Brookhaven National Laboratory

sPHENIX

RIKEN

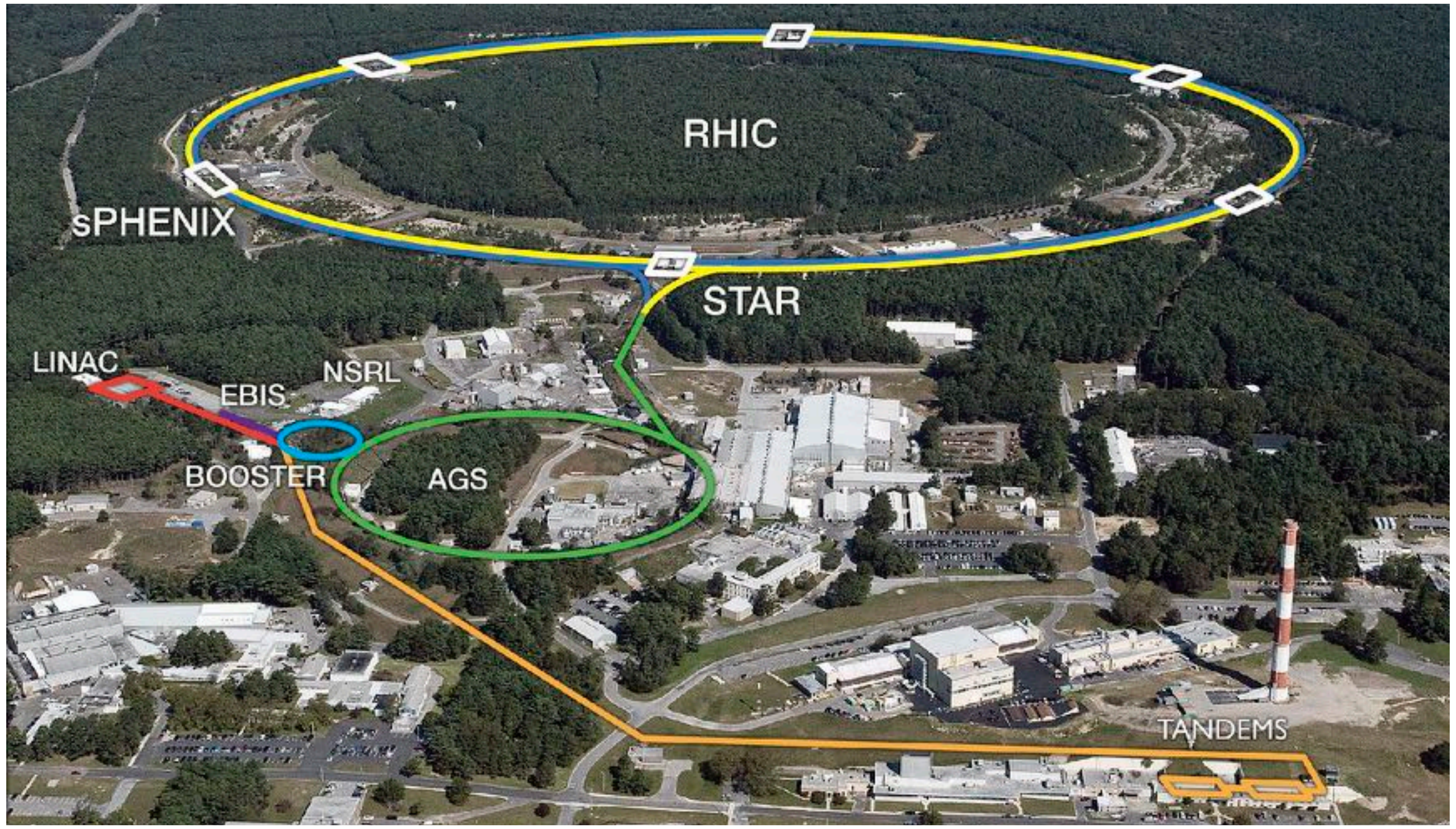
HP2024 NAGASAKI

12th International Conference
on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
2024/09/22– 2024/09/27

Measurement of $dE_T/d\eta$ in Au+Au collisions at 200 GeV with sPHENIX at RHIC

Genki Nukazuka (RIKEN)
for the sPHENIX Collaboration

sPHENIX Collaboration



Relativistic Heavy Ion Collider (RHIC)

- First collisions in 2000
- p+p, Au+Au, O+O, etc
- $p^{\rightarrow(\uparrow)} + p^{\rightarrow(\uparrow)}$
- $\sqrt{s_{NN}}$ ~ 7 — 500 GeV

- The collaboration was formed in 2016.
- State-of-the-Art Jet Detector at RHIC
- Quark-Gluon Plasma (QGP) and Cold-QCD
- About 350 members
  from more than 50 institutions
  and 11 countries
- Home Page: https://www.sphenix.bnl.gov/

sPHENIX Collaboration at HP2024

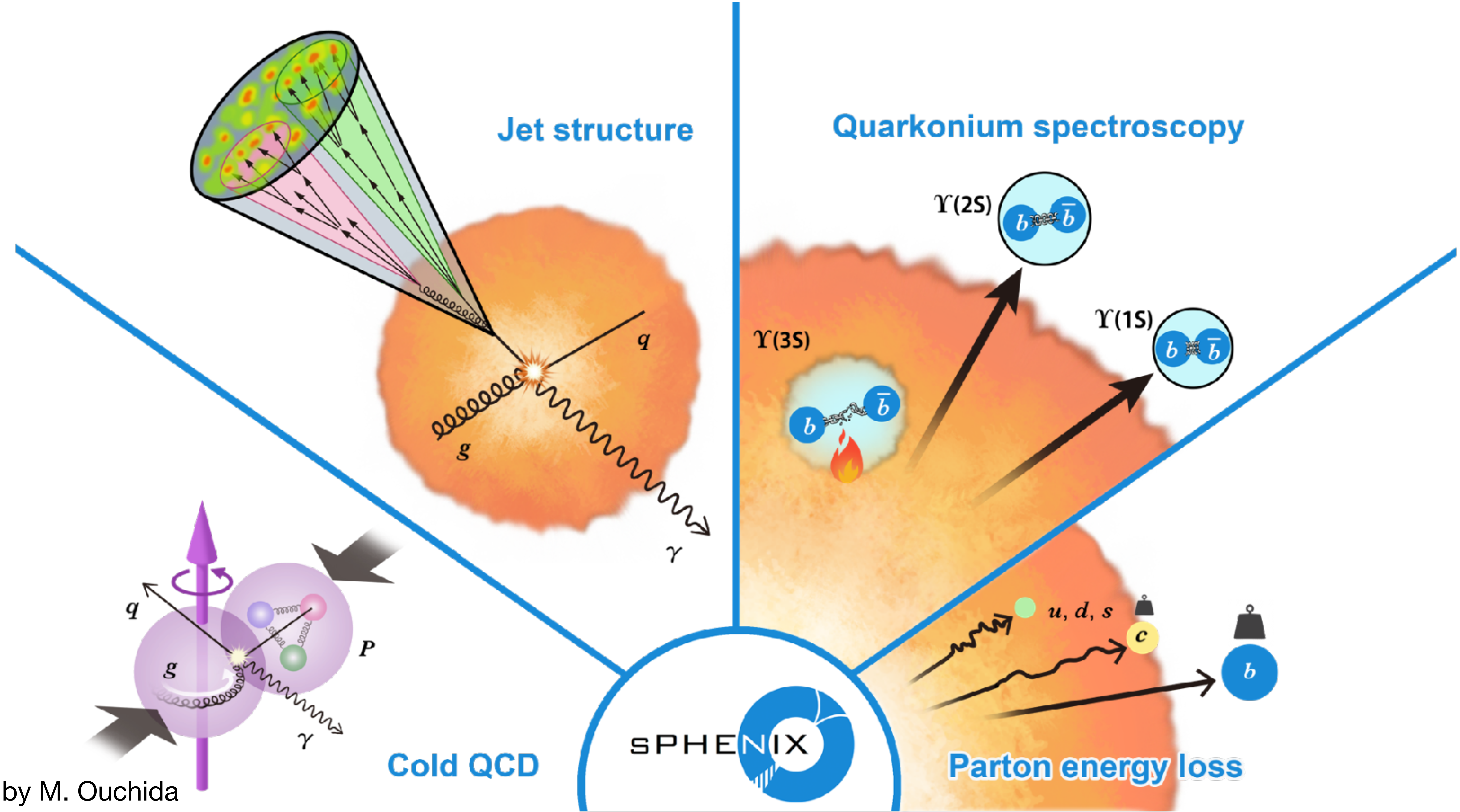
Talks

- A. Hodges,
  "The sPHENIX Experiment At RHIC", Sep. 23rd 11:55

Posters

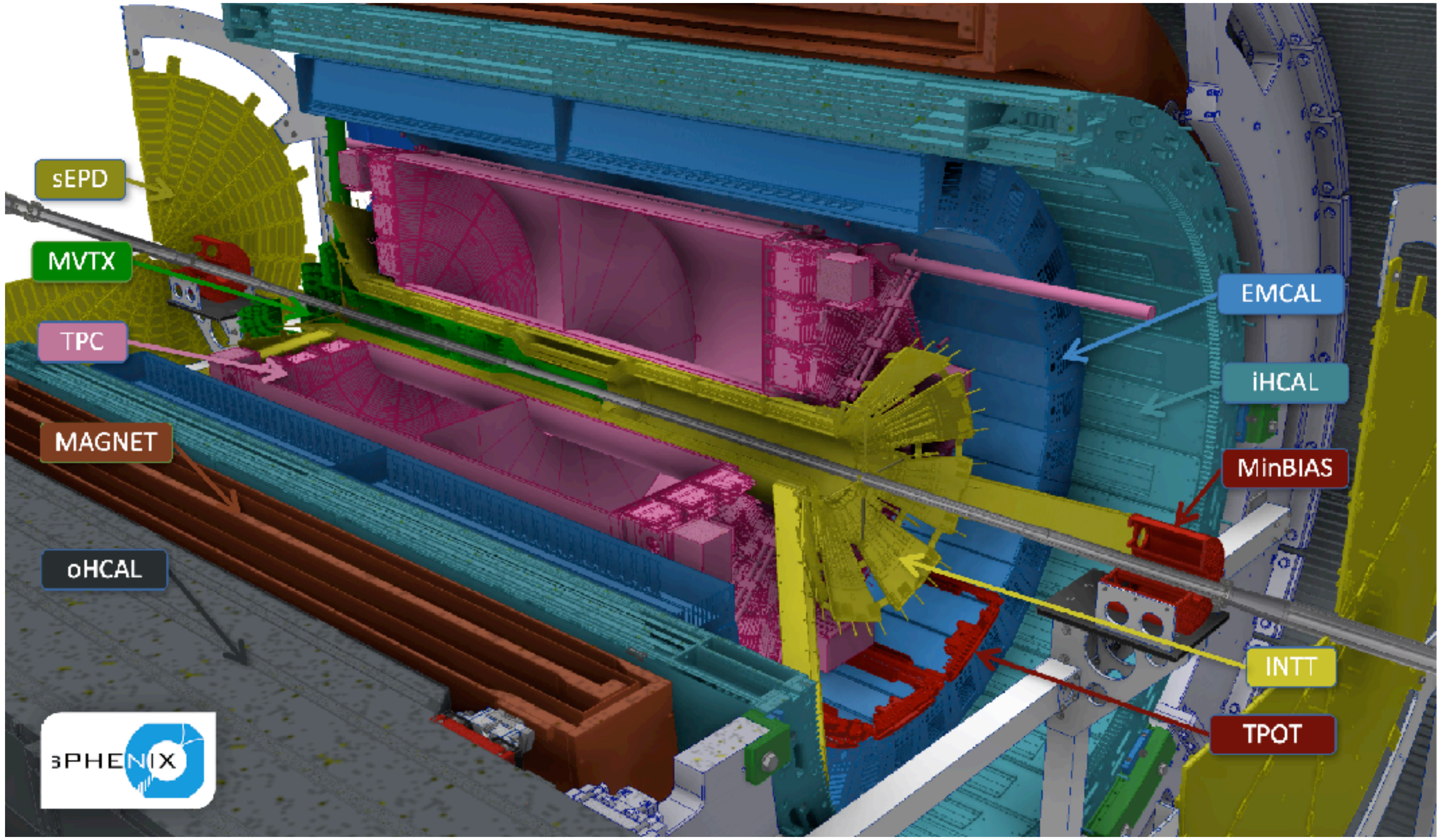
- H. Bossi,
  "Intelligent experiments through real-time AI: Fast Data Processing and Autonomous Detector Control for sPHENIX and future EIC detectors", Sep. 24th
- R. Kunnawalkam Elayavalli,
  "High-p_T physics with the sPHENIX calorimeters in the inaugural physics Run-24", Sep. 24th.
- Y. Go,
  "Novel use of AI generative models for heavy ion experiments", Sep. 24th.
- M. Ikemoto,
  "Position alignments and vertex determination for sPHENIX INTT detector", Sep. 24th.
- M. Liu,
  "Strange and Heavy Flavor Physics with the sPHENIX Trackers in the Inaugural Physics Run-24", Sep. 24th
- B. Kimelman,
  "Underlying event characterization in 200 GeV Au+Au collisions for jet measurements with the sPHENIX detector", Sep. 24th
- C. W. Shih,
  "Intermediate Silicon Tracker in sPHENIX at RHIC", Sep. 24th

sPHENIX Physics Programs



Illustrated by M. Ouchida

sPHENIX Detector



A first hadron calorimeter in midrapidity at RHIC for jet reconstruction.
Acceptance of the full azimuthal angle 2π and $|\eta| < 1.1$ in $|z_{vtx}| < 10$ cm.

sPHENIX Detector

Calorimeter system

4.9 hadronic interaction length in total

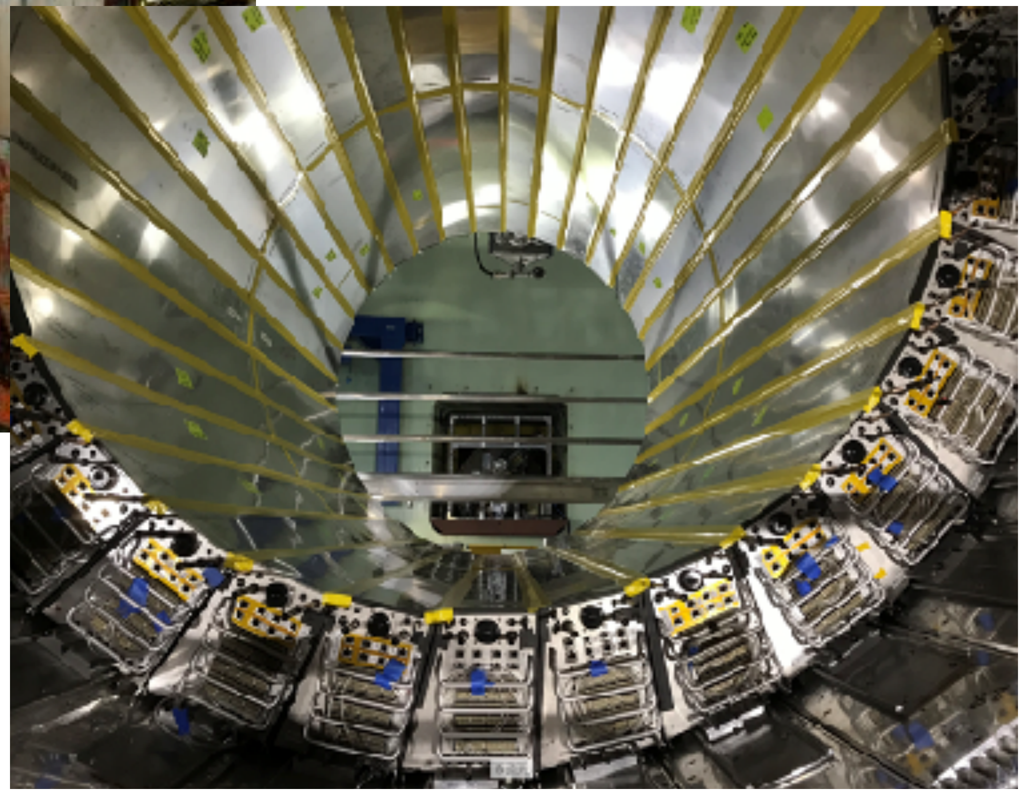
Outer and Inner Hcal (Hadronic Calorimeter)

- Al (inner)/steel (outer) absorber plates & scintillating tiles
- Tower size: $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
- Calibrated with cosmic muons

EMcal (Electromagnetic Calorimeter)

- consists of tungsten powder and scintillating fibers
- Tower size: $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$
- Calibrated with π^0 mass peak in η rings

Hcal



EMcal

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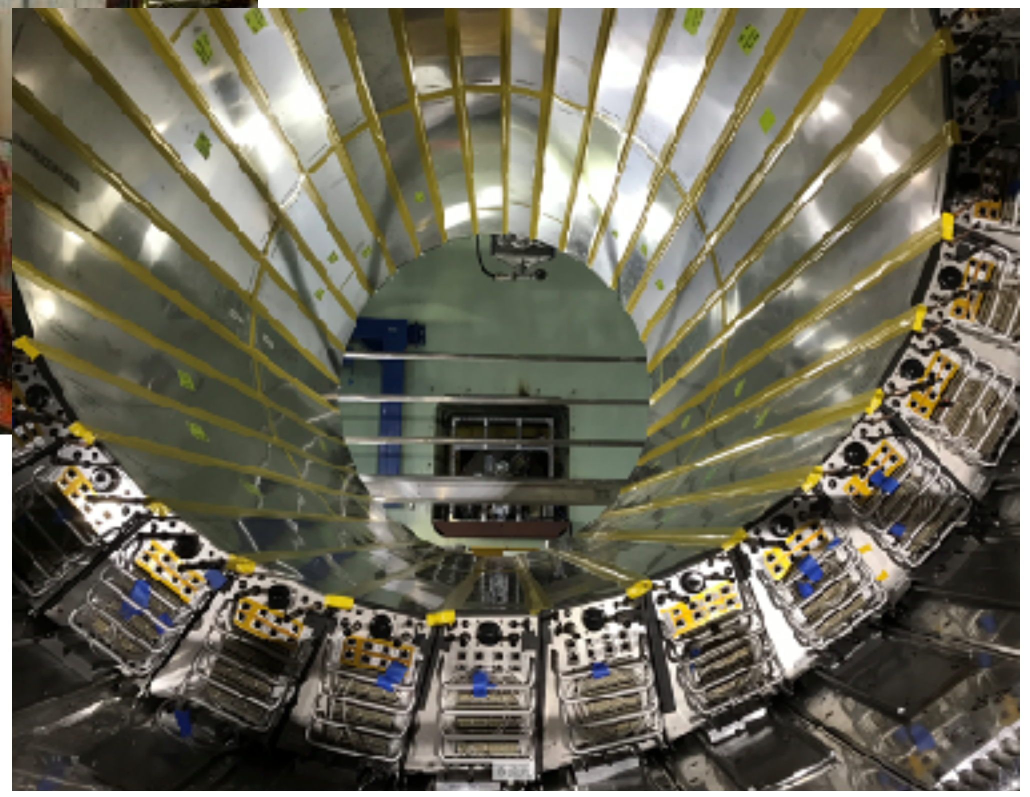
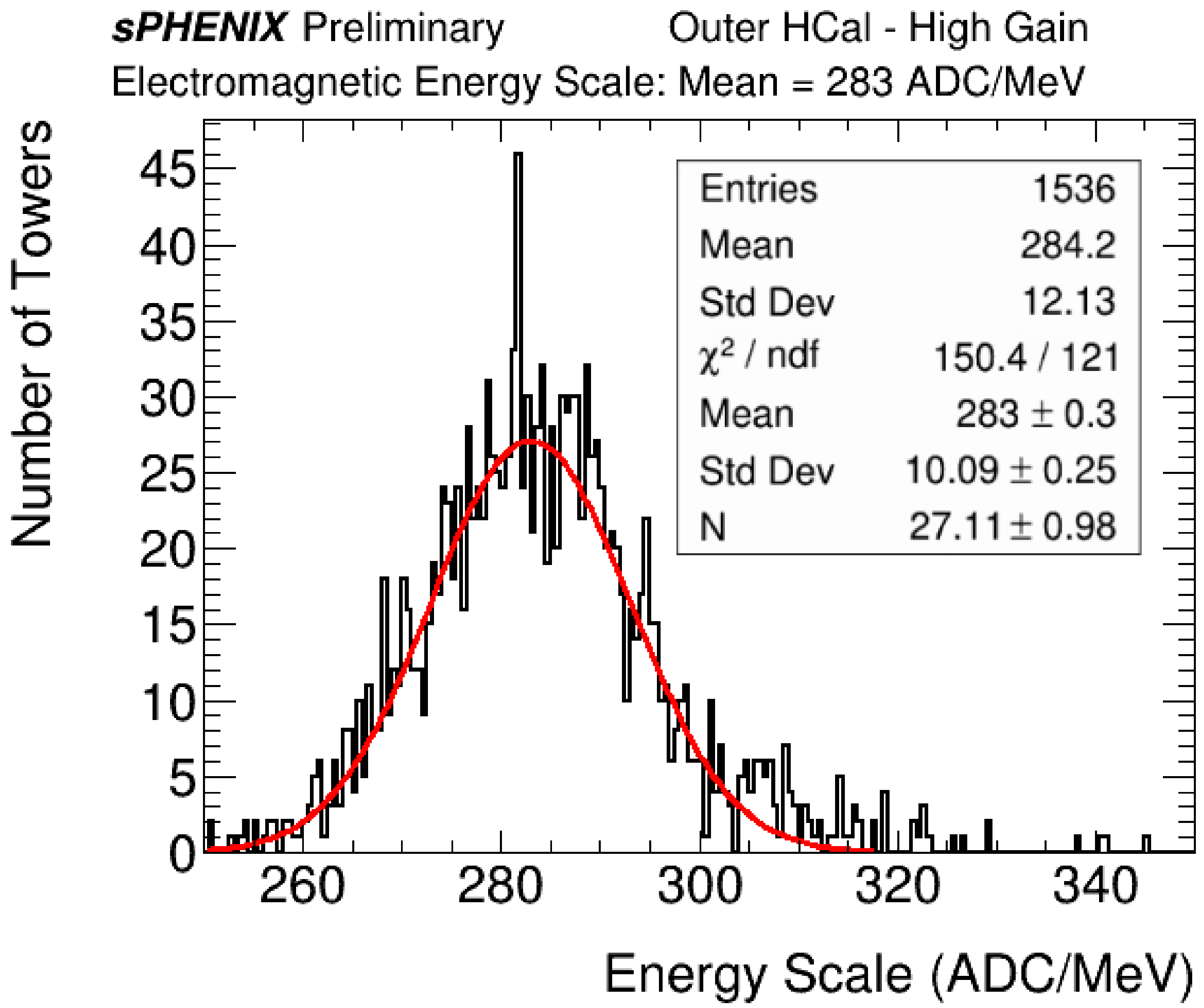
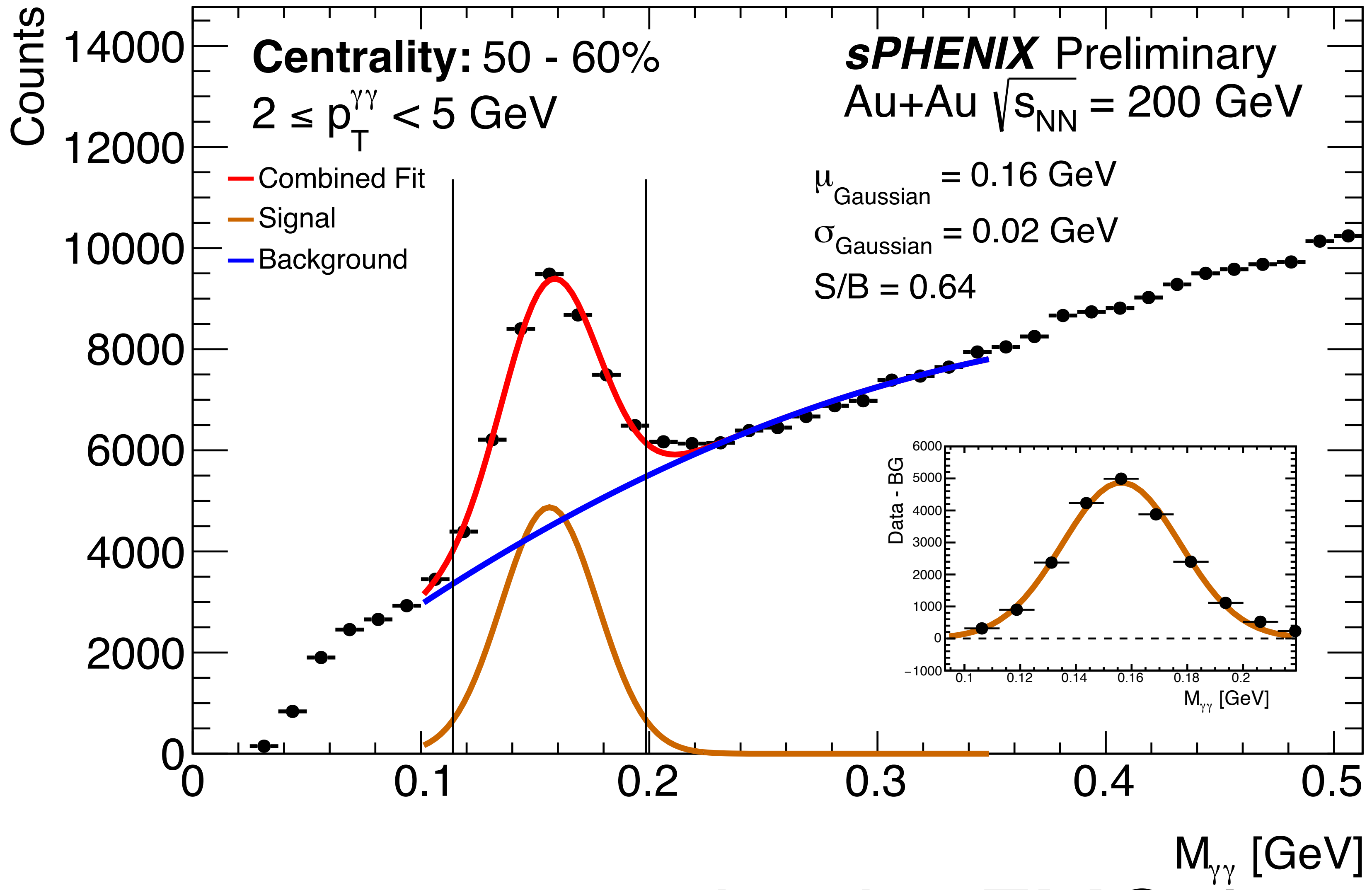


EMcal



Energy calibration of HCal with cosmic rays.



π^0 reconstruction by EMCal

sPHENIX Detector

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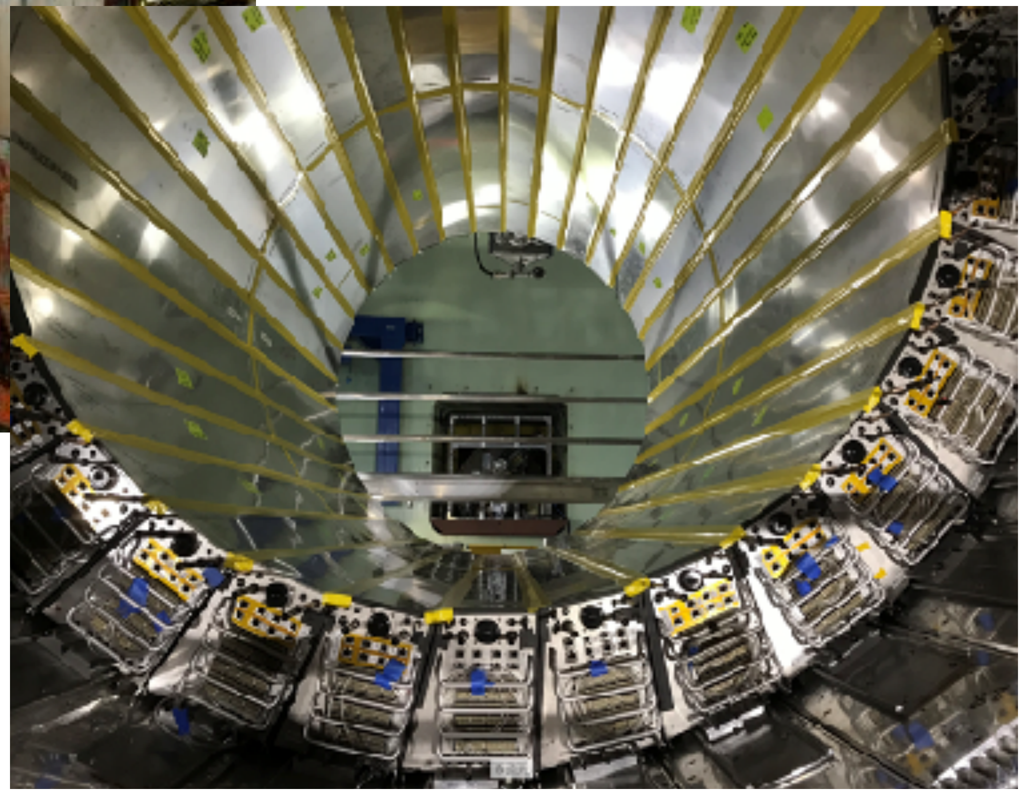

EMcal

Tracking system ($|\eta|<1.1$ for $|z_{vtx}|<10$ cm)

TPC (Time Projection Chamber, r < 80 cm)

TPOT (TPC Outer Tracker)

INTT (Intermediate Silicon Tracker, r < 10 cm)

MVTX
(MAPS-based Vertex Detector, r < 4 cm)

sPHENIX Detector

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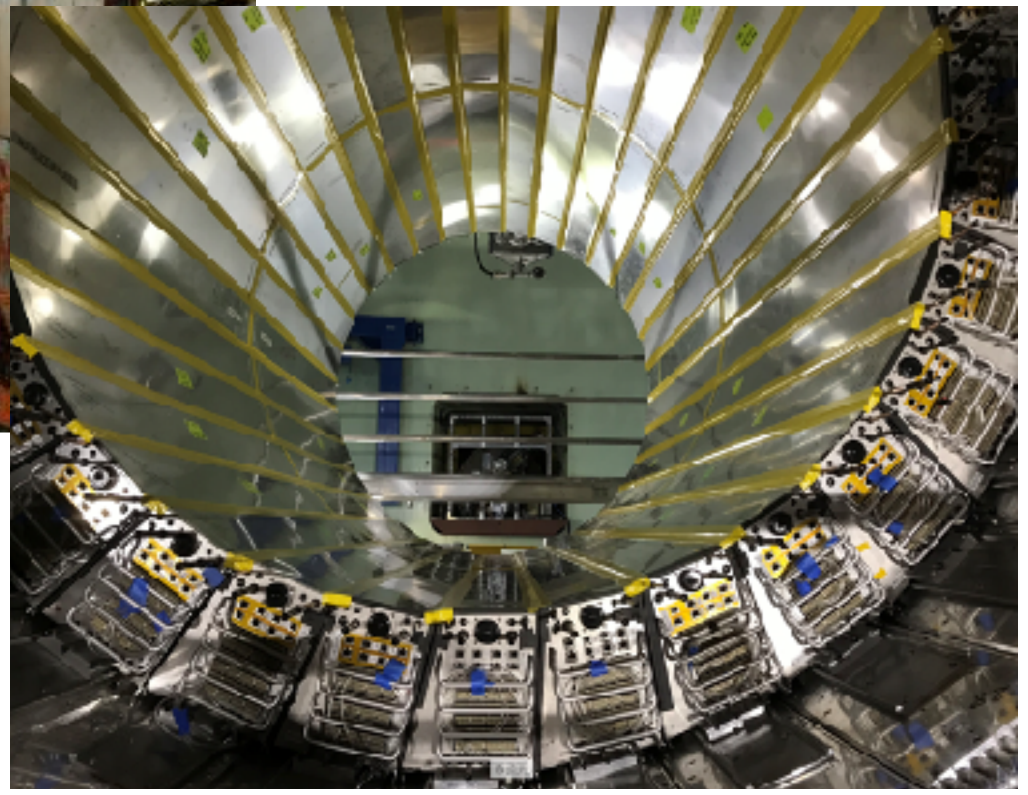

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MBD

Forward detectors

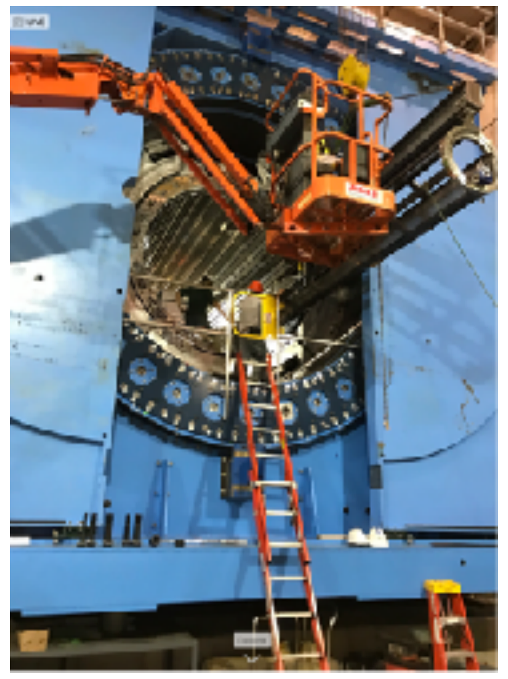
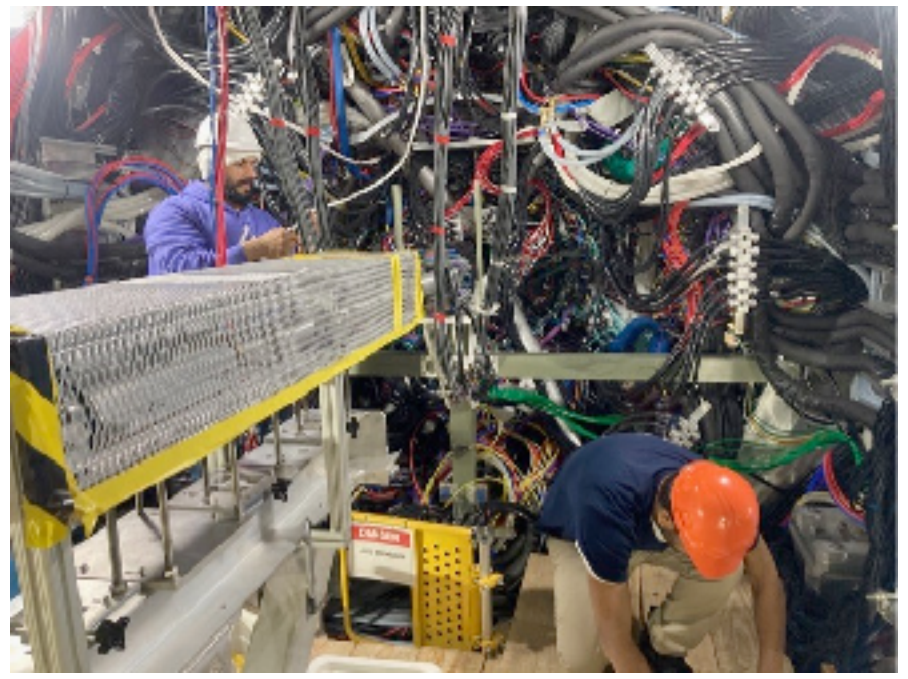
MBD (Minimum Bias Detector, $3.51 < |\eta| < 4.61$)

- Comprised of Photomultiplier Tube counters
- Provides minimum bias trigger, z vertex determination, and centrality determination
- Reuse of PHENIX BBC but moved by 1 m in z-direction

sEPD (sPHENIX Event Plane Detector, $2.0 < |\eta| < 4.9$)

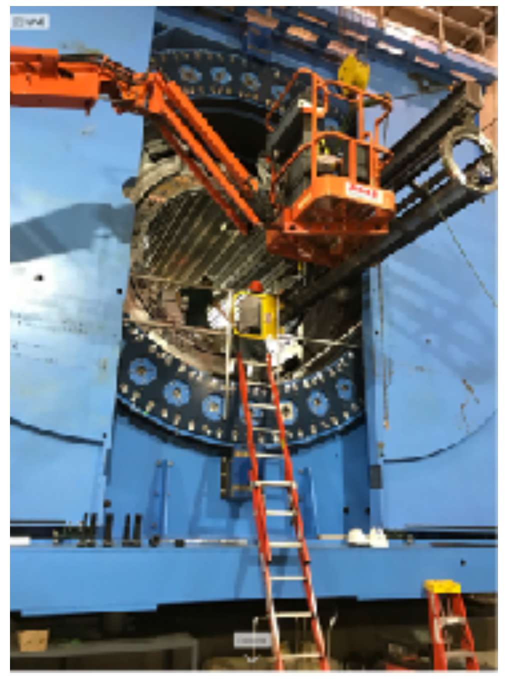
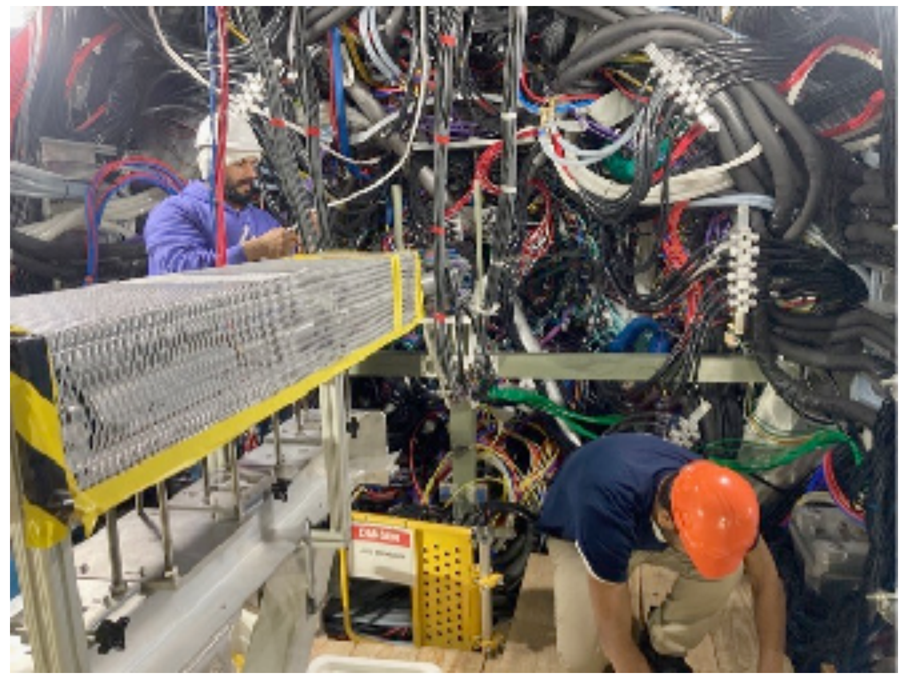
ZDC (Zero Degree Calorimeter) at z =± 18.5 m

Commissioning Run 2023 With AuAu at 200 GeV

- April: The construction was finished.
- May: The first beam came

Commissioning Run 2023 With AuAu at 200 GeV


- April: The construction was finished.
- May: The first beam came

The dataset used in this analysis

- Small dataset from commissioning
- Prioritized full acceptance of calorimeters
- EMCal + HCal + MBD subsystems
- Centrality intervals 0-60% as determined by MBD

- Aug/1st: The run was ended by the accelerator failure
- Aug—Sep: Commissioning with cosmic ray measurements

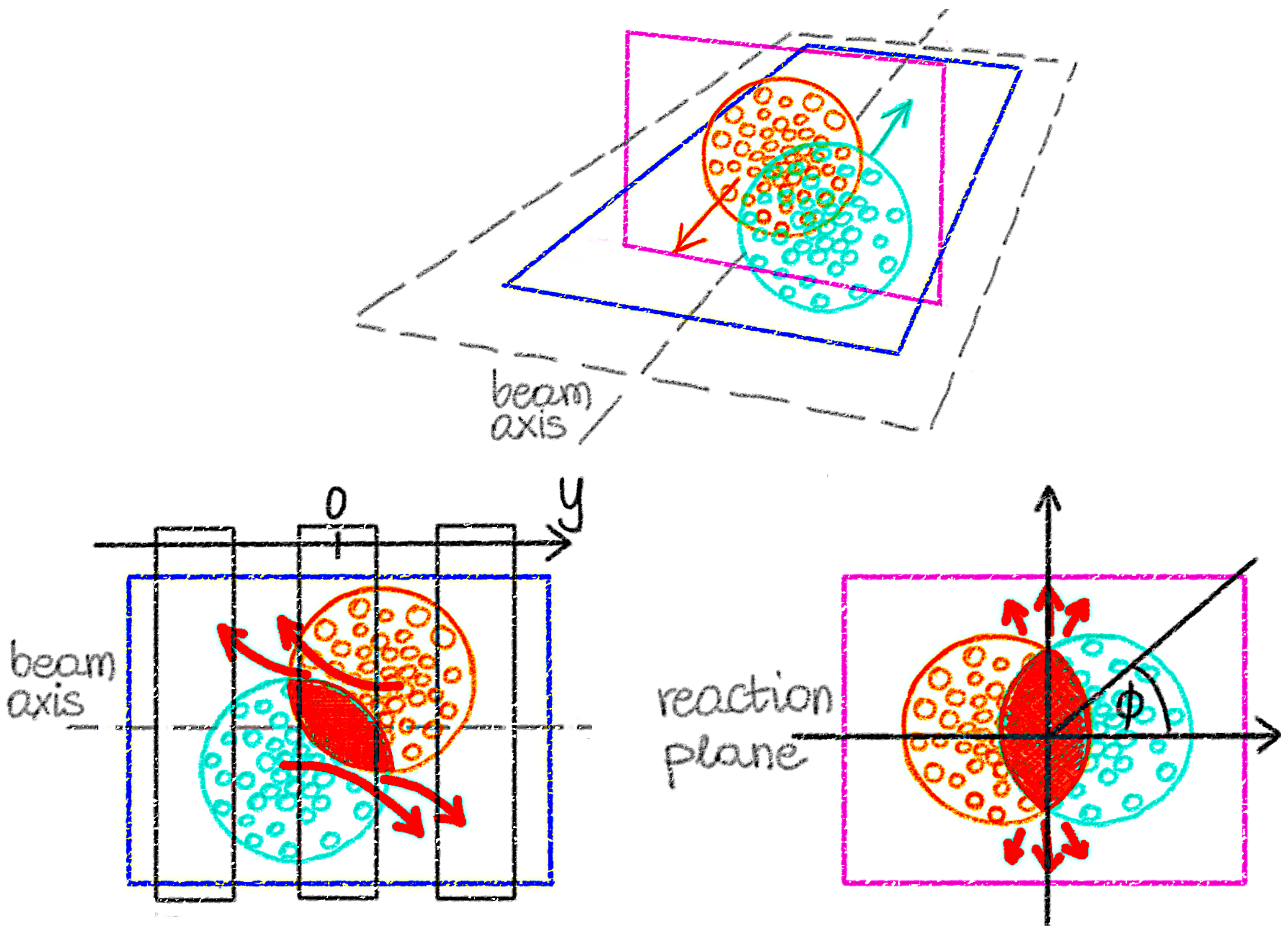
$dE_T/d\eta$ Measurement

The conference note for more details

Longitudinal expansion of QGP medium via measurement of $dE_T/d\eta$

Initial energy density via measurement of $dE_T/d\eta$

Heavy ion collisions at RHIC and LHC have measured Bjorken energy densities greater than energy densities predicted from Lattice QCD for the transition from hadron gas to QGP



$dE_T/d\eta$ is a good starting point for the brand-new experiment, sPHENIX.

arXiv:2402.10183

$dE_T/d\eta$ Measurement

The conference note for more details

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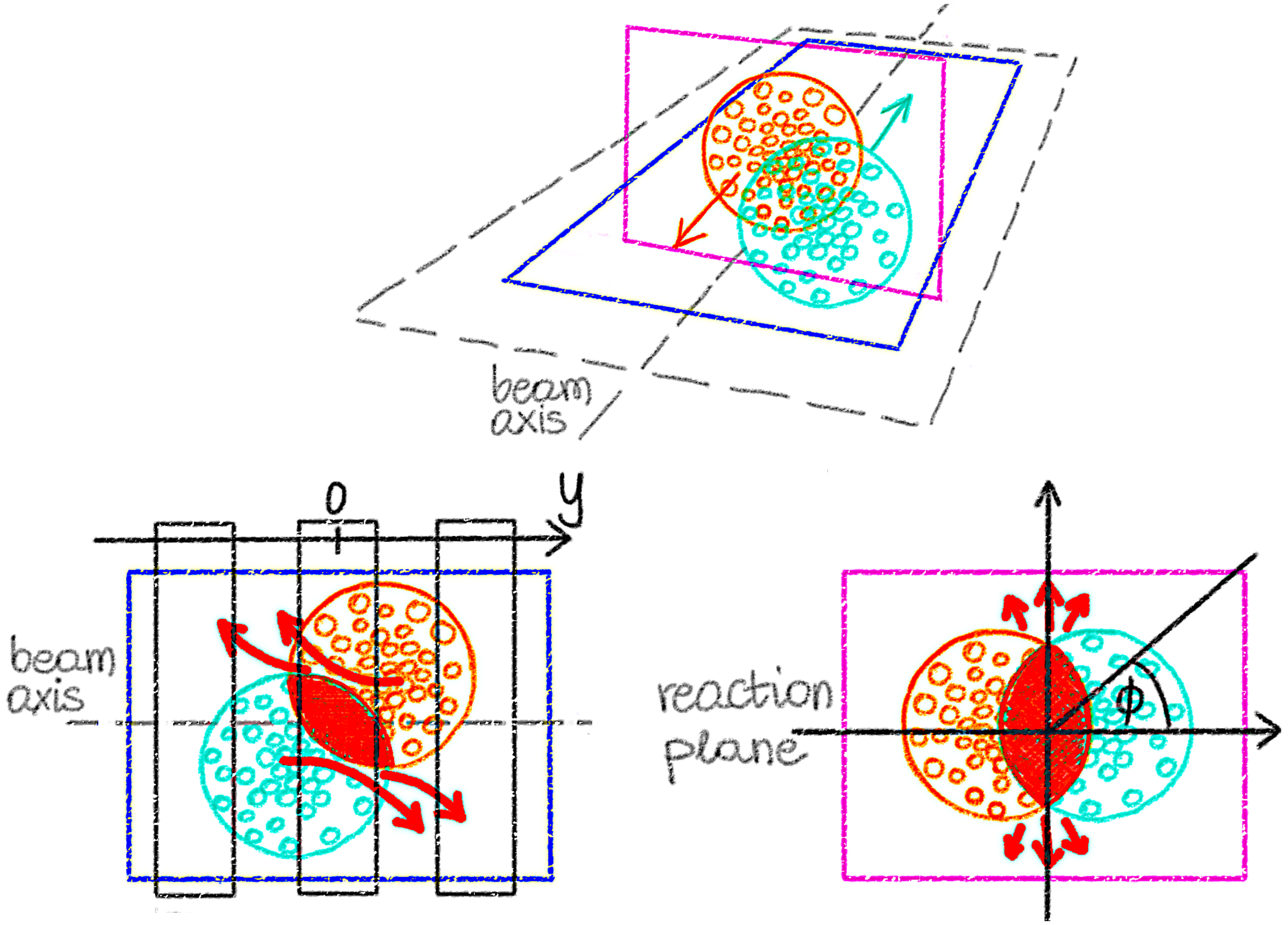

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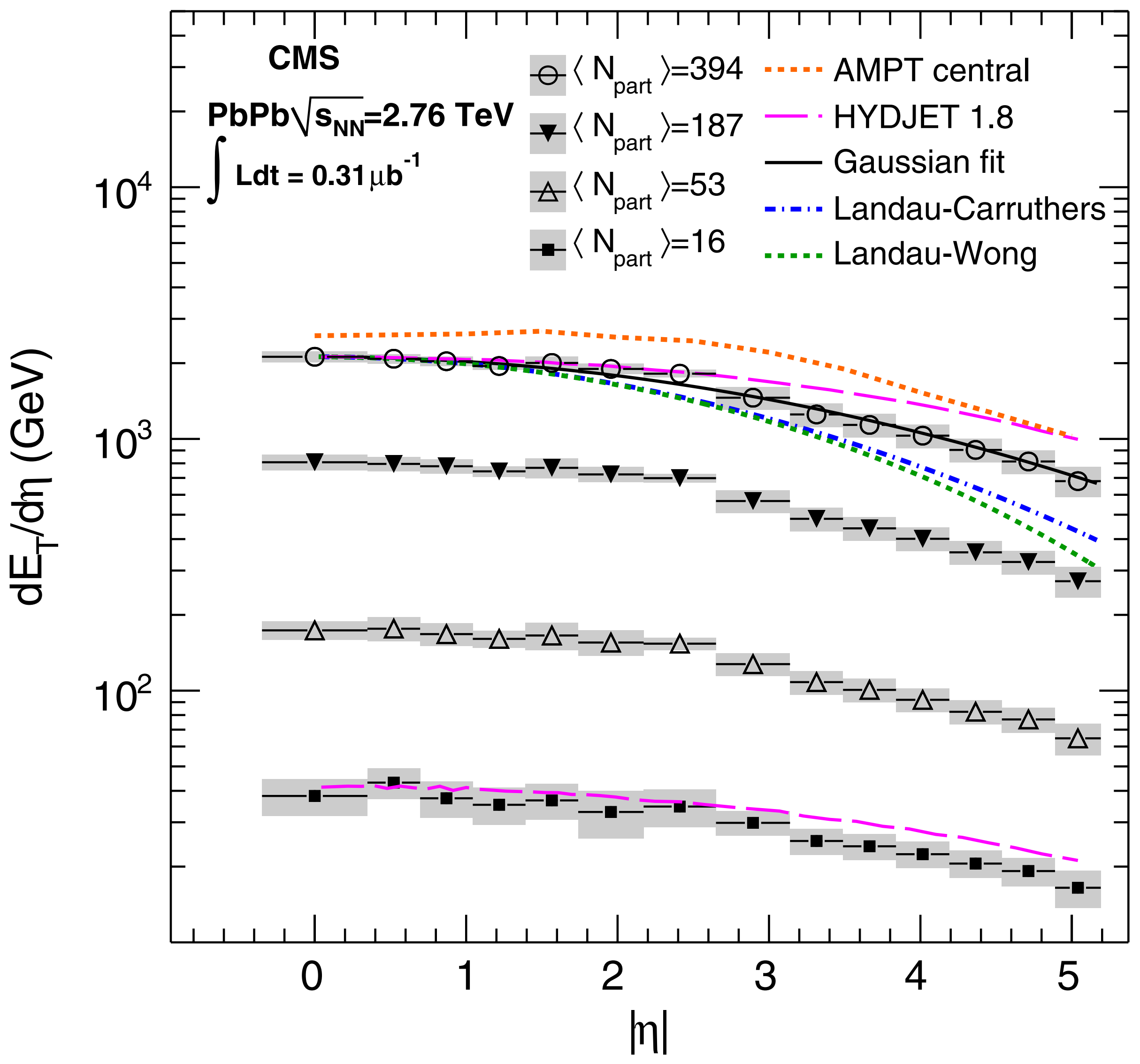
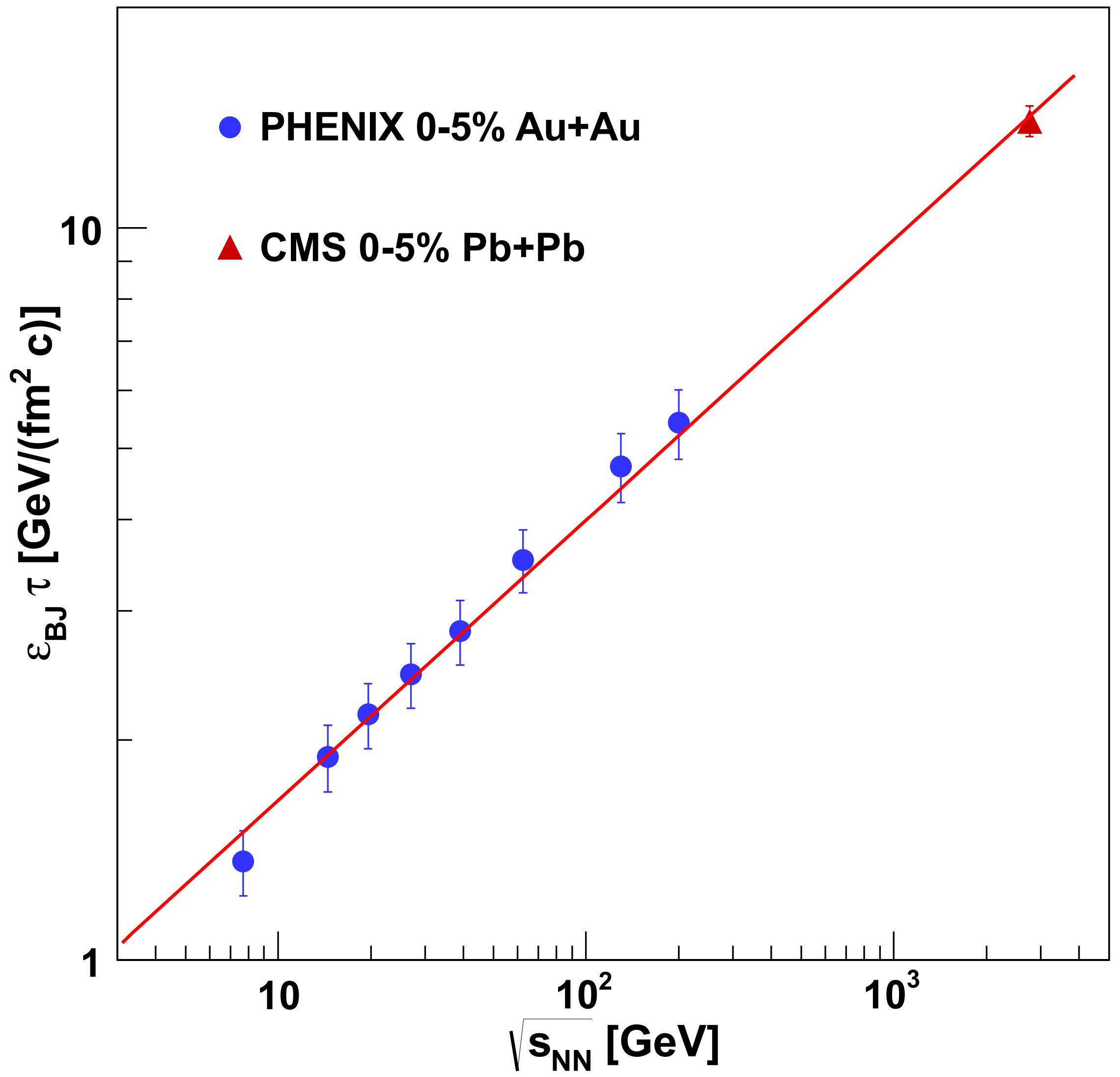
Initial energy density via measurement of $dE_T/d\eta$

Heavy ion collisions at RHIC and LHC have measured Bjorken energy densities greater than energy densities predicted from Lattice QCD for the transition from hadron gas to QGP

Previous measurements of $dE_T/d\eta$ and ϵ_{BJ} via $dE_T/d\eta$:



CMS, PRL109 (2012) 152303



Nucl. Phys.A 956 (2016) 842

$dE_T/d\eta$ is a good starting point for the brand-new experiment, sPHENIX.

Correction Factors From Simulation

Reconstruct total E_T from each calorimeter layer's measurement of $\Sigma E_{T,\text{ tower}}(\eta)$:

- Correction factors are needed to correct for detector acceptance/response.
- Created using HIJING events reweighted to match particle spectra from PHENIX and STAR.

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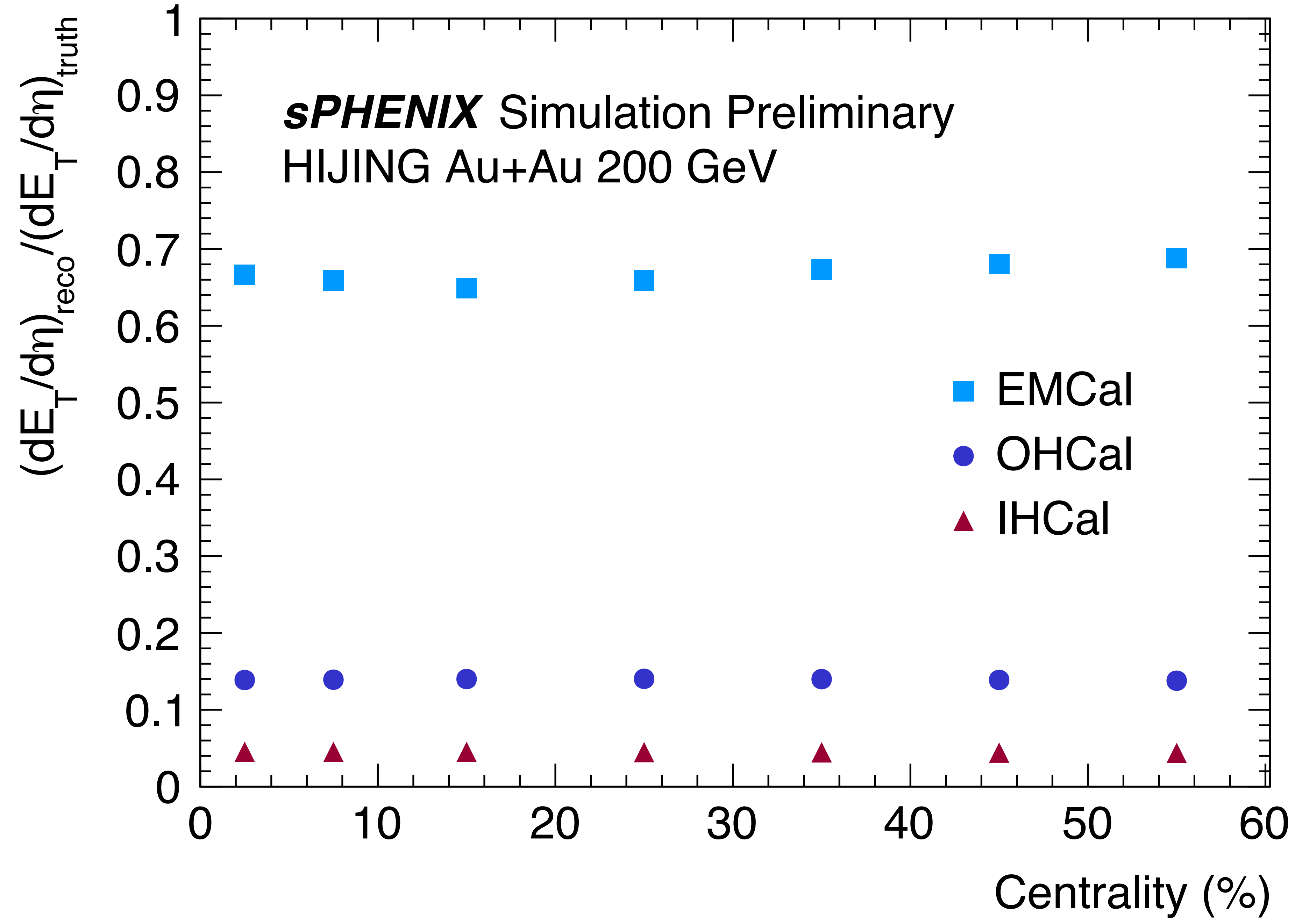
- Created using HIJING events reweighted to match particle spectra from PHENIX and STAR.

Correction factor:

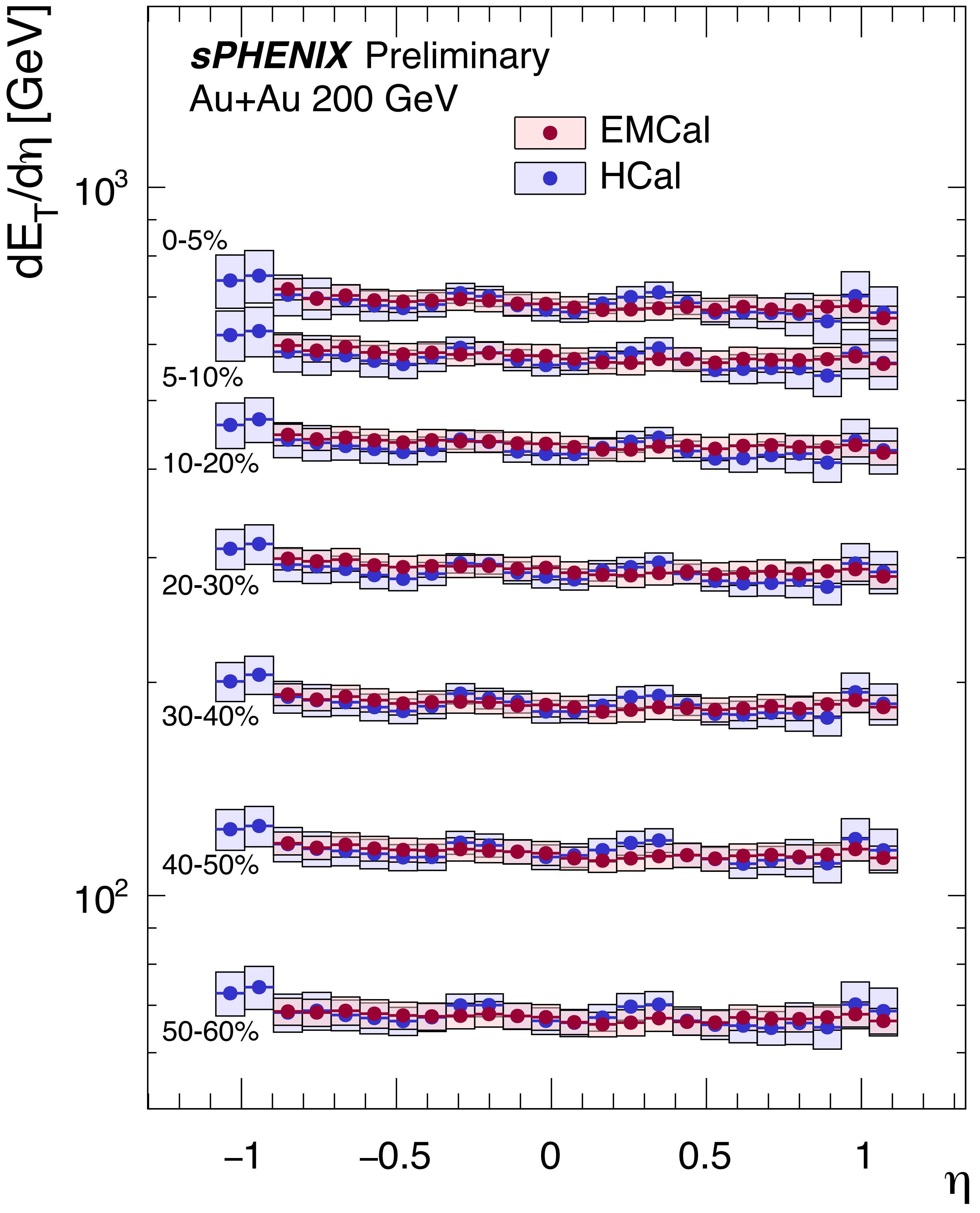
$$C(\eta) = \frac{\sum E_{T,\text{ tower}}(\eta)}{\sum E_{T,\text{ particle}}(\eta)}$$

- $E_{T,\text{ tower}} = E_{\text{tower}} \sin\theta$ for each calorimeter in the simulation
- $E_{T,\text{ particle}} = E_{\text{particle}} \sin\theta$ for all collision final state particles within the detector's acceptance
- Factors show the ratio of reconstructed $dE_T/d\eta$ to truth $dE_T/d\eta$ for each calorimeter layer.

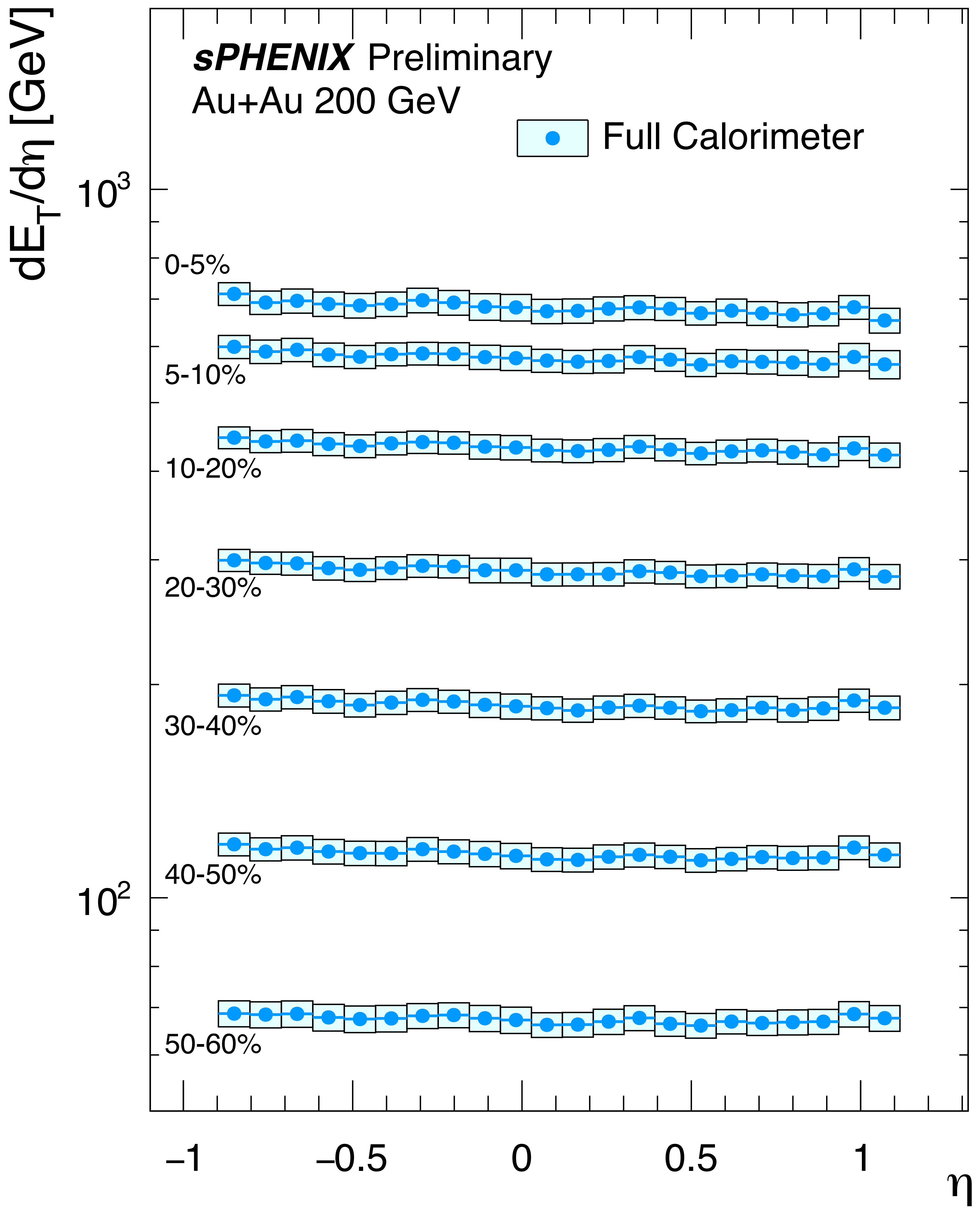


EMCal sees ~66% of truth $dE_T/d\eta$!!!
Inner/Outer HCals see 4% and 14% of truth $dE_T/d\eta$

Fully Corrected $dE_T/d\eta = \frac{\sum E_{T,\,\mathrm{tower}}(\eta)}{C(\eta)}$



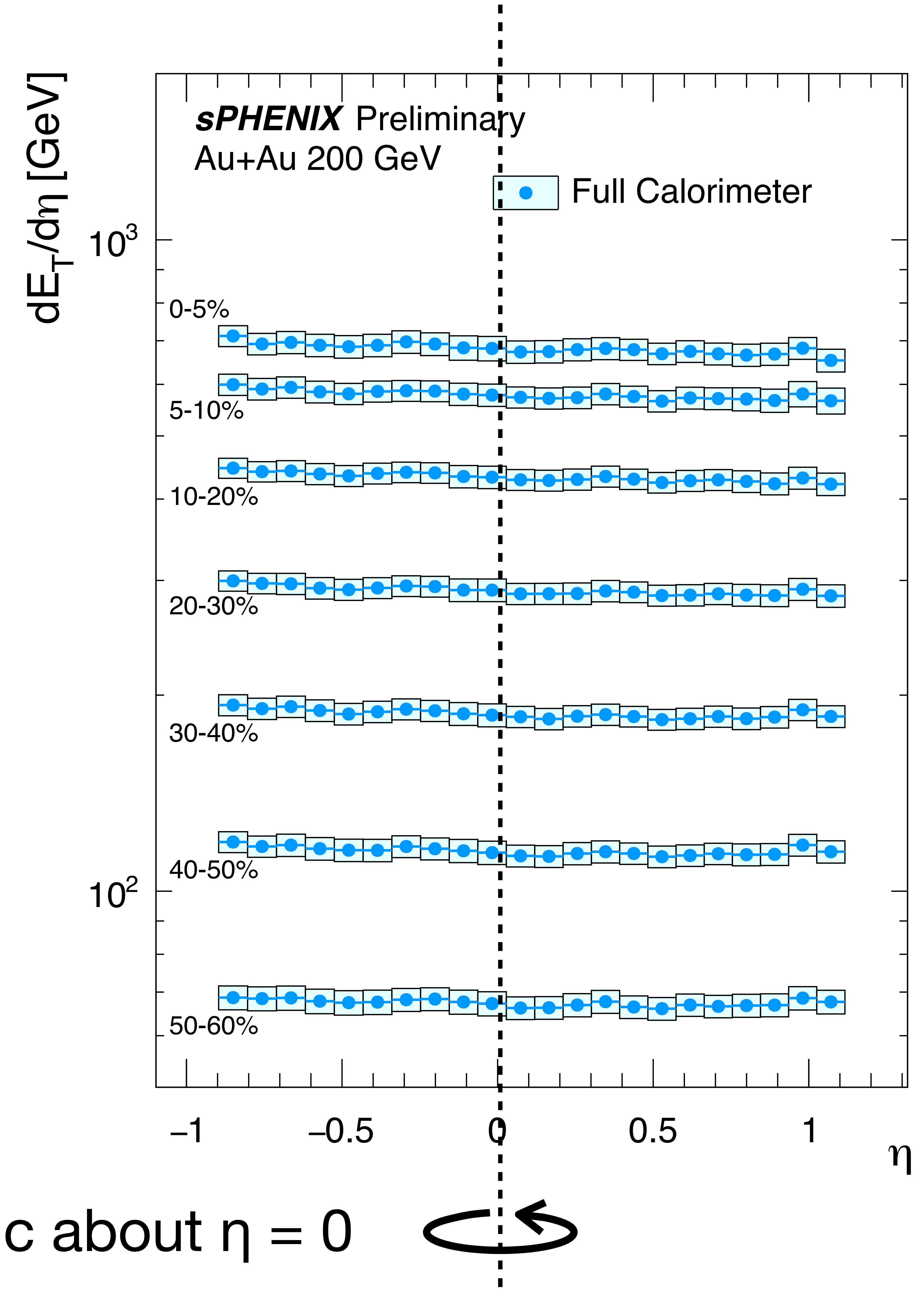
EMCal & IHCal + OHCal



EMCal + HCals

Strong dependence on centrality can be seen.
Good agreement b/w EMCal, HCal, and full calorimeter results was confirmed!

Fully Corrected $dE_T/d\eta = \frac{\sum E_{T,\,\text{tower}}(\eta)}{C(\eta)}$

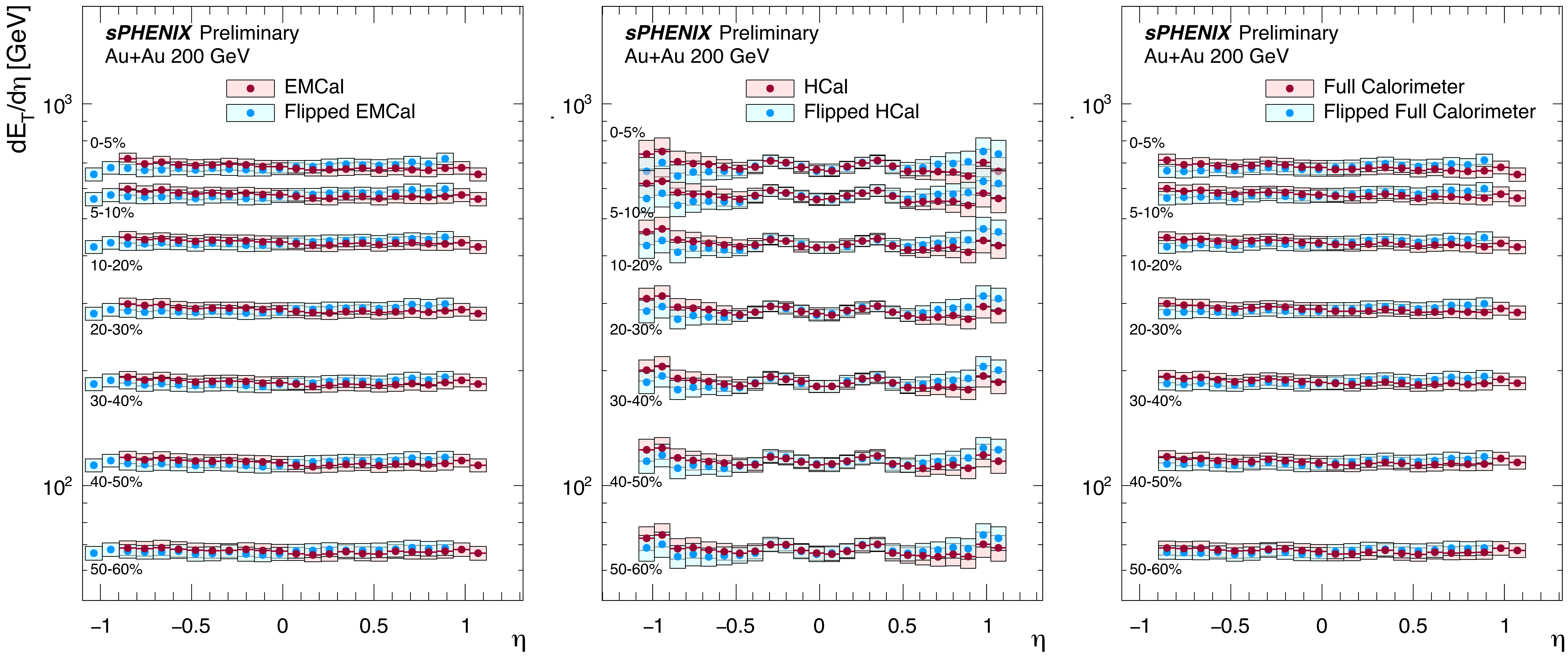


Symmetrical check

$dE_T/d\eta$ has to be symmetric about η = 0

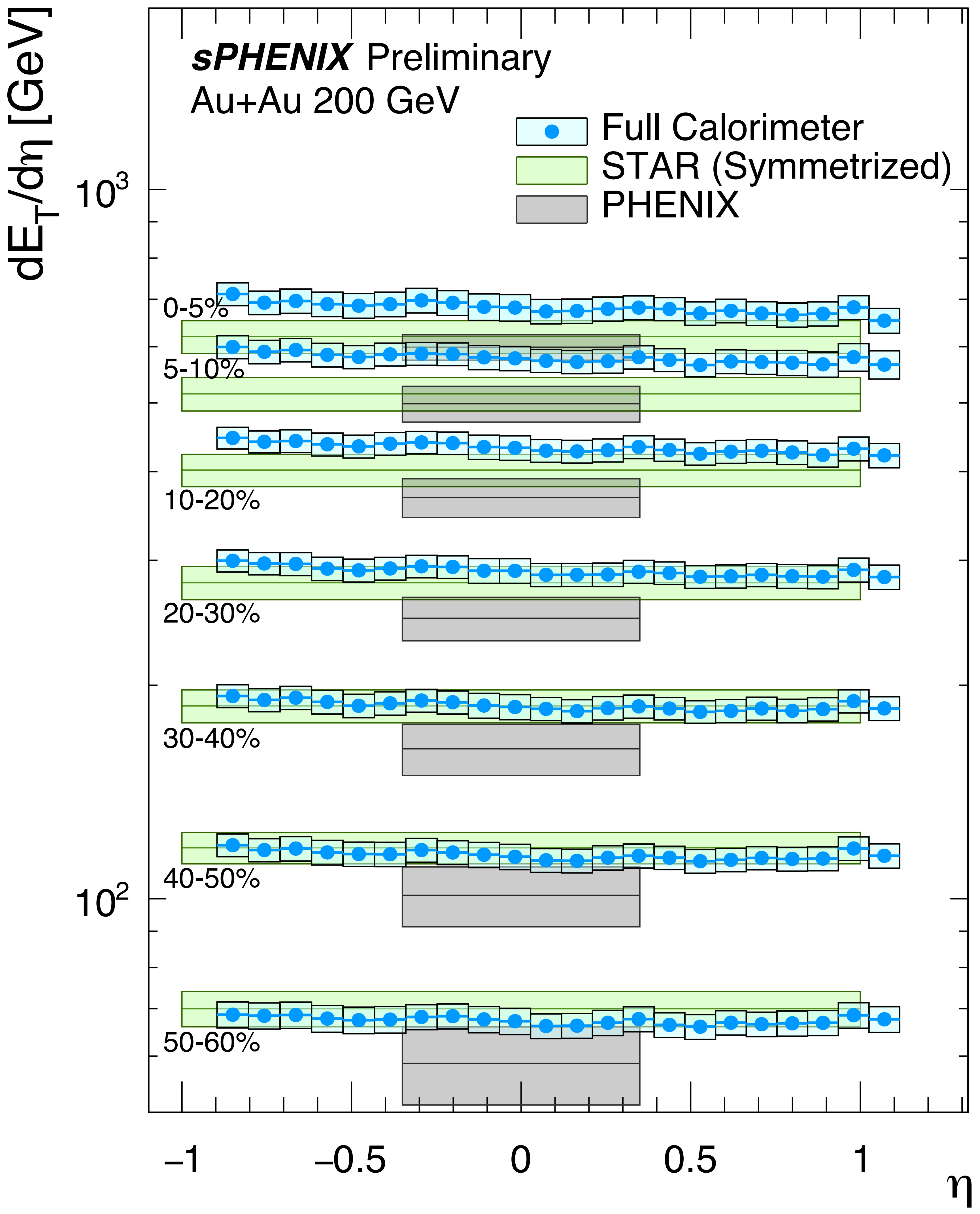
Fully Corrected $dE_T/d\eta = \frac{\sum E_{T,\,\mathrm{tower}}(\eta)}{C(\eta)}$

Symmetrical check



EMCal, HCal, and full calorimeter results are symmetric about η = 0 within uncertainties!

$dE_T/d\eta$: Comparison to PHENIX/STAR Results



Comparison of sPHENIX full calorimeter $dE_T/d\eta$ measurements to the STAR/PHENIX measurements

to PHENIX

sPHENIX results are consistently higher than PHENIX's for all centrality bins but agree within uncertainties for mid-central bins 30 – 60%

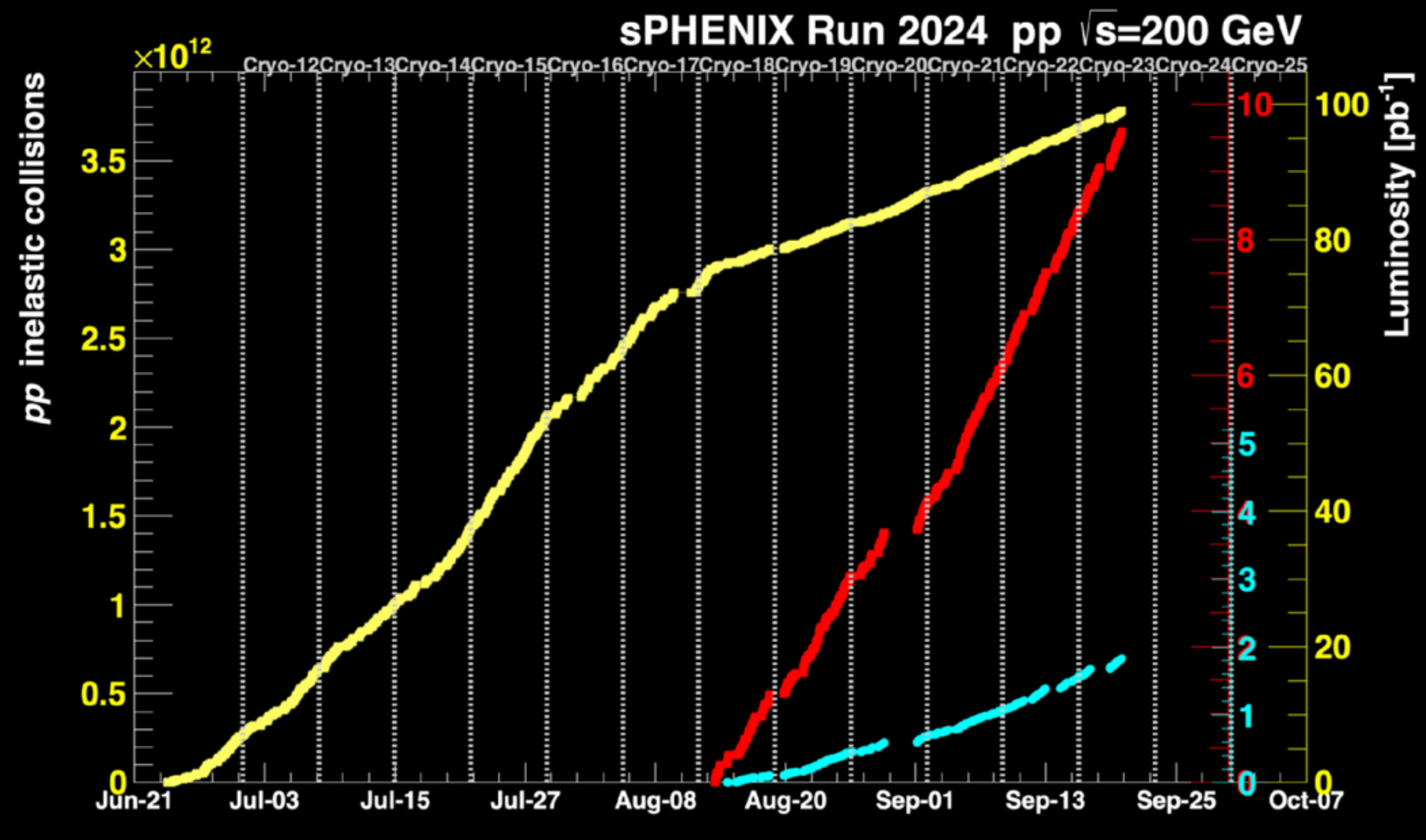
to STARs

sPHENIX results are above the STAR's in the centrality range of 0 — 10% but are in agreement in other centrality intervals

The sPHENIX results are given as a function of preliminary centrality. It will be updated using quantities like $\langle N_{part} \rangle$ soon.

Run Status

- pp run will be completed on Sep. 30th.
- The AuAu commissioning run will be in Oct., and the major AuAu measurement will carried out in 2025.

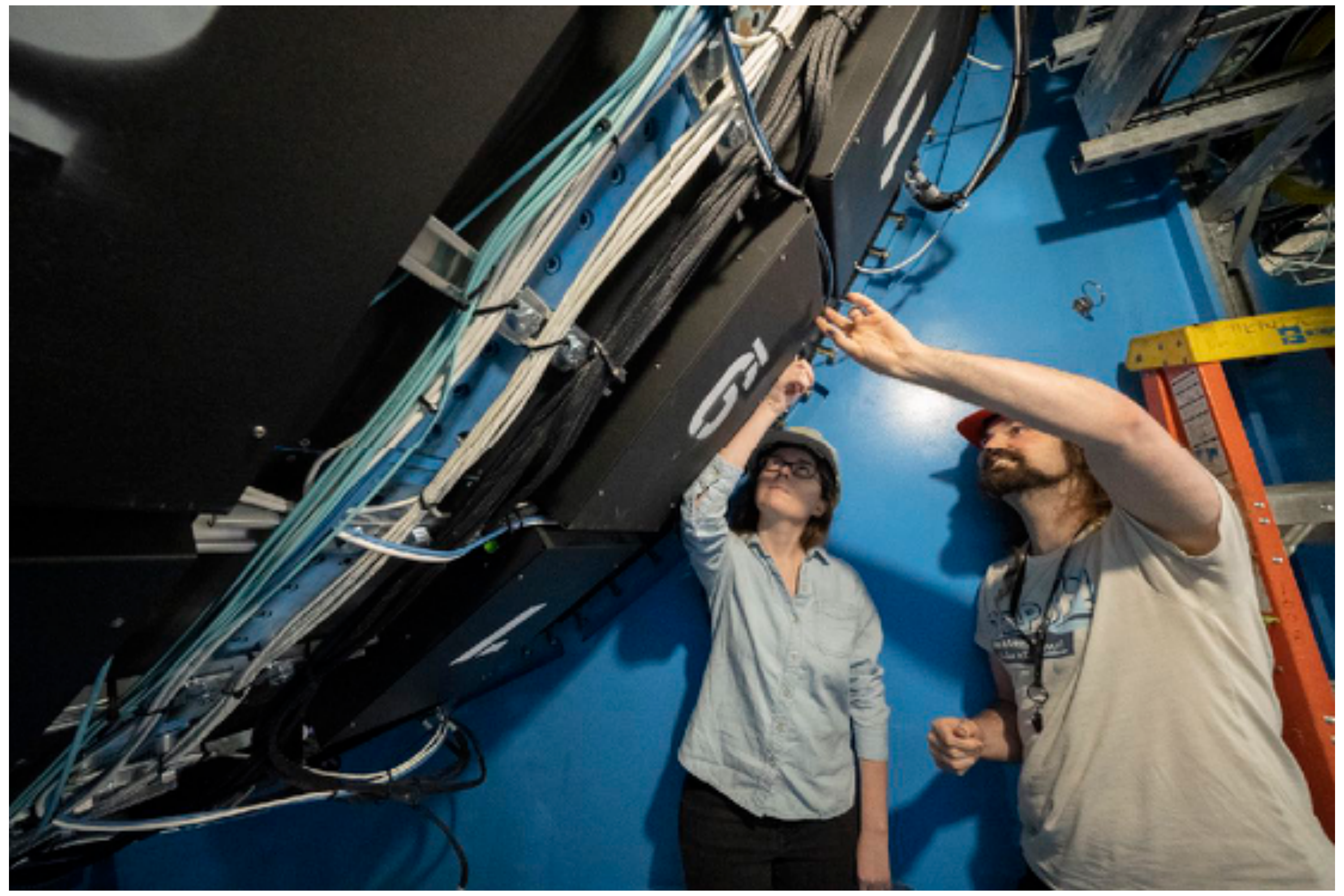


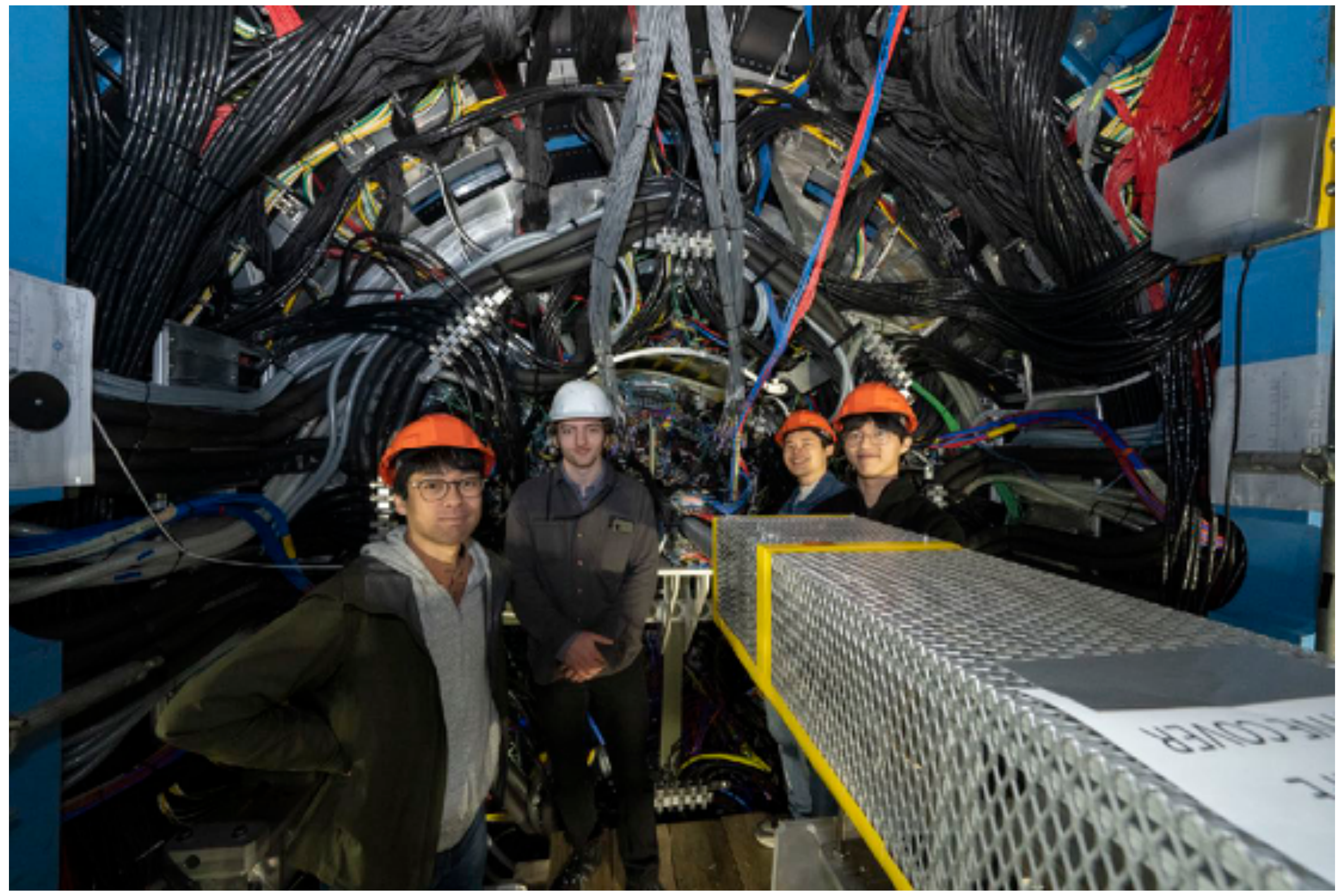
- Calorimeter Data
  - 0 mrad crossing angle
  - More than ×2 stats achieved
- All detector data
  - +1.5 mrad
  - $|z_{vtx}| < 10$ cm
  - ~20% of the run goal achieved
- Tracker streaming data
  - +1.5 mrad
  - $|z_{vtx}| < 10$ cm
  - ~40% of the run goal achieved

We appreciate the RHIC Collider Accelerator Division for providing good beam.

Summary

- sPHENIX studies QGP and Cold-QCD at RHIC in BNL.
- $dE_T/d\eta$: Fully corrected calorimeter results agree with PHENIX/STAR results. See the conference note for more details.
- pp run is almost finished. Commissioning with AuAu is in the next month.
- AuAu mass data taking will be performed in 2025.
- $dE_T/d\eta$ measurement will be updated with new AuAu data taken in 2024 and 2025.

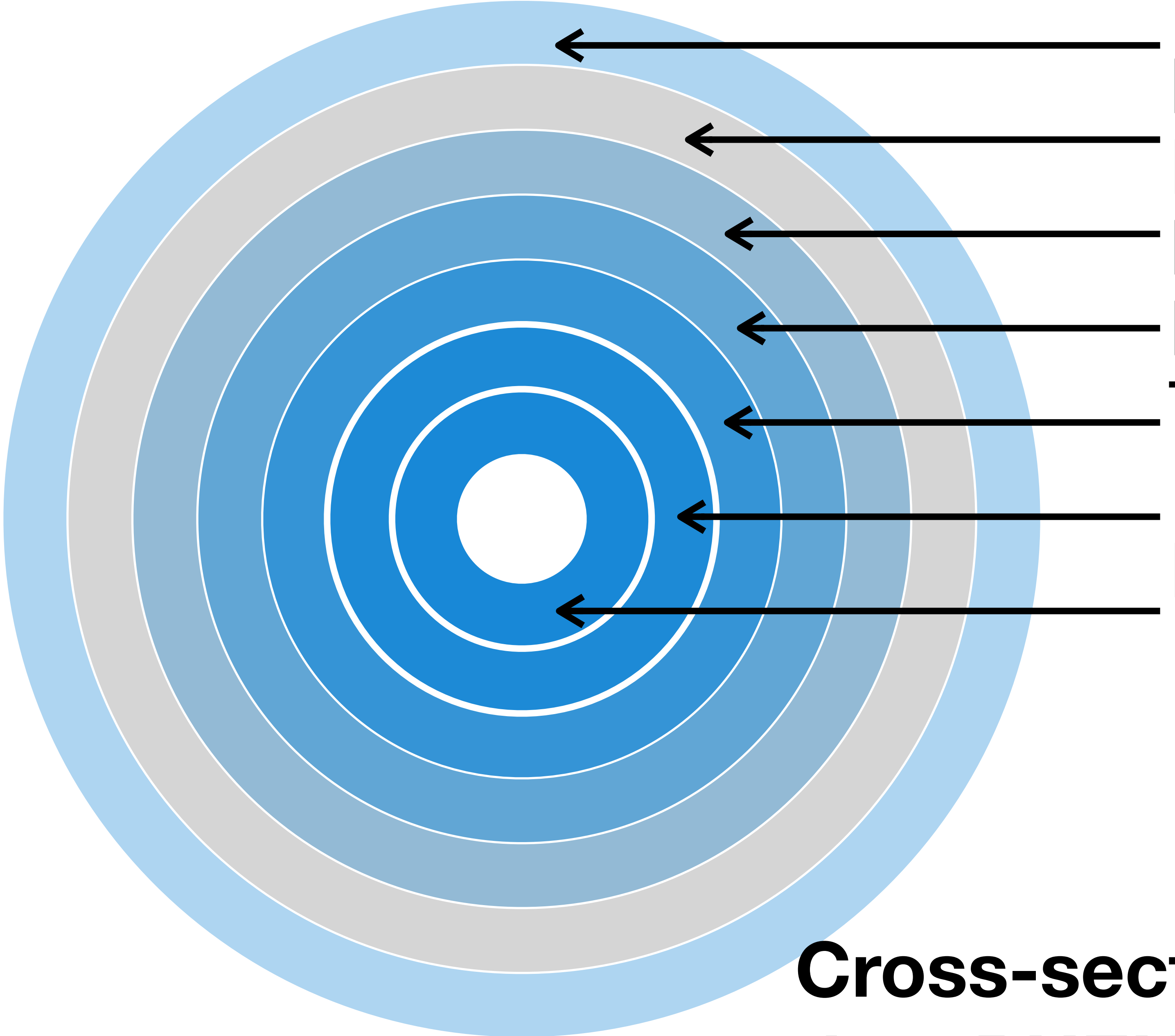




BACKUP

sPHENIX Detector

Magnet



Cross-section of the sPHENIX detector

Magnet

Superconducting solenoid magnet from Babar at SLAC provides 1.5 T

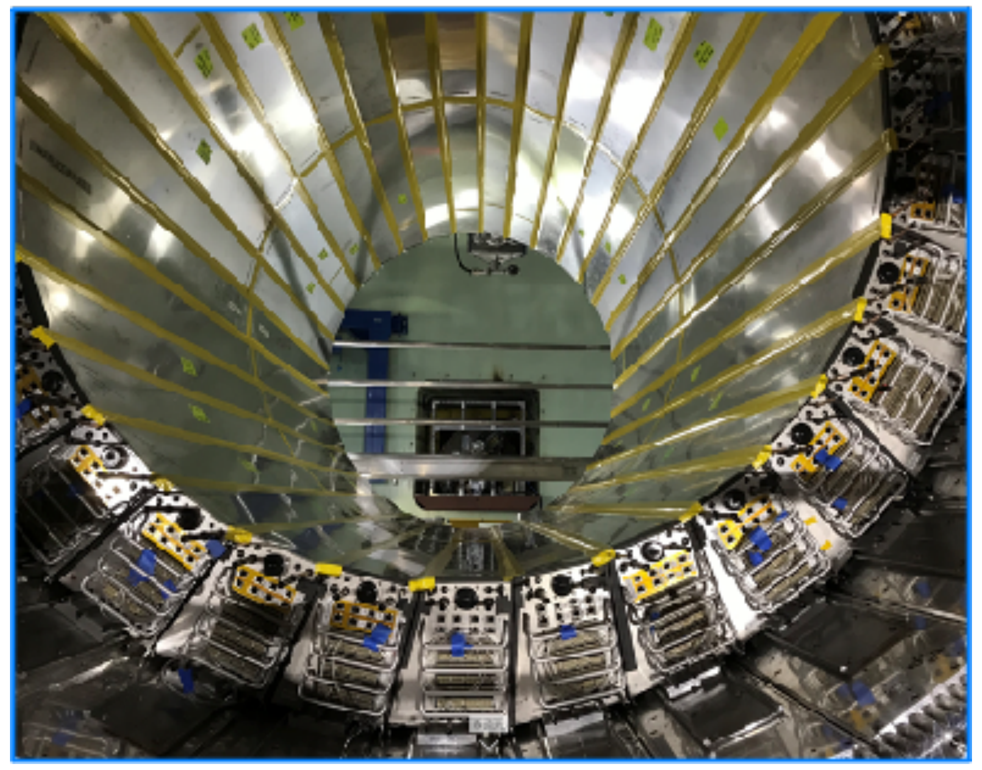
Outer and Inner Hcal (Hadronic Calorimeter)

- Inner part: non-magnetic metal and scintillator
- Outer part: Iron and scintillator
- Measurements can be done before multiple scattering of hadron shower by the cryostat for the magnet

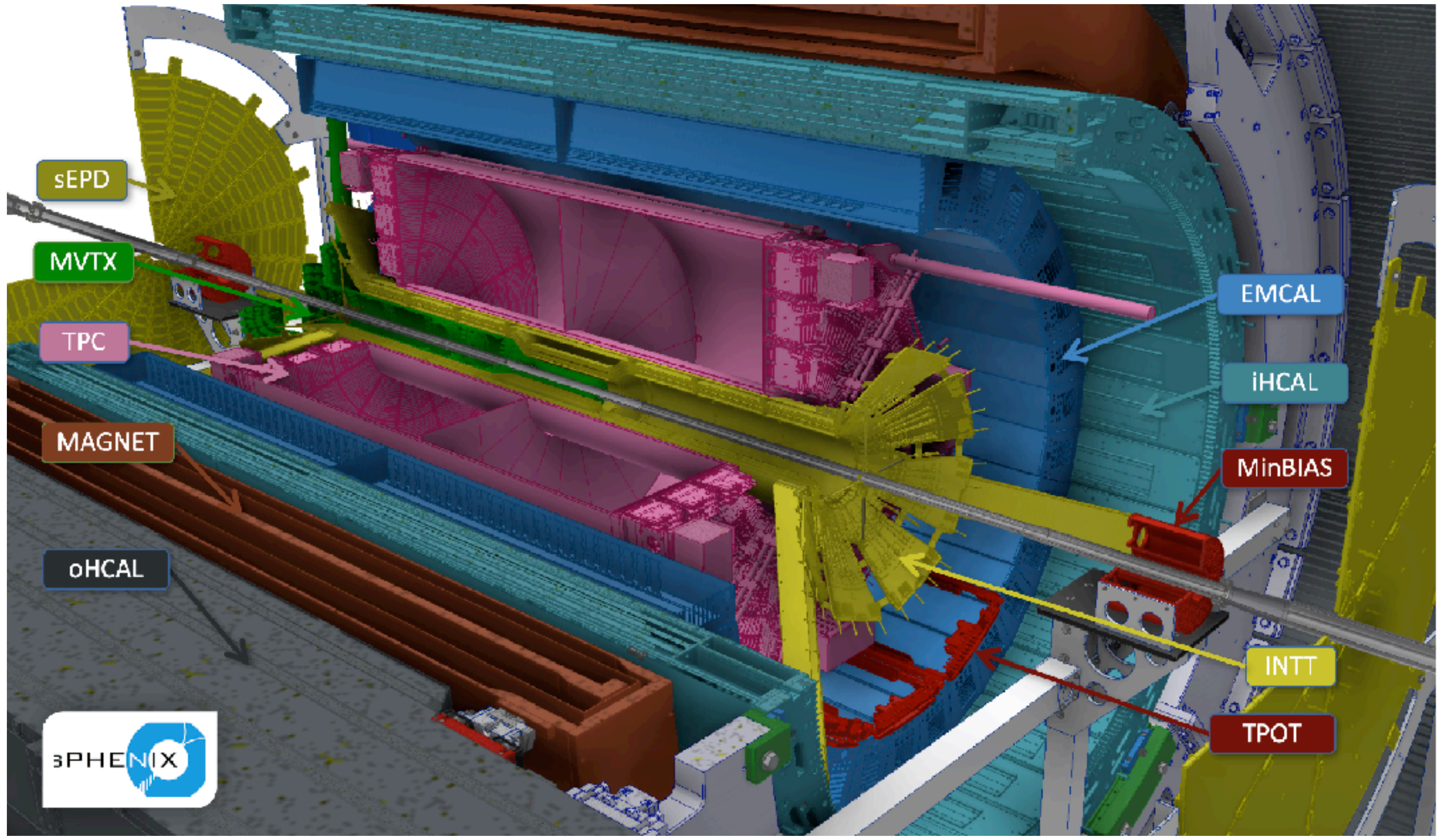
EMcal (Electromagnetic Calorimeter)

- consists of tungsten powder and scintillating fibers
- compact, small segmentation ($\Delta\eta \times \Delta\phi = 0.024 \times 0.024$)

Hcal

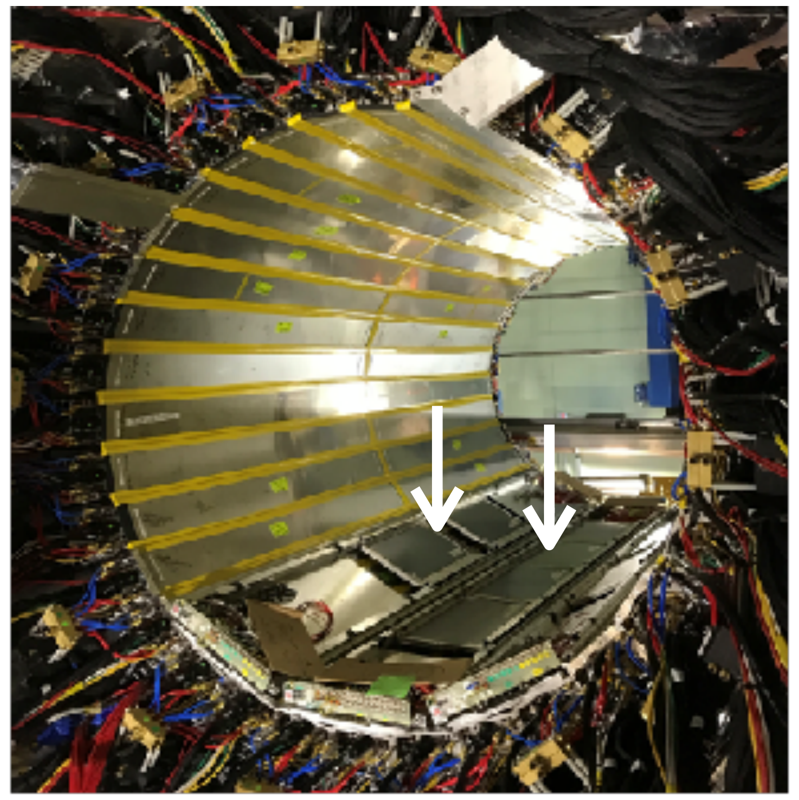


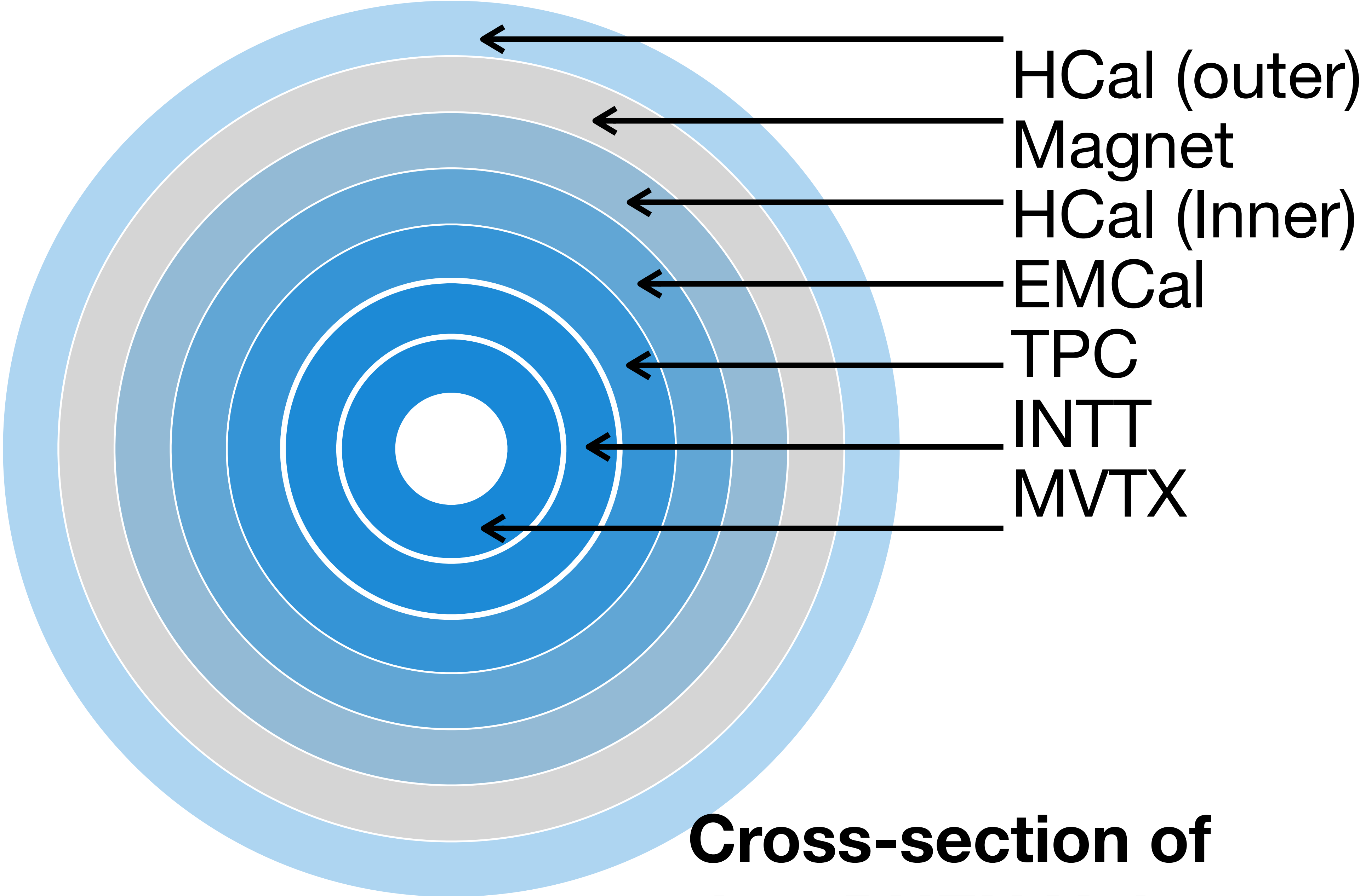
EMcal



sPHENIX detector

sPHENIX Detector

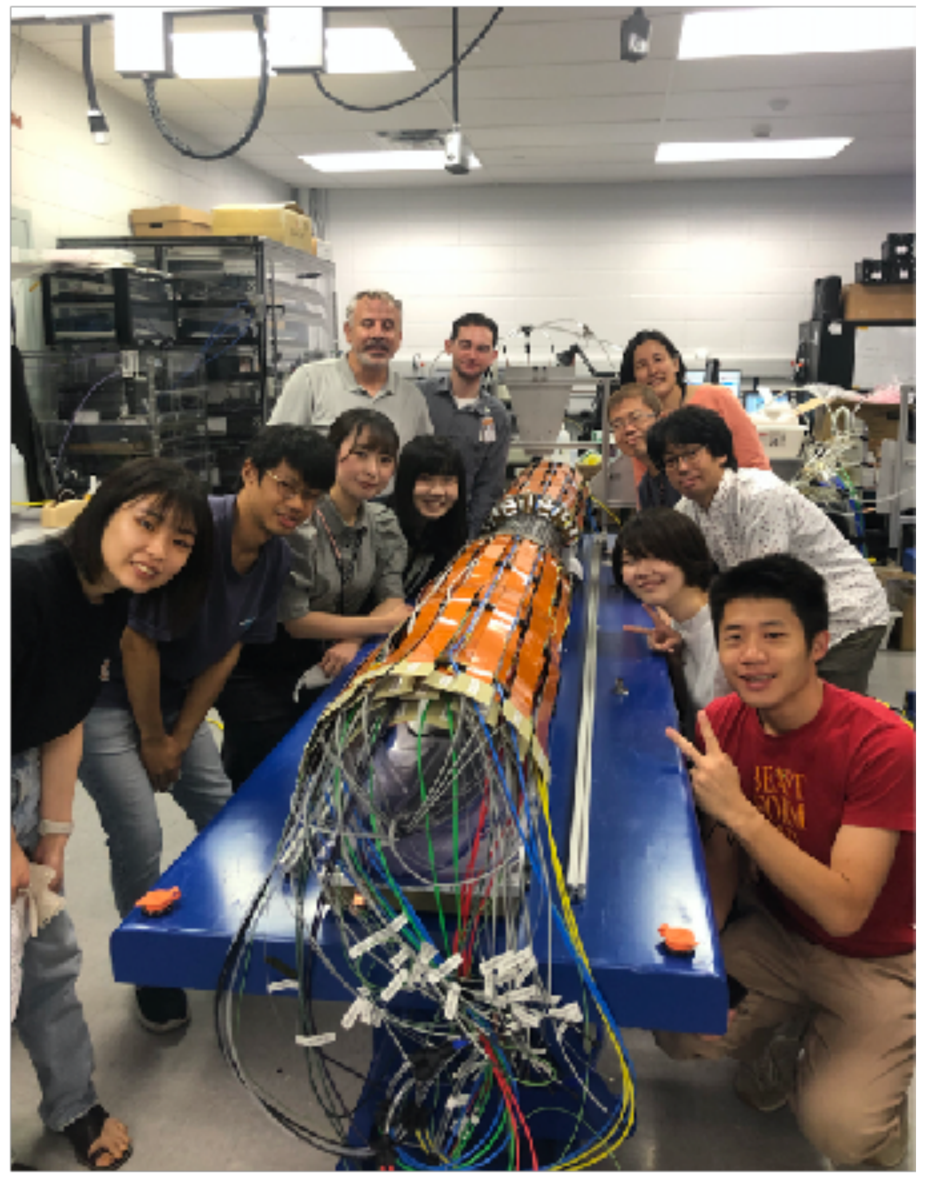

TPOD

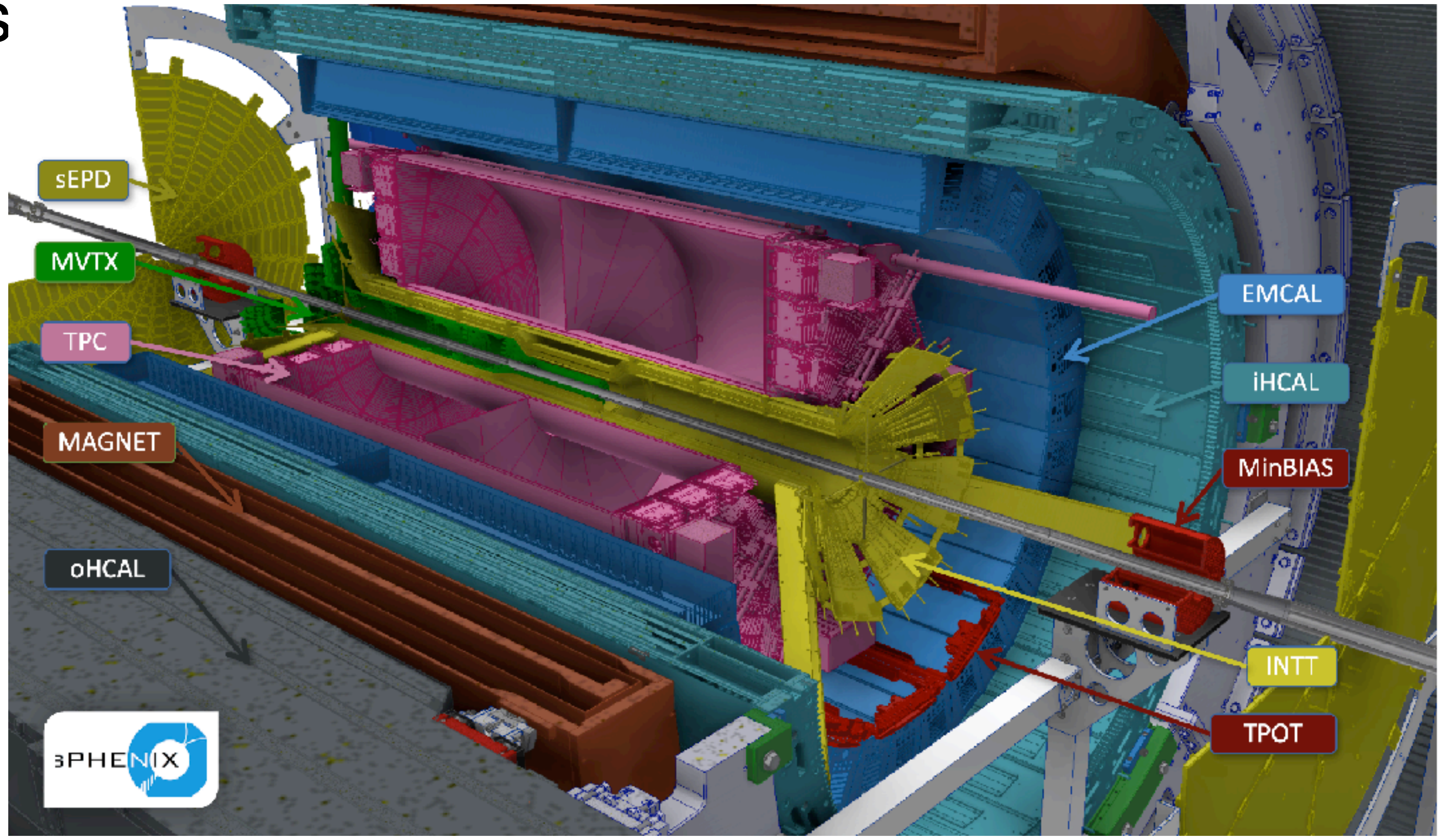


Cross-section of the sPHENIX detector

Tracking detectors

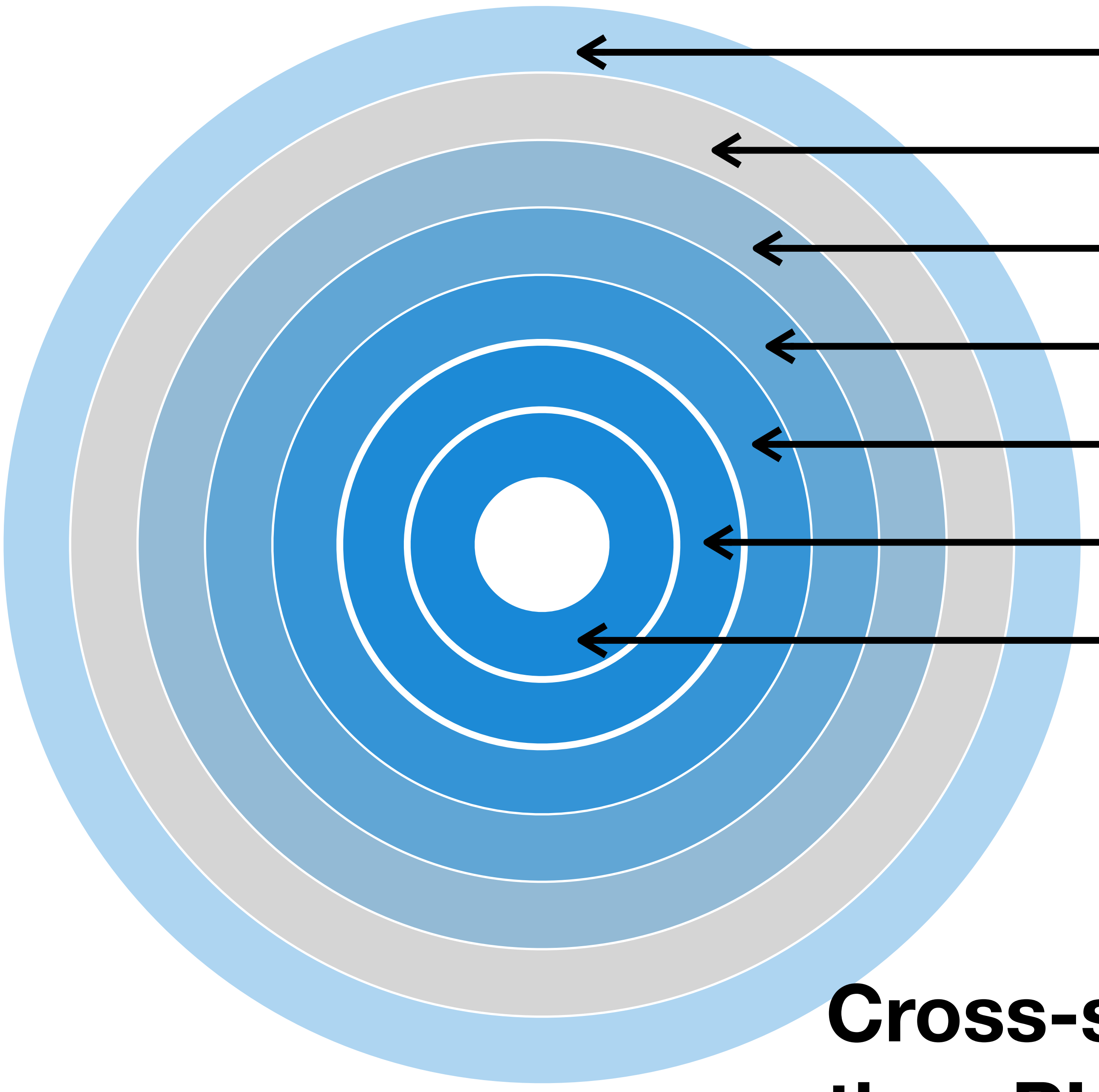
- **TPC** (Time Projection Chamber)
  - r < 80 cm
  - contributes great momentum resolution
- **TPOT** (TPC Outer Tracker)
  - Micromegas
  - for calibration of beam-induced space charge distortions
- **INTT** (Intermediate Silicon Tracker)
  - r < 10 cm
  - tracking between TPC and MVTX with good timing resolution
- **MVTX** (MAPS-based Vertex Detector)
  - r < 4 cm
  - Monolithic active pixel detector with 30 μm pitch for precise vertexing


INTT



sPHENIX detector

sPHENIX Detector



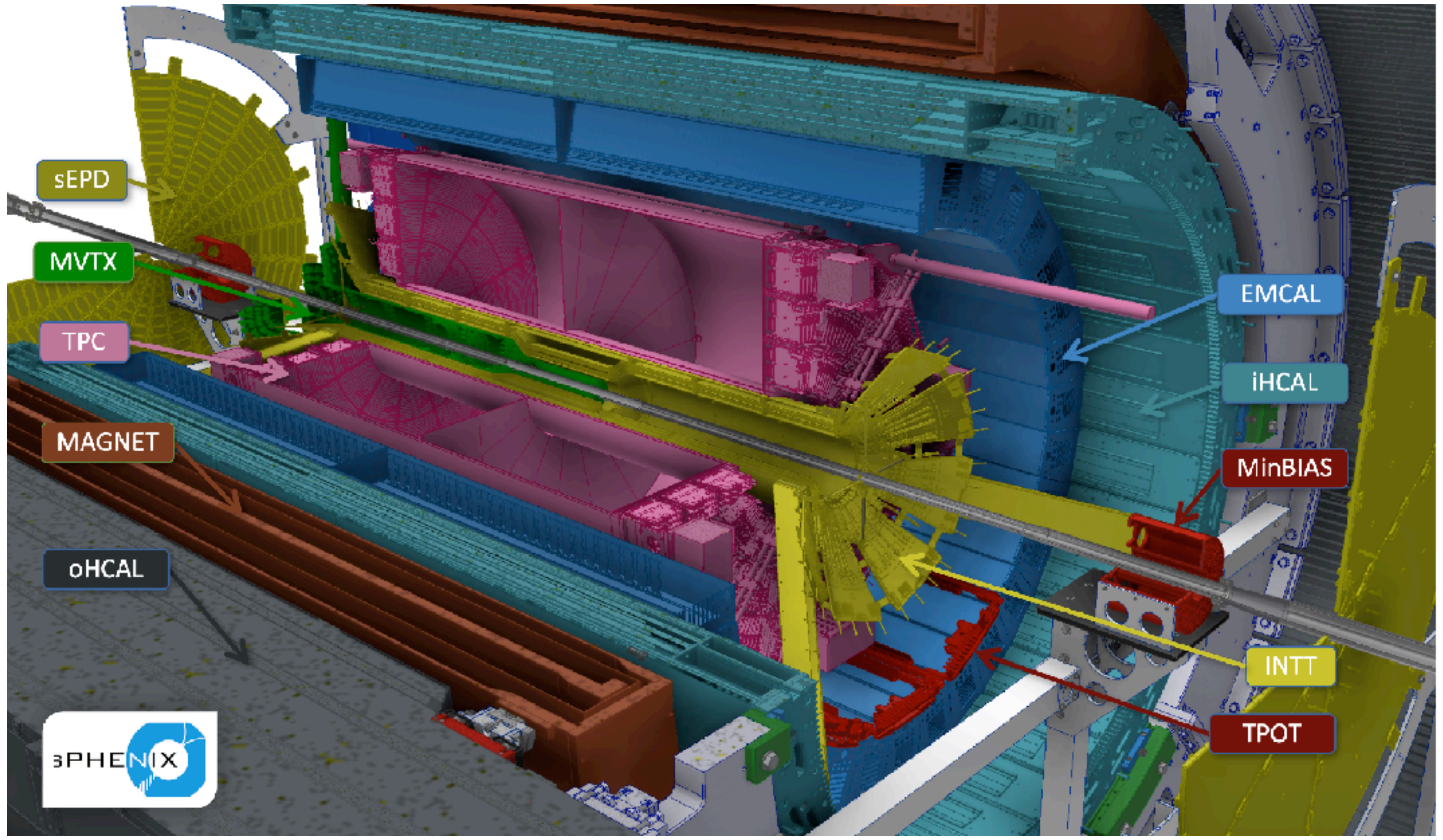
Cross-section of the sPHENIX detector

Forward Detectors

- **MBD** (Minimum Bias Detector)
  - $3.51 < |\eta| < 4.61$
  - provides minimum bias trigger, reuse of the PHENIX BBC
- **sEPD** (sPHENIX Event Plane Detector)
  - $2.0 < |\eta| < 4.9$
  - contributes to the great event place resolution
- **ZDC** (Zero Degree Calorimeter)
  - $z = \pm 18.5$ m
  - works for centrality and luminosity measurements and trigger

sEPD

MBD



sPHENIX detector

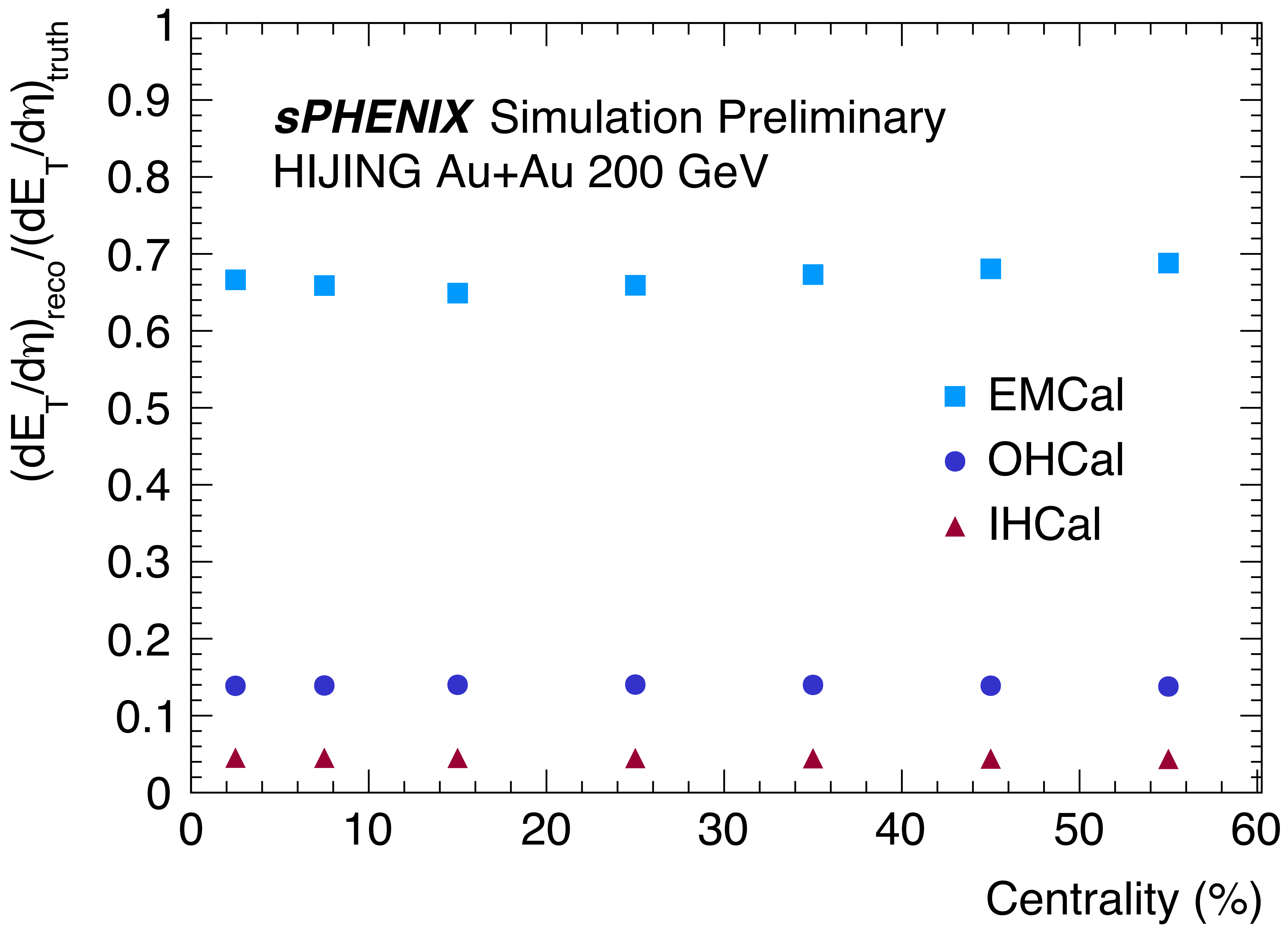
Systematic Uncertainty

The conference note

	Calibration	Hadronic response	MC	ZS	Accept.	Z-vertex	Total
EMCal	1.5-1.7	3.0	1.0-1.2	0.3-2.0	0.5-0.9	0.2	3.7-4.3
OHCal	1.2-1.3	3.4-3.6	2.9-4.3	0.3-0.4	0.7-1.2	0.4	5.1-6.0
Full Calo	1.2-1.3	3.0-3.1	1.4-1.9	0.2-1.6	0.4-0.9	0.2	3.8-4.2

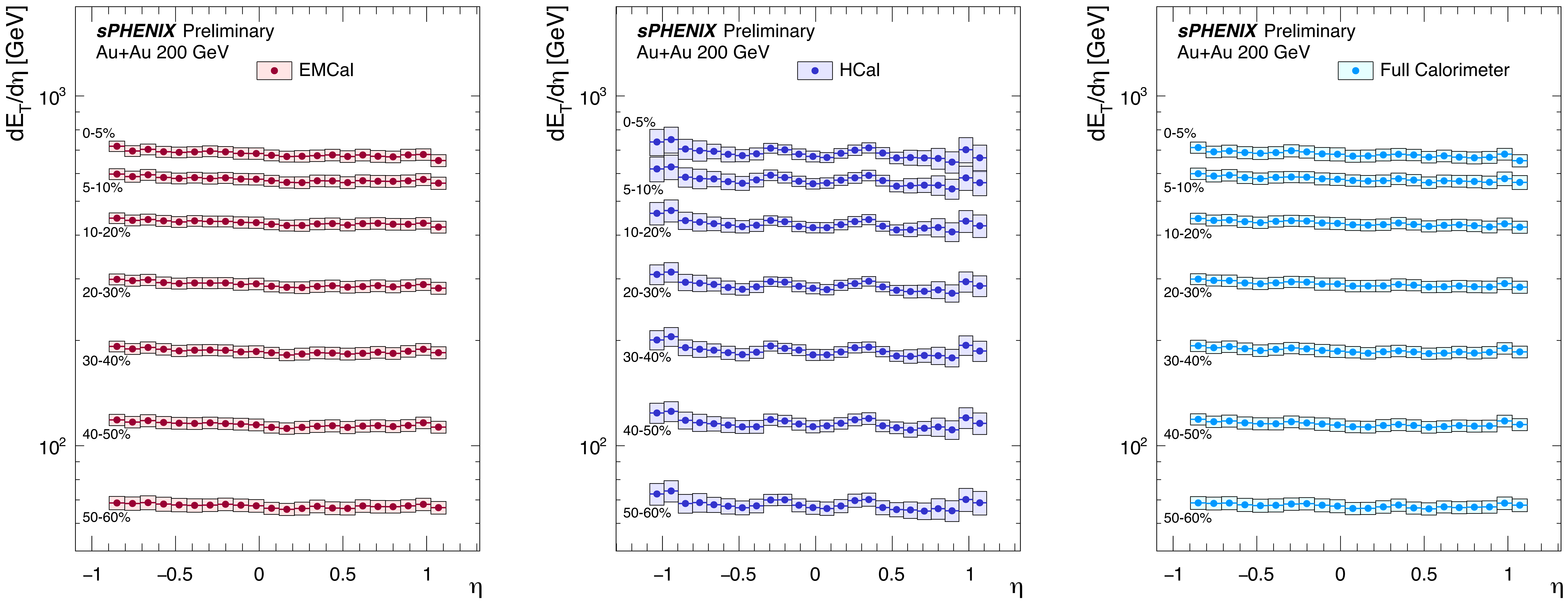
Table 1: Summary of mean systematic uncertainties over measurement η range for $dE_T/d\eta$ measurements from each calorimeter for the full range of measurement centrality bins. Uncertainty values listed above are given in percentages. Listed hadronic response uncertainty only includes MC contributions presently. MC uncertainty refers to the uncertainty related to correction factors derived from MC.

Figs



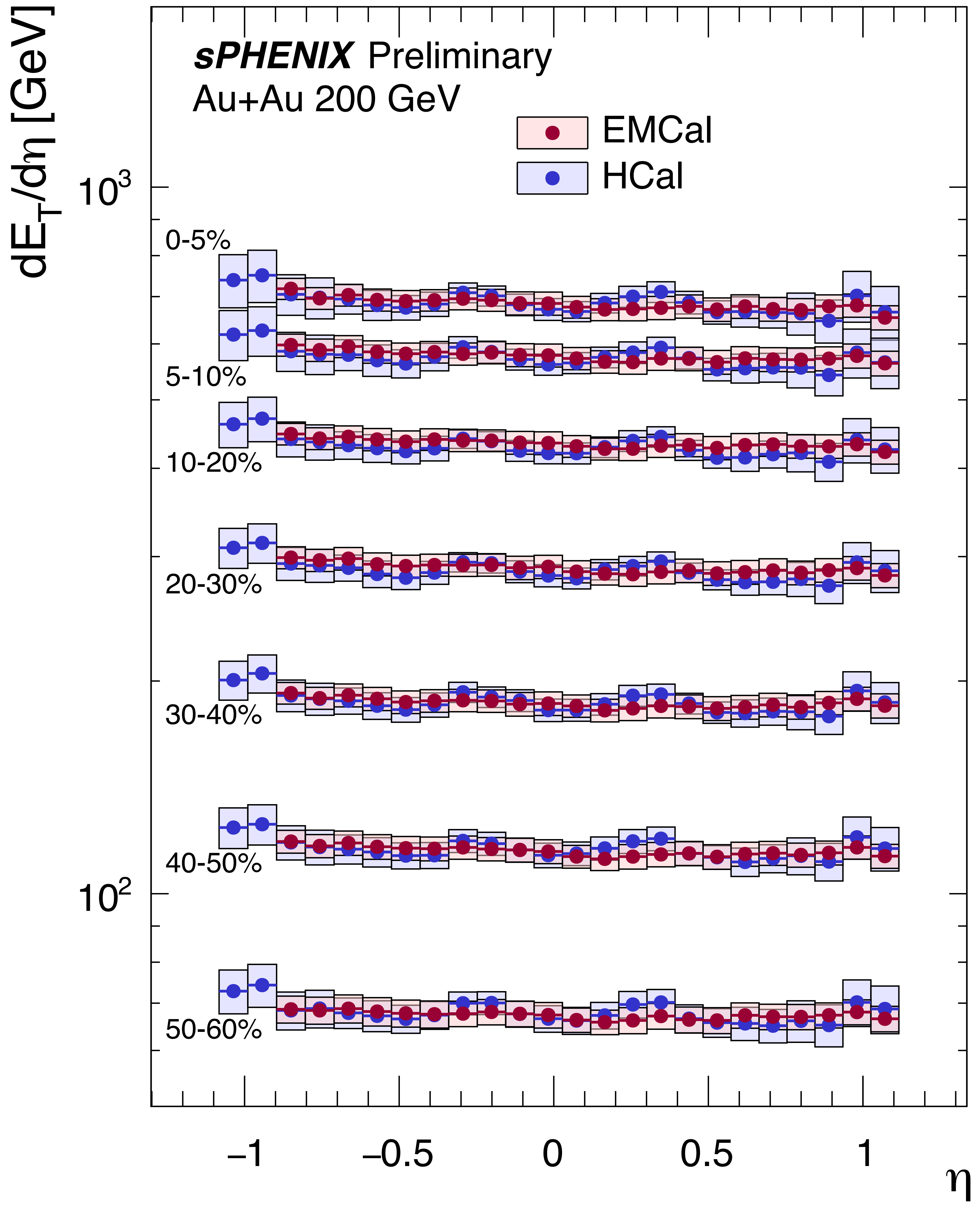
Mean correction factor value of reconstructed $dE_T/d\eta$ for $|\eta| < 0.5$ divided by generator-level $dE_T/d\eta$, for sPHENIX calorimeter sub-systems as a function of centrality for range 0-60% centrality.

Figs



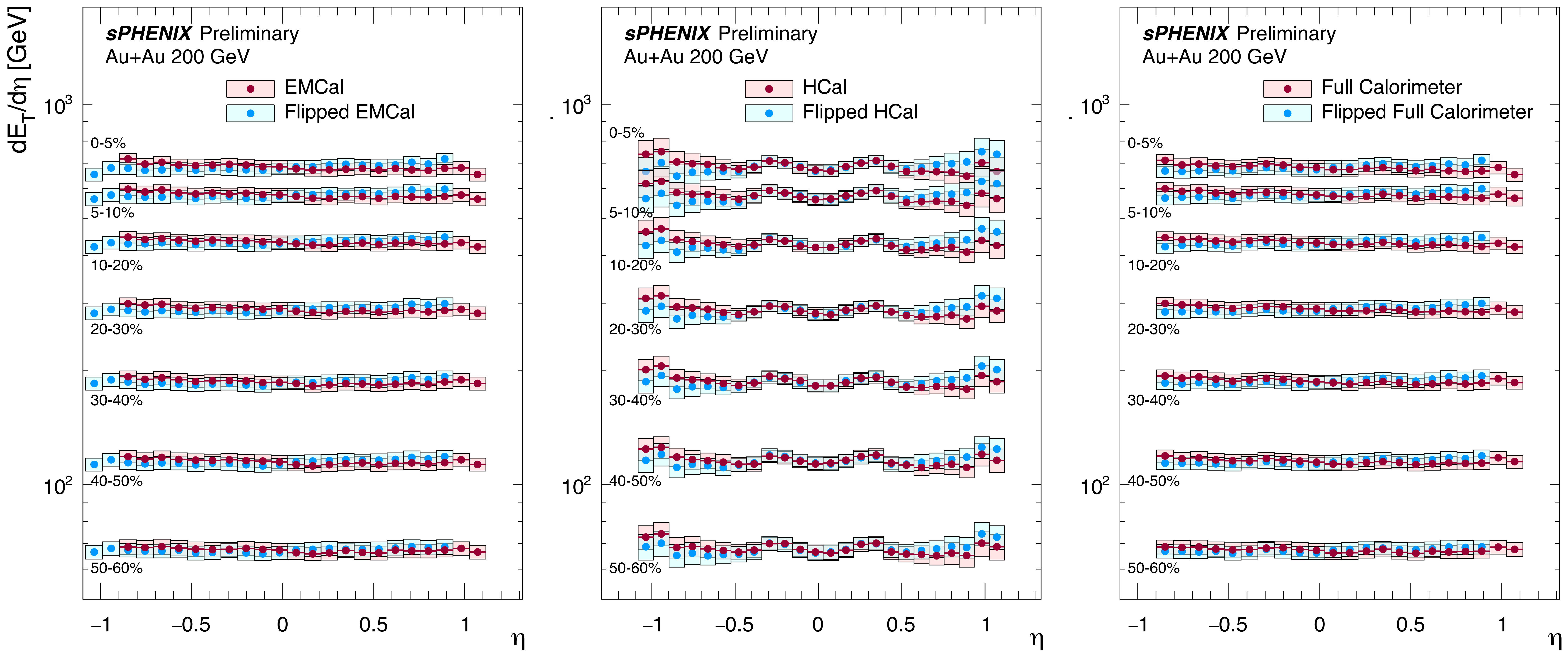
Fully corrected $dE_T/d\eta$ measurements over measurement range $-1.1 < \eta < 1.1$ for HCal-only results and $-0.9 < \eta < 1.1$ for EMCal-only and full calorimeter system results.

Figs



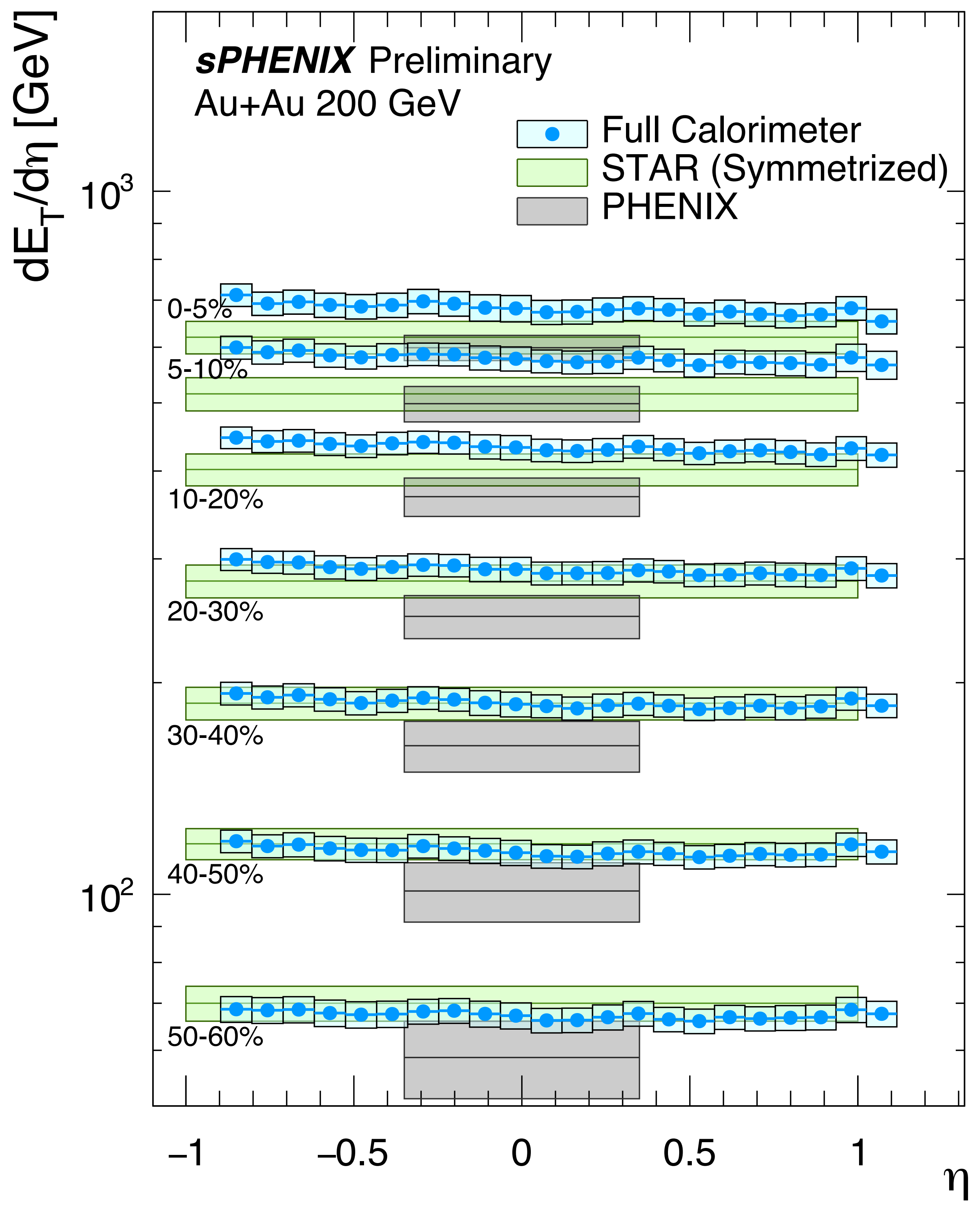
Comparison of fully corrected $dE_T/d\eta$ measurements for EMCal-only results ($-0.9 < \eta < 1.1$) and HCal-only results ($-1.1 < \eta < 1.1$).

Figs



Comparison of fully corrected $dE_T/d\eta$ measurements over measurement range $-1.1 < \eta < 1.1$ for HCal-only results and $-0.9 < \eta < 1.1$ for EMCal-only and full calorimeter system results.

Figs



Fully corrected $dE_T/d\eta$ measurements over measurement range $-0.9 < \eta < 1.1$ using the full sPHENIX calorimeter system. STAR and PHENIX measurements are included for comparison.