Run group measurements: Inclusive Spin Structure

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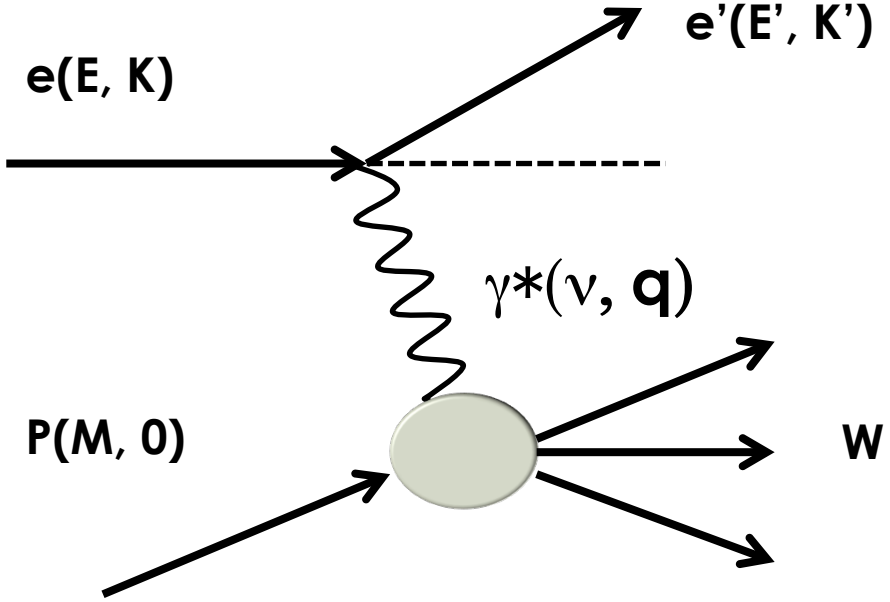
Outline

- Physics Motivation
- Experiment
- Projections
- Summary and Outlook

Inclusive Electron Scattering



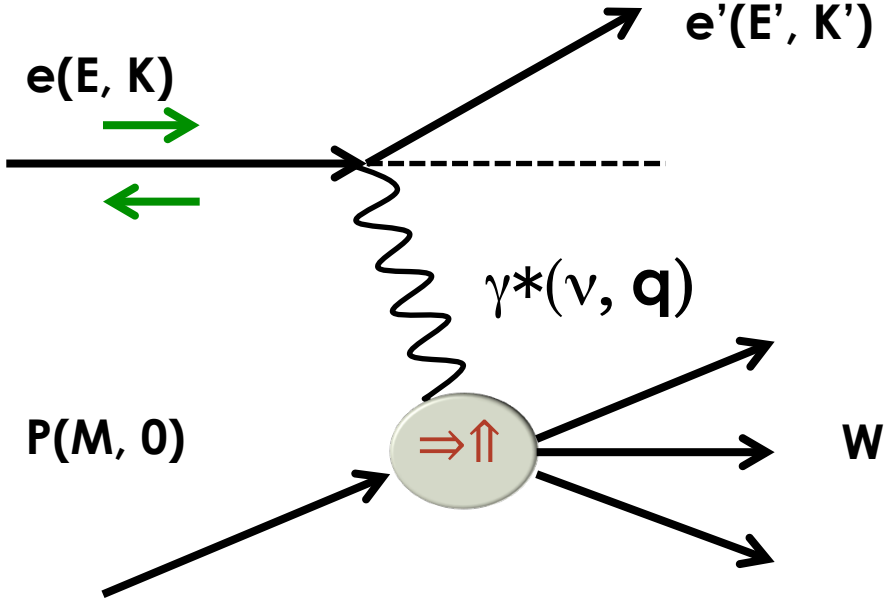
Q^2 :Four-momentum transfer
x : Bjorken variable ($=Q^2/2M\nu$)
ν : Energy transfer
M : Nucleon mass
W : Final state hadronic mass

Inclusive unpolarized cross section:

$$\frac{d^2\sigma}{dE'd\Omega} = \sigma_{Mott}\left[\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)tan^2\frac{\theta}{2}\right]$$

Structure Function which indicates the parton distribution

Inclusive Electron Scattering



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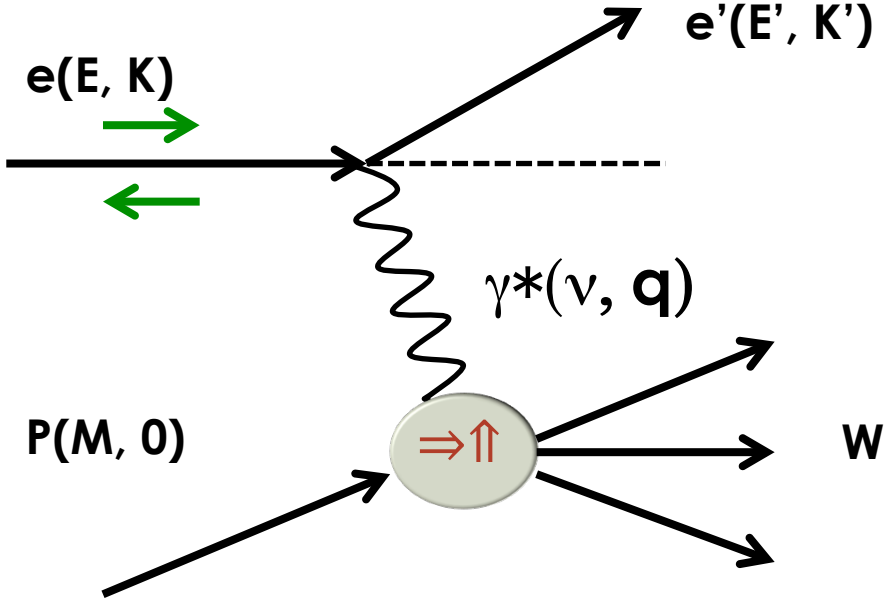
2 addition Structure Function which related to the polarized parton distribution

How to get g_2



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

HallB 12-06-109
A1 and g1

T $$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2 sin\theta}{MQ^2}\frac{E'^2}{\upsilon^2 E}[\upsilon g_1(x,Q^2) + 2Eg_2(x,Q^2)]$$

SoLID SIDIS-NH3
E12-11-108

Spin Structure Function in Parton Model

- g_1 related to the polarized parton distribution functions

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

- g_2 is zero in the naive parton model

  non-zero value carries information of quark-gluon interaction

  Ignoring quark mass effect of order O(m_q/Λ_{QCD})

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \bar{g}_2(x,Q^2)$$

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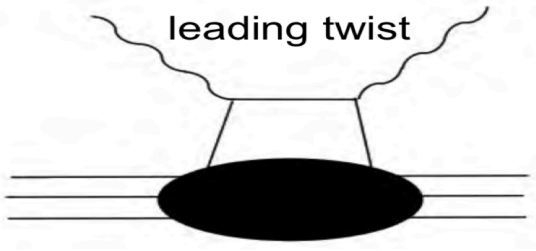

related to amplitude for scattering off asymptotically free quarks

- leading twist related to g_1 by Wandzura-Wilczek relation

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

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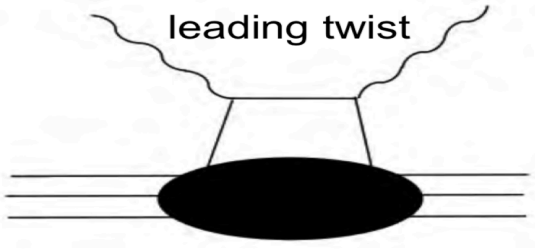

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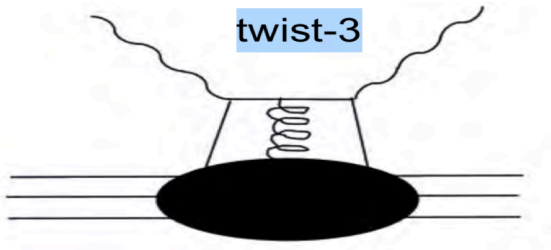
- g_2- g_2^{WW} : a clean way to access twist-3 contribution, quantify q-g correlations



quark-gluon interaction and the quark mass effects

d_2 : twist-3 matrix element

d_2: the x^2 moment of $\bar{g}_2(x,Q^2)$, twist-3 matrix element

$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

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

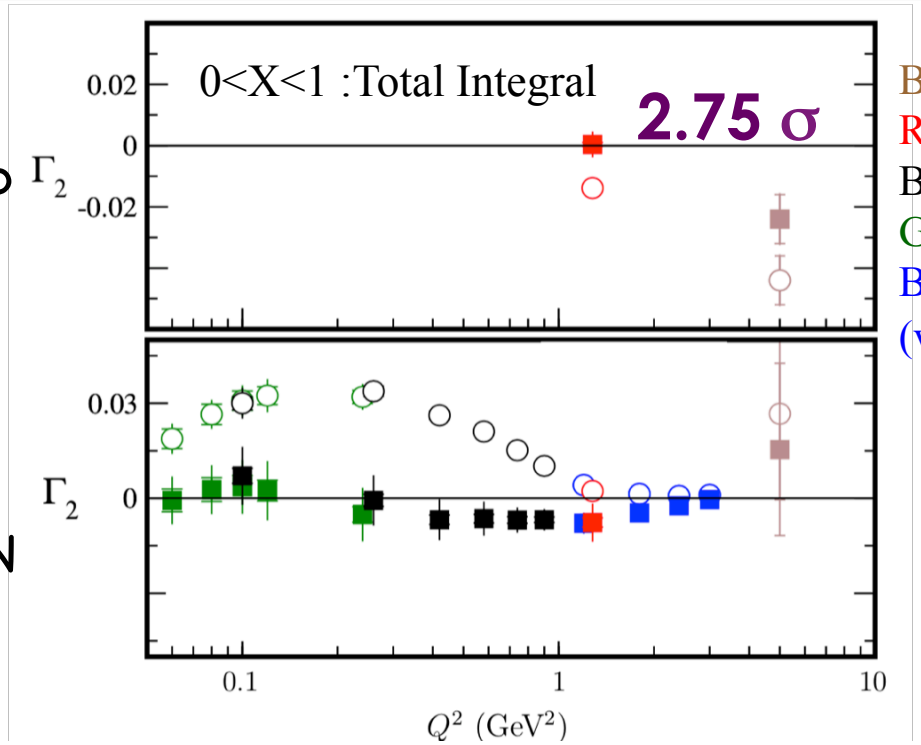
- ✓ Calculate on the Lattice.
- ✓ Link to the transverse force acting on the quark that absorbed the virtual photon in a transversely polarized nucleon, and thus to the Sivers effect[1, 2, 3] .

d_2 at lower Q^2 → d_2 at large Q^2

provides a mean to study the transition from perturbative to nonperturbative behavior and to quantify higher-twist effects.

related to the color polarization, which describes how the color electric and magnetic fields respond to the nucleon spin.

Test the Burkhardt-Cottingham (BC) Sum Rule



Brawn: SLAC E155x (Q^2~0.8−8.2 GeV^2, 0.02 <x< 0.8)
Red: Hall C RSS (Q^2≈1.3 GeV^2, W<1.910 GeV)
Black: Hall A E94-010
Green: Hall A E97-110 (preliminary)
Blue: Hall A E01-012
(very preliminary)

$$\Gamma_2 = \int_0^1 g_2(x)dx = 0$$

BC = Measured+low_*x*+Elastic

Measured: Measured x-range

low-*x*: refers to unmeasured low x part of the integral. Assume $g_2 = g_2^{WW}$

Elastic: From well know elastics form Factors

- violation for proton at large Q^2 (from SLAC data)
- But found satisfied for the neutron (HallA data)

Proton g_2 Existing Data

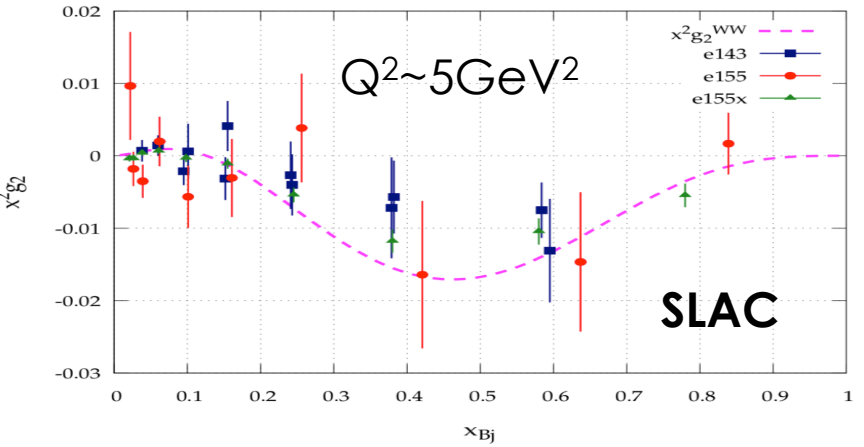
- First precise measurement of proton g_2 from SLAC, averaged $Q^2 \approx 5$ GeV^2
- HERMES: $0.004<x<0.9$, $0.18<Q^2<20$ GeV^2
- Measurement form Jefferson Lab:
  - RSS – medium Q^2:

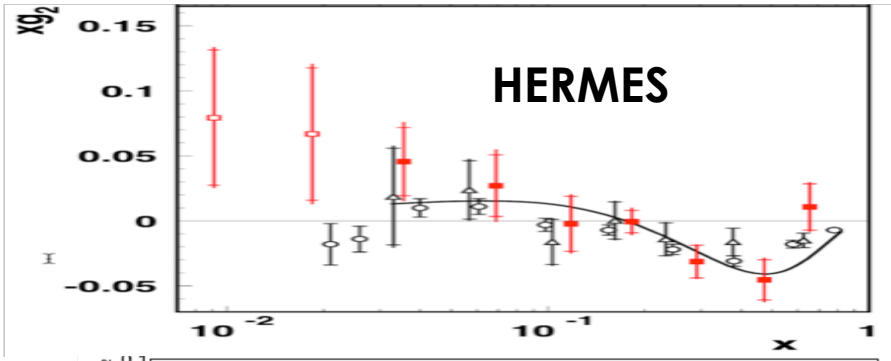
    $1 < Q^2 < 2\ GeV^2$ -- Published

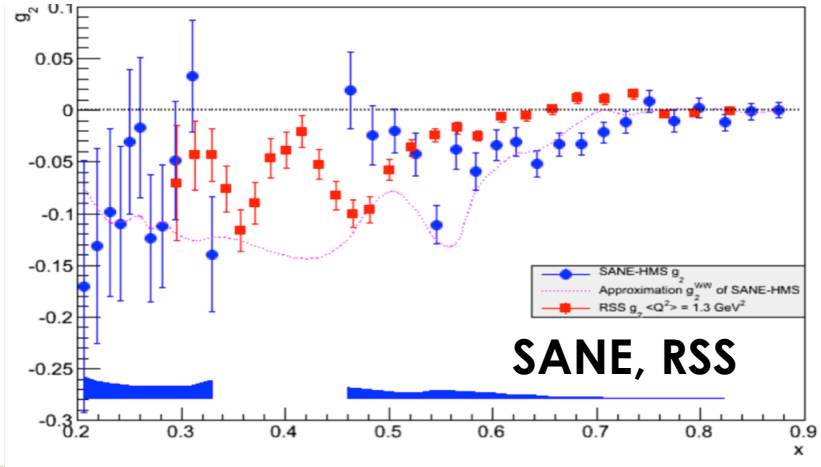
    K.Slifer, O. Rondon et al. PRL 105, 101601 (2010))
  - SANE – high Q^2 :

    $2 < Q^2 < 6\ GeV^2$ --arXiv: 1805.08835
  - g2p -- low $Q2$:

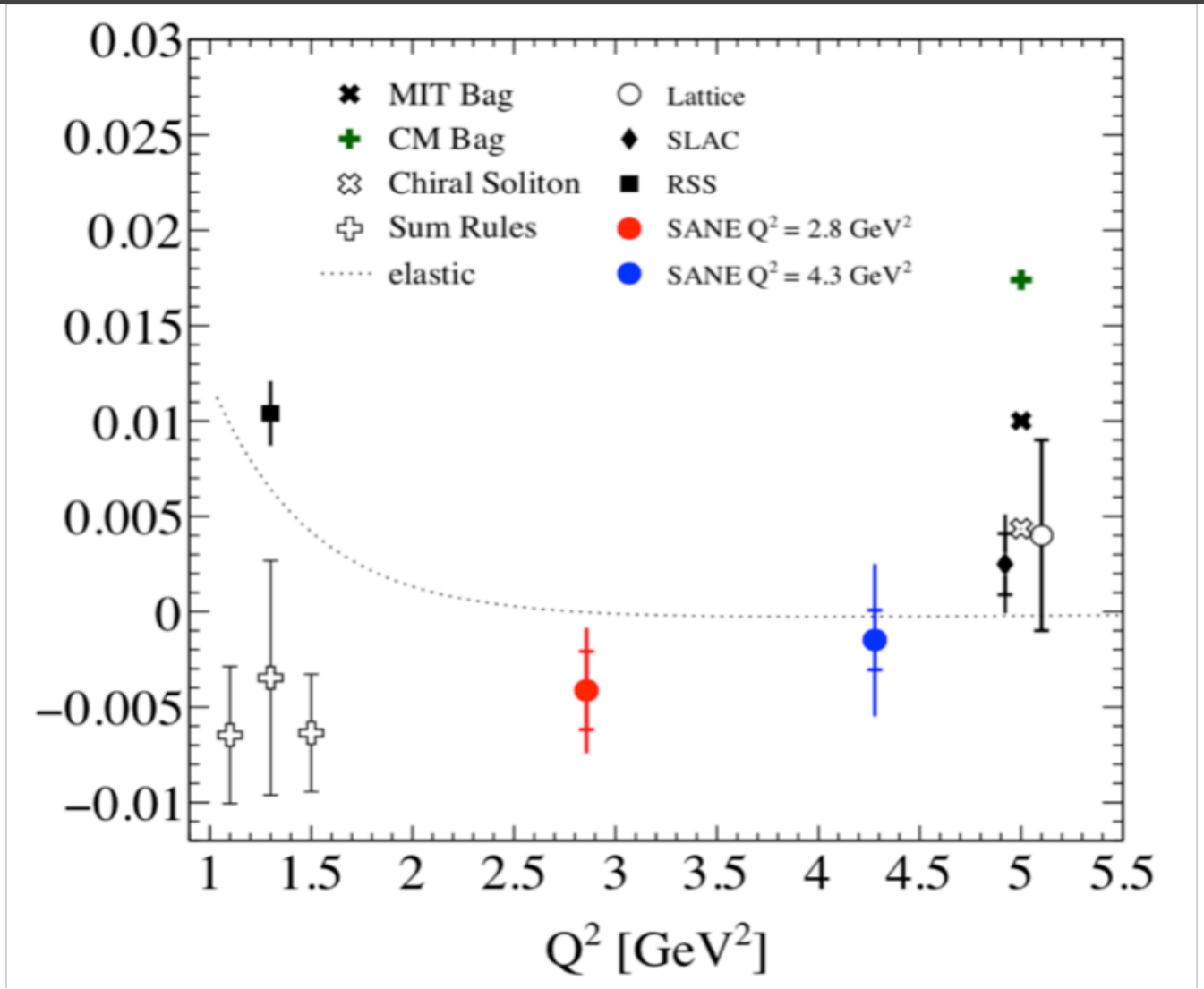
    $0.02 < Q^2 < 0.2\ GeV^2$ -- Analysis in progress







Proton d_2 Existing Data



Revealing Color Forces with Transverse Polarized Electron Scattering Arxiv:1805.08835

Experiment: SIDIS Transversely Polarized Proton (E12-11-108)

- JLab/UVa polarized NH3 target with upgraded design of the magnet
- Target spin-flip every two hours with average in-beam polarization of 70%
- Two Beam energies: 11 GeV and 8.8 GeV
- Polarized luminosity with 100nA current: 5.9e35 $cm^{-2}s^{-1}$
- Beamline chicane to transport beam through 5T target magnetic field (already designed for g2p expt.)

- Measure **proton** spin asymmetries $A_\perp(x, Q^2)$, structure function $\mathbf{g_2(x, Q^2)}$ at momentum transfer $1<Q^2<11$ GeV^2 and Bjorken x $0.05<x<0.97$.

- Study x and Q^2 dependence, twist-3 effects, moments of $g_2(x, Q^2)$ and comparison with Lattice QCD predictions.

Event Rates

Event rates from corresponding proposal:

Process	Forward angle 11 GeV	Large angle 11 GeV	Forward angle 8.8 GeV	Large angle 8.8 GeV
$(e,e\pi^+)$	187 Hz	11.6 Hz	161 Hz	7.3 Hz
$(e,e\pi^-)$	243 Hz	14.6 Hz	235 Hz	10.5 Hz
single e^-	22.2 kHz	0.65 kHz	34.5 kHz	0.87 kHz
single π^-	299 kHz	0.65 kHz	260 kHz	0.39 kHz
single π^+	520 kHz	2.73 kHz	455 kHz	1.65 kHz

SIDIS-NH3

55 days 11 GeV
27 days 8.8 GeV

Single e trigger?

Process	Rate Forward angle 11 GeV	Rate Large angle 11 GeV	Rate Forward angle 8.8 GeV	Rate Large angle 8.8 GeV
$(e,e\pi^+)$	1467 Hz	192 Hz	810 Hz	117 Hz
$(e,e\pi^-)$	1010 Hz	120 Hz	554 Hz	73 Hz
single e^-	88.5 kHz	11.0 kHz	151 kHz	16.5 kHz
high energy photon	623 kHz	51.5 kHz	596 kHz	37 kHz
single π^+	2.90 MHz	20.2 kHz	2.5 MHz	13.4 kHz
single π^-	1.77 MHz	14.5 kHz	1.47 MHz	9.2 kHz
single K^+	226 kHz	5.9 kHz	185 kHz	4.1 kHz
single K^-	54.6 kHz	1.2 kHz	39.9 kHz	0.6 kHz
single proton	1.15 MHz	13.8 kHz	0.99 MHz	9.4 kHz
low energy photon	200 MHz	-	200 MHz	-

SIDIS-3He

48 days 11 GeV
21 days 8.8 GeV

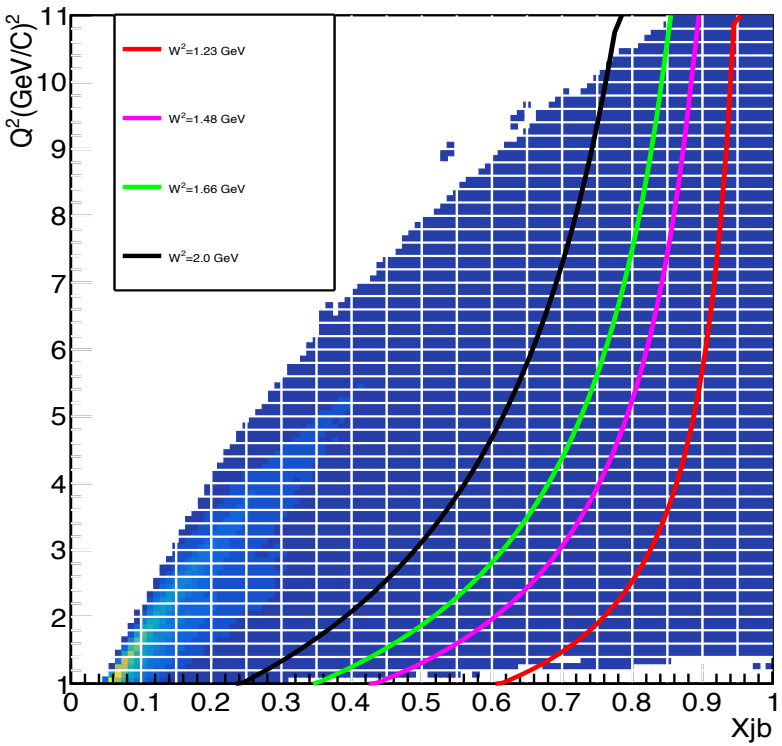
Coincident trigger?

proposal PR12-11-108 and PR12-09-014

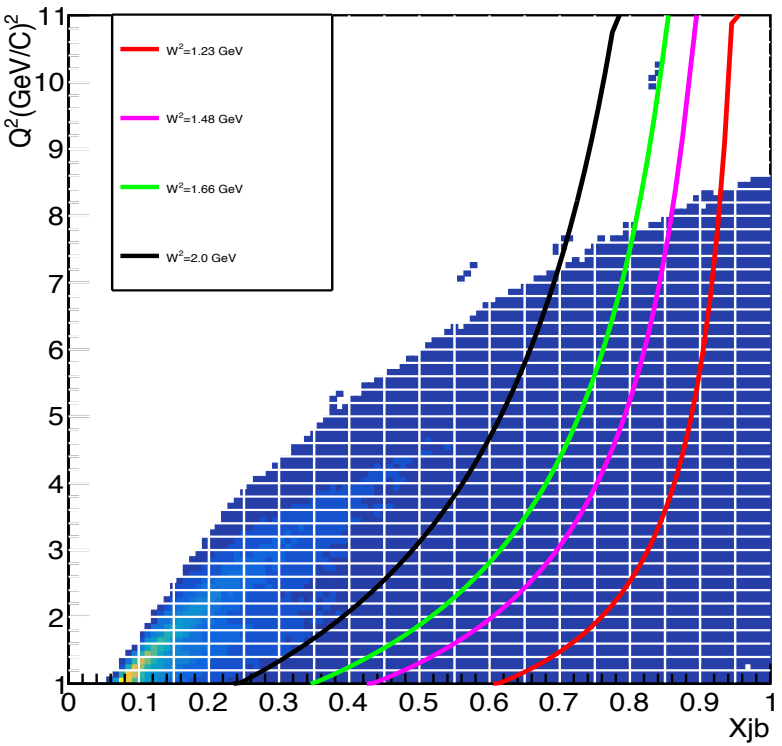
Kinematic Coverage

- Generated inclusive QE+resonance+DIS events:
  The W<3 GeV Peter Bosted fit
  The W>3 GeV world PDF sets
- GEMC+detector acceptance

11GeV beam



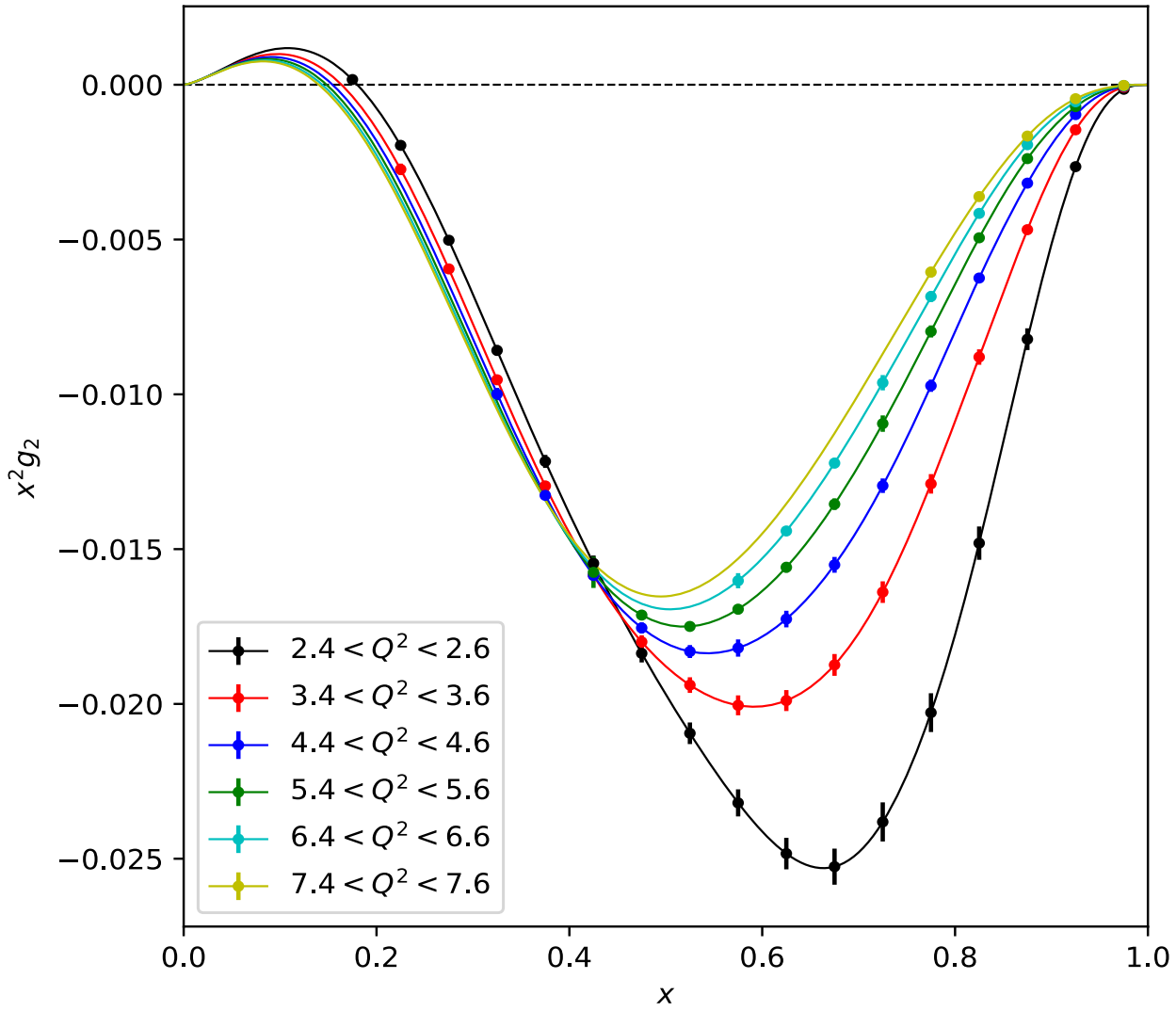
8.8GeV beam



$\Delta X=0.05$ and $\Delta Q^2=0.2$ (GeV/c)^2

Projections: x^2g_2

Beam E_0= 8.8 GeV, polarization 70%, Dilution 0.17



- F2 from global PDFs (CT14)
- Error bar: Pure statistic error
- The systematic errors will be estimated in the future proposal, including the g_1 contribution, the azimuthal angle resolution, the acceptance and etc …

From Chao Gu

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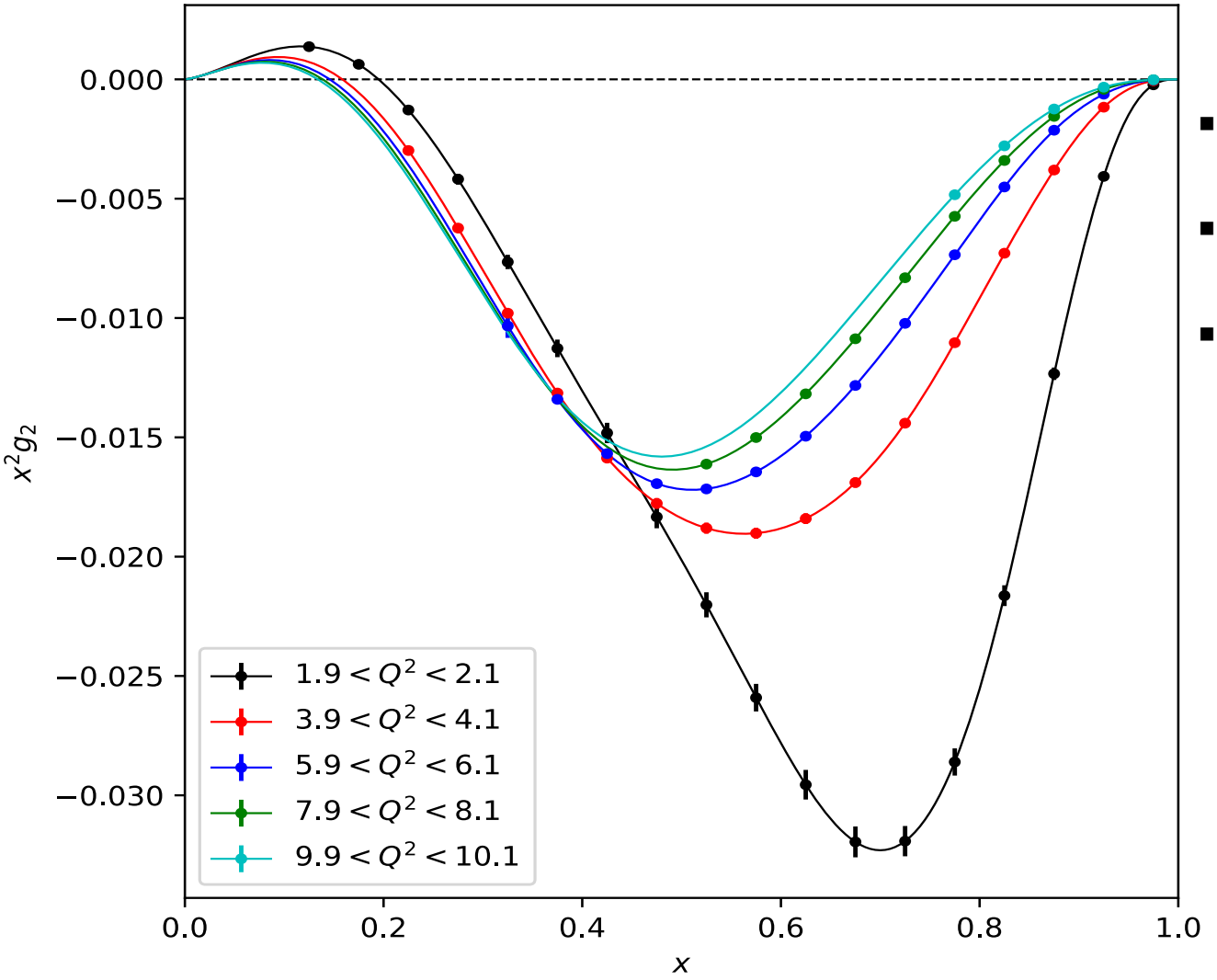

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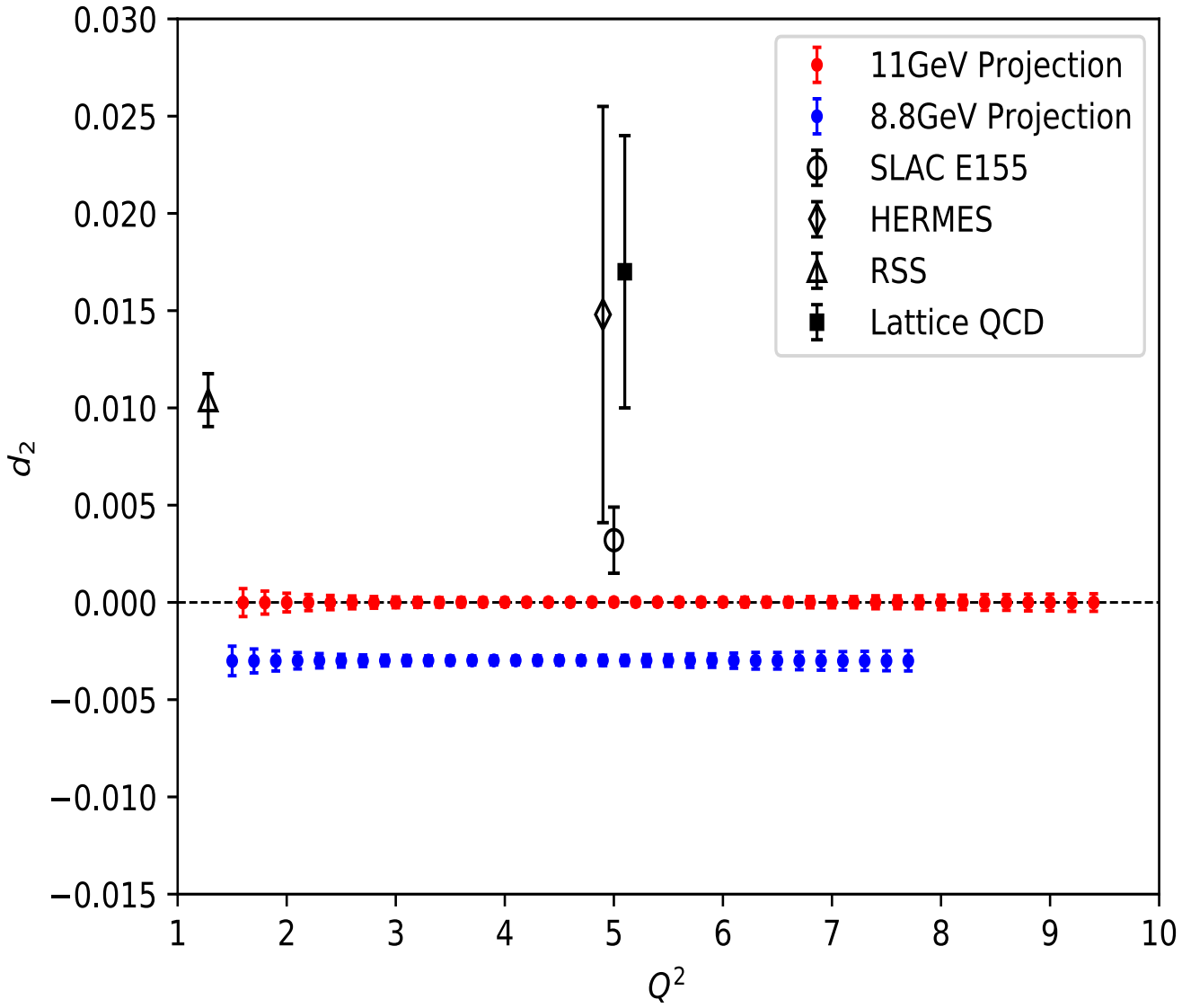
Projections: d_2



- Error bar: Pure statistic error
- $g_2$ww from model at unmeasured x regions

From Chao Gu

Summary and Outlook

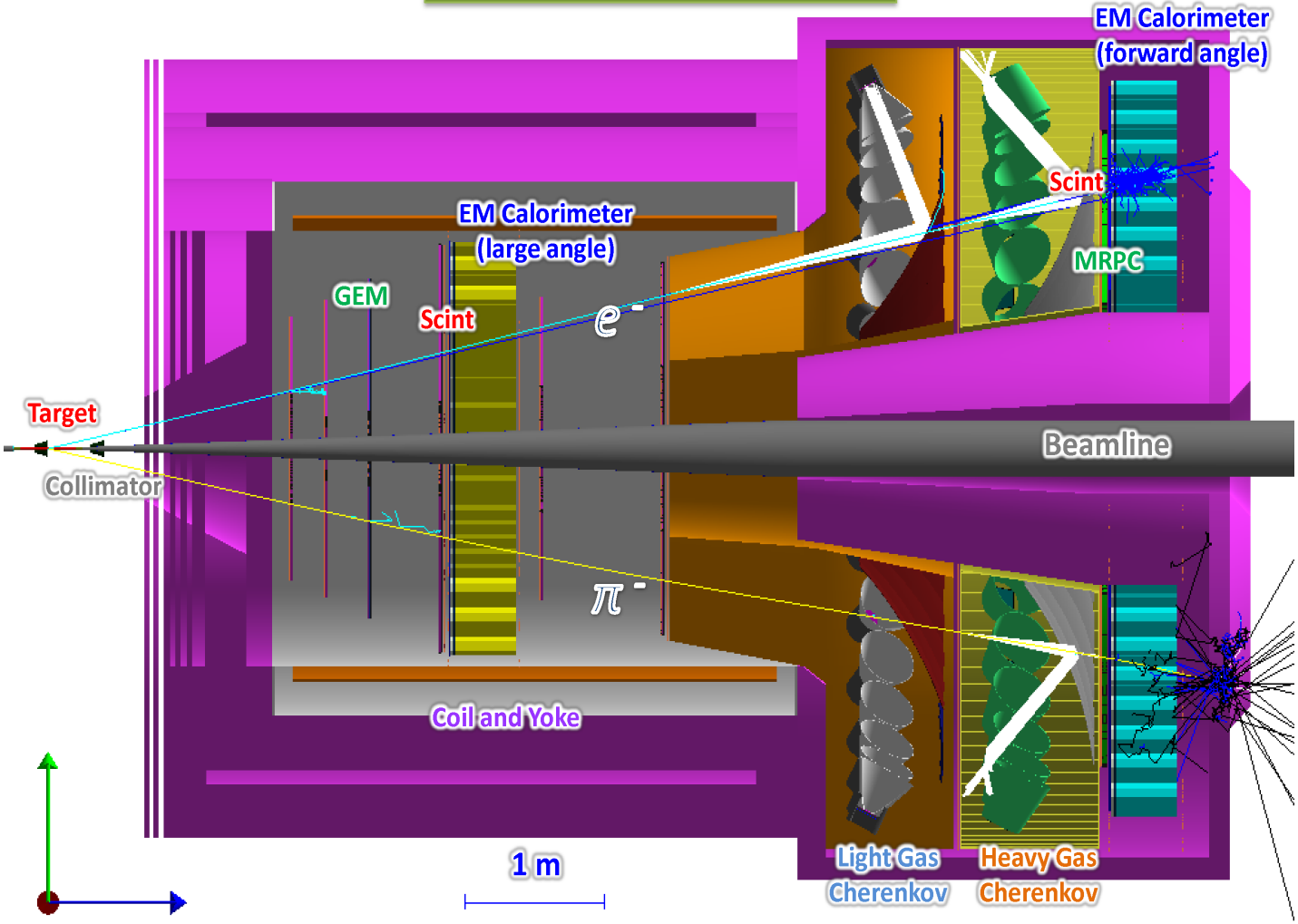
- Precision measurement of the proton and neutron spin structure function (g^p_2 and g^n_2) and Asymmetries A_2 form SIDIS experiment with transversely polarized NH3, 3He, and longitudinally polarized 3He targets.

- Study x and Q^2 dependence, twist-3 effects, moments of $g_2(x, Q^2)$ and comparison with Lattice QCD predictions.

- More simulation work and writing the proposal.

Welcome to join us!

SoLID (SIDIS and J/ψ)



Backups

How to get g_2 by using the real target polarizations

Target polarization is not exactly perpendicular to the beam line

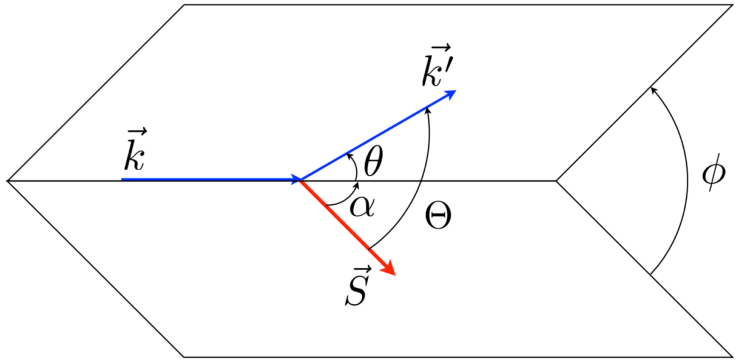
$$\tilde{A}_\perp = \frac{1}{f_{RC}}\left[\frac{C_1}{fP_t}\left(\left(\frac{N_L - N_R}{N_L + N_R}\right)\frac{1}{P_b} - A_{EW}\right) + C_2\right] + A_{RC}$$

$$g_2 = \frac{yF_1}{2E'(\cos\Theta - \cos\alpha)}\left[\tilde{A}_\perp \nu \frac{(1+\epsilon R)}{1-\epsilon} - \frac{g_1}{F_1}[E\cos\alpha + E'\cos\Theta]\right]$$

$$A_2 = \gamma(g_1 + g_2)/F_1$$

$$\cos\Theta = \sin\alpha\sin\theta\cos\Phi + \cos\alpha\cos\theta$$

$\alpha = \pi/2$ $\Theta = 0, \pi$



F1 was calculated from global fit on F2 and $R=\sigma_L(x, Q2)/\sigma_T(x, Q2)$

https://arxiv.org/abs/hep-ex/0204028v1

g2

More general g2 can be written by:

$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M}h_T(y,Q^2) + \zeta(y,Q^2)\right]\frac{\mathrm{d}y}{y}$$

quark transverse momentum contribution

twist-3 part which arises from quark-gluon interactions