

Recent physics results from sPHENIX

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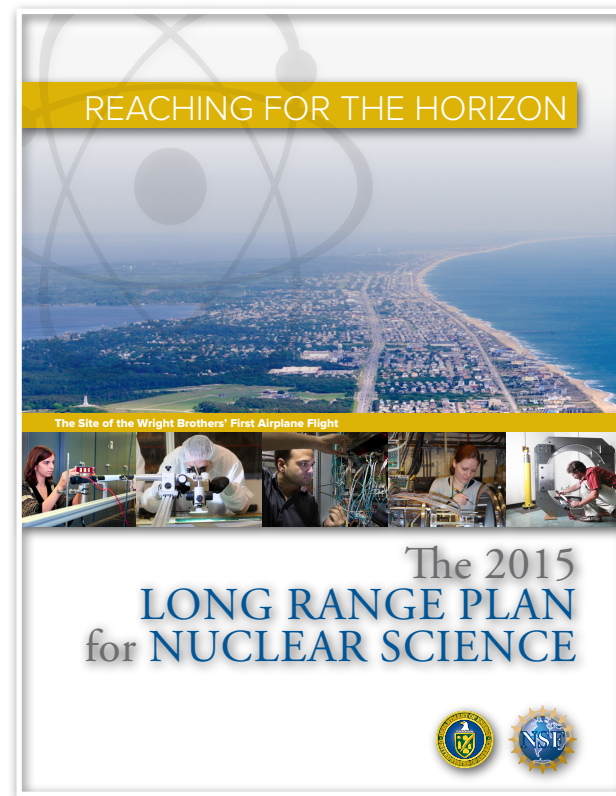
National Central University

Taiwan EIC meeting
July 30th, 2026

The sPHENIX experiment



Long Range Plan 2015, page 22



There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

2012: Proposal released

2015: LRP recommendation

2012 - 2023: Ten-year preparation for detector construction

2023 - 2026: Three-year data taking
(polarized p+p, Au+Au and O+O collision systems)

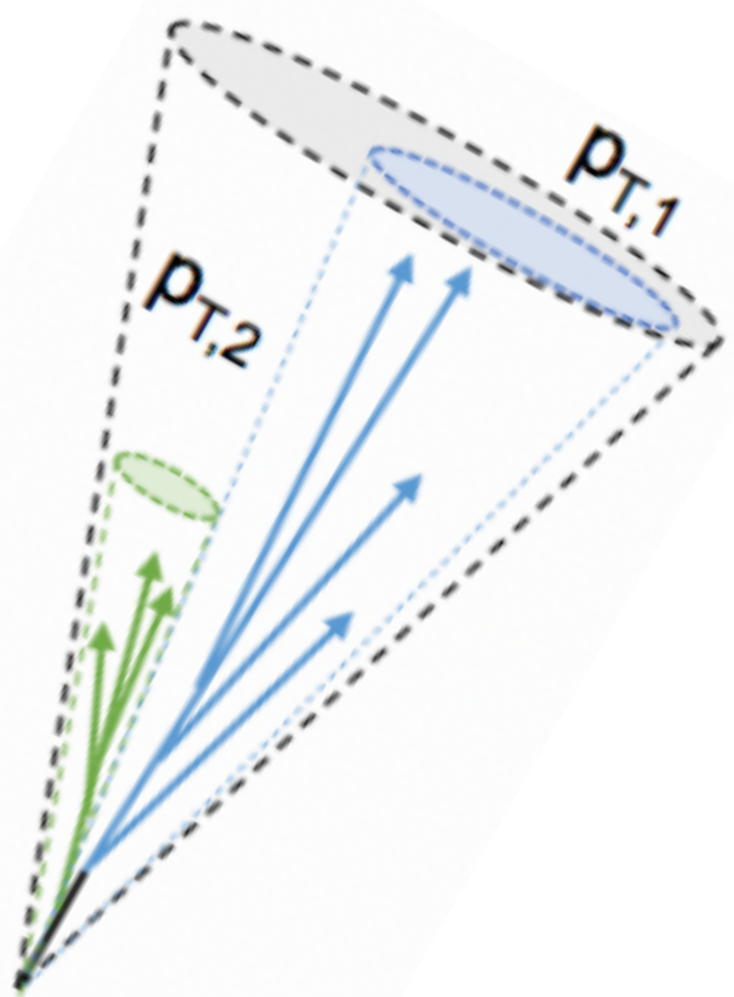
2026 - 203?: Full analysis phase



sPHENIX detector @ RHIC

Jet Physics

Jet correlations &
Jet structure



Heavy Flavor

Parton energy loss

u, d, s

charm

bottom

Quarkonium Spectroscopy

Sequential quarkonia
melting

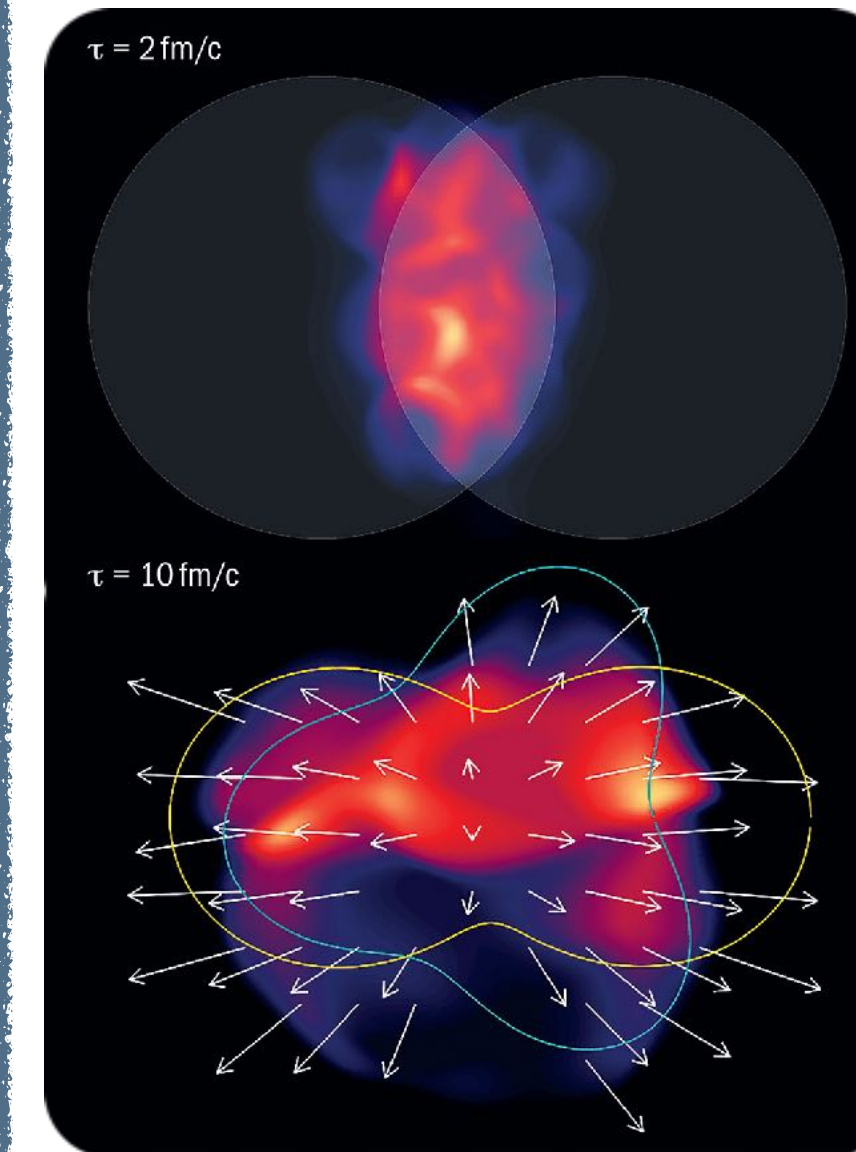
$b\bar{b}$
 $\Upsilon(1S)$
0.28 fm

$b\bar{b}$
 $\Upsilon(2S)$
0.56 fm

$b\bar{b}$
 $\Upsilon(3S)$
0.78 fm

Bulk physics

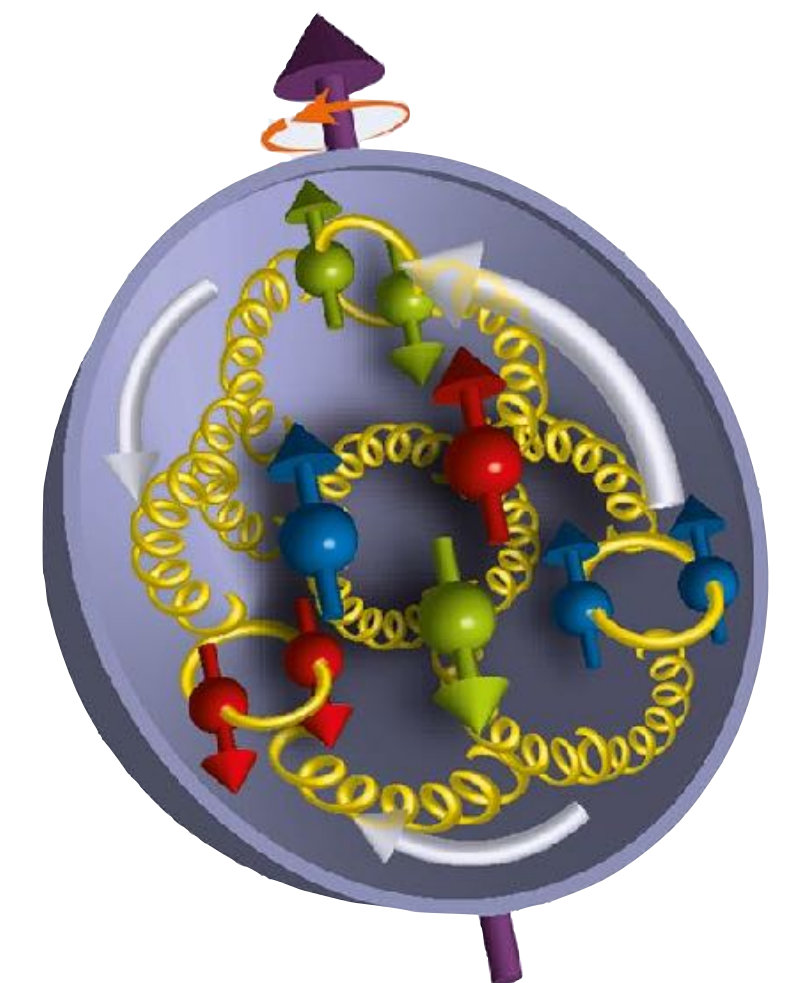
Global and collective
properties of medium



MUSIC [arXiv:1209.6330](https://arxiv.org/abs/1209.6330)

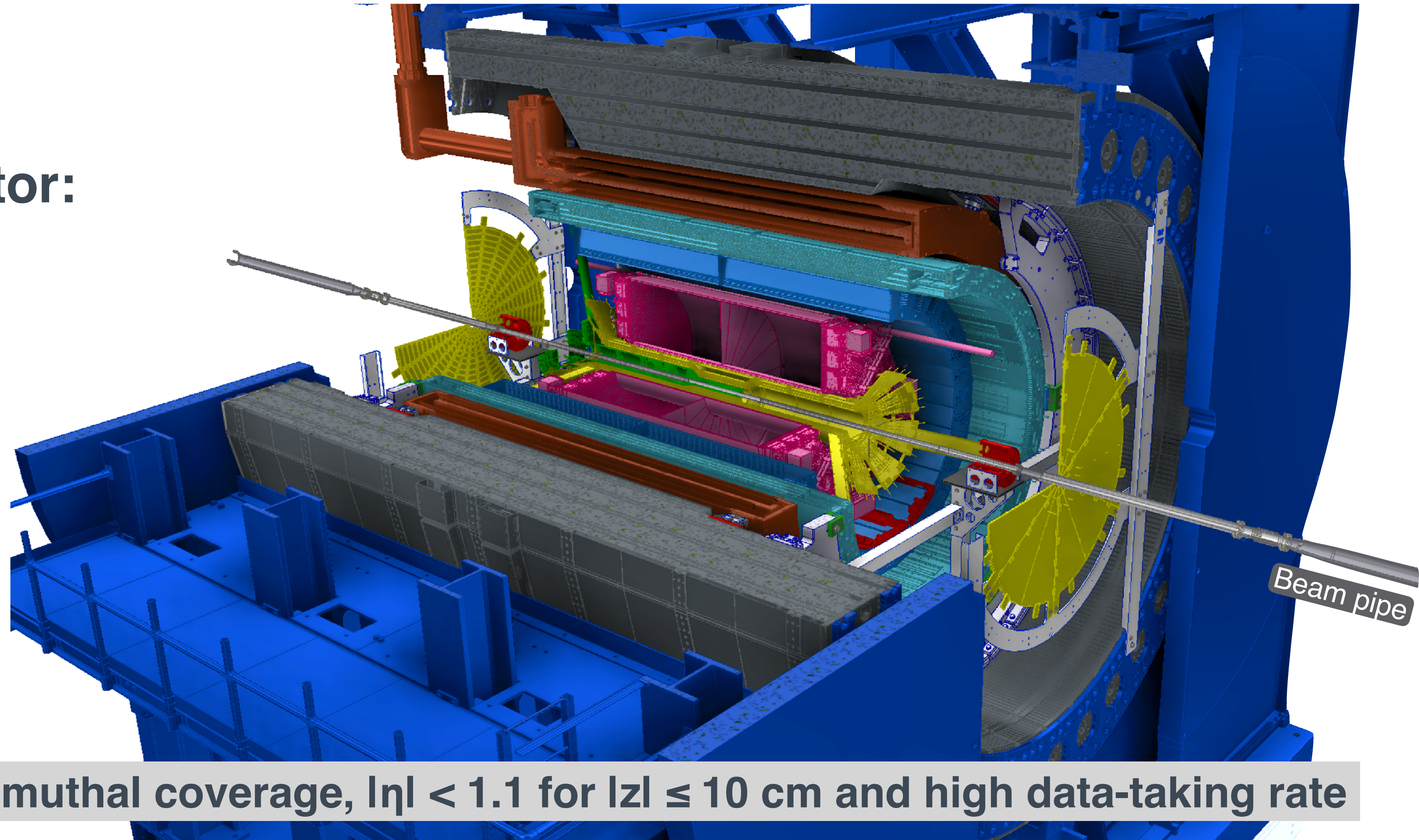
Cold QCD

Proton spin &
Nucleon structure



sPHENIX serves as the central and essential component to complete science mission of RHIC to reveal the nature of the QGP

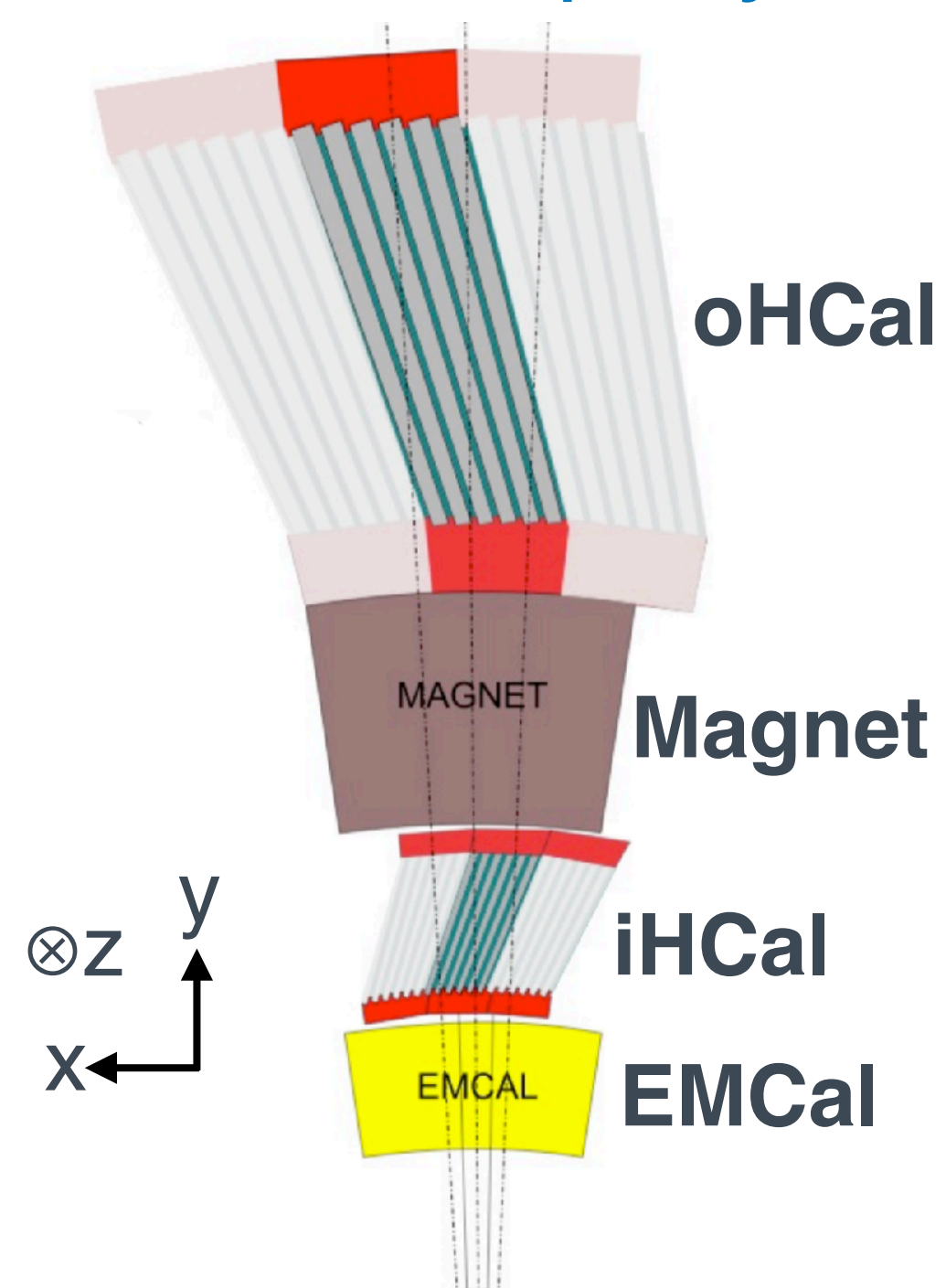
**sPHENIX detector:
11 subsystems**



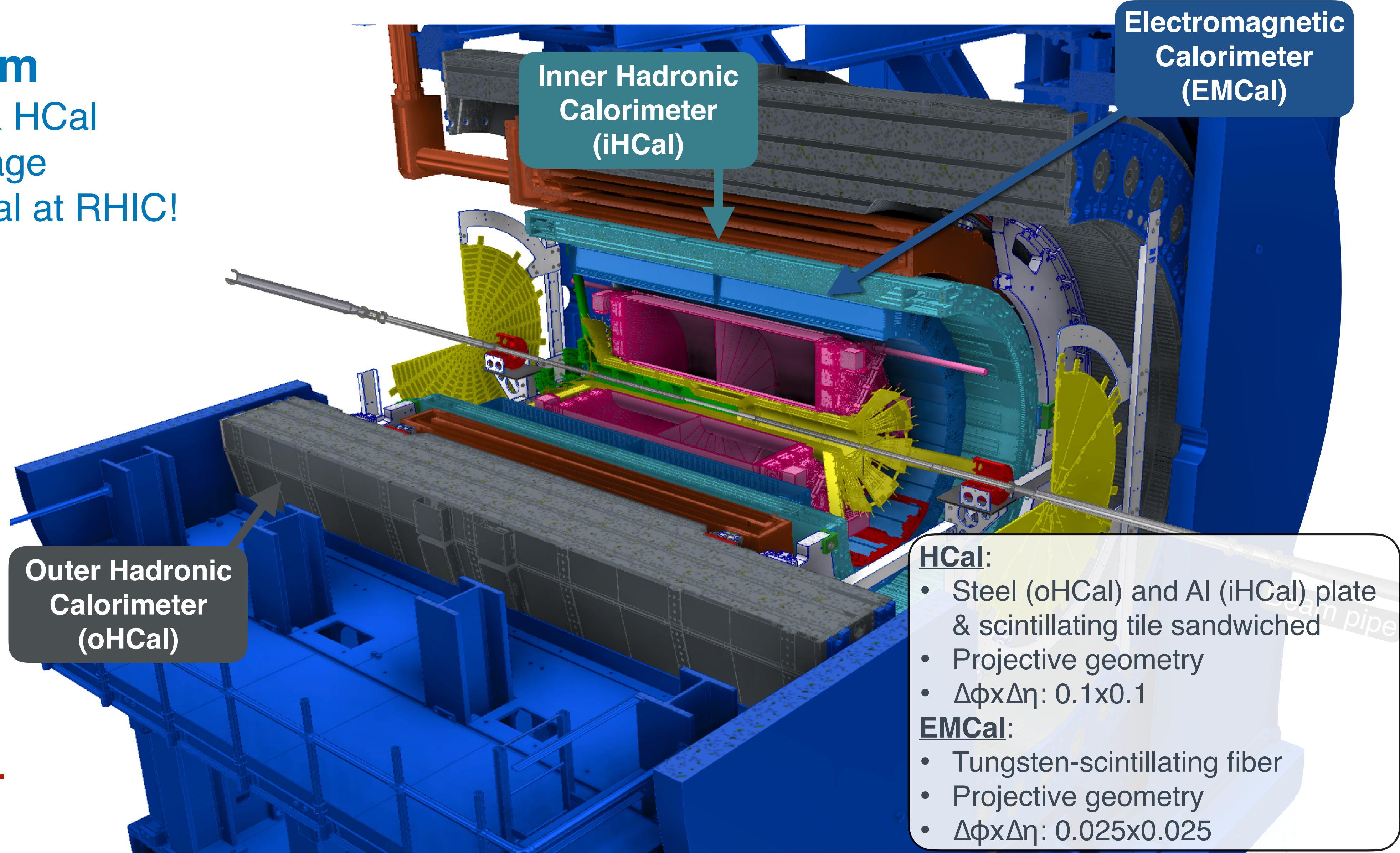
sPHENIX: Full azimuthal coverage, $|η| < 1.1$ for $|z| ≤ 10$ cm and high data-taking rate

Calorimeter system

- Mid-rapidity EMCal & HCal
- Full azimuthal coverage
- First mid-rapidity HCal at RHIC!

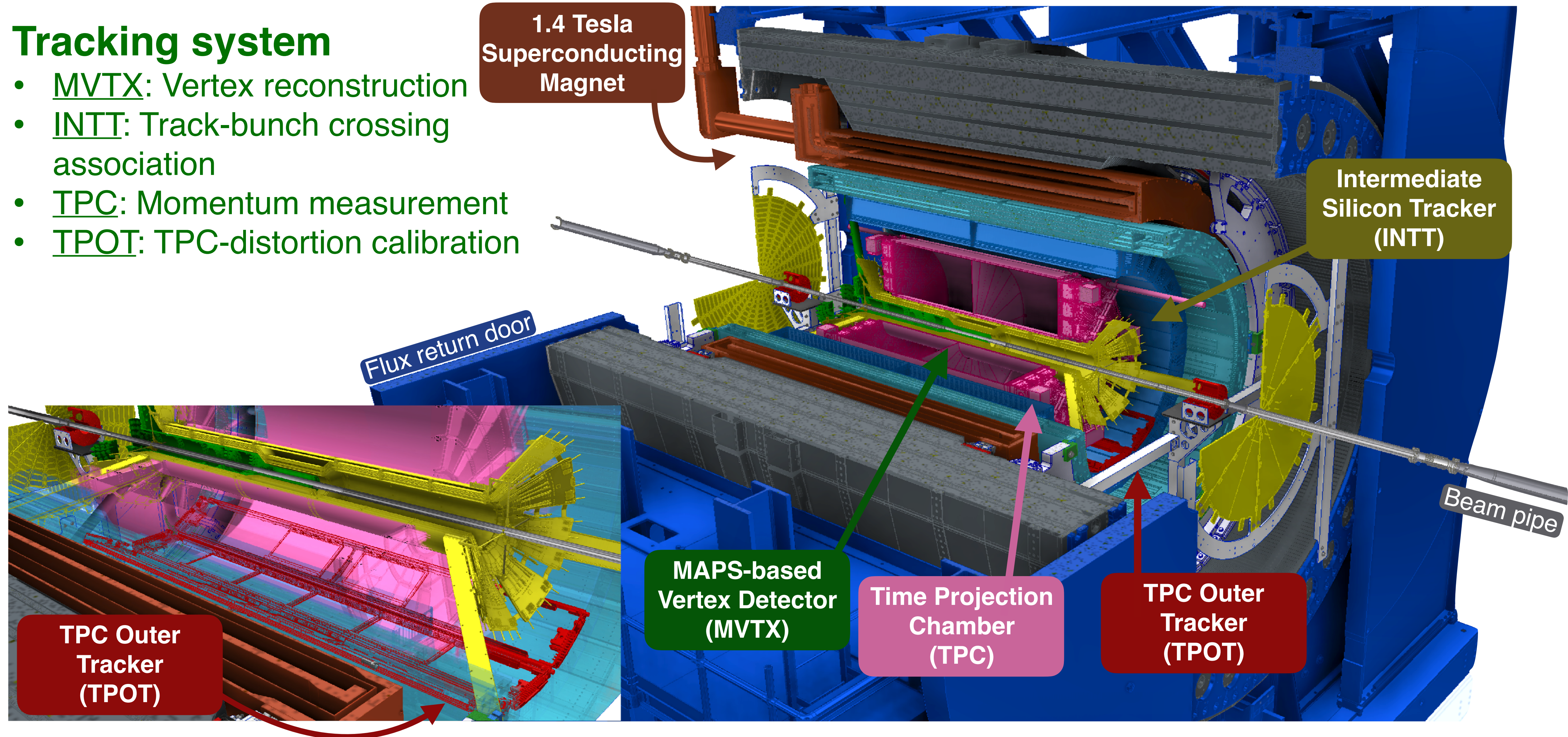


Sampling calorimeter
 $\sim 5 \lambda_i$ in total



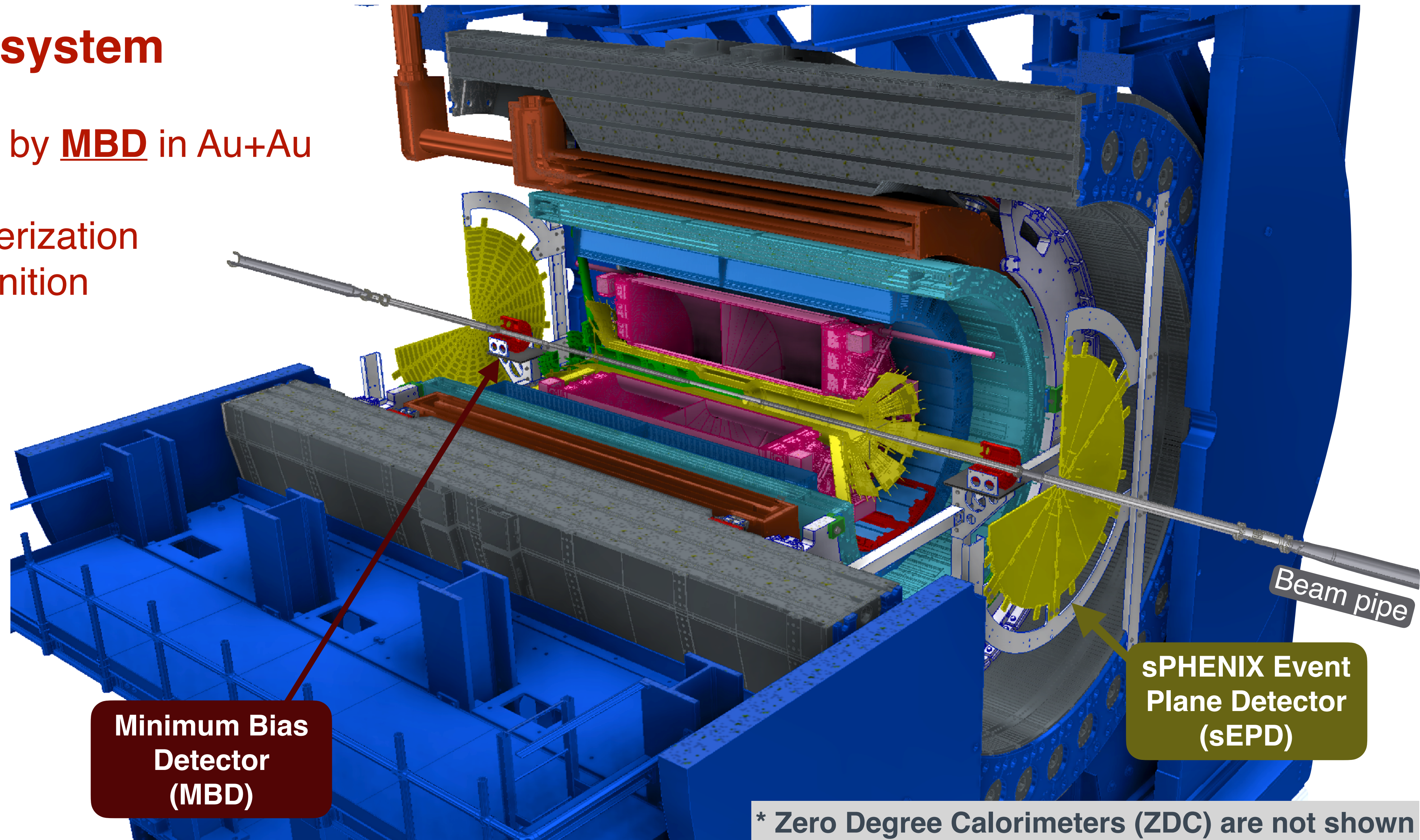
Tracking system

- MVTX: Vertex reconstruction
- INTT: Track-bunch crossing association
- TPC: Momentum measurement
- TPOT: TPC-distortion calibration



Forward detector system

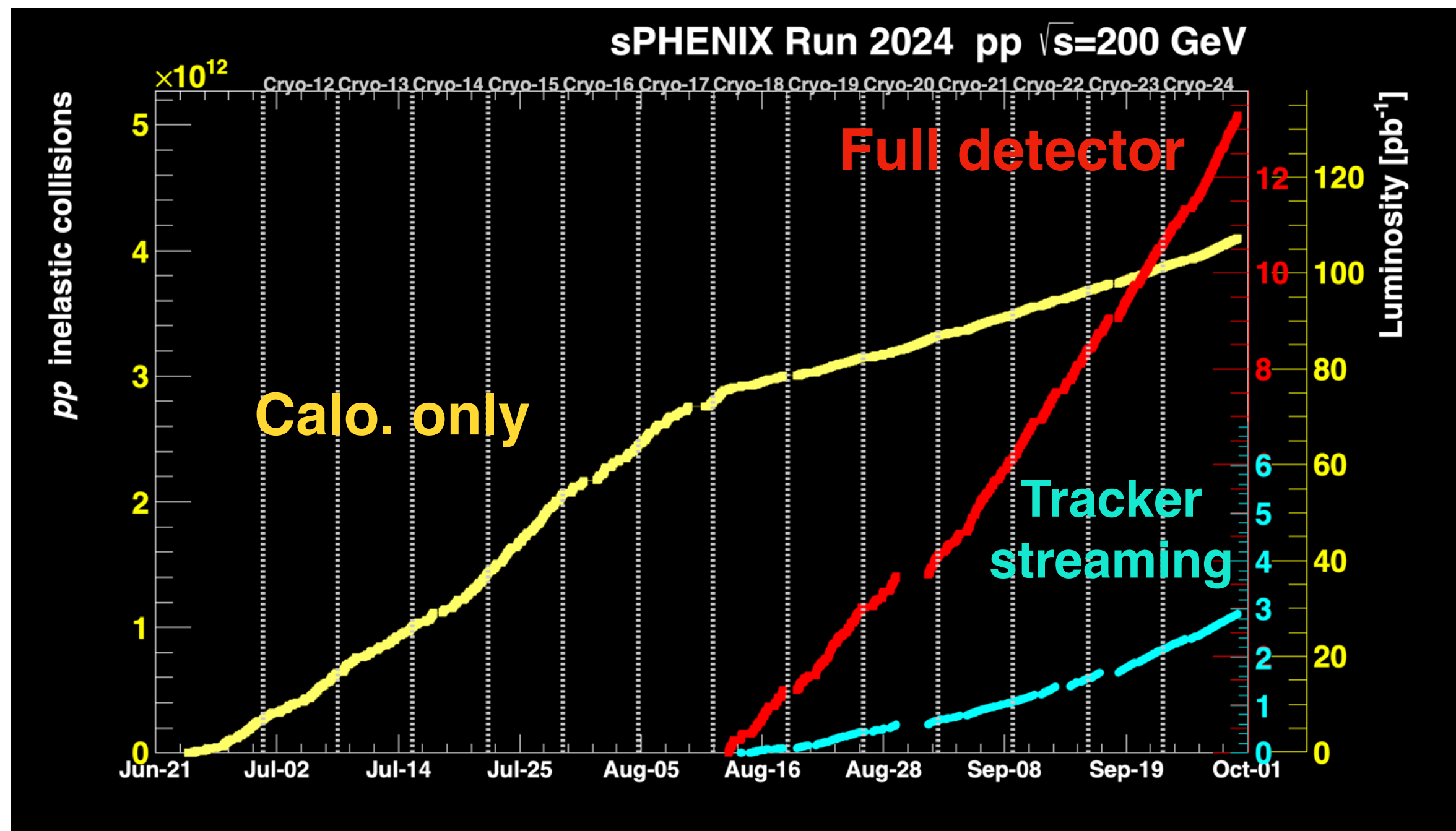
- MBD + sEPD + ZDC
- Minimum bias trigger by **MBD** in Au+Au and p+p collisions
- Global event characterization
 - Minimum bias definition
 - Event centrality
 - Reaction plane



sPHENIX data taking 2024



Year	Request		Reality		
	Weeks	Run plan	Weeks	Species	Goal
2024	28 weeks	p [↑] +p p [↑] +Au	22	p [↑] +p	Au+Au baseline and spin, cold-QCD measurments
			3	Au+Au	Commissioning of TPC and MVTX*



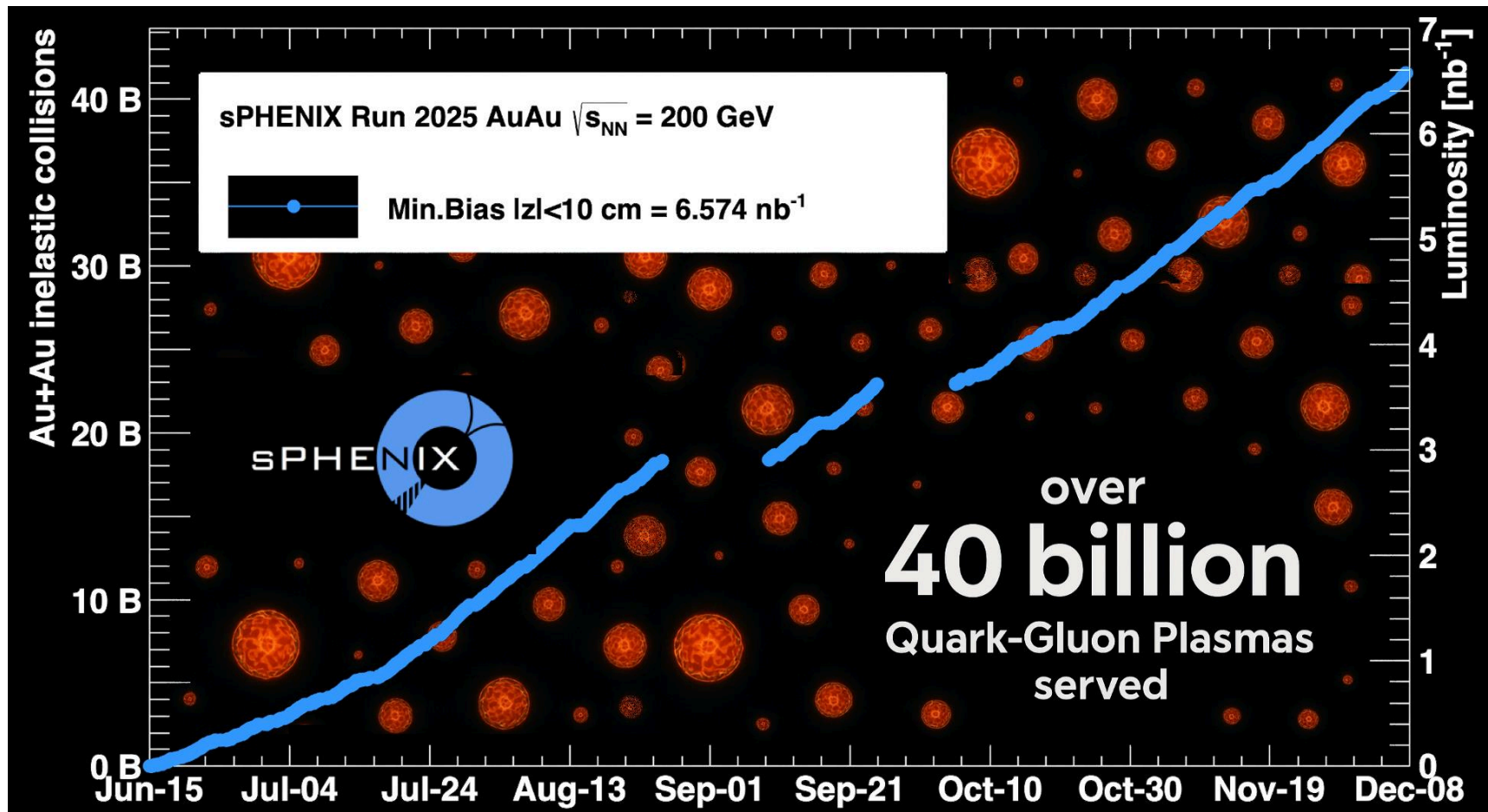
Polarized proton-proton collisions in Run 2024

- Calorimeter only data: 107.4 pb⁻¹ → 240% of Run Goal
- Full detector data: 13.28 pb⁻¹ → 30% of Run Goal
- Tracker streaming data: 2.90 pb⁻¹ → 65% of Run Goal

*Run24 sPHENIX Au+Au data also used for physics analyses

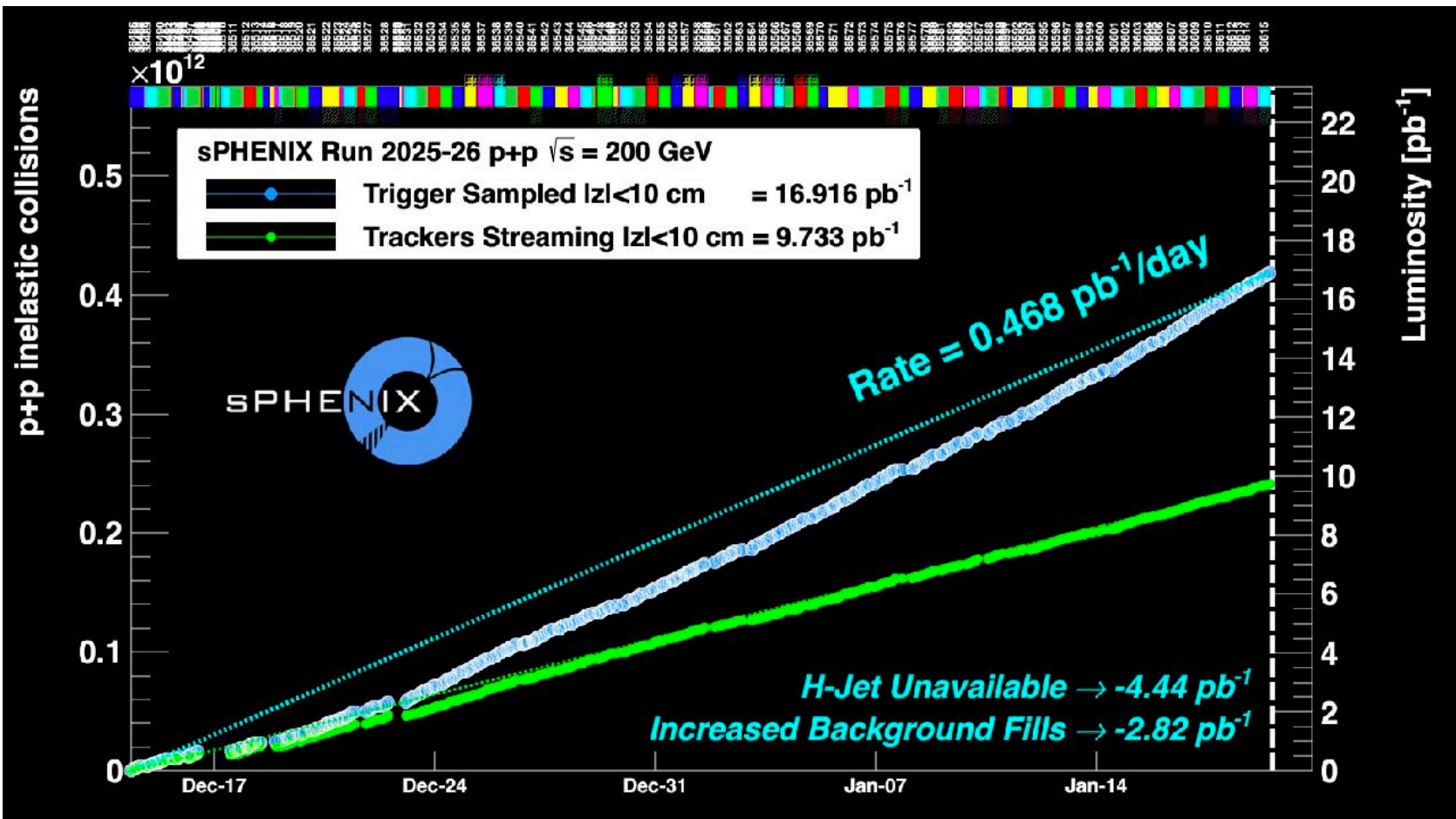
Year	Request		Reality		
	Weeks	Run plan	Weeks	Species	Goal
2025 2026	28 weeks	Au+Au	22	Au+Au	Golden Au+Au dataset
			6	p [↑] +p	Additional full-detector p+p data
			6 days	O+O	Small system

Au+Au collision data taking



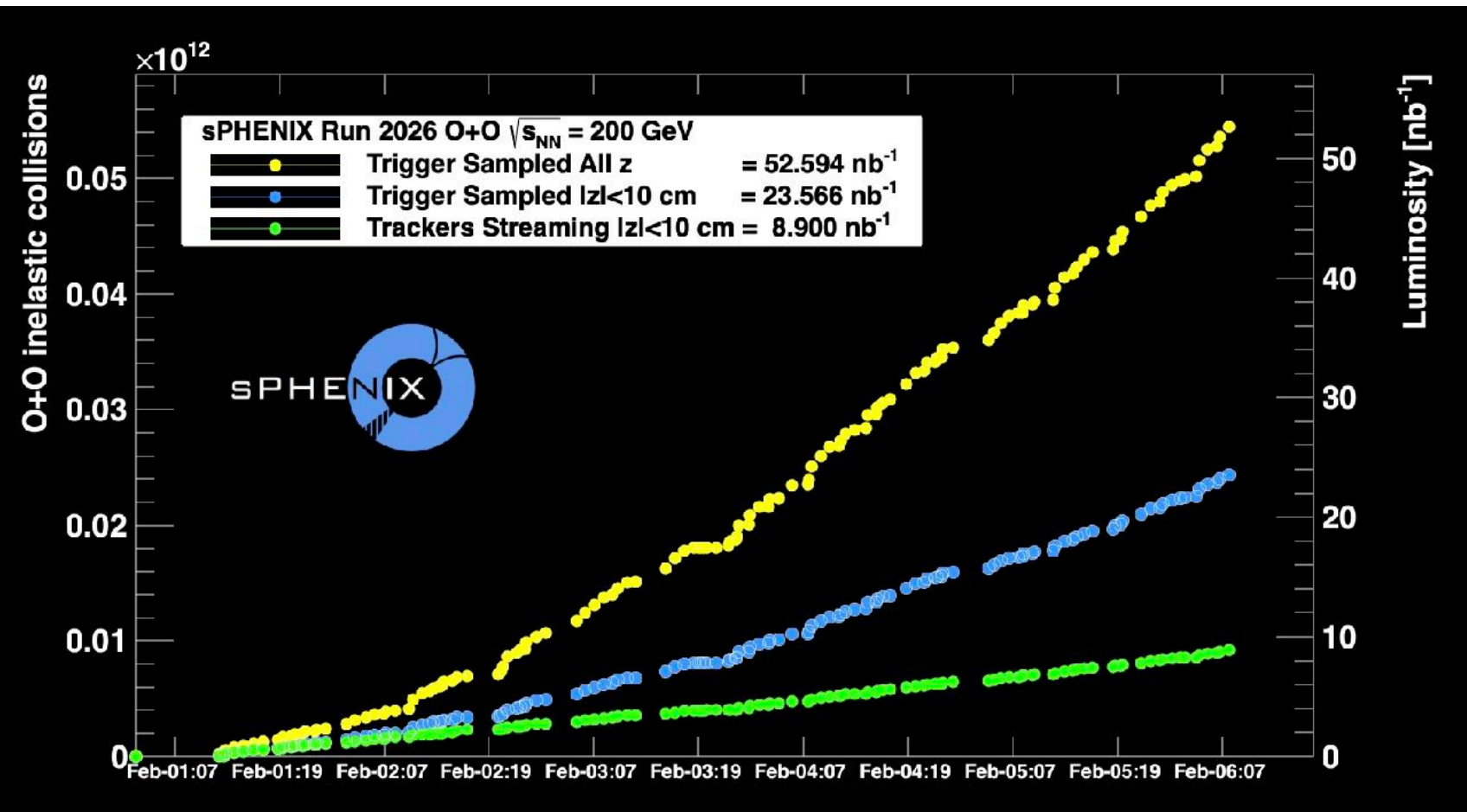
6.6 nb⁻¹ achieved → 94% program goal

Polarized proton-proton collisions



In total: 25/pb, 67% program goal

Oxygen-Oxygen collisions



In total: 24/nb, 181% program goal

sPHENIX first collision (Au+Au): May 17, 2023, last collision (O+O): February 6, 2026

I was very lucky to witness both events

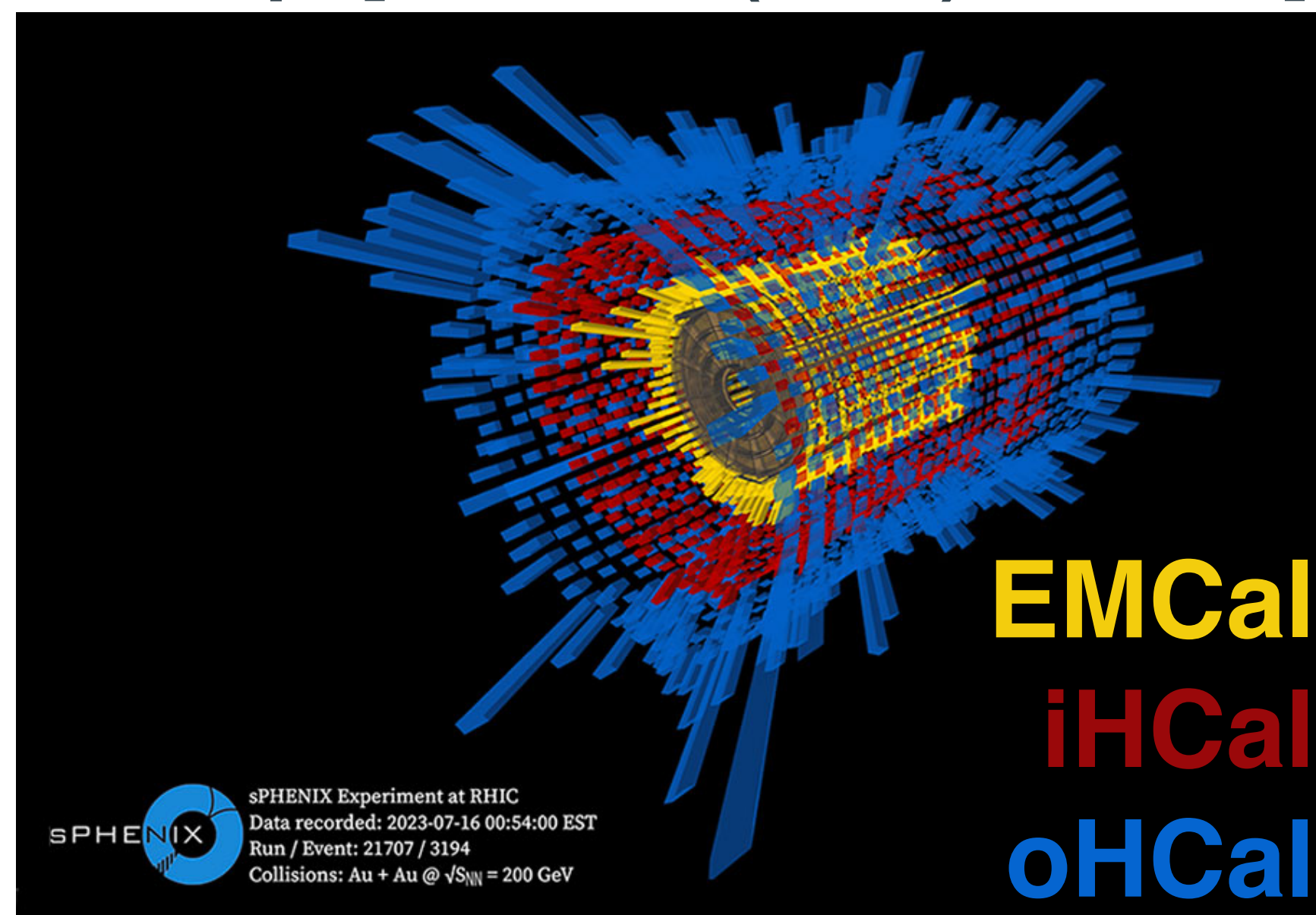
Bulk measurements in Au+Au collisions at sPHENIX



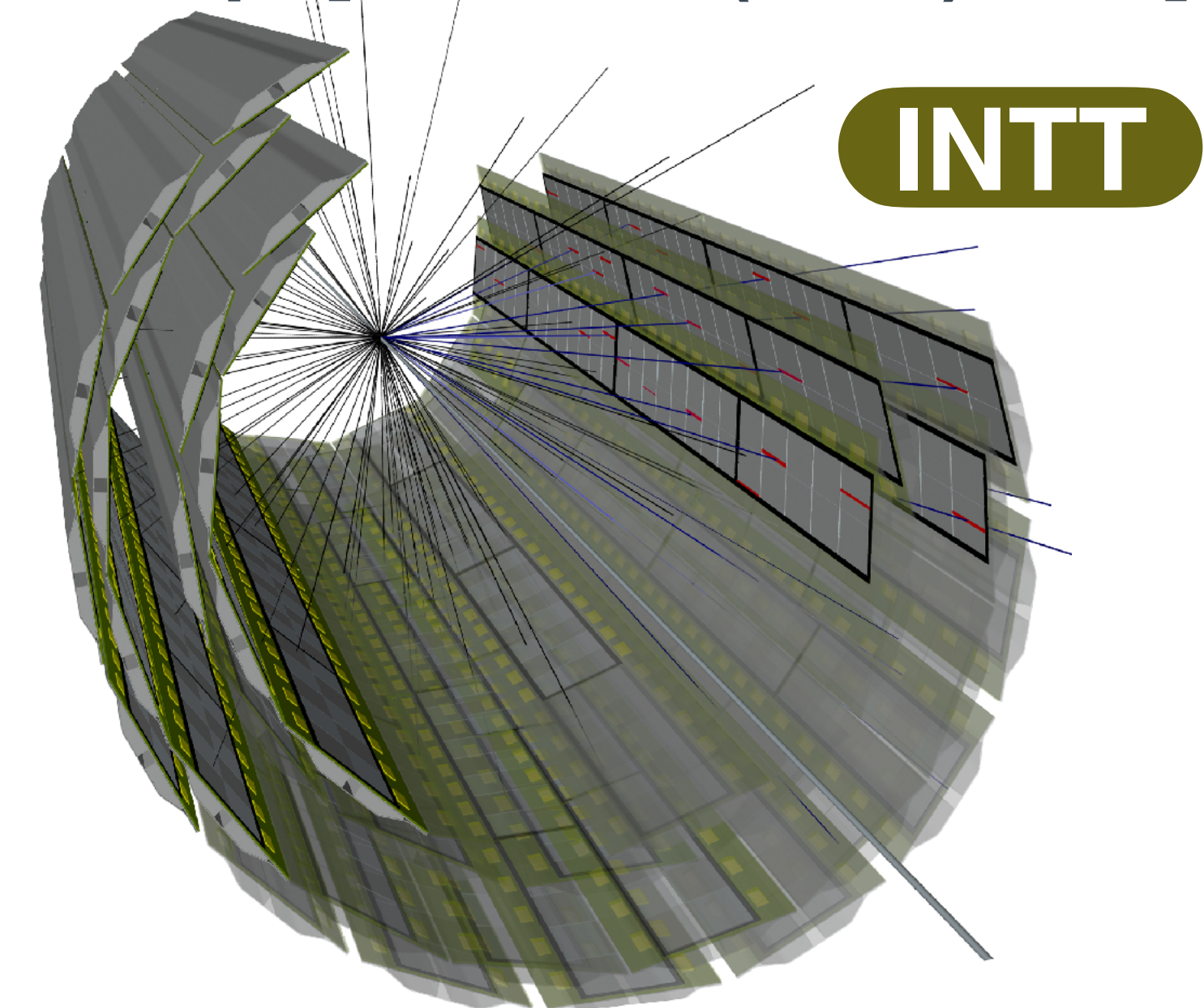
w/ Run24 Au+Au collision data

- Energy ($dE_T/d\eta$) and particle ($dN_{ch}/d\eta$) densities: dependence on colliding systems, energies, and geometry place constraints on theories
- sPHENIX is expected to match the previous experimental measurements at RHIC
- These first sPHENIX measurements serve as standard candles to validate performance
- First physics publications

$dE_T/d\eta$ - [PRC 112 (2025), 024908]

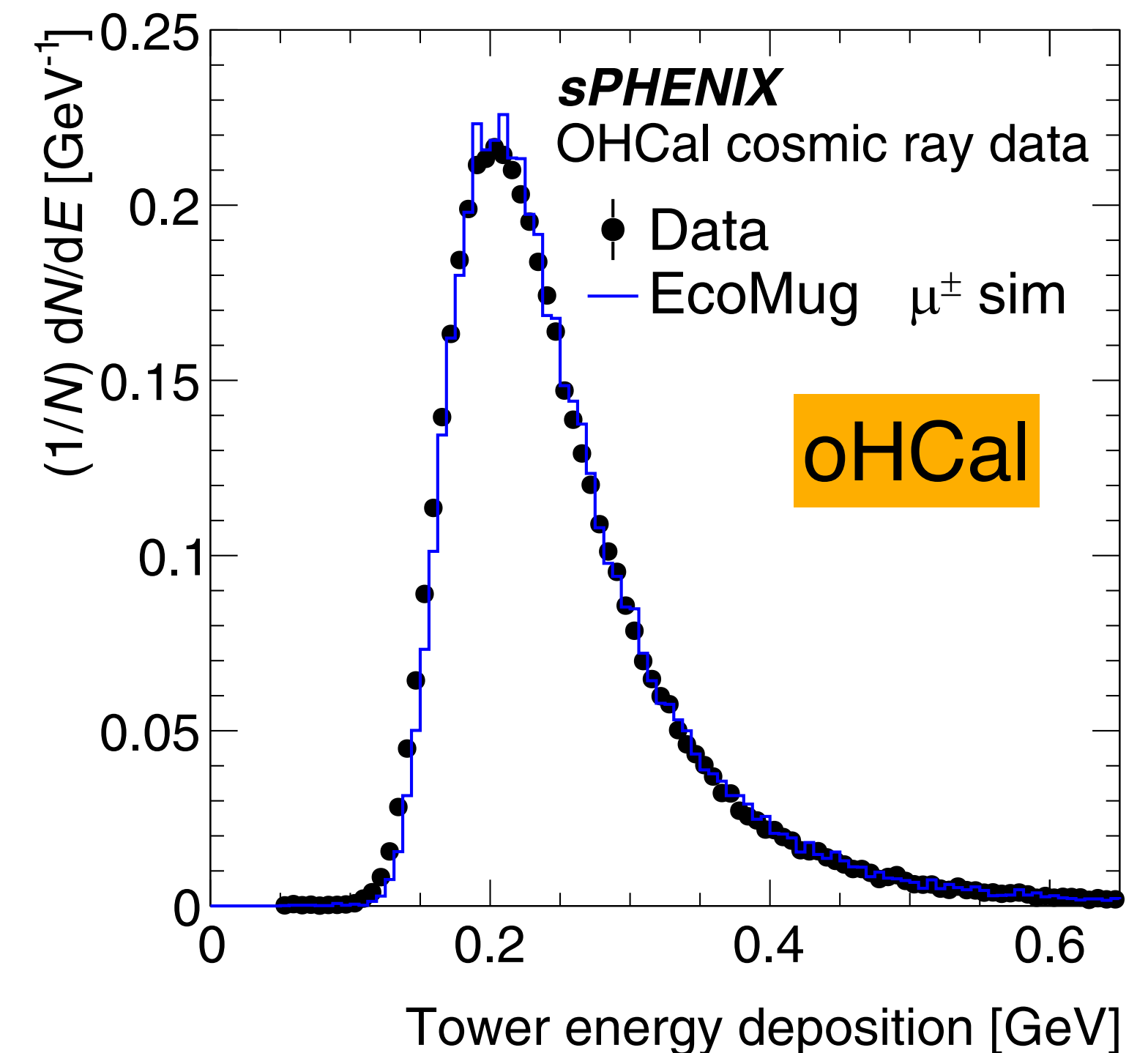
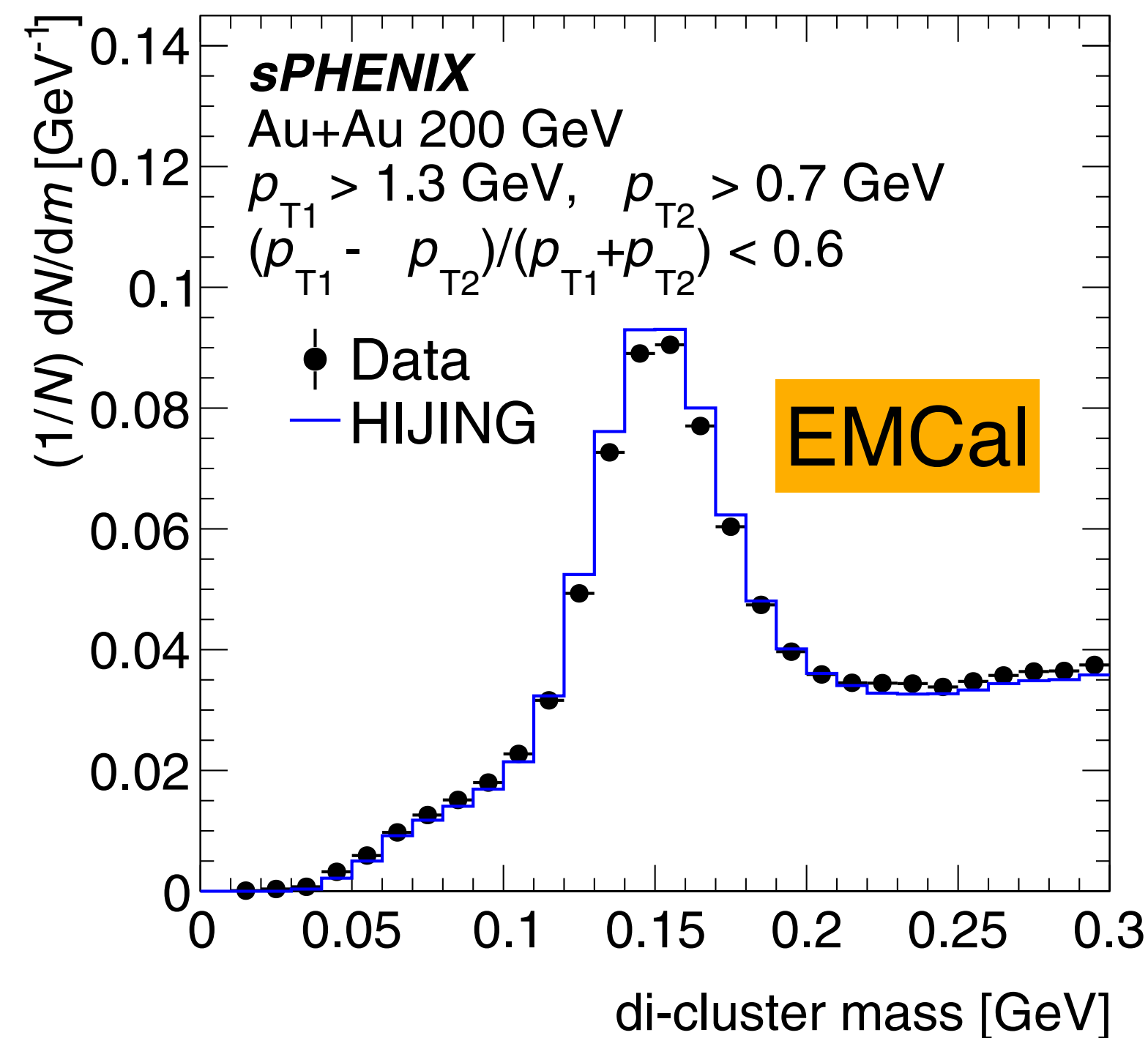


$dN_{ch}/d\eta$ - [JHEP 08 (2025), 075]



- **EMCal**: matching $\pi^0 \rightarrow \gamma\gamma$ mass peak between data and simulation
- **HCal**: matching the observed MIP peak from cosmic ray muons between data and simulation & an additional factor applied for correcting the measured scintillator MIP energy to an estimated energy deposition in both scintillator and absorber
- **$dE_T/d\eta$ in particle level**: Correction factors applied to detector-level $dE_T/d\eta$, to account for detector acceptance, low- p_T charged particles, losses in the magnet region, etc

sPHENIX Final! -
[\[PRC 112 \(2025\), 024908\]](#)

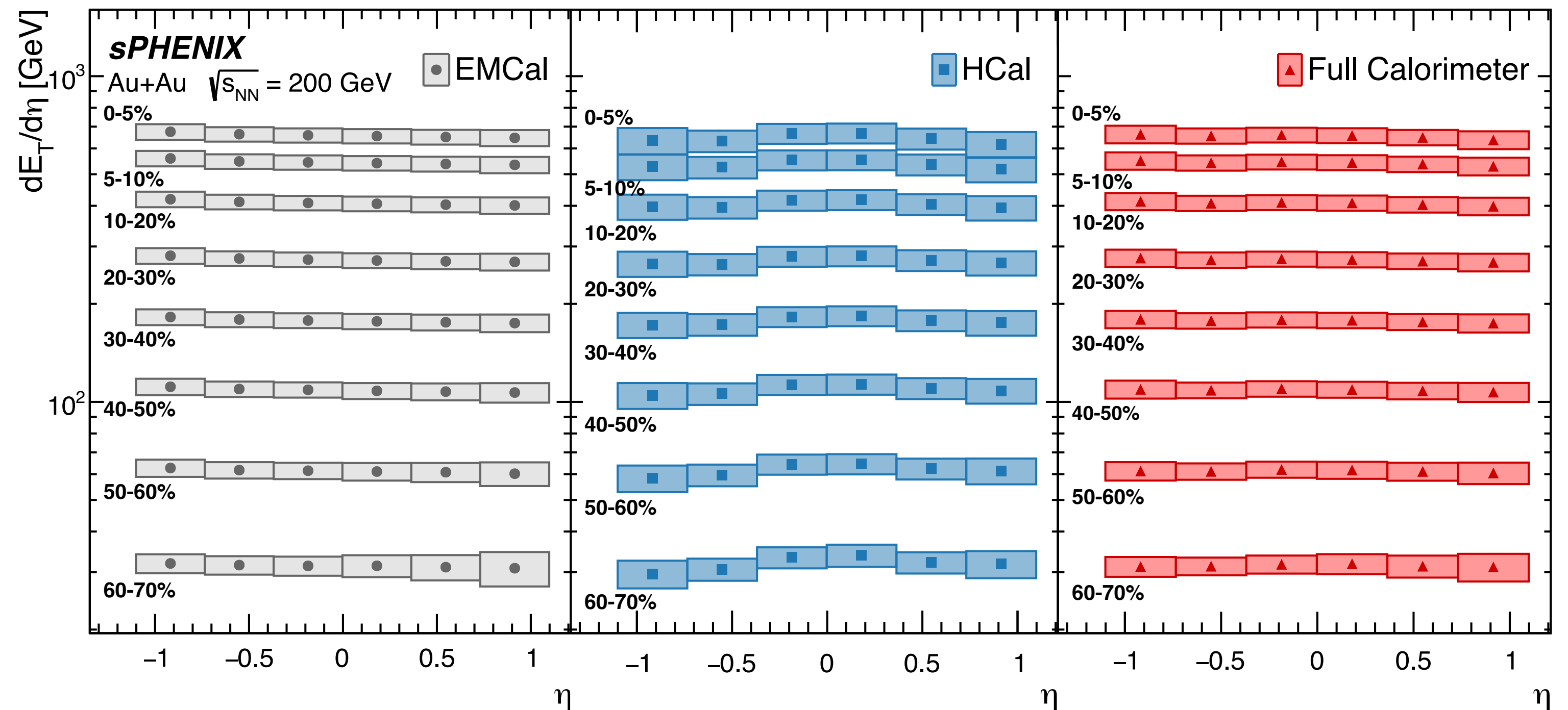


Measurement of $dE_T/d\eta$ in Au+Au collisions



- $dE_T/d\eta$: Transverse energy per unit pseudorapidity, estimating the initial energy density
- Calorimeter-based standard candle measurement
- Measured by the sPHENIX full barrel calorimeter system, EMCal + HCal (separated and combined)
- **$dE_T/d\eta$ in particle level**: Correction factors applied to detector-level $dE_T/d\eta$, to account for detector acceptance, low- p_T charged particles, losses in the magnet region, etc

sPHENIX Final! -
[PRC 112 (2025), 024908]



Excellent agreement between EMCal and HCal measurements

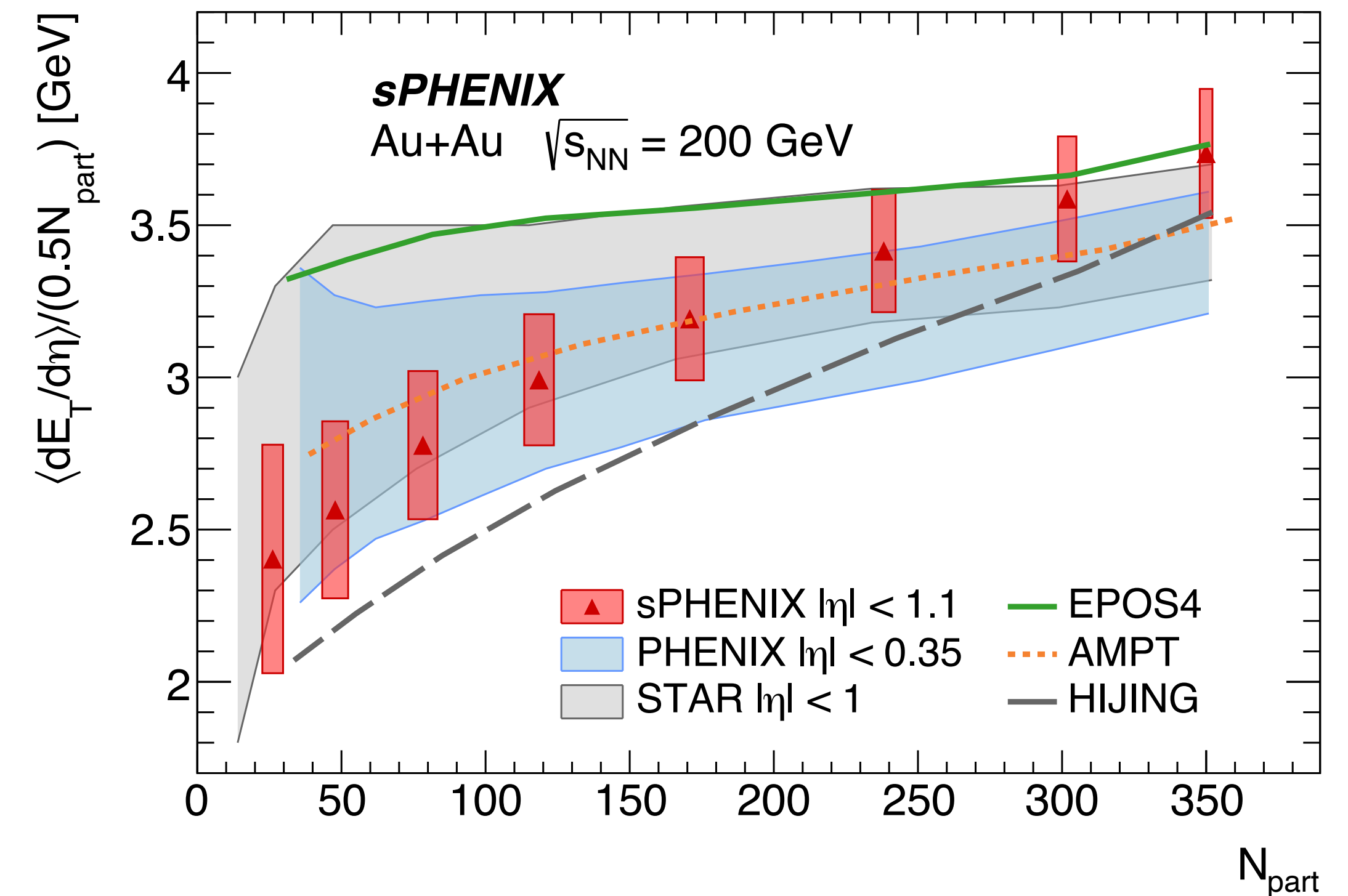
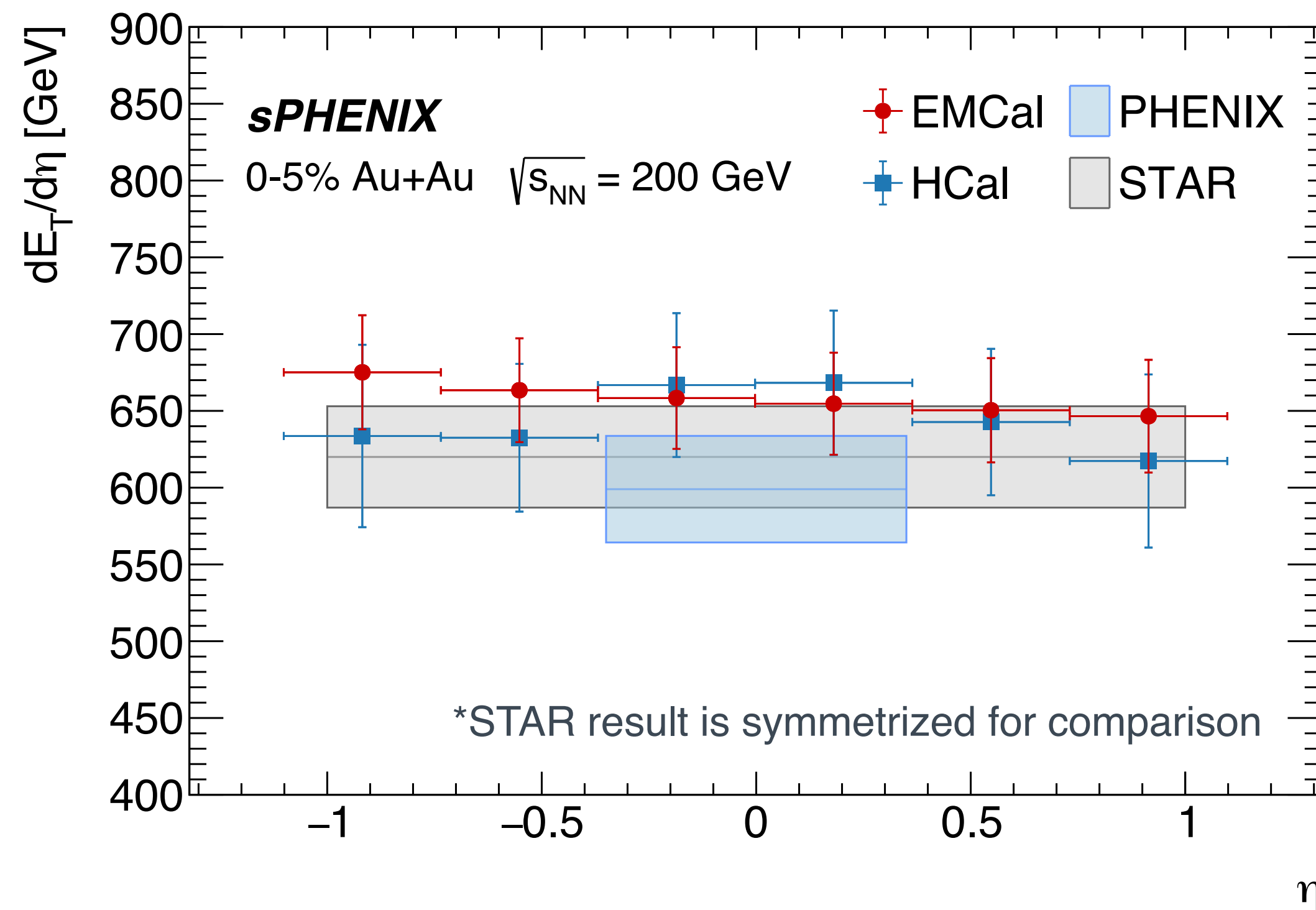
Sensitive to energy deposited from different particle species

Measurement of $dE_T/d\eta$ in Au+Au collisions



sPHENIX Final! - [PRC 112 (2025), 024908]

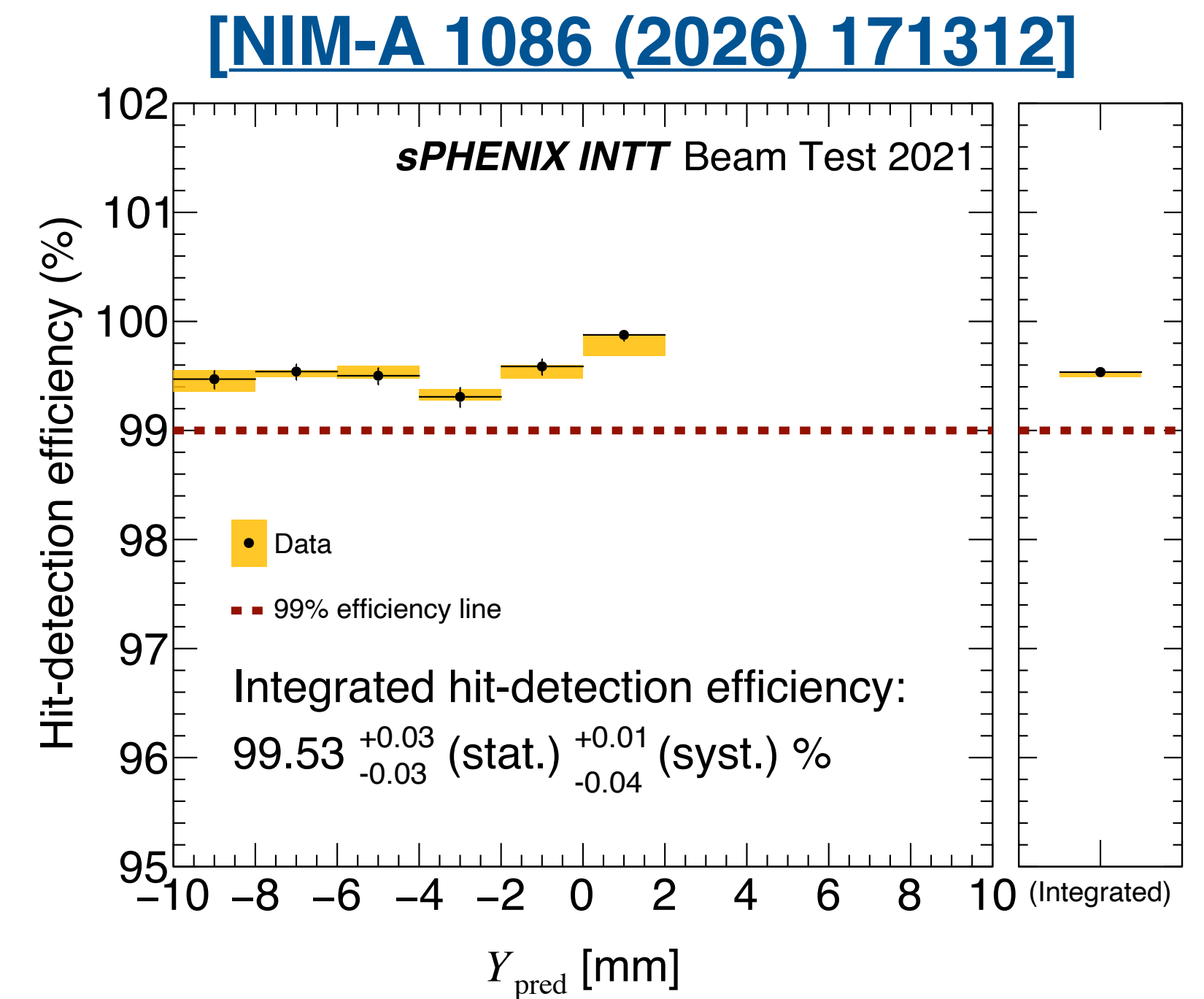
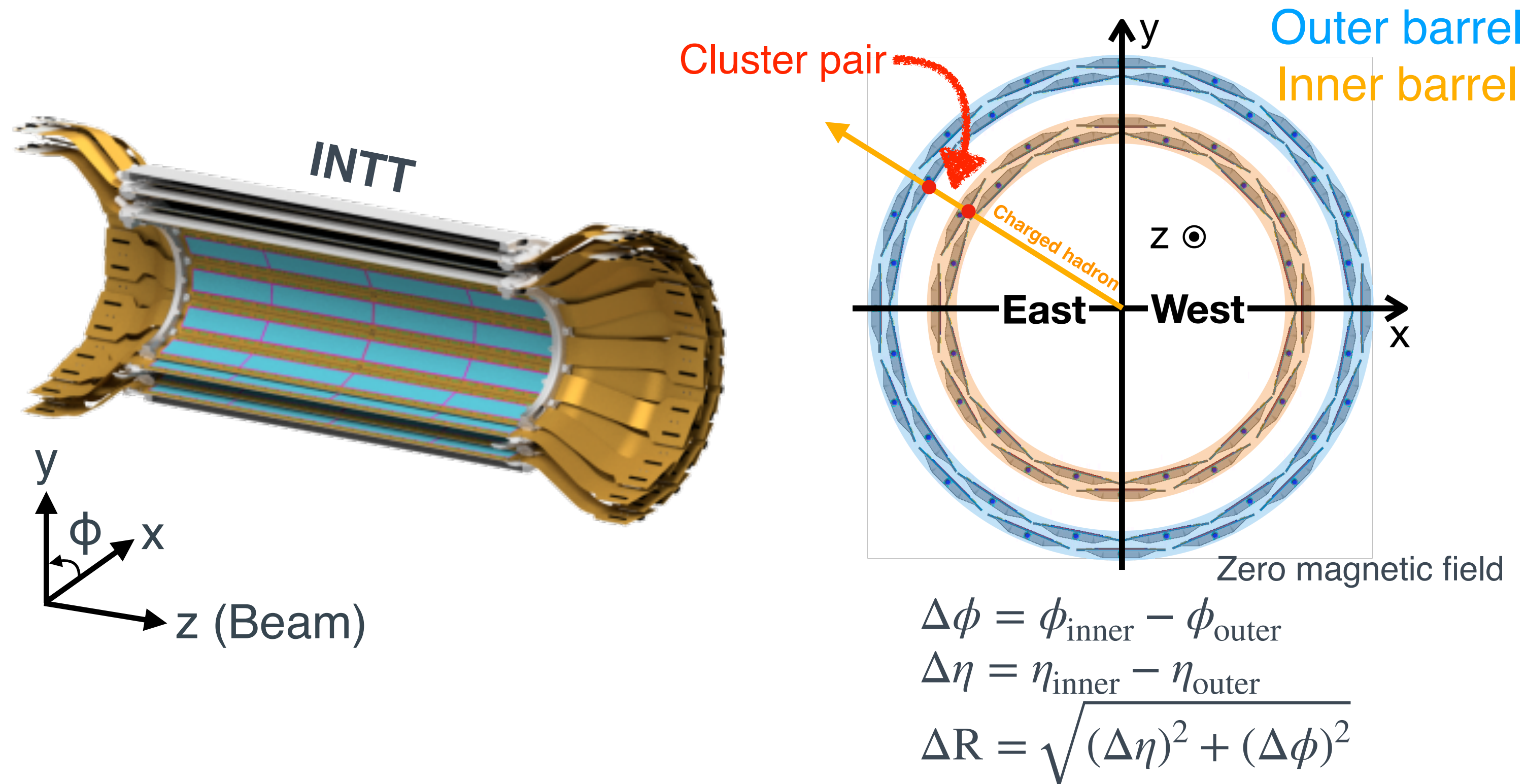
w/ Run24 Au+Au collision data



- sPHENIX measurements of $dE_T/d\eta$ as a function of η and normalized $dE_T/d\eta$ as a function of N_{part} , are consistent with previous RHIC measurements
- The sPHENIX measurement offers additional granularity in η and improved uncertainties in peripheral events, and is best described by the AMPT model

Measurement of $dN_{ch}/d\eta$ in Au+Au collisions

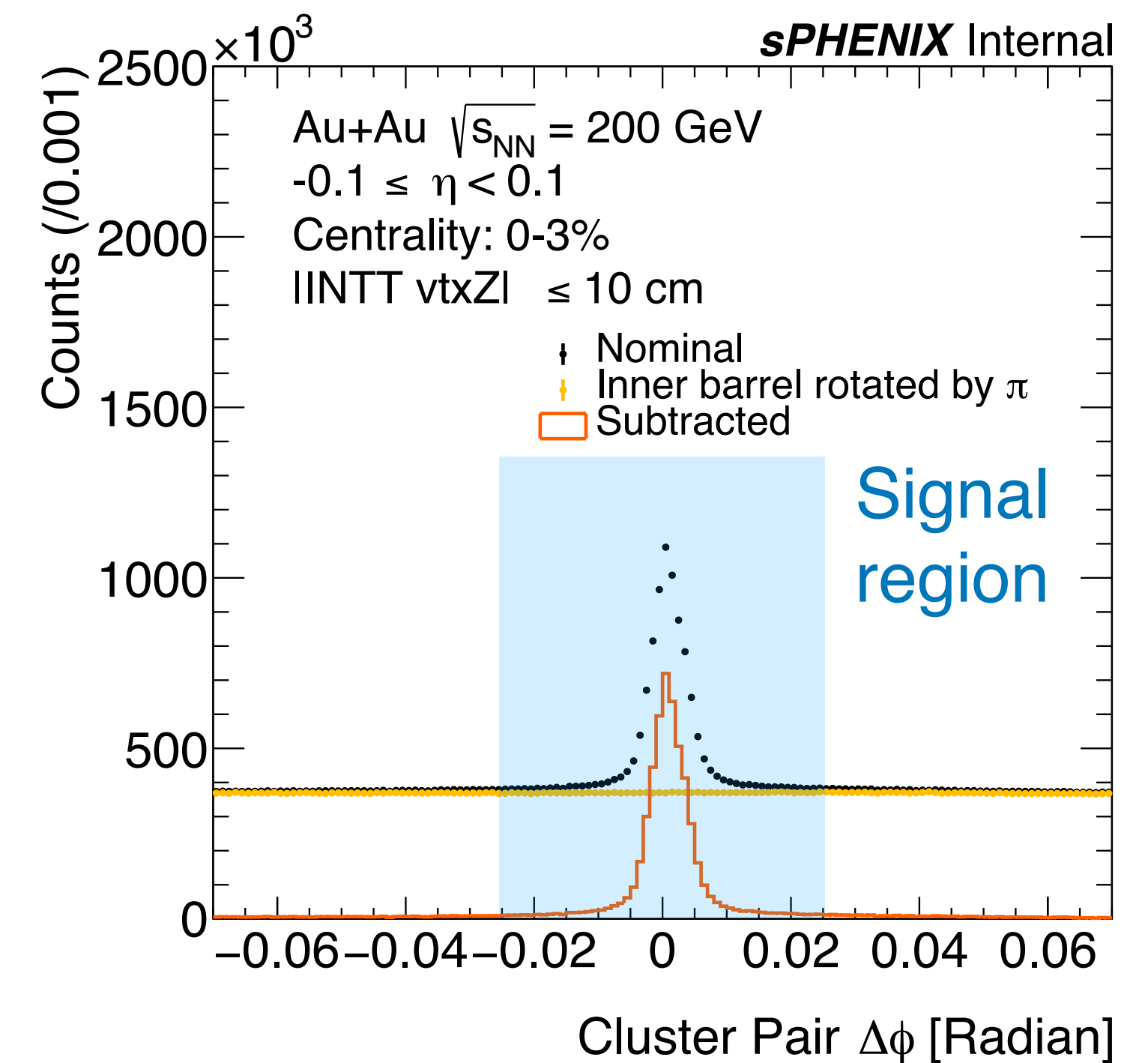
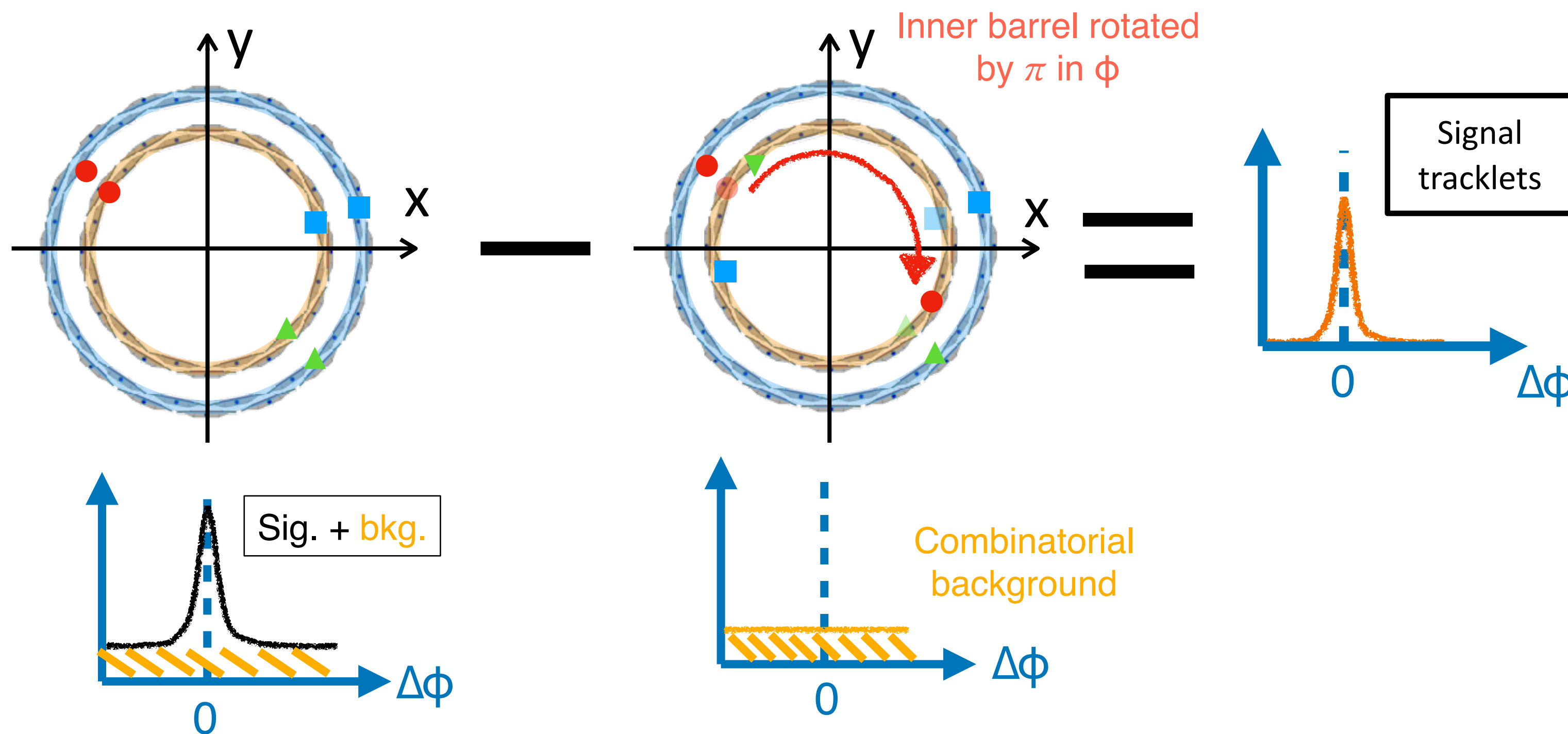
- $dN_{ch}/d\eta$: Charged hadron multiplicity per unit pseudorapidity tracing total entropy production
- Tracking-based standard candle measurement
- Charged hadron yields extracted by counting INTT cluster pairs



Hit-detection efficiency > 99%
confirmed in beam test

Tracklet reconstruction - combinatoric method

- Bin $\Delta\phi$ values of good cluster pairs into a 1D histogram according to the η of the cluster pair and the event centrality. The distribution consists of signal cluster pairs (tracklets) and contributions from combinatorial pairs
- Combinatorial background is estimated by the same pairing procedure after rotating the inner-barrel clusters by π in ϕ , and is subtracted from the nominal $\Delta\phi$ distribution
- Corrections applied to account for detector acceptance, reconstruction efficiency, etc



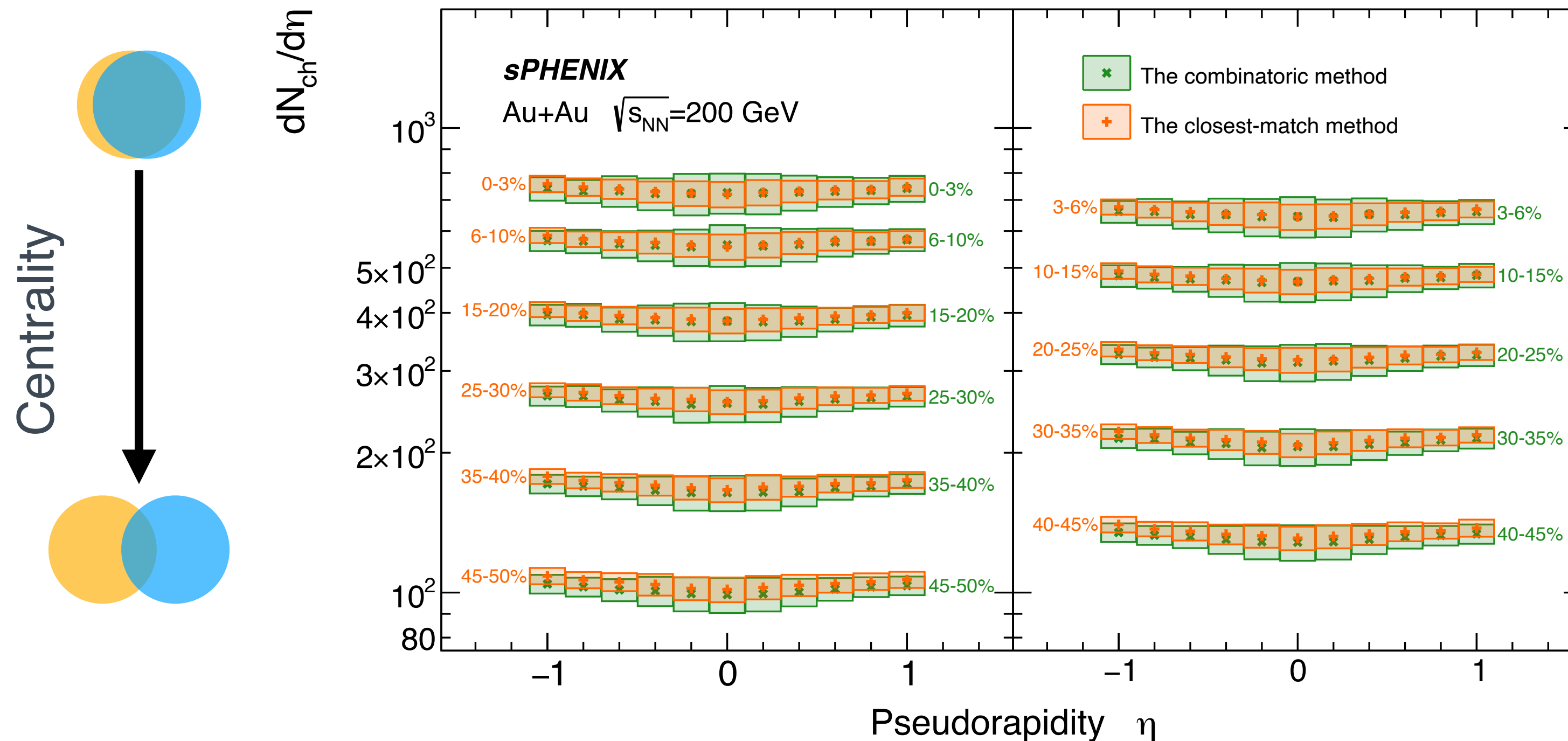
*Analysis method inspired by PHOBOS and PHENIX publications

Measurement of $dN_{ch}/d\eta$ in Au+Au collisions

w/ Run24 Au+Au collision data

- The closest-match method:

- Tracklet counting by the smallest angular-separation cluster pairs ($\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$)
- A single INTT cluster can only be associated with one tracklet

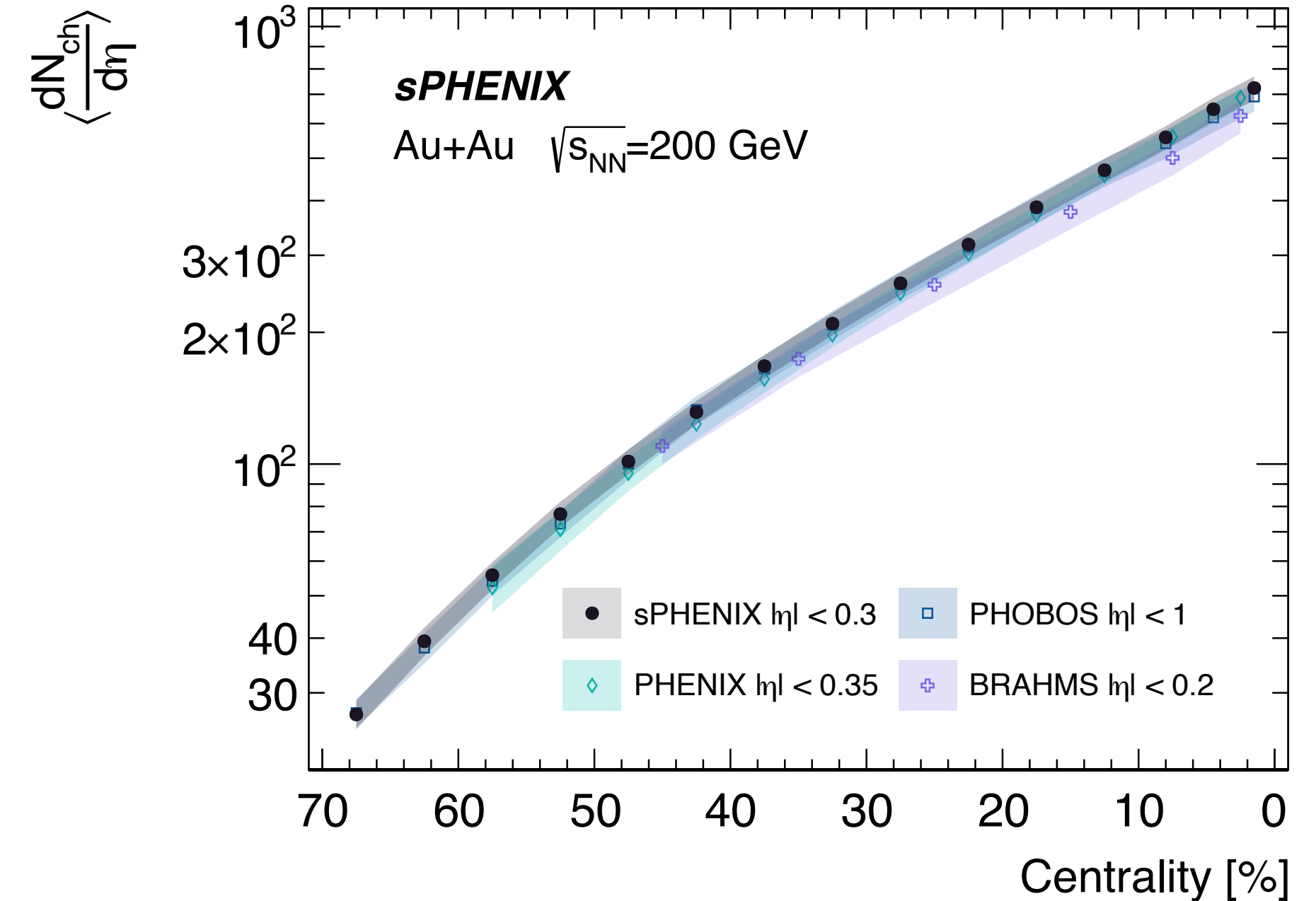
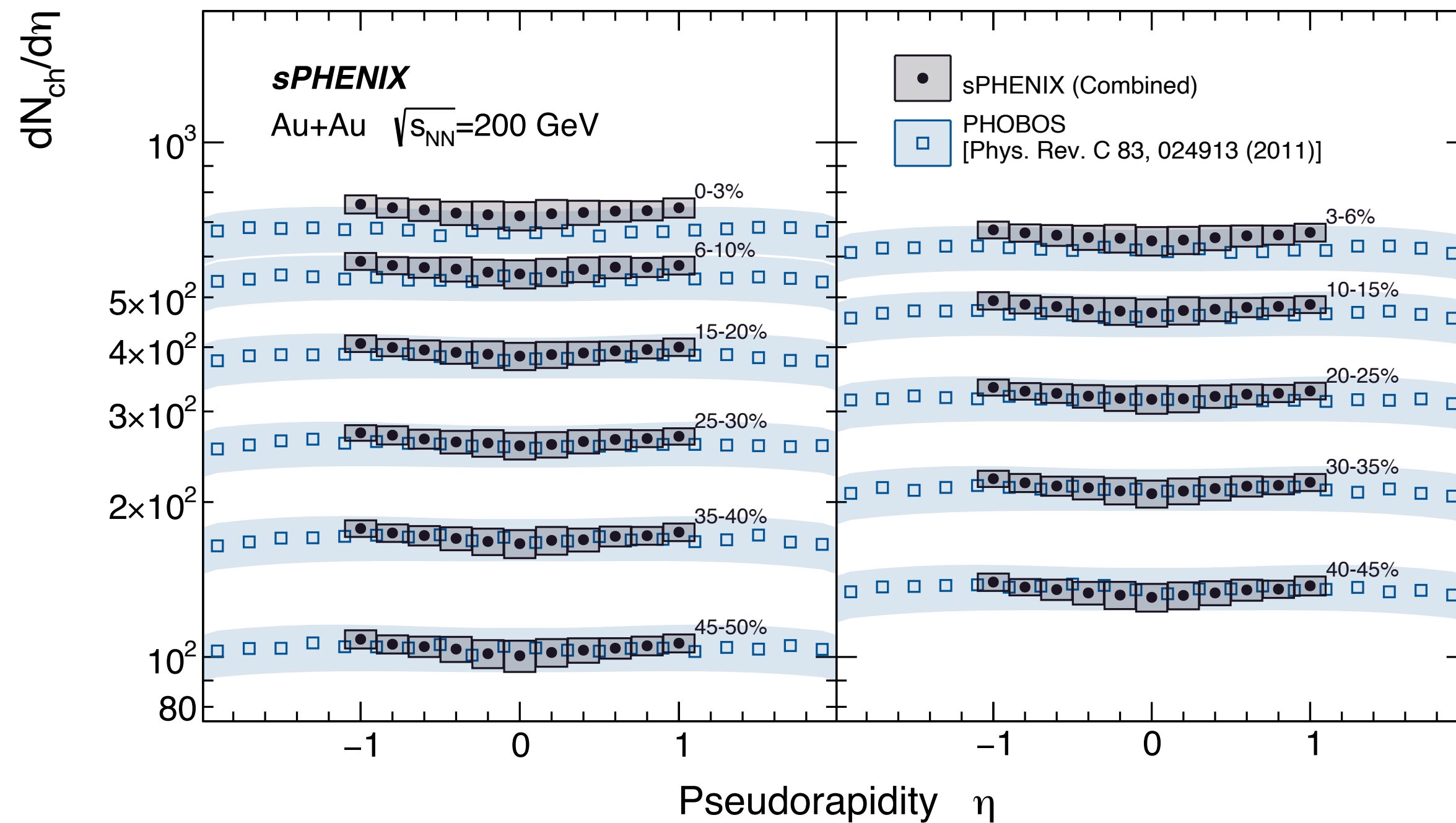


sPHENIX Final! -
[JHEP 08 (2025), 075]

Results from two analysis methods are consistent with each other, and are combined

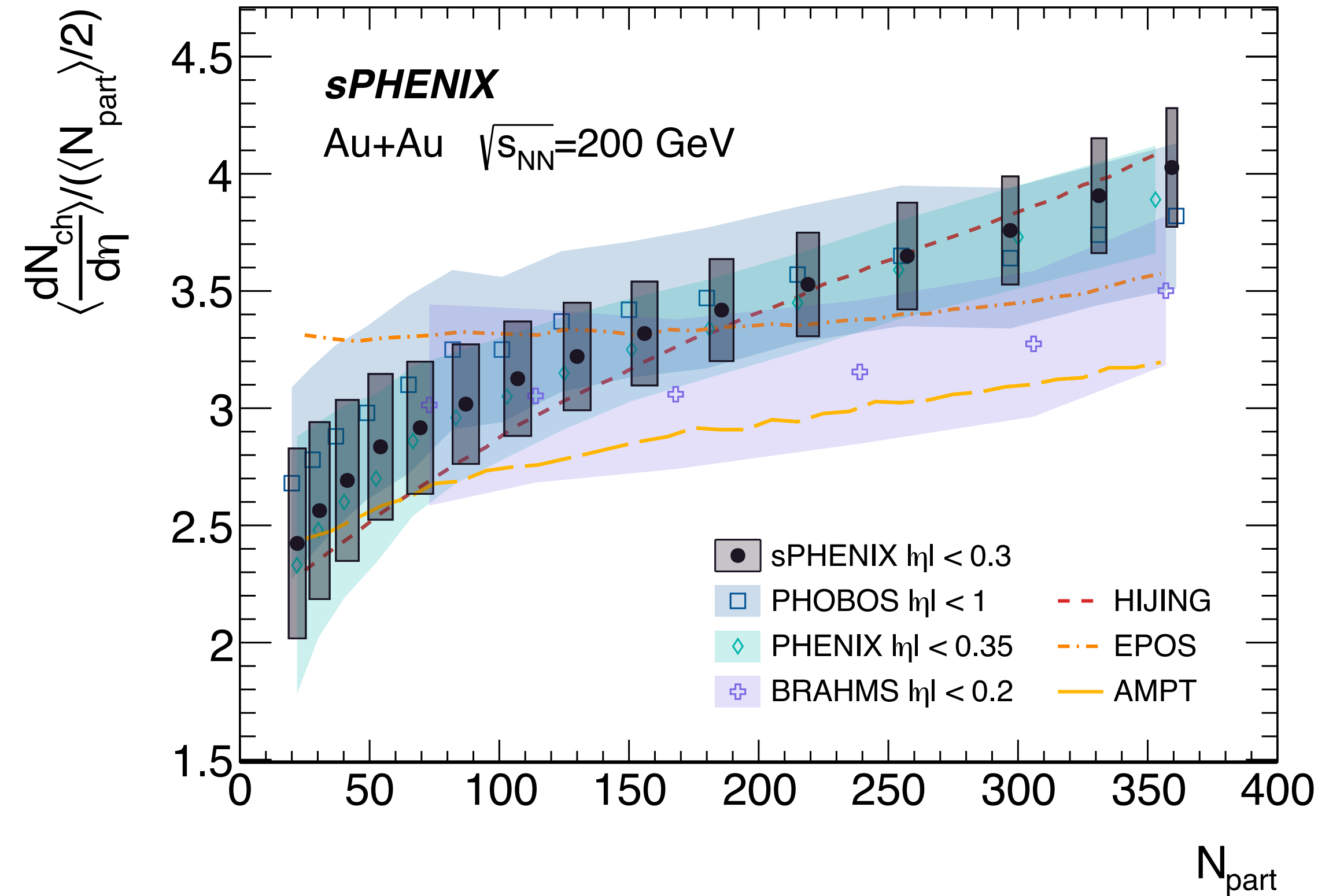
Measurement of $dN_{ch}/d\eta$ in Au+Au collisions

sPHENIX Final! - [JHEP 08 (2025), 075]



- sPHENIX final $dN_{ch}/d\eta$ vs. η consistent with the PHOBOS results across various centrality classes and η bins with improved uncertainties
- sPHENIX $dN_{ch}/d\eta$ averaged over $|\eta| < 0.3$ as a function of event centrality
 - Charged hadron multiplicity increases with collision centrality
 - sPHENIX $dN_{ch}/d\eta|_{|\eta|<0.3}$ in most central 3% of events = 723.4 ± 45.3 (syst.)

Measurement of $dN_{ch}/d\eta$ in Au+Au collisions



- Mid-rapidity $dN_{ch}/d\eta$ per participant pair as a function of N_{part}
 - Consistent with all previous RHIC results and offers improved uncertainties in mid-centrality events
 - The normalized charged-particle density increases faster than N_{part} , presumably due to the contribution of hard processes
 - Best described by the HIJING model

Isolated prompt photon production in p+p collisions

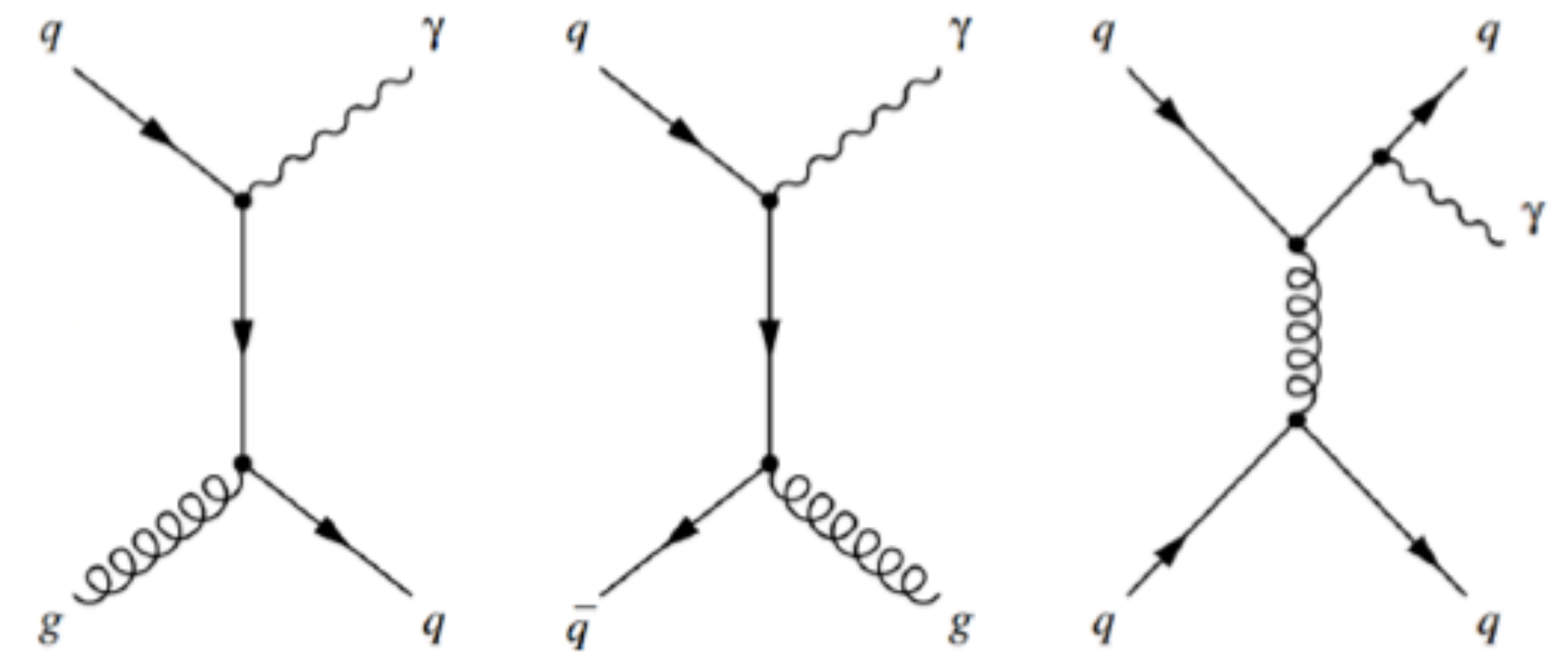
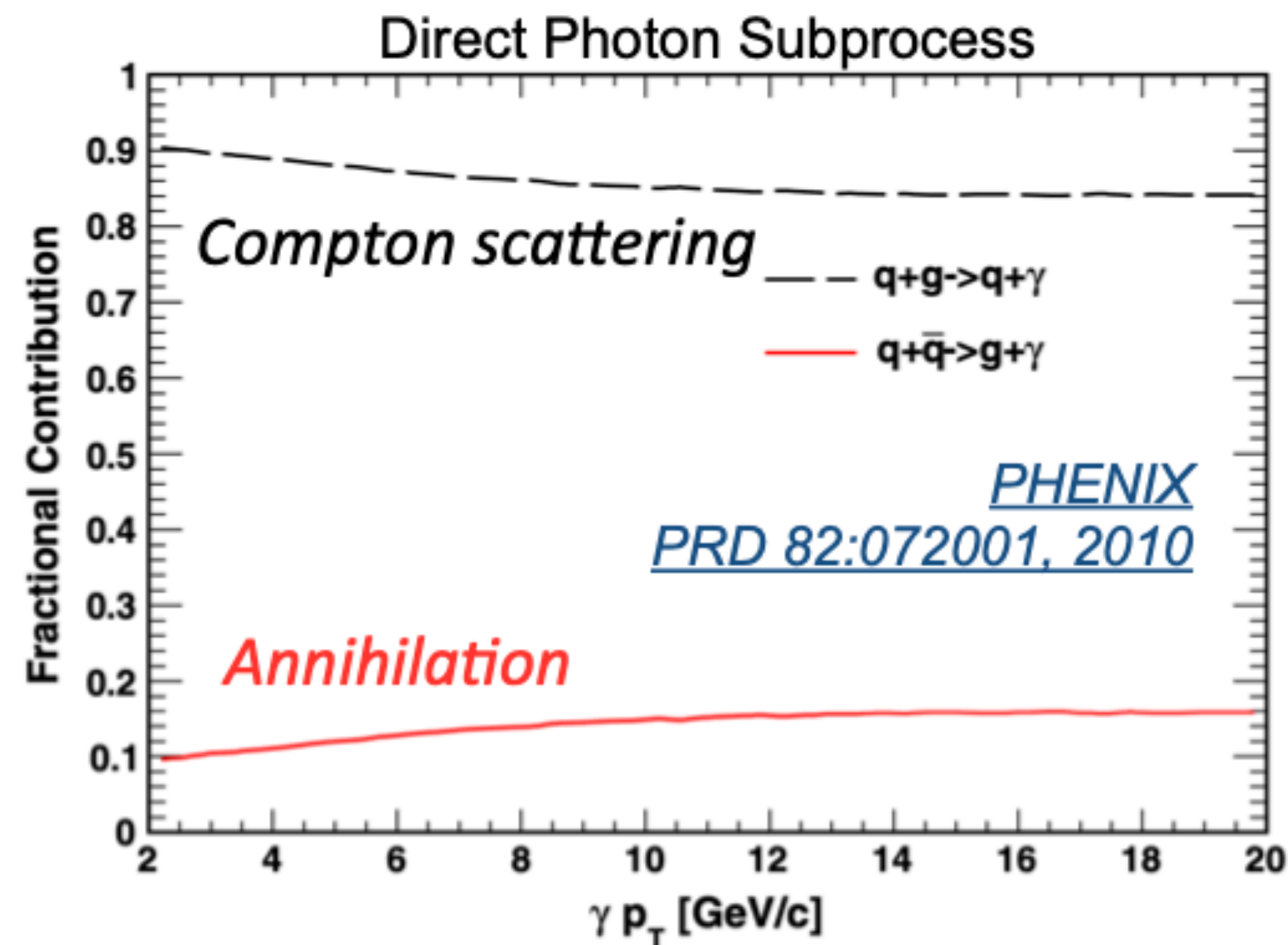
What are Prompt Photons?

- **Direct Photons**

- ➔ produced from primary vertex of hard scattering
- ➔ processes : Compton scattering, Annihilation

- **Fragmentation Photons**

- ➔ radiated from partons after the primary hard scattering



Compton scattering

Annihilation

Fragmentation

Direct photons

Prompt photons

= Direct + Fragmentation photons

Direct photons are predominantly produced by
Compton scattering

➔ sensitive to **gluon** parton distribution function!

- Isolation condition in truth-level

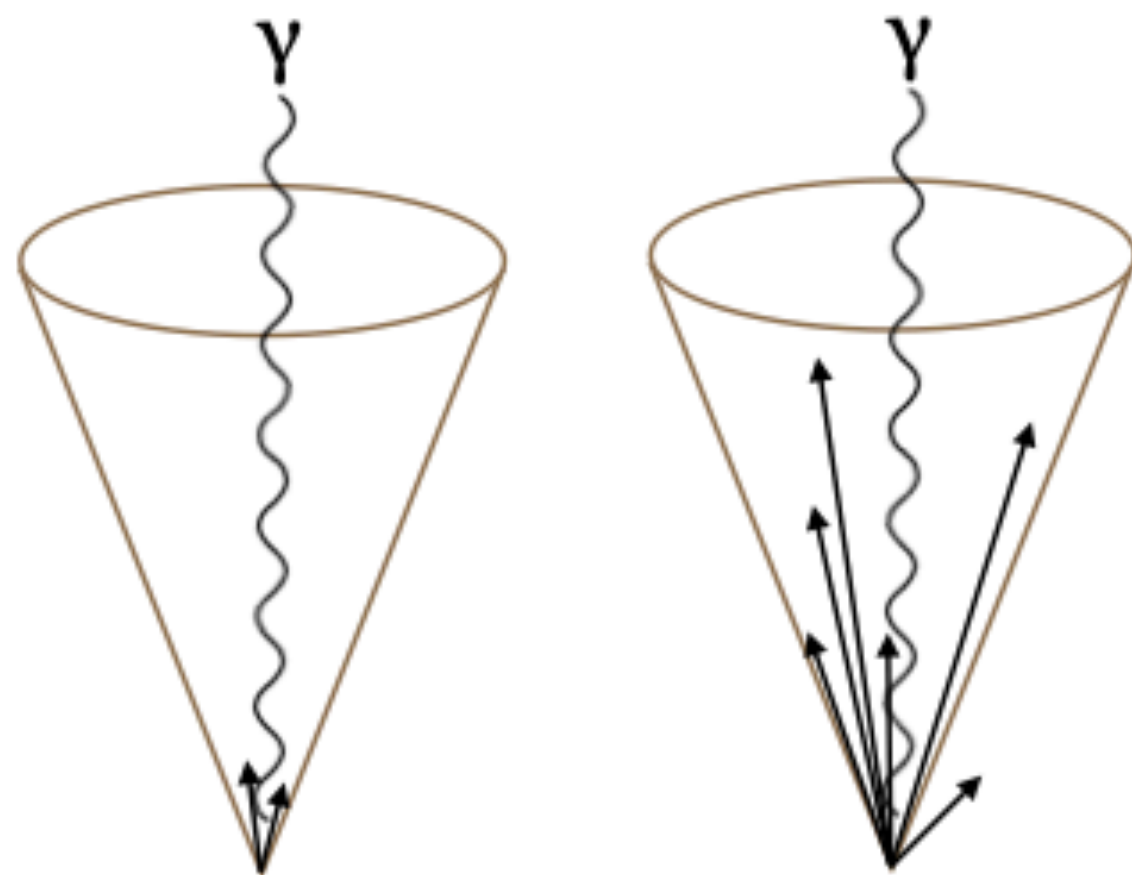
- ➔ suppresses **fragmentation photon** contribution and contains most of **direct photons**
- ➔ Sum of particle energies in a cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3$ around the photon, with $E_T^{iso} < 4$ GeV
- ➔ Discrimination between **isolated direct and fragmentation photons** is **arbitrary** in experiment

- Isolation condition in reconstruction

- ➔ suppresses significant **background (decay) photons** originated from neutral mesons

Isolated

Non-isolated

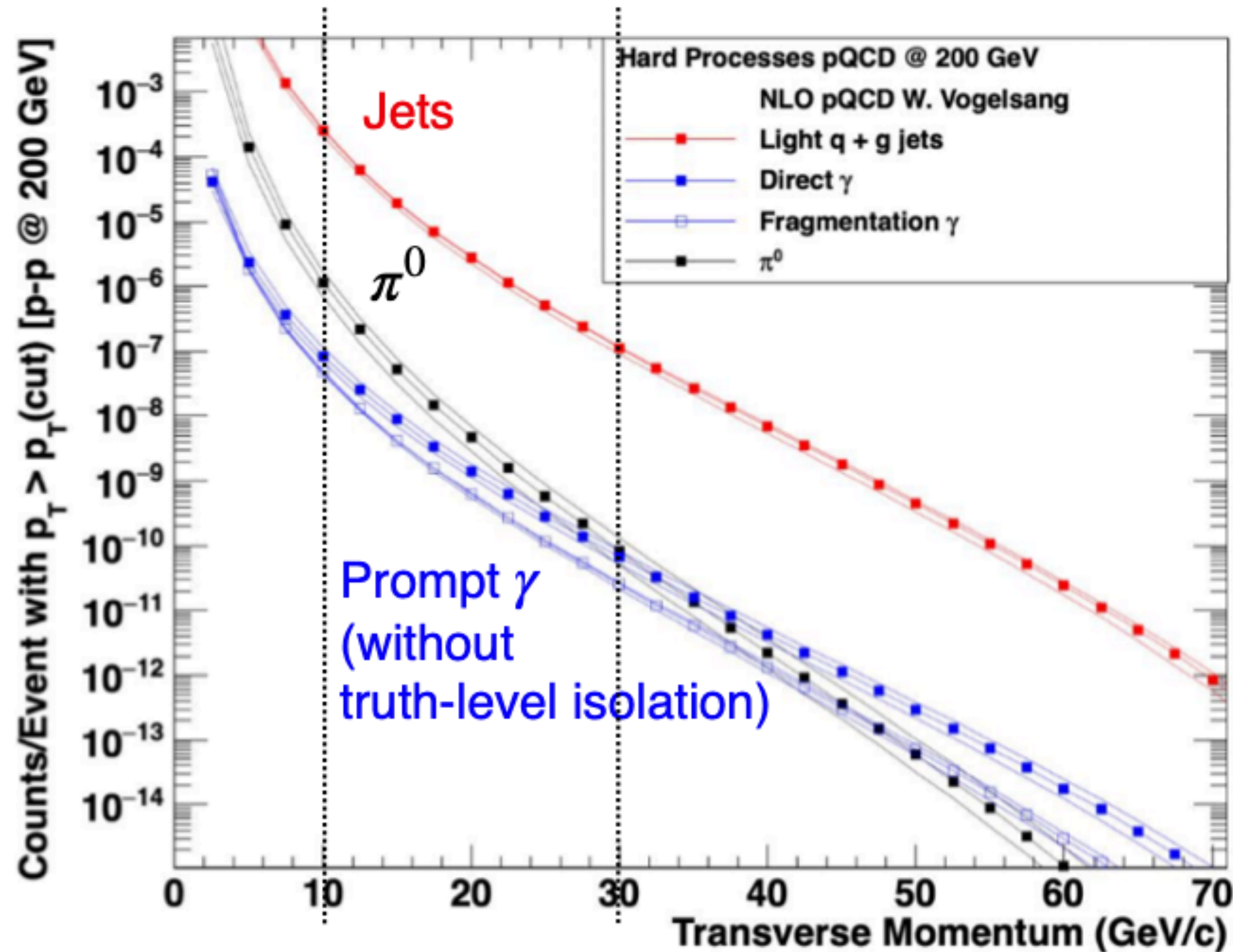


- ➔ decayed from hadrons such as $\pi^0 \rightarrow \gamma + \gamma$
- ➔ major background of prompt photons

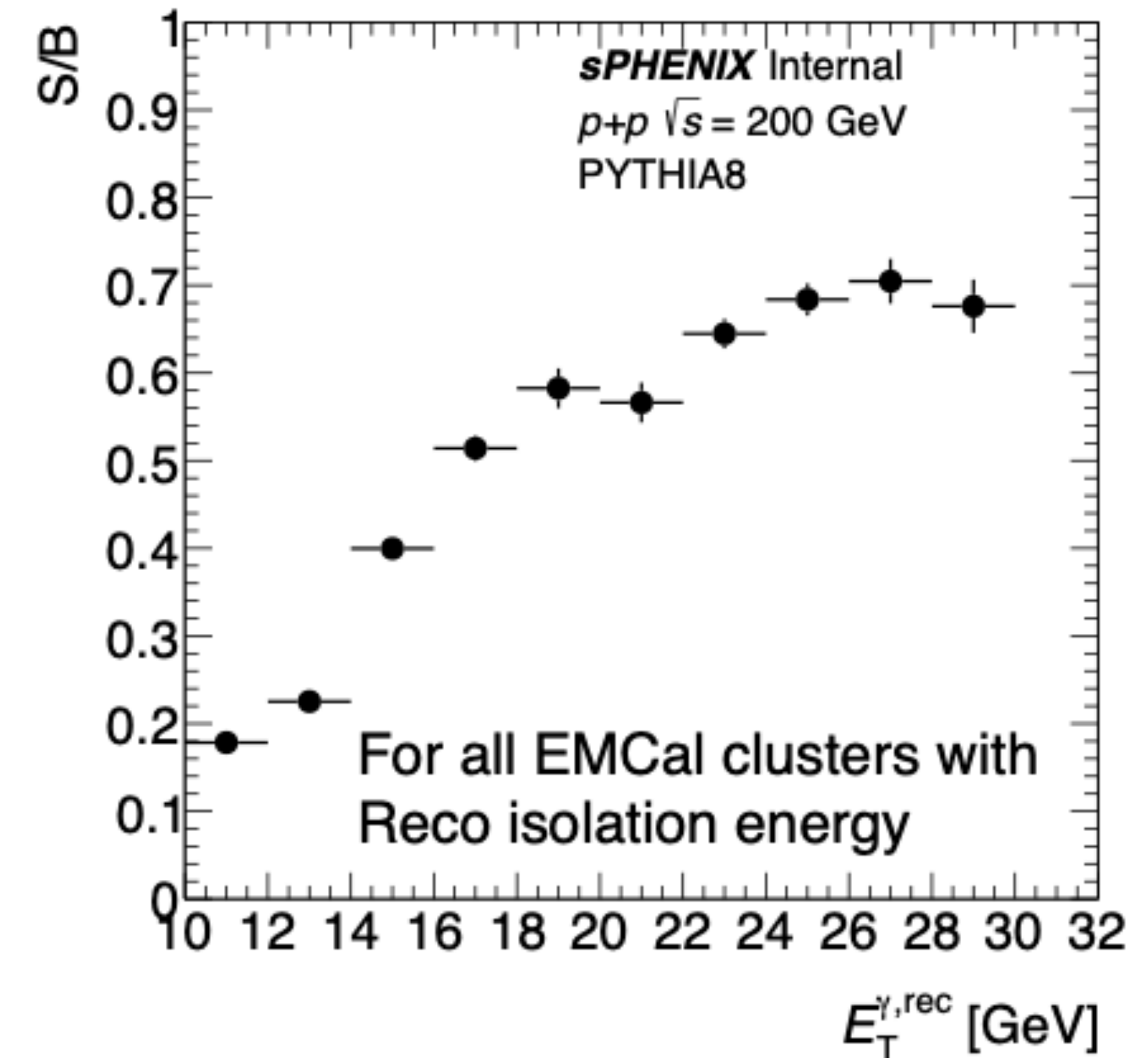
*often produced inside jets, so their **decay photons** are typically **not isolated***

Major background

- Much higher cross section for π^0 and jets compared to prompt γ

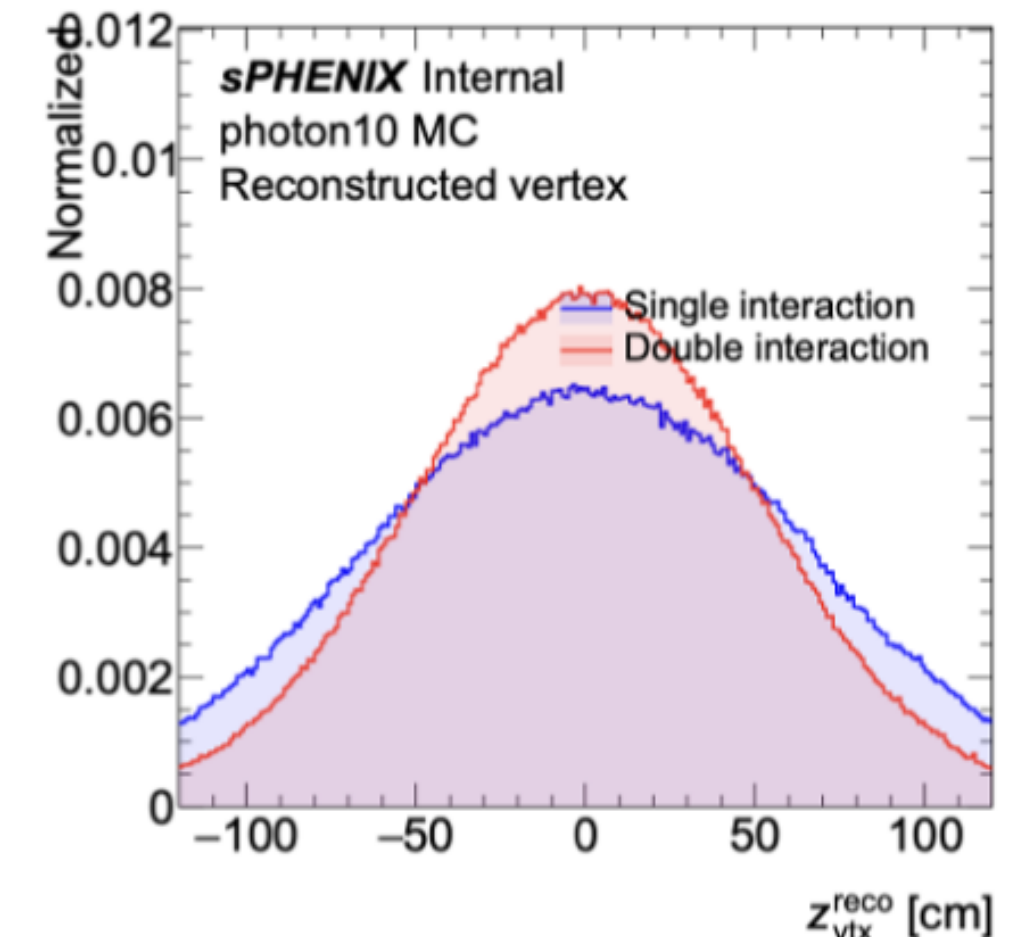
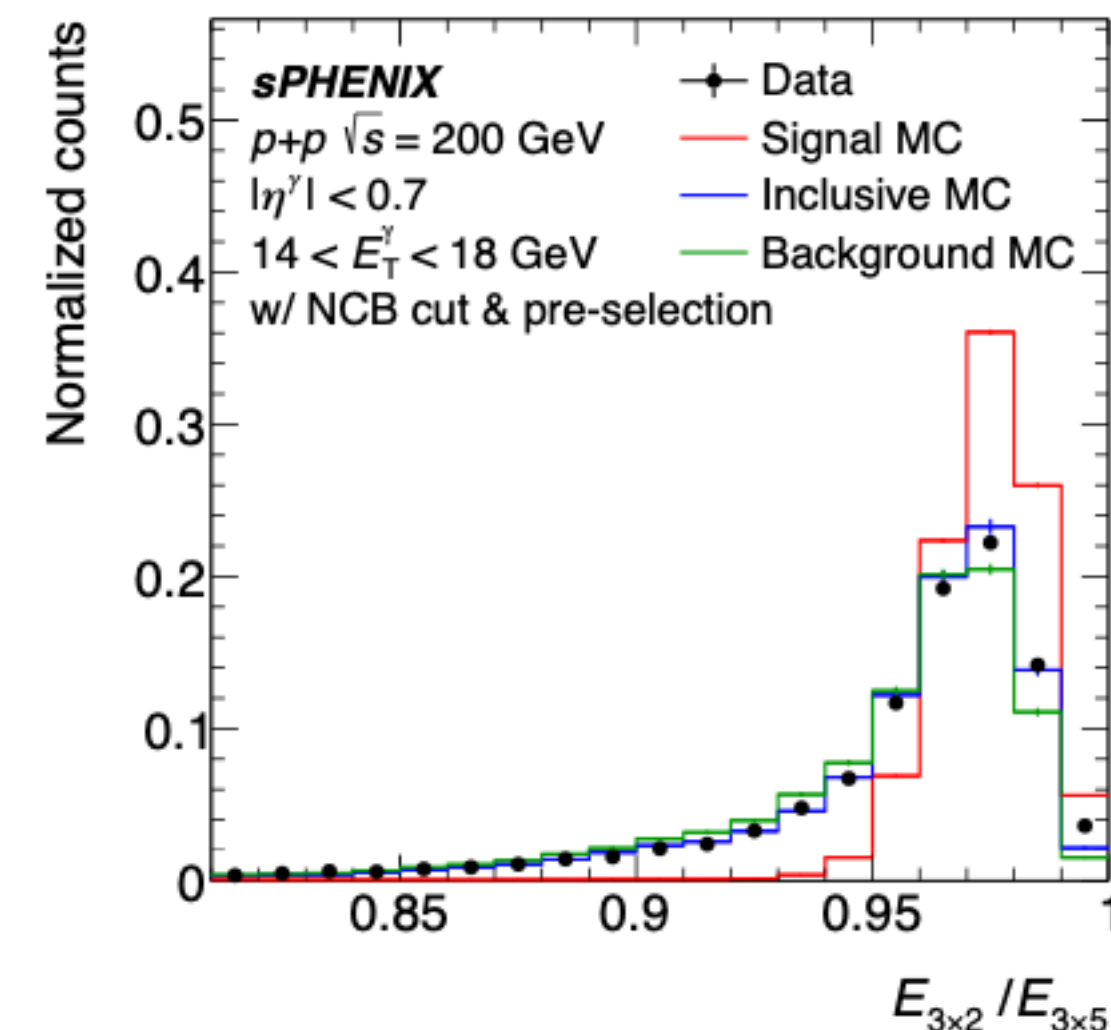
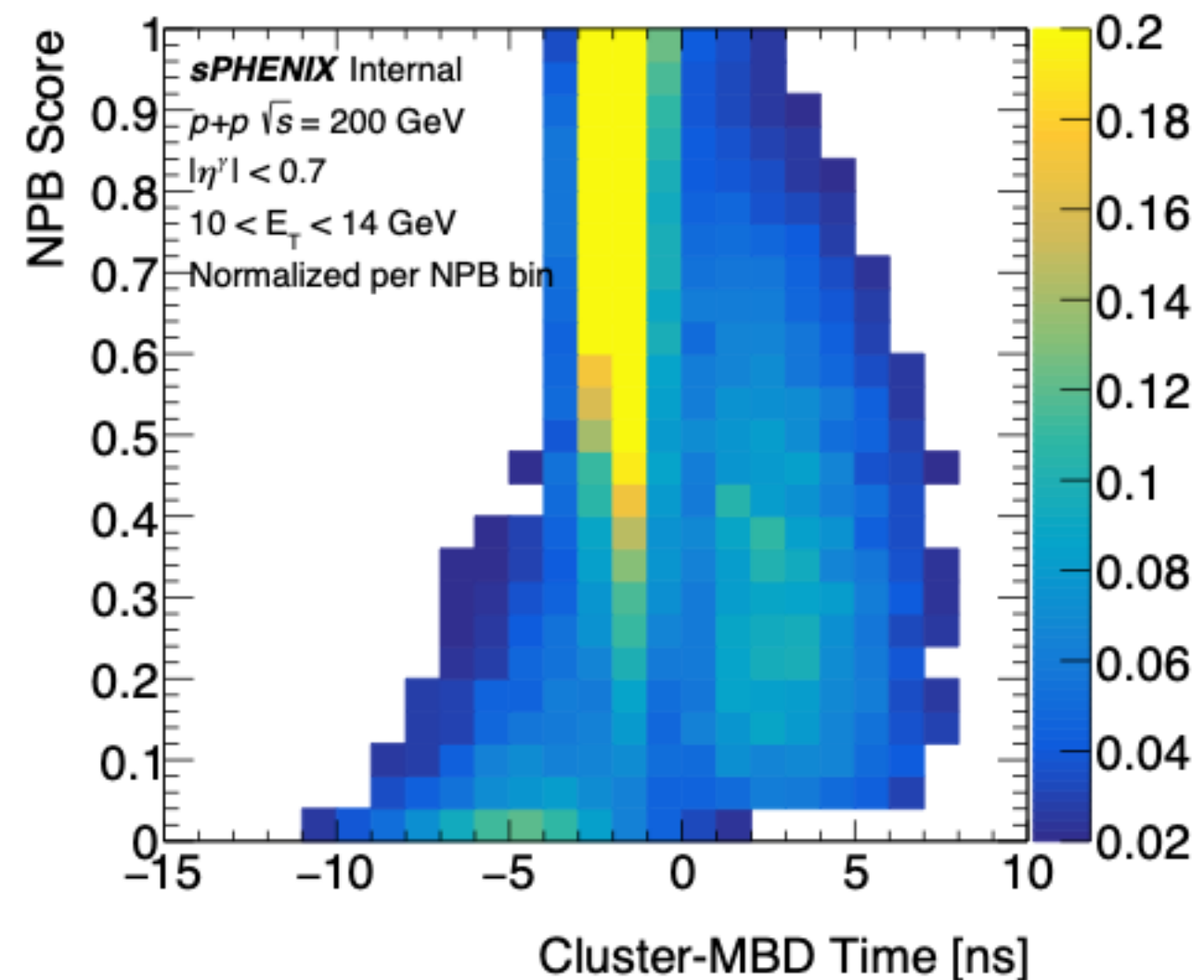
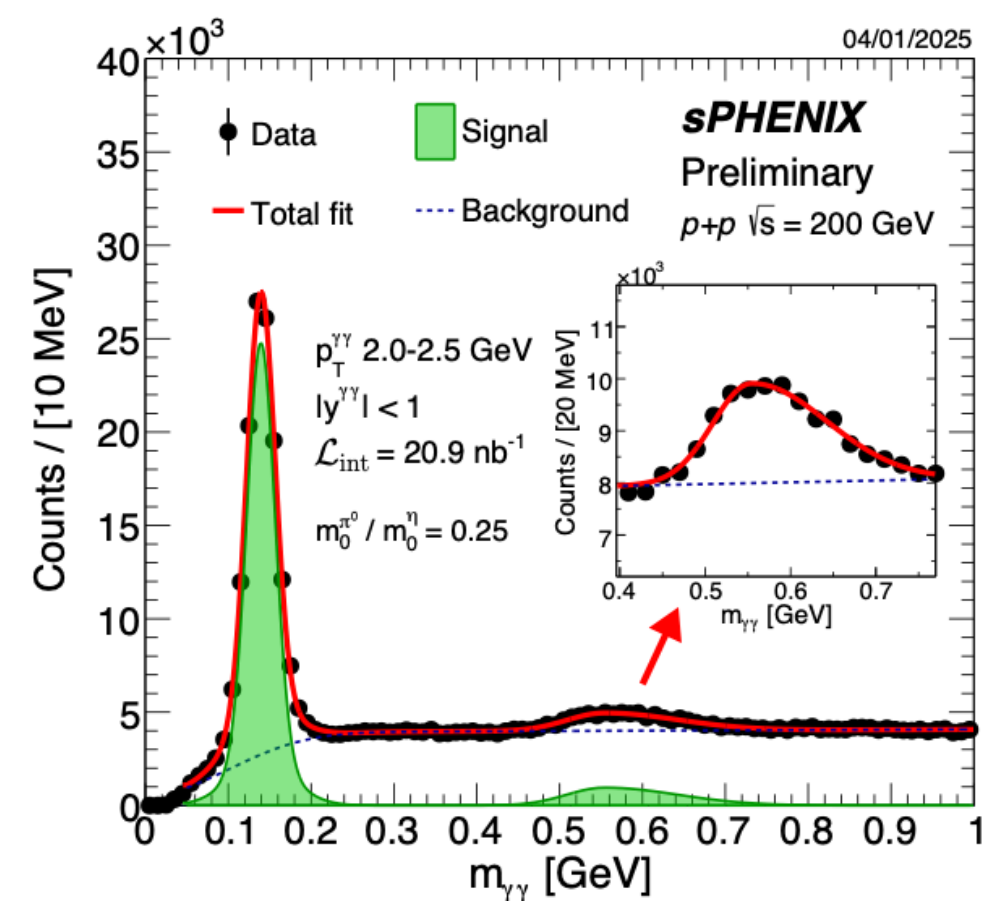


- Major background
 - ➔ decay photons (e.g. π^0, η)
 - suppress them using shower shape identification
 - ➔ jets
 - suppress them using isolation



Calibrations and pre-selections

- Energy calibration for EMCal: using neutral mesons (π^0 and η)
- To suppress non-collisional background using EMCal cluster timing by a BDT model
- Pre-selection based on shower shape variables to
 - reject residual electronic noise and poorly reconstructed clusters
 - remove regions where the photon ID BDT score is strongly correlated with the reconstructed isolation energy
- Calibrations for in-time pile-up in MC (multiple collisions in a single bunch crossing)
 - In-time pile-up centralizes the z-vertex distribution, reconstructed based on timing
 - Mix the non-pile-up MC events with double-interaction MC events by a ratio based on the raw collision rate in data (in-time pile-up rate in zero crossing: 0.22 (0.08 in 1.5 mrad))
- Trigger efficiency corrections



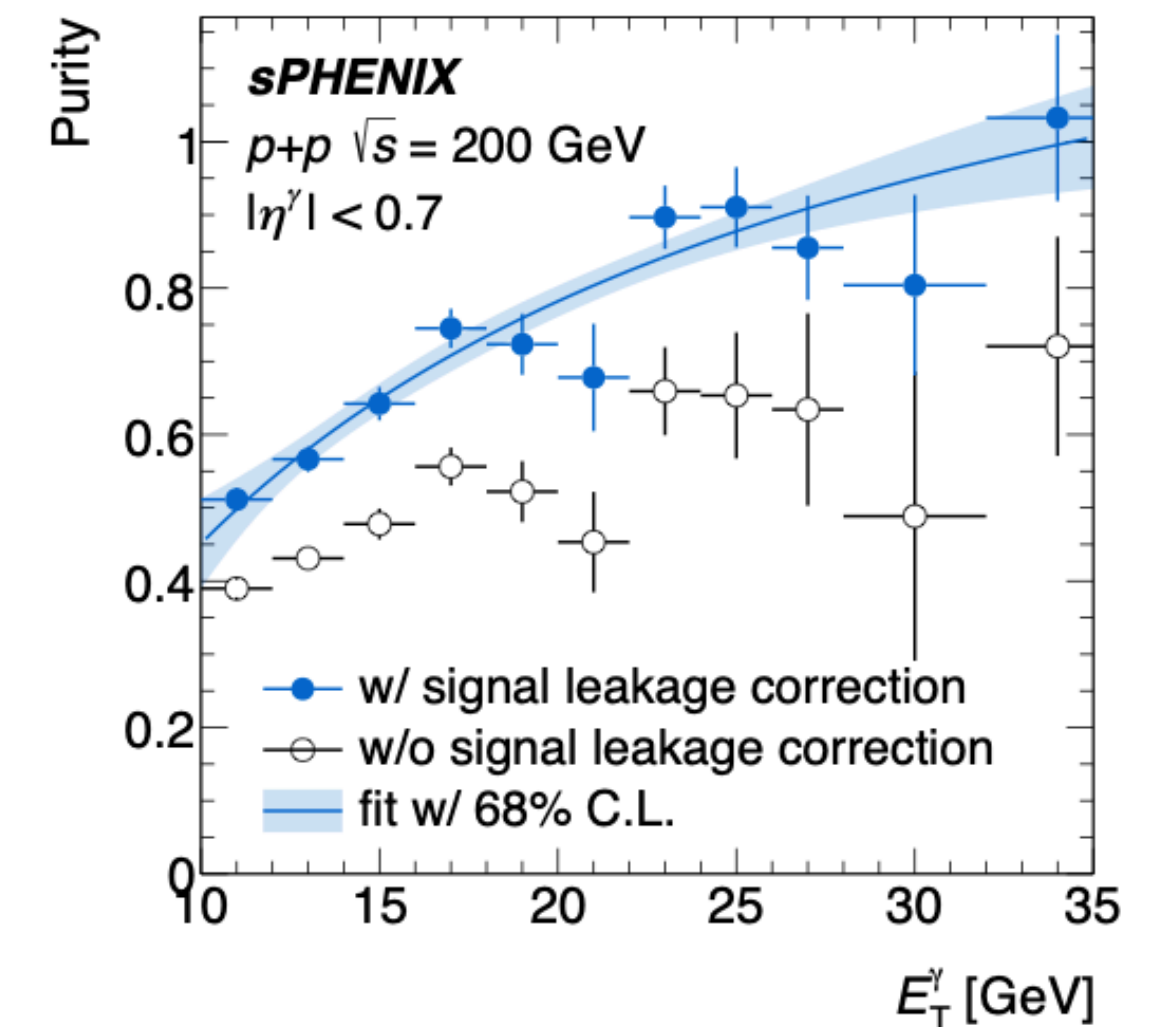
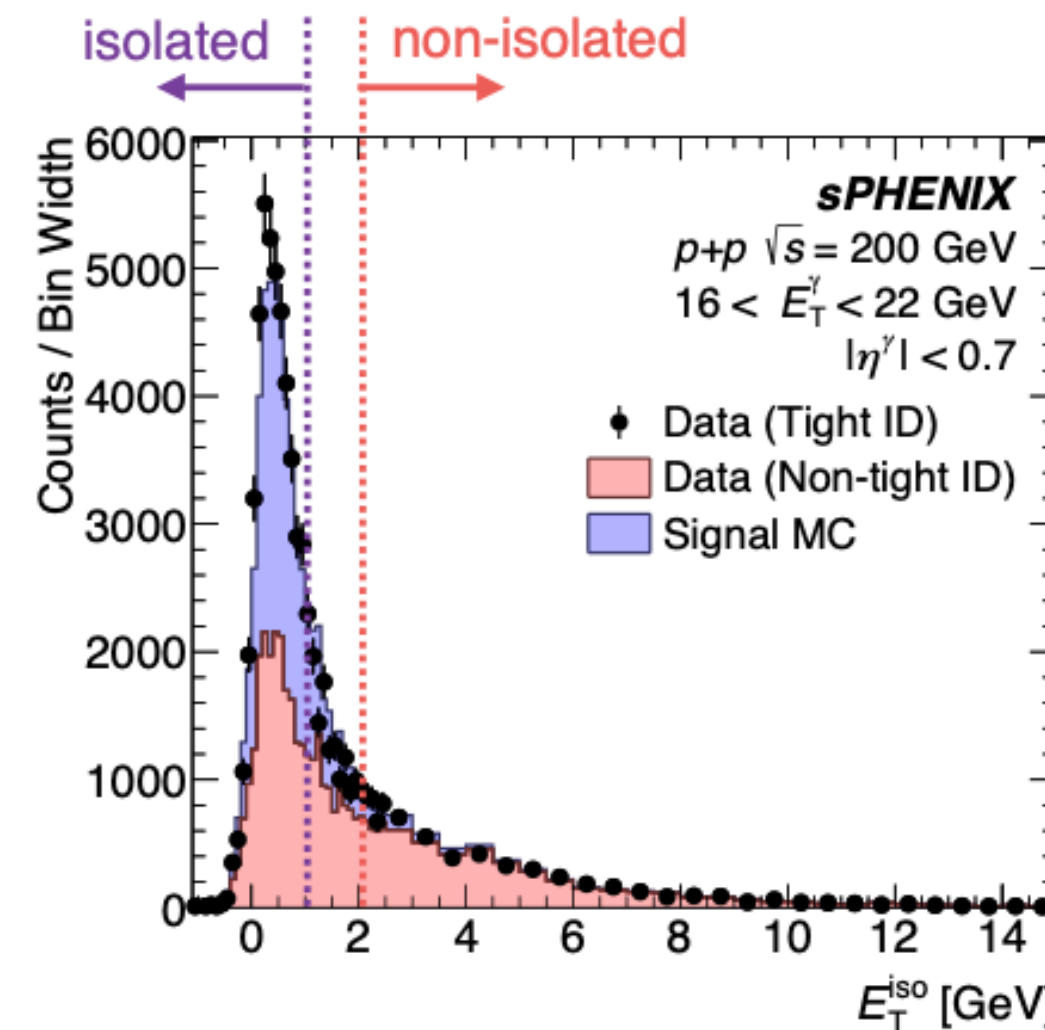
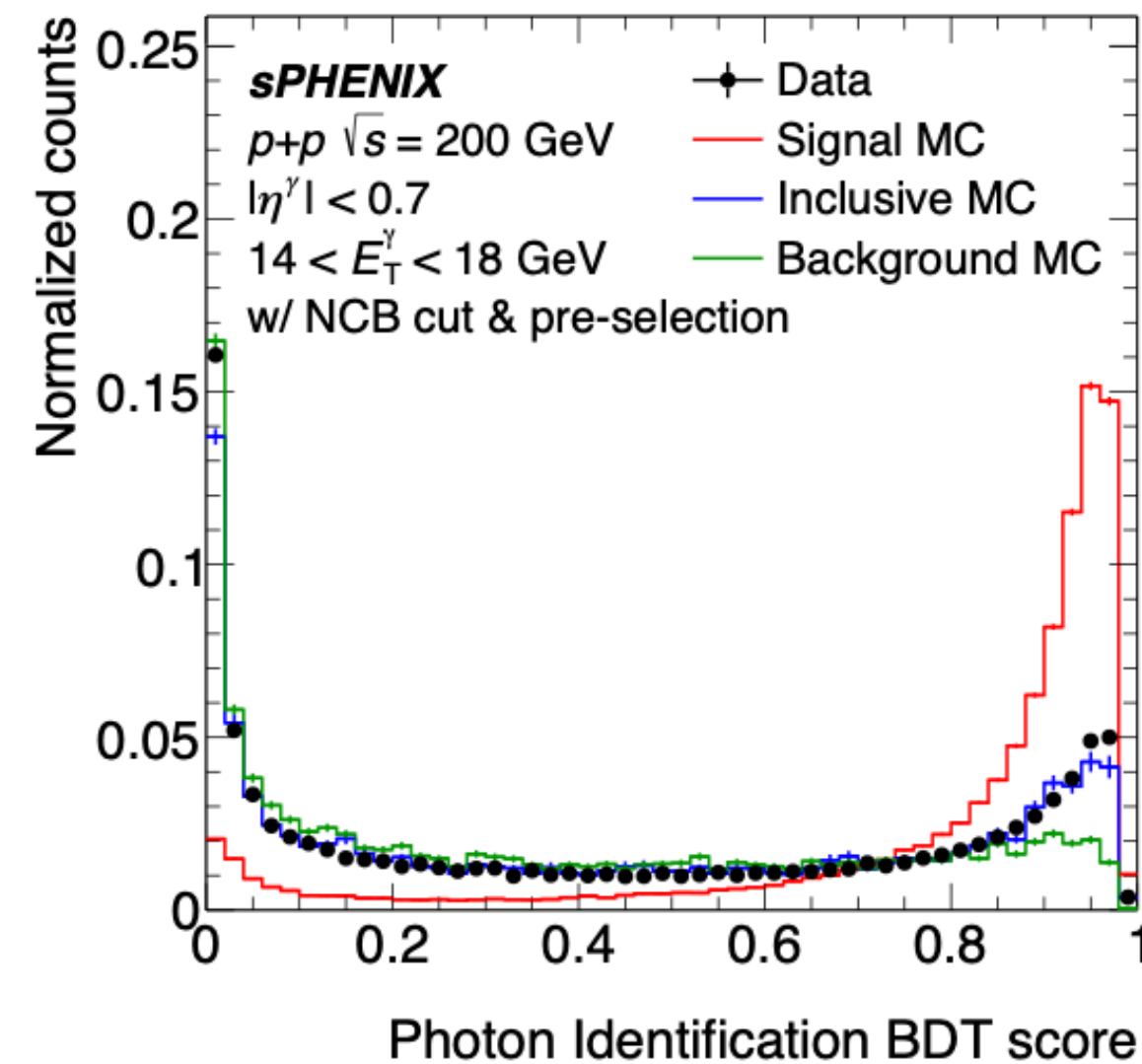
Isolated photon reconstruction

- Double-sideband method
 - EMCal cluster shower shape score and isolation energy
- EMCal cluster shower shape score by XGBoost
 - ID BDT is trained using signal (photon-jet) and inclusive (jet; by tagging non-truth-signal photons) MC
 - 8 shower shape variables + η , E_T , z-vertex as input features
- Isolation energy based on Topocluster (R=0.4)
 - Excluding the Photon cluster
 - Isolation energy scaled by 20% in MC to match data
- Statistical treatment to account for irreducible background and signal leakage

$$N_{\text{signal}}^A = N_{\text{raw}}^A - N_{\text{raw}}^B \cdot \frac{N_{\text{raw}}^C}{N_{\text{raw}}^D}$$

$$N_{\text{signal}}^A = N_{\text{raw}}^A - \left[\left(N_{\text{raw}}^B - f^{B,MC} N_{\text{signal}}^A \right) \cdot \frac{\left(N_{\text{raw}}^C - f^{C,MC} N_{\text{signal}}^A \right)}{\left(N_{\text{raw}}^D - f^{D,MC} N_{\text{signal}}^A \right)} \right]$$

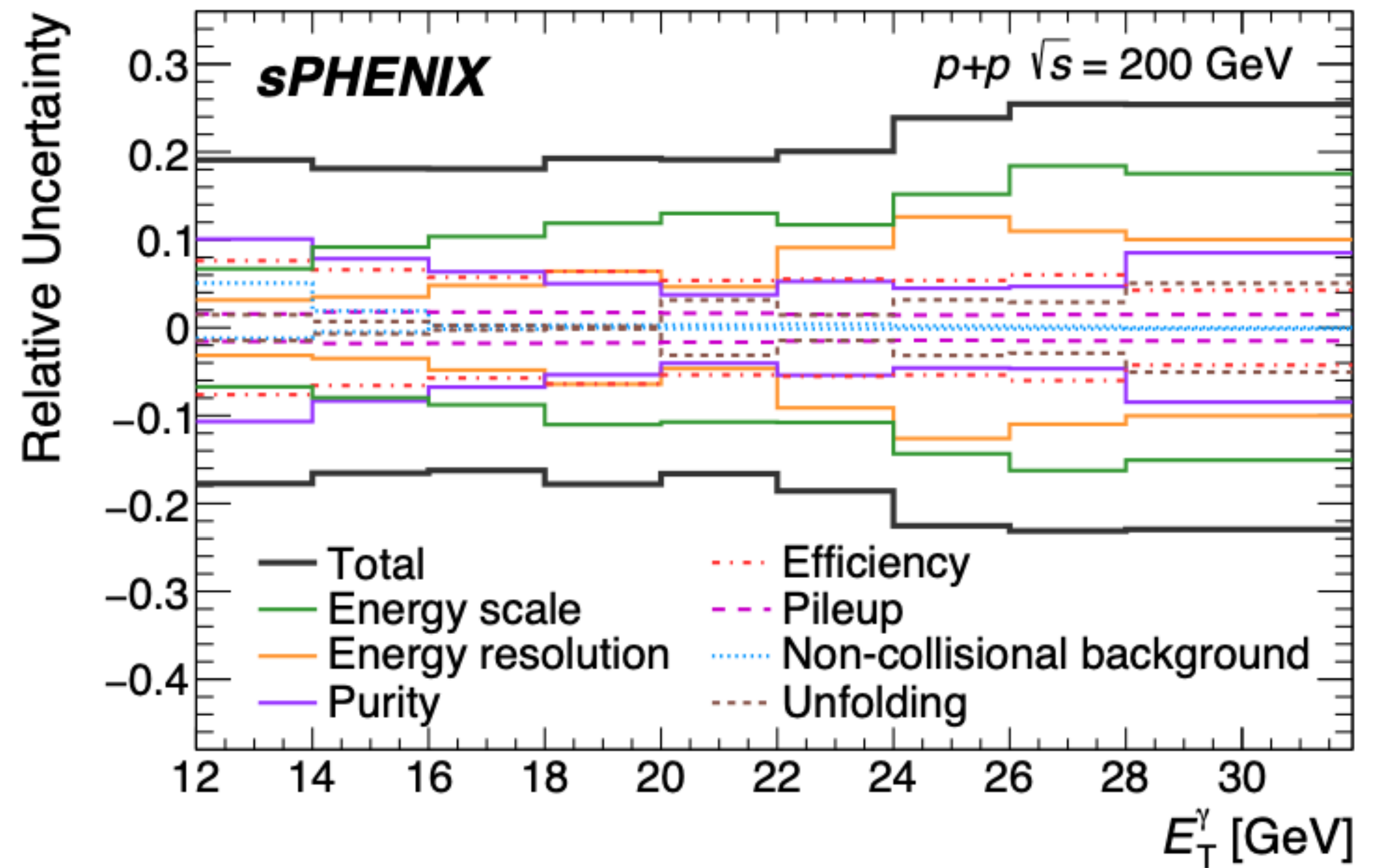
γ^{ID} (BDT response)		C: non-tight, isolated	D: non-tight, non-isolated
		A: tight, isolated	B: tight, non-isolated
		$E_T^{\text{iso, reco}}$	



Systematic uncertainty

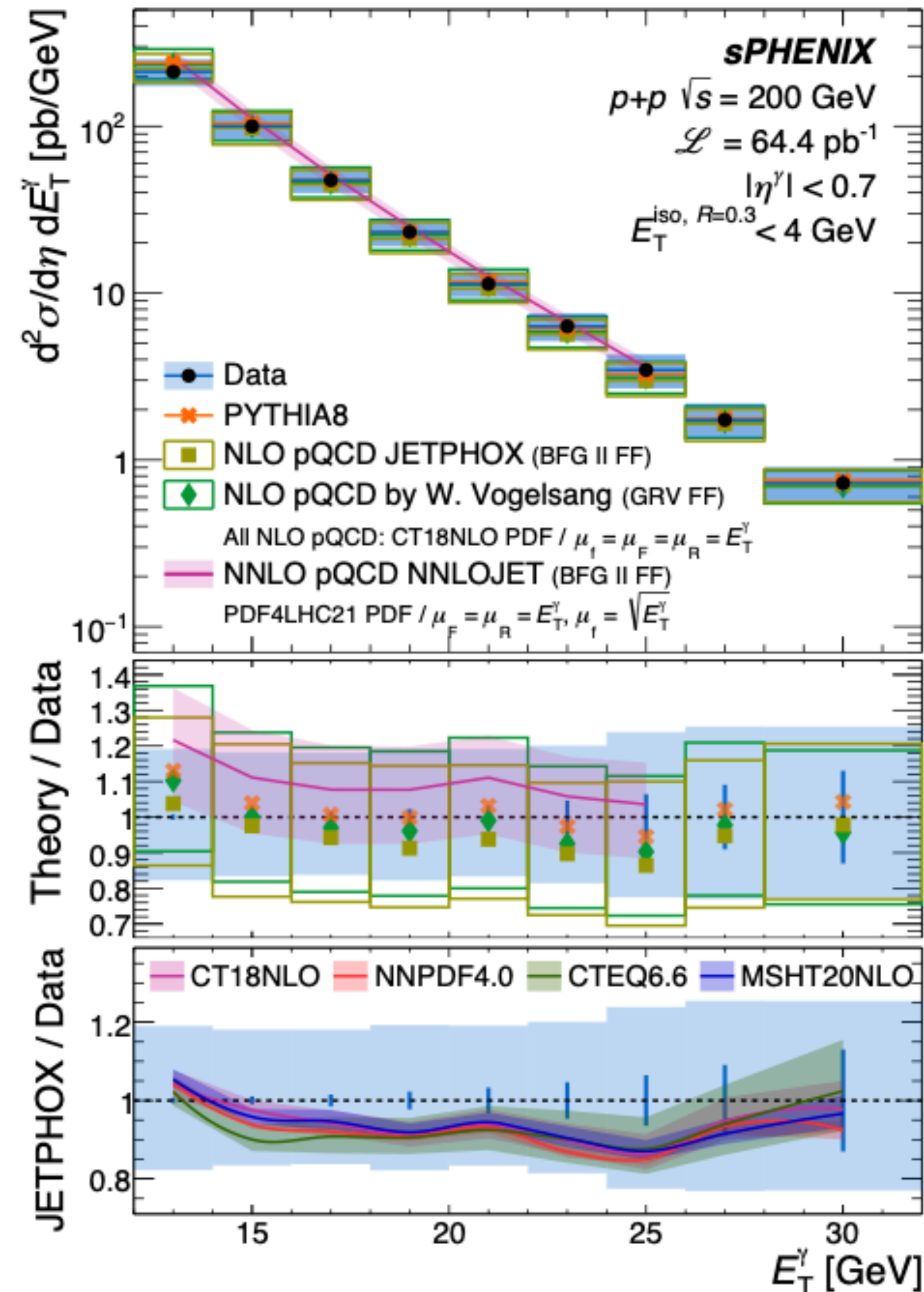
sPHENIX Final! - [arXiv.2607.03892], submitted to PRC

- **Energy scale**: energy scale up and down 1.1%, up to 1% energy scale linearity systematic
- **Energy resolution**: p_T dependent upper and lower bound for the extra smearing
- **Purity**:
 - ➔ Non-iso gap
 - ➔ Min non-tight BDT score
 - ➔ Purity fit function & error band
 - ➔ MC purity non-closure
- **Efficiency**: ID BDT threshold
- **Pileup**: PU fraction change in MC
- **NCB**: NCB BDT > 0.3 or 0.7
- **Unfolding**: w/o prior reweighting and different number of iterations
- **Lumi uncertainty**: propagate from MBD cross section



sPHENIX Isolated Prompt Photon

sPHENIX Final! - [arXiv.2607.03892], submitted to PRC



- **Theory comparison**

- ➔ **PYTHIA8**: Detroit tune

- ➔ **NLO pQCD JETPHOX**: CT14LO PDF + BFG II FF

- ➔ **NLO pQCD W. Vogelsang**: CT14LO PDF + GRV FF, no hadronization, no E_T^{iso} cut

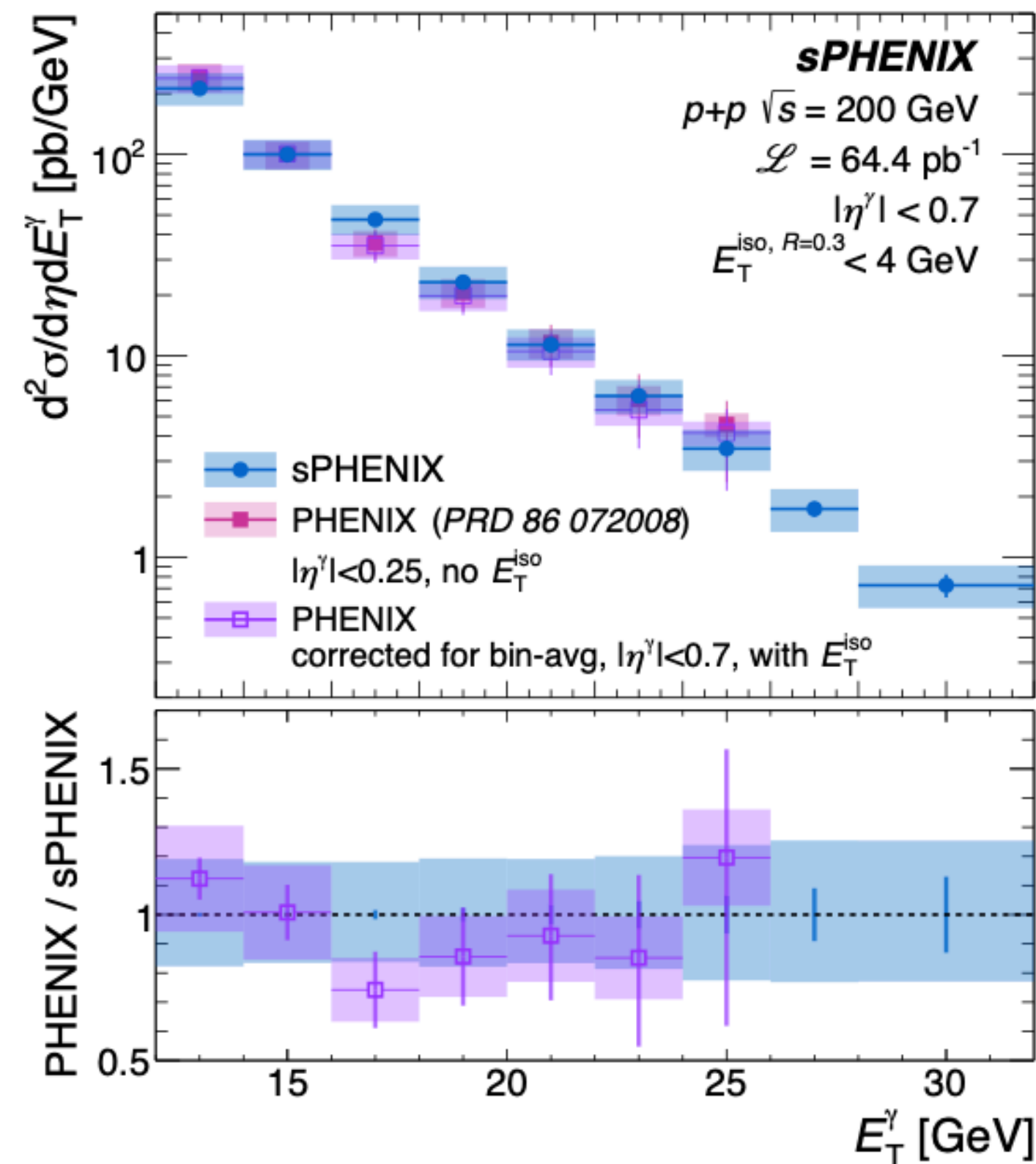
- ➔ **NNLO pQCD NNLOJET**: PDF4LHC21 PDF + BFG II FF

- **NNLOJET** is about 1.2x higher than the corresponding NLO prediction

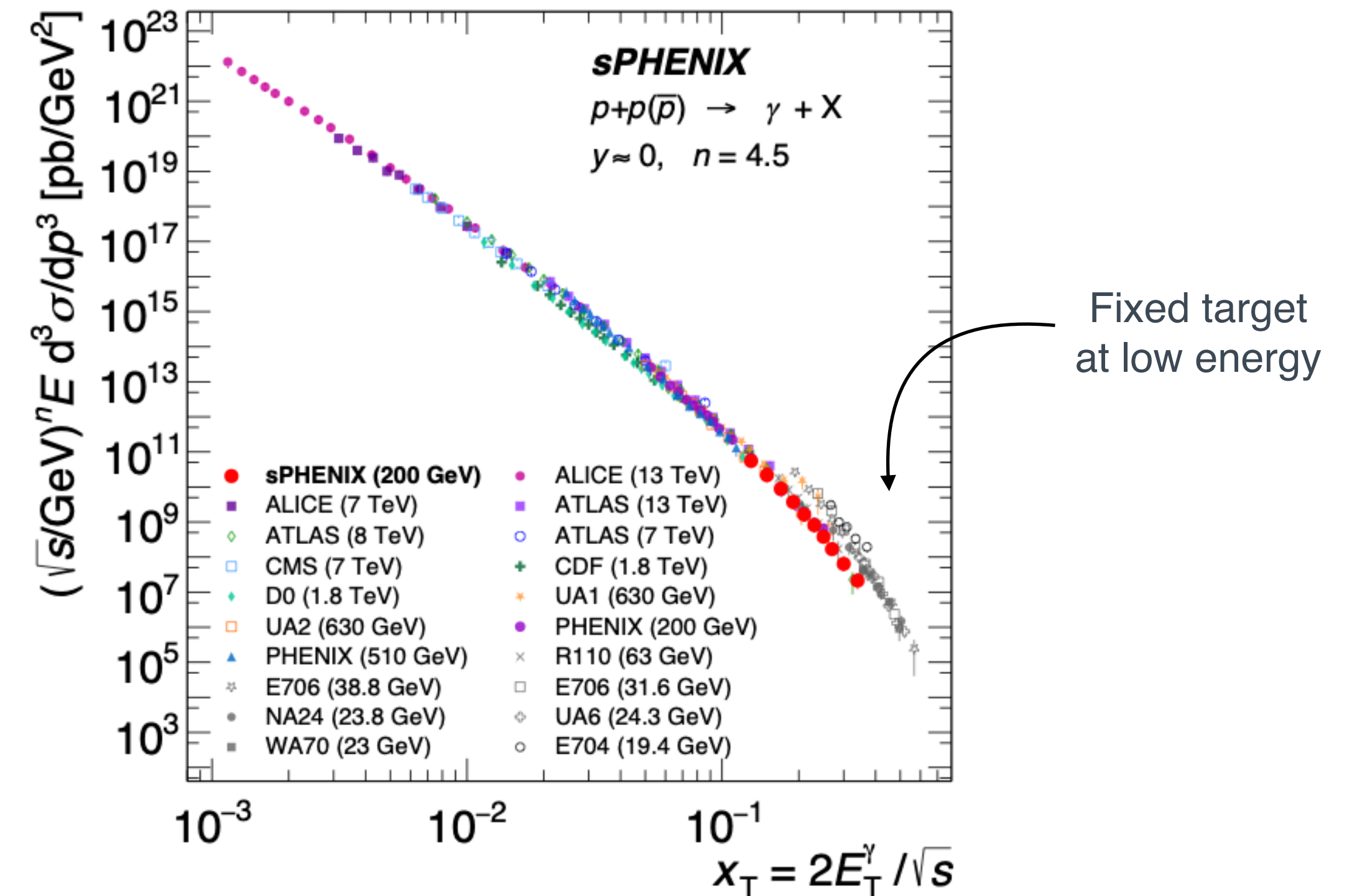
All predictions consistent with data within uncertainties

Comparing with PHENIX and x_T scaling

sPHENIX Final! - [\[arXiv.2607.03892\]](https://arxiv.org/abs/2607.03892), submitted to PRC



Experiments spanning from $\sqrt{s}=19.4 \text{ GeV}$ to 13 TeV



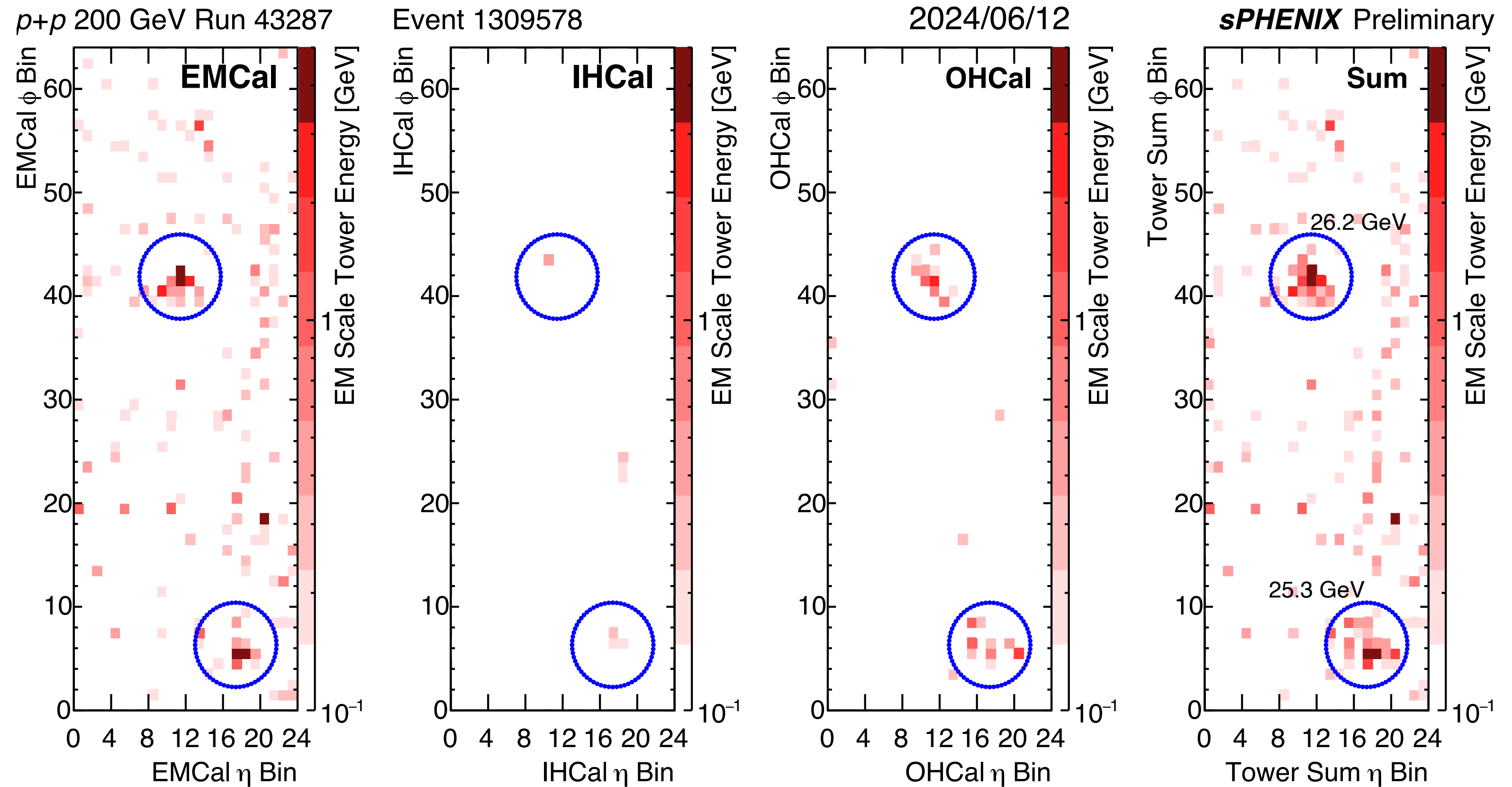
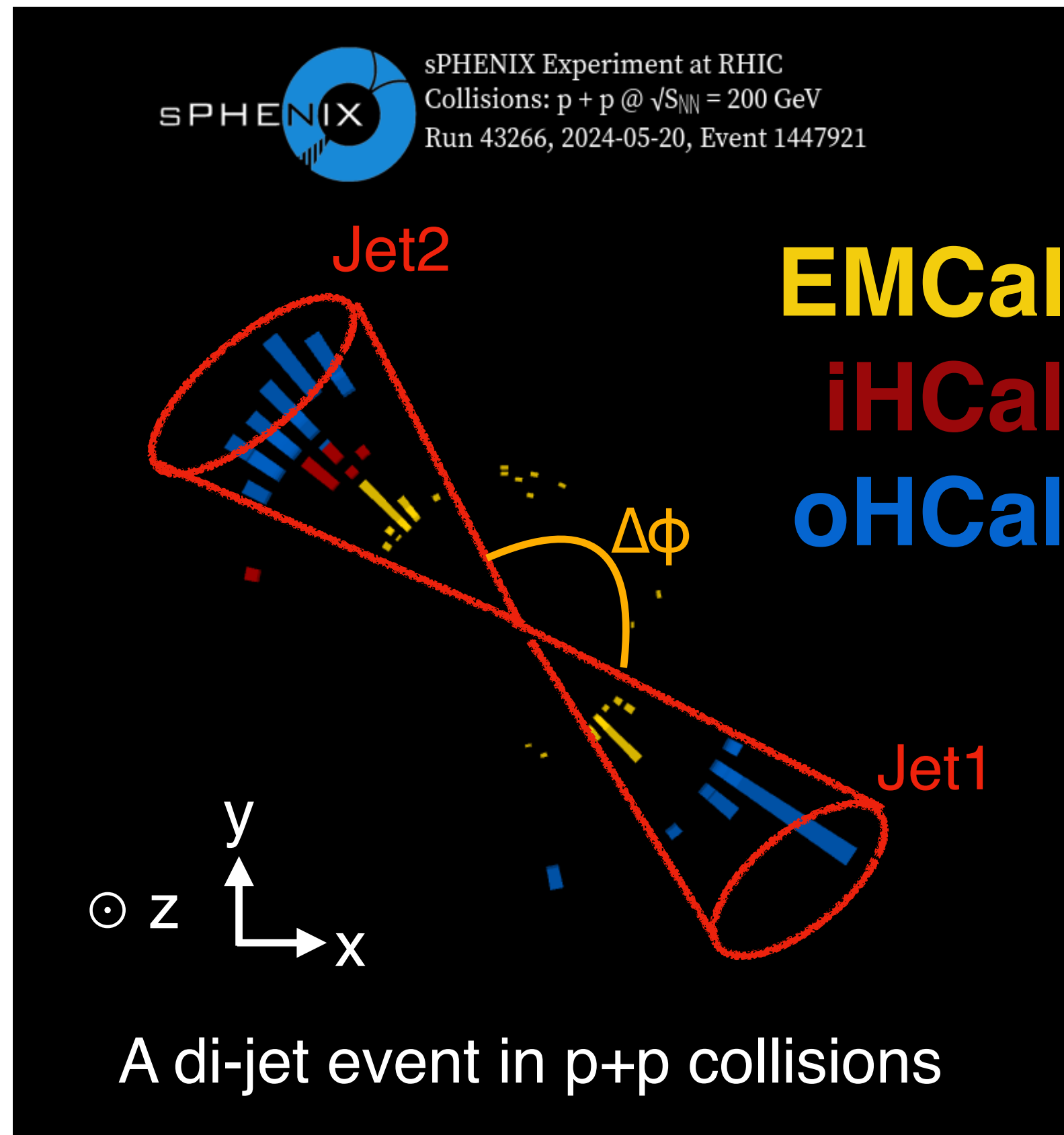
- Consistent with PHENIX measurements (after some corrections on PHENIX data)
 - sPHENIX has a higher E_T reach with better statistical precision
- sPHENIX is consistent with the global trend
 - Reaching $x_T = 0.32$, highest at RHIC

Di-jet measurement at sPHENIX



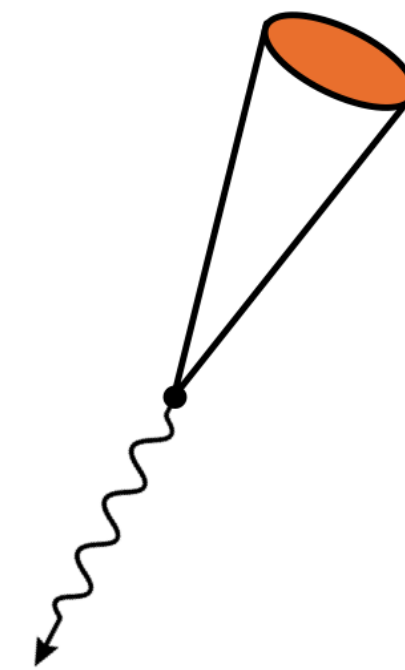
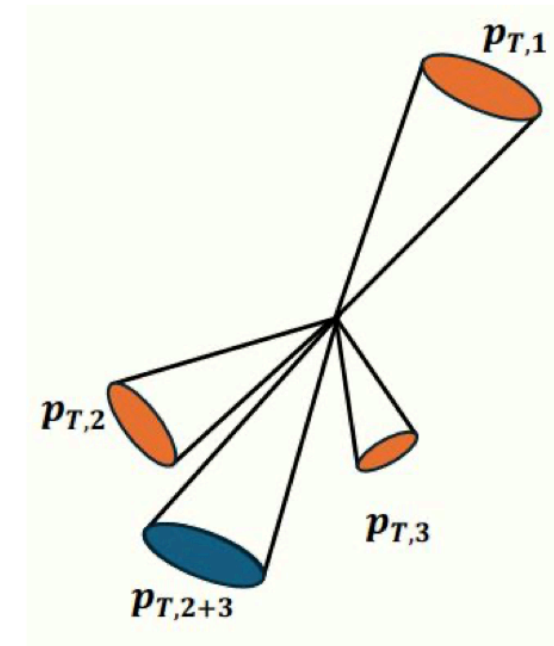
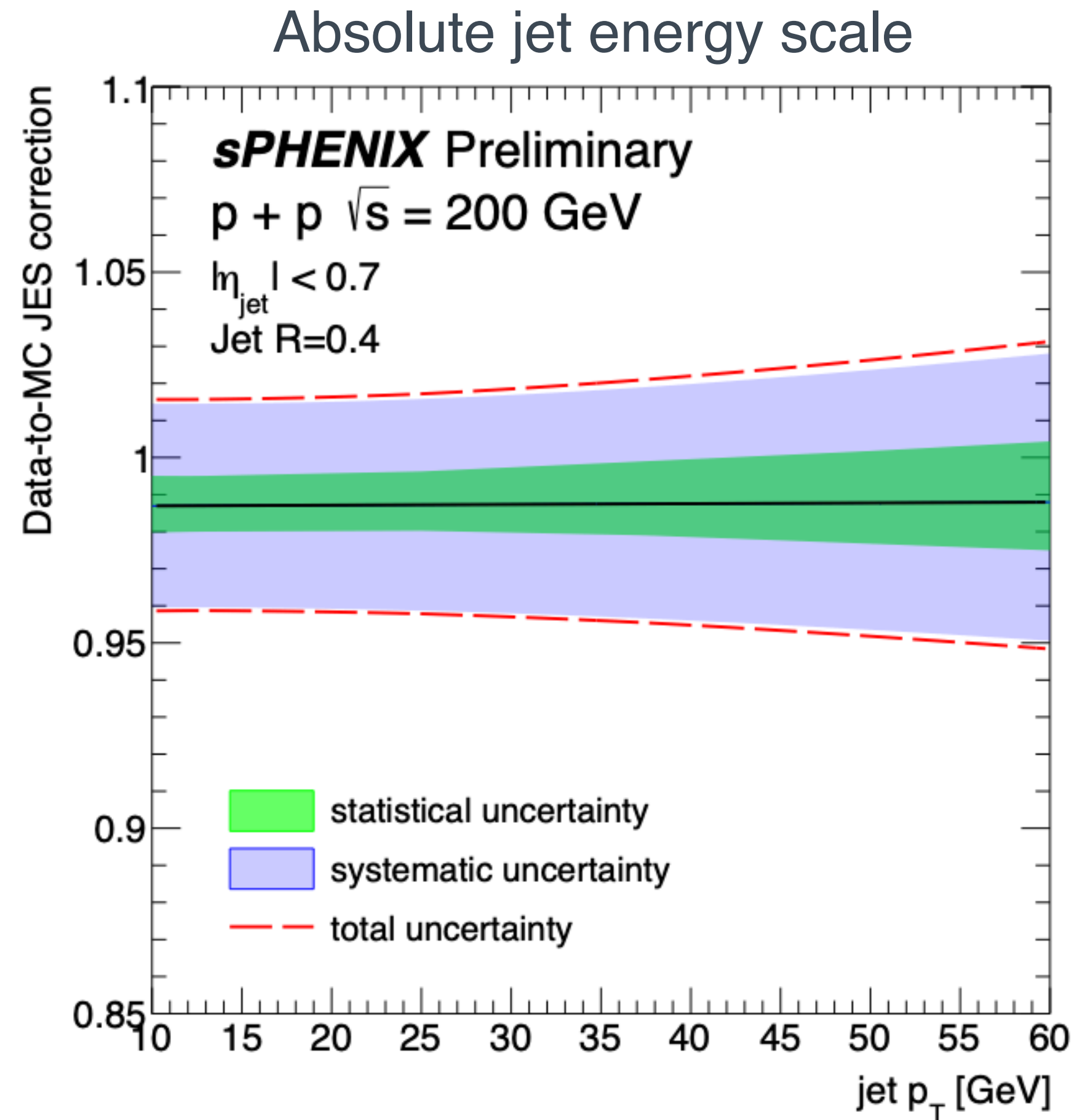
w/ Run24 p+p collision data

$$x_J = p_{T,2}/p_{T,1}, \text{ where } p_{T,1} \text{ is the leading jet}$$

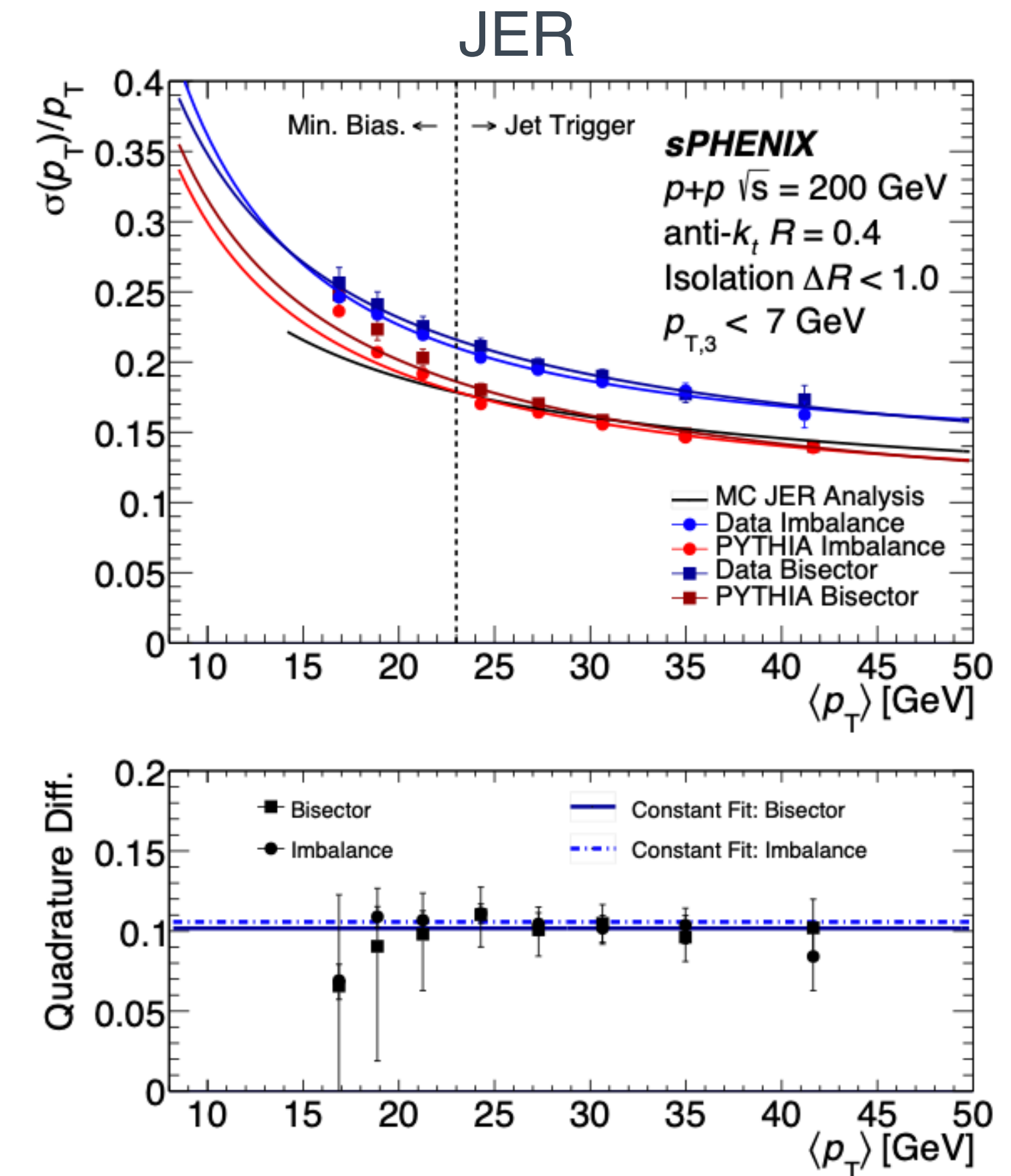


In this particular event, $x_J = 25.3 \text{ GeV}/26.2 \text{ GeV} = 0.96$

In-situ jet energy scale (JES) and jet energy resolution (JER)



Use γ -jet and multi-jet channels to calibrate the jet energy scale over $10 < p_T^{\text{jet}} < 60 \text{ GeV}$

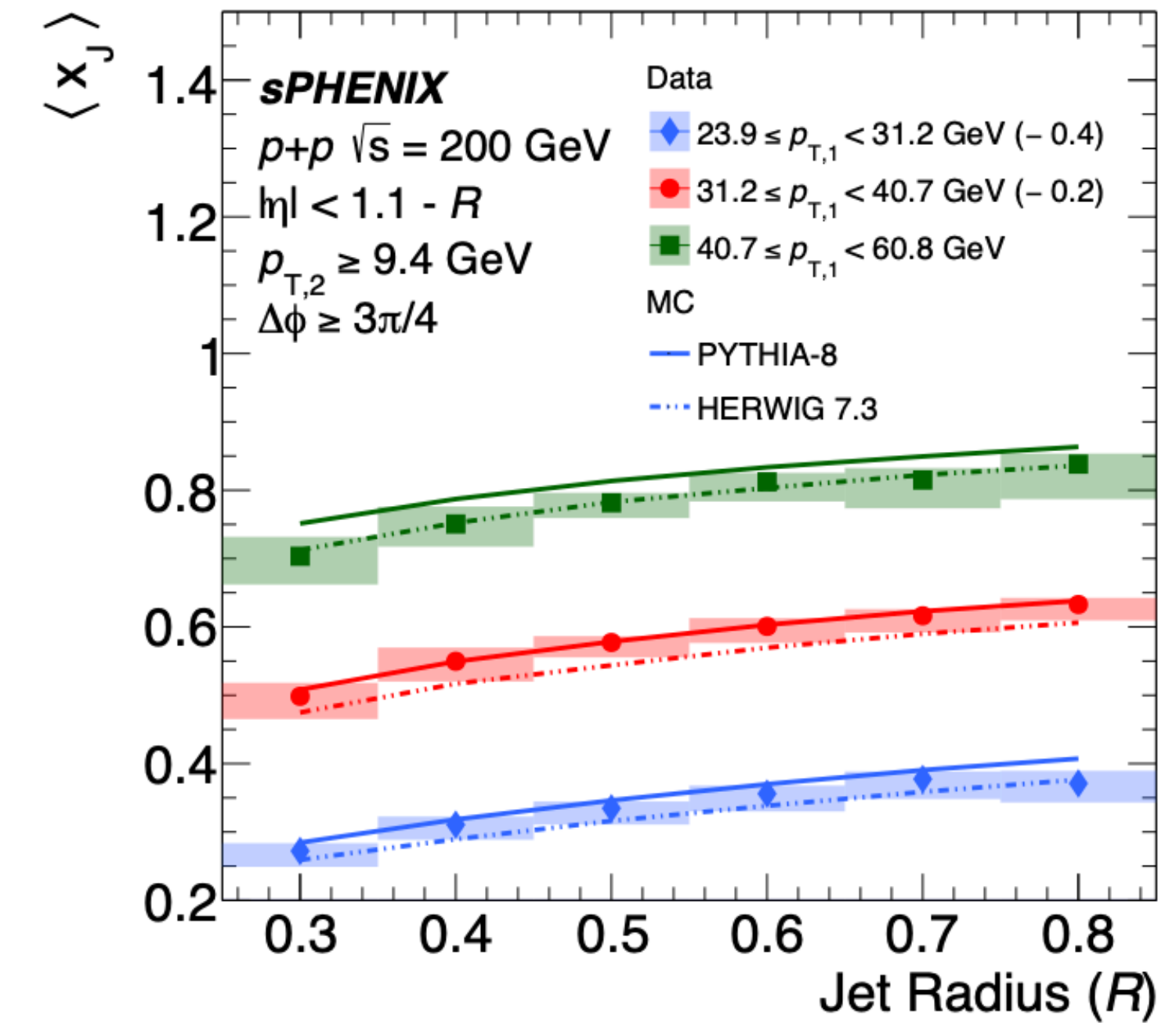
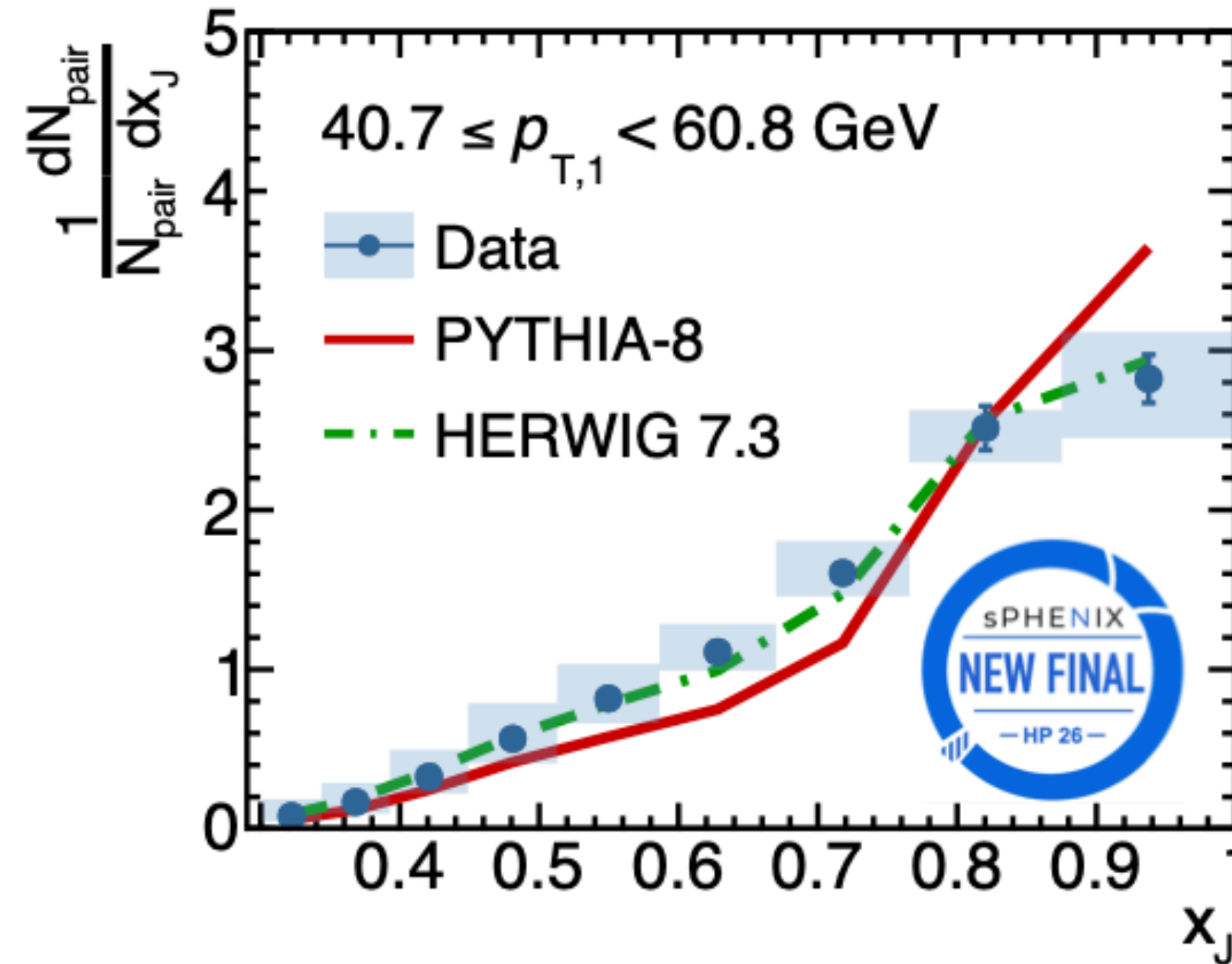
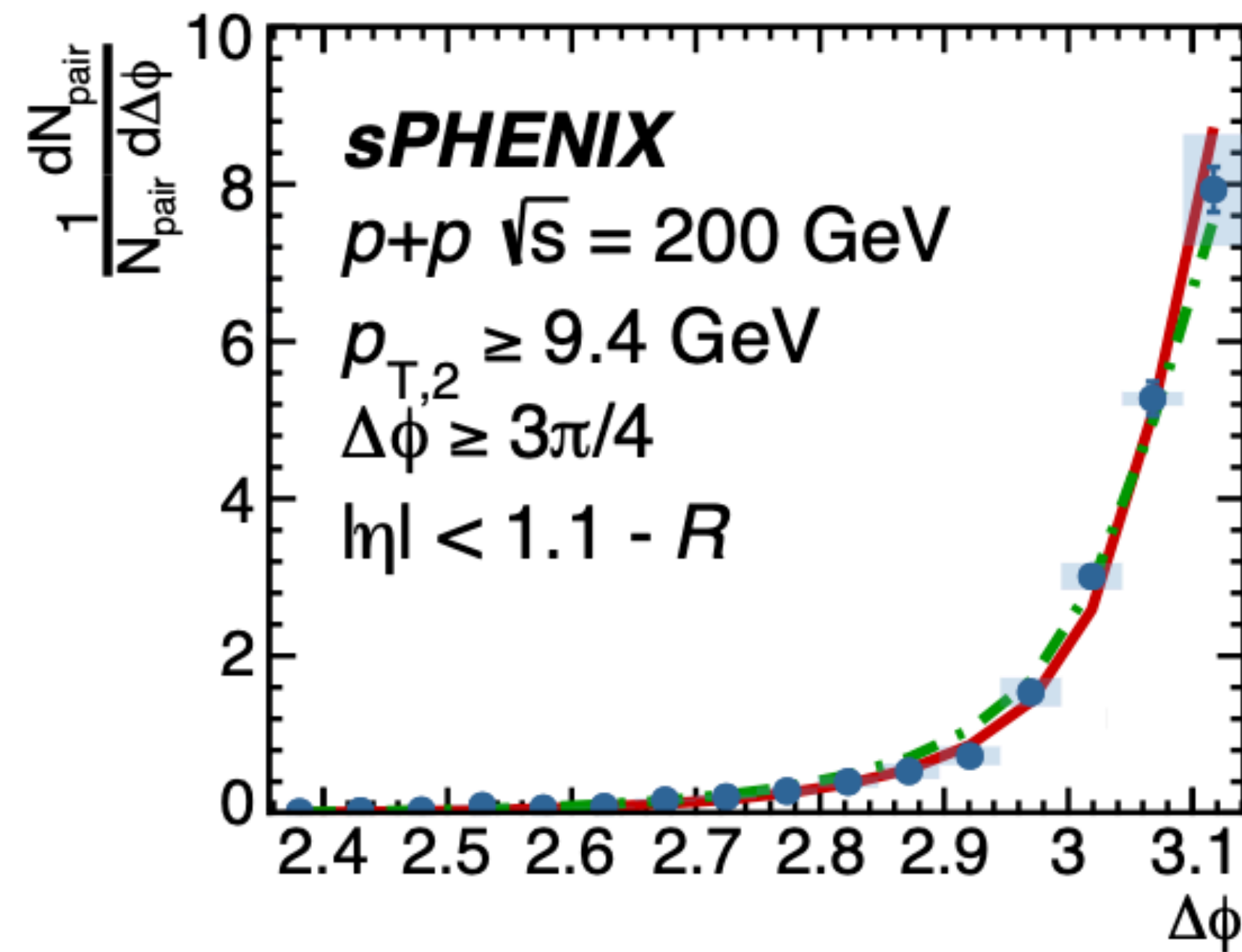


JER compared for data and MC using bisector & imbalance methods
 MC smeared to match the JER performance in data

Dijet asymmetry in p+p 200 GeV at sPHENIX



sPHENIX Final! - [arXiv.2606.17184], submitted to PRL

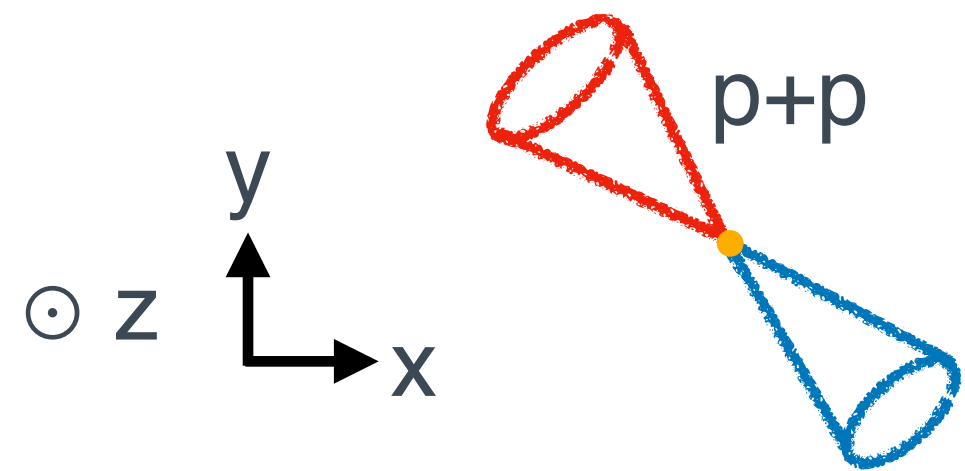


- Detector response corrected via full 2D unfolding
- Clear back-to-back dijets in $\Delta\phi$ and symmetric momentum balance in x_j
- Well described by both Pythia and Hwewig generators
- Measurements for $R=0.3$ to 0.8 , useful for a comprehensive understanding on MPI, hadronization, and non-perturbative corrections. Baseline for Au+Au measurement
- First time fully reconstructed jet at RHIC

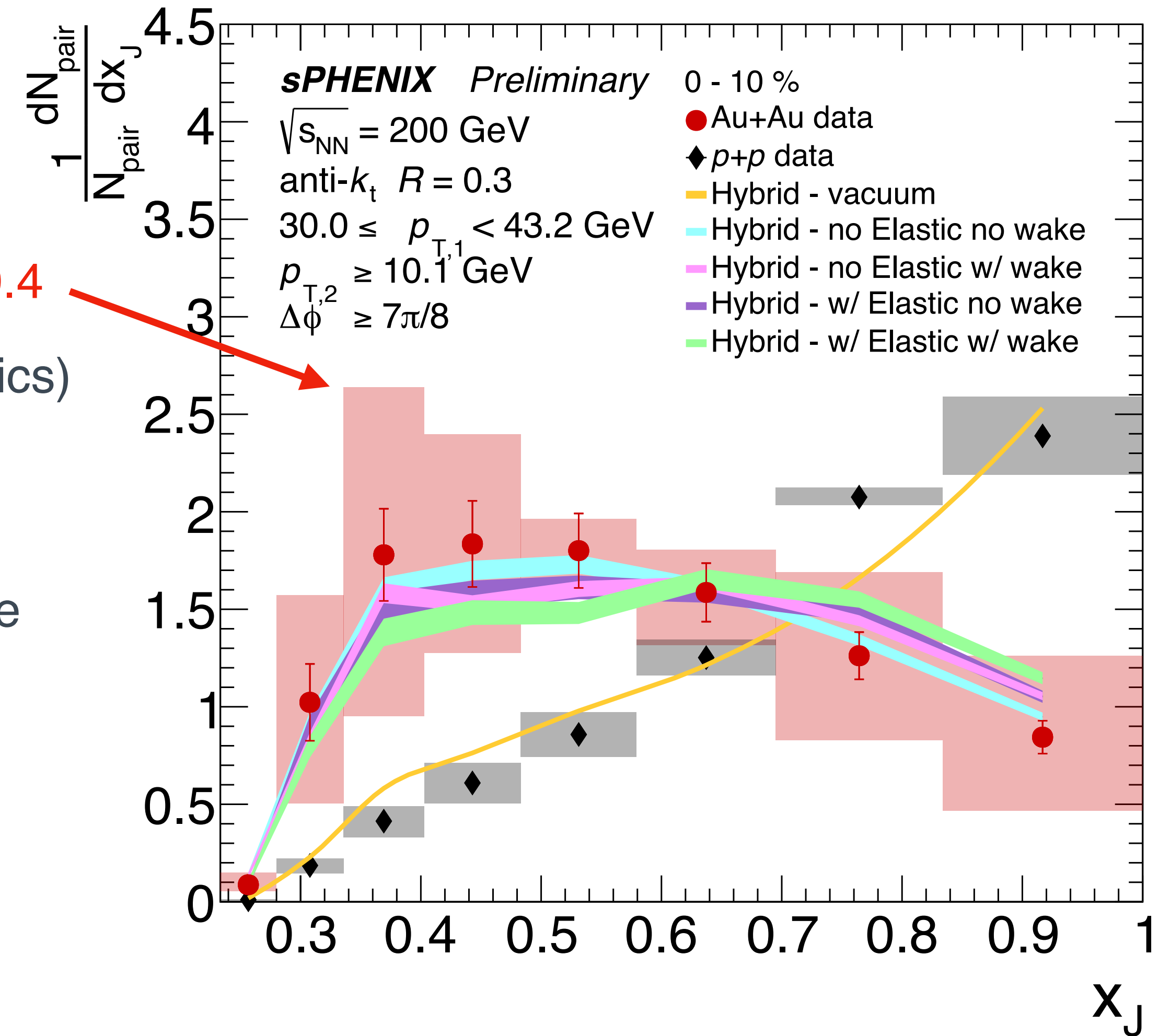
Di-jet imbalance measurement

w/ Run24 p+p and Au+Au collision data

- Anti- k_T jets, jet cone size $R = 0.3$
- $|\Delta\phi| \geq 7\pi/8$, $30 \leq p_{T,1} \leq 43.2$ GeV
- 2D unfolding in $p_{T,1}$ and $p_{T,2}$
- Au+Au data: ~ 0.1 nb $^{-1}$ (1.5% of total sPHENIX Au+Au statistics)
- Jets in Au+Au collisions: underlying event subtracted
- Di-Jet imbalance in Au+Au collision primarily coming from the two jets experiencing different in-medium modifications



Peak at 0.4



Significant modification in Au+Au compared to pp
The first jet-quenching measured by sPHENIX!

- sPHENIX is a next-generation experiment at RHIC specialized for measuring hard-probe observables with high precision
 - Detector construction completed in 2023, lifetime data taking ended on Feb 6, 2026
 - Collected abundant Au+Au collision, polarized p+p and O+O collision data
- First physics publications on measurement of $dE_T/d\eta$ and $dN_{ch}/d\eta$ in Au+Au collisions
 - $dE_T/d\eta$ measured by the calorimeter system is consistent with previous RHIC measurements, and provides additional granularity in η and improved uncertainties in peripheral events
 - $dN_{ch}/d\eta$ obtained using INTT agrees with previous RHIC results, and offers improved uncertainties in the mid-centrality events
 - Benchmarks for the performance of global event characterization, calorimeter, and tracking systems, laying the foundation for the broad physics program of sPHENIX!
- Isolated prompt photon production in p+p 200 GeV measured using 2D side-band method
 - Consistent with pQCD predictions within uncertainties
 - Consistent with PHENIX measurements with higher E_T reach and smaller statistical uncertainties
 - Agrees with global E_T scaling (highest x_T reach at RHIC)
- Di-jet asymmetry in p+p 200 GeV
 - Data-driven calibration for JES and JER, fully unfolded for detector effects
 - First time fully reconstructed jet at RHIC
 - x_j and $\Delta\phi$ peaked at 1 in p+p events
- Significant modification in Au+Au compared to pp. The first jet-quenching measured by sPHENIX!



Thank you for your attention!

sPHENIX Run25 start party

