Experimental overview: Nucleon spin structure

Lots of input from:
E. Aschenauer, A. Bressan, J. Drachenberg, J.P. Chen, R. Fatemi, S. Kuhn, F. Kunne, G. Schnell, A. Vossen
+ various DIS14 and Transversity14 slides

NSAC 2014 Longe Range Plan
~~Cold~~ Cool QCD Town Meeting,
Temple U, September 13, 2014

Ralf Seidl
(RIKEN)

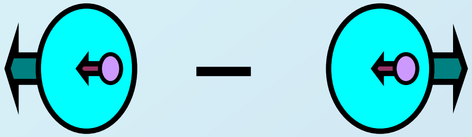
Spin and Nucleon structure: Test-bed to theories

- Spin is extremely relevant to the understanding of matter , many surprises when studying spin quantities
- naïve spin composition by otherwise successful quark model not valid → Spin crisis
- Traditional pQCD did not care about transverse momenta and expected small transverse spin effects→ Large asymmetries seen, resulting in boost of our theoretical understanding of the nucleon AND QCD, connection to LHC

Outline

- Valence, sea quark and gluon helicities
  - DIS status
  - SIDIS, W improvements
  - Gluons from SIDIS and RHIC
  - Near term improvements (high x at Jlab, lower x gluon reach at RHIC)
  - EIC
- TMDs
  - Consolidation of Sivers and Collins effects, evolution(?), connection to pp very interesting
  - AN findings
  - Ways to disentangle AN contributions,
  - Near term improvements (high x at Jlab, DY,W/Z at COMPASS, STAR and fsPHENIX)
  - EIC
- GPDs →Andreas Metz
  - Recent results
  - Future improvements
- Various new detectors or upgrades

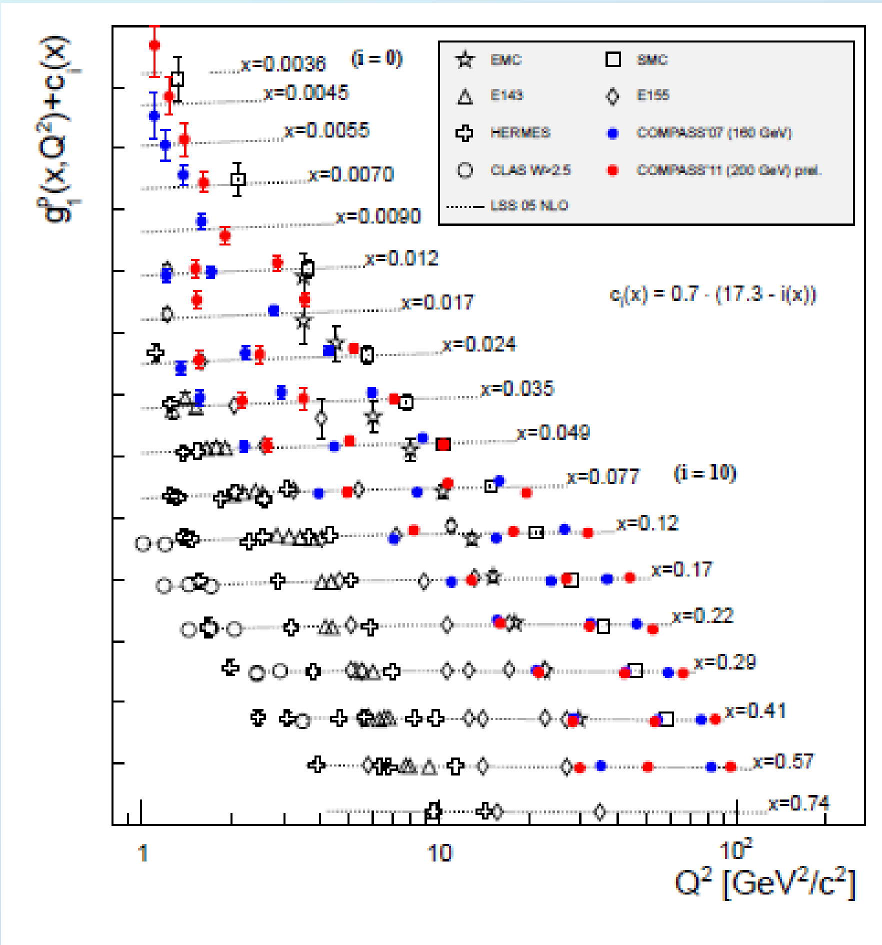
Longitudinal Spin: Main Questions

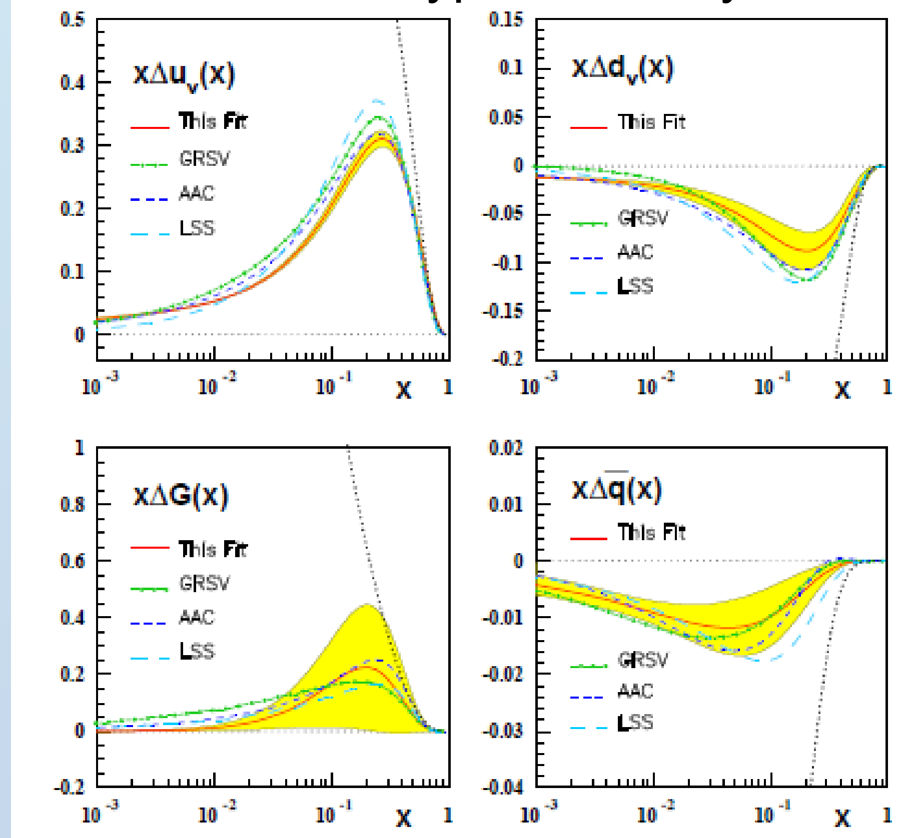


- The momentum of the proton is made up to 50% by gluons and 50% by quarks, is it similar for the spin?
- What happens to quark spins when approaching x=1, helicity retention?
- The unpolarized sea is not symmetric, is the polarized sea symmetric?
- Are the strange (and other sea) quark helicities really negative at unmeasured low x?
- Not just spins but also Orbital angular momentum can contribute – does it? If so, how much?

Current highlights: Quark helicities via inclusiv DIS fits

+ β decay and Hyperon decay info

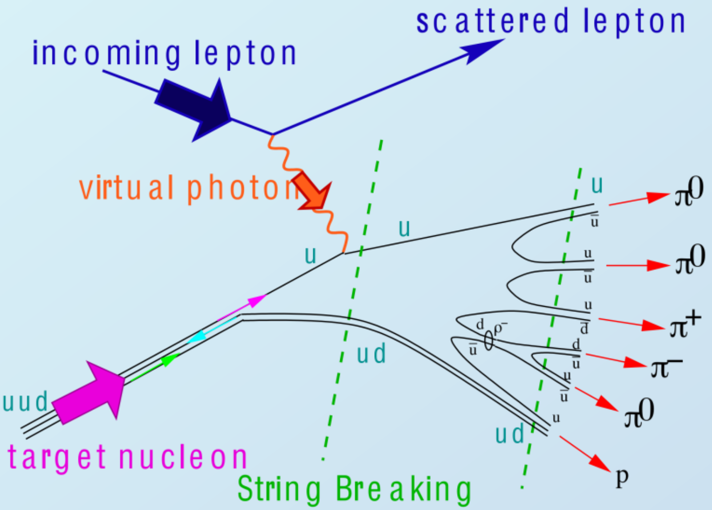


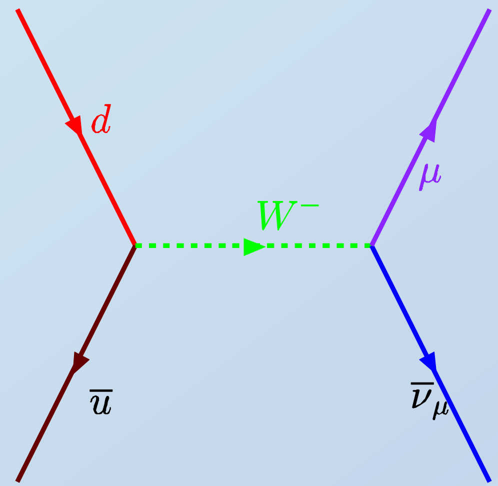


$$A_1(x) \propto \frac{g_1}{F_1} \propto \frac{\sum_q e_q^2 \Delta q(x)}{\sum_q e_q^2 q(x)}$$

Bluemlein Boettcher 2010: Nucl.Phys. B841 (2010) 205-230
Also: Jimenez et al, Phys.Rev. D89 (2014) 034025 including higher twist study

Flavor information via SIDIS and W production in pp

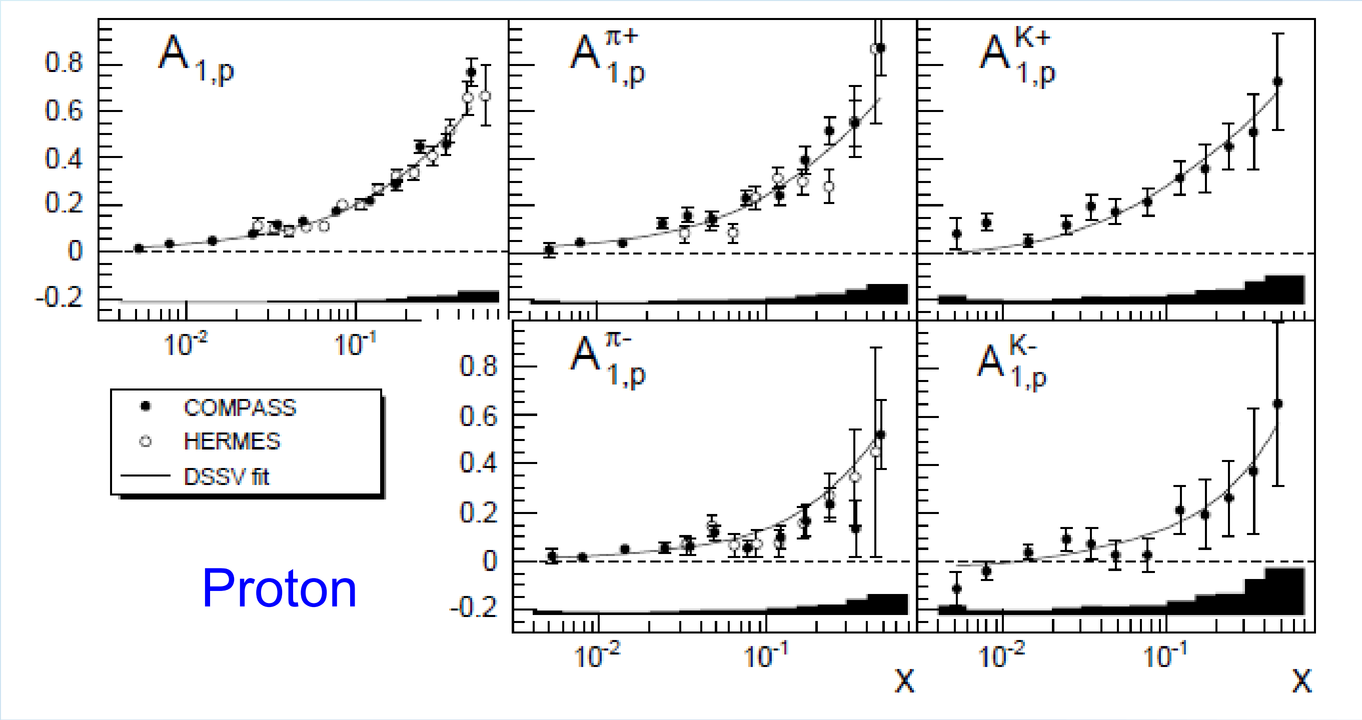




- Semi-inclusive DIS: detect at least one final state hadron
- Hadron type relates to initial parton via fragmentation functions (important new results from Belle, Babar, RHIC, LHC and SIDIS)

- W production in pp collisions selects participating quark and antiquark flavors and its helicity

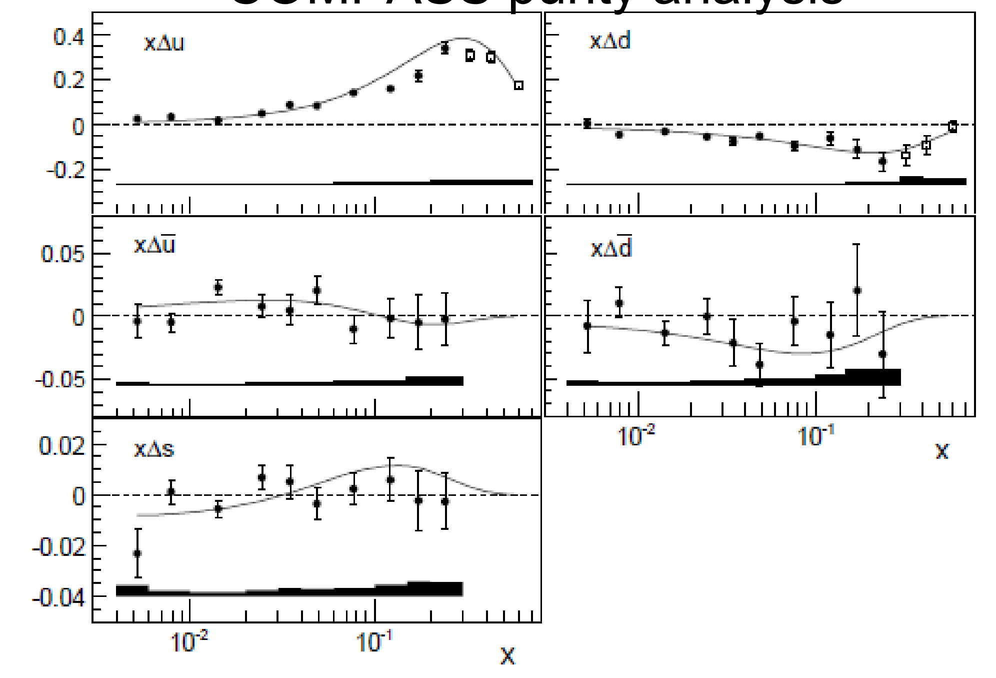
Current highlights: sea quark helicities



Phys.Lett. B690 (2010) 466-472 (proton)
Phys.Lett. B680 (2009) 217-224 (deuteron)

Current highlights: sea quark helicities

COMPASS purity analysis



Current highlights: sea quark helicities

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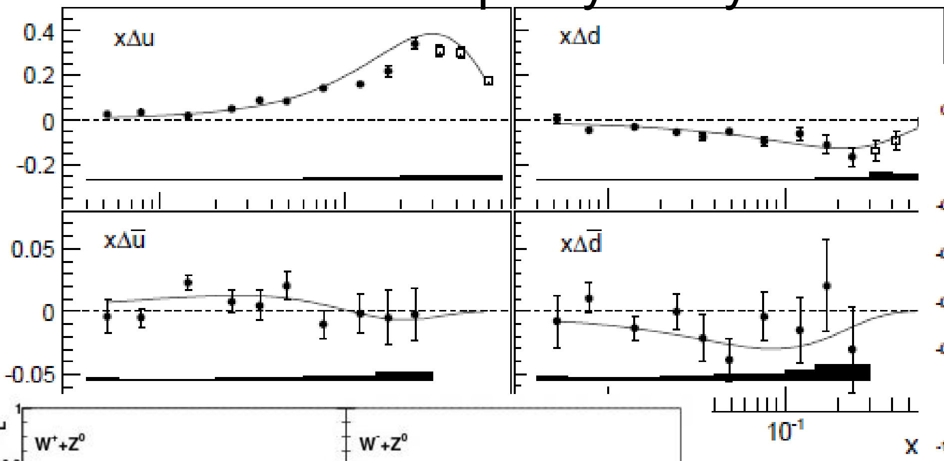
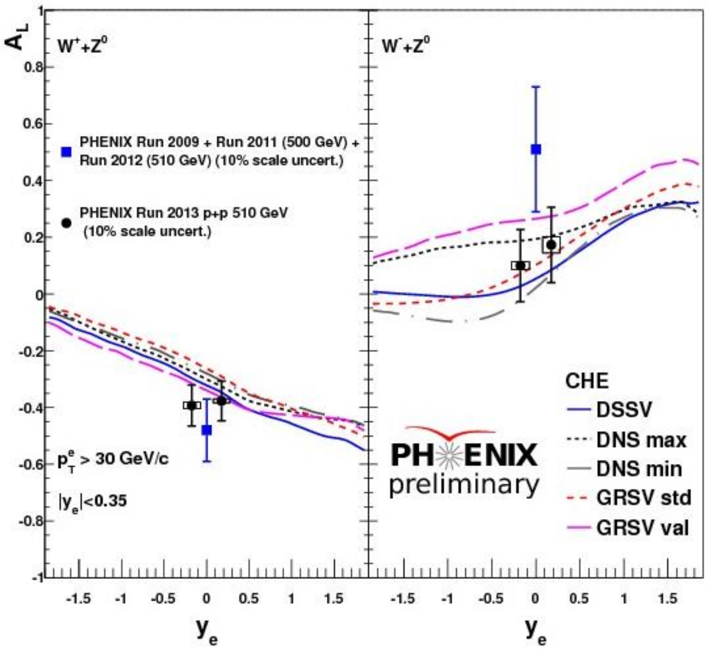
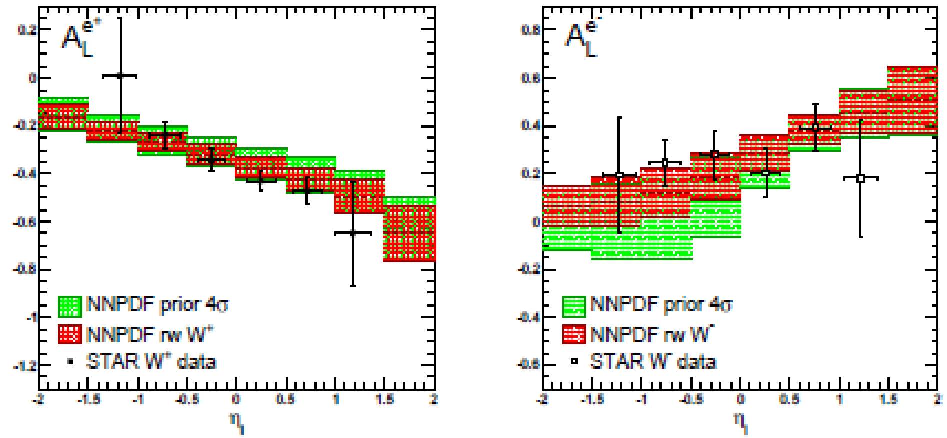




STAR: PRL 113 (2014) 072301



NNPDFpol1.1: E. Nocera et al.. arXiv:1406.5539

Current highlights: sea quark helicities

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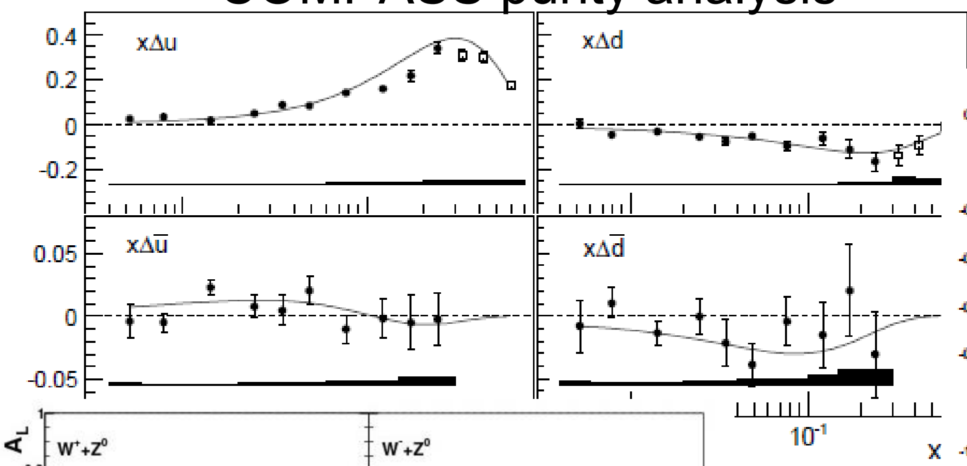

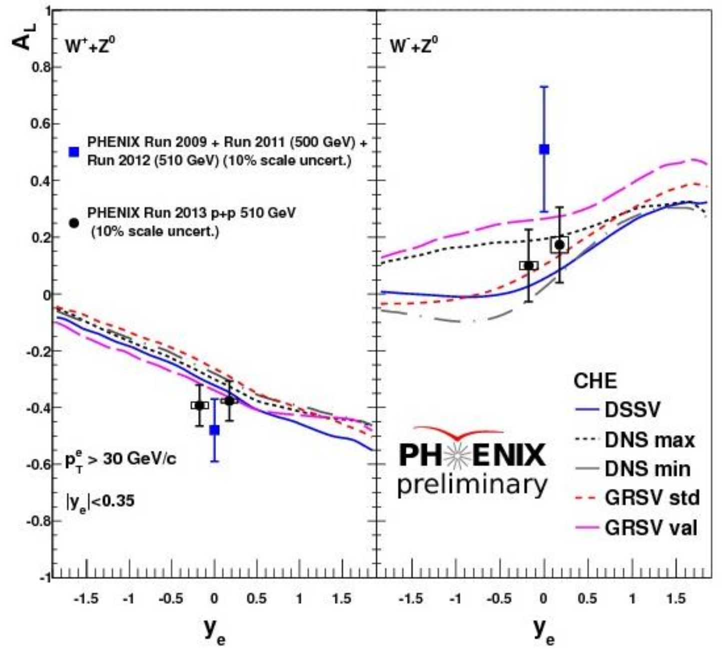

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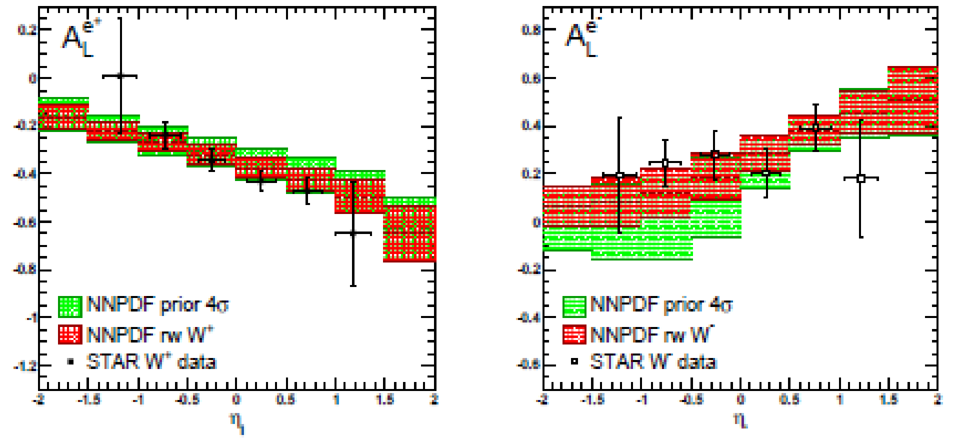

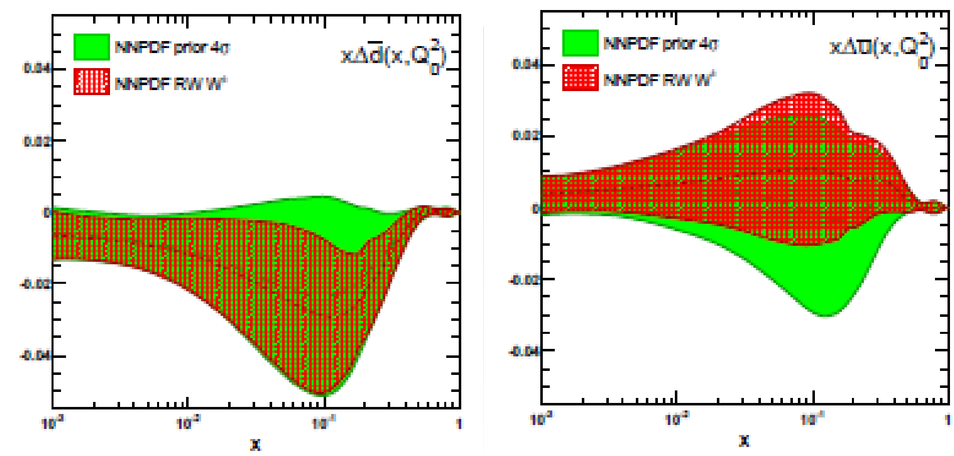

NNPDFpol1.1: E. Nocera et al..
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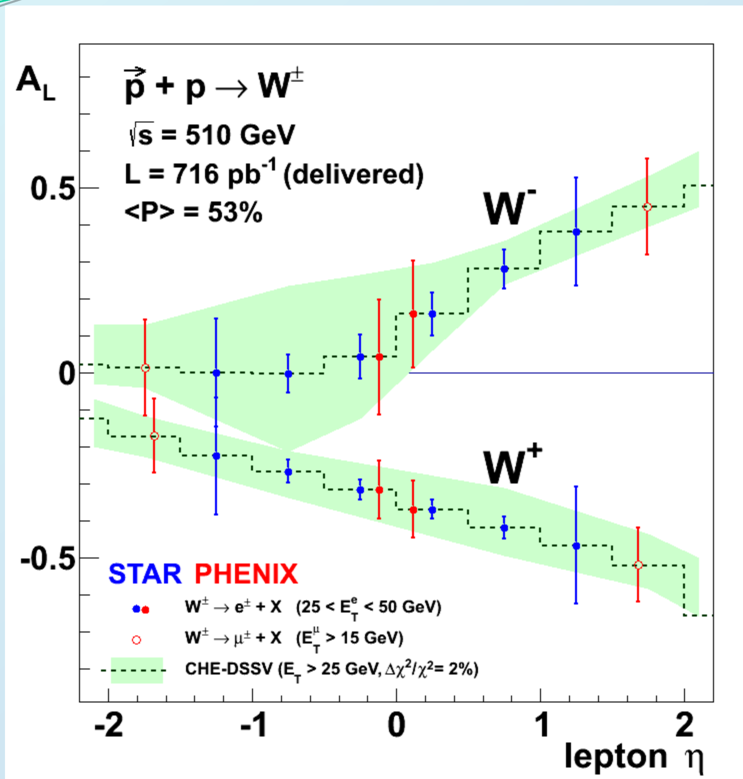
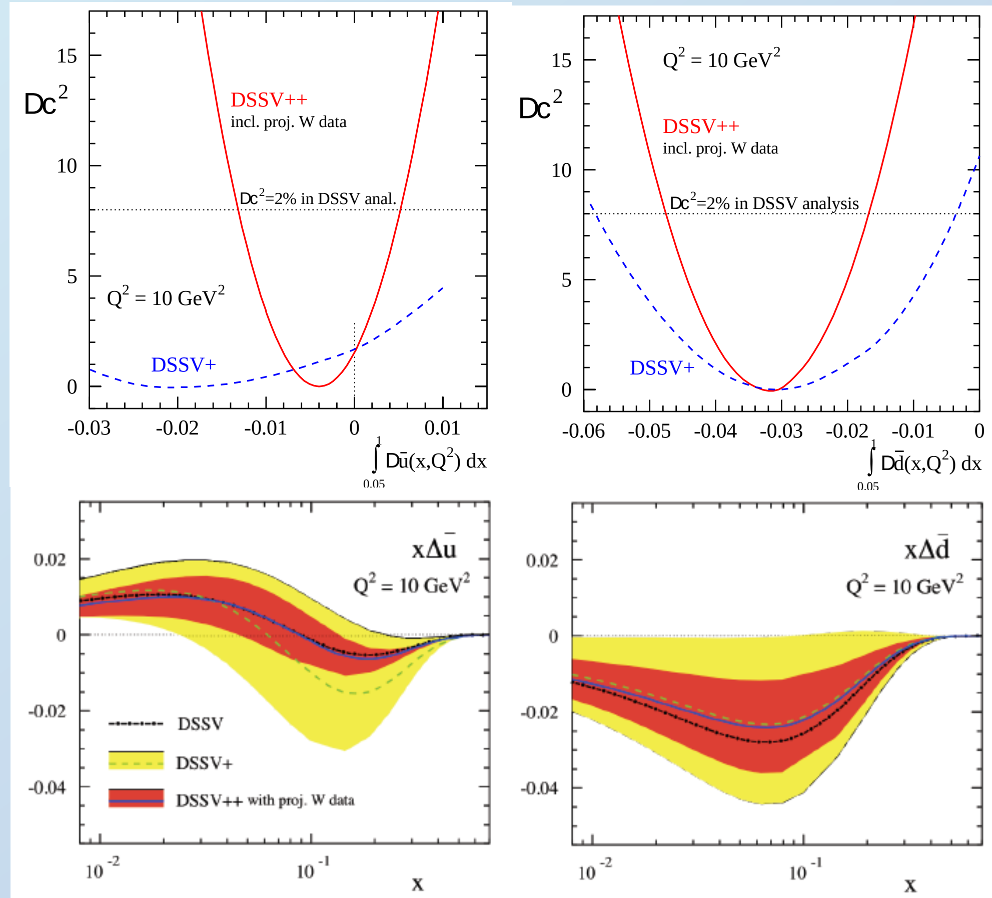
Near future: is polarized sea symmetric?



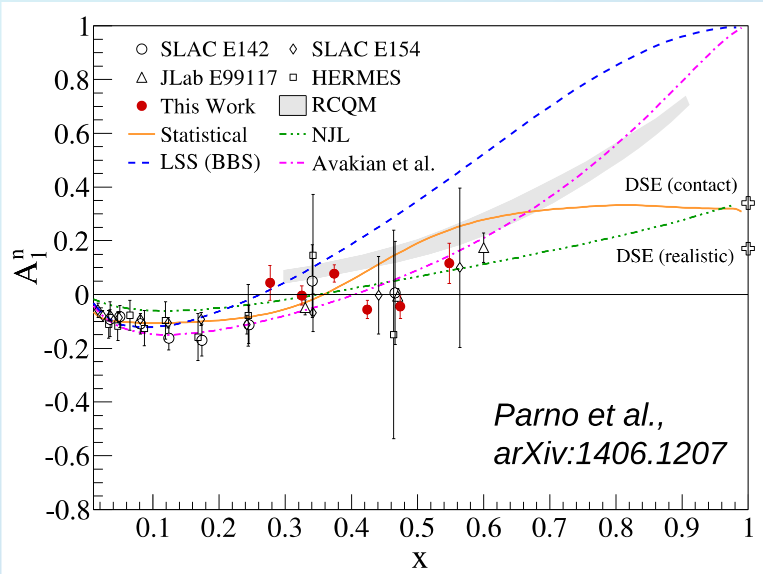


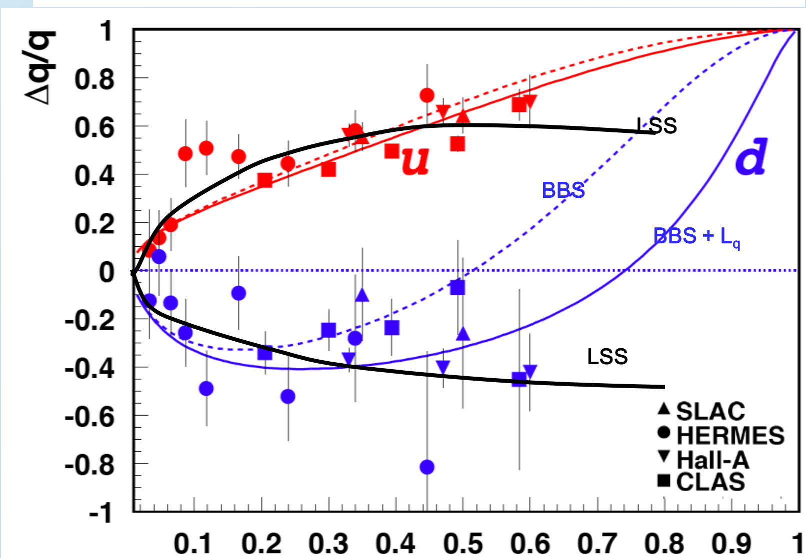
- Total 2011-2013 RHIC W data:
  - Substantial uncertainty improvement of the sea quark helicities
  - DSSV framework ready to include W asymmetries
  - NNPDF ready for Ws (but still need to include SIDIS)

arXiv:1304.0079

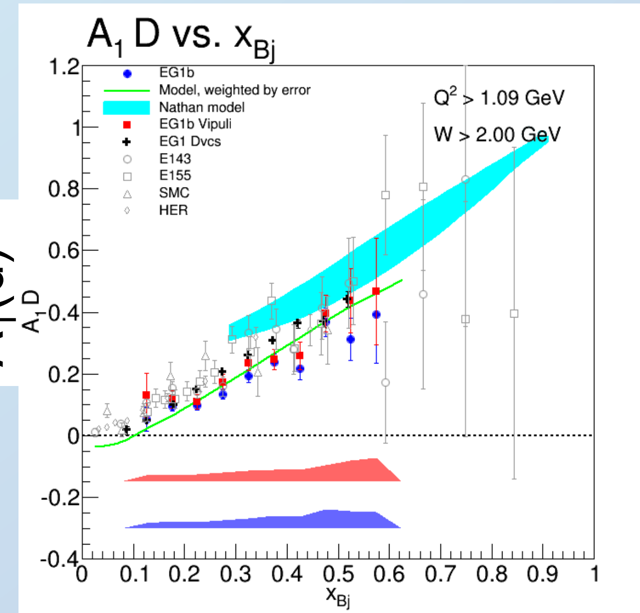
g_1 and Quark helicities at large x

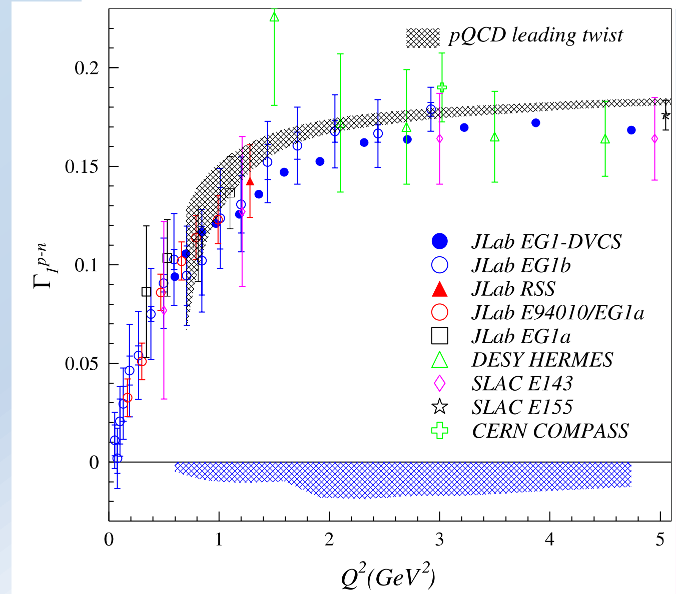
Hall A





CLAS



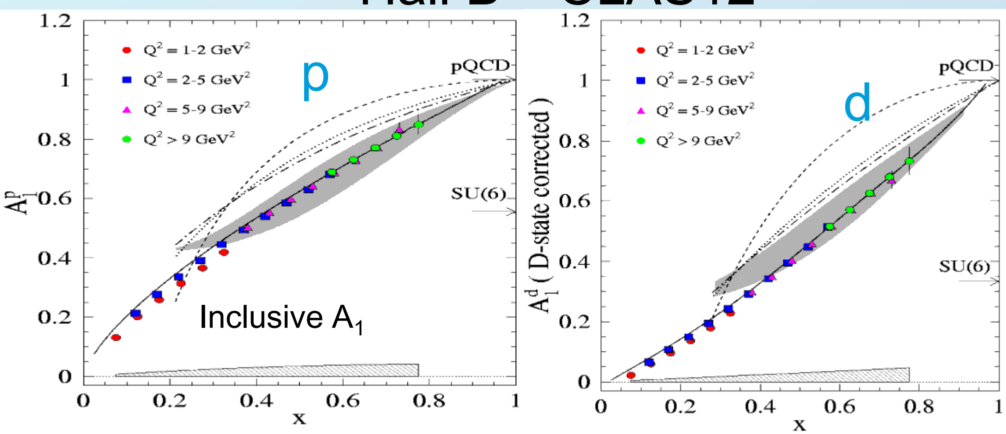


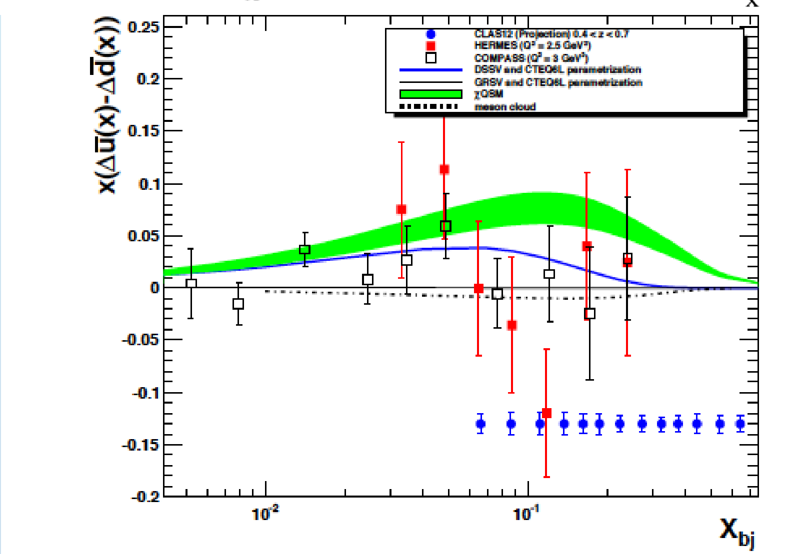
Phys.Rev. C90 (2014)
Phys.Lett. B641 (2006) 11-17

Near future: high x helicities

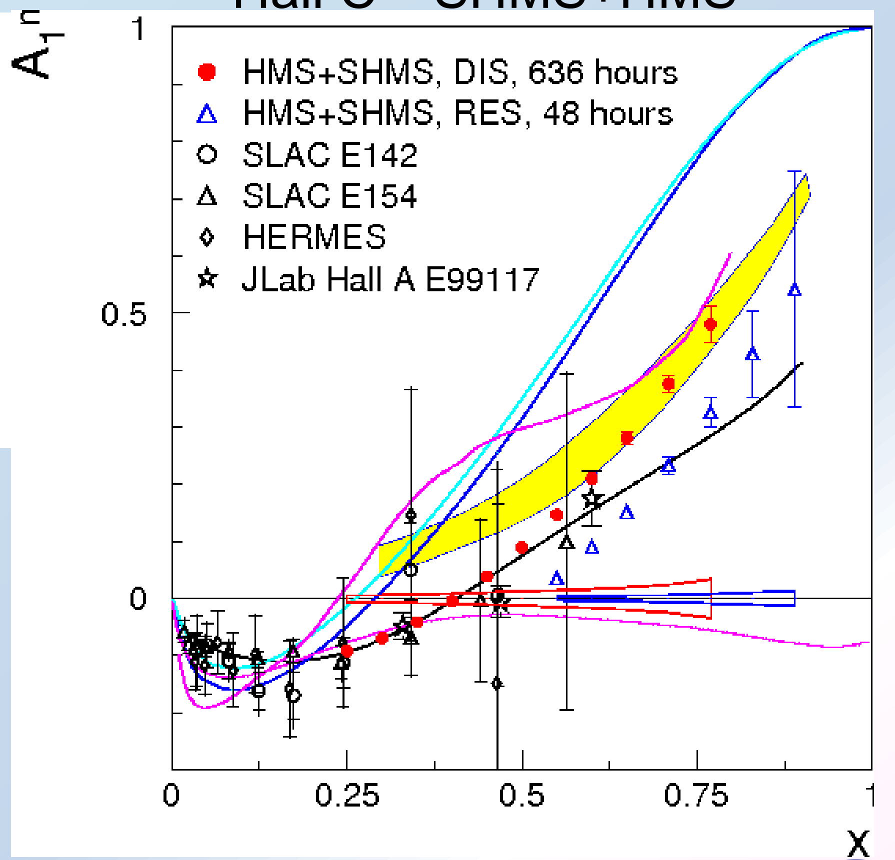
Flag-ship measurements of 12 GeV Upgrade

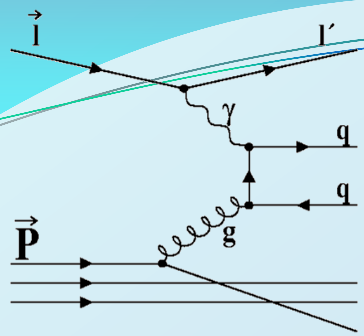
Hall B – CLAS12





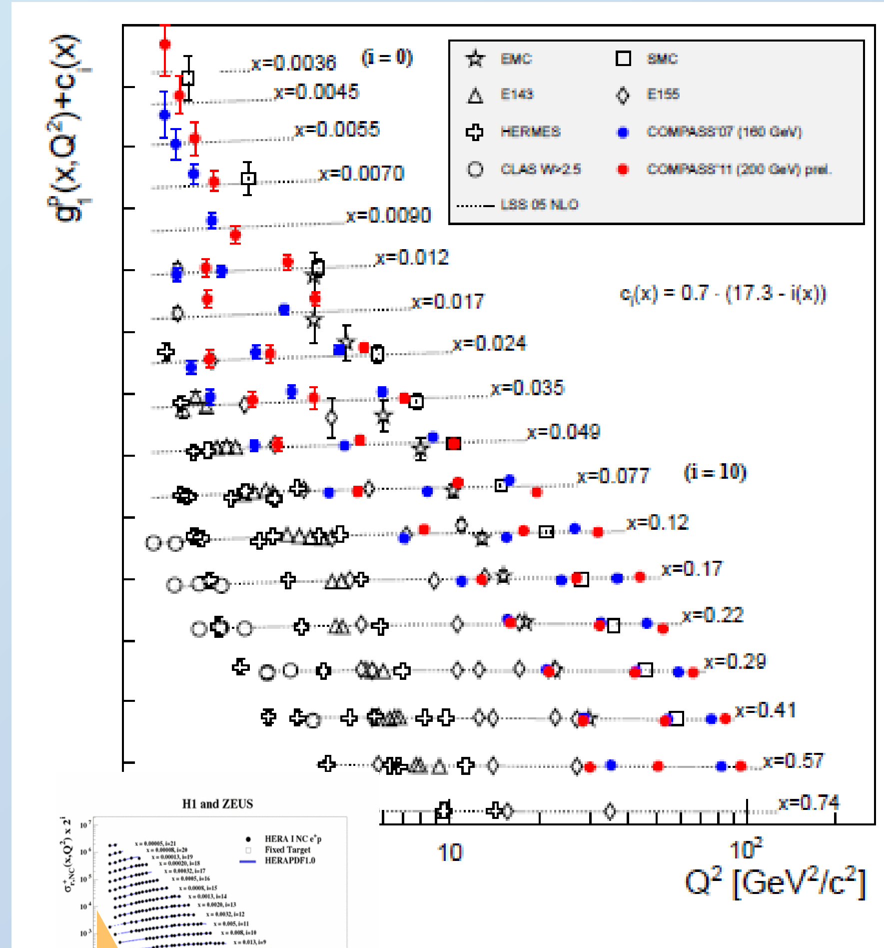
Hall C – SHMS+HMS

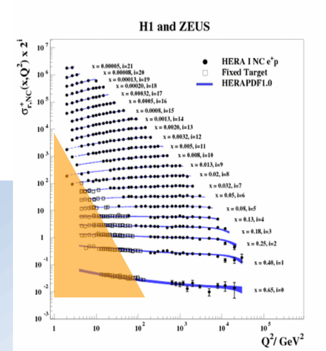




Gluon polarization

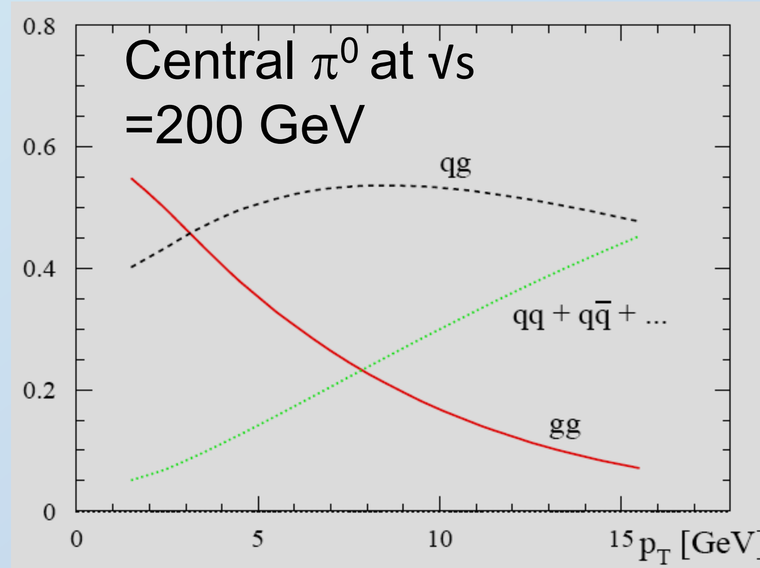
- Barely access via DIS data through DGLAP evolution (no large Q^2 lever arm)
- Some access in SIDIS through high Pt hadrons and charmed mesons

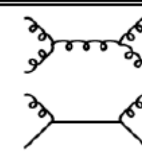
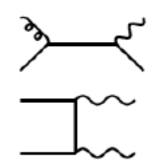
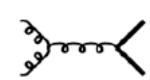




Gluon polarization

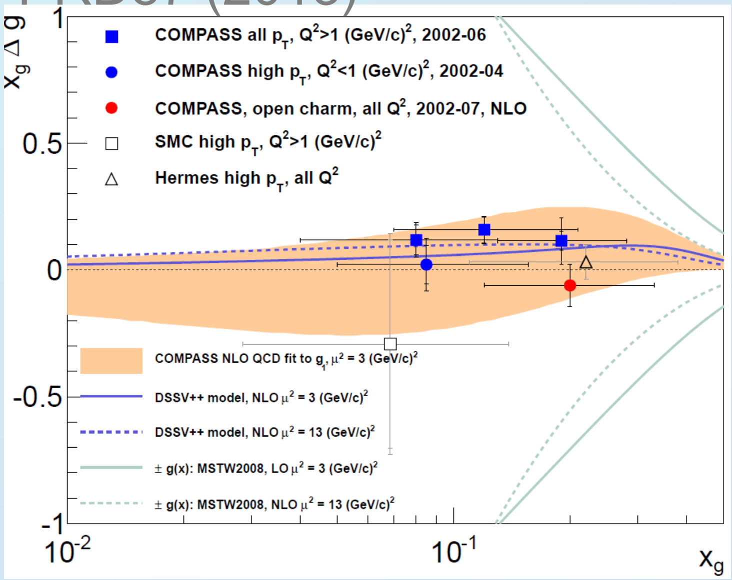
- Barely access via DIS data through DGLAP evolution (no large Q^2 lever arm)
- Some access in SIDIS through high Pt hadrons and charmed mesons
- Polarized pp collisions at LO in α_S sensitive to gluons



Reaction	Dom. partonic process	probes	LO Feynman diagram
$\vec{p}\vec{p} \to \pi + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	
$\vec{p}\vec{p} \to \text{jet(s)} + X$	$\vec{g}\vec{g} \to gg$ $\vec{q}\vec{g} \to qg$	Δg	(as above)
$\vec{p}\vec{p} \to \gamma + X$ $\vec{p}\vec{p} \to \gamma + \text{jet} + X$ $\vec{p}\vec{p} \to \gamma\gamma + X$	$\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{g} \to \gamma q$ $\vec{q}\vec{\bar{q}} \to \gamma\gamma$	Δg Δg $\Delta q, \Delta\bar{q}$	
$\vec{p}\vec{p} \to DX, BX$	$\vec{g}\vec{g} \to c\bar{c}, b\bar{b}$	Δg	

Current highlights: gluon helicities

COMPASS, PLB718(2013), PRD87 (2013)



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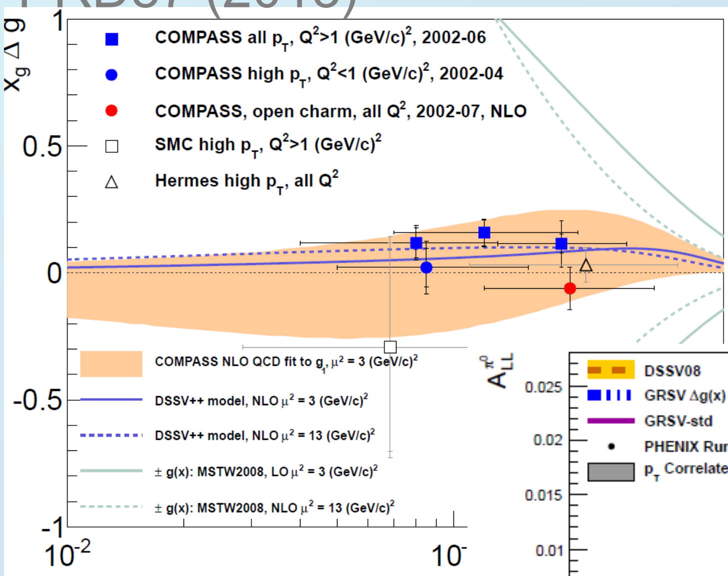
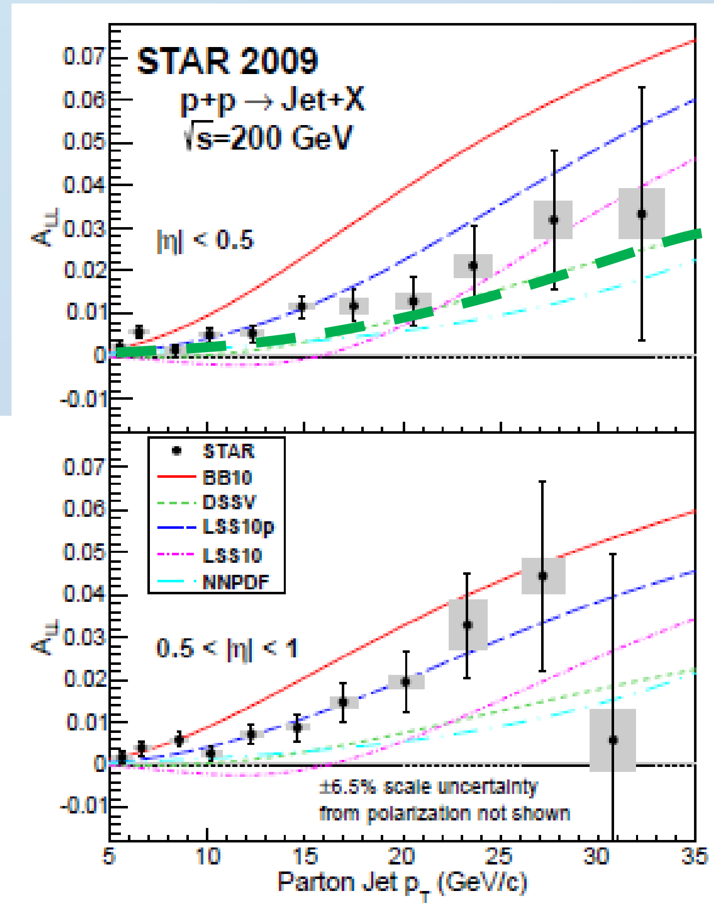
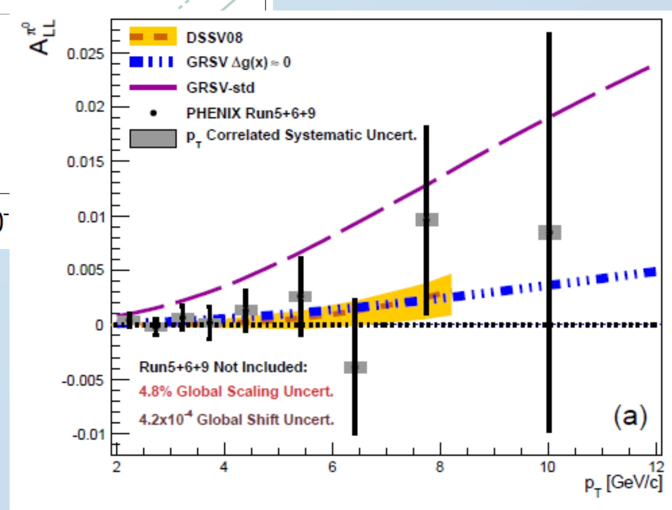


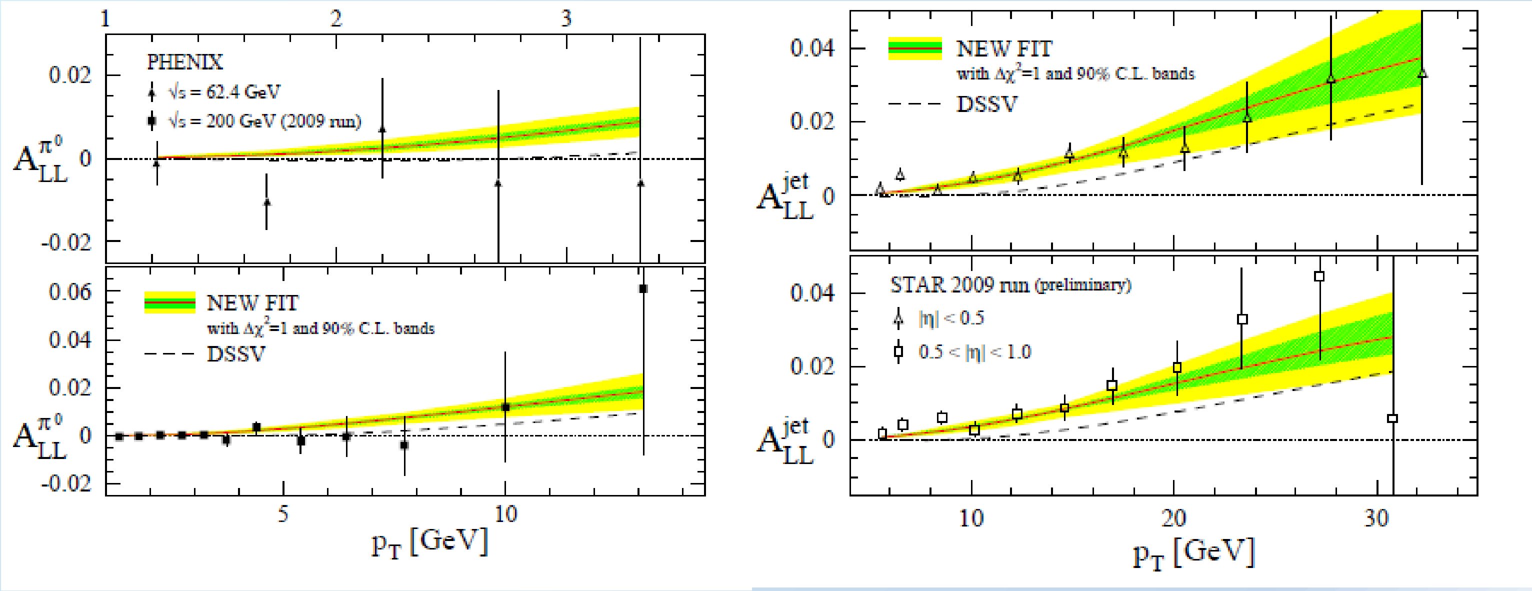
STAR: arXiv:1405.5134





PHENIX: Phys.Rev. D90 (2014) 012007

DSSV++



- DSSV:Phys.Rev.Lett. 113 (2014) 012001

- Nonzero gluon spin in measured x range
- Similar conclusion from NNPDFpol1.1 arXiv:1406.5539

- Pions at slightly smaller x
- and smaller Pt → Δg smaller due to evolution

Press interest in nonzero gluon spin

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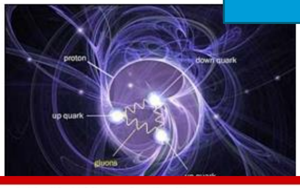
Proton Spin Mystery Gains a New Clue

Physicists long assumed a proton's spin came from its three constituent quarks. New measurements suggest particles called gluons make a significant contribution

Jul 21, 2014 | By Clara Moskowitz

Protons have a constant spin that is an intrinsic particle property like mass or charge. Yet where this spin comes from is such a mystery it's dubbed the "proton spin crisis." Initially physicists thought a proton's spin was the sum of the spins of its three constituent quarks. But a 1987



Low x, not covered so far →more forward pp, EIC

IOP Physics World - the member magazine of the Institute of Physics

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Gluons get in on proton spin

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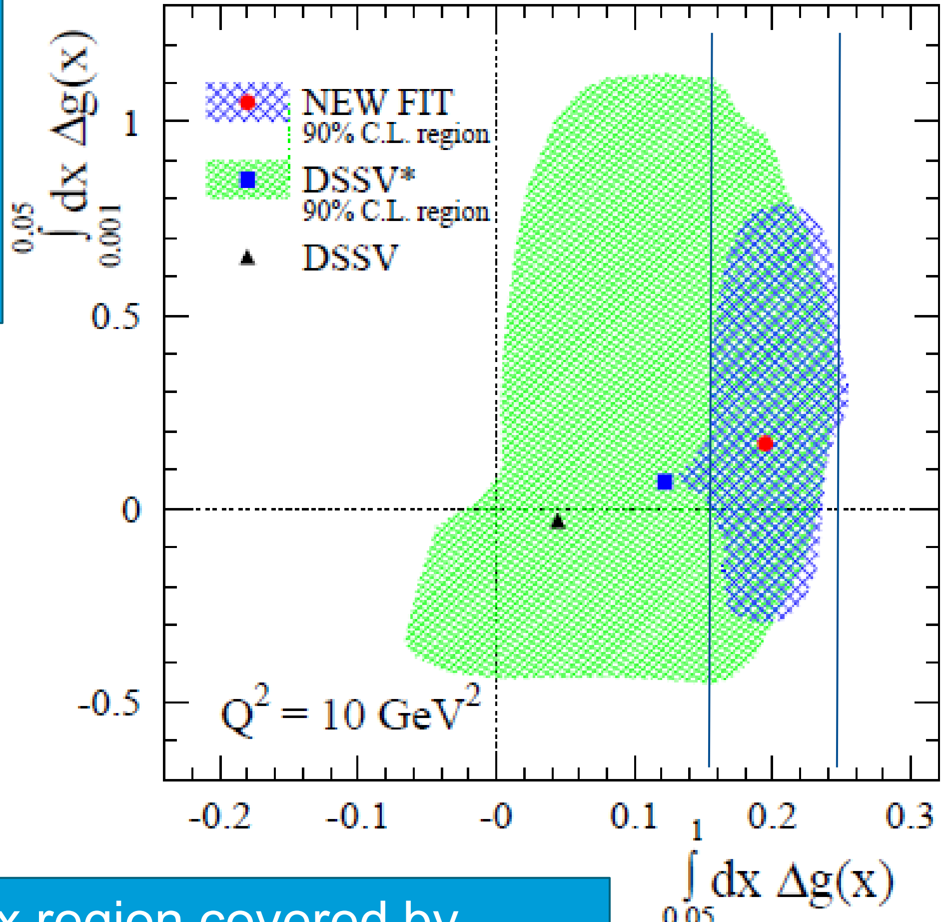
Synopsis: Gluons Chip in for Proton Spin



x region covered by current RHIC and DIS results

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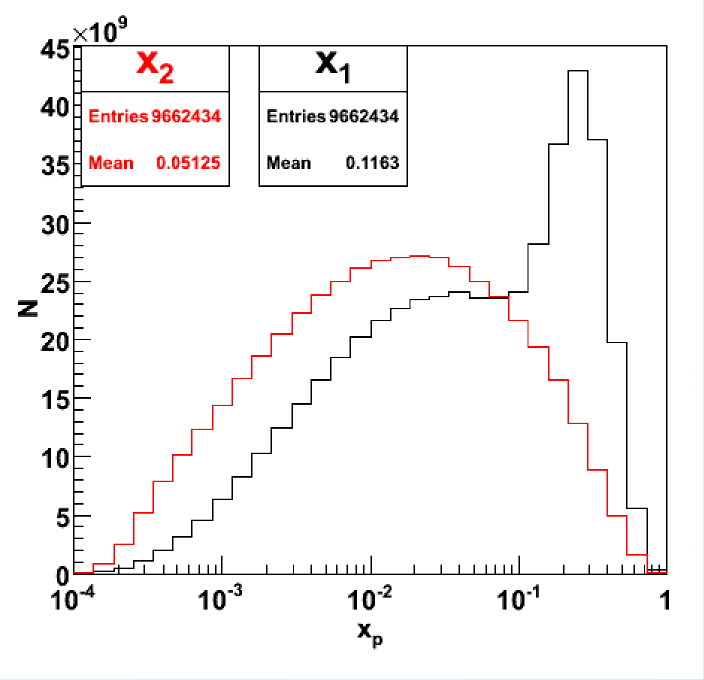
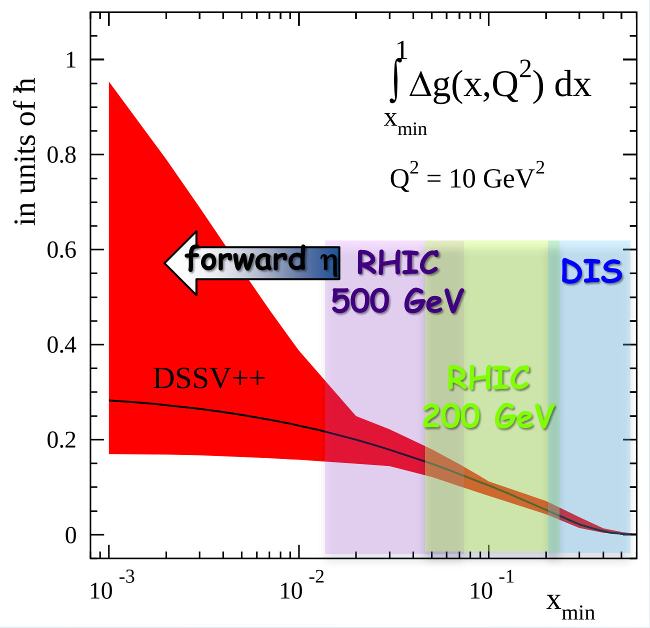
Near future: extend gluon x range

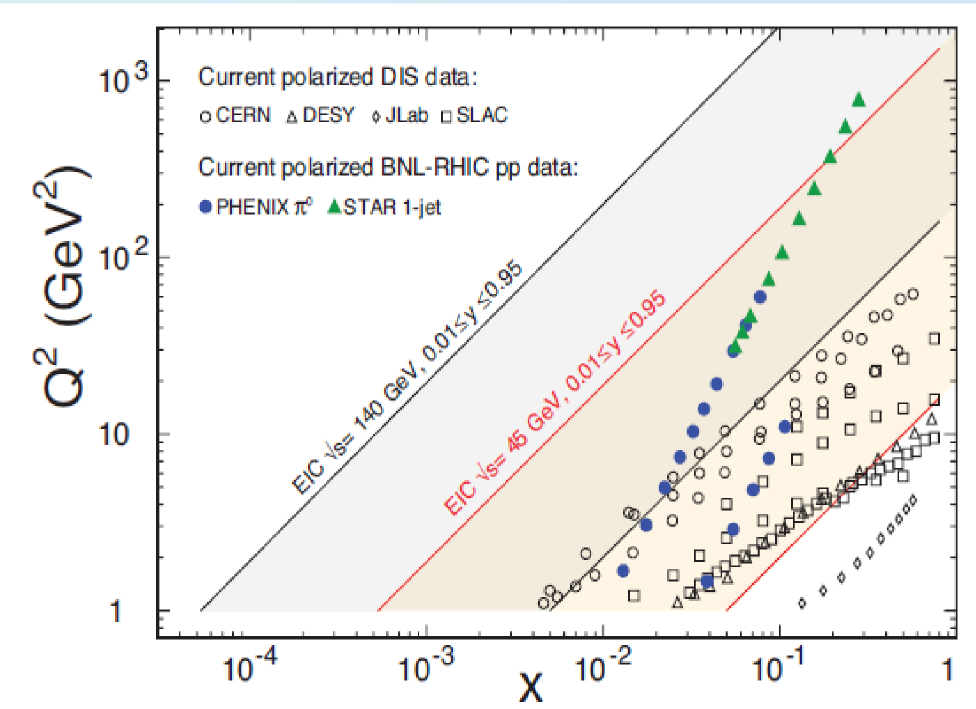
Forward π^0 in $3.1<\eta<3.9$, p_T>1GeV



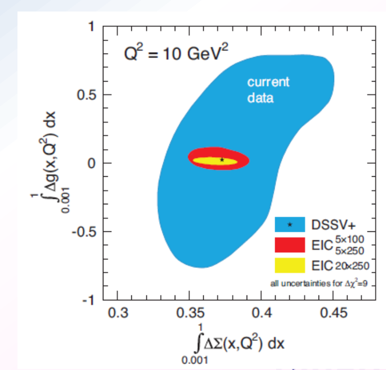


- Existing 2013 + future data will extend gluon x coverage below $x=10^{-2}$ in forward pion and jet measurements
- Di-jets to scan x range
- Improved precision in central jet and pion measurements

Longer term question: sea and gluons contributions at lower x? →EIC



- Answer questions whether light quark sea is really symmetric or not
- Resolve strange helicity puzzle (or shoot down $SU(3)_f$ applicability from hyperon decays)
- Large impact on integrals



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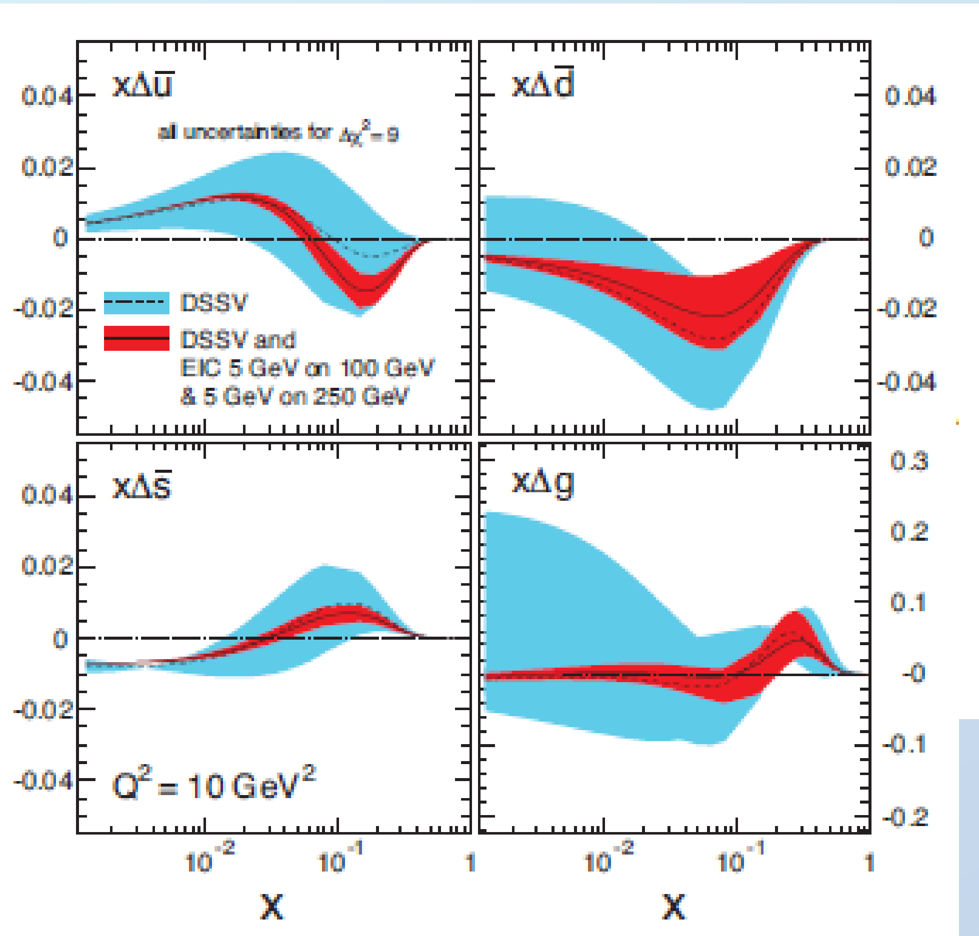

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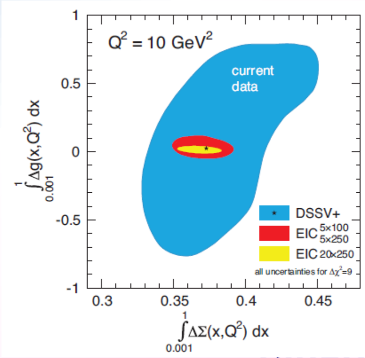
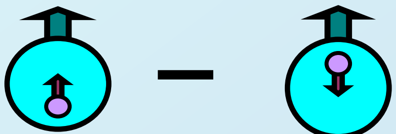
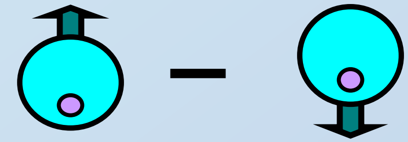


Transverse spin: Main questions

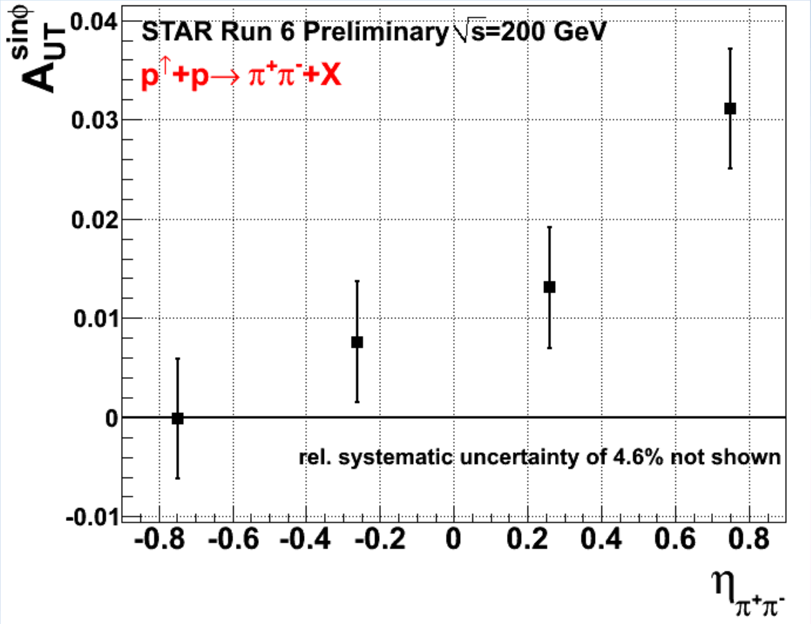




- How are quarks and gluons distributed in transverse momentum space?
- What do we learn from all the different spin and orbit correlations (obviously OAM needed for nonzero Sivers function, but so do anomalous magnetic moments)
- Is our understanding of TMDs via gauge links correct? → universality, sign change of Sivers and Boer-Mulders function
- How do Transversity distributions differ from helicity distributions?
  - connection to lattice calculations via tensor charge
  - Any sizeable sea?
- what is the connection between SIDIS and pp?

Transversity

- Collins and dihadron SIDIS (HERMES,COMPASS, HallA) and Collins FF (Belle, BABAR) results very consistent,
- "global" fits to pion Collins (Torino) and di-hadron (Pavia) with similar transversitites
- Still need to be included in fits:
  - First Collins and di-hadron results from RHIC.
  - Kaon SIDIS results
  - preliminary Kaon FF from Belle



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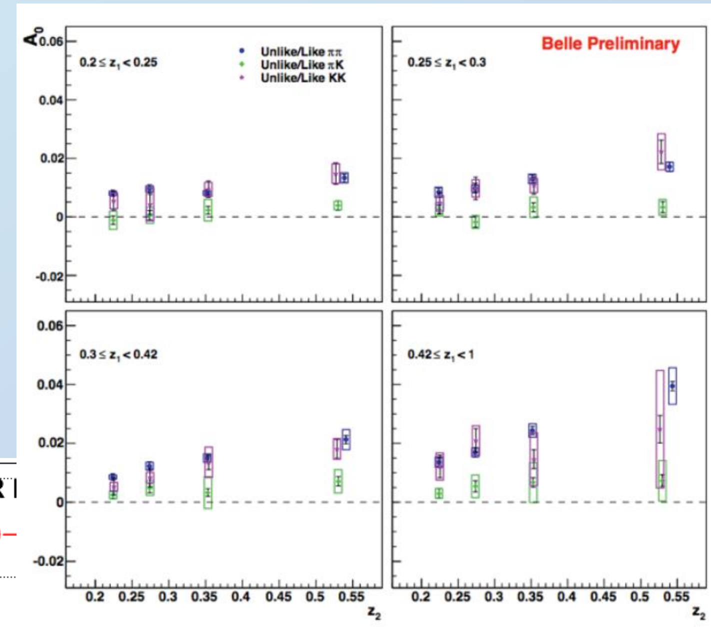
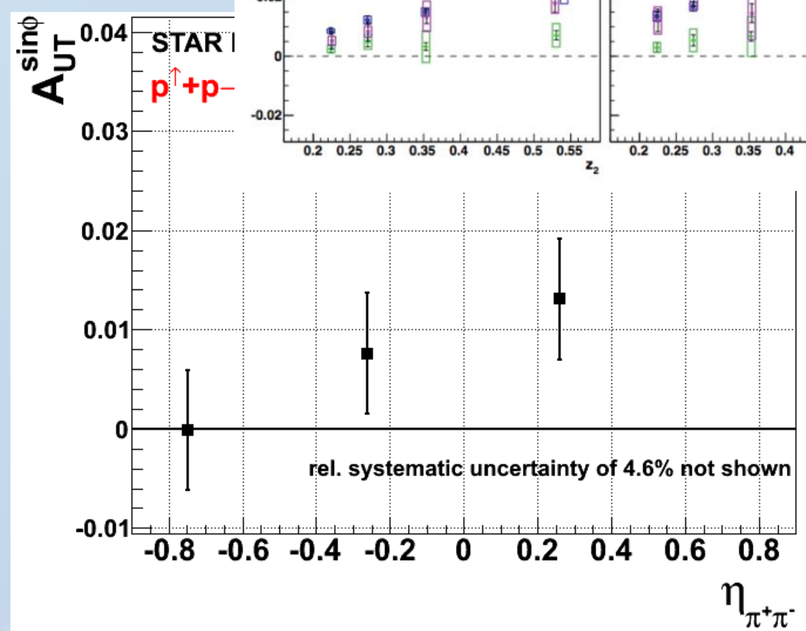
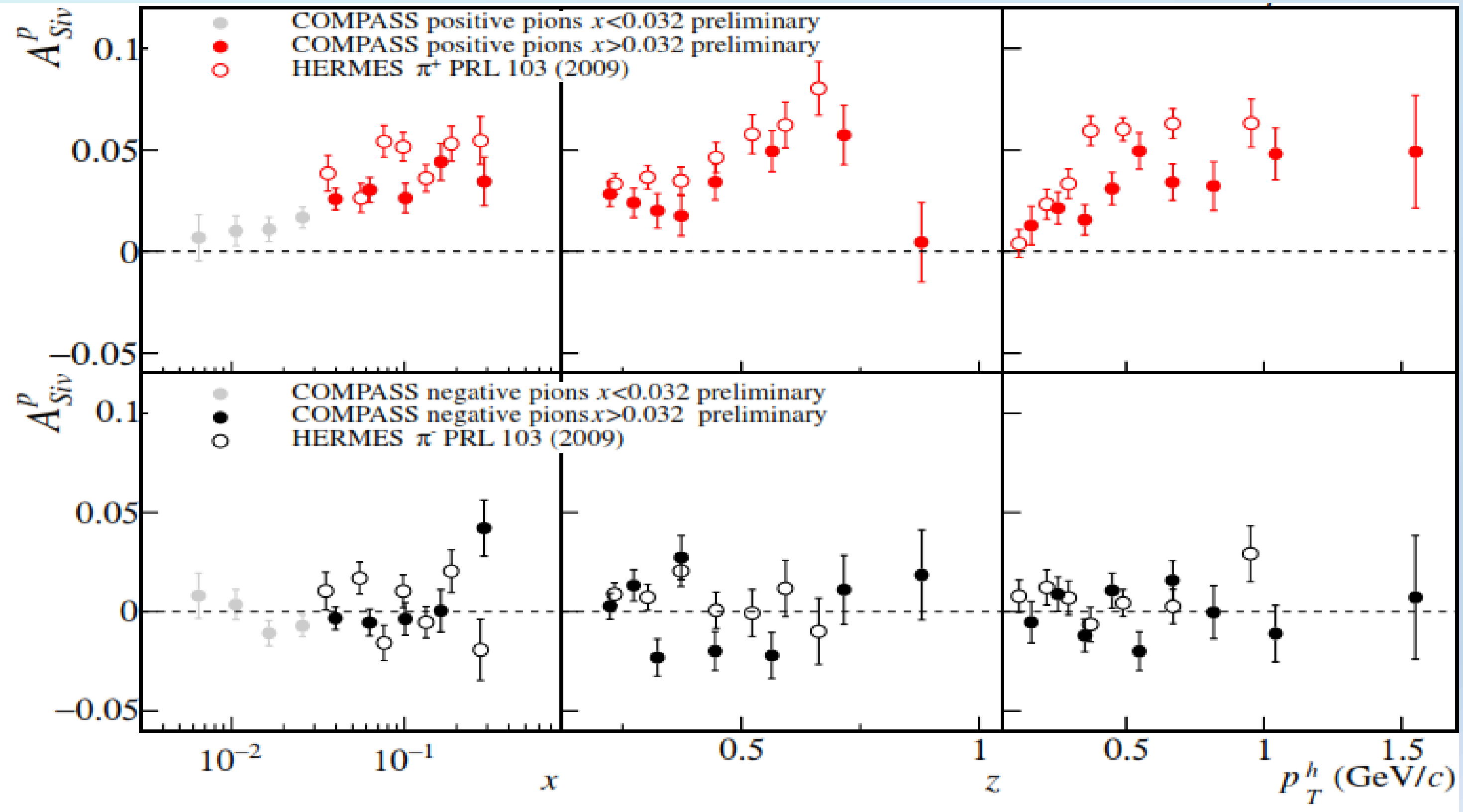




(Almost) Consolidation of Sivers in SIDIS



- Similar effect on proton targets, but smaller magnitude at higher scale – effect of evolution

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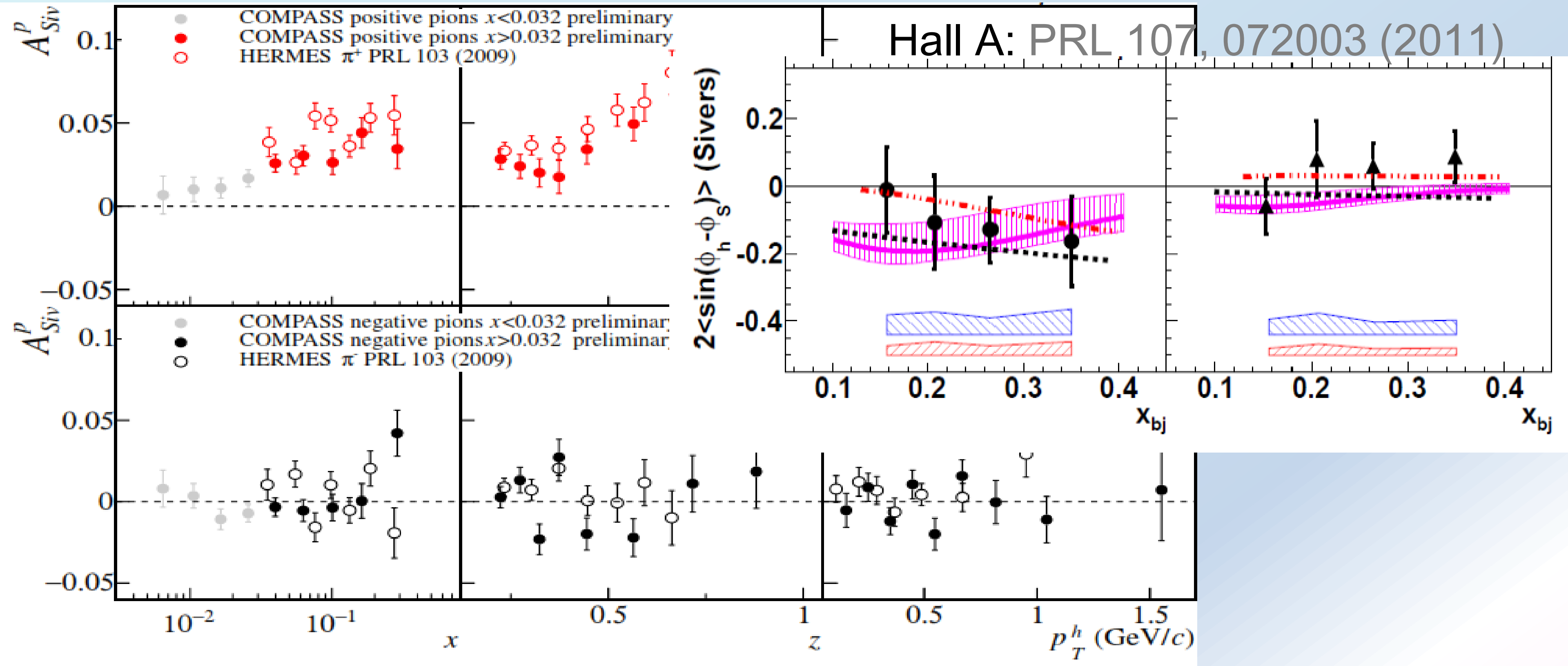

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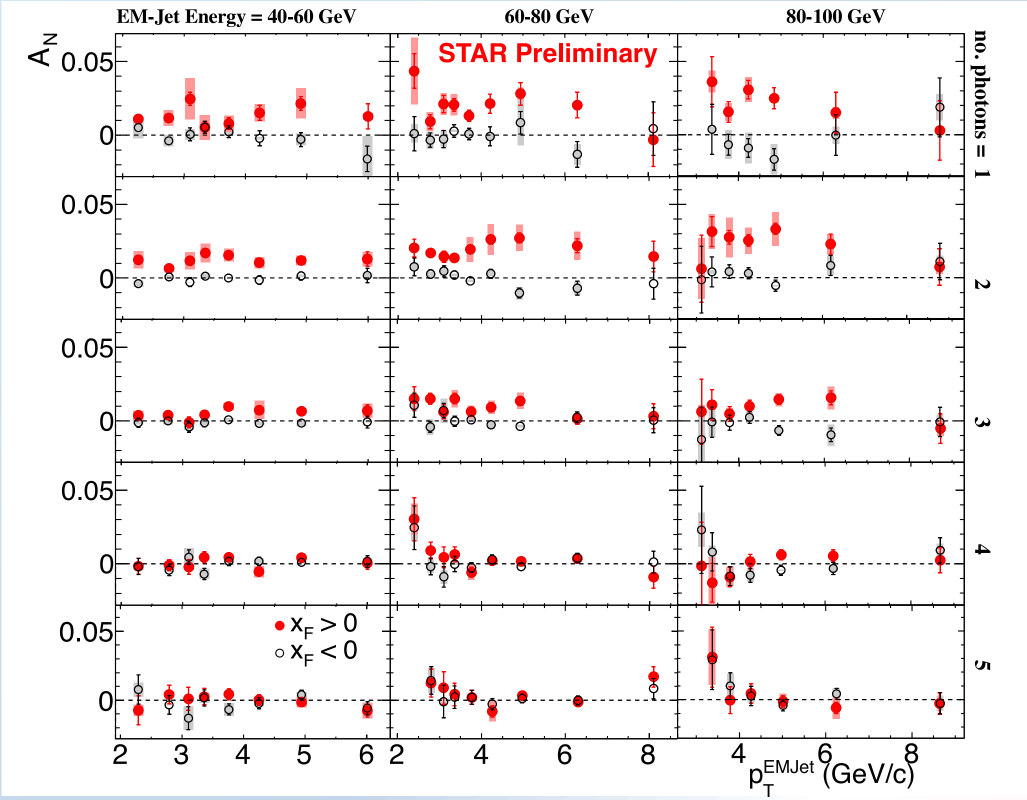
Connection to pp A_Ns

- higher twist contributions related to Sivers and Collins kt moments
- However, more higher twist functions exist
- Initial assumptions of Sivers-like only contributions not correct or at least of wrong sign
- Indications of smaller asymmetries in more “jetty” events could point to other mechanism such as diffraction
- All backward and central asymmetries zero (pions, eta, jets) --indication of small forward jets



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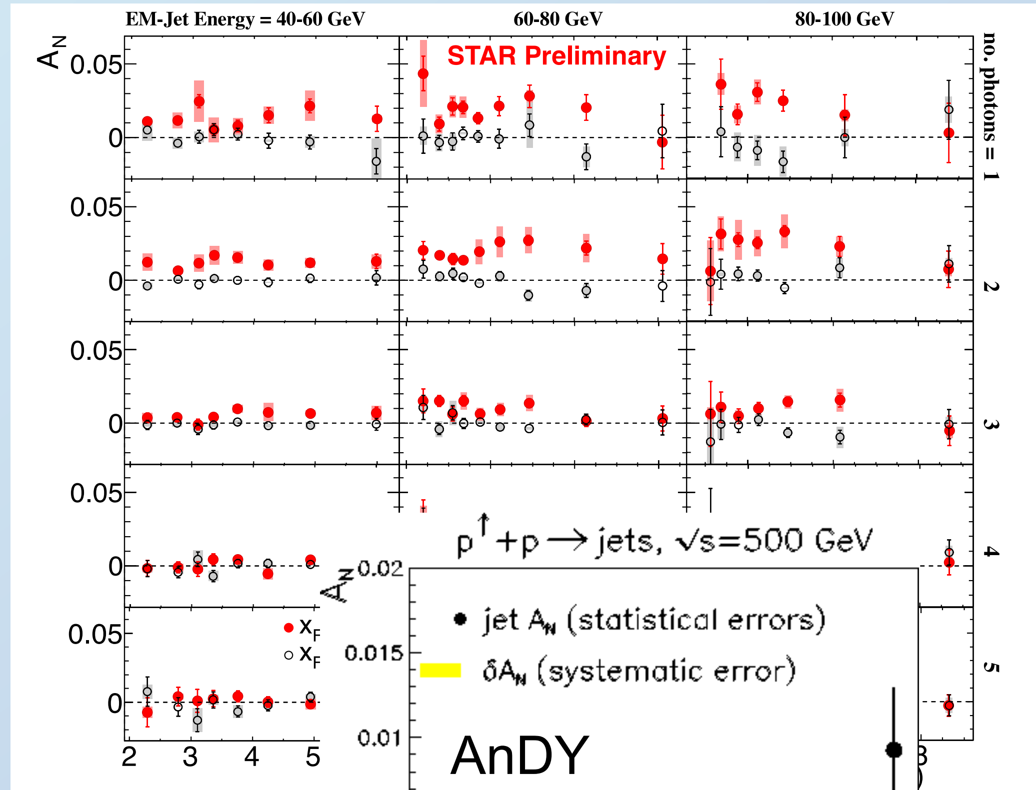
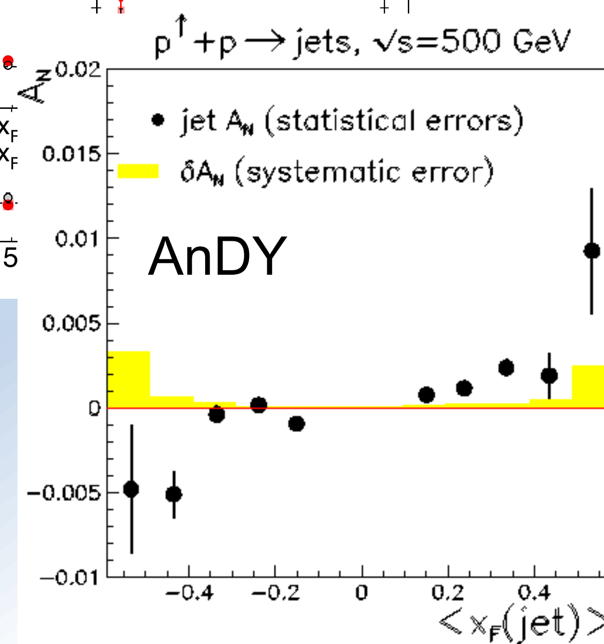
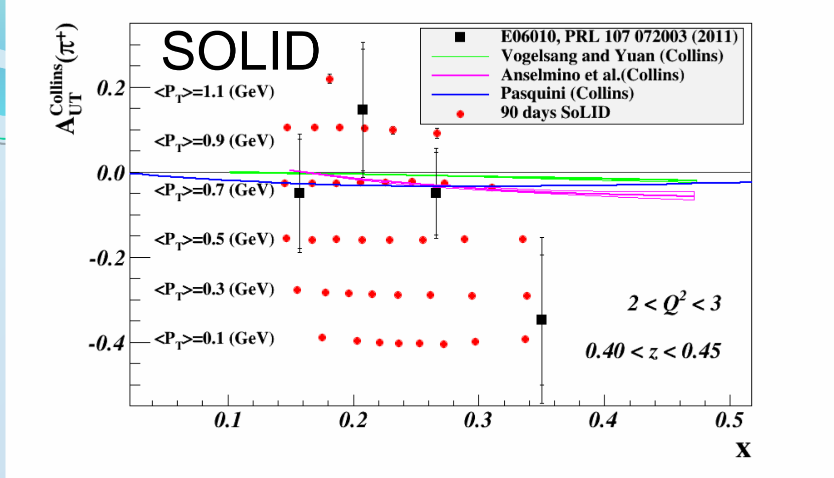
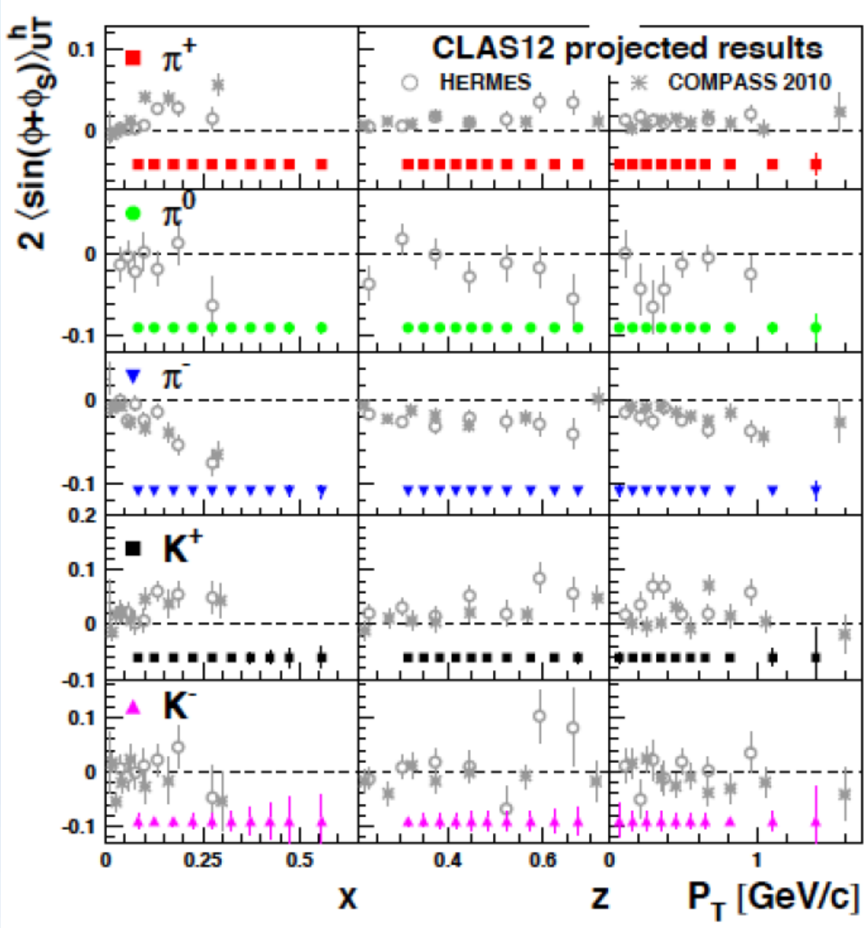




Near future

- Precise higher x Sivers and Collins measurements from Jlab at 11 GeV
- More IFF and Collins measurements from RHIC
- Forward direct photon and jet measurements at RHIC
  - Dis-entangle initial state and final state contributions to A_Ns
  - Roman pots in STAR





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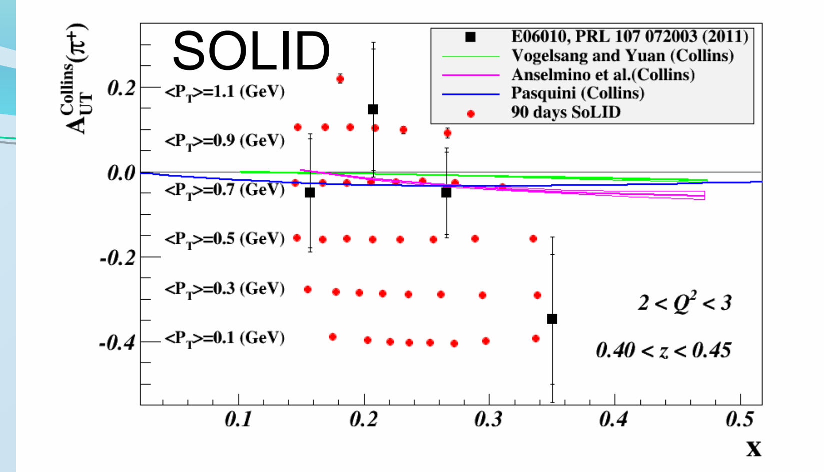
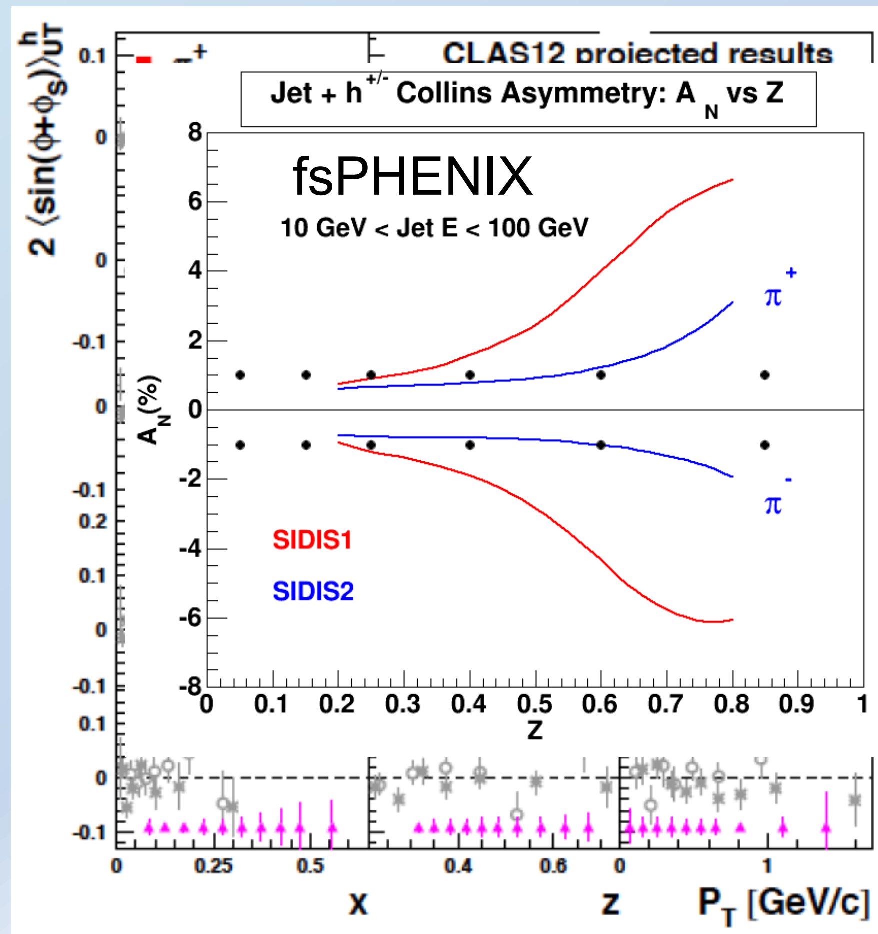
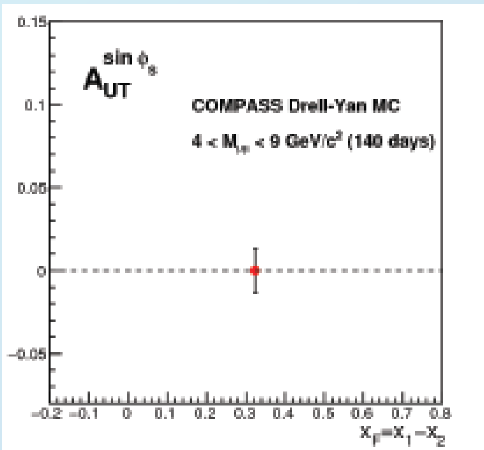
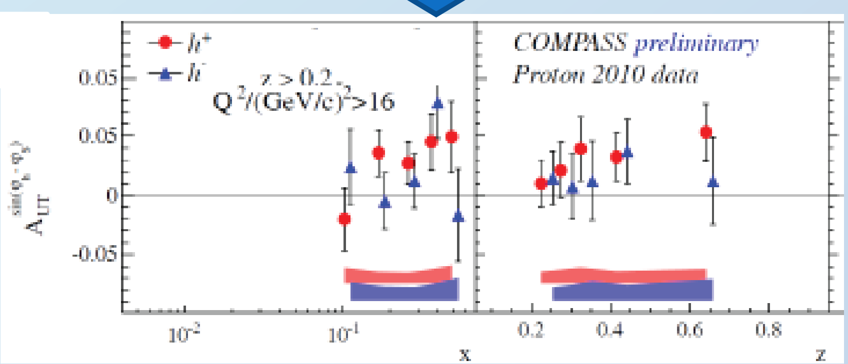




Sivers SIDIS-DY: The sign change?



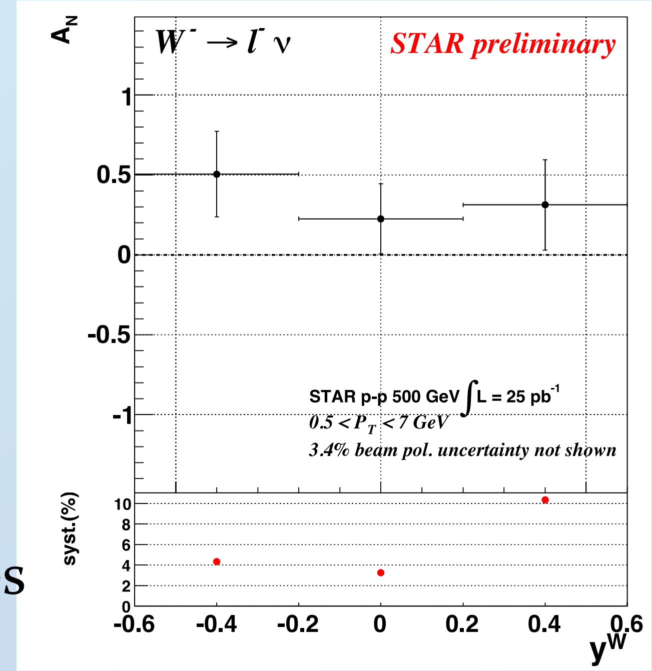


- Re-analysis of 2010 data in same Q^2 range as DY shows still sizeable asymmetry of 4-5 % → direct comparison to DY measurement in one experiment possible
- 140 days of data-taking sufficient to see sign change on the 2 sigma level
- will need additional confirmation:
  - more Compass running>2017?
  - RHIC
  - FNAL??

Chiosso@Transversity 2014

DY Sivers sign change in the US

- Possible 2016 510 GeV pp data taking: STAR W A_Ns (reconstruction of W kinematics)
  - feasability study shown at DIS2014
  - Also forward electron DY?
- 200 and 500 GeV polarized pp at RHIC~2020+ : DY capabilities at STAR and fsPHENIX
- Polarized target in E906: unfortunately wrong kinematics – mostly sensitive to sea Sivers (but also interesting)
- Polarizing Main Injector very unlikely



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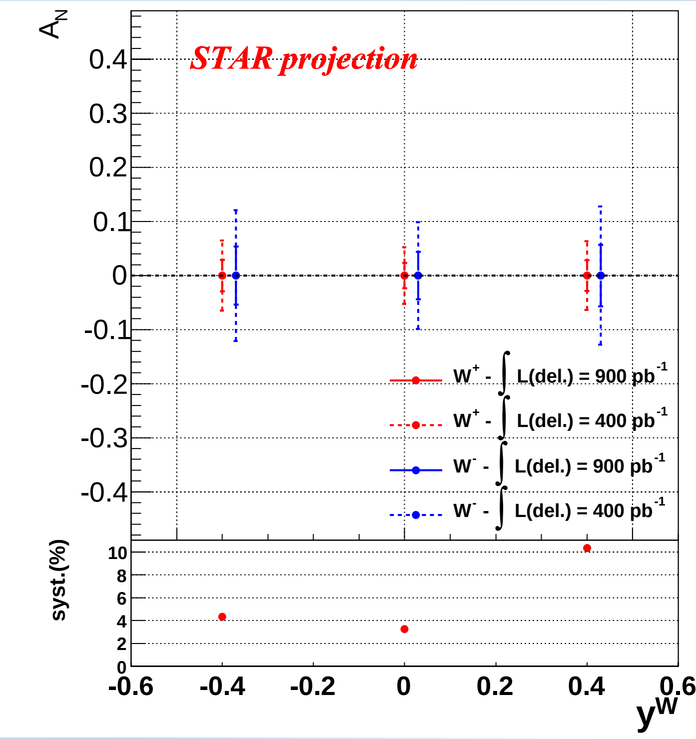

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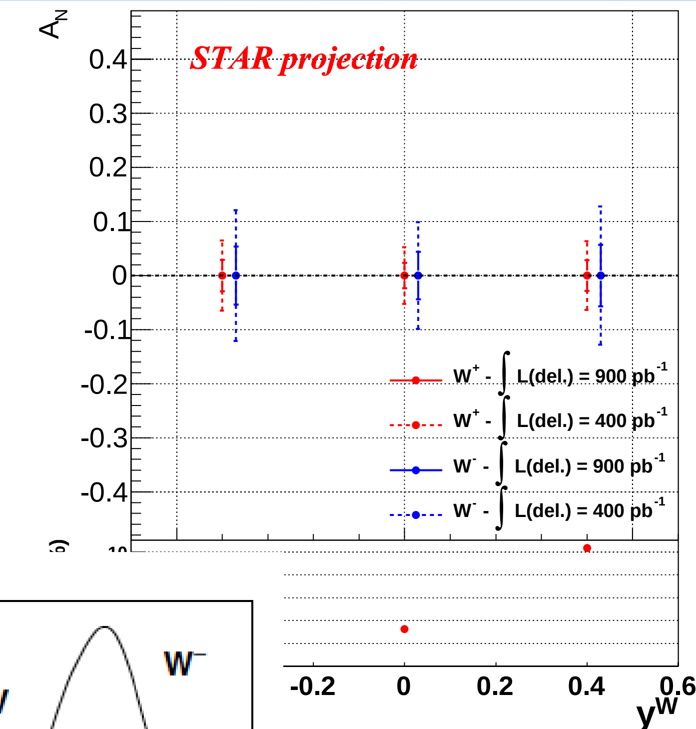

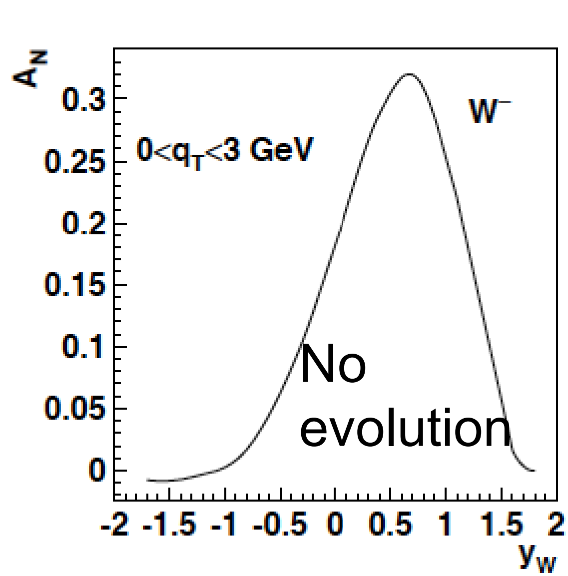

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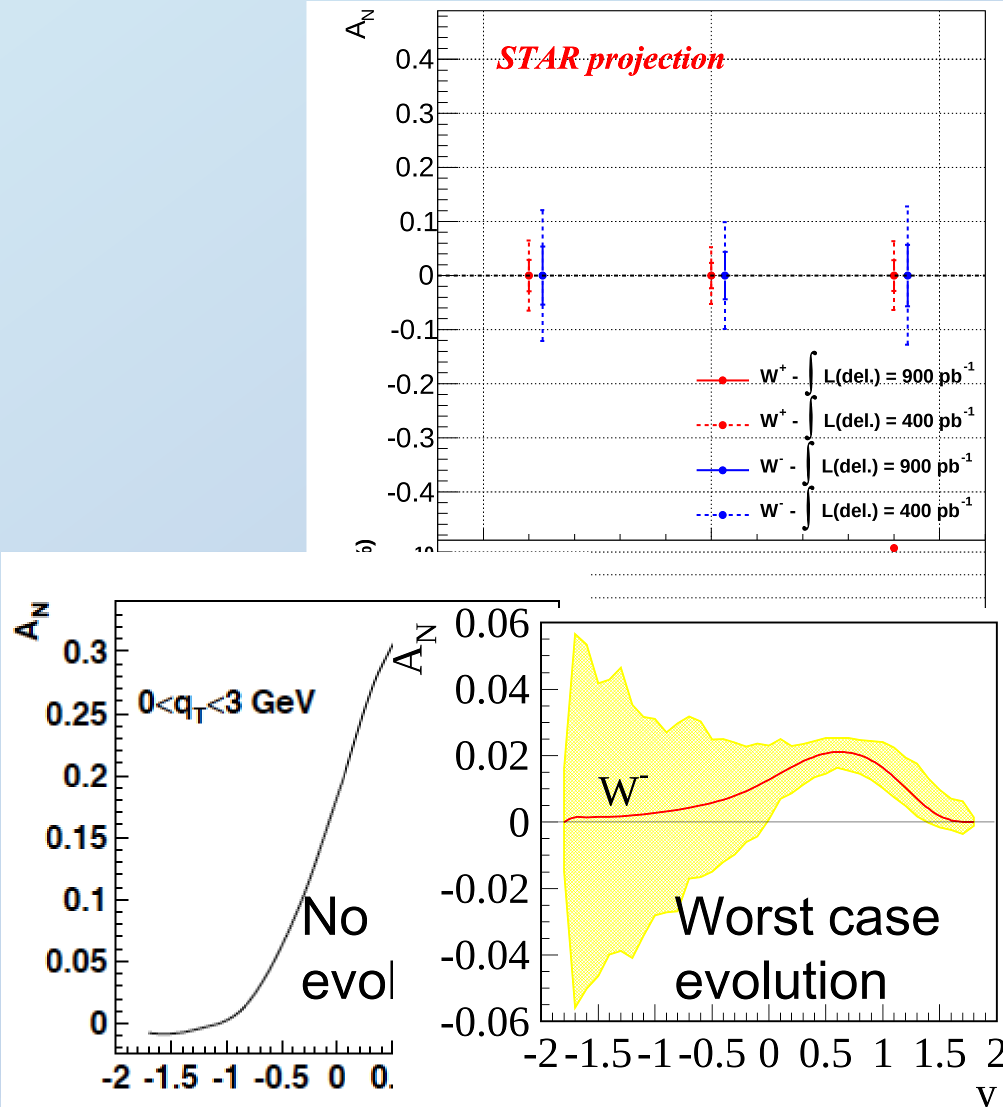
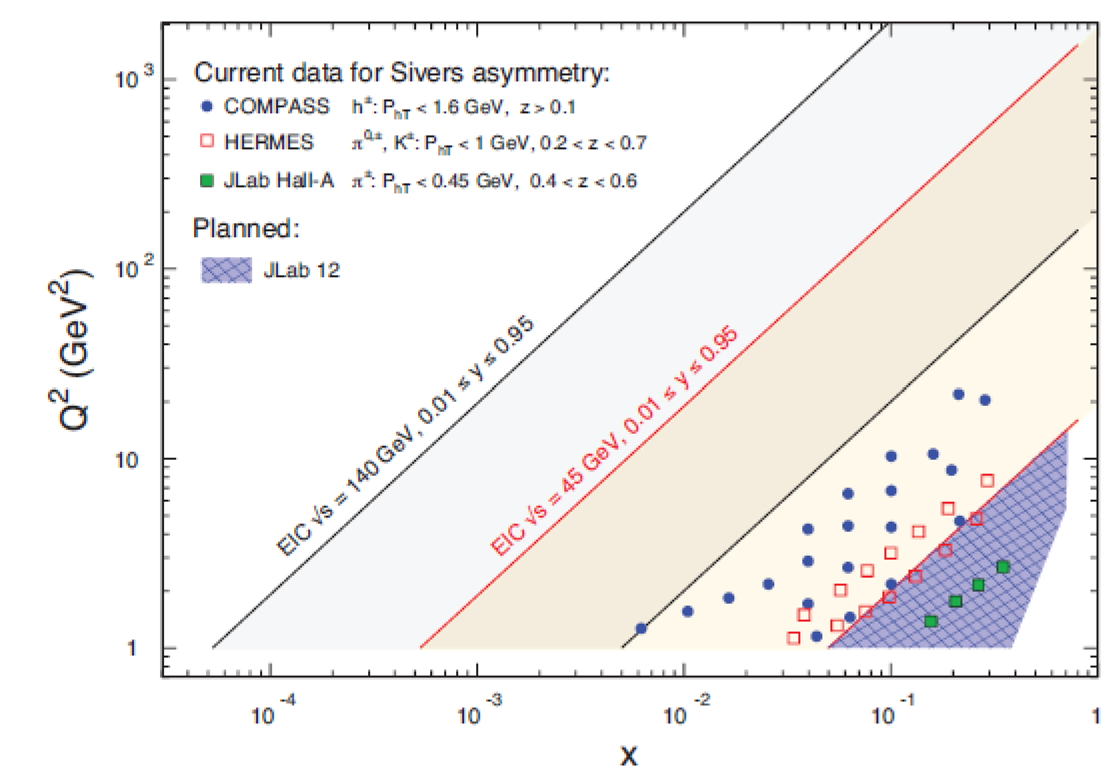


Longer Term: sea Sivers and 3d momentum tomography: → EIC



Also ideas on how to access gluon Sivers via D meson production

Similar reach for Transversity → Tensor charges of the nucleon for various Quark flavors and comparison to Lattice calculations

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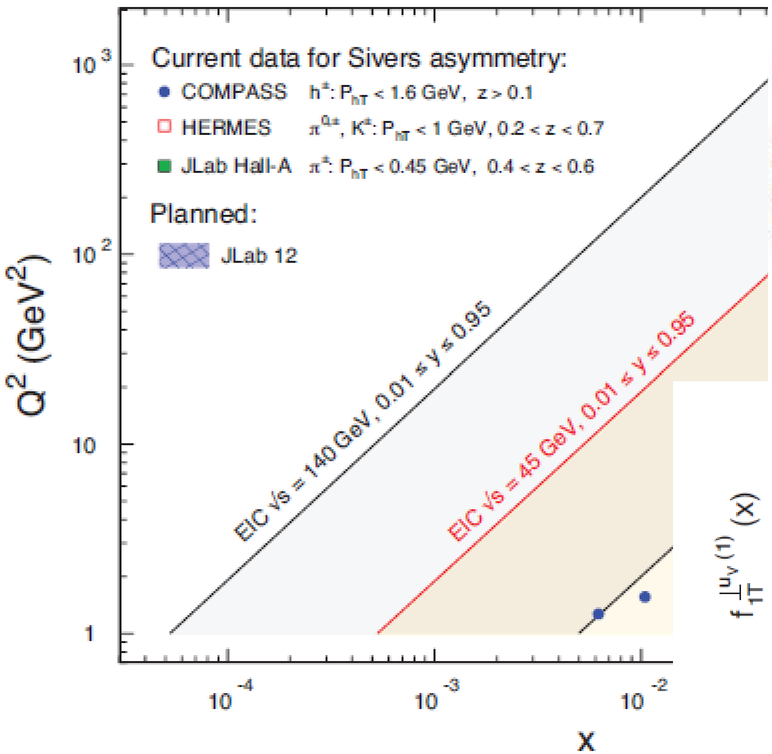

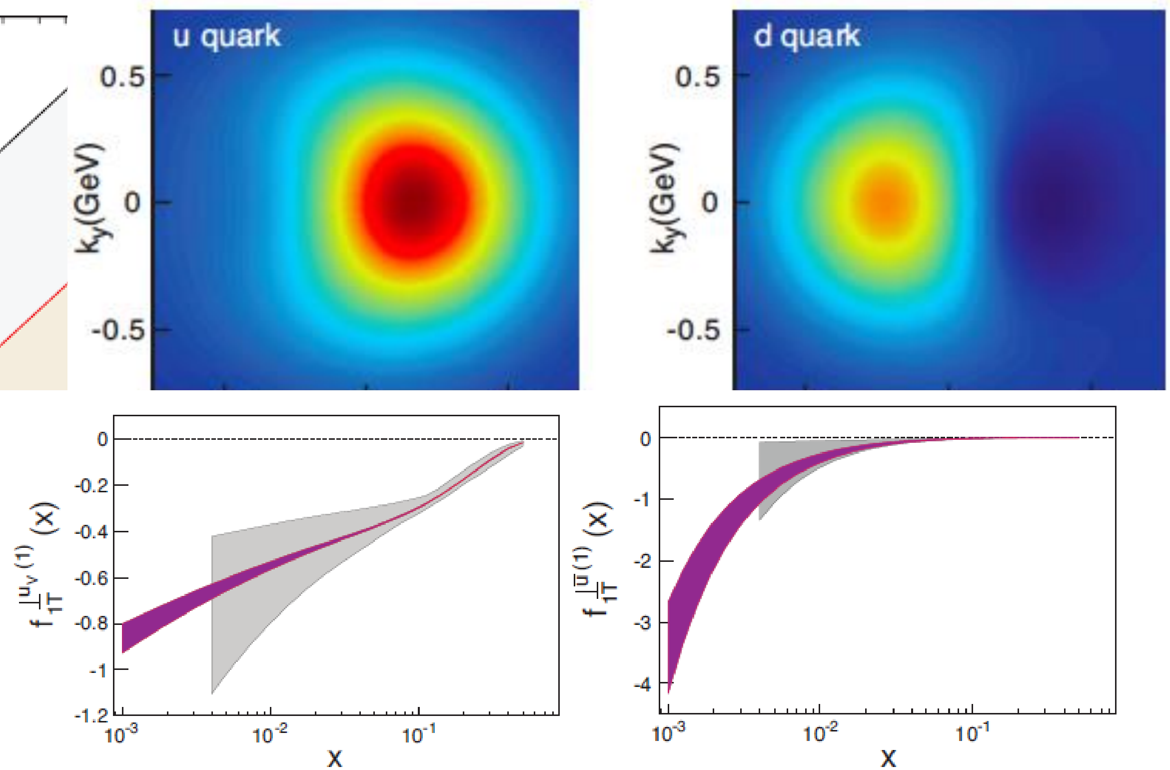

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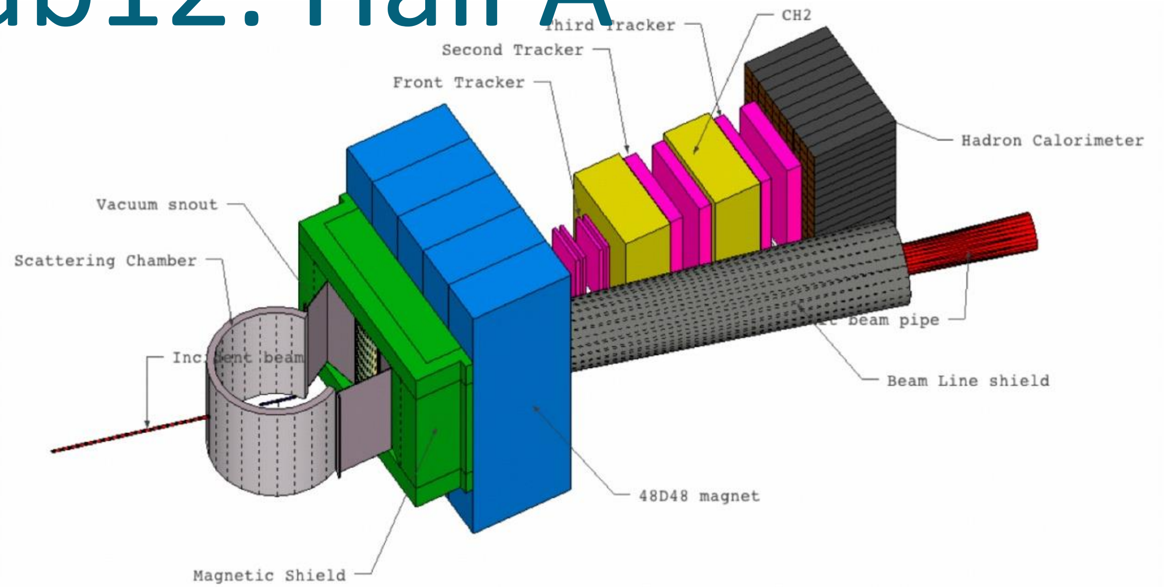
Planned experiments

And upgrades in the near future

Jlab12: Hall A

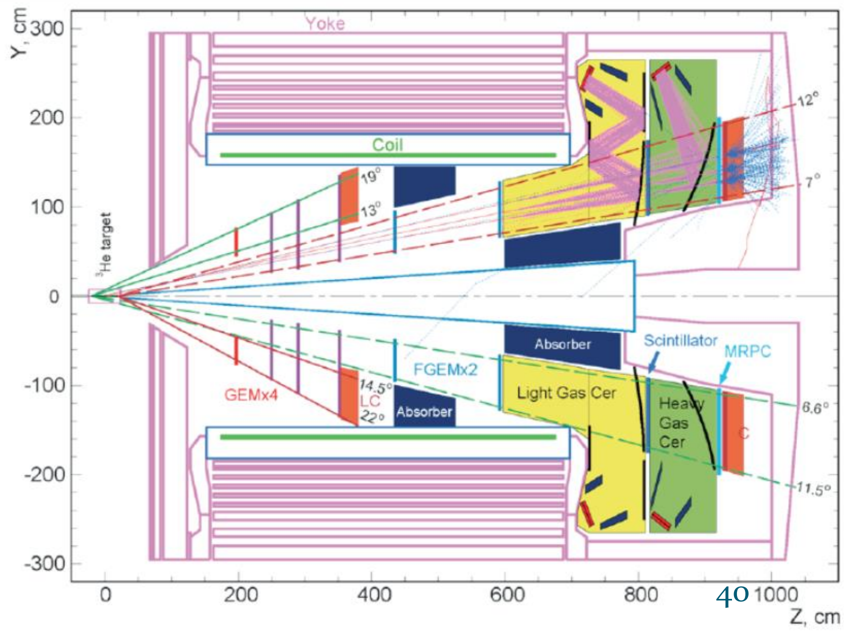
Super Big Byte

- (Moderately) large acceptance
- Full PID (K and π)
- Well-matched to high-luminosity ^{3}He target

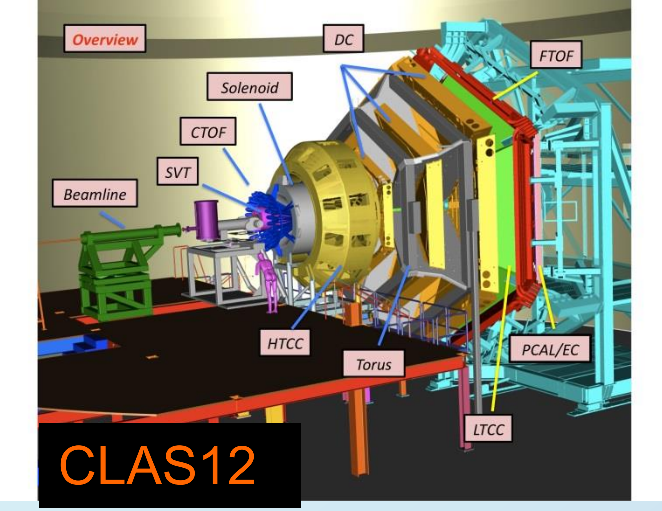


SoLID

- Large acceptance (2π)
- Kinematic coverage out to moderately large P_T
- Capable of quite high luminosity (10^{36} $cm^{-2}s^{-1}$)
- Requires major new funds



JLab12: Hall B



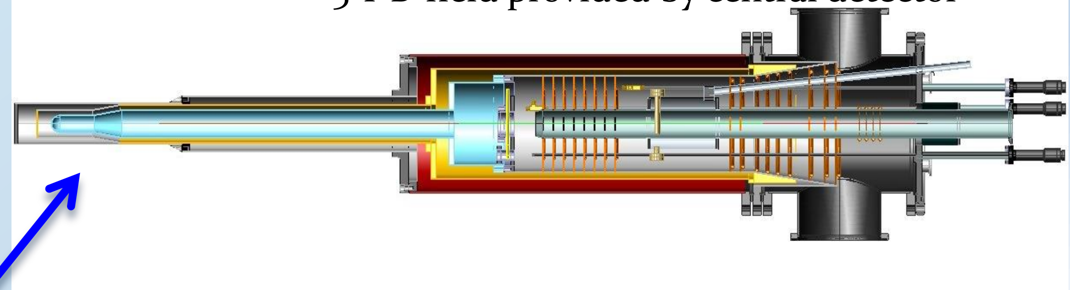
- VERY large acceptance
- Full PID (K and π)
  (K ID requires major new funds for RICH)
- Moderately high luminosity (10^{35} $cm^{-2}s^{-1}$) (matched to NH_3, ND_3)

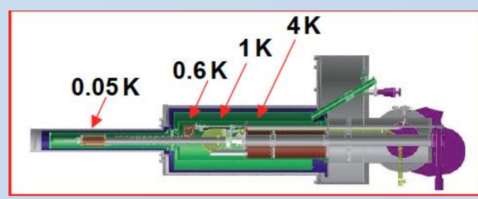
Polarized Targets

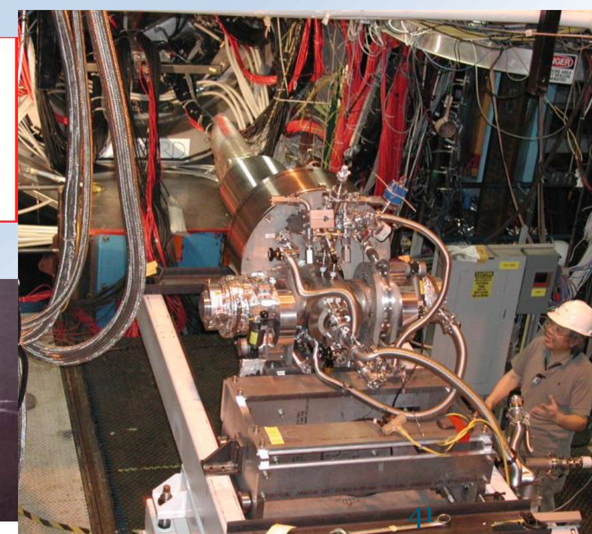
- Standard DNP longitudinal NH_3, ND_3 targets
  (funded by NSF MRI, under construction)
- HD-Ice target
  (suitability for e^- beam remains to be demonstrated)

Future longitudinally polarized target for CLAS12 (11 GeV program at Jefferson Lab)

- Horizontal ^4He evaporation cryostat
- 5 T B-field provided by central detector

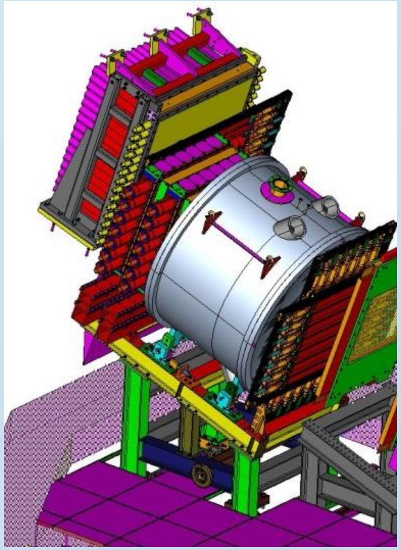


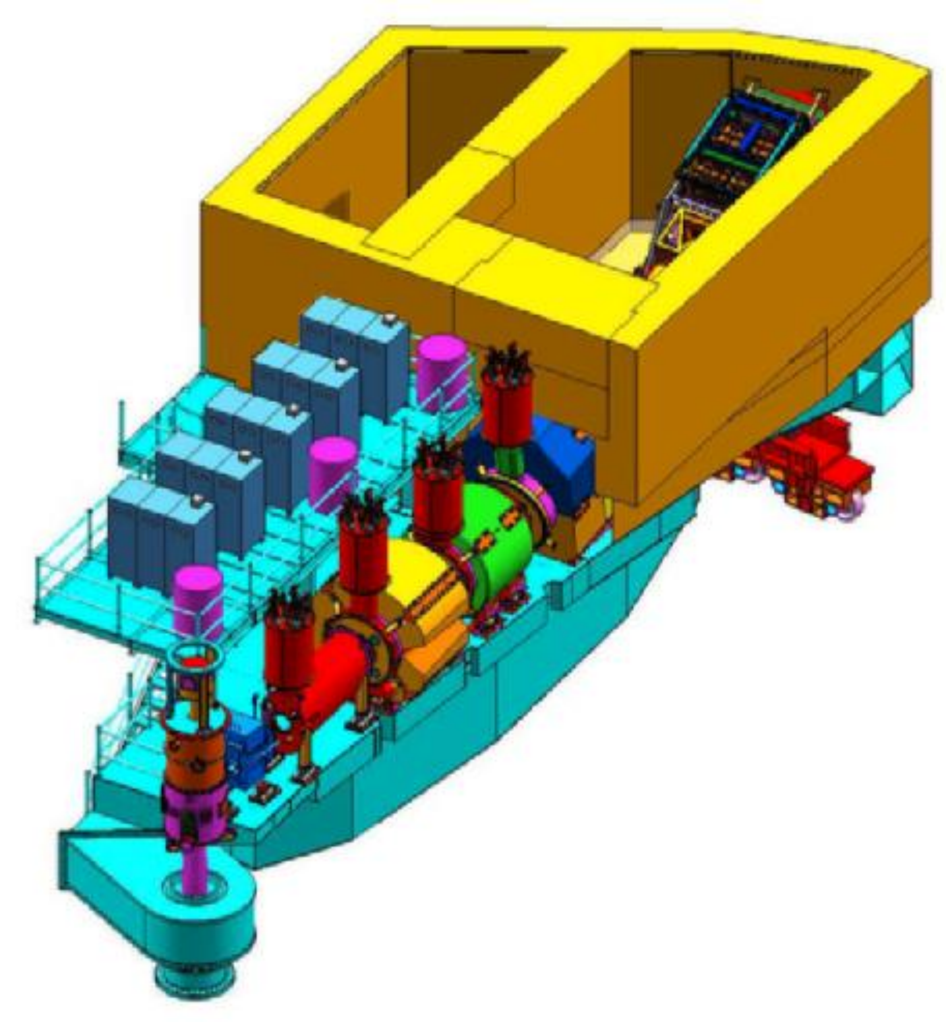




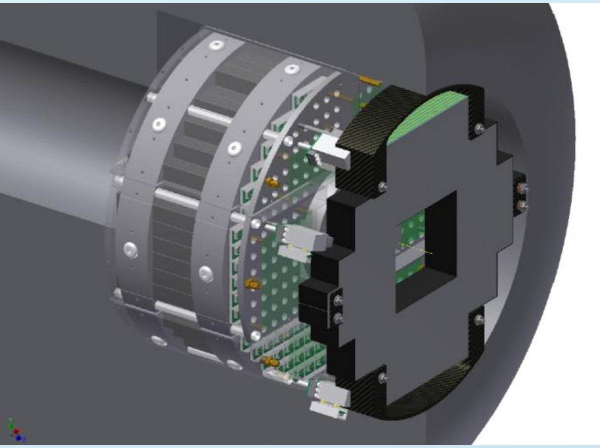
JLab12: Hall C

- Super HMS
  - High momentum capability and resolution
  - Full PID
  - High luminosity polarized ^3He target (as in Hall A)

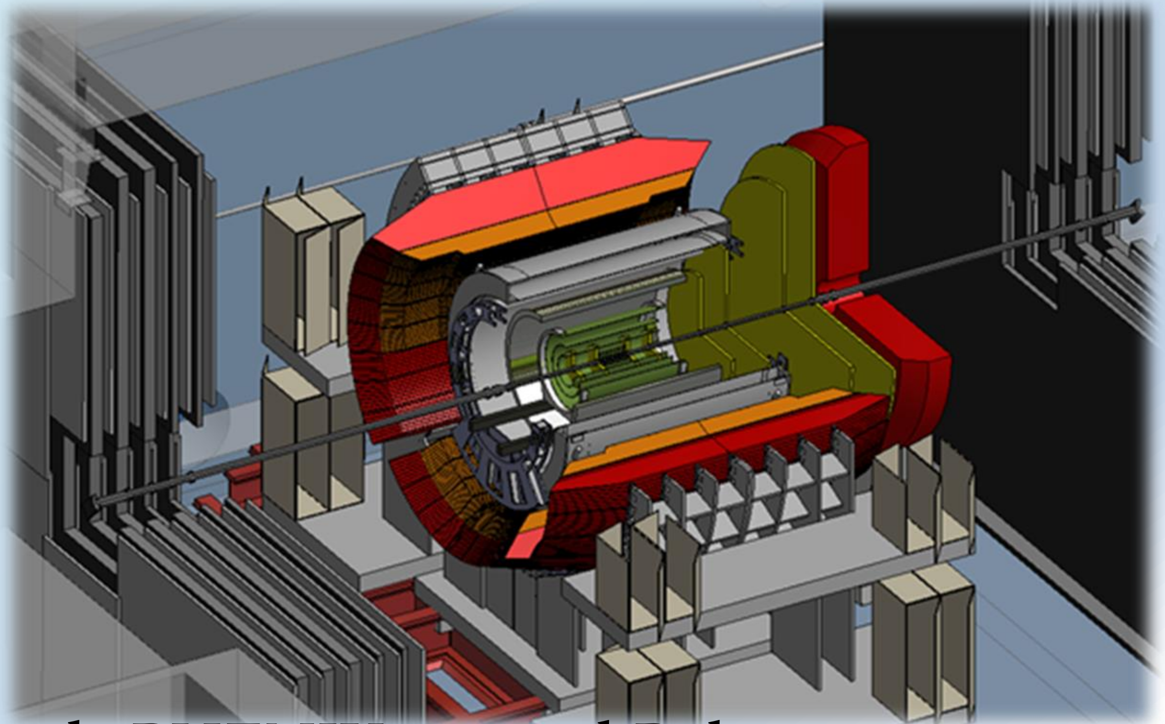




RHIC: PHENIX and fsPHENIX



Forward Preshower (MPC-EX), currently being installed



- Utilize proposed central sPHENIX around Babar magnet + initially forward GEM tracking and hadronic calorimetry up to $\eta = 4$
- Maximal overlap with zero-day eRHIC detector including IR constraints

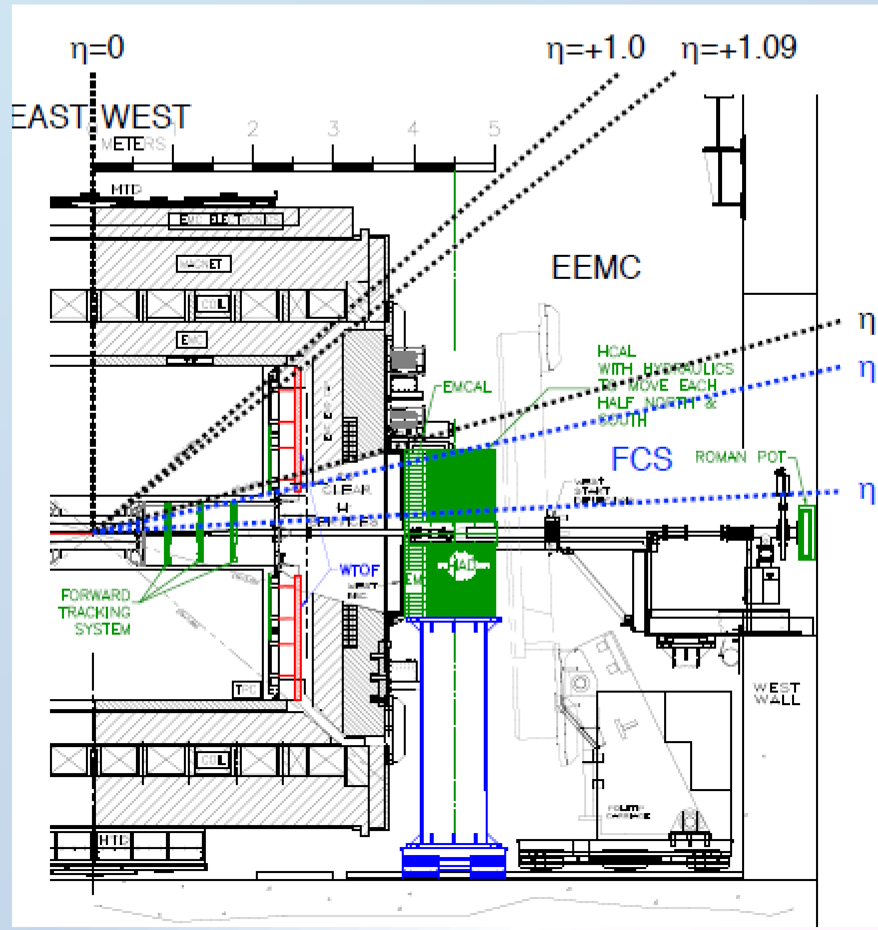
RHIC: STAR upgrades

- Onging:
  - FMS-Preshower
  - Roman Pots Phase-II*
  - FMS-Postshower
- 2020+
  - ECal:

    Tungsten-Powder-Scintillating-fiber 2.3 cm Moliere Radius, Tower-size: 2.5x2.5x17 cm^3 23 X_0
  - HCal:

    Lead and Scintillator tiles, Tower size of 10x10x81 cm^3
    4 interaction length
  - Tracking:

    Silicon mini-strip detector 3-4 disks at z ~70 to 140 cm
    Each disk has wedges covering full 2π range in ϕ
    and 2.5-4 in η other options still under study



Summary2

- Recent highlights in nucleon spin structure (since last LRP)
  - Valence and sea quark helicities (SIDIS, W)
  - Gluon spin from RHIC
  - Consolidation of Sivers and Collins effects in SIDIS, evolution(?), connection to pp very interesting
  - GPDs
- Near term progress
  - Sivers sign change test (COMPASS, RHIC)
  - Lower x gluons from RHIC and improved Δqbar precision
  - Jlab 11GeV valence quark helicites (d helicity retention?), multi-dimensional transversity and Sivers measurements
- Longer term progress
  - Gluon and quark sea helicities to much lower x
  - Transverse Spatial and momentum imaging of the nucleon, tensor charge

Backup

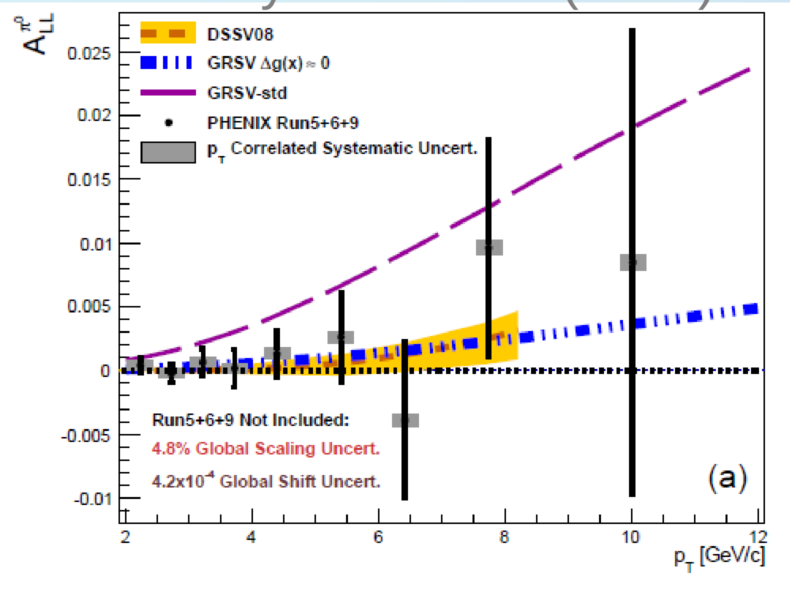
Summary

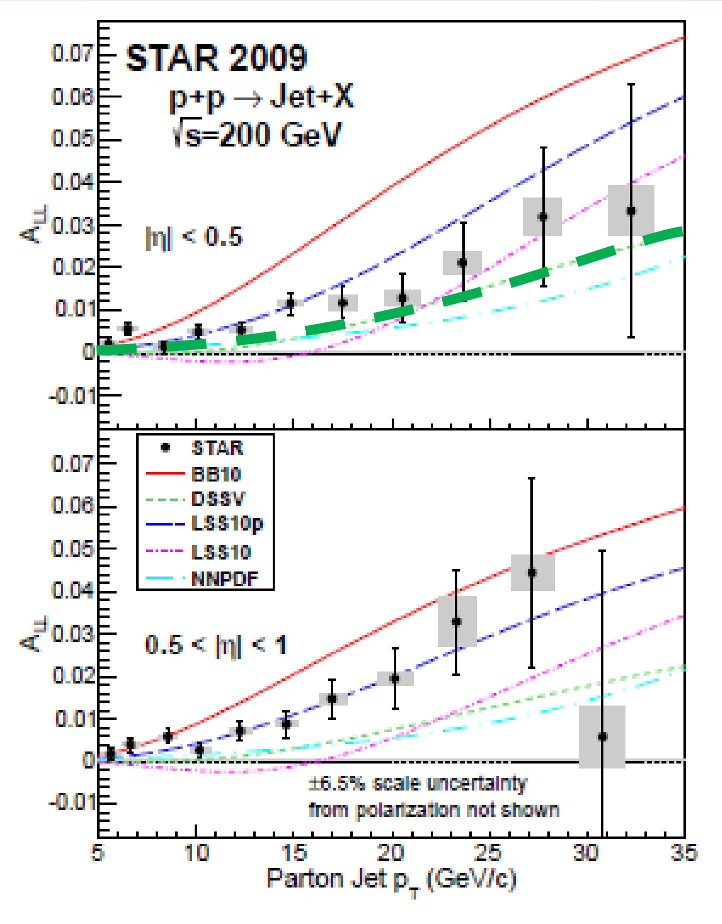
	$<10^{-3}$	$10^{-3} - 10^{-2}$	$10^{-2} - 10^{-1}$	$0.1 - 0.4$	>0.4	Questions
Δq						Helicity retention?
Δg						Nonzero? Rest of Sum rule?
Δqbar						Light sea symmetric?, low x negative?
Quark OAM						Direct integral not possible → models
Gluon OAM						Via higher Twist GPDs?
Spatial tomography						
Sivers, TMDs						Sign Change? Evolution, connection to ANs?
Transversity						Tensor charge, calibration for lattice?

Final 2009 RHIC A_{LL} results

PHENIX: Phys.Rev. D90 (2014) 012007

STAR: arXiv:1405.5134

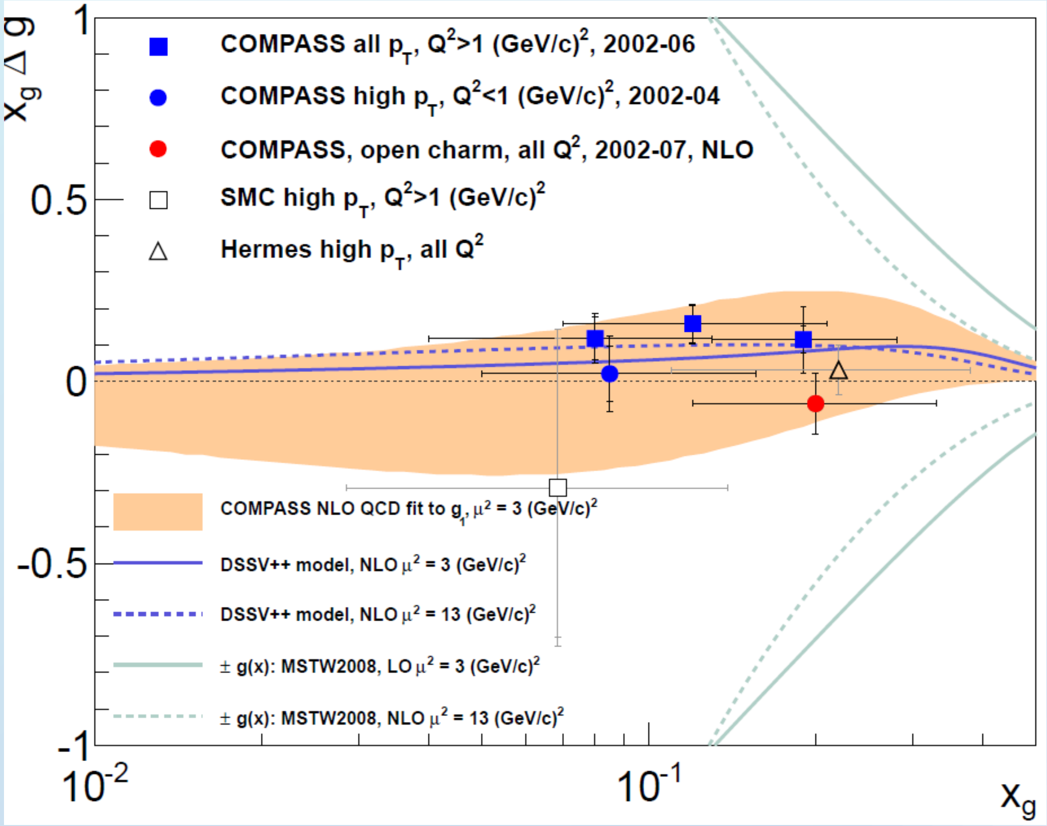


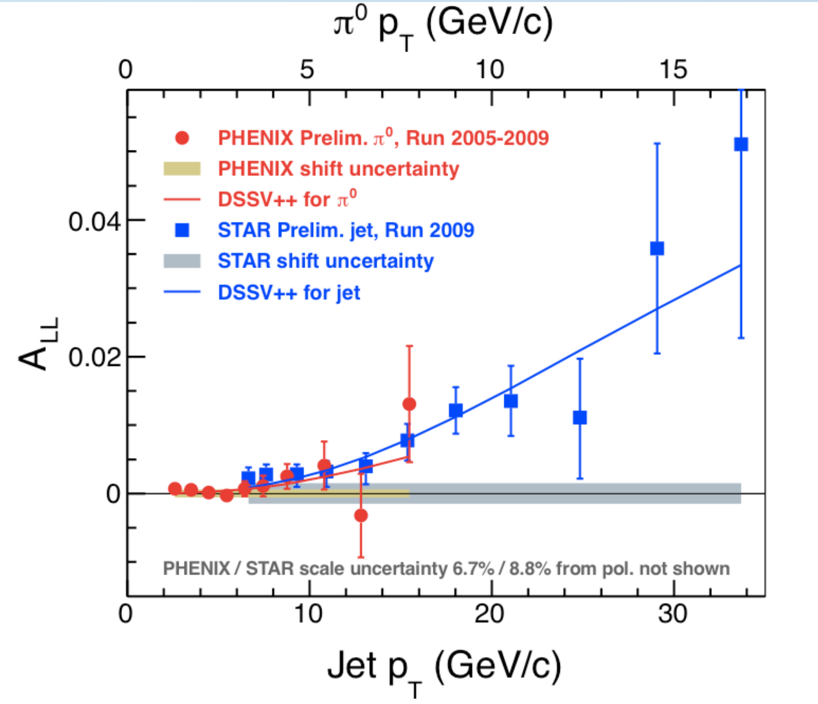


- +various other published results such as charged pion A_{LL}s, η A_{LL}, HF electron A_{LL}

Current highlights: gluon helicities

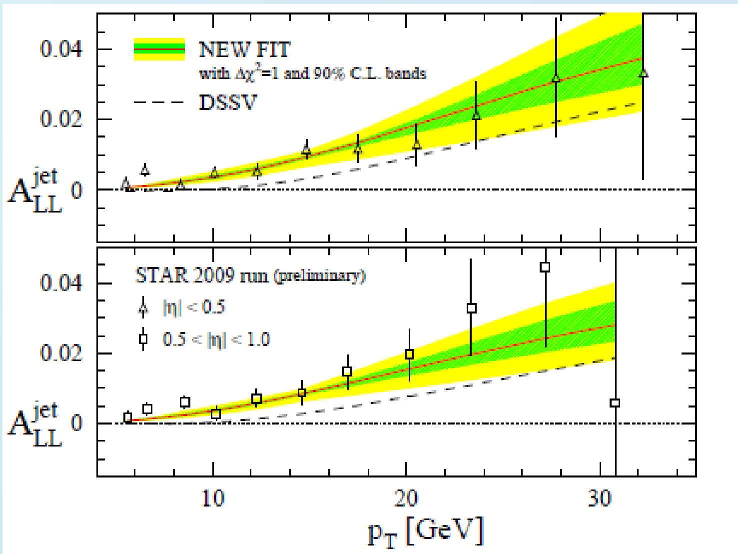
COMPASS, PLB718(2013), PRD87 (2013)

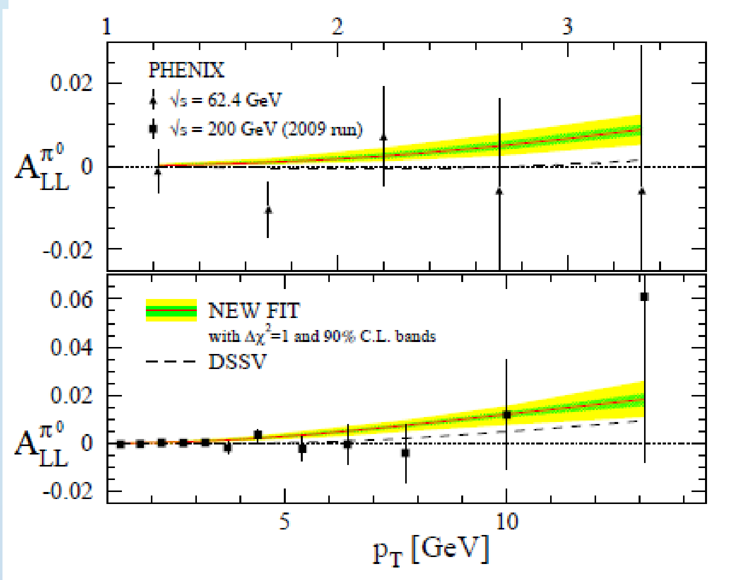


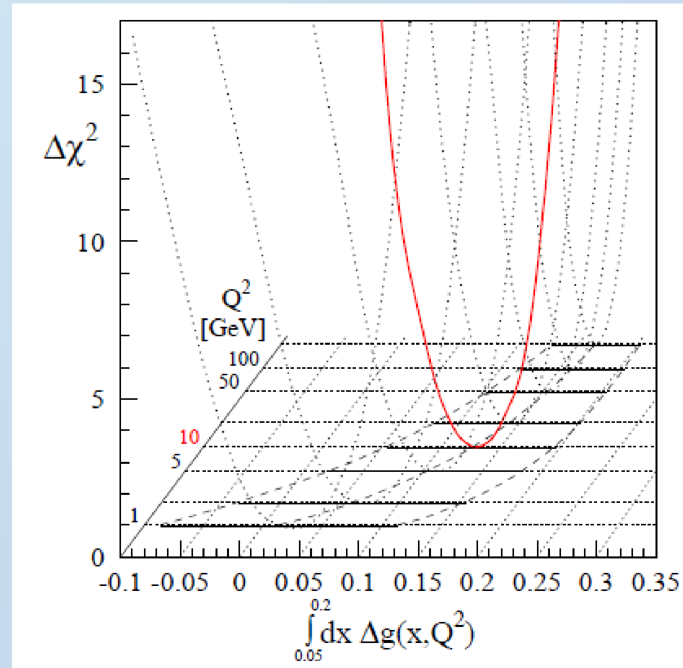


- DSSV:Phys.Rev.Lett. 113 (2014) 012001

DSSV++







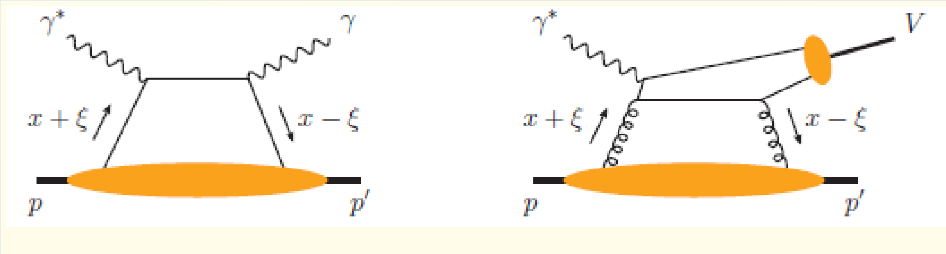
- Pions at slightly smaller x
- and smaller Pt → Δg smaller due to evolution

- DSSV:Phys.Rev.Lett. 113 (2014) 012001

GPDs: Orbital angular momentum (OAM) and spatial imaging

- Some indications for OAM from magnetic moments of p and n, nonzero-ness of Sivers function
- Ji sum rule allows quantitative access to J_q via exclusive reactions:

$$J^q = \frac{1}{2}\int dx\, x\, [H^q(x,\xi,t=0) + E^q(x,\xi,t=0)]$$



- GPDs related to regular pdfs and form factors:

H(x,0,0)→ q(x), $\widetilde{H}$ →Δq

$$\sum_q e_q \int dx\, H^q(x,\xi,t) = F_1^p(t)\,, \qquad \sum_q e_q \int dx\, E^q(x,\xi,t) = F_2^p(t)$$

- Any access to gluon OAM only via Twist 3

$t = (p' - p)^2$ →FT of impact parameter → spatial structure

Transverse momentum dependent distributions (TMDs)

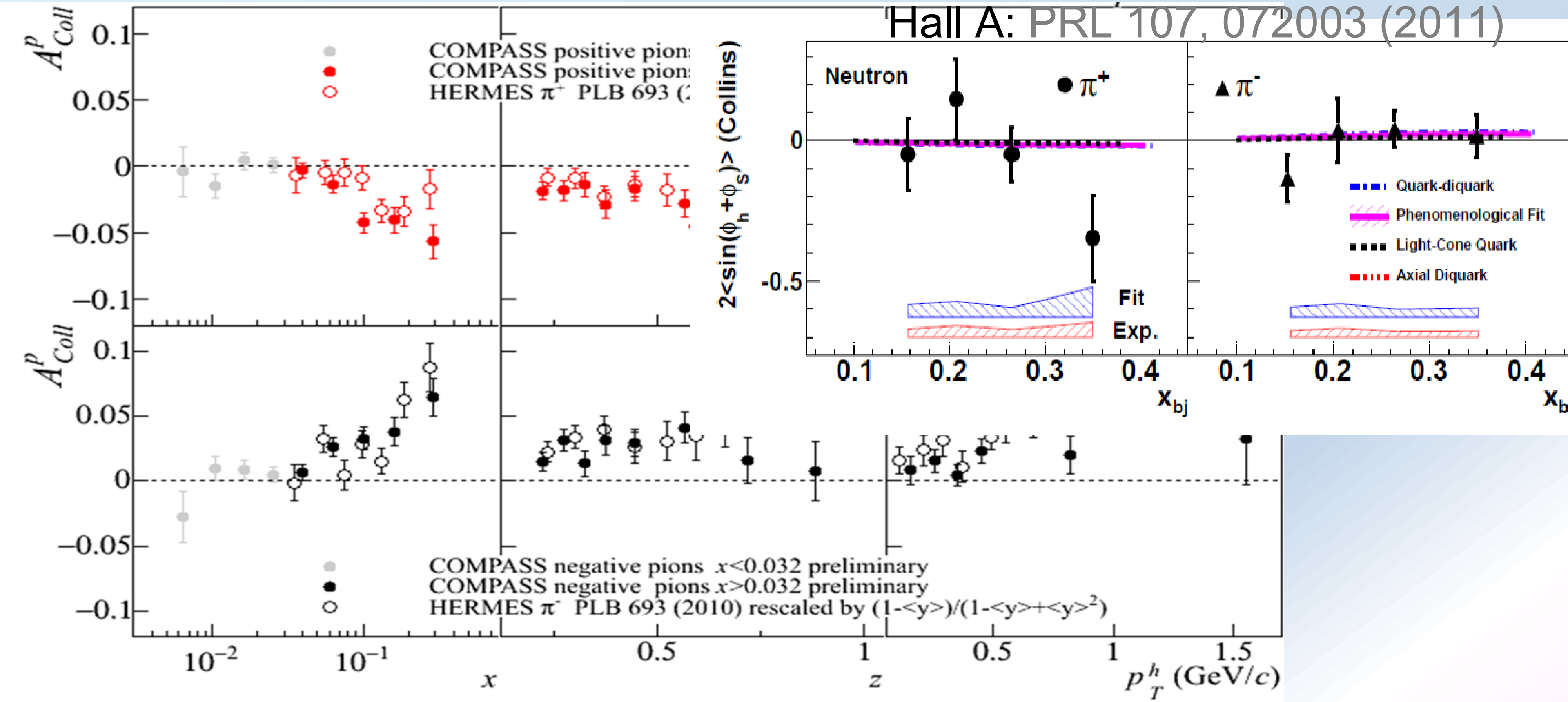
		Quark polarization		
		Unpolarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1 =$		$h_1^{\perp} =$ −
	L		$g_1 =$ −	$h_{1L}^{\perp} =$ −
	T	$f_{1T}^{\perp} =$ −	$g_{1T} =$ −	$h_1 =$ − $h_{1T}^{\perp} =$ −

S.Pisano, Transversity 14

Status at 2007

- HERMES Collins Asymmetries indirectly confirmed by first Belle FF results, consistent with zero COMPASS deuteron result, first global fit by Torino group
- Sivers function discovered by HERMES, zero COMPASS result on deuteron
- Transverse single spin asymmetries from ZGS, AGS,E704 and RHIC
- what is the connection between SIDIS and pp?

Consolidation of Collins x transversity



- Very good agreement for HERMES and COMPASS proton results, despite substantially different scales (at around x=0.2 Q^2 4 vs 12)
- Hall A He3 results within expectations

The Spin sum rule

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

Jaffe, Manohar

$$\Delta\Sigma = \int dx \left[(\Delta u(x) + \Delta\overline{u}(x)) + (\Delta d(x) + \Delta\overline{d}(x)) + (\Delta s(x) + \Delta\overline{s}(x))\right]$$

- Other decompositions exist
- ΔΣ and ΔG can be accessed in longitudinally polarized (SI)DIS and pp collisions
- more on orbital angular momentum later

Deeply Virtual Compton Scattering

Unpolarized cross sections, unpolarized beam and target

$$\sigma_0 \sim \mathrm{Re}\{F_1 H - \frac{t}{4M^2} F_2 E - \xi^2 (F_1 + F_2)(H + E)\}$$

Polarized beam and Unpolarized target (BSA)

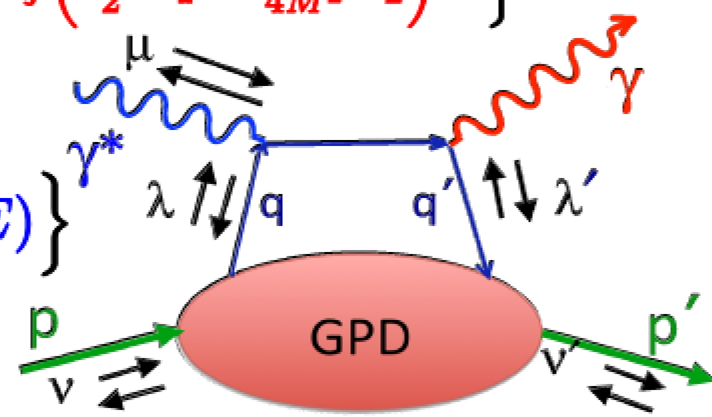
$$A_{LU} \sim \mathrm{Im}\left\{F_1 H + \xi(F_1 + F_2)\tilde{H} + \frac{t}{4M^2} F_2 E\right\}$$

Unpolarized beam and Polarized target (TSA)

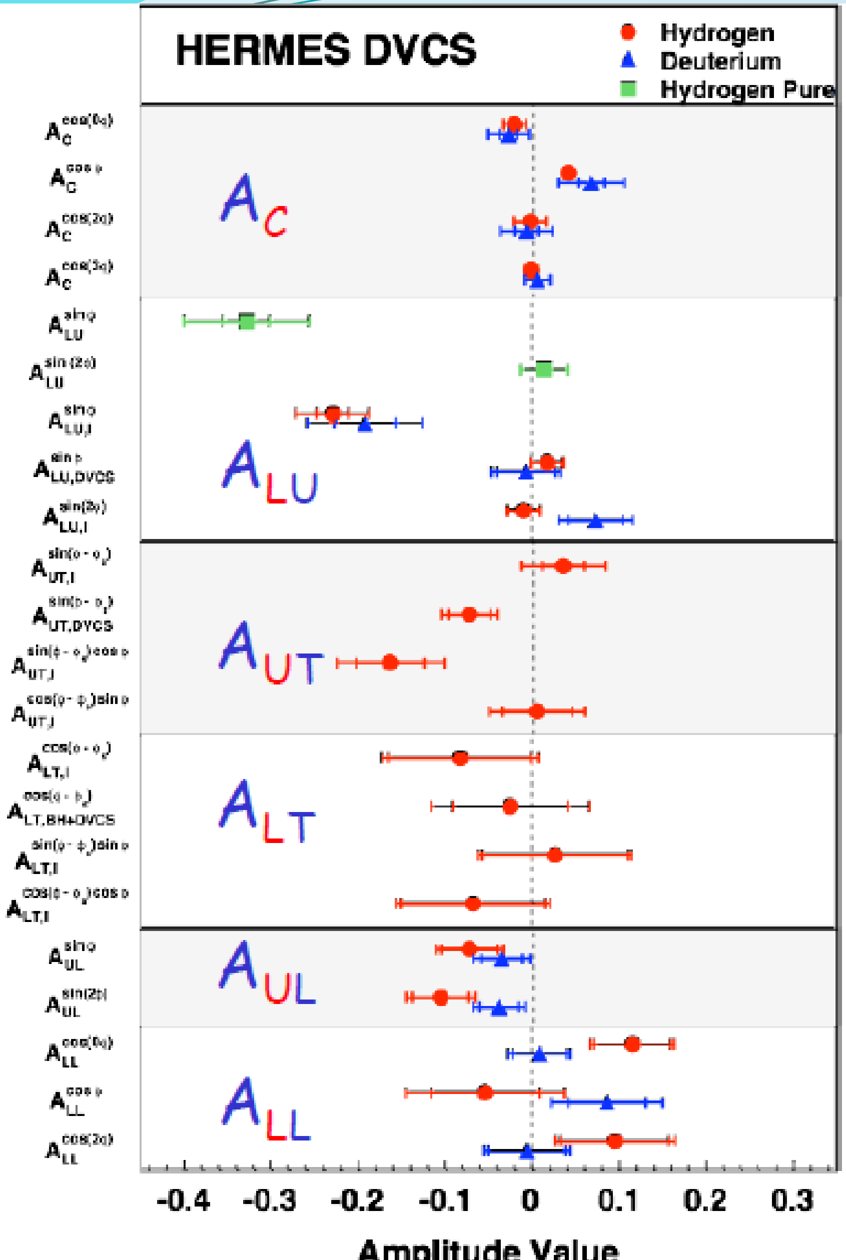
$$A_{UL} \sim \mathrm{Im}\left\{F_1 \tilde{H} + \xi(F_1 + F_2)\left(H - \frac{x_B}{2} E\right) - \xi\left(\frac{x_B}{2} F_1 - \frac{t}{4M^2} F_2\right)\tilde{E}\right\}$$

Polarized beam and Polarized target (DSA)

$$A_{LL} \sim \mathrm{Re}\left\{F_1 \tilde{H} + \xi(F_1 + F_2)(H + \frac{x_B}{2} E)\right\}$$



A.Kim, Transversity 14



Beam charge asymmetry
GPD H

H: PRL 87 (2001) 182001
PR D 75 (2007) 011103
JHEP 11 (2009) 083
JHEP 07 (2012)032
JHEP 10 (2012) 042 (recoil det.)
JHEP 01 (2014) 077 (recoil det.)
D: Nucl. Phys. B 829 (2010) 1
nuclei: PR C 81 (2010) 035202

Beam helicity asymmetry
GPD H

Transverse target-spin asymmetries
GPD E

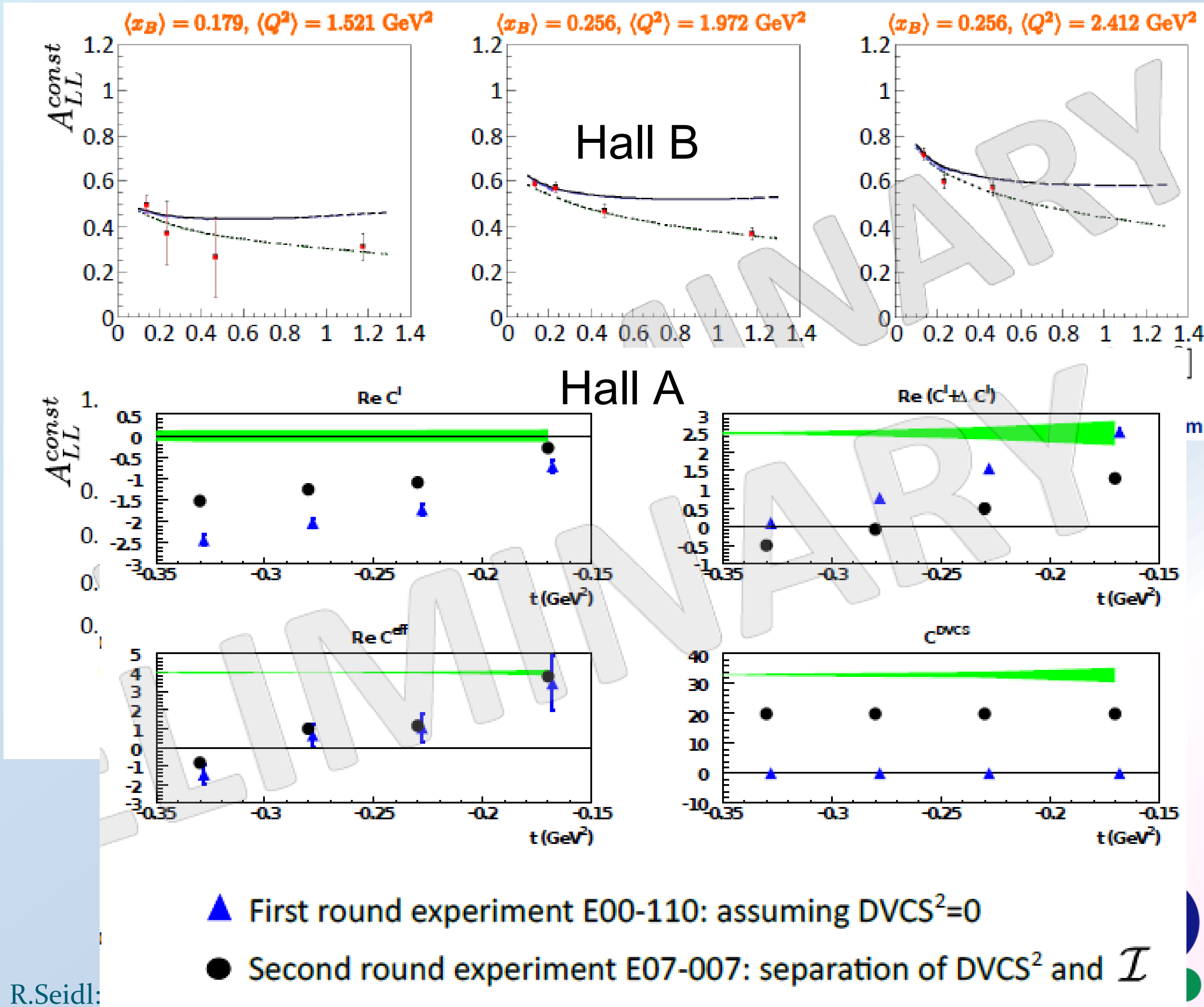
H: JHEP 06 (2008) 066
H: PLB 704 (2011) 15

Longitudinal target spin asymmetries
GPD $\tilde{H}$

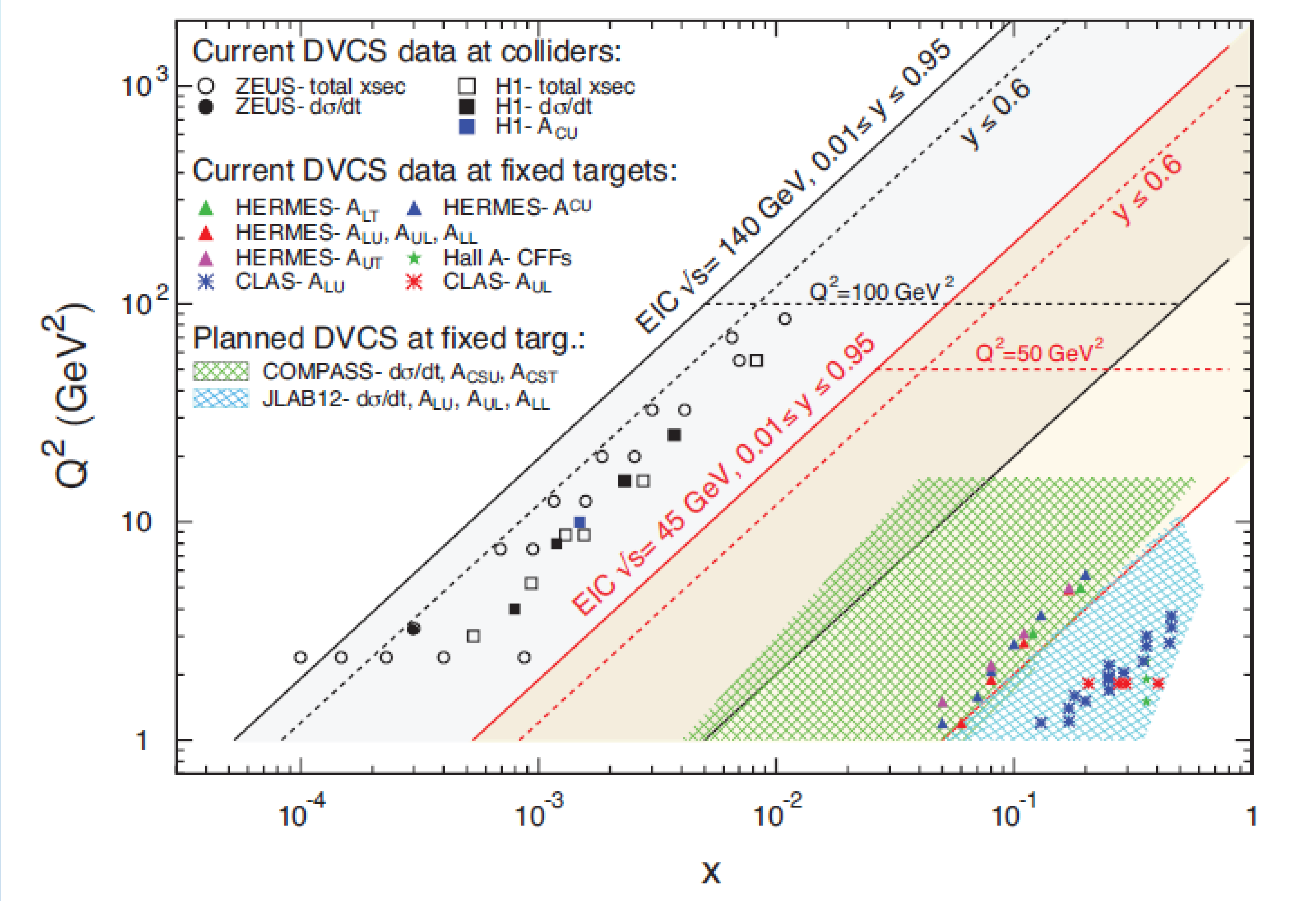
H: JHEP 06 (2010) 019
D: Nucl. Phys. B 842 (2011) 265

More DVCS and exclusive measurements

- Various Jlab results, much more to come with 11GeV
- Considerations to measure GPDs at STAR with Roman Pots in UPC

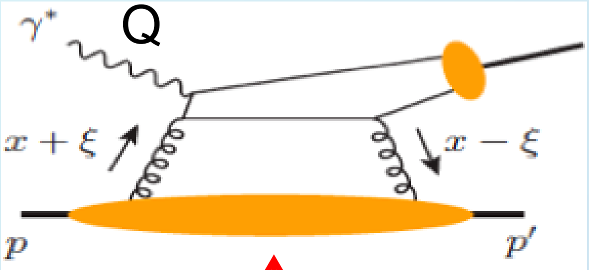


DVCS reach with an EIC



Spatial imaging of gluon density

- Exclusive vector meson production:



J/Ψ, Φ, …

↑ t-dep

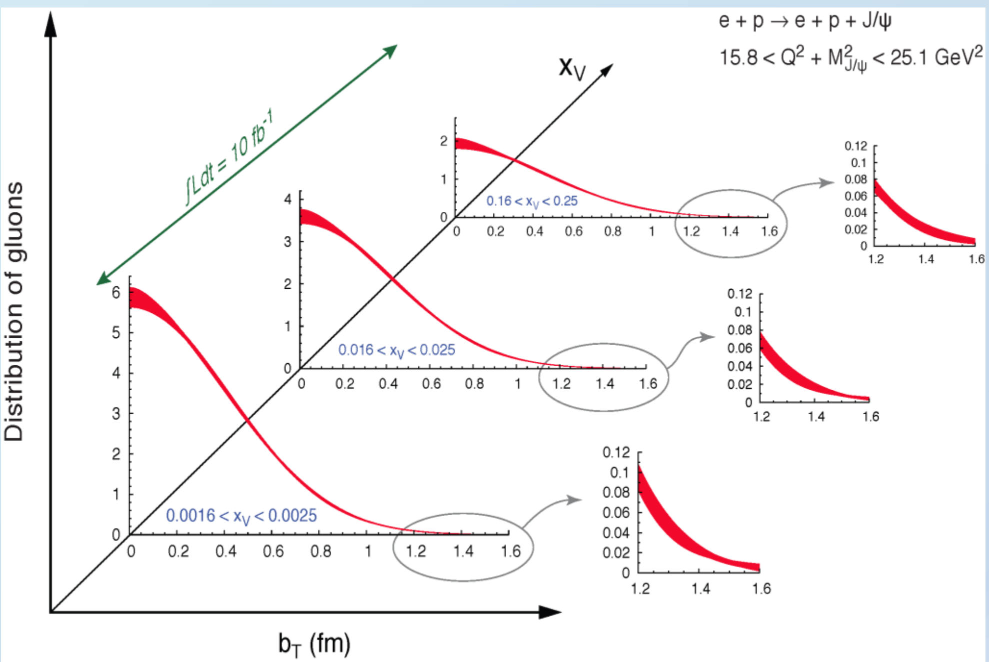
$$\frac{d\sigma}{dx_B dQ^2 dt}$$

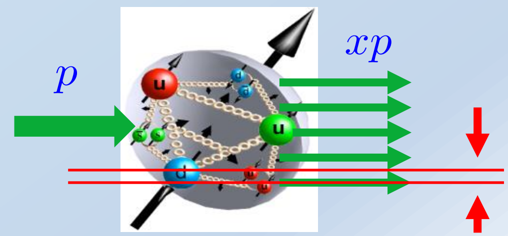
✧ Fourier transform of the t-dep

➡ Spatial imaging of glue density

✧ Resolution ~ 1/Q or 1/M_Q

- Gluon imaging from simulation:





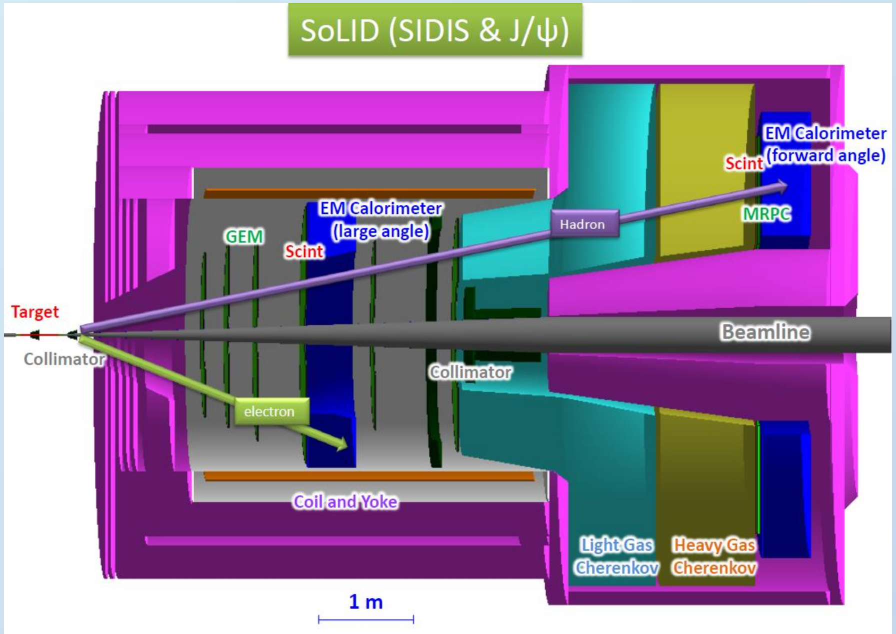
$$W^2 = (p+q)^2; \quad M_N^2 = p^2$$

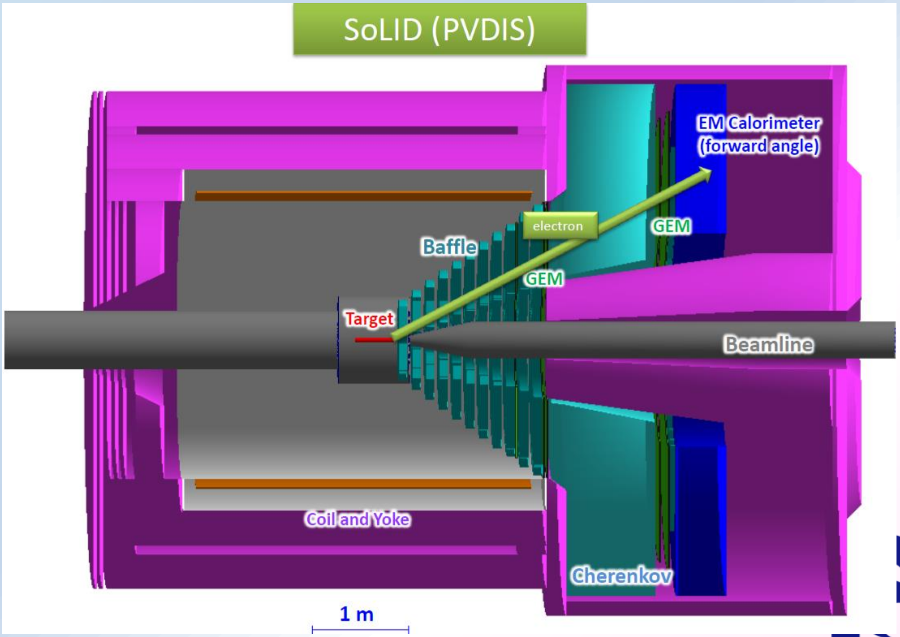
Images of gluons
from exclusive
J/ψ production

Overview of SoLID

Solenoidal **L**arge **I**ntensity **D**evice

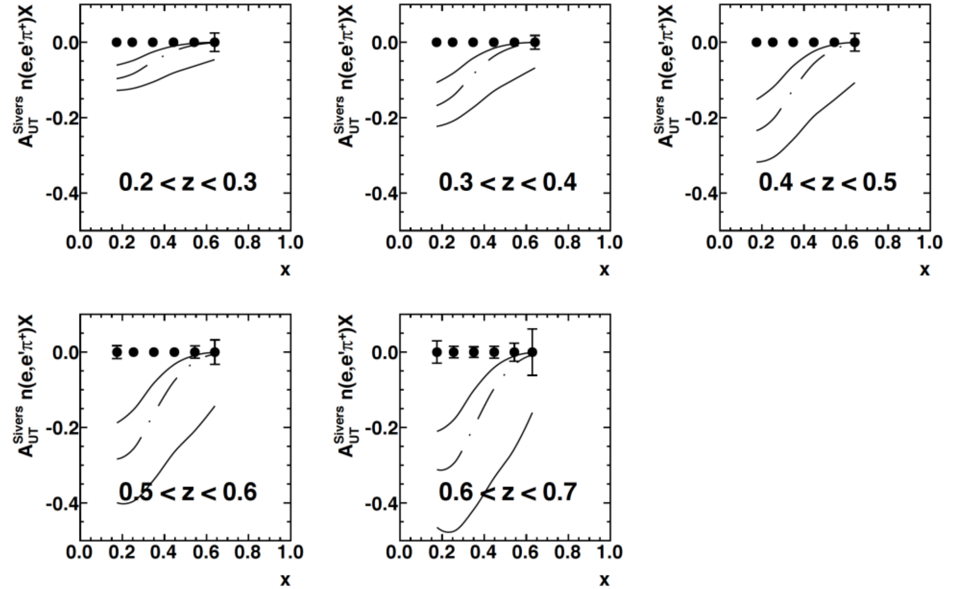
- **Full exploitation of JLab 12 GeV Upgrade**
  → A **Large Acceptance** Detector **AND** Can Handle **High Luminosity** (10^{37}-10^{39})
  Take advantage of latest development in detectors , data acquisitions and simulations
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-*x* region and threshold J/ψ
- **5 highly rated experiments approved**
  Three SIDIS, PVDIS, J/ψ production
  Parasitic: di-hadron, Inclusive-SSA, and much more …
- **Strong collaboration** (200+ collaborators from 50+ institutes, 11 countries)
  Significant international contributions

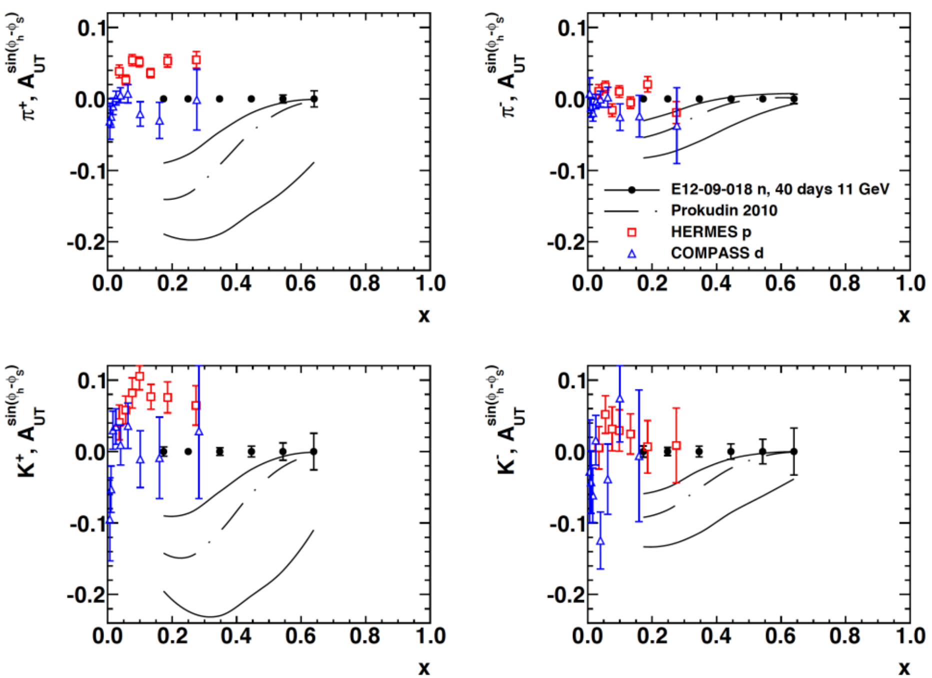




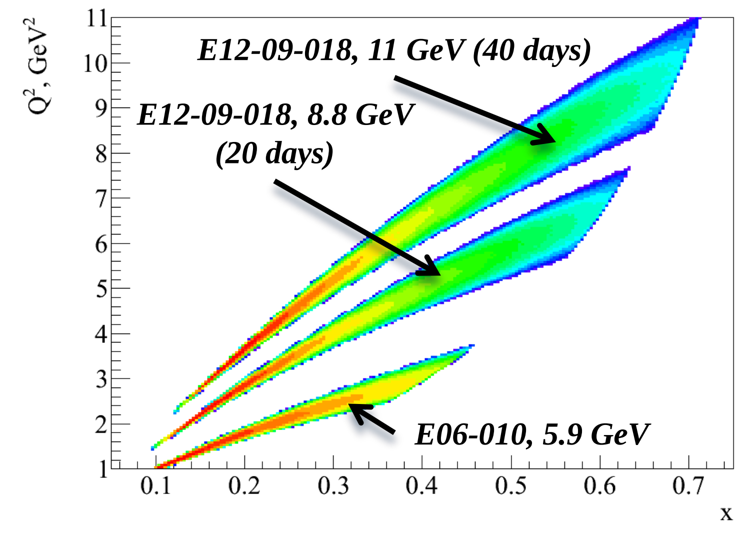
Neutron SIDIS Using SBS+BB

- JLab E12-09-018—***approved for 64 beam-days in Hall A by JLab PAC38, A- scientific rating***
- Transverse target single-spin asymmetries in ^{3}**He**(e,e'h)X (h=$\pi^{\pm,0}$, $K^{\pm}$)
  - Collins and Sivers effects
  - Precision input to global TMD extraction
- ~100X higher statistical figure-of-merit for neutron than HERMES proton data
- **First precision measurements in a multi-dimensional kinematic binning**



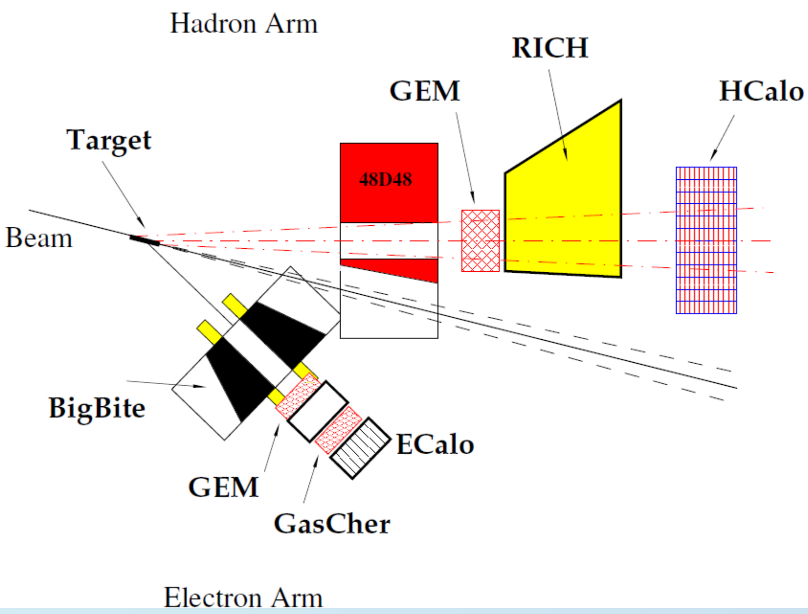


$\pi^{\pm}$, $K^{\pm}$ neutron Sivers asymmetries compared to HERMES, COMPASS, phenomenological fit

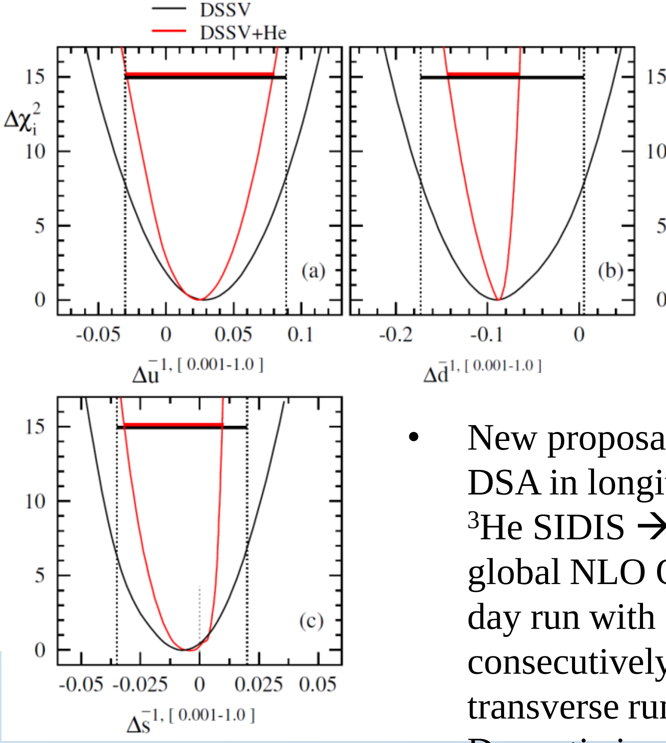


- Data at two beam energies provide a range of Q^2 at fixed x
- *Can run in first few years of JLab 12 GeV—possibly as early as 2017*

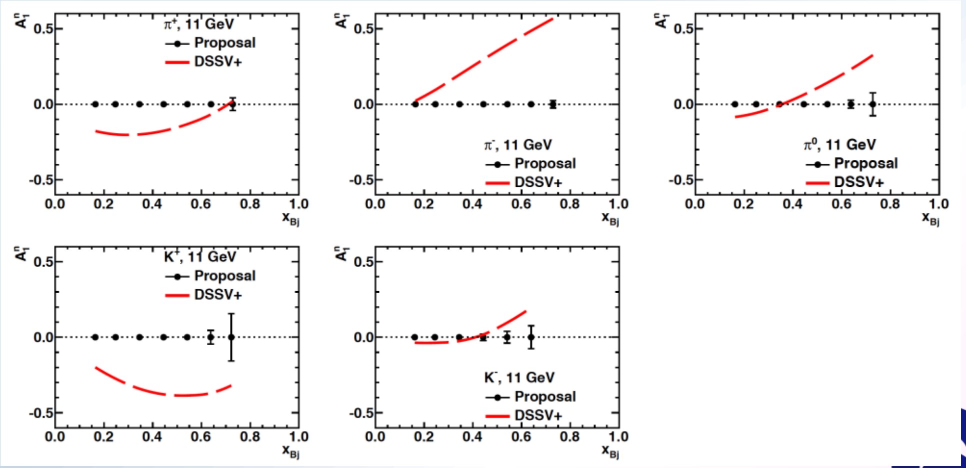
RIKEN



Re-use of HERMES RICH for Charged Hadron PID



- New proposal to JLab PAC—DSA in longitudinally polarized ^{3}He SIDIS → Impact to DSSV global NLO QCD analysis of 30-day run with SBS+BB—could run consecutively with approved transverse run.
- Dramatic impact to dbar polarization!



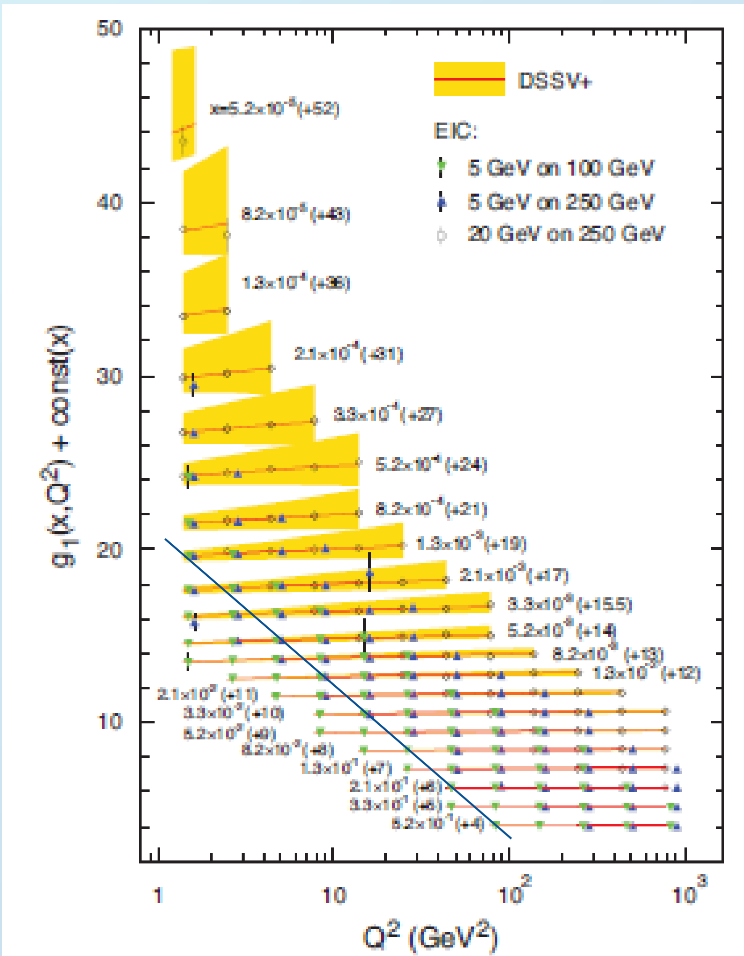
Main EIC references

- Long 2011 INT writeup: Gluons and the quark sea at high energies: Distributions, polarization, tomography
  Daniel Boer *et al.*. Aug 2011. 547 pp., e-Print: **arXiv:1108.1713**
- EIC White paper: Electron Ion Collider: The Next QCD Frontier - Understanding the glue that binds us all
  A. Accardi *et al*.. Dec 2012. 146 pp., e-Print: **arXiv:1212.1701**
- PHENIX based Detector concept: Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid
  PHENIX Collaboration (A. Adare *et al.*). Feb 5, 2014. 59 pp. e-Print: **arXiv:1402.1209**
- eRHIC CDR: **eRHIC Design Study An Electron-Ion Collider at BNL** E.C. Aschenauer *et al.*, arXiv:1409.

EIC key mesurements (Helicity)

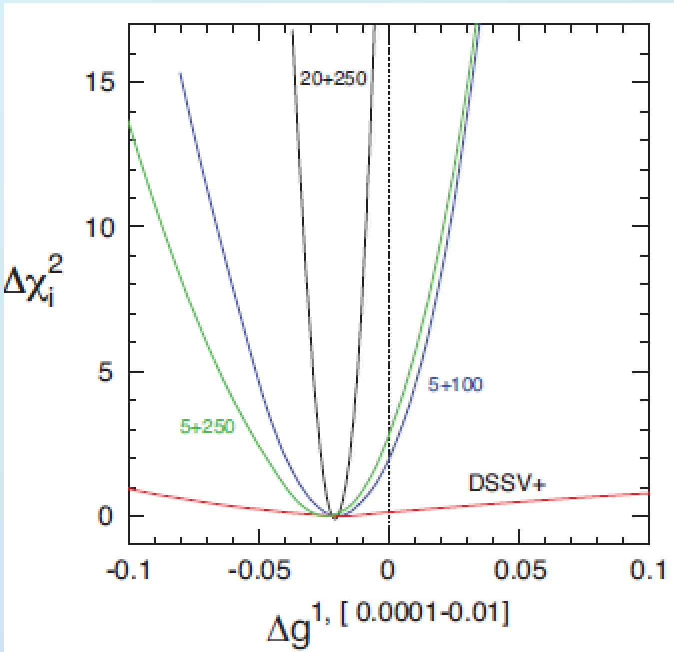
Deliverables	Observables	What we learn	Requirements
polarized gluon distribution Δg	scaling violations in inclusive DIS	gluon contribution to proton spin	coverage down to $x \simeq 10^{-4}$; $\mathcal{L}$ of about 10 fb^{-1}
polarized quark and antiquark densities	semi-incl. DIS for pions and kaons	quark contr. to proton spin; asym. like $\Delta\bar{u} - \Delta\bar{d}$; Δs	similar to DIS; good particle ID
novel electroweak spin structure functions	inclusive DIS at high Q^2	flavor separation at medium x and large Q^2	$\sqrt{s} \geq 100\,\text{GeV}$; $\mathcal{L} \geq 10\ \text{fb}^{-1}$ positrons; polarized d or ^{3}He beam

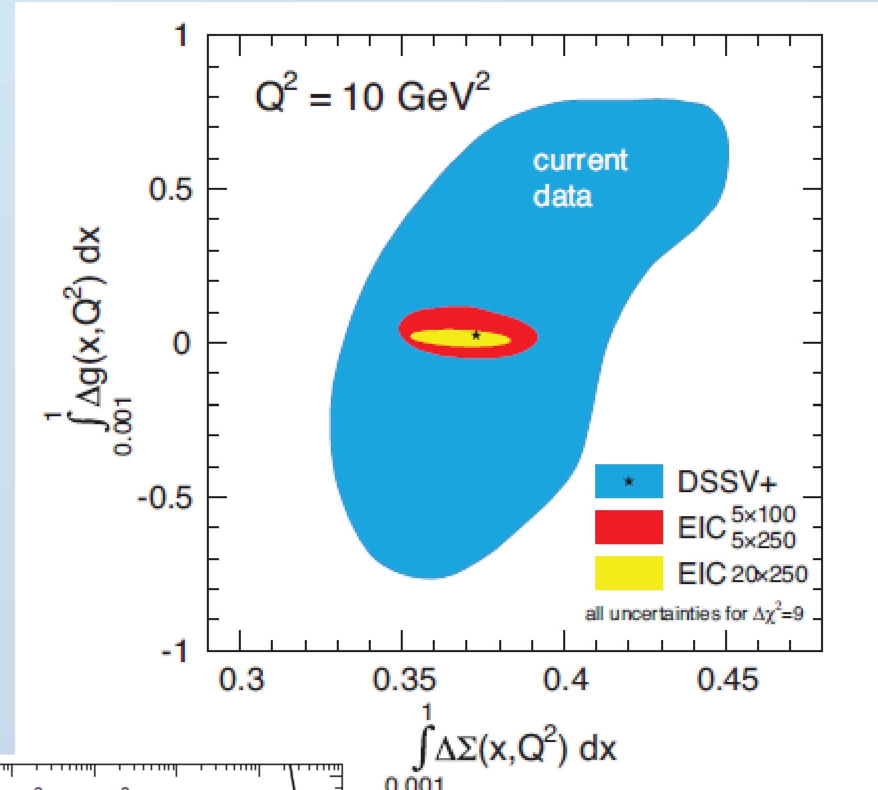
Inclusive DIS



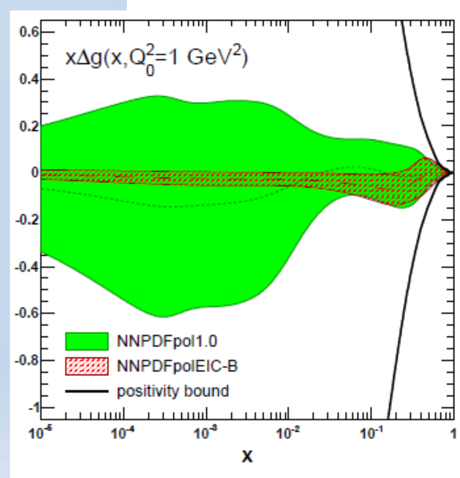
- Several orders of magnitude of Q^2 at same x allows to determine gluon helicity via DGLAP evolution
- Inclusive DIS is certainly not statistics limited
- Main systematics expected from y reconstruction

Gluon polarization

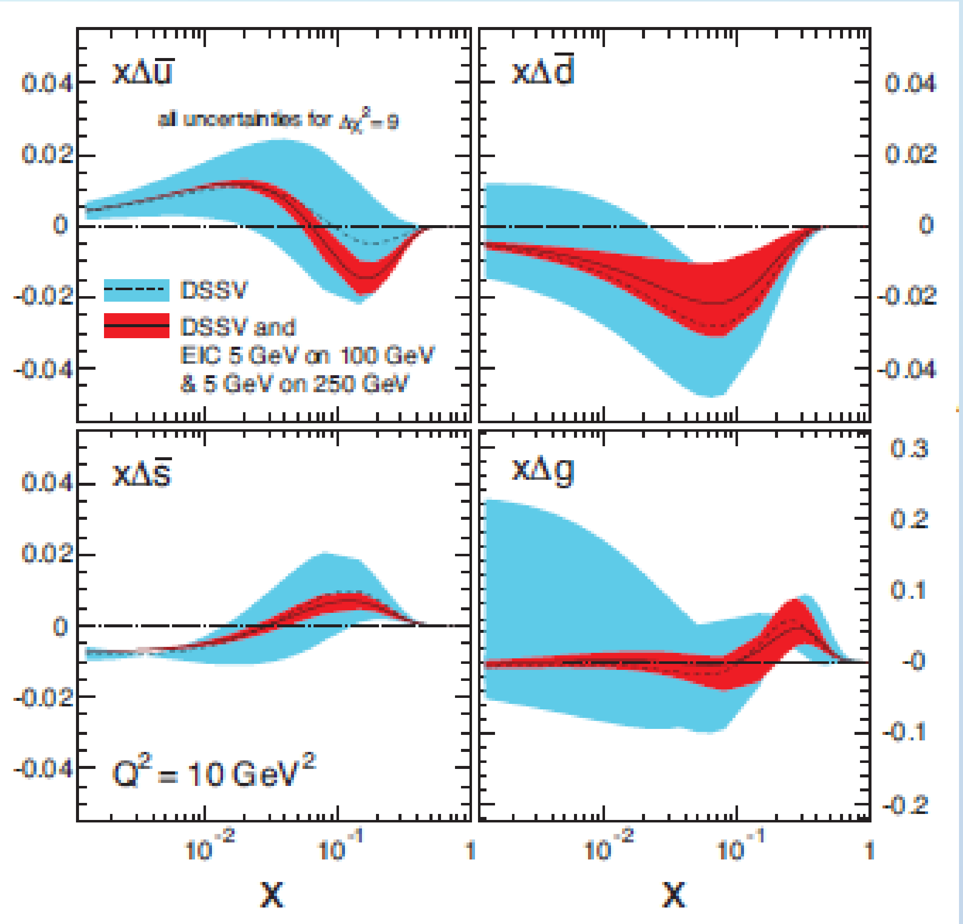




- 1 year of EIC running will pin down gluon polarization

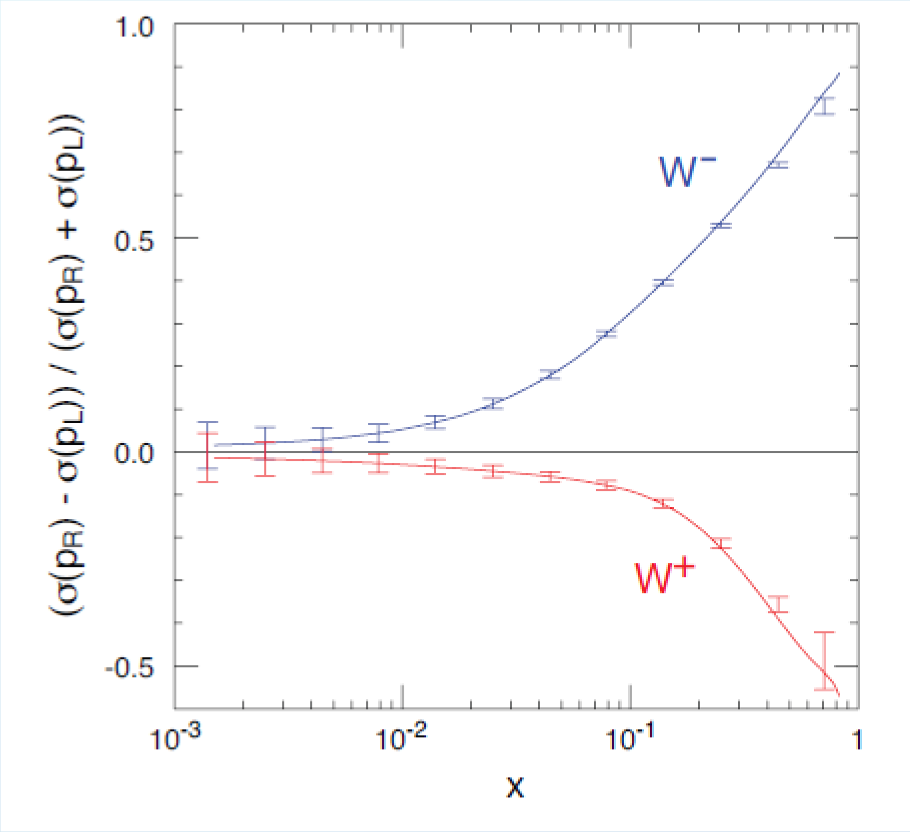


Sea quarks



- Answer questions whether light quark sea is really symmetric or not
- Resolve strange helicity puzzle (or shoot down $SU(3)_f$ applicability from hyperon decays)

CC DIS

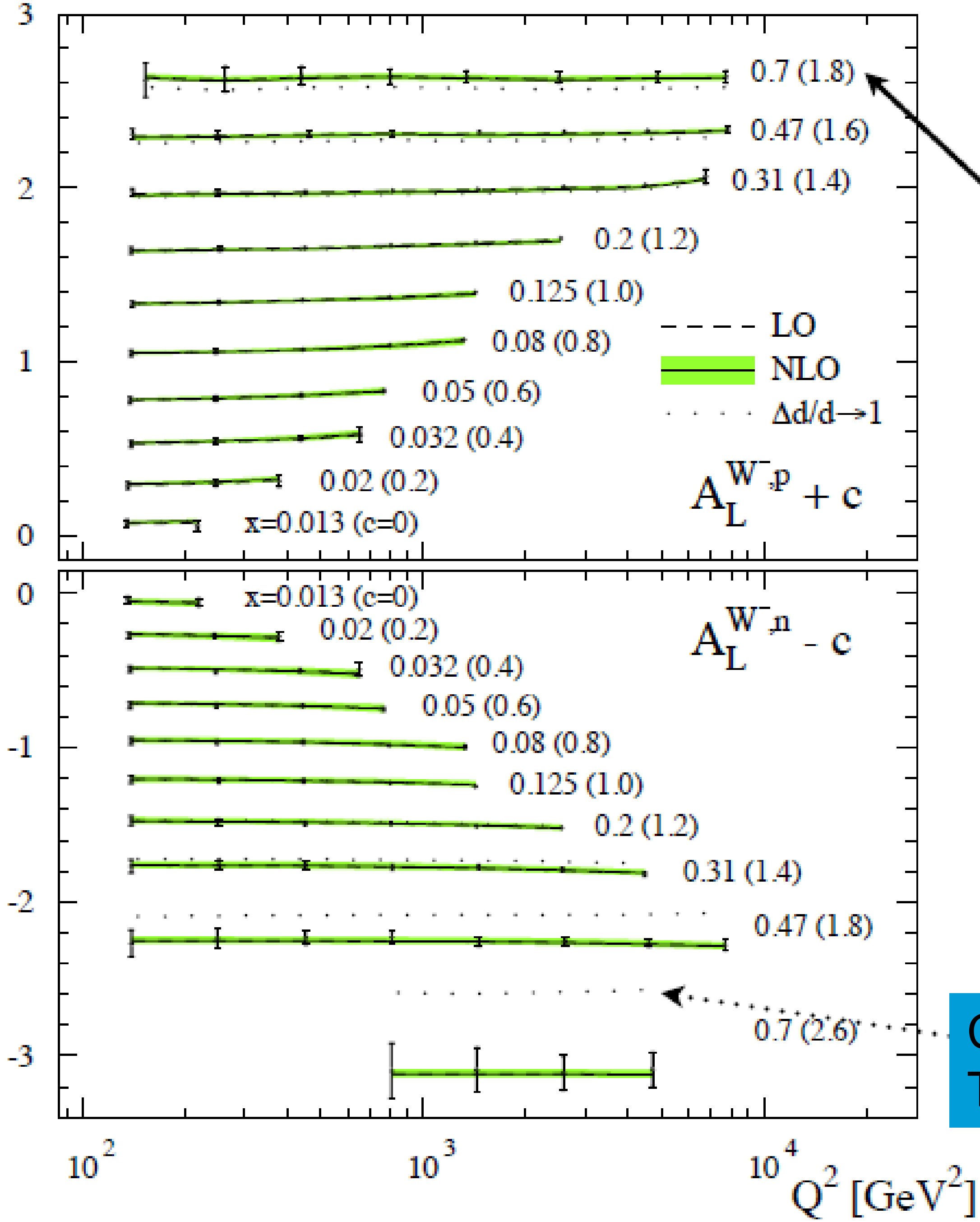


$$g_1^{W^-}(x,Q^2) = \left[\Delta u + \Delta \bar{d} + \Delta c + \Delta \bar{s}\right](x,Q^2)\,,$$
$$g_5^{W^-}(x,Q^2) = \left[-\Delta u + \Delta \bar{d} - \Delta c + \Delta \bar{s}\right](x,Q^2)\,,$$

- Gain even more flavor sensitivity with the weak interaction:

$$e\,\overrightarrow{p} \rightarrow \nu_e X$$

A_L^W results

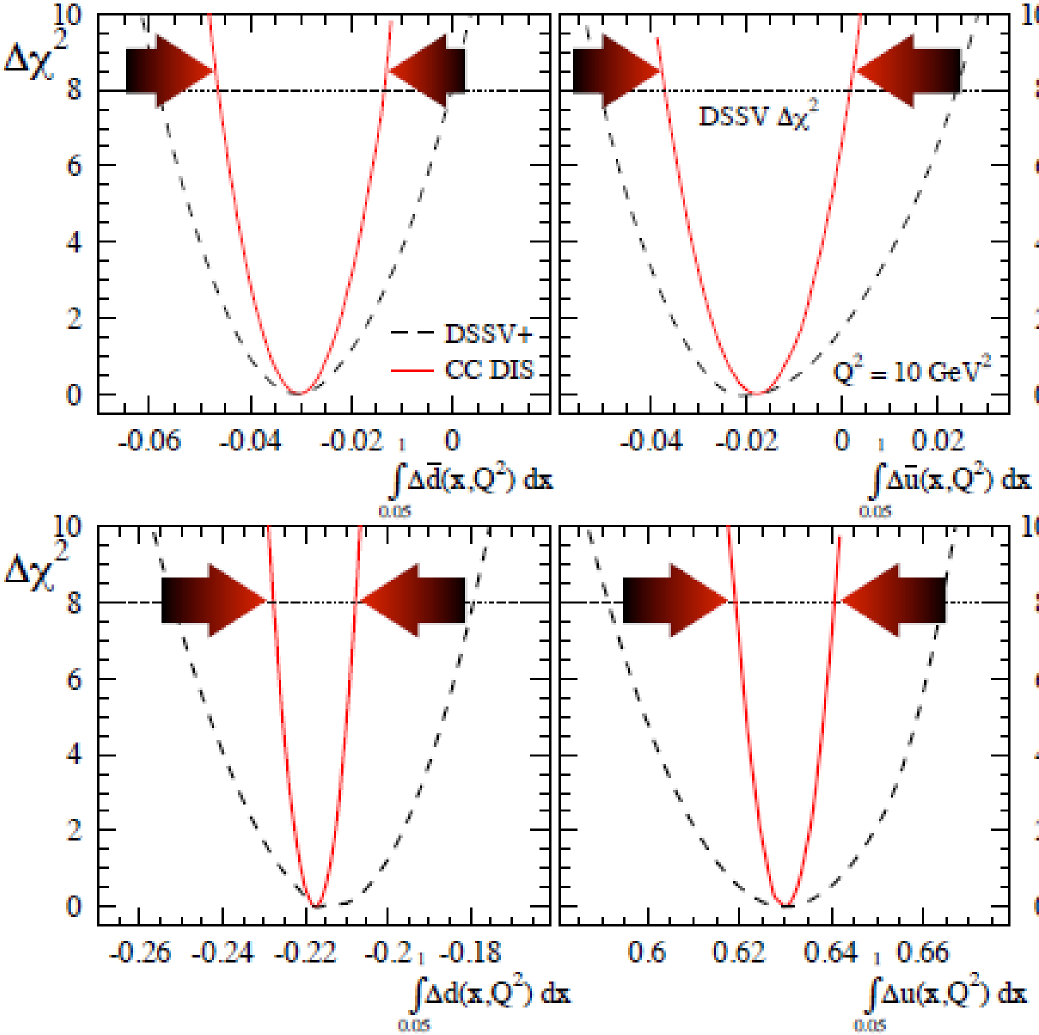


- Large A_L^W at large x ~80%
- NLO effects small
- $\sigma(A_L^W)/A_L^W$ small
  - <~5% for **p**
  - <~8% for **n**
  - ~25% at x limits

helicity retention

Charged current DIS at an EIC;
T. Burton at DIS2014

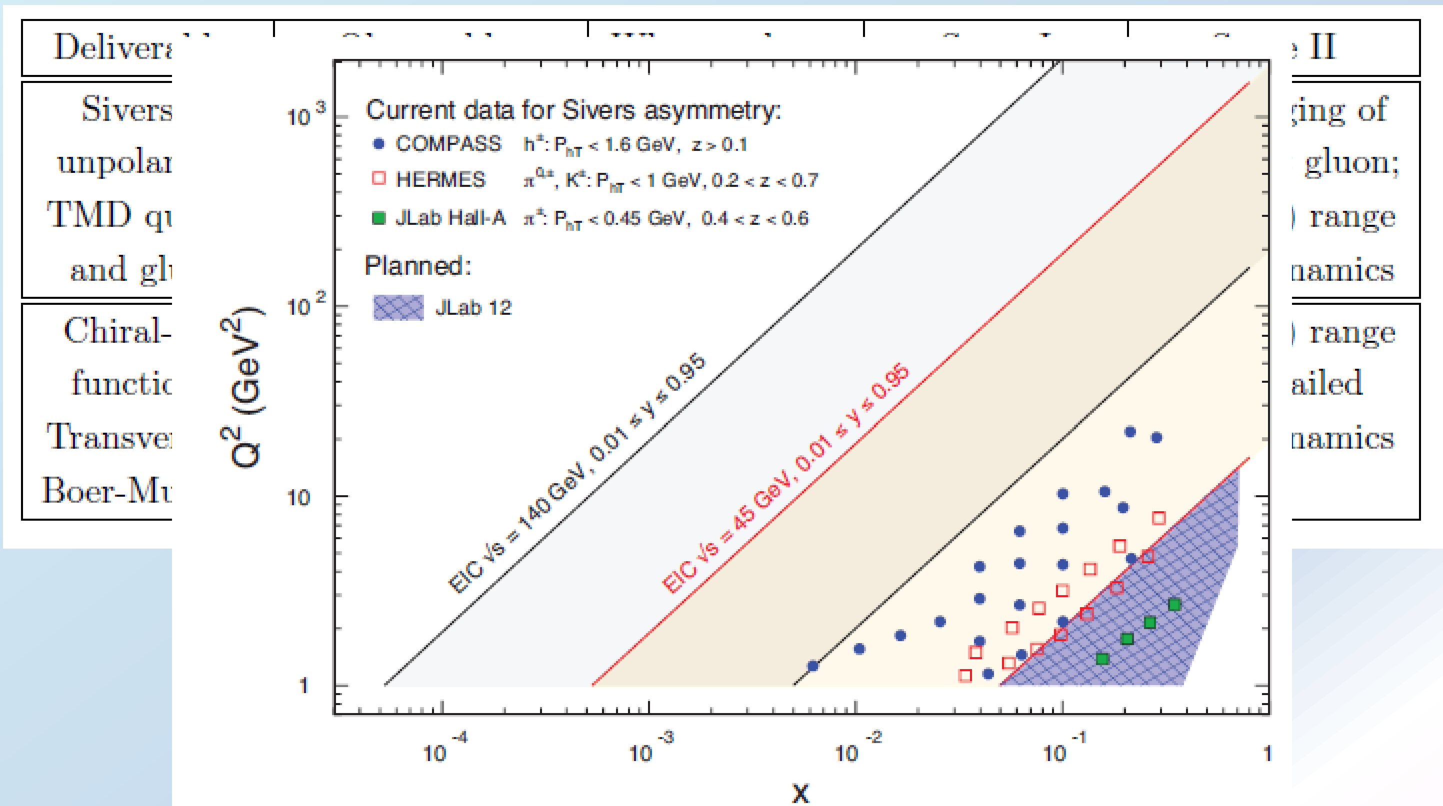
Impact on global analyses

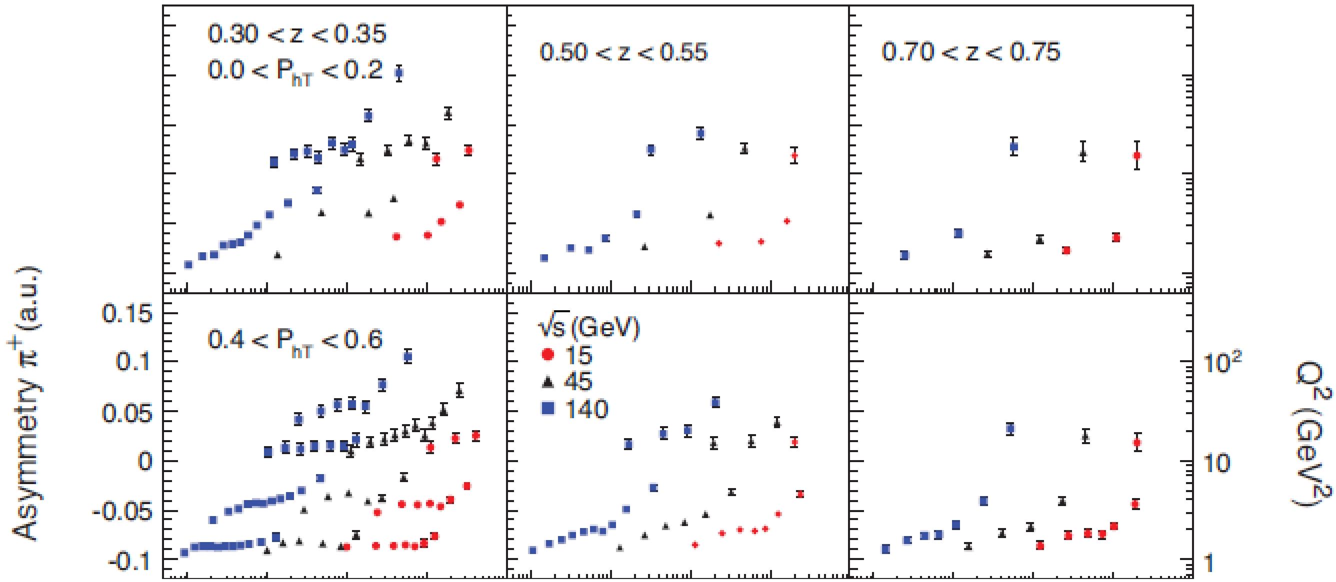


- Constrain **u**, **d** & **anti-q** helicities
- Flavour constraint independent of **fragmentation**
- Important cross check on **SIDIS**
  - low Q^2, higher

Charged current DIS at an EIC; T. Burton at DIS2014

Sivers function





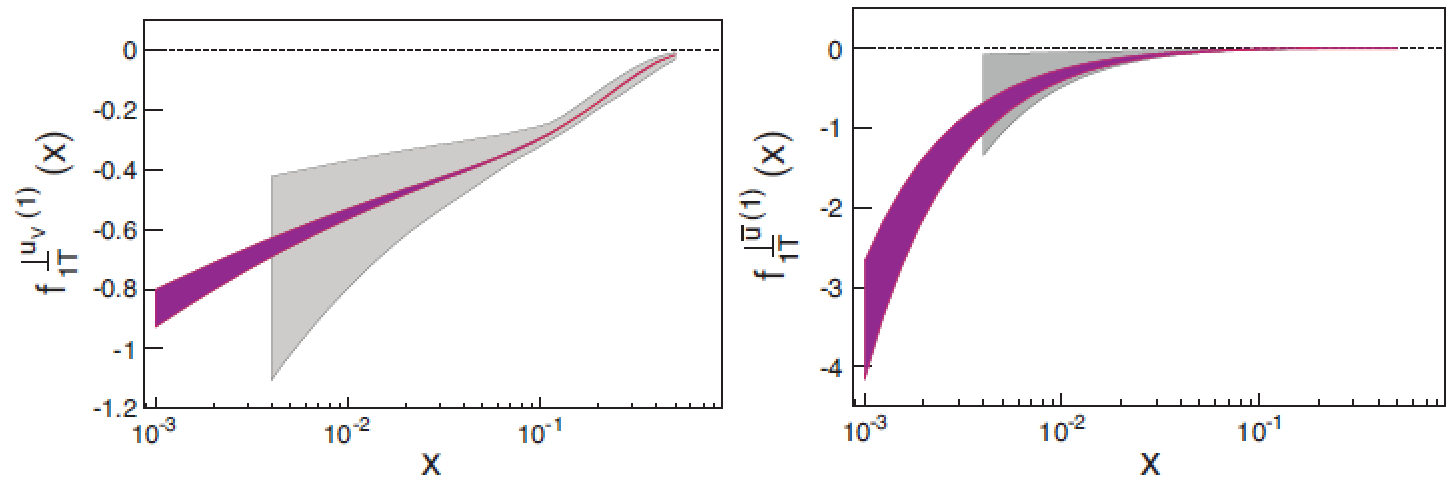
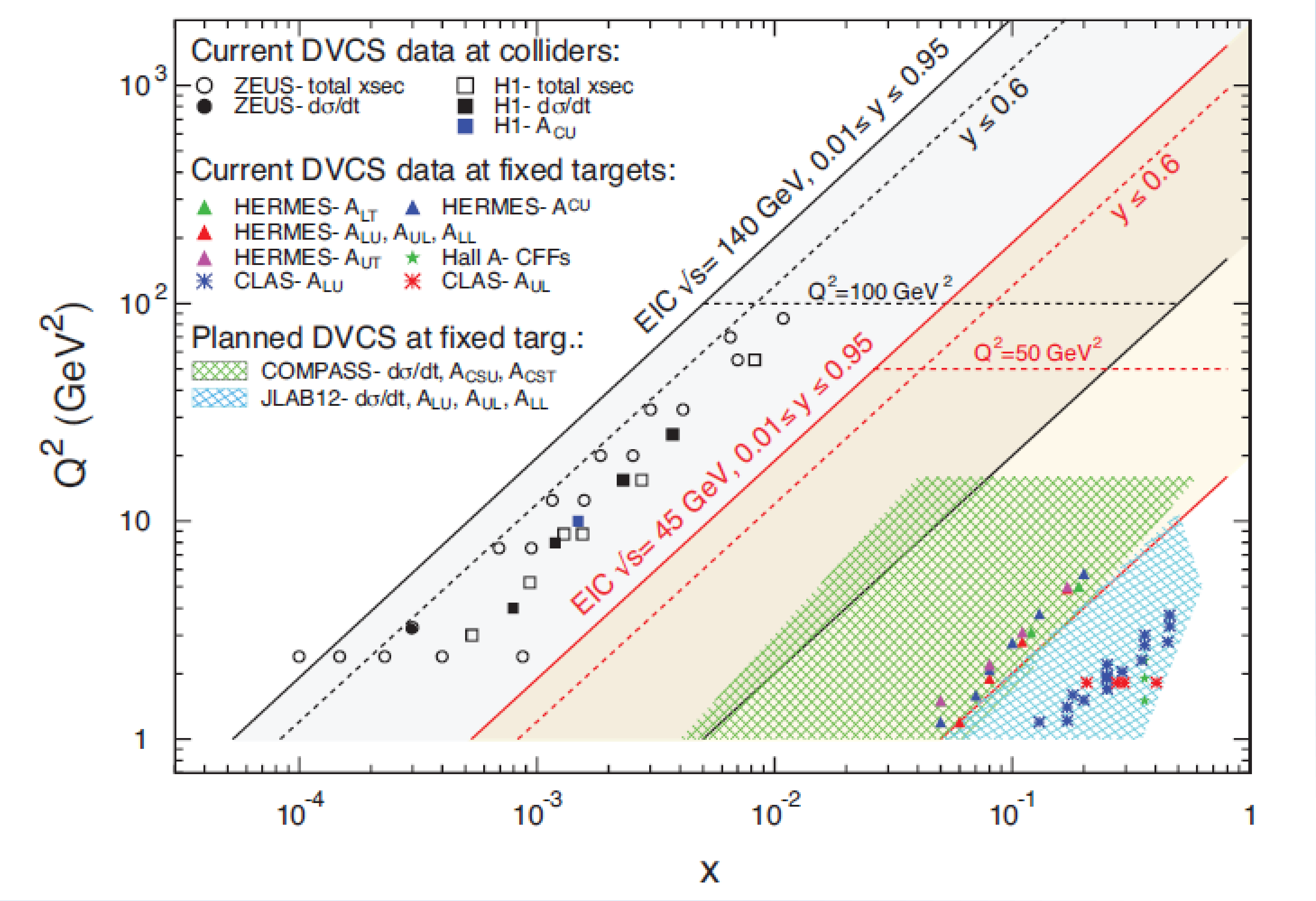


Figure 2.16: Comparison of the precision (2-σ uncertainty) of extractions of the Sivers function for the valence (left) $u_v = u - \bar{u}$ and sea (right) $\bar{u}$ quarks from currently available data [69] (grey band) and from pseudo-data generated for the EIC with energy setting of $\sqrt{s} = 45$ GeV and an integrated luminosity of 10 fb^{-1} (purple band with a red contour). The uncertainty estimates are for the specifically chosen underlying functional form.

3 dimensional spatial structure

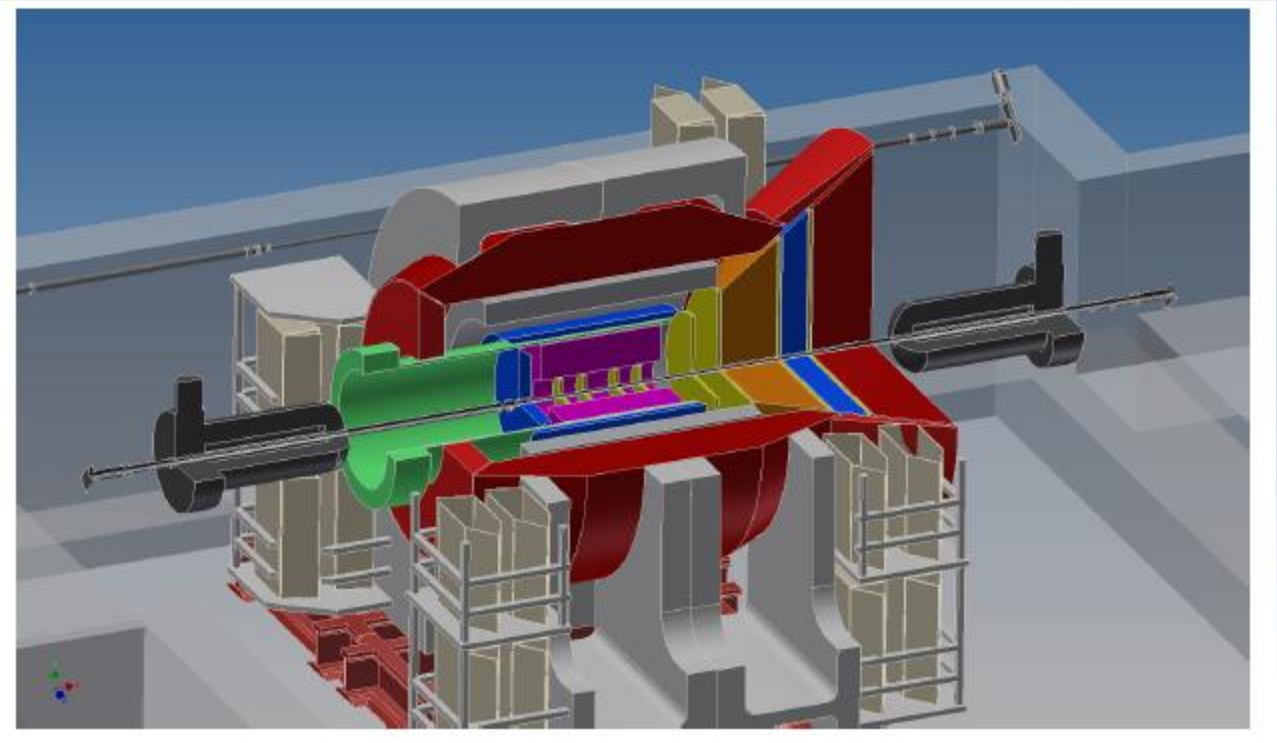
Deliverables	Observables	What we learn	Requirements
GPDs of sea quarks and gluons	DVCS and $J/\Psi, \rho^0, \phi$ production cross-section and polarization asymmetries	transverse spatial distrib. of sea quarks and gluons; total angular momentum and spin-orbit correlations	$\int dt\, L \sim 10$ to $100\,\mathrm{fb}^{-1}$; leading proton detection; polarized e^- and p beams; wide range of x and Q^2; range of beam energies; e^+ beam valuable for DVCS
GPDs of valence and sea quarks	electro-production of π^+, K and ρ^+, K^*	dependence on quark flavor and polarization	

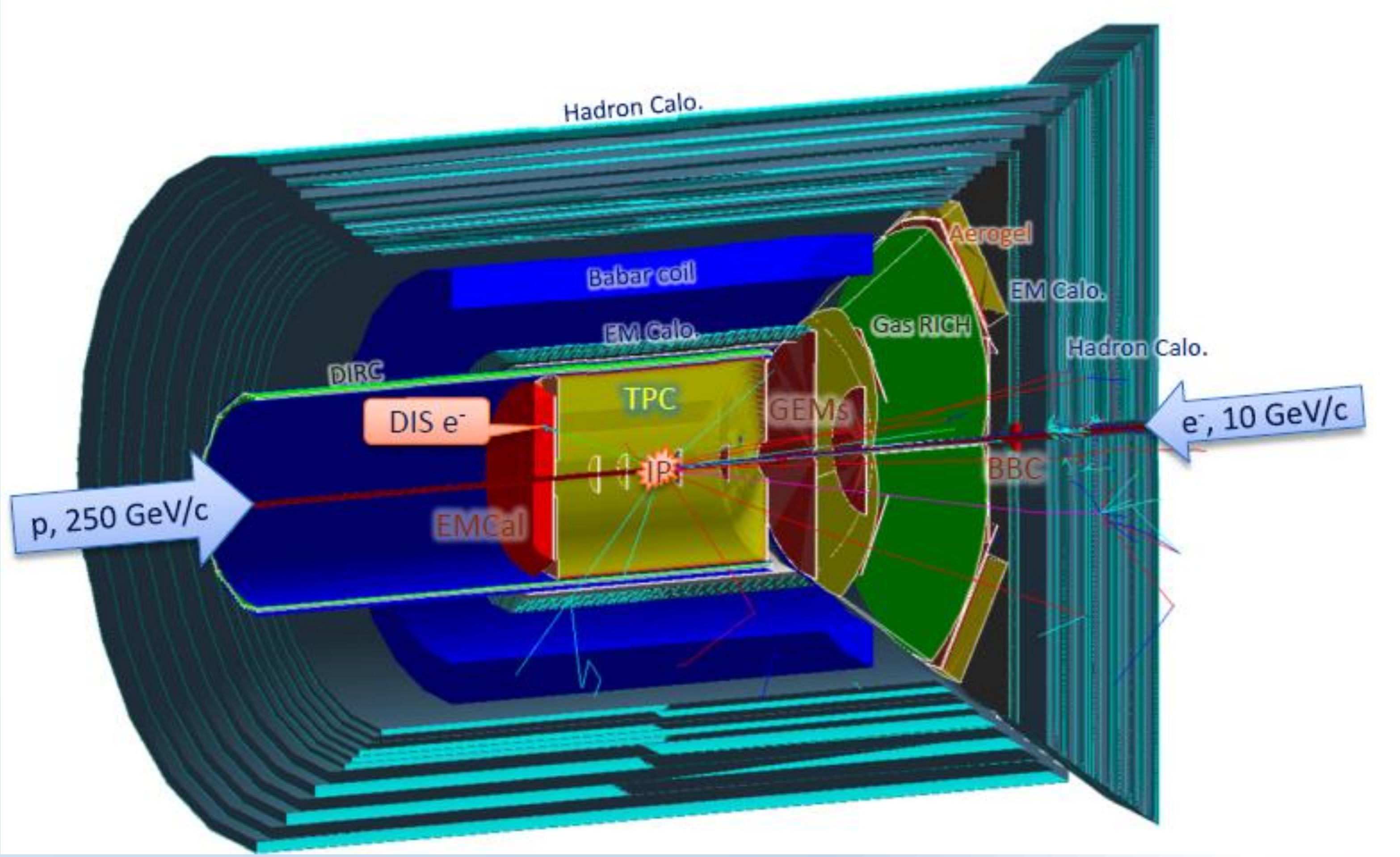
Table 2.3: Key measurements for imaging partons in the transverse plane. With energies in stage I, one can in particular investigate the transition from the valence to the sea quark regime and measure the processes in the lower block, whereas stage II provides access to a wide region dominated by sea quarks and gluons.



Current DVCS data at colliders:
ZEUS- total xsec
ZEUS- dσ/dt
H1- total xsec
H1- dσ/dt
H1- A_CU
Current DVCS data at fixed targets:
HERMES- A_LT
HERMES- A_CU
HERMES- A_LU, A_UL, A_LL
HERMES- A_UT
Hall A- CFFs
CLAS- A_LU
CLAS- A_UL
Planned DVCS at fixed targ.:
COMPASS- dσ/dt, A_CSU, A_CST
JLAB12- dσ/dt, A_LU, A_UL, A_LL
EIC √s= 140 GeV, 0.01≤ y ≤ 0.95
y ≤ 0.6
EIC √s= 45 GeV, 0.01≤ y ≤ 0.95
y ≤ 0.6
Q²=100 GeV²
Q²=50 GeV²
Q² (GeV²)
x

sPHENIX based eRHIC detector




Hadron Calo.
Aerogel
Babar coil
EM Calo.
Gas RICH
EM Calo.
Hadron Calo.
DIRC
TPC
DIS e-
GEMs
e-, 10 GeV/c
IP
BBC
p, 250 GeV/c
EMCal

Very high energy PID

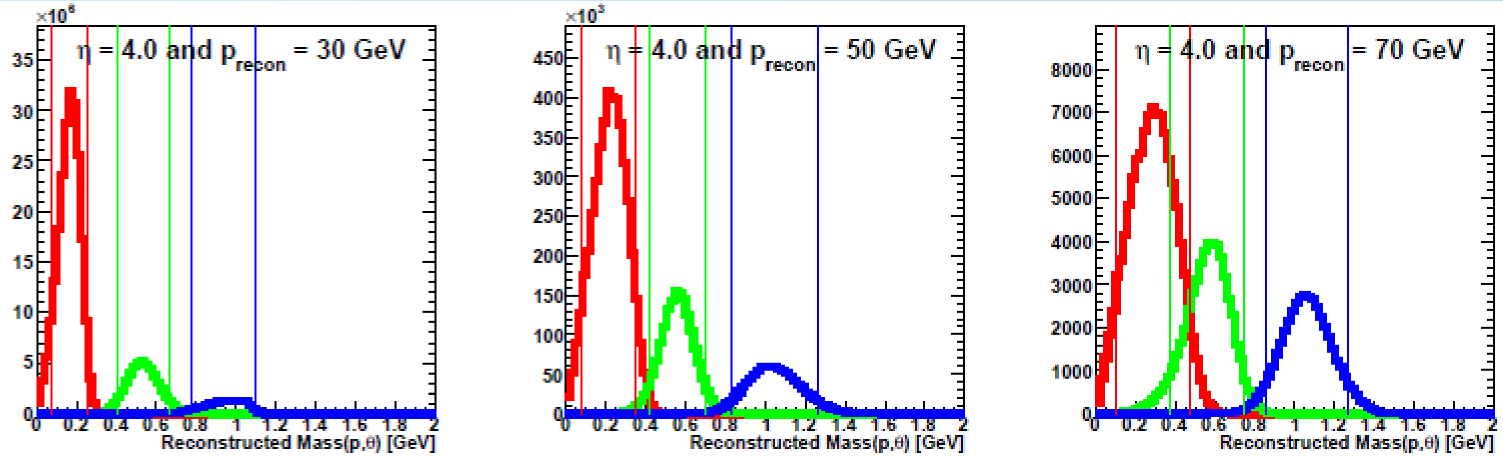
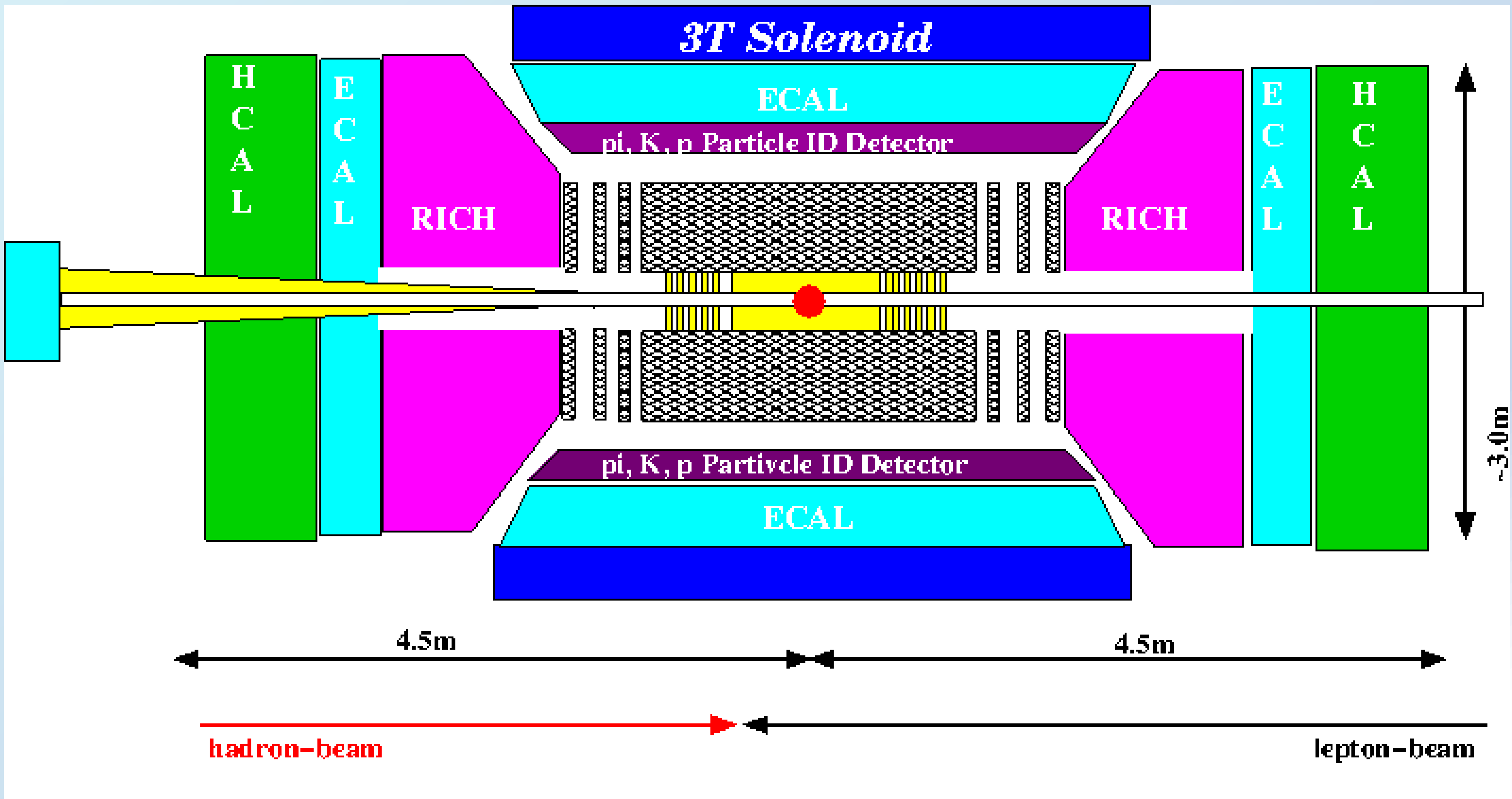


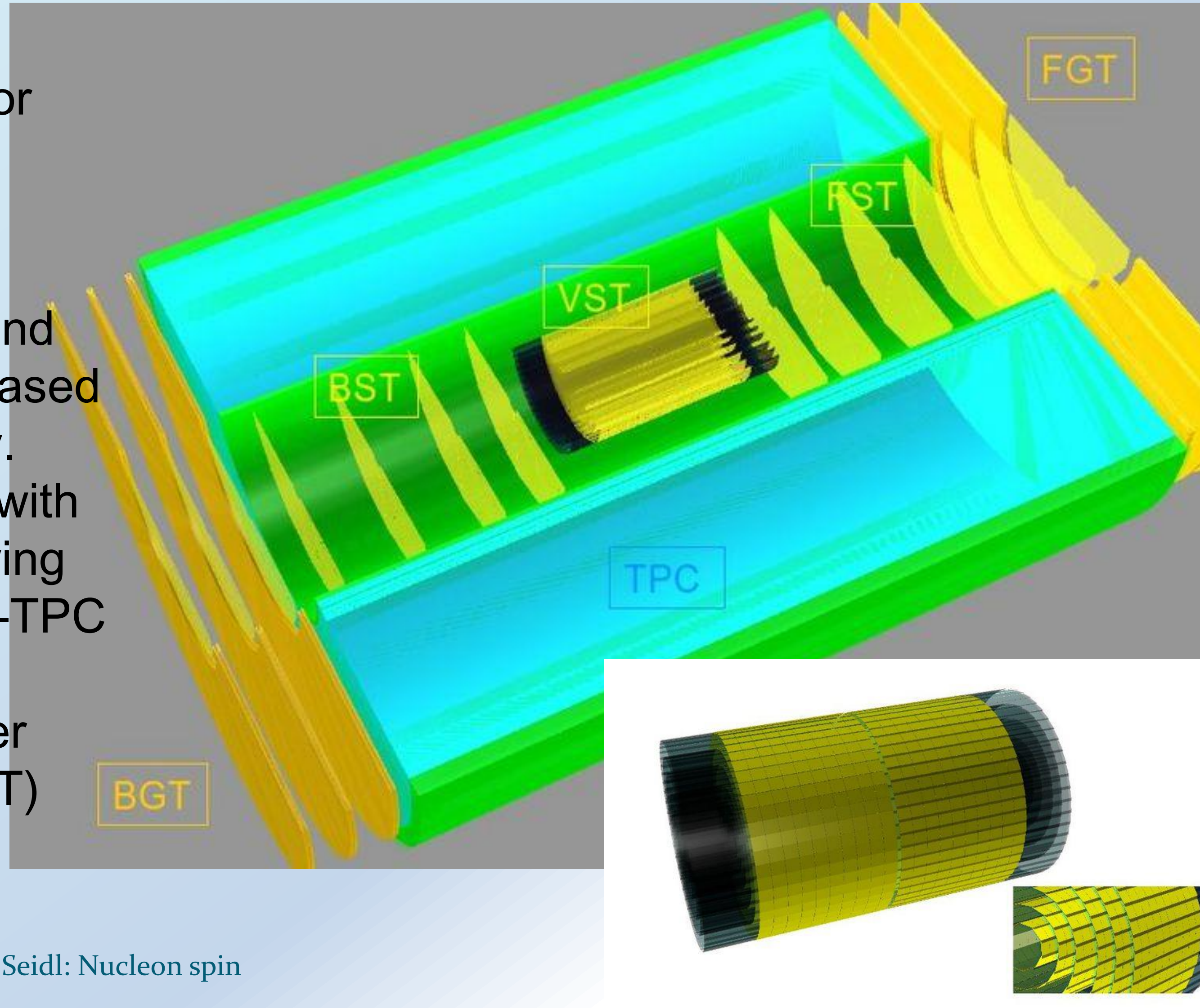
Figure 3.9: Reconstructed mass distribution via $m(p,\theta_{Crk})$ at $\eta = 4$ for reconstructed momenta 30 GeV/c (left), 50 GeV/c (middle) and 70 GeV/c (right), for pions (red), kaons (green) and protons (blue), with the parent momentum and particle abundances from the PYTHIA generator. Vertical lines indicate the symmetric mass cuts corresponding to 90% efficiency. Note that particle true momentum is on the average smaller than reconstructed momentum, see Figure 3.10.

Dedicated eRHIC detector



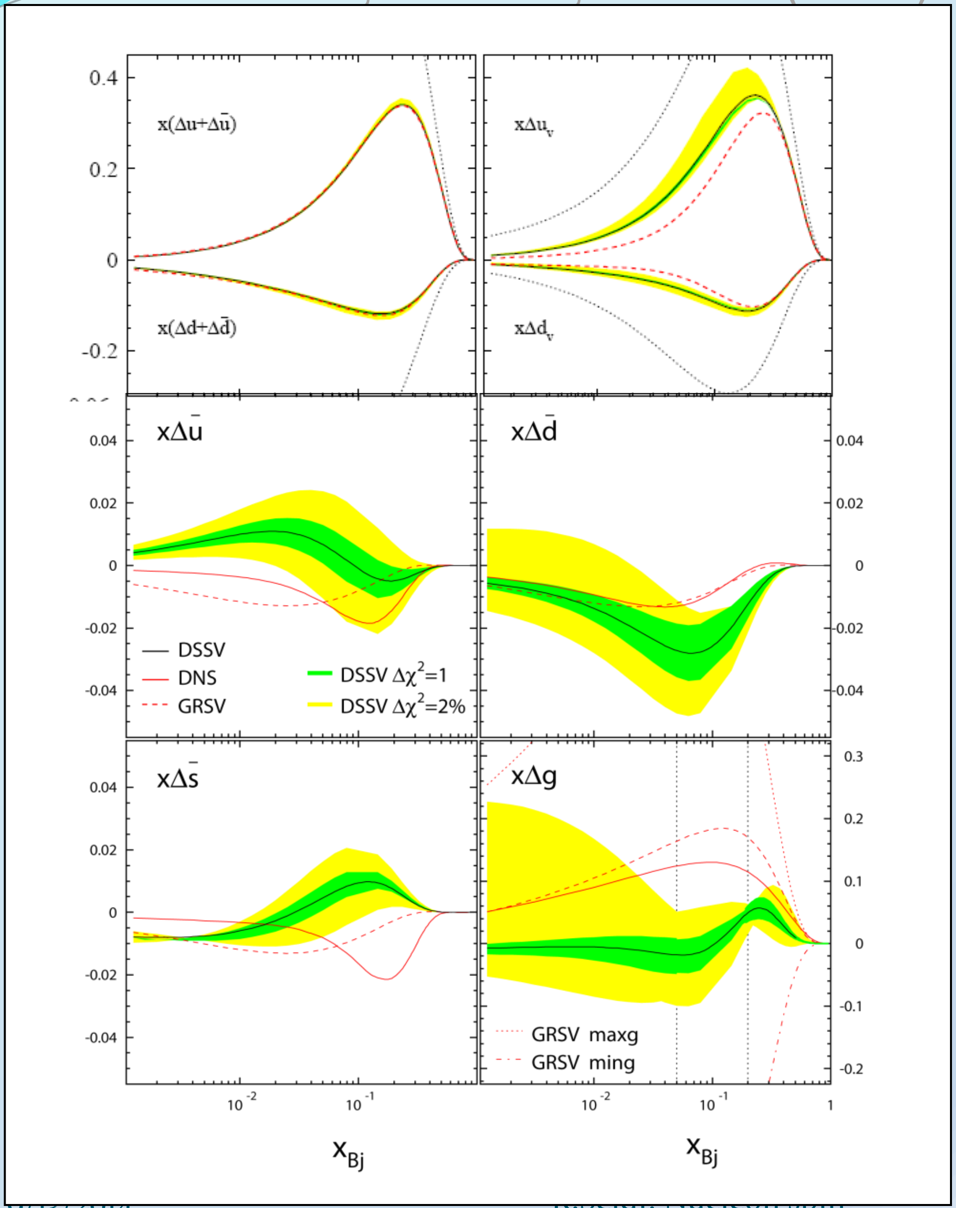
Dedicated detector inner

- Barrel micro-vertex tracking (VST)detector based on MAPS-technology.
- Forward / Backward vertex tracker (FST and BST)detector disks based on MAPS-technology.
- Barrel-Tracker: TPC with GEM read-out, following the design of the ILC-TPC
- Forward / Backward: possible GEM Tracker planes (FGT and BGT)



Most recent global analysis : DSSV

de Florian et al., PRL101, 072001 (2008)

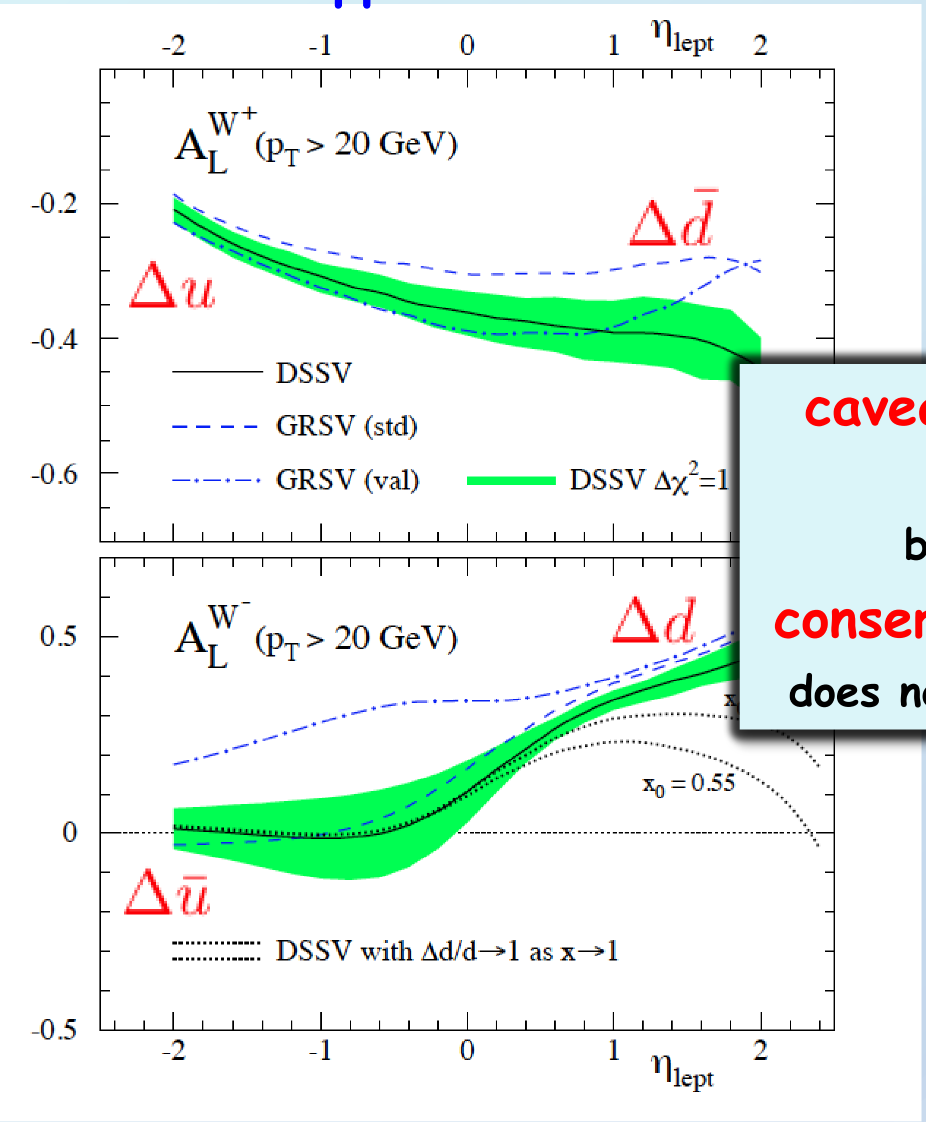


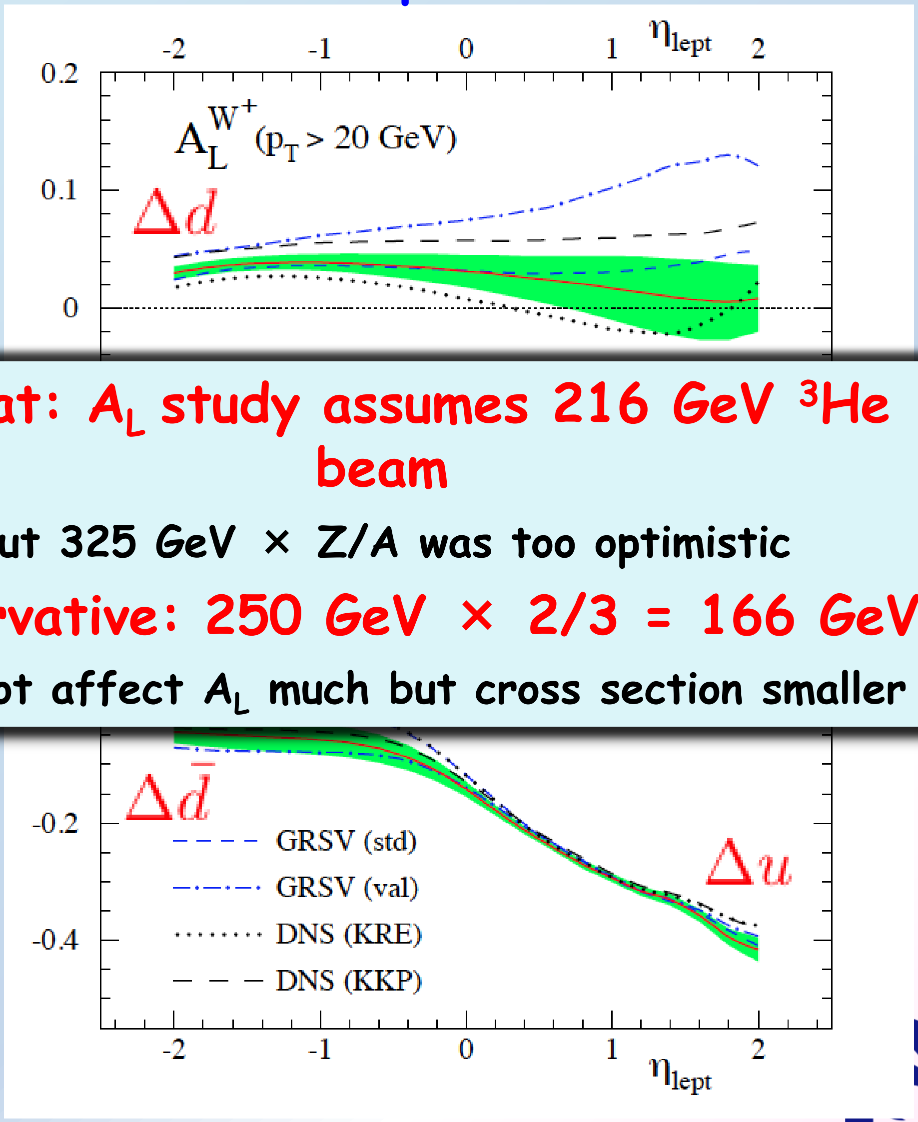
- NLO analysis
- Inclusion of SIDIS data before COMPASS
- Inclusion of RHIC A_{LL} data(from 200GeV)
- Using most recent NLO fragmentation functions (DSS)
- Large uncertainties still for sea quarks
- Decay data forces Δs to become negative at small x
- RHIC data results in node to Δg

W Outlook ^{3}He p collisions

Marco Stratman

pp @ 500 GeV | **^{3}He p @ 432 GeV**





caveat: A_L study assumes 216 GeV ^{3}He beam

but 325 GeV × Z/A was too optimistic

conservative: 250 GeV × 2/3 = 166 GeV

does not affect A_L much but cross section smaller