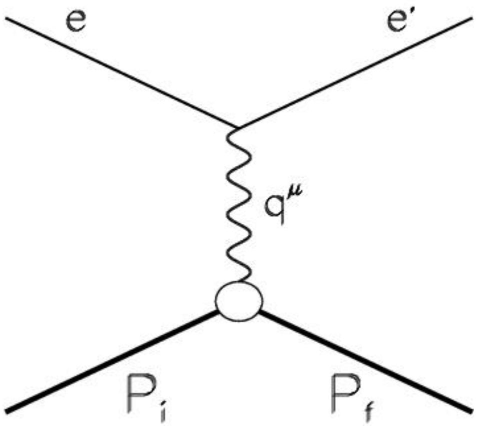
E12-09-019 G_M^n up to Q^2=13.5 (GeV/c)^2 by Ratio Method

- Form factors
- Combining n & p form factors
- GMn by ratio method
- Hall A GMn

In one-photon exchange approx.



$$j^\mu = ieN(p_f)\{\gamma^\mu F_1(Q^2) + i\sigma^{\mu\nu} q_\nu \frac{\kappa}{2M} F_2(Q^2)\} N(p_i)$$

Where $Q^2 = -q^\mu q_\mu$

$$\frac{d\sigma}{d\Omega}(E,\theta) = \eta\sigma_{Mott}[(F_1^2 + \kappa^2\tau F_2^2) + 2\tau(F_1 + \kappa F_2)^2 \tan^2(\frac{\theta}{2})]$$

Where $\tau = Q^2/4M^2$

Or with $G_E = F_1 - \tau\kappa F_2$ and $G_M = F_1 + \kappa F_2$

$$\frac{d\sigma}{d\Omega}(E,\theta) = \eta\sigma_{Mott}[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2(\frac{\theta}{2})]$$

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\eta\sigma_{Mott}}{1+\tau}[G_E^2 + \frac{\tau}{\varepsilon} G_M^2]$$

Where

$$1/\varepsilon = 1 + 2(1+\tau)\tan^2(\theta/2)$$

Rosenbluth separation

Non-relativistic interpretation:

G_E and G_M are F.T. of charge and magnetization density

Relativistic:

$G_E(Q^2)$ and $G_M(Q^2)$ are F.T. components of distributions in Breit frame *for that Q^2*. Boost back to common target frame is (highly) non-trivial.

Combining neutron and proton form factors

Isovector form factor $G^p_{E/M} - G^n_{E/M}$ insensitive to disconnected quark loops. Ideal test case for lattice-QCD

Model-independent extraction of individual u/d flavor contributions.
(assuming s-quark contributions are negligible)
Notation: F^d and F^u are d- and u-quark (plus anti-quark) contributions associated with *proton* current.

$$\left.\begin{aligned} F^p_{1,2} &= \frac{2}{3}F^u_{1,2} - \frac{1}{3}F^d_{1,2} \\ F^n_{1,2} &= \frac{2}{3}F^d_{1,2} - \frac{1}{3}F^u_{1,2} \end{aligned}\right\} \qquad \begin{aligned} F^u_{1,2} &= 2F^p_{1,2} + F^n_{1,2} \\ F^d_{1,2} &= F^p_{1,2} - 2F^n_{1,2} \end{aligned}$$

Separated quark form factors (extracted using all four nucleon form factors) set sum rules on GPDs

$$\int_{-1}^{1} dx\, H^{q}(x,\xi,Q^2) = F_1^{q}(Q^2)$$

$$\int_{-1}^{1} dx\, E^{q}(x,\xi,Q^2) = F_2^{q}(Q^2)$$

The Hall A G_M^n Measurement
E12-09-019

$\boxed{G_M^n}$

Ratio Method:

Measure quasi-elastic scattering from deuteron tagged by coincident nucleon: d(e,e’p) and d(e,e’n)

$$R'' = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'n)}}{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'p)}} \xrightarrow[\text{corr.}]{\text{nucl.}} \frac{\left(\frac{d\sigma}{d\Omega}\right)_{n(e,e')}}{\left(\frac{d\sigma}{d\Omega}\right)_{p(e,e')}} \xrightarrow[1\gamma]{} \frac{\eta\frac{\sigma_{\text{Mott}}}{1+\tau}\left(\left(G_E^n\right)^2+\frac{\tau}{\varepsilon}\left(G_M^n\right)^2\right)}{\left(\frac{d\sigma}{d\Omega}\right)_{p(e,e')}}$$

$$\xrightarrow[\text{Electric}]{\text{neutron}} \boxed{R = \frac{\eta\sigma_{\text{Mott}}\frac{\tau/\varepsilon}{1+\tau}\left(G_M^n\right)^2}{\left(\frac{d\sigma}{d\Omega}\right)_{p(e,e')}}}$$

Many systematic effects (experimental and theory) cancel in ratio.

Expect very small correction for Electric because small
form factor and large kinematic weighting of Magnetic

Systematics

Ratio Method is insensitive to:

- Target thickness
- Target density
- Beam current
- Beam structure
- Live time
- (electron) trigger efficiency
- Electron track reconstruction
- Electron acceptance

$$R'' = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'n)}}{\left(\frac{d\sigma}{d\Omega}\right)_{d(e,e'p)}}$$

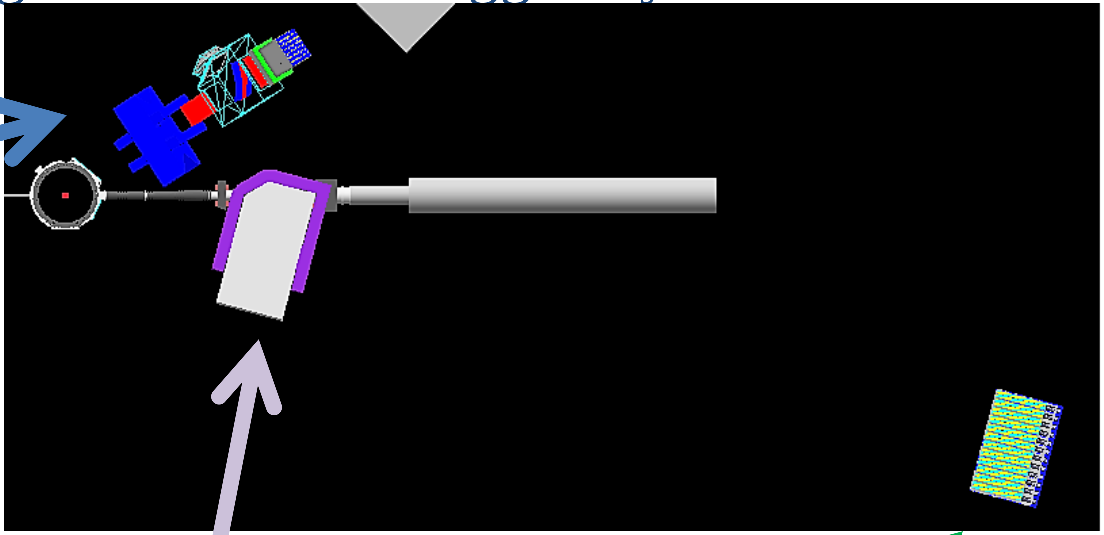
Important to understand:

- Neutron efficiency/proton efficiency ← HCal almost ideal
- Neutron acceptance/proton acceptance

Technique

Ratio Method:

Measure quasi-elastic scattering from deuteron tagged by coincident nucleon: d(e,e'p) and d(e,e'n)



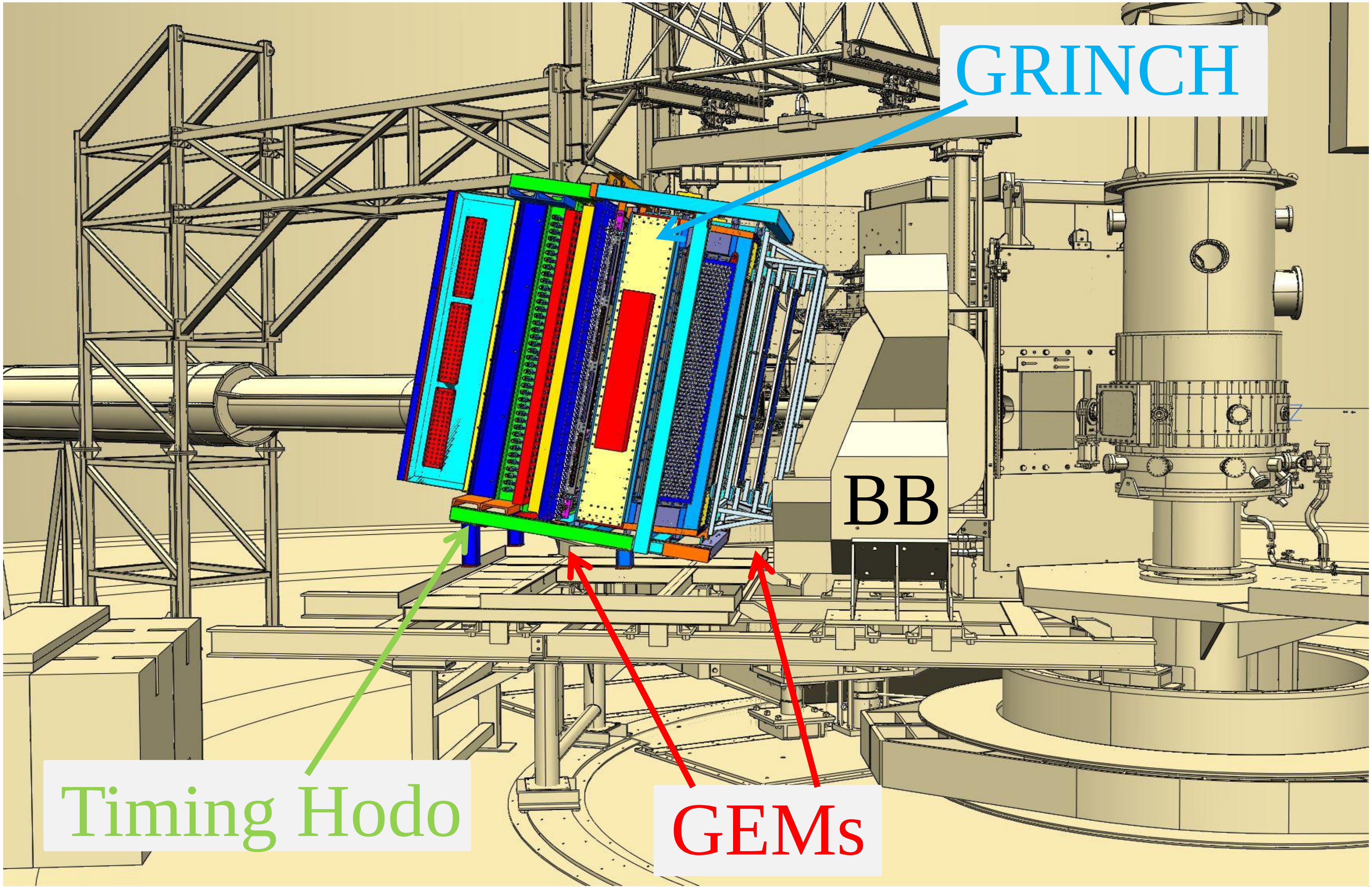
BigBite as electron arm
(Beam left)
Identifies q-vector ($\vec{q}$)

HCal-J as hadron detector with CDet in front (Beam right)

48D48 (SBS spectrometer magnet)
Deflects protons vertically on HCal-J to distinguish from neutrons

Fiducial cut in BigBite selects high, matched acceptance for n and p.

Electron arm –Existing BigBite spectrometer Instrumented with GEMs from SBS

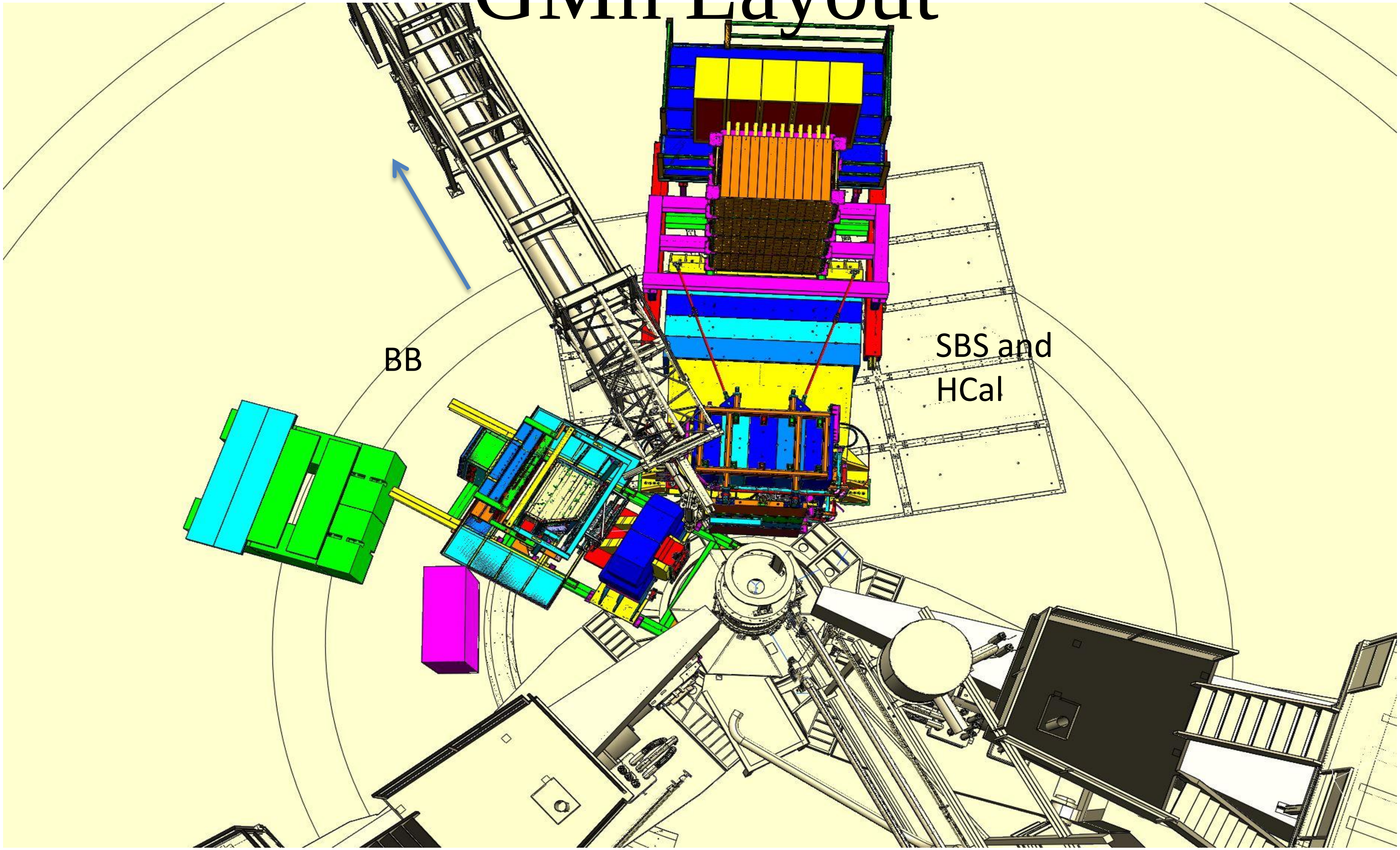

GRINCH

BB

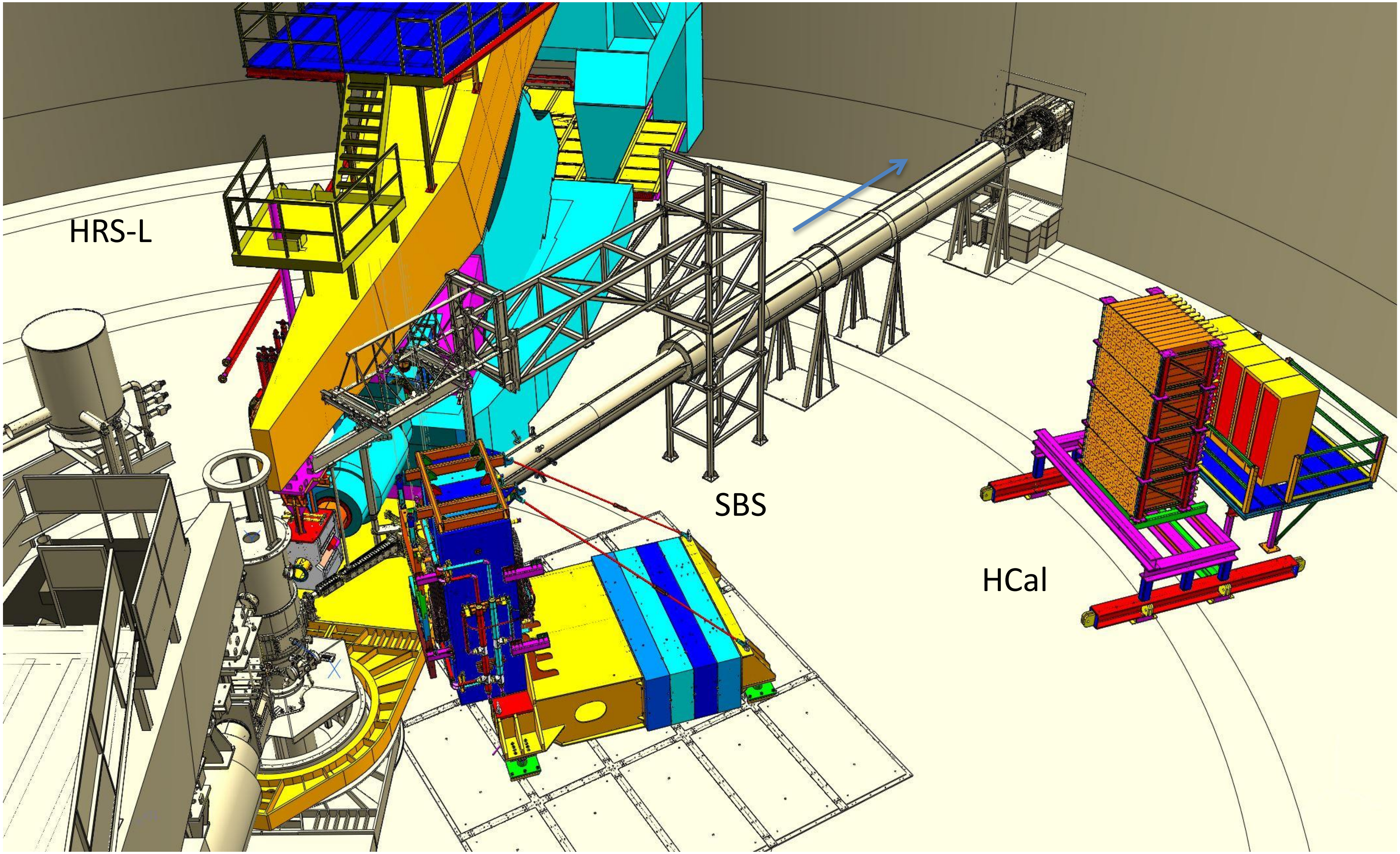
Timing Hodo

GEMs

GMn Layout



Calibration Layout



proposed

configuration	Q^2 $(GeV/c)^2$	E_{Beam} (GeV)	θ_{BB} (deg.)	θ_{SBS} (deg.)	d_{BB} (m)	d_{48D48} (m)	48D48 field integral (T-m)	Luminosity (10^{38}/A/cm^2/s)	dHCal (m)
1	3.5	4.4	32.5	31.1	1.80	2.00	1.40	0.7	6.2
2	4.5	4.4	41.9	24.7	1.55	2.25	1.70	1.4	6.2
3	6.0	4.4	64.3	15.6	1.55	2.25	0.70	2.8	11
4	8.5	6.6	46.5	16.2	1.55	2.25	1.20	2.8	11
5	10.0	8.8	33.3	17.9	1.75	2.25	1.30	1.4	13
6	12.0	8.8	44.2	13.3	1.55	2.25	1.20	2.8	14
7	13.5	8.8	58.5	9.8	1.55	3.10	0.70	2.8	17
8 & 9	3.5/6.0	calibration of HCal using L-HMS at kinematics of config. 1 &3							

modified

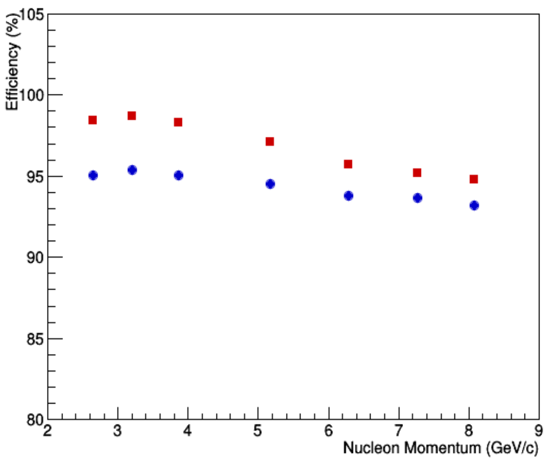
configuration	Q^2 $(GeV/c)^2$	E_{Beam} (GeV)	θ_{BB} (deg.)	θ_{SBS} (deg.)	d_{BB} (m)	d_{48D48} (m)	48D48 field integral (T-m)	Luminostiy (10^{38}/A/cm^2/s)	dHCal (m)
1	3.5	4.4	32.5	31.1	1.80	2.00	1.71	0.7 (2.8 ?)	7.2
2	4.5	4.4	41.9	24.7	1.55	2.25	1.71	1.4(2.8 ?)	8.5
3	5.7	4.4	58.4	17.5	1.55	2.25	1.71	2.8	11
4	8.1	6.6	43.0	17.5	1.55	2.25	1.65	2.8	11
5	10.2	8.8	34.0	17.5	1.75	2.25	1.60	1.4(2.8 ?)	11
6	12.0	8.8	44.2	13.3	1.55	2.25	1.50	2.8	14
7	13.5	11.0	33.0	14.8	1.55	3.10	0.97	2.8	17
			θ_{L-HRS}						
8	6.06	4.4	61.1,64.3 67.5,70.7	14.8		3.10	1.71	0.93	17
9	4.4	4.4	39.,42.	25.5		3.10	1.71	0.93	17

Hadron Calorimeter (HCal) built for Super BigBite Spectrometer

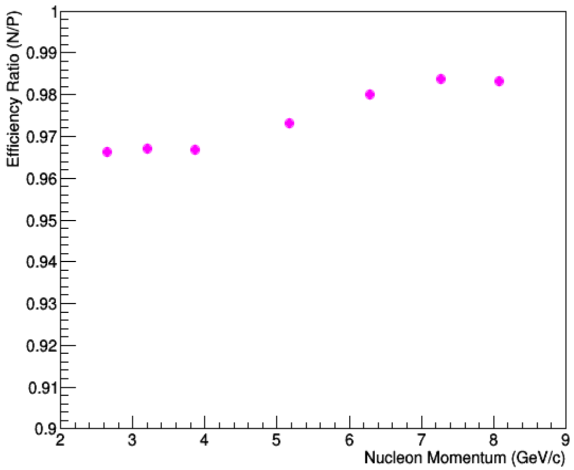
Iron/scintillator sampling calorimeter

- 12X24 identical module
- High energy-deposition
  - High threshold
  - High Luminosity
- Excellent spatial resolution
  - -Tight cut on nucleon direction (wrt q-vector)
- High efficiency for n and p
  - Nearly equal (cancel in ratio)

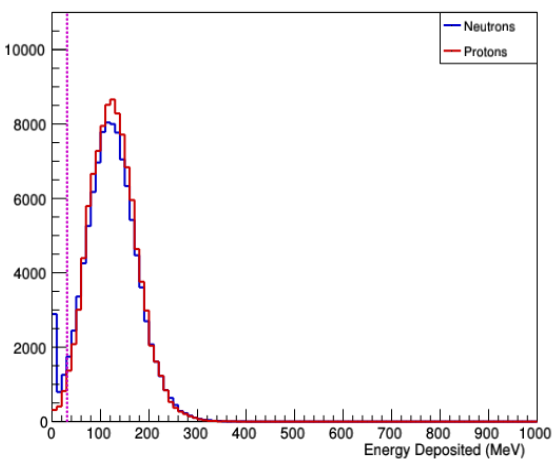
HCAL Efficiency (E_T=1/4E_{peak}) (3x3 cluster)



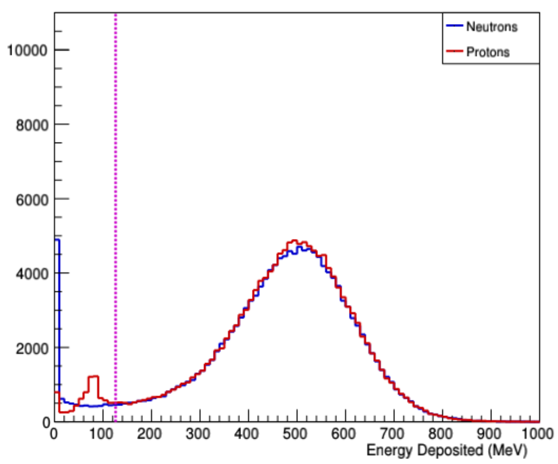
HCAL Efficiency Ratio (N/P) (E_T=1/4E_{peak}) (3x3 cluster)



P=2.64 GeV/c Energy Deposited (3x3 cluster, GMn acceptance)



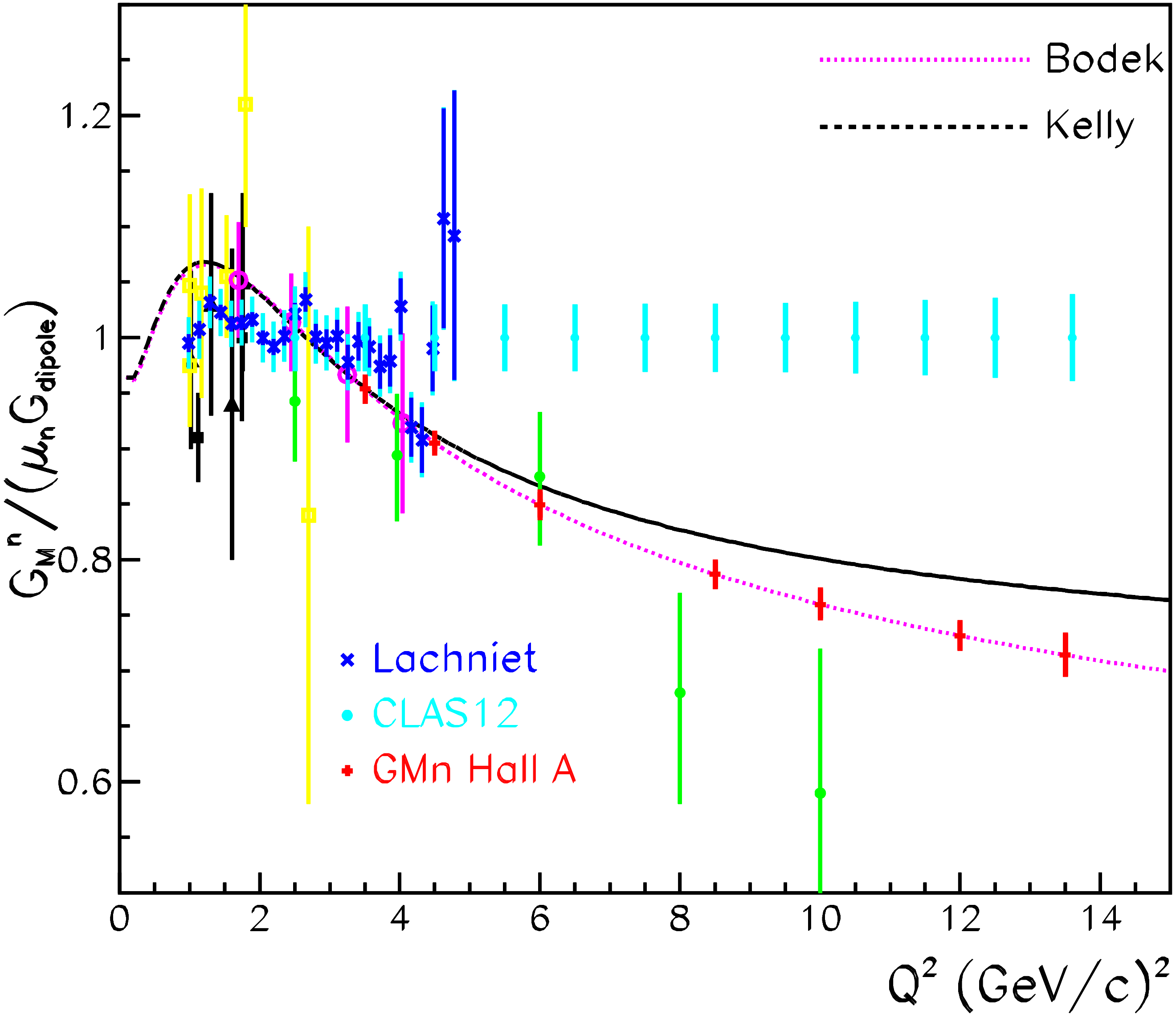
P=8.08 GeV/c Energy Deposited (3x3 cluster, GMn acceptance)



Calibration of HCal

Elastic electrons in BigBite for p(e,e’)p

Dedicated run on LH2 target using HRS
to measure π^+ in p(γ, π^+)n with bremsstrahlung
end point method.
At p_n = 3 & 4 GeV/c with HCal at 17 m



E12-07-104 W. Brooks, G. Gilfoyle, J. Lachniet, W. Vineyard

E12-09-019 B. Quinn, J. Annand, R. Gilman, B. Wojtsekhowski

Status

Equipment nearing end of construction

Assembly and commissioning at JLab in progress

ERR last week (Thur/Fri)

- ~~Awaiting~~ (Just received) formal committee response
- Several recommendations to address
- Hope for successful review before next scheduling meeting

Possible schedule

Complete commissioning by end of 2018

Begin installation in hall early 2019?

- Long ~~10mo~~ (5-6 mo) installation period

Ready to run fall 2019 ?

Nuclear Corrections

Corrections to d(e,e’n) and d(e,e’p) almost identical ➔cancel in ratio

Arenhovel (low Q^2) finds small (<1% when wide-angle tail is cut) corrections at 1 GeV/c and decreasing at larger Q^2

S. Jeschonnek found ratio of full calc (S. Jeschonnek and J.W. Van Orden Phys. Rev. C 62 (2000) 044613) to PWIA calc. for Kinematics of earlier CLAS e5 measurements.

Ratio almost identical for n and p ➔tiny corrections

Q^2 (GeV/c)	FSI corr.
1	0.99980
2	0.99971
3	0.99966
4	0.99962
5	0.99962

Additional nuclear effects due to Fermi motion manifest as PWIA calculation of coefficients a,b,c, and d:

$$R_{\text{PWIA}} = \frac{a\left(G_M^n\right)^2 + b\left(G_E^n\right)^2}{c\left(G_M^p\right)^2 + d\left(G_E^p\right)^2} \qquad \text{c.f.} \qquad R_{\text{Free}} = \frac{\frac{\tau}{\varepsilon}\left(G_M^n\right)^2 + \left(G_E^n\right)^2}{\frac{\tau}{\varepsilon}\left(G_M^p\right)^2 + \left(G_E^p\right)^2}$$

Q^2 (GeV/c)	PWIA corr.
16	1.0032
18	1.0046

Using Jechonnek’s code, found $R_{\text{PWIA}}/R_{\text{Free}}$ (neglecting neutron Electric form factor) for planned kinematics and cuts. < 0.5%

Two-photon Corrections

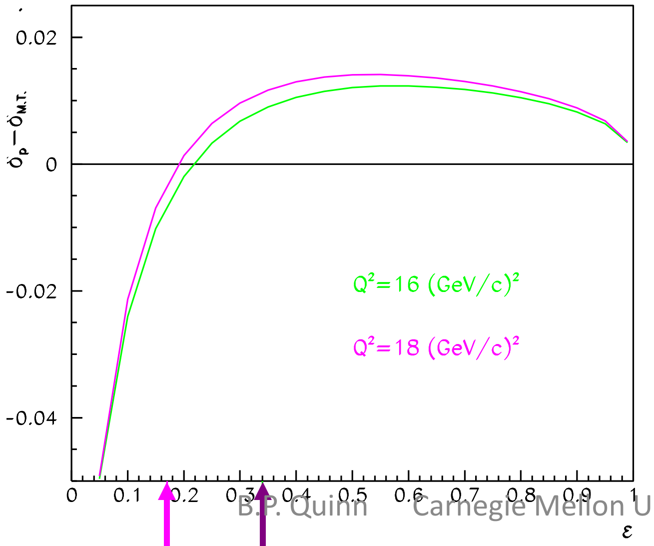
Usual complication of two-photon corrections is for separation of small form factor from large one. Small epsilon-dependence has big effects. We extract the larger Magnetic form factor.

$$\frac{\left(\frac{d\sigma}{d\Omega}\right)_{n(e,e')}}{\left(\frac{d\sigma}{d\Omega}\right)_{p(e,e')}} \approx \frac{\eta\frac{\sigma_{\text{Mott}}}{1+\tau}\left(\left(G_E^n\right)^2+\frac{\tau}{\varepsilon}\left(G_M^n\right)^2\right)(1+\delta_n)}{\left(\frac{d\sigma}{d\Omega}\right)_{p(e,e')}(1+\delta_p)}$$

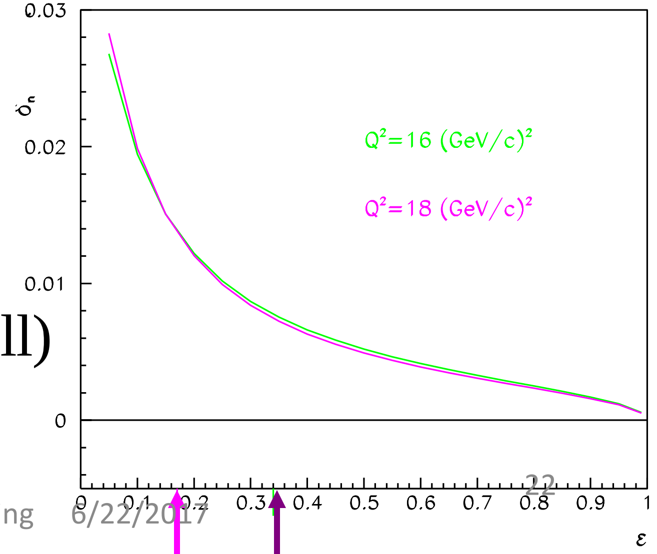
Corrections may not tend to cancel in ratio (P.G. Blunden, W. Melnitchouk and J.A.Tjon, Phys. Rev. C 72 (2005) 034612). Recent results at these kinematics:

Q^2=16 GeV^2 δ_n-δ_p=-0.15% Q^2=18 GeV^2 δ_n-δ_p = 1.8 %

Not specific to ratio technique, affect *any* elastic cross section measurement at these kinematics



$\delta_p - \delta_{\text{IR divergent}}$



δ_n (full)