RHIC & AGS
Annual Users' Meeting 2021

This meeting will be held as a virtual event.
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Future Cold-QCD Physics Program with STAR

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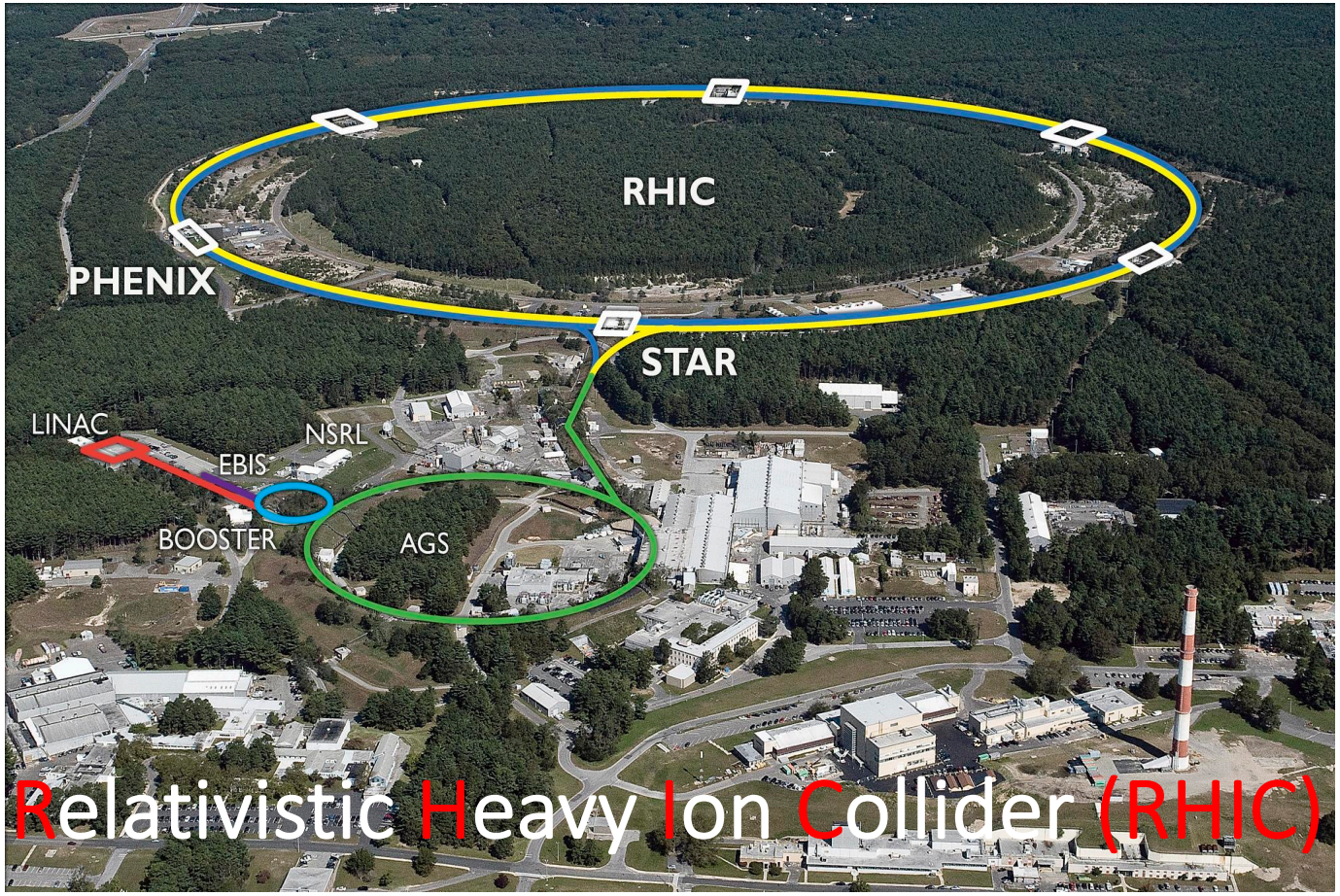
Office of Science

Outline:

- STAR Upgrades
- Cold QCD Physics for 2022+
  - Transverse Spin Measurement;
  - Unpolarized Physics;
- Summary



STAR Detector Upgrades for BES-II

inner TPC (2019)

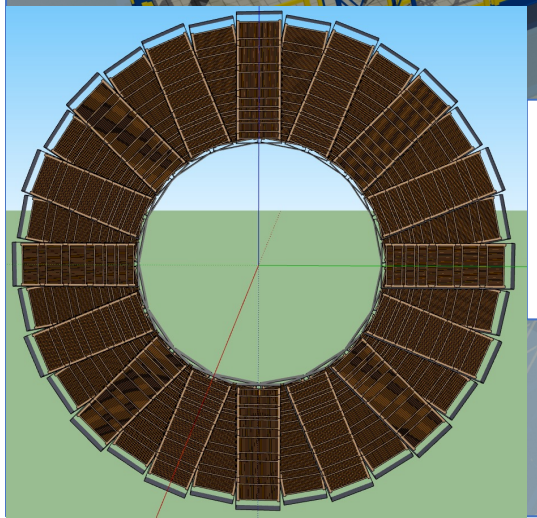
$|\eta| < 1.5$

- Replace all inner TPC sectors;
- Increase rapidity coverage;
- Improve momentum and dE/dx resolution;
- Extend low p_T reach from 125 MeV/c to 60 MeV/c;

Event Plane Detector (2018)

$2.1 < |\eta| < 5.1$

- Extend rapidity coverage;
- Improve triggering capabilities;
- Improve event plane resolution;

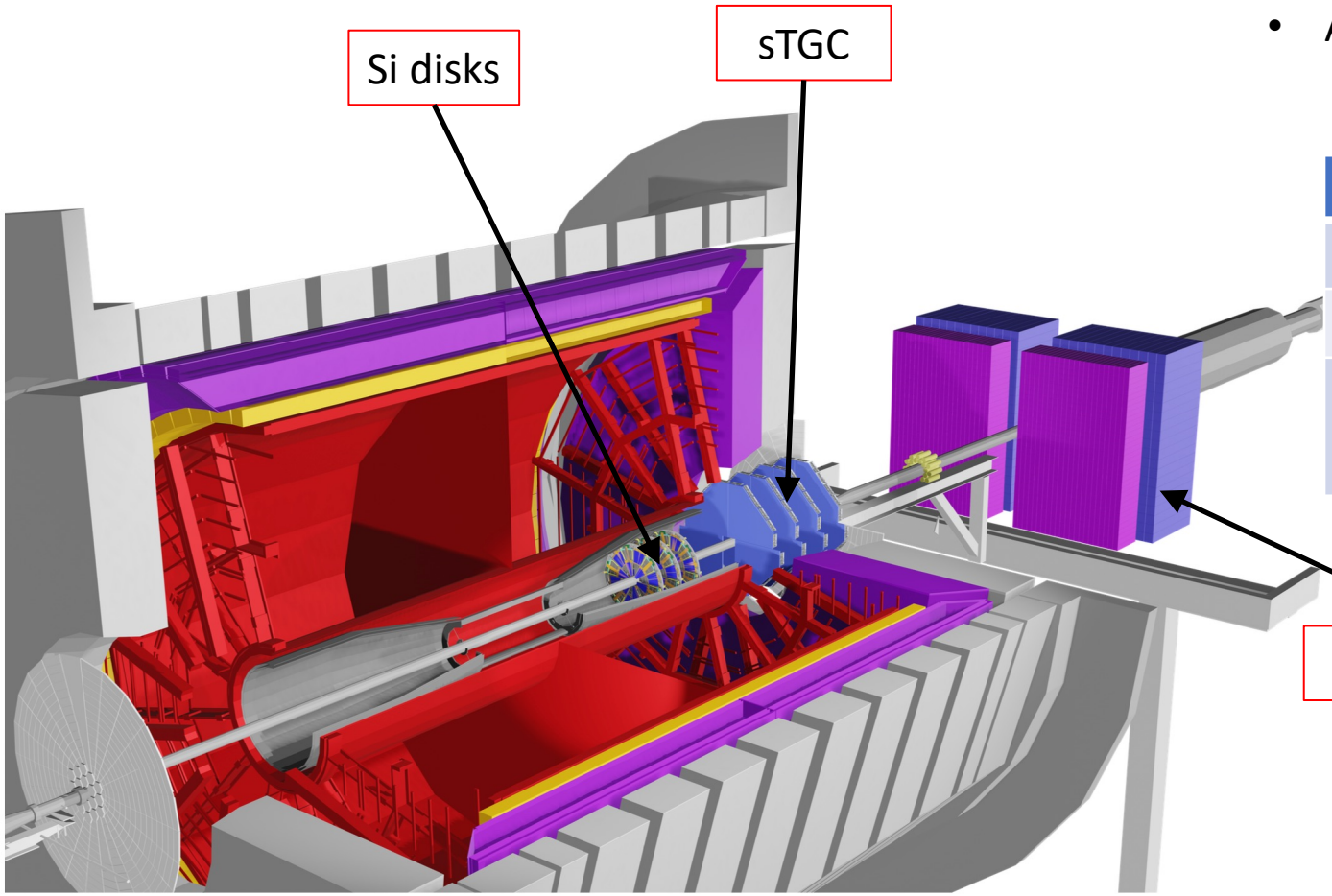


Endcap Time of Flight (2019)

$-1.5 < \eta < -1$

- Extend PID from η = -1 to -1.5;
- Enhance the fixed target program;

STAR Forward Upgrade Ongoing:



- At $2.5 < \eta < 4$
  - Si disks + small-strip Thin Gap Chamber (sTGC) for tracking;
  - Electromagnetic and hadronic calorimeters.

Detector	p+p and p+A	A+A
ECal	~$10\%/\sqrt{E}$	~$20\%/\sqrt{E}$
HCal	~$50\%/\sqrt{E}$ + 10%	---
Tracking	Charge separation Photon background suppression	0.2< p_T < 2 GeV/c, with 20-30% $1/p_T$

Cold QCD Physics for 2022+

Mid Rapidity → **Forward Rapidity**

$-1.5 < \eta < 1.5$

Physics Topics:

Improve statistical precision:

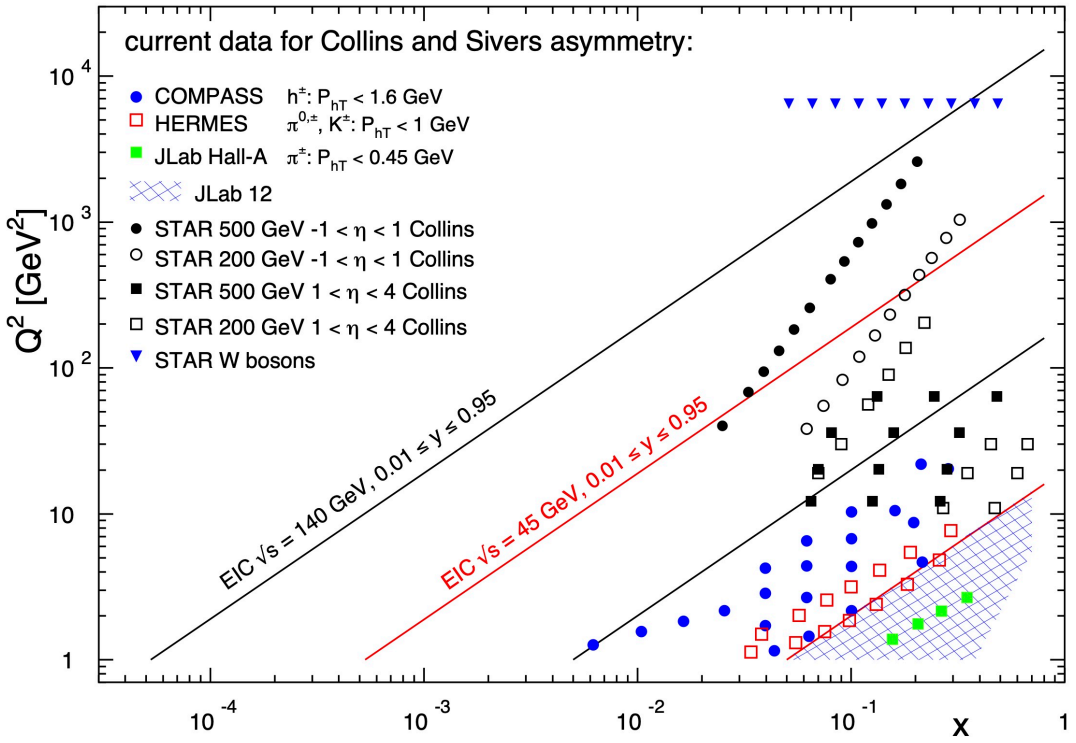
- Sivers effect in dijet and W/Z production;
- Collins effect for hadrons in jets;
- Transversity and IFF
- Diffractive studies for spatial imaging of nucleon
- Measurement of GPD E_g through UPC J/Ψ
- Nuclear PDF and fragmentation function;

$2.5 < \eta < 4$

Physics Topics:

- TMD measurements at high x
  - Transversity, Collins;
  - Sivers through DY and jets
- UPC J/Ψ GPD at forward rapidity;
- Nuclear PDFs and FF:
  - R_{pA} for direct photons & DY, and hadrons
- Gluon Saturation through di-hadrons, γ-Jets, di-jets

All of these measurements are critical to the scientific success of EIC to test universality and factorization



$\sqrt{s}$ (GeV)	Species	Luminosity	Year
510	$p^{\uparrow}+p^{\uparrow}$	400 pb^{-1}	2022
200	$p^{\uparrow}+p^{\uparrow}$	235 pb^{-1}	2024
200	$p^{\uparrow}+Au$	1.3 pb^{-1}	2024

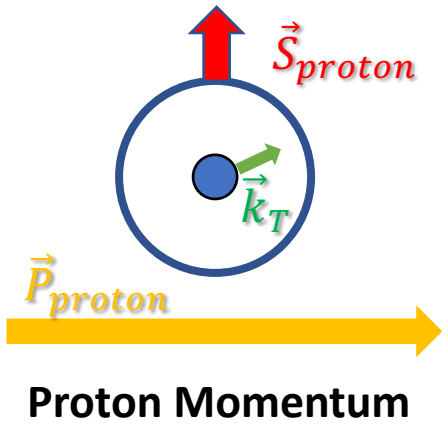
- Kinematic coverage for 200 and 500 GeV p+p at STAR is 0.005<x<0.5;
- Provides best overlap with the *x*-Q^2 coverage of EIC.

Sivers and Collins Effect

Sivers effect:

- In a transversely polarized proton, the constituent parton has a flavor dependent intrinsic transverse momentum:

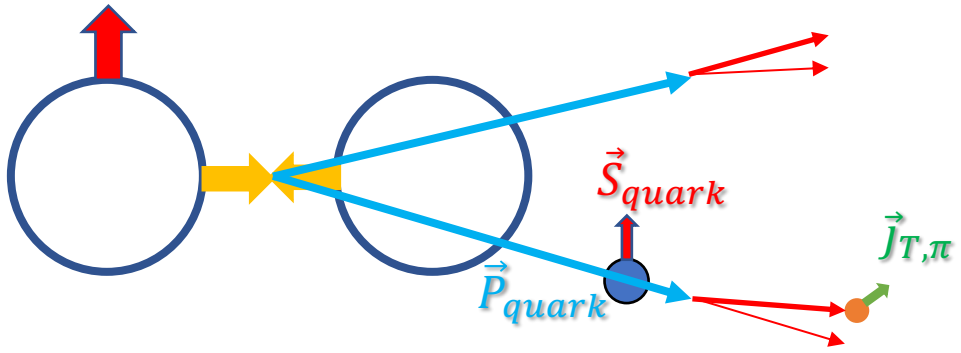
$$\langle \vec{S}_{proton} \cdot (\vec{P}_{proton} \times \vec{k}_T) \rangle \neq 0$$



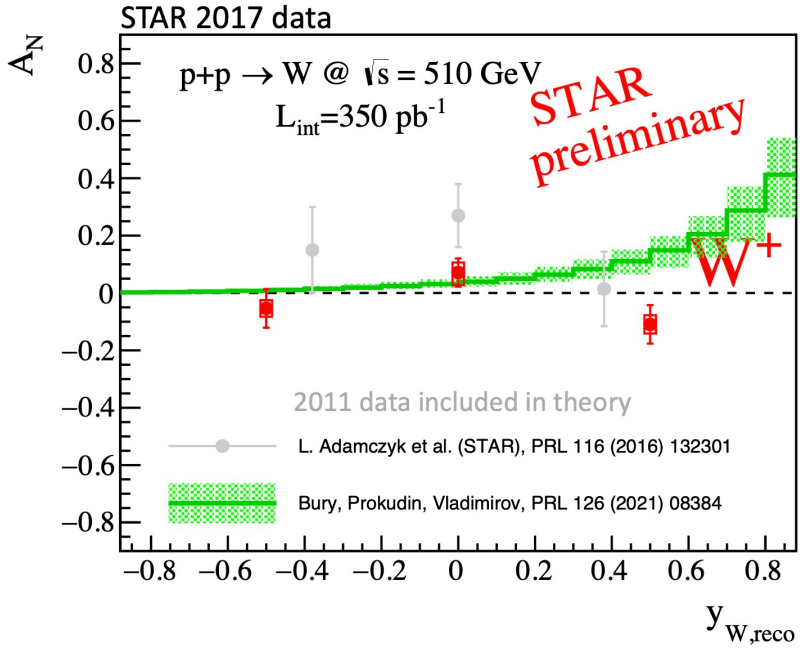
Collins effect:

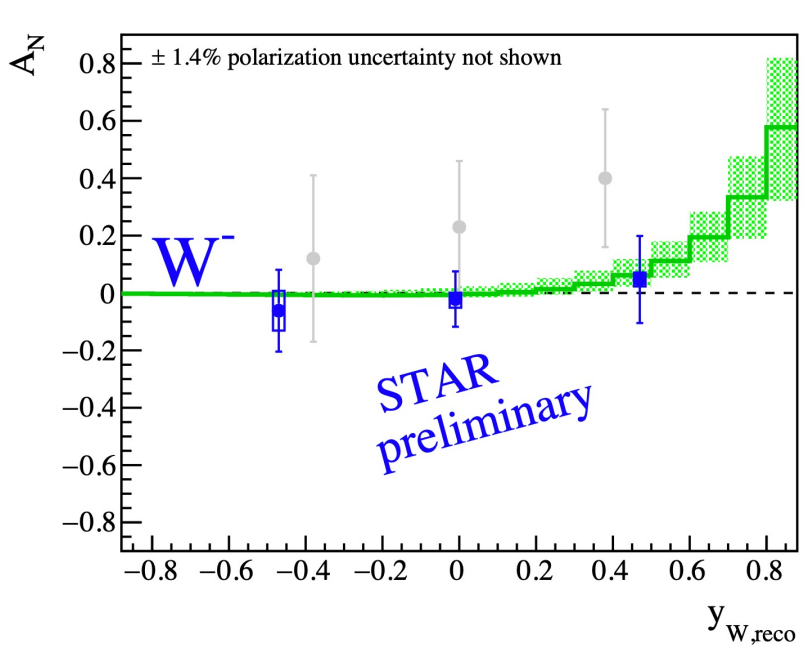
- Correlation between the polarization of a scattered quark and the momentum of a hadron fragment transverse to the scattered quark direction:

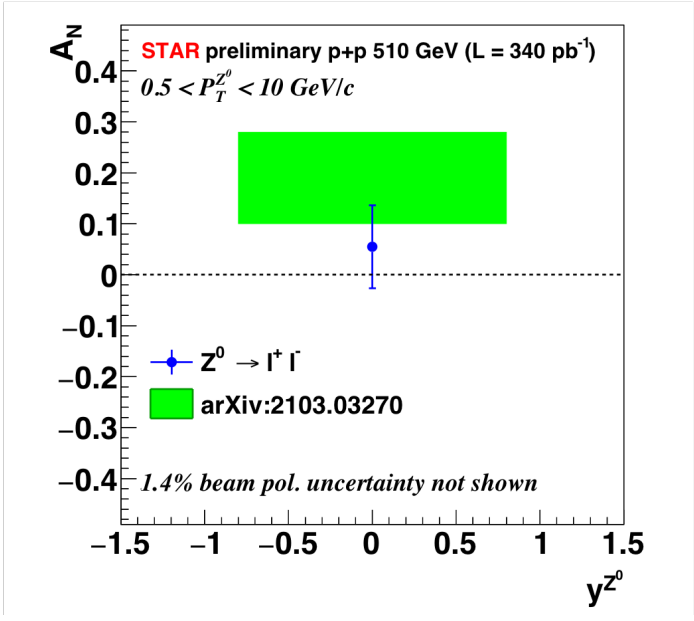
$$\langle \vec{S}_{quark} \cdot (\vec{P}_{quark} \times \vec{J}_{T,\pi}) \rangle \neq 0$$



A_N for $W^{\pm}$ and Z



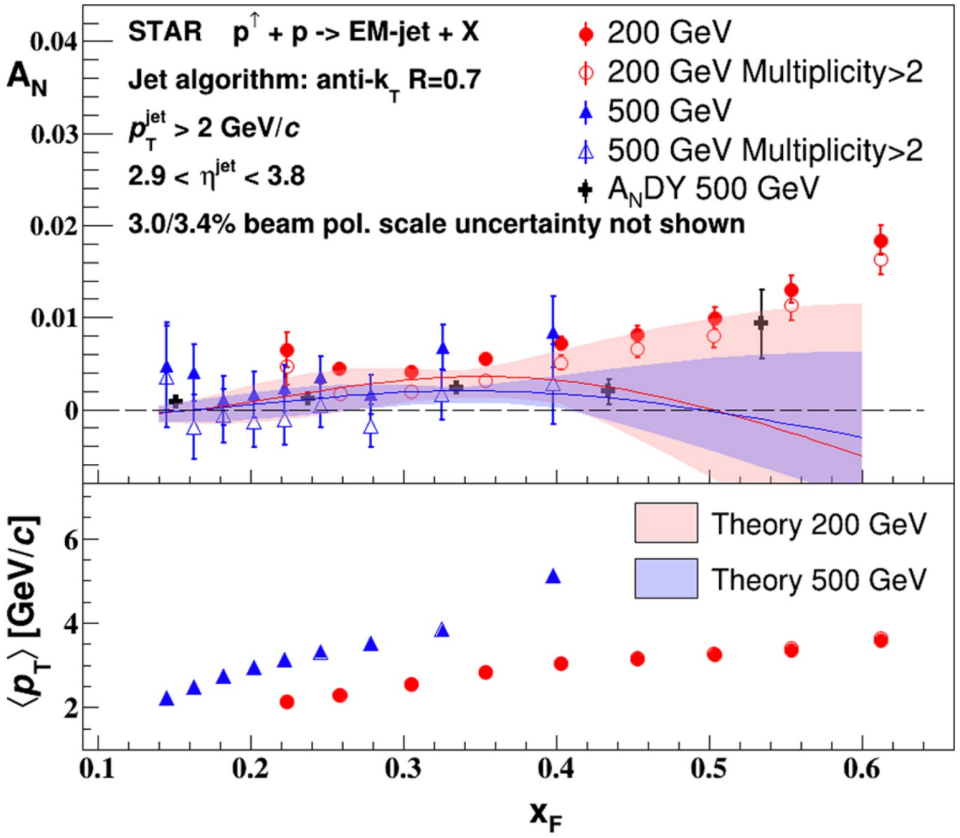




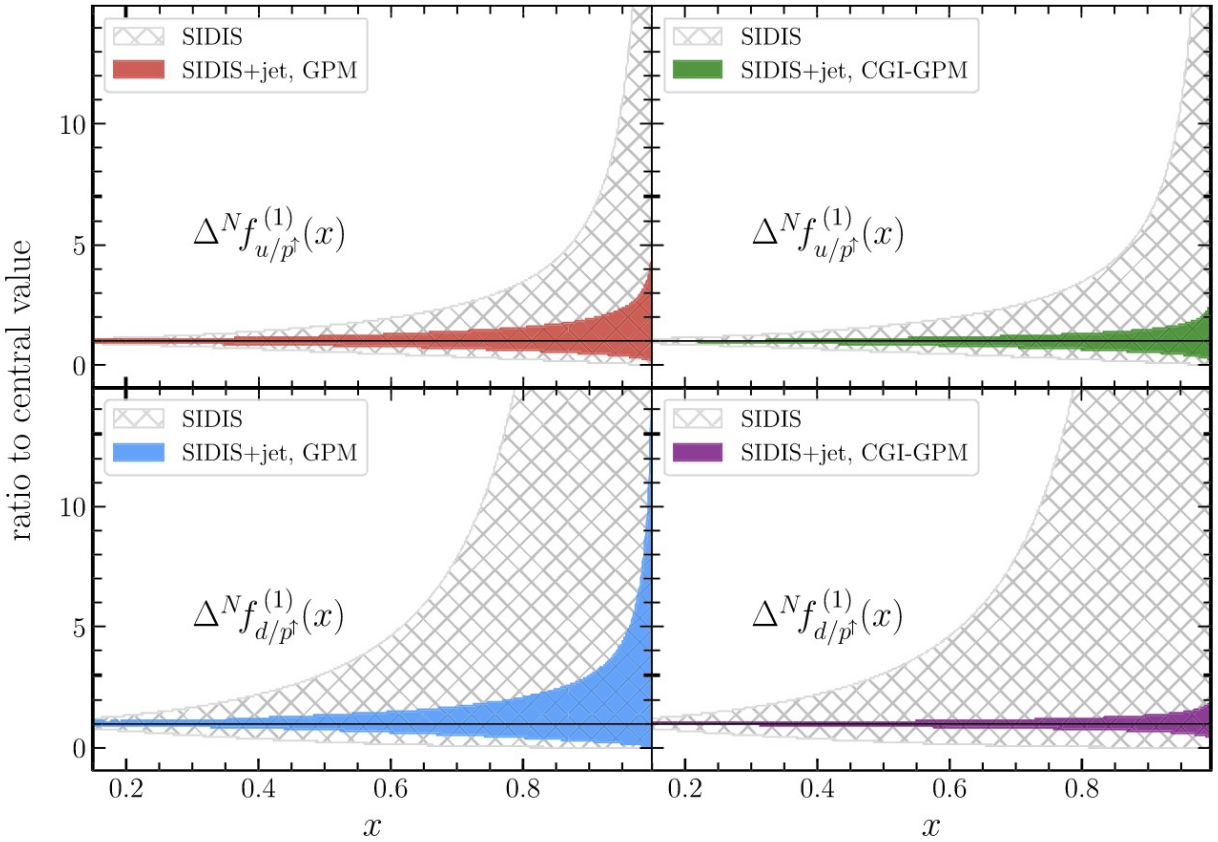
- iTPC upgrade will push the measurements to larger rapidity, where the asymmetry is expected to be large;
- Run-22 will increase the statistics by about a factor of 2, and this would enhance quantitatively testing the limits of factorization and universality.

A_N for Forward Jet

STAR, Phys. Rev. D 103, 092009 (2021)

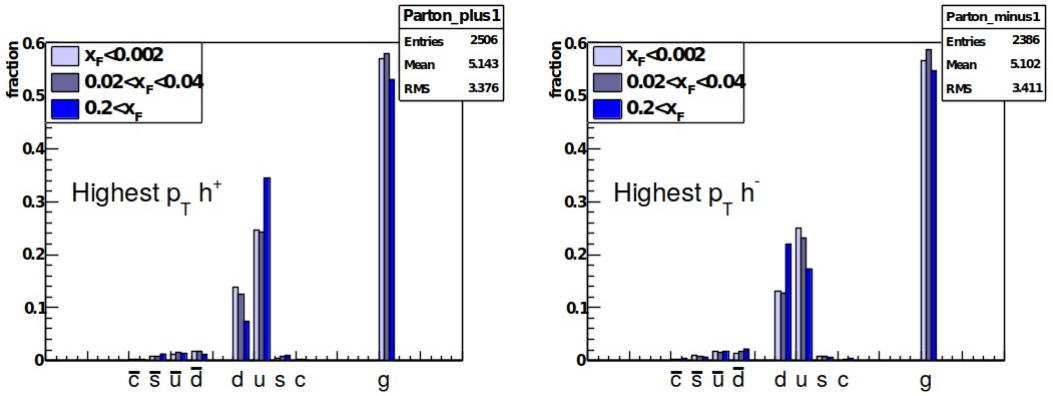


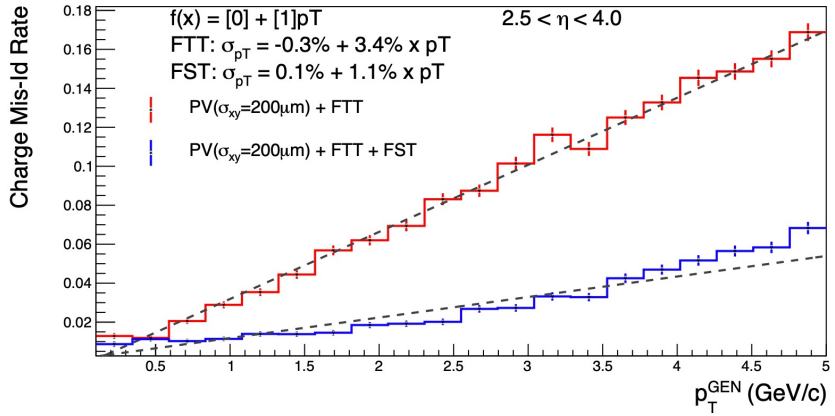
M.Boglione et.al., PLB 815, 136135 (2021)

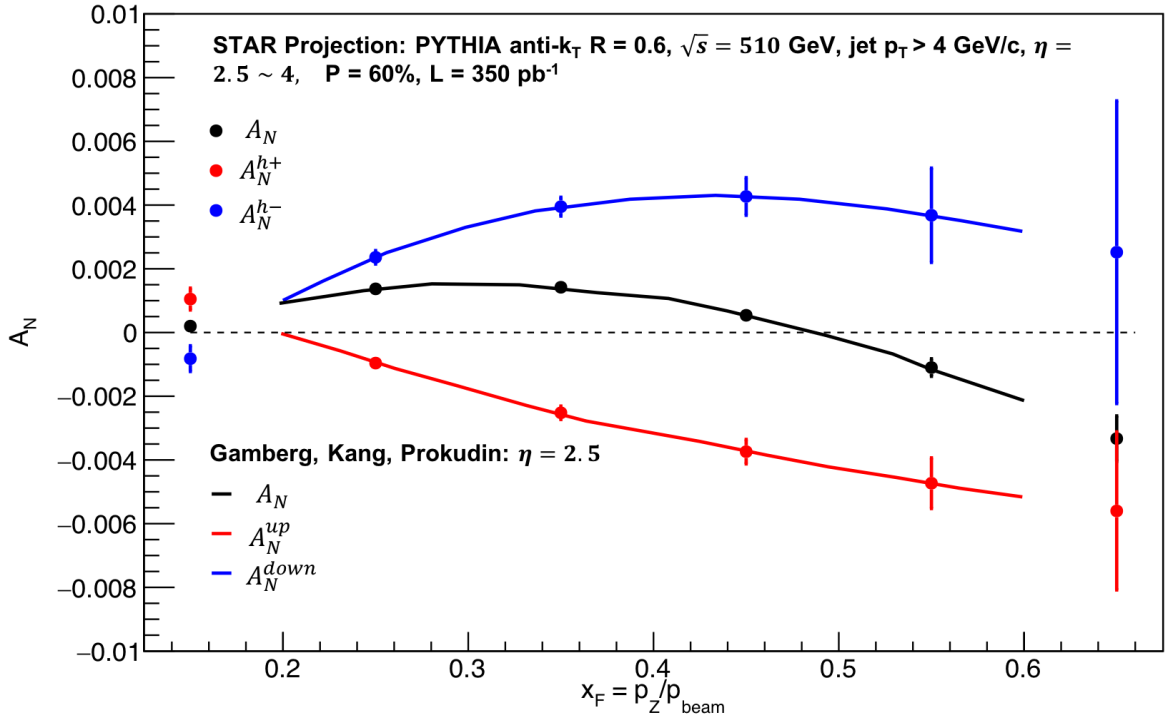


- The published STAR forward inclusive EM-jet result shows small TSSA;
- This result significantly reduces the uncertainty of the quark Sivers function extracted from SIDIS at momentum fraction x > 0.2.

A_N for Forward Jet

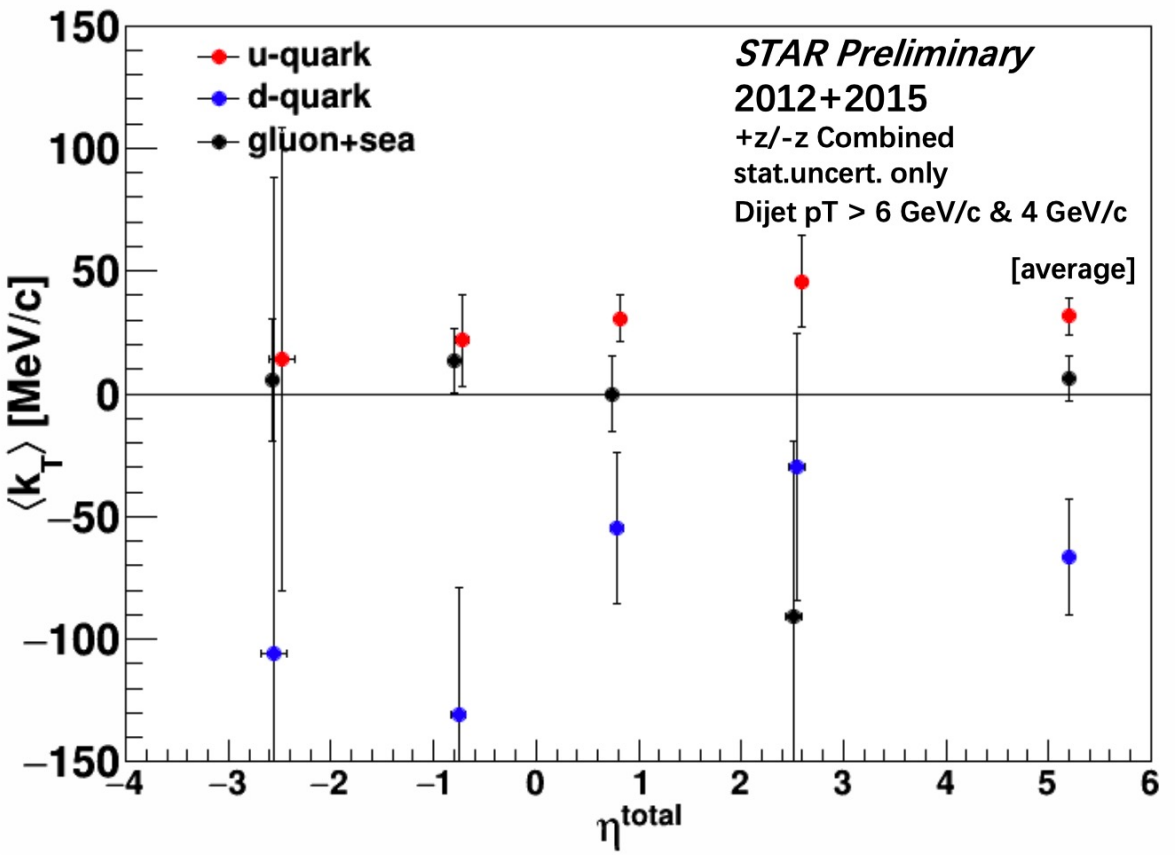


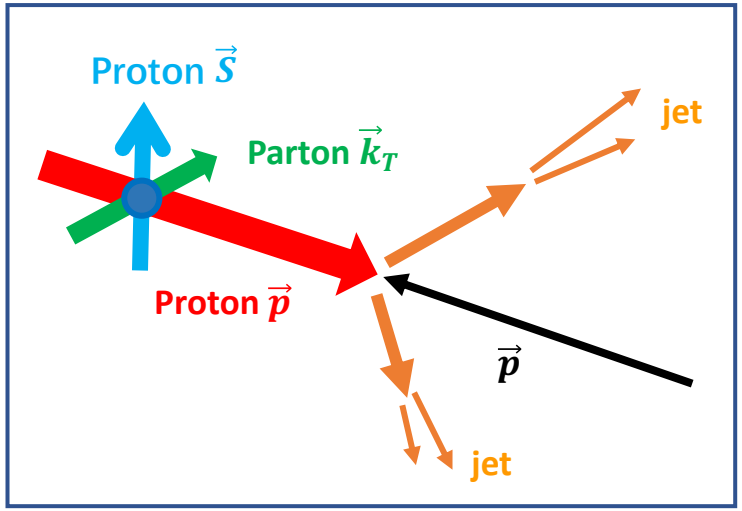


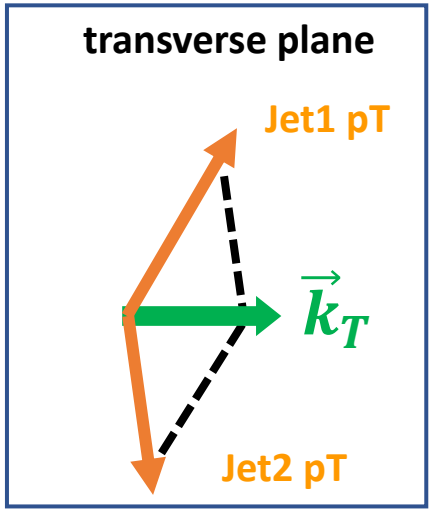


- Enhancement of the u/d quarks for positively/negatively charged leading hadrons at forward rapidity;
- FST+FTT provide very good charge identification capability, precise measurement can be made with the Forward Upgrades;
- Will provide a quantitative test on the relation between the ETQS correlation and the Sivers function.

Sivers Effect from Dijet Measurement

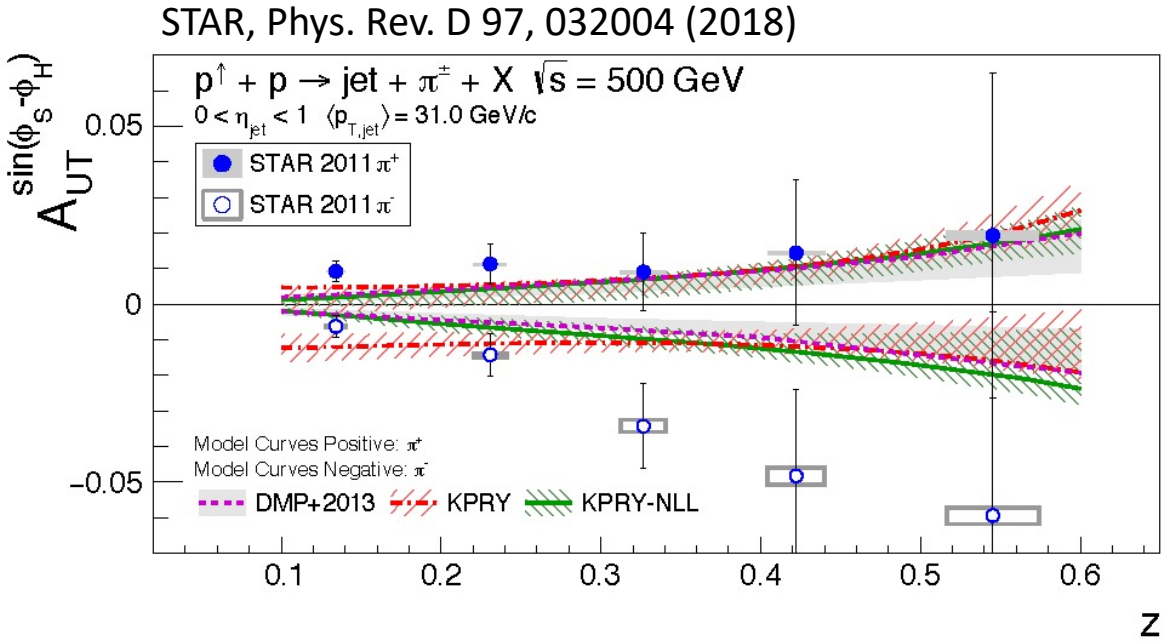


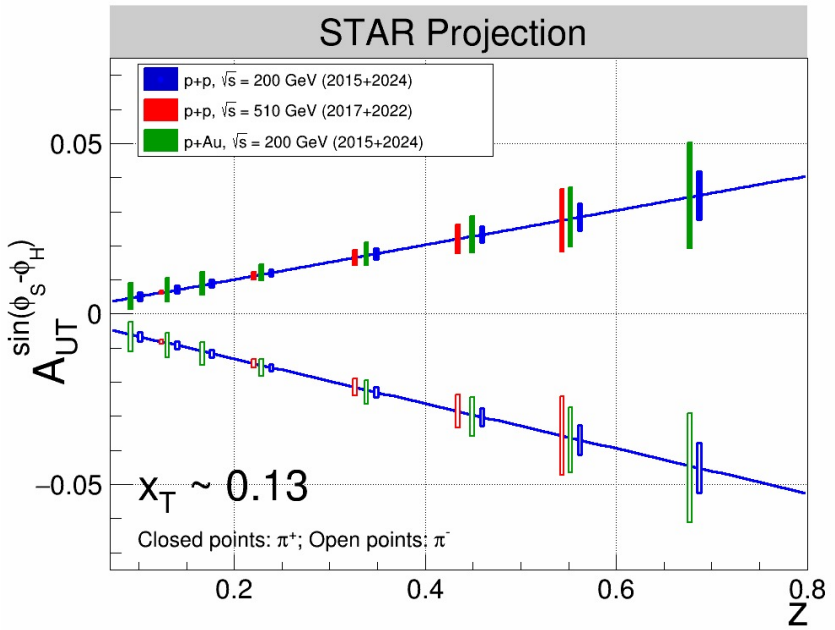




- First observation of non-zero Sivers asymmetries in dijet production in polarized p+p collisions;
- $\langle k_T^u \rangle \approx 31$ MeV/c, $\langle k_T^d \rangle \approx -55$ MeV/c, $\langle k_T^{g+sea} \rangle \approx 0$ MeV/c;
- With Forward Upgrades, measurement can be extended to larger pseudo-rapidity (for η^{total} from 1.5 ~ 7).

Collins Asymmetry at Mid-Rapidity

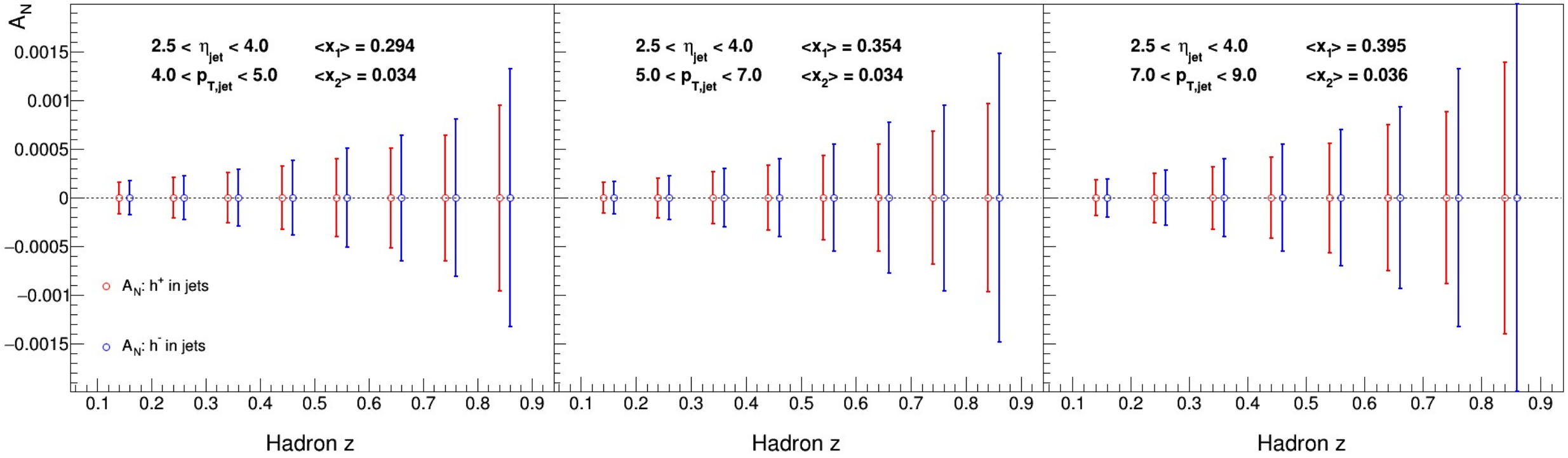




- First Collins asymmetry measurements in pp collisions are reasonably described by two recent calculations that combine the transversity distribution from SIDIS with the Collins FF from e^+e^- collisions;
- iTPC will extend the measurement to $0 < \eta < 1.5$, and improve the dE/dx resolution by 20-25%;
- 14 times more luminosity were recorded in 2017 compared to 2011, while additional 16 times more will be taken in 2022;
  - Similar improvements for Interference fragmentation function (IFF);
  - IFF correlates quark polarization to azimuthal distribution of final state hadron pairs.

Collins Asymmetry at Forward Rapidity

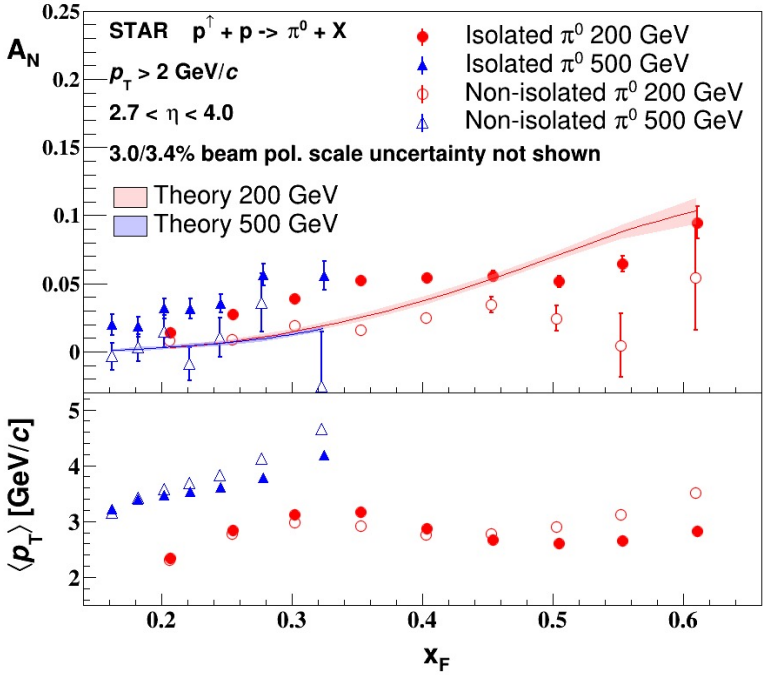
Pythia: $p^{\uparrow} + p \rightarrow jet + \ h^{\pm} + X, \sqrt{s} = 510$ GeV



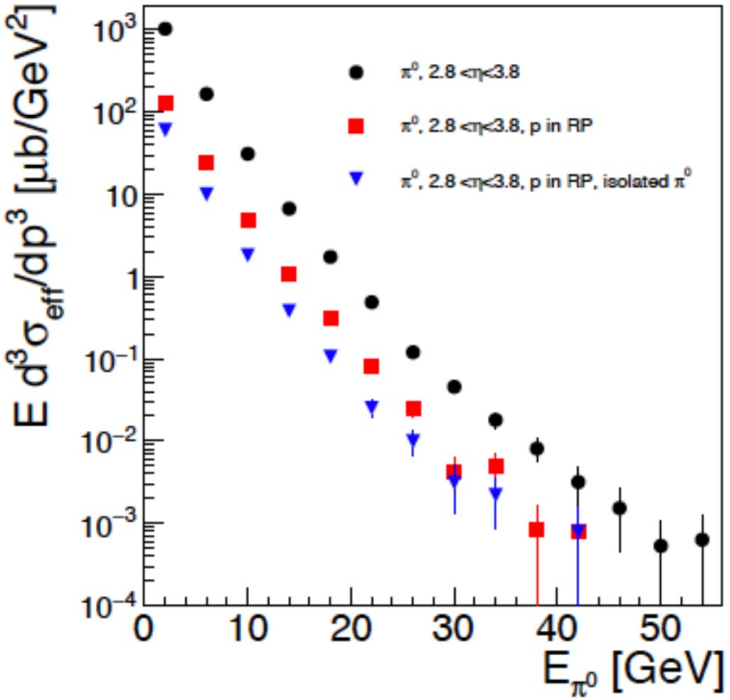
- Very precise measurement can be made with the Forward Upgrades.

Diffractive Processes

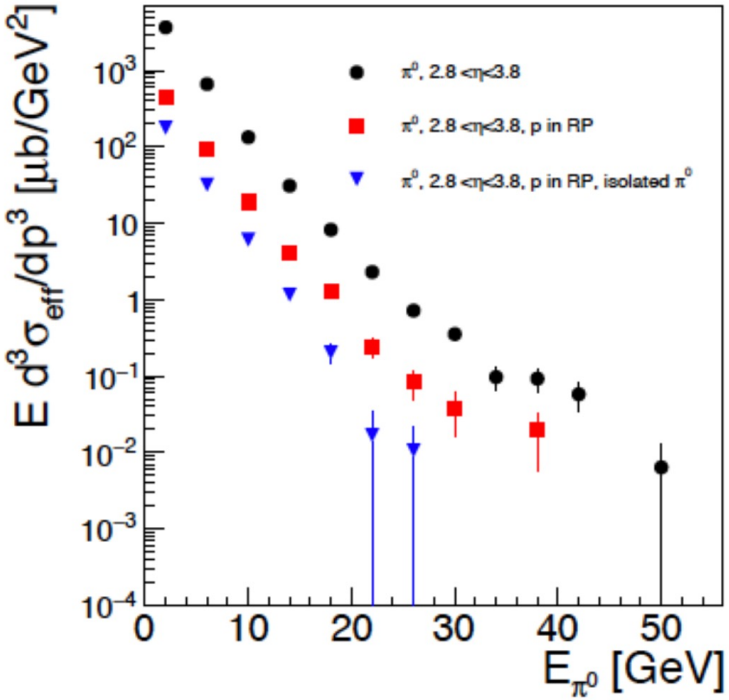
STAR, Phys. Rev. D 103, 092009 (2021)



Pythia: $\sqrt{s}$=200 GeV

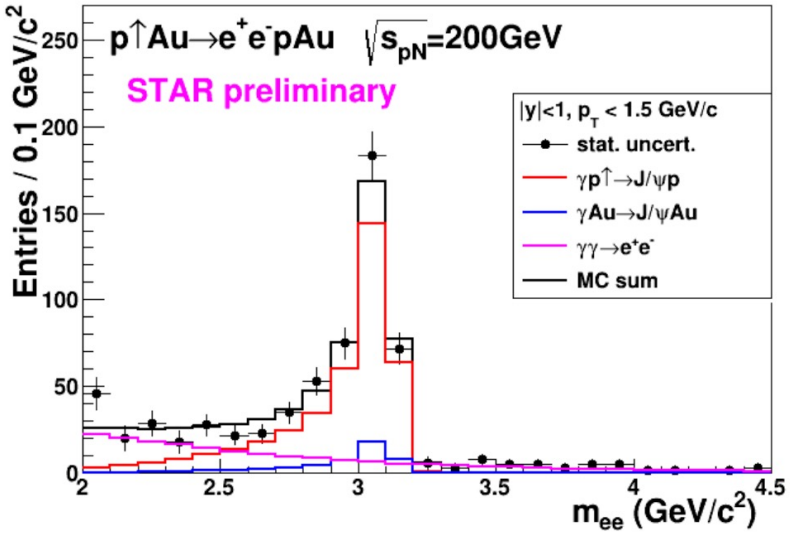


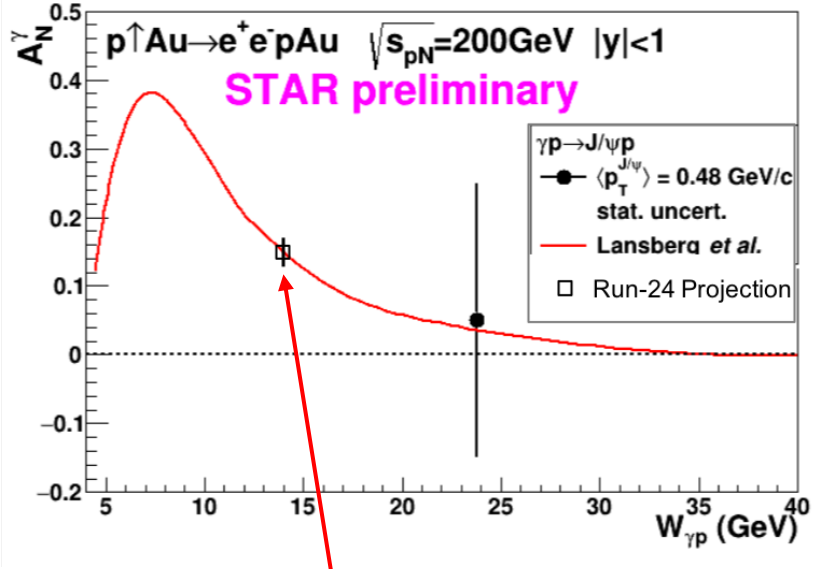
$\sqrt{s}$=500 GeV

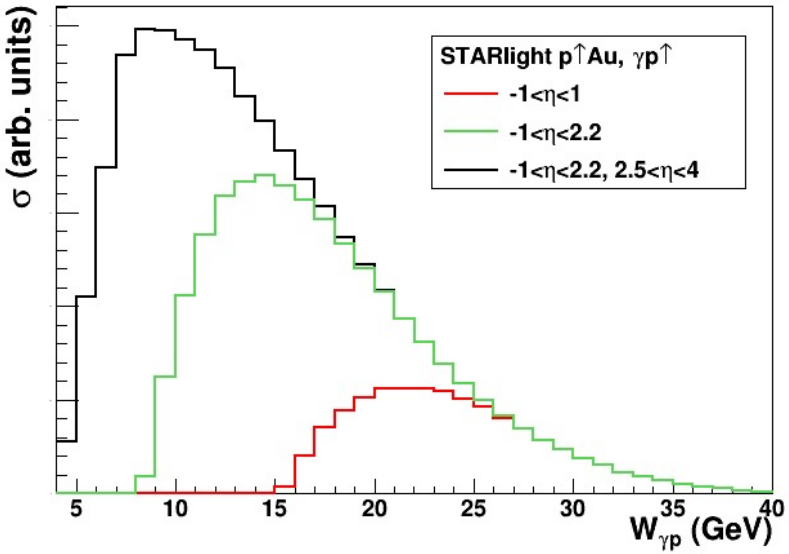


- Large transverse single spin asymmetry for "isolated" π^0 indicates its A_N may come from diffractive process;
- With Forward Upgrades, full jets will be reconstructed (with rapidity gap) to study this process.

Generalized Parton Distribution Function

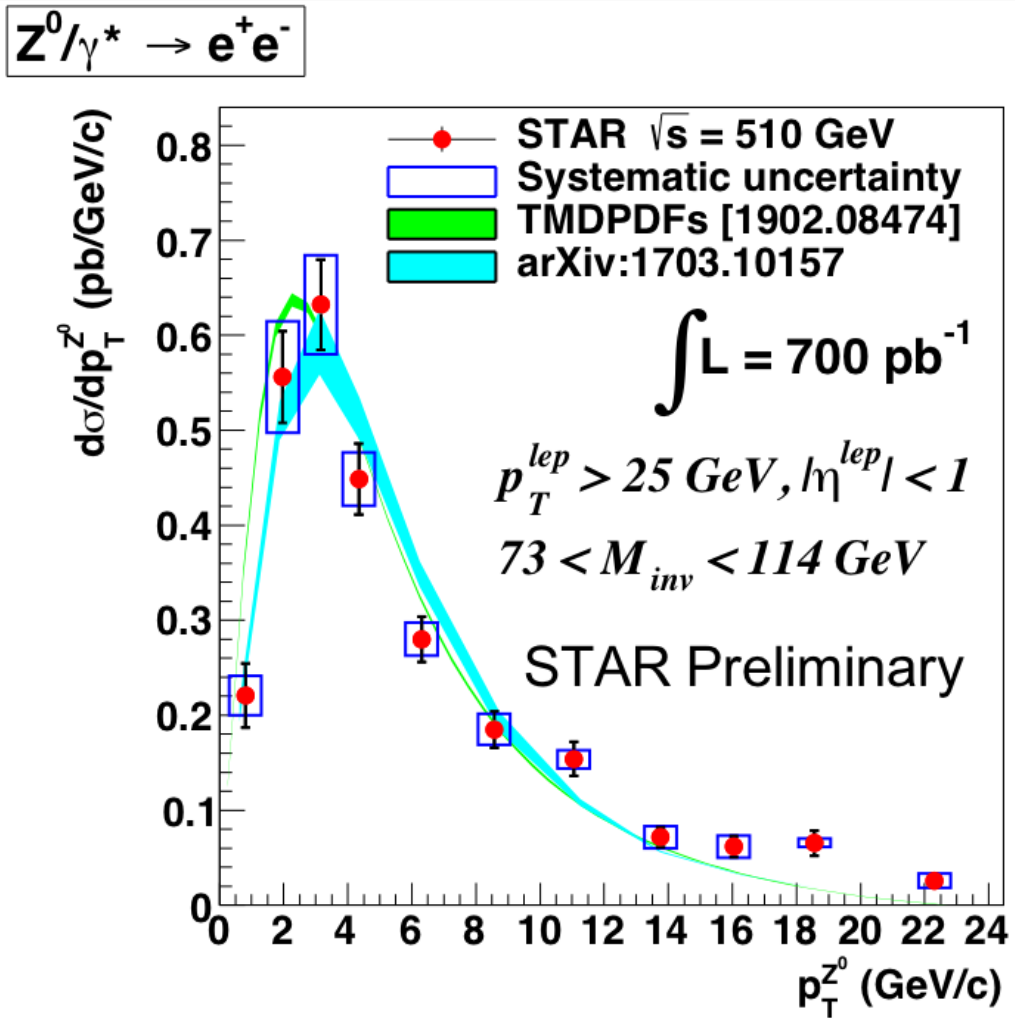


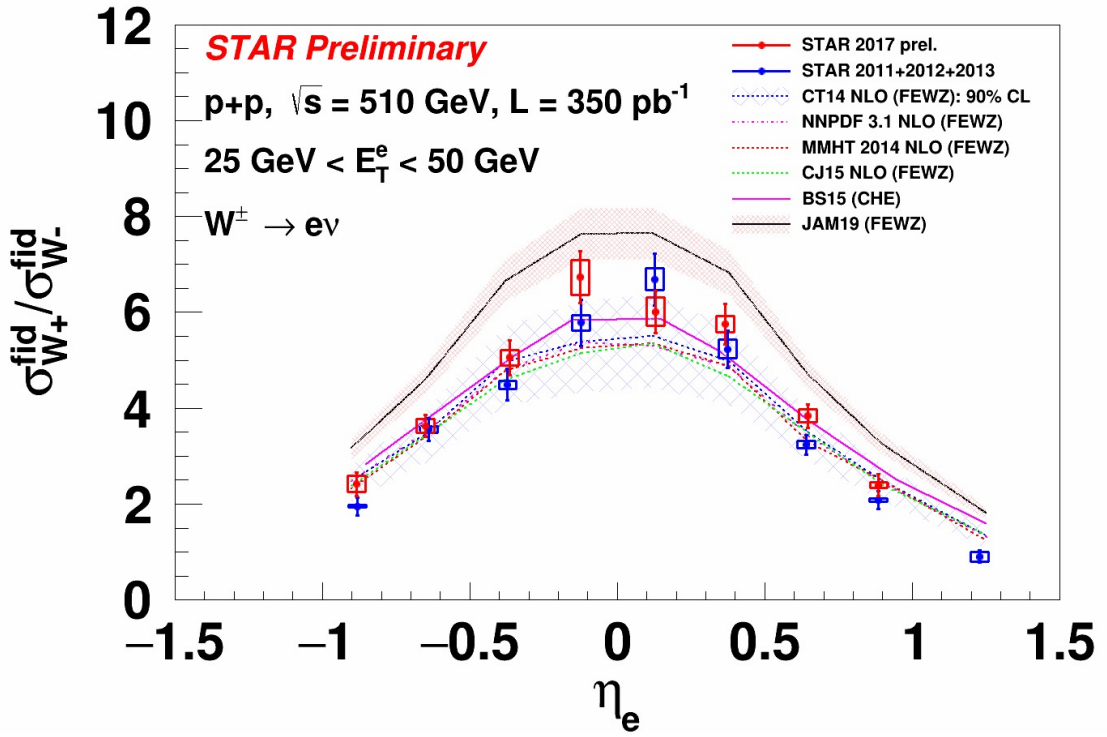




- Exclusive J/ψ TSSA measurement in Ultra Peripheral Collision (UPC);
- Access GPD E_g for gluons, sensitive to spin-orbit correlation;
- iTPC and forward detectors will enable high-impact measurements
  - A factor of 9-10 more data combined with iTPC and forward upgrades, expected statistical error 0.02 for $\langle W_{\gamma p} \rangle$ = 14 GeV.

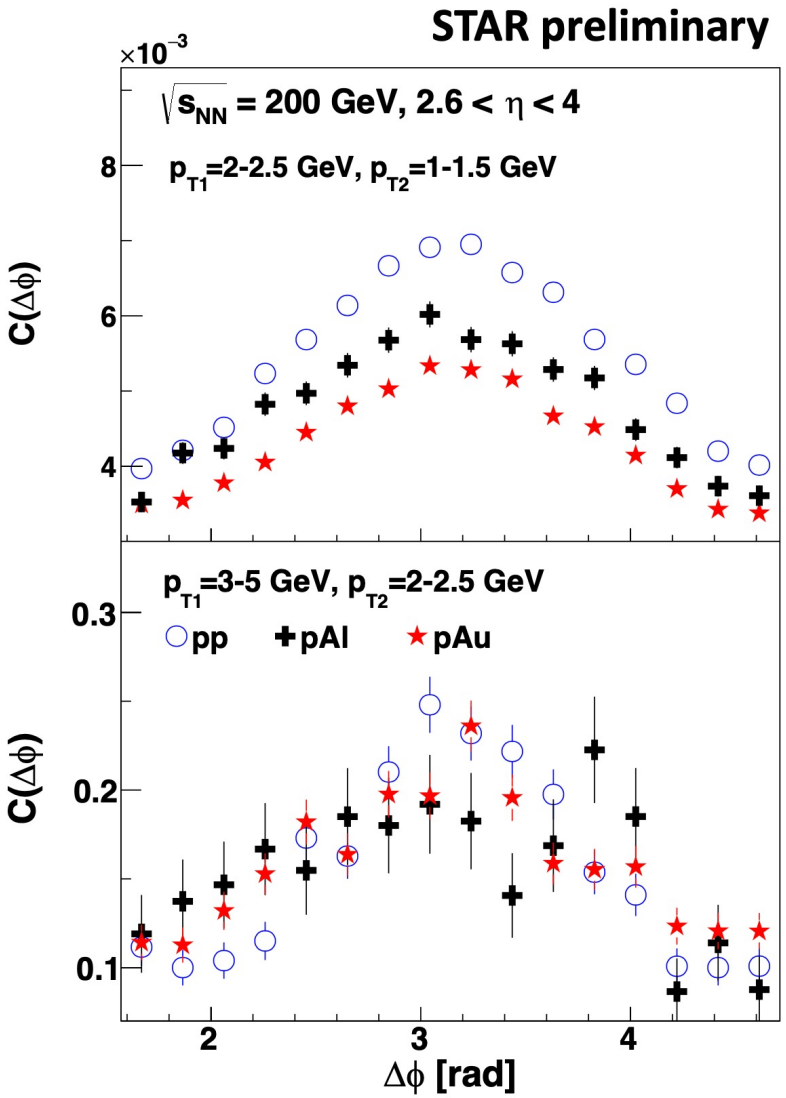
$W^{\pm}$ and Z Cross Section

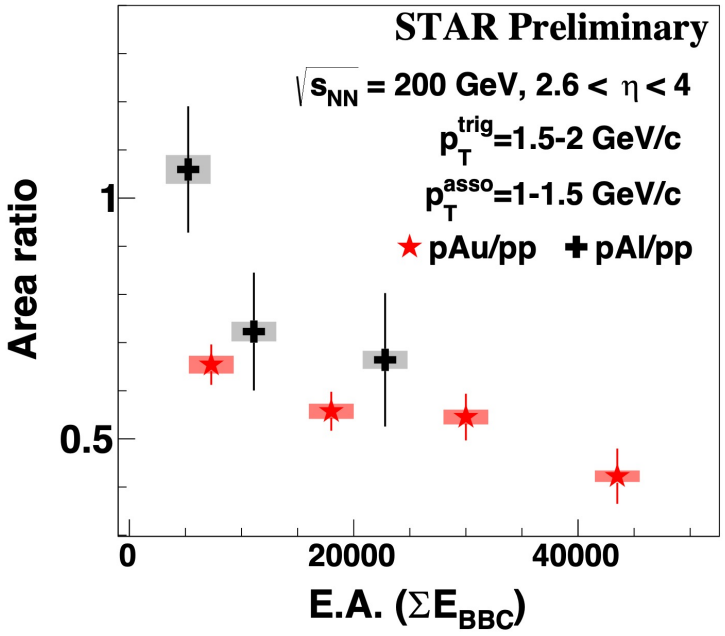


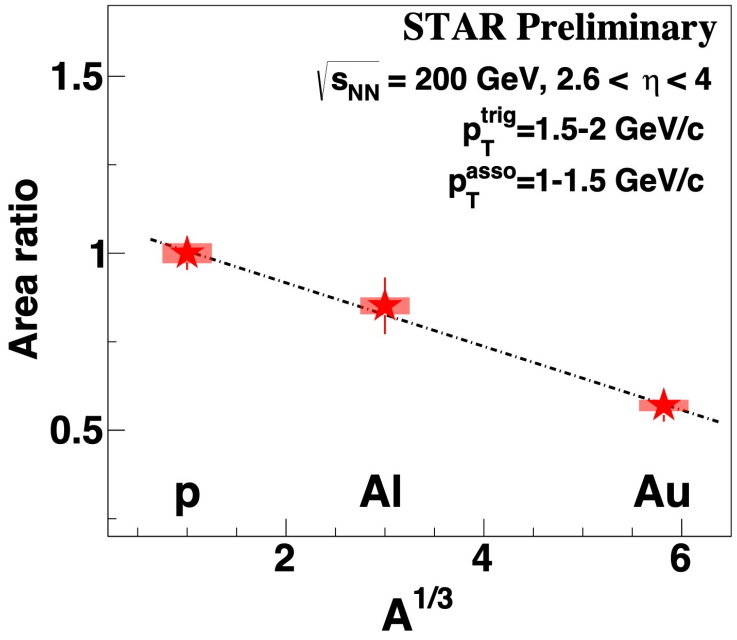


- W cross-section ratio is sensitive to $\frac{\bar{d}}{\bar{u}}$;
- Z cross section can constrain unpolarized TMD PDFs;
- Improved measurements with 2022 data.

Gluon Saturation

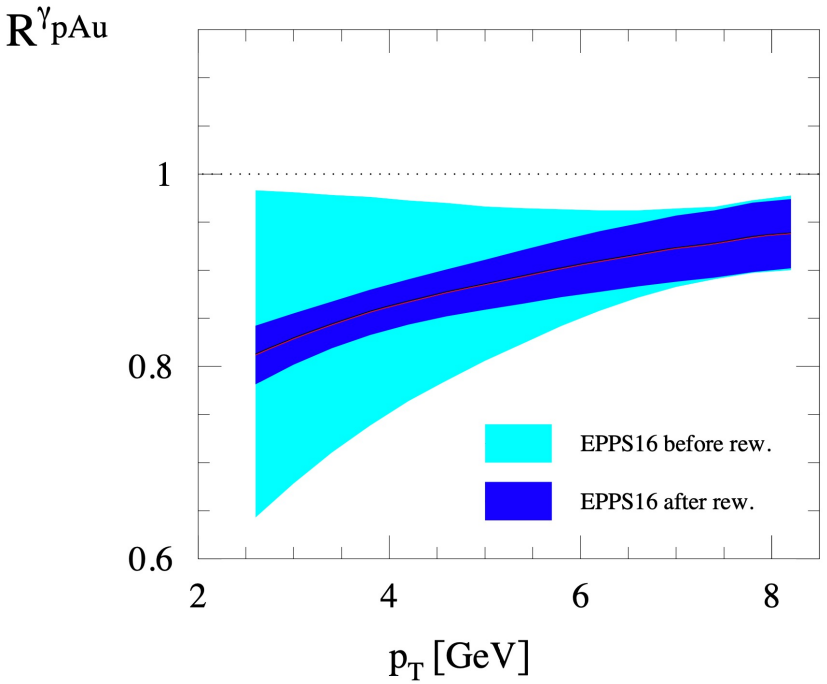


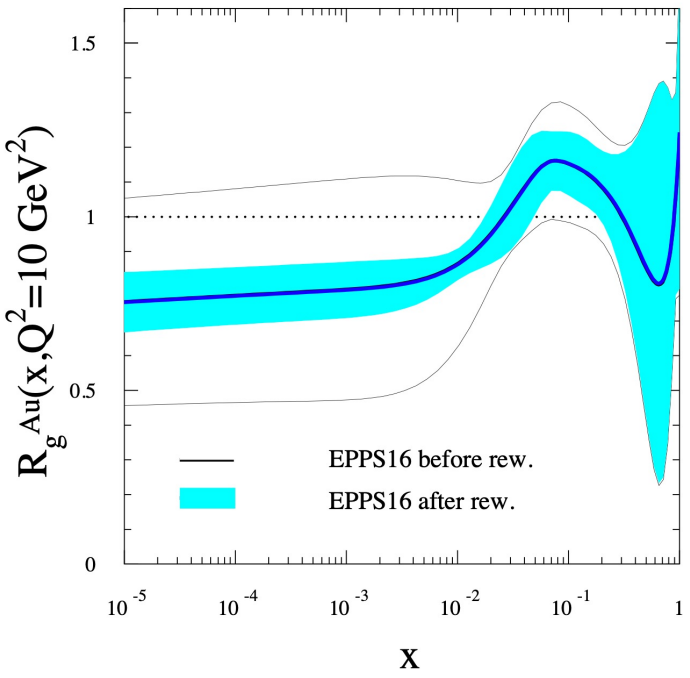


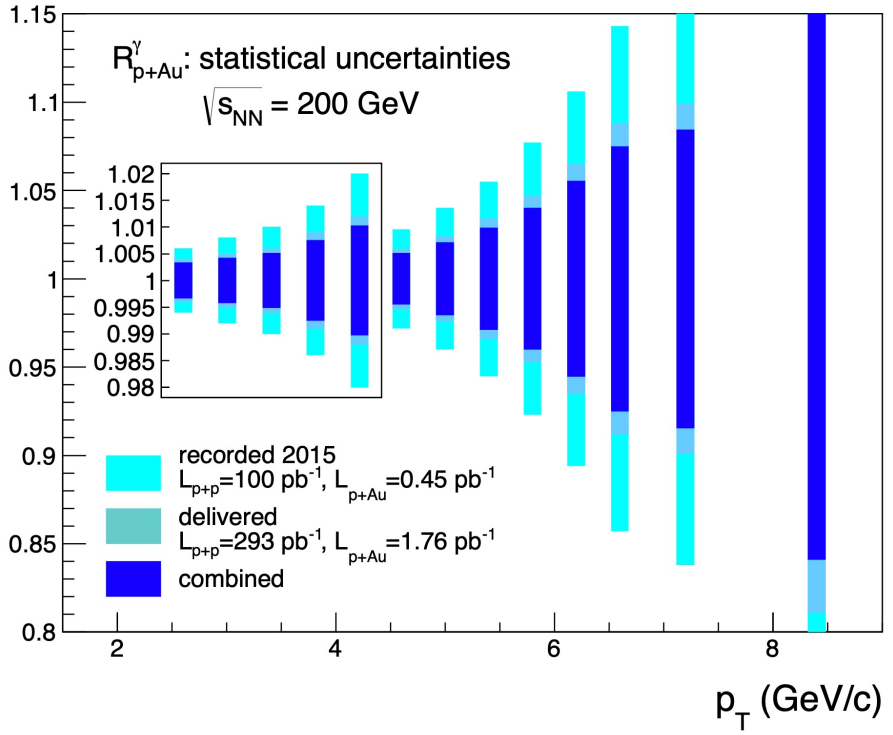


- Forward rapidity provides an unique opportunity to probe high gluon densities in p+Au collisions;
- STAR Forward Upgrades enable characterization of non-linear gluon effects through charged di-hadrons, γ-jet, di-jets.

Nuclear PDF



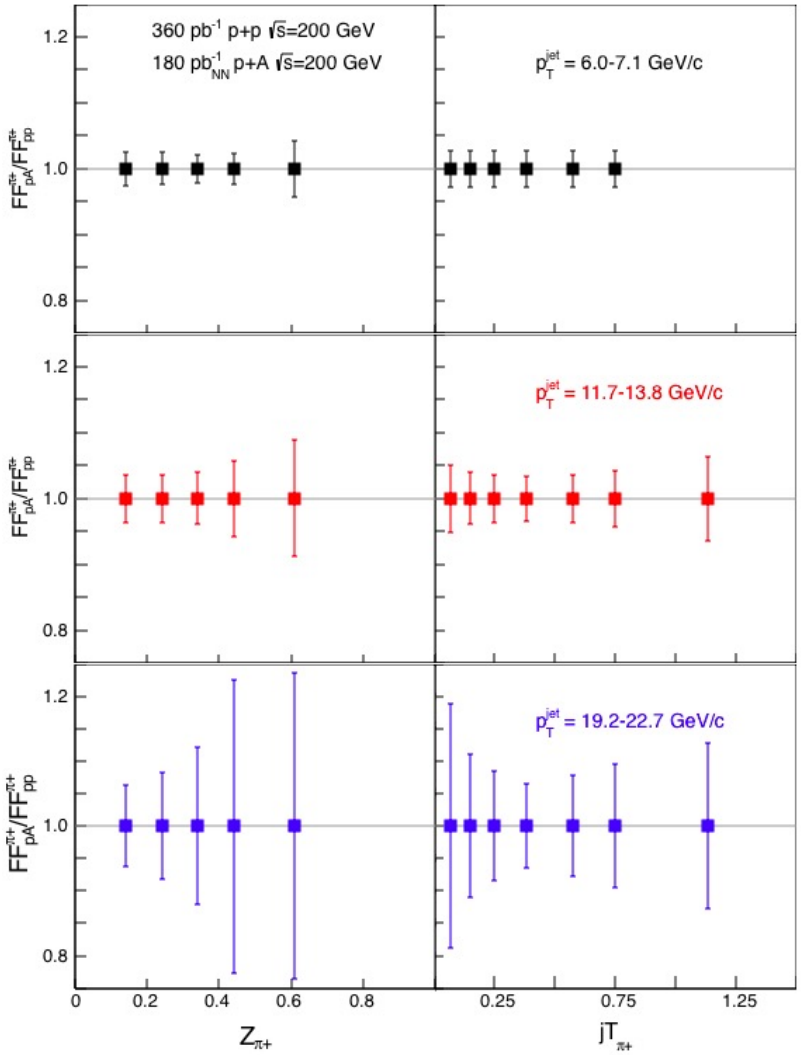


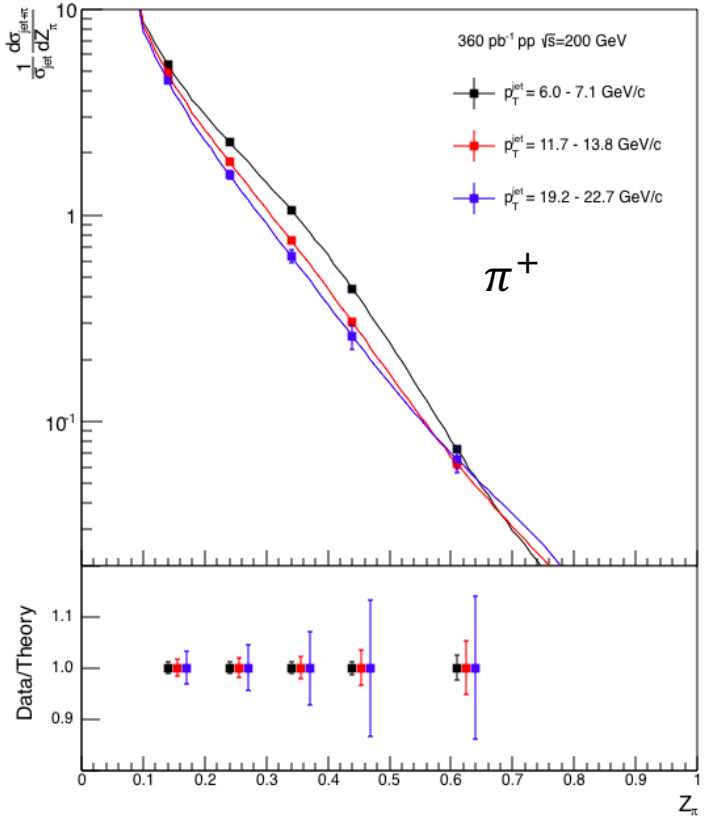


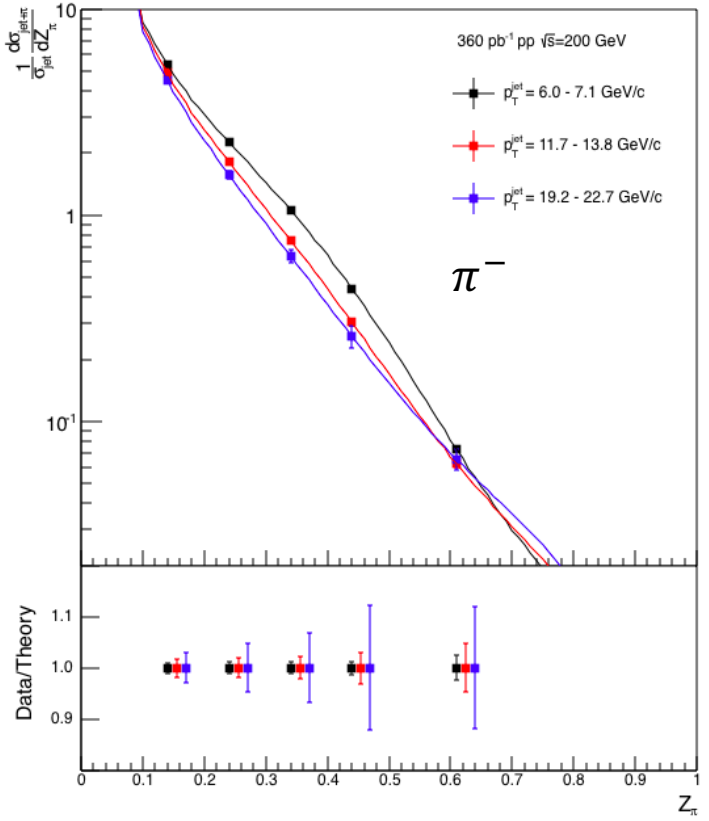
- Direct photon measurement: constrain nuclear gluon distribution in a broad x range;
- Contribute to a stringent test of the universality of nuclear PDFs when combined with data from EIC.

Hadron in Jet Fragmentation Functions

D. Florian et.al. Phys. Rev. D 91,014035 (2015)
T. Kaufmann et.al. Phys. Rev. D 92,054015 (2015)







- Hadron distributions within jets are closely related to the gluon fragmentation functions;
- Precise measurements can be carried out for charged pion, kaon and proton at STAR.

Summary

- The Forward Upgrades are progressing very well, will be fully installed in 2022;
  - FCS is taking data and under commissioning at the moment;
  - Silicon and sTGC full system installation on schedule;
- Unique forward and midrapidity physics with the combination of the existing and ongoing detector upgrades at STAR;
  - The extended acceptance at mid-rapidity due to the iTPC;
  - Improved triggering capabilities thanks to the EPD;
- Essential to fully realize the scientific promise of future Electron Ion Collider;
  - Overlap kinematic coverage with EIC;
  - Establish the validity and limits of factorization and universality.