



**26th** International  
Symposium on Spin Physics  
A Century of Spin

2025/09/19

26th International Symposium on Spin Physics

# Central rapidity jet transverse single spin asymmetry measurements in proton-proton collisions with sPHENIX

Genki Nukazuka (RIKEN)  
on behalf of the sPHENIX Collaboration



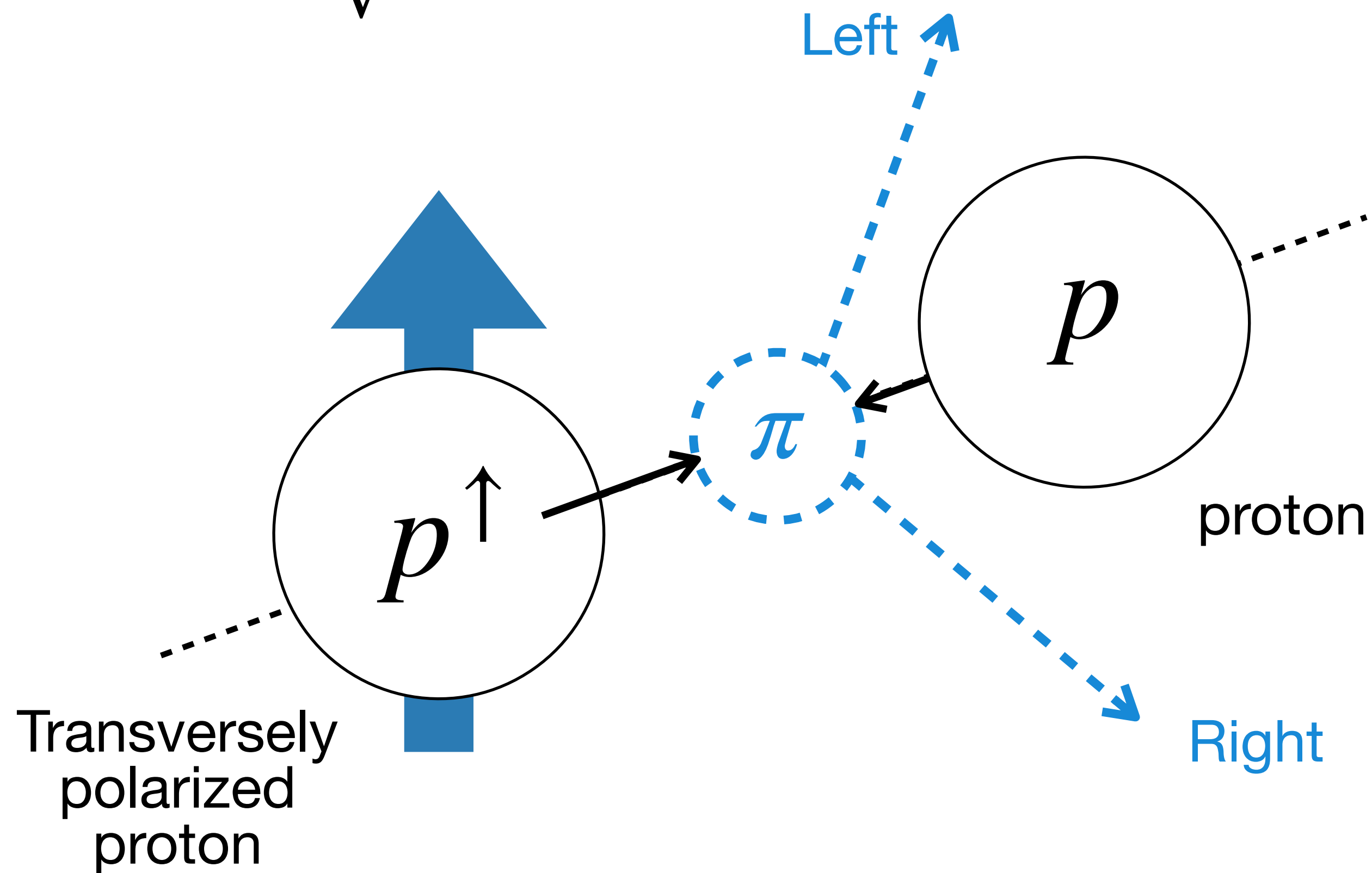
sPHENIX Collaboration meeting (2024)



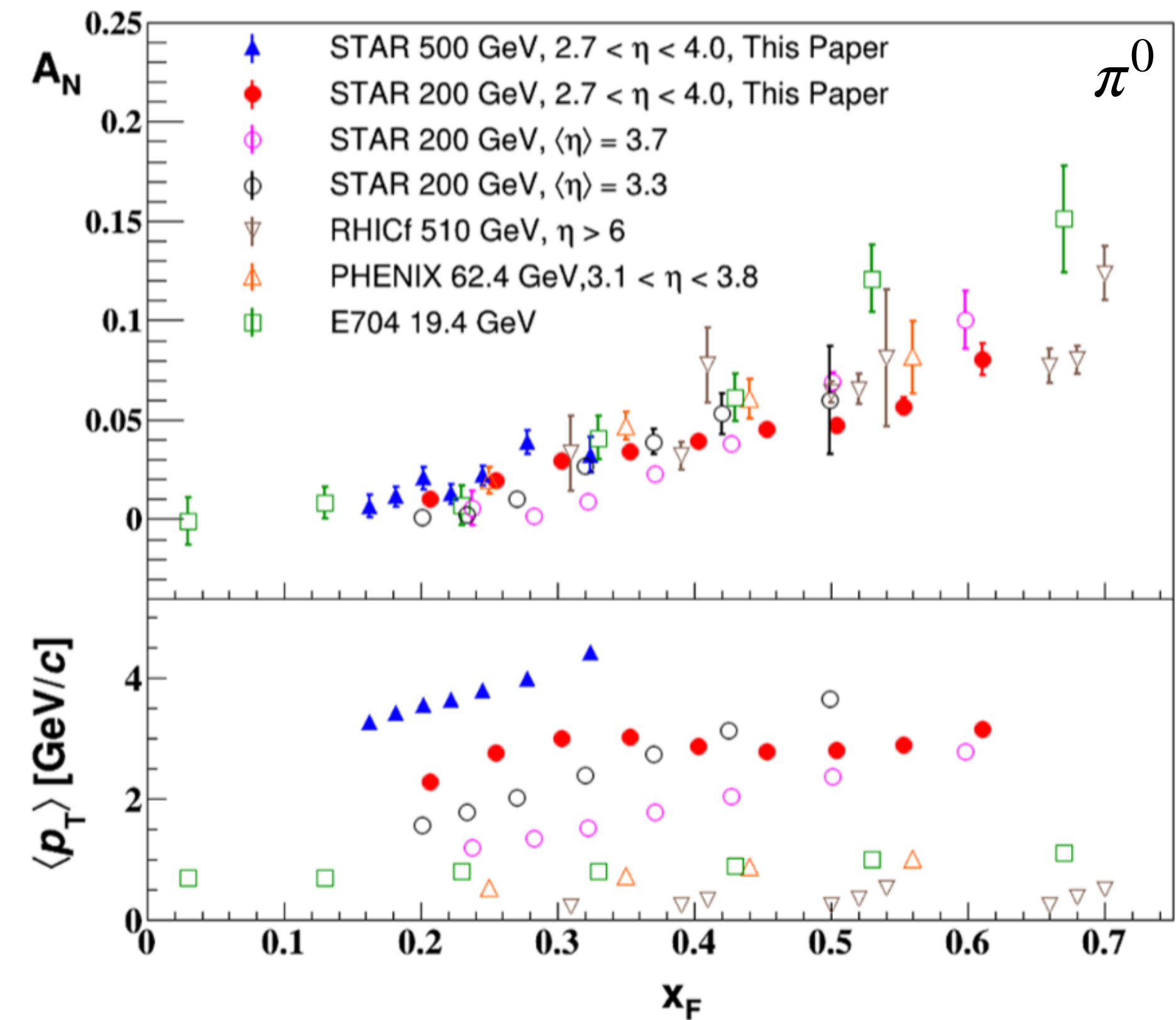


# Transverse Single Spin Asymmetry

Large left-right asymmetry in  $p^\uparrow + p \rightarrow \pi + X$  has been observed with different  $\sqrt{s}$ .



$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$



Experiment: up to 30%

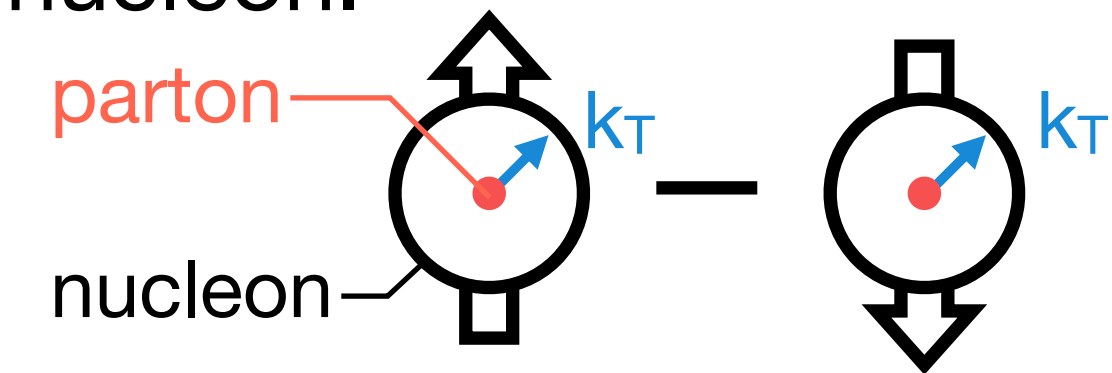
Leading order calc. in pQCD:  $\sim 0.01\%$

# Transverse Single Spin Asymmetry

## Transverse-momentum dependent (TMD) distribution functions and fragmentation functions

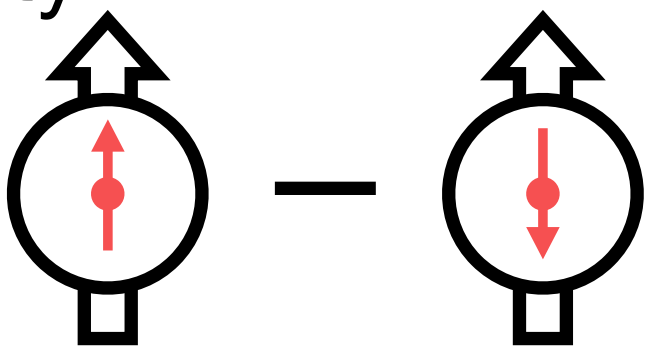
### Sivers mechanism

Correlations of nucleon transverse spin and parton transverse momentum in the nucleon.



### Collins mechanism

- Transversity



- Collins fragmentation function  
Spin dependent fragmentation function of a transversely polarized parton into a final-state hadron

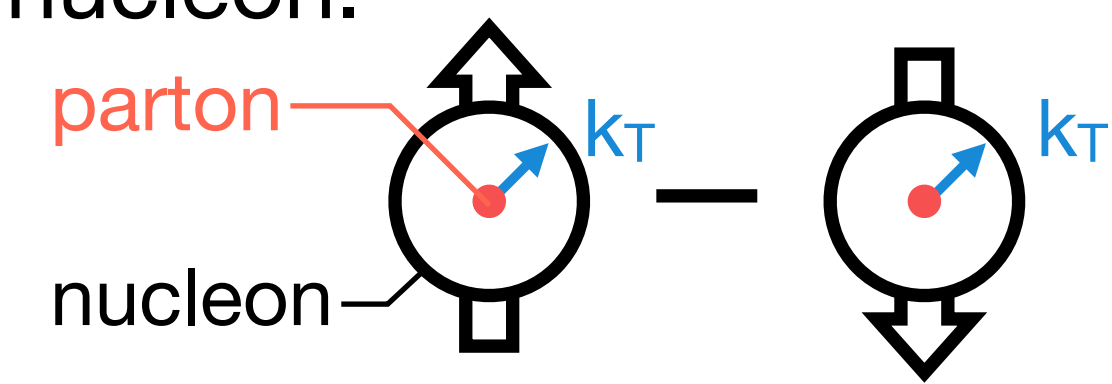
		Spin state of nucleon		
		No pol.	Long.	Trans.
Spin state of quark	No pol.	Number density		Sivers
	Long.		Helicity	Worm-Gear
	Trans.	Boer-Mulders	Worm-Gear	Transversity Pretzelosity

# Transverse Single Spin Asymmetry

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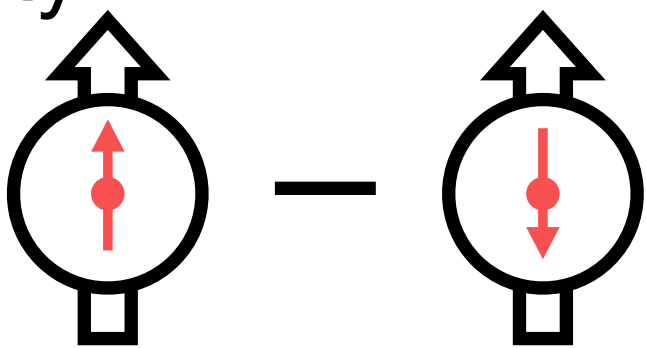
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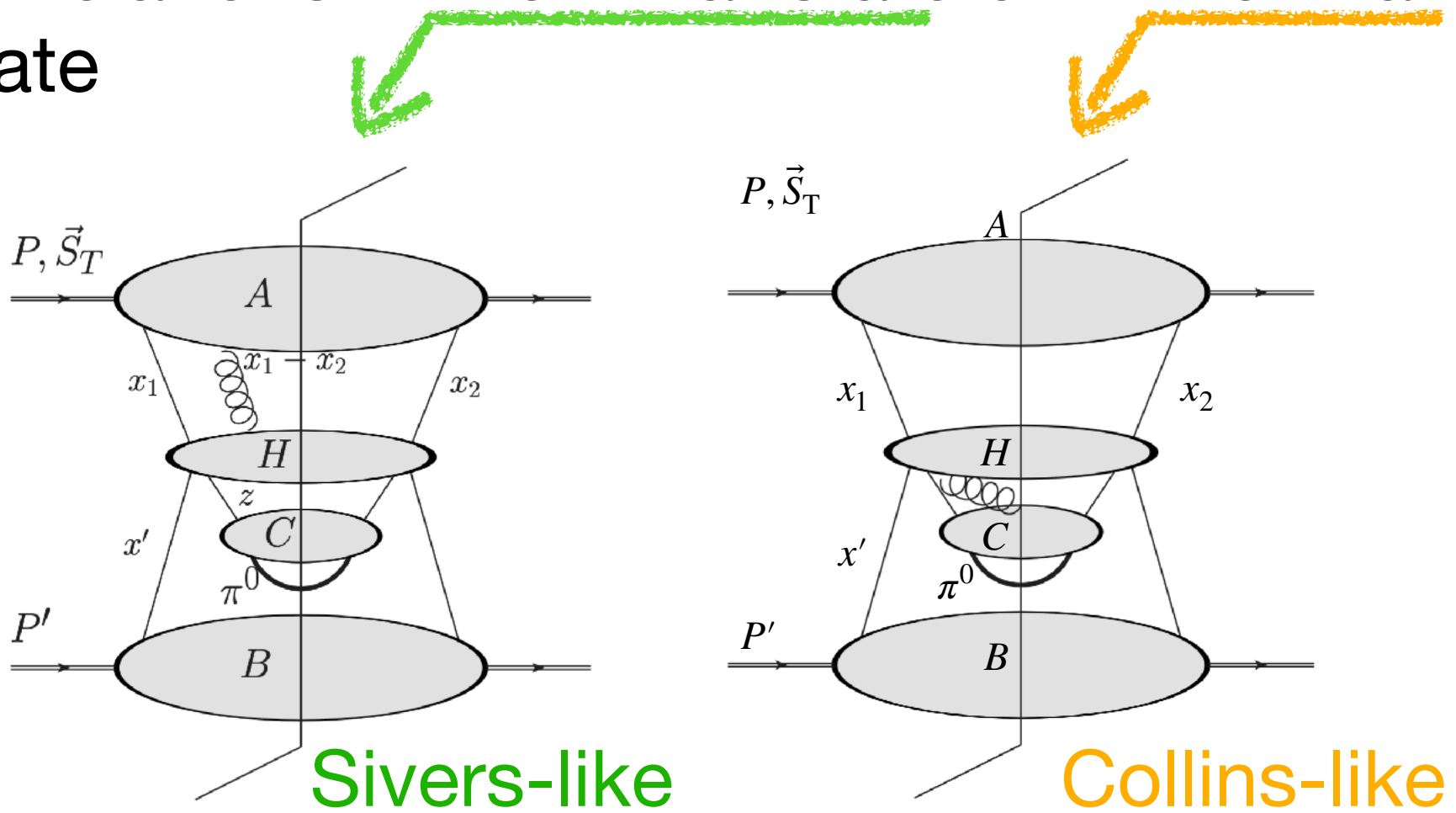
- Transversity



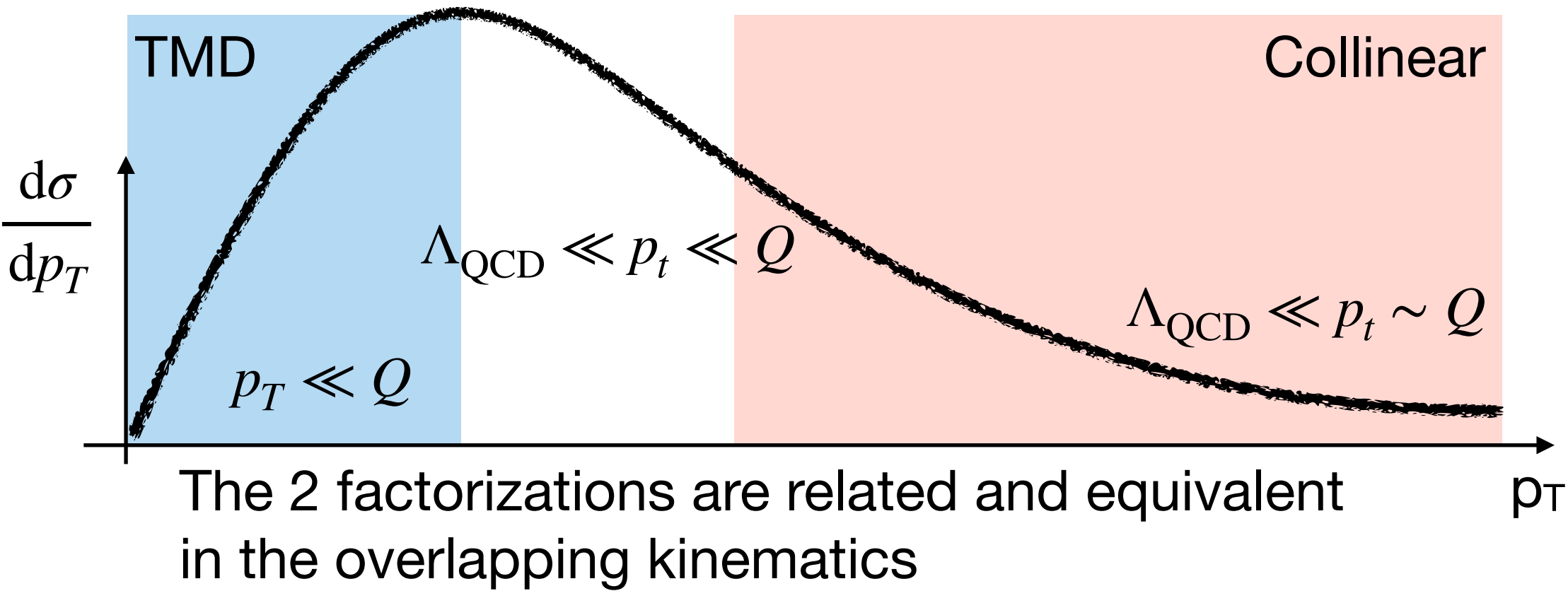
- Collins fragmentation function  
Spin dependent fragmentation function of a transversely polarized parton into a final-state hadron

## Multi-parton correlation in twist-3 collinear factorization

Twist-3 Quark-gluon-quark and Tri-gluon correlations in the initial-state or in the final-state

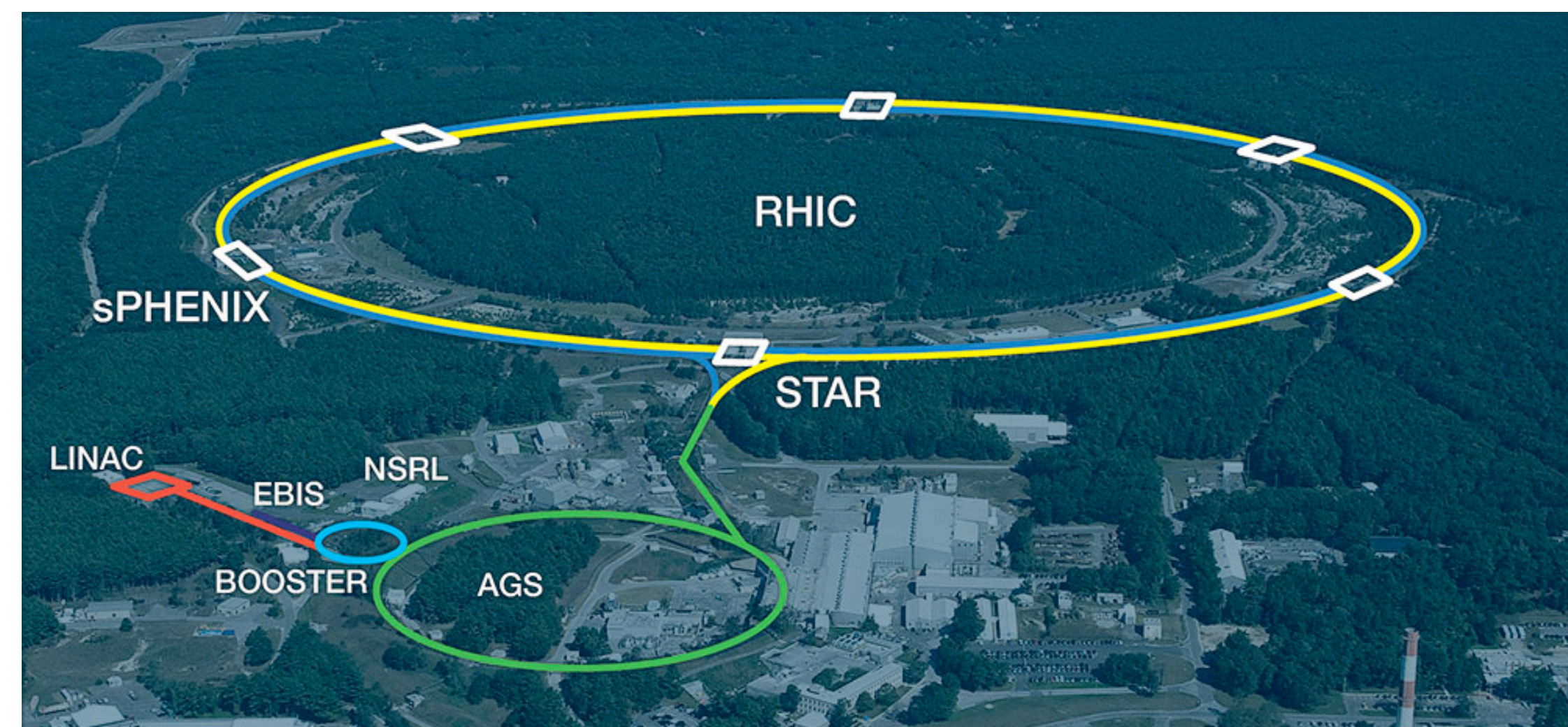
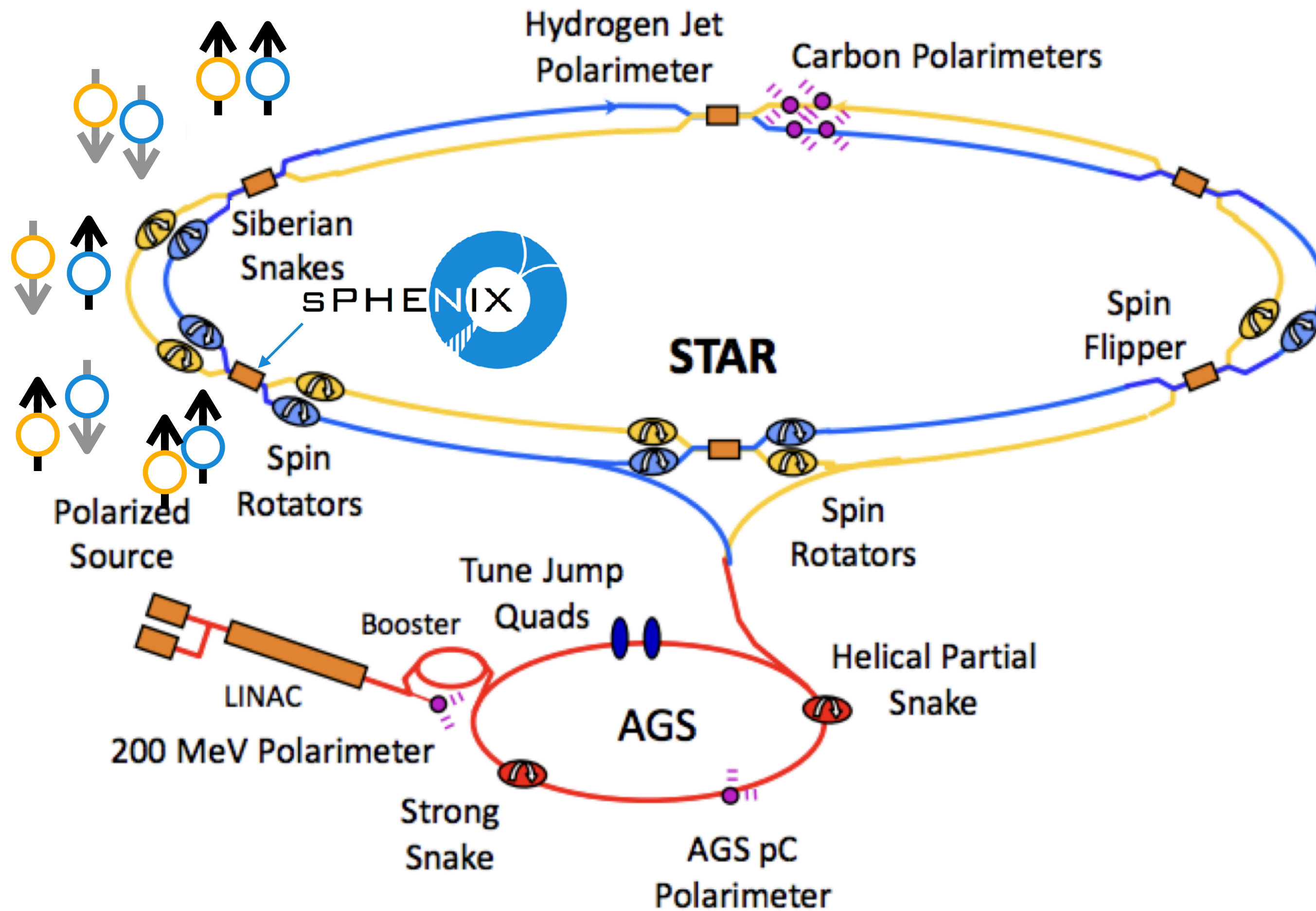


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# Relativistic Heavy Ion Collider



# World's first and only polarized proton+proton collider

- Provide polarized proton+proton collisions up to  $\sqrt{s} = 510 \text{ GeV}$

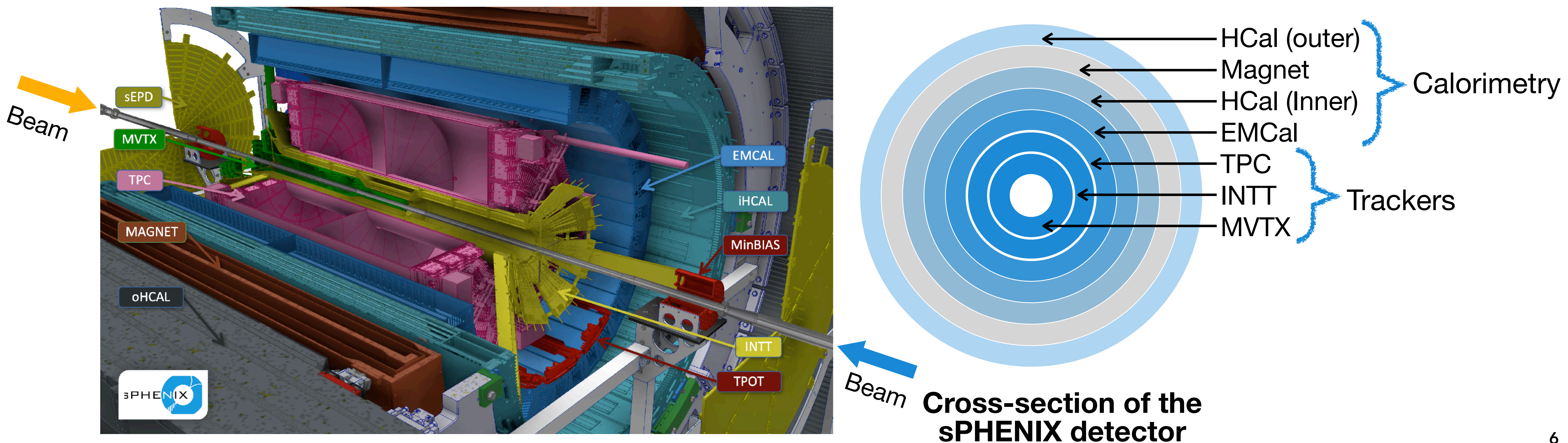
## High (50-60%) transverse polarization and frequent spin flips

- Siberian snakes minimize depolarizing effect
- Spin rotators allow changing from vertical to radial or longitudinal polarization.
- proton-Carbon and hydrogen gas jet polarimeters measure the polarization.



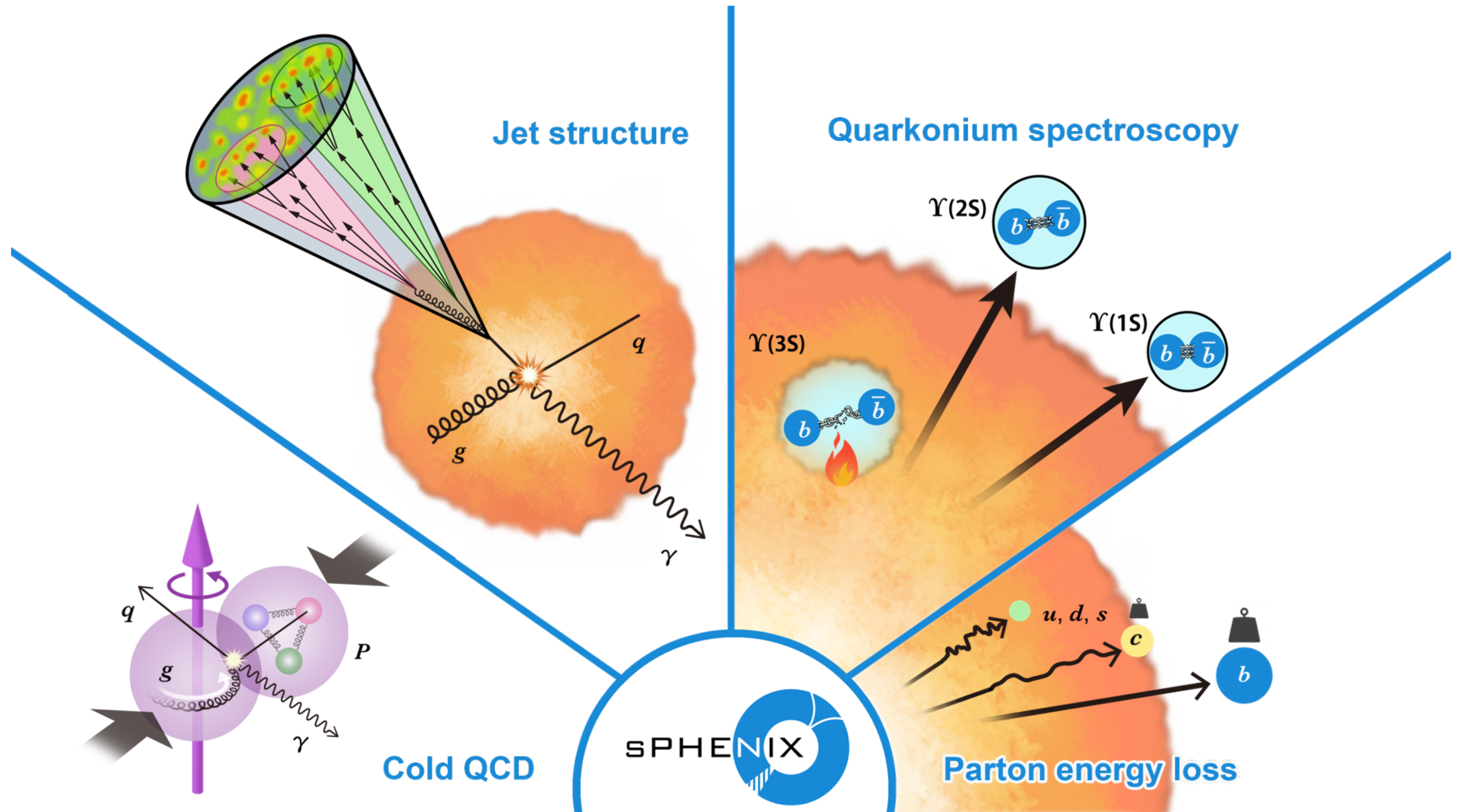
# sPHENIX Collaboration

- State-of-the-Art Jet Detector at RHIC
- Study of quark-gluon-plasma and Cold-QCD
- About 400 scientists and students from 14 countries
- Full azimuthal and  $|\eta| < 1.1$  acceptance for collisions in  $\pm 10$  cm





# Main Physics Programs at sPHENIX





# Run 2024

## 2023 ✓

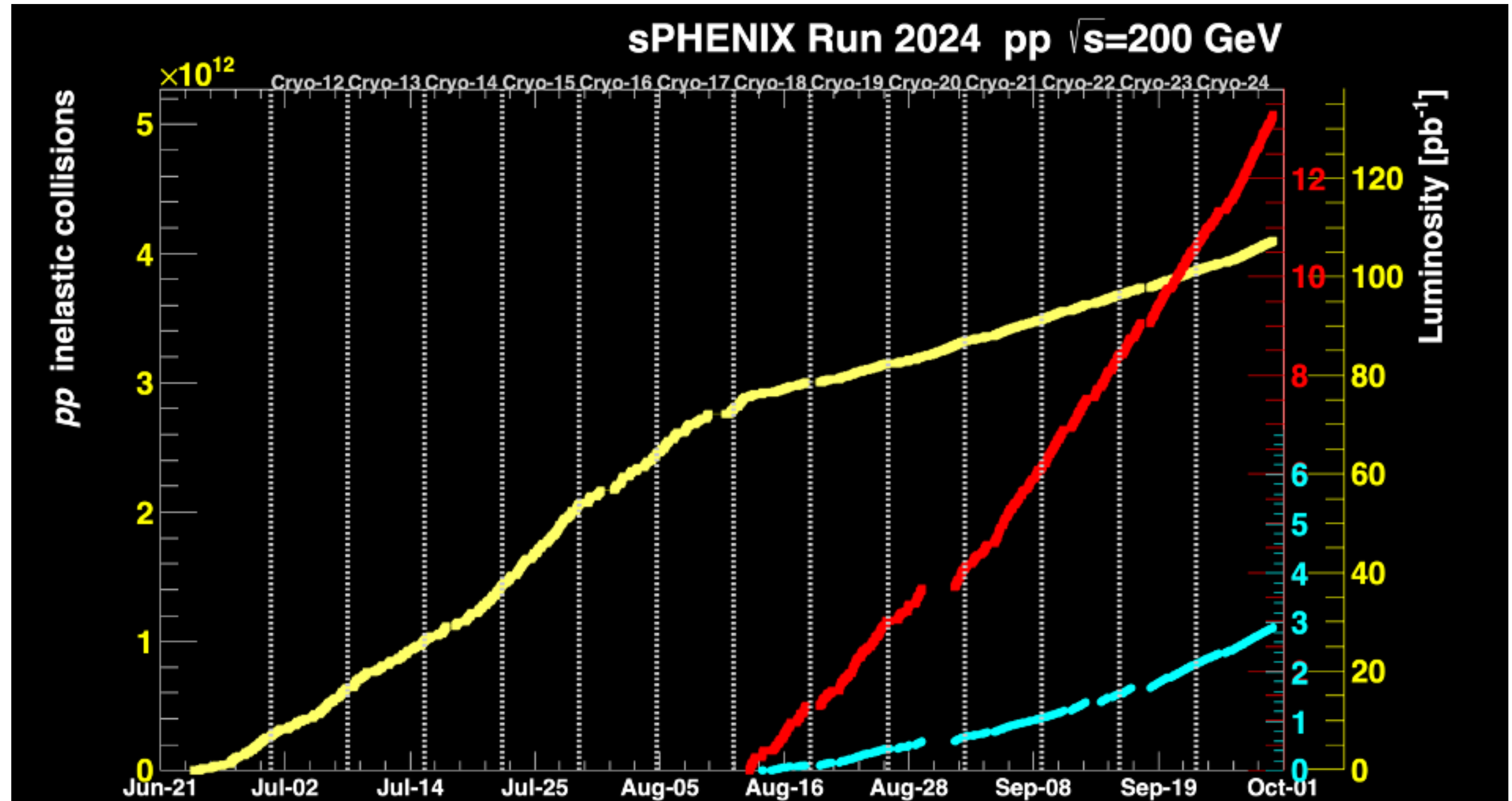
- AuAu,  $\sqrt{s_{NN}} = 200$  GeV, commissioning

## 2024 ✓

- $p^\uparrow p^\uparrow$ ,  $\sqrt{s} = 200$  GeV, commissioning and data taking
- AuAu,  $\sqrt{s_{NN}} = 200$  GeV, commissioning

## 2025

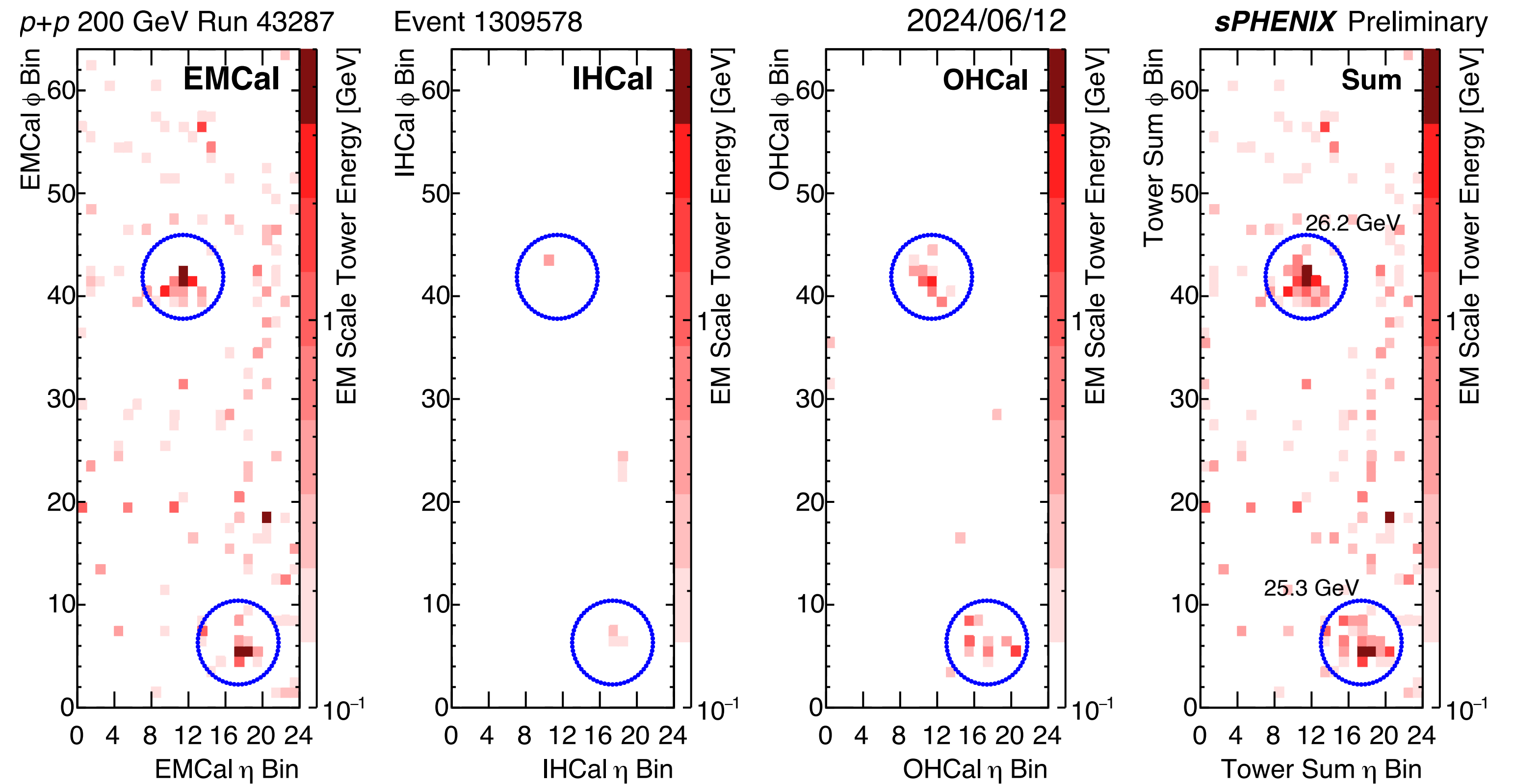
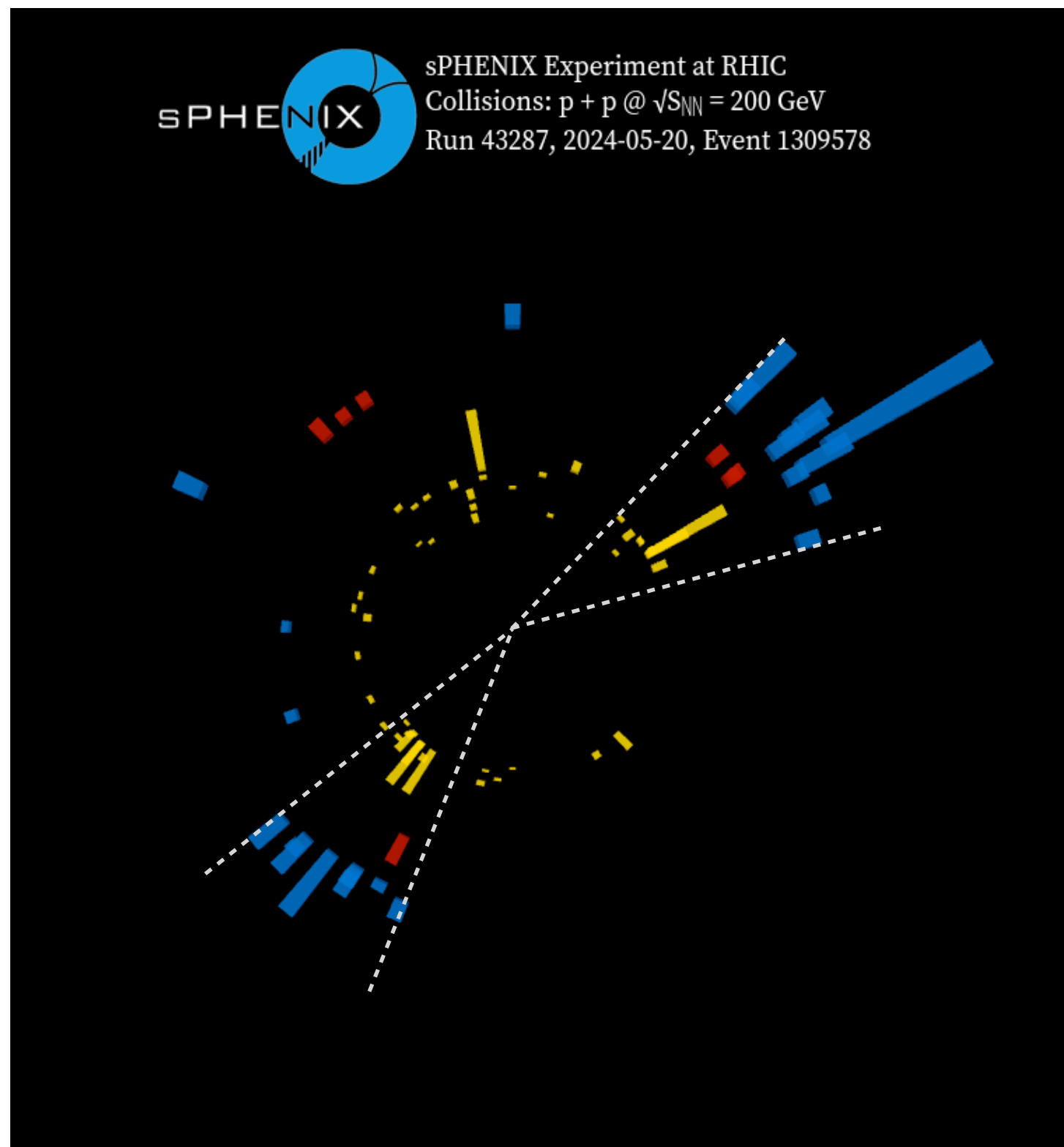
- AuAu,  $\sqrt{s_{NN}} = 200$  GeV, data taking
- additional measurement under discussion



- Calorimeter data: 107  $\text{pb}^{-1}$
- 0 mrad crossing angle
- More than twice luminosity goal achieved



# Run 2024, Dijet event display



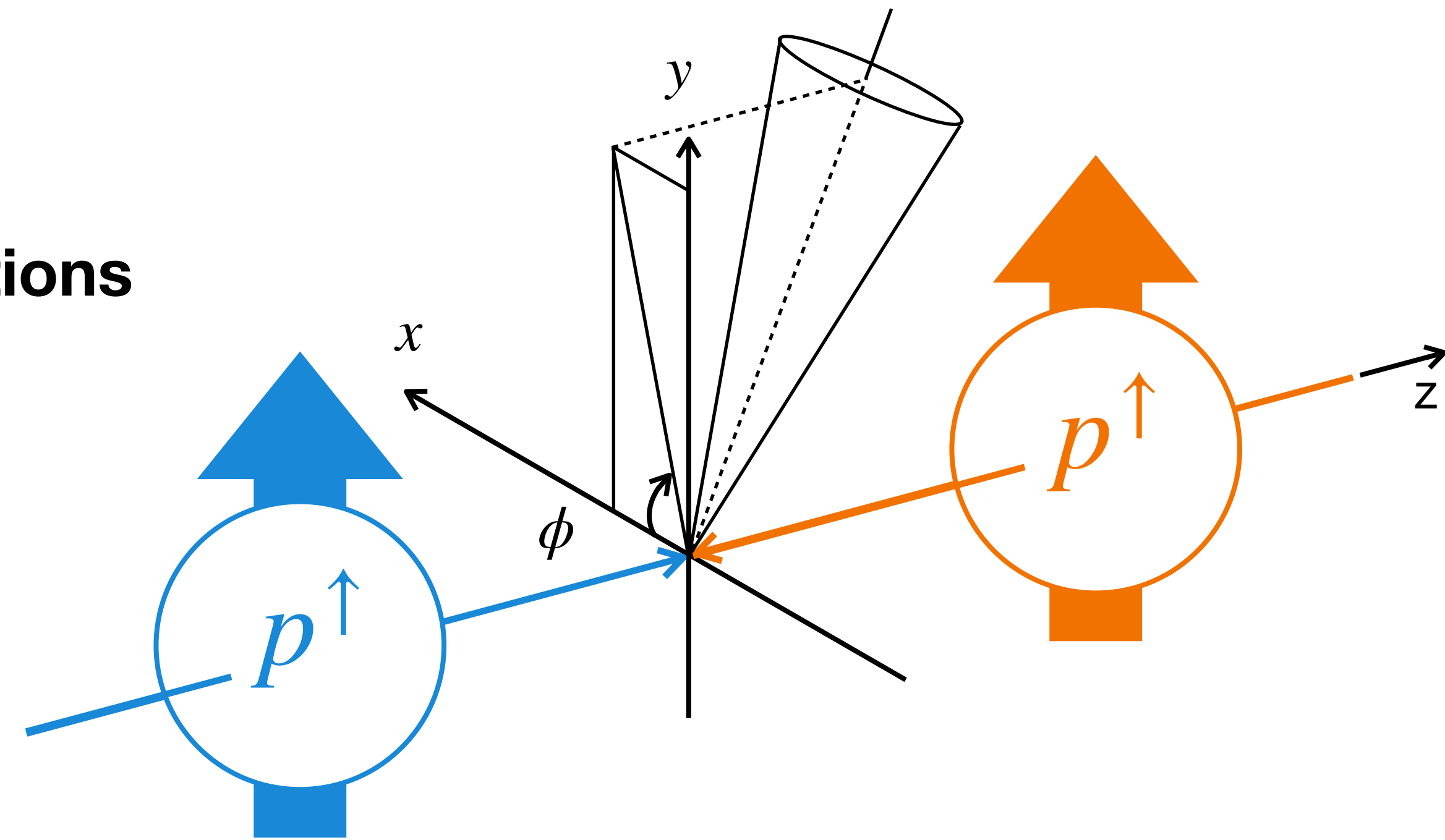
Dijet event display and energy distributions of the calorimeters.  
We could make them at the beginning of the physics data taking.

# Inclusive jet $A_N$

Powerful probe for initial-state partonic interactions  
and insensitive to final-state effect.

Transverse single-spin asymmetry  
(TSSA):

$$\frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} = A_N \sin \phi = \frac{1}{P} \varepsilon_N \sin \phi$$





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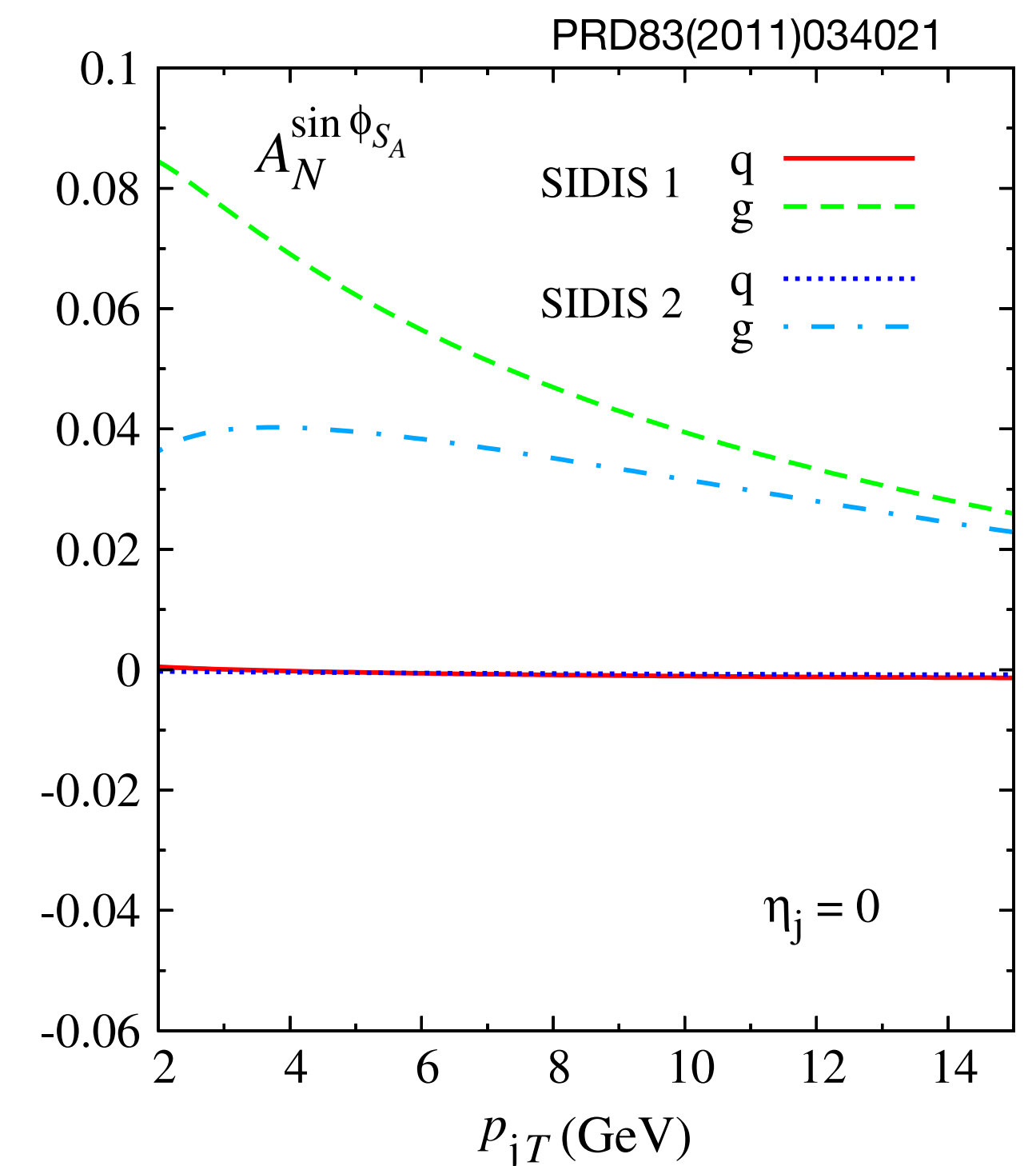
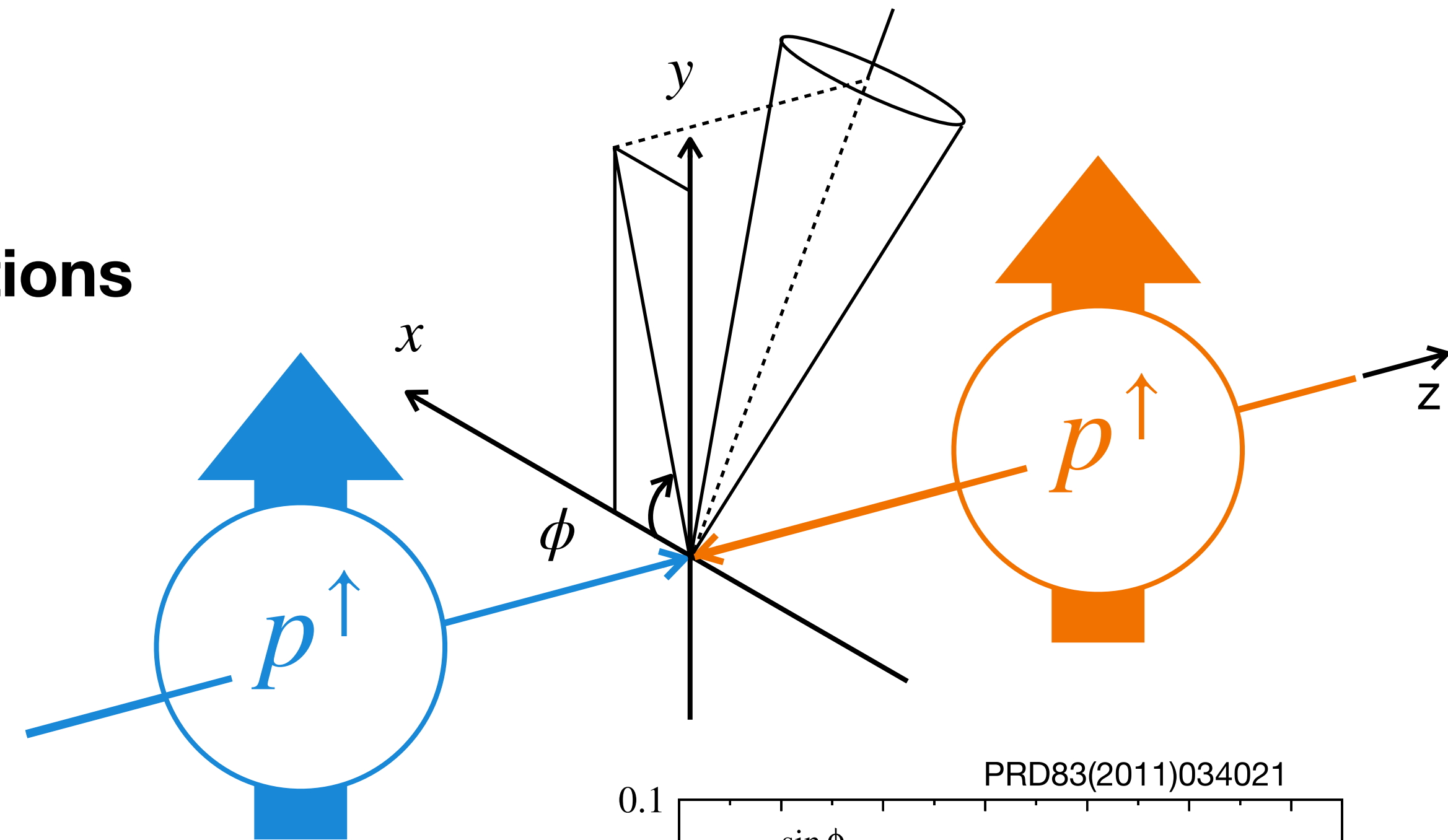
$$\frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} = A_N \sin \phi = \frac{1}{P} \varepsilon_N \sin \phi$$

TSSA of inclusive jet:

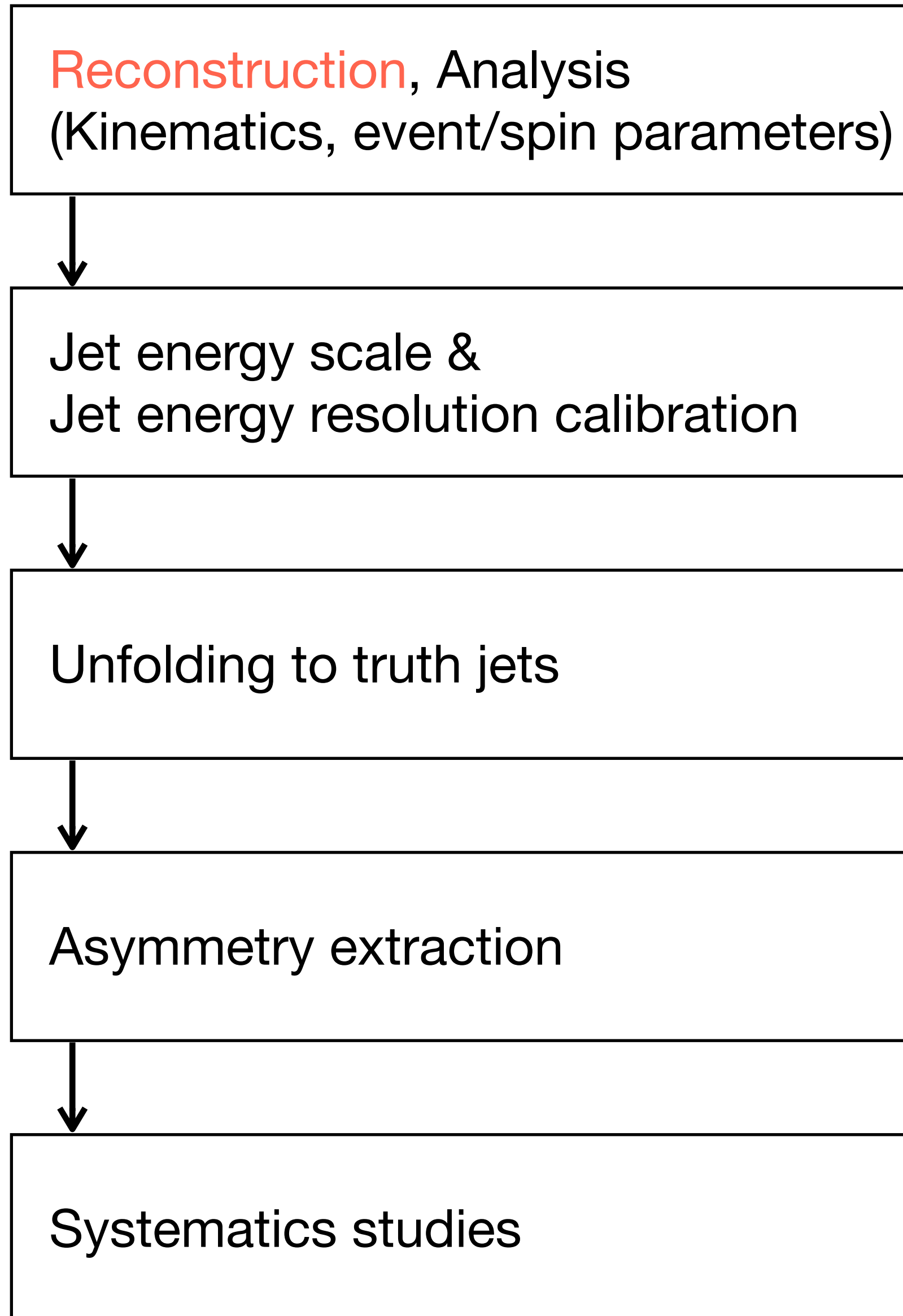
Collinear twist-3 quark-gluon correlation inside transversely polarized proton (Efremov-Teryaev-Qiu-Sterman function) can be studied, which is related to Sivers function:

$$T_{q,F}(x, x) = - \int d^2 k_\perp \frac{|k_\perp^2|}{M} f_{1T}^{\perp,q}(x, k_\perp^2) \Big|_{\text{SIDIS}}$$

Inclusive jet  $A_N$  becomes more sensitive to the gluon Sivers function in the low  $p_T$  region as the contribution of hard-scattered gluons is large.



# Inclusive jet $A_N$ ( $p^\uparrow + p \rightarrow \text{jet} + X$ )

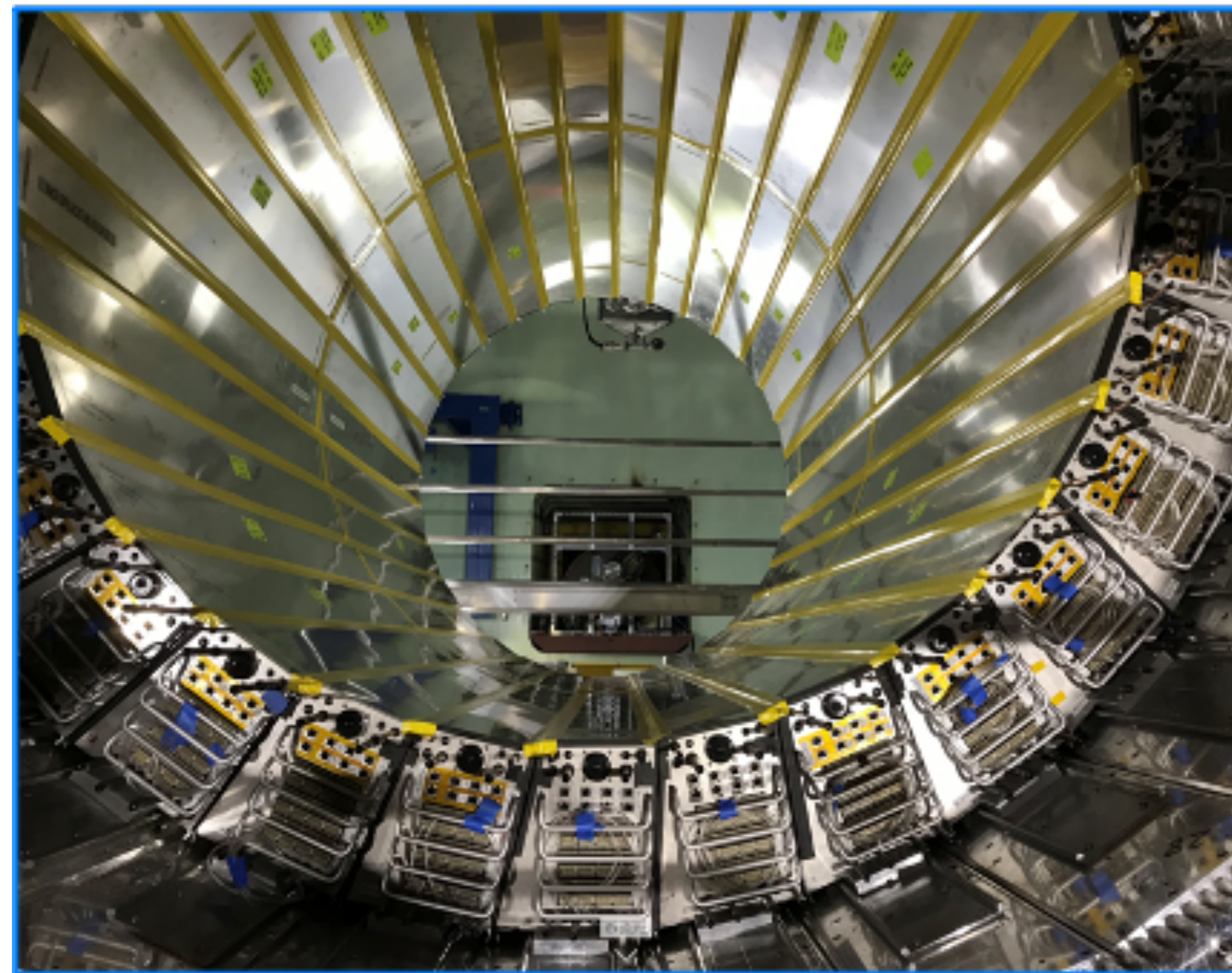




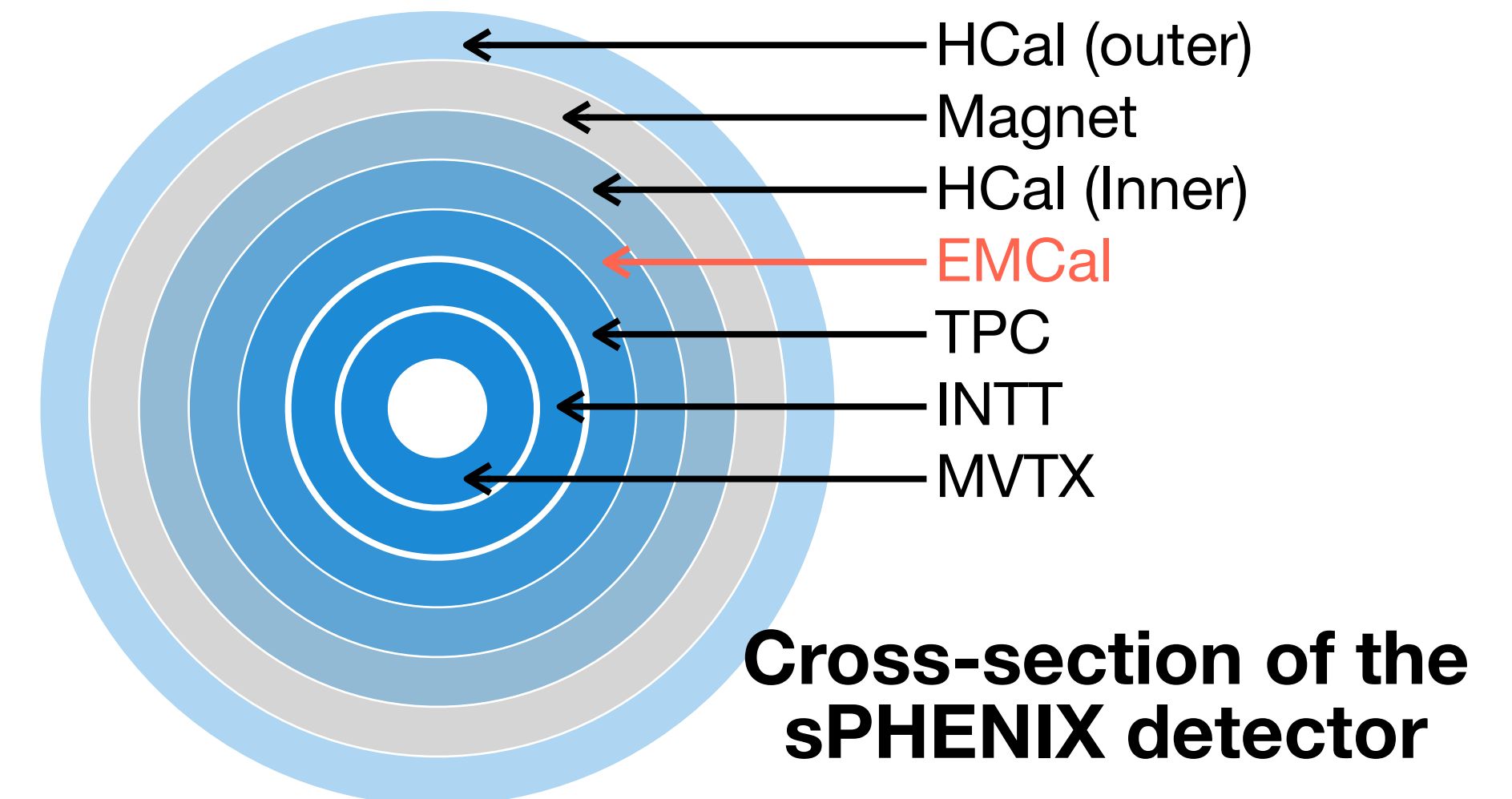
# Jet Measurements at sPHENIX

## Electromagnetic calorimeter

- Tungsten powder + scintillating fibers
- Compact design, small segmentation ( $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$ )



EMcal

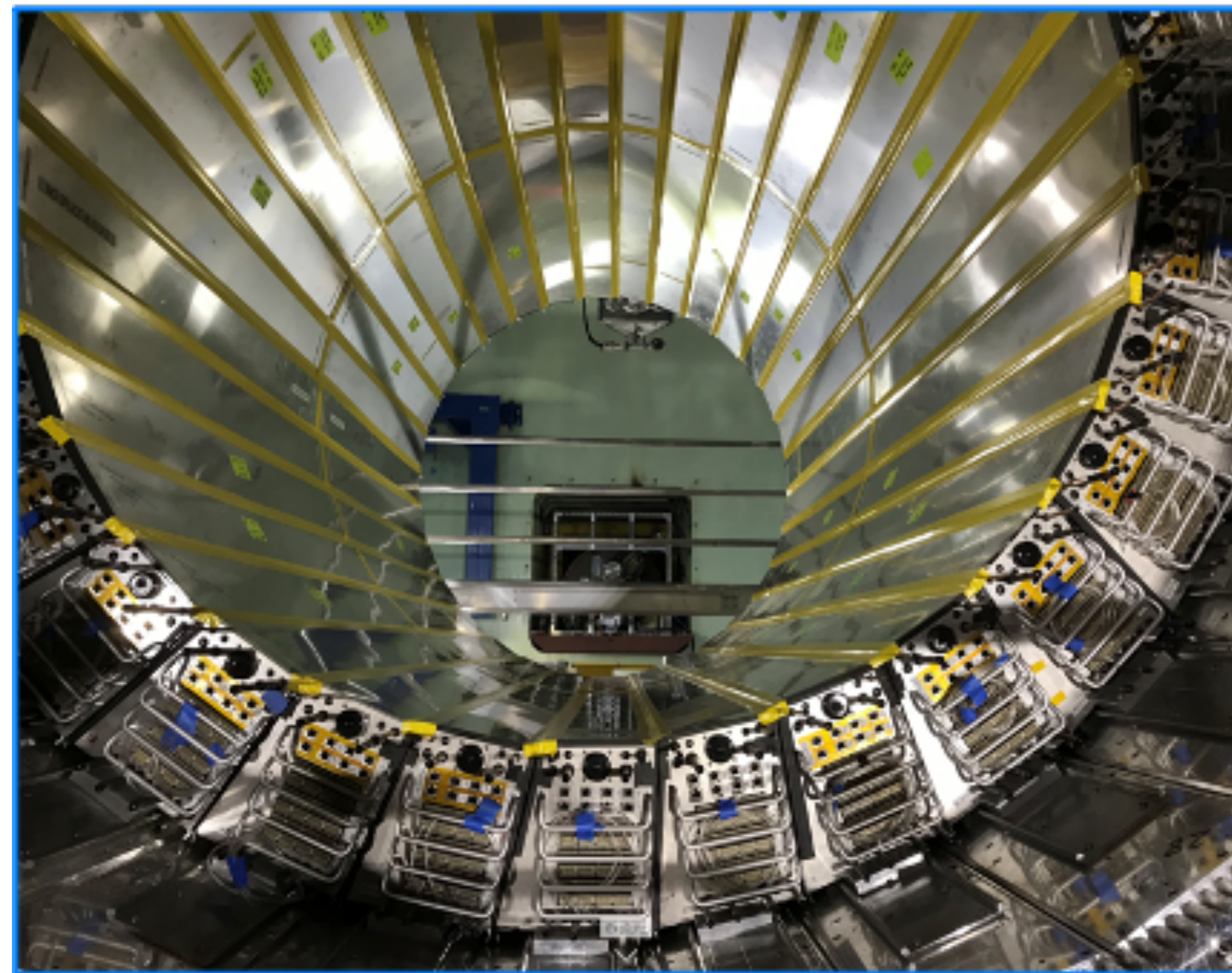




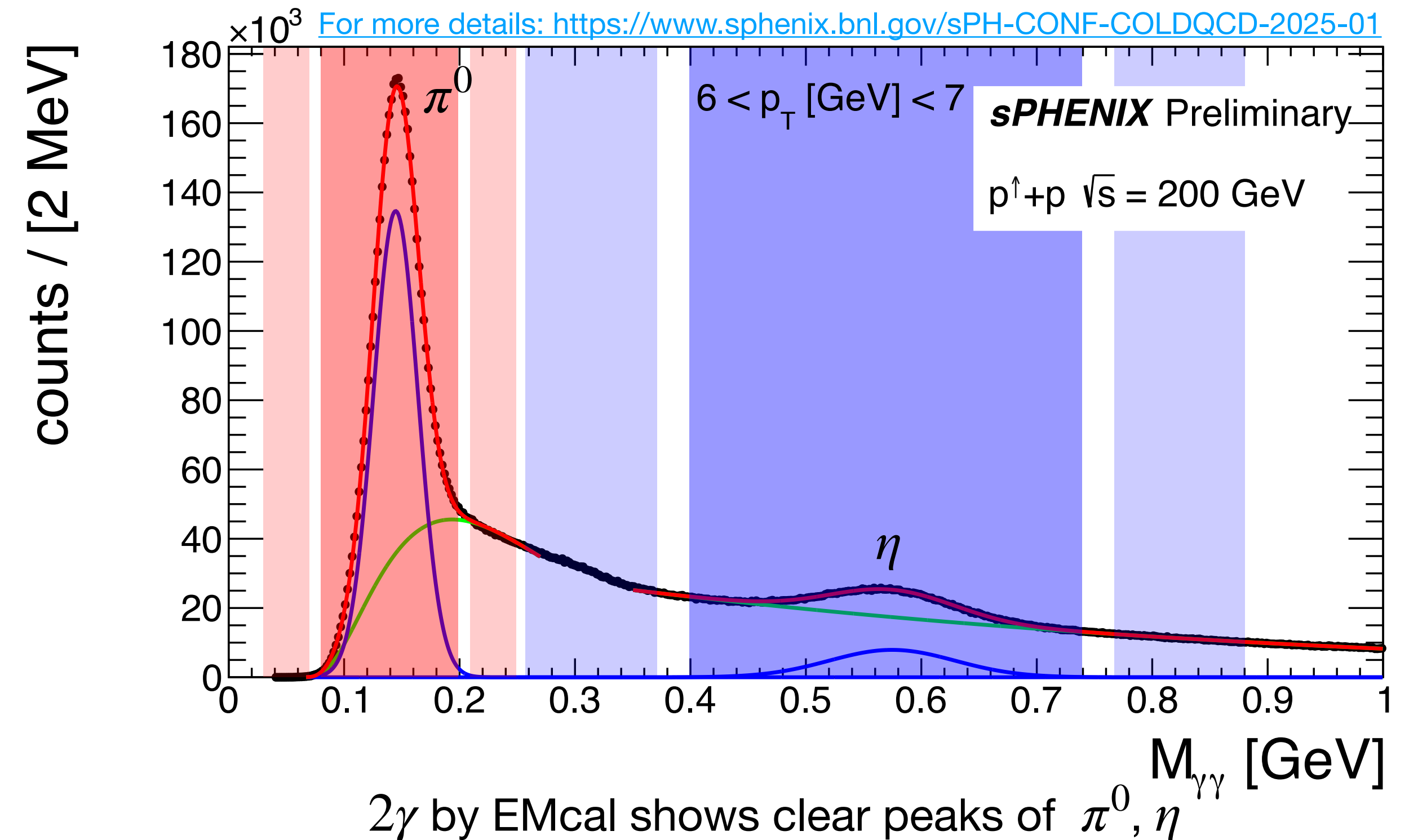
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EMcal



**Neutral meson transverse single spin asymmetries and prospects for the  $D^0$  transverse single spin asymmetry in polarized proton collisions with sPHENIX**  
*Devon Loomis*

10:20 - 10:50



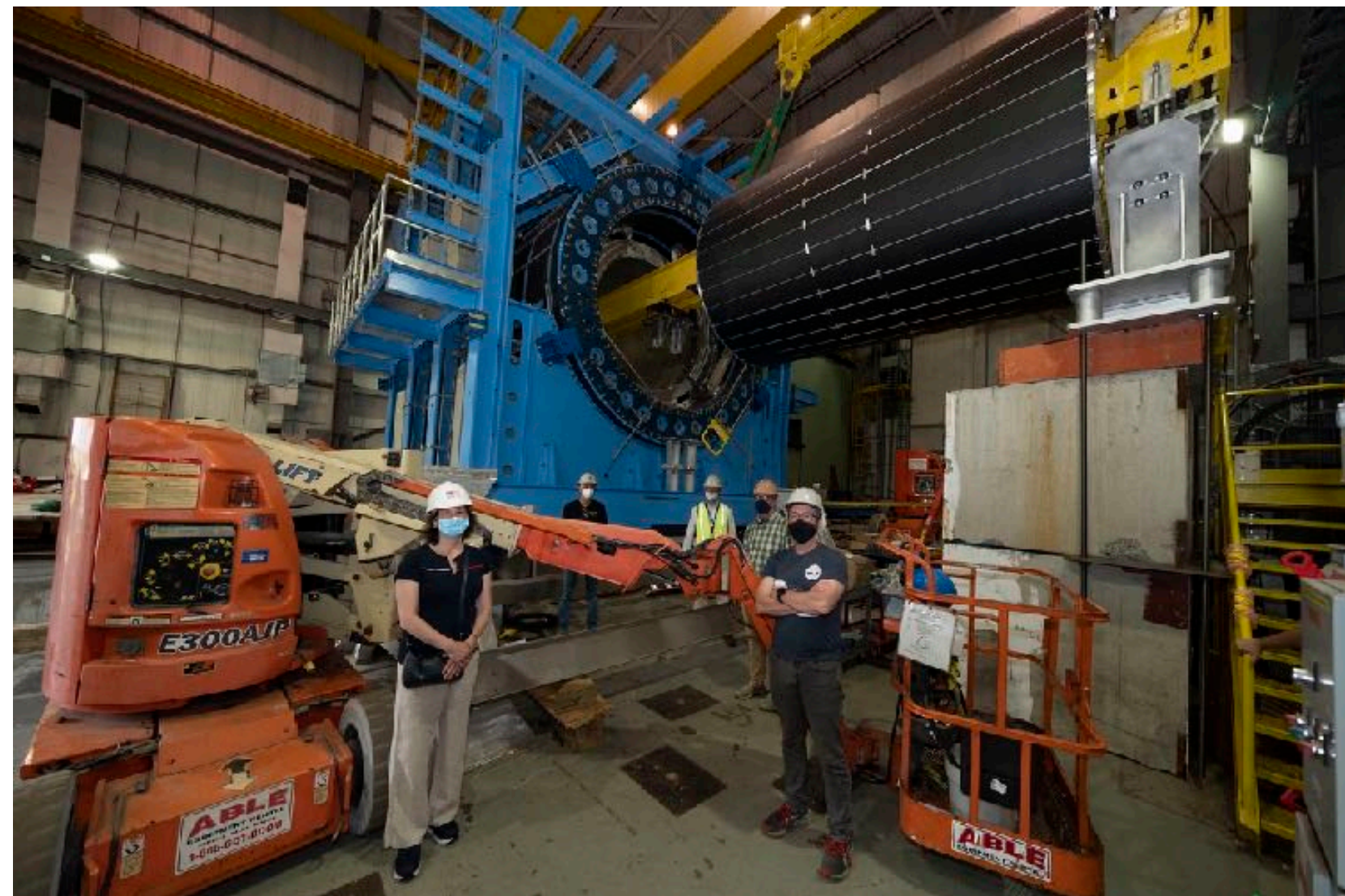
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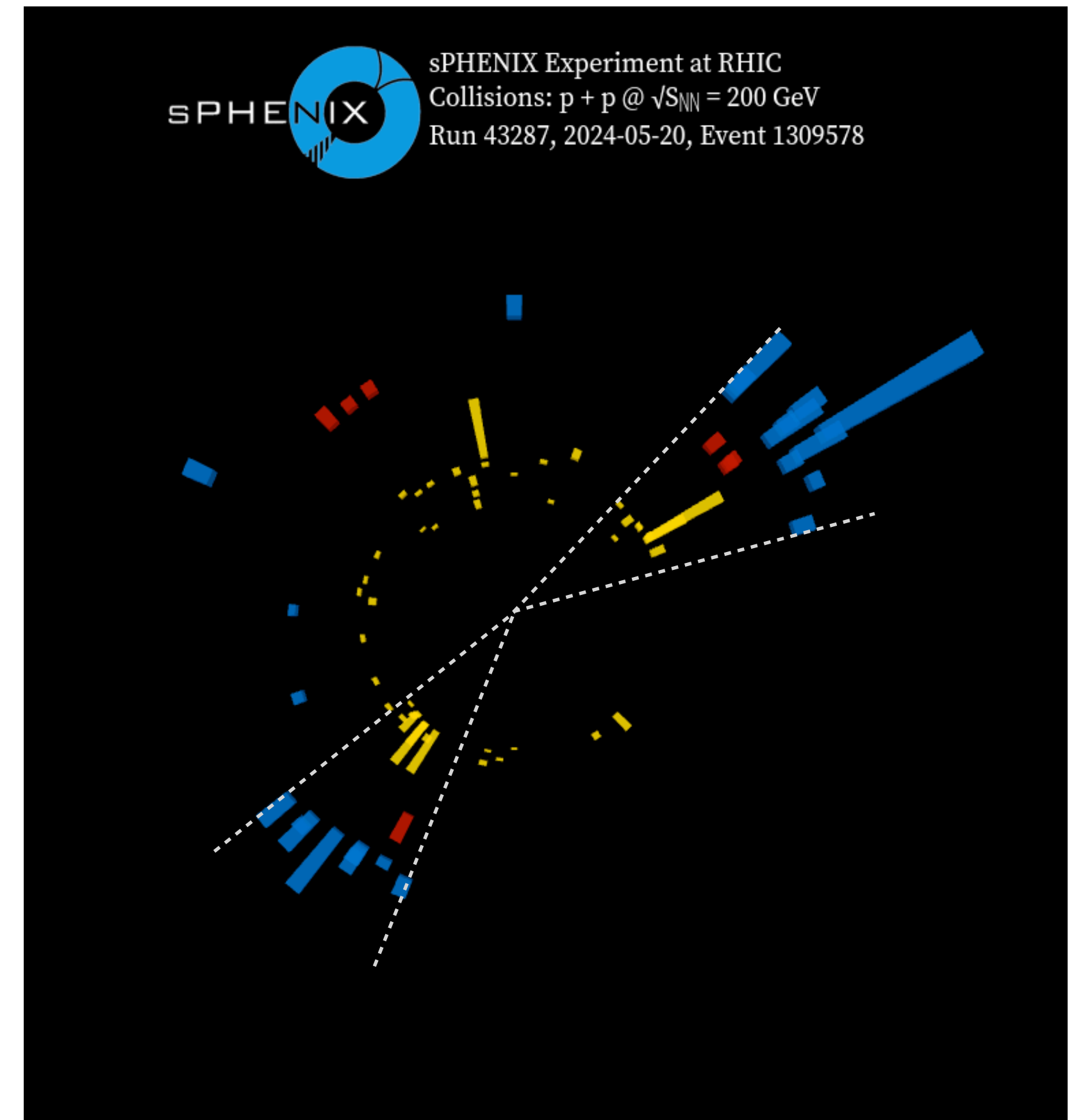
- Tungsten powder + scintillating fibers
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## Hadronic calorimeter

- Inside of the magnet: aluminum and scintillating tiles
- Outside of the magnet: steel + scintillating tiles
- Measurements before multiple scattering of hadron shower by the cryostat for the magnet is possible.
- HCal enables unbiased jet triggering



Hcal installation

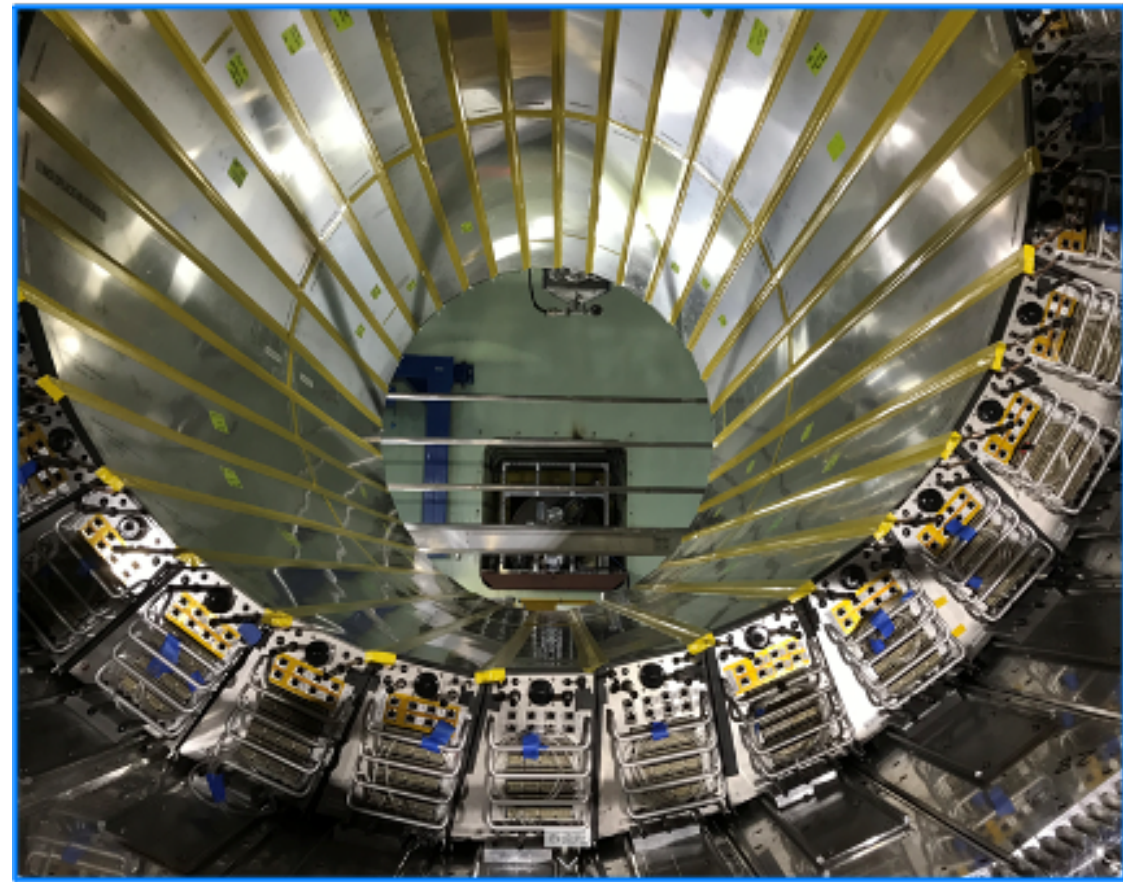




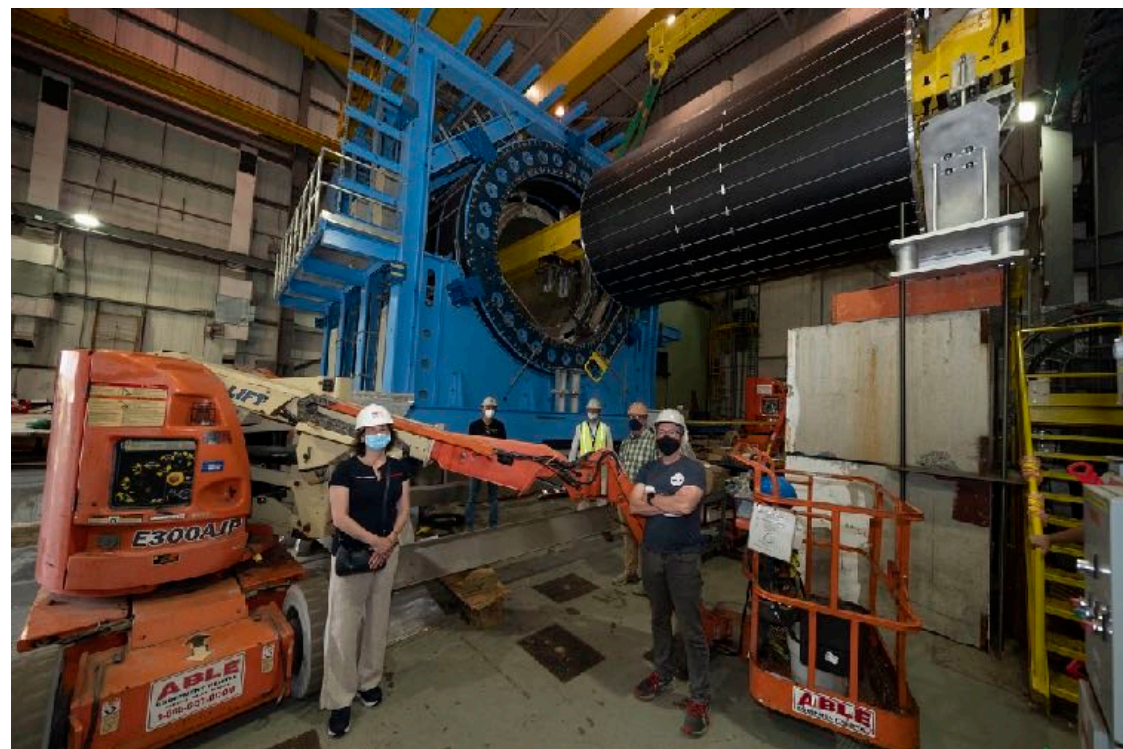
# Jet Measurements at sPHENIX

## Jet measurement

- A good probe to study the initial-state as insensitive to the final-state effect.
- Anti- $k_T$  algorithm with the cone radius of 0.4 is used.
- Jet reconstruction using calorimeter data shows very good performance.



EMcal



Hcal



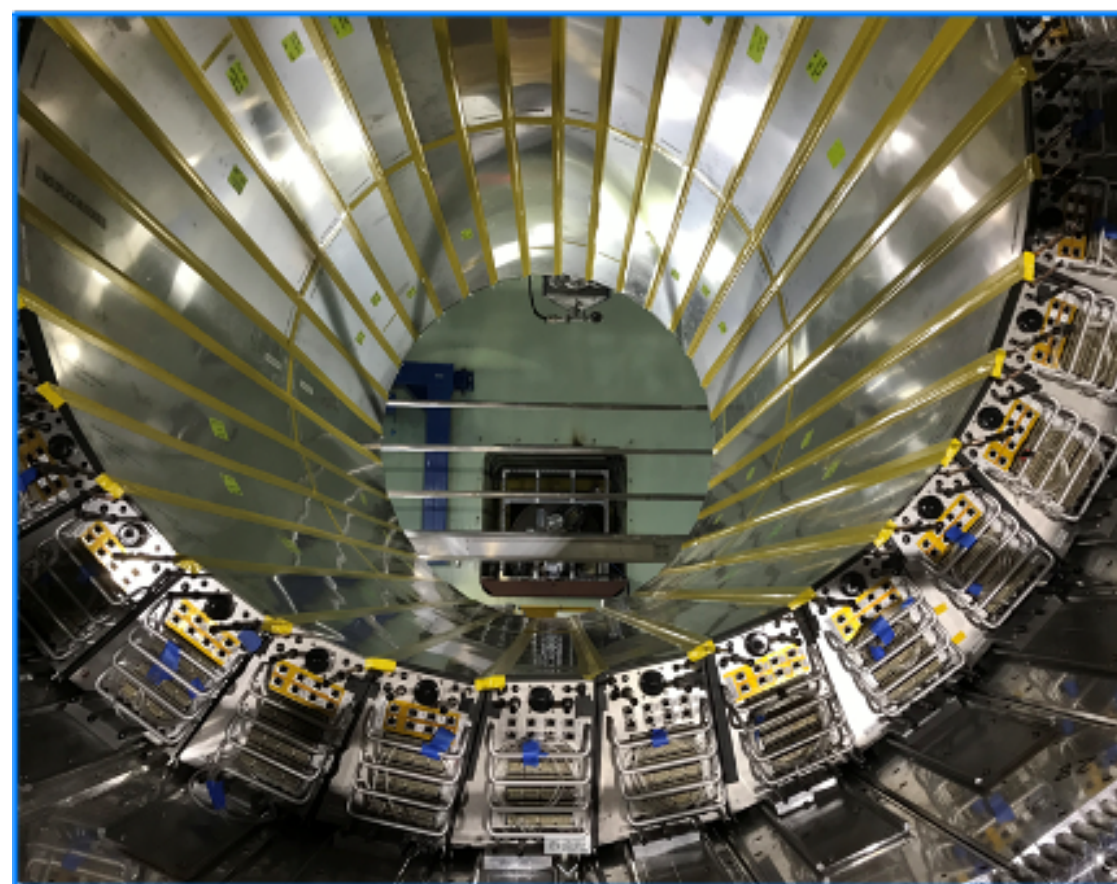
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Conference note:

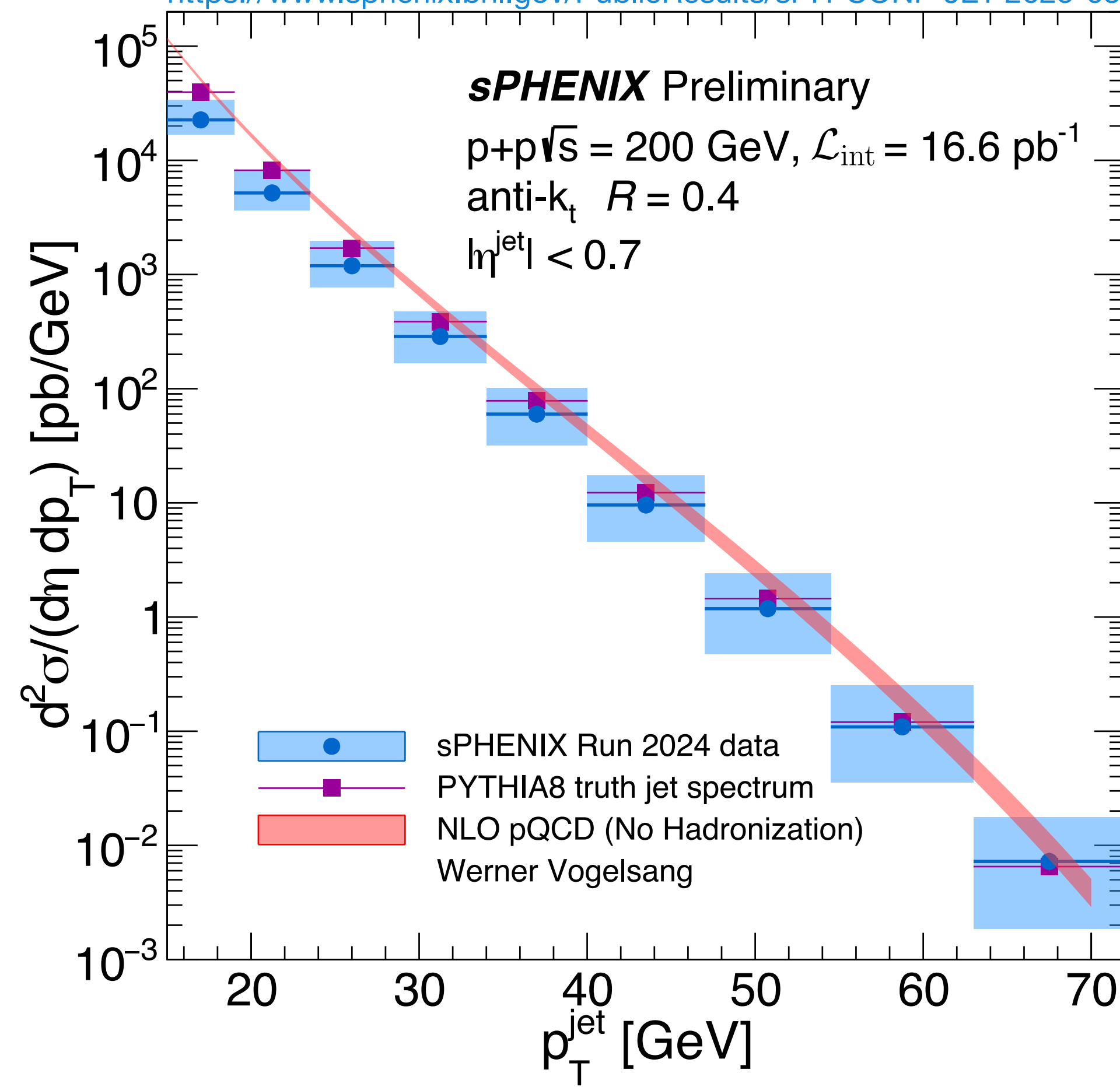
<https://www.sphenix.bnl.gov/PublicResults/sPH-CONF-JET-2025-03>



EMcal



Hcal



Fully unfolded jet cross-section measurement with pp data. Good agreement between our measurement and the theoretical calculation was confirmed. We could reach up to 70 GeV. Only 15% of data was used.



# Inclusive jet $A_N$ ( $p^\uparrow + p \rightarrow \text{jet} + X$ )

Reconstruction, **Analysis**  
(Kinematics, event/spin parameters)

Jet energy scale &  
Jet energy resolution calibration

Unfolding to truth jets

Asymmetry extraction

Systematics studies

- **Reconstruction:** Anti- $k_T$  jet with  $R = 0.4$  using calorimeter data
- **Trigger:** Minimum bias North & South trigger fired
- **Trigger:** At least one of jet triggers (8, 10, 12 GeV) fired
- **Event:**  $|z_{\text{vtx}}| < 60$  cm
- **Event:** Beam polarization  $> 30\%$
- **Jet:**  $|\eta_{\text{jet}}| < 1.1 - R = 0.7$
- **Jet:** Calorimeter energy fraction  
Jets with too much energy concentration to EMCal/iHcal/oHcal are not used.



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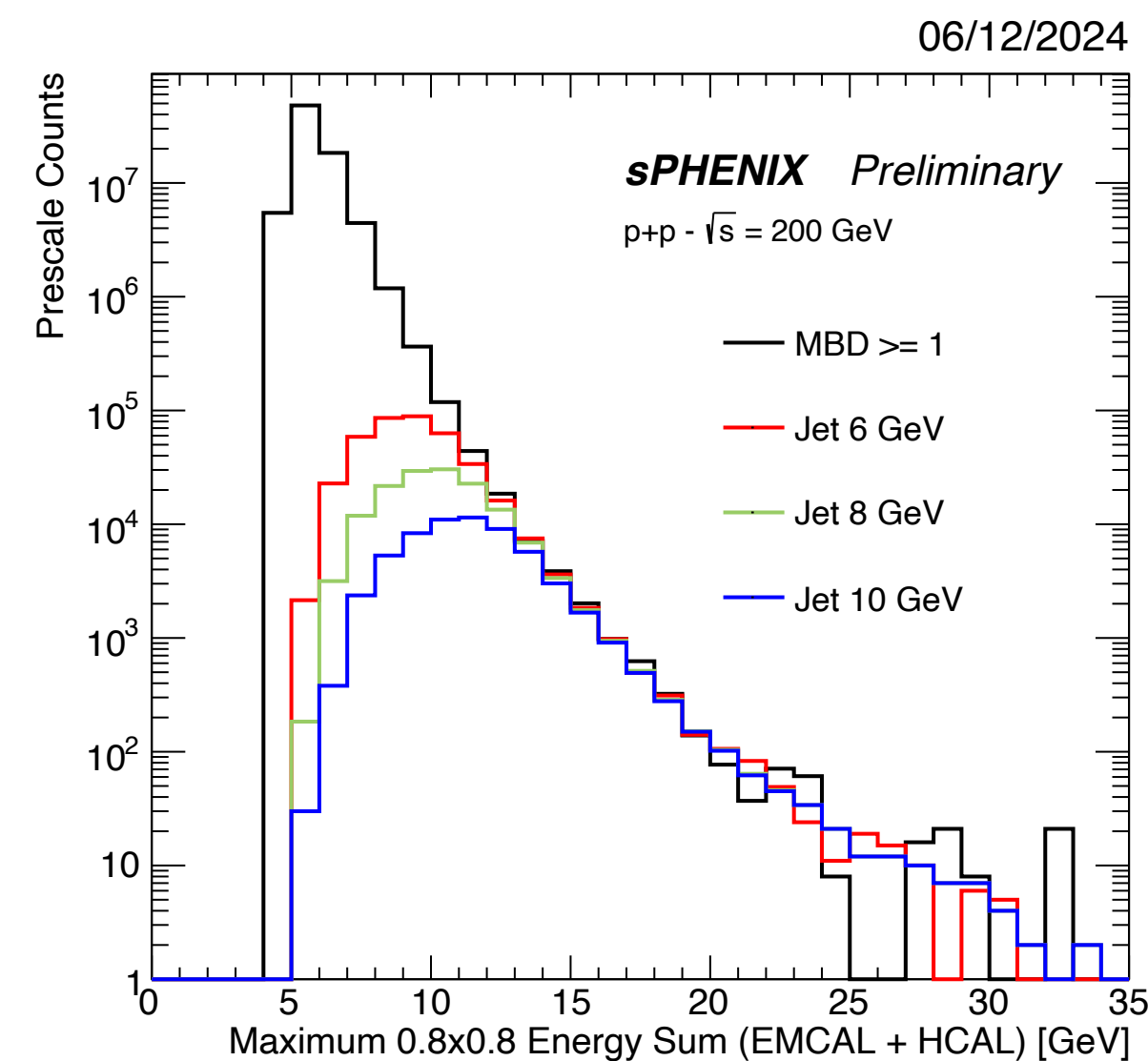
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Jet trigger performance

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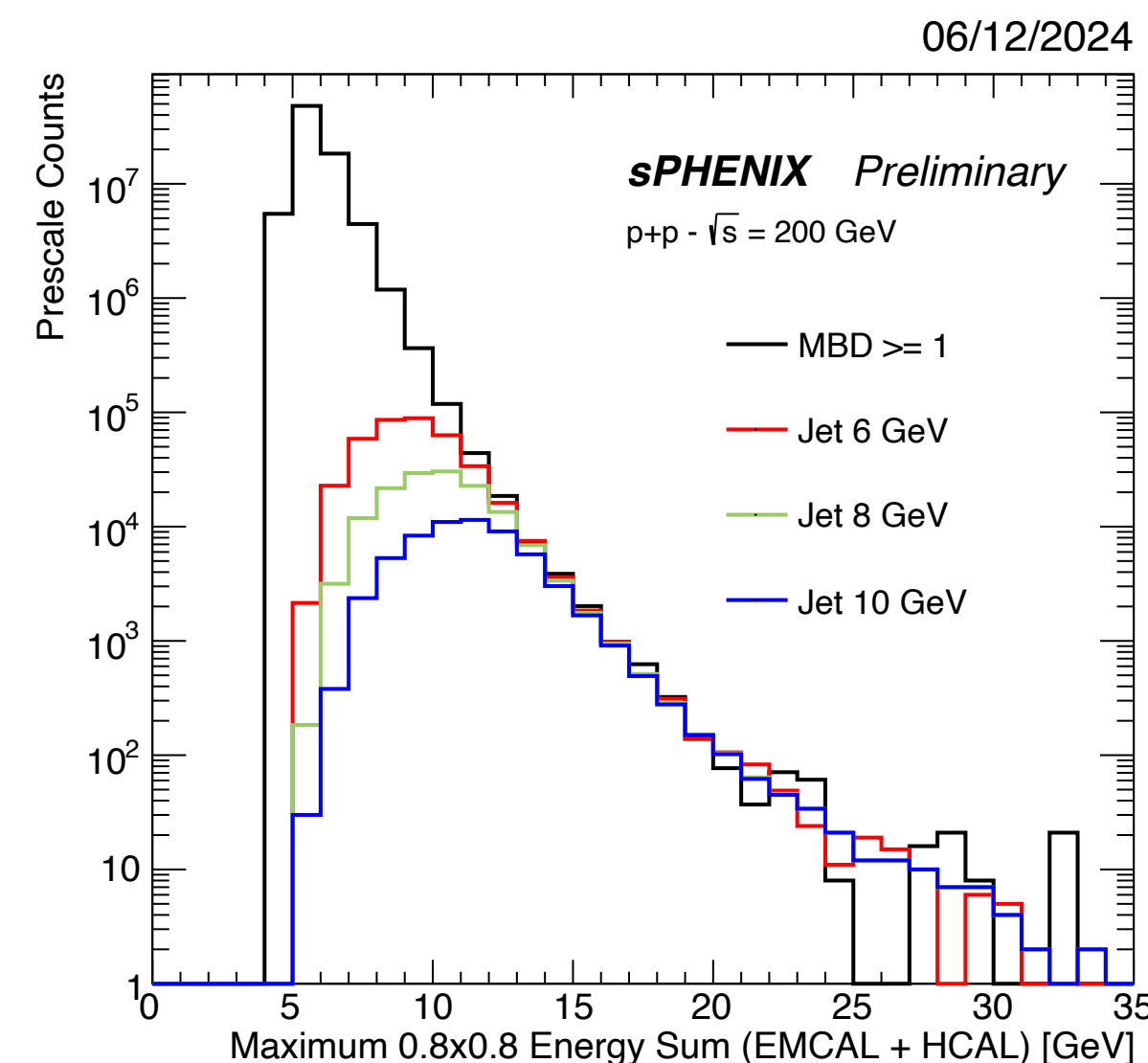
Jet energy scale &  
Jet energy resolution calibration

Unfolding to truth jets

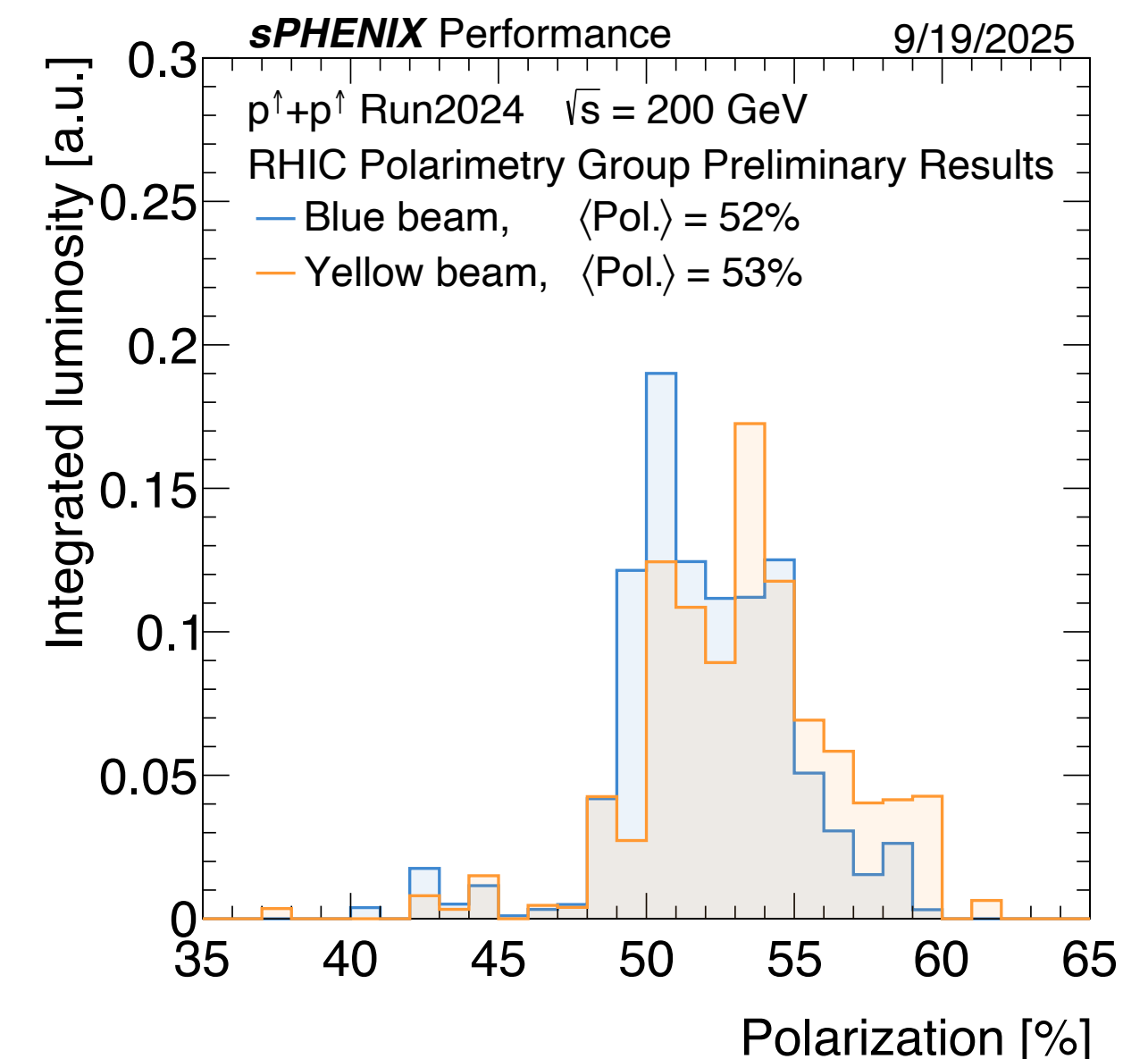
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Jet trigger performance



Beam polarization



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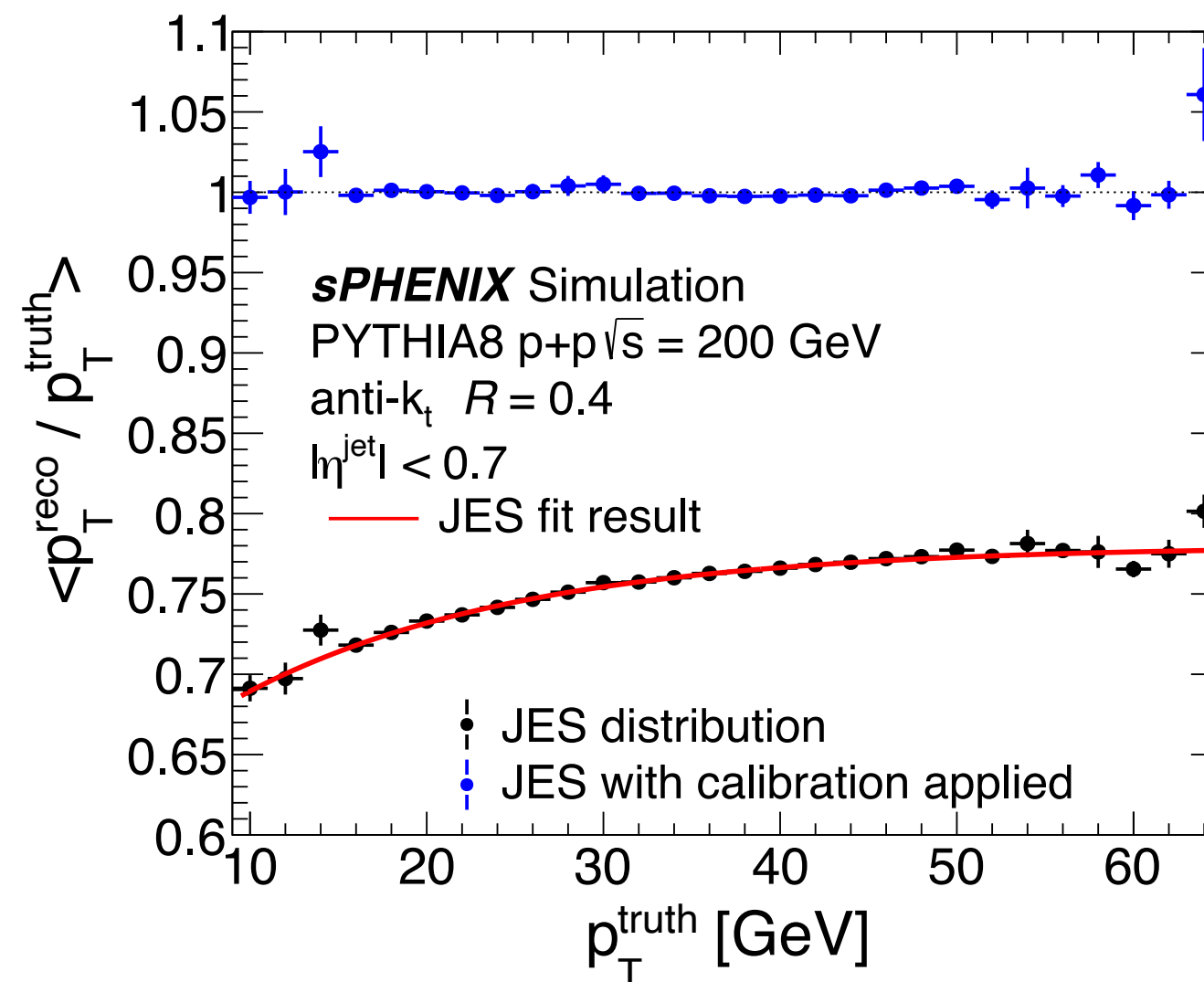
✓ Reconstruction, Analysis  
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✓ Unfolding to truth jets

Asymmetry extraction

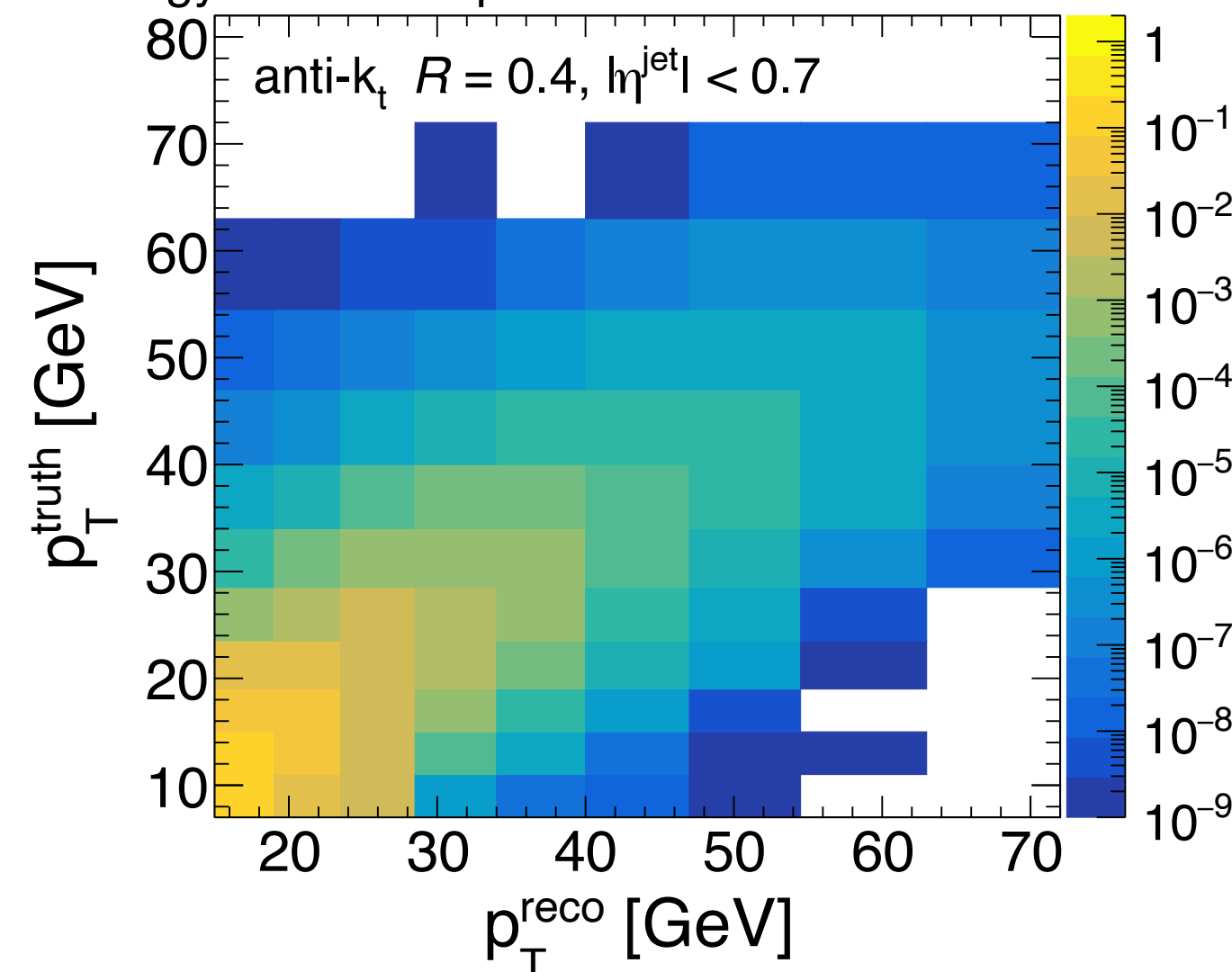
Systematics studies



← Calibrated  $\frac{\langle p_T^{\text{reco}} \rangle}{\langle p_T^{\text{truth}} \rangle}$  with MC data

←  $\frac{\langle p_T^{\text{reco}} \rangle}{\langle p_T^{\text{truth}} \rangle}$  with MC data

*s*PHENIX Simulation PYTHIA8  $p+p \sqrt{s} = 200$  GeV  
Energy fraction requirement



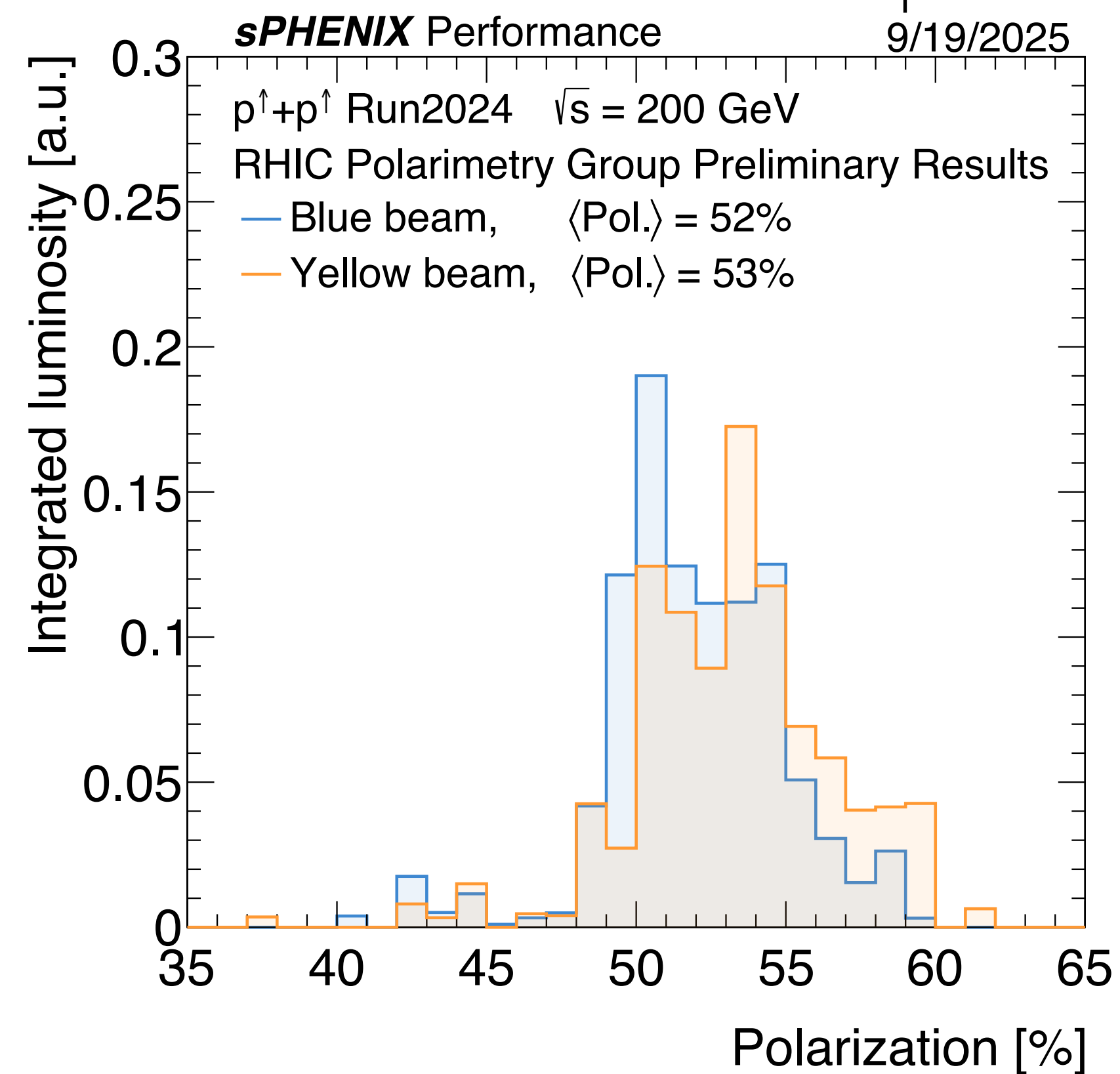
Response matrix ( $p_T^{\text{reco}}$  vs  $p_T^{\text{truth}}$ )  
used in the unfolding correction.  
The full/half closure tests confirmed  
that unfolding correction reproduce  
the input truth spectrum within  
statistical uncertainties.



# Inclusive jet $A_N$ : Asymmetry extraction

Transverse single spin asymmetry for the inclusive jet production

$$\frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} = A_N \sin \phi = \frac{1}{P} \varepsilon_N \sin \phi$$





# Inclusive jet $A_N$ : Asymmetry extraction

## Transverse single spin asymmetry for the inclusive jet production

$$\frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} = A_N \sin \phi = \frac{1}{P} \varepsilon_N \sin \phi$$

### Relative luminosity formula

Difference of #jet and #jet at the same  $\phi$  with opposite beam spin

Correction of the luminosity difference depending on spin polarity is applied.

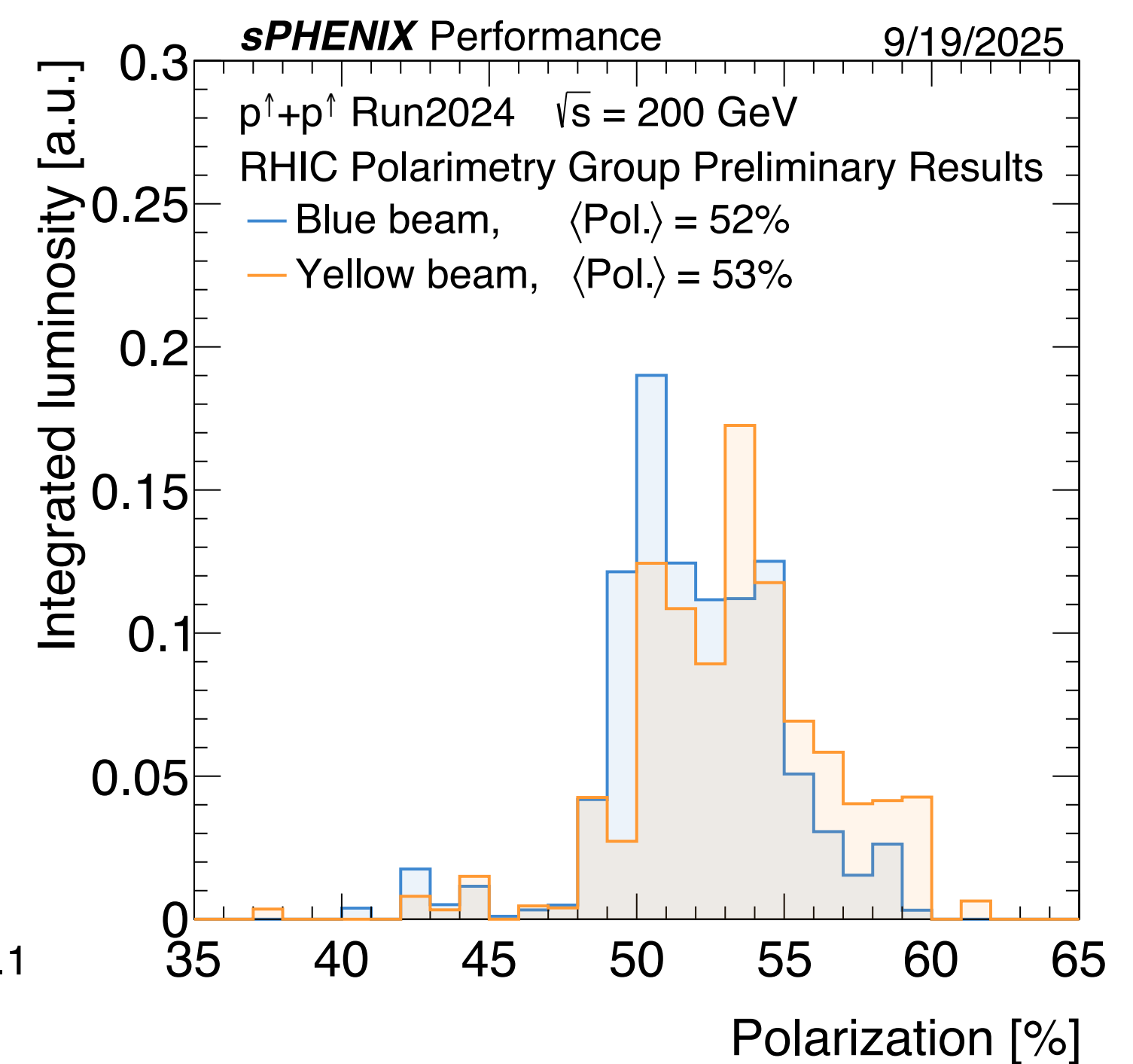
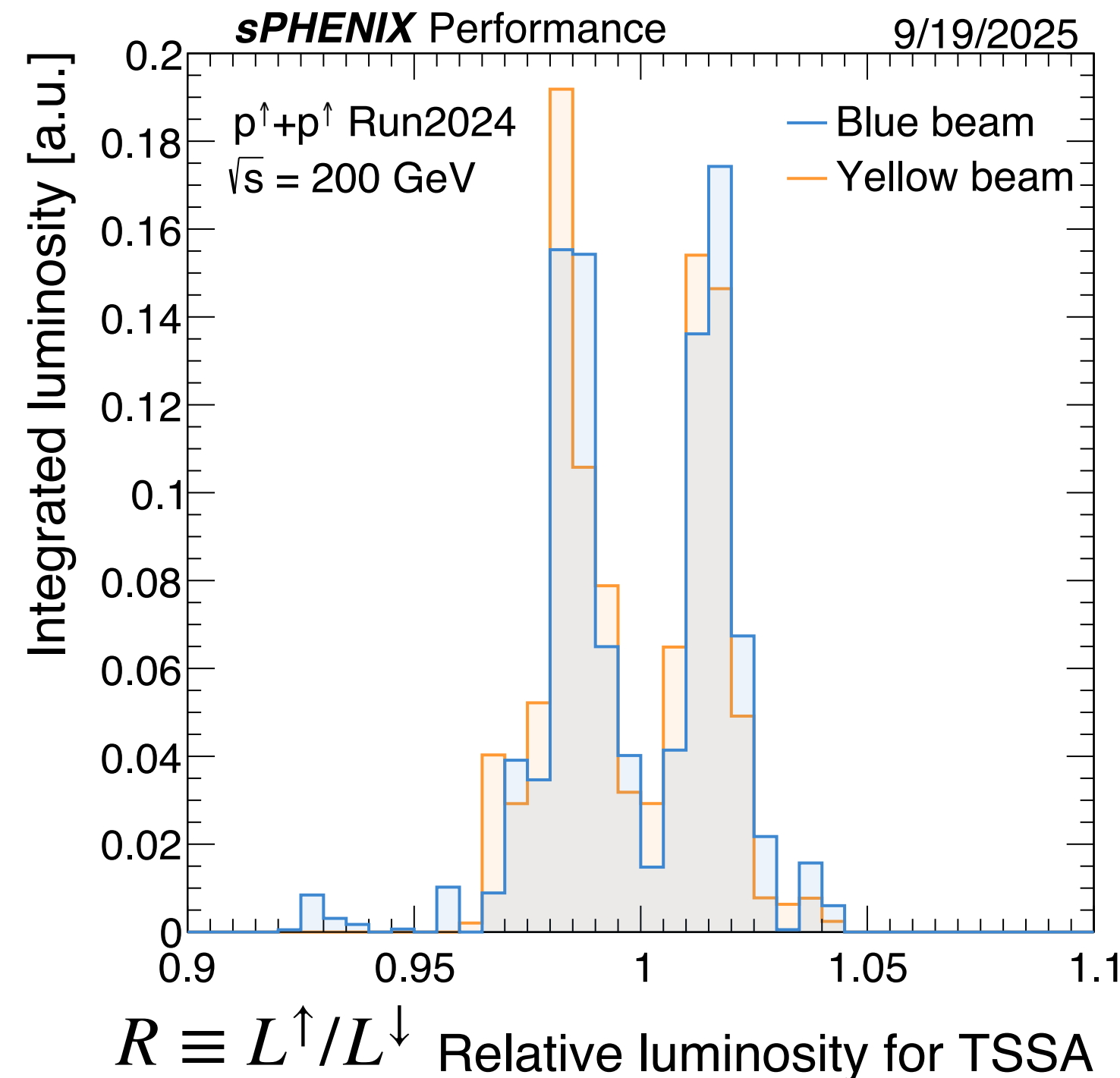
$$\varepsilon_N \equiv \frac{N^\uparrow(\phi) - RN^\downarrow(\phi)}{N^\uparrow(\phi) + RN^\downarrow(\phi)}$$

### Square root formula

Combinations of #jet with ( $\phi$  or  $\phi+180^\circ$ ) and (up or down) polarization form the asymmetry.

Both the luminosity difference and the detector acceptance effect are canceled.

$$\varepsilon_N \equiv \frac{\sqrt{N^\uparrow(\phi)N^\downarrow(\phi + \pi)} - \sqrt{N^\downarrow(\phi)N^\uparrow(\phi + \pi)}}{\sqrt{N^\uparrow(\phi)N^\downarrow(\phi + \pi)} + \sqrt{N^\downarrow(\phi)N^\uparrow(\phi + \pi)}}$$

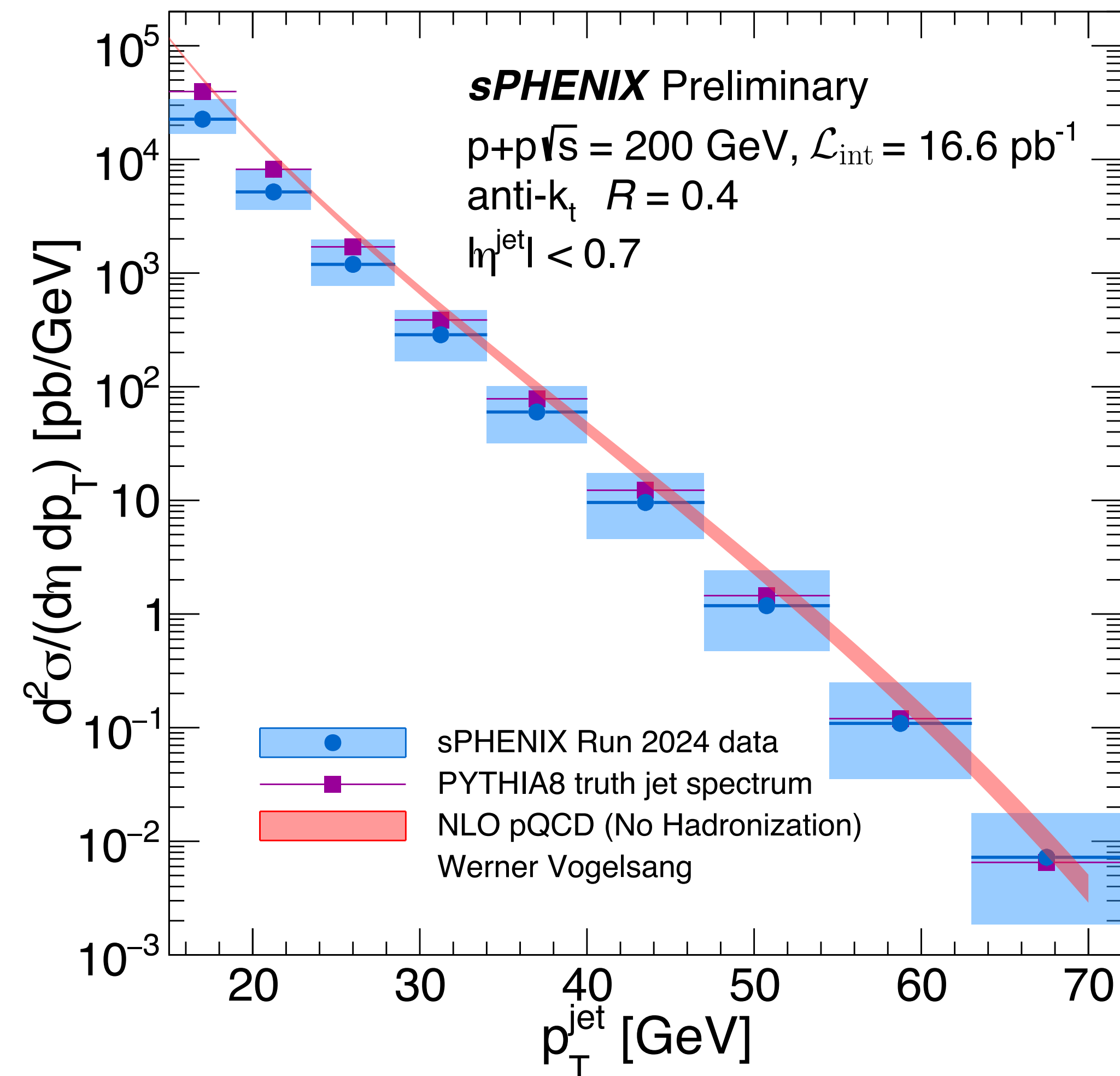


**Preliminary results  
are almost there.  
Stay tuned!**



# Summary

- Inclusive jet  $A_N$ : Powerful tool to study collinear twist-3 quark-gluon correlation function.
- The sPHENIX detector has been operated since 2023.
- The detector commissioning in 2024 was successfully completed.
- Transversely polarized proton-proton measurement was performed in 2024.
- First jet measurement at sPHENIX
  - The jet reconstruction shows great performance. The preliminary cross-section of inclusive jet production well agree with the theoretical calculation.
  - Preliminary asymmetry measurement is coming soon.



## 55. Isolated Photon transverse single spin asymmetries with sPHENIX

Jaein Hwang (Korea University)

9/24/25, 9:40 AM

Three-dimensional struc...

Oral

3-dimensional structure ...

## 53. Neutral meson transverse single spin asymmetries and prospects for the D0 transverse single spin asymmetry in polarized proton collisions with sPHENIX

Devon Loomis

9/24/25, 10:20 AM

Three-dimensional struc...

Oral

3-dimensional structure ...

Visit us: <https://www.sphenix.bnl.gov/PublicResults>



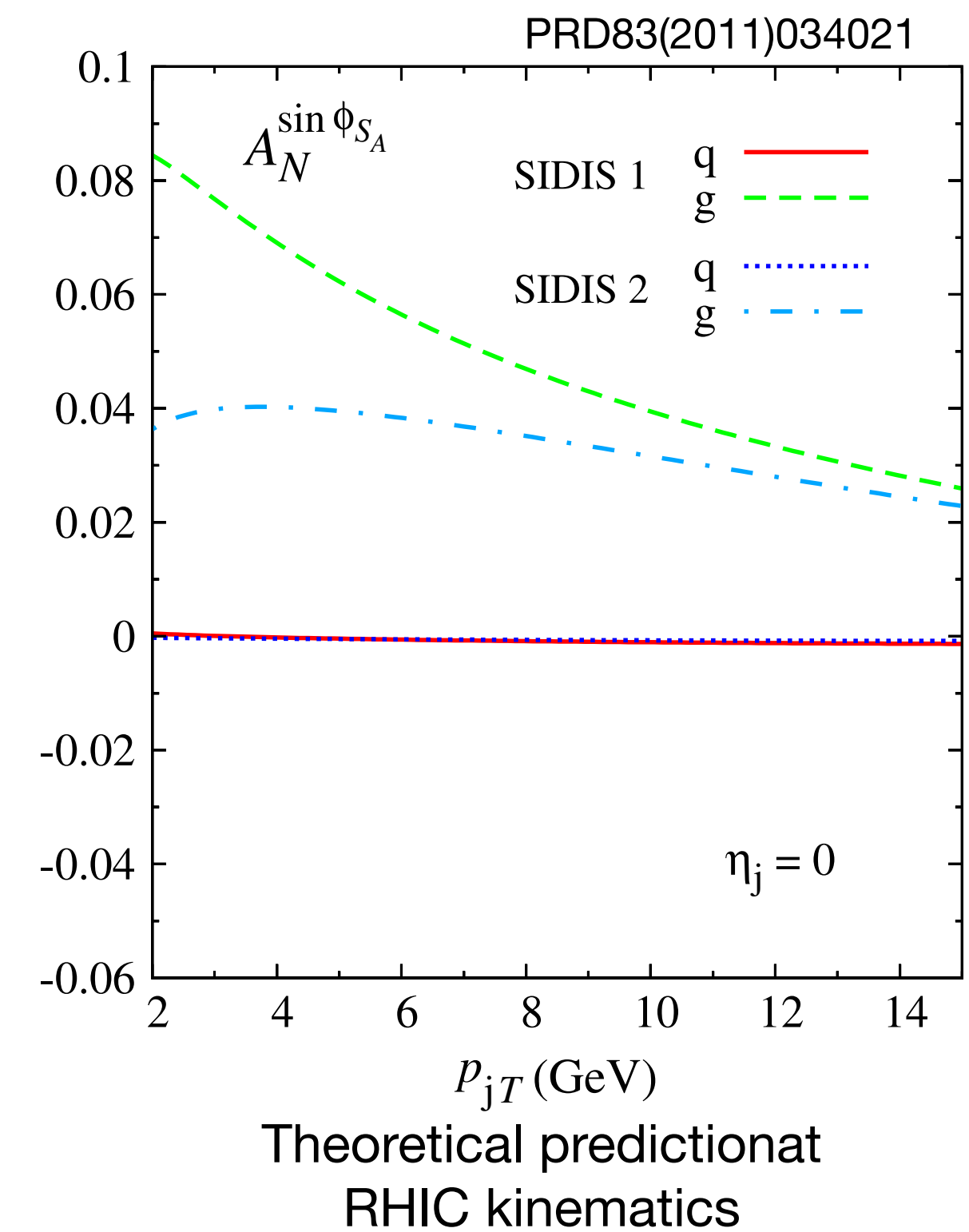
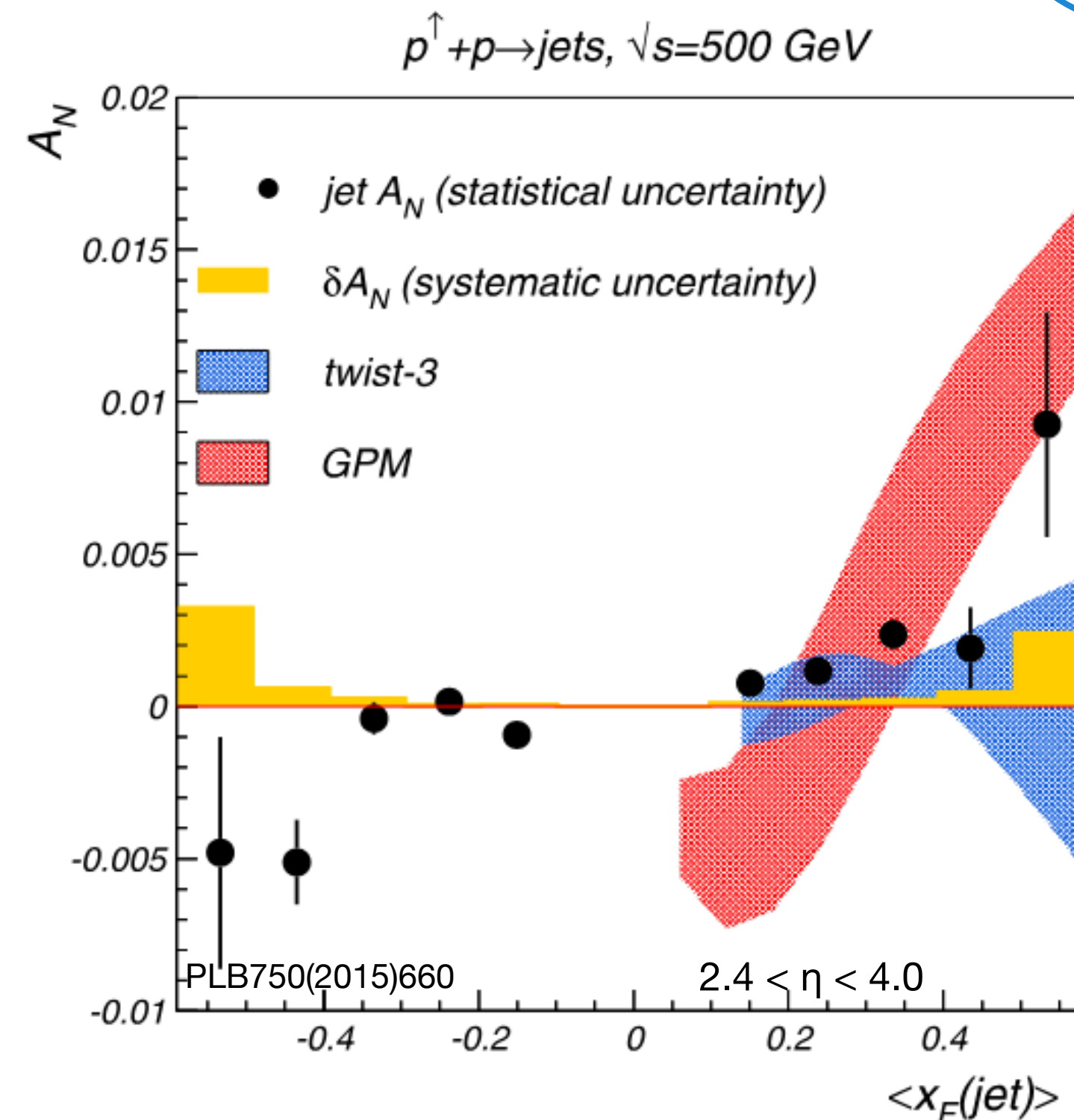
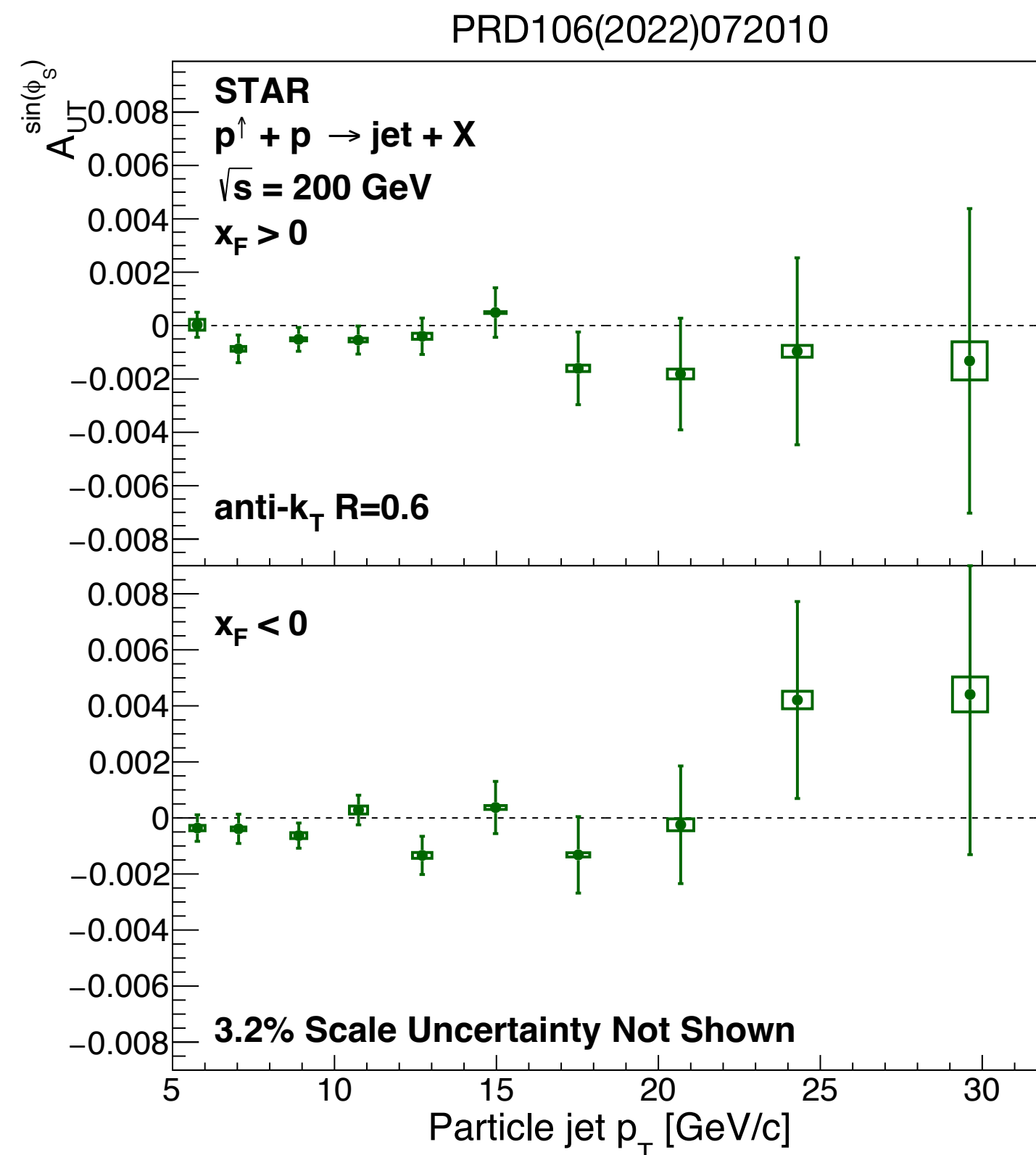
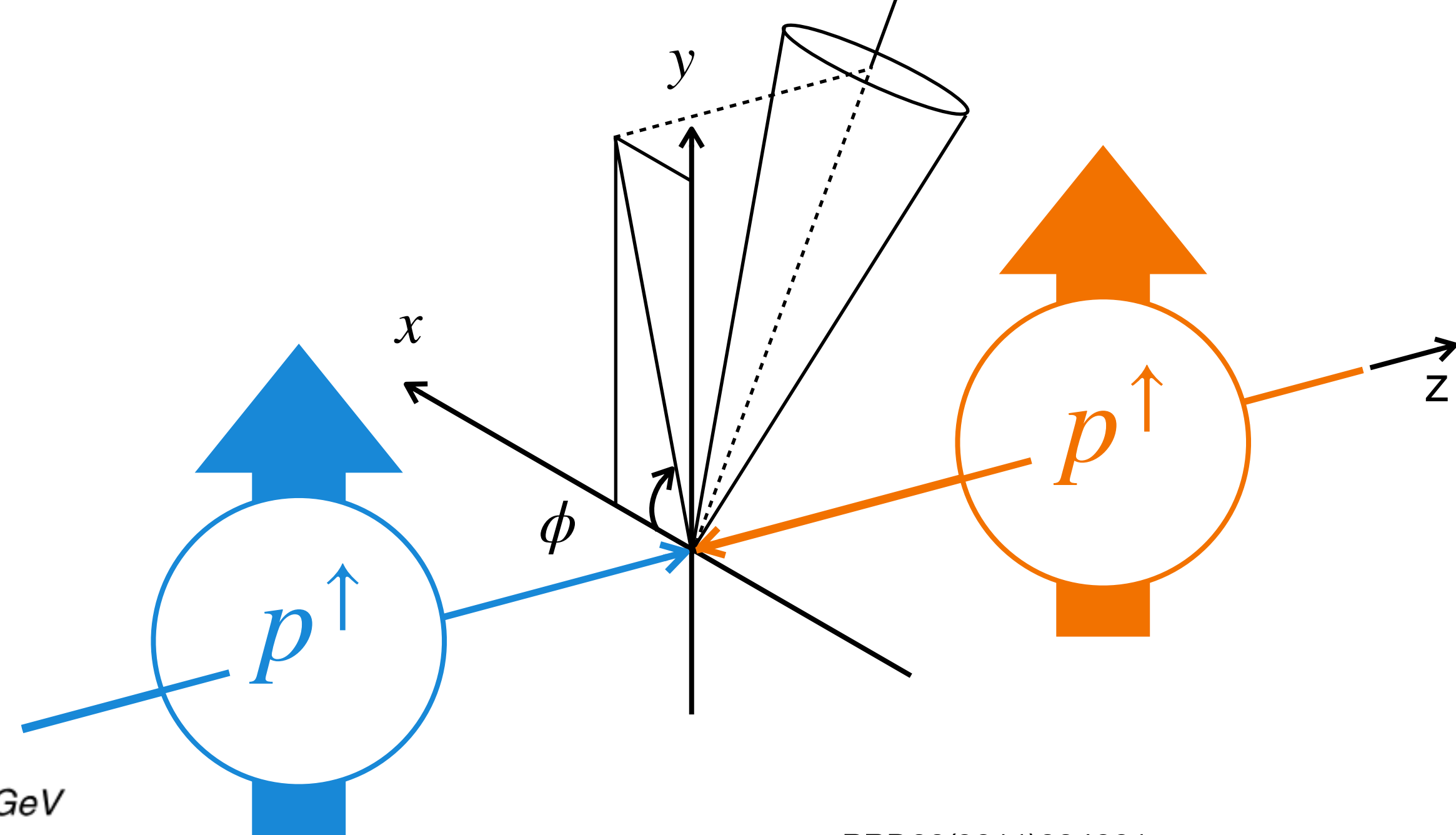
# Backup slides

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Inclusive jet  $A_N$  measurement by STAR and  $A_N$ DY.