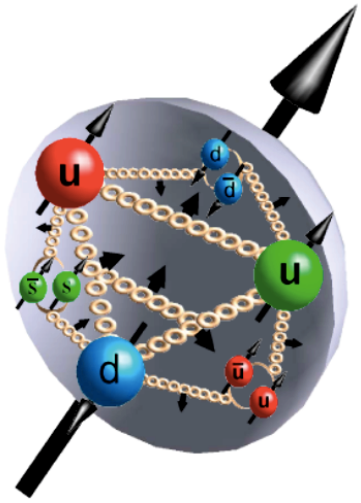
Spin physics results from STAR

Nikola Poljak
University of Zagreb
For the STAR Collaboration

13.09.2014.

Diffraction 2014

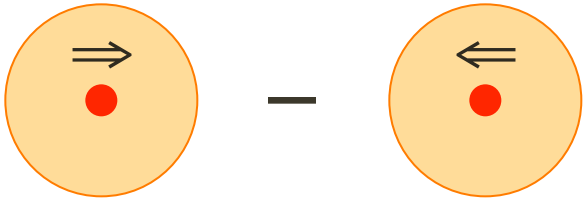
Contributions to the proton's spin



Consider a proton moving to the right

Proton spin ⇒

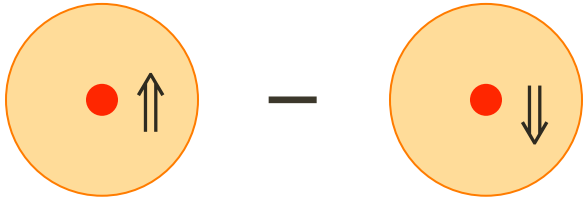
$\Delta q(x)$
$\Delta g(x)$



Longitudinal Polarization

Proton spin ⇑

$\delta q(x)$



Transverse Polarization

Transversity

Polarized DIS: ~0.3
Puzzling for ~25 years

Relatively poorly constrained but S_g coming into focus!

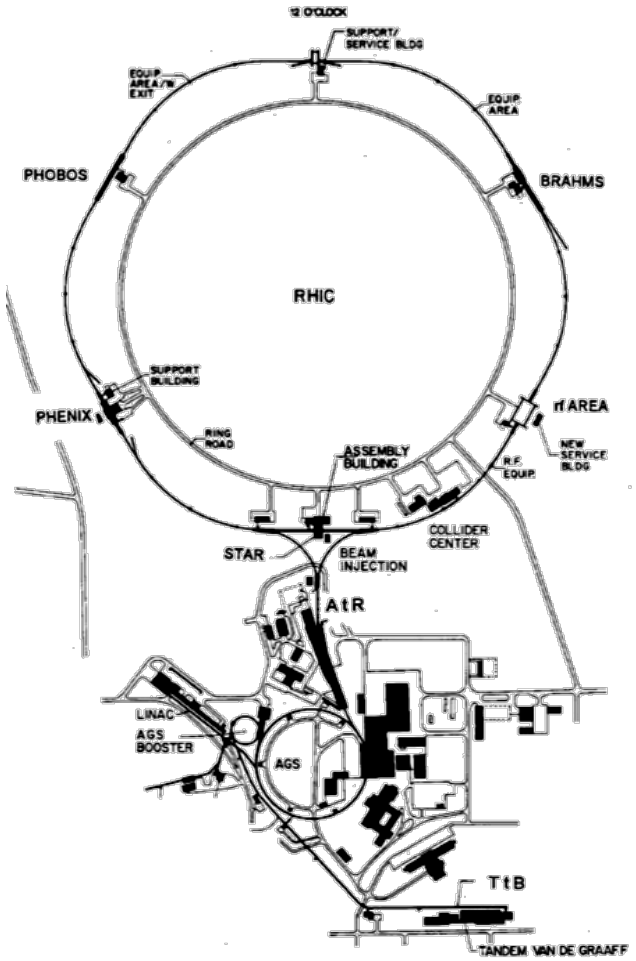
Proton spin sum rule: $\frac{1}{2}\hbar = \frac{1}{2}\sum_q S_q^z + S_g^z + \sum_q L_q^z + L_g^z$

Understanding spin in proton collisions at STAR

$$\frac{1}{2}\hbar = \frac{1}{2}\sum_q S_q^z + S_g^z + \sum_q L_q^z + L_g^z$$

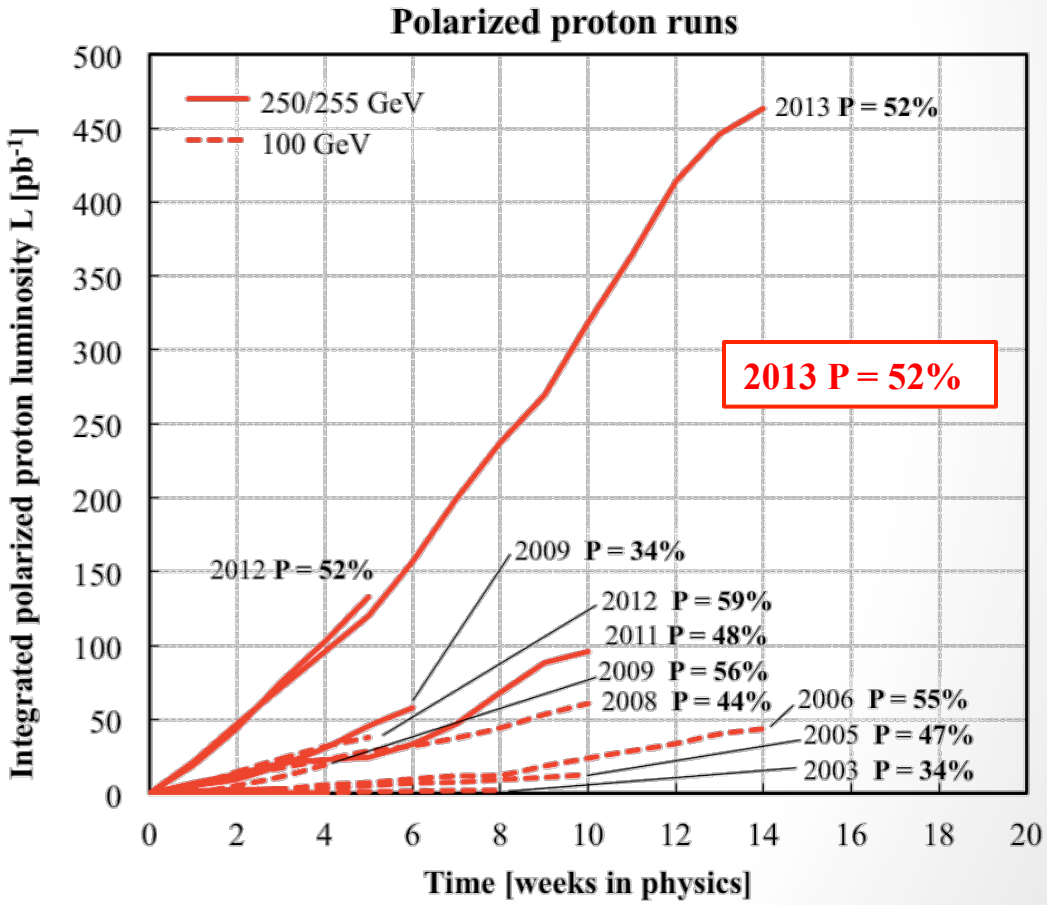
- Probing gluon polarization with jets and π^0's
  - Probing sea quark polarization with W's
  - Probing transverse structure with hadrons
    - And with W's, Z's, and other probes
      - Looking to the future

Relativistic Heavy Ion Collider



NIM A499, 245 (2003)

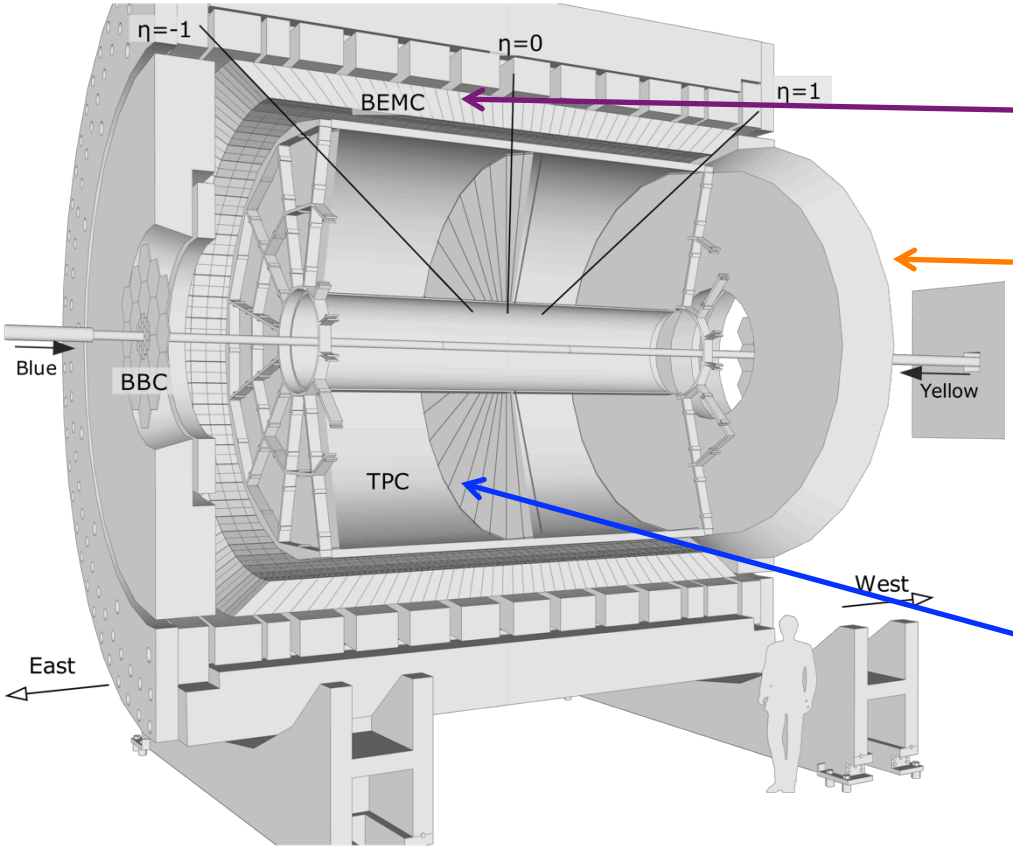
- Spin rotators provide choice of spin orientation *independently of experiment*
- Spin direction varies bucket-to-bucket (9.4 MHz)
- Spin pattern varies fill-to-fill
- Variable proton beam energy



Solenoidal Tracker at RHIC (STAR)

Inclusive hadron measurements: Barrel ElectroMagnetic Calorimeter (BEMC) + Endcap ElectroMagnetic Calorimeter (EEMC) and Forward Meson Spectrometer (FMS) *FPD (east) not shown* (neutral) / TPC (charged)

Jet and W/Z measurements: TPC +Barrel + Endcap EMC



Barrel EMC

Endcap EMC

Forward Meson Spectrometer

Time Projection Chamber

Understanding spin in proton collisions at STAR

$$\frac{1}{2}\hbar = \frac{1}{2}\sum_q S_q^z + S_g^z + \sum_q L_q^z + L_g^z$$

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  - Probing Sea Quark Polarization with W's
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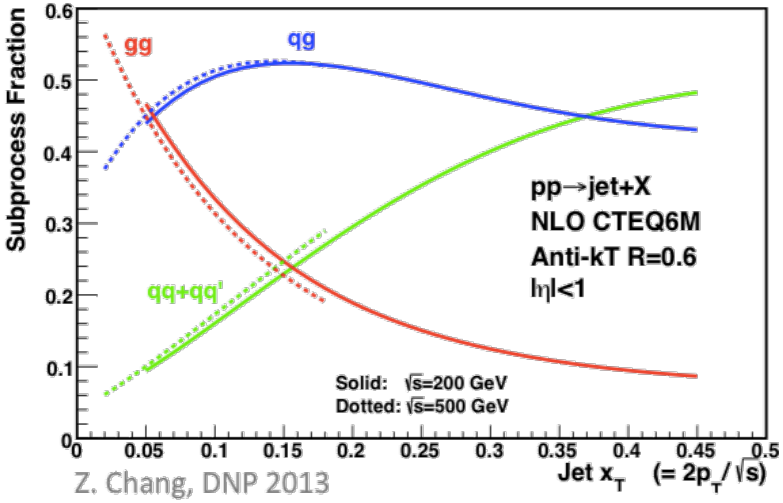
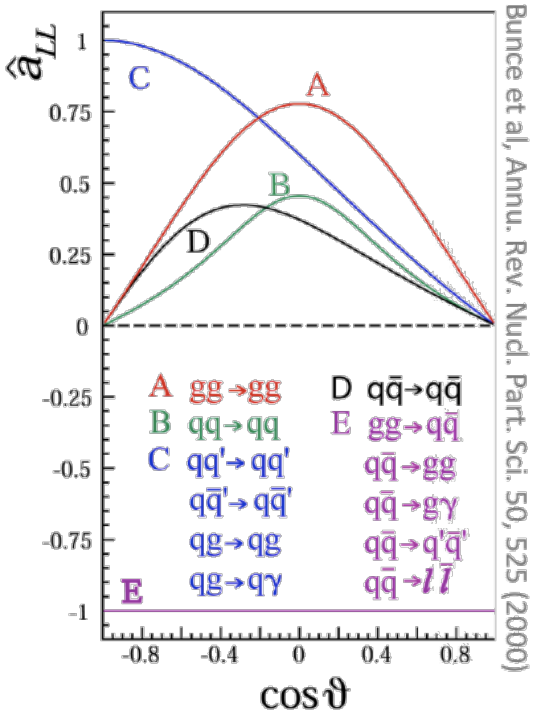
Probing polarized gluon PDF's with jets

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

A_{LL} for, e.g. jets, sensitive to ***polarized PDF's*** (Δf) and ***partonic asymmetry***, $\hat{a}_{LL}$



Z. Chang, DNP 2013

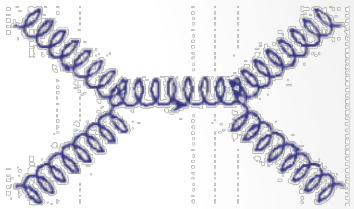


Bunce et al, Annu. Rev. Nucl. Part. Sci. 50, 525 (2000)

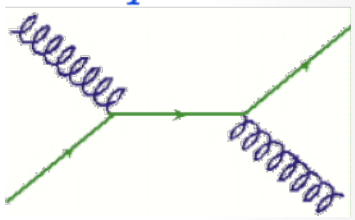
Asymmetries at different values of p_T or $\sqrt{s}$

→ ***sample different mix of partonic subprocesses***

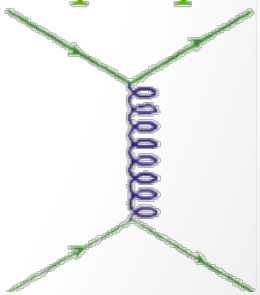
$\frac{\Delta G}{G} \frac{\Delta G}{G}$



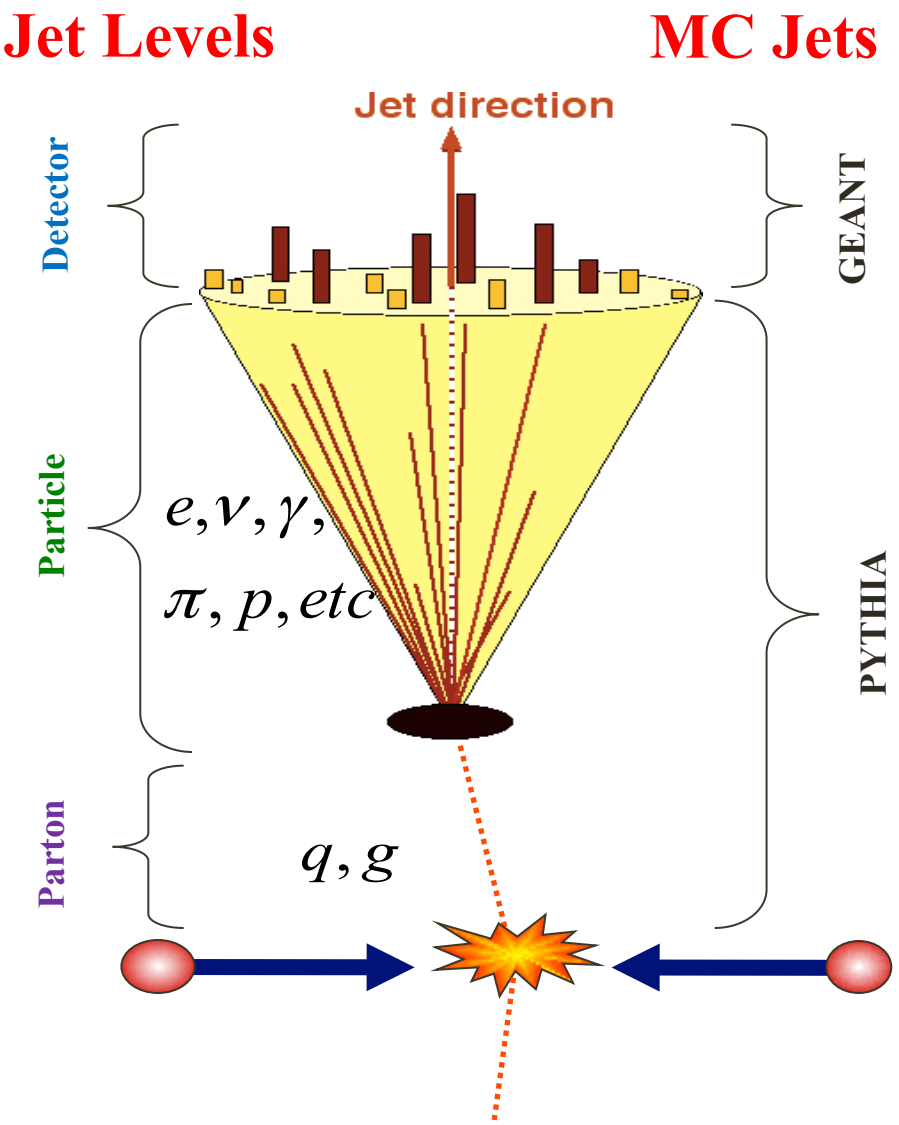
$\frac{\Delta q}{q} \frac{\Delta G}{G}$



$\frac{\Delta q}{q} \frac{\Delta q}{q}$



Jet reconstruction



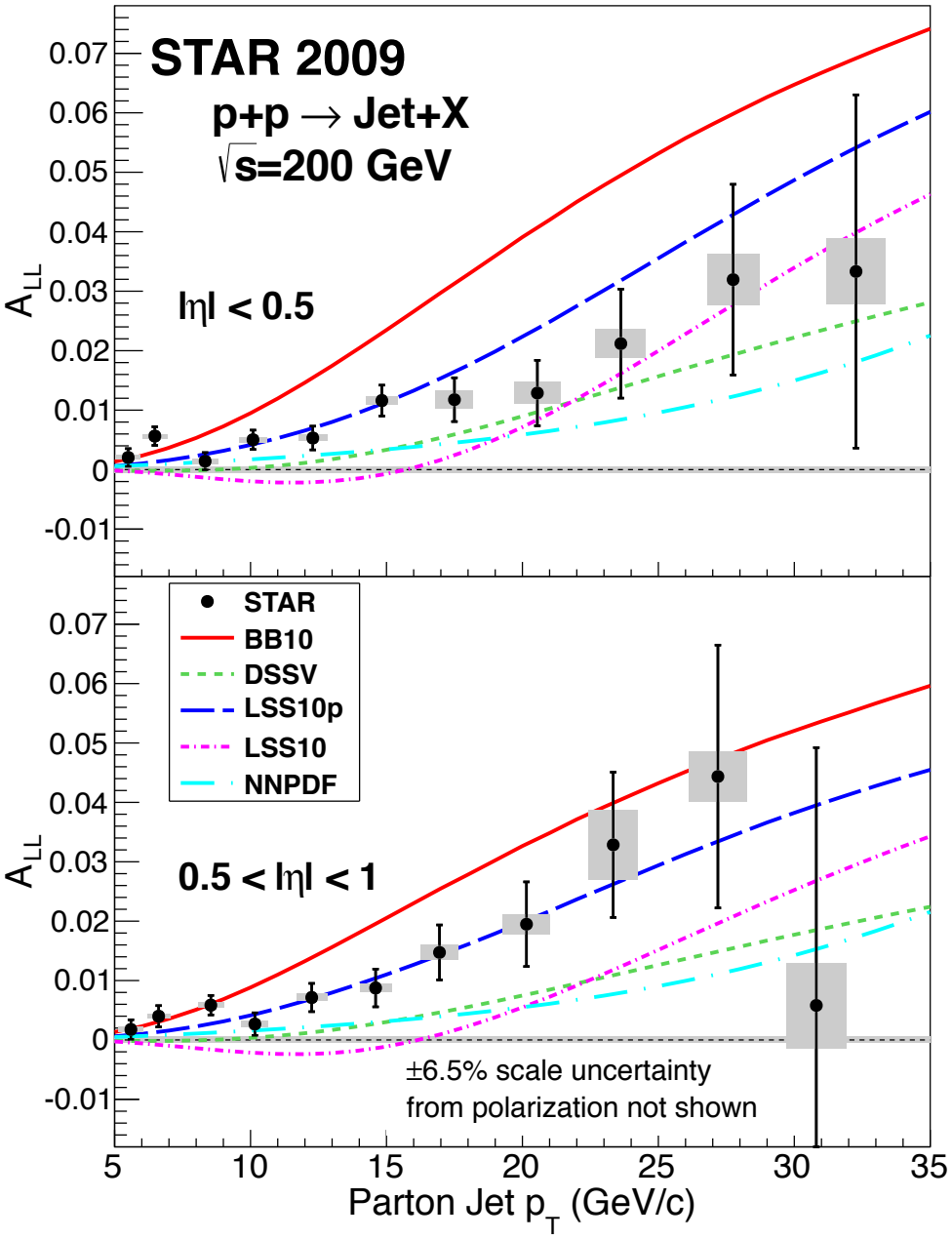
STAR has:

- Full azimuthal coverage
- Charged particle tracking from TPC for $|\eta| < 1.3$
- E/BEMC provide electromagnetic energy reconstruction in the range of $-1 < \eta < 2.0$

Anti-K_T Jet Algorithm:

- Radius = 0.6
- Used in both data and simulation

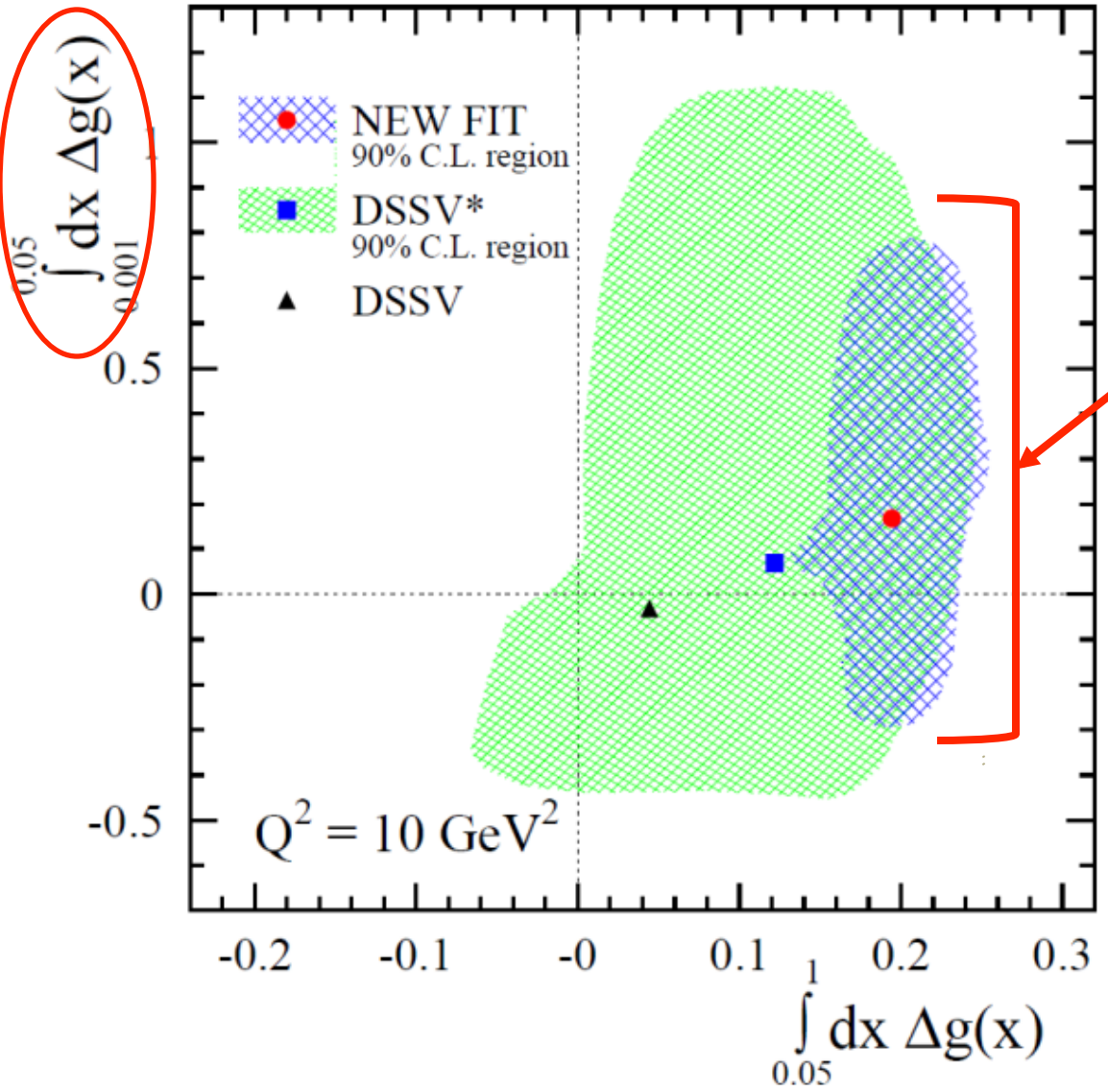
arXiv:1405.5134



- 2009 results (showing A_{LL} as a function of parton-jet p_T) have 3 to 4 times better statistical precision than 2006 results
- Two pseudorapidity ranges emphasize different partonic kinematics
- Results lie consistently above the 2008 DSSV fit! (the first global analysis to include RHIC data - Phys.Rev. D80 (2009) 034030)

DSSV -> DSSV* -> New DSSV Fit Results

PRL **113,** 012001 (2014)



- Integral of $\Delta g(x)$ in range $0.05 < x < 1.0$ increases substantially, now significantly above zero.
- Uncertainty on integral over low *x* region is still sizable

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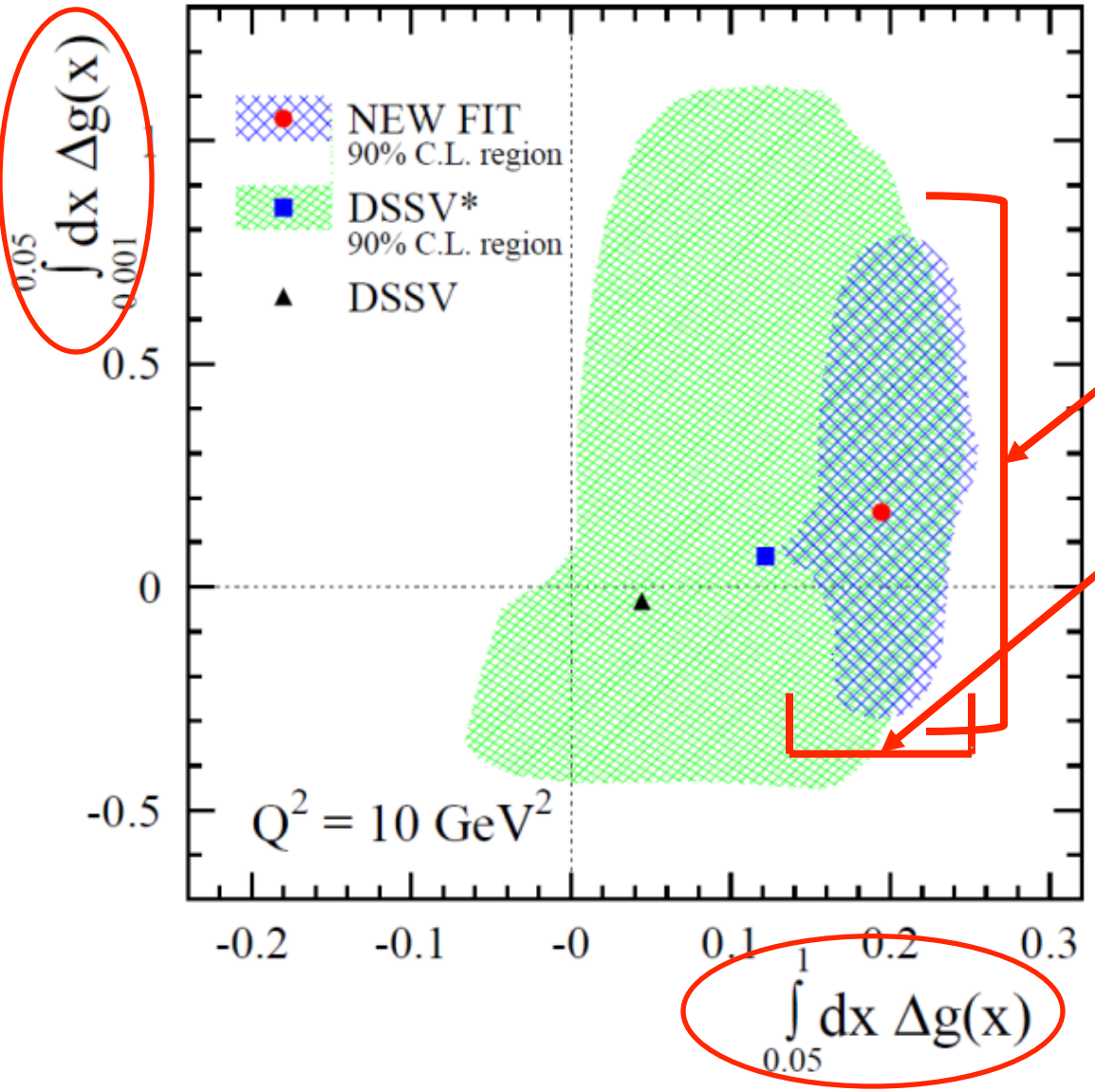

- Integral of $\Delta g(x)$ in range $0.05 < x < 1.0$ increases substantially, now significantly above zero.
- Uncertainty on integral over low *x* region is still sizable
- Uncertainty shrinks substantially from DSSV* to new DSSV fit

First firm evidence of non-zero gluon polarization!

Probing low *x* gluons with π^0 A_{LL}

STAR has measured π^0 A_{LL} in three different pseudorapidity ranges to assess different kinematics, different fragmentation, different systematics etc.
PRD 80, 111108(R), PRD 89, 012001 (2014), Wissink SPIN2008

No large asymmetries seen

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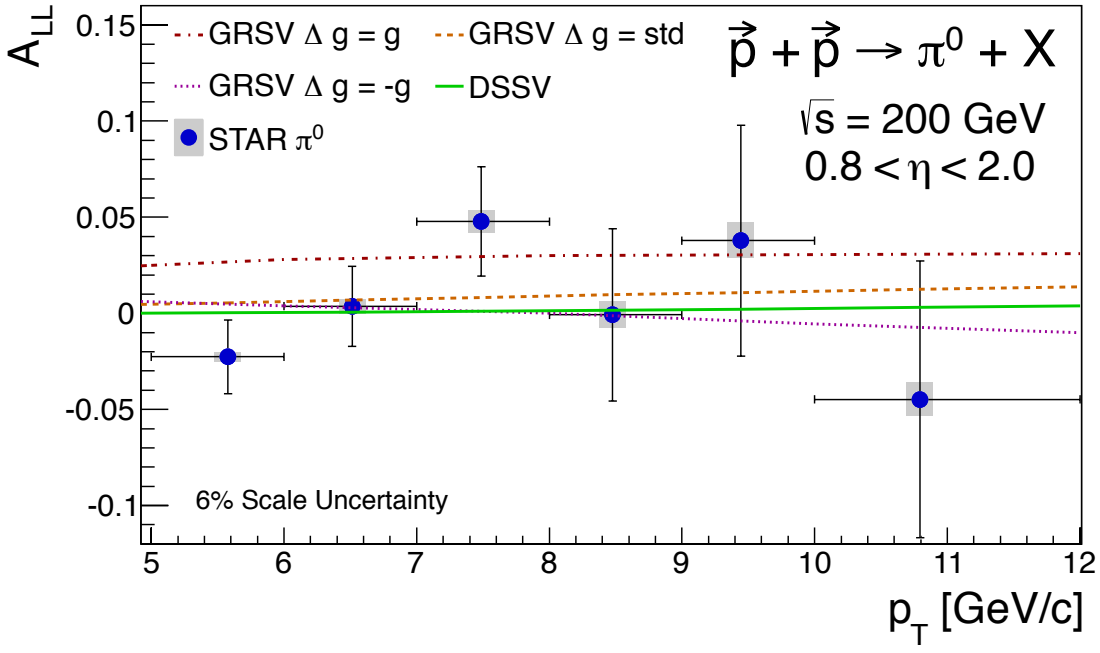
No large asymmetries seen

2006 data, PRD **89**, 012001 (2014)



- Work underway with 2012 dataset (10x lumi.) at intermediate pseudorapidity, projected large improvement in stat. uncertainty
- Higher CoM energy
  - 200 → 510 GeV
  - Pushes to lower *x* gluon
- Additional data at 510GeV from the FMS (2012 and 2013 forward)

Understanding spin in proton collisions at STAR

$$\frac{1}{2}\hbar = \frac{1}{2}\sum_q S_q^z + S_g^z + \sum_q L_q^z + L_g^z$$

- Probing Gluon Polarization with Jets and π^0's
- Probing Sea Quark Polarization with W's
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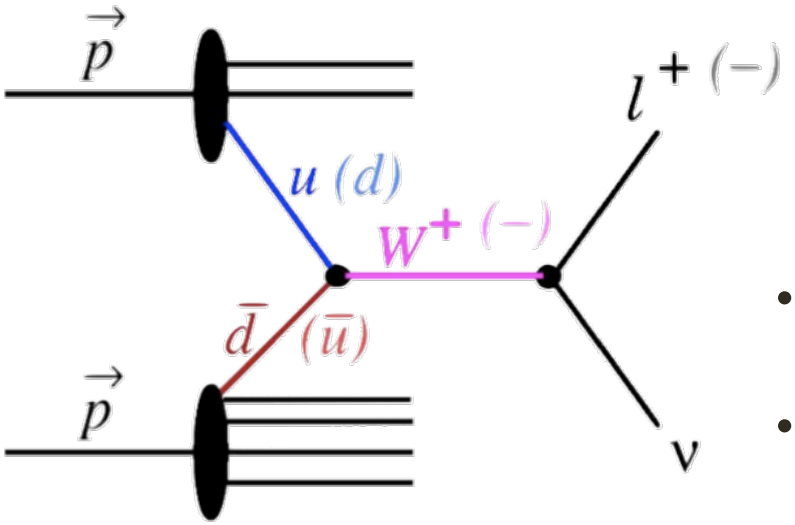
Probing Sea Quark Polarizations With W's



$$u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$$

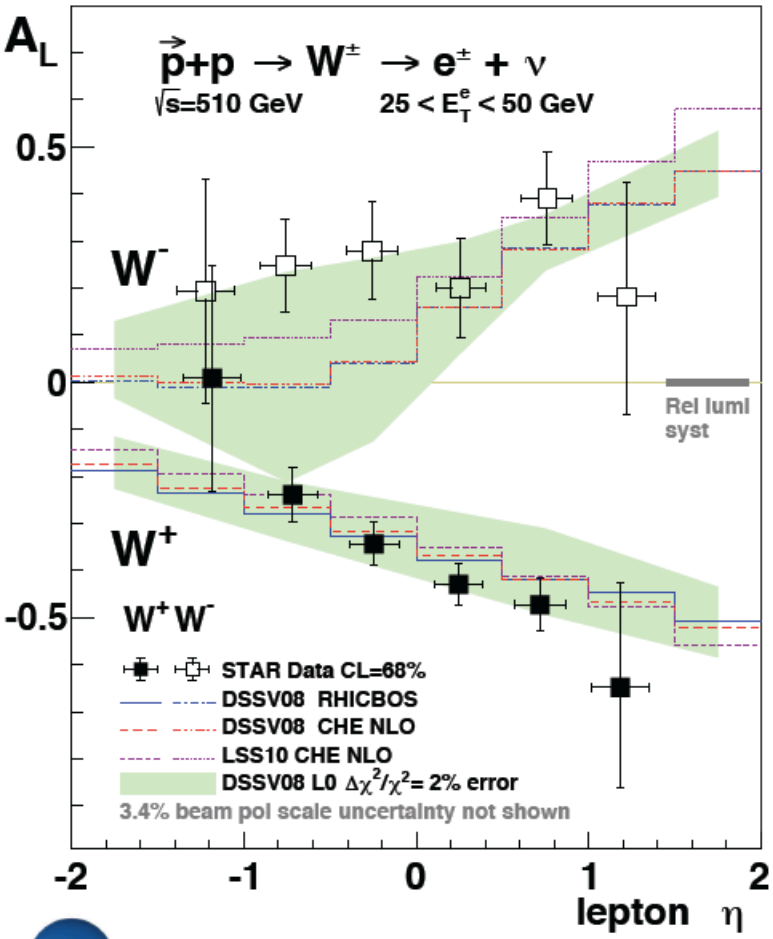
$$d + \bar{u} \rightarrow W^- \rightarrow e^- + \bar{\nu}$$

- Direct coupling of W's to the quarks and antiquarks of interest
- Longitudinally, excellent probes of sea quark polarizations, but also an important probe of transverse physics

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \quad \Rightarrow \quad A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

Measure single-spin asymmetry: helicity flip in one beam while averaging over the other

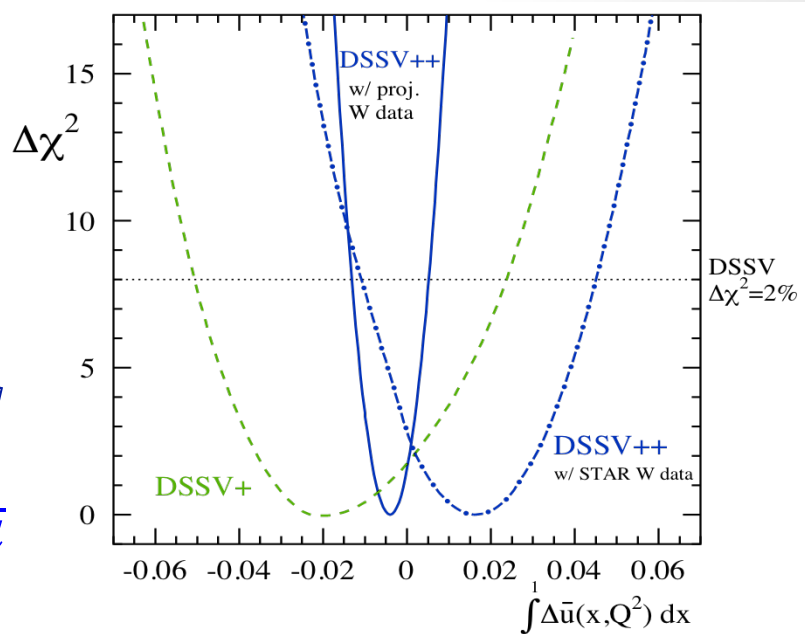
2012 W (u and d) results



NEW arXiv:1404.6880

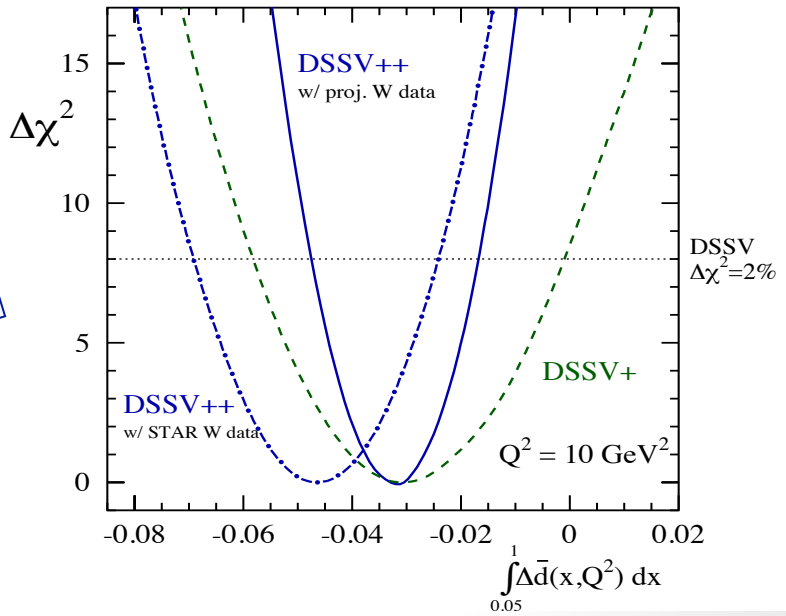
$\Delta\bar{u}$

arXiv:nucl-ex/1304.0079



STAR data move the world sea quark fits!

$\Delta\bar{d}$



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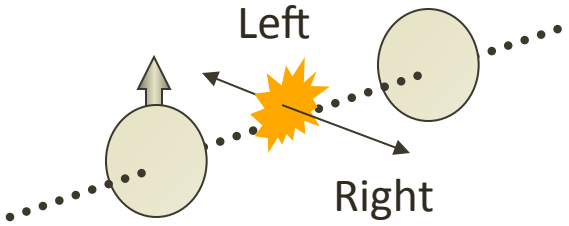
Transverse spin asymmetry A_N



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

A_N: a difference in cross-section between particles produced to the left and right

Theory Expectation:

Small asymmetries at high energies

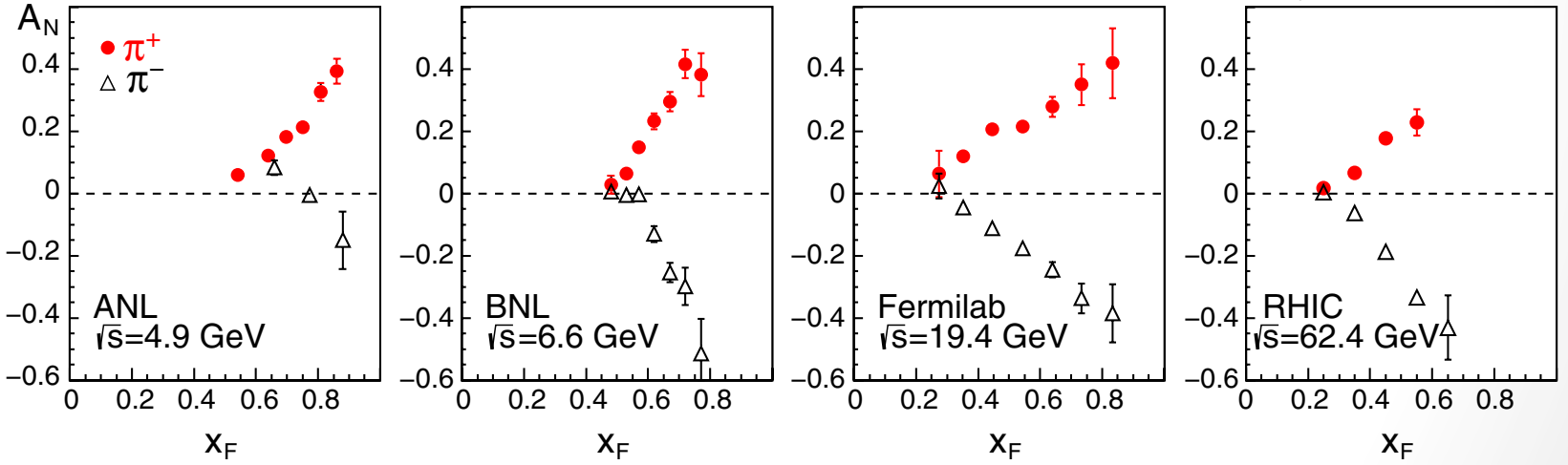
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

$$A_N \propto \frac{m_q}{p_T}$$

Experiment:

(E704, Fermi National Laboratory
Phys. Lett. B 261 (201) Phys. Lett. B 264 (462))

Rev. Mod. Phys., Vol. 85, No. 2



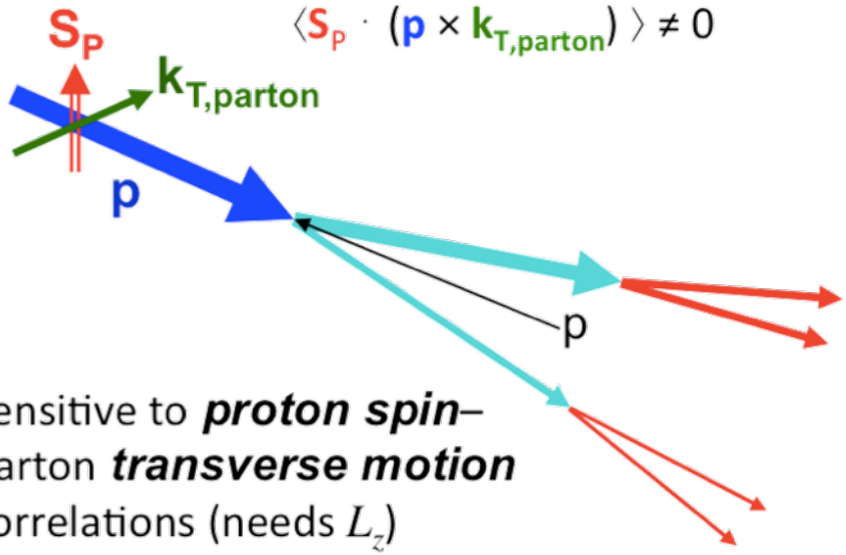
Anomalously large A_N observed for nearly 40 years!

$$x_F = \frac{p_{z,\pi}}{p_{z,\max}} = \frac{p_{z,\pi}}{\sqrt{s}/2}$$

Mechanisms for transverse single-spin asymmetries

Sivers mechanism: asymmetry in the forward jet or γ *production*

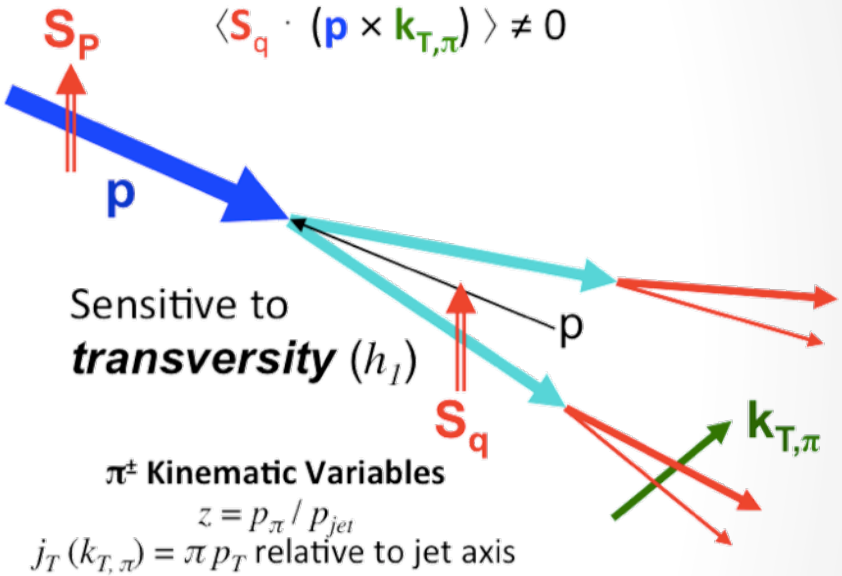
D. Sivers, PRD 41, 83 (1990); 43, 261 (1991)



Sensitive to ***proton spin–*** parton ***transverse motion*** correlations (needs L_z)

Collins mechanism: asymmetry in the forward jet *fragmentation*

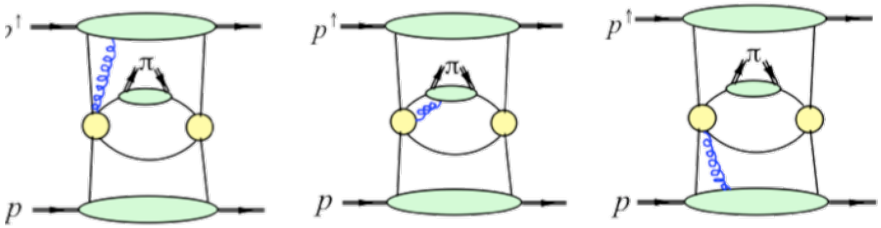
J. Collins, NP B396, 161 (1993)



$\pi^{\pm}$ Kinematic Variables

$z = p_\pi / p_{jet}$

$j_T\,(k_{T,\pi}) = \pi\, p_T$ relative to jet axis



Y. Koike, RSC Discussion (2004)

Twist-3: Asymmetry from multi-parton correlation functions (PRL 67, 2264) or equivalent mechanism for fragmentation functions (PRD 89, 111501 R)

Correlators closely related to k_T moments of TMDs (NPB 667, 201)

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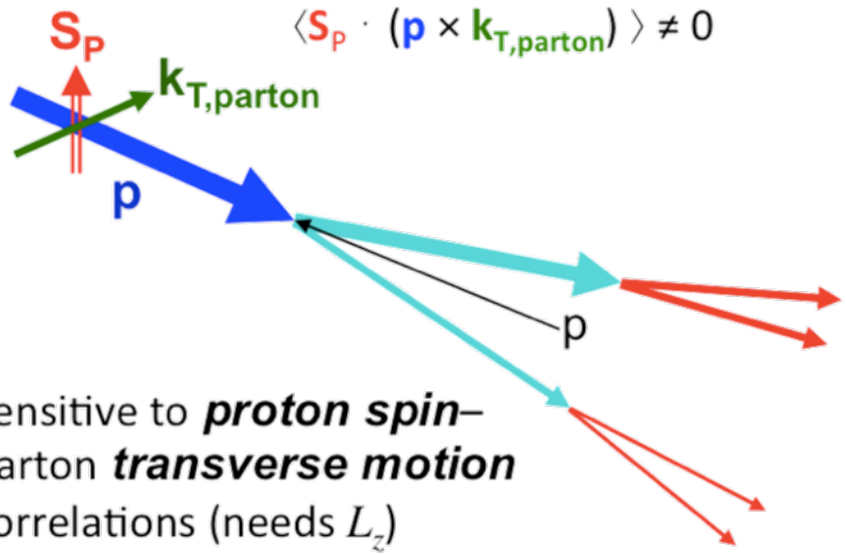

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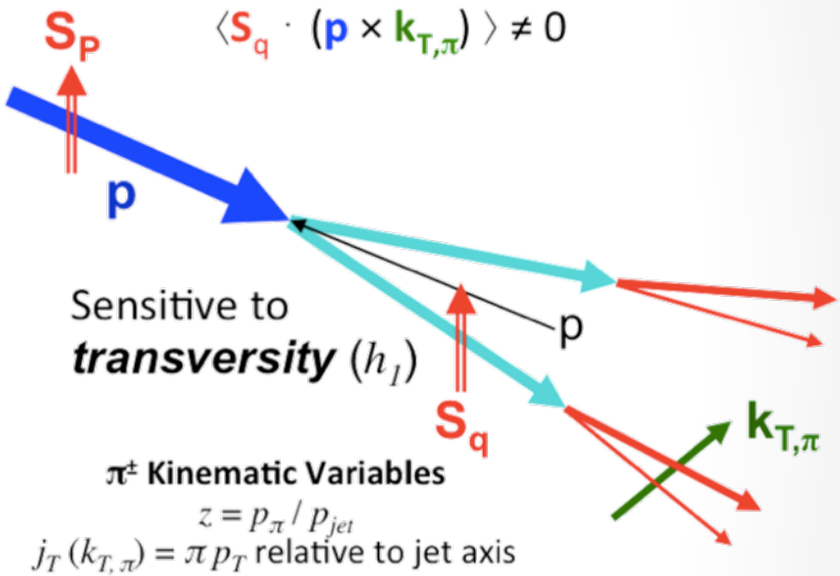

$\pi^{\pm}$ Kinematic Variables

$z = p_\pi / p_{jet}$

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Separate Sivers and Collins:

Go beyond inclusive production – *e.g. jets, W/Z, direct photons*

Sivers ~ $\sin(\phi_S)$

ϕ_S—*angle between spin and event plane*

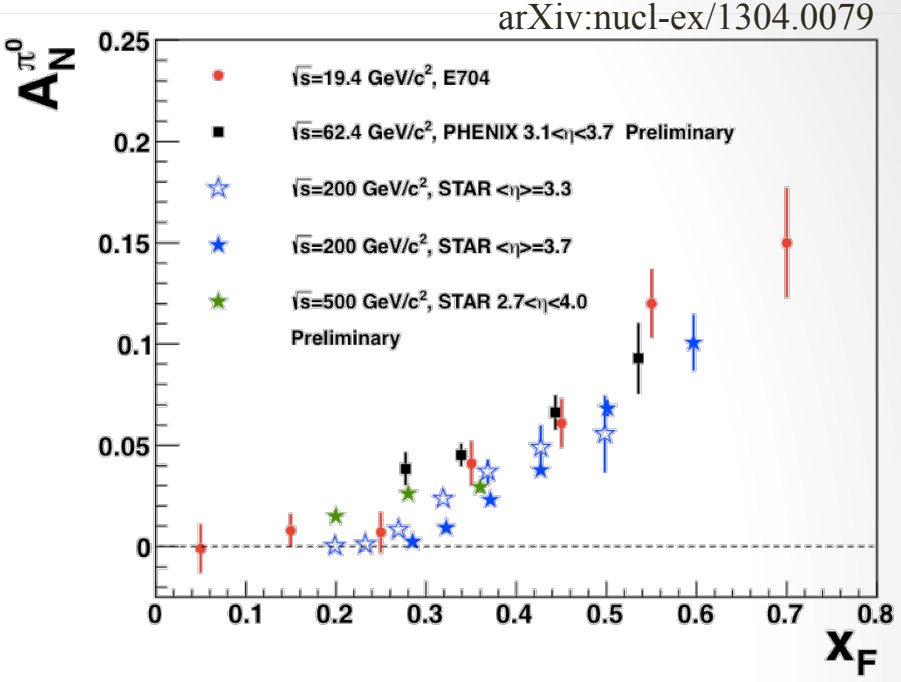
Collins ~ $\sin(\phi_S - \phi_h)$

ϕ_h—*angle of hadron around jet axis*

A_N results from STAR

- Features of A_N
  - Large A_N persists at STAR
  - Observed at various √s and η
  - x_F dependence as expected
  - large asymmetries persist at high p_T
  - larger in η's than π^0's?

arXiv:nucl-ex/1304.0079



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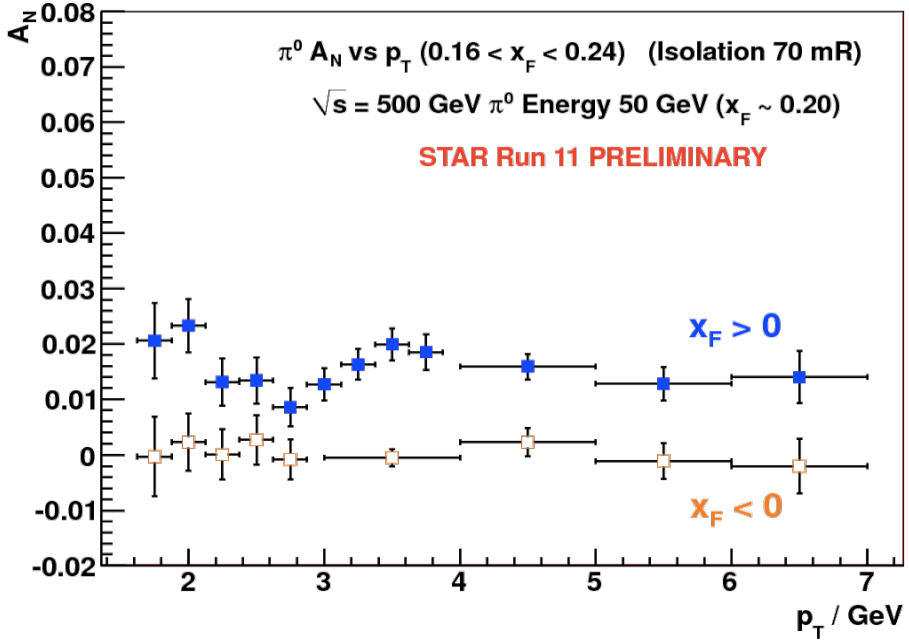
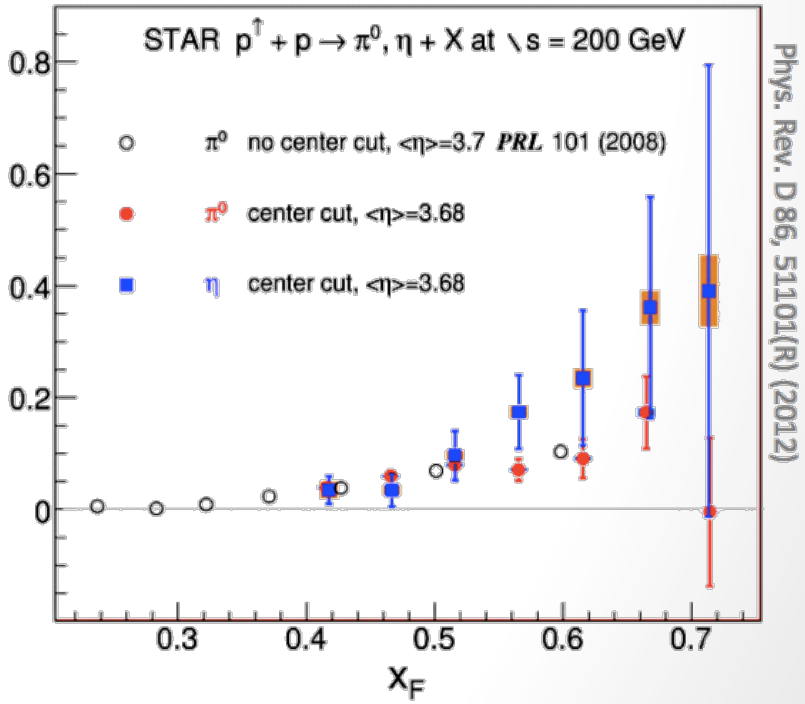
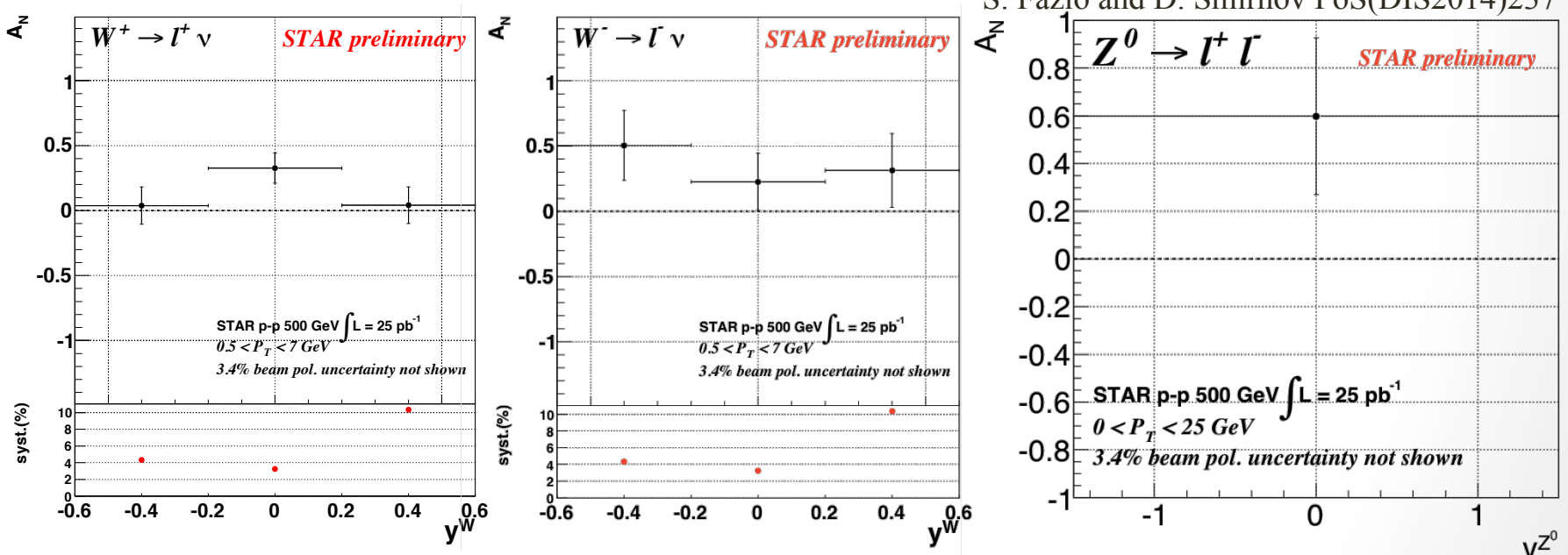




$A_N(W^{+/-}, Z^0)$ results

- A_N in Drell-Yan, W/Z production provide excellent complement to SIDIS
  - Attractive from a theoretical perspective (**no fragmentation function needed** as for π^0's, etc., W **couples directly** to proton **sea quarks**)
  - **Sivers function changes sign** when comparing with transverse asymmetries from SIDIS (Collins, J. C., 2002, Phys. Lett. B 536, 43)
  - Test the universality and factorization of TMD's, constrain their evolution – important tests of QCD
  - Analysis completely reconstructs the bozons

S. Fazio and D. Smirnov PoS(DIS2014)237



Projections for 2016 show $A_N(W^{+/-},Z^0)$ will constrain sea quark Sivers distribution ***and*** make a statement on the Sivers sign change

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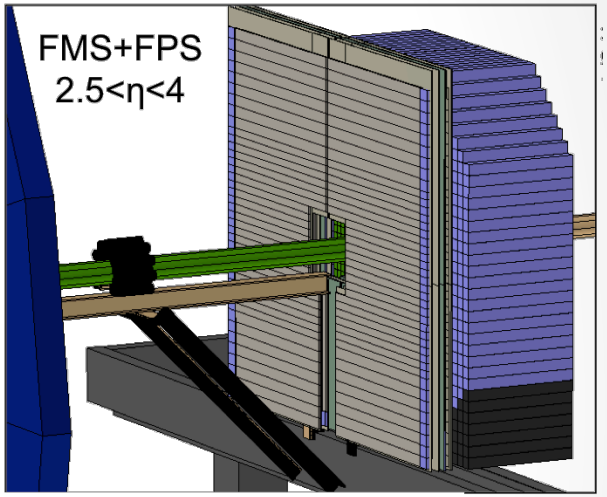
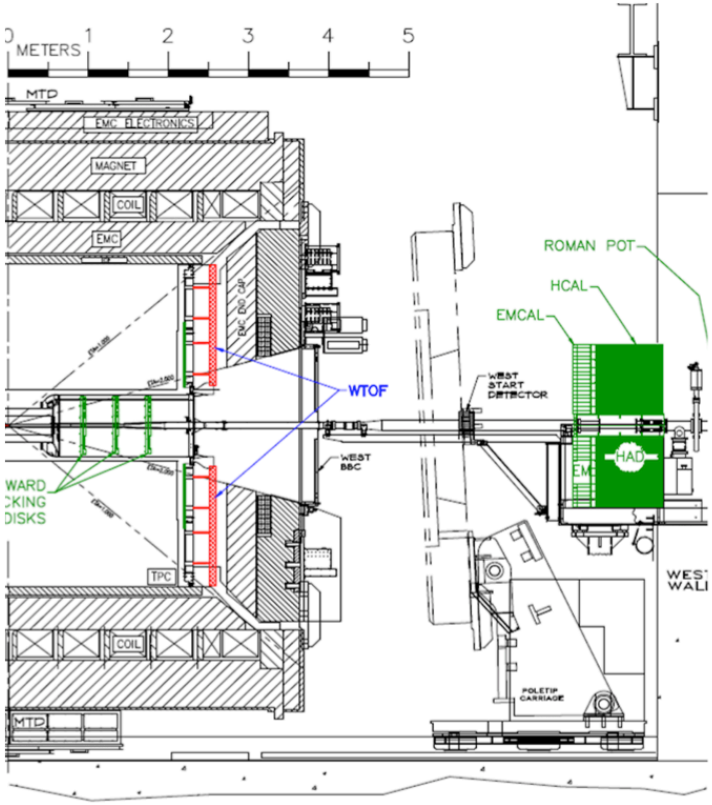
Forward Calorimetry Upgrade: 2015 and 2020

FMS (forward EM calorimetry) Preshower Upgrade in 2015

- Allows separation among photons, π^0's, charged hadrons, and electrons
- Supports direct photon and DY measurements (no frag. functions, universality tests)

STAR FMS-PreShower:





2020 forward upgrade:
ECal: Tungsten powder scintillating fiber, $23X_0$, 2.3cm Mol.
HCal: Lead+scintillator tiles, 10x10x81 cm^3, $4X_0$

- Dijet measurements – direct access to parton x
- Means to measure low x gluon distribution - an attractive probe to $x \approx 10^{-3}$ before the EIC era (arxiv 1212.1701)

Conclusions and outlook

After 25 years, **evidence of non-zero gluon polarization** in the proton

Pushing to **lower *x* gluons**

W's and Z's improving our understanding of **sea quark polarizations**

Exploration of large transverse asymmetries continues

Efforts to **disentangle initial-state (e.g. Sivers) and final-state (e.g. Collins) effects**; and **confirming both in a pp environment**

Large datasets on hand, analyses underway

Detector upgrades continue

Stay tuned and

Thank you!