A New, Robust Beam Modulation Strategy for Hall-C and Hall-A

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for the beam modulation team

A SEARCH FOR NEW PHYSICS

Qweak

22nd July 2009

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Recall from Collaboration Meeting

Recall from Collaboration Meeting

- Single coil approach for upstream modulation.
  (pair of coils approach will be presented)

- Optical design for upstream modulation being finalized by us for position and angle.
  Mike Tiefenback's "coil pair" recommendation set us back 1-2 months, but seems feasible and offers several advantages.
  (detailed calculation with pair of coils will be presented)

- Coils for upstream beam modulation are on site and will be installed by accelerator techs.
  (will be installed this end 2009 or beginning of 2010)

- Prototype Trim-II power supply and function generator is on hand for testing.
  (bench test results will be shown with apparatus)

Ref: http://qweak.jlab.org/doc-private/ShowDocument?docid=910

Clock time and modulation amplitude calculation

Clock time and modulation amplitude calculation

Should one want to measure sensitivities to 10% statistical accuracy, the required measurement times for *a single beam parameter* are:

$A_{modulation}$	Clock Time Required 10% DF (Hours)	Clock Time Required 1% DF (Hours)	Clock Time Required 0.1% DF (Hours)
1 ppm	43	430	4300
10 ppm	0.43	4.3	43

These times are easily scaled to preferred statistical error.

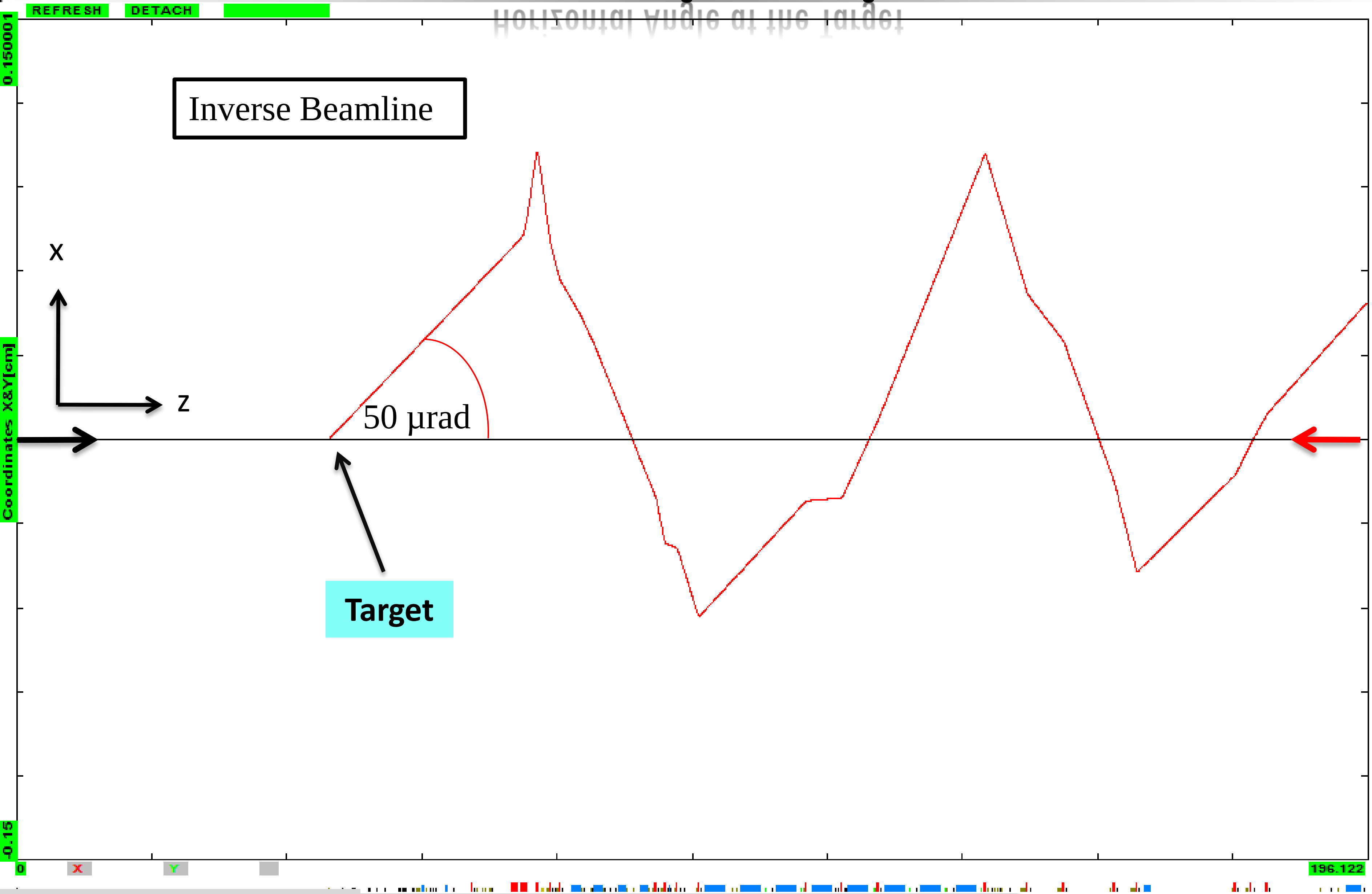
To estimate dX_i for Abeam = 10 ppm, we need the detector sensitivities.

Beam Parameter	Single Detector Sensitivity	Assumed Cancellation	Whole Detector Sensitivity	Modulation Amplitude for 10 ppm
Position	10 ppb/nm	50	0.2 ppb/nm	50 µm
Angle	10 ppb/nrad	50	0.2 ppb/nrad	50 µrad
Energy	1 ppb/ppb	1	1 ppb/ppb	10 ppm (~10 keV)

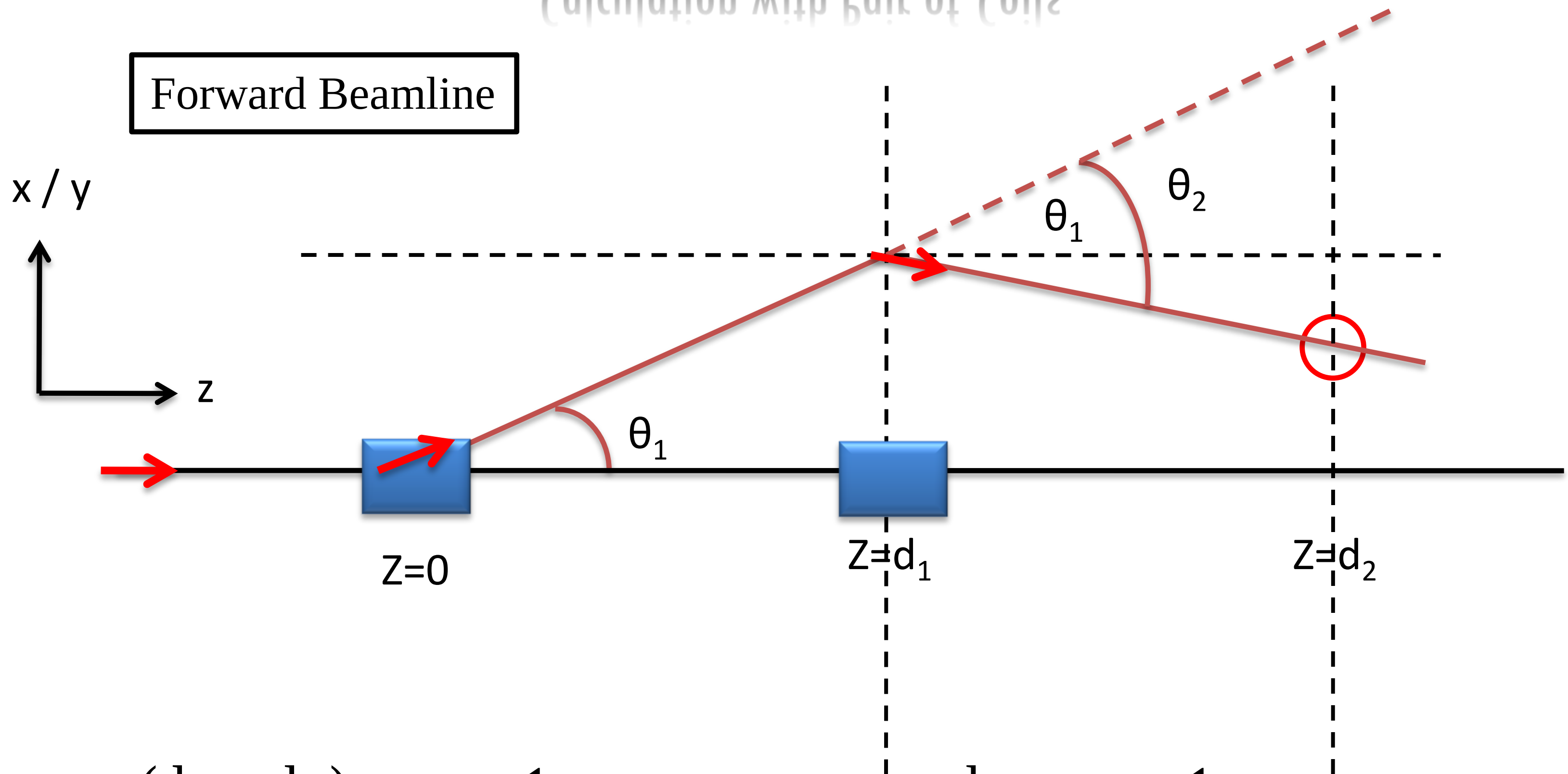
We believe these magnitudes are sufficiently larger than natural beam jitter that the latter does not appreciably affect the measurement times.

Ref: http://qweak.jlab.org/doc-private/ShowDocument?docid=910

Horizontal Angle at the Target



Calculation with Pair of Coils

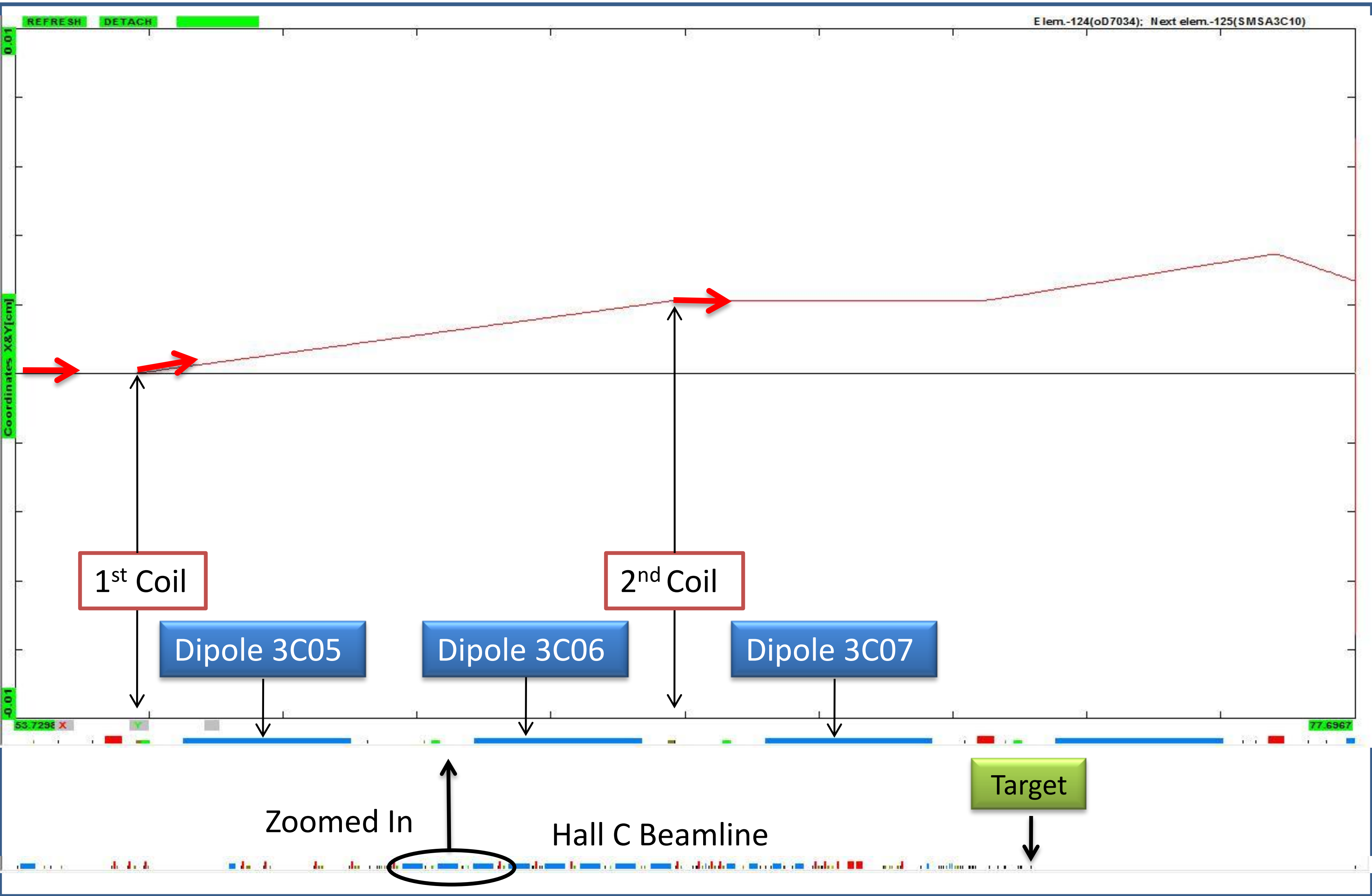


$$\theta_1 = -\frac{(d_2 - d_1)}{d_1} T' + \frac{1}{d_1} T \qquad \theta_2 = \frac{d_2}{d_1} T' - \frac{1}{d_1} T$$

Where
$$T = X_m, Y_m$$
$$T' = X_m', Y_m'$$

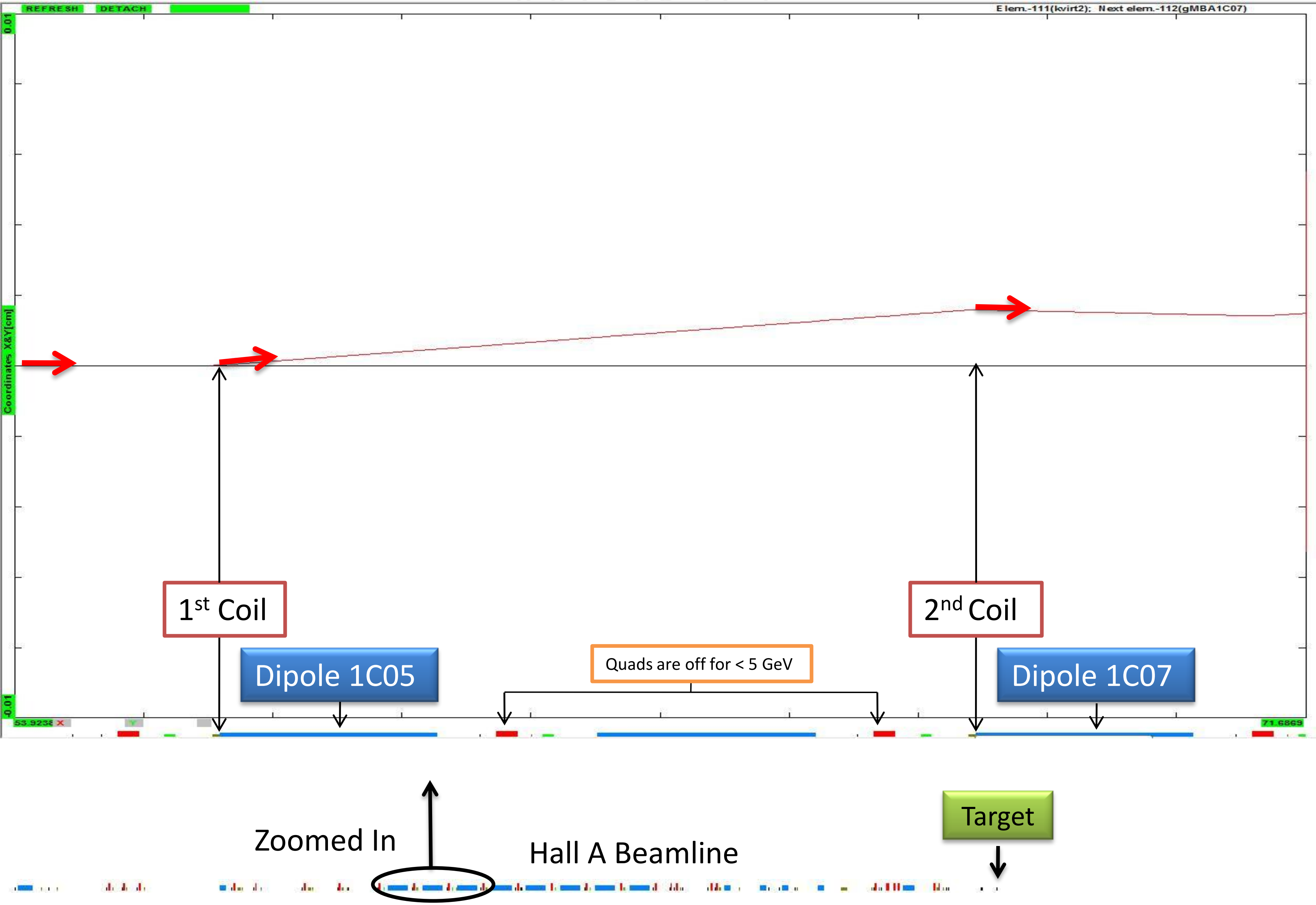
Hall-C Coil Positioning

Hall-C Coil Positioning

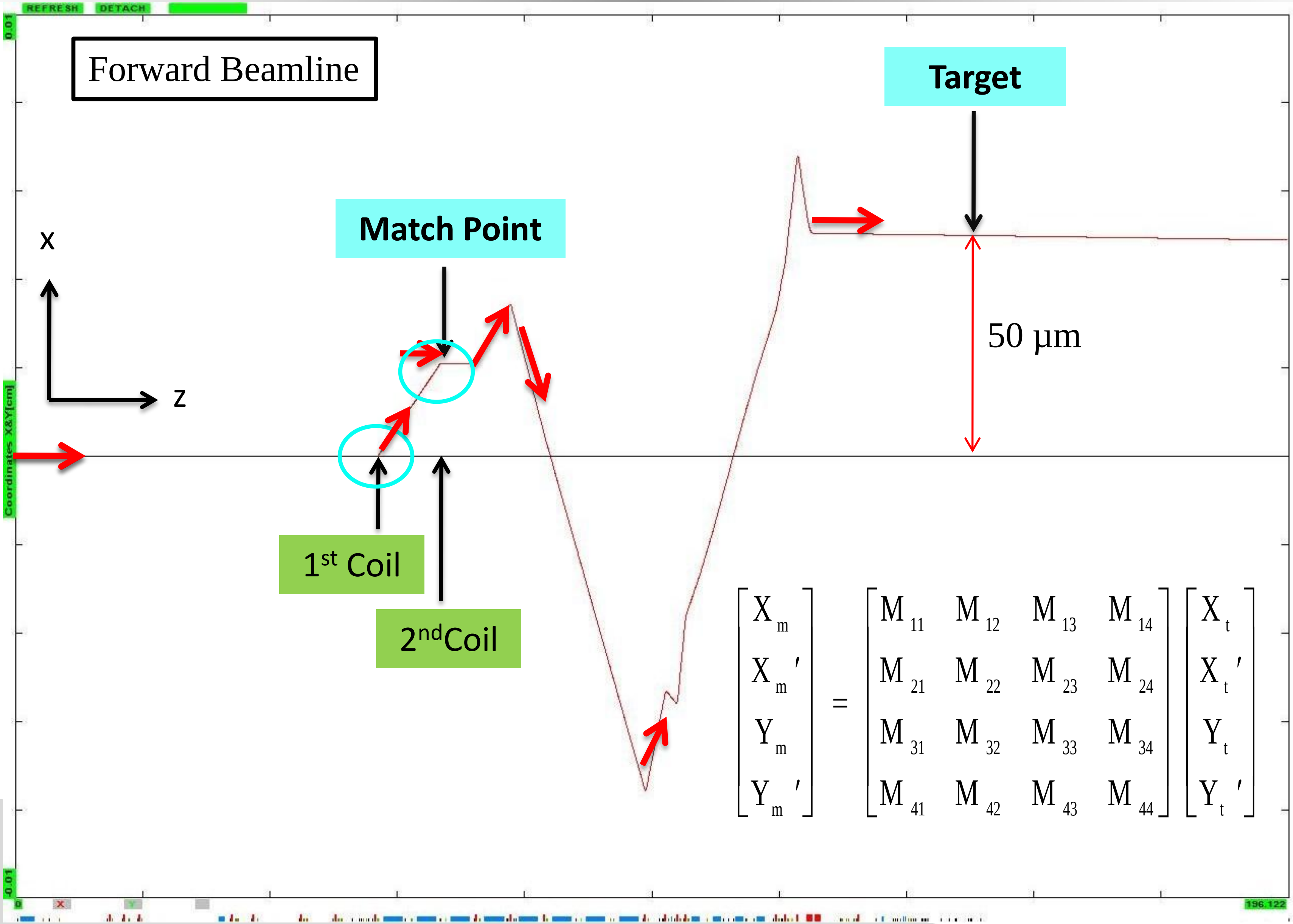


Hall-A Coil Positioning

Hall-A Coil Positioning

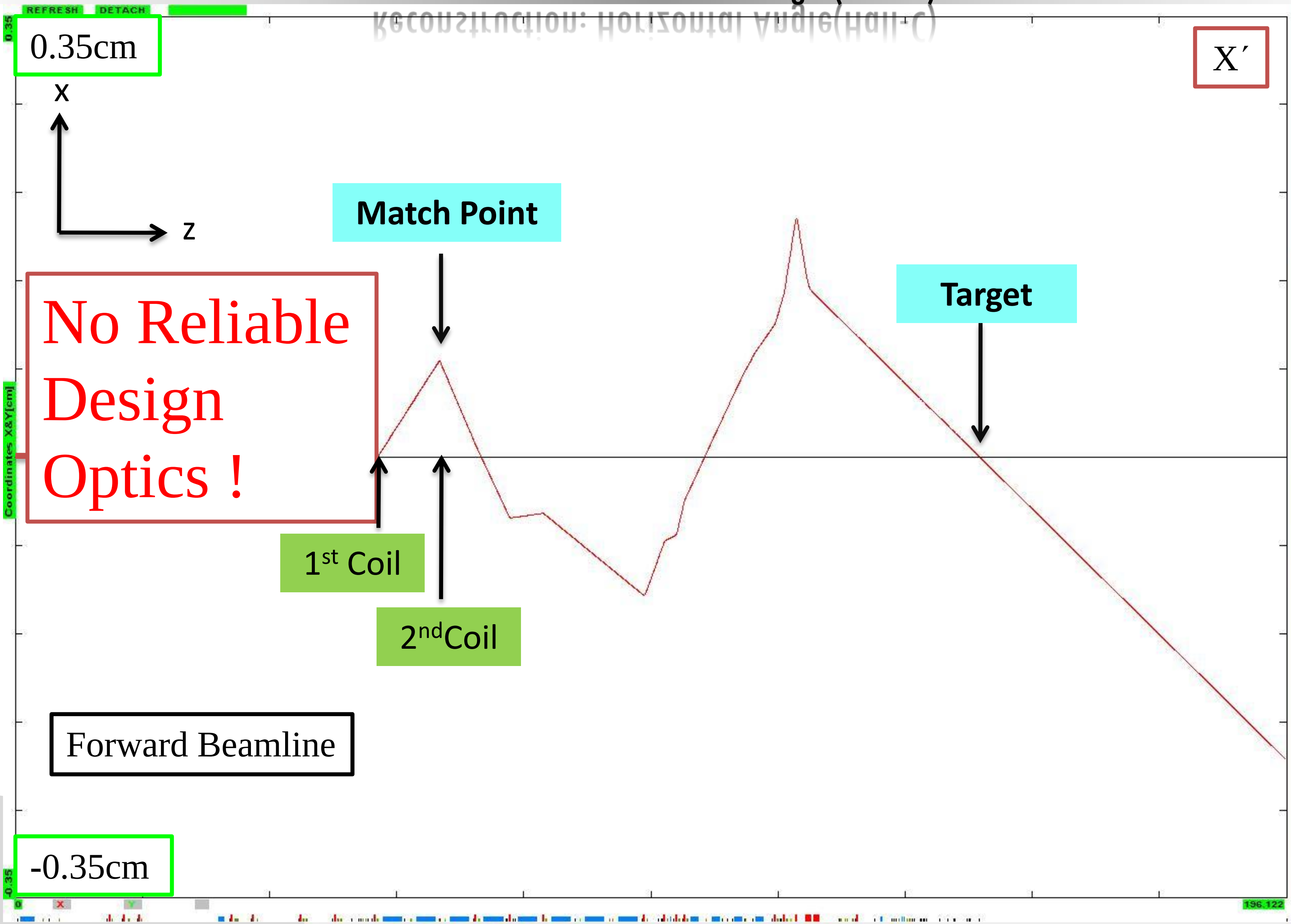


Calculation with Pair of Coils

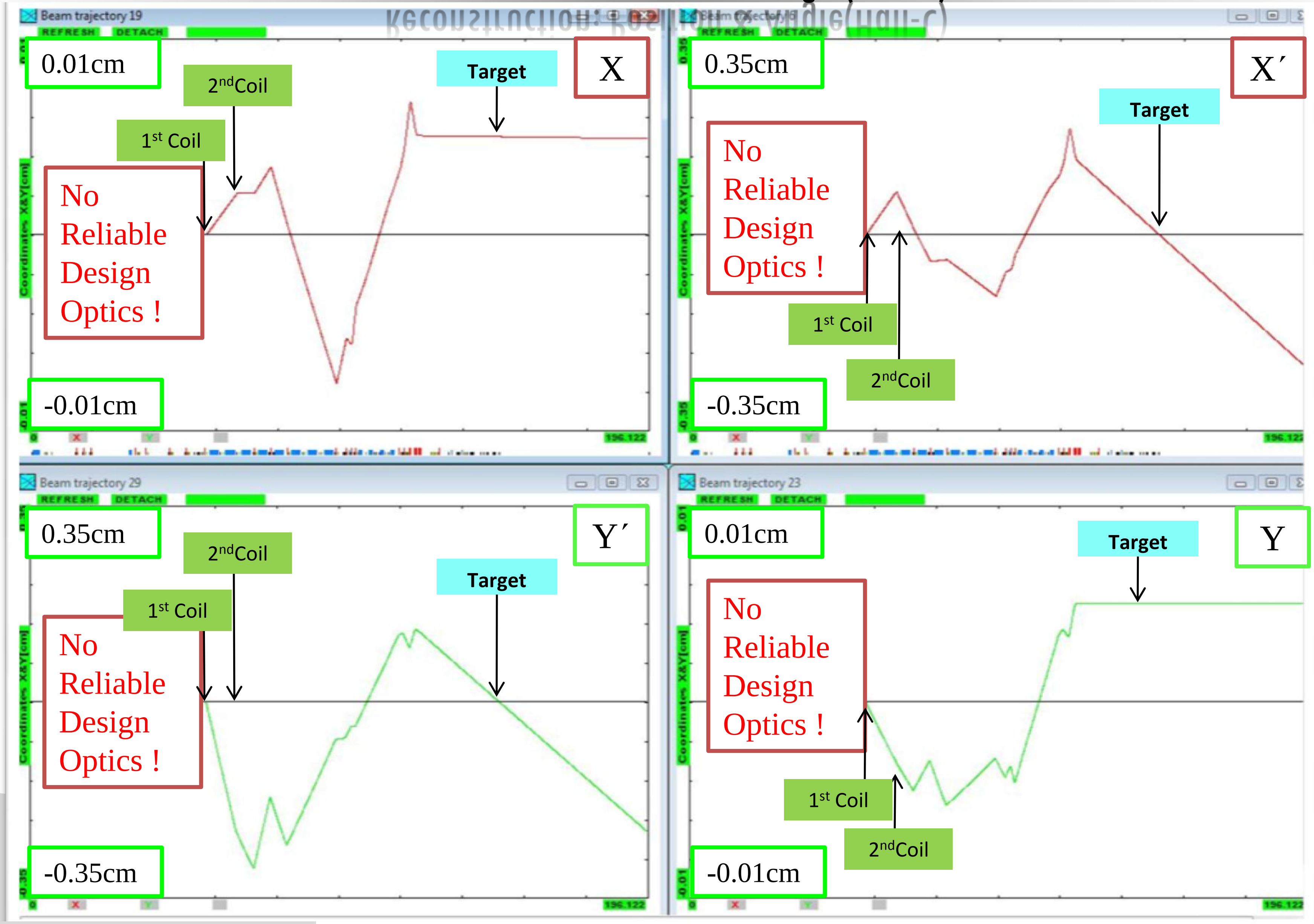


$$\begin{bmatrix} X_m \\ X_m' \\ Y_m \\ Y_m' \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix} \begin{bmatrix} X_t \\ X_t' \\ Y_t \\ Y_t' \end{bmatrix}$$

Reconstruction: Horizontal Angle(Hall-C)



Reconstruction: Position & Angle(Hall-C)



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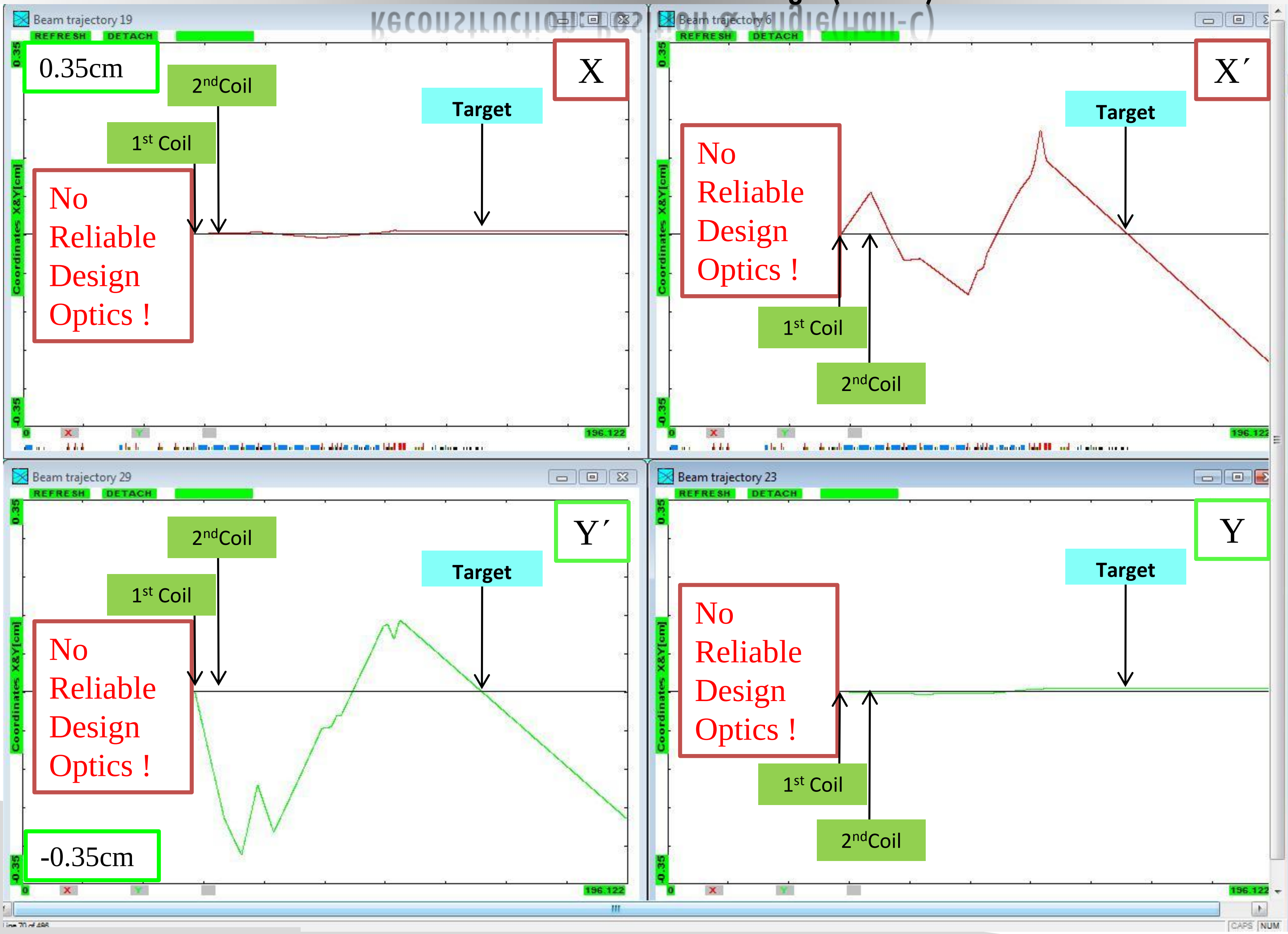
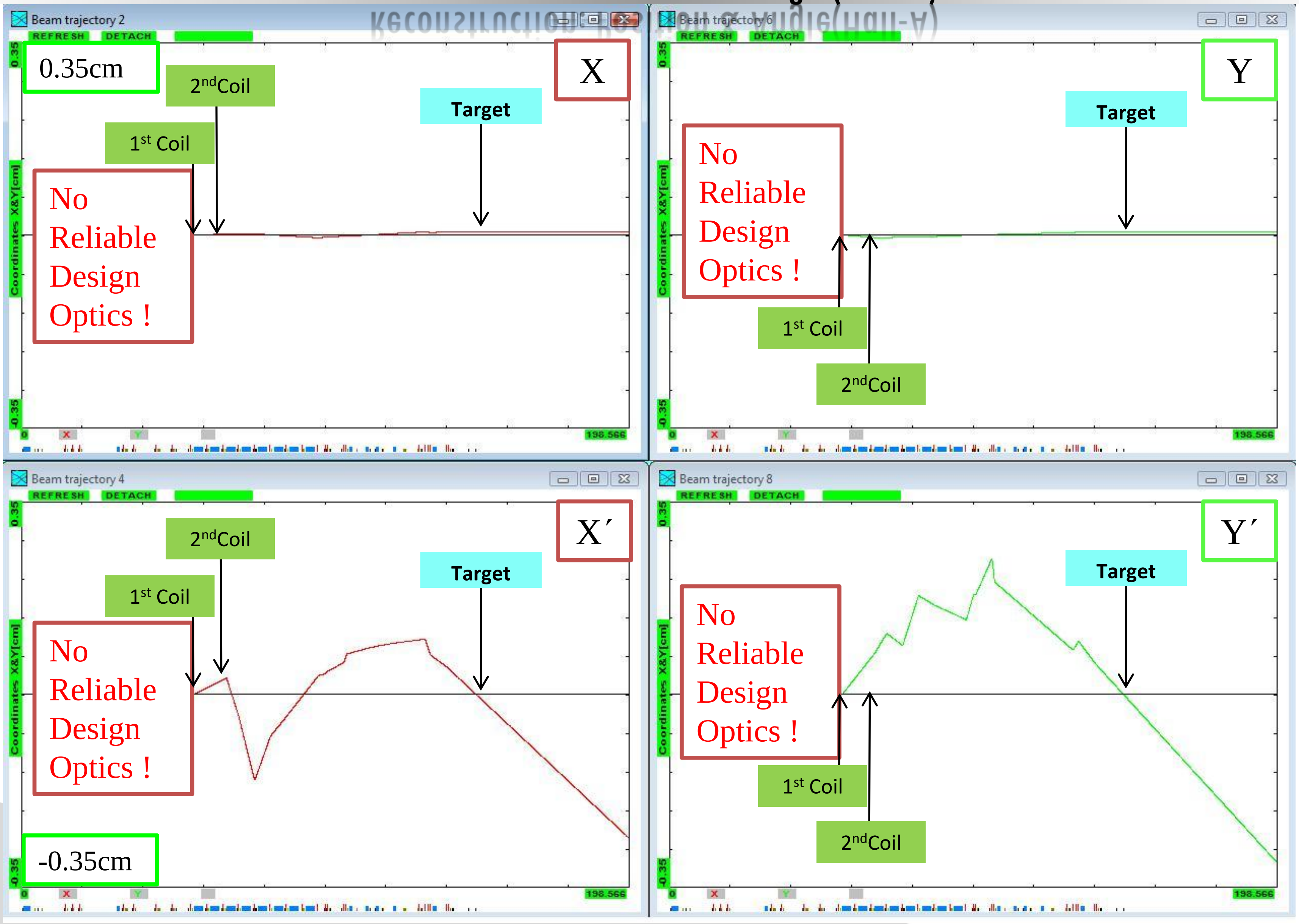
Reconstruction: Position & Angle(Hall-C)



Reconstruction: Position & Angle(Hall-A)



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Beam Modulation Calibration Constant(Hall-C)

Beam Parameter	Modulation Amplitude for 10 ppm	Current through 1st Coil I_1 (A)	Field Integrals for 1st Coil BdL_1 (G-cm)	Current through 2nd Coil I_2 (A)	Field Integrals for 2nd Coil BdL_2 (G-cm)	Tune Parameters (BdL_2 / BdL_1)
X	50 μm	0.026	8.5	-0.026	-8.5	-1.00
X′	50 μrad	0.94	312.0	-2.37	-786.24	-2.52
Y	50 μm	-0.038	-12.5	0.050	16.5	-1.32
Y′	50 μrad	2.88	-950.0	-1.32	437.0	-0.46

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Beam Modulation Calibration Constant(Hall-A)

Beam Modulation Calibration Constant(Hall-A)

Beam Parameter	Modulation Amplitude for 10 ppm	Current through 1st Coil I_1 (A)	Field Integrals for 1st Coil BdL_1 (G-cm)	Current through 2nd Coil I_2 (A)	Field Integrals for 2nd Coil BdL_2 (G-cm)	Calibration Constant (BdL_2 / $BdLI_1$)
X	50 µm	0.013	I_1 = 4.3	-0.017	I_1 = -5.5	-1.2791
X′	50 µrad	0.242	I_1 = 80.0	-1.737	I_1 = -573.3	-7.1667
Y	50 µm	-0.039	I_1 =-13.0	0.023	I_1 =7.5	-0.5750
Y′	50 µrad	0.606	I_1 =200.0	-0.193	I_1 =64.0	0.3200

Tests

Tests

To make sure that the planned hardware could provide the required field integral at frequencies of up to 500 Hz, we did the following bench tests:

✓Powered a JLab MAT(HF) coil with a Trim-II power supply at 10Hz-500Hz

✓Determined that only sinusoidal waveforms are feasible

✓Determined I_{max} = 5A based on the observed coil temperature rise

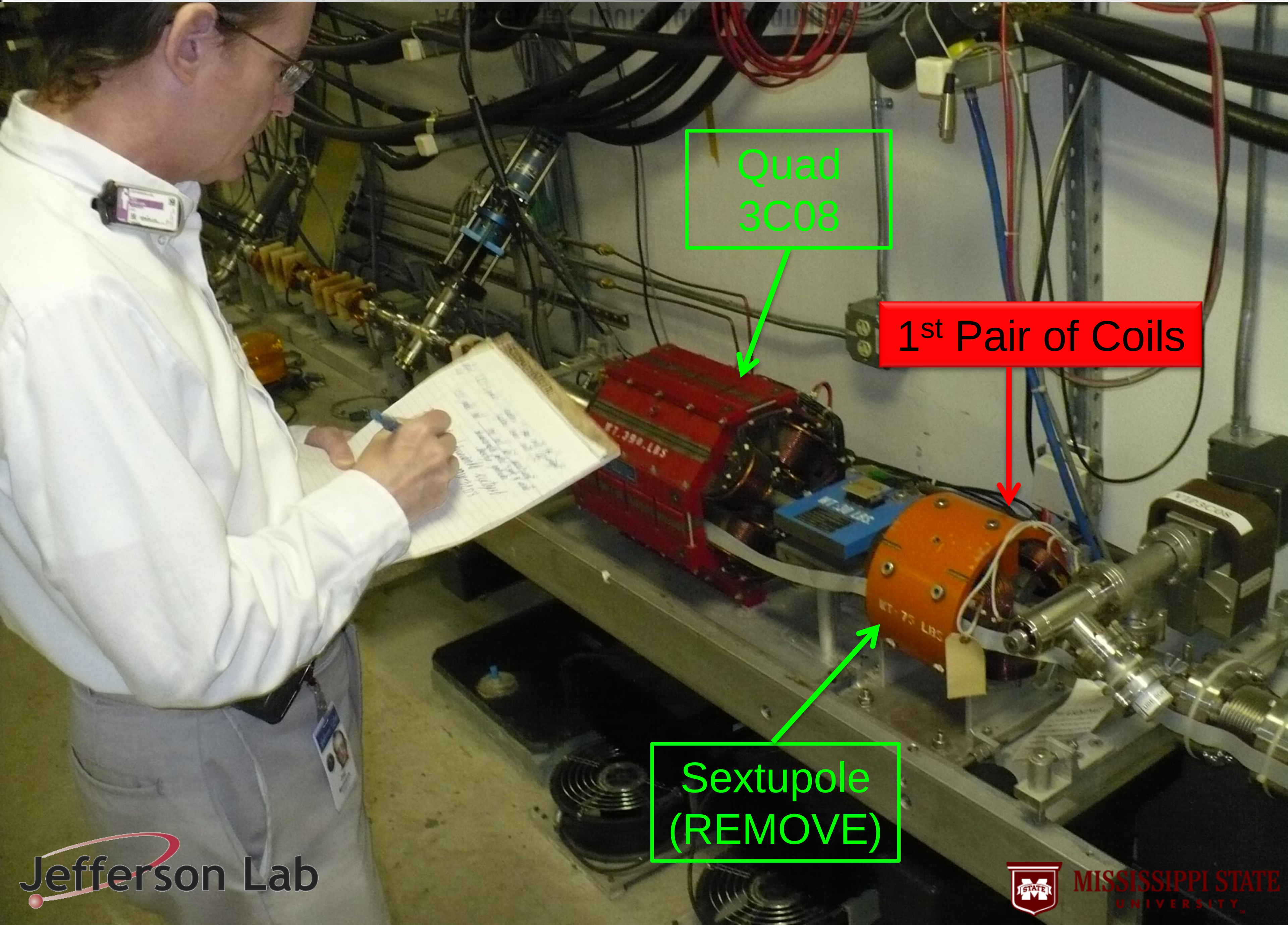
✓Determined that Trim-II can be used reliably up to 250 Hz with 3A output

✓Measured the field integral with a GMW Hall Probe (confirming Sarin Phillips' results)

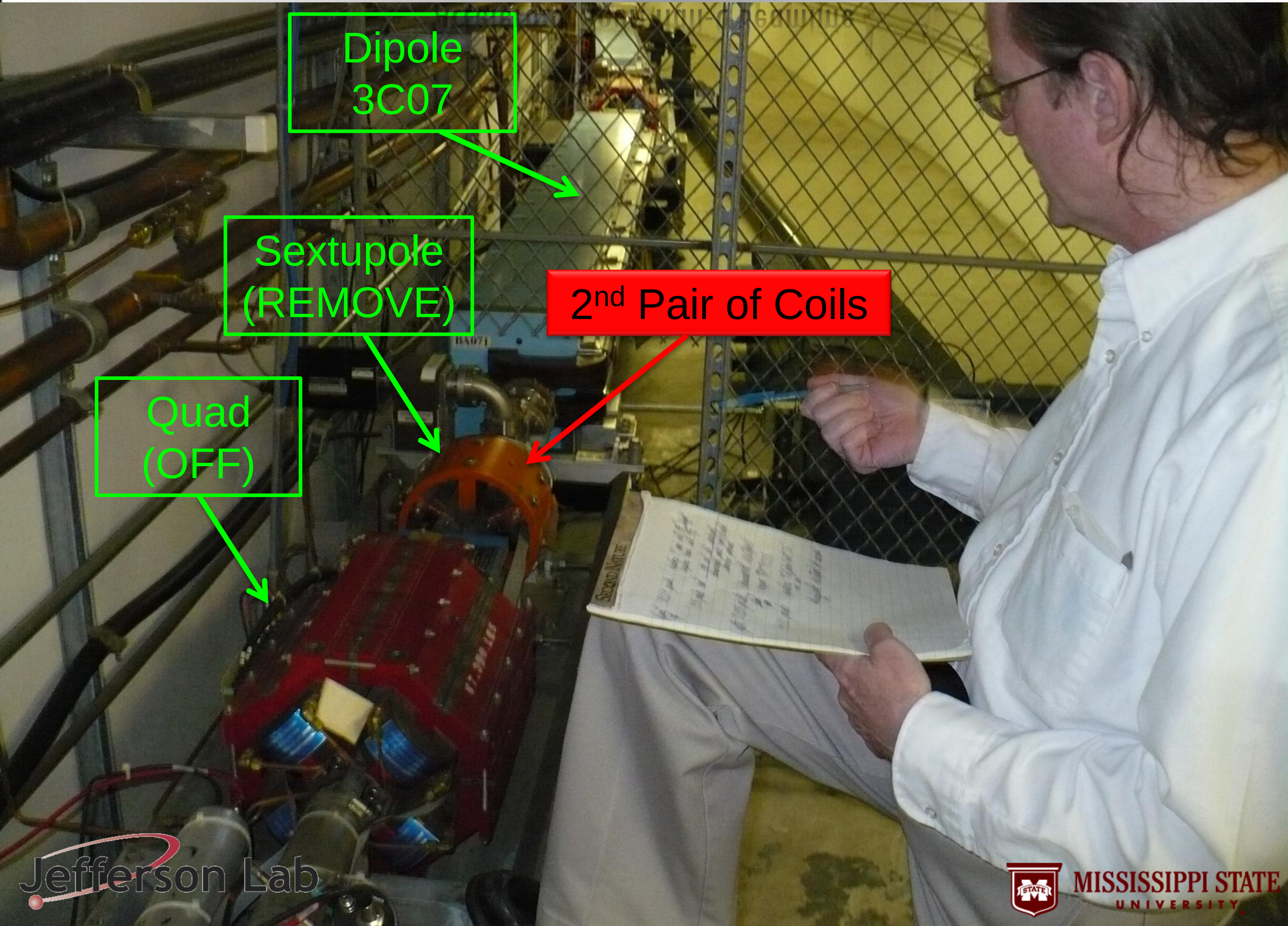
✓Monitored the output waveform quality using a LEM current transducer

✓Drove two coils simultaneously from our FANUC VME function generator

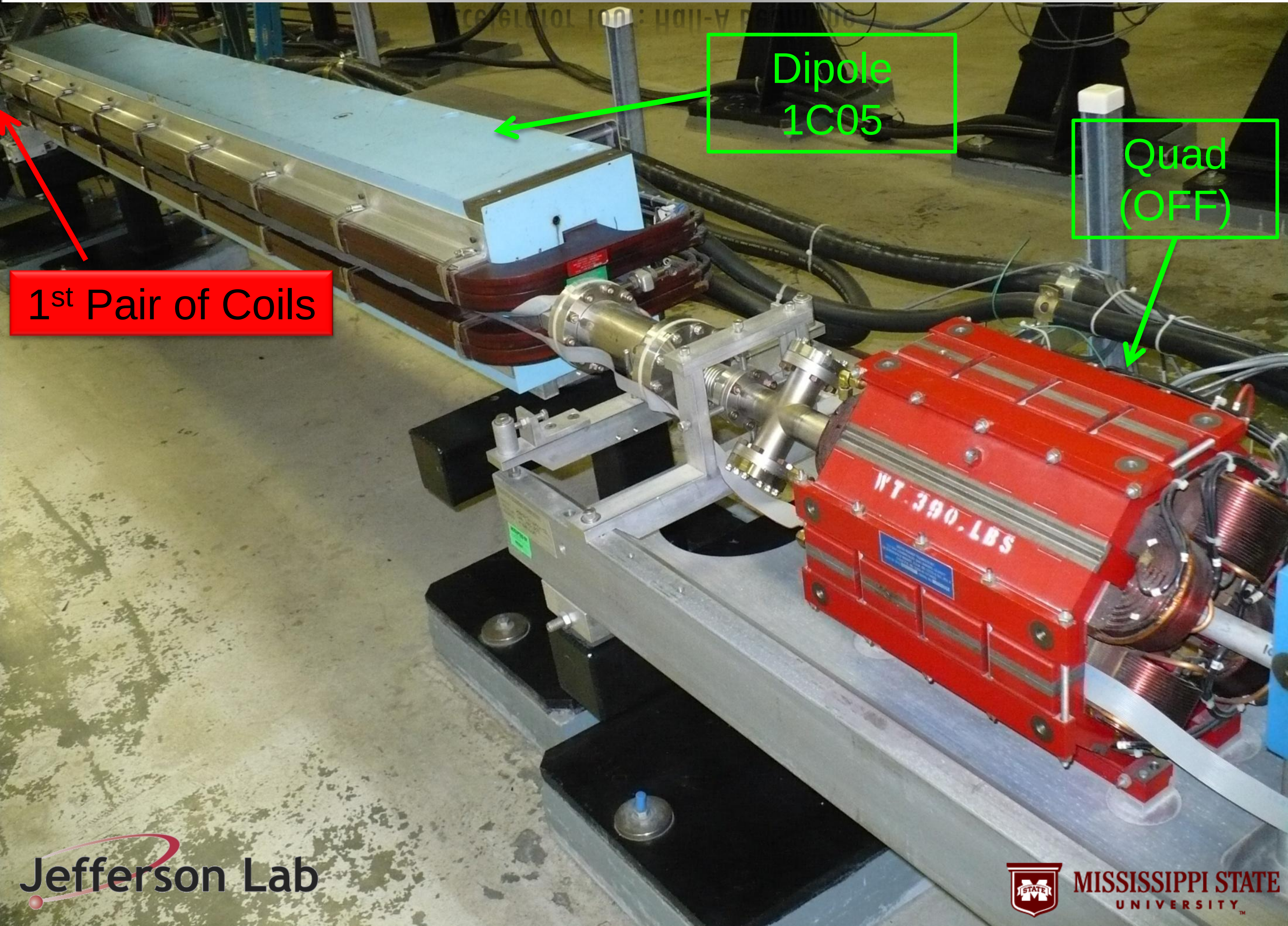
Accelerator Tour: Hall-C Beamline



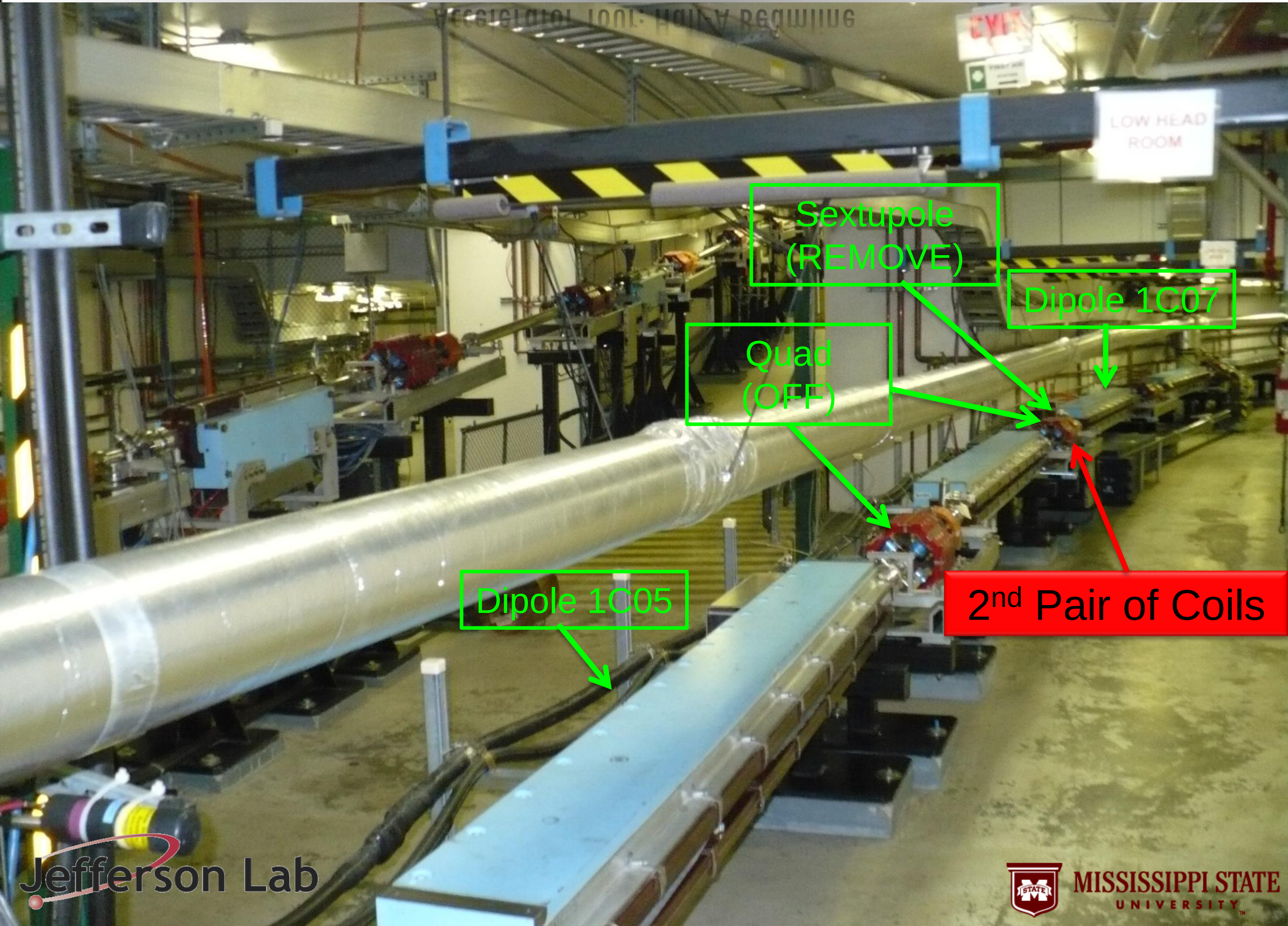
Accelerator Tour: Hall-C Beamline



Accelerator Tour: Hall-A Beamline



Accelerator Tour: Hall-A Beamline



Summary

- Potential for calculation of beam sensitivities with 10 % statistical accuracy each day
- Coil positioning is defined by using OPTIM
- Bench tests with a pair of coils with VME-4145 signal generator and TRIM-II were successful
- Actual locations have been located in the beamline for coils both for Hall-C and Hall-A
- Technicians may install hardware end of 2009or beginning of 2010
- Working on control system
- This new strategy for beam modulation with a pair of coils will benefit any parity violating experiment.

Thank You

nur@jlab.org

References

References

[1] http://www.jlab.org/qweak/

[2] http://www-bdnew.fnal.gov/pbar/organizationalchart/lebedev/OptiM/optim.htm

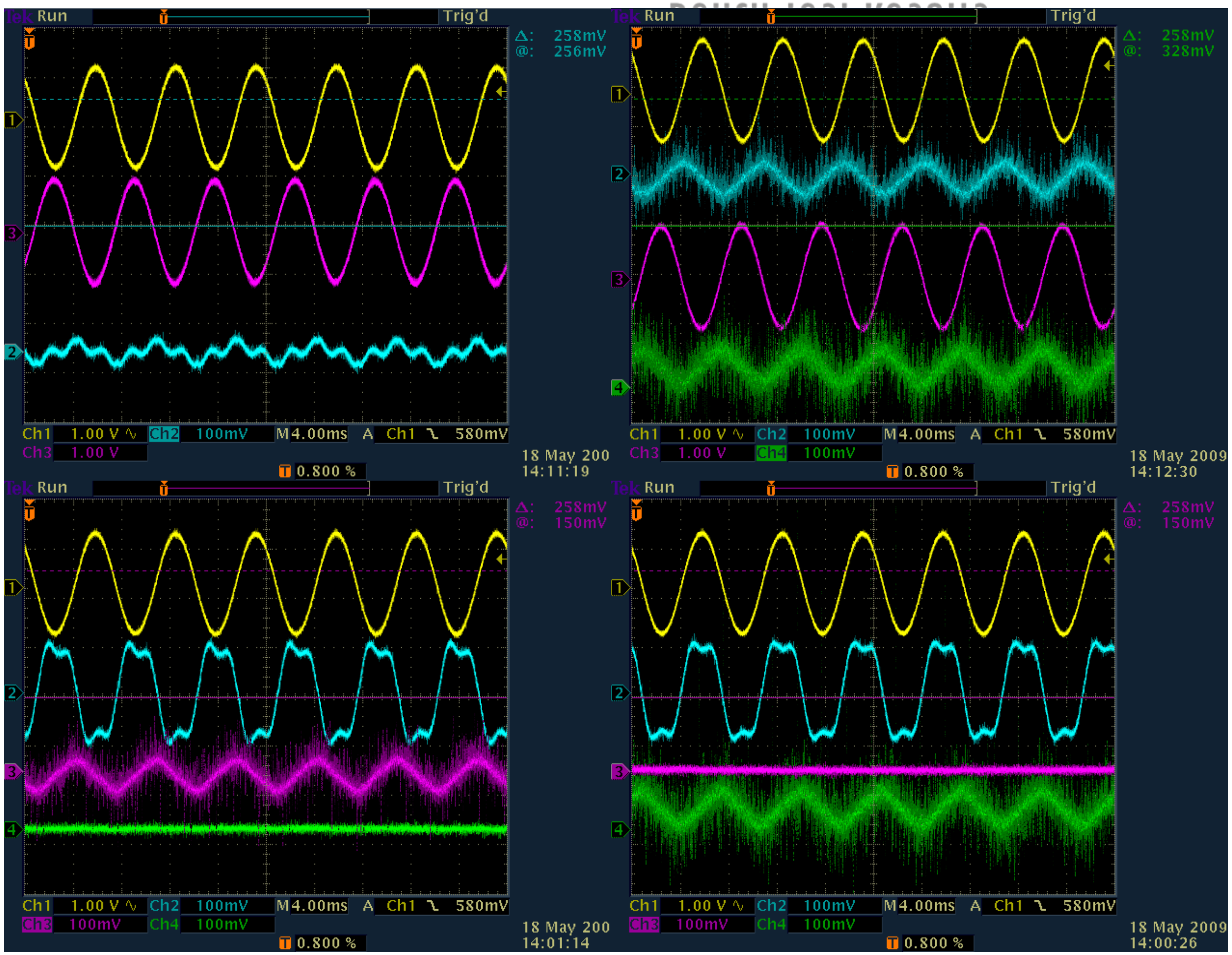
[3] Nuruzzaman, PPT, Q^{p}_{weak} Collaboration Meeting, 1st Order Beam Modulation in the 3C Line

[4] Private communication with Mike Tiefenback

[5] Private communication with Jay Benesch

Extra Slides

Bench Test Results

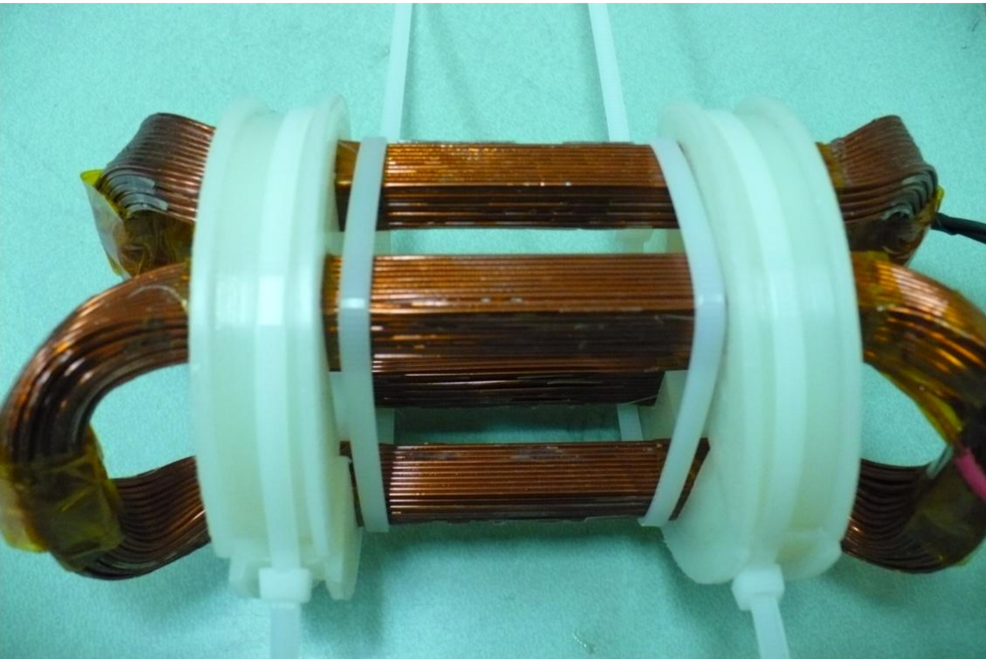


Clockwise from left corner:

1. Two inputs from VME signal generator & LEM current transducer
2. Two inputs from VME and two output from TRIM II
3. One input from VME, LEM output & TRIM II output
4. One input from VME, LEM output & TRIM II output

Single TRIM-II

Pair of Coils



Objective

Objective

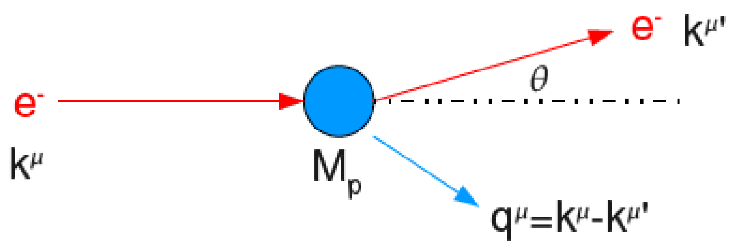
$$dA = \frac{1}{\sqrt{N}} = 10^{-6} \text{ (i.e., 1 ppm)}$$

$$N = 10^{12} \text{ counts} = Rt$$

$$t = \frac{N}{R} = \frac{10^{12} \text{ counts}}{8 \times 800 \times 10^{6} \text{Hz}} = 156.25 \text{ seconds}$$

Kinematics

Kinematics



Momentum transfer squared: $Q^2 = -q^\mu q_\mu = -(k^\mu - k^{\mu\prime})^2$

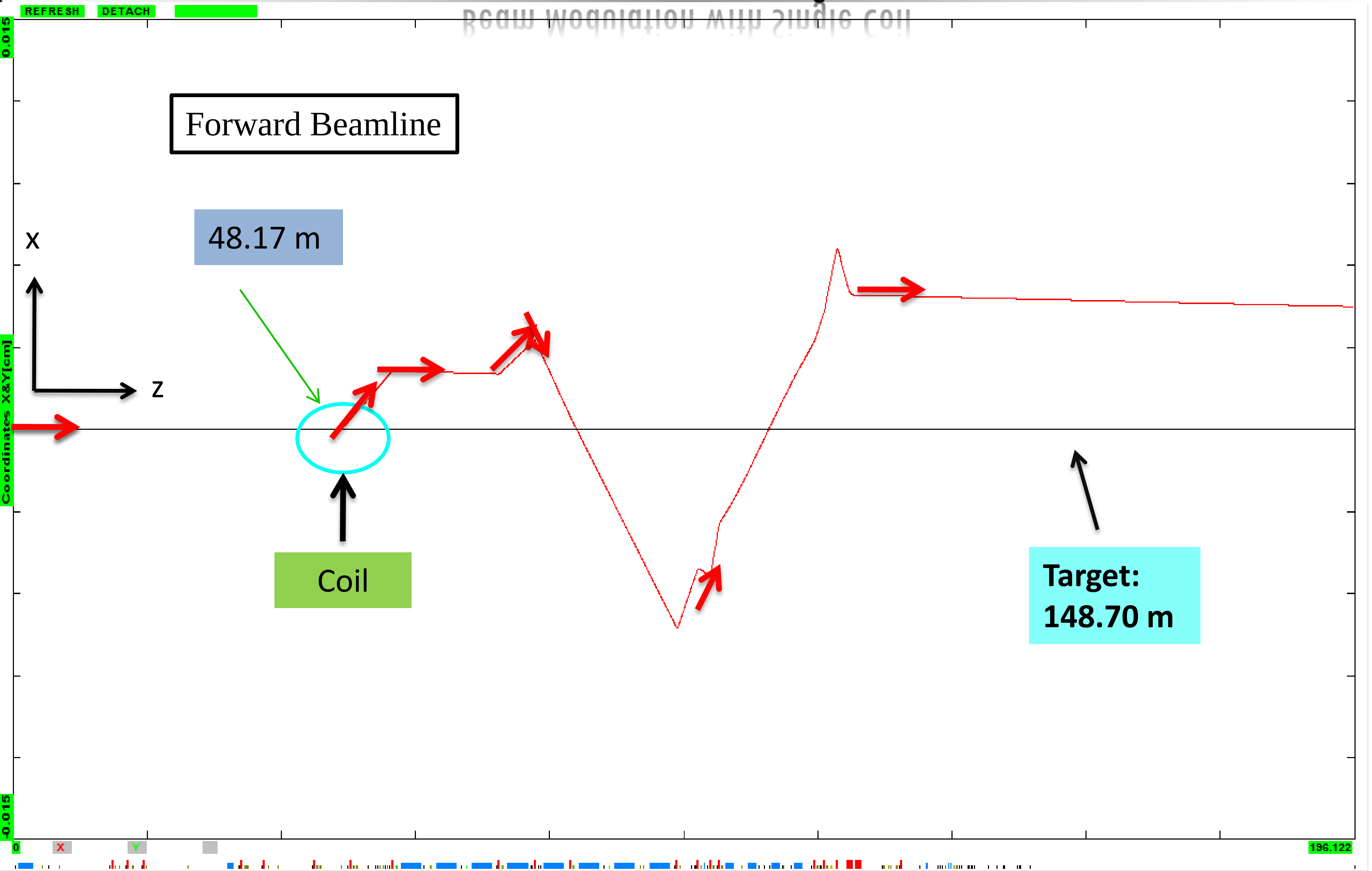
$$Q^2 = 4EE' \sin^2 \theta/2$$

$$E' = \frac{E}{1 + \frac{2E}{M} \sin^2 \theta/2}$$

$$\boxed{Q^2 = \frac{4E^2 \sin^2 \theta/2}{1 + 2\frac{E}{M} \sin^2 \theta/2}}$$

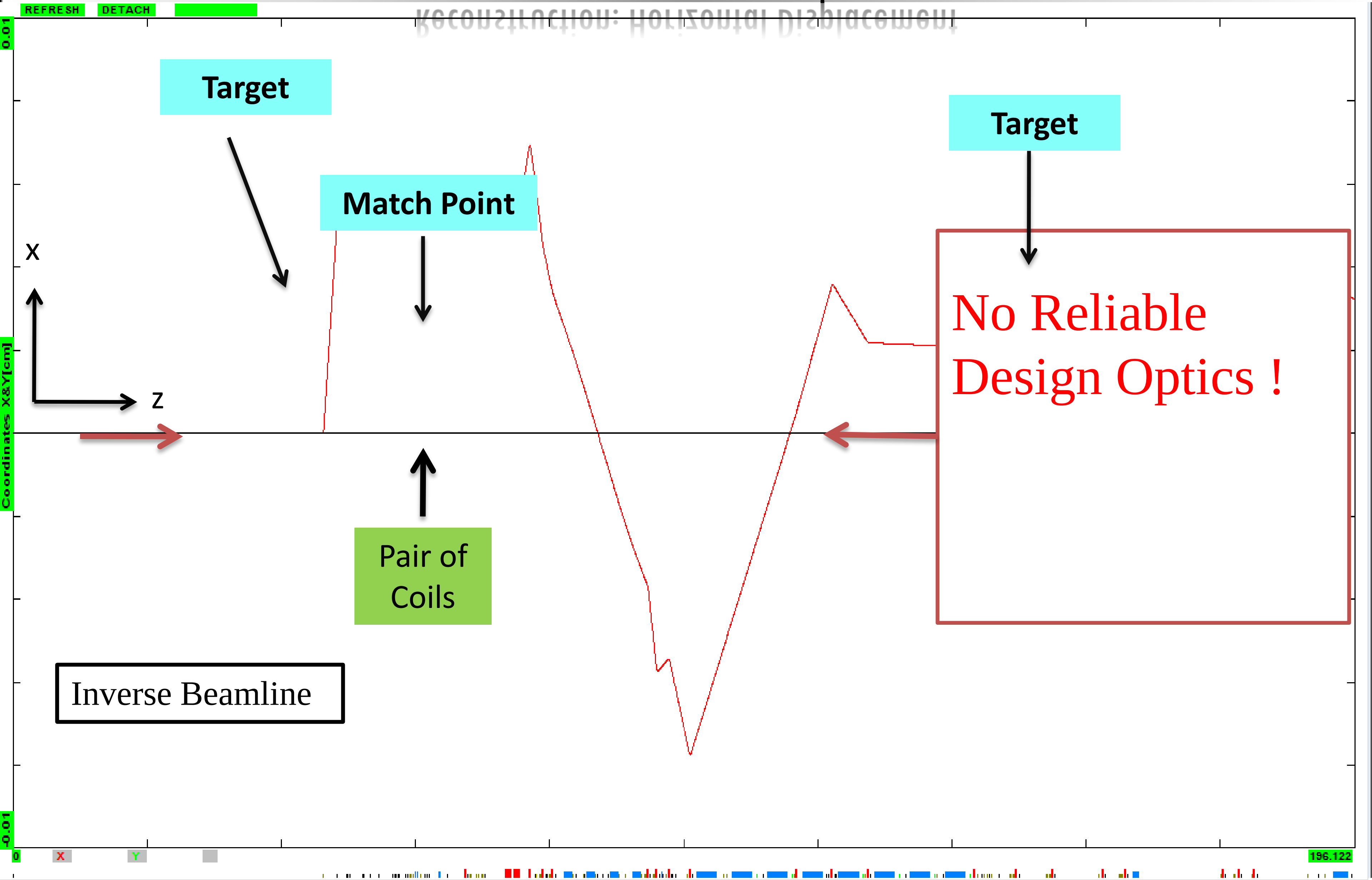
[6]

Beam Modulation with Single Coil

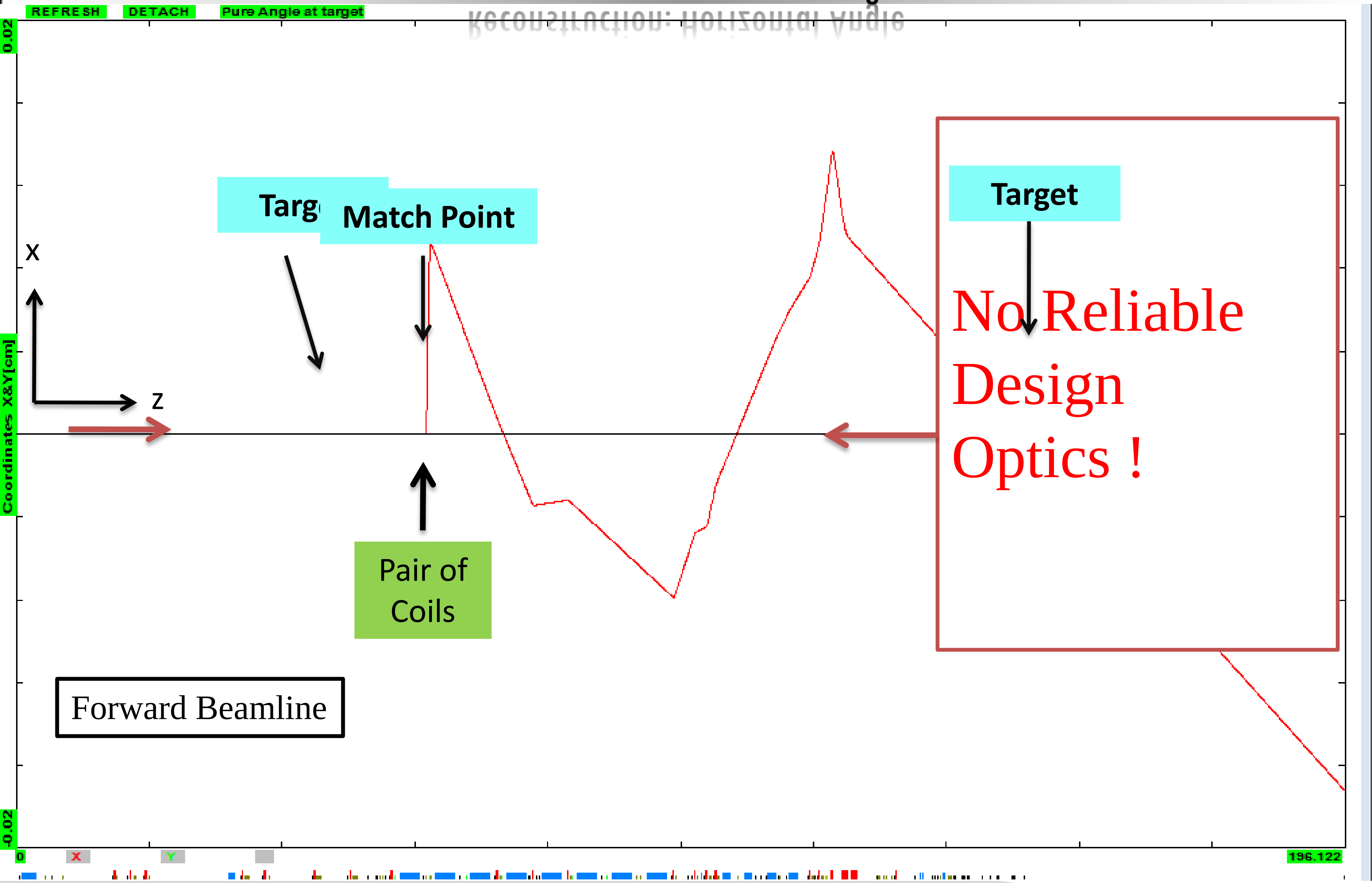


10G-cm

Reconstruction: Horizontal Displacement



Reconstruction: Horizontal Angle



Beam Modulation with Pair of Coils

Beam Modulation with Pair of Coils

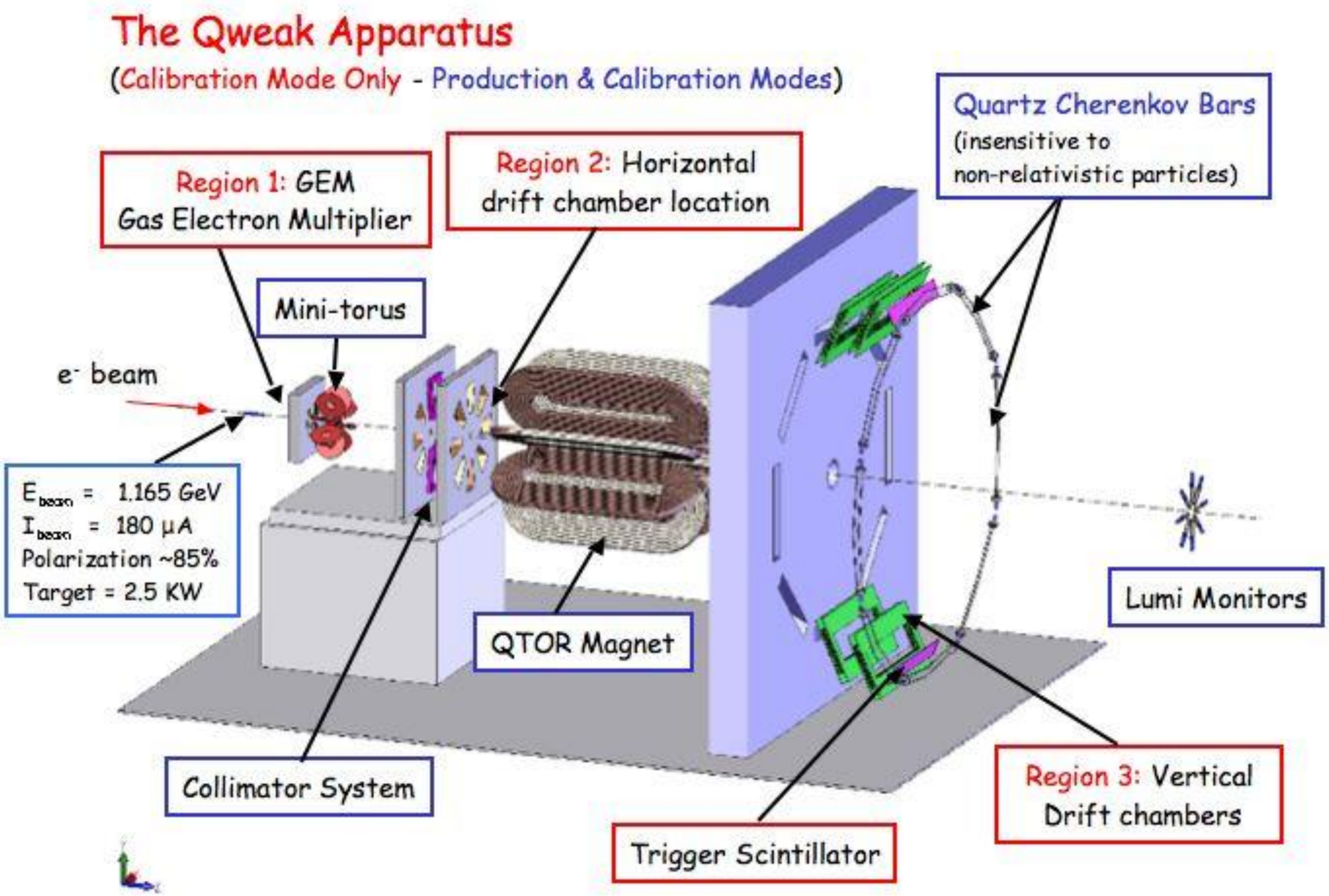
- In a meeting with Accelerator Ops[4], it was strongly suggested we consider a pair of coils for beam modulation!
- This is more complicated than our previous strategy of placing single coils at orbit zero crossings.

Advantages of Using Pair of Coils:

- ✓Greater Flexibility in Coil Positioning
- ✓Coil Positions does not depend upon Design Optics
- ✓The Coil pair is compact in 100 cm rather than being scattered over 100 m of beamline

The Q^p_{weak} Apparatus

The Q^p_{weak} Apparatus



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Recall from last presentation

Recall from last presentation

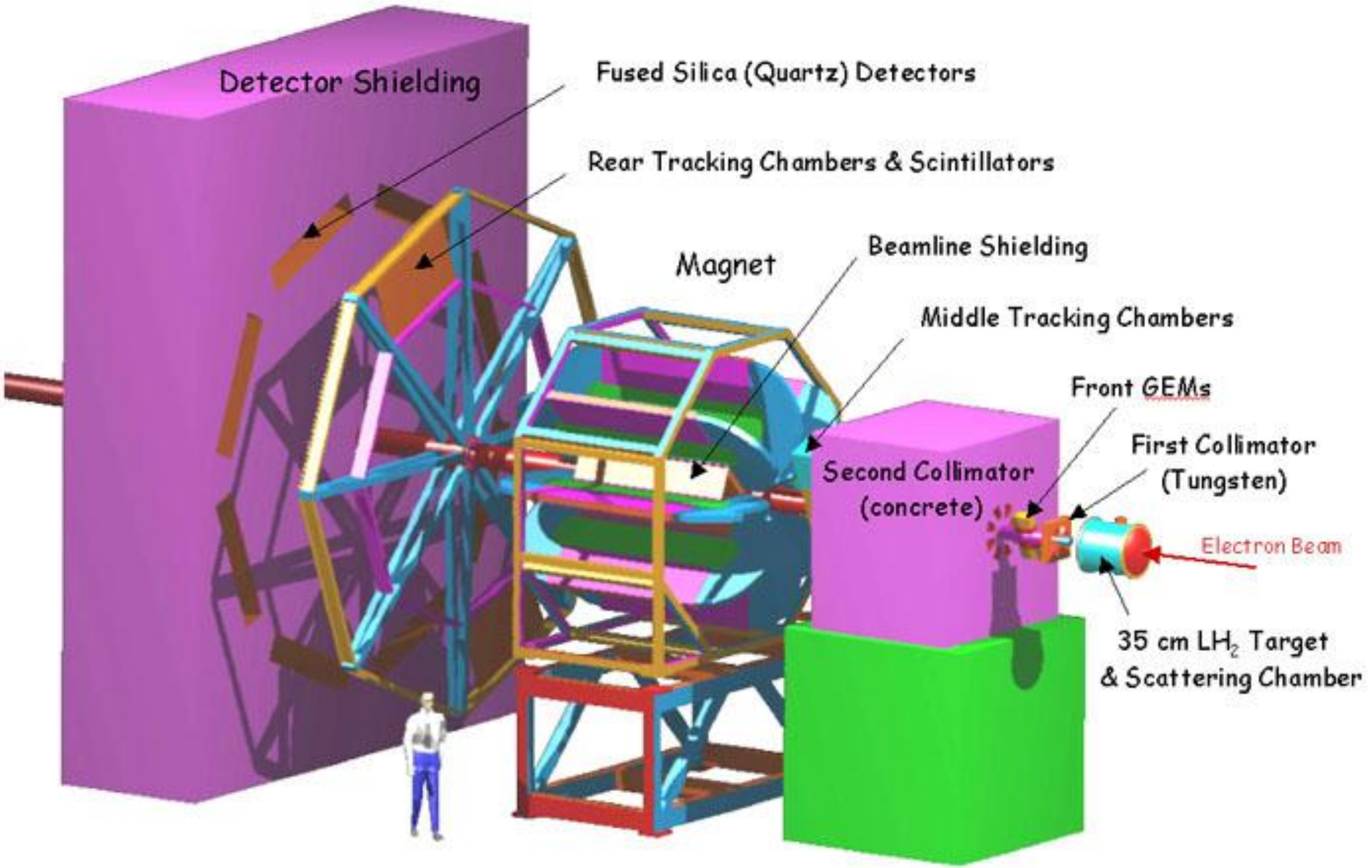
Before beam arrives, check that coils are operational and have the expected fields and polarities. Verify that we can partition runs into modulated and non-modulated fractions.

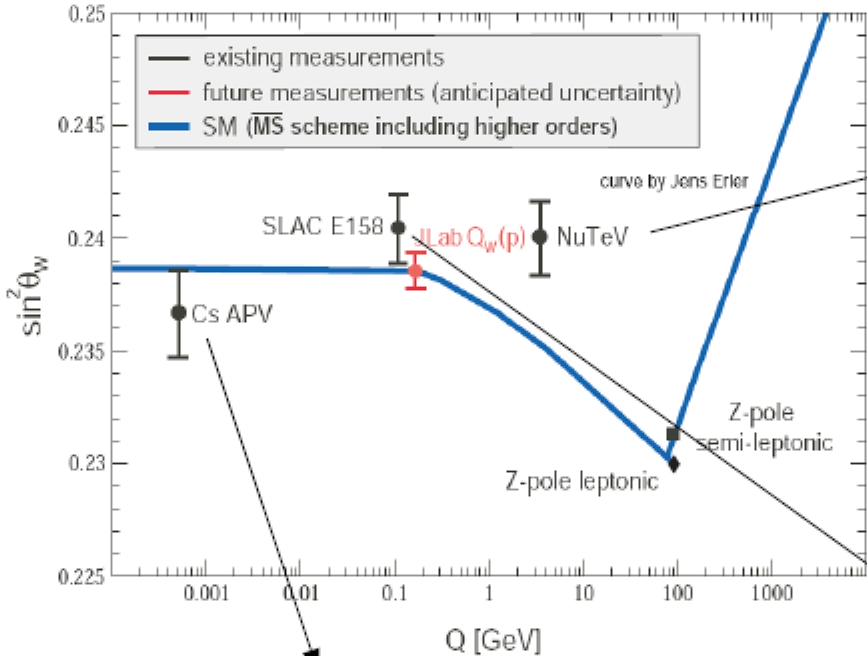
The rest of beam commissioning requires current mode:

- Verify that we can safely modulate the beam.
  (showing in results)
- Finalize waveform and frequency for modulation.
  (showing in results)
- Finalize magnitudes for position and angle modulation.
  (showing in results)

Ref: http://qweak.jlab.org/doc-private/ShowDocument?docid=910

The Q^p_{weak} Apparatus





Did not account for some systematic effects such as charge symmetry violation, strangeness, target corrections (Fe target, not isoscalar)

see, for example:
Londergan, Thomas, Phys. Rev. D **67** 111901 (2003)

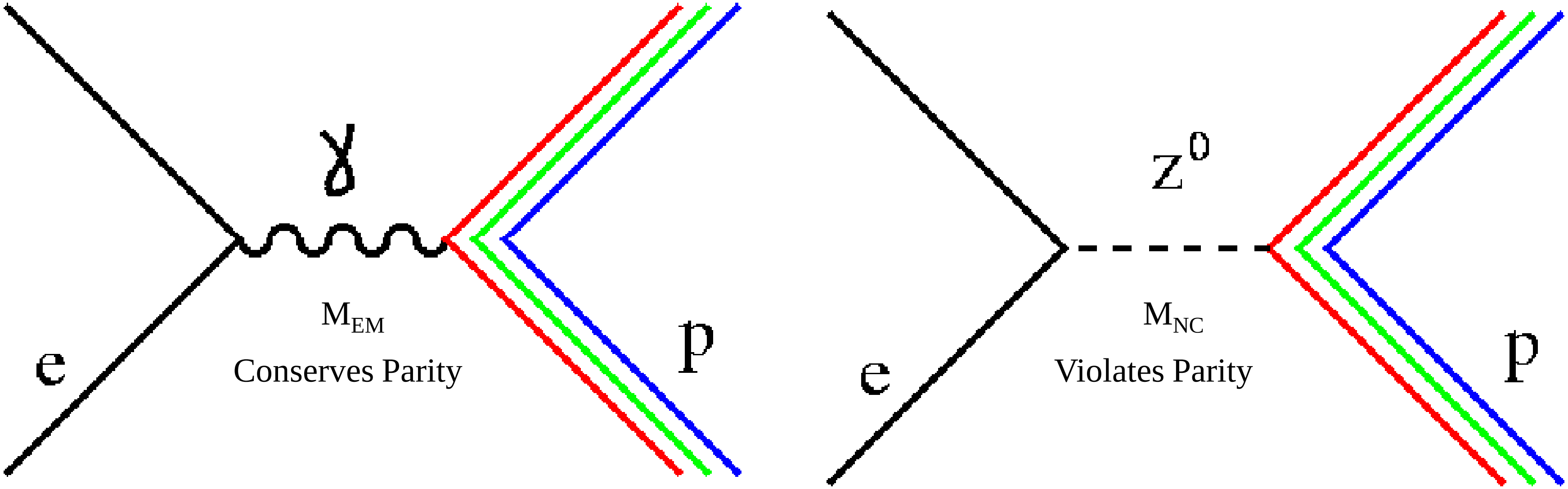
Agrees with the Standard Model, errors too large to place significant constraints on new physics

Large theoretical uncertainties
2009 calculation by Porsev *et al.*:

0.2381(11)

(arXiv:0902.0335v1 [hep-ph])

The Q^p_{weak} Basics



$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{2\,M_{NC}}{M_{EM}} \sim 0.2 \text{ ppm}$$

As $Q^2 \rightarrow 0$, $\theta \rightarrow 0$

$$A_{PV} = \frac{-G_F}{4\pi\alpha\sqrt{2}} = [Q^2 Q^p_w + Q^4 B(Q^2)]$$

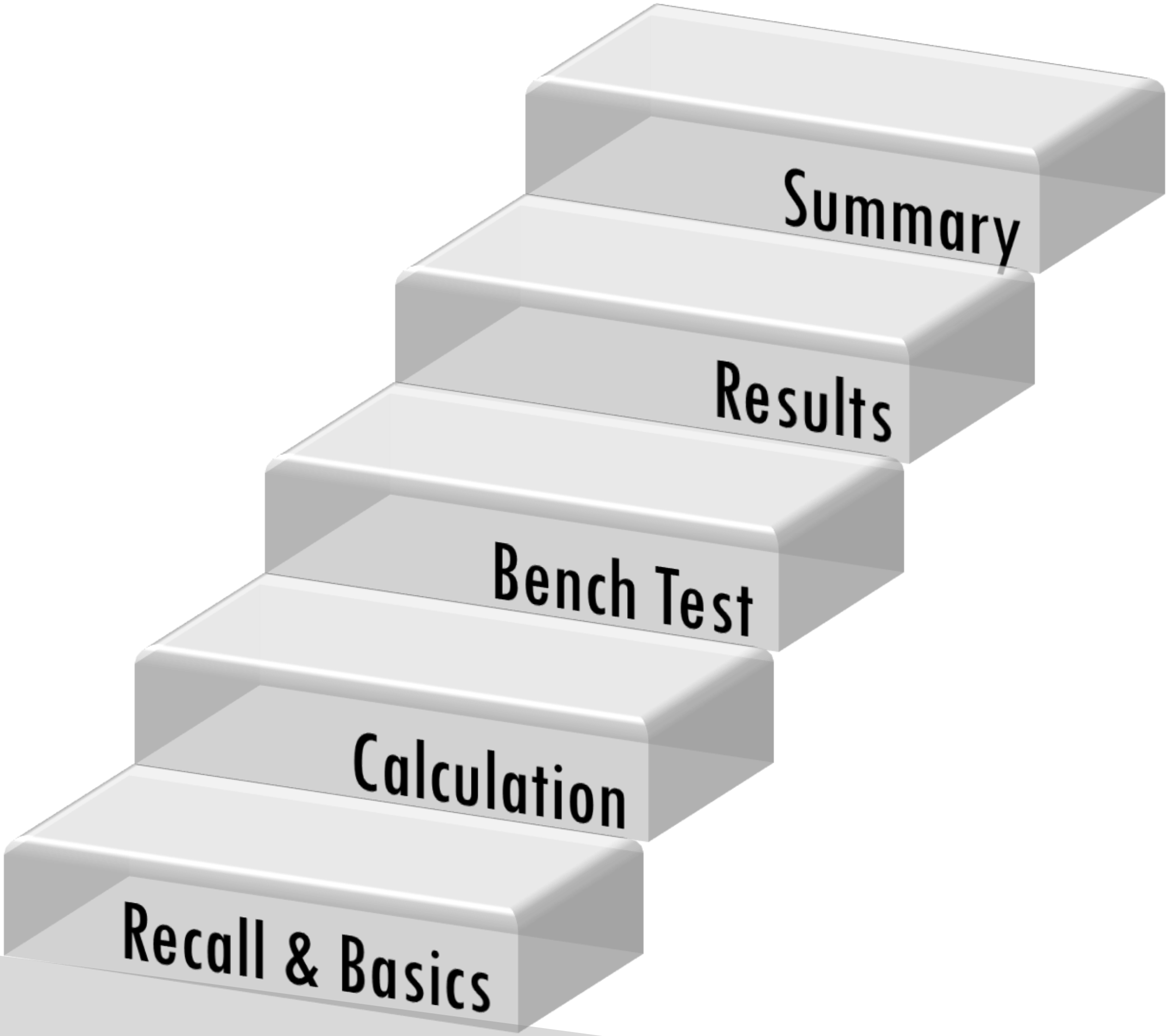
Weak Charge $Q^p_w = 1 - 4\sin^2\theta_w$	Hadronic contribution contains $G^{\gamma}_{E,M}$ and $G^{z}_{E,M}$

[6]

OVERVIEW

- Recall & Basics
- Calculation
- Bench Test
- Results
- Summary

OVERVIEW



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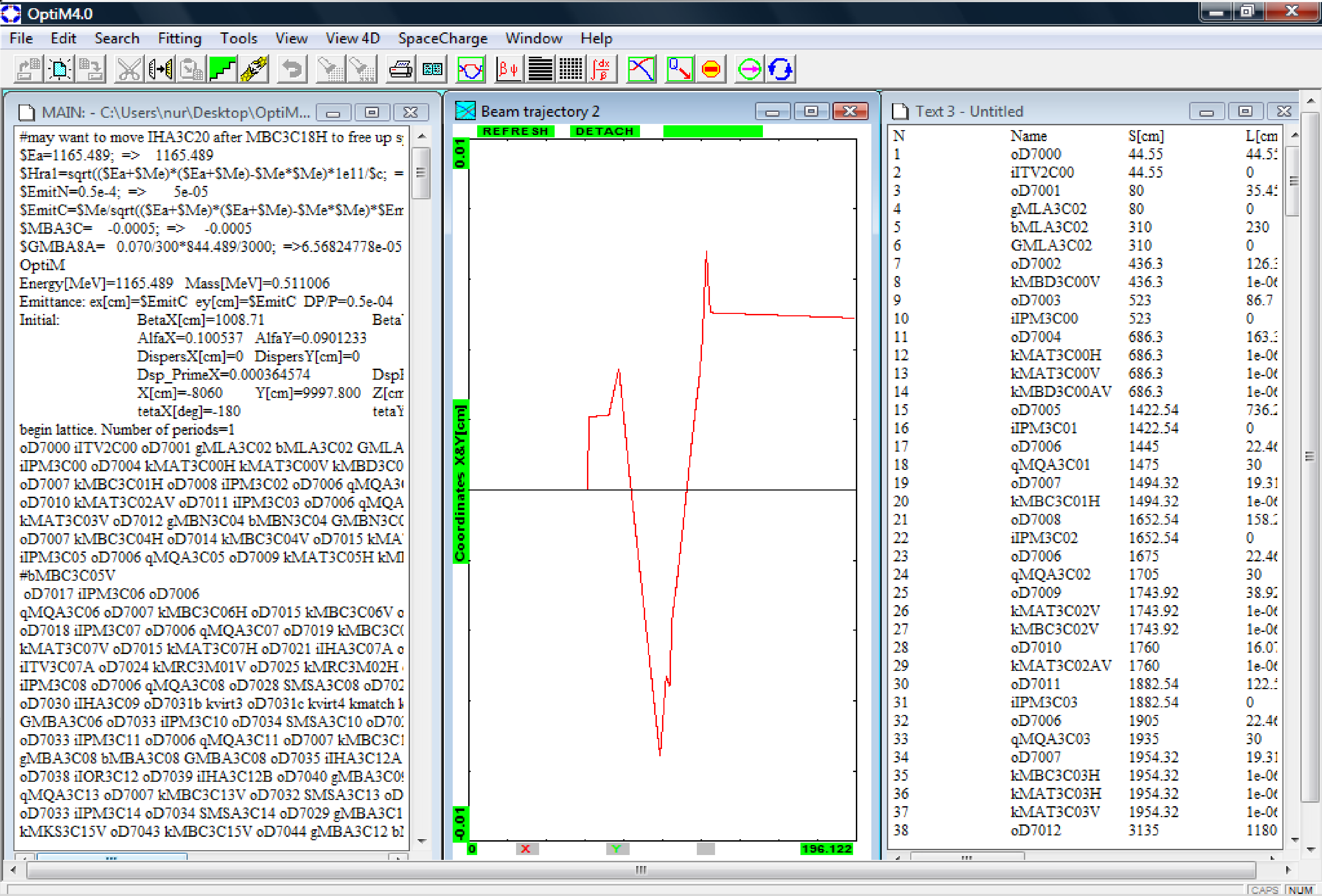
OPTIM is a Computer code for linear and non-linear optics calculations written by Valery Lebedev

OPTIM program has following ingredients:

- There is an input deck which contains all the information
- All the components are arranged in a order
- Different field strength are defined in the main deck for a particular beam energy(which can be scaled to any desired energy when executed)
- The distances between the different components are defined in the main deck with their proper lengths and orientation angle.
- The radiation is also included in the calculation.

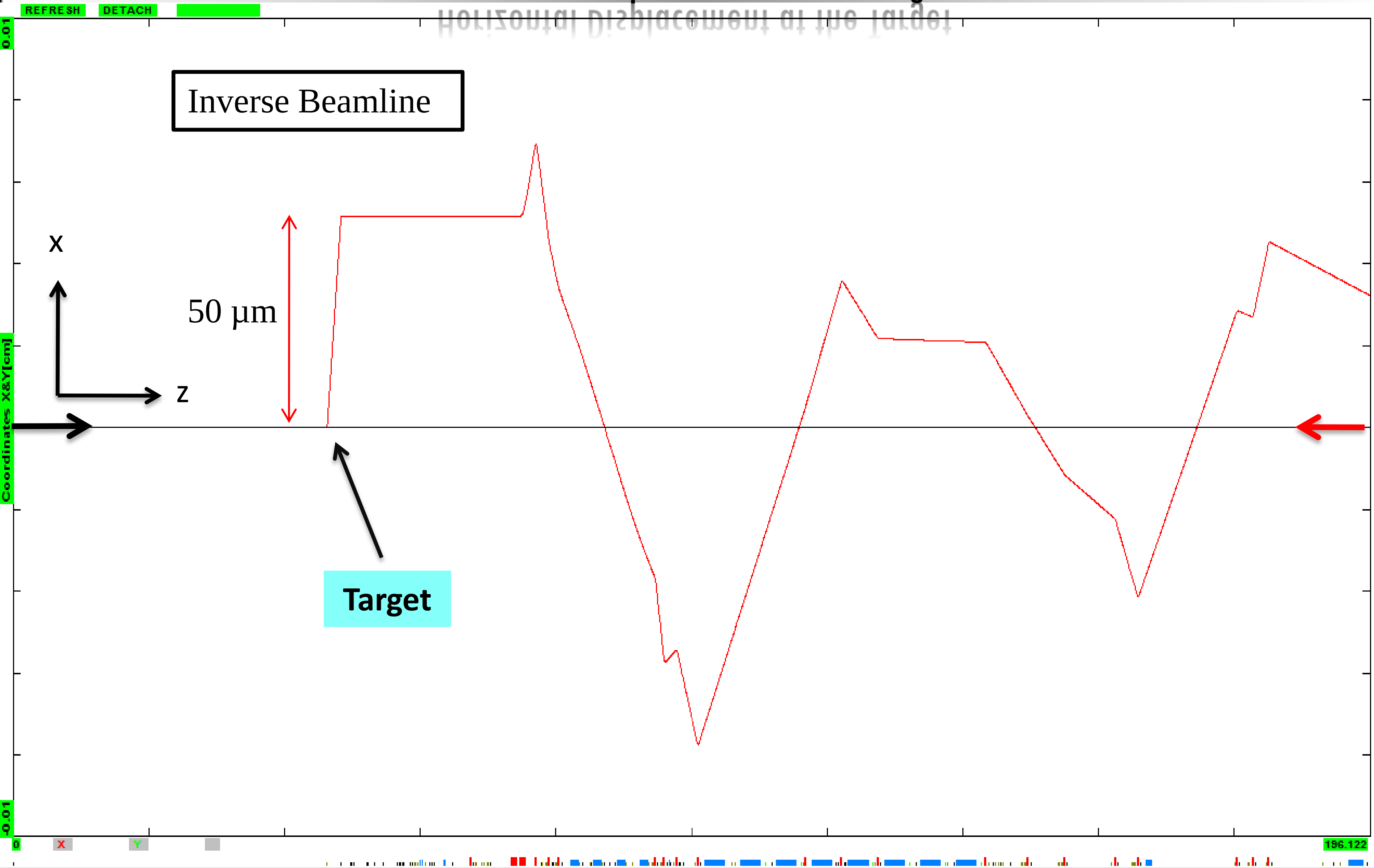
Ref: http://www-bdnew.fnal.gov/pbar/organizationalchart/lebedev/OptiM/optim.htm

OPTIM



Ref: http://www-bdnew.fnal.gov/pbar/organizationalchart/lebedev/OptiM/optim.htm, Private communication with Jay Benesch

Horizontal Displacement at the Target

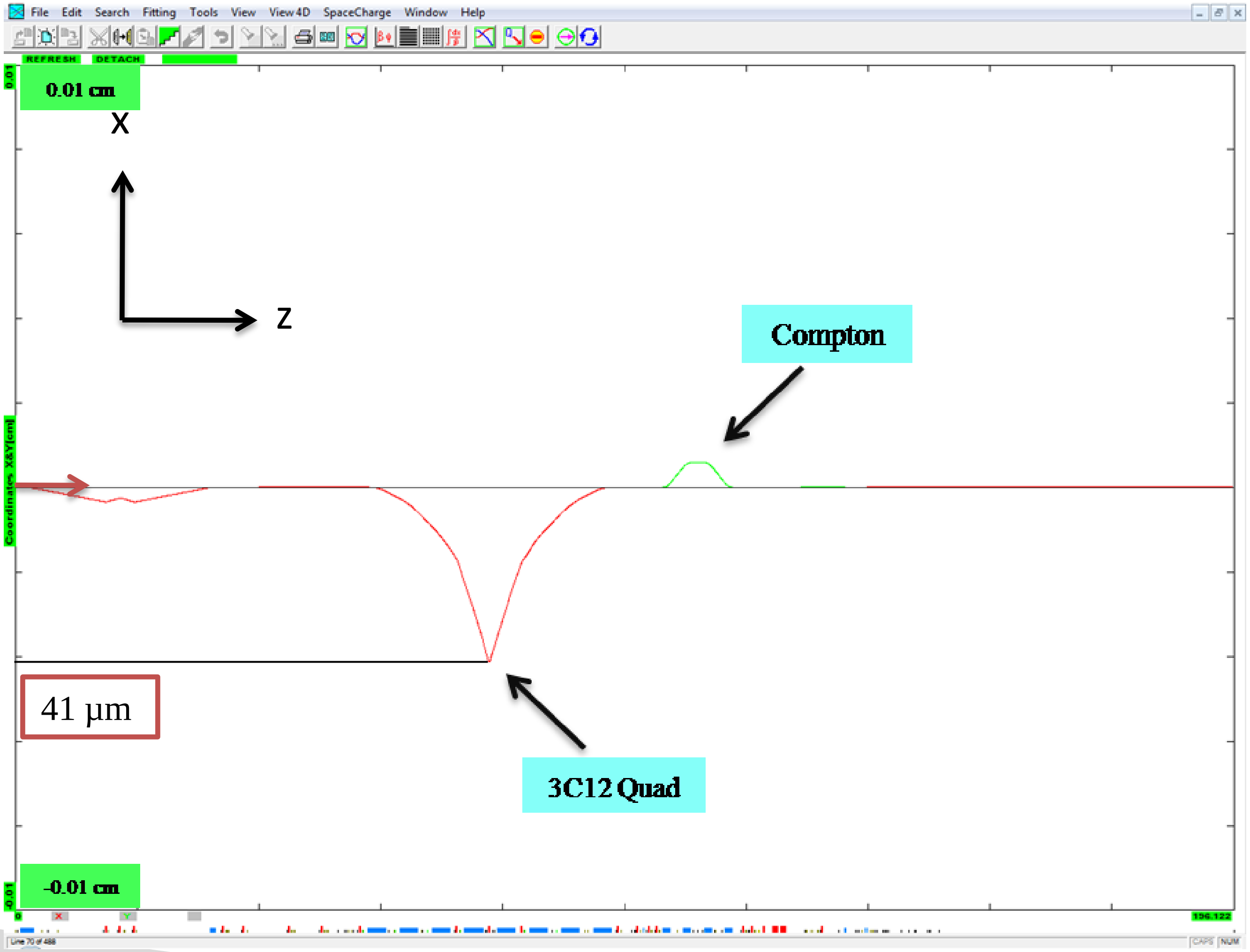


Energy Modulation

Calculation is for 10 ppm

RED -Horizontal

GREEN -Vertical



Energy Modulation Calculation

Starting with 10 ppm change in Energy

$T_{3C12} = M\ T_{target}$

$$
\begin{bmatrix} X \\ P_x \\ Y \\ P_y \\ E \end{bmatrix}_{3C12} =
\begin{array}{ccccc}
X[\mathrm{cm}] & P_x & Y[\mathrm{cm}] & P_y & \frac{dP}{P} \\
\end{array}
\begin{bmatrix}
+6.893389\times10^{-01} & -9.279272\times10^{+02} & -3.096262\times10^{-16} & -3.096262\times10^{-16} & +4.110475\times10^{+02} \\
-5.360389\times10^{-04} & +2.172234\times10^{+00} & +2.172234\times10^{+00} & +2.975534\times10^{-15} & -5.151228\times10^{-01} \\
-1.228709\times10^{-16} & +3.317806\times10^{-14} & -6.094898\times10^{-01} & -3.505004\times10^{+03} & -1.040840\times10^{+00} \\
-5.141329\times10^{-19} & -1.749177\times10^{-16} & -5.994758\times10^{-04} & -5.088133\times10^{+00} & -1.026614\times10^{-03} \\
+1.347567\times10^{-01} & +4.148947\times10^{+02} & -1.752520\times10^{-06} & +1.697645\times10^{+00} & -1.602343\times10^{+01} \\
+0.000000\times10^{-00} & +0.000000\times10^{-00} & +0.000000\times10^{-00} & +0.000000\times10^{-00} & +1.000000\times10^{-00}
\end{bmatrix}
\begin{bmatrix} X \\ P_x \\ Y \\ P_y \\ E \end{bmatrix}_{target}
$$

$X_{3C12} = M_{11}\ X_t + M_{12}\ X_t^{'} + 0 + 0 + M_{15}(dP/P)_t$

$(dP/P)_t = (X_{3C12} - M_{11}\ X_t - M_{12}\ X_t^{'}\ )/M_{15}$

$(dP/P)_t \sim X_{3C12}\ /M_{15}$

$\boxed{X_{3C12} = 41\ \mu m}$

$\boxed{M_{15} = 4.1\ m}$

That means we are getting 10 ppm modulation at the target

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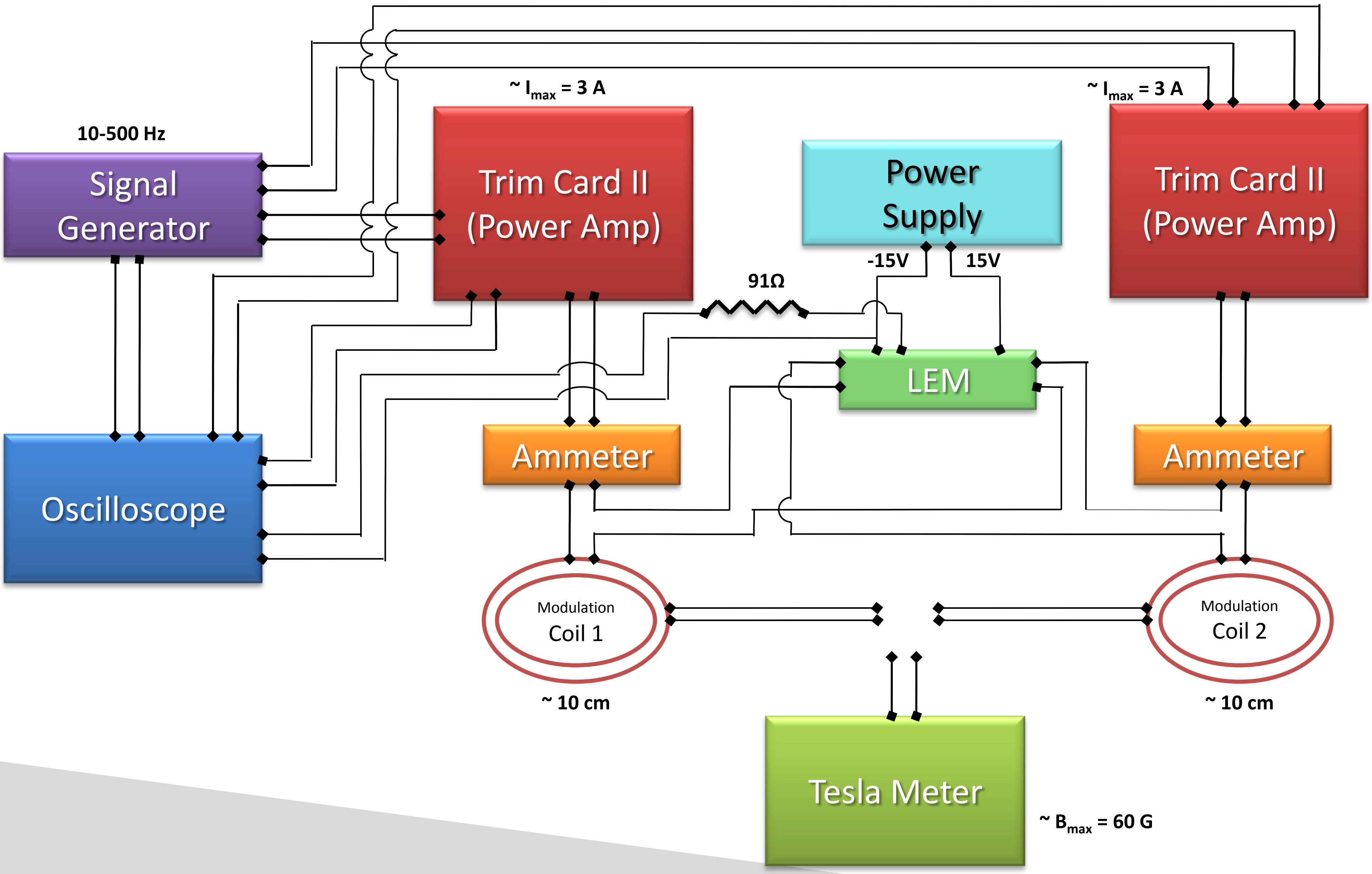
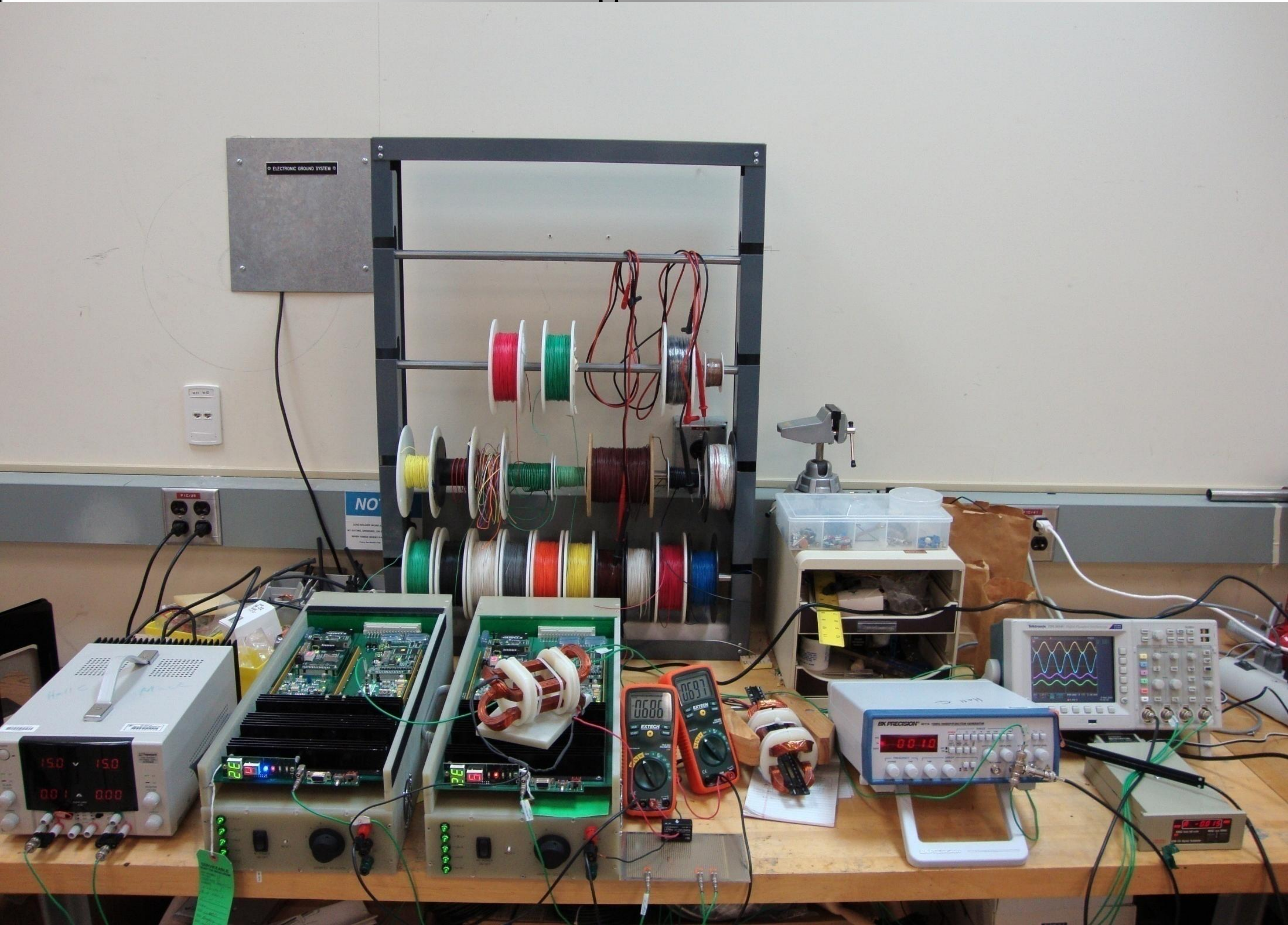
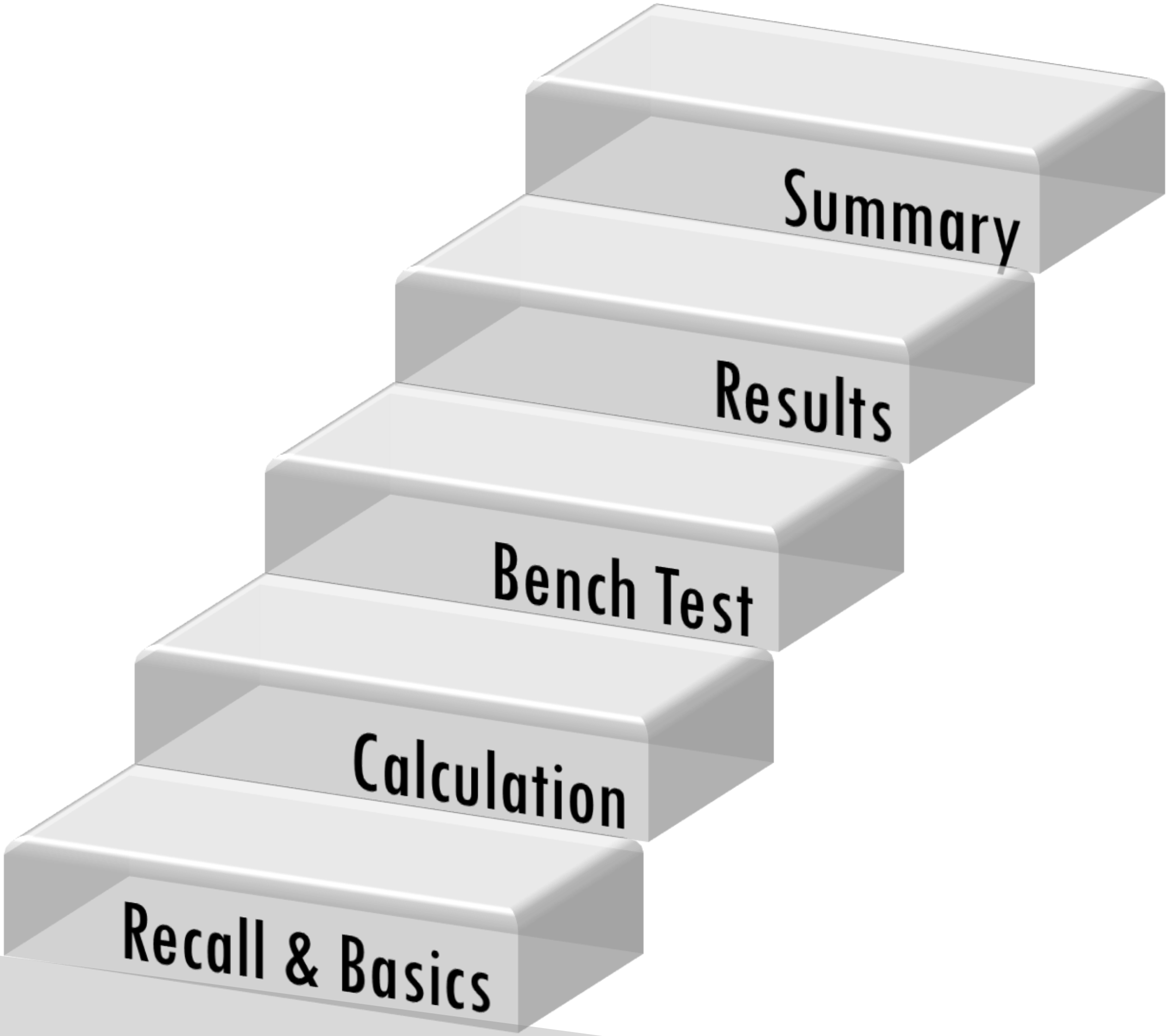
Circuit Diagram



Apparatus



OVERVIEW



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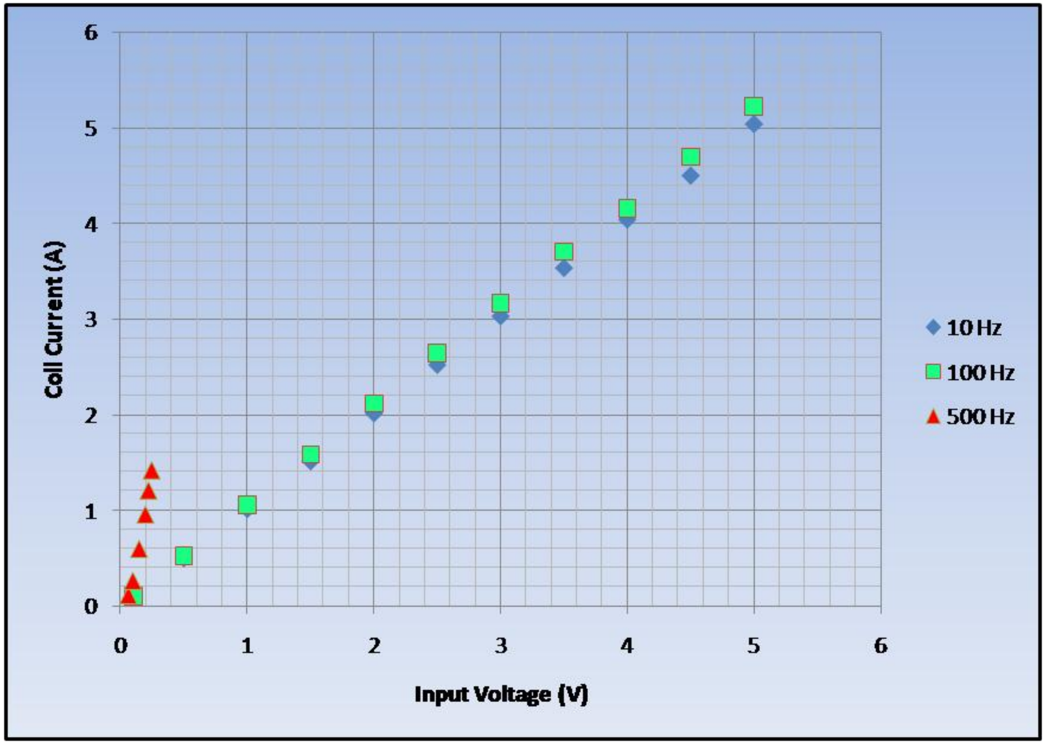
Bench Test Results

Bench Test Results

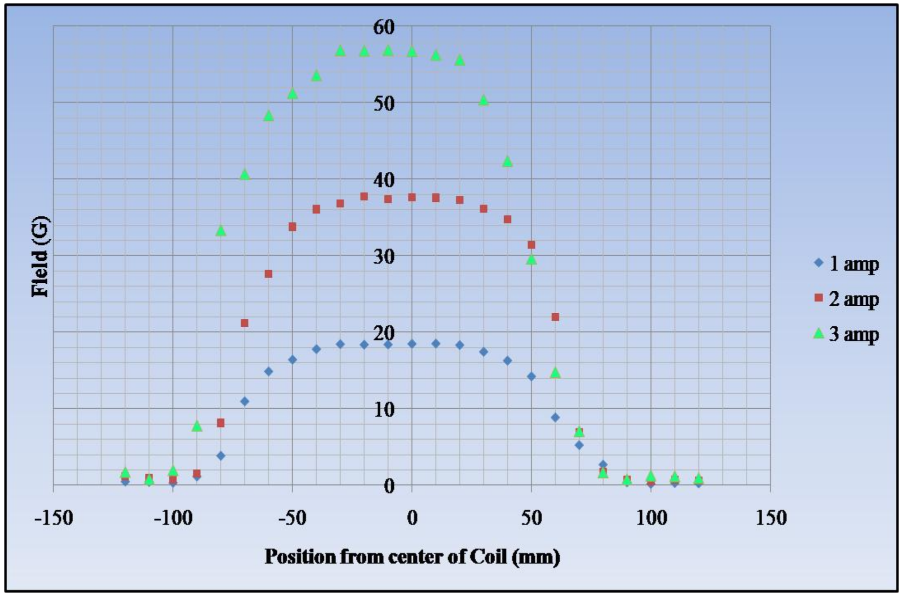


The power amp. voltage vs. coil current

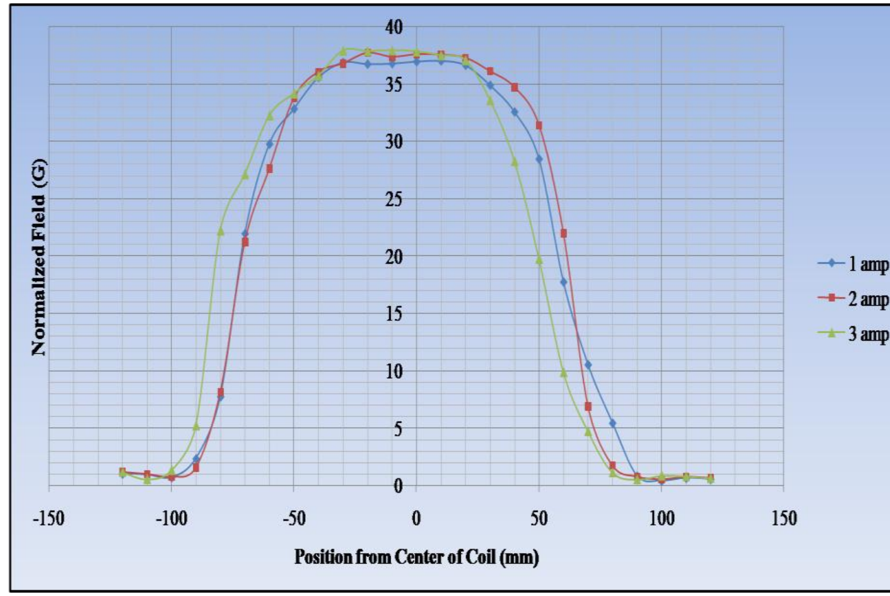
Sinusoidal waveforms have been used

Bench Test Results

Bench Test Results



Field integrals for different currents

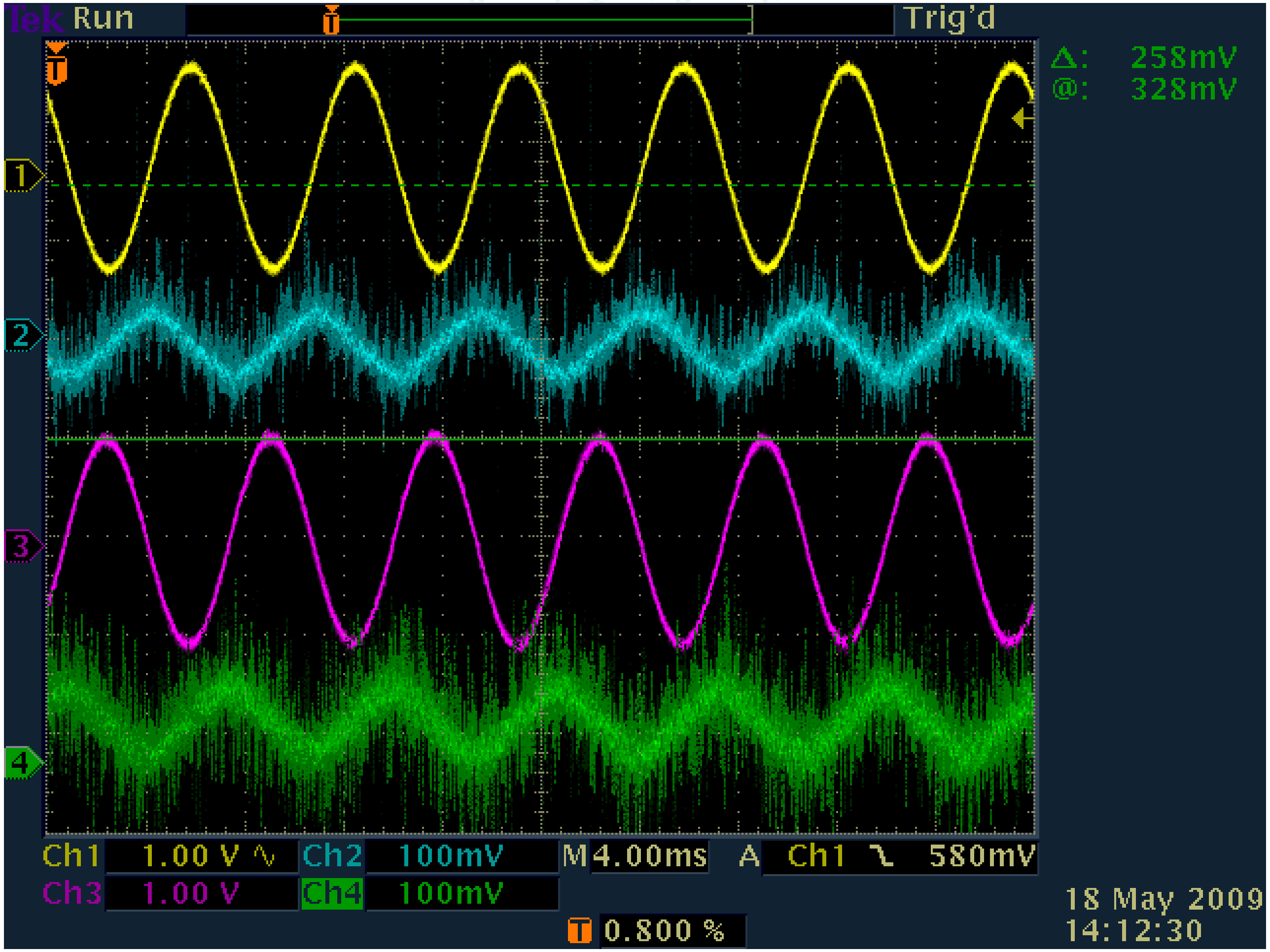


Normalized field integrals w.r.t. 2 amps.

Magnet Constant (B/I) ~30 G/Amp
Length of the Coil ~ 10 cm
Field Integral (B/I) × Length ~ 300 G-cm/ Amp × I

Bench Test Results

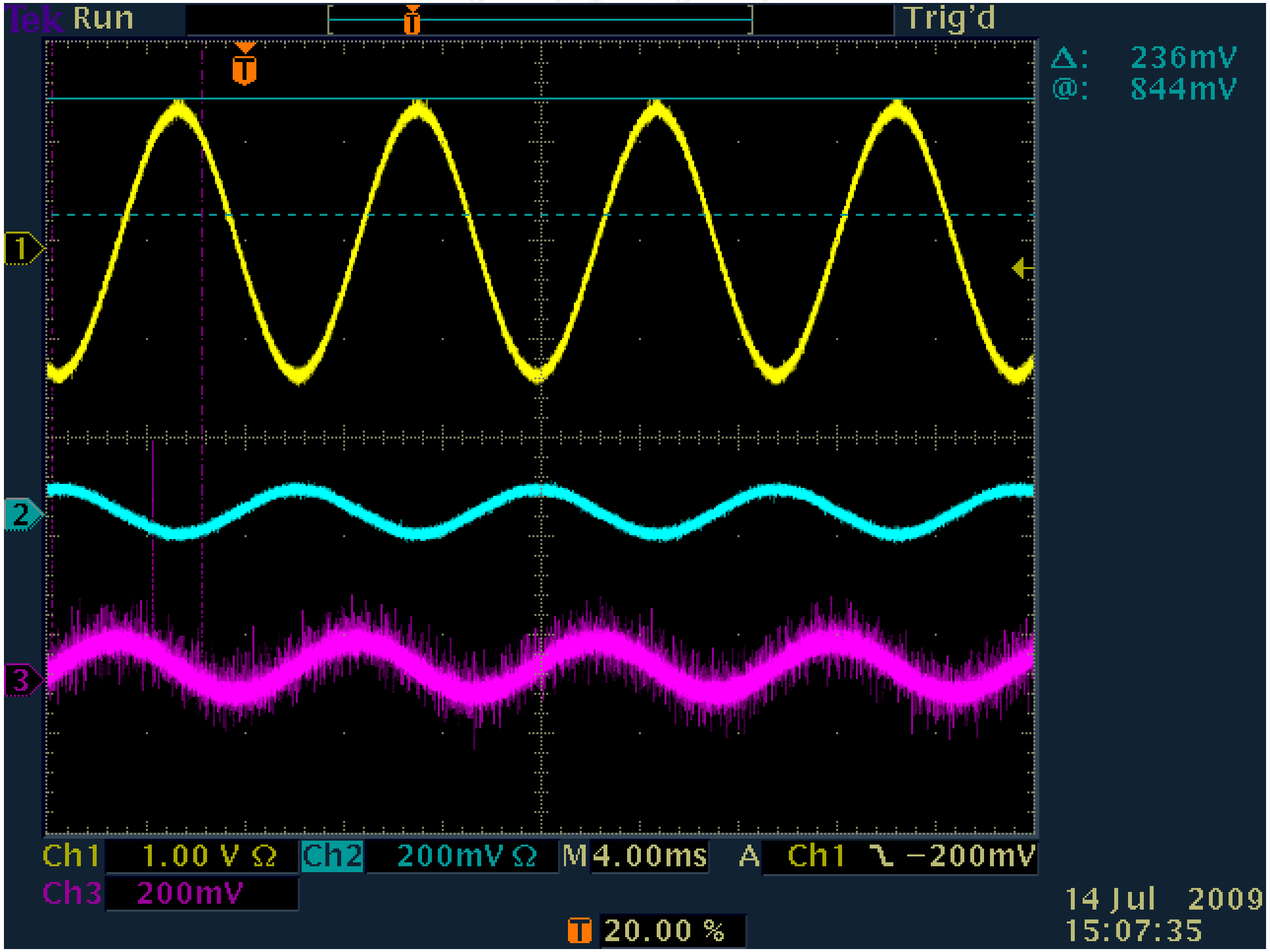
Bench Test Results



Two inputs from VME signal generator and two output from TRIM II

Bench Test Results

Bench Test Results



Input from VME signal generator, output from LEM current transducer & output from TRIM II

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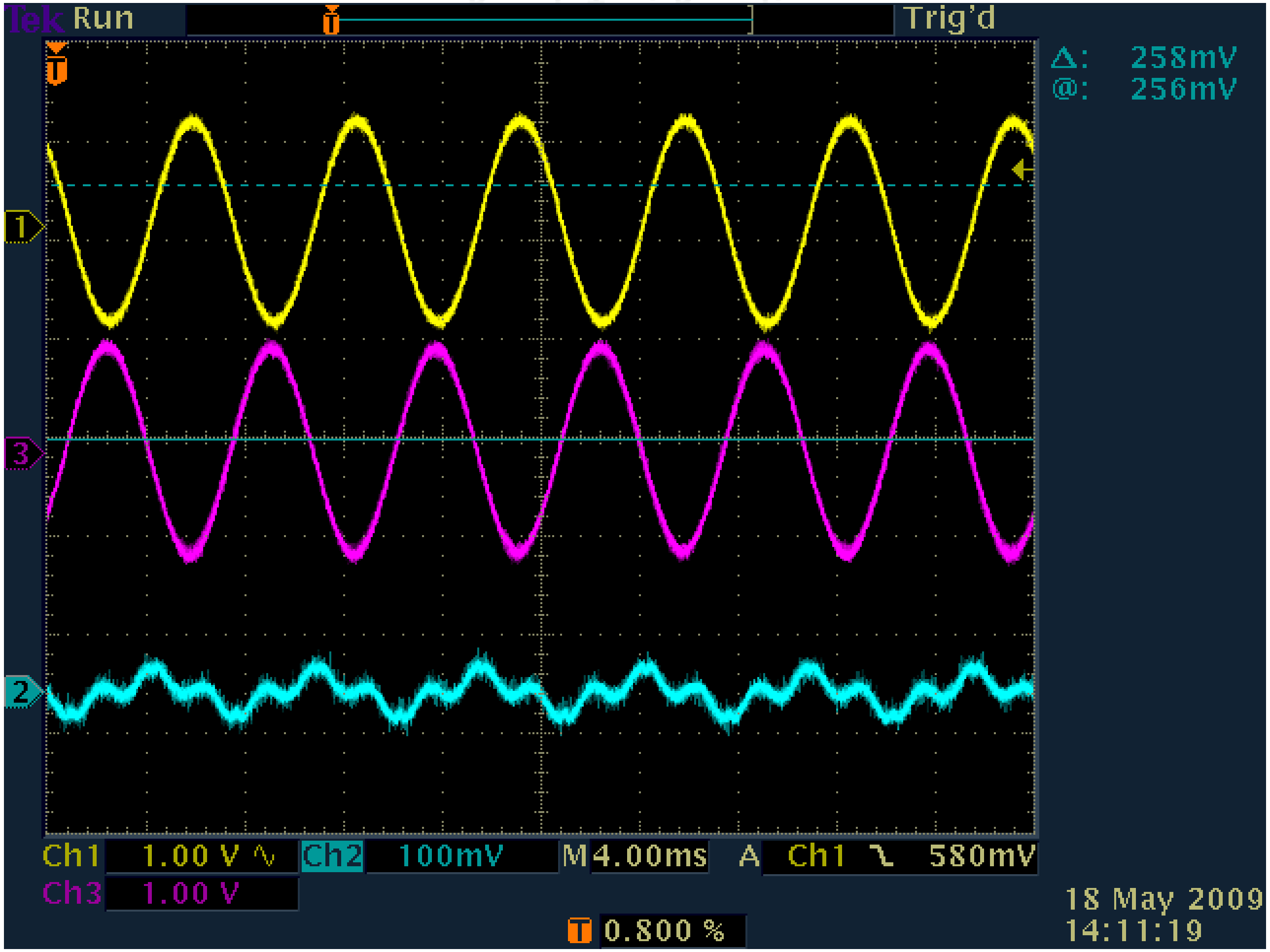
Bench Test Results

Bench Test Results



Two inputs from VME signal generator and output from LEM current transducer

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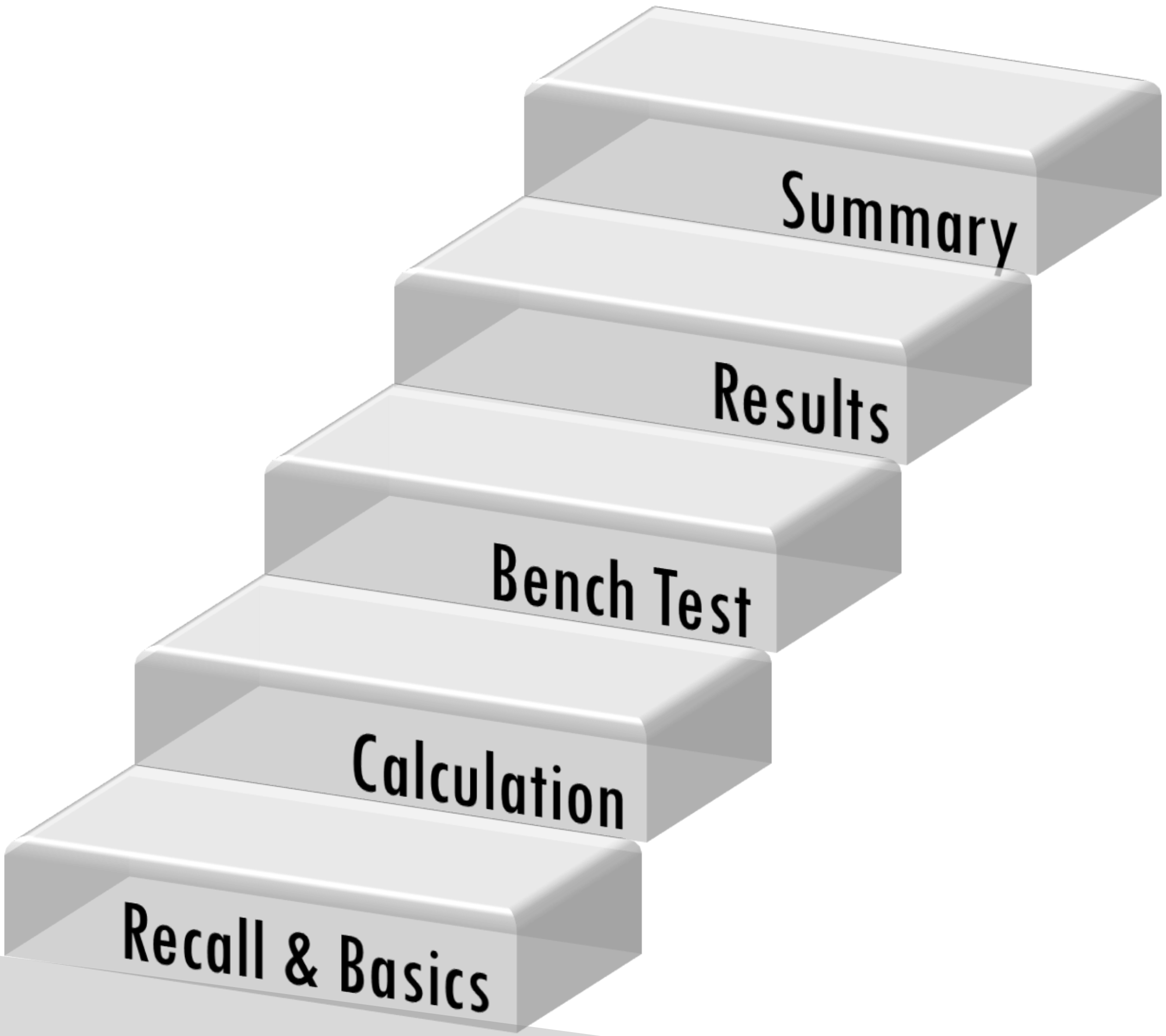
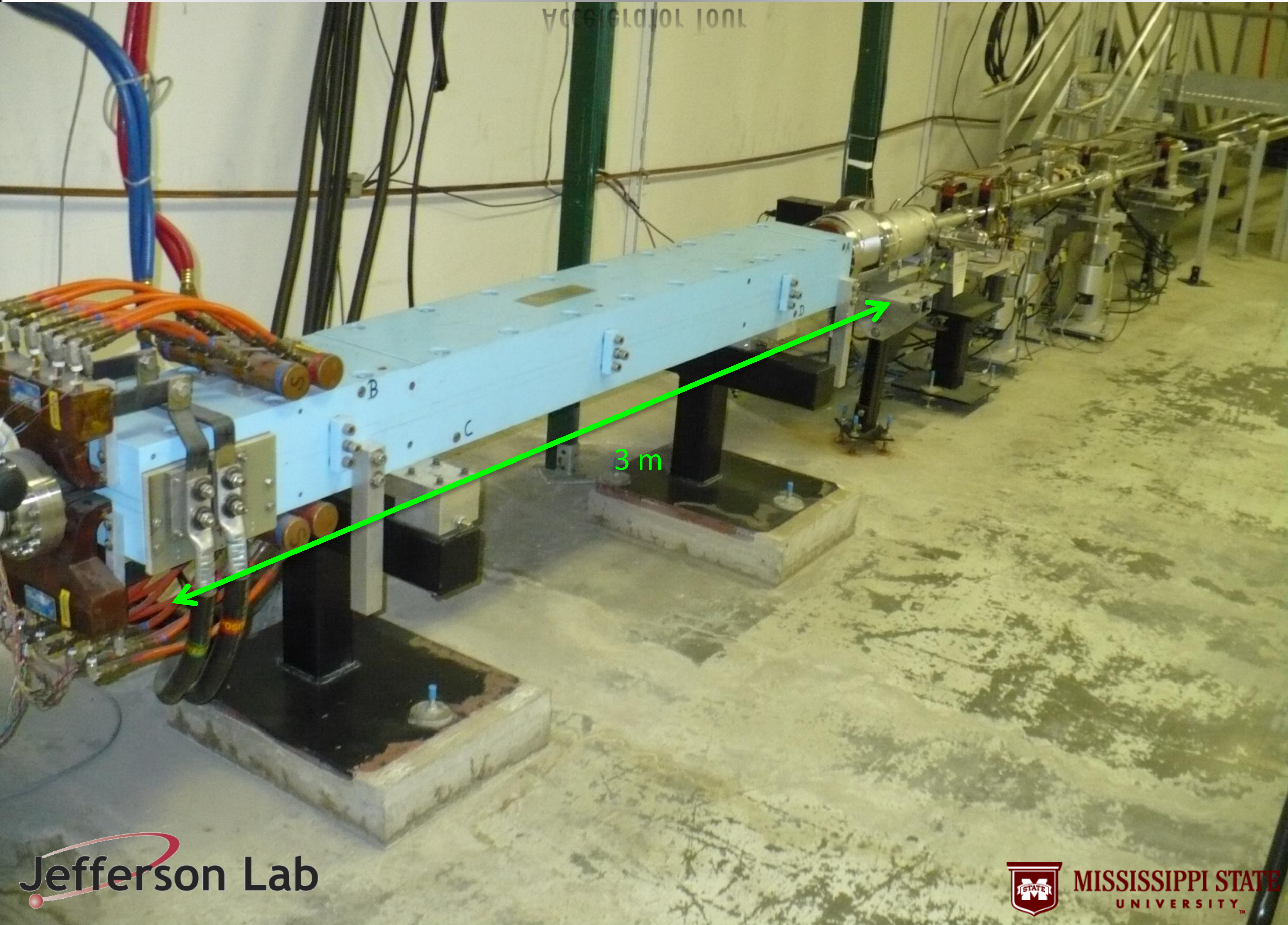
OVERVIEW



Accelerator Tour



Jefferson Lab

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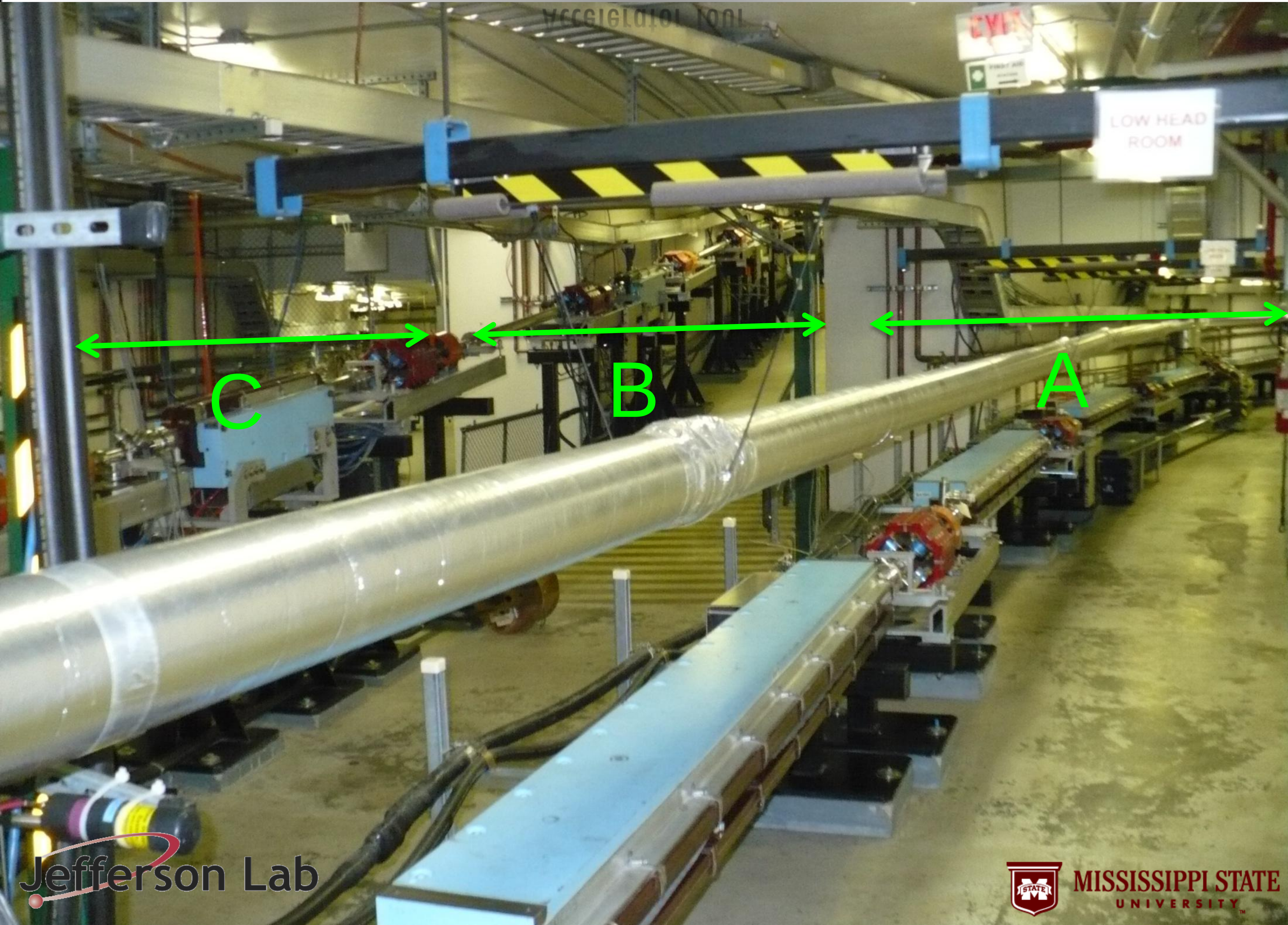
Accelerator Tour



Accelerator Tour