Recent Jet & Photon Measurements from sPHENIX

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AUM 2026

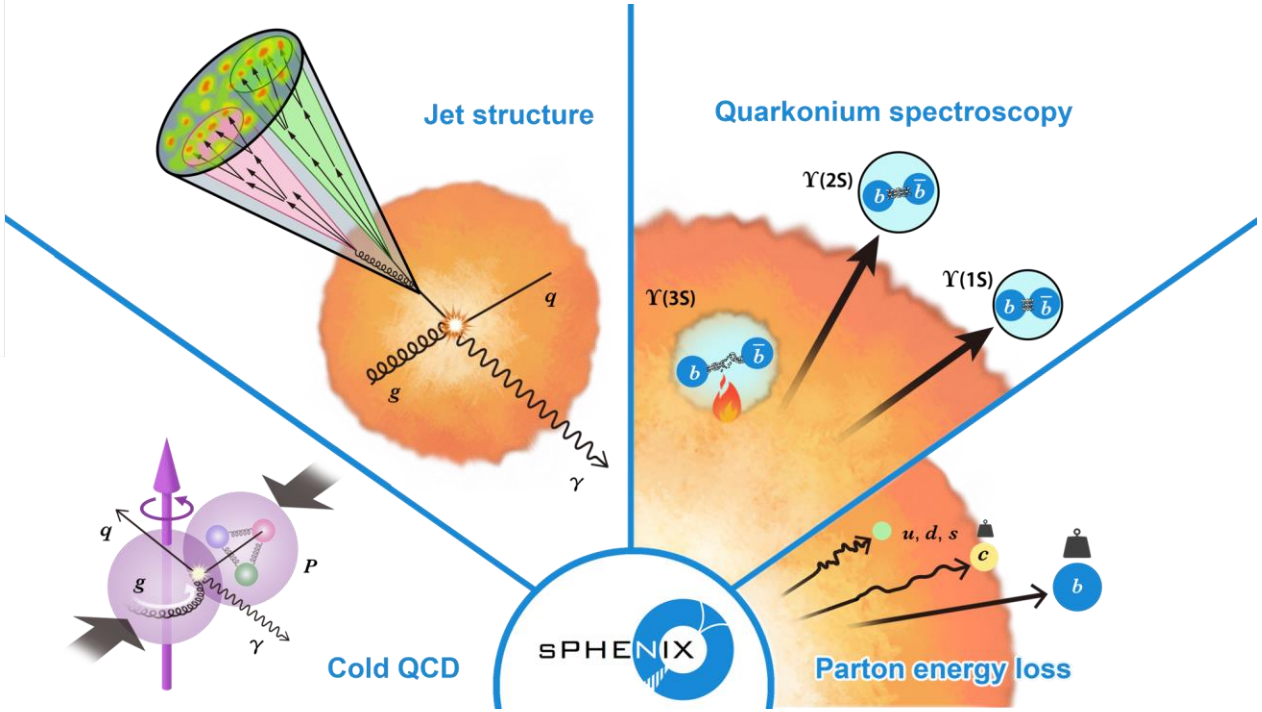
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

The sPHENIX Mission

2015 US NP LRP

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.**

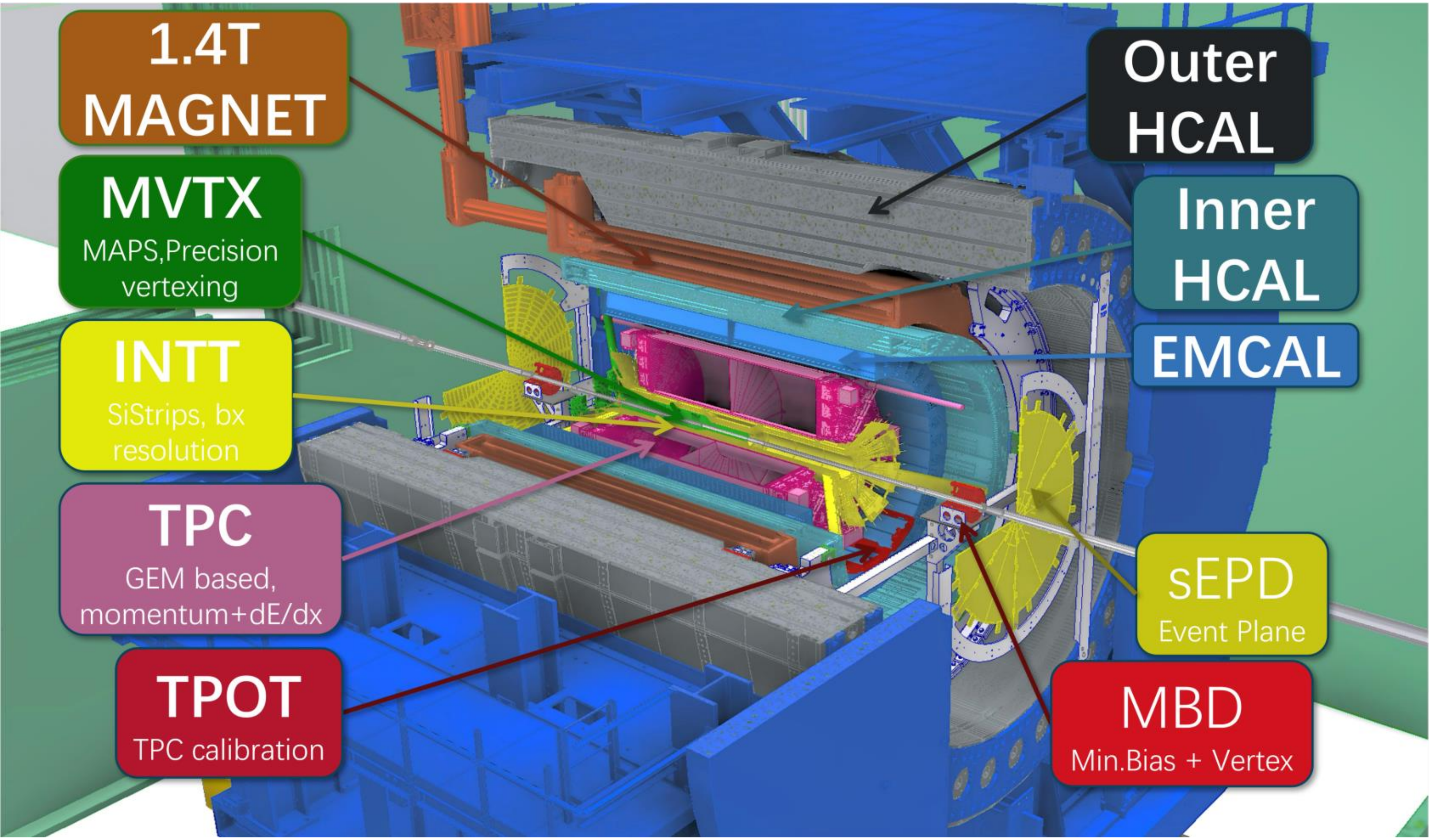
The Science Pillars of sPHENIX



To investigate strongly interacting nuclear matter with precision high p_T probes, we need to measure the QGP (Au+Au) and a reference (p+p). What we need:

- Powerful DAQ and trigger system
- Large acceptance in η and ϕ
- Fully capture for hardon and electromagnetic showers
- Precision tracking

The sPHENIX Detector



ZDC
18.5 m away from collision point

- The first new experiment at RHIC in over two decades and the first at RHIC to include a barrel hadronic calorimetry - first data in 2023.
- Full calorimetry with coverage in $|\eta| < 1.1$ and full azimuth in ϕ allows for unbiased jet measurement.
- Precision multi-subsystem tracking allows for precision vertexing, timing and momentum resolution.
- High DAQ rate 15 kHz trigger system. Extended streaming readout tracking detectors allows to sample unbiased pp collisions at ~200kHz.

sPHENIX Timeline and Data Taking

2023

Detector installation completed

Au+Au Commissioning run

Cut short by accelerator incident

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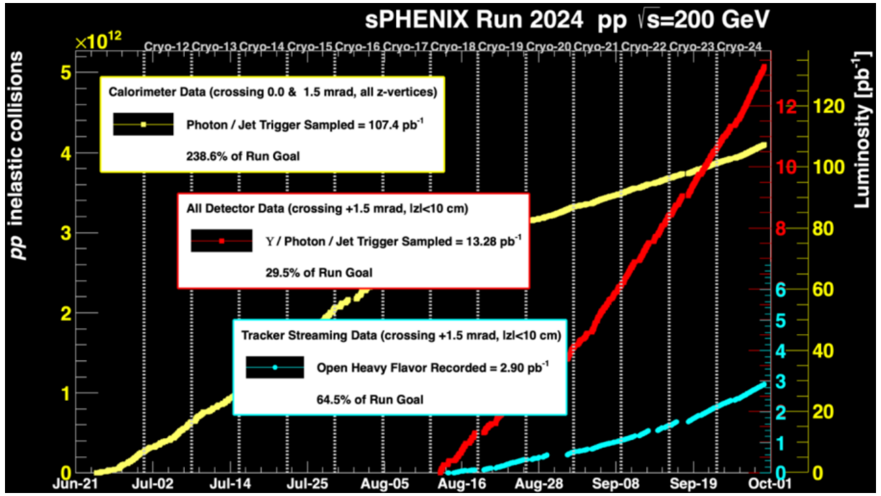
2024

p+p physics data taking

Calorimeter-only: 107/pb

All subsystem: 13/pb



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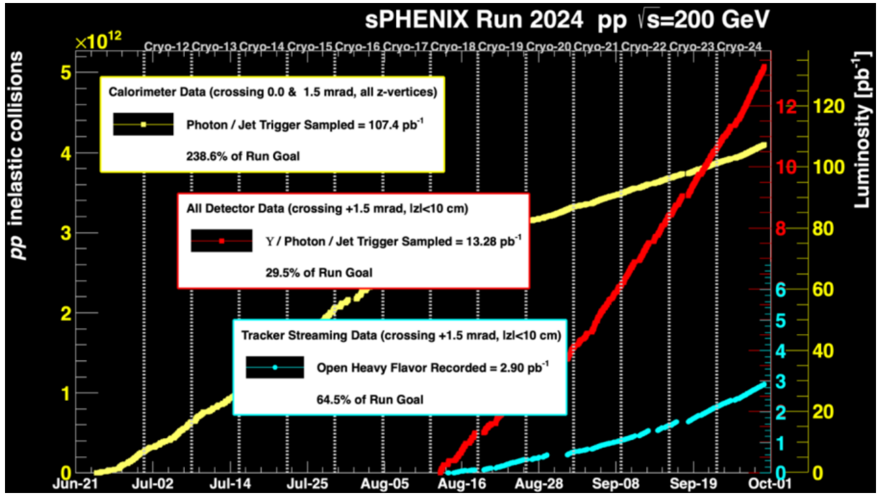
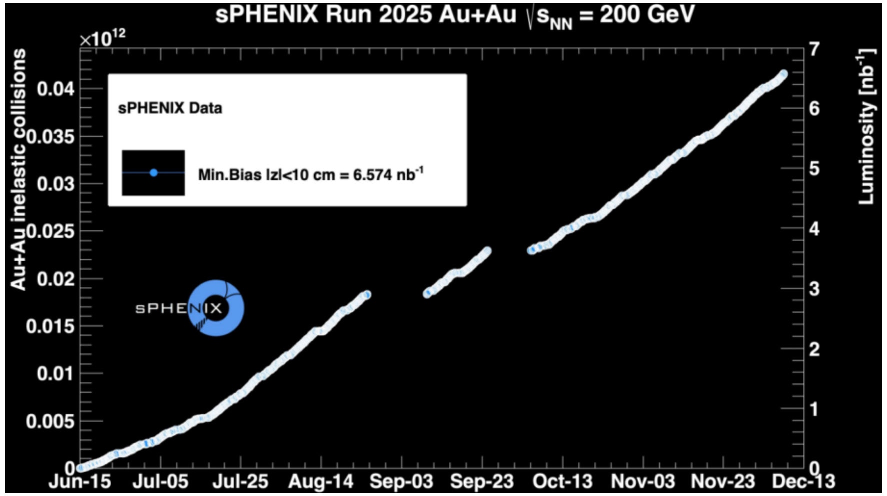
2025

Au+Au all subsystem: 6.6/nb





sPHENIX Timeline and Data Taking

sPHENIX

2023

Detector installation completed
Au+Au Commissioning run
Cut short by accelerator incident

2024

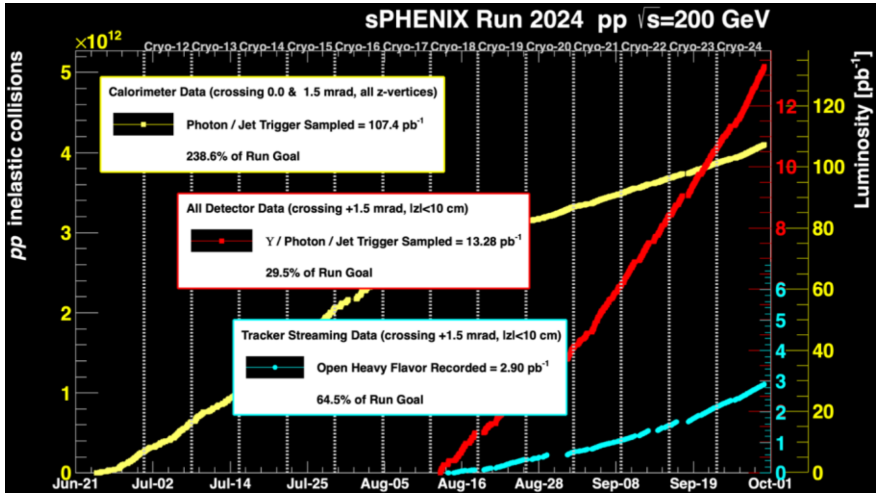
p+p physics data taking
Calorimeter-only: 107/pb
All subsystem: 13/pb

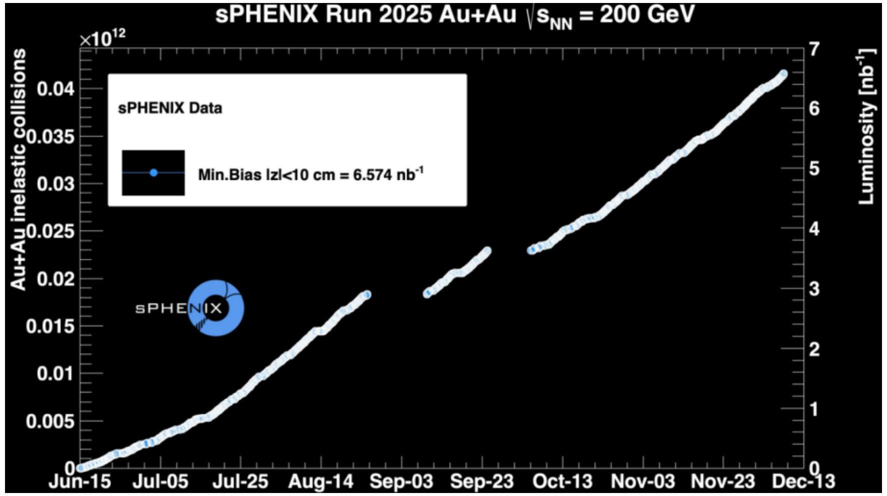
2025

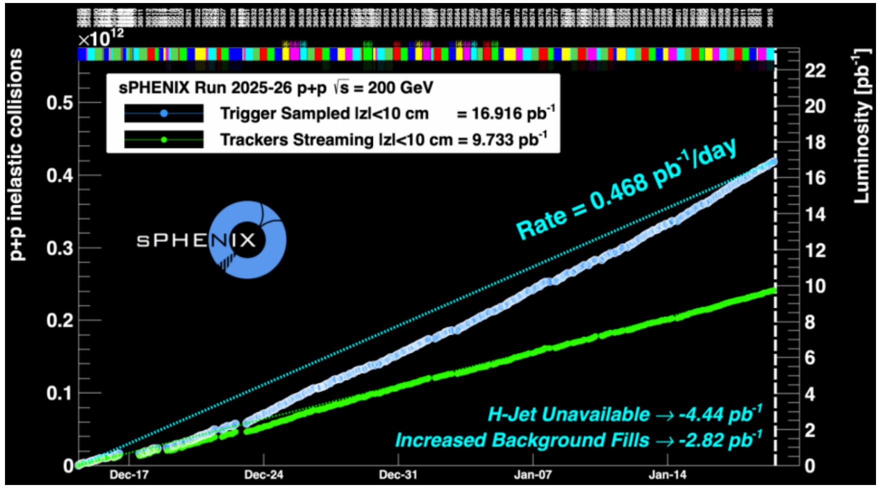
Au+Au all subsystem: 6.6/nb

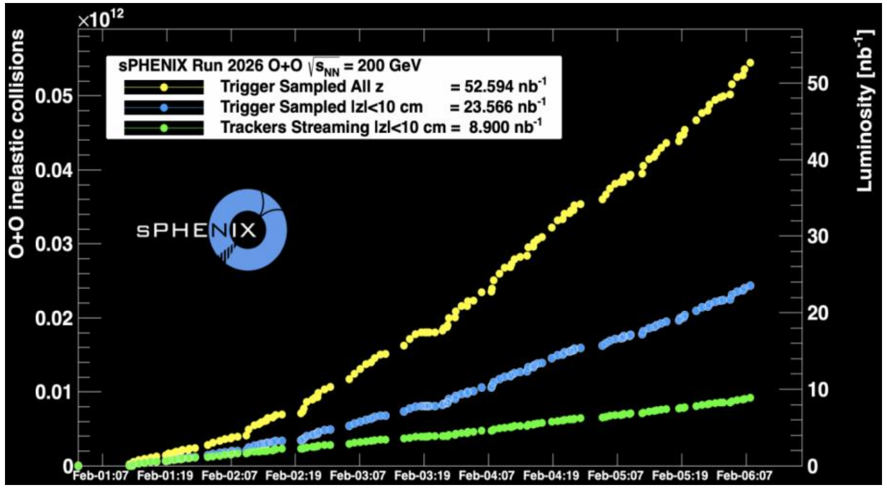
2026

p+p all subsystem: 17/pb
O+O calorimeter-only: 52.6/nb
O+O all subsystem: 23.6/nb









Production of Prompt Photons

Prompt photons (Direct + Fragmentation Photons) are predominantly produced in QCD 2-to-2 hard scattering subprocess and provides a stringent test of pQCD predictions.

- Direct Photons

➡ produced from primary vertex of hard scattering.

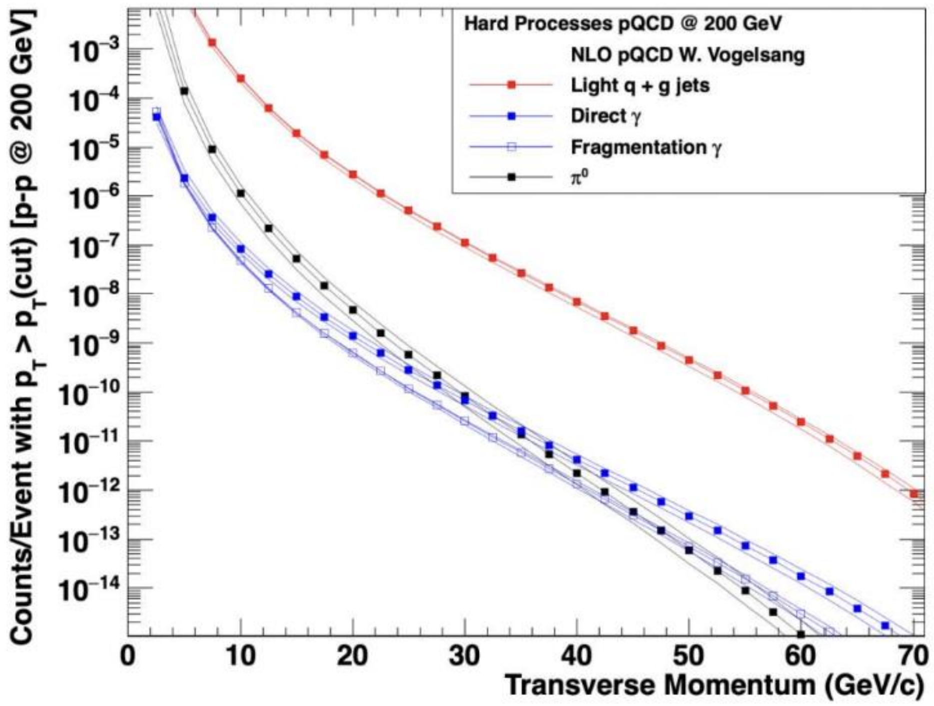
➡ processes : Compton scattering, Annihilation.

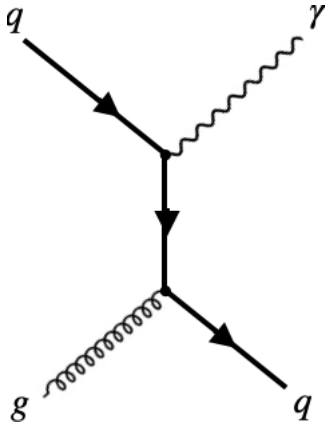
- Fragmentation Photons

➡ radiated from partons after the primary hard scattering.

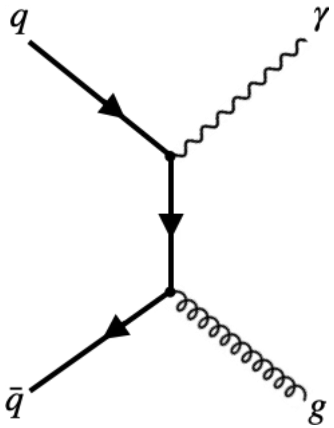
- Direct photons are predominantly produced by Compton scattering

➡ sensitive to gluon parton distribution function.

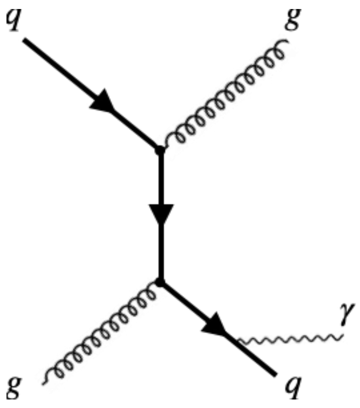




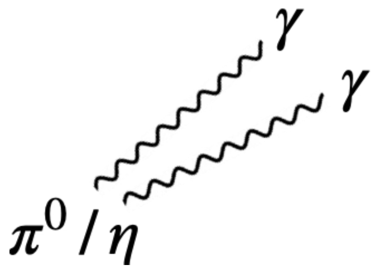
Compton Scattering



Annihilation



Fragmentation



Decay photons

Photon Identification: Isolation and Shower shape

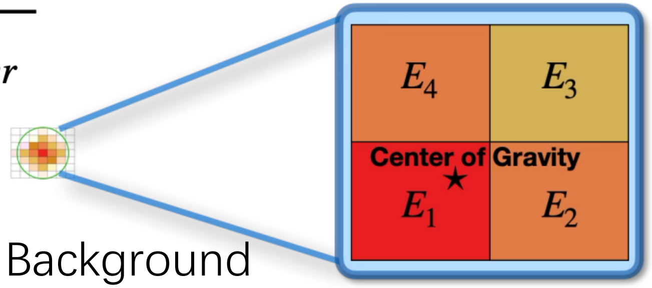
- Photon **Identification** using EMCal shower shapes, for preliminary total 5 shower shapes are used, for instance:

- Energy weighted second moment of EMCal tower in η/ϕ:

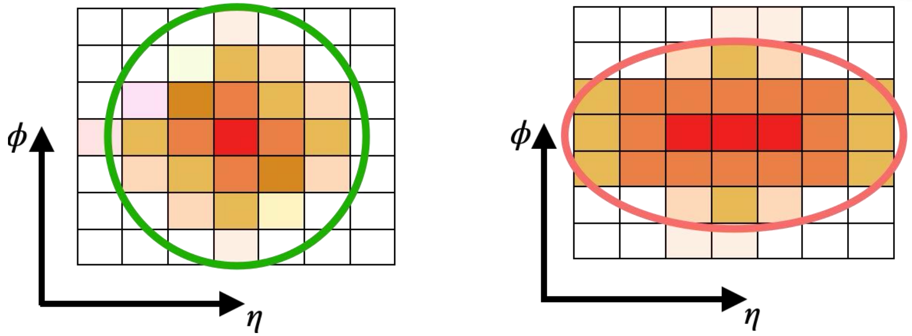
$$w_\eta = \frac{\sum_i E_i(\eta_i - \bar{\eta})^2}{\sum_i E_i}$$

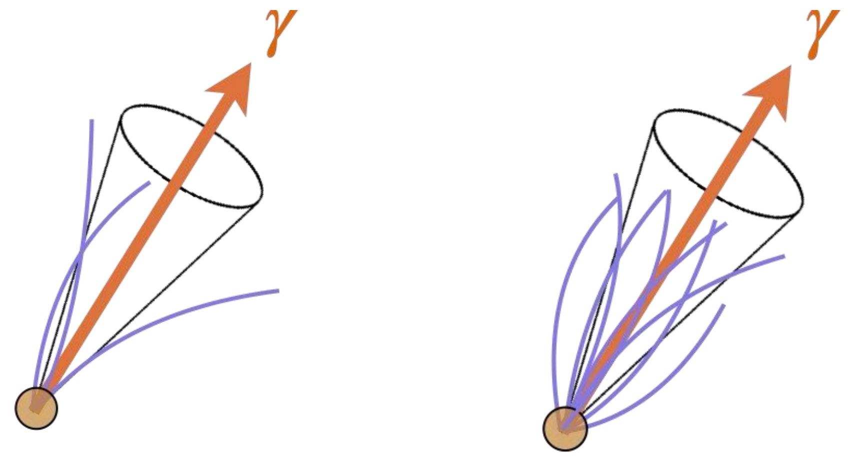
- Fraction of core energy w.r.t total cluster Energy:

$$E_{t1} = \frac{\sum_{i=1}^{4} E_i}{E_{cluster}^{tot}}$$



Signal
Background



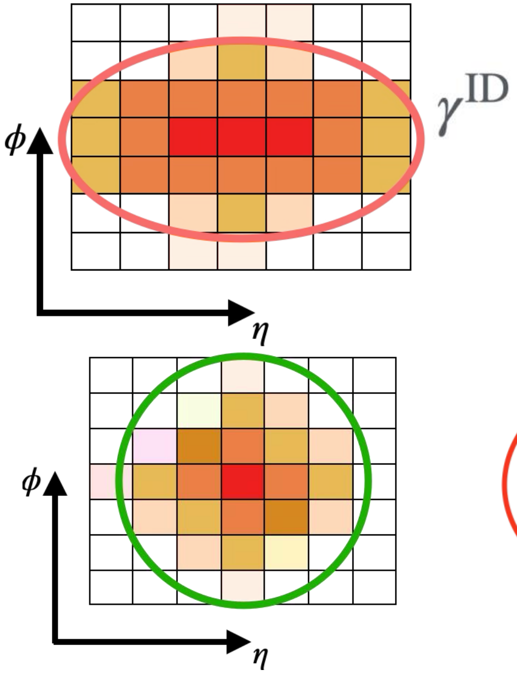


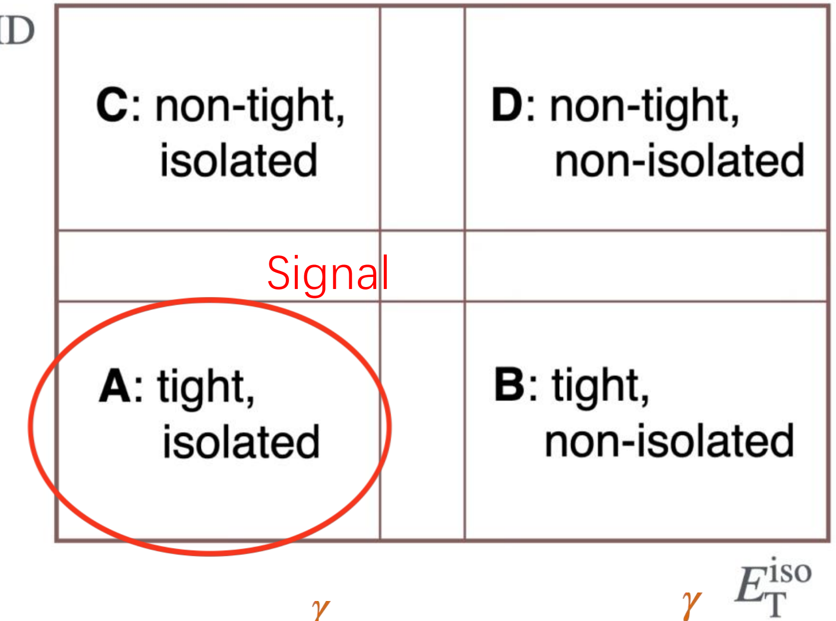
- Background (decay) photons originated from neutral mesons which often produced inside jets, so their decay photons are typically not isolated.

- Direct γ usually isolated from hadrons around the isolation cone.

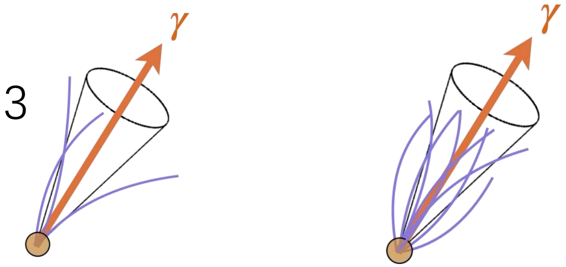
- Isolation requirements are imposed to reduce the contributions of fragmentation photons.

Photon Purity Estimation: 2D Side-band





Cone size R = 0.3



$$E_T^{iso} = E_T^{EMCal+HCal} - E_T^{cluster}$$

- **Signal**
  - Isolated EMCal cluster
  - With single photon shower shape
- **Background** (mostly from neutral mesons)
  - Come with jets, non-isolated
  - With non-single photon shower shape
- **Irreducible background** exist in signal region, must be statistically subtracted
- **Data-driven purity estimation**

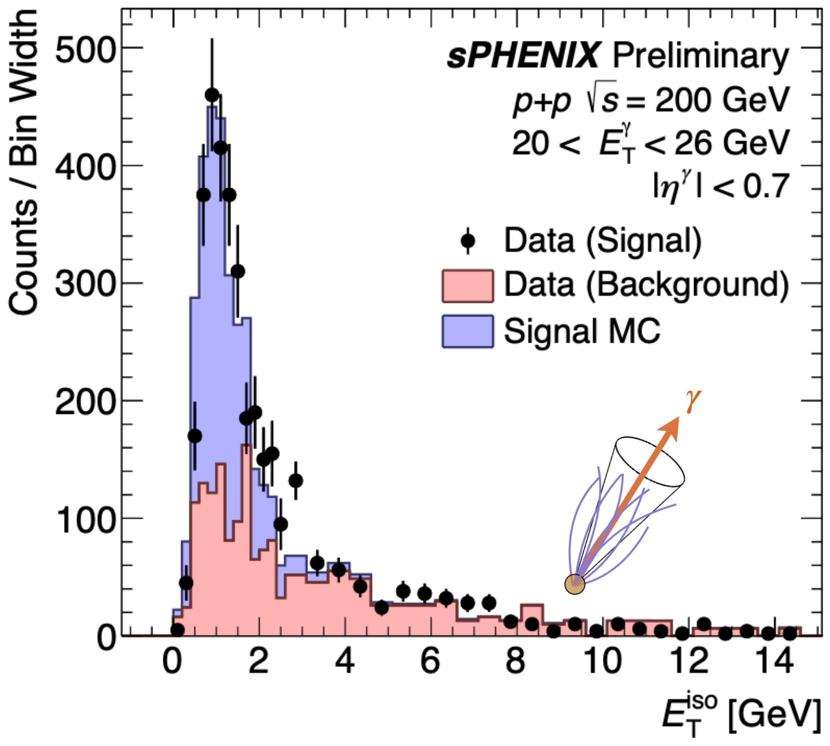
$$N_{\text{signal}}^{A} = N_{\text{raw}}^{A} - N_{\text{raw}}^{B} \cdot \frac{N_{\text{raw}}^{C}}{N_{\text{raw}}^{D}}$$

MC Correction →

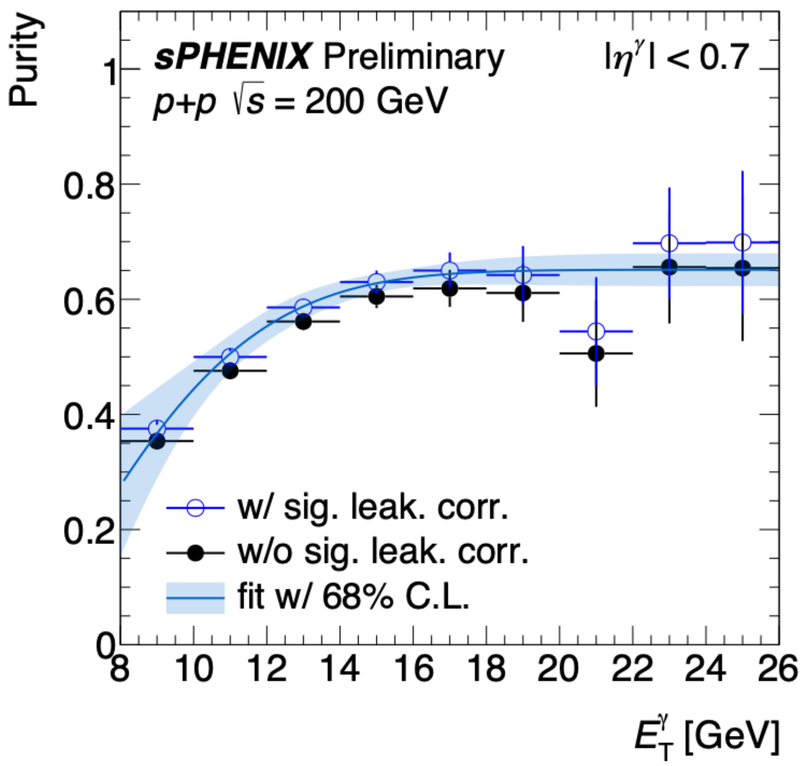
$$N_{\text{signal}}^{A} = N_{\text{raw}}^{A} - \left[\left(N_{\text{raw}}^{B} - f^{B,\text{MC}}\, N_{\text{signal}}^{A}\right) \cdot \frac{\left(N_{\text{raw}}^{C} - f^{C,\text{MC}}\, N_{\text{signal}}^{A}\right)}{\left(N_{\text{raw}}^{D} - f^{D,\text{MC}}\, N_{\text{signal}}^{A}\right)} \right]$$

Photon Purity Estimation: 2D Side-band

Irreducible background exist in signal region ⟶ must be statistically subtracted
Data-driven purity estimation



Isolation energy distribution for **data** compared to background enhanced data+ signal MC



Measured purity,
only small correction from MC

Prompt Isolated Photons in p+p

- Results unfolded for detector effect.

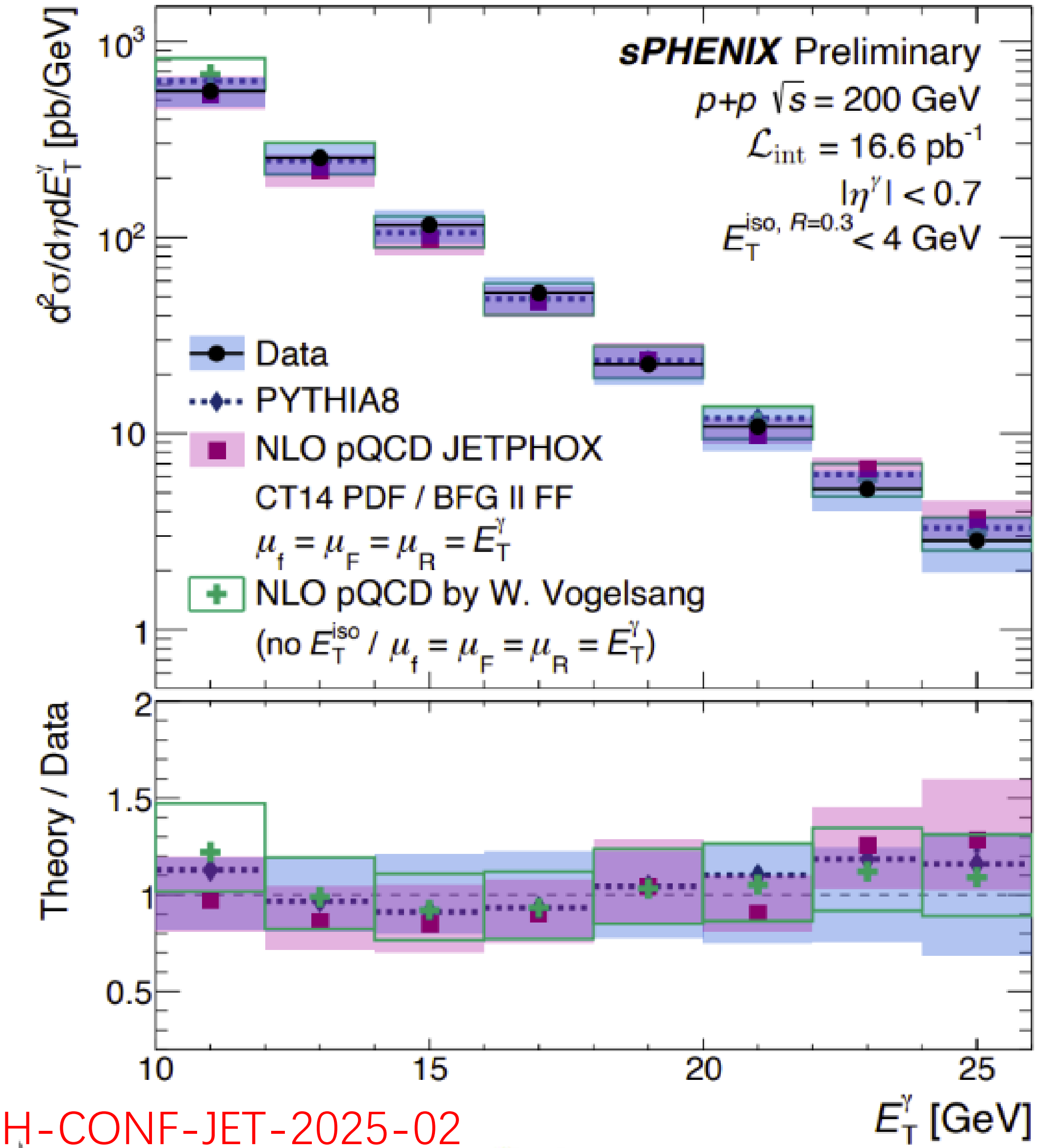
- 15% of the full p+p dataset used.

- EM energy scale dominant source for systematic uncertainty.

- Agrees with three theory results:
1) Pythia8 Detroit tuning
2) JETPHOX: NLO pQCD, CT14LO PDF + BFG II fragmentation functions
3) NLO pQCD by W. Vogelsang (no iso cut)

- Provides a clear path toward future γ–jet measurements and jet-quenching studies in Au+Au collisions.

- Recent study shows further improvement using Boosted Decision Tree.



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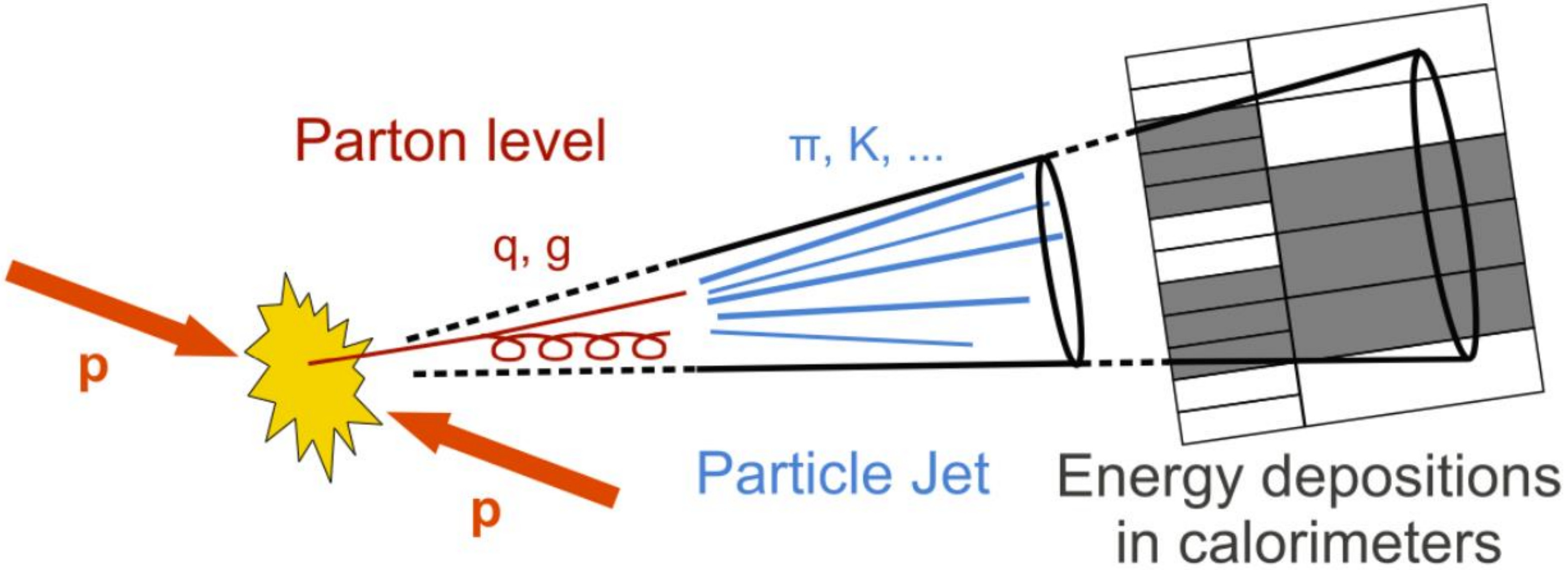
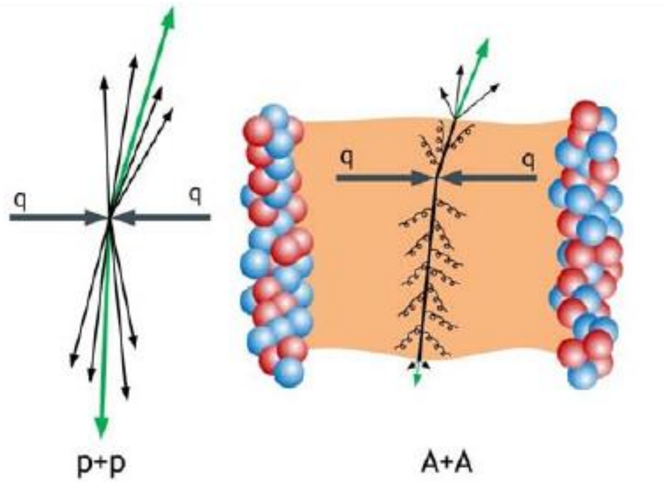
Jet: A Probe of the QGP

The hard scattering events, initial high-energy interactions between the partons (quarks and gluons) from the colliding nuclei, occur almost instantaneously after the collision.
The partons that are scattered will trigger a cascade of parton emissions. This process results in the formation of collimated bunches of stable hadrons known as **jets**.





Jets are a proxy for partons. They are sensitivity to the partonic dynamics. A way to connect the initial-state parton to the final-state hadrons.
Especially in the heavy ion collisions, jets traverse the QGP, they undergo modifications due to interactions with the medium. The primary effect of these interactions is the energy loss of the partons within the QGP, which is a phenomenon known as "jet quenching."

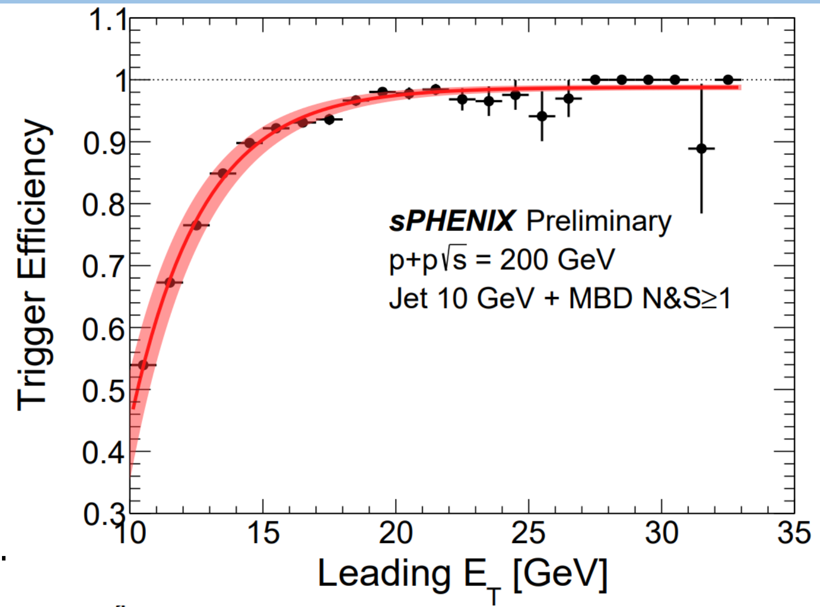
Jet Cross Section Measurement

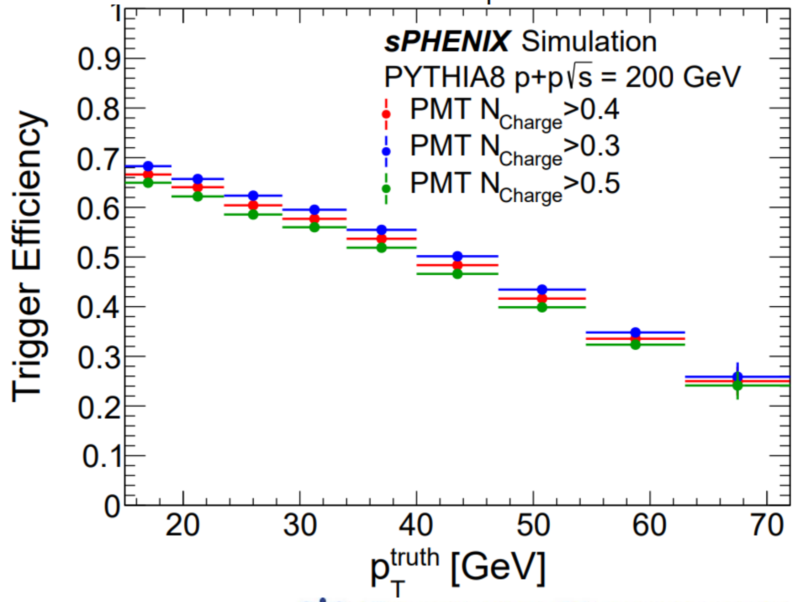
The jet cross section in p+p collision is an important baseline measurement for future sPHENIX jet analysis. We can verify the data quality and calorimeter performance. The p+p jet cross section will be used as a reference for the R_{AA} measurement.

The event selections:

- Use a Jet + MBD trigger to select events.
  Requires the z-vertex to be within 30 cm of the nominal interaction point.
  Requires the jet η within detector acceptance.

- Separately applies two background event filters:
  1) Dijet requirement:
     Subleading jet E / Leading jet E > 0.3
     $|\Delta\phi(\text{Subleading jet - Leading jet})| > 3\pi/4$
  2) Energy fraction requirement:
     Jet EMCal energy fraction within 10 – 90%
     Jet oHCal energy fraction within 10 – 90%
     Jet iHCal energy fraction: 0 – 90%





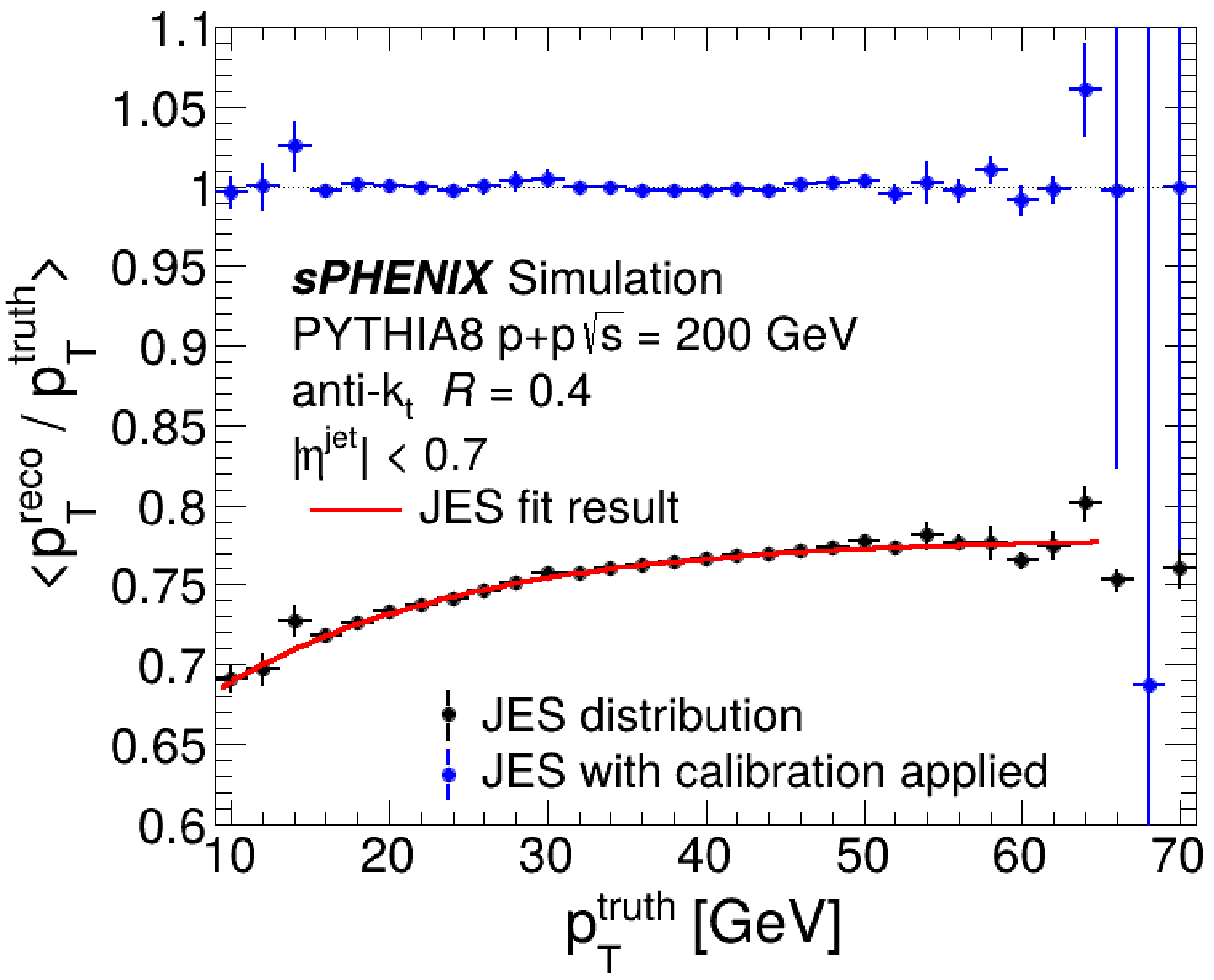
Jet Energy Scale Calibration

- Due to the non-compensating nature of the calorimeters, there is a systematic shift of the Jet Energy Scale.

- We derived an energy scale calibration with PYTHIA generated events going through a GEANT4 simulation of the sPHENIX detector.

- Truth–reco jet matching is done with $\Delta R < 0.3$ (0.75 of the jet radius).

- A closure test is done with the calibration function. The jet energy scale after this calibration is close to 1.



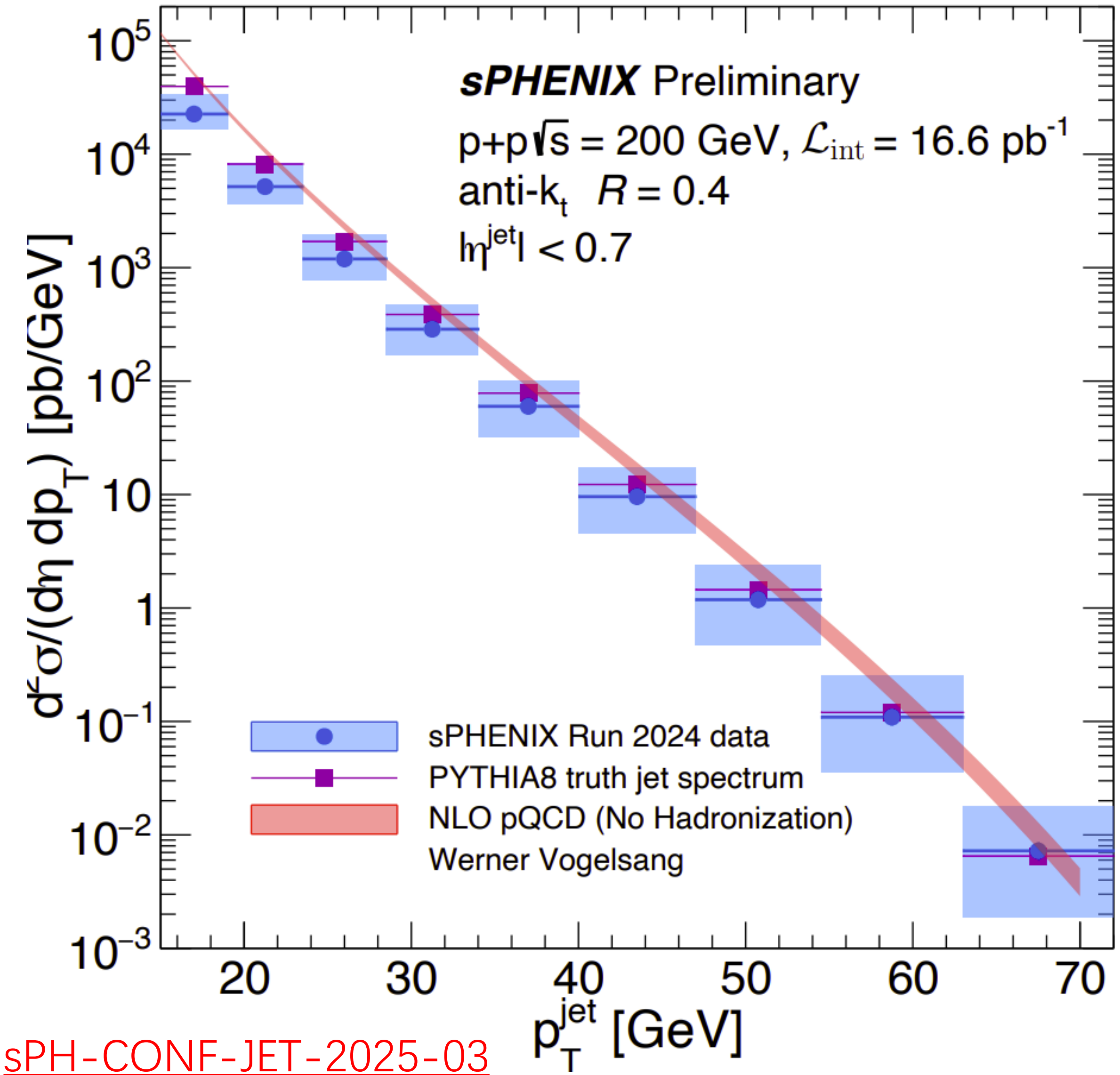
Inclusive Jet Cross Section in p+p

- Unfolded cross section of R=0.4 anti-k_t jets in p+p collisions.

- Pushing to the highest p_T jets observed at RHIC and only 15% of full luminosity used for this analysis.

- PYTHIA8 Detroit tune agrees within uncertainties with data, and NLO pQCD calculation does not include hadronization.

- Systematic uncertainty dominated by jet energy scale uncertainty on the hadronic response (from test beam) and expected to improve significantly with future *in situ* hadronic shower studies.



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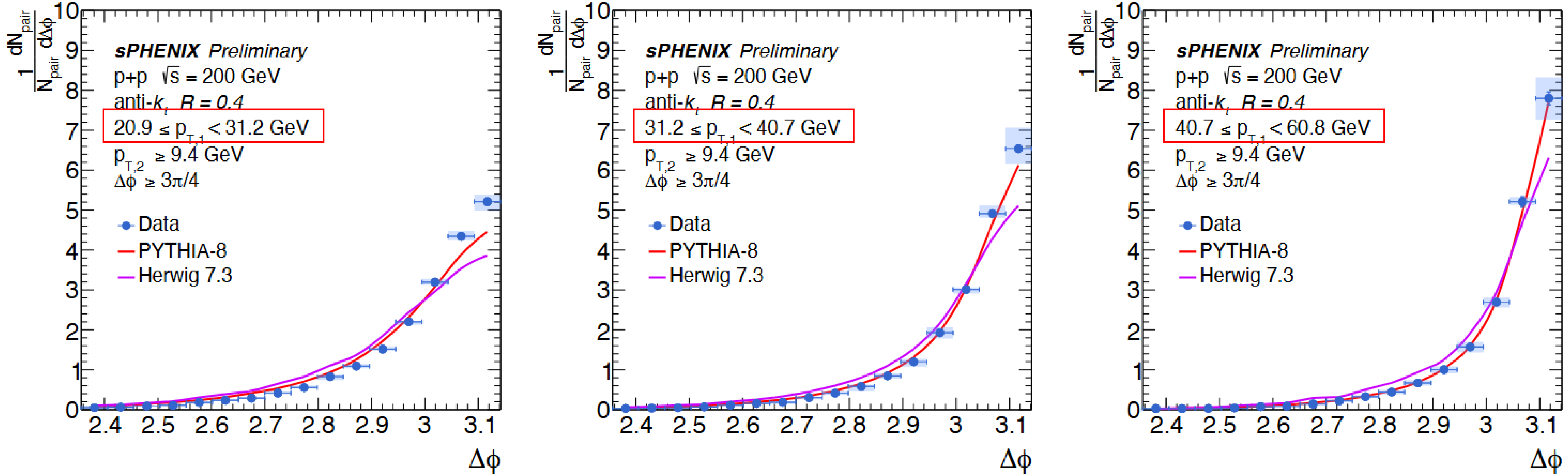
Dijet Correlations in p+p

- Higher leading → steeper $\Delta\phi$ (more back-to-back di-jets)
- Phthia8 largely in agreement with data. Herwig 7.3 shows less peaked distribution than data



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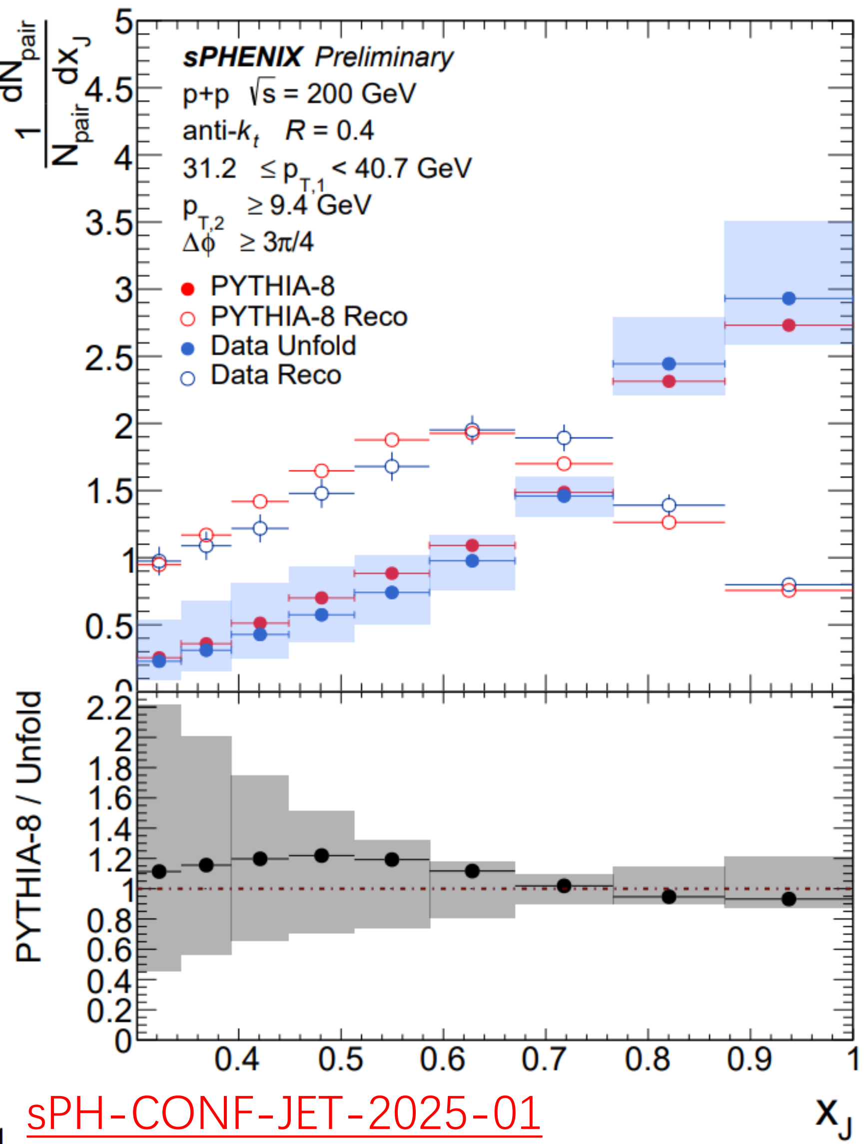
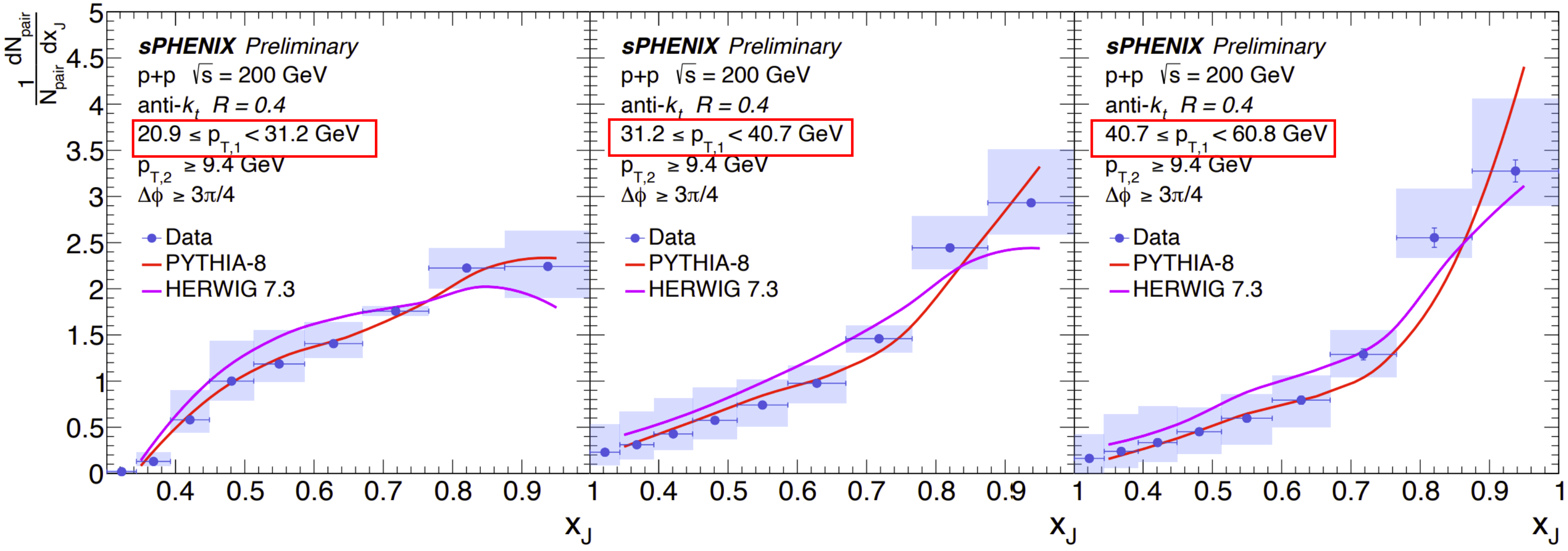
Raw and Unfolded Dijet x_J in p+p

- $x_J = p_{T,2}/p_{T,1}$, where $p_{T,1}$ is leading jet and $p_{T,2}$ is sub leading jet.
- Back-to-back jets are selected $\Delta\phi$>3π/4. 2D unfolding in $p_{T,1}$ and $p_{T,2}$.
- Jet energy resolution dominates systematic uncertainty.
- Pythia agrees with unfolded data within uncertainties.





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In the City of New York

Au+Au Dijet x_J

- First sPHENIX measurement of jet energy loss in QGP with full-jet x_J and observe large suppression. Only ~0.1 nb^{-1} of Au+Au data (~1.5% of Au+Au data we have).

- Unfolded x_J with $\Delta\phi > 7\pi/8$, R=0.3 and leading jet p_T = 30.0 - 43.2 GeV.

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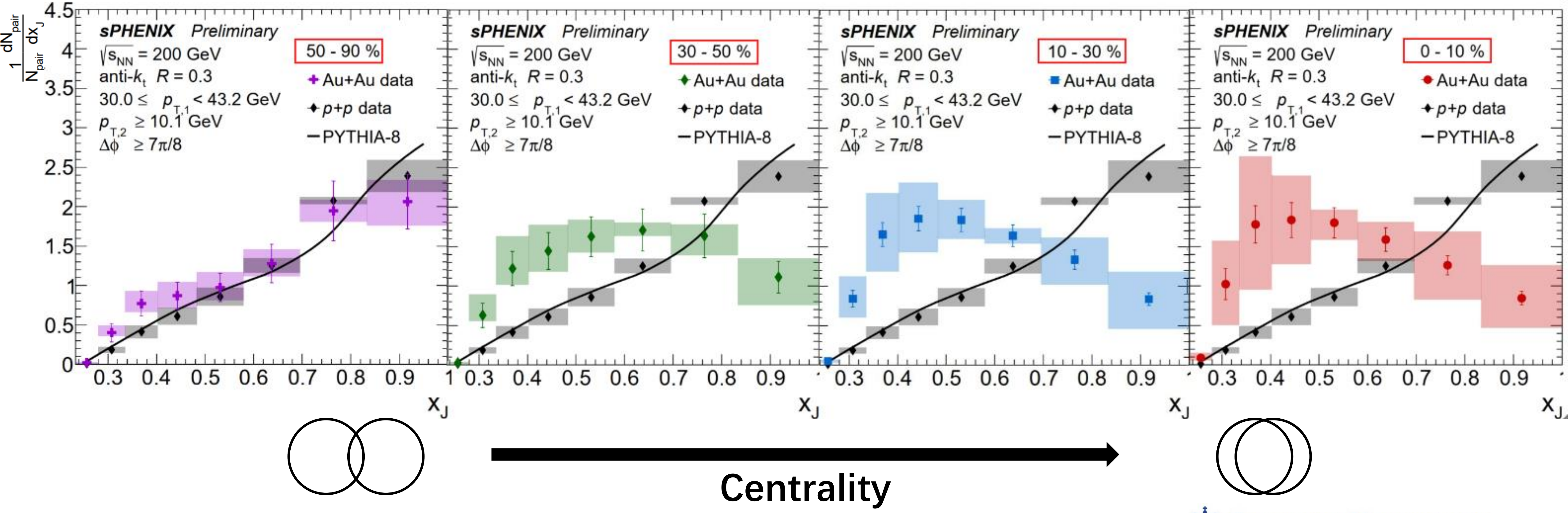
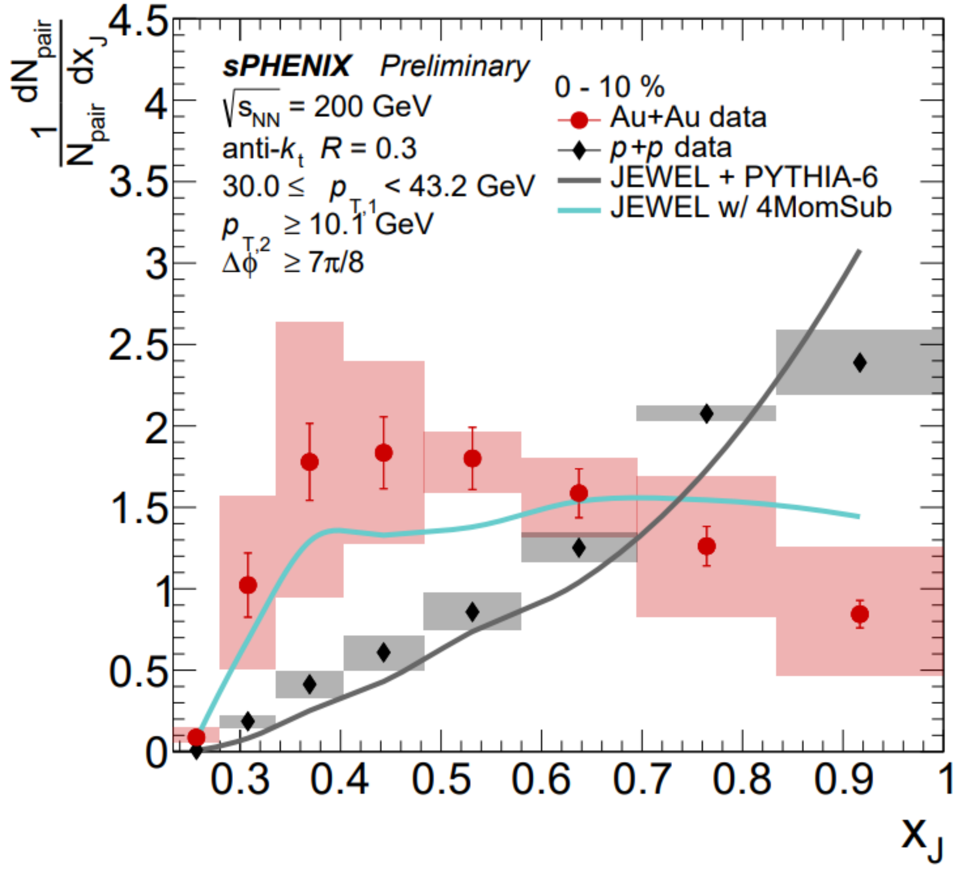
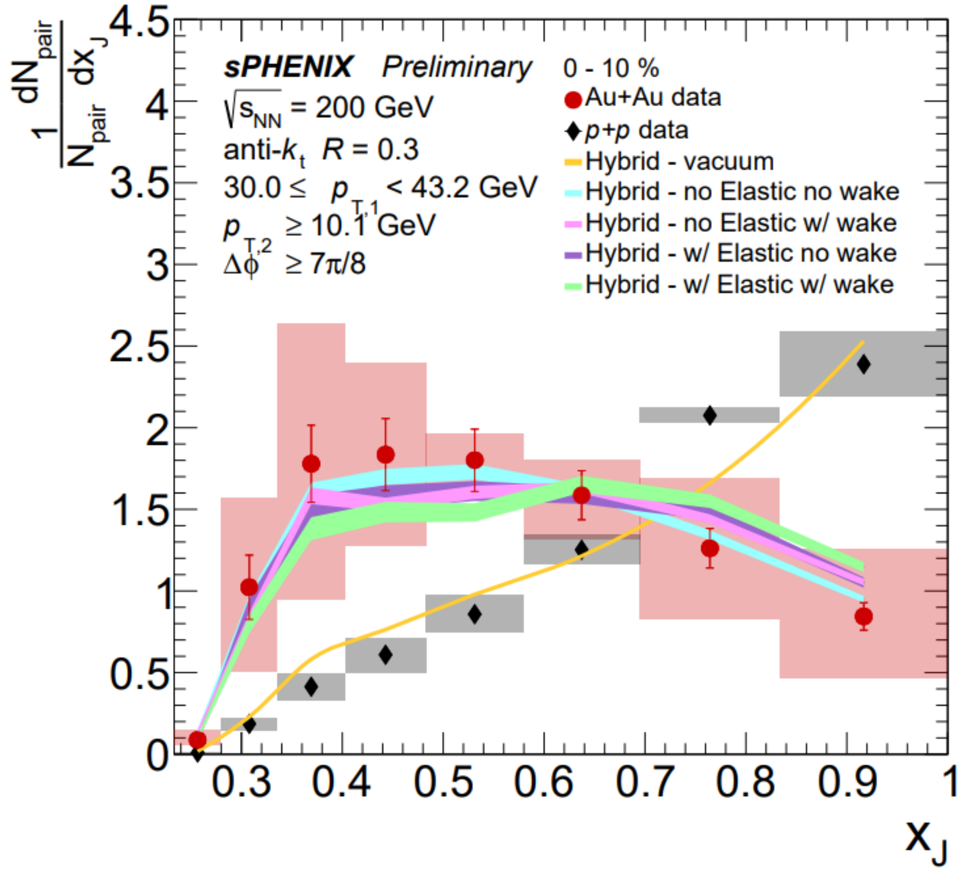


Au+Au Dijet x_J

• Qualitatively consistent with JEWEL and consistent with all hybrid model with various forms of medium response.





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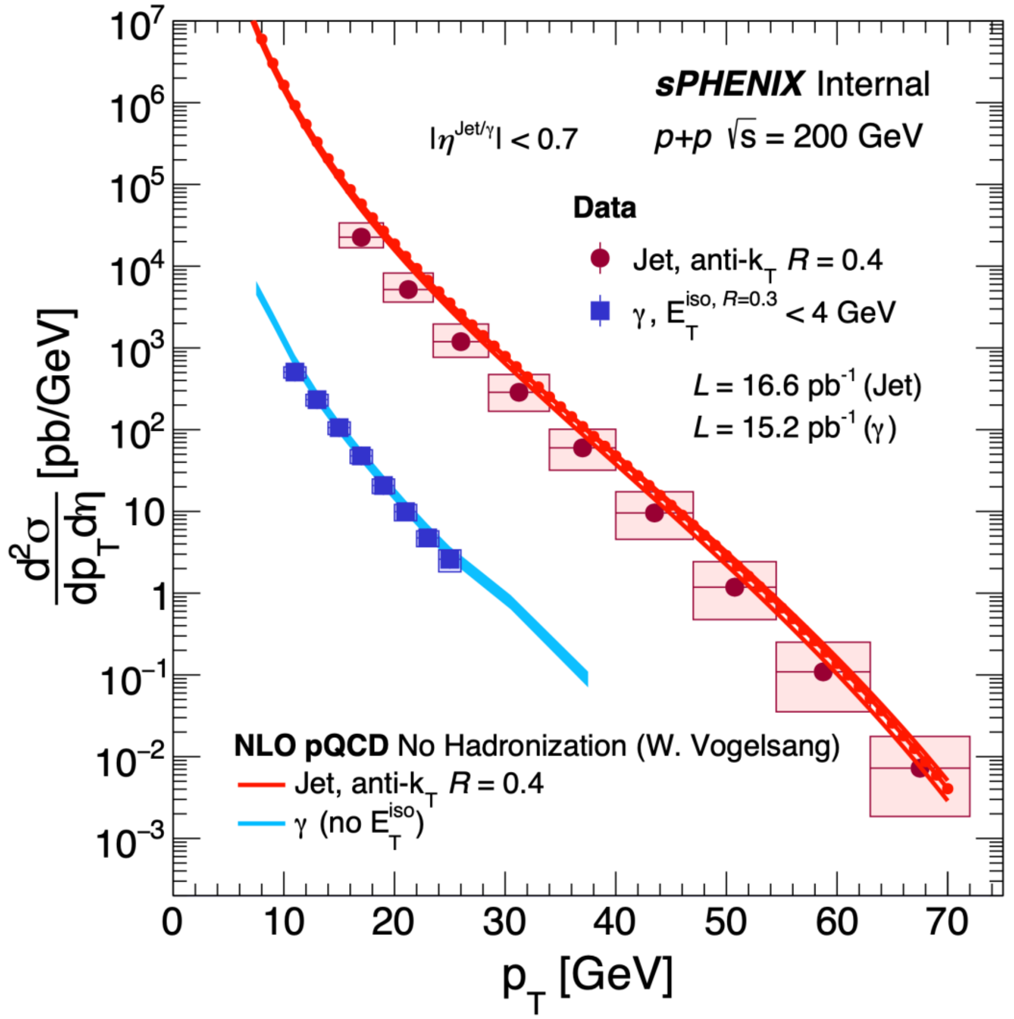
Summary

- sPHENIX established baseline in p+p for calorimeter.
- First full jet measurements at RHIC which are pushing explored phase space with a small fraction of the data.
- First preliminary energy loss measurements with dijet x_J in Au+Au.
- Prompt photon p_T differential cross section.
- Lots more data in hand for more differential measurements and jet-substructure measurements with tracking.
- Lots more result with large data set!



sPHENIX Public Results

Thanks for your attention