Measurement of $\mathrm{G_E^n/G_M^n}$ by the Double Polarised $^2\mathrm{H}(\vec{e},e'\vec{n})$ Reaction

Proposal PR12-17-004 to PAC 45

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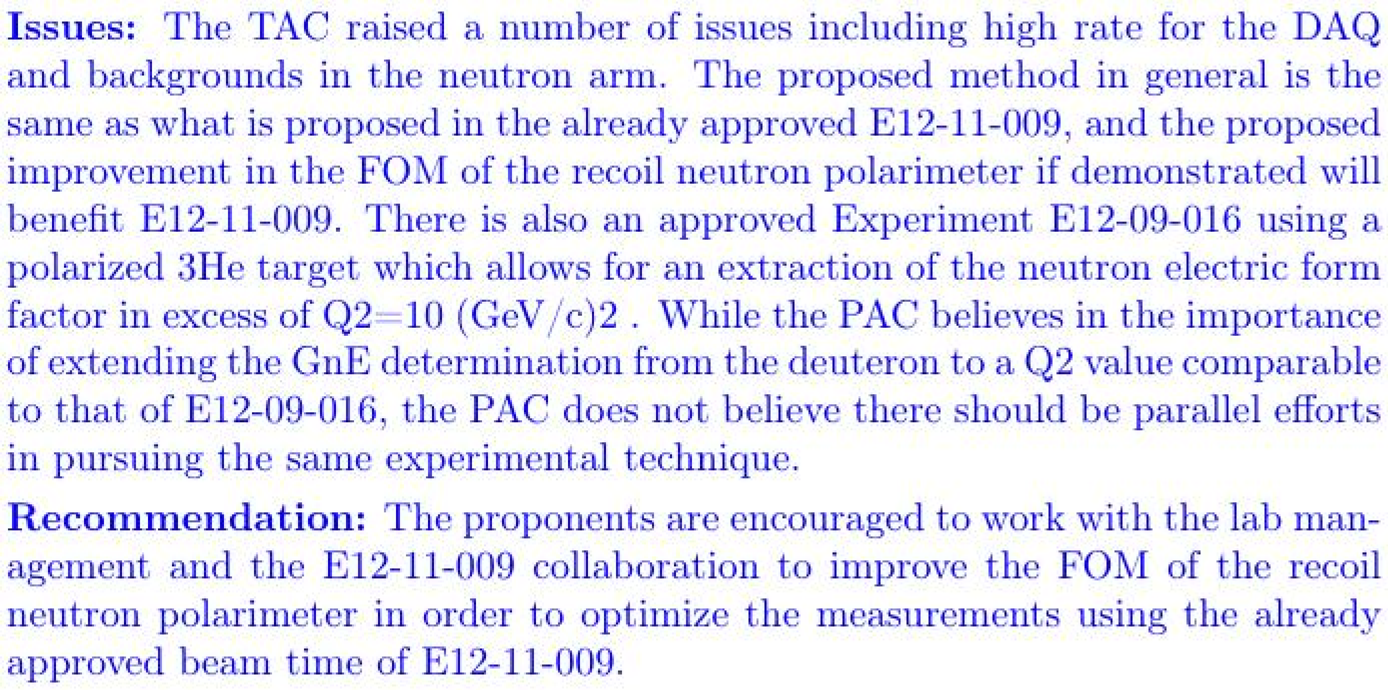
for the
Hall-A and SBS Collaborations

PAC Response to LOI12-15-003

(the precursor to PR12-17-004)



Issues: The TAC raised a number of issues including high rate for the DAQ and backgrounds in the neutron arm. The proposed method in general is the same as what is proposed in the already approved E12-11-009, and the proposed improvement in the FOM of the recoil neutron polarimeter if demonstrated will benefit E12-11-009. There is also an approved Experiment E12-09-016 using a polarized 3He target which allows for an extraction of the neutron electric form factor in excess of Q2=10 (GeV/c)2 . While the PAC believes in the importance of extending the GnE determination from the deuteron to a Q2 value comparable to that of E12-09-016, the PAC does not believe there should be parallel efforts in pursuing the same experimental technique.

Recommendation: The proponents are encouraged to work with the lab management and the E12-11-009 collaboration to improve the FOM of the recoil neutron polarimeter in order to optimize the measurements using the already approved beam time of E12-11-009.

- Discussions with CGEN group who proposed E12-11-009
  B. Sawatzky and M. Kohl have joined PR12-17-004 as co-spokespersons
  W. Tireman has joined PR12-17-004 as collaborator
- Request 100 hr for 1 data point @ $Q^2 = 4.5$ (GeV/c)^2
  Identical kinematics to $Q^2 = 4.5$ (GeV/c)^2 G_{Mn}/G_{Mp} point (SBS experiment E12-09-019)
- Configure SBS neutron polarimeter to measure both np→pn and np→np scattering channels...include detectors for large-angle, low-momentum protons, additional to small-angle, high-momentum proton detector
- Compare polarimetry FoM np→np and np→pn
  Use results to optimize polarimetry at higher Q^2 (up to 9.3 (GeV/c)^2)

The Need for G_{En}/G_{Mn} Data at Higher Q^2

- In terms of Q^2 range and precision, neutron measurements still lag way behind proton measurements
- For measurements in space-like domain at medium-high Q^2 JLab is the only viable lab. Quasi-elastic electron scattering from neutron in ^{2}H, ^{3}He…
- Double polarised experiments since ~ 1990

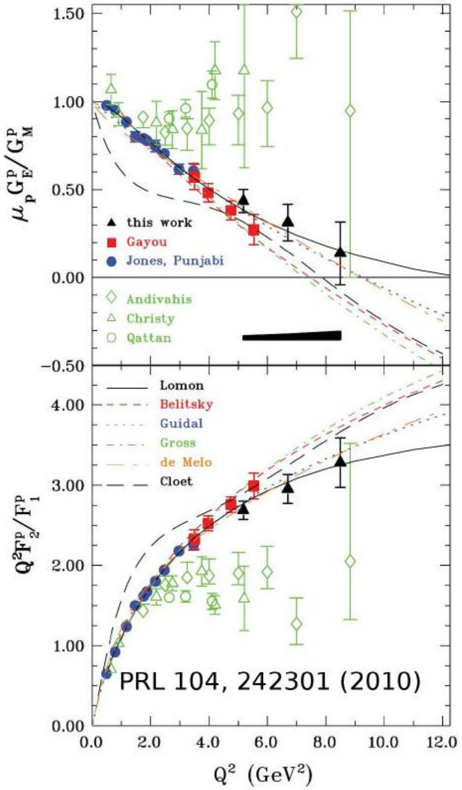
  Better access to relatively small G_{En} (compared to G_{Mn})

  Low sensitivity to possible two-photon exchange effects

  (viz. different G_{Ep}/G_{Mp} from Rosenbluth and double polarized experiments)
- JLab: E12-09-016 G_{En}/G_{Mn} with polarized electron beam & ^{3}He target up to Q^2 of ~10 (GeV/c)^2
- Independent verification of results necessary…alternative method with polarized electron beam, unpolarized ^{2}H target and polarimeter to measure polarisation transfer to recoiling neutron.
- QE signal much cleaner with ^{2}H target compared to ^{3}He
- ^{2}H experiment should, as far as possible, match kinematic range and precision of ^{3}He experiment.
- Up to now no recoil polarimetry measurement at $Q^2 > 1.5$ (GeV/c)^2

Scaling of EM Form Factors

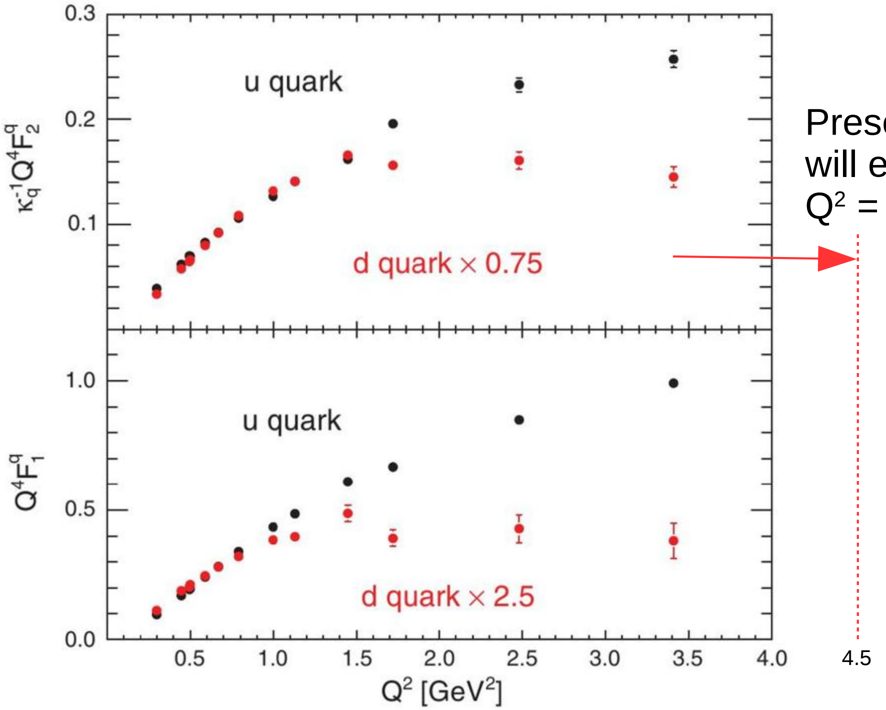
Proton/Neutron distributions



PRL 104, 242301 (2010)

Flavor-separated u/d distributions

PRL 106, 252003 (2011)



Present measurement will extend separation to Q^2 = 4.5(GeV/c)^2

No RP data with ^{2}H target
Q^2 > 1.5 (GeV/c)^2

$$G_E = F_1 - \tau F_2 \qquad G_M = F_1 + F_2 \qquad F^u_{1,2}(Q^2) = F^n_{1,2} + 2F^p_{1,2} \qquad F^d_{1,2}(Q^2) = 2F^n_{1,2} + F^p_{1,2}$$

Most cited JLab publication: M.Jones et al., PRL 84(2000),1398

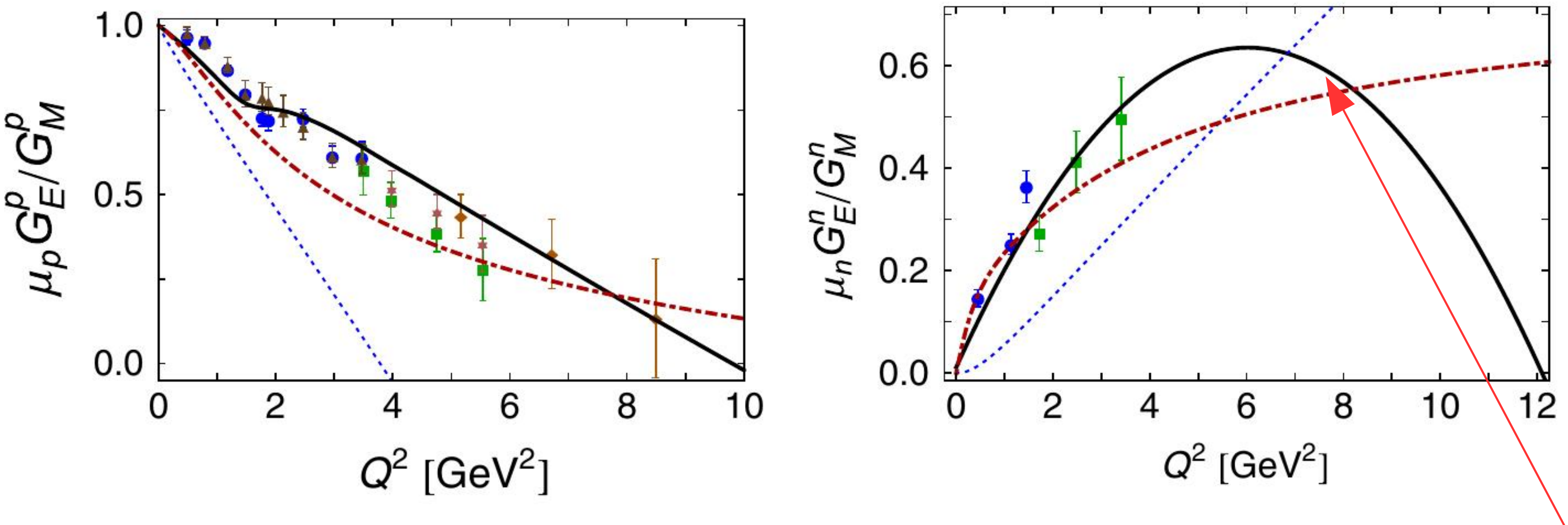
Double polarized experiments show that $\mu_p G_{Ep} \neq G_{Mp}$

u/d flavour separation….quite different u,d dependence on Q^2

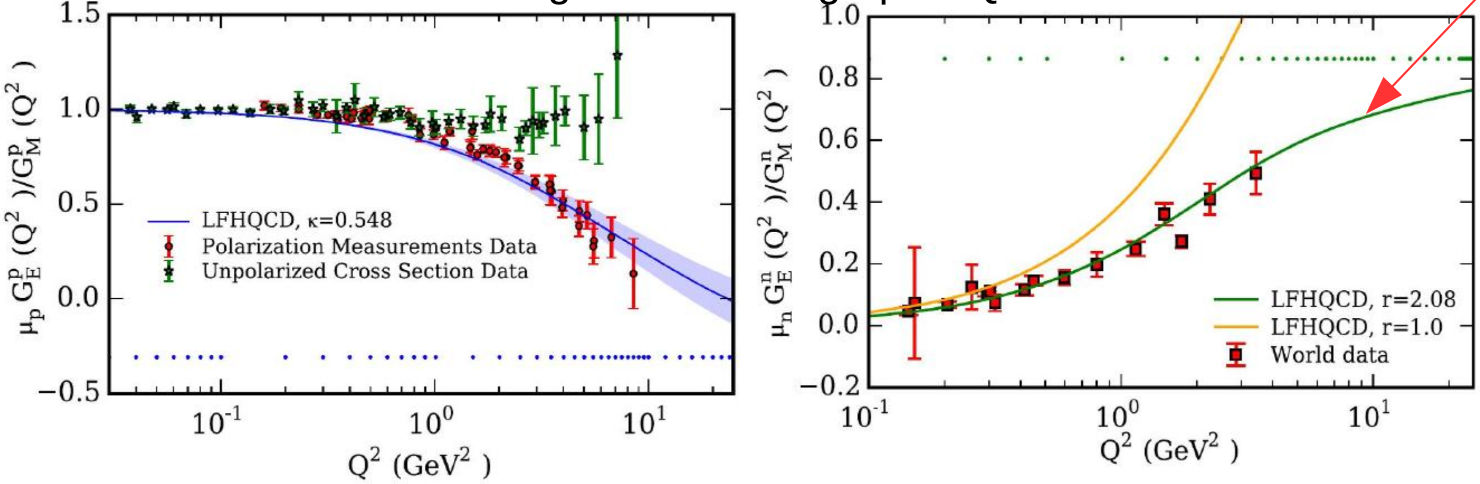
diquark configuration?

Continuing Theoretical Interest in G_E/G_M

J. Segovia et al., Few-Body Syst. 55 (2014), 1185.
DSE common framework N-elastic and Δ-transition form factors



R. S. Sufian et al., Phys. Rev. D95(2017),014011.
Light Front Holographic QCD



Different theoretical frameworks...
Very different predictions for $\mu_n G_{En}/G_{Mn}$
Vital to have new data

Summary of Experimental Method

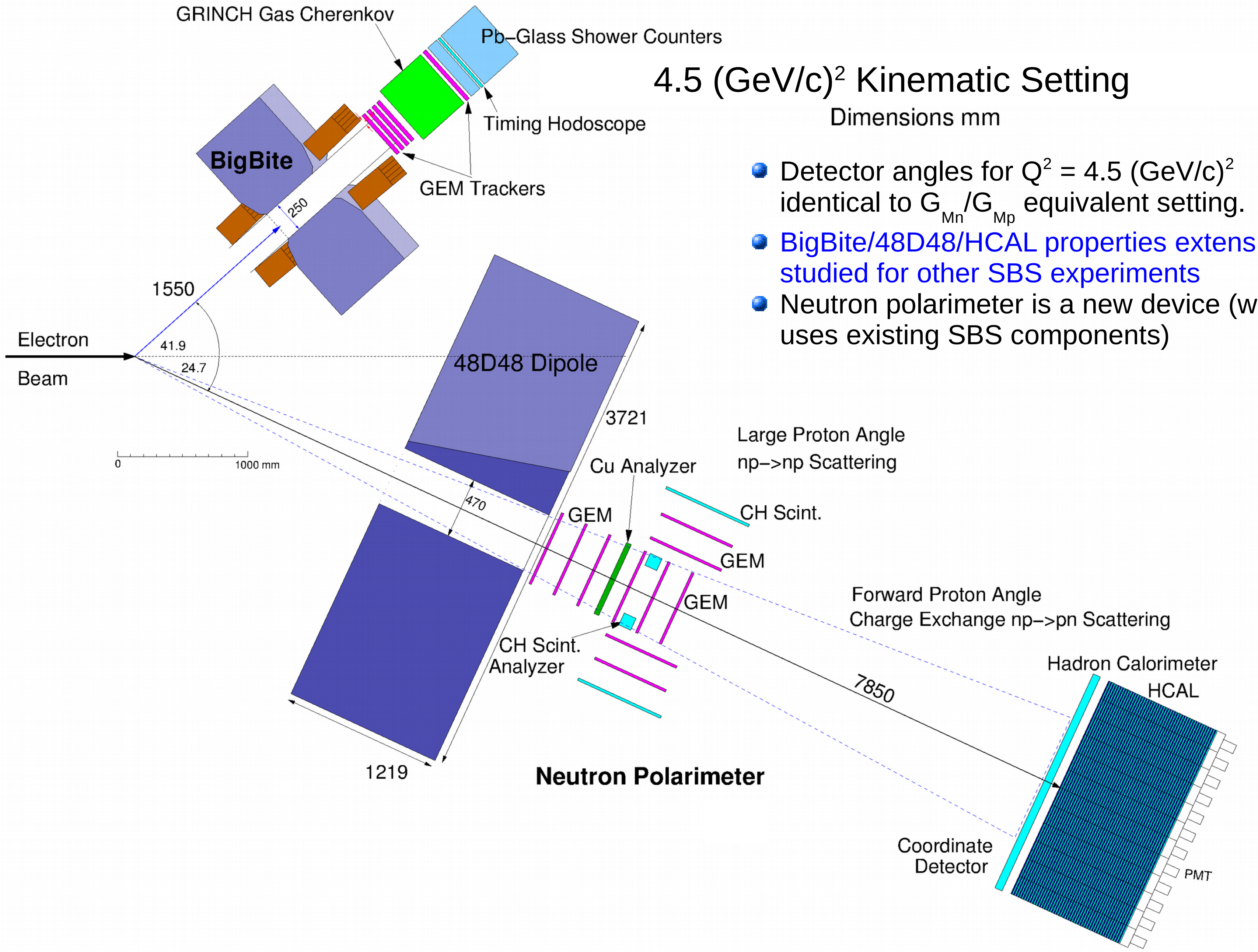
Obtain G_{En}/G_{Mn} for Q^2 of 4.5…..eventually up to ~ 9 $(GeV/c)^2$

Measure double-polarised $^2H(\overrightarrow{e},e'\overrightarrow{n})p$

As opposed to E12-09-016 $\overrightarrow{^3He}(\overrightarrow{e},e'n)pp$

- Polarization ratio of final-state neutron P_x/P_z → G_{En}/G_{Mn} (precess P_z → P_y in dipole magnetic field)
- Cryogenic D_2 Target 10 cm long
- 40 µA 80% polarized electron beam, L = 1.26 x 10^{38} $cm^{-2}s^{-1}$
- BigBite e' detector (same configuration as E12-09-019 G_{Mn}/G_{Mp})
- SBS Neutron polarimeter: acceptance well matched to electron arm Polarimeter detects high-momentum, small angle protons produced by np→pn **AND** low-momentum large-angle protons produced by np→np scattering
- **Apart from polarimeter very similar to G_{Mn}/G_{Mp} E12-09-019 setup**

Experiment Layout



4.5 $(GeV/c)^2$ Kinematic Setting

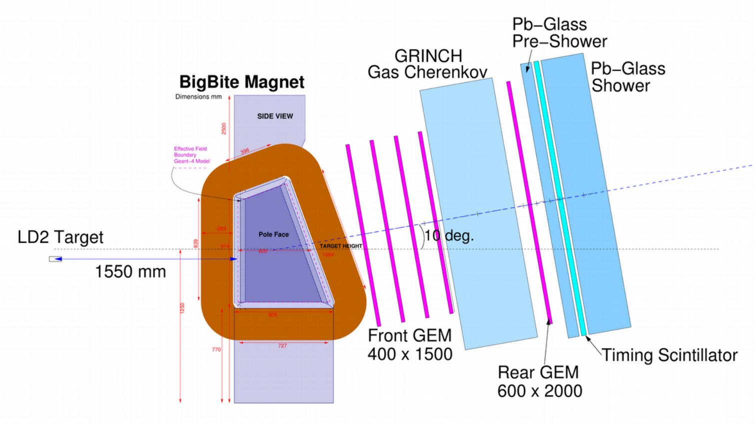
Dimensions mm

- Detector angles for $Q^2 = 4.5\ (GeV/c)^2$ identical to G_{Mn}/G_{Mp} equivalent setting.
- BigBite/48D48/HCAL properties extensively studied for other SBS experiments
- Neutron polarimeter is a new device (which uses existing SBS components)

Experimental Components Common to E12-09-019

E12-09-019 Scheduled 2019 (Readiness Review June 2017)

Electron Spectrometer BigBite

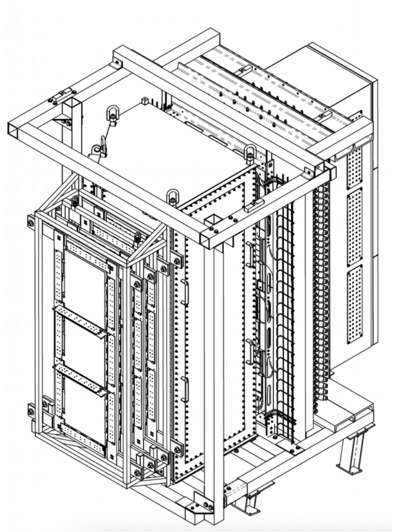


$\Omega \sim 55$ msr

$\delta p/p \sim 0.5\%$

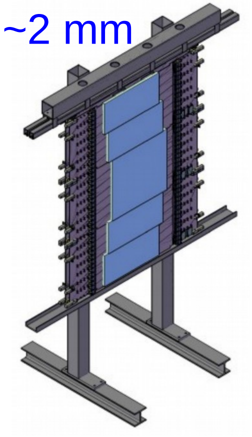
$\delta\theta \sim 1$ mr

$\delta z \sim 2$ mm @ target



Coordinate Detector CDet

$\delta x, \delta y \sim 2$ mm

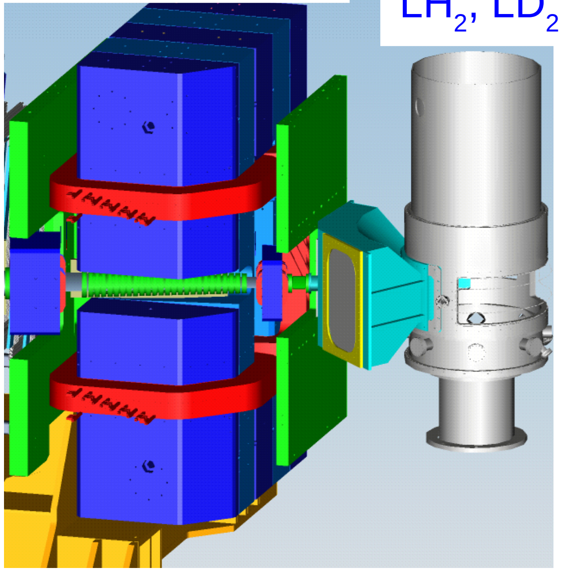


48D48 Dipole

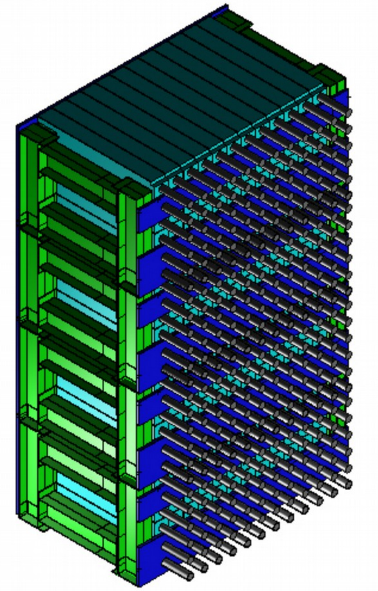
~2 Tm integrated field

Hall-A Target

LH_2, LD_2, C-foil



Hadron Calorimeter HCAL

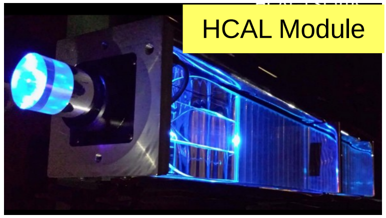


80 – 90% efficiency

multi-GeV p and n

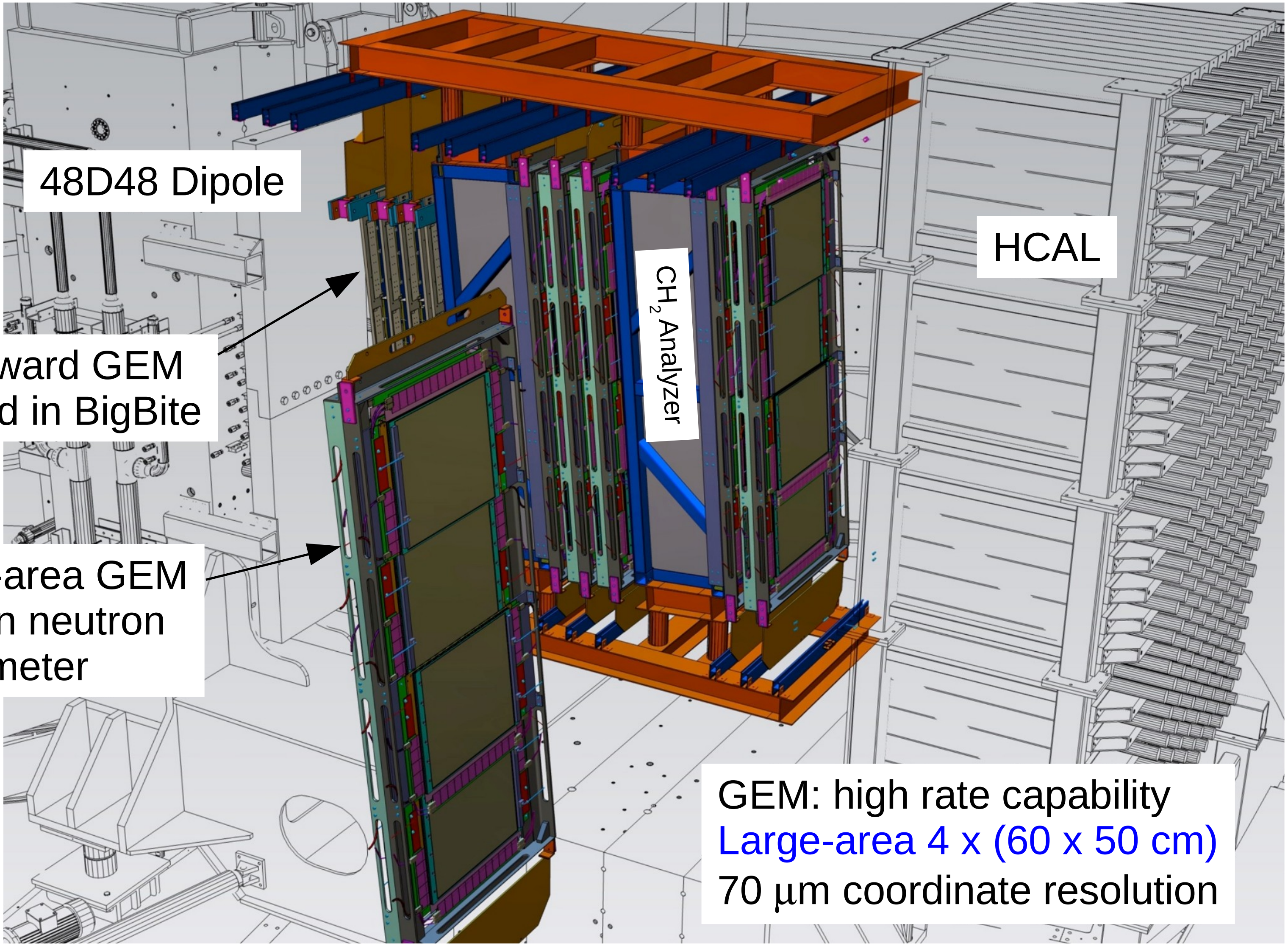
Effective suppression of soft background

~0.5 ns timing resolution



Gas Electron Multiplier (GEM) Chambers

Proton polarimeter for E12-07-109 G_{Ep}/G_{Mp}



48D48 Dipole

HCAL

CH_2 Analyzer

Forward GEM used in BigBite

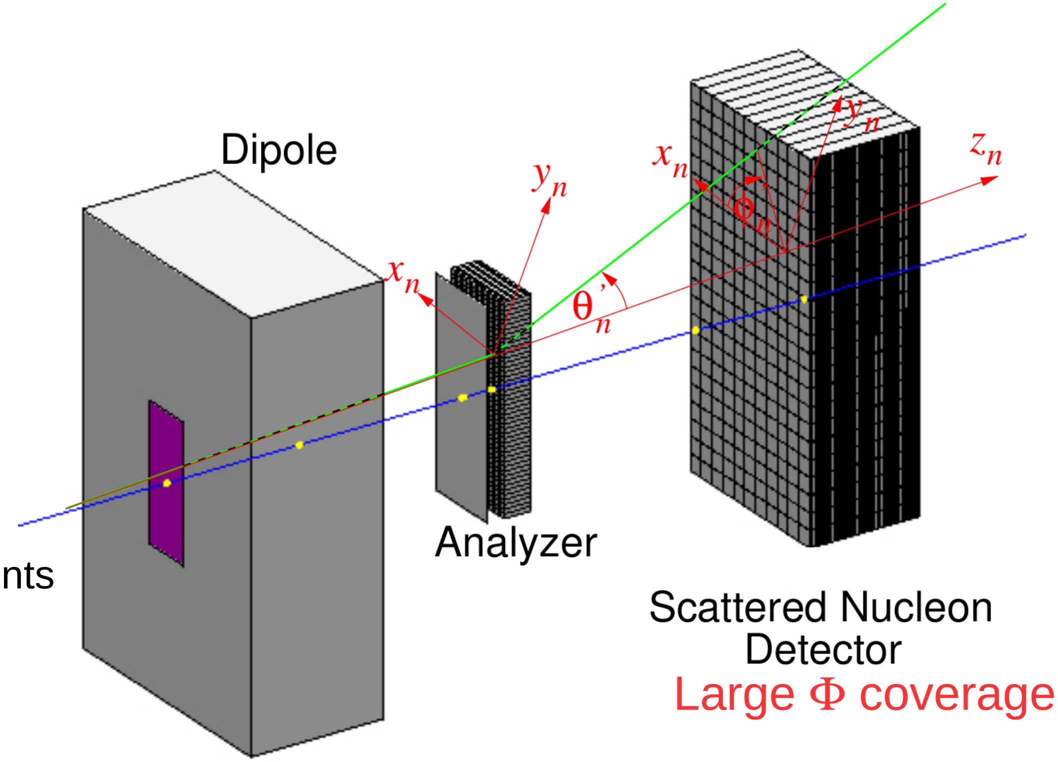
Large-area GEM used in neutron polarimeter

GEM: high rate capability
Large-area 4 x (60 x 50 cm)
70 µm coordinate resolution

G_E/G_M using Recoil Polarimetry

A.I.Akhiezer et al., JEPT 33 (1957),765
R.G.Arnold, C.E.Carlson and F.Gross, Phys.Rev. C23(1981),363

$$\begin{aligned} P_x &= -hP_e \frac{2\sqrt{\tau(1+\tau)}\tan\frac{\theta_e}{2} G_E G_M}{G_E^2+\tau G_M^2(1+2(1+\tau)\tan^2\frac{\theta_e}{2}} \\ P_y &= 0 \\ P_z &= hP_e \frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2\frac{\theta_e}{2}}\tan\frac{\theta_e}{2} G_M^2}{G_E^2+\tau G_M^2(1+2(1+\tau)\tan^2\frac{\theta_e}{2})} \\ \frac{P_x}{P_z} &= \frac{1}{\sqrt{\tau+\tau(1+\tau)\tan^2\frac{\theta_e}{2}}}\cdot\frac{G_E}{G_M} \end{aligned}$$



Large Φ coverage

Recoil Polarimetry...
N-N scattering $V_{so}(\boldsymbol{l.s})$→

ϕ dependence → transverse polarisation components

$$\sigma(\theta'_n,\phi'_n) = \sigma_\circ\left(1+P_e\alpha_{eff}\left[P_x^n\sin\phi'_n+P_y^n\cos\phi'_n\right]\right)$$

Precession angle of nucleon P_z through dipole

$$\chi = \frac{2\mu_N}{\hbar c\beta_N}\int_L B.dl$$

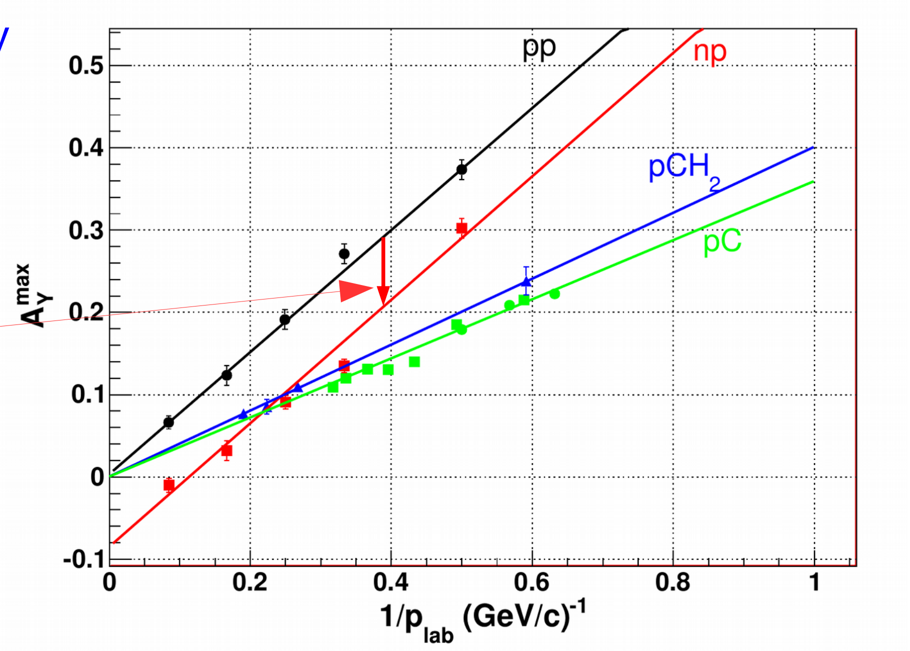
Integrated Field ~2 Tm: $\chi\rightarrow 70°$ as $\beta_n\rightarrow 1$

Nucleon Polarimetry
A_y Elastic (-like) N-N Scattering

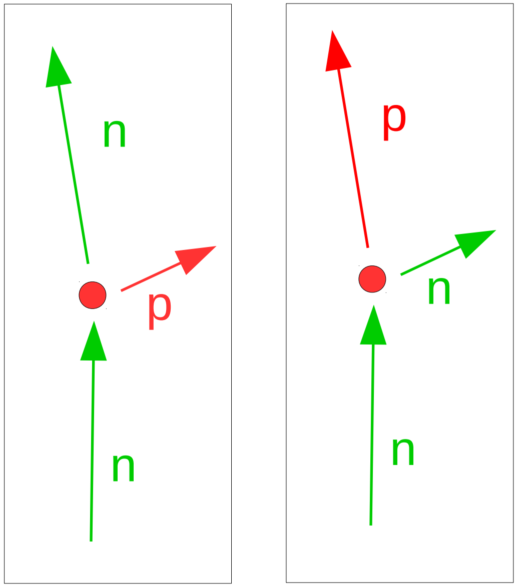
- Elastic np→np or pp→pp for highest A_y value. LH_2 analyser possibly not feasible technically at JLab
- Proton A_y measurements C, CH_2: detect forward proton + X undetected
  This does not select elastic or quasi-elastic exclusively
- Empirical p+C value of A_y ~0.5 of free elastic p-p scattering
  Fermi-motion smearing of the elastic signal
  Inelastic contamination
- A_y for pp→pp scales as $1/p_{lab}$
  np→np has similar slope but negative offset
- Up to recently no data on n+C→n+p+X at p_{lab}~several GeV/c (nor for any complex nucleus)

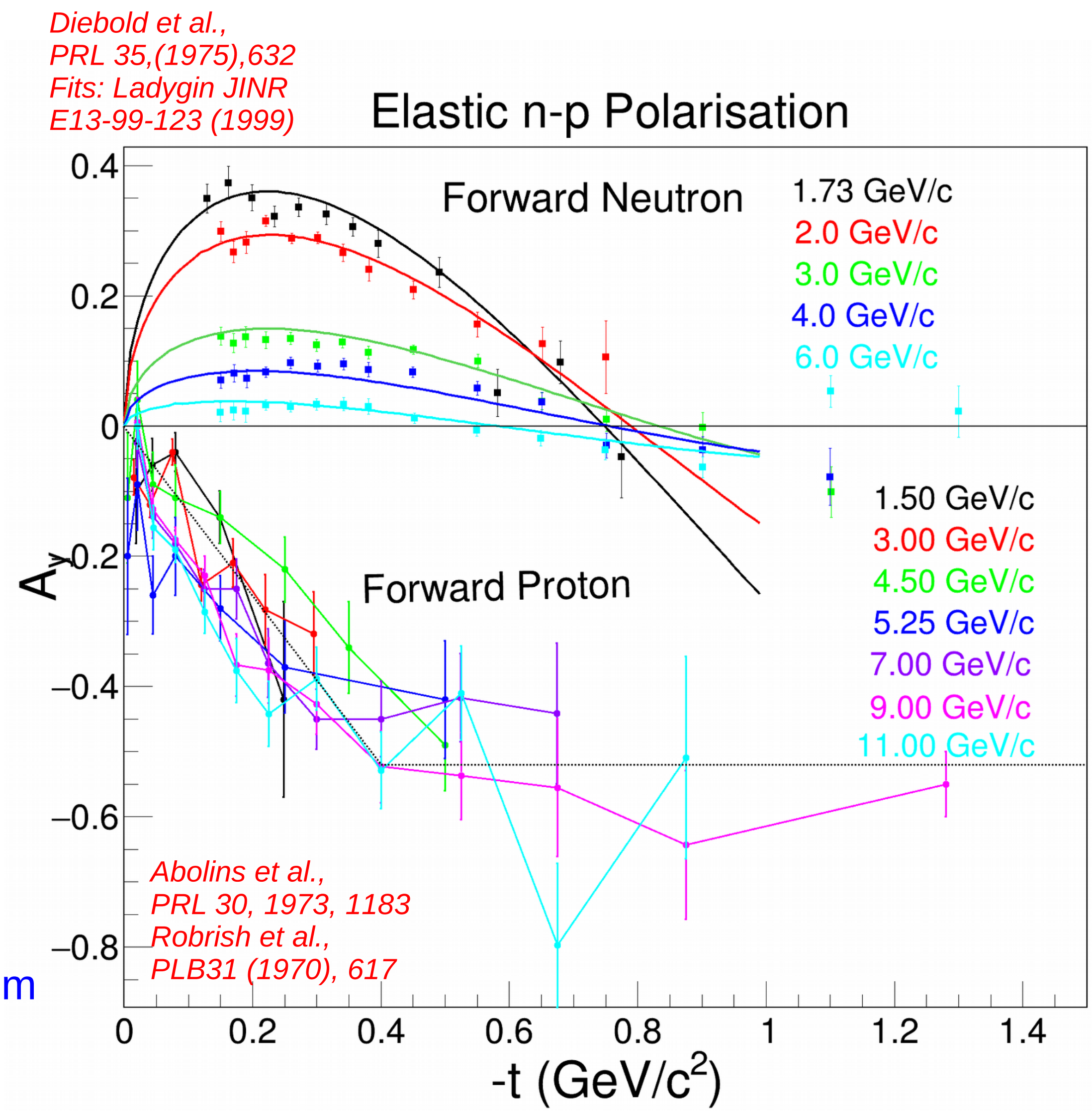
Peak Analysing Power of N-N Scattering
A_y^{max} @ $p_\perp$ ~ 300 - 400 MeV/c

●🟥 R. Diebold et al., PR. 35(1975), 632.
S.L. Kramer et al., PRD17(1978), 1709.
▲ L.S. Azhgirey et al., NIM A538(2005), 431.
🟩 N.E. Cheung et al., NIM A363(1995), 561.
● I.G. Alekseev et al., NIM A434(1999), 254.



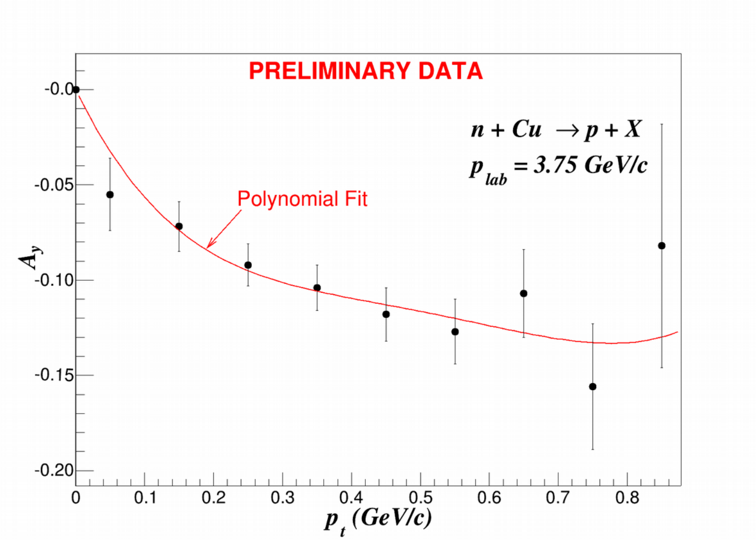
n-p Elastic: Forward Neutron vs. Forward Proton

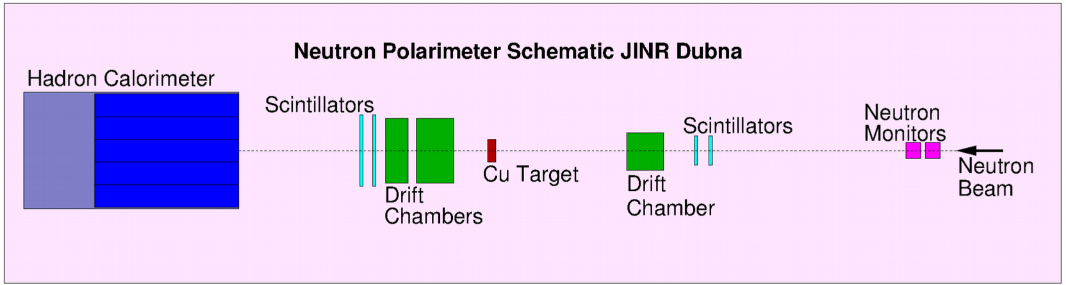


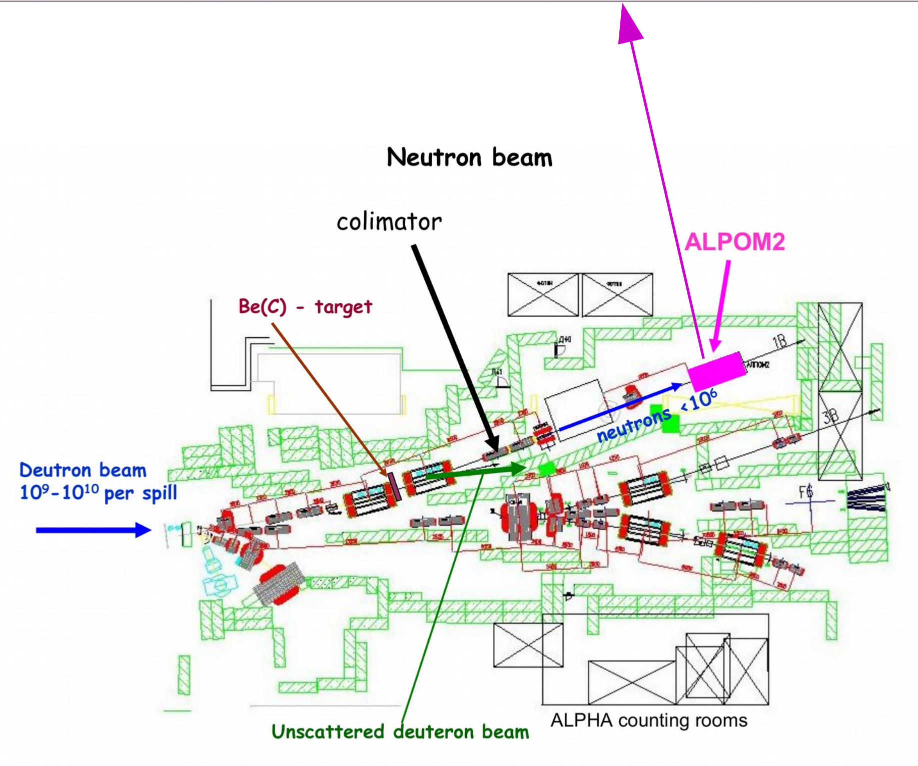


- Measurements from 1970's
- A_y for n-p (or p-n) falling rapidly with increasing neutron momentum
- A_y for charge-exchange n-p large at sufficiently large t (θ_p ~ few deg.)
- No apparent strong incident momentum dependence for charge-exchange A_y
- $\sigma_{np\rightarrow np}$ factor ~10 higher than $\sigma_{np\rightarrow pn}$

The Dubna Experiment



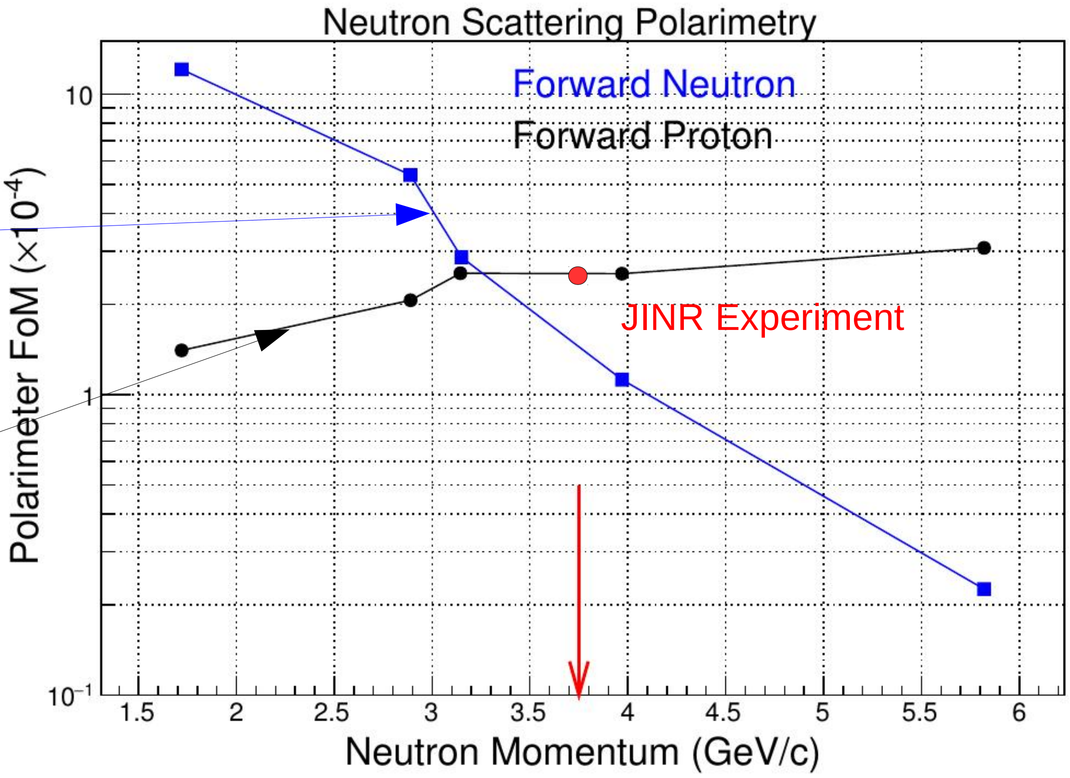




- JINR Dubna Nov 16 – Feb 17.
- Measure asymmetries polarized np→pn C, CH, CH_2, Cu Target
- p_{lab}: 3.0 – 4.2 GeV/c
- Extract A_y as a function of $p_t = p_{lab} sin\theta$
- Cu asymmetry similar to C
- Use polynomial fit to Cu data to calculate FoM of JLab neutron polarimeter

Polarimeter Figure of Merit

$$\mathcal{F}^2(p_n) = \int \varepsilon(p_n, \theta_n^{'})\, A_y^2(p_n, \theta_n^{'}) d\theta_n^{'}$$



Plastic scintillator analyzer
np→np (forward neutron)

Cu analyzer
np→pn (forward proton)

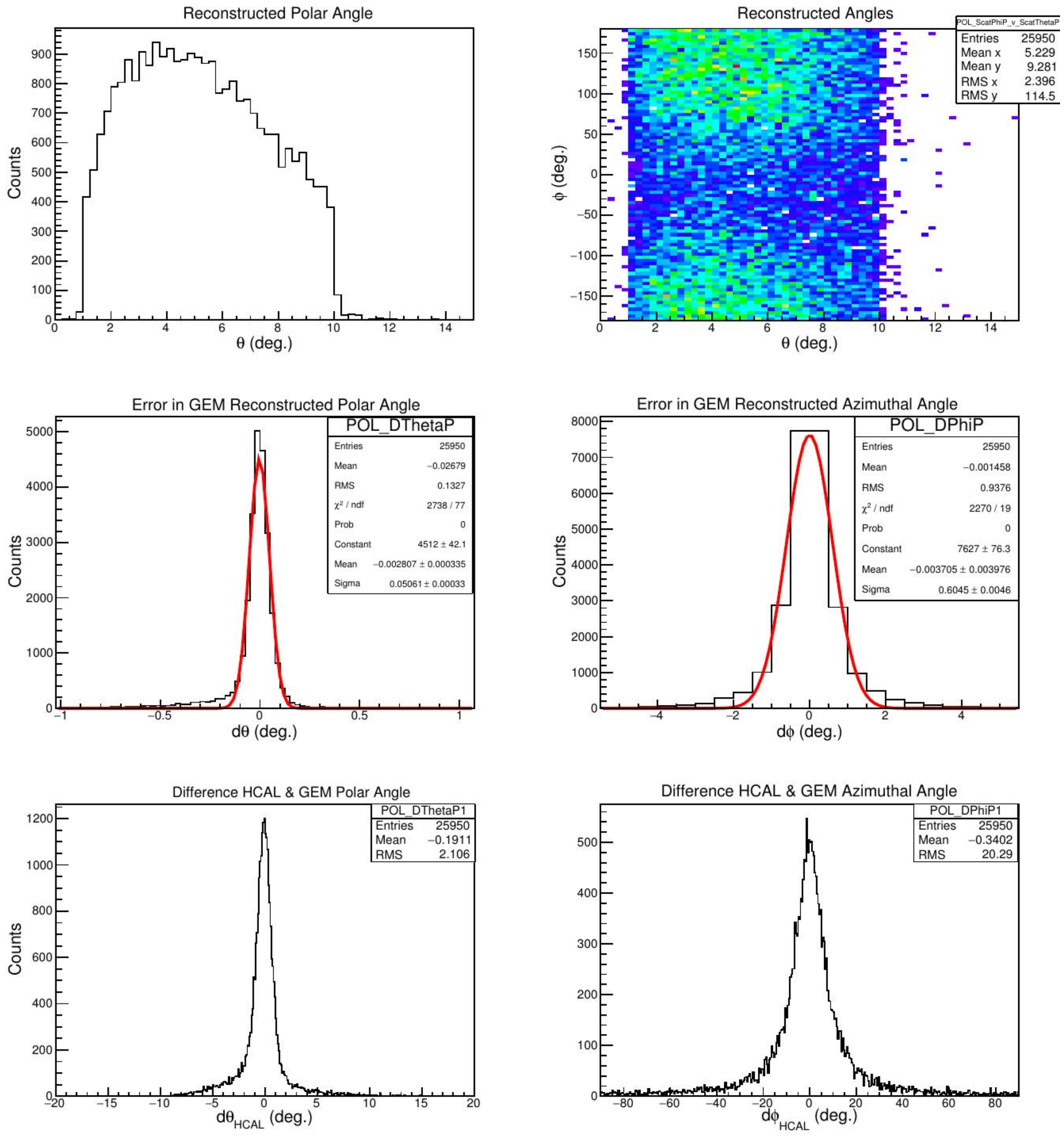
- Calculate efficiency of polarimeter as function of θ_N by Monte Carlo
- A_y for free np→np: JINR fit to $\boldsymbol{p_n}$ and $\boldsymbol{t}$ dependence. Scale A_y by 0.5 for ^{12}C scattering
- A_y for np→pn on Cu: New measurement from JINR
  Assume A_y depends on p_t only
  Similar to free np→pn scattering

Forward Proton Angle Reconstruction by GEM

- Reconstruct analyzer hit position and proton angle using GEM position info.

  σ_θ ~ 0.05 deg.

  σ_ϕ ~ 0.6 deg.
- Select polar scattering angle... range depends on p_{lab}
- Select calorimeter energy deposit > ½ peak channel
- Polarimeter detection efficiency ~3%
- Polarimeter similar to Dubna setup...expect similar effective analyzing power

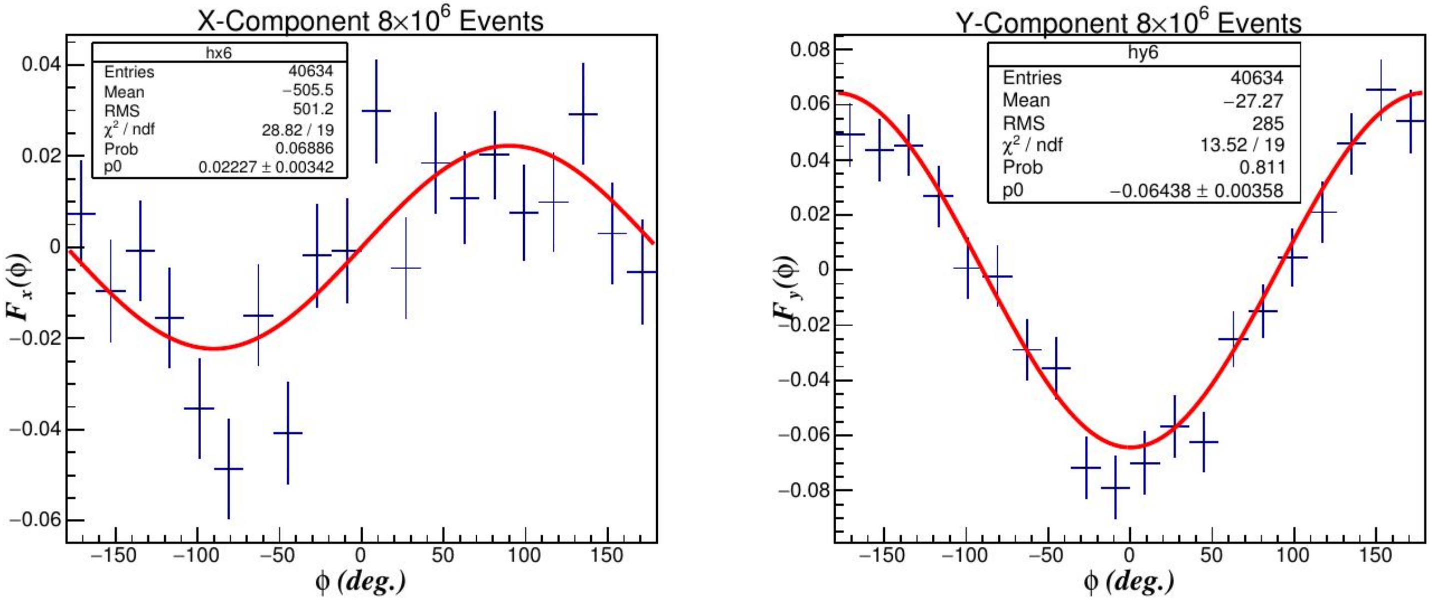


Obtaining Polarisation Components $P_x P_y$

$$\sigma(\theta_n, \phi_n) = \sigma(\theta_n)\left\{1 + P_e A_y^{eff}(P_x \sin\phi_n + P_y \cos\phi_n)\right\}$$

8 x 10^6 simulated events, p_{lab} = 3.15 GeV/c

Proposed data point: 18 × 10^6 incident neutrons


X-Component 8×10⁶ Events

Y-Component 8×10⁶ Events

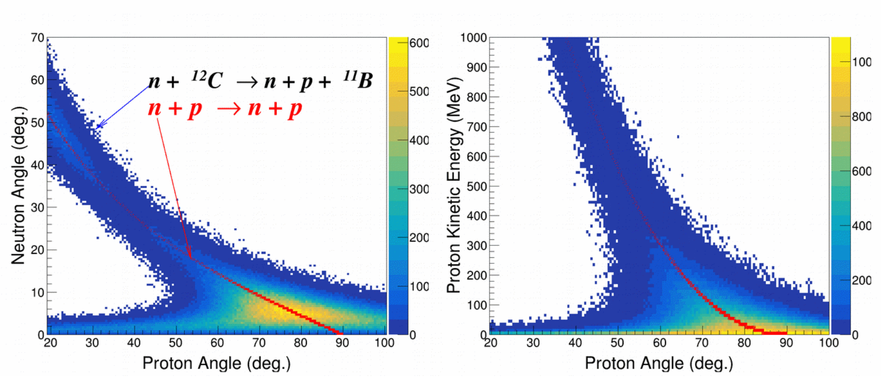
- 4 Comb. beam helicity, SBS dipole polarity $F(\phi_n) = C\{1 \pm |P_x^*| \sin\phi_n \pm |P_y^*| \cos\phi_n\}$
- Unpolarized Distribution $C = F_{++} + F_{--} + F_{+-} + F_{-+}$
- Polarized Distributions $F_x = (F_{++} - F_{-+} + F_{+-} - F_{--})/C$

$$F_y = (F_{++} - F_{+-} + F_{-+} - F_{--})/C$$

- Effective analyzing power of polarimeter ~0.9 × $np \rightarrow pn$ scattering analyzing power
- Its the same for x and y polarisation components
- No significant dependence on p_{lab}

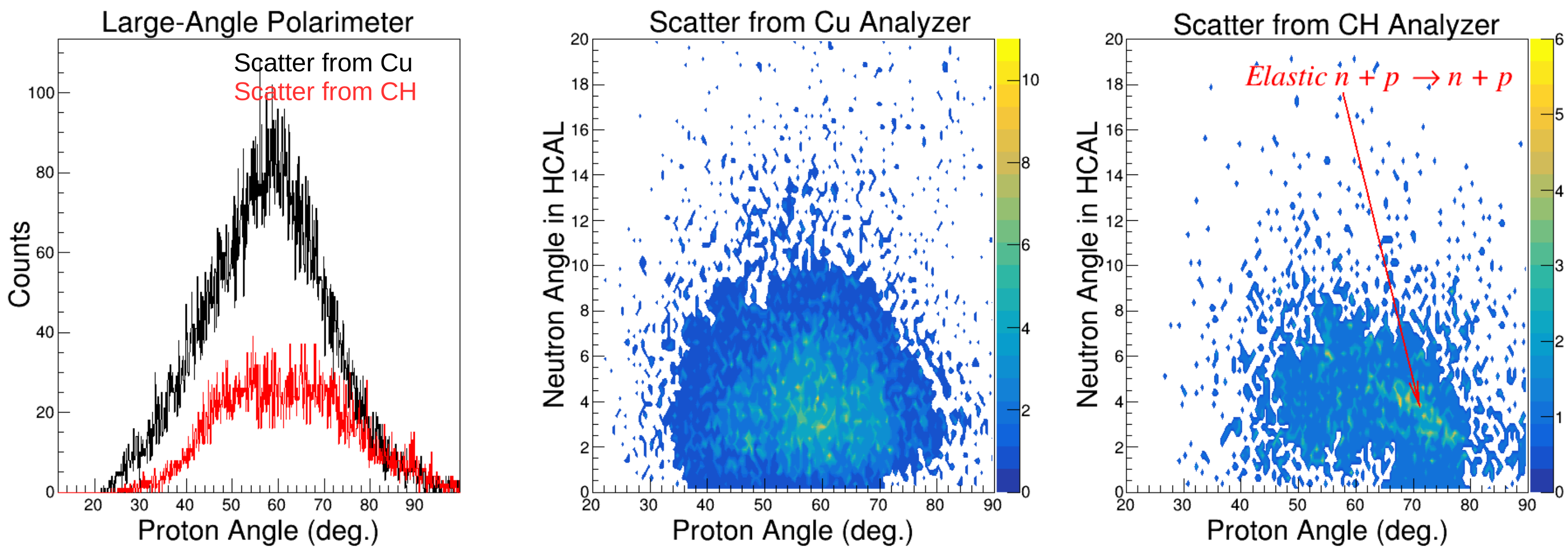
Large-Angle-Proton Polarimetry

Incident Neutron Momentum 3.15 GeV/c
Fermi smearing of proton angle

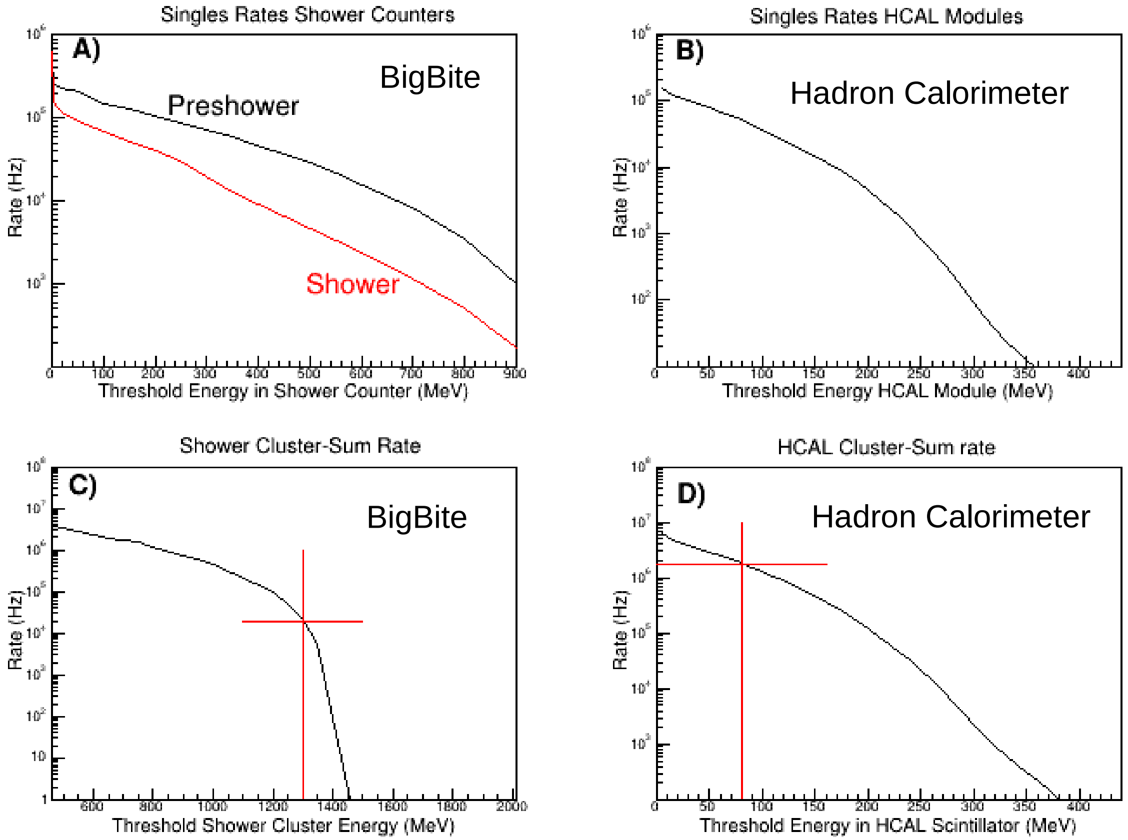


- QE n-p scattering from ^{12}C or ^{57}Cu
  Fermi smearing of large-angle recoiling proton
- ~1% incident neutrons scatter in Cu making detected large angle proton track
- ~0.4% neutrons scatter in CH making detected large angle proton track
- ~25% of detected large-angle protons have coincident energetic neutron in HCAL

Geant-4 Calculation 3.15 GeV/c Incident Neutrons



Trigger Rates @ 40 μA on 10 cm D_2



- Cluster-sum rate in BigBite Pb-Glass
  ~ 20 kHz at threshold of 1.3 GeV (65% $E_{e'}$)
- Cluster-sum rate in HCAL
  ~ 1.7 MHz at threshold of 0.5 E_{peak} for 3 GeV/c nucleons
- BigBite-HCAL coincidence rate for Δt ~ 50 ns: **1.7 kHz**
- DAQ should handle 5 kHz comfortably

Hadron Arm Tracking Detector Rates

4.4 GeV electrons 10 cm D_2 target

Detector	Rate kHz/cm^2
GEM 1	62
GEM 2	63
GEM 3	62
GEM 4	11
GEM 5	11
GEM 6	14
GEM 7	9
GEM 8	27
GEM 9	5
GEM 10	19
CDet 5	30

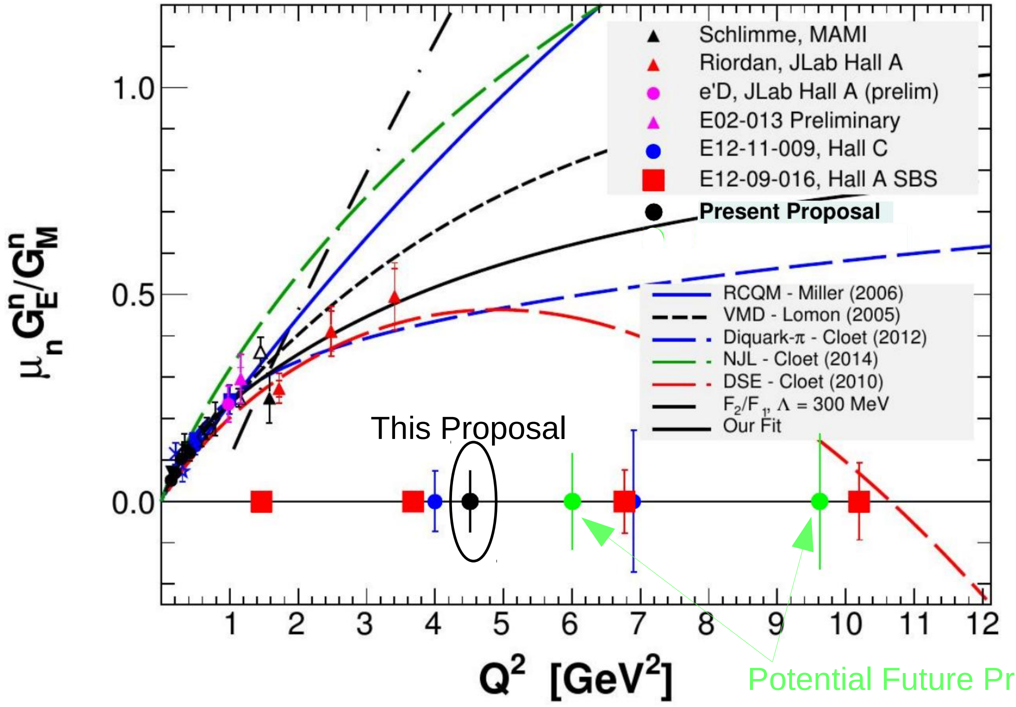
- GEM rates mainly from soft photons
  Rates factor ~10 lower than G_{ep}/G_{mp}
- Beamline shield reduces rates in side detectors
- Well defined $\boldsymbol{q}$ vector from BigBite
  Fermi-smeared QE nucleon “spot” @ analyzer area ~ 100 cm^2 →
  GEM rate within spot ~1.5 MHz
- ~5% chance GEM accidental hit
  if Δt ~ 35 ns (GEM σ_t ~ 6 ns)
- Clean track reconstruction expected

Precision @ L = 1.26 × 10^{38} $cm^{-2}s^{-1}$

Charge exchange np→pn on Cu Analyzer

$$\delta P = \sqrt{\frac{2}{N_{inc}\mathcal{F}^2}} \qquad R = \mu_n G_E^n / G_M^n$$

E_{beam} (GeV)	Q^2 $(GeV/c)^2$	p_n (GeV/c)	Rate (Hz)	FoM × 10^{-4}	Time (hr)	δP	δR
4.4	**4.5**	**3.15**	**48.8**	**2.53**	**100**	**0.019**	**0.078**
6.6	6.0	3.97	26.0	2.53	150	0.024	0.12
8.8	9.3	5.82	2.9	3.08	750	0.029	0.17



This Proposal

Potential Future Proposal

- Current request is for $Q^2 = 4.5\ (GeV/c)^2$
- Estimates from Geant-4 Monte Carlo model + Dubna measurement
- δR based on Glaster G_{En} and Kelly G_{Mn} EMFF parametrisation
- Expect overall systematic error to be ~3.0%

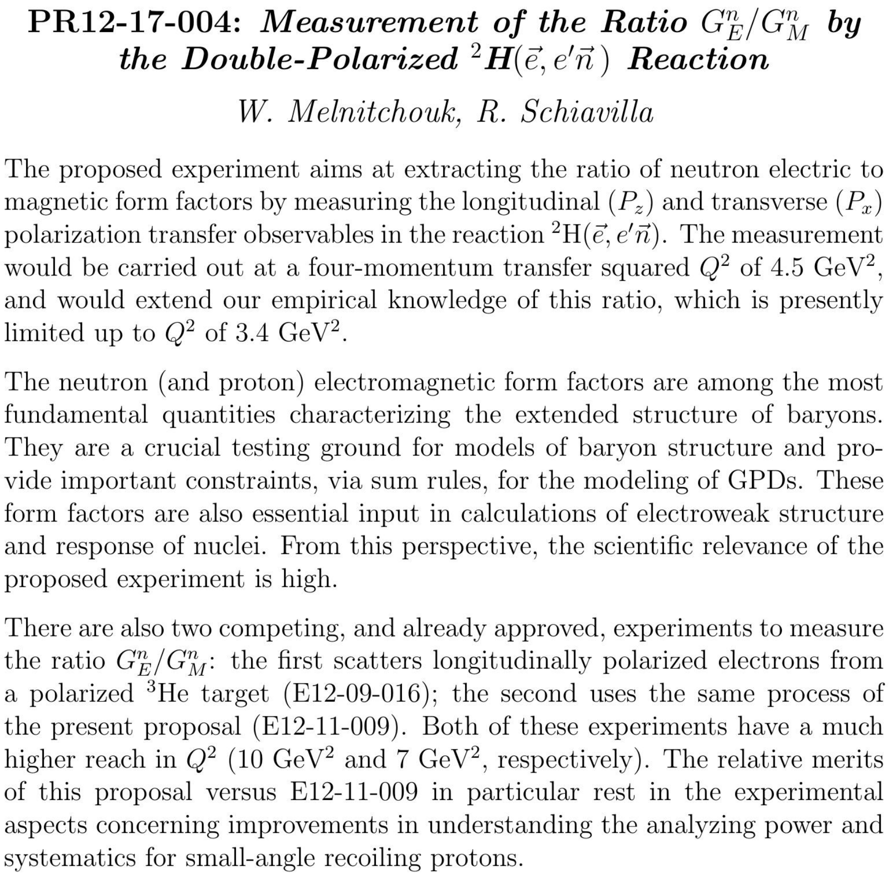
Summary

- We propose a high precision measurement of **G_{En}/G_{Mn} at $Q^2 = 4.5$ (GeV/c)^2**
- Method QE $^2\mathrm{H}(\vec{e},e'\vec{n})$ measure recoil neutron polarization
- BigBite and SBS (configured as a polarimeter) are highly suited to a double polarised, recoil-nucleon polarimetry measurement of G_{En}/G_{Mn}
- Request 100 hr of beam....running together with E12-09-019 G_{Mn}/G_{Mp}
- Data will provide comparison of np→pn and np→np scattering as a neutron polarization analyzer
- Return to future PAC with proposal for higher Q^2 points once best method of polarimetry in Hall-A or Hall-C established

Thanks for your attention

Backup

TAC Theory and Reply



PR12-17-004: ***Measurement of the Ratio*** G_E^n/G_M^n ***by the Double-Polarized*** $^2\boldsymbol{H}(\vec{e}, e'\vec{n})$ ***Reaction***

W. Melnitchouk, R. Schiavilla

The proposed experiment aims at extracting the ratio of neutron electric to magnetic form factors by measuring the longitudinal (P_z) and transverse (P_x) polarization transfer observables in the reaction $^2\text{H}(\vec{e}, e'\vec{n})$. The measurement would be carried out at a four-momentum transfer squared Q^2 of 4.5 GeV^2, and would extend our empirical knowledge of this ratio, which is presently limited up to Q^2 of 3.4 GeV^2.

The neutron (and proton) electromagnetic form factors are among the most fundamental quantities characterizing the extended structure of baryons. They are a crucial testing ground for models of baryon structure and provide important constraints, via sum rules, for the modeling of GPDs. These form factors are also essential input in calculations of electroweak structure and response of nuclei. From this perspective, the scientific relevance of the proposed experiment is high.

There are also two competing, and already approved, experiments to measure the ratio G_E^n/G_M^n: the first scatters longitudinally polarized electrons from a polarized ^{3}He target (E12-09-016); the second uses the same process of the present proposal (E12-11-009). Both of these experiments have a much higher reach in Q^2 (10 GeV^2 and 7 GeV^2, respectively). The relative merits of this proposal versus E12-11-009 in particular rest in the experimental aspects concerning improvements in understanding the analyzing power and systematics for small-angle recoiling protons.

We see this experiment as a stepping stone towards an experiment which will extend the Q^2 range for a recoil polarimetry experiment up to around 9 (GeV/c)^2.
For such an experiment the analyzing power (A_y) of the neutron scattering process, used to determine the neutron polarization, is a major uncertainty in determining a Figure of Merit (FoM) for the experiment. Although the value of A_y cancels in the ratio GEn/GMn, the FoM and hence the statistical uncertainty of the measurement depends on A_y^2. Systematic uncertainties will be relatively small compared to statistical.
We have addressed the lack of neutron Ay data by measuring the polarized, charge-exchange reaction n+A→ p+X at JINR Dubna (A = C, CH, CH2, Cu). Here the proton is knocked out at forward-angle with high-energy. However no polarized data exists for the non-charge-exchange reaction on complex nuclei at multi-GeV energy. This process gives a high-energy forward neutron and a low-energy large-angle recoiling proton. Free, polarized n-p scattering data suggest that at multi-GeV energies the analyzing power of the latter process will be low relative to charge exchange scattering, but never the less it is potentially useful to polarimetry.
Thus we have designed an experiment which has a two-fold purpose:

1. To provide a value of G_{En}/G_{Mn} at Q^2 = 4.5 (GeV/c)^2, which will be the highest value of Q^2 obtained in a double-polarized experiment to date.
2. To provide comparative data on the polarimetry FoM using charge-exchange and non-charge-exchange scattering processes. This information will be used to guide the design of any future experiment (including E12-11-009) which seeks to extend the upper limit of Q^2 obtained in a recoil-polarimetry measurement.

TAC Physics and Reply

1.This experiment proposes to run with the same target, luminosity, beam line, and a very similar spectrometer configuration as SBS experiment E12-09-109 (G_{Mn}), which had a readiness review in June, 2017. Thus, it is assumed here that technical issues concerning any of the E12-09-019 components, in particular the target, the detector systems in BigBite, the SBS magnet, beam steering, Coordinate Detector and HCAL system, have already been addressed elsewhere.
The final report of the readiness review for E12-09-019 was released on 21 June 2017. This contains a number of recommendations which the SBS collaboration as a whole are in the process of implementing.

2. The DAQ data volume will be significantly higher than in E12-09-109 because of the additional GEM tracker planes in this experiment (six polarimeter planes plus four planes in the large-angle proton detection system). Since the luminosity of this experiment will beroughly one order of magnitude lower than in SBS experiment E12-07-109 (G Ep), where simulations have already demonstrated the feasibility of tracking with GEM chambers at high rates in SBS, this is not expected to be analysis issue, but only one of increased data volume. While not believed to be problematic, an estimate of the anticipated event size is missing from the proposal and thus the data volume estimate is not motivated.
We thank the technical committee for pointing out this omission from the proposal. The data volume stipulated in the cover form for the proposal is an under estimate. The amount of data collected per event will be roughly similar to E12-07-109. The estimated maximum data rate for the latter is ~250 MB/s at an interrupt rate of ~5 kHz, which equates to a total volume of ~100 TB over 5 days of production running for the present measurement. Data compression schemes for SBS as a whole are under investigation.

3. The passive Cu analyzer block is straightforward. No issues are foreseen.

4.The polarimeter assembly requires a mounting platform or similar. This either already exists or should be straightforward to construct.
The proton polarimeter for the G Ep/GMp experiment E12-07-109 will have a mountingplatform for the GEM chambers and analyzer blocks. Parts of this assembly will be useable for this experiment, but undoubtedly some new construction will be necessary. Detailed design work will commence if this proposal is accepted.

5.The proposed large-angle proton detection system consists of two active-analyzer scintillator bars, four 60 x 200 cm GEM assemblies, and two additional timing scintillators. It would be important to demonstrate with simulations that these systems will perform as expected in the open SBS geometry and in the presence of low-momentum charged particle background swept by the magnet. In particular, there could be a non-negligible flux at near-parallel incidence to the GEM planes, which would interfere with tracking in these chambers. The authors indicate that they are already in the process of developing these simulations.
Monte Carlo simulations are in progress to estimate the rates in the large angle detectors and also their acceptance for n-p scattering. The horizontal field in the 48D48 SBS dipole deflects charged particles mainly in the vertical plane. For particles produced in the target vicinity the GEM chambers situated immediately downstream of the 48D48 aperture actually experience higher rates than the large-angle GEMs which are situated at the side, outside of direct view of the target. Simulations performed for E12-07-109 predict that the bulk of the GEM rate is due to soft photons. It is also clear that the exit beam line also produces a substantial flux of radiation, which will produce high rates in the beam-line-side counters. Preliminary studies for this experiment show that Pb shielding is effective in suppressing rates in the large-angle, beam-line-side detectors.

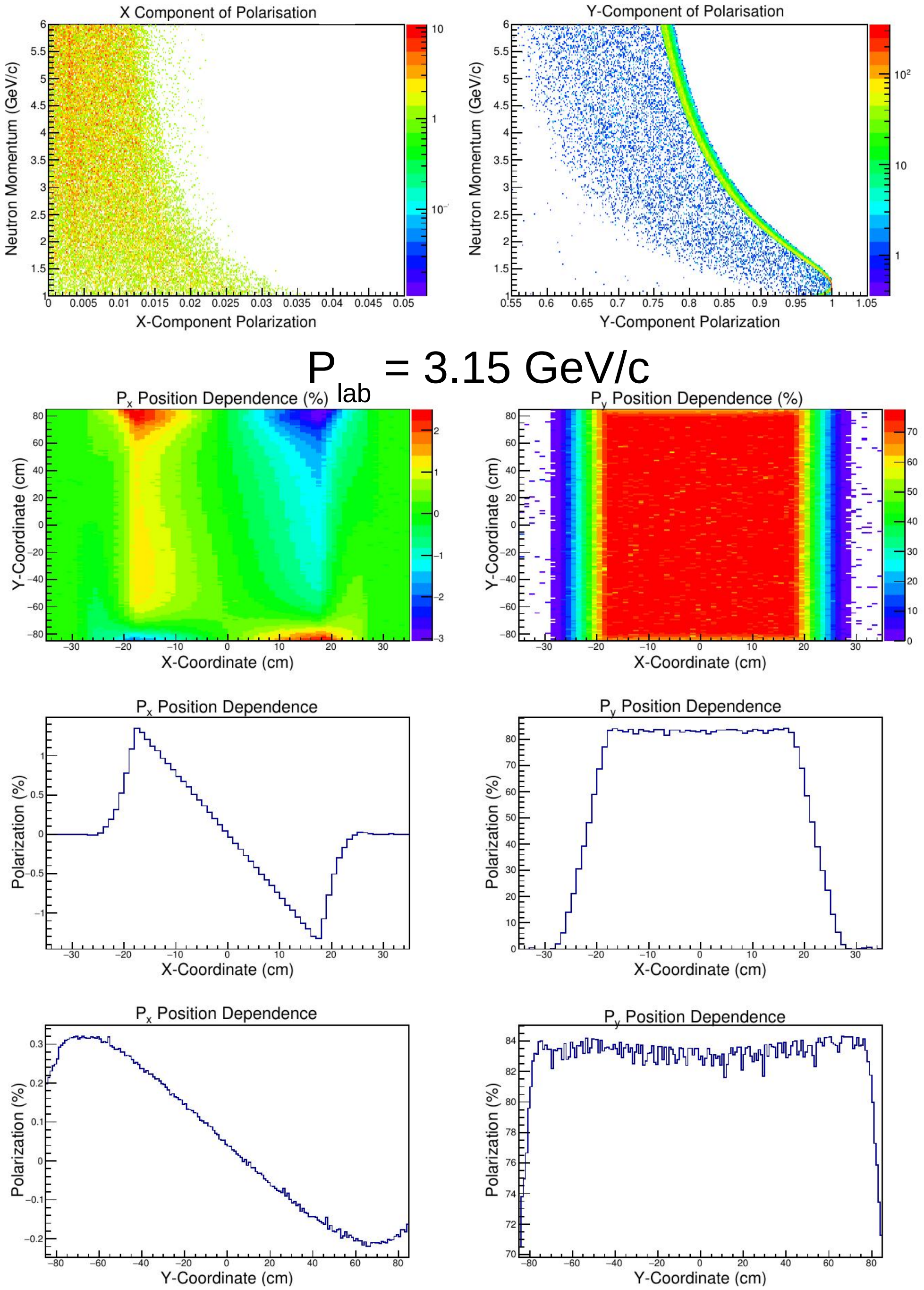
6.If run in conjunction with (i.e. immediately following) E12-09-109, spectrometer settings and optics calibrations could be reused from that experiment. The beam time request reflectsthis scenario, i.e. no time is requested for calibrations, and only a minimal setup time of 12 hours is assumed.
We anticipate that the bulk of the setting up for the polarimeter components (ie detector systems additional to E12-09-019) would be carried out prior to the start of beam for E12-09-019. Change over would involve the moving of the these components into the SBS acceptance and coupling the data readout electronics into the main DAQ. We believe that 12 hr is a reasonable time to accomplish this, given careful consideration of the setup before beam delivery starts.

7.If not run in conjunction with E12-09-109, this would be a large installation experiment. Additional setup and calibration time would be needed.
This is indeed true. We have purposely limited the scope of the present experiment so that the beam time requirement for production running is modest, and would not represent a large overhead on top of E12-09-019. Running in conjunction with E12-09-019 represents an efficient use of personnel and minimises the required floor time.

Systematic Uncertainties

- Non-equal values A_y for P_x and P_y. Simulations show no significant variations. Max. size of error of the P_x/P_y ratio is ∼ 1%.
- Azimuthal angle acceptance non-uniformity...Simulations consistent with cancellation after beam helicity flip and precession angle reversal (reversal of 48D48 field). Max. size of error ∼ 1%.
- Non-uniformity of the magnetic field results in a small $P_z \rightarrow P_x$ mixing. Neutron path through the dipole reconstructed accurately. After correction an overall uncertainty of 1% estimated
- Reproducibility of the spin precession angle after polarity reversal. At a precession angle of 60◦, a 2% difference in integrated field would give 1% difference in rotated component $P_z \rightarrow P_y$.
- Variation in the angle of spin precession through the dipole magnet. Correction factor can be evaluated event by event. The estimated uncertainty is 0.25%.
- Dilution of the asymmetry by accidental background. The background is estimated to be at the 1% level which can be subtracted without significant error.
- Contamination of the quasi-elastic signal by inelastic processes. A deuteron measurement will have clean rejection of the inelastic background. Estimated 1.5% contribution
- **Total systematic uncertainty ~ 3%**

Spin Precession in 48D48 Dipole

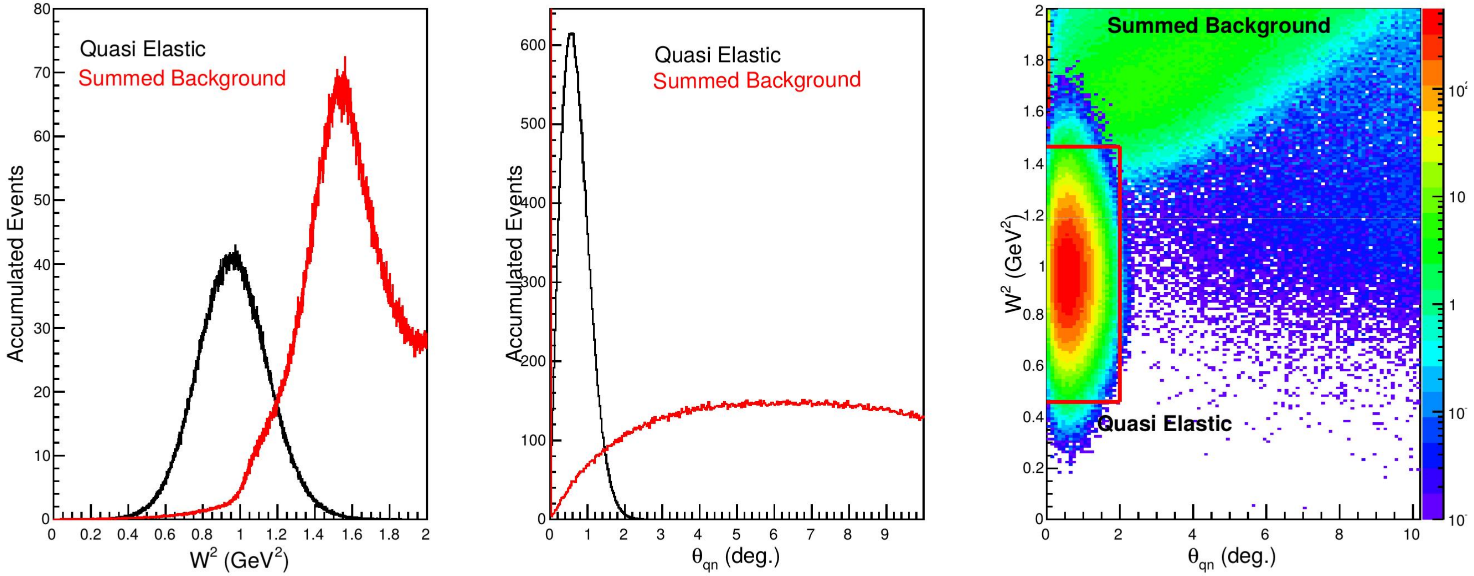


P_{lab} = 3.15 GeV/c

- Nucleon spin precession calculated in Geant-4.10 Earlier G4 have problems with neutron spin precession
- TOSCA field map, no field clamps fitted
- Start neutrons with spin (0,0,1) at target, track through dipole field, record spin components at analyser
- Max spin transfer z → x ~3%
- Smoothly varying, can be corrected, polarimeter has good position resolution
- Max sys. error to P_x/P_z ~ 1%

d(e,e’n) QE Signal Separation

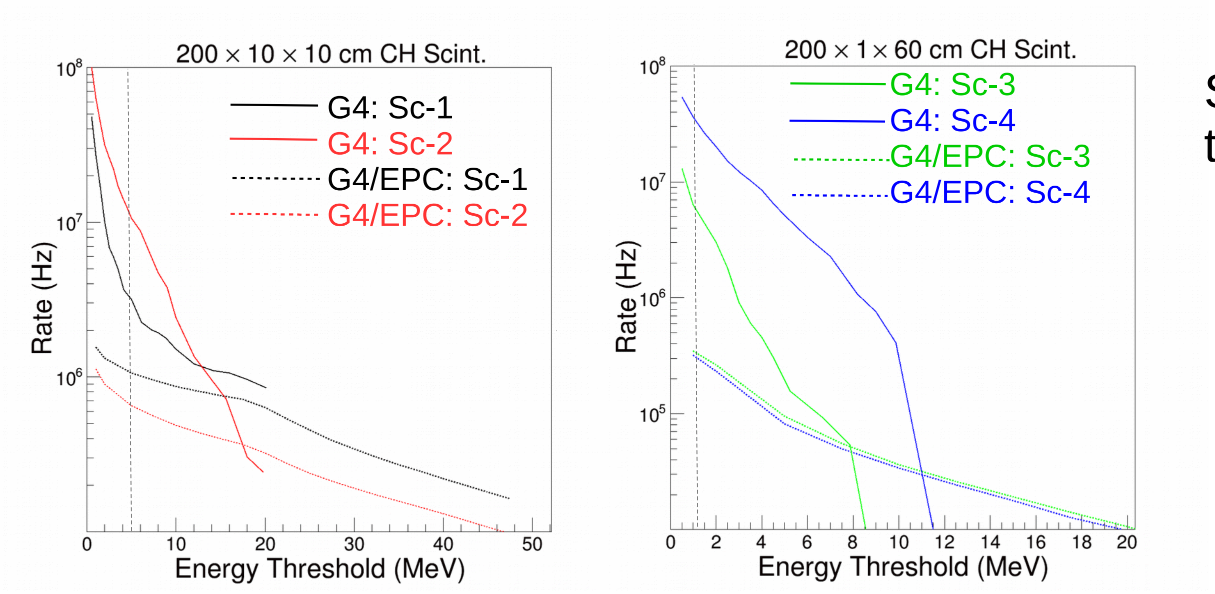
QFS: J. W. Lightbody and J. S. O’Connell, Computers in Physics 2(1988),57



- BigBite: clean separation of electrons from π^- (GRINCH and Preshower/Shower)
- Polarimeter: clean separation of d(e,e’n) from d(e,e’p) (front GEM)
- *d(e,e’n)* QE signal has some contamination, mainly from pion electroproduction
- Use QFS code to calculate QE and non-elastic cross sections
  MC procedure folds in detector resolution effects
- Combination of W^2 and θ_{qn} to separate QE from non-elastic
- “Red-box” cut: 98.5% QE events accepted, non-elastic background 1.5% of QE strength
- Cleaner separation of QE for *d(e,e’n)* compared to *^{3}He(e,e’n)* (polarized target G_{En}/G_{Mn})

Preliminary: Large Angle Polarimeter Rates

Polarimeter: Large-Angle Scintillators



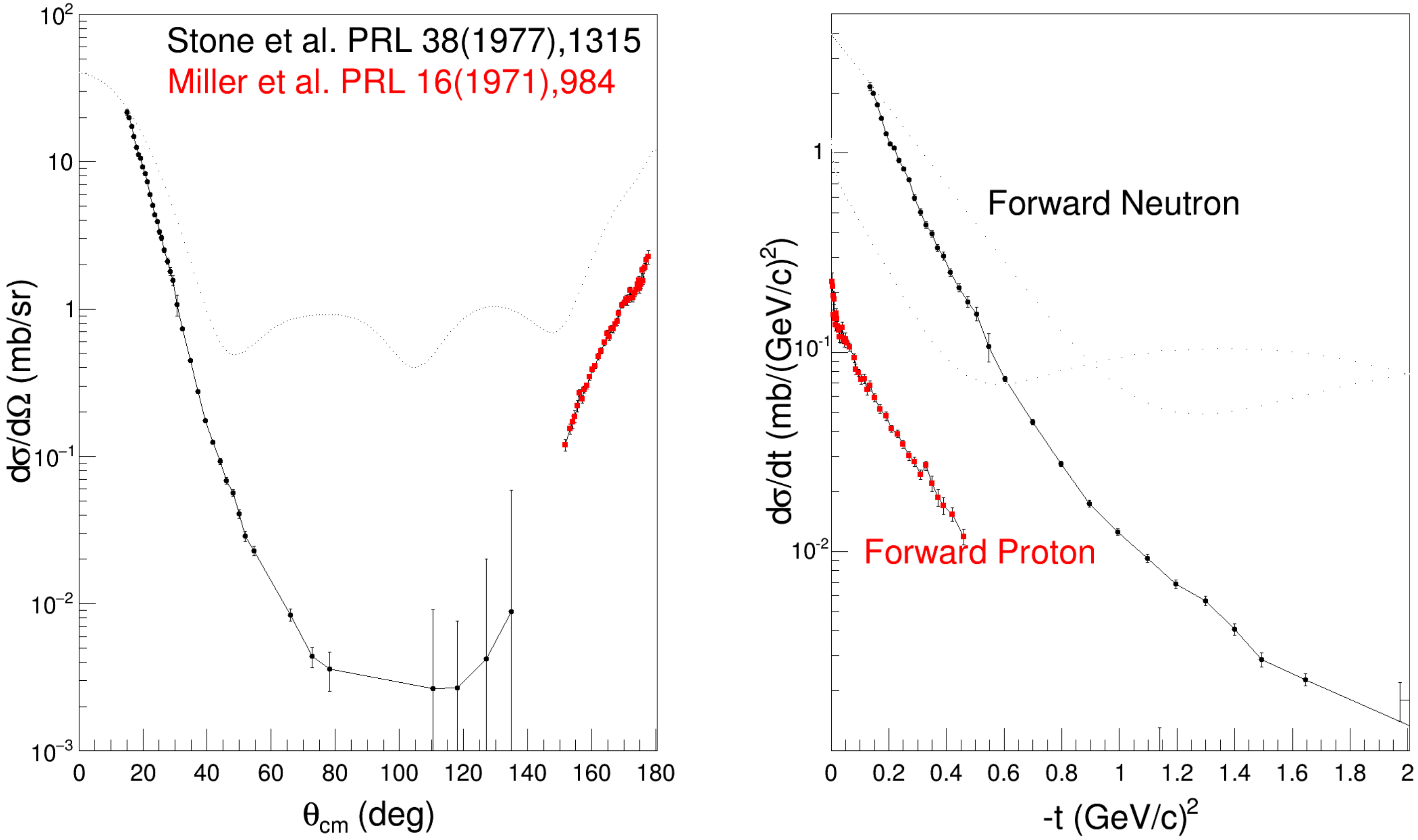
Scintillators will require to be segmented

- Calculations made with Geant-4
- 4.4 GeV electrons on 10 cm D_2, use G4 electromagnetic and hadronic physics models to sample produced particle types and 4-momenta
  Need huge number of events to obtain reasonable hadron sample
- Use code EPC to calculate differential cross section $\sigma(p,\theta)$ for p,n,π^0,π^-,π^+ electro production
  In G4 use these to generate particles at the target position and then track through BB/SBS

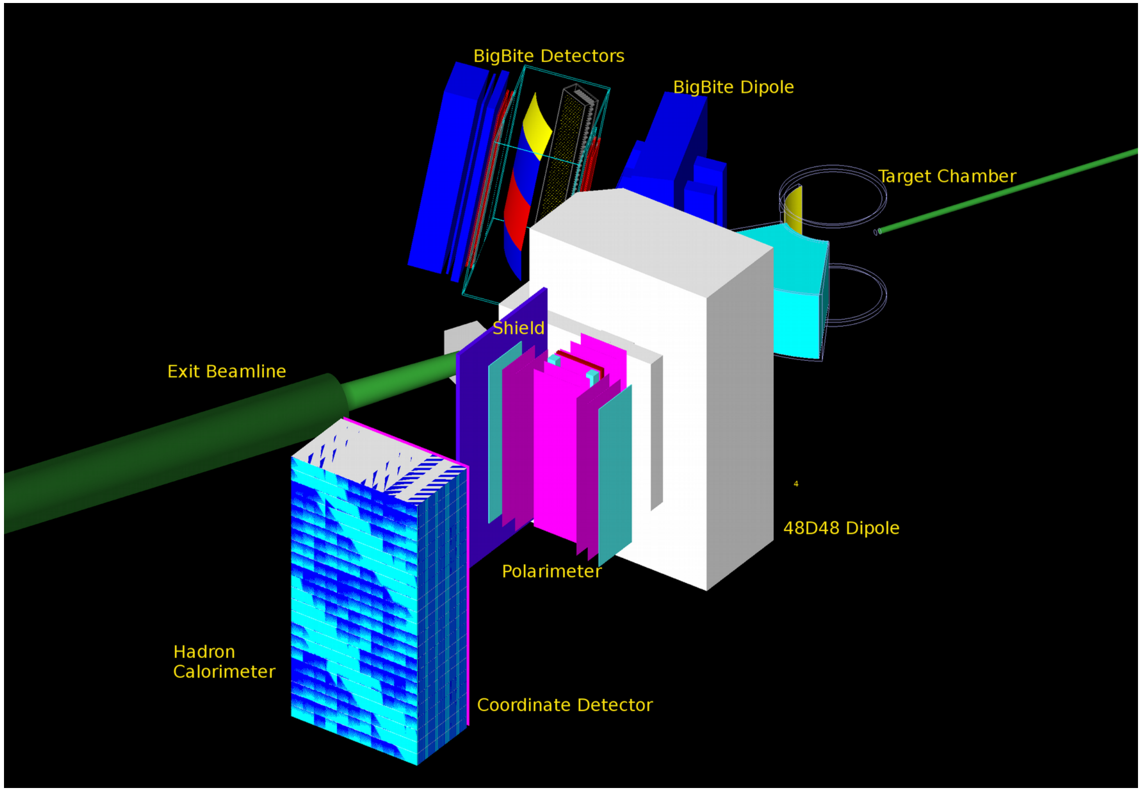
EPC: J. W. Lightbody and J. S. O'Connell,
Computers in Physics 2(1988),57

n-*p* Elastic Cross Section

p_{lab} = 5 GeV/c



The Geant-4 Model



- Geant4.10.03: add ϕ dependence polarised nucleon elastic and QE scattering
- Record signal amplitude and time from each detector element.
- Analyse simulated data as in real experiment.
- Calculate element rates 4.4, 6.6, 8.8 GeV, 40 μA on 10 cm LD_2
  ($\mathfrak{L} = 1.26 \times 10^{38}$ $cm^{-2}s^{-1}$)
- Simulate n-p scattering processes in polarimeter….angle resolution, acceptance efficiency
- Reconstruct polar, asimuthal angles….ϕ distributions give effective analyzing power of polarimeter