Helicity: Experimental Status

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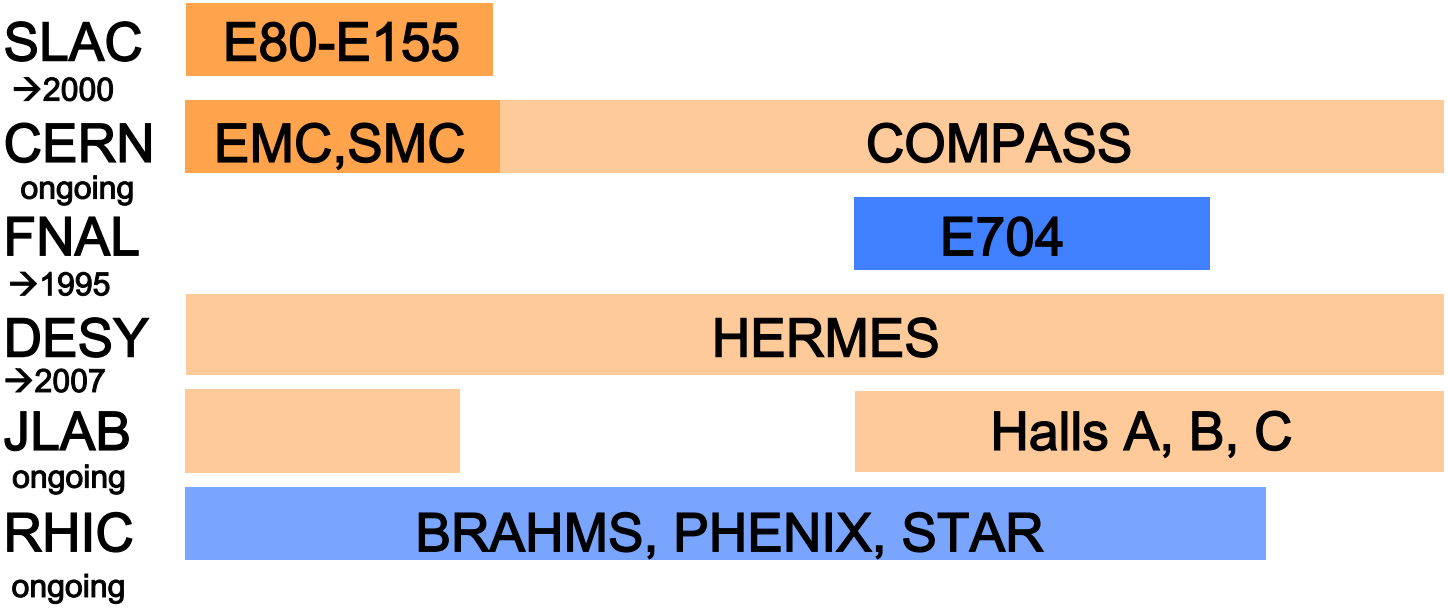
Content

- **The Experimental Effort**
- **Quark and Sea Quark Helicity**
  - ➔ DIS, SIDIS, pp
  - ➔ new FFs for global analysis
  - ➔ results from global analysis (previous talk!)
  - ➔ (high x)
- **Gluon Helicity**
  - ➔ DIS, SIDIS, pp
  - ➔ results from global analysis (previous talk!)
  - ➔ extending x-range at RHIC
  - ➔ low x at the EIC
- **Goals and Some Resulting Challenges for the EIC**

Nucleon Spin Structure: 35 Years of Experiment

Quark Helicity – Gluon Helicity – Transverse Spin – GPDs – L_z



DIS, SIDIS

polarized pp

Experimental Access to Helicity Parton Distributions: polarized DIS

Inclusive deep inelastic scattering (DIS) at SLAC, CERN, DESY & JLab

$$(e,\mu) + (p, d, {}^3He) \rightarrow (e,\mu) + X$$

Observables: $A_{\parallel}, A_{\perp} \Rightarrow A_1, A_2 \Rightarrow g_1(x,Q^2), g_2(x,Q^2)$

spin dep. cross section asymmetries ➔ spin dep. structure functions

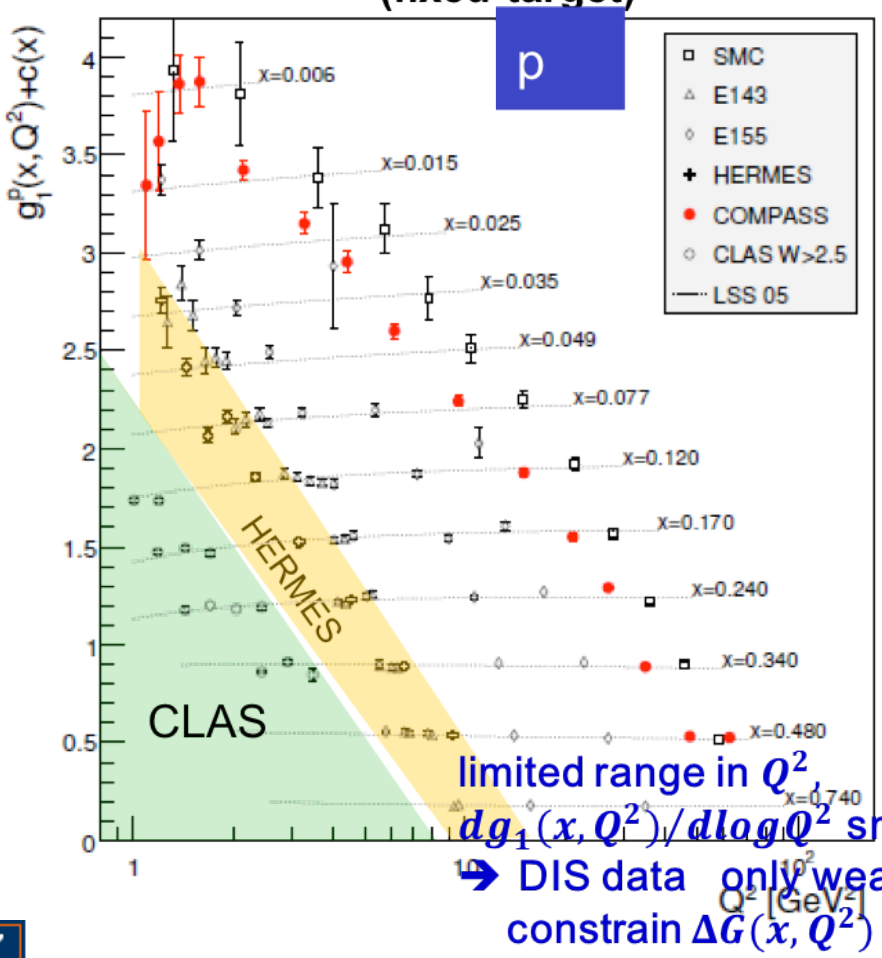
QCD analysis of $g_1(x,Q^2)$ yields quark helicity distributions $\Delta q(x,Q^2)$ and for sufficiently large kinematic coverage in Q^2 scale dependence will yield $\Delta G(x,Q^2)$.

DIS vs nucleon spin structure:

- o determine quark and gluon helicity distributions
  - ➔ proton spin decomposition
- o test sum rules for structure functions and evolution

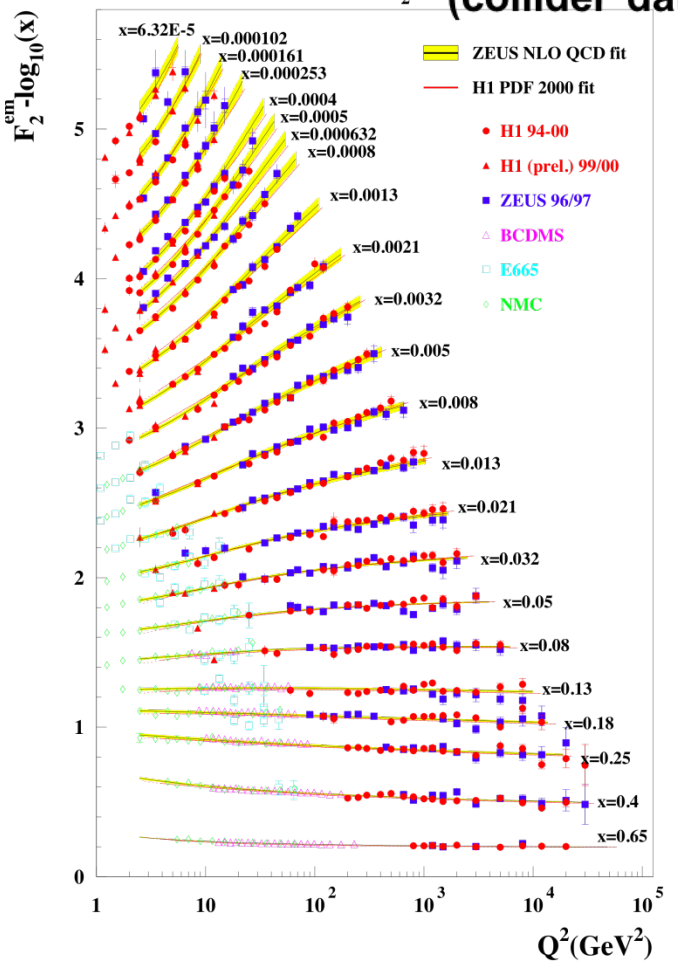
Polarized DIS: Kinematic Coverage

polarized DIS: $1 < Q^2 < 80\ GeV^2$
$0.006 < x < 0.7$
(fixed target)

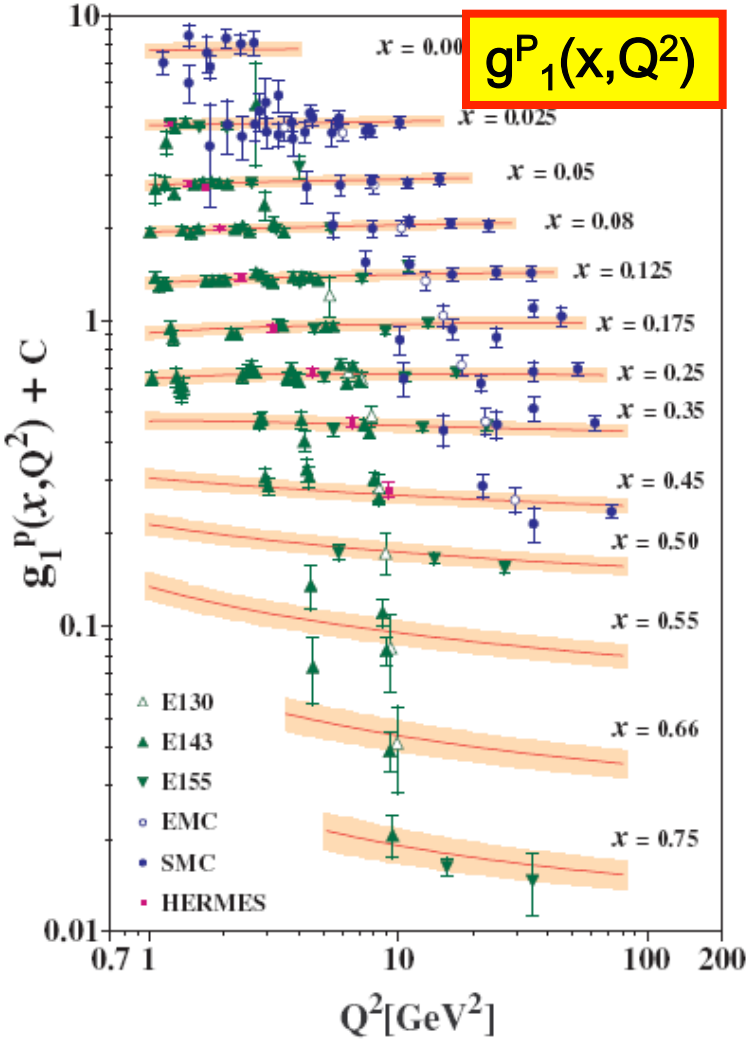


limited range in Q^2,
$dg_1(x,Q^2)/dlogQ^2$ small
➔ DIS data only weakly constrain $\Delta G(x,Q^2)$

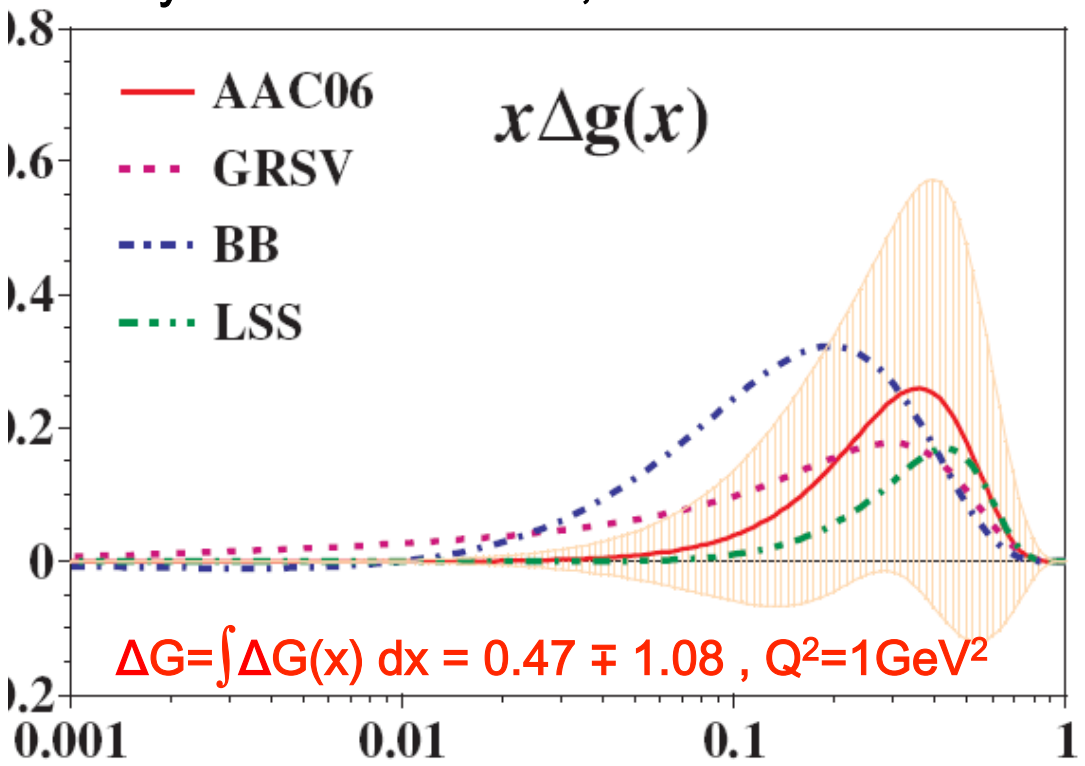
un-polarized DIS: $1 < Q^2 < 80,000\ GeV^2$
$0.0006 < x < 0.7$
HERA F_2 (collider data)



Gluon Spin Contribution $\Delta G(x)$ from Scaling Violation of $g_1(x,Q^2)$ in DIS



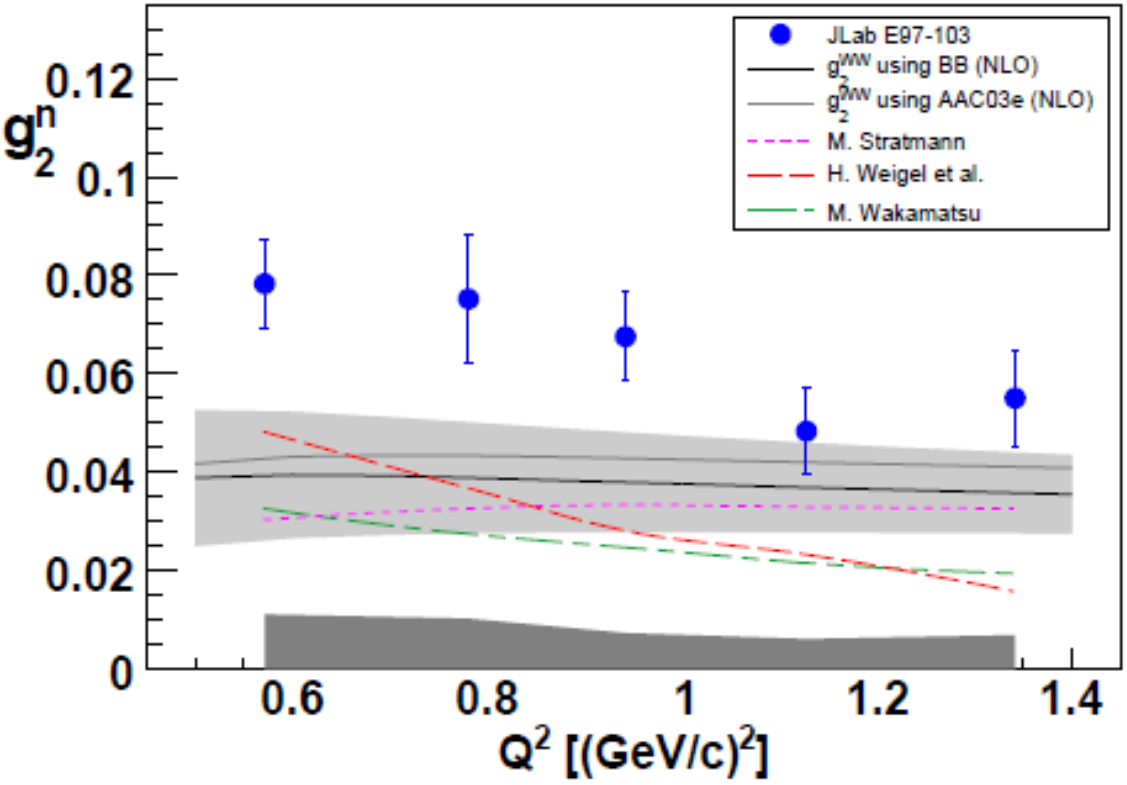
Hirai, Kumano, Saito
Phys.Rev.D74:014015,2006



Fixed Target: Higher Twist at low Q^2 ?

Explicit evidence for higher twist contributions for $Q^2 < 1GeV^2$

Hall A at Jlab, Kramer et al. PRL 95(2005)142002



OPE result:

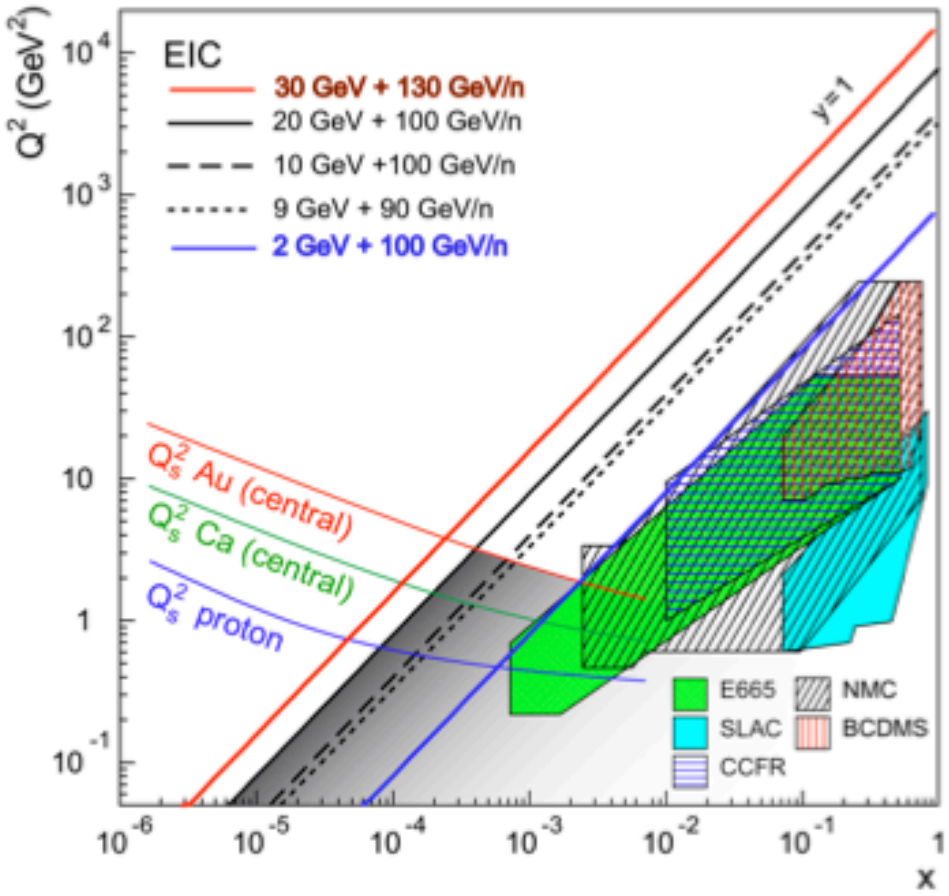
$$g_2(x,Q^2) = g_2{}^{WW}(x,Q^2) + g_2{}^{HT}(x,Q^2)$$

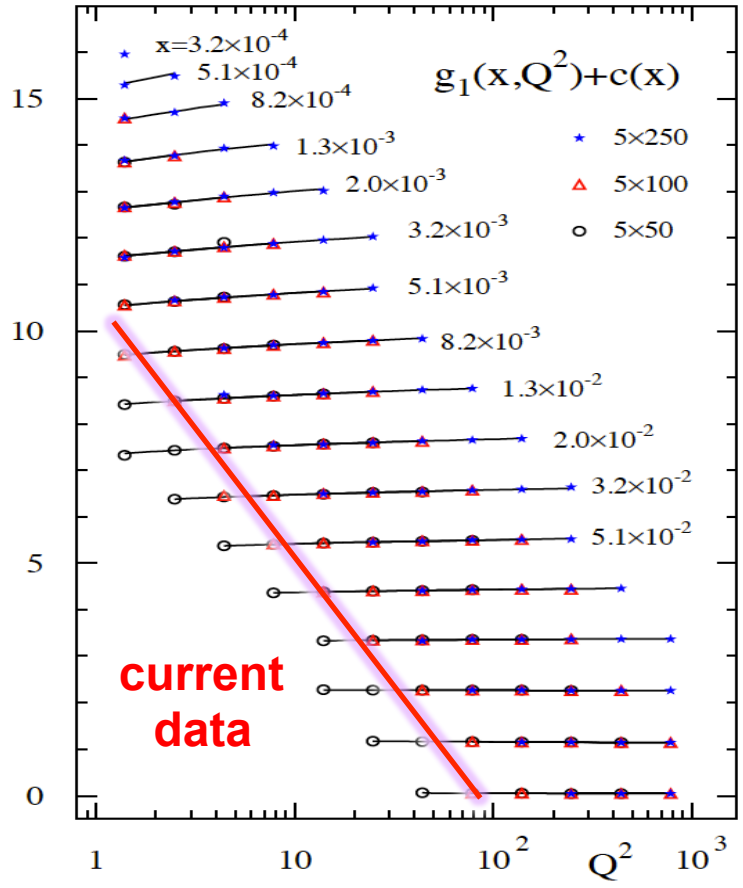
The Wandzura-Wilzeck term is purely leading twist:

$$g_2{}^{WW}(x,Q^2) = g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y}\,dy$$

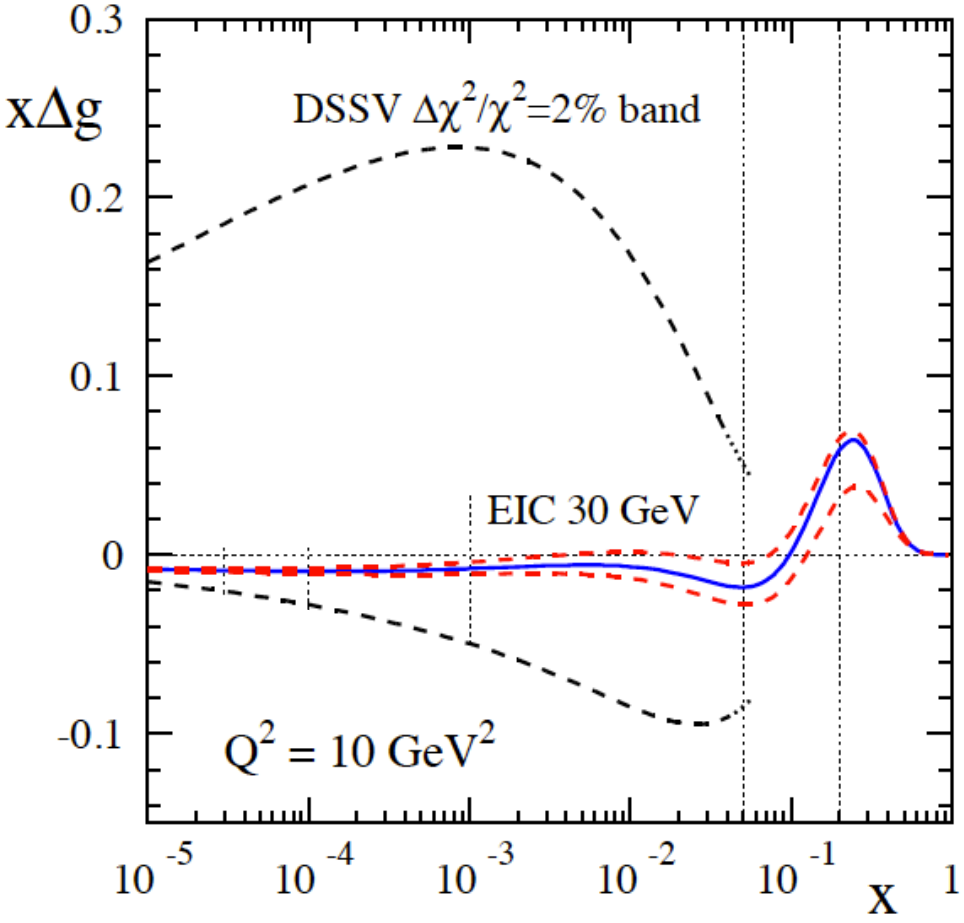
Polarized DIS at EIC : Kinematic Coverage

EIC: $1 < Q^2 < 2000\ GeV^2$ $\quad 0.0001 < x < 0.7$ **for p_p=325 GeV and p_e=30 GeV**





Polarized DIS at EIC : Kinematic Coverage



Sassot, Stratmann

$$dg_1(Q^2)/d\log Q^2 \longrightarrow \Delta G(x, Q^2)$$

Experimental Access to Helicity Parton Distributions: polarized SIDIS

Inclusive deep inelastic scattering (DIS)

$$(e,\mu) + (p, d, {}^3He) \rightarrow (e,\mu) + h + X$$

Observables: ${A_1}^h$ spin dep. cross section asymmetries in inclusive hadron production

QCD analysis of ${A_1}^h(x,Q^2)$ yields quark and anti-quark helicity distributions $\Delta q(x,Q^2)$ and for final states selecting photon-gluon fusion $\Delta G(x,Q^2)$.

SIDIS for nucleon spin structure:

- o determine quark and gluon helicity distributions
  - ➔ proton spin decomposition
- o test sum rules for structure functions and evolution
- o test asymptotic behavior of helicity distributions

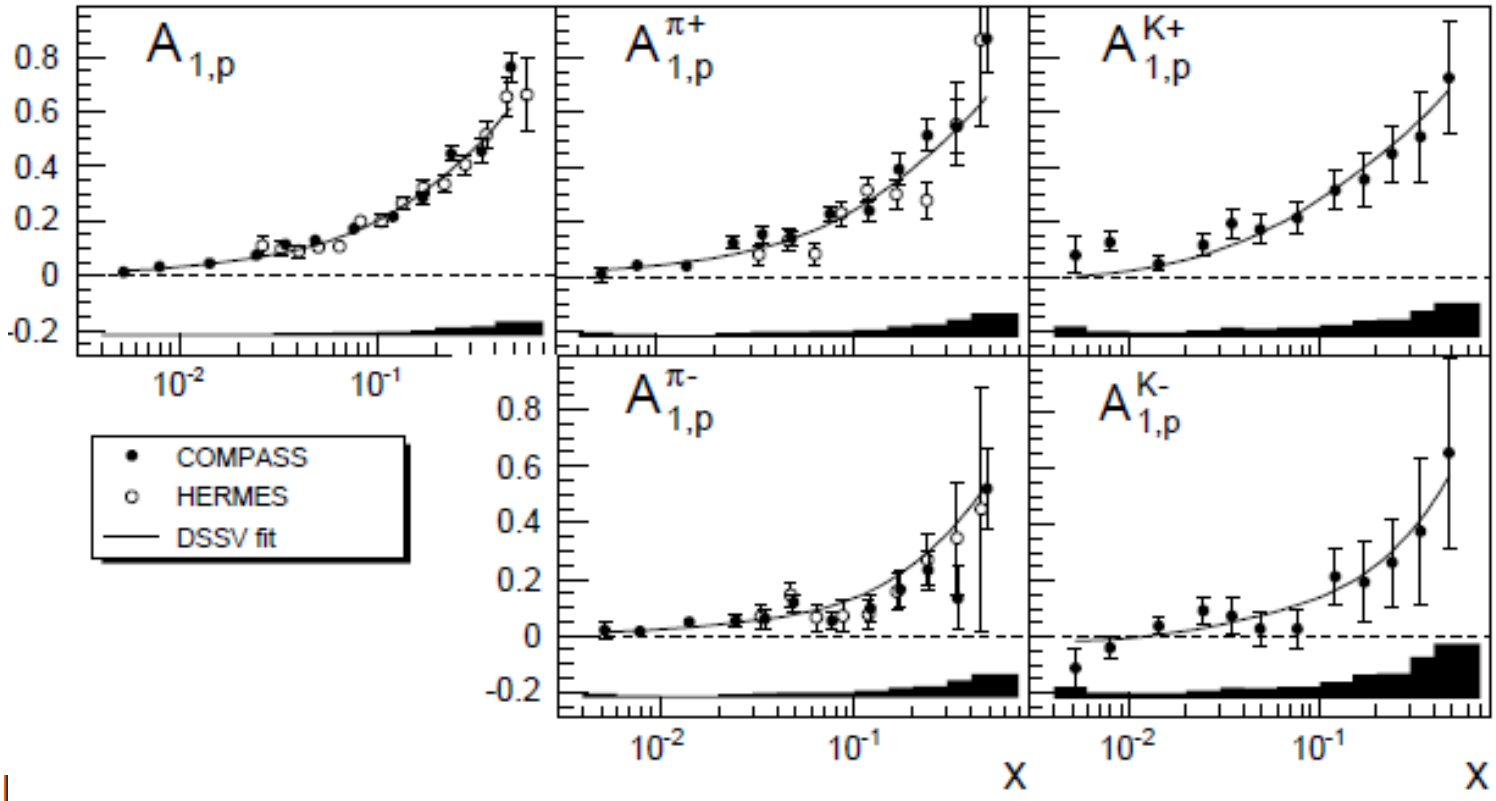
Polarized SIDIS: Sensitivity to Quark and Sea-Quark Distributions

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

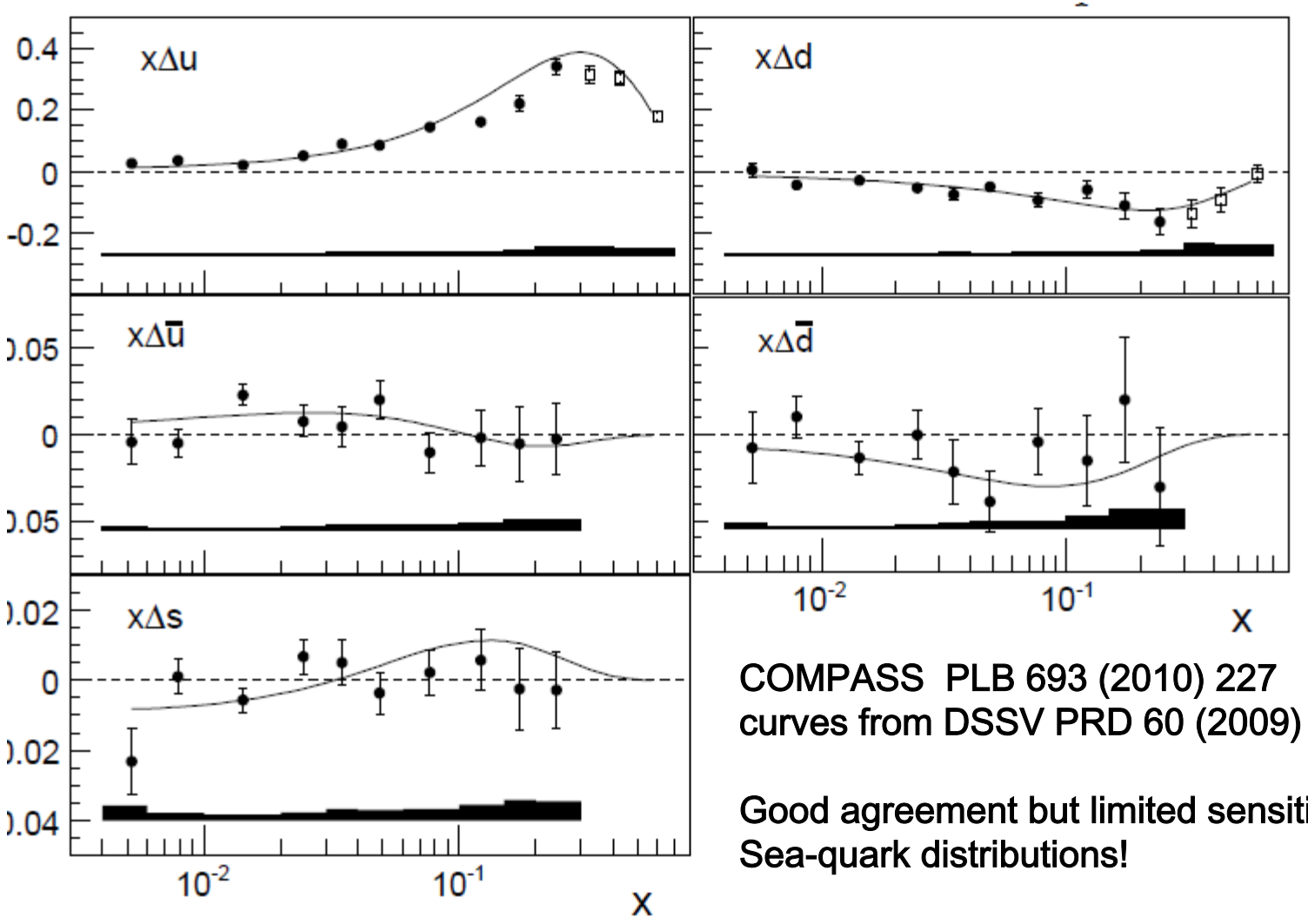
$h = \pi^{+,-}, K^{+,-}, inclusive$

unknown: $\Delta u, \Delta d, \Delta\bar{u}, \Delta\bar{d}, \Delta s$

COMPASS & HERMES proton data



Polarized SIDIS: Sensitivity to Quark and Sea-Quark Distributions

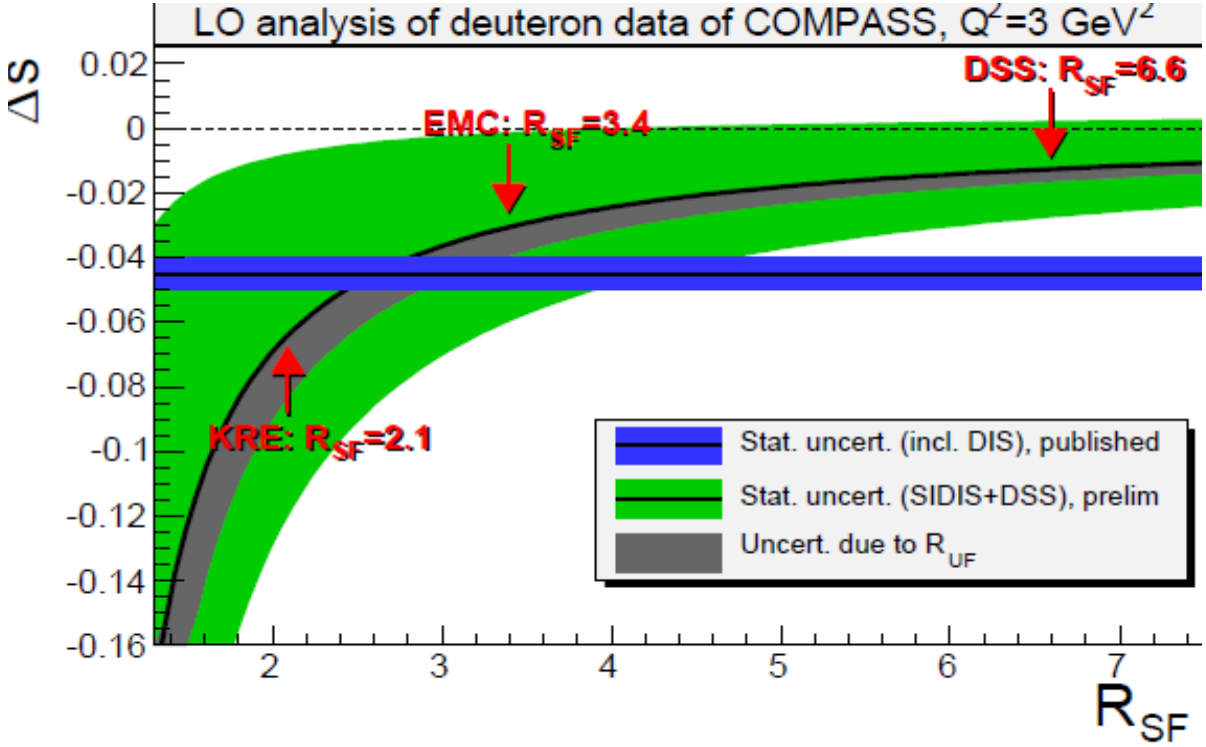


COMPASS PLB 693 (2010) 227
curves from DSSV PRD 60 (2009) 034030

Good agreement but limited sensitivity for Sea-quark distributions!

Polarized SIDIS: Strange Sea Polarization vs Kaon FF

- $2\Delta S = \int_0^1 [\Delta s(x) + \Delta\bar{s}(x)]dx$ is negative from A_1 $\rightarrow 2\,\Delta S = -0.09 \pm 0.01 \pm 0.02$
- ΔS obtained in SIDIS depends strongly on choice of FFs
- $R_{SF} = {D_s}^{K-}/{D_{\bar{u}}}^{K-} = {D_{\bar{s}}}^{K+}/{D_u}^{K+}$ is especially important



Information from e^+e^- on Hadron FFs for Extraction of Quark-Gluon Structure in Inclusive SIDIS (and pp)

Example: extraction of the quark helicity distributions from the QCD analysis of SIDIS data for A_1 with pions and kaons:

$$A_1^{\pi,K} \quad \text{in } l + p \longrightarrow (\pi, K) + X$$

From A_1^h to $\Delta q(x)$

extract

$$A_1^h(x, Q^2, z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

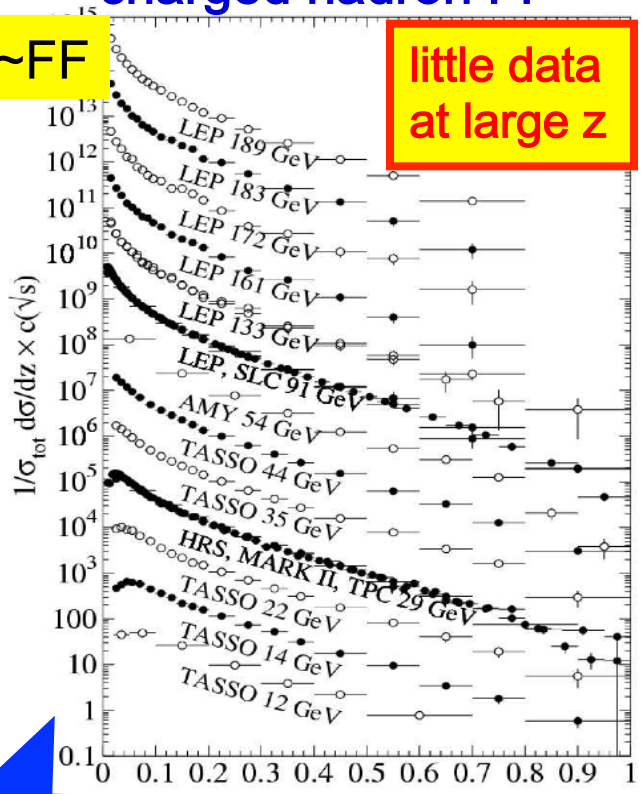
COMPASS

FFs partially from e^+e^-

e^+e^- information on charged hadron FF

~FF

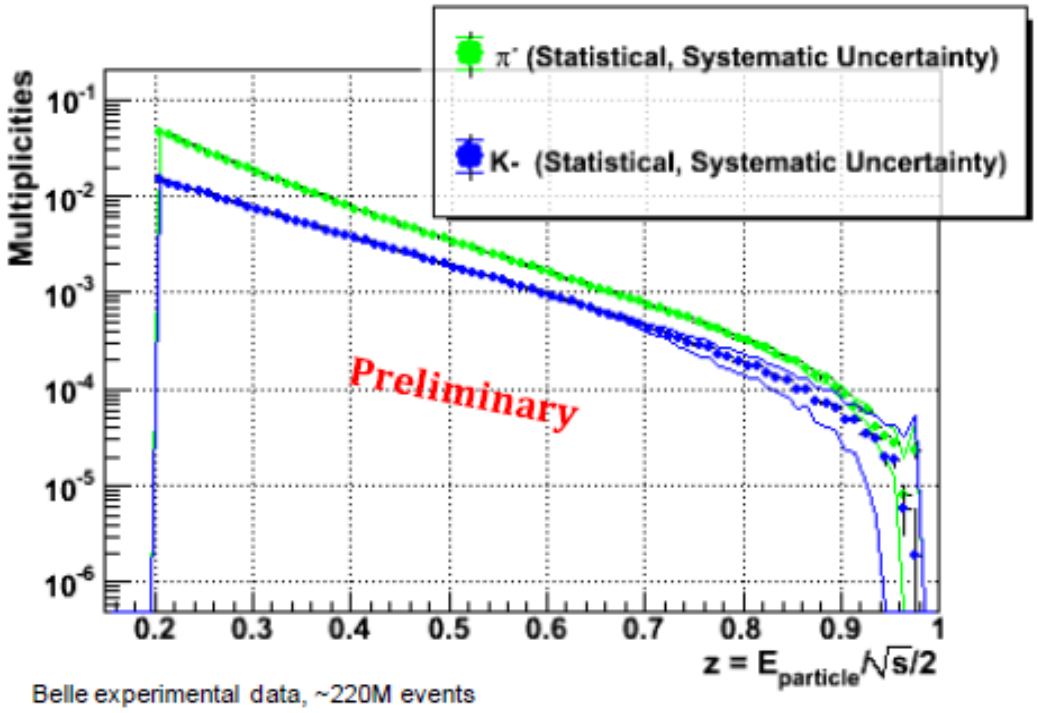
little data at large z



$$z = \frac{E^h}{\sqrt{s}/2}$$

Possible Improvement: Use Precision FF Information from e^+e^- in Belle

Belle: Charged $h^{+/-}$, pions, kaons,



Belle experimental data, ~220M events

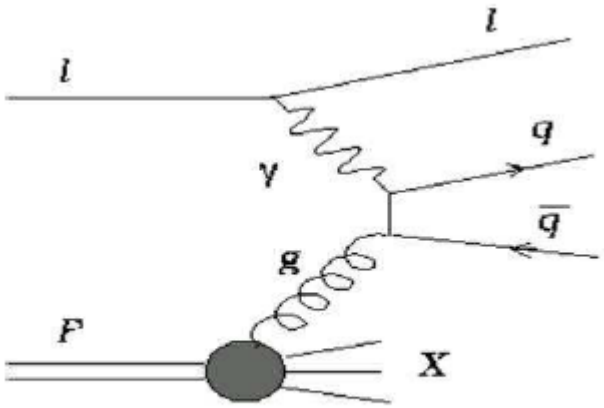
Systematic uncertainties: z ~0.6: 1% (2%) for π (K);
z ~0.9: 14% (50%) for π (K)

Preliminary Belle result for negative pions and kaons
(Martin Leitgab for Belle at DIS)

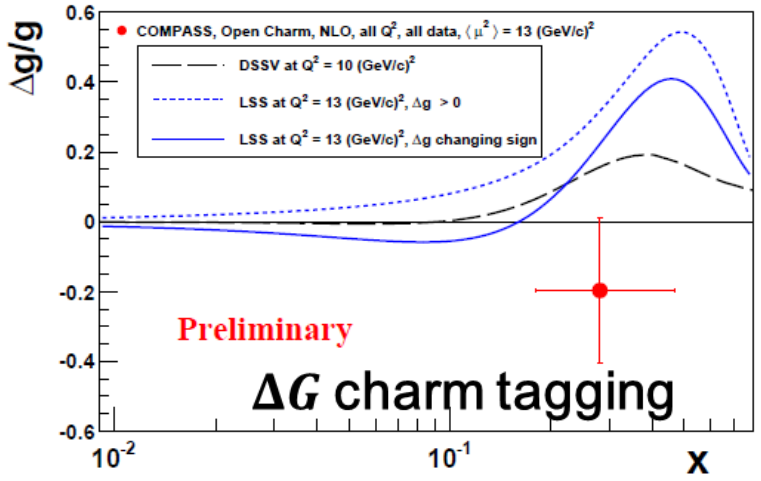
√s=10.52 GeV

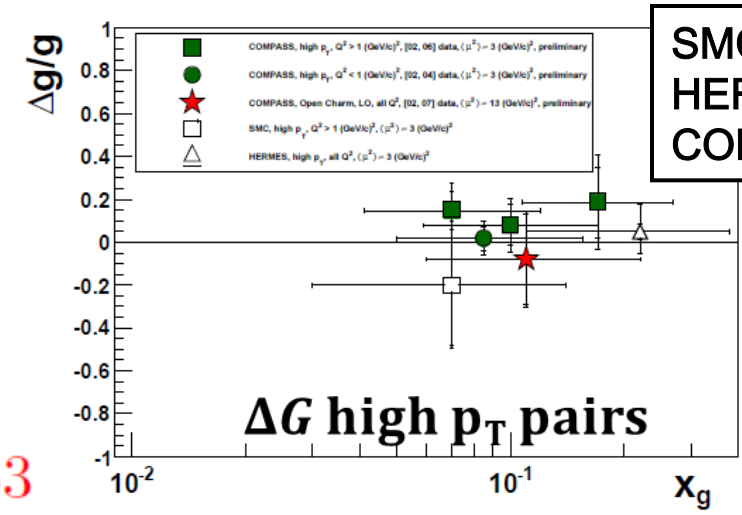
Pions
Kaons

Constraining $\Delta G(x, Q^2)$ in SIDIS/COMPASS through Photon Gluon Fusion



Photon Gluon Fusion: PGF





SMC
HERMES
COMPASS

Experimentally (LO):

(a) tag charm (D-Meson)

$$\Delta G/G = -0.08 \pm 0.21 \pm 0.11$$

(b) high p_T hadron pairs

$$\Delta G/G = 0.125 \pm 0.060 \pm 0.063$$

Experimental Access to Helicity Parton Distributions: polarized pp

Inclusive polarized proton-proton scattering (pp)

$$p + p \rightarrow (h, jet) + X \quad \text{and} \quad p + p \xrightarrow{W \rightarrow l\nu} l + X$$

Observables: $A_{LL}^{h,jet}$ spin dep. cross sec. asymmetries for hadron or jet prod.

$A_L^{W \rightarrow l\nu}$ single spin asymmetry for cross. sec. in W-prod.

QCD analysis of $A_{LL}^{h,jet}(x, Q^2)$ constrain $\Delta G(x, Q^2)$ and

QCD analysis of $A_L^{W \rightarrow l\nu}(x, Q^2)$ constrain $\Delta q(x, Q^2)$ and $\Delta \bar{q}(x, Q^2)$.

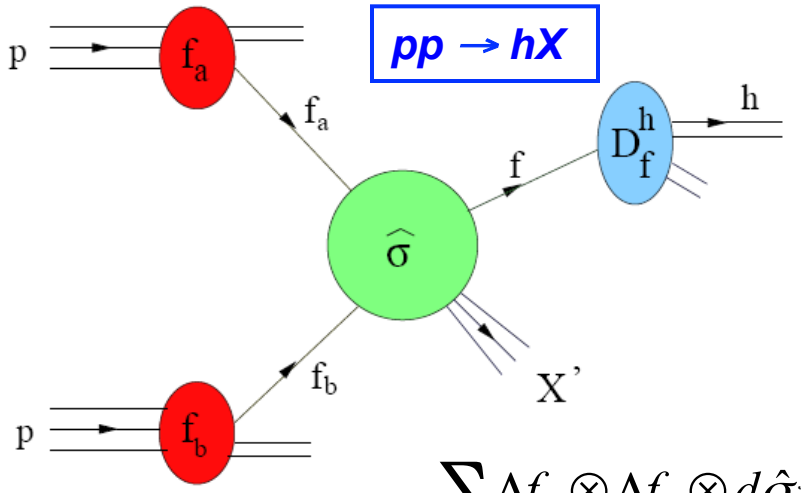
Polarized pp

o determine quark, anti-quark and gluon helicity distributions

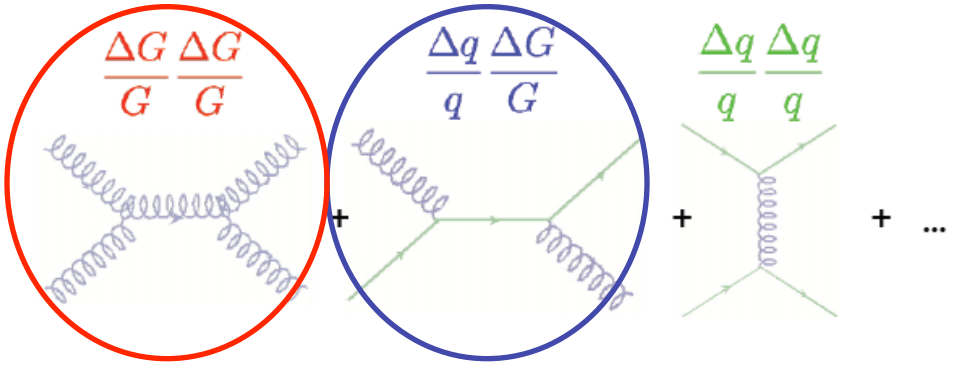
➔ proton spin decomposition

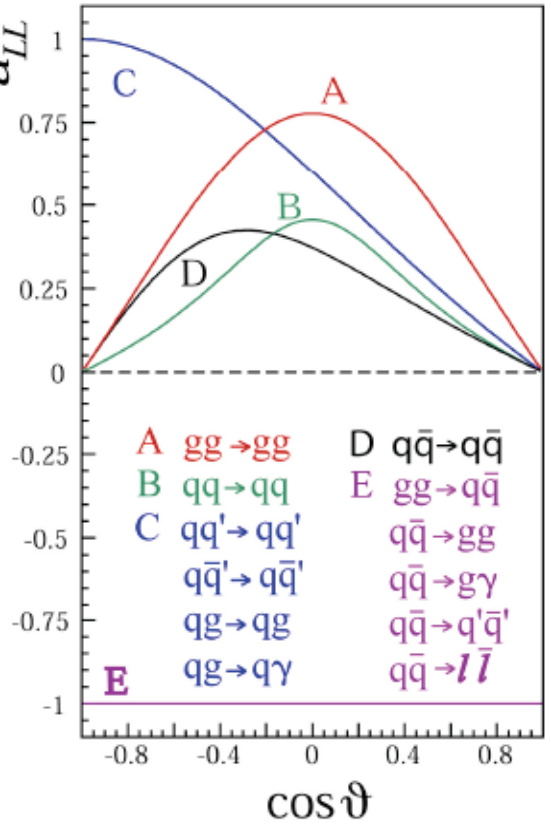
o test asymptotic behavior of helicity distributions

Probing ΔG in Polarized pp Collisions



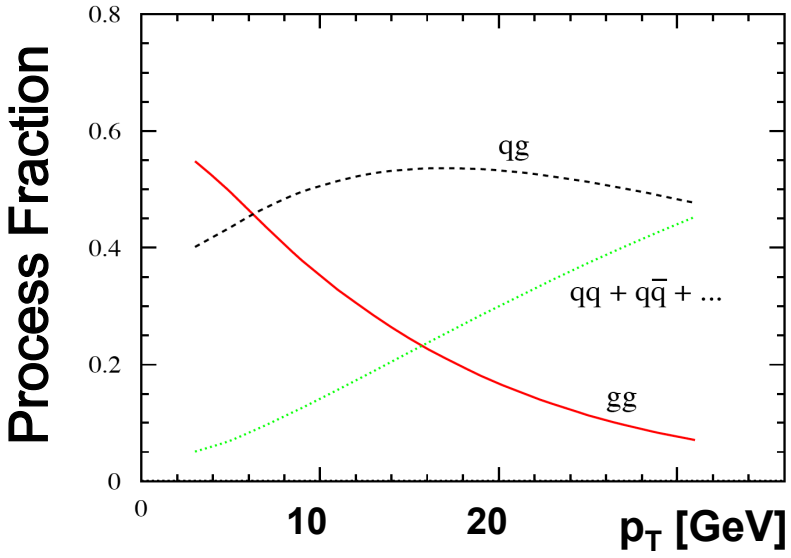
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$



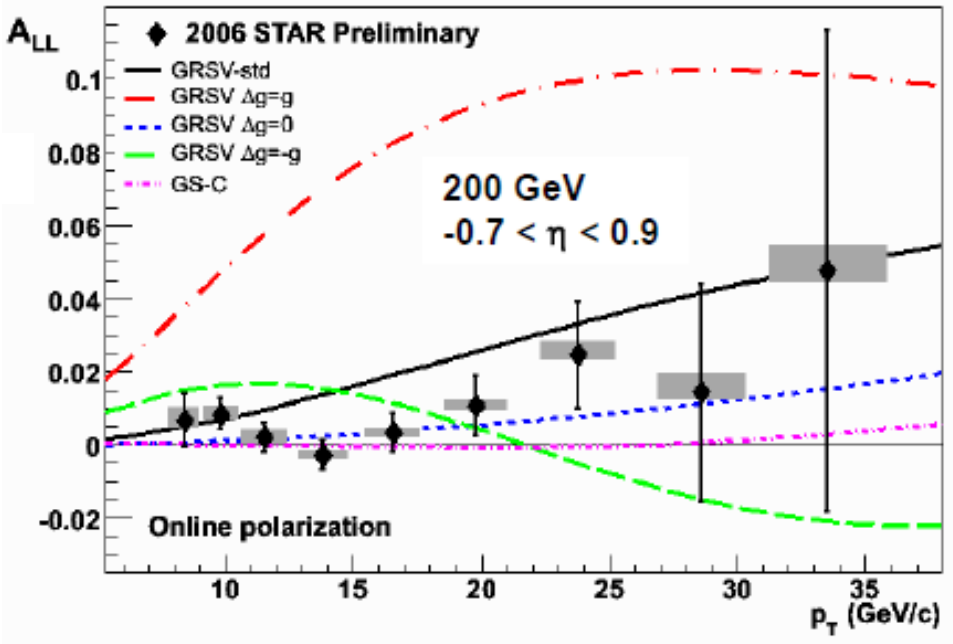


Double longitudinal spin asymmetry A_{LL} is sensitive to ΔG

Double Spin Asymmetries A_{LL} for Inclusive Jets Observed with STAR



STAR Preliminary Run6 , √s=200 GeV

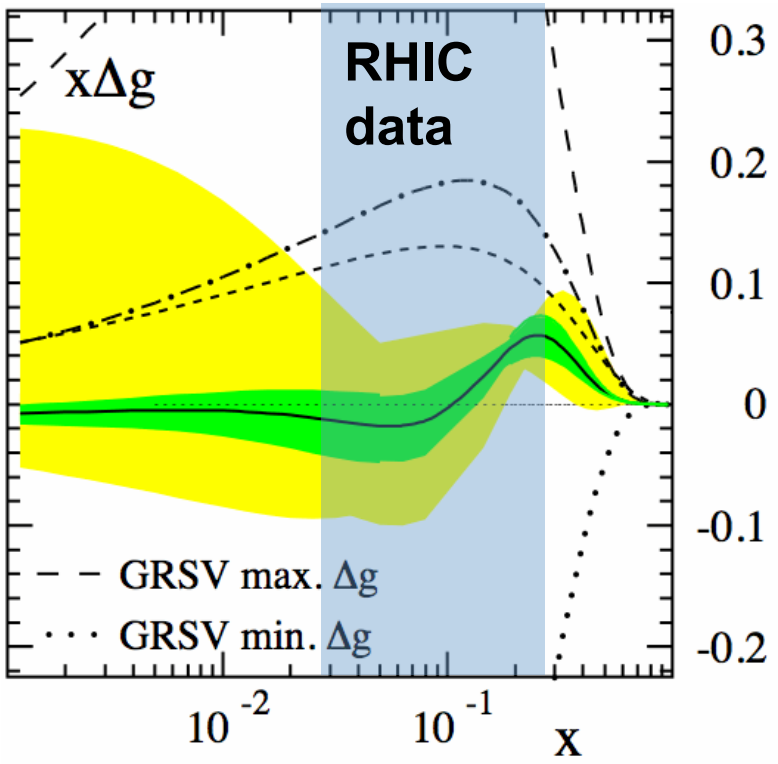


Good discriminative power between calculations with different assumption for ΔG

ΔG: Global QCD Based Fit

DSSV:
Daniel de Florian
Rodolfo Sassot
Marco Stratmann
Werner Vogelsang

- Phys. Rev. Lett. 101, 072001(2008)
- First truly global analysis of all available polarized data including RHIC results



A node?

Uncertainty estimation:

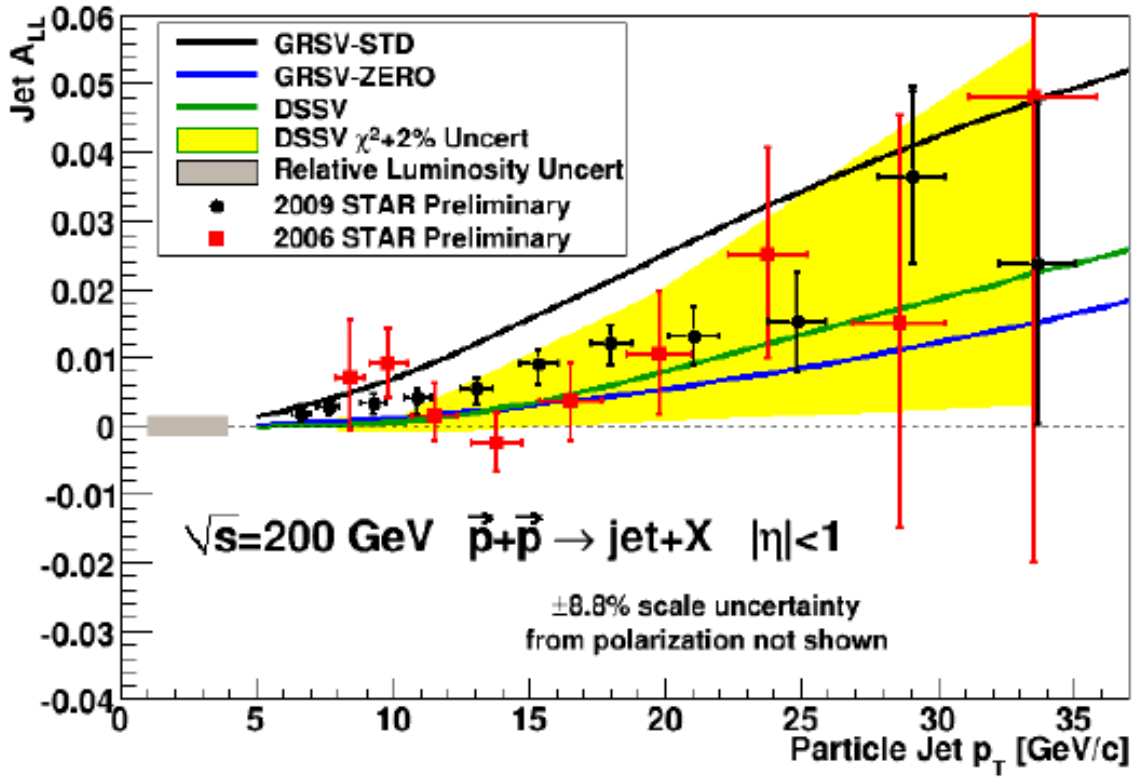
$\Delta\chi^2=1$

$\Delta\chi^2/\chi^2=2\%$

TABLE II. First moments $\Delta f_j^{1,[x_{\min}\to 1]}$ at $Q^2 = 10$ GeV^2.

	$x_{\min}=0$ best fit	$x_{\min}=0.001$ $\Delta\chi^2=1$	$x_{\min}=0.001$ $\Delta\chi^2/\chi^2=2\%$
$\Delta u+\Delta\bar{u}$	0.813	$0.793^{+0.011}_{-0.012}$	$0.793^{+0.028}_{-0.034}$
$\Delta d+\Delta\bar{d}$	−0.458	$-0.416^{+0.011}_{-0.009}$	$-0.416^{+0.035}_{-0.025}$
$\Delta\bar{u}$	0.036	$0.028^{+0.021}_{-0.020}$	$0.028^{+0.059}_{-0.059}$
$\Delta\bar{d}$	−0.115	$-0.089^{+0.029}_{-0.029}$	$-0.089^{+0.090}_{-0.080}$
$\Delta\bar{s}$	−0.057	$-0.006^{+0.010}_{-0.012}$	$-0.006^{+0.028}_{-0.031}$
Δg	−0.084	$0.013^{+0.106}_{-0.120}$	$0.013^{+0.702}_{-0.314}$
$\Delta\Sigma$	0.242	$0.366^{+0.015}_{-0.018}$	$0.366^{+0.042}_{-0.062}$

Run 9 Jet A_{LL} : STAR Preliminary



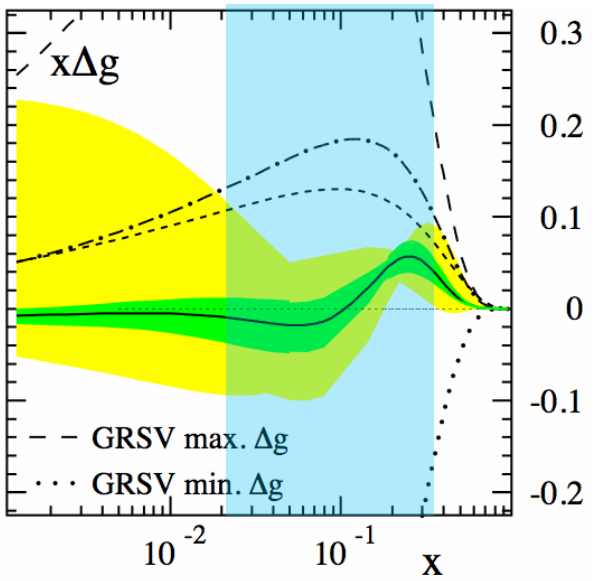
Run9:

×3-4 smaller stat. uncertainties than in Run6:

- ✓ **Trigger upgrade**
- ✓ DAQ upgrade (increased rate, lower E_T threshold)

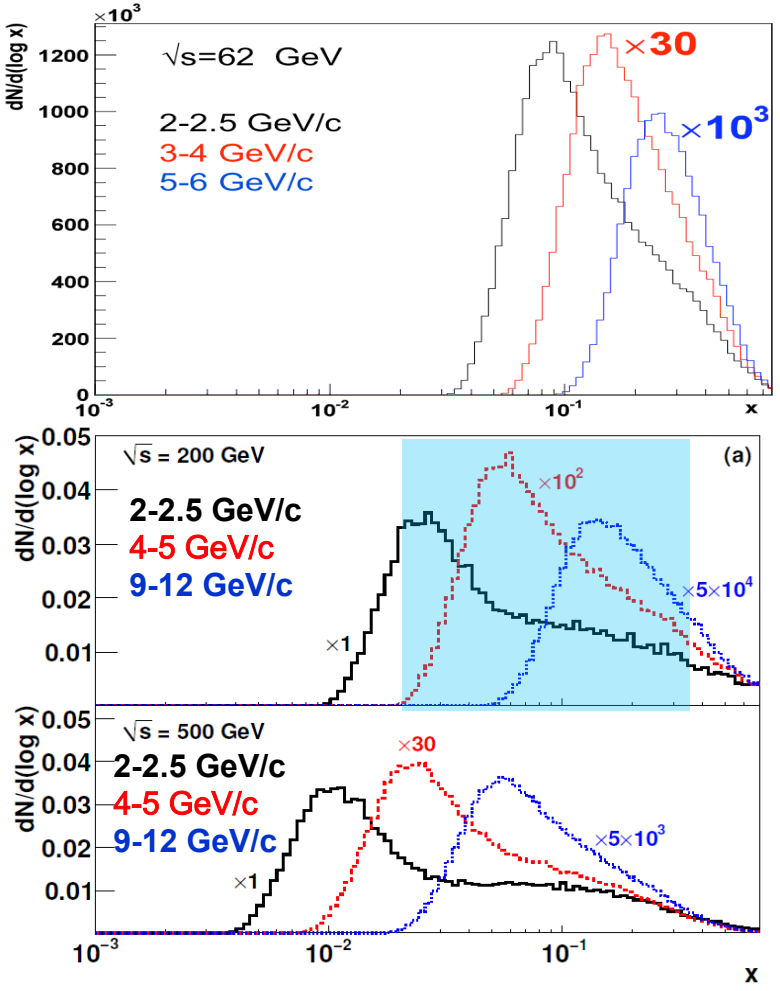
STAR Run 9 data suggest positive ΔG~0.1. These measurements will be continued in parallel to the W-data taking and the large **statistic for the W-sample will lead to a precise measurements of A_{LL} !**

Extend x-Range ⇒ Different √s



⇐

π^0 at $|\eta|<0.35$: x_g distribution vs p_T bin

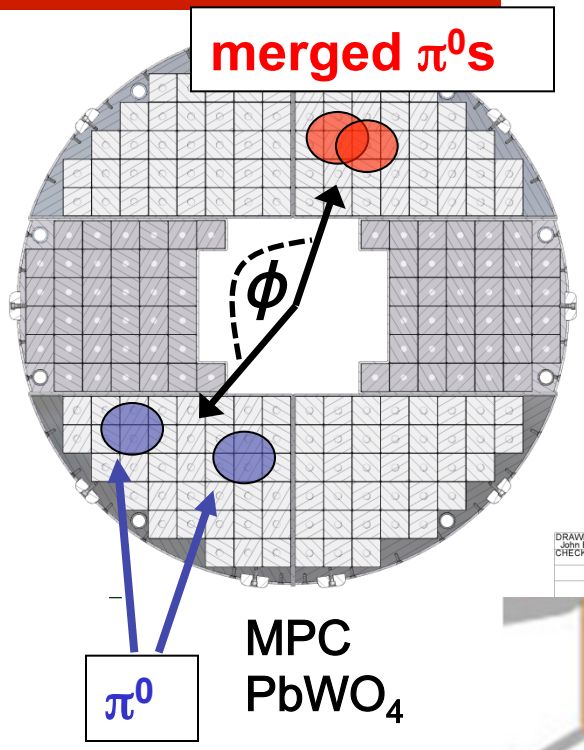


√s=62 GeV

√s=200 GeV

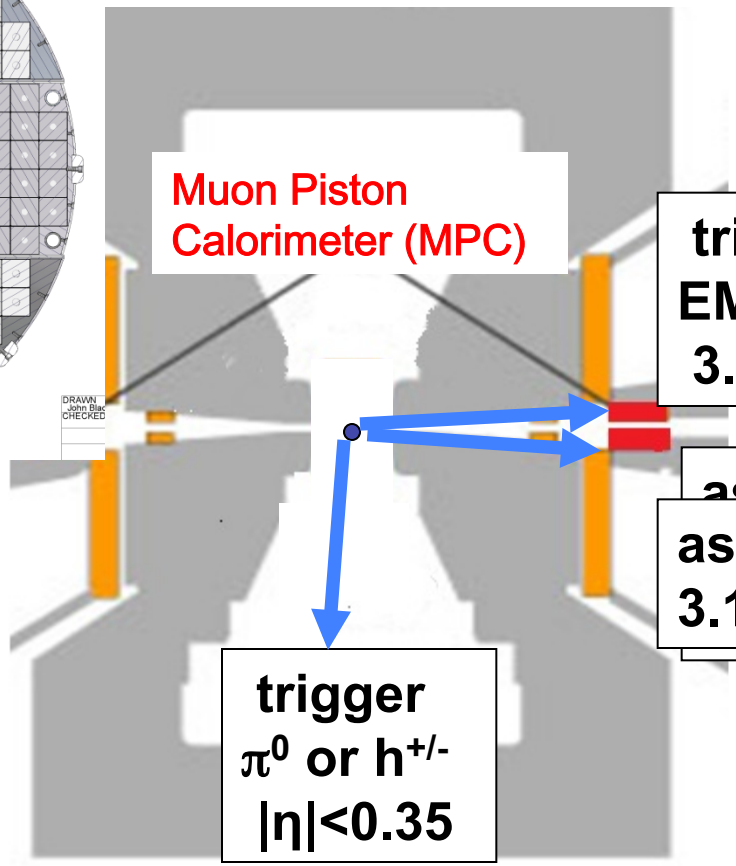
√s=500 GeV

Probing Low x Through Forward Di-Hadrons



mid-fwd x_{gluon} ~ 10^{-2}

fwd-fwd x_{gluon} ~ 10^{-4}-10^{-3}



p

Backward direction
(South) ←

Forward direction
(North) →

Side View

PHENIX Muon Piston Calorimeter

Technology → ALICE(PHOS)

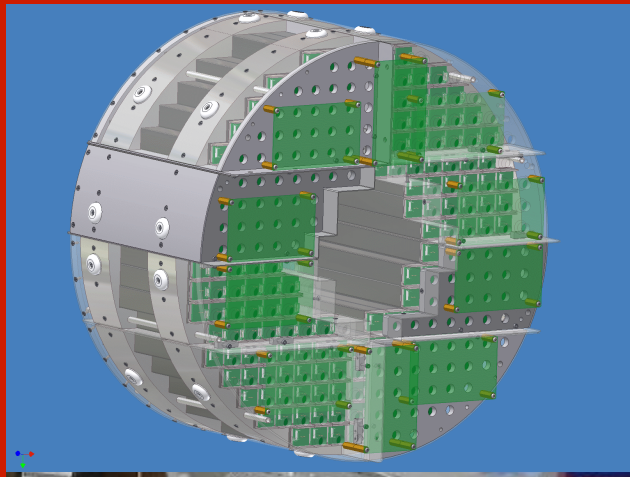
$PbWO_4$

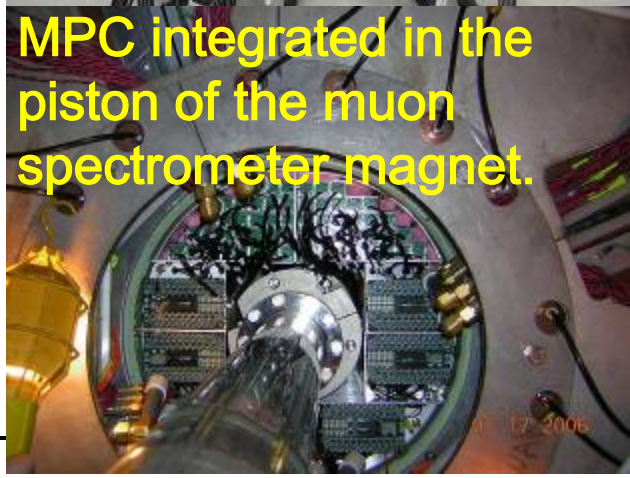
avalanche photo diode readout

Acceptance:

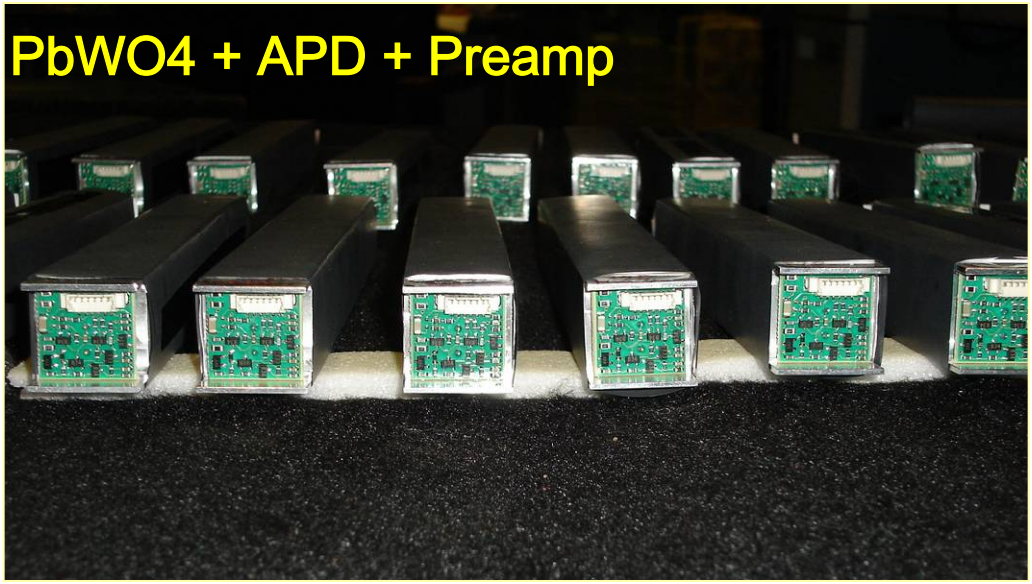
$3.1 < \eta < 3.9,\ 0 < \varphi < 2\pi$

$-3.7 < \eta < -3.1,\ 0 < \varphi < 2\pi$

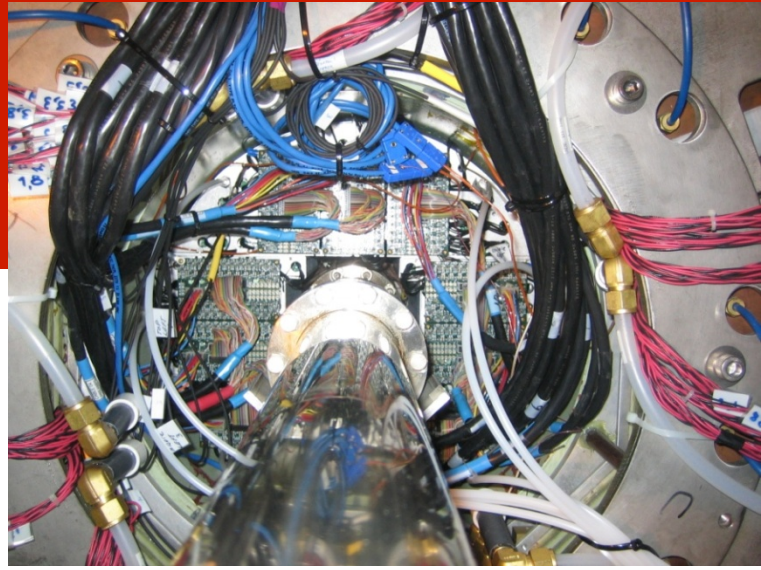




Both detectors were installed for 2008 d-Au run.



ΔG at low x

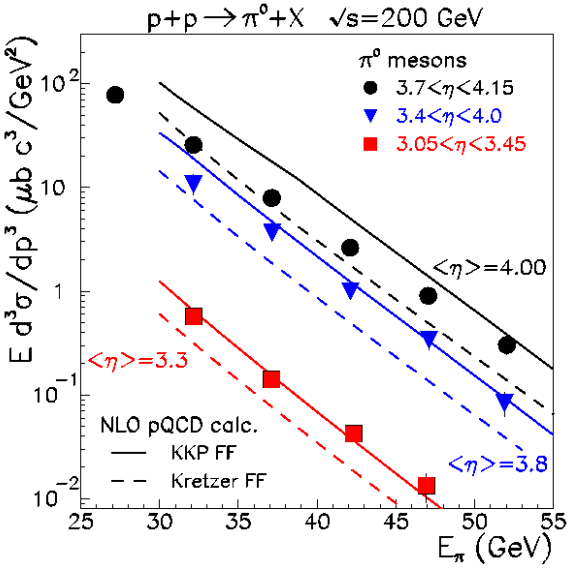


Muon Piston Calorimeter (MPC): $PbWO_4$

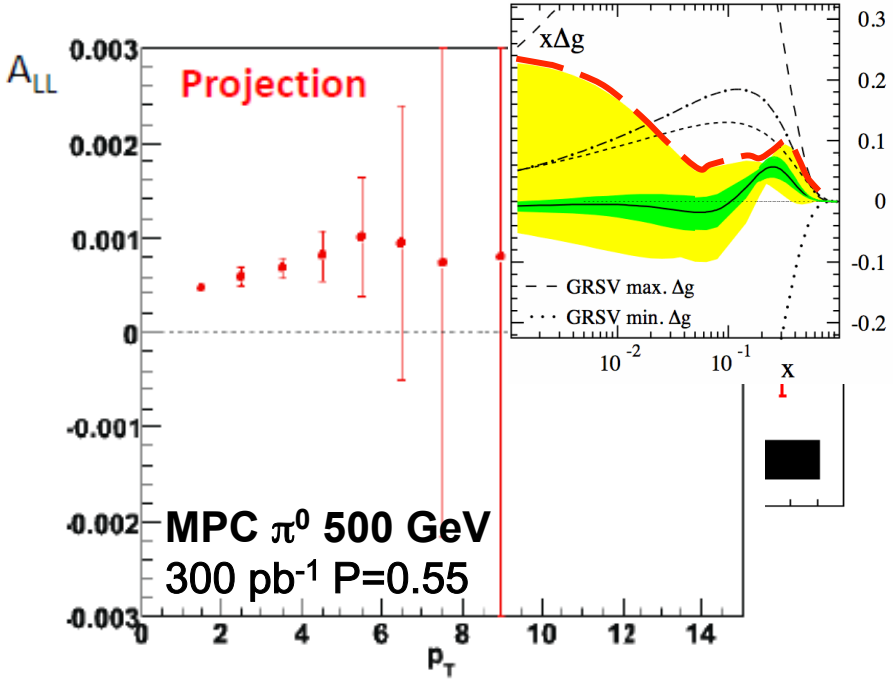
- $3.1 < |\eta| < 3.9$, 2π azimuth
- Gives access to lower: $x \rightarrow 10^{-3}$
- Fully available from 2008

STAR: π^0 forward rapidity

PRL 97, 152302



pQCD seems working even at forward rapidities



Summary Helicity Experiment

Much progress still needed:

- gluon distribution, gluon spin contribution
- reliable flavor decomposition of quark spin distribution
- strange polarization
- measure high x-region at large Q^2

- only EIC can
  - ➔ extend kinematics to low x and high Q^2
  - ➔ carry out measurements in current x-range with high statistical precision and at scales that will allow a model independent interpretation of the data

EIC: Helicity Structure, Wish List

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

Goals: (I) Precise measurements of **ΔΣ and ΔG and therefore total L_z**

present ΔΣ = 0.35 ∓ 0.06

➔ ∓ 0.02 ?

present ΔG = 0.1 0∓ 0.1 + extrapolation uncertainty

➔ ∓ 0.02 ?

QCD tests!

(II) Bjorken sumrule to 2% (factor 5 better than present) !

(III) g_1 evolution to 2%

(IV) Can L_z be directly accessed (in a model independent way)?

Helicity Structure ➔ Measurements

Inclusive:	g_1 (including evolution) and g_5 for proton and ^{3}He or d beams
Semi inclusive:	A_{LL} for identified charged pions and kaons
Exclusive:	DVCS
Jets:	A_{LL} for di-jets
Heavy flavor:	A_{LL} for D^0

➔Full acceptance detector with hadron pID capabilities, heavy flavor tagging, jet reconstruction, excellent momentum resolution, precise relative luminosity monitors and local polarimeters !

Helicity Structure ➔ Needs & Input

Absolute polarimeter: < 2% (both beams)

Local polarimeters: < 2% (both beams)

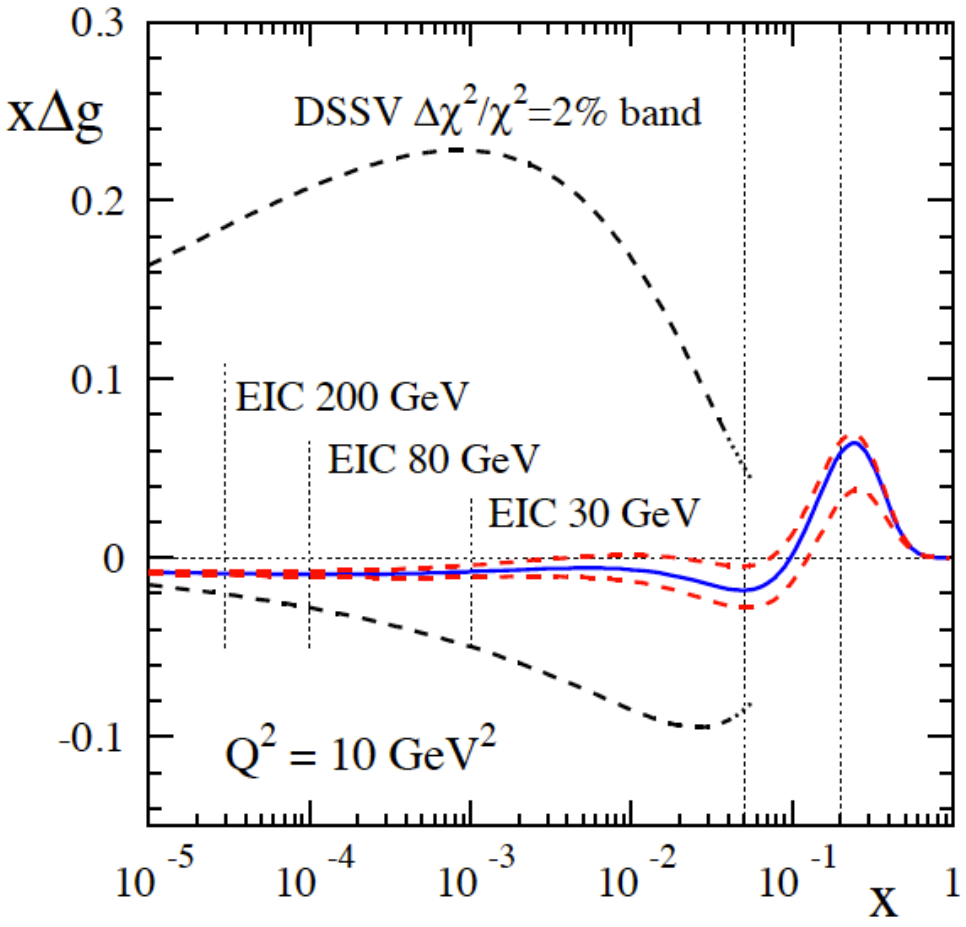
Extrapolation uncertainties: < 2%

pQCD framework for PDF extraction: test with cross section
➔ normalization (luminosity) to < 2%

Fragmentation functions: need to be know to < 2%

Control of radiative corrections: < 2%

$\Delta G(x)$ at EIC



Generalized Parton Distributions to Access Orbital Angular Momentum …

GPDs H^u, H^d, E^u, E^d provide access to total quark contribution to proton angular momentum in exclusive processes $l + N \rightarrow l' + N + \gamma$

Proton spin sum

$$\tfrac{1}{2} = \tfrac{1}{2}(\Delta u + \Delta d + \Delta s) + L_q + J_g$$

J^q

$$J^q = \frac{1}{2}\int_{-1}^{1} x\,dx \left[H^q(x,\xi,0) + E^q(x,\xi,0)\right]$$

X. Ji, Phy.Rev.Lett.78,610(1997)