



# Determining the CEBAF Beam Energy

by

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and  
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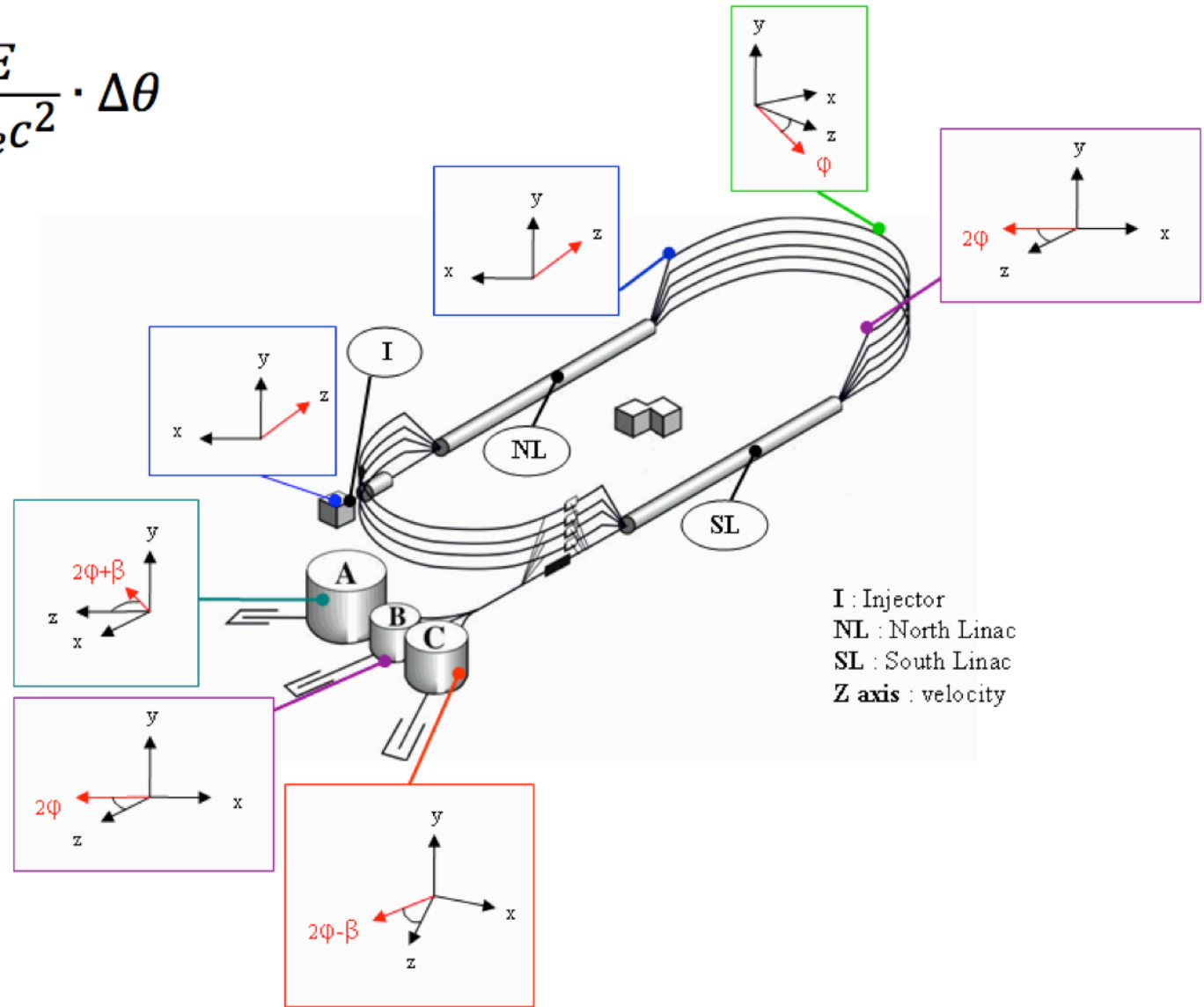
**Jefferson Lab**  
Thomas Jefferson National Accelerator Facility

# 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 (  $\sim 2E^{-4}$  dE/E)
- Elastic Scattering
  - Dedicated elastic setup, eP, measure electron proton scattering angles ( $\sim 2E^{-4}$  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  $\sim 2E^{-4}$  dE/E)

# Spin Precession At CEBAF

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



# New Spin Calculator App

Thanks to Department of Energy SULI Student Gina Mayonado

The image shows the Xcode IDE on the left and the iPhone 6.1 Simulator on the right. The simulator displays the 'Spin Precession' app interface with a table of polarization data.

**Code Snippet (Swift):**

```

// Created by Gina Mayonado on 6/8/13.
// Copyright (c) 2013 Gina Mayonado. All rights reserved.

#import "Screen2ViewController.h"

@interface Screen2ViewController ()
@end

@implementation Screen2ViewController

-(IBAction)calculate { //Calculate precession and polarization

    //Variables
    float w = ([textFieldw.text floatValue]); //Wien angle
    float I = ([textFieldI.text floatValue]); //Injector Energy
    float N = ([textFieldN.text floatValue]); //North Linac Energy
    float S = ([textFieldS.text floatValue]); //South Linac Energy

    //Initial spin precession
    float a = w+(I+N)*180/440.65; //Spin precession after first bend

    //180 corresponds to bend angle
    //440.65 is (g-2/2m) constant

#define RADIANS( degrees ) ( degrees * M_PI / 180 ) //degrees to radians in order to take cosine (to find percent of polarizat

    //***** HALL A *****

    //Bend angle of Hall A is 37.5 degrees
    //x's correspond to precession
    //r's correspond to polarization
    //(I+(N+S)*k) represents energy around a full pass. (I+(N+S)*k+N) represents energy around first bend

    //Calculations
    float x1 = a+(I+(N+S)*1)*37.5/440.65; //Hall A 1st pass precession
    float r1 = cos(RADIANS(x1)); //Hall A 1st pass percent of polarization
    
```

**App Interface (Simulator):**

Carrier 8:14 AM

Spin Precession Table

	INJECTOR ENERGY	N LINAC ENERGY	S LINAC ENERGY	WIEN ANGLE
	60	1200	800	5.2

PERCENT OF POLARIZATION

	HALL A	HALL B	HALL C
1	0.91	-0.94	0.96
2	-0.93	-0.99	-0.99
3	-1.00	0.94	-0.71
4	0.89	0.48	-0.09
5	0.30	0.44	-0.94

TOTAL SPIN PRECESSION

	HALL A	HALL B	HALL C
1	695	520	345
2	3039	2693	2348
3	7016	6500	5984
4	12627	11941	11255
5	19872	19016	18160

Buttons: Calculate, C, AC

# Beam Energy From Total Precession

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

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

NOTE: The Hall A and C polarimeters receive more attention to systematics than 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 precesses  $>20k$  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

# Beam Energy – Single Hall

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

## Energy Output

3489.95

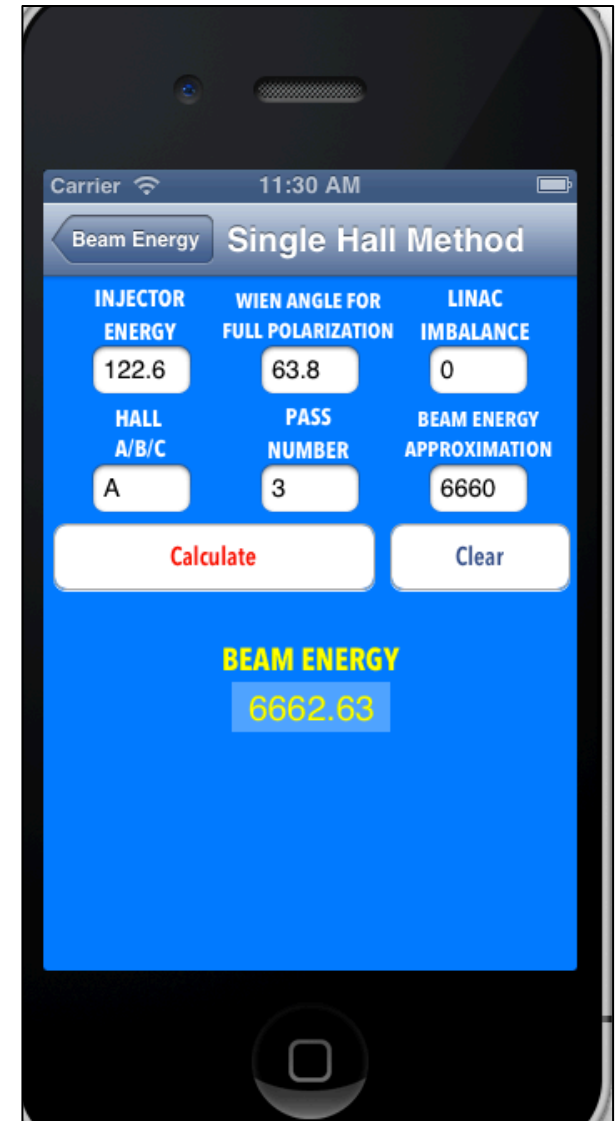
4547.51

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	$483.36 \pm 0.84$	$37.4913 \pm 0.0102$	$5681.10 \pm 10.03$	0.176
Møller A-Møller C	$960.45 \pm 0.88$	$74.9687 \pm 0.0060$	$5645.30 \pm 5.17$	0.092
Compton A-Møller B	$484.34 \pm 1.44$	$37.4913 \pm 0.0102$	$5692.62 \pm 17.03$	0.299
Compton A-Møller C	$961.43 \pm 1.46$	$74.9687 \pm 0.0060$	$5651.07 \pm 8.61$	0.152
Møller B-Møller C	$477.09 \pm 0.83$	$37.4774 \pm 0.0115$	$5609.49 \pm 9.89$	0.176

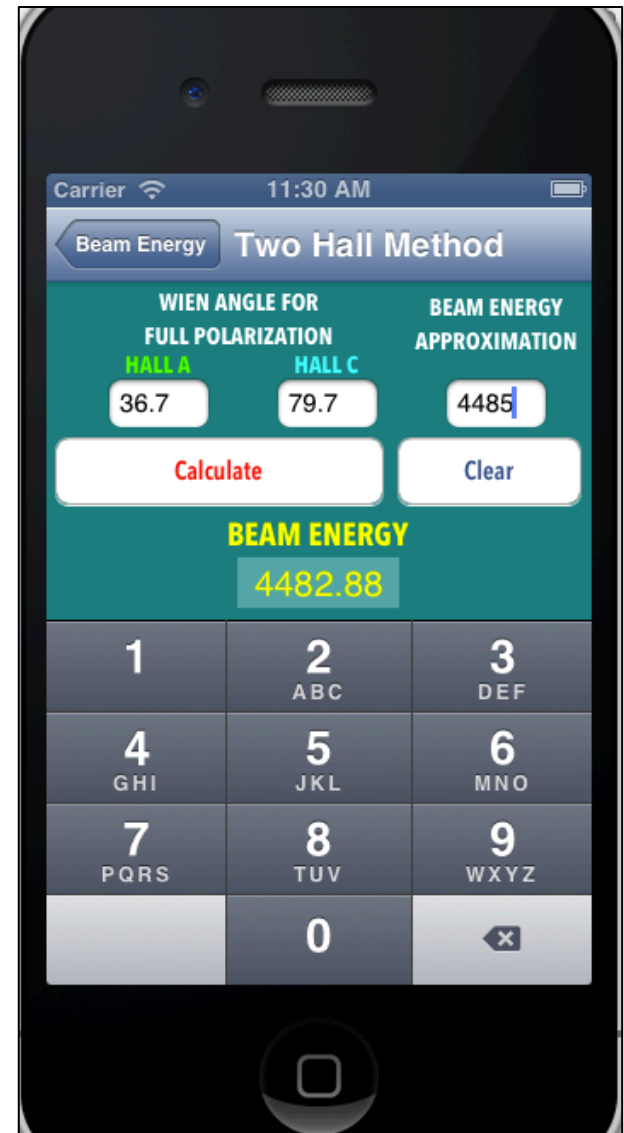
Hall A and C give smallest errors since the opening angle between them is twice as large as A and B or B and C.

Repeating this same measurement at 11 GeV has a factor of two better sensitivity; so can be provide a  $\sim 5E-4$  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

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

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.

# Beam Energy from Integral Field and Angle

Deviations from the average for the eight down in the ARC

Avg (5-12)	1,607,581	2,355,398	2,796,953 [G-cm]
BA1C05	0.02%	0.00%	-0.03%
BA1C06	0.00%	-0.01%	0.03%
BA1C07	-0.02%	0.02%	0.04%
BA1C08	-0.01%	0.04%	0.03%
-			
BA1C09	0.00%	-0.04%	-0.04%
BA1C10	0.00%	0.00%	-0.01%
<b>BA1C11</b>	<b>0.03%</b>	<b>0.01%</b>	<b>-0.02%</b>
BA1C12	-0.01%	-0.01%	-0.01%
<b>BA1C11</b>	<b>0.02%</b>	<b>-0.01%</b>	<b>-0.03%</b> (a repeat measurement)

NOTE: The 9<sup>th</sup> dipole is systematically different then the other eight at the 1E-3 level.  
Need to figure out if that was always true.

# Current Man Power

- Luke Myers (review/analysis of Bdl data)
- Seare Farhat (continuing spin dance coding)
  - will shift to Bdl codes in coming months
- David Gaskel (long term for two hall spin dance)
- Vernin Pascal (consulting/original designer)
- Rick Gonzales (technical help)
  - Was able to get the mapper to run during g2p
  - Requested new multiplexer and telsameter which have arrived but not yet installed

# 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.

1 <sup>st</sup>	2.12 GeV
2 <sup>nd</sup>	4.23 GeV
3 <sup>rd</sup>	6.35 GeV
4 <sup>th</sup>	8.46 GeV
5 <sup>th</sup>	10.6 GeV

