# Precision Measurement of the neutron $d_2$: Towards the Electric $\chi_E$ and Magnetic $\chi_B$ Color Polarizabilities


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# Precision Measurement of the neutron $d_2$: Towards the Electric $\chi_E$ and Magnetic $\chi_B$ Color Polarizabilities

Hall A Collaboration Experiment (Approved: PAC29)

- Goal:
  Determine the neutron $d_2$ at $\langle Q^2 \rangle = 3$ GeV$^2$

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

- An Experiment in Hall A:
  - ➡ A polarized electron beam of 4.6, 5.7 GeV and polarized $^3$He target
  - ➡ Measure unpolarized cross section for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction $\sigma_0^{^3\mathrm{He}}$ in conjunction with the transverse asymmetry $A_\perp^{^3\mathrm{He}}$ and the parallel asymmetry $A_\parallel^{^3\mathrm{He}}$ for $0.2 < x < 0.65$ with $2 < Q^2 < 5$ GeV$^2$.

- Beamtime Allocation:
  - ➡ **13** PAC days to achieve a statistical uncertainty of $\Delta d_2^n = 5\times10^{-4}$

# Polarized deep inelastic cross sections

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

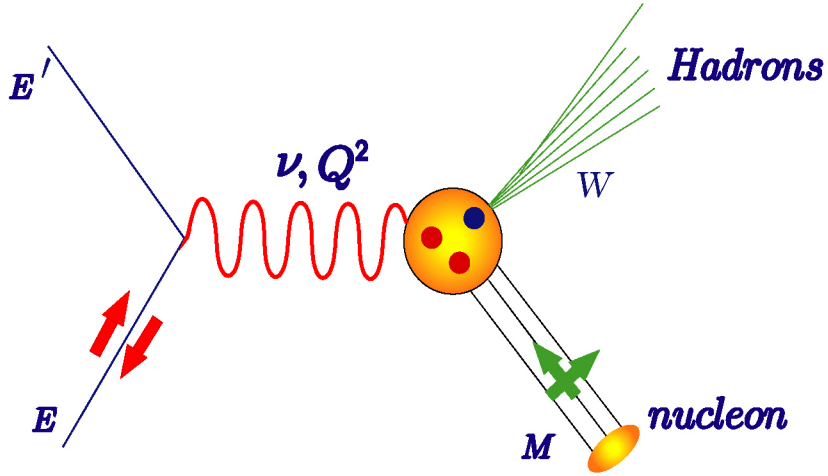
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right] = \Delta\sigma_{\perp}$$

$Q^2$ = 4-momentum transfer squared of the virtual photon.

$\nu$ = energy transfer.

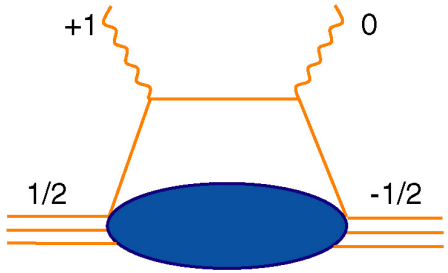
$\theta$ = scattering angle.

$x = \frac{Q^2}{2M\nu}$ fraction of nucleon momentum carried by the struck quark.



# $g_2$ and Quark-Gluon Correlations

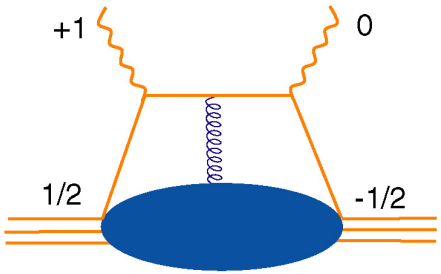
twist-2




Carry one unit of orbital angular momentum

QCD allows the helicity exchange to occur in two principle ways

twist-3




Couple to a gluon

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

- a twist-2 term (Wandzura & Wilczek, 1977):

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

- a twist-3 term with a suppressed twist-2 piece (Cortes, Pire & Ralston, 92):

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

transversity

quark-gluon correlation

# Moments of Structure Functions

$$\Gamma_1(Q^2) = \int_0^1 g_1(x, Q^2)\, dx = \mu_2 + \frac{\mu_4}{Q^2} + \frac{\mu_6}{Q^4} + \cdots$$

leading twist

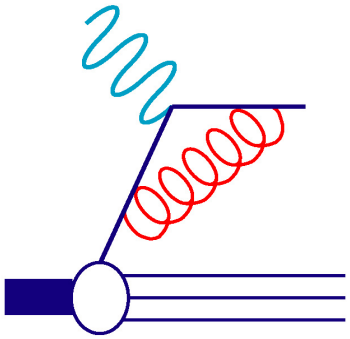
higher twist

$$\mu_2^{p,n}(Q^2) = (\pm \frac{1}{12} g_A + \frac{1}{36} a_8) + \frac{1}{9}\Delta\Sigma$$ + pQCD corrections

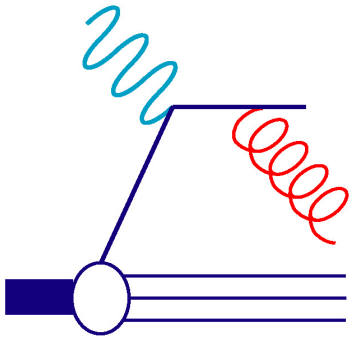
$g_A = 1.257$ and $a_8 = 0.579$ are the triplet and octet axial charge, respectively

$\Delta\Sigma$ = singlet axial charge

(Extracted from neutron and hyperon weak decay measurements)



$$\begin{aligned} g_A &= \Delta u - \Delta d \\ a_8 &= \Delta u + \Delta d - 2\Delta s \\ \Delta\Sigma &= \Delta u + \Delta d + \Delta s \end{aligned}$$



pQCD radiative corrections

# Moments of Structure Functions (continued)

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

Twist - 2 (TMC) Twist - 3 Twist -4

where $a_2$, $d_2$ and $f_2$ are higher moments of $g_1$ and $g_2$

e.g. $$d_2(Q^2) = \int_0^1 x^2[2g_1(x,Q^2) + 3g_2(x,Q^2)]dx = 3\int_0^1 x^2\,\overline{g_2}(x,Q^2)dx$$

$$a_2(Q^2) = \int_0^1 x^2 g_1(x,Q^2)\,dx$$

- To extract $f_2$, $d_2$ needs to be determined first.
- Both $d_2$ and $f_2$ are required to determine the color polarizabilities

# Color "polarizabilities"

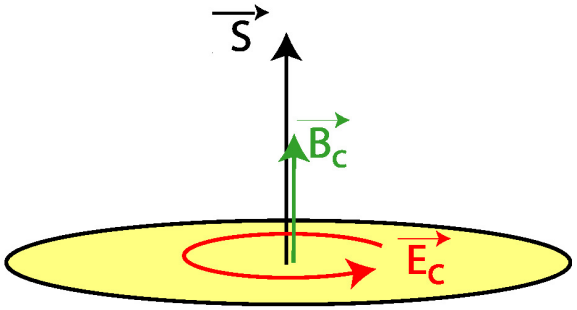
## How does the gluon field respond when a nucleon is polarized ?

Define color magnetic and electric polarizabilities (in nucleon rest frame):

$$\chi_{B,E}\, 2M^2 \vec{S} \;=\; \langle PS|\vec{O}_{B,E}|PS\rangle$$

where $\vec{O}_B = \psi^\dagger g \vec{\boldsymbol{B}} \psi$

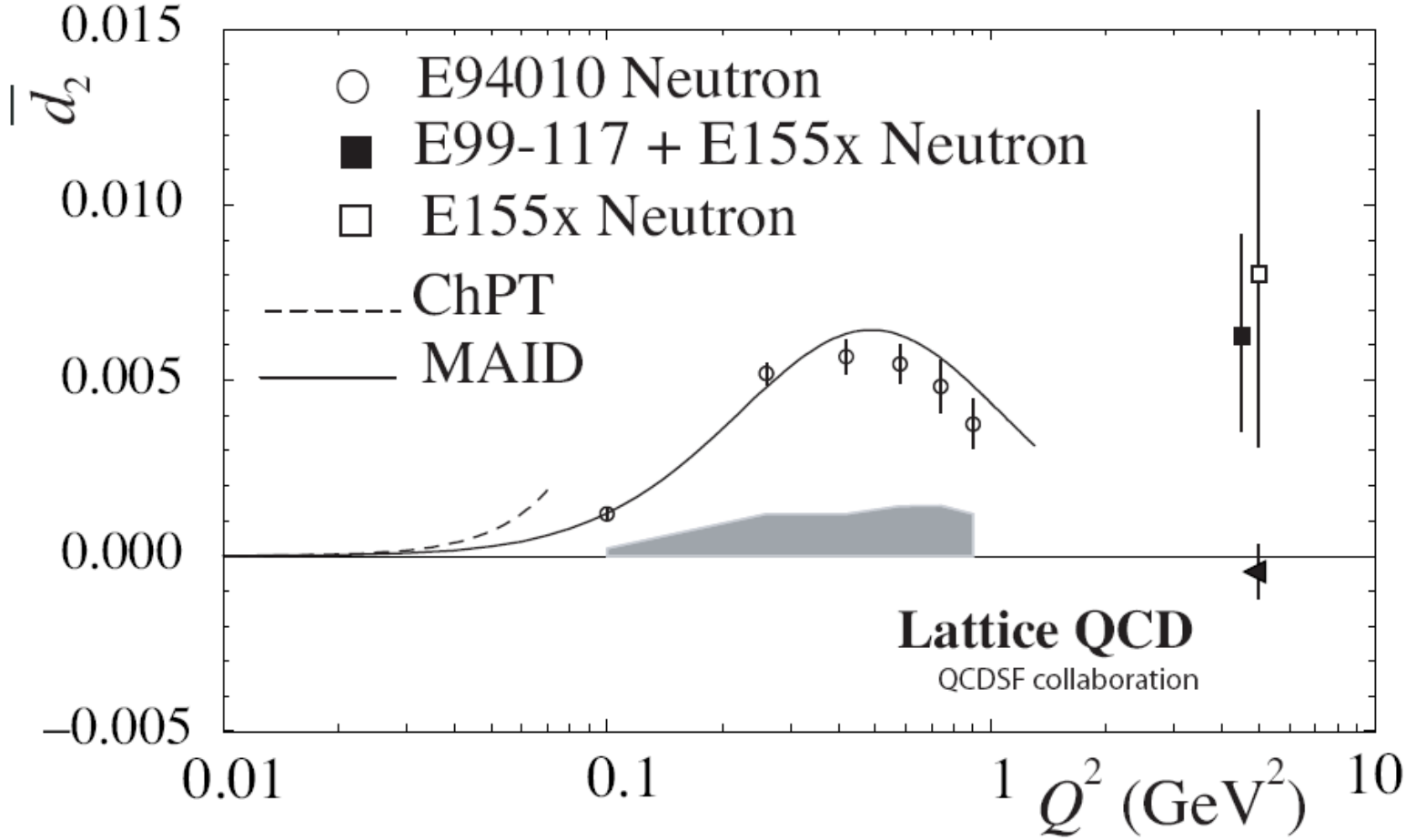
$\vec{O}_E = \psi^\dagger \vec{\alpha} \times g \vec{\boldsymbol{E}} \psi$




$$\chi_E^n = (4d_2^n + 2f_2^n)/3$$
$$\chi_B^n = (4d_2^n - f_2^n)/3$$

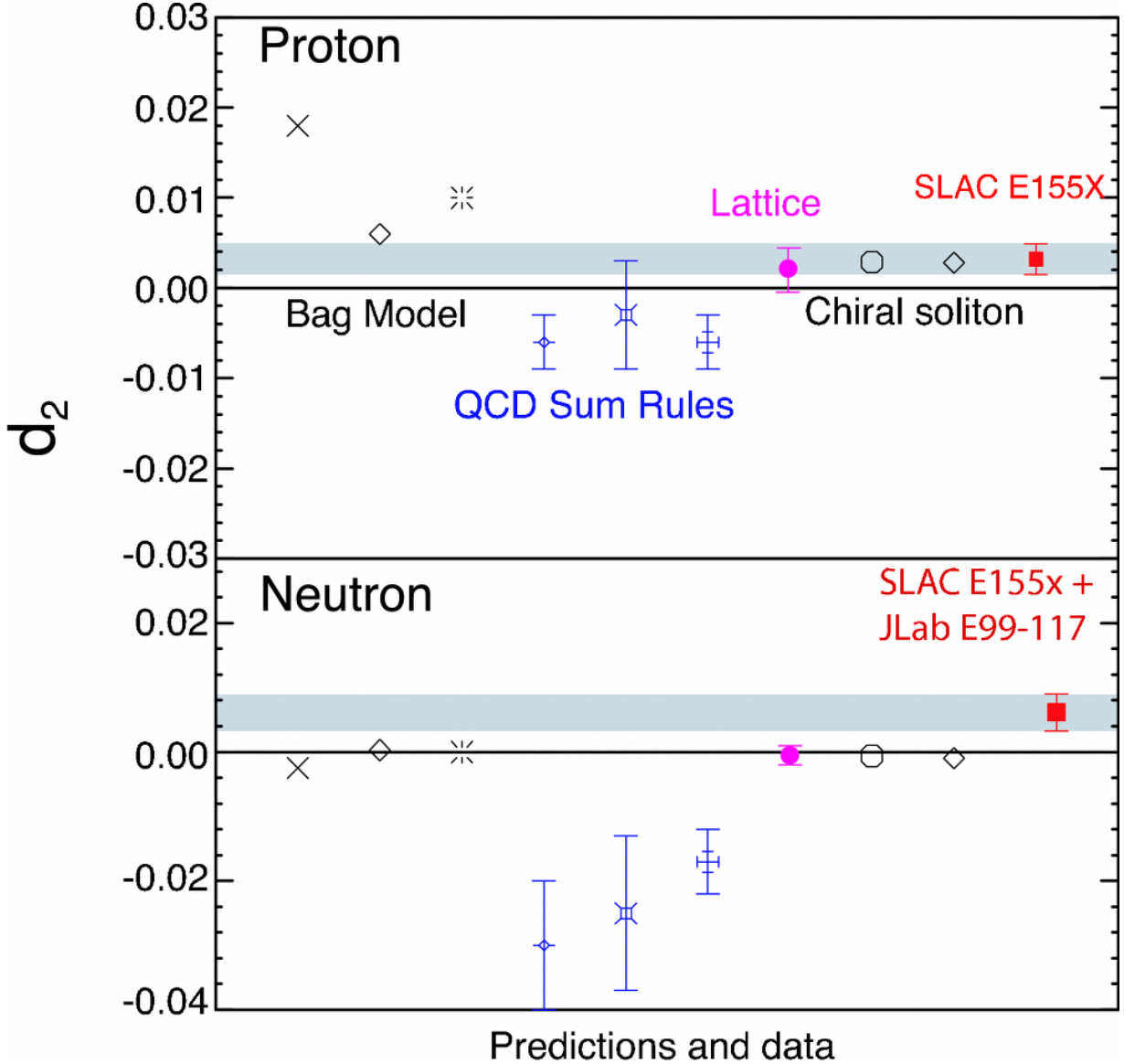
$\chi_E$ and $\chi_B$ represent the response of the color $\vec{B}$ & $\vec{E}$ fields to the nucleon polarization

# World Data on $\bar{d}_2$




(nucleon elastic contribution suppressed)

# Model evaluations of $d_2$



# The Experiment

- A 4.6 and 5.7 GeV polarized electron beam scattering off a polarized $^3$He target
- Measure unpolarized cross section for $^3\vec{\mathrm{He}}(\vec{e}, e')$ reaction $\sigma_0^{^3\mathrm{He}}$ in conjunction with the parallel asymmetry $A_{\parallel}^{^3\mathrm{He}}$ and the transverse asymmetry $A_{\perp}^{^3\mathrm{He}}$ for 0.23 < x < 0.65 with 2 < $Q^2$ < 5 GeV$^2$.
  - ➡ Asymmetries measured by BigBite at a single angle: $\theta$ = 45°
  - ➡ Absolute cross sections measured by L-HRS
- Determine $d_2^n$ using the relation

$$\begin{aligned}\tilde{d}_2(x,Q^2) &= x^2[2g_1(x,Q^2)+3g_2(x,Q^2)] \\ &= \frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0\left[\left(3\frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}+\frac{4}{y}\tan\frac{\theta}{2}\right)A_\perp+\left(\frac{4}{y}-3\right)A_\parallel\right]\end{aligned}$$

where,

$$A_\perp = \frac{\sigma^{\downarrow\Rightarrow}-\sigma^{\uparrow\Rightarrow}}{2\sigma_0} \qquad A_\parallel = \frac{\sigma^{\downarrow\Uparrow}-\sigma^{\uparrow\Uparrow}}{2\sigma_0}$$

$$A_\perp^{^3He} = \frac{\Delta_\perp}{P_bP_t\cos\phi} \qquad A_\parallel^{^3He} = \frac{\Delta_\parallel}{P_bP_t}$$

$$\Delta_\perp = \frac{(N^{\uparrow\Rightarrow}-N^{\uparrow\Rightarrow})}{(N^{\uparrow\Rightarrow}+N^{\uparrow\Rightarrow})} \qquad \Delta_\parallel = \frac{(N^{\downarrow\Uparrow}-N^{\uparrow\Uparrow})}{(N^{\downarrow\Uparrow}+N^{\uparrow\Uparrow})}$$

# Kinematics of the measurement

| $E_i$ (GeV) | bin central $p$ (GeV) | $x$ | $\Delta x$ | $Q^2$ ($GeV^2$) | $W$ (GeV) | Rate (Hz) | | |
|---|---|---|---|---|---|---|---|---|
| 5.700 | 1.603 | 0.696 | 0.097 | 5.35 | 1.79 | 3.0 | | |
| 5.700 | 1.450 | 0.607 | 0.081 | 4.84 | 2.00 | 5.0 | | |
| 5.700 | 1.312 | 0.532 | 0.069 | 4.38 | 2.18 | 7.0 | | |
| 5.700 | 1.187 | 0.468 | 0.059 | 3.96 | 2.32 | 8.9 | Single | |
| 5.700 | 1.074 | 0.413 | 0.051 | 3.59 | 2.44 | 10.4 | BigBite | |
| 5.700 | 0.971 | 0.365 | 0.044 | 3.24 | 2.55 | 11.6 | Spectrometer | |
| 5.700 | 0.878 | 0.324 | 0.038 | 2.93 | 2.65 | 12.5 | Setting | |
| 5.700 | 0.794 | 0.288 | 0.034 | 2.65 | 2.73 | 13.1 | | |
| 5.700 | 0.718 | 0.256 | 0.029 | 2.40 | 2.80 | 13.5 | | |
| 5.700 | 0.650 | 0.229 | 0.026 | 2.17 | 2.86 | 13.8 | | |
| | | | | | | | $Time_\perp$ hours | $Time_\parallel$ hours |
| **Total (5.7 GeV data set)** | | | | | | | 172 | 8 |

- L-HRS used to measure total cross section at 10 momentum settings.
  - ➡ will also reverse the field to monitor $\pi^-/\pi^+$ and $e^-/e^+$ asymmetries
- BigBite takes all asymmetry data with single setting.
  - ➡ Optimized to minimize error on $d^2$
- 180 hours for 5.7 GeV data set

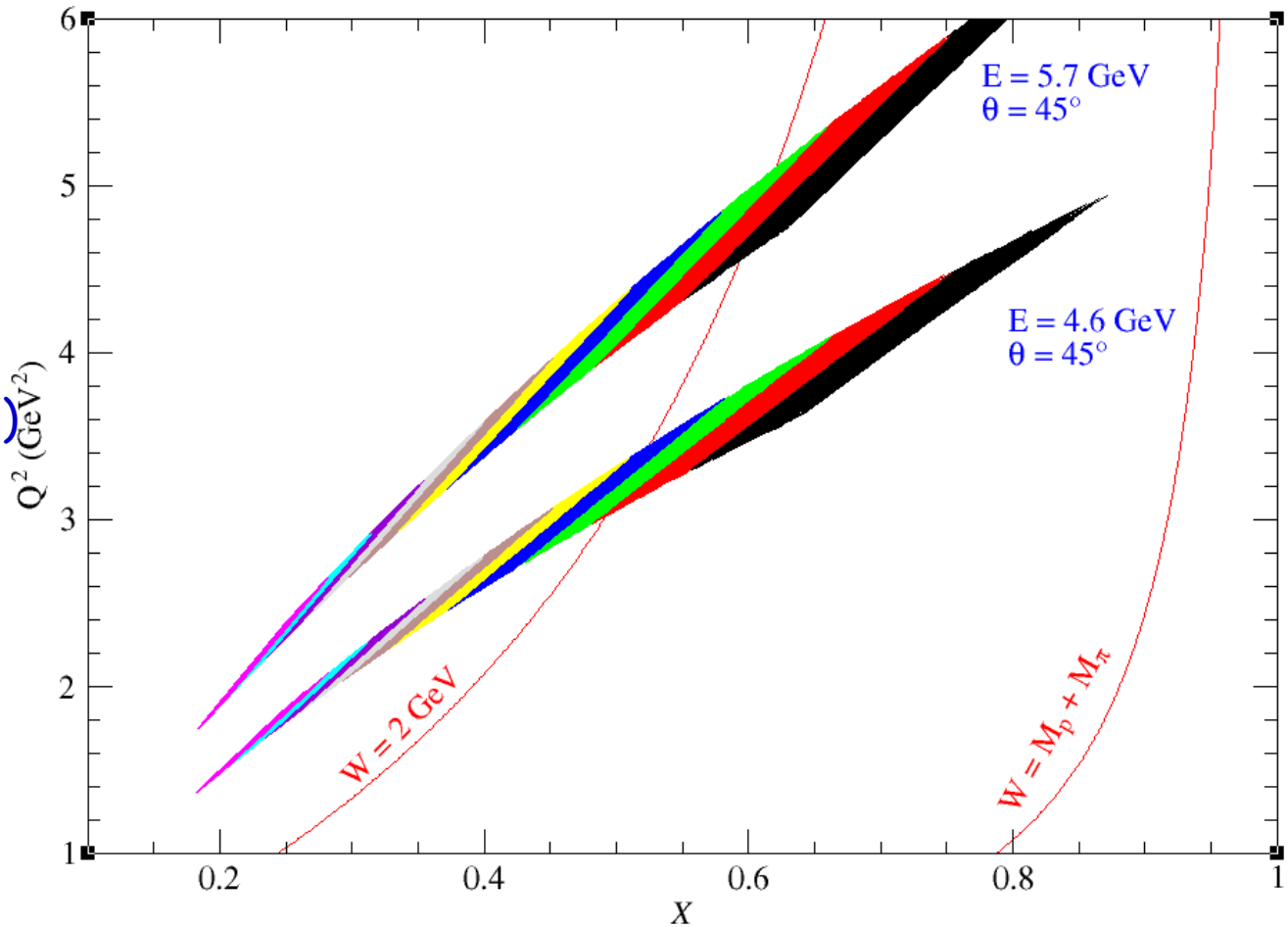
# Kinematics continued...

| $E_i$ (GeV) | bin central $p$ (GeV) | $x$ | $\Delta x$ | $Q^2$ ($GeV^2$) | $W$ (GeV) | Rate (Hz) | | |
|---|---|---|---|---|---|---|---|---|
| 4.600 | 1.502 | 0.696 | 0.118 | 4.05 | 1.63 | 4.22 | | |
| 4.600 | 1.366 | 0.607 | 0.097 | 3.68 | 1.81 | 7.95 | | |
| 4.600 | 1.243 | 0.532 | 0.080 | 3.35 | 1.96 | 10.8 | | |
| 4.600 | 1.131 | 0.468 | 0.067 | 3.05 | 2.08 | 14.1 | Single | |
| 4.600 | 1.028 | 0.413 | 0.057 | 2.77 | 2.19 | 16.8 | BigBite | |
| 4.600 | 0.933 | 0.365 | 0.049 | 2.51 | 2.29 | 18.9 | Spectrometer | |
| 4.600 | 0.847 | 0.324 | 0.042 | 2.28 | 2.38 | 20.3 | Setting | |
| 4.600 | 0.768 | 0.288 | 0.036 | 2.07 | 2.45 | 21.3 | | |
| 4.600 | 0.696 | 0.256 | 0.032 | 1.88 | 2.52 | 21.8 | | |
| 4.600 | 0.633 | 0.229 | 0.028 | 1.71 | 2.57 | 22.0 | | |
| | | | | | | | $\text{Time}_\perp$ hours | $\text{Time}_\parallel$ hours |
| **Total (4.6 GeV data set)** | | | | | | | 72 | 8 |

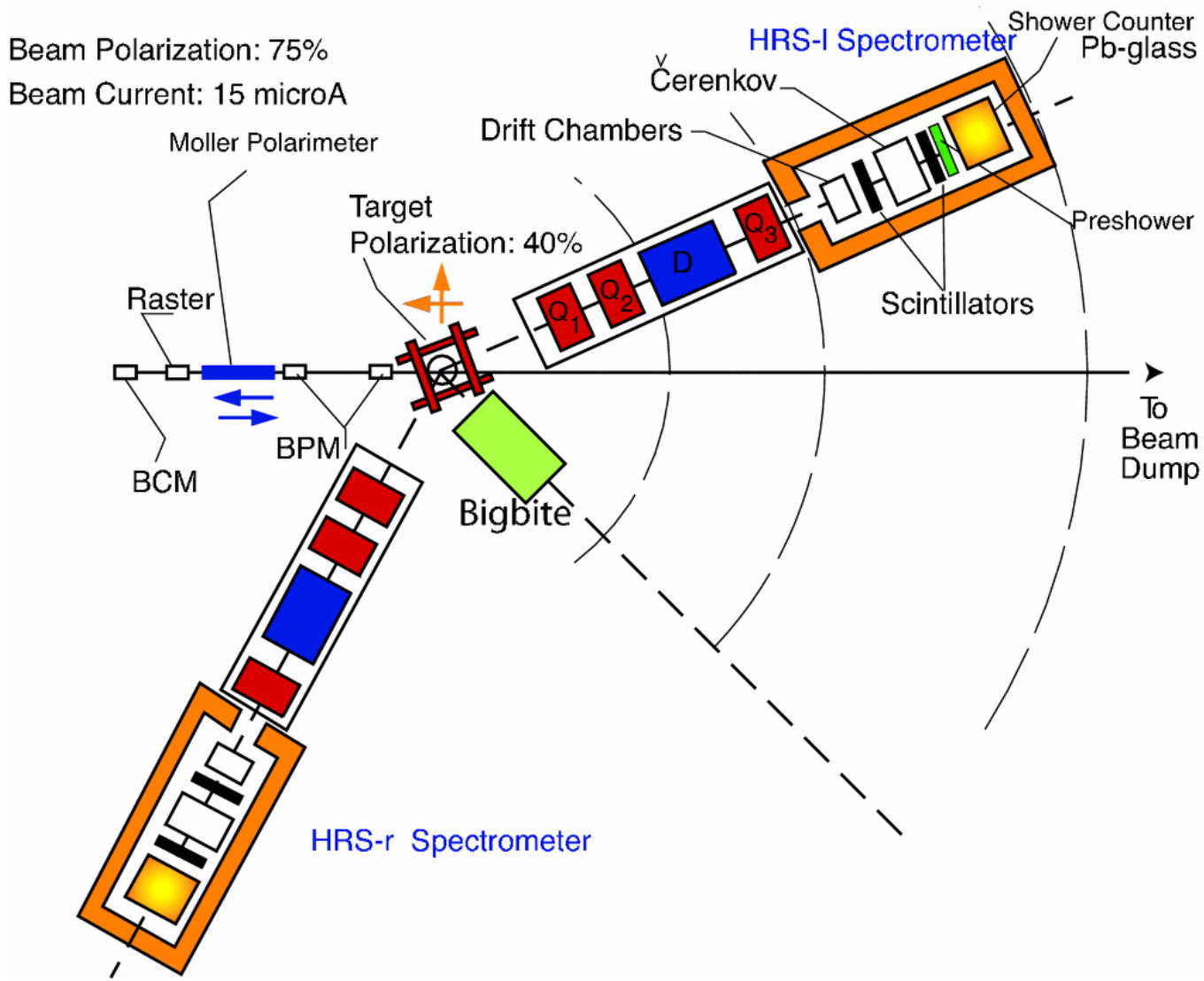
- L-HRS used to measure total cross section at 10 momentum settings.
- BigBite takes all asymmetry data with single setting.
  - ➡ Focus is measuring $Q^2$ evolution of $x^2\bar{g}_2$
- +80 hours for 4.6 GeV data set
  - ➡ add 48 hours calibration and overhead
    - ➥ **TOTAL: 308 hours (13 days)**

# Kinematics of the measurement

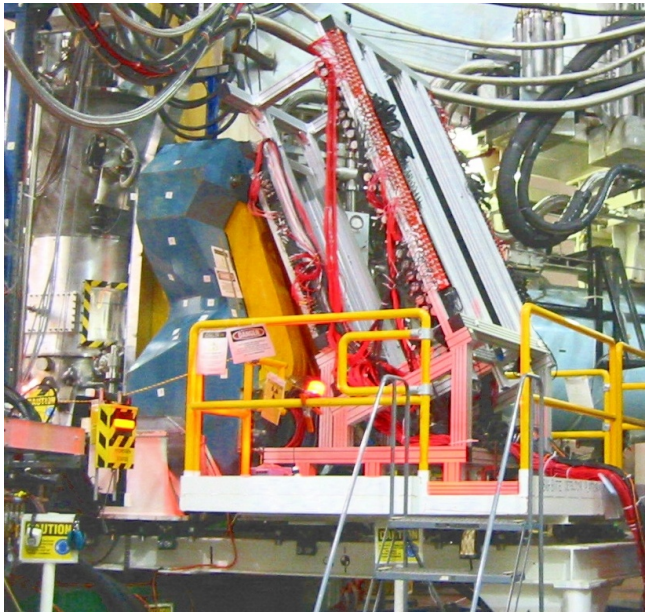
- Two beam energies 4.6 and 5.7 GeV (4 pass, 5 pass)
- BigBite fixed at single scattering angle (θ=45°) (data divided into 10 bins during analysis)
- Avoid resonance region as much as possible.

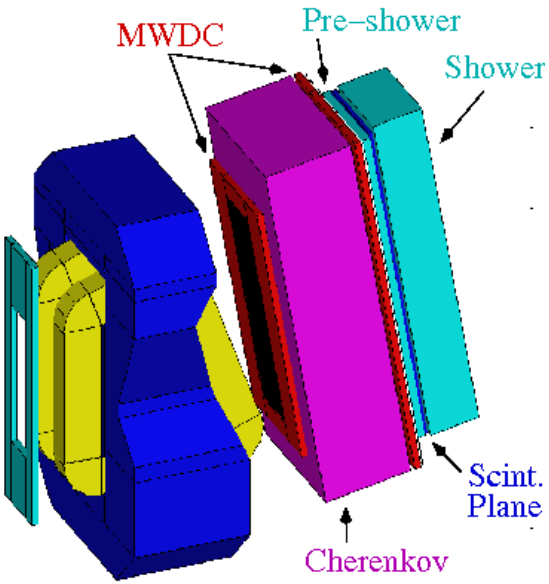


# Floor configuration for this experiment



# BigBite Configuration






- non-focusing, large acceptance, open geometry
- $\Delta p/p$ = 1 – 1.5% (@ 1.2 T) $\sigma(W)$ = 50 MeV
- angular resolution 1.5 mr, extended target resolution 6 mm
- large solid angle: ~64 msr
- detector package
  - ➡ 2 MWDCs, segmented trigger, Pb-glass shower
  - ➡ Gas Cherenkov (new)

# Cherenkov Design Parameters

- Dimensions: 200cm x 60cm x 60cm
  - ➡ located in gap between first and second wire chamber with minimal modifications to BigBite frame
- Radiator gas: $C_4F_{10}$ (or Freon12)
  - ➡ n = 1.0015 (1.0011)
  - ➡ $\pi$ threshold: 2.51 GeV/c (2.98 GeV/c)
  - ➡ ~20 (13) photo-electrons / 40 cm electron track
    - Quartz PMT (Photonis XP4318 or equiv.)
    - mirror reflectivity: ~90%, 10% loss at PMT-gas interface
  - ➡ >99% efficient with 3-4 p.e. threshold
    - negl. pion contamination
      **minimum** $\pi$/e rejection ratio 1000:1 online

# Background Rates

- MC simulation by Degtyarenko et al. (tested in Halls A and C)
- Online cuts include:
  - ➡ BB magnet sweeps particles with p < 200 MeV/c
  - ➡ GEN BB trigger: shower+pre-shower+scint
    - ↳ provide ~10:1 online hadron rejection (or better)
  - ➡ ~550—600 MeV threshold on shower
  - ➡ 4—5 p.e. threshold on Cherenkov
    - ↳ heavily suppress random background
    - ↳ negl. pion contamination (~100 Hz knock-ons)
- Total estimated trigger rate (GEN trig + Cherenkov): 2—5 kHz

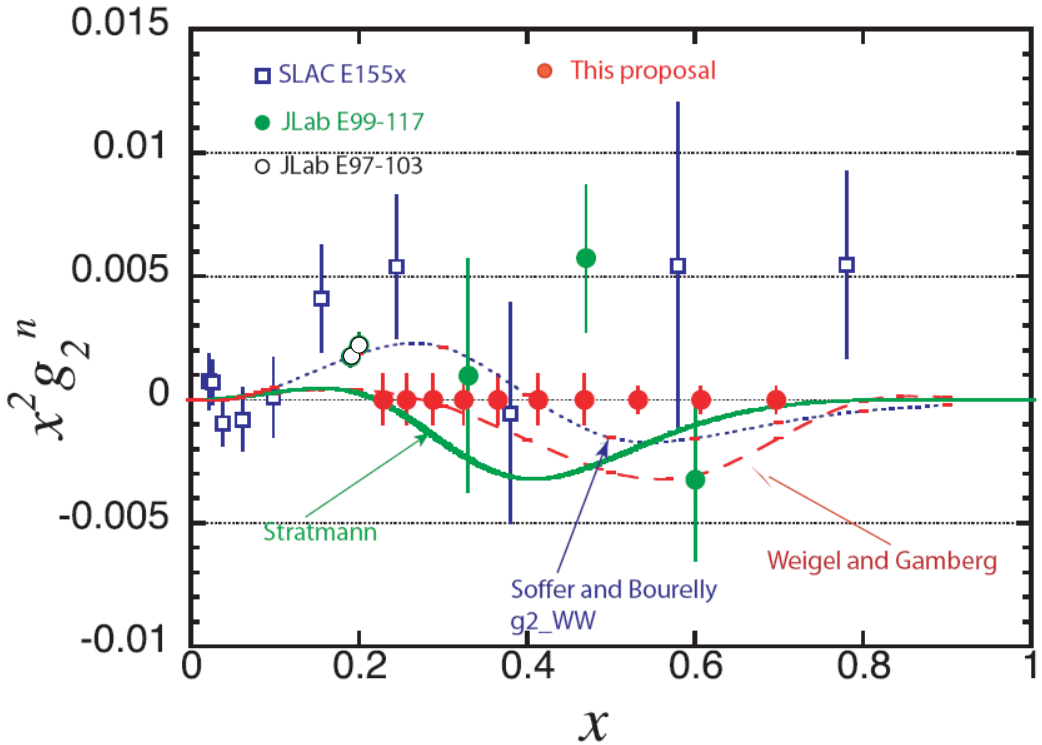
Online triggers

| | |
|---|---|
| e- | 2-5 kHz |
| e+ | <1 kHz |

| | |
|---|---|
| π- | 90 kHz |
| π+ | 90 kHz |
| p | 50 kHz |
| n | 50 kHz |

Removed via online cuts

# Projected $x^2g_2(x,Q^2)$ results

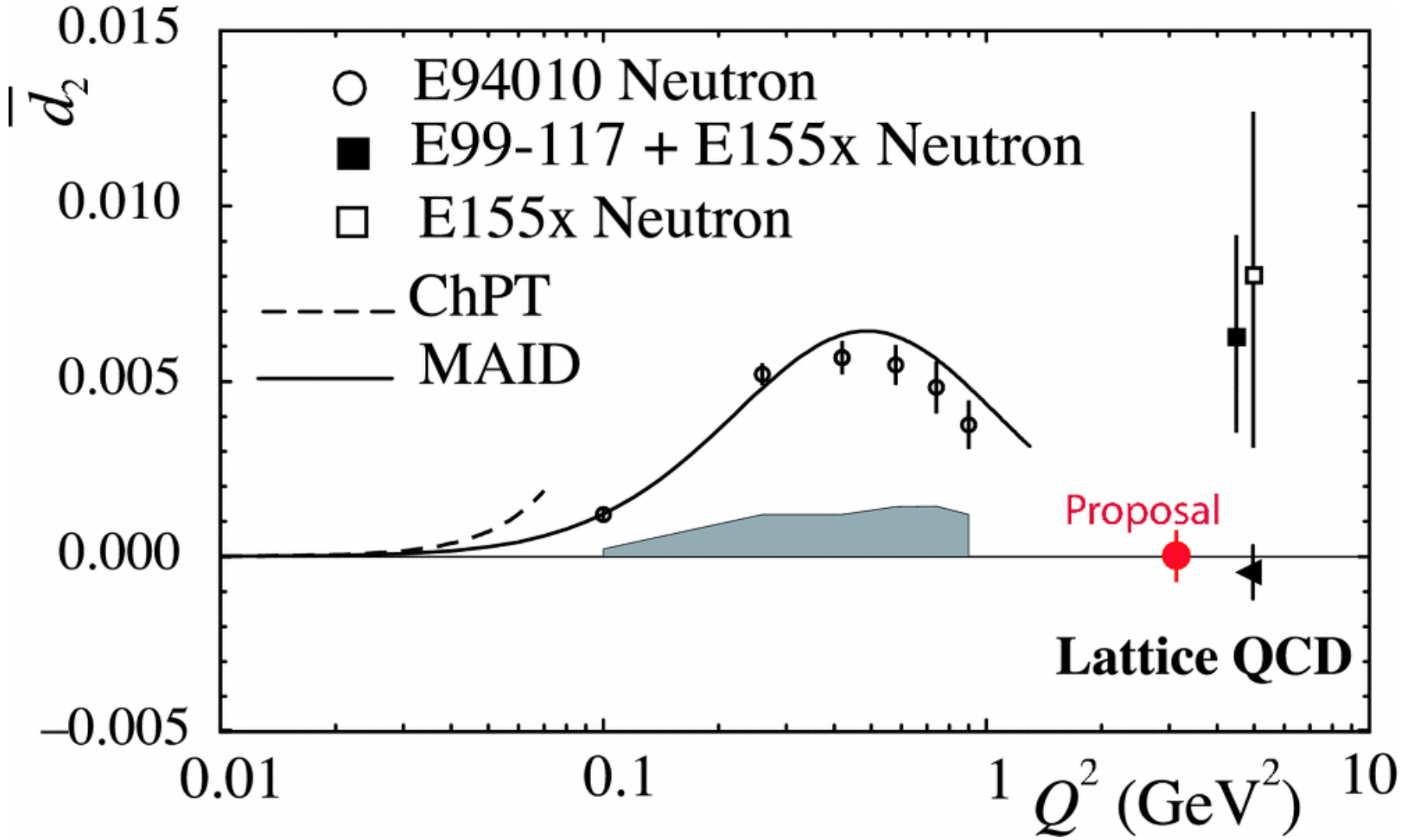



- $g_2$ for $^3$He is extracted directly from L and T spin-dependent cross sections measurements within the same experiment.
- The nuclear corrections will be applied to the moments not to the structure functions.
- SLAC E155x $g_2$ data points at high x are evolved from $Q^2$ as large as 16 $GeV^2$ to 5 $GeV^2$

# Systematic Error Contributions to $d_2^n$

| | | |
|---|---|---|
| **Target polarization** | | 4 % |
| **Beam polarization** | | 3 % |
| **Asymmetry (raw)** | | |
| | • Target spin direction (0.5°) | $\approx 1.5 \times 10^{-3}$ |
| | • Beam charge asymmetry | 200 ppm |
| **Cross section (raw)** | | |
| | • PID efficiency | $\approx$ 1 % |
| | • Background Rejection efficiency | $\approx$ 1 % |
| | • Beam charge | $<$ 1 % |
| | • Beam position | $<$ 1 % |
| | • Acceptance cut | 2-3 % |
| | • Target density | 2-3 % |
| | • Nitrogen dilution | 2-3 % |
| | • Dead time | <1 % |
| | • Finite Acceptance cut | <1% |
| **Radiative corrections** | | $\leq$ 10 % |
| **From $^3$He to Neutron correction** | | 5 % |
| **Total effect** | | $\leq$ 10 % |
| **Estimate of contributions** | $\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$ | $4.8 \times 10^{-4}$ |
| **from unmeasured regions** | $\int_{0.70}^{0.999} \tilde{d}_2^n \, dx$ | $5.0 \times 10^{-5}$ |
| Projected absolute statistical uncertainty | | $\Delta d_2 \approx 5.4 \times 10^{-4}$ |
| Projected absolute systematic uncertainty assuming $d_2 = 5 \times 10^{-3}$ | | $\Delta d_2 \approx 5 \times 10^{-4}$ |

# Expected Error on $d_2$



# Summary

- We will precisely measure the neutron $d_2^n$ at $Q^2 \approx 3.0$ GeV$^2$.
  - ➡ Determine asymmetries in conjunction with an absolute cross section measurement over the region ($0.23 < x < 0.65$)
  - ➡ Also, measure $Q^2$ evolution of $x^2\bar{g}_2$ over the same x region

- Provide a benchmark test for theory (lattice QCD).
  - ➡ we can achieve a statistical uncertainty of $\Delta d_2^n = 5 \times 10^{-4}$
    - ↳ four times better then existing world average!
- Dramatically improve our knowledge of $g_2^n(x)$
  - ➡ double the data points for $x > 0.2$, all with better precision

- Utilize standard Hall A equipment with one addition:
  - ➡ new Gas Cerenkov detector for BigBite

## Beamtime Allocation

- 13 PAC days of polarized beam divided between 4.6 and 5.7 GeV.
  - ➡ 244 hours of transverse settings, 16 hours of longitudinal settings, and 48 hours of overhead and calibration.

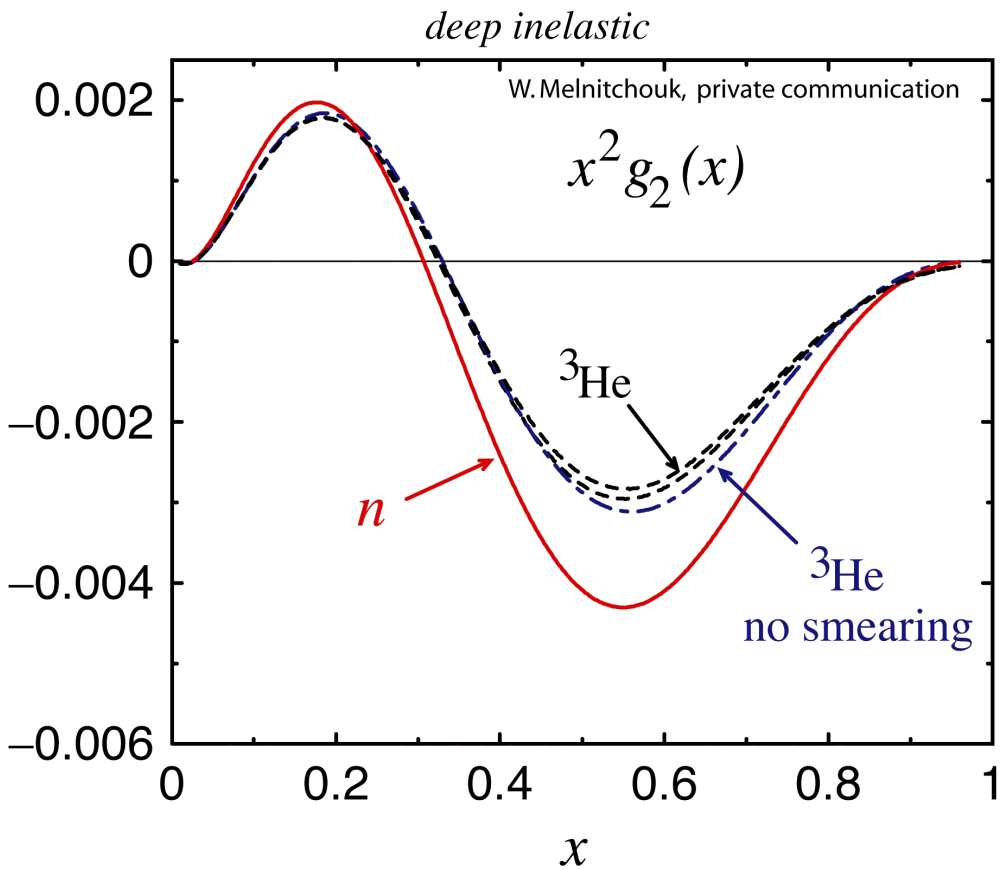
# Extra Slides

# Nuclear corrections

- Convolution method using the impulse approximation and realistic ground state wave functions of $^3$He (in Bjorken limit: $g_1^{^3He}$ related to $g_1^N$).
  - Variational Method,
    - C. Ciofi degli Atti & S. Scopetta, Phys. Lett. B 404 (1997) 223, for $g_1$, for $g_2$, S. Scopetta. private communication
  - Faddeev
    - F. Bissey et al. Phys. Rev. C 64 (2001) 024004

- Finite $Q^2$ effects (both $g_1^N$ and $g_2^N$ contribute to $g_1^{^3He}$ and to $g_2^{^3He}$)
  - S.A. Kulagin and W. Melnitchouk

# From $^3$He to Neutron




✓Correction large for $g_2$ but much smaller for $d_2$

✓About 5% difference between additive or convolution methods or between potential models

$$d_2^n = d_2^{^3He}/(1-\delta^c) \qquad \text{with} \qquad \delta^c \approx 0.35$$

$$\Delta\delta^c \approx 0.15\delta^c \approx 0.05 \qquad \Rightarrow \qquad \Delta d_2^n/d_2^n \approx 5\%$$

# Nuclear corrections (continued)

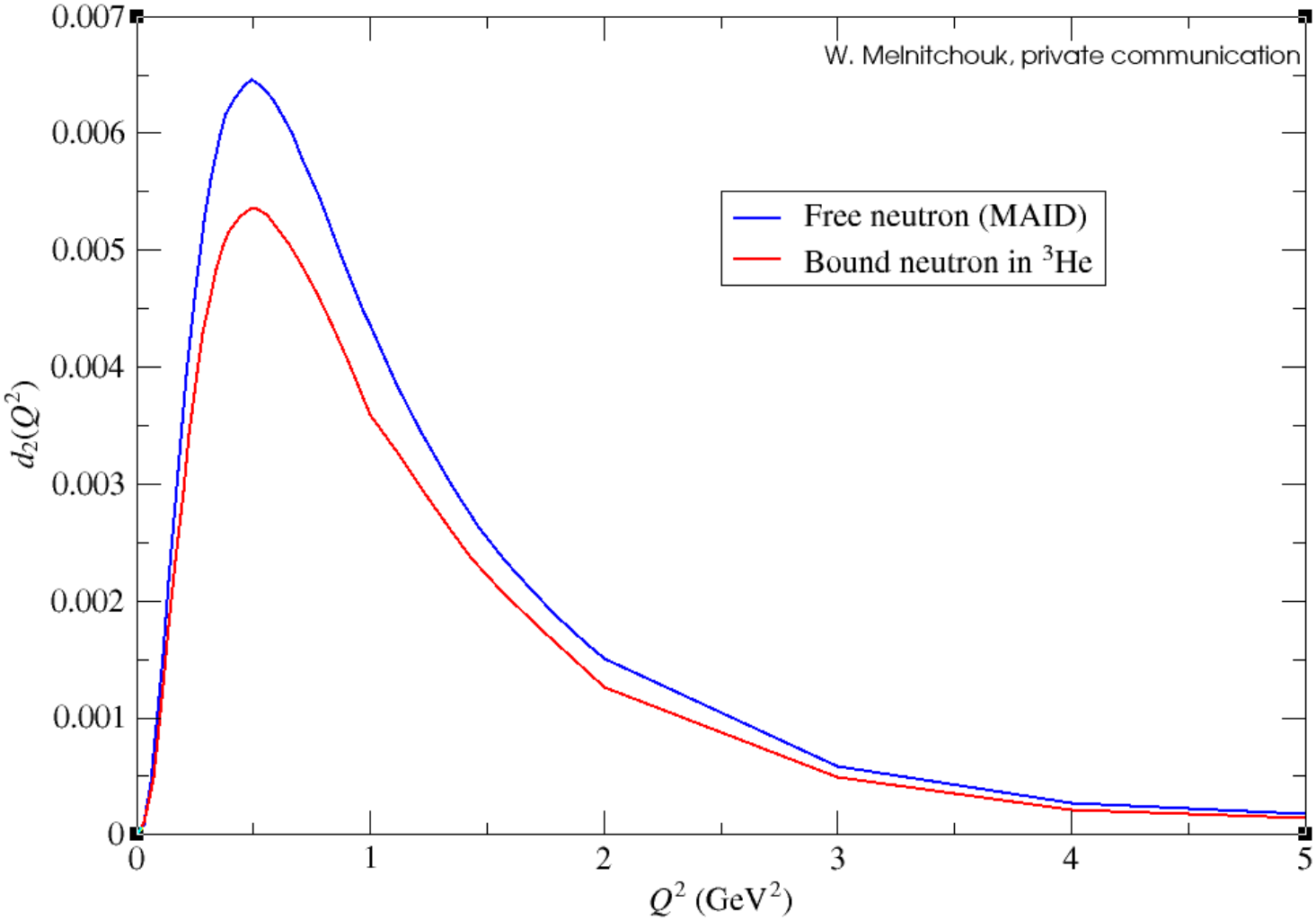
$$S(\vec{p},E) \;=\; \frac{1}{2}\left(f_0 + f_1\vec{\sigma}_N\cdot\vec{\sigma}_A + f_2\left[\vec{\sigma}_N\cdot\hat{p}\;\vec{\sigma}_A\cdot\hat{p}\;-\frac{1}{3}\vec{\sigma}_N\cdot\vec{\sigma}_A\right]\right)$$

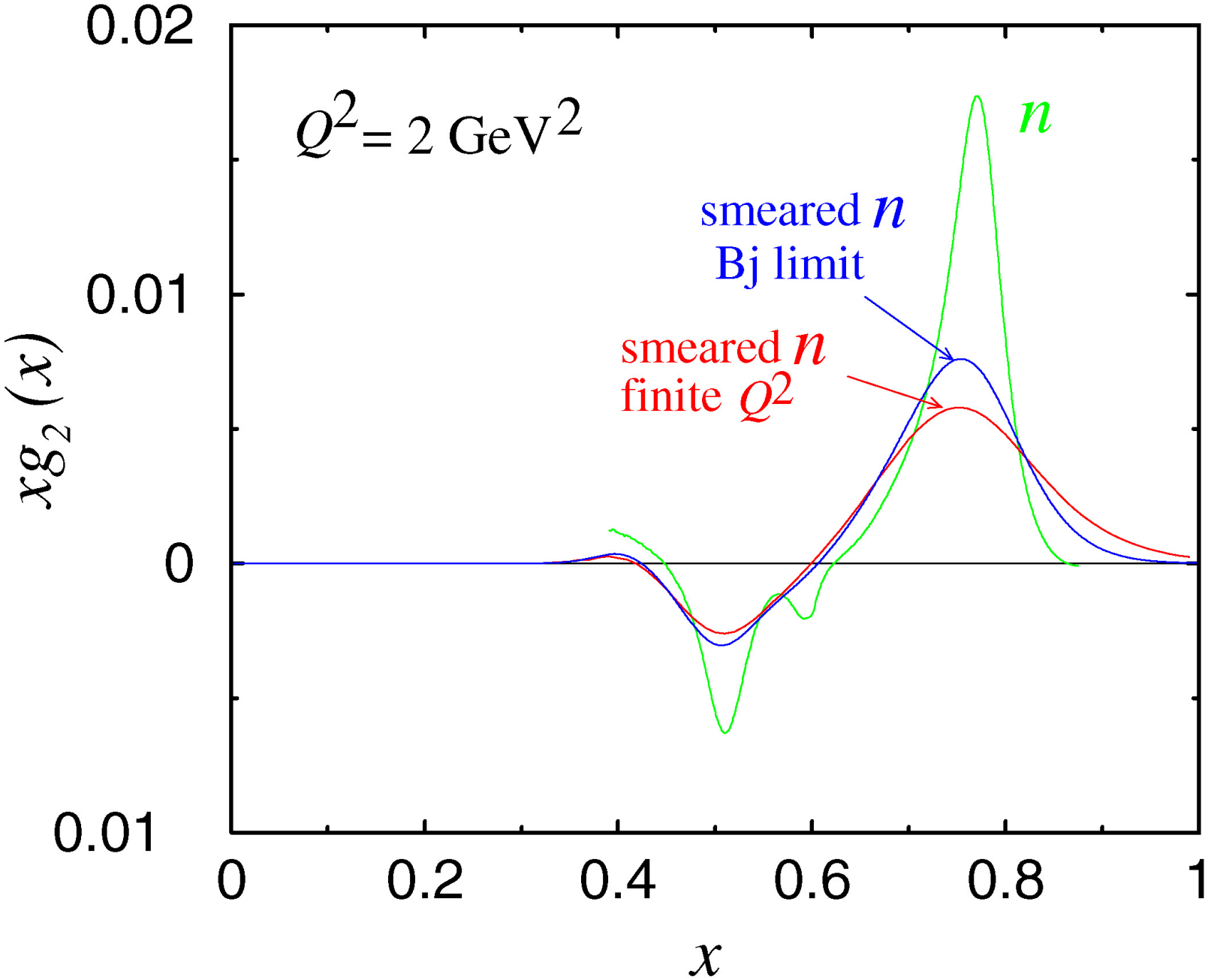
$$\begin{aligned}
& x g_1^{^3\mathrm{He}}(x,Q^2) + (1-\gamma^2) x g_2^{^3\mathrm{He}}(x,Q^2) \\
= & \sum_{N=p,n}\int d^3p\; dE\; (1-\frac{\epsilon}{M})\left\{\left[\left(1+\frac{\gamma p_z}{M}+\frac{p_z^2}{M^2}\right) f_1 + \left(-\frac{1}{3}+\hat{p}_z^2+\frac{2\gamma p_z}{3M}+\frac{2p_z^2}{3M^2}\right) f_2\right]\; z g_1^N(z,Q^2)\right. \\
& \left. + (1-\gamma^2)(1+\frac{\epsilon}{M}\left[f_1+\left(\frac{p_z^2}{\vec{p}^2}-\frac{1}{3}\right) f_2\right]\frac{z^2}{x} g_2^N(z,Q^2)\right\}
\end{aligned}$$

$$\begin{aligned}
& x g_1^{^3\mathrm{He}}(x,Q^2) + x g_2^{^3\mathrm{He}}(x,Q^2) \\
= & \sum_{N=p,n}\int d^3p\; dE\; (1-\frac{\epsilon}{M})\left\{\left[\left(1+\frac{p_x^2}{M^2}\right) f_1 + \left(\vec{p}_x^{\,2}-\frac{1}{3}+\frac{2p_x^2}{3M^2}\right) f_2\right] z g_1^N(z,Q^2)\right. \\
& \left. + \left[\left(1+\frac{p_x^2}{M^2}(1-z/x)\right) f_1 + \left(\vec{p}_x^{\,2}-\frac{1}{3}+\frac{2p_x^2}{3M^2}(1-z/x)-\frac{\gamma p_z \hat{p}_x^2}{M}\frac{z}{x}\right) f_2\right] z g_2^N(z,Q^2)\right\}
\end{aligned}$$

with $\gamma = \sqrt{1+4M^2x^2/Q^2}$ a kinematical factor parameterizing the finite $Q^2$ correction, $\epsilon \equiv \vec{p}^2/4M - E$, and $z = x/(1+(\epsilon+\gamma p_z)/M)$.

# Nuclear corrections (continued)




$Q^2 = 2\ \mathrm{GeV}^2$
$n$
smeared $n$
Bj limit
smeared $n$
finite $Q^2$
$xg_2(x)$
$x$
0.02
0.01
0
0.01
0
0.2
0.4
0.6
0.8
1

# How $g_2(x,Q^2)$ is usually obtained

$$g_2(x,Q^2) = \frac{\nu}{2E}\left[\frac{\nu\left[1+\epsilon \boldsymbol{R}(x,Q^2)\right](1+\gamma^2)\boldsymbol{F_2}(x,Q^2)\boldsymbol{A_\perp}(x,Q^2)}{(1-\epsilon)2x\left[1+\boldsymbol{R}(x,Q^2)\right]E'\sin\theta_e} - \boldsymbol{g_1}(x,Q^2)\right]$$

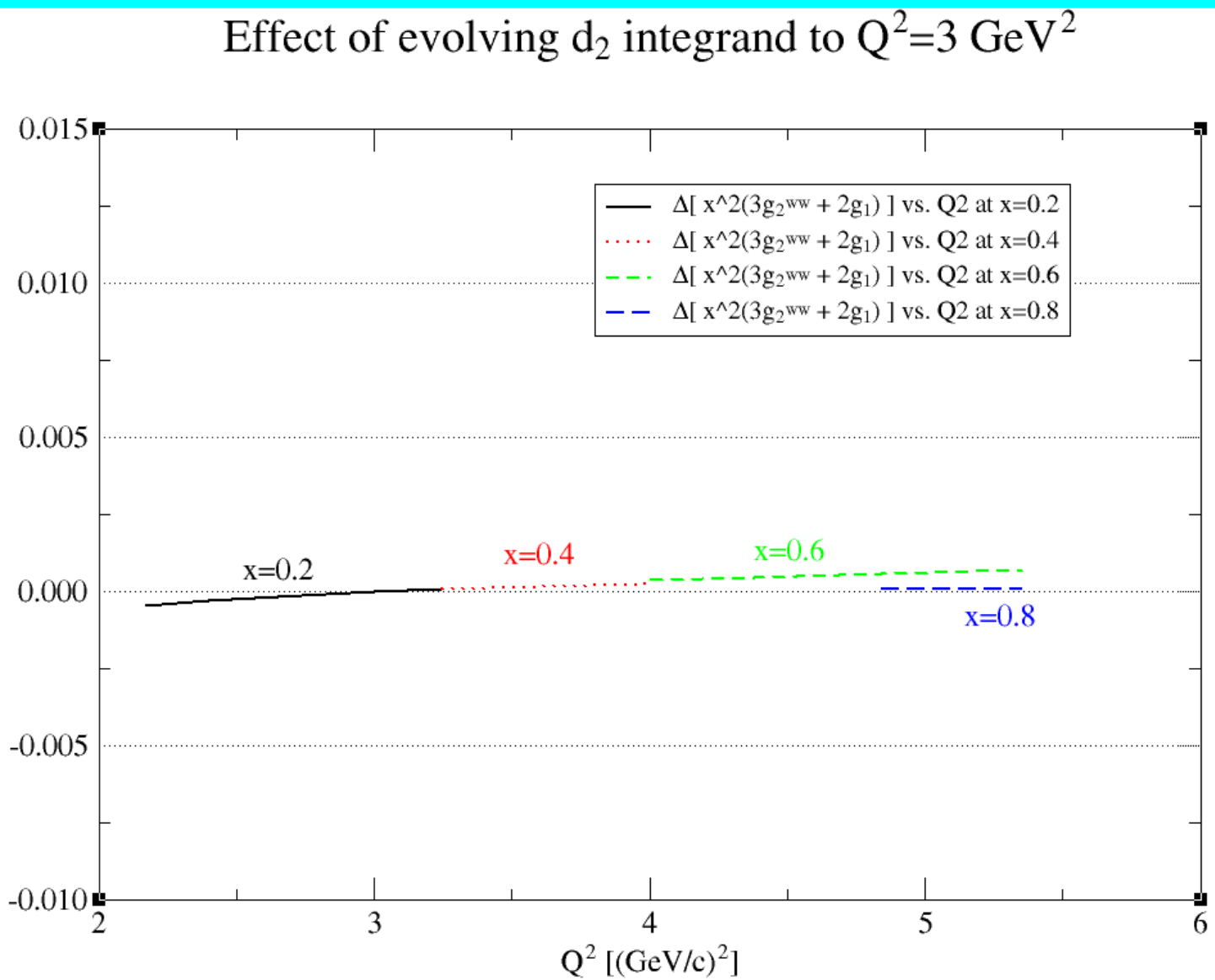
where $\nu = E - E'$, $\gamma^2 = Q^2/\nu^2$ and $\epsilon^{-1} = 1 + 2\left[1+\gamma^{-2}\right]\tan^2\theta/2$

$\boldsymbol{F_2}(x,Q^2)$ NMC fit

$\boldsymbol{g_1}(x,Q^2)$ Fit to the data and evolution to a constant $Q^2$

$\boldsymbol{R}(x,Q^2)$ SLAC fit

# $d_2$ integrand evolution from $g_1$ and $g_2^{ww}$



# Theory and Technical Comments

Theory Review Comments

The proposed experiment aims at the precise determination of the neutron polarized structure function $g_2$. In particular, the experiment focuses on the precise measurement of the $d_2$ moment of $g_2$. Toward this end, both the $g_1$ and $g_2$ structure functions have to be measured so that the Wandzura-Wilczek twist-2 piece of $g_2$ can be subtracted leaving the twist-3 part as the lowest-order contribution in the twist expansion. The extracted $d_2$ moment is of significant theoretical interest since it provides information on sub-leading twist contributions. It can also provide an additional test of lattice calculations of the nucleon moments of structure functions. Several lattice groups, including LHPC, are currently pursuing a precise calculation of $d_2$.

The proposed experiment adequately addresses criticism from past PAC reviews about the reliability of the extraction of $d_2$ of the neutron from data on $^3$He, and about the interpretation of the data as the twist 3 moment due to contamination from higher twist contributions.

Technical Review Comments

- 1. This proposal requires a large installation effort, both for BigBite and for the polarized 3He target.
- 2. How will the spectrometer target acceptance be limited to exclude the target cell windows? What length target cells will be used, 30 or 40 cm?
- 3. The call for proposals specified assuming 80% beam polarization. The days requested should be adjusted to this.

**Individual Proposal Report**

**Proposal:** PR-01-111

**Title:** Measurement of the Neutron $d^n_2$ Matrix Element: a Linear Combination of the Electric $\chi_E$ and Magnetic $\chi_B$ Color Polarizabilities.

**Spokespersons:** X. Jiang and Z.-E. Meziani

**Motivation:** The motivation is to test model calculations (in particular, lattice models) of the $d^n_2$ matrix element, which in the framework of the Operator Product Expansion is sensitive to twist-three quark-gluon correlations, and to electric and magnetic color polarizabilities.

**Measurement and Feasibility:** The measurement uses longitudinally polarized electron scattering from polarized $^3$He to measure the spin structure functions $g_1(x)$ and $g_2(x)$ at fixed $Q^2$=2 $(GeV/c)^2$. The spin asymmetry for inclusive electron scattering is measured in the standard Hall A spectrometers. The $d^n_2$ matrix element is evaluated by integrating $x^2(2g_1+3g_2)$ over the measured region, with extrapolations to x=0 and x=1 to cover the unmeasured regions. Models are used to correct for the difference between a polarized $^3$He nucleus and a free polarized neutron. The experiment appears to be feasible, building on a foundation of several similar experiments in Hall A. The experiment could provide a factor-of-four smaller error than existing data for the neutron $d^n_2$ matrix element.

**Issues:** The principal issue is that the integral will be strongly affected by contributions in the resonance region, which may introduce significant higher-twist contributions, clouding the interpretation in terms of quark-gluon correlations. A secondary concern is the reliability of the extraction of the value of $d^n_2$ of the neutron from the data on $^3$He. Since the nuclear effects are largest at high x, it is not obvious that these are negligible in an integral that is weighted by $x^2$.

**Recommendation:** Defer

**Scientific Rating**: N/A

**Proposal:** PR 03-107

**Title:** Measurement of the Neutron $d_2$: Towards the Electric $\chi_E$ and Magnetic $\chi_B$ Color Polarizabilities.

**Spokespersons:** Z.-E. Meziani, S. Choi, and X. Jiang

**Motivation:** The aim of the experiment is a precise determination of moments of the neutron spin structure functions, namely the integral of $g_2^n$ and the $x^2$-moment of a particular combination of $g_1$ and $g_2$, called $d_2$. In the framework of the Operator Product Expansion, the latter is sensitive to twist-3 quark–gluon correlations, and to electric and magnetic color polarizabilities. This quantity would be compared to lattice QCD predictions and to other model calculations.

**Measurement and Feasibility:** The measurement uses scattering of longitudinally polarized electrons from a polarized $^3$He target, to measure longitudinal and transverse asymmetries, together with the unpolarized cross section, from which the spin structure functions $g_1(x)$ and $g_2(x)$ are extracted at fixed $Q^2 = 2$ (GeV/c)$^2$. The experiment is optimized to minimize the uncertainty on $d_2$, obtained by integrating $x^2(2g_1 + 3g_2)$ over the measured region ($x$ from 0.24 to 0.8). Extrapolations to $x = 0$ and $x = 1$ are applied to cover the unmeasured regions. A correction to account for the difference between a polarized $^3$He and a free polarized neutron is applied. The experiment uses existing equipment and proven techniques. **It is judged feasible.** It would complement the low $Q^2$ results obtained by E-94-010 and the (significantly less precise) SLAC determination of $d_2^n$ at 5 (GeV/c)$^2$. Lattice QCD calculations performed at $Q^2 = 2$ (GeV/c)$^2$ should be available in the near future, enhancing the interest in the measurement.

**Issues:** **The principal issue is that the measured integral is dominated by contributions in the resonance region, thus making the interpretation in terms of color polarizabilities doubtful. However, investigating whether the twist expansion breaks down in this region is of interest, and connected to the question of quark-hadron duality.** Nuclear corrections seem to be under control for the moment being addressed, $d_2^n$.

**The PAC would have liked to see this experiment performed, but due to limitations in the available beam time, the proposal cannot be accepted at this time.**

**Recommendations:** **Defer with Regret.**