The Gluon Contribution to the Nucleon Spin

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- **Introduction**
- **ΔG from scaling violations of $g_1(x,Q^2)$**
- **The Bjorken Sum Rule**
- **ΔG from charm production**

Where is the nucleon spin ?

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

~ 0.25

$q+\bar{q}$ spin contribution

Gluon spin contribution

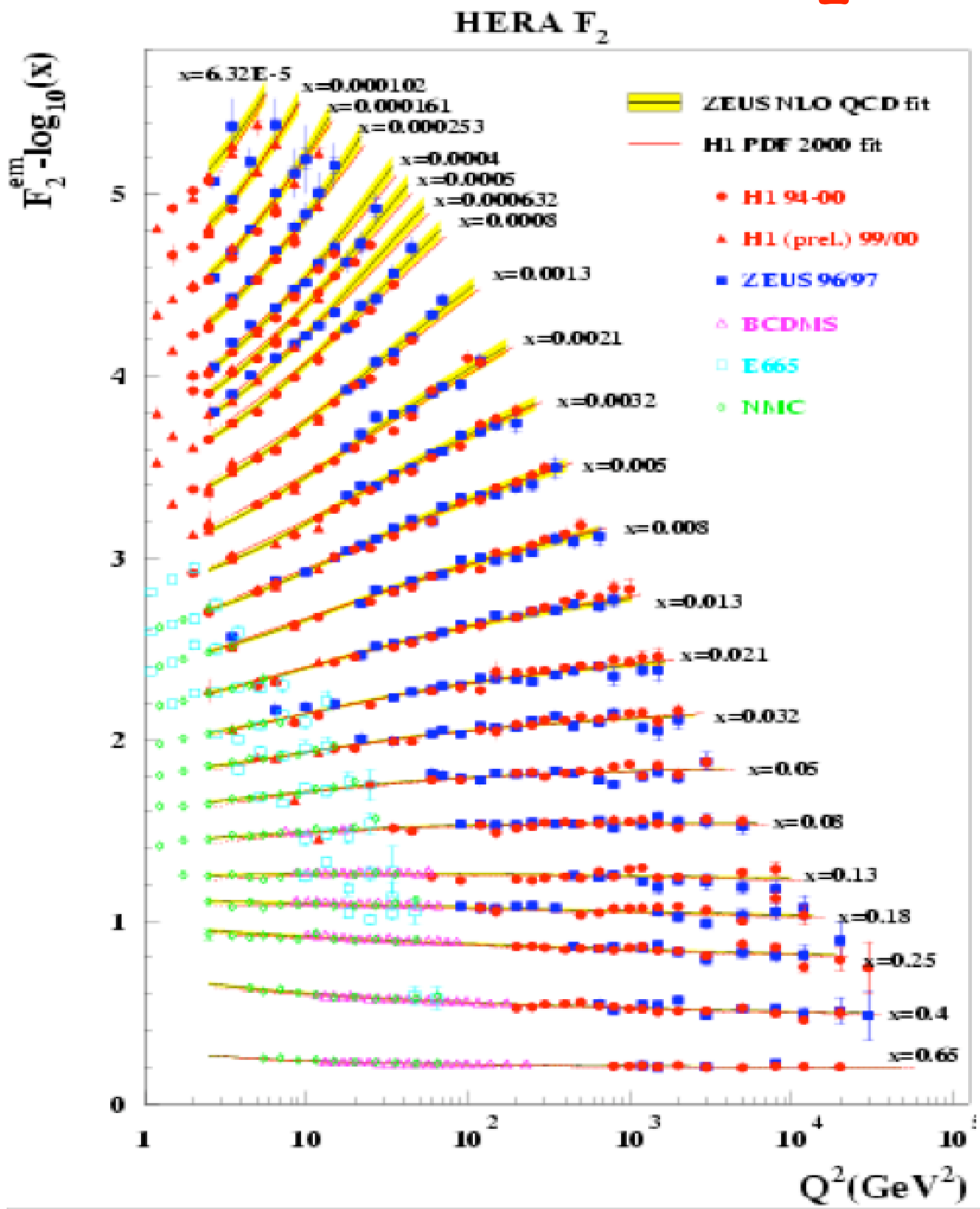
Orbital ang. momenta

$$\frac{1}{2}\int_0^1 dx\,[\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}]$$

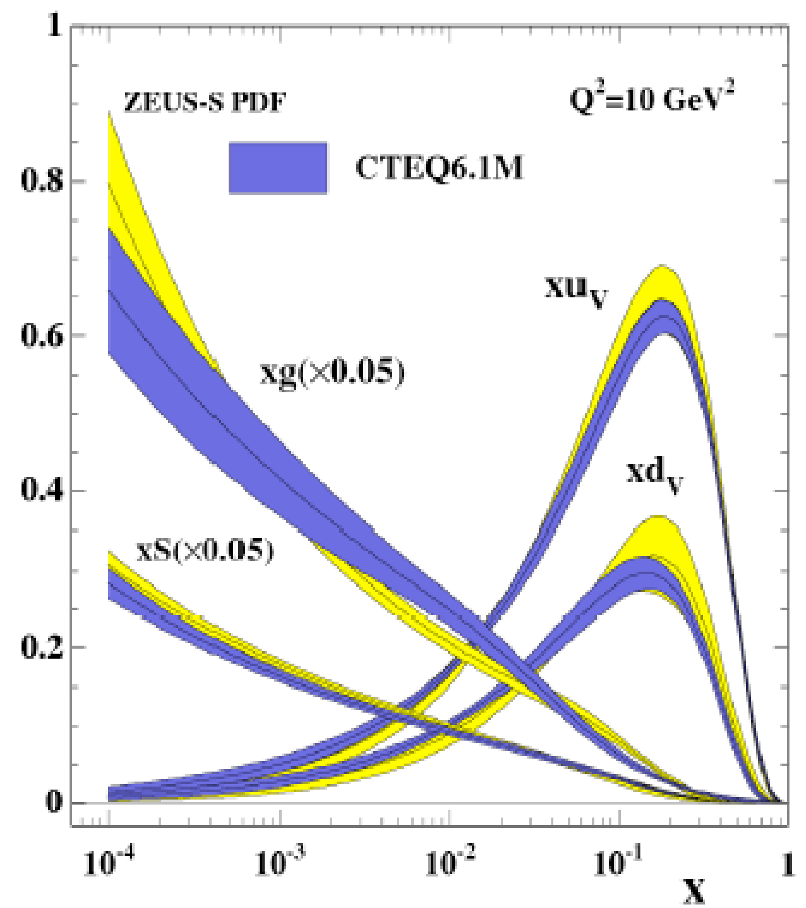
$$\int_0^1 dx\,\Delta g(x)$$

?

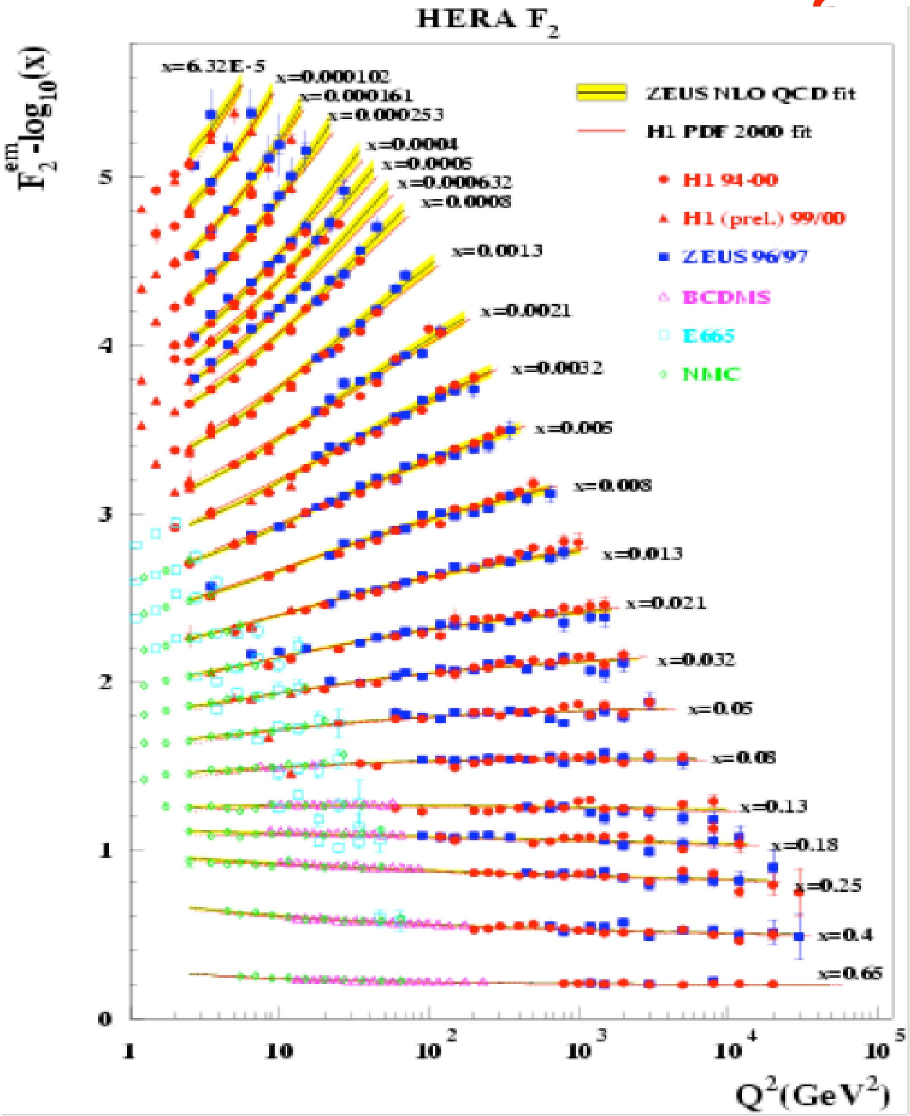
World Data on F_2^p Structure Function



Next-to-Leading-Order (NLO) perturbative QCD (DGLAP) fits

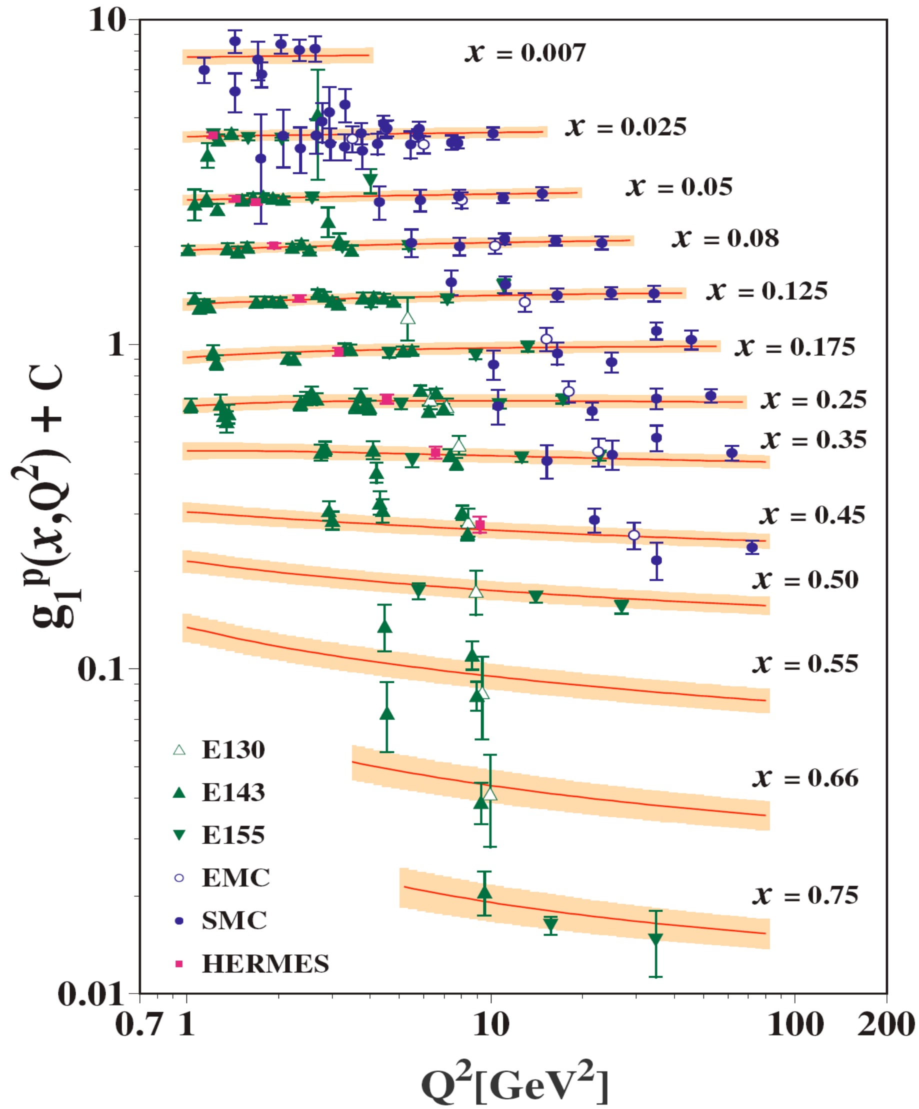


World Data on F_2^p



4 orders of magnitude in x and Q2

World Data on g_1^p

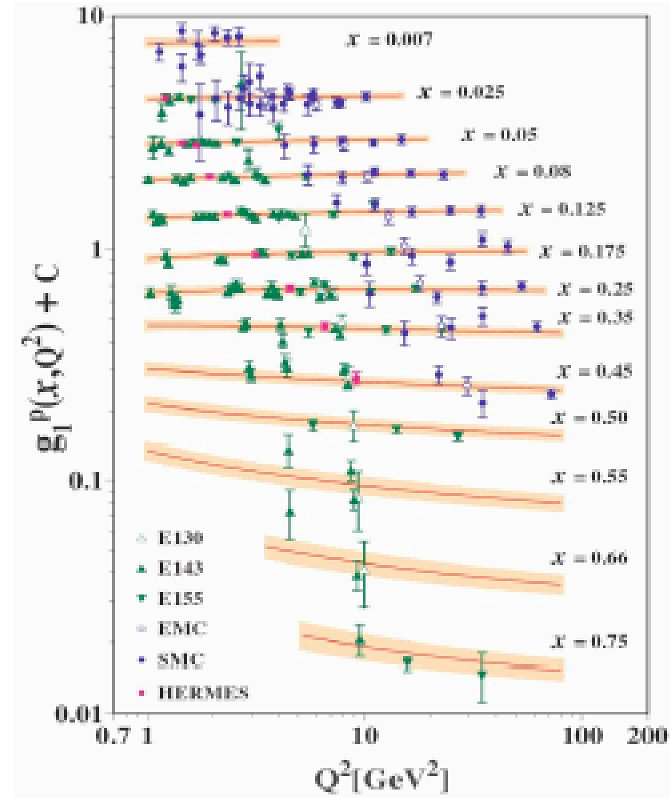


< 2 orders of magnitude, precision much worse !

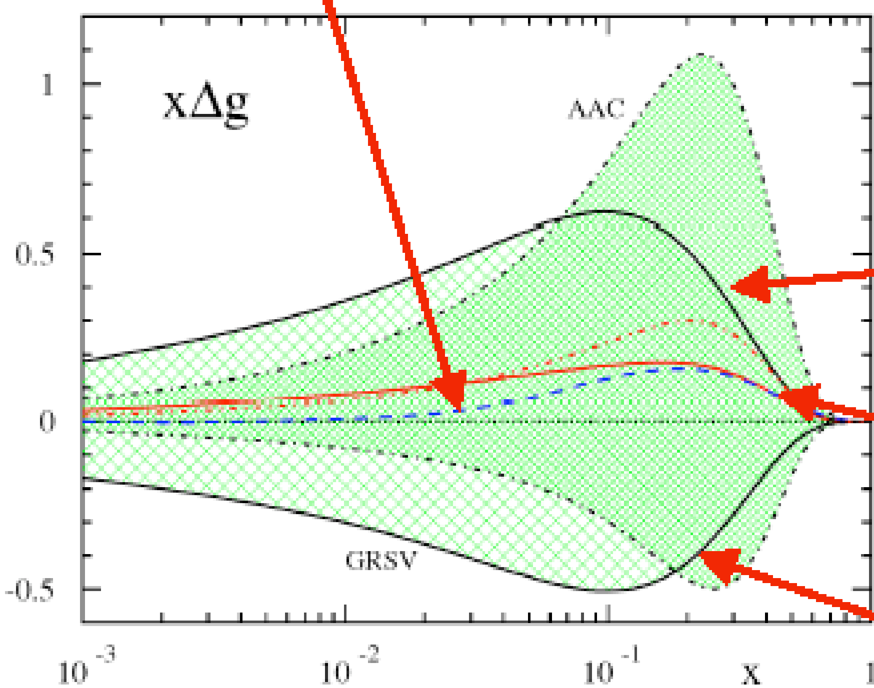
The gluon spin distribution Δg

Not much information until recently:

$$\frac{d\,g_1}{d\log(Q^2)} \propto \frac{\alpha_s}{2\pi} P_{qg} \otimes \Delta g(x, Q^2) \; + \; \text{quark contrib.}$$



Bag model Chen, Ji $\Delta G \approx 0.3$



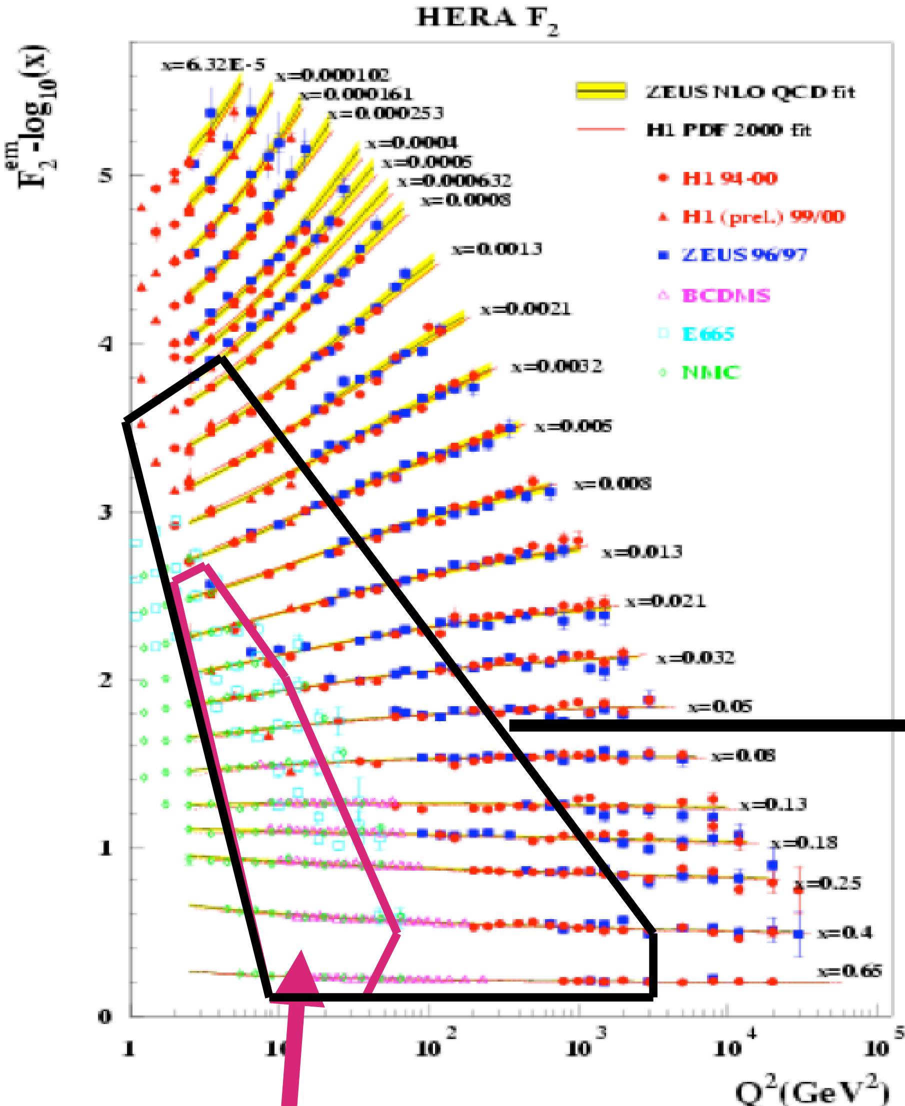
$\Delta G \approx 1.8 \; (@\,1\mathrm{GeV}^2)$

"axial anomaly" Altarelli et al.

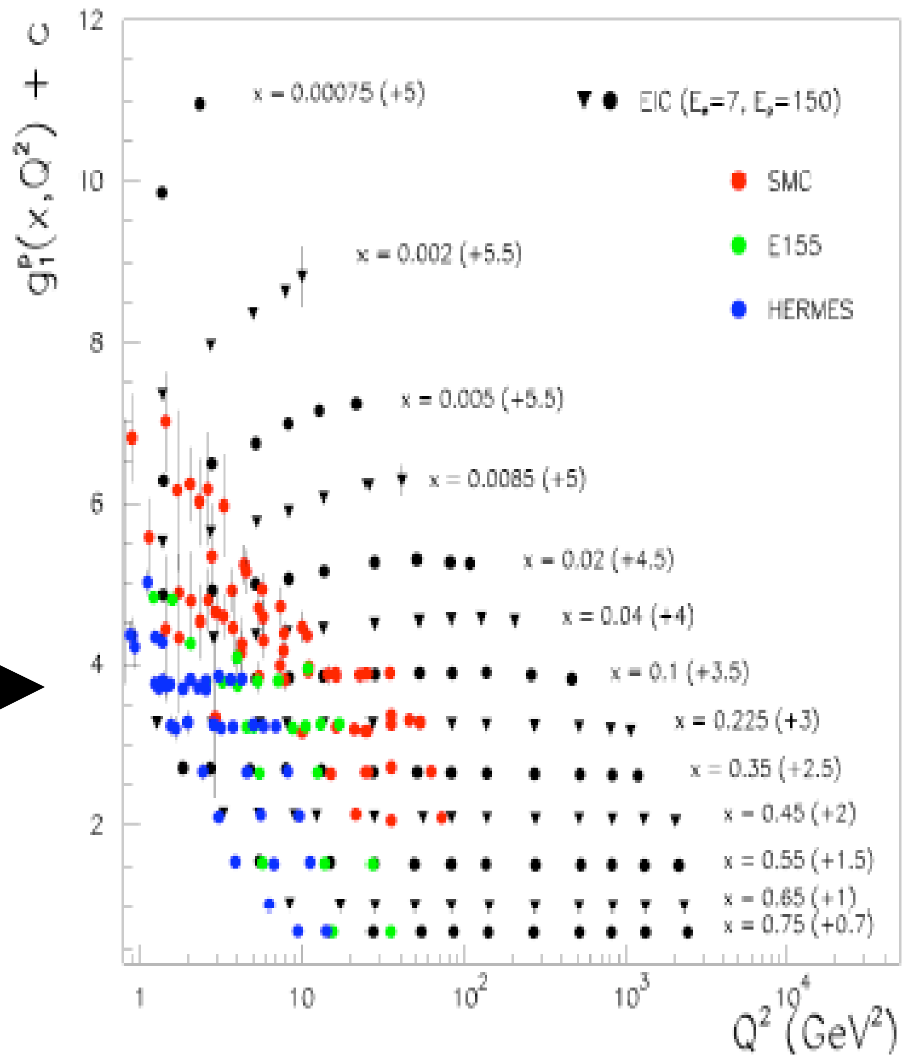
$\Delta G \approx 0.4$

$\Delta G \approx -1.7$

World Data on F_2^p



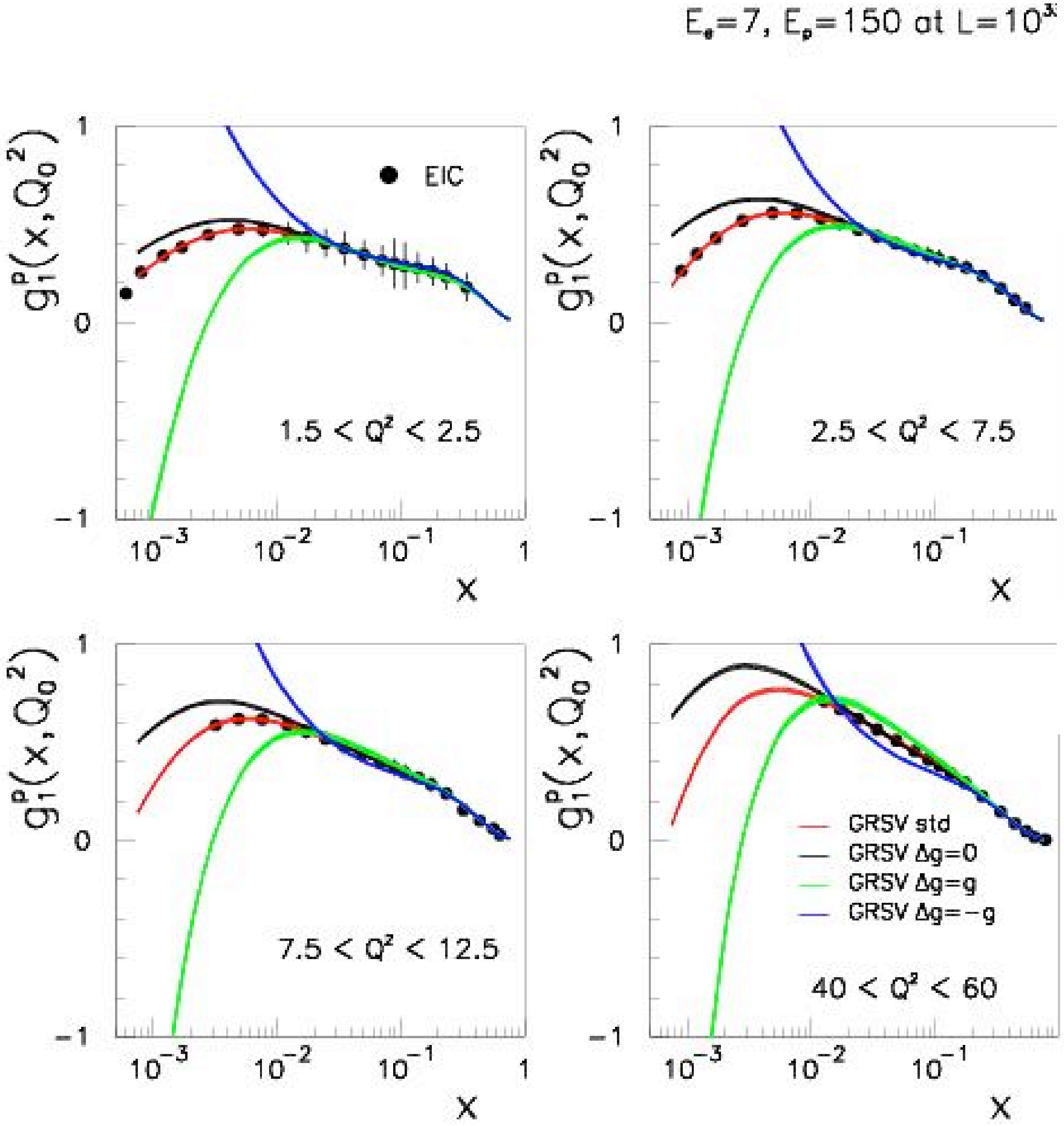
EIC Data on g_1^p

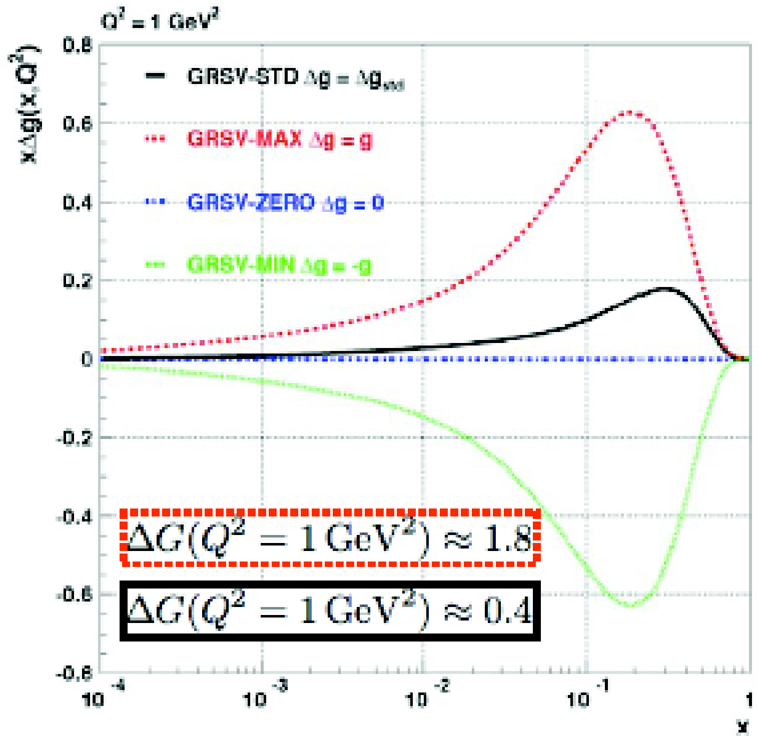


Region of existing g_1^p data

An EIC makes it possible!

ΔG from scaling violations of g_1





- **Bjorken's sum rule**

$$\int_0^1 \mathrm{d}x\, g_1^{ep-en}(x,Q^2) = \frac{1}{6}\frac{g_A}{g_V}\left\{1 - \frac{\alpha_s(Q^2)}{\pi} - \frac{43}{12}\frac{\alpha_s^2(Q^2)}{\pi^2} - 20.215\frac{\alpha_s^3(Q^2)}{\pi^3}\right\}$$

high-order perturbation theory

$$+ \frac{M^2}{Q^2}\int_0^1 x^2\,\mathrm{d}x \left\{\frac{2}{9}g_1^{ep-en}(x,Q^2) + \frac{1}{6}g_2^{ep-en}(x,Q^2)\right\}$$

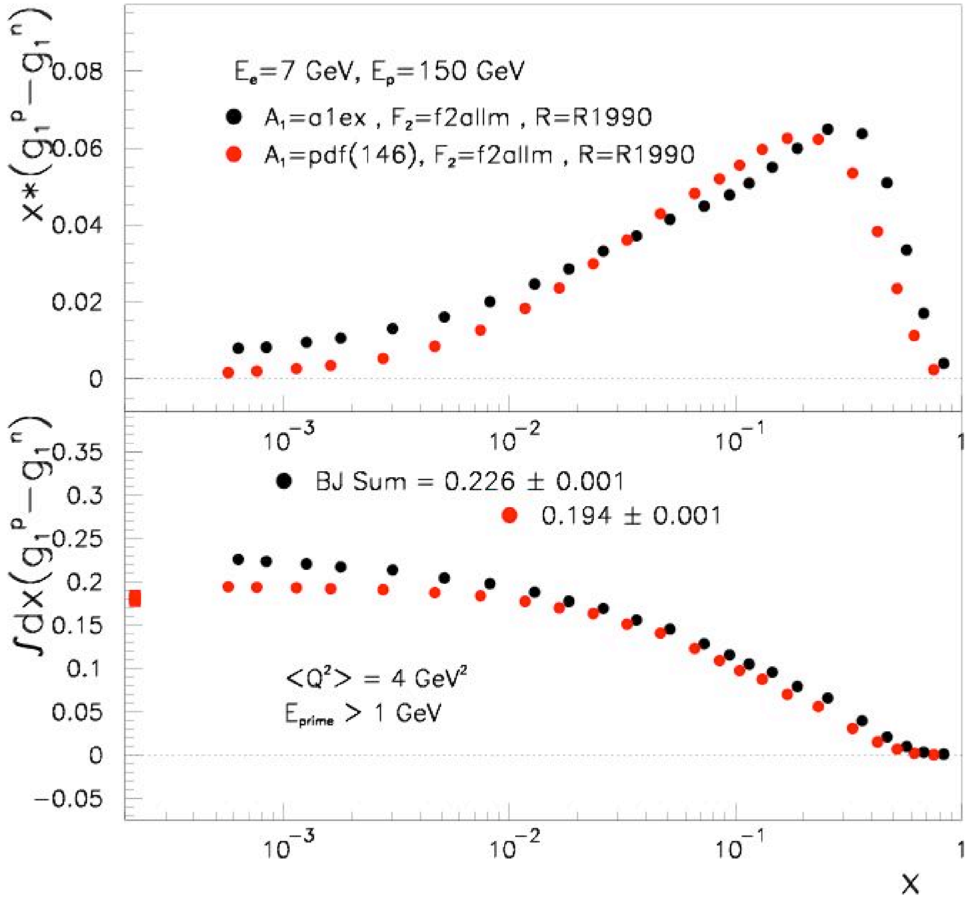
target-mass corrections

$$-\frac{1}{Q^2}\frac{4}{27}\mathcal{F}^{u-d}(Q^2)$$

Twist-4 matrix elements $\sim \langle \bar{q}\tilde{F}q \rangle$

- **Precision QCD. Currently tested at ~10%. Can it be tested at ~1 or 2% ?**

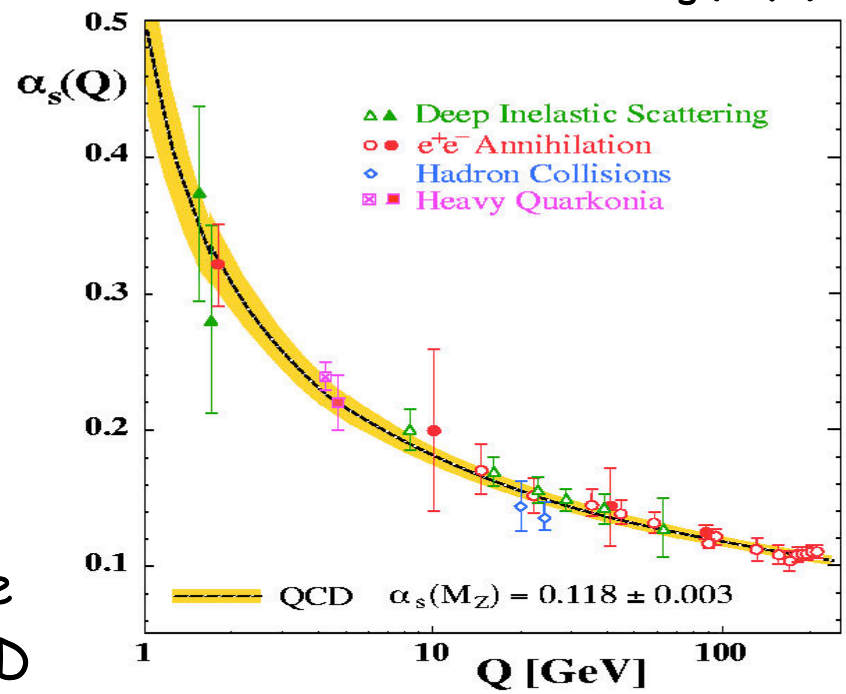
Bjorken Sum Rule: $\_{1}^{p}$ - $\_{1}^{n}$ = 1/6 g_A [1 + _(_$_s$)]



Needs:

O(1%) Ion Polarimetry!!!

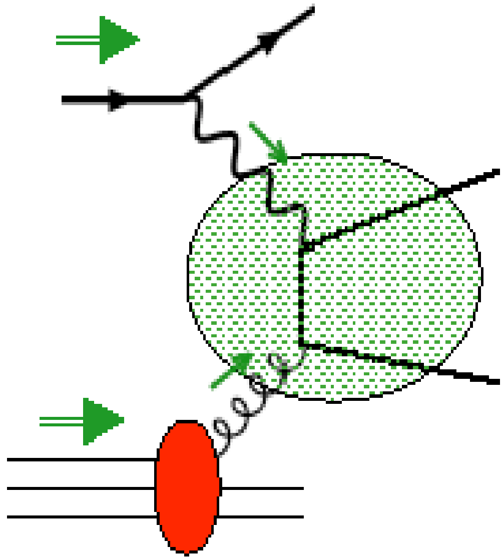
Holy Grail: excellent determination of $\alpha_s(Q^2)$



- Sub-1% statistical precision at ELIC (averaged over all Q^2)
- 7% (?) in unmeasured region, in future constrained by data and lattice QCD
- 3-4% precision at various values of Q^2

Polarized gluon distribution via charm production

very clean process !

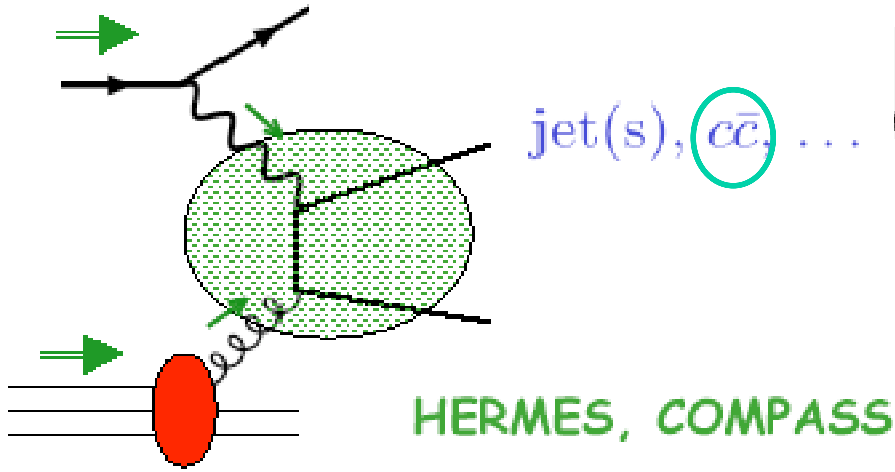


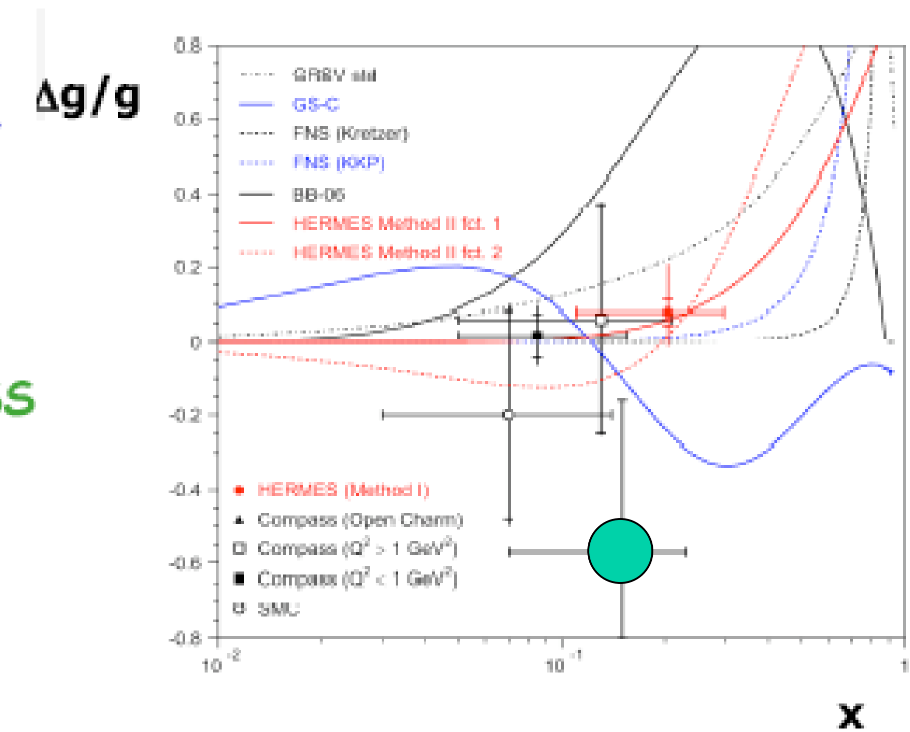
c ⟶ **D mesons**

$\bar{c}$ ⟶ **$\bar{D}$ mesons**

LO QCD: asymmetry in D production directly proportional to Δ G/G

Polarized gluon distribution via charm production





problems: luminosity, charm cross section, **background !**

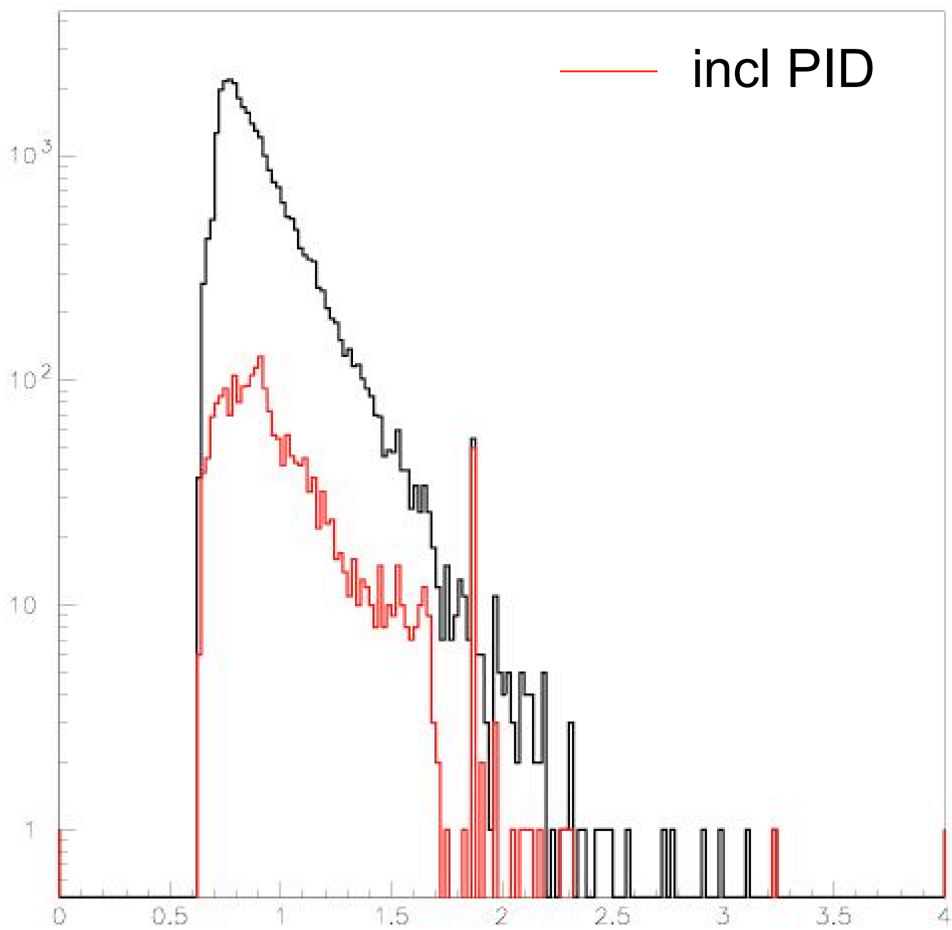
Polarized gluon distribution via charm production

starting assumptions for EIC:

- vertex separation of 100μm
- full angular coverage (3<Θ<177 degrees)
- perfect particle identification for pions and kaons (over full momentum range)
- detection of low momenta particles (p>0.5 GeV)
- measurement of scattered electron (even at very small scattering angles)
- 100% efficiency

very demanding detector requirements !

Polarized gluon distribution via charm production



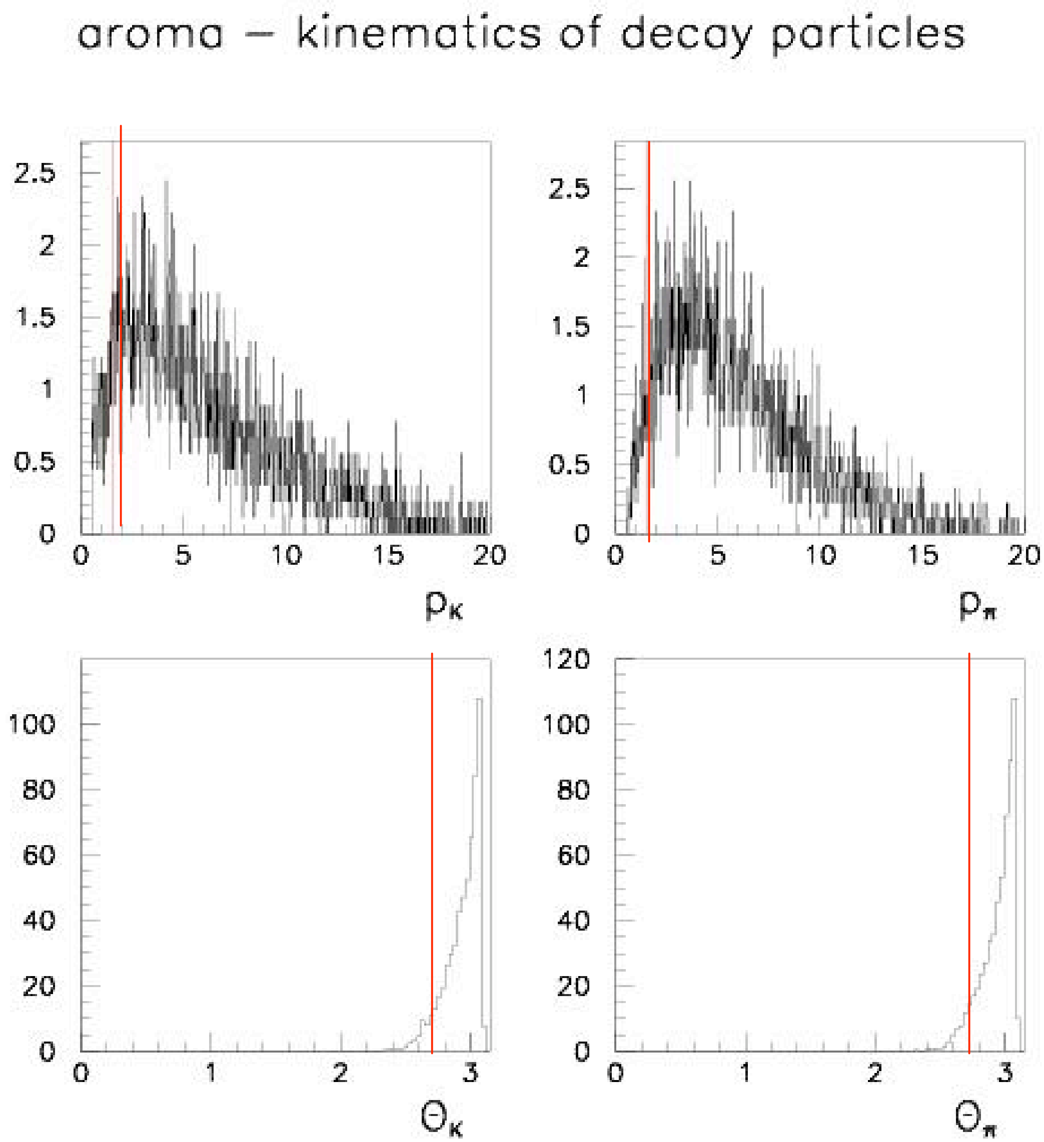
invariant mass of K π system

Background suppression:

Separation of primary and secondary vertex absolutely essential !

Pion/kaon separation very helpful !

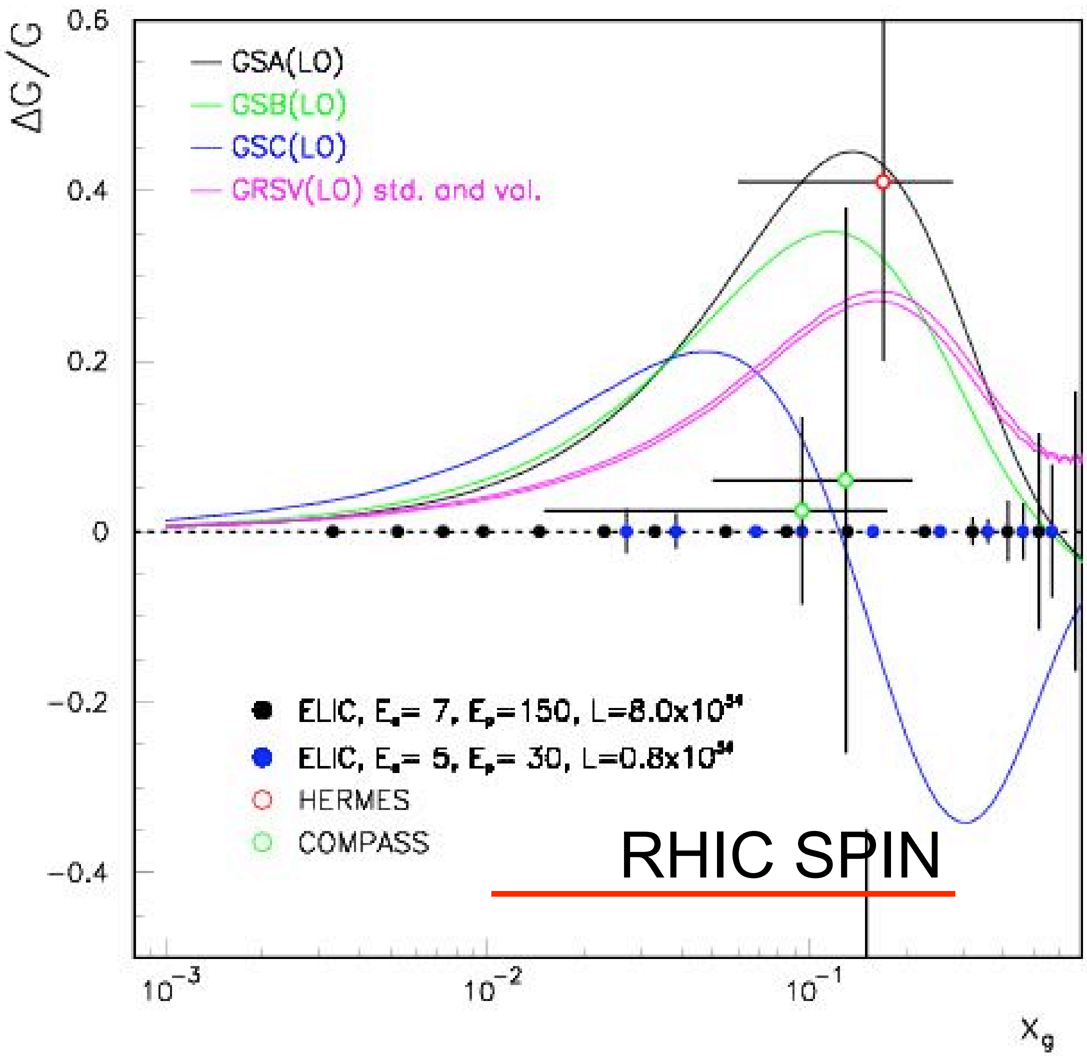
Polarized gluon distribution via charm production



Momenta of decay kaon and pion:
$1.5 < p < 10$ (15) GeV

Angles of decay kaon and pion:
$160^0 < \Theta < 177^0$

Polarized gluon distribution via charm production



Precise determination of Δ G/G for

$0.003 < x_g < 0.4$

at common Q^2 of 10 GeV^2

however...

Polarized gluon distribution via charm production

Precise determination of Δ G/G for

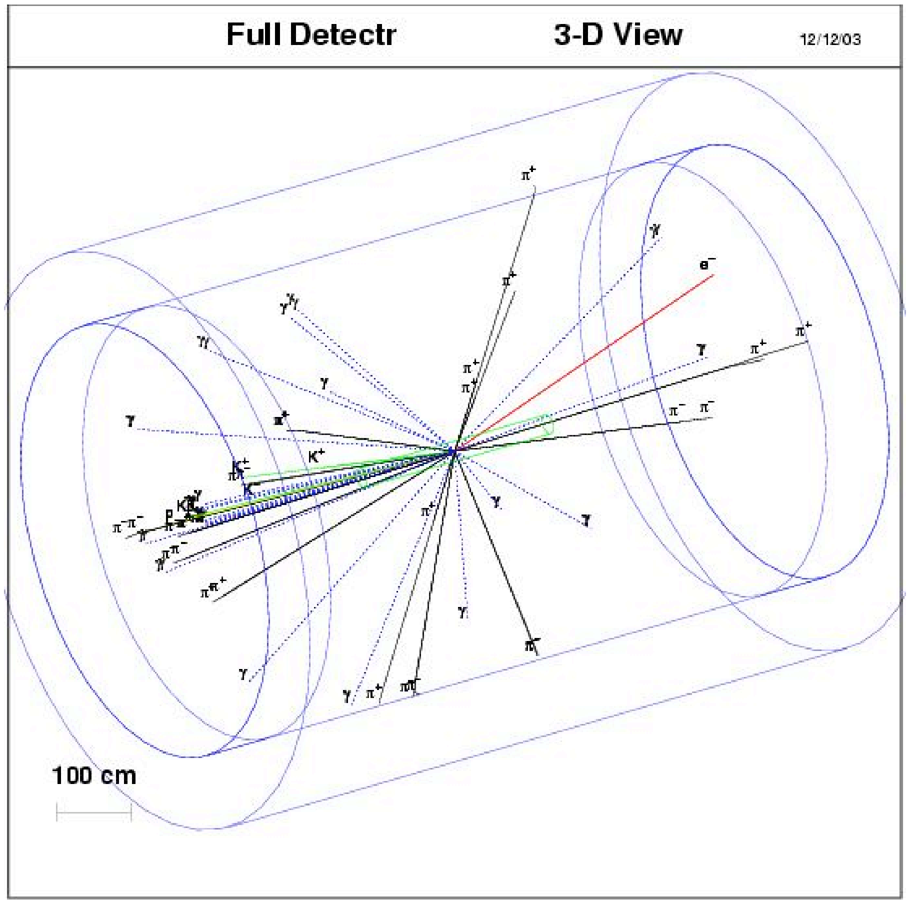
$0.003 < x_g < 0.4$

at common Q^2 of 10 GeV^2

If:

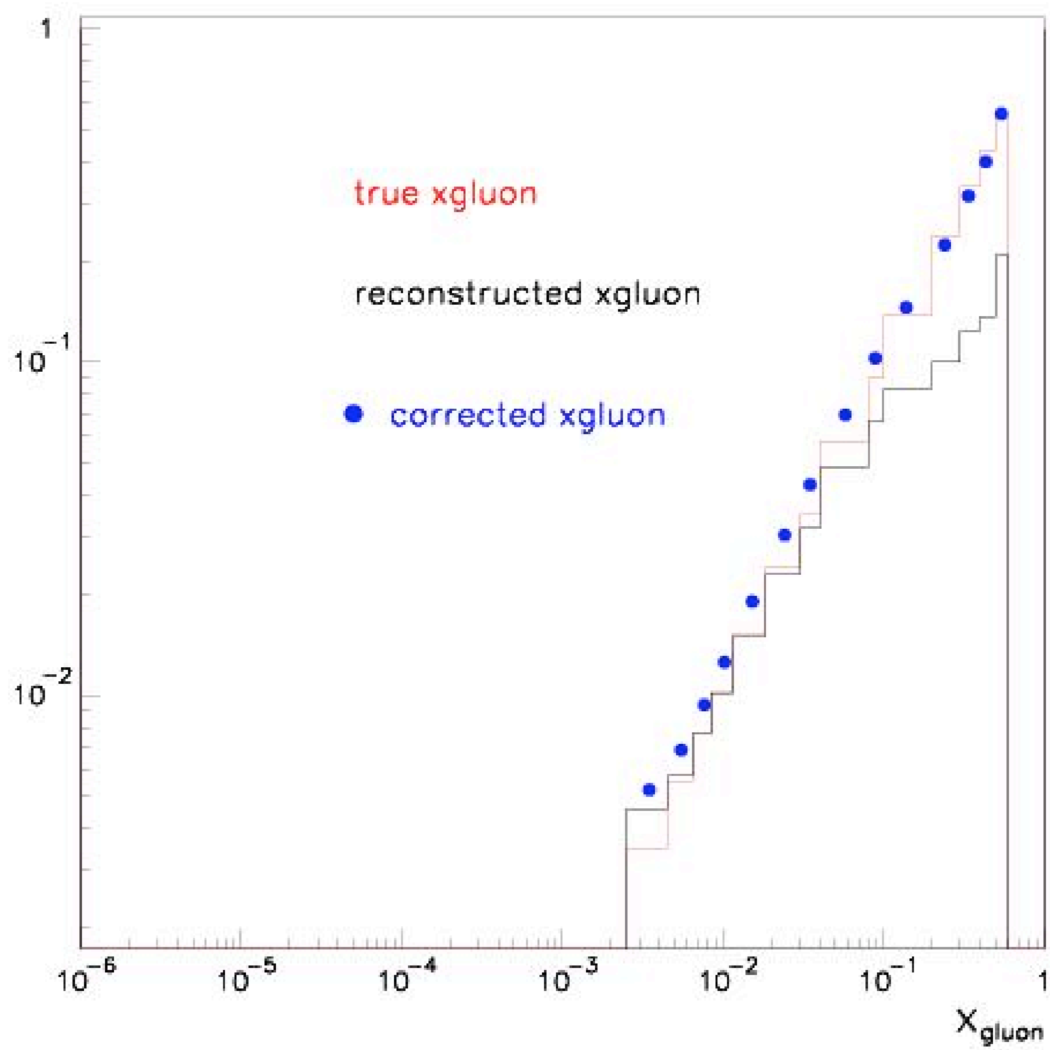
- We can measure the scattered electron even at angles close to 0^0 (determination of photon kinematics)
- We can separate the primary and secondary vertex down to about 100 μm
- We understand the fragmentation of charm quarks (✔)
- We can control the contributions of resolved photons
- We can calculate higher order QCD corrections (✔)

charm production: detector consequences



- Need to measure the scattered electron at angles close to 0^0 ➔ how ?
- Need to separate the primary and secondary vertex down to about 100 μm ➔ how to determine the primary vertex ?
- For charm decay products need to instrument only ± 15-20^0 around proton direction
- Simple set of silicon disks might be sufficient for vertex detection
- Momenta of decay products between 1.5 and 10(15) GeV

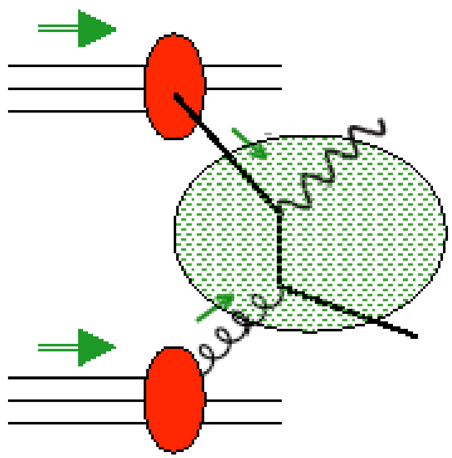
charm production: influence of fragmentation

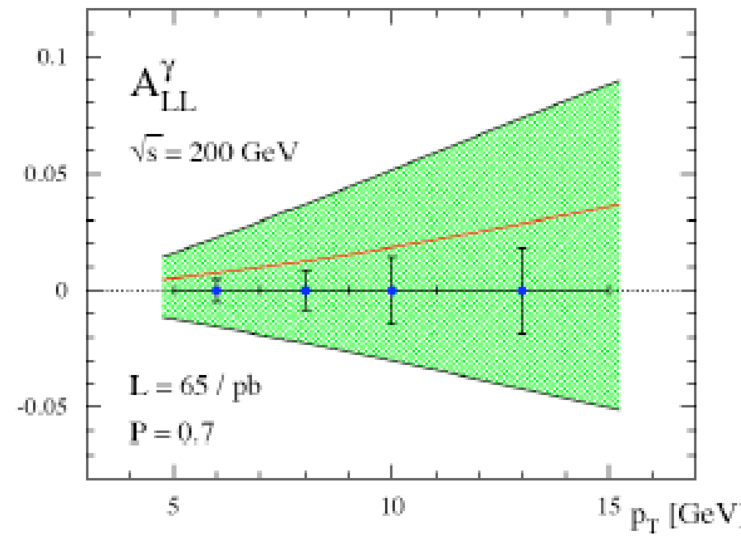


$x_g^{rec} = x(s_{hat}/Q^2+1)$
$s_{hat} = 4\ M_{inv}^2$

correction presently by simple parametrisation of x_g-x^{rec} vs xg

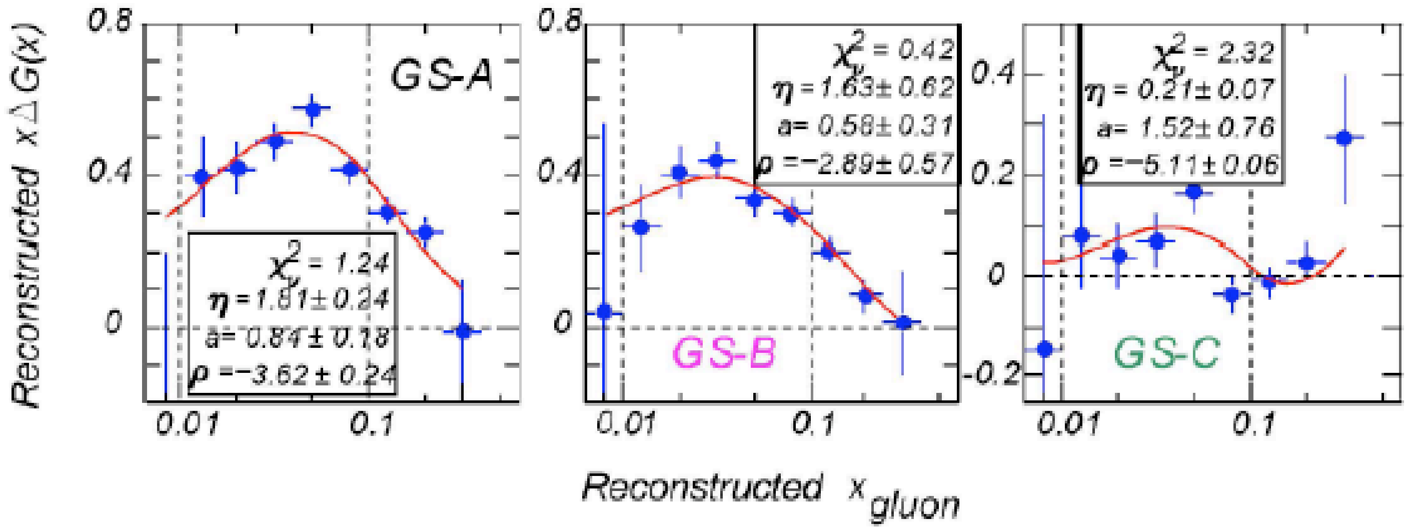
Future: Polarized gluon distribution from RHIC





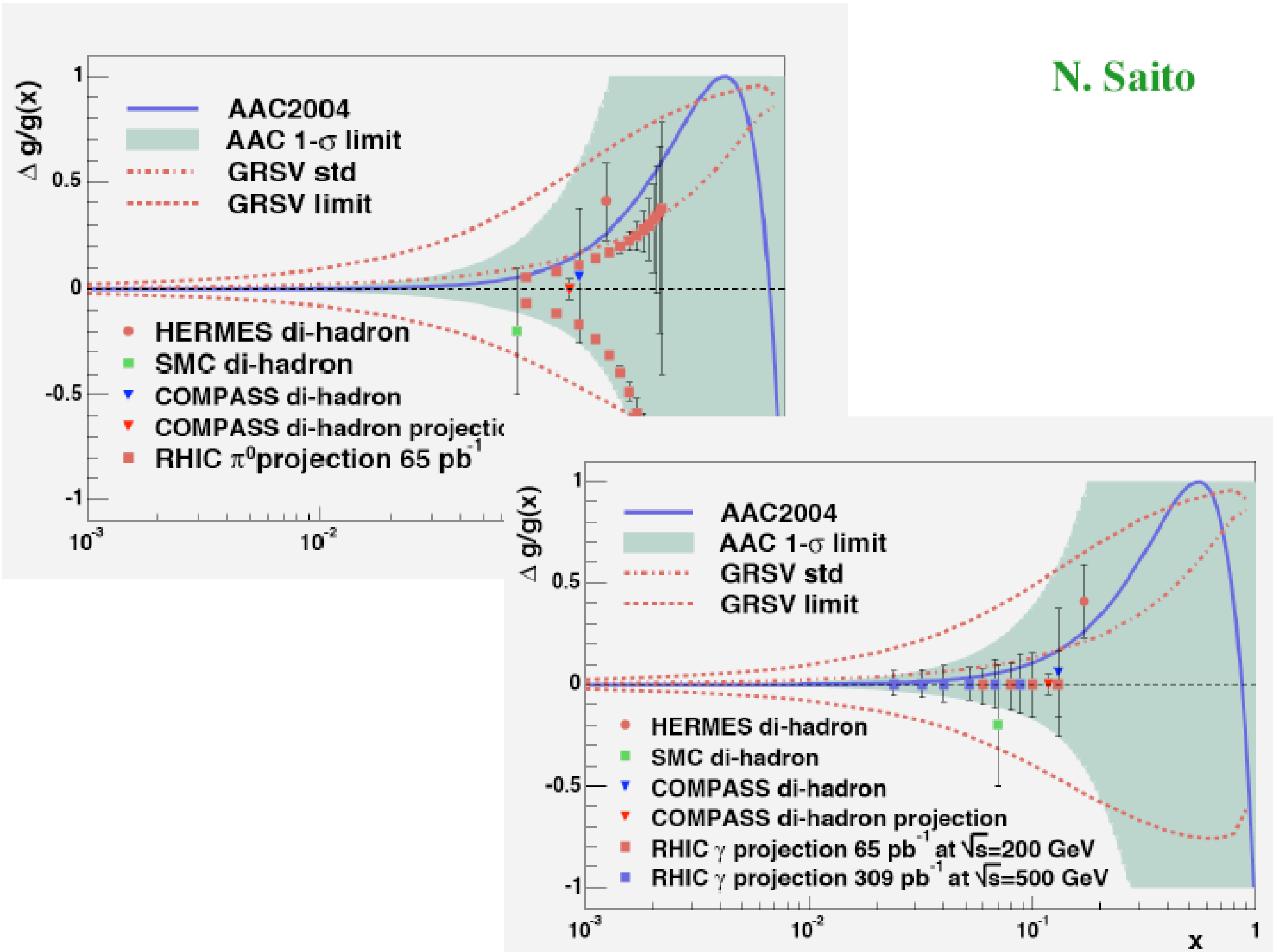
$\vec{p} + \vec{p} \rightarrow \gamma + jet + X$ with STAR + EEMC at

$\sqrt{s}$ = 200 GeV (320 pb^{-1}) + $\sqrt{s}$ = 500 GeV (800 pb^{-1})

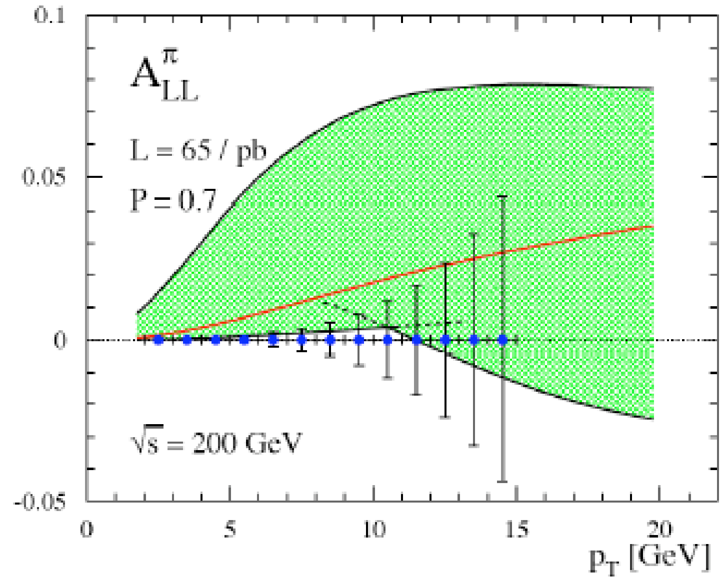


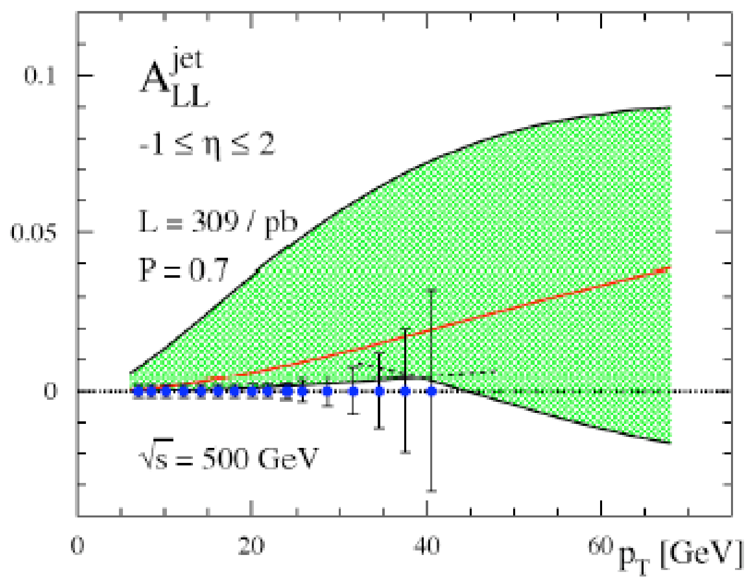
Future: Polarized gluon distribution from RHIC

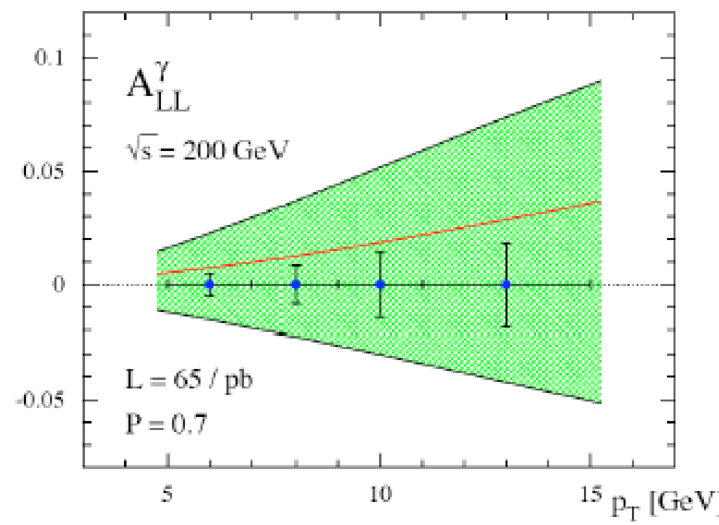
N. Saito



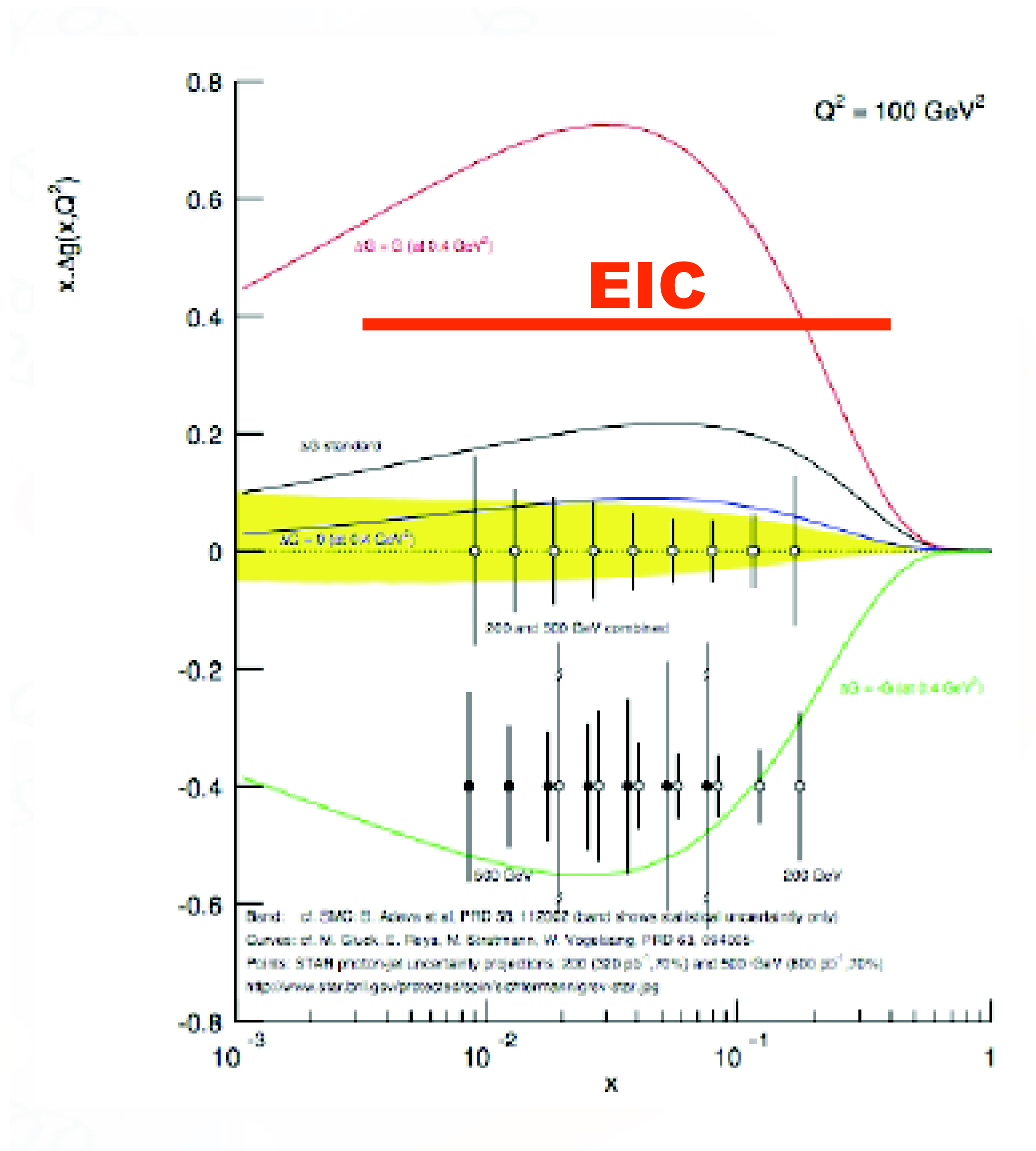
Future: Polarized gluon distribution from RHIC







Future: x $\Delta g(x,Q^2)$ from RHIC and EIC



EIC

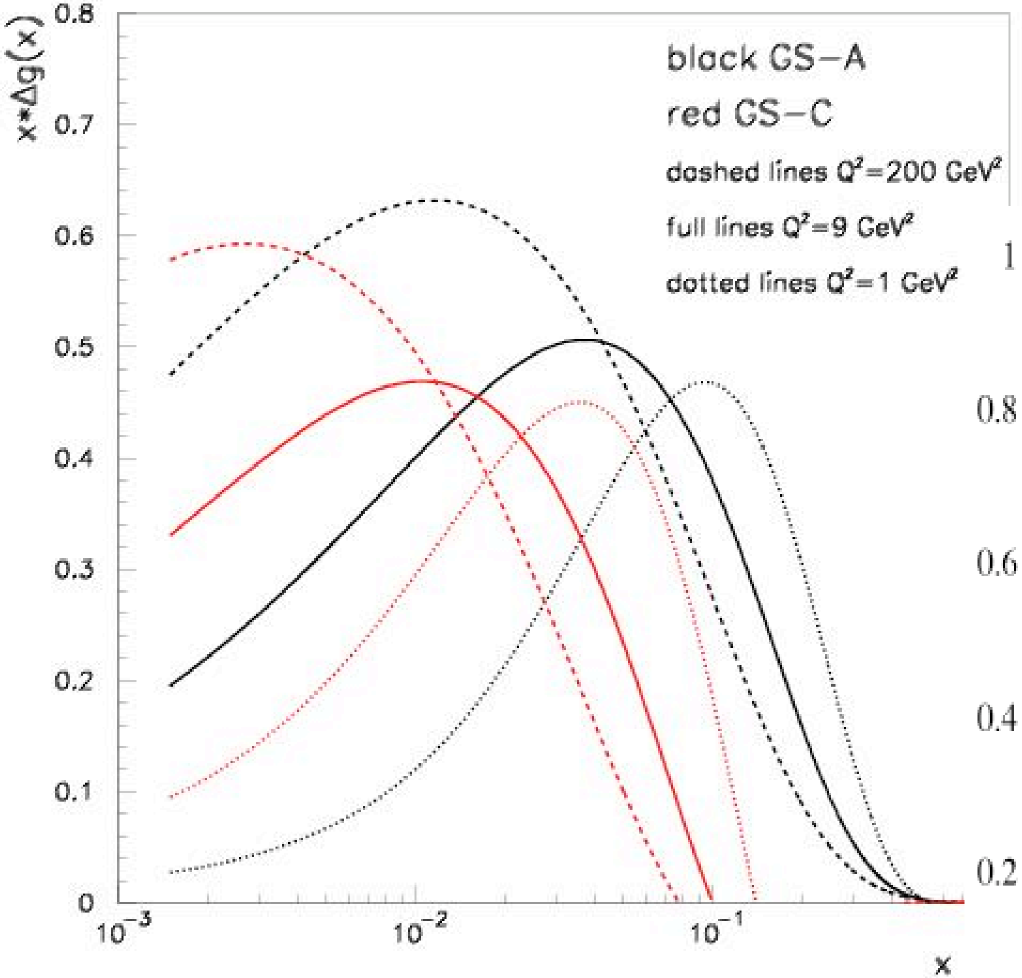
0.003 < x < 0.5

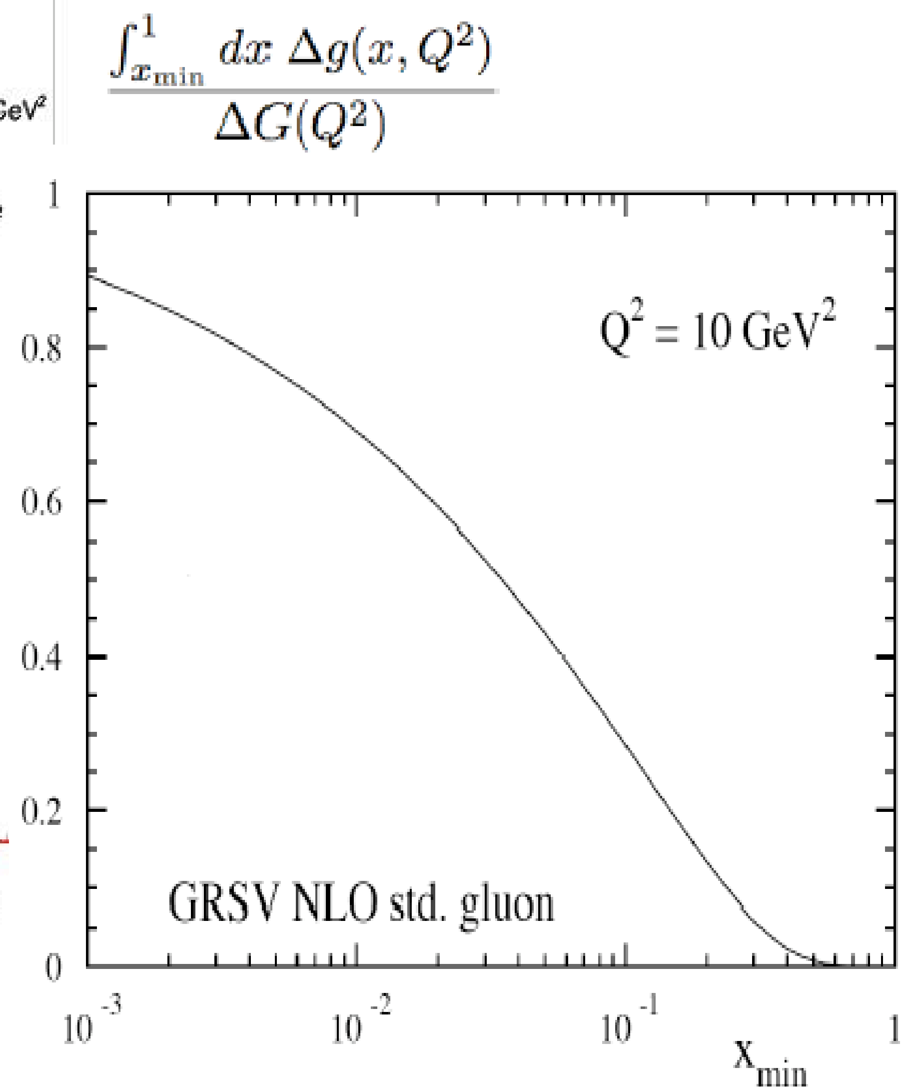
uncertainty in **$x\Delta g$**

typically < 0.01

!!!

Polarized gluon distribution vs Q^2





Next Steps

- determine sensitivity of g_1 to different "realistic" models for ΔG (including different functional forms !)
- generate pseudo EIC data and include in full QCD fit procedure (including estimates of systematic uncertainties !)
- determine precision of Bjorken Sum measurement as function of Q^2 (including extrapolations)
- study fragmentation in charm production
- include other charm decay channels (including D* tagging)
- **get first estimates of systematic uncertainties**
- **specify more clearly detector requirements for different processes**

Summary

EIC is the ideal machine to finally determine the contribution of the gluons to the nucleon spin!

- measurements of g_1 will allow
  - a determination of $\Delta G/G$ from its scaling violation
  - a statistically very precise determination of the Bjorken Sum (systematics due to uncertainty in proton beam polarization ???)

- measurements of charm cross section asymmetries will provide a precise determination of $\Delta G/G$ for $0.003<x<0.5$ at a fixed value of Q^2 of $\sim 10\ GeV^2$

……. provided we can
  - measure the scattered electron at extremely small angles
  - separate the primary and secondary vertex with sufficient precision
  - control the contribution of resolved photons
- more work needed to define the necessary detector requirements !