Energy Calibration at LEP

Spins, Tides
and
Vagabond Currents

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Polarization at LEP

Under the influence of synchrotron radiation, the LEP beams polarize spontaneously (align their spins) in the transverse (vertical) direction.

Polarization is a slow and delicate process which requires a lot of care and special machine conditions!

Ideal machine:

\[ P_T^{\text{max}} = 92.4\% \]

At LEP:

- record \( P_T = 57\% \)
- routine \( P_T = 5 \) - 10\%
- Up to 60.6 GeV
Resonant Depolarization

The number of precessions/turn $\nu$ is proportional to the energy:

$$\nu = \frac{g_e - 2}{2} \frac{E}{mc^2} = \frac{E[\text{MeV}]}{440.6486(1)[\text{MeV}]}$$

To determine the energy:

Measure $\nu$!

Principle:
- Get a fast magnet (“kicker”).
- Sweep the B-field and observe $P_T$.
- If kicker frequency and $\nu$ match, $P_T$ is rotated away from the vertical axis.

Fast sweeping horizontal B field

Resonant depolarization
Resonant Depolarization II

In the control room:

- Sweep the magnet frequency over a selected interval (~ 22 Hz).
- Observe the effect on $P_T$.

Intrinsic accuracy:

$\Delta E < 0.4 \text{ MeV}$

$\Delta E/E < 10^{-5}$

This is more than one order of magnitude better than any other method!

But it requires an large amount of DEDICATED beam time!
Z Resonance Scans

Good regions for $P_T$ are $\sim 50$ MeV wide and spaced by 441 MeV.

Convenient for Z mass and width measurements!

Calibrations cannot be performed during “physics” (no $P_T$ with colliding beams)

Extrapolation in time

Beam energy model
Stressed Rings

Sensitivity of the energy to circumference changes:

\[ \frac{\Delta E}{E} = -\frac{1}{\alpha \frac{\Delta C}{C}} \]

The beam samples different fields.

At LEP resonant depolarization is sensitive to circumference changes of \( \Delta C/C \sim 10^{-9} \)!

1991: the first calibrations revealed unexplained fluctuations of the beam energy. A SLAC ground motion expert suggested... tides!
Earth Tides

Tide bulge of a celestial body of mass $M$ at a distance $d$:

$$\Delta R \sim \frac{M}{2d^3}(3\cos^2\theta - 1)$$

$\theta$ = angle(vertical, the celestial body)

Earth tides:

- The Moon contributes 2/3, the Sun 1/3.
- NO 12 hour symmetry (direction of Earth rotation axis).
- Not resonance-driven (unlike Sea tides!).
- Accurate predictions.
Moonrise over LEP

**Fall of 1992**: The historic tide experiment!

The total strain is $4 \times 10^{-8}$ ($\Delta C = 1$ mm)

Nov. 11th 1992

Tide prediction
Success in the Press!

Moon Found Behind Particle-Accelerator Puzzle

GENEVA (IHT) — Scientists at the Europe-
ian Laboratory for Particle Physics will have to
calibrate their instruments on the Large Electron
Positron collider outside Geneva.

Long puzzled by variations in the energy of
the circulating beam made up of hundreds of
millions of subatomic particles, physicists have
discovered that these correspond exactly
to minute deformations in the Earth’s crust
caused by lunar attraction. Over the 27 kilome-

Physicists look to the moon for atomic answers

La lune trouble le CERN

L’énergie des particules circulant dans l’anneau
du LEP se modifie en fonction des phases lunaires.

Underground Water

1993: Unexpected energy “drifts” over a few weeks were traced to cyclic circumference changes of ~ 2 mm/year.

Driving “forces”:
- Underground water
- Rainfall
- Lake levels
- Other?

Circumference change measured with the radial beam position.

Correlates with lake level ...

"Heavy" Rainfall

1999 LEP run
The Crack in the Model

Spring of 1994: the beam energy model seemed to explain all observed sources of energy fluctuations...

EXCEPT:

An unexplained energy increase of 5 MeV was observed in ONE experiment.

It will remain unexplained for two years…
The Field Ghost

**Summer 1995** : the first field measurements inside ring dipoles.

The data showed (unexpected):

- Short term fluctuations
- Long term increase (hysteresis)

$\Rightarrow$ Energy increase of $\sim 5$ MeV over a LEP fill!
- Quiet periods in the night!

Human activity!

But which one??
Pipebusters

The explanation was given by the Swiss electricity company EOS...

I blast your pipes!

Vagabond currents from trains and subways

Source of electrical noise and corrosion (first discussed in ...1898!)

DC railway

Vagabond (Earth) current

~80%

~20%
Vagabonding Currents

LEP is affected by the French DC railway line Geneva-Bellegarde

A DC current of 1 A is flowing on the LEP vacuum chamber.

Entrance/exit points:
- Injection lines (Point 1)
- Point 6 (Versoix river)
November 1995: Measurements of

- The current on the railway tracks
- The current on the vacuum chamber
- The dipole field in a magnet

correlate perfectly!

Because energy calibrations were usually performed:

- At the end of fills (saturation)
- During nights (no trains!)

we “missed” the trains for many years!

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Epilogue

• 5 years (1991-1995) were needed to unravel most of the beam energy “mysteries”.

• Many other effects besides tides and trains are included in the LEP energy model. There is not enough time to give details ... 

• More than 50 24-hour days of machine time were devoted to energy calibration between 1993 and 2000...

• The LEP Energy Calibration Working Group was a very successful collaboration between physicist from the machine and the experiments, building ties between the two communities.

• The mass and width of the Z boson were measured with a remarkable accuracy (see forthcoming talks). The beam energy contributes ~ 1.5 MeV to the total errors. Work is in progress on for the W mass...
LEP Laser Polarimeter

- Si-W calorimeter
- Movable absorber (Pb)
- Detectors
- Synchrotron light monitor
- Nd-YAG laser (100 Hz)
- Laser pulse
- Expander
- Rotating λ/2 plate
- Mirror
- Laser polarimeter
- Optical bench
- Backscattered Photons
- Mirror
- Electron detector
- Positron bunch (11 kHz)
- Focussing mirror for positron measurement
- Electron bunch (11 kHz)
- Positron detector
- LIR 3 mrad
- 313 m

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