Measurement of beam energy at LEP2

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on behalf of the LEP Energy Group

Outline

- Status of 'standard' extrapolation method
- Direct measurement with Magnetic Spectrometer
- Direct measurement using Q_s v V_{RF}
- Measurements using LEP2 event data
- summary and outlook

LEP 1 regime

Δm_Z = $\pm$ 1.2 MeV $\pm$ 1.7 MeV

(expt) (LEP energy)

$\Delta\Gamma_Z$ = $\pm$ 2.0 MeV $\pm$ 1.2 MeV

(expt) (LEP energy)

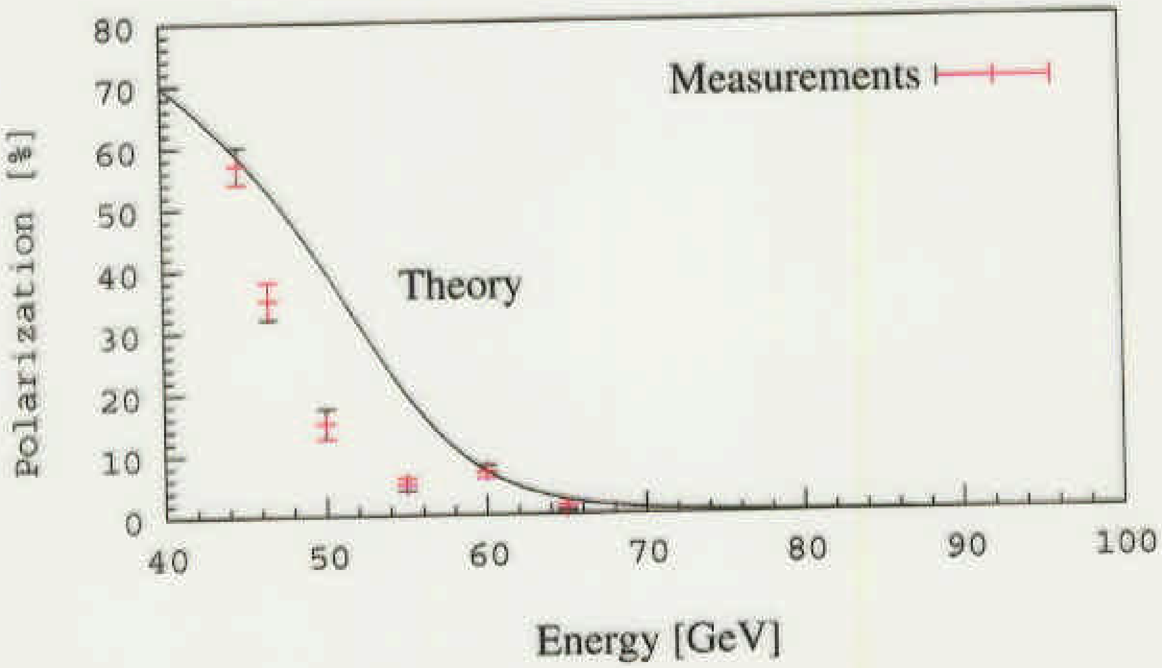
main tools: resonant depolarisation and good monitoring

LEP 2 regime

expected $\Delta m_W \simeq$ 30 to 40 MeV

so target is Δm_W(LEP energy) $\lesssim$ 10 MeV

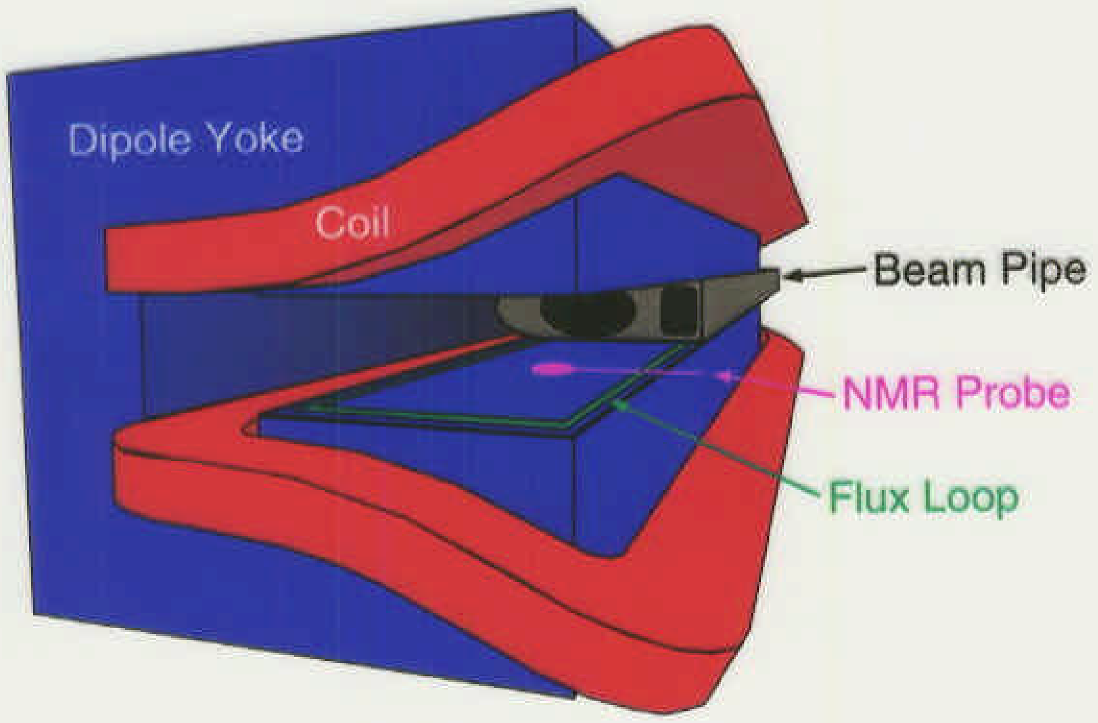
an easy job for the LEP energy group? unfortunately not !



Magnetic Extrapolation

Now $E_b \propto \oint B \, . dl$

so we can exploit magnetic measurements:

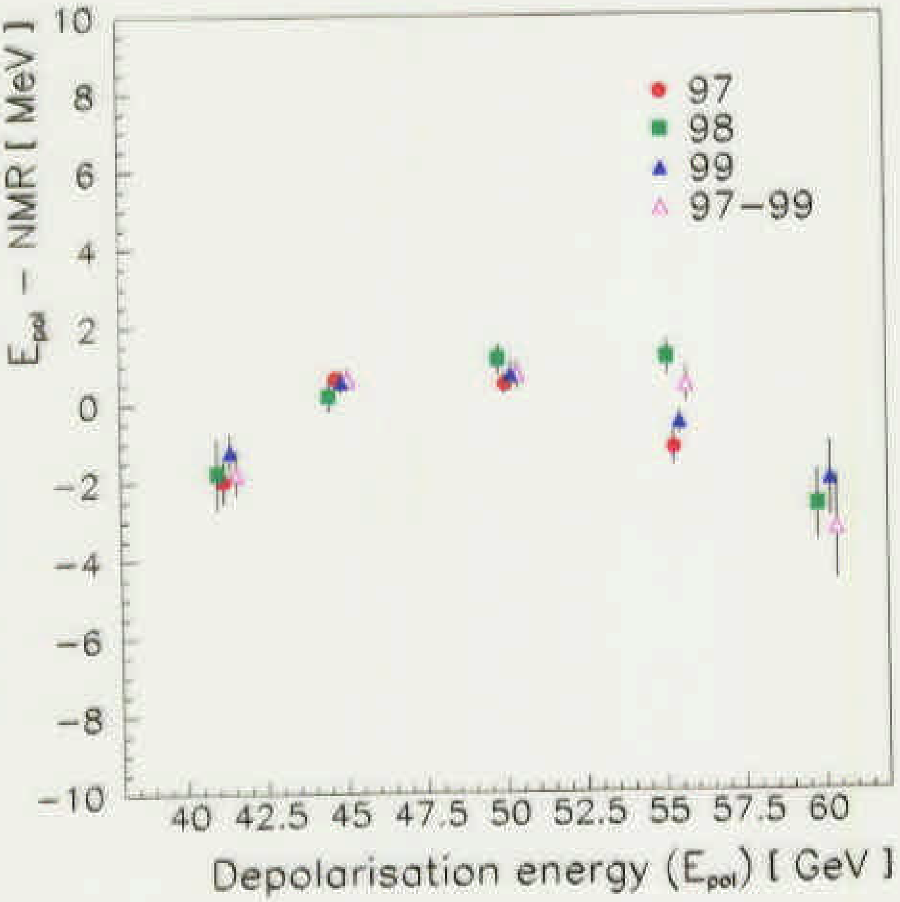


	NMR probes	Flux loop
Accuracy	10^{-6}	$\sim 10^{-4}$?
Readout	Continual	Dedicated cycles
Sampling	16/3200 dipoles	96.5% of field
Longevity	Short – but replacable	radiation damage

Magnetic Extrapolation Method

- calibrate NMR probes against E_{pol} from resonant depolarisation at low energy (40-60 GeV)

20 fills with 2 or more energy points



- apply this calibration in W^+W^- regime ($\sim$ 100 GeV)

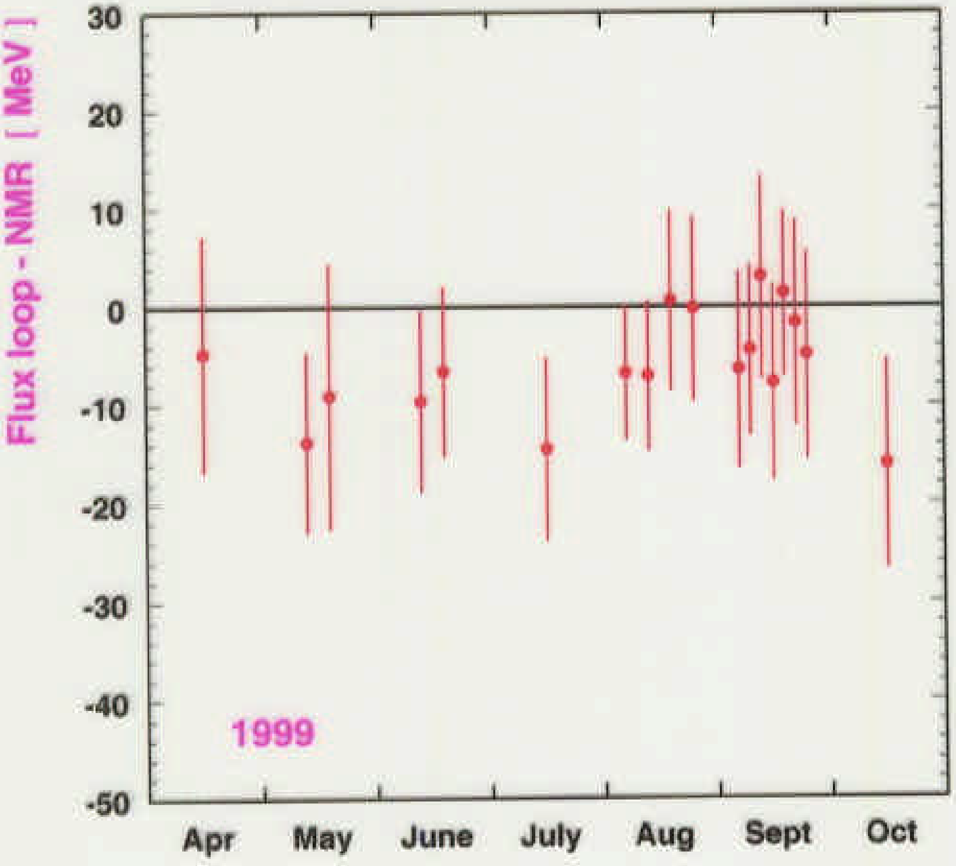
It works and is stable! **However:**

- we are only sampling 16 magnets out of 3200..
- uncertainty in how any non-linearities will extrapolate

Assigning the extrapolation error

Error assigned by cross-calibrating against flux loop (FL):

- Assuming $\oint B \, . \, dl$ seen by FL $\propto E_b$
- Cross-calibrating NMRs vs FL in dedicated cycles
- Looking at residuals at high energy

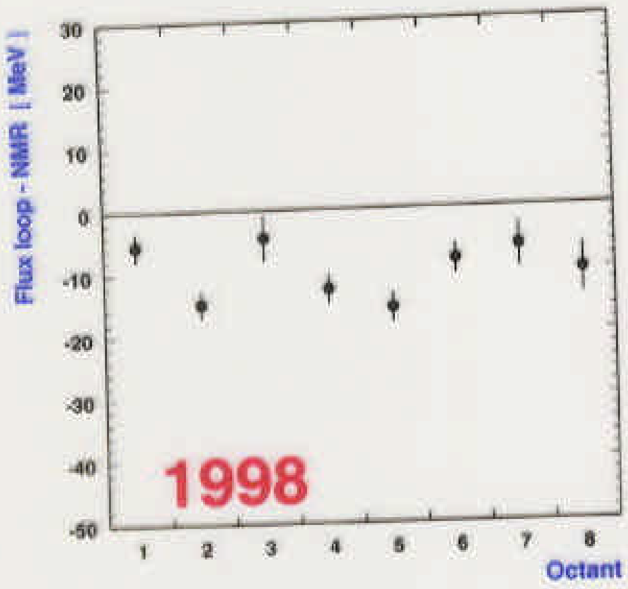


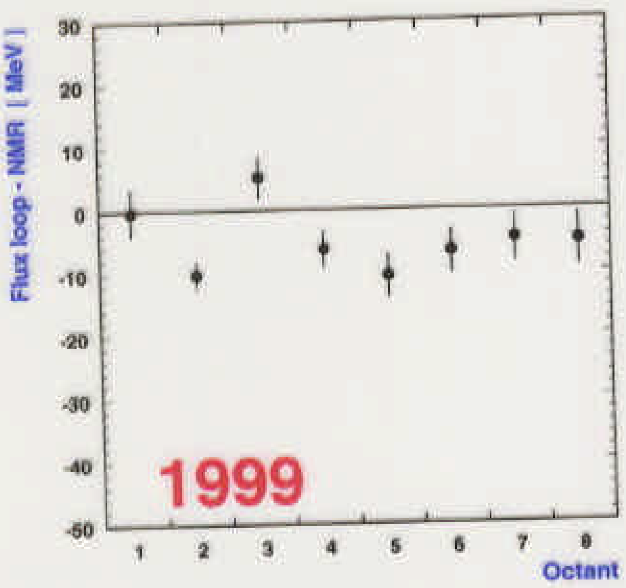
→ No evidence of sizable non-linearity

→ FL extrapolation error $\simeq$ 15 MeV

reproducibility of Flux Loop

Flux loop read out for each of 8 octants





flux loop stable year to year

current status of energy error determination

central values and errors on E_b available upto 1999

example: breakdown of errors for 1999 data

source	error in MeV
NMRs, flux loop and extrapolation	19
polarisation, e^+ e^- diff, optics diff.	4
other (tide, correctors ...)	3
IP specific (RF, dispersion)	5
TOTAL	21

previous years: 25 MeV for 1997, 20 MeV for 1998

correlation $\simeq$ 70 to 90 % between years

LEP energy error translates to $\Delta m_W \simeq$ 17 MeV

error relies heavily of Flux Loop method:

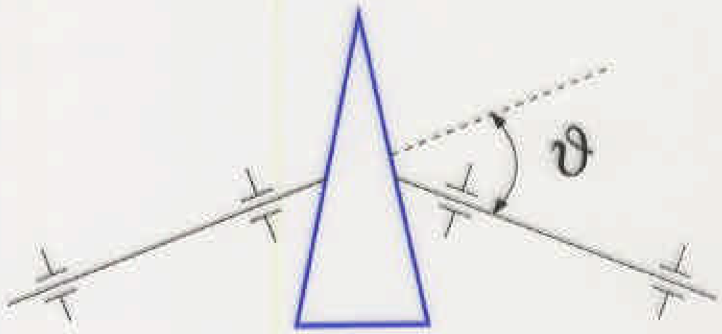
but is Flux Loop really representative of ring as a whole ???

the LEP spectrometer

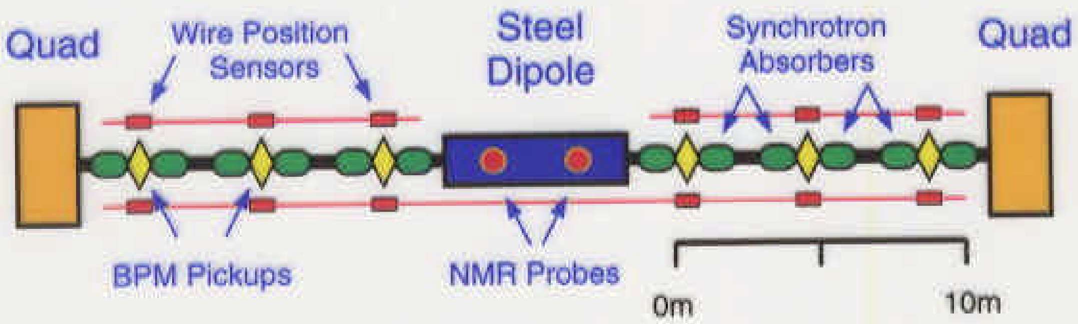
- Require alternative method which measures $\mathrm{E_b}$ directly to check the exptrapolation

The idea (1997) :

$$\Delta\theta \propto \frac{\oint B \, . \, dl}{\mathrm{E_b}}$$



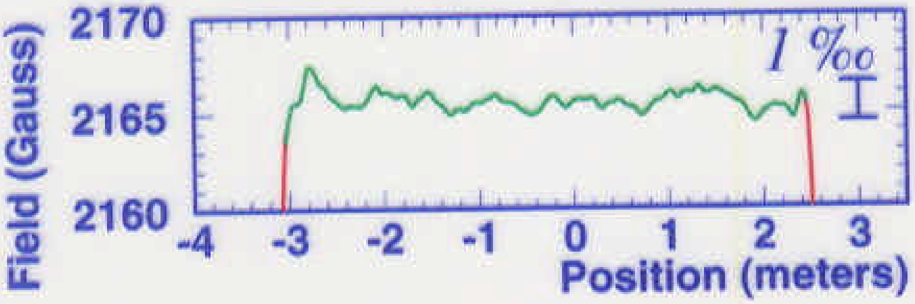
The reality (1999) :



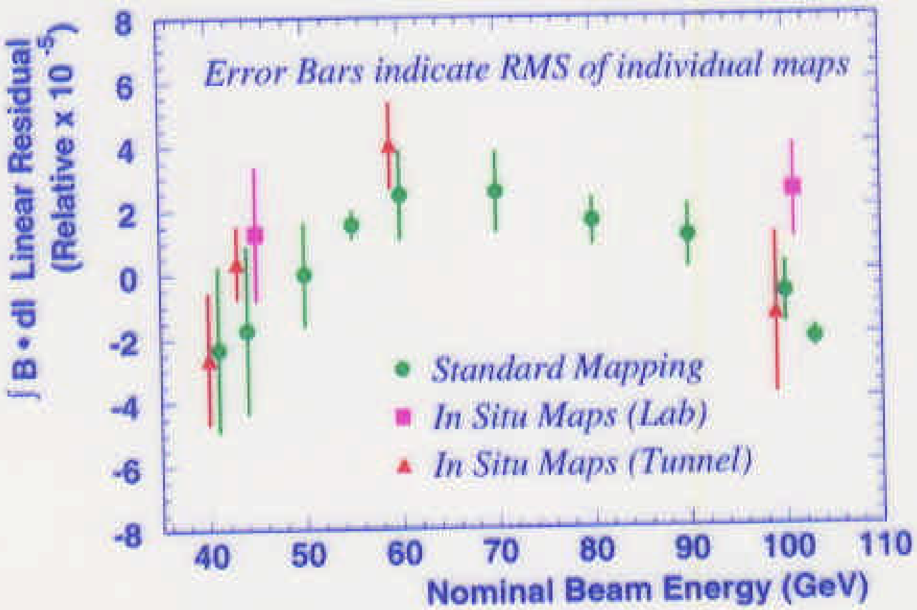
- has to work in a very hostile environment
  - → special electronics
  - → shielding against synchrotron radiation for Beam Position Monitors (BPM)
- require accuracy of $\simeq 1\mu$m for BPM - achieved
- to achieve $<10^{-4}$ accuracy must cross-calibrate vs RDP

Measurement of $\oint B \cdot dl$

- Prior to installation in LEP, magnet field integral was mapped (many times) with moving arm with NMRs and Hall probe:



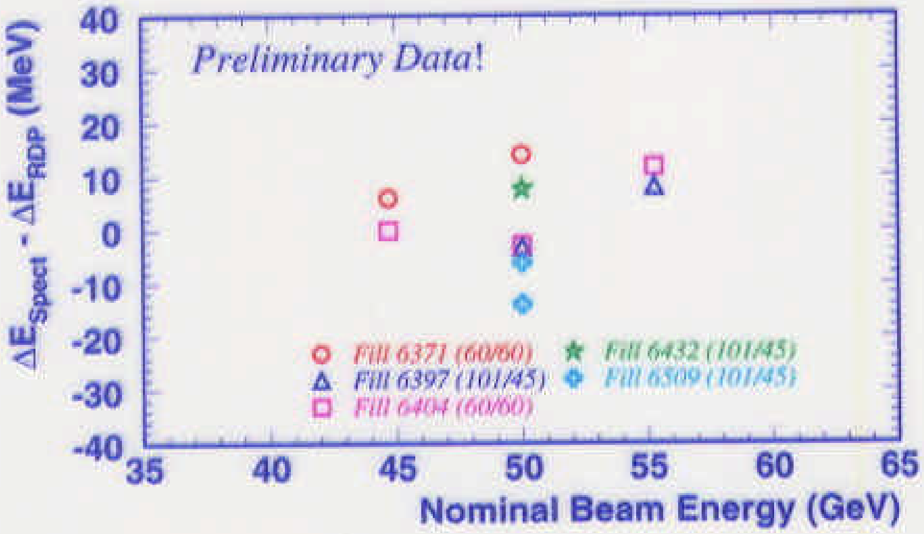
- results of these maps can be fitted to local fields read out by fixed NMRs (which remain in place during LEP operation)



- good consistency
- will be remapped at end of LEP running

preliminary results of spectrometer

- performance in resonant depolarisation (RDP) region



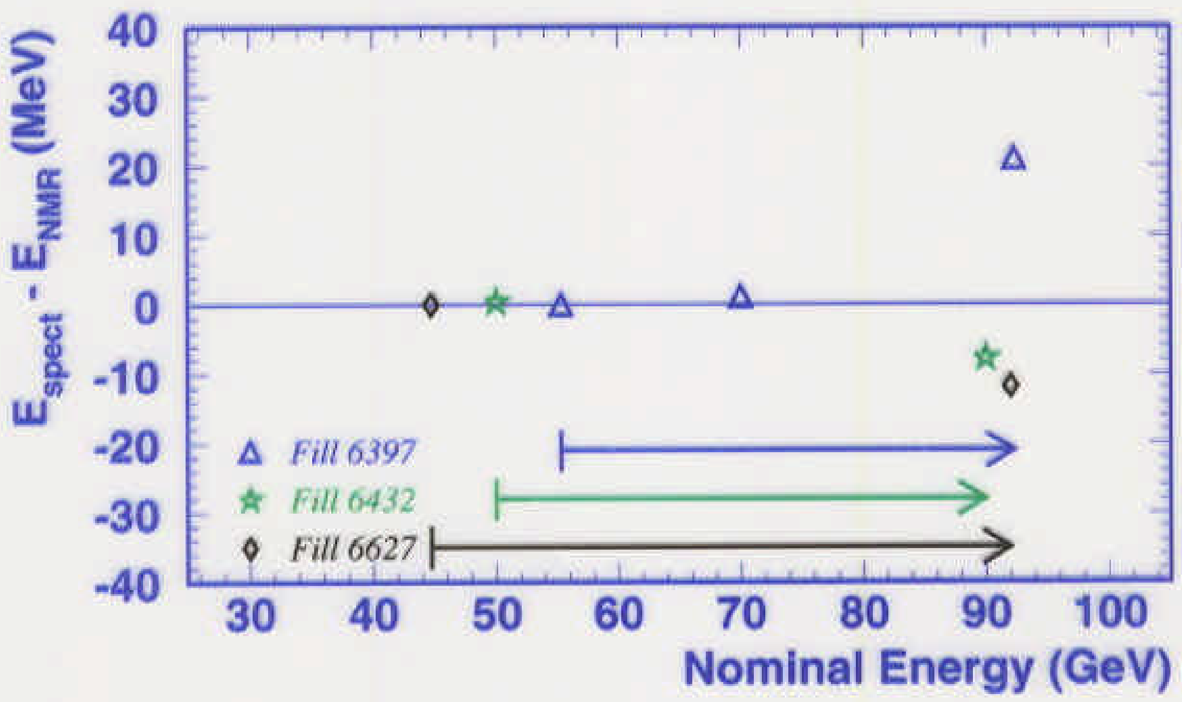
$$\Delta E_{\rm spect} - \Delta E_{\rm pol} = 3 \pm 8 \text{ MeV (rms)}$$

Assumed error contributions

Source	RDP cross-check	High Energy
$\oint B \, . dl$	1.5 MeV	3.0 MeV
RDP/NMR related	2.0 MeV	3.0 MeV
Spect $\rightarrow < E_b >$	3.0 MeV	5.5 MeV
BPM	4.0 MeV	8.0 MeV
Total	6 MeV	11 MeV

..and at high energy

- normalise to RDP at 'low' energy
- ramp to 'physics' energies and compare with NMR method



very preliminary result from 1999 data (3 measurements)

$$E_{spect} - E_{NMR} = 0.5 \pm 15 \text{ MeV (rms)}$$

→ first direct measurement at LEP 2 energy scale !

For 2000:

- more measurements to gain statistics and understand systematics
- synchrotron radiation appears to be more problematic than in 1999

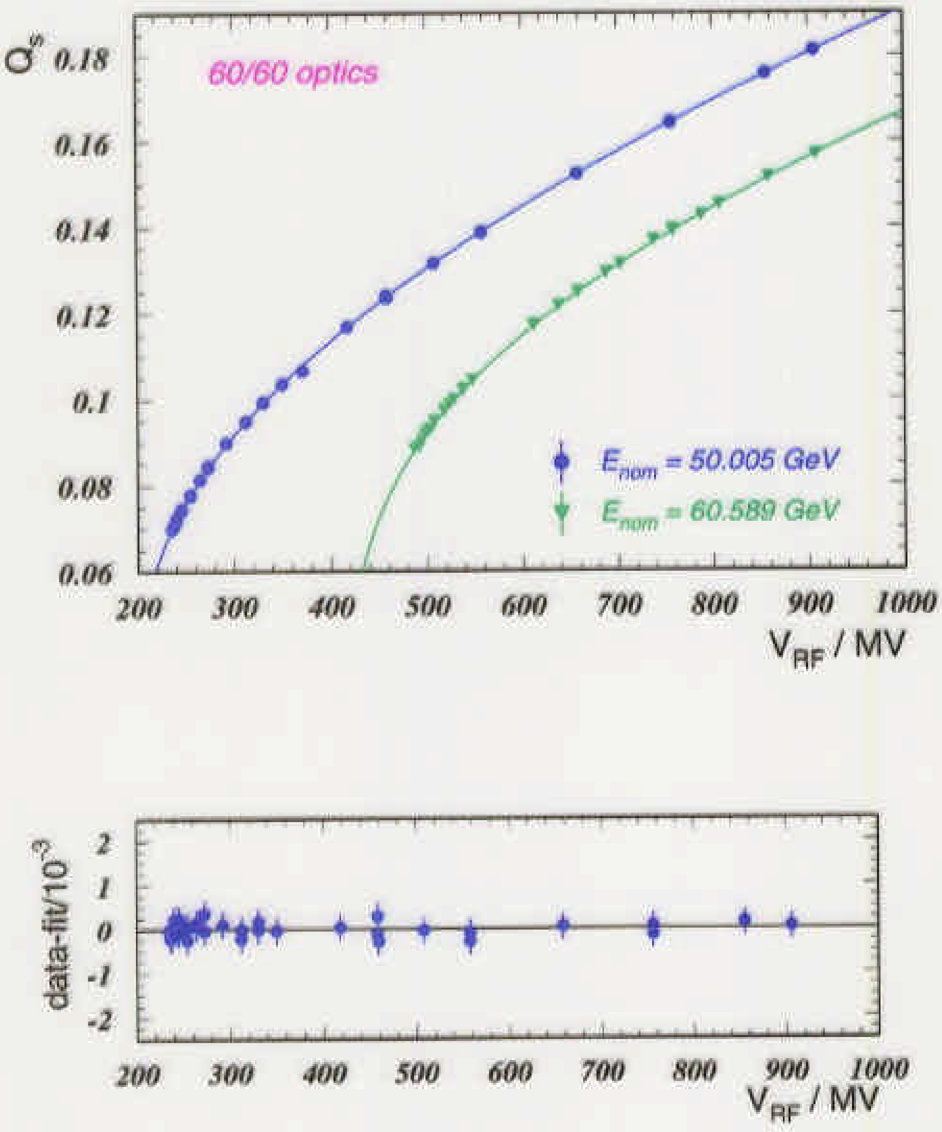
Beam energy from Q_s v V_{RF}

E_b can be extracted from the energy loss $U_0 \propto E_b^4/\rho$

and can be measured from the synchrotron tune vs $V_{\rm RF}$:

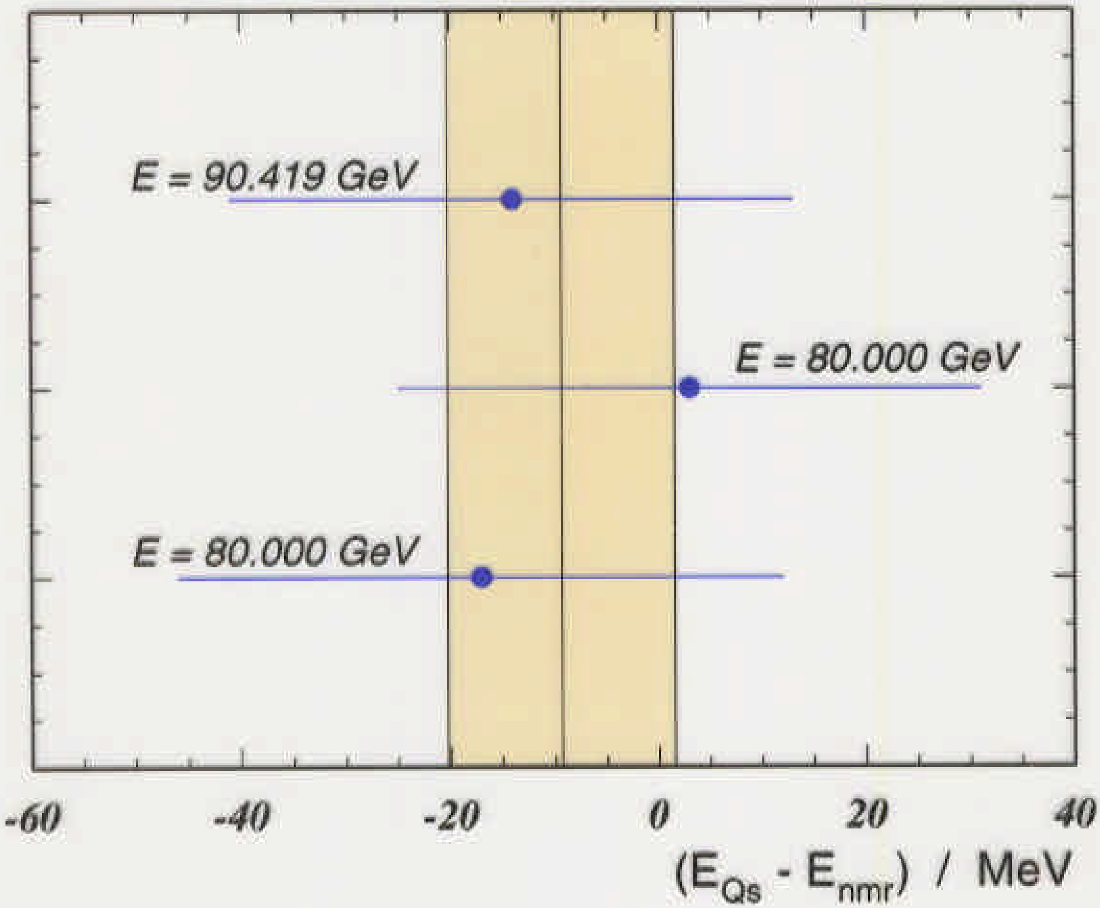
$$Q_s^2 = \left(\frac{\alpha_c\, h}{2\pi \mathrm{E_b}}\right)\ \sqrt{(e^2\, V_{\rm RF}^2\ -\ U_0^2)}$$

in practice more detailed model used



Q_s v V_{RF} - checking the extrapolation

3 measurements in 1998/9 above 80 GeV



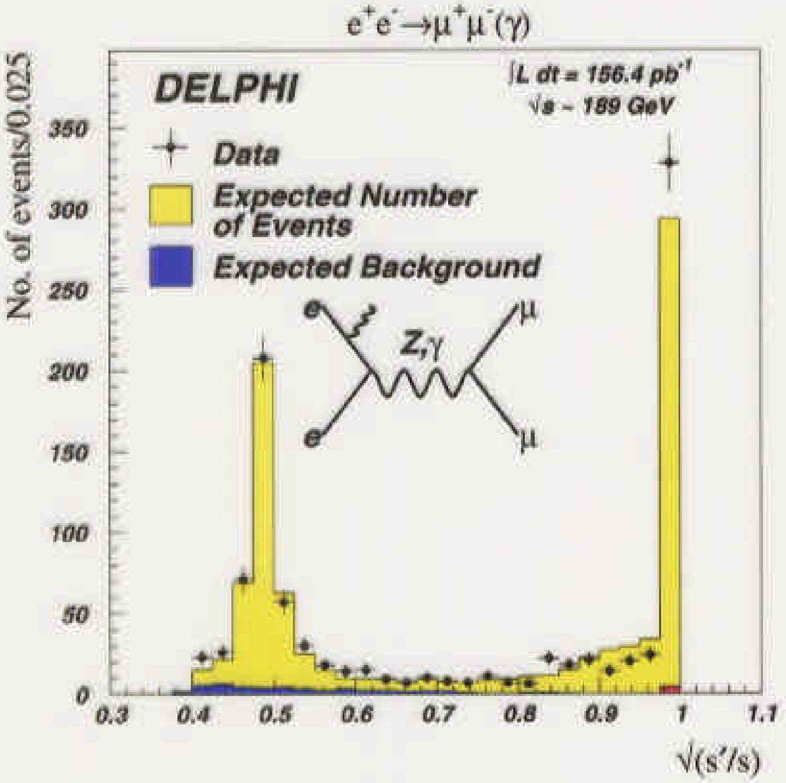
$E_{QS} - E_{NMR} = -9 \pm 11$ MeV (rms)

- effective bending radius of LEP is an important parameter
- results are very encouraging

more measurements taking place in 2000

Beam energy from the event data

from radiative return to Z using $e^+e^- \to f\bar{f}$



- DELPHI (prelim ICHEP 2000) using $\mu^+\mu^-$ data 1997-9

  $E_{data} - E_{LEP} = 80 \pm 101$ (stat) ± 58 (syst) MeV

- ALEPH (PLB 464, 339) using $q\bar{q}$ data (from 1997)

  $E_{data} - E_{LEP} = -15 \pm 95$ (stat) ± 40 (syst) MeV

AVERAGE: $E_{data} - E_{LEP} = 27 \pm 77$ MeV

- potential statistical error from all LEP expts

  $\simeq 40$ MeV ($\mu^+\mu^-$) and 15 MeV ($q\bar{q}$)

but systematics must be controlled at this level

- worthwhile ! encourage all experiments to do it !

Summary and outlook

- present (extrapolation) method gives

  $\Delta E_b \simeq$ 20 MeV $\rightarrow$ $\Delta m_W \simeq$ 17 MeV

- method stable year to year, but maybe difficult to improve
- cross-checks from

a) spectrometer

b) Q_s v V_{RF}

confirm extrapolation method

- next (and final!) step is to convert these cross-checks

  into quantitative results