Determination of the LEP Beam Energy

EPS-HEP 99

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Tampere, Finland

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CERN/EP

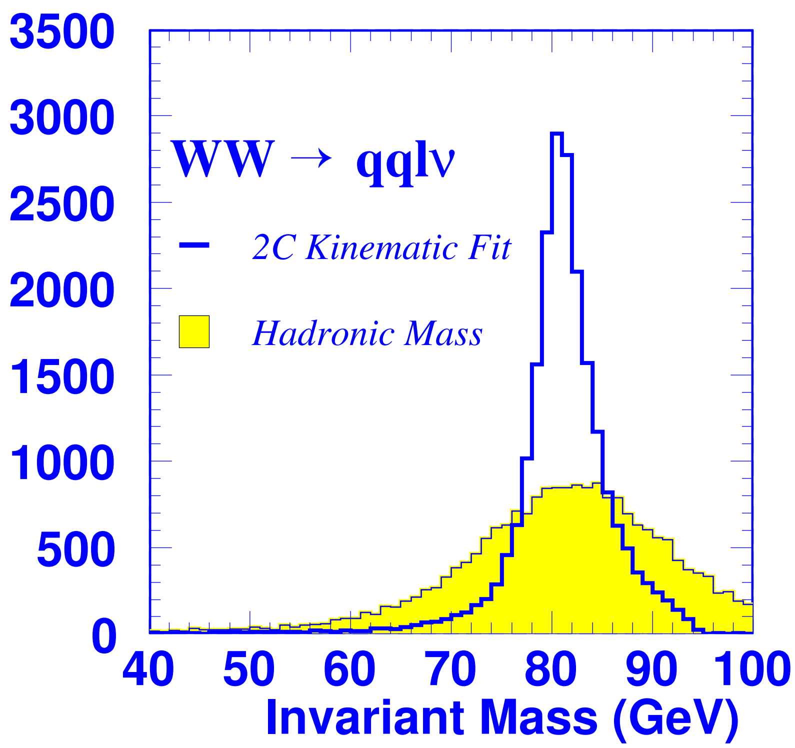
Representing the

LEP Energy Working Group

Special Thanks to the CERN/SL Division!

LEP II Energy Needs

W Boson Mass



- Kinematic Fit improves resolution on M_W
- Need to know Beam Energy $\quad \frac{\delta M_W}{M_W} \approx \frac{\delta E_{Beam}}{E_{Beam}}$

$\Rightarrow$ Scale Error common to all experiments

LEP II Combined

Expected Statistical Error: $\delta M_W \sim 25 MeV$

Beam Energy Goal: $\delta E_{Beam} \sim 10 MeV$

$$\Rightarrow \frac{\delta E_{Beam}}{E_{Beam}} \sim 10^{-4}$$

LEP II Energy Tools

Resonant Depolarization

High Precision technique used extensively for M_Z

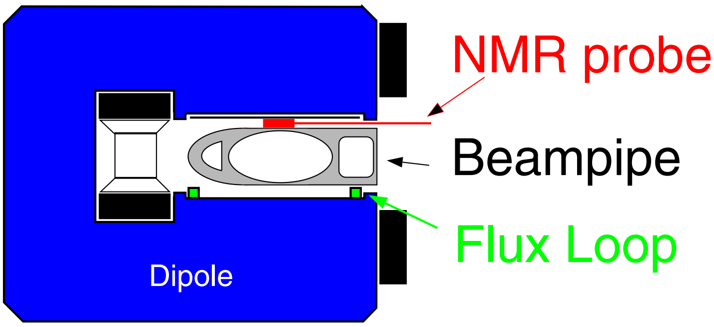
Spin Precession Frequency: $\nu_s = \frac{g_e - 2}{2m_e c^2}\langle E_{Beam}\rangle$

Intrinsic Resolution: $\delta E_{Beam} \approx 200 keV$

$\Rrightarrow$ Currently works up to E_{Beam} ~ 60 GeV

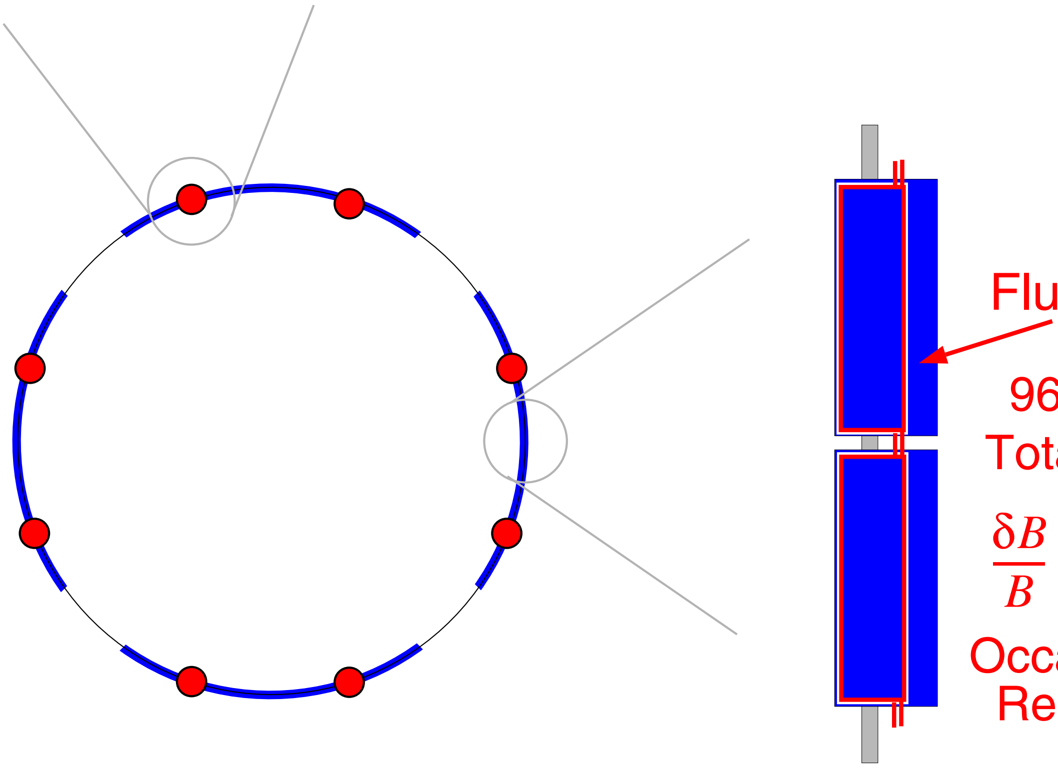
Total Bending Field

$E_{Beam} \propto \oint B_{\perp} dl$



16 Probes $\frac{\delta B}{B} \sim 10^{-6}$

Continuous Readout



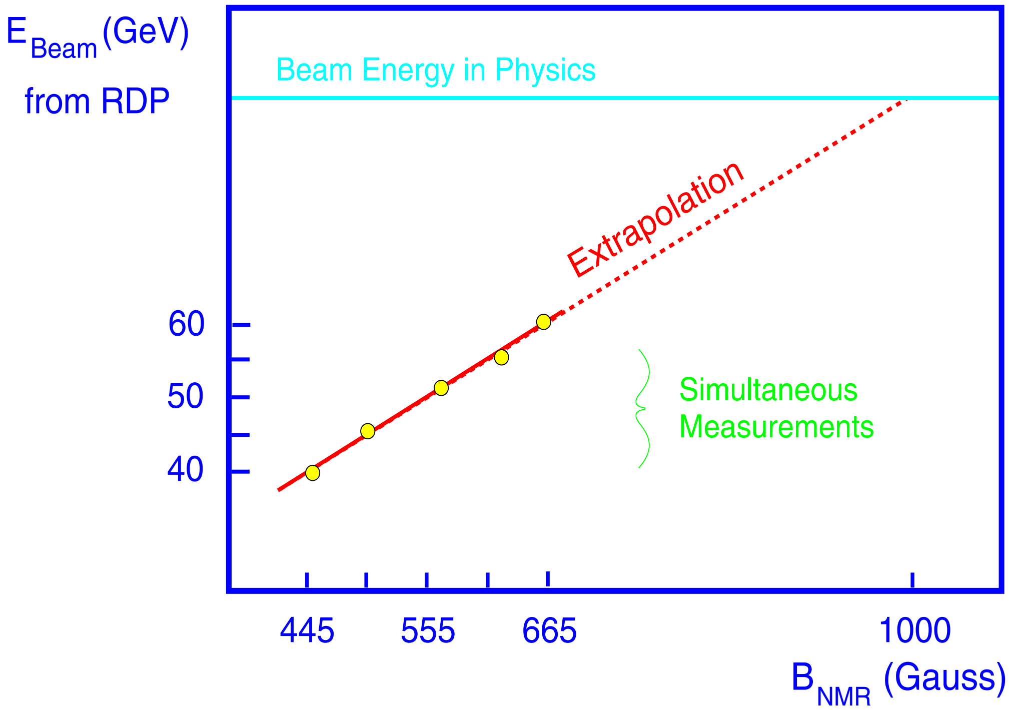
96.5% of Total Field

$\frac{\delta B}{B} \sim 10^{-4}$

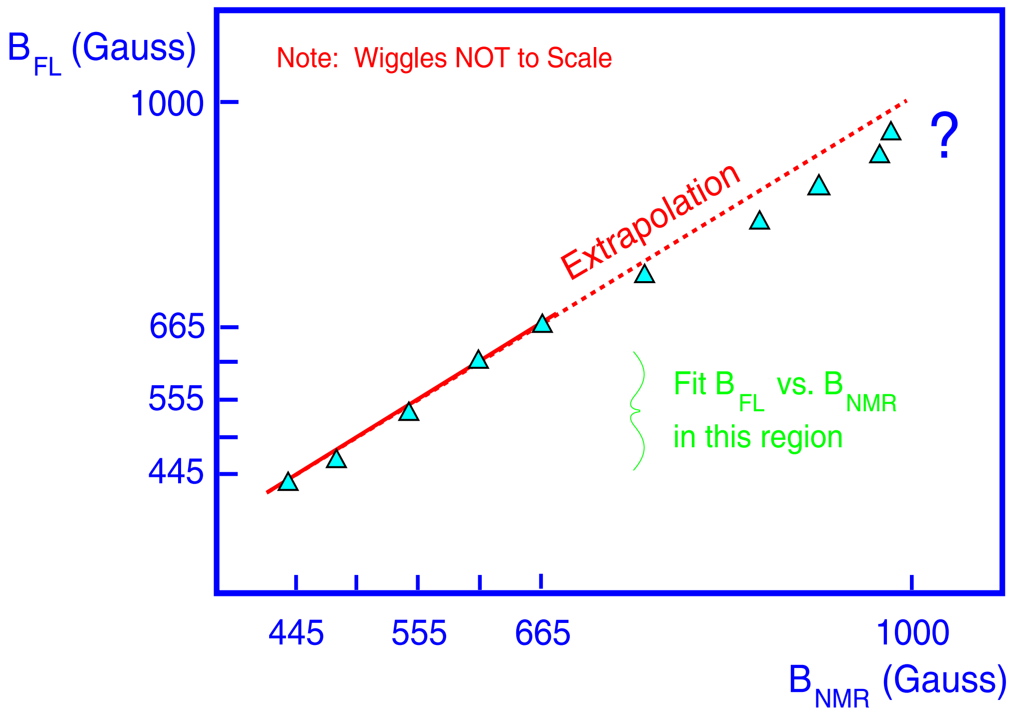
Occasional Readout

Extrapolation Method

Step 1: Calibrate NMRs with RDP



Step 2: Cross Check Linearity with Flux Loop

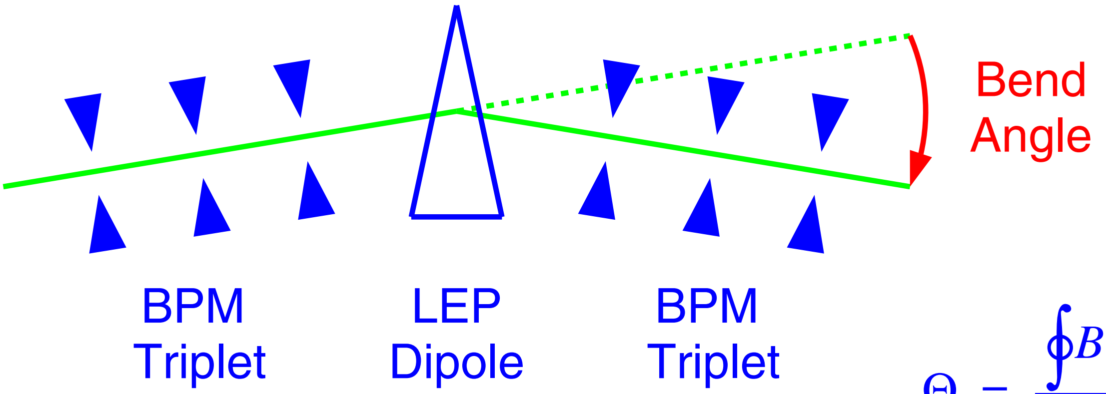


Current Precision: $\delta E_{Beam} = 20 MeV$ at $E_{Beam} = 95 GeV$

$\Rrightarrow$ Dominated by NMR - Flux Loop difference

LEP Spectrometer Project

Inline Spectrometer Concept



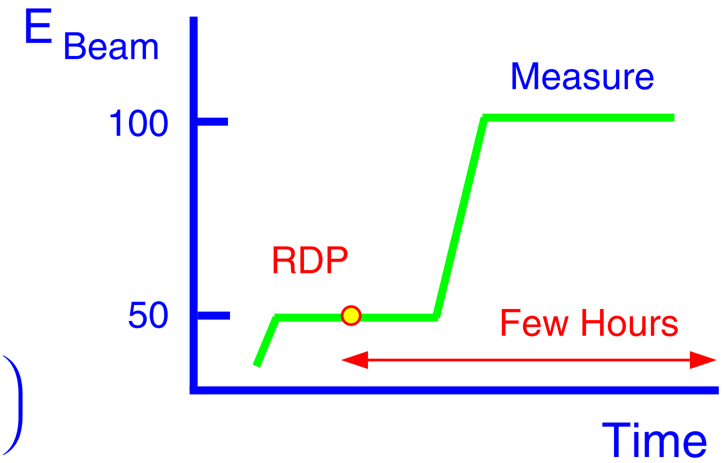
$$\Theta = \frac{\oint B dl}{E_{Beam}}$$

- Use dipole which ramps with LEP
- BPM Triplets measure bend angle Θ
- $\oint B dl$ from Local NMR and precision Field Map

Relative Energy Measurement

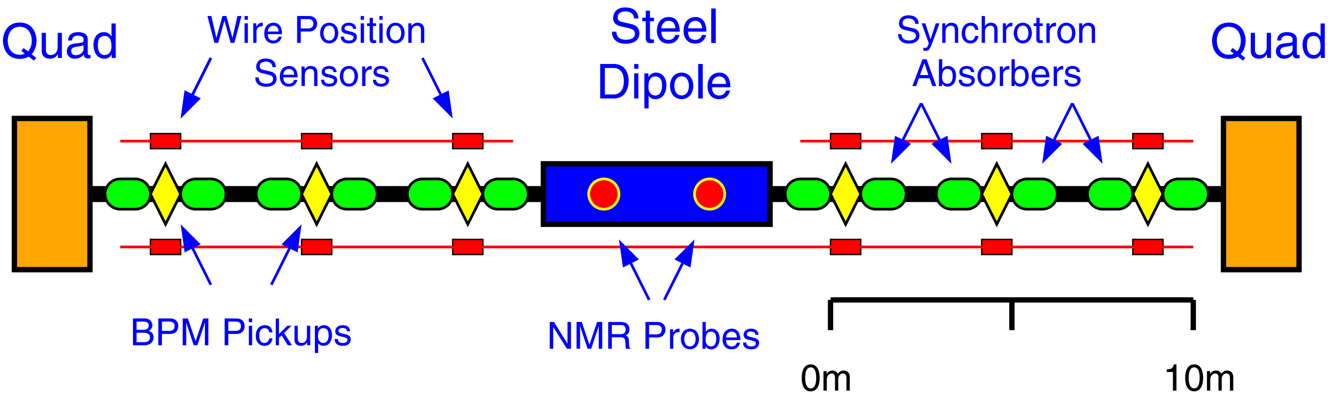
- Calibrate Spectrometer using RDP
- Ramp immediately to Physics Energy
- Direct Measurement of E_{Beam} in ratio

$$\frac{E^{100}_{Beam}}{E^{50}_{Beam}} = \frac{\left.\oint B dl\right|_{100}}{\left.\oint B dl\right|_{50}} \left(\frac{\Theta}{\Theta + \Delta\Theta} \right)$$



Spectrometer Design

Near LEP IP3:



$$\Theta = 4.8mRad \Rrightarrow \delta x_{BPM} \sim 1\mu m$$

Stability required for a few hours only!

$\Rrightarrow$ Must be stable as machine energy doubles...

Beam Pickups

- Mechanical and Thermal Stability
- Precise and Stable Electronics

Capacitive Wire Position Sensors

- Independent Position Monitoring
- Limit Rotations of Triplet Arms

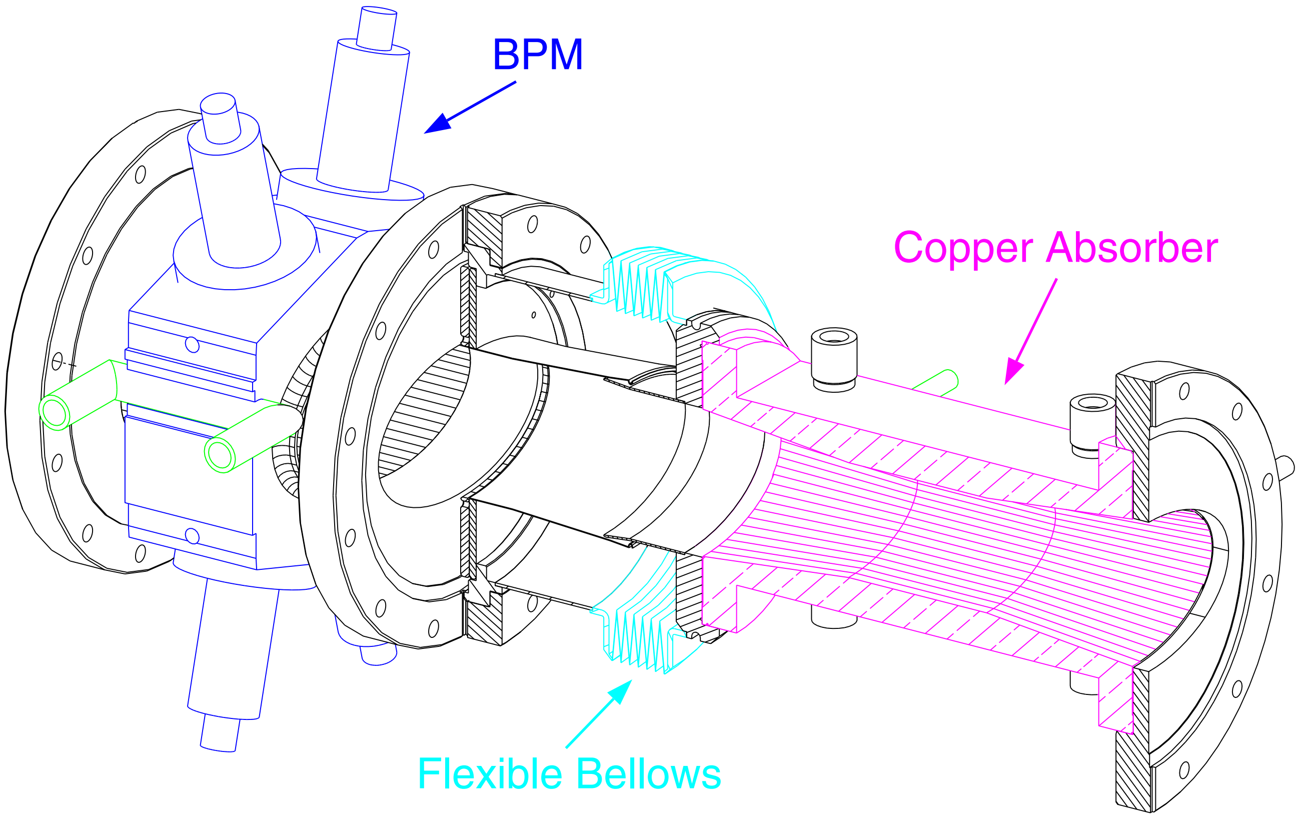
Magnet System

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

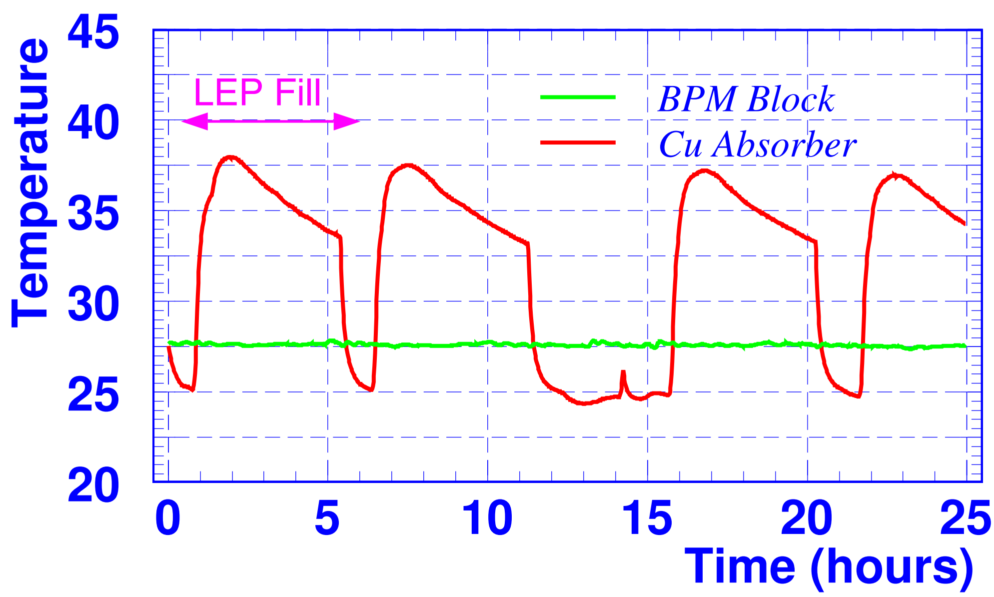
Prototype (one arm) installed in 1998

$\Rrightarrow$ Full Installation for 1999 LEP Run

Synchrotron Shielding



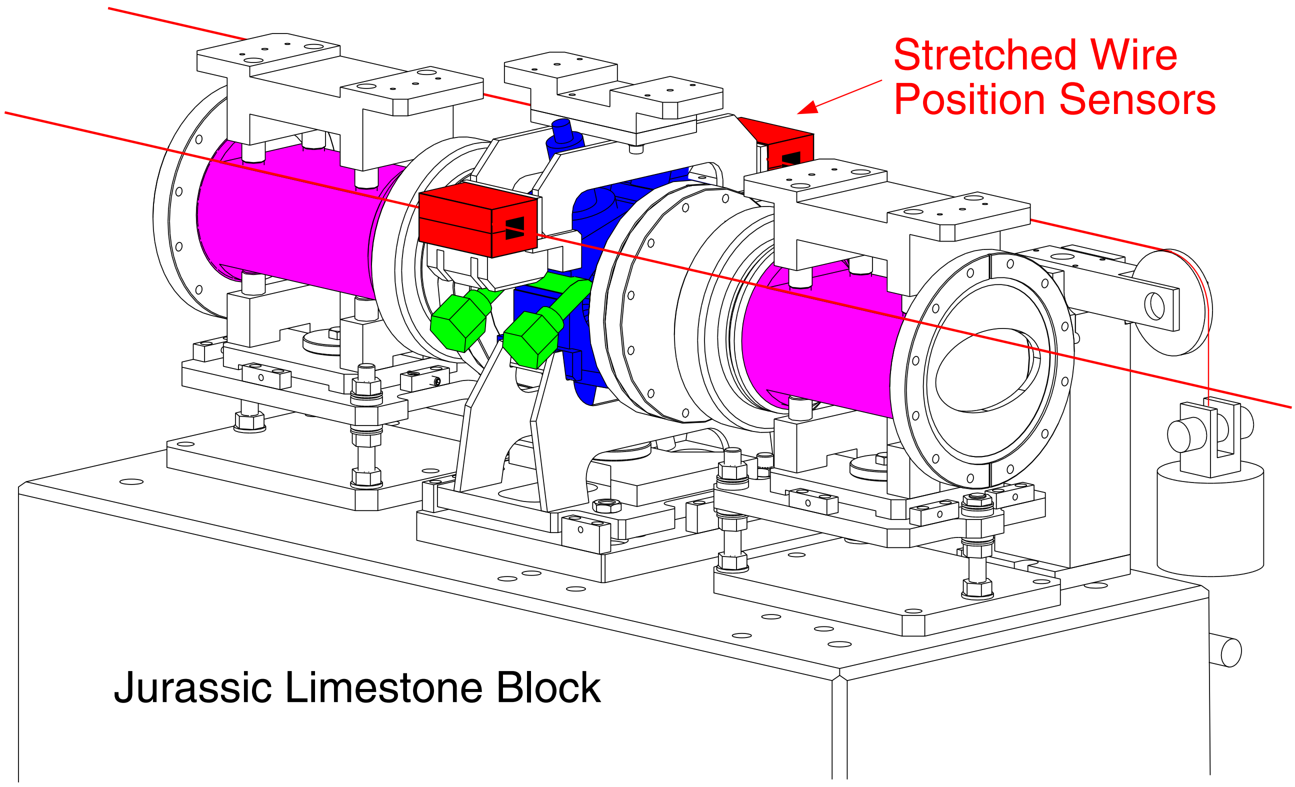
Synchrotron Power α $(E_{Beam})^4$



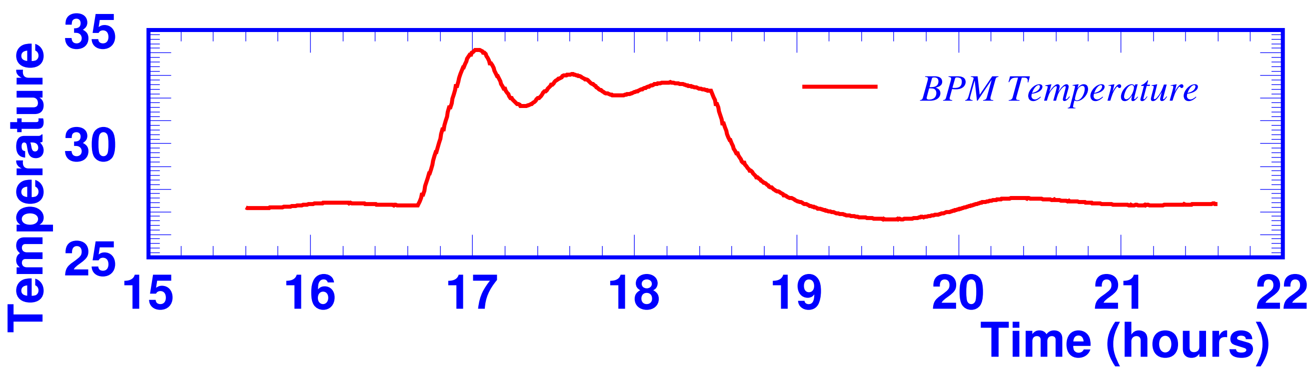
BPM buttons: $\dfrac{\Delta x}{\Delta T} \approx \dfrac{1\,\mu m}{1°C}$

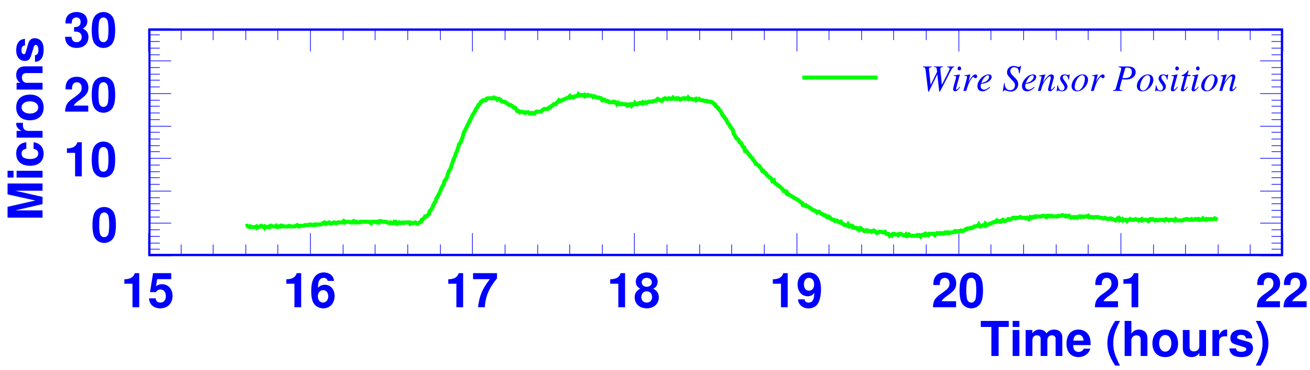
$\Rightarrow$ Independent Regulation of BPMs to ~ $0.2°C$

Wire Position System



Independent monitor of BPM positions





Position Resolution ~ 0.2 μm!

⇛ Use to verify that system is stable

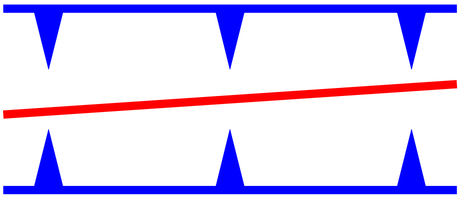
High Precision Electronics

- Common Amplifier Stage for all Inputs
- Sub-micron stability in Synchrotron Light Sources

⇛ Custom modules for LEP still being commissioned...

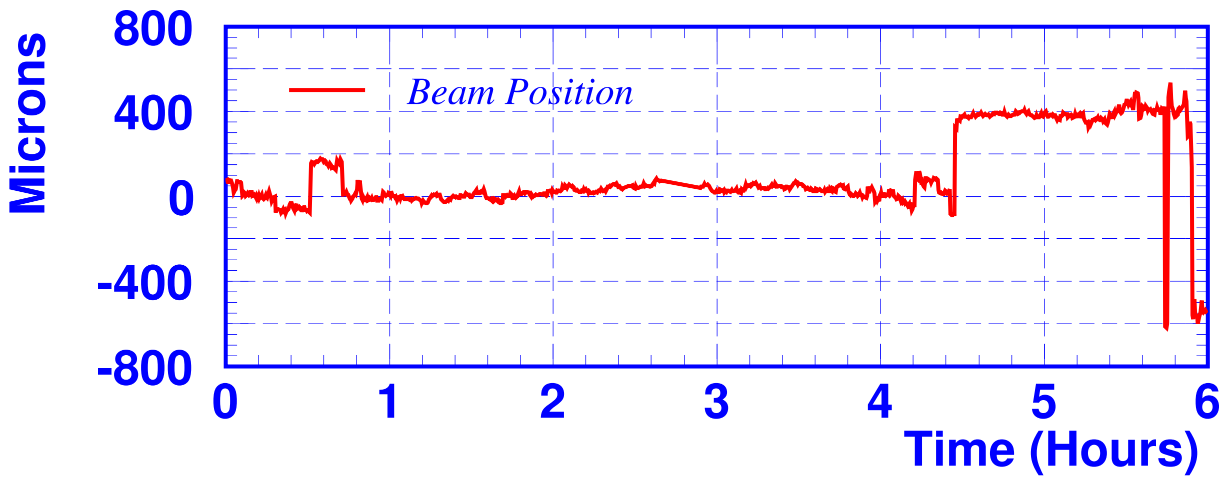
1998 Performance

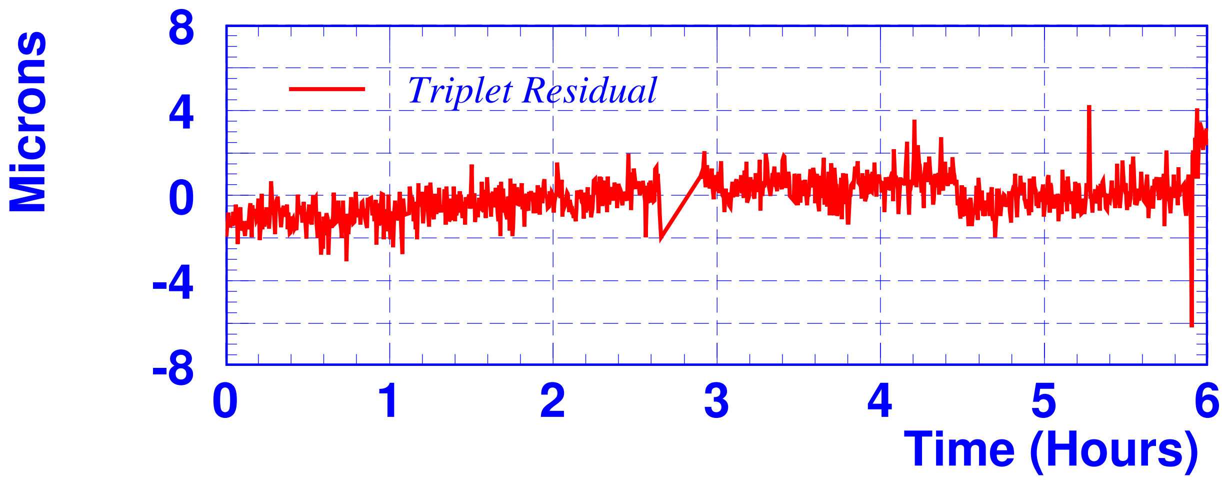
BPM Triplet



⇛ Triplet Residual

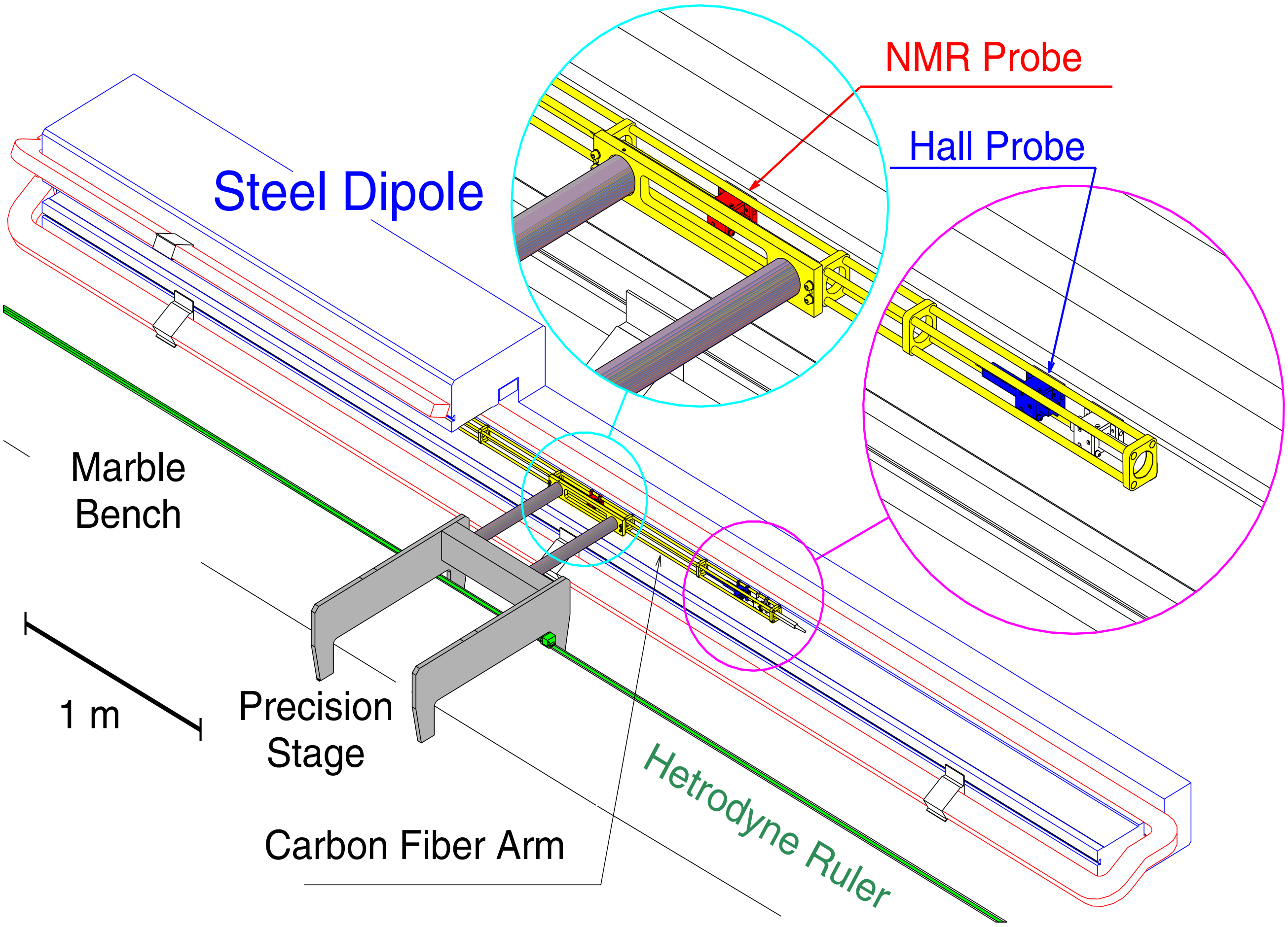
$$T = \frac{(x_1 + x_3)}{2} - x_2$$



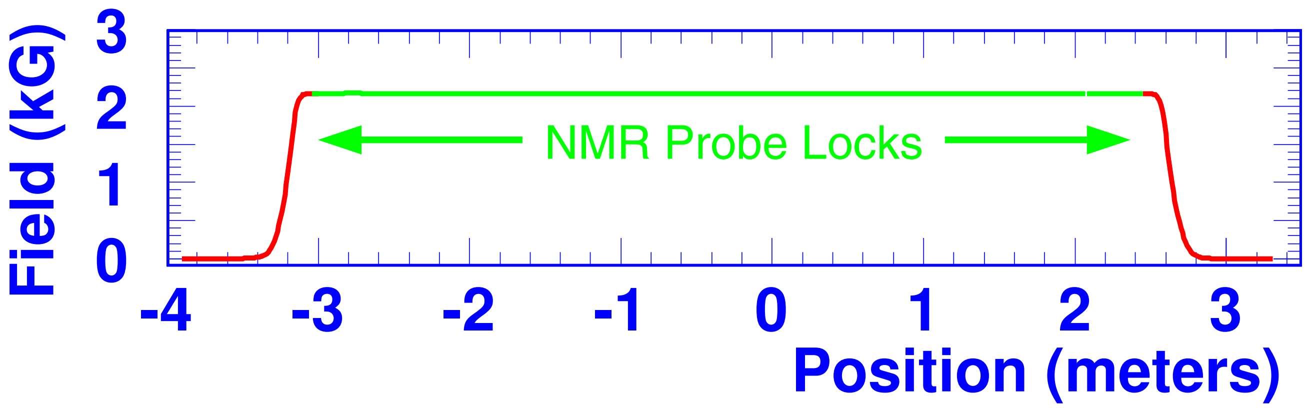


Resolution: $\sigma_{BPM} = 0.9\mu\mathrm{m}$

Magnet Mapping



Need $\oint B\,dl$ as $f(B_{Ref})$



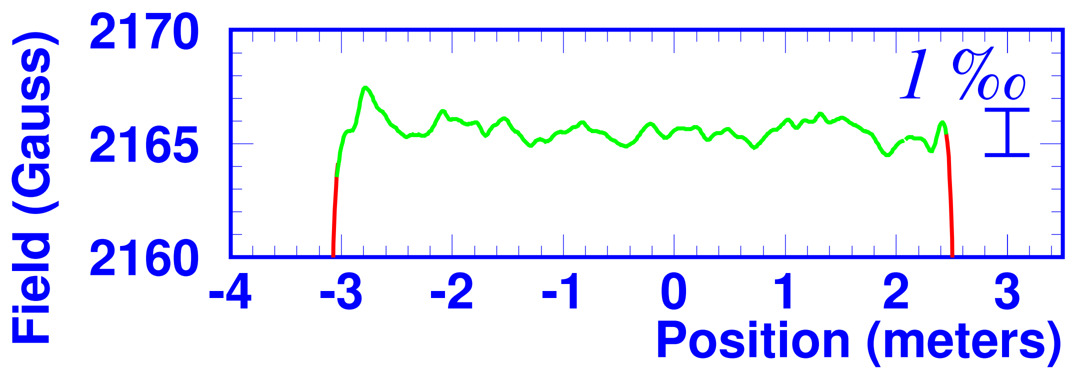
NMR Probe: $\delta B/B \sim 10^{-6}$ over 90%

Hall Probe: $\delta B/B \sim 10^{-4}$ over 10%

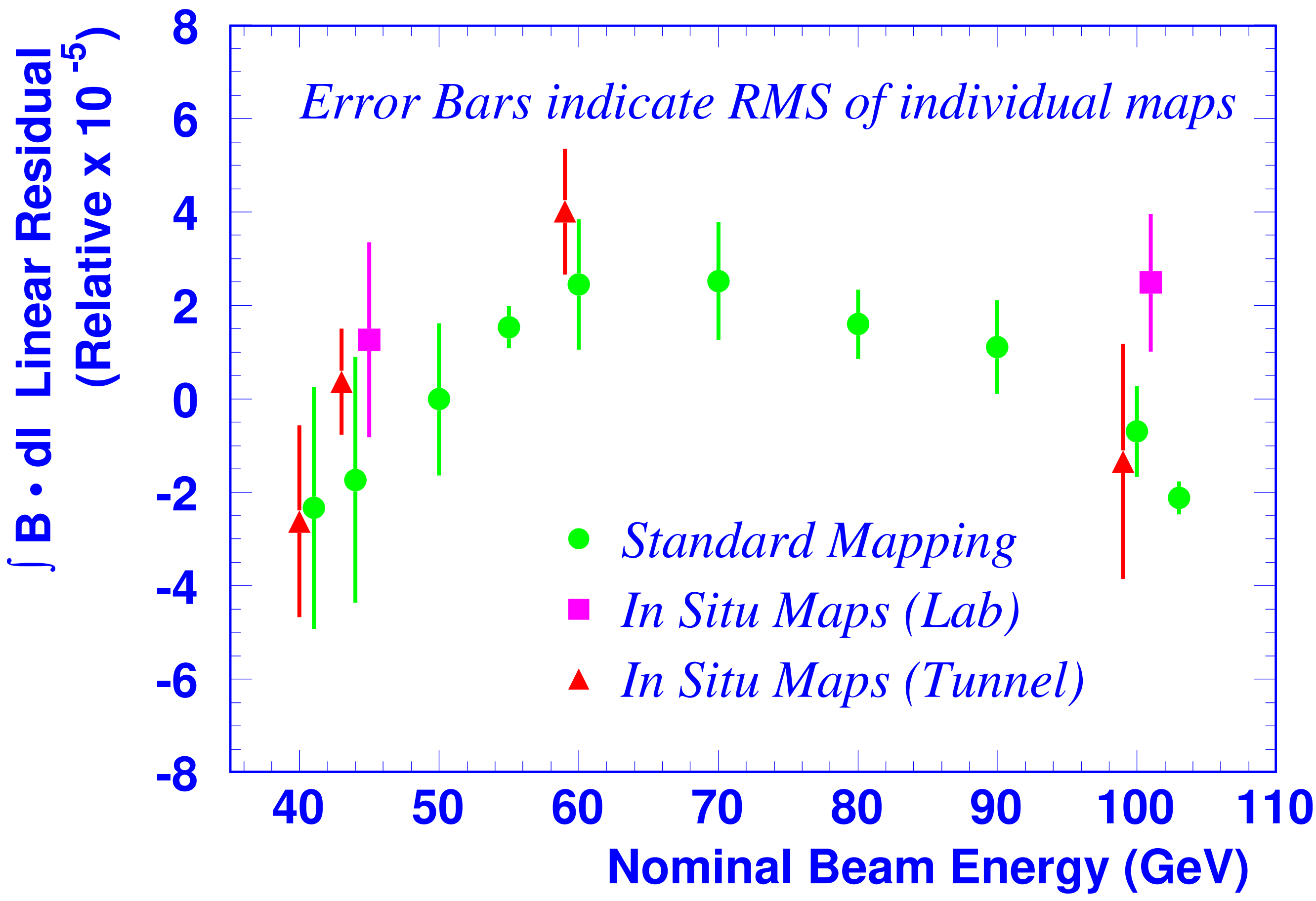
$\Rightarrow$ Independent *In Situ* measurements also made!

Mapping Results

Single Map



Non-Linearity Curve



Analysis still underway, but results look promising...

LEP II Energy Summary

LEP II Beam Energy

- Resonant Depolarization extended to 60 GeV
- Extrapolation method used to get to Physics Energy
- Precision limited by Flux Loop-NMR comparison

$$1997: \frac{\delta E_{Beam}}{E_{Beam}} = \frac{25 MeV}{92 GeV} \Rightarrow 3\times10^{-4}$$

$$1998: \frac{\delta E_{Beam}}{E_{Beam}} = \frac{20 MeV}{95 GeV} \Rightarrow 2\times10^{-4}$$

LEP Spectrometer Project

- Direct measurement of E_{Beam} at Physics Energies
- Aim to reduce error to 1×10^{-4}
- Independent check of Extrapolation method
- All components at or near desired precision

Spectrometer Timeline

September 1997: Project proposed to CERN SL Division
January 1998: Project approved by CERN directorate
March 1998: Design Prototype installed for 1998 run
October 1998: New MBI Dipole delivered to CERN
December 1998: Magnetic Mapping begins
April 1999: Final system installed for 1999 run

$\Rrightarrow$ Commissioning continues, first measurements soon...