



PROJECT

BEAM POSITION MONITOR AND ENERGY ANALYSIS

MEPAS SCHOOL 2015

DATE **16-NOV.**

STUDENT **DAVID PAVEL JUAREZ LOPEZ**

 **Fermilab** 

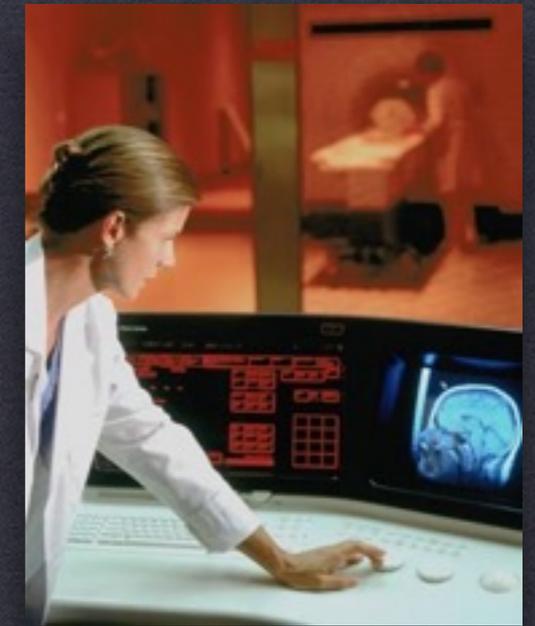
TALKING POINTS

- * Motivation
- * Introduction to FAST Facility
- * Accelerator Beam Lattice
- * Theory
- * Measurements and Simulations
- * Conclusions

MOTIVATION

* **Medicine**

- **Magnetic resonance imaging**
- **Cancer therapy**
- **Diagnostic instrumentation**



* **Industry**

- **Power transmission**
- **Transportation**
- **Biomedicine**



* **Computing**

- **The World Wide Web**
- **The Grid**



- * Food sterilization
- * Medical isotope production
- * Simulation of cancer treatments
- * Reliability testing of nuclear weapons
- * Scanning of shipping containers
- * Proposed combination of PET and MRI imaging
- * Improved sound quality in archival recordings
- * Parallel computing
- * Ion implantation for strengthening materials
- * Curing of epoxies and plastics
- * Data mining and simulation
- * International relations
- * Nuclear waste transmutation
- * Remote operation of complex facilities
- * ...

BIZARRE APPLICATIONS

WHY VAN GOGH'S SUNFLOWERS ARE WILTING



VAN GOGH'S PIGMENT UP CLOSE: PLUMBONACRITE REVEALED AS INTERMEDIATE IN DEGRADATION OF RED LEAD

Pigment Discoloration DOI: 10.1002/ange.201411691

Plumbonacrite Identified by X-ray Powder Diffraction Tomography as a Missing Link during Degradation of Red Lead in a Van Gogh Painting**

*Frederik Vanmeert, Geert Van der Snickt, and Koen Janssens**

Pigments International Edition: DOI: 10.1002/anie.201505840
German Edition: DOI: 10.1002/ange.201505840

Evidence for Degradation of the Chrome Yellows in Van Gogh's *Sunflowers*: A Study Using Noninvasive In Situ Methods and Synchrotron-Radiation-Based X-ray Techniques

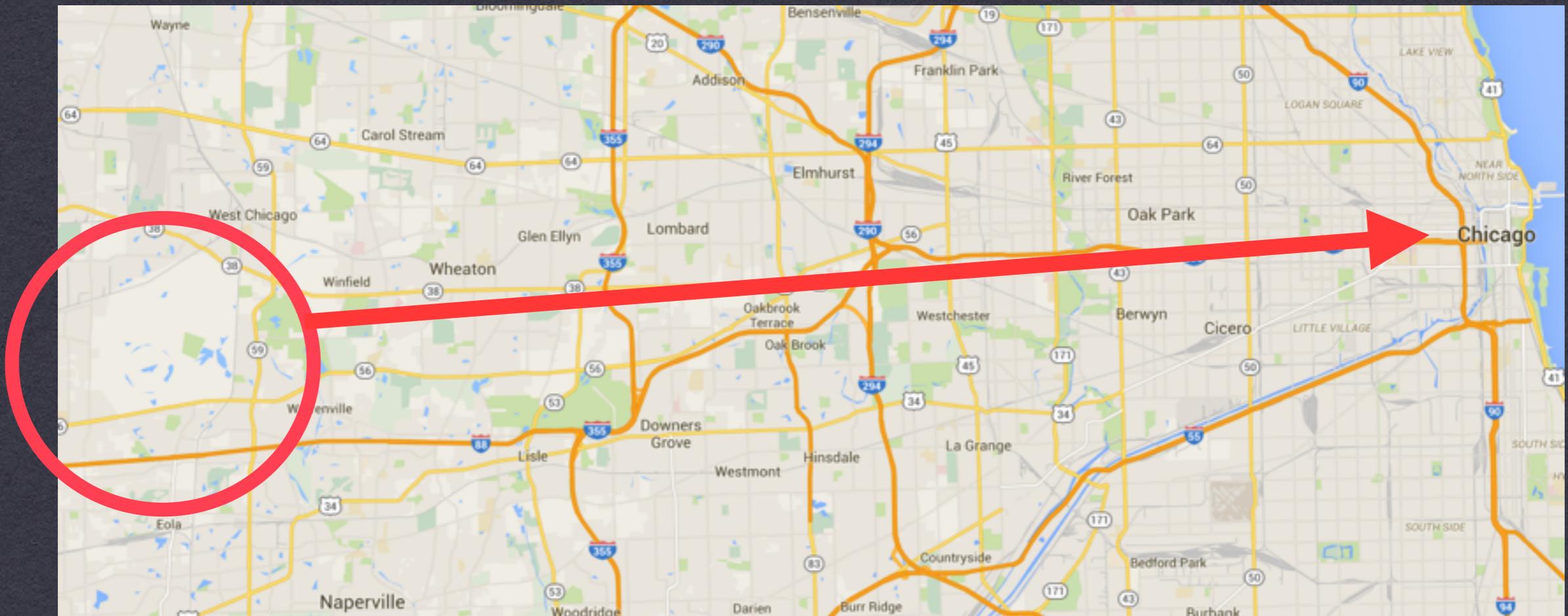
Letizia Monaco, Koen Janssens, Ella Hendriks, Frederik Vanmeert, Geert Van der Snickt, Marine Cotte, Gerald Falkenberg, Brunetto Giovanni Brunetti, and Costanza Miliani*



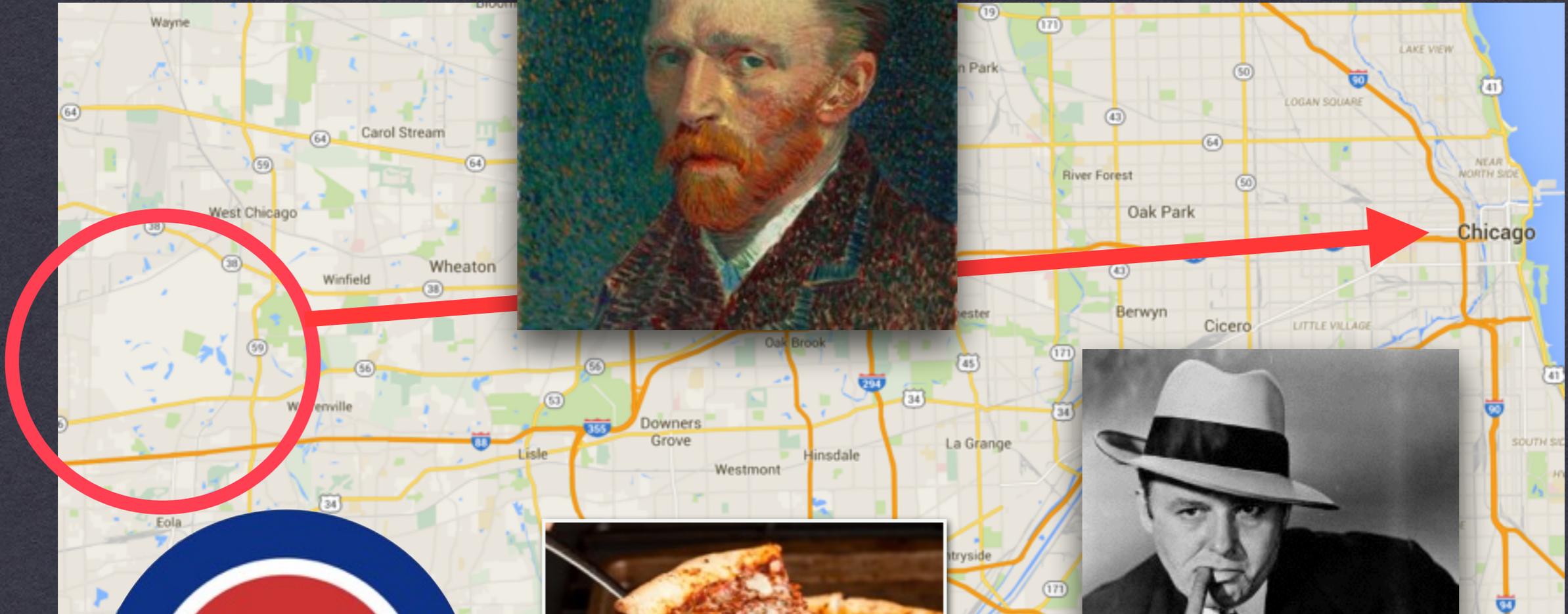
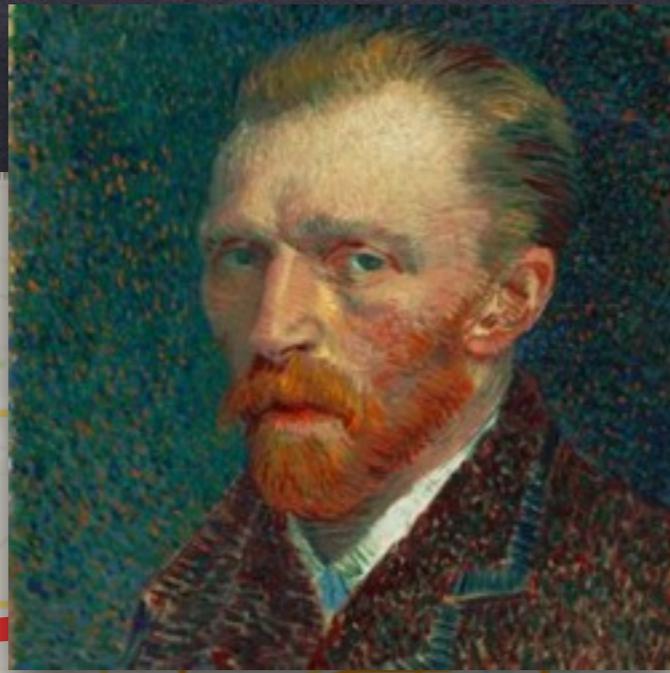
X-RAY EXAMINATION SHOWS HOW CHROME YELLOW DARKENS

INTRODUCTION TO FERMILAB ACCELERATOR SCIENCE AND TECHNOLOGY

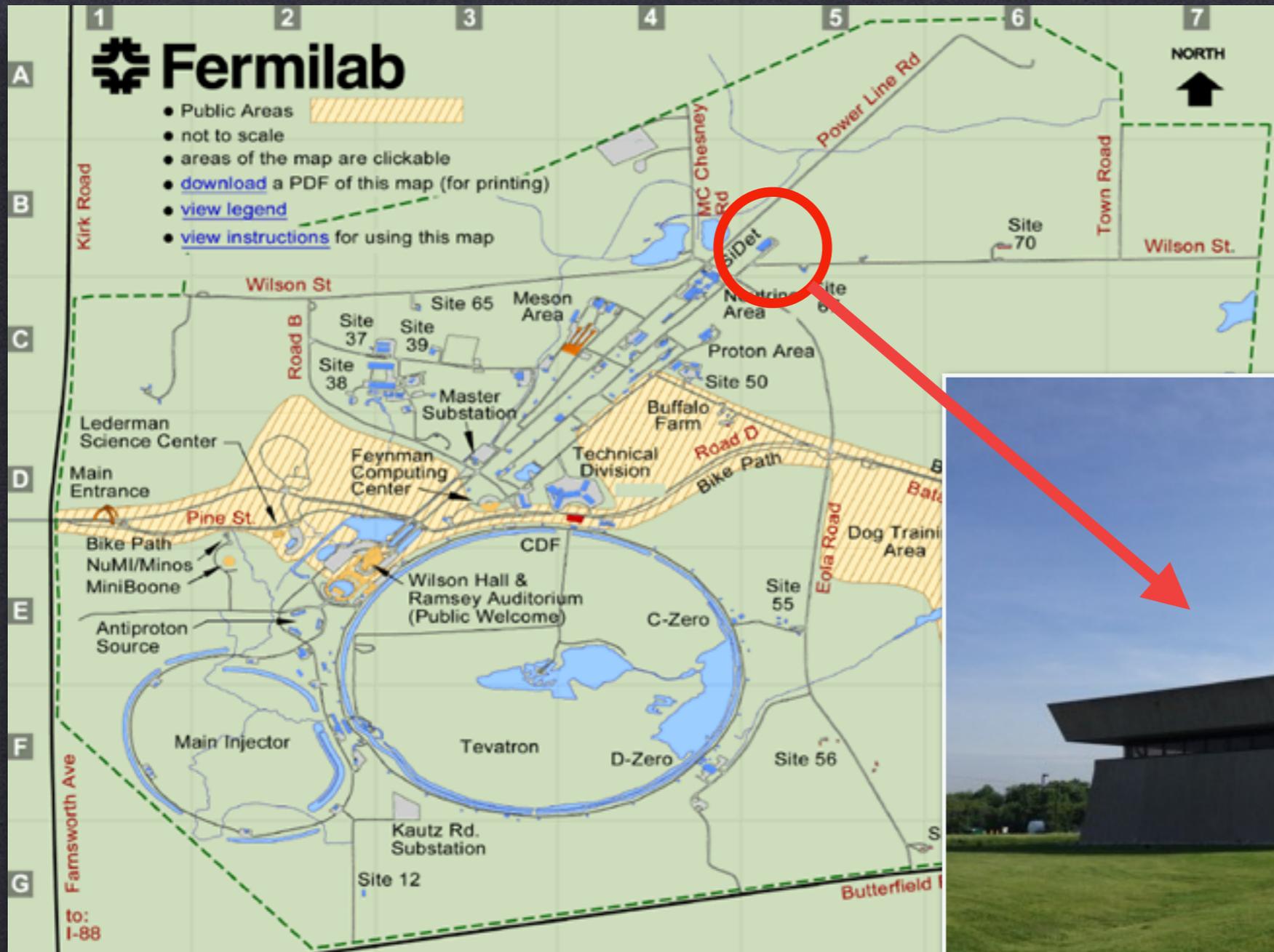
WHERE IS FERMILAB? - 50KM FROM CHICAGO



WHERE IS FERMILAB? - 50KM FROM CHICAGO

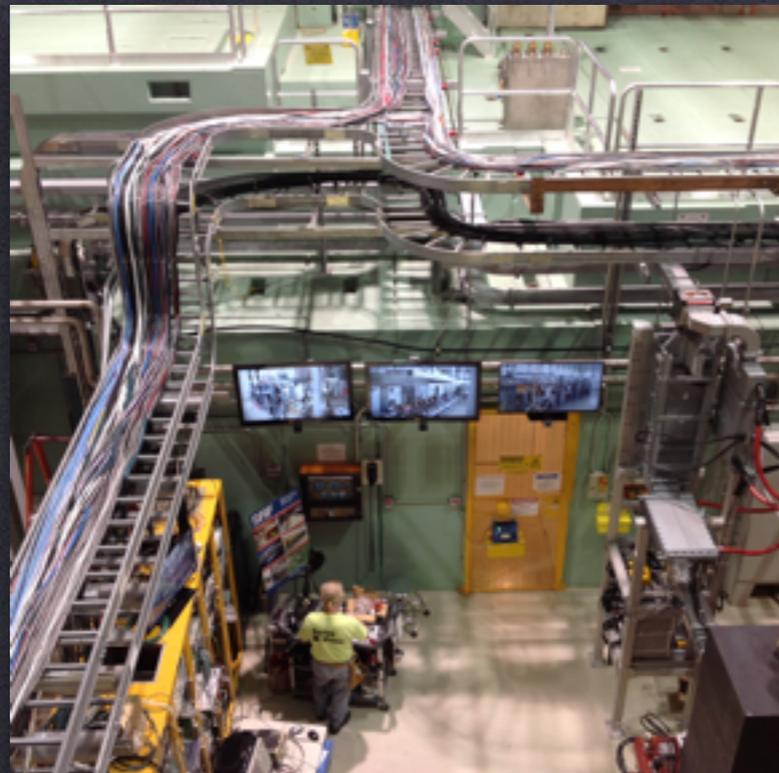


OVERVIEW OF FAST FACILITY



<http://www.fnal.gov/>

NML BUILDING



FAST: WHAT IS IT?

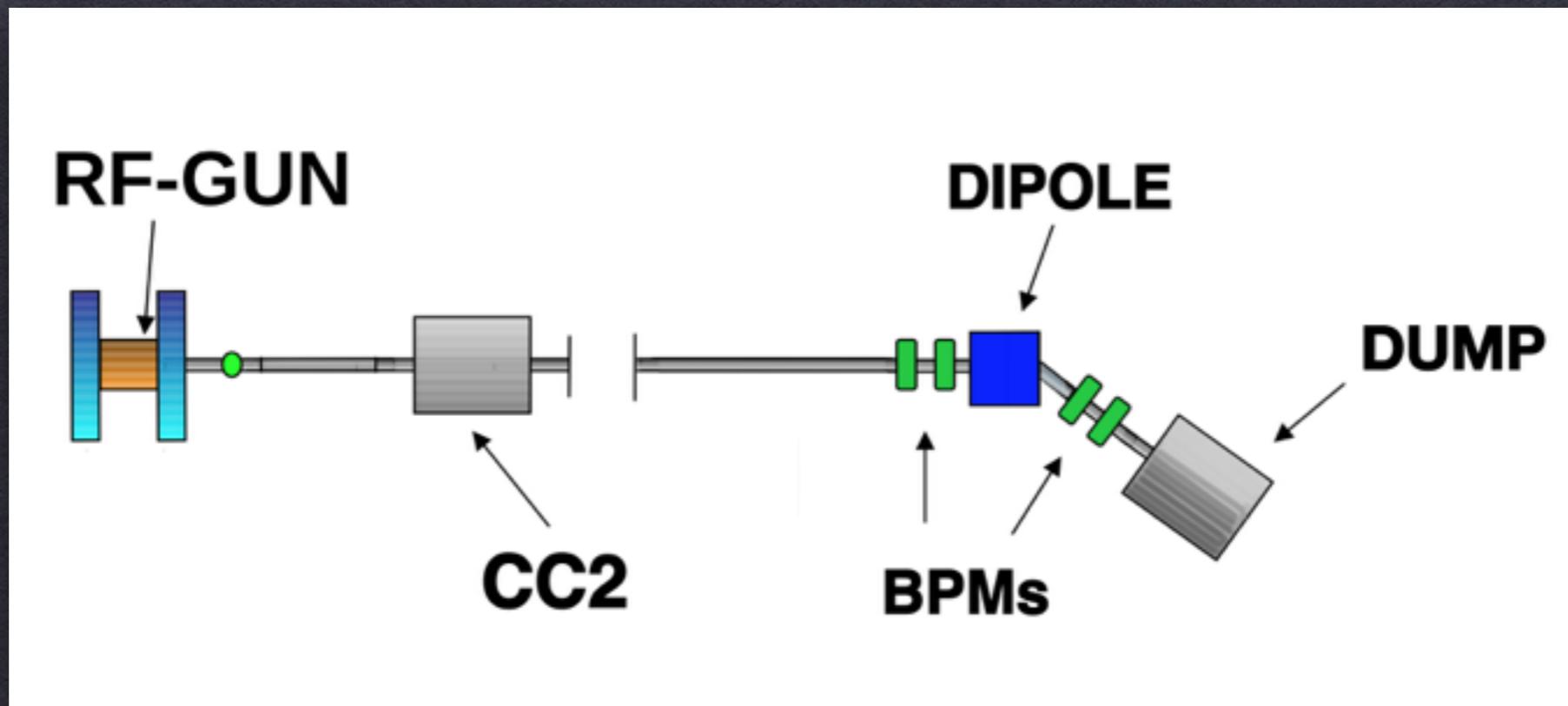
The Fermilab Accelerator Science and Technology (FAST) program is based on the capability provided by an SRF linac (which provide electron beams from 50 MeV to nearly 1 GeV) and a small storage ring to enable a broad range of beam-based experiments to study fundamental limitations to beam intensity and to develop transformative approaches to particle-beam generation

WHAT DO WE GOING TO DO:

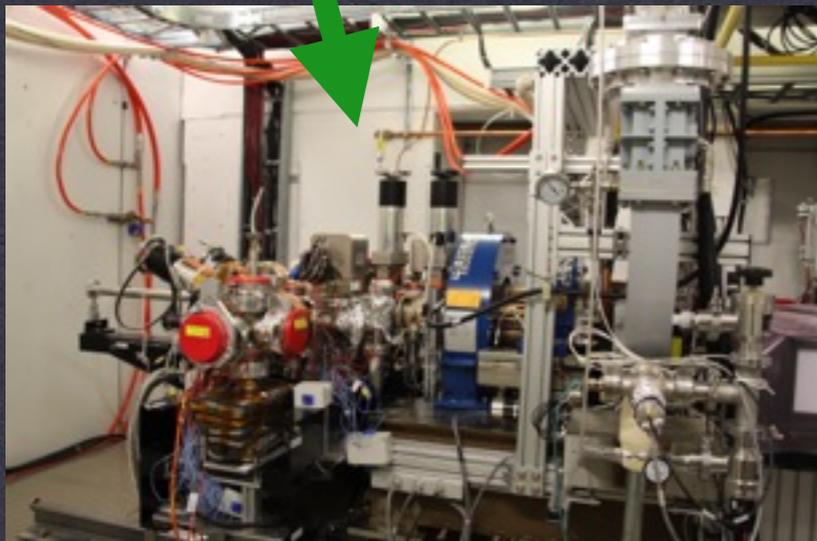
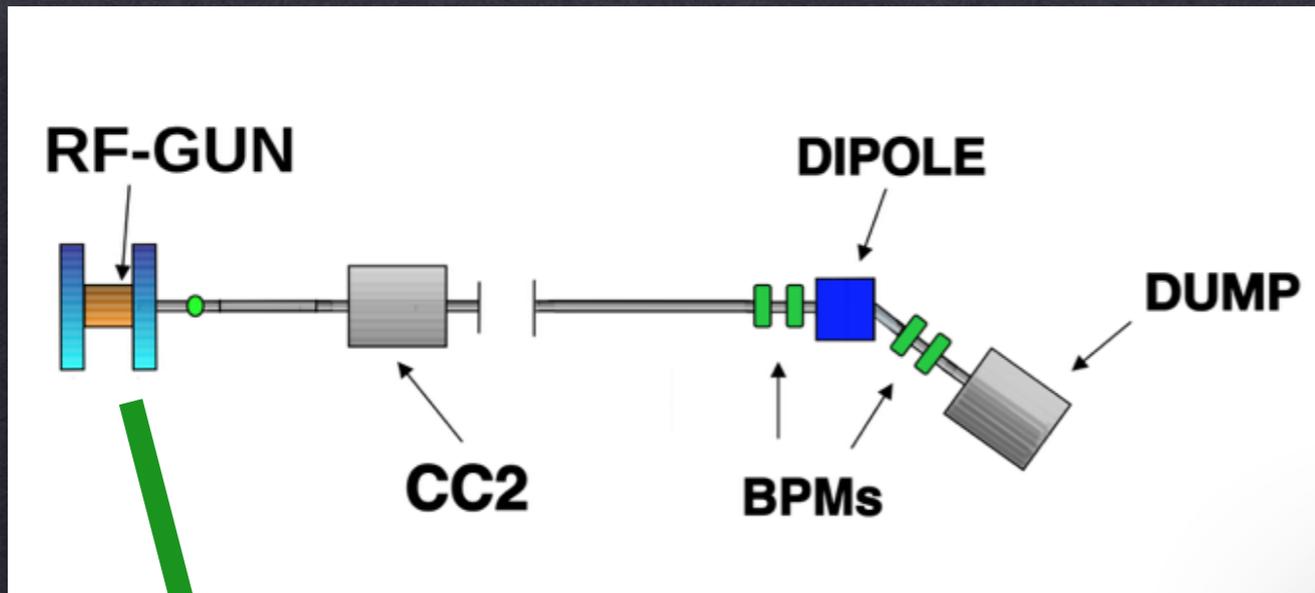
Measure the gun energy

ACCELERATOR BEAM LATTICE

ACCELERATOR LATTICE

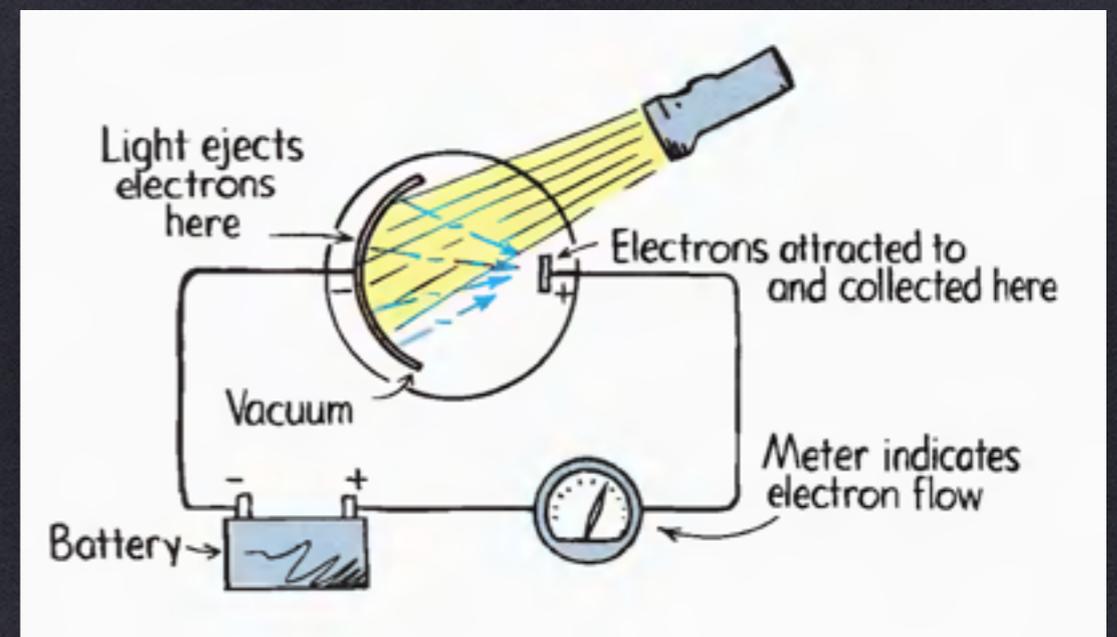


ACCELERATOR LATTICE



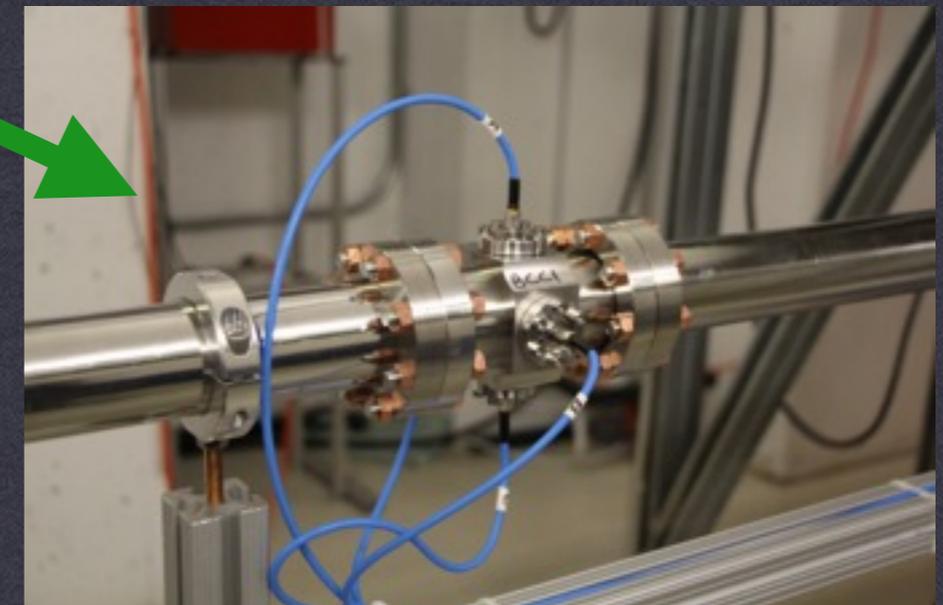
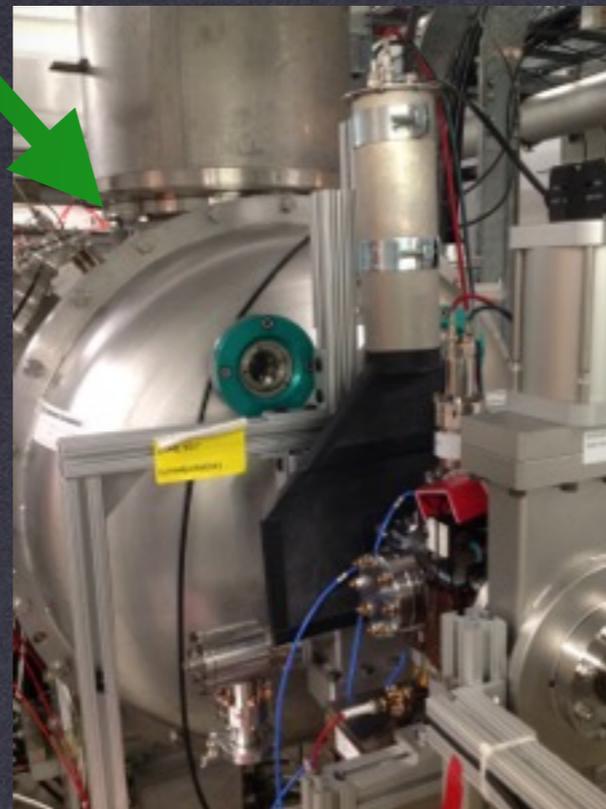
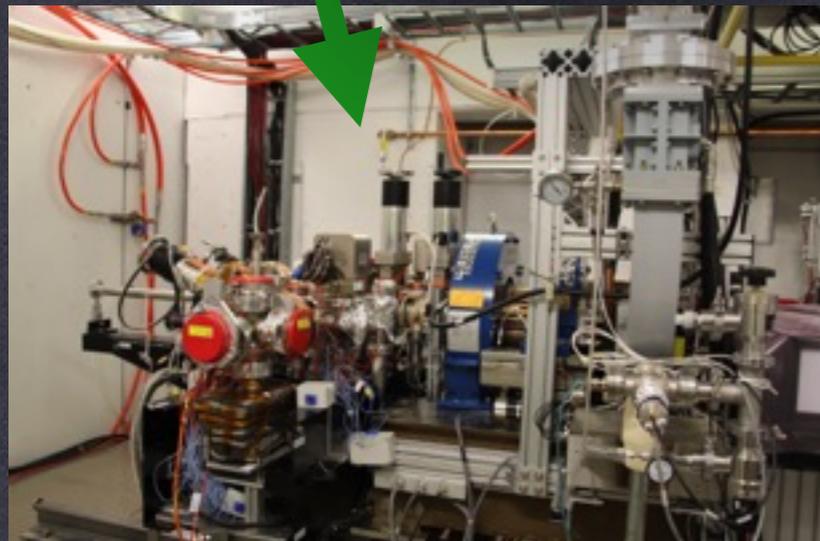
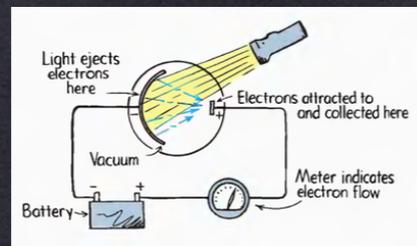
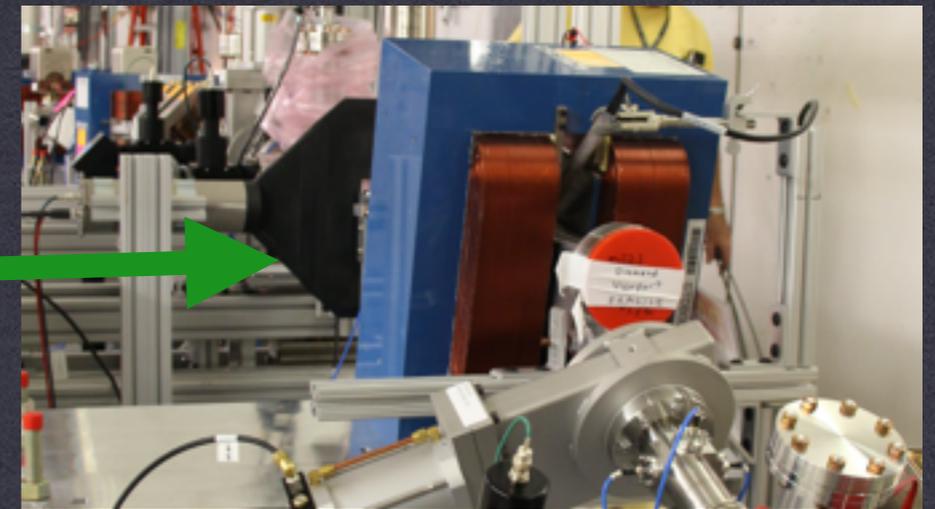
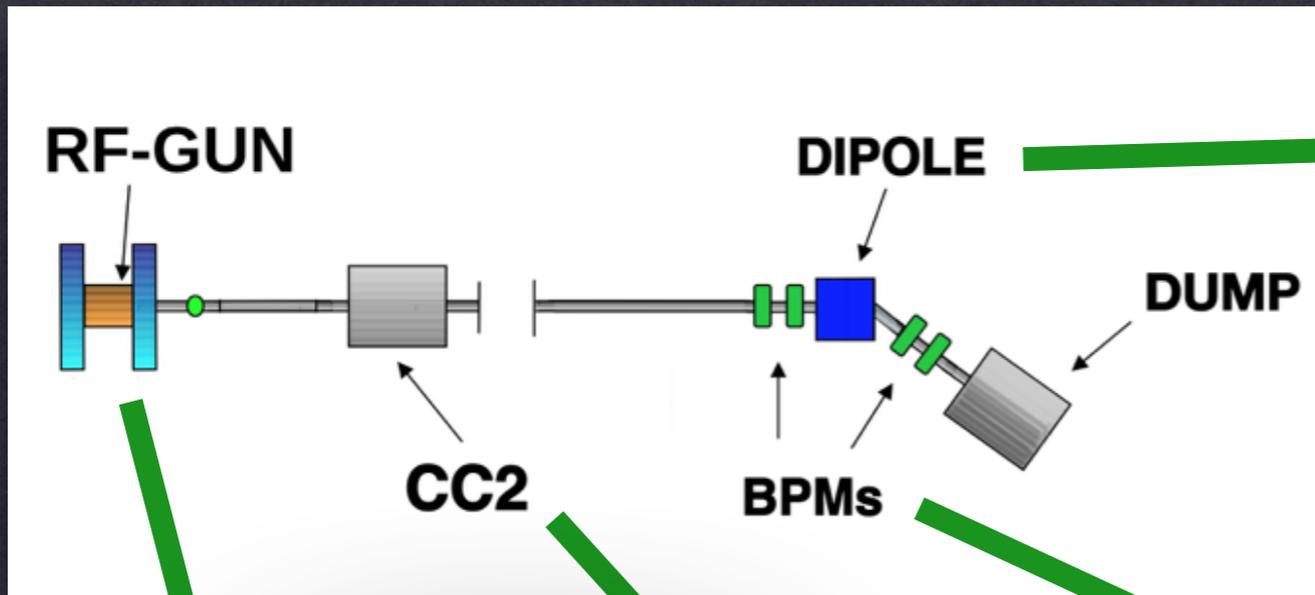
$B = 1010.99844 \pm 0.0014 \text{ G}$
 $L_{\text{eff}} = 0.2064687 \text{ m}$
 Current of 3 A
 Angle of 22.5°

PHOTOELECTRIC EFFECT



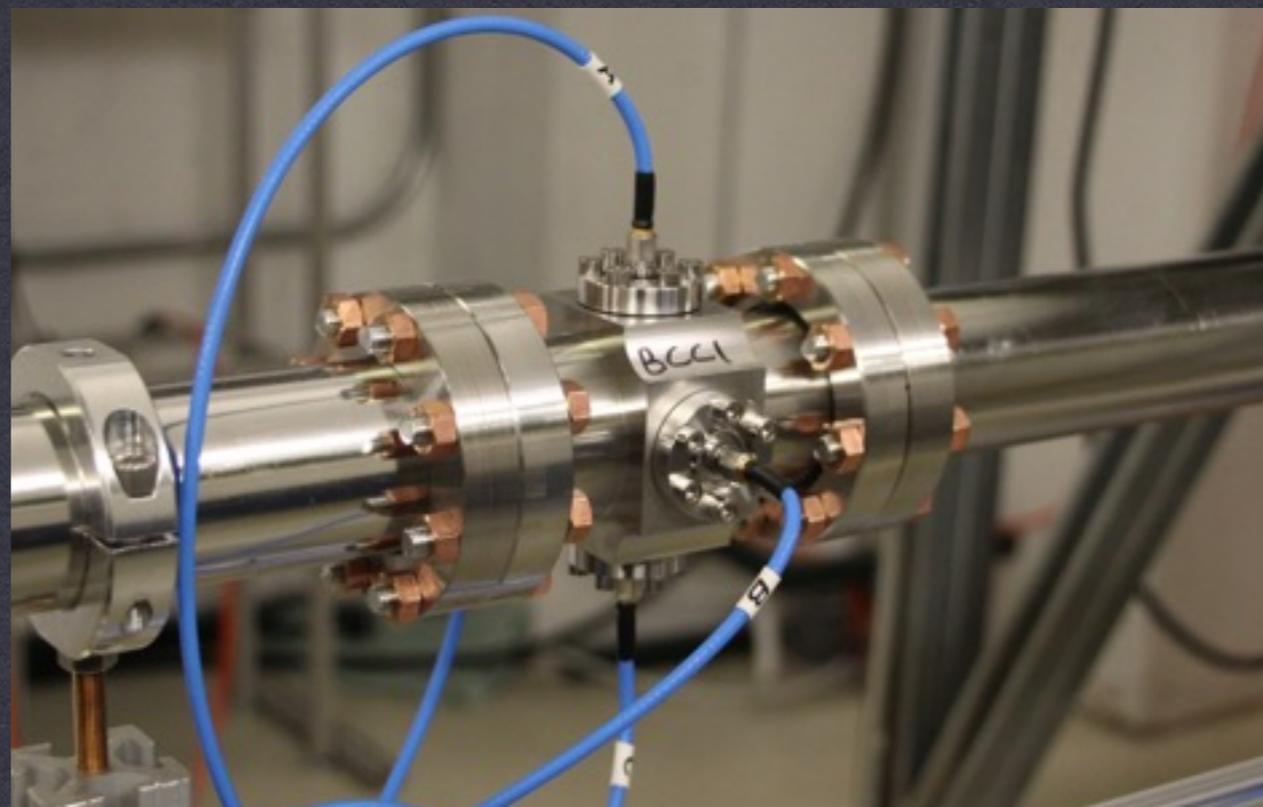
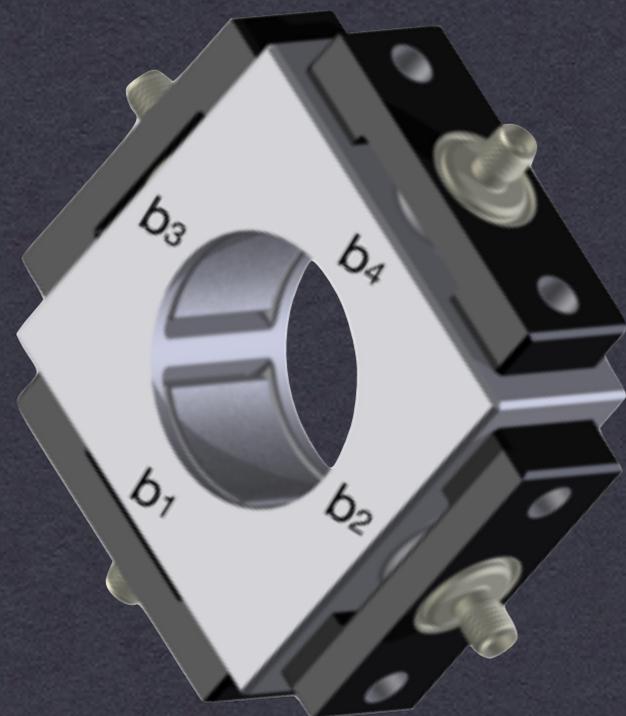
REFERENCE: CONCEPTUAL PHYSICS - P. HEWITT 10ED.

ACCELERATOR LATTICE



B = 1010.99844 +/- 0.0014 G
 L_{eff} = 0.2064687 m
 Current of 3 A
 Angle of 22.5°

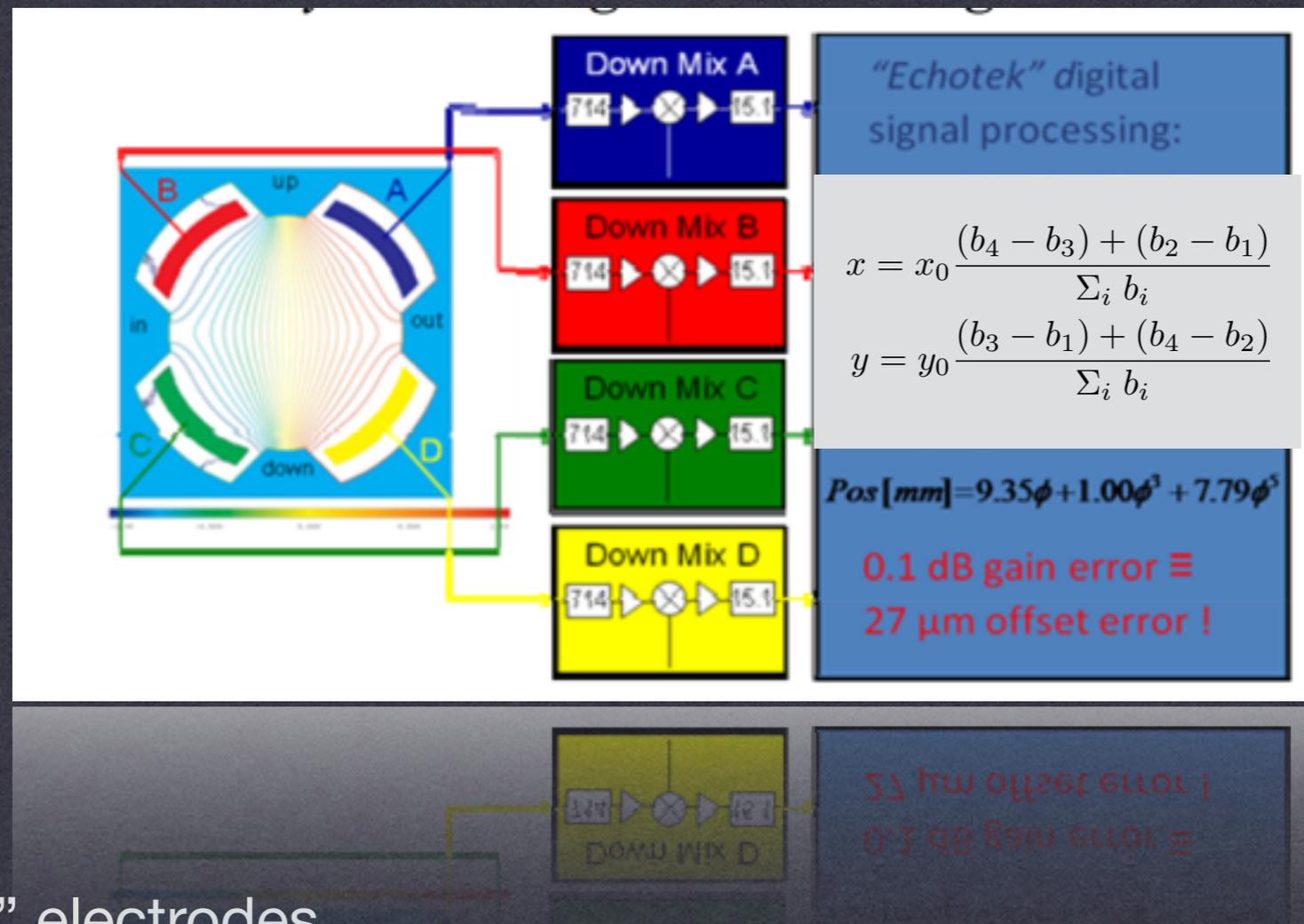
BEAM POSITION MONITOR



- * Button Style BPM
- * $V(b_1, b_2, b_3, b_4) \rightarrow P(x, y)$
- * Design Resolution of $50 \mu\text{m}$

BEAM POSITION MONITOR

BUTTON STYLE



- * Four “Button” electrodes
- * Arranged symmetrically under 45°
- * Design Resolution of 50 μ m

Proceedings of DIPAC09, Basel, Switzerland MOPD19
HIGH RESOLUTION BPMS
WITH INTEGRATED GAIN CORRECTION SYSTEM

SOME OF THE PICKUP NON-LINEARITIES ARE TAKEN INTO ACCOUNT BY APPLYING A 5TH ORDER POLYNOMIAL TO FIT THE CALCULATED EQUIPOTENTIALS.

THEORY

From Lorentz

$$\mathbf{F} = q \left(\mathbf{E} + \frac{1}{c} \mathbf{v} \times \mathbf{B} \right)$$

$$\mathbf{F} = \frac{d\mathbf{p}}{dt} = \frac{e}{c} (\mathbf{v} \times \mathbf{B})$$

Integrating and substituting $v=r/t$

$$p = \frac{e}{c} B r$$

For a rectangular magnet

$$l_{arc} = \alpha r = l_{eff} \cdot \frac{\alpha}{\sin \alpha}$$

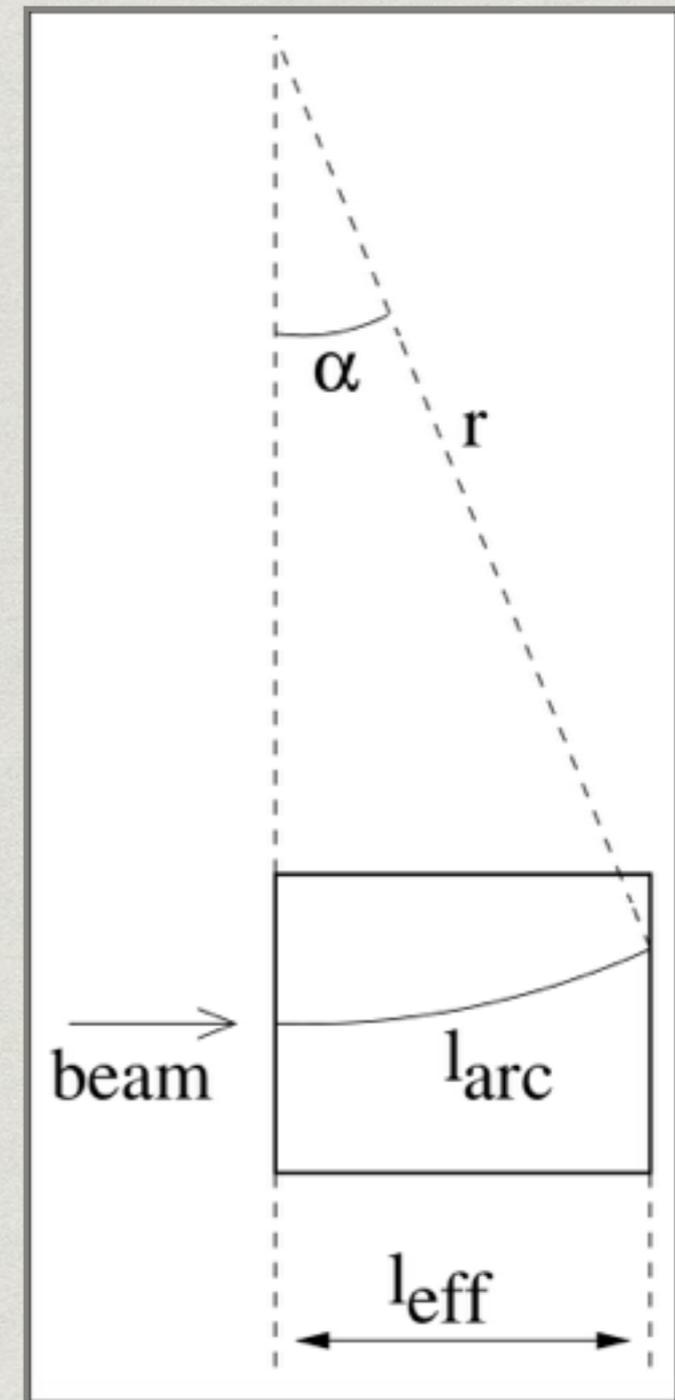
The field integral along the trajectory inside the dipole

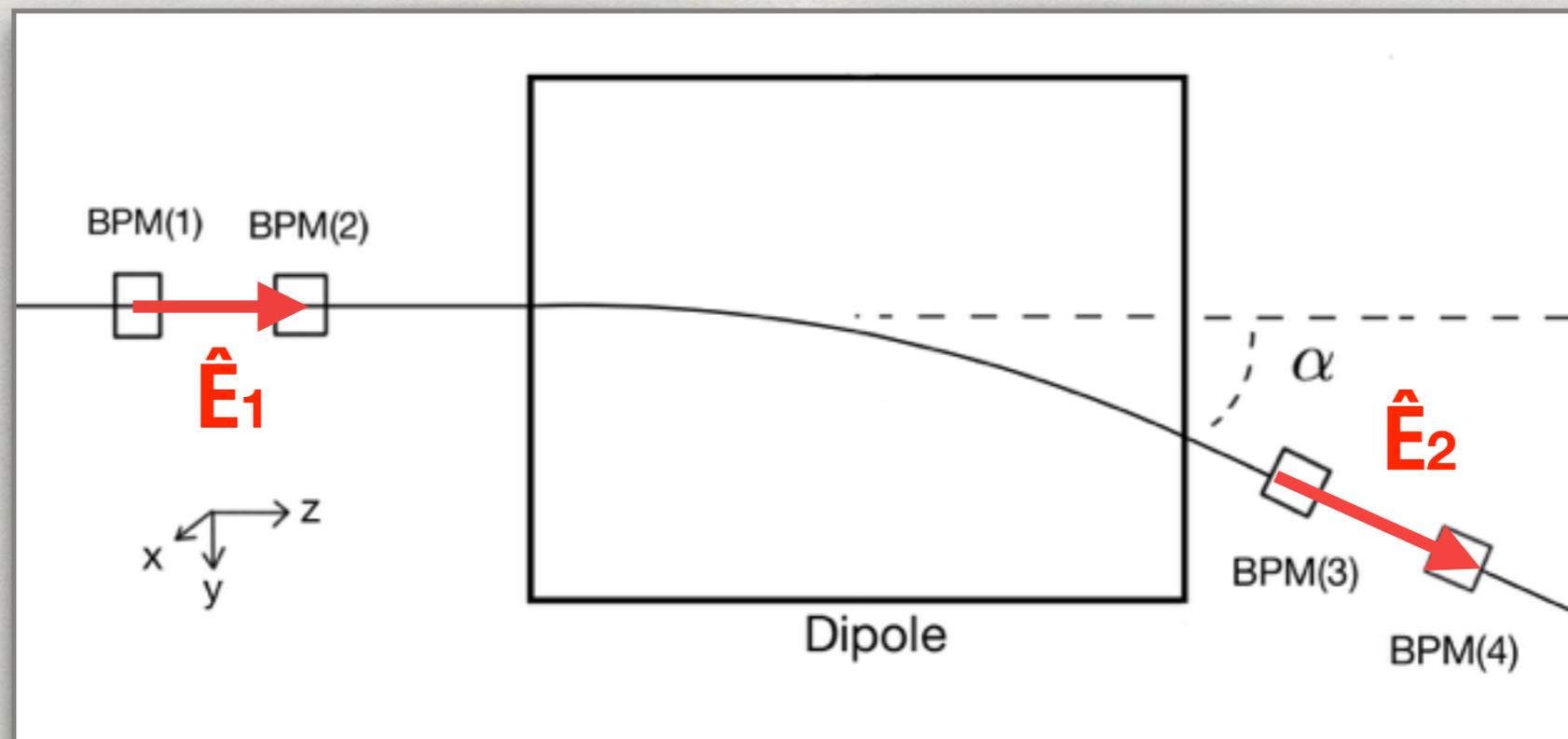
$$\int \mathbf{B} \cdot d\mathbf{s} = B \cdot l_{arc}$$

The energy for an ultra-relativistic particle $E = cp$

$$E = e \cdot \frac{B}{\sin \alpha} \cdot l_{eff}$$

$$0 < \alpha < \pi/2$$





$$\mathbf{P}_1 = (X_1, Y_1, Z_1)$$

$$\mathbf{P}_2 = (X_2, Y_2, Z_2)$$

$$\mathbf{P}_3 = (X_3, Y_3, Z_3)$$

$$\mathbf{P}_4 = (X_4, Y_4, Z_4)$$

$$\hat{\mathbf{E}}_1 \times \hat{\mathbf{E}}_2 = |\hat{\mathbf{E}}_1| |\hat{\mathbf{E}}_2| \sin \alpha \hat{\mathbf{i}}$$

$$E = e \left(\frac{\hat{\mathbf{E}}_1 \times \hat{\mathbf{E}}_2}{|\hat{\mathbf{E}}_1| |\hat{\mathbf{E}}_2|} \right)^{-1} B \cdot l_{eff}$$

MEASUREMENTS AND CALCULATIONS

FROM THE DATA TOOK ON 1 MAY 2015

```

PA N10 Gun Parameters<NoSets> - ACNET Java Console
File View Help
PA PB PC PD PE SA SB SC SD SE Util GxPA1 GxPA2
N10 Gun Modulator 2 SET D/A A/D Com-U PTools
--FTP> *SA X=A/D X=TIME Y=D:LCMTOT,D:95HR ,U:HSTOWB,D:OUTTMP
COMMAND ... Eng-U I= 0 I= 0 , 0 , 0
--< 4>+ On+ AUTO F= 3600 F= 200 , 20 , 100 , 100
RF timing vacuum llrf magnets water diag misc.
N:CMCTS0 Gun Mod Tr 05-JUN-2015 14:35:09
N:CMCTS1 Gun Mod Tr 05-JUN-2015 10:29:17
N:CMCTS2 Gun Mod Tr 04-JUN-2015 17:20:44
N:CMCTS3 Gun Mod Tr 04-JUN-2015 14:59:35
N:CMCTS4 Gun Mod Tr 03-JUN-2015 16:39:40
N:CMCTS5 Gun Mod Tr 01-JUN-2015 18:03:35
N:CMCTS6 Gun Mod Tr 29-MAY-2015 16:45:40
N:CMCTS7 Gun Mod Tr 29-MAY-2015 16:45:40
N:CMCTS8 Gun Mod Tr 29-MAY-2015 16:45:40
N:CMCTS9 Gun Mod Tr 29-MAY-2015 16:45:40
N:CMCUPT NML Gun Mod Up Time -3E+08 Sec

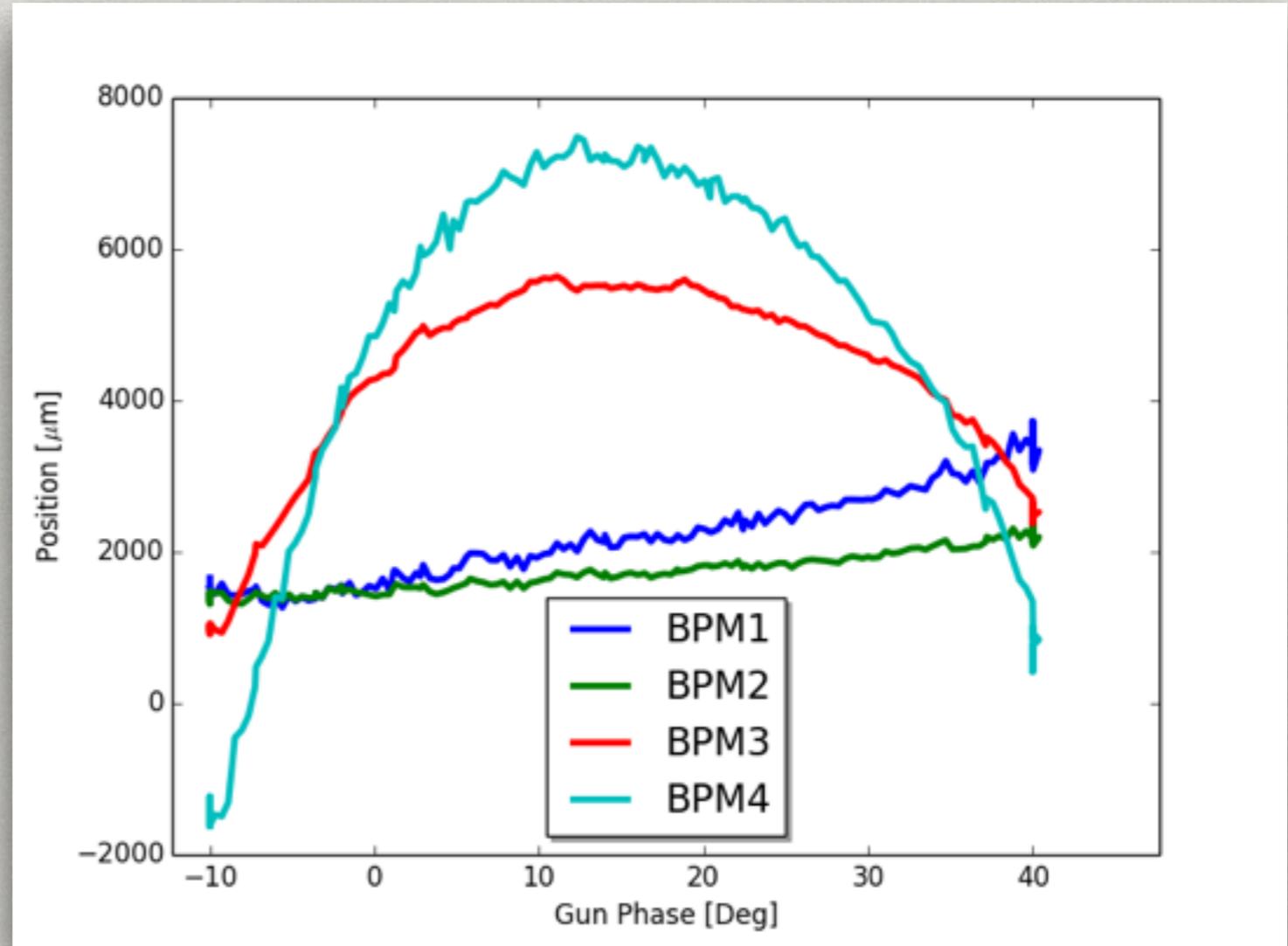
! Parameters of Gun Phase and BPMs
-N:GRESPP Gun SP Phase Esecon 26 26 deg
-N:B120PV BPM6 Vertical Positio 999999
-N:B121PV BPM13 Vertical Positi 999999
-N:B122PV BPM7 Vertical Positio 999999
-N:B123PV BPM8 Vertical Positio 999999
    
```

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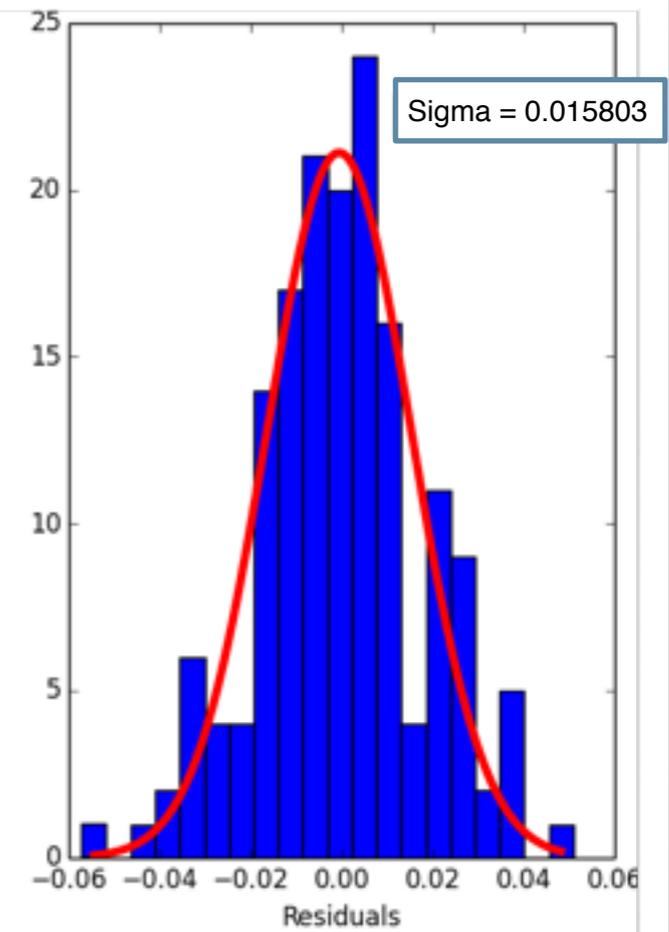
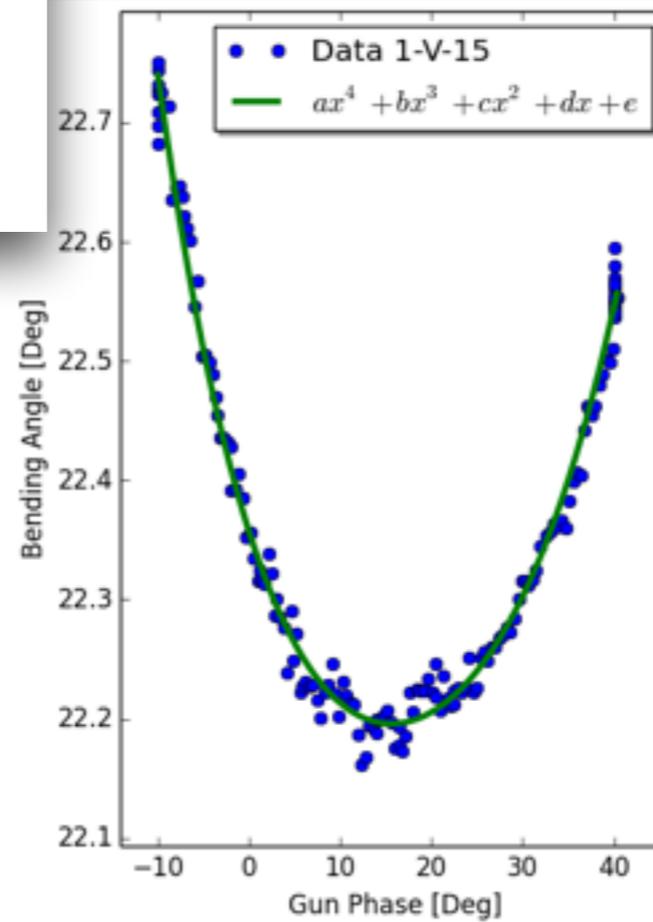
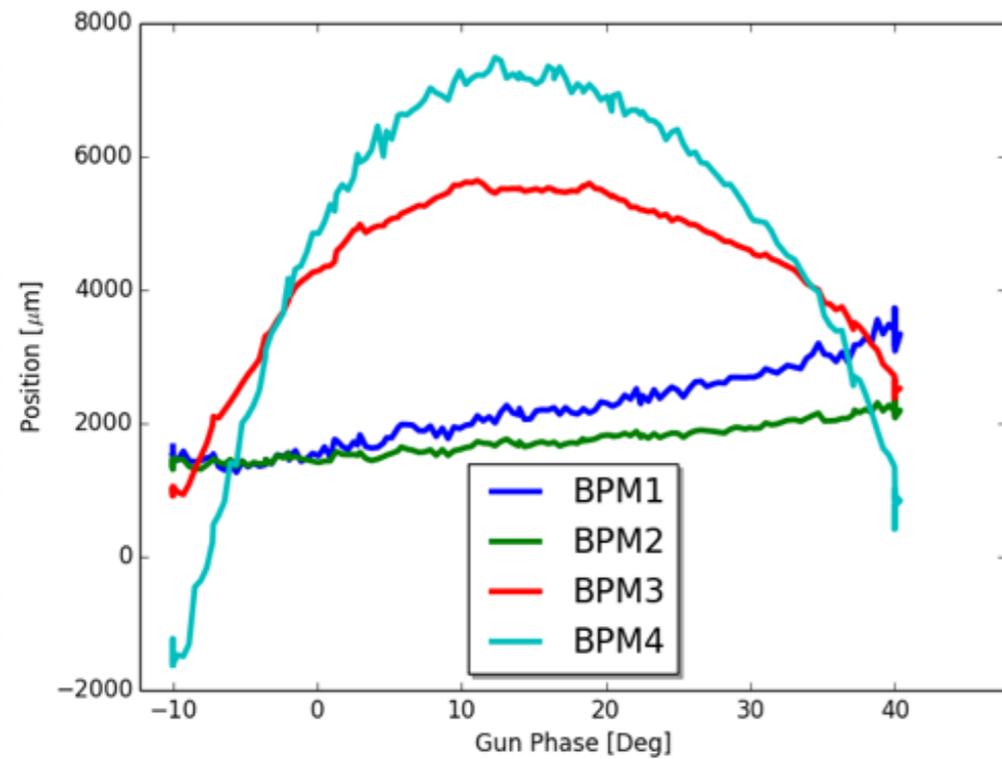
PA:N <INDEX> Class: <WebUser> - ACNET Java Console
File View Help
PA PB PC PD PE SA SB SC SD SE Util GxPA1 GxPA2
N New Muon Lab +Cnds++Pgm_Tools
Synoptic Overviews Cryomodules NML Cryogenics
2 25 OM1 & K6 Parameter 48 NML Cryo Synoptic
3 NML Monitor 26 OM2 Parameters 49 South Frig Survey
4 Laser Synoptic 27 50 North Frig Survey
5 CC2 Overview 28 51 Gen Cryo Survey
6 OM Overview 29 52 TL CC2 OM1 Survey
7 30 53 Cryo Details
Front End 31 NML Misc 54
9 Laser Room RF 55
10 Gun Parameters 33 Gun Modulator Ctrl 56
11 CC1/CC2 Parameters 34 OM1 Modulator Ctrl Users
12 Simulation 35 58
13 36 59
14 Beamline Params 37 60
Inst & Diagnostics 38 61
16 NML Wire Position 39 62
17 OM1 LLRF Lite 40 Machine Protection
18 41 64
19 Controls 65 MPS Parameters
20 Diagnostic Table 43 NML Sequencer Utilities
21 Image Tool 44 Real Time Plotter 67 Vacuum parameters
22 Emittance Tool 45 Java Time Plot 68 Water parameters
23 Inst Parameters 46 69 ASTA Vacuum

Messages

    
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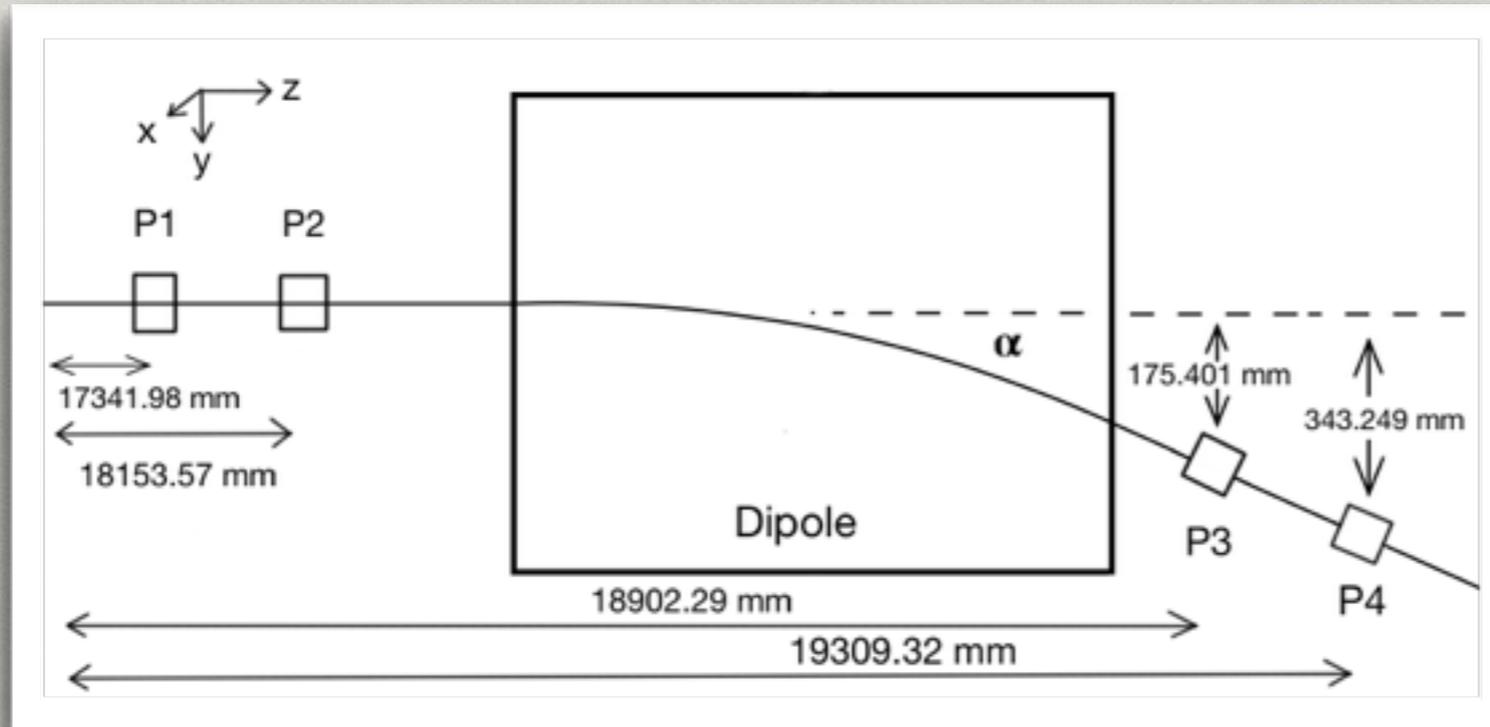
FROM THE DATA TOOK ON 1 MAY 2015



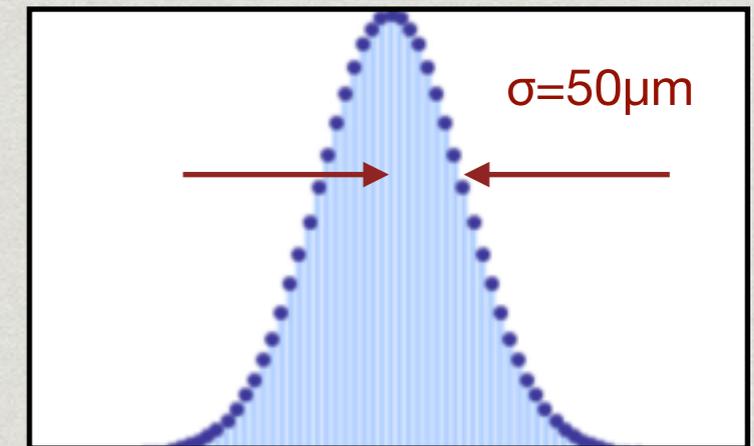
$a = 3.00270739e-07,$
 $b = -2.32514143e-05,$
 $c = 1.16676811e-03,$
 $d = -2.40022927e-02,$
 $e = 2.23567900e+01$

SIMULATING ERRORS ON THE BPMS

ACCELERATOR LATTICE



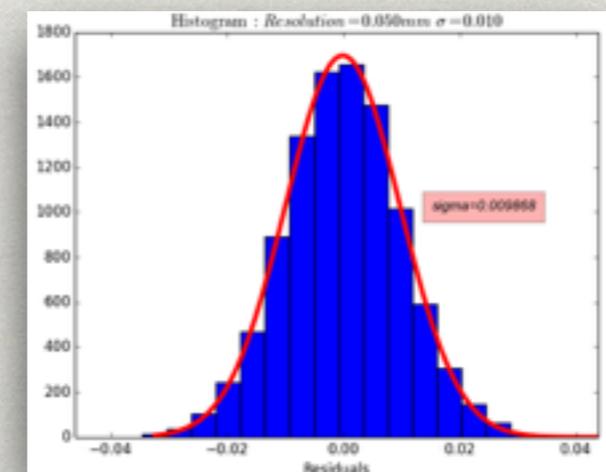
Making an error



$$\begin{aligned} \mathbf{P1} &= [x1 \pm \epsilon_1, y1 \pm \epsilon_1, z1] \\ \mathbf{P2} &= [x2 \pm \epsilon_2, y2 \pm \epsilon_2, z2] \\ \mathbf{P3} &= [x3 \pm \epsilon_3, y3 \pm \epsilon_3, z3] \\ \mathbf{P4} &= [x4 \pm \epsilon_4, y4 \pm \epsilon_4, z4] \end{aligned}$$

Residuals
Histogram

- Making errors with Normally-Distribution Random Numbers
- Calculate the Bending Angle
- Compute the residuals
- Make a histograms and fit a Gaussian

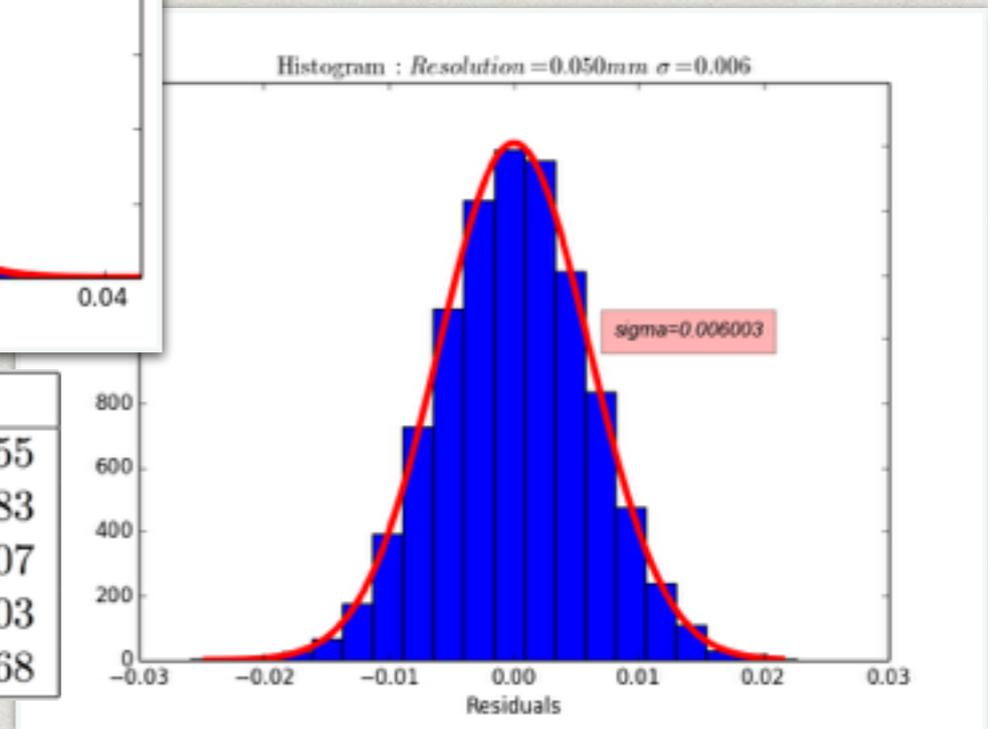
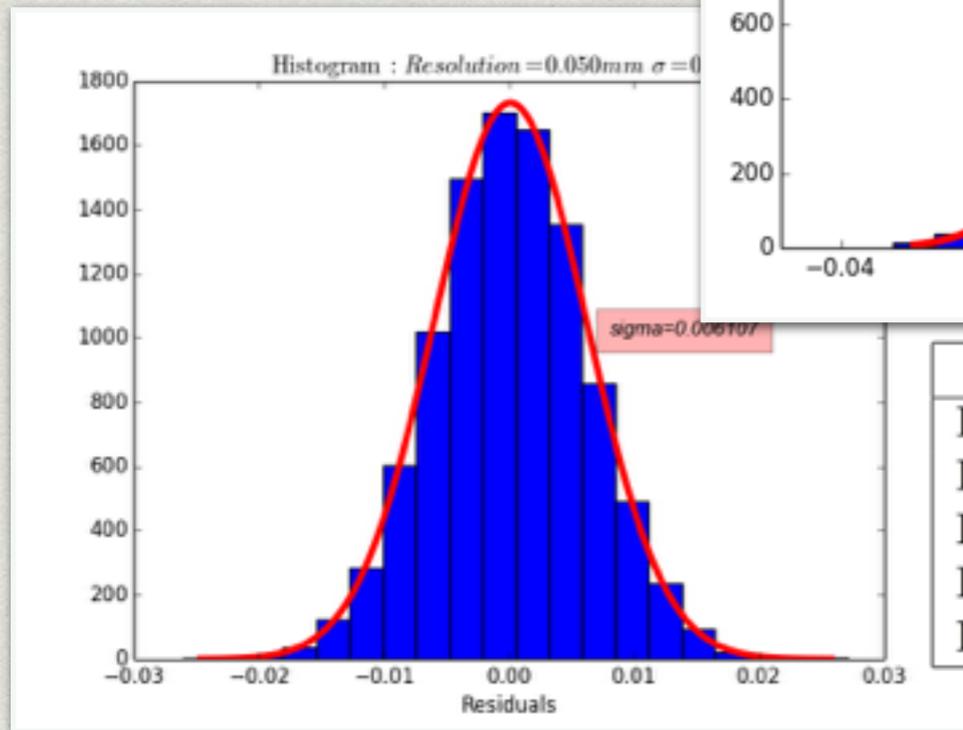
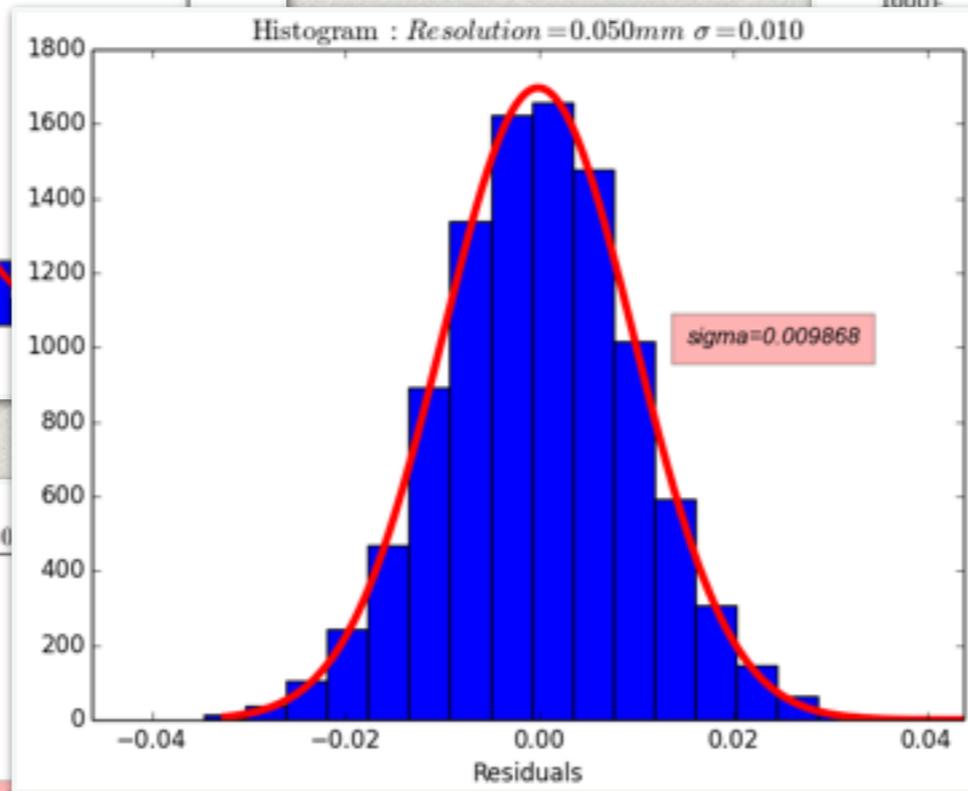
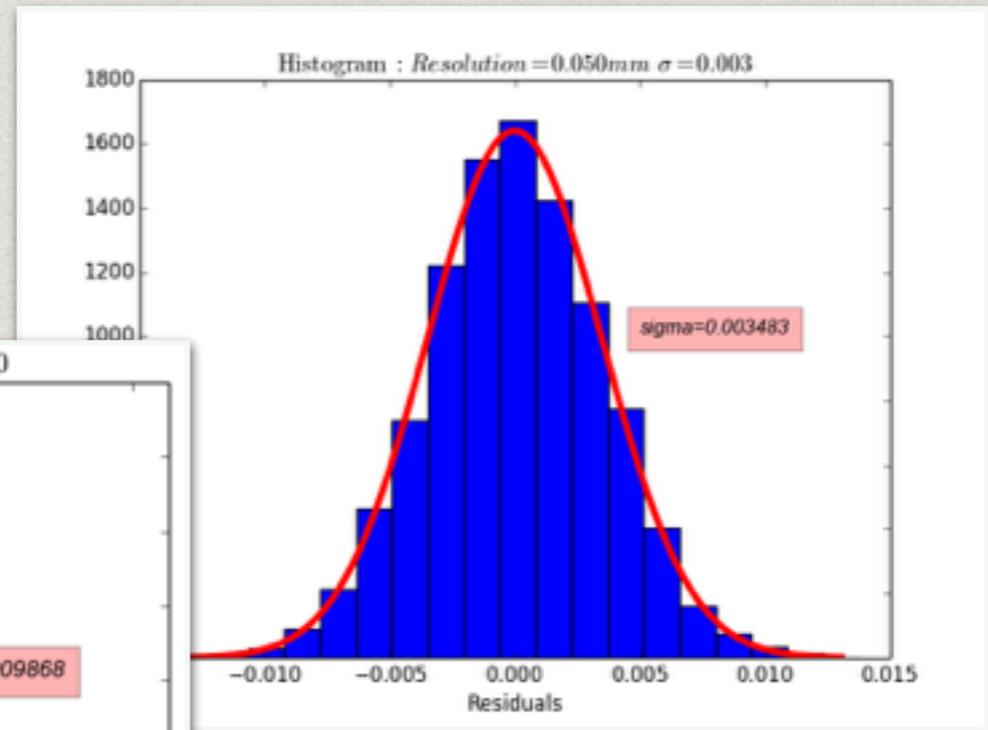
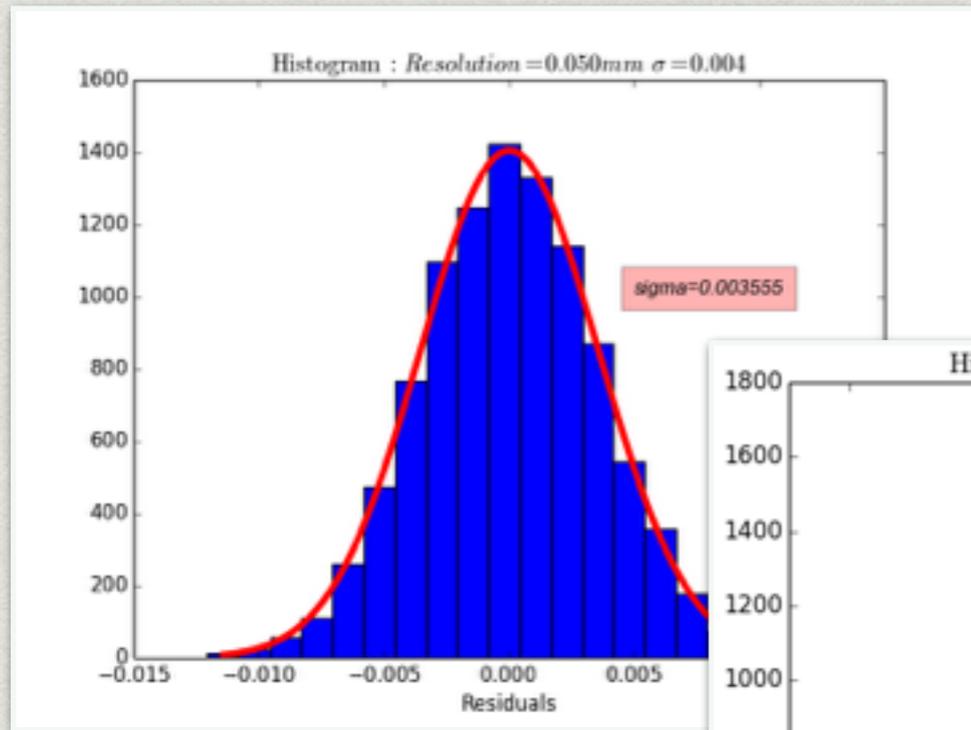


BPM ERROR USING NORMALLY-DISTRIBUTION RANDOM NUMBERS

BPM1

BPM2

BPMs

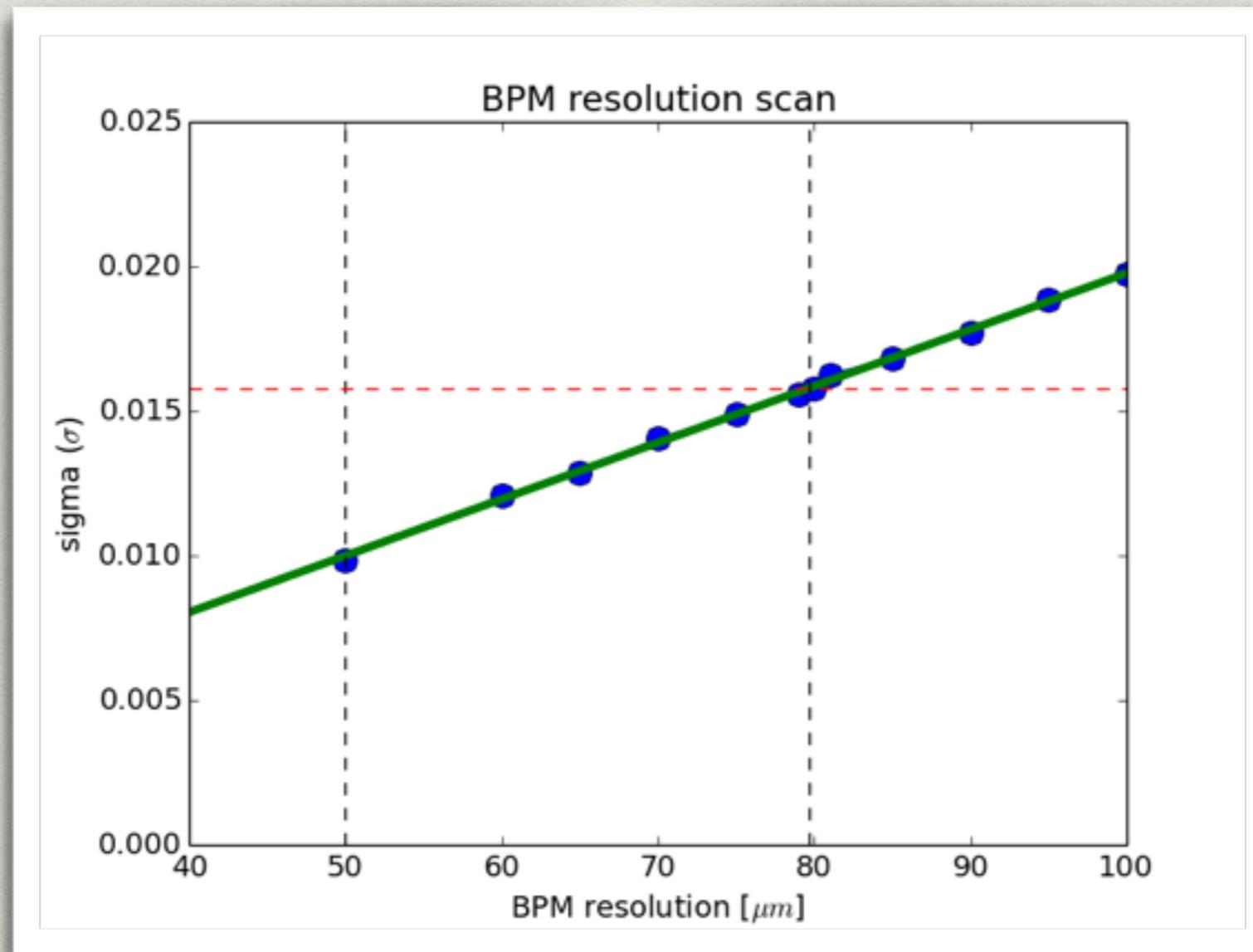


BPM Resolution = 50μm	
BPM1	$\sigma_{RBA} = 0.003555$
BPM2	$\sigma_{RBA} = 0.003483$
BPM3	$\sigma_{RBA} = 0.006107$
BPM4	$\sigma_{RBA} = 0.006003$
BPMs (all)	$\sigma_{RBA} = 0.009868$

BPM3

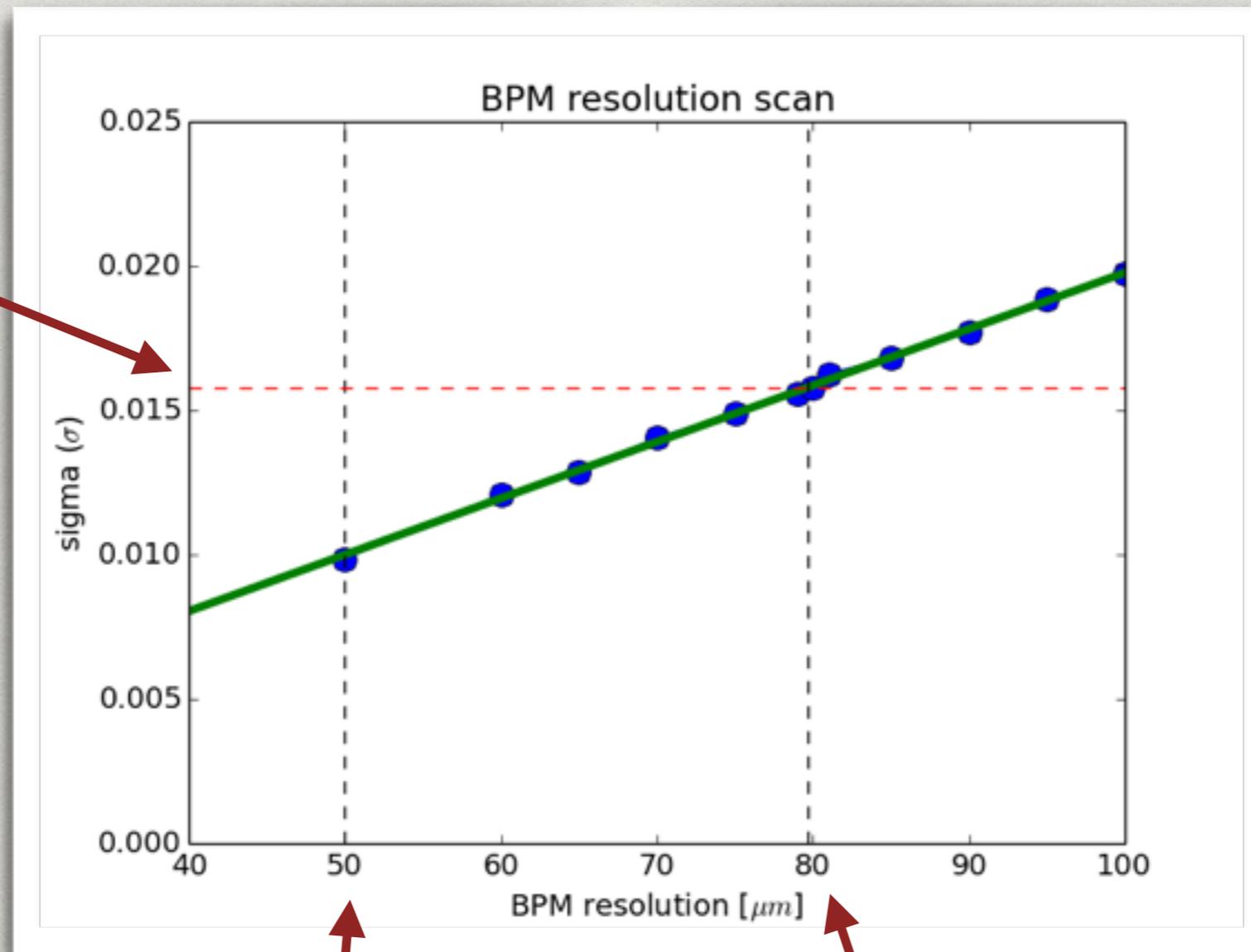
BPM4

VARIATING THE BPM RESOLUTION



VARIATING THE BPM RESOLUTION

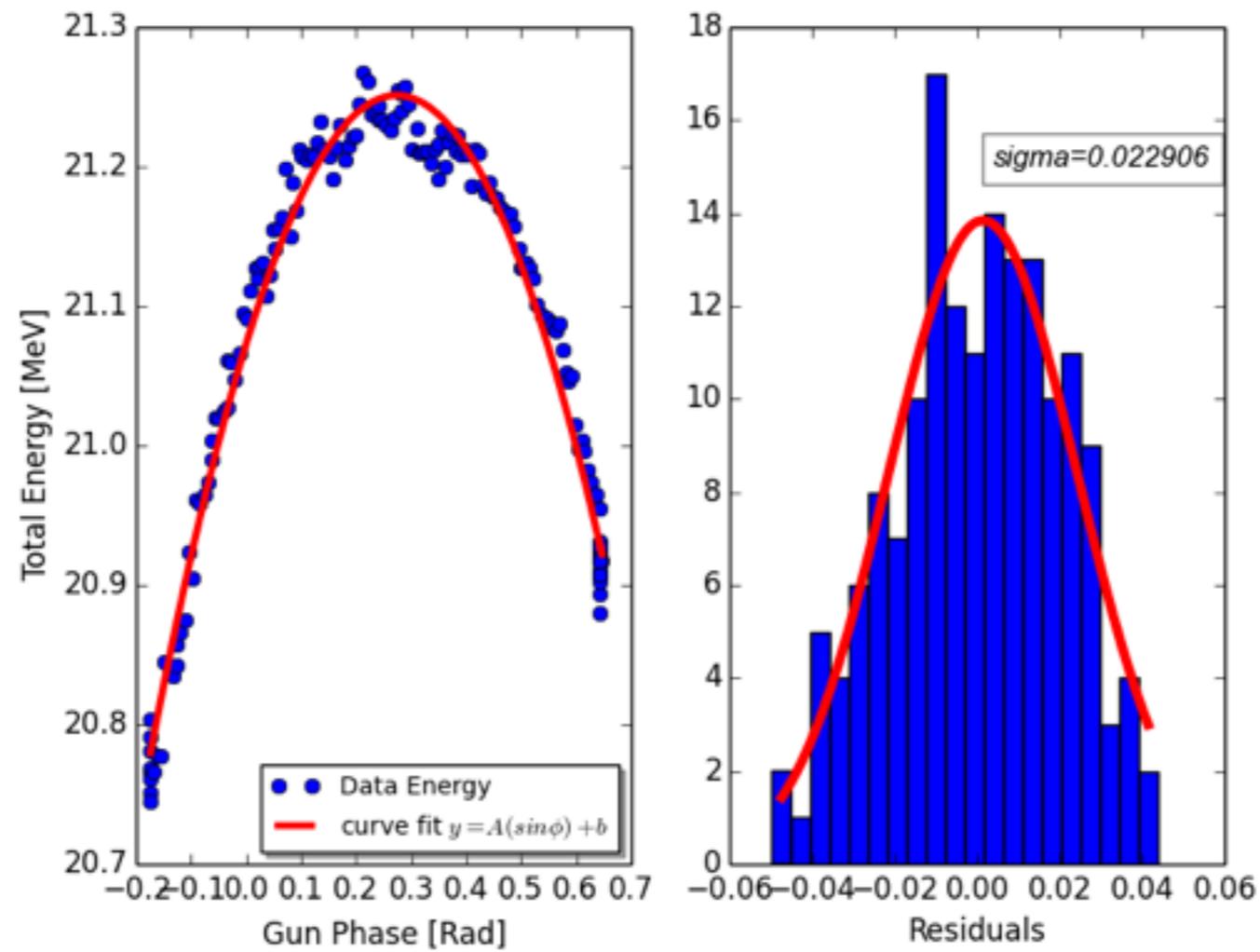
DATA



**BPM DESIGN
RESOLUTION**

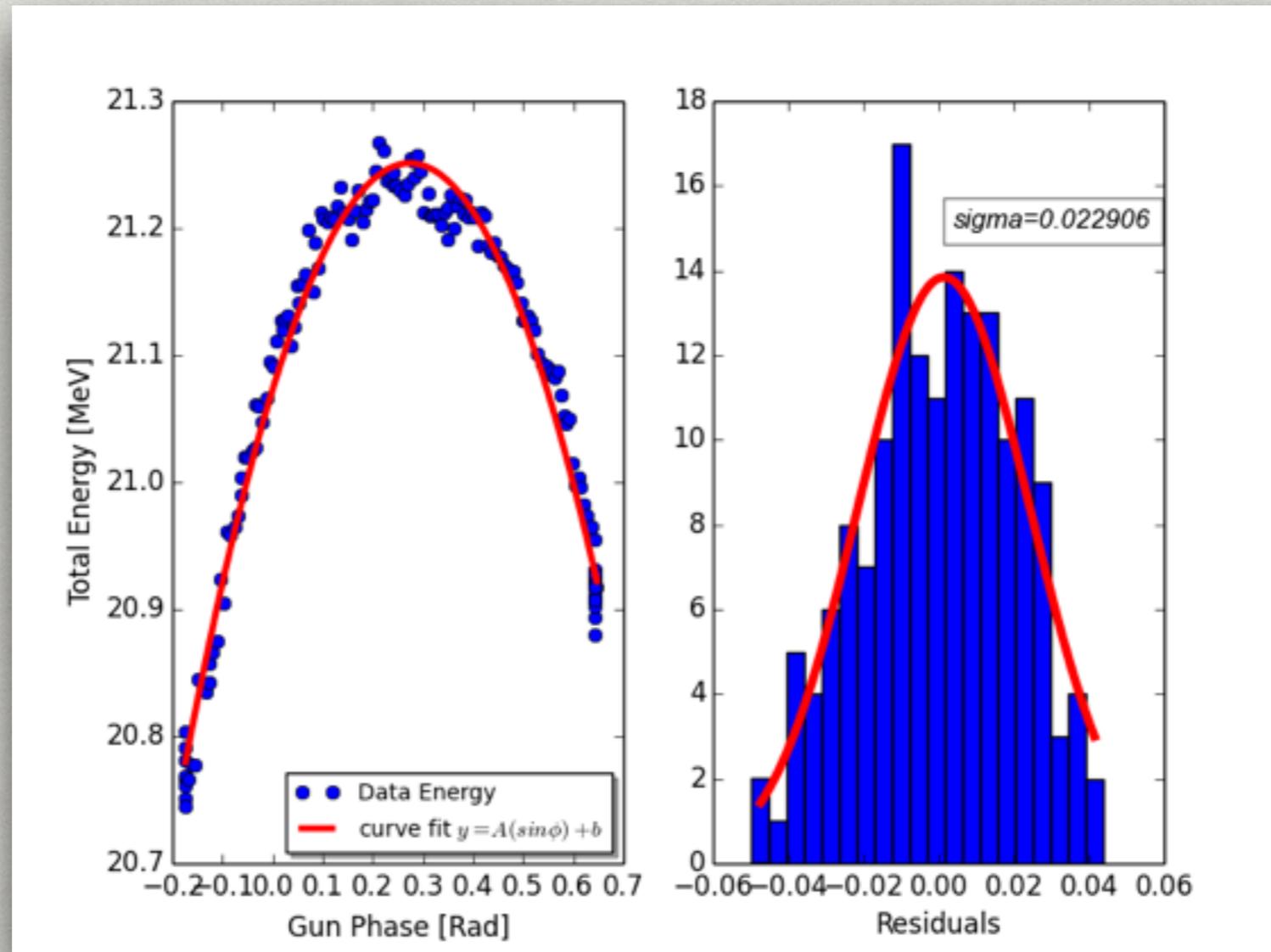
**BPM ACTUAL
RESOLUTION**

ENERGY OF THE BEAM



A = 4.77736446 b = 16.47368479

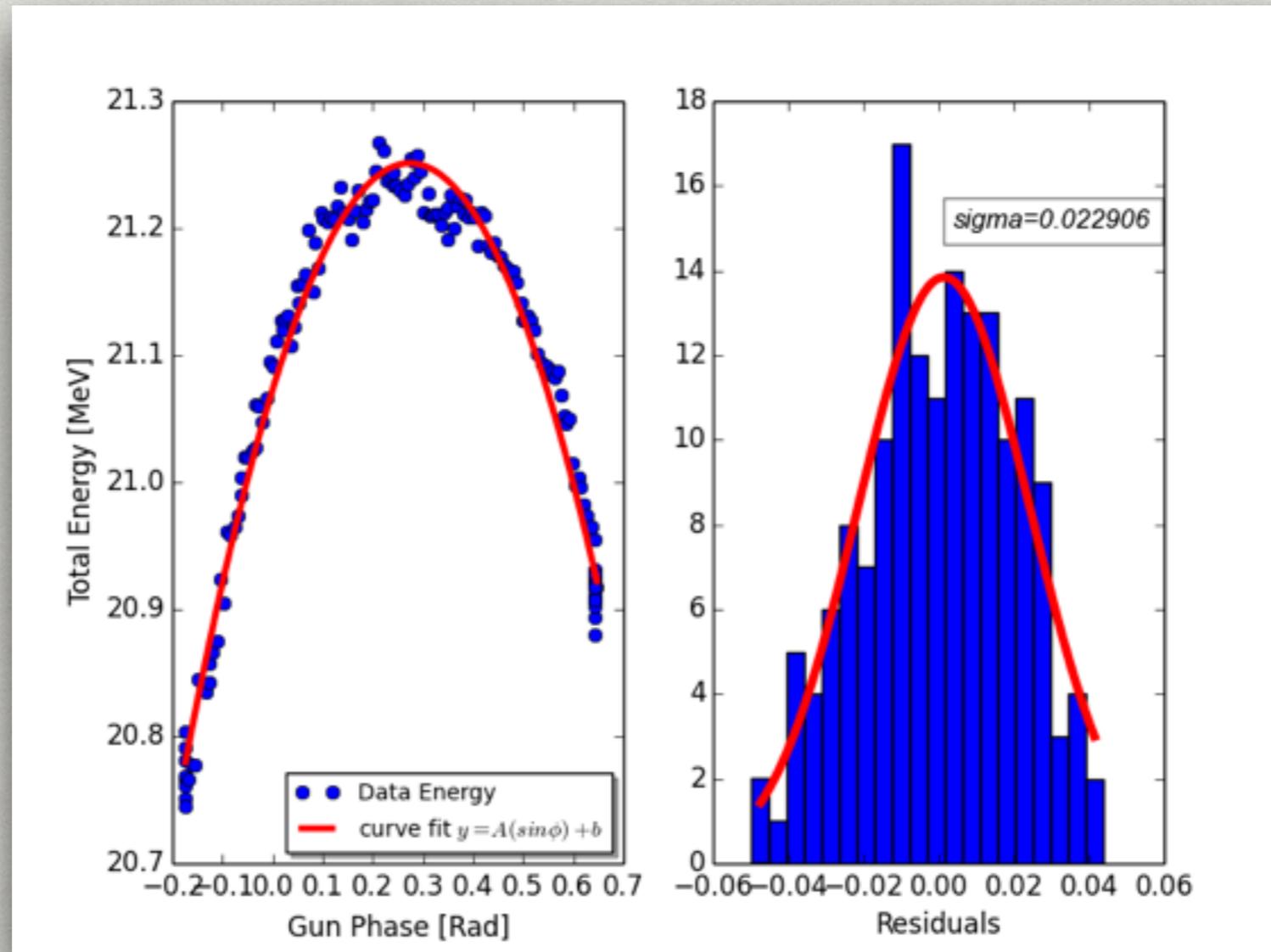
ENERGY OF THE BEAM



$A = 4.77736446$ $b = 16.47368479$

$$E_{Total} = E_{Gun} \cdot \sin \phi + ECC2$$

ENERGY OF THE BEAM



A = 4.77736446 b = 16.47368479

$$E_{Total} = E_{Gun} \cdot \sin \phi + E_{CC2}$$

CONCLUSIONS

CONCLUSIONS:

We measured the read-back from the BPMs and we calculated the bending angle in function of the gun phase, did a curve fit and calculated the residuals to get the standard deviation.

We did a simulation to compute the bending angle with and without an error created with normally-distribution random numbers and calculated the residuals to get the standard deviation.

We compared the standard deviations between the data and the simulation to get the actual BPMs resolution, that is 80 μ m rather than the design resolution that is 50 μ m

We calculate the Total energy = 21.251049 \pm 0.024585 MeV
the Gun energy = 4.777364 \pm 0.024585 MeV and the
CC2 energy = 16.473684 \pm 0.024585 MeV

QUESTIONS

