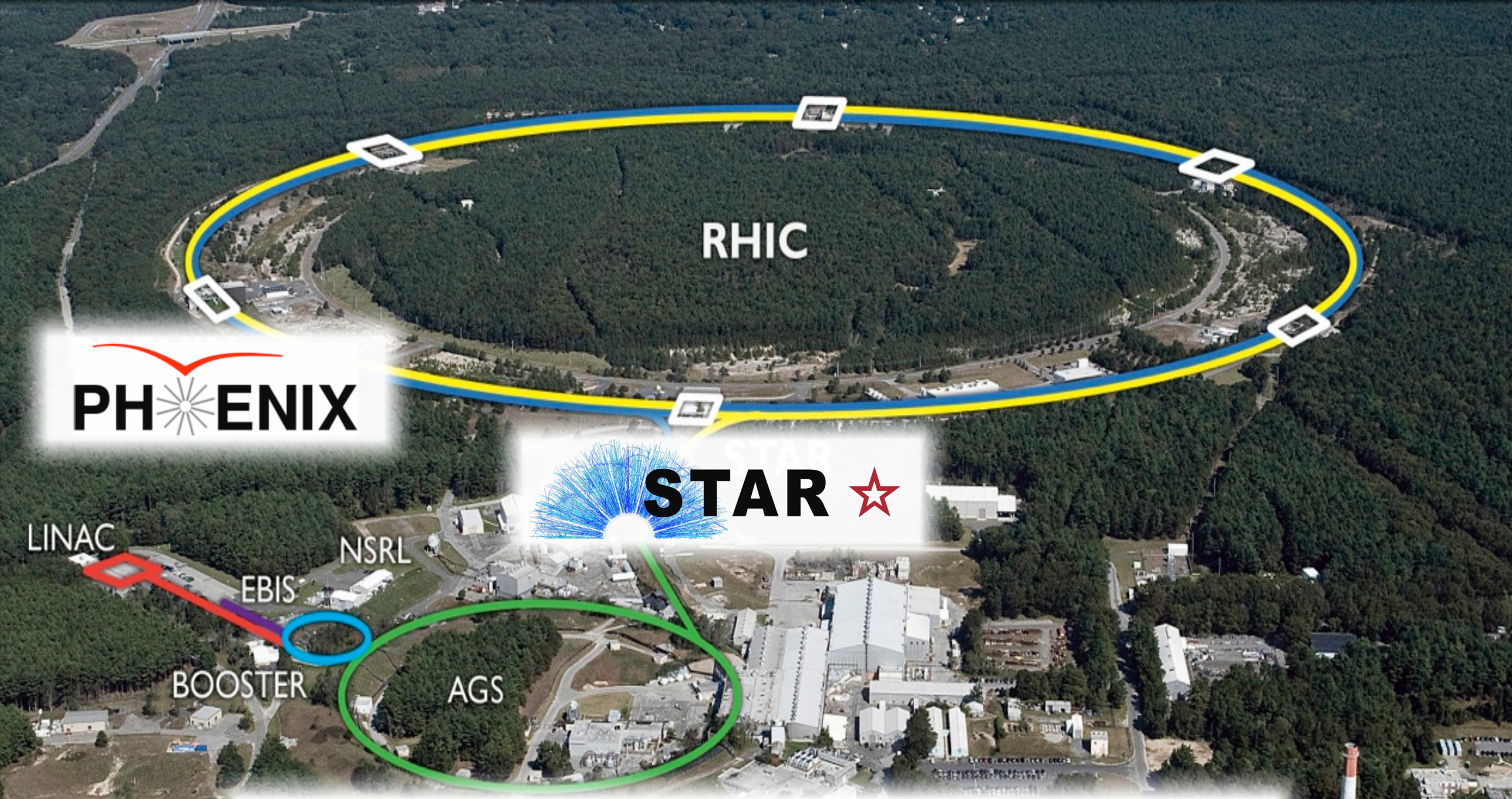


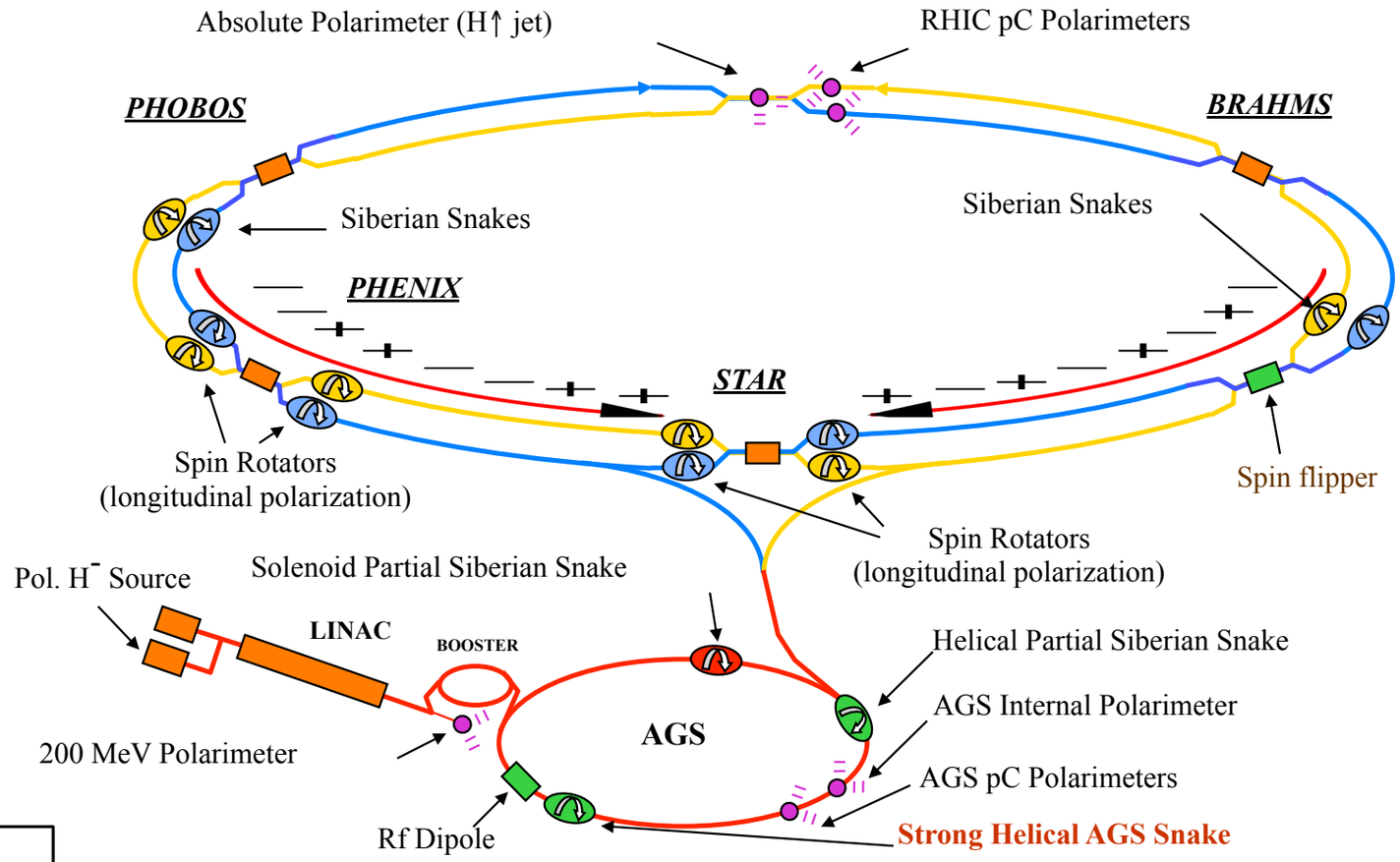
RHIC $\vec{p}+\vec{p}$ Future Plans

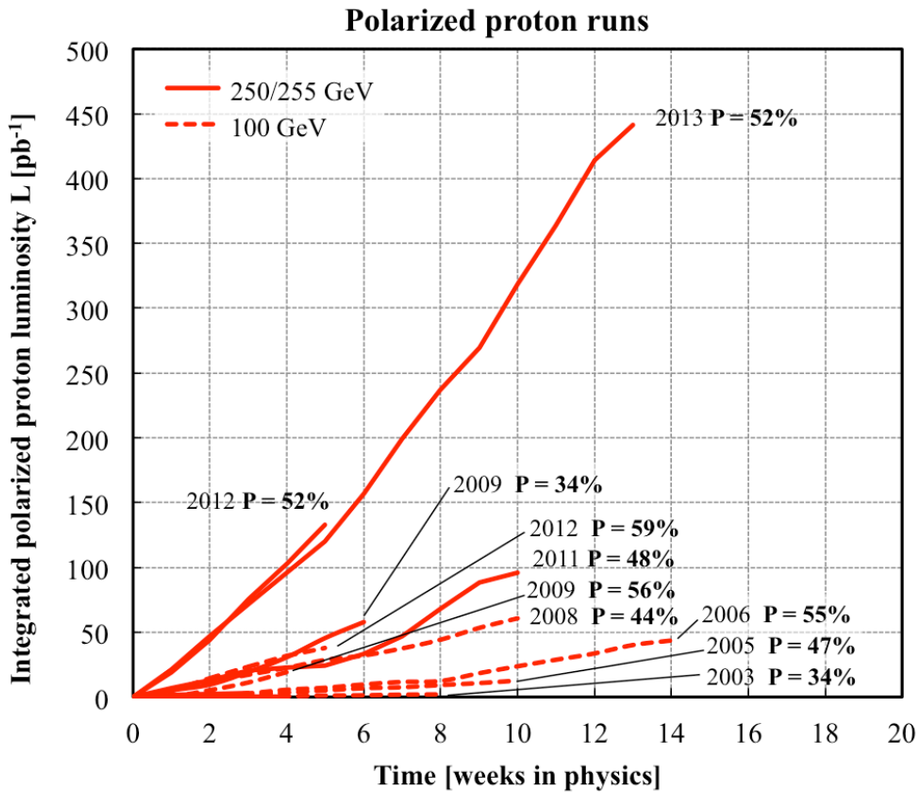
Justin Stevens

QCD Frontier 2013

RHIC Machine Overview

- Versatile accelerator complex with many ions used to date: $\vec{p}$, d, Cu, Au, U
- Wide range of $\sqrt{s}$ energies studied already
  - Au+Au: 7.7 - 200 GeV
  - $\vec{p}+\vec{p}$: 62.4 - 510 GeV



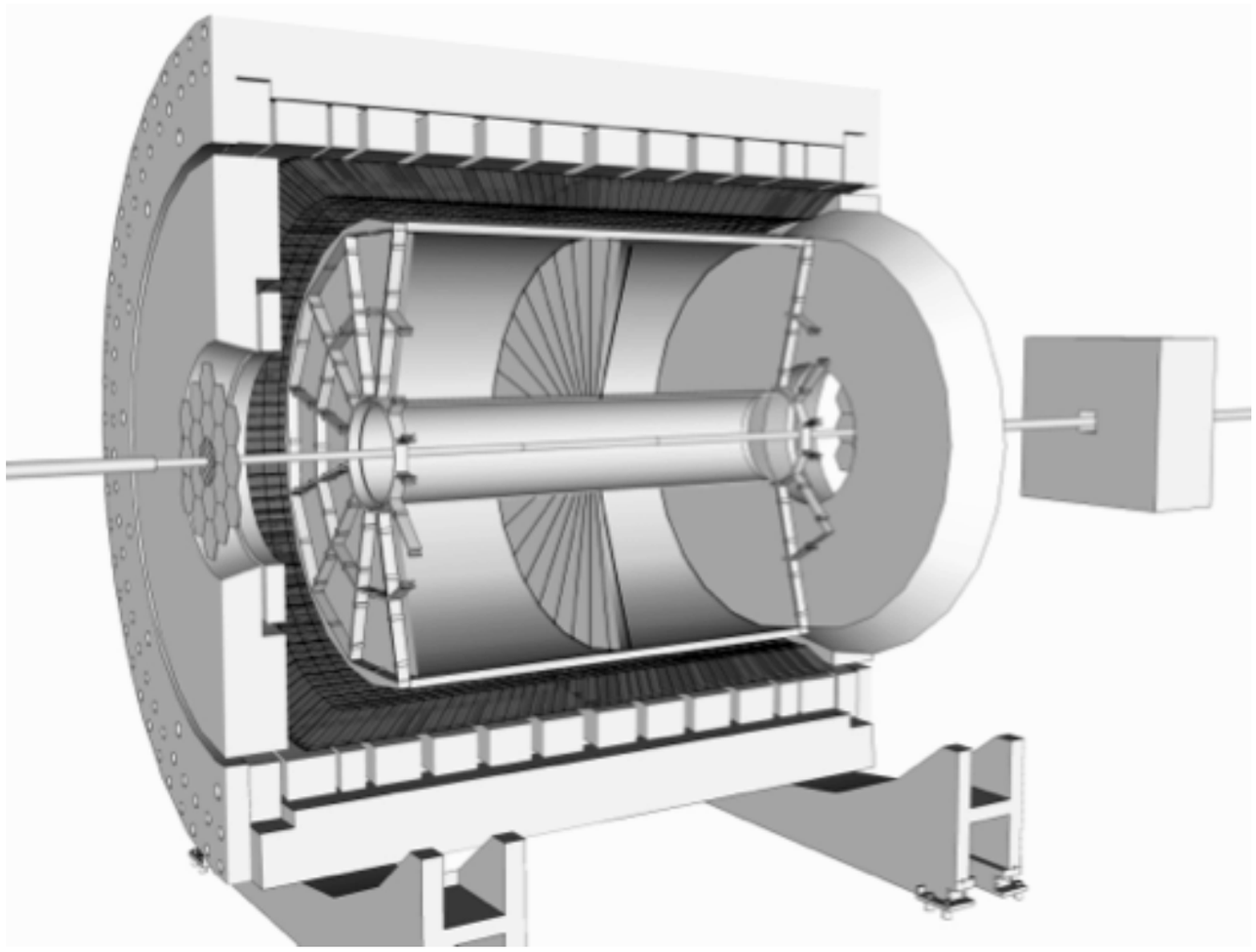


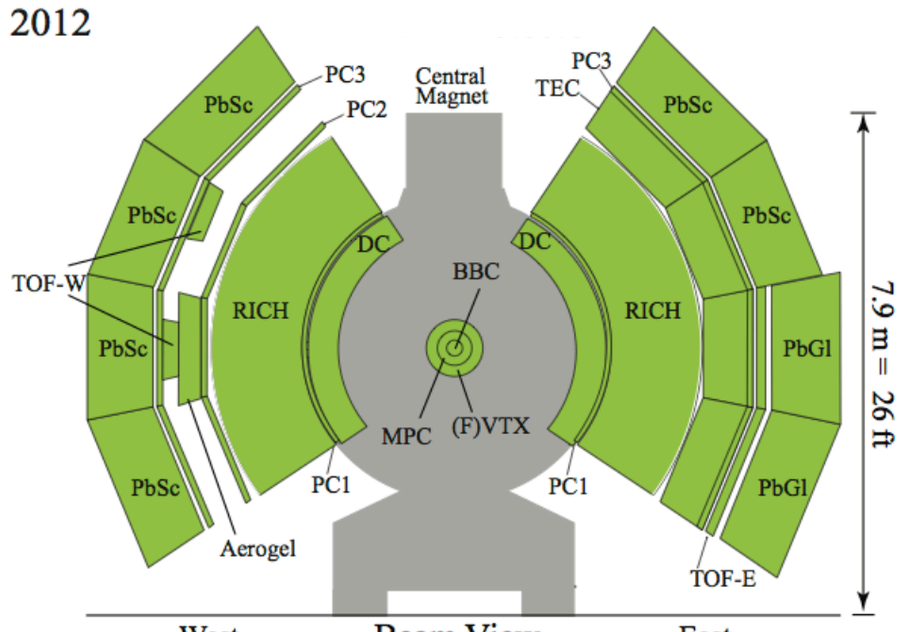
- Luminosity and polarization in recent years
  - 200 GeV: 8 pb^{-1}/week with P ≈ 63% (2012)
  - 500 GeV: 50 pb^{-1}/week with P ≈ 53% (2013)
- Electron-lens upgrades in 2014 to provide ~2x higher $\vec{p}+\vec{p}$ luminosity
- First polarized $\vec{p}$+A planned for 2015

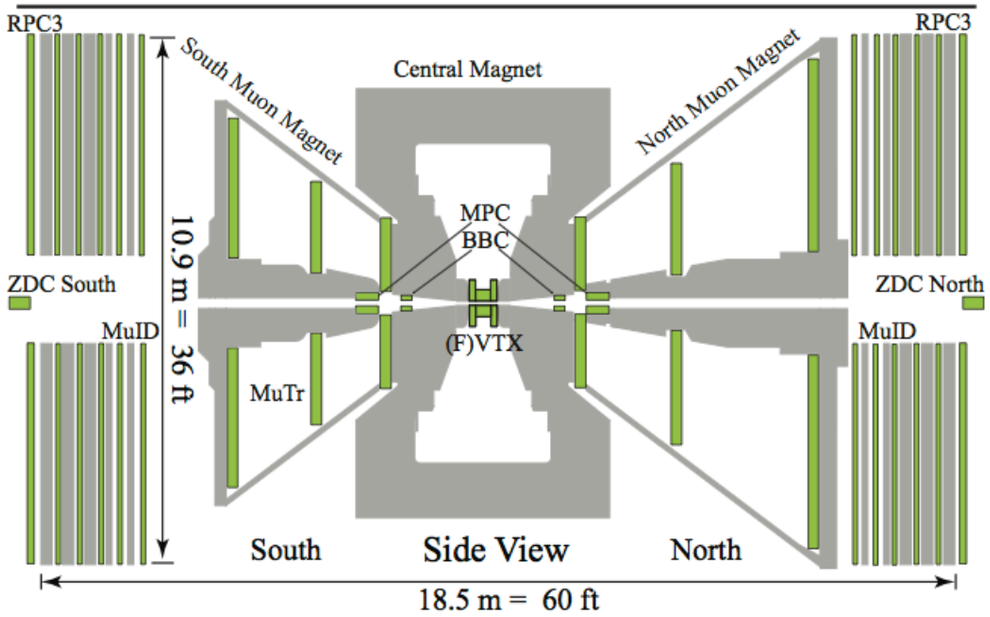
STAR and PHENIX Detectors

STAR ☆

PHENIX

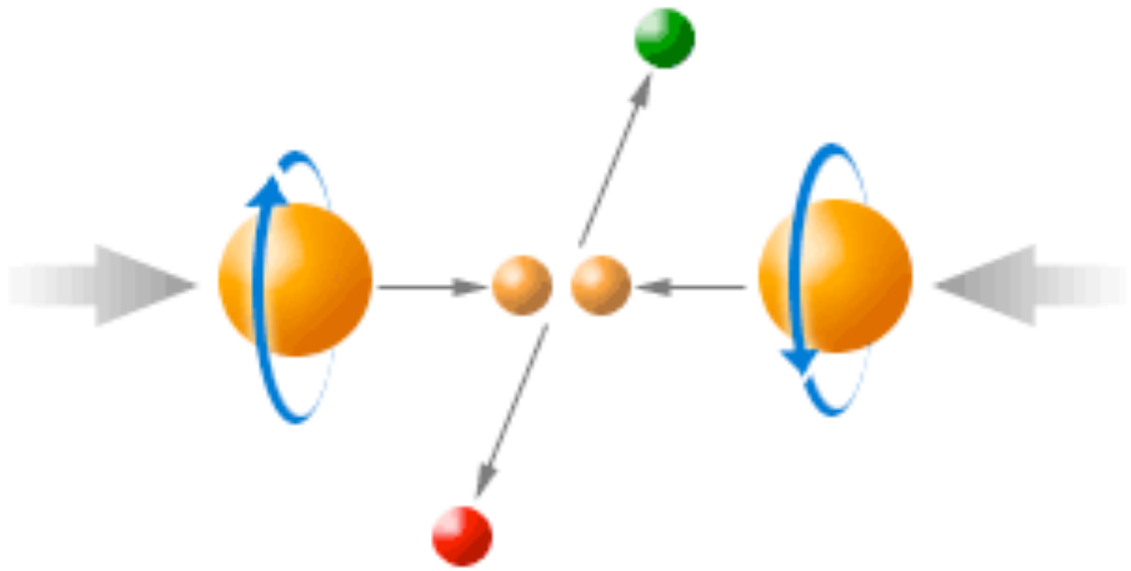




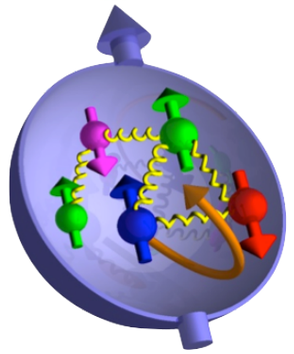


- Complementary strengths in the current detector systems
- Future upgrades at forward rapidity required for some measurements

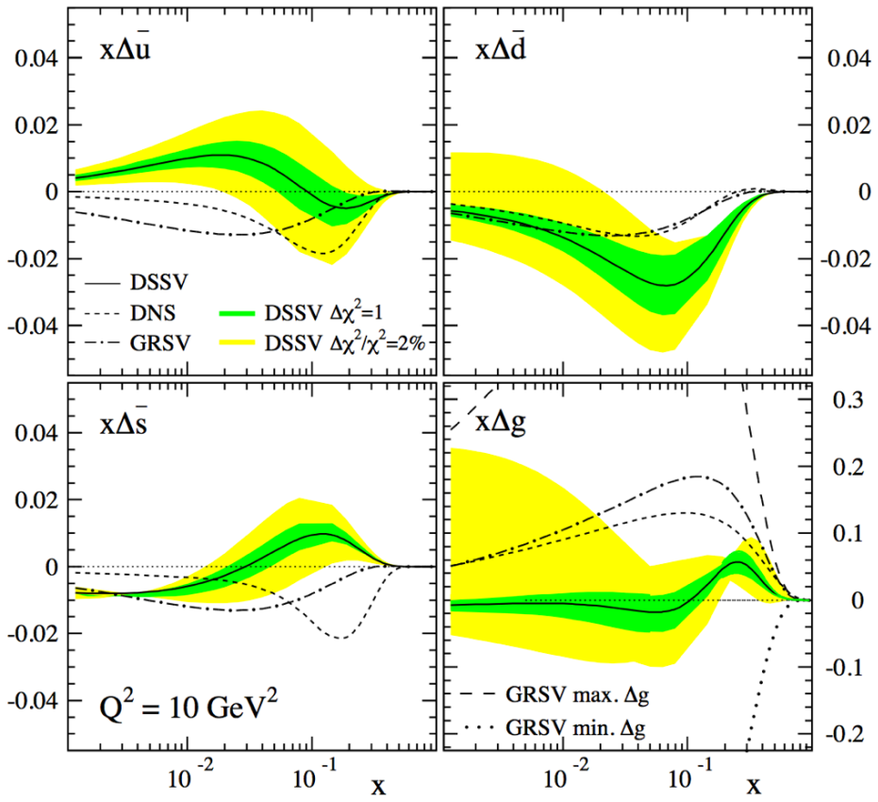
Helicity Structure of the Proton



Proton Spin Puzzle



DSSV 2008 Global Analysis



PRL **101**, 072001 (2008)
PRD **80**, 034030 (2009)

$$\langle S_p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

$$\Delta\Sigma = \int \left(\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}\right) dx$$

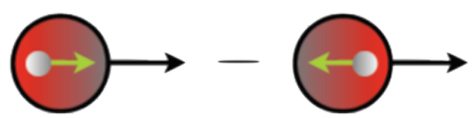
Integral of quark polarization is well measured in DIS to be ~30%; current decomposition from SIDIS but sea not well constrained

$$\Delta G = \int \Delta g\,(x)\, dx$$

Directly probed in polarized proton collisions at RHIC

Helicity PDF

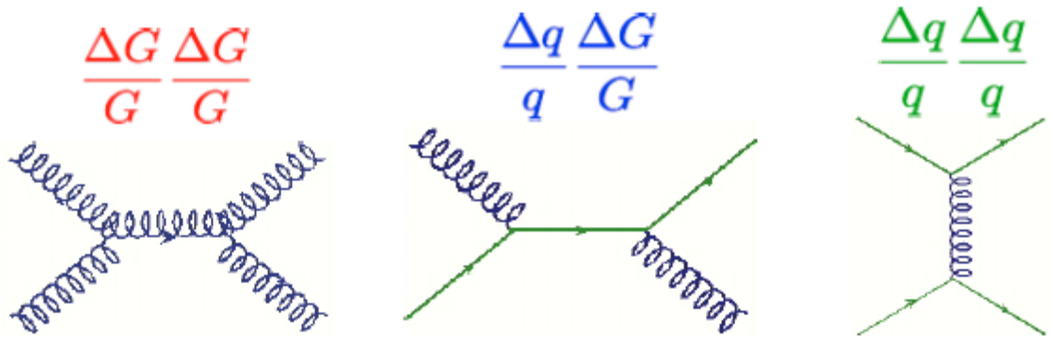
$$\Delta f(x) =$$

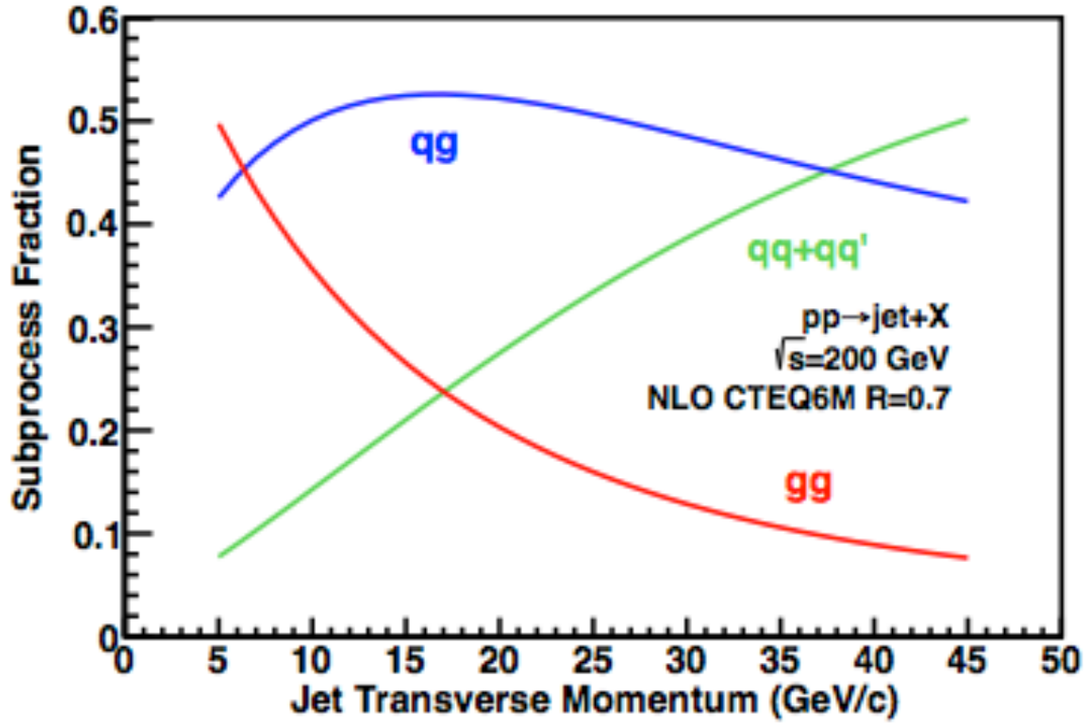


$$f^{+}(x) - f^{-}(x)$$

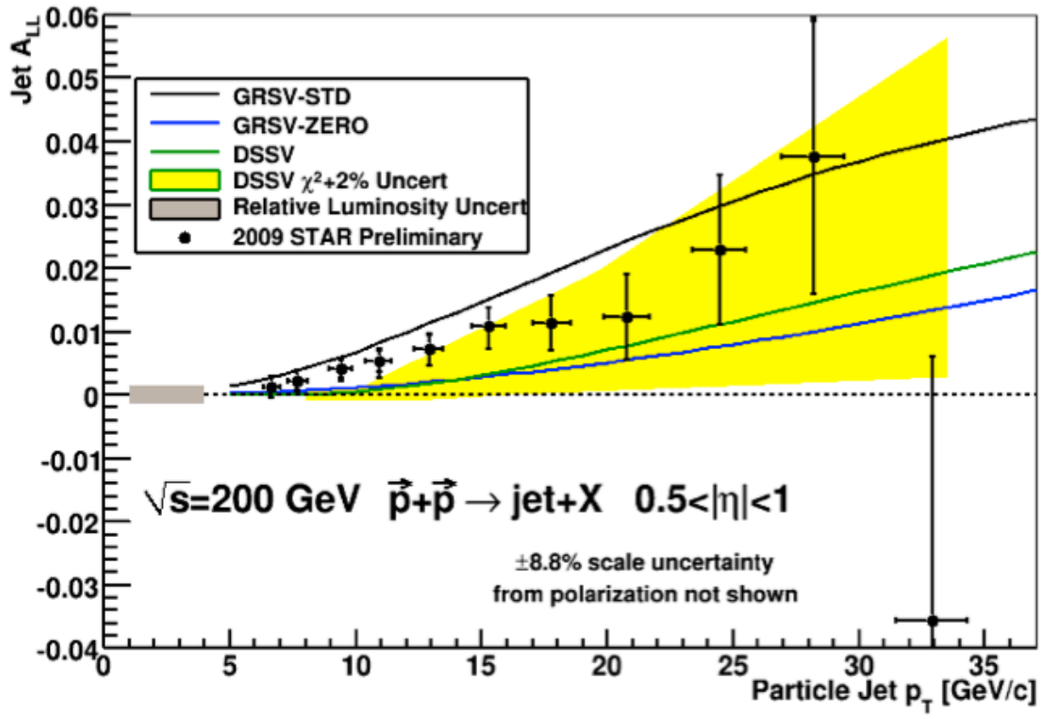
Gluon polarization

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

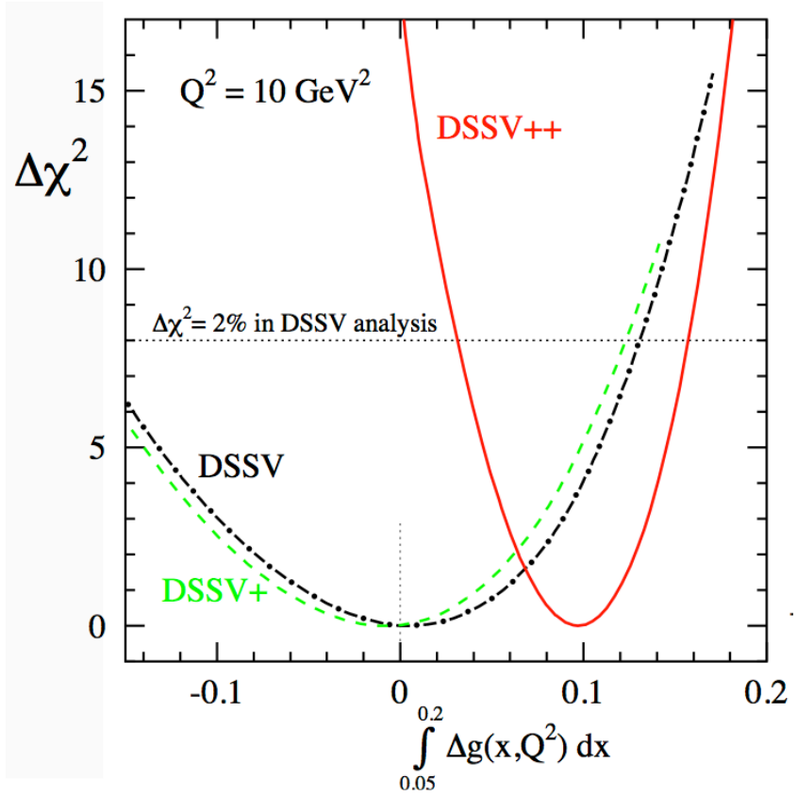


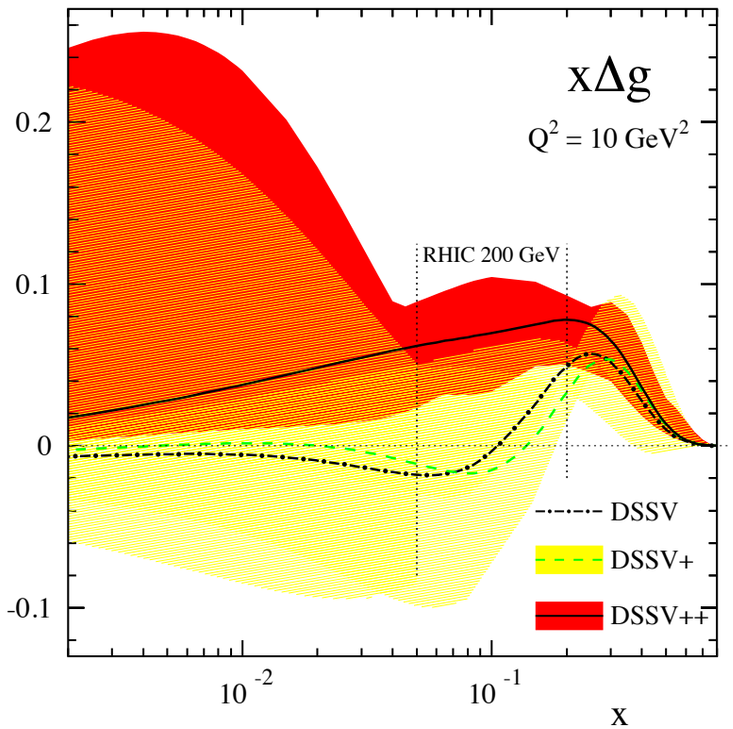


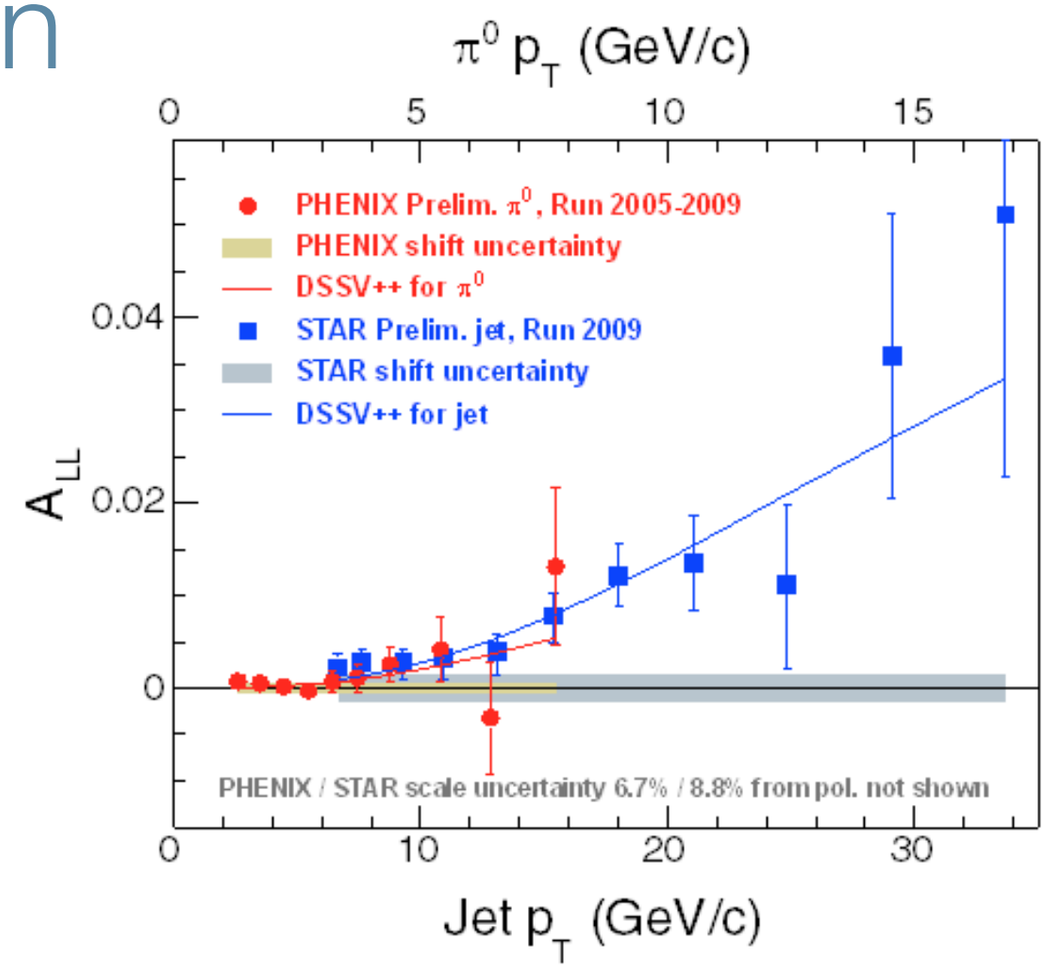
- For most of the RHIC kinematics, **qg** and **gg** dominate, making A_{LL} for inclusive probes (jets, π^0s, etc) sensitive to gluon polarization
- 2009 data from RHIC lie above the DSSV 2008 curve, but what does it mean for Δg?



Gluon polarization







- DSSV++ is a new, preliminary global analysis from the DSSV group which includes 2009 preliminary PHENIX and STAR A_{LL} data

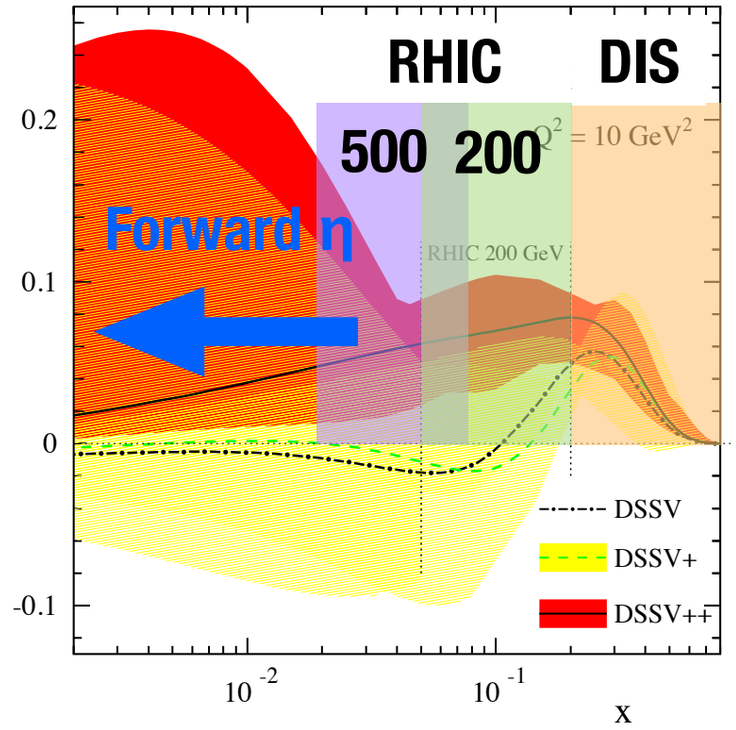
$$\int_{0.05}^{0.2} \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2)\,dx = 0.10^{+0.06}_{-0.07}$$

- First experimental evidence of non-zero gluon polarization in the RHIC range ($0.05 < x < 0.2$)

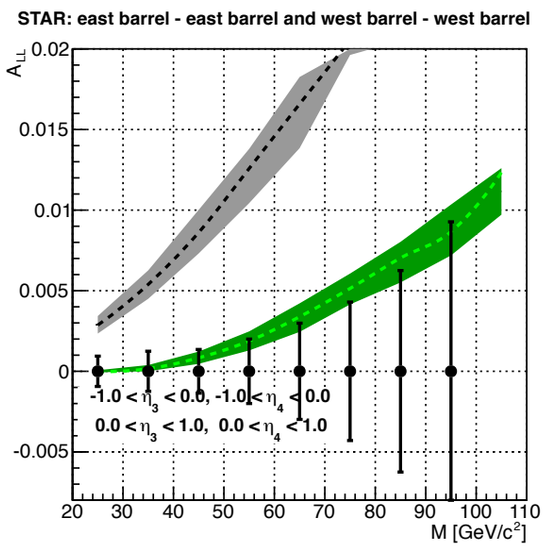
Gluon polarization: low-x_g

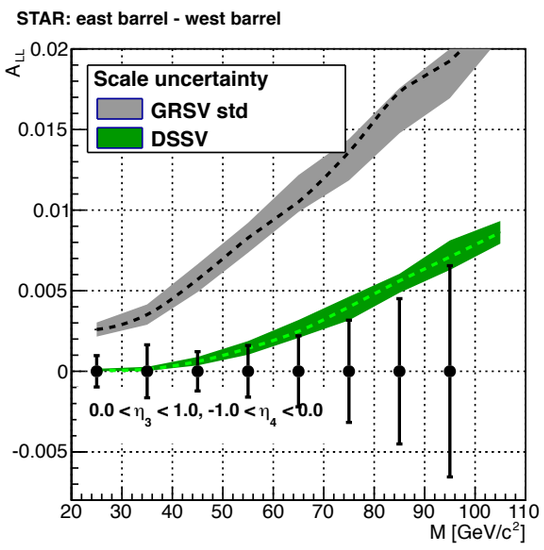
- Higher $\sqrt{s}$ and forward rapidities probe the low-x_g region
- Correlated probes are sensitive to the x dependence of Δg
- 2011-2013 collected large dataset at $\sqrt{s}$ = 500 GeV

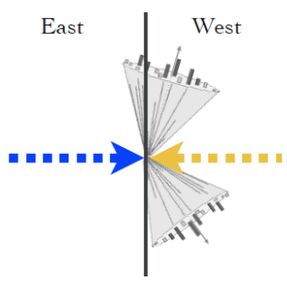
$$x_1, x_2 = \frac{M}{\sqrt{s}} \exp\left(\pm \frac{\eta_3 + \eta_4}{2}\right)$$

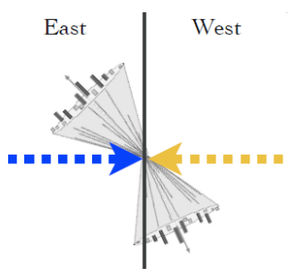


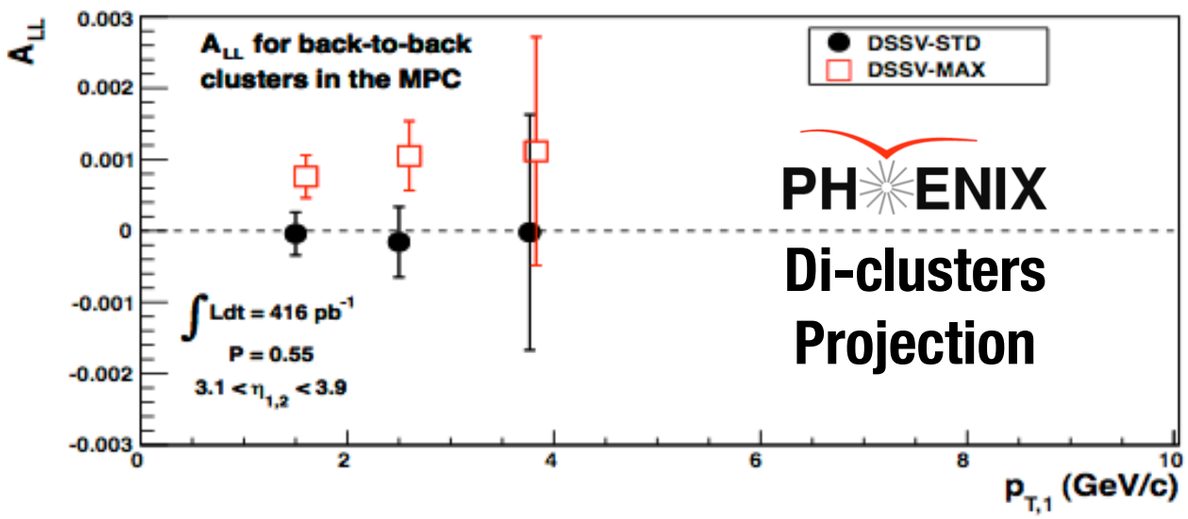
STAR Di-jet Projection

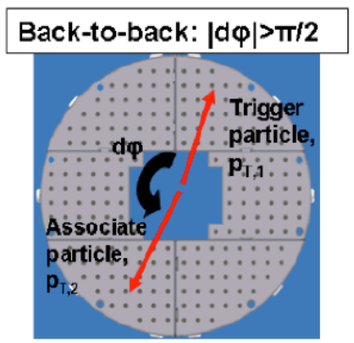


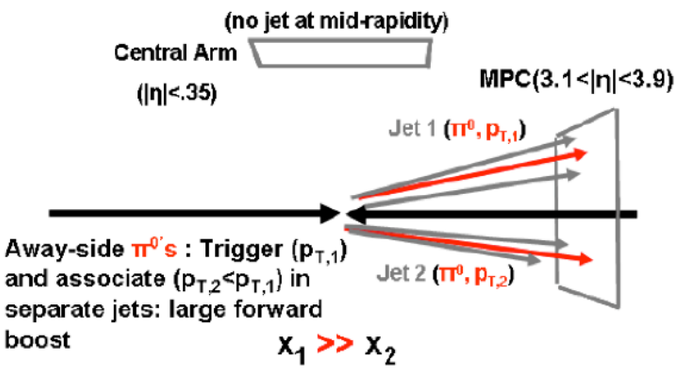






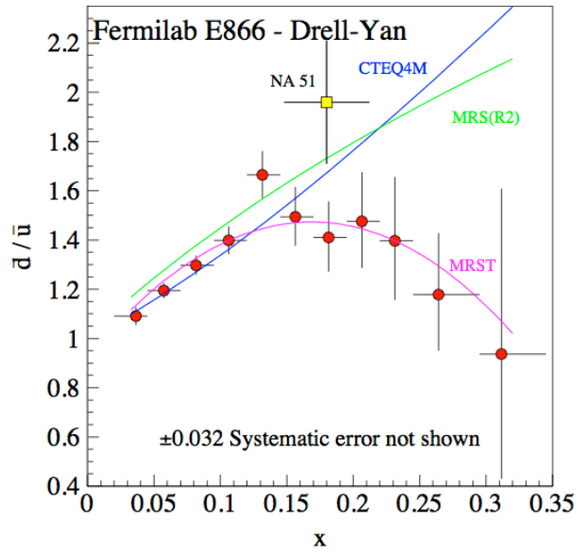


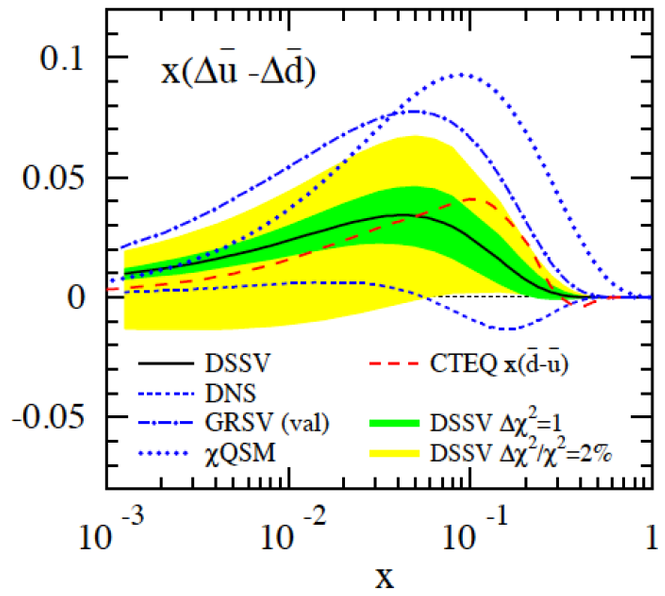




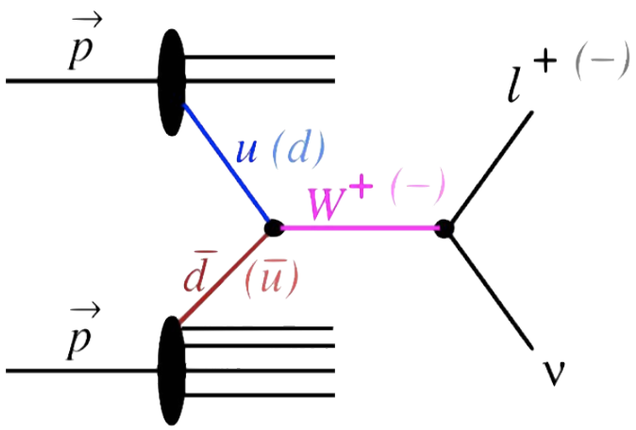
Sea Quark Flavor Asymmetry

- Flavor asymmetry $\bar{d}/\bar{u}$ observed in unpolarized Drell-Yan
- Polarized flavor asymmetry not well constrained





W production



- Ws couple directly to the quarks and antiquarks of interest
- V-A coupling of the weak interaction leads to perfect spin separation

Measure single-spin asymmetry:

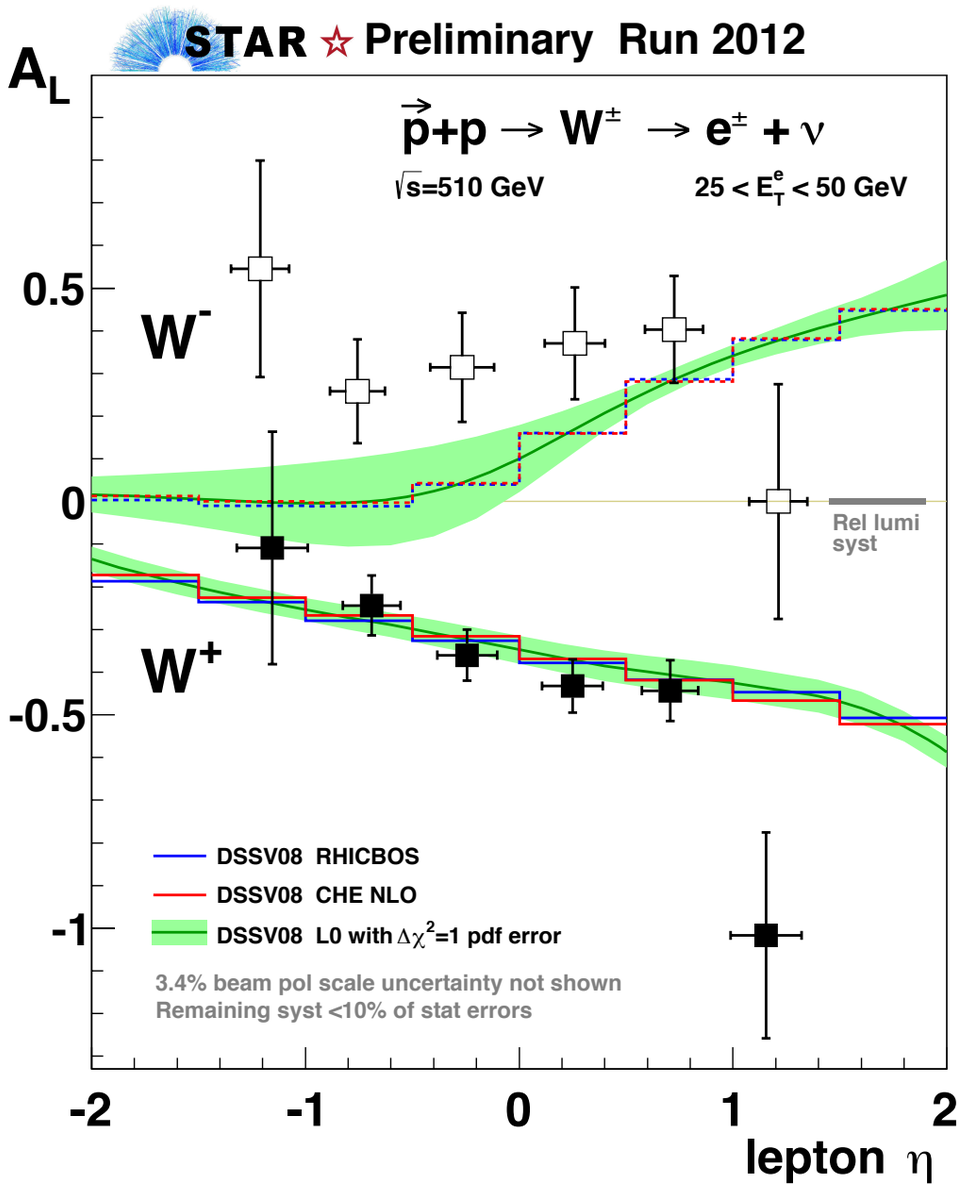
(Helicity flip in one beam while averaging over the other)

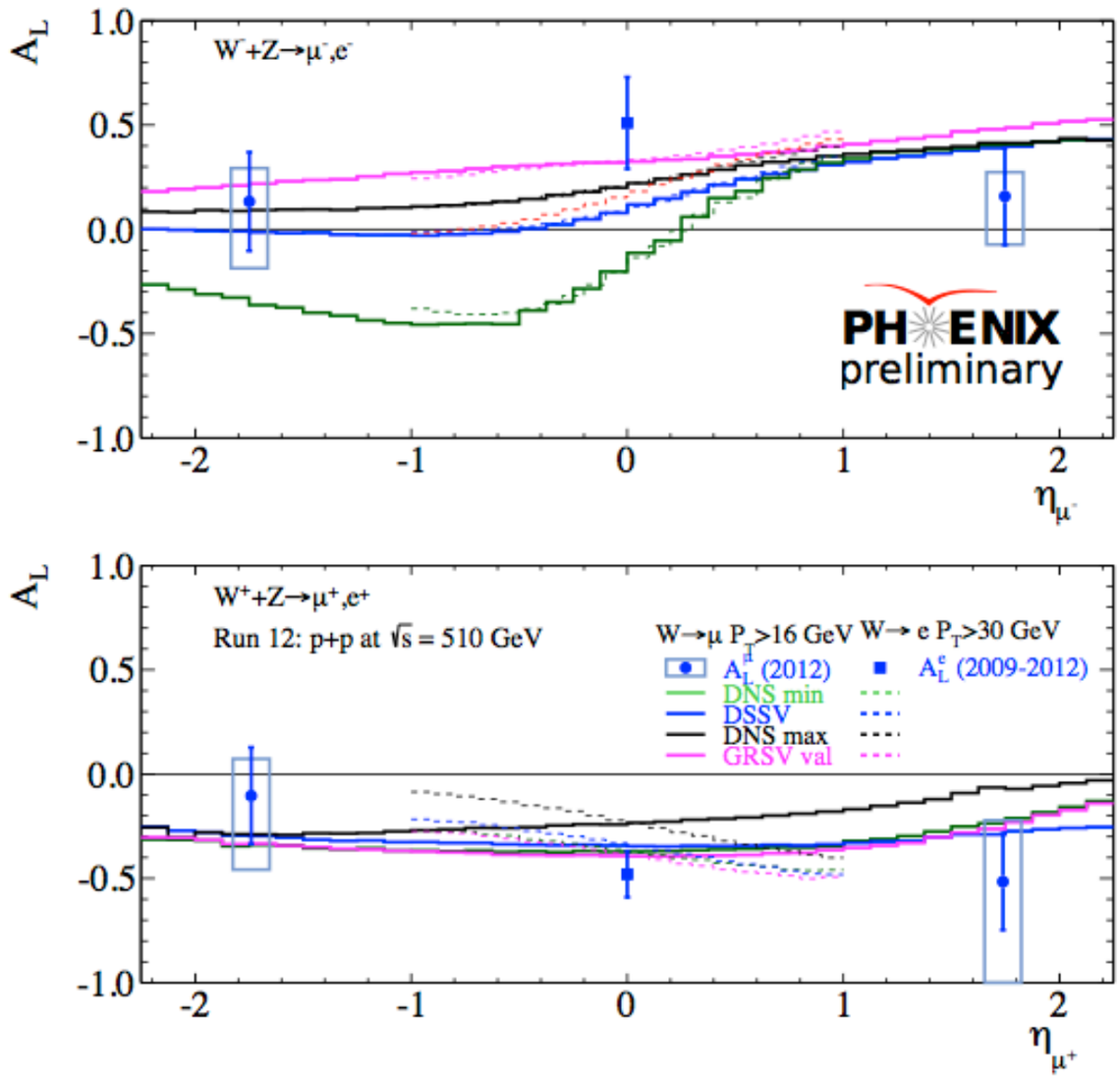
$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

$$A_L^{W-} \propto \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

$$A_L^{W+} \propto \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

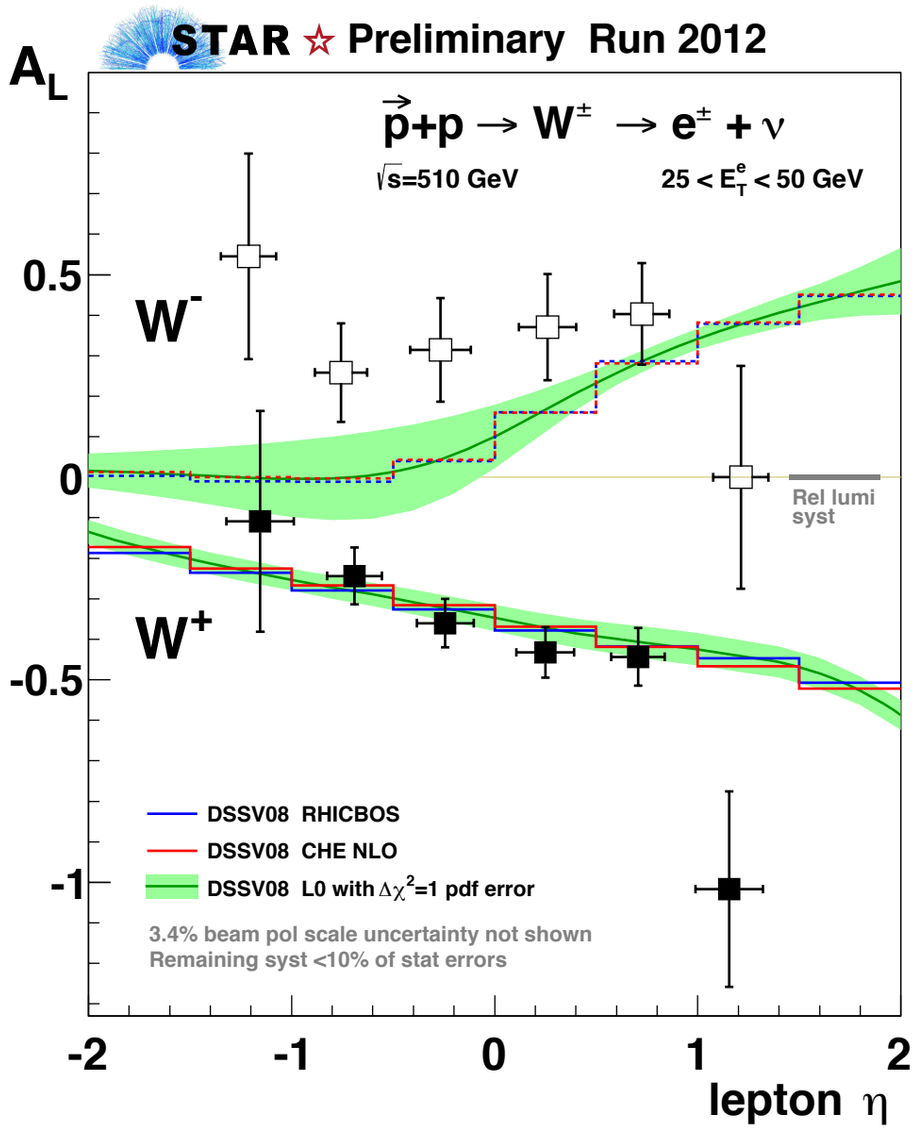
Recent Results for W $A_L(\eta)$

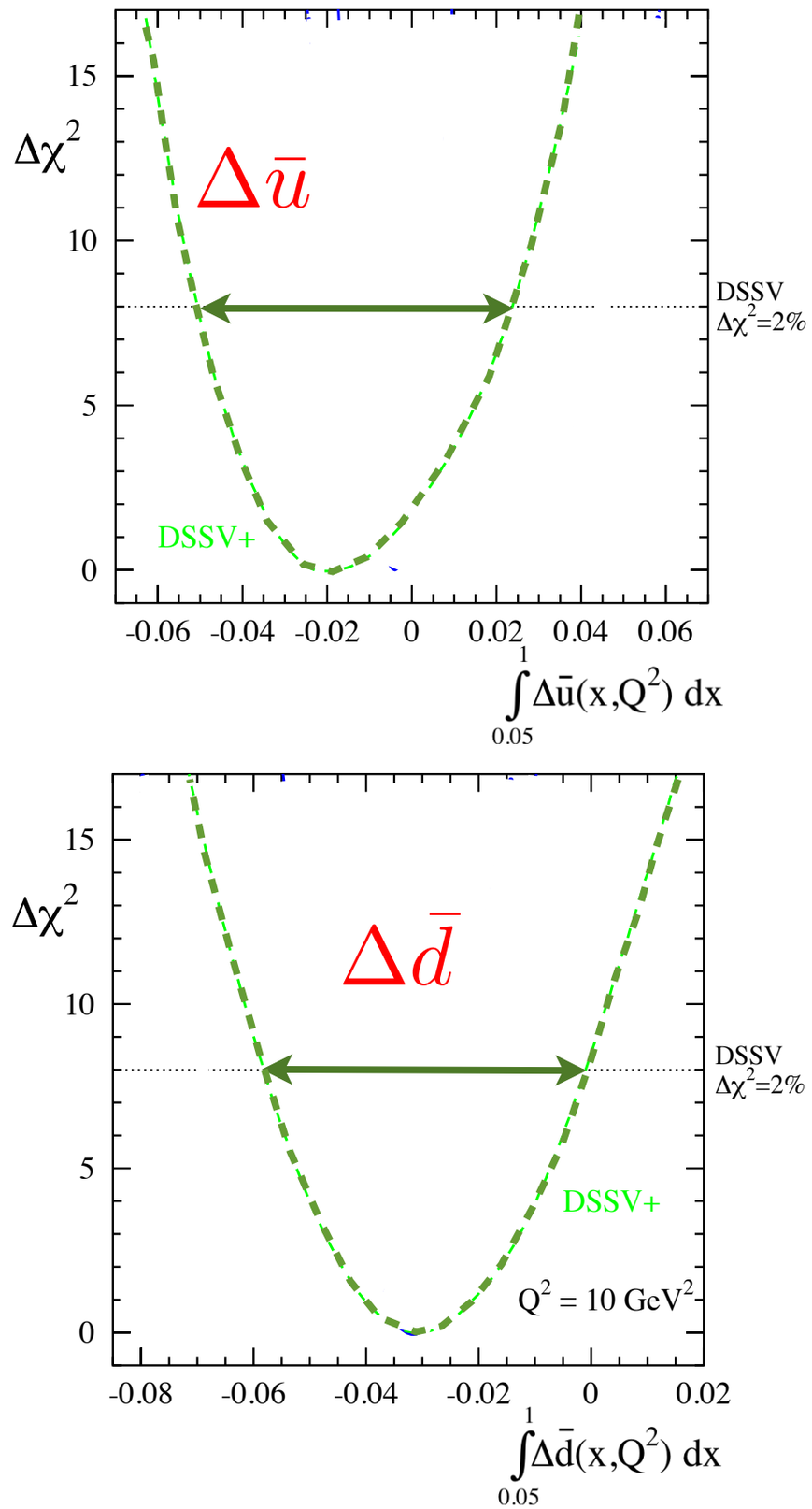




- First measurement of the rapidity dependence of W A_L from 2012 data
- Complementary results from PHENIX and STAR at different rapidities

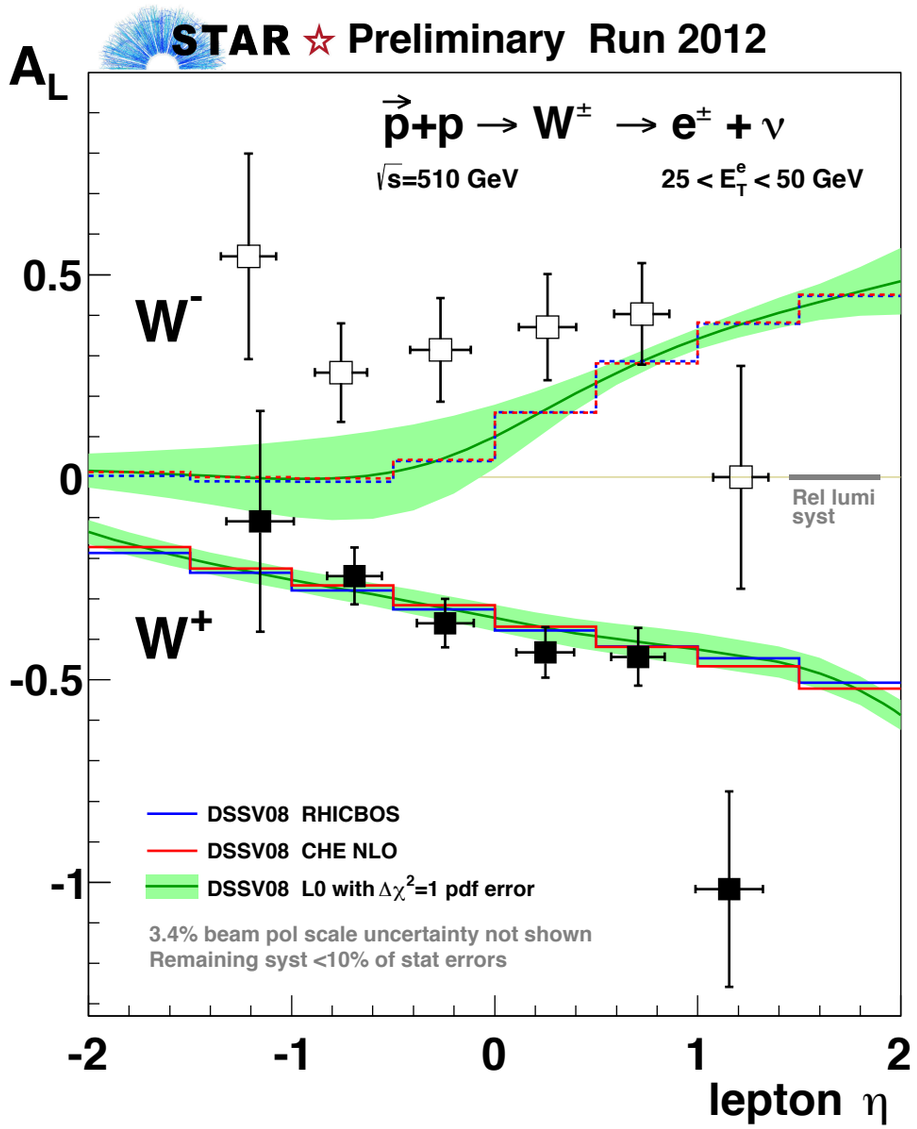
Sea Quark Polarization

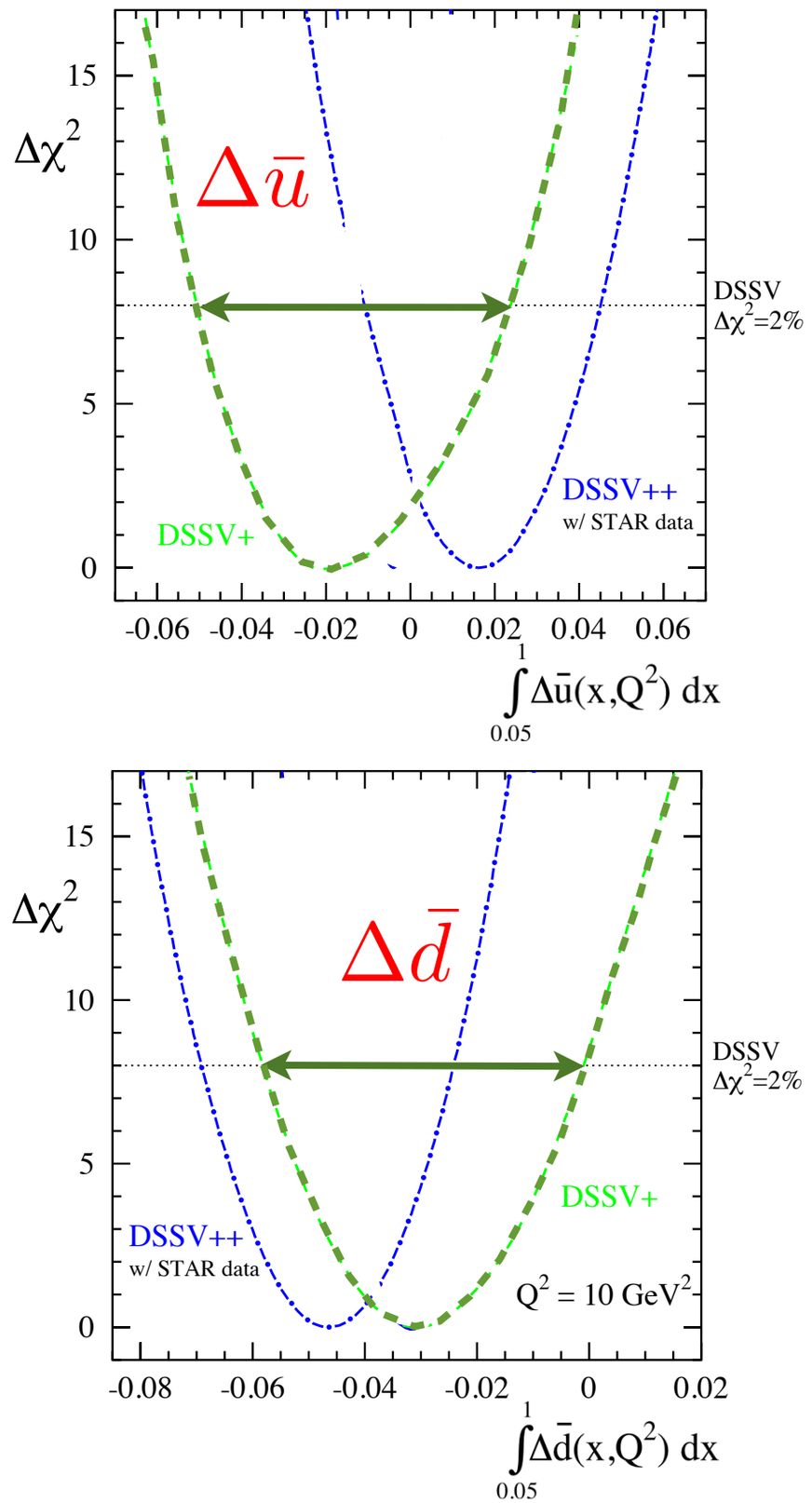




- DSSV++ is a new, preliminary global analysis from the DSSV group which includes 2012 STAR W A_L
- Higher precision data already collected in 2013 will further improve the constraints on the sea quark polarization

Sea Quark Polarization





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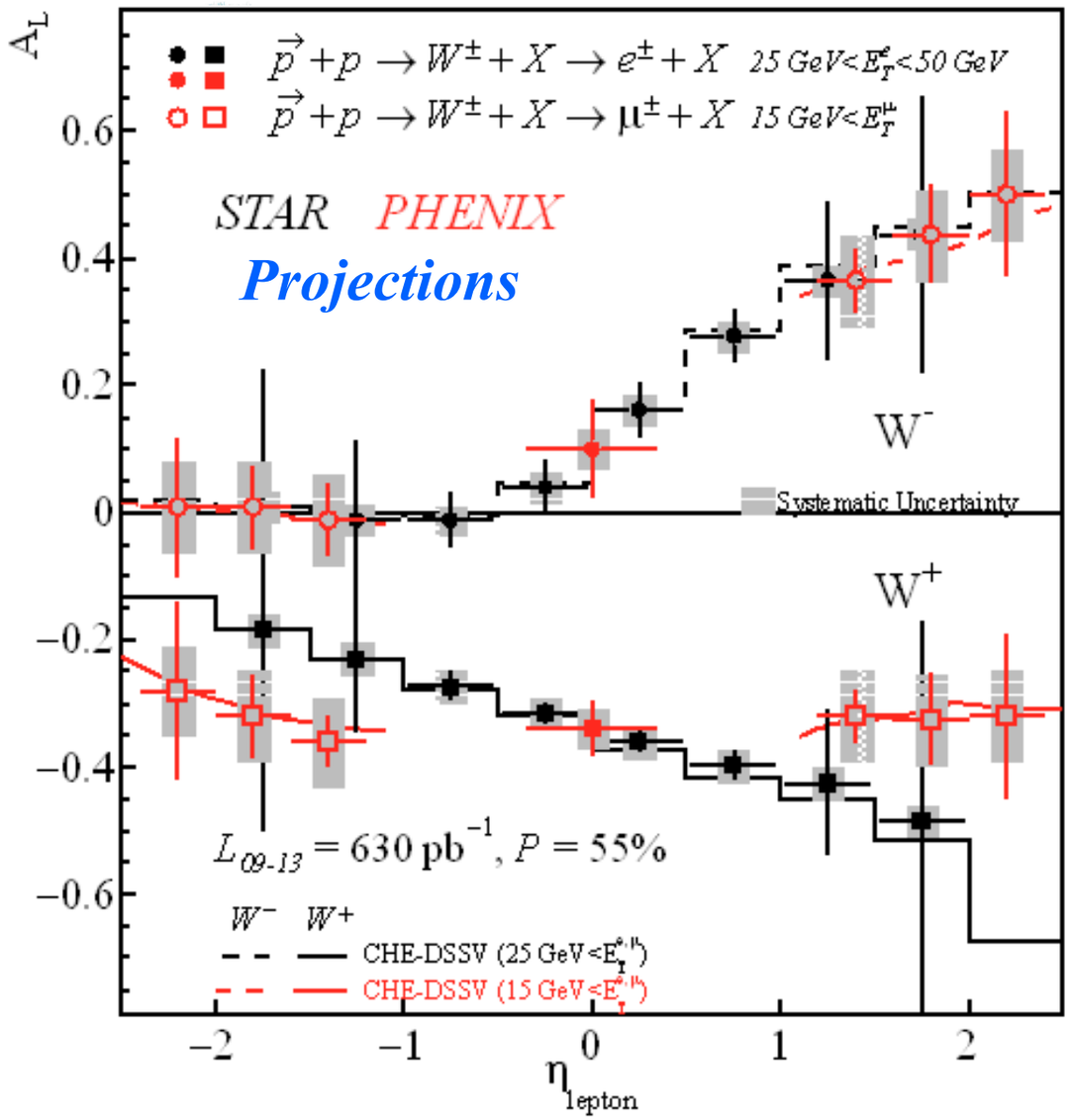
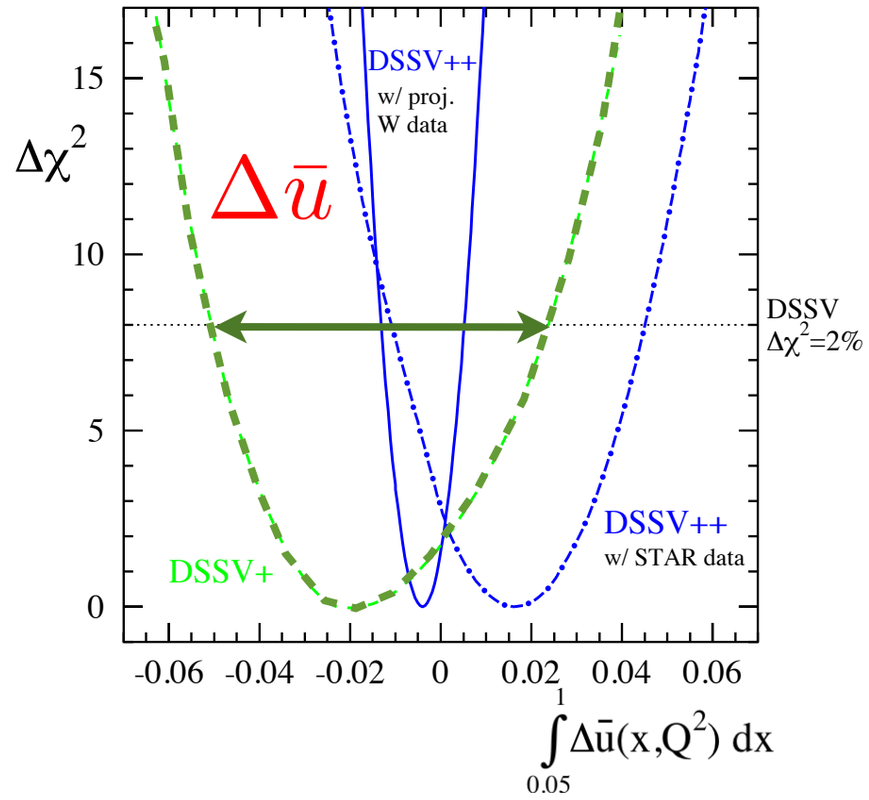
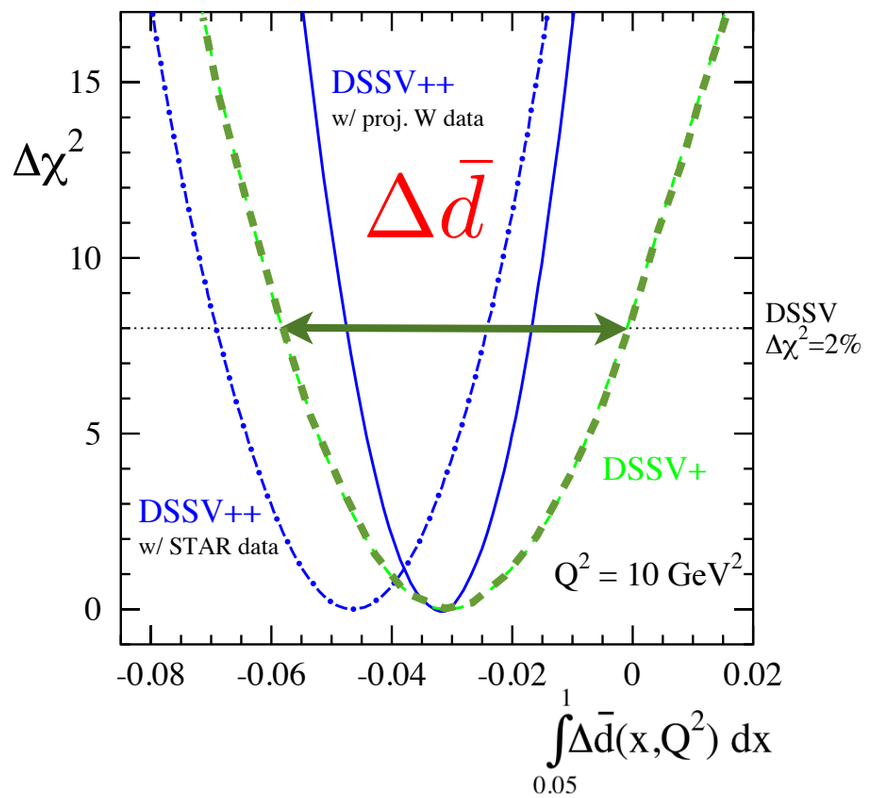
Sea Quark Polarization

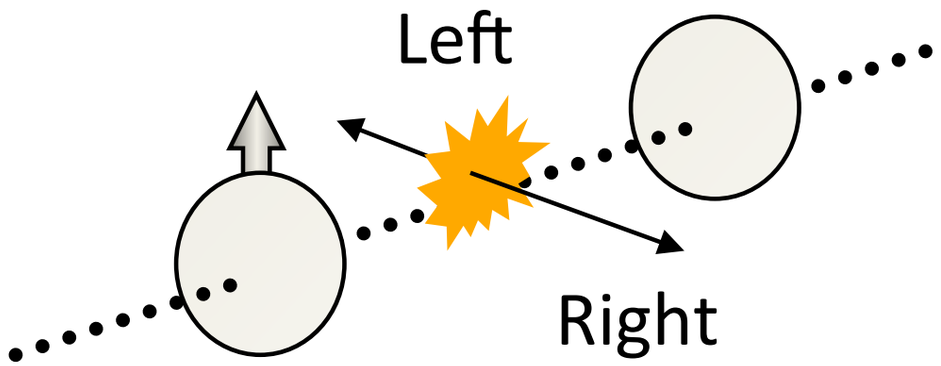




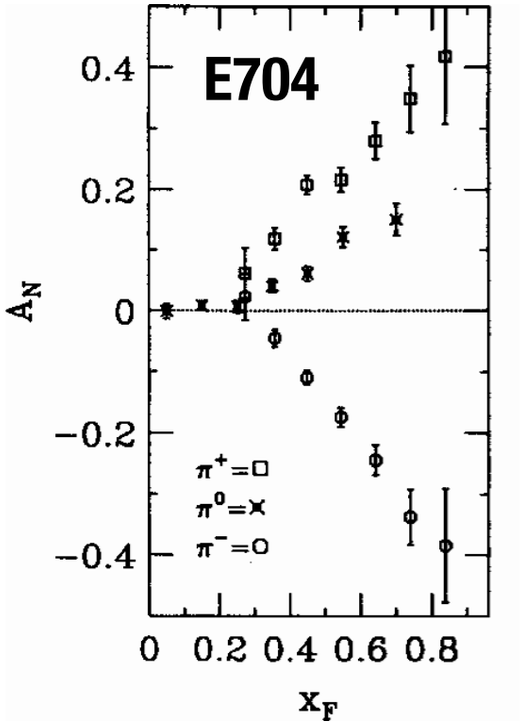


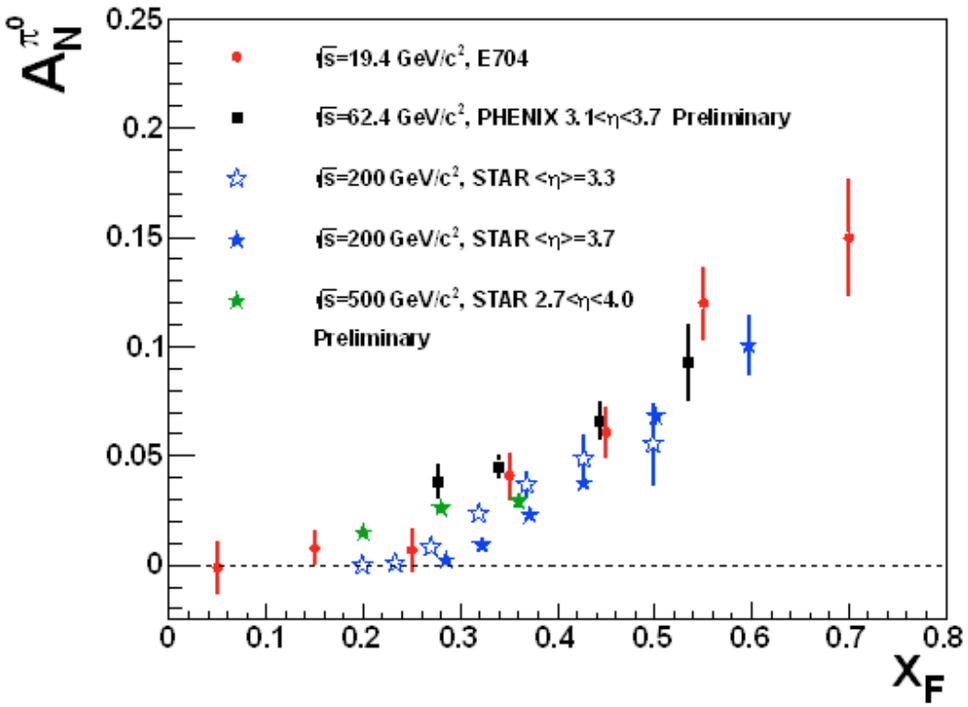
- DSSV++ is a new, preliminary global analysis from the DSSV group which includes 2012 STAR W A_L
- Higher precision data already collected in 2013 will further improve the constraints on the sea quark polarization

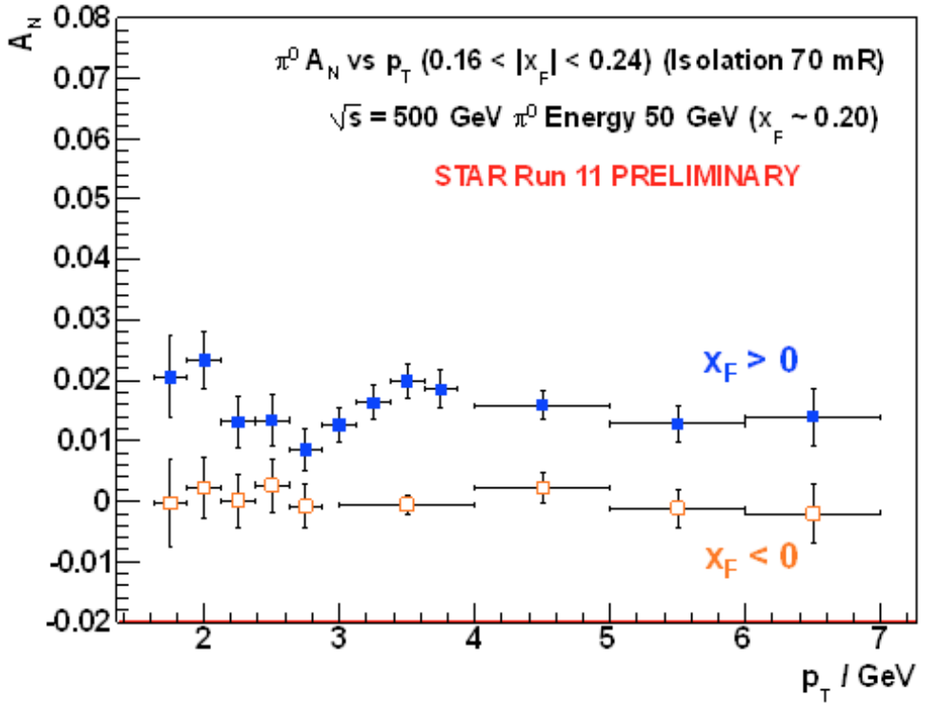
Transverse Spin Structure of the Proton



Transverse Spin Asymmetries: A_N







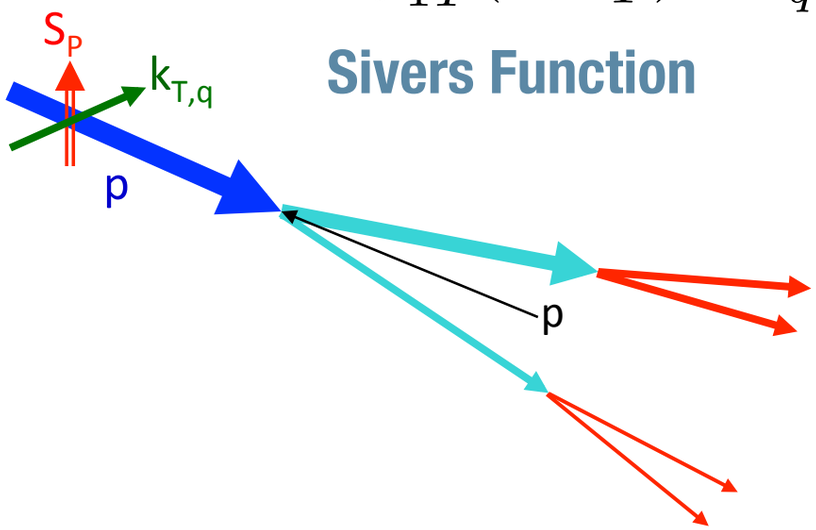
- Large A_N for inclusive hadrons observed at forward rapidity from fixed target energies up to $\sqrt{s}$ = 500 GeV at RHIC, with no indication of $1/p_T$ falloff as initially predicted
- To understand these large asymmetries, one typically looks beyond the collinear, leading twist framework (ie. TMDs and twist-3):
  - New observables needed to disentangle effects from initial state spin-k_T correlations, spin-dependent fragmentation in the final state, or ...?

Understanding A_N

Sivers: asymmetry in the forward jet or photon production

$$d\sigma^{\uparrow} \propto f_{1T}^{q}(x, k_T^2) \cdot D_q^h(z)$$

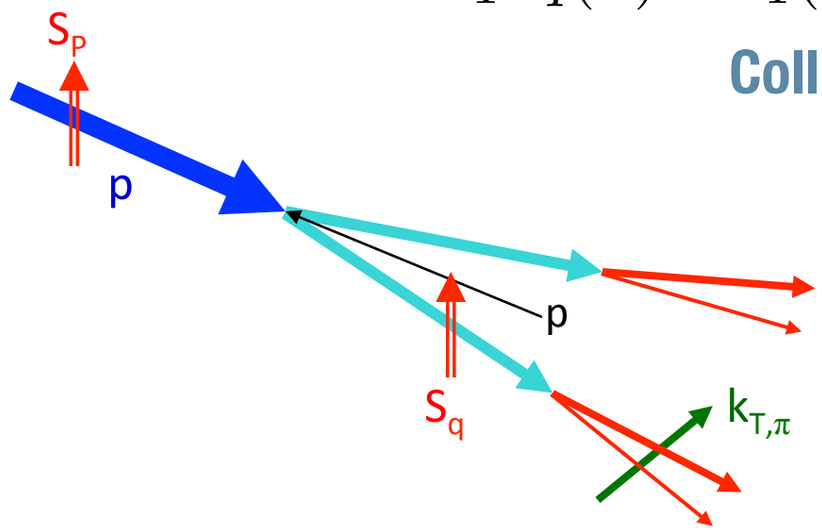
Sivers Function



Collins: transversity with asymmetry in the jet fragmentation

$$d\sigma^{\uparrow} \propto \Delta_T\, q(x) \cdot H_1(z, k_T^2)$$

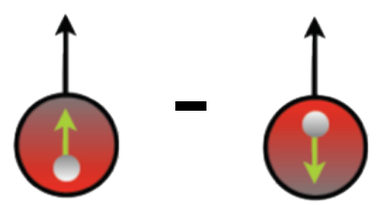
Collins FF



- Jets, direct photons, Drell-Yan all proposed to access Sivers effect directly (no fragmentation)
- Collins mechanism can be probed with hadron azimuthal distributions within a jet
- Access to transversity through Collins and Interference Fragmentation Functions

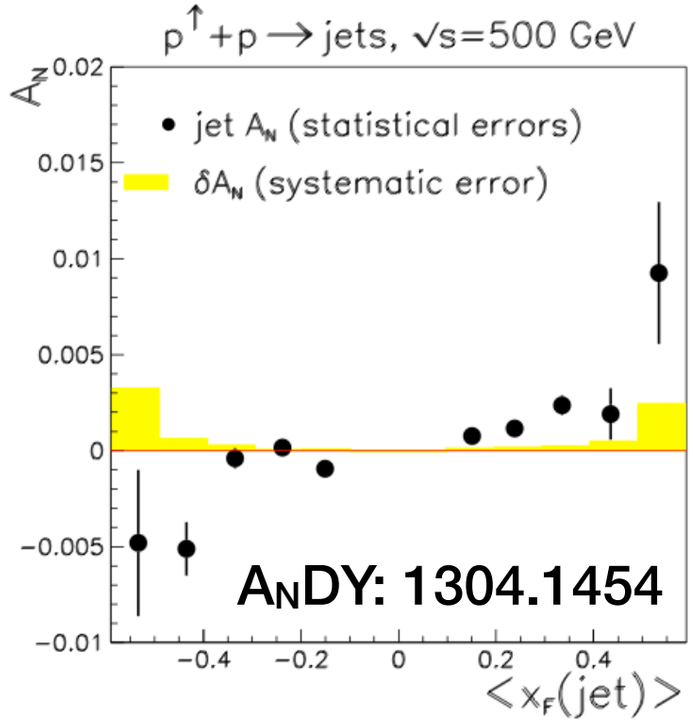
Transversity: chiral odd, can be compared to tensor charge from lattice QCD

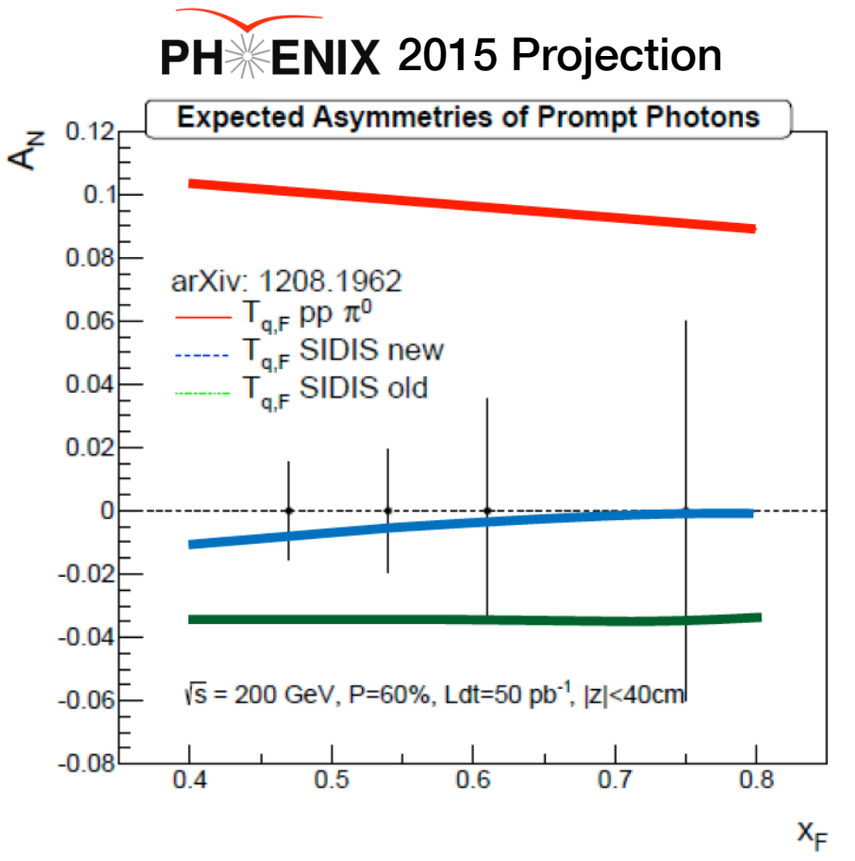
$$\Delta_T\, q(x) =$$



Sivers

- Inclusive jet production only sensitive to Sivers
  - Mid-rapidity jet and π^0 consistent with zero, and constrains gluon Sivers function
  - Recent A_NDY result at forward rapidity: small, but non-zero asymmetry (naively expected due to $A_N(\pi^+) \approx -A_N(\pi^-)$)





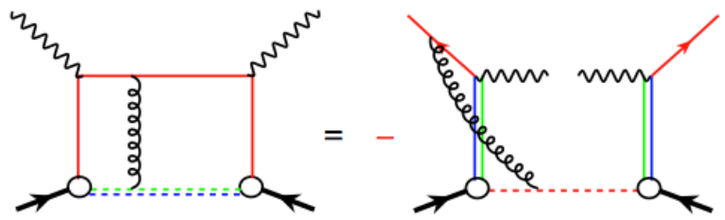
$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x,k_\perp^2)|_{\text{SIDIS}}$$

- Forward prompt photon production
  - Direct photons sensitive exclusively to Sivers, but fragmentation photons contain some dilution from Collins
  - Sivers extracted from **pp** and **SIDIS** give significantly different predictions for A_N due to process dependence of Sivers function
  - Pre-shower upgrades to forward EM calorimeters (2015) in progress for PHENIX and planned for STAR should differentiate these predictions

Sivers

- Drell-Yan type reactions (γ*, W±, Z) provide cleanest approach to verify the sign change (luminosity hungry)
- Caveat: no TMD evolution! (talk later today)

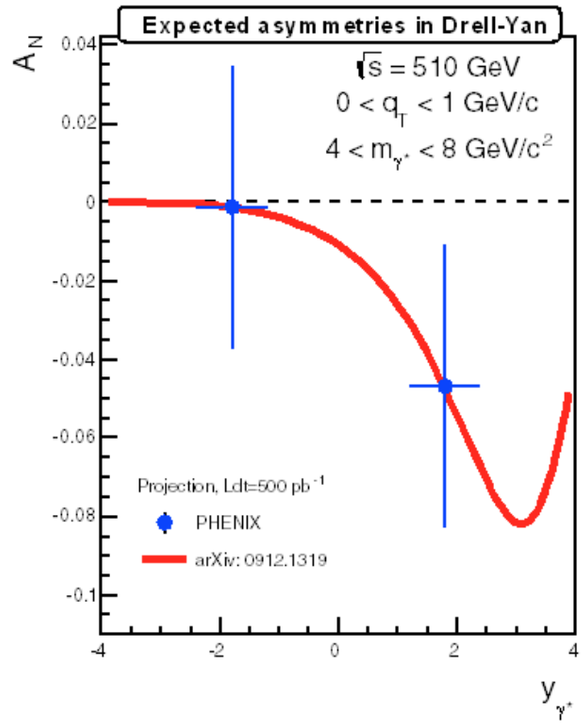
$$\Delta^N f_{q/h^\uparrow}^{\text{SIDIS}}(x, k_\perp) = -\Delta^N f_{q/h^\uparrow}^{\text{DY}}(x, k_\perp)$$



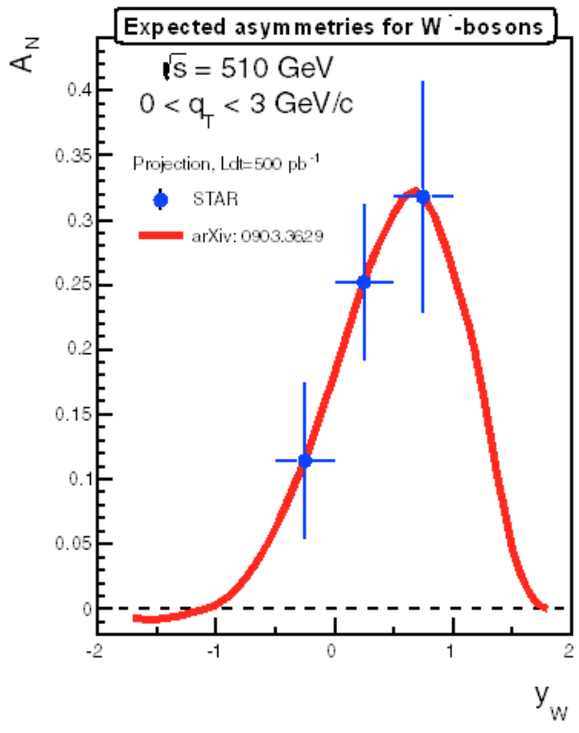
SIDIS = – DY

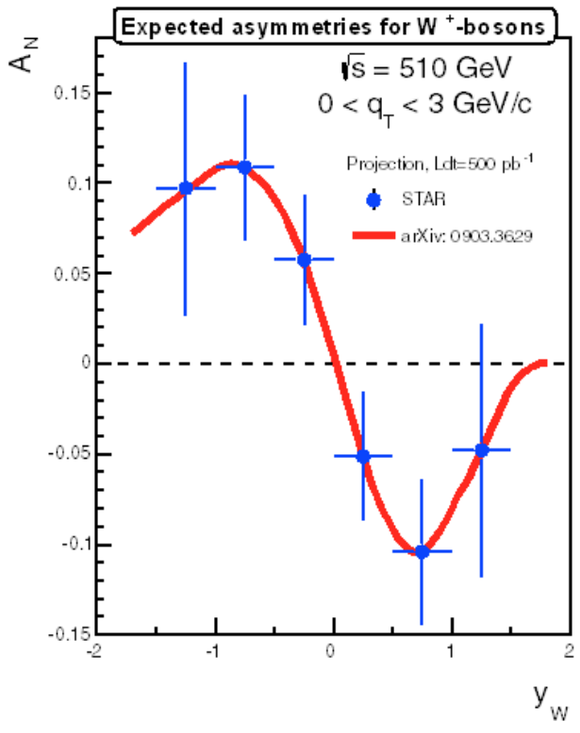
Phys.Rev. D81 (2010) 054020

Current PHENIX DY A_N Projection



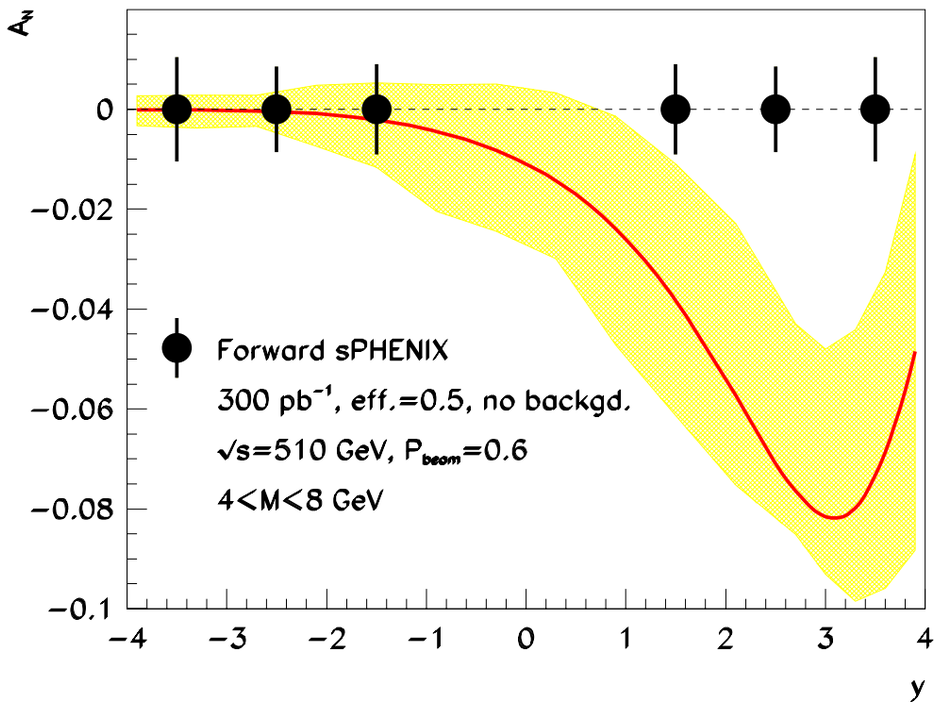
Current STAR W A_N Projections





Theory: PRL **103,** 172001 (2009)

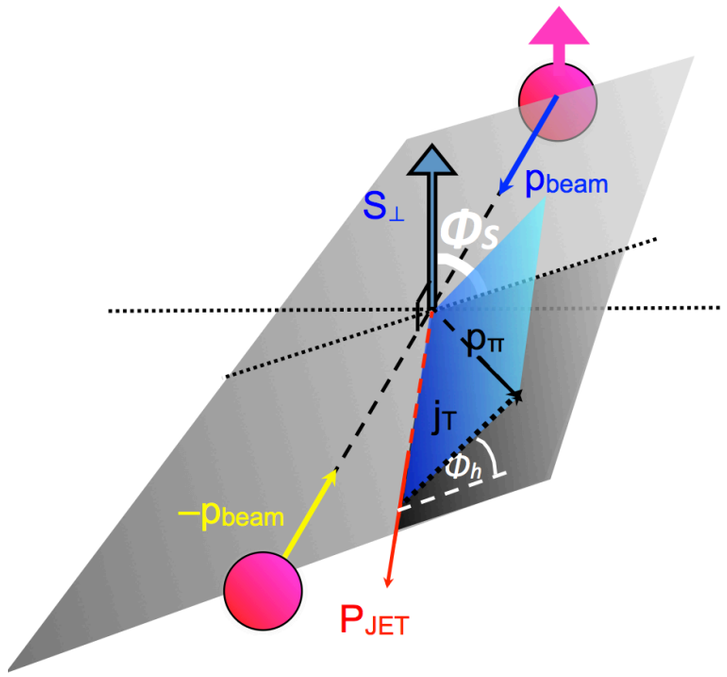
sPHENIX Upgrade DY A_N Projection



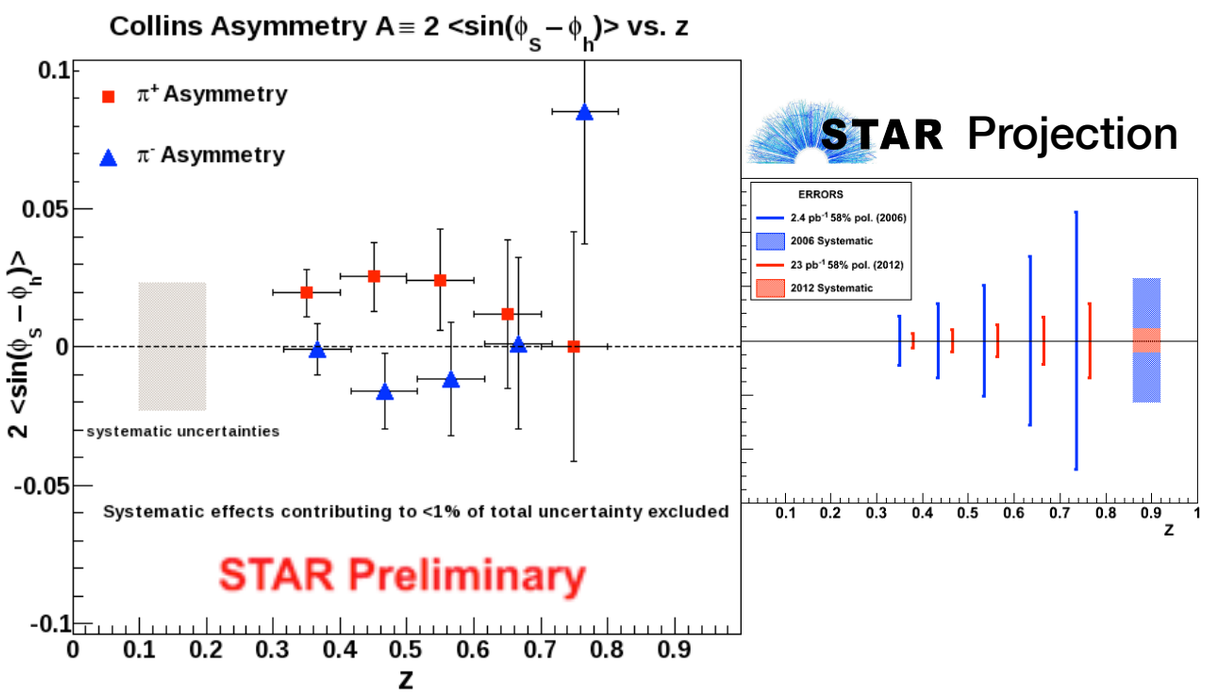
Theory: PRD **81,** 054020 (2010)

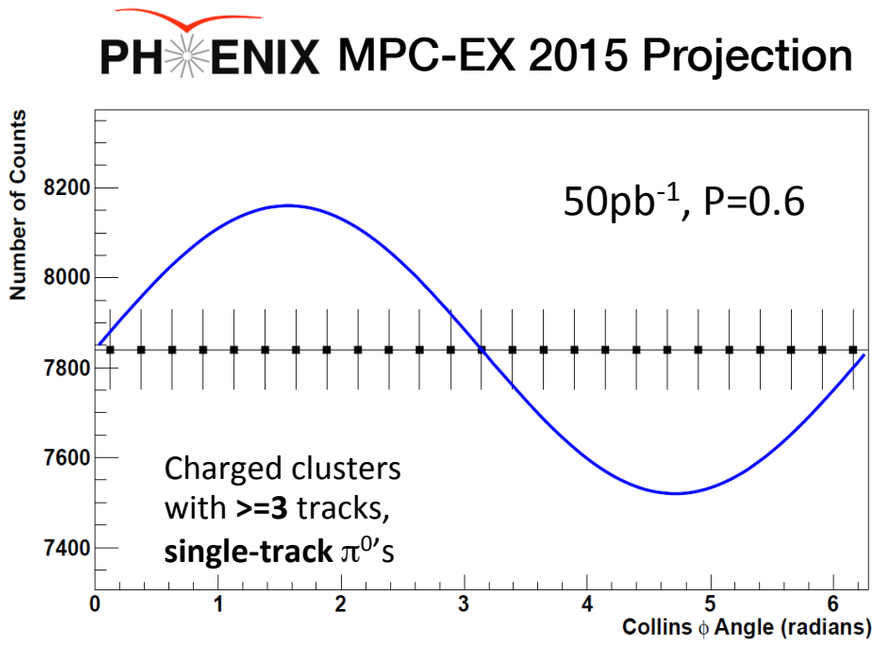
Collins: Transversity

- Access through hadron azimuthal asymmetries in jets by reconstructing the jet (quark) thrust axis
- Studied at mid-rapidity by STAR, with hints of an asymmetry observed at 200 GeV (expect much improved precision with data from 2012+2015)
- Forward rapidity measurement needed:
  - Possible jet surrogate from PHENIX MPC-EX upgrade clustering charged track hits
  - Comprehensive forward detector upgrade needed for full jet reconstruction, charge discrimination and hadron PID



PRL **100**, 032003 (2008)





Interference FF: Transversity

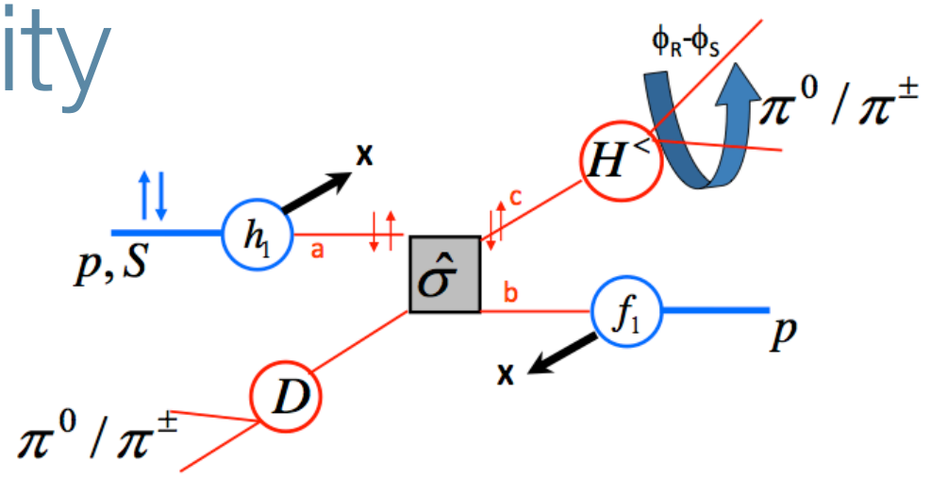
- Spin dependence of di-hadron azimuthal distribution sensitive to transversity

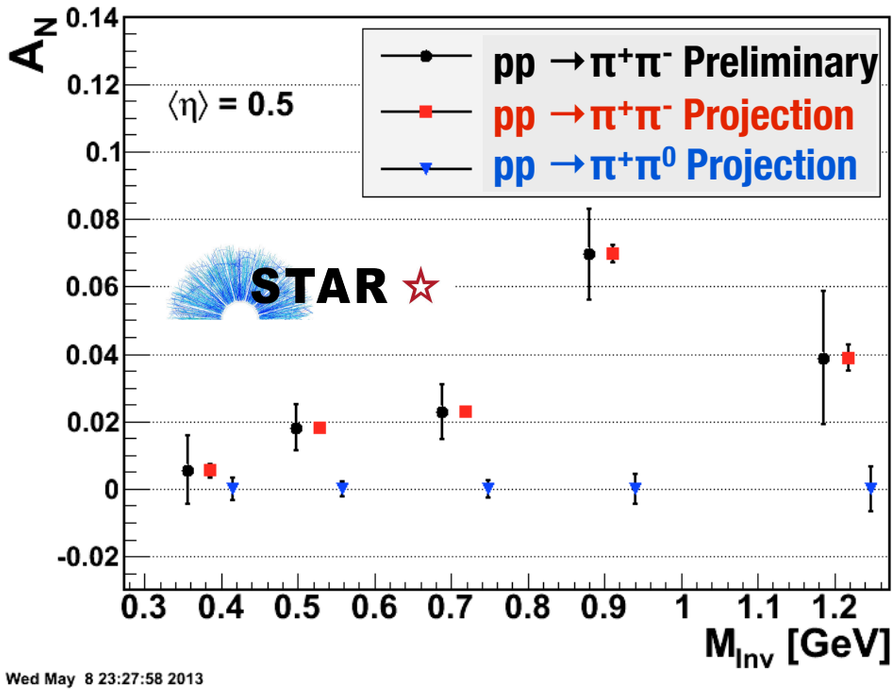
$$d\sigma_{UT} \propto \Delta_T\, q(x) \cdot H_1^{<}(z, M)$$

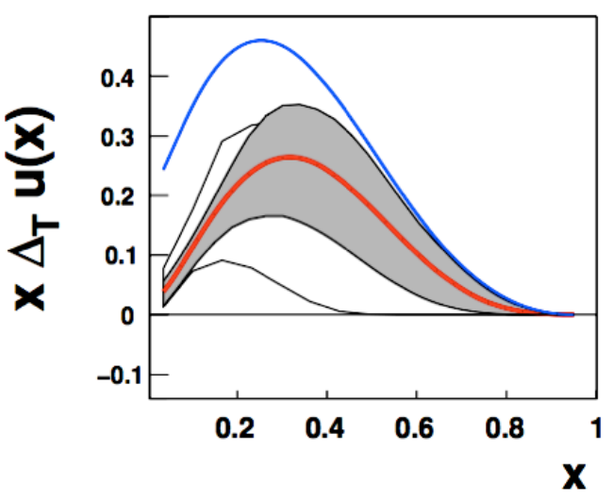
- Results at mid-rapidity from STAR show significant asymmetries (first significant measurement that isolates contributions from transversity in $\vec{p}+\vec{p}$)

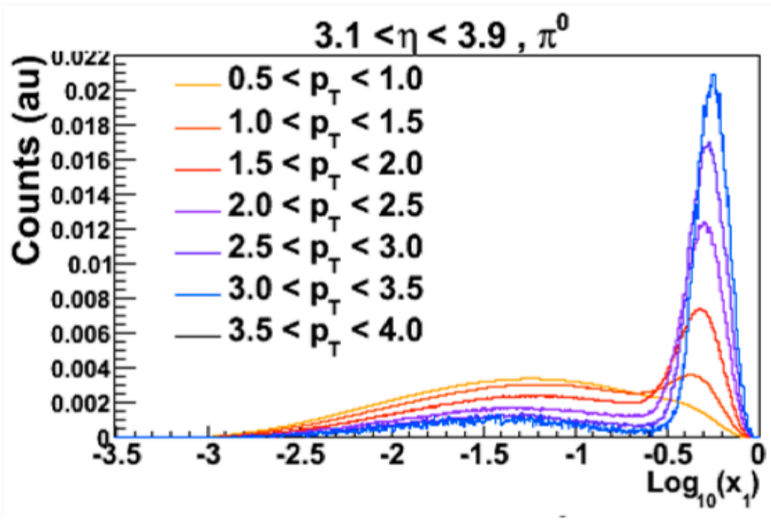
- Upgrade to STAR TPC rapidity coverage extends reach up to $x_B \sim 0.4$

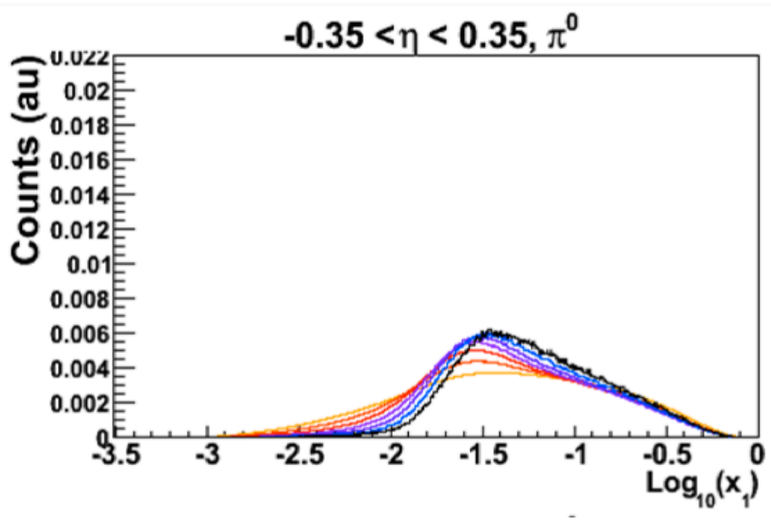
- Forward rapidity upgrades would provide access to even higher x_B









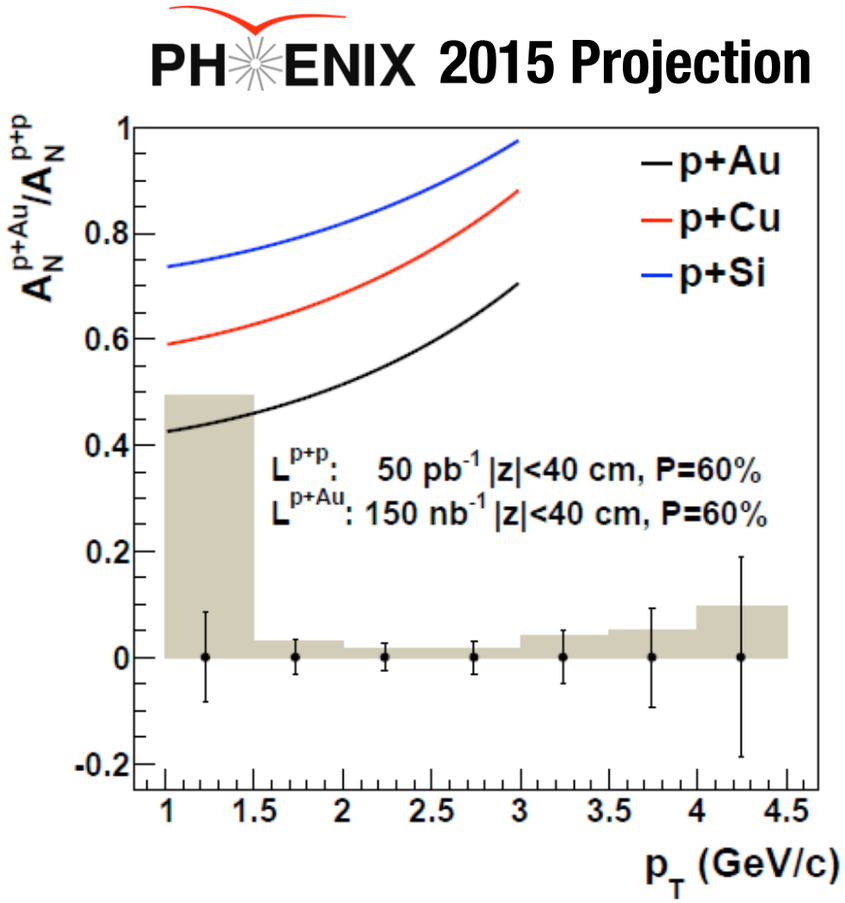


Polarized $\vec{p}$+A

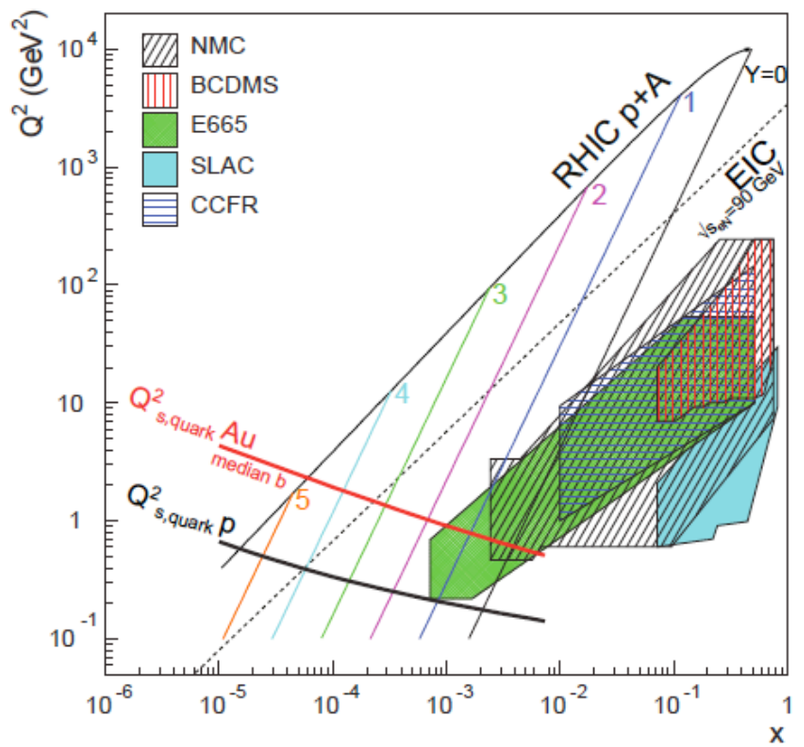
- The ratio of forward inclusive hadron A_N at low p_T is expected to be sensitive to the saturation scale Q_s

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

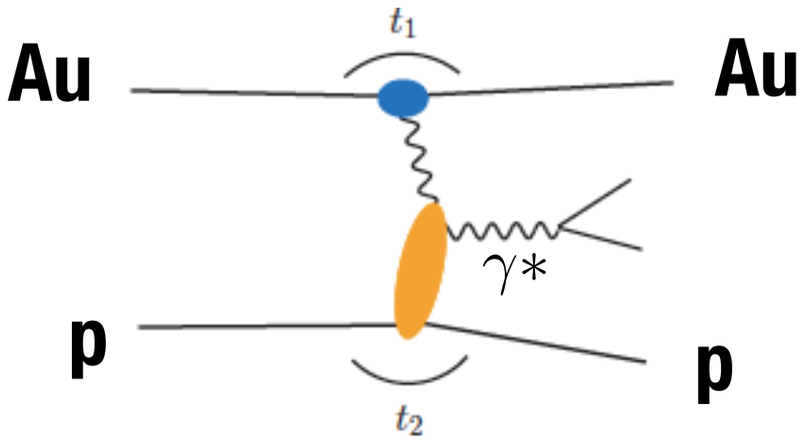
PRD 84, 034019 (2011)

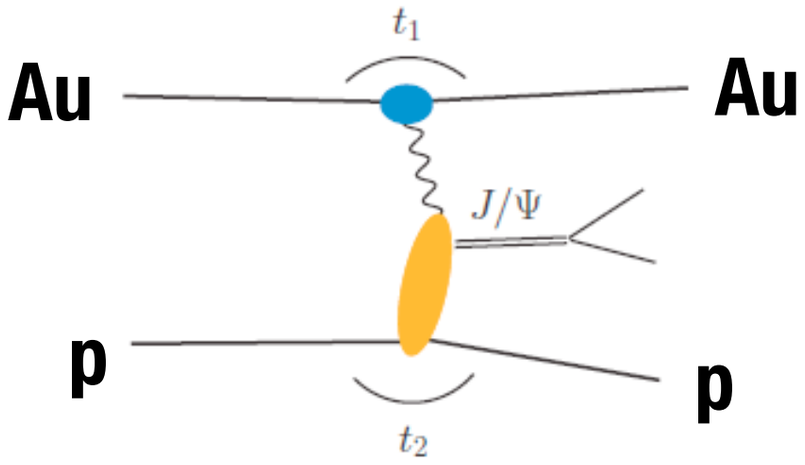


- First $\vec{p}$+Au run planned for 2015 with STAR and PHENIX forward EM calorimeter upgrades
- A unique capability of RHIC!



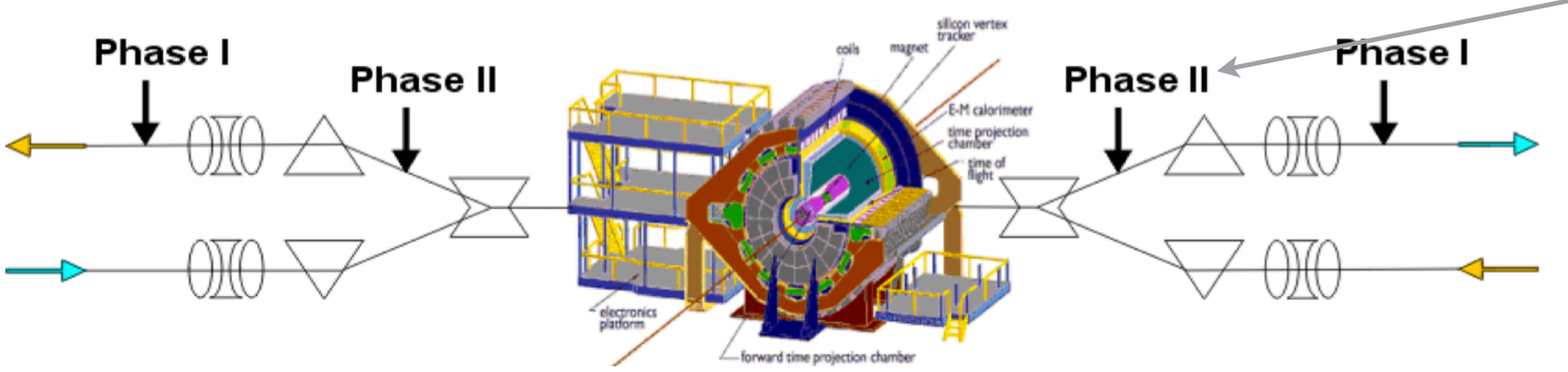
GPDs at STAR

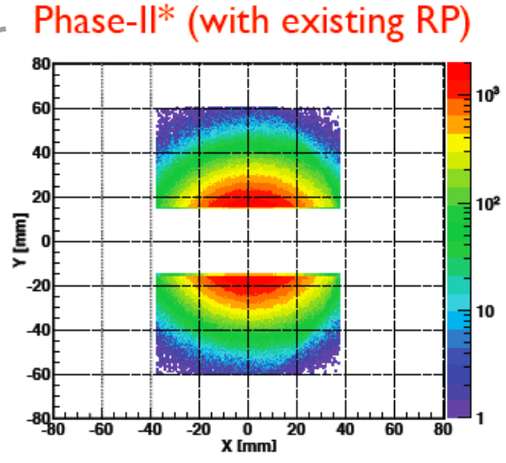




From $\vec{p}$+Au to γ^*+$\vec{p}$

- Measure A_N for exclusive ultra-peripheral (large impact parameter) di-lepton production
- Select very small t_1, to get quasi-real photon from Au beam
- Provides access to GPD E_g (TCS)
- First $\vec{p}$+A run expect a few hundred J/ψ (decay leptons at mid-rapidity)
- Ensure exclusivity with Roman Pots upgrade



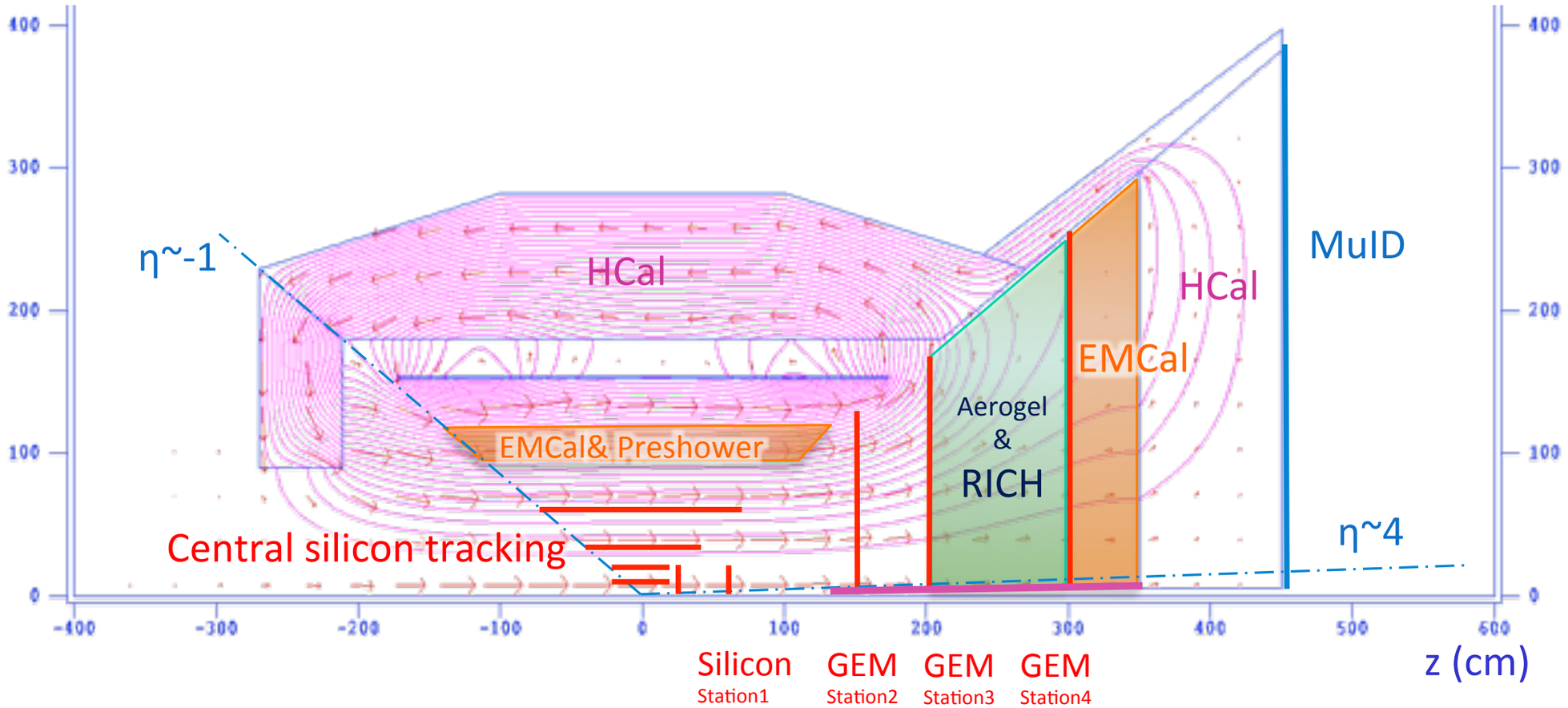


Detector Upgrade Strategy

- Current plan is for $\vec{p}$+$\vec{p}$ and $\vec{p}$+A running in 2015-16, followed by accelerator down time and Beam Energy Scan runs for ~4 years
- Recent charge from BNL-ALD Bernd Mueller to provide LOI from the collaborations on polarized $\vec{p}$+$\vec{p}$ and $\vec{p}$+A running in ~2021-2022
- Physics case being developed together for the $\vec{p}$+$\vec{p}$ and $\vec{p}$+A programs and the detector upgrades they require
- Upgrades serve $\vec{p}\vec{p}$/$\vec{p}$A/AA as well as $\vec{e}$A/$\vec{e}\vec{p}$ program for an eRHIC

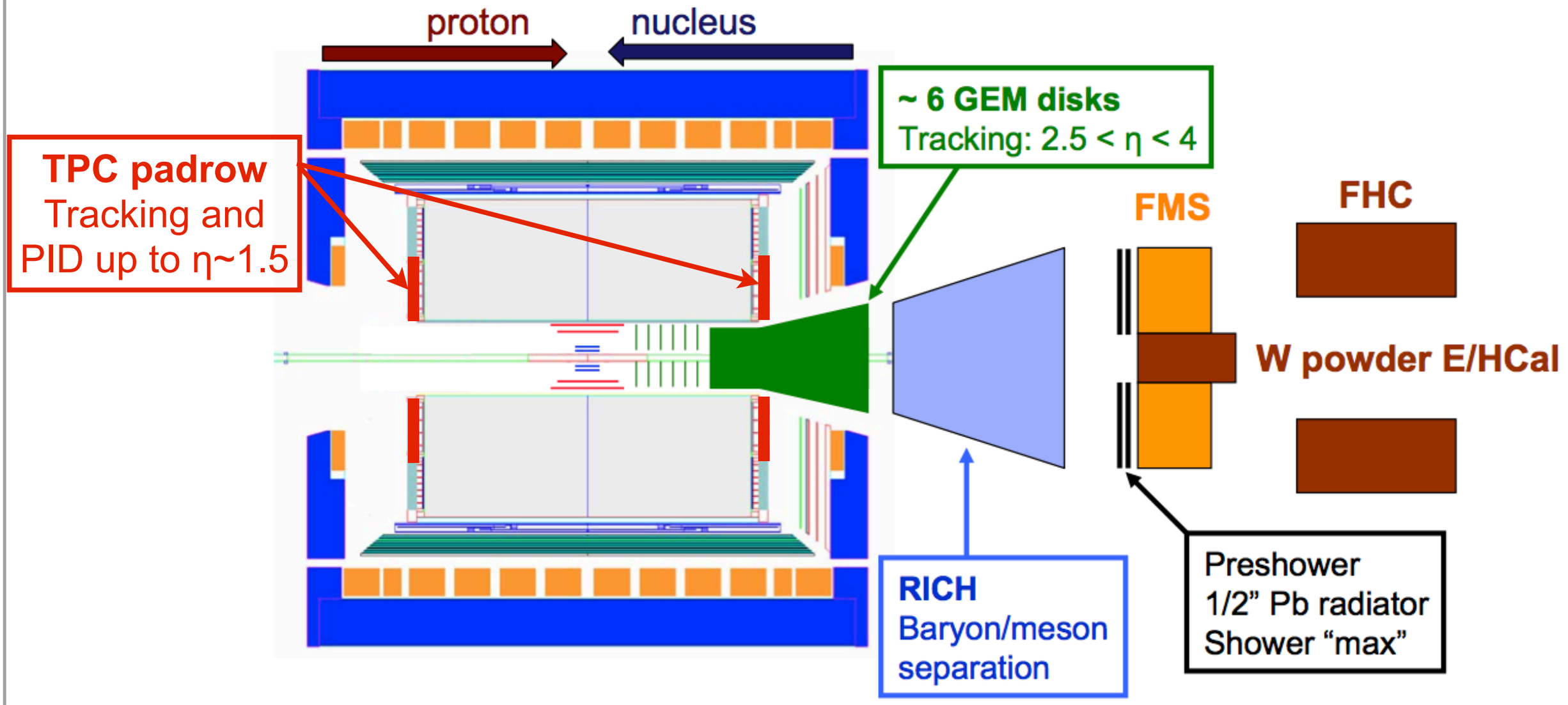
Observable	Tracking	Hadron PID	HCAL	ECAL	Preshower
Drell-Yan	X		B	X	X
Direct ɣ	B		B	X	B
Jets (Sivers and ΔG)			X	X	
Jet+Hadron (Collins)	X	X	X	X	
IFF (Transversity)	X	X		X	
Lambda D_{LL} (Δs)	X	X	X	X	X

sPHENIX Upgrade Concept



- Central rapidity upgrade (arXiv:1207:6378) focused on jet physics in A+A collisions, MIE submitted to DOE (April 2013)
- Forward detector concept covers a larger range in rapidity (1<η<4)
- Considering magnetic field shaper for very forward tracking

STAR Upgrade Concept



- Build off of current mid-rapidity capabilities with upgrades focused on the forward rapidity region
- R&D for forward W powder calorimeter and forward tracking concepts already underway

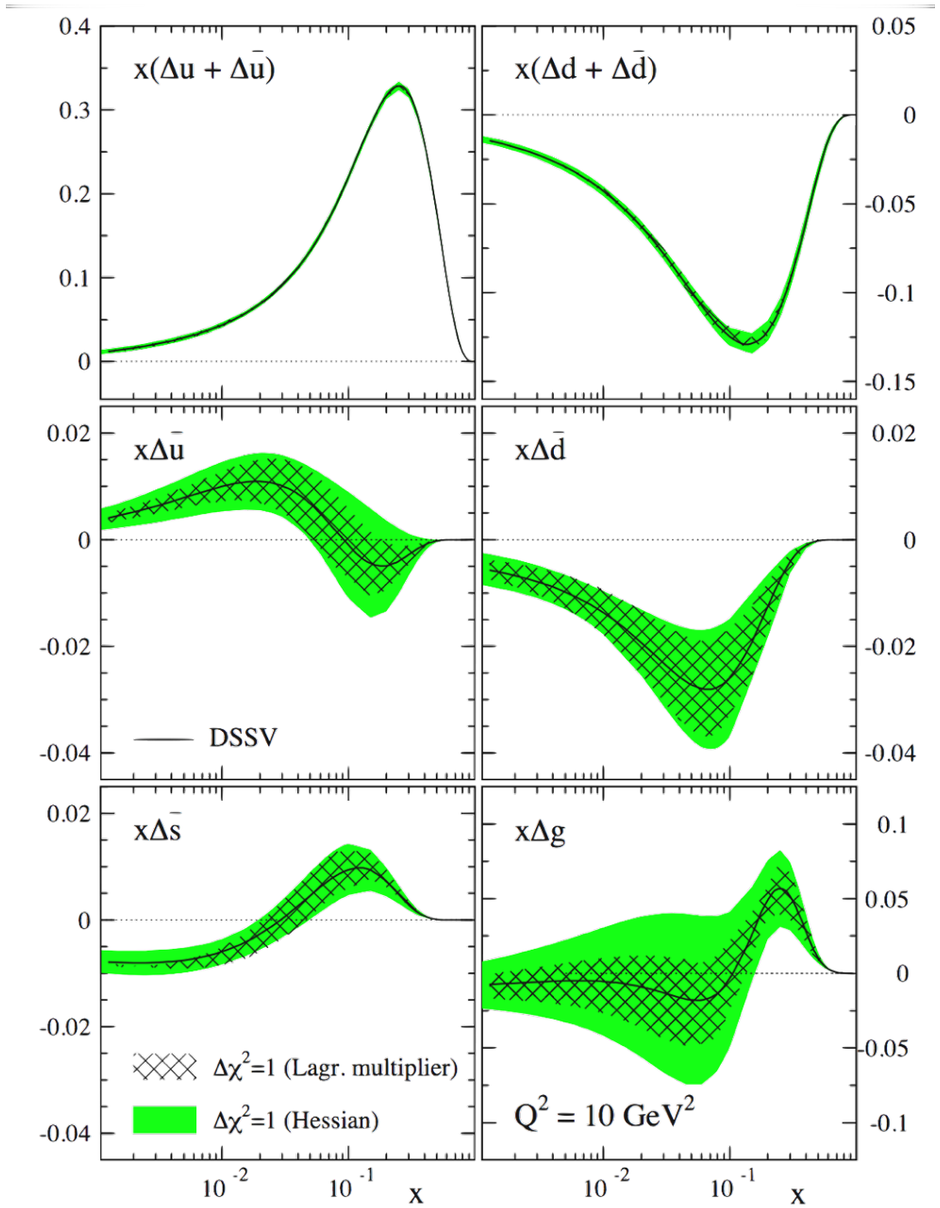
Summary

- RHIC is a versatile machine with unique capabilities in $\vec{p}$+$\vec{p}$ and $\vec{p}$+A
- Recent longitudinal results are having a significant impact on our understanding of the gluon and sea quark helicity distributions, with more data to be analyzed
- Current plans for transverse $\vec{p}$+$\vec{p}$ running in the next few years will provide new insight into the large A_N observed at RHIC through direct photon, Collins asymmetries, and other measurements
- The first polarized $\vec{p}$+A collisions will provide new access to saturation physics and GPDs at RHIC
- Longer term upgrades are planned to capitalize on the unique capabilities of RHIC and transition to an EIC

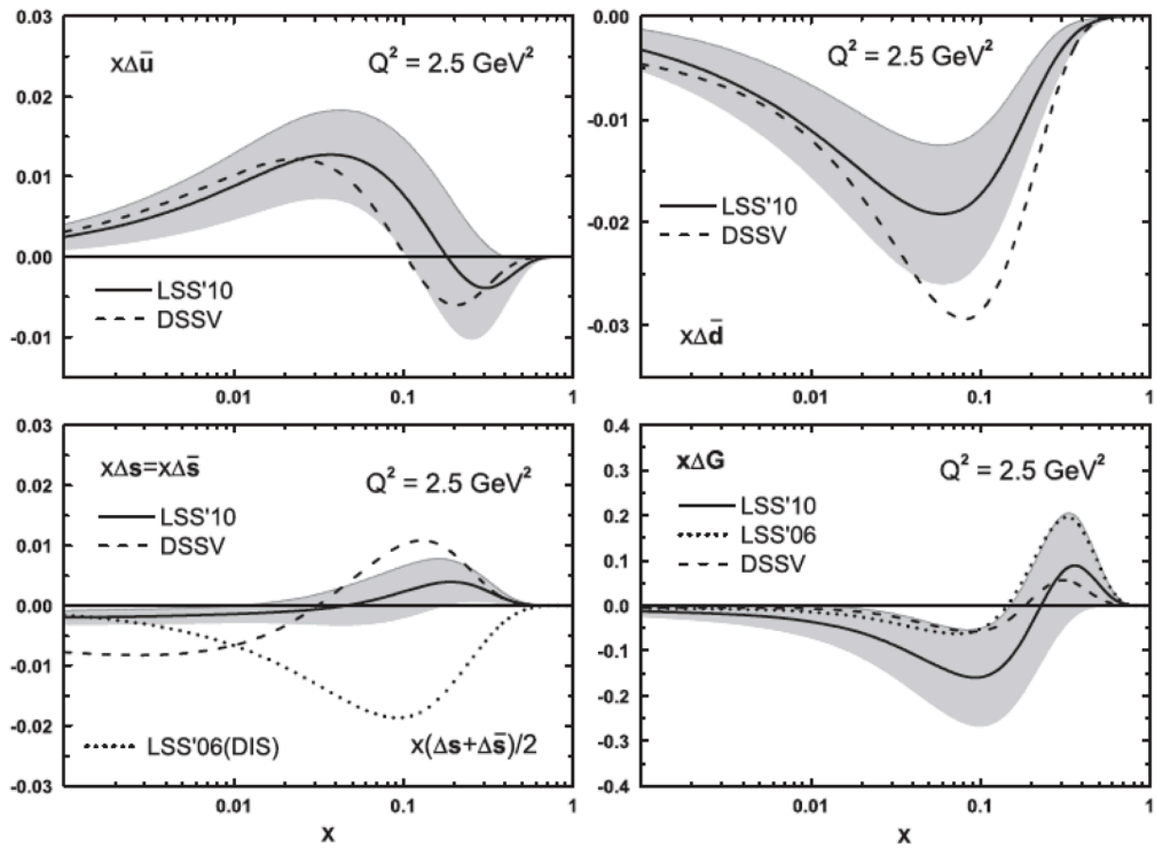
Backup

Polarized PDFs

DSSV08 Global Analysis

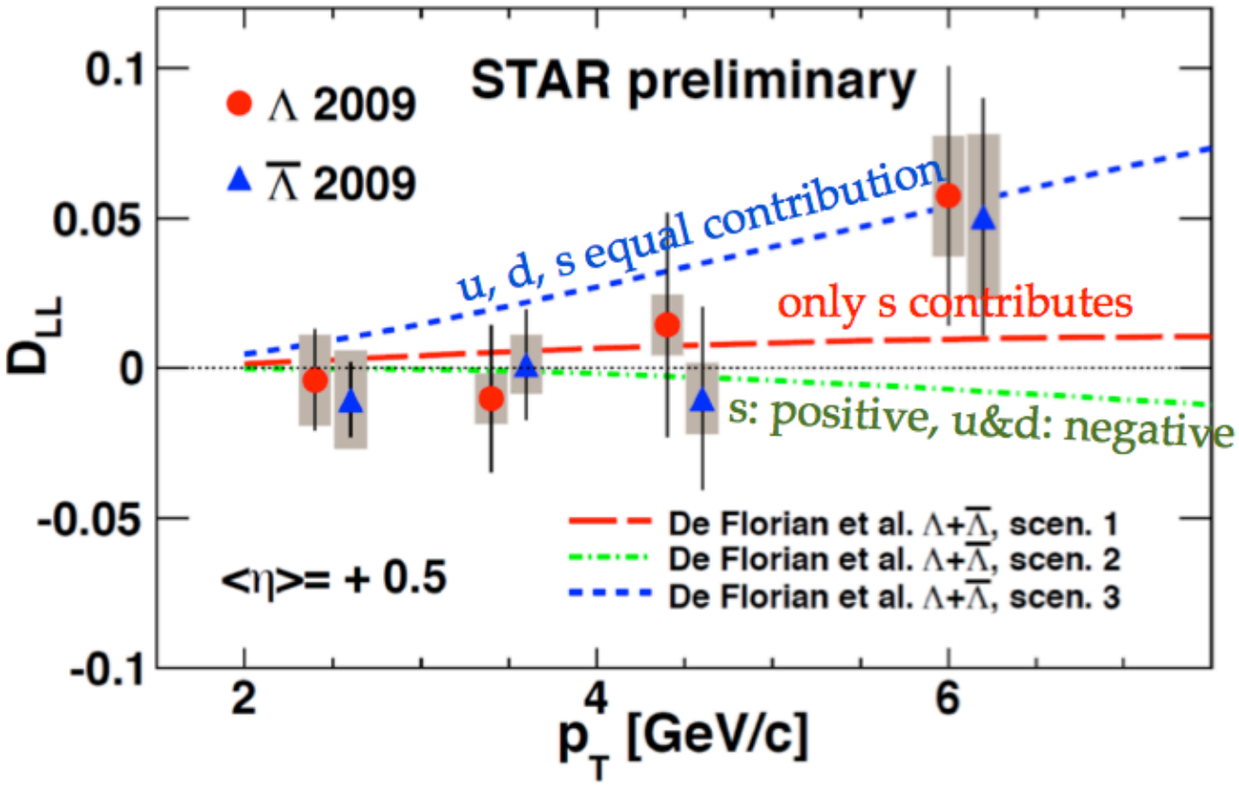


LSS10 Global Analysis

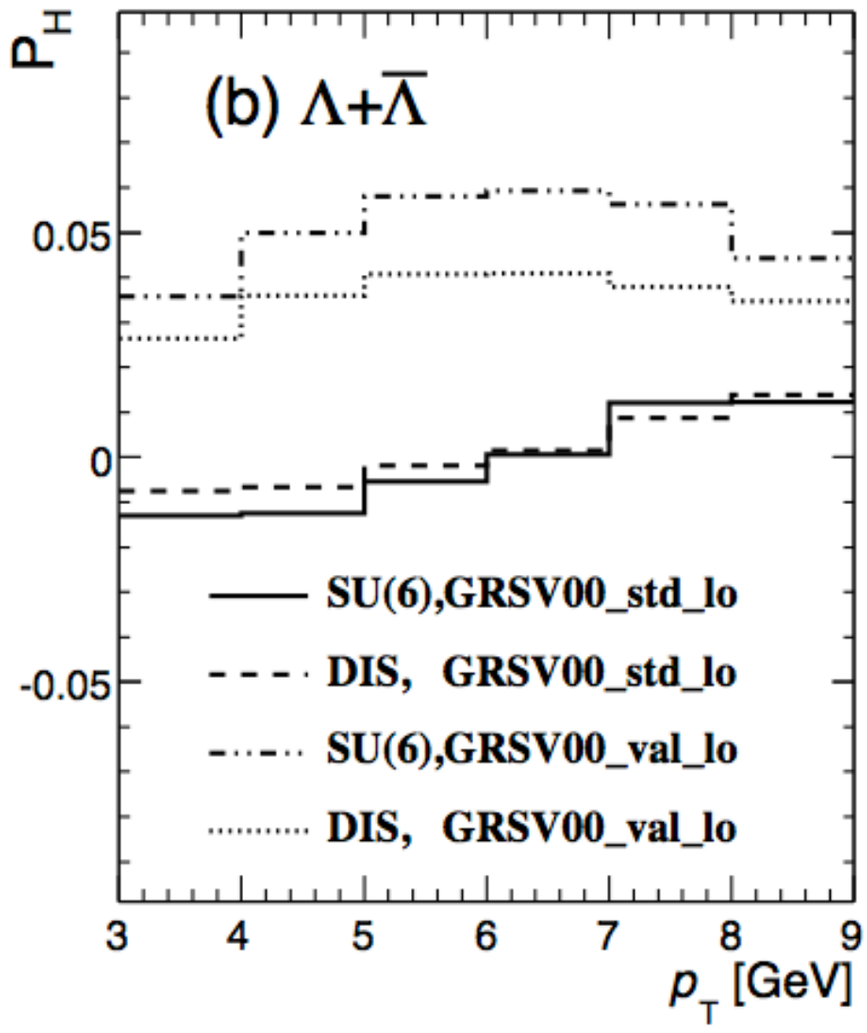


Strange Quark Polarization

Mid-rapidity: |η|<1



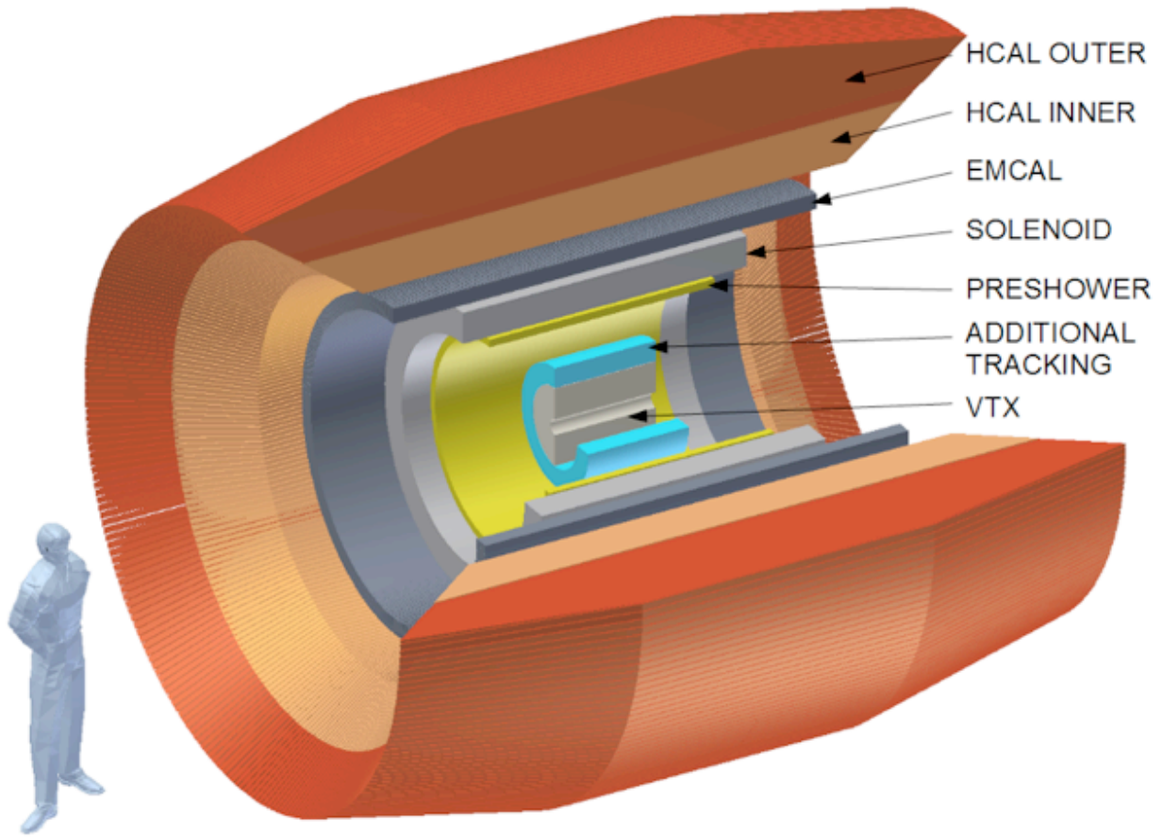
Forward Rapidity: 2.5<η<3.5



PRD **81,** 057501 (2010)

- Λ-Hyperon spin transfer D_{LL} is sensitive to strange sea quark polarization
- Current measurements limited to mid-rapidity, without hadronic calorimetry to directly trigger on Λs
- With hadronic calorimetry/tracking could extend to forward rapidity with a dedicated trigger

sPHENIX Mid-rapidity

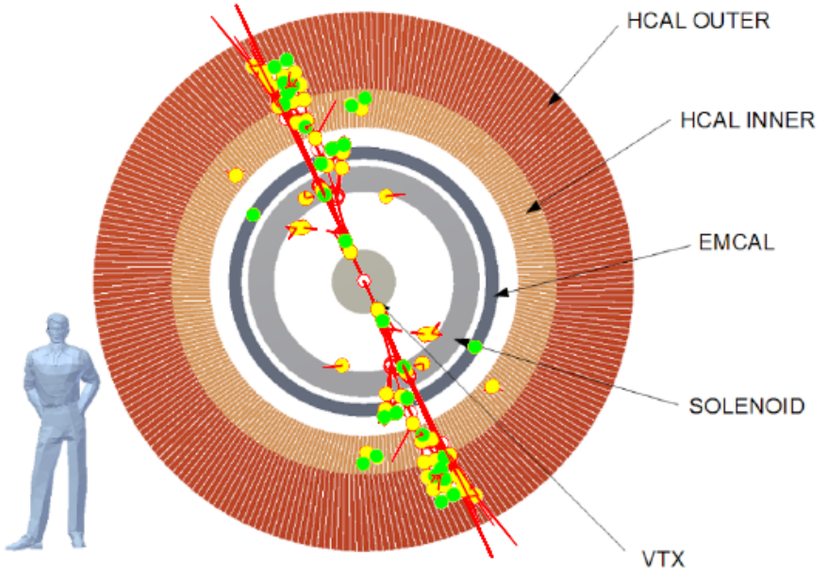


Use jets as a tool to investigate the constituents and dynamics of the sQGP in the region of strongest coupling through its transport coefficients

PHENIX

An Upgrade Proposal from the PHENIX Collaboration

July 1, 2012
Updated March 22, 2013



arXiv:1207.6378