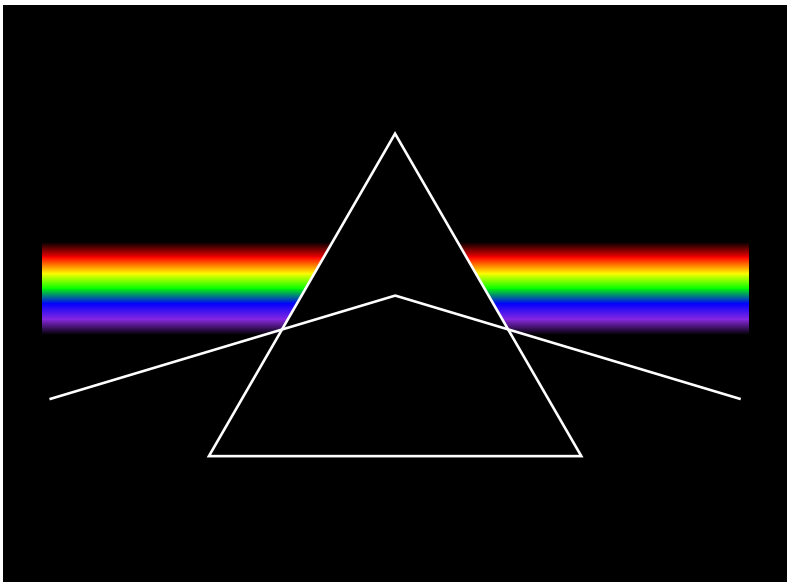
The LEP Spectrometer Project



Michael D. Hildreth, University of Notre Dame

LCWS 2000, FNAL, October 26, 2000

Thanks to the members of the LEP Spectrometer Working Group:

R. Assman, E. Barbero-Soto, C. Bovet, W. Coosemans, D. Cornuet, B. Dehning, G. De Rijk, G.P. Ferri, R. Genand, A. Hidalgo, M. Hildreth, N. Hilleret, W. Kalbreier, P. LeClere, J. Matheson, G. Mugnai, Y. Muttoni, S. Meyers, J. Palacios, R. Perret, M. Placidi, J. Prochnow, F. Roncarolo, M. Sassowsky, E. Torrence, R. Valbuena, G. Vismara, L. Vos, J. Wenninger, W. Weterings, G. Wilkinson

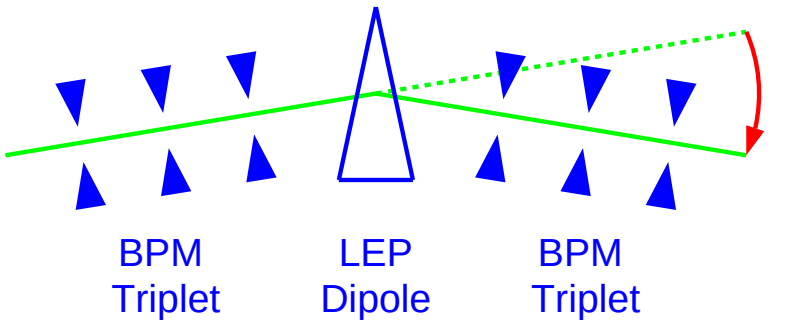
Motivation/Overview

Precision measurement of W mass is a primary goal of LEP2:

- Experimental Precision will reach 30-35 MeV
- Energy Error should not the be dominant systematic
- Extrapolation of energy scale using RDP+Magnetic information gives an error of 20-25 MeV

$\Rightarrow$ Direct Measurement of Physics Beam Energy Needed

The LEP (Inline) Spectrometer Project



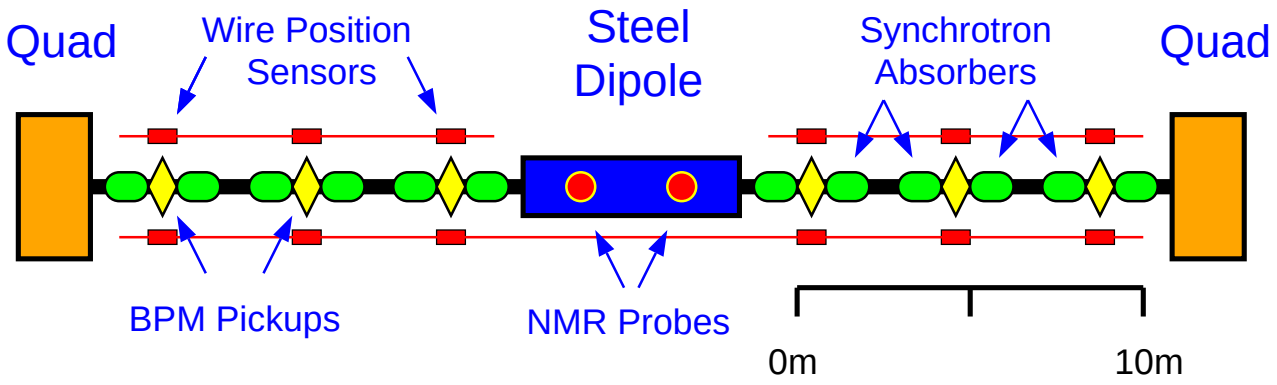
$$\theta = \frac{\oint B \cdot d\ell}{E_{\rm beam}}$$

Goal: Relative Energy Measurement to 1×10^{-4}

- Spectrometer cross-calibrated with RDP at lower energy
- Ramp LEP ring (and dipole) to Physics Energy
- Direct measurement of $E_{\rm beam}$ in ratio of bend angles

The LEP Spectrometer

Near LEP IP3, We installed (in 1999)



Available space dictated $\theta = 4.8$ mrad, Lever arm ~ 10 m:

BPM Resolution in bending plane $\Rightarrow \delta x_{\rm BPM} \sim 1\mu{\rm m}$

Stability required for a few hours only

BUT must be stable as machine energy doubles

Beam Pickups

- Mechanical and Thermal stability
- Precise and Stable Electronics

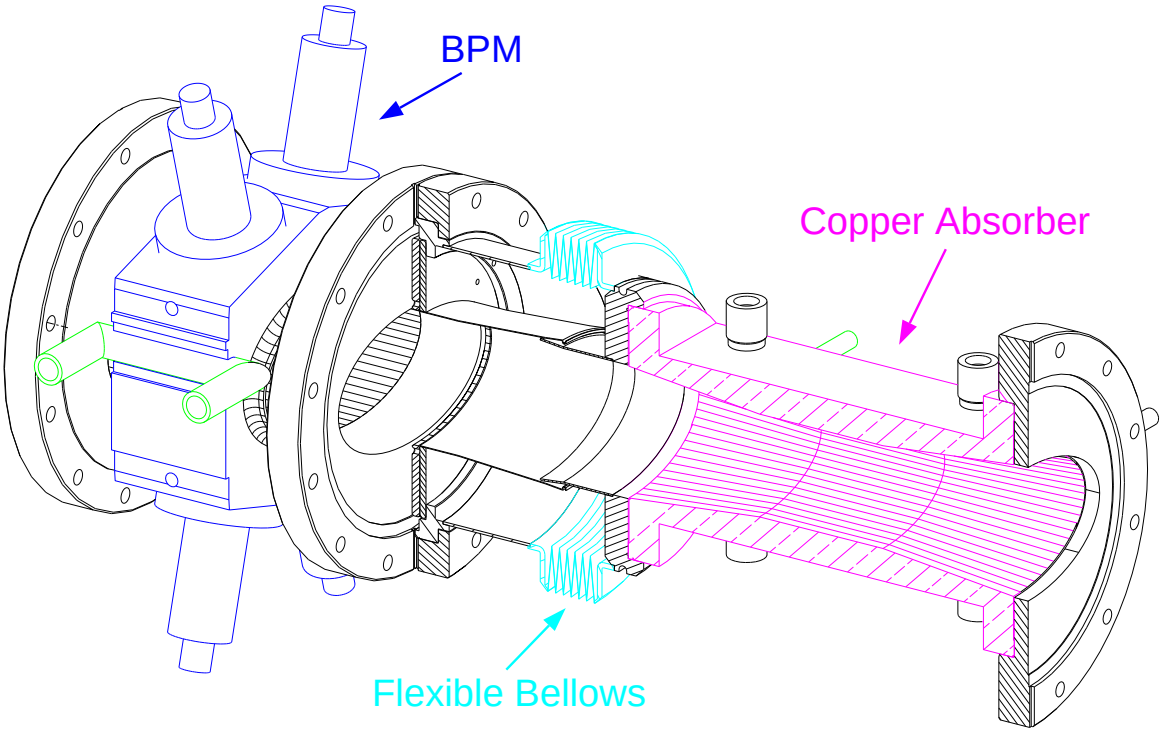
Capacitive Wire Position Monitors

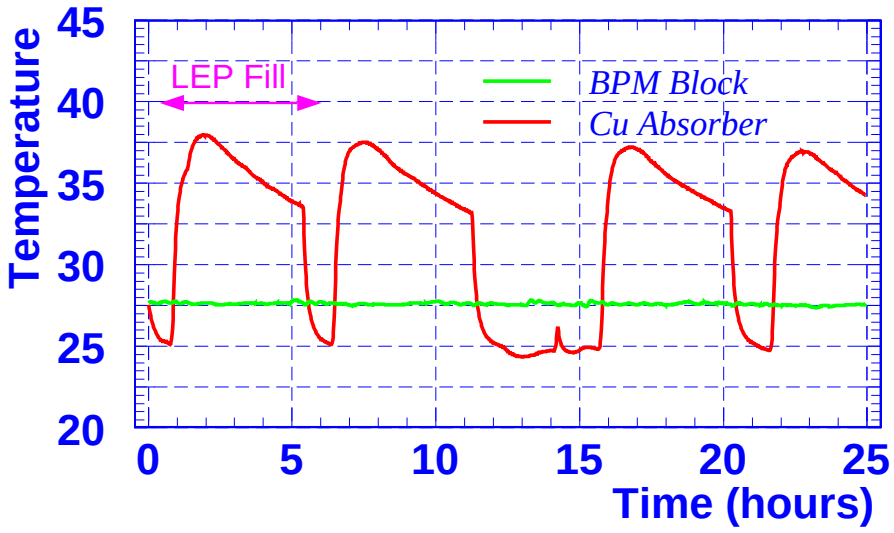
- Independent Position Monitoring
- Limit Rotations of Triplet Arms

Magnet System

- Well-Behaved Steel Dipole
- NMR Instrumentation
- Precision Field Map

BPM Assembly

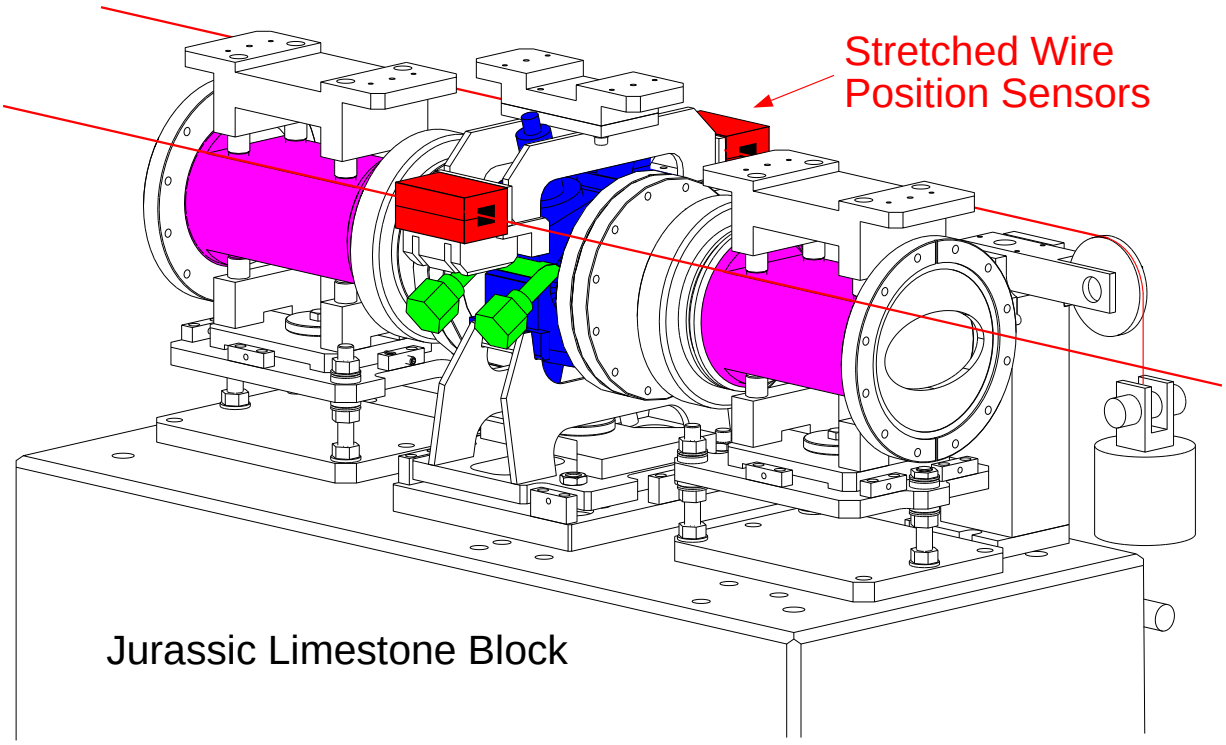




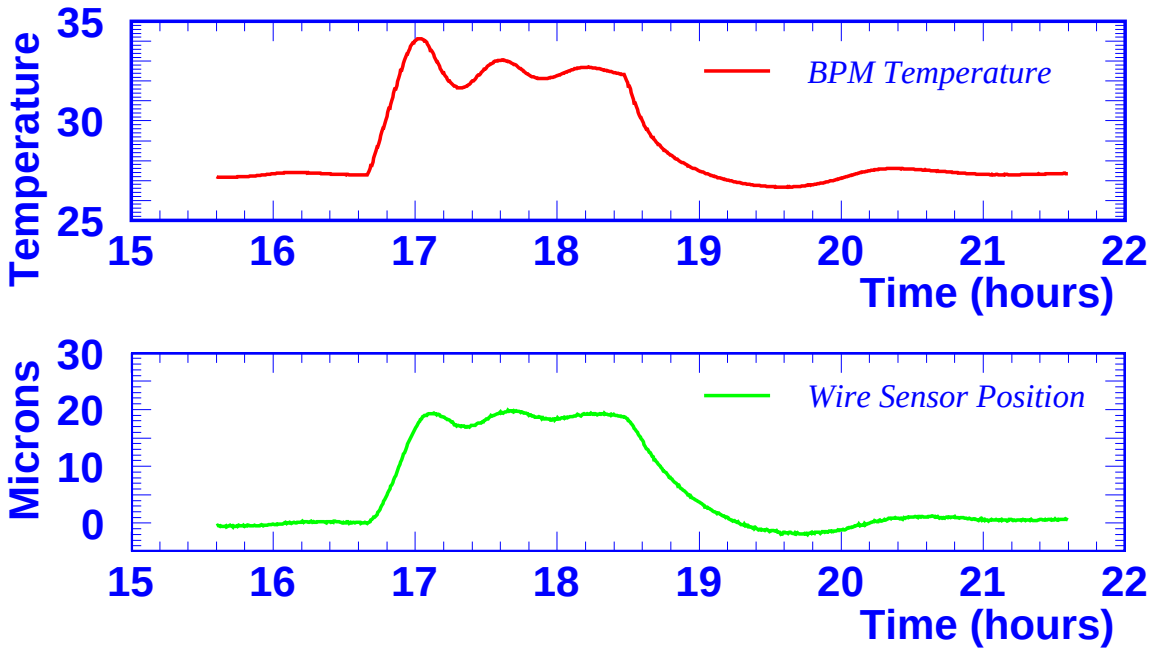
Aluminum BPM Yoke: $\frac{\Delta x}{\Delta T} \approx \frac{1\mu\mathrm{m}}{1^{\circ}\mathrm{C}}$

$\Rightarrow$ Independent Cooling Circuit regulates BPMs to $\leq 0.2^{\circ}\mathrm{C}$

Mechanical Stability



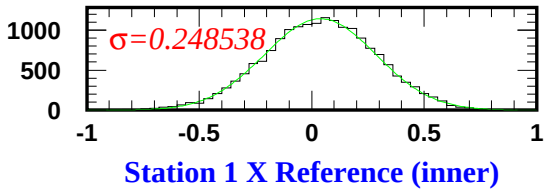
Wire system provides independent monitor of BPM positions:



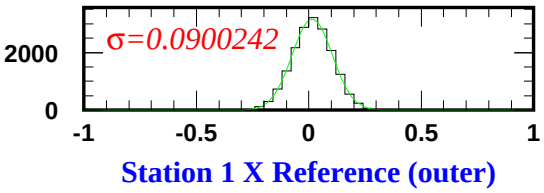
Used to verify overall mechanical stability

Stretched Wire System

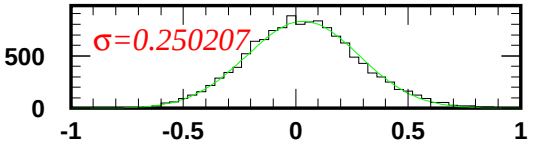
Wires - X Resolutions



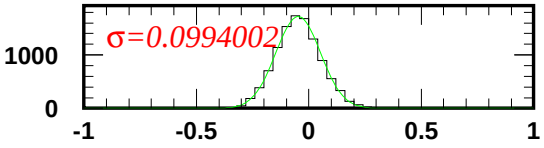
Station 1 X Reference (inner)



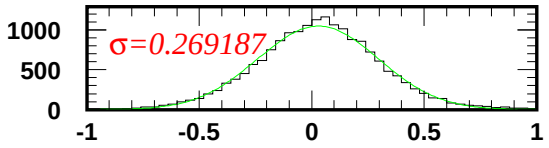
Station 1 X Reference (outer)



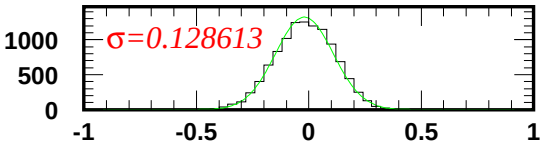
Station 1 X Position (inner)



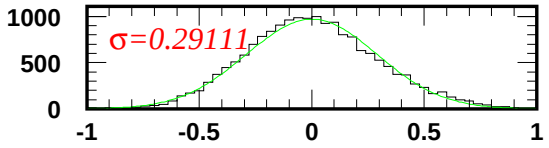
Station 1 X Position (outer)



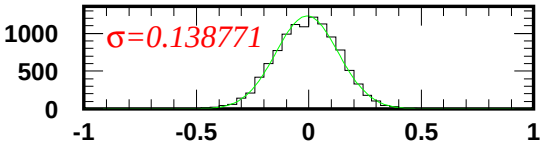
Station 2 X Position (inner)



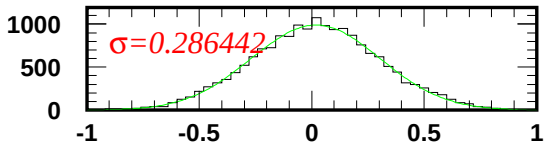
Station 2 X Position (outer)



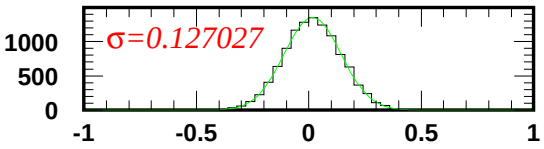
Station 3 X Position (inner)



Station 3 X Position (outer)



Station 3 X Reference (inner)



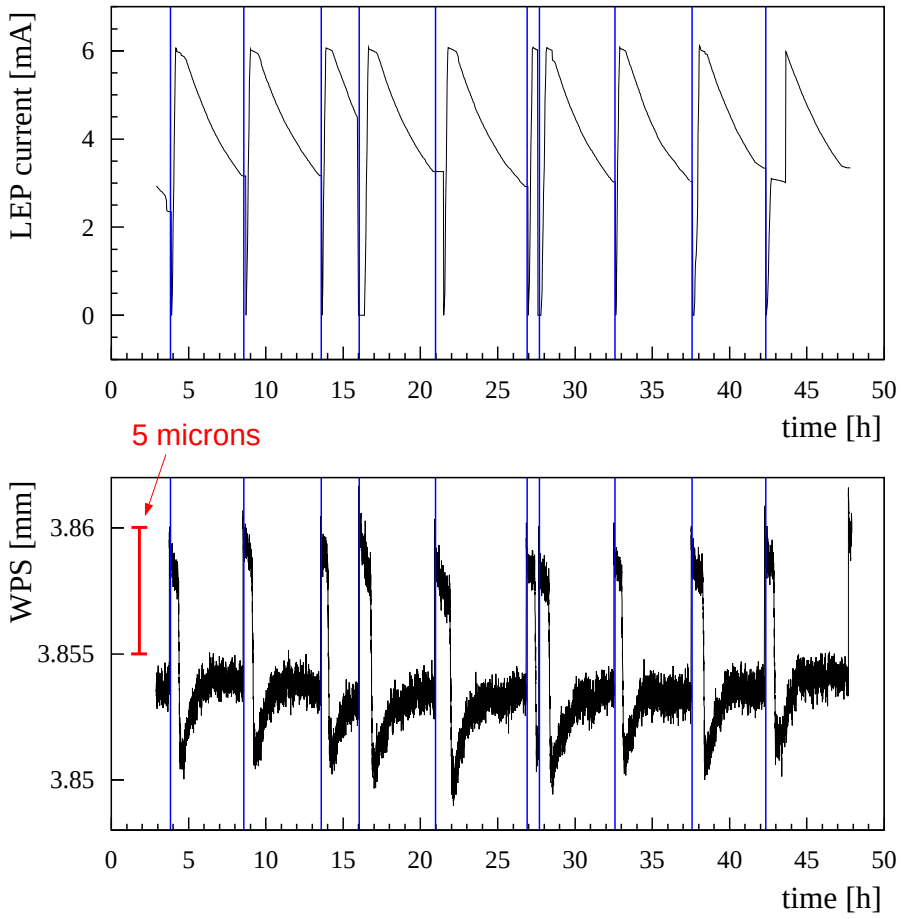
Station 3 X Reference (outer)

Horizontal position resolution ~ 200 nm without beam!

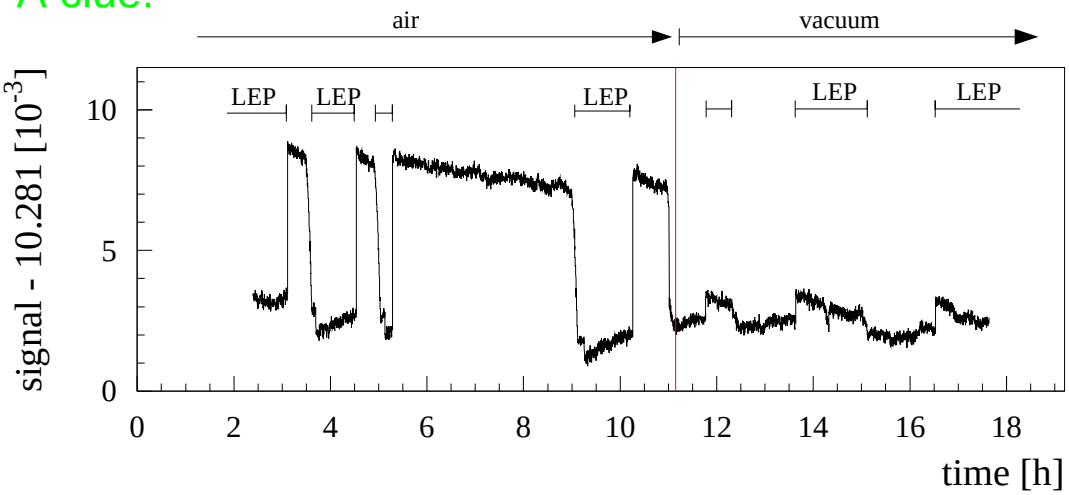
Vertical resolution even better...

Fun with Synchrotron Radiation

JUMPS in wire position seen, correlated with ramp of LEP:



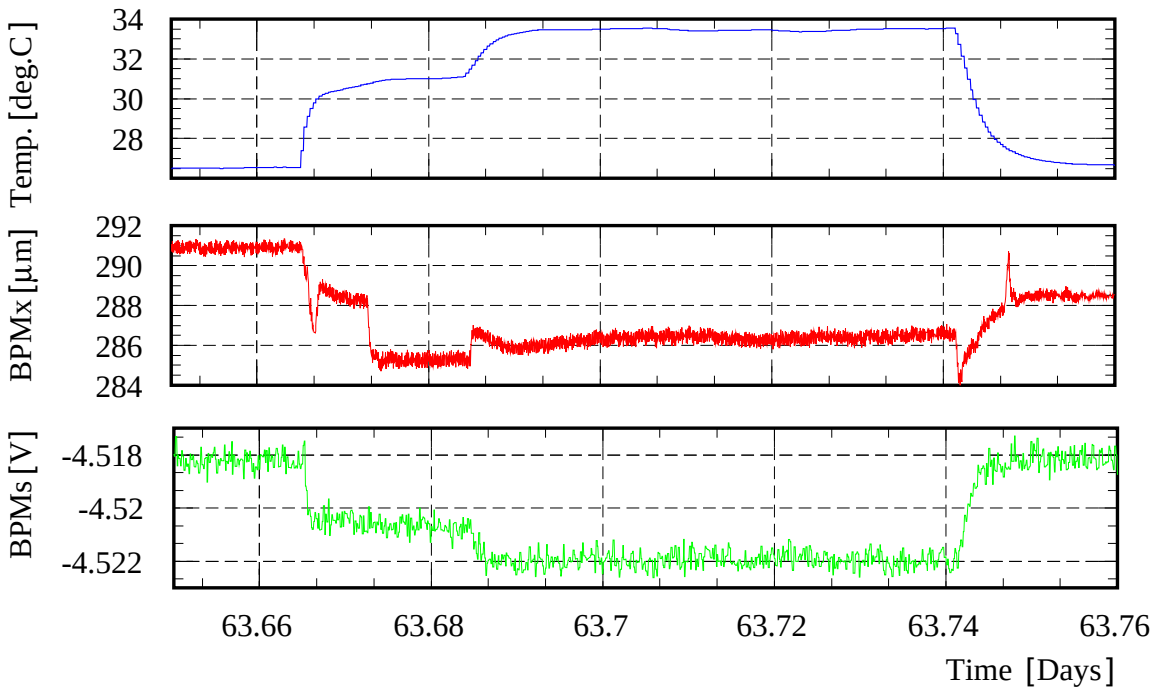
A clue:



MUCH better shielding installed for 2000 running

BPM Stability

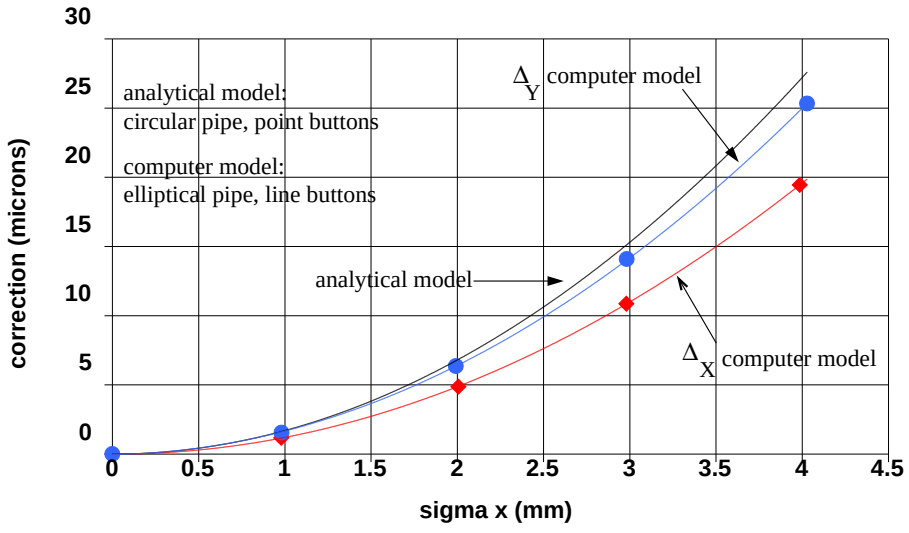
Electronics Sensitivity to Temperature:



Now regulated to better than 0.1° C

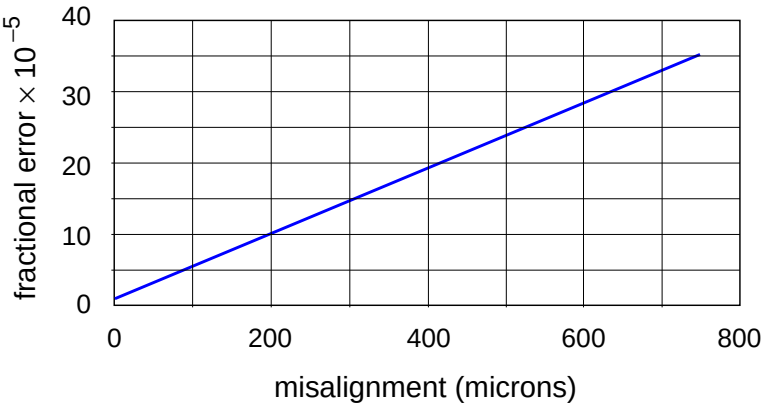
Other Concerns studied:

- effects of RF frequency shifts on response
- effects of varying beam current
- effects of beam size and offset

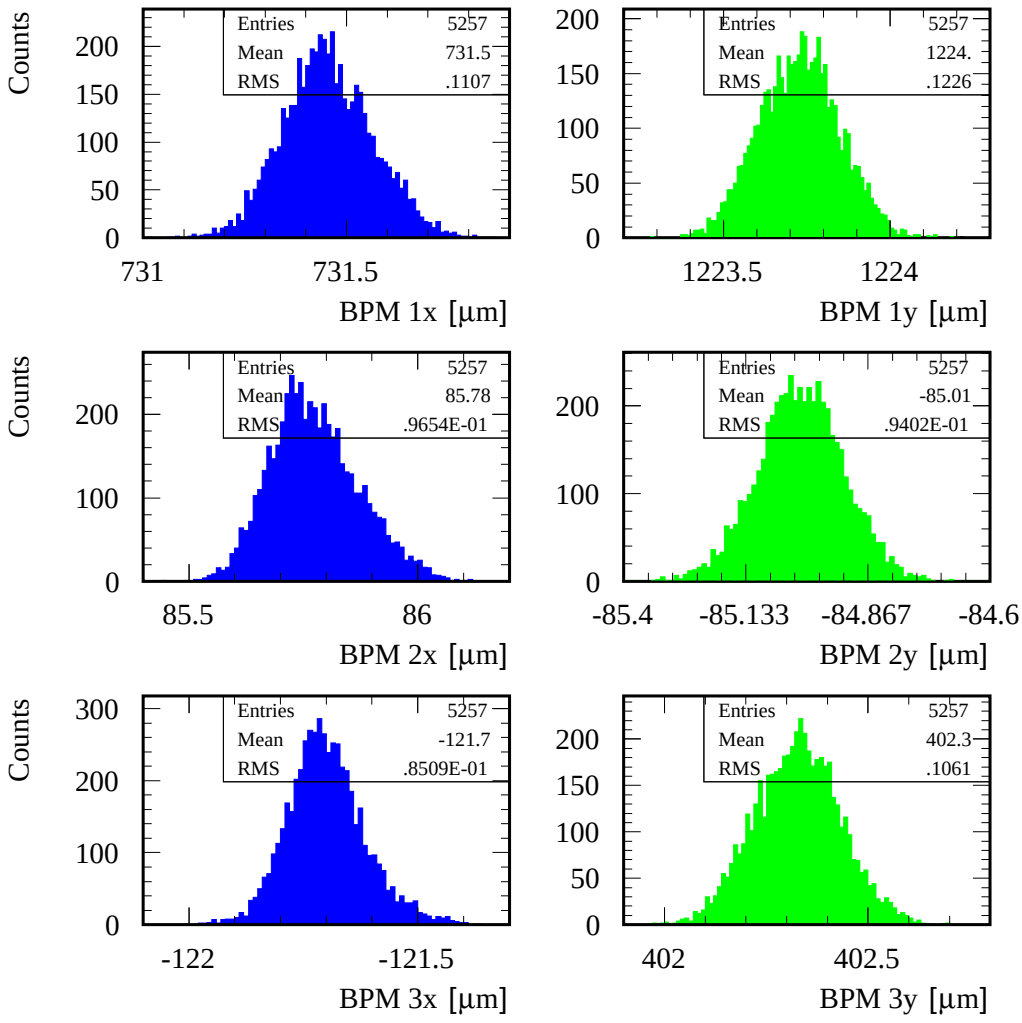


BPM Stability

★ β-variation across spectrometer $\Rightarrow$ alignment tolerance:



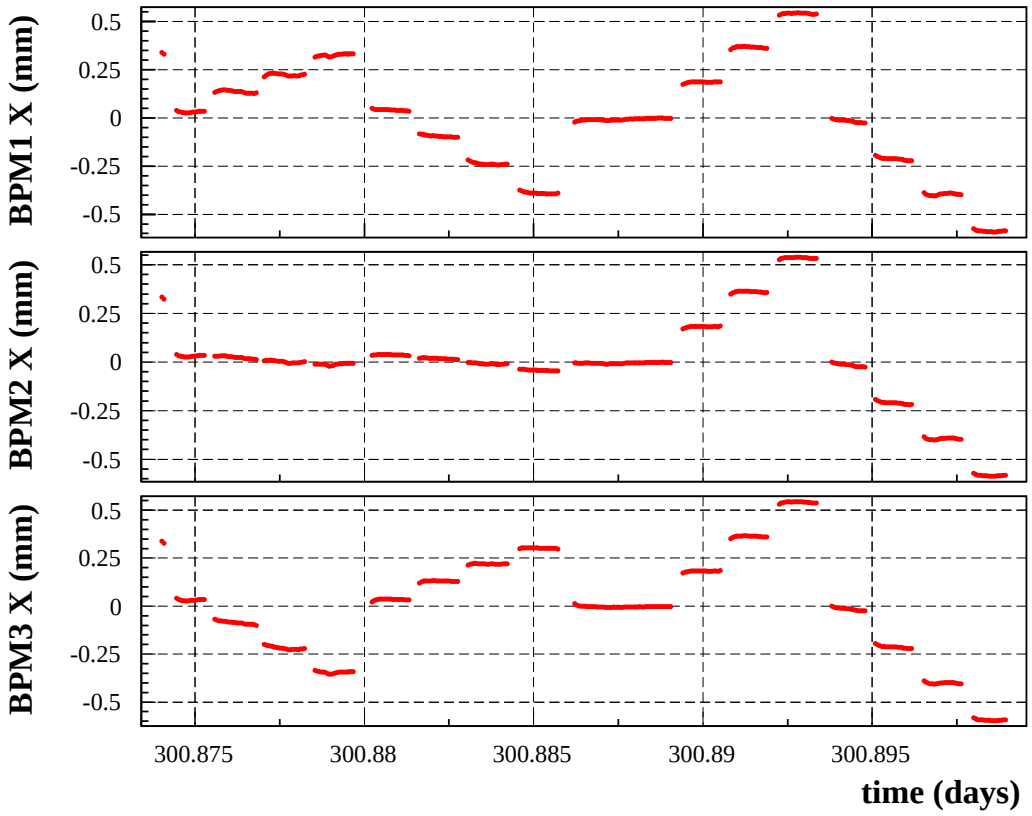
Test Bench Stability:



BPM resolution $\sim$ 100 nm in stable conditions!

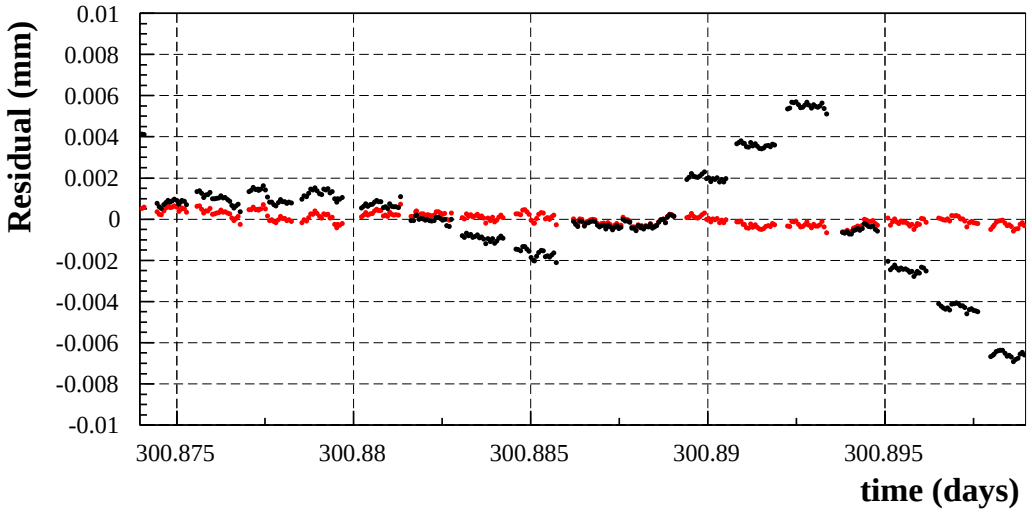
BPM Gain Calibration with Beam

During measurements, Bumps put across each BPM triplet



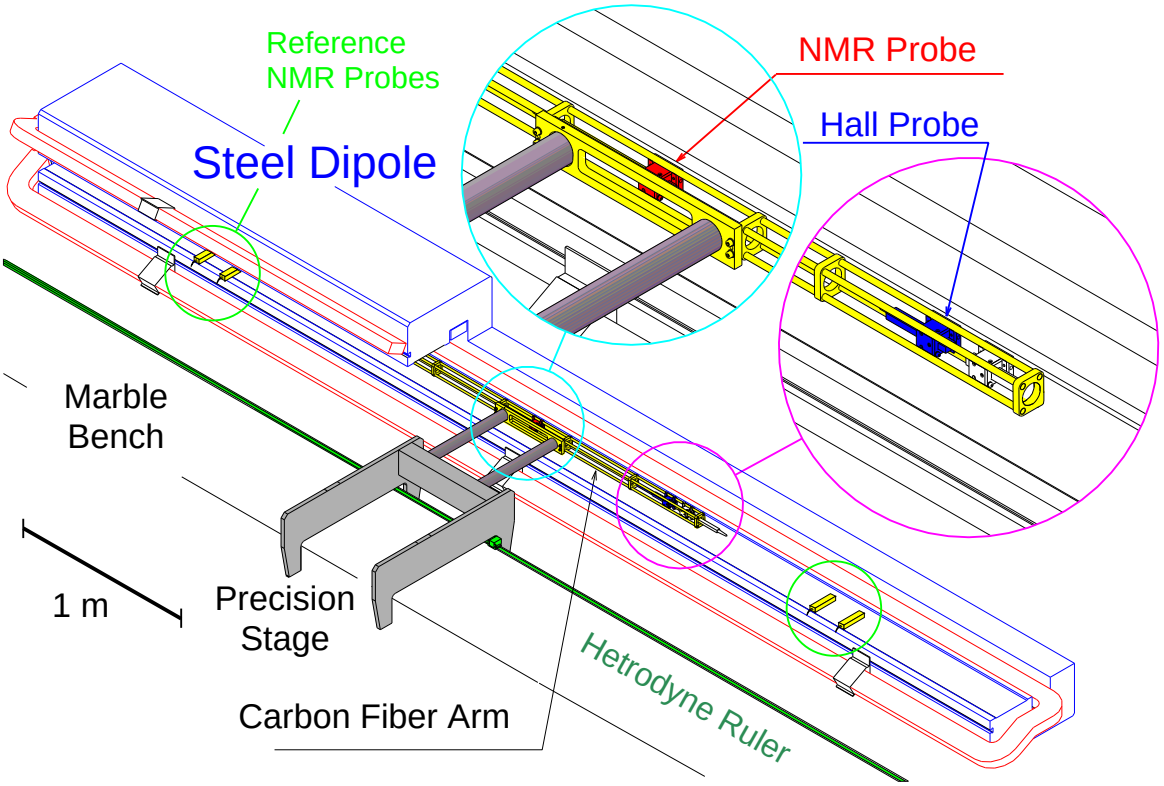
Linear Extrapolation gives relative gain of each pickup

Triplet residual:



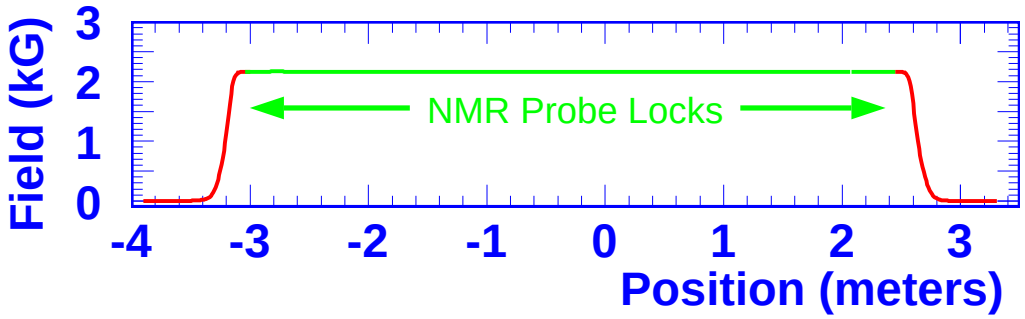
$\sigma(\text{Triplet}) \approx 300$ nm After Calibration $\Rightarrow$ 200 nm/BPM

Magnet Mapping

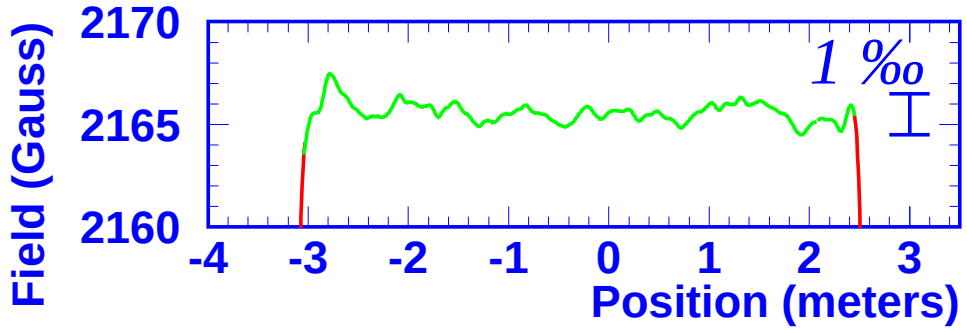


Strategy: Measure $\oint B \cdot d\ell$ as $f(B_{\mathrm{Ref}})$, using

NMR Probe $(\frac{\delta B}{B} \sim 10^{-6})$, Hall Probes $(\frac{\delta B}{B} \sim 10^{-4})$ (Ends)



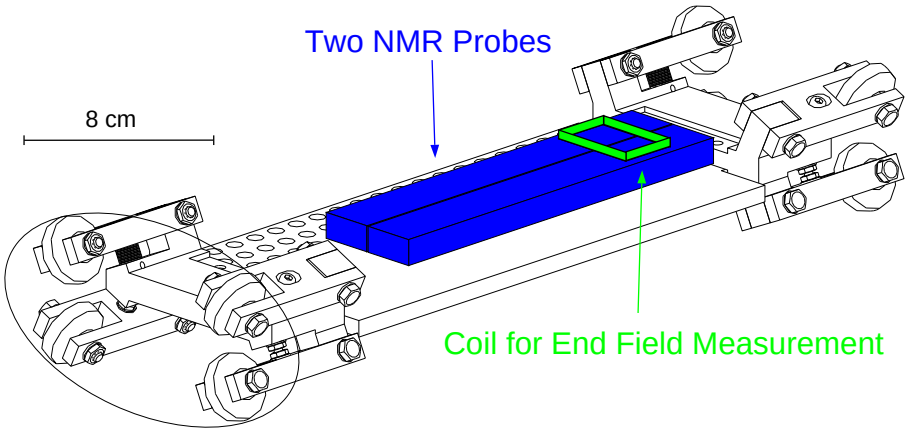
Single Map:



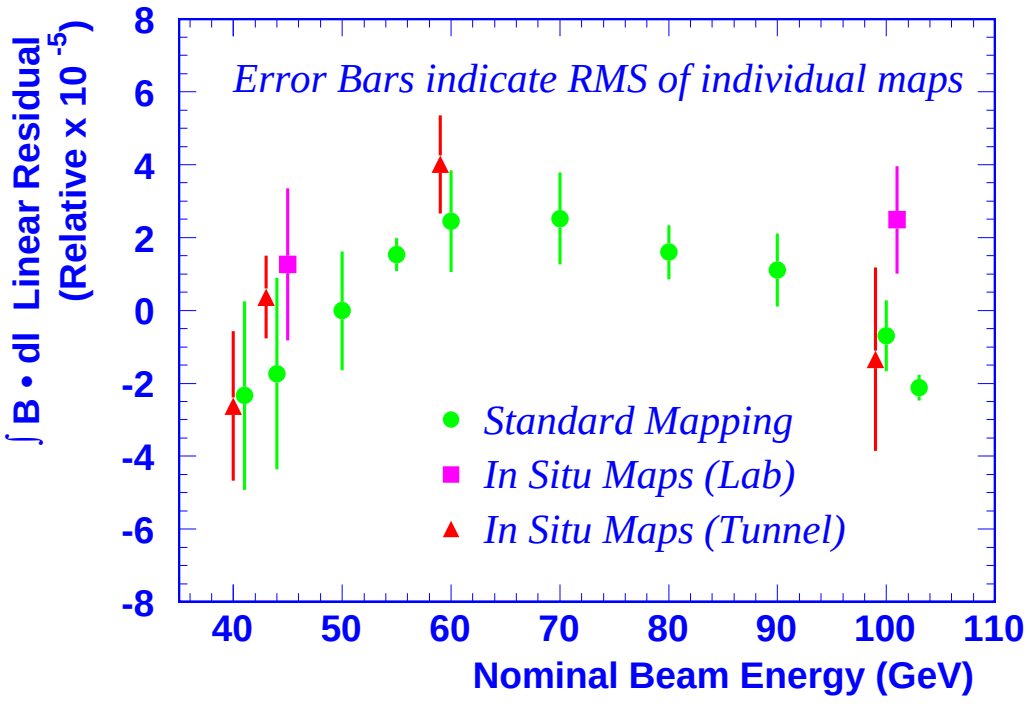
Magnet Mapping Campaign

Hundreds of maps carried out

- Different Temperatures, Field levels, Ramp speeds, magnet insulation, rotating coils, phases of the moon, etc.
- 3-D maps of field uniformity over aperture
- Also, maps in beampipe, in tunnel, using the Mole:

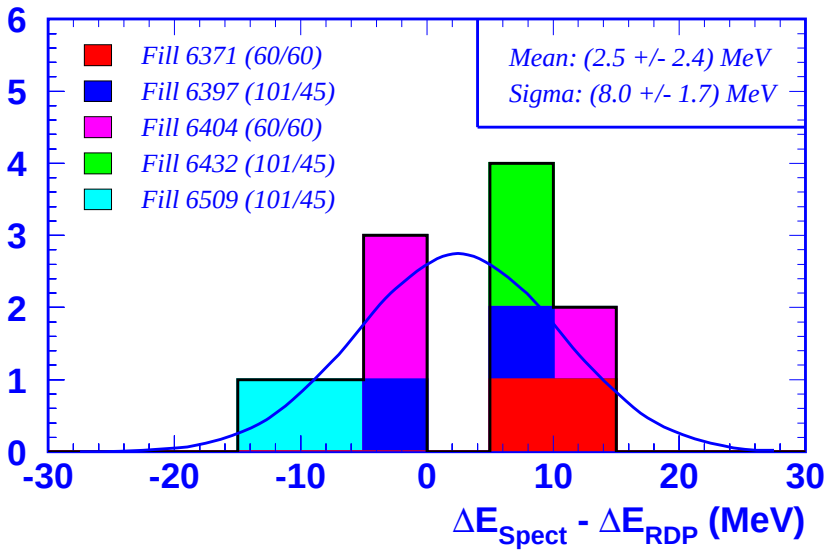


Preliminary Results:

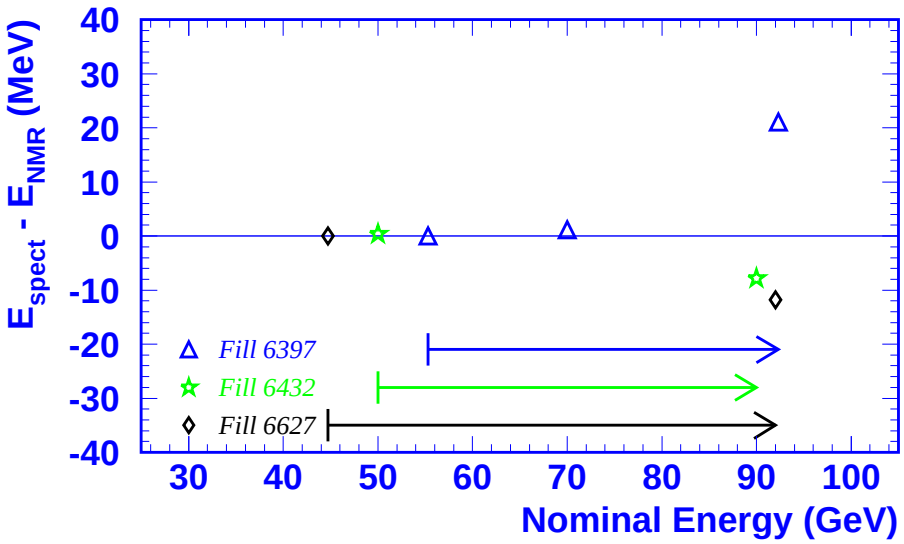


Preliminary 1999 Results

Comparison with Resonant Depolarisation Energy:



Comparison with LEP2 Energy Model at Physics Energy:



$$\text{RMS}(E_{\text{Spect}} - E_{NMR}) = 14.7\ \text{MeV}$$

$$(E_{\text{Spect}} - E_{NMR}) = (0.5 \pm 10.4)\ \text{MeV}$$

Conclusions/Projections

Technial Tolerances Met in Stable Situations:

- Independent Temperature Regulation established
- Wire sensors monitor position to 100 nm
- BPMs good to 200-300 nm
- Relative Magnetic field known to better than 3×10^{-5}
- Beam-based BPM alignment method developed

$\Rightarrow$ First direct measurement of LEP2 Physics Energy in 1999

2000 Running redux: Lots more data and some anomalies

- New BPM movers for horizontal position adjustment
- Better shielding
- Better understanding of electronics configuration
- Unexplained gain drifts on some of the BPMs
  - $\longrightarrow$ *after* intercalibration
  - $\longrightarrow$ could be synchrotron radiation
- Effects of ambient magnetic field
  - $\longrightarrow$ always monitored with flux gates
  - $\longrightarrow$ local vacuum pumps have magnetic elements
  - $\longrightarrow$ magnet power supply cables along LEP wall
- Need to cross check RF model with two beam experiments