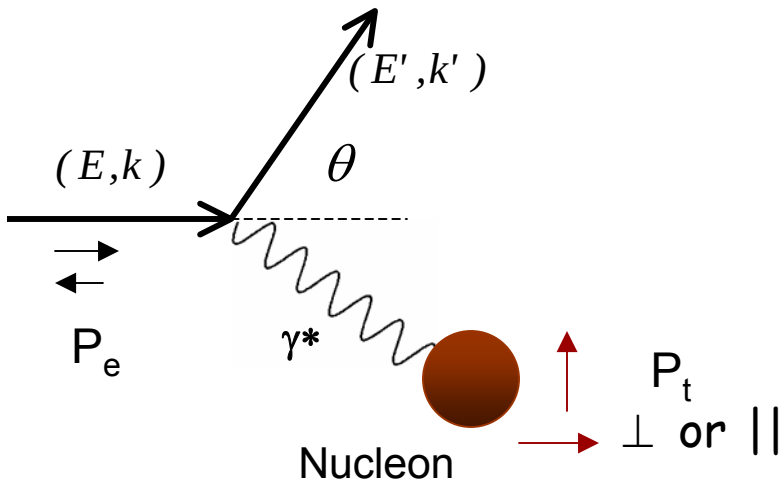
The physics of 11 GeV in Hall-C : Spin structure

Vipuli Dharmawardane
(Jefferson Lab)

OUTLINE

- Formalism
- Physics overview
- Projected errors

Double polarized inclusive electron scattering



- Longitudinally and transversely polarized targets
- Longitudinally polarized beam
- Inclusive electron scattering

$$\frac{d^2\sigma\uparrow\downarrow}{d\Omega dE'} - \frac{d^2\sigma\uparrow\uparrow}{d\Omega dE'} = \frac{4\alpha^2 E'}{Q^2 M E \nu}\left[(E + E'\cos\theta)g_1(x,Q^2) - 2xMg_2(x,Q^2)\right]$$

$$\frac{d^2\sigma\rightarrow\downarrow}{d\Omega dE'} - \frac{d^2\sigma\rightarrow\uparrow}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^2 E M \nu}\sin\theta\left[g_1(x,Q^2) + \frac{4xME}{Q^2}g_2(x,Q^2)\right]$$

- Electron asymmetry

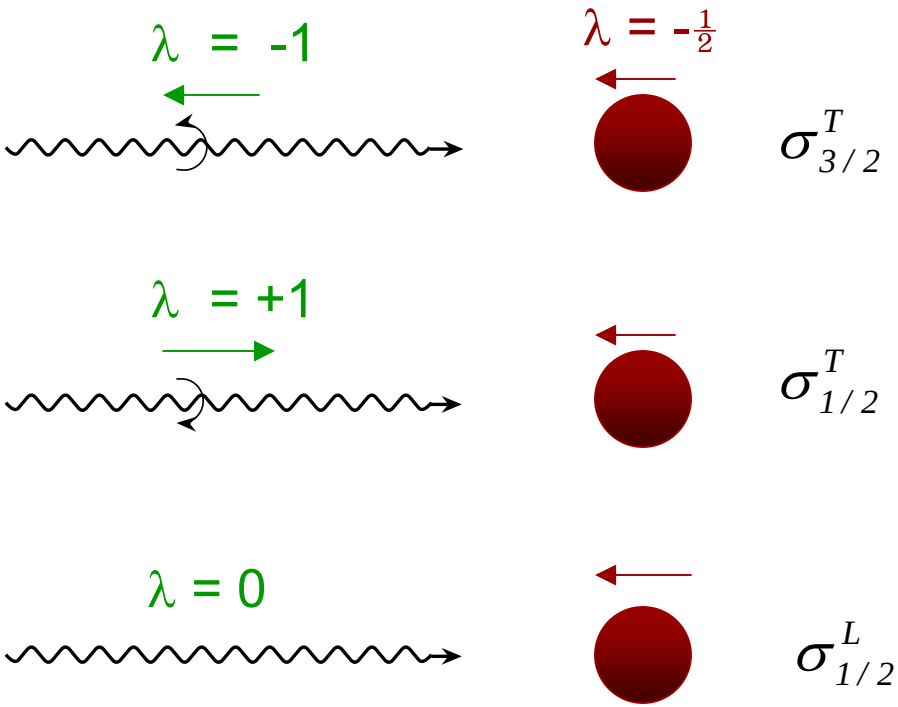
$$A_{||}(x,Q^2) = \frac{\frac{d\sigma}{dE'd\Omega}(\uparrow\downarrow) - \frac{d\sigma}{dE'd\Omega}(\uparrow\uparrow)}{\frac{d\sigma}{dE'd\Omega}(\uparrow\downarrow) + \frac{d\sigma}{dE'd\Omega}(\uparrow\uparrow)}$$

$$A_{\perp}(x,Q^2) = \frac{\frac{d\sigma}{dE'd\Omega}(\rightarrow\downarrow) - \frac{d\sigma}{dE'd\Omega}(\rightarrow\uparrow)}{\frac{d\sigma}{dE'd\Omega}(\rightarrow\downarrow) + \frac{d\sigma}{dE'd\Omega}(\rightarrow\uparrow)}$$

Virtual photon asymmetries

Virtual photon

Nucleon



Virtual photon asymmetries A_1 and A_2

- $$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}}$$
- $$A_2 = \frac{2\sigma^{TL}_{1/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}}$$

$$\boxed{\begin{aligned} A_{||} &= D(A_1 + \eta A_2) \\ A_{\perp} &= d(A_2 - \zeta A_2) \end{aligned}}$$

$$D = \frac{1-\varepsilon E'/E}{1+\varepsilon R},\ \eta = \frac{\varepsilon\sqrt{Q^2}/E}{1-\varepsilon E'/E},\ d = \sqrt{\frac{2\varepsilon}{1+\varepsilon}}D,\ \varsigma = \frac{1+\varepsilon}{2\varepsilon}\eta,\ \varepsilon = (1+2(1+\frac{\nu^2}{Q^2})\tan^2(\theta/2))^{-1}$$

Q^2 evolution of the spin structure function g_1

➢ $Q^2 \to \infty$ quarks behave as free particles

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x)$$

Gluon radiation

➢ At finite but large Q^2 additional corrections

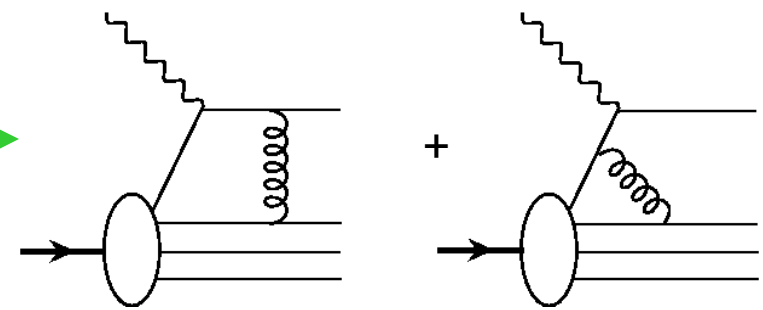
NLO

$g \to q + \bar{q}$

- Describable in pQCD
- Distribution functions in DGLAP equations
- Slow logarithmic Q^2 dependence

➢ At moderate Q^2 higher twist effects

- Interactions between the struck quark and the other quarks in the nucleon
- Inversely proportional to Q^2 → large at small Q^2



Virtual photon asymmetry A_1 at large x

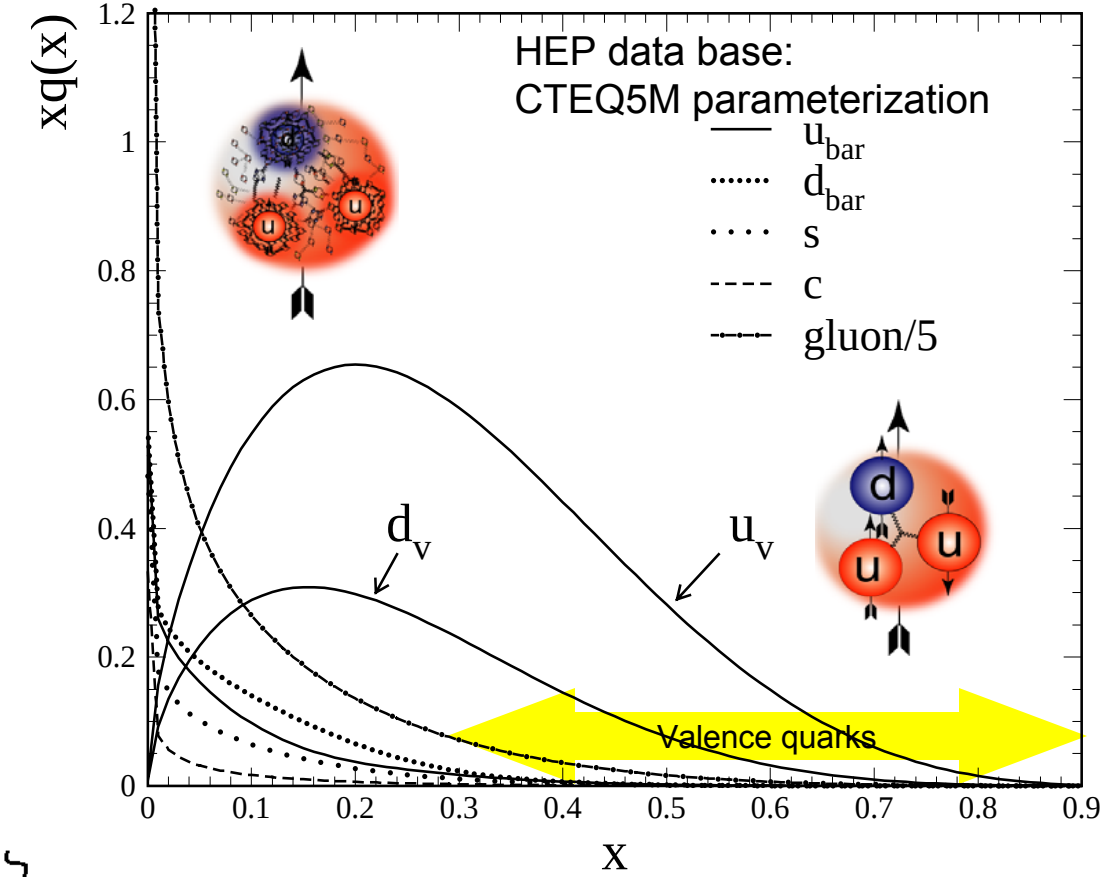
DIS region

minimal Q^2 dependence

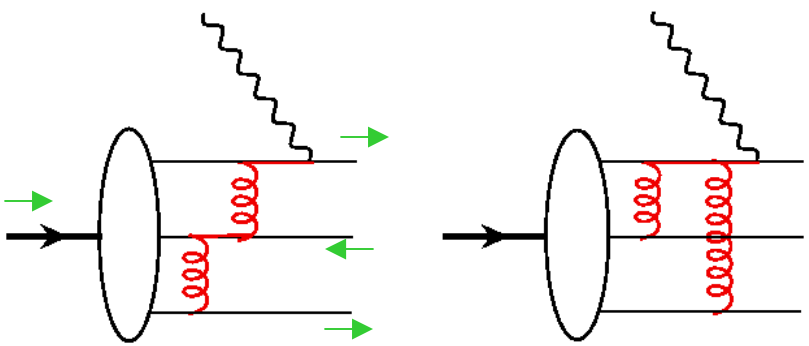
$$A_1(x,Q^2) \approx \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$

LO $\rightarrow$ $$\frac{\sum e_i^2 \Delta q_i(x)}{\sum e_i^2 q_i(x)}$$

- Valence quarks dominate at large x



❑ $x \rightarrow 1$ in pQCD



- Minimal gluon exchanges
- Spectator pair have opposite helicities
- $A_1 \rightarrow 1$

Farrar and Jackson
PRL 35, 1416 (1975)

Predictions for A_1 at large x

- **SU(6)**

$$A_1^p = \frac{5}{9}, \quad A_1^n = 0$$

- **Hyperfine perturbed QM**
  - makes S=1 pairs more energetic than S=0 pairs
  - At large x struck quark carry the spin of the nucleon

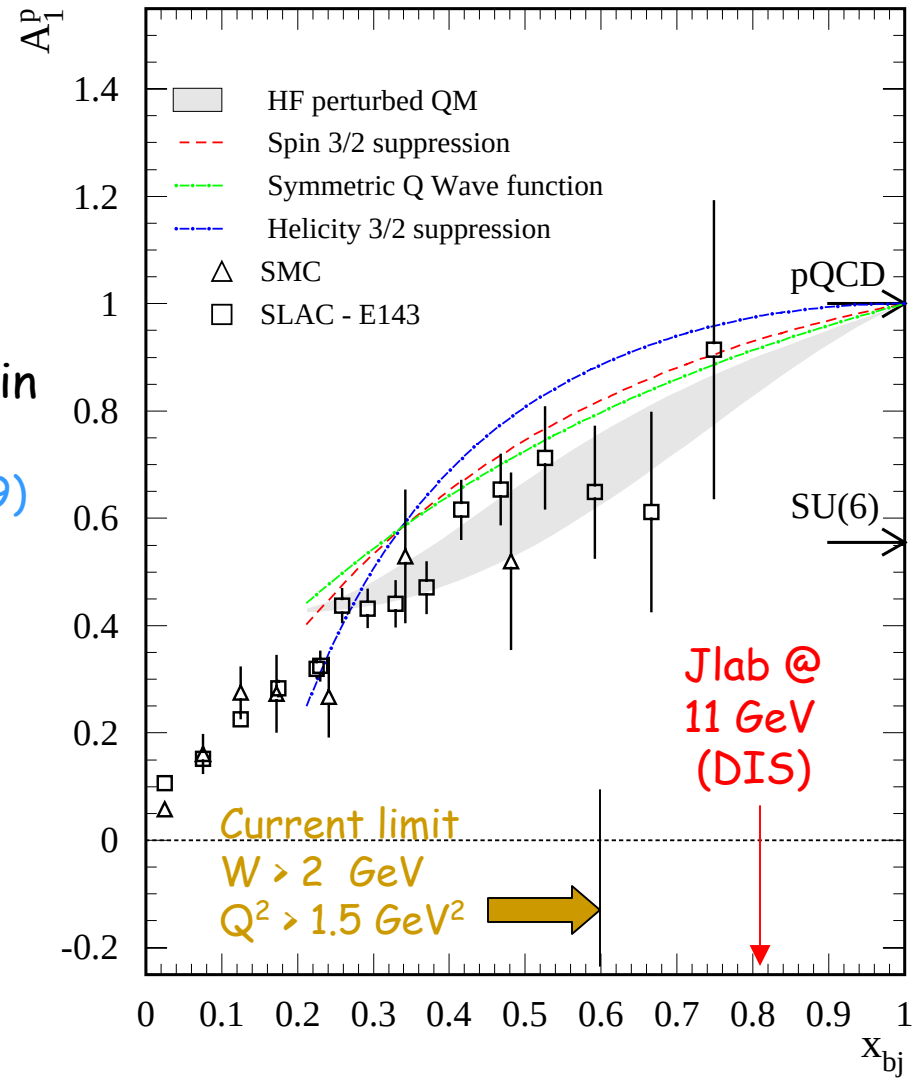
N. Isgur , Phys. Rev. D **59**, 34013 (1999)

- **Duality**
  - suppress transitions to specific resonances in the final state

$$\gamma + N \rightarrow N^*$$

states in 56^+ and 70^-

F. Close and W. Melnitchouk
Phys. Rev. C 68, 035210 (2003)



Projected errors: $A_1(x)$ for the proton

- Beam time@ 85 nA
  11 GeV 500 hours parallel
  500 hours transverse

  9 GeV 200 hours parallel
  300 hours transverse

- 80% beam and target polarization

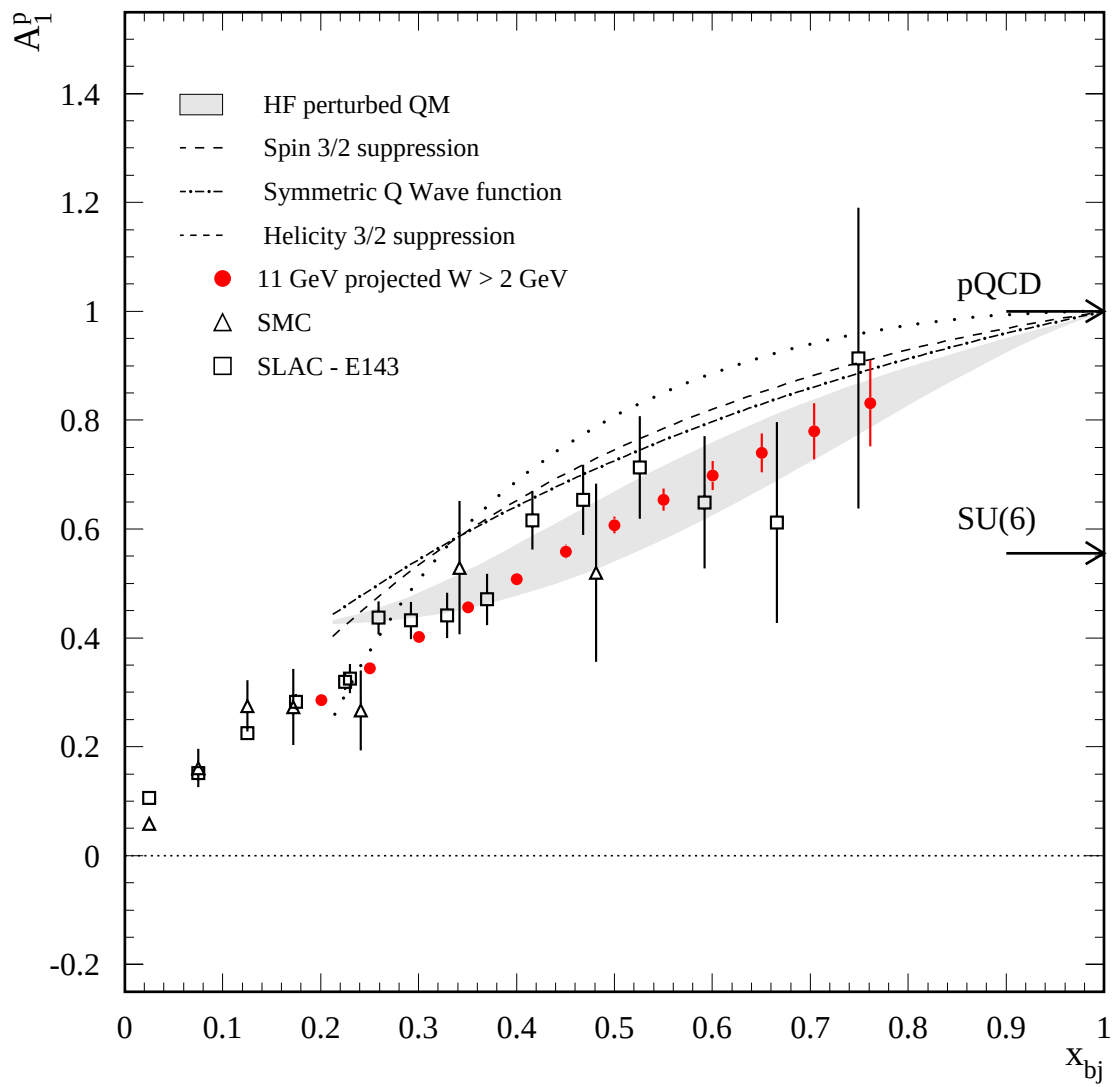
- UVa NH3 target : Dilution factor 0.15

- Cross-section Models: NMC parameterization and R1998

- BETA (proposed SANE) detector (θ = 30 deg)

- Q^2 coverage ≈ 4.5-12.5 GeV^2

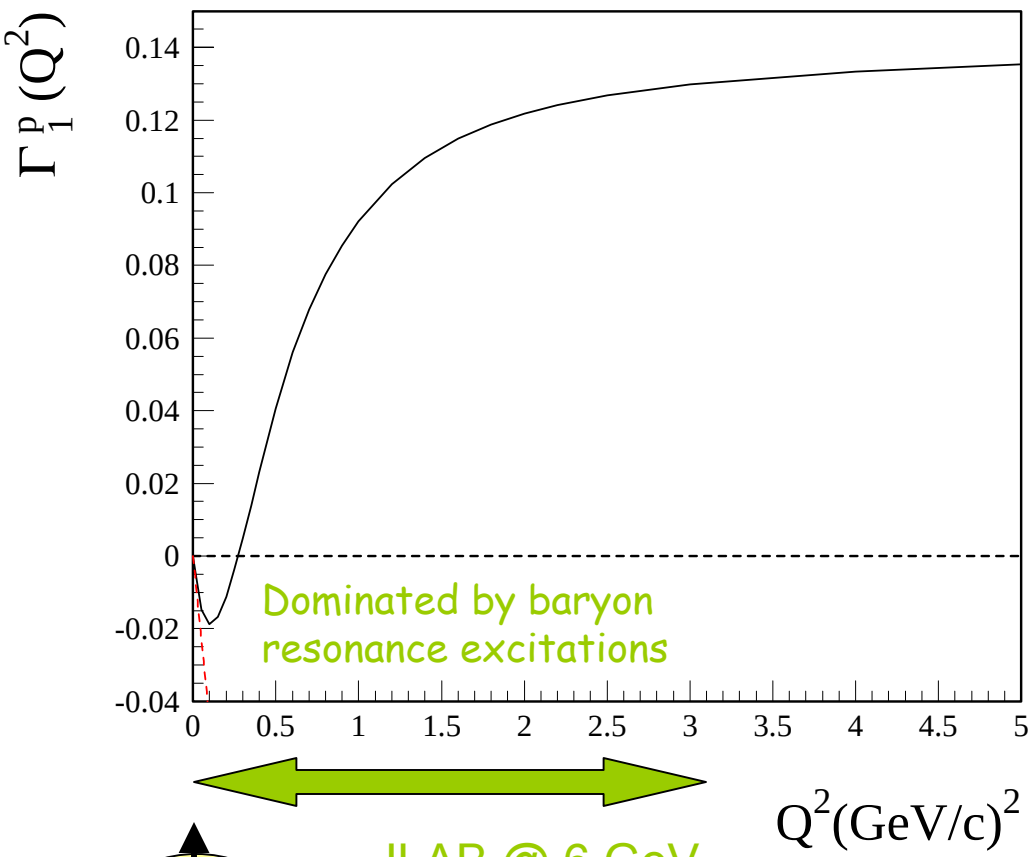
- X (W > 2 GeV) ≈ 0.2-0.8



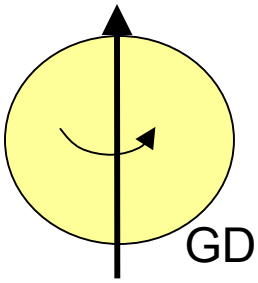
First moment of $g_1(x,Q^2)$

$$\Gamma_1(Q^2) = \int_0^{x(W=1.07)} g_1(x,Q^2)dx$$

Elastic contribution excluded



JLAB @ 6 GeV



$Q^2 = 0$

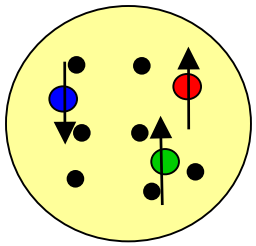
GDH Sum rule

g_1 has to be measured over the entire x region

Single partons Bjorken Sum Rule

$$\Gamma_1^p - \Gamma_1^n = \frac{g_A}{6}$$

$Q^2 \rightarrow \infty$



- Closely related to the spin carried by quarks

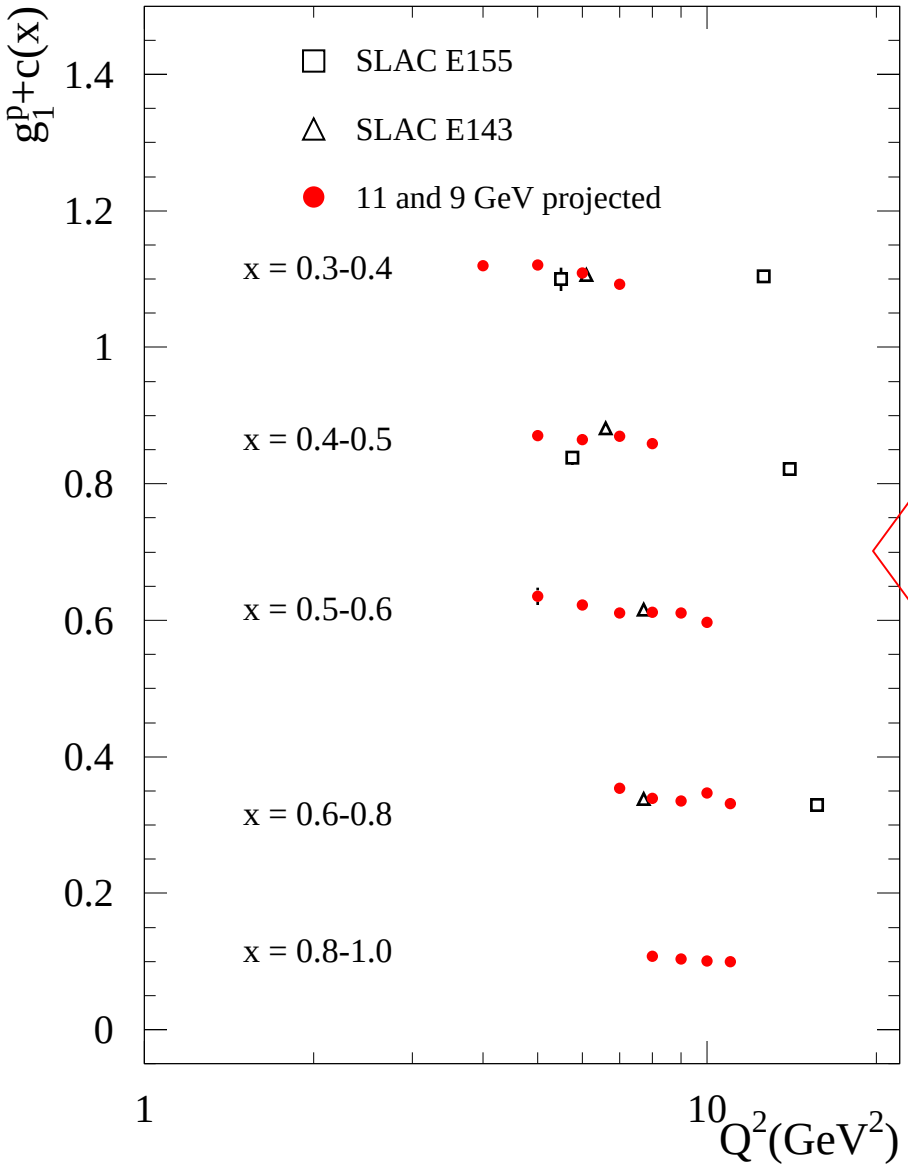
At large Q^2

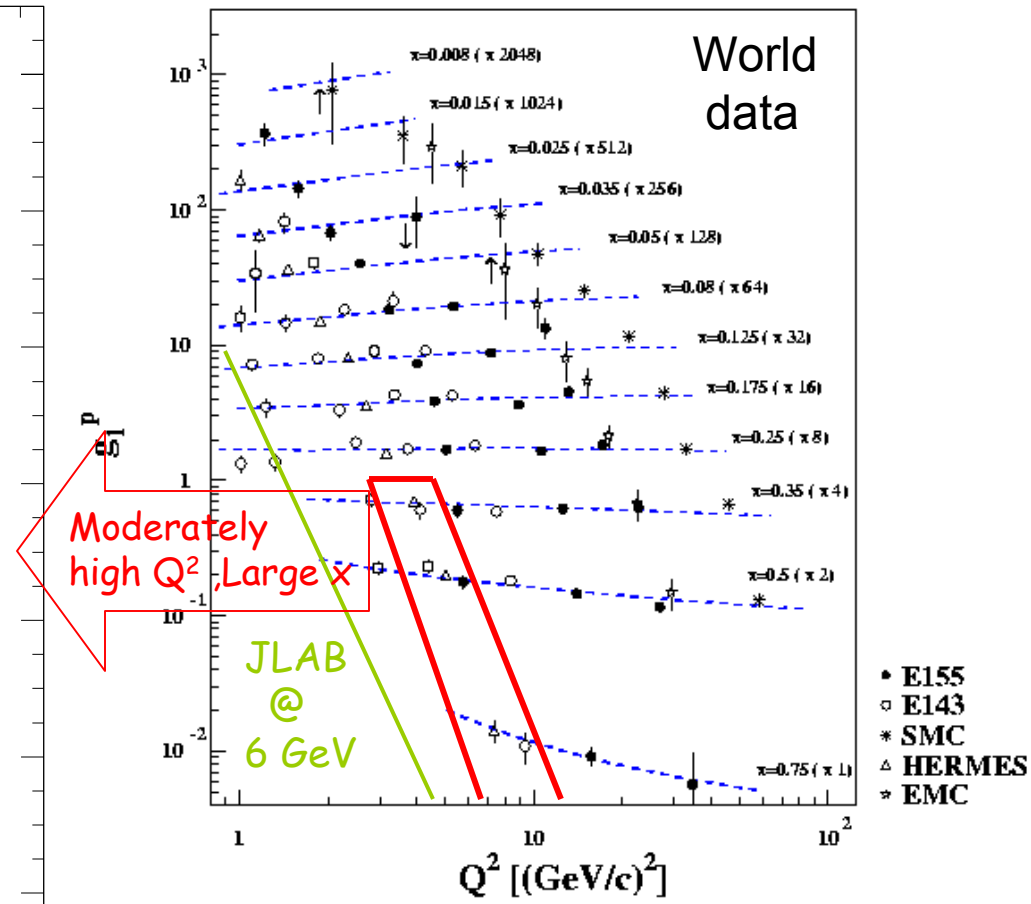
- Along with the other known quantities the fraction of the nucleon spin carried by quarks can be extracted

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$

30±10% SLAC data Evaluated at $Q^2 = 5\ GeV^2$

Spin structure function g_1



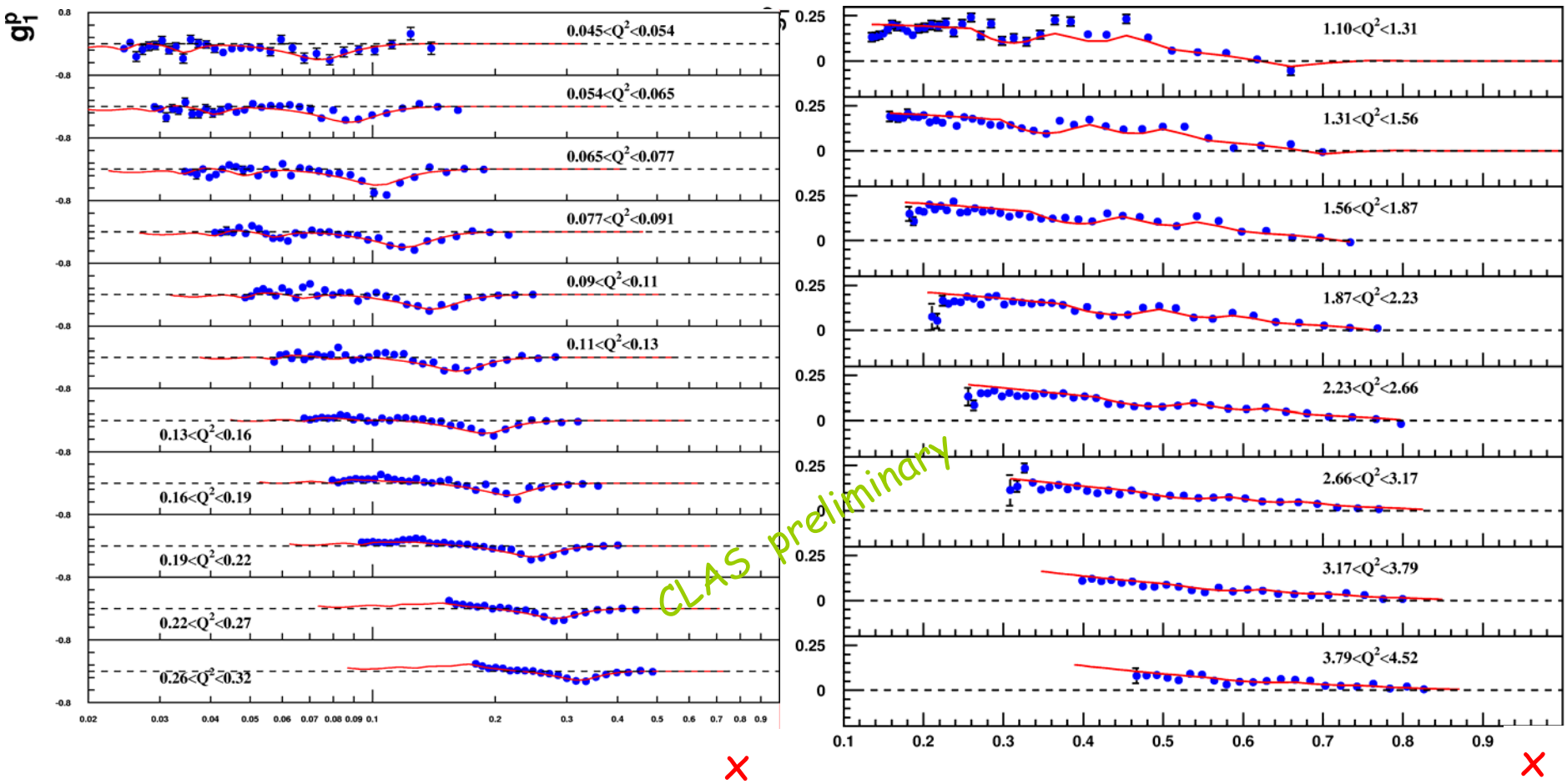


- Large x region is not well measured
- Our understanding of $\Delta\Sigma$ can be improved

$g_1(x,Q^2)$ for the Proton (JLAB @ 6 GeV)

$g_1^p(x)$ for E = 1.6 GeV

$g_1^p(x)$ for E = 5.6 GeV



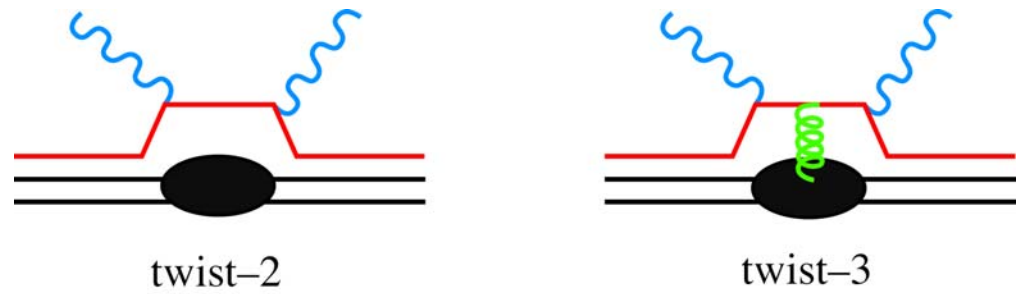
- Q^2 coverage 0.04 – 4.5 GeV^2

Second moment of g_1 and g_2 : d_2

$$d_2(Q^2) = \int_0^1 x^2 \left[2g_1(x,Q^2) + 3g_2(x,Q^2)\right] dx$$

twist-3 matrix elements

- Describes how the gluon field inside the nucleon responds when the nucleon is polarized



- x^2 weighting emphasizes high x region

- Required to extract twist 4 matrix elements of the nucleon

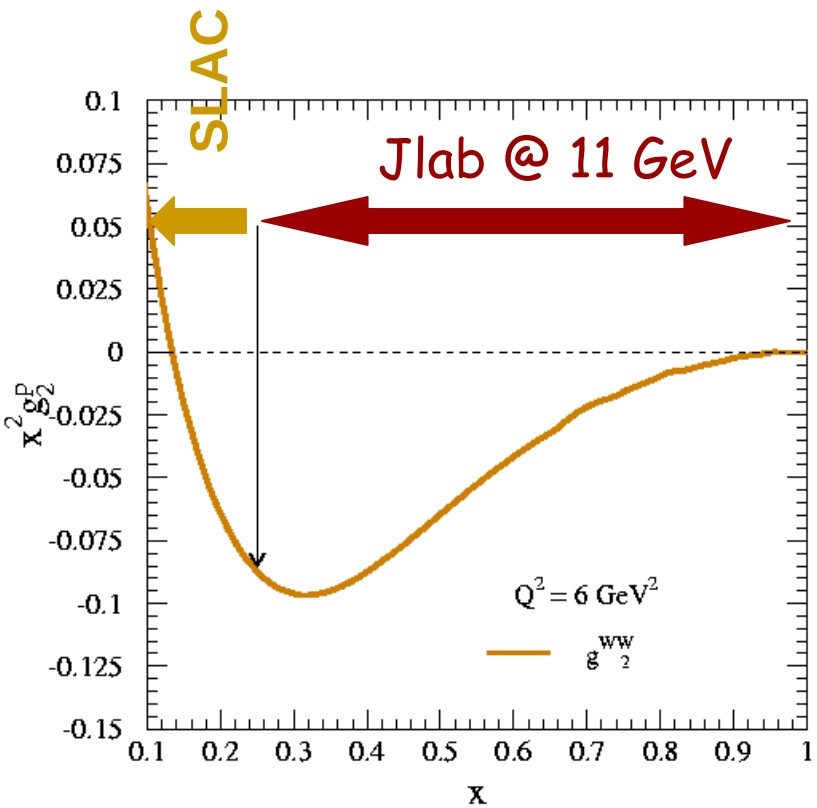
$$\Gamma(Q^2) = \int_0^1 g_1(x,Q^2)dx = \mu_2 + \frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \ldots\ldots\ldots\ldots$$

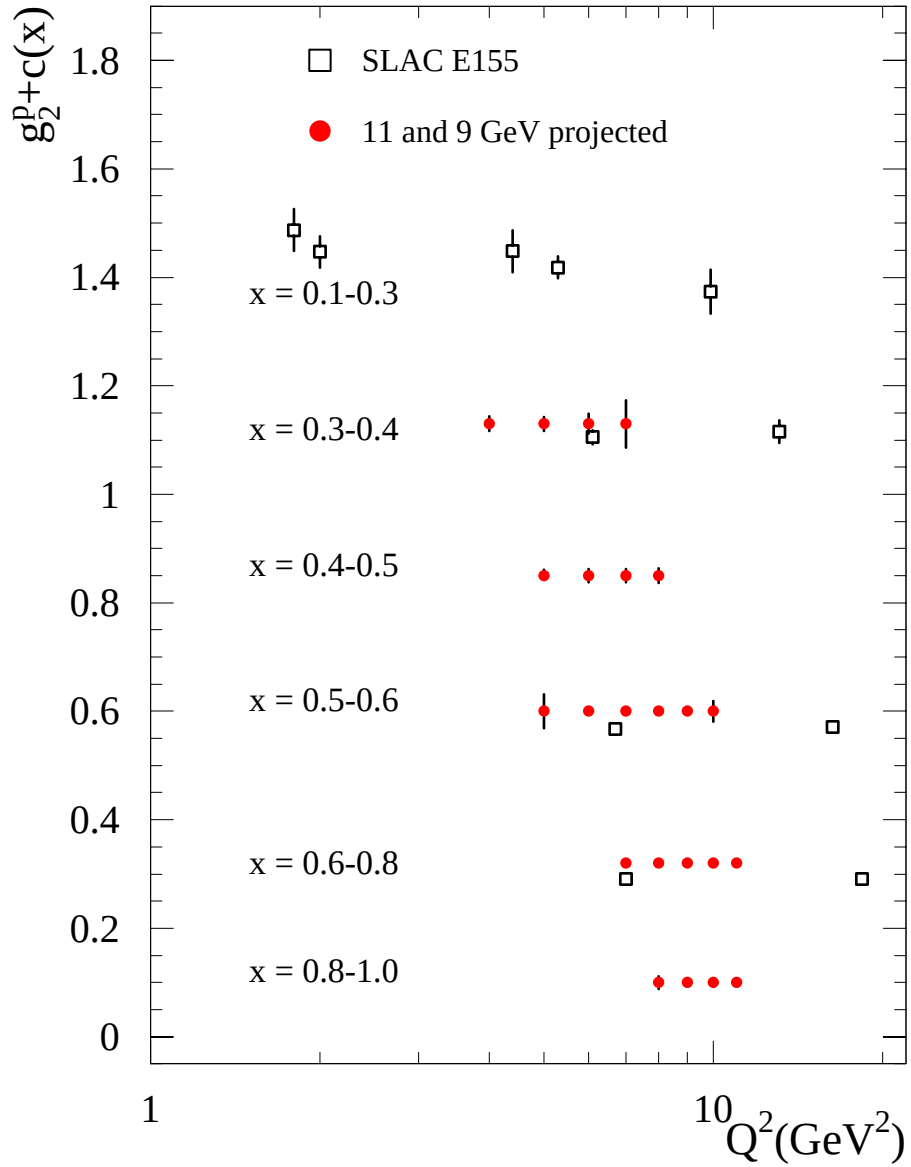
$$\mu_4(Q^2) = \frac{1}{9} M\left[a_2(Q^2) + 4d_2(Q^2) - 4f_2(Q^2)\right]$$

twist-2 twist-3 twist-4

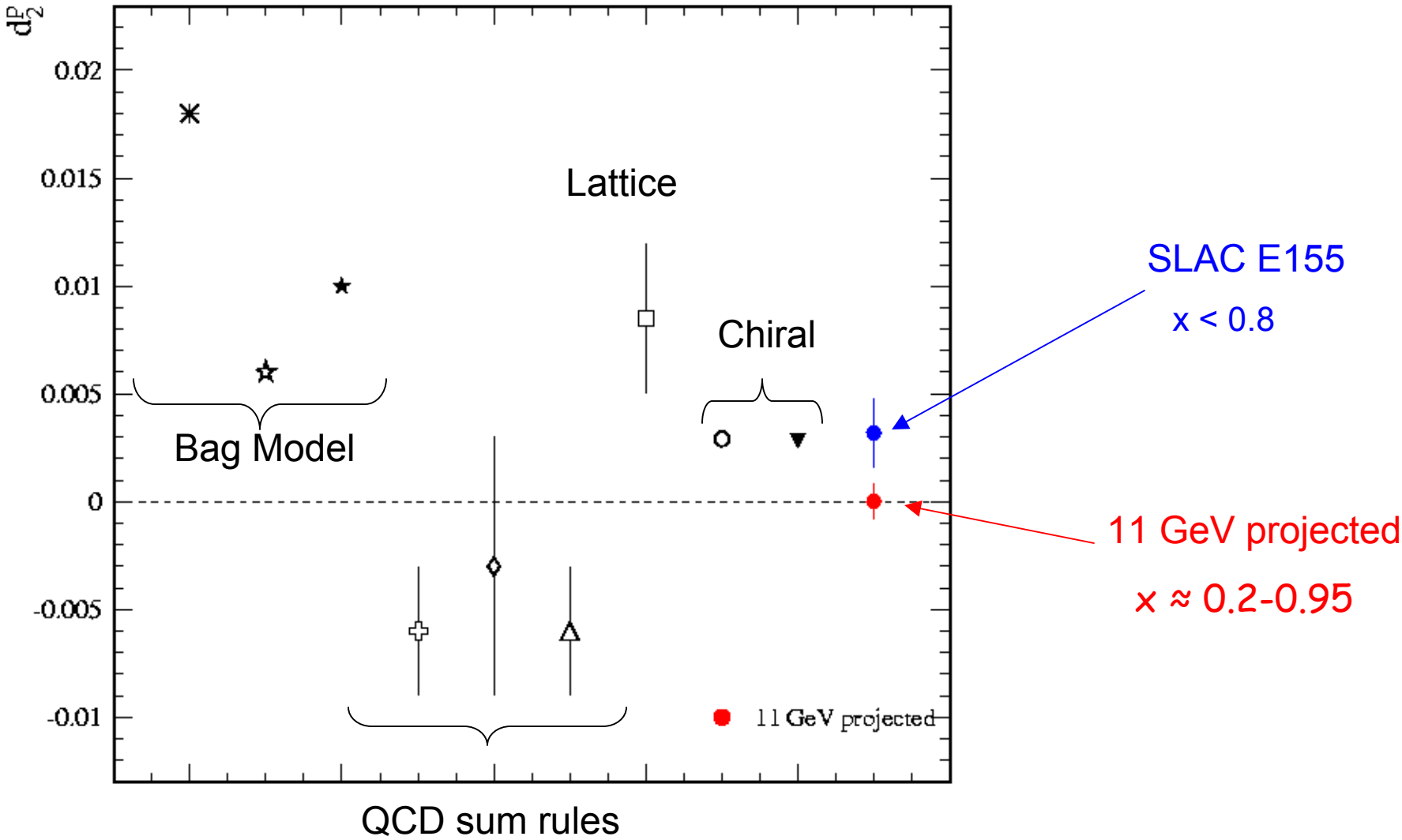
Spin structure function g_2

- Contribution to d_2 is large at large x





d_2 projected error



Summary

- The upgrade energy of 11 GeV allows to reach high Q^2, large x (valence) region

- Provide insight into spin structure of the nucleon at large x
  - Our undersanding of $\Delta\Sigma$ can be improved
  - The error of d_2 can be reduced by a factor of two
  - Hall-C has the advantage of separating A_1 from A_2
    ⇨ smaller systematic errors

- Cover a wide range of kinematics, inaccessible at other labs