Low Q^2 Elastic Measurements

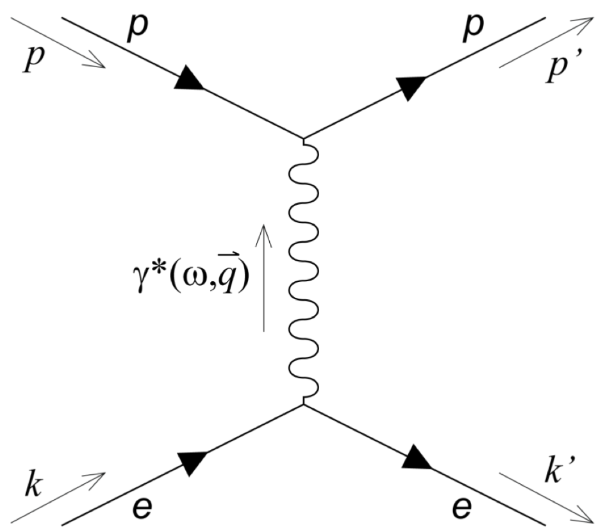
1) Hydrogen Elastic (polarized)
2) Carbon Elastic (^{10}B coming!)
3) Gas Target Elastic Scattering: H,D,^{3}H,^{3}He, and ^{12}C

Proton Form Factors

Electron elastic scattering from proton:

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott} \frac{1}{1+\tau}[G_E^2 + \frac{\tau}{\varepsilon} G_M^2]$$

$$(\tau = \frac{Q^2}{4M^2}, \varepsilon = [1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}]^{-1})$$



Sachs Form Factors:

Electric: $G_E(Q^2)$

Magnetic: $G_M(Q^2)$

$Q^2=0$

$$G_{Ep}(0) = 1 \quad G_{Mp}(0) = \mu_p$$
$$G_{En}(0) = 0 \quad G_{Mn}(0) = \mu_n$$

Approximated by Dipole Form

$$G_D(Q^2) = (1 + \frac{Q^2}{0.71GeV^2})^{-2}$$
$$\mu_P \frac{G_E}{G_M} = 1$$

Excellent paper on the Sachs form factors as well as the original 0.81 fm radius of "standard dipole" from:
L. Hand et al. **Rev.Mod.Phys. 35 (1963) 335,** 10.1103/RevModPhys.35.335

Rosenbluth Separation

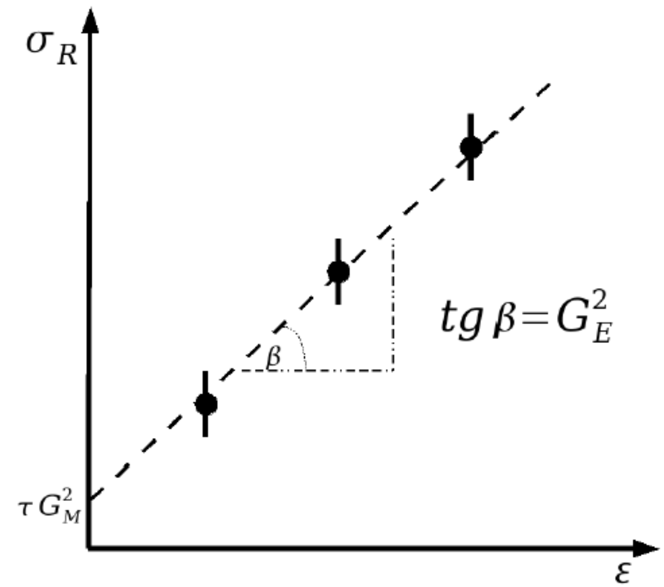
unpolarized beam on unpolarized target, cross section measurement.

$$\sigma_R \equiv \frac{d\sigma}{d\Omega}\frac{\varepsilon(1+\tau)}{\sigma_{Mott}} = \tau G_M^2(Q^2) + \varepsilon G_E^2(Q^2)$$

Method: Vary ε at fixed Q^2, fit linearly

Slope → G^2_E

Intercept → G^2_M

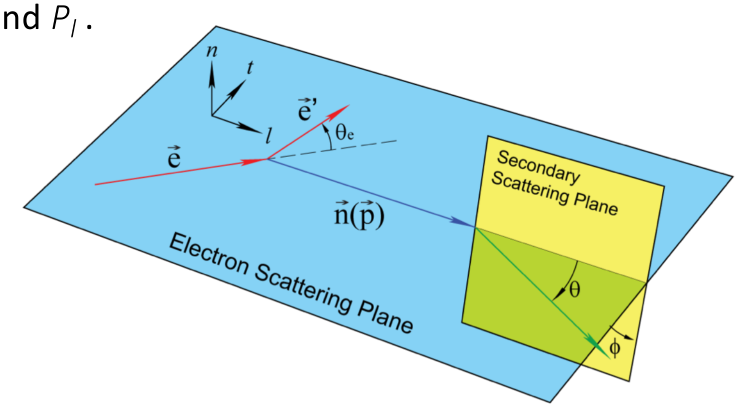


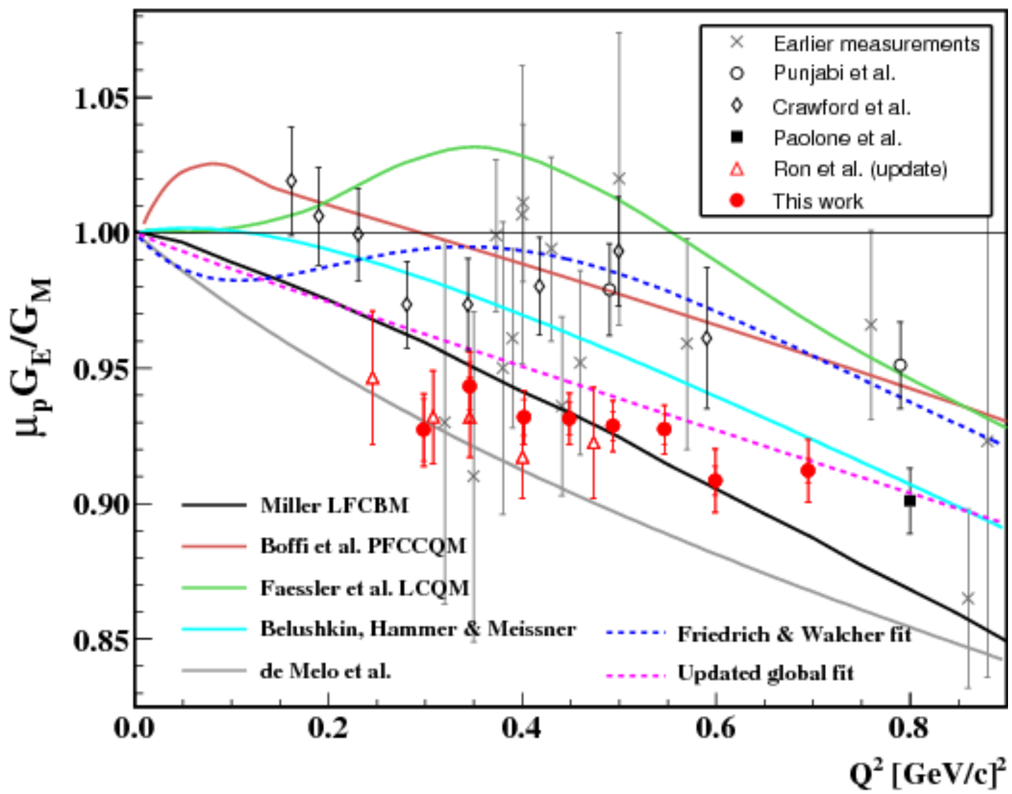
Limitations

- σ is not sensitive to G_E at large Q^2 and not sensitive to G_M at small Q^2
- Limited by accuracy of cross section measurement at different settings.
- Radiative correction, two-photon exchange, etc.

Recoil Polarization

• Direct measurement of form factor ratios by measuring the ratio of the transferred polarization P_t and P_l .





Advantages:

- Only one measurement is needed for each Q^2.
- Much better precision than a cross section measurement.
- Two-photon exchange effect small.
- Complementary to XS measurement.

Limitations

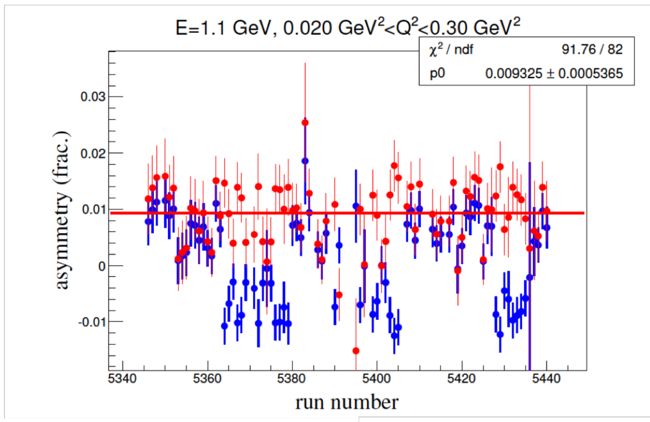
- **Limited by ability to detect the recoiling proton.**

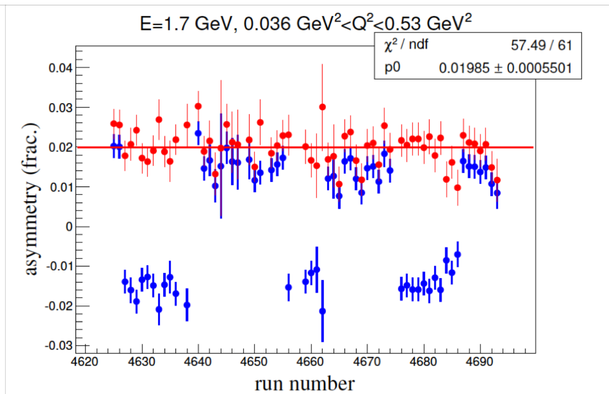
X. Zhan *et al.*, Phys.Lett. B705 (2011) 59-64. 10.1016/j.physletb.2011.10.002 (164 citations as of 30 January 2019)

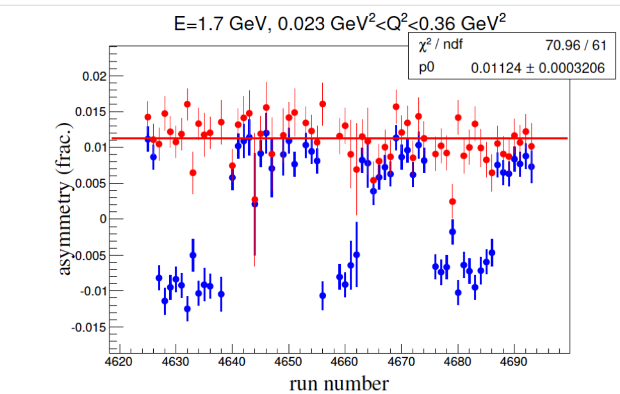
Analysis of Low Q^2 Asymmetries Complete

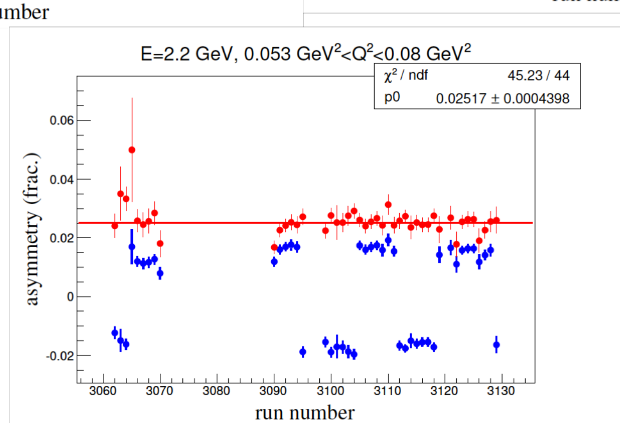
Jessica Campbell and Moshe Friedman have independently done the analysis and gotten very similar same result

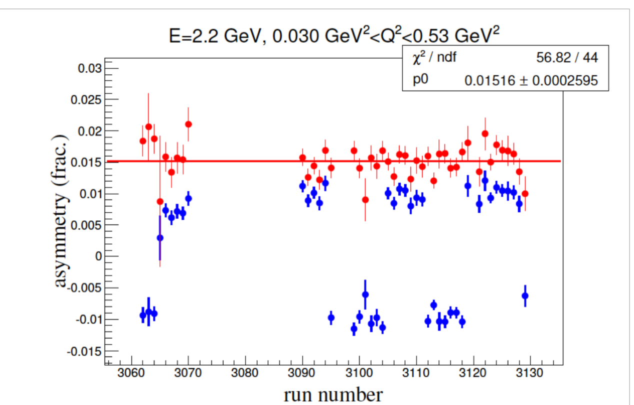
Blue: Raw Data, Red: Correcting for half-wave plate and polarization of beam and target









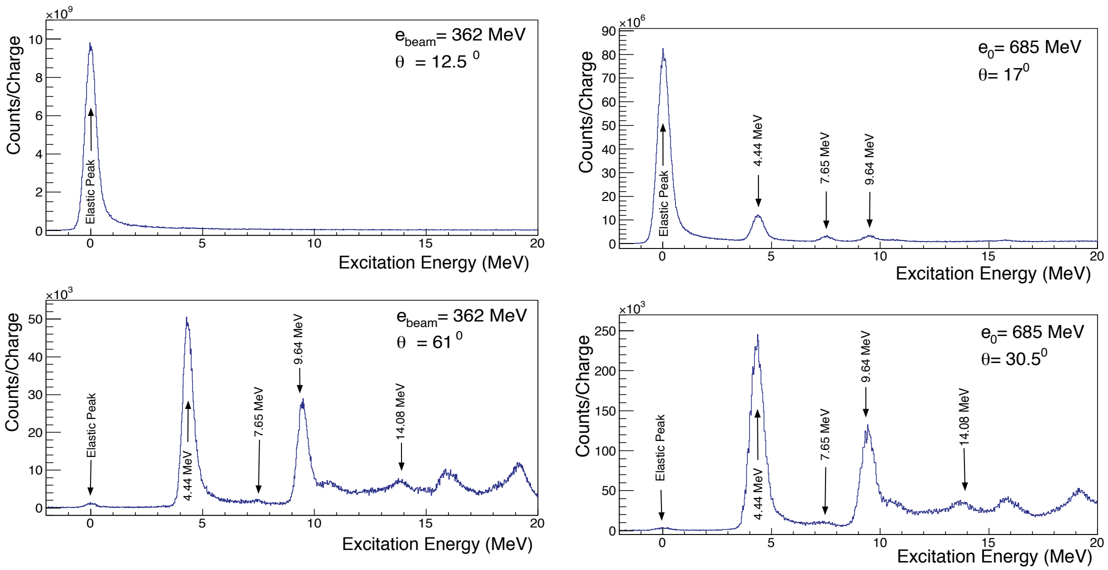


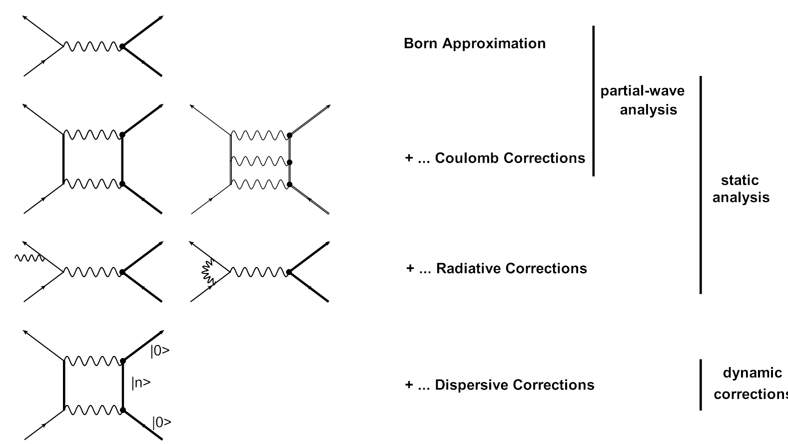
LEDEX Experiment (Data Mining)

Low **E**nergy **D**euteron **E**xperiments
E05004 A(Q) at low Q in ed elastic scattering
E05004Ext low Q ^{11}B and ^{7}Li elastic scattering
E05103 low energy deuteron photodisintegration
Low Q^2 (starts at q ~ 0.4 fm^{-1}) → some data @ q_{min}

E (MeV)	θ (Deg.)	E' (MeV)	q (fm^{-1})	q_{eff} (fm^{-1})
362	12.5	361.722	0.399	0.394
362	61.0	356.056	1.847	1.821
685	17.0	683.170	1.025	1.017
685	30.5	679.237	1.819	1.805

Shown is Carbon Elastic Data





Analysis by Al Amin Kabir with Paul Gueye, https://arxiv.org/abs/1805.12441

LEDEX Experiment (Data Mining)

<u>L</u>ow <u>E</u>nergy <u>D</u>euteron <u>Ex</u>periments

E05004 A(Q) at low Q in ed elastic scattering

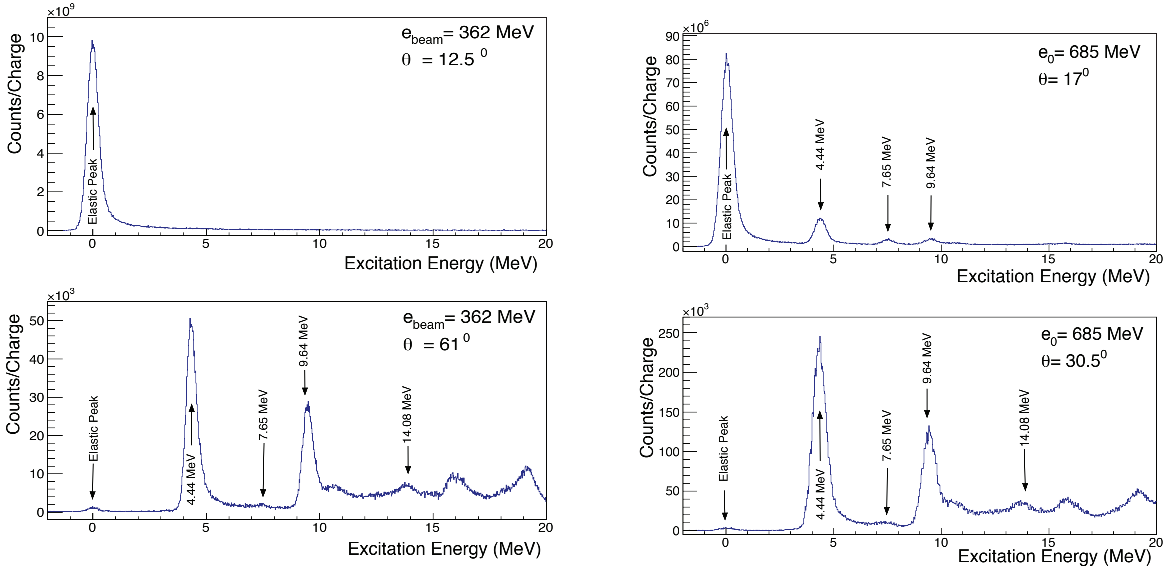
E05004Ext low Q ^{11}B and ^{7}Li elastic scattering

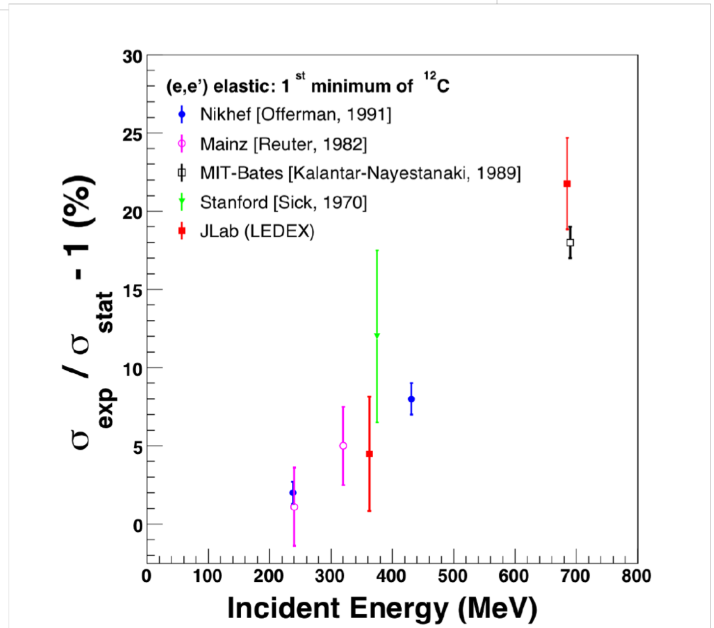
E05103 low energy deuteron photodisintegration

Low Q^2 (starts at q ~ 0.4 fm^{-1}) → some data @ q_{min}

E (MeV)	θ (Deg.)	E' (MeV)	q (fm^{-1})	q_{eff} (fm^{-1})
362	12.5	361.722	0.399	0.394
362	61.0	356.056	1.847	1.821
685	17.0	683.170	1.025	1.017
685	30.5	679.237	1.819	1.805

Shown is Carbon Elastic Data





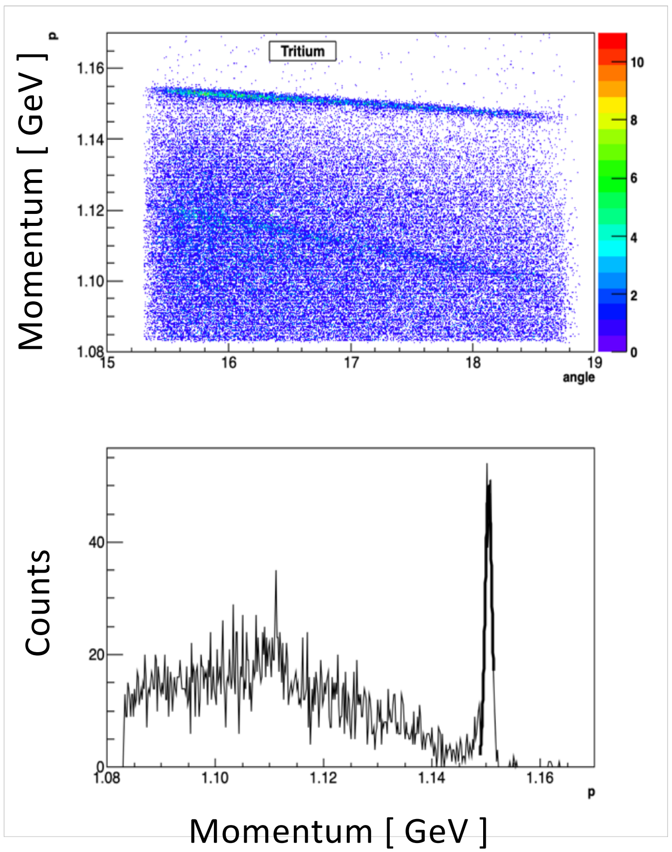
Paul Gueye looking into new dedicated experiment result was simply statistics limited and **^{10}B elastic paper coming**!

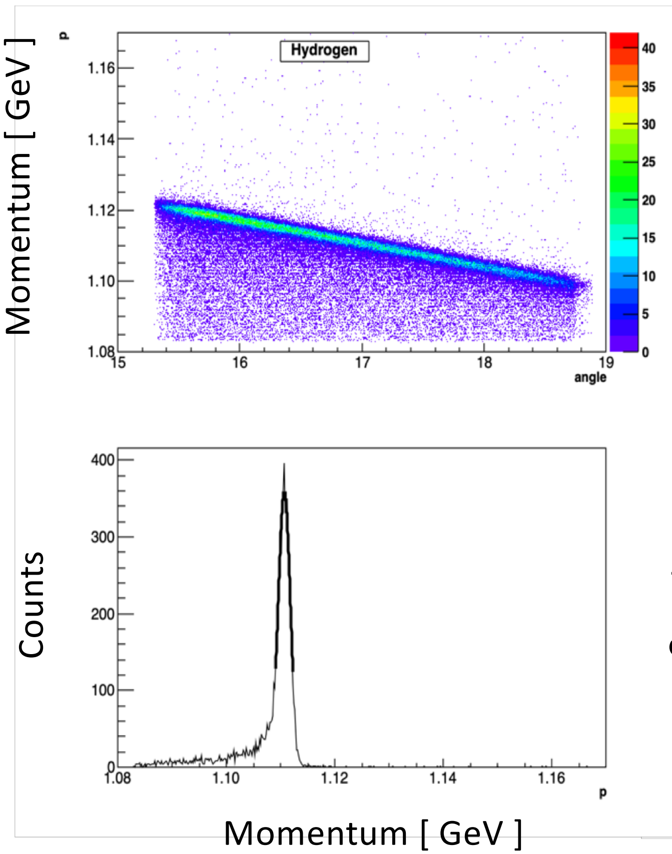
First 12 GeV "1/2 Pass" Running

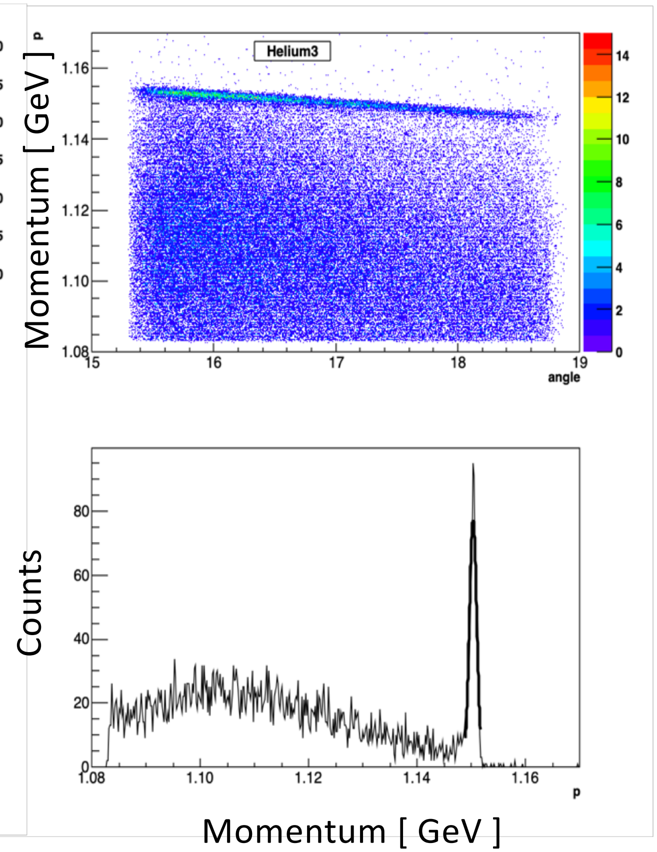
With a couple shifts of collaborative accelerator/physics beam in Nov. 2018 (in preparation for the Hypernuclear exp.) we did the following:

- 1) Demonstrated half-pass running
- 2) Cross Calibrated ARC1/ARC2/Hall A ARC
- 3) Determined The Beam Energy with left HRS
- **4) Discovered Our "Pure" Tritium Cell is ~1.6% Hydrogen**
- 5) Got Elastic Data On H/D/T/3He at 3 fm^{-2} (data for Leiqaa Kurbany)

Example Elastic Runs From Gas Cells

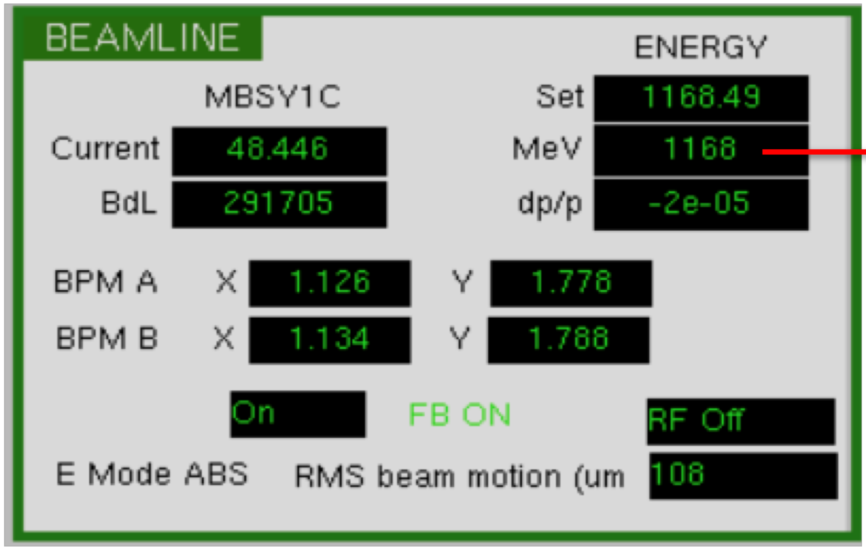






This data can be used to check the beam energy.

- Use the spectrometer constants as determined during 6 GeV
- Determine the beam energy.
- Use to help understand difference between Hall A ARC and Accelerator energies.



Accelerator Reported Energy
(based on 6 GeV ARC/eP data)

ARC Energy Measurements

- 1st Pass Measurements
  - https://logbooks.jlab.org/entry/3429708 (dispersive)
  - 2.222(1) GeV vs. 2.218(2) GeV epics Calc. (aka Tiefenbach energy)
  - 1.0018 scale factor to convert Tiefenbach energy (a.k.a. hallap)
  - Systematic uncertainty on the new energy is 5E-4
- 3rd Pass Measurements
  - https://logbooks.jlab.org/entry/3446303 (acromatic)
  - https://logbooks.jlab.org/entry/3432968 (dispersive)
  - 6.427(3) GeV Measured vs. 6.407(6) GeV epics. Calc.
  - 1.003 scale factor
- 4th Pass Measurements
  - https://logbooks.jlab.org/entry/3448841 (dispersive)
  - 8.520(4) GeV Measured vs. 8497(8) GeV epics calc.
  - 1.003 scale factor
- 5th Pass Measurements
  - https://logbooks.jlab.org/entry/3442118 (acromatic)
  - https://logbooks.jlab.org/entry/3443032 (dispersive)
  - 10.587(5) GeV vs. 10.589(10) GeV epics calc.
  - Serendipitous agreement (saturation & sync. radiation effects)

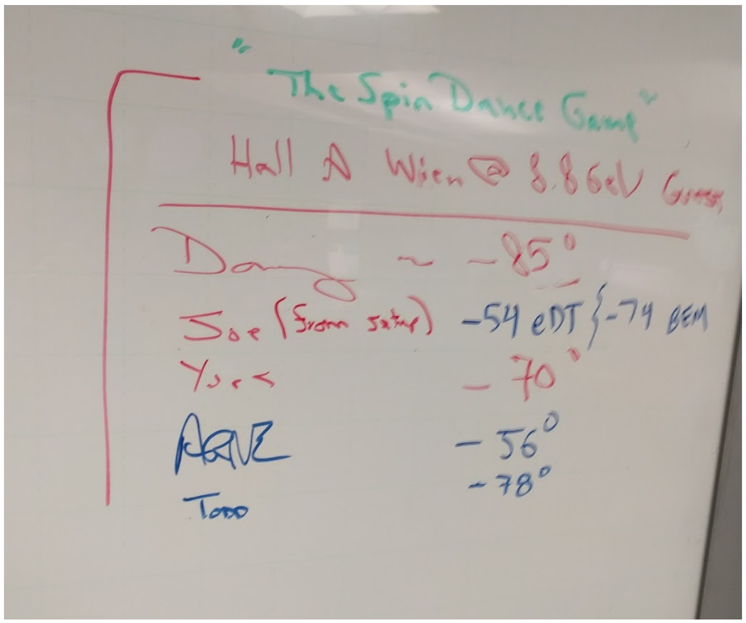
Energy does shift vs. time so best to use epics calc. value and the scale factor to get a run by run beam energy for any given run period.

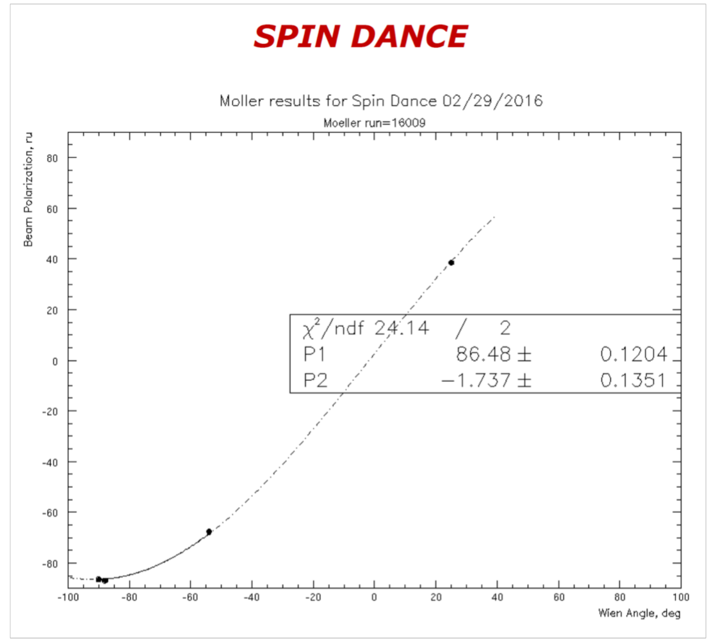
BOTH ARC Energy and Halla:p are precise (and reproducible) but which (if either) is accurate?!

Beam Energy from Spin Dance

One way to check the energy measurements is to use them to make Wien angle predictions.

Predictions Based on different energy calculations.





Fit of Moller data gave 86.5 degrees

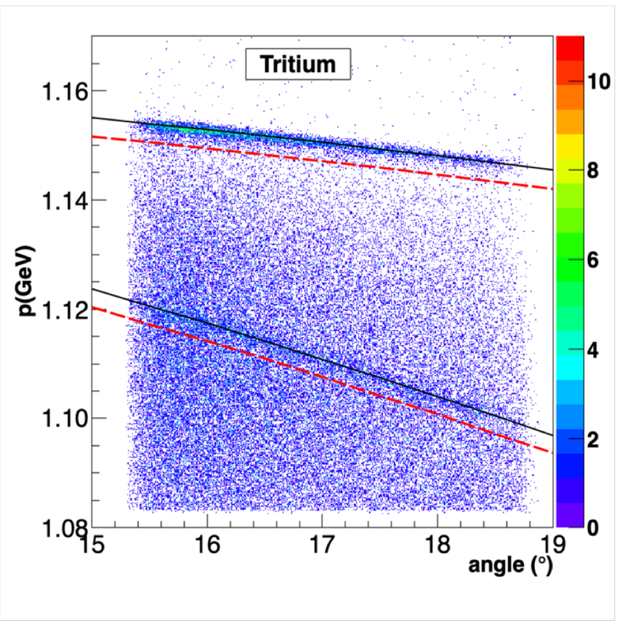
Recently (Winter 2018), MCC just used the ARC energy results to set Wien and was able to reproducibly get high polarization to Hall B for many different energies.

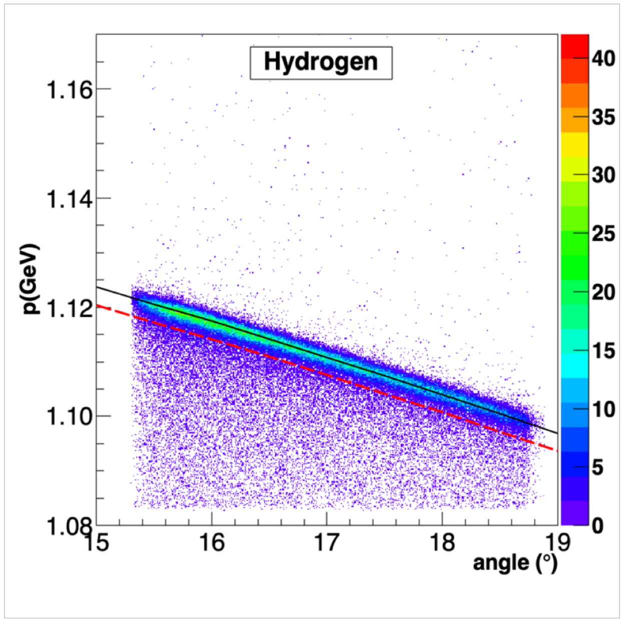
Beam Energy Check With HRS

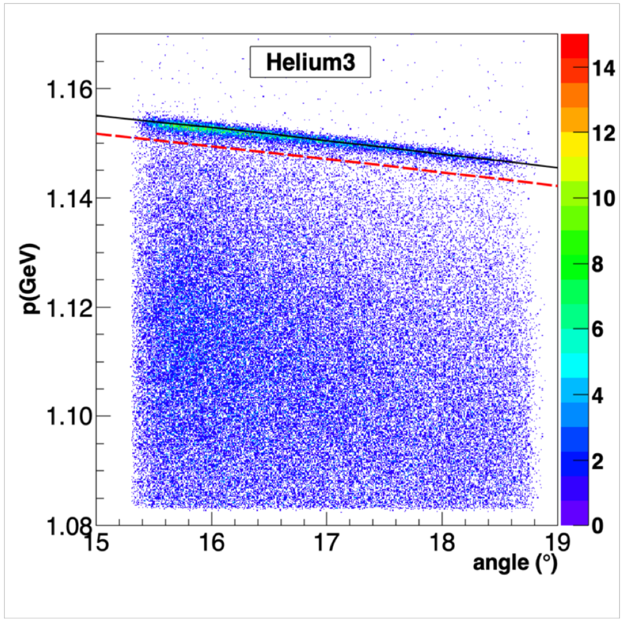
(energy loss corrections have been included)

Accelerator energy = 1168 MeV

Measured Energy = 1171.5(5) MeV







Elastic Measurements During Tritium Run Period

Tritium Experiment E12-14-009: Ph.D. student Leiqaa Kurbany [UNH]

	Target	Beam Energy	Angle	Elastic E'	Q2 [fm-2]	LHRS central momentum	Run Number	Good Event Counts
December 2017	1H	2.21	17.001	2.004	9.946	2.001	910, 911	>50000
	1H	2.21	22.001	1.886	15.604	1.879	931	>50000
Spring 2018	3H	2.21	15.004	2.152	8.334	2.158	3040-3042	>50000
	3He	2.21	15.004	2.152	8.334	2.158	3043-3046	>50000
	C	2.21	15.004	2.195	8.501	2.158	3032-3039	
	3H	2.21	15.004	2.152	8.334	2.212	3055-3060	>10000
	3He	2.21	15.004	2.152	8.334	2.212	3047-3054	>10000
	1H	2.21	15.004	2.046	7.922	2.051	3064-3067	>50000
	1H	2.21	21.778	1.892	15.337	1.896	3094-3095	>50000
	1H	2.21	23.891	1.839	17.896	1.843	3162	>50000
	1H	2.21	25.952	1.786	20.454	1.79	3118	>50000
	1H	2.21	28.006	1.732	23.040	1.737	3177	>50000
	1H	2.21	30.001	1.680	25.564	1.683	3137	>50000
	1H	2.21	42.025	1.376	40.198	1.379	93047, 93063, 93082	>40000
Fall 2018	1H	4.318	24.016	3.088	59.320	3.1	93588, 93599, 93626	>40000
	1H	4.318	17.009	3.594	34.892	3.57	3621	>50000
	1H	4.318	28.004	2.806	72.908	2.85	94014	<10000
	1H	1.171	17.009	1.110	2.923	1.128	3989	>50000
	3H	1.171	17.009	1.150	3.028	1.128	3991	>10000
	3He	1.171	17.009	1.150	3.028	1.128	3992	>10000
	2H	1.171	17.009	1.140	3.001	1.128	3993	>40000
	C	1.171	17.009	1.166	3.069	1.128	3996-3997	
	Multifoils	1.171	17.009	1.166	3.069	1.128	3995	
	1H	4.318	13.201	3.850	22.577	3.93	111702	>40000

Many Low Q^2 Results Coming From Hall A!