U.S. DEPARTMENT OF ENERGY JSA

Determination of the Beam Energy

(ARC Energy & Spin Precession)

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with support from

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ARC Energy Measurements

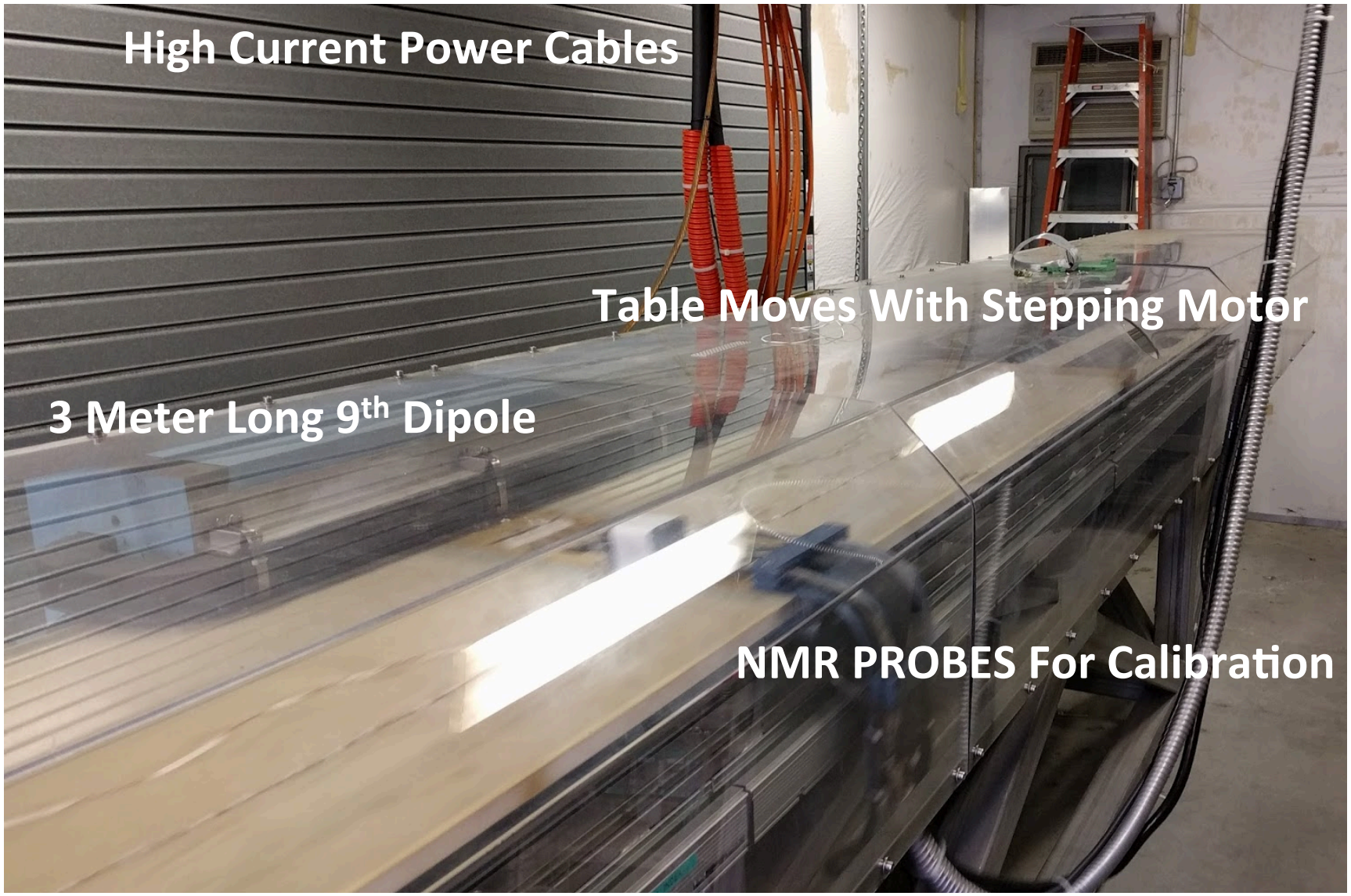
- **Makes Use of The Eight Dipoles That Bend Beam From Acc. Into Hall A**
  - **And a 9th sister dipole that is connect in series with the other eight**
- Angle Measurements
  - HARPS (we can now do HARP scan with pulse beam, in 6 GeV era needed CW)
  - Beam Position Monitors (BPM)
- Quadrupole Centering
  - Checked by turning on and off the magnets
  - Makes Orbit Corrects Negligible
- Bdl Measurements
  - Map the 9th dipole to make best estimate of the other 8 dipoles (located in the tunnel).
  - Use NMR to get an absolute field calibration
- To leading order (with beam quad. centered) *p* of the beam given by:
- Higher order corrections (such as sync. radiation) added in full calculations.

$$p = k\frac{\int \vec{B}\cdot\vec{dl}}{\theta}$$

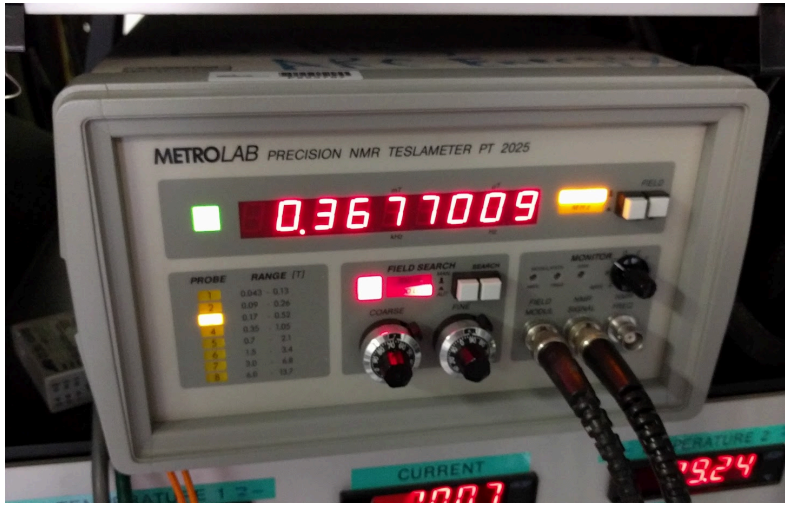
$$\text{where } k = 0.299792\ \text{GeV rad T}^{-1}\ \text{m}^{-1}/c.$$

- By turning the quadrupoles off (dispersive optics) the corrections are minimized.

Electromagnetic Induction & NMR to get Bdl



NMR Measurements



NMR can stay locked while the probe is moving through the dipole.

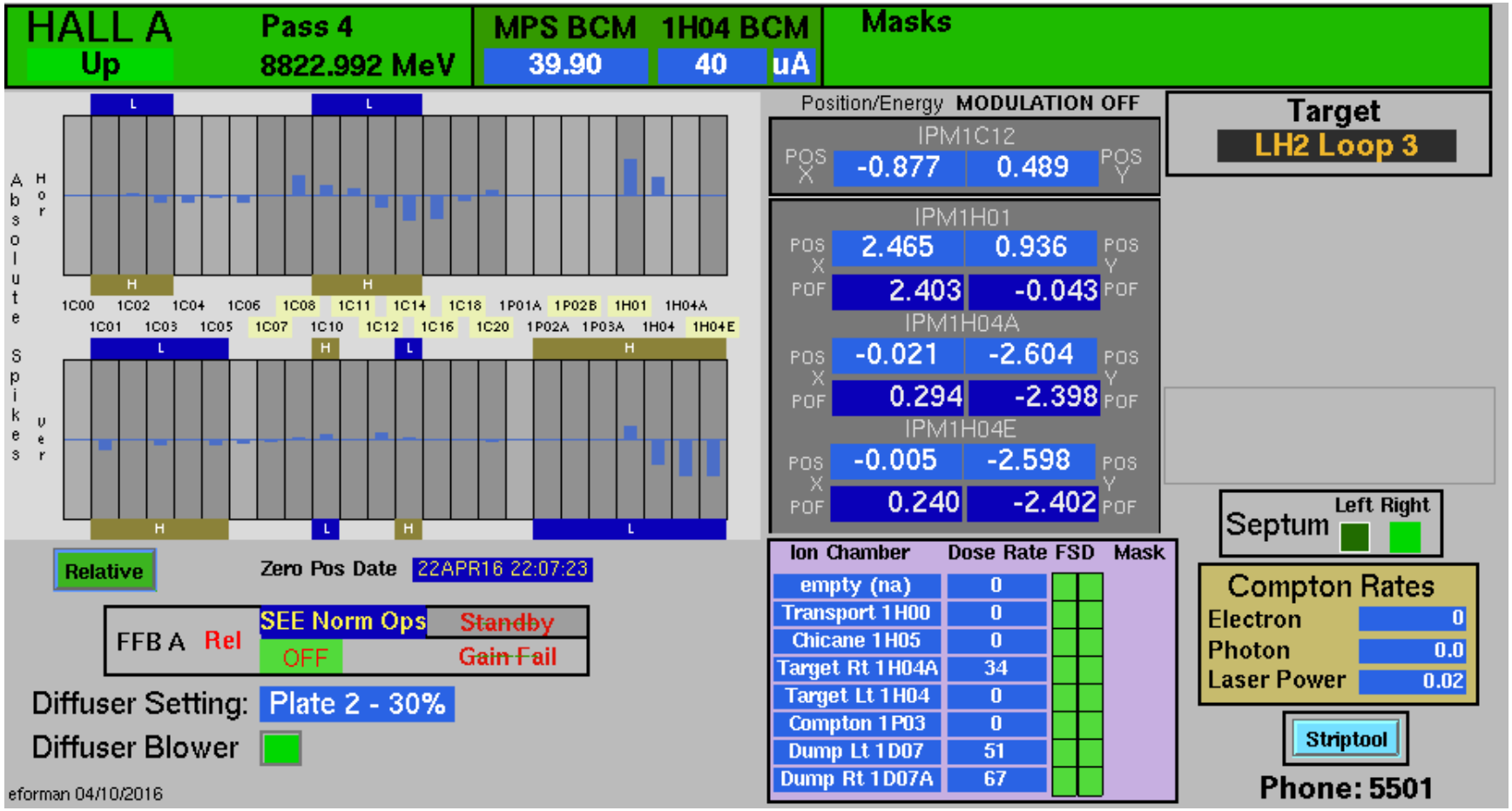
This is only possible due to the very homogenous field of the magnet.

The trickiest part is the fringe field.

Calibrated Magnet Current Measurement

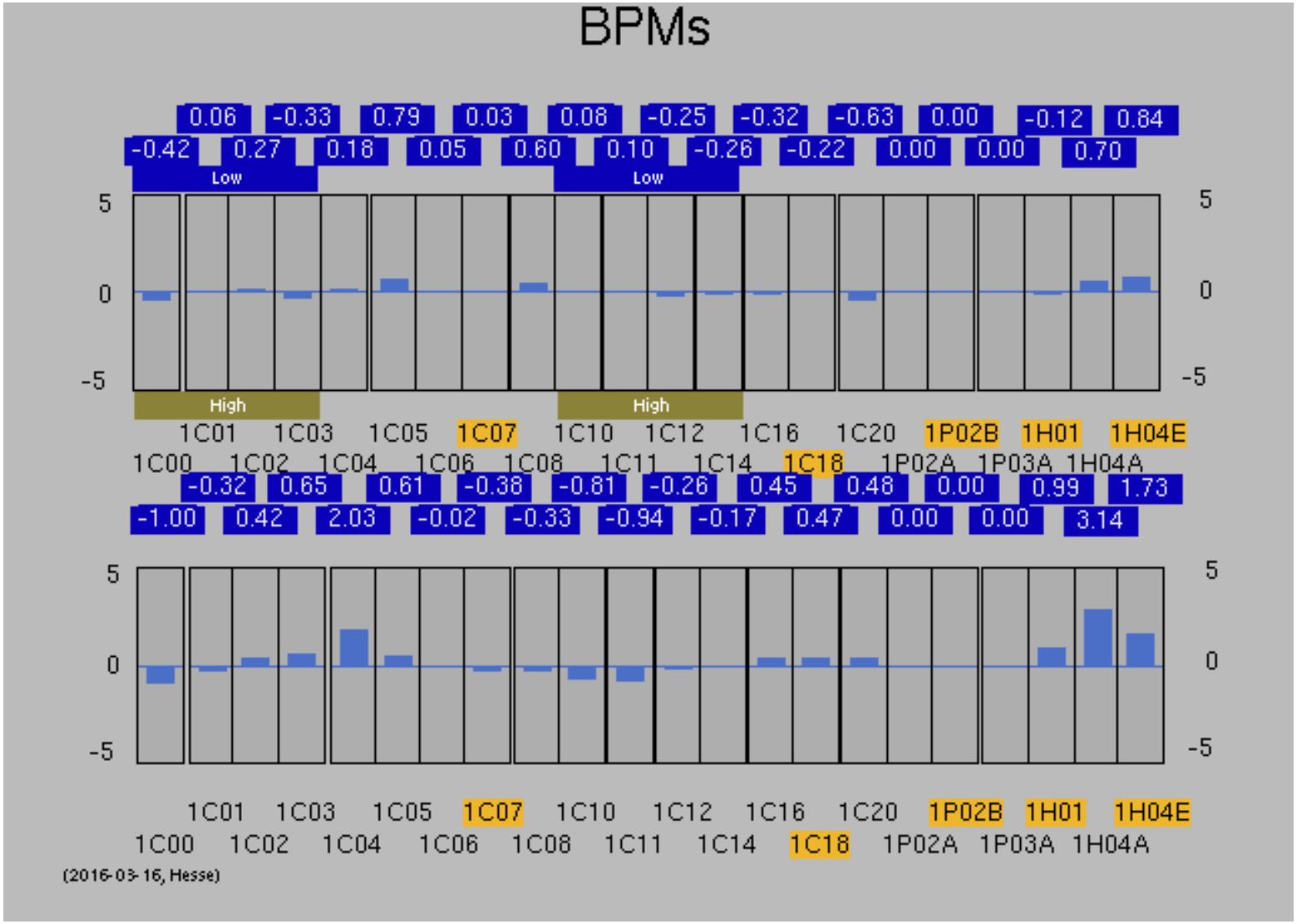
Ultrastab Saturn Unit with a NIST Calibration Certificate (i.e. Calibrated Current Transducer)

Example Bad Orbit with Quadrupole Steering



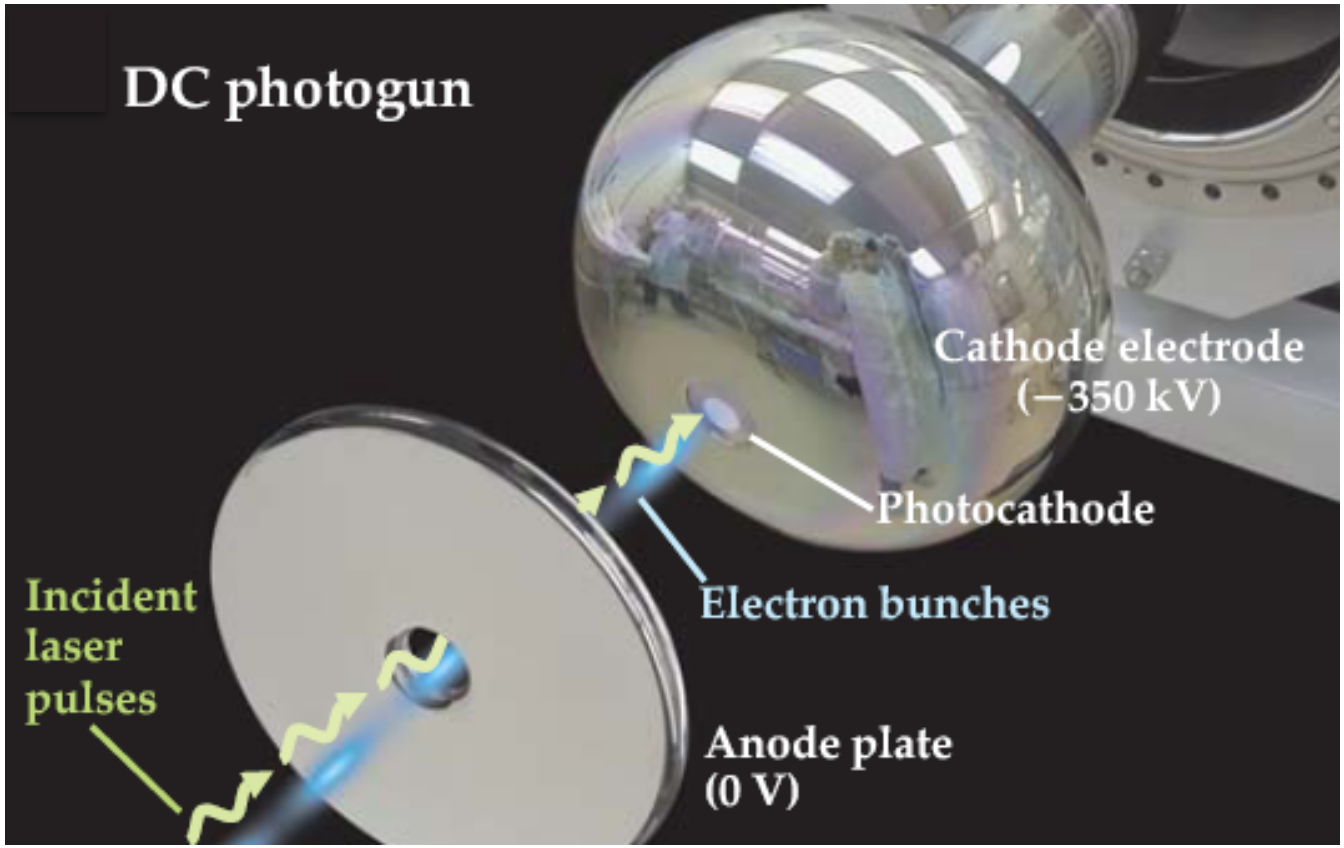
Note the 8823 MeV was used initially to set the Wien for 4th pass.
The Hall A ARC measurement found the energy to be 8842 MeV.

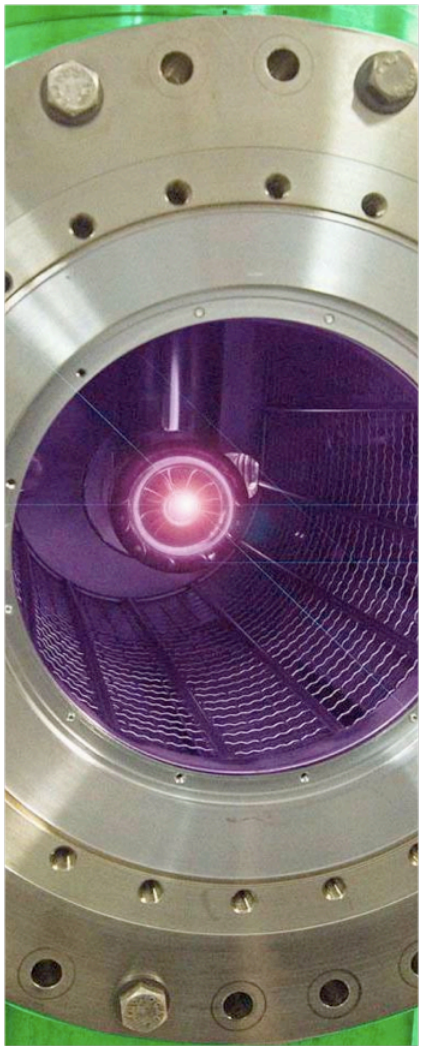
Near Ideal Orbit With Quads Off



Polarized Beam & Spin Precession Can Determine Beam Energy

C. Hernandez-Garcia, P. G. O'Shea and M. L. Stutzman, Physics Today **61N2** (2008) 44.

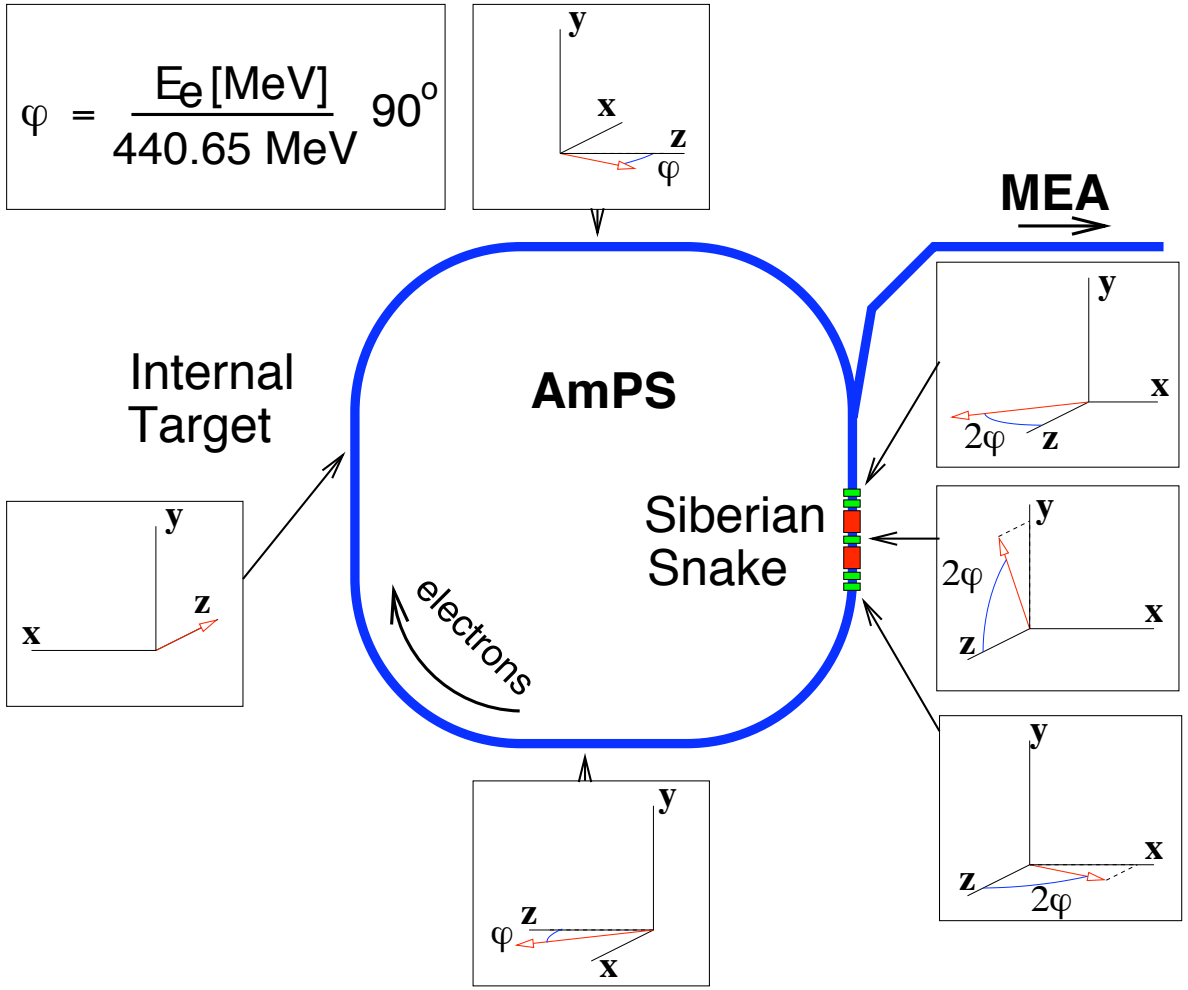




- Strained GaAs Photocathode
- Ultra-High Vacuum (Ions Destroy Cathodes)

Spin Precession In Storage Ring

Beautiful demonstration of the electron's anomalous magnetic moment and QED.

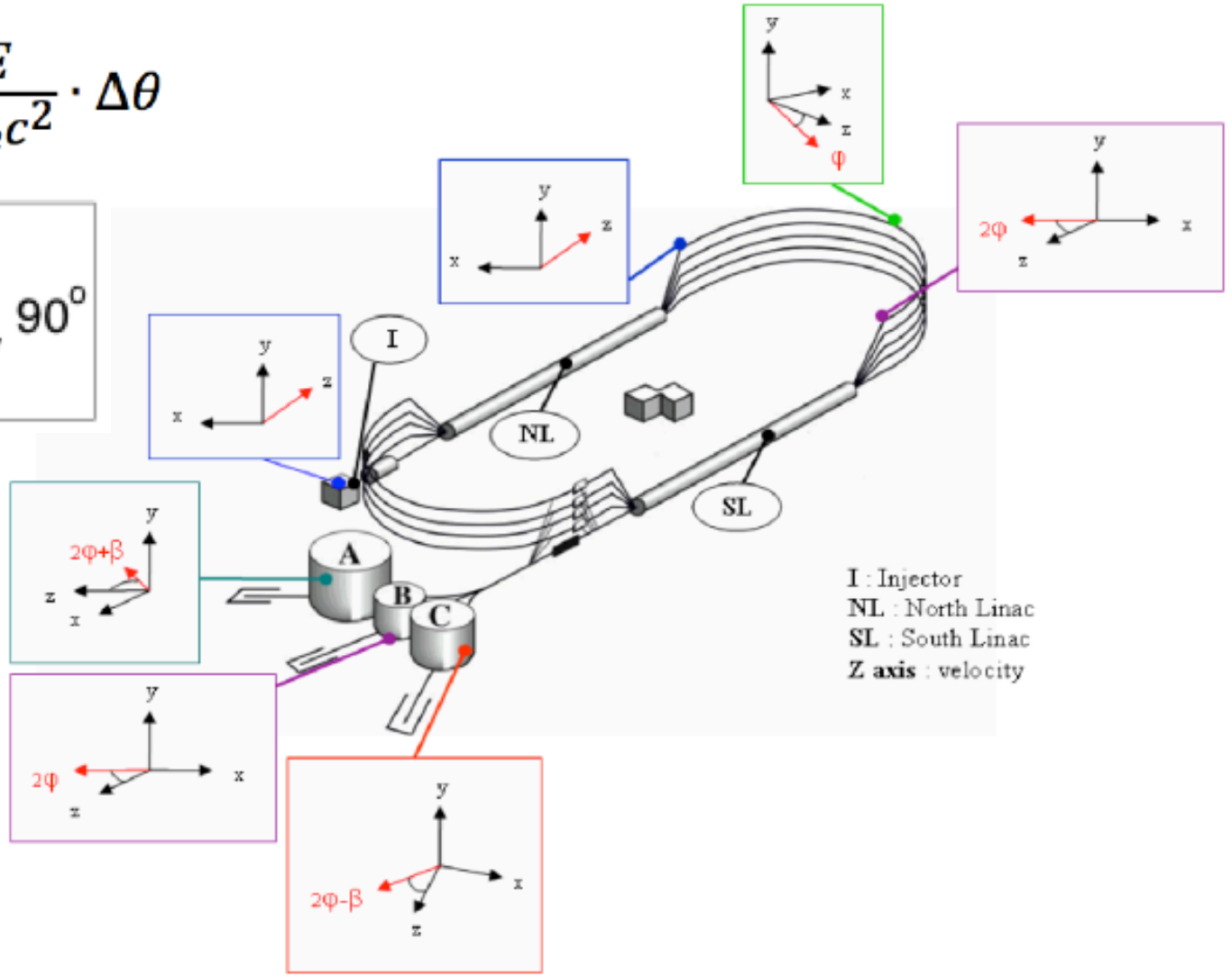


This is more complicated for spin-1 particle which is why EIC is going with an 8 layout.

Spin Precession in CEBAF

$$\Delta\varphi = \frac{g-2}{2} \cdot \frac{E}{m_e c^2} \cdot \Delta\theta$$

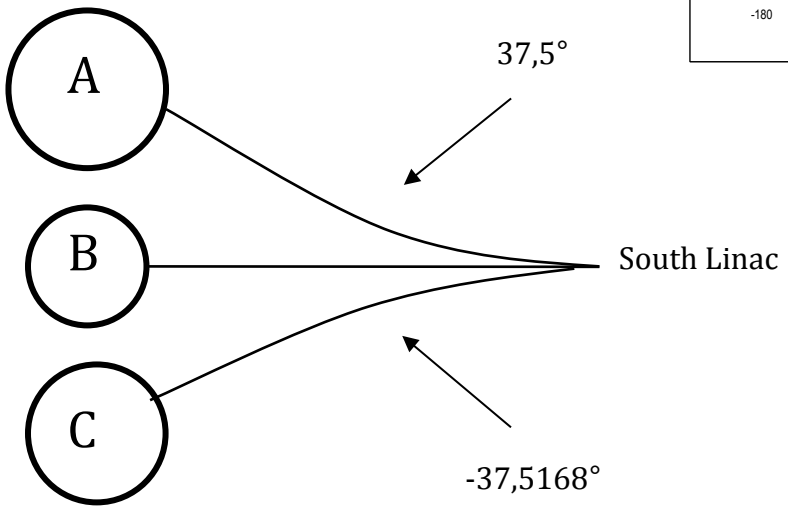
$$\varphi = \frac{E_e\,[\mathrm{MeV}]}{440.65\ \mathrm{MeV}}\ 90^{\circ}$$

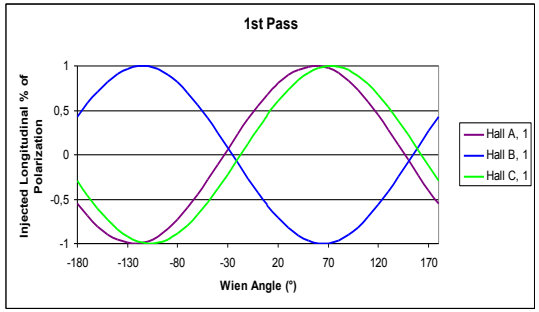


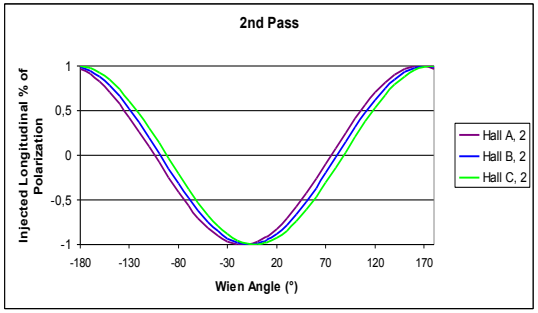
Magic CEBAF Energy (2.12 GeV/pass)

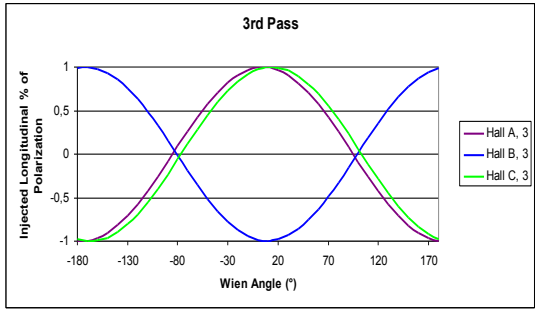
With the 12 GeV upgrade, these energies become available.

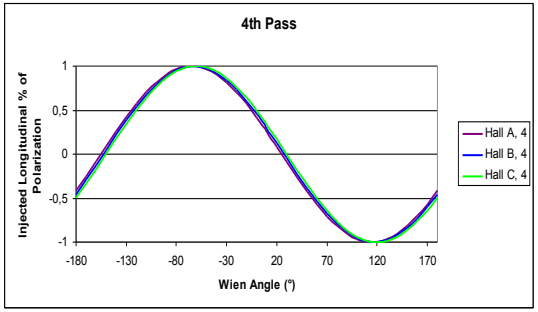
1st	2.12 GeV
2nd	4.23 GeV
3rd	6.35 GeV
4th	8.46 GeV
5th	10.6 GeV

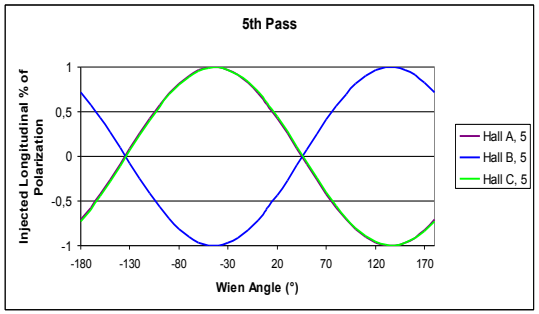








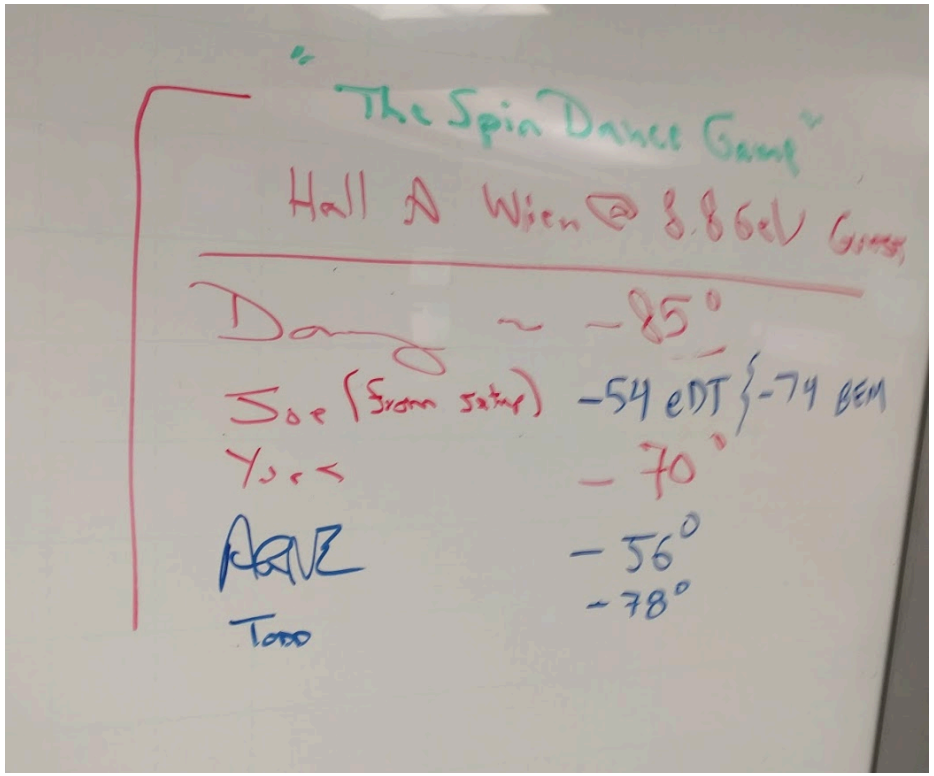




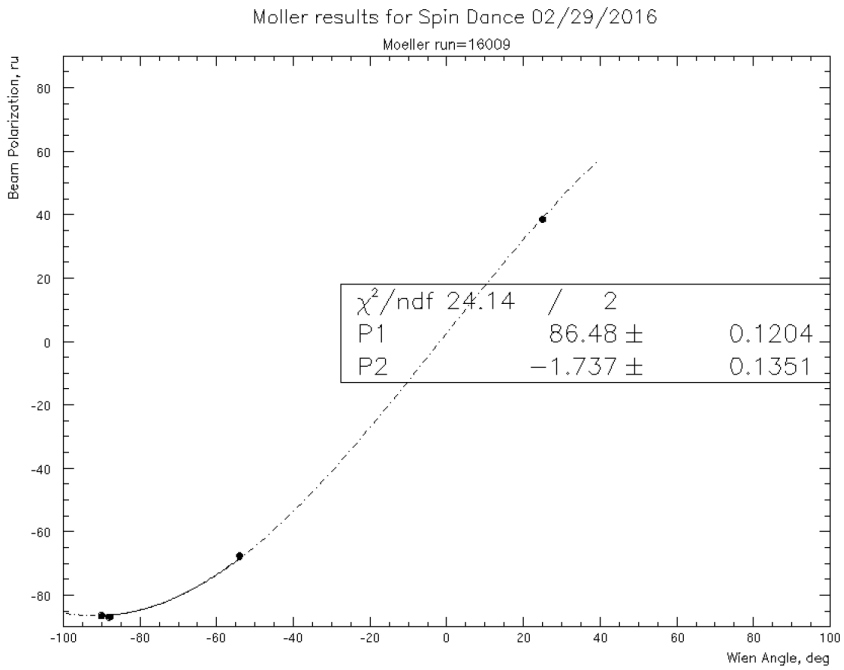
Beam Energy from Spin Dance

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

Prediction Based on ARC Energy



SPIN DANCE



Fit of Moller data gave 86.5 degrees

For 11 GeV we just used the ARC energy results & Joe's full model (including sync. Radiation) and we transported full long. polarization the first try. (with >20k degrees of total precession!)

Since the results, we have been getting near full polarization by simply using the ARC energy.

ARC Energy Measurements

Oct. through Dec. 2016

- 1st Pass Measurements
  - https://logbooks.jlab.org/entry/3429708 (dispersive)
  - 2.222(1) GeV vs. 2.218(2) GeV epics Calc. (aka Tiefenbach energy)
  - 1.002 scale factor

- 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)

  - **NOTE: 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.**

Current Status

- The “Hall A” energy (or Tiefenbach energy) in the start and end of runs is based on 6 GeV calibrations though it does nicely correct for shifts in the Bdl or *bad* orbits.
- For most energies, the ARC energy measurements show a systematic scale factor between the measured energy and the “6 GeV era” epics value.
- At 5th pass (11 GeV) there is serendipitous agreement. (sync. radiation & magnet saturation)
- NOTE: Epics calculated value is not equal set energy.