Jets at sPHENIX: toward probing the early stages

Yeonju Go

Brookhaven National Laboratory / Stony Brook University

EMMI Workshop: Probing the early stages with jets

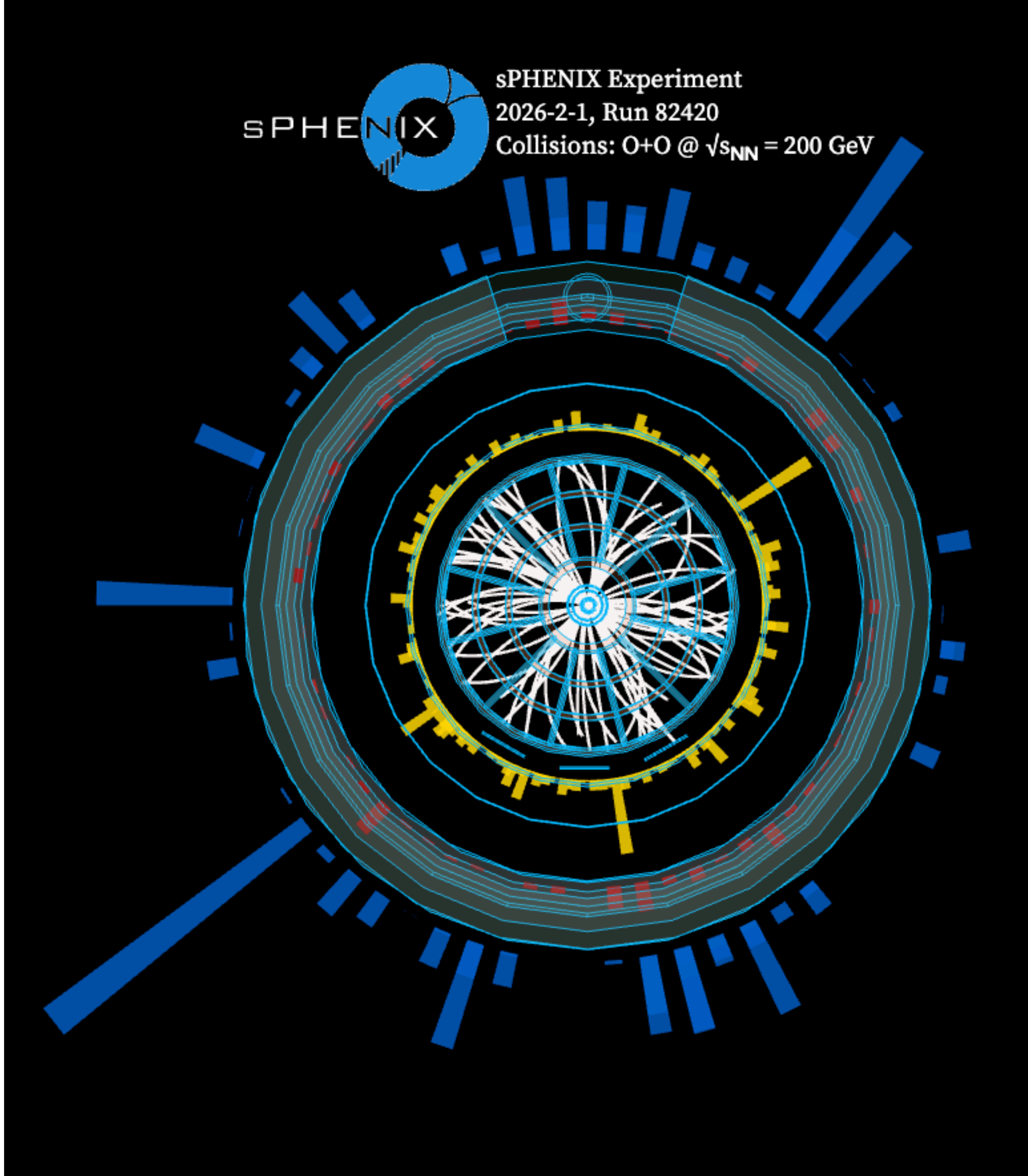
GSI, Darmstadt, Germany

July 13-17th 2026

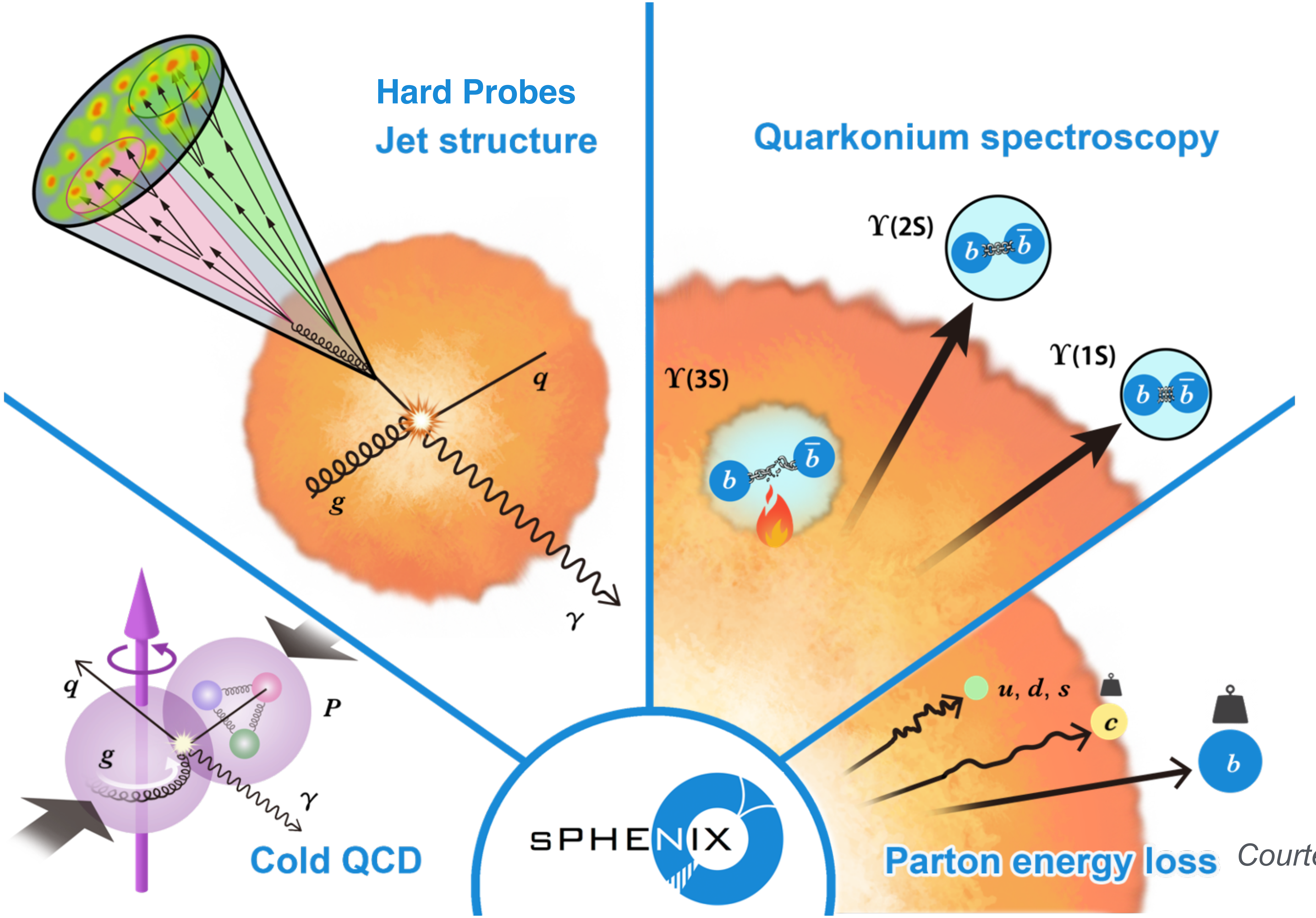
Stony Brook University

Brookhaven National Laboratory

U.S. DEPARTMENT of ENERGY

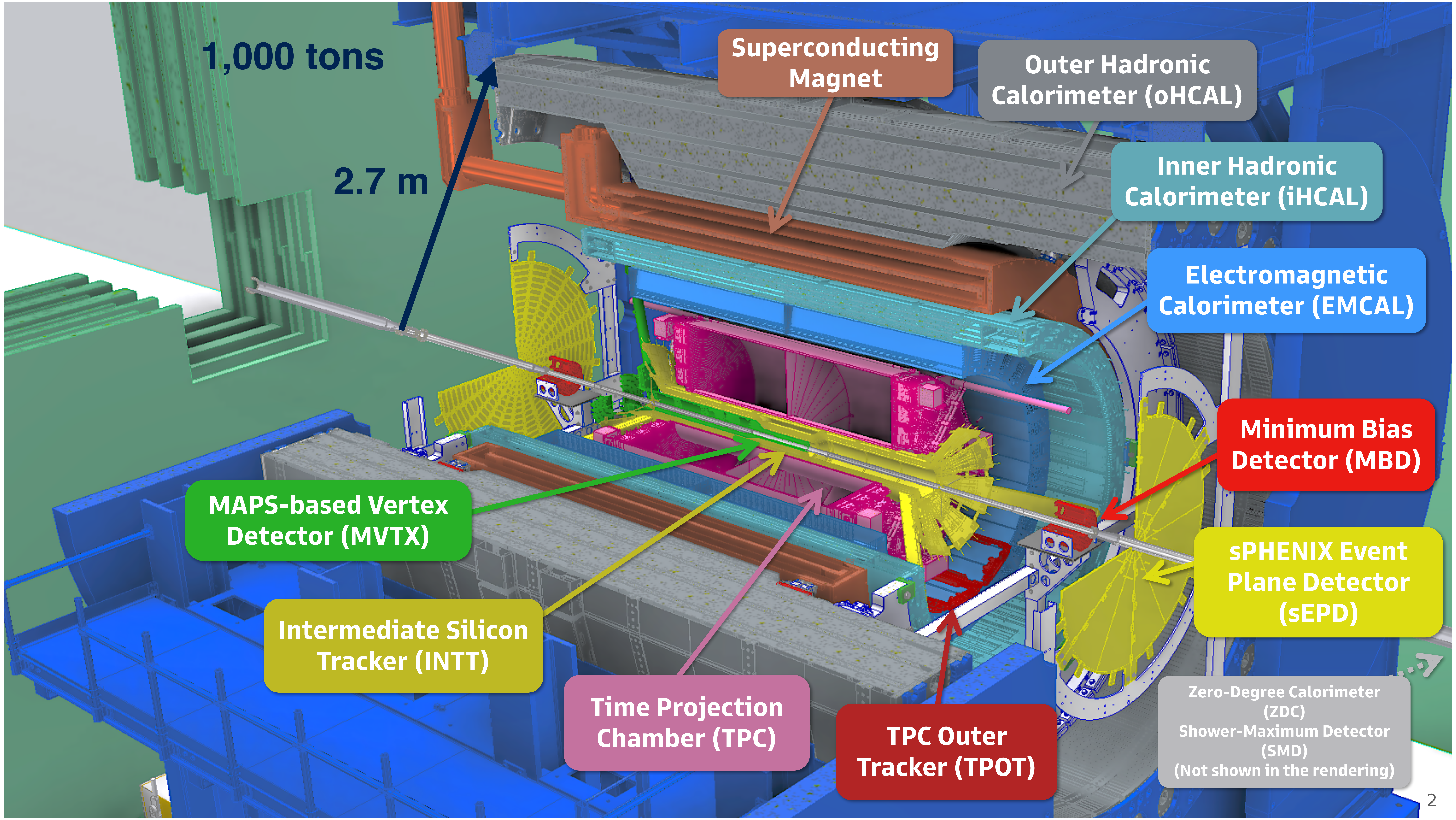


sPHENIX Physics Goal



Courtesy of Misaki Ouchida (Hokkaido University)

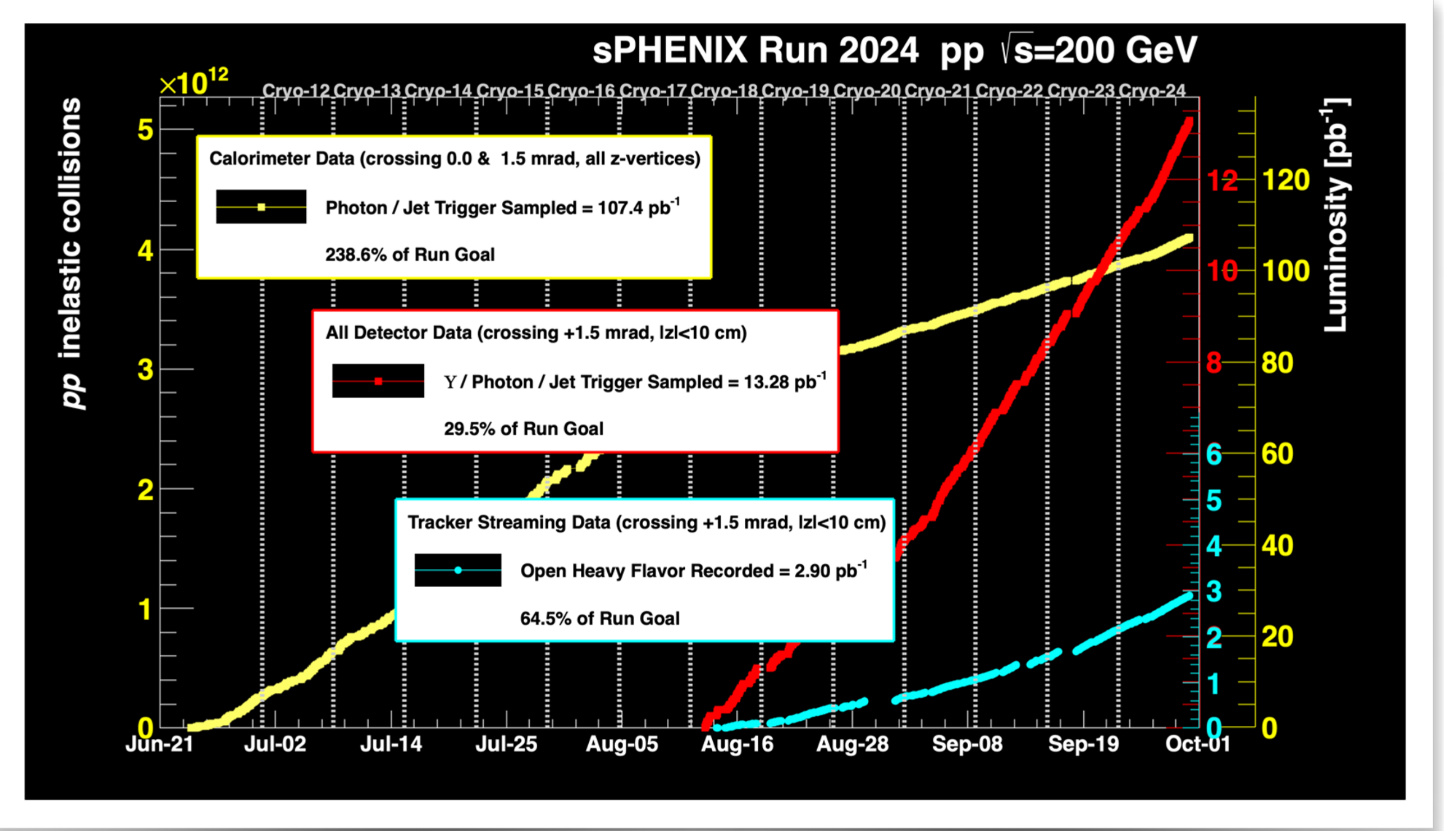
sPHENIX Experiment at RHIC

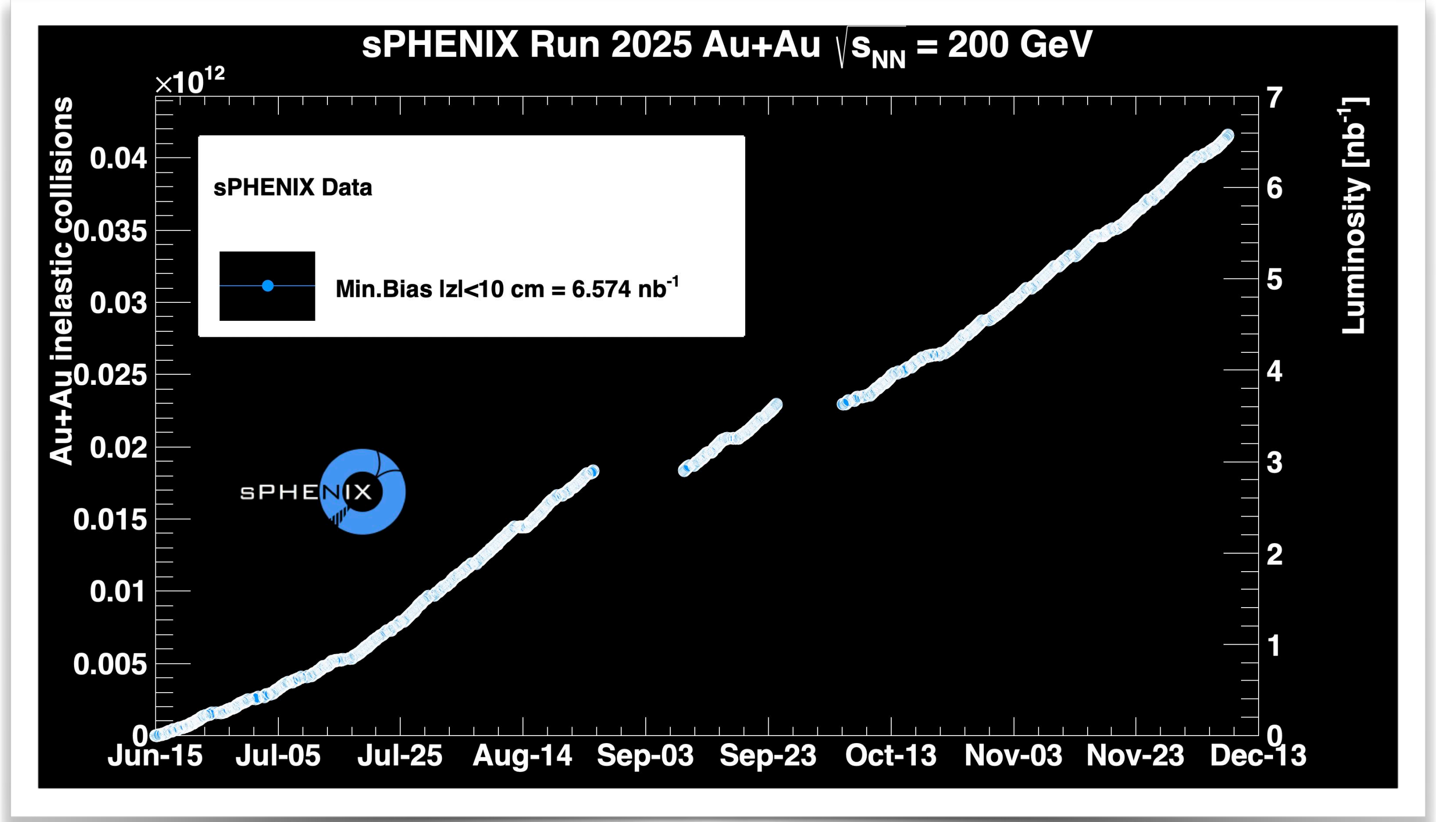


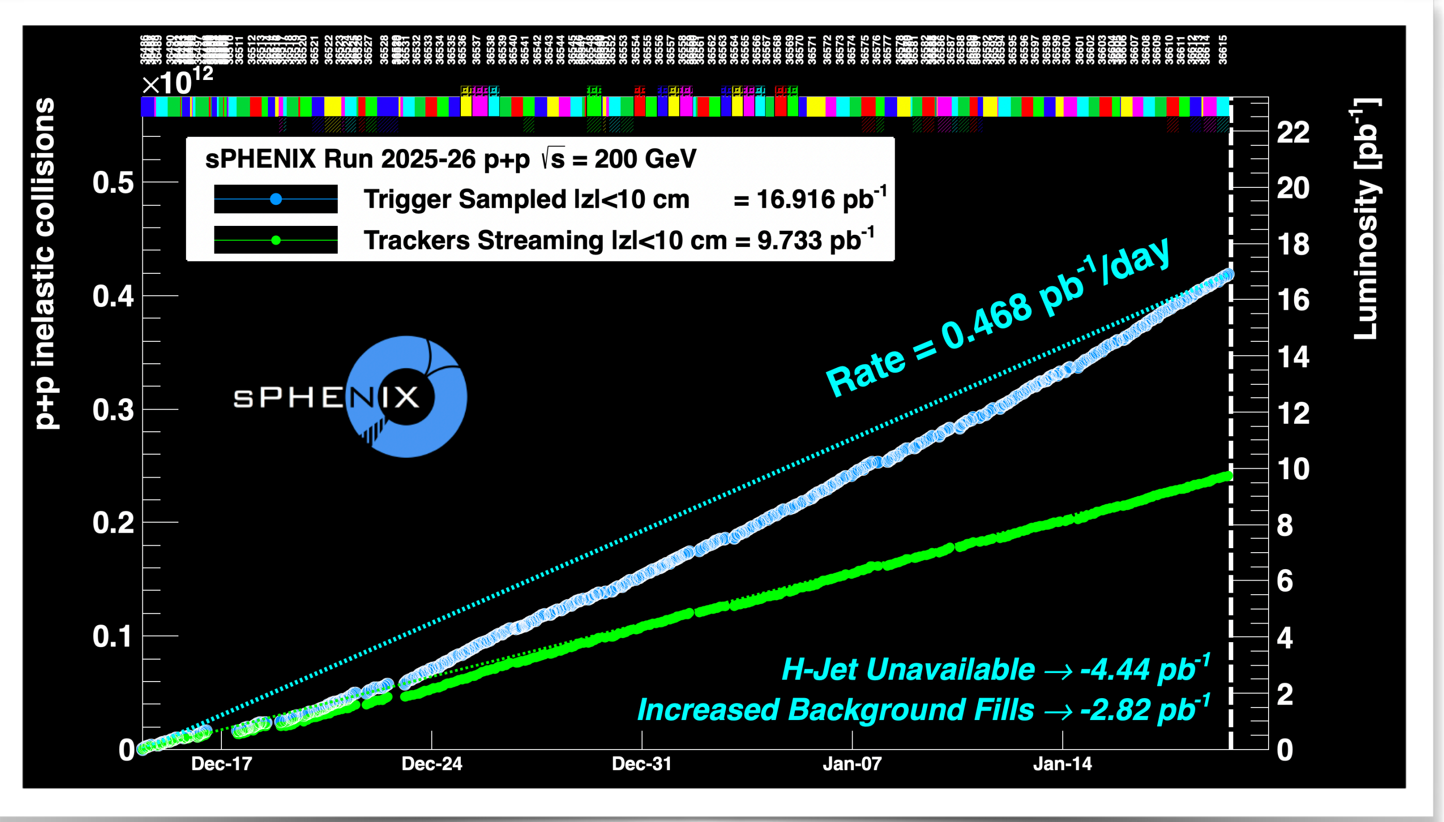
- New detector at RHIC
- First hadronic calorimetry at mid-rapidity at RHIC
  - ➡ unbiased jet trigger/ reconstruction
  - ➡ large acceptance (hermetic, $|\eta|<1.1$)
- High precision tracking system
  - ➡ MVTX+INTT+TPC +TPOT
- High data readout rate (15kHz DAQ)

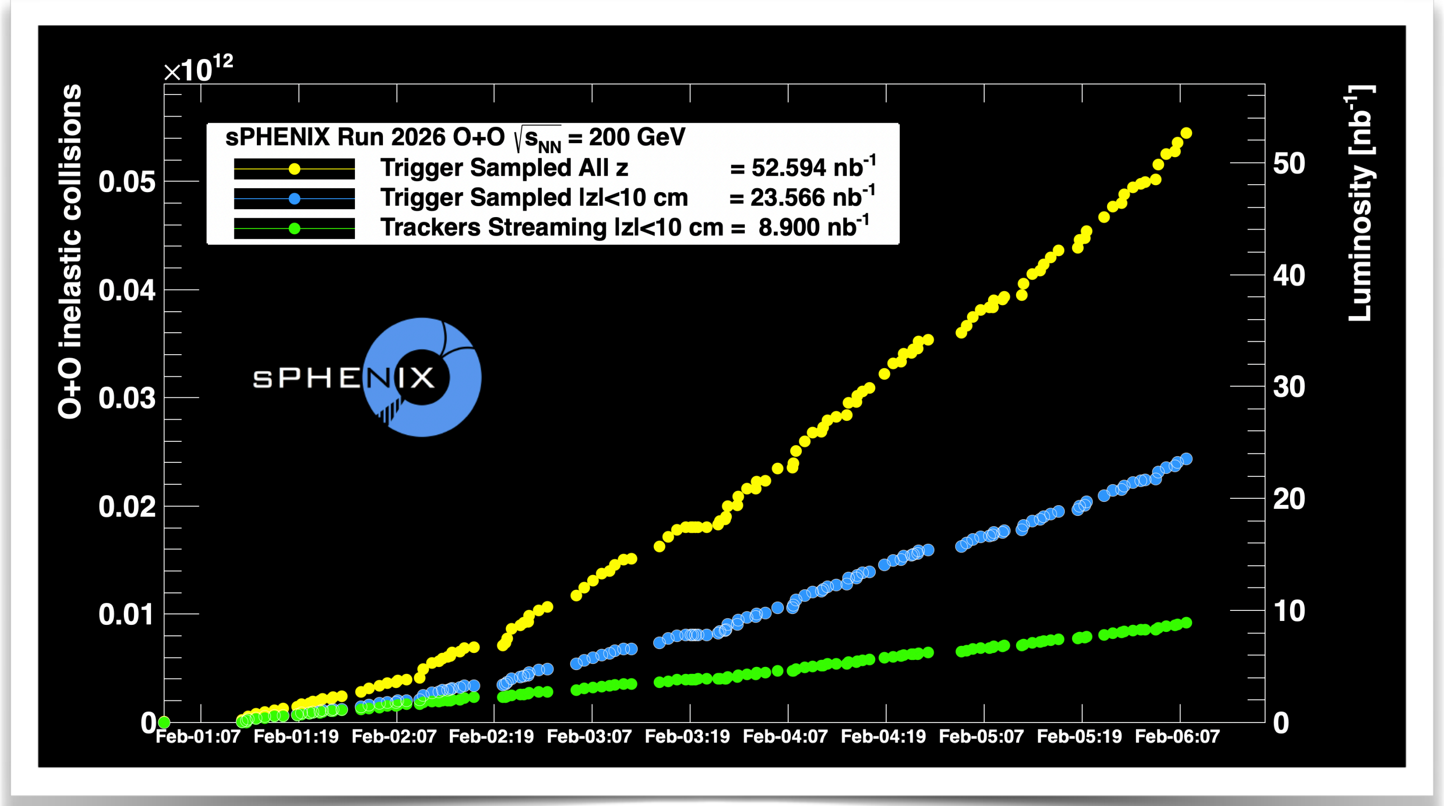
sPHENIX Data Taking

- **Data taking for 3 years: 2023-2026** (Last RHIC run on 6th Feb., 2026)
  - ➡ sPHENIX collected 300 PB out of RHIC's total 450 PB of data over 25 years









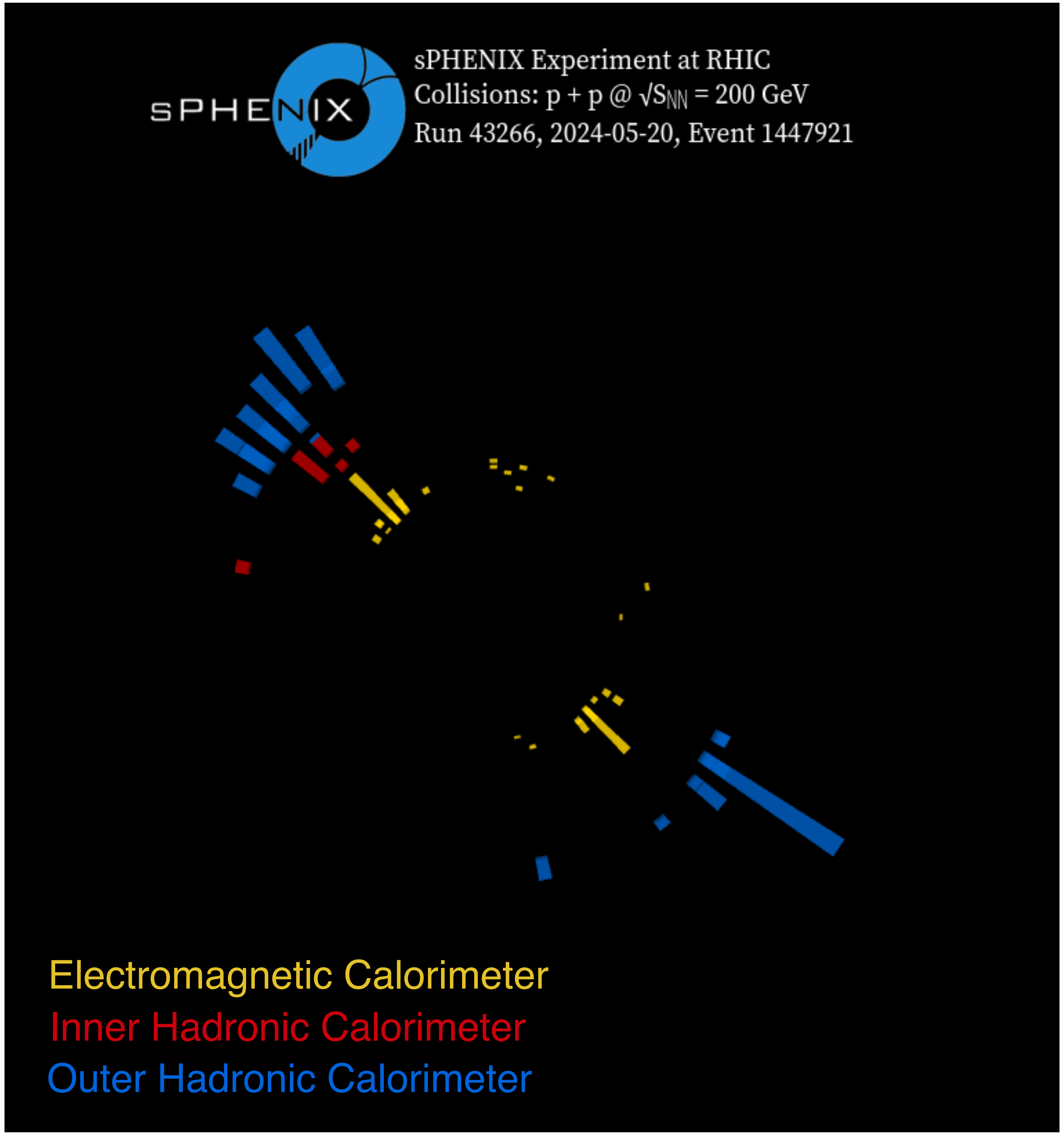
2023 → **2024** → **2025/2026**

- 2023: Commissioning Au+Au collisions
- 2024: Commissioning & *p+p* collisions
- 2025/2026: **Au+Au** & ***p+p*** & **O+O collisions**

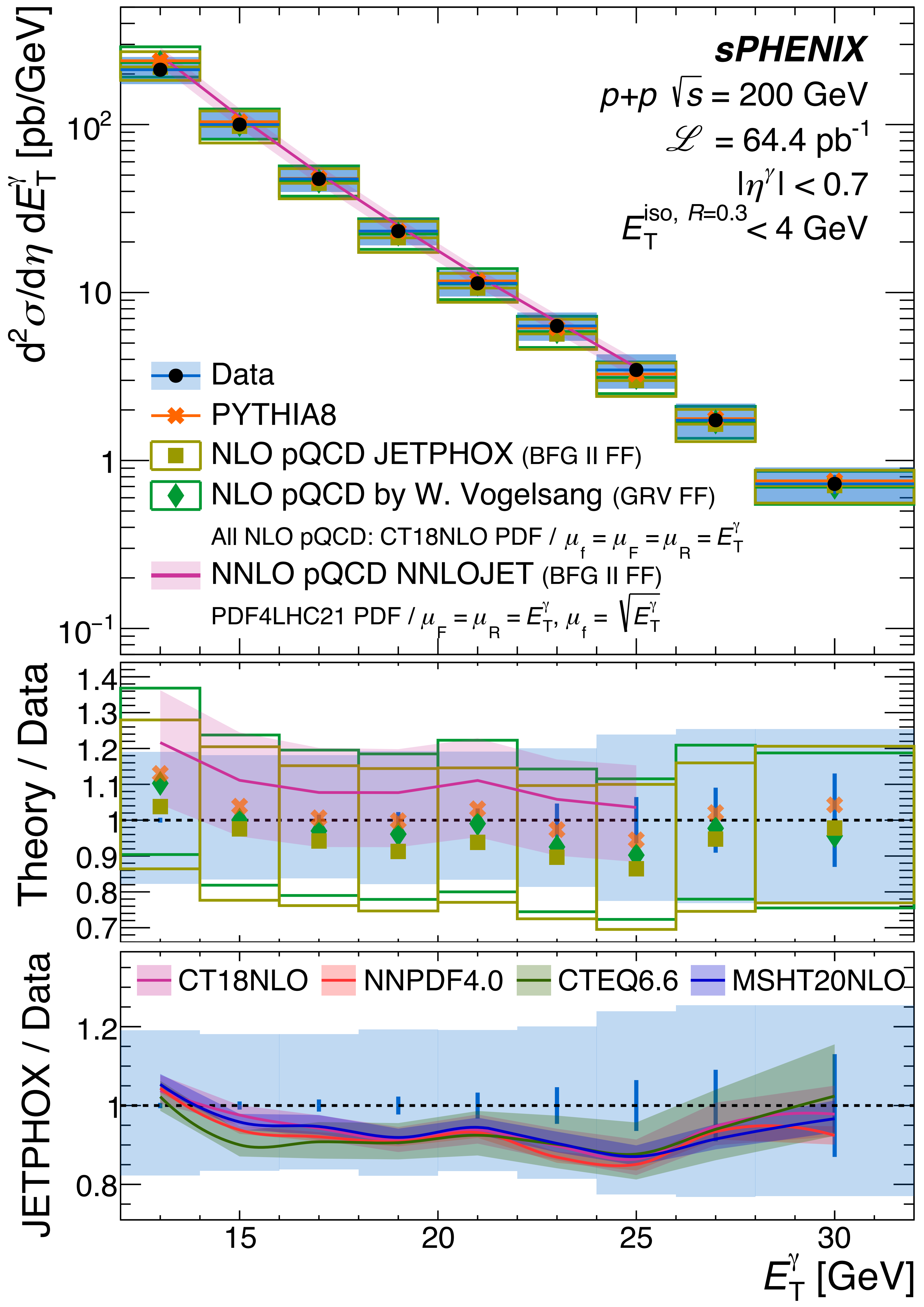
p+p	115/pb *
Au+Au	6.6/nb
O+O	53/nb *

* calorimeter only dataset luminosity

Setting the p+p baseline with photons and jets



Isolated Prompt Photons in p+p



[sPH-JET-2026-02](#) [arXiv:2607.03892](#)

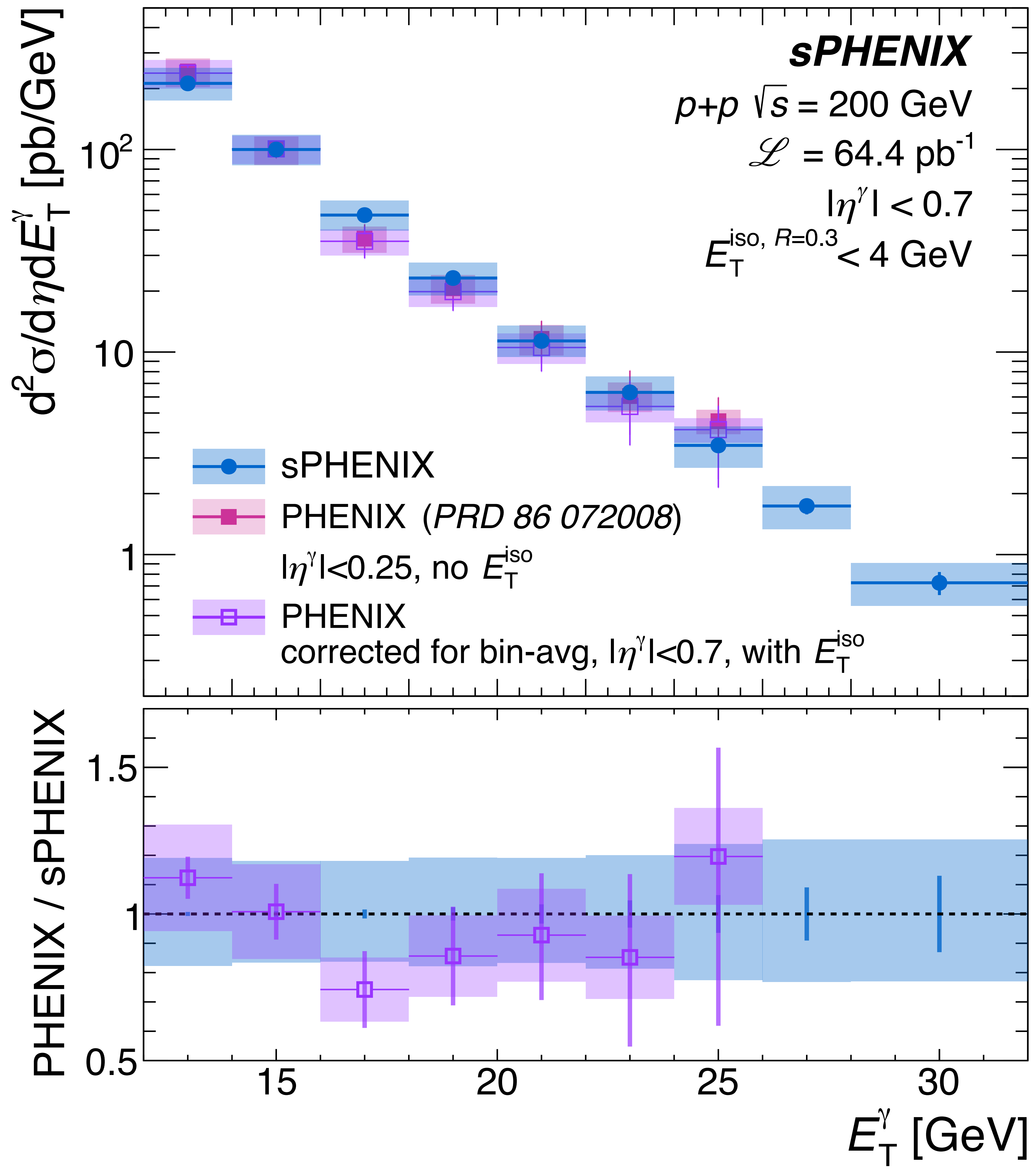
- Isolated prompt photons in p+p test pQCD calculations and provide sensitivity to the gluon PDF
- $E_T^{\text{iso}} < 4$ GeV within ΔR = 0.3
- Gateway to γ-jet measurements
- **Theory comparison**
  - ➡ **PYTHIA8**: Detroit tune
  - ➡ **JETPHOX**: NLO pQCD, CT18NLO PDF, BFG II FF
  - ➡ **NLO pQCD W. Vogelsang**: NLO pQCD, CT18NLO PDF, GRV FF
  - ➡ **NNLO pQCD NNLOJET**: NNLO pQCD, PDF4LHC21 PDF, BFG II FF
    - *NNLO is about 1.2x larger than NLO*

All pQCD NLO & NNLO predictions consistent with data within uncertainties

Isolated Prompt Photons in p+p

[sPH-JET-2026-02](#) [arXiv:2607.03892](#)

- Comparison with previous RHIC measurement: Extended E_T reach with improved statistical precision



Isolated Prompt Photons in p+p

sPH-JET-2026-02 arXiv:2607.03892

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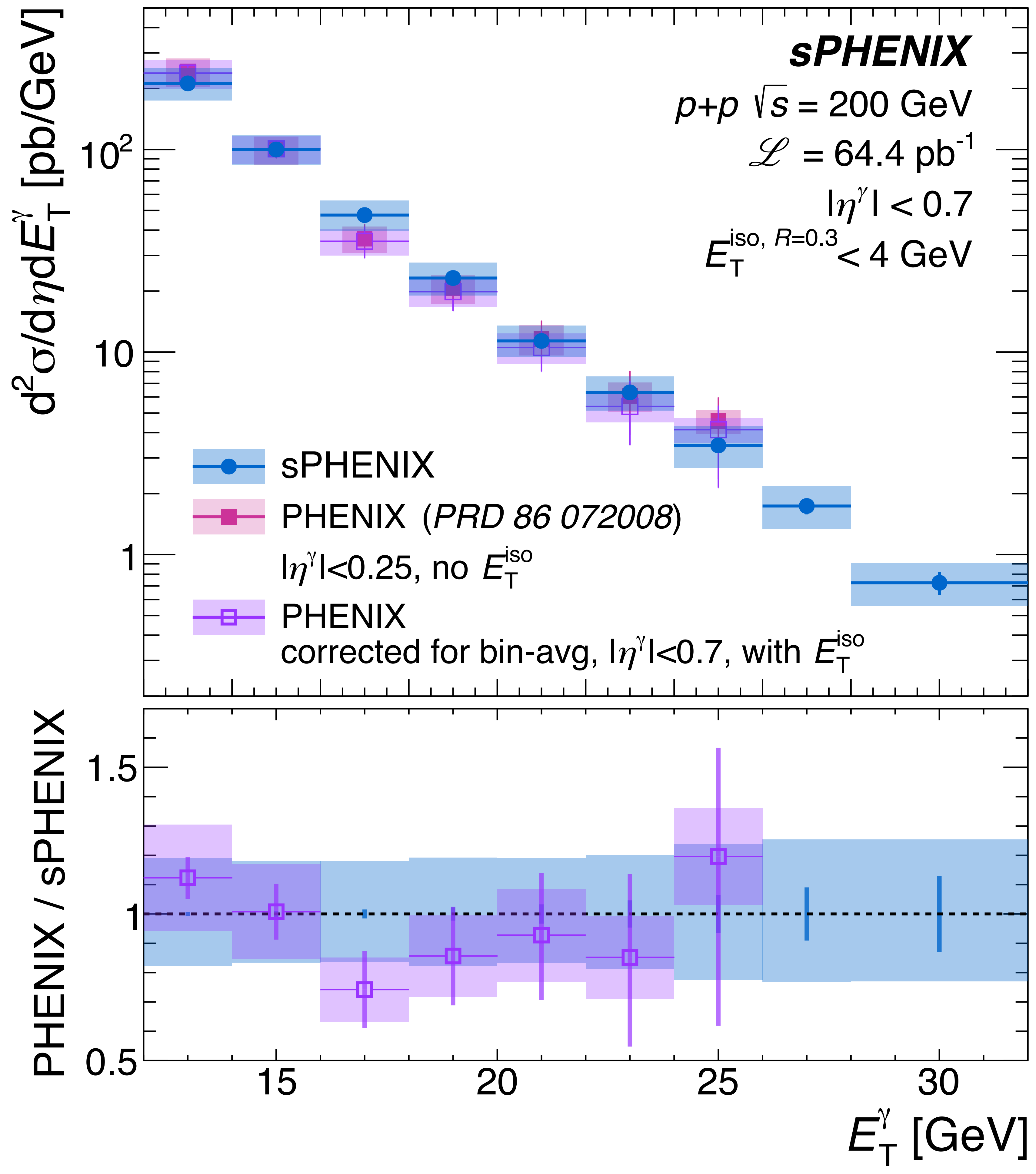
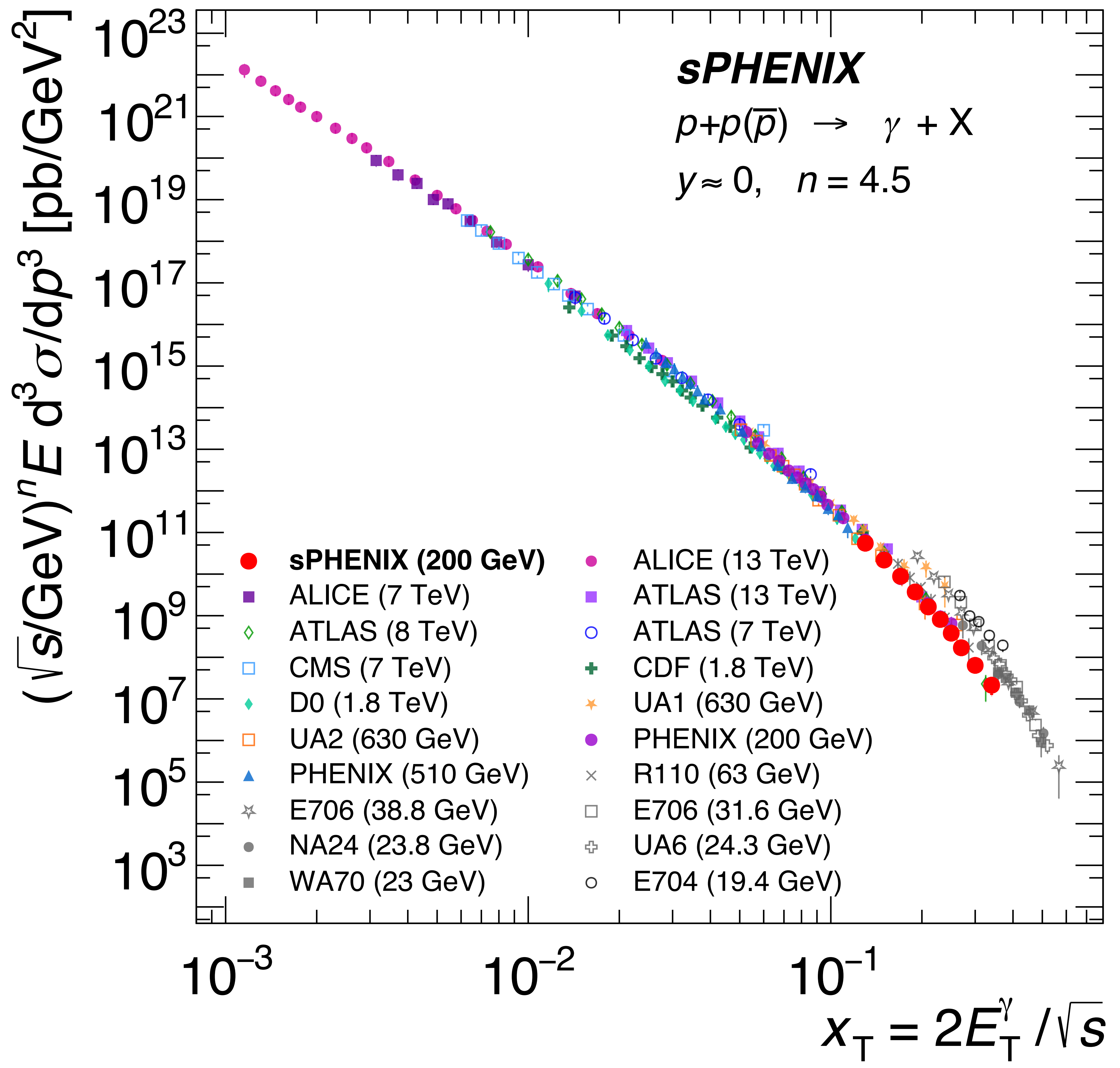
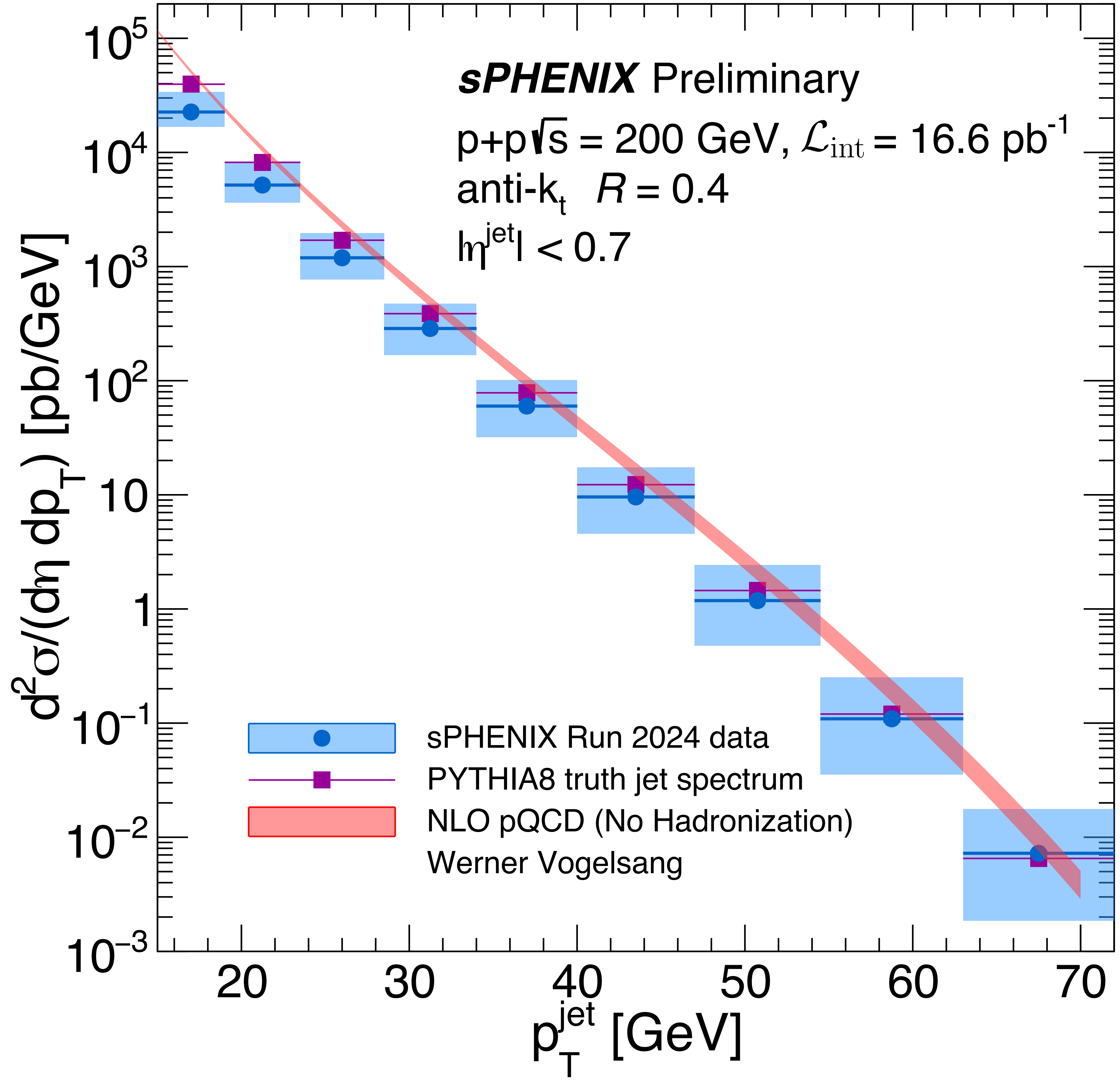




- sPHENIX is consistent with the global x_T-scaling trend
- At $\sqrt{s}$ = 200 GeV, sPHENIX reaches $x_T \approx 0.32$, the highest x_T reach at RHIC

Inclusive Jet Cross Section in p+p

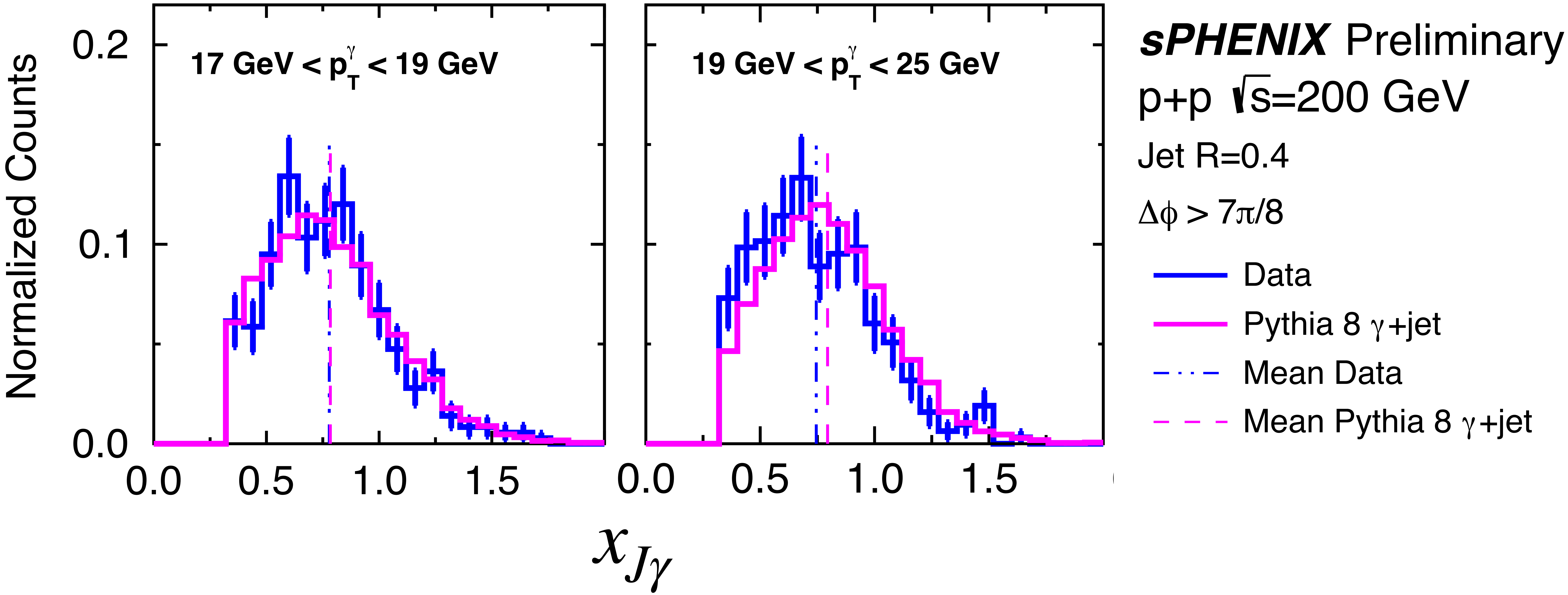
sPH-CONF-JET-2025-03



- **Unprecedented kinematic reach up to 70 GeV (Bjorken $x \sim 0.7$ at $\sqrt{s}$ = 200 GeV)**
- This preliminary result used only **15%** (16 pb^{-1}) of the full p+p dataset collected
  - ➡ *Final results will benefit from substantially improved statistical precision*
- Systematic uncertainty dominated by **jet energy scale** on the hadronic response (from test beam)
  - ➡ expected to improve with in-situ calibration
- **Theory comparison**
  - ➡ **PYTHIA8**: Detroit tune
  - ➡ **NLO pQCD W. Vogelsang**: no hadronization

Photon+jet in p+p

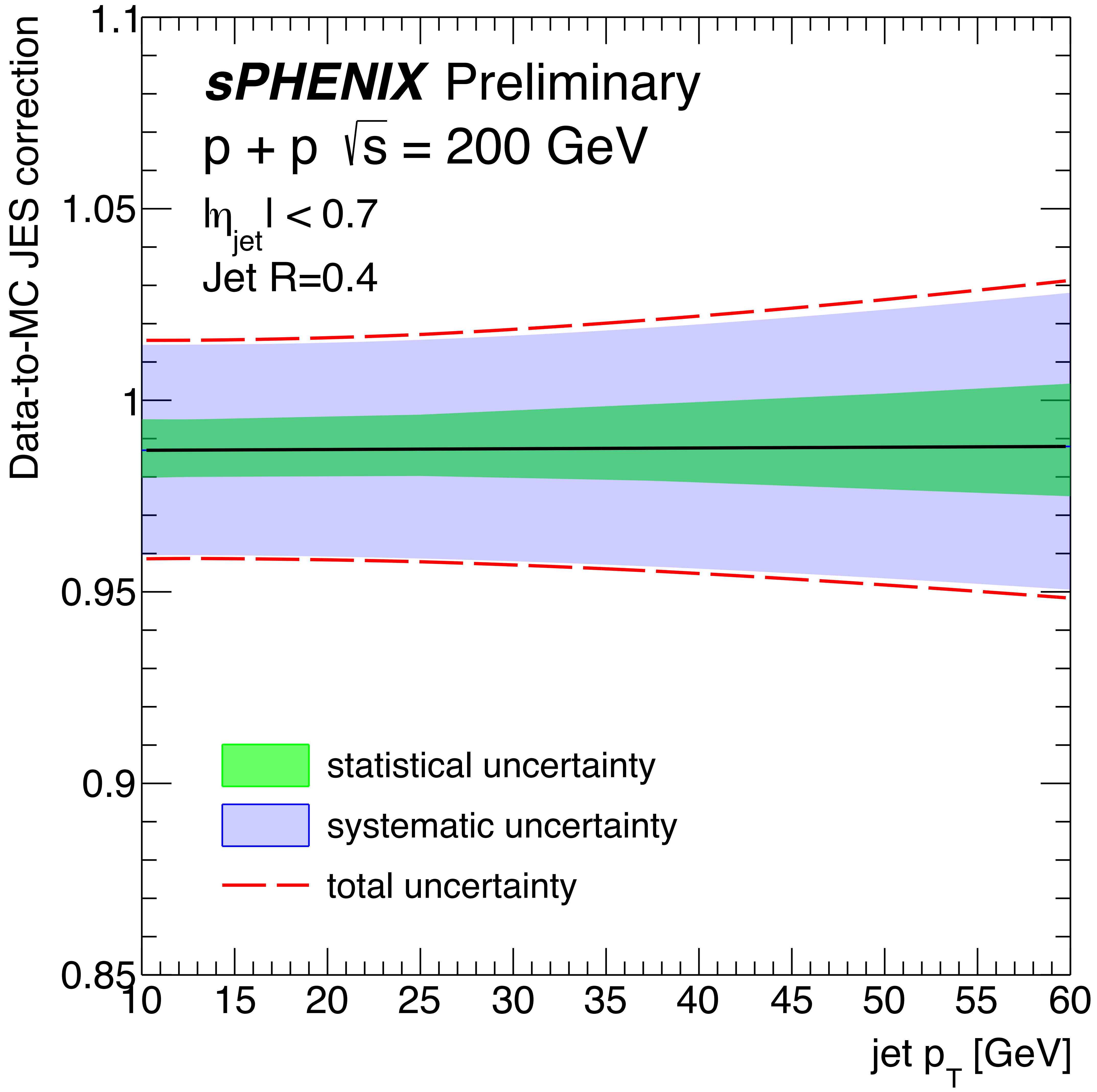
sPH-CONF-JET-2026-01



- **In-situ jet energy calibration** using photon-tagged jets
- Photon+jet in p+p also establish the *baseline for that in heavy ion collisions*
  - ➡ *Fully-corrected and unfolded photon+jet results for final result*

In-situ jet calibration in p+p

sPH-CONF-JET-2026-01



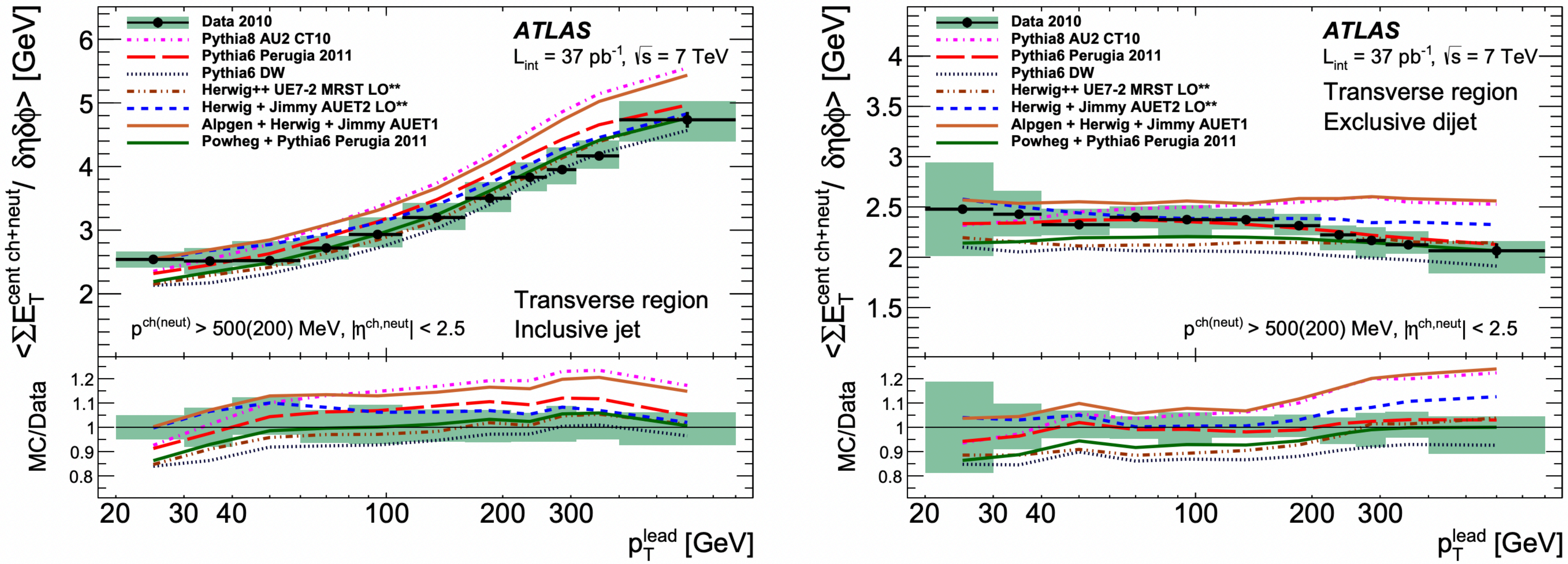
- Use **photon+jet** and **multi-jet** events to *calibrate the jet energy scale* (JES) over a broad range, $10 < p_T < 60$ GeV
- Global Data-to-MC fit derived using both channels to determine absolute JES correction and uncertainties

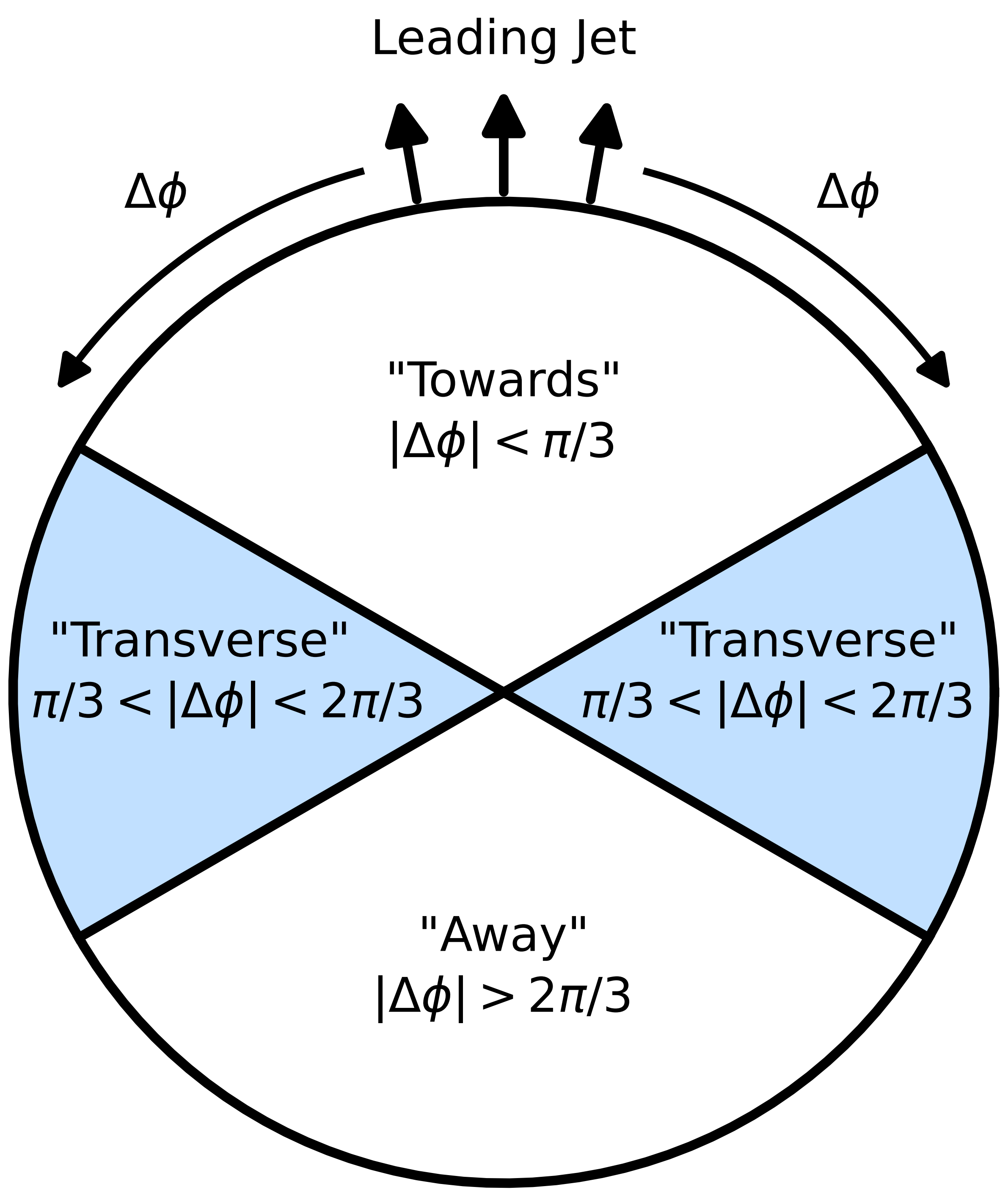
Tuning MC in p+p

Underlying Event with Jets in p+p

sPHENIX

[ATLAS, EPJC 74 (2014) 8, 2965](#)



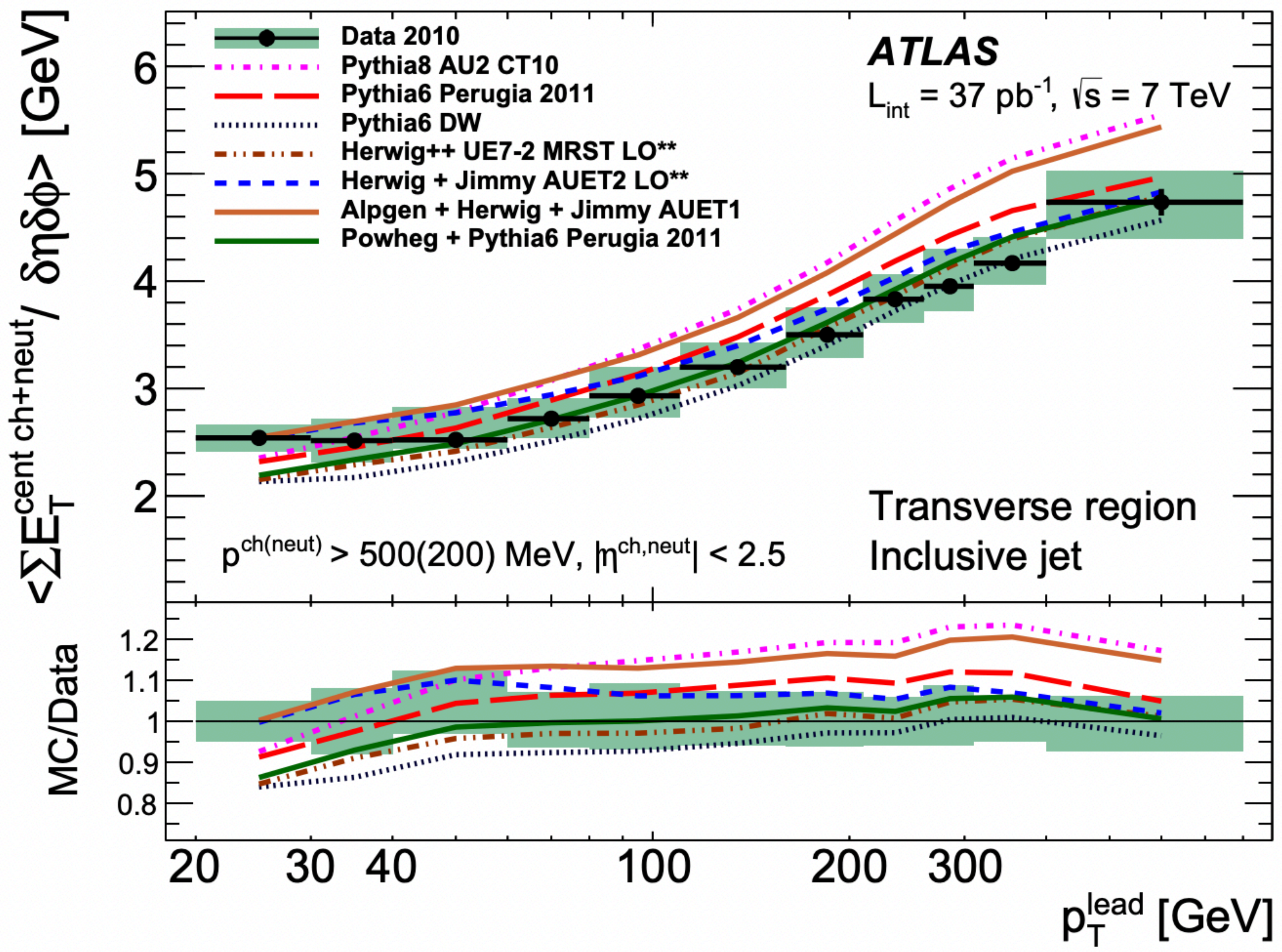


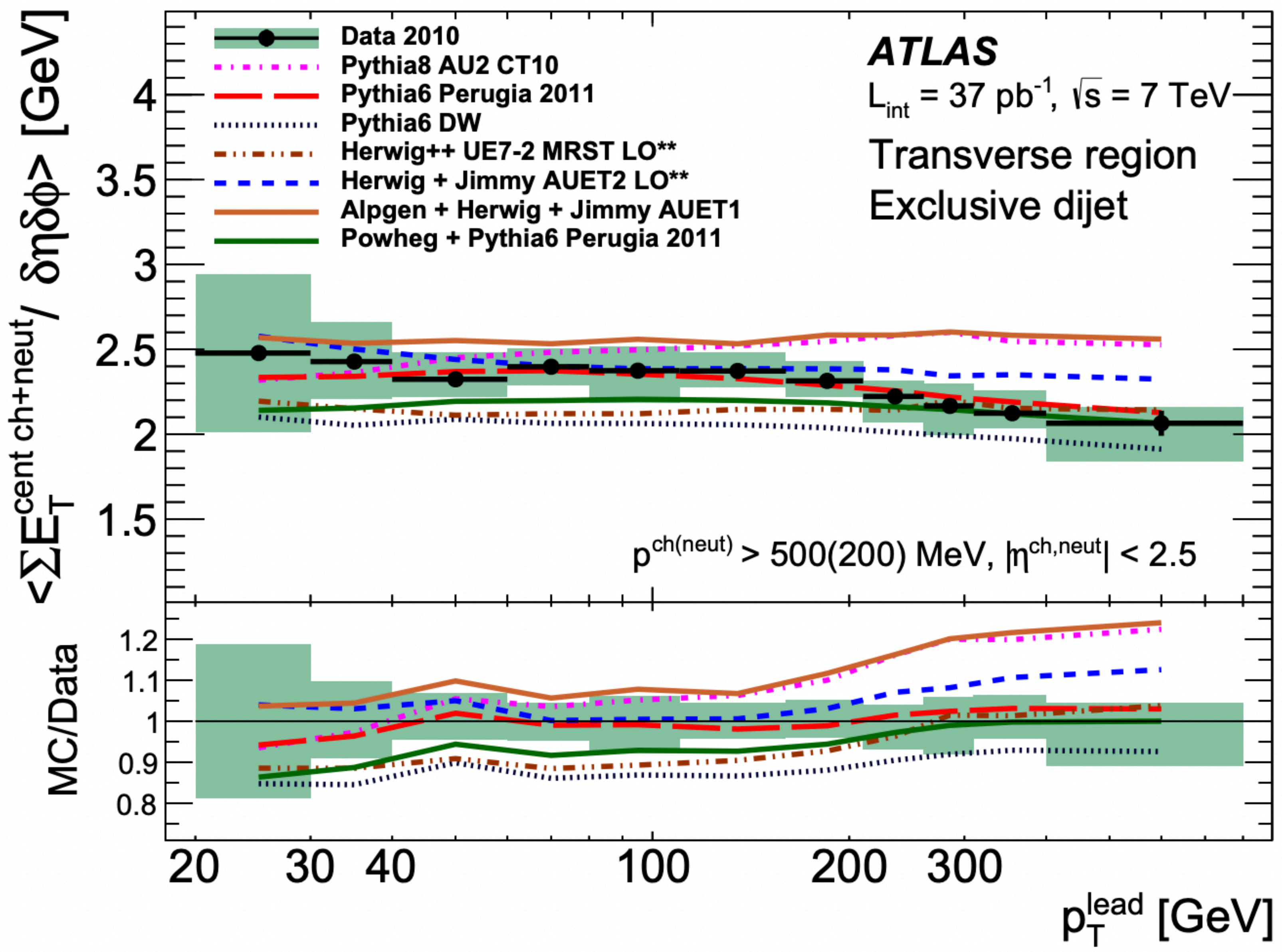
- At the LHC, the **energy density in the transverse region** is correlated with the **leading-jet p_T** for inclusive jet events, but anti-correlated for exclusive dijet events

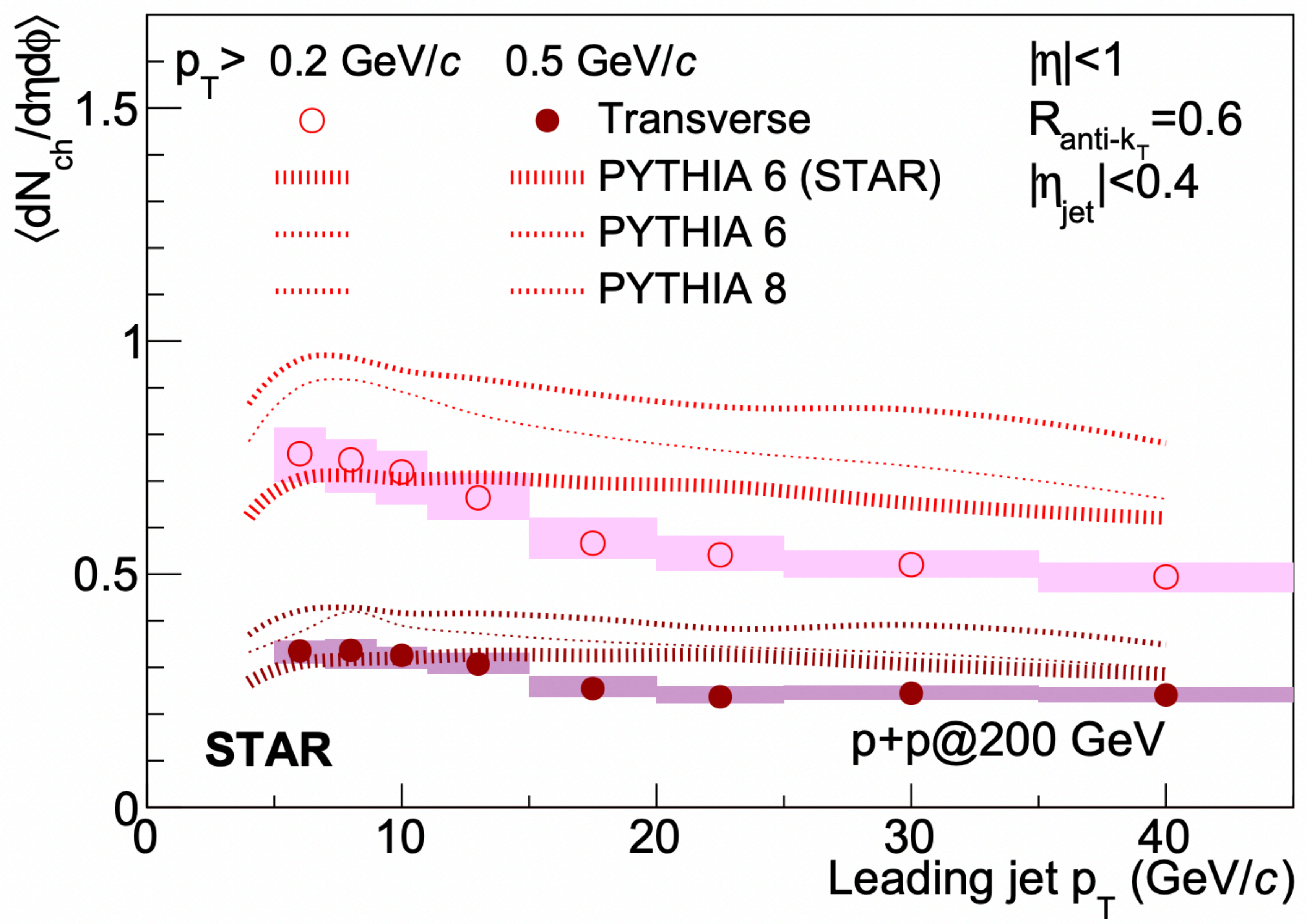
Underlying Event with Jets in p+p

ATLAS, EPJC 74 (2014) 8, 2965

STAR, PRD 101 (2020) 5, 052004







- At the LHC, the **energy density in the transverse region** is correlated with the **leading-jet p_T** for inclusive jet events, but anti-correlated for exclusive dijet events
- RHIC probes higher x, where *energy conservation plays a more important role*
- STAR observed an anti-correlation between charged-particle multiplicity and the leading-jet p_T

Underlying Event with Jets in p+p

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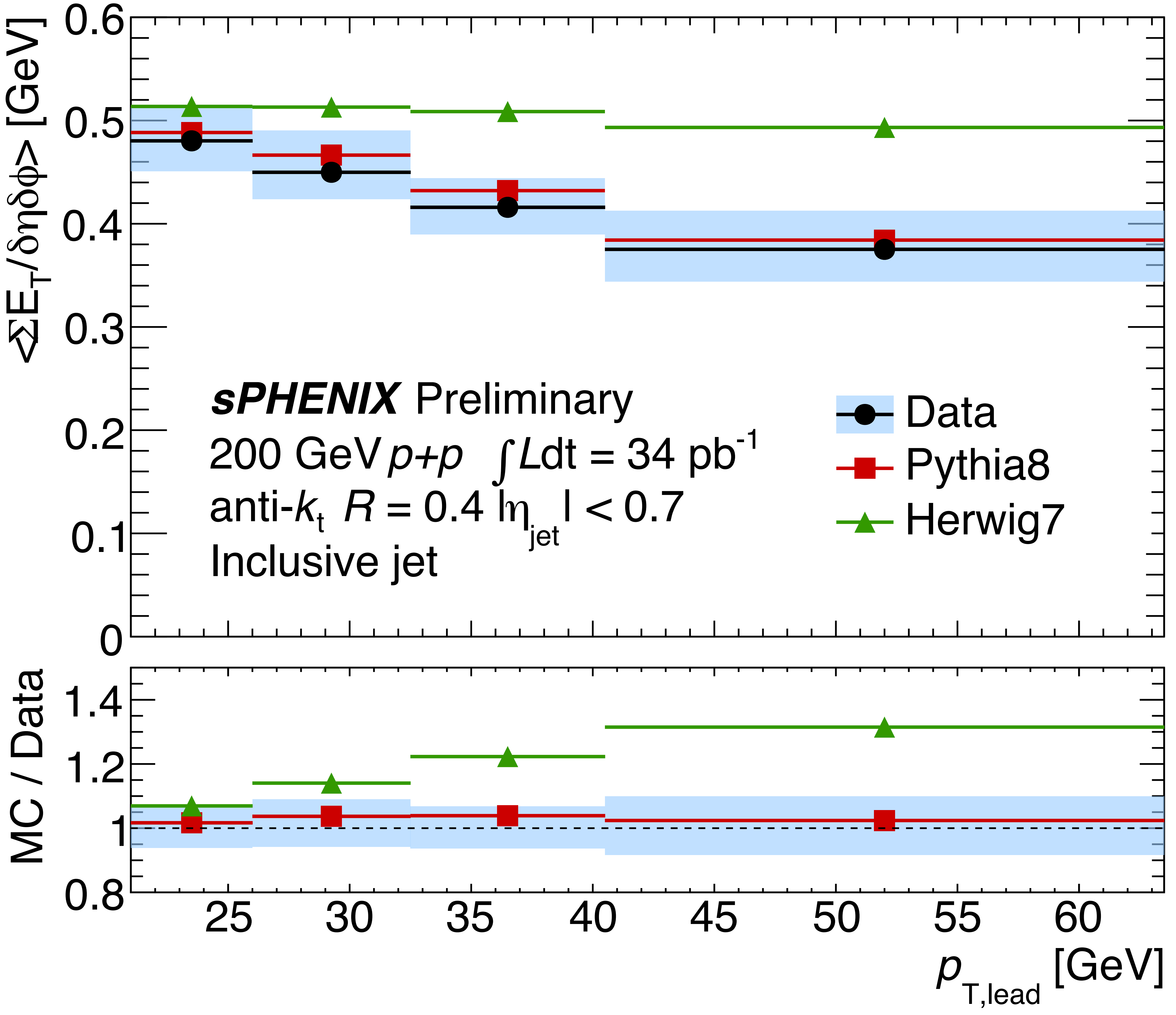
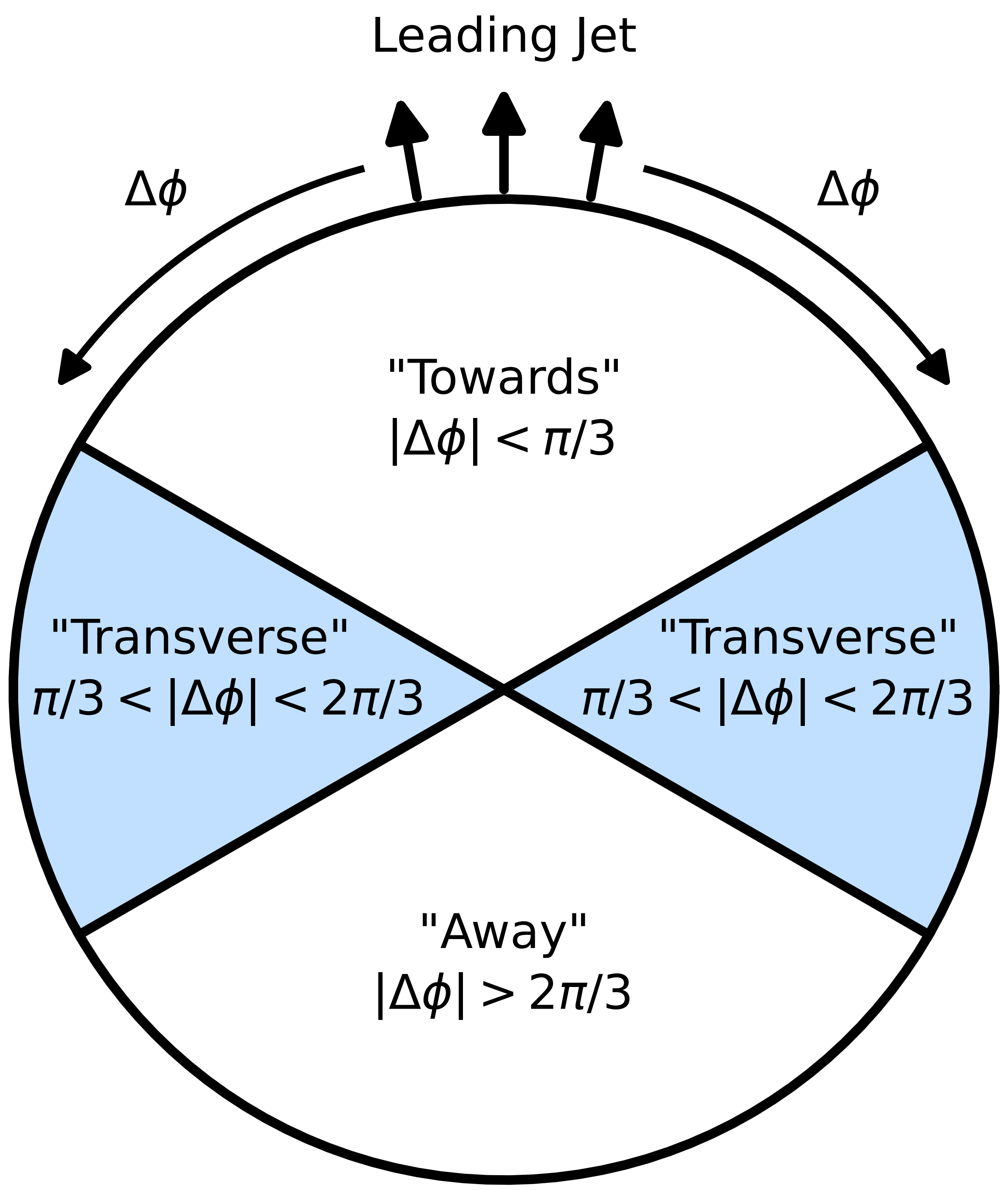


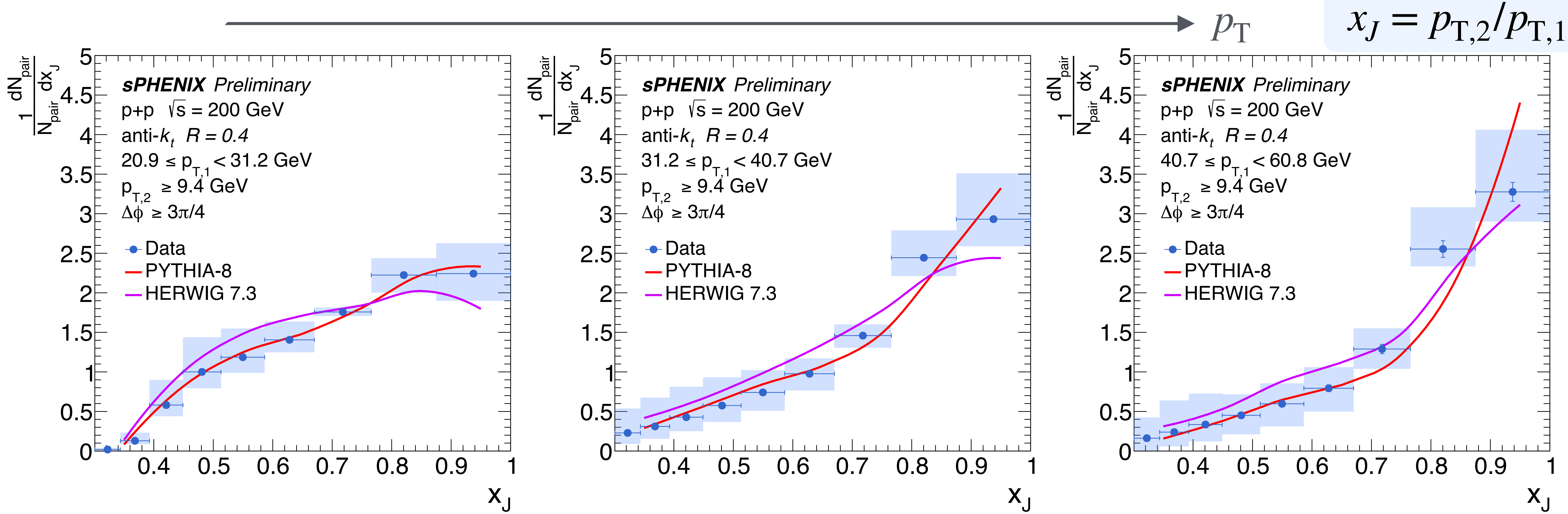
HERWIG7 disagrees with **the data**. The result proves *valuable input for future MC tuning*

- An **anti-correlation** is observed between the transverse-region energy density and the leading-jet p_T
  - ➡ At higher x, less energy is available for underlying-event activity
- **A similar trend** is observed for both inclusive jet and exclusive dijet events
  - ➡ This suggests a *larger fraction of back-to-back dijet topologies in the probed x range*



Di-jet Momentum Imbalance (x_J) in p+p

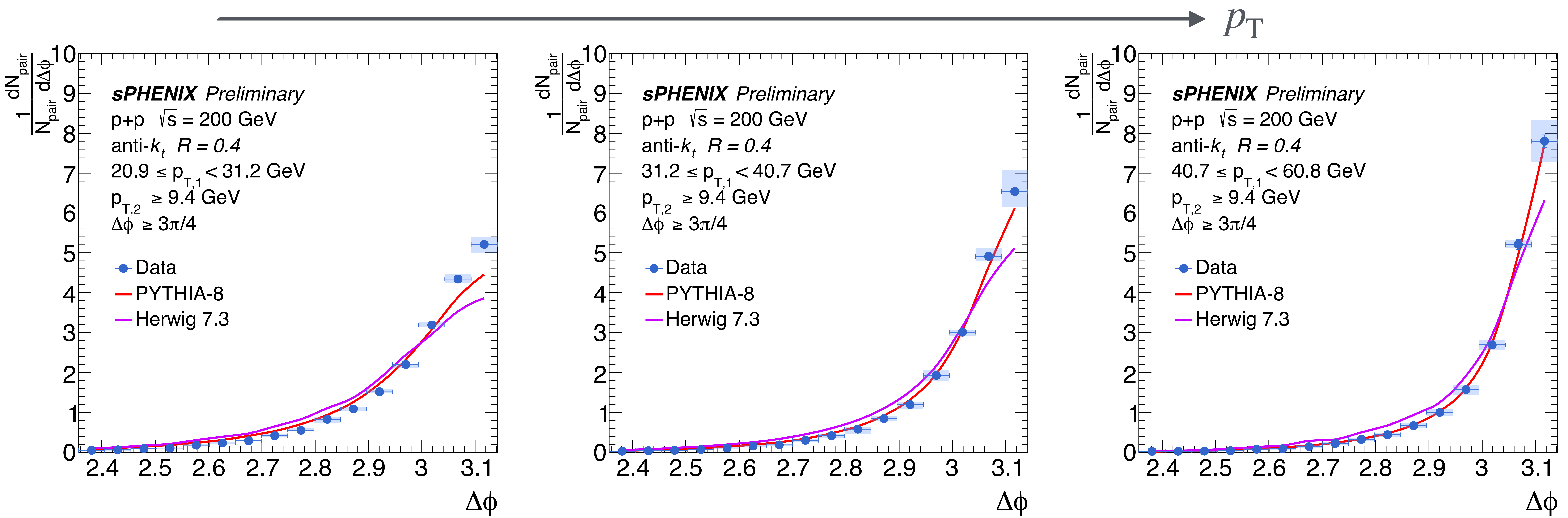
$x_J = p_{\mathrm{T},2}/p_{\mathrm{T},1}$



- **Higher leading p_{T}** → steeper x_J (**more balanced di-jets**)
  - ➡ consistent with suppressed higher-order splittings at large Q^2 where α_s is smaller
- Data slightly favors **PYTHIA-8** over **HERWIG 7.3**

arXiv:2606.17184
sPH-JET-2026-01

Di-jet Acoplanarity ($\Delta\phi$) in p+p



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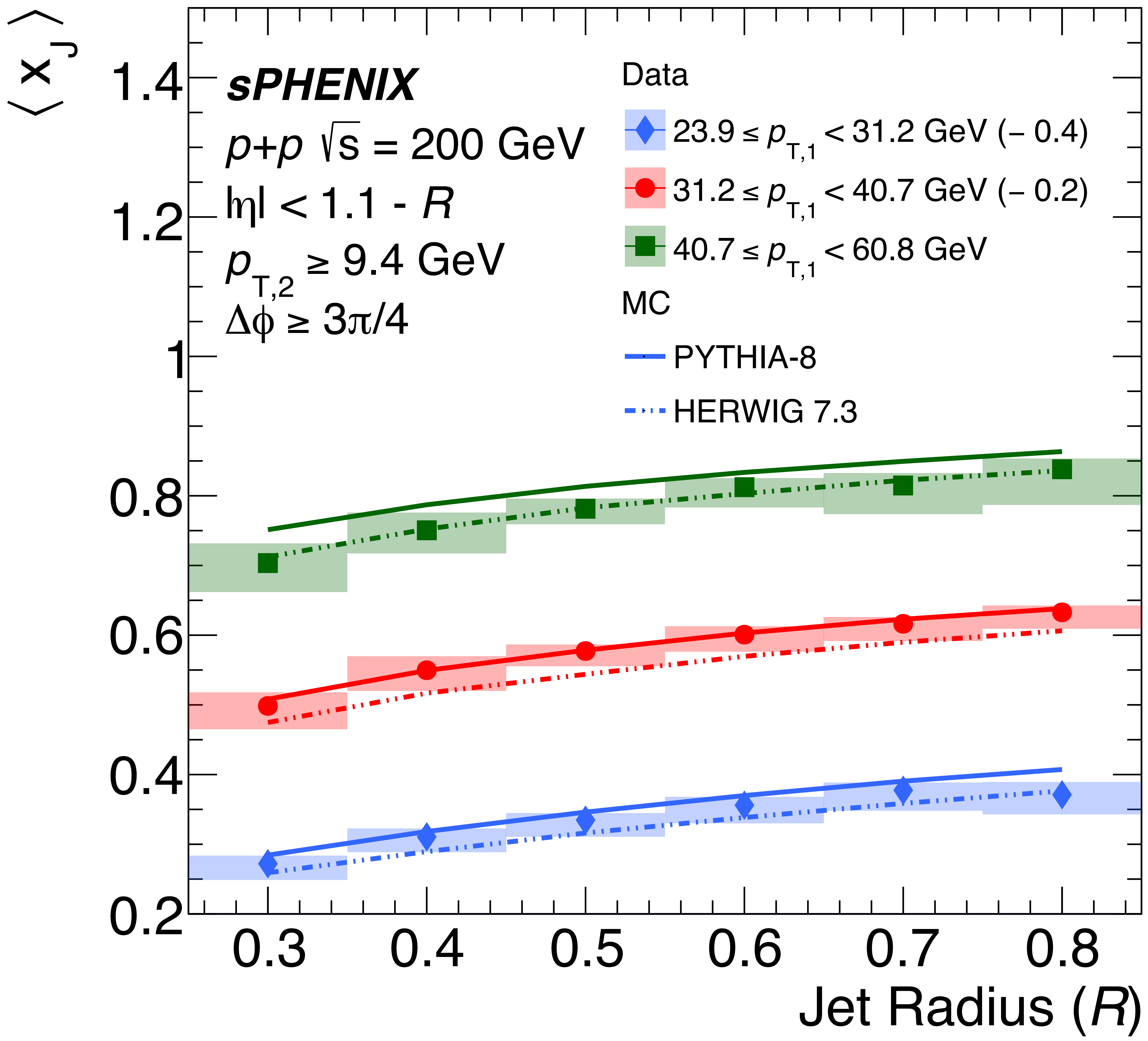
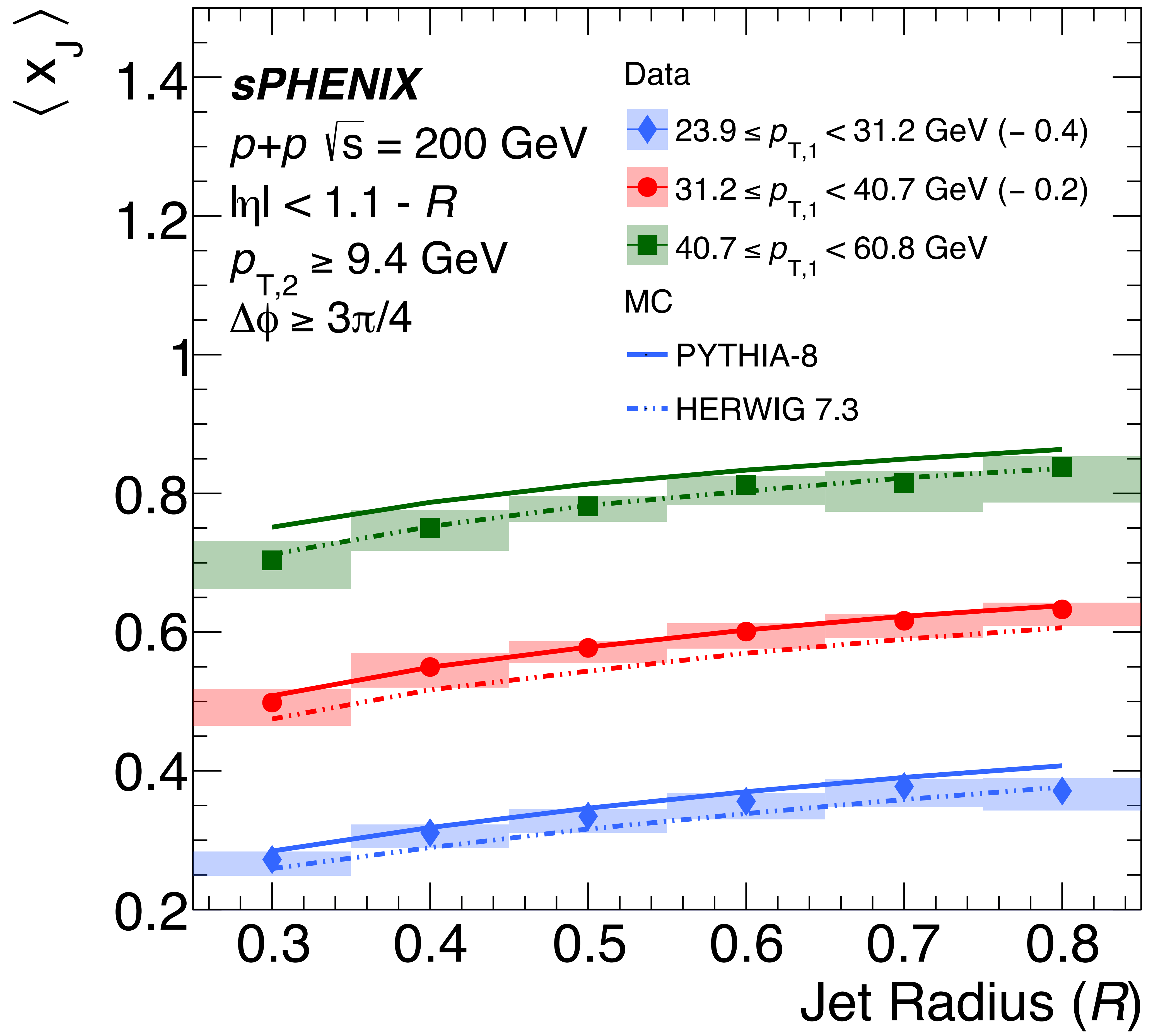
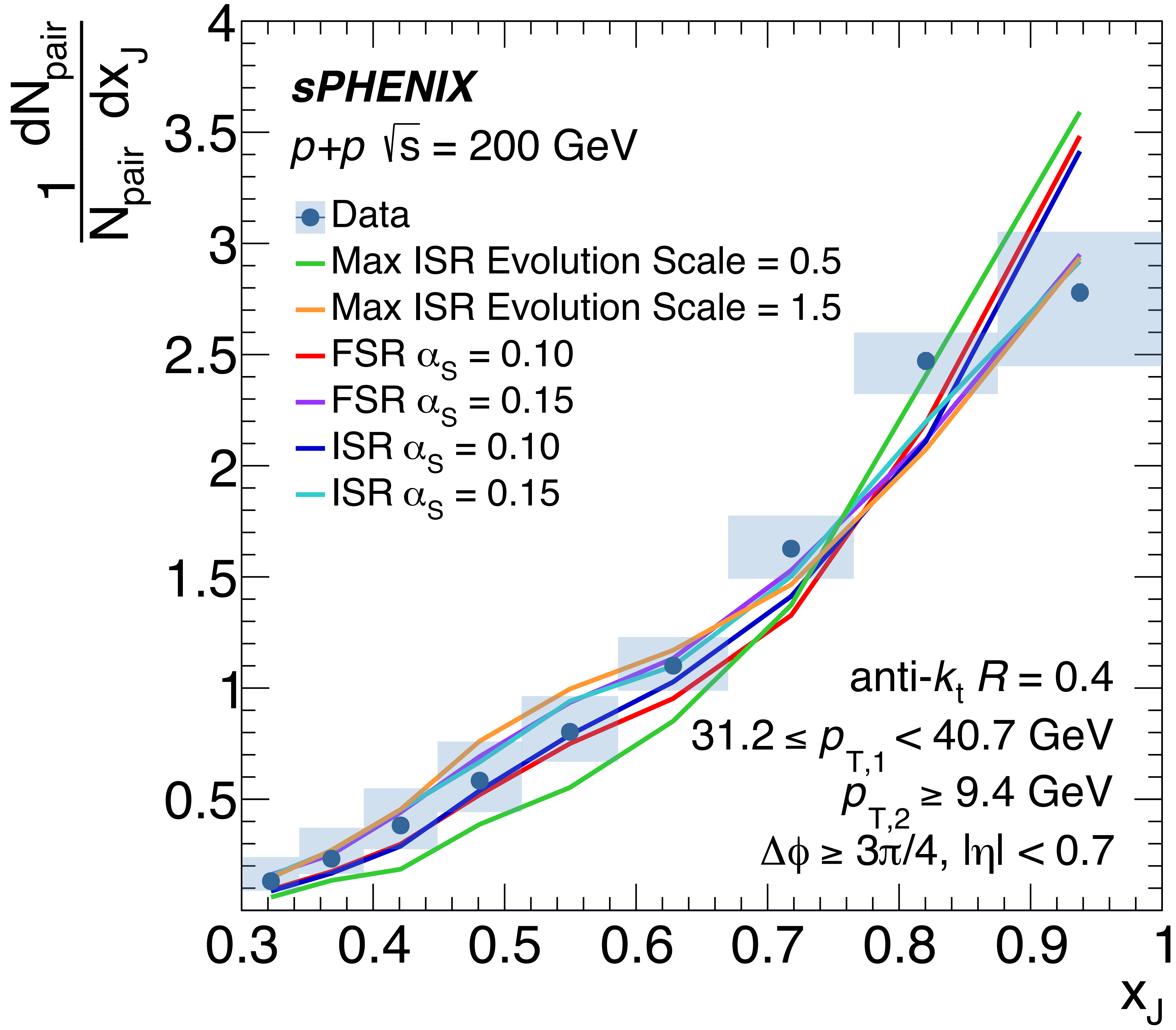
Di-jets in p+p



- Measurements with jet R=0.3-0.8 provide comprehensive understanding on MPI, hadronization, and non-perturbative corrections

Di-jets in p+p





- Measurements with jet R=0.3-0.8 provide comprehensive understanding on MPI, hadronization, and non-perturbative corrections

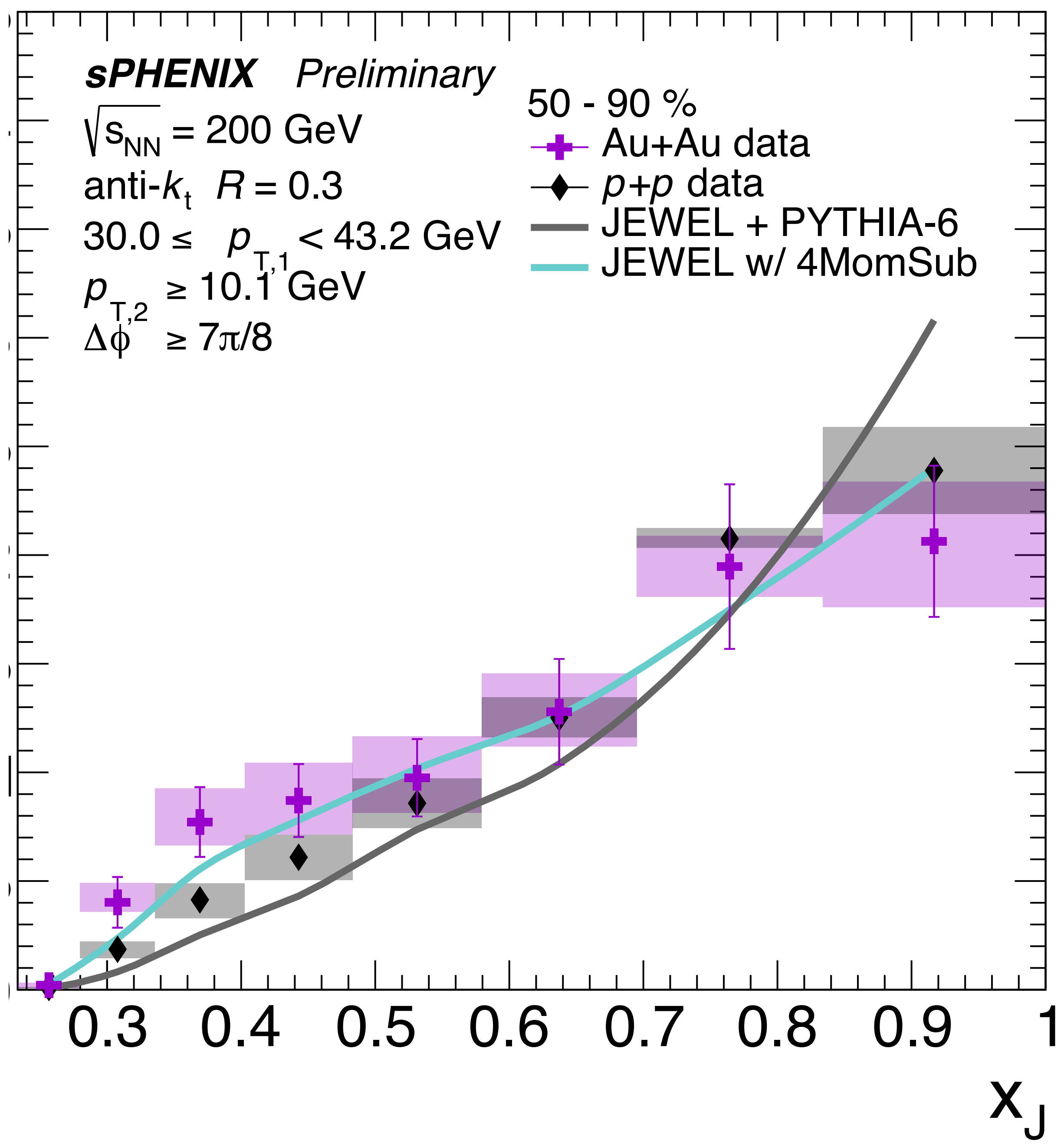
The results provide input for tuning MC, especially parton-shower and underlying-event models, at RHIC energies

Jet Energy Loss in Au+Au

Di-jet x_J in Au+Au

sPH-CONF-JET-2025-05

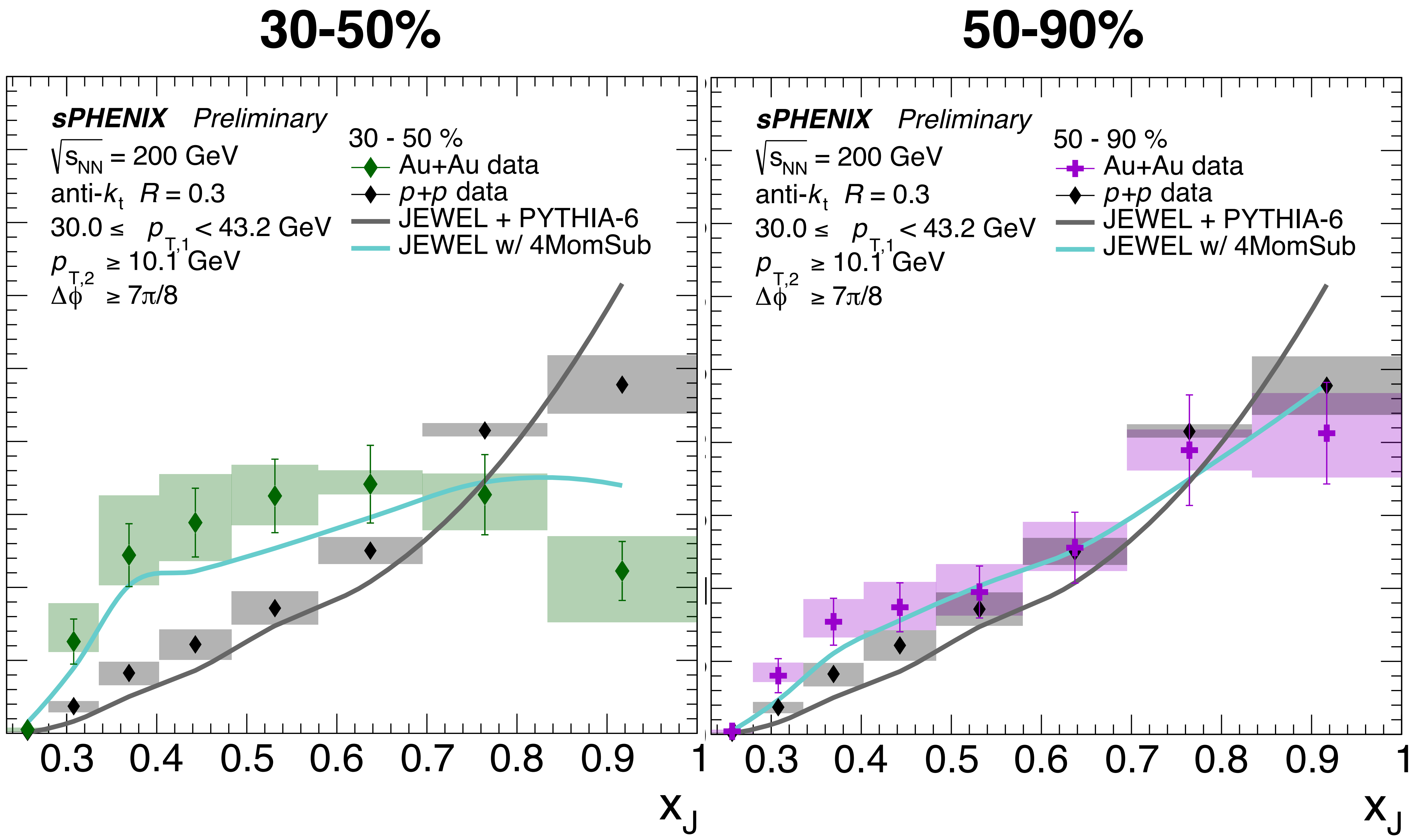
50-90%



- First unfolded x_J measurement using fully reconstructed jets with both EMCal and HCal
- **Centrality-dependent of x_J imbalance → jet quenching signature**
- JEWEL 2.4.0 with recoil + 4MomSub qualitatively describes the data

Di-jet x_J in Au+Au

sPH-CONF-JET-2025-05



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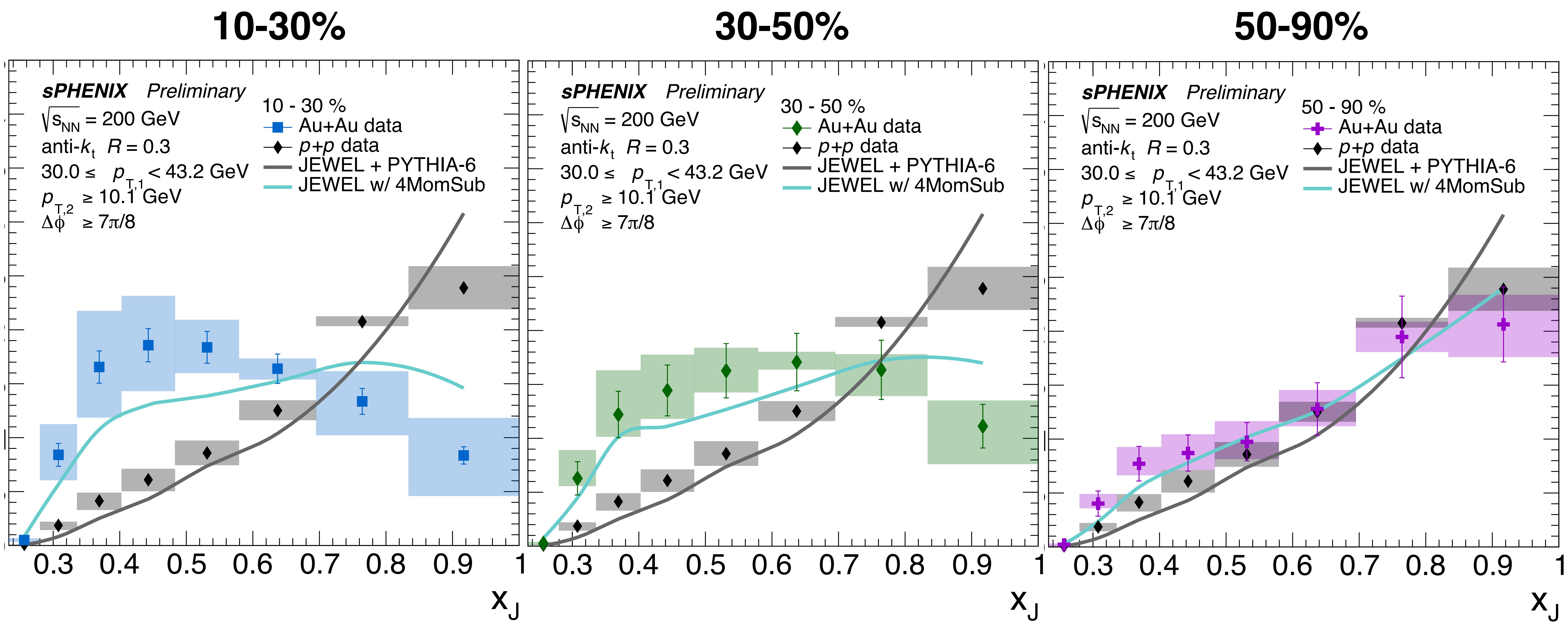

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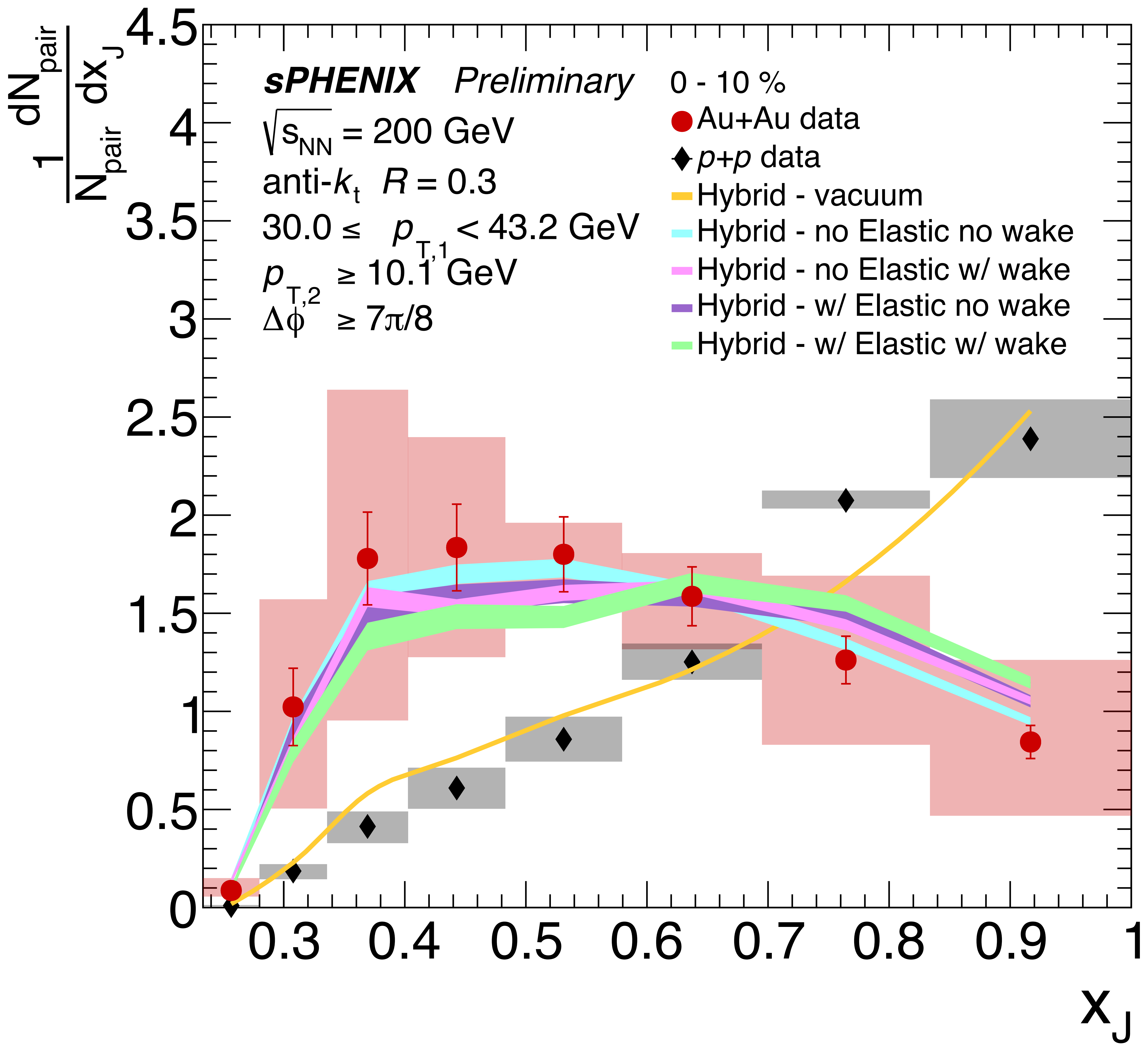
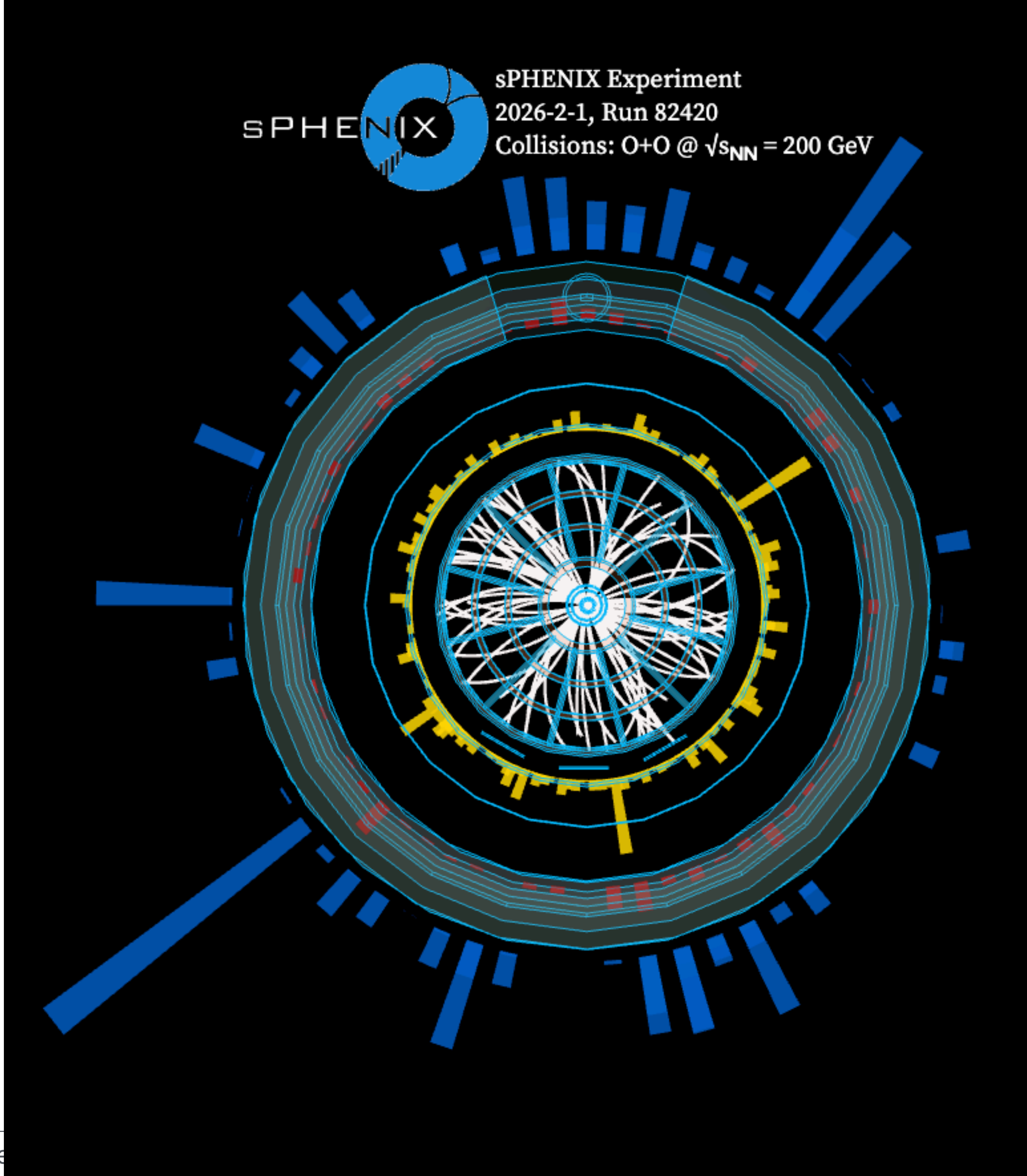


- **The data are consistent with Hybrid** model predictions for all four configurations, *with and without elastic scattering* and *with and without a medium wake*

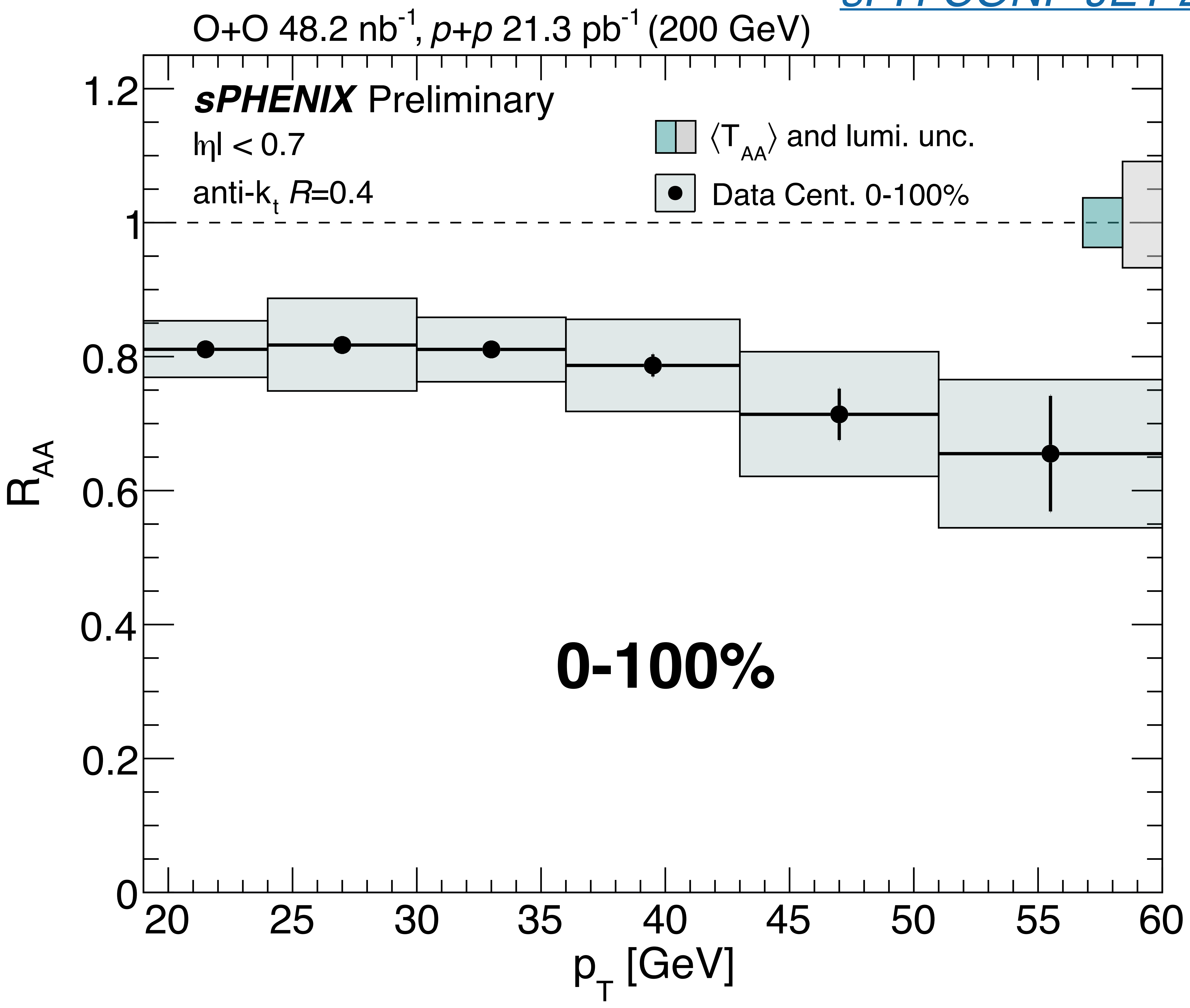
Jets in O+O



sPHENIX
sPHENIX Experiment
2026-2-1, Run 82420
Collisions: O+O @ $\sqrt{s_{NN}}$ = 200 GeV

Jet R_{AA} in O+O

sPH-CONF-JET-2026-02



- Suppression of jet yields in O+O

Jet R_{AA} in O+O

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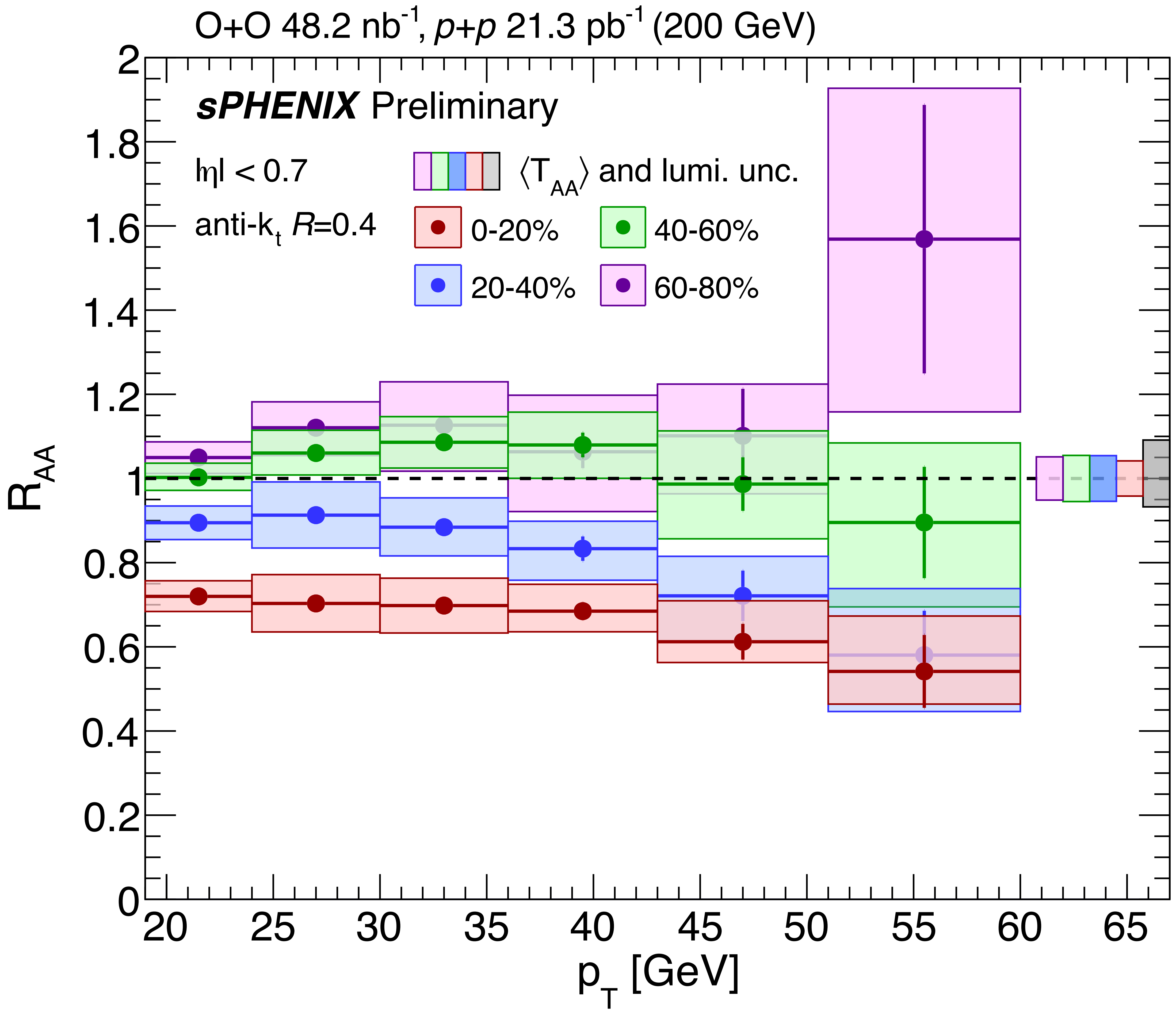

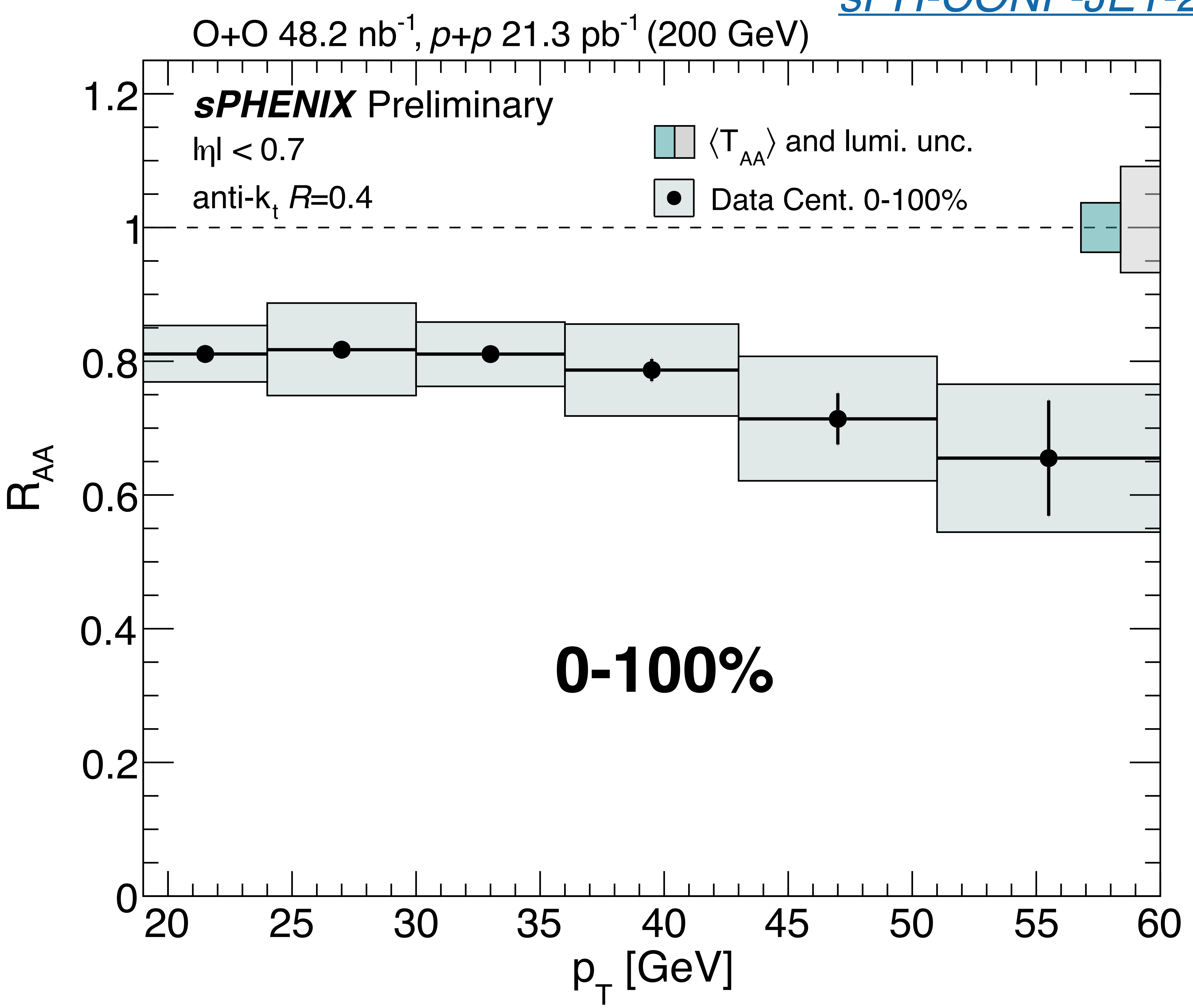

- Clear centrality ordering found in jet R_{OO}
- Stronger suppression for central collisions
- Suppression of jet yields in O+O

Jet R_{AA} in O+O: Energy Loss? nPDF?

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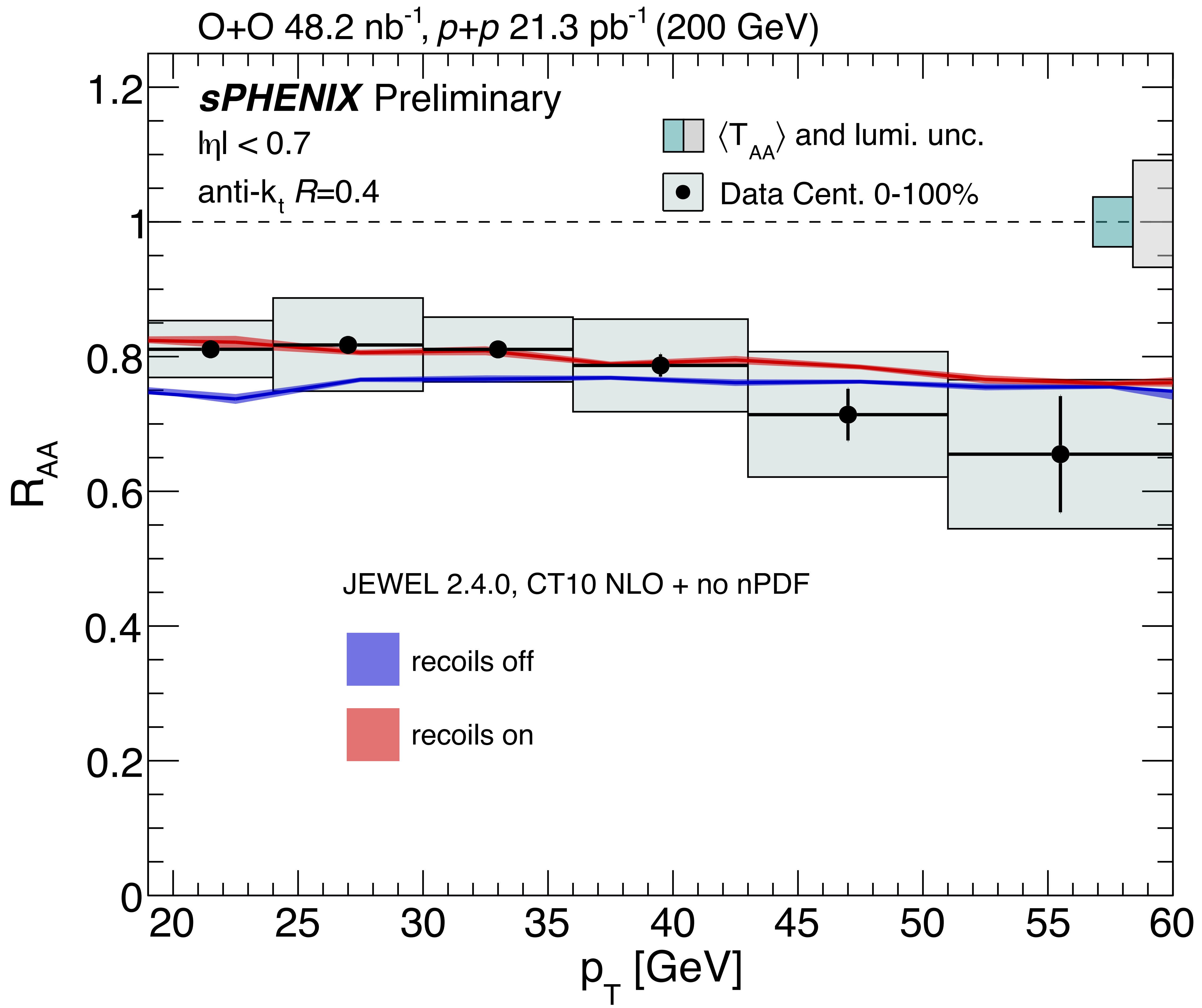

- JEWEL 2.4.0 w/o nPDF consistent with data
- Modest effect with recoils enabled

Jet R_{AA} in O+O: Energy Loss? nPDF?

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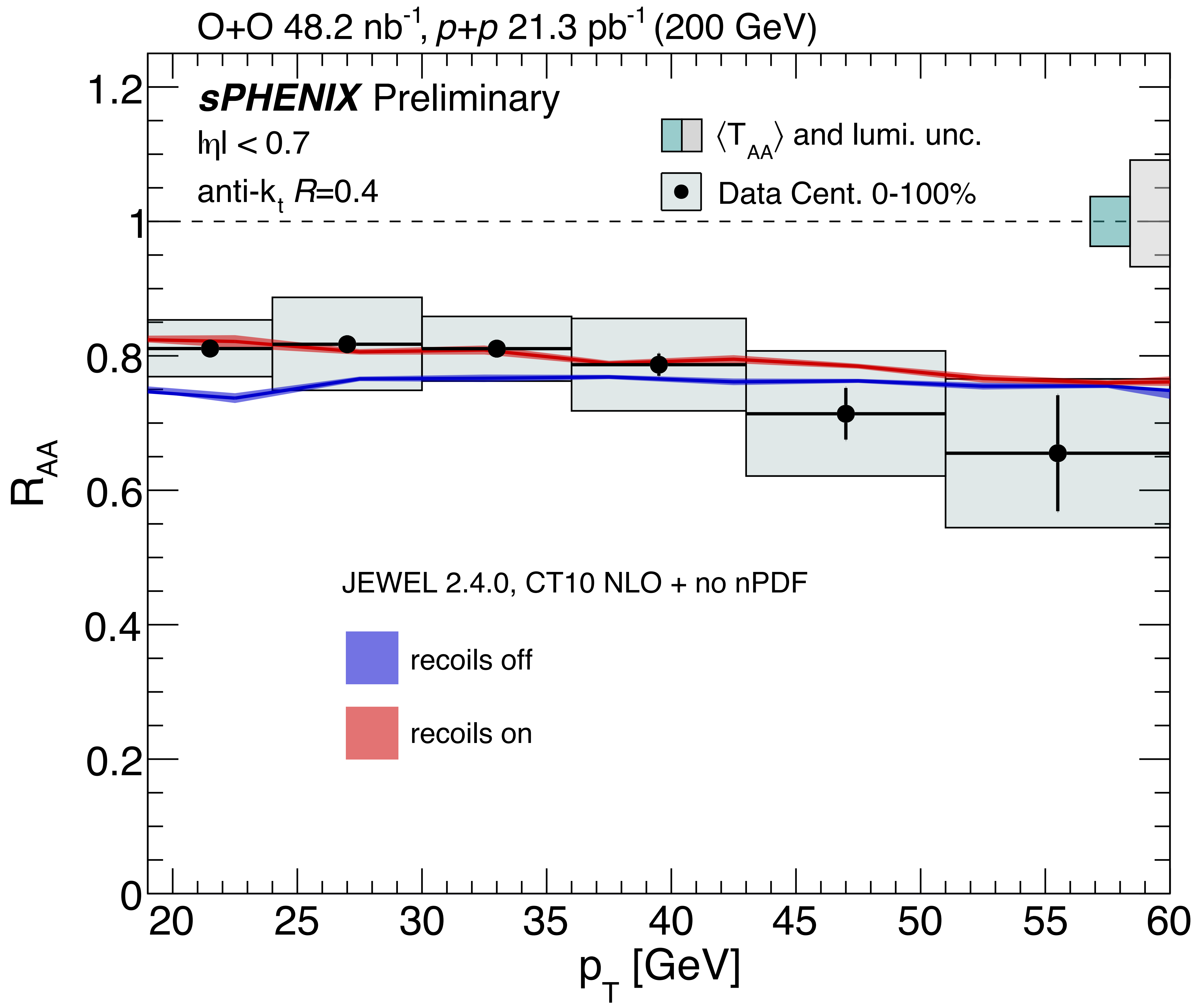
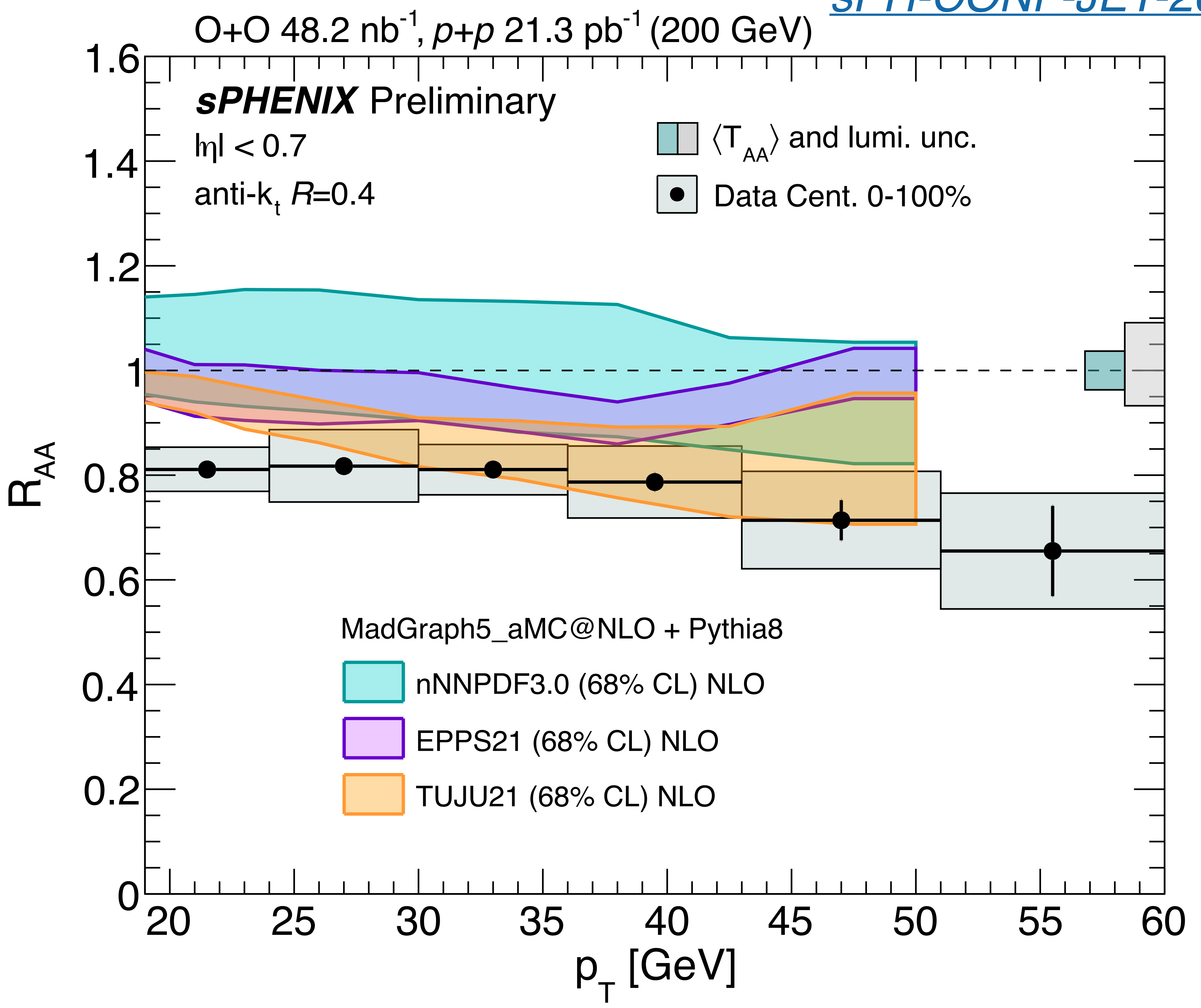


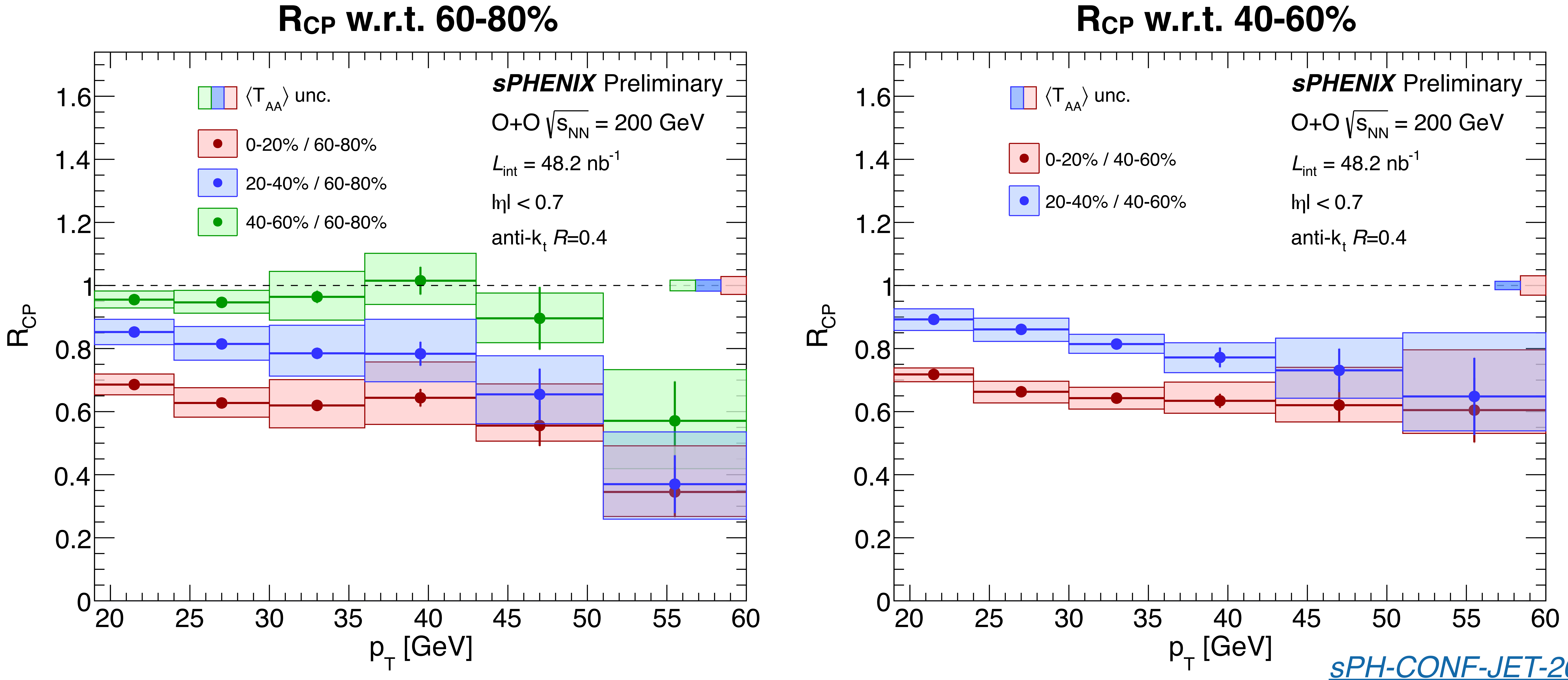


- JEWEL 2.4.0 w/o nPDF consistent with data
- Modest effect with recoils enabled

- The measured R_{AA} is lower than the PYTHIA8 + nPDF baseline predictions

➡ note) nPDF prediction bands are for charged jets

Jet R_{CP} in O+O



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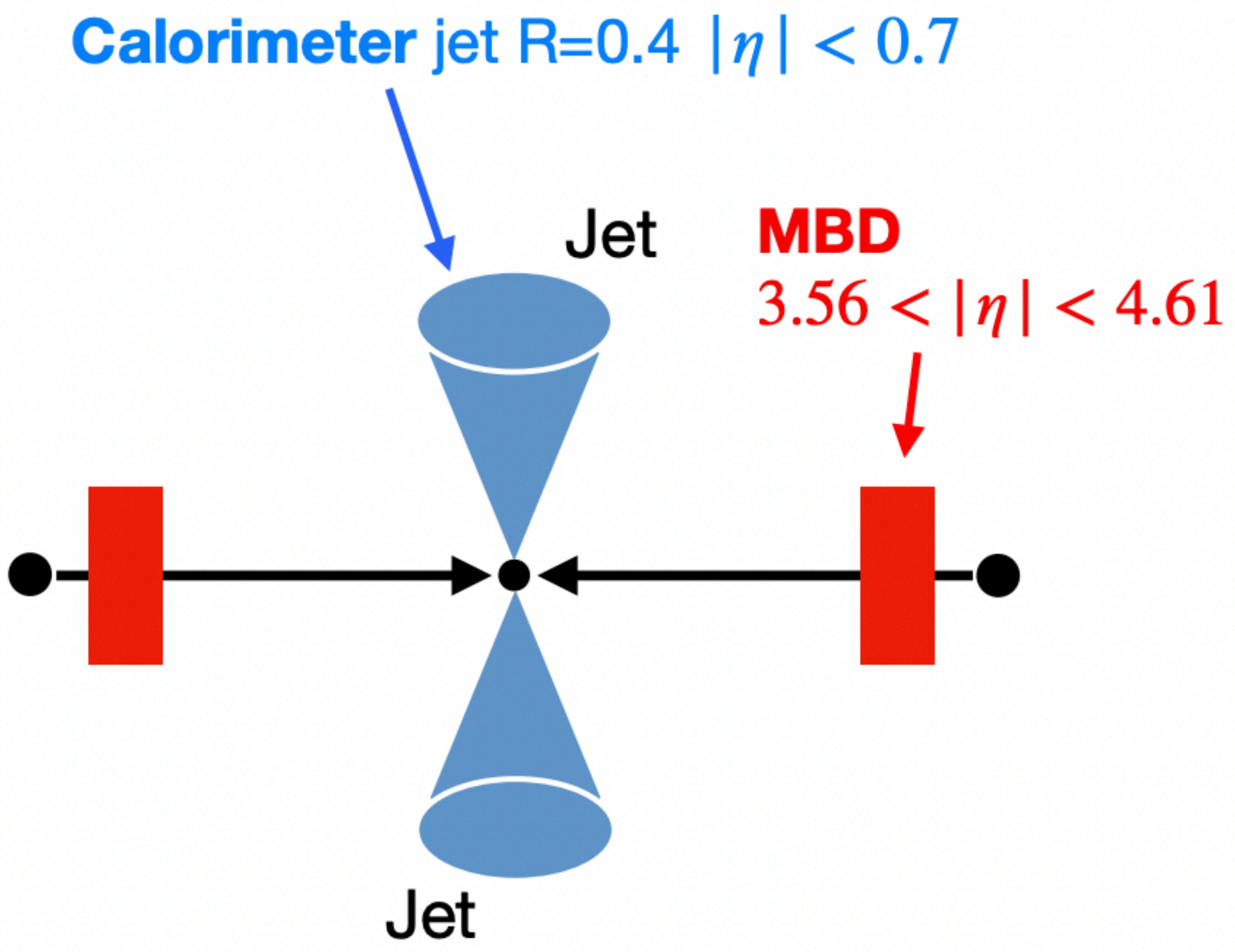
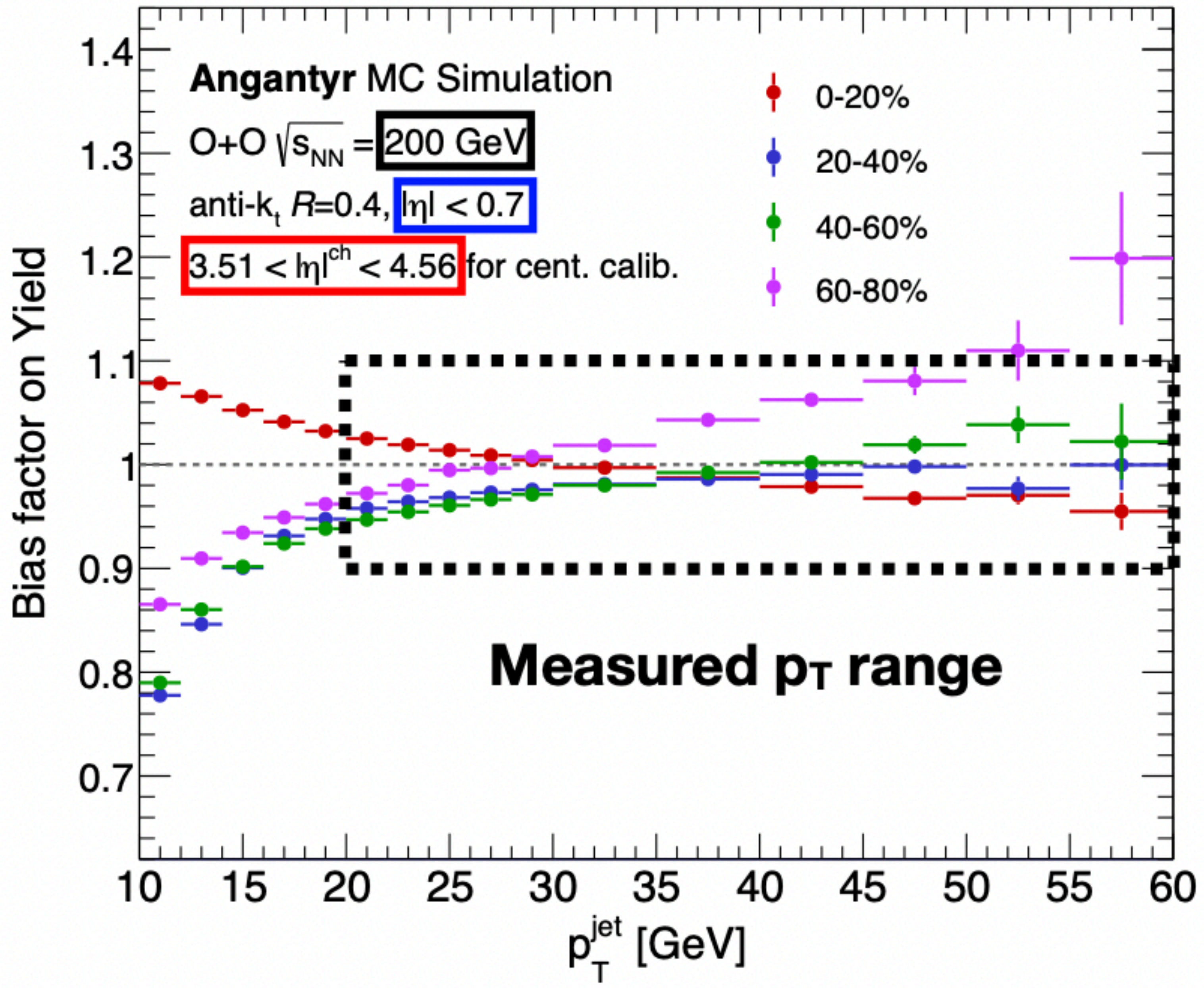
- **Clear centrality ordering**, with reduced sensitivity to nPDF effects compared with R_{AA}

➡ jet quenching

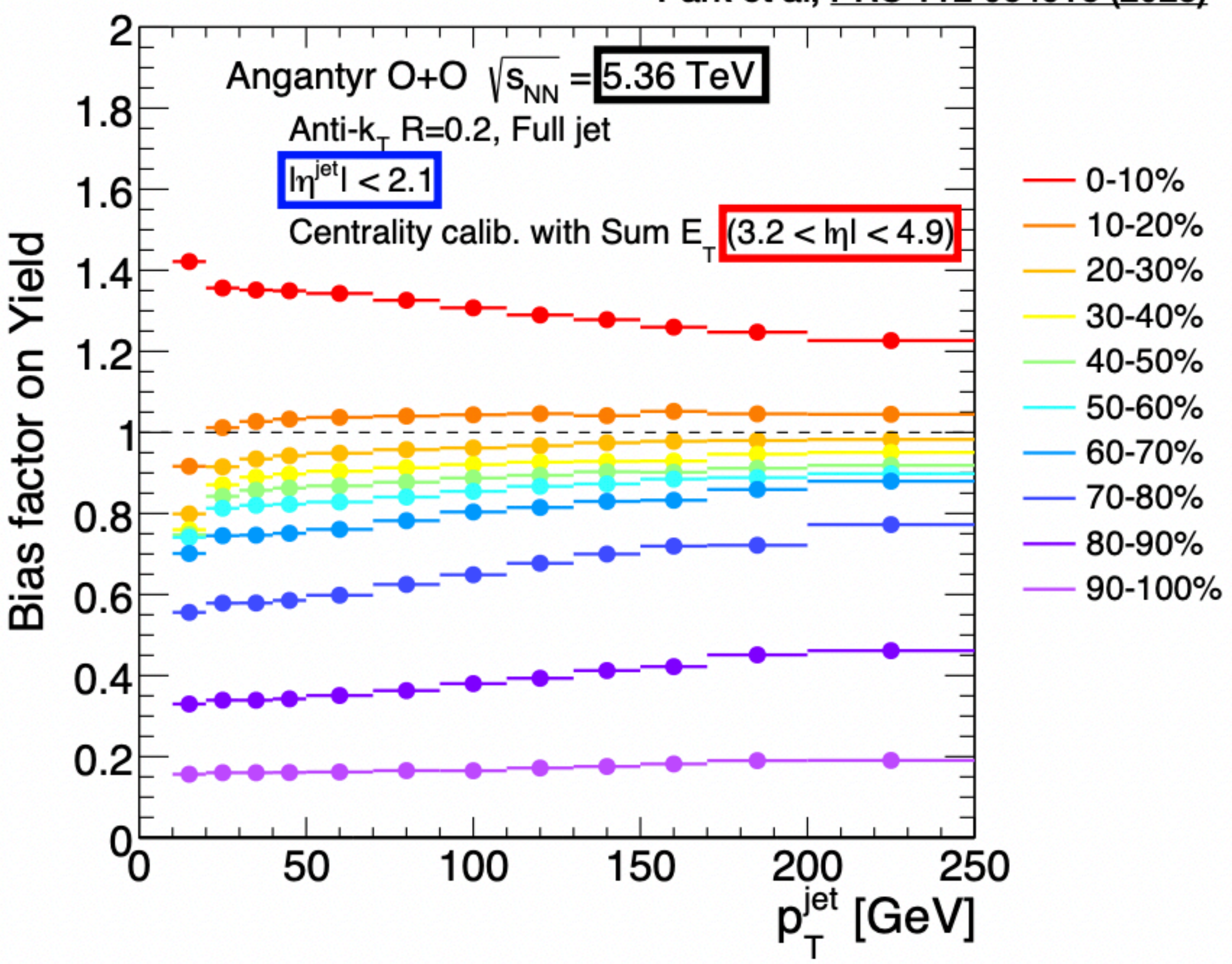
Centrality Bias Effect in Small Systems

Jaebeom Park's slide @HP2026





Park et al, PRC 112 064916 (2025)

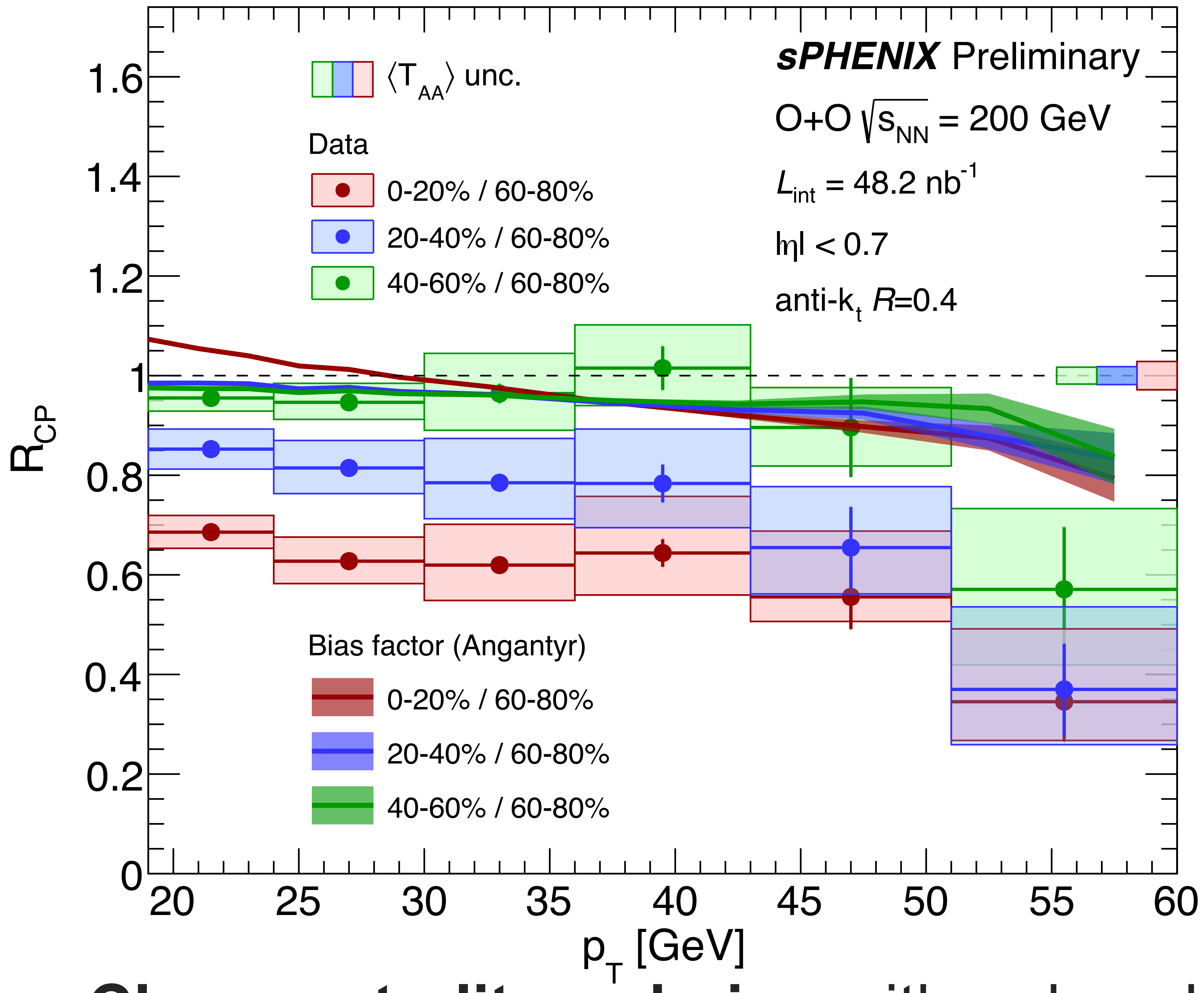


- **Centrality bias** caused by **hard probes** in **mid-η** and **soft particle** production in **forward-η**
- **Much smaller** bias effects at **RHIC energy** with **sPHENIX acceptance**

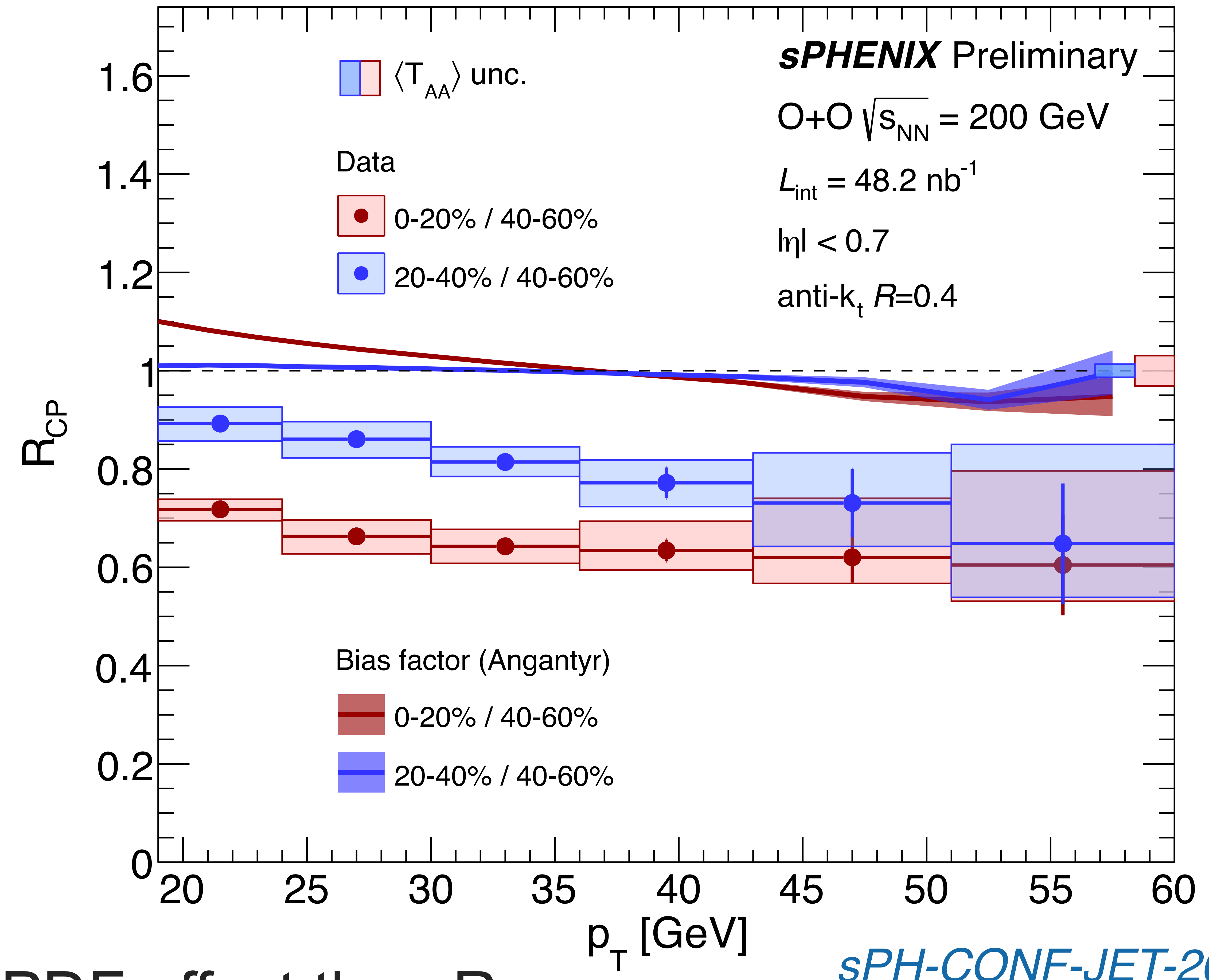
Jet R_{CP} in O+O

sPHENIX

R_{CP} w.r.t. 60-80%



R_{CP} w.r.t. 40-60%



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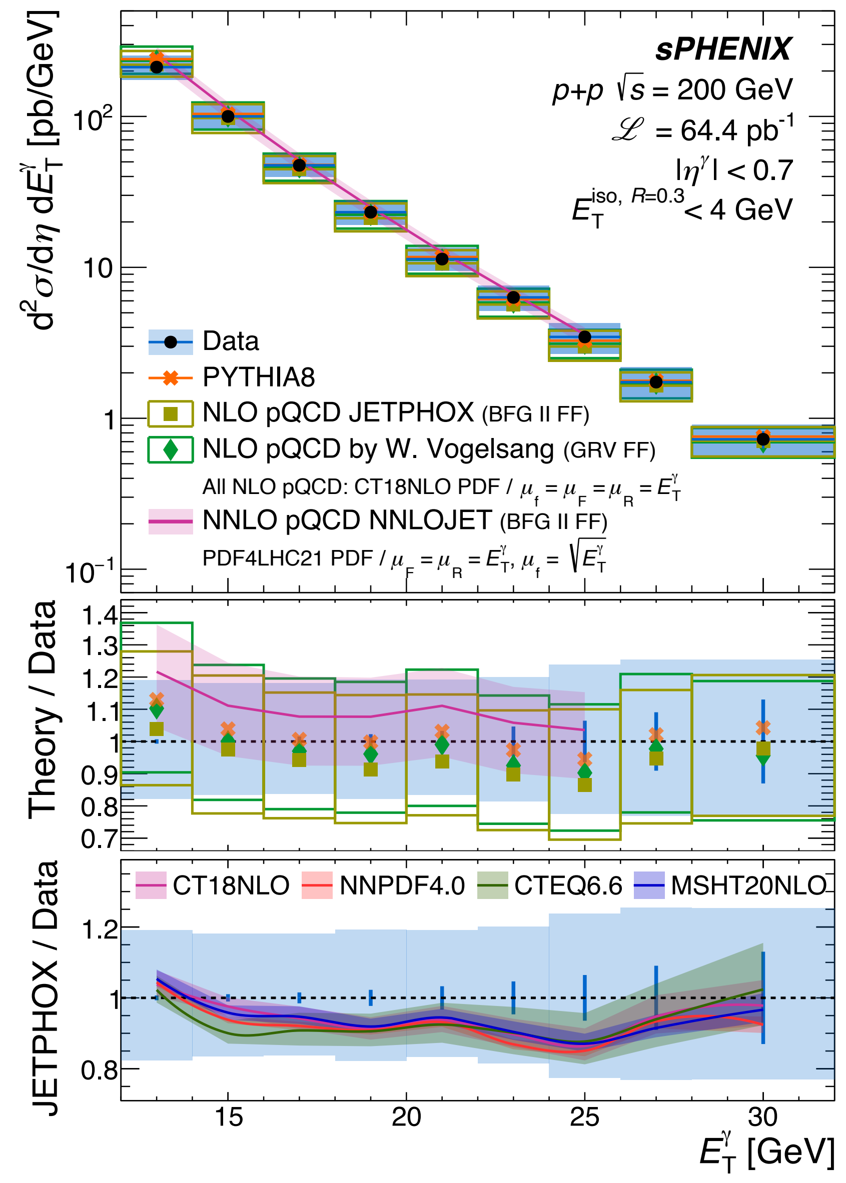
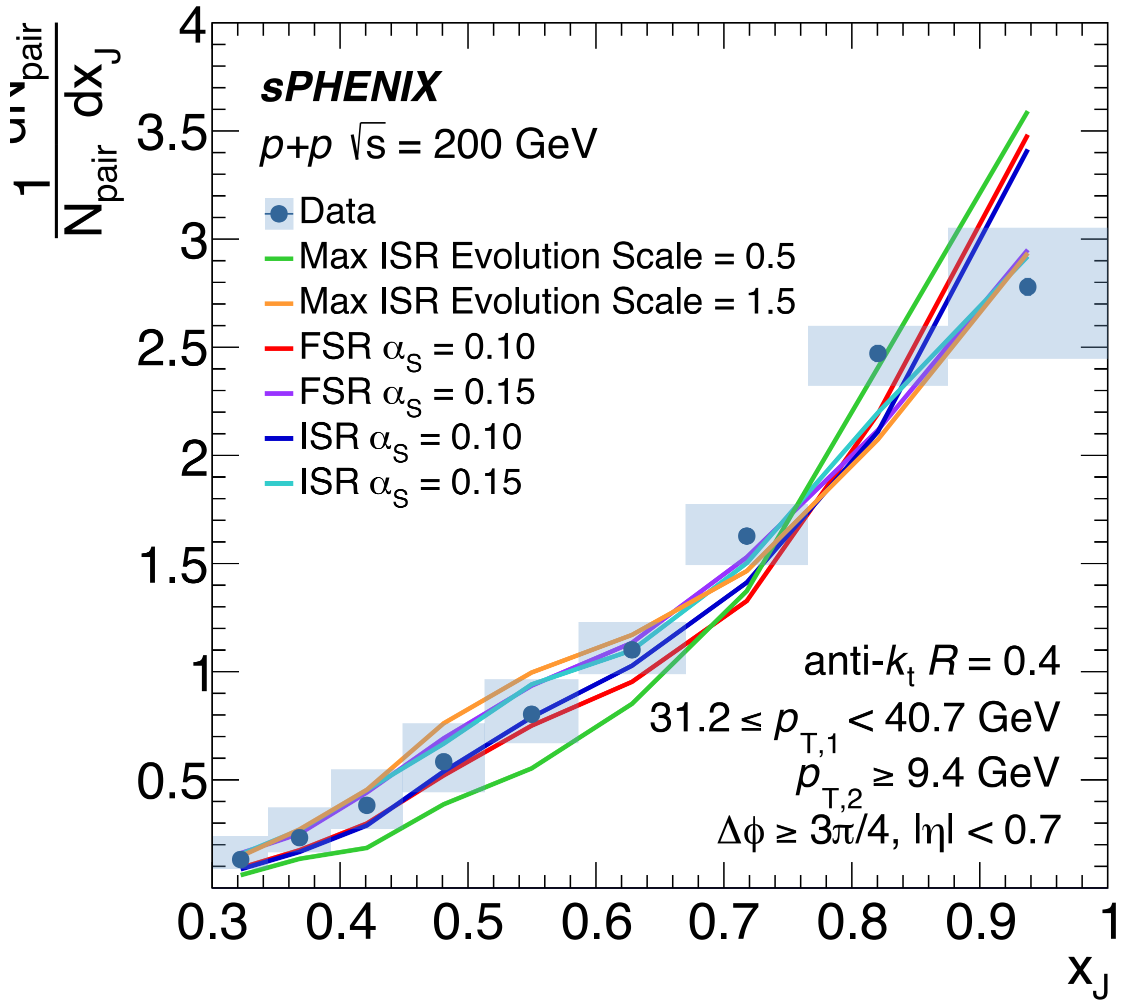
- **Clear centrality ordering** with reduced nPDF effect than R_{AA}
- The *estimated centrality-bias effect is at most 10%*
  - ➡ This bias is insufficient to explain the suppression observed in central collisions

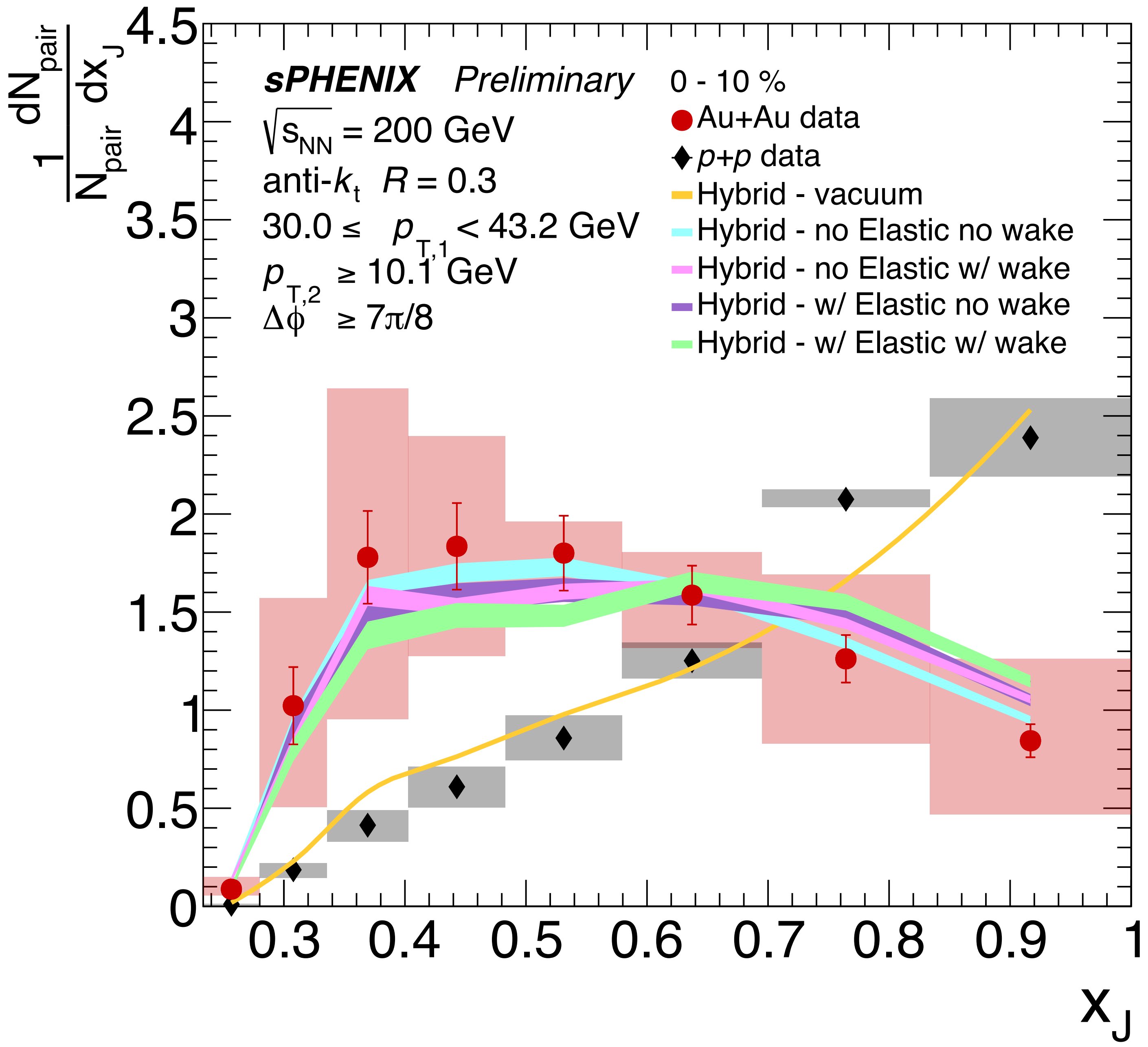
So far we've measured …

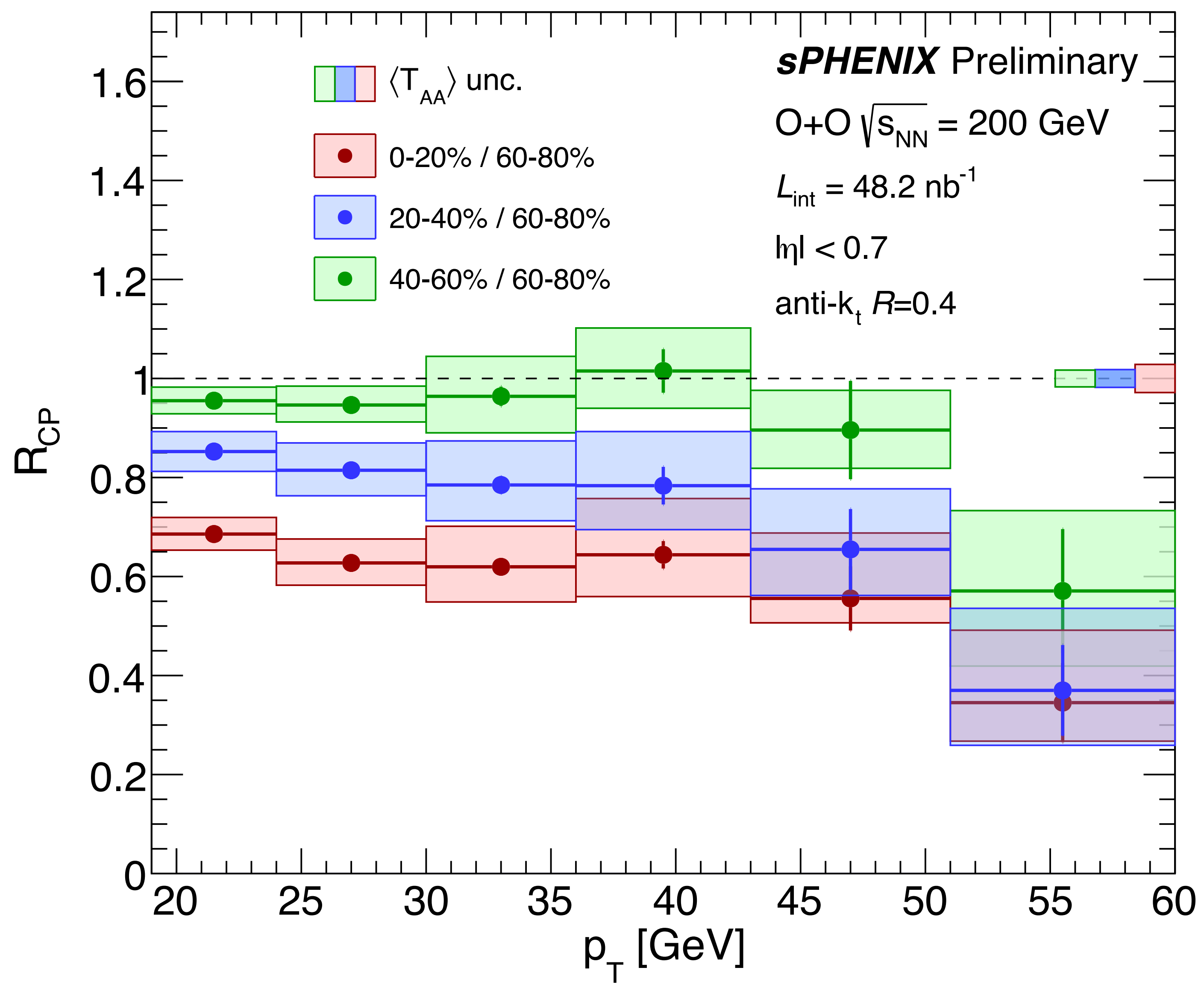
First jet measurements in sPHENIX

p+p ········ **Au+Au** ········ **O+O**









What's coming next?

Upcoming sPHENIX jet measurements

- Finalize **precision p+p baselines** using the full dataset
  - ➡ Dijet correlations, inclusive jets, underlying event, isolated prompt photons, and photon-tagged jets, etc

Upcoming sPHENIX jet measurements

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  - ➡ Dijet correlations, inclusive jets, underlying event, isolated prompt photons, and photon-tagged jets, etc
- Extend **jet measurements to Au+Au and O+O** collisions
  - ➡ R_{AA}/R_{CP}, dijet imbalance, photon+jet correlations, acoplanarity, jet-hadron correlations, jet substructure measurements, etc

Upcoming sPHENIX jet measurements

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  - ➡ Dijet correlations, inclusive jets, underlying event, isolated prompt photons, and photon-tagged jets, etc
- Extend **jet measurements to Au+Au and O+O** collisions
  - ➡ R_{AA}/R_{CP}, dijet imbalance, photon+jet correlations, acoplanarity, jet-hadron correlations, jet substructure measurements, etc
- Measure **jet substructure** across collision systems
  - ➡ Soft Drop observables, fragmentation functions, jet shapes, jet mass, and the Lund plane, etc

Upcoming sPHENIX jet measurements

- Finalize **precision p+p baselines** using the full dataset
  - ➡ Dijet correlations, inclusive jets, underlying event, isolated prompt photons, and photon-tagged jets, etc

- Extend **jet measurements to Au+Au and O+O** collisions
  - ➡ R_{AA}/R_{CP}, dijet imbalance, photon+jet correlations, acoplanarity, jet-hadron correlations, jet substructure measurements, etc

- Measure **jet substructure** across collision systems
  - ➡ Soft Drop observables, fragmentation functions, jet shapes, jet mass, and the Lund plane, etc

- Use **system-size dependent measurements including jet substructure** to constrain **early-time dynamics**
  - ➡ System-size (Au+Au vs O+O) and jet-substructure dependence can help separate early-time effects from later in-medium jet modification

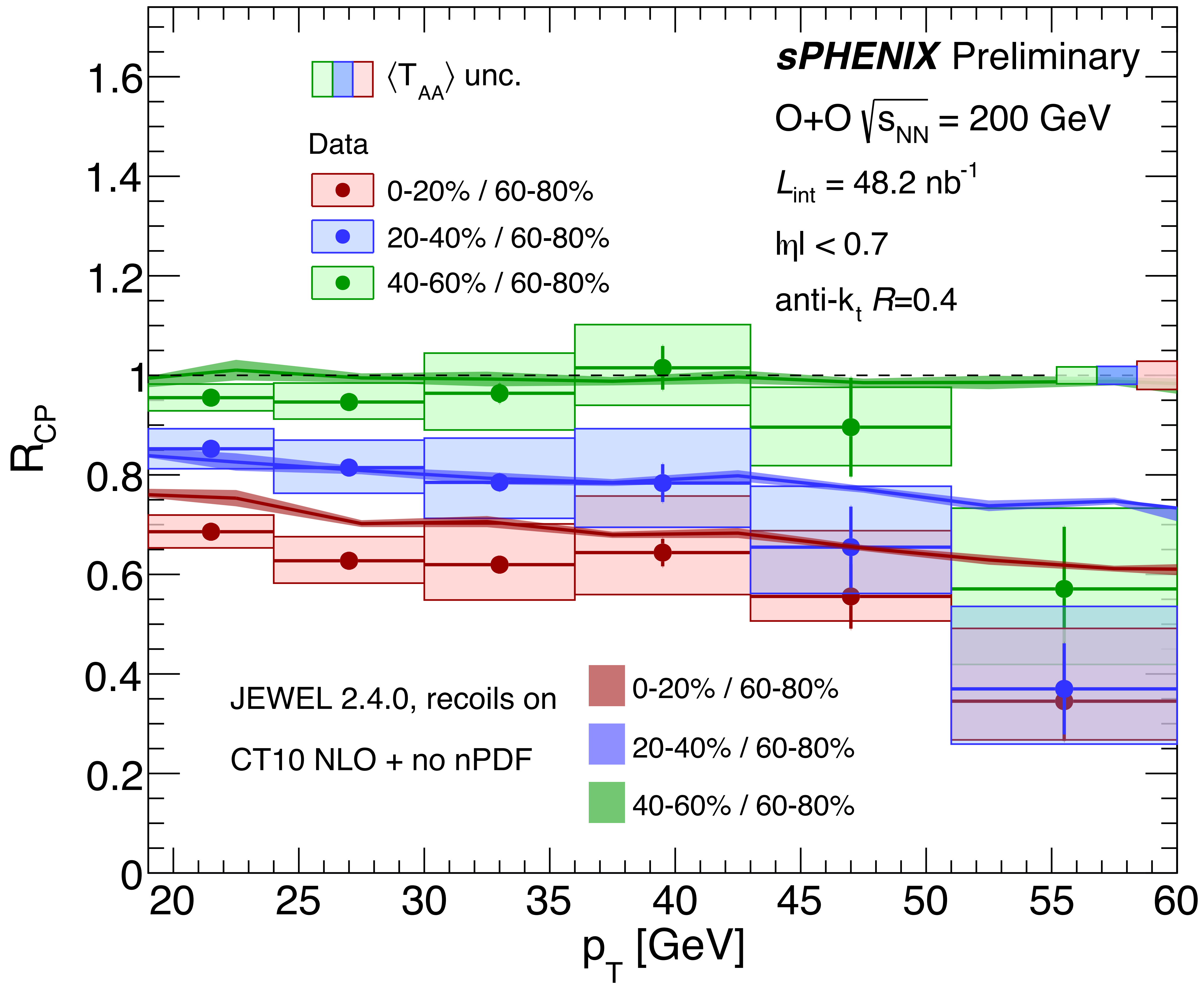
Summary

- **sPHENIX** collected **large datasets for a rich jet physics program**
  - ➡ calorimeter only dataset: **p+p 115/pb, O+O 53/nb**
  - ➡ all subsystem triggered: **p+p 25/pb, O+O 24/nb, Au+Au 6.6/nb**
- **Jets at RHIC** provide sensitivity to the **scale dependence of jet modification**
  - ➡ Compared with the LHC, RHIC provides steeper jet p_T spectra, a larger quark-jet fraction, and access to higher x; **complementary to that at the LHC**
- Early p+p measurements establish precision baselines for jet modification studies
- Upcoming jet measurements including **jet substructures** in p+p, O+O, and Au+Au will help disentangle effects from the early stages from final-state parton energy loss in the QGP

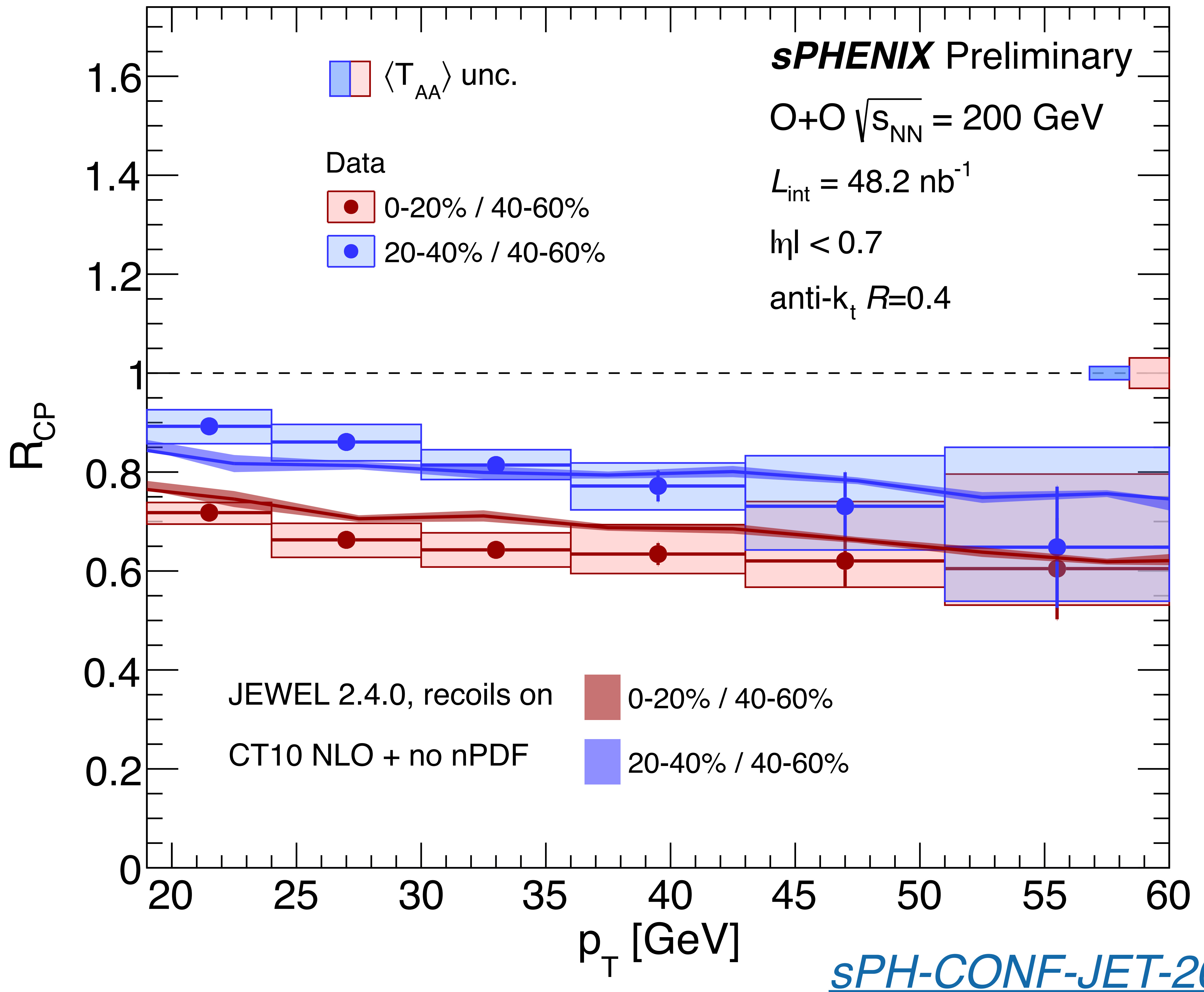
BACKUP

Jet R_{CP} in O+O

R_{CP} w.r.t. 60-80%



R_{CP} w.r.t. 40-60%



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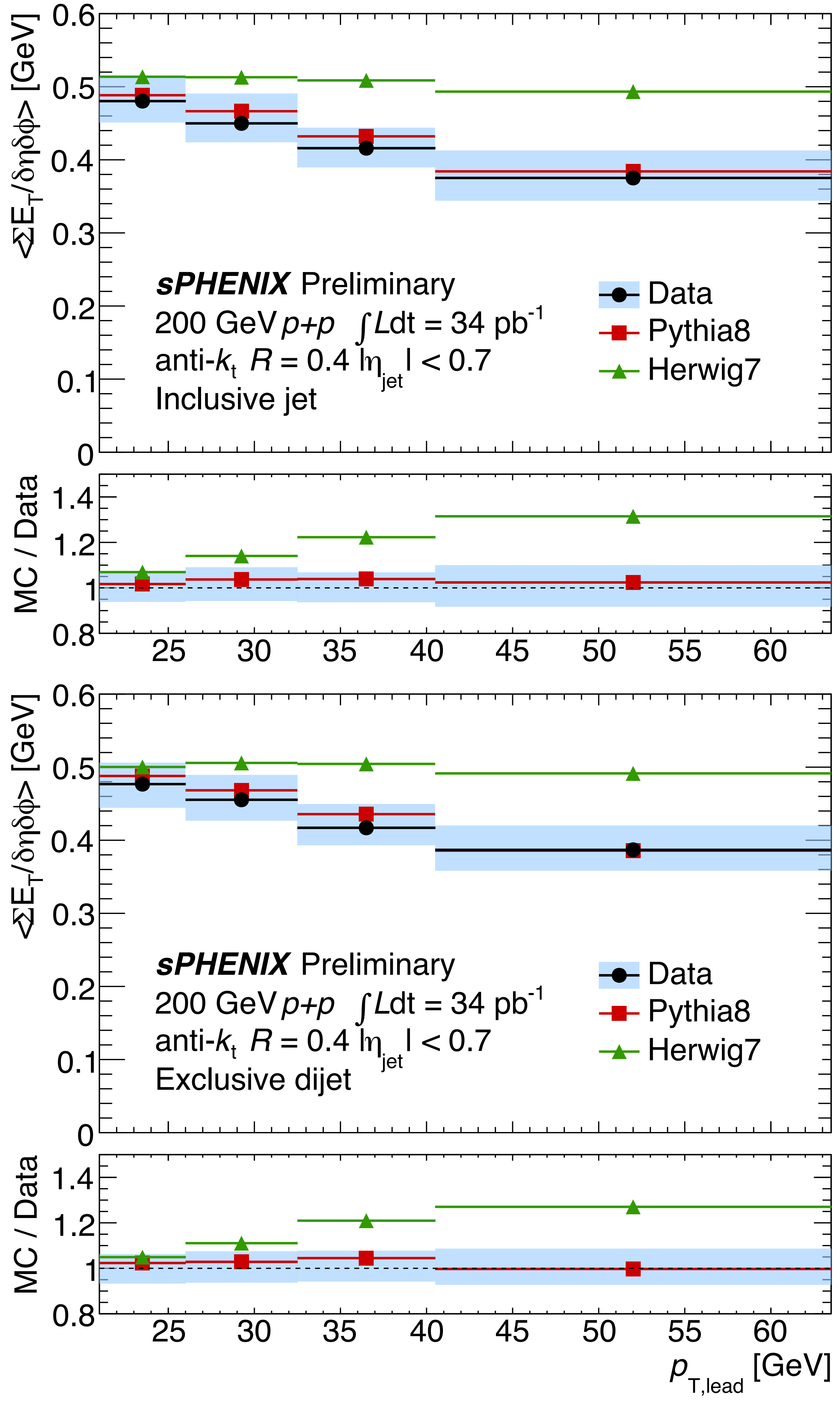
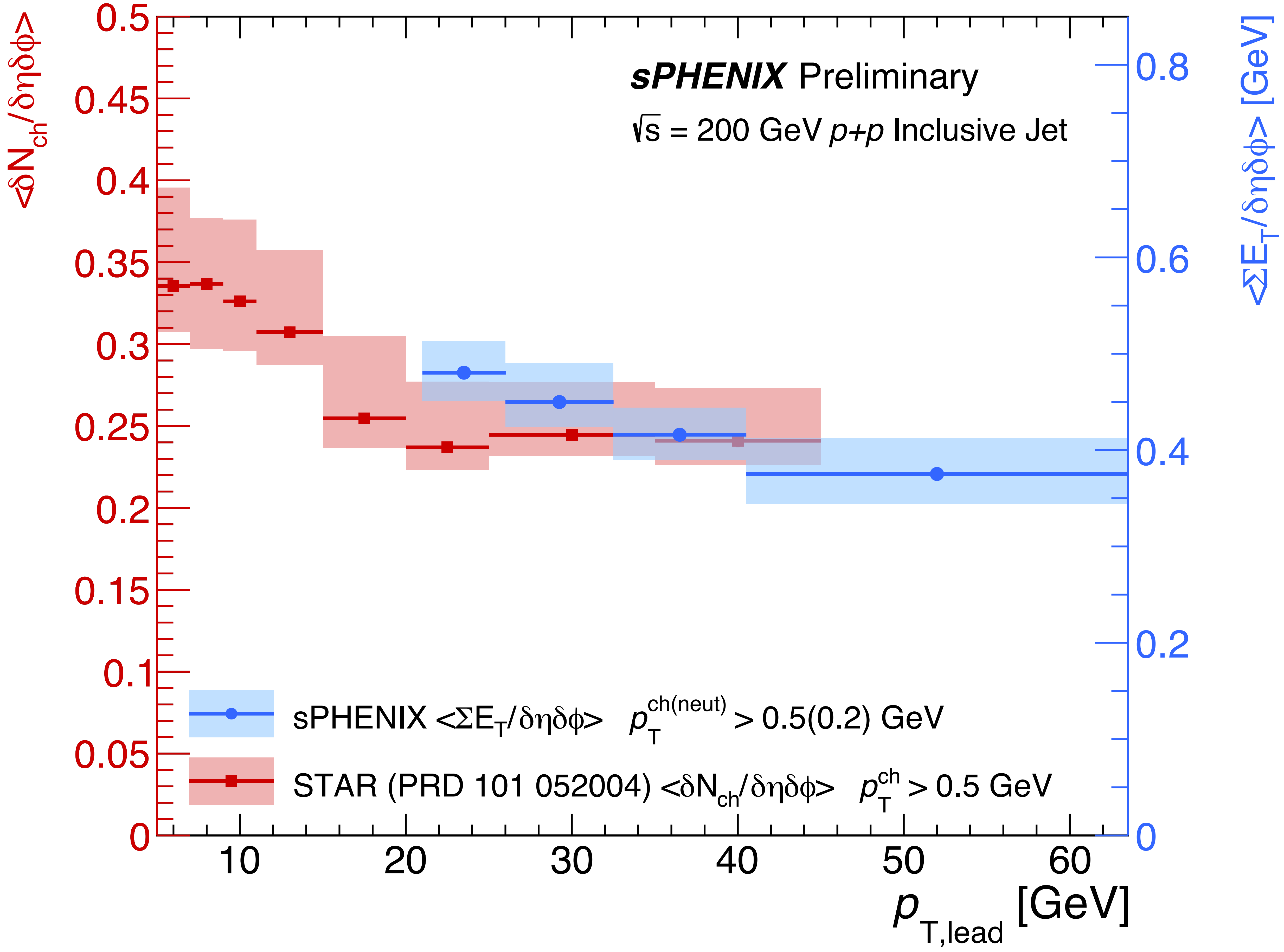
- JEWEL qualitatively describes the data

Underlying Event with Jets in p+p





- Input for tuning the MC event generator

Jets in O+O

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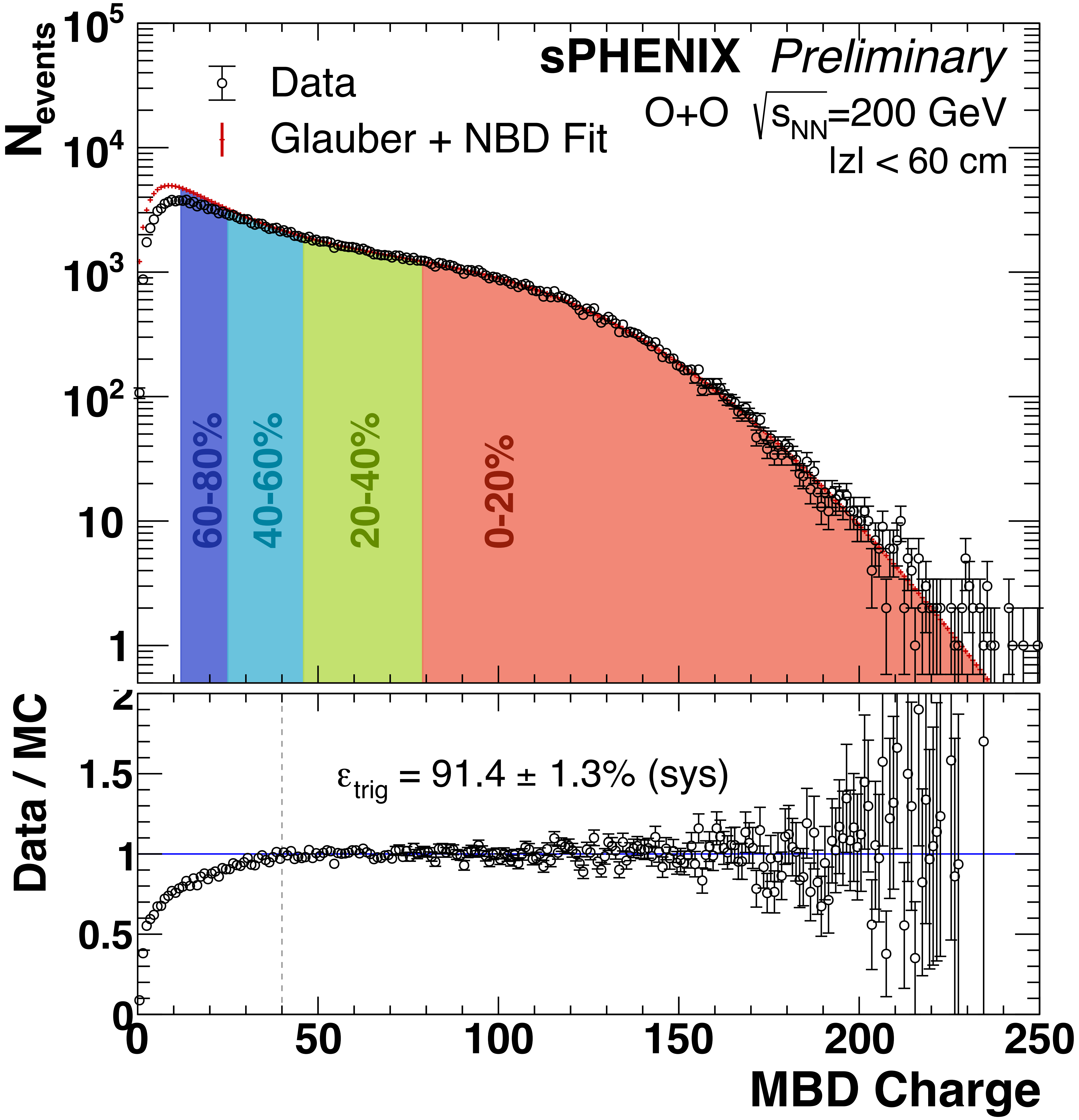
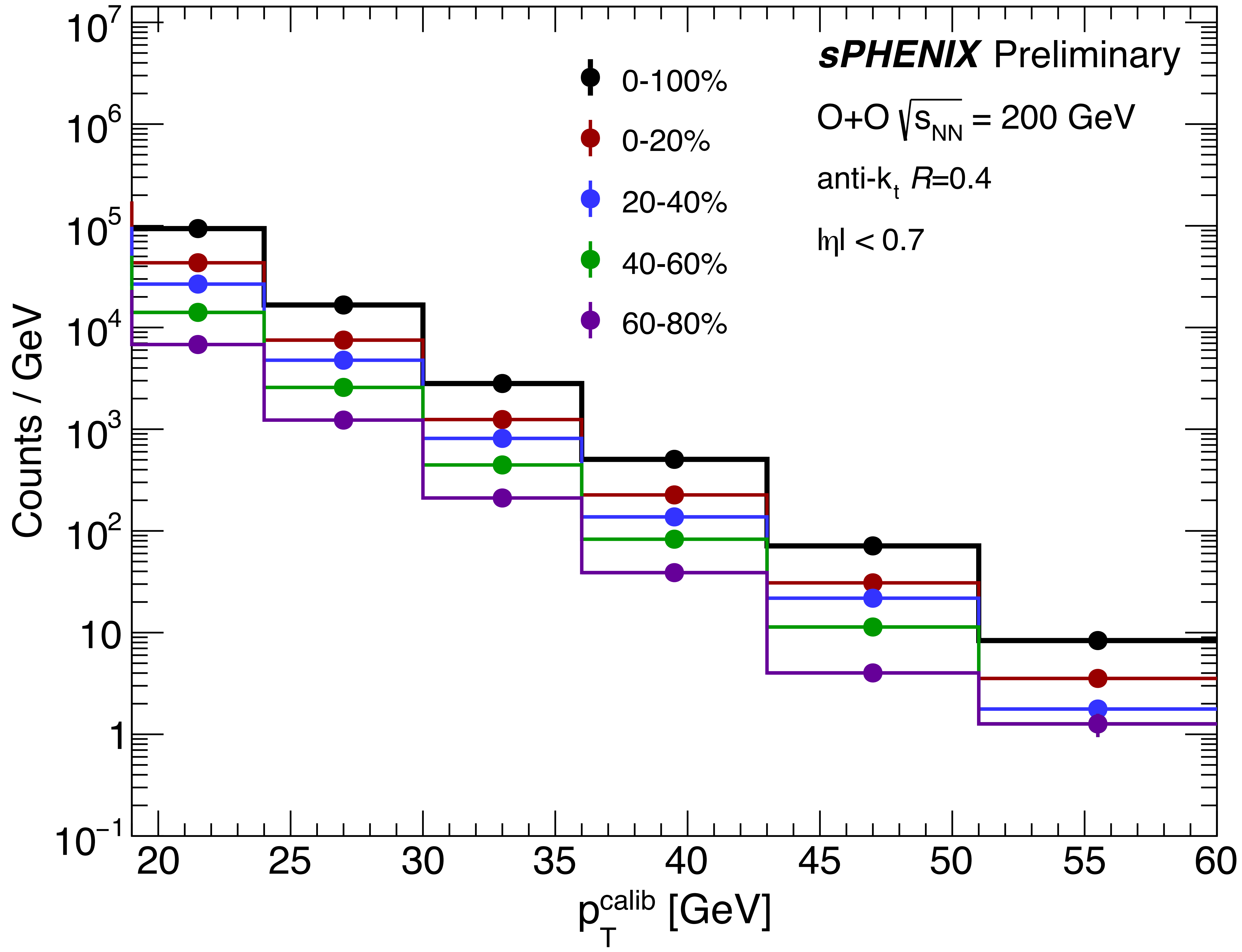
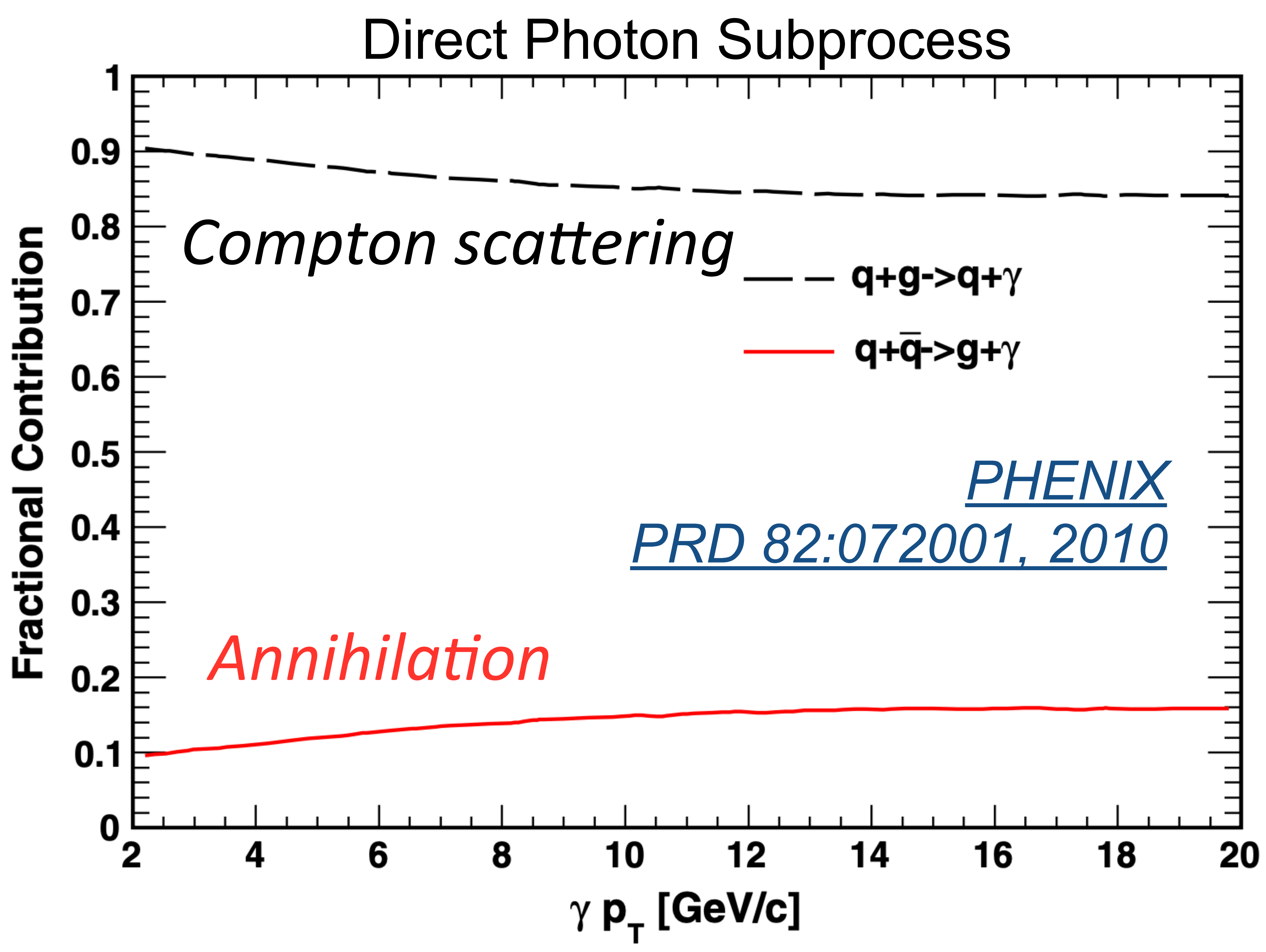
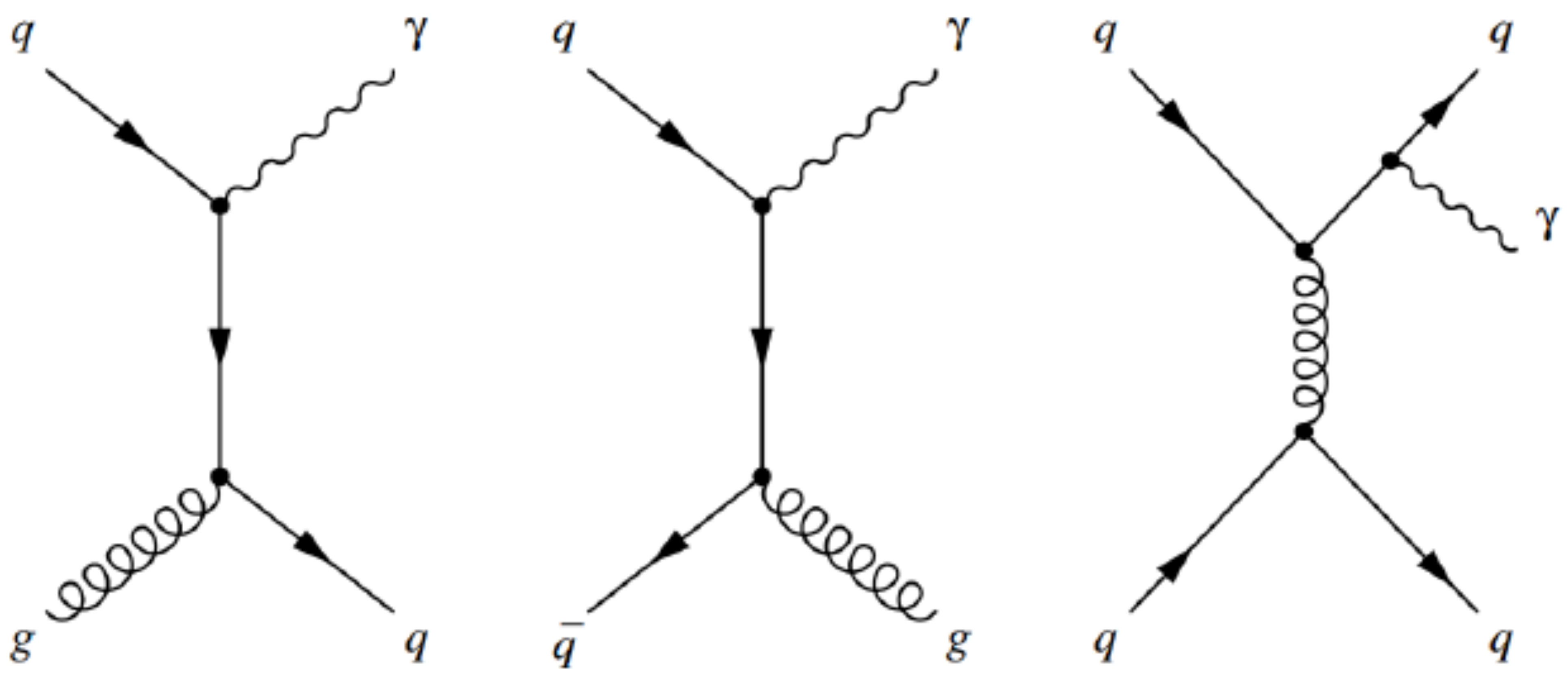




What are Prompt Photons ?

- **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

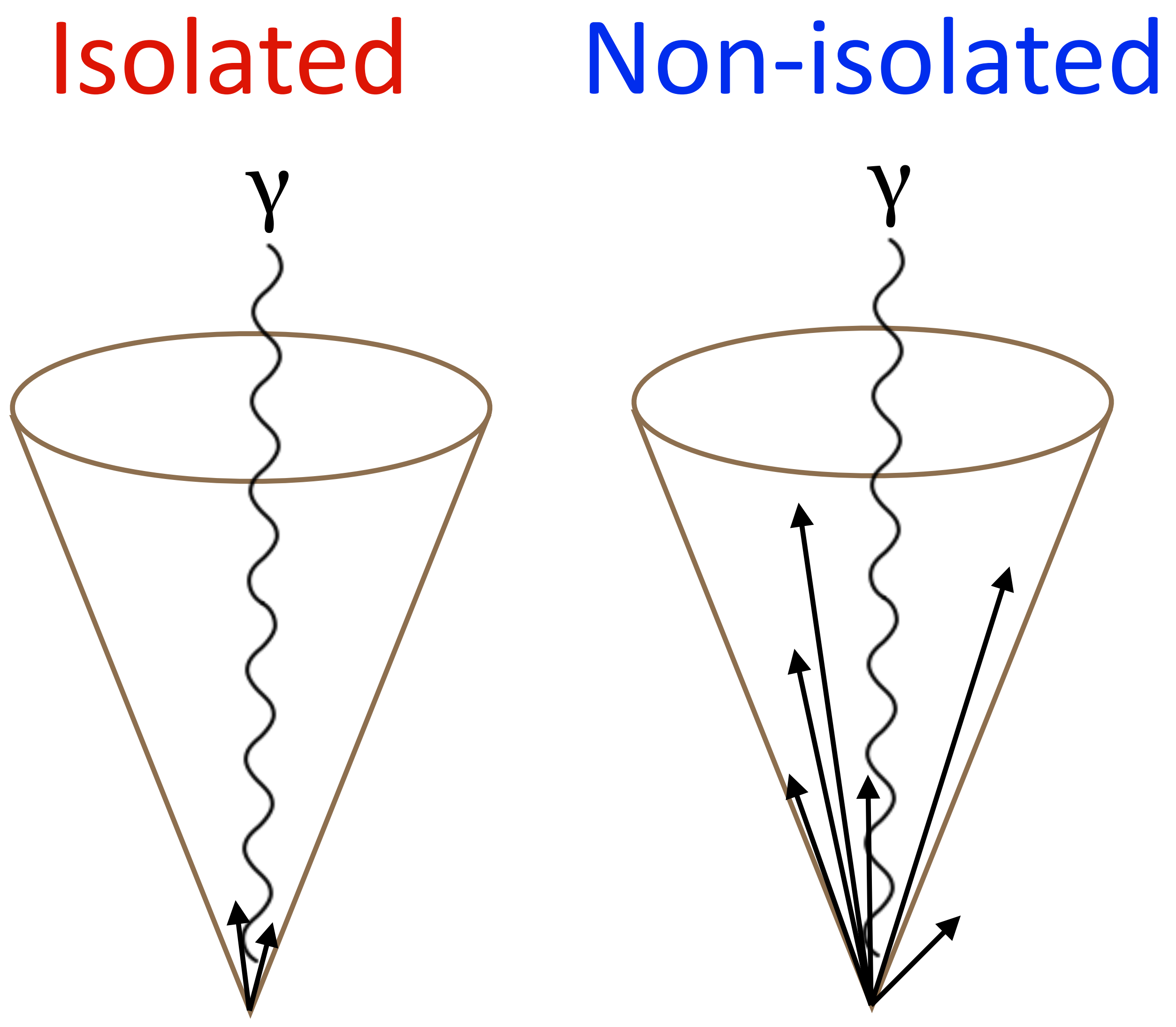
Direct photons *are predominantly produced by* ***Compton scattering***

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

Isolated Photons

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

- **Isolation condition in reconstruction**
  - ➡ suppresses significant background (decay) photons originated from neutral mesons

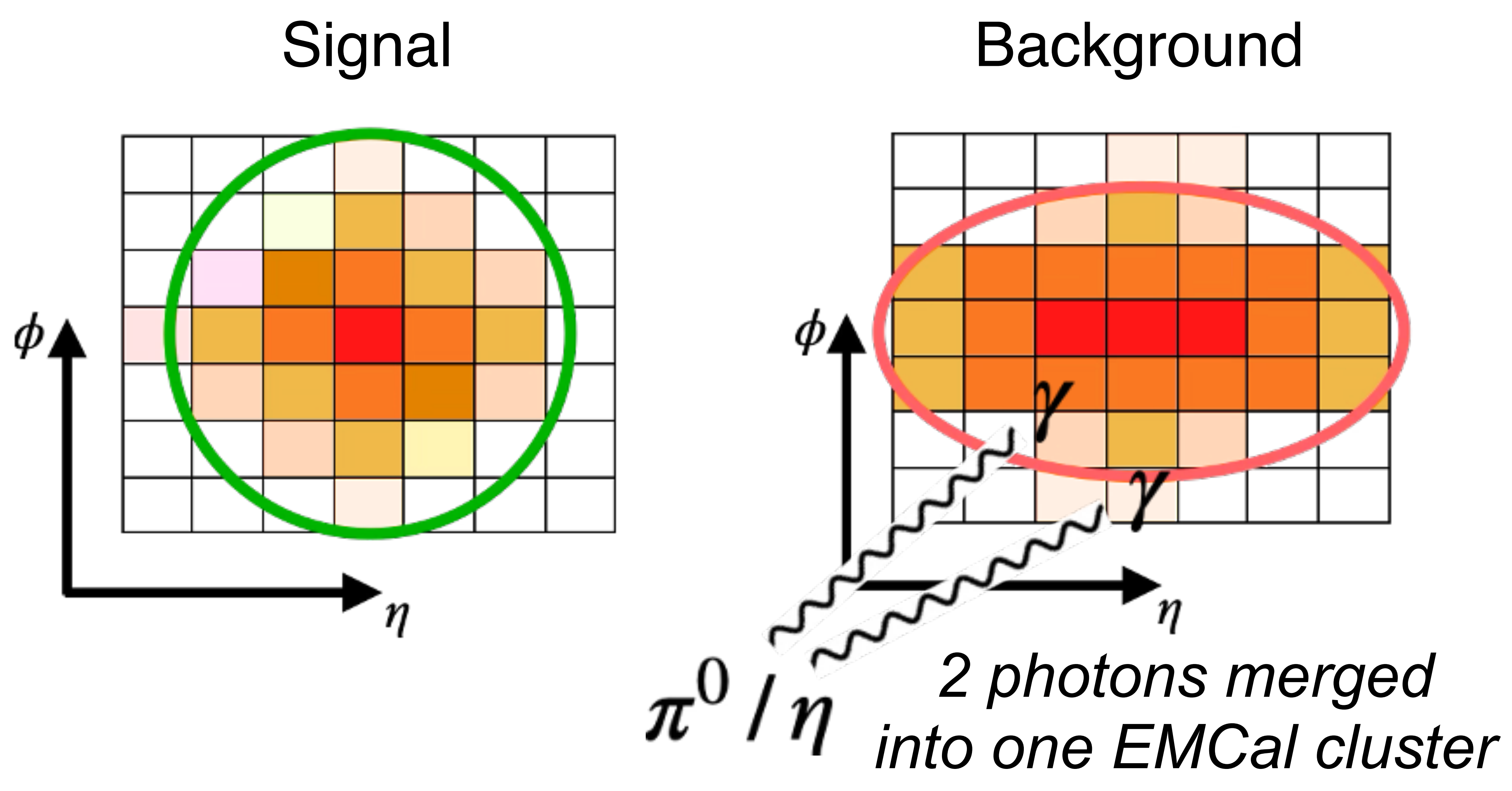


- ➡ decayed from hadrons such as $\pi^0 \rightarrow \gamma+\gamma$
- ➡ major background of prompt photons

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

Photon Identification

- Use EMCal shower shapes to distinguish signal (prompt) photons from background (decay) photons



Photon Identification

- Use EMCal shower shapes to distinguish signal (prompt) photons from background (decay) photons

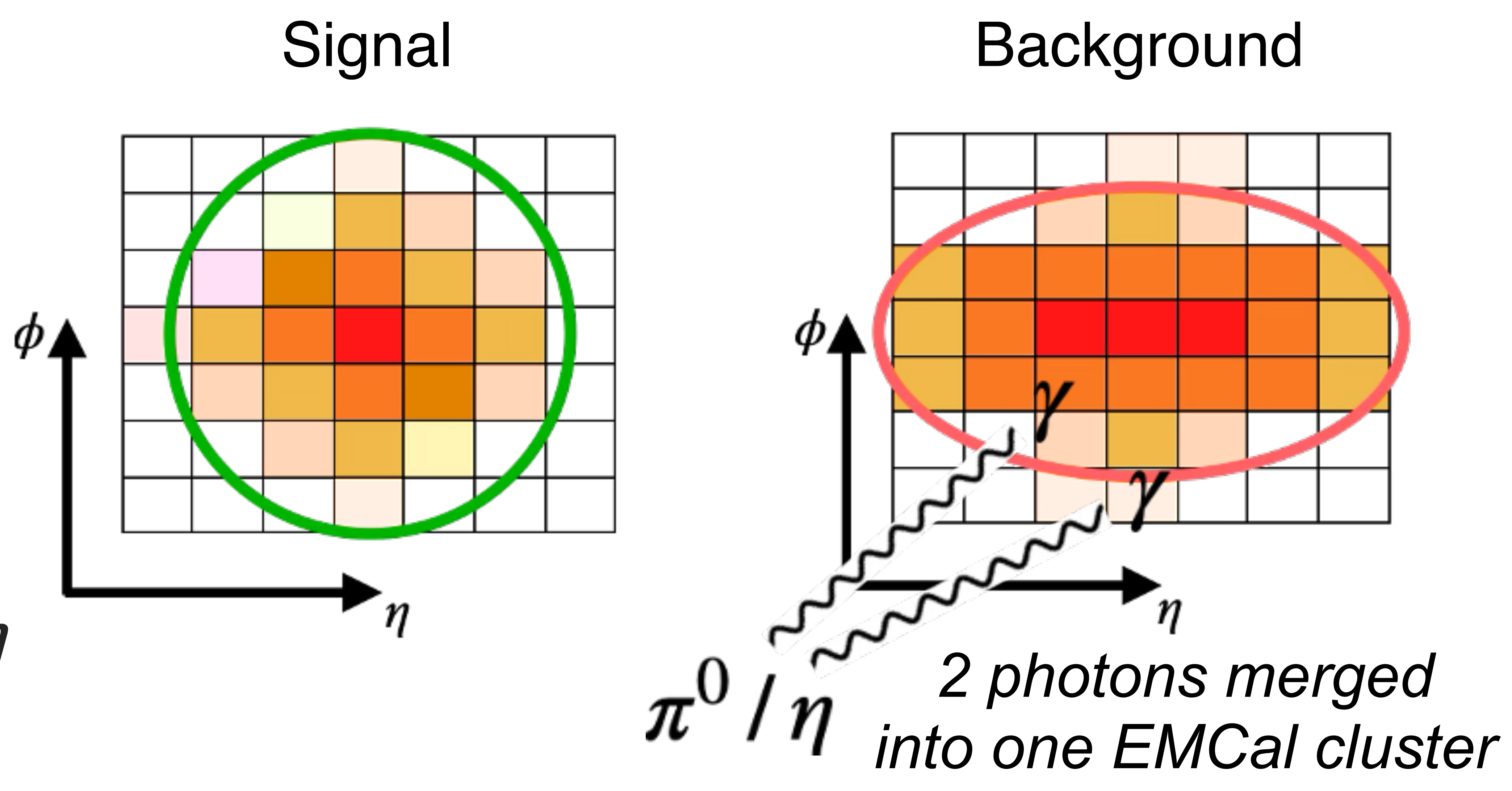
- **Five highly discriminating shower-shape variables** are used for photon identification (*"tight" ID*)
  - ➡ Energy-weighted second moment of EMCal towers (i) in η

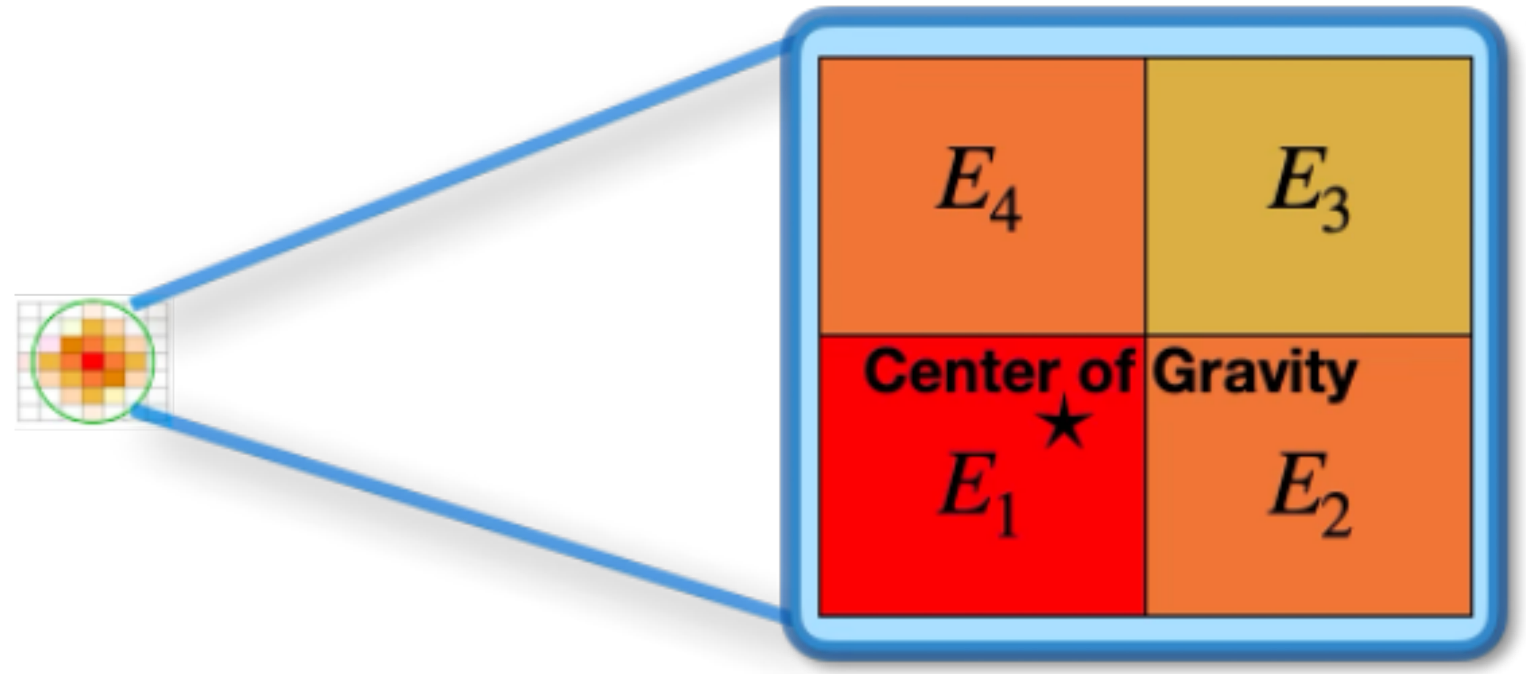
$$w_\eta = \frac{\sum_i E_i(\eta_i - \bar{\eta})^2}{\sum_i E_i}$$

  - ➡ Fraction of core energy w.r.t total cluster energy

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

  - ➡ …





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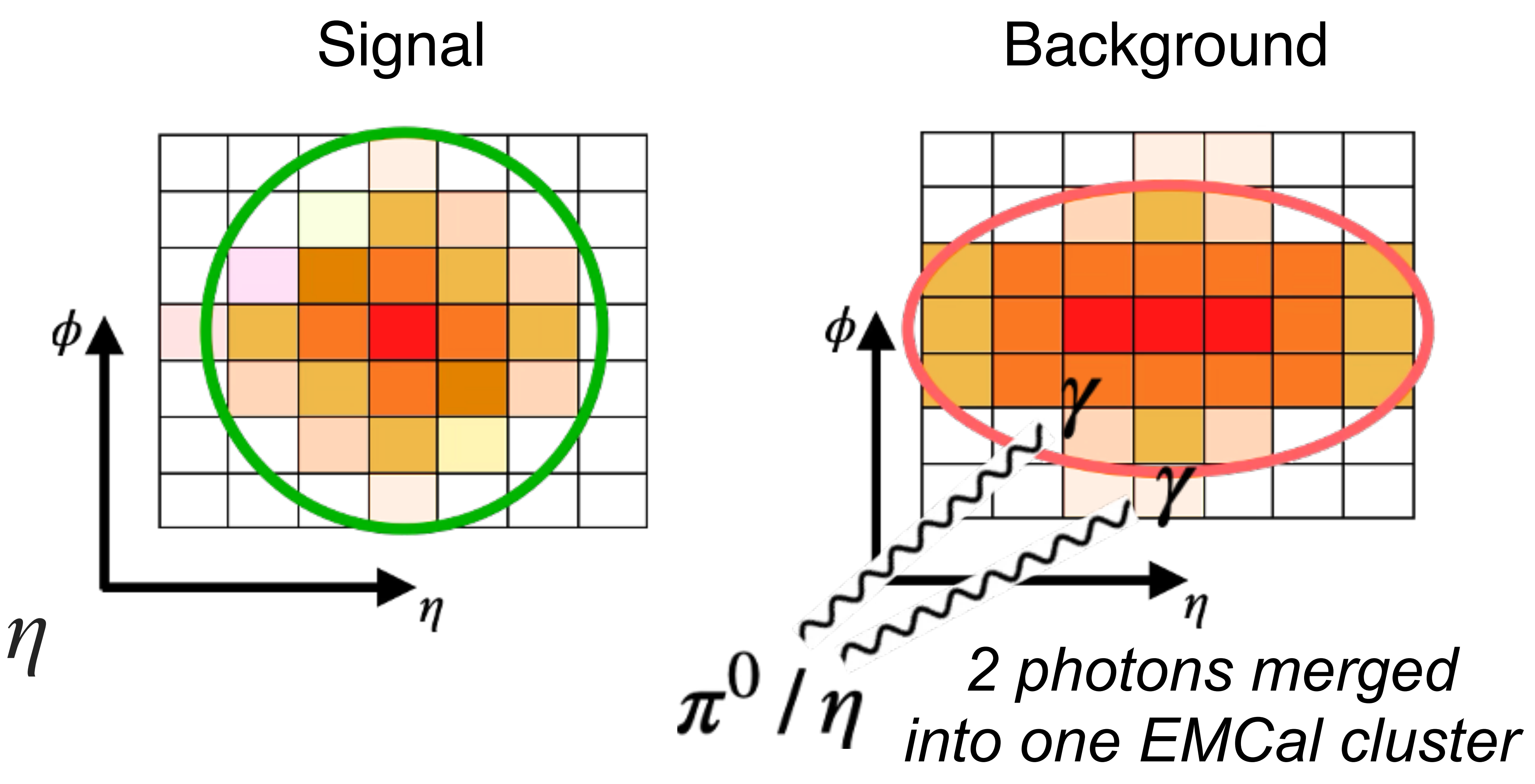

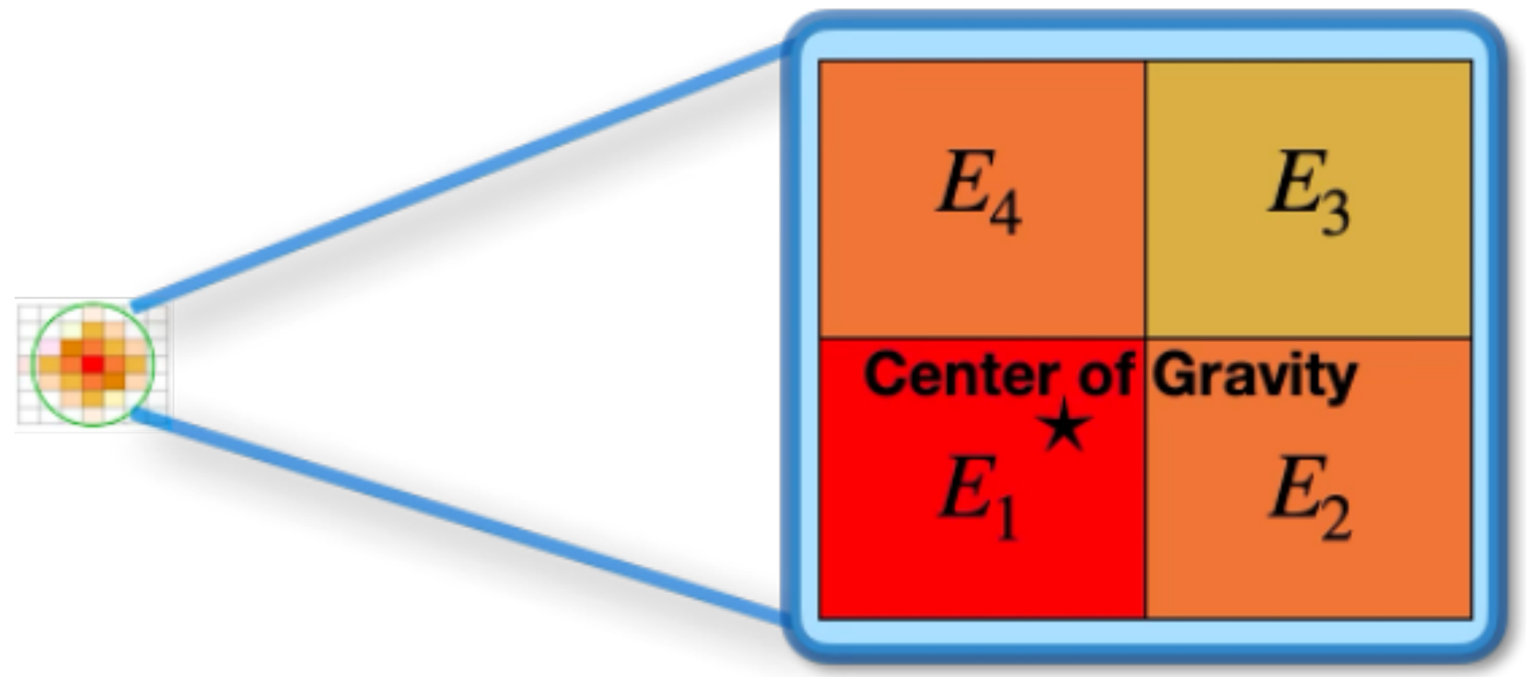

Recent study shows further improvement using Boosted Decision Tree (BDT)
→ *stay tuned for the finalized result with BDT !*

Inclusive Jets

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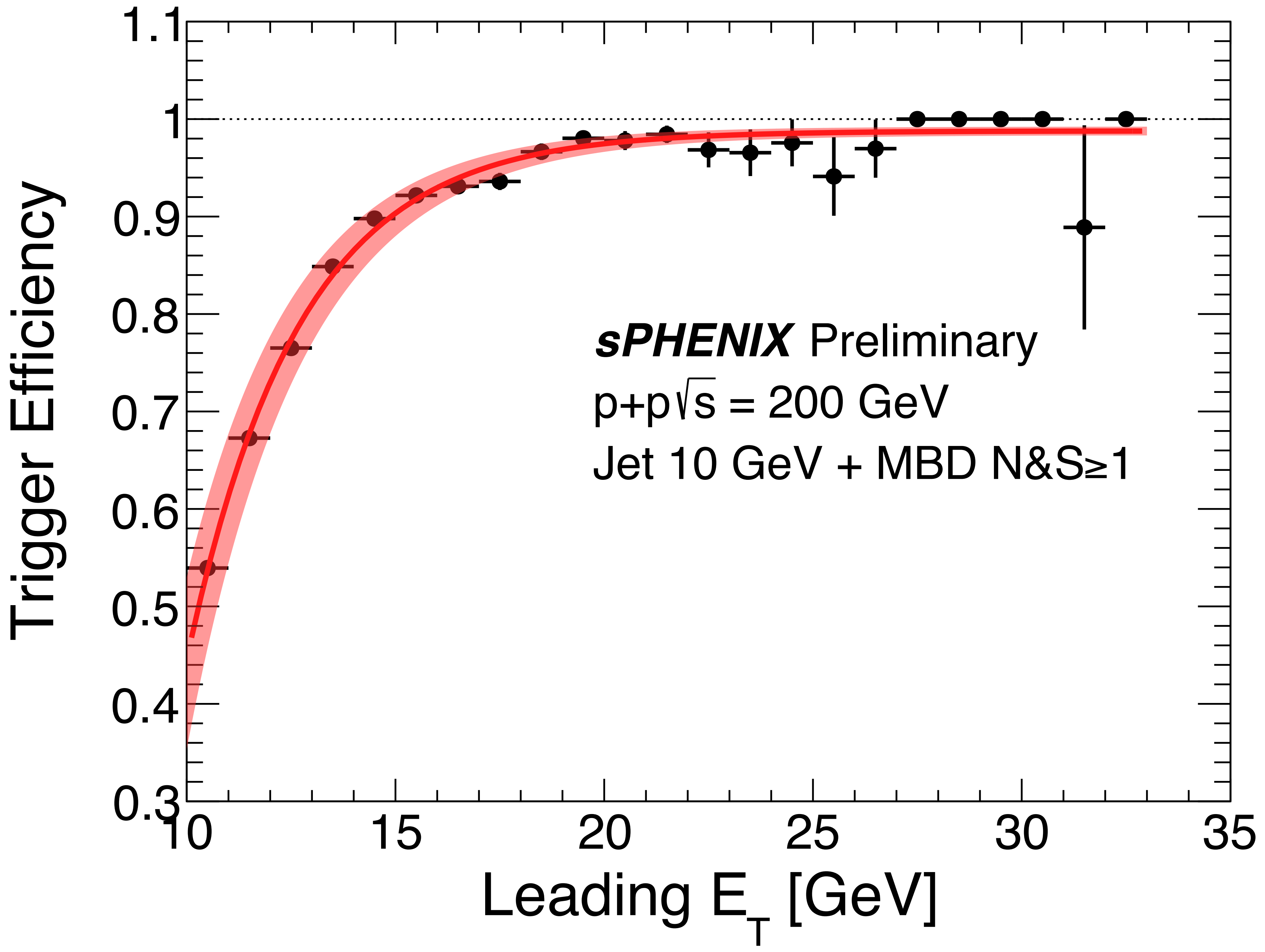

- Jets are **triggered and reconstructed** using 3 layers of calorimeters (EMCal, iHCal, oHCal)
  ➡ **First mid-rapidity HCal at RHIC**; unbiased triggering

Inclusive Jets

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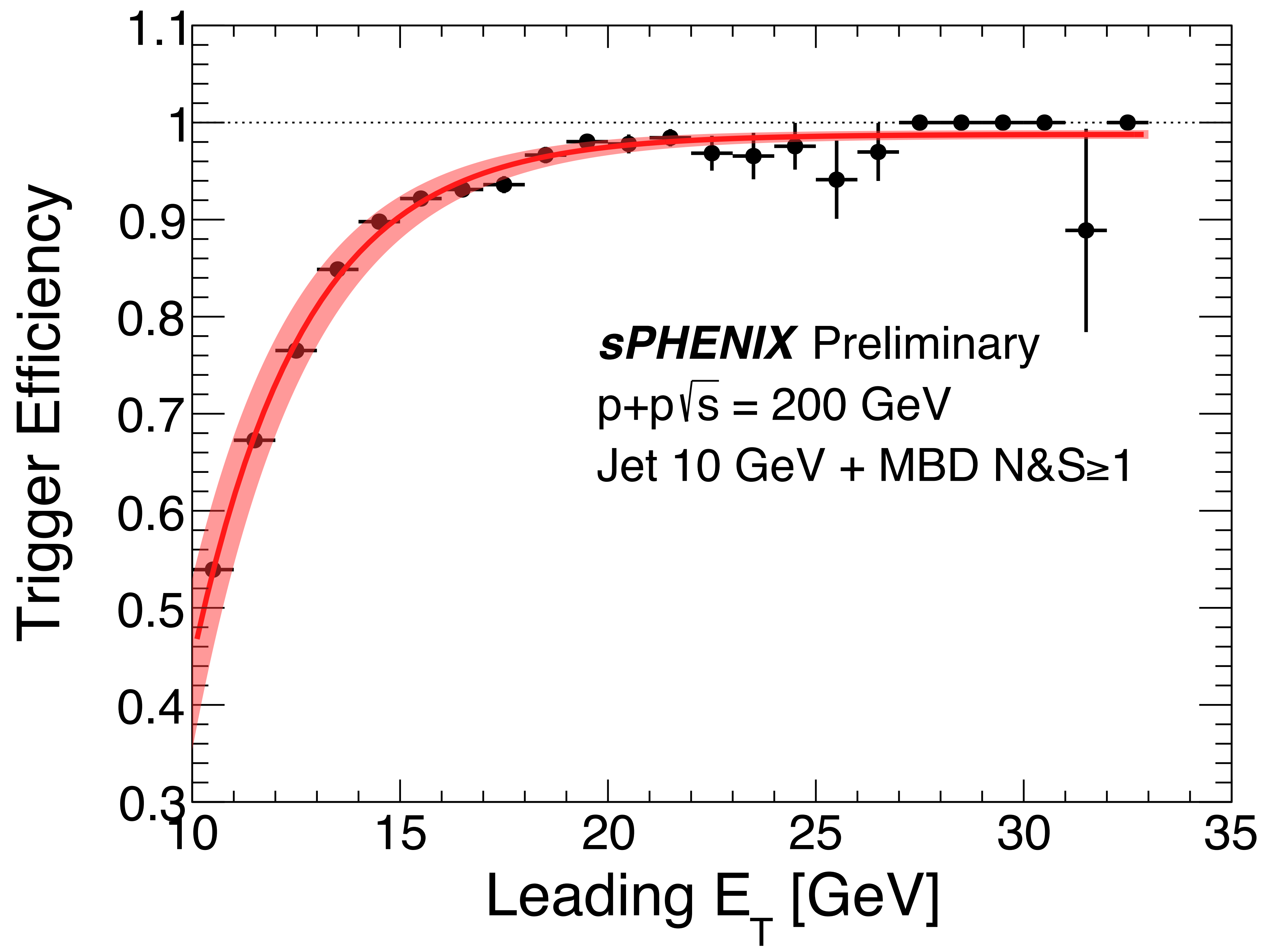

- **Beam-induced and cosmic background** are rejected
  - ➡ Di-jet $\Delta\phi > 3\pi/4$
  - ➡ Energy fraction in each calorimeter layer

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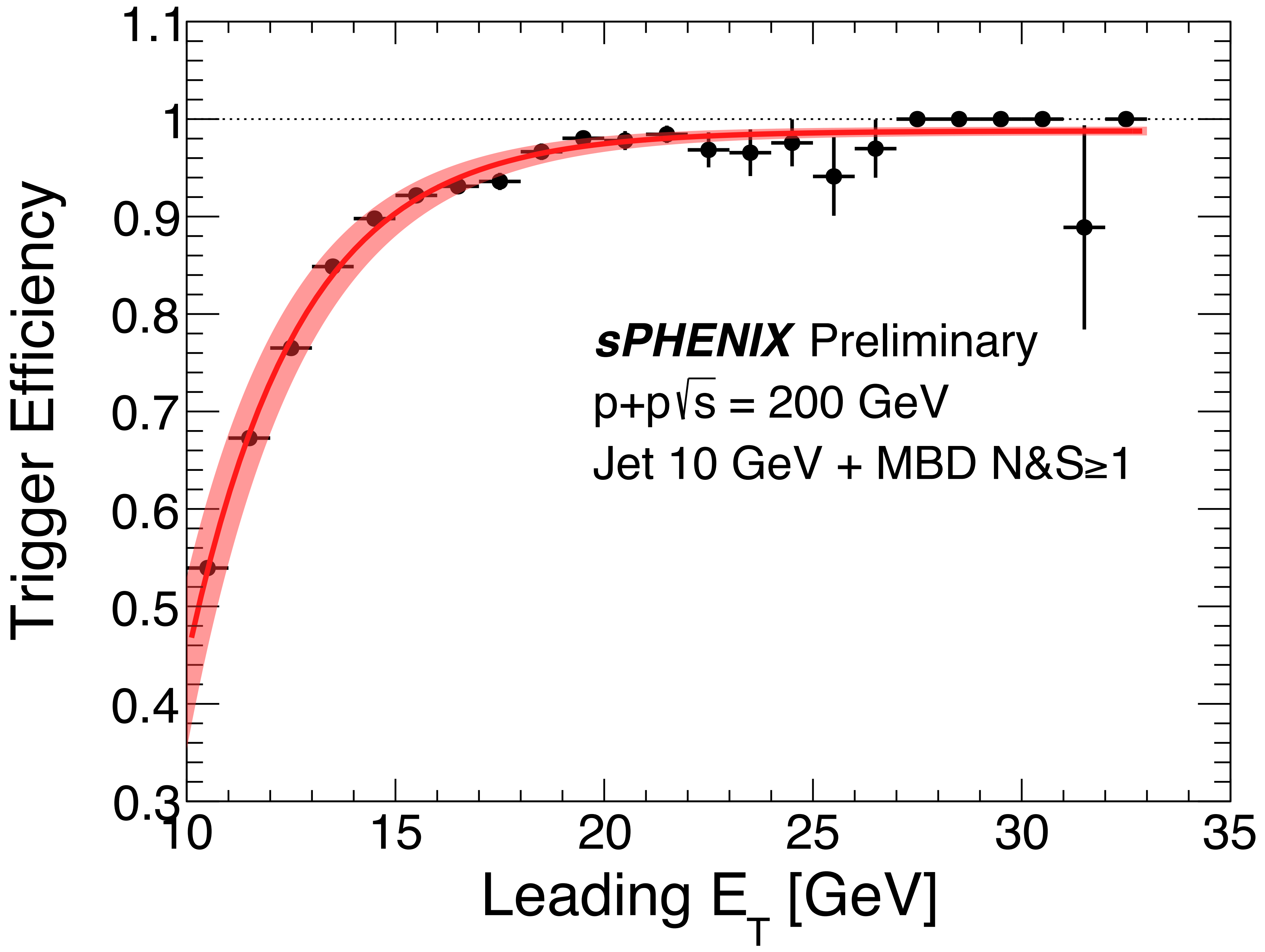

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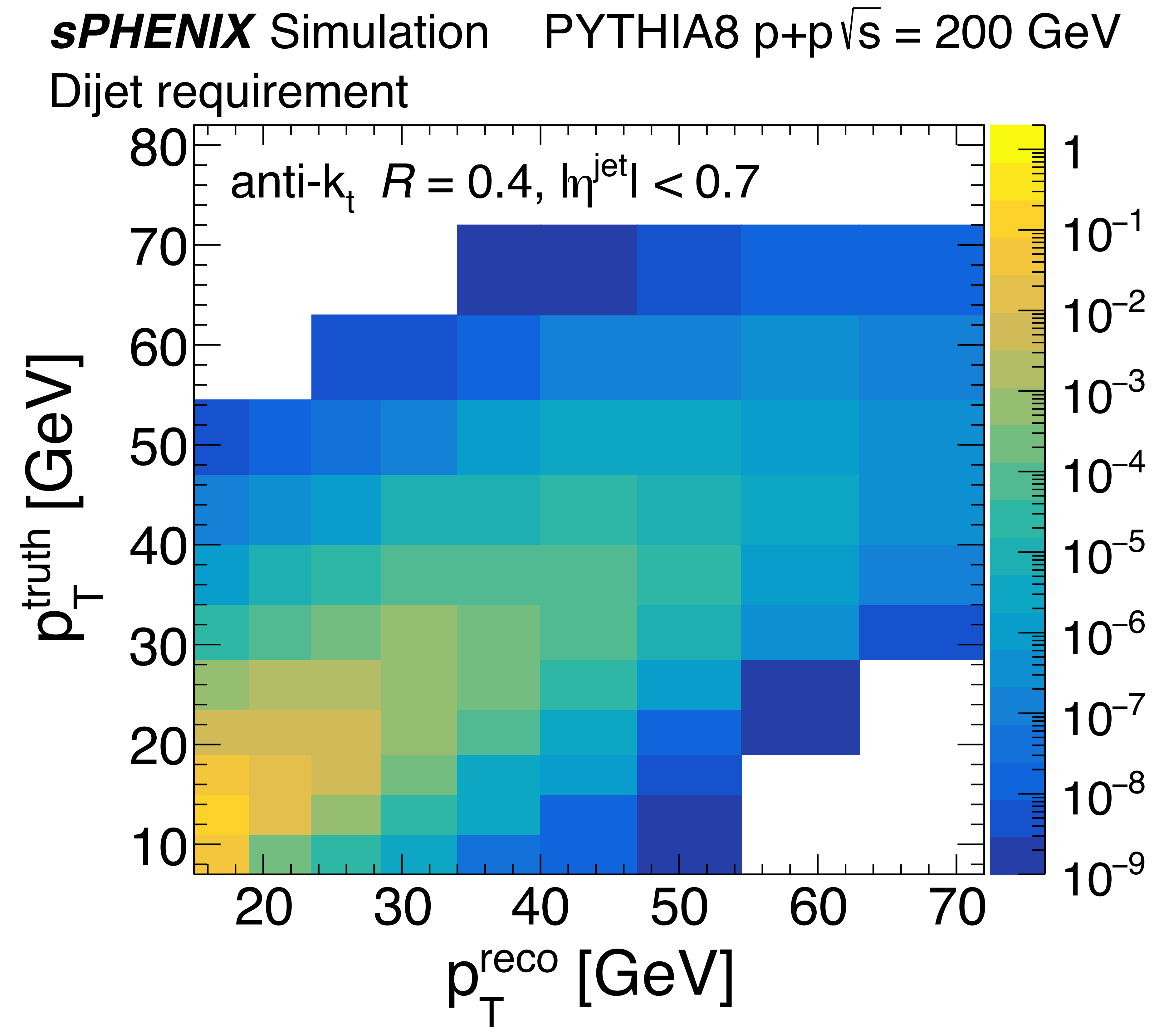

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- **Unfolded** to correct for detector effect / energy resolution