LEP Coordinator's Report

LEPC – 11 November 1997

Pippa Wells

- 1997 performance
- Schedule for 1998
- LEP2 Energy Calibration status
  - Overview
  - Polarisation/NMR/flux-loop method
  - Radiative return events
  - Spectrometer
  - Moller scattering

Schedules and Statistics plots can be found here:

http://nicewww.cern.ch/SL/opnews/pageswww/LEPss.html

What happened in 1997

	Planned	Realised	
	Days	Days	pb^{-1}
MD	22	19	
Critical days	0	1	
Z running at start	$\gtrsim$6	12	2.3
LEP 1.5 running	0	7	6.2
High Energy Running 90/60	104	67	59.9
High Energy Running 102/90	0	6	3.9
Total	132	114	73.4

“MD” includes

- Energy calibration
- Cryogenics and optics MD
- 2 days recabling of 6-poles for 102/90 optics test

Many thanks and congratulations for the consistently excellant performance in all aspects this year

Average of 0.9pb^{-1} per day at high energy compared to prediction of 1.0pb^{-1}. Consistently better in latter part of year.

LEP experiment data taking efficiency 80–95%

1998 schedule

Draft schedule unchanged

- Close ring and start cold check out 24 April.
  Short delay due to cryogenics???
- Set up with beam from 11 May, but experiments should be ready for beam from 4 May
- MD schedule to be planned after Chamonix workshop in January 1998
- Present schedule stops on 1 November. Request week in reserve first week of November in case of startup delay?

Nominally gives 157 days of running.

- $\approx$ 10 days Z running
- $\leq$ 30 days MD (number to be finalised)
- $\Rightarrow \approx$ 117 days of high energy running

Optimal way to run machine to be discussed at Chamonix.

- Higher energy will be available in 1999 after cryogenic plant upgrades and more cavities installed
- Priorities of L vs. E to be discussed
- 102/90 optics performed very well

A question of optics

x/y denotes horizontal/vertical phase advance (degrees) of betatron (transverse) oscillation per FODO cell in the arcs

FODO $\equiv$ Focussing-Quad, dipoles, Defocussing-Quad, dipoles

90/60 has been very successful for Z running and for LEP2 in 1996–1997

High focusing optics (i.e. larger phase advance) gives

- low emittance, smaller beam size, $\Rightarrow$ higher $\mathcal{L}$ and lower background for experiments
- less RF accelerating voltage for same energy
- but not good for Z running (beam–beam effects larger, limits current per bunch in collision)

Need to reconfigure sextupole power distribution for different phase advance.

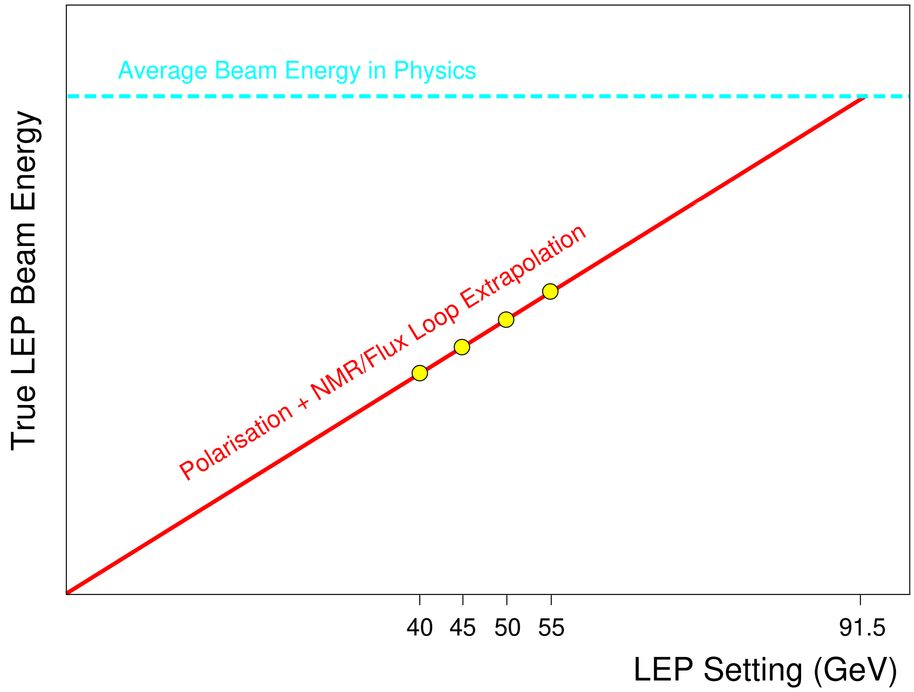
Test of 102/90 VERY PROMISING

Possible scenario for 1998

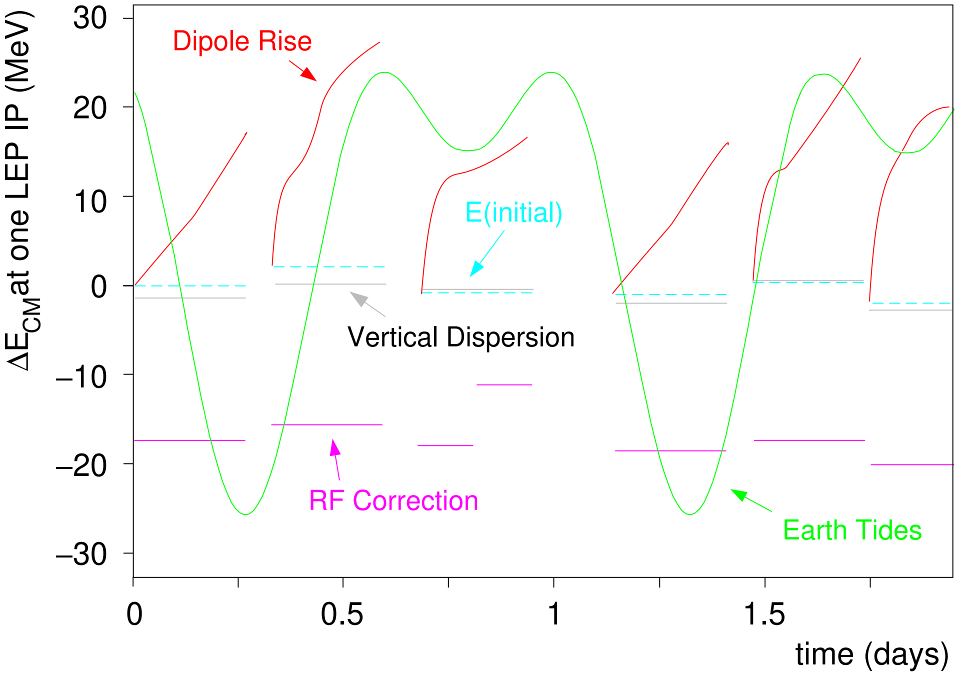
- 90/90 optics for Z running
- 102/90 optics for high energy running $\Rightarrow$ higher energy for same RF

LEP2 Energy Model

Part 1: Magnetic Extrapolation to set overall Energy Scale



Part 2: Calculation of Fill-to-Fill Energy Variation at LEP IPs



Quantifying the Energy Model

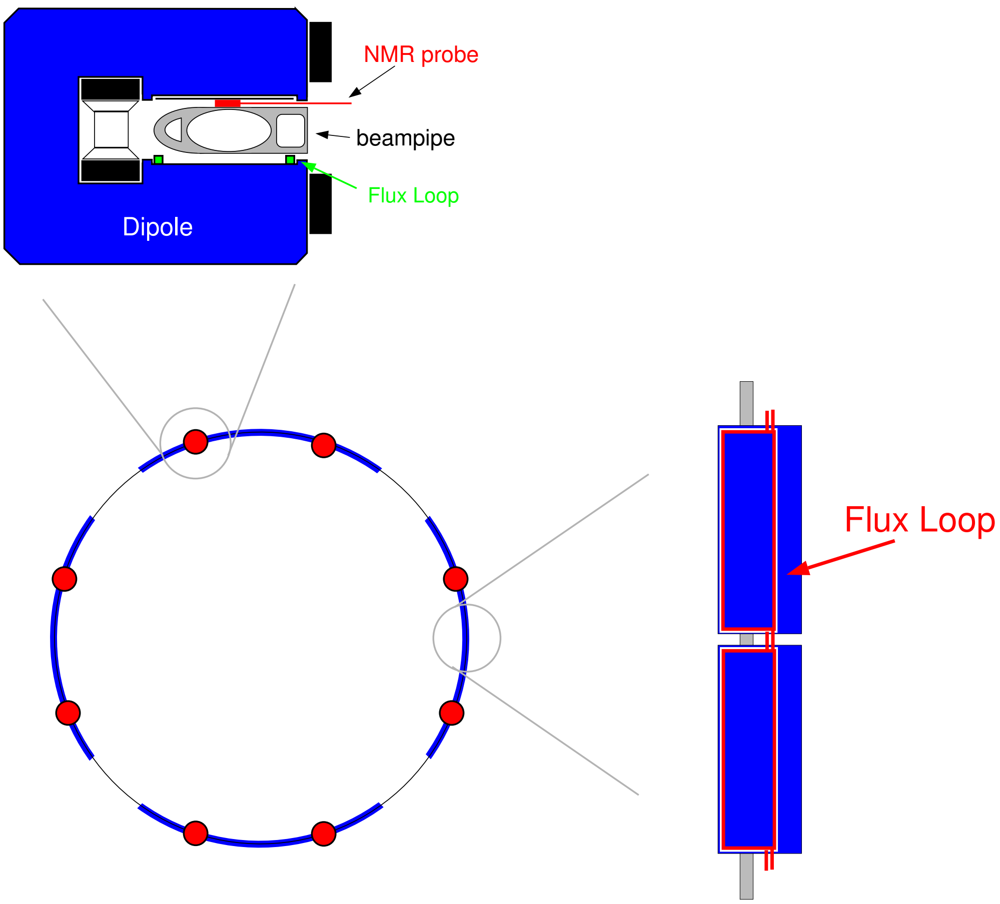
	ΔE_{beam}	$\sigma_E(96)$	$\sigma_E(Z^0)$
New problem for LEP2:			
– Overall Energy Scale	$35\,\mathrm{GeV}$	$30\,\mathrm{MeV}$	
Same methods as LEP1:			
Dipole Effects (changes to Dipole $\oint Bd\ell$):			
– Rise per fill	$\sim 15\,\mathrm{MeV}$	$2\,\mathrm{MeV}$	$1\,\mathrm{MeV}$
– Horizontal Corrector Settings	$\sim 2\,\mathrm{MeV}$	$1\,\mathrm{MeV}$	$0.4\,\mathrm{MeV}$
Quadrupole Effects (changes to Quadrupole $\oint Bd\ell$):			
– Earth Tides (daily)	$\sim 30\,\mathrm{MeV}$	$1\,\mathrm{MeV}$	$0.2\,\mathrm{MeV}$
– Geological shifts (weeks)	$\sim 30\,\mathrm{MeV}$	$1\,\mathrm{MeV}$	$0.2\,\mathrm{MeV}$
IP-Specific Effects (local changes to E_{beam}):			
– RF Corrections	$\sim 20\,\mathrm{MeV}$	$5\,\mathrm{MeV}$	$0.7\,\mathrm{MeV}$
– Vertical collision offsets	$\sim 1-2\,\mathrm{MeV}$	$1\,\mathrm{MeV}$	$0.4\,\mathrm{MeV}$

The targets

- LEP2: $\sigma(M_W) \approx 30$ MeV
- LEP1: $\sigma(M_Z), \sigma(\Gamma_Z) \approx 2$ MeV

Energy Extrapolation

Hardware: Provides a "measure" of $\oint B d\ell$



NMRs:

- Precision: $\sim 1 \times 10^{-6}$
- read out: every 30 seconds
- only measures B-field over small area
- 16 probes for 3200 dipoles

Flux Loop:

- Precision: $\sim 1 \times 10^{-4}$?
- read out: $\sim$ weekly
- only measures 97% of total B-field. Missing:

  "10%" dipoles (end of arcs)
  injection dipoles
  fringe fields
  quadrupoles

LEP2 error at the end of 1996

Discuss error in Ebeam $\equiv$ error in the W mass.

Error in 1996 at Ebeam=86 GeV was 30 MeV

- Largely based on a single fill with resonant depolarisation (RDP) measurement at 45 and 50 GeV.
- Apparent precision of FL/NMR vs RDP was around 2 MeV over this 5 GeV interval (relative error 4×10^{-4}).
- "Linear extrapolation" with this precision would give an error of 15 MeV at 86 GeV.
- Error inflated to 30 MeV because
  - No estimate of reproducibility from fill to fill
  - No fills with more than two energy points $\Rightarrow$ No check of non-linearity
  - No work on the possible precision for the 3% of bending field outside the flux loop

Application to 1997

- With no improvements, error at Ebeam=91.5 GeV would be about 35 MeV

1997 Polarisation measurements

Date	41 GeV	44 GeV	50 GeV	55 GeV	Optics
17/08/97		•			90/60
06/09/97		•	•		60/60
30/09/97		•	•		60/60
02/10/97	•	•	•	•	60/60
10/10/97		•			90/60
11/10/97	•	•	•	•	60/60
29/10/97	•	•			60/60

90/60 was standard physics optics in 1996 and 1997

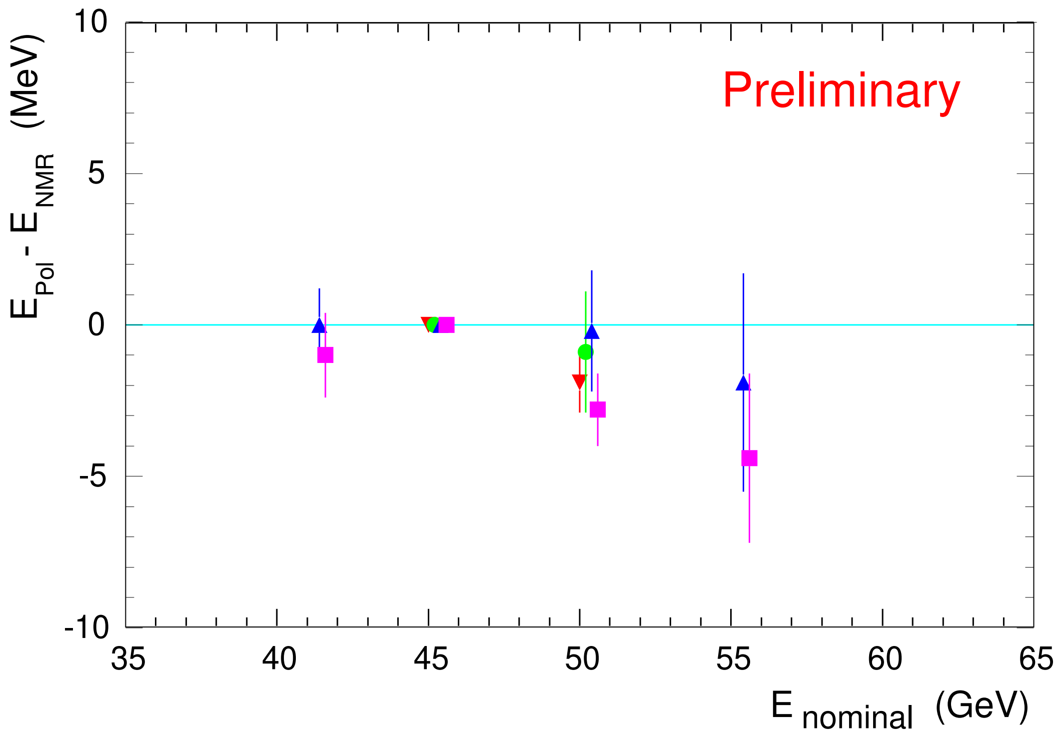
60/60 is a dedicated polarisation optics to improve level of polarisation at high energy

- 5 fills with more than one energy point,
- 2 fills with 4 energy points ($\Rightarrow$ first linearity check)
- Lever arm increased from 5 to 14 GeV
- Maximum polarised energy increased from 50 to 55 GeV

NMR/Epol Comparison

- Normalise each NMR at 44 GeV for each fill.
- For other energies, average over NMR's. Derive error from their spread.
- Average of NMR's agrees reasonably well with Epol
- Slopes reproduced fill-to-fill

For this plot, show differences from 44 GeV point where NMR's are calibrated $\Rightarrow$ no error at 44 GeV



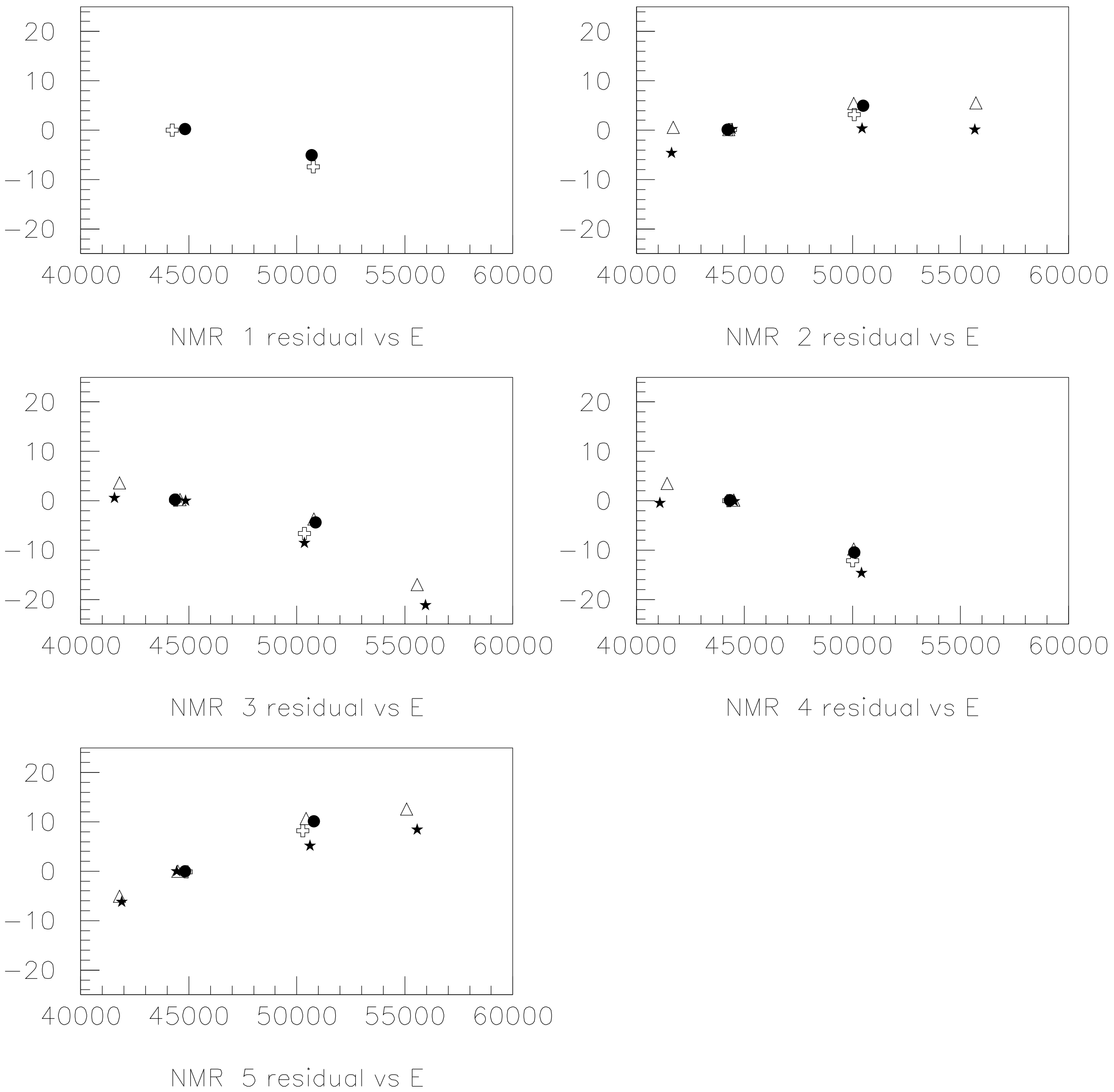
(Symbols indicate different fills.)

Straight line fit to these data would correspond to 10 ± 5(stat) MeV discrepency, extrapolating from 55 to 90 GeV

NMR/Epol Comparison

- Slopes vary from octant-to-octant and magnet-to-magnet
- Reproduced fill-to-fill for each probe.

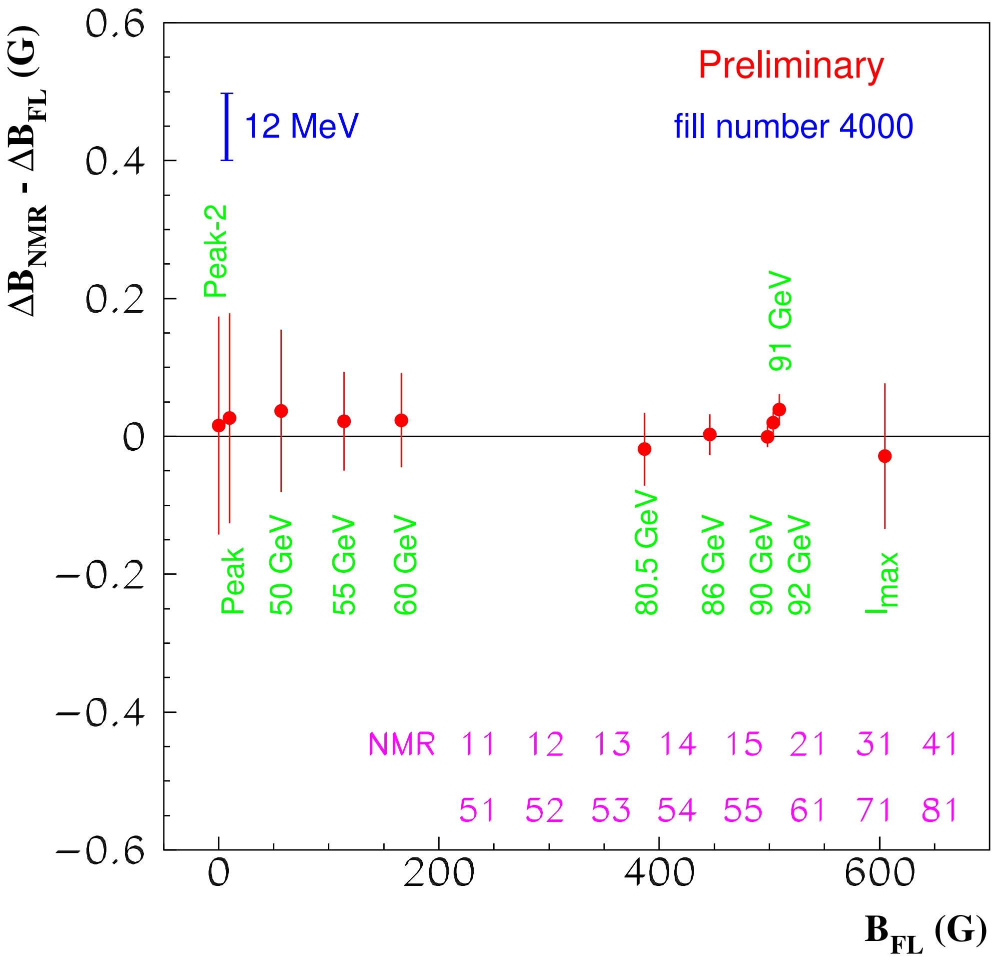
Example: the 5 probes in octant 1



(Symbols indicate different fills.)

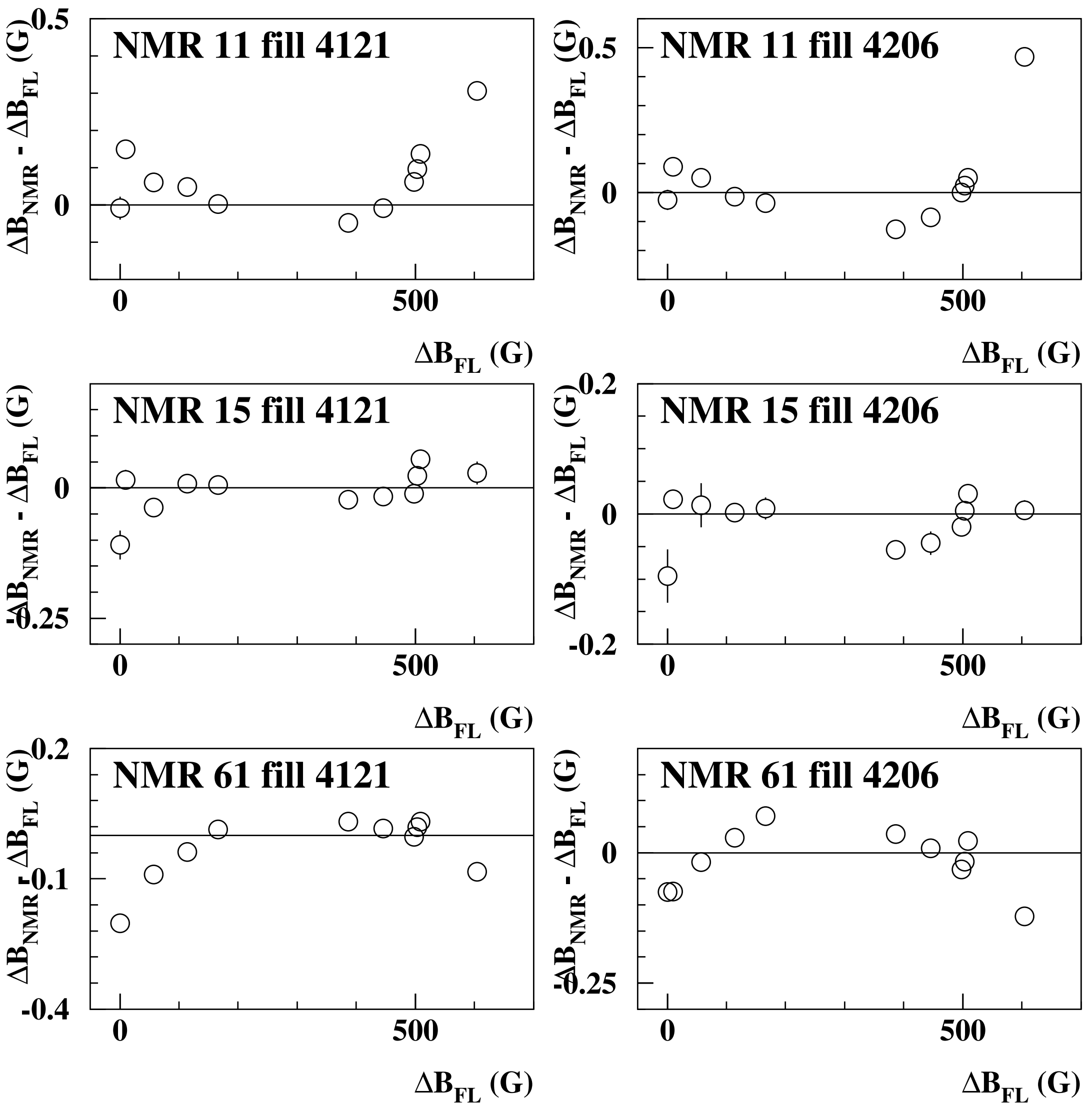
NMR/Flux Loop Comparison

- Average over NMR's. Derive error from their spread.
- Average of NMR's agrees well with flux loop
- Example shown is for one measurement. This behaviour is repeated from fill-to-fill



NMR flux-loop comparison

- Octant-to-octant and magnet-to-magnet, behaviour varies.
- Slopes are not constant with energy
- But behaviour is reproduced from fill-to-fill



Detailed correlation of individual NMR behaviour relative to flux loop and polarisation is not yet understood

Speculate about the error?

Great success of polarisation this year $\Rightarrow$ should reduce the uncertainty

But examination of the new data is very preliminary
$\Rightarrow$ impossible to draw reliable conclusions at this stage.

Energy from average of all NMR's seems to be consistent with polarisation or fluxloop data at $\mathcal{O}$(10 MeV) level.

- Detailed behaviour of an individual NMR compared to flux loop is not "linear".
- Consistency of probe-to-probe behaviour compared with polarisation and with flux-loop is NOT established

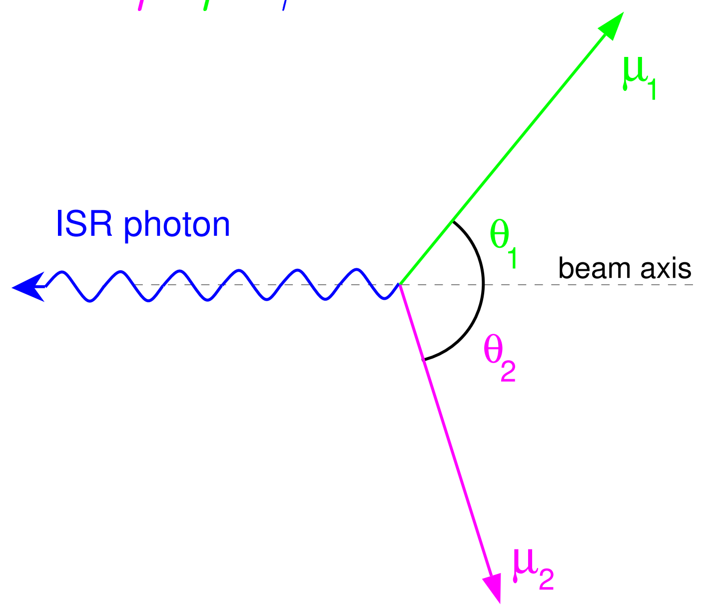
$\Rightarrow$ Need a lot of work to derive "non-linearity" contribution to the error

Larger 1% uncertainty on the behaviour of unmeasured 3% of the bending field would add 10MeV (for 35 GeV extrapolation) in quadrature to the uncertainty. Needs work to control these uncertainties.

$\Rightarrow$ Plan extra measurements in 1998.

Radiative return events

Example, $e^+e^- \rightarrow \mu^+\mu^-\gamma$



For coplanar muons (3-body kinematics),

$$\frac{E_\gamma}{E_{beam}} \equiv x_\gamma = \frac{2\sin(\theta_1+\theta_2)}{\sin(\theta_1+\theta_2)+\sin\theta_1+\sin\theta_2}$$

$$E_{beam} = \frac{M_Z}{2\sqrt{1-x_\gamma}}$$

Ebeam is derived from the very precisely known Z mass

Gives an independent measure for each IP

Precision using Radiative Returns

Statistical errors have been derived from preliminary studies of 183 GeV data and large Monte Carlo samples.

Similar results from ALEPH, DELPHI and OPAL.

For 500pb^{-1}, 4 experiments, assuming all data at 183 GeV

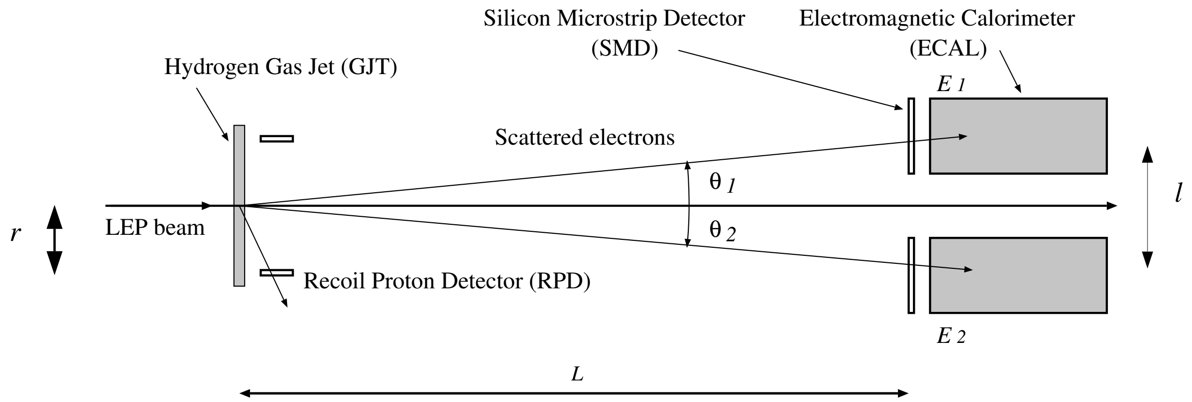
- $qq\gamma$ events $\Rightarrow$ stat error $\approx$16 MeV in Ebeam
- $\mu\mu\gamma$ events $\Rightarrow$ stat error $\approx$40 MeV in Ebeam
- $ee\gamma$ events are expected to have worse precision from the extra background
- Dominant reduction in stats from running at higher energy is from the fall off of the cross section. Reduction in detection efficiency at 200 GeV typically $\approx$5%

Potentially large systematic errors

- Most important is modelling of ISR. (In discussion with S. Jadach et al). Large differences (> 100MeV) have been seen between some different generators.
- Jet modelling uncertainties - these also enter for the W mass measurement.
- The RF model is again needed to estimate the longitudinal boost at the IP.

Moller Scattering Experiment

J. Field et al



LEP beam scatters off a Hydrogen Gas Jet Target

Two-body kinematics:

$$E_{beam} = \frac{8m_e}{\Theta^2}\frac{1}{1-\kappa^2} - m_e$$

where $\Theta \equiv \tan\theta_1 + \tan\theta_2$ and $\kappa = \cos\theta^*$ and is given by

$$\kappa_A = \frac{\tan\theta_1 - \tan\theta_2}{\tan\theta_1 + \tan\theta_2} \quad or \quad \kappa_B = \frac{E_1 - E_2}{E_1 + E_2}$$

Dominant systematics for methods A and B are different.

Moller Scattering Status

Errors/constraints

- Cross calibrate with resonant depolarisation, so do not need absolute geometry.
- Control l=20 cm to 1 μm (stability of SMD)
- Control L=30 m to 150 μm by ep scattering. This implies controlling r to 1mm.
- Beam x,y position/profile measured from Moller events
- Statistical error negligible
- ISR and binding corrections studied

$\Rightarrow$ Intrinsic error $\lesssim 2$MeV (NIM A385 (1997) 445)

RF model to extrapolate from detector to IP $\Rightarrow$ $\approx$10MeV error

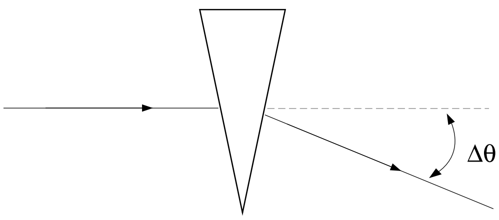
Status

- SMD design based on L3 “SLUM” (3 planes of double sided wafers)
- Calorimeter design similar to CMS lead tungstenate (120 crystals)
- GJT - fruitful discussions with Genoa. Open questions on interface to LEP.
- Time scale - proposal to LEPC in March ’98 with approval in September ’98 would allow construction for running in 2000

LEP Spectrometer

M. Hildreth, E. Torrence and SL specialists

Concept:

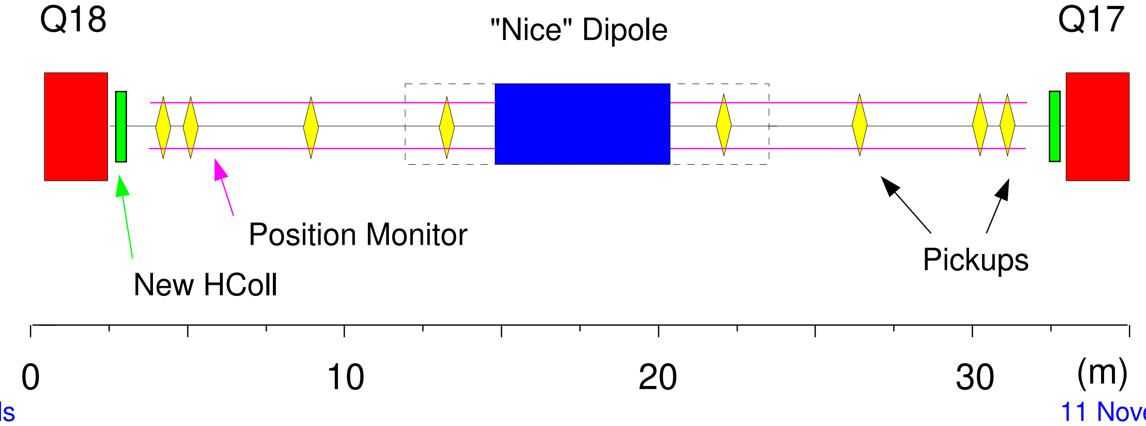


$$\Delta\theta \propto \frac{\oint B \cdot d\ell}{E_{beam}}$$

In practice:

- Precisely map a dipole somewhere in LEP lattice with NMR(s) to track B-field and space for BPMs
- Precision Beam Position Monitors measure incoming and outgoing angle
- Absolute calibration from resonant depolarisation
- Measure change in $\Delta\theta$ at different E $\Rightarrow$ linearity cross check at 1×10^{-4} (10 MeV) precision

Example of realistic layout:



Spectrometer constraints/status

Aim to control each uncertainty to 10^{-4} to achieve 10MeV

- At least one suitable location identified (2 isolated dipoles in dispersion region)
- Candidate dipole magnets consistent with installation in LEP are being compared. (Replace existing doublet with a “nice” magnet, independent power supply.)
- Field map of $\oint B \cdot d\ell$ of dipole with a relative precision of 10^{-4} between 45 and 90 GeV difficult but possible.
- BOMs with stable resolution on horizontal beam position of $\sim 1\mu m$ achievable with standard LEP pickups, customised electronics
  - Modified pickup being tested in the tunnel now
  - Additional electronics to be developed with industry
- Mounting for BOM/beampipe assembly that is stable to a micron is possible in principle.
- Position monitoring of probes to less than a micron using stretched wire (CLIC)
- Extra collimators to protect from synchrotron radiation.
- Should be able to use existing lengths of spare beam pipe to mount pickups.

Plan to install “Phase 1” for 1998 running. Study stability & precision.

Conclusions

- Very successful running in 1997
- 102/90 high focussing, low emittance optics looks good
- Successful polarisation measurements. Detailed agreement of flux-loop and Epol w.r.t. NMR not established. Challenge is to control non-linearity contribution to extrapolation uncertainty
- LEP Energy Group strongly supports efforts to make a direct measurement of beam energy at physics energy and cross check the extrapolation method
- Radiative return events unlikely to provide precise cross check
- Spectrometer project aiming for 10 MeV will make phase 1 test to assess precision in 1998
- Moller technique also sufficiently precise in principle