Precision Measurement of the neutron d_2: Towards the Electric χ_E and Magnetic χ_B Color Polarizabilities

Huan Yao

Post Doc:Brad Sawatzky
Advisor: Zein-Eddine Meziani
Temple University, JLab

X. Zheng
Argonne National Laboratory, Argonne, IL 60439, USA

P. Bertin
Université Blaise Pascal De Clermont-Ferrand, Aubiere 63177, France

J.-P. Chen, E. Chudakov, C. W. de Jager, R. Feuerbach, J. Gomez, J. -O. Hansen, D.W. Higinbotham, J. LeRose, W. Melnitchouk, R. Michaels, S. Nanda, A. Saha, B. Wojtsekhowski
Jefferson Lab, Newport News, VA 23606, USA

S. Frullani, F. Garibaldi, M. Iodice, G. Urciuoli, F. Cusanno
Istituto Nazionale di Fiscica Nucleare, Sezione Sanità, 00161 Roma, Italy

R. DeLeo, L. Lagamba
Istituto Nazionale di Fiscica Nucleare, Bari, Italy

A.T. Katramatou, G.G. Petratos
Kent State University, Kent, OH 44242

W. Korsch
University of Kentucky, Lexington, KY 40506, USA

W. Bertozzi, Z. Chai, S. Gilad, M. Rvachev, Y. Xiao
Massachusetts Institute of Technology, Cambridge, MA 02139, USA

L. Gamberg
Penn State Berks, Reading, PA, 19610 USA

F. Benmokhtar, R. Gilman, C. Glashausser, E. Kuchina, X. Jiang (co-spokesperson), G. Kumbartzki, R. Ransome
Rutgers University, Piscataway, NJ 08855, USA

Seonho Choi(co-spokesperson)
University of Seoul, Seoul, South Korea

B. Sawatzky (co-spokesperson), F. Butaru, A. Lukhanin, Z.-E. Meziani (co-spokesperson), P. Solvignon, H. Yao
Temple University, Philadelphia, PA 19122, USA

S. Binet, G. Cates, N. Liyanage, J. Singh, A. Tobias
University of Virginia, Charlottesville, VA 22901, USA

D. Armstrong, T. Averett, J. M. Finn, K. Griffioen, T. Holmstrom, V. Sulkosky
College of William and Mary, Williamsburg, VA 23185, USA

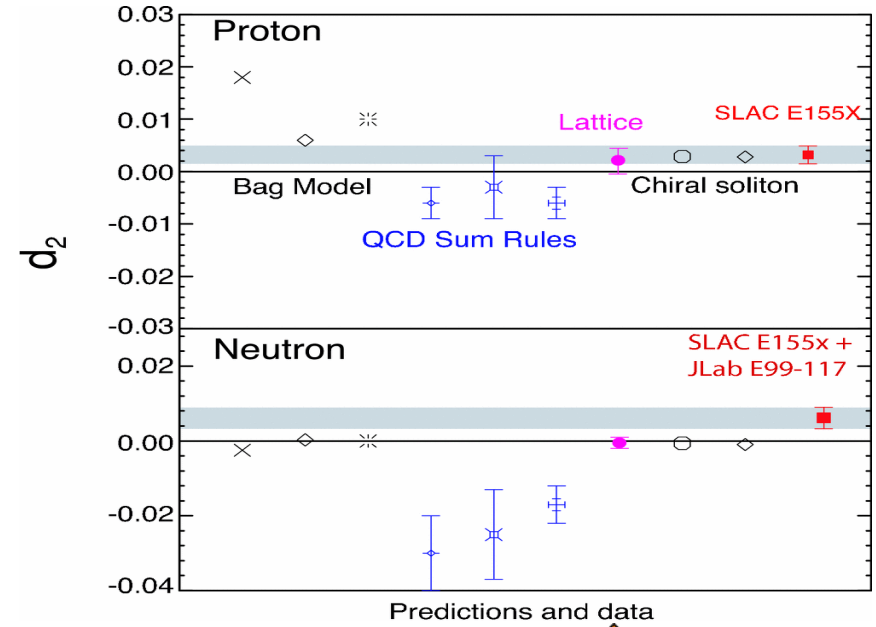
Overview of this talk

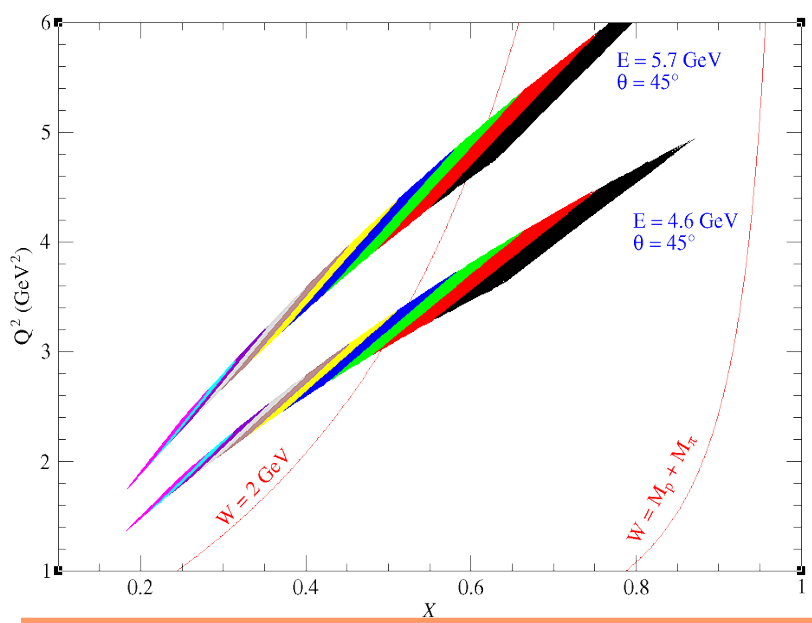
- Brief overview of d_2^n experiment.
- BigBite Electron Package
- New Cerenkov for BigBite
  - Design
  - Optics
  - Backgrounds
  - Radiator Gas
  - Timeline and Milestones

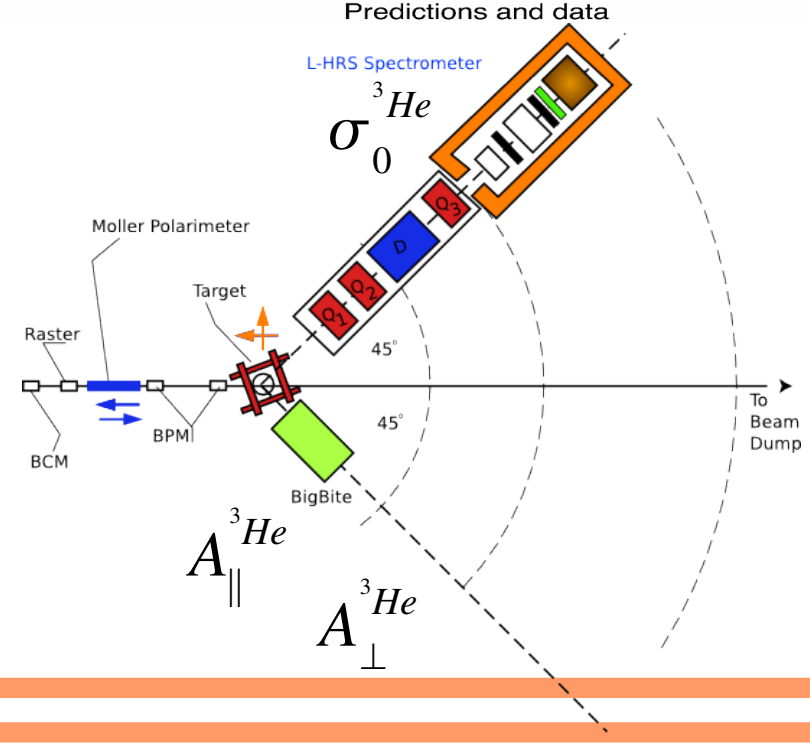
Brief Overview of d_2^n

$$d_2^n(Q^2)=\int_0^1 \tilde{d}_2(x,Q^2)\,dx=\int_0^1 x^2[2g_1^n(x,Q^2)+3g_2^n(x,Q^2)]\,dx$$

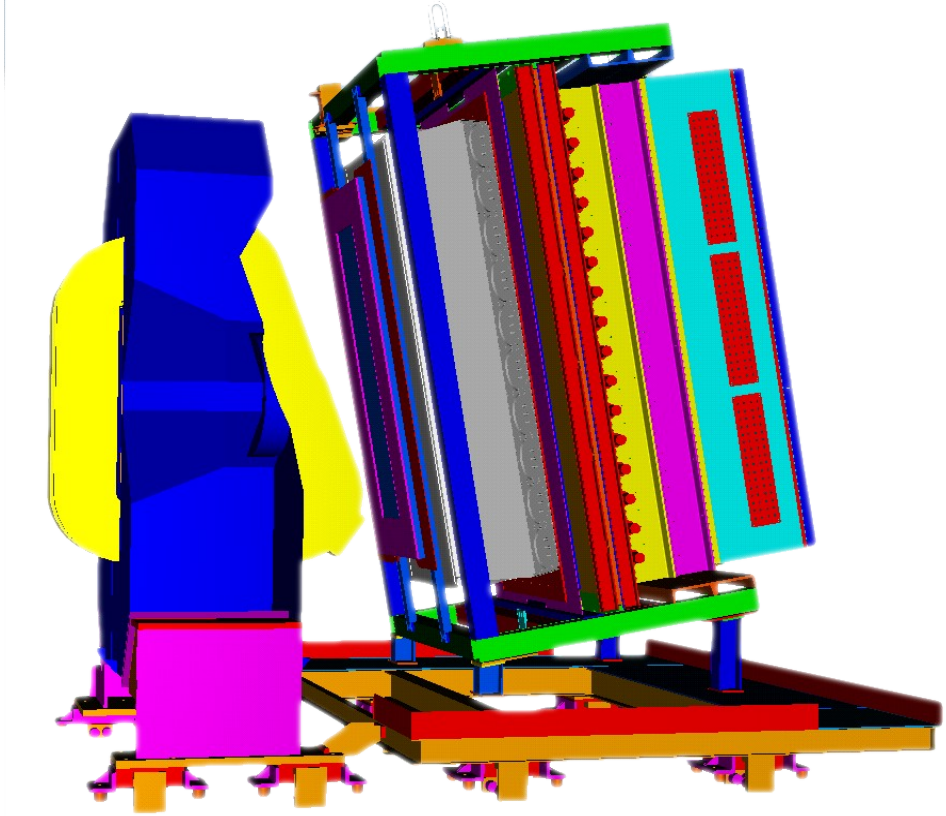
- Determine the neutron d_2 at $\langle Q^2\rangle = 3\ \mathrm{GeV}^2$ using a polarized electron beam of 4.6 and 5.7 GeV and polarized ^{3}He target
- 13 PAC days to achieve a statistical uncertainty of $\Delta d_2^n = 5\times10^{-4}\ fm^2$







BigBite Electron Package



- 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
  - 3 MWDCs, segmented trigger, Pb-glass shower
  - Gas Cerenkov (new)

- MC background 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 (Total energy)
  - 3—5 p.e. threshold on Cerenkov
- Total estimated trigger rate (GeN trig + Cerenkov): 2—5 kHz

Online triggers		Removed via online cuts	
$e-$	$2-5$ kHz	$\pi-$	90 kHz
$e+$	<1 kHz	$\pi+$	90 kHz
		p	50 kHz
		n	50 kHz

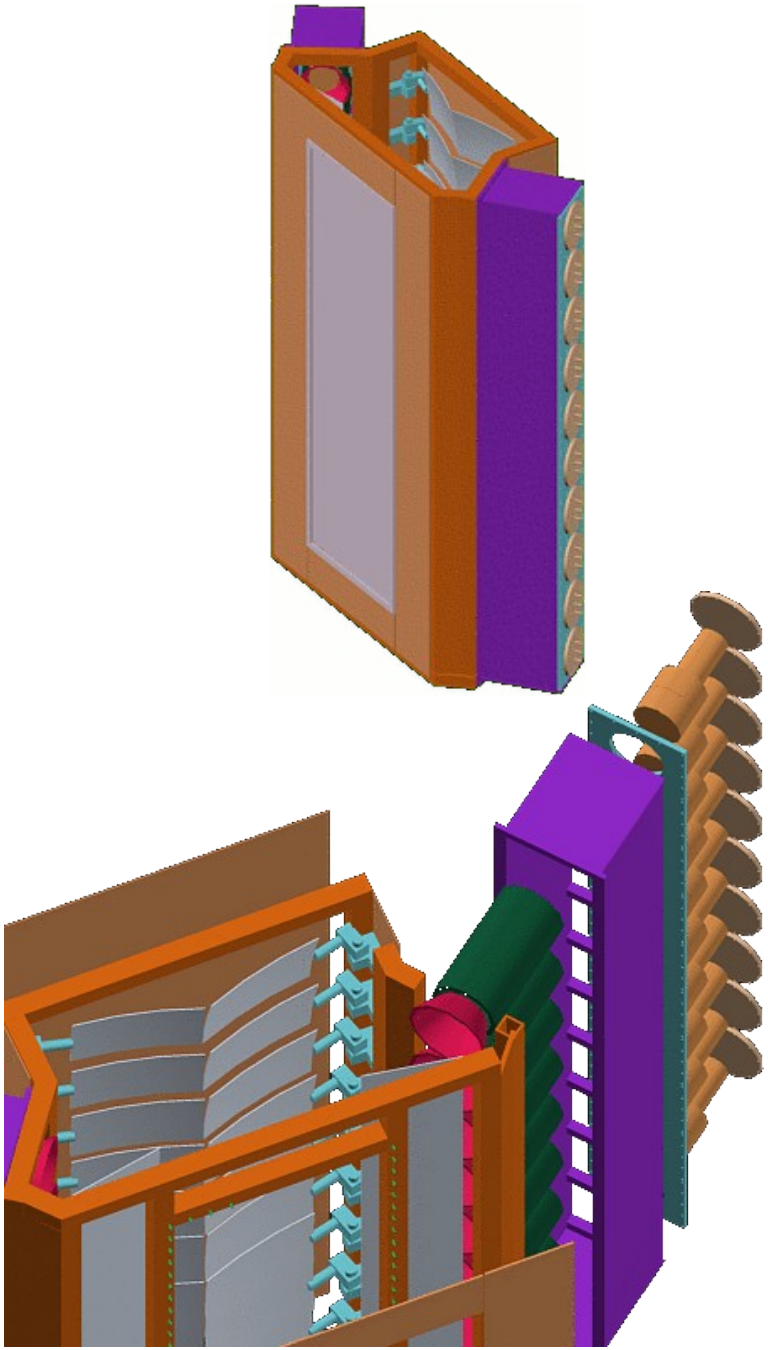
Cerenkov for BigBite

Design Parameters

- Dimensions: 200cm x 60cm x 60cm
  - sandwiched between wire chambers

- Radiator gas: C_4F_{10}
  - n = 1.0015
  - π threshold: 2.51 GeV/c
  - ~25 photo-electrons / 40 cm electron track
    - Quartz PMT (Photonis XP4518)
    - mirror reflectivity: ~90%, 10% loss at PMT-gas interface

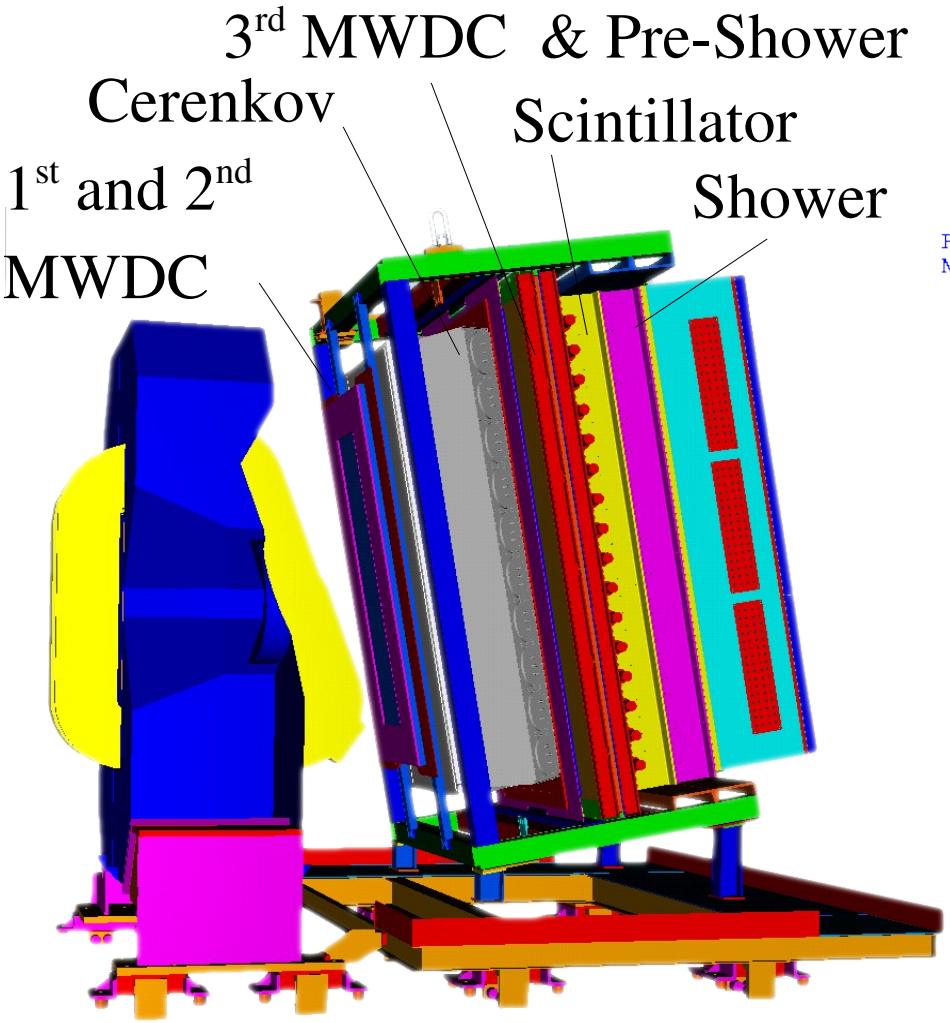
- >98% efficient with 3-4 photoelectrons threshold
  - negl. pion contamination **minimum** π/e rejection ratio 500:1 online (probably better)

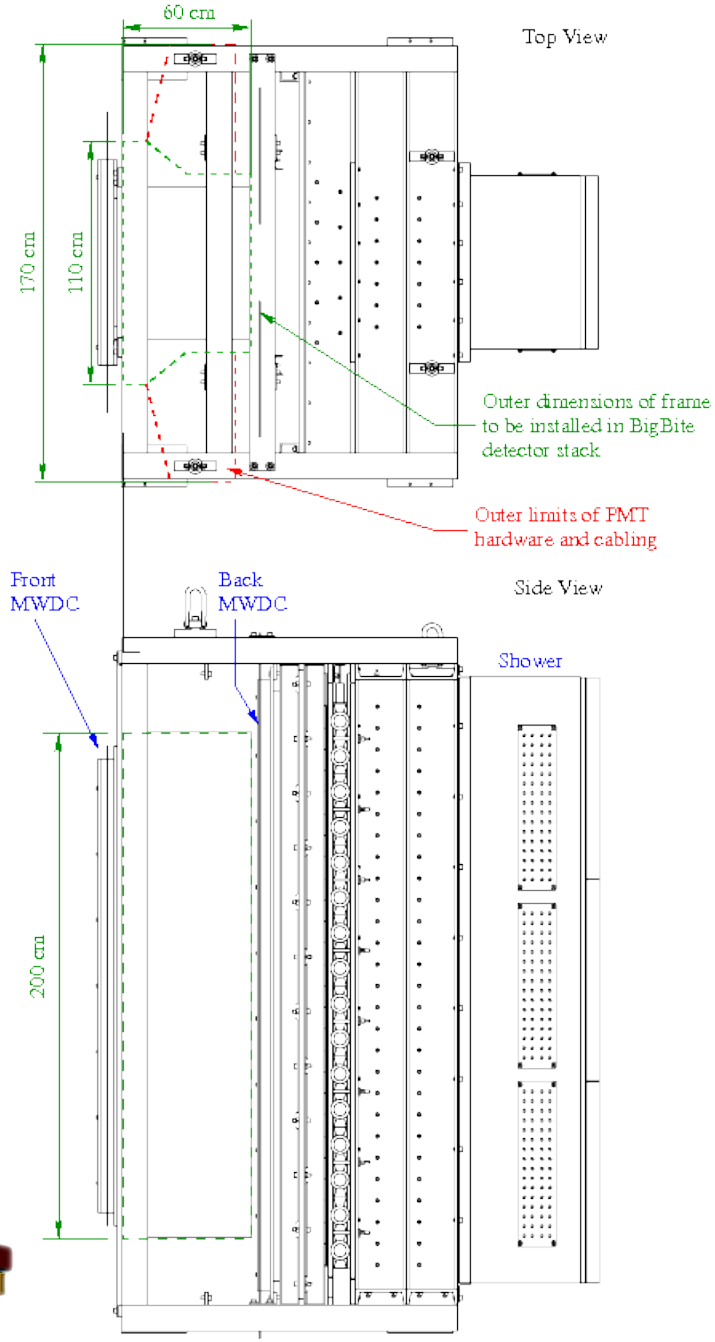


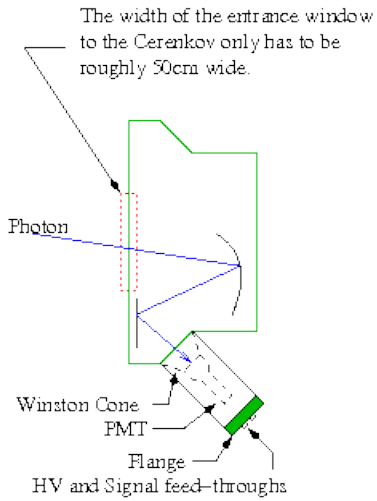
Cerenkov Frame

Ed K. (Temple engineer) is developing CAD drawings

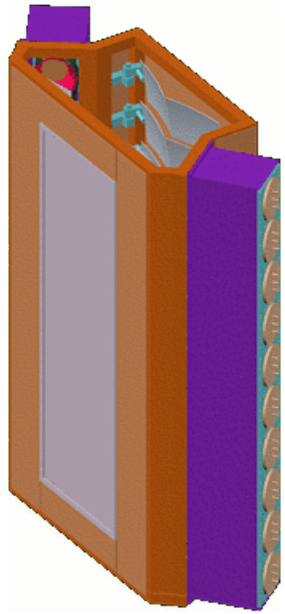
Al Gavalya (JLab) is local contact for integration into BB Detector stack



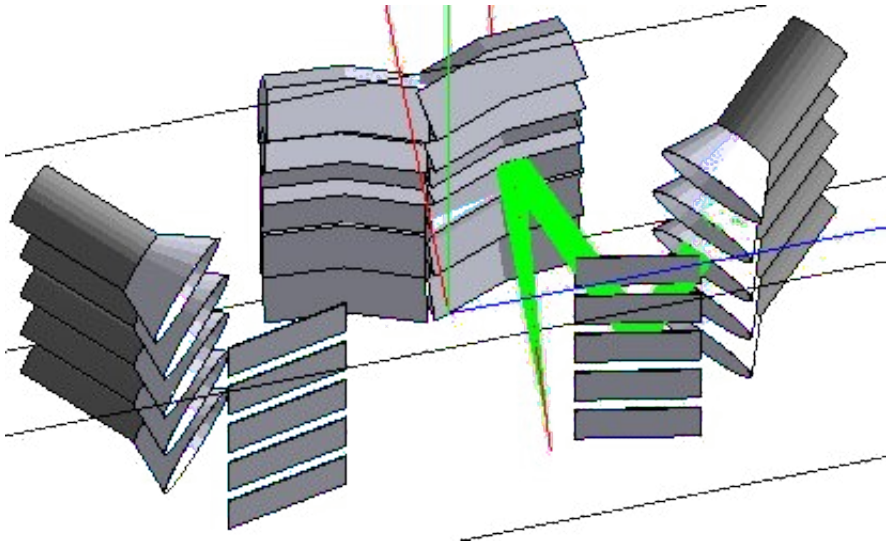


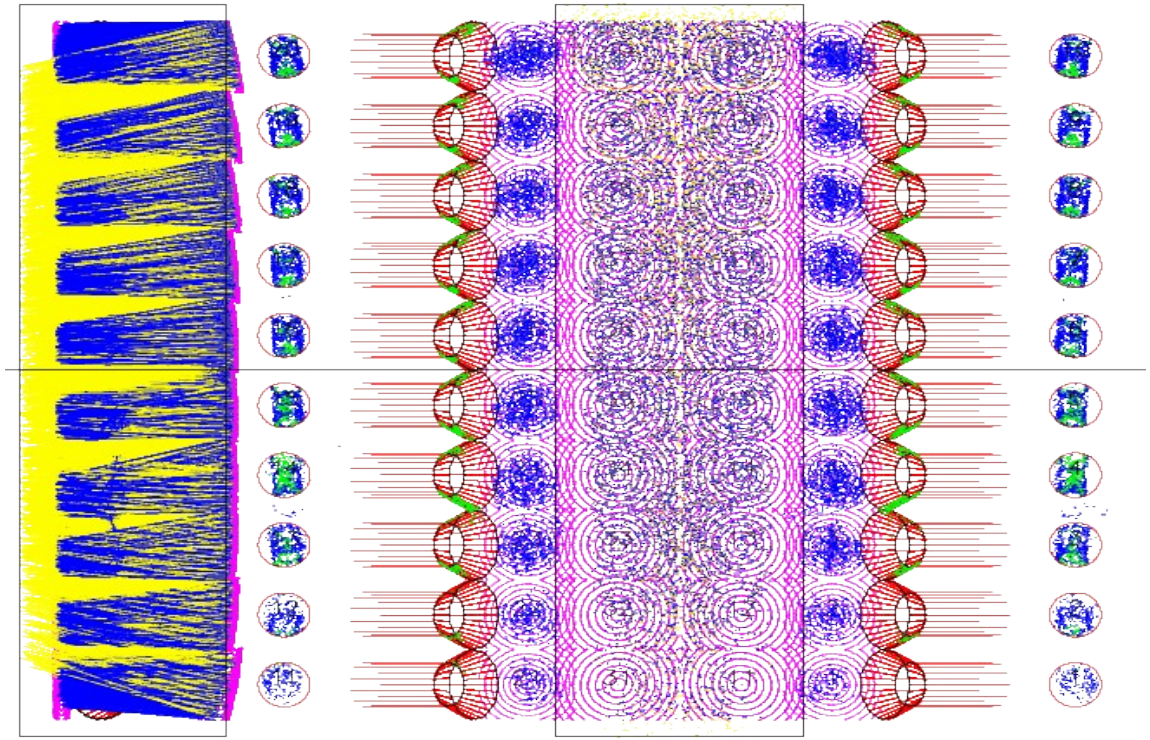


NOTE: The drawings are not necessarily to scale.



Cerenkov Optics





- Limited space required compact 3 mirror design
- Large BB momentum acceptance drove the need for pseudo-Winston Cones
  - low-mom. e^- focused higher on PMT face
  - high-mom. e^- focused lower on PMT face
- Ray trace models indicate > 95% collection efficiency with this optic design
- Two independent ray-trace models agree

Cerenkov Gas Selection

- We will use C_4F_{10} at 1 atm
  - currently used in Hall B Cerenkov
- Detected photo-electron model assumes
  - 40 cm track in gas,
  - absorption losses in radiator,
  - scaled by 0.7 to accommodate losses at mirrors and PMT surface.
- Same model applied to current Hall A short Cerenkov reproduces measured photoelectrons to within 20%

Gas	n	e^- thr. (MeV/c)	π thr. (MeV/c)	Detected p.e.'s	
				Burle 8854	Quartz PMT
N_2	1.0003	21	5926	3.2	5.4
CO_2	1.0004	17	4671	5.4	9
Freon12	1.0011	11	2984	11	16
C_4F_{10}	1.0015	9	2522	14	25

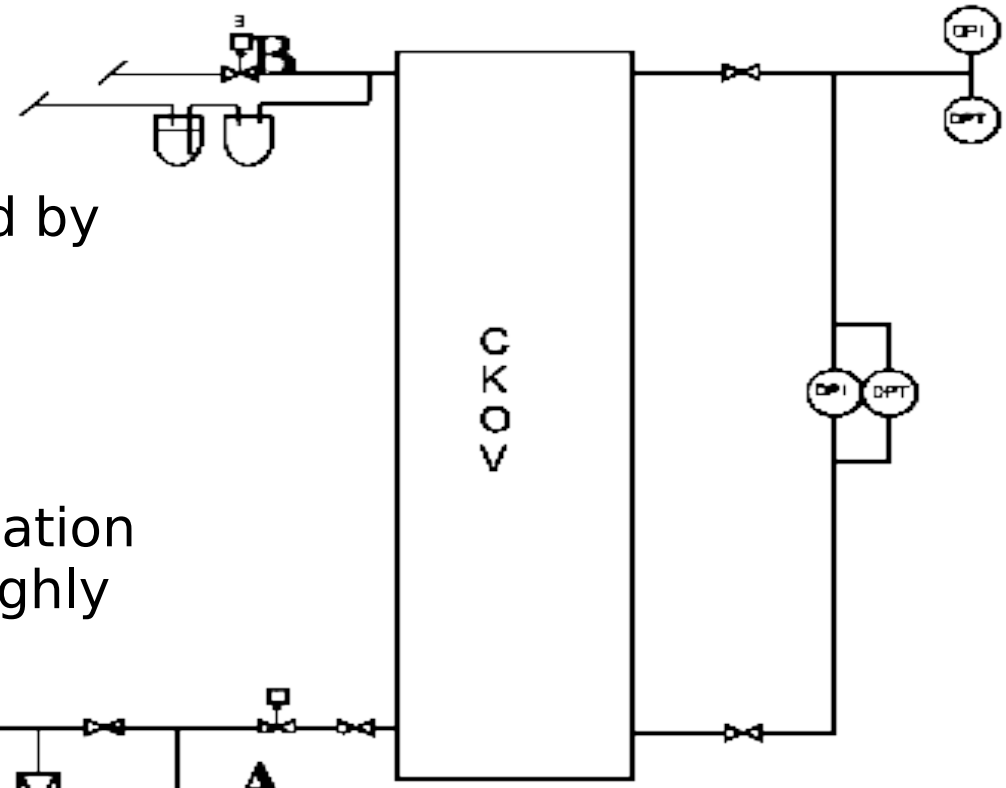
Gas System

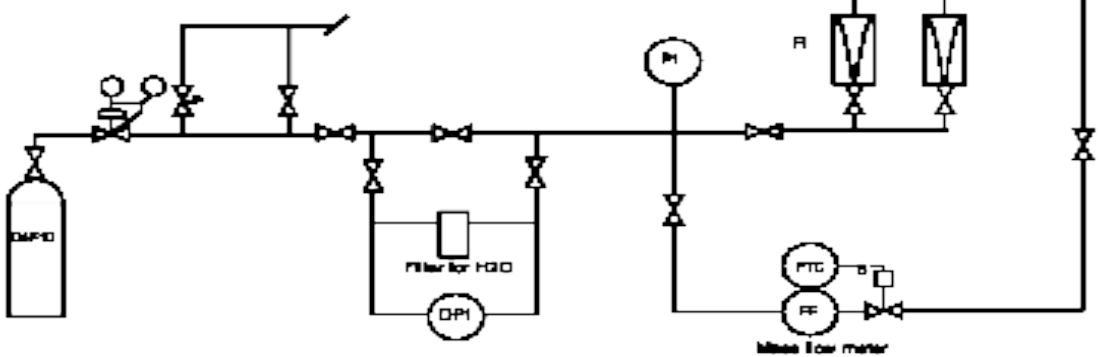
Tank pressure will be maintained at slightly above 1 atm.

relative underpressure compensated by fill from tank

relative overpressure vented

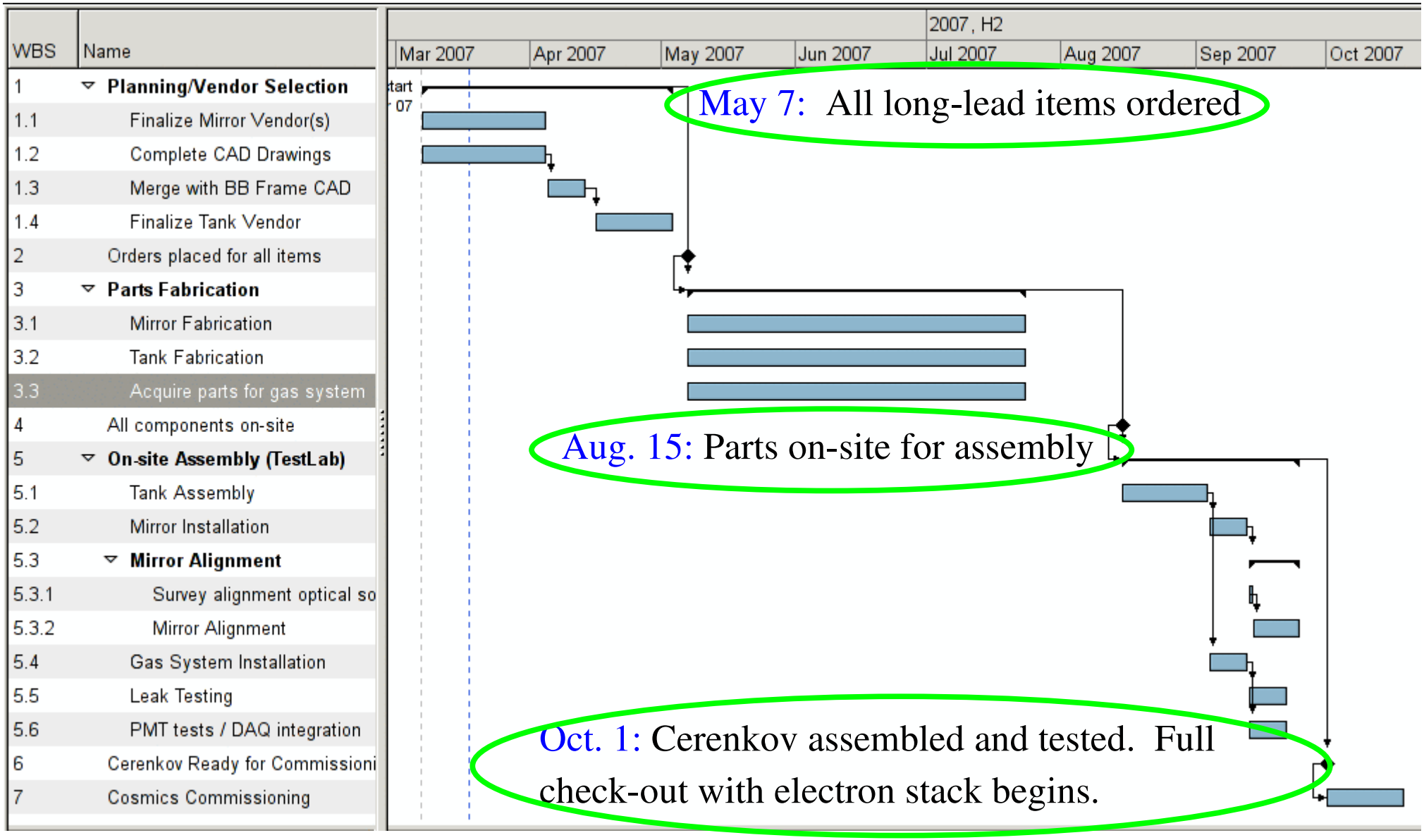
gas losses due to pressure compensation estimated to be 18 liters/day (roughly $35/day at current pricing).



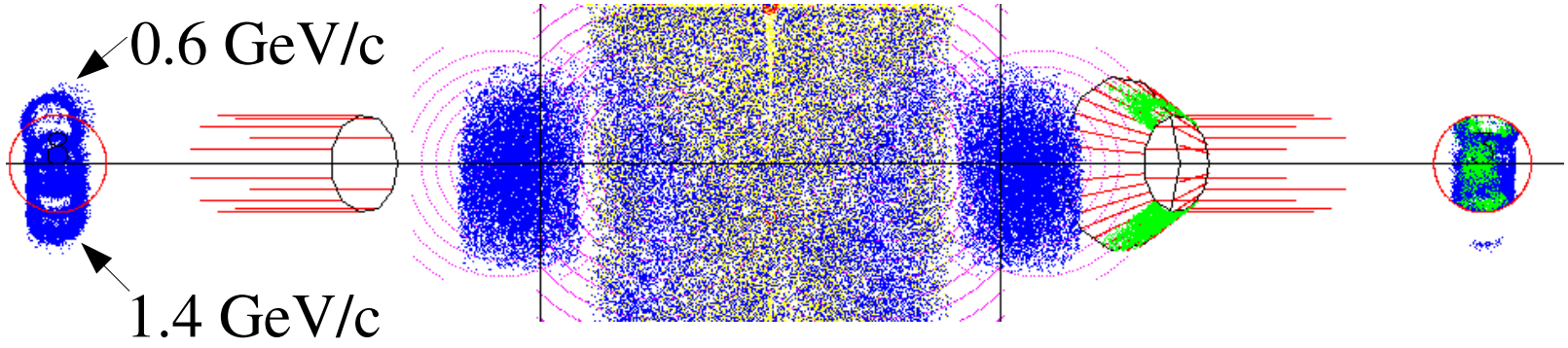


Same system used for FNAL E907 C_4F_{10} Cerenkov

Cerenkov Timeline and Milestones



Effect of Winston Cone



Background / Magnetic Field Effects on PMTs

The effect of BigBite's residual magnetic field at the PMT location was empirically examined during GeN.

- within mu-metal shield field dropped to <0.02 Gauss
  - also observed that the shielded PMT performance was independent of the PMT orientation within the the fringe field

Background rates in bare PMT also studied during GeN

- 3” quartz-face PMT was studied during GeN production runs
  - rate with 1” Al shielding and 3 p.e. discrim. threshold: ~ 1.8 kHz/μA
- After scaling to account for 5” PMT and Transversity kinematics
  - rate with 1” Al shielding and 3 p.e. discrim. threshold: ~ 10 kHz/uA
- For 100ns coinc. between 10 kHz Shower ANDed w/ 20 PMT Cerenkov
  - Worst case: 2 kHz random contribution
  - Segmented trigger (planned) will reduce rate by 5—10x
- Anticipate < 400 Hz of randoms for d_2^n
  - should be conservative (d_2 at 45˚, above estimates at 30˚)

When atmospheric pressure falls valve A closes and valve B opens, venting C4F10 to the atmosphere. When the atmospheric pressure rises valve B closes and valve A opens allowing the mass flow meter to replentish the gas in the Cerenkov tank.

A differential pressure transducer measures the weight of the C4F10 gas column. Another transducer measures the relative pressure between the tank and atmosphere.

Manual flow meters will be used to fill the tank.

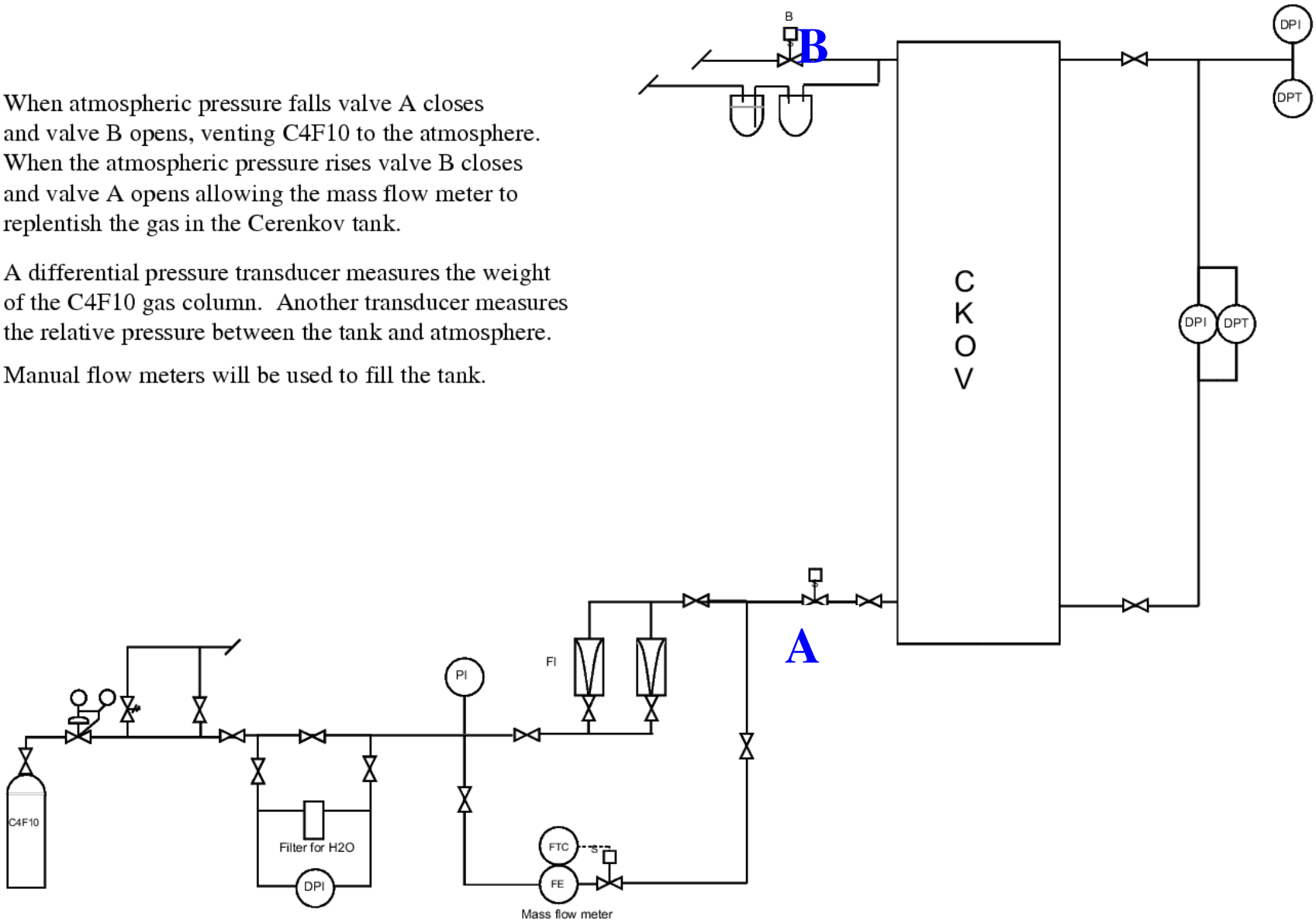


Photo-electron Yield

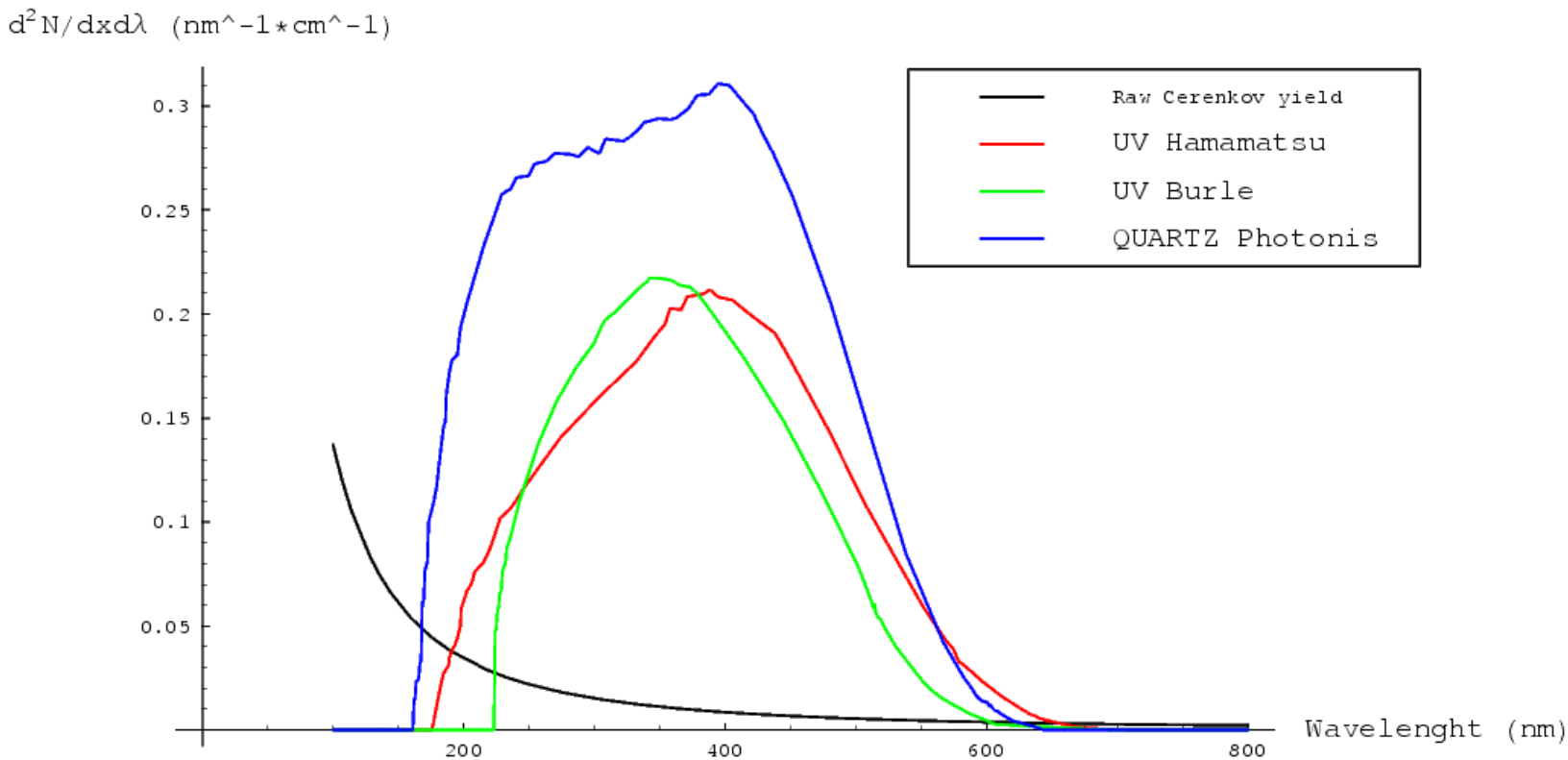


Figure 5: Differential photo-electron (p.e.) yield per wavelength (in nm) per unit distance in radiator (in cm). The three colored curves represent the quantum efficiencies (q.e.) of three characteristic 5" PMTs ((i.e.) p.e.'s per photon). The black curve is the raw Cerenkov differential photon yield. Integrating the product of the Cerenkov yield and the q.e. gives a first-order estimate of the PMT response to an electron track in the radiator.

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Precision Measurement of the neutron d_2: Towards the Electric χ_E and Magnetic χ_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 in $\sigma_0^{^3\mathrm{He}}$ junction 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

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

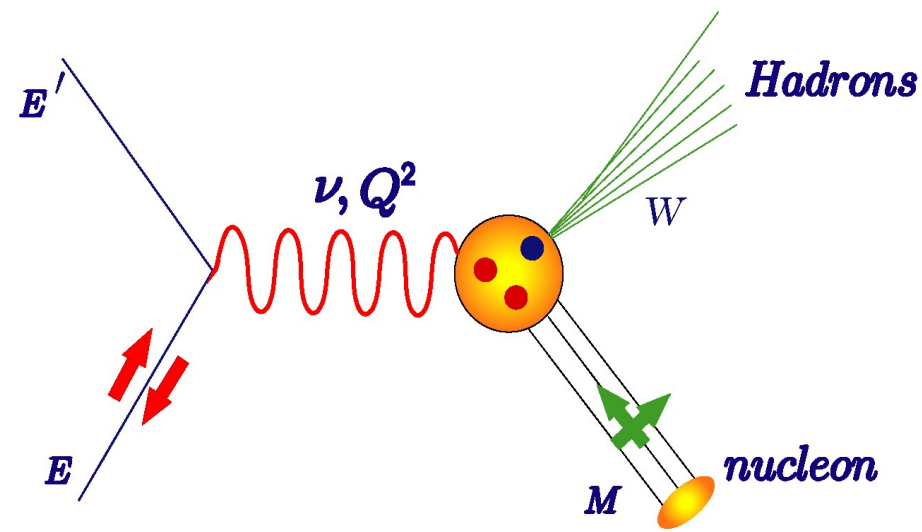
$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta}{MQ^2}\frac{E'^2}{\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right] = \Delta\sigma_{\perp}$$

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

ν = energy transfer.

θ = scattering angle.

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

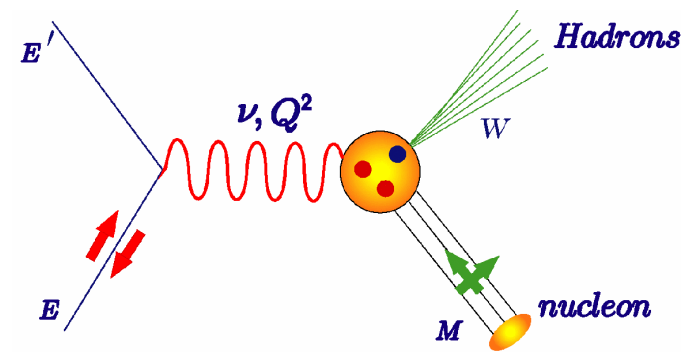


What the heck is g_1 and g_2?

- The "g's" play a role analogous to the "F's" in the unpolarized cross section

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2\sin^4\frac{\theta}{2}}\left(\frac{2}{M}F_1(x,Q^2)\sin^2\frac{\theta}{2} + \frac{1}{\nu}F_2(x,Q^2)\cos^2\frac{\theta}{2}\right)$$

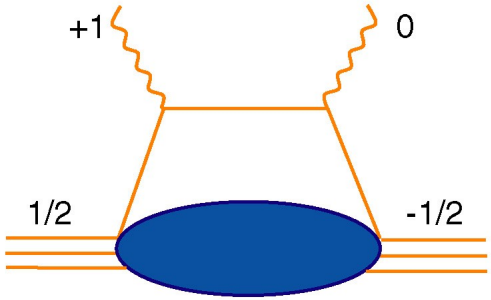
- g and F encode information about the internal structure of the target nucleon
  - ➡ You can measure them,
  - ➡ You can compute them,
  - ➡ But what do they mean?



- The Parton Model
  - ➡ Assume hadrons composed of free particles called 'partons'
  - ➡ F_1 (and F_2) reflect the probability of finding a parton (ie. quark) with momentum fraction 'x'
  - ➡ g_1 reflects the difference in probabilities between quarks with spin aligned parallel and anti-parallel to the nucleon spin
  - ➡ g_2 ???

g_2 and Quark-Gluon Correlations

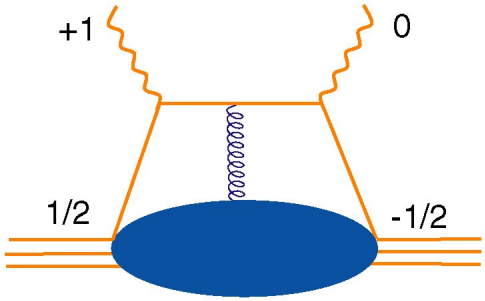
twist-2



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

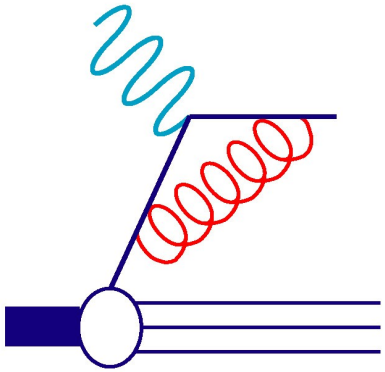
higher twist

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

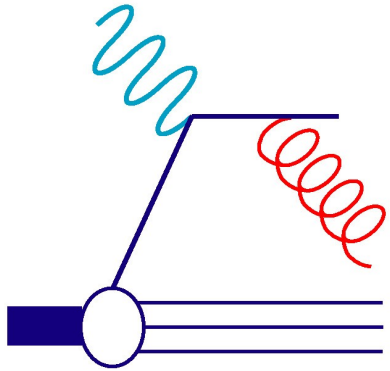
$g_A = 1.257$ and $a_8 = 0.579$ are the triplet and octet axial charge, respectively

$\Delta\Sigma$ = 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"

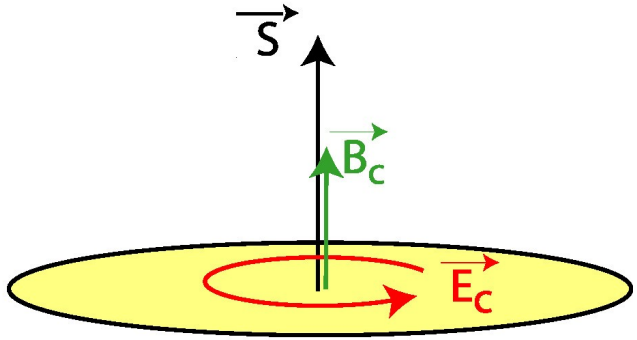
How does the gluon field respond when a nucleon is polarized ?

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

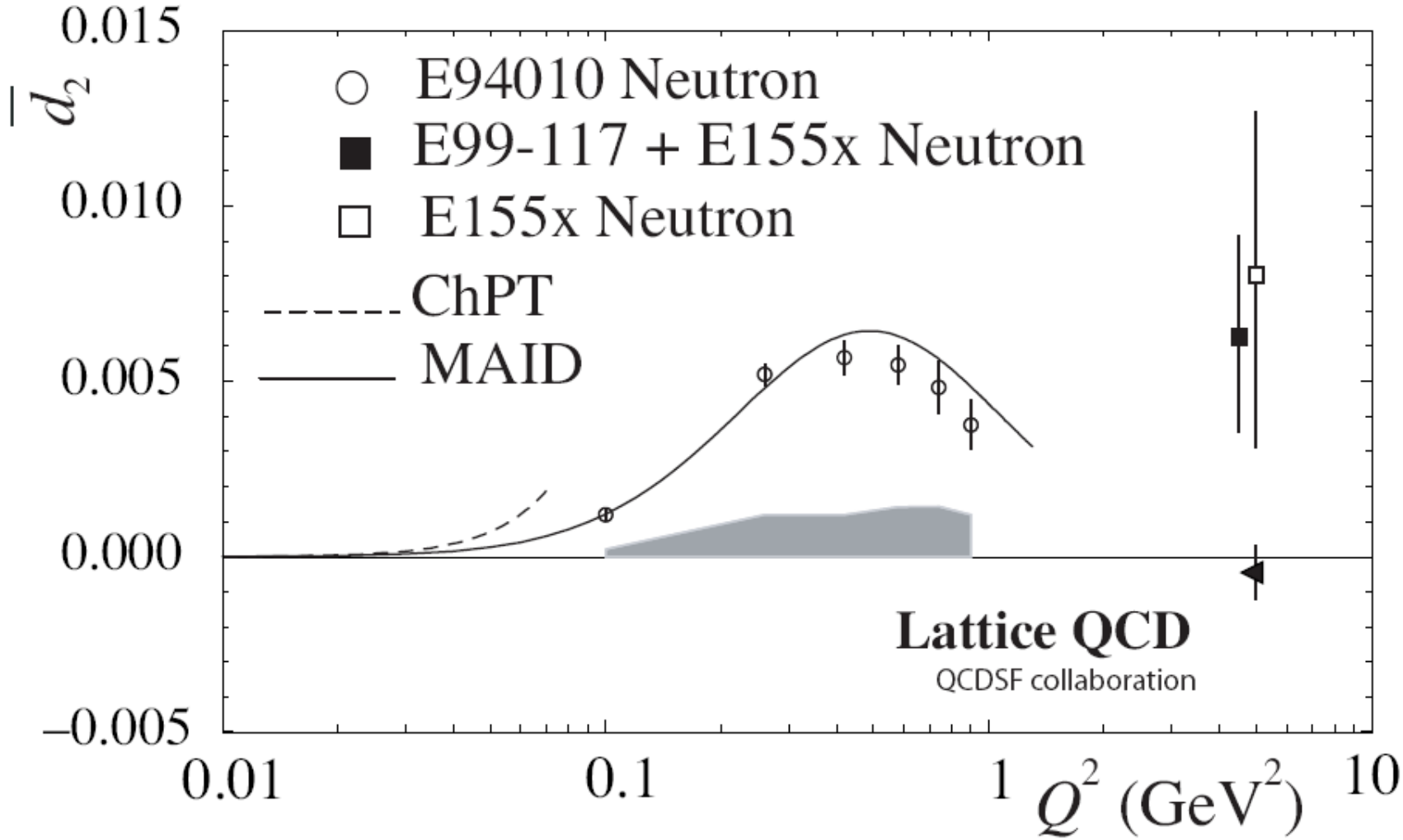
$\vec{O}_E = \psi^\dagger \vec{\alpha} \times g \vec{\boldsymbol{E}} \psi$



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

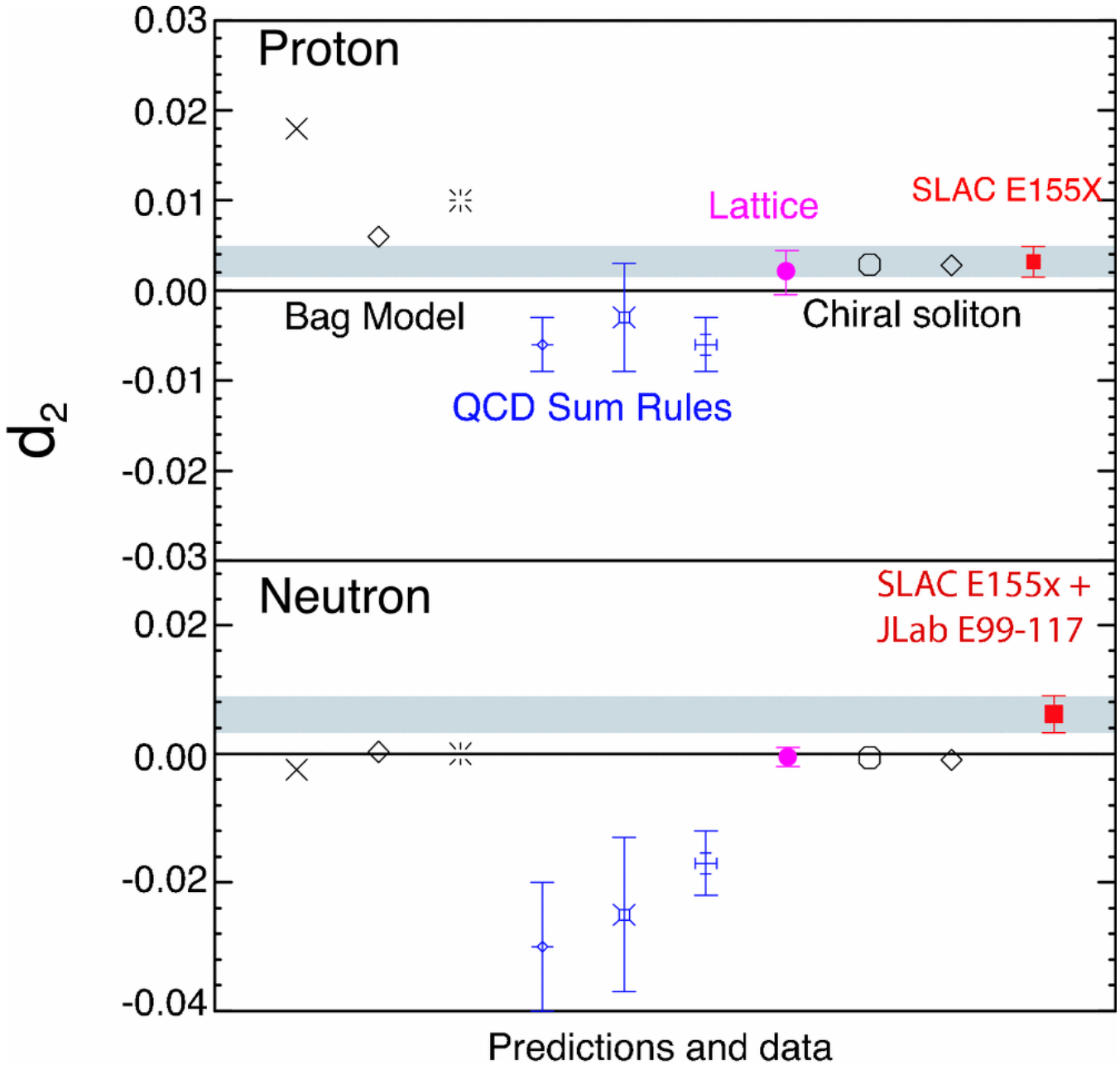
χ_E and χ_B represent the response of the color $\vec{B}$ & $\vec{E}$ fields to the nucleon polarization

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 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: θ = 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	Δx	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 π^-/π^+ 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	Δx	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

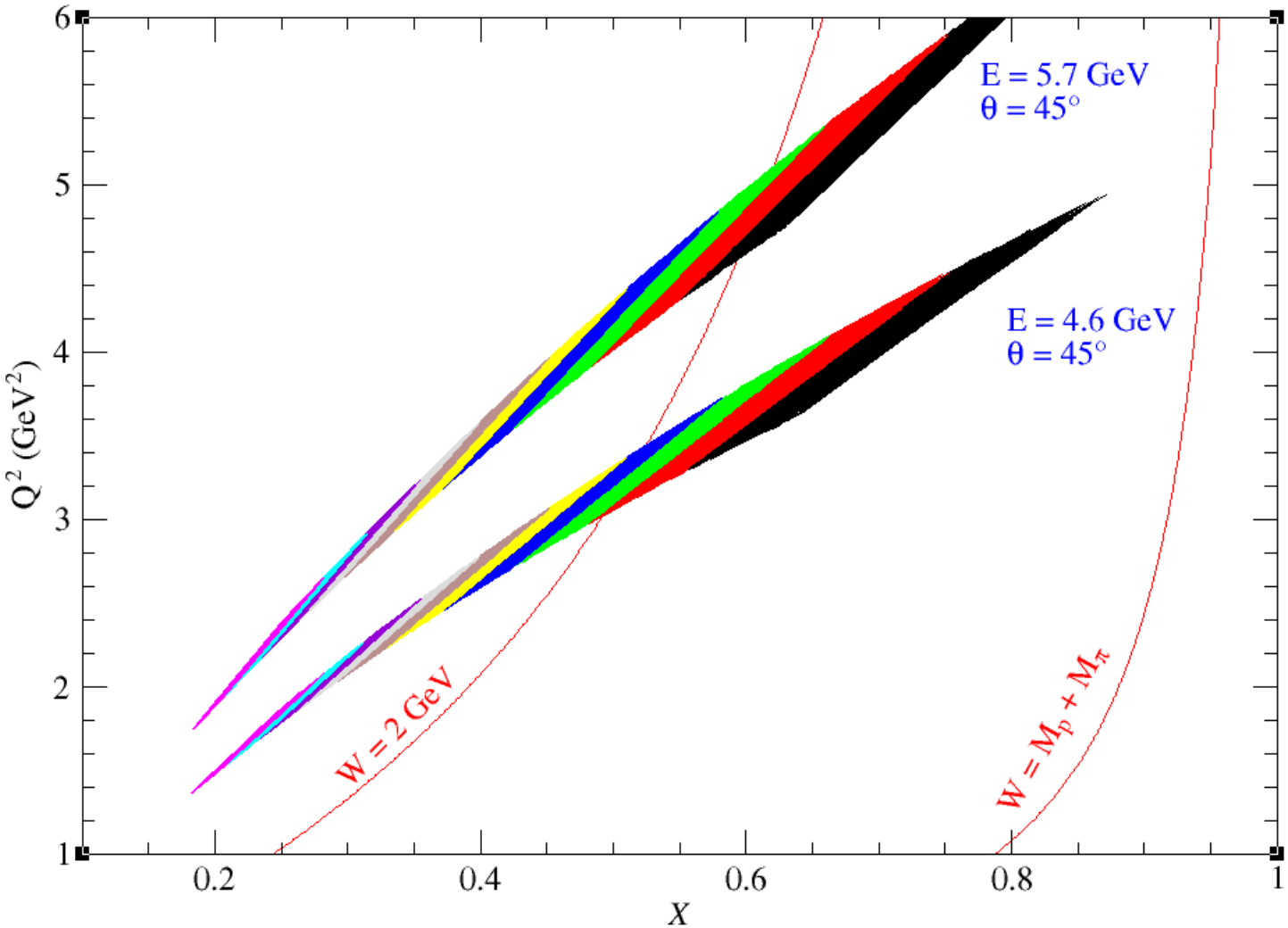
- L-HRS used to measure total cross section at 10 momentum settings.
- BigBite takes all asymmetry data with single setting.
  - ➡ Focus is measuring Q^2 evolution of $x^2\bar{g}_2$
- +80 hours for 4.6 GeV data set
  - ➡ add 48 hours calibration and overhead
    - ➥ **TOTAL: 308 hours (13 days)**

Kinematics of the measurement

- Two beam energies
  4.6 and 5.7 GeV
  (4 pass, 5 pass)

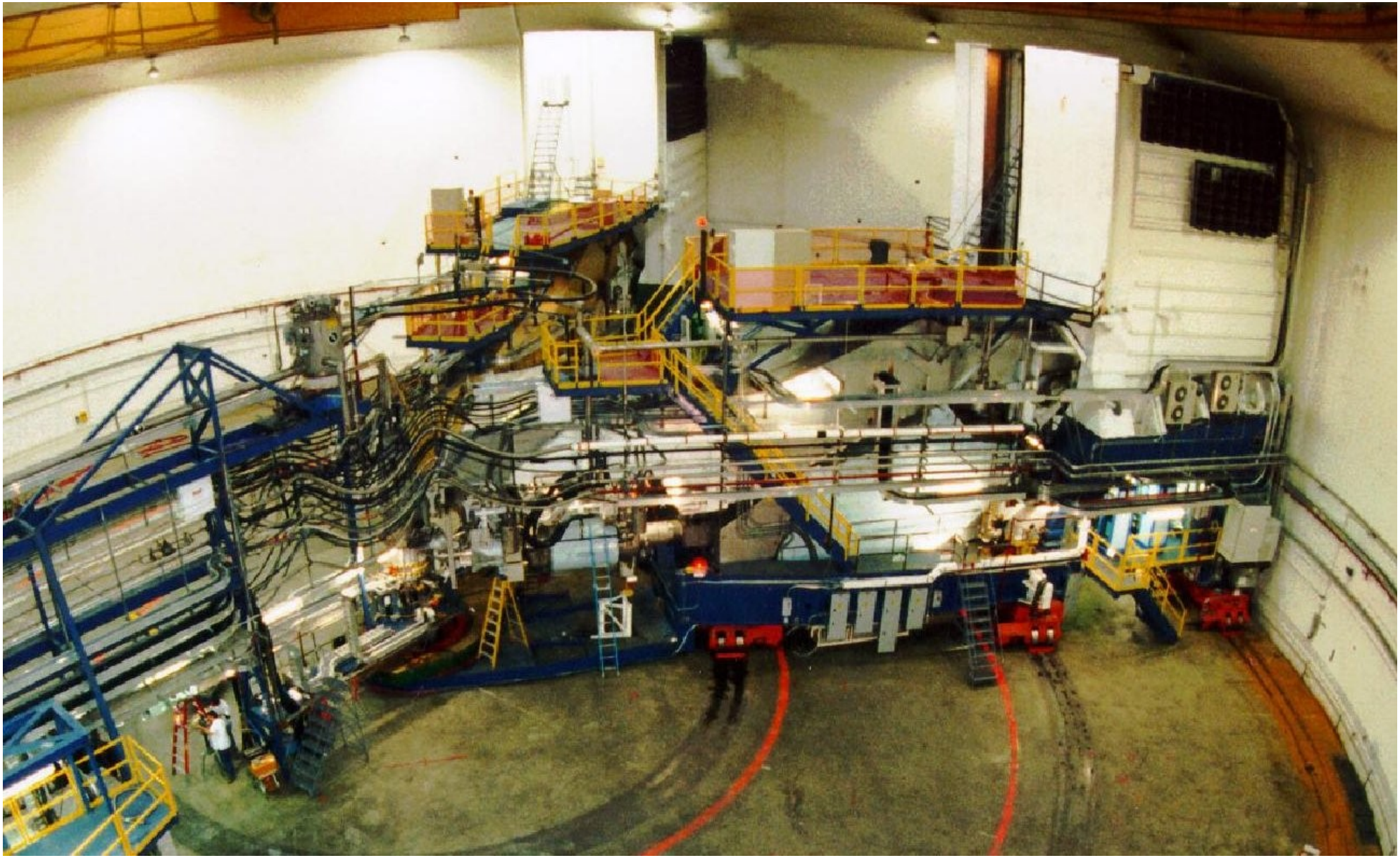
- BigBite fixed at single scattering angle (θ=45°)
  (data divided into 10 bins during analysis)

- Avoid resonance region as much as possible.

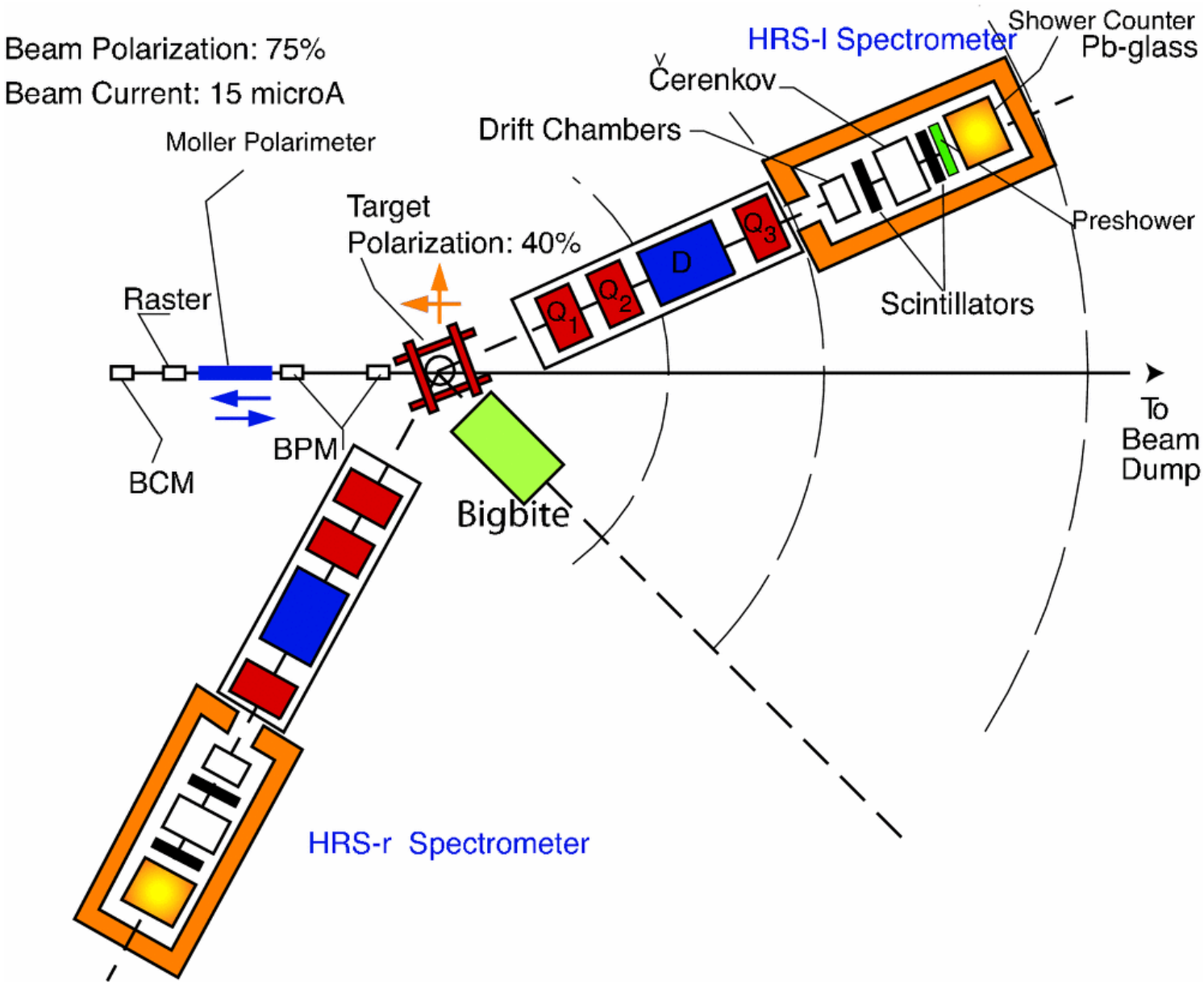


Jefferson Lab, Newport News, VA

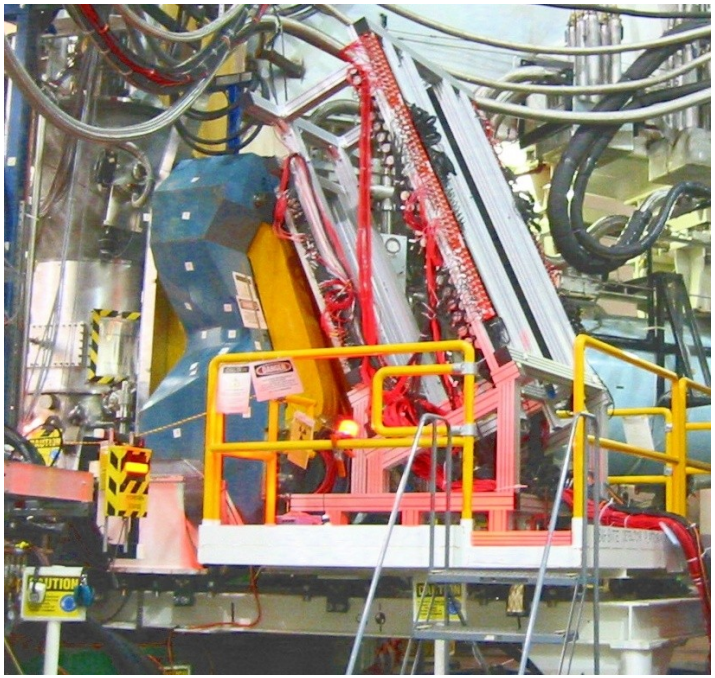
Jefferson Lab – Hall A

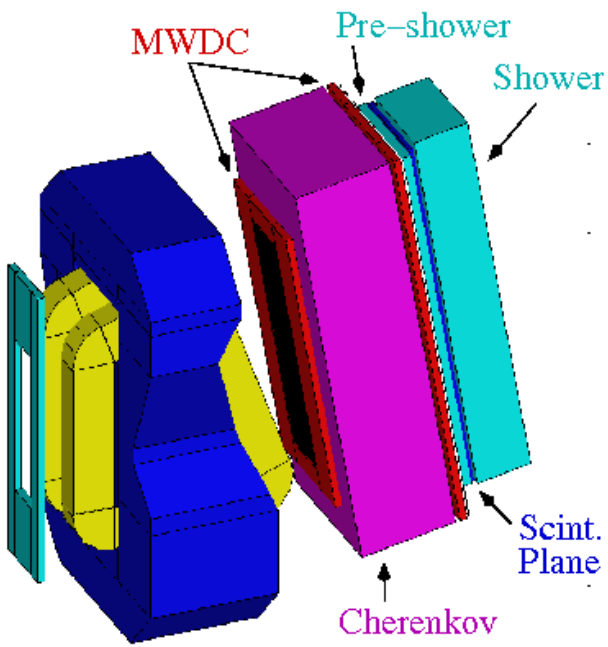


Floor configuration for this experiment



BigBite Configuration



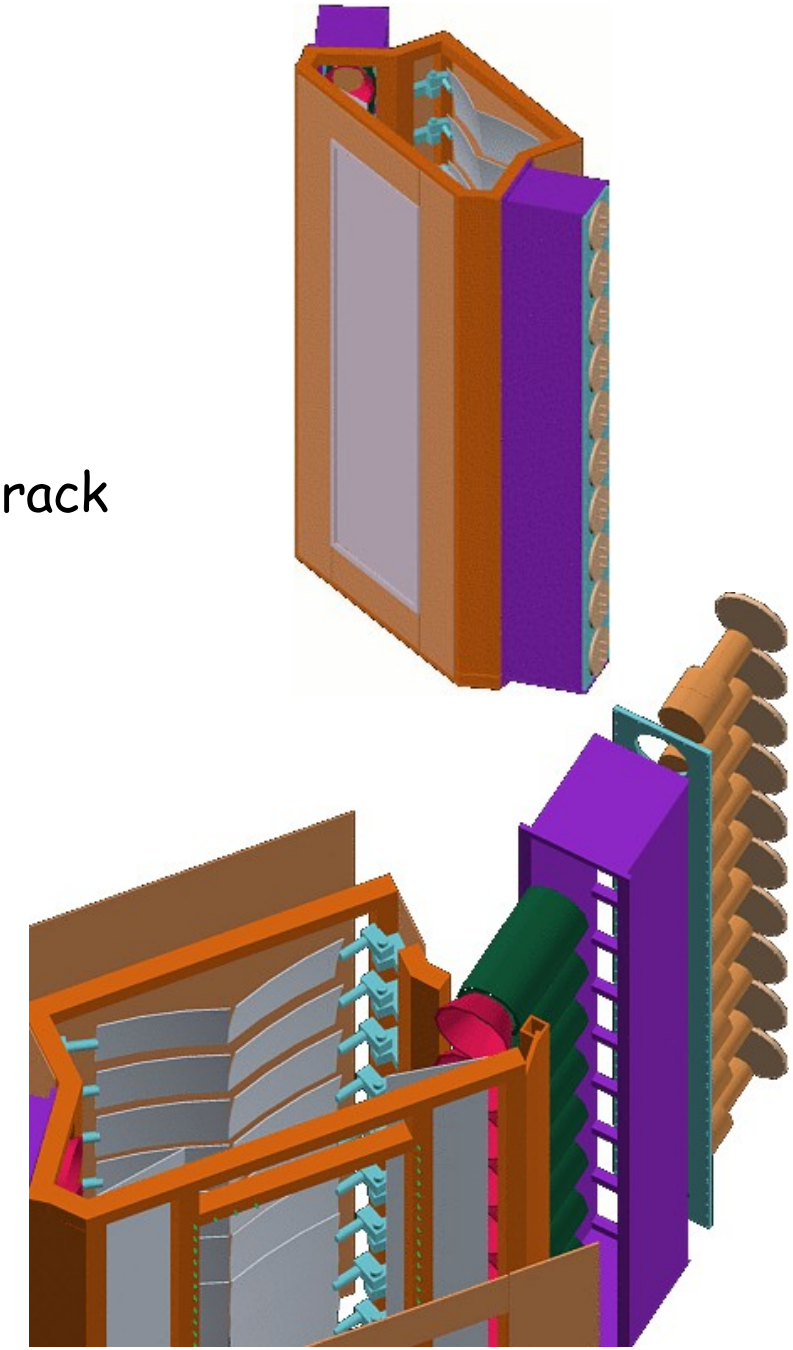


- non-focusing, large acceptance, open geometry
- $\Delta p/p$ = 1 – 1.5% (@ 1.2 T) $\sigma(W)$ = 50 MeV
- angular resolution 1.5 mr, extended target resolution 6 mm
- large solid angle: ~64 msr
- detector package
  - ➡ 3 MWDCs, segmented trigger, Pb-glass shower
  - ➡ Gas Cherenkov (new)

Cherenkov Design Parameters

- Dimensions: 200cm x 60cm x 60cm
  - ➡ sandwiched between wire chambers
- Radiator gas: C_4F_{10} (or Freon12)
  - ➡ n = 1.0015 (1.0011)
  - ➡ π threshold: 2.51 GeV/c (2.98 GeV/c)
  - ➡ ~20 (13) photo-electrons / 40 cm electron track
    - Quartz PMT (Photonis XP4518)
    - mirror reflectivity: ~90%, 10% loss at PMT-gas interface

- >99% efficient with 3-4 p.e. threshold
  - negl. pion contamination
    minimum π/e rejection ratio 1000:1 online



Background Rates

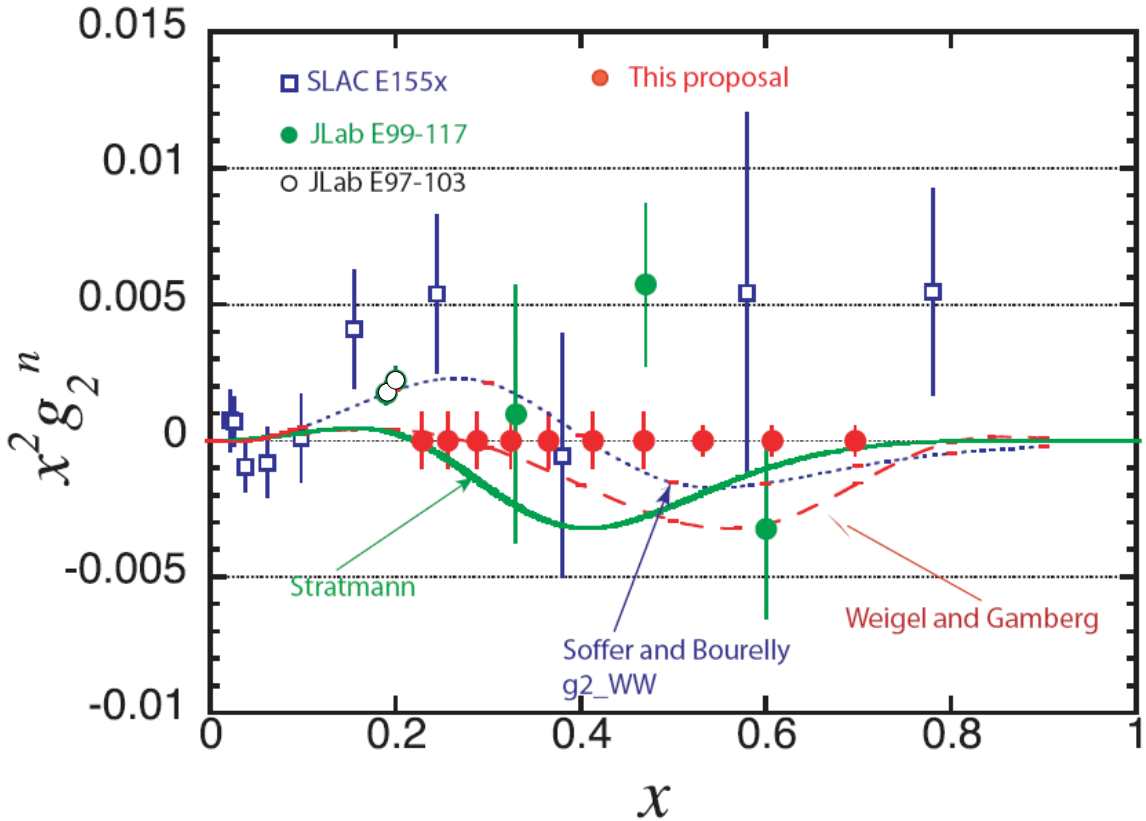
- MC simulation by Degtyarenko et al. (tested in Halls A and C)
- Online cuts include:
  - ➡ BB magnet sweeps particles with p < 200 MeV/c
  - ➡ GeN BB trigger: shower+pre-shower+scint
    - ↳ provide ~10:1 online hadron rejection (or better)
  - ➡ ~550—600 MeV threshold on shower
  - ➡ 4—5 p.e. threshold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

e-	2-5 kHz	π-	90 kHz
e+	<1 kHz	π+	90 kHz
		p	50 kHz
		n	50 kHz

Online triggers

Removed via online cuts

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

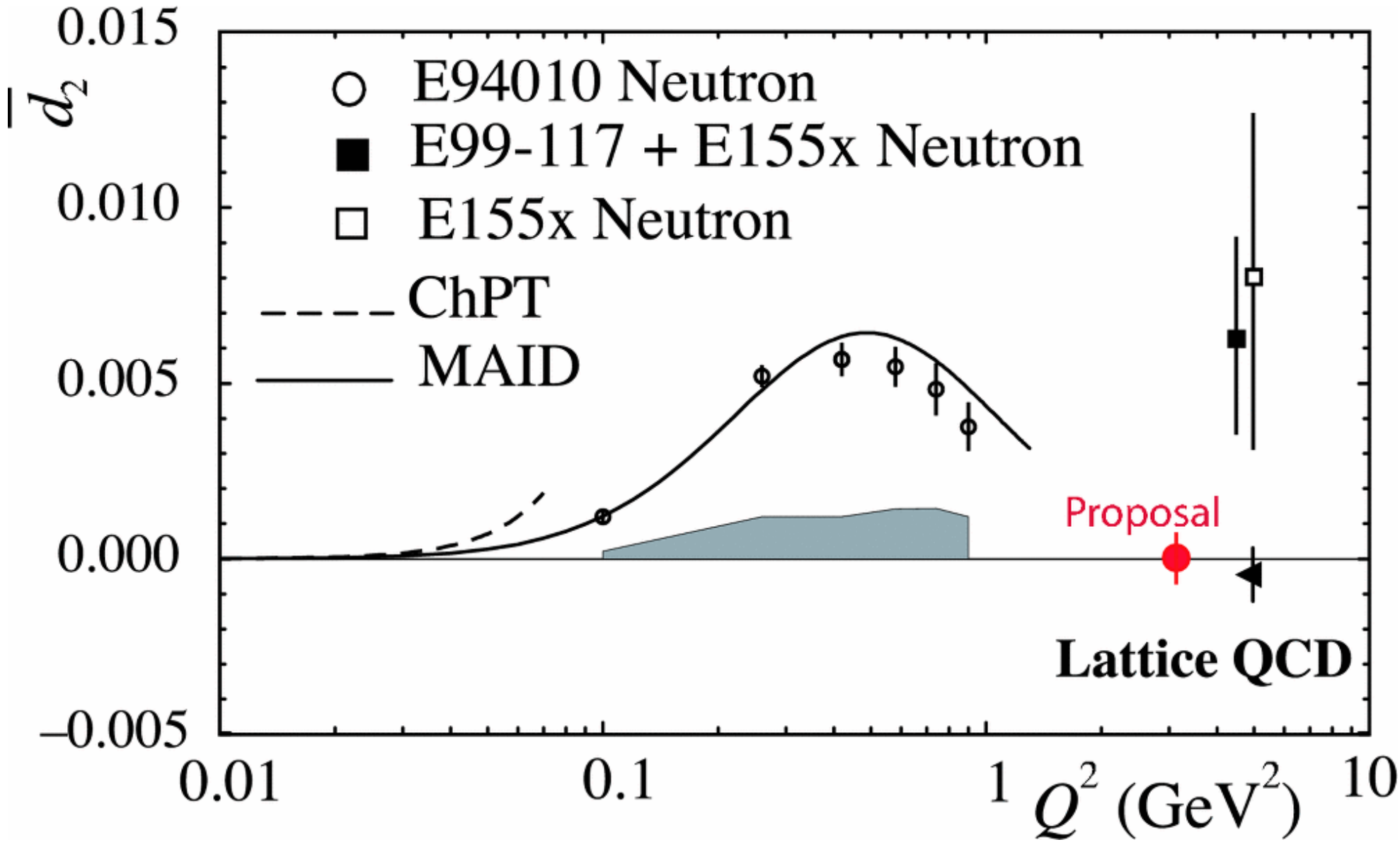


- g_2 for ^{3}He is extracted directly from L and T spin-dependent cross sections measurements within the same experiment.
- The nuclear corrections will be applied to the moments not to the structure functions.
- SLAC E155x g_2 data points at high x are evolved from Q^2 as large as 16 GeV^2 to 5 GeV^2

Systematic Error Contributions to d_2^n

Item description	Subitem description	Relative uncertainty
Target polarization		3 %
Beam polarization		3 %
Asymmetry (raw)		
	• Target spin direction (0.1°)	$< 5 \times 10^{-4}$
	• Beam charge asymmetry	< 50 ppm
Cross section (raw)		
	• PID efficiency	≈ 1 %
	• Background Rejection efficiency	≈ 1 %
	• Beam charge	< 1 %
	• Beam position	< 1 %
	• Acceptance cut	2-3 %
	• Target density	< 2%
	• Nitrogen dilution	< 2%
	• Dead time	<1%
	• Finite Acceptance cut	<1%
Radiative corrections		≤ 5 %
From ^{3}He to Neutron correction		5 %
Total systematic uncertainty		≤ 10 %
Estimate of contributions to d_2 from unmeasured regions	$\int_{0.003}^{0.23} \tilde{d}_2^n \, dx$	4.8×10^{-4}
	$\int_{0.70}^{0.999} \tilde{d}_2^n \, dx$	5.0×10^{-5}
Projected absolute statistical uncertainty on d_2		$\Delta d_2 \approx 5 \times 10^{-4}$
Projected absolute systematic uncertainty on d_2 (*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 $x^2 g_2$ 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
- **Tentatively scheduled for early 2008**

12 GeV Measurement

The proposal for Hall C and SHMS/HMS

- An Experiment in Hall C: (approved! Pac30, 2007)
  - A polarized electron beam of 11.0 GeV and polarized ^{3}He target
  - Measure $\Delta\sigma_\perp = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$, $\Delta\sigma_\parallel = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}$ for $^3\vec{\mathrm{He}}(\vec{e},e')$ reaction using both the SHMS and HMS running in parallel for 3 kinematic settings each
    - SHMS: (p_0= 8.0 GeV/c, θ = 11.0°), (p_0= 7.0 GeV/c, θ = 13.3°), (p_0= 6.3 GeV/c, θ = 15.5°)
    - HMS: (p_0= 4.2 GeV/c, θ = 13.5°), (p_0= 5.0 GeV/c, θ = 16.4°), (p_0= 3.4 GeV/c, θ = 20.0°)
- Determine d_2^n and g_2^n using the relations:

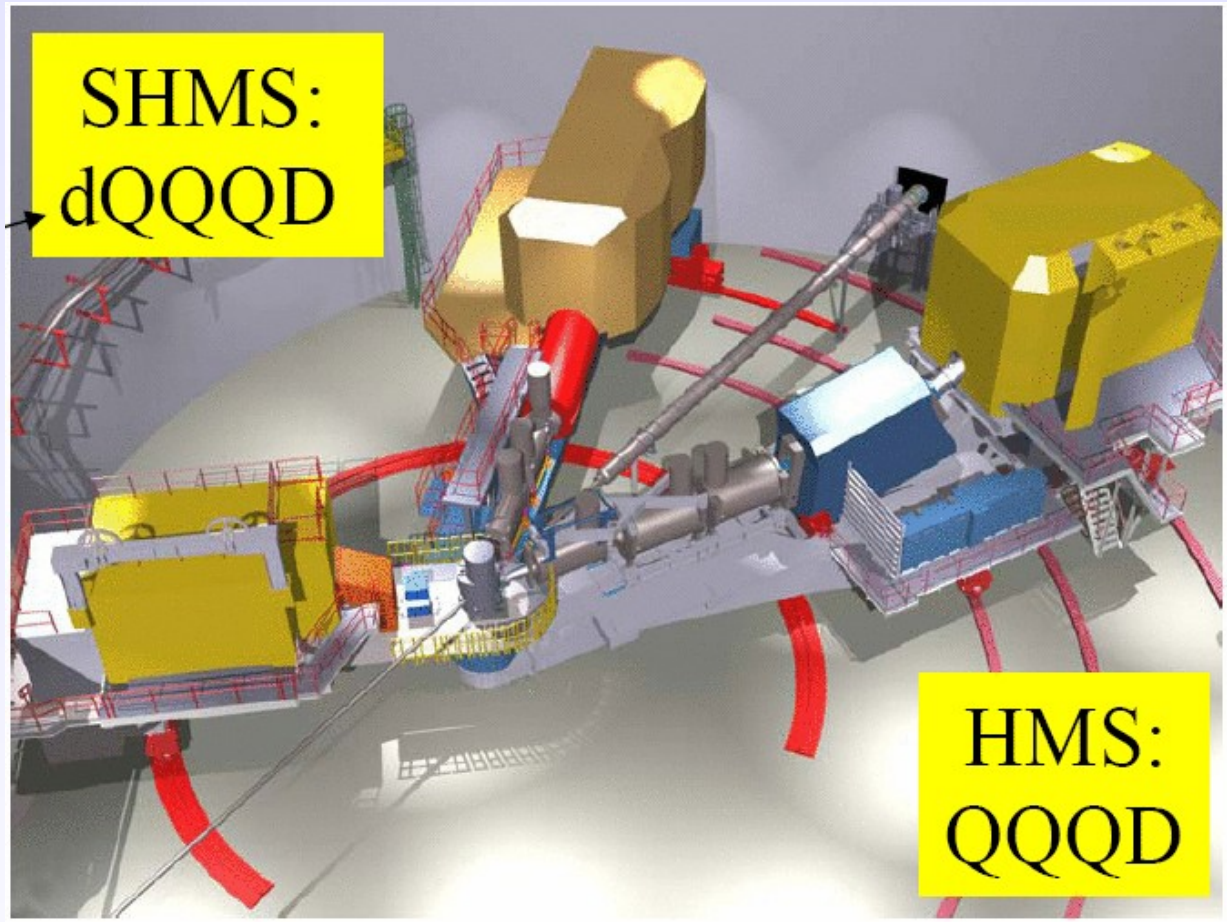
$$\tilde{d}_2 = x^2(2g_1+3g_2) = \frac{MQ^2\nu}{8\alpha_e^2}\frac{E}{E'}\frac{x^2(4-3y)}{(E+E')}\left[\Delta\sigma_\parallel + \left(\frac{4-y}{(1-y)(4-3y)\sin\theta_e} - \cot\theta_e\right)\Delta\sigma_\perp\right]$$

$$g_2 = \frac{MQ^2\nu^2}{4\alpha_e^2}\frac{1}{2E'(E+E')}\left[-\Delta\sigma_\parallel + \frac{E+E'\cos\theta_e}{E'\sin\theta_e}\Delta\sigma_\perp\right]$$

where $\Delta\sigma_\parallel = \sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}$, $\Delta\sigma_\perp = \sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}$ and $y = \nu/E$.

I_{beam} = 10 μA
P_{beam} = 0.8
P_{targ} = 0.5

Floor layout for Hall C

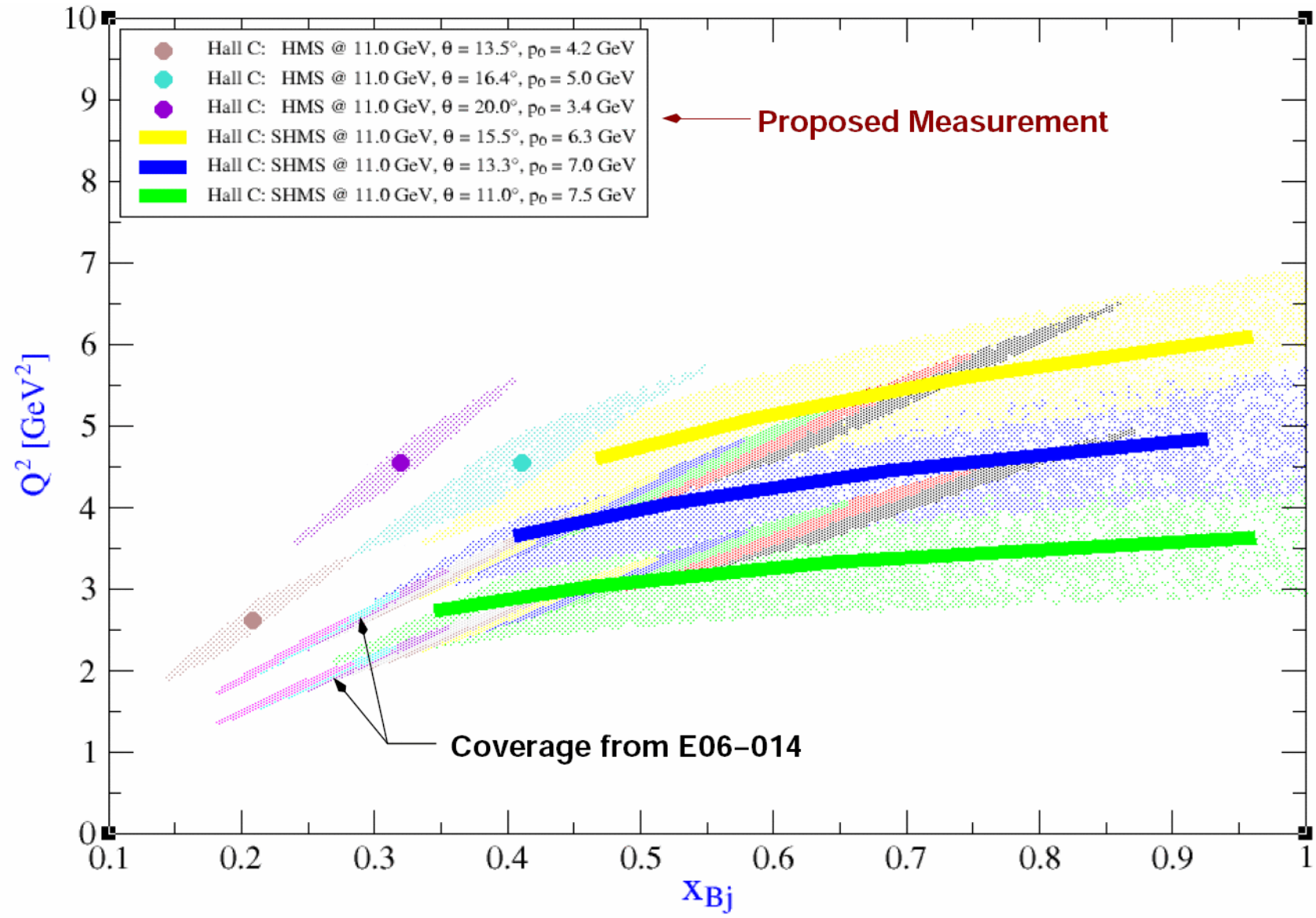


Hall C

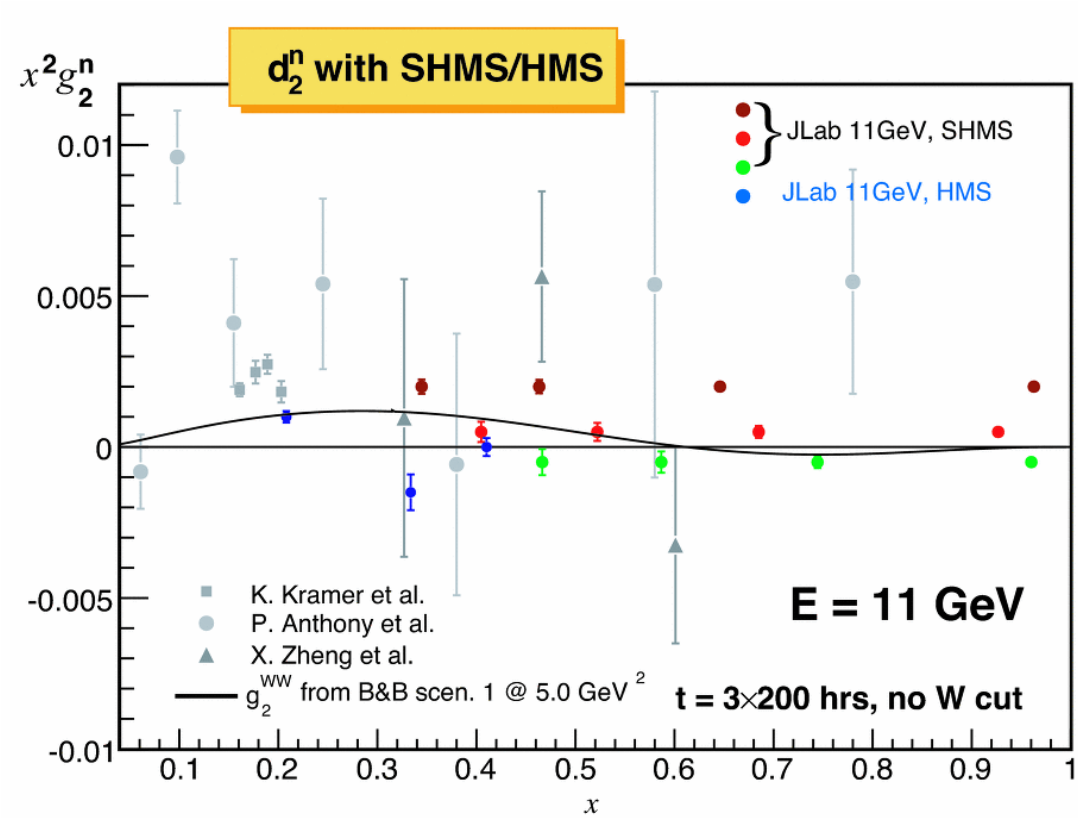
- One beam energy
  - ➡ 11 GeV
- Each arm measures a total cross section independent of the other arm.
- Experiment split into three pairs of 200 hour runs with spectrometer motion in between.

- SHMS collects data at Θ = 11°, 13.3° and 15.5° for 200 hrs each
  - ➡ data from each setting divided into 4 bins
- HMS collects data at Θ = 13.5°, 16.4° and 20.0° for 200 hrs each

Kinematics for Hall C (cont…)



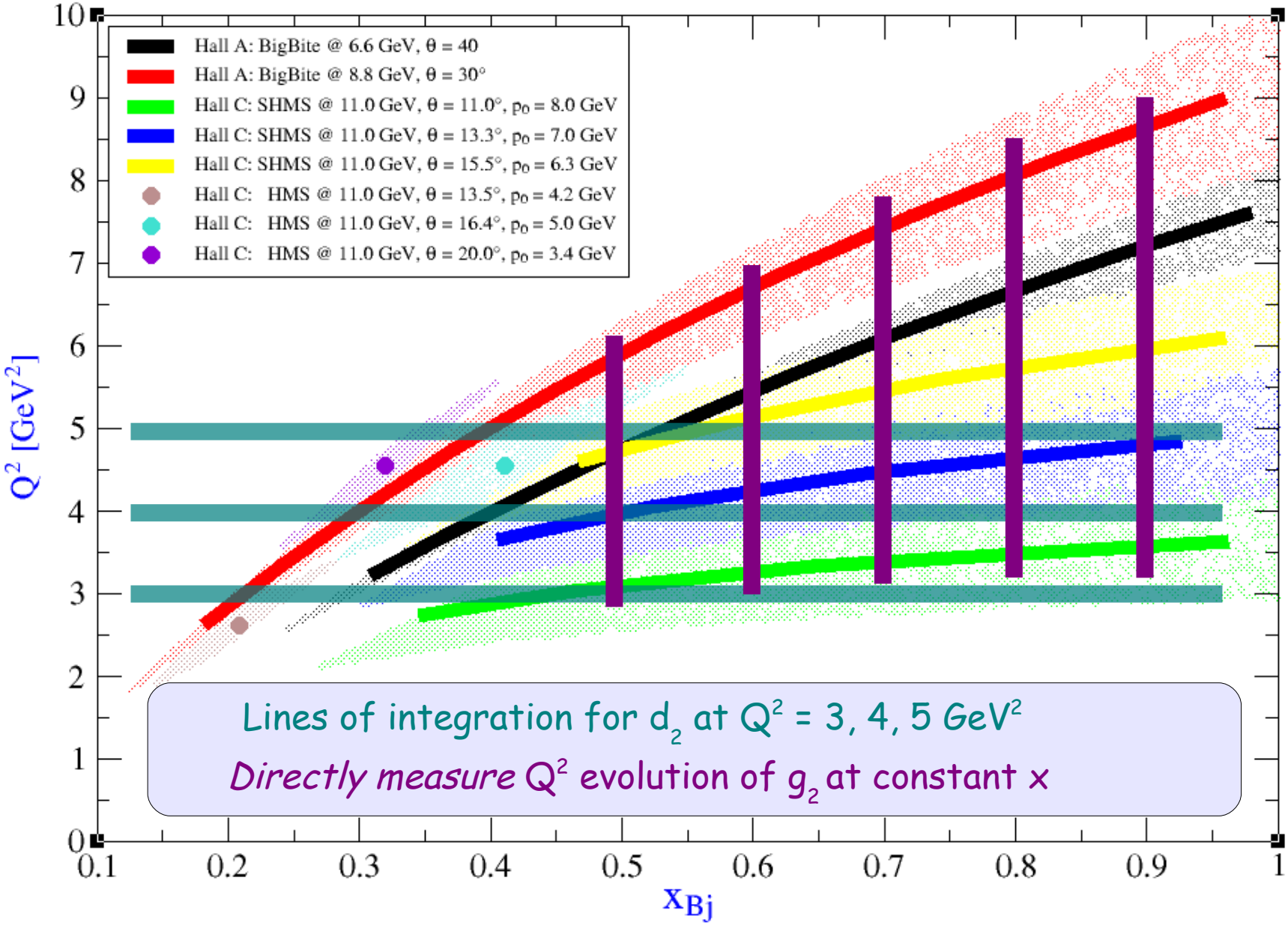
Projected $x^2 g_2(x,Q^2)$ results from Hall C



Projected points are vertically offset from zero along lines that reflect different (roughly) constant Q^2 values from 2.5—6 GeV^2.

- g_2 for ^{3}He is extracted directly from L and T spin-dependent cross sections measured within the same experiment.
- Strength of SHMS/HMS:
  nearly constant Q^2 (but less coverage for $x < 0.3$)

d_2 and g_2 evolution (both Halls)



Lines of integration for d_2 at Q^2 = 3, 4, 5 GeV^2

Directly measure Q^2 evolution of g_2 at constant x

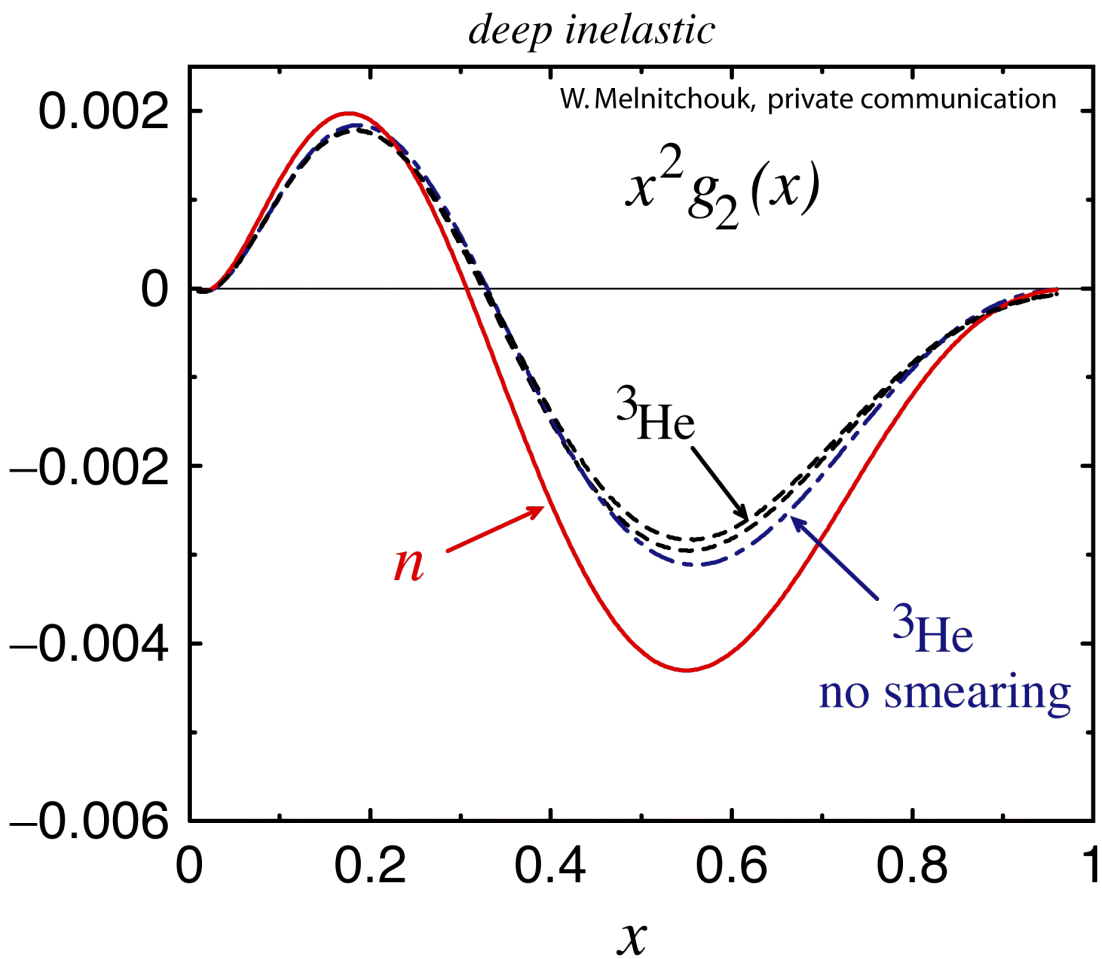
Extra Slides

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)

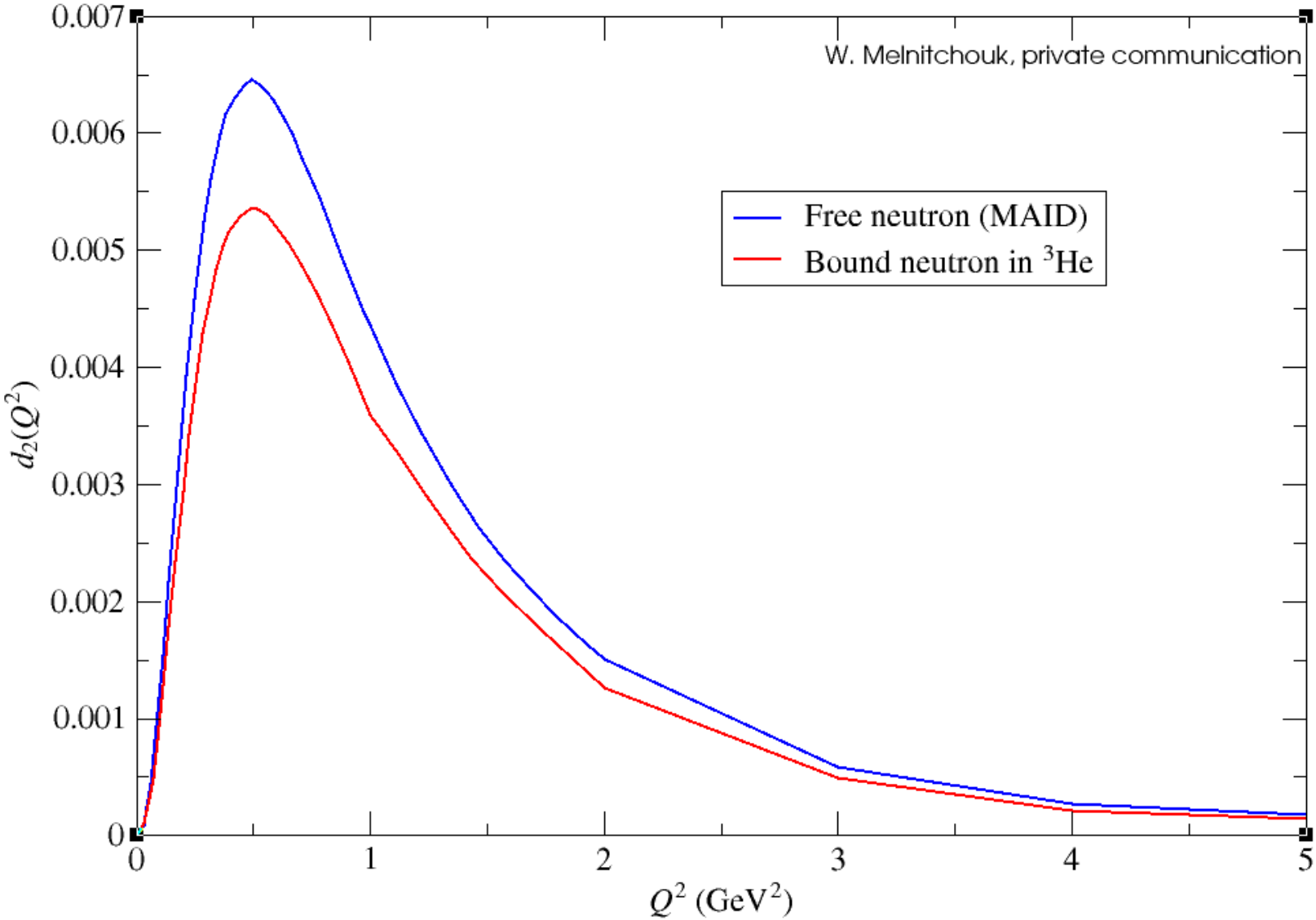
$$S(\vec{p},E) \;=\; \frac{1}{2}\left(f_0 + f_1\vec{\sigma}_N\cdot\vec{\sigma}_A + f_2\left[\vec{\sigma}_N\cdot\hat{p}\;\vec{\sigma}_A\cdot\hat{p}\;-\frac{1}{3}\vec{\sigma}_N\cdot\vec{\sigma}_A\right]\right)$$

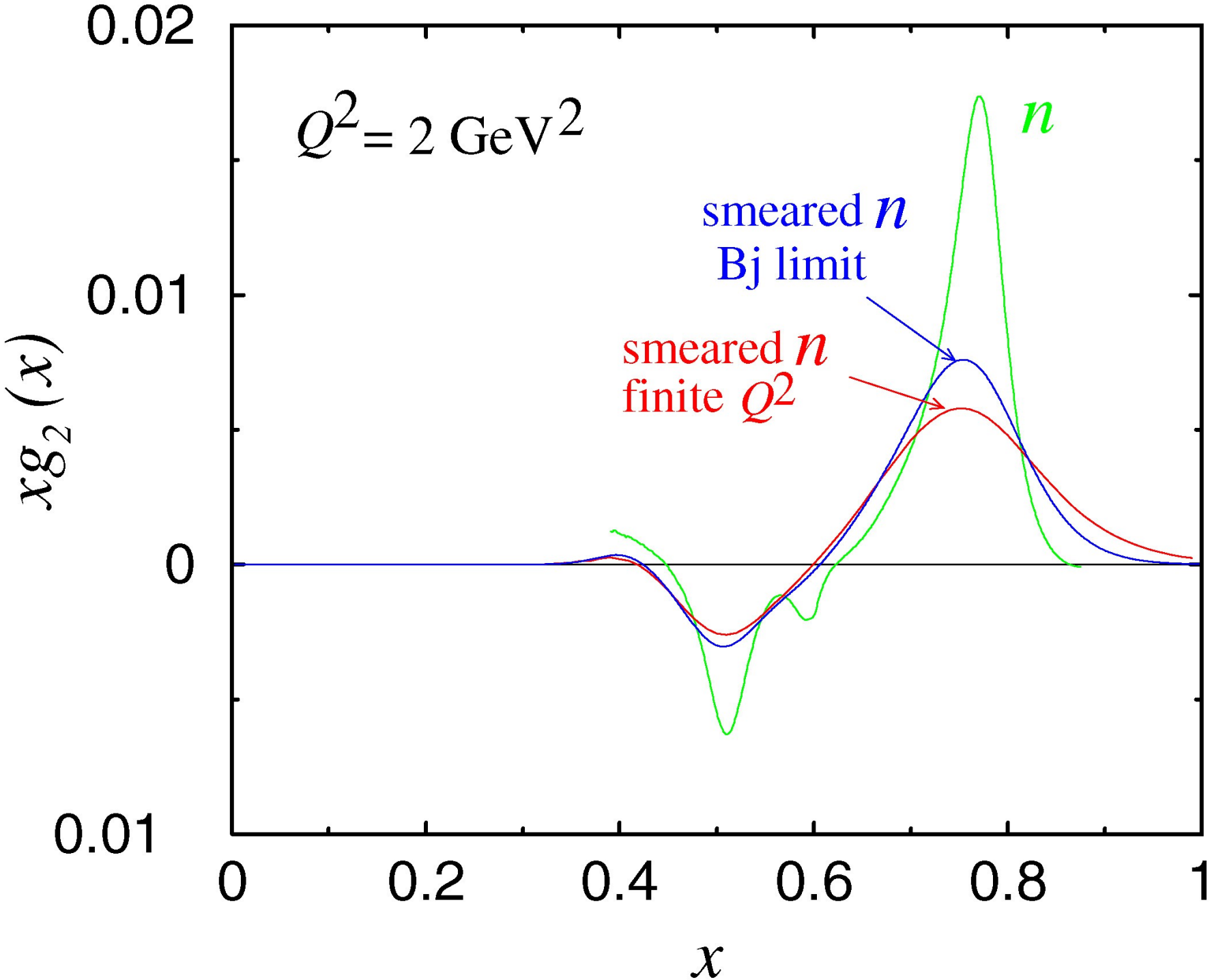
$$\begin{aligned}
& x g_1^{^3\mathrm{He}}(x,Q^2) + (1-\gamma^2) x g_2^{^3\mathrm{He}}(x,Q^2) \\
= & \sum_{N=p,n}\int d^3p\; dE\; (1-\frac{\epsilon}{M})\left\{\left[\left(1+\frac{\gamma p_z}{M}+\frac{p_z^2}{M^2}\right) f_1 + \left(-\frac{1}{3}+\hat{p}_z^2+\frac{2\gamma p_z}{3M}+\frac{2p_z^2}{3M^2}\right)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

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

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
0.02
0.01
0
0.01
0
0.2
0.4
0.6
0.8
1
x
$xg_2(x)$

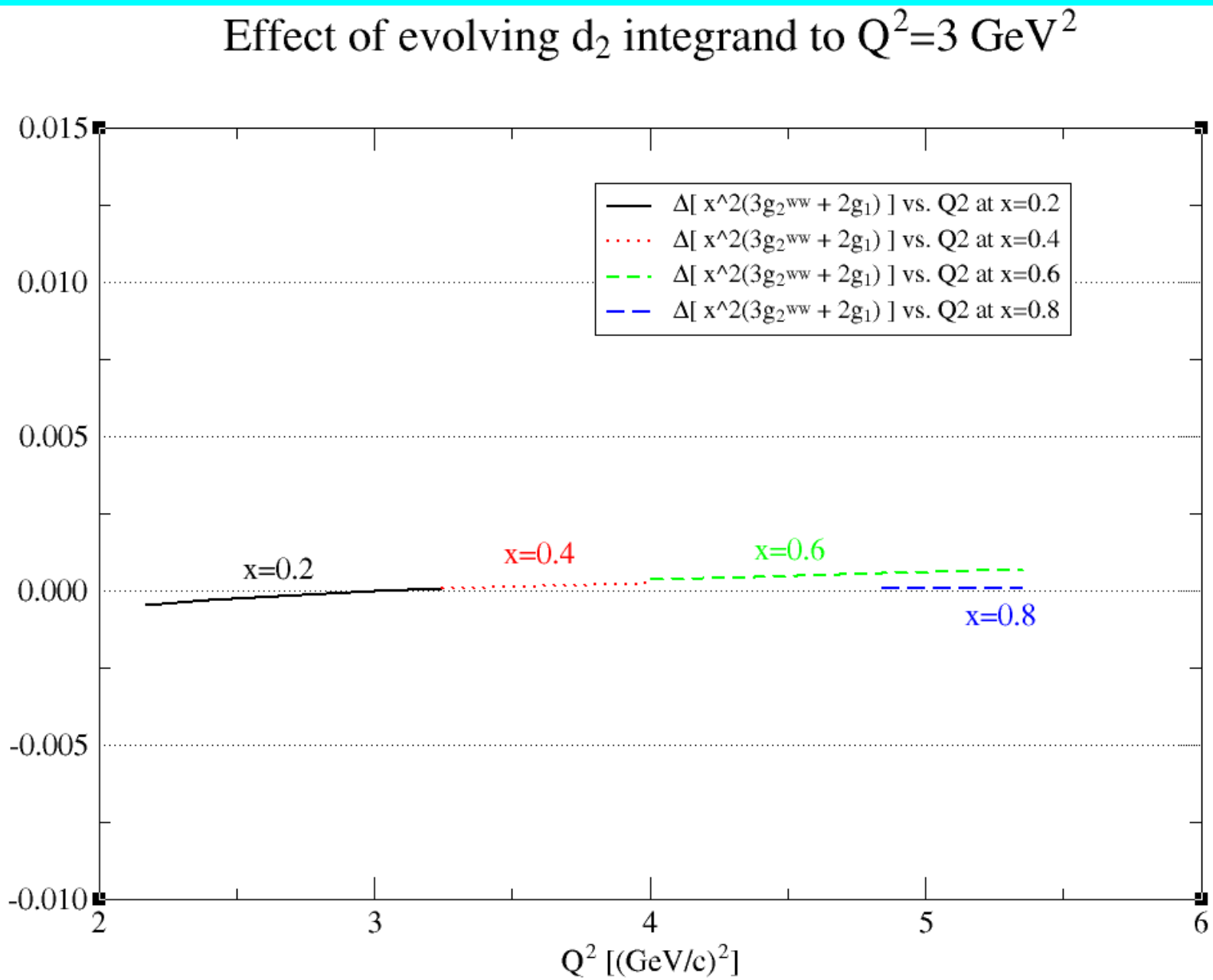
How $g_2(x,Q^2)$ is usually obtained

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

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}