Open Questions in Hadron (Spin) Structure

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Other directly connected talks:

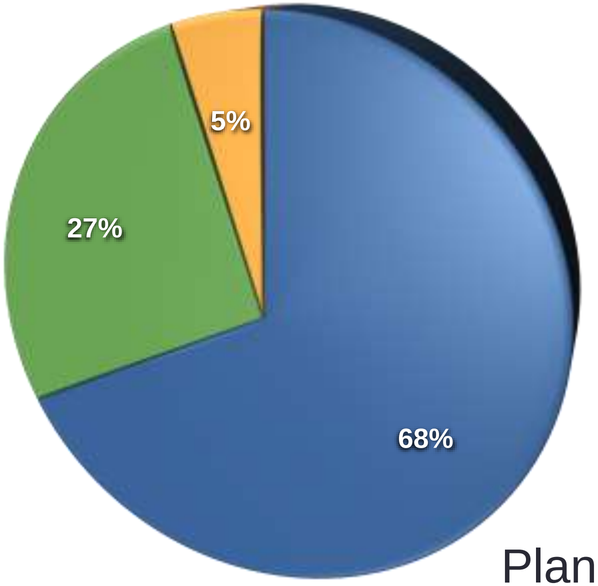
- PANDA and measurements
  - Facility and planned first measurements
  - James Ritman (13/10/2014)
  - Paula Gionetti (16/10/2014)
- COMPASS at CERN
  - Results and plans for future
  - Tobias Weisrock (14/10/2014)
- JLab and JLab12 Experiments
  - Results and plans
  - Patrizia Rossi (16/10/2014)

Its probably most effective for me to emphasize complementary Measurements at RHIC (some JLab), FNAL and the future at Electron Ion Collider

Plan for today's talk

- QCD the right theory for Strong Interactions:
  - Do we understand it?
  - Understanding hadron structure absolutely essential step towards this broader goal
- Longitudinal and transverse spin structure of the nucleon
  - Recent experimental results ➔ interpretation & limitations
- Near-future (detector upgrades) and far-future initiatives (Electron Ion Collider)

Our Universe:



Planck 2013 Results

- 68% Dark energy
- 27% Dark matter
- 5% Visible matter

- What makes up the mass of the **visible universe?**

Atomic mass (visible matter): 99.9% from nuclear mass

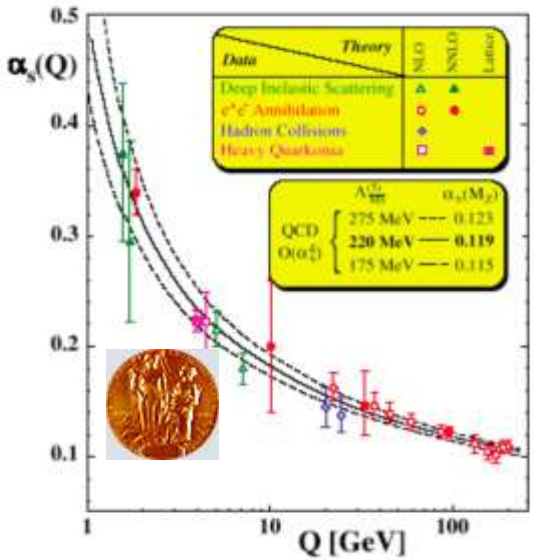
Nuclear Mass: all of it from **nucleon mass**

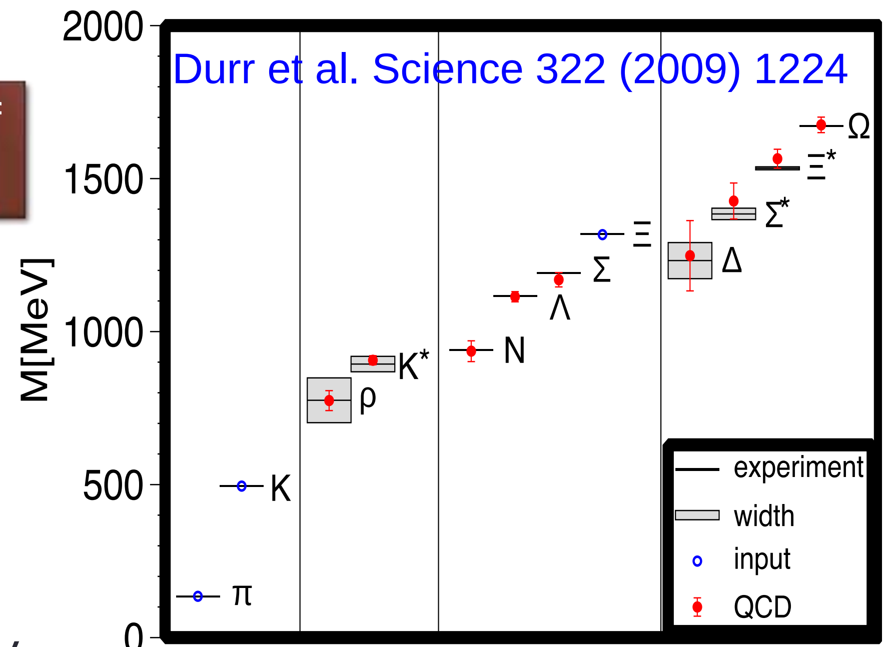
Nucleon mass? ➔ **energy of massless *gluons* and almost massless up & down quarks**

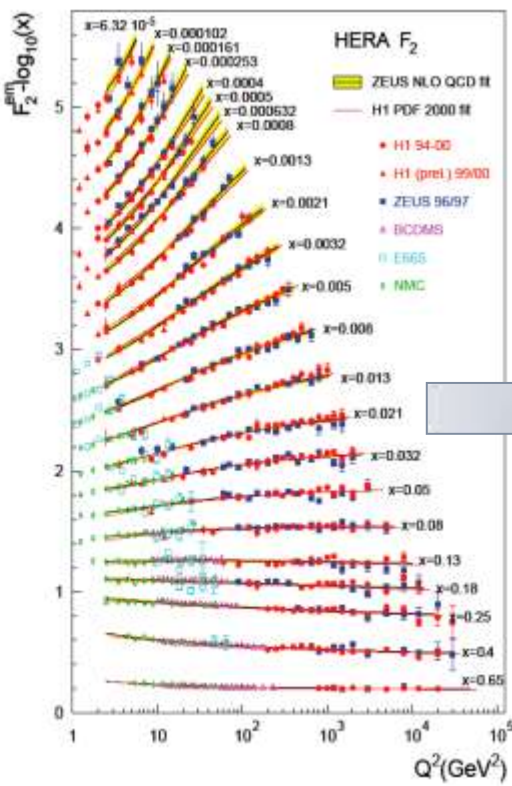
Gluon & quark interactions & dynamics make up the entire mass of the visible universe!

➔ *"Mass without mass" – John Wheeler*

Successes of QCD

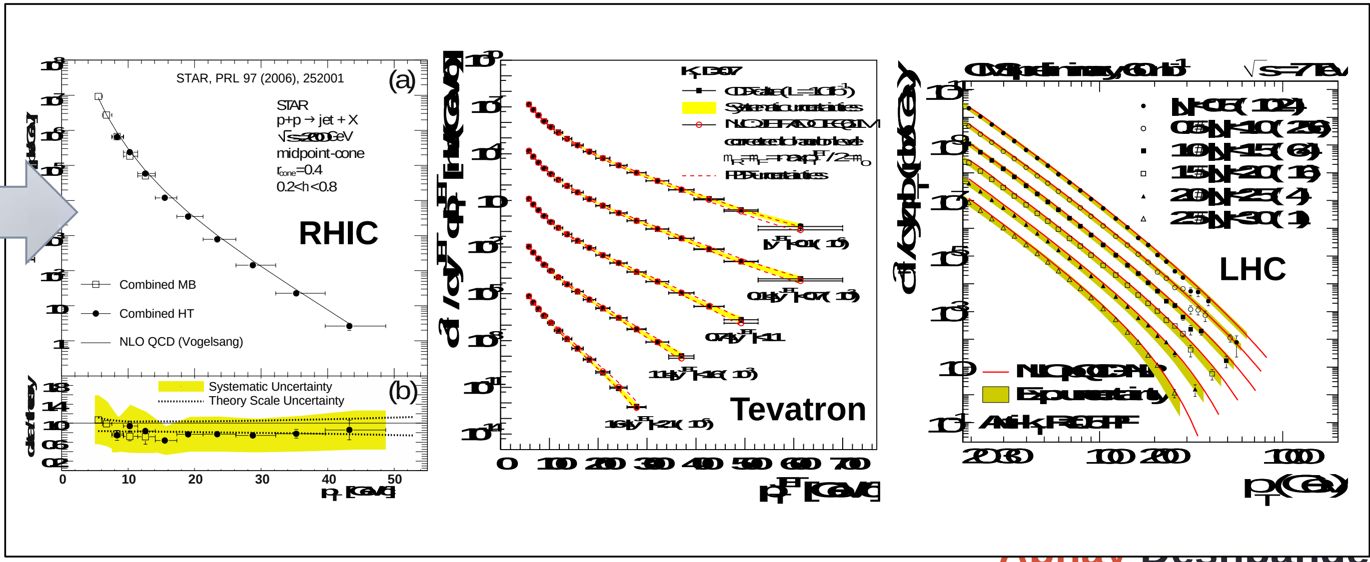






Measure **e-p** 0.3 TeV:

➔ Use pQCD Calculate **p-p, p-pbar Jet x-sctn** at 0.2, 2, 7 TeV



"Folks, we should stop testing QCD, and start understanding it." Yuri Dokshitzer (ICHEP'98, Vancouver)

QCD is the correct theory of strong interactions, but do we understand it?

How well do we understand the role of gluons in QCD?

How well do we understand the sea quarks?

Knowing the properties and interactions of partons, can we explain the nucleon spin?

F. Wilczek (XXIV Quark Matter 2014)

Quarks (and Glue) at Frontiers of Knowledge

Challenges, Opportunities

The study of the strong interactions is now a mature subject - we have a theory of the fundamentals* (QCD) that is correct* and complete*.

In that sense, it is akin to atomic physics, condensed matter physics, or chemistry. The important questions involve emergent phenomena and "applications".

Emergent Phenomena

Schizophrenic Protons?

We have two very different pictures of protons, in the lab frame (quark model) and in the infinite momentum frame (parton model). Each is very successful.

How does one proton manage to become the other? Are there intermediate pictures?

"Spin" Is Very Important & Critical in Experimental Studies

Experiments that fundamentally changed the way we think about nature:

- Stern Gehrlach (1921)

  Space quantization associated with direction
- Goudschmidt & Uhlenbeck (1926)

  Atomic fine structure and electron spin magnetic moment
- Stern (1933)

  Proton anomalous magnetic moment $\mu_p = 2.79$
- Kusch (1947)

  Electron anomalous magnetic moment $\mu_e=1.00119$
- Yale-SLAC Collaboration (Prescott & Hughes et al., 1978)

  Electro-Weak interference in polarized e-D: parity non-conservation
- European Muon Collaboration (1989)

  The proton spin crisis

- It could be effectively argued that the 20th century was a

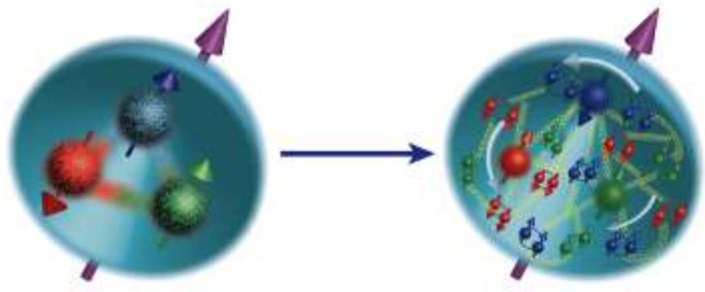
Century of Spin Surprises

V. Hughes

In fact, it has been said by various **theorists:**

"*Experiments with "spin" have killed more theories than any other single physical property"* *E. Leader*

"*If theorists had their way, they would ban all experiments with spin"* *(jokingly) J.D.Bjorken*



Our Understanding of Nucleon Spin vs. Time

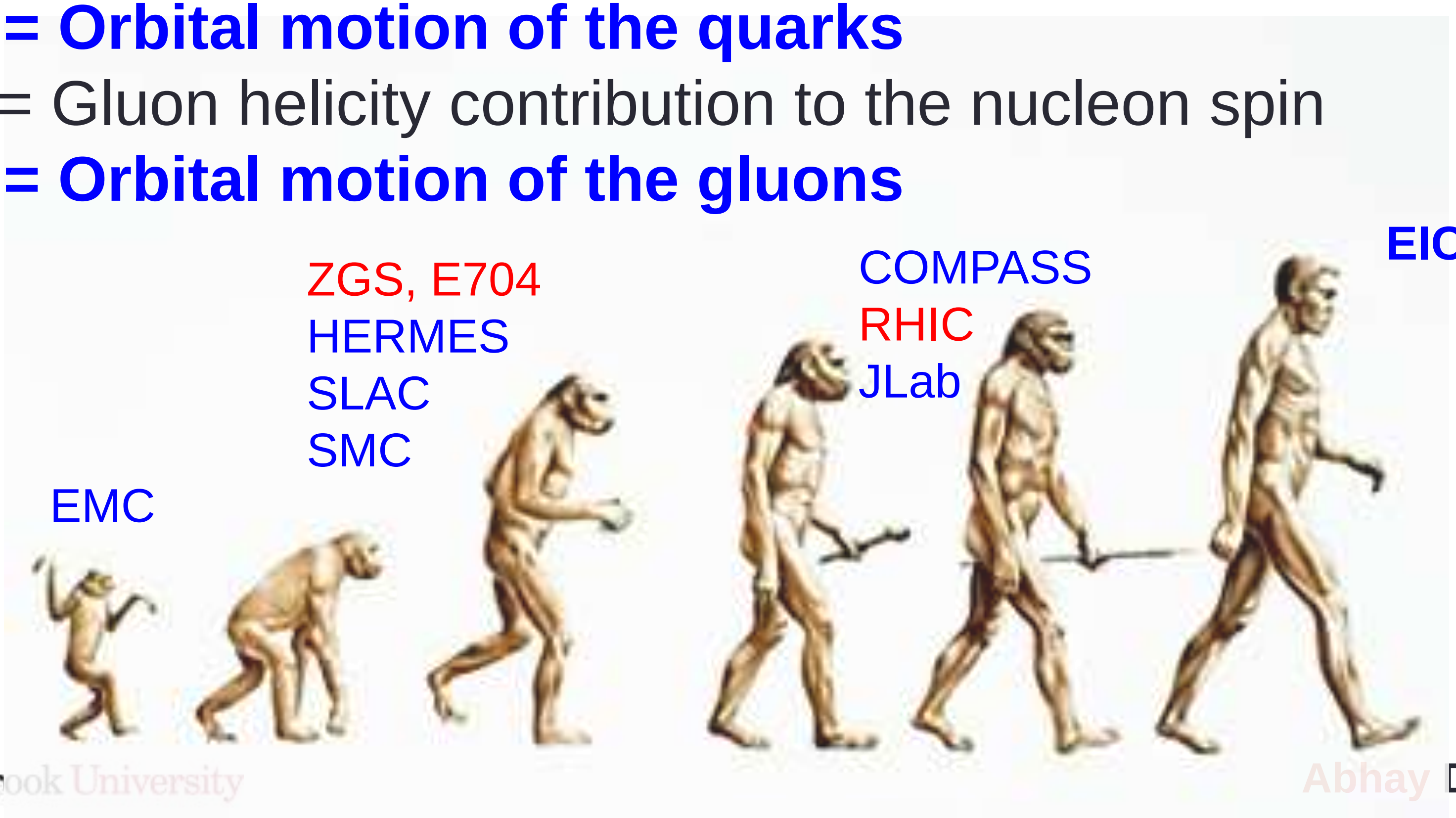
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{Q,G}$$

$\Delta\Sigma$ = Quark + anti-quark helicity contribution to nucleon spin

L_Q = Orbital motion of the quarks

ΔG = Gluon helicity contribution to the nucleon spin

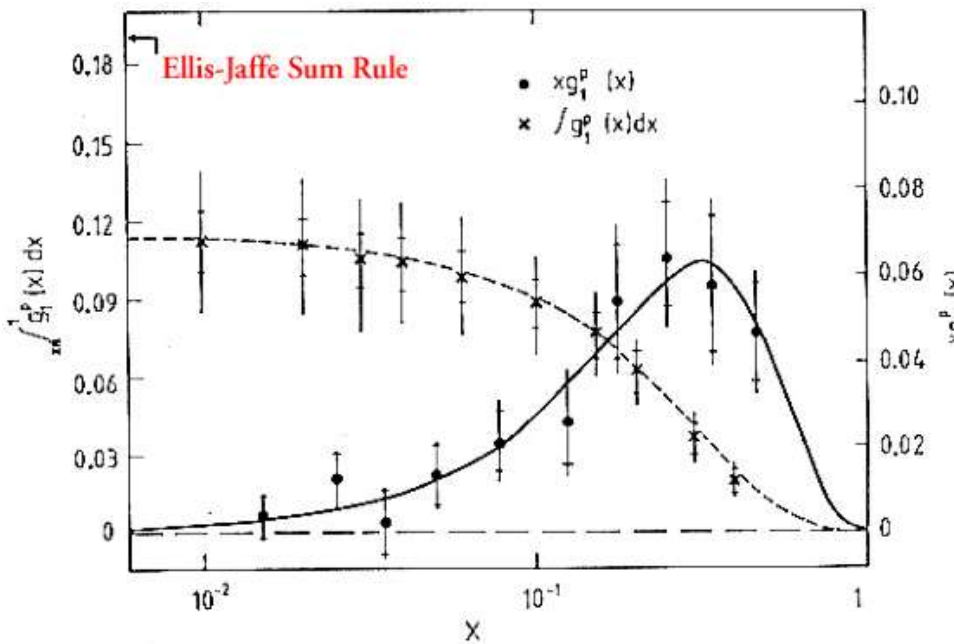
L_G = Orbital motion of the gluons

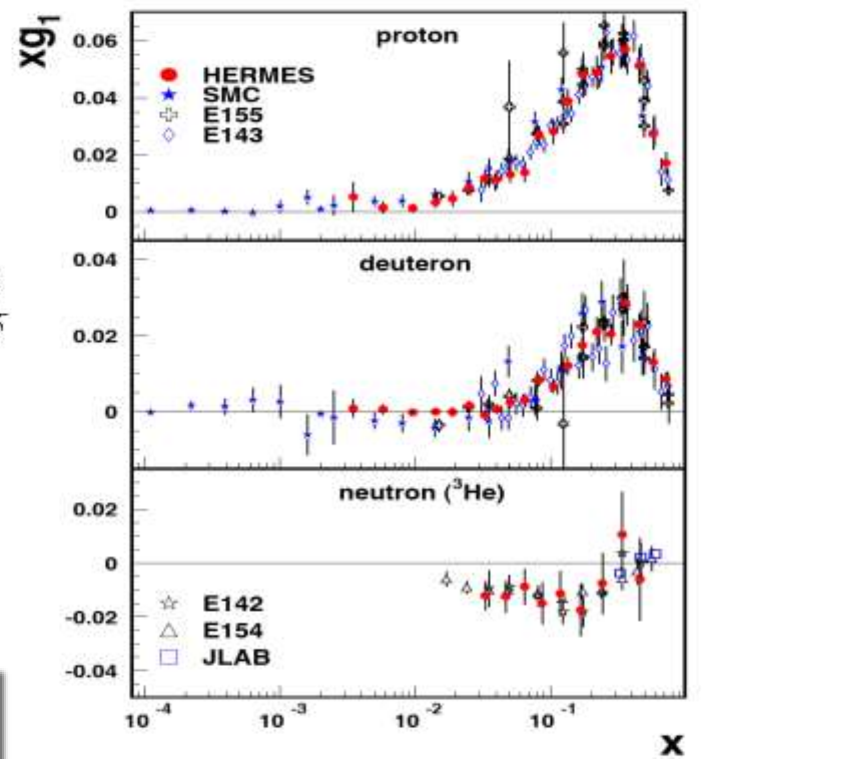


Deep Inelastic Scattering: The Spin Crisis

Quarks carry only about 25% of the nucleon spin

What carries the remaining spin of the proton?





Strong suggestion → Glue !

Aftermath of EMC Spin Crisis

Naïve quark model: ½ = ΔΣ/2, where ΔΣ = 1, from and ΔΣ= Δu+Δd+Δs ➔ Relativistic effects bring ΔΣ ~ 0.6, but

➔ we found ΔΣ ~ 0.3

If quarks don't carry the nucleon spin: who does? Gluons and possible orbital motion of quarks and gluons!

$$\Delta\Sigma(Q^2) = \Delta\Sigma' - \boxed{N_f \frac{\alpha_S(Q^2)}{2\pi} \Delta g(Q^2)}$$

Altarelli & Ross
Carlitz & Collins
Mueller et al.

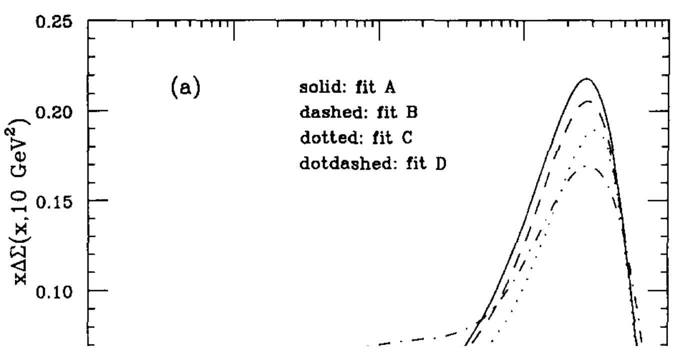
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \boxed{\Delta G} + \boxed{L_{Q,G}}$$

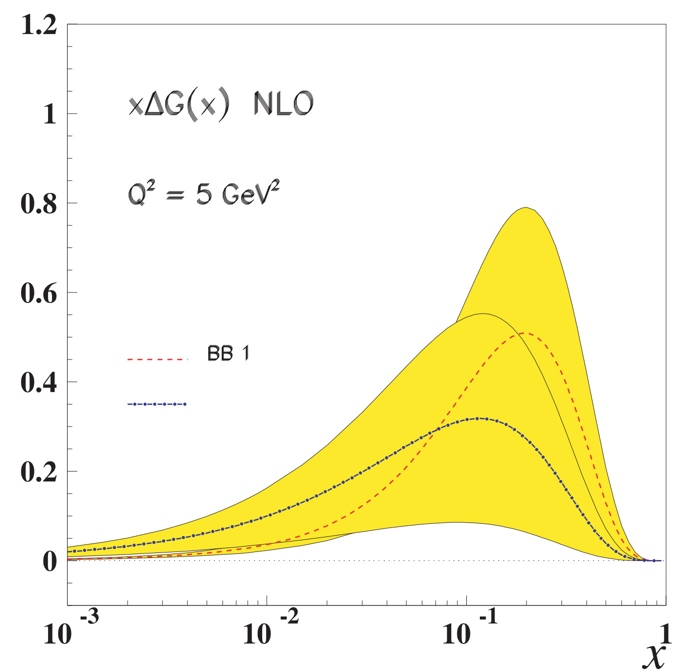
High expectations from ΔG

Altarelli et al. NP B 496 (1997) → NLO pQCD analysis of inclusive DIS in AB scheme

Experimental	±0.05	±0.04	±0.4	±0.05
Fitting	±0.05	±0.05	±0.5	±0.07
α_s and a_8	±0.03	±0.01	±0.2	±0.02
Thresholds	±0.02	±0.05	±0.1	±0.01

G. Altarelli et al./Nuclear Physics B 496 (1997) 337–357



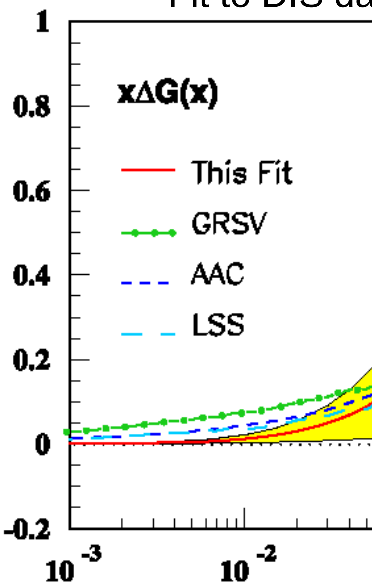


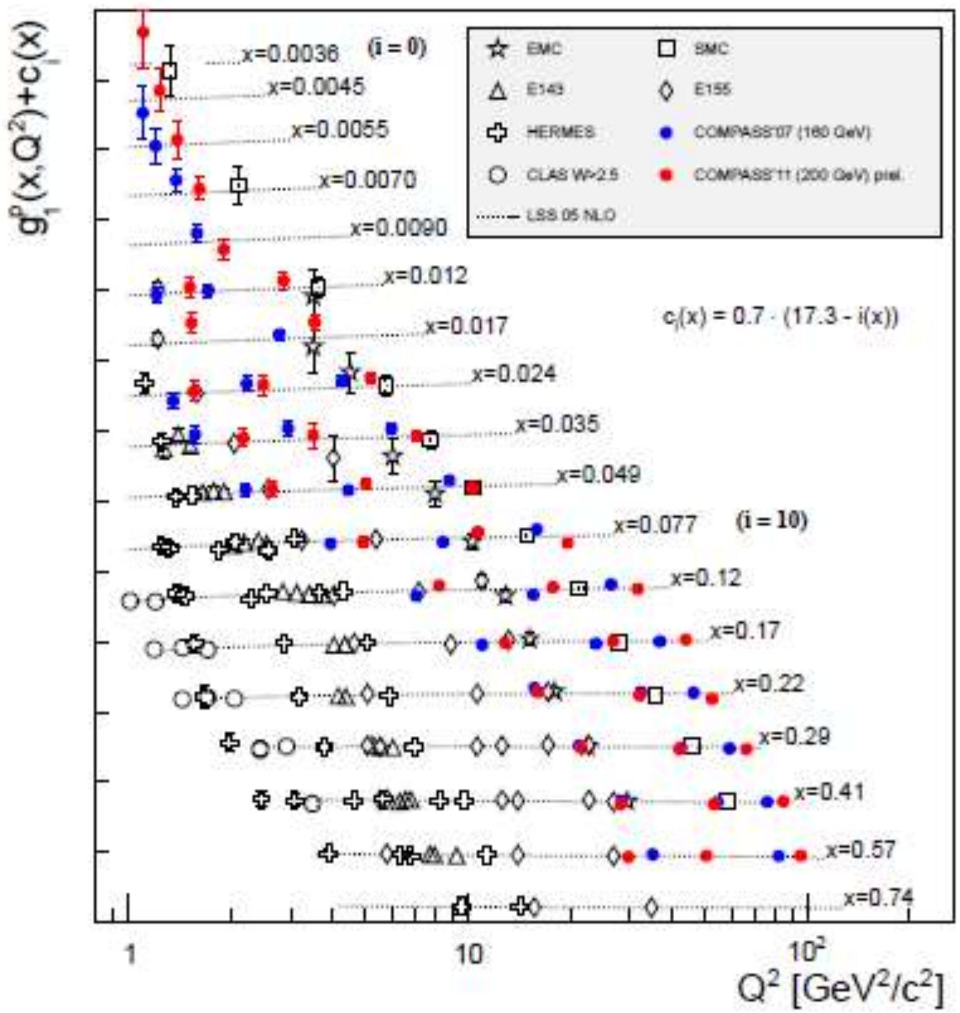
Blumlein et al. NP A721 (2003)
→ NLO pQCD in MSbar Scheme:
ΔG at Q^2=4 GeV^2 ~ 1.0 +/- 0.7

Also see: PRD 58 112002 (1998) for detailed discussion uncertainties

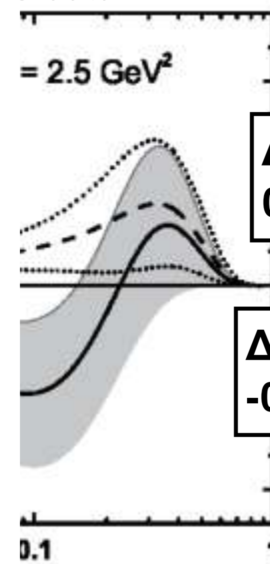
Gluon Spin extraction without RHIC data:

Blümlein & Böttcher, NP
Fit to DIS da





4018 (2010)
S data



ΔG = 0.32±0.19

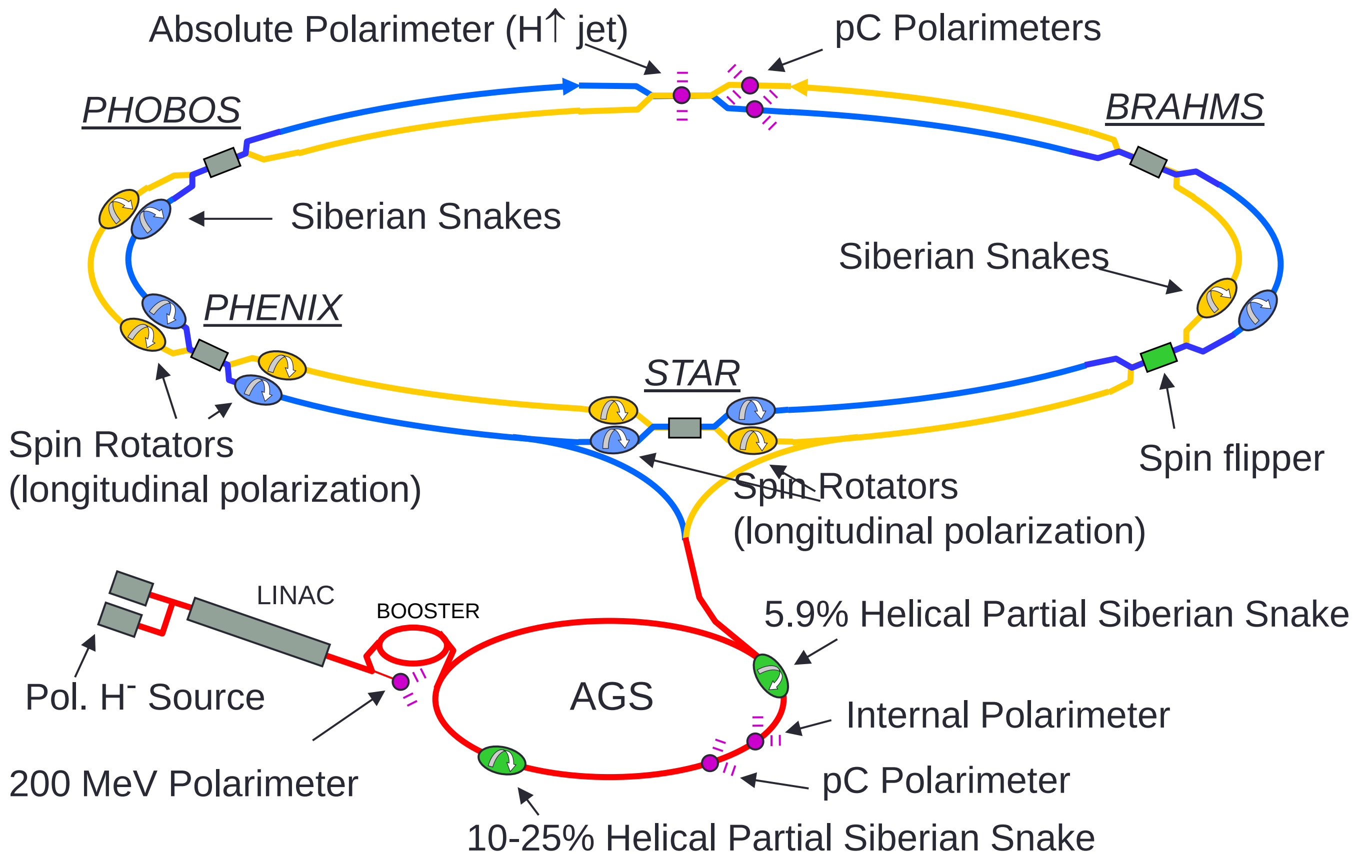
ΔG = -0.34±0.46

- Despite m … 1-2010) the gluon det…

Motivation for RHIC Spin:

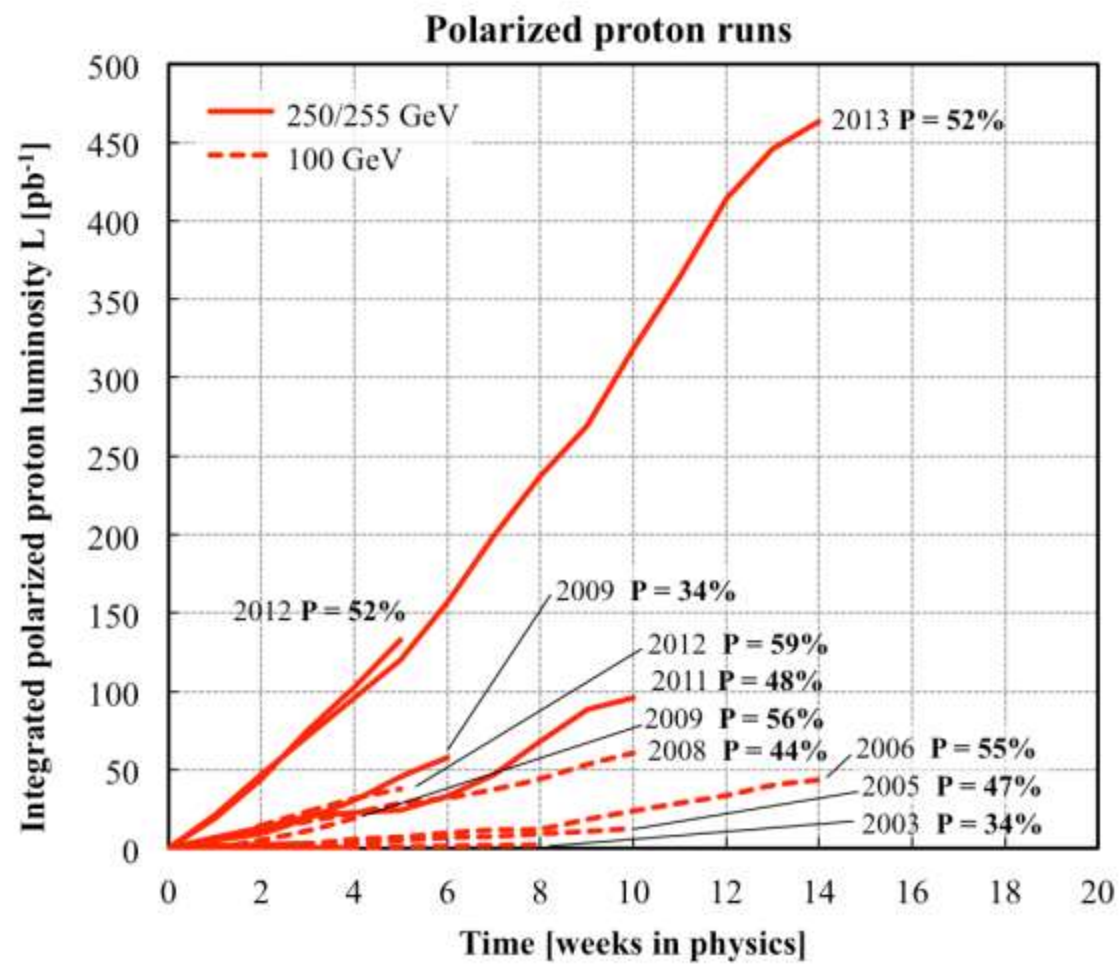
- How much spin of the protons do the gluons (ΔG) carry?
  - Technical know-how (Siberian Snakes, Spin Rotators, polarimetry ideas) to do this at high energy evolved around the time (mid/late-1990s)
- Why $\Delta\Sigma$ (quark + anti-quark's spin) small? Are quark and anti-quark spins anti-aligned?
  - Polarized *p*+p at high energy, through parity violating (u-dbar or ubar-d) W+/- production
- A severe need for investigations of the surprising transverse spin effects

RHIC as a Polarized Proton Collider



Without Siberian snakes: $\nu_{sp} = G\gamma = 1.79\ E/m \rightarrow$ ~1000 depolarizing resonances
With Siberian snakes (local 180° spin rotators): $\nu_{sp} = ½ \rightarrow$ no first order resonances
Two partial Siberian snakes (11° and 27° spin rotators) in AGS

RHIC polarized collider: a success!



Runs 4,5,6 & 9 with 100 GeV beams

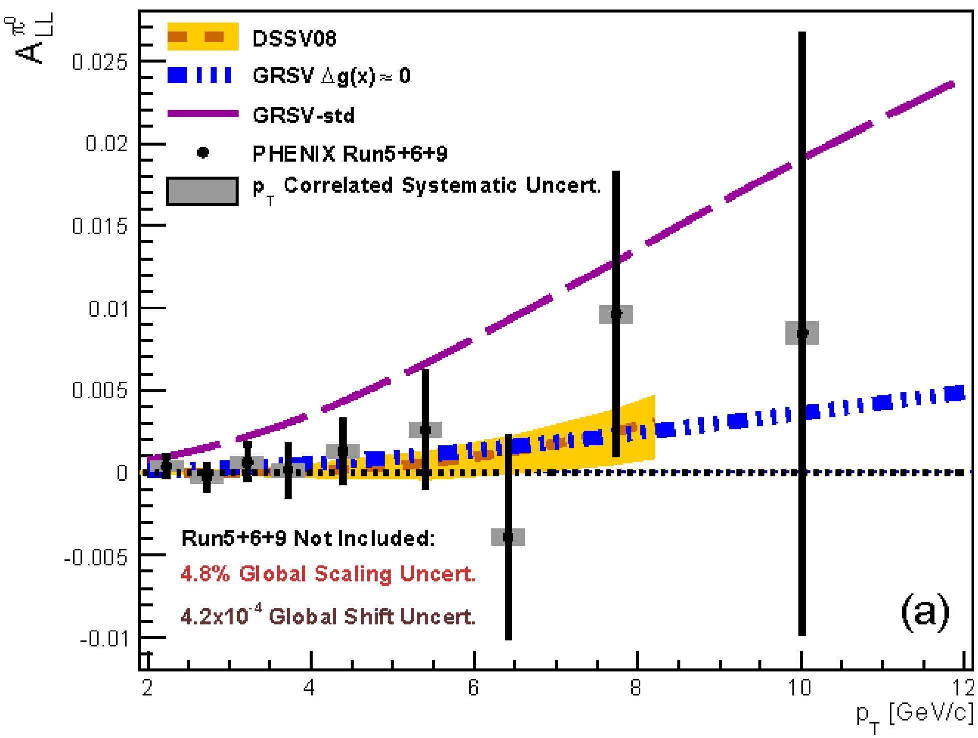
- ΔG, transverse spin

Runs 9,11,12, 13 with 250 GeV beams

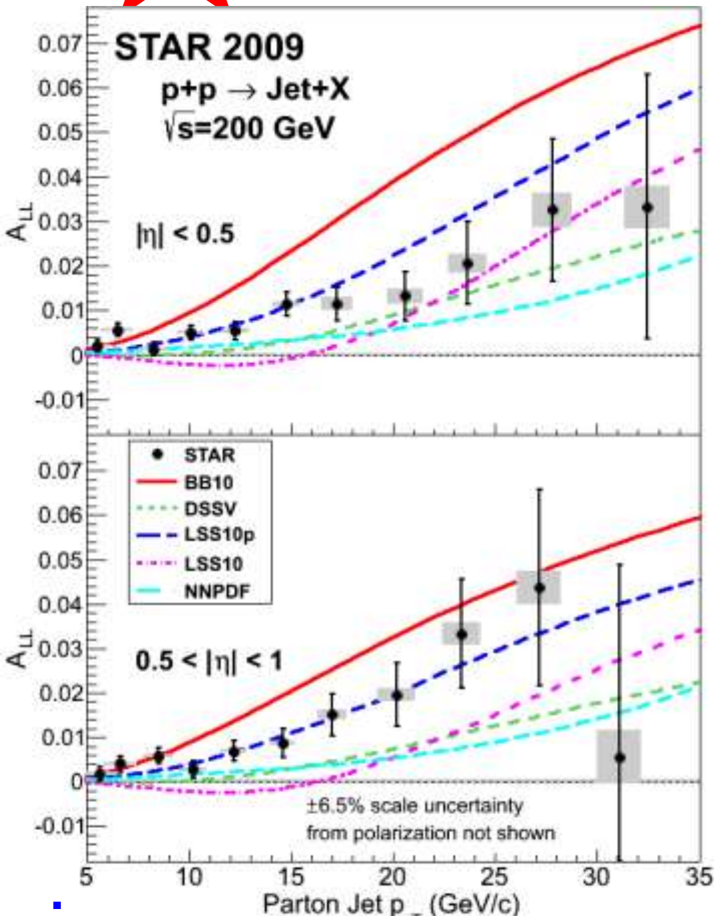
- ΔG, W-Physics

ΔG: 2009 RHIC data:

PHENIX PRD 90, 012007



STAR arXiv:1405.5134

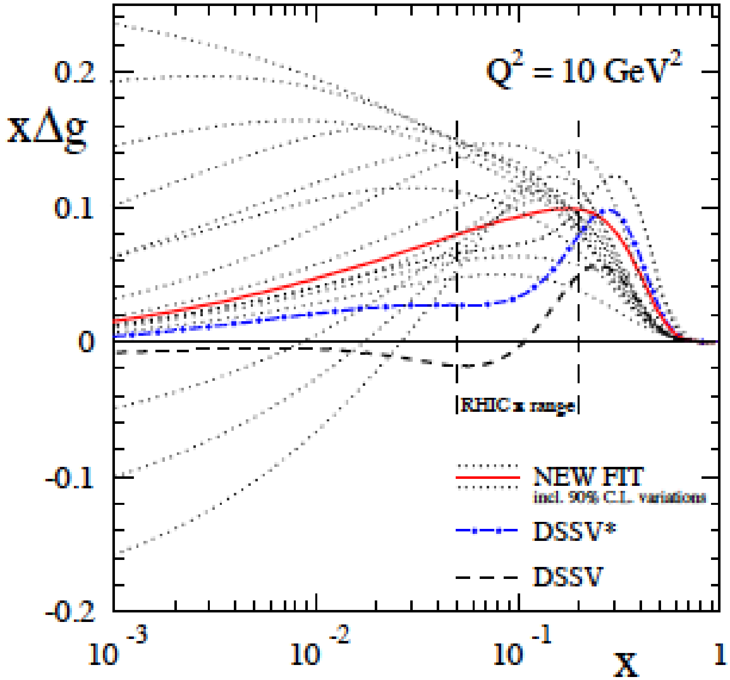


Double Longitudinal Spin Asymemtrry = A_{LL} ;

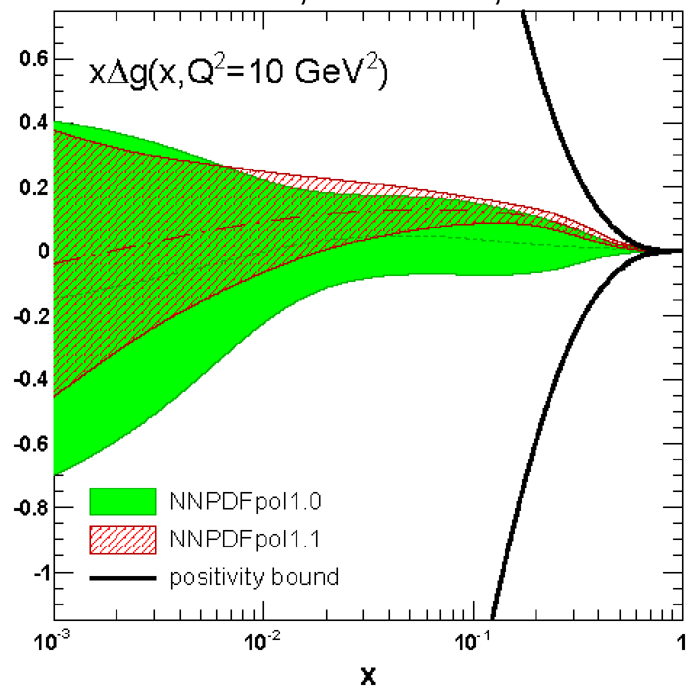
➔ proportional to the ΔG in the proton

Impact of RHIC data: Global fit @ NLO

DSSV, PRL 113, 012001



NNPDF, NPB 887, 276



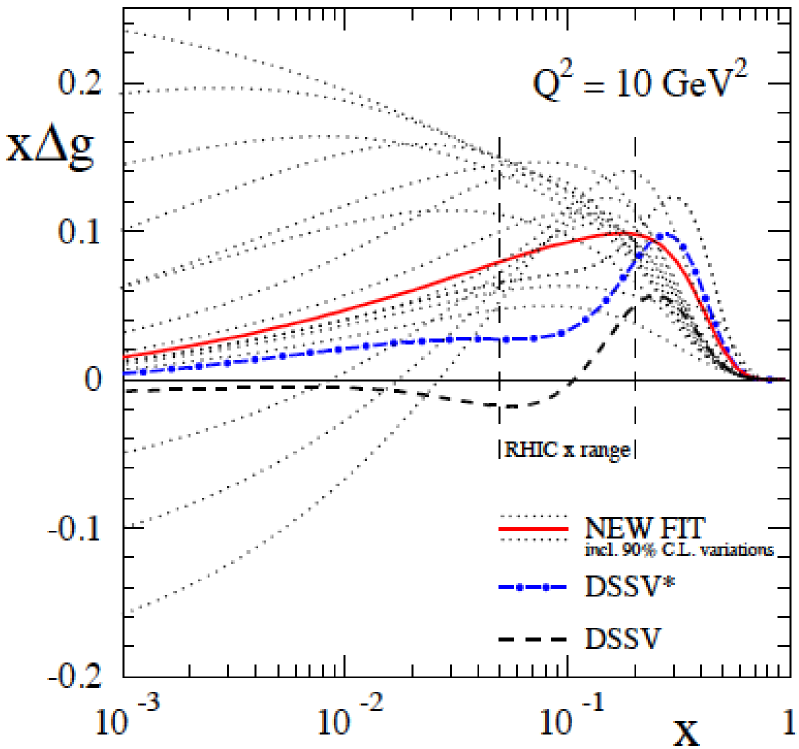
DSSV & NNPDF have released results for PDFs with RHIC 2009 data sets.
Positive gluon polarization in the measured region:

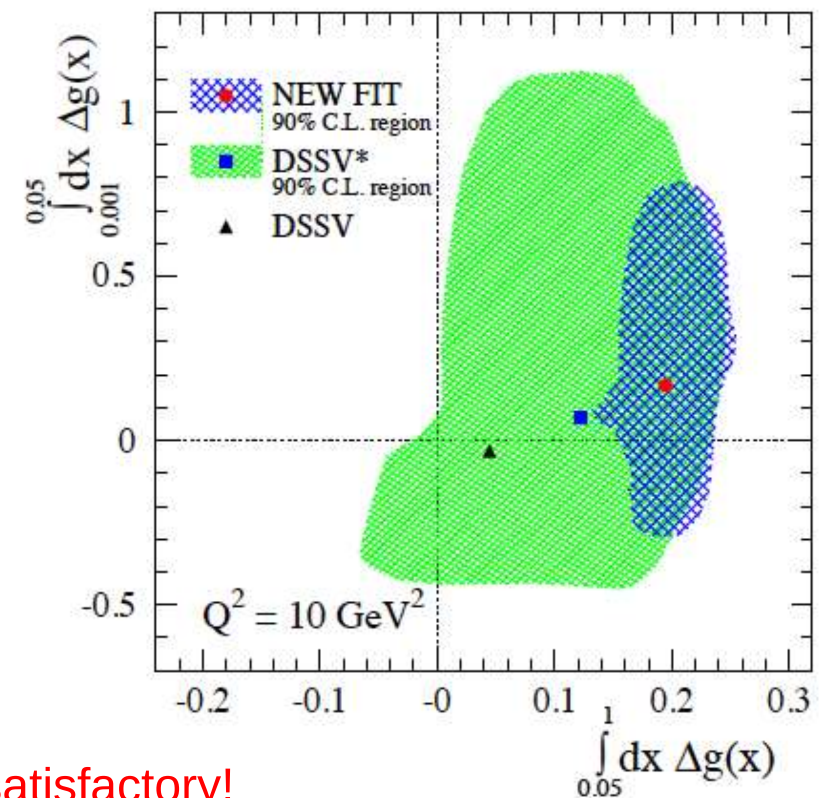
- **DSSV : 0.19 (+0.06)(-0.05) at 90% CL for 0.05 < x**
- **NNPDF : 0.23 (+0.07)(-0.07) for 0.05 < x < 0.5**

DSSV Message: Low-x is still “open”

D. deFlorian et al., arXiv:1404.4293

Wide spread at low x (x<0.05) of alternative fits consistent within 90% of C.L.





Dramatic impact on Delta-G but far from satisfactory!

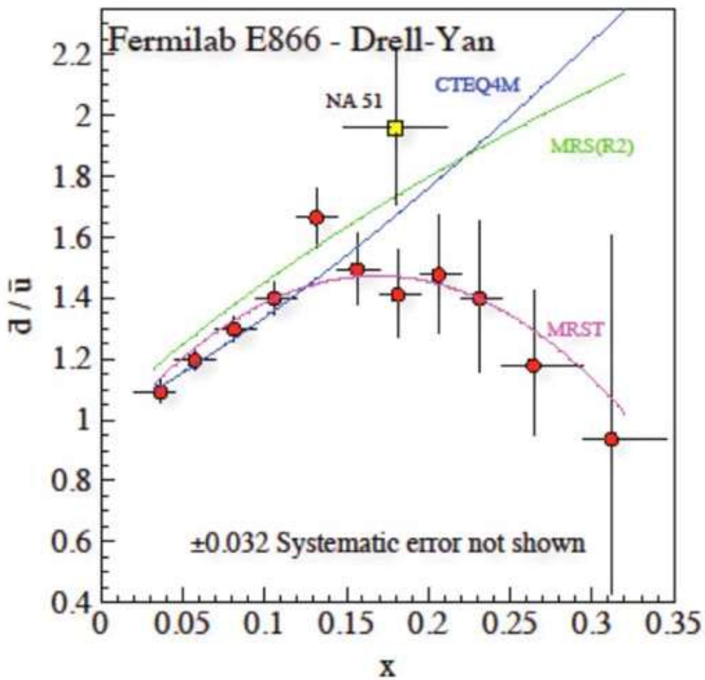
Improving ΔG but only in a limited x-region, large uncertainties in the low-x

➔ *Forward rapidity in jets and π^0 may be useful but far from “game over”*

➔ *Future **Electron Ion Collider***

Sea quarks?

$$\Delta\Sigma = \int_0^1 (\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})\,dx$$



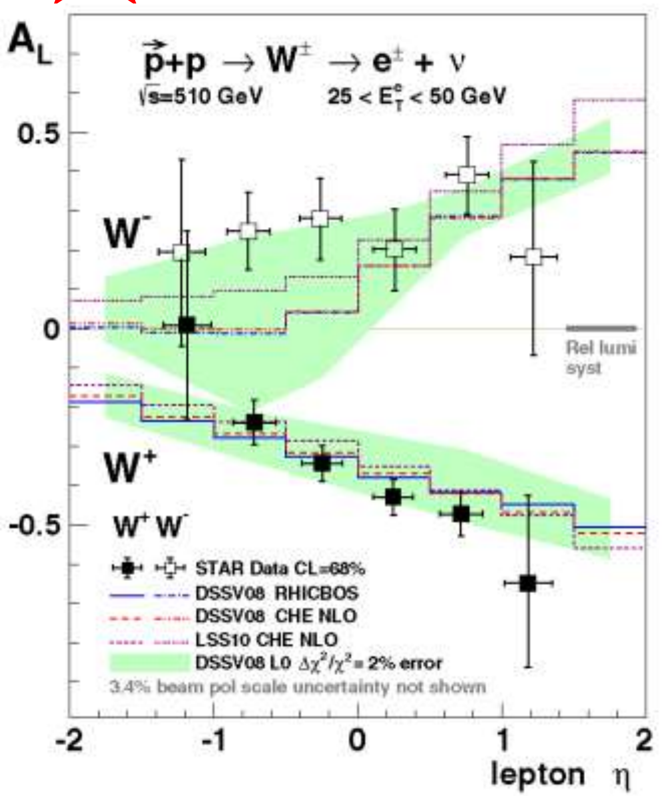
PRD **64**, 052002 (2001)

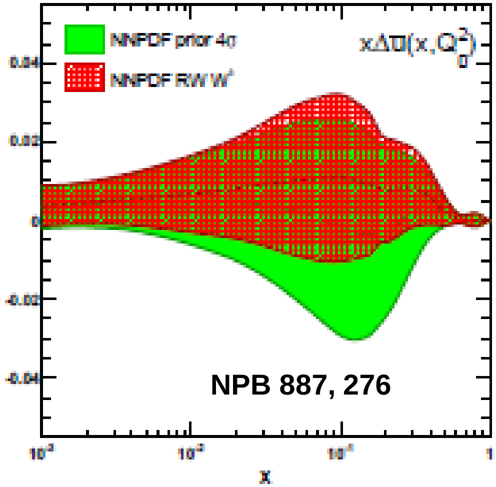
$$\bar{d} > \bar{u}$$

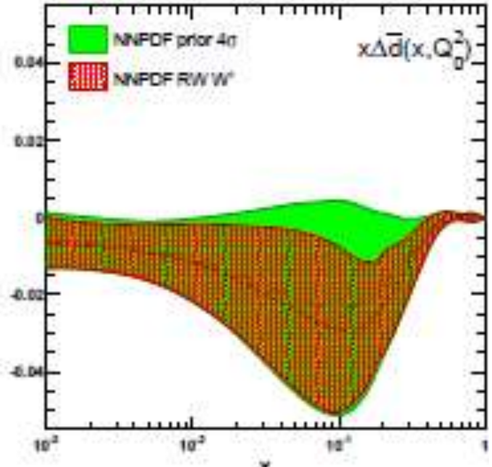
- Polarized DIS measured Δq+Δqbar; SIDIS ➔ flavor separation, but uncertainties large
- FNAL E866 found surprising distribution in unpolarized antiquarks
- **Surprises in *polarized antiquarks*?**
- **W+/- (u$\bar{d}$ or $\bar{u}$d) production at RHIC**
  - Complementary to SIDIS
  - No Fragmentation uncertainties
  - Theoretically extremely clean

RHIC preliminary influence:

STAR PRL 113, 072301







FNAL

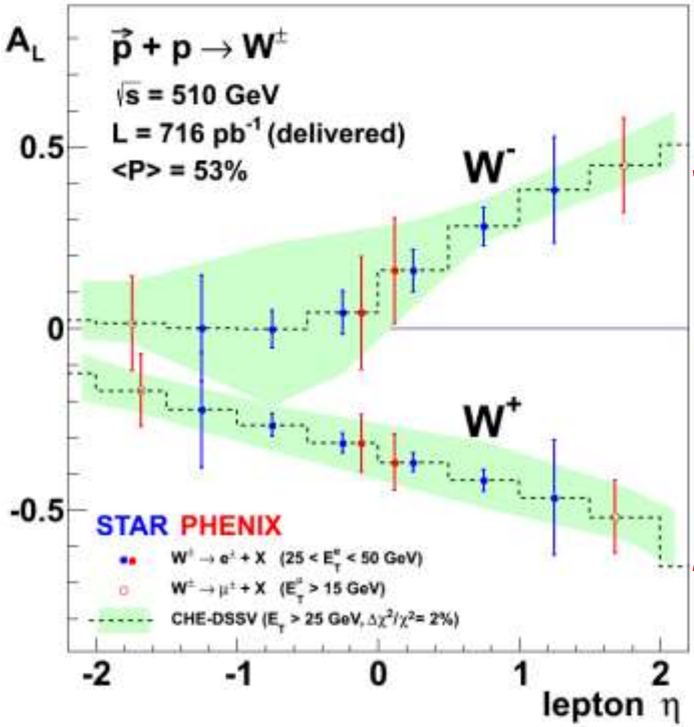
$\bar{d} > \bar{u}$

But RHIC:

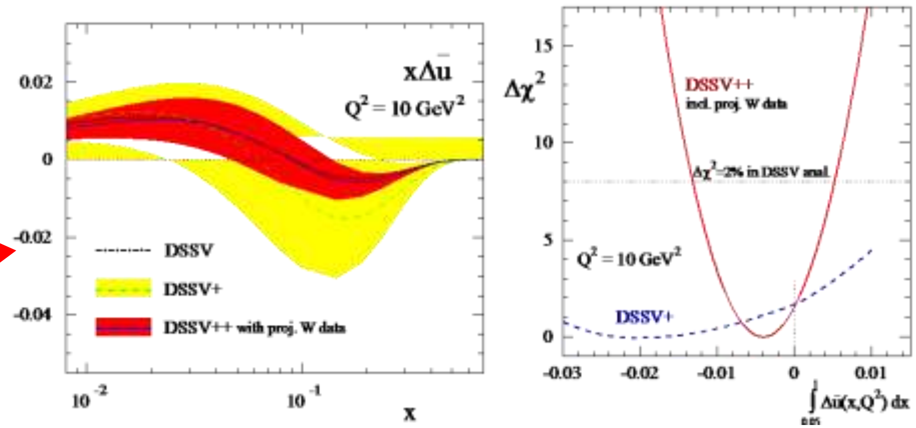
$\Delta\bar{u} > \Delta\bar{d}$

A_L Single Spin W+/- production asymmetry in p+p collisions at 500 GeV

More to come from RHIC:

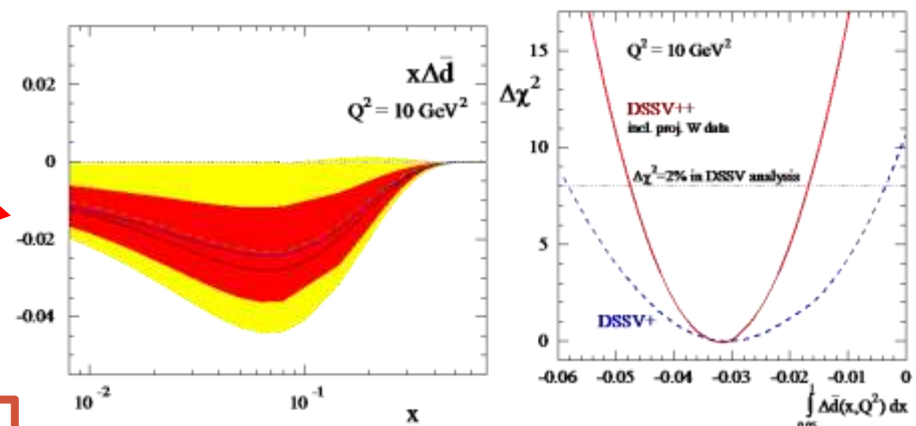


$\Delta\bar{u}$



arXiv:1304.0079

$\Delta\bar{d}$



2009-13 (already on tape) stat. uncertainty and impact studies

Room for future improvement with additional data

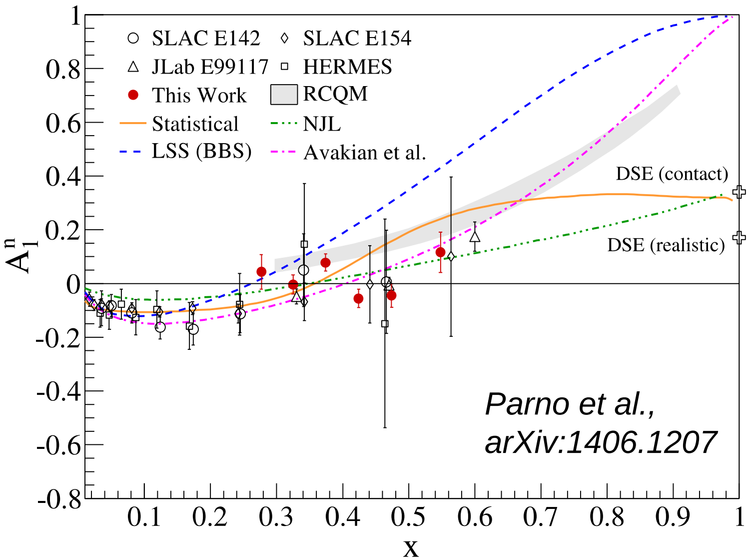
High x behavior of $g_1^{p,n}$ @ JLab12

Quark helicity in the valence region:

- Simple expectation: at high x, the nucleon properties must be imparted by the “high-x” valence quark.
- A stringent prediction of QCD!
- Experimental tests at JLab(now) or JLab12(future)

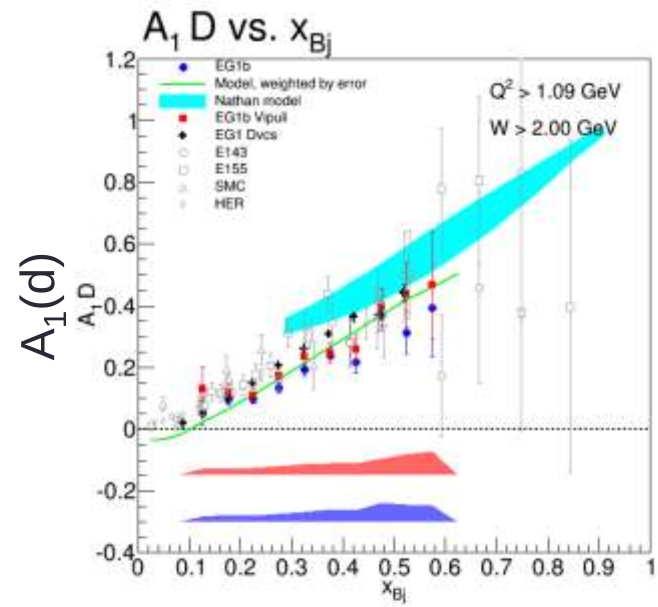
g_1 and Quark helicities at large x

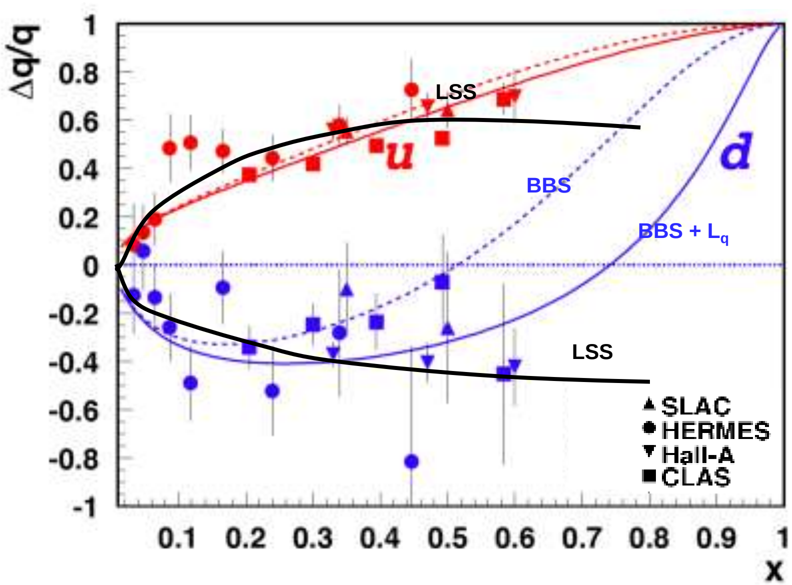
Hall A



DSE Dyson Schwinger Equ. Roberts et al. PLB 727 249 (2013)

CLAS





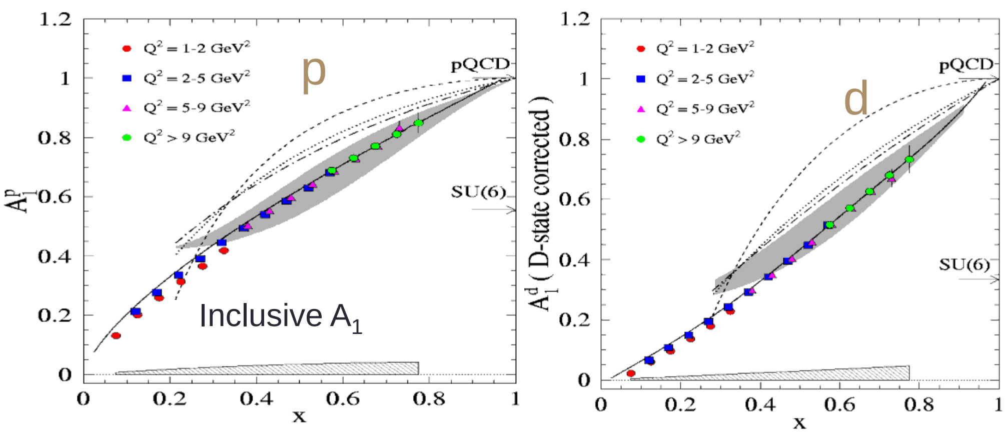
Phys.Rev. C90 (2014)

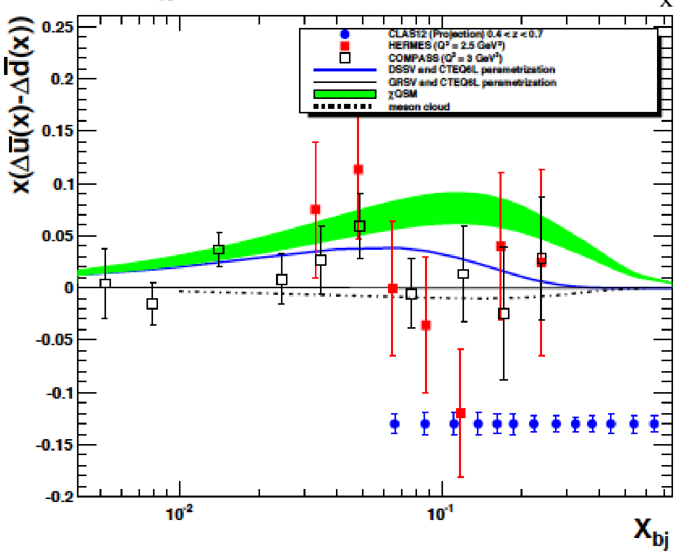
Phys.Lett. B641 (2006) 11

Near future: high x helicities

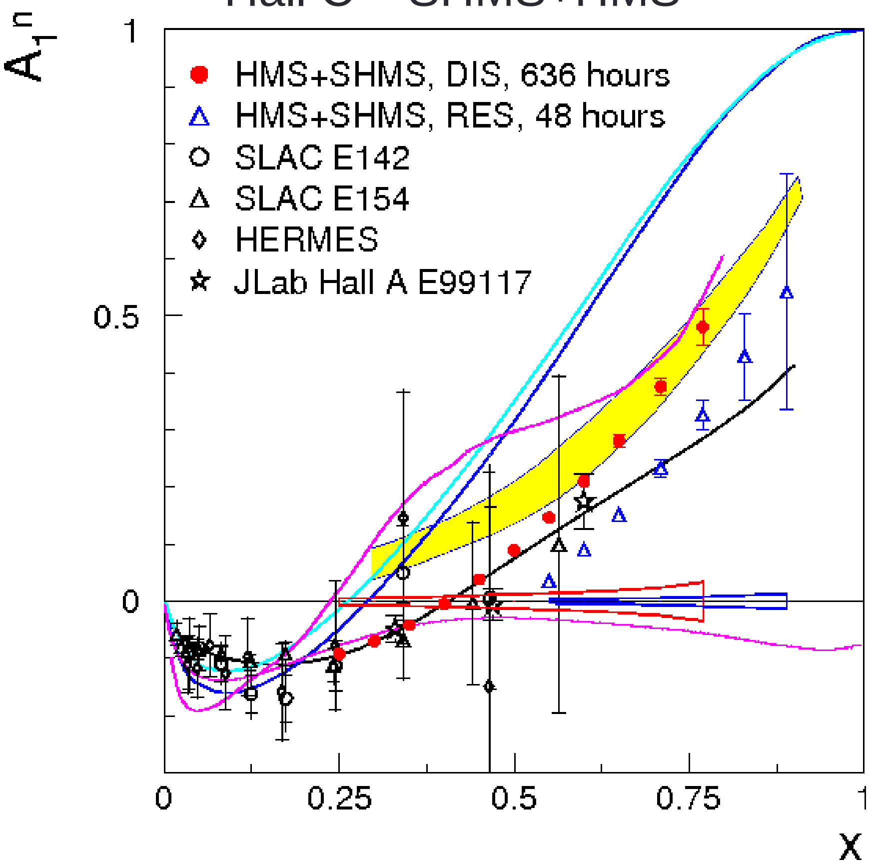
Flag-ship measurements of 12 GeV Upgrade

Hall B – CLAS12

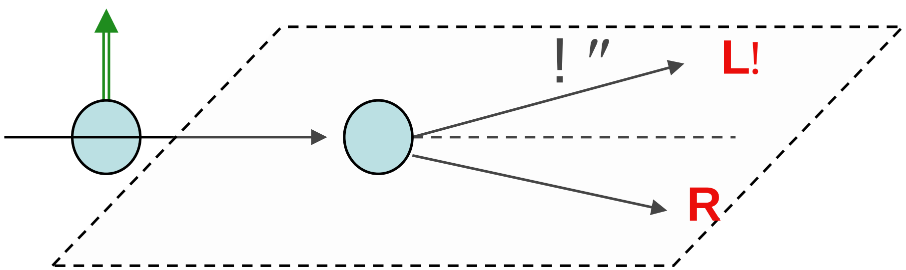




Hall C – SHMS+HMS



Transverse spin introduction



$$A_N = \frac{N_L - N_R}{N_L + N_R}$$

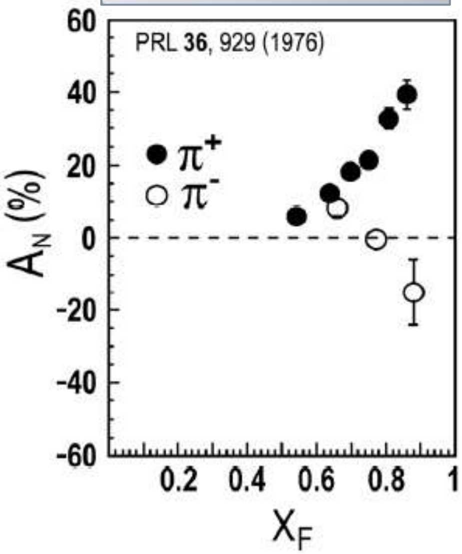
$$A_N \approx \frac{m_q \alpha_S}{p_T} \approx 0.001$$

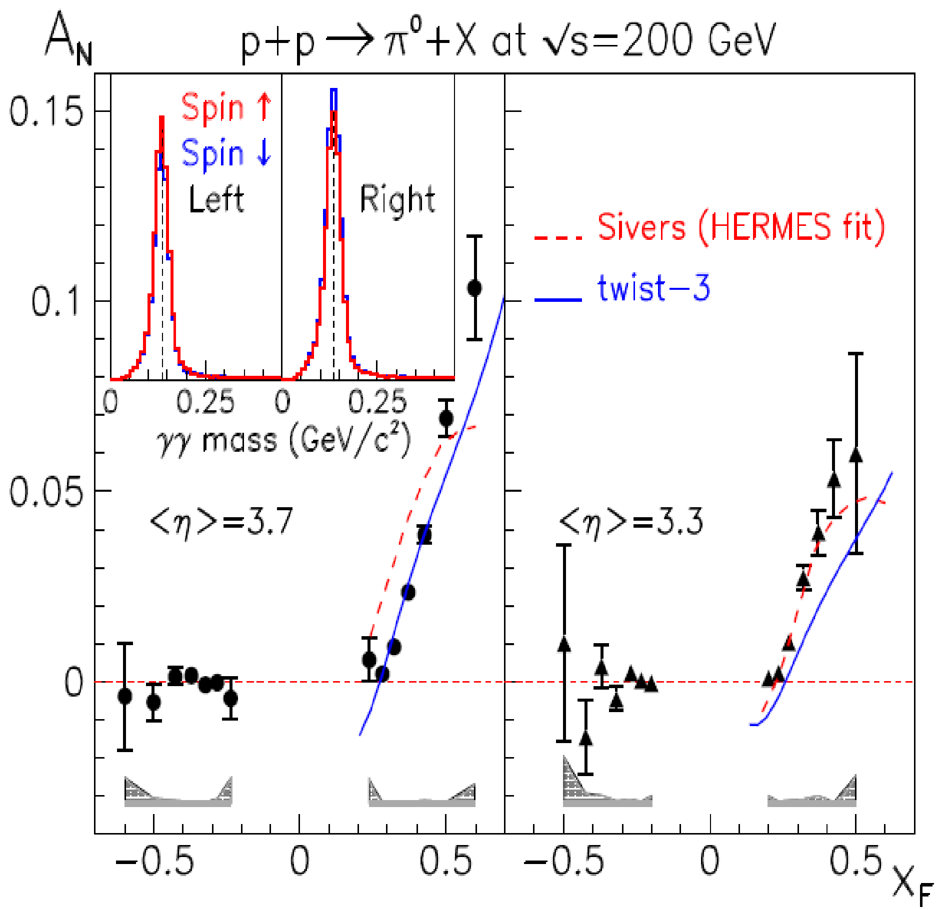
Kane, Pumplin, Repko
PRL 41 1689 (1978)

SSA in hard scattering expected to be small, but large effects observed in pion & (recently) neutron production..

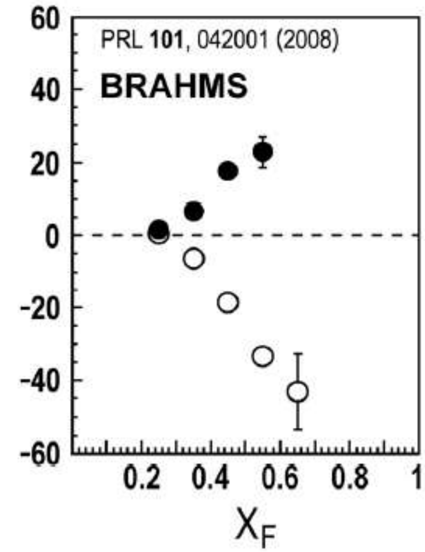
Pion asymmetries: at most CM energies!

ZGS/ANL
√s=4.9 GeV





RHIC
√s=62.4 GeV



Suspect soft QCD effects at low scales, but they seem to remain relevant to perturbative regimes as well

Transverse spin: What could be the origin?

How are quarks and gluons distributed in transverse momentum space?

Different spin and orbit correlations (obviously OAM needed for nonzero Sivers function, but so do anomalous magnetic moments)

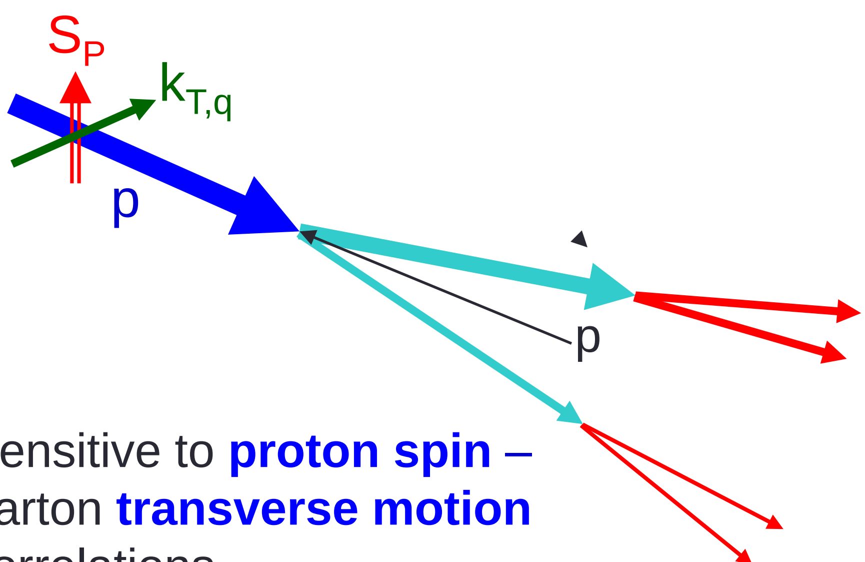
Is our understanding of TMDs via gauge links correct? → universality, sign change of Sivers Distribution? Measure Sivers asymmetry in DY/SIDIS

Transversity distributions? How different are they from normal spin structure functions g1?

All above questions need: complementary probes in experiments: p-p, e-p, pbar-p

Possible origins for A_N: near future at RHIC

Sivers mechanism:
asymmetry in jet or γ production

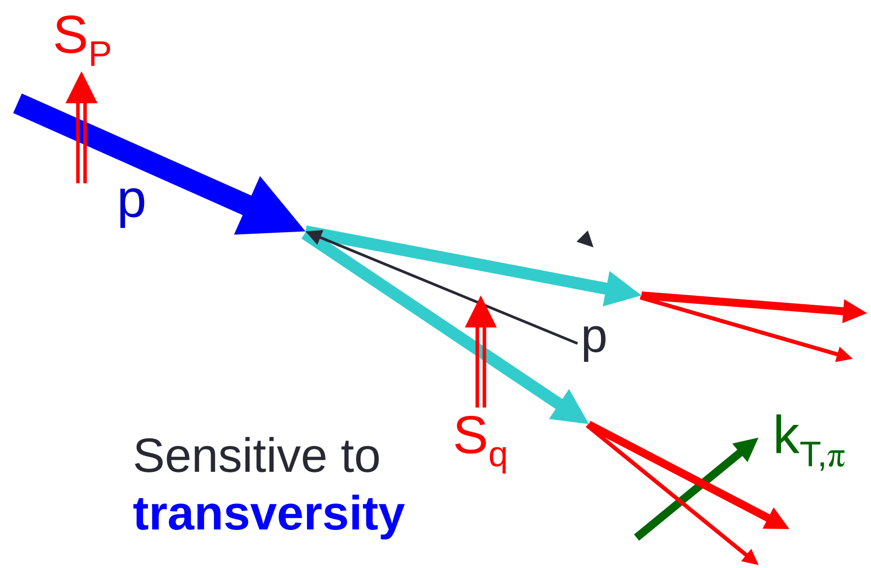


Sensitive to **proton spin** – parton **transverse motion** correlations

Signatures:
- ✓ A_N for jets or direct photons

NOT Universal
- ✓ Sign change from SIDIS to DY

Collins mechanism:
asymmetry in jet fragmentation



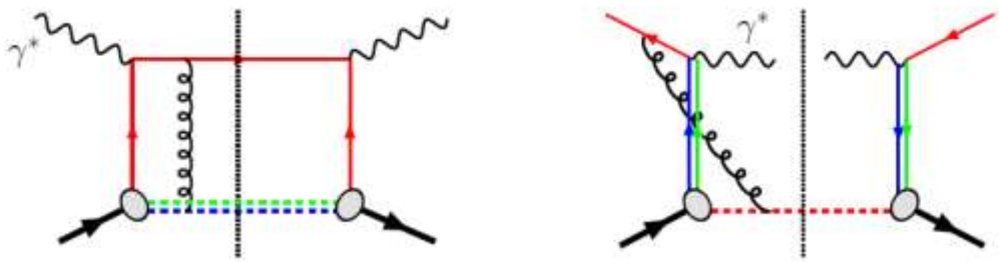
Sensitive to **transversity**

Signatures:
- ✓ Collins effect
- ✓ Interference fragmentation

Believed to be Universal

Color interactions in QCD:

- Non-universality of Sivers Function (DIS vs. DY)
- Critical test of TMD Factorization



Attractive FSI
DIS

Repulsive FSI
Drell-Yan

$\text{Sivers}_{\text{DIS}} = - \text{Sivers}_{\text{DY/W/Z0/}\gamma}$

Will explore in future 500 GeV Runs

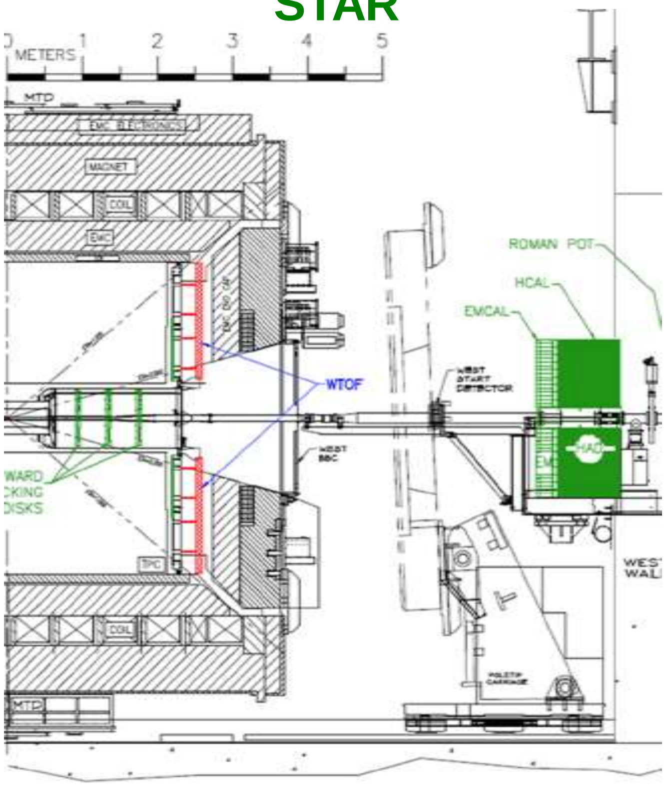
STAR also plans TMD evolution studies using W's

Both PHENIX and STAR installing upgrades for 2015 for direct photon DY measurement at forward rapidity

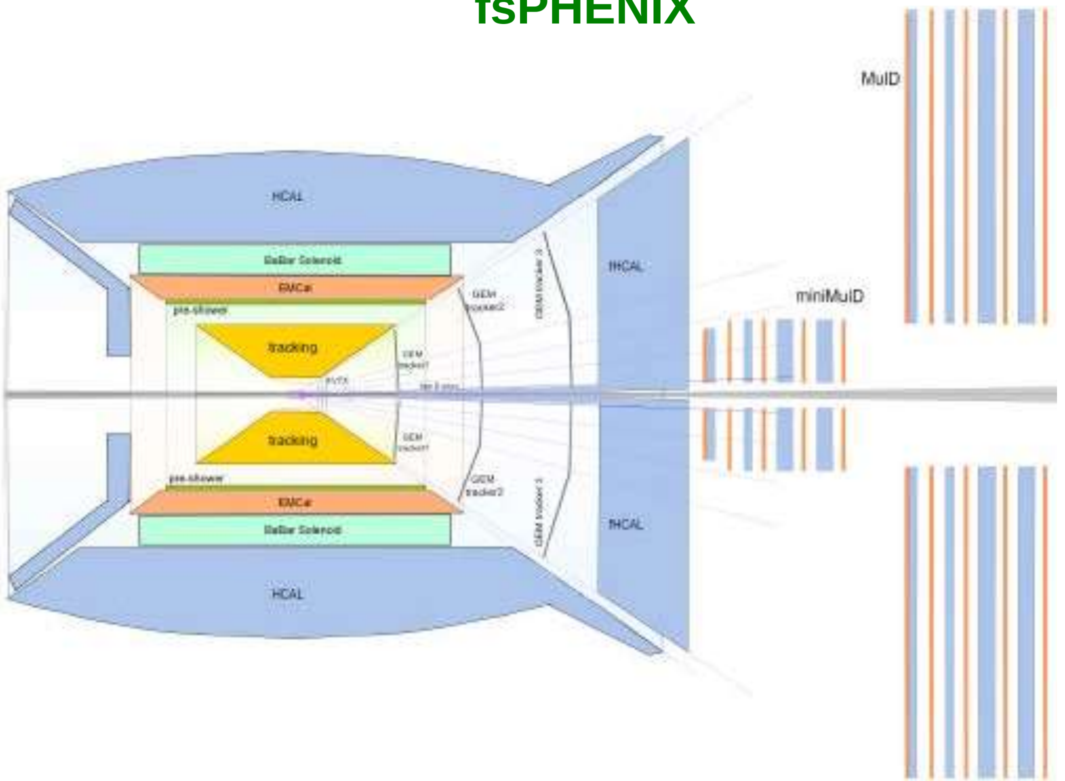
Opportunities at PANDA: Drell Yan sector for future precision studies

STAR & PHENIX Upgrades

STAR



fsPHENIX



- Forward jets & di-jets for low-x gluons
- Transverse spin:
  - ✧ Precision TMDs through jets at forward rapidity
  - ✧ Precision A_N(DY) for Sivers measurements

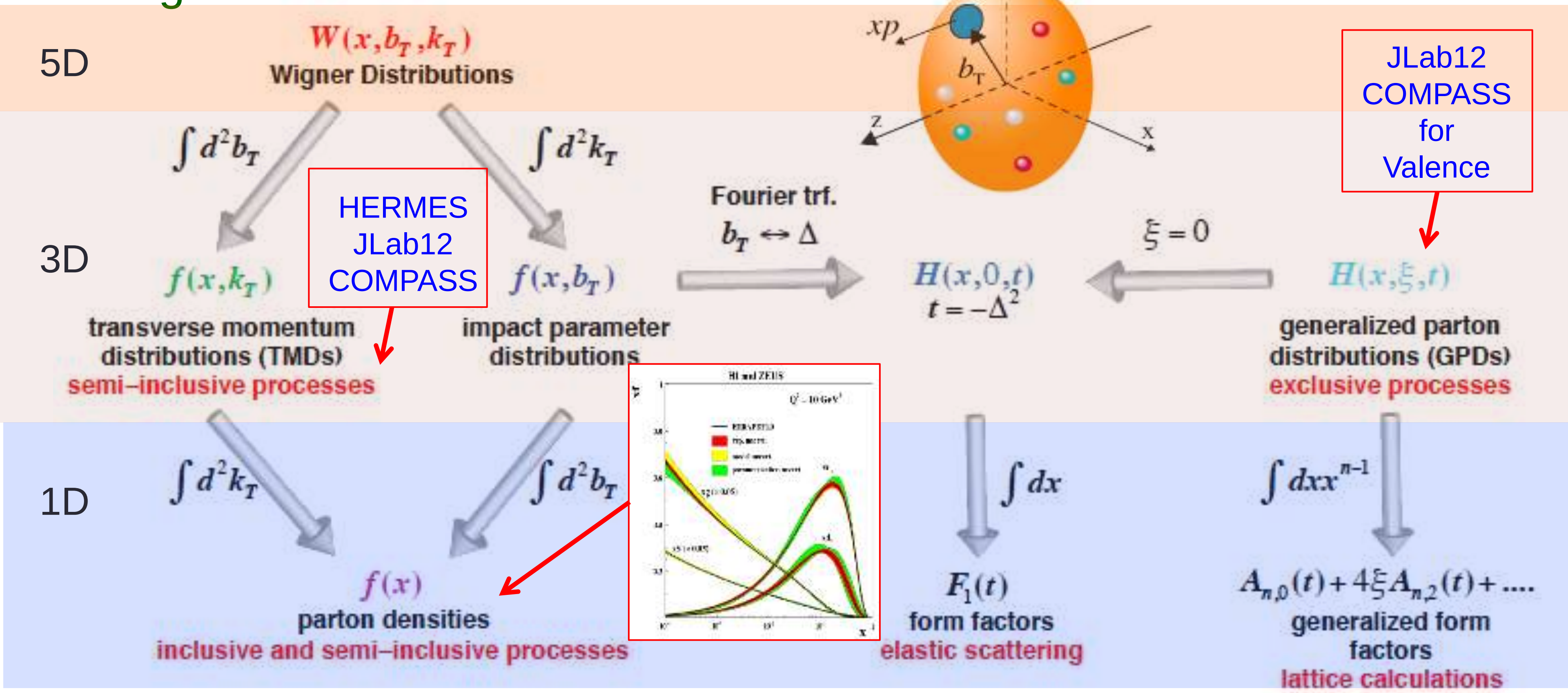
But a more complete picture of the nucleon structure including its spin has emerged over ….

Aided by theoretical developments & data from fixed target polarized DIS at COMPASS & JLab and p-p at RHIC experiments

We aspire to complete this unified picture of the nucleon structure and the parton dynamics

Unified view of the Nucleon Structure

❑ Wigner distributions:

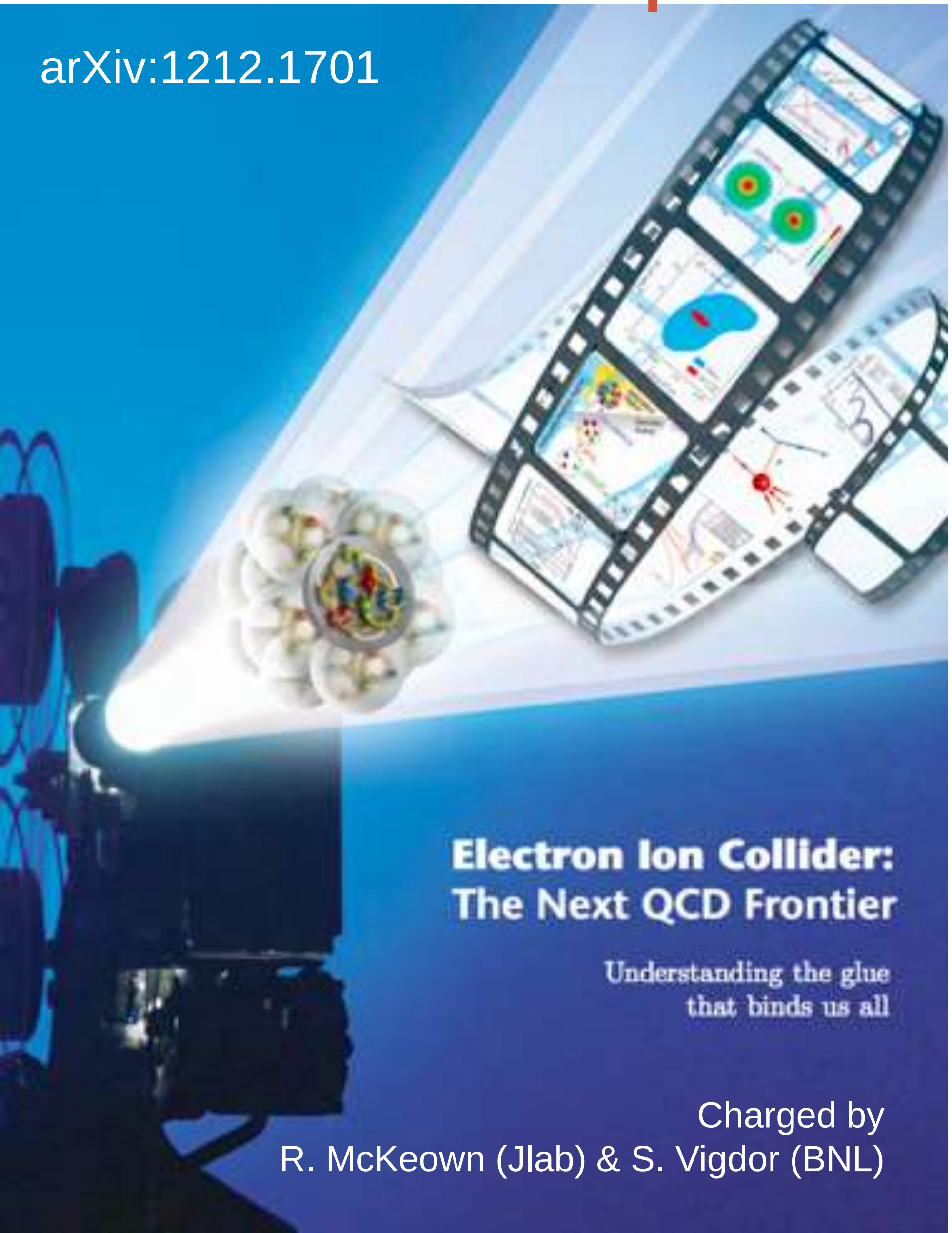


❑ EIC – 3D imaging of partons: Quarks (fixed target) , Gluons (collider)

✧ TMDs – confined motion in a nucleon (semi-inclusive DIS)

✧ GPDs – Spatial imaging of quarks and gluons (exclusive DIS)

White Paper: EIC Science Case



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Nucleon spin structure (inclusive e+N):
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GPD's and exclusive reactions:
M. Diehl (DESY) and F. Sabatie (Saclay)

TMD's and hadronization and SIDIS:
H. Gao (Duke) and F. Yuan (LBNL)

Parton Propagation in Nuclear Medium:
W. Brooks (TSFM) and J. Qiu(BNL)

Electroweak physics:
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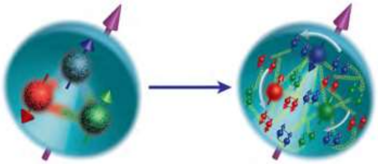
Senior Advisors:
A. Mueller (Columbia) and R. Holt (ANL)

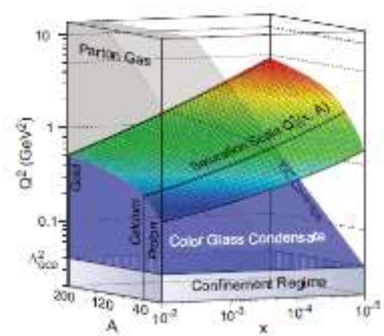
Successful thanks to many other co-authors and contributions

Science of EIC

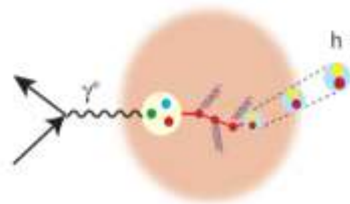


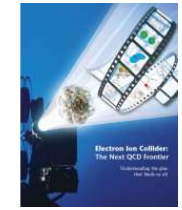
- **How are sea quarks/gluons and their spins distributed in space and momentum inside the nucleon?**
  - How are these quark and gluon distributions correlated with the over all nucleon properties, such as spin direction?
  - What is the role of the motion of sea quarks and gluons in building the nucleon spin?

- **Where does the saturation of gluon density set in?**
  - Is there a simple boundary that separates the region from the more dilute quark gluon matter? If so how do the distributions of quarks and gluons change as one crosses the boundary?
  - Does saturation produce matter of universal propertie in the nucleon and all nuclei viewed at nearly the speed of light?



Science of EIC…

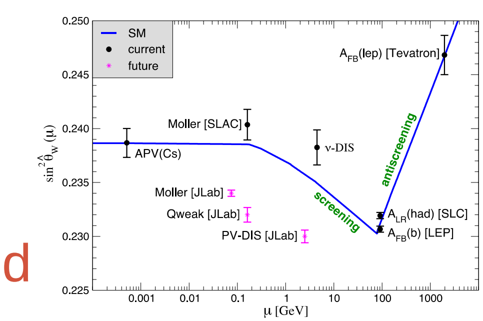




- **How does the nuclear environment affect the distribution of quarks and gluons and their interaction in nuclei?**
  - How does the transverse spatial distribution of gluons compare to that in the nucleon?
  - How does matter respond to fast moving color charge passing through it? Is this response different for light and heavy quarks?

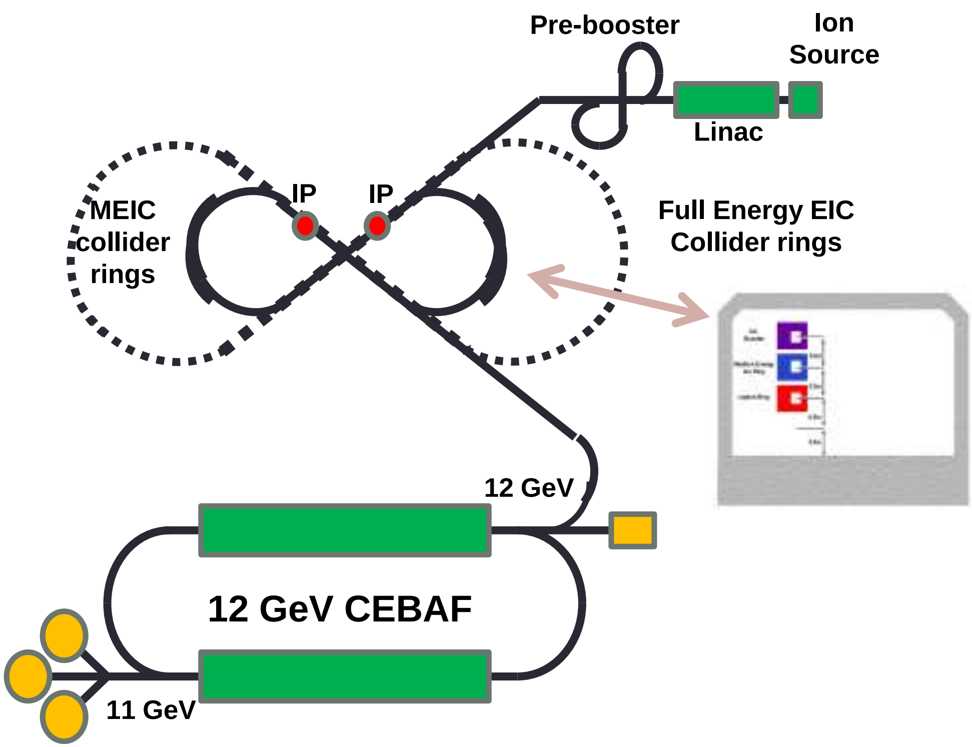
- **Electro-Weak Physics and possible searches for physics beyond the SM:**
  - Precision measurement of evolution of the $\mathrm{Sin}^2\Theta_W$
  - Limits on charged lepton flavor violation ($e \rightarrow \tau$)(?)

Will need the highest energy and luminosity of the collid

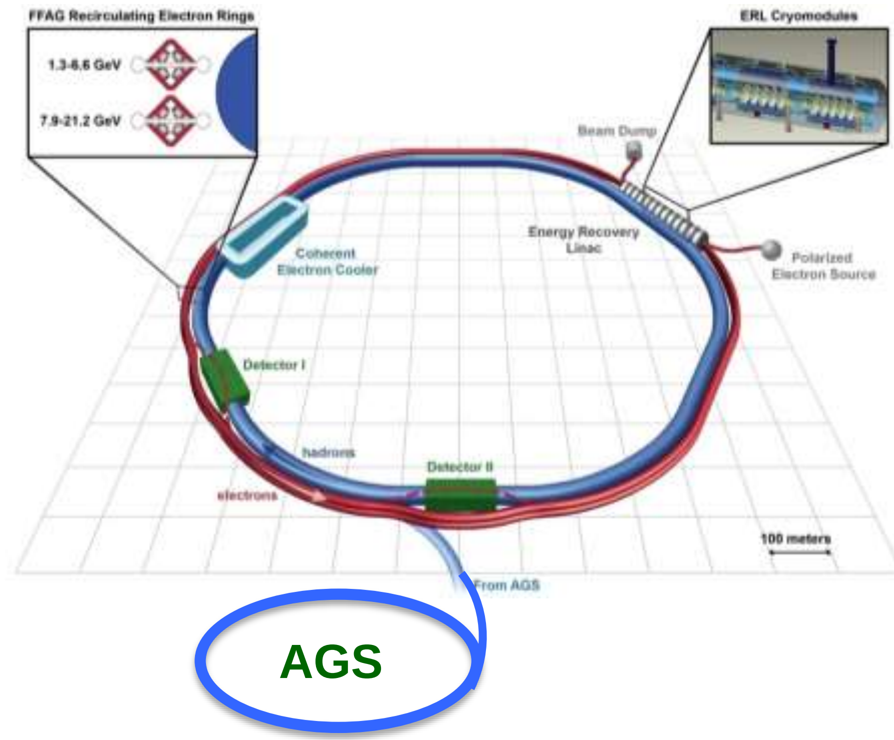


U.S.-based EICs – the Machines

MEIC (JLab)

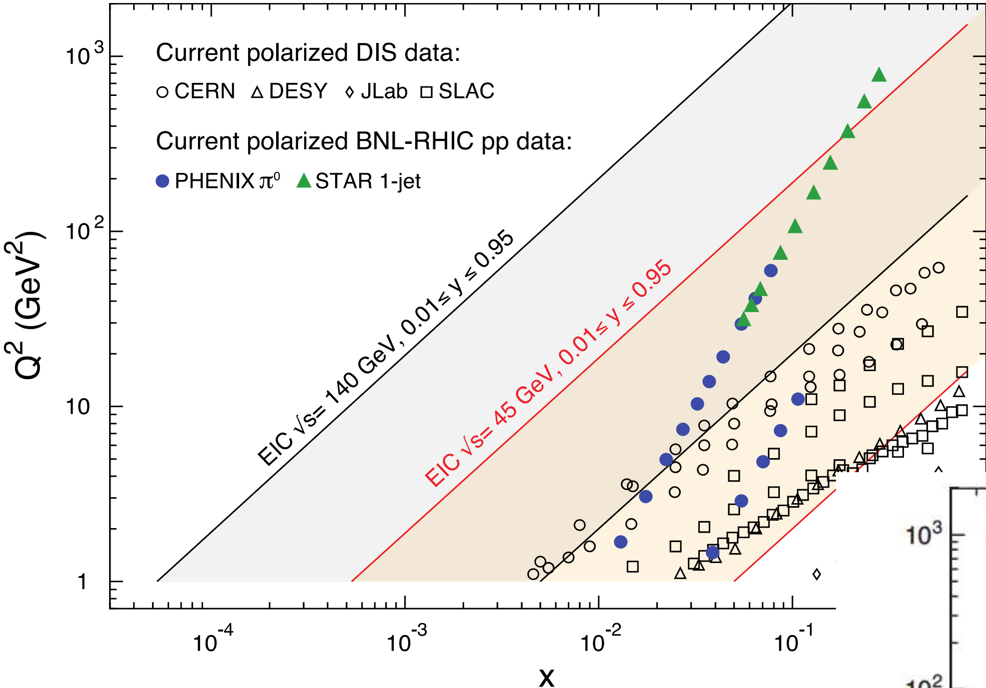


eRHIC (BNL)



- ✧ First polarized electron-proton/light ions collider in the world
- ✧ First electron-nucleus (various species) collider in the world
- ✧ Both cases make use of existing facilities

US EIC: Kinematic reach & properties

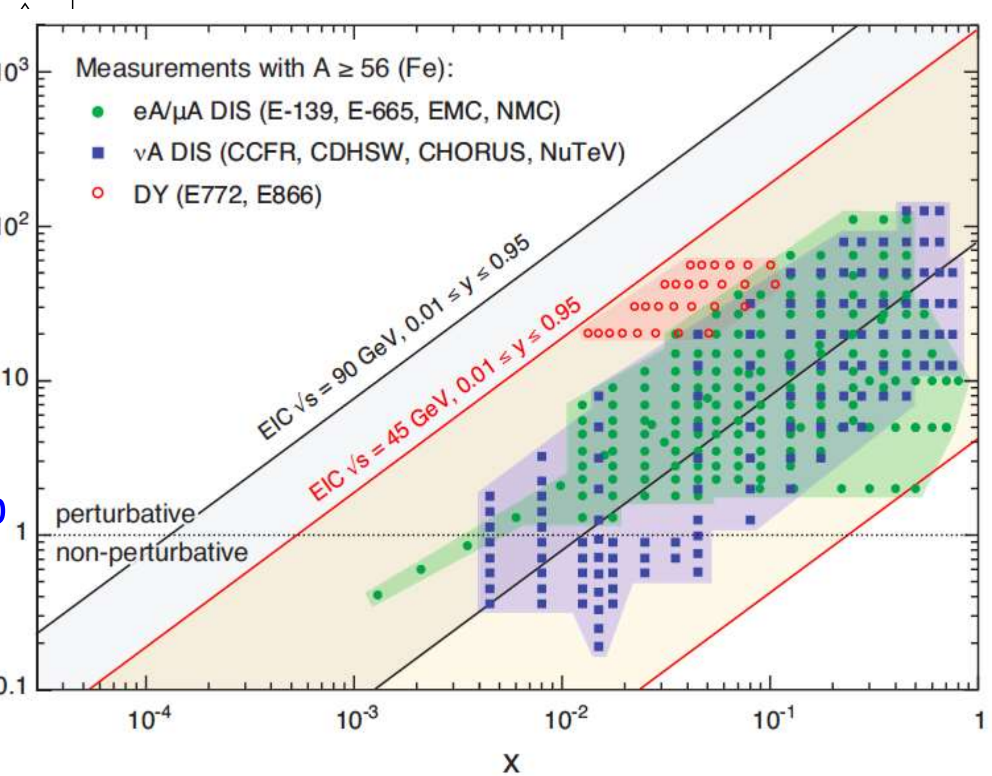


For e-N collisions at the EIC:

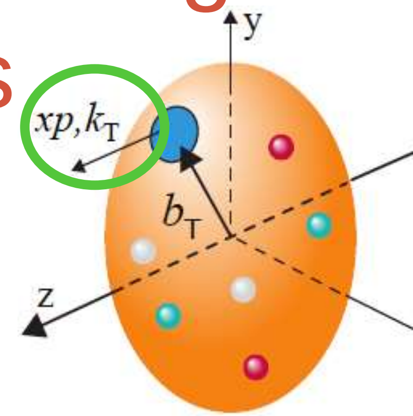
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ **e beam 5-20 GeV**
- ✓ Luminosity L_{ep} ~ **$10^{33\text{-}34}$** $cm^{-2}sec^{-1}$
  100-1000 times HERA
- ✓ Variable center of mass energy

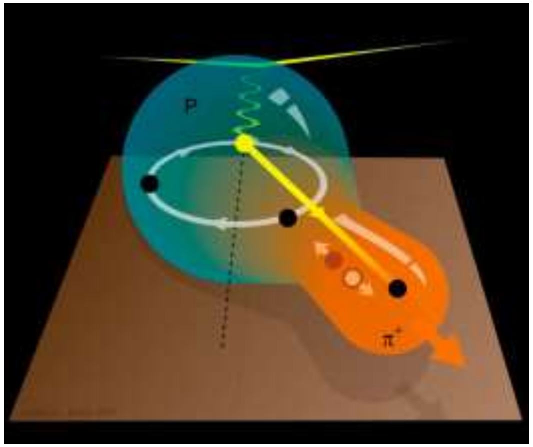
For e-A collisions at the EIC:

- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy



Semi-Inclusive DIS ➔ Best for measuring Transverse Momentum Distributions





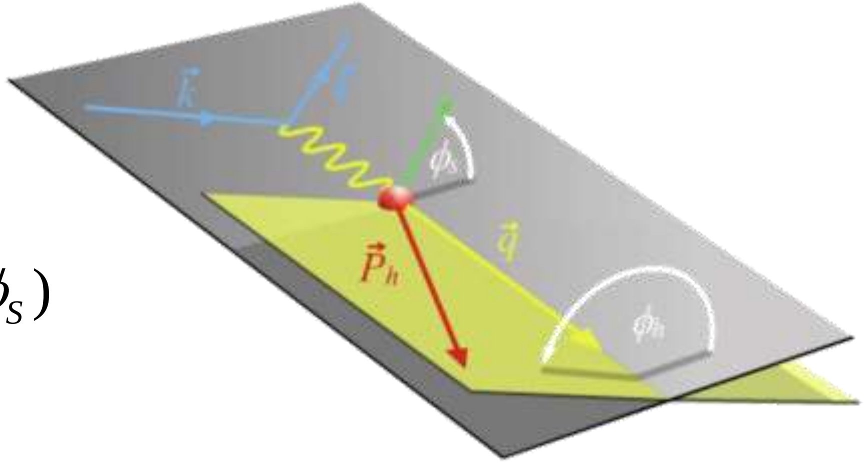
- Naturally, two scales:
  - ✧ high Q – localized probe
    To "see" quarks and gluons
  - ✧ Low p_T – sensitive to confining scale
    To "see" their confined motion
  - ✧ *Theory – QCD TMD factorization*

- Naturally, two planes:

$$A_{UT}(\varphi_h^l,\varphi_S^l)=\frac{1}{P}\frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}}$$

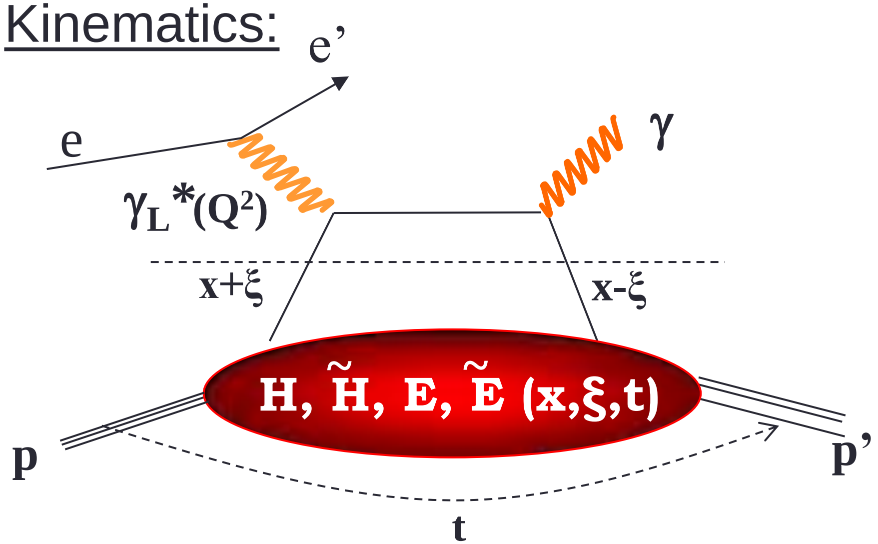
$$=A_{UT}^{Collins}\sin(\phi_h+\phi_S)+A_{UT}^{Sivers}\sin(\phi_h-\phi_S)$$

$$+A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S)$$



Exclusive DIS

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

Measure of resolution power

$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

$$t = (p-p')^2, \xi = \frac{x_B}{2-x_B}$$

Exclusive events:
e + **(p/A)** → e'+ **(p'/A')**+ γ / J/ψ / ρ / ϕ
detect **all** event products in the detector

Allow access to the spatial distribution of partons in the nucleon
Fourier transform of spatial distributions → GPDs
GPDs → Orbital Angular Momenta!

$$\frac{1}{2} = J_Q + J_G$$

$$J_Q = \frac{1}{2}\Delta\Sigma + L_Q$$

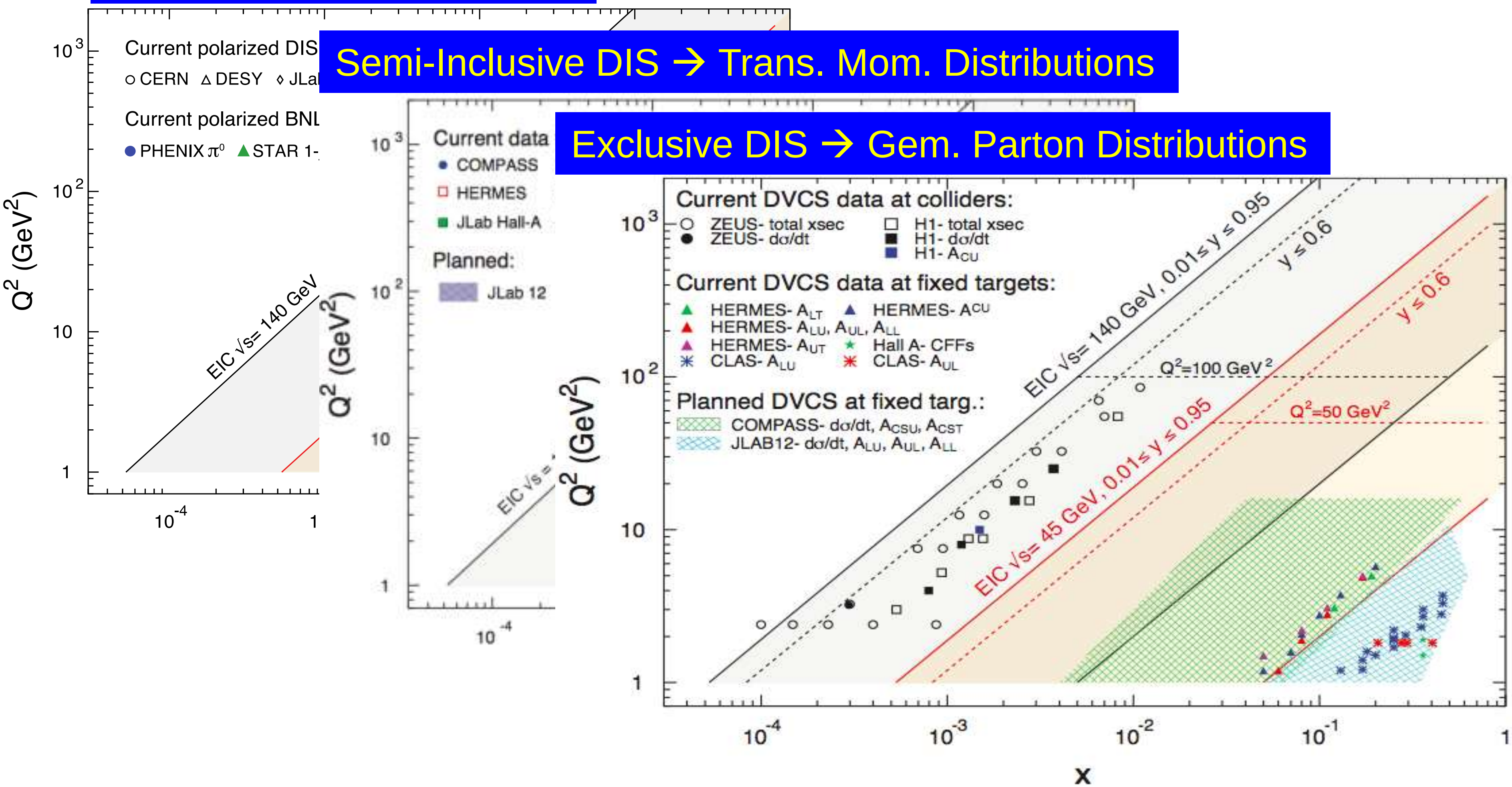
$$J_G = \Delta G + L_G$$

Enormous Kinematic Reach of EIC (e-p)

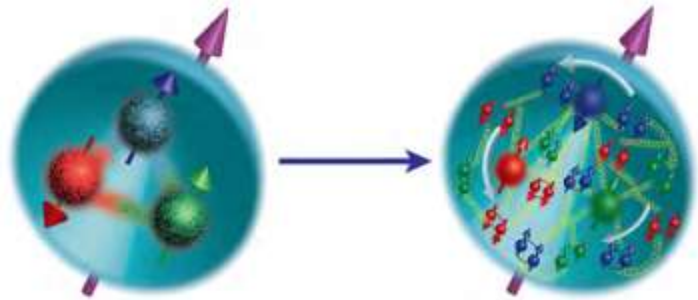
Inclusive DIS → $F_{2/L}$, g_1, ….

Semi-Inclusive DIS → Trans. Mom. Distributions

Exclusive DIS → Gem. Parton Distributions

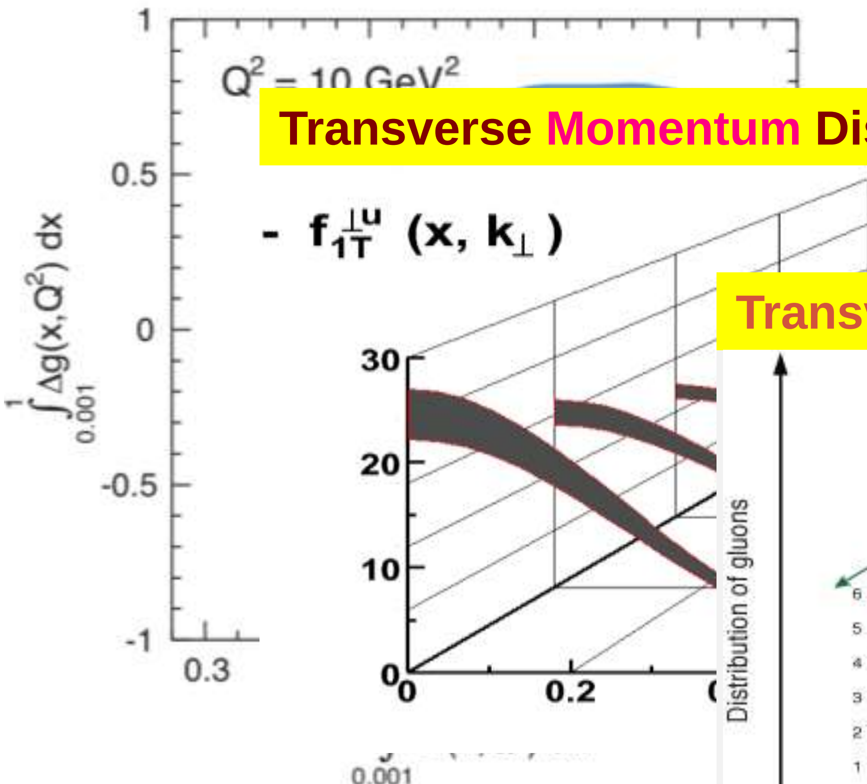


Most comprehensive picture of the proton structure yet!



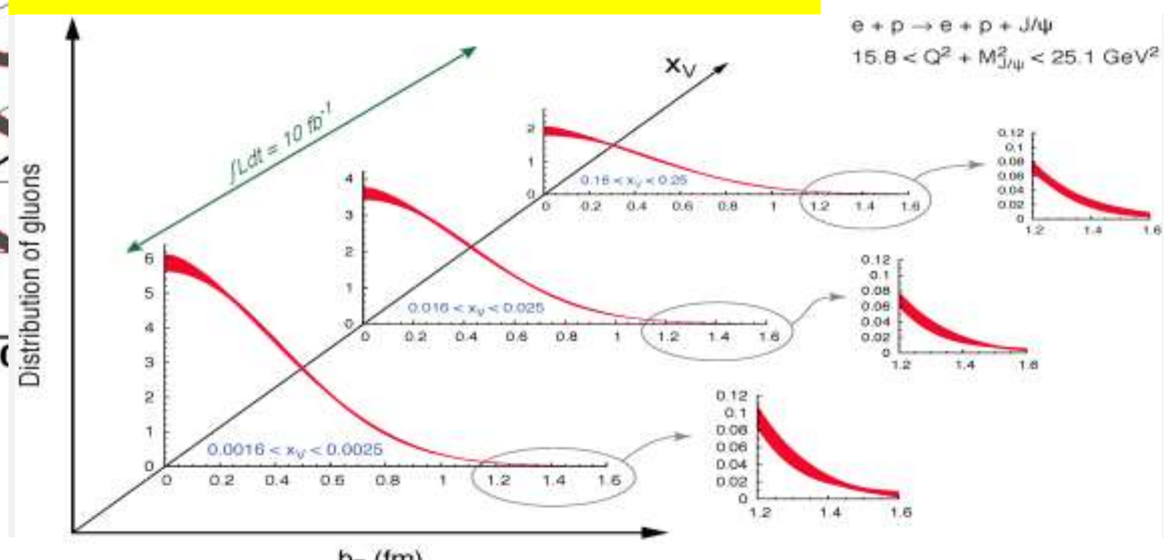
Helicity Distributions: ΔG and $\Delta\Sigma$

Transverse Momentum Distributions



$Q^2 = 2.4\ GeV^2$

Transverse Position Distributions



Intuitively: position + momentum ➔ Orbital motion

An immediate check/impact:

❑ **Quark GPDs and its orbital contribution to proton's spin:**

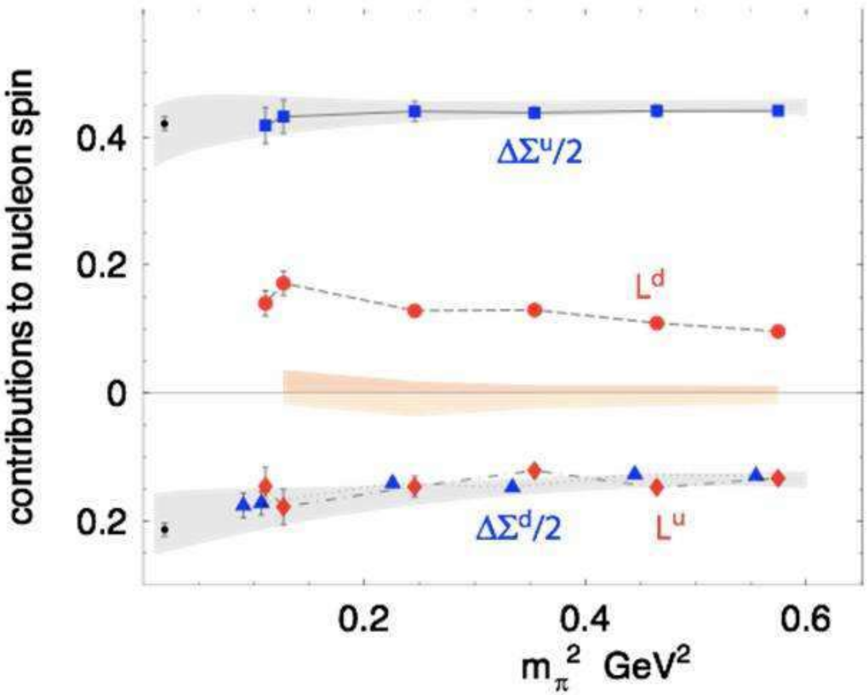
$$J_q = \frac{1}{2} \lim_{t\to 0} \int dx\, x \left[H_q(x,\xi,t) + E_q(x,\xi,t)\right] = \frac{1}{2}\Delta q + L_q$$

The first meaningful constraint on quark orbital contribution to proton spin by combining the sea from the EIC and valence region from JLab 12

This could be checked by Lattice QCD

$L_u + L_d \sim 0$?

There are also more recent ideas Of calculating parton distribution functions on Lattice:
X. Ji et al. arXiv 1310.4263; 1310.7471; 1402.1462
& Y.-Q. Ma, J.-W. Qiu 1404.6860



EIC in the US DOE context:

❑ NSAC Long-Range Plan (2007):

"An **Electron-Ion Collider (EIC)** with **polarized** beam has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**."

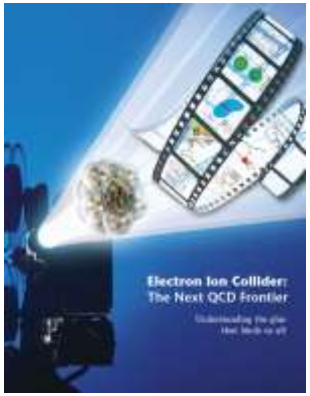
❑ NSAC Facilities Subcommittee (2013):

The Subcommittee ranks an EIC as **Absolutely Central** in its ability to contribute to world-leading science in the next decade."

❑ NSAC Long-Range Planning (2014/15):

Strong Endorsement for the EIC at the Temple U. QCD Town Meeting; September 13-15, 2014:

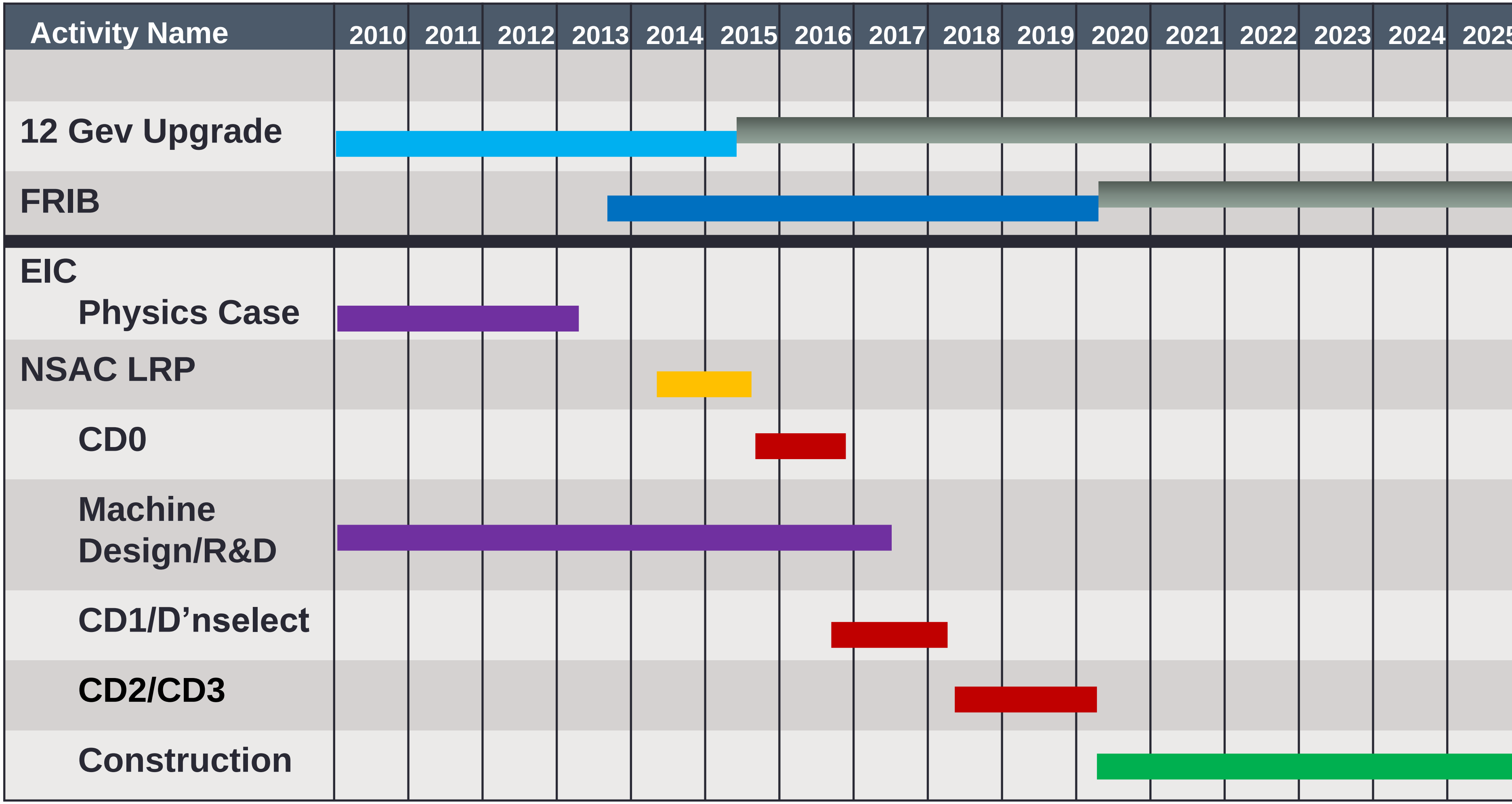
"A high luminosity, high-energy polarized Electron Ion Collider (EIC) is the U.S. NP QCD community's highest priority for future new construction."



Important "first step".
Be cautiously optimistic!

EIC @ Realization Possible Time Line

Modified by AD Based on H. Montgomery, JLab Director



Time line not too different that BNL's plan

Emergent picture of the nucleon:

RHIC has definitively shown that in x > 0.05, the GLUON's spin contribution to nucleon is small. Future facility should aim to make precise measurements at lower x.

RHIC seems to shown that quark anti-quark polarized PDFs are broadly consistent with expectations from fixed target SIDIS

Transverse spin physics at RHIC → the laboratory to test our understanding of QCD: Input data from e-p, e-e and theory → see if prediction for p-p hold! Jury is out on this, as it is an on-going effort with current and future forward physics/detector upgrade plans.

High x behavior of spin structure functions: JLab and JLab12

Summary & outlook:

Understanding proton spin as an emergent and collective phenomena based on quark/gluon helicities and interactions is crucially important to our understanding of QCD:

- Theory + Data from experiments at SLAC, CERN, DESY, RHIC and future (EIC & FAIR) essential….

Nucleon spin = Helicities + partonic transverse momentum and spatial distributions ➔ after years of disconnected efforts in measuring individual components $\Delta\Sigma$, ΔG, form factors, TMDs, GPDs, now a **unified formalism** has evolved

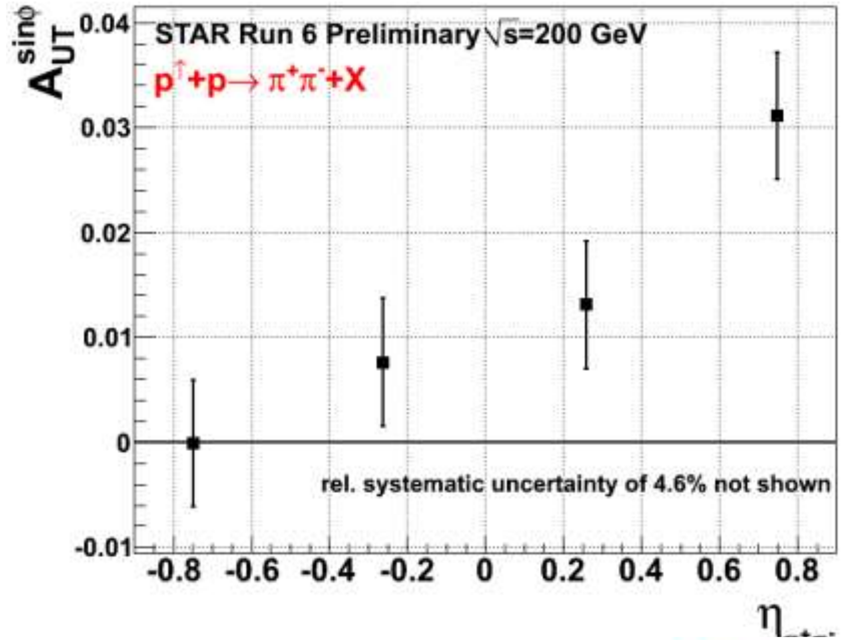
While fixed target polarized experiments along with theoretical advances have done a tremendous start**: the future Electron Ion Collider** will realize the dreams to seeing the proton as a 3D object ➔ **enhancing our understanding of emergent phenomena of QCD**

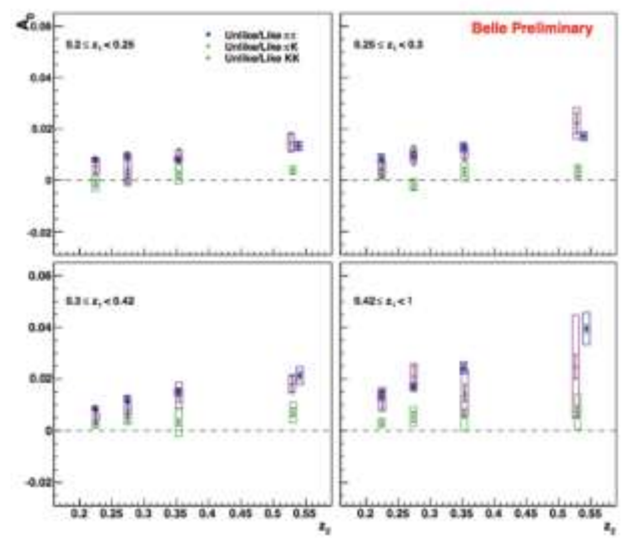
- Discussions on EIC realization now underway in the US
- Join now and make an impact: Invitation!

Thank You

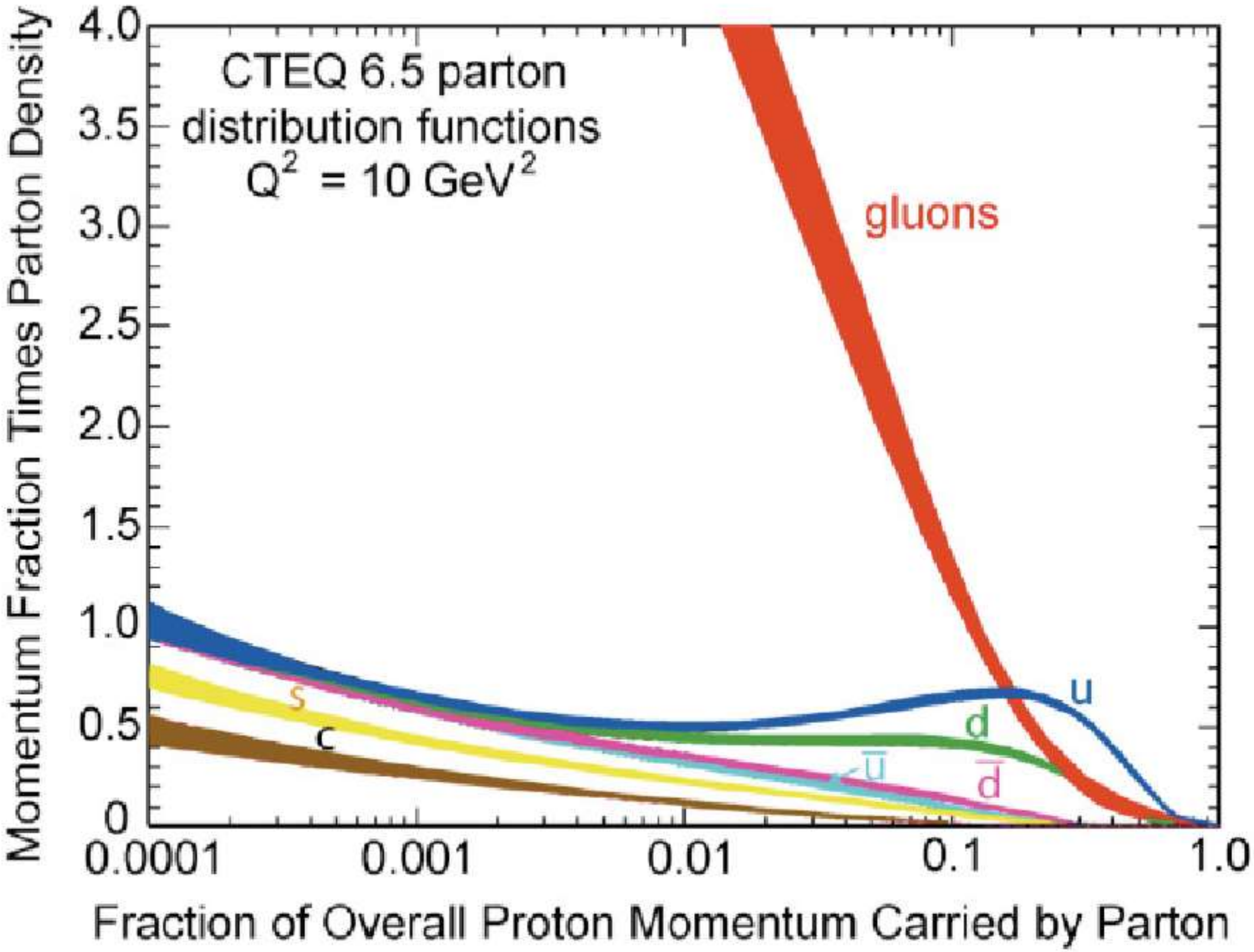
Transversity

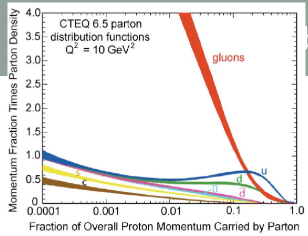
- Collins and dihadron SIDIS (HERMES,COMPASS, HallA) and Collins FF (Belle, BABAR) results very consistent
- “global” fits to pion Collins (Torino) and di-hadron (Pavia) with similar transversities
- Still need to be included in fits:
  - First Collins and di-hadron results from RHIC.
  - Kaon SIDIS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





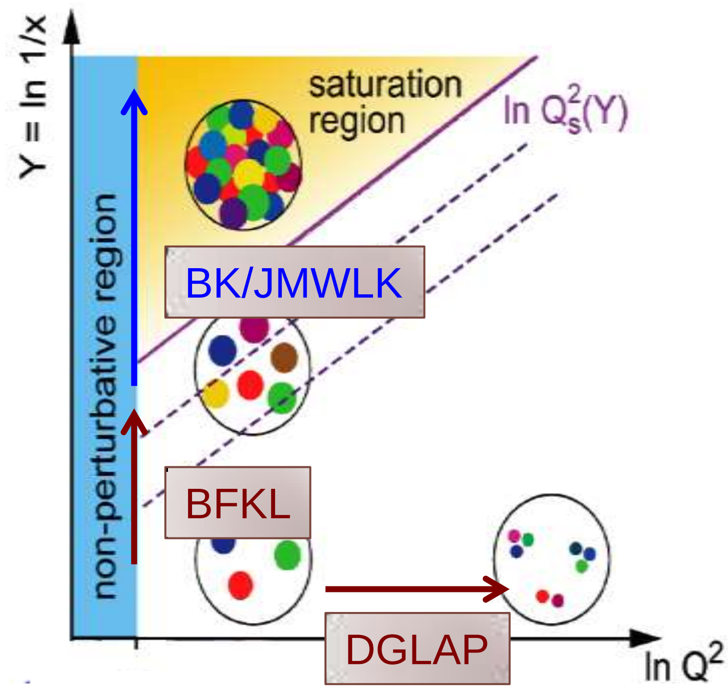
Gluon distribution from HERA!





Physics at Low x?

See Ann. Rev. Nucl Part (60) 2010 F. Gelis et al., , arXiv:1002.0333)

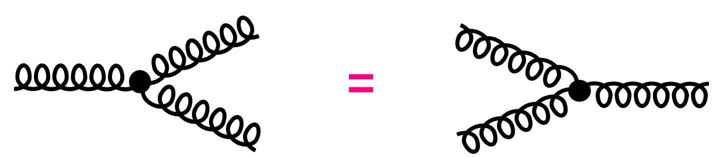


Method of including **non-linear** effects (McLerran, Venugopalan)

- Small coupling, high gluon densities
- BK/JMWLK equations lead to a Saturation Scale $Q_S(Y)$

Linear QCD
BFKL: gluon emission

Nonlinear QCD
BK/JMWLK gluon recombination



At Q_S

Strongly correlated gluonic system? Universal? Properties?

Need a higher energy e-p collider than HERA! ➔LHeC

Or ➔ Nuclei: naturally enhance the densities of partonic matter

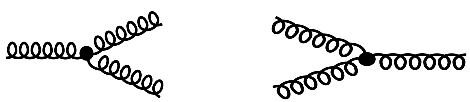
Why not use Nuclear DIS at high energy?

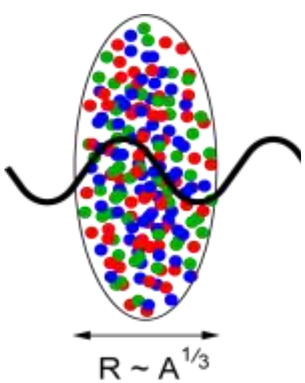
Exploring a new phase of matter:

Probe the ***NUCLEI*** with the:
Electron Ion Collider (EIC)

Probe high gluonic density matter, find what "Q_s" is!

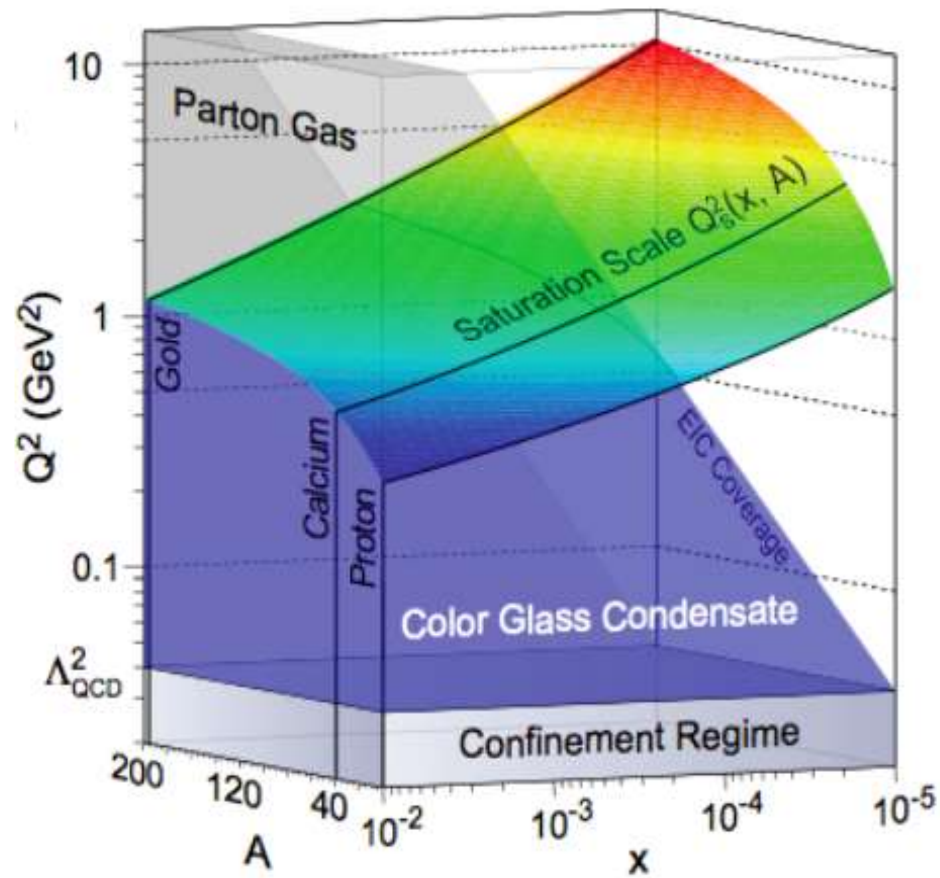
Balance between





Kowalski, Teany
PRD 68:114005

$$(Q_s^A)^2 \approx c Q_0^2 \left(\frac{A}{x}\right)^{1/3}$$



$L \sim (2m_N x)^{-1} > 2 R_A \sim A^{1/3}$

Enhancement of Q_S with A, not energy

Probing Gluon Saturation….

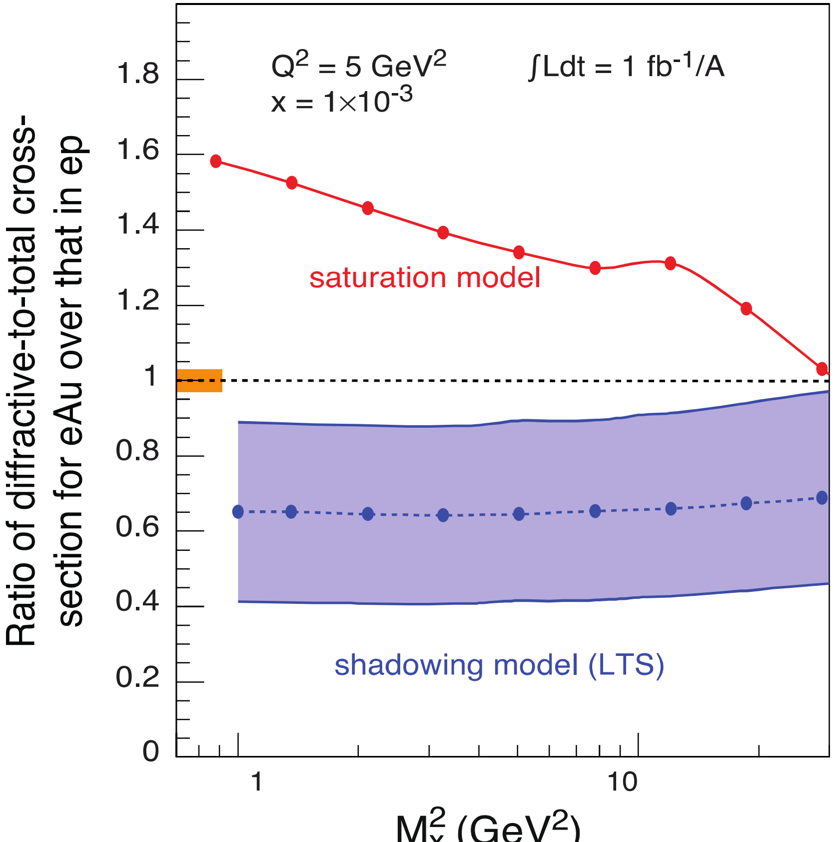
- F_2 (quark+ antiquark) & F_L(gluons) at low x (classic inclusive measurement)

$$g(x,Q^2) \propto \frac{\delta F_2}{\delta \ln Q^2} \qquad F_L(x,Q^2) \propto g(x,Q^2)$$

Diffraction: $\sigma_{\text{diff}} \propto [g(x,Q^2)]^2$

At HERA: ep observed 10-15%
If CGC/Saturation: then
Diffraction eA expect ~25-30%

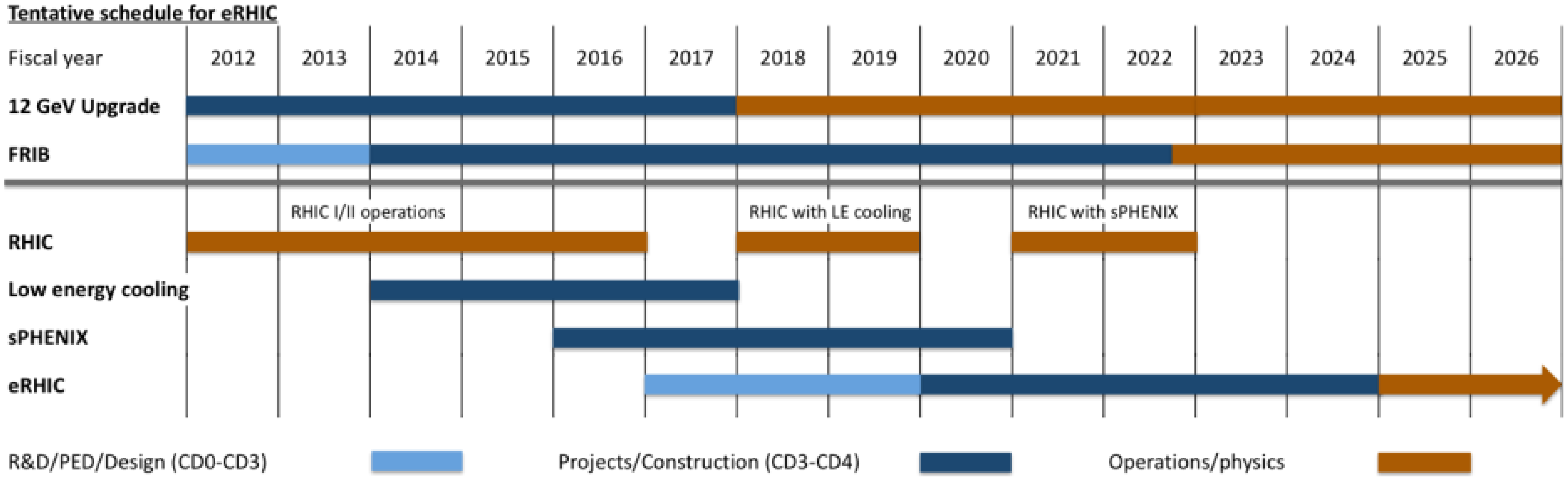
Diffractive to Total cross section ratio for eA/ep



Experimental challenges in diffractive measurements drive the detector and IR design: non trivial, but manageable

Tentative schedule (eRHIC)

Berndt Mueller
October 2014

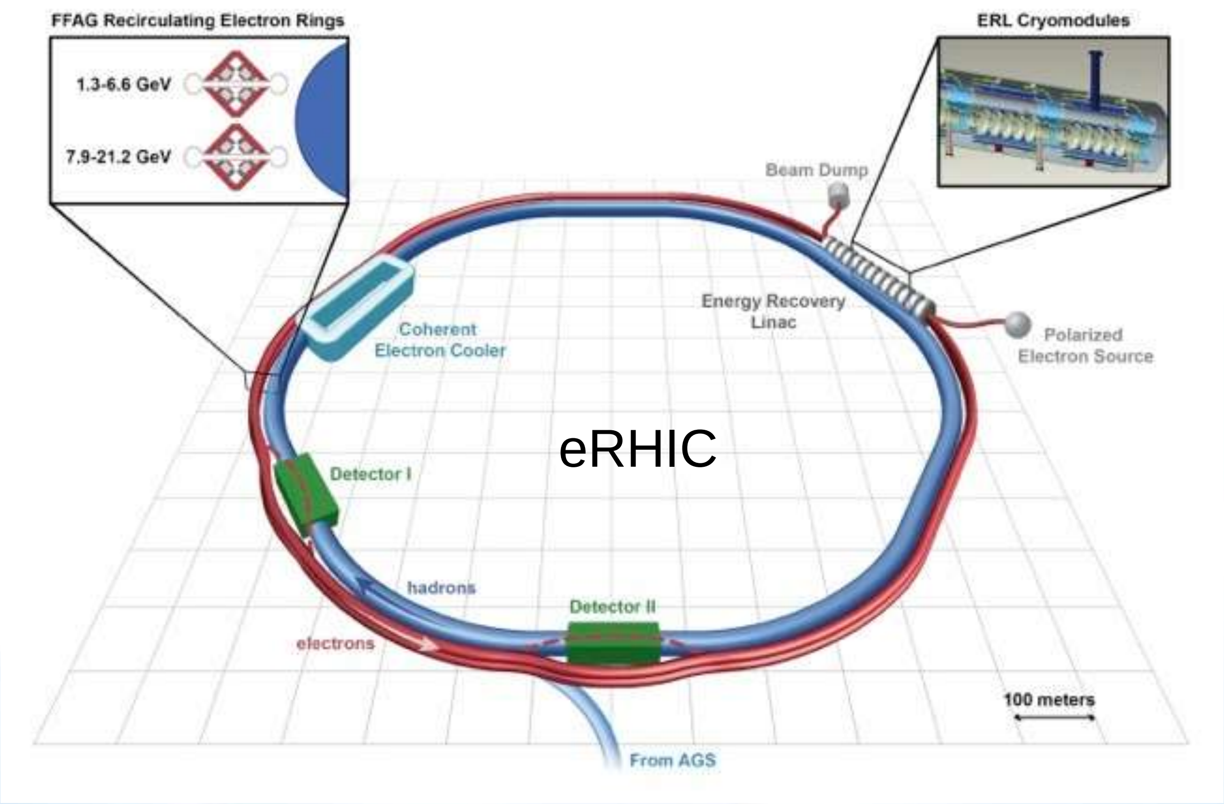


Time line shown in JLab management talks not different:
Construction of MEIC can proceed while JLab12 operations.

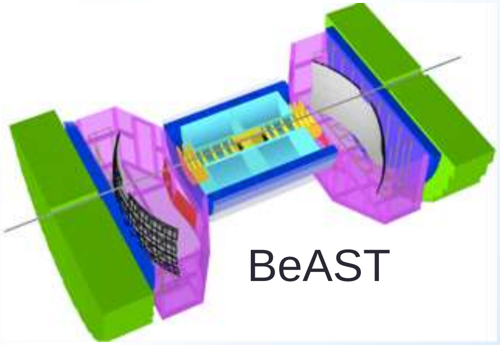
EIC : eRHIC Design

eRHIC ERL + FFAG ring design @ $10^{33}/cm^2s$

21.2 GeV e^- + 255 GeV p or 100 GeV/u Au.

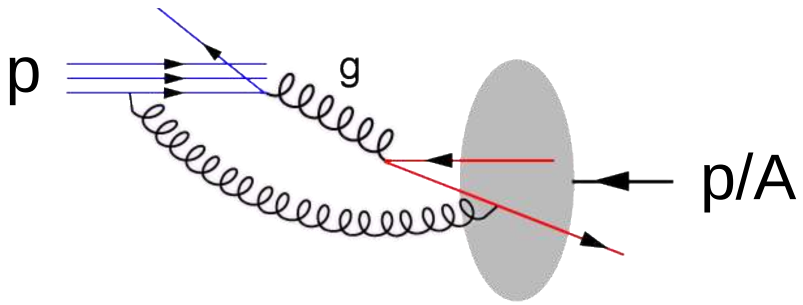


Detector Options



Berndt Mueller

Hadron-Hadron

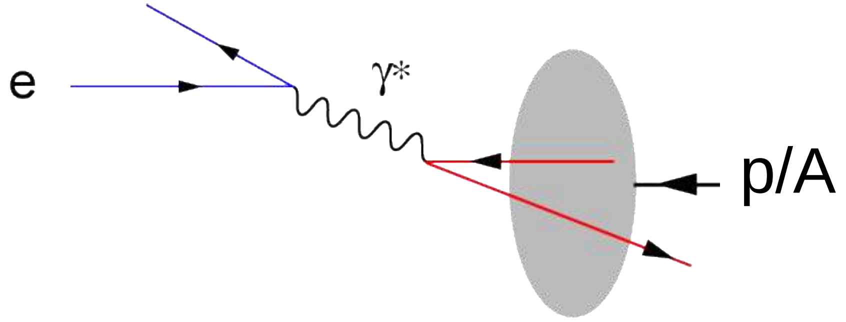


Probe & target complex

Soft interactions before collisions can destroy factorization, i.e. nuclear wave function affected

Kinematics imprecisely determined

Electron-Hadron (DIS)



Probe point like

No initial state soft interactions, factorization preserved

Kinematics precisely determined

Why a collider?

- A collider brings a very wide kinematic range in the observables in their measurable coordinates

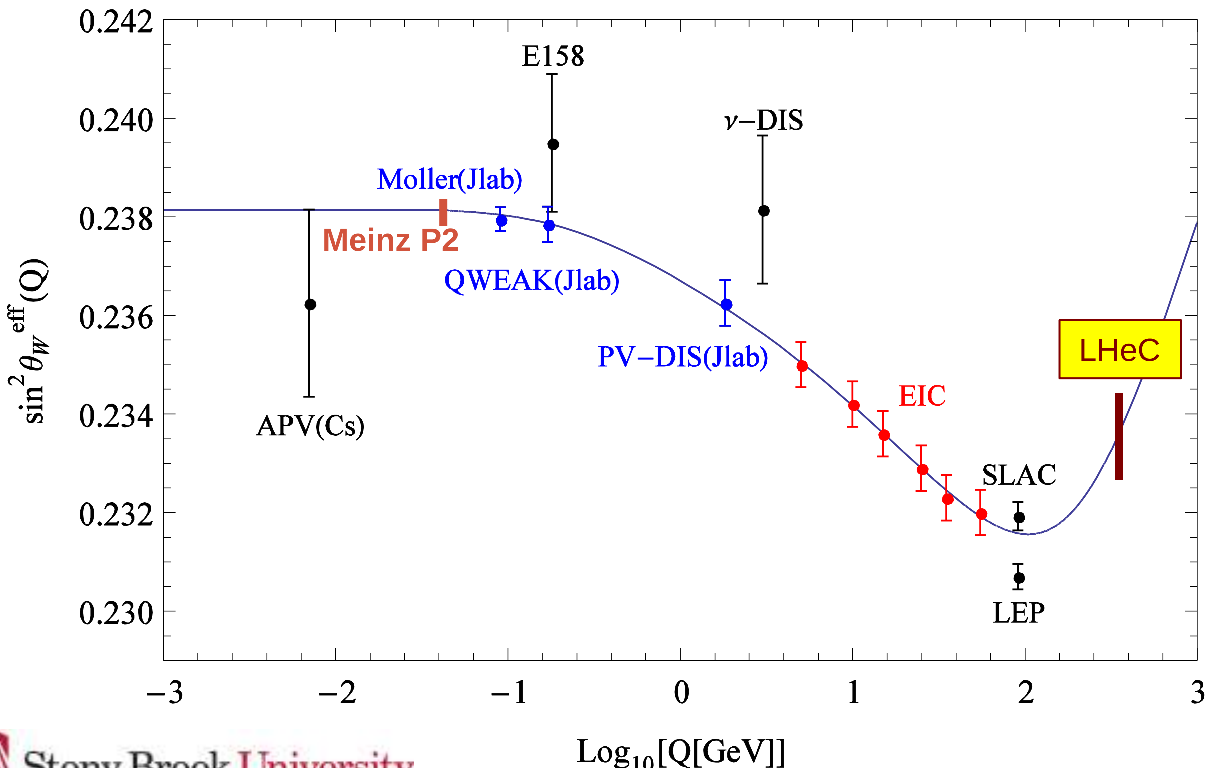
- A high energy collider brings access to low-x and high Q^2
  - Low x ➔ largest uncertainties since no spin measurements there
  - Large Q^2 ➔ large arms to see and test Q^2 evolution in variables

- Compared to solid state fixed target experiments, the target and beam fragments in a collisions fly in different directions

- Rapid “target” and “beam” spin “flips” helps brings experimental systematics under control

$\mathrm{Sin}^2\Theta_W$ with the EIC: Physics Beyond SM

- Precision parity violating asymmetry measurements e/D or e/p
- Deviation from the “curve” may be hints of BSM scenarios including: Lepto-Quarks, RPV SUSY extensions, E_6/Z’ based extensions of the SM



Black: measurements

Blue: near future measurements

Red: US EIC projections

Maroon: LHeC Projection