Jet performance studies of sPHENIX with early data and simulation

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sPHENIX

VANDERBILT UNIVERSITY

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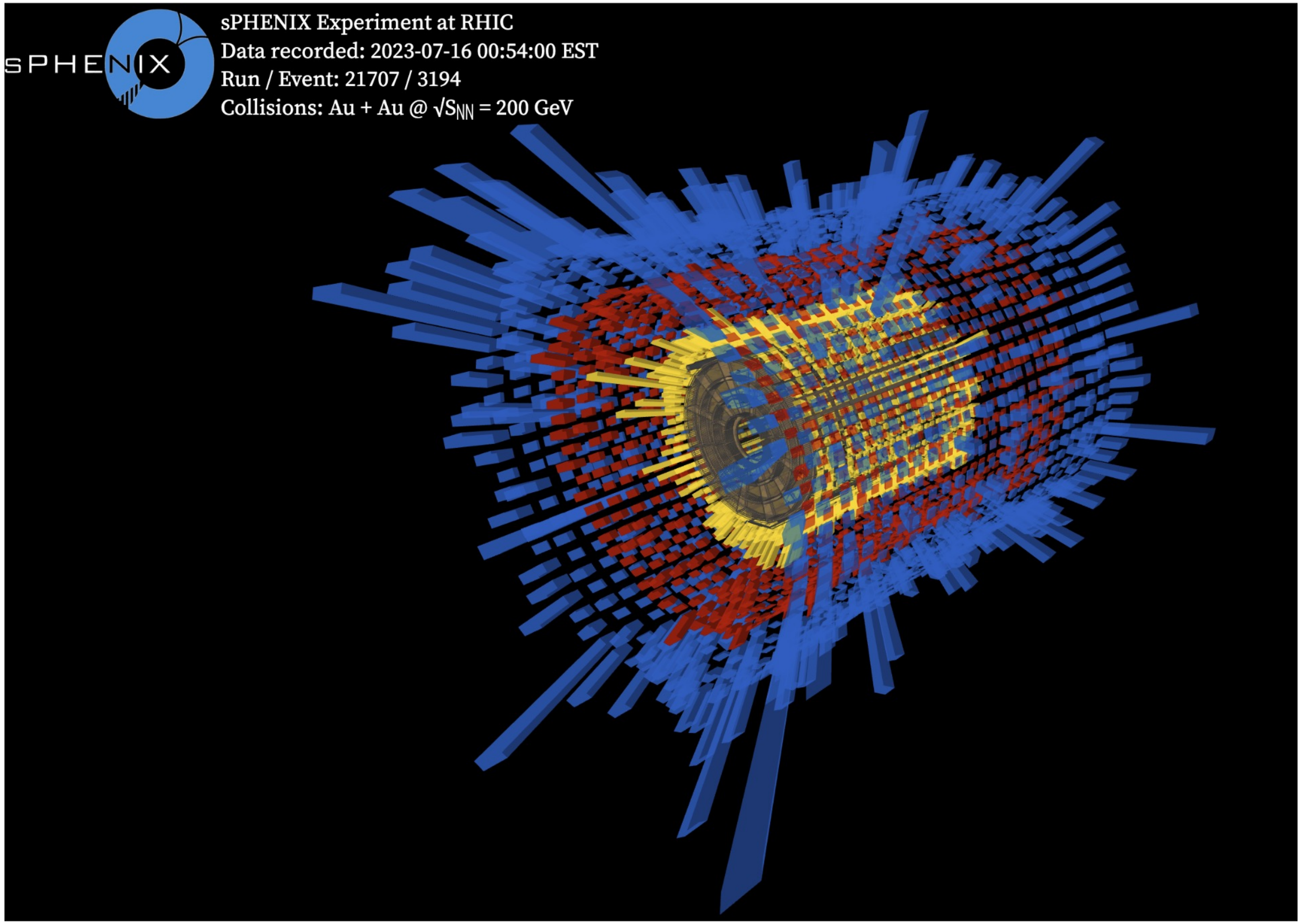
Outline

- The sPHENIX Experiment
- Commissioning Progress
- Future Analyses



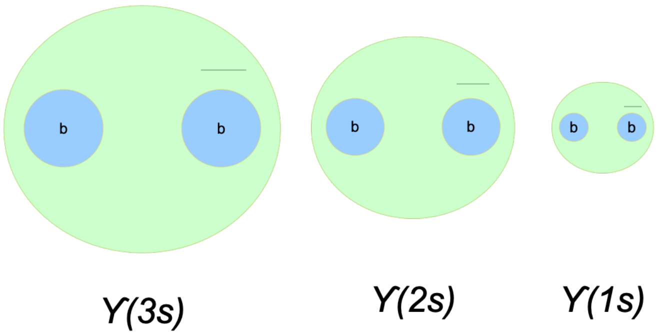
The Physics of sPHENIX

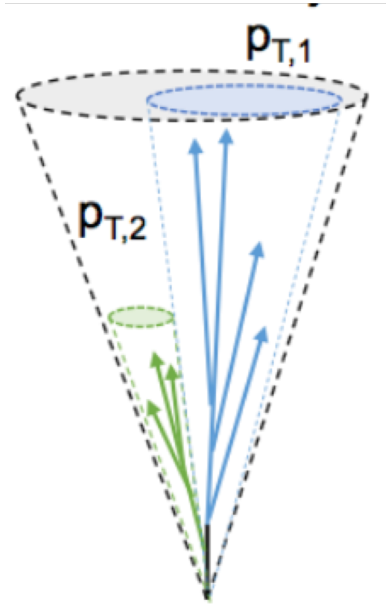
Quarkonium spectroscopy
vary size of probe

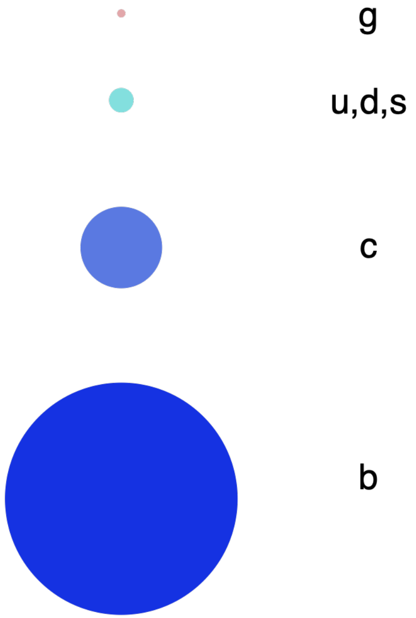
Jet structure
vary momentum/angular scale of probe

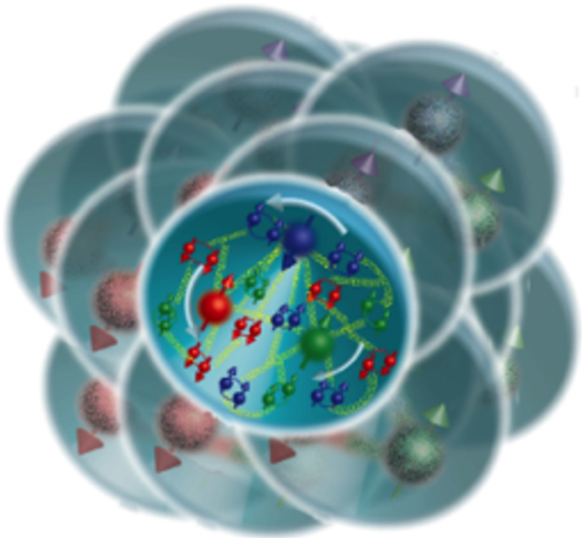
Parton energy loss
vary mass/momentum of probe

Cold QCD
study proton spin, transverse-momentum, and nuclear effects



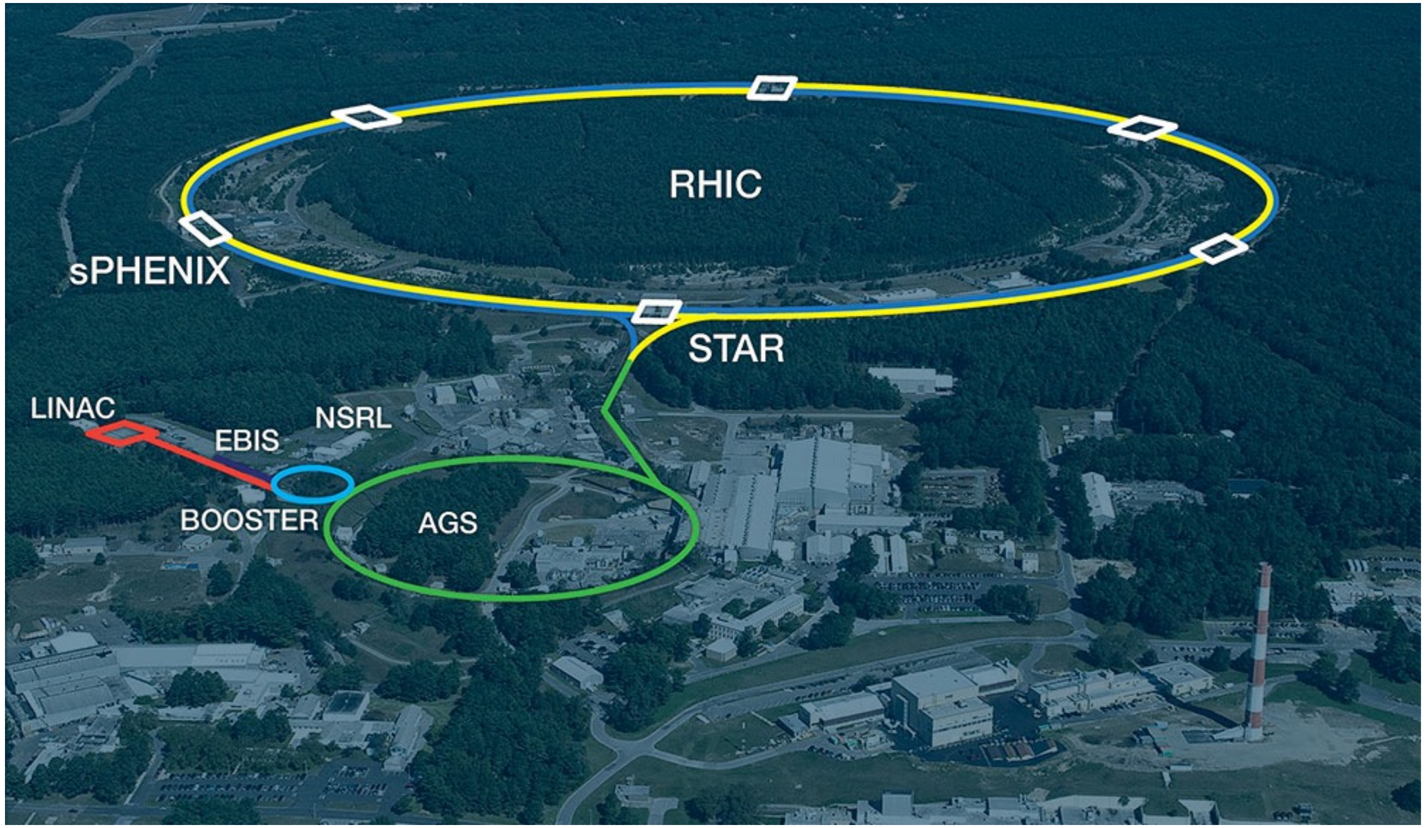






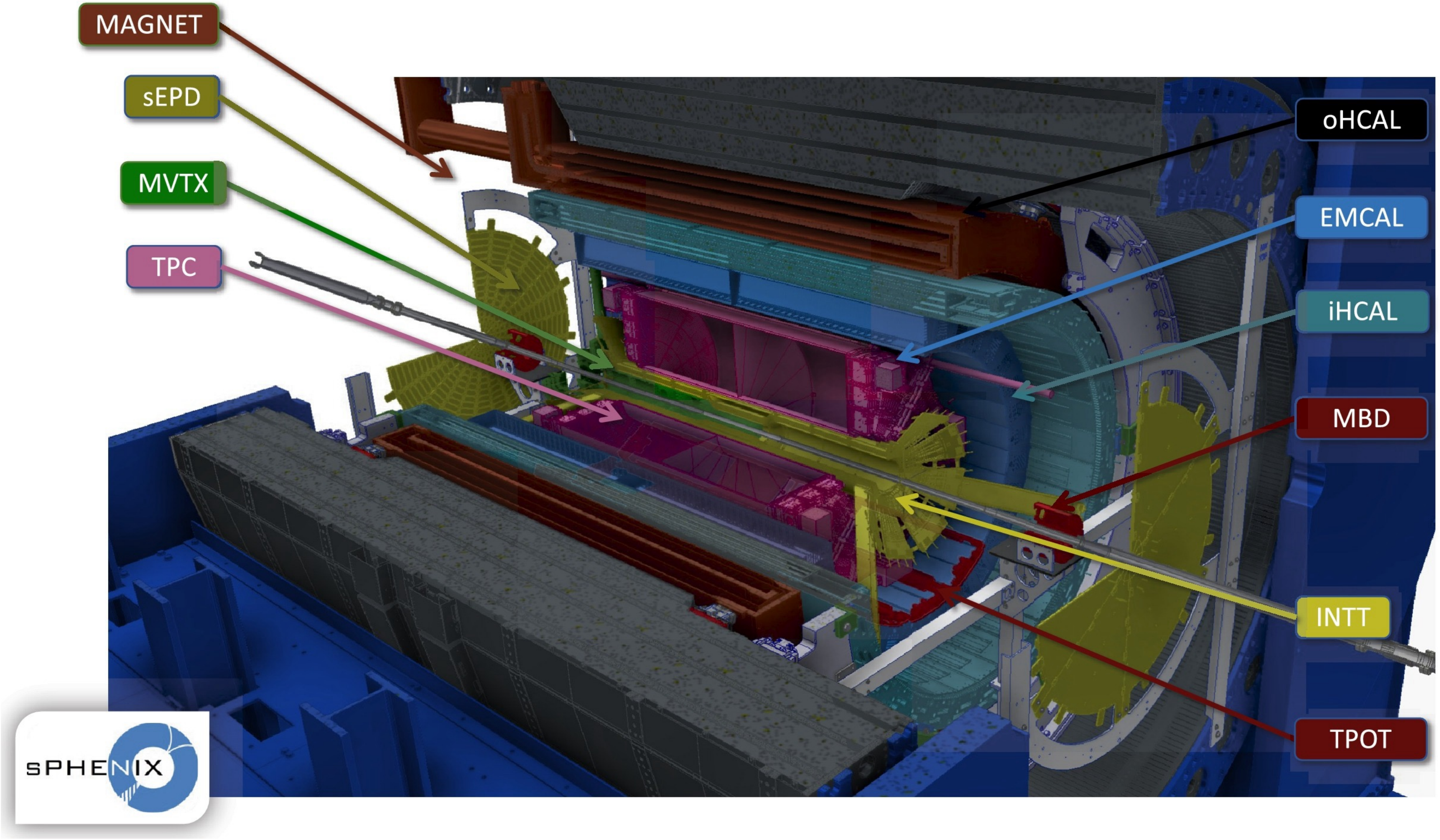
The sPHENIX Experiment

- First new detector at the Relativistic Heavy Ion Collider (RHIC) in ~20 years
- 2015 Long Range Plan deemed sPHENIX essential
- 2023 Long Range Plan stated necessary to complete sPHENIX science program



sPHENIX Detector Overview

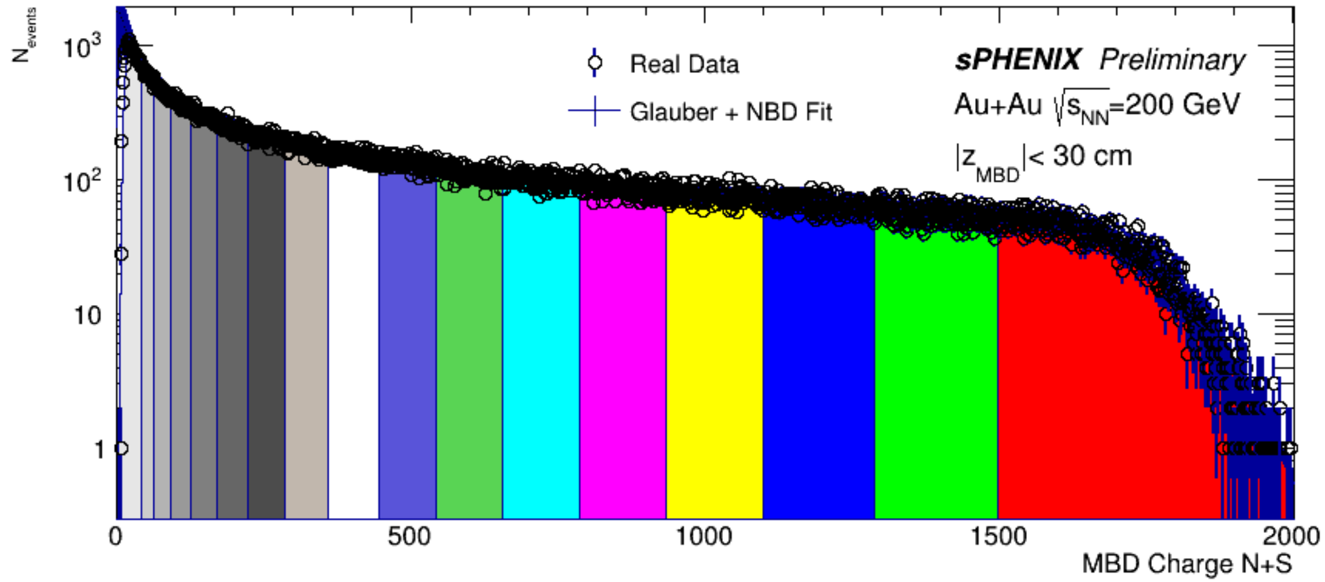
- Precision vertexing and tracking with MVTX, INTT, TPC, and TPOT
- High acceptance calorimetry with EMCAL, iHCAL, and oHCAL
- 1.4 T superconducting solenoid
- Event characterization with the MBD, sEPD, and ZDC
- High DAQ rate (15 kHz trigger) + streaming readout for tracking

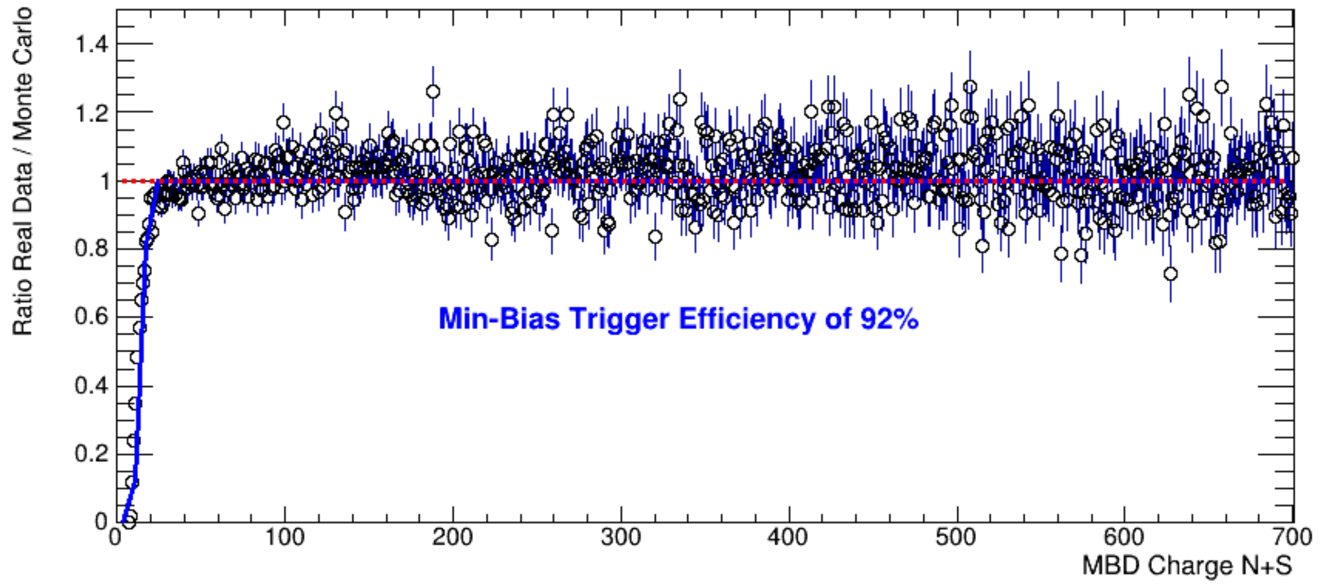


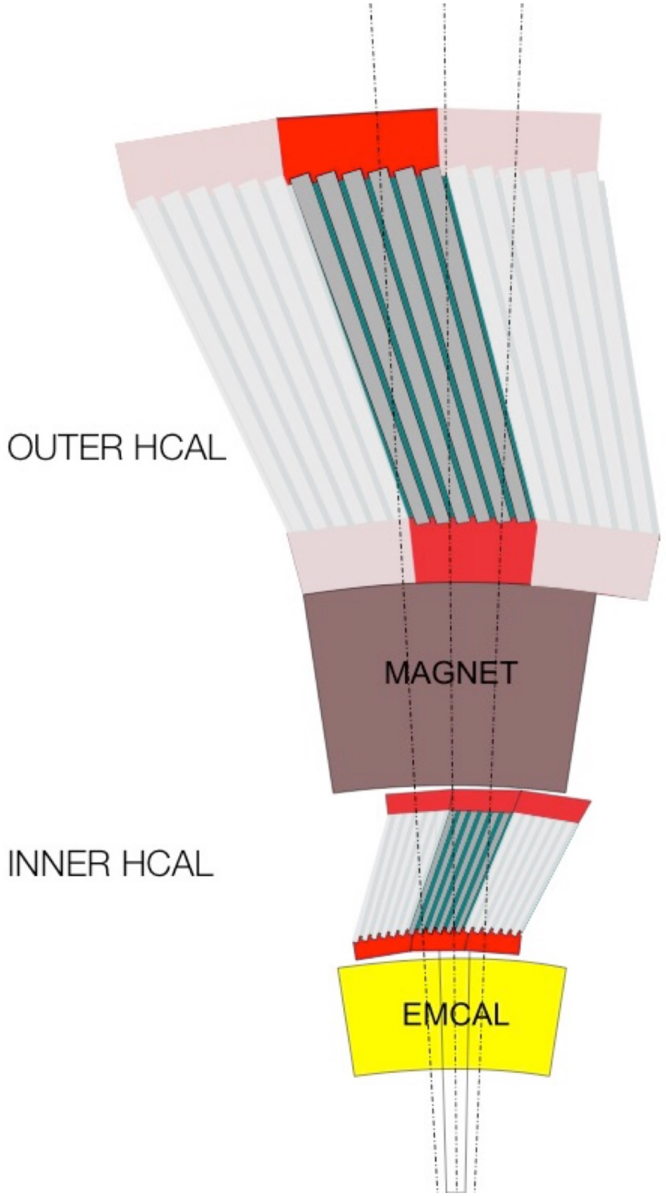
Centrality in sPHENIX

- Glauber model + NBD Fit matches MBD total charge distributions well
- High min-bias trigger efficiency of 92%

08/30/2023



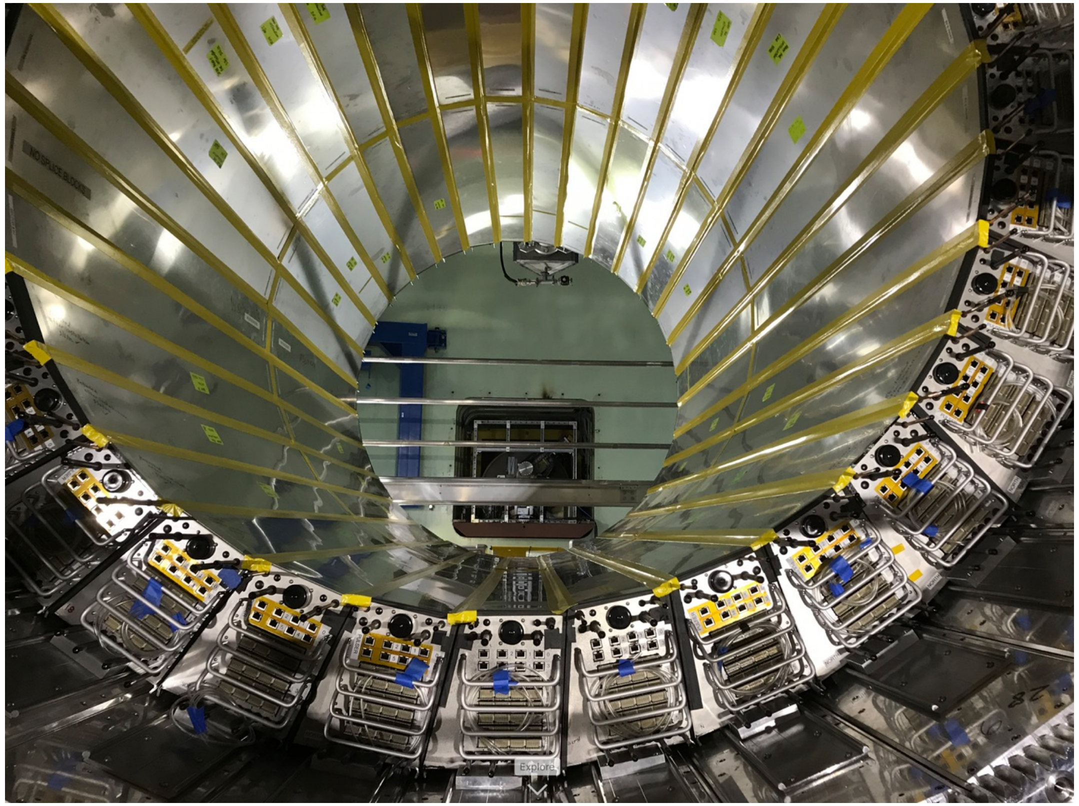




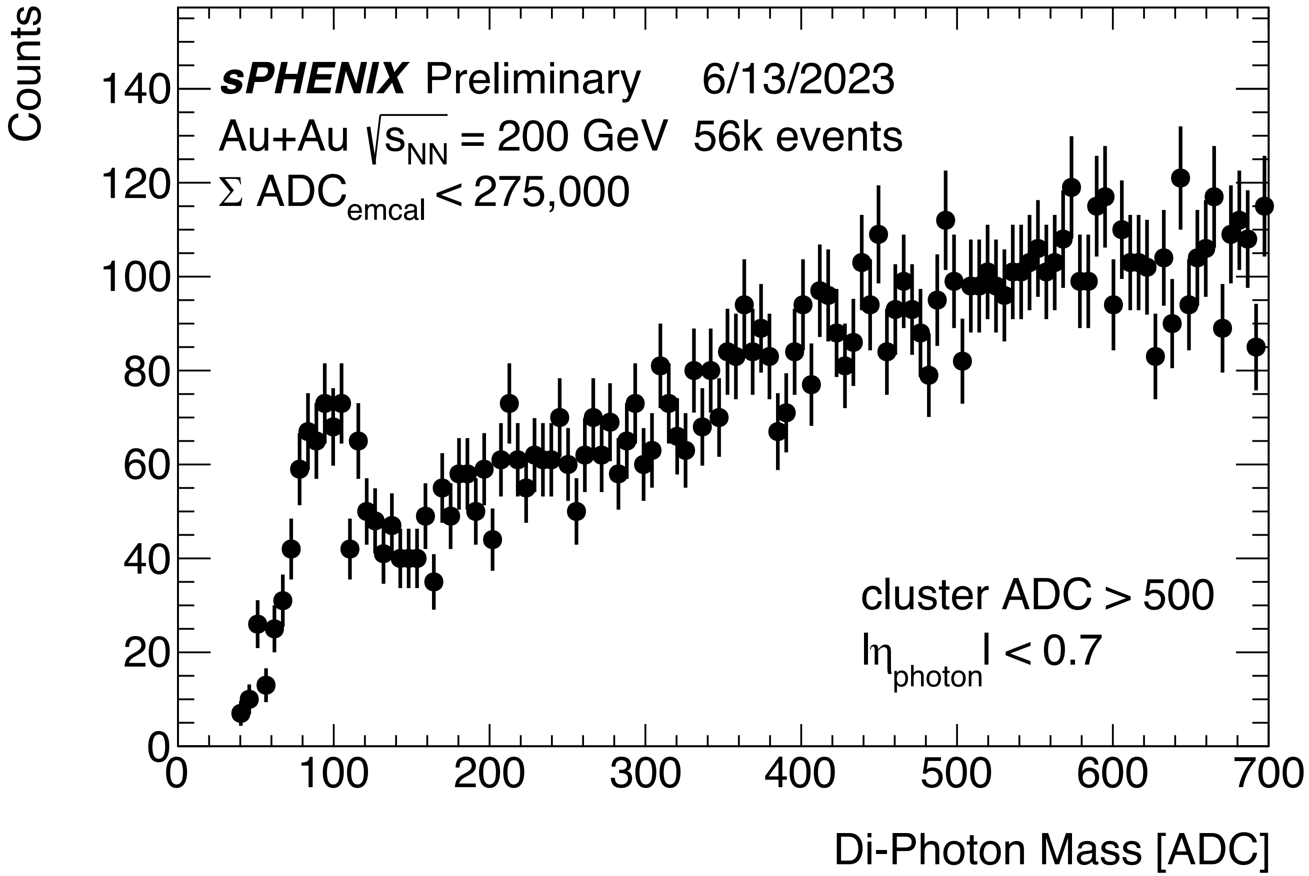
sPHENIX Calorimeters

- Large acceptance covering all of midrapidity
  - $|\eta|<1.1$
  - Full 2π azimuthal coverage
- Hadronic calorimeter system allows first measurement of neutral hadron component of midrapidity jets at RHIC
  - Reduces fragmentation bias

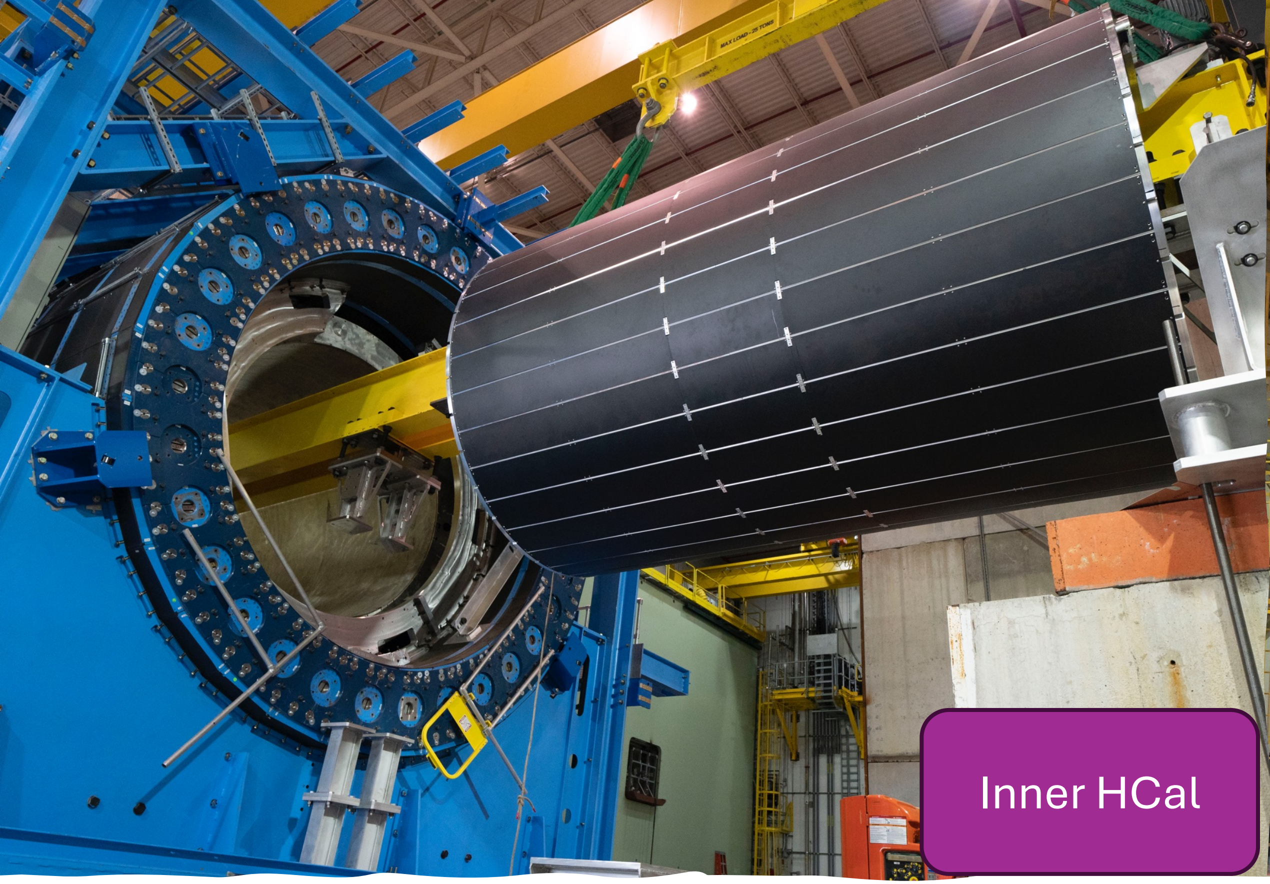
EM Calorimeter

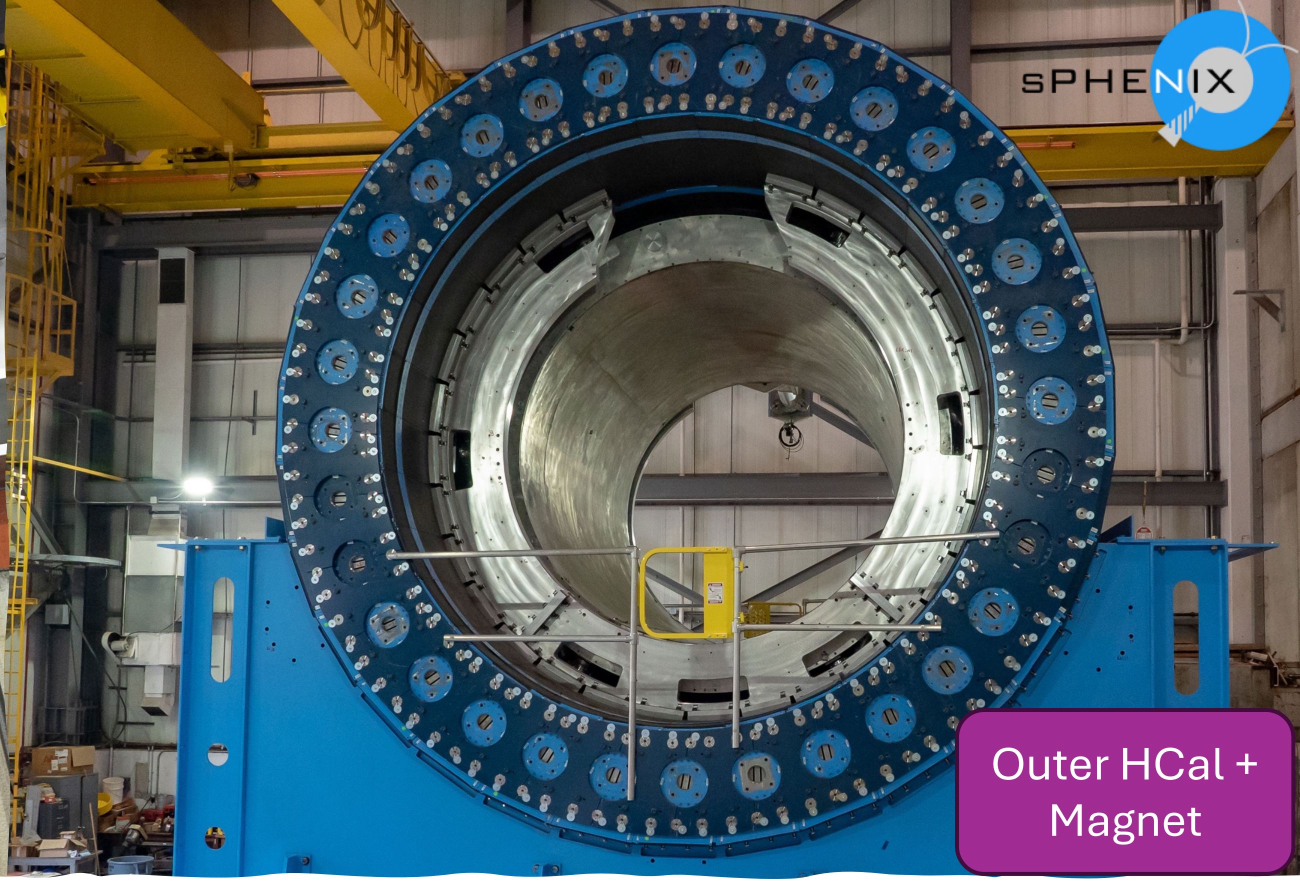


IEEE Trans. Nuc. Sci., vol. 68, no. 2, pp. 173-181

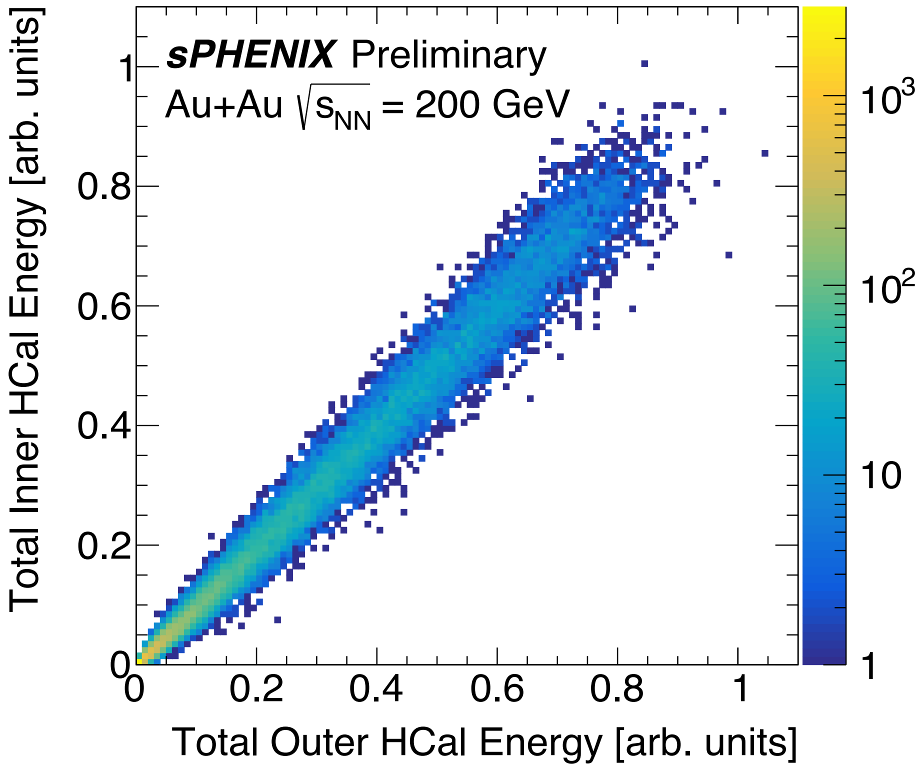


- Calibrated to π^0 mass peak
- Early data, more recent calibrations expected to provide much sharper peak

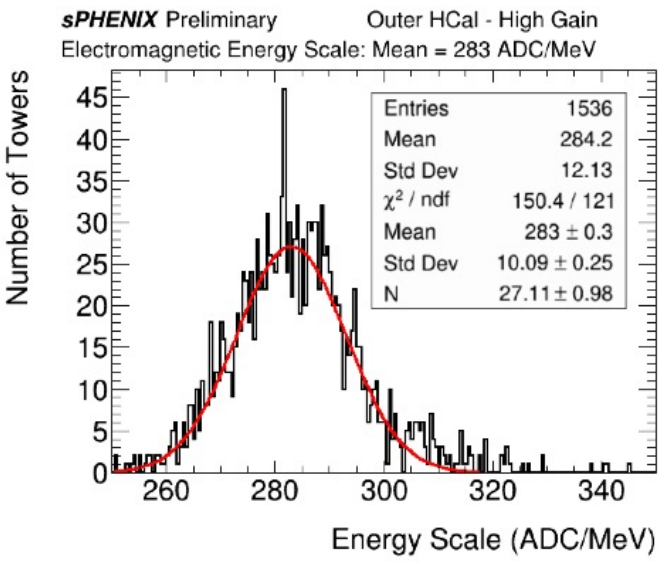




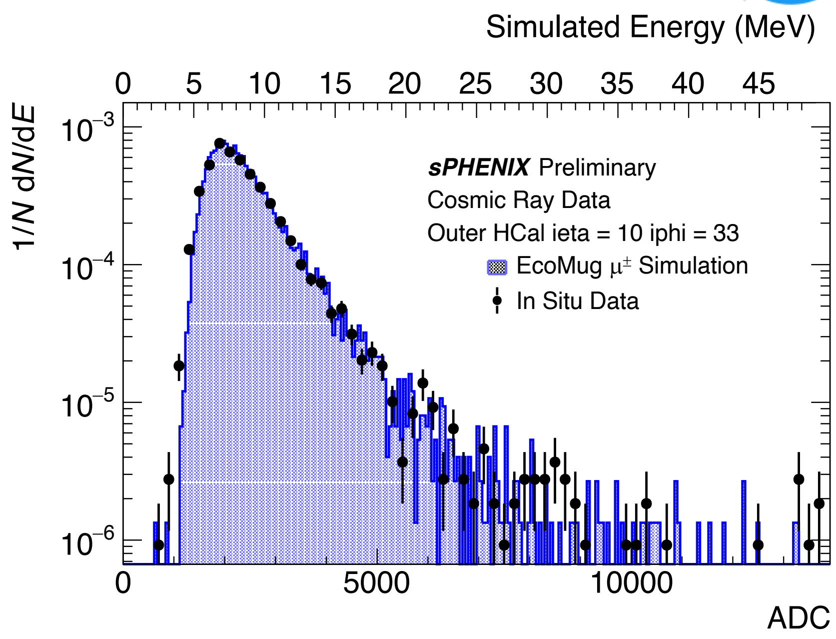
Hadronic Calorimeters



Good correlation between inner and outer HCals



HCal calibrated to EM scale with cosmic rays



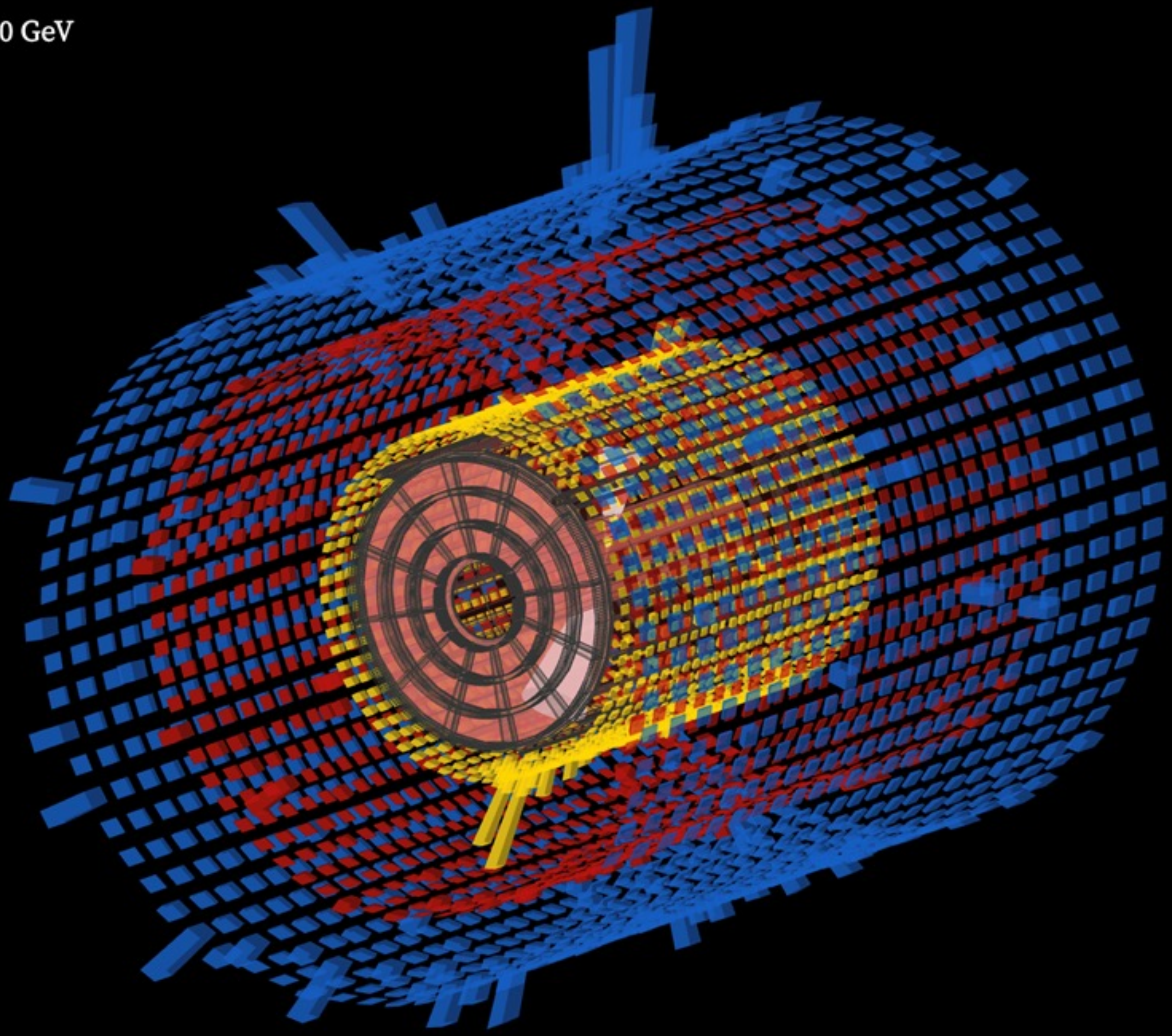
Calibrated HCal data from cosmic rays matches simulation

Hadronic Calorimeters

sPHENIX Experiment at RHIC
Run / Event: 21615 / 1362
Collisions: Au + Au @ $\sqrt{S_{NN}}$ = 200 GeV

sPHENIX Run 2023

- First commissioning run with Au+Au collisions in May 2023



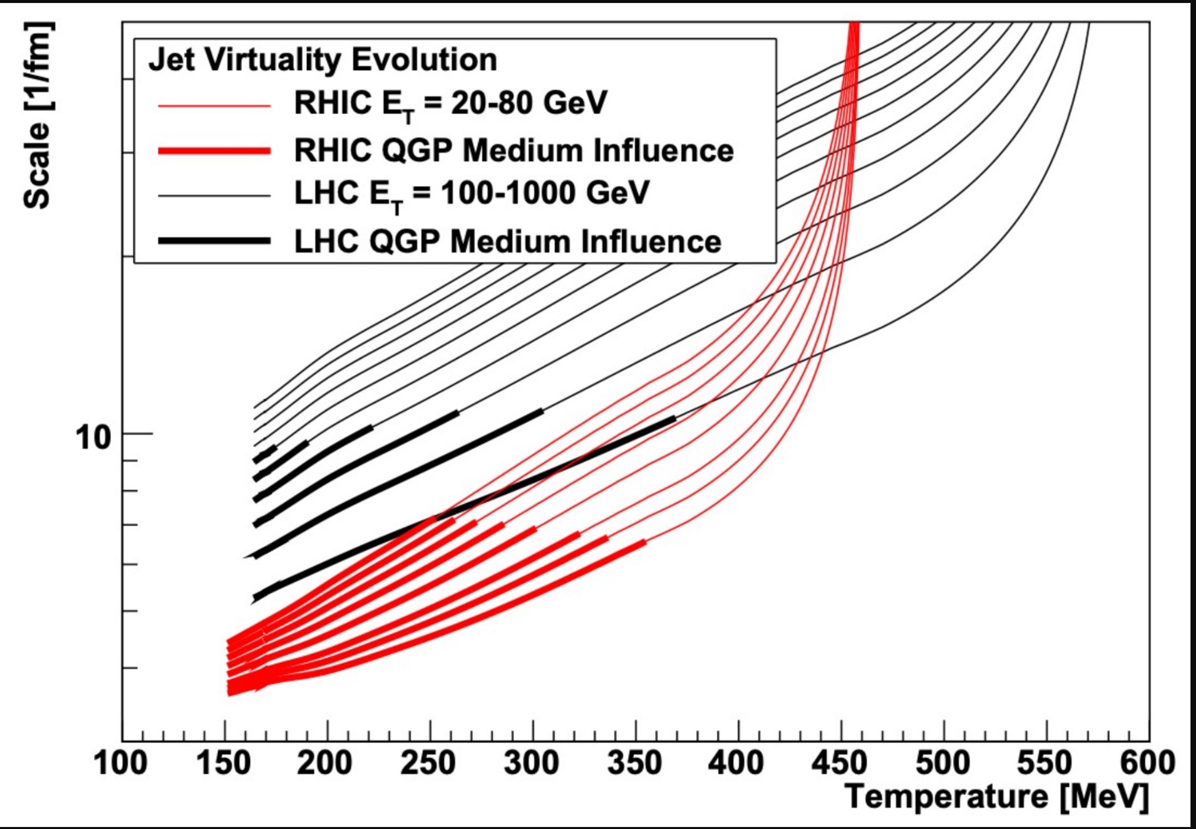
sPHENIX Run 2023

- First commissioning run with Au+Au collisions in May 2023
- RHIC failure in August led to run ending 8 weeks early
- Significant commissioning progress during and after run
  - Despite the limited nature of commissioning data, several "standard candle" measurements in Au+Au data are now in progress

Why Study Jets in Heavy Ion Collisions?

- Probe created during initial hard scattering and experiences full evolution of system
- QGP at RHIC is different from at the LHC!
  - Temperature & evolution
- Different quark vs gluon jet mixture at RHIC and LHC
- Lower kinematic range
  - Radiation close to QGP medium scale early in the collision

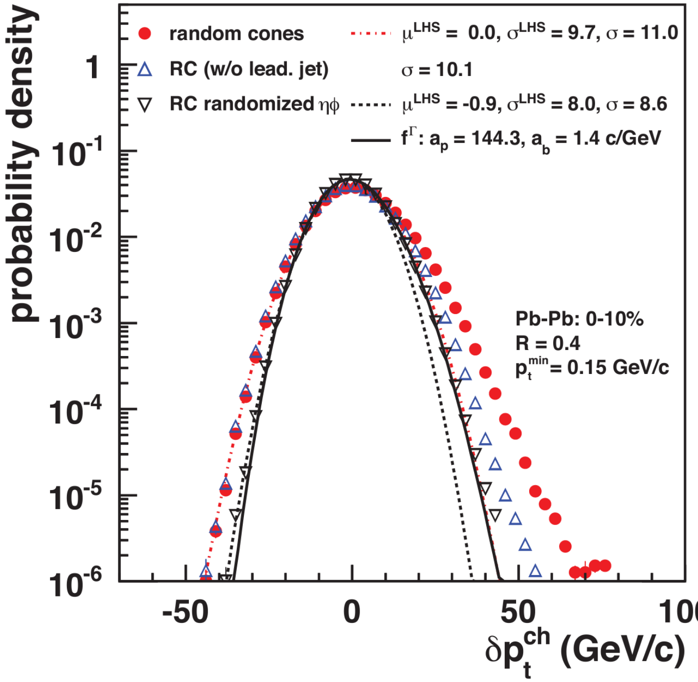
PHENIX Upgrade Proposal



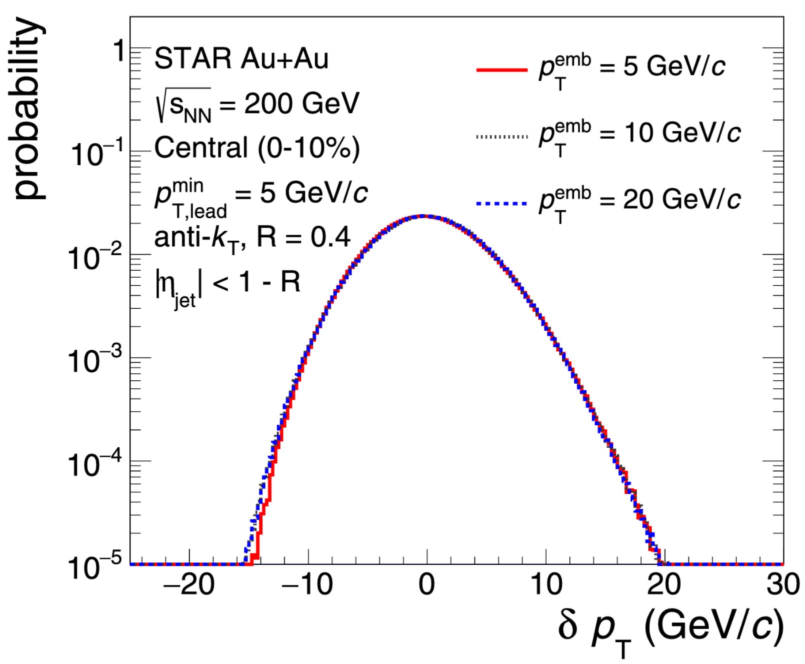
Characterization of Underlying Event

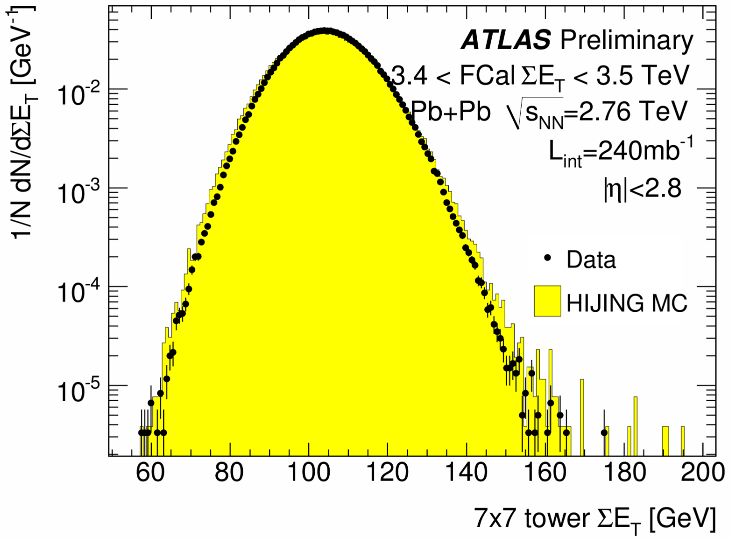
- All jets sit on top of a (mostly) soft Underlying Event (UE)
- Necessity for jets → all experiments characterize the UE!
- Different methods are used

ALICE JHEP 2012, 53 (2012)

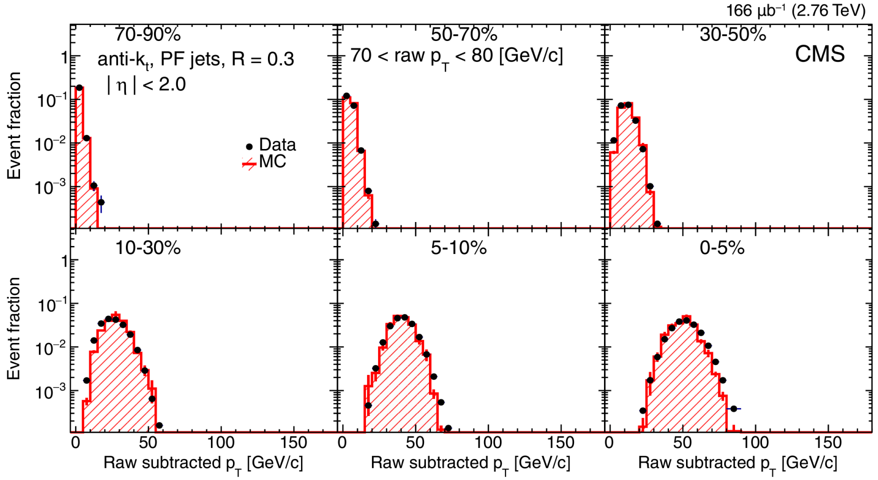


STAR Phys. Rev. C 102 (2020) 054913





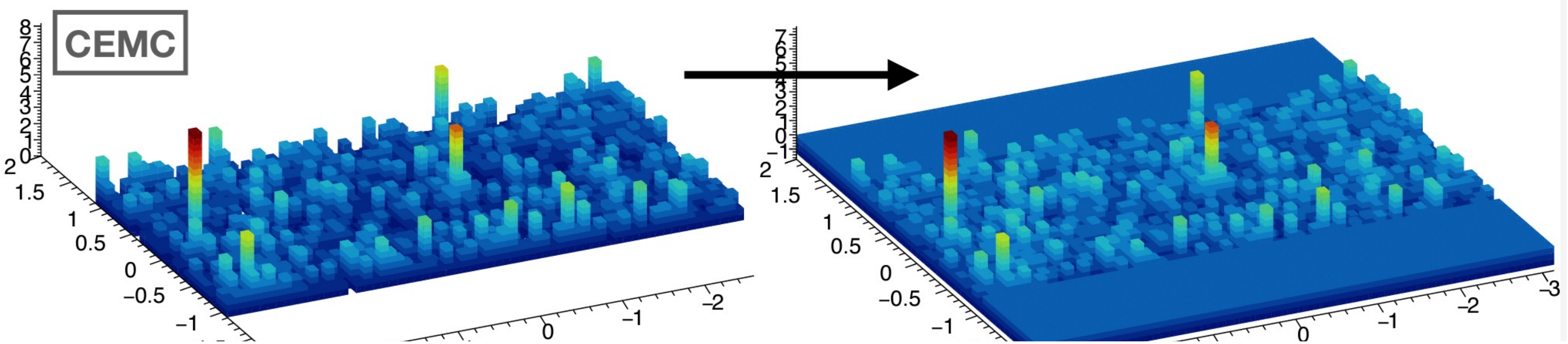
ATLAS ATLAS-CONF-2012-045



CMS Phys. Rev. C 96 (2017) 015202

sPHENIX Characterization of Underlying Event

- Multiplicity method
  - $p_T = p_{T,jet}^{raw} - \rho_{mult} * \{N_{comp} - \langle N_{signal} \rangle * p_T^{raw}\}$
  - *Phys. Rev. C* 108 (2023) 2, L021901
- Iterative subtraction method (ATLAS style)
  - Find small R seed jets, remove and find mean E with v_2 modulation



- ρ*A (area) method

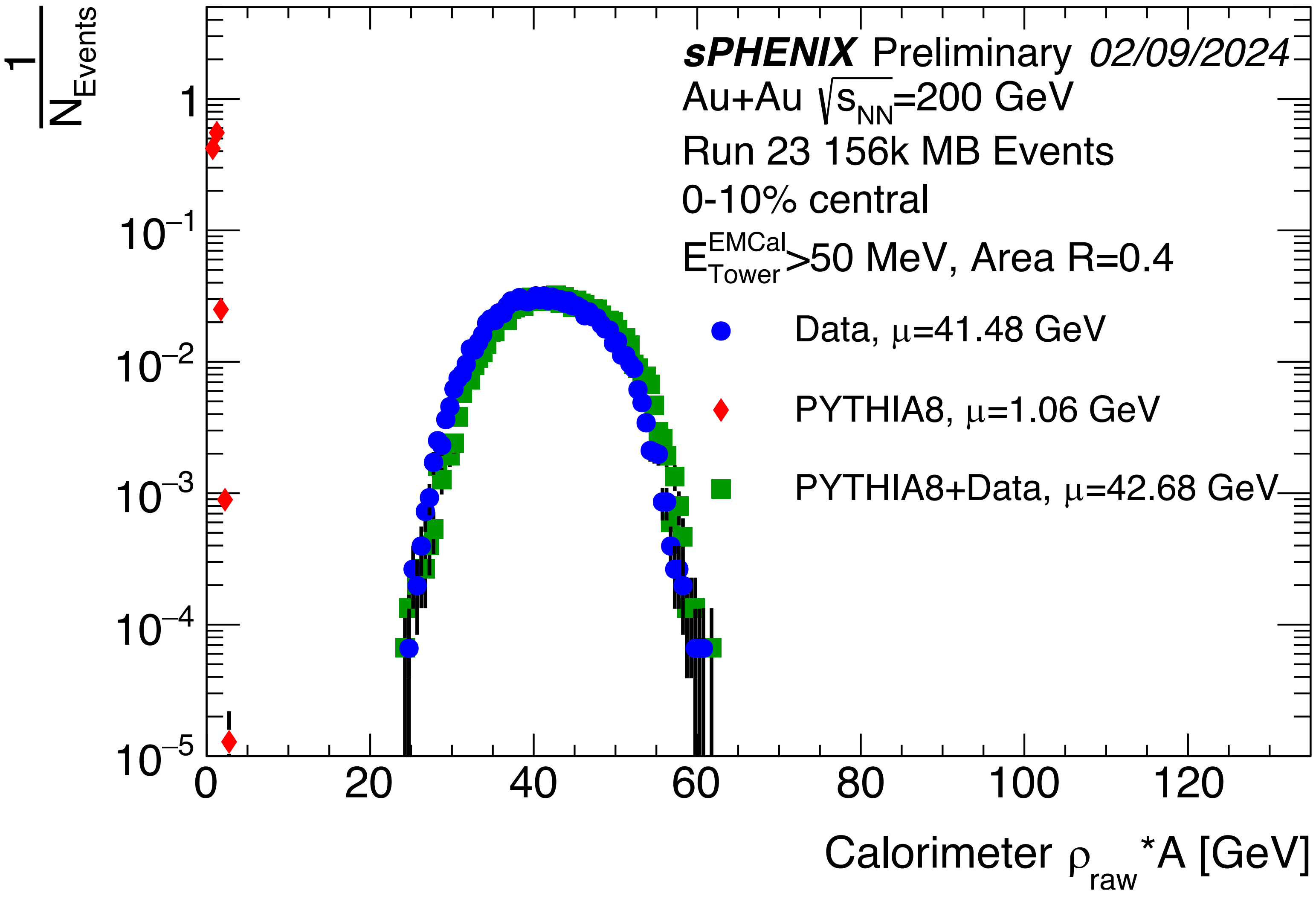
What is ρ*A?

- ρ is the median p_T/Area of all k_T jets in the event (generally the leading 2 jets are removed)

1. Distribute soft ghosts uniformly in y and φ
2. Run k_T clustering on event
3. Drop leading 2 jets
4. Determine median p_T/A in event

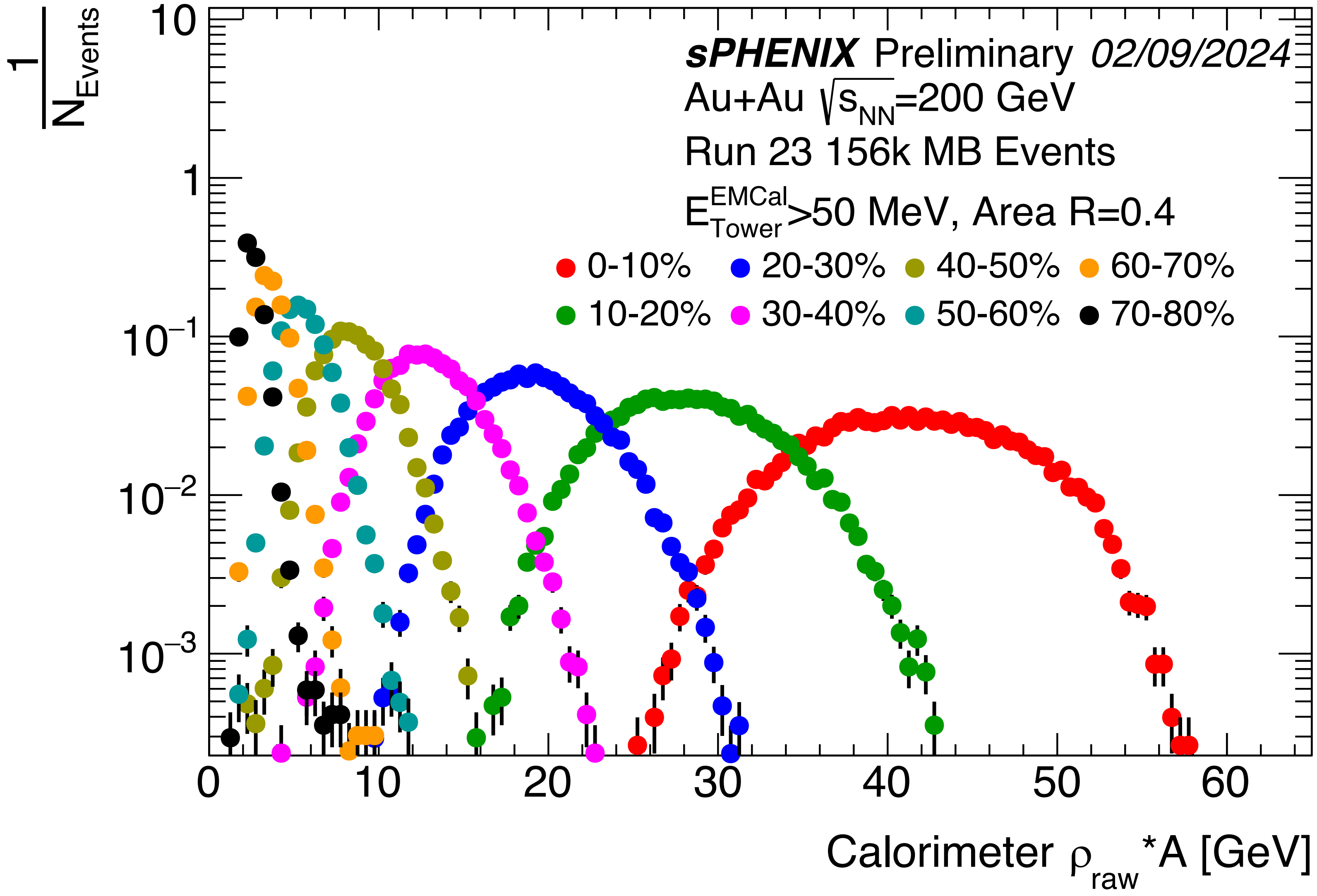
- ρ*A gives the median p_T of the UE
- Towers assumed to have m=0

sPHENIX UE Distribution



- Underlying event in calorimeter data from Run 23 shows a Gaussian-like distribution of ρ_{raw}*A in central collisions
- Embedding of PYTHIA8 into data shows slight increase, consistent with addition of UE from pp
    - Embedding of MC into data shown to be crucial in limiting systematic uncertainties on jets and other calorimeter measurements in Au+Au environment
    - Embedding performed on tower level

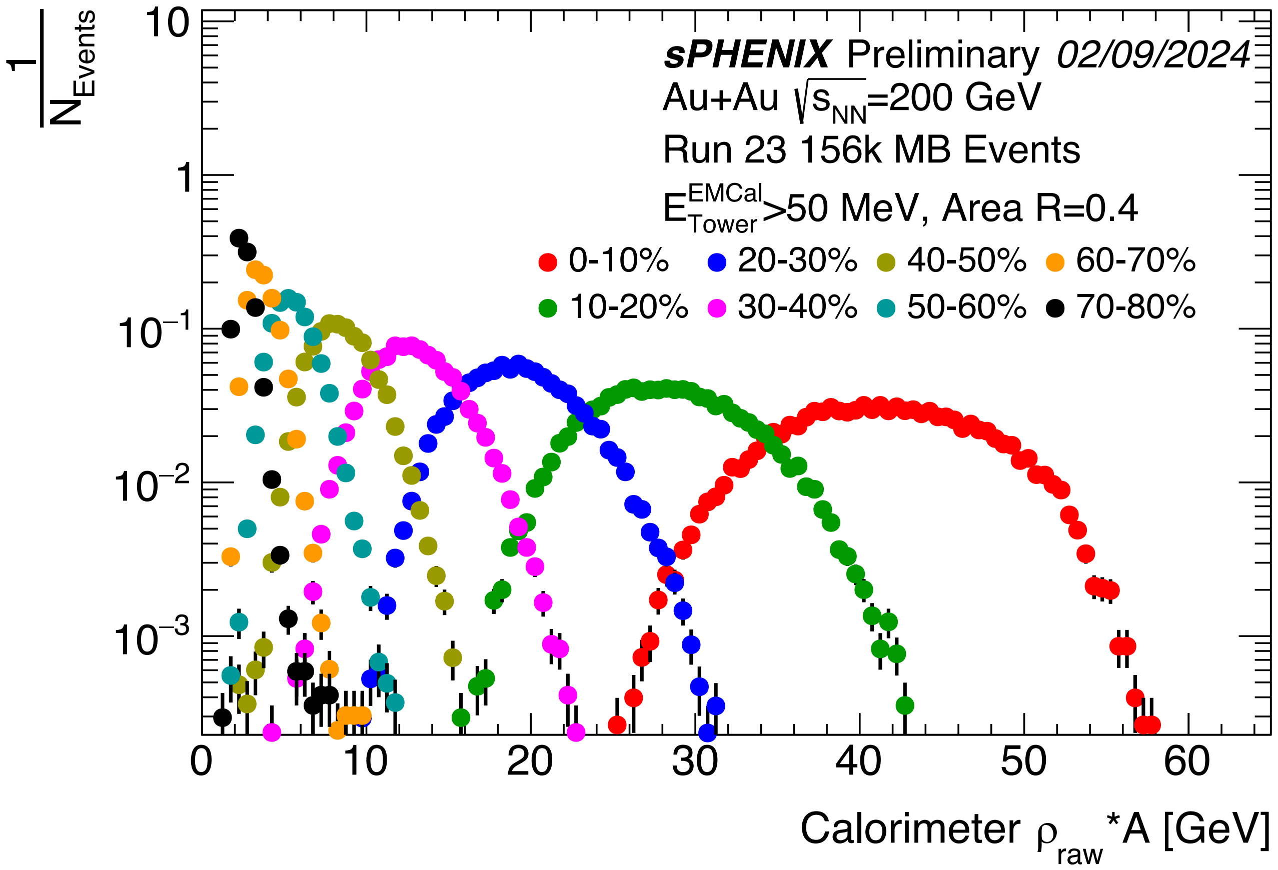
sPHENIX UE Distribution



Clear centrality trend:

- Gaussian in central collisions
- More skewed in peripheral collisions

sPHENIX UE Distribution



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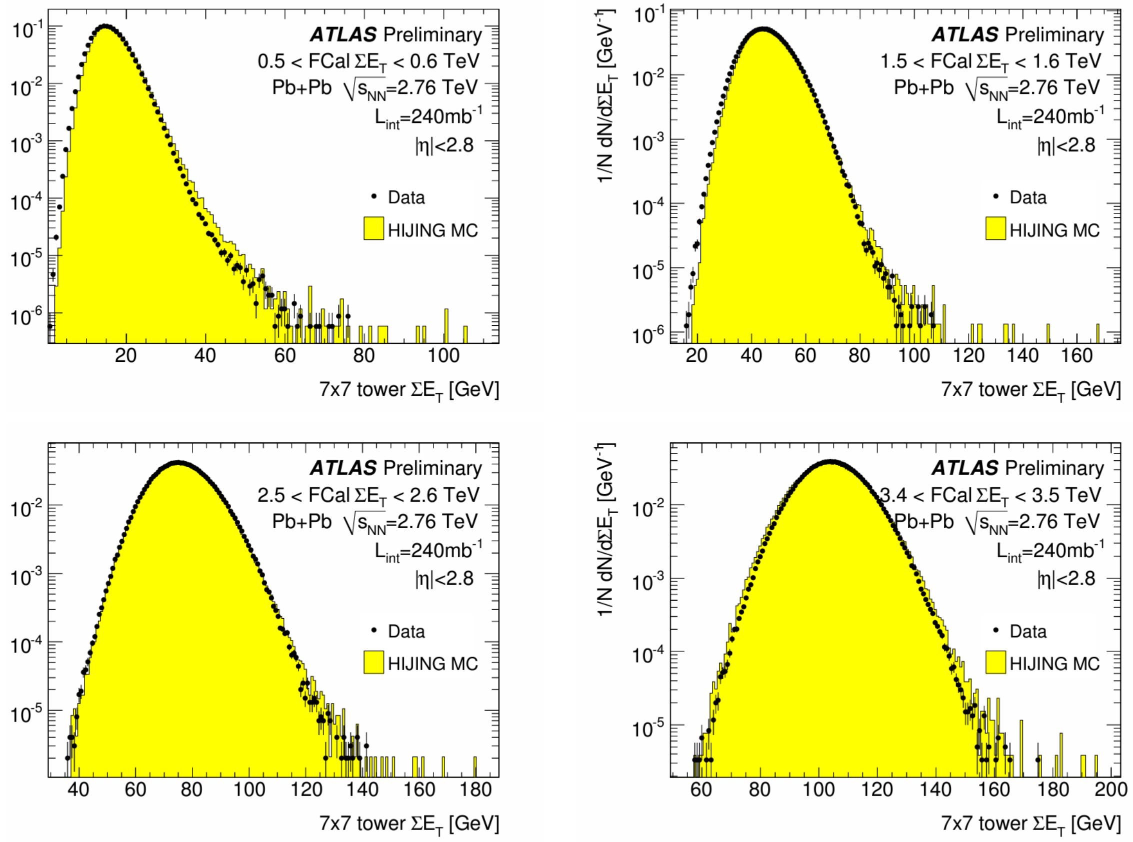
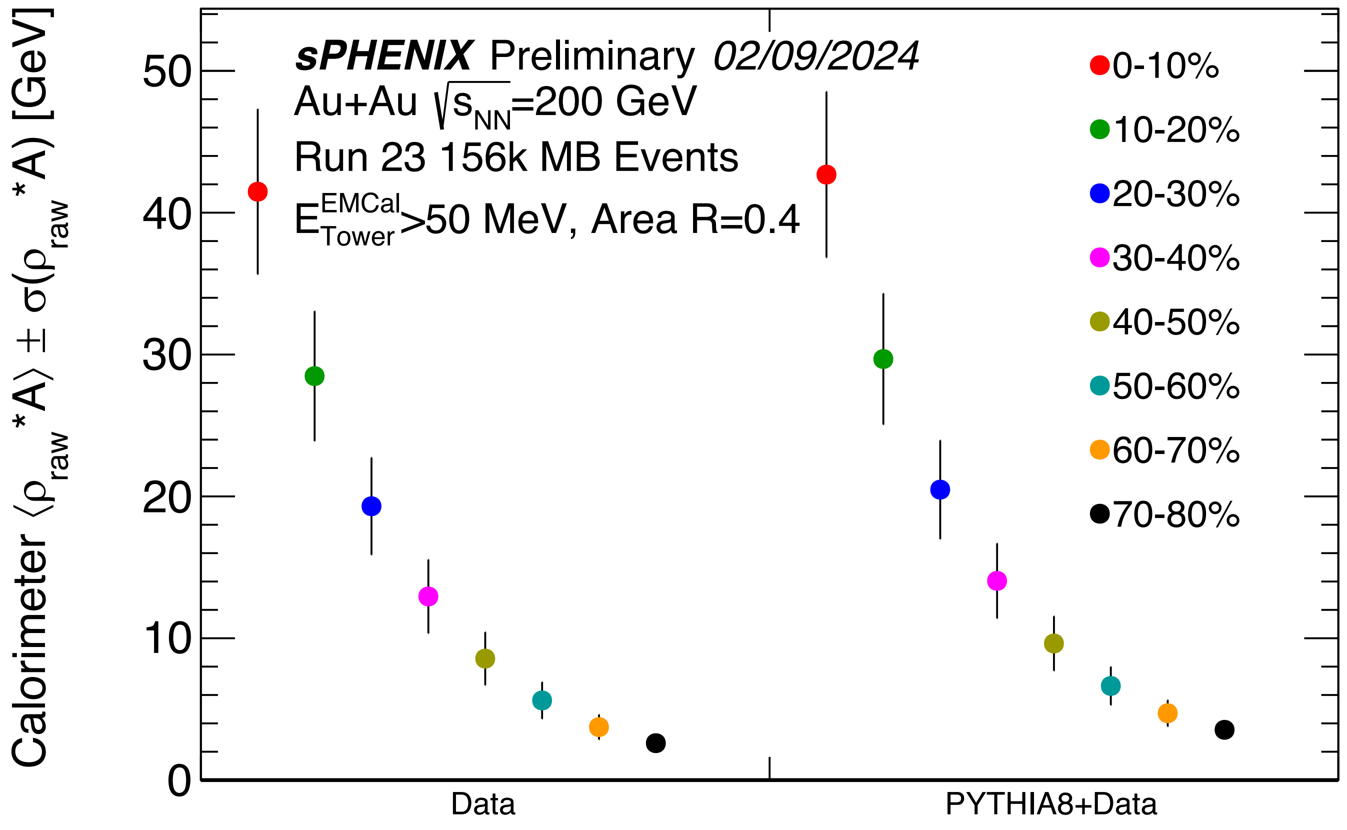
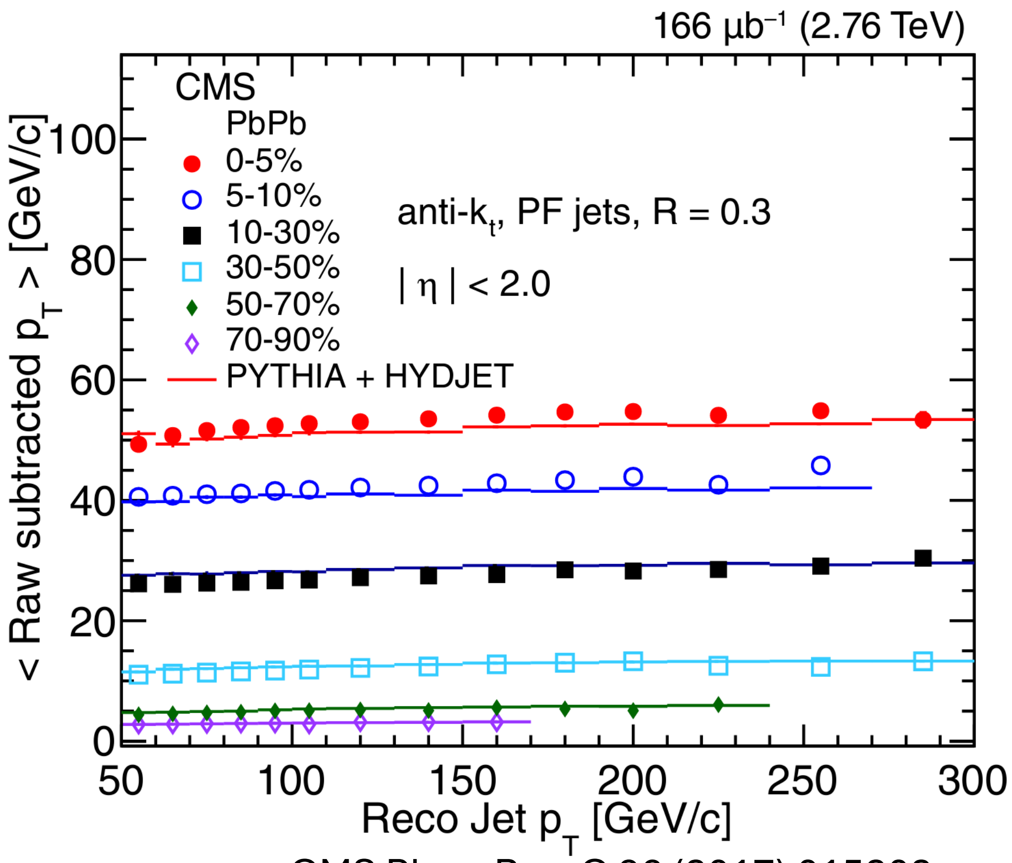


ATLAS distribution shows similar shape across all centralities

Mean UE p_T

Similar centrality trend in mean p_T between CMS and sPHENIX





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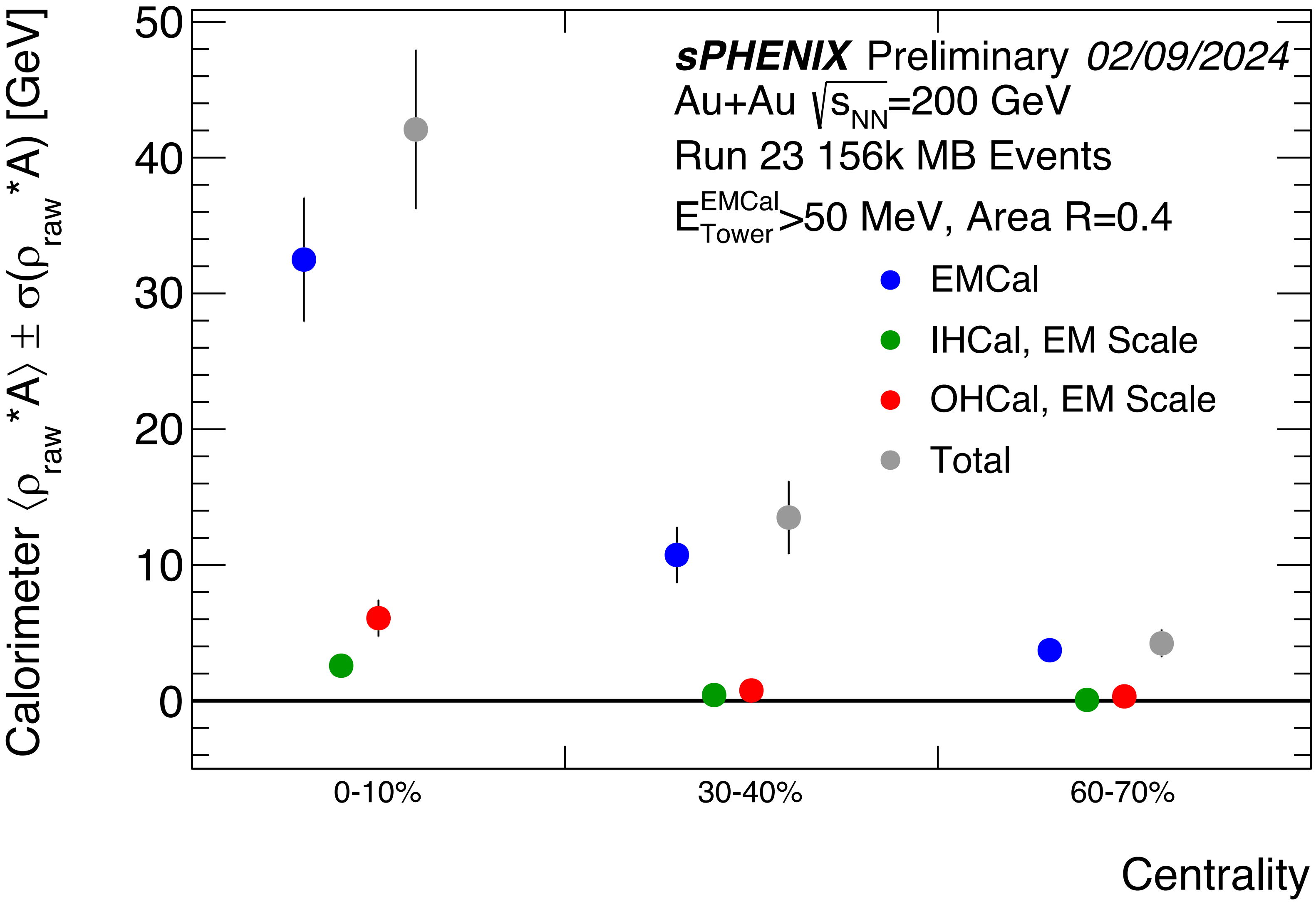
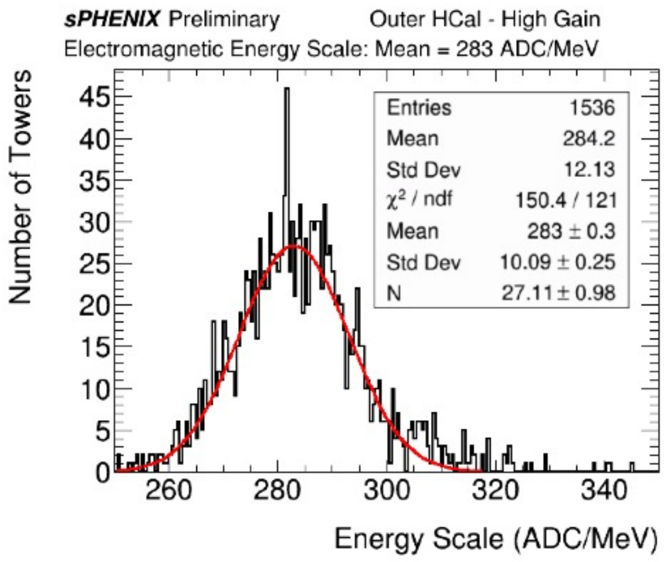
Calorimeter Factorization

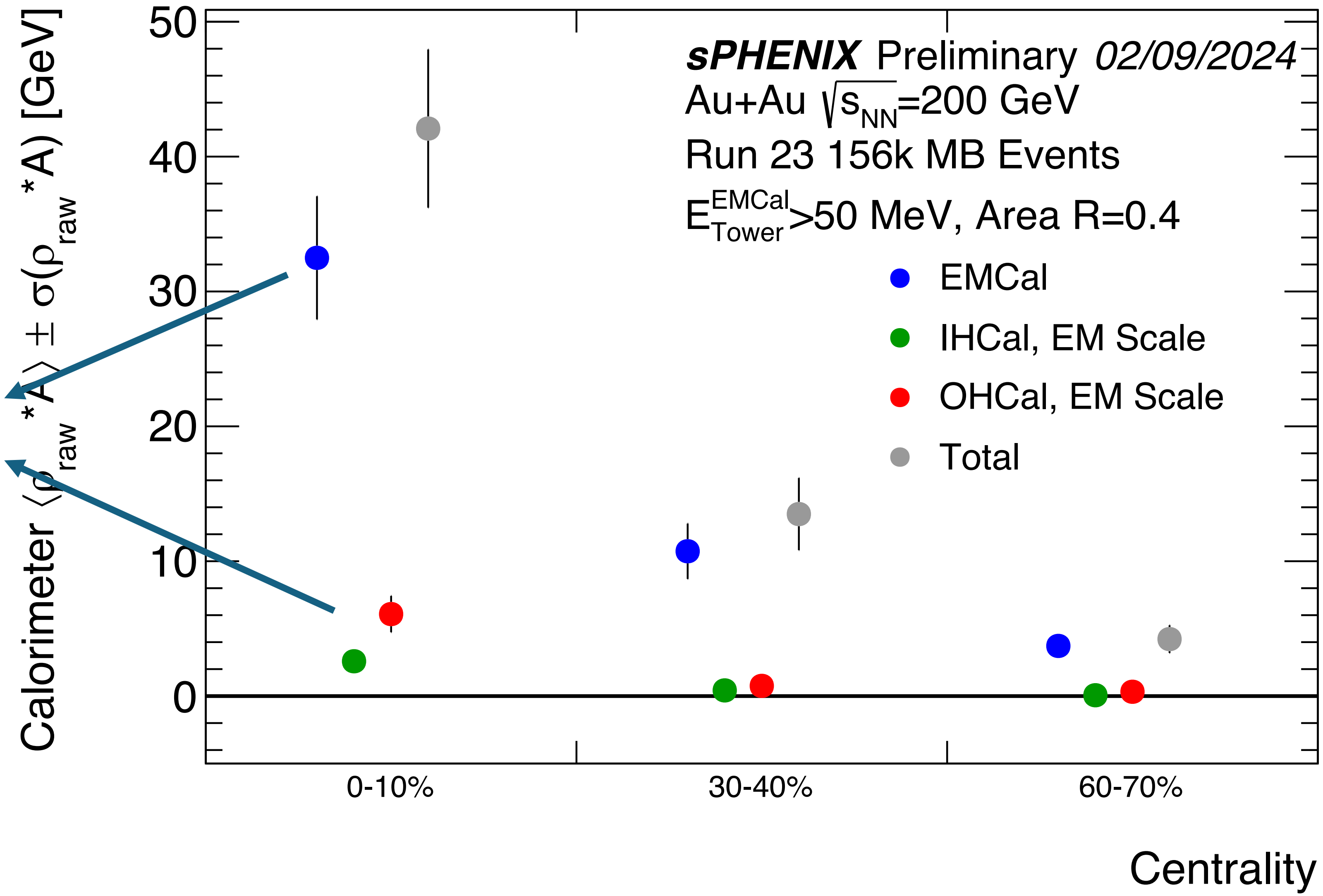
- ρ_{raw}*A calculated using inputs from each individual calorimeter
- EMCal dominates UE distribution due to low p_T
- Addition of contributions from each calorimeter matches total
- ρ_{raw}*A is factorizable!



Calorimeter Factorization



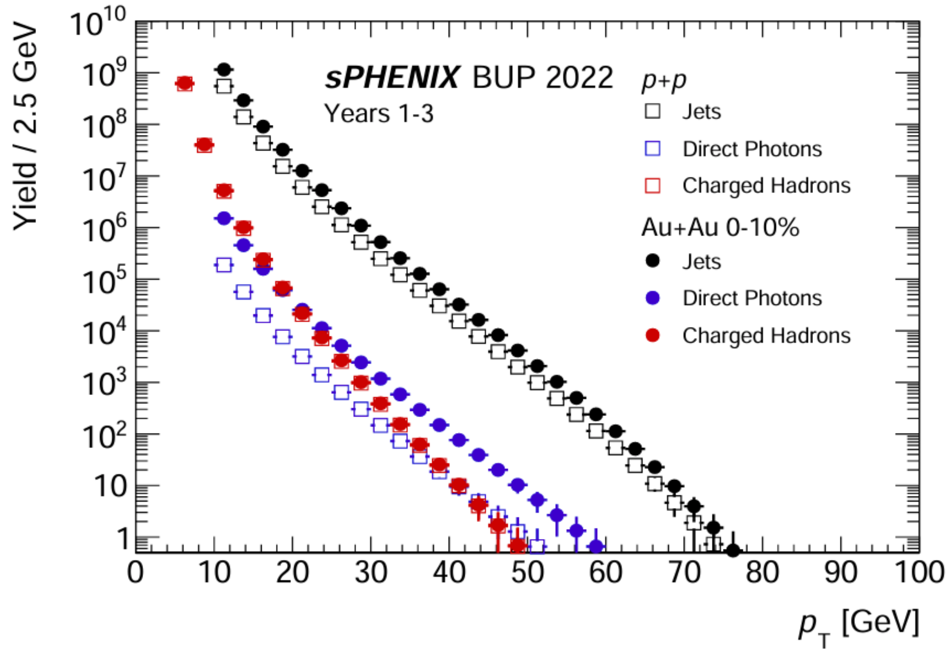
- HCals calibrated to EM scale, not hadronic scale
- Full jet energy scale will be corrected with simulation and data driven checks

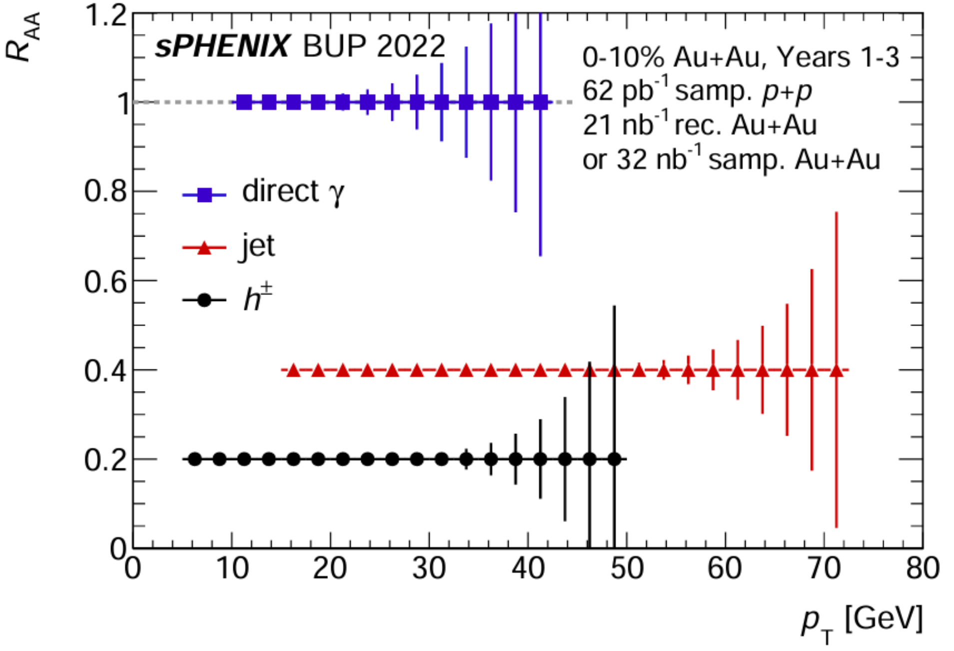


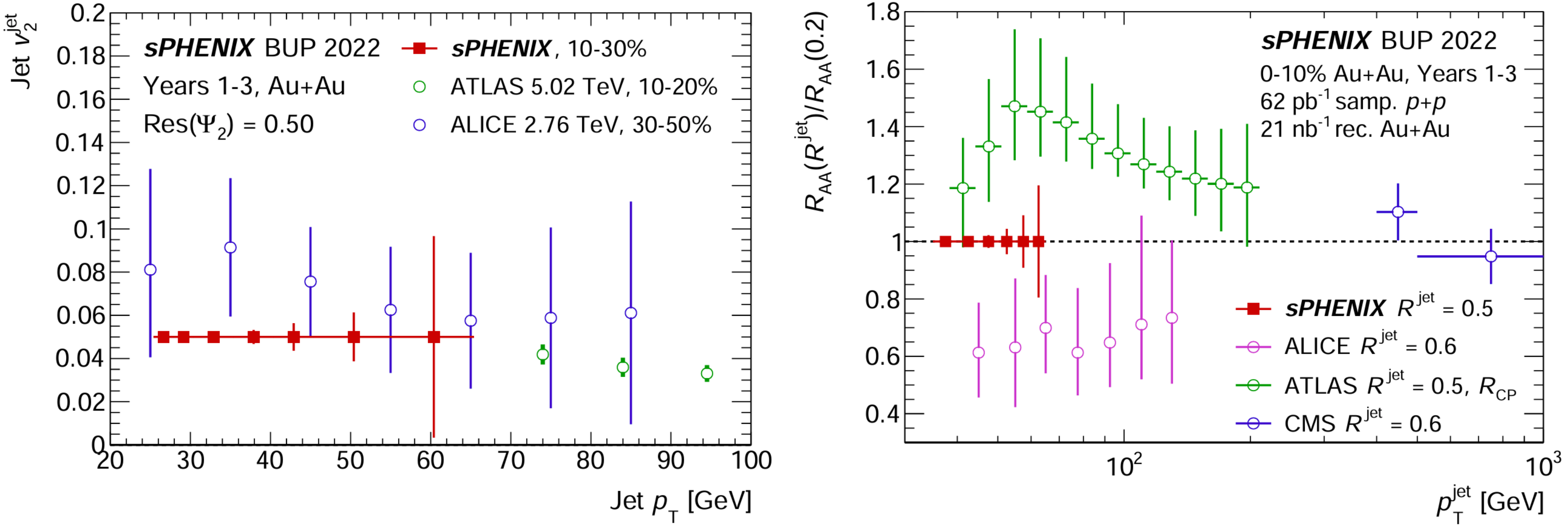
Projections for Runs 24 and 25

- Predicted significance using 62 pb^{-1} for pp and 32 nb^{-1} for Au+Au (optimal scenario)
- Jet measurements to high p_T
  - Overlap with LHC measurements!
- Precision measurements at low p_T
- High statistics for:
  - Direct photons (γ-jet measurements)
  - Charged hadrons (fragmentation functions, substructure)

Signal	Au+Au 0–10% Counts	p+p Counts
Jets $p_T > 20$ GeV	6 800 000 ($R_{AA} = 0.4$)	6 700 000
Jets $p_T > 40$ GeV	20 000 ($R_{AA} = 0.4$)	19 000
Direct Photons $p_T > 20$ GeV	9 200 ($R_{AA} = 1$)	3 700
Charged Hadrons $p_T > 25$ GeV	1 300 ($R_{AA} = 0.2$)	2 600







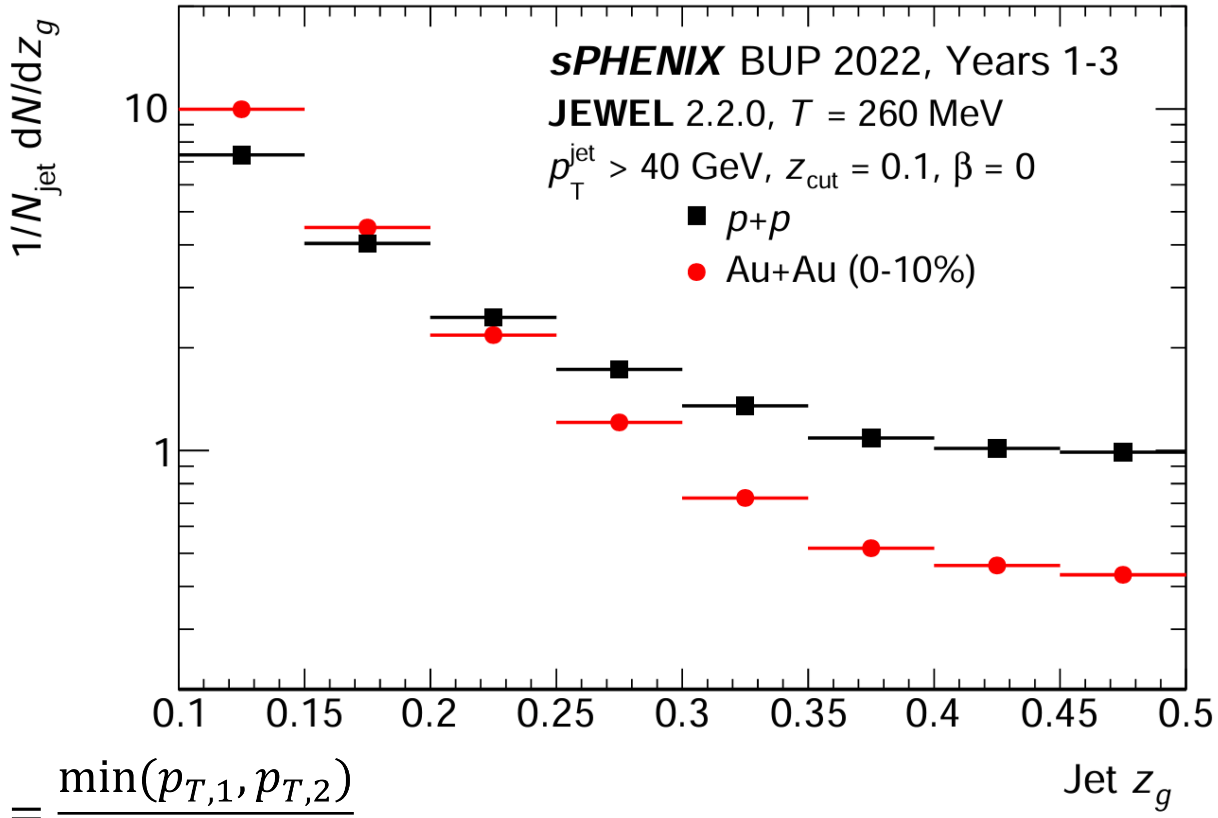
Jet v_2 and jet R_{AA} double ratio will have significant reduction in statistical uncertainties and allow direct comparison to the LHC

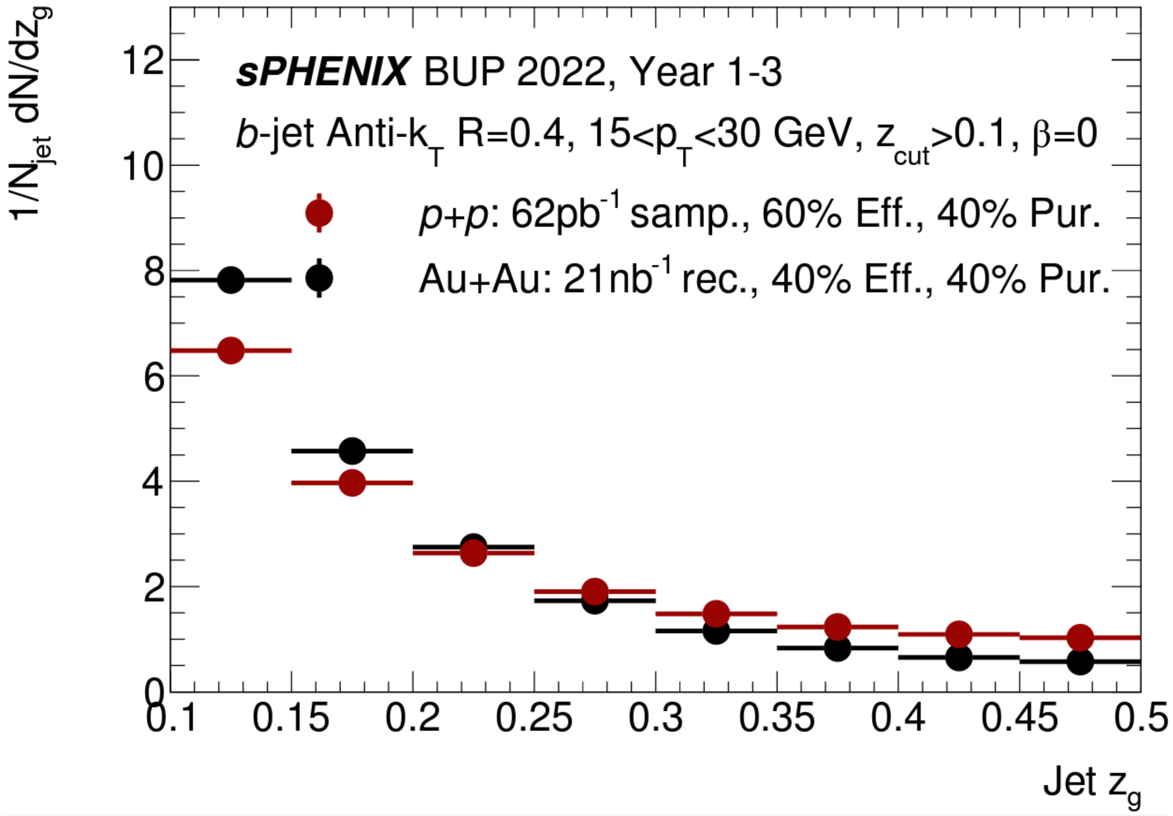
Complimentary Measurement to the LHC

Jet Substructure

B. Kimelman (Vanderbilt University) WWND 2024

Precise measurement of jet substructure, including in b-jets





$$z = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$$

SoftDrop condition: $z > z_{cut}\theta^{\beta}$

z_g is first splitting that satisfies SoftDrop condition

b-jets tagged using heavy flavor decay vertex

Conclusions

- sPHENIX is well equipped to perform precise and significant jet measurements
- Considerable progress has been made toward commissioning using Run 23 data
- Good understanding of the underlying event
- Many exciting measurements to come with pp and Au+Au data in Run 24 and Au+Au in Run 25