DNP2020

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of the American Physical Society
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~~Hyatt Regency Hotel, New Orleans, LA~~

APS physics

Azimuthal Transverse Single-Spin Asymmetries of Charged Pions Within Jets from Polarized pp Collisions at $\sqrt{s}$= 200 GeV

Ting Lin, for STAR Collaboration

Texas A&M University

STAR

TEXAS A&M UNIVERSITY

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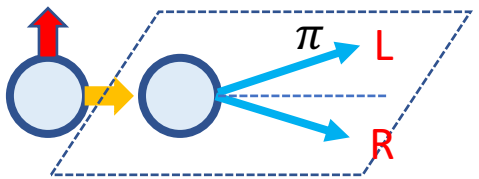
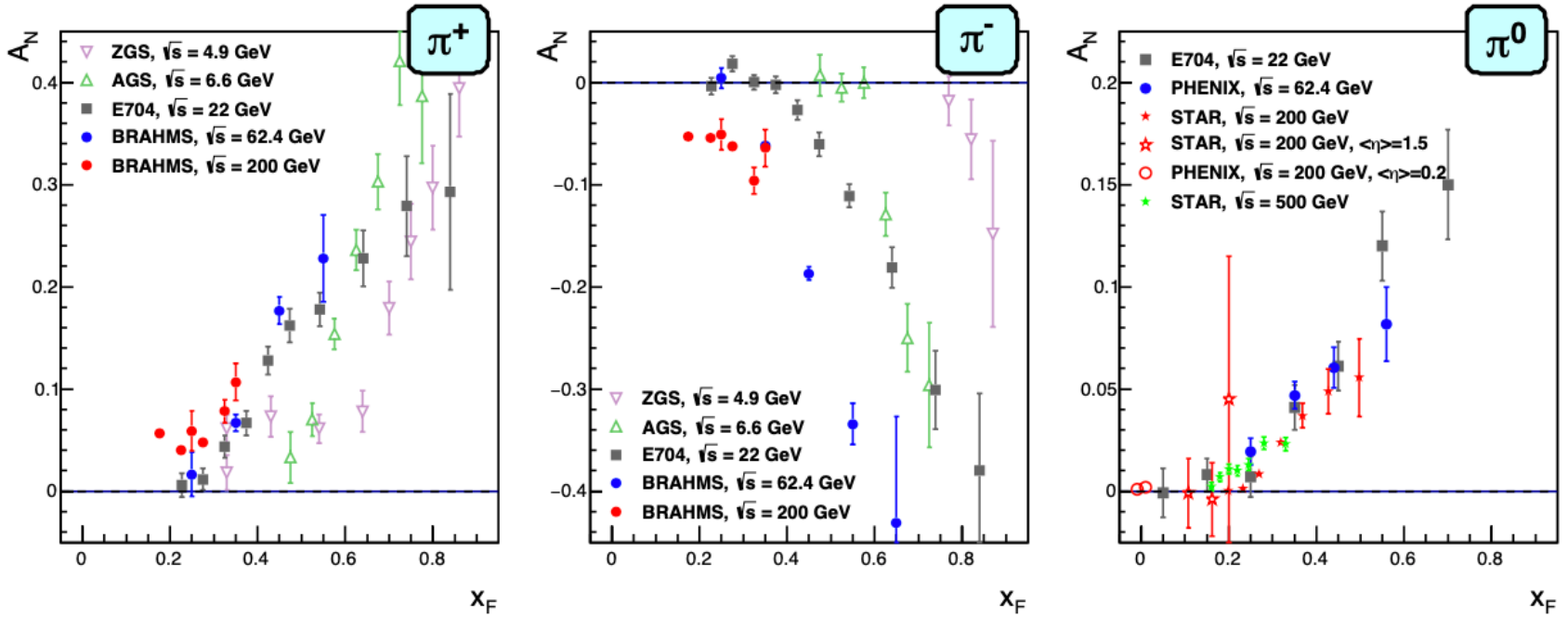
Challenges in Transverse Single-Spin Asymmetry

- Large transverse single-spin asymmetry (A_N) has been measured in transversely polarized proton-proton collisions;
- pQCD predicts very small asymmetries in the hard scattering process;
- Twist-3 and transverse momentum dependent (TMD) frameworks are developed to describe this transverse spin effect;

Elke Aschenauer *et al.* arXiv:1602.03922 [nucl-ex]



$$A_N = \frac{N_L - N_R}{N_L + N_R}$$

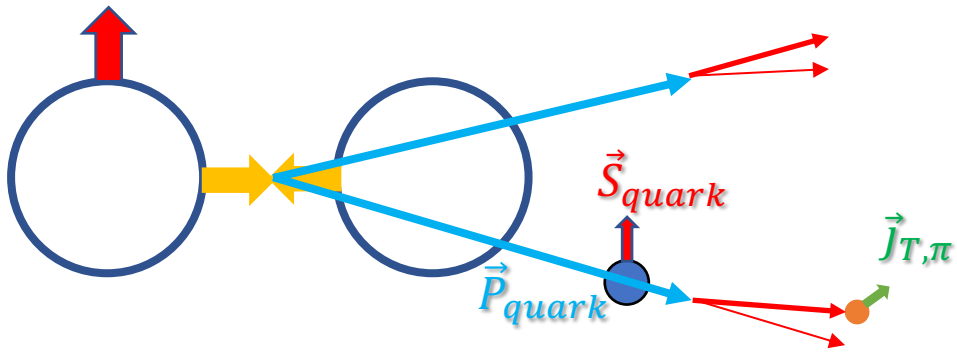


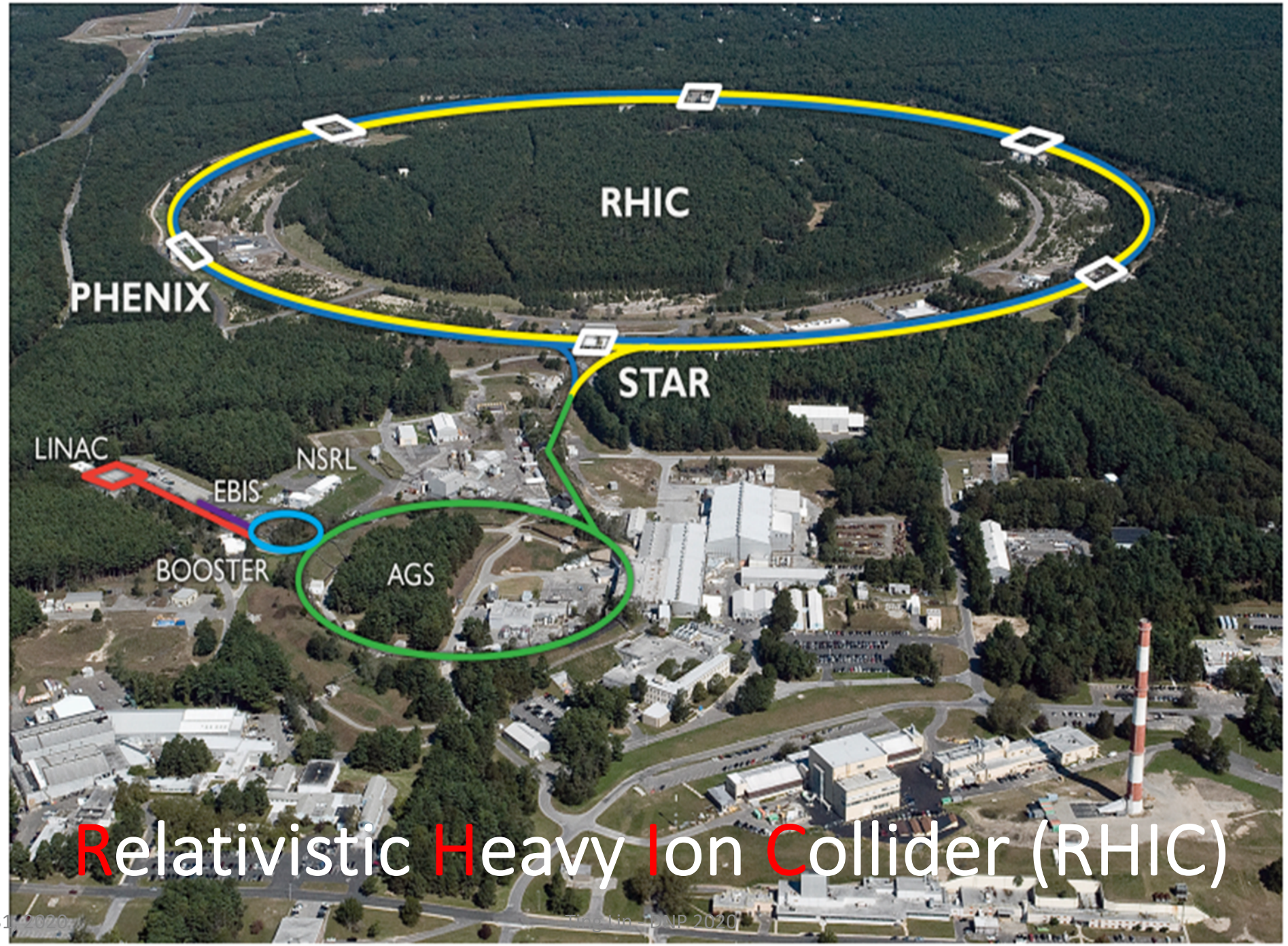
Collins Effect

Correlation between the polarization of a scattered quark and the momentum of a hadron fragment transverse to the scattered quark direction:

- Collins effect combines the quark transversity in the proton with the spin-dependent Collins fragmentation function, leading to azimuthal modulations of identified charged hadron yields about the jet axis;
  - Integral of transversity gives the nucleon tensor charge;
  - Difference of helicity and transversity has direct x-dependent connection to quark orbital angular momentum;
  - Collins fragmentation function in pp probes fundamental questions regarding factorization, universality, and evolution of TMDs.

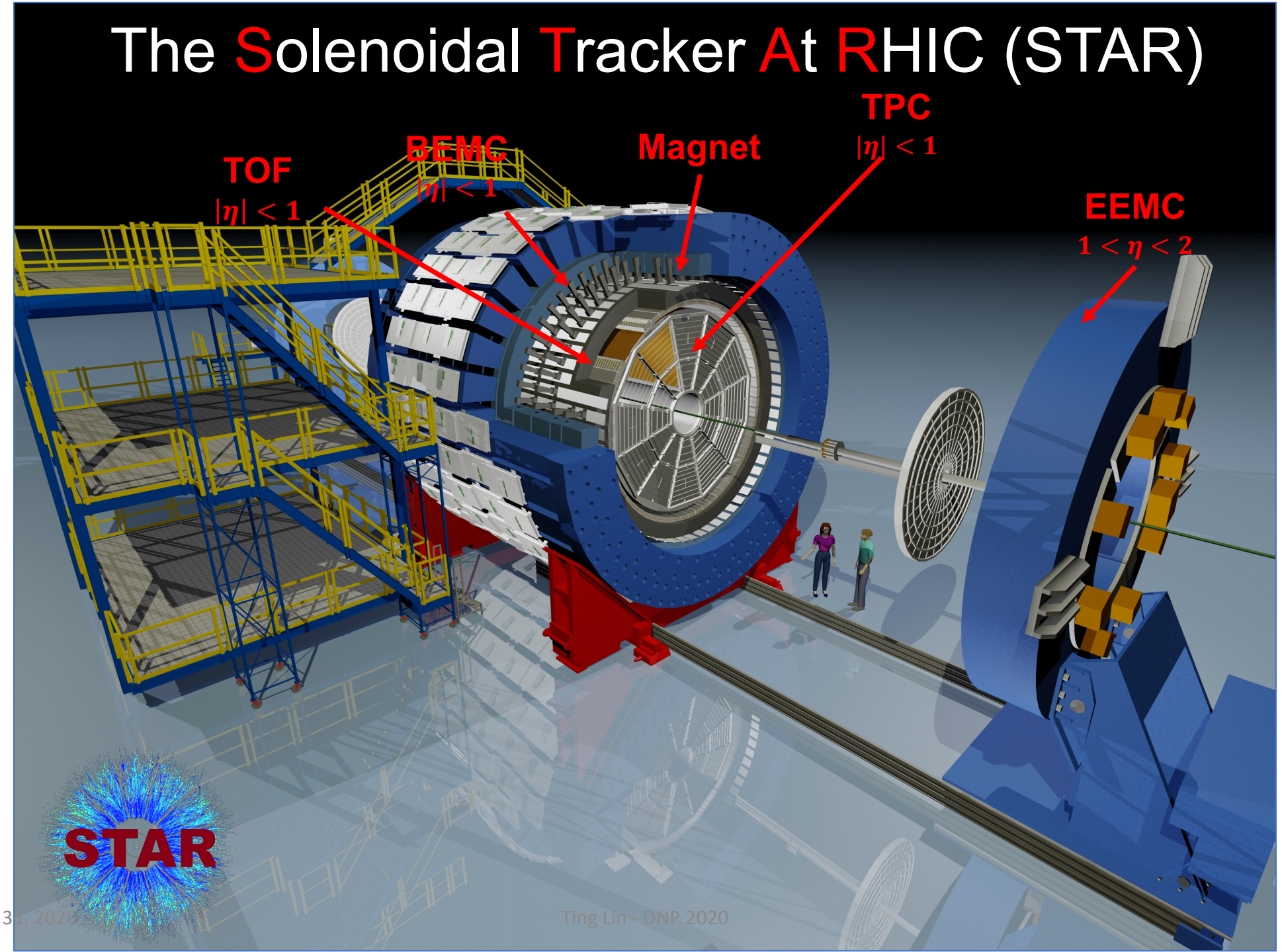
$$\langle \vec{S}_{quark} \cdot (\vec{P}_{quark} \times \vec{J}_{T,\pi}) \rangle \neq 0$$





Relativistic Heavy Ion Collider (RHIC)

The Solenoidal Tracker At RHIC (STAR)



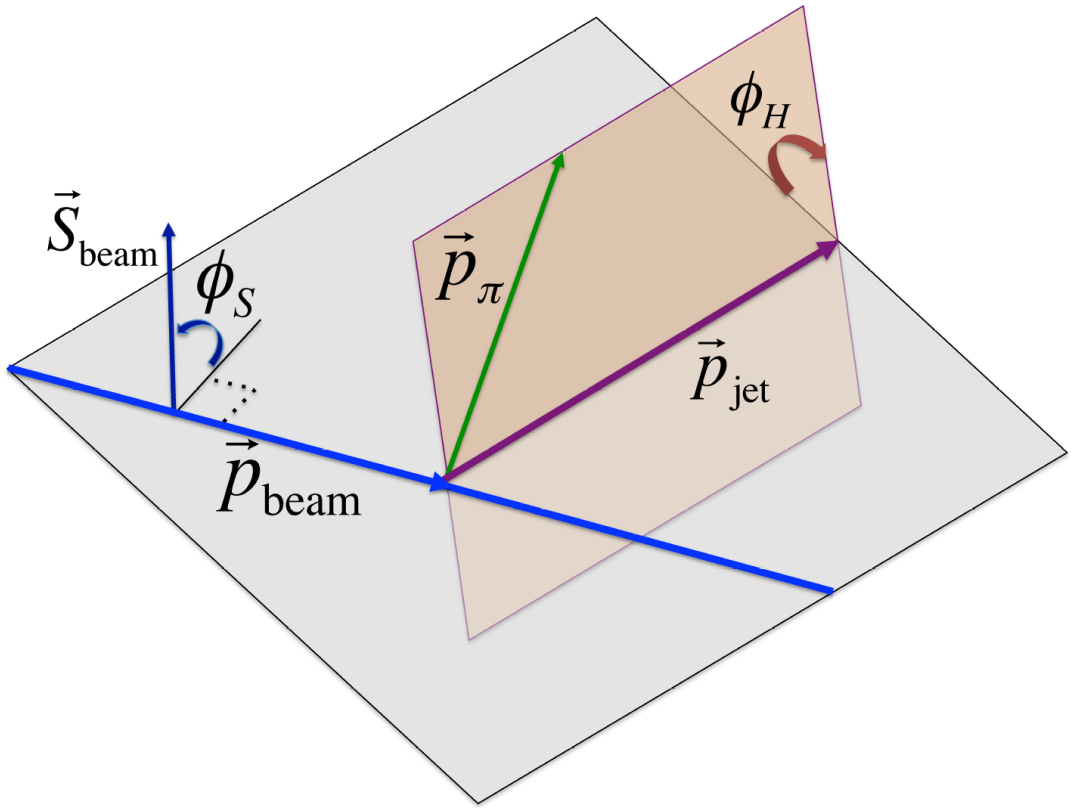
Transverse Single-Spin Asymmetry

- For pions within jets, the spin dependent cross section is:

$$d\sigma^{\uparrow}(\phi_S,\phi_H) - d\sigma^{\downarrow}(\phi_S,\phi_H)$$
$$\sim \mathrm{d}\Delta\sigma_0 \sin(\phi_S)$$
$$+\mathrm{d}\Delta\sigma_1^{-} \sin(\phi_S - \phi_H) + \mathrm{d}\Delta\sigma_1^{+} \sin(\phi_S + \phi_H)$$
$$+\mathrm{d}\Delta\sigma_2^{-} \sin(\phi_S - 2\phi_H) + \mathrm{d}\Delta\sigma_2^{+} \sin(\phi_S + 2\phi_H)$$

- Different modulations of the transverse single-spin asymmetry can be isolated and studied:

$$A_{UT}^{\sin(\phi)} \sin(\phi) = \frac{\sigma^{\uparrow}(\phi) - \sigma^{\downarrow}(\phi)}{\sigma^{\uparrow}(\phi) + \sigma^{\downarrow}(\phi)}$$



STAR Collaboration: Phys. Rev. D 97, 032004 (2018)
Umberto D'Alesio *et al*. Phys. Rev. D 83, 034021 (2011)

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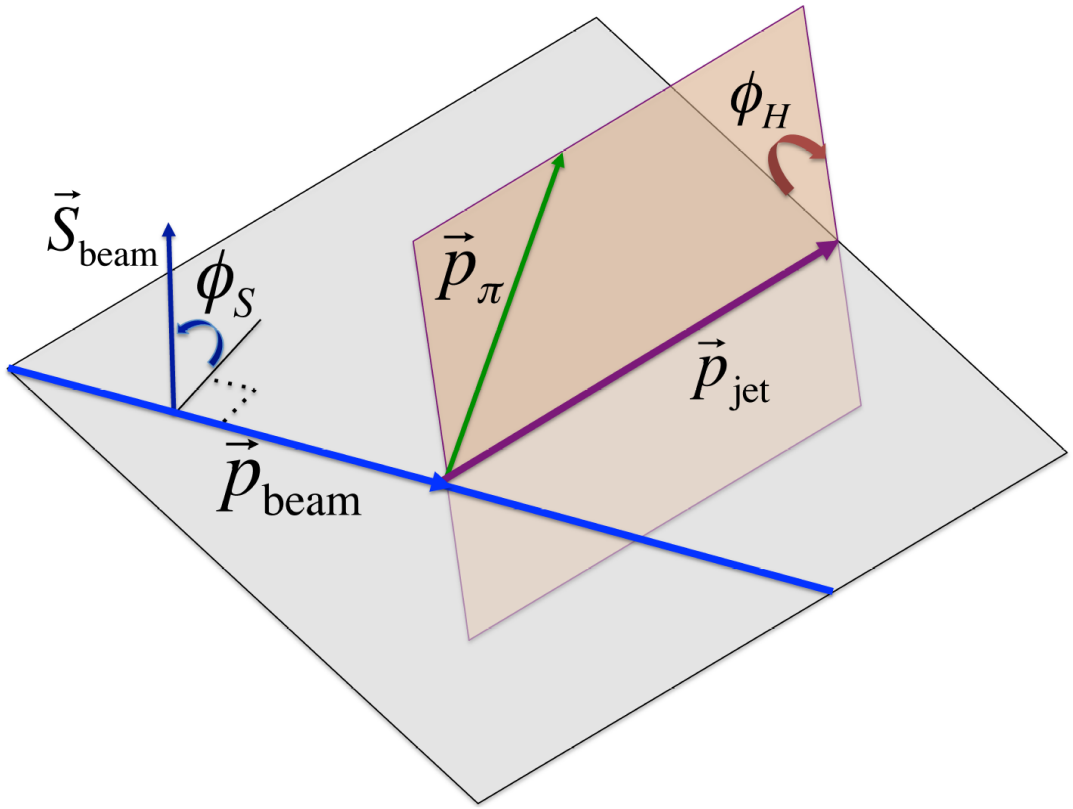

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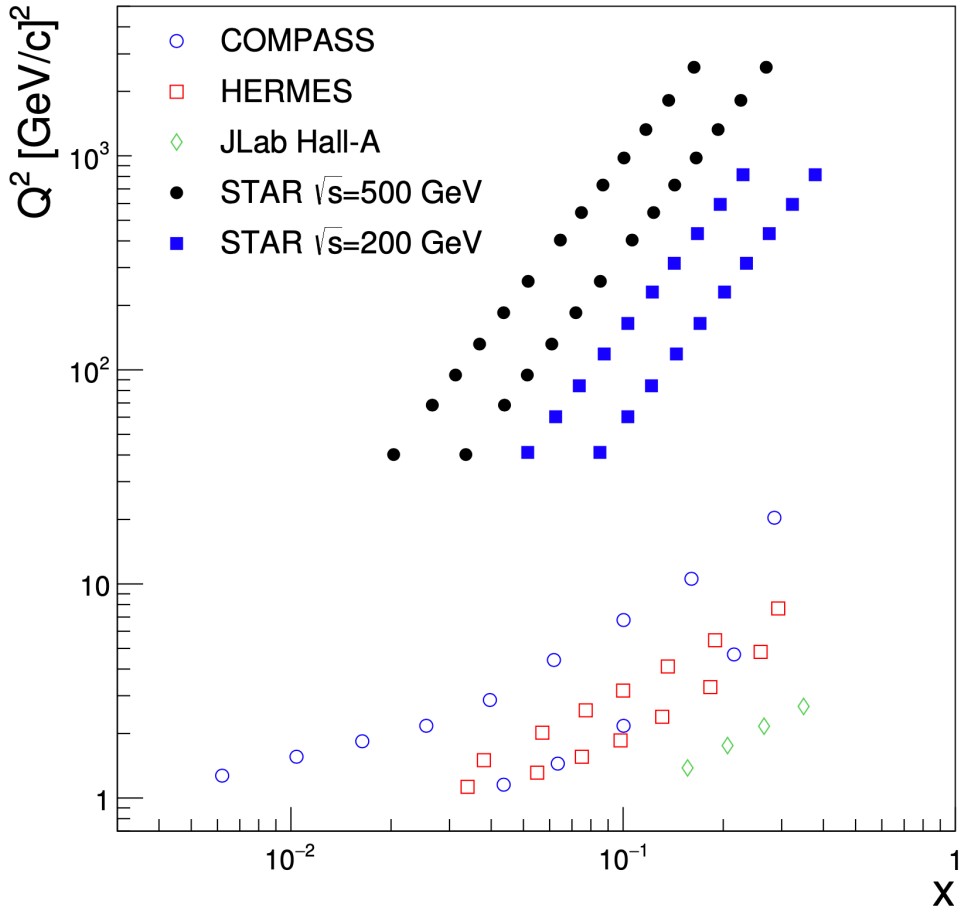
Collins Effect in pp

$$A_{UT}^{\sin(\varphi_S-\varphi_H)} \propto \frac{\sum_{a,b,c} \boldsymbol{h_1^a(x_1,\mu)}\ f_b(x_2,\mu)\ \sigma_{ab\to c}^{\text{Collins}}\ \boldsymbol{H_{1,h/c}^{\perp}(z_h, j_T; Q)}}{\sum_{a,b,c} f_a(x_1,\mu)\ f_b(x_2,\mu)\ \sigma_{ab\to c}^{\text{unpol}}\ D_{h/c}(z_h, j_T; Q)}$$

Kang *et al.*, JHEP 11, 068 (2017) and PLB 774, 635 (2017)

- Collins effect in pp involves a mixture of collinear and TMD factorization
  - Initial jet production involves the collinear transversity $\boldsymbol{h_1^a}$
  - Polarized quark then fragments according to the TMD Collins fragmentation function $\boldsymbol{H_{1,h/c}^{\perp}}$
- Cleaner kinematic separation of transversity and TMD physics than SIDIS, which convolutes the TMD transversity with the Collins FF

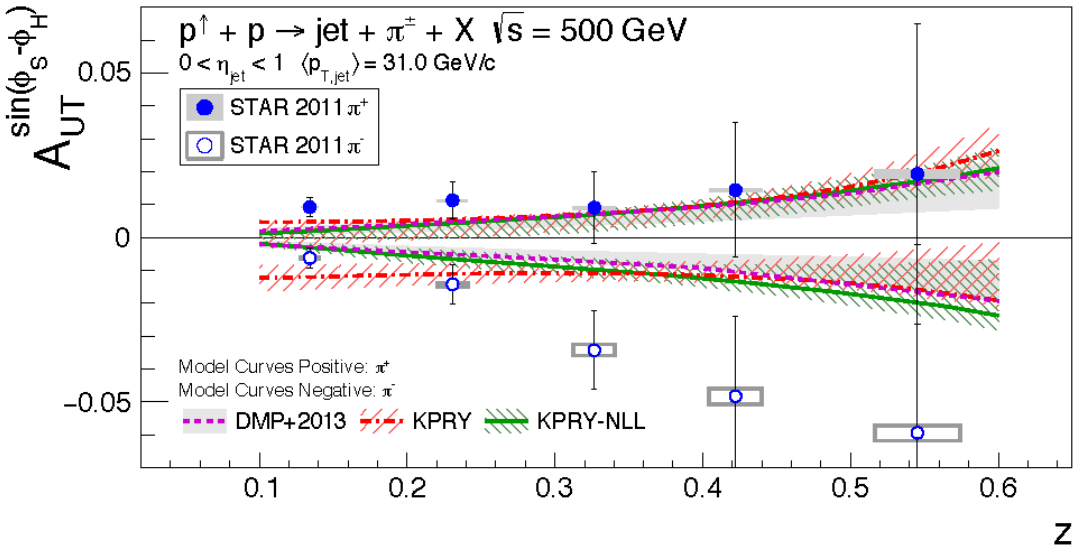
Kinematic Coverage



- STAR covers a similar range in momentum fractions (*x)* to that of SIDIS experiments with much higher Q^2
- Collins effect in pp provide a direct probe of the Collins fragmentation function and enable the test of its evolution, universality and factorization breaking in the TMD formalism.

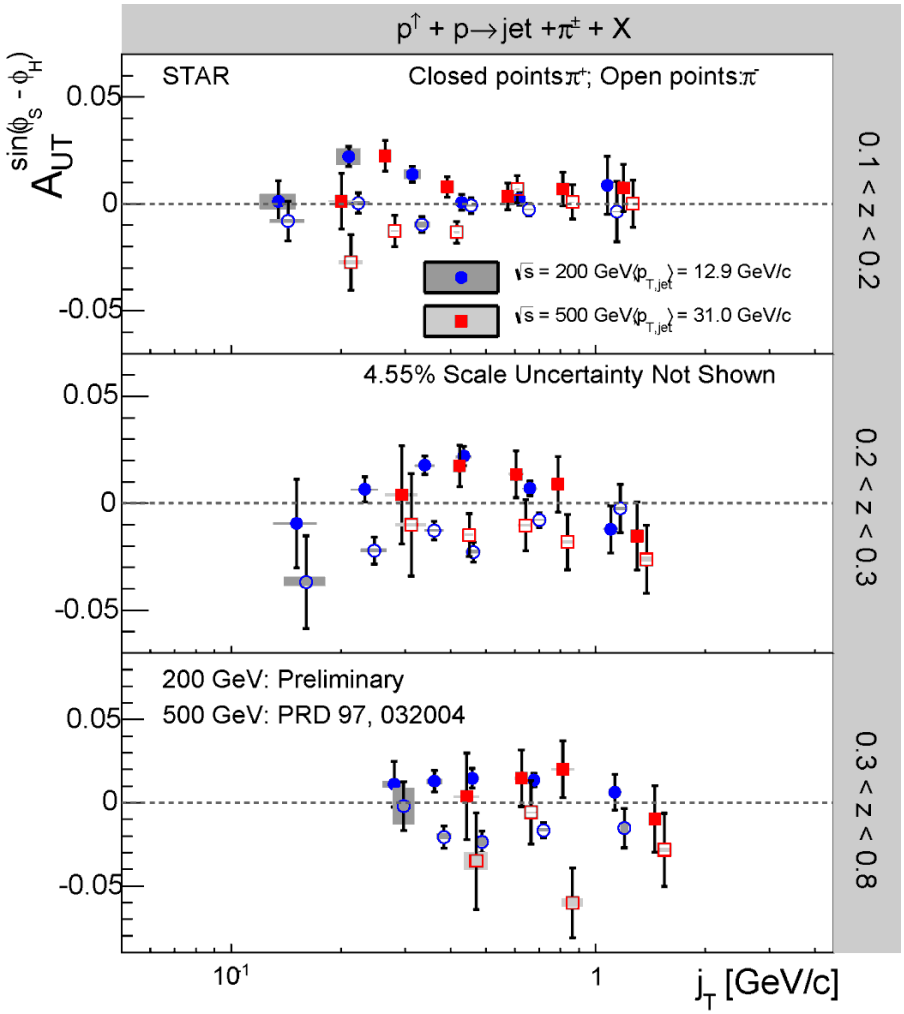
Collins Asymmetry from STAR

STAR Collaboration: Phys. Rev. D 97, 032004 (2018)



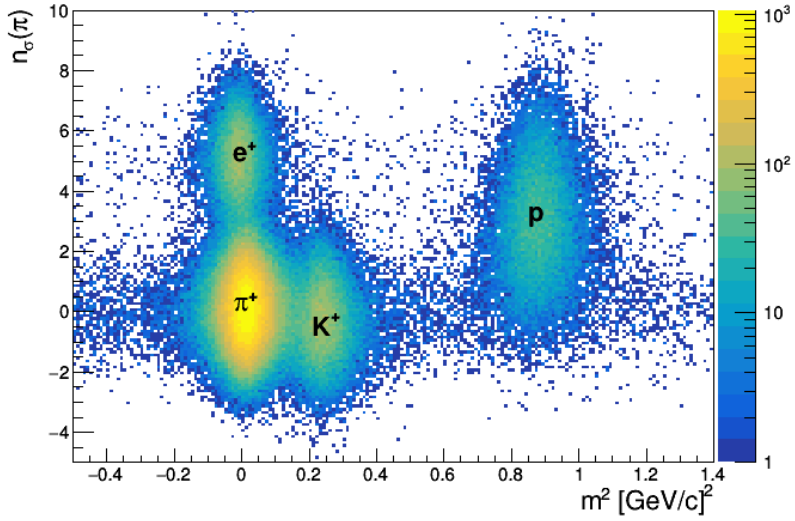
- First Collins effect measurements in pp collisions are reasonably described by two recent calculations that combine the transversity distribution from SIDIS with the Collins FF from e^+e^- collisions
- Both 200 and 500 GeV pp results hint that the asymmetry peak shifts to higher j_T as z increases

Spin2018: 2012 pp200GeV
2011 pp500GeV

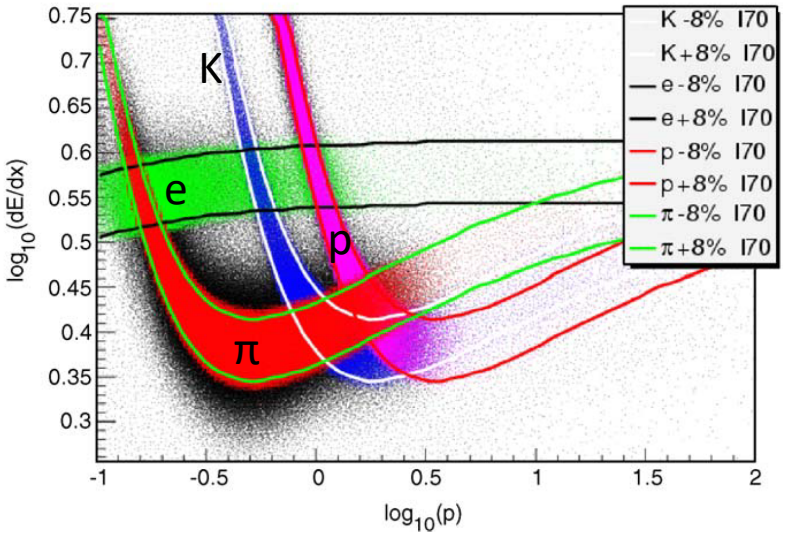


2015 Collins Analysis at STAR

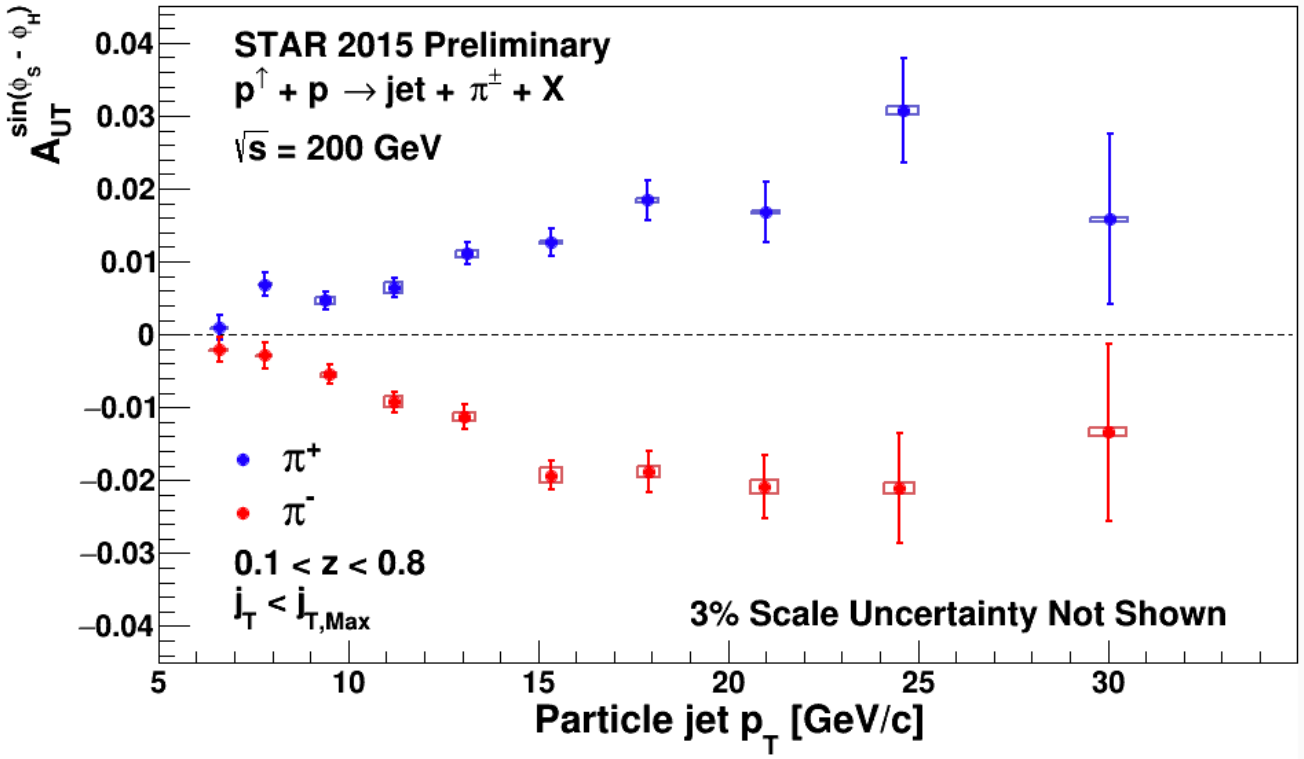
- $52\mathrm{pb}^{-1}$ transversely polarized p+p data at $\sqrt{s}$ = 200 GeV, twice as 2012;
- 57% average beam polarization;
- Particle identification from TPC and TOF;

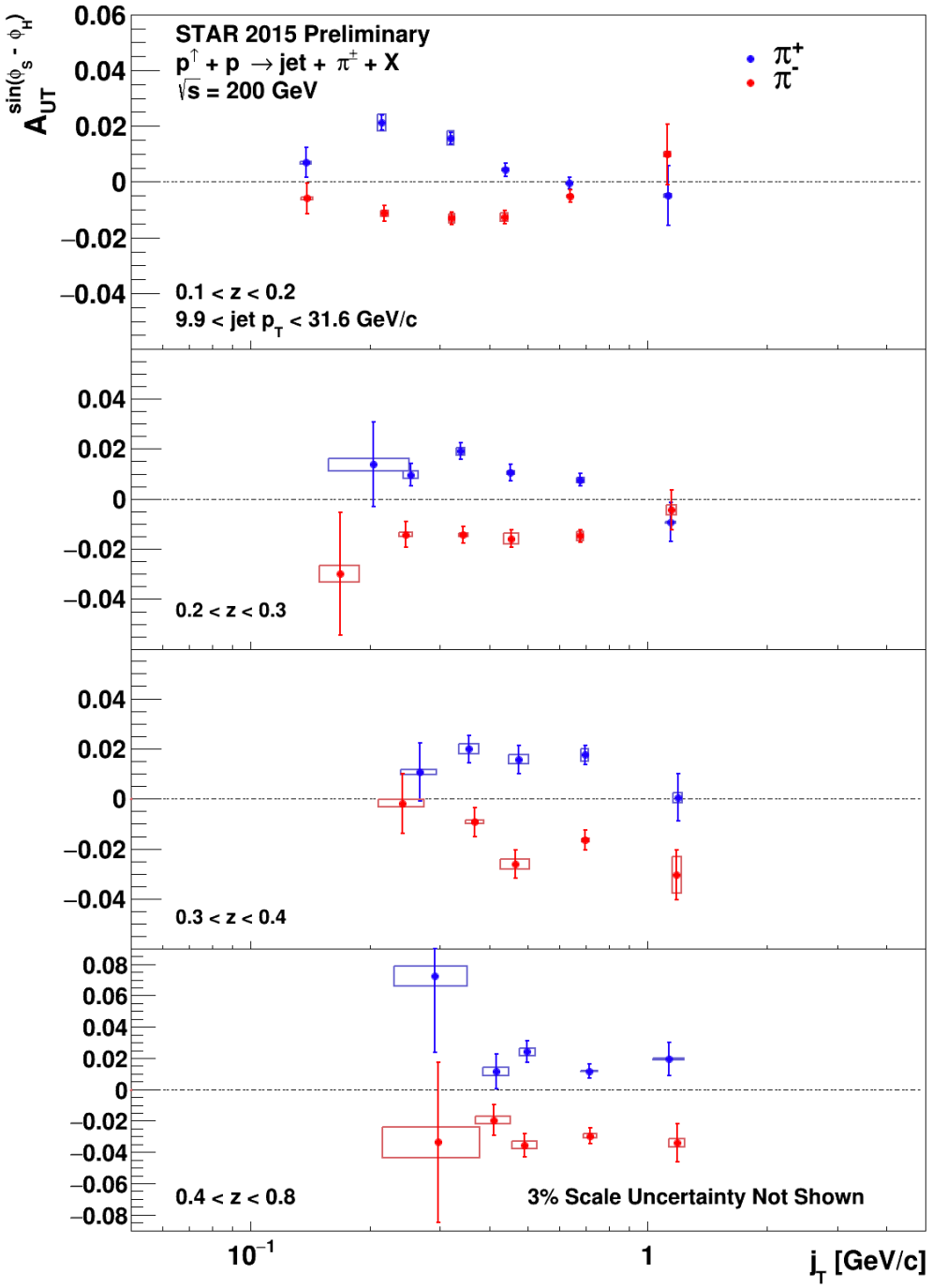


Ming Shao *et al.* NIM A558 (2006)



$\pi^{\pm}$ Azimuthal Distribution in Jets





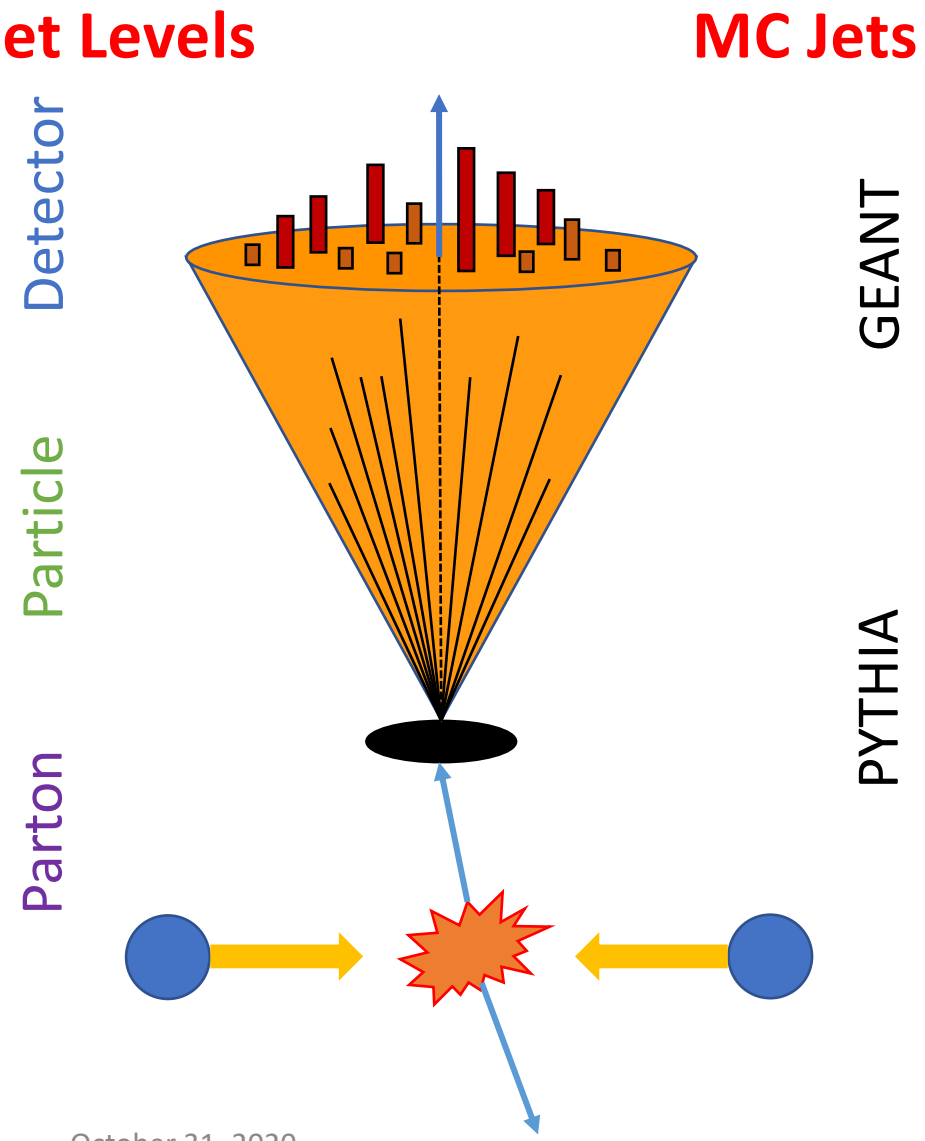
- Collinear transversity is probed most directly in the jet p_T and eta dependence;
- Collins TMD FF is sensitive to the (j_T, z) dependence.

Conclusion

- We present the most precise measurement of Collins asymmetry for charged hadrons inside jets at 200 GeV pp collisions to date;
- 200 GeV pp provides sensitivity up to $x \sim 0.4$, where SIDIS statistics are very limited;
- These results are consistent with the previous STAR results and have smaller statistical and systematic uncertainties;
- Similar x coverage with SIDIS and overlap with the $x - Q^2$ coverage of EIC, providing critical tests for factorization, universality and evolutions in TMD frameworks.

Back Up

Jet Reconstruction



Anti-K_T Algorithm:

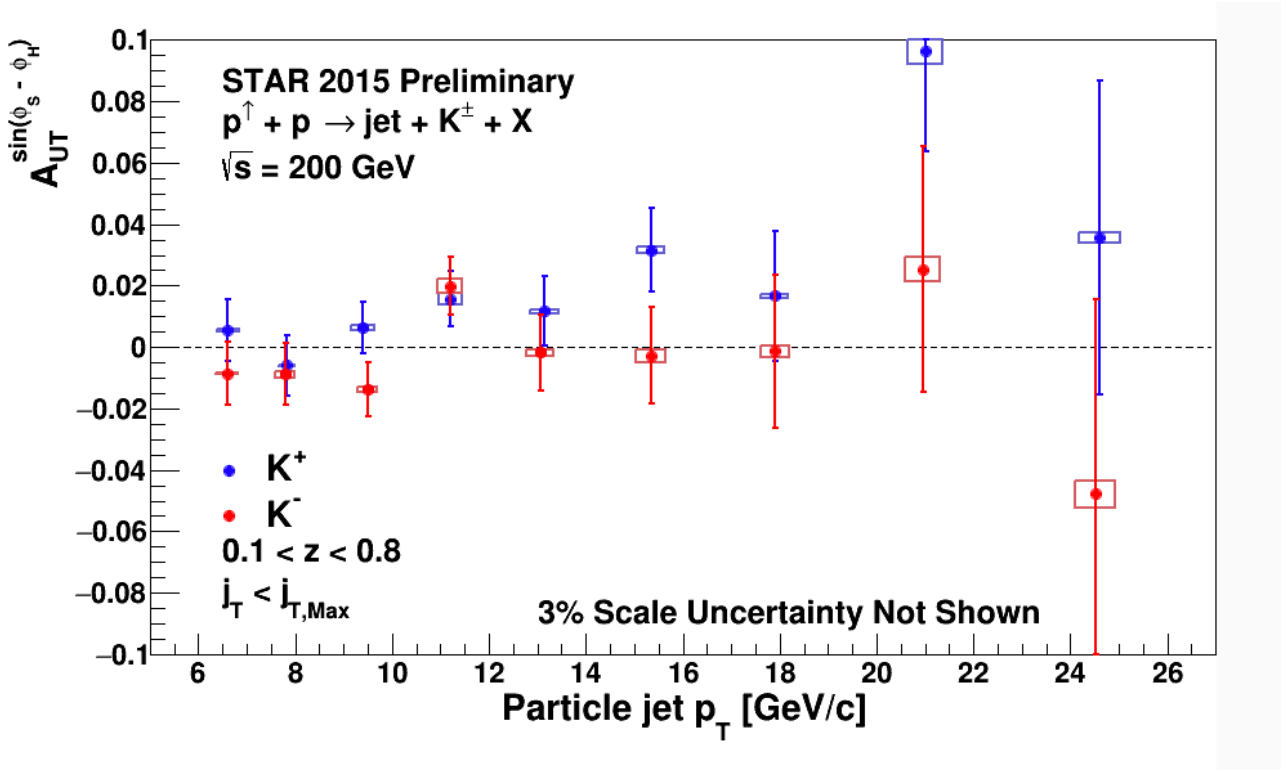
- Radius = 0.6
- Less sensitive to underlying event and pile-up effects
- Used in both data and simulation

Simulation: PYTHIA 6.4 with STAR adjustment of Perugia 2012

Three Simulation Levels :

- Parton – hard scattered partons involved in 2->2 hard scattering event from Pythia
- Particle – partons propagate and hadronize into stable and color-neutral particles
- Detector – detector response to the stable particles

$K^{\pm}$ Azimuthal Distribution in Jets



- K^+, which can be produced through favored fragmentation of a valence u quark, has asymmetries that are about 1.5-sigma larger than π^+.
- K^-, which is produced by unfavored fragmentation, has asymmetries that are consistent with zero at the current precision.
- Both observations are similar to SIDIS.