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

Run-Group Proposal in parallel to E12-10-006

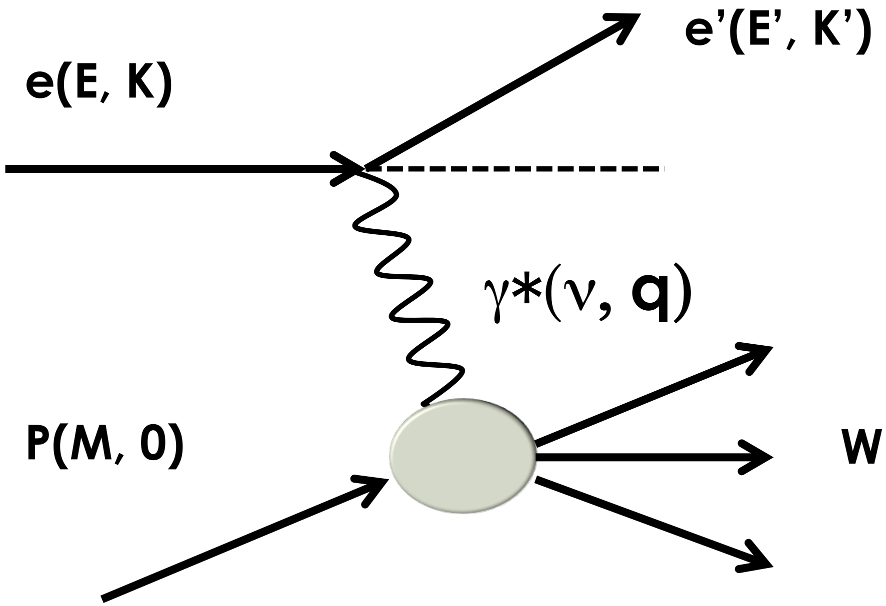
Spokesperson: Chao Peng[1] and Ye Tian[2]
E12-10-006 collaboration and SoLID collaboration

06/09/2020

- **Physics Motivation**
- **Experiment**
- **Expected Results**
- **Summary**

1: Argonne National Laboratory, Argonne, IL; 2: Syracuse University, Syracuse, NY

Inclusive Electron Scattering



Q^2 : Four-momentum transfer

x : Bjorken variable(=$Q^2/2M\nu$)

ν : Energy transfer

M : Nucleon mass

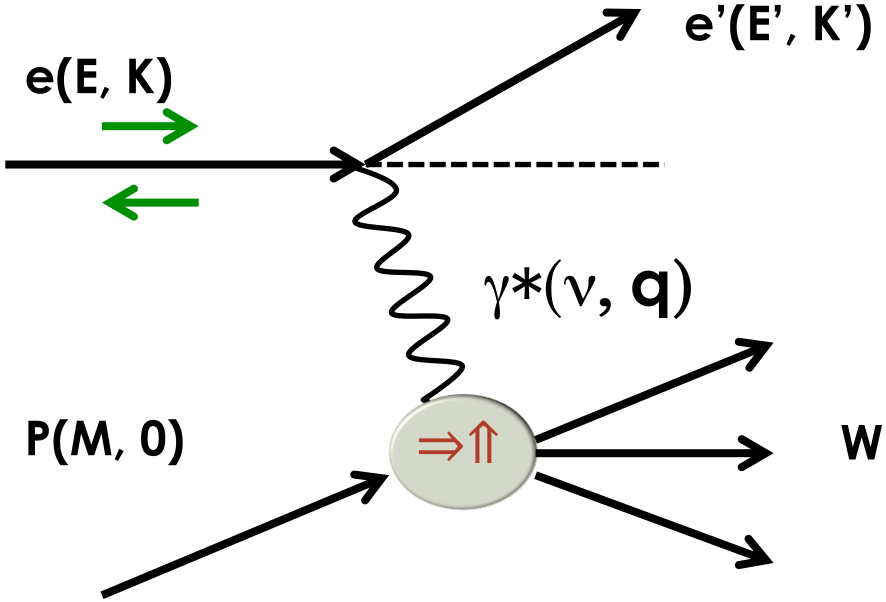
W : Final state hadronic mass

Inclusive unpolarized cross section:

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

spin averaged structure functions

Inclusive Electron Scattering



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

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 $O(m_q/\Lambda_{QCD})$

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

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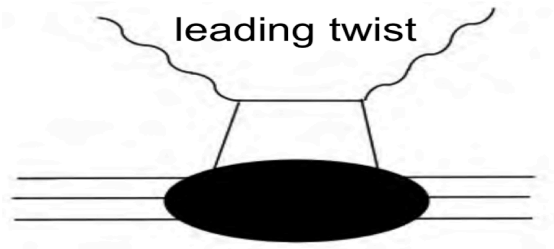

related to amplitude for scattering off asymptotically free quarks

- 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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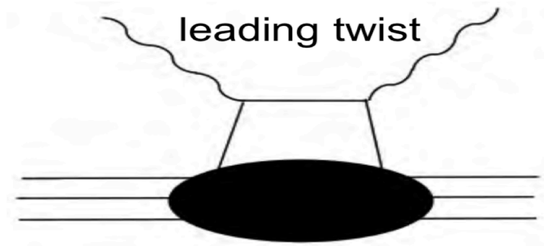

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g}_2(x,Q^2)$$

related to amplitude for scattering off asymptotically free quarks

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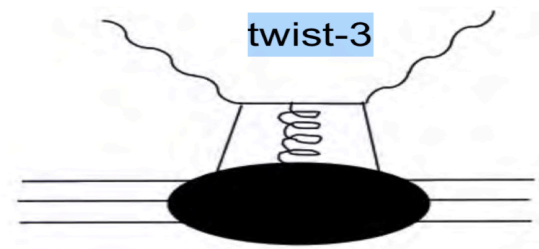


$$\bar{g}_2(x,Q^2) = -\int_x^1 \frac{\partial}{\partial y}\left[\frac{m_q}{M} h_T(y,Q^2) + \zeta(y,Q^2)\right]\frac{dy}{y}$$

quark transverse momentum contribution

twist-3 part which arises from quark-gluon interactions

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

Sensitive to large-x behavior

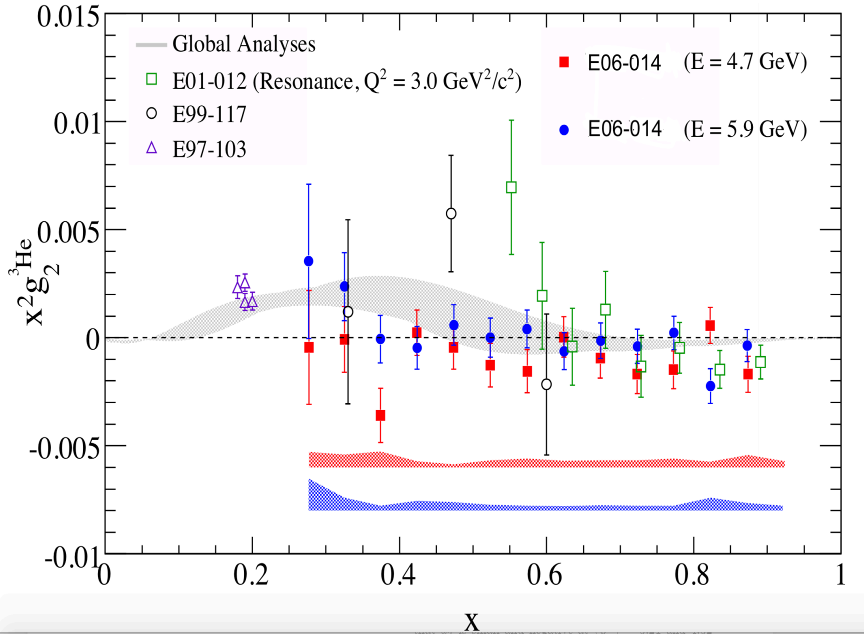
$$d_2(Q^2) = 3\int_0^1 x^2[g_2(x,Q^2) - g_2^{WW}(x,Q^2)]dx$$

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

- ✓ Calculable on the Lattice.
- ✓ A clean way to access twist-3 contribution, quantify q-g correlations

Existing Neutron g_2 Data

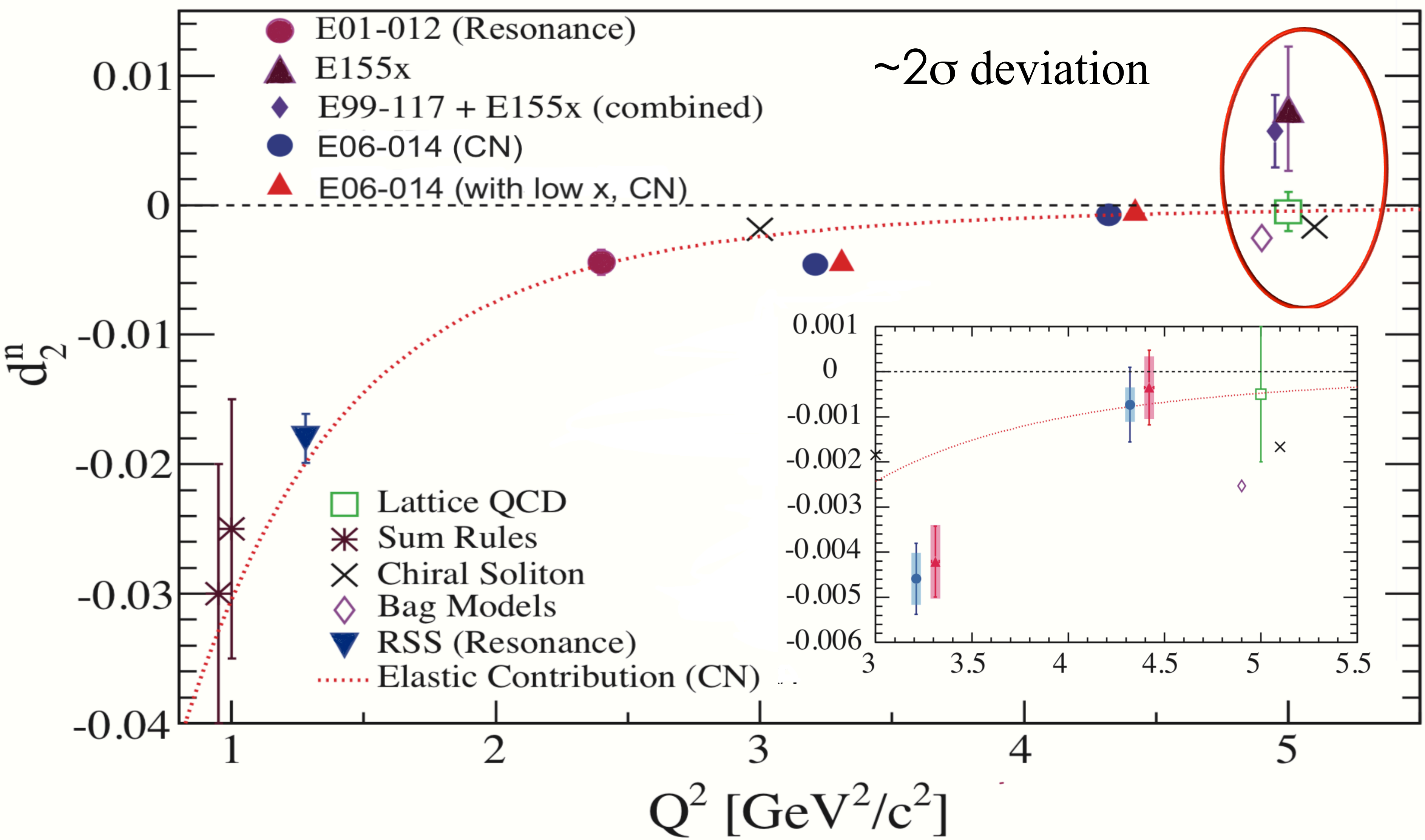
- First precise measurement of neutron g_2 from SLAC, averaged $Q^2 \approx 5$ GeV^2
- Measurement form Jefferson Lab: E<6GeV
- The ongoing Hall C d^n_2 E12-06-121, $0.2 < x < 0.95$ and $2.5 < Q^2 < 7$ GeV^2, SHMS and upgraded HMS with six kinematic settings.
- We propose to measure g^n_2 at $x>0.1$ and $1.5 < Q^2 < 10$ GeV^2, SoLID



Graph Reference arXiv:1603.03612v3

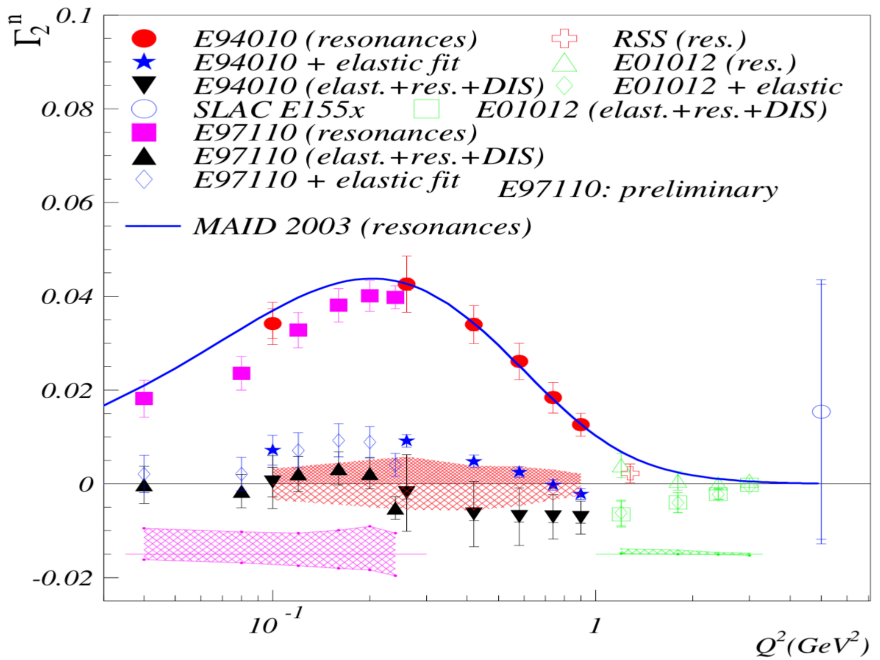
^{3}He	g_2^n, d_2^n, Γ_2^n	$0.5 \le W \le 2.5\ GeV$	$0.1 \le Q^2 \le 0.9$	JLAB E94–010 [29]
^{3}He	g_2^n	$x = 0.2$	$0.57 \le Q^2 \le 1.34$	JLAB E97–103 [30]
^{3}He	g_2^n, d_2^n	$x = 0.33, 0.47, 0.6$	2.7,3.5,4.8	JLAB E99–117 [2]
^{3}He	g_2^n	$x < 0.1$	$0.035 \le Q^2 \le 0.24$	JLAB E97–110 [31]
^{3}He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

Existing Neutron d_2 Data



Revealing Color Forces with Transverse Polarized Electron Scattering Arxiv:1805.08835

Test the Burkhardt-Cottingham (BC) Sum Rule



arXiv:1807.05250

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

- Validity conditions:

✓ g_2 is well-behaved, Γ2 is finite

✓ g_2 is not singular at $x_{Bj} = 0$

- It is verified from world data at $0<Q^2<5$ 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

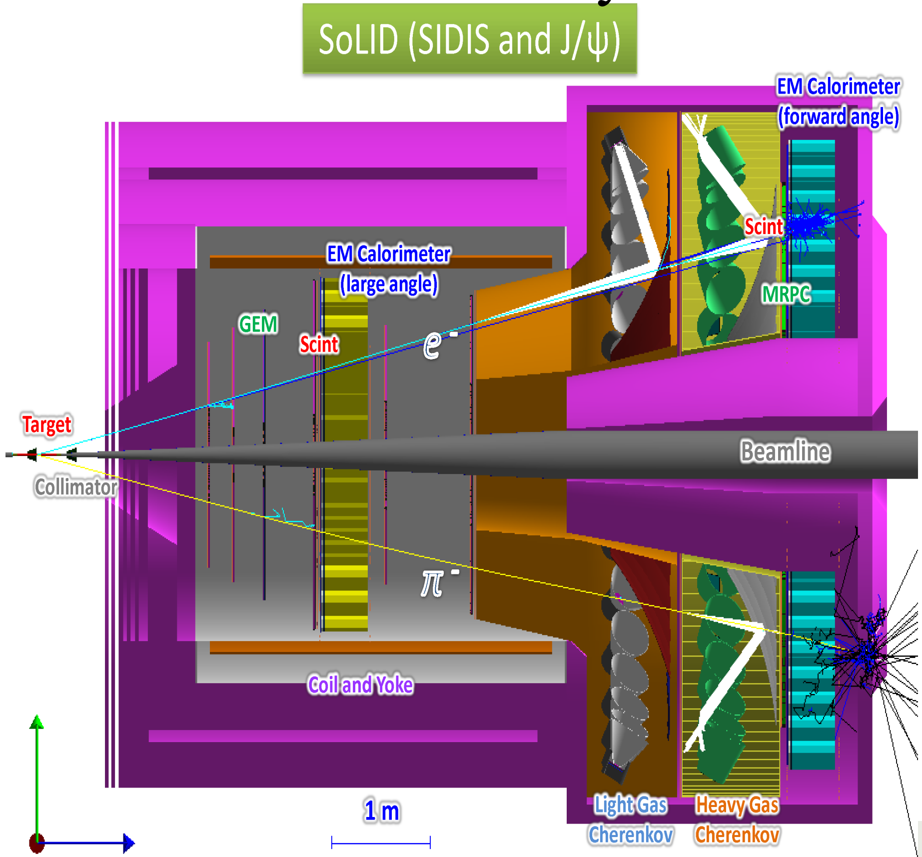
Measured: Measured x-range

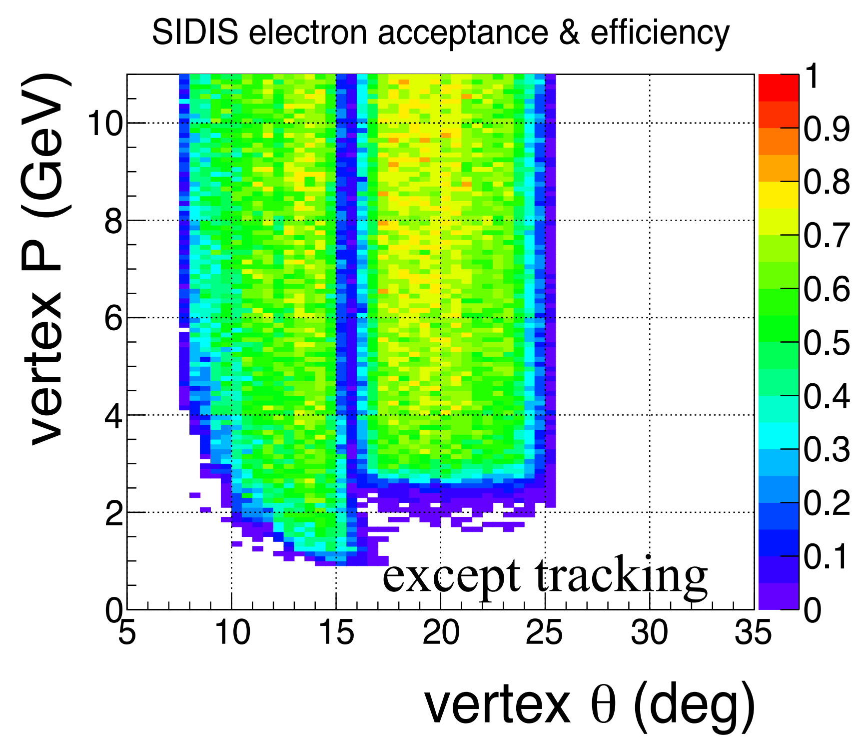
low-*x*: refers to unmeasured low x part of the integral. Assume $g_2 = g_2^{WW}$

Elastic: From well know elastics form Factors

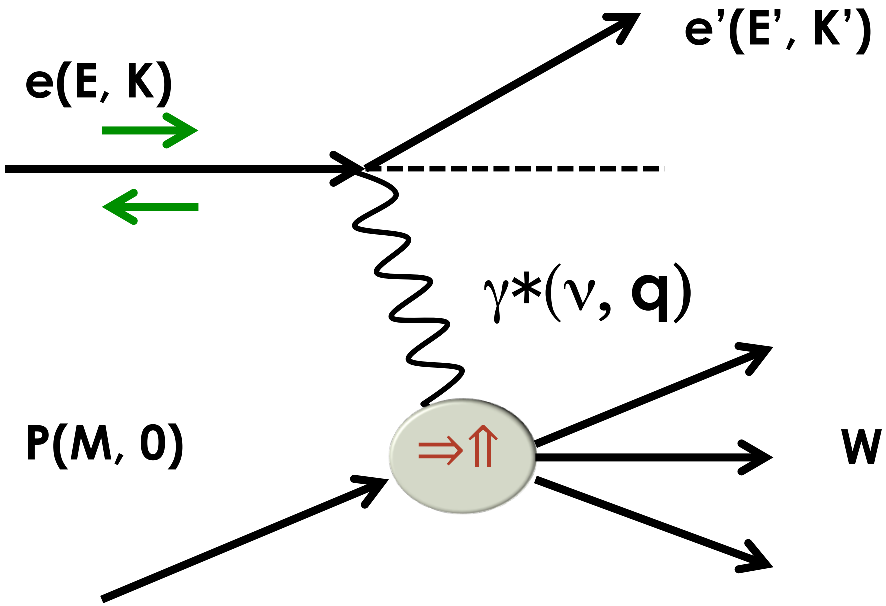
Experiment: SIDIS Transversely Polarized ^3He (E12-10-006)

- Use the existing proposed experimental setups w/o changes
- JLab Hall A polarized ^3He target
- High in-beam polarization ~ 60%
- Two Beam energies: 11 GeV and 8.8 GeV
- Polarized luminosity with 15uA current: $1e^{36}\ cm^{-2}s^{-1}$





Extract g_2 from Cross Section Differences



Q^2 : Four-momentum transfer
x : Bjorken variable ($=Q^2/2M\nu$)
ν : Energy transfer
M : Nucleon mass
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L $$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2}{MQ^2}\frac{E'}{\nu E}\left[(E + E'\cos\theta)g_1(x, Q^2) - 2Mx\,g_2(x, Q^2)\right]$$

SoLID SIDIS Longitudinally Polarized 3He (E12-11-007)

T $$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2 E'^2}{MQ^2\upsilon^2 E}\sin\theta\cos\phi_{rela}\left[g_1(x, Q^2) + \frac{2E}{\upsilon}g_2(x, Q^2)\right]$$

SoLID SIDIS Transversely Polarized 3He (E12-10-006)

Expected Event Rates

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

SIDIS-3He E12-10-006

48 days 11 GeV

21 days 8.8 GeV

DAQ limit 100kHz

Coincident trigger

20 – 30% fluctuation

>15kHz

Free prescaled single electron trigger

FA+LA single electron trigger rate: 103kHz/10=10.3KHz

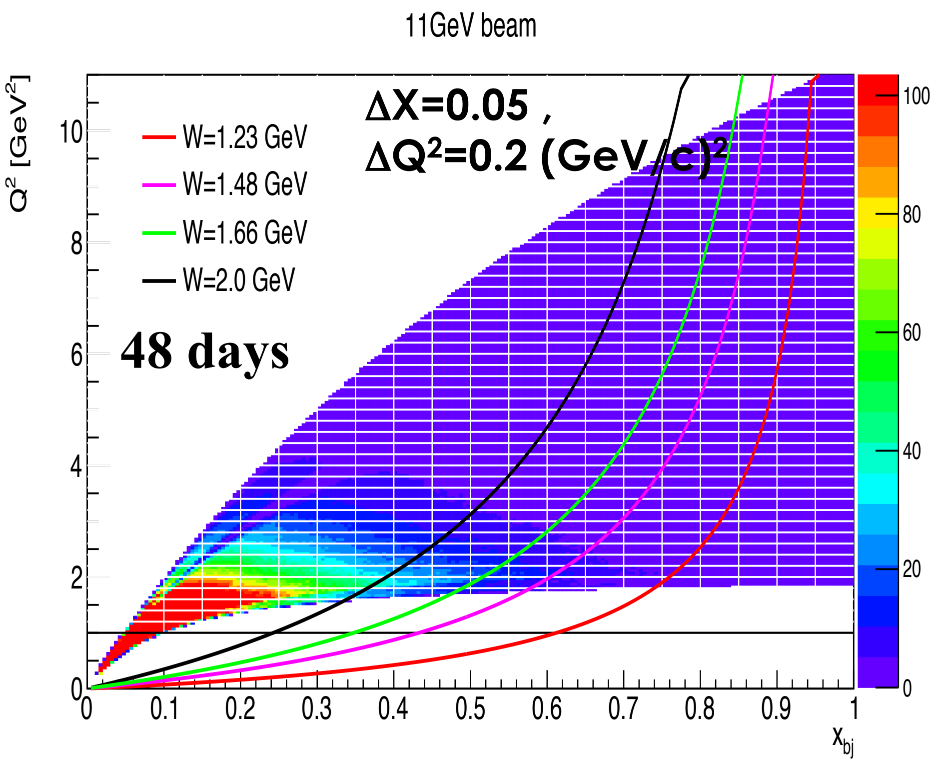
Projection

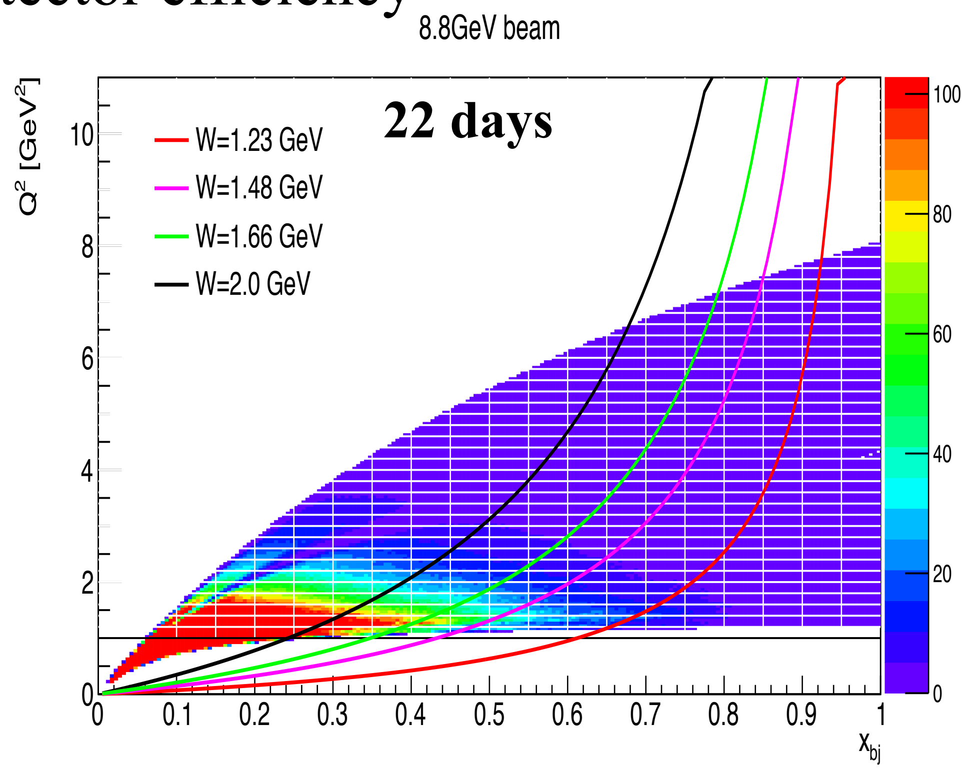
Reusable random coincidence trigger rate:

54kHz+15kHz=69kHz, which is equivalent to103kHz/2

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+detector efficiency





❖ Measure **neutron** spin structure function **g_2 (x, Q²)** at momentum transfer $1.5<Q^2<9.5$ GeV² and Bjorken x $0.1<x<0.9$. For $Q^2 > 8.5$ Ge², we will measure the x > 0.6 region.

Systematic Error Estimation

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

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

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)	$\sim 8 \times 10^{-4}$

Dominate g2 systematic errors

$\theta = 8.5^\circ \sim 9.5^\circ$

Elastic event at 2.2GeV

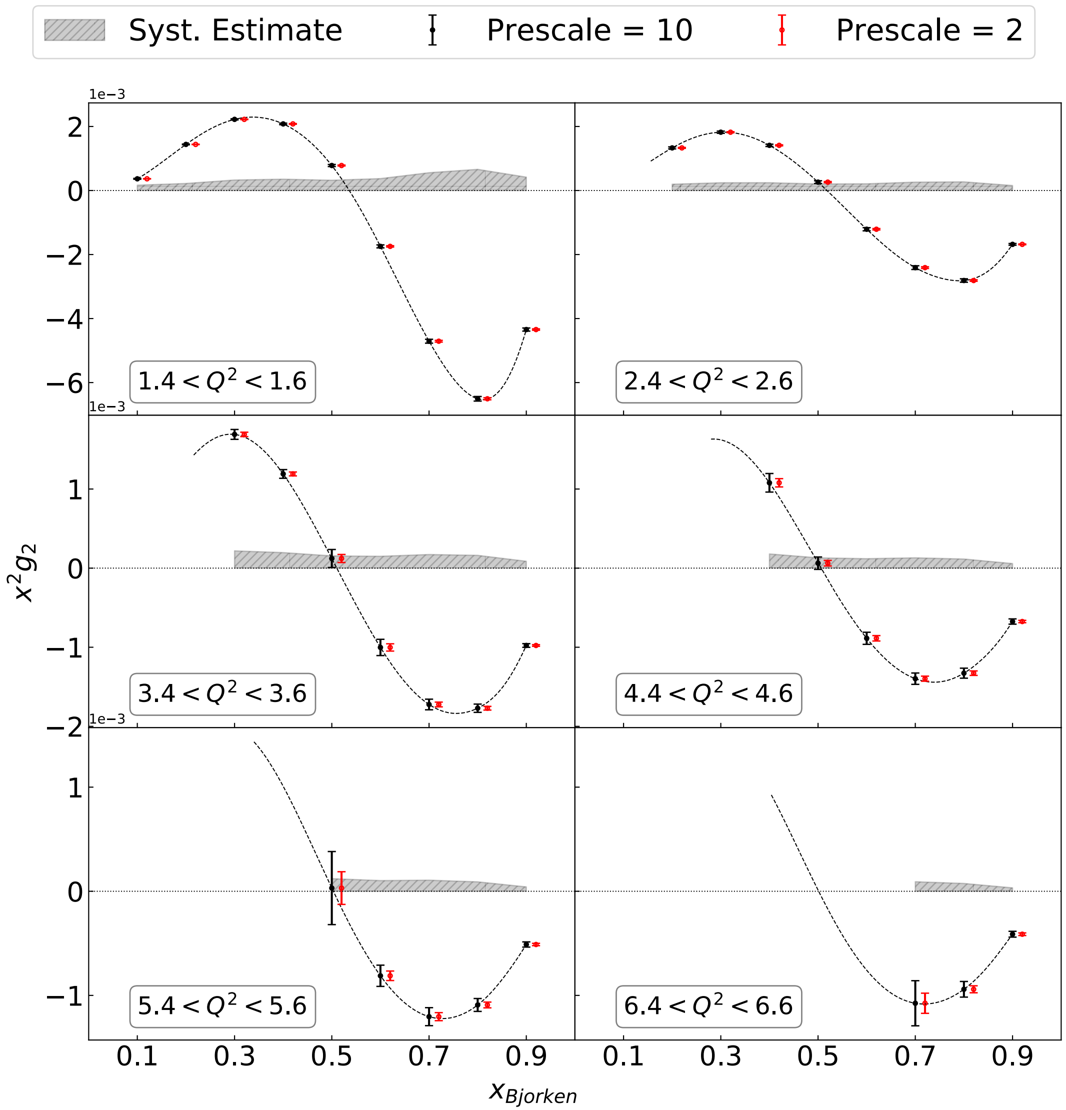
0.234 M events/hr

Nuclear Effects:

- Effective polarization approximation---- intermediate x values and at W above the resonance region
- Weak Binding Approximation-----nucleon resonance region or at large x

Projections: x^2g_2

Beam E_0= 8.8 GeV, polarization 60%, Dilution 0.17



- F2 from New Muon Collaboration (NMC) parameterization
- R= g^n_1/F^n_1 from SLAC
- Errors:
  - error bars ---- statistic errors
  - shadow regions---- systematic error

Projections: $x^2 g_2$

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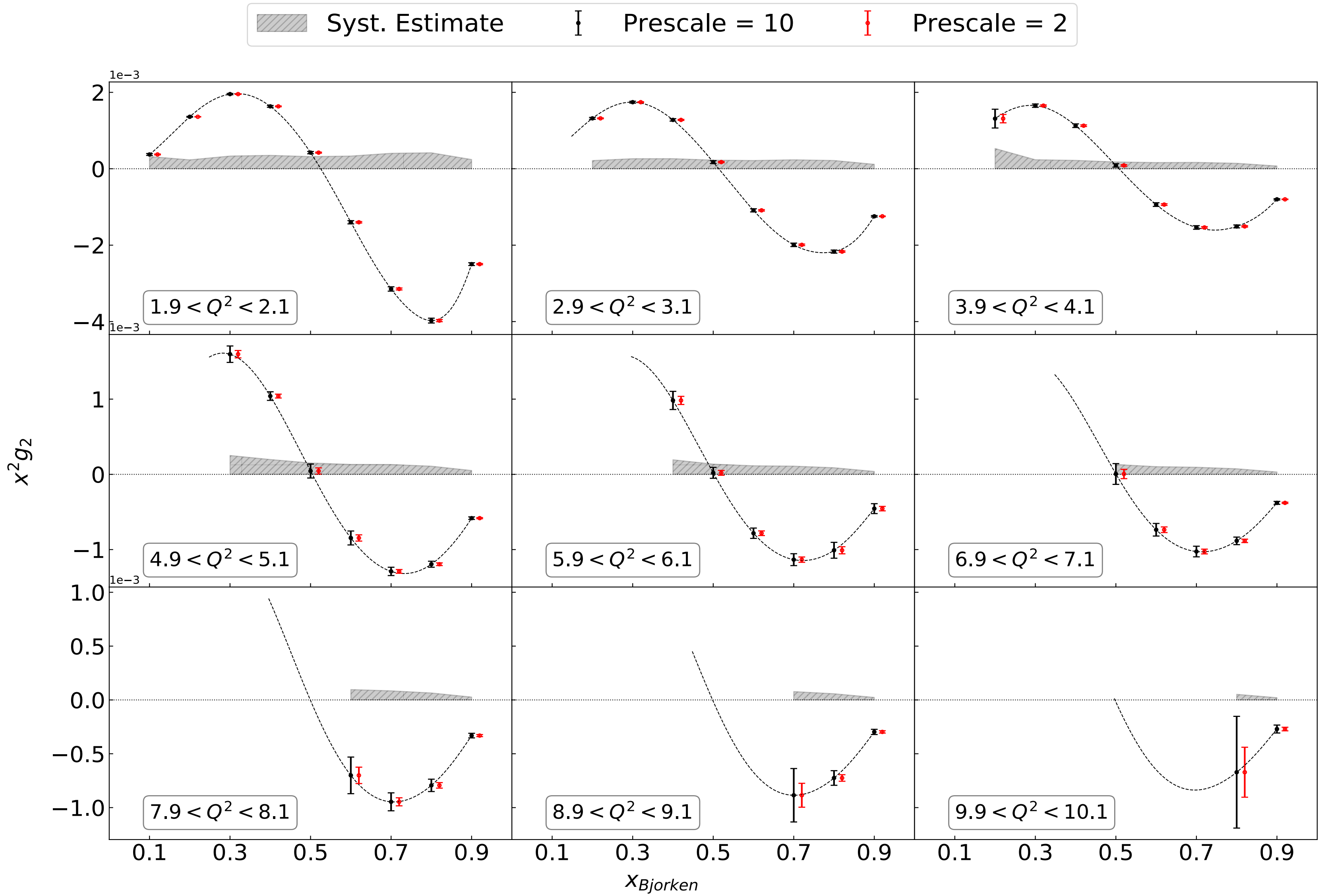
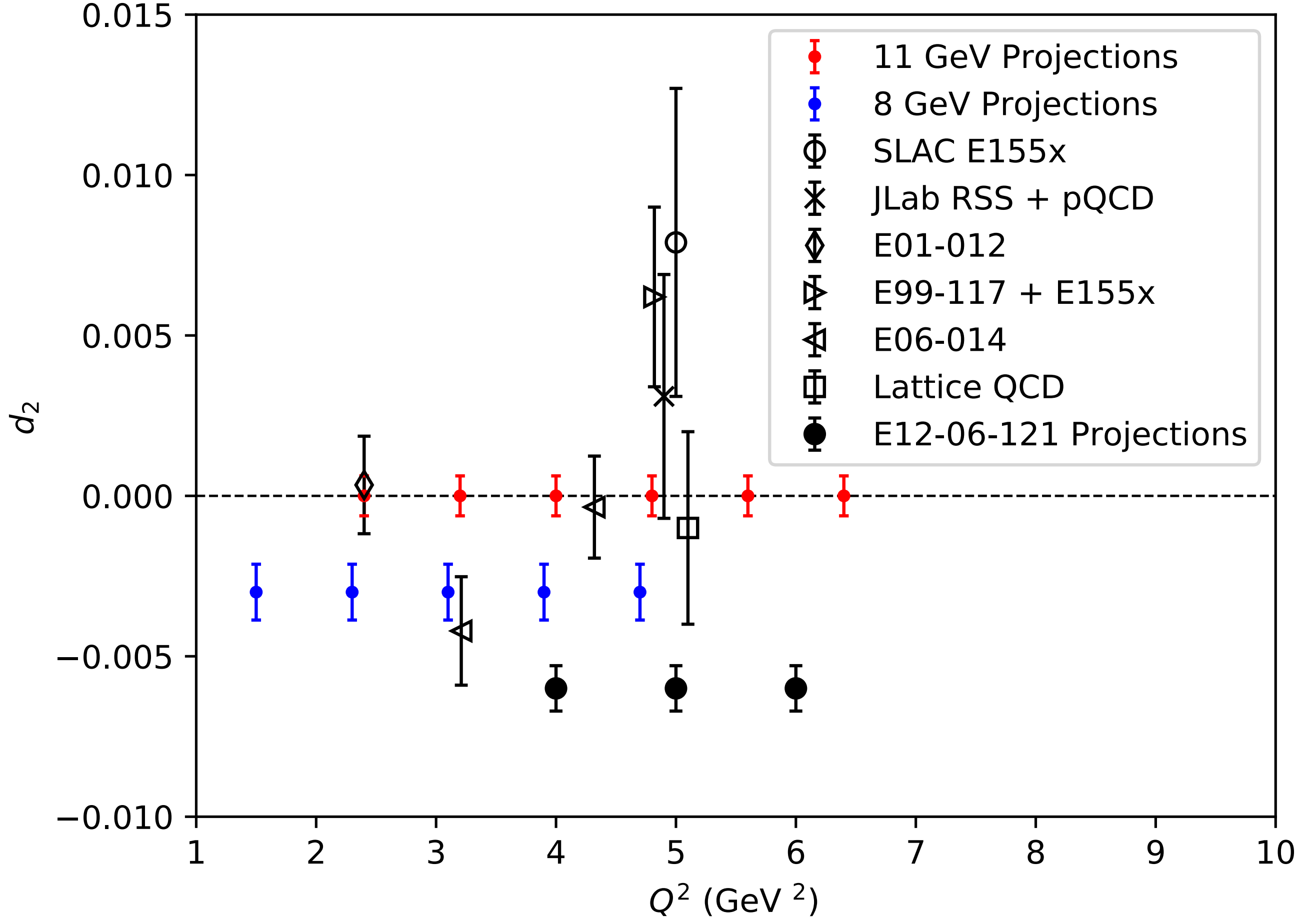


Projections: d_2



✧ Rescale factor "10"

✧ The x coverage requirement limits the d_2 projection to the region of $Q^2 < 6.5$ GeV.

❖ $x_{min} > 0.40$ within the kinematic coverage to obtain the d_2 moments, and assigned 15% error for filling the unmeasured region.

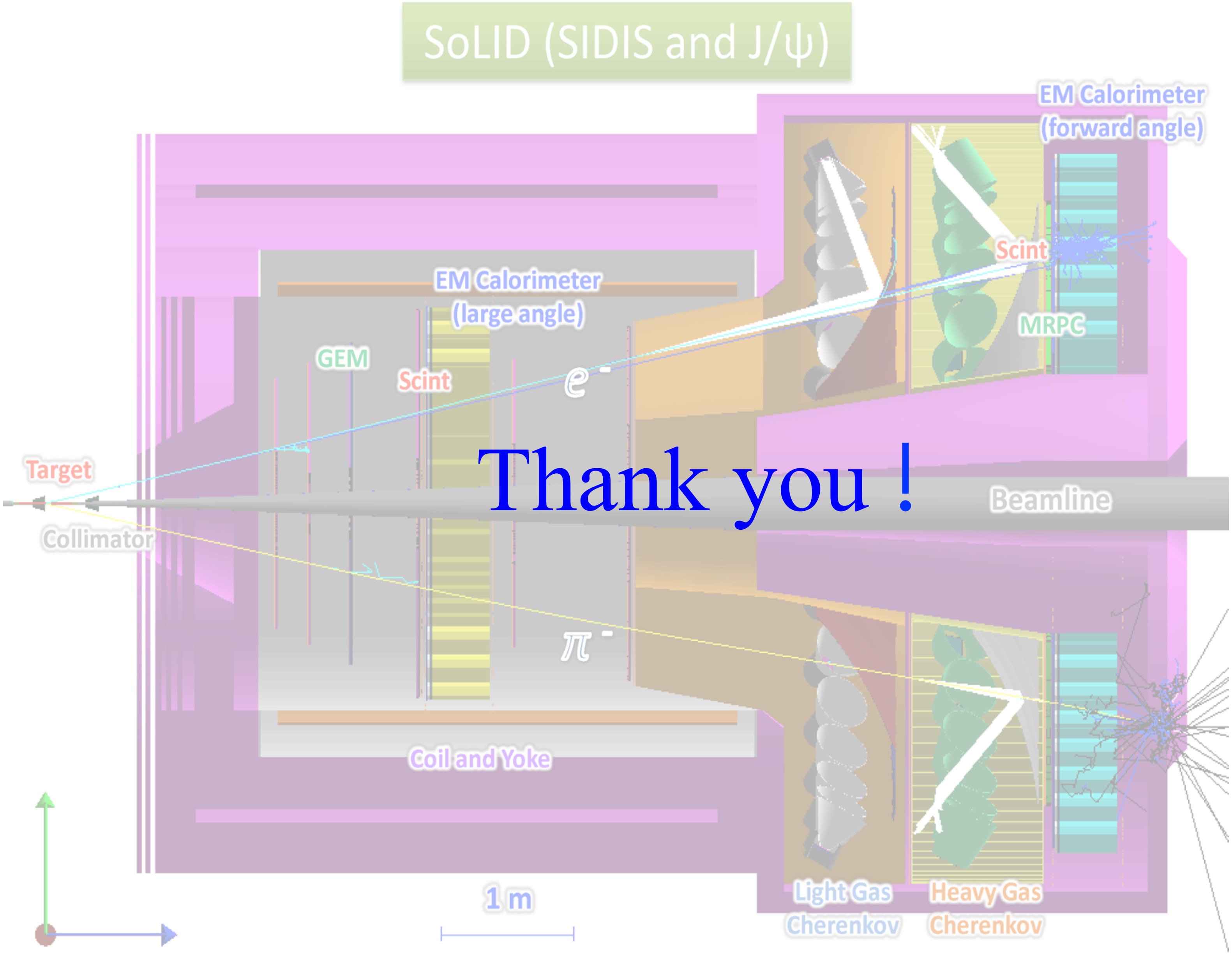
❖ Both statistical and systematic uncertainties from the cross section difference measurements are propagated into the projections

Summary

- We propose a run group measurement that runs simultaneously with SoLID E12-10-006 to measure the inclusive cross section difference for doubly polarized ^3He scattering.

- The proposed measurement, combined with the longitudinally polarized ^3He data from E12-11-007, enable the precise extraction of $g^n_2(x, Q^2)$ and $d^n_2(x, Q^2)$ at $x>0.1$ and $1.5<Q^2<10$ GeV^2.

- The proposed dataset provides an opportunity to better understand the twist-3 matrix element $d^n_2(x, Q^2)$ and hence the associated quark-gluon correlations within the neutron. Q^2 evolution of d^n_2 provide 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 !