Using Polarimetry to Determine the CEBAF Beam Energy

by

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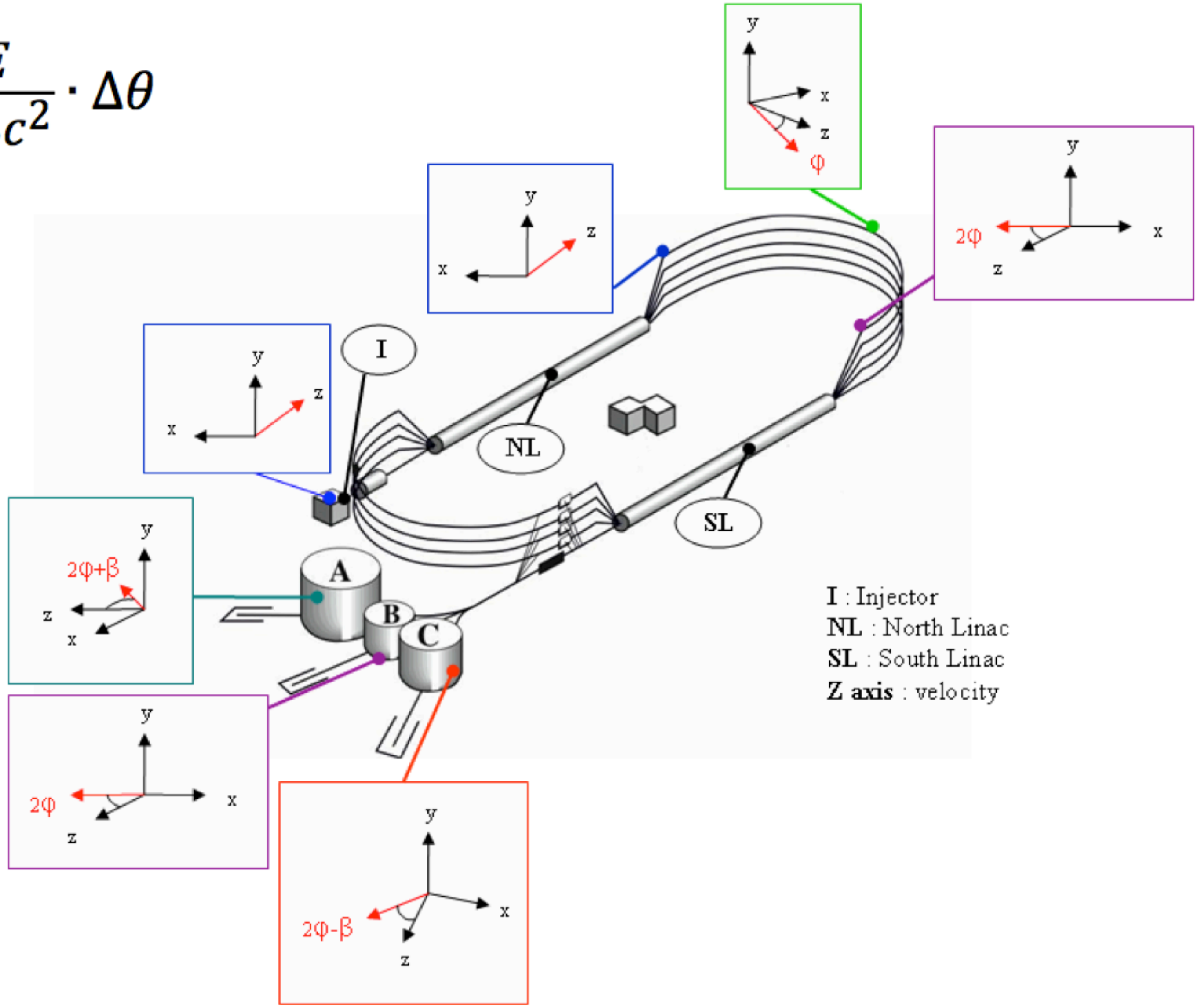
Beam Energy for 6 GeV CEBAF

- ARC Energy Method
  - Use dipole nine magnets connected in series
    - Eight magnets bend the beam into the hall
    - Ninth magnets can be mapped with NMR
  - Measure angle of beam at start and end of bend
  - Use dispersive optics for best precision (~2E-4 dE/E)
- Elastic Scattering
  - Dedicated elastic setup, eP, measure electron proton scattering angles (~2E-4 dE/E)
  - Use spectrometers to measures angles and/or momentum
- Spin Precession
  - Using the polarized source and the many Jefferson Lab polarimeters to determine the energy (also ~2E-4 dE/E)

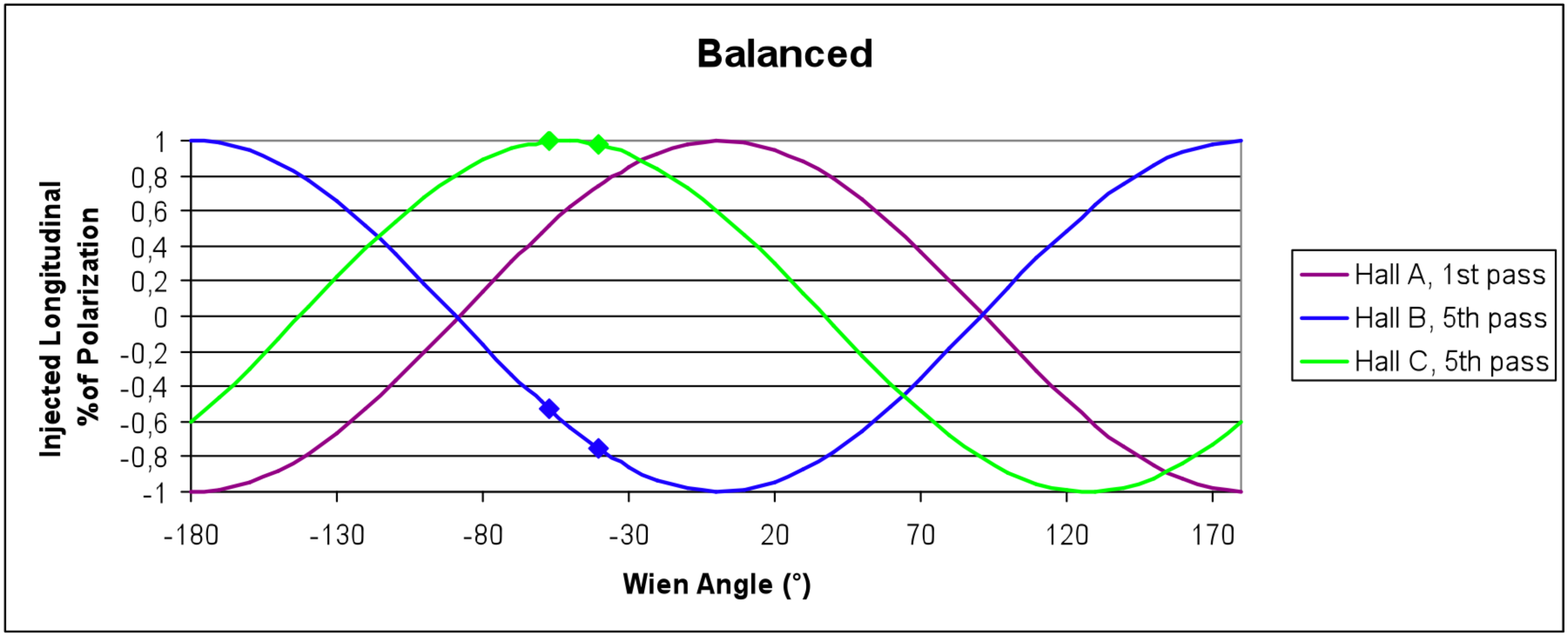
Spin Precession At CEBAF

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



Example CEBAF Setup

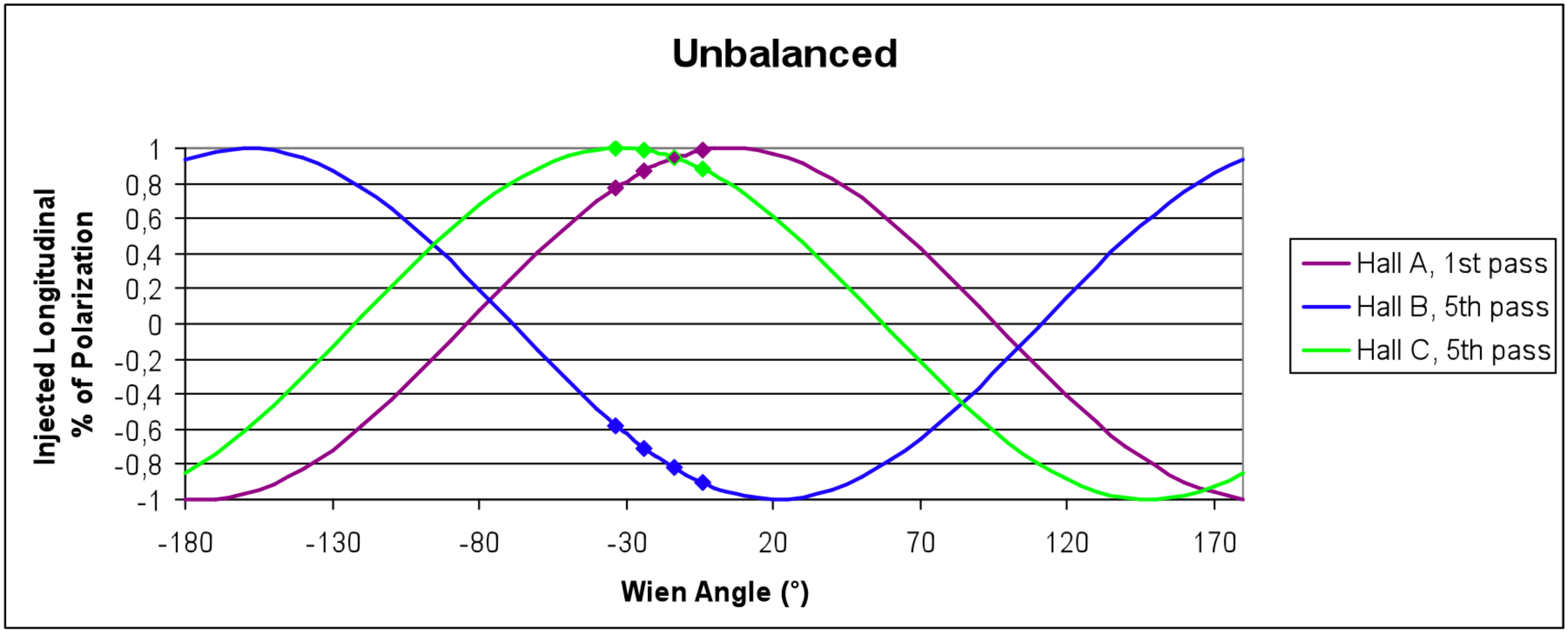
Select a beam energy and Wien angle based on physics requirements of the Halls
(63.5 MeV Injector Energy and 565 MeV Per Linac Per Pass)



- Machine setup with balanced (i.e. energy match linacs).
- Hall C required polarization (GEP-III) and Hall's A & B requested polarization.

Imbalanced Linacs

Needed to give Hall A & C high polarization without changing the beam energy for Hall B.
(63.5 MeV Injector Energy and 555 MeV & 575 MeV Per Linacs)



- With imbalanced the linacs, we were able to boost the polarization.
- 10 MeV was removed from the North linac and 10 MeV was added to the South linac.

Beam Energy From Total Precession

J. M. Grames et al., Phys. Rev. ST Accel. Beams 7 (2004) 042802.

Polarimeters	Ψ (deg)	E (MeV)
Mott-Compton	10 985.94 ± 1.37	5649.21 ± 0.89
Mott-Møller A	10 984.96 ± 0.71	5648.70 ± 0.65
Mott-Møller B	10 501.60 ± 0.64	5647.20 ± 0.66
Mott-Møller C	10 024.51 ± 0.69	5649.03 ± 0.71

NOTE: The Hall A and C polarimeters receive more attention to systematics then the Hall B polarimeter due to the requirements of the experiments (e.g. G0, HAPPEX, Qweak, etc.).

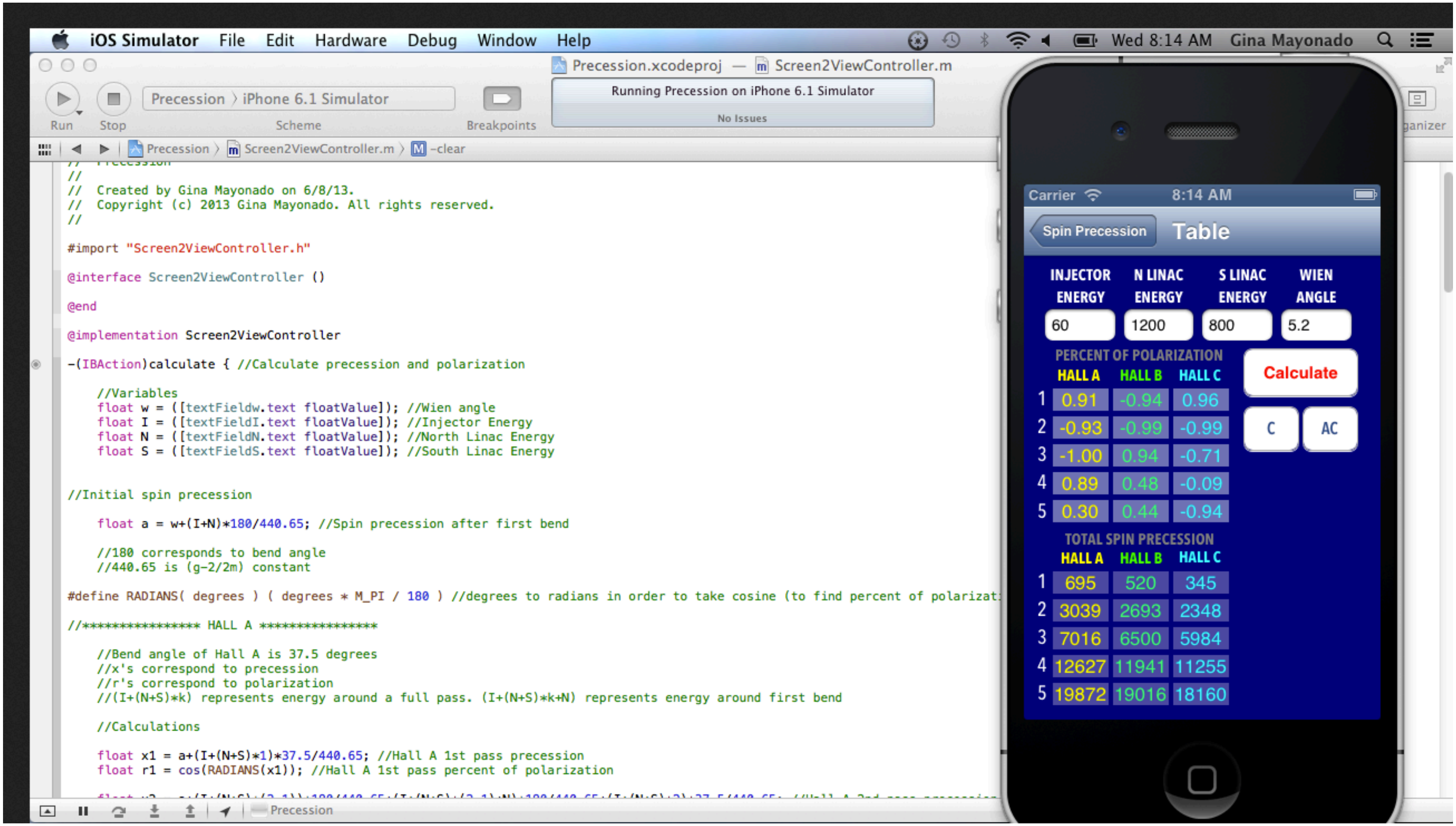
Even so, full spread these results is only 2 MeV (5648 +/- 1 MeV) so already 2E-4 level.

Using Spin At 12 GeV

- At 11 GeV, the beam processes >20k degrees before arriving in Hall A.
- 2 MeV of beam energy change (balanced) is a 5 degree change in the precession.
- Phase can be determined to the degree level with Compton (~8 hrs)
- That would be 9E-5 !! dE/E with just a single hall
- BUT accelerator systematics have to be under control
  - Injector Energy
  - Linac Balance (relative difference in energy)
  - Calibration of Wien angle

New Spin Calculator App

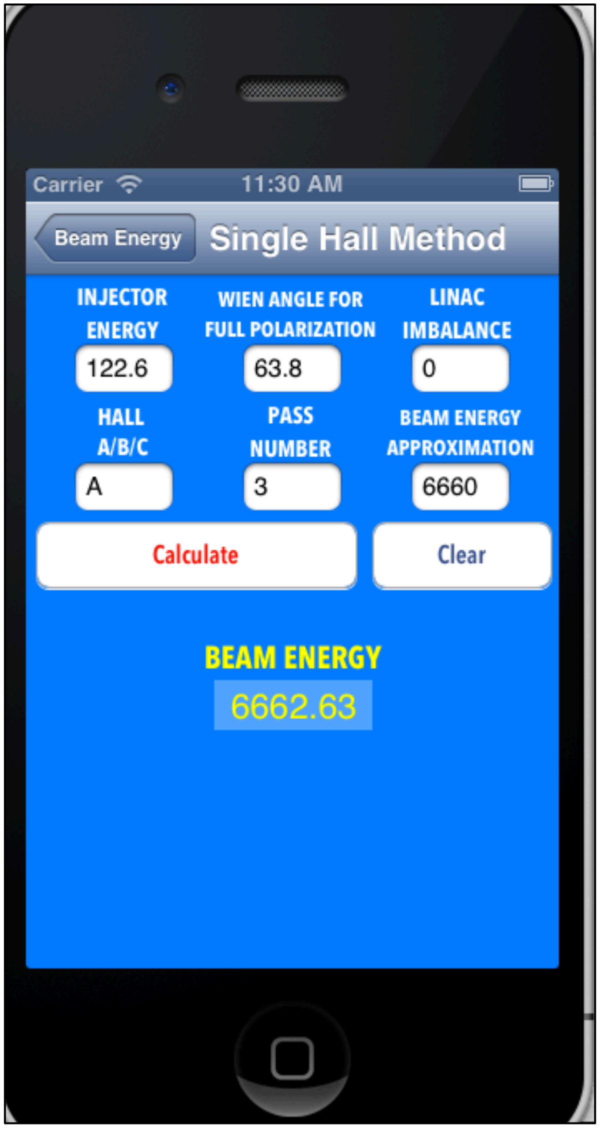
Thanks to Department of Energy SULI Student Gina Mayonado



Beam Energy – Single Hall

- Known parameters needed:
  - Injector energy
  - Linac imbalance
  - Wien angle that gives full polarization
- Outputs multiple solutions

Energy Output
3489.95
4547.51
5605.07
6662.63
7720.19
8777.75



Energy By Precession Differences

J. M. Grames et al., Phys. Rev. ST Accel. Beams 7 (2004) 042802.

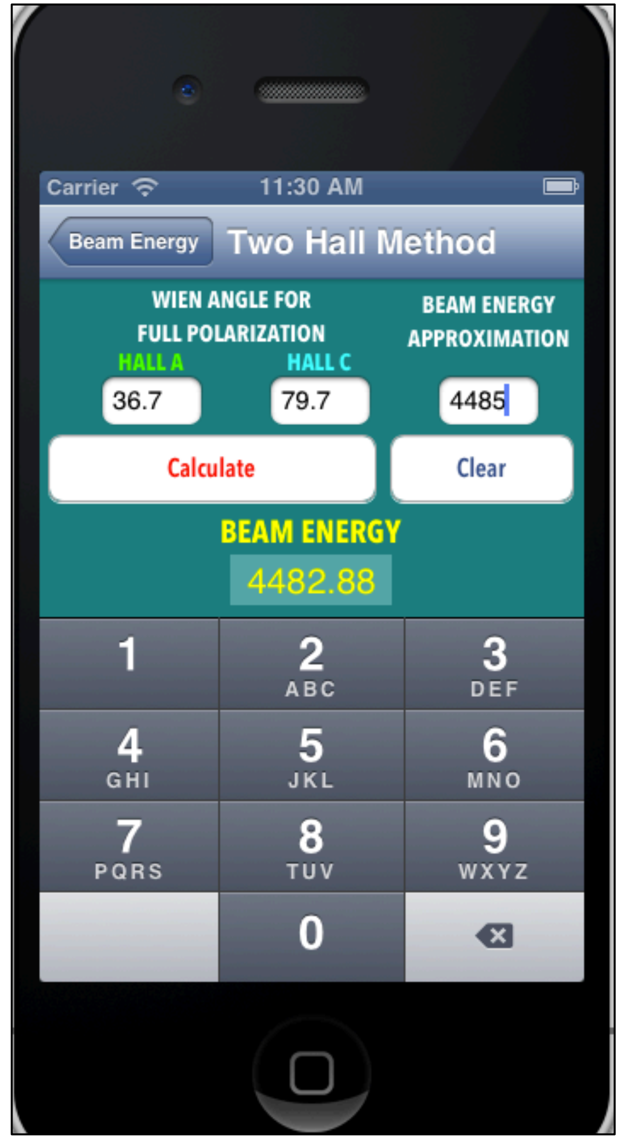
Polarimeters	$\Delta\Psi$ (deg)	$\Delta\Theta$ (deg)	E (MeV)	$\frac{\sigma_E}{E}$ (%)
Møller A-Møller B	483.36 ± 0.84	37.4913 ± 0.0102	5681.10 ± 10.03	0.176
Møller A-Møller C	960.45 ± 0.88	74.9687 ± 0.0060	5645.30 ± 5.17	0.092
Compton A-Møller B	484.34 ± 1.44	37.4913 ± 0.0102	5692.62 ± 17.03	0.299
Compton A-Møller C	961.43 ± 1.46	74.9687 ± 0.0060	5651.07 ± 8.61	0.152
Møller B-Møller C	477.09 ± 0.83	37.4774 ± 0.0115	5609.49 ± 9.89	0.176

Hall A and C give smallest errors since the opening angle between them is twice as large as A and B or B and C.

Repeating this same measurement at 11 GeV has a factor of two better sensitivity; so can be provide a ~5E-4 level absolute measurement with almost no systematic error.

Beam Energy – Two Hall

- Known parameters needed:
  - Wien angles for full polarization in both Halls
- Less systematic errors
  - No accelerator setting dependence.
  - Only uses spin precession from beam switchyard into the halls.



Synchrotron Radiation

- Radiation from charged particles accelerated in a curved path

$$\delta E\,(in\ MeV) = 0.0885 \times \frac{[E\,(in\ GeV)]^4}{R\ (in\ m)}$$

Beam Energy (MeV)	Energy Loss (MeV)	Change in Spin Precession (deg)
2302.632	0.01	-0.01
4482.686	0.29	-0.04
6662.604	1.88	-0.16
8842.629	7.32	-0.48
11022.643	21.32	-1.16

At 11 GeV this is a 2E-3 correction that we need to control to the 10% level.

Working on adding this correction into the spin calculator code.

Summary

- Would like multiple ways to determine the energy of the Jefferson Lab electron beam with at the ~2E-4 level.
- ARC Energy Measurements during 6 GeV provided ~2E-4 measurements and being readied for 12 GeV
  - For 12GeV All ARC Magnets have been refurbished and remapped
  - After over a decade magnets all still with 1E-4 Bdl of each other.
- Elastic Scattering while great at 6 GeV becomes impractical at 12 GeV (cross sections get very small)
- Spin Precision Gets Better As The Energy Goes Up
  - From injector to Halls over 20k degrees rotation at 11 GeV
  - Synchrotron radiation starts to become important
- **Making APPS is a fun way to engage new students!**

Magic CEBAF Energy (2.12 GeV/pass)

At 2.12 GeV per pass, the passes give full polarization the all three of the current halls.

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