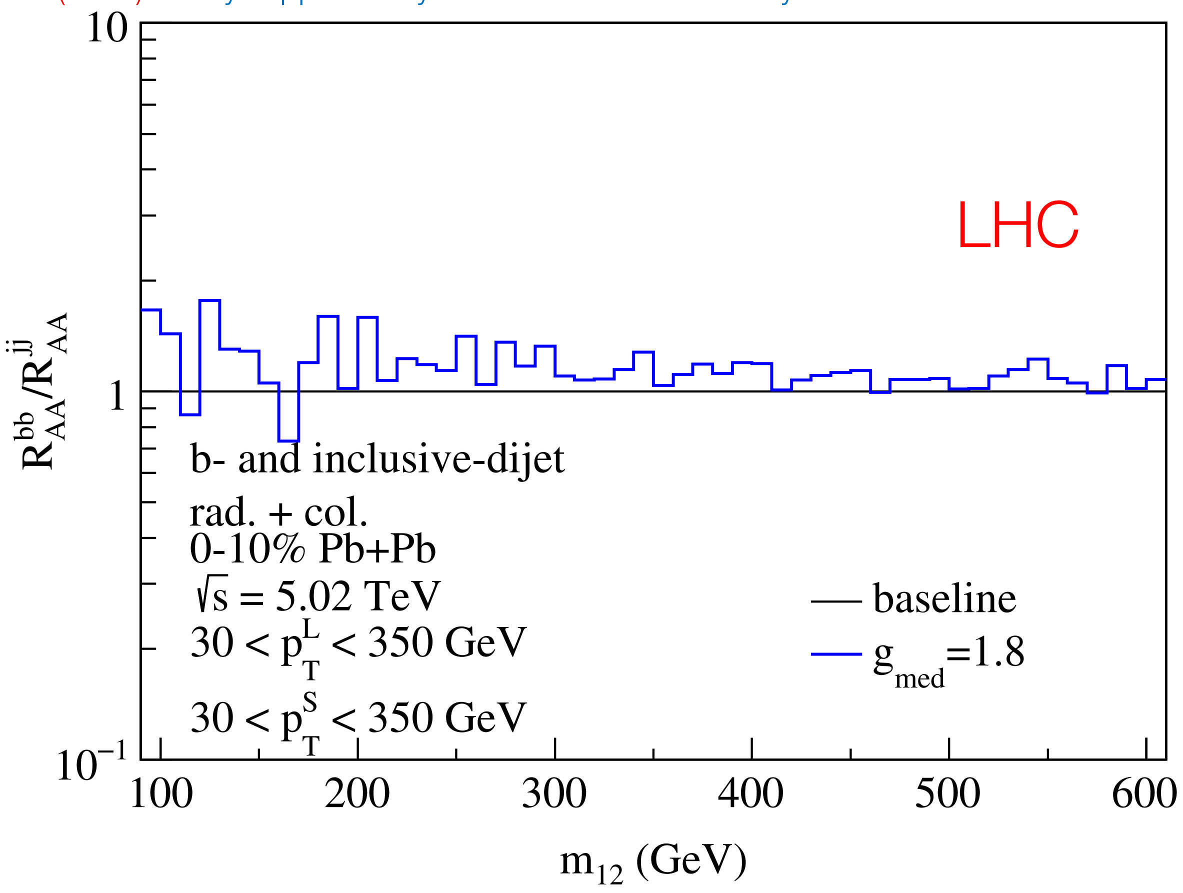


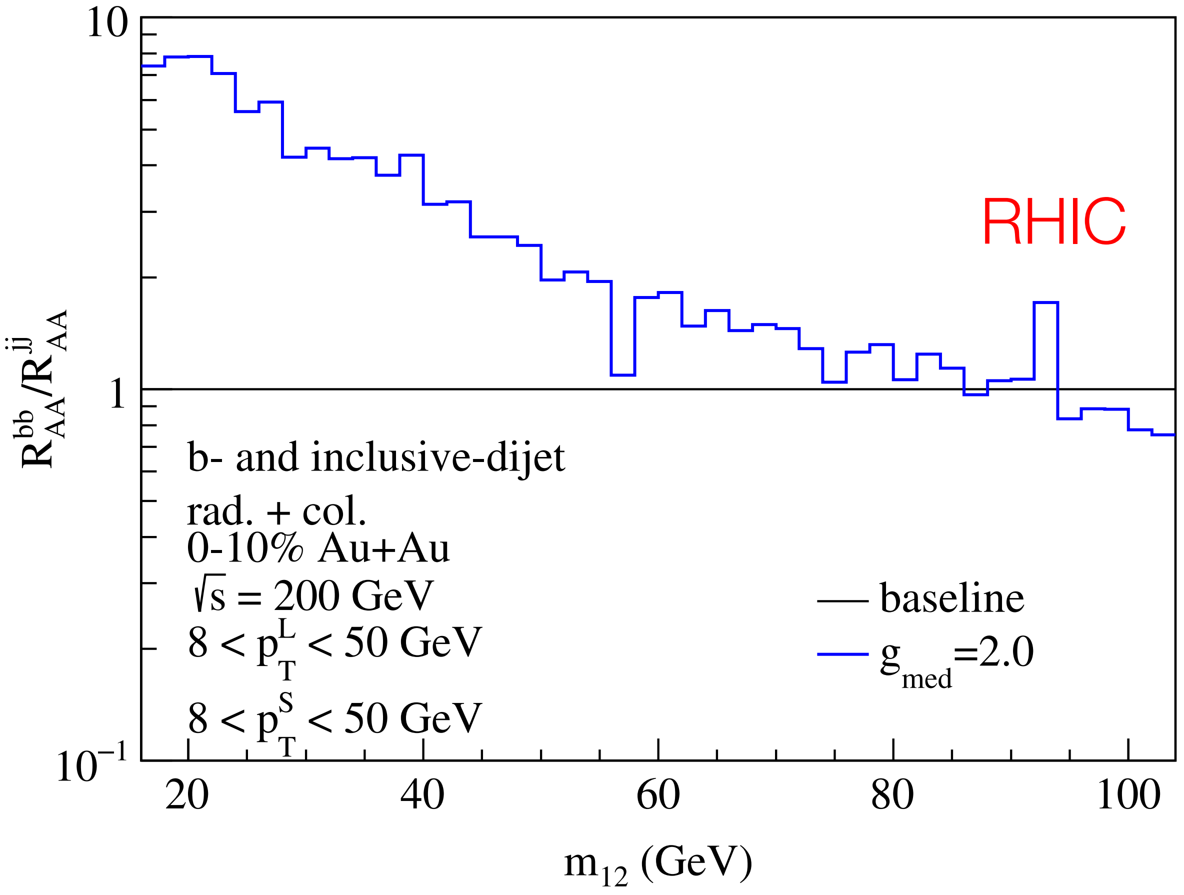


At comparable jet energies, much smaller contribution from ISR/FSR at RHIC, as well as smaller smearing from UE fluctuations

Same observables, different kinematics: Dijet mass ratios

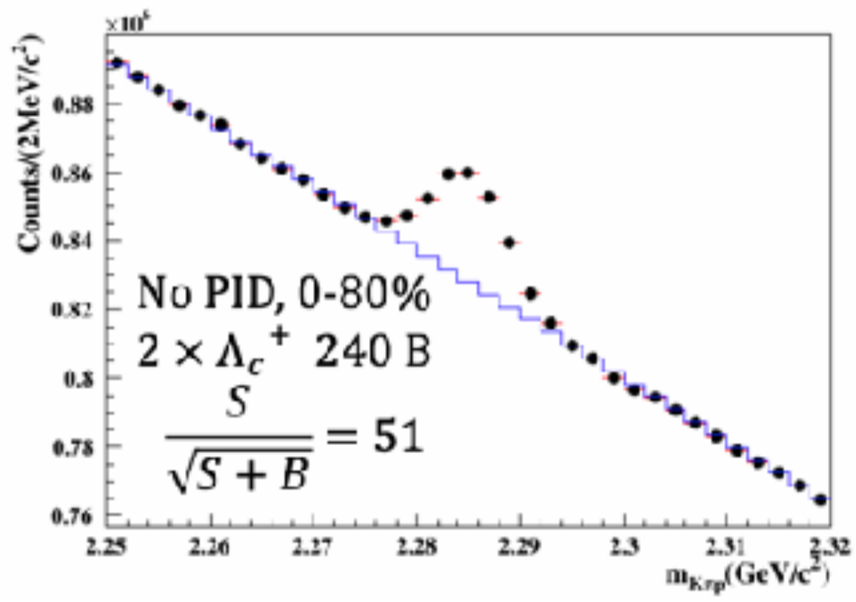
Z-B Kang, J Reiten, I Vitev, B Yoon, "Light and heavy flavor dijet production and dijet mass modification in heavy ion collisions", Phys. Rev. D99 034006 (2019) Partly supported by LANL LDRD motivated by and connected to sPHENIX



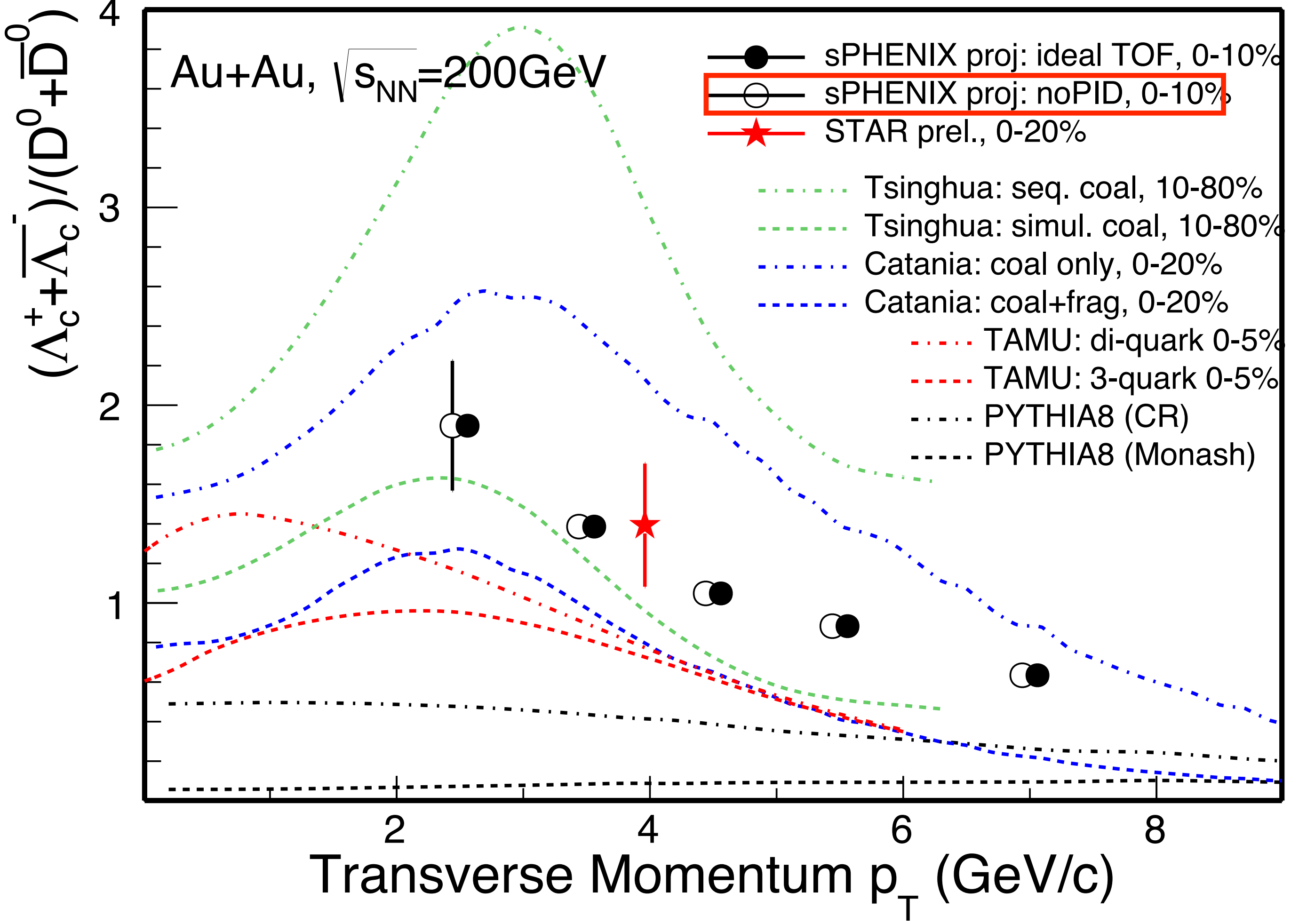


New class of observables enabled at RHIC by b-tagging capability in sPHENIX

sPHENIX vs current RHIC results: Λ_c - Hadronization

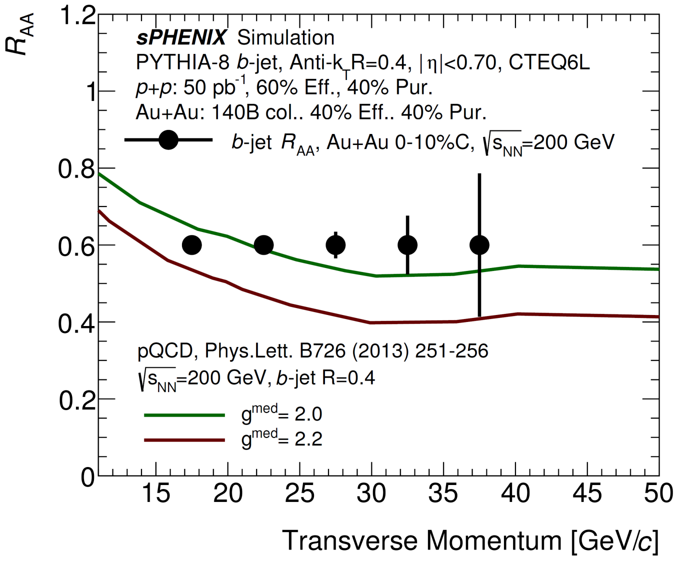


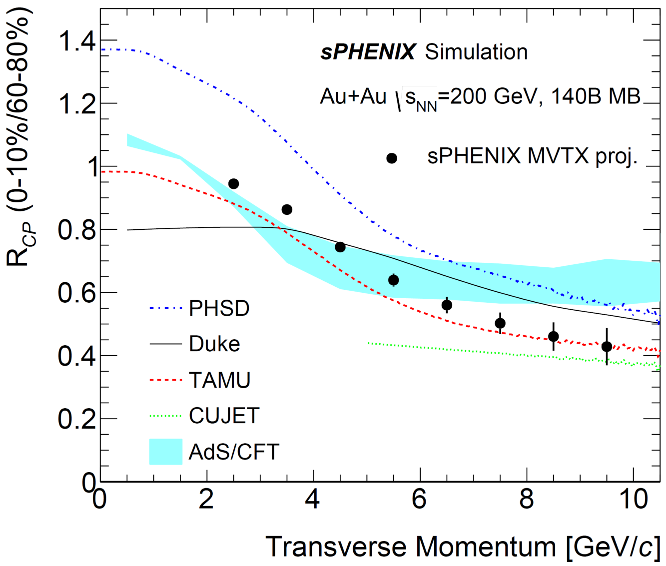
complex decay topologies enable high S/B in baseline sPHENIX



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

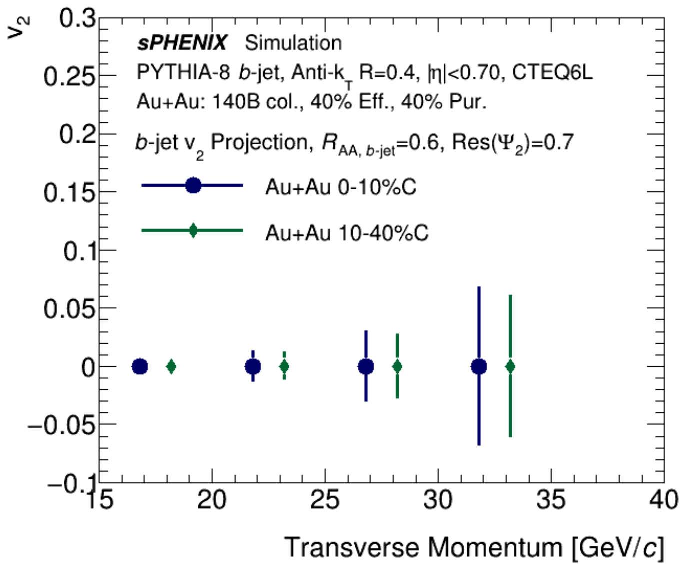
b-tagged jet R_{AA}

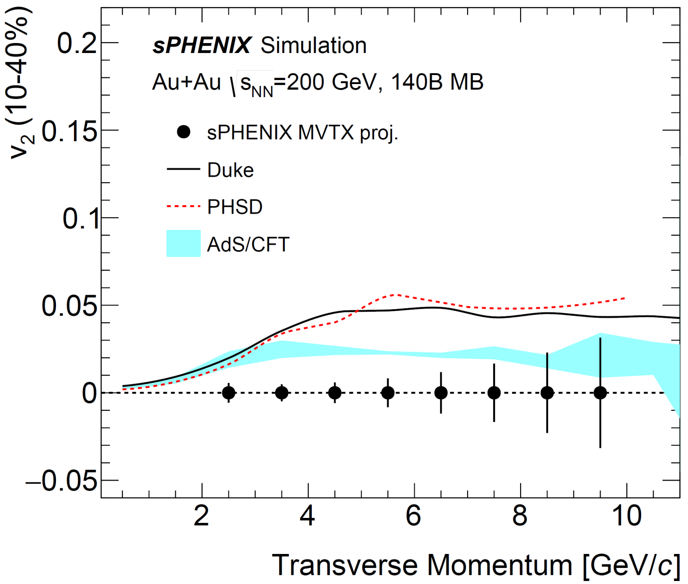




B-meson R_{CP}

b-tagged jet v_2



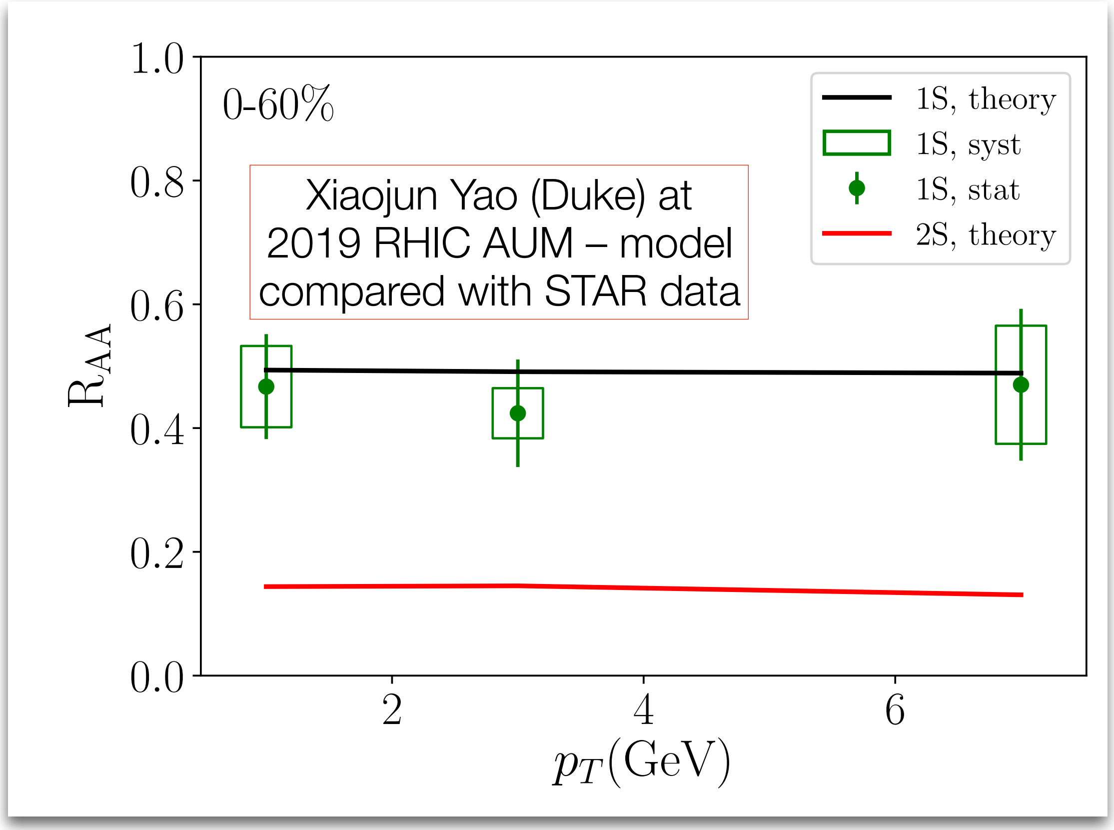


B-meson v_2

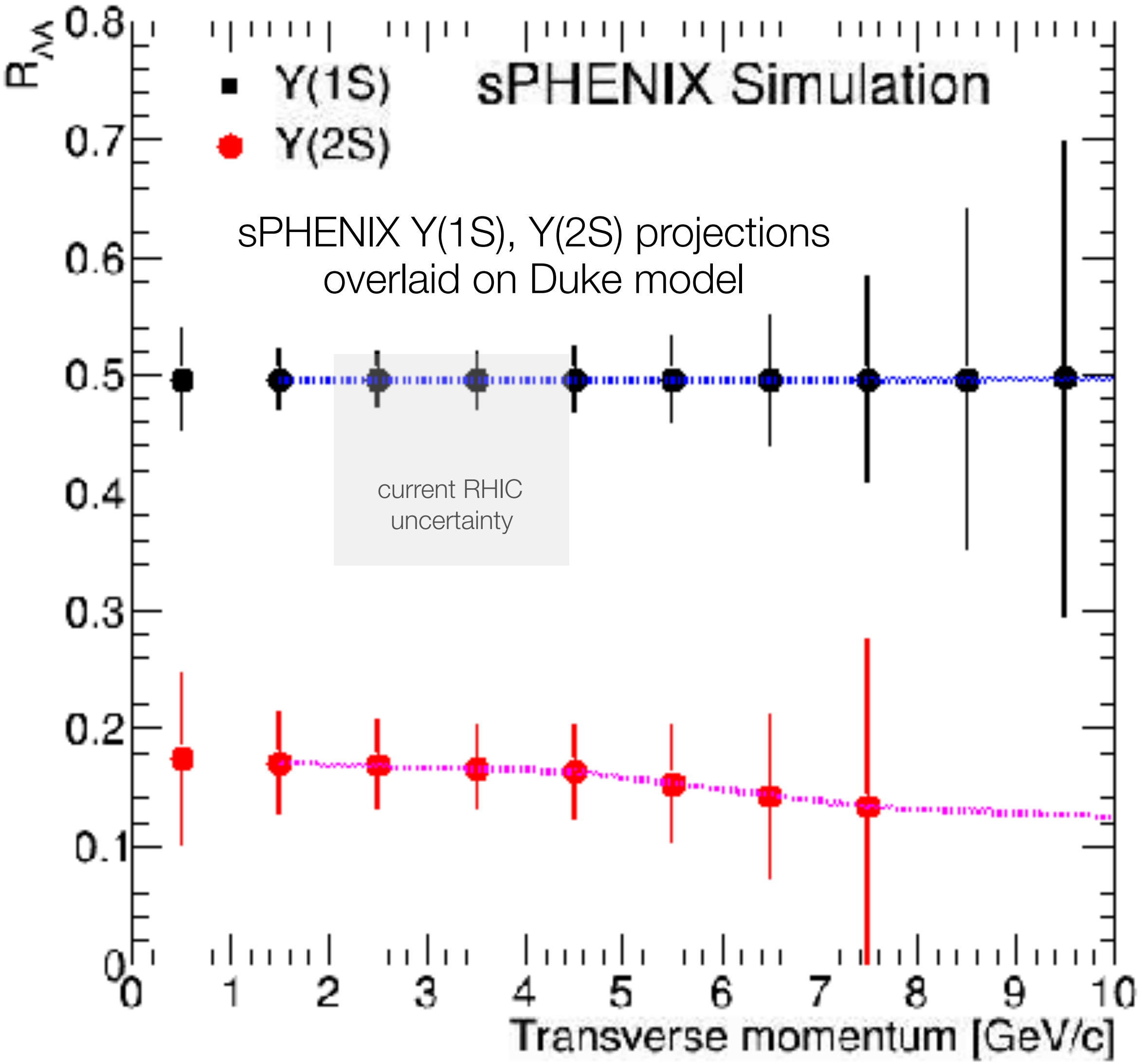
sPHENIX vs current RHIC results: Υ(nS) family

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

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



Following discussions with sPHENIX collaborators X.Yao generated projections in sPHENIX acceptance

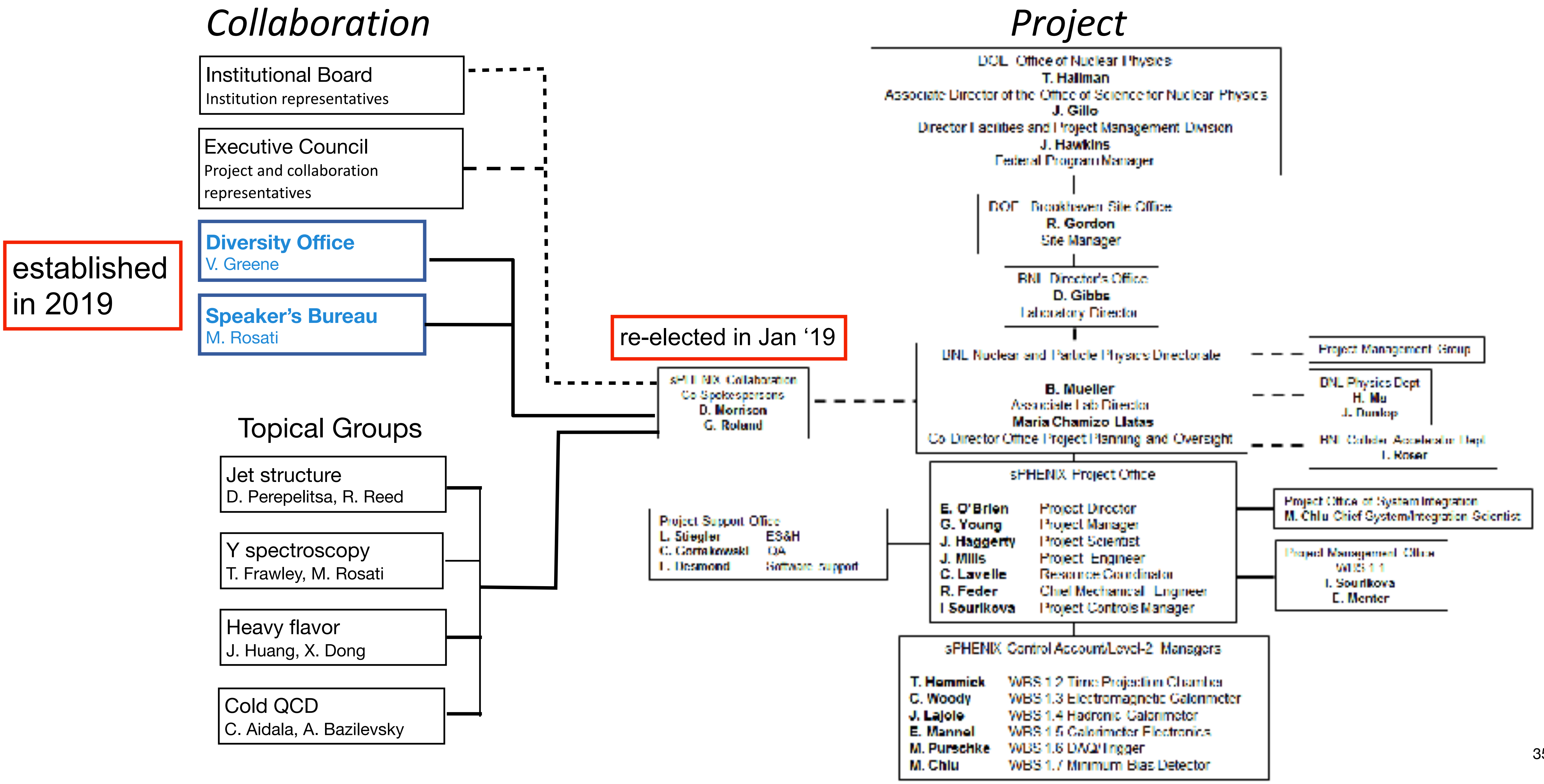


Summary

- 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
  - Requires combination of high precision tracking, full calorimetry, large acceptance and high rate brings qualitatively new capabilities
- 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

sPHENIX organization



Comparison of projected FF uncertainties

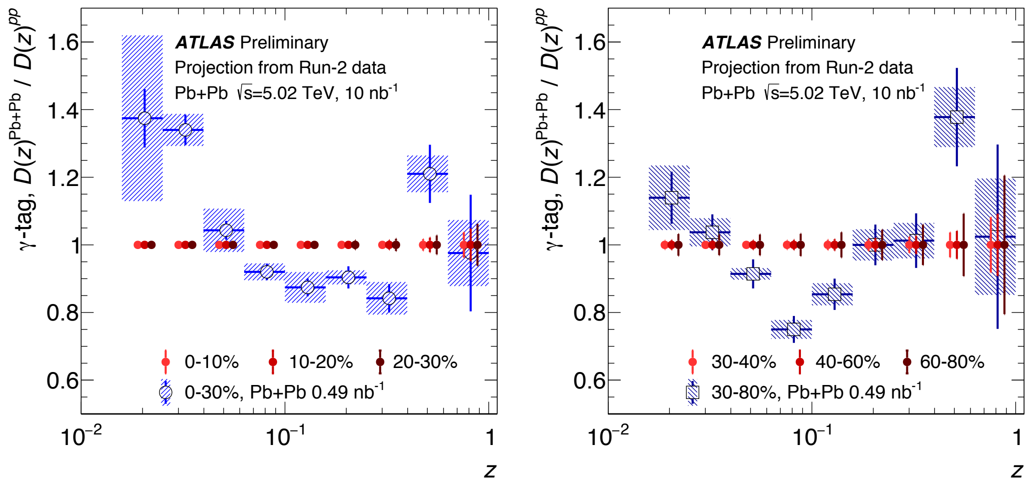


Fig. 35: Projection of the statistical precision that can be reached for the ratio of jet fragmentation functions in Pb–Pb and pp collisions, $R_{D(z)}$, of jets recoiling from a photon. The left panel shows the projection for the most central collisions while the right panel for the more peripheral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

CERN Yellow Report projections for Runs 3, 4

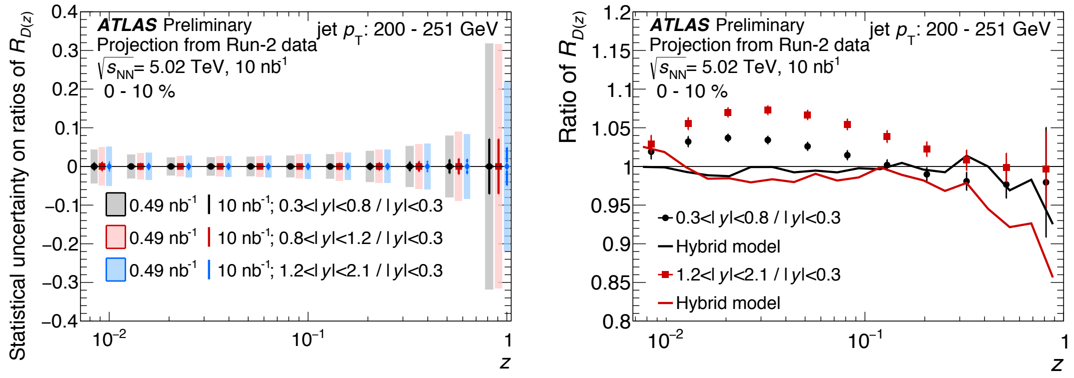
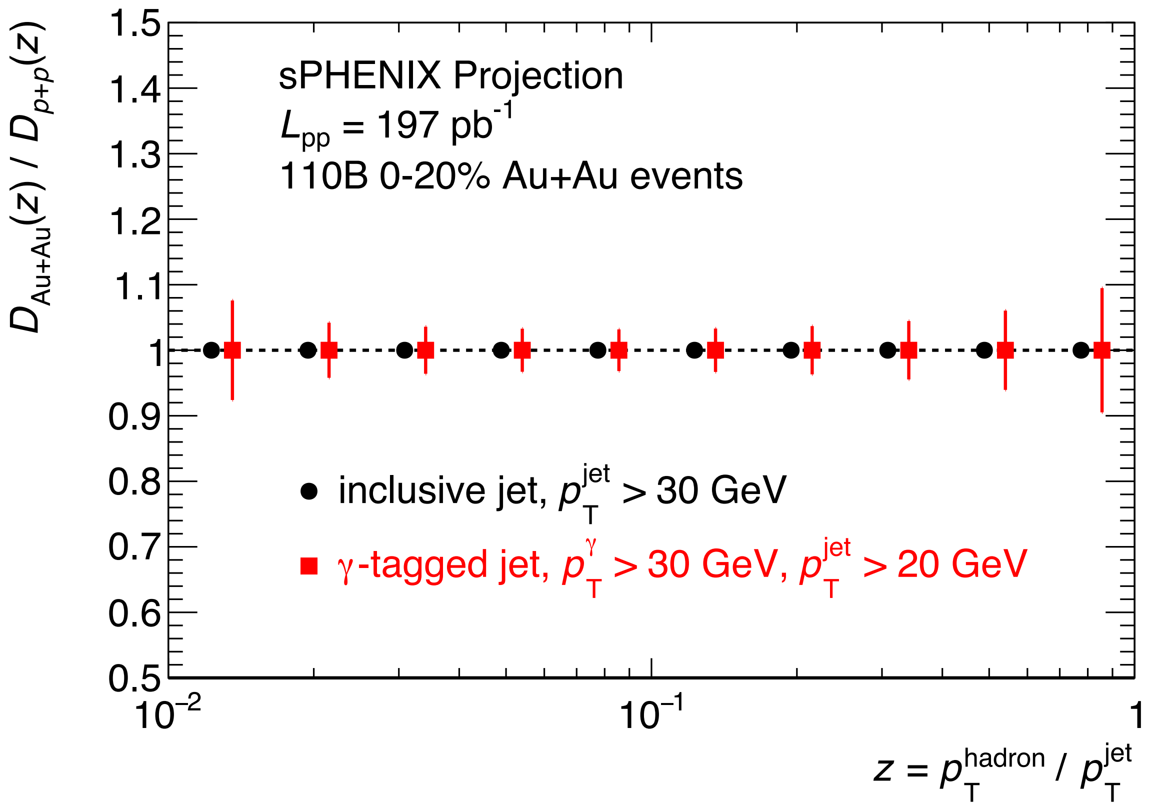


Fig. 33: Projection of the precision that can be reached for the modification of jet fragmentation function, $R_{D(z)}$, measured in jet p_T interval 200 − 251 GeV/c. In the left panel the statistical uncertainty on the measurement with the shaded boxes corresponding to 0.49 nb^{-1} while the vertical bars are for 10 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

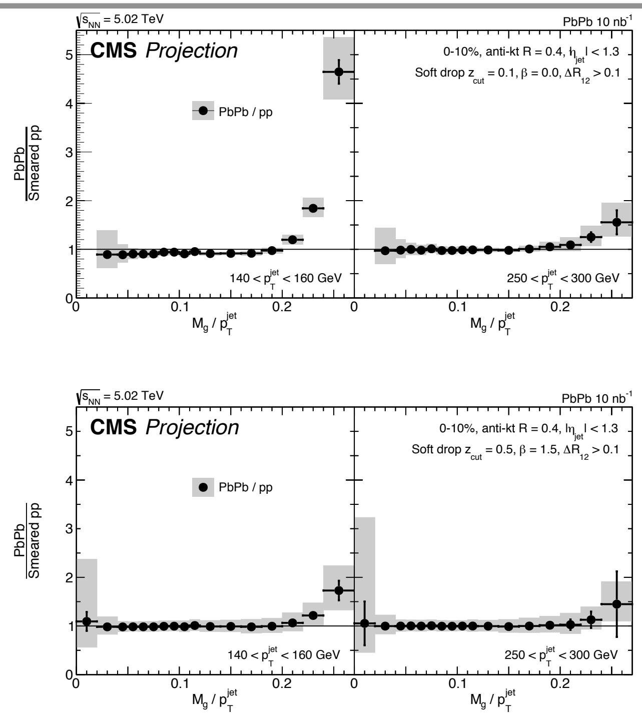
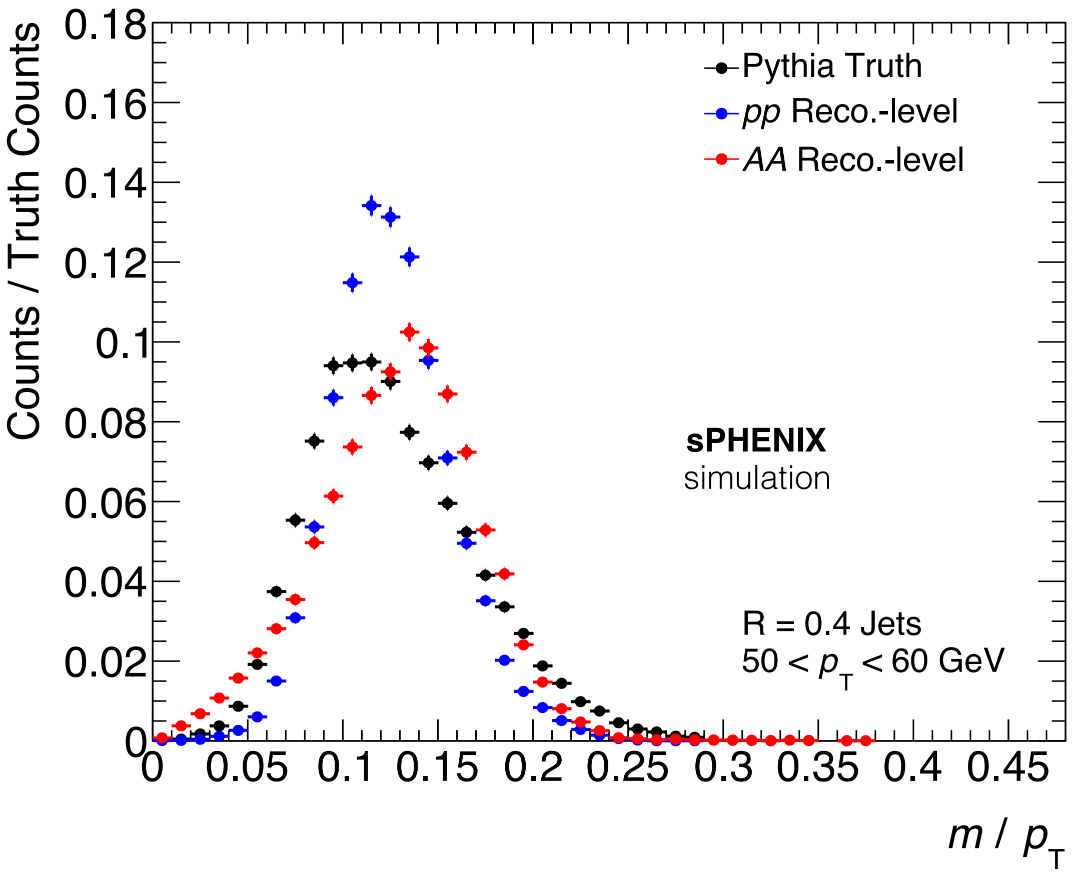


Fig. 37: Jet mass distribution with grooming setting $(z_{cut}, \beta) = (0.1, 0.0)$ (Upper panels) and $(z_{cut}, \beta) = (0.5, 1.5)$ (Lower panels). [8]

CERN Yellow Report projections for Runs 3, 4



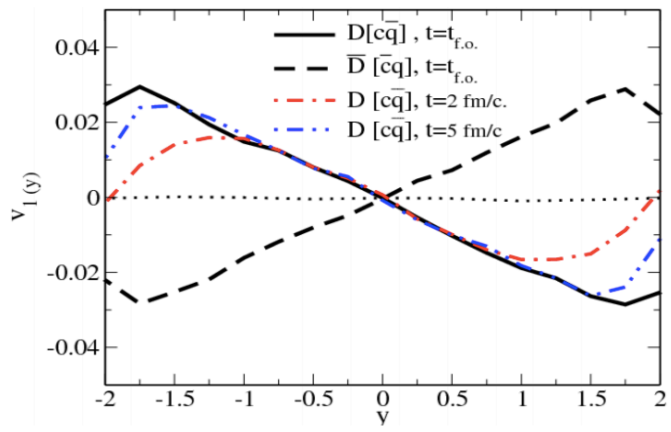
CMS groomed mass / p_T (left) — c.f. sPHENIX version w/ <u>ungroomed</u> mass (right)

➡ new observable enabled by constituent mass subtraction

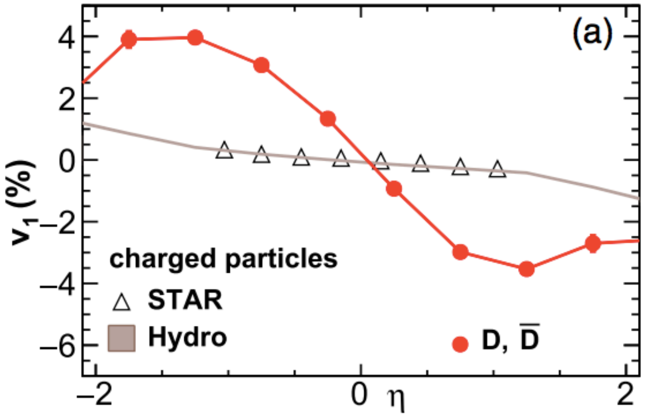
➡ general conclusion: can pick kinematic regions where UE effects are small

D^0 v_1 - Direct Access to Initial B Field

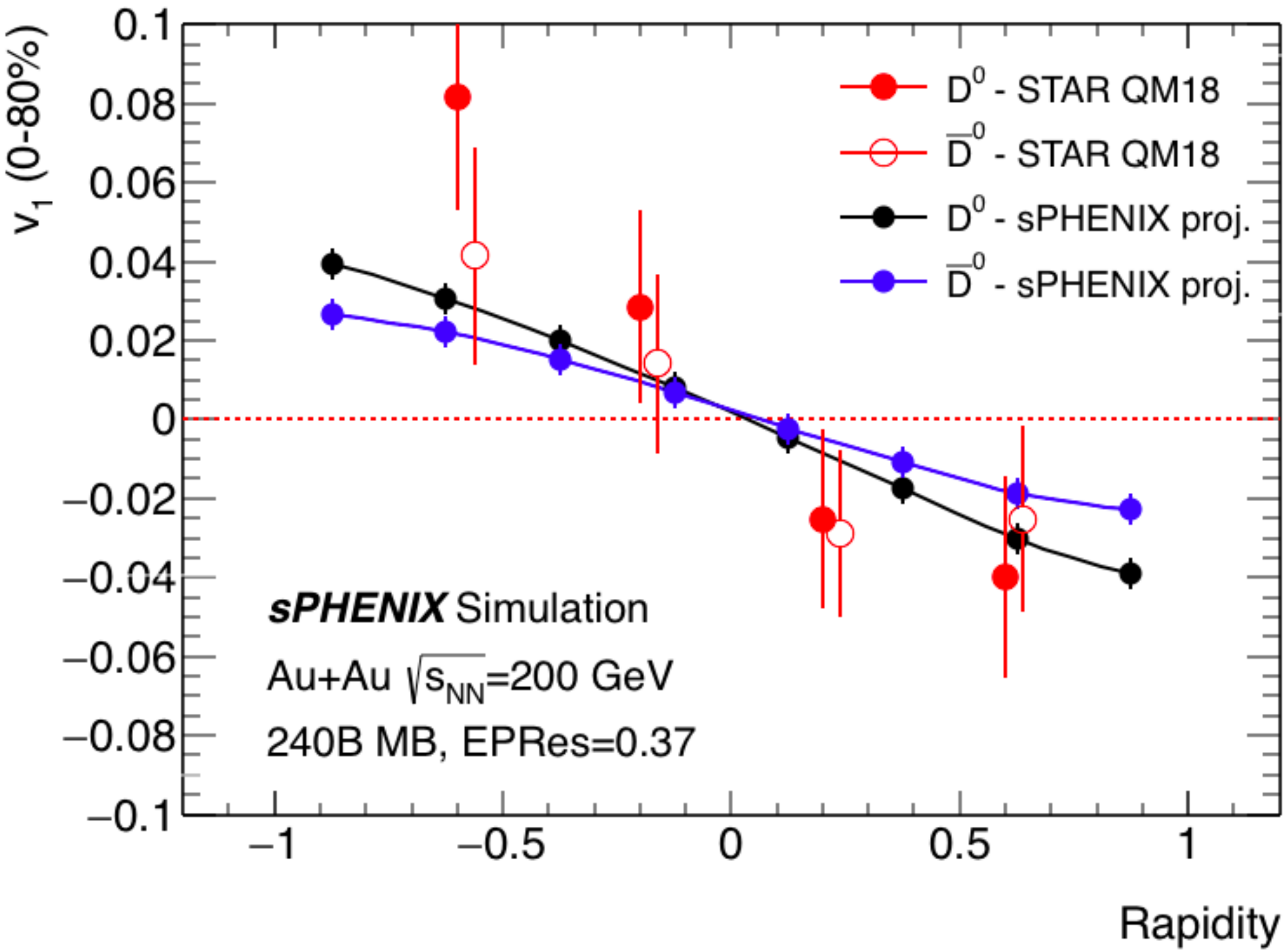
init. B -> v1(D) = -v1(Dbar)



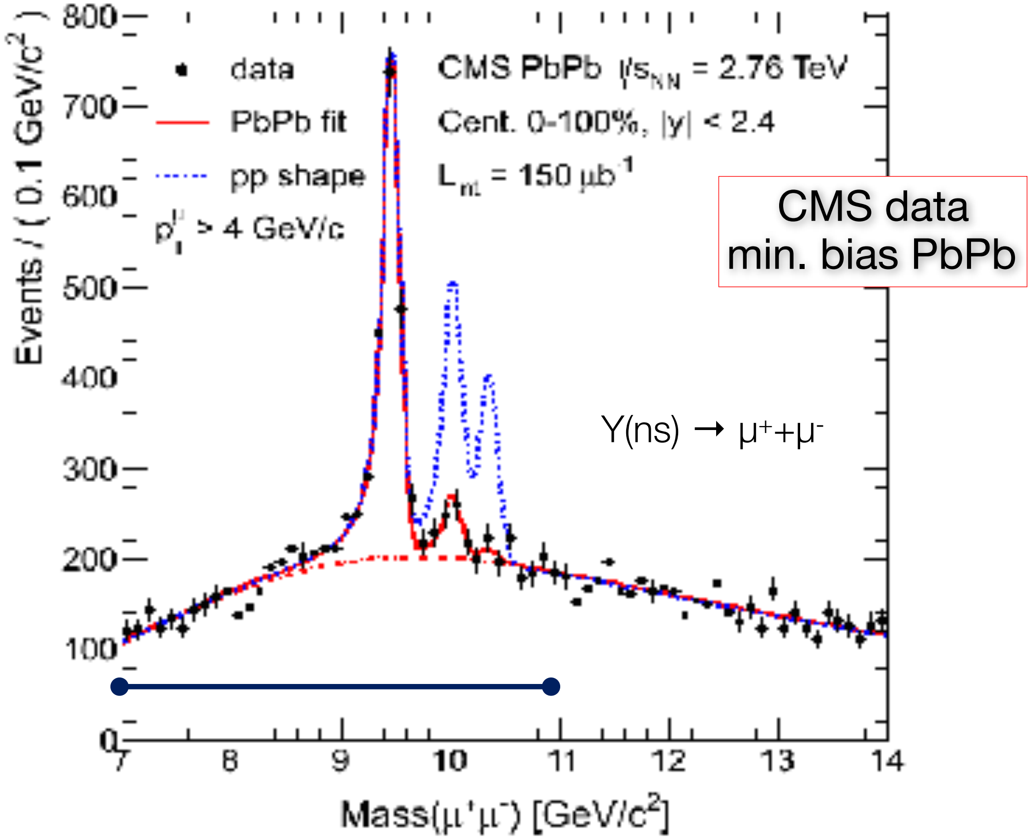
tilt QGP -> v1(D) = v1(Dbar) >> v1(h)

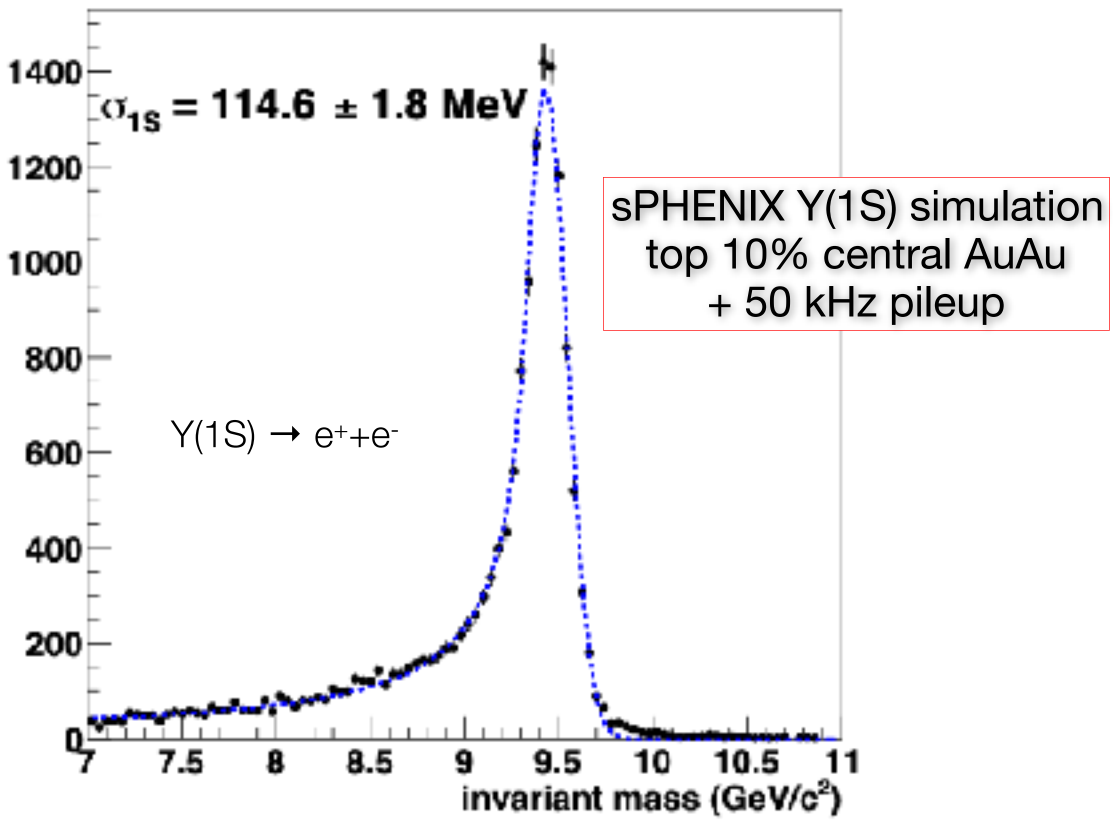


Need: Good ZDC-SMD detector to improve
1st EP resolution



Upsilons at sPHENIX and LHC

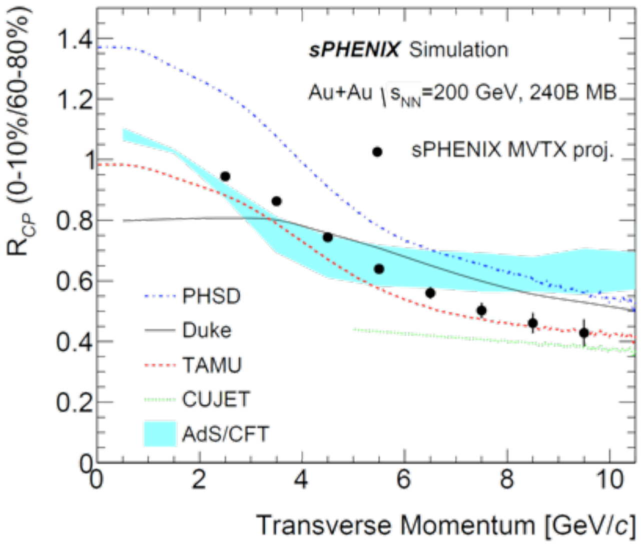


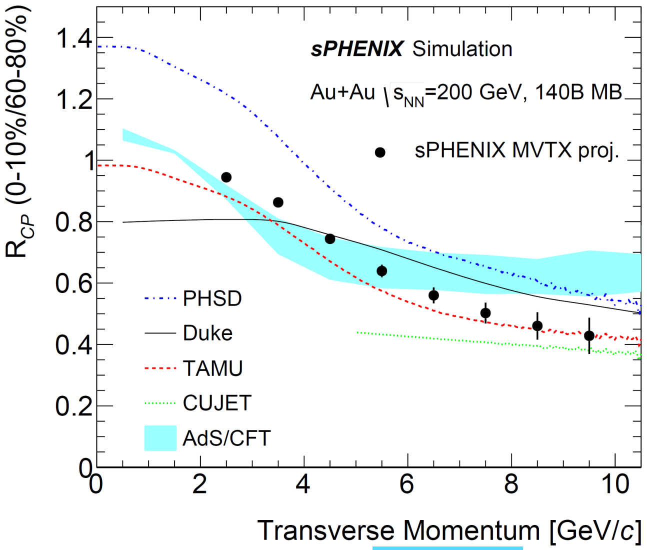


Differential suppression of Y(nS), temperature dependence of QGP Debye screening length

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

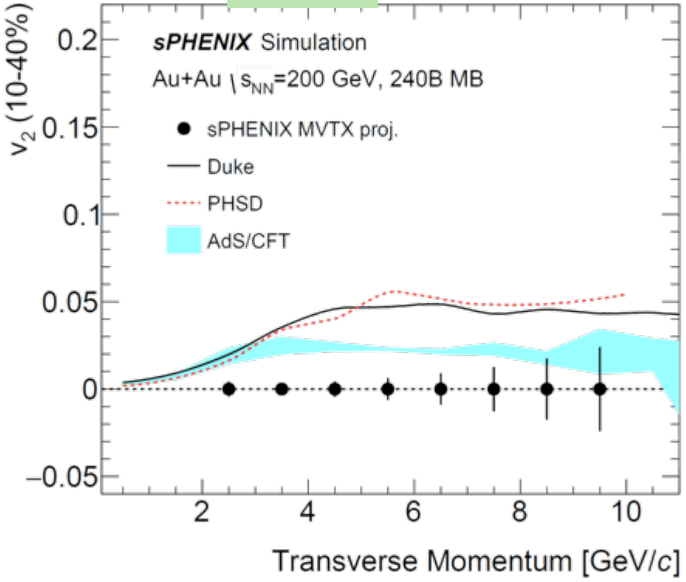
5-yr vs. 3-yr

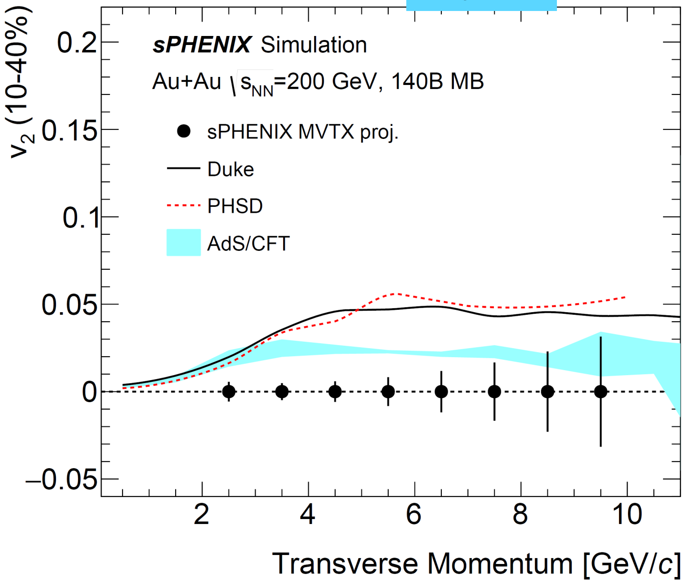




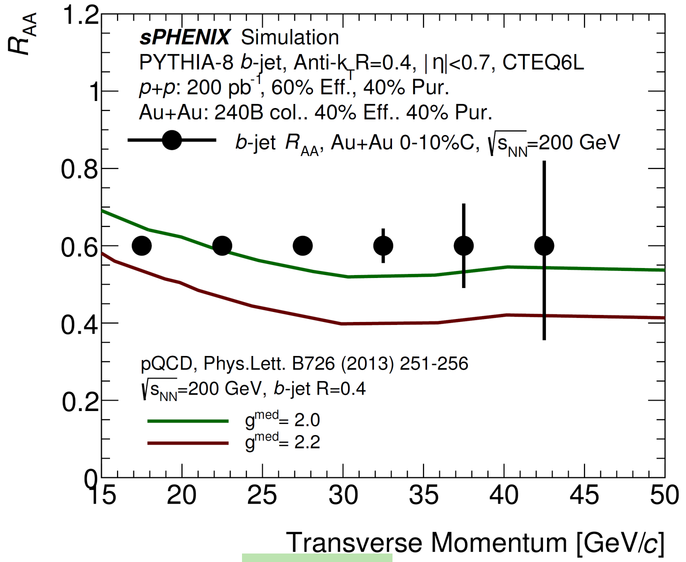
5 year

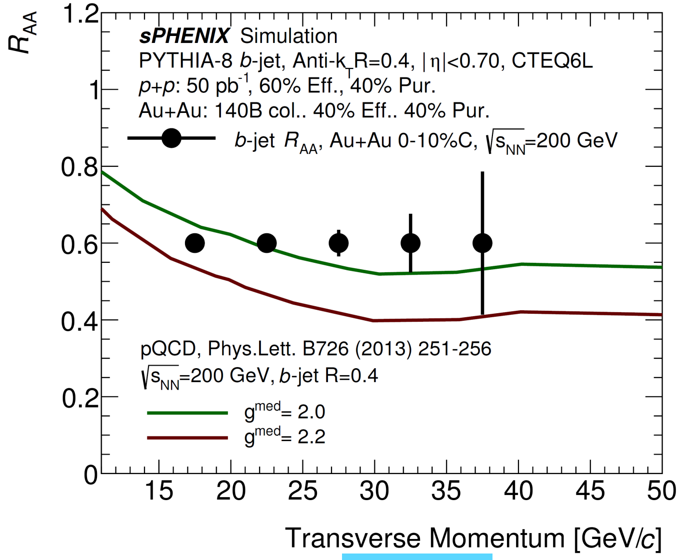
3 year





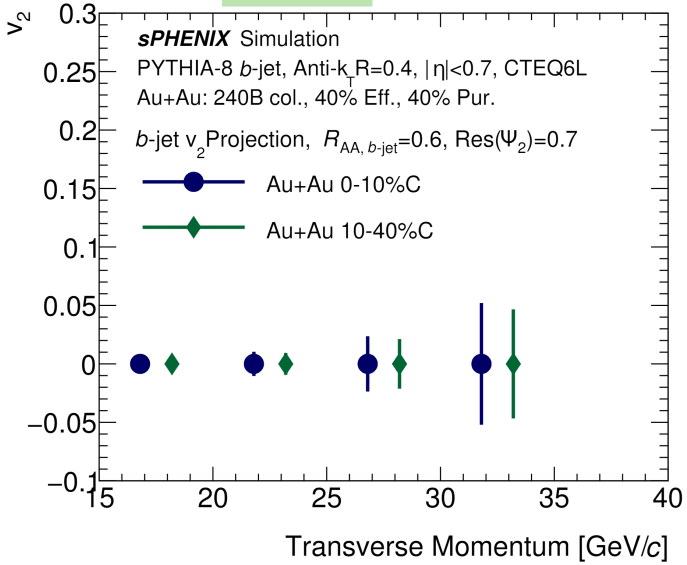
5-yr vs. 3-yr

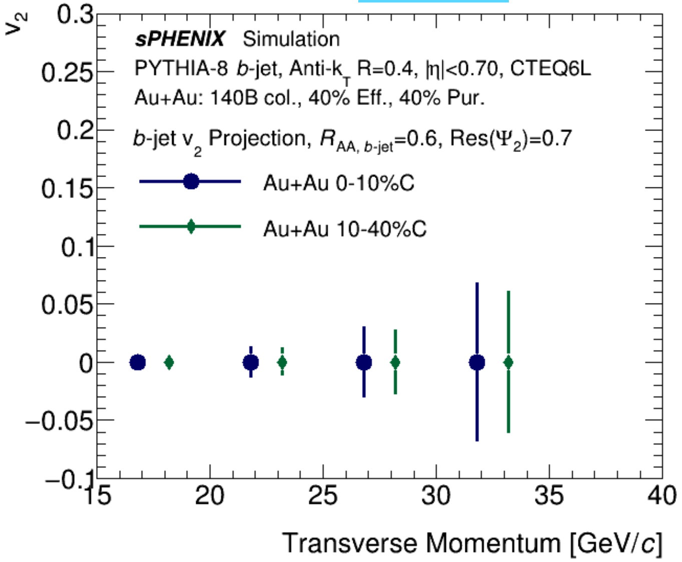




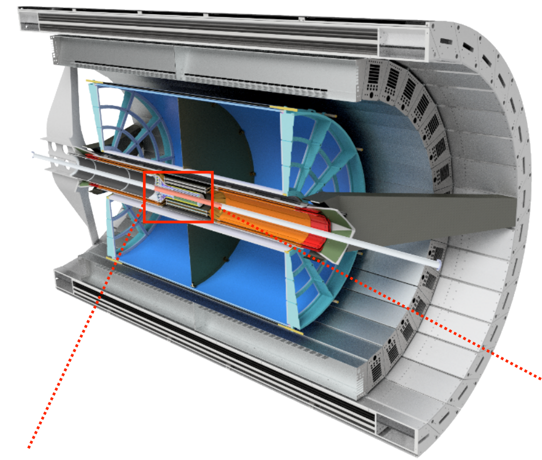
5 year

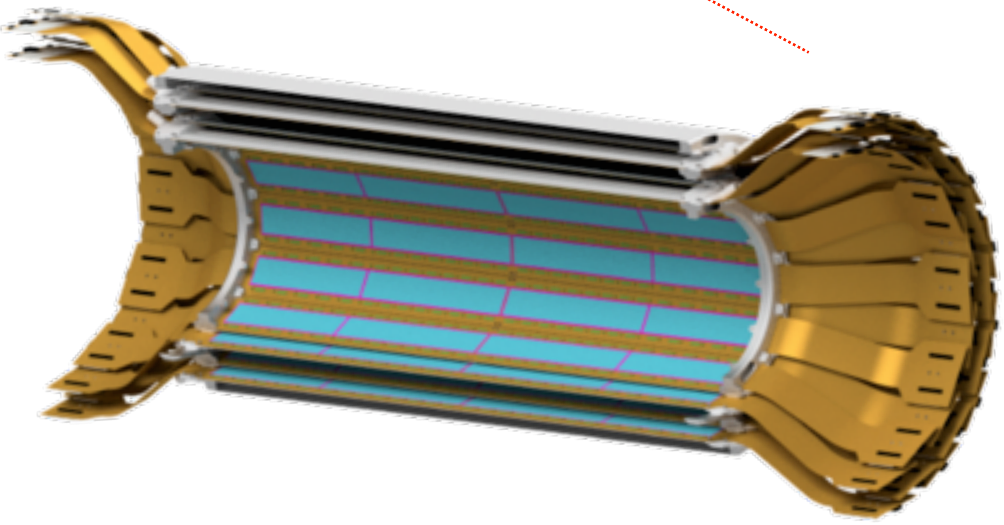
3 year

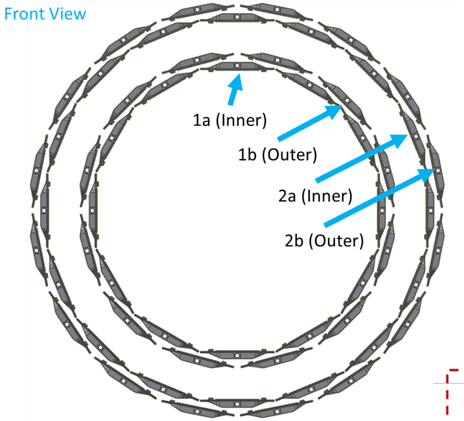


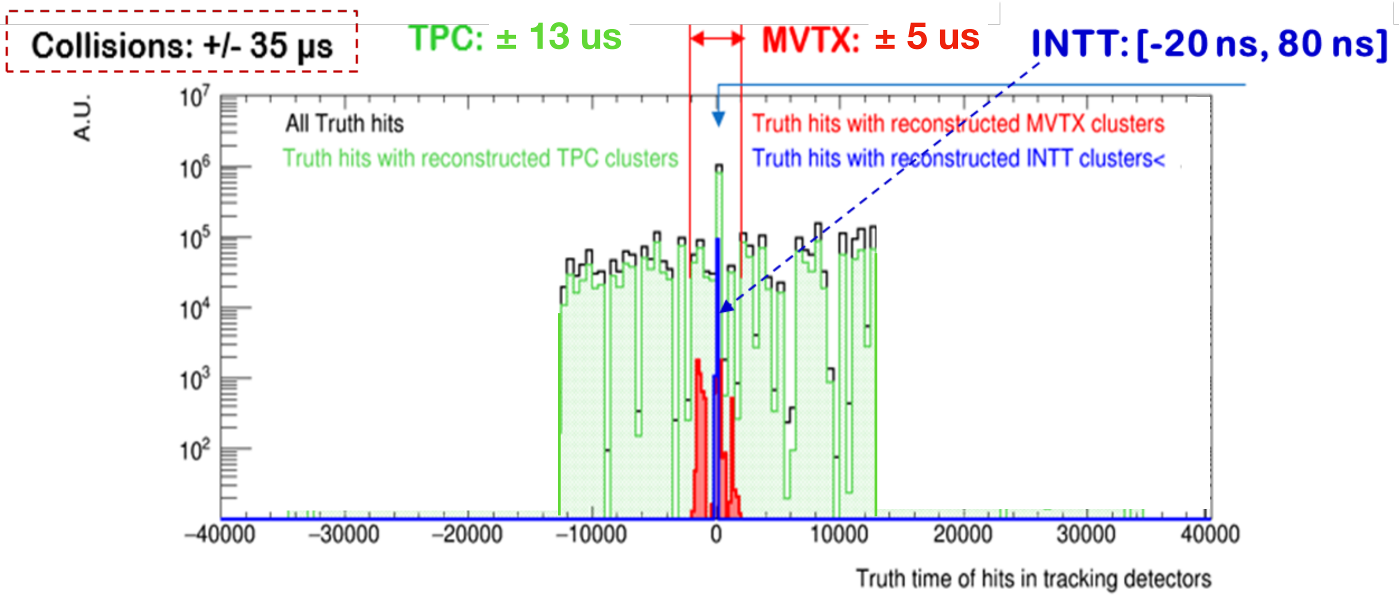


INTT





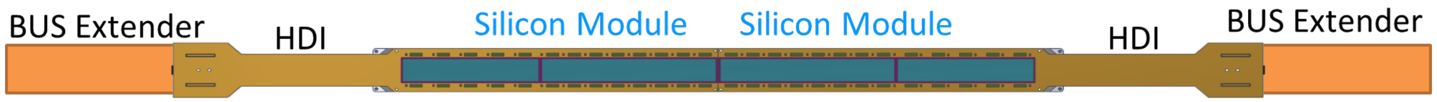


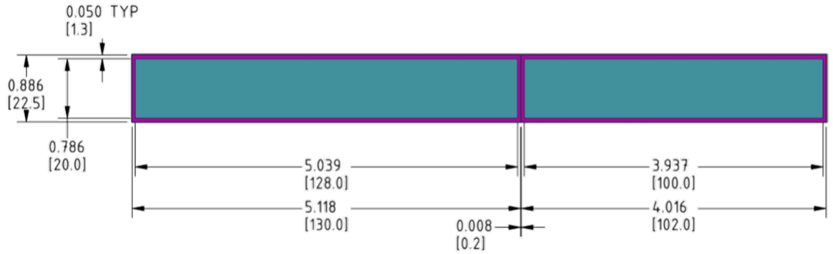


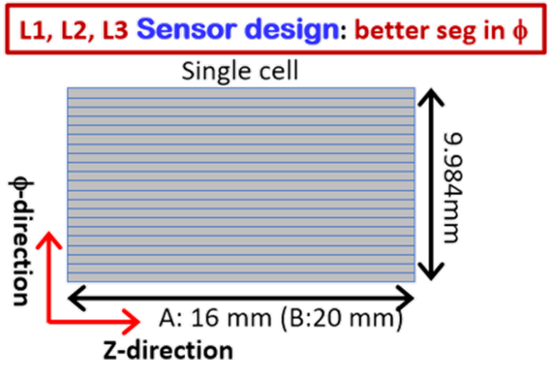
RIKEN PURDUE UNIVERSITY BROOKHAVEN NATIONAL LABORATORY 國立中央大學 National Central University 奈良女子大学 Nara Women's University

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

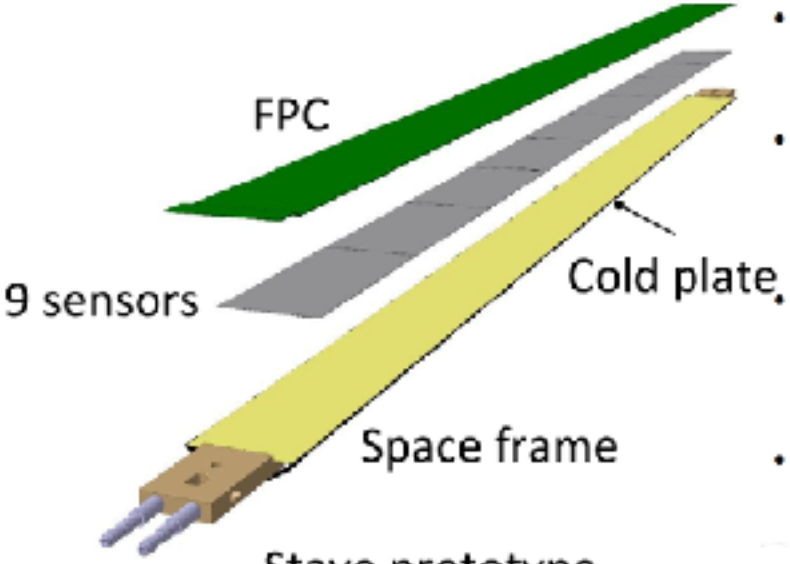
Thickness: 320 um
Pitch: 9.984 mm/128 = 78 um
Φ-length (single sensor) = 22.5 mm
F-length (active area) = 20.0 mm
Z-length type-A (single sensor) = 130.0 mm
Z-length type-A (active area) = 128.0 mm
Z-length type-B (single sensor) = 102.0 mm
Z-length type-B (active area) = 100.0 mm

MVTX

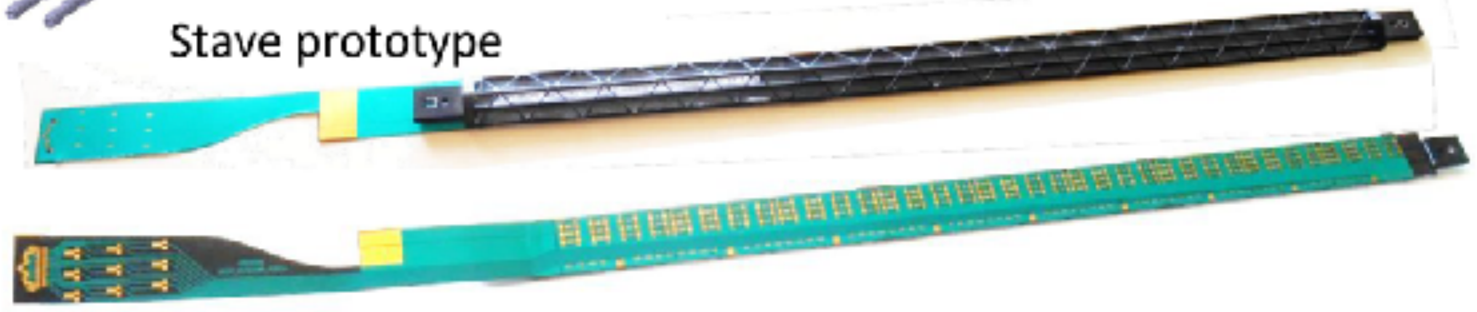
sPHENIX

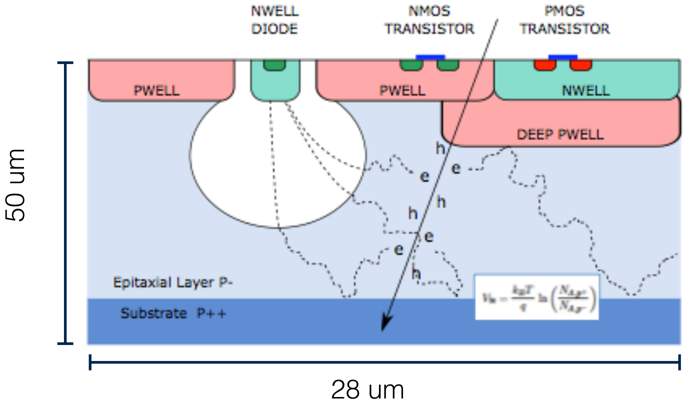
ALICE Pixel Detector

- 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, $40mW/cm^2$, 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: $15x271.2\ mm^2$, 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 $40\ mW/cm^2$.



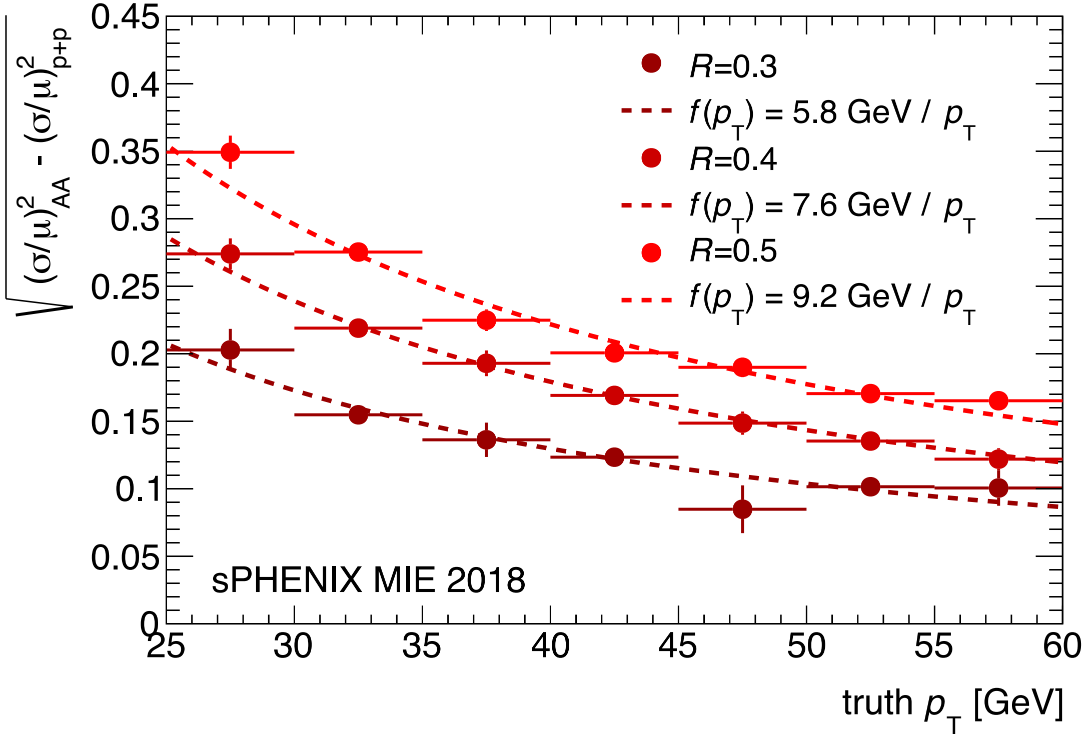


Jet performance

Deconvolution of UE term in Au+Au response

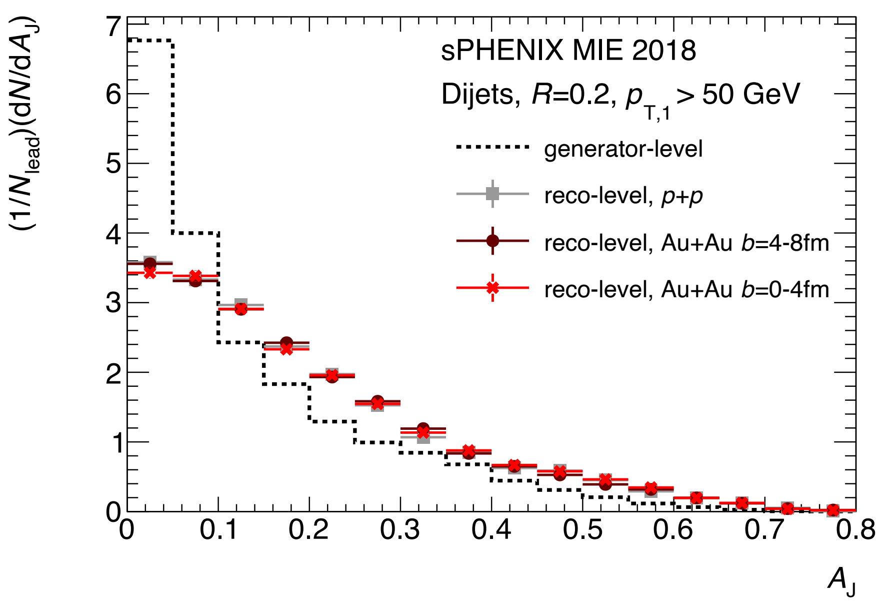
$$\frac{\sigma_{p_\mathrm{T}}}{p_\mathrm{T}} = \frac{n}{p_\mathrm{T}} \oplus \frac{s}{\sqrt{p_\mathrm{T}}} \oplus c$$

Noise Stochastic Constant

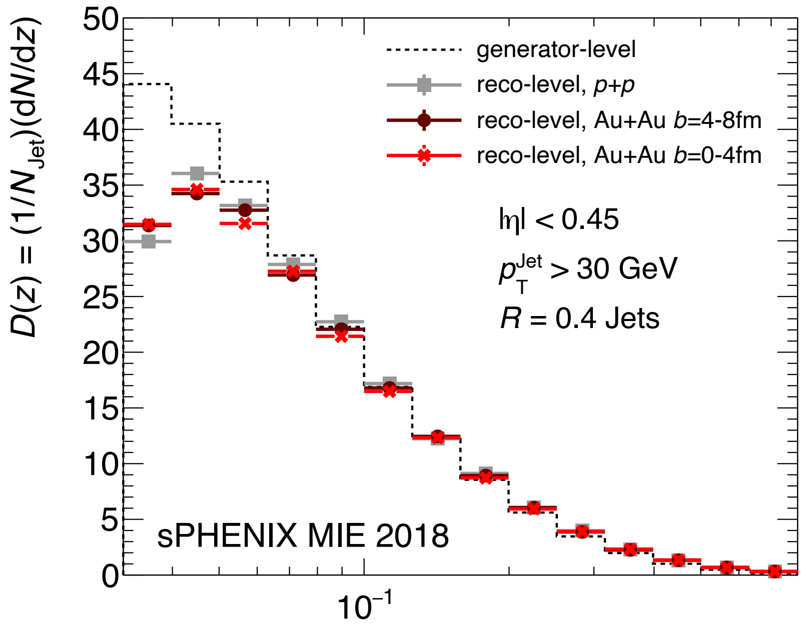


- One advantage of purely calorimetric measurement: reconstruction proceeds identically in *pp* and Au+Au
  - ➡ can understand Au+Au response as *pp* response ⊗ UE
  - ➡ identical, i.e. sensitivity of response to fragmentation, in both systems

Jet performance summary



di-jet p_T balance

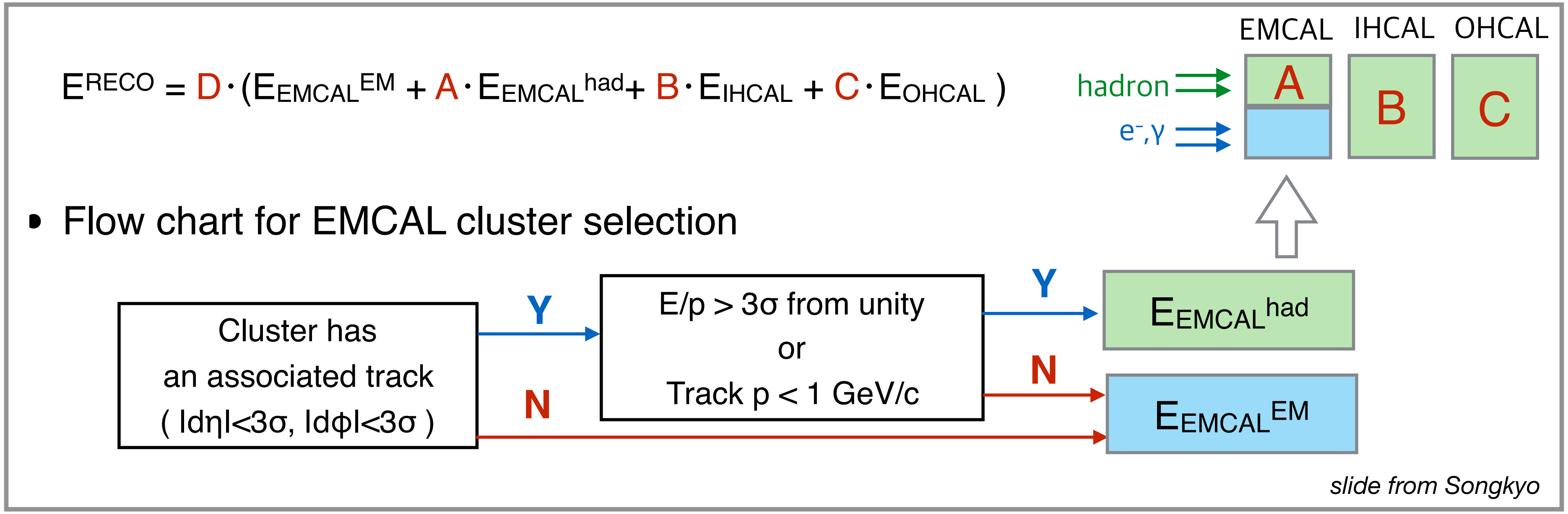


inclusive jet FF

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

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

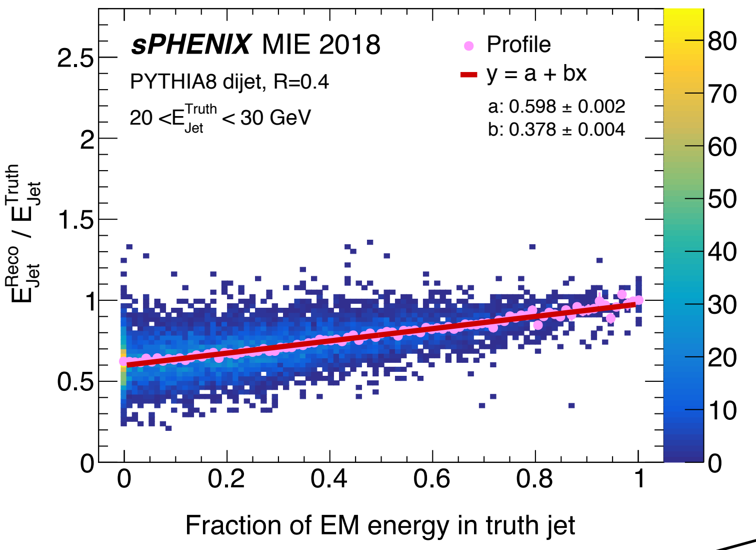
Jet energy calibration

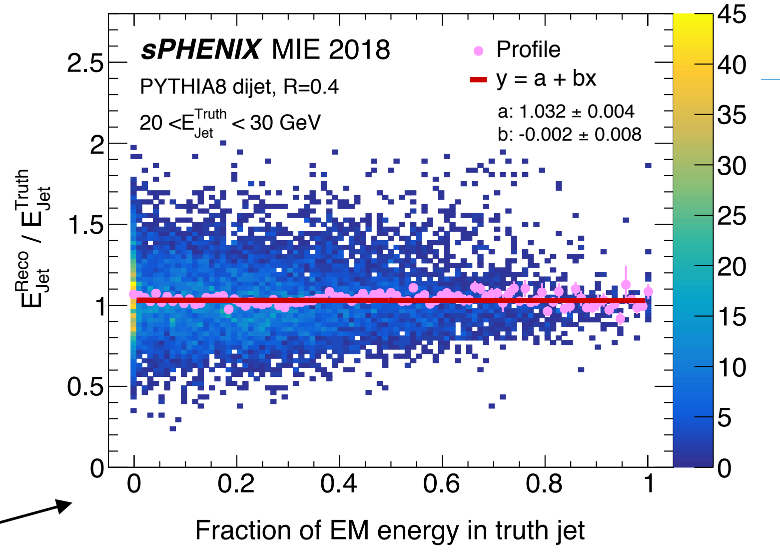


Exploring calibration schemes based on multiplicative scale factors for each calorimeter layer

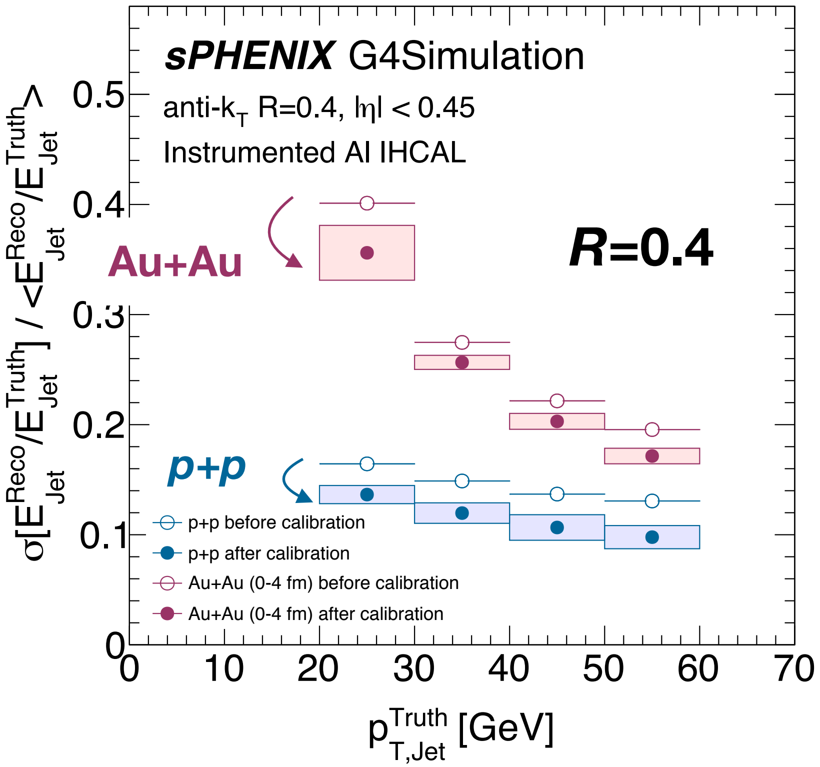
- separation of EMCal energy into e/γ (no track or E/p ~ 1 track) and hadronic (track with $E^{EM}/p < 1$)
- discussion of *in situ* validation with γ+jet events in *p*+*p*

Jet calib



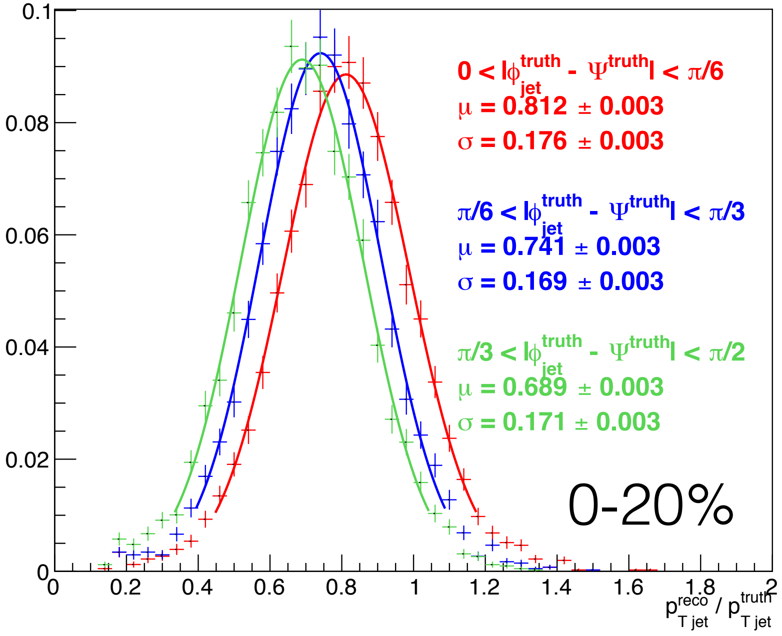


Response nearly independent of truth-EM fraction (i.e. fragmentation) in p+p

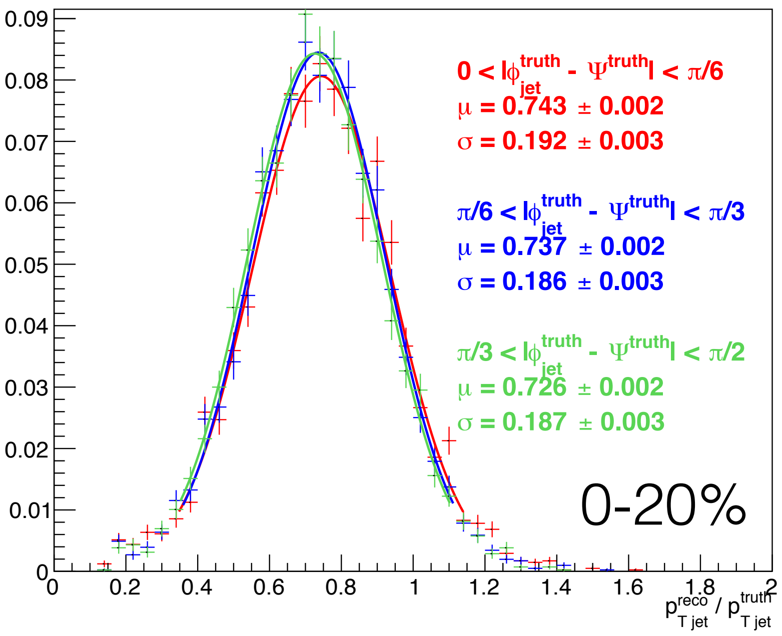


ϕ-dependent jet performance

HI jet reco w/o flow determination…

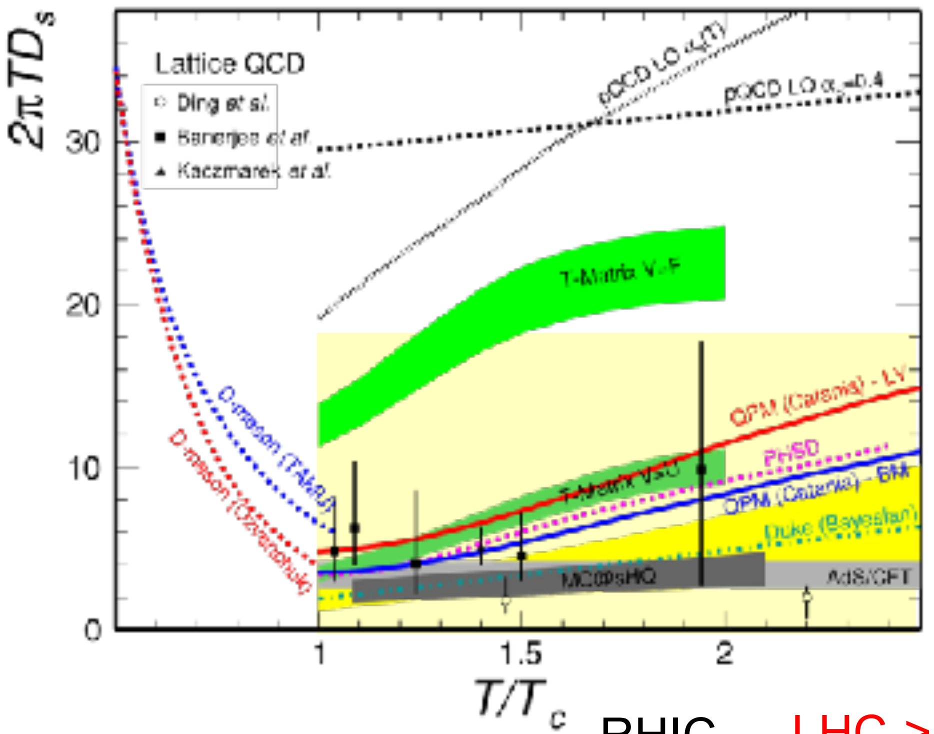


HI jet reco **WITH** flow determination

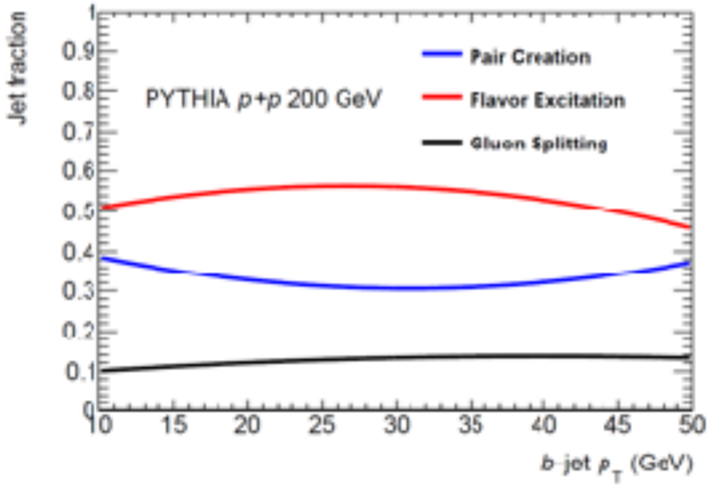


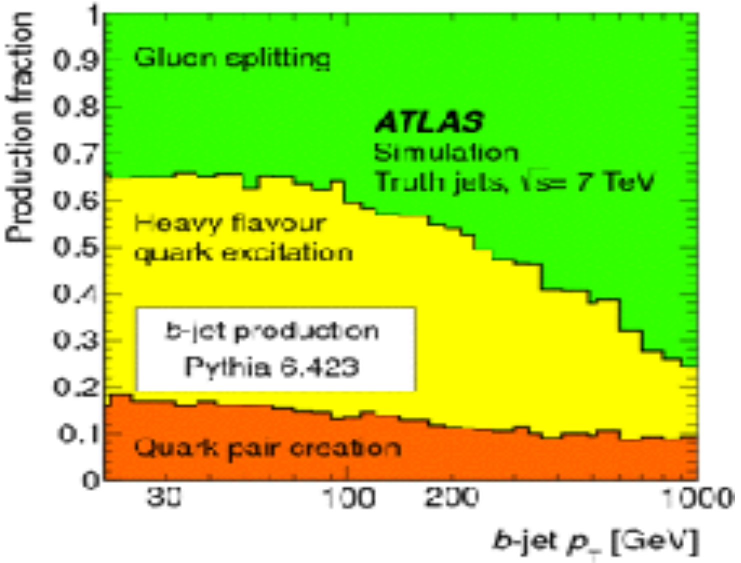
RHIC vs. LHC

A. Adare et al., 1501.06197



RHIC LHC->





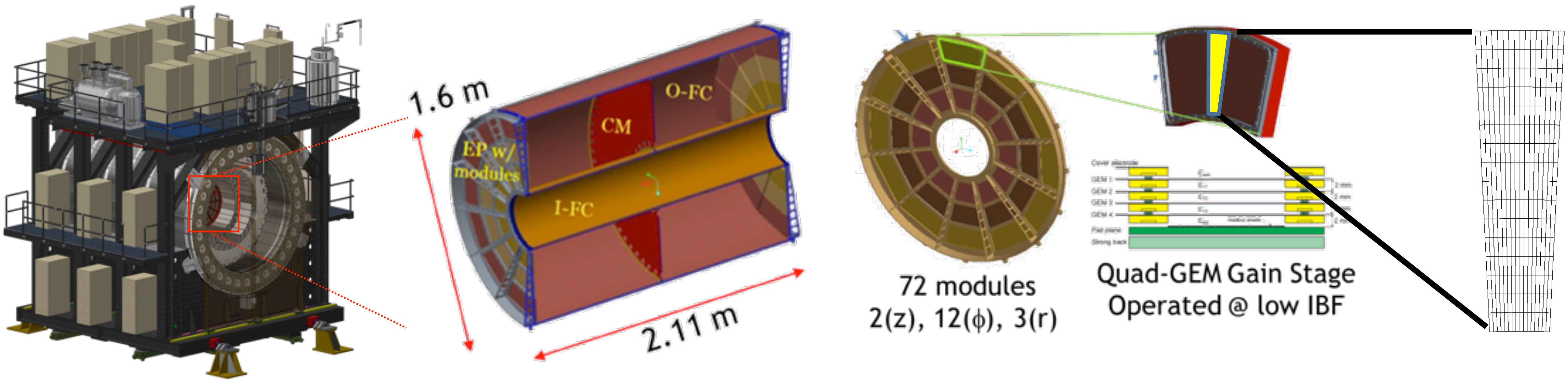
Complementarity: RHIC vs. LHC

- 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 < 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 < 35% RMS	Same
Hadronic Calorimeter	Preinstall, Bench Test	Each sector with an absolute energy pre-calibration to a precision of < 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