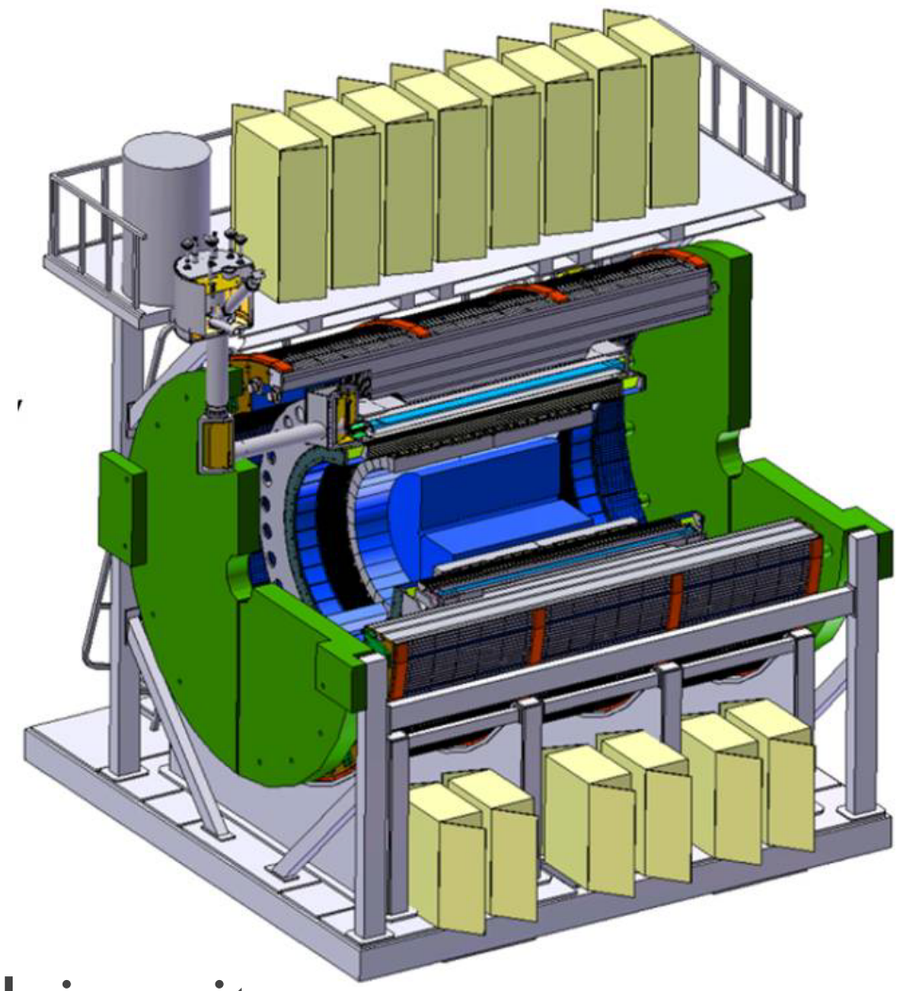
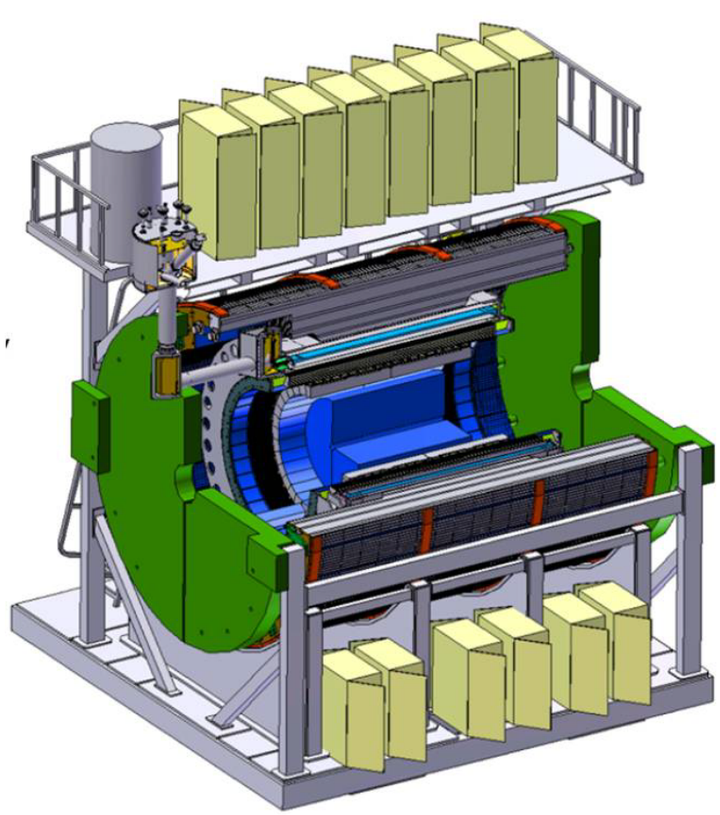
sPHENIX Physics Beyond Jet/Upsilon



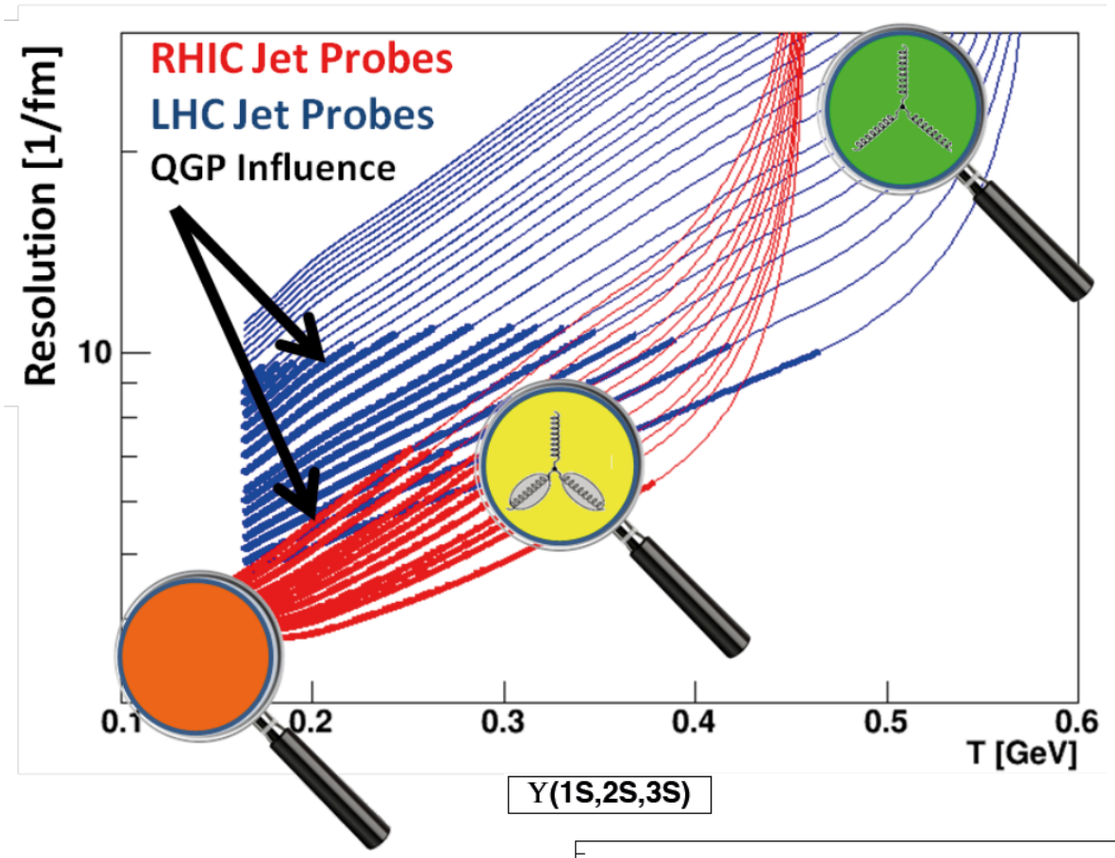
- sPHENIX detector and physics program
- Physics opportunities with forward instrumentation

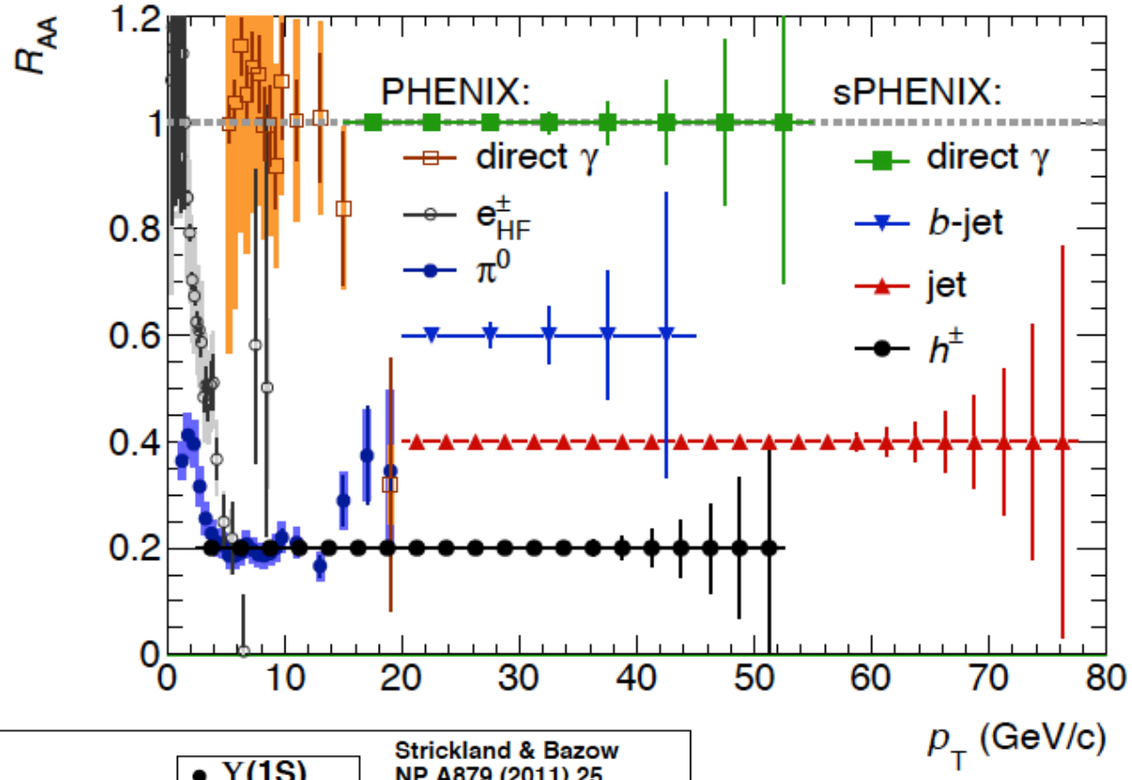
Nils Feege
Stony Brook University
RHIC and AGS Open Forum Meeting at the 2015 APS-DNP
Santa Fe, NM, October 29 2015

The new eight o'clock experiment

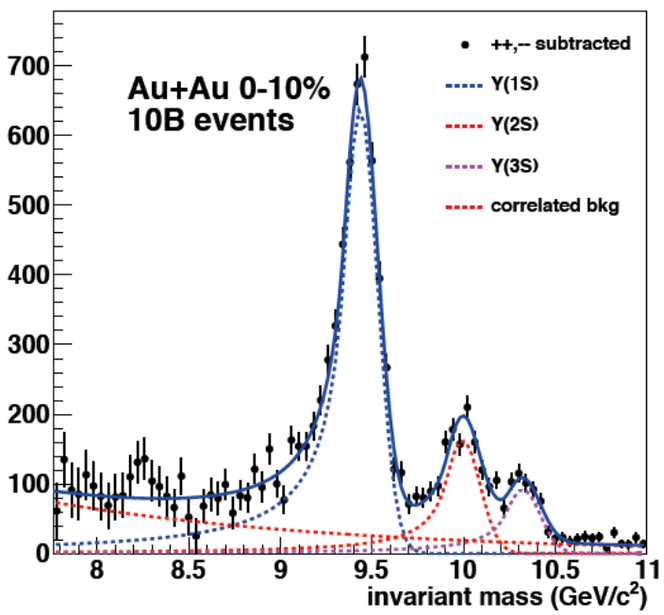


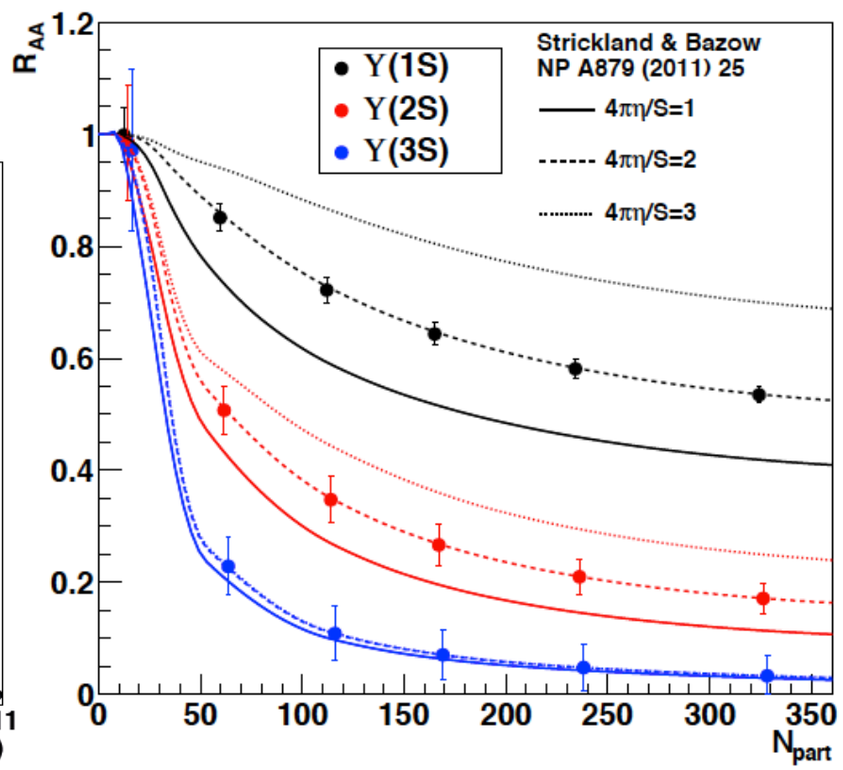
Core physics program in 2020 / 2021





Υ(1S,2S,3S)





LRP: Reaching for the Horizon

"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

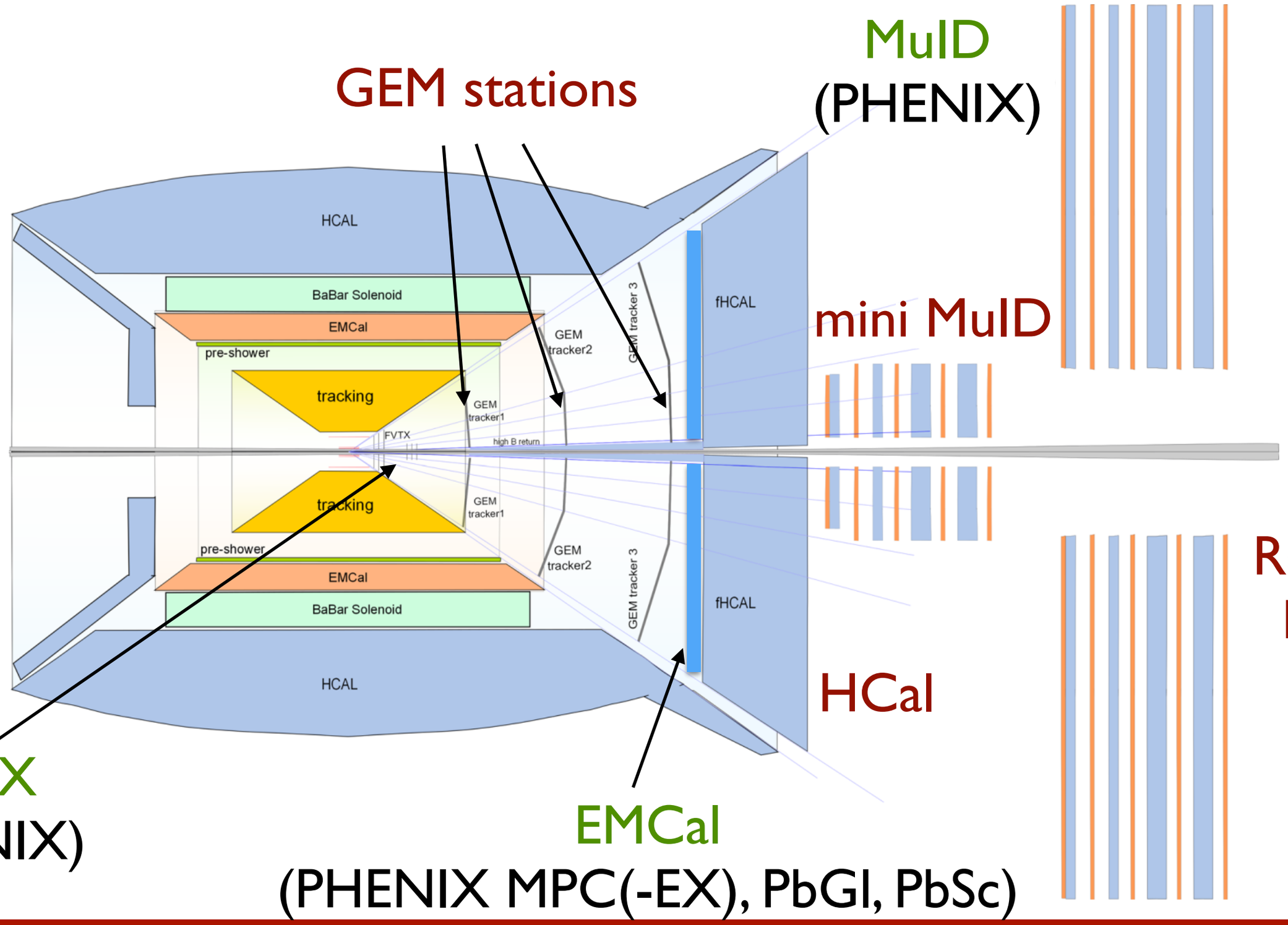
"The upgraded RHIC facility provides unique capabilities that must be utilized to explore the **properties and phases of quark and gluon matter** in the highest temperatures of the early universe and to explore the **spin structure of the proton**."

What additional physics can we do with sPHENIX in 2020 / 2021?

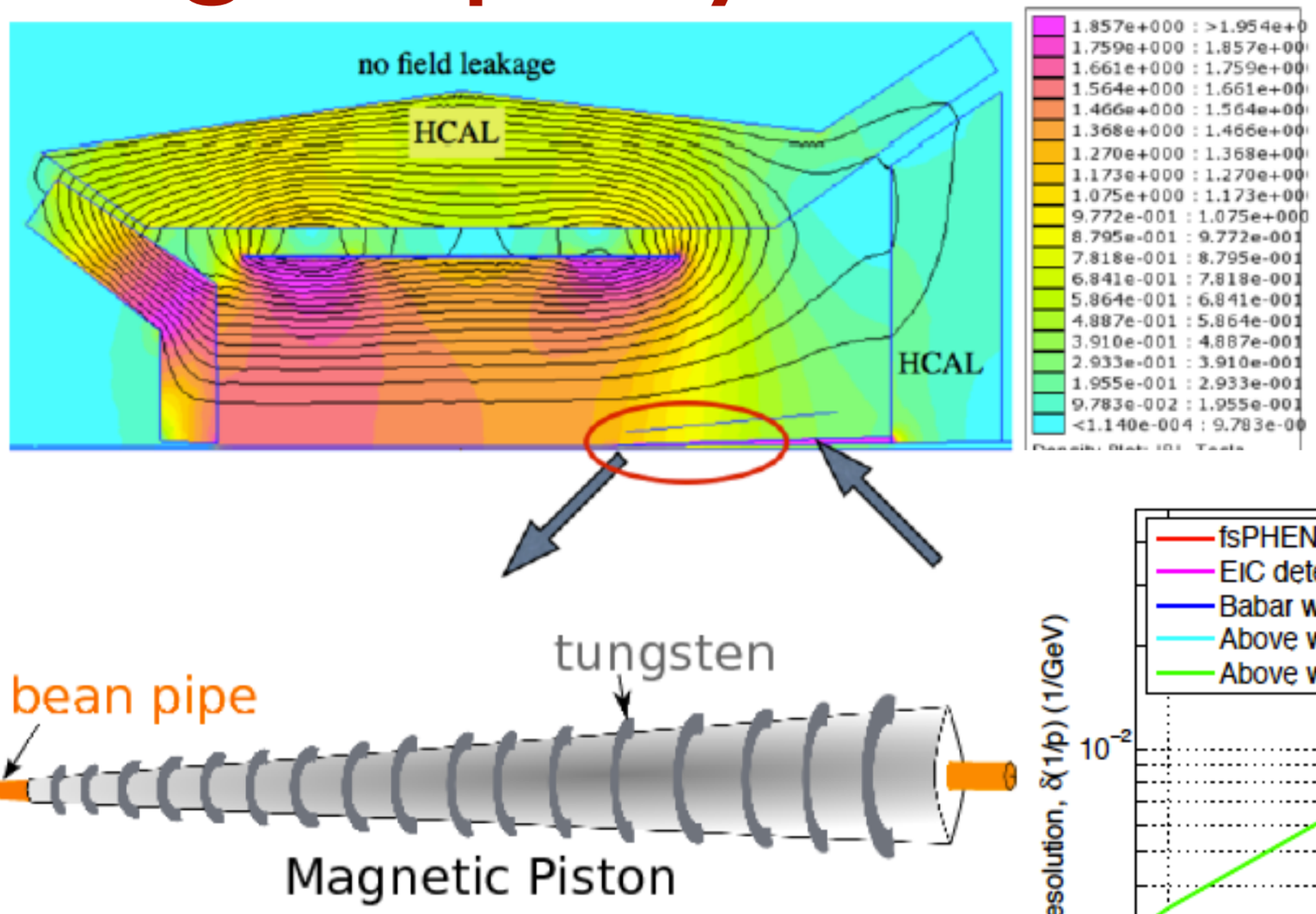
high η

- Fragmentation functions
- Jet single-spin asymmetries
- Drell-Yan and Modified Universality
- Probing gluon saturation via spin asymmetries
- Diffraction and accessing GPDs

A forward detector option at 1<η<4

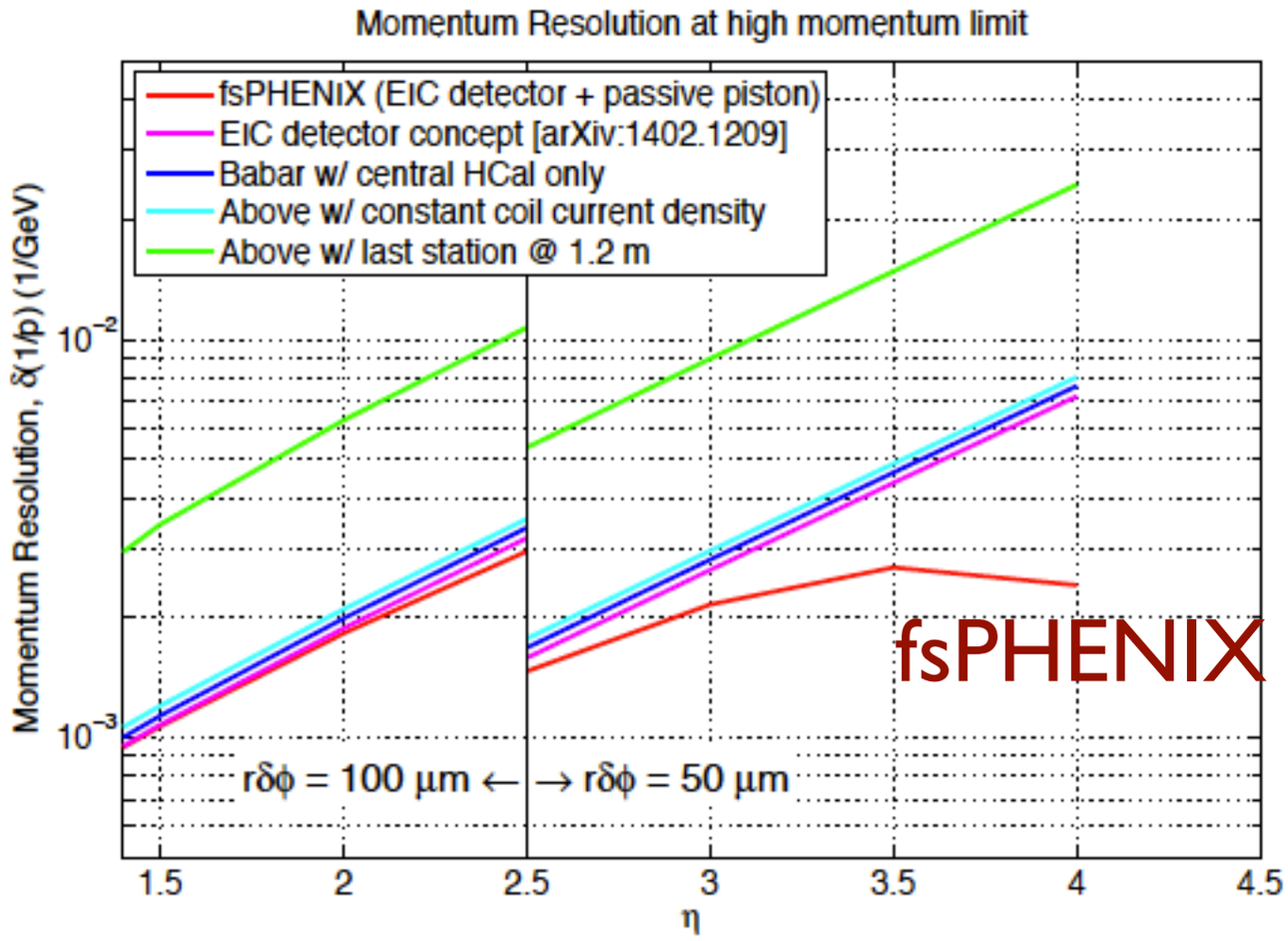


High rapidity momentum resolution

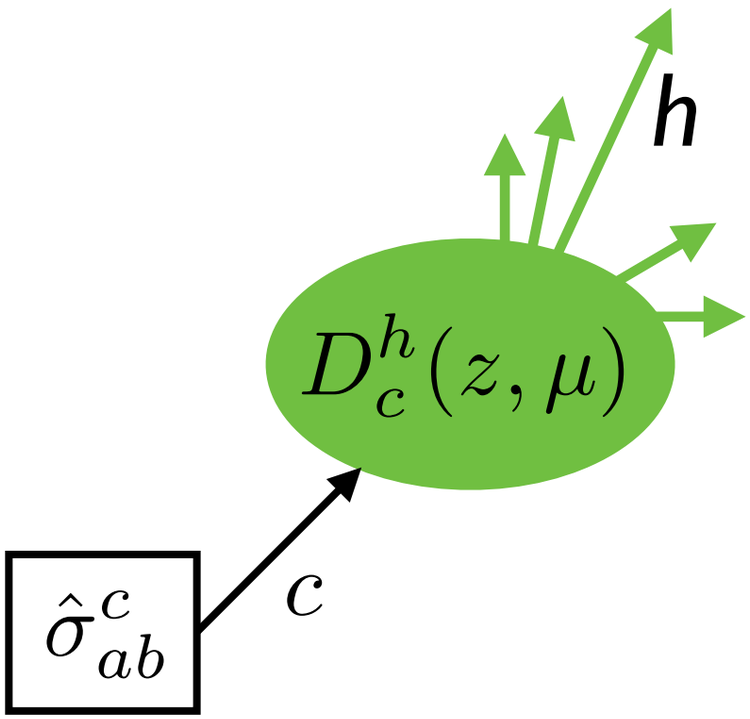


BaBar solenoid: 1.5 T

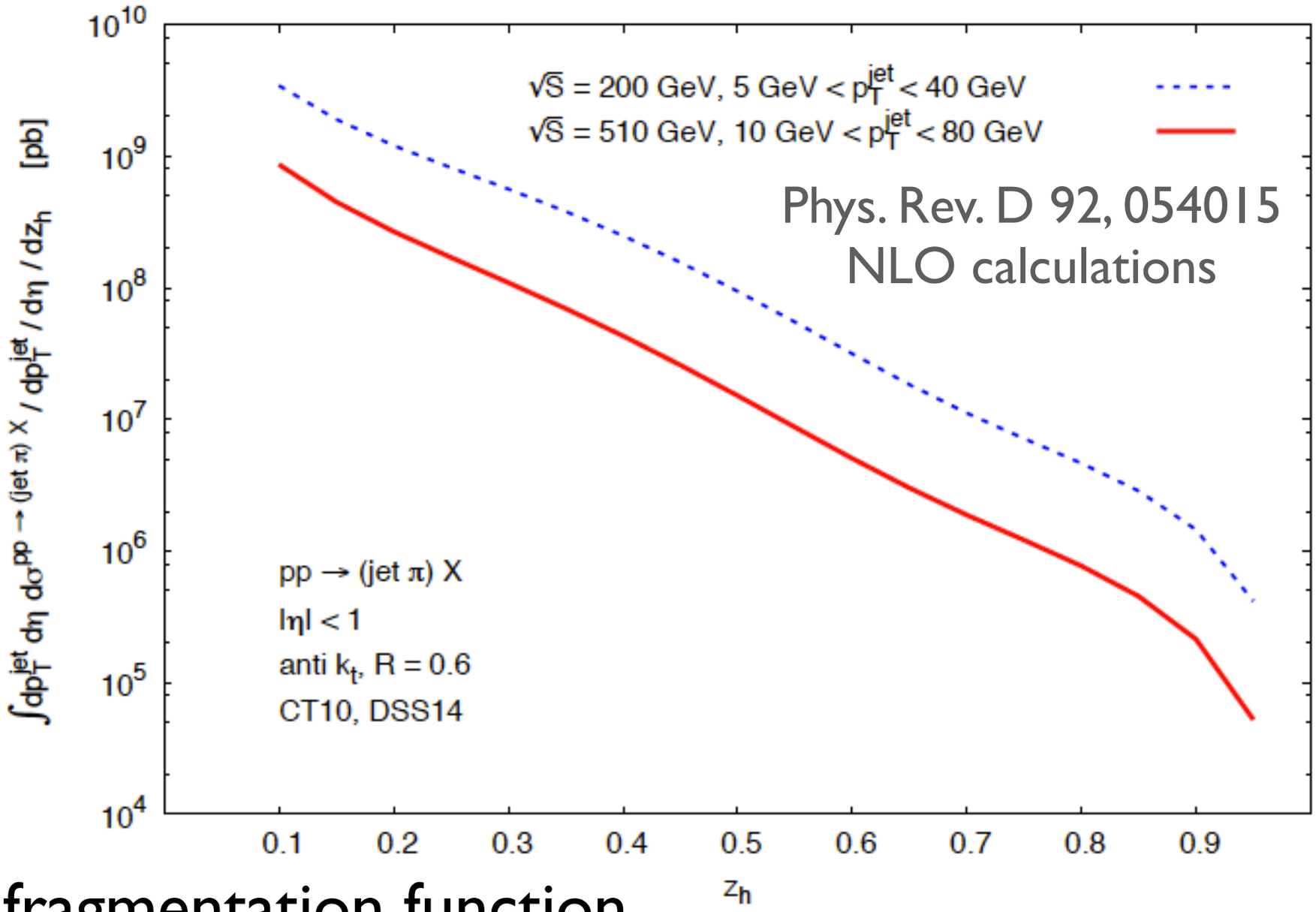
Passive field shaper
Hipperco-50



Probing hadron fragmentation in jets

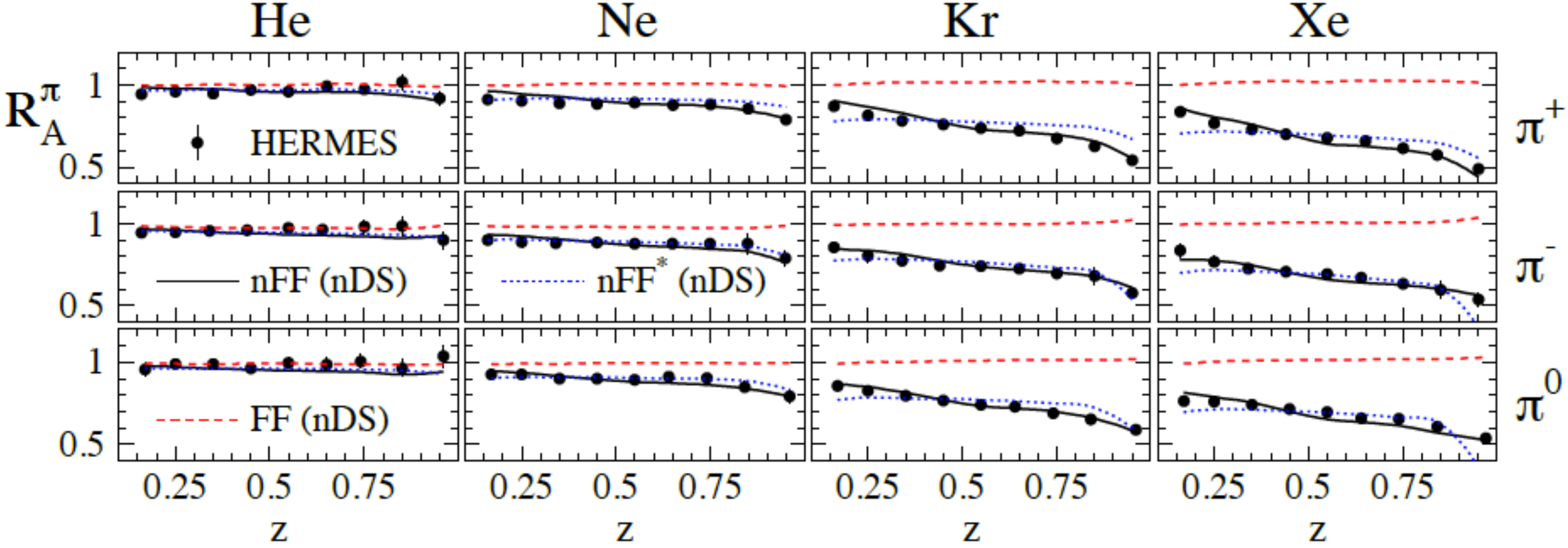


$$z_h \equiv p_T / p_T^{jet}$$



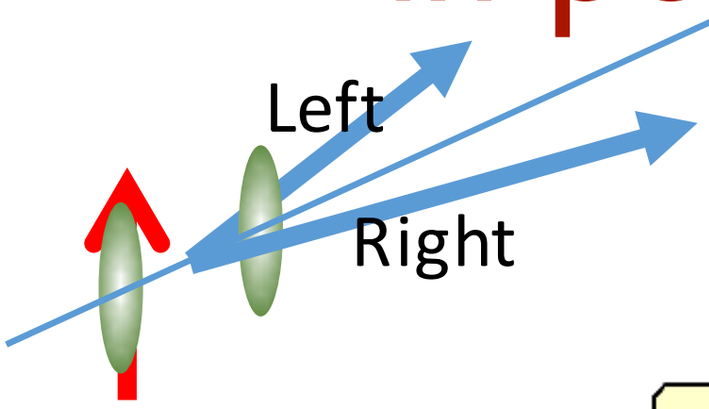
- LO: $z_h = z$ → scan fragmentation function
- pp: probe gluon fragmentation function directly
- TPC: *dE/dx* → leading hadron ID

How does the nuclear environment affect fragmentation functions?



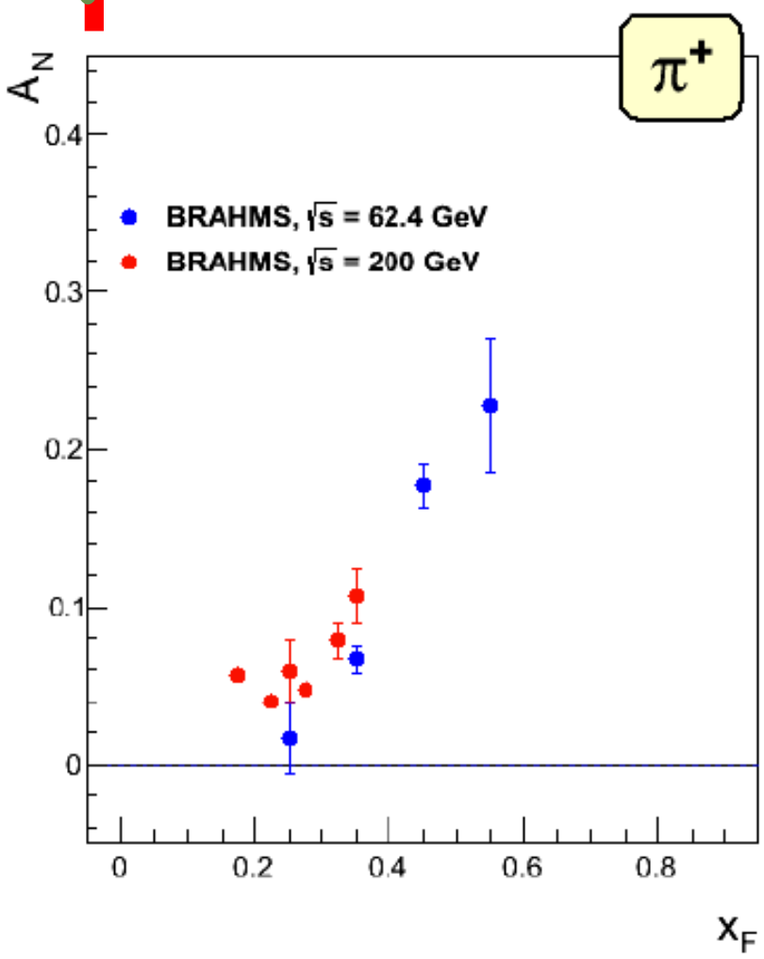
Does this behavior persist at high Q^2?

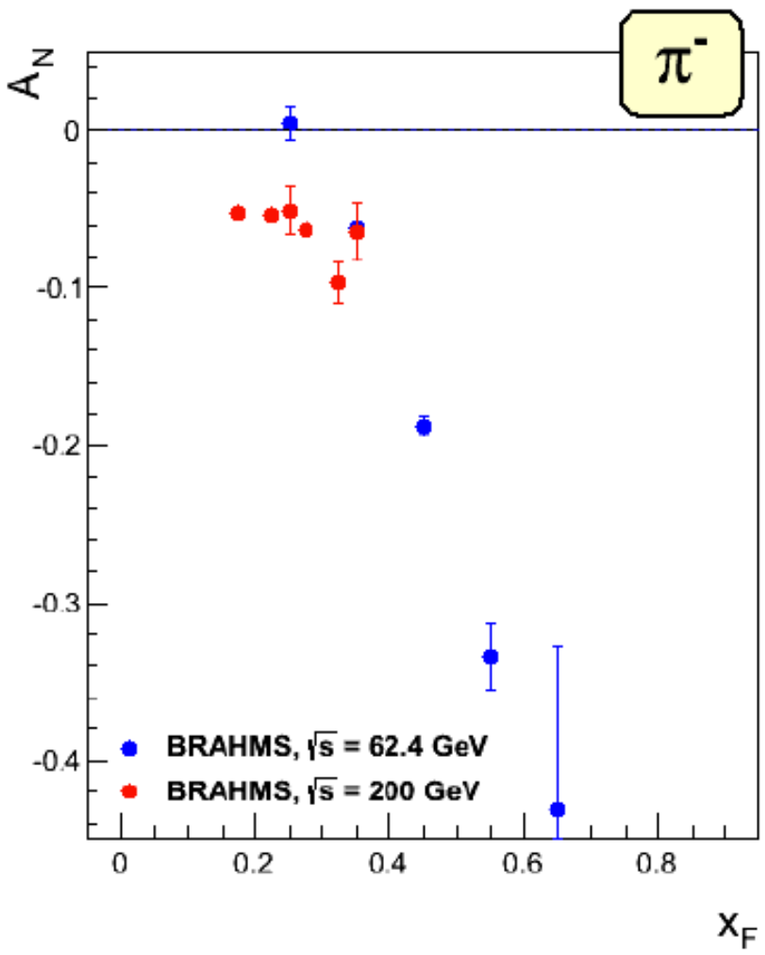
Transverse single spin asymmetries in polarized pp collisions

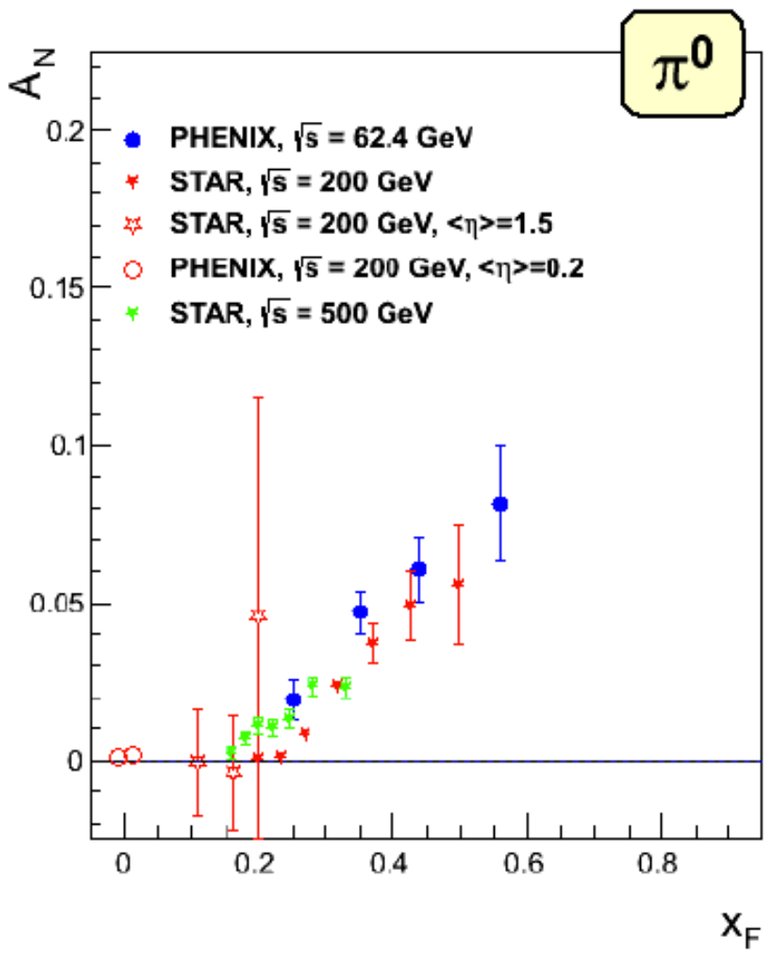


$$A_N = \frac{1}{P}\frac{\sigma_L^{\pi} - \sigma_R^{\pi}}{\sigma_L^{\pi} + \sigma_R^{\pi}}$$

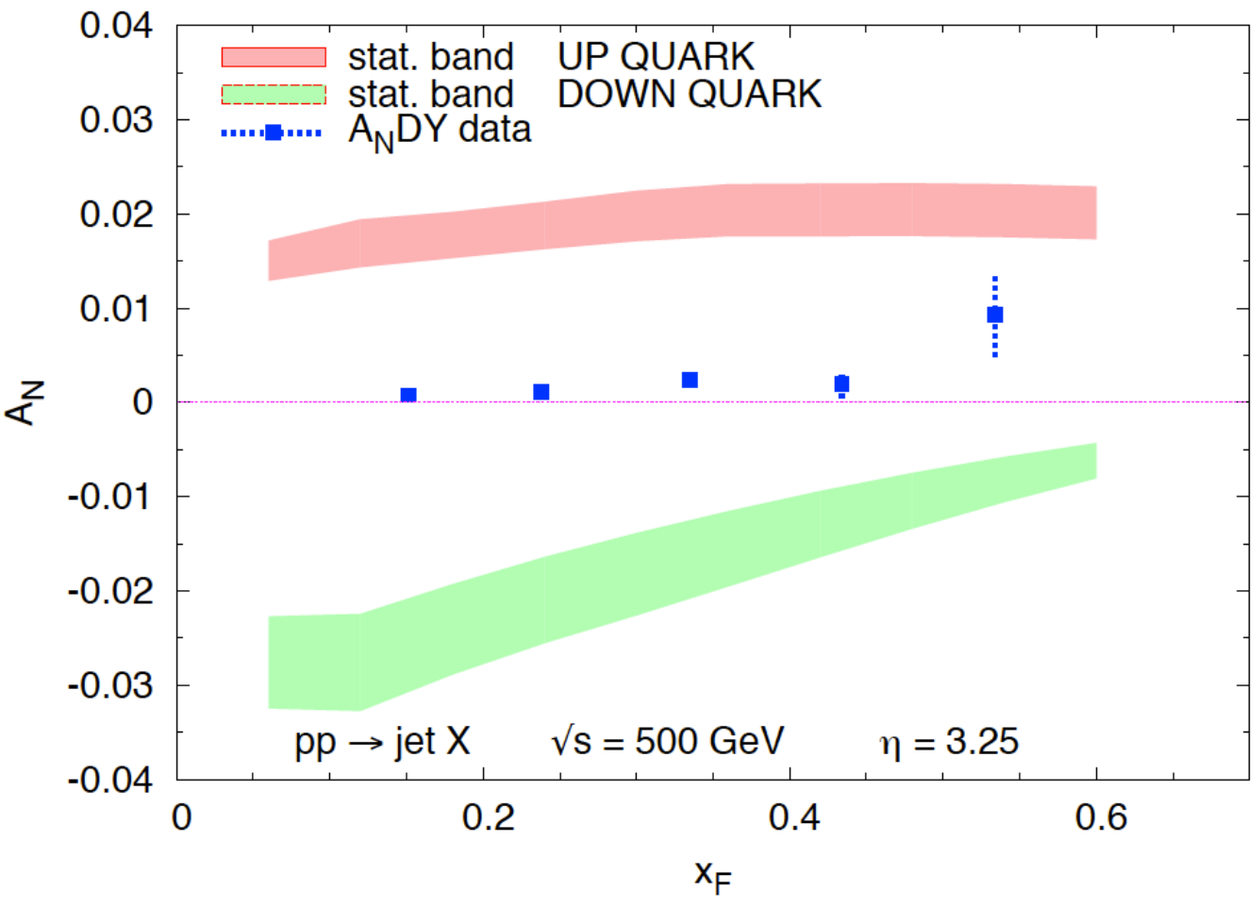
Single-pion final states

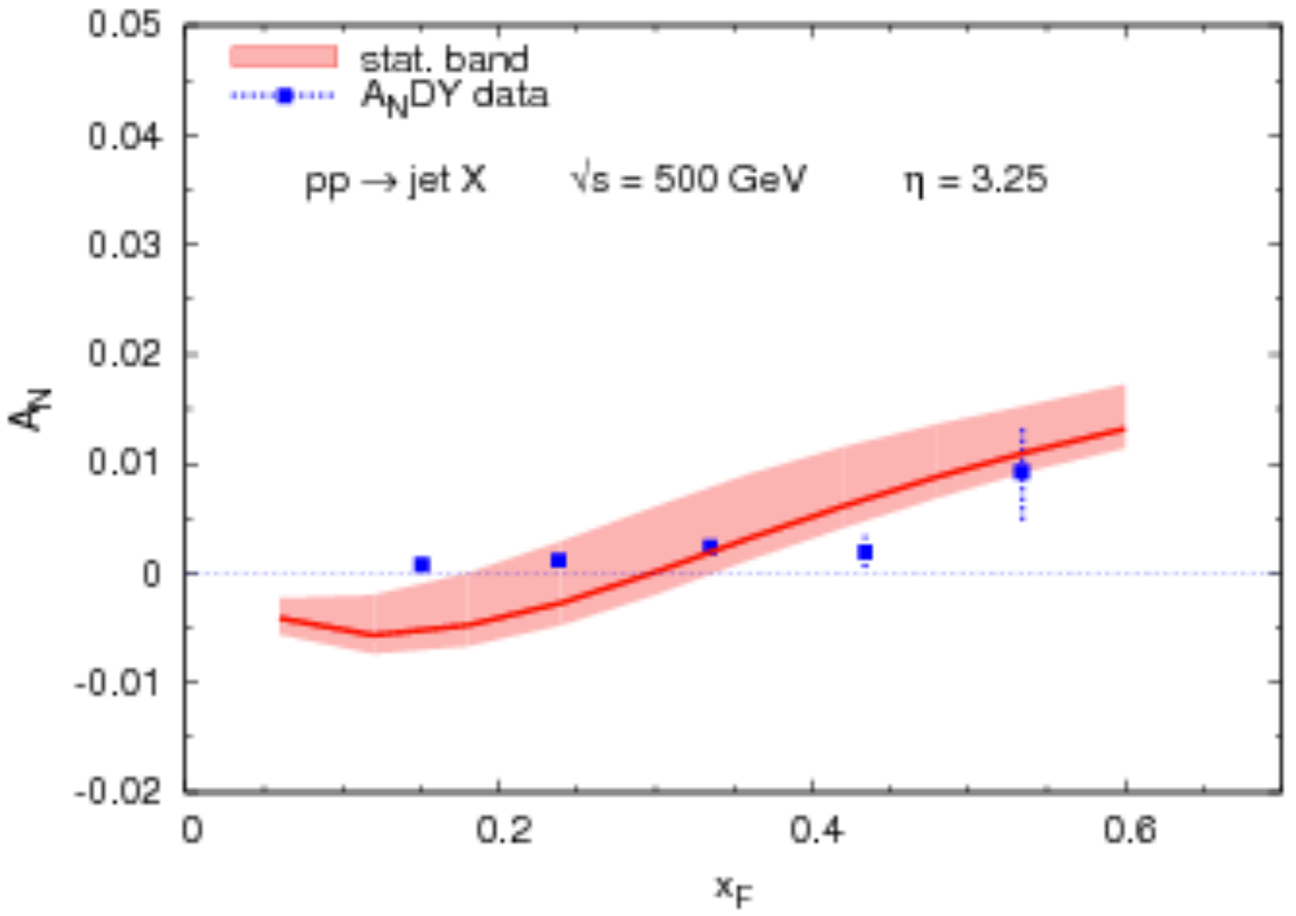






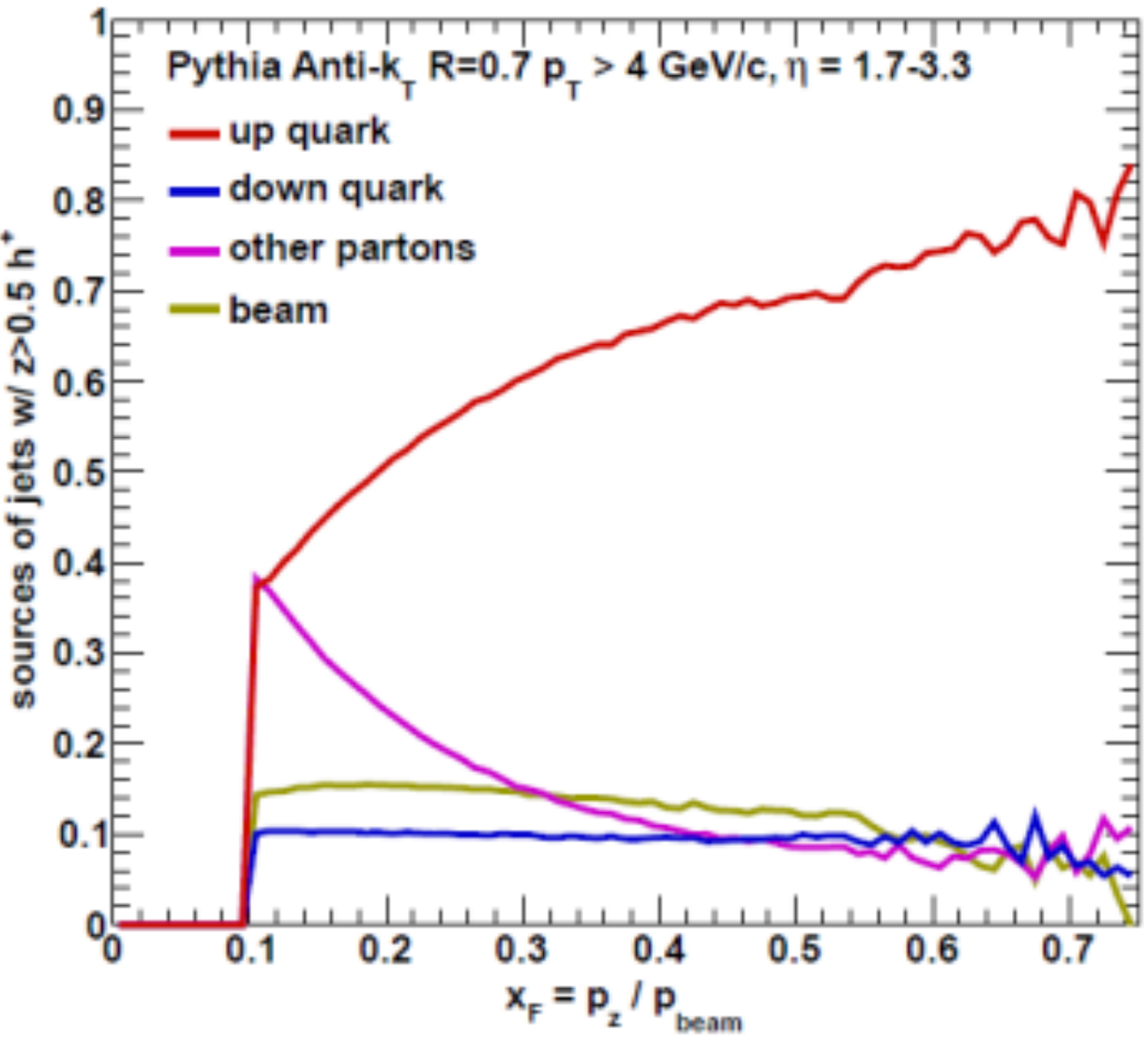
Why are inclusive jet asymmetries smaller than those for single hadrons?



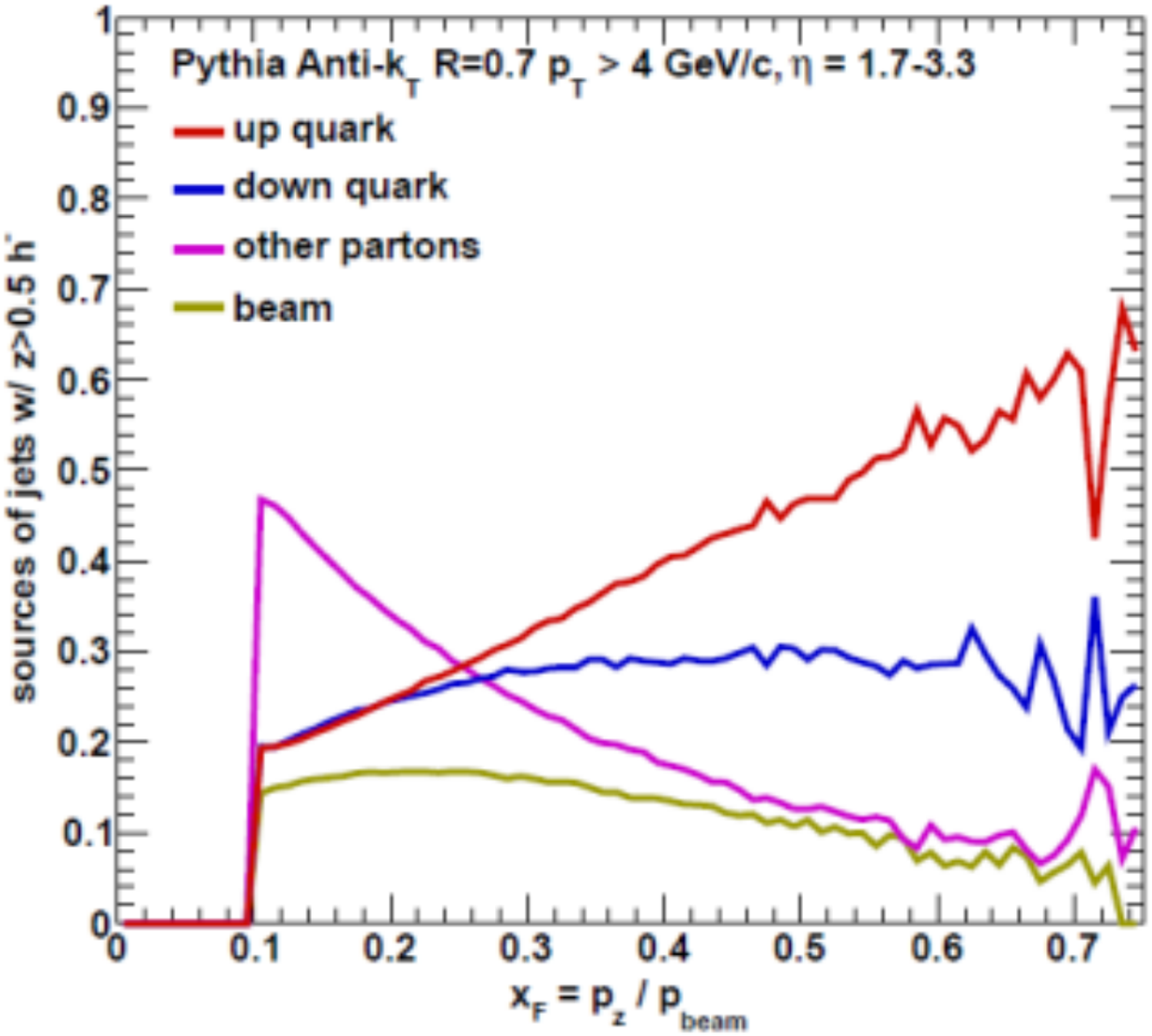


How to distinguish ‘up’ and ‘down’ quark jets in an experiment

Jets with **positive** z>0.5 hadron

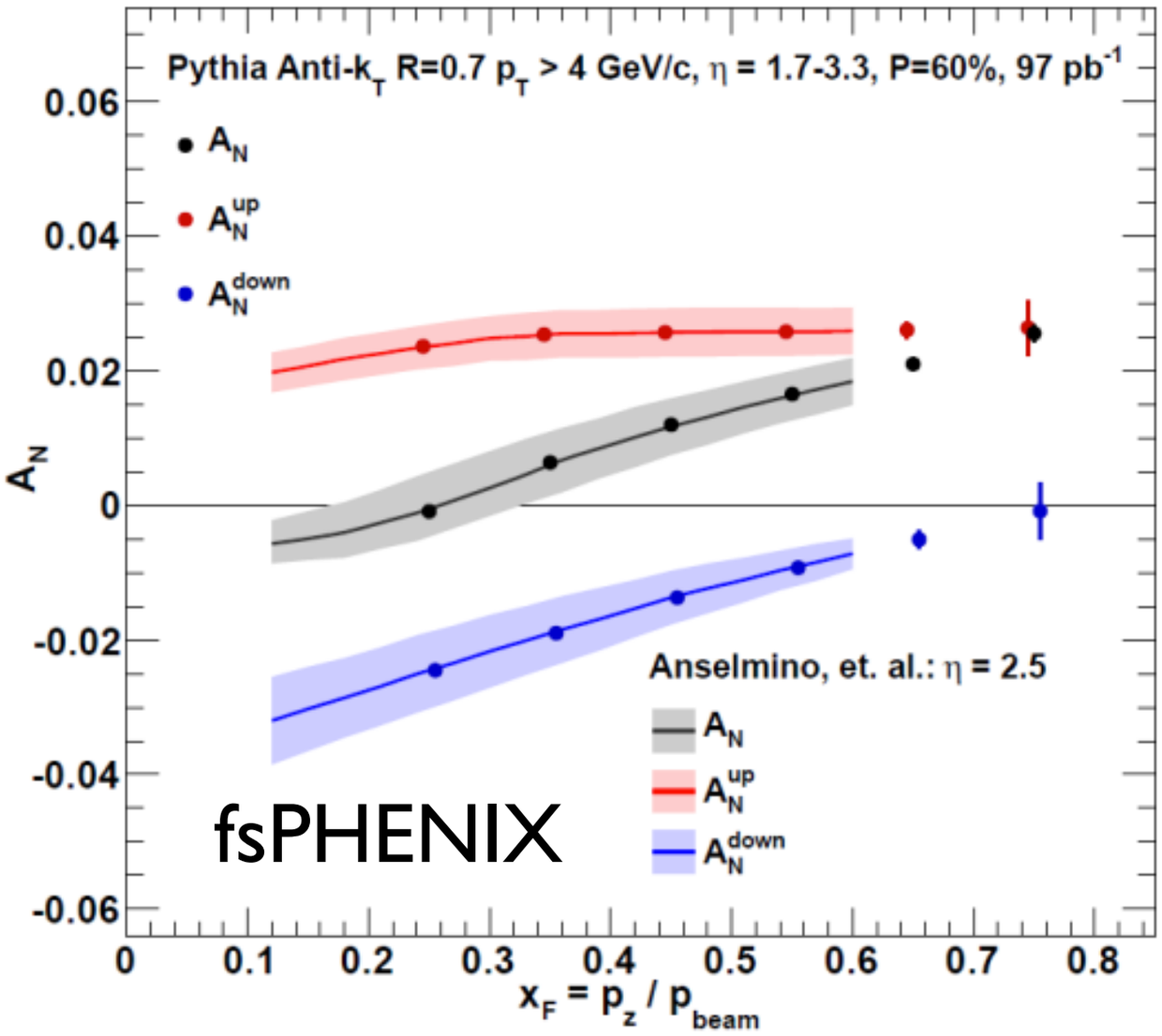


Jets with **negative** z>0.5 hadron

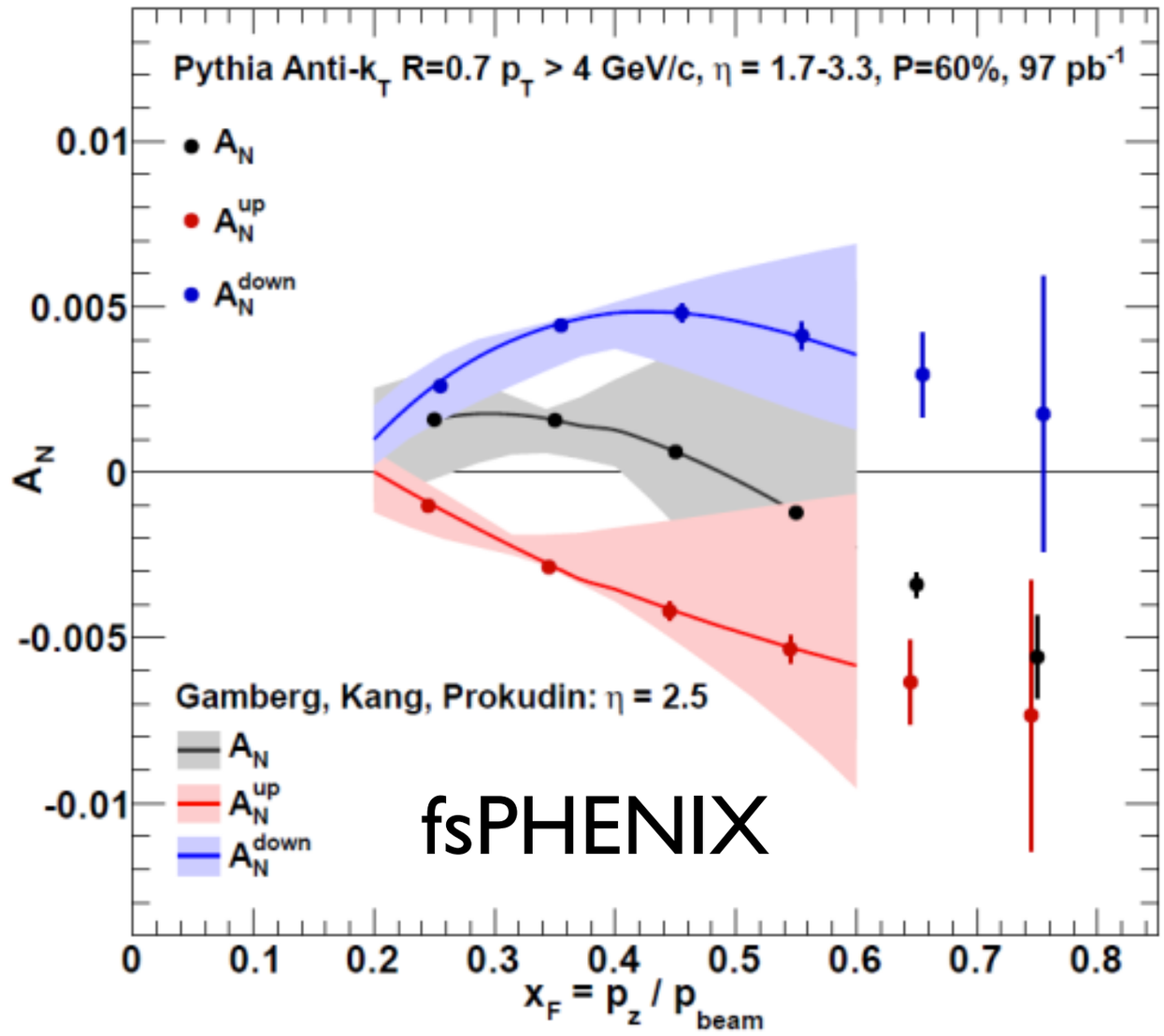


Jet and leading hadron charge measurements can test models

Anselmino et. al. : Phys Rev. D 88 054023 (2013)

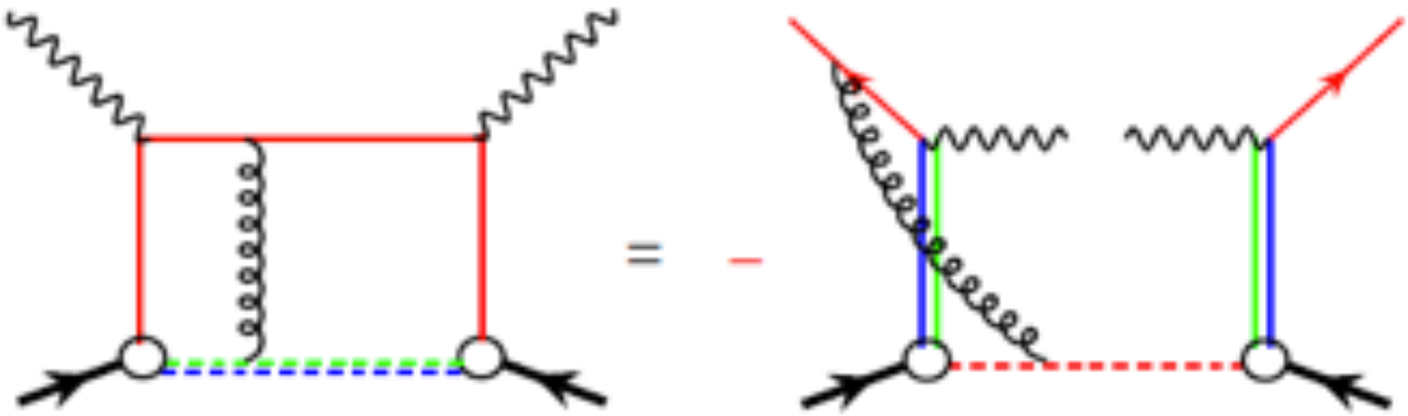


Gamberg, Kang and Prokudin: Phys Rev. Lett. 110:232301 (2013)

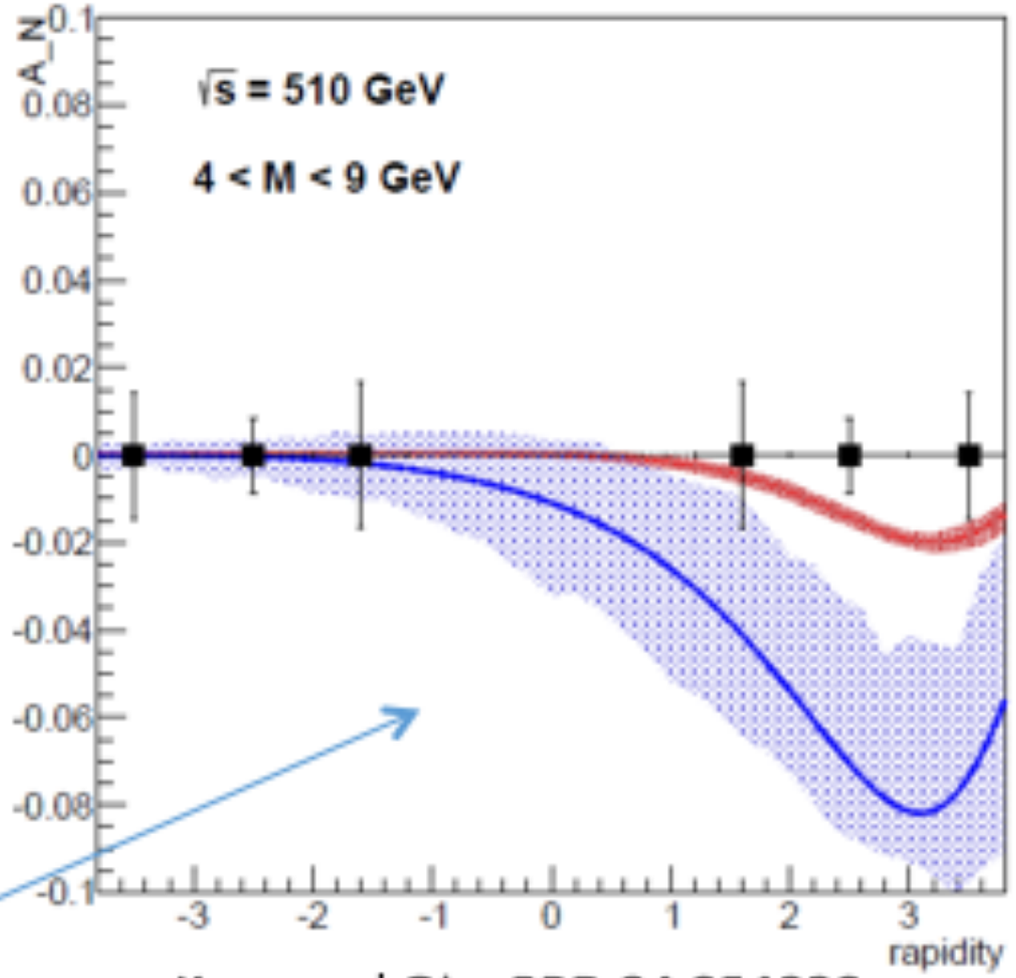


Drell-Yan and Modified Universality

$$\Delta^N f_{q/h^\uparrow}^{\mathrm{SIDIS}}(x, k_\perp) = -\Delta^N f_{q/h^\uparrow}^{\mathrm{DY}}(x, k_\perp)$$



SIDIS = – DY



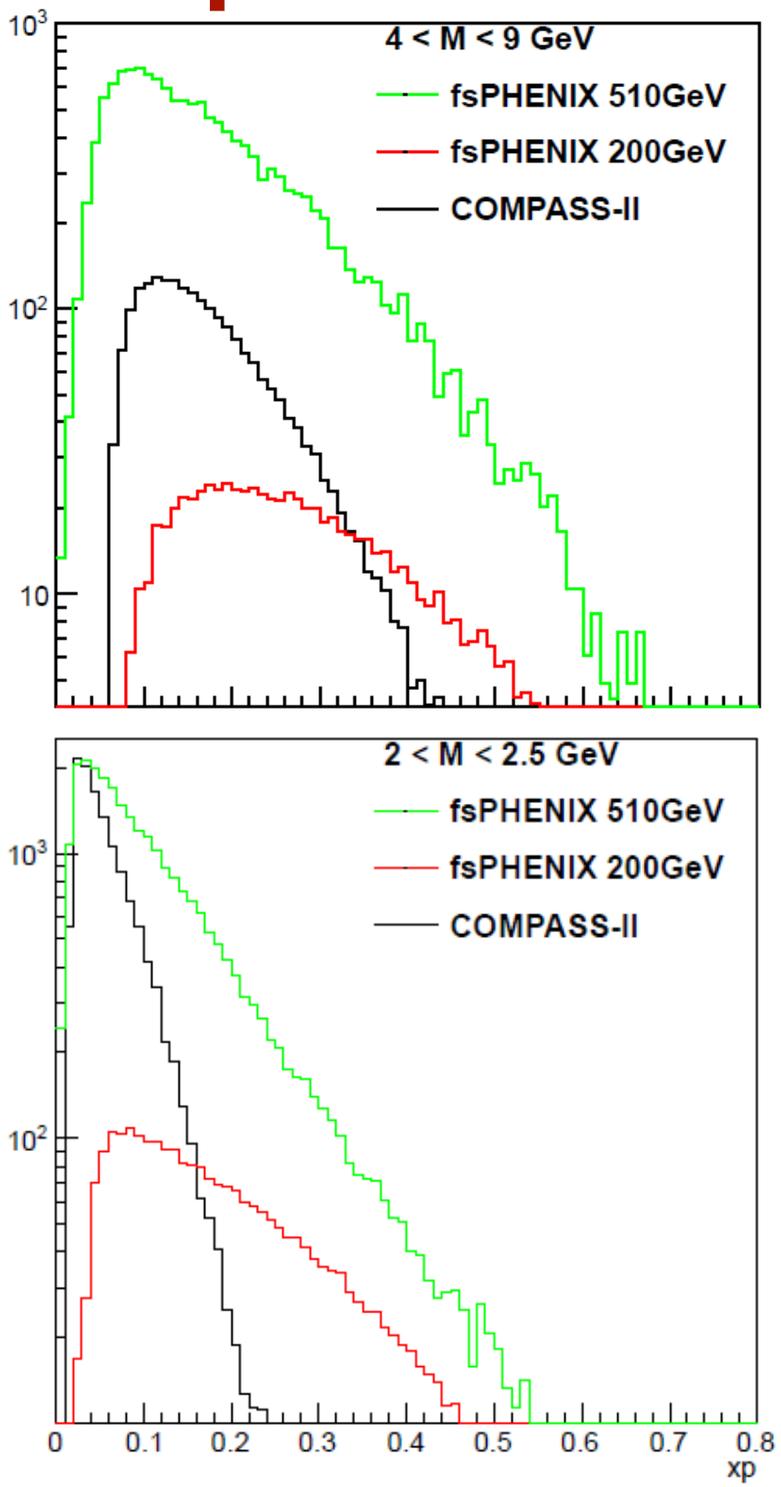
Kang and Qiu, PRD 84 054020

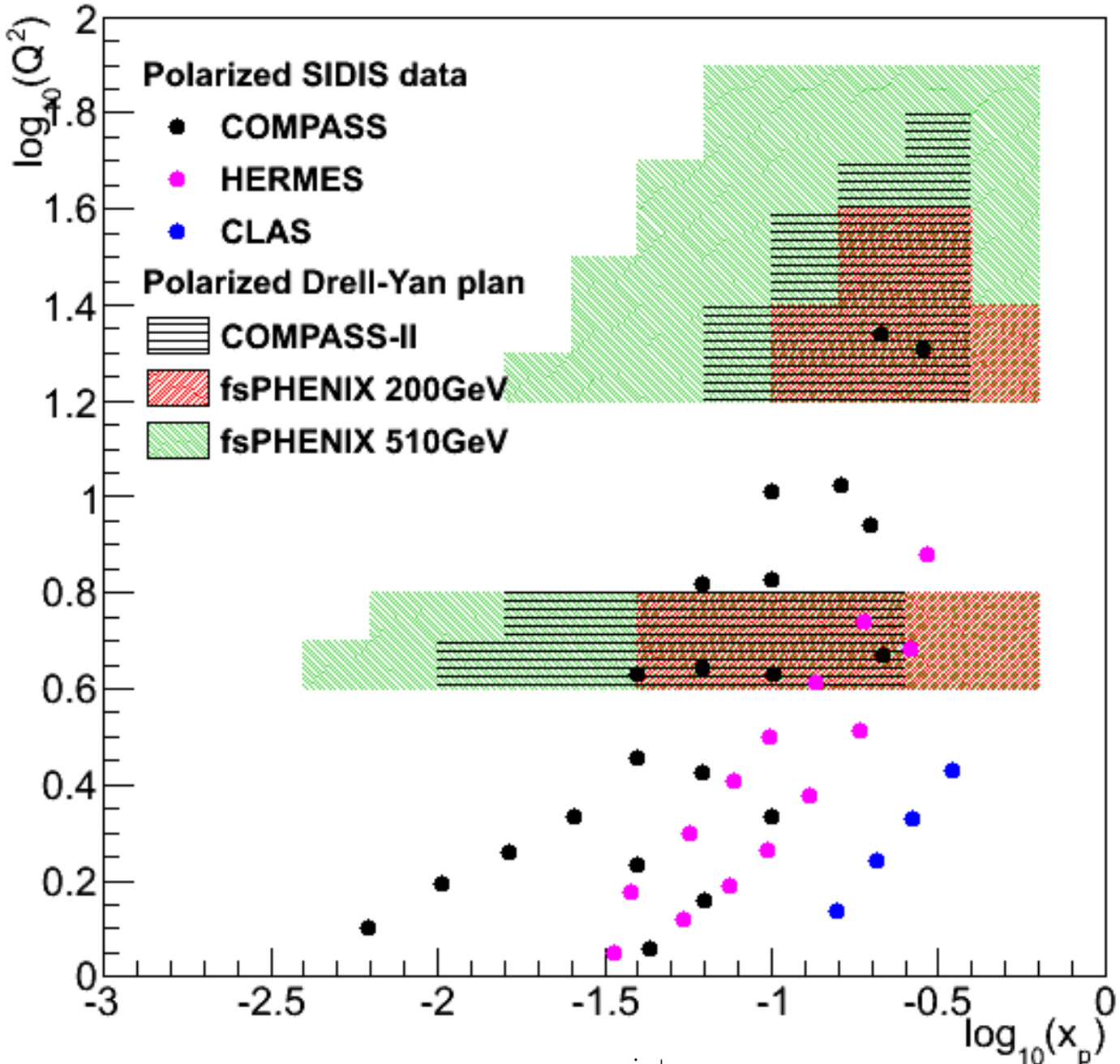
Exchevarria et. al., arXiv 1401.5078

How does evolution change anticipated asymmetries?

Complementing COMPASS DY data

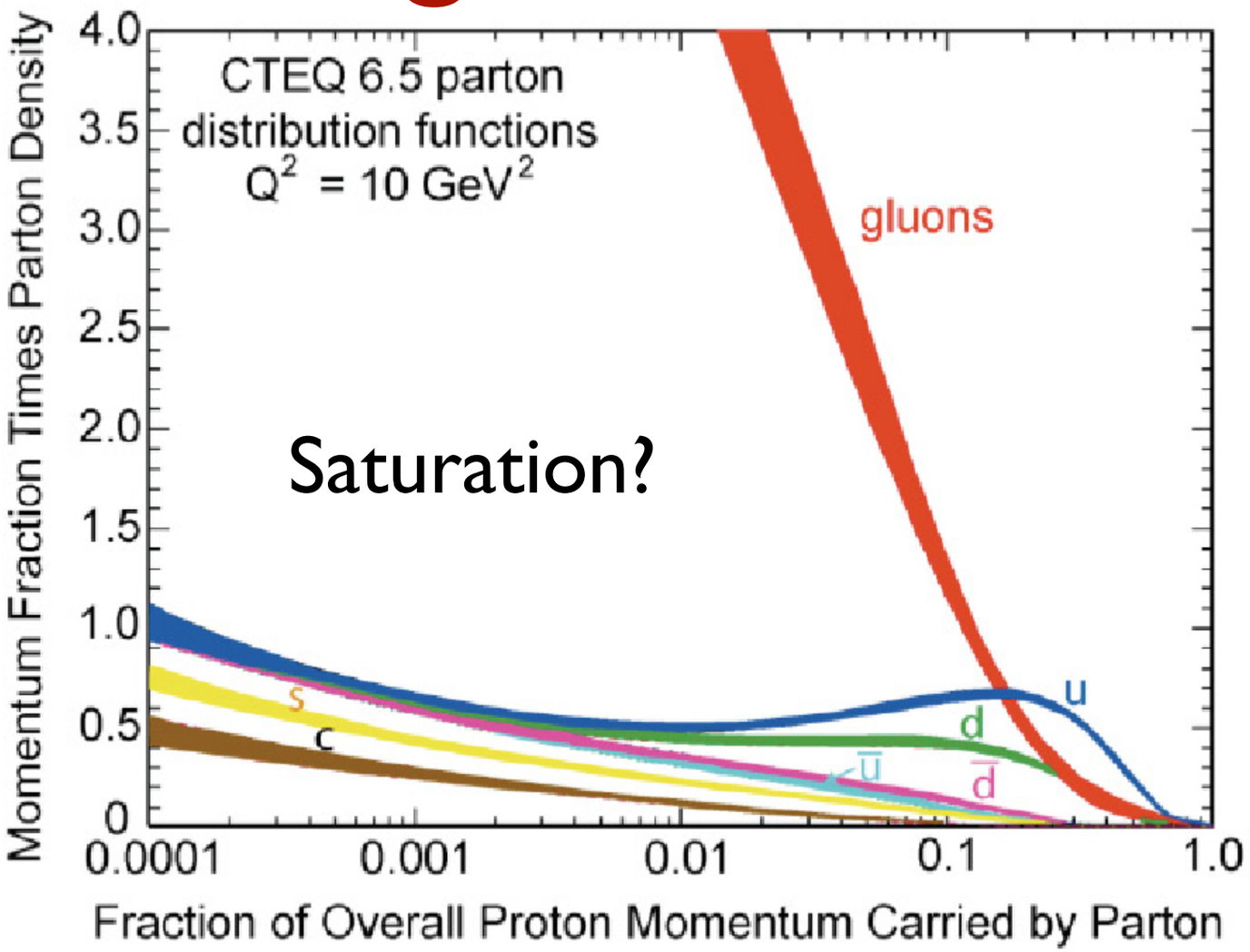
$$FoM = (1/\delta A_T^{\sin\phi_S})^2 = \frac{N}{2}P^2$$

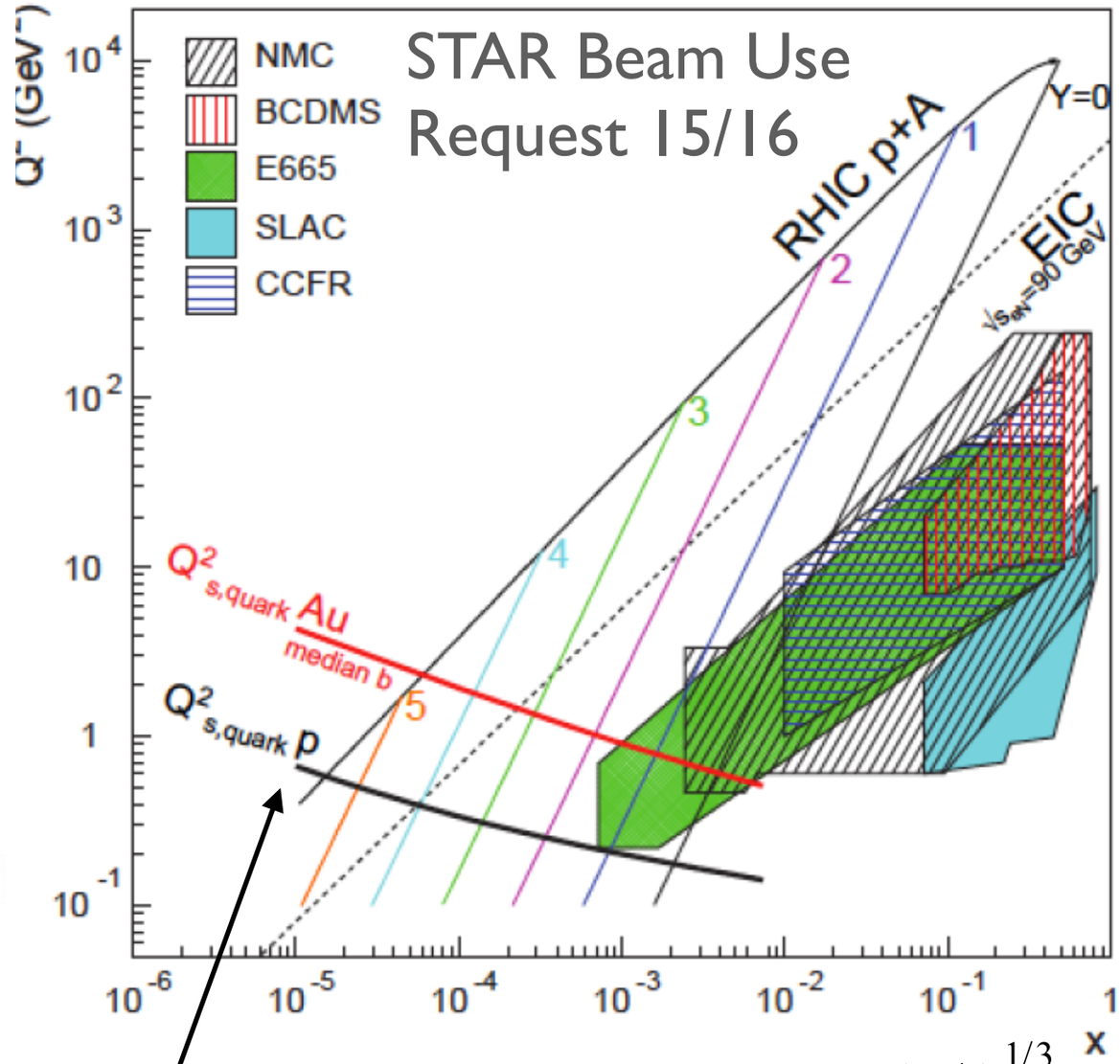




Shaded regions deliniate $\delta A_T^{\sin\phi_S} < 0.1$

Cold nuclear matter: Probing gluons at high densities with pA collisions



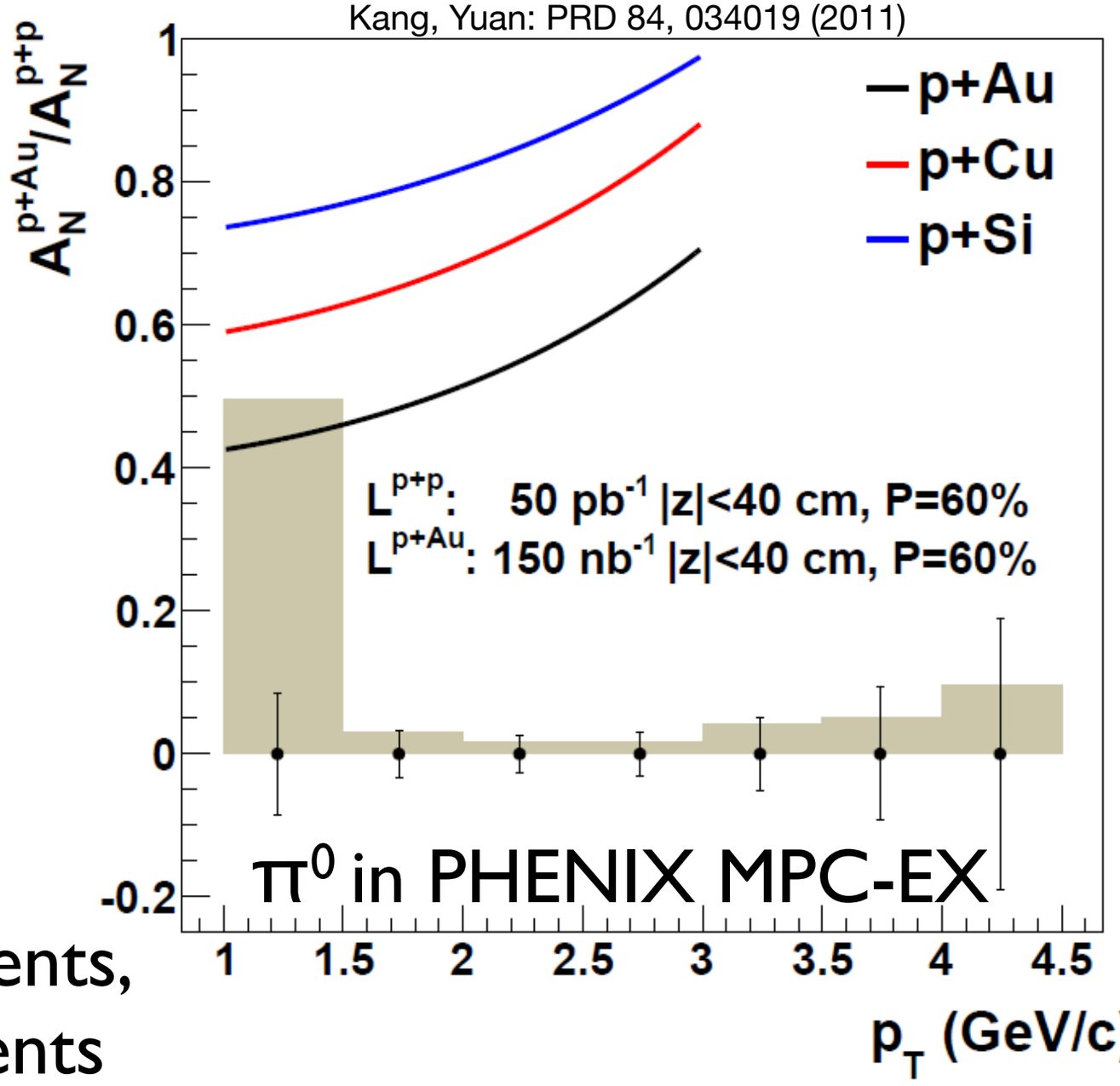


Saturation predicted at $\left(Q_S^A\right)^2 \approx cQ_0^2\left(\frac{A}{x}\right)^{1/3}$

Using spin as a tool to investigate gluon saturation

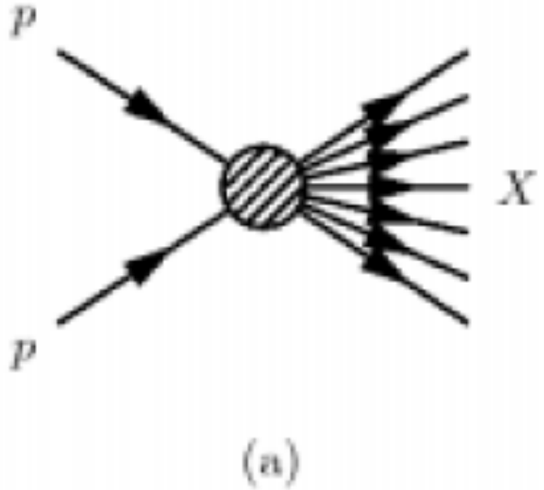
$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 \ll Q_s^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{\frac{P_{h\perp}^2 \delta^2}{Q_{sp}^4}}$$

Y. Kovchegov & M.D. Sievert: PRD 86, 034028 (2012)
Kang, Yuan: PRD 84, 034019 (2011)

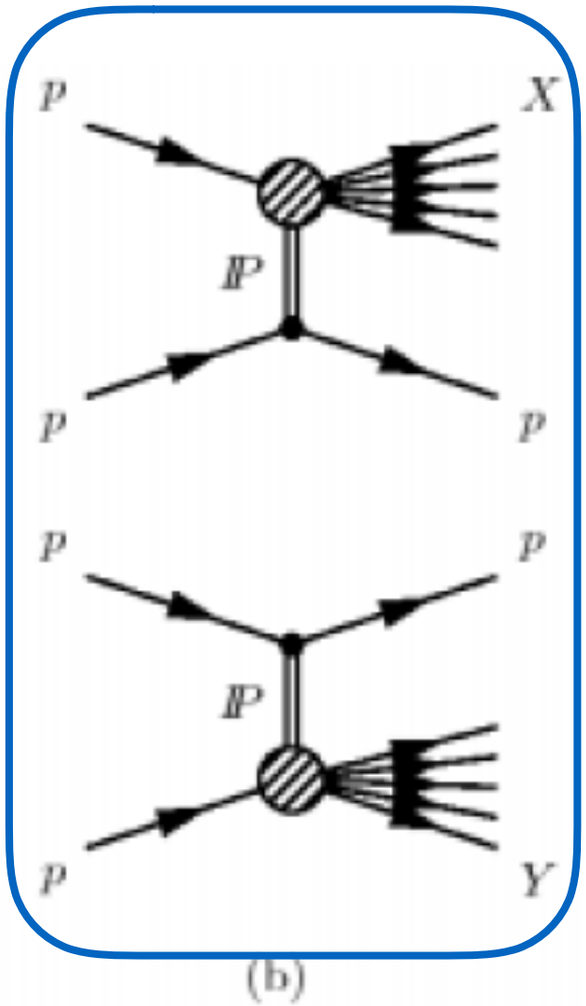


fsPHENIX:
Extend direct photon measurements, add Drell-Yan and jet measurements

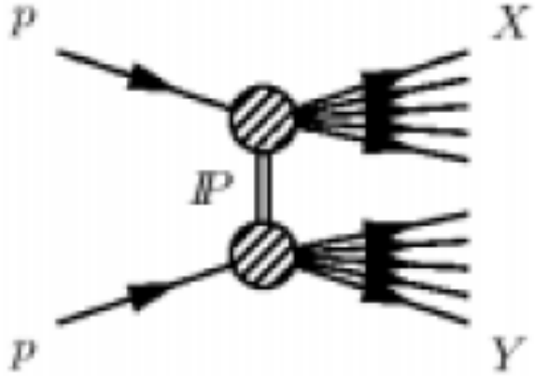
Diffractive measurements



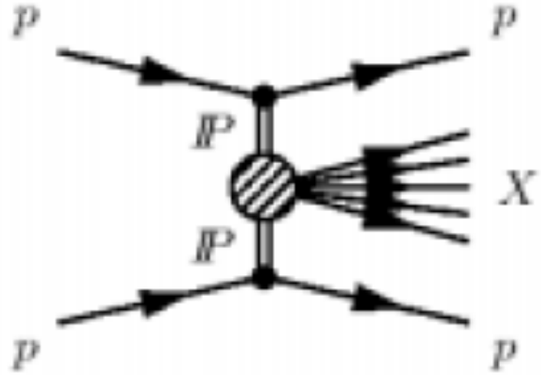
non-diffractive



single-diffractive



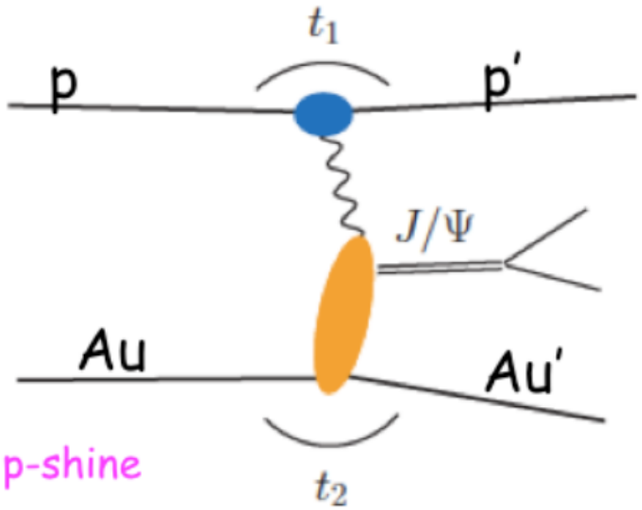
double diffractive



central diffractive

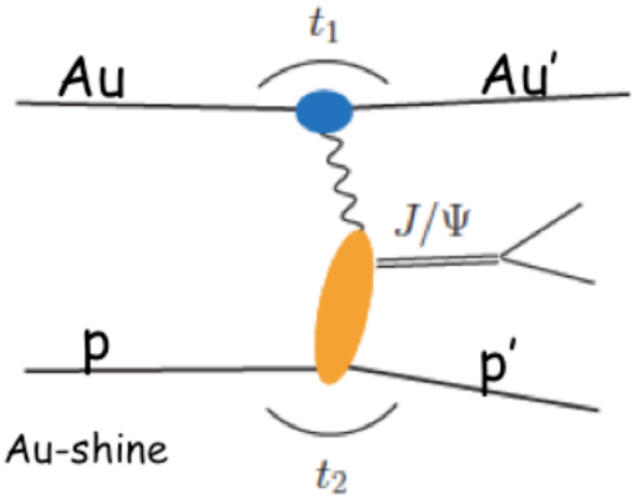
Connection between transverse single-spin asymmetry and diffraction?

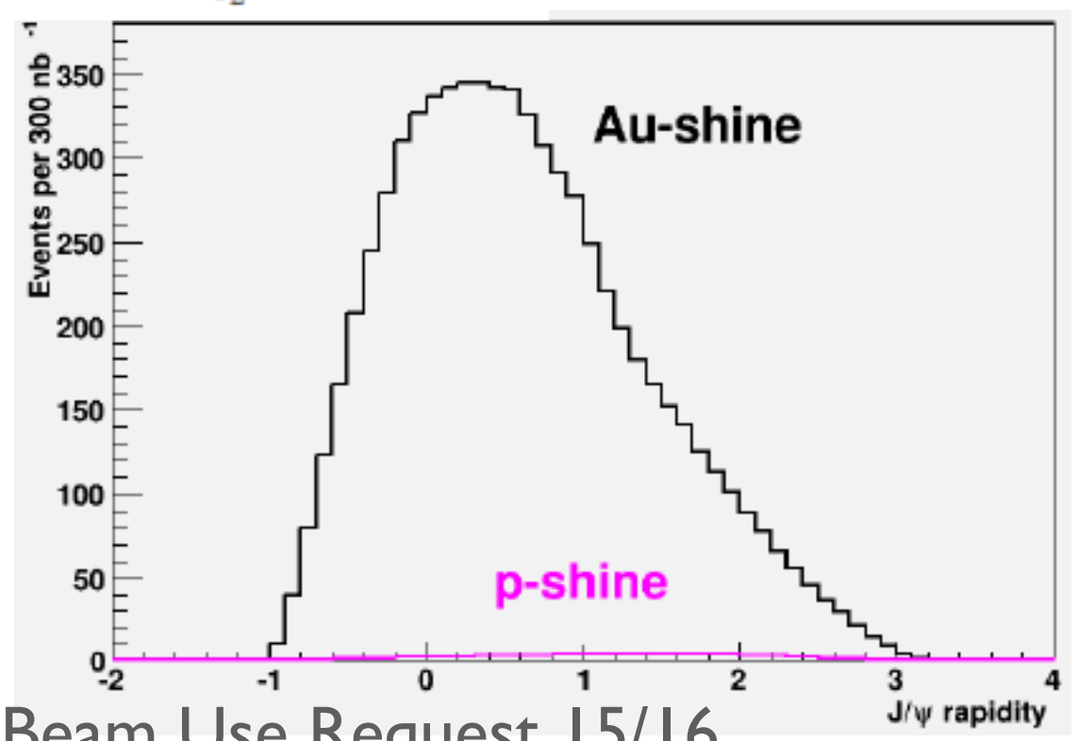
Ultra-peripheral collisions can access GPD E for gluons at RHIC

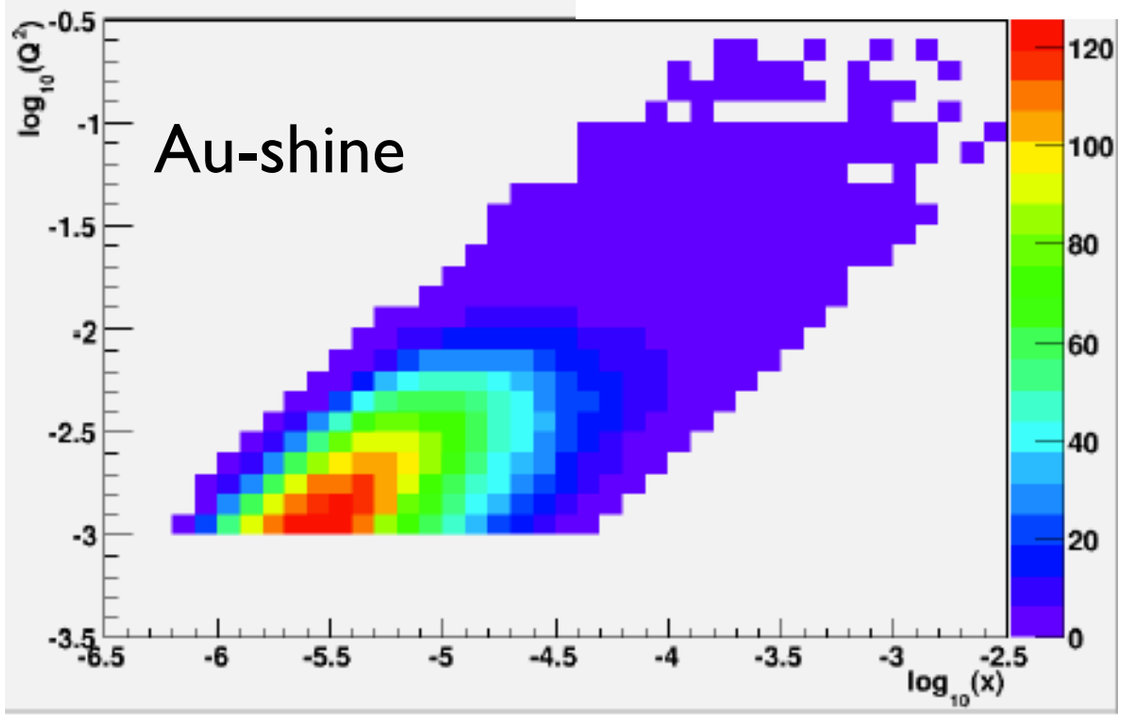


$A_N \neq 0 \rightarrow$ GPD E $\neq 0$

set scale for EIC measurements



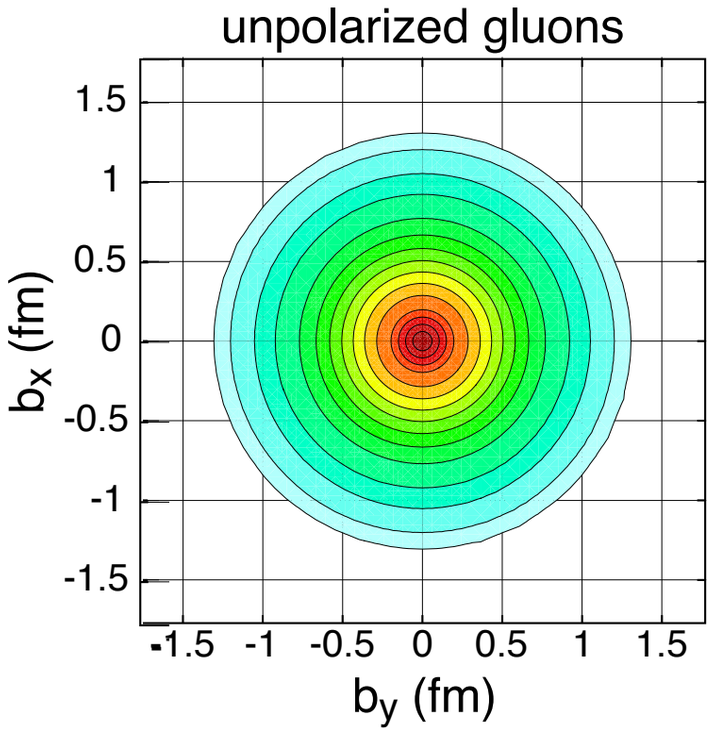


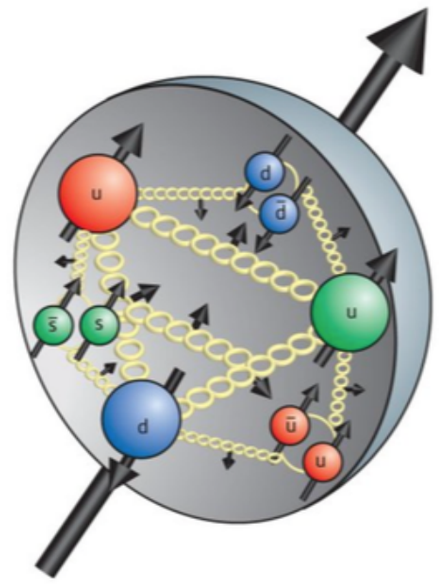


STAR Beam Use Request 15/16

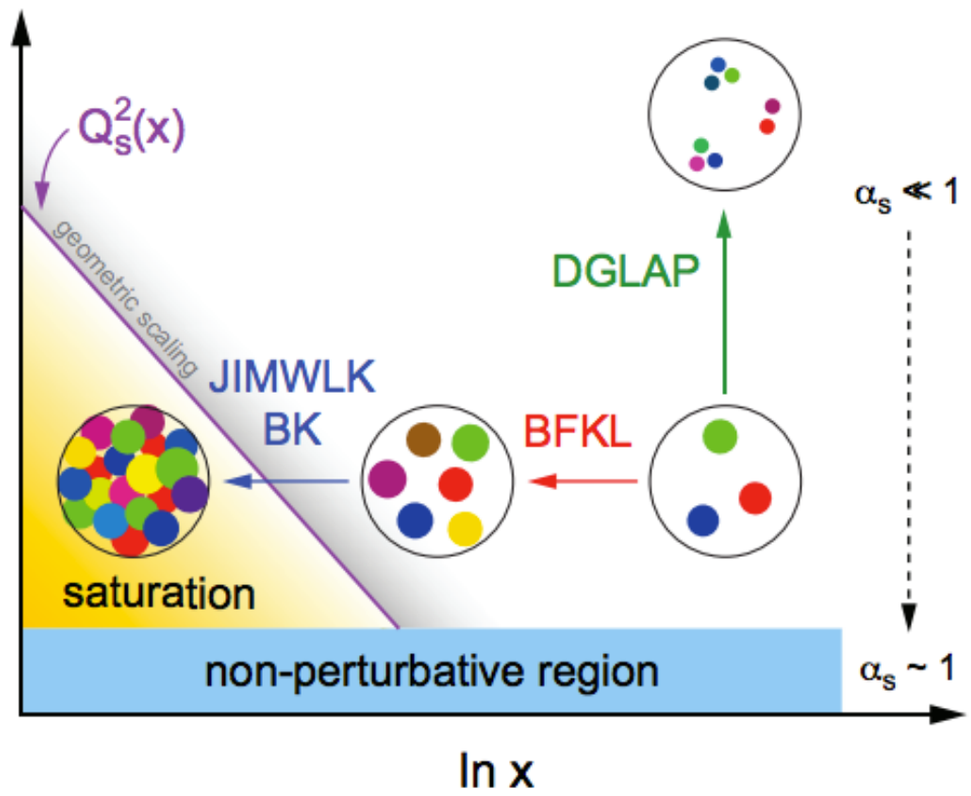
arXiv:1212.1701v3

The EIC- "A Bridge Between Quarks / Gluons And Nuclei"

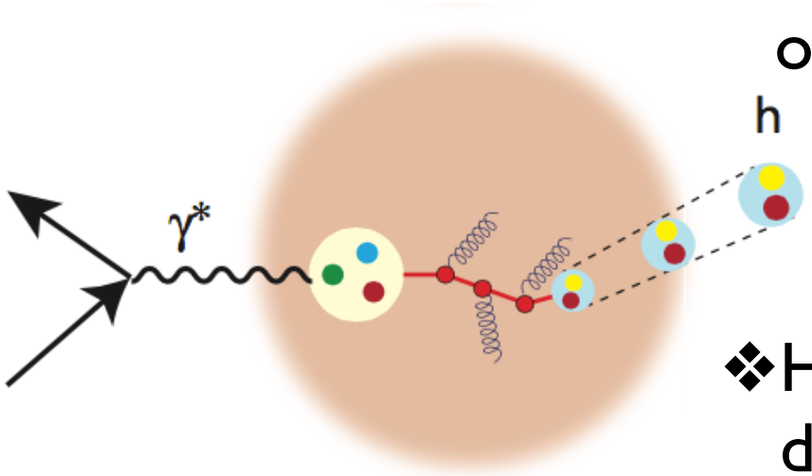




❖How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

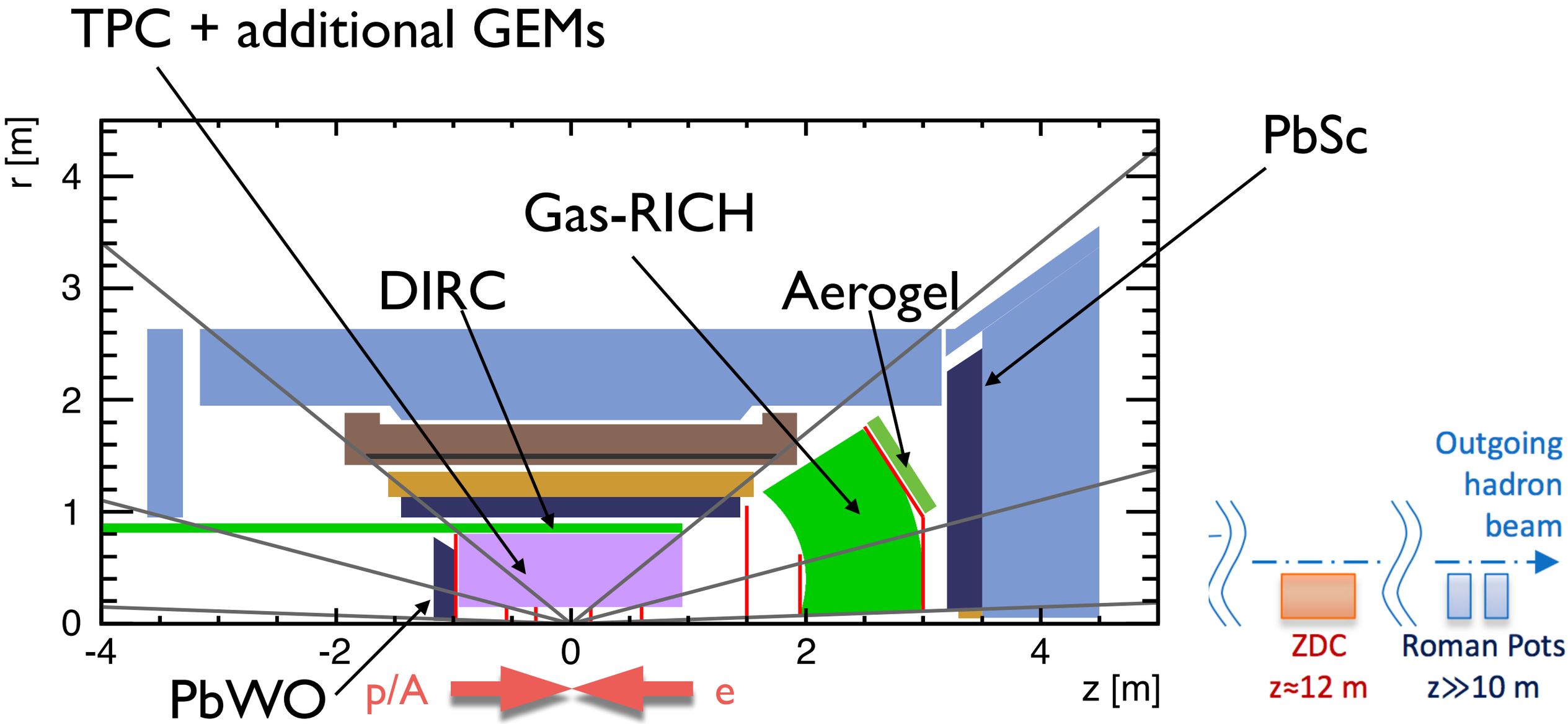


❖Where does the saturation of gluon densities set in?

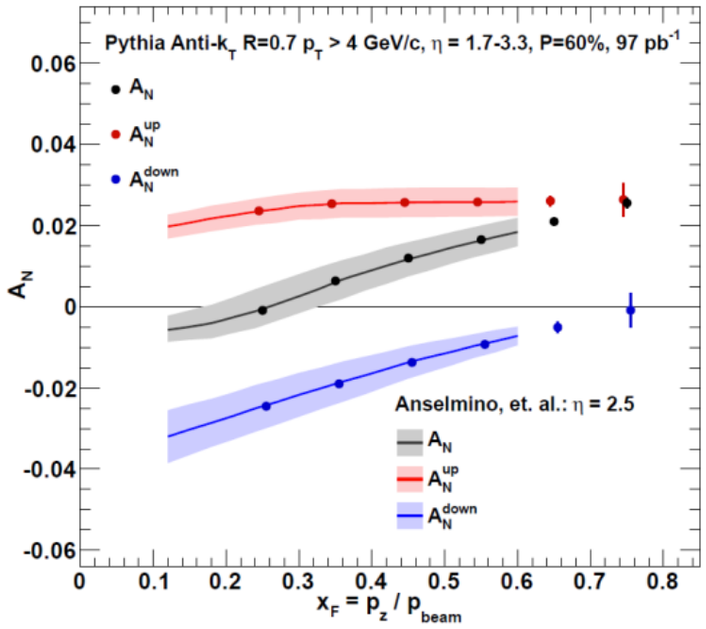


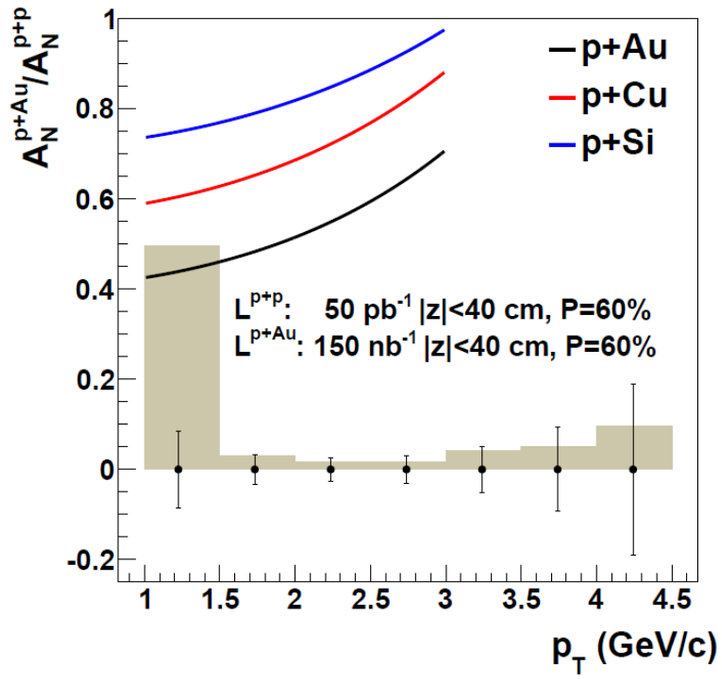
❖How does the nuclear environment affect the distribution of quarks and gluons and their propagation?

Evolution of fsPHENIX into an Electron Ion Collider experiment

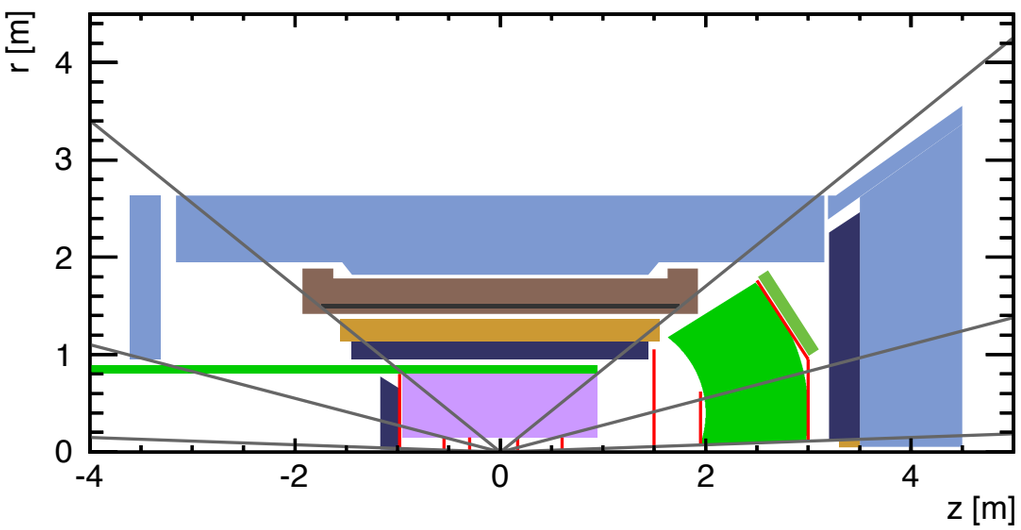


Summary





sPHENIX + additional forward instrumentation can utilize the unique RHIC capabilities to significantly add to our exploration of spin phenomena and cold nuclear matter.



The forward upgrade is a natural next step in the evolution of sPHENIX into a full-fledged EIC experiment.

ADDITIONAL SLIDES

Possible sources of transverse single spin asymmetries

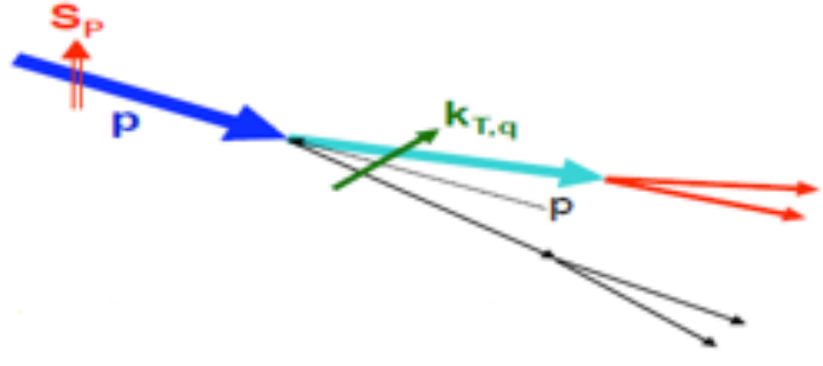
"Sivers effect"

TMD: Correlation between nucleon spin and parton k_T.

Phys. Rev. D **41**, 83 (1990)
Phys. Rev. D **43**, 261, (1991)

$$d\sigma^{\uparrow} \propto \bar{f}_{1T}^{\perp q}(x,k_\perp^2)\cdot D_q^h(z)$$

Sivers distribution



Twist-3: Quark-gluon correlations in polarized hadron

Phys. Rev. D **59**, 014004 (1998)

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

Also evolution…

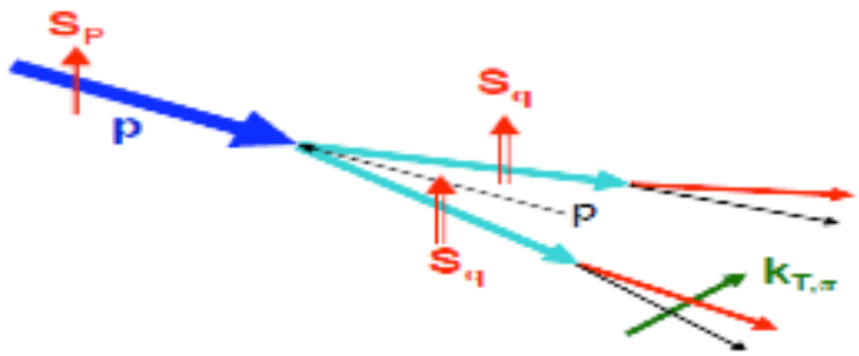
"Collins effect"

TMD: Transversity distributions + Spin dependent fragmentation functions

Nucl. Phys. B 396, 161 (1993)

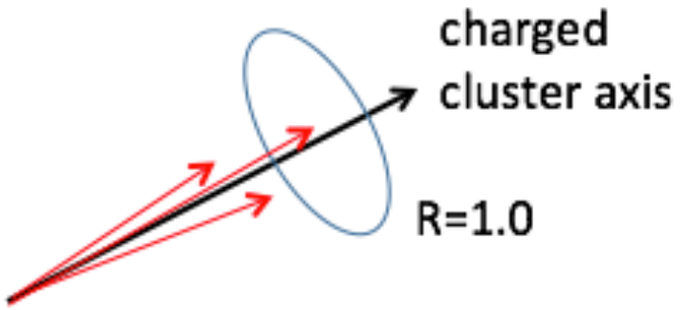
$$d\sigma^{\uparrow} \propto \delta q(x)\cdot H_1^{\perp}(z_2,\bar{k}_\perp^2)$$

Transversity Collins FF

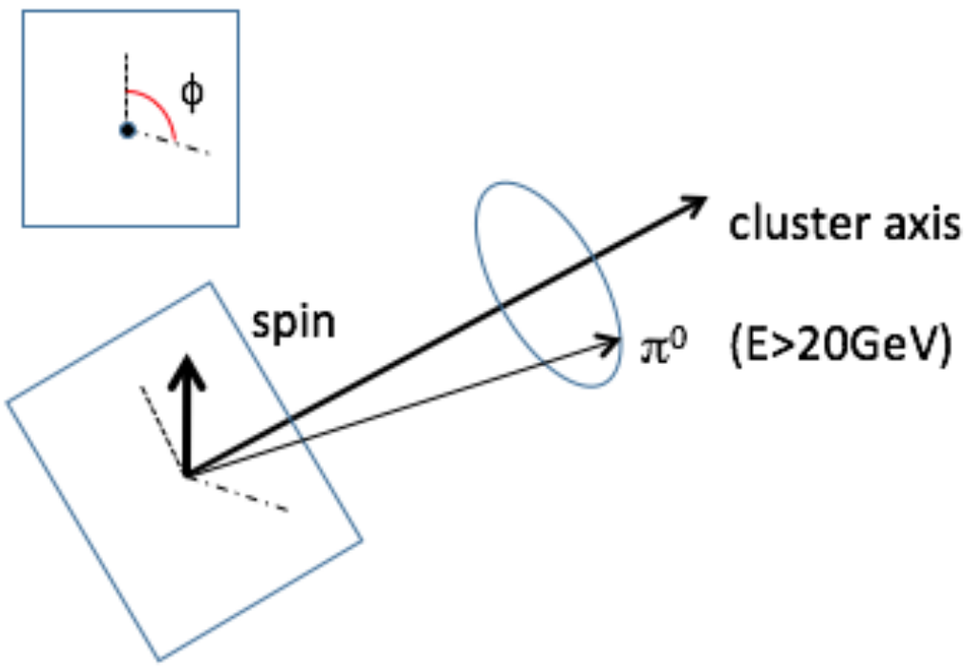


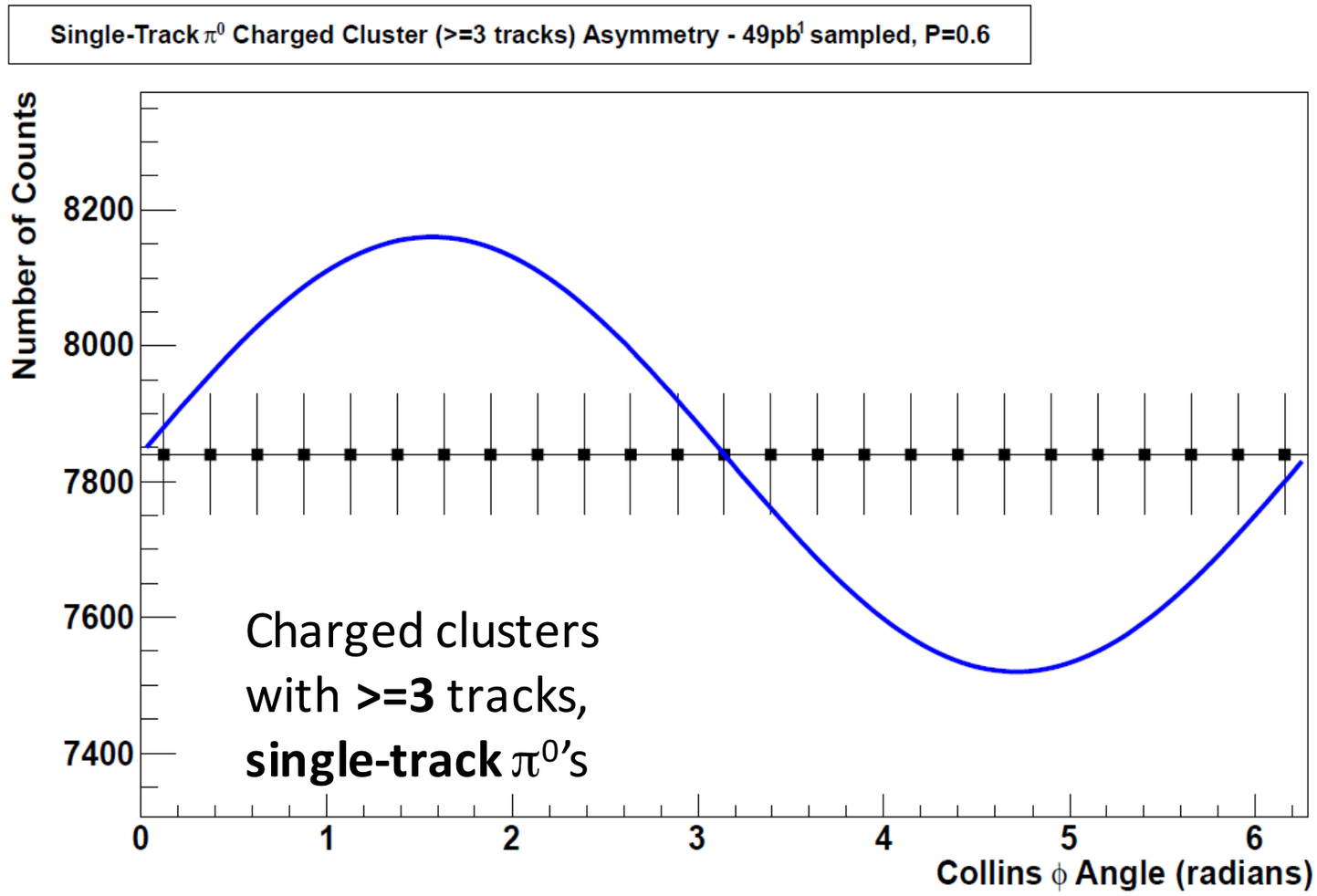
Twist-3: Transversity combined with twist-3 quark-gluon fragmentation function

fsPHENIX Collins Asymmetry

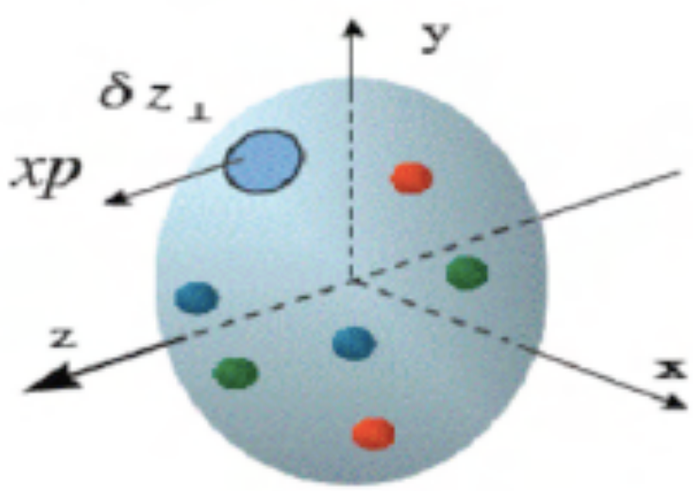


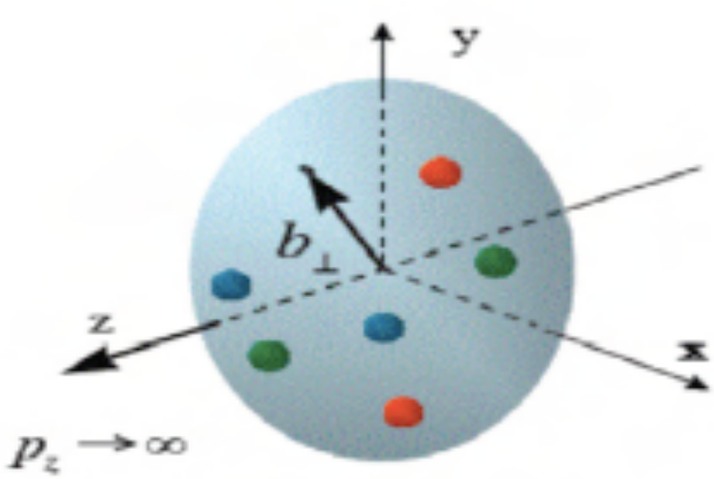
- All tracks given equal weight
- Select the cluster with highest number of tracks

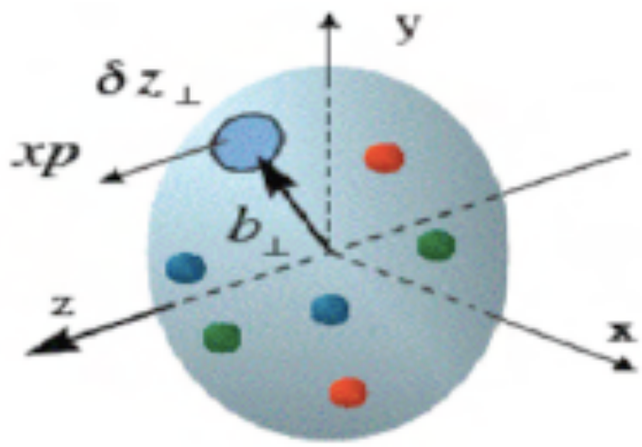


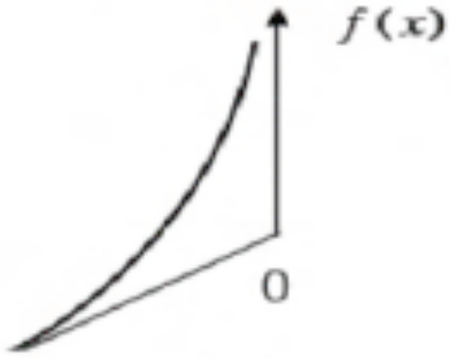


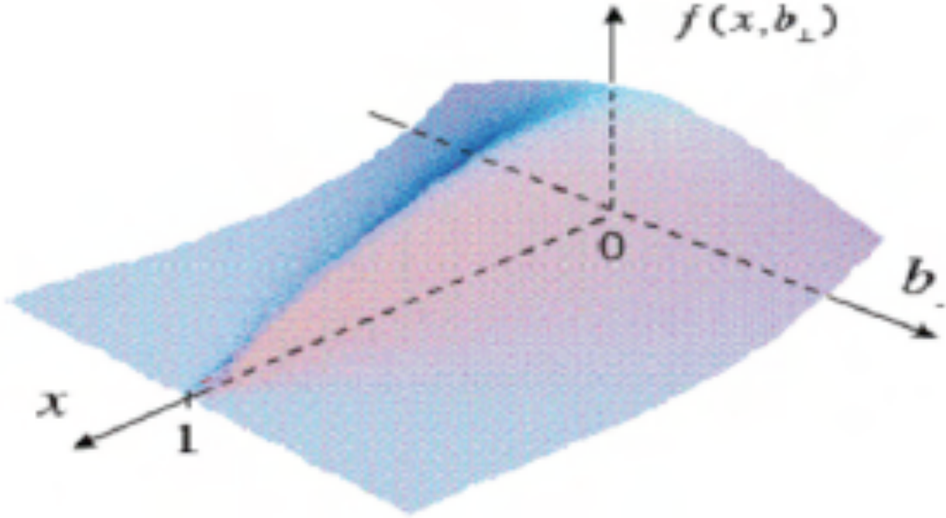
Generalized Parton Distributions







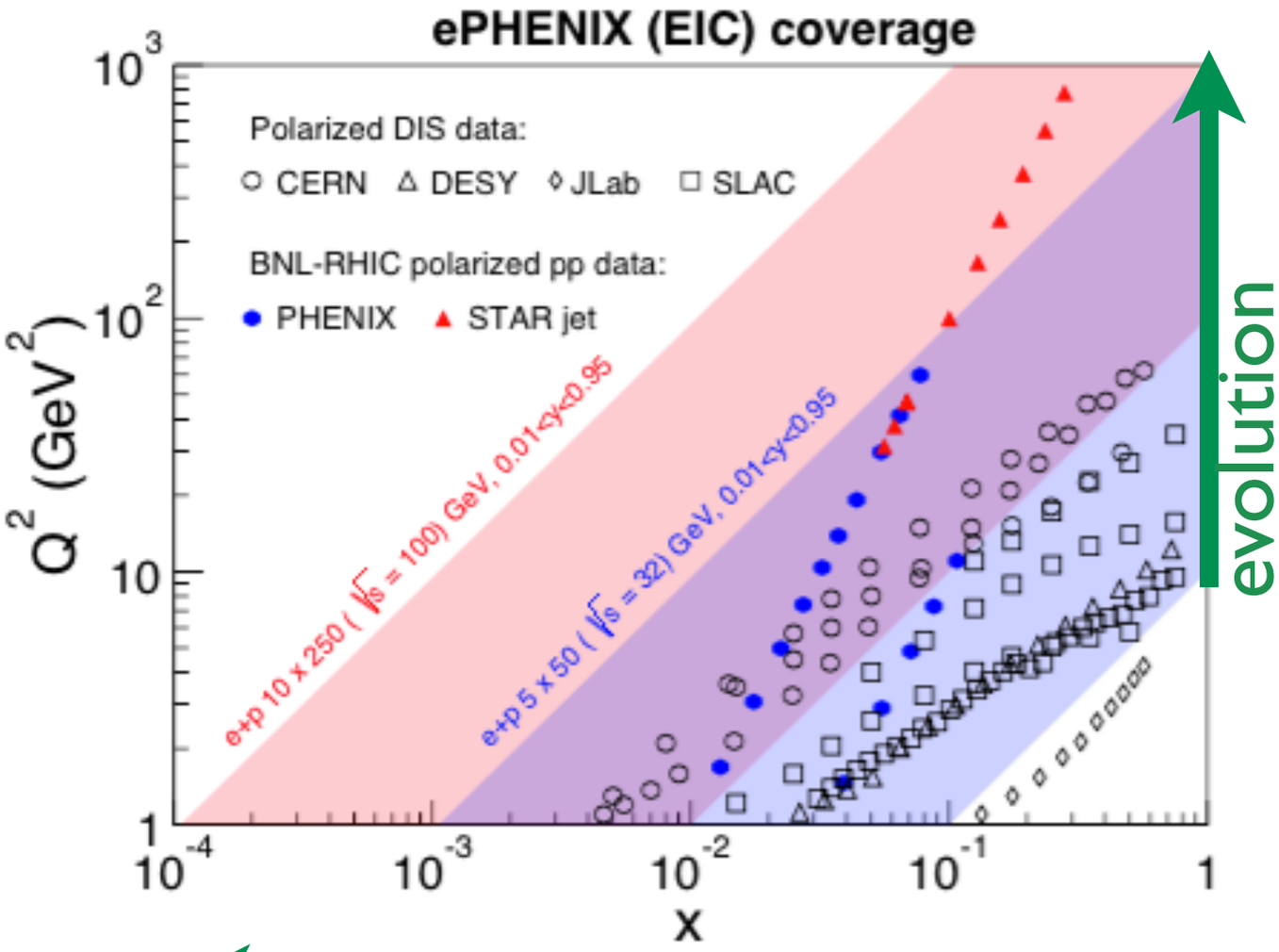




Parton Density Functions 1D + ‘Form Factors’ 2D = GPDs 2+1 D

Proton Structure: Longitudinal Spin

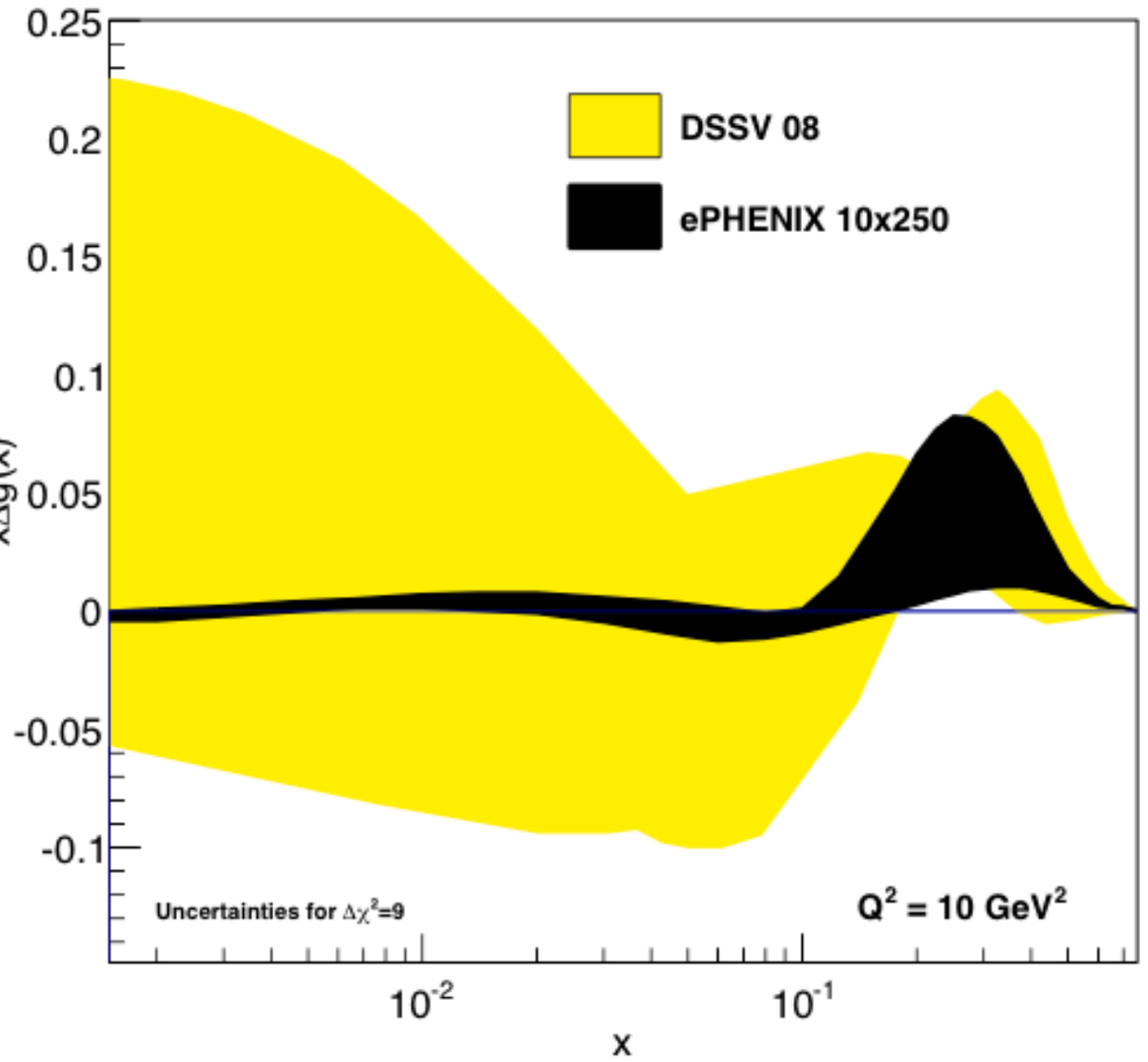
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$



valence to low-x physics

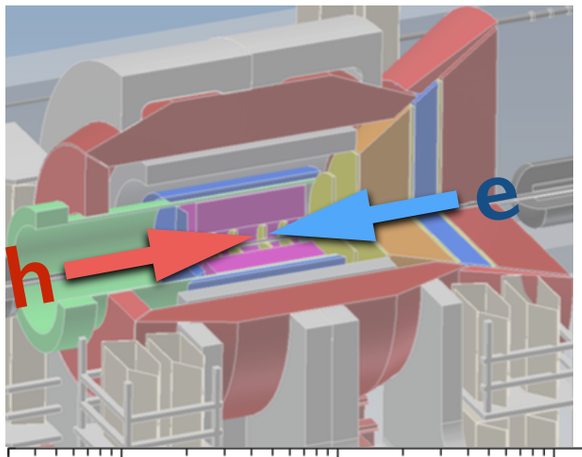
PHYTHIA generator and ePHENIX acceptance/efficiencies

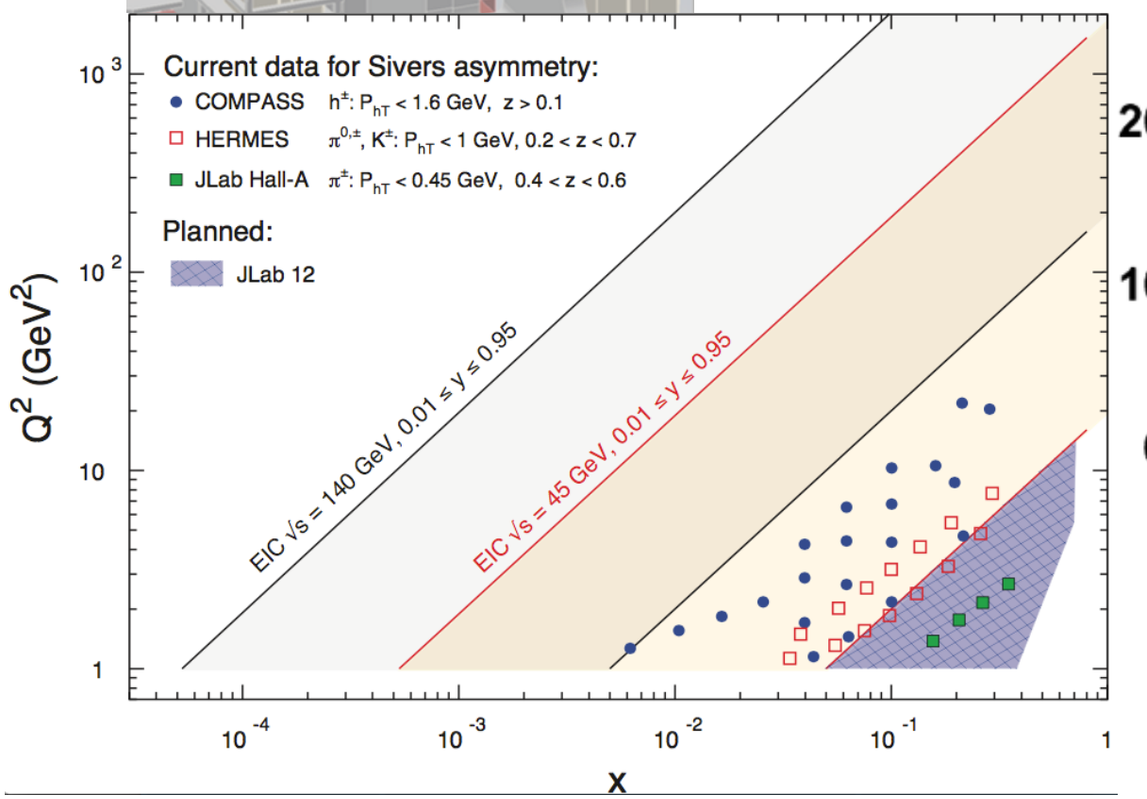
10 fb^{-1} at 10GeV×250GeV



arXiv:1402.1209v1

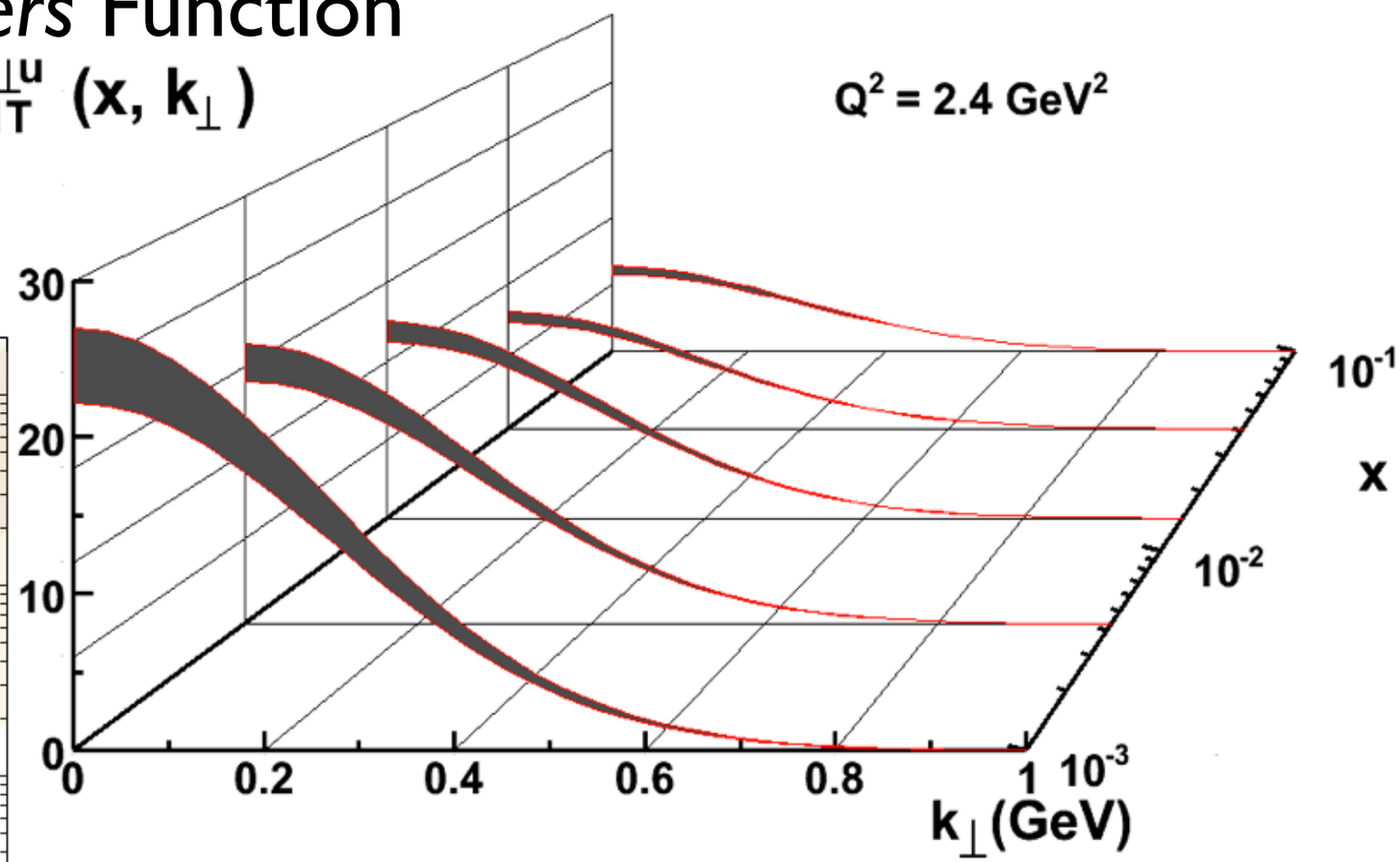
SIDIS: Transverse Momentum Dependent Parton Distributions





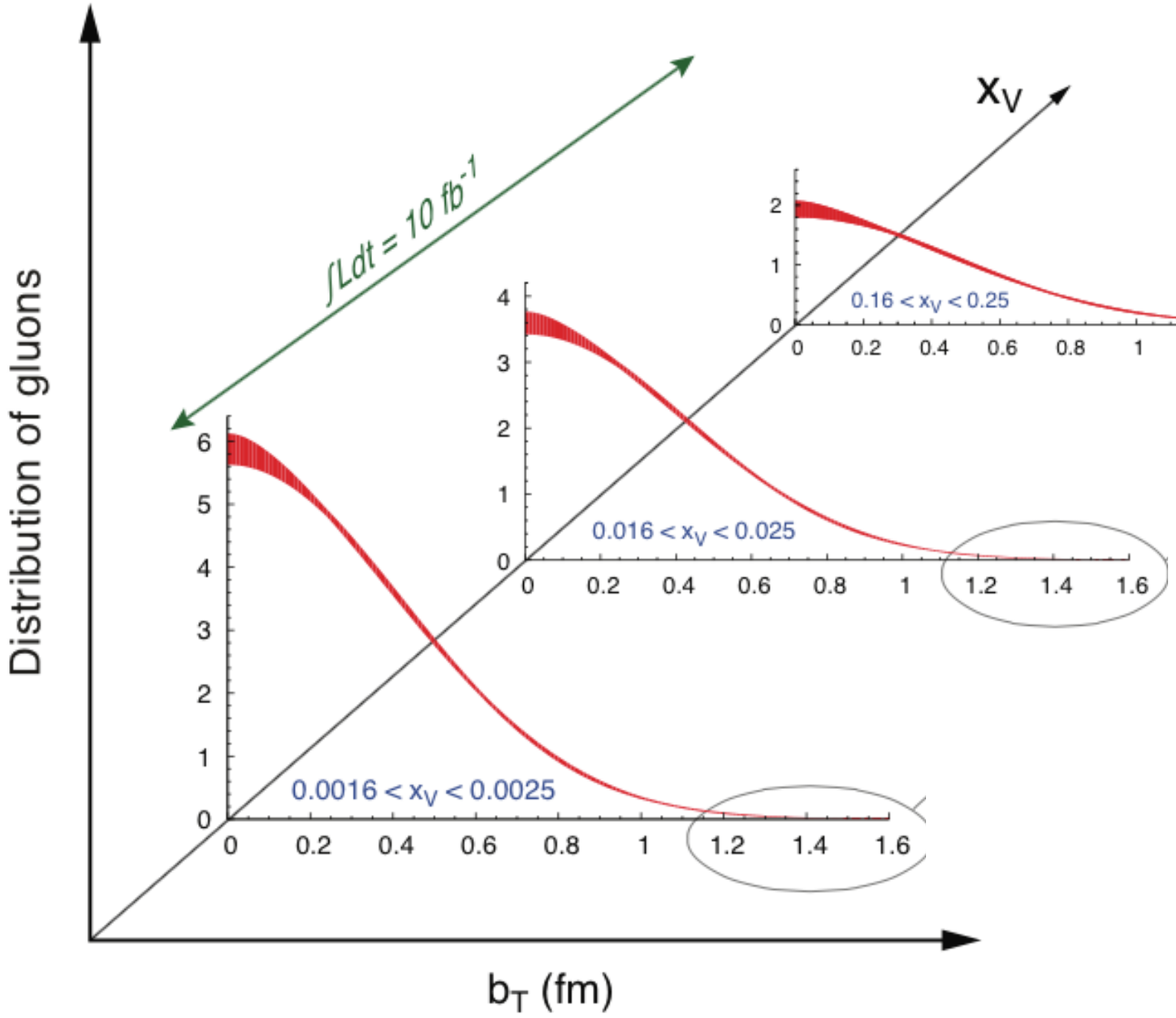
Sivers Function

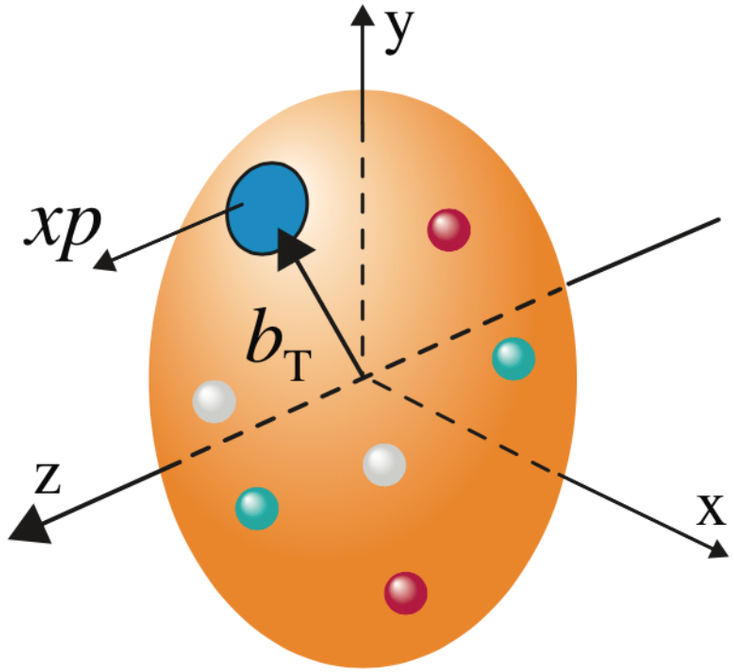
- $f_{1T}^{\perp u}(x, k_\perp)$



arXiv:1212.1701v3

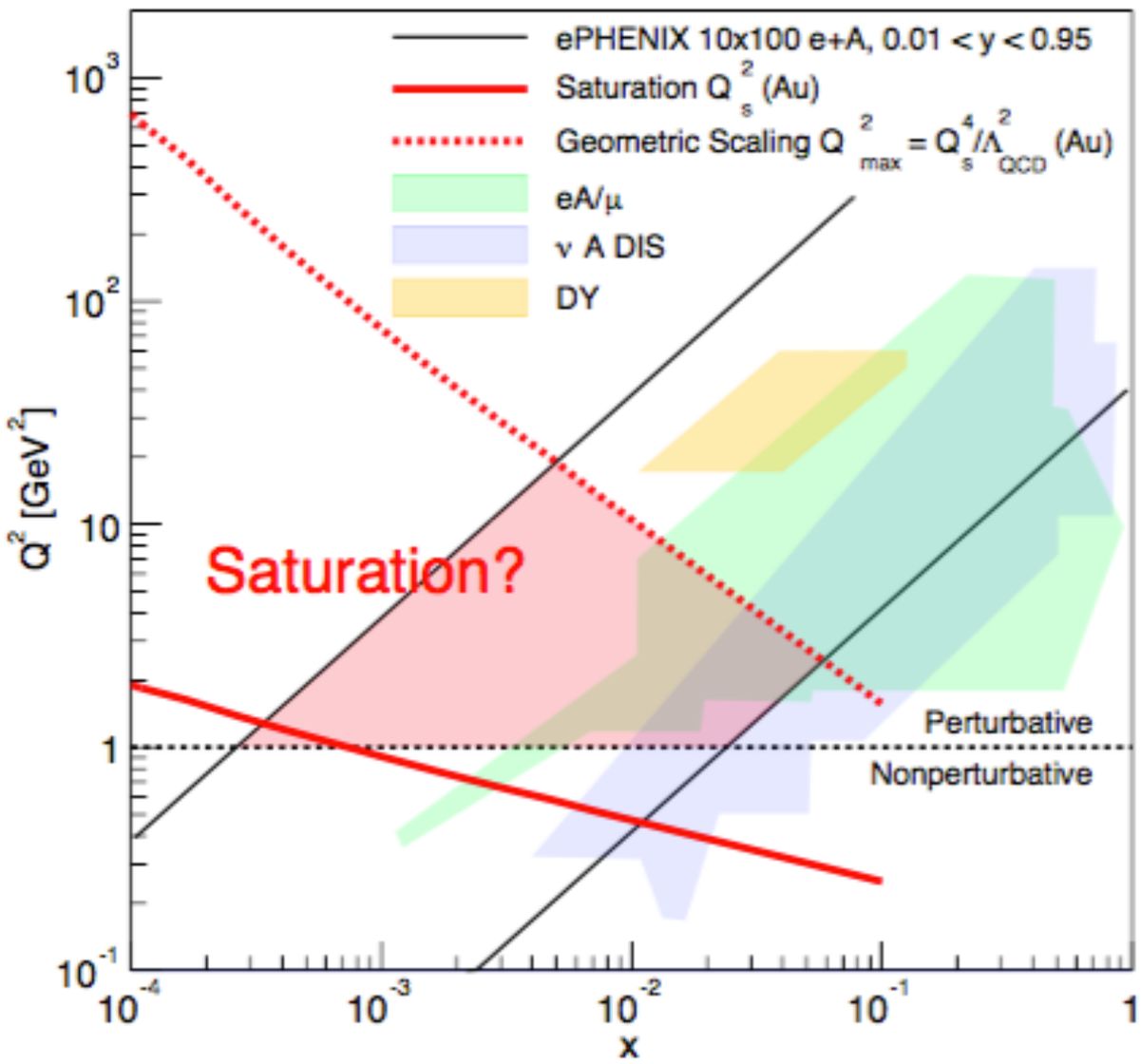
Exclusive Measurements: 3D Imaging of Gluon Distribution (GPDs)

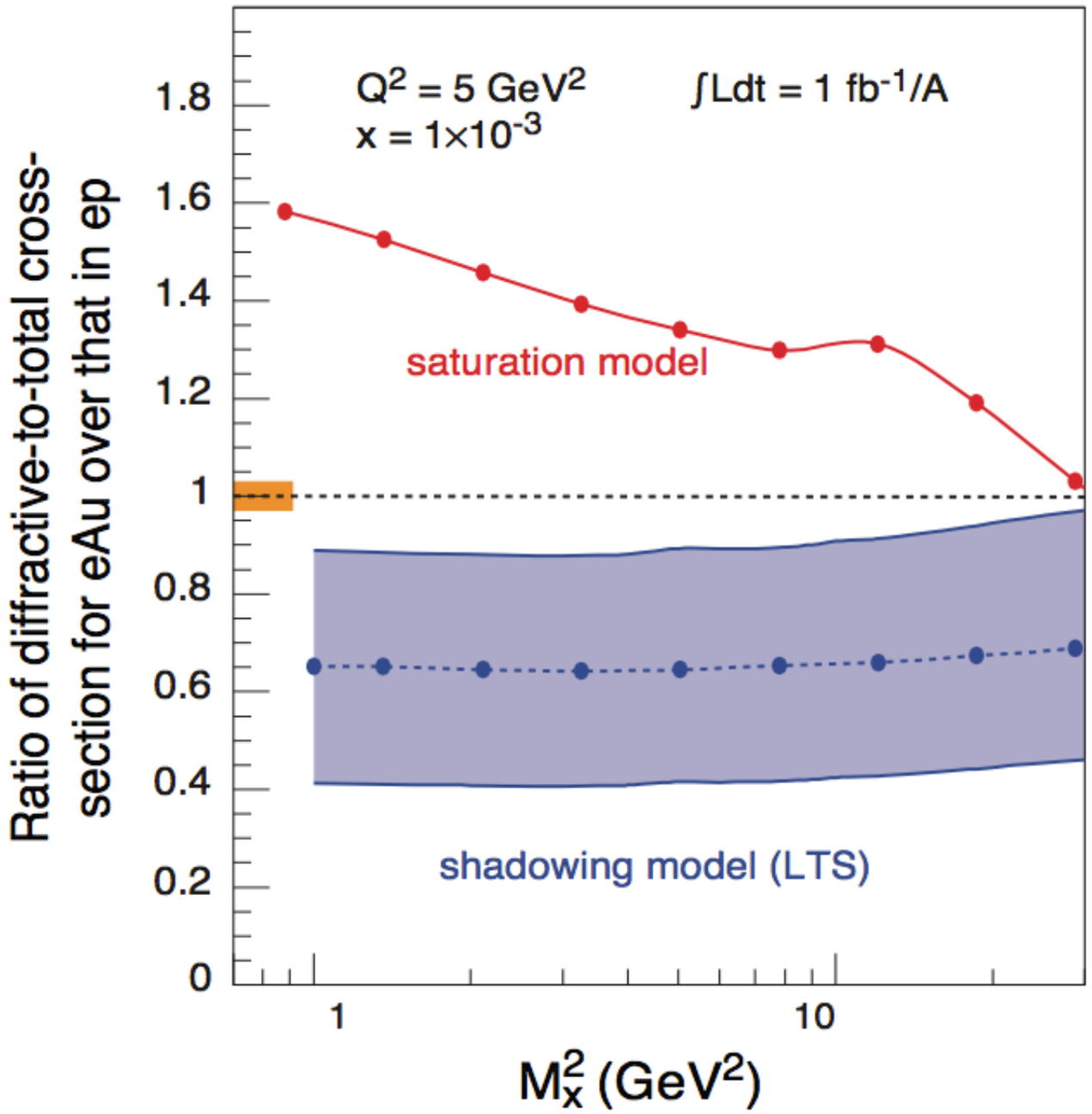




Gluon Saturation

$$Q_s^2(x) \propto \left(\frac{A}{x}\right)^{1/3}$$





Parton Propagation in Nuclear Matter