Physics with (un)polarized proton-nucleus collisions at STAR/RHIC

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for the STAR Collaboration

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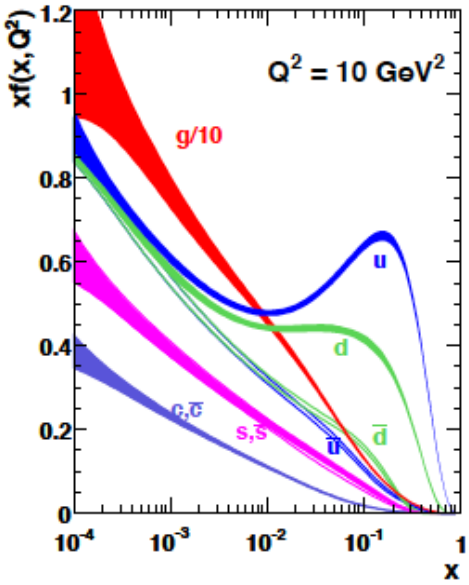
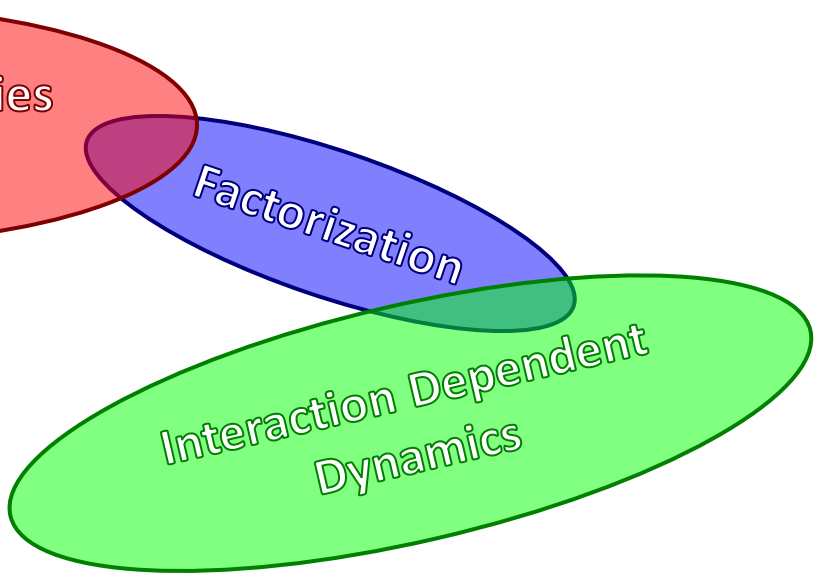
BROOKHAVEN NATIONAL LABORATORY

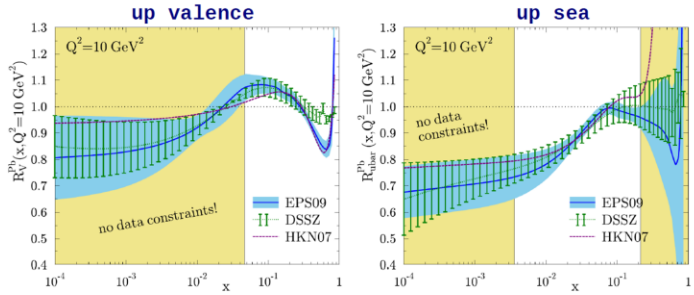
U.S. DEPARTMENT OF ENERGY | Office of Science

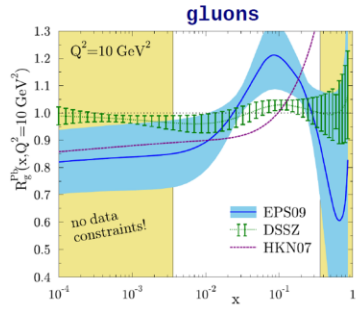
Structure of Strongly Interacting Matter



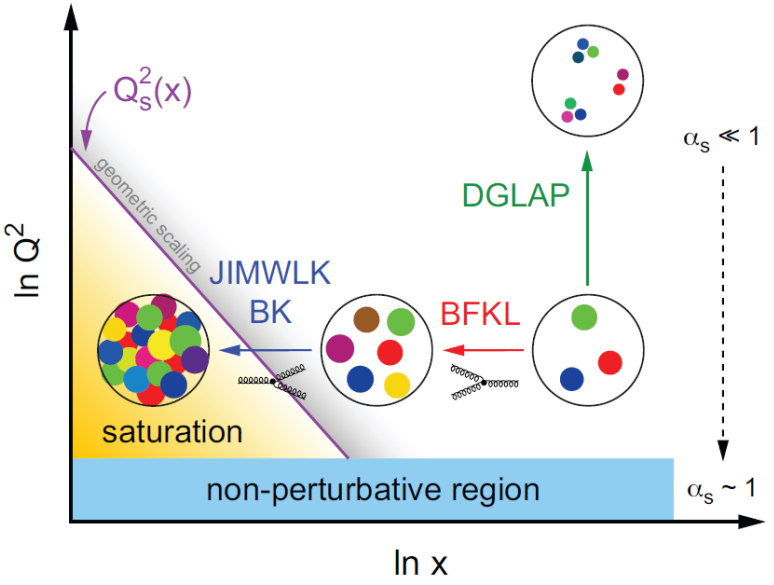
MSTW 2008
EPJ C63







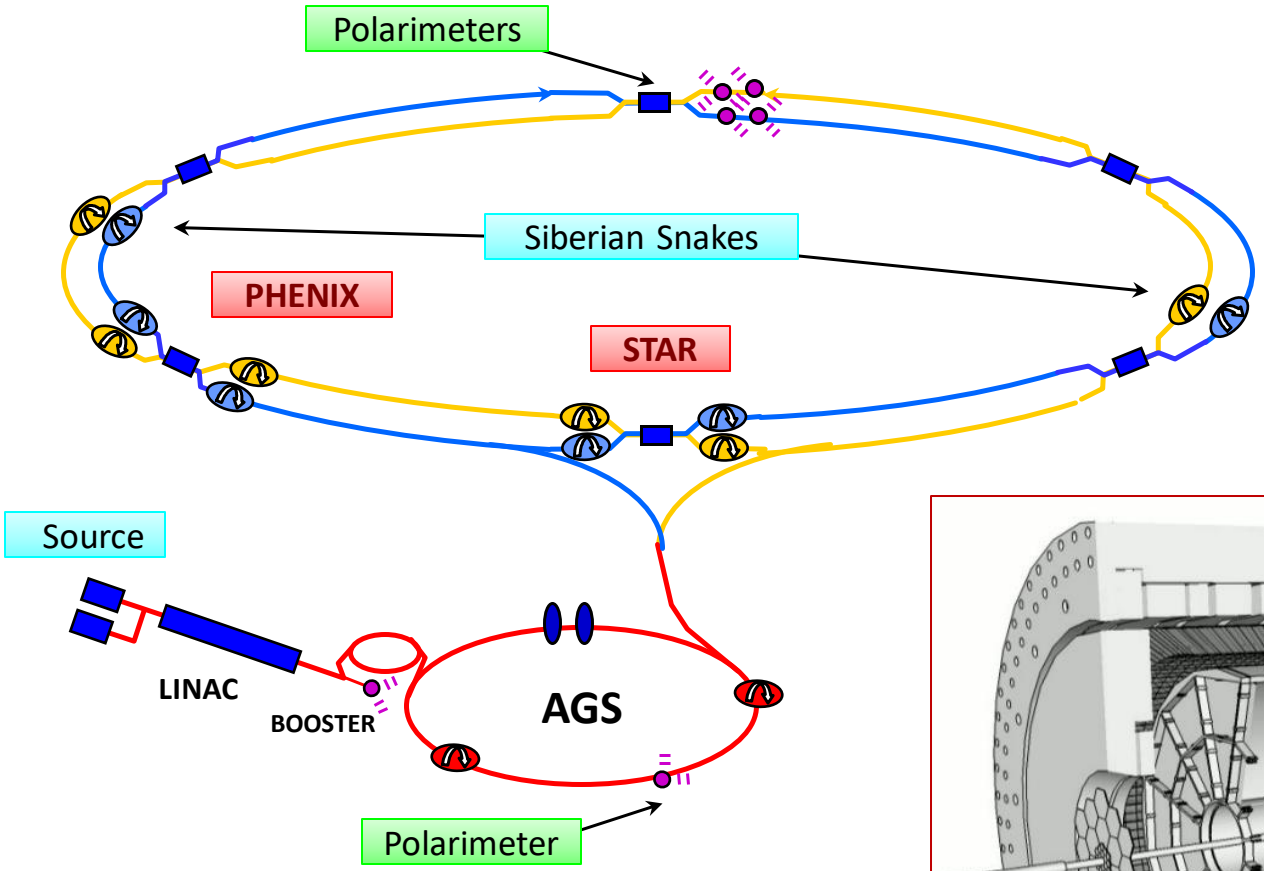
$R^{Pb}(x) = f^{Pb}(x)/f^{p}(x)$
$Q^2 = 10\ \mathrm{GeV}^2$
H. Paukkunen
DIS 2014



The Nucleus…

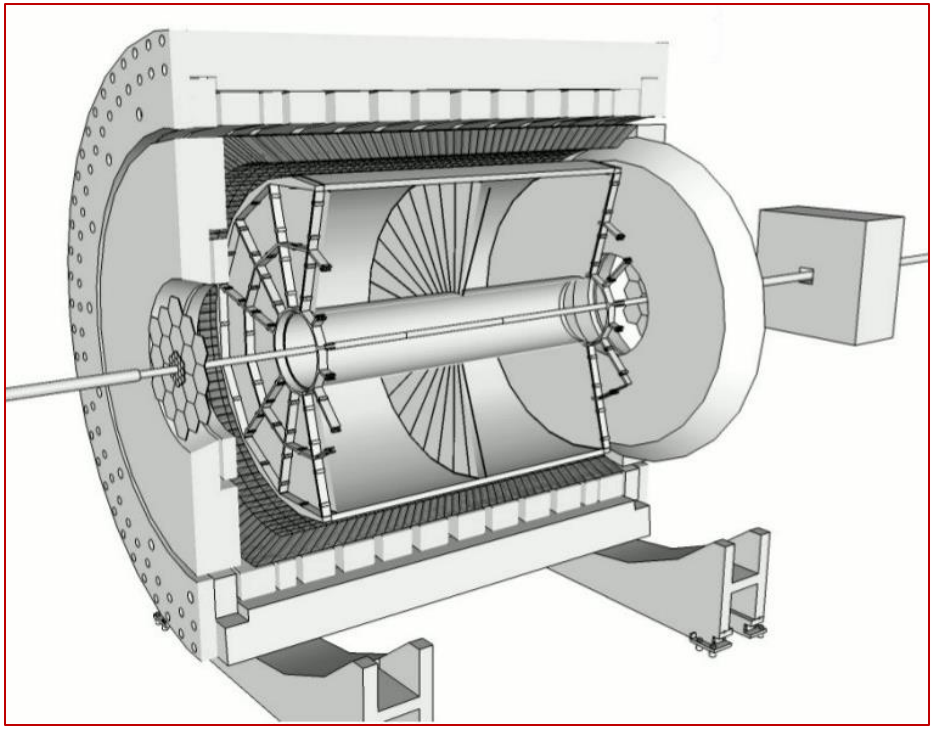
- What is the fundamental quark-gluon structure of light and heavy nuclei?
- Can we experimentally find and explore a universal regime of strongly correlated QCD dynamics?
- What is the role of saturated strong gluon fields, and what are the degrees of freedom in this strongly interacting regime?
- Can the nuclear color filter provide insight into propagation, attenuation and hadronization of colored probes.

STAR @ RHIC



RHIC 2015

- $\vec{p} + p, L_{\text{int}} = 40 + 50\ \text{pb}^{-1}$
- $\vec{p} + Al, L_{\text{int}} = 1.0\ \text{pb}^{-1}$
- $\vec{p} + Au, L_{\text{int}} = 0.45\ \text{pb}^{-1}$



STAR 2015

$-1 < \eta < 1$	TPC, TOF, BEMC
$2.5 < \eta < 4.0$	FPS, FMS

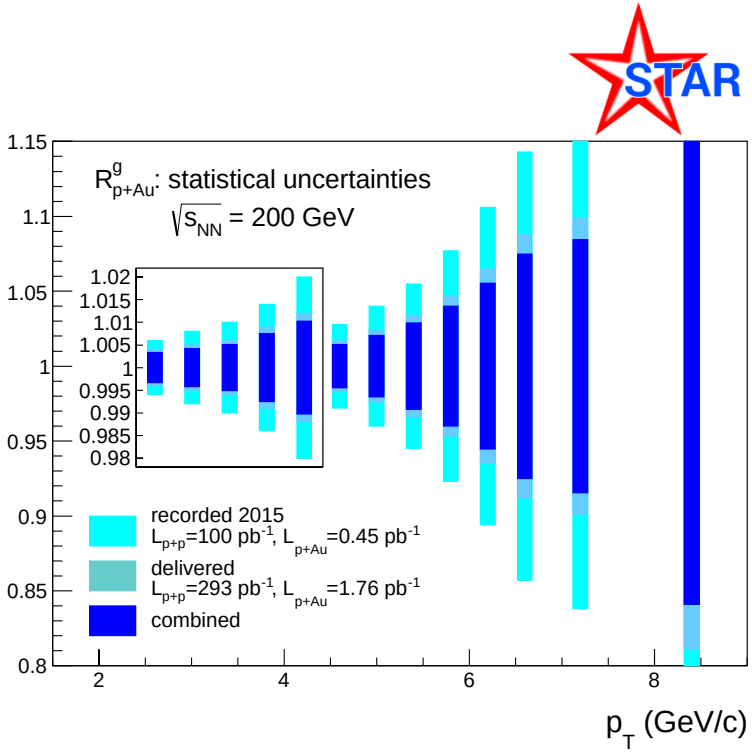
Nuclear Modification: $R_{pA}(\gamma_{dir})$

- RHIC: $p + A$
- Moderate Q^2
- Medium to low x
- $2.5 < \eta_p < 4.0$
- Direct photon

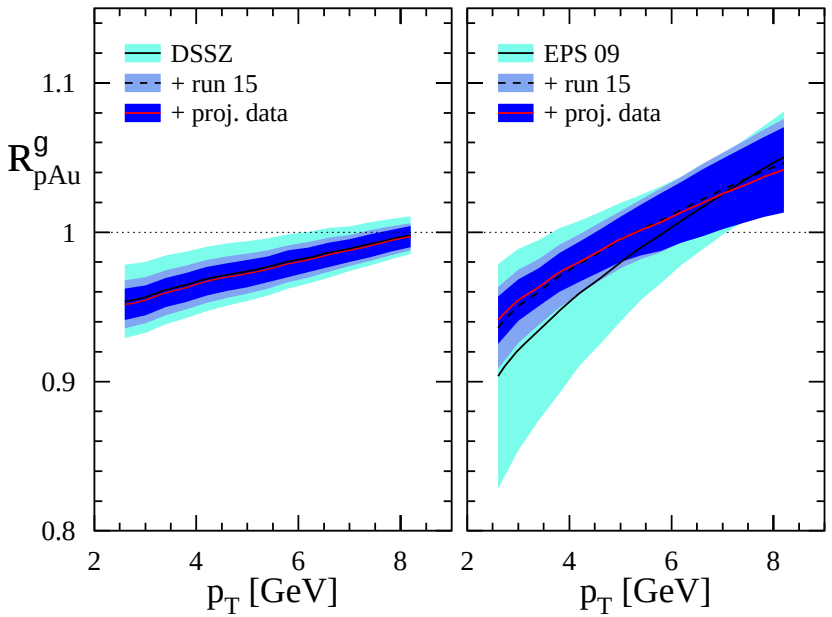
$$R_{pA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN^{pA}}{dN^{pp}}$$

RHIC 2015

- $p + Al, L_{\text{int}} = 1.0\ \text{pb}^{-1}$
- $p + Au, L_{\text{int}} = 0.45\ \text{pb}^{-1}$



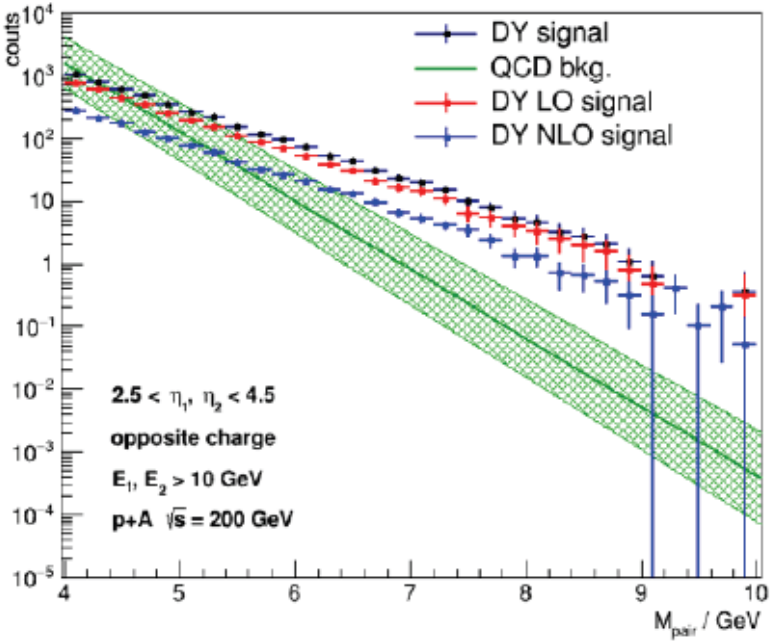
Reweighting procedure
JHEP1412 (2014) 100

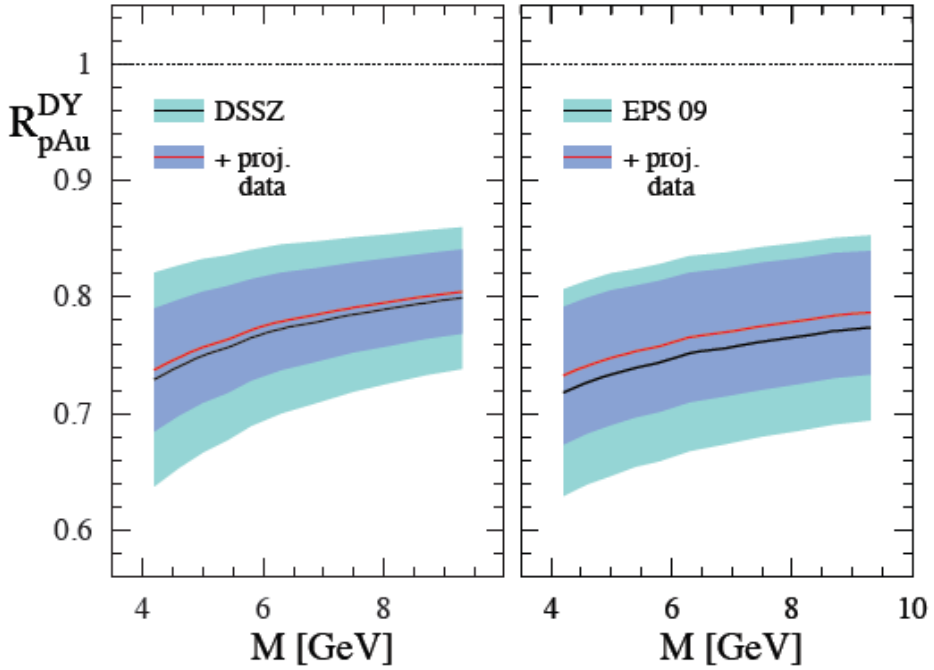


Nuclear Modification: $R_{pA}(\gamma^*_{DY})$

- RHIC: $p + A$
- Moderate Q^2
- Medium to low x
- $2.5 < \eta_p < 4.5$
- Drell-Yan production

- Drell-Yan at forward η
- 2017: $p + p$ @ $\sqrt{s} = 500$ GeV
- 2023: $p + p/Al/Au$ @ $\sqrt{s_{NN}} = 200$ GeV

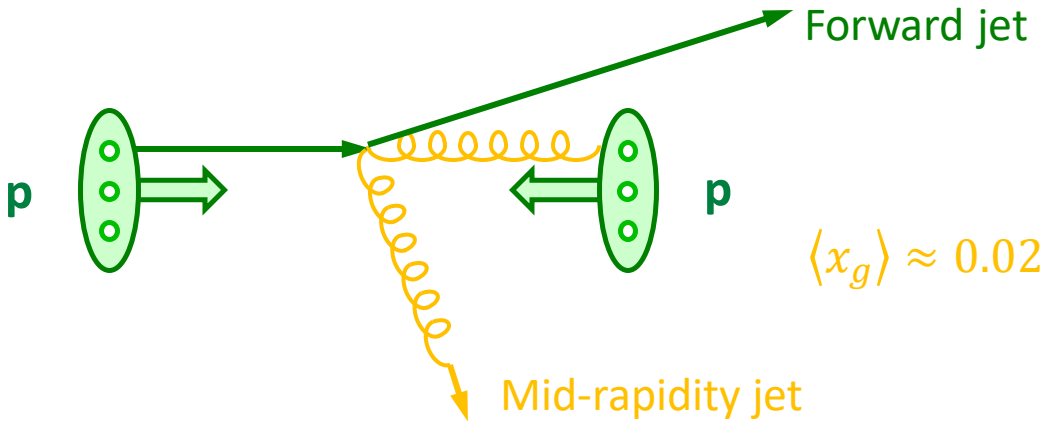




Back-to-back Correlations

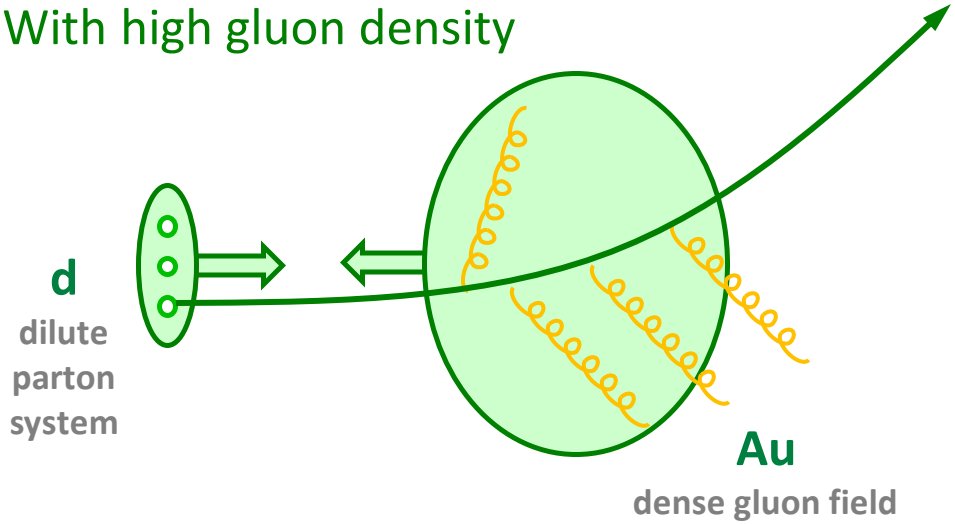
In $p + p$:

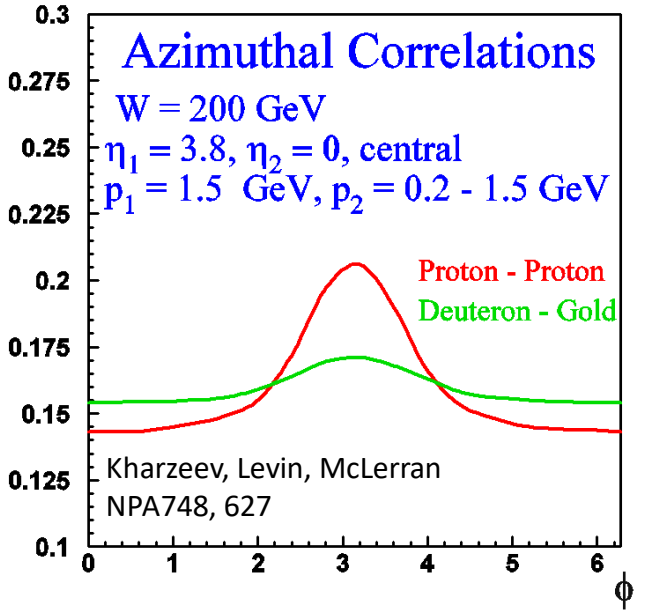
- pQCD $2 \rightarrow 2$ process
- Back-to-back dijet



$\langle x_g \rangle \approx 0.02$

- With high gluon density

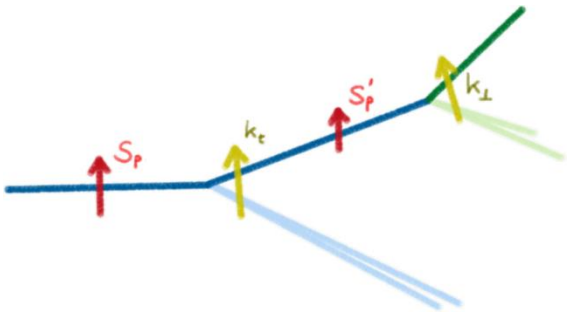


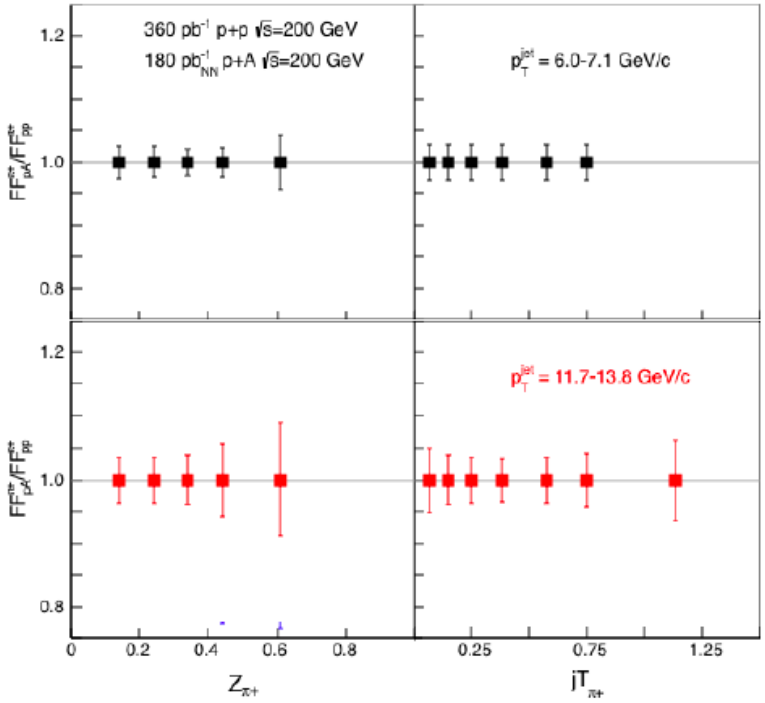


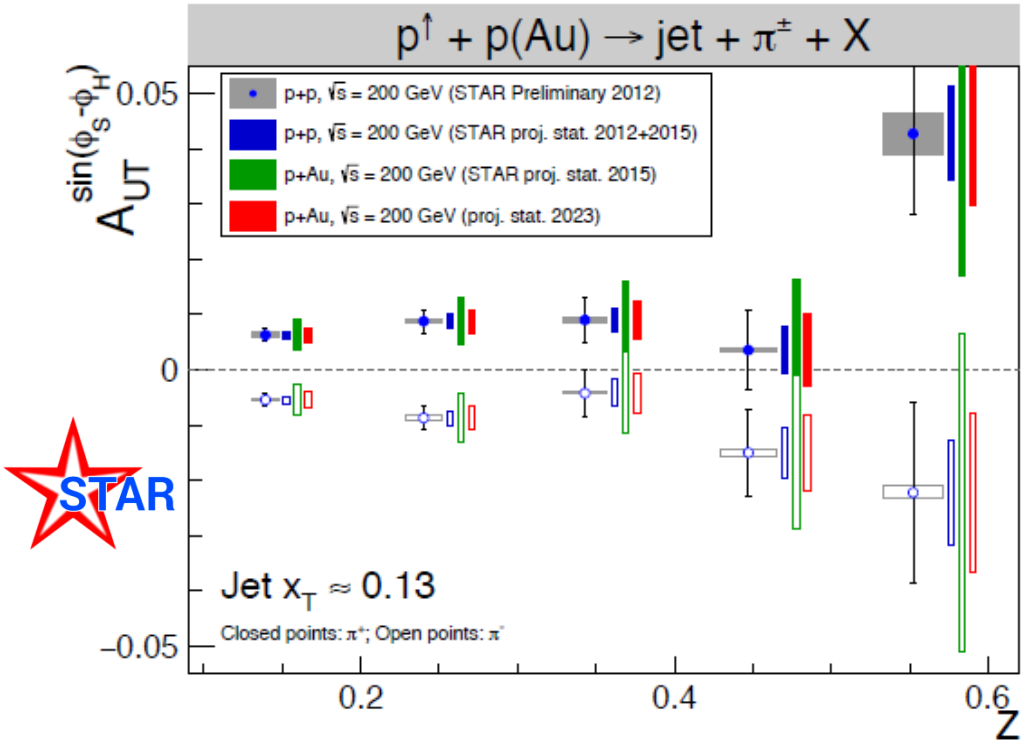
- Monojet: p_T is balanced by many gluons
- Color Glass Condensate predicts suppression of back-to-back correlation
- Forward kinematics: $x_g \approx 10^{-3} \sim 10^{-4}$ ($p + A \rightarrow \pi^0 + \pi^0$ in FMS)

Nuclear Fragmentation Functions

- Identified hadron in jet: e^+e^-, SIDIS, $p+p$
- Unique: gluon fragmentation in $p+p/A$
- Test universality: $e+A$ and $p+A$
- Spin dependent fragmentation (Collins effect)







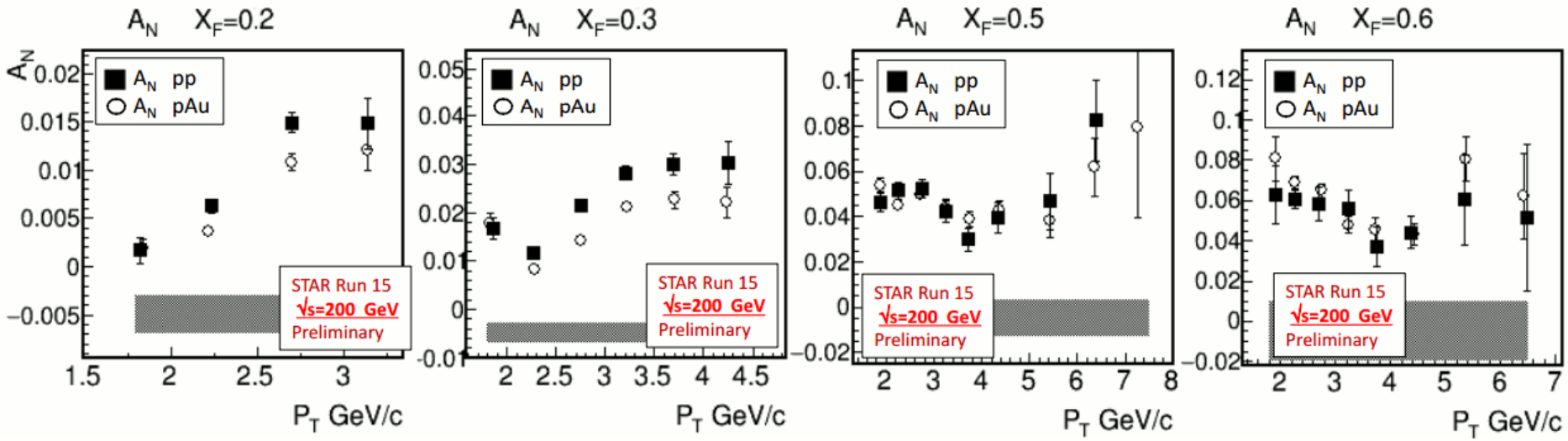
Nuclear Effects in $A_N(\pi^0)$

- Polarized: Transverse spin asymmetries
- RHIC Run 2015
  - $\vec{p}+p/\ \vec{p}+Al\ /\ \vec{p}+Au$
- Nuclear effects on fragmentation process
- Possibly gluon saturation effects (CGC)

STAR FMS

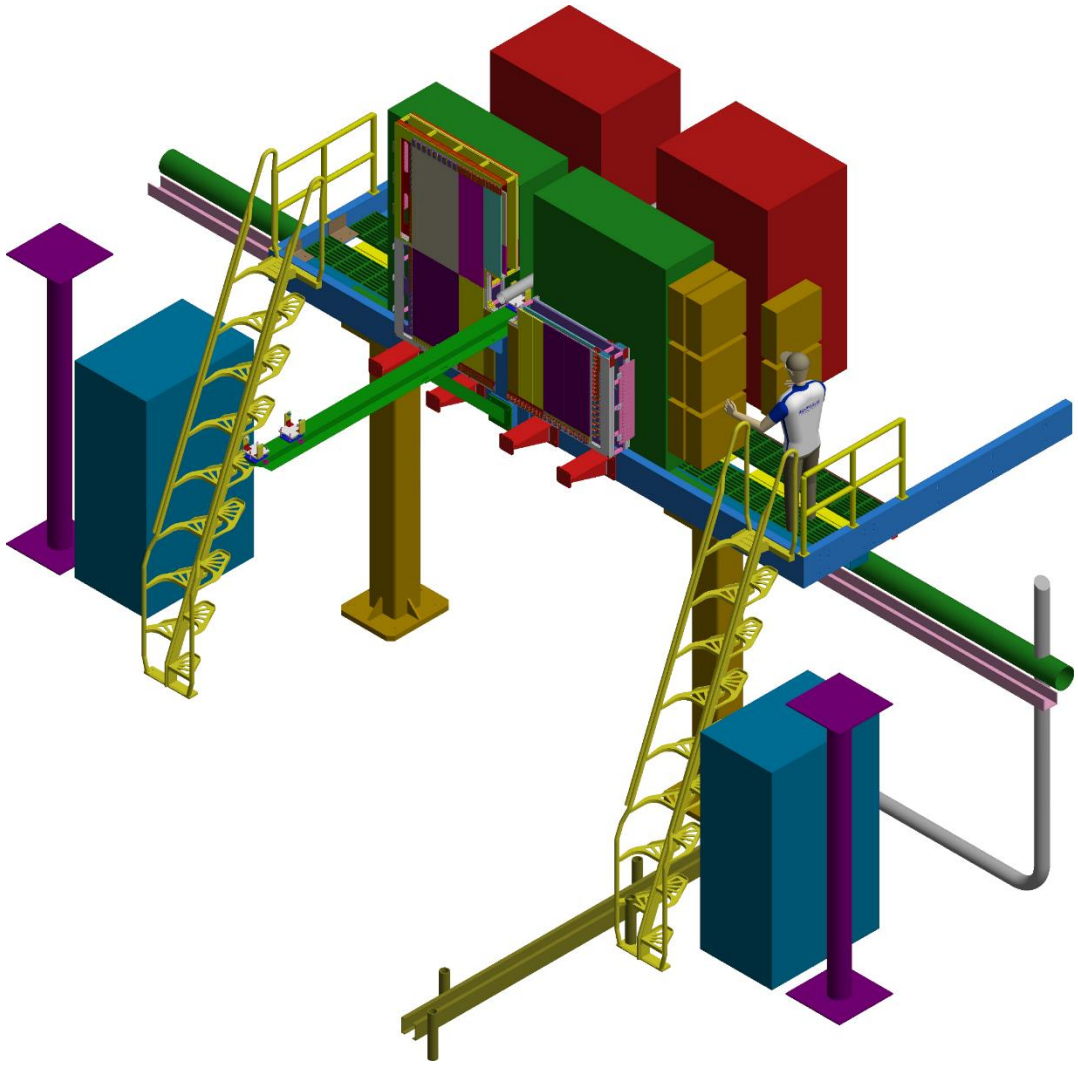
$2.5 < \eta_p < 4.0$

$p+p\ @\ \sqrt{s} = 200\ \mathrm{GeV}$



No suppression can be observed so far.

Forward Calorimeter Upgrade in STAR



Forward rapidities

- $2.3 < \eta < 4.0$

Preshower detector

EM calorimeter

- PHENIX PbSc

Hadronic calorimeter

- $L = 4 \cdot \lambda_I$

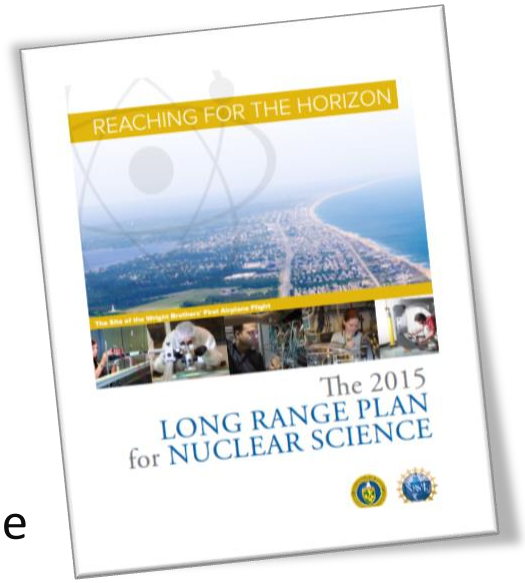
Four additional layers of Si strip trackers (within magnet / central barrel)

RHIC Cold QCD Schedule

Year	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
2017	$p^{\uparrow}p$ @ 510	400 pb^{-1} 12 weeks	Sensitive to Sivers effect non-universality through TMDs and Twist-3 $T_{q,F}(x,x)$ Sensitive to sea quark Sivers or ETQS function Evolution in TMD and Twist-3 formalism	A_N for γ, $W^{\pm}$, Z^0, DY	A_N^{DY}: Postshower to FMS@STAR
			Transversity, Collins FF, linearly pol. Gluons, Gluon Sivers in Twist-3	$A_{UT}^{\sin(\phi_s-2\phi_h)}$ $A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, $A_{UT}^{\sin(\phi_s)}$ for jets	None
			First look at GPD Eg	A_{UT} for J/Ψ in UPC	None
2023	$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Yes Forward instrum.
			evolution of ETQS fct. properties and nature of the diffractive exchange in p+p collisions.	A_N for γ A_N for diffractive events	None None
2023	$p^{\uparrow}Au$ @ 200	1.8 pb^{-1} 8 weeks	What is the nature of the initial state and hadronization in nuclear collisions	R_{pAu} direct photons and DY	R_{pAu}(DY):Yes Forward instrum.
			Nuclear dependence of TMDs and nFF	$A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF	None
			Clear signatures for Saturation	Dihadrons, γ-jet, h-jet, diffraction	Yes Forward instrum.
2023	$p^{\uparrow}Al$ @ 200	12.6 pb^{-1} 8 weeks	A-dependence of nPDF,	R_{pAl}: direct photons and DY	R_{pAl}(DY): Yes Forward instrum.
			A-dependence of TMDs and nFF	$A_{UT}^{\sin(\phi_s-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF	None
			A-dependence for Saturation	Dihadrons, γ-jet, h-jet, diffraction	Yes Forward instrum.

(* Beam energy scan II and full energy $Au + Au$ running not shown)

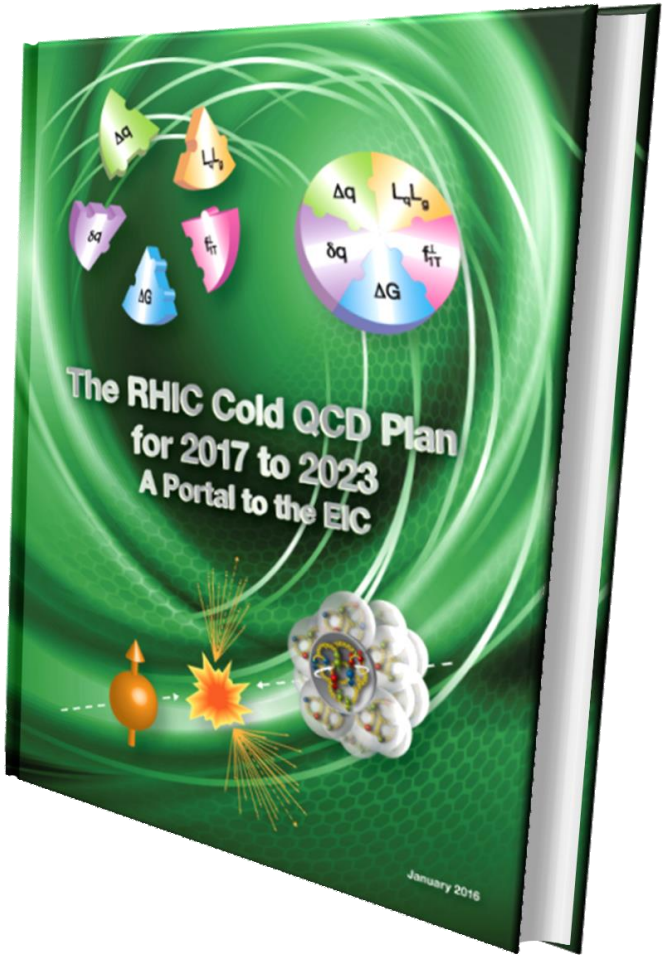
Summary



As recommended in the

- Utilize existing RHIC infrastructure
- Complete measurements that are unique in $p + p$ and $p + A$
- Pursue measurements that will optimize the program at a future electron-ion collider

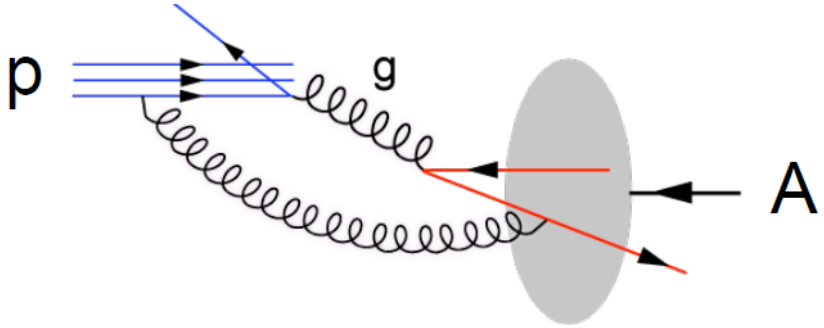
Additional investments in detector upgrades are necessary to complete these goals.

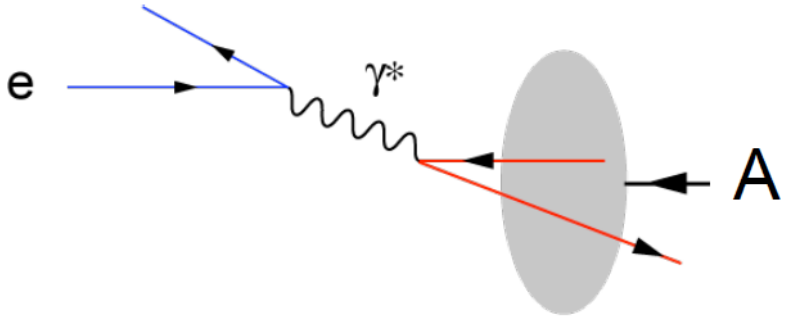


arxiv:1602.03922

BACK UP

Complementarity $p + A$ / $e + A$

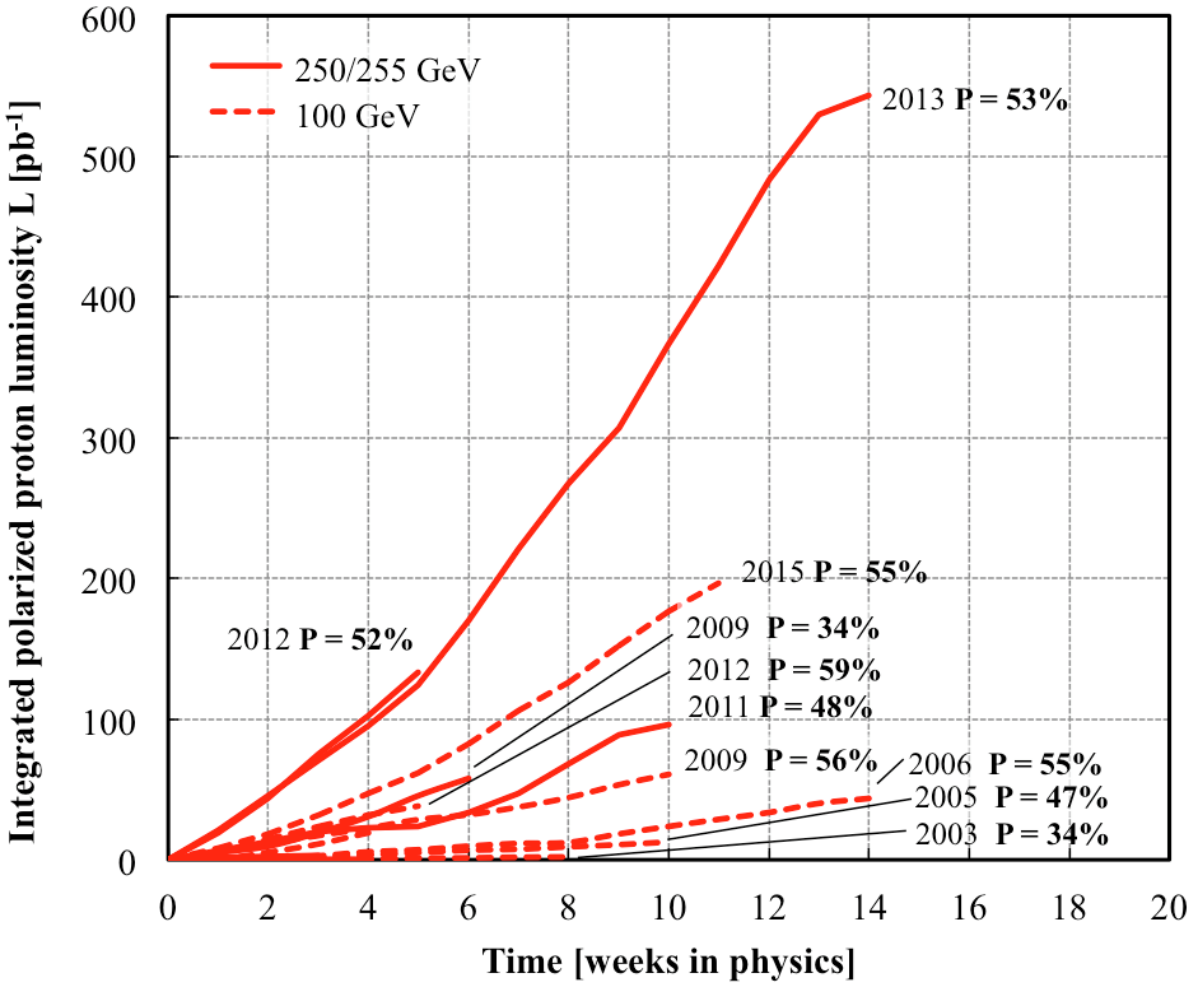




- Directly probing gluons
- Large cross-sections
- Initial state effects
- Cold nuclear matter energy loss
- Ridge
- Flow coefficients v_n
- Particle correlations
- Transverse momentum dependence

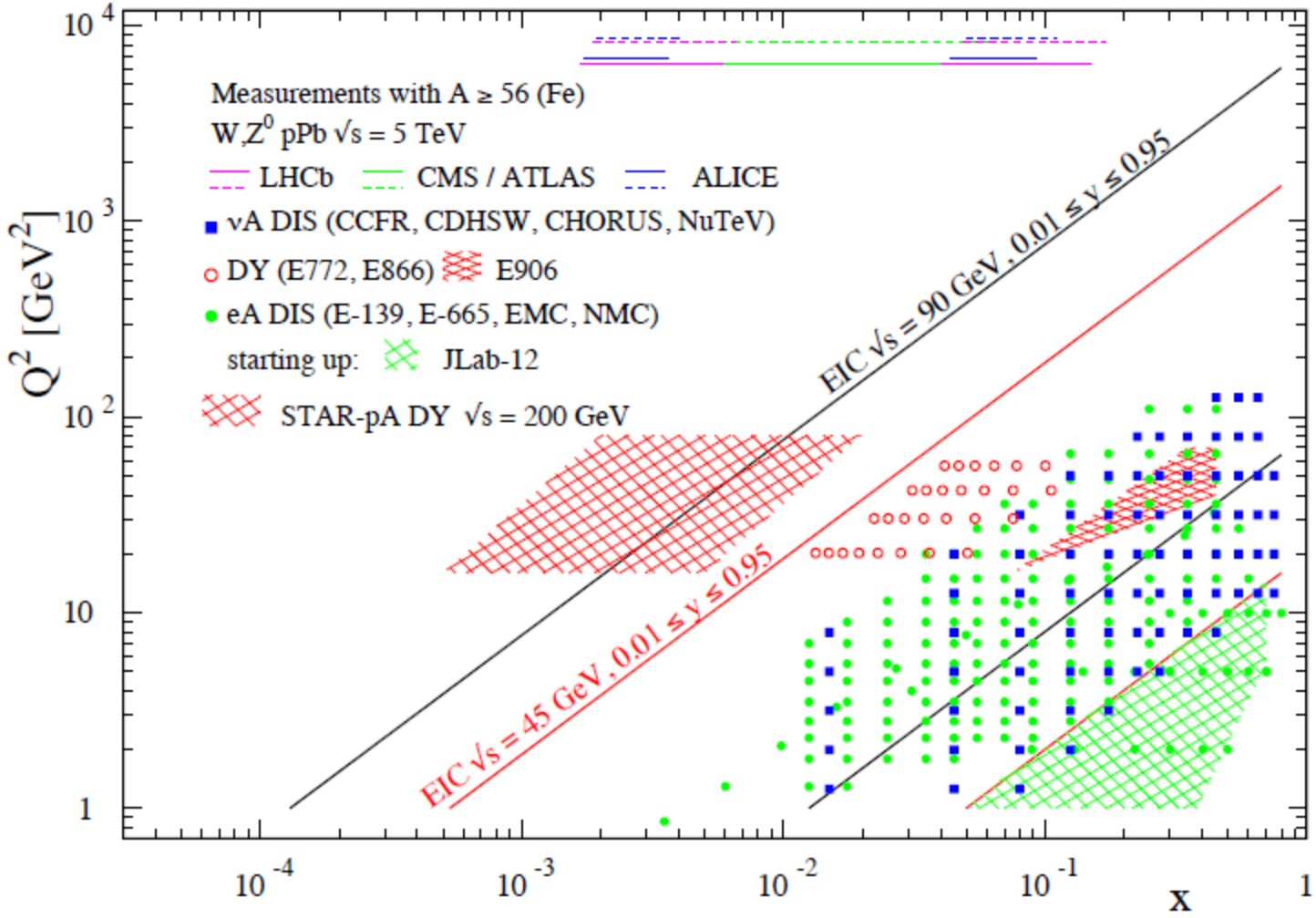
- High precision
- Partonic kinematics (Q^2, x, ν)
- Photoproduction
- Tagging of high N_{ch} events
- Ridge
- Flow coefficients v_n
- Particle correlations
- Transverse momentum dependence
- Spatial distributions

RHIC Performance



Consistent improvement in delivered luminosity and beam polarizations

Kinematic Coverage



Collins Fragmentation: $\sin \phi_S - \phi_H$