A Precision Measurement of Inclusive g_2 , d_2 with SoLID on Polarized ^3He at 8.8 and 11 GeV

A Run-Group Proposal in parallel to E12-10-006/E12-11-007

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For the SoLID collaboration

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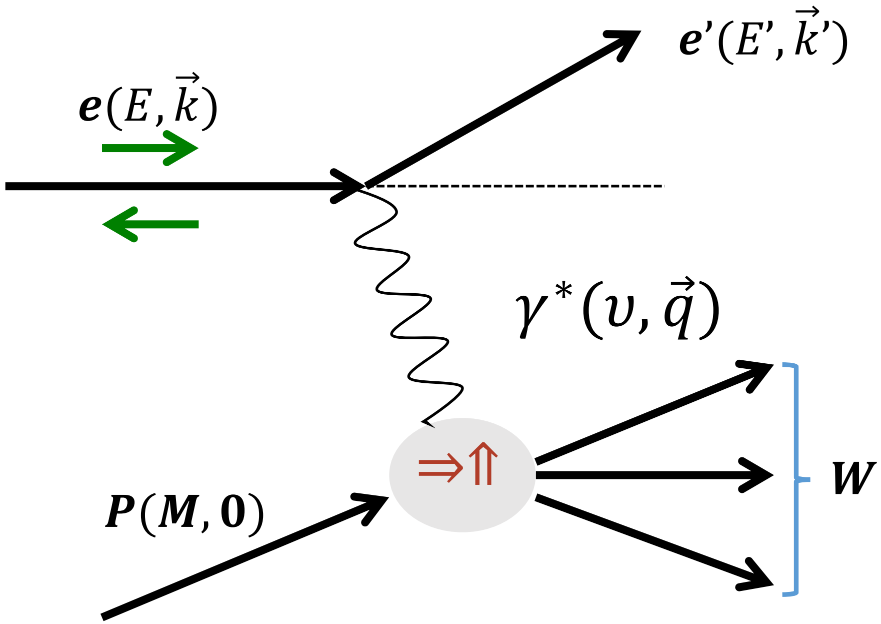
Inclusive Electron Scattering



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

$$\frac{d^2\sigma}{dE'd\Omega} = \sigma_{Mott}\left[\begin{array}{c}\frac{1}{\nu}F_2(x,Q^2) + \frac{2}{M}F_1(x,Q^2)tan^2\frac{\theta}{2} \\ +\gamma g_1(x,Q^2) + \delta g_2(x,Q^2)\end{array}\right]$$

spin dependent Structure Function

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})

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

- leading twist related to g_1 by Wandzura-Wilczek relation

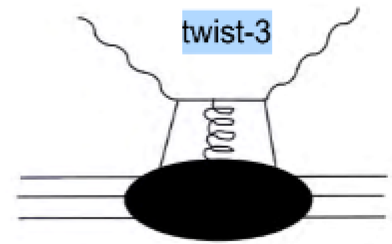
$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$

Neutron d_2 and Twist-3 Matrix Element

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

quark transverse momentum contribution

twist-3 part which arises from quark-gluon interactions



d_2: the x^2 moment of $\bar{g}_2(x,Q^2)$

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

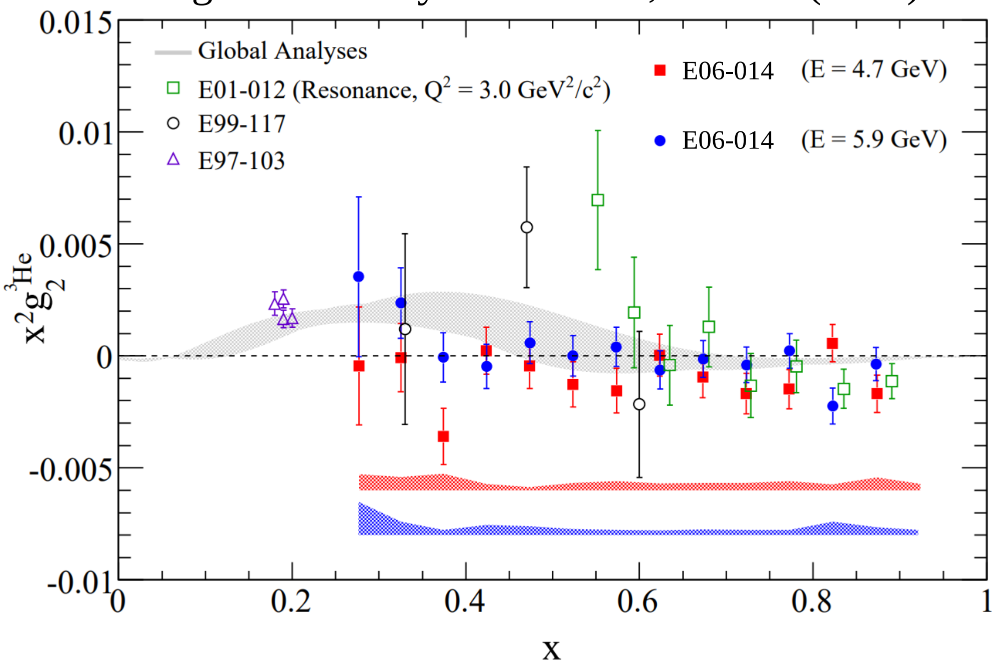
$$= \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx$$

- ✓ Calculable on the Lattice.
- ✓ A clean way to access twist-3 contribution
- ✓ Dominated by high x data because of weighting

Existing Neutron g_2 Data

- First precise measurement of neutron g_2 from SLAC, averaged $Q^2 \approx 5$ GeV^2
- Measurements from JLab 6 GeV era
- The ongoing Hall C d_2^n E12-06-121, $0.2 < x < 0.95$ and $2.5 < Q^2 < 7$ GeV^2, with SHMS and upgraded HMS
- We propose to measure g_2^n with SoLID at $x > 0.1$ and $1.5 < Q^2 < 10$ GeV^2

Figure from Phys. Rev. D 94, 052003 (2016)



^{3}He	g_2^n, d_2^n, Γ_2^n	$0.5 \leq W \leq 2.5\ GeV$	$0.1 \leq Q^2 \leq 0.9$	JLAB E94–010 [29]
^{3}He	g_2^n	$x = 0.2$	$0.57 \leq Q^2 \leq 1.34$	JLAB E97–103 [30]
^{3}He	g_2^n, d_2^n	$x = 0.33, 0.47, 0.6$	2.7,3.5,4.8	JLAB E99–117 [2]
^{3}He	g_2^n	$x < 0.1$	$0.035 \leq Q^2 \leq 0.24$	JLAB E97–110 [31]
^{3}He	g_2^n, d_2^n	$0.25 \leq x \leq 0.9$	3.21,4.32	JLAB E06–014 [14]
^{3}He	g_2^n, d_2^n	$0.55 \leq x \leq 0.9$	$0.7 \leq Q^2 \leq 4.0$	JLAB E01–012 [33]

Exsiting Neutron d_2 Data

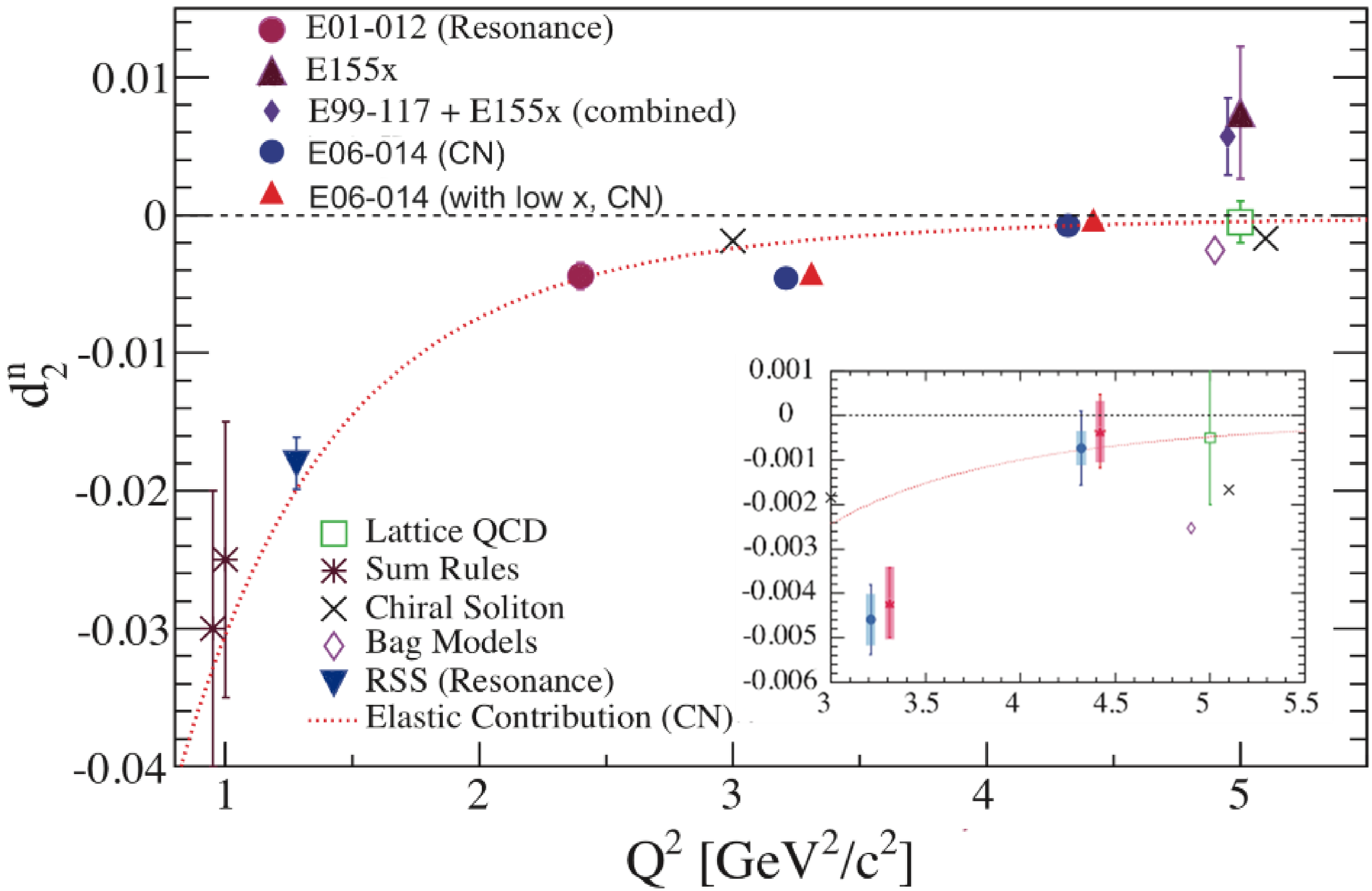
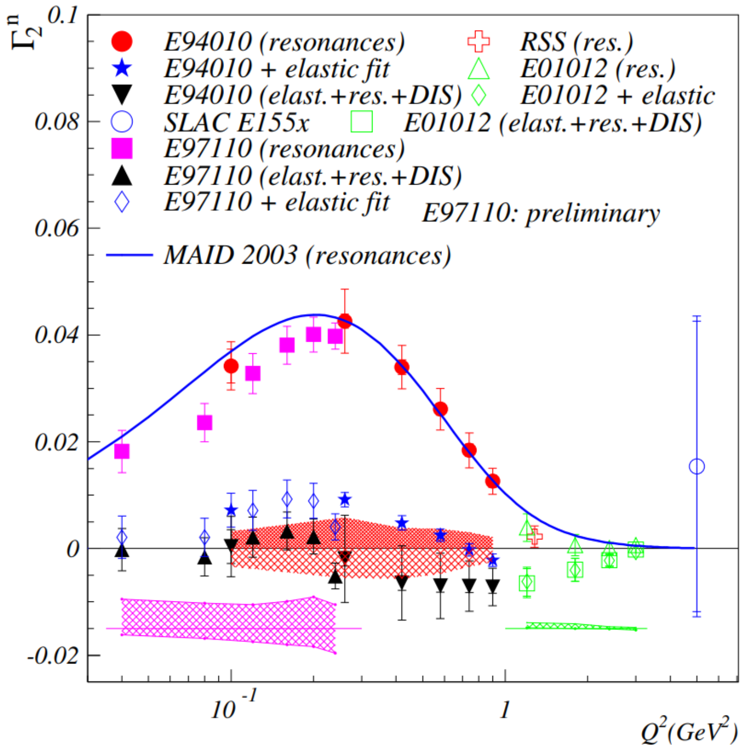


Figure from Phys. Rev. Lett., 113(2):022002, 2014

Test the Burkhardt-Cottingham (BC) Sum Rule

Figure from arXiv: 1807.05250



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

- Validity conditions:
- ✓ g_2 is well-behaved, Γ_2 is finite
- ✓ g_2 is not singular at $x_{Bj} = 0$

- It is verified from world data at $0 < Q^2 < 5\ \mathrm{GeV}^2$

- Elastic and the inelastic contributions to the wrist moment of g_2 cancel for low and moderate Q^2

BC = Measured + Low-x + Elastic

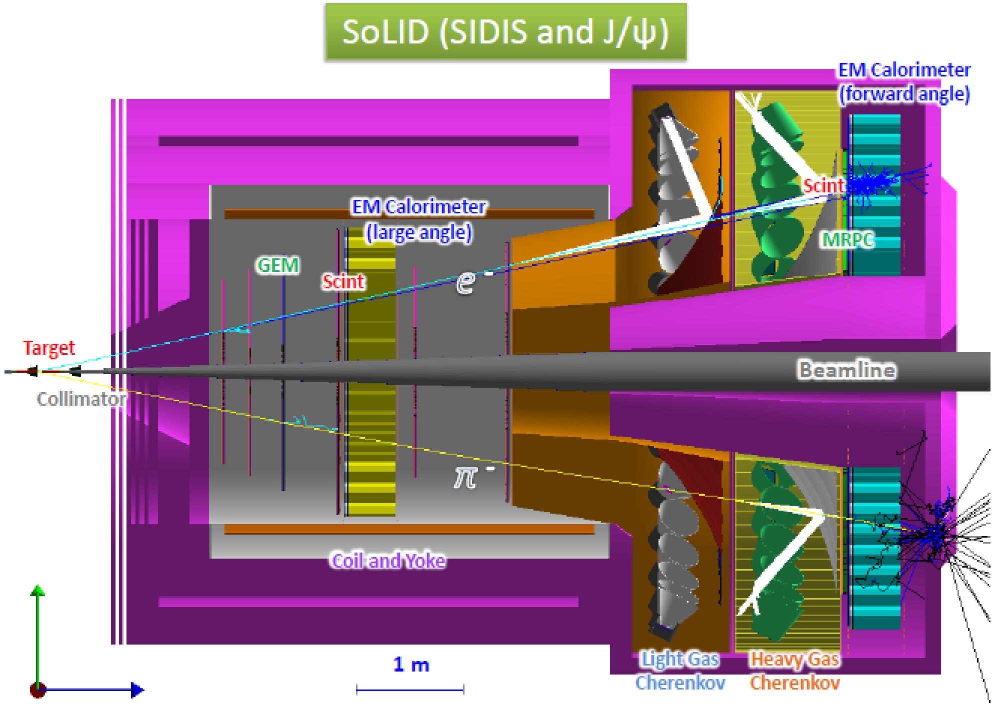
Measured: Measured x-range

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

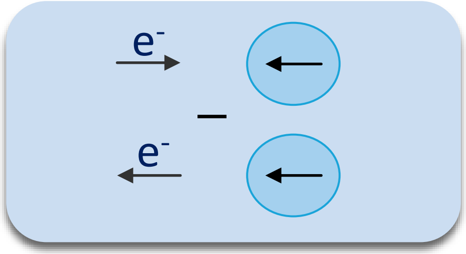
Elastic: From elastics form factors

SoLID SIDIS-^{3}He Experiments

- SoLID SIDIS layout without changes
- E12-10-006: Transversely polarized ^{3}He target
- E12-11-007: Longitudinally polarized ^{3}He target
- High in-beam polarization ~ 60%
- Two Beam energies: 11 GeV and 8.8 GeV
- Polarized luminosity with 15 uA current: 1e^{36} cm^{-2}s^{-1}

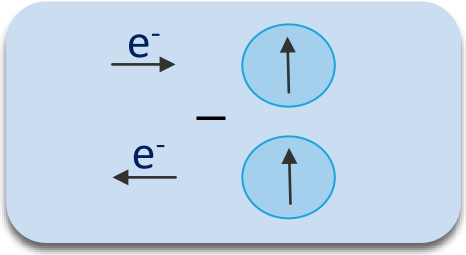


Extraction of g_2



E12-11-007:

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}}$$



E12-10-006:

$$A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$

$$\Delta\sigma_{\parallel,\perp} = 2\sigma_0 A_{\parallel,\perp}$$

$$g_1 = \frac{MQ^2}{4\alpha^2}\frac{\nu E}{(E-\nu)(2E-\nu)}\left[\Delta\sigma_{\parallel} + \tan\frac{\theta}{2}\Delta\sigma_{\perp}\right],$$

$$g_2 = \frac{MQ^2}{4\alpha^2}\frac{\nu^2}{2(E-\nu)(2E-\nu)}\left[-\Delta\sigma_{\parallel} + \frac{E+(E-\nu)\cos\theta}{(E-\nu)\sin\theta}\Delta\sigma_{\perp}\right]$$

Expected Event Rates

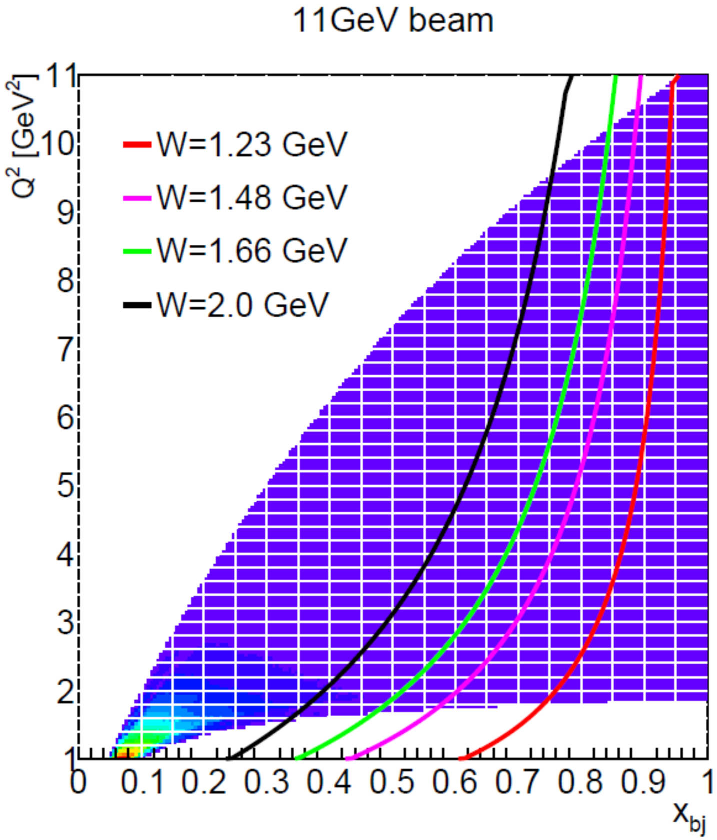
More than 15 kHz free trigger space with 100 kHz DAQ limit
Dedicated single electron trigger rate: 103 kHz/10 = 10.3 kHz
Reusable random coincidence trigger rate: 69 kHz

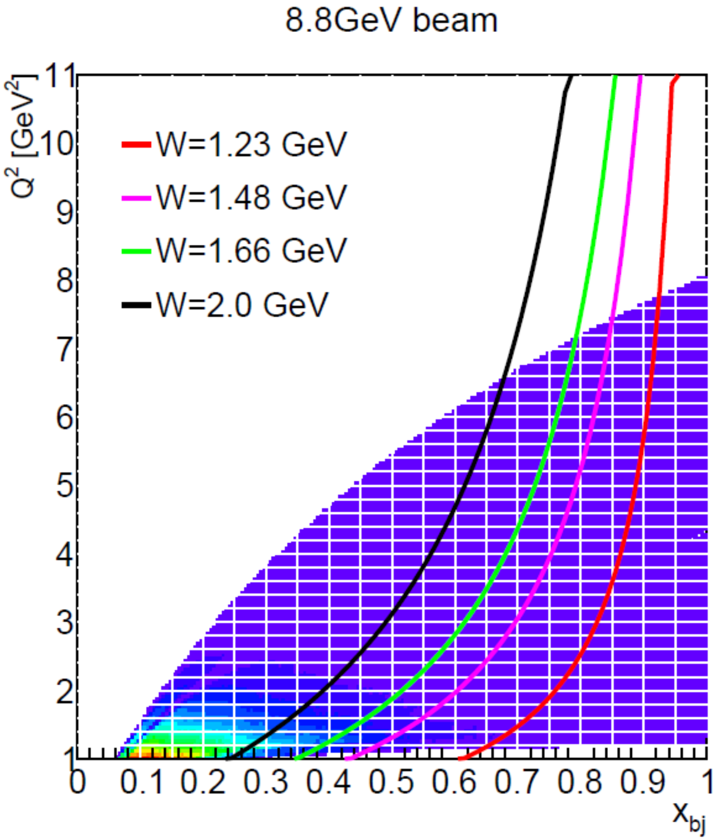
Rate (kHz) Ecal 7 modules	EC+LGC+SPD 3He+up+down widow
FA e^-	59+1.15+1.8
FA hadron no e^-	28.6+3.9+5.6
LA e^-	4.1+3.6+2.6
LA hadron no e^-	7.7+6.5+3.8
FA MIP (hadron) trigger	8013+2591+3887
SIDIS coincidence	31.2
Hadron coincidence	14.7+2.52+2.61=19.83
Total rate	< 85 kHz

Rates Estimation for E12-06-110

Kinematic Coverage

Configuration	Approved Beam Time (hours)
E12-10-006 (Transverse) @ 11 GeV	1152
E12-10-006 (Transverse) @ 8.8 GeV	504
E12-11-007 (Longitudinal) @ 11 GeV	538
E12-11-007 (Longitudinal) @ 8.8 GeV	228



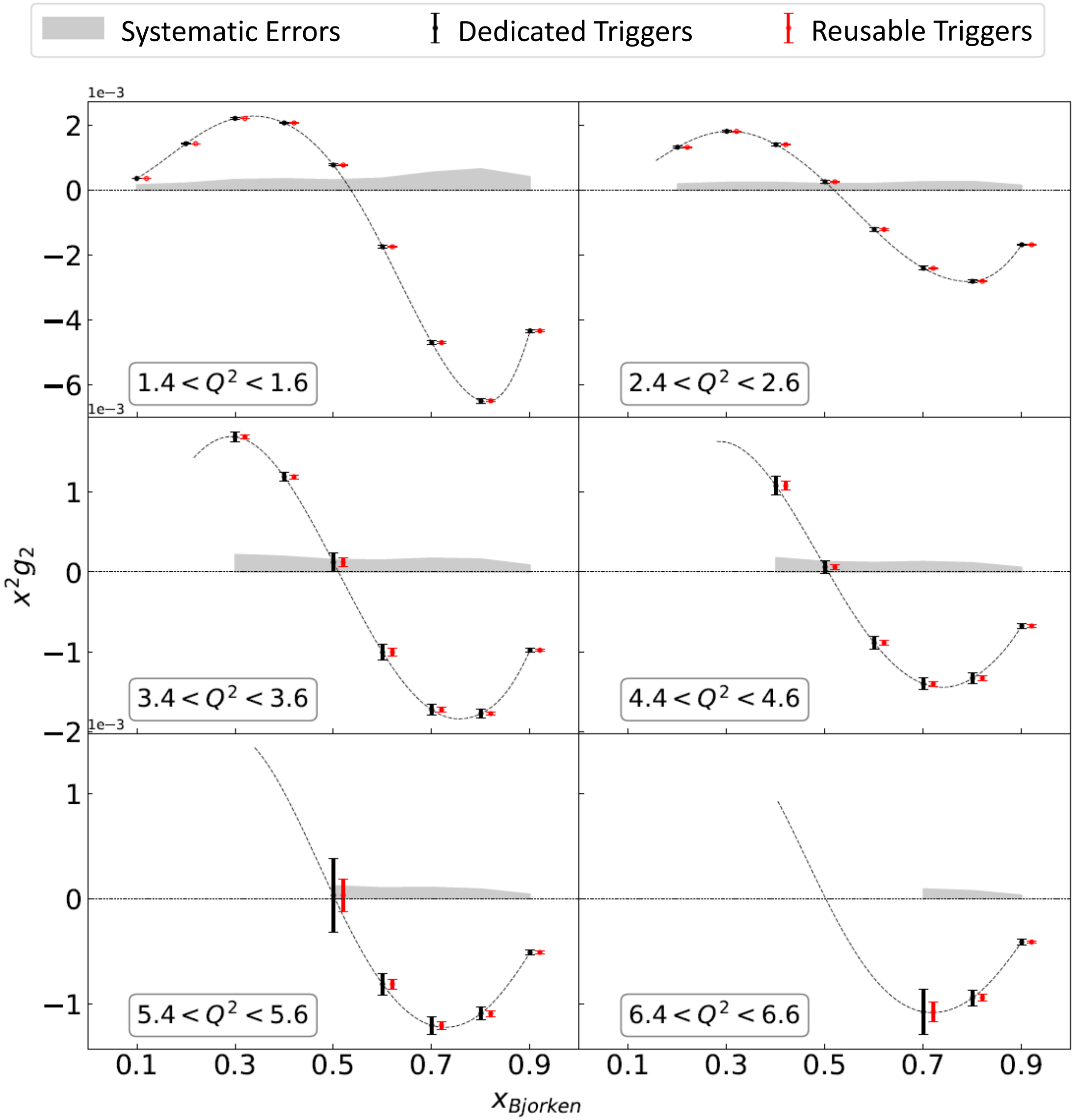


Systematic Uncertainty Estimate

Source	Systematic Uncertainty
Cross Sections	
Detector acceptance	5.0%
Detector efficiencies	3.0%
Target density	2.0%
Beam charge	1.0%
Background subtraction	3.0%
Asymmetries	
Dilution effects	$< 1.0\%$
Beam polarization	$< 2.0\%$
Target polarization	3.0%
Charge asymmetry	$< 10^{-4}$
Pion asymmetry	$< 5 \times 10^{-4}$
Unfolding Procedure	
Nuclear corrections	$\sim 5.0\%$
Radiative corrections	$\sim 3.0\%$
Physics Results	
Cross sections	$< 10.0\%$
g_2 syst.	$\sim 10^{-3}$-10^{-4}
d_2 stat.	$\sim 3 \times 10^{-4}$
d_2 syst. (11 GeV)	$\sim 5 \times 10^{-4}$
d_2 syst. (8.8 GeV)	$\sim 8 \times 10^{-4}$

Projections – x^2g_2 @ 8.8 GeV

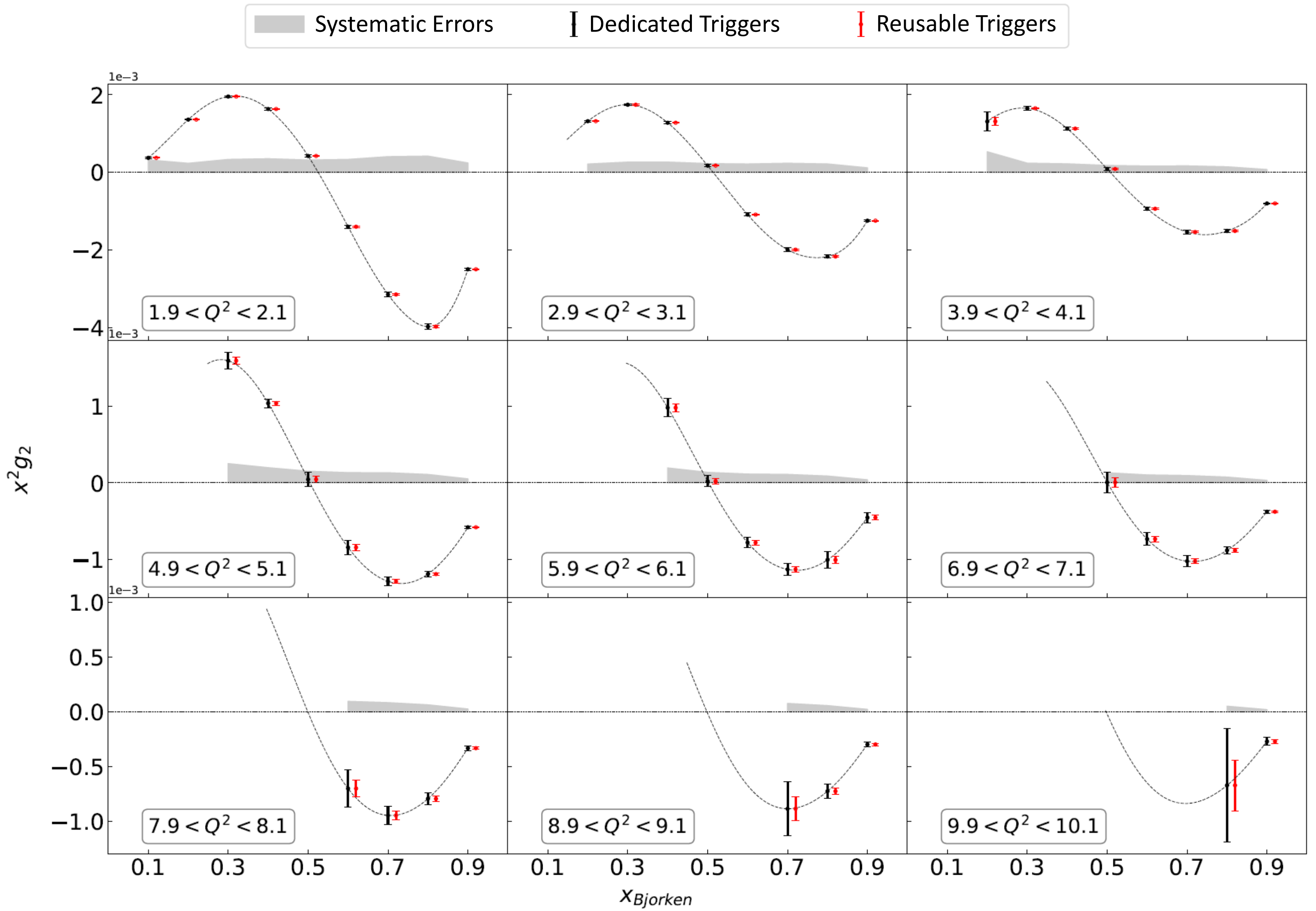
Assumed 55% target polarization, 85% beam polarization, 0.17 nitrogen dilution



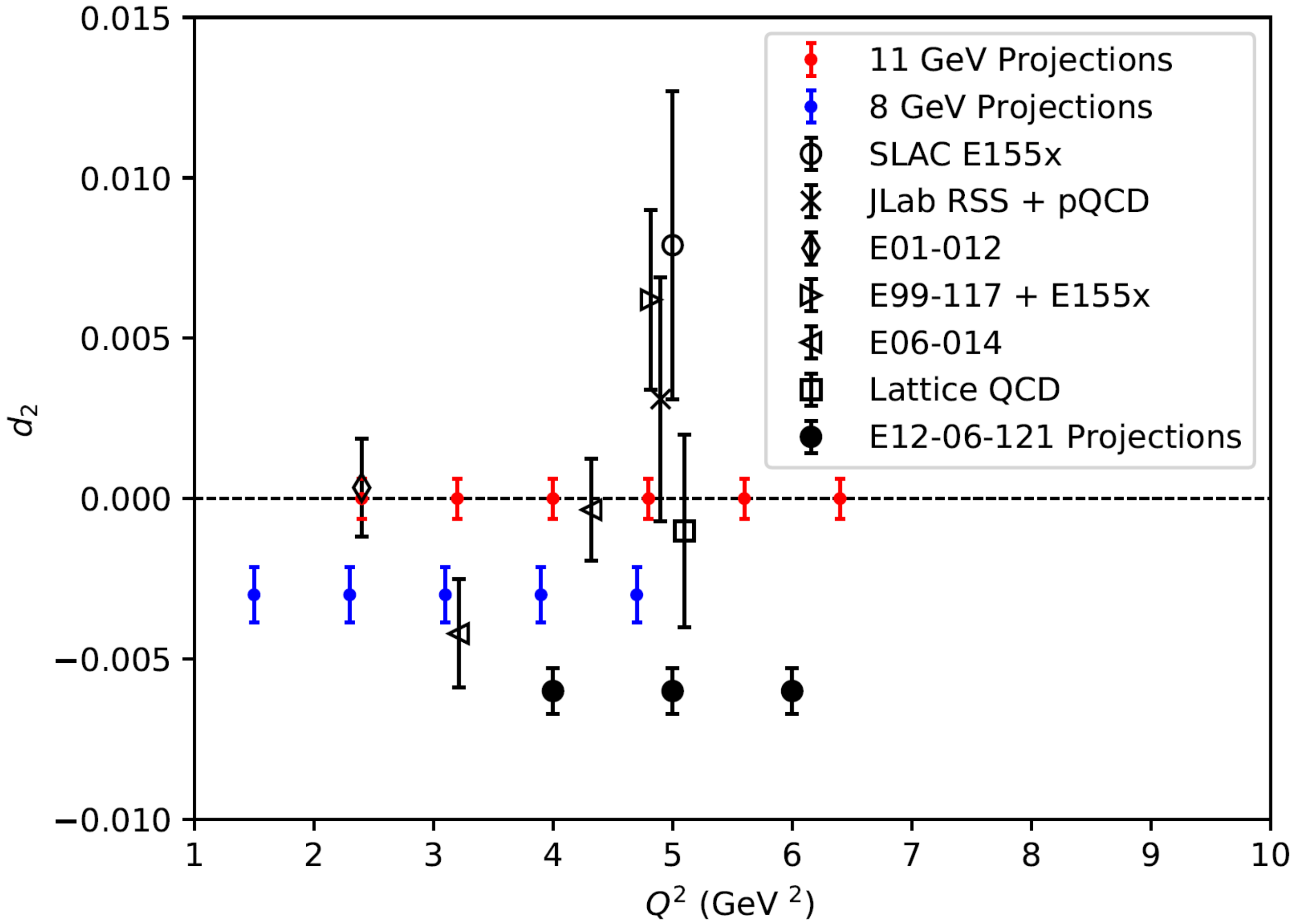
- Dedicated triggers assumes a prescale factor of 10
- F_2 from New Muon Collaboration (NMC) parameterization
- $R = g^n_1/F^n_1$ from SLAC
- Errors:
  - Error bars - statistic errors
  - Shades - systematic errors

Projections – x^2g_2 @ 11 GeV

Assumed 55% target polarization, 85% beam polarization, 0.17 nitrogen dilution



Projections – d_2



- ✧ Results from dedicated triggers (prescale factor 10)
- ✧ Statistic and systematic errors combined
- ✧ Systematic errors dominate
- ✧ Require $x_{min} > 0.4$ to obtain d_2
- ✧ d_2 for $Q^2 < 6.5$ GeV^2

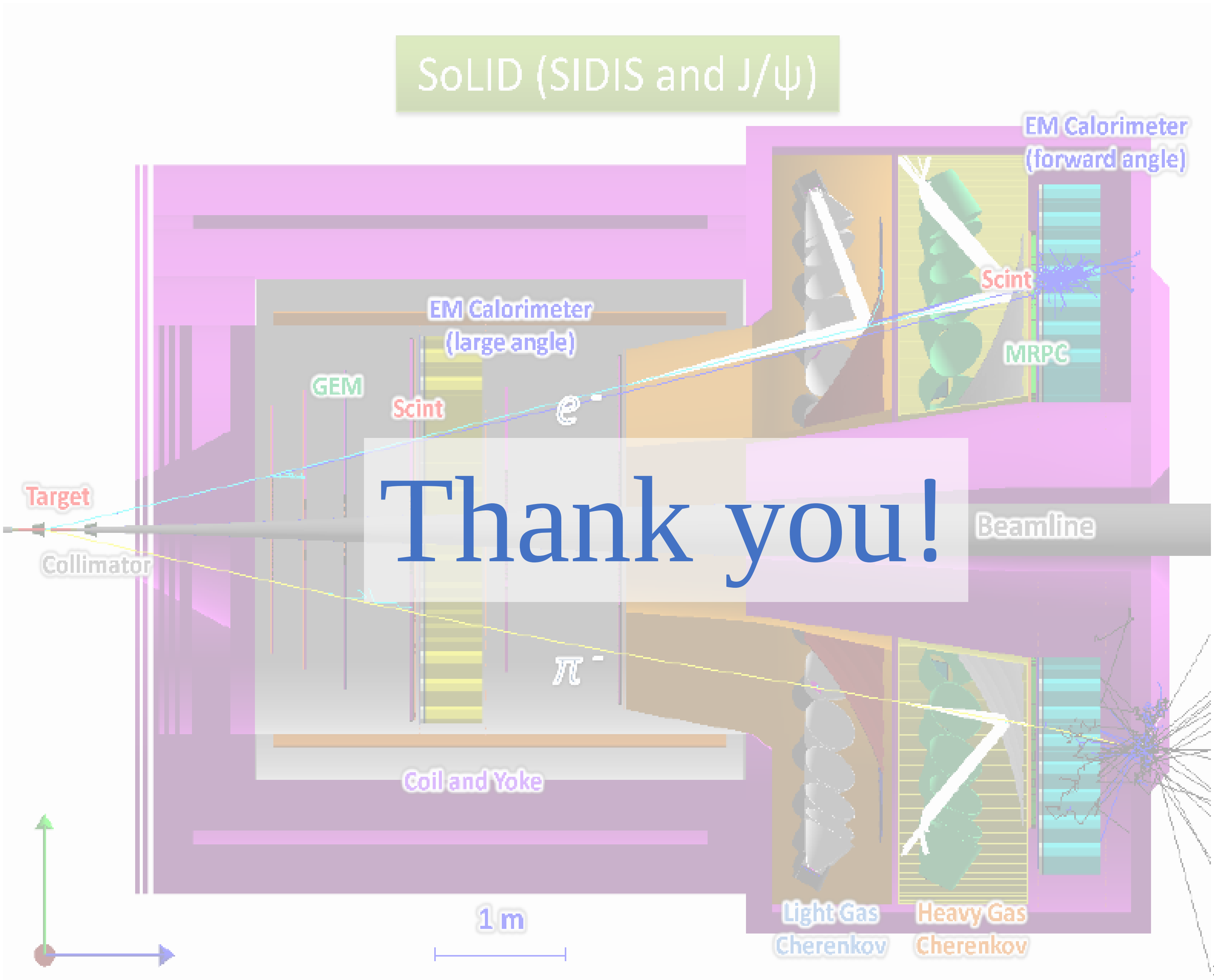
Summary

- We propose a parasitic measurement with SoLID-SIDIS ^{3}He experiments E12-10-006 and E12-11-007 to extract neutron g_2 at $x > 0.1$ and $1.5 < Q^2 < 10$ GeV^2

- Neutron d_2 can be extracted for $Q^2 < 6.5$ GeV^2

- The proposed dataset provides an opportunity to better understand the twist-3 matrix element $d_2(Q^2)$ and hence the associated quark-gluon correlations within the neutron

- Q^2 evolution of $d_2(Q^2)$ provides a direct test of Lattice QCD.


SoLID (SIDIS and J/ψ)
EM Calorimeter
(forward angle)
Scint
MRPC
EM Calorimeter
(large angle)
GEM
Scint
e-
Target
Collimator
Beamline
π-
Coil and Yoke
1 m
Light Gas
Cherenkov
Heavy Gas
Cherenkov

Thank you!