E12-11-009 C-GEn

The Neutron Electric Form Factor at Q^2 up to 7 $(GeV/c)^2$ from the Reaction $^2H(e,e'n)^1H$ via Recoil Polarimetry

Spokespersons
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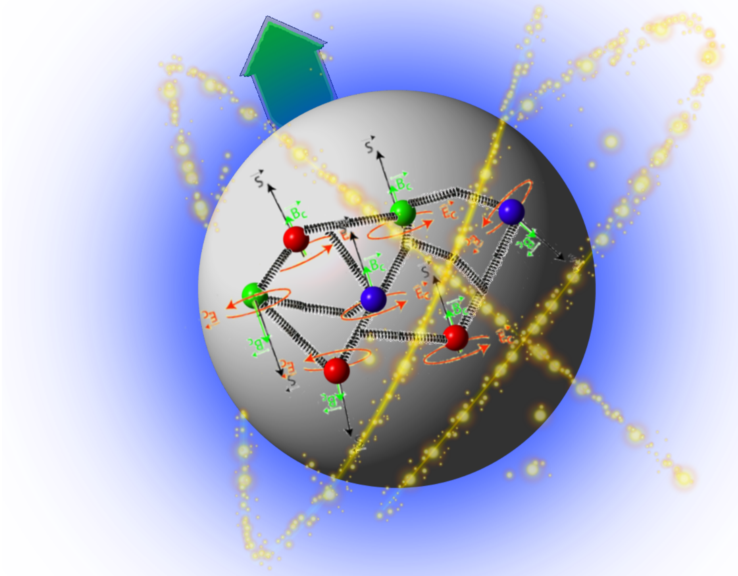
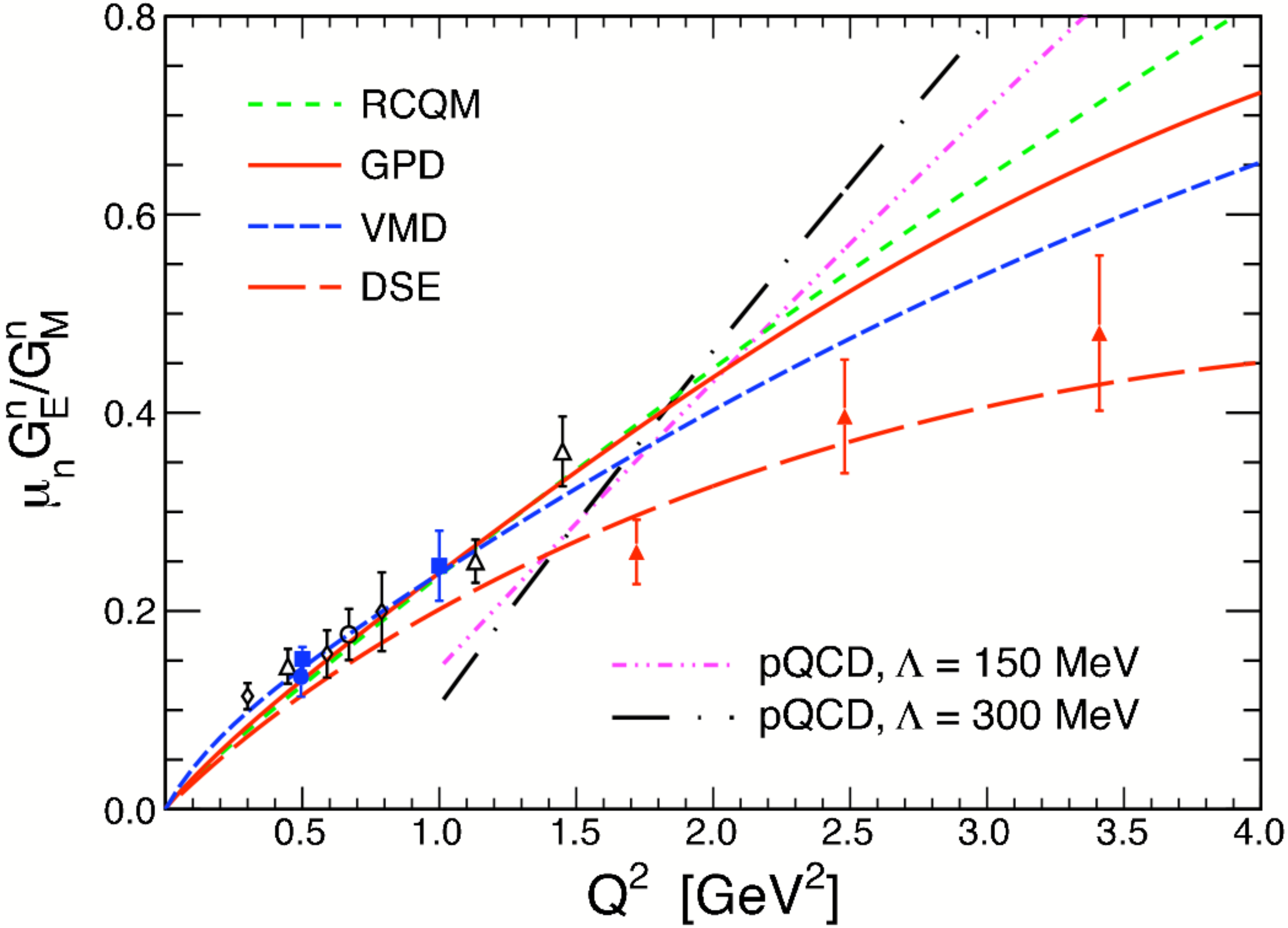
Special thanks: Will Tireman (N. Michigan Univ.)



GEn: What can we learn?

- Measurement of neutron form factors lags that of the proton
  - → no free neutron target, lower cross sections
- Measuring GEn at high Q^2 provides insight into:
  - Form Factors in domain with small pion cloud contributions
    - Many available calculations do not include pion cloud contributions
  - Flavor decomposition of *u, d* quark contributions (negl strange quarks) [Cates (2011); Qattan & Arrington et al. (2012)]
  - Sensitive to *u, d* quark distributions in nuclear core
  - Model-independent extraction of neutron infinite-momentum frame transverse charge density [Miller (2007); Venkat et al. (2010)]
  - Test of QCD-based calculations
    - Lattice QCD: isovector form factor (GEp – GEn)
      - IVFF cancels disconnected diagrams that are hard to compute
    - Dyson Schwinger Equation calculations

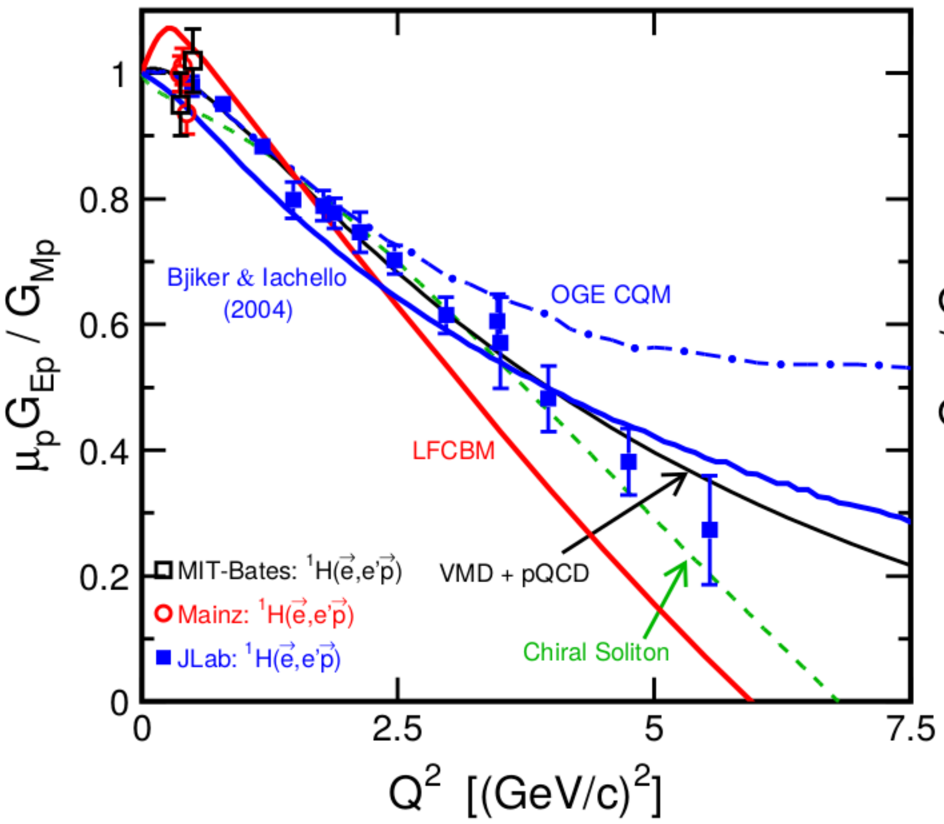
Predictions for GEn



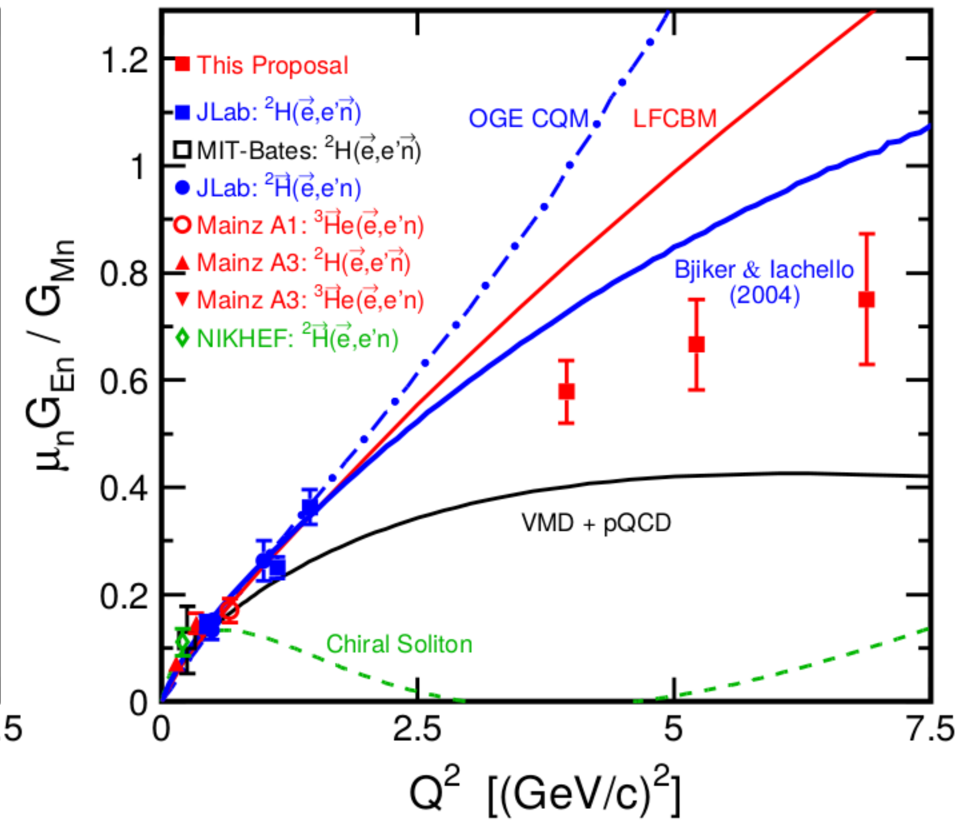
Plot from Riordan et al., PRL 105 (2010) 262302

Predictions for GEn

Proton



Neutron



Predictions for GEn

Proton **Neutron**

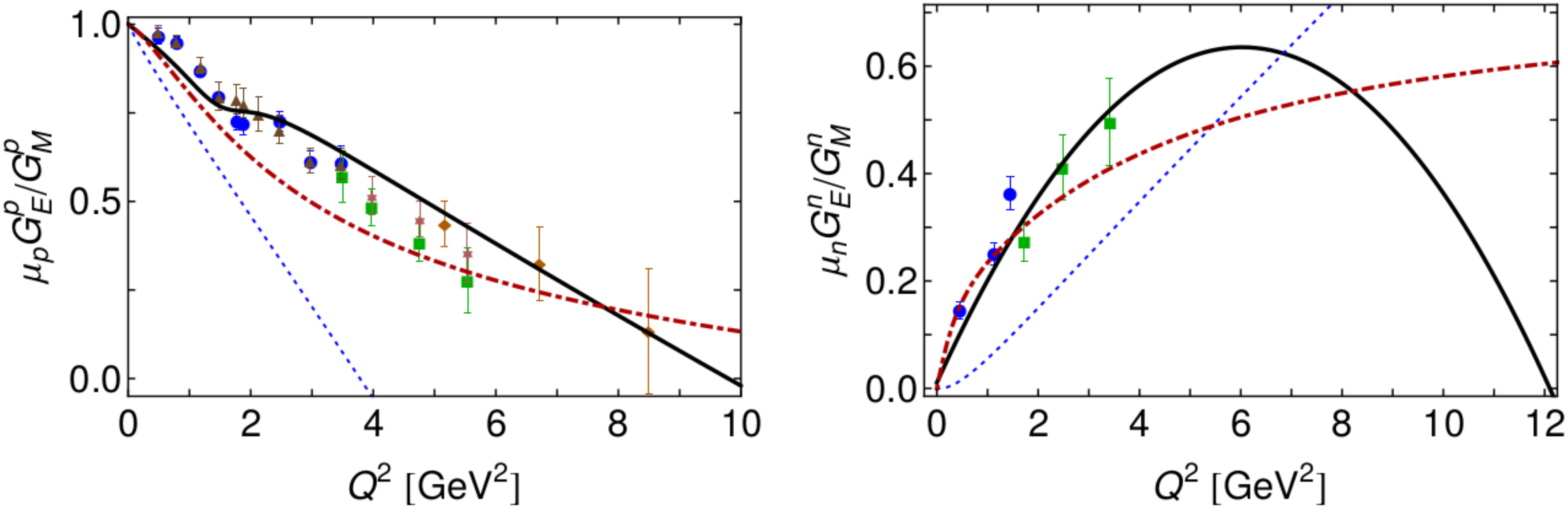
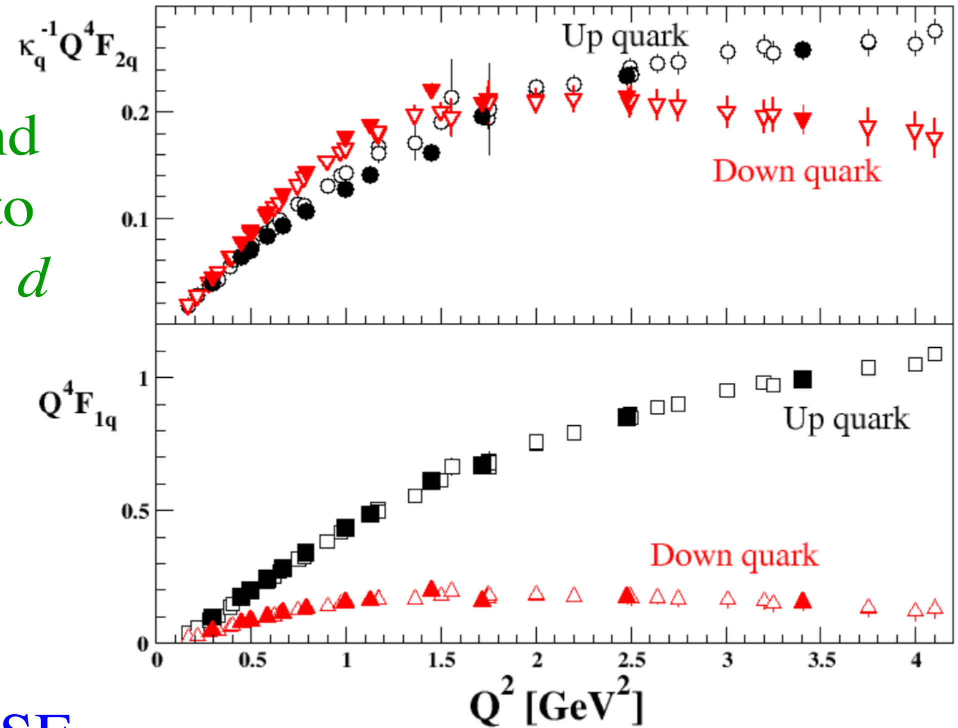


Fig. 3 *Left panel*: normalised ratio of proton electric and magnetic form factors. Curves: *solid, black* – result obtained herein, using our QCD-kindred framework; *Dashed, blue* – CI result [18]; and *dot-dashed, red* – ratio inferred from 2004 parametrisation of experimental data [65]. Data: blue circles [68]; green squares [69]; brown triangles [70]; purple asterisk [71]; and orange diamonds [72]. *Right panel*: normalised ratio of neutron electric and magnetic form factors. Curves: same as in left panel. Data: blue circles [73]; and green squares [74].

Segovia, Cloet, Roberts, Schmidt: arXiv:1408.2919 (2014)

Flavor Decomposition

- Flavor decomposition
  - assume charge symmetry and combine FF data from *n, p* to extract information about *u, d* quark contributions
  - Precision data required to constrain input parmetrizations of FFs
- Reduction of *d* vs *u* related to diquark correlations in *q(qq)* DSE approach

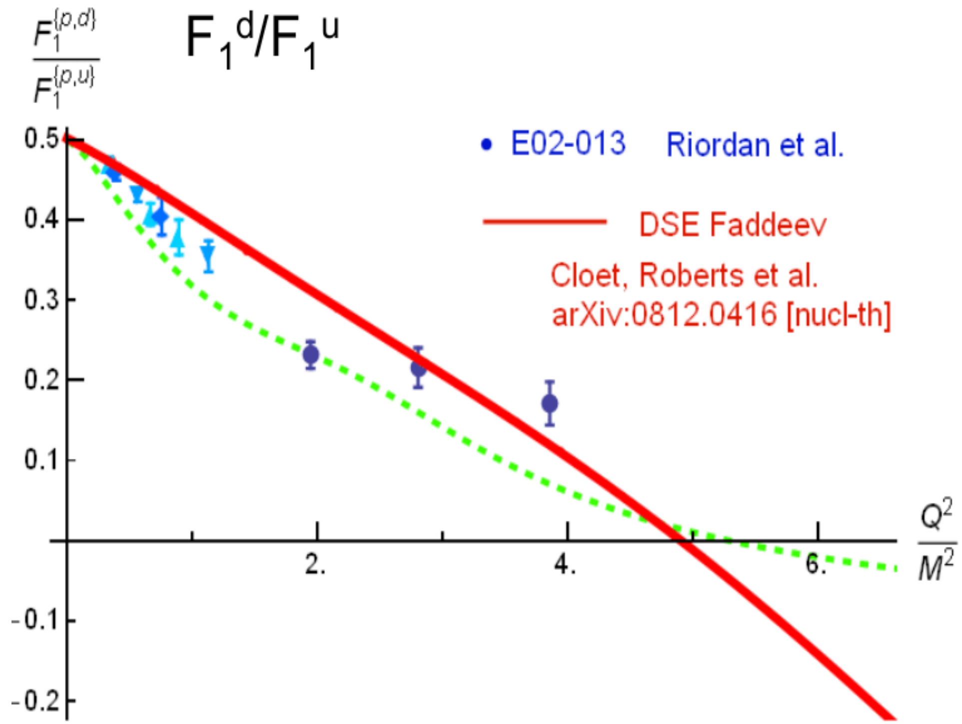


$$F_{(1,2)u} = 2F_{(1,2)p} + F_{(1,2)n}$$
$$F_{(1,2)d} = F_{(1,2)p} + 2F_{(1,2)n}$$

G. Cates et al., PRL106 (2011) 252003
I.A. Qattan & J. Arrington, PRC86 (2012) 065210

Flavor Decomposition and Scaling

- Separate *u*, *d* in comprehensive analysis of nucleon form factors
  - Study non point-like scalar, axial-vector diquark correlations
- Singly-represented *d*-quark is most likely to be struck in association with 1^+ diquark & these FF contributions are soft
- *u*-quark is predominantly linked with 0^+ diquark contributions

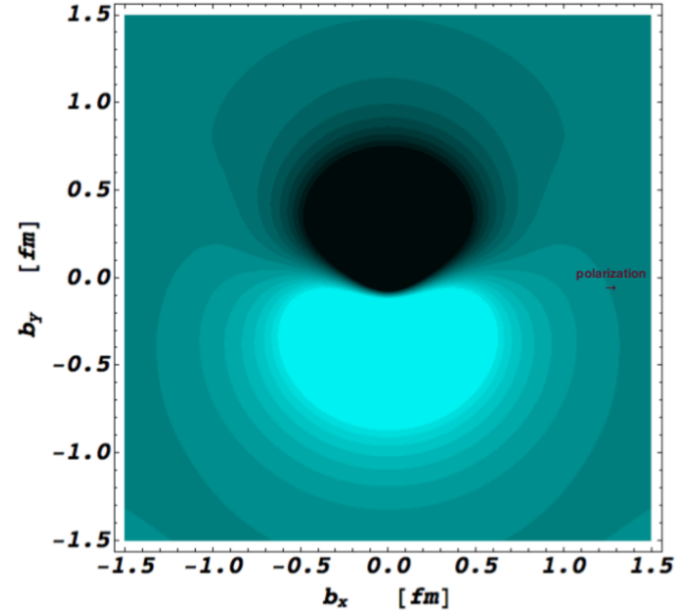


- Follows that
  - *d*-quark Dirac FF is softer than that of *u*-quark
  - F_1^d/F_1^u passes through zero
  - Location of zero depends on relative probability of $1^+/0^+$ diquarks in proton

Segovia, Cloet, Roberts, Schmidt
arXiv:1408.2919 [nucl-th]

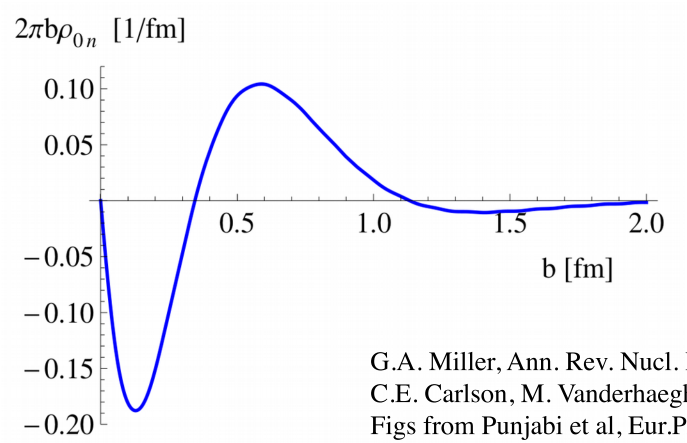
Transverse Charge Density

- Transverse charge density of Neutron
  - positive charge density in 'middle' sandwiched by negative densities

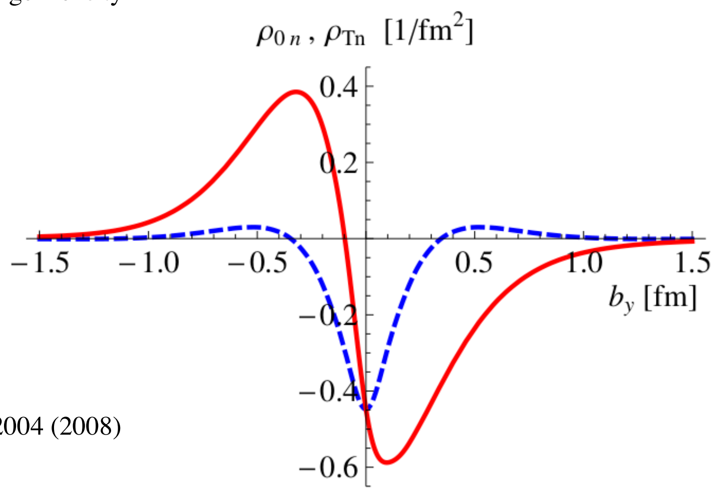


$$\rho(b) = \int_0^\infty \frac{dQ\,Q}{2\pi} J_0(Qb) \frac{G_E(Q^2) + \tau G_M(Q^2)}{1+\tau}$$

Unpolarized Charge Density

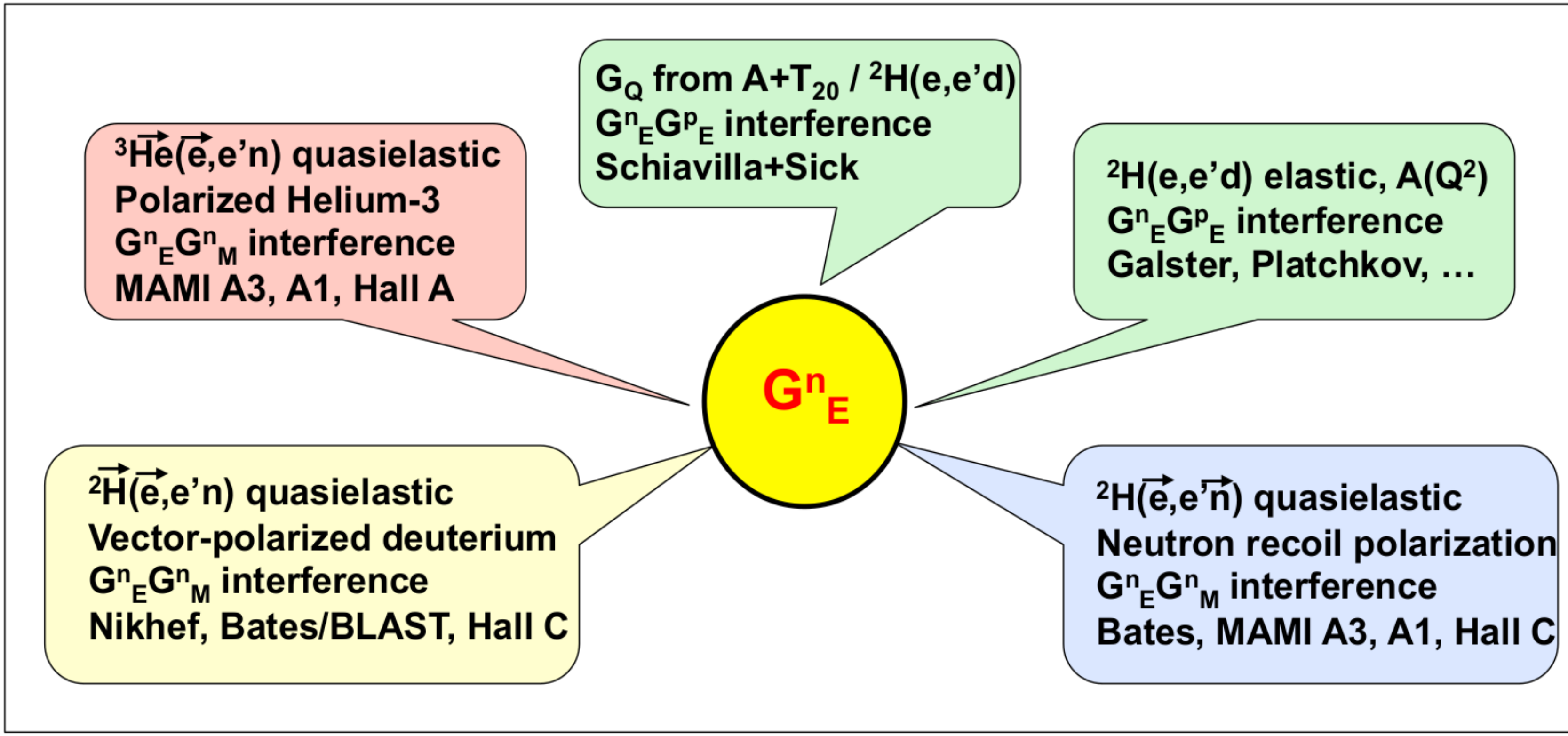


Polarized Charge Density



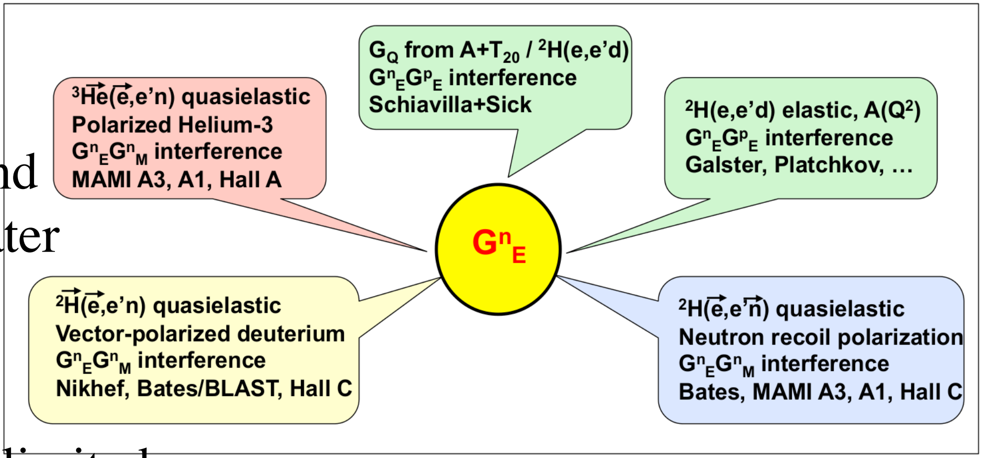
G.A. Miller, Ann. Rev. Nucl. Part. Sci. 60, 1 (2010)
C.E. Carlson, M. Vanderhaeghen, Phys. Rev. Lett. 100, 032004 (2008)
Figs from Punjabi et al, Eur.Phys.J. A51 (2015) 79

Neutron Electric Form Factor: GEn



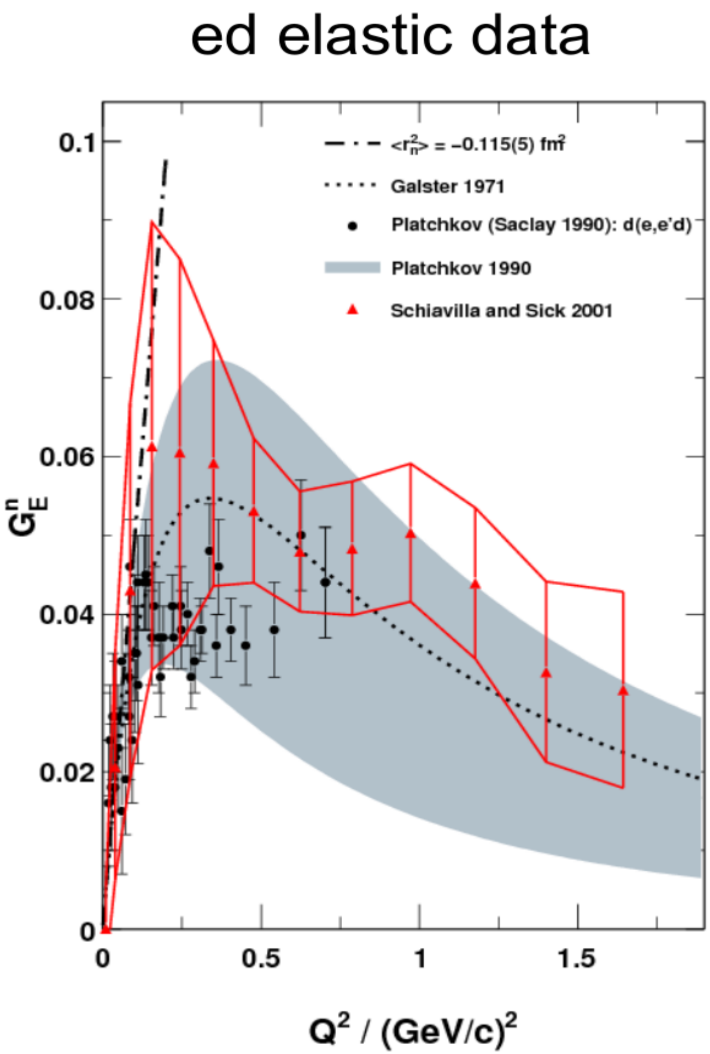
Neutron Electric Form Factor: GEn

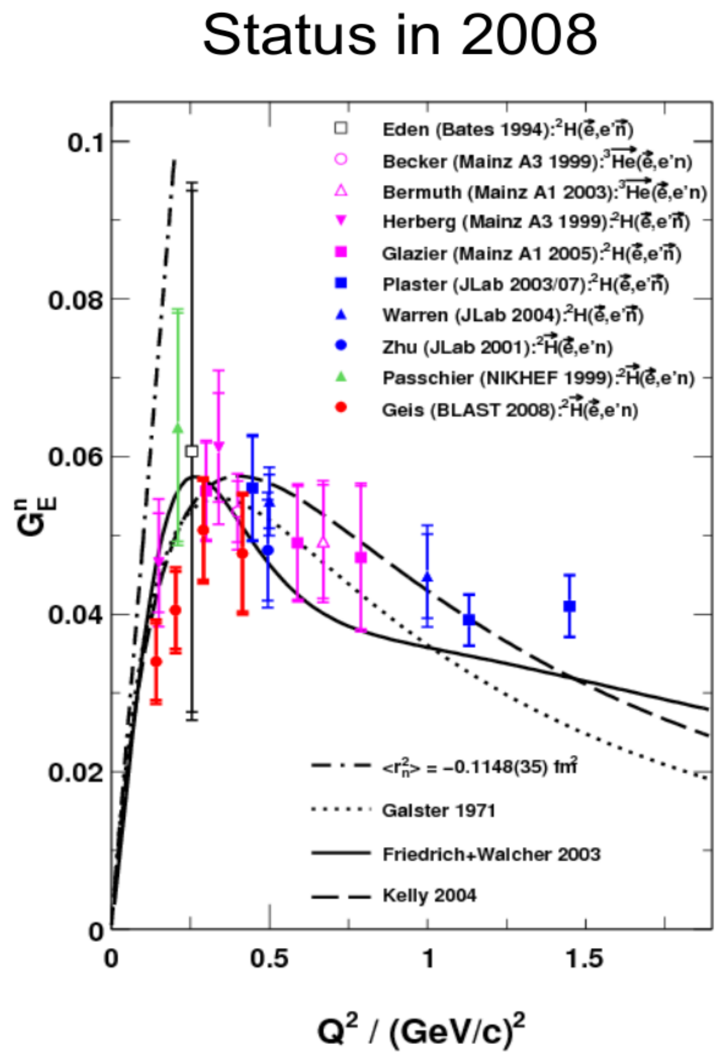
- Challenges moving to high Q^2
  - No free neutron target
    - rely on Elastic or QE scattering and extract the neutron contribution later
  - GEn is small
    - L-T separation is not practical
    - Polarized ^{2}H target → luminosity limited
  - Minimize effect of nuclear corrections (FSI, MEC, …)



- Solution: *High Luminosity Double Polarization Methods*
    - Polarized ^{3}He target → high FOM, high Q^2 reach
      - somewhat more complicated systematics, nuclear corrections
    - Measure polarization transfer with an unpolarized ^{2}H target
      - good systematic controls, "middle range" Q^2 reach

World Data on GEn

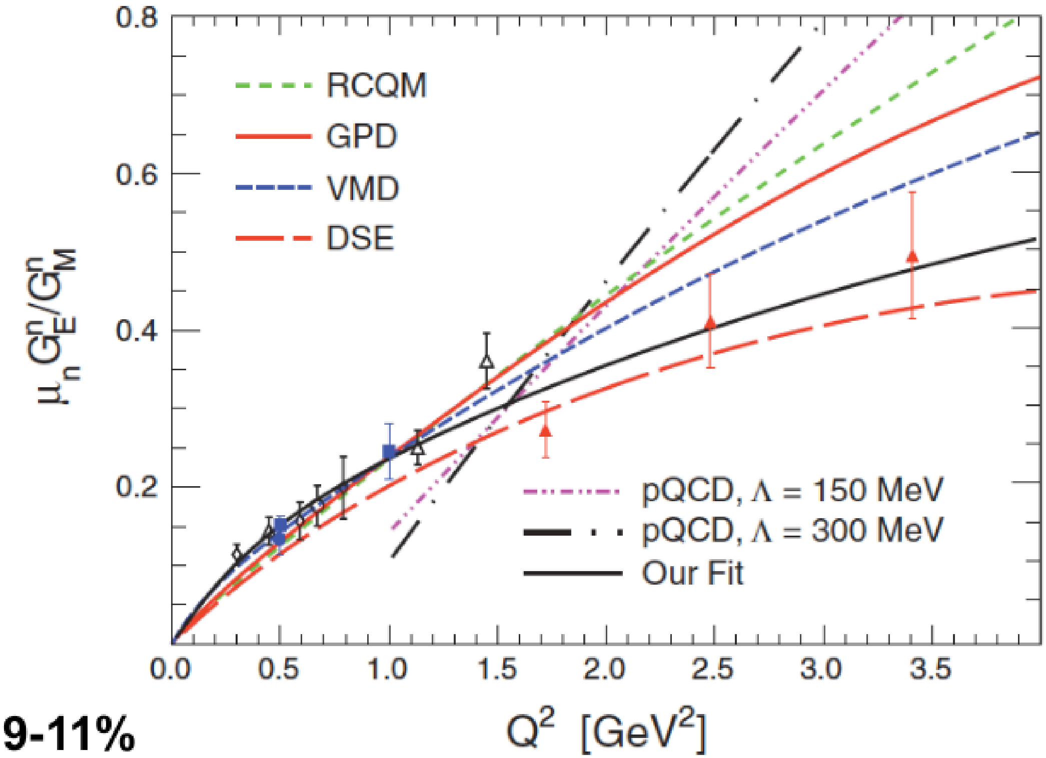




Measuring GEn to Higher Q^2

Hall A / E02-013, S. Riordan et al., PRL105 (2010) 262302

Polarized He-3, Q^2=1.2, 1.7, 2.5, 3.5 (GeV/c)^2



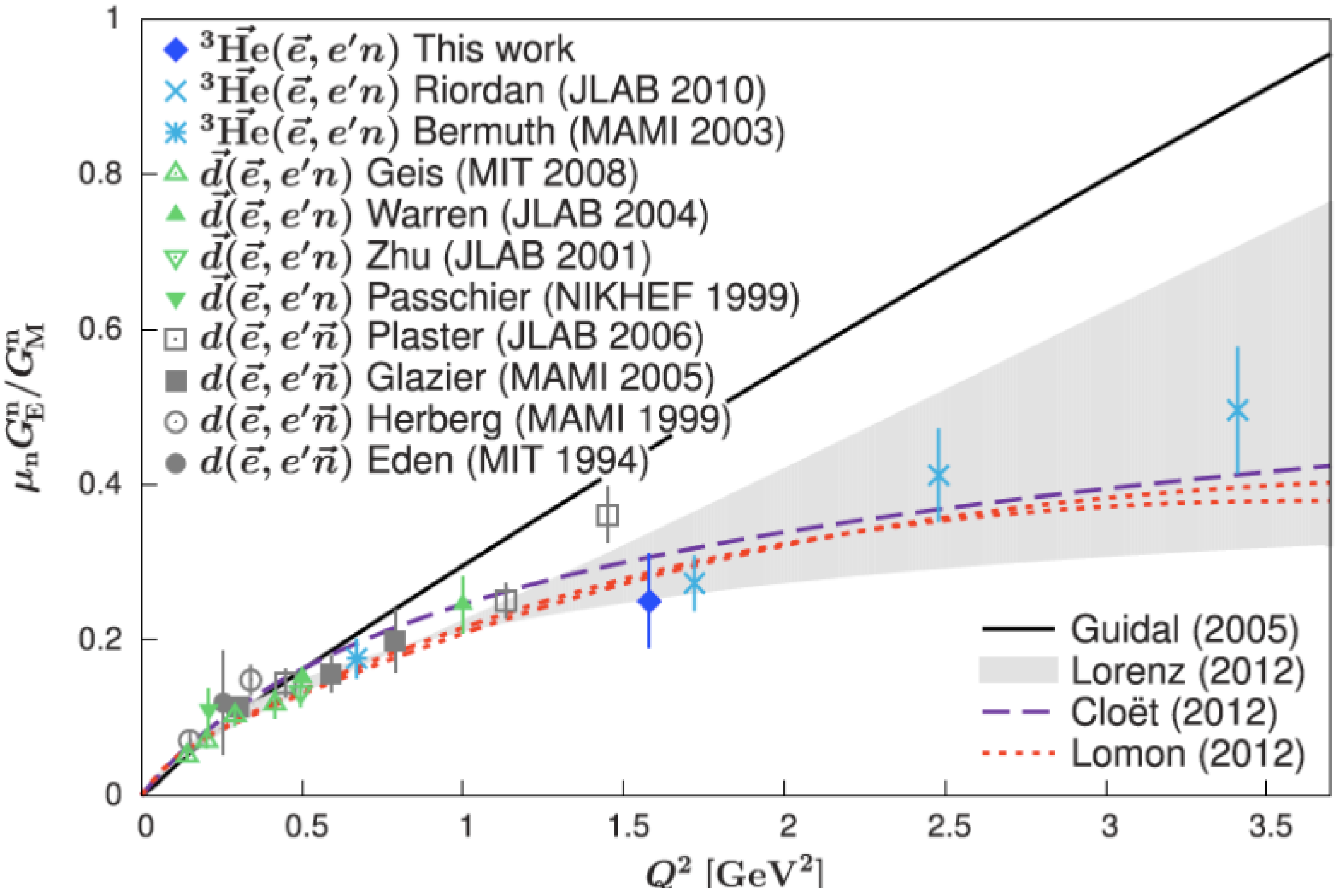
Sys. errors: 9-11%

$\langle Q^2 \rangle$ [GeV^2]	g_n ± stat ± syst	G_E^n ± stat ± syst	G_M^n	P_{He}	P_n	P_e	$D_{p/n}$	D_{in}	Other
1.72	0.273 ± 0.020 ± 0.030	0.0236 ± 0.0017 ± 0.0026	0.020	0.076	0.033	0.055	0.033	0.011	0.025
2.48	0.412 ± 0.048 ± 0.036	0.0208 ± 0.0024 ± 0.0019	0.024	0.059	0.024	0.031	0.036	0.027	0.023
3.41	0.496 ± 0.067 ± 0.046	0.0147 ± 0.0020 ± 0.0014	0.026	0.047	0.016	0.026	0.032	0.060	0.026

Mainz GEn measurement (2013)

A1 Collaboration, B.S. Schlimme et al., PRL111 (2013) 132504

Polarized He-3, Q^2=1.58 (GeV/c)^2



Largest sys. error: Pion cont. (4.8%), spin angle (3.8%), Total=7%
PWIA correction (-3.6%), FSI found negligible

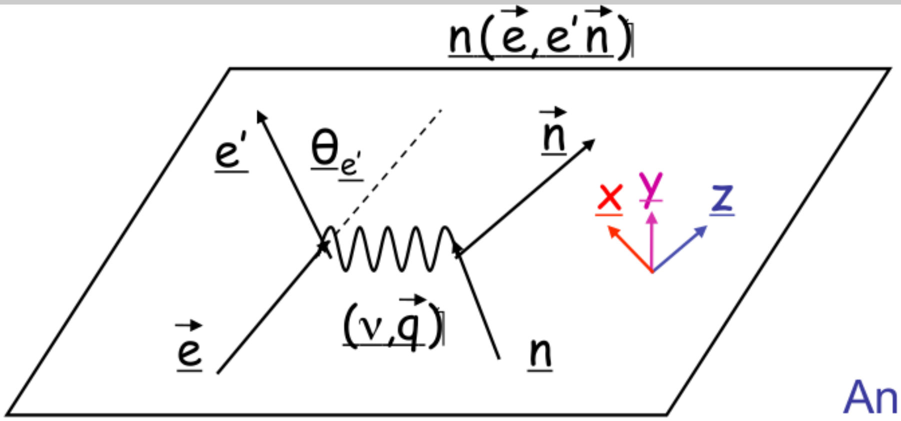
E12-11-009 CGEN Collaboration

- GEn via recoil polarization in deuteron electrodisintegration
  R. Madey, S. Kowalski, B. Anderson

- 6 GeV era Proposals
  - E93-038: $Q^2 = 0.45$, 1.13, and 1.45 (GeV/c) 2
    - R. Madey, PRL91 (2003) 122002; B. Plaster, PRC73 (2006) 025205
  - PR-01-106 (PAC20), PR-02-009 (PAC 21): $Q^2 = 2.4$ (GeV/c)^2
  - PR-04-003 (PAC25): $Q^2 \rightarrow 4$ (GeV/c)^2
  - PR-04-110 (PAC26): $Q^2 = 4.3$ (GeV/c)^2
- 12 GeV era Proposals
  - PR-09-006 (PAC34, Jan 2009): $Q^2 \rightarrow 7$ (GeV/c)^2
  - E12-11-009 update approved at PAC37 (Jan. 2011)

- Collaboration restructured in 2014/15
  - Updated Spokespeople:
    J. Arrington, M. Kohl, B. Sawatzky, A. Semenov
  - Refresh collaborator list and redistribute responsibilities

Recoil polarization technique



electron scattering plane

Recoil polarization

$$P_x = -P_e K_t G_{En} G_{Mn}$$

$$P_z = P_e K_\ell G_{Mn}^2$$

Analyzed by second scattering in polarimeter with analyzing power A_Y

Ratio Technique: Measure P_x and P_z → $\frac{P_x}{P_z} = -\frac{K_t}{K_\ell}\frac{G_{En}}{G_{Mn}}$ → small systematics $A_Y(q)$ and P_e cancel

- Electrons detected in new Hall C SHMS
- Neutron spin precession in dipole magnet
- Neutron detected, polarization analyzed in NPOL via *up-down* asym ξ
  - Two linear combinations of P_x and P_z (2 *precession angles*, χ)
    - » $\xi(\chi) = A_y [\, P_x \cos\chi \; + \; P_z \sin\chi \,]$

Asymmetry Extraction

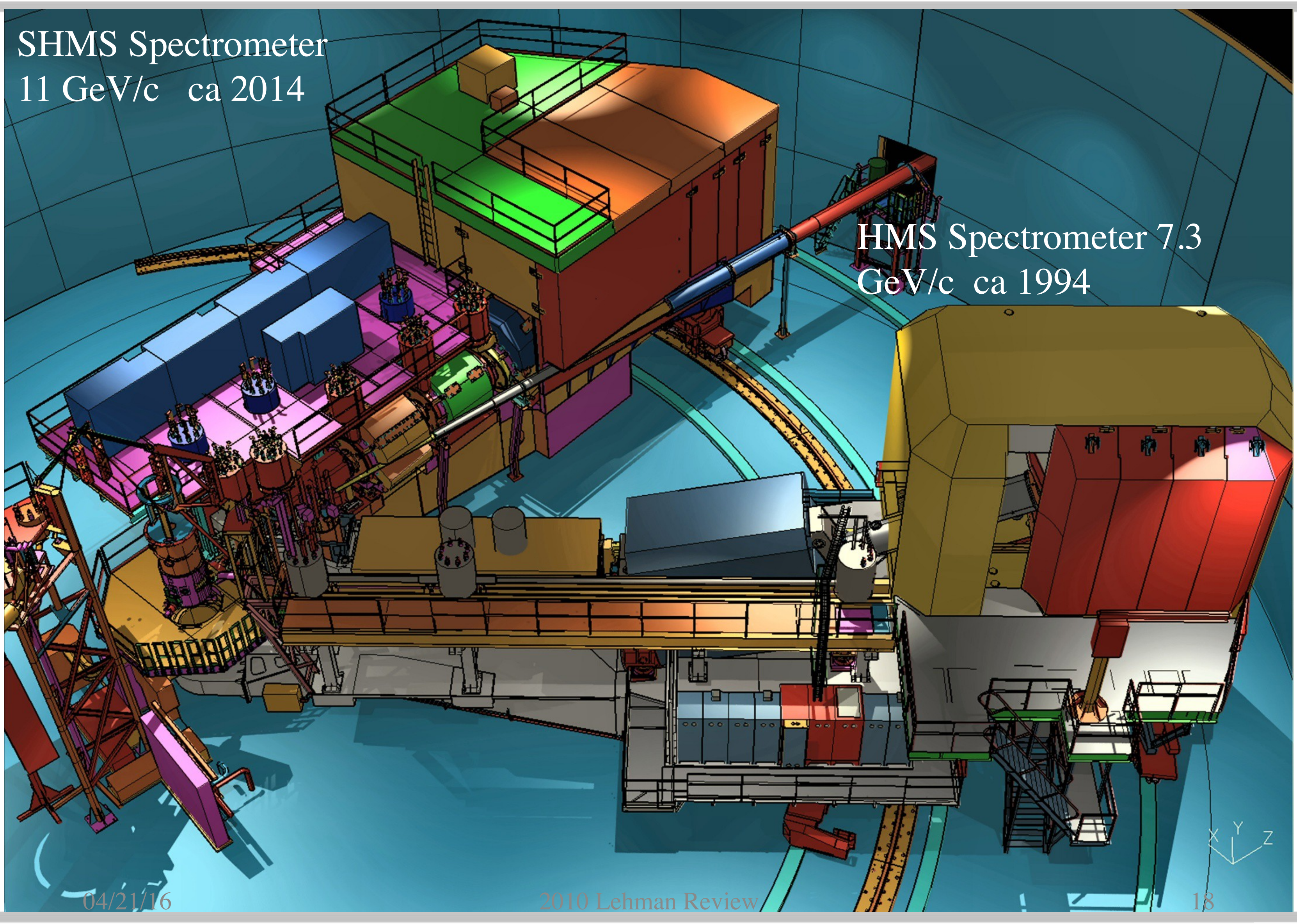
- "Cross Ratio" technique

$$r = \sqrt{\frac{N_U^+ N_D^-}{N_D^+ N_U^-}} \longrightarrow \boxed{\xi = \frac{r-1}{r+1}}$$

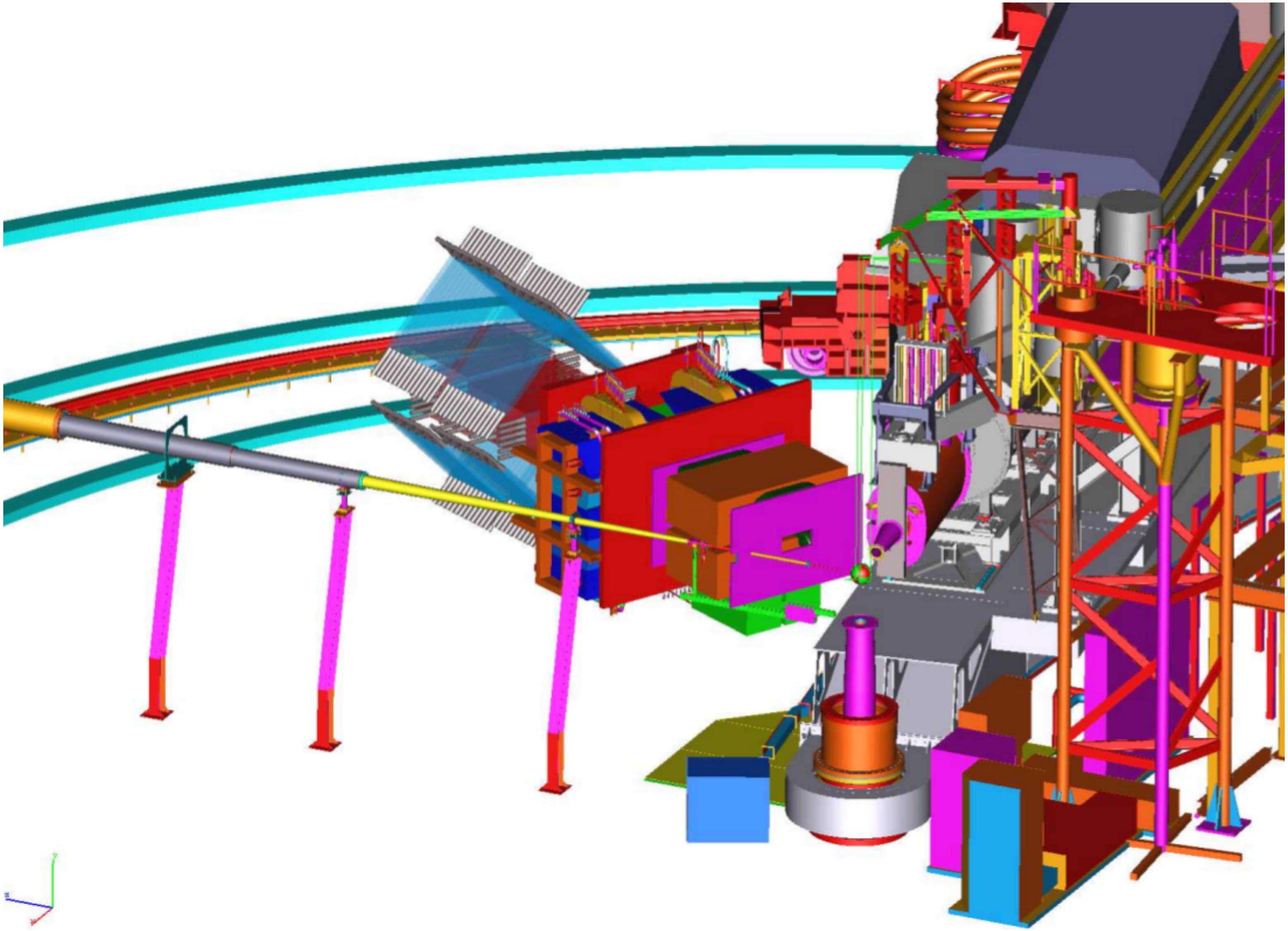
- N = extracted yield in Up (Down) detector array
  for beam helicity state + (-)

- Ratio r (and extracted asym ξ) insensitive to:
  – relative U/D detector efficiencies, solid angles
  – relative integrated charge (and target luminosities) for +/- beam helicity states

Hall C and the 12 GeV Upgrade

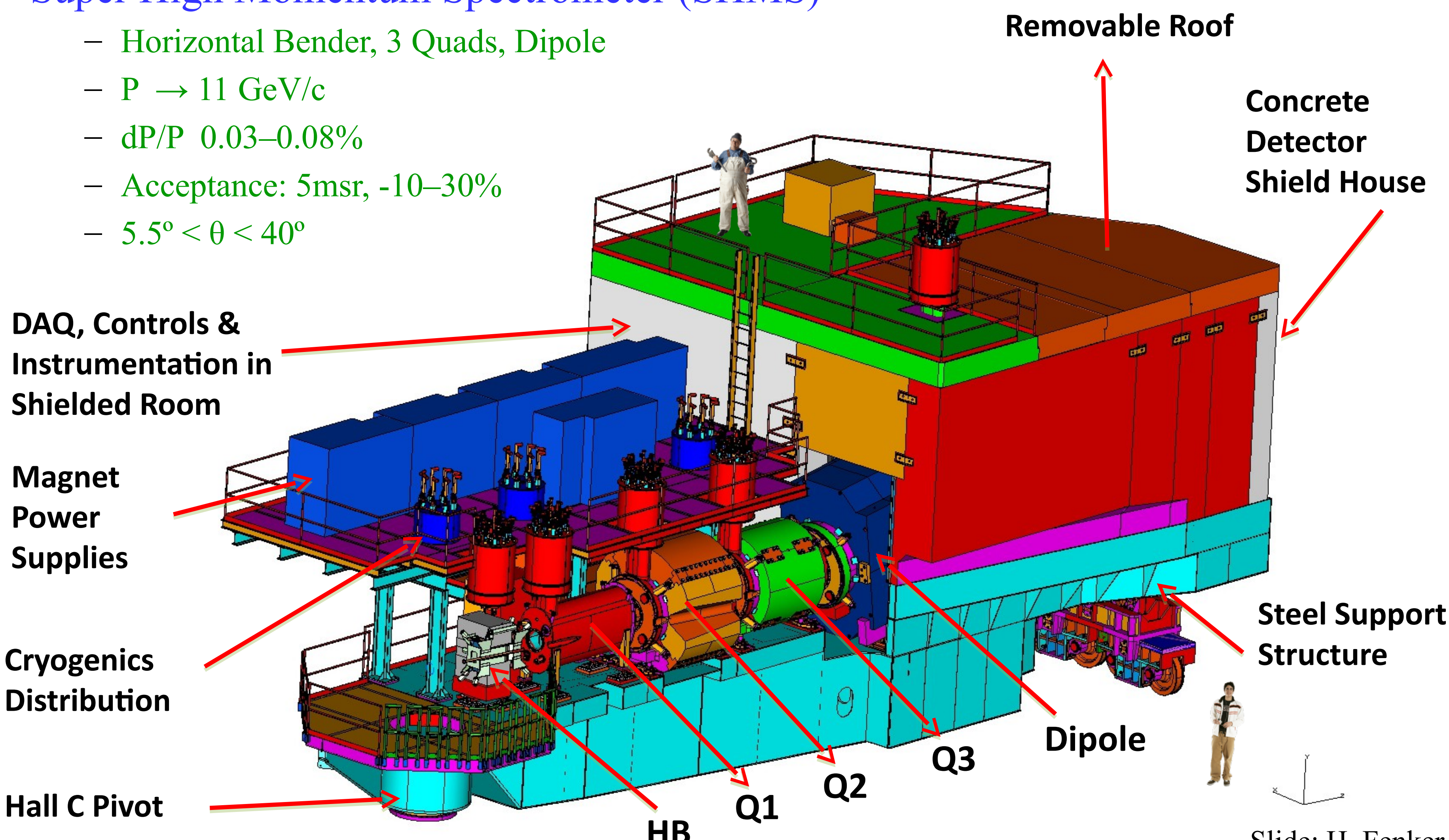


NPOL Magnets and Internal Detectors



Hall C after 12 GeV Upgrade: SHMS

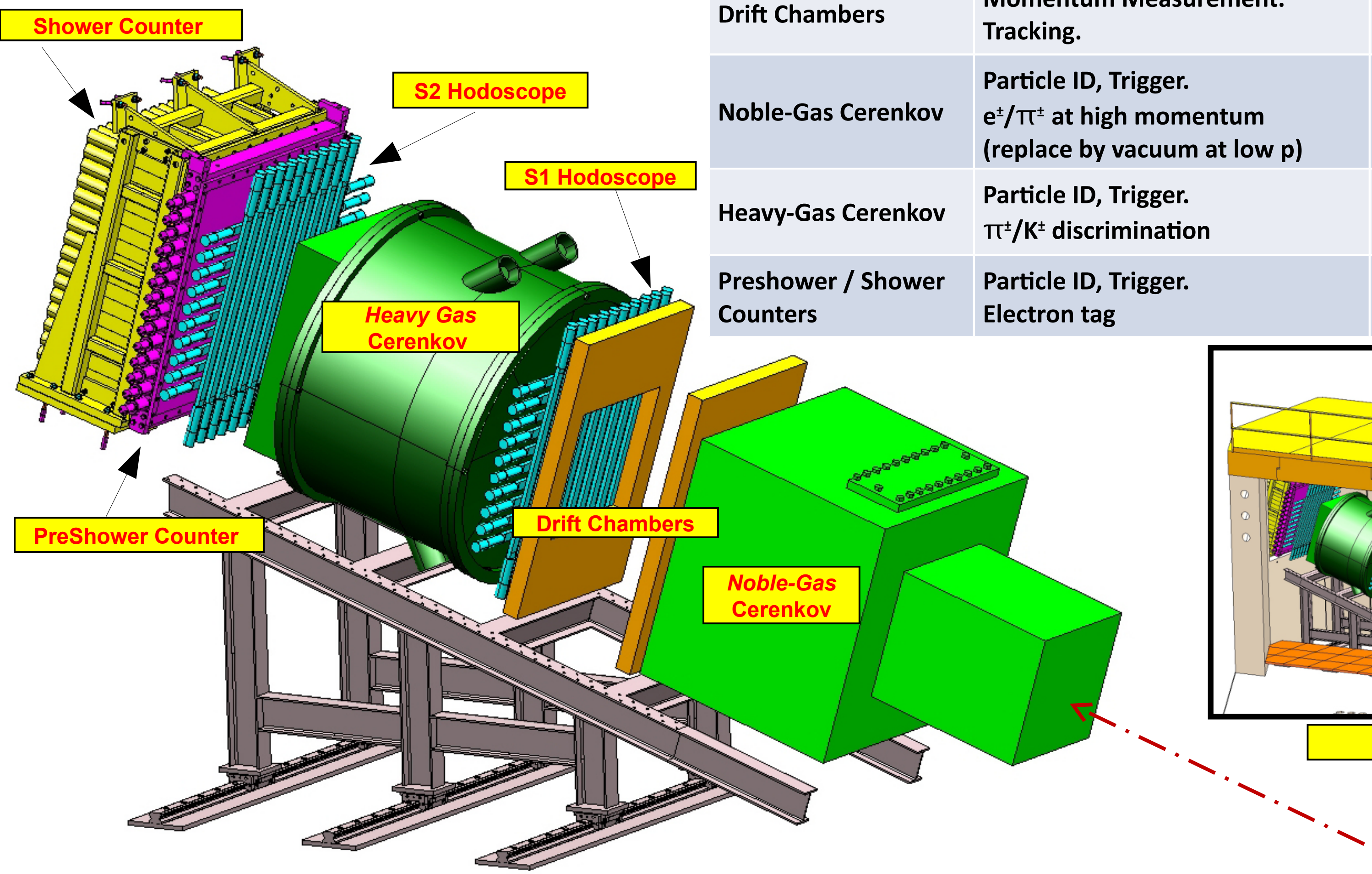
- Super High Momentum Spectrometer (SHMS)
  - Horizontal Bender, 3 Quads, Dipole
  - P $\rightarrow$ 11 GeV/c
  - dP/P 0.03–0.08%
  - Acceptance: 5msr, -10–30%
  - $5.5^o < \theta < 40^o$

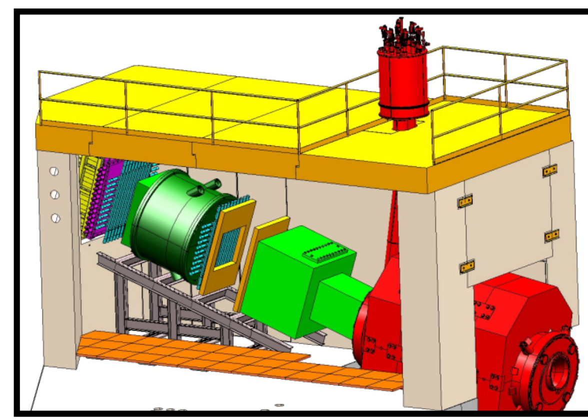


Slide: H. Fenker

SHMS Detector System

DETECTOR	PURPOSE	NOTES
S1XY, S2XY Hodoscopes	Lowest-level Trigger. Time reference	
Drift Chambers	Momentum Measurement. Tracking.	5mm max. drift 300 micron resolution
Noble-Gas Cerenkov	Particle ID, Trigger. $e^{\pm}/\pi^{\pm}$ at high momentum (replace by vacuum at low p)	Vary Ar/Ne mixture to set index at $\pi^{\pm}$ threshold.
Heavy-Gas Cerenkov	Particle ID, Trigger. $\pi^{\pm}/K^{\pm}$ discrimination	C_4F_8O – Vary pressure to set index at $K^{\pm}$ threshold
Preshower / Shower Counters	Particle ID, Trigger. Electron tag	





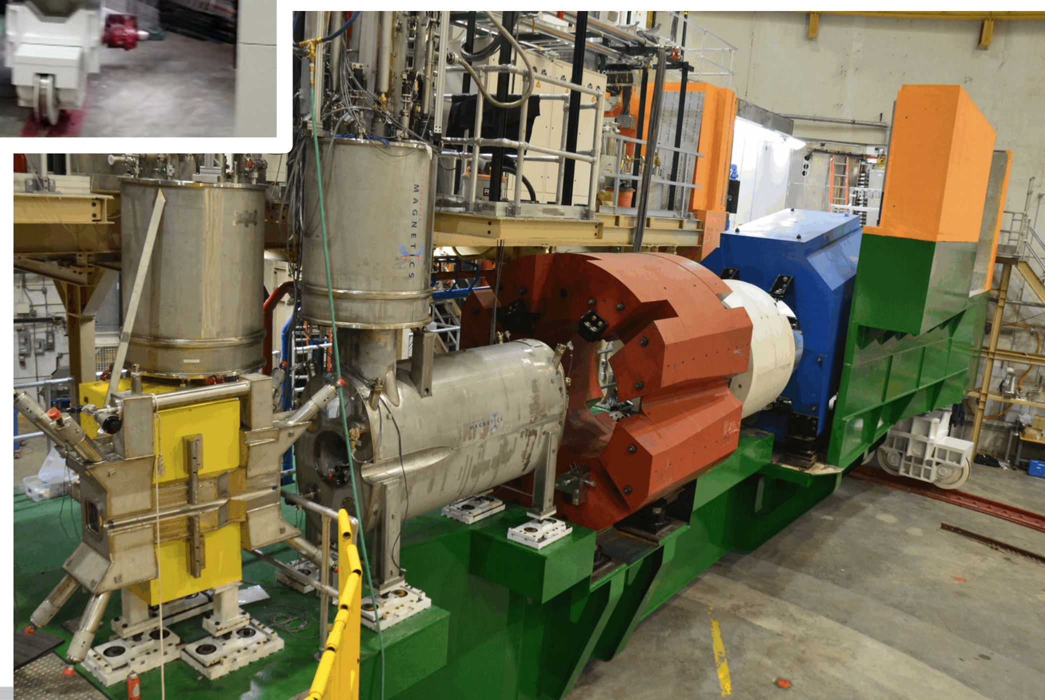
SHMS Detector Hut

Slide: H. Fenker

Progress in Hall C in 2015

- "Back Half" of detector stack installed
- "Front Half" to be installed after dipole

- HB and Q1 Magnets installed/tested
- Yokes for D, Q2, Q3 in place on the Carriage



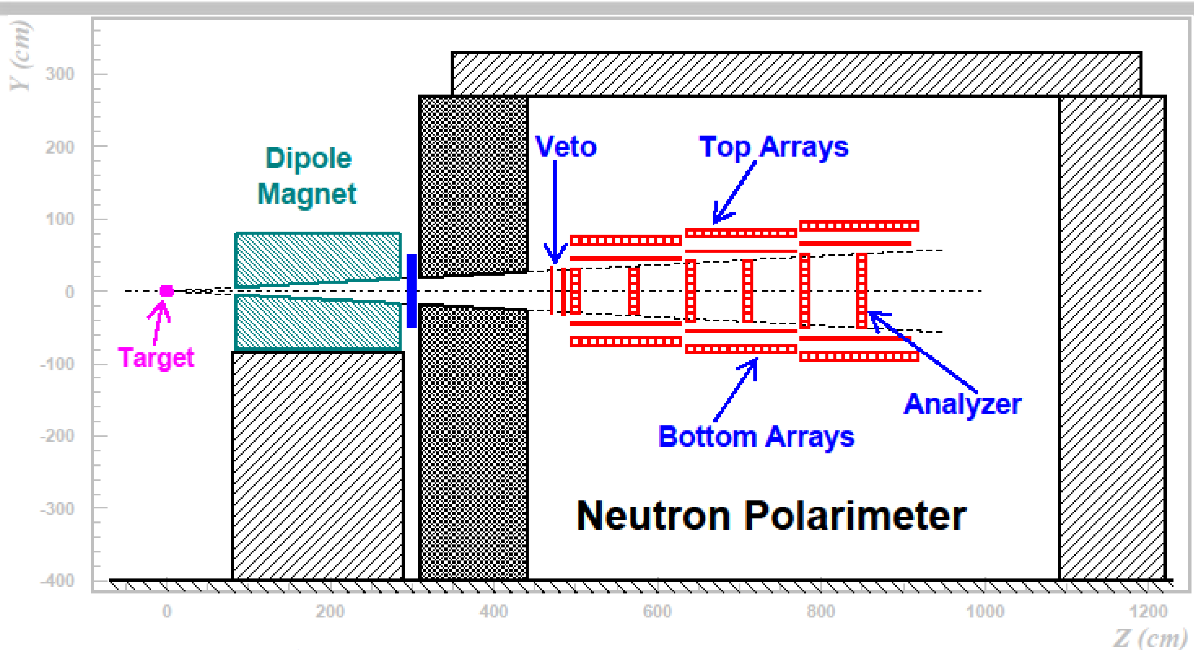
Neutron Polarimeter Components

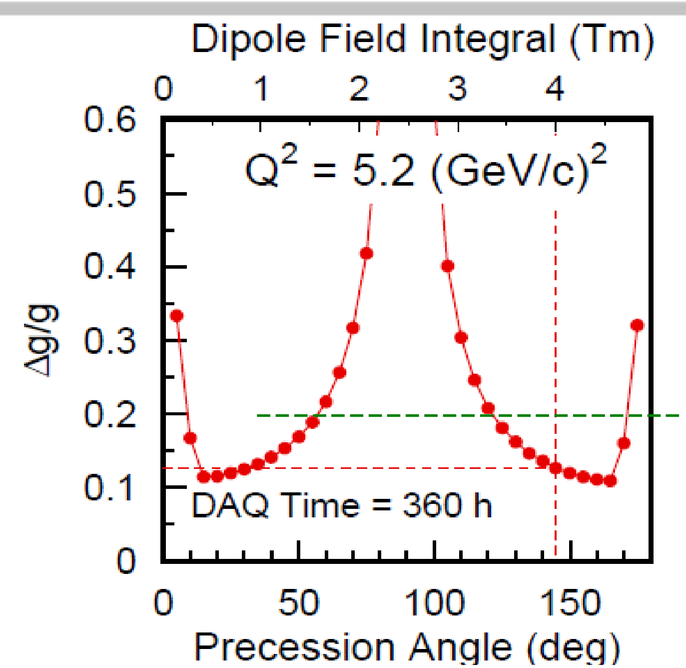
- Magnetic field to precess the neutron spin
  - Also important to suppress charged backgrounds and keep detector rates "ALARA"

- Shielded bunker around Polarimeter
  - Suppress backgrounds, beamline, dump, "sky-shine"

- Polarimeter detector array (plastic scintillator)
  - Analyzer bars in path of the recoil neutron
  - Top/Bottom detector arrays to measure the asymmetry → GEn/GMn ratio

Precession Magnet Requirements





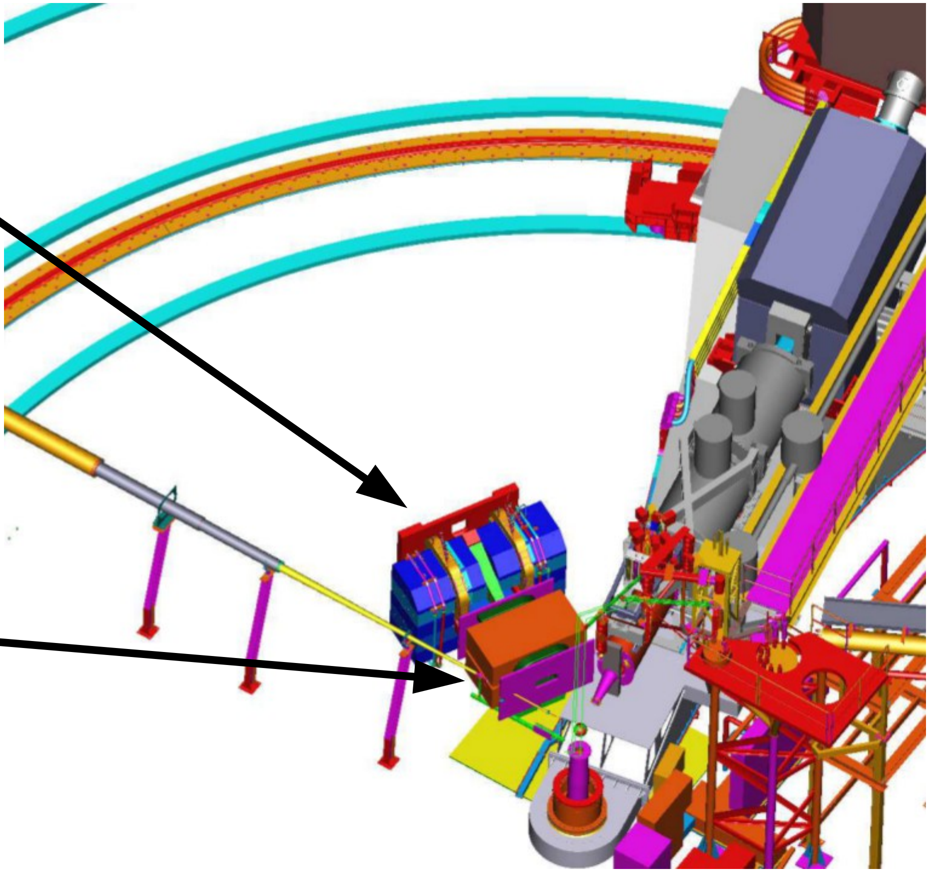
where, $g \equiv G_E/G_M$

- Field serves two functions
  - precess the neutron spin to maximize detected asym (low *or* high field OK, but 'medium' == no good)
  - suppress charged backgrounds from target (*need high-field*)
- Optimal B·dl : 4.3 T·m
  - We're shooting for 4.0 T·m
- This is not possible with a single warm magnet → Need to stack two!

Charybdis + BNL 48D48

- BNL 48D48
  - B·dl of 2.0 T·m @ 2 kA
  - Aperture
    - 122 cm high
    - 47 cm wide (w/ shims: 31.8 cm)
    - 122 cm along z-axis
  - Pole center: $\theta = 28°$, R = 4.64m
  - Back side / Shield wall: R = 5.5 m
- Charybdis
  - B·dl of 2.15 T·m @ 590 A (E93-038)
  - Aperture
    - 21 cm high (adj)
    - 56 cm wide
    - 1.22 m along z-axis
  - Pole center: $\theta = 28°$, R = 2.5m

Will the two magnets fit? Yes!



Charybdis + BNL 48D48

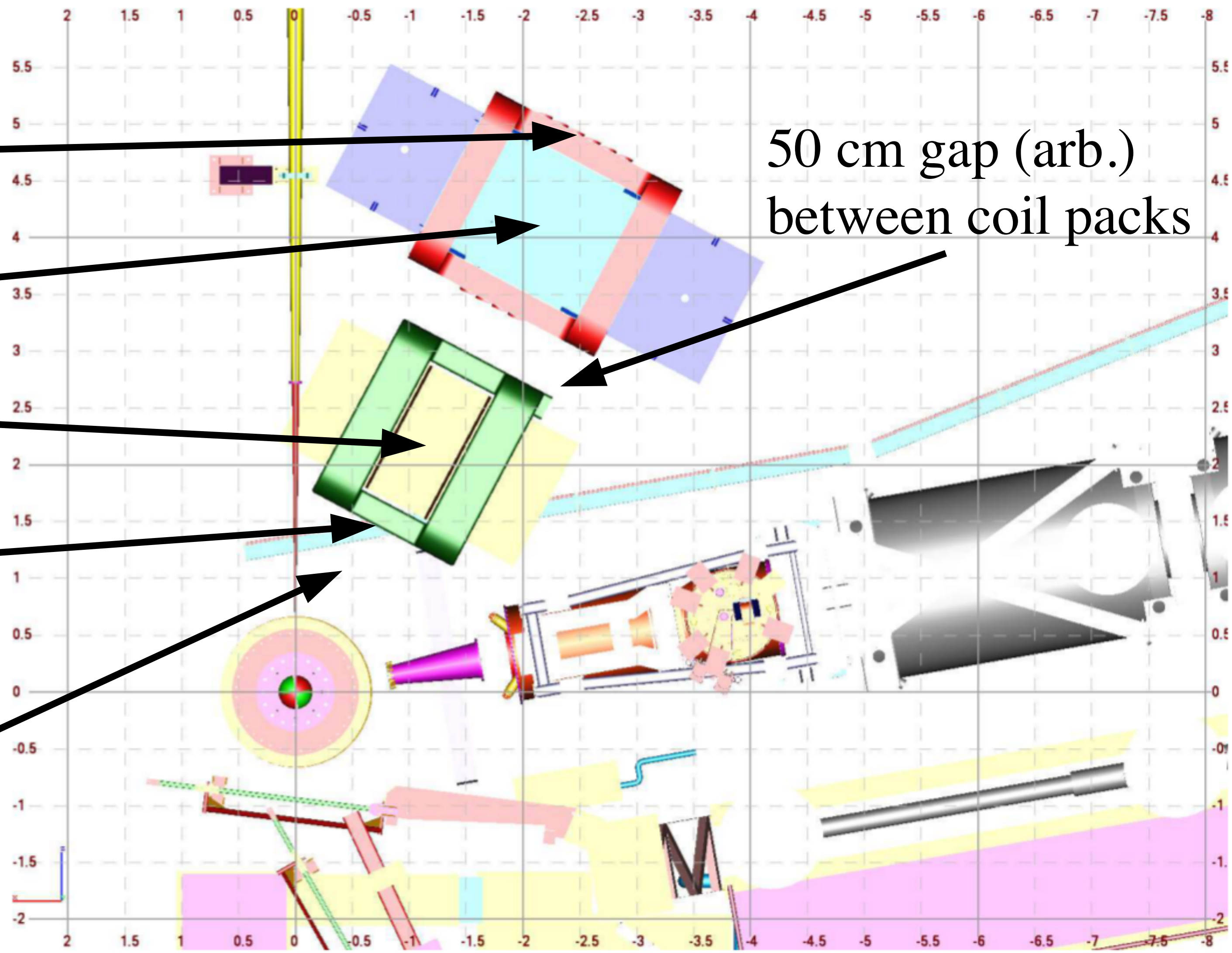
R=5.5 m

R=4.64 m

R=2.49 m

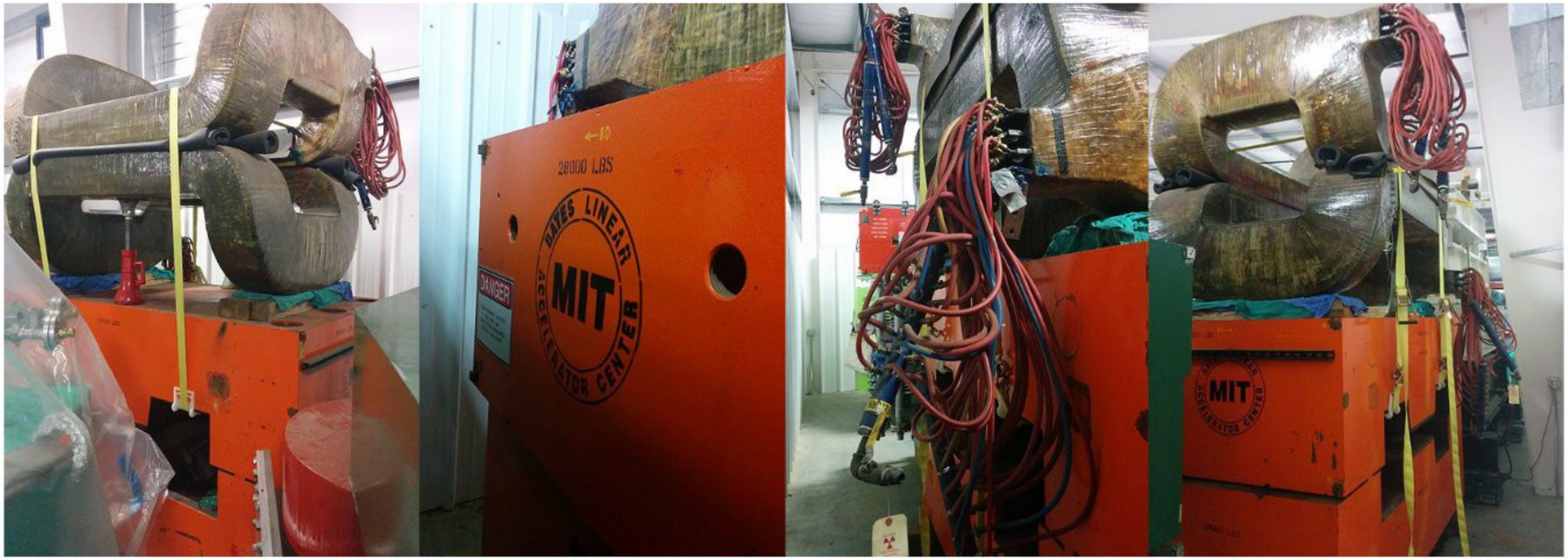
R=1.66 m

Field clamp
R=1.5m
(not shown)



50 cm gap (arb.)
between coil packs

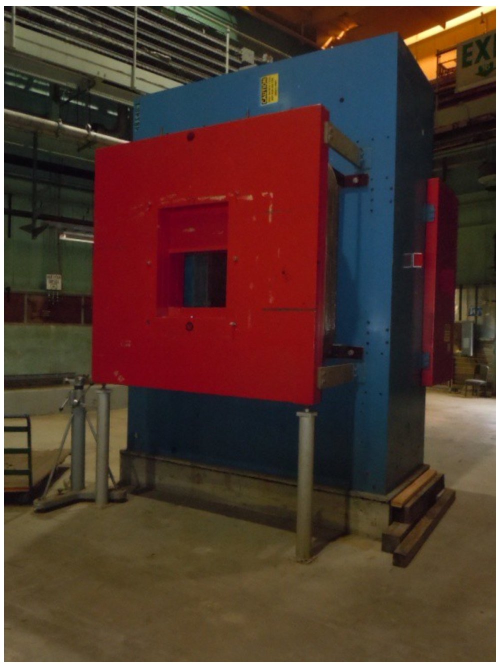
Magnet #1: Charybdis (used for E93-038)



- On site at JLab in ESB
  - Yoke, coil packs, and water manifolds in good shape
  - Aperture: 21 cm high • 56 cm wide • 1.22 long
- Power supply options: SOS-D1, BigBite, Moller Quad
- Not much to be done here – looks good!

Magnet #2: BNL 48D48 Magnet

- BNL 48D48 magnet
  - SBS magnet is a modified 48D48 (docs, shipping costs, contacts available)
  - BNL has at least one more in good condition, “parts” of others in boneyard



Front

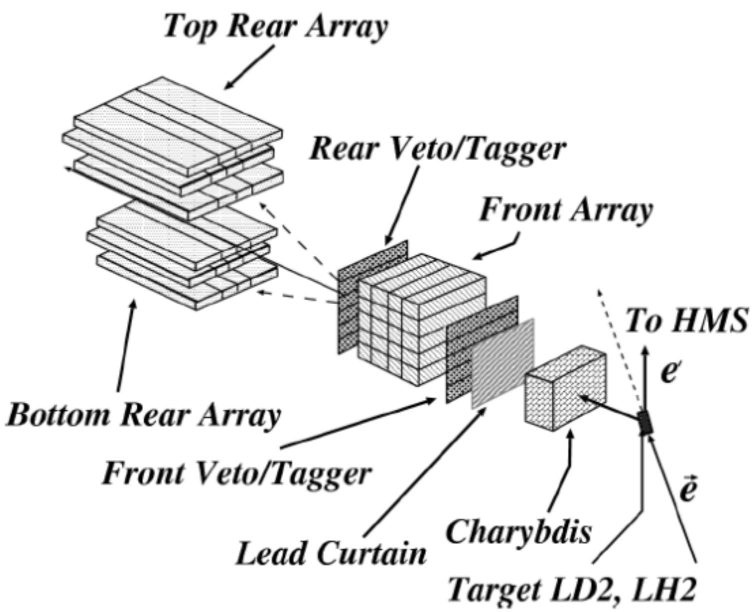
- B·dl of 2.0 T·m @ 2 kA
- Aperture:
  - 122 cm high
  - 47 cm wide (w/ shims: 31.8 cm)
  - 122 cm along z-axis
  - Power supply options at JLab
    - Hall C QTor supply

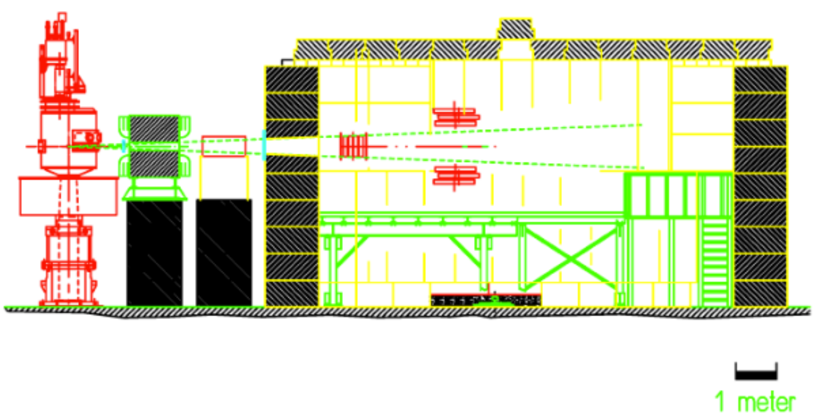
Rear

Neutron Polarimeter

Evolution and Improvements
from Initial Design

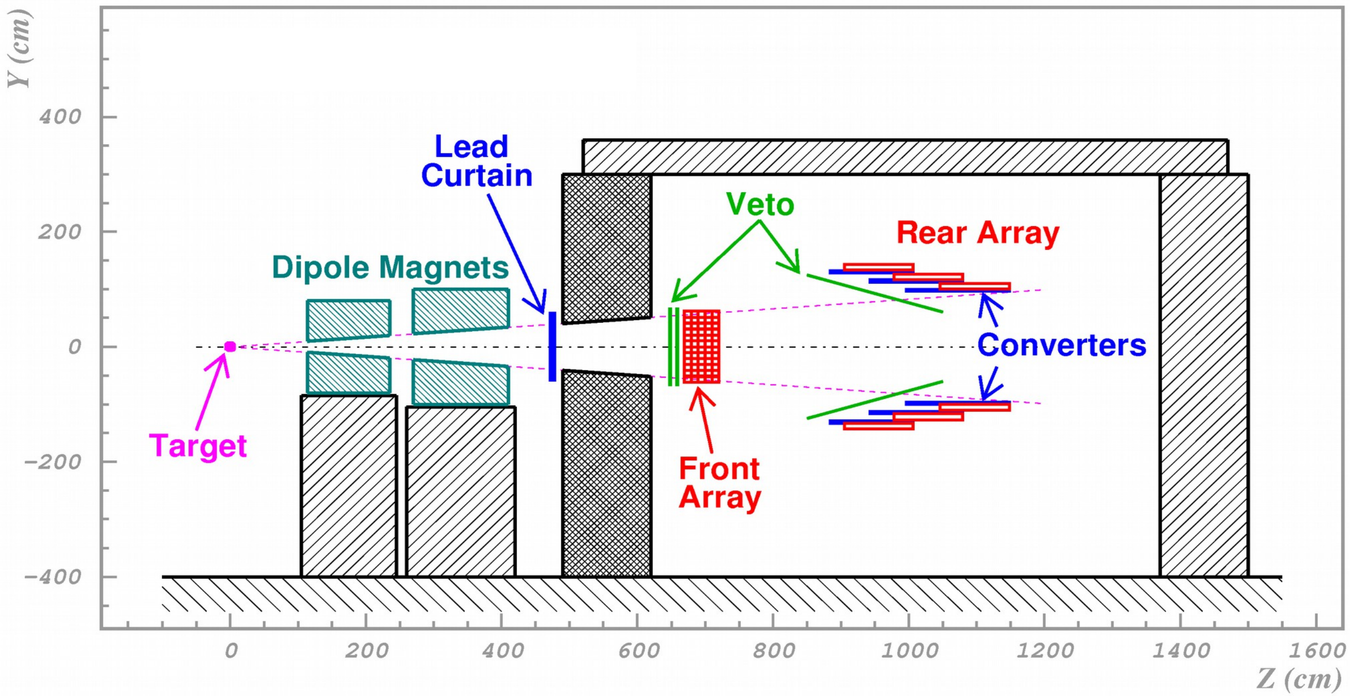
Polarimeter: History / E93-038





- Beam charge asymmetry, polarimeter efficiency and A_y cancel in "super-ratio" and ratio of asymmetries
- Operation at high luminosity: front array segmented, rear array shielded from direct view of target; detectors located in the bunker
- PROBLEM : NOT suitable for measurements at higher Q^2
- Difficult to reach small scattering angles (max of Ay at high energies)
- Relatively small efficiency
- Solution proposed for 2004 proposal (viz., bigger front array & converters in the rear array) not sufficient

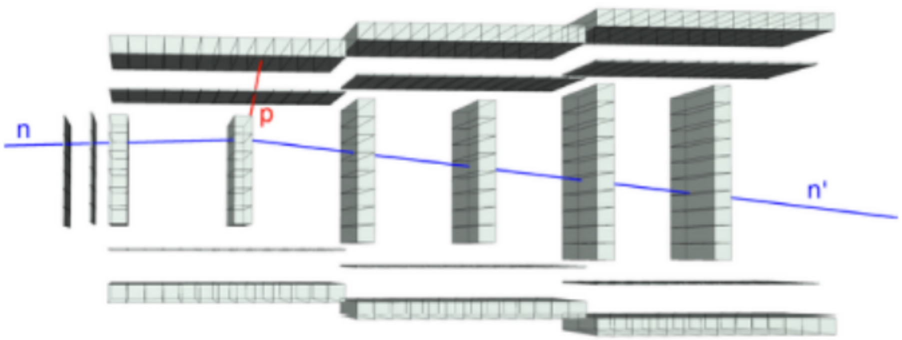
Initial E09-006 NPOL based on successful 6 GeV experiment

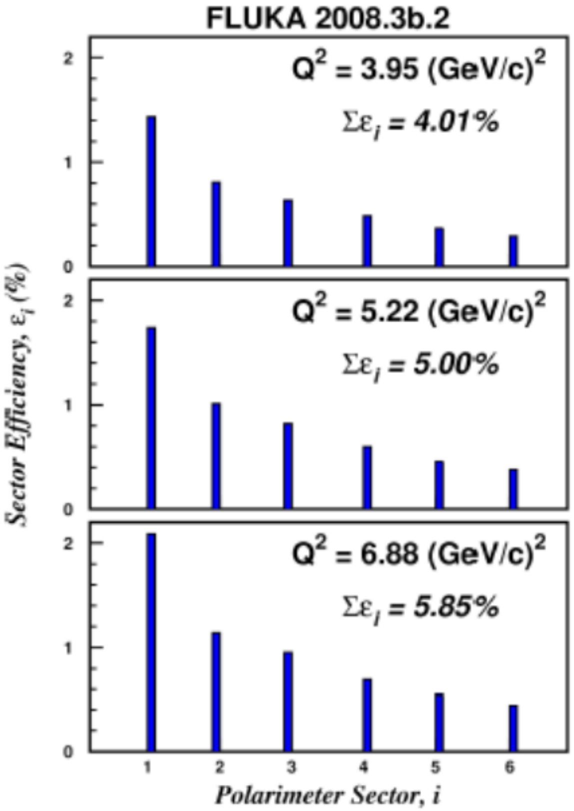


- "Mark 1" (2004) design issues:
  - Can't reach small neutron scattering angles (ie. max A_y)
  - neutron detection efficiency in top/bottom arrays relatively low
- Came back to PAC37 with much improved NPOL design

Upgraded Polarimeter (PAC37)

PAC37 : Detection of Recoil Protons Instead of Scattered Neutrons





* Easy detection of 300-500 MeV protons via TOF and dE-E techniques

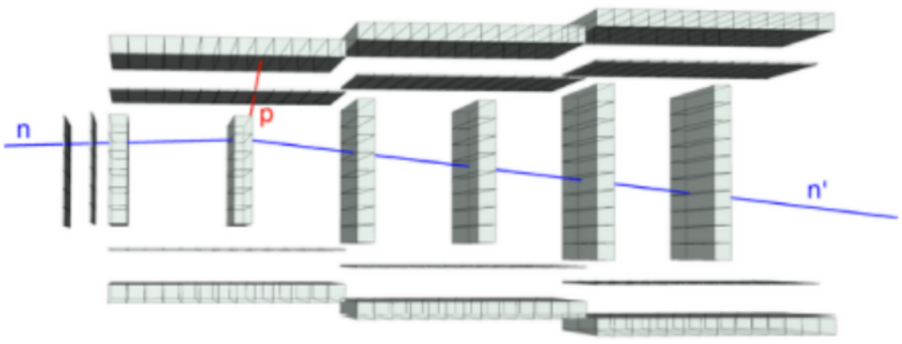
* Comfortable access to the small scattering angles of neutrons

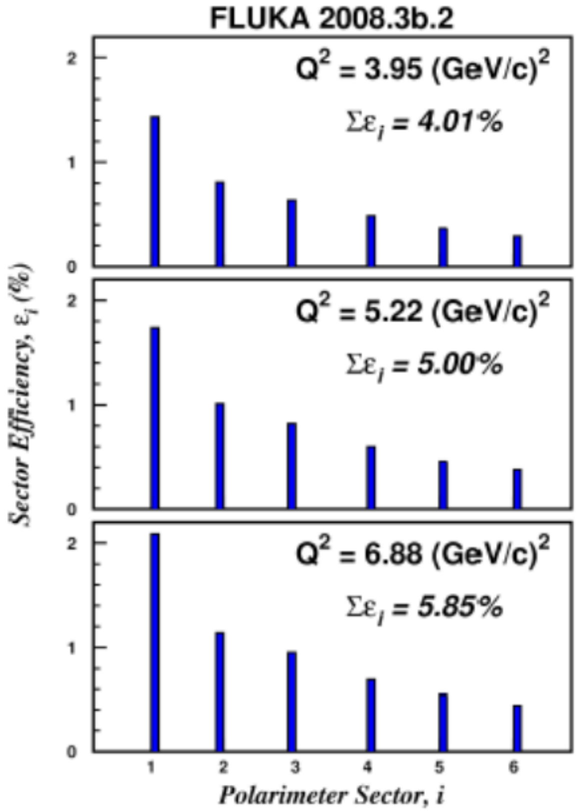
* Segmented and distributed analyzer (easy escape of protons and control on double-scattered neutrons)

- Efficiency was ~3x (~4x) higher at $Q^2 = 4\ (7)\ (GeV/c)^2$
- FOM was ~2x (~3x) higher at $Q^2 = 4\ (7)\ (GeV/c)^2$

Upgraded Polarimeter (PAC37)

PAC37 : Detection of Recoil Protons Instead of Scattered Neutrons





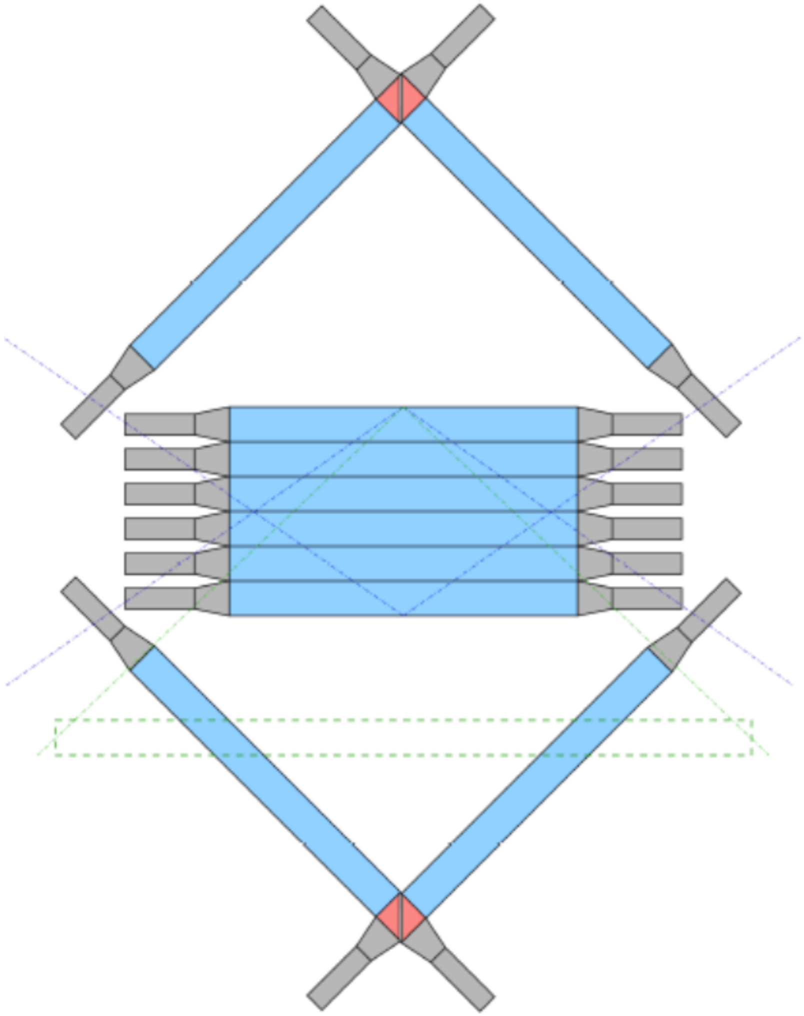
* Easy detection of 300-500 MeV protons via TOF and dE-E techniques

* Comfortable access to the small scattering angles of neutrons

* Segmented and distributed analyzer (easy escape of protons and control on double-scattered neutrons)

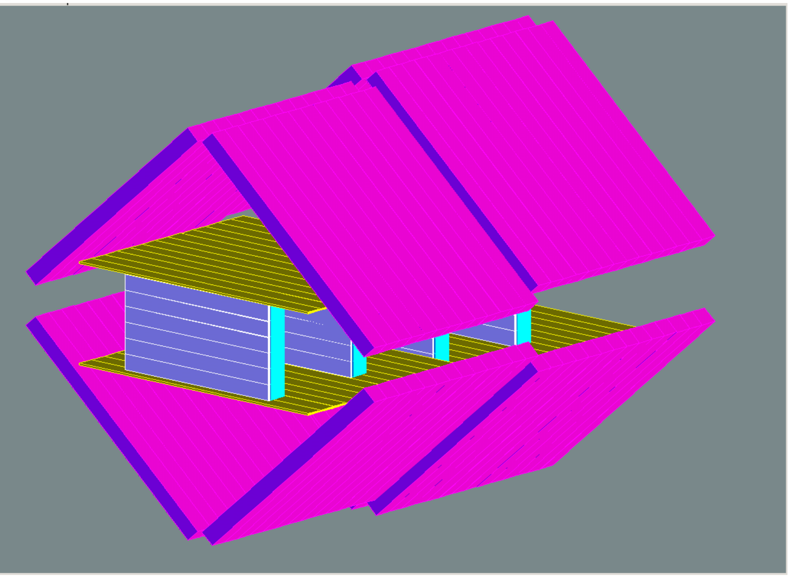
* Issues:
  - No full coverage of top/bottom acceptance
  - 5th and 6th Sections (too small efficiency with too many detectors)

Improving the acceptance … “Plan B” (Now)



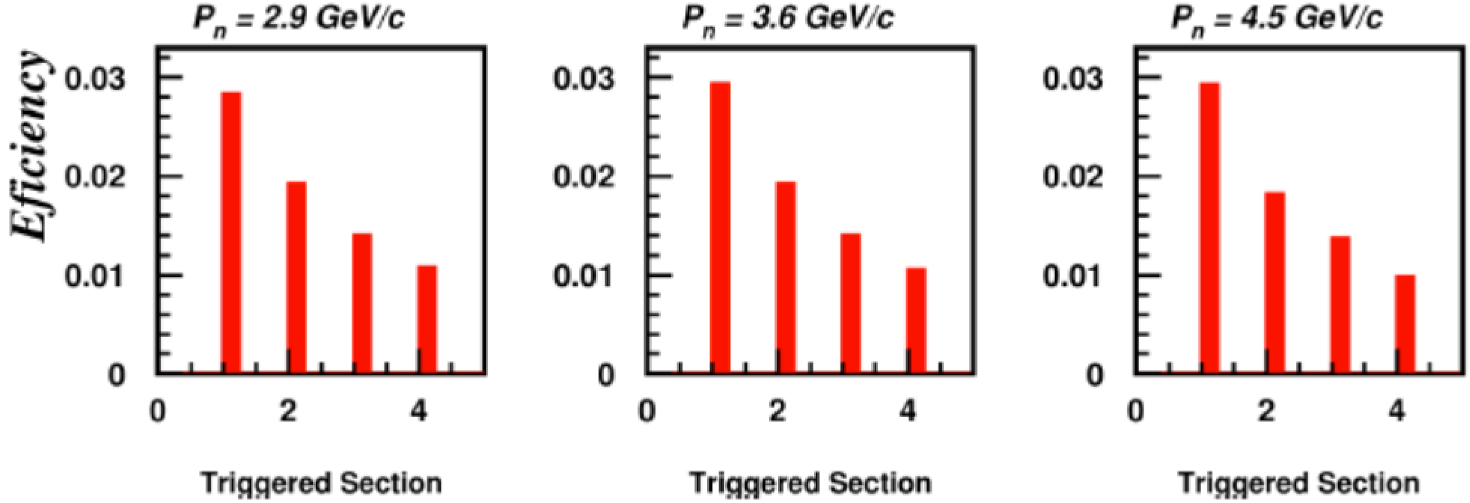
- Remove the rear arrays (low eff. anyway) and rearrange to make top/bottom arrays more “hermetic”
- Longer flight path also improves ToF discrimination for background rejection
- Increased segmentation of top and bottom detectors

Updated Neutron Polarimeter



- Simulation:
  - Fluka 2011.2.9 + MCEEP-generated neutron flux
- Visible increase in polarimeter efficiency for each sector even with only 4 sections in the polarimeter

  ~ 7% for all kinematics

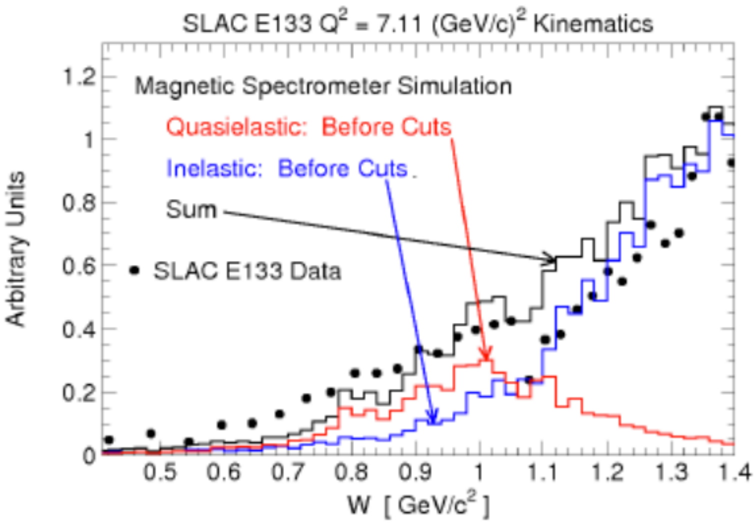


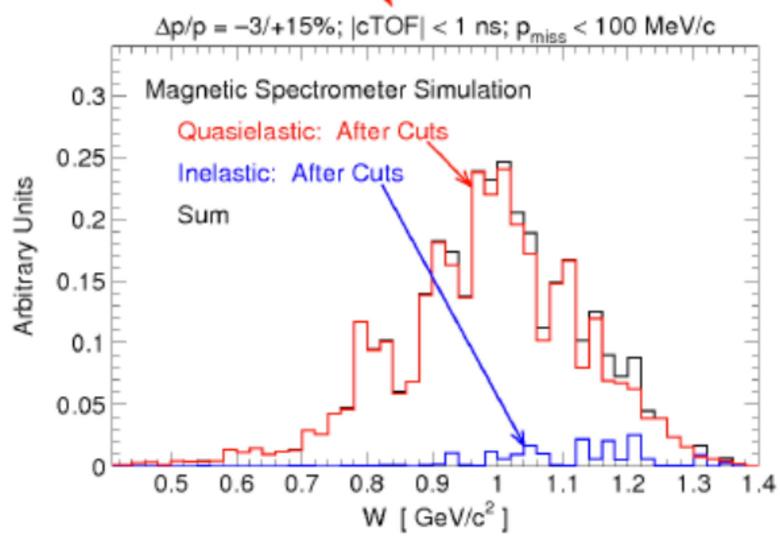
Good timing for clean QE event selection

Time Resolution of Analyzer: Selection of Quasielastic *en*

Cut on the SHMS-NPOL Analyzer time difference is an important part of selection of e-n quasielatic scattering events in the target.

High mean-time resolution (as better as possible, but definitely better than 1 ns) is desired for neutron bars in the polarimeter analyzer.





A. Semenov

Kinematics

Four-Momentum Transfer, Q^2 $(\mathrm{GeV}/c)^2$	3.95	5.22	6.88
Beam Energy, E_0 (GeV)	4.4	6.6	11.0
Electron Scattering Angle, θ_e (deg)	36.53	26.31	16.79
Scattered Electron Momentum, P_e (GeV/c)	2.288	3.815	7.330
Neutron Scattering Angle, θ_n (deg)	28.0	28.0	28.0
Neutron Momentum, P_n (GeV/c)	2.901	3.602	4.511
Neutron Kinetic Energy, T_n (GeV)	2.110	2.783	3.668
Flight Path, x (m)	5.0	5.0	5.0
Precession Angle, χ (deg)	147.3	144.8	143.1
Field Integral to Precess Neutron Spin through χ Degree, $B\Delta l$ (Tm)	4.0	4.0	4.0

Table 1: Kinematic conditions at a neutron scattering angle of 28.0^o. Also listed is the dipole magnet field integral $B\Delta l$ required to precess the neutron polarization vector.

Systematic Uncertainties

Projected to similar to E93-038

(a) χ = ±40° precession

(b) χ = 0°/±90° precession

Source	$\langle Q^2 \rangle$ [(GeV/c)^2] $0.447^{(a)}$	$1.132^{(a)}$	$1.132^{(b)}$	$1.450^{(a)}$	$1.45^{(b)}$
Beam Polarization *	1.6	0.7	0.4	1.2	0.3
Charge-Exchange **	<0.1	<0.1	0.1	<0.01	0.2
Depolarization	<0.1	0.1	<0.1	<0.1	0.6
Positioning/Traceback	0.2	0.3	0.3	0.4	0.4
Precession Angle	1.1	0.3	0.1	0.5	0.1
Radiative Corrections	0.7	0.1	0.1	0.1	0.1
Timing Calibration	2.0	2.0	2.0	2.0	2.0
Total of Above Sources	2.9	2.2	2.1	2.4	2.2

* Mitigated by changing dipole state frequently.

** Assessed by running with LH2 target.

Total error will be <u>statistics dominated</u>

Kinematics, Beam Request (PAC37)

80 μA beam, 80% polarization, 40-cm LD_2 target

Four-Momentum Transfer, Q^2 $(\mathrm{GeV}/c)^2$	3.95	5.22	6.88
Beam Energy, E_0 (GeV)	4.4	6.6	11.0
Electron Scattering Angle, θ_e (deg)	36.53	26.31	16.79
Scattered Electron Momentum, P_e' (GeV/c)	2.288	3.815	7.330
Neutron Scattering Angle, θ_n (deg)	28.0	28.0	28.0
Neutron Momentum, P_n (GeV/c)	2.901	3.602	4.511

- Requested: 60 days
- Stat. uncertainty [assumes BLAST fit]: 10.1% 12.7% 16.3%
- Syst. uncertainty 2.5–3% for all settings
- Beam Time on LD2 [days] 10 15 30
  Beam Time (LH2, etc) [days] 1 1.5 2.5
  60d production + 7d checkout w/beam: 67 total PAC days
- Three Q^2 values, overlap with 6 GeV data,
  extend well into region of 12 GeV ^{3}He measurement

Kinematics, Beam Approved (PAC41)

80 μA beam, 80% polarization, 40-cm LD_2 target

Four-Momentum Transfer, Q^2 $(\mathrm{GeV}/c)^2$	3.95	~~5.22~~	6.88
Beam Energy, E_0 (GeV)	4.4	~~6.6~~	11.0
Electron Scattering Angle, θ_e (deg)	36.53	~~26.31~~	16.79
Scattered Electron Momentum, P_e' (GeV/c)	2.288	~~3.815~~	7.330
Neutron Scattering Angle, θ_n (deg)	28.0	~~28.0~~	28.0
Neutron Momentum, P_n (GeV/c)	2.901	~~3.602~~	4.511

- PAC41 Approved: 50 days, only two settings
- Stat. uncertainty [assumes BLAST fit]: 10.1% ~~12.7%~~ <15%
- Syst. uncertainty 2.5–3% for all settings
- Beam Time on LD2 [days] 10 ~~15~~ 36
  Beam Time (LH2, etc) [days] 1 ~~1.5~~ 2.5
  50d production + 7d checkout w/beam: 57 total PAC days
- Two Q^2 values: one overlap with 6 GeV data,
  2nd as high as possible with optimal statistics

Predictions for GEn

Considering shifting point 6.88 → 6.0 $(\mathrm{GeV}/c)^2$ to improve precision

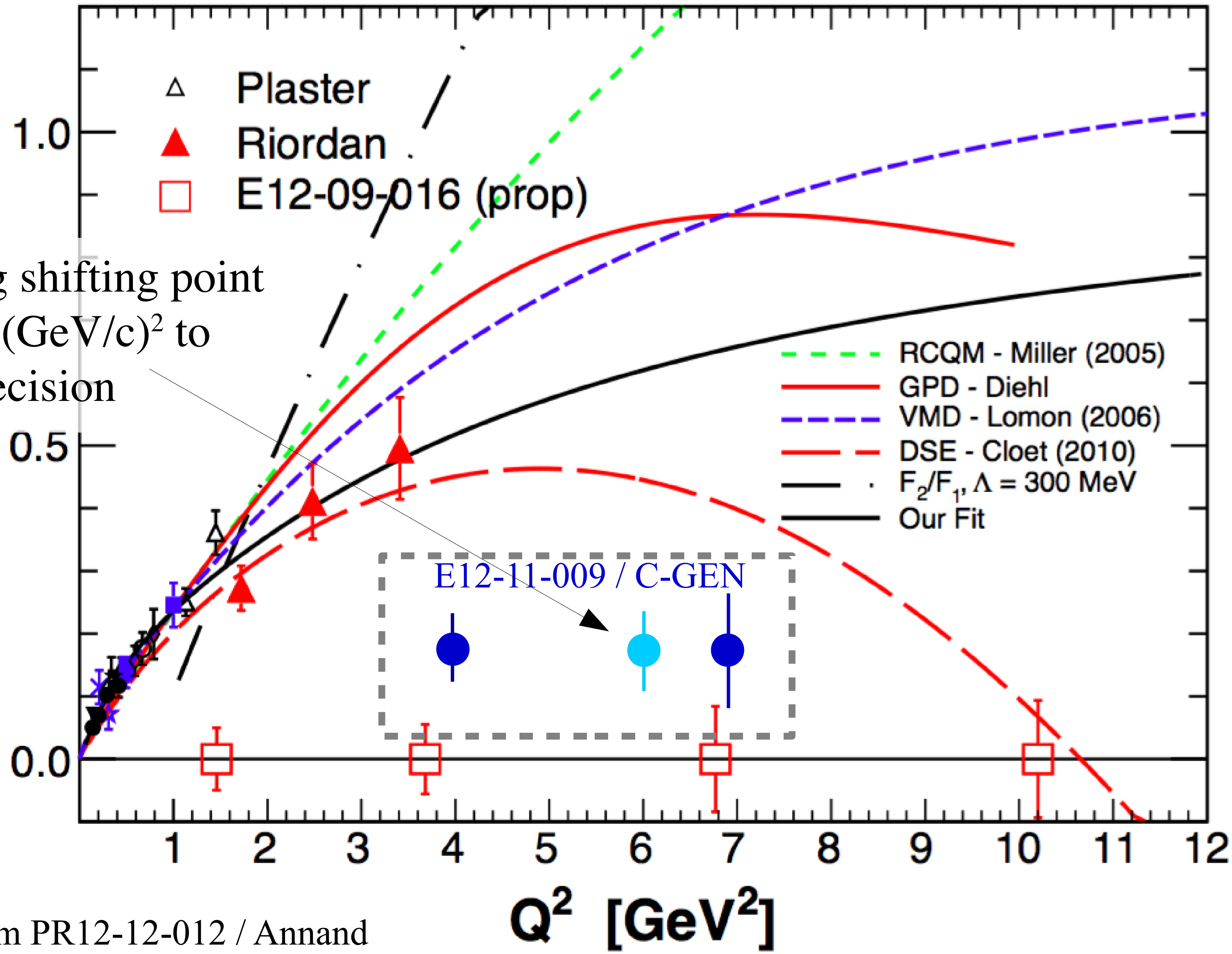
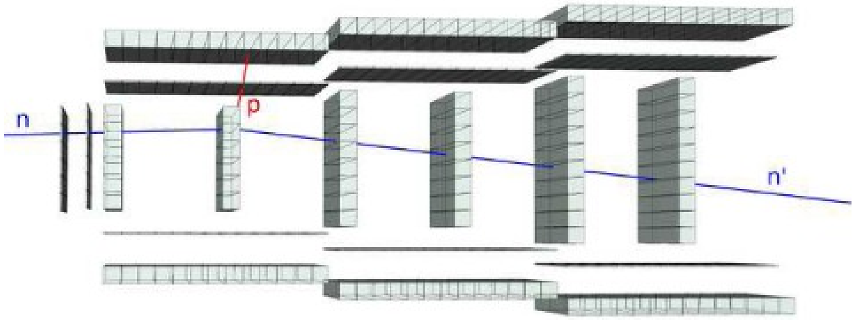


Figure from PR12-12-012 / Annand

Detector Simulation



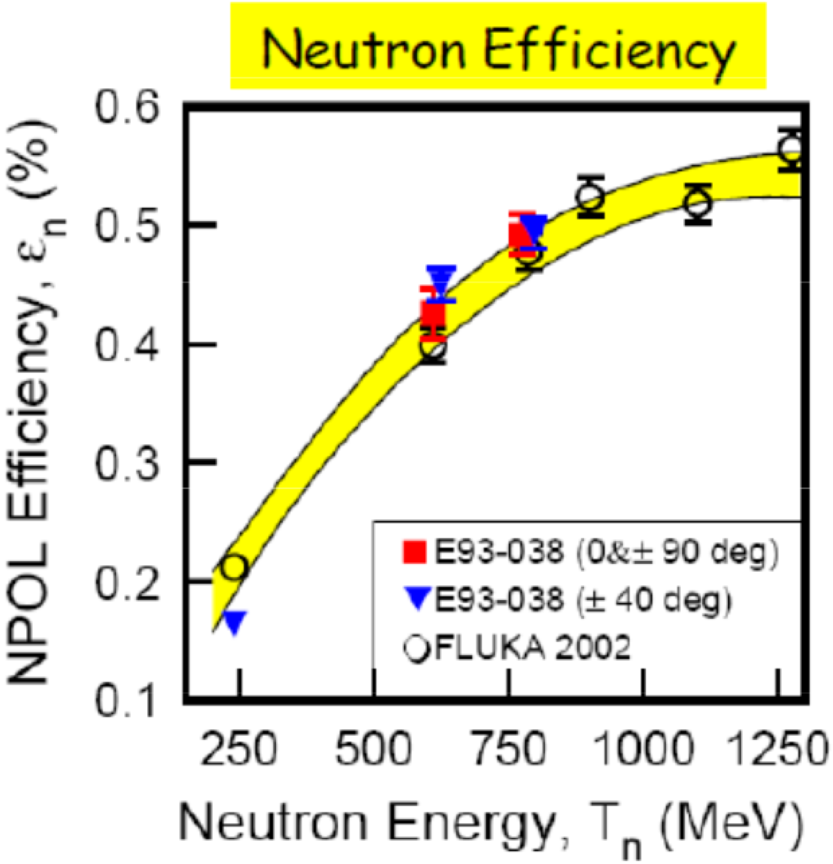
- **Approach to calculating rates, selection of QE events, etc… not changed with new design**
  - MCEEP (including radiative effects) for rate/acceptance
  - GENGEN simulation for selection of QE events (calibrated against JLab, SLAC data from 1-7 GeV^2)

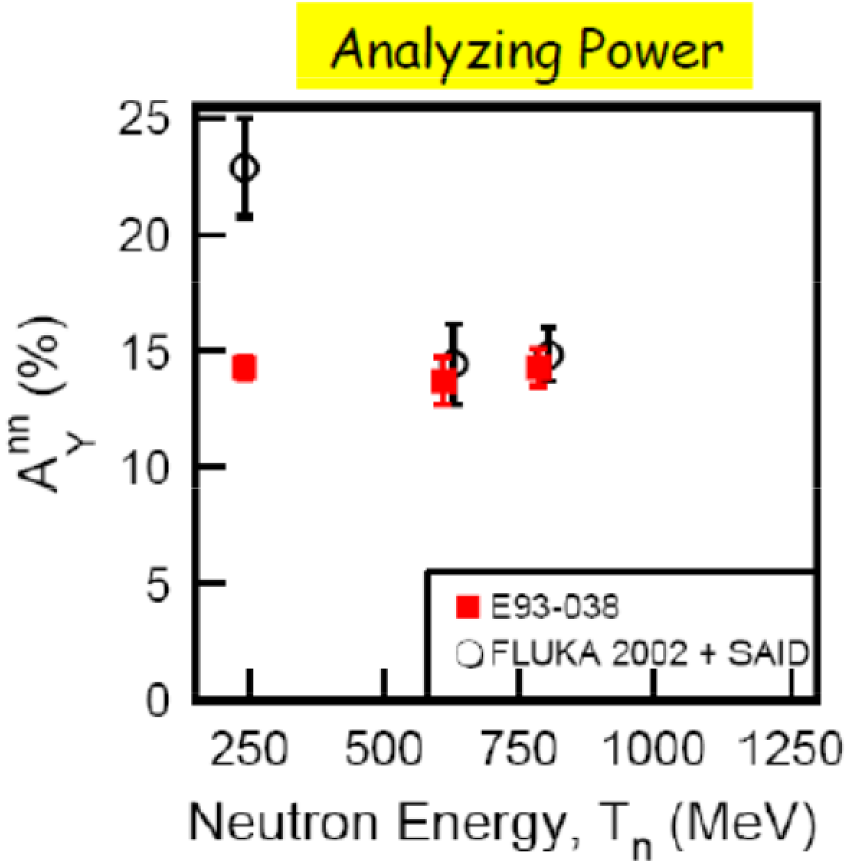
- **Modeling of the new analyzer**
  - FLUKA for proton, neutron interactions [Pb shield, veto, analyzing scintillators, top/bottom arrays], include estimated inefficiency and impact of PID cuts on rates
  - Background spectra from P. Degtyarenko's code (Geant3.21/GCALOR/DINREG)
  - Take rates from all particles to estimate background
  - Use elastic/QE n-p scattering only for physics rates
  - Assume analyzing power from inclusive n-CH_2 scattering, even though dilution from Carbon will be less as only n-p and not n-n QE events contribute

- **Conservative approach taken:** [FOM α $N \cdot A_y^2 \cdot P_e^2$]
  - Figure of merit (FOM) increased by >50% from PAC35 version (same polarimeter), as we replaced conservative estimates for factors we hadn't fully evaluated and made small geometry optimizations
  - Accounted for inefficiencies in SHMS, top/bottom arrays, etc… in addition to overall analyzer efficiency
  - Assumed conservative dipole field and gap values with assumption that final parameters would provide improved FOM. If not, we can go to low field option which has same (or greater) FOM

- **Note: this design optimized for high Q^2 where increasing momentum of struck protons increases the efficiency**

NPOL Simulation vs Data: E93-038

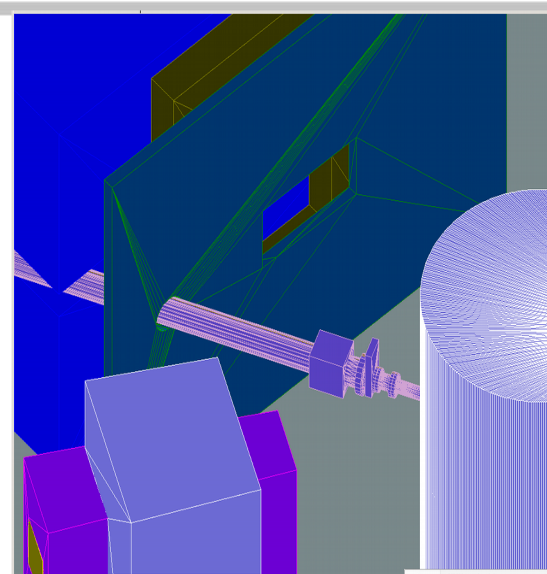


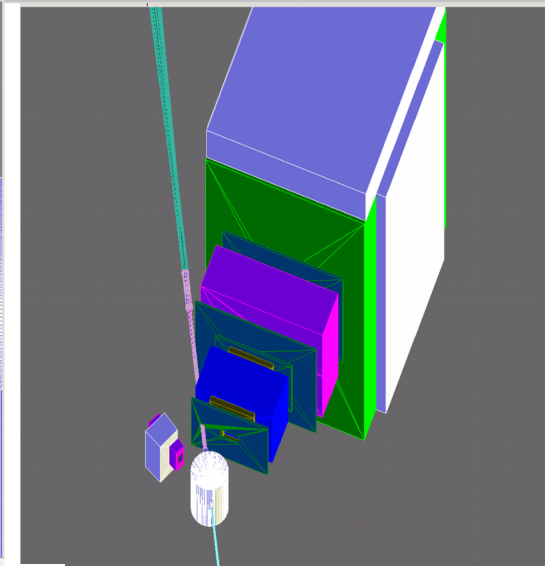


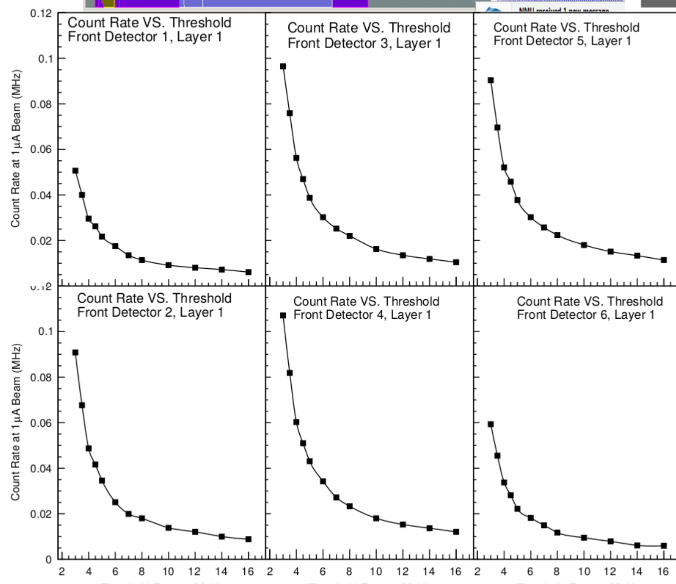
Agreement between simulation/data basis for extrapolation into higher neutron energy range

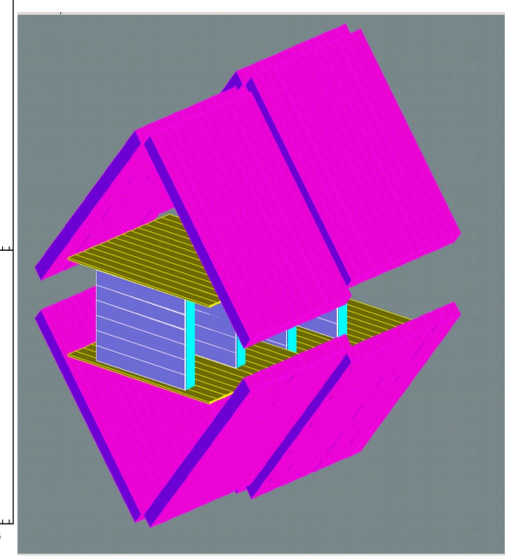
GEANT4 Simulation in Development

- Will Tireman (N. Michigan Univ.) & student
- Reimplementation of experiment “from scratch”
  - Includes full beamline, dump, Experimental Hall, portions of SHMS, complete NPOL w/ shield hut
- Fully integrated simulation (vs. MCEEP + FLUKA + external codes)
- Allows cross checks of historical simulation, plus more rapid prototyping of new ideas (ie. CX channel)









Summary / Outlook

- E12-11-009 / C-GEN approved for 50 days in Hall C (*Earliest* run slot would be 2020+)
  - Low Q^2 point at 4 $(\text{GeV/c})^2$ (~10% stat. err)
    - overlap with E02-013 ^{3}He data
  - High Q^2 point at either:
    - 6.88 $(\text{GeV/c})^2$ (~14% stat. err)

      ~ OR ~
    - 6.0 $(\text{GeV/c})^2$ (~10% stat. err)
- Extends Q^2 coverage for GEn into region that discriminates between several models
- Provides a critical cross check against the pol. ^{3}He meas. that can reach → 10+ $(\text{GeV/c})^2$
  - Different target, different systematics, different extraction technique
- Extrapolation of proven recoil polarimetry technique using toolkit refined from earlier measurements at JLab

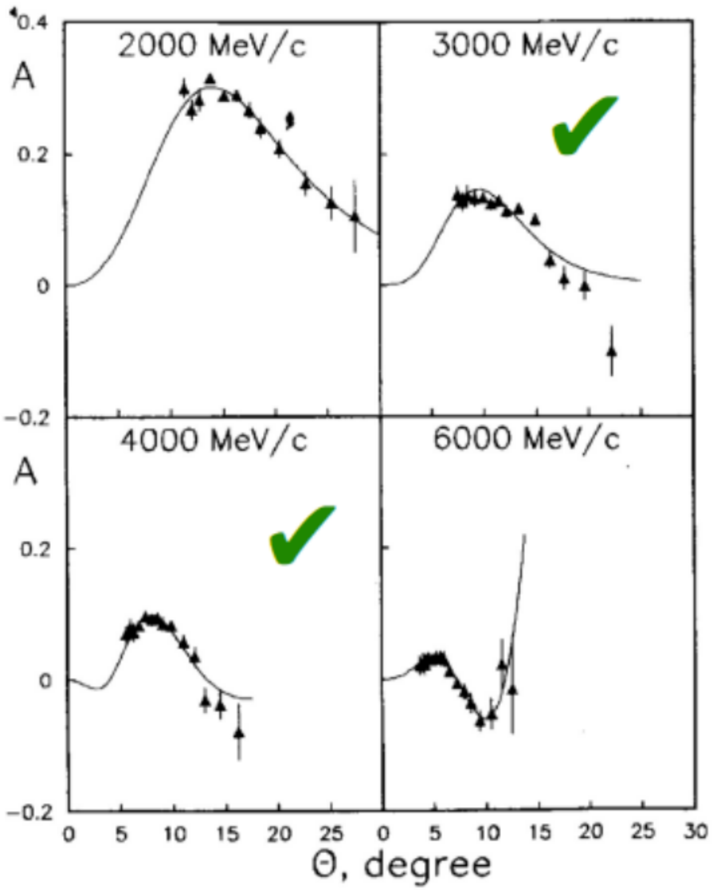
<u>Miscellaneous Comments</u>

- New GEANT4 simulation being developed to cross check proposal numbers and rerun error/rate estimates for current NPOL design
  - Investigating charge-exchange channel is also on the ToDo list
- MRI for NPOL under development

Misc. Backup

Optimal use of Analyzing Power

Control on Scattering Angle to Maximize Ay for Elastic and QE *np*



V.P. Ladygin, JINR preprint E13-99-123

* Non-zero analyzing power is located at small scattering angles of neutrons (with possible flip at higher angles)

* Control of the neutron scattering angle with accuracy of 1.5-2 degrees requires the control of recoil proton scattering angle with accuracy of 5-6 degrees; that requires 10-15-cm z-position resolution in the top/bottom arrays. Our polarimeter provides ±5-7 cm (with 10-cm bars)

OK

A. Semenov

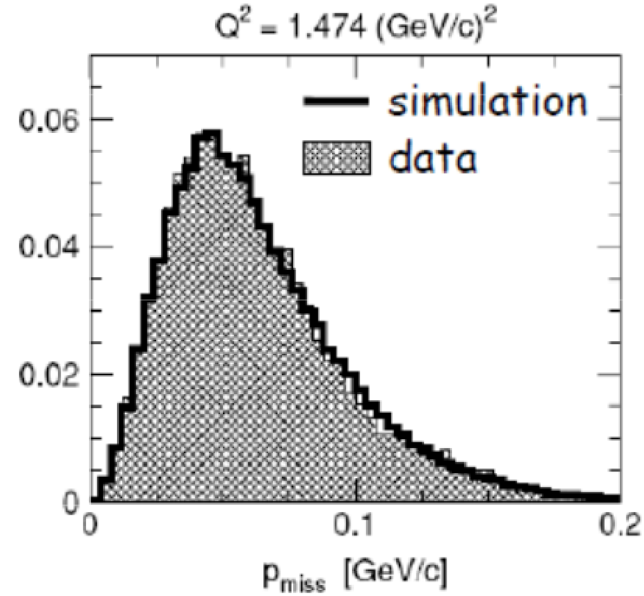
FSI corrections

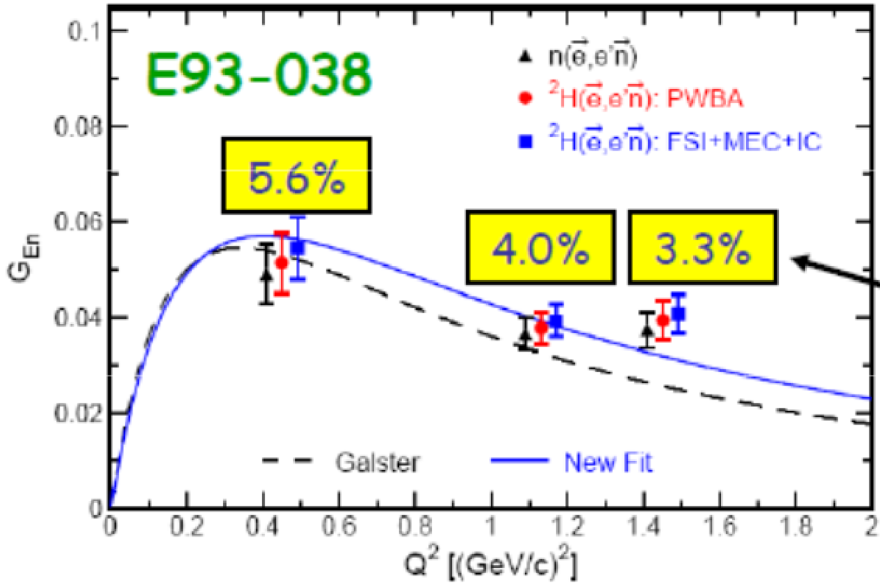
Arenhövel FSI+MEC+IC model

for $^2H(e,e'n)^1H$ averaged over acceptance [2 independent simulations]

1) Relativistic PWBA model for kinematic acceptance

2) FSI+MEC+IC corrections





With similar range of acceptance/cuts in p_{miss}, 3.3% should be robust estimate of upper range for FSI corrections at Q^2 = 2.8/4.3 $(GeV/c)^2$

Two-photo exchange for Neutron G_E/G_M

PHYSICAL REVIEW C **72**, 034612 (2005)

Two-photon exchange in elastic electron-nucleon scattering

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(Received 13 June 2005; published 30 September 2005)

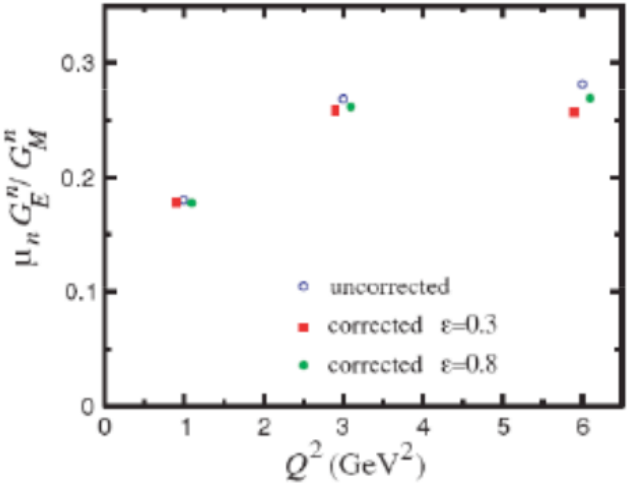


FIG. 14. (Color online) Effect of 2γ exchange on the ratio of neutron form factors $\mu_n G_E^n/G_M^n$ using polarization transfer. The uncorrected points (open circles) are from the parametrization in Ref. [16], and the points corrected for 2γ exchange correspond to $\varepsilon = 0.3$ (filled squares) and $\varepsilon = 0.8$ (filled circles) (offset for clarity).

In the Jefferson Lab experiment [42] to measure G_E^n/G_M^n at $Q^2 = 1.45$ GeV^2 the value of ε was around 0.9, at which the 2γ correction was ≈2.5%. In the recently approved extension of this measurement to $Q^2 \approx 4.3$ GeV^2 [43], the 2γ correction for $\varepsilon \approx 0.82$ is expected to be around 3%. Although small, these corrections will be important to take into account to achieve precision at the several-percent level. Furthermore, the two-photon exchange effects may also need to be taken into account when extracting the neutron magnetic form factor G_M^n from cross-section data.

2-gamma correction smaller than statistical error

Target Notes

- Target requirements in proposal:
  - 15 cm LH_2 cell at 80 μA (~ 500 W, should be fine)
    - Should select one of the new cells: 10 cm *or* 20 cm avail.
  - 40 cm LD_2 cell at 80 μA (~*1500 W, non-trivial!*)
    - high power target, non-trivial cryo requirements
      - LD_2 needs "on the edge", but *just* doable with ESR-I's 15K supply
    - Silviu's new cell model can likely be adapted to 40 cm cell (~ $15k + development time)
    - probably a long lead item

- Hall C "Standard" 10, 20 cm cells (under development)
  - Goal: < 1% density loss for 20 cm LH_2 100 μA w/ 2mm raster

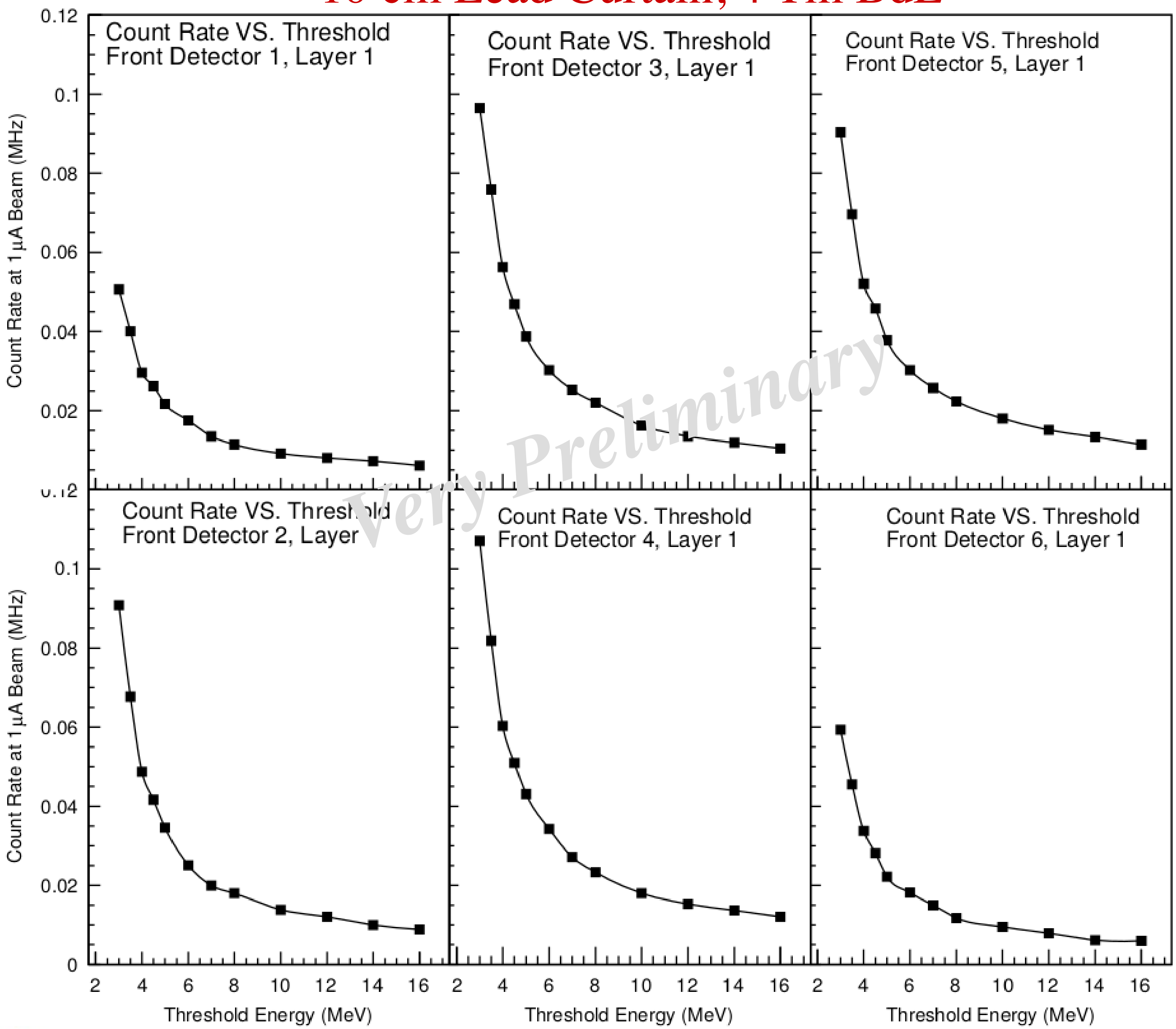
Channel Count for "Plan B"

- 216 scintillator bars
  - 108 (10x10 cm^2) E counters (top + bottom)
  - 52 (1x10 cm^2) dE vetos (top + bottom)
  - 28 (10x10 cm^2) analyzer bars
    - very high rates in forward analyzers
  - 28 (1x10 cm^2) analyzer vetos
    - very high rates, need good timing & short pulse widths
- All bars double-ended readout
  - 432 PMTs
  - High res timing: R+L (offline) coincidence on analyzer bars + vetos (56 bars, 112 ch)
    - BG suppression
    - position information (100 ps hardware timing resolution assumed)
  - Coarser timing (~ 1ns) on dE/E bars (160 bars, 320 ch)
  - Energy/ADC:
    - dE/E on upper/lower bars,
    - walk-correction on TDC timing
- NPOL readout electronics likely located in the Hall
  - not enough patch cables to run upstairs

Rates at front detector plane

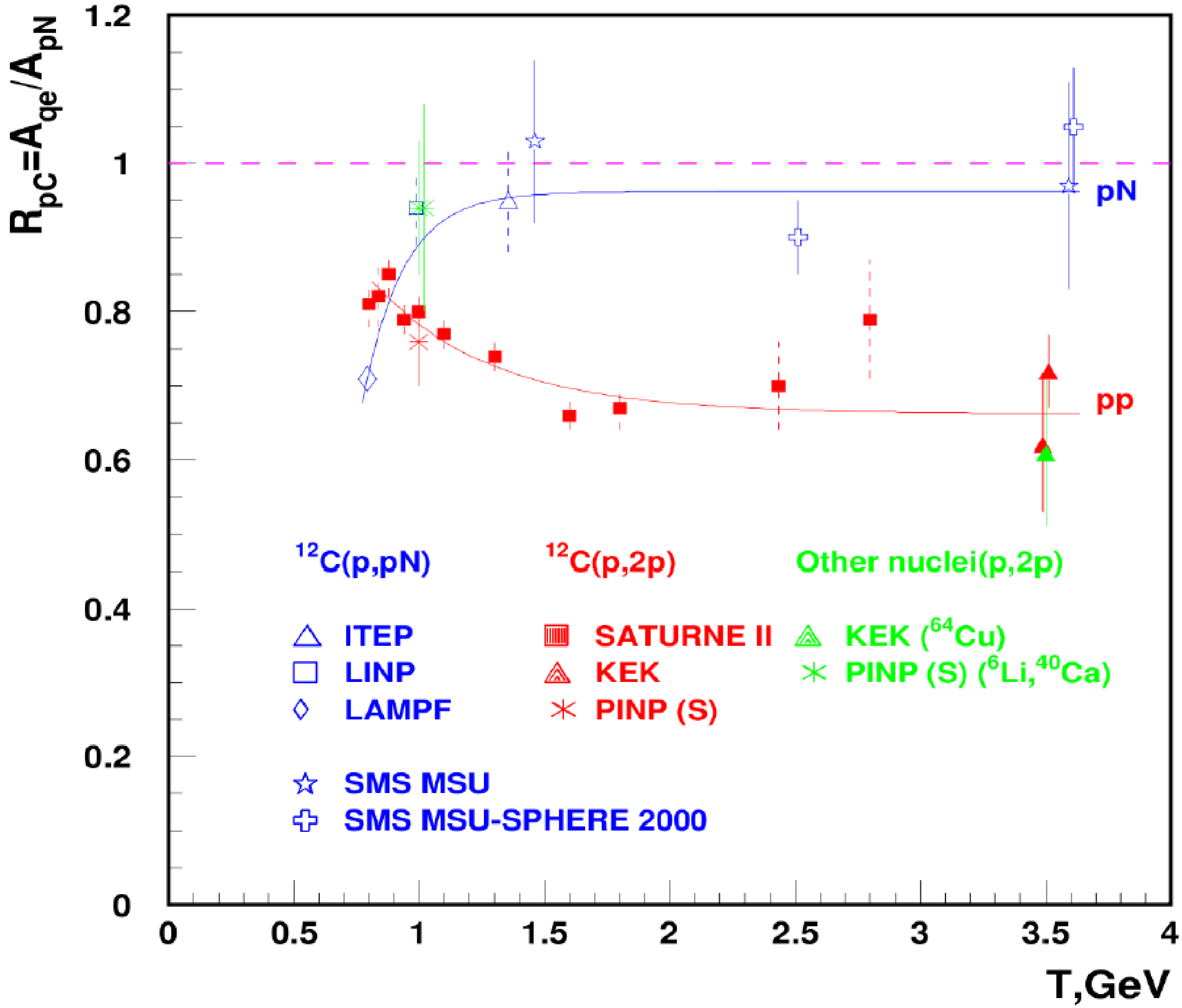
Flux at 28°, E=4400 MeV, 40-cm LD2

10 cm Lead Curtain, 4 Tm BdL



- Rates are high, but perhaps (barely) tolerable at 70 uA.
- 15 cm Pb sheet will be looked at next.
- Still some open questions about these early G4 results need to be understood (ie. neutron flux difference vs DINREG...)

Ay for Quasielastic np



A.A. Yershov et al., Int. Spin Phys. Symposium, Trieste, 2004

Statistical Impact of Moving NPOL

- Initial proposal had NPOL at R = 5m
  - Can *not* achieve desired B•dl with iron-core magnet(s) in ~3m space between NPOL and target.
- Updated dual-magnet layout requires NPOL at R=7m

Q^2	3.95	5.22	6.88
MCEEP rate @ 5m (Hz)	73.02	52.73	39.10
MCEEP rate @ 7m (Hz)	60.07	38.57	26.11
Ratio (Rate@7/Rate@5)	0.82	0.73	0.69
1/SQRT(Ratio)~Stat Uncert	1.10	1.17	1.20

Not too bad!

Note: 5m/7m = 0.71
(5m/7m)^2 = 0.51

- Ratio is better than naïve solid angle scaling due to impact of QE cross section convolution and SHMS acceptance.

Figure of Merit: PAC37 → Plan B

Figure-of-Merit

P_n (MeV/c)	2.9	3.6	4.5
Ay(np)	0.1	0.08	0.06
Eff (QE+ela)	0.016	0.013	0.0090
Eff (Inela)	0.056	0.061	0.0621
FOM(QE+ela) $\times 10^4$	1.64	0.80	0.32
FOM(Inela) $\times 10^4$	1.40	0.97	0.56
FOM(Total) $\times 10^4$	3.04	1.77	0.88
Cos_corr	0.85	0.85	0.85
FOM(Corr) $\times 10^4$	2.58	1.50	0.75
FOM (PAC37) $\times 10^4$	2.07	1.68	1.06

BNL 48D48 Costs (< *$100k*)

- Shipping to JLab — $8k
  - 5 truckloads @ $1300/load (based on Hall A SBS shipment)
- Miscellaneous hardware — $15k
  - water/power manifolds, bolts, tension rods, etc
  - replacement estimate from R. Wines (SBS)
- Support Stand — $15k
  - nothing fancy, steel/concrete blocks would work
- Power Supply — —
  - QTOR, Super BigBite (schedule dependent)

TOTAL (*Rounding up and multiply by 2x*) : < $100k

- Unknowns
  - Coil pack condition looks promising, but is not guaranteed
    - Hall A has set of BNL coils on-site now (could be our primary coils, or spares)
    - Initial tests are positive: one is in good shape; second is being cleaned up.

Detectors Available

Neutron Detectors:

32 10 x 10 x 100 cm in HAND
2 10 x 10 x 100 cm at KSU
34 4 x 5 x 40” in HAND
68 Total

~80 10 x 10 x 160 cm from Hall A GEn

So need 16 more 10 x 10 x 100 cm for Plan A
Plan B OK, using the 160 cm detectors

Additionally, there exists: (could be cut and machined)

8	4 x 20 x 40 in	detectors at KSU
3	4 x 10 x 40 in	detectors at KSU
?	4 x 10 x 40 in	detectors in HAND
16	10 x 22.5 x 400 cm	detectors from BLAST

Veto Detectors: 22 (Hall C) + 24 (Hand) + ??

B. Anderson (10/2013)