

# Energy Calibration at LEP

Spins, Tides  
and  
Vagabond Currents



LEP fest 10.10.2000

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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 :

$$P_T^{max} = 92.4\%$$

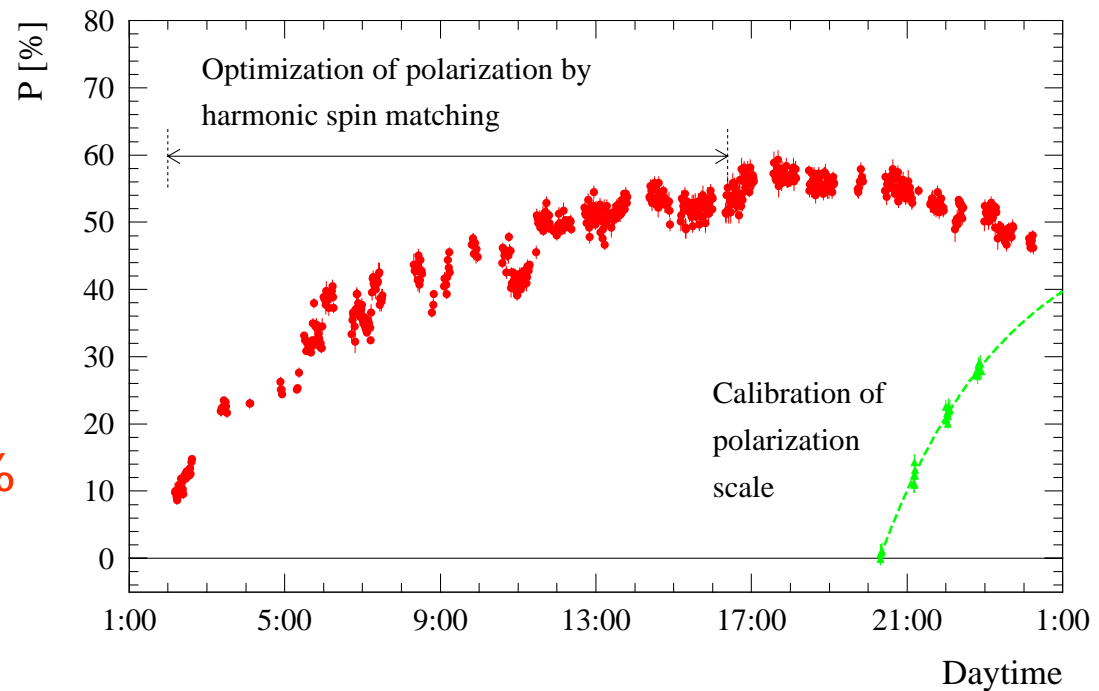
At LEP :

record  $P_T = 57\%$

routine  $P_T = 5 - 10\%$



Up to 60.6 GeV



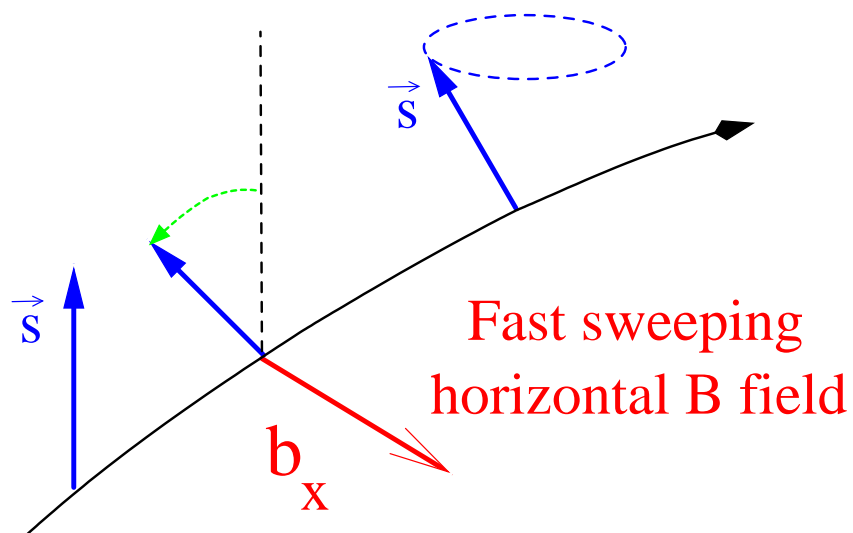
# Resonant Depolarization

The interest of  $P_T$ : **magnetic moments precess in B-fields.**

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

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

**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.

**Resonant depolarization**

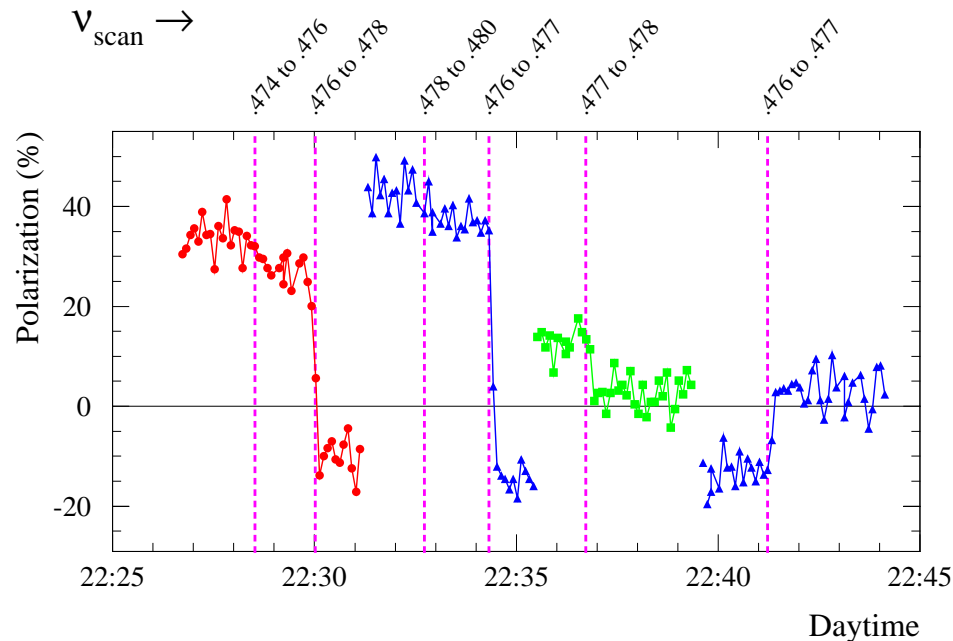
# Resonant Depolarization II

In the control room :

- Sweep the magnet frequency over a selected interval ( $\sim 22$  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 !

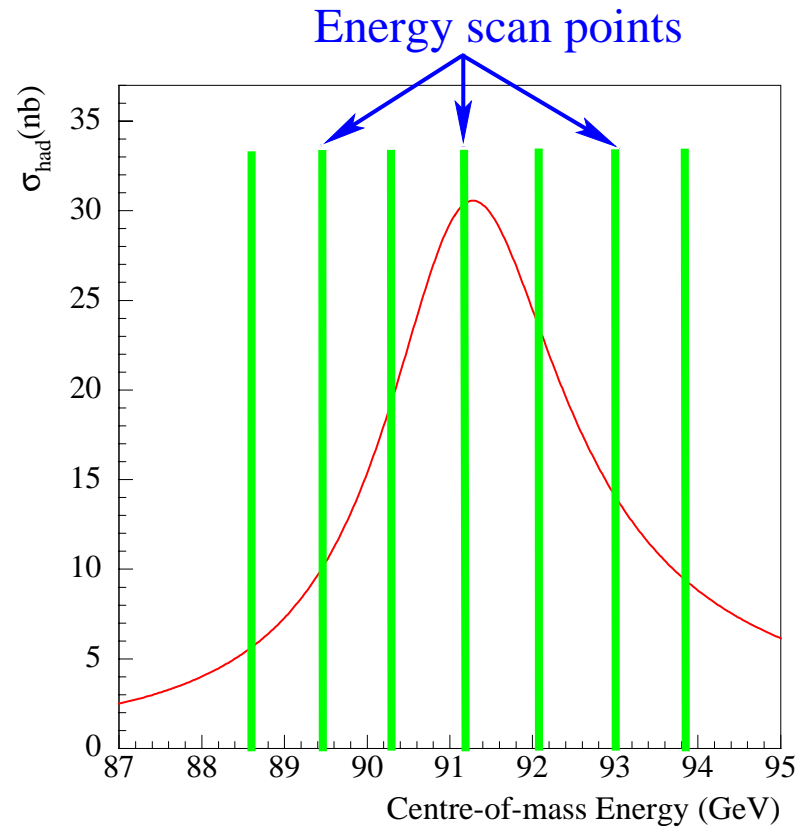
Calibrations cannot be performed during “physics” (no  $P_T$  with colliding beams)



Extrapolation in time



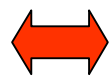
Beam energy model



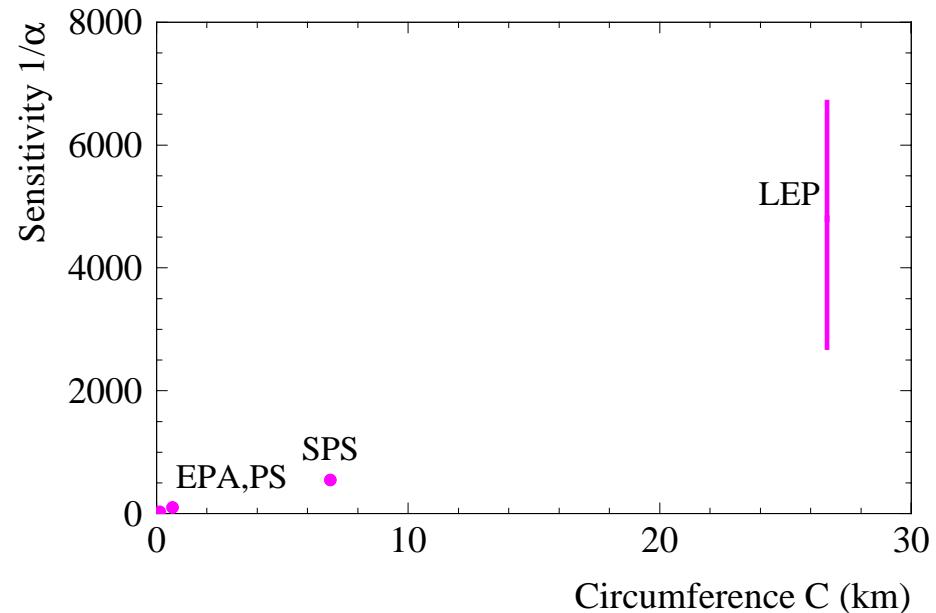
# Stressed Rings

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

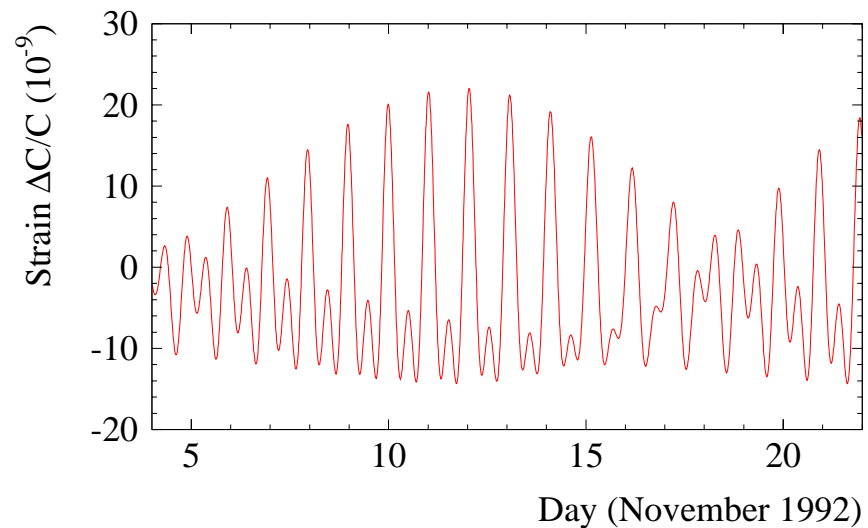
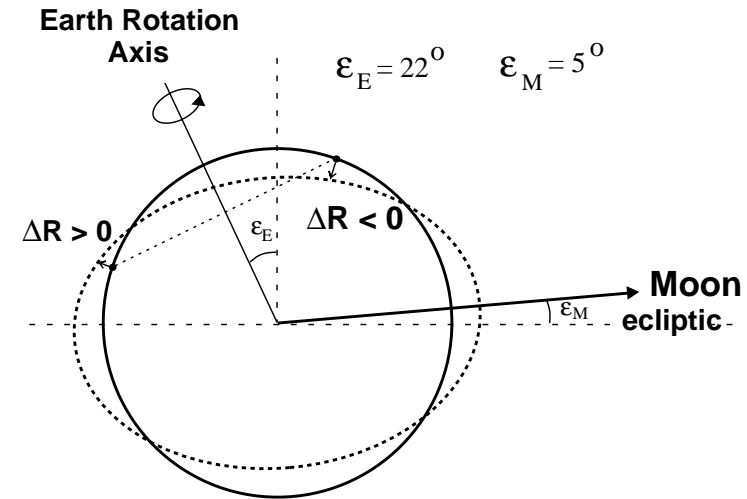
Tide bulge of a celestial body  
of mass  $M$  at a distance  $d$  :

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

$\theta$  = 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.

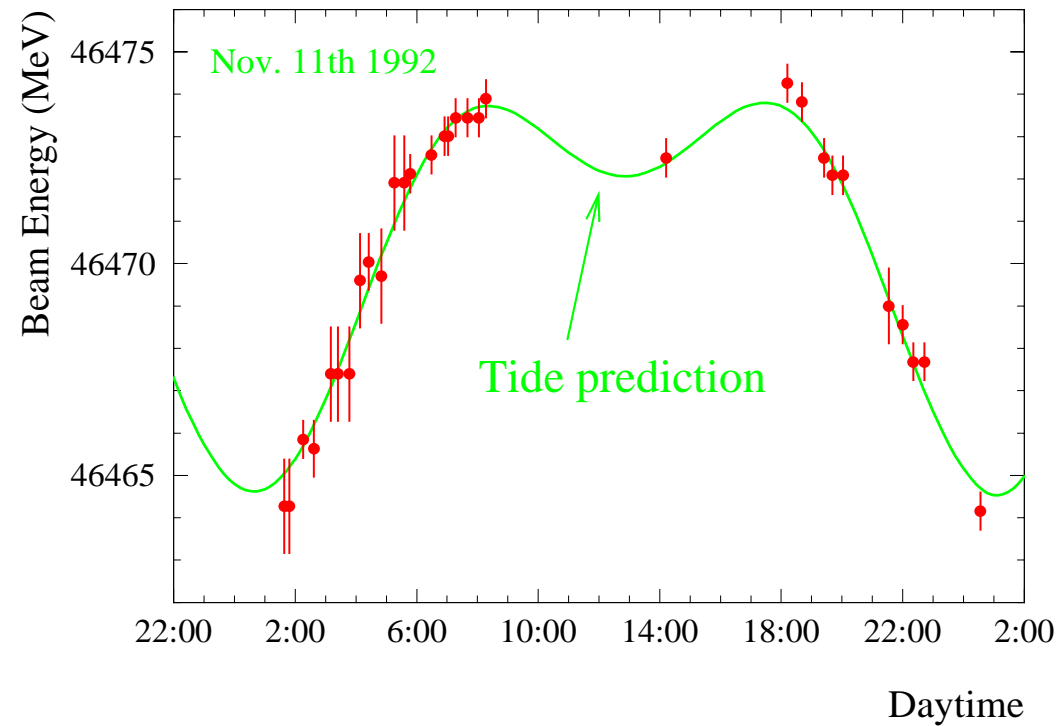




# Moonrise over LEP



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



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



# Success in the Press !

## Moon Found Behind Particle-Accelerator Puzzle

By MALCOLM W. BROWNE

For more than a year, physicists at the world's largest particle accelerator in the Swiss Alps, CERN, have been puzzled by a phenomenon that has baffled scientists for decades.

### In Physics, the Moon Factor

GENEVA (IHT) — Scientists at the European Laboratory for Particle Physics will have to consult the phase of the moon in future before calibrating 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 now discovered that these correspond exactly to minute deformations in the Earth's crust caused by lunar attraction. Over the 27 kilome-

ter, scientists suggested that lunar tidal effects might be responsible, but conventional experiments that proved beyond doubt that he was right.

The LEP accelerator straddles the border of France and Switzerland — or, more precisely, it is an acronym for "Large Electron-Positron collider," operated by the 16-nation European Organization for Nuclear Physics (CERN). Since LEP began operation in 1989, it has produced the most precise measurements of the

particle's mass to more than three figures of matter.

In a telephone interview on Tuesday, Dr. Evans said that now that the effect of lunar cycles on the energies of LEP's particle beams was known, adjustable corrections could be applied to all the data that the machine produces. "From now on, high-energy physicists will need to keep almanacs and tide tables handy when they do their calculations," he said.

When Dr. Albert Hofmann of CERN and his colleagues tested the concept with a long and exhausting experiment last week, they recorded a constant pattern of fluctuations in the en-

ergy of LEP's particle beams which matched fluctuations in the moon's position to within a few parts in a million.

Change in Tomer's Die

The moon's gravitational pull directly affects electron-positron pairs, positronium and antiprotonium. LEP's range of the moon's slightly larger track of 4000 km in width is extended, causing a 2.7-billion-volt charge on one side of the ring to be slightly higher than on the other. Such fluctuations in the energy of the beams with the



## SCIENCES

Au LEP, près de Genève

### Les effets de Lune dévoilés par les physiciens

Dans le grand accélérateur européen de particules, les mesures de précision ont parfois été perturbées.

## 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.

### PHYSIQUE DES PARTICULES Mystère élucidé Comment la lune a trompé le CERN : les physiciens expliquent

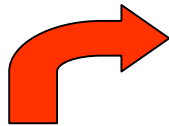
Les scientifiques ont enfin trouvé l'origine d'une imprécision qui entachait leurs expériences : des « marées terrestres » provoquées par la lune.

# Underground Water

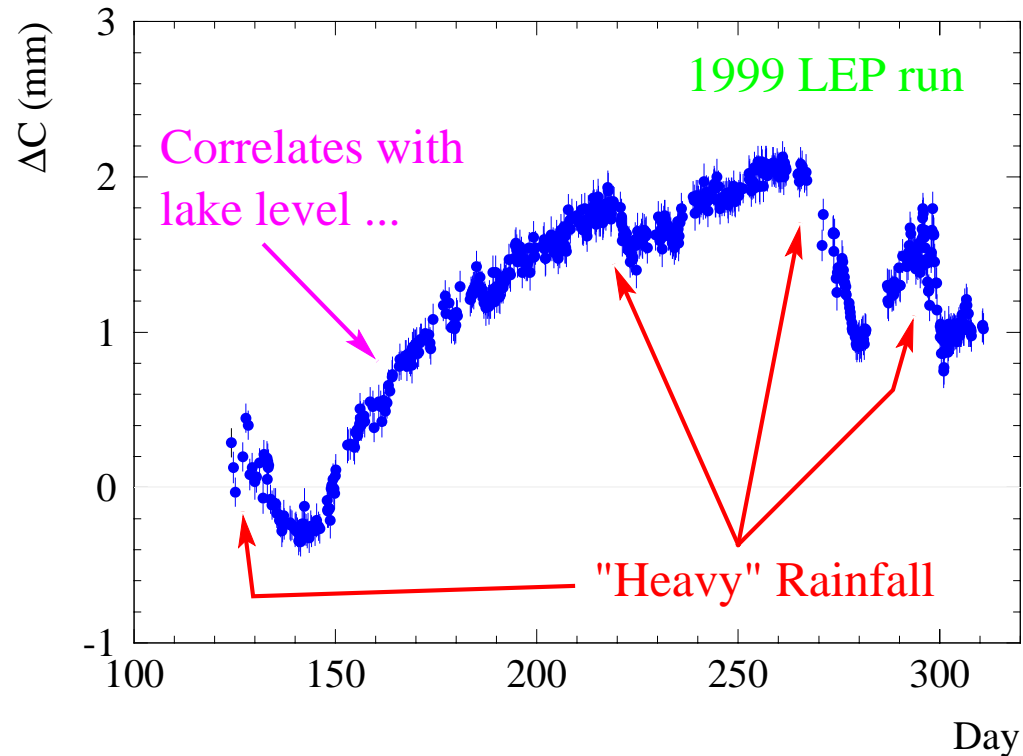
1993 : Unexpected energy “drifts” over a few weeks were traced to **cyclic circumference changes of  $\sim 2$  mm/year**.

Driving “forces” :

- Underground water
- ➔ Rainfall
- Lake levels
- Other ?



Circumference change measured with the radial beam position.

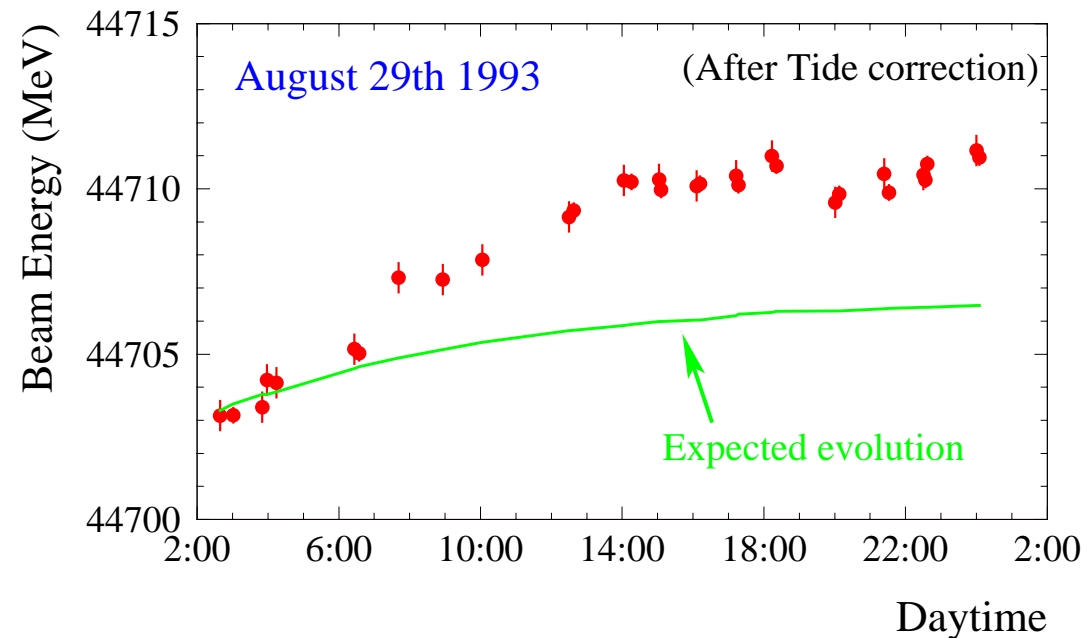


# The Crack in the Model

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

**EX CEPT :**

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.

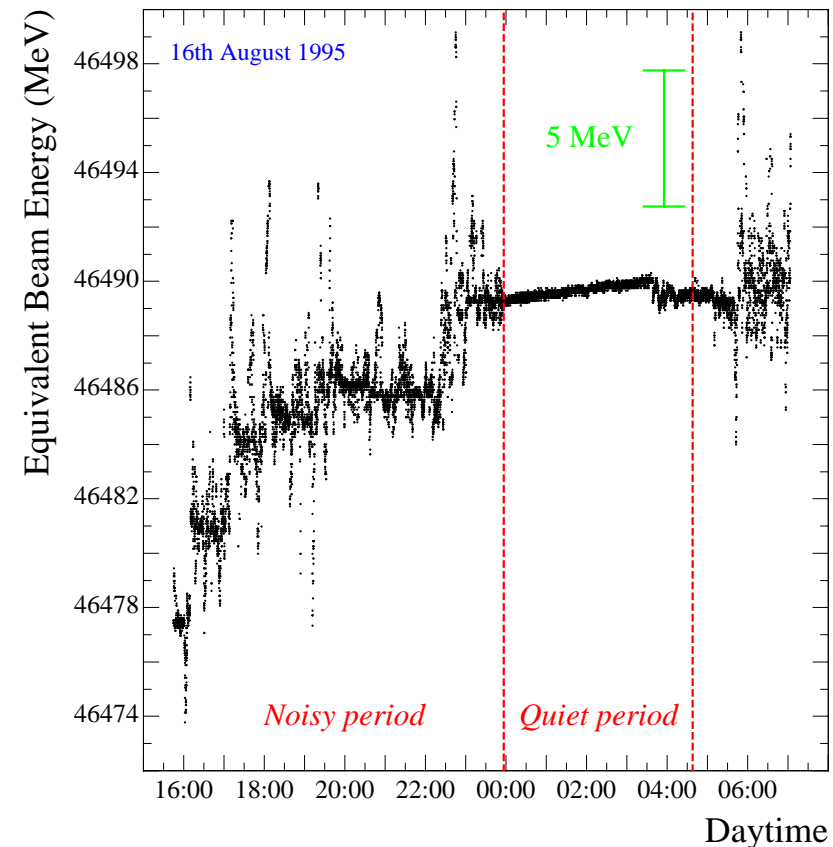
The data showed (unexpected) :

- Short term fluctuations
- Long term increase (hysteresis)
- ➔ Energy increase of  $\sim 5$  MeV over a LEP fill !
- Quiet periods in the night !



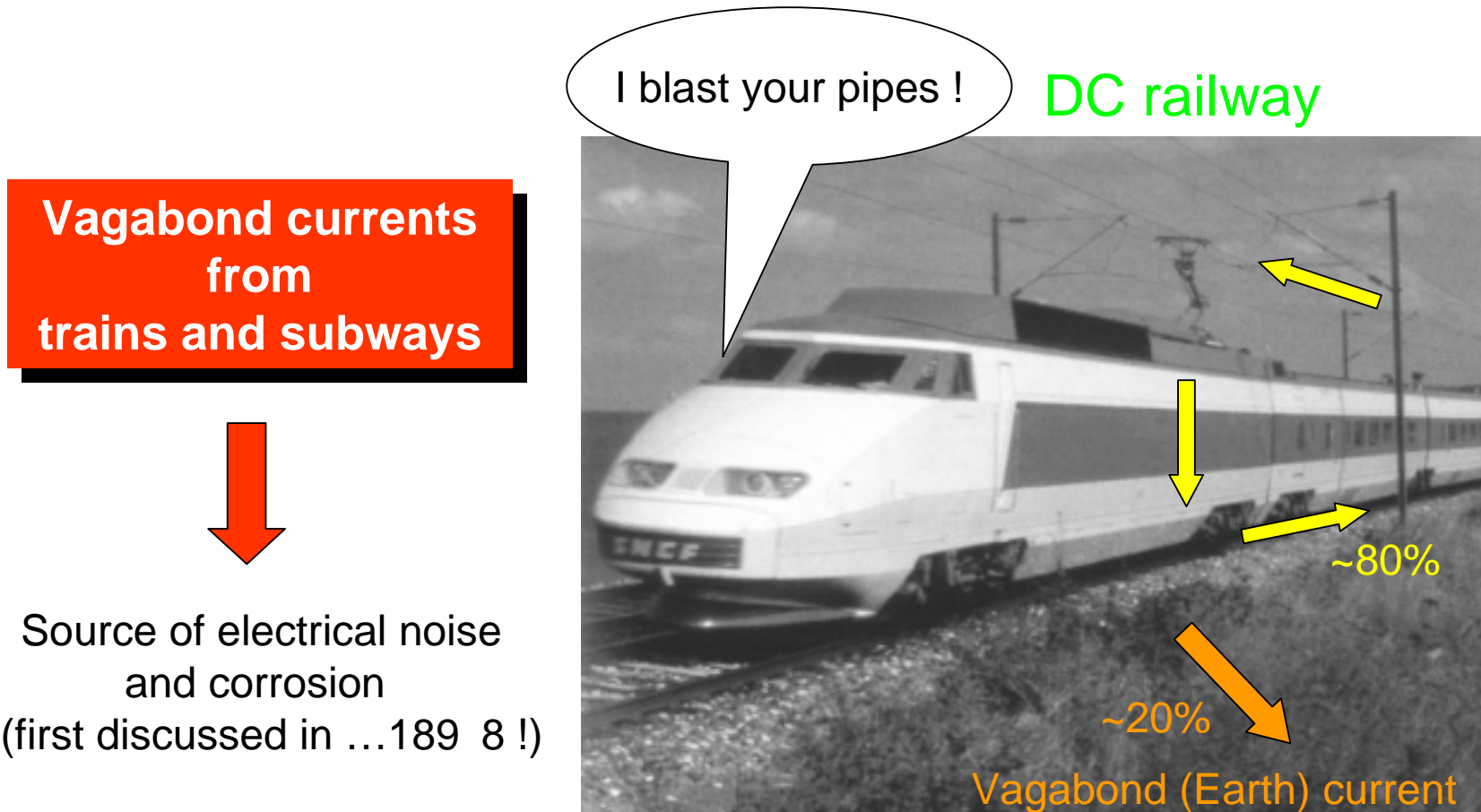
**Human activity !**

But which one ??



# Pipebusters

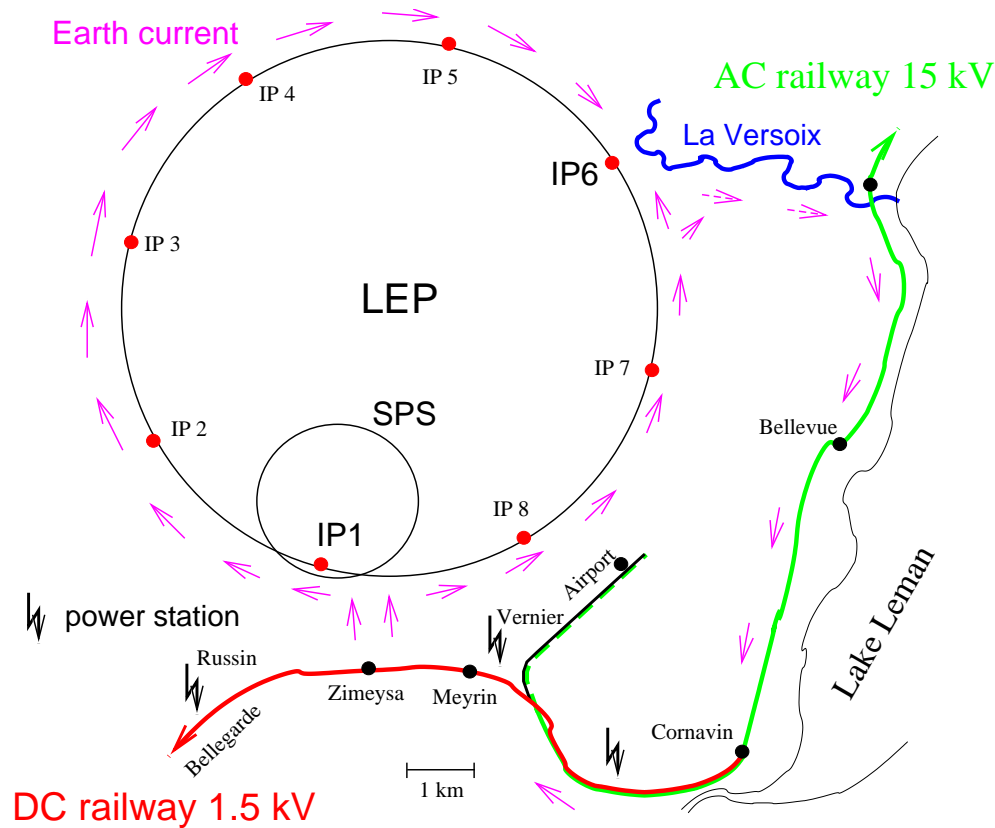
The explanation was given by the Swiss electricity company EOS...



# 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)

# TGV for Paris

November 1995 : Measurements of

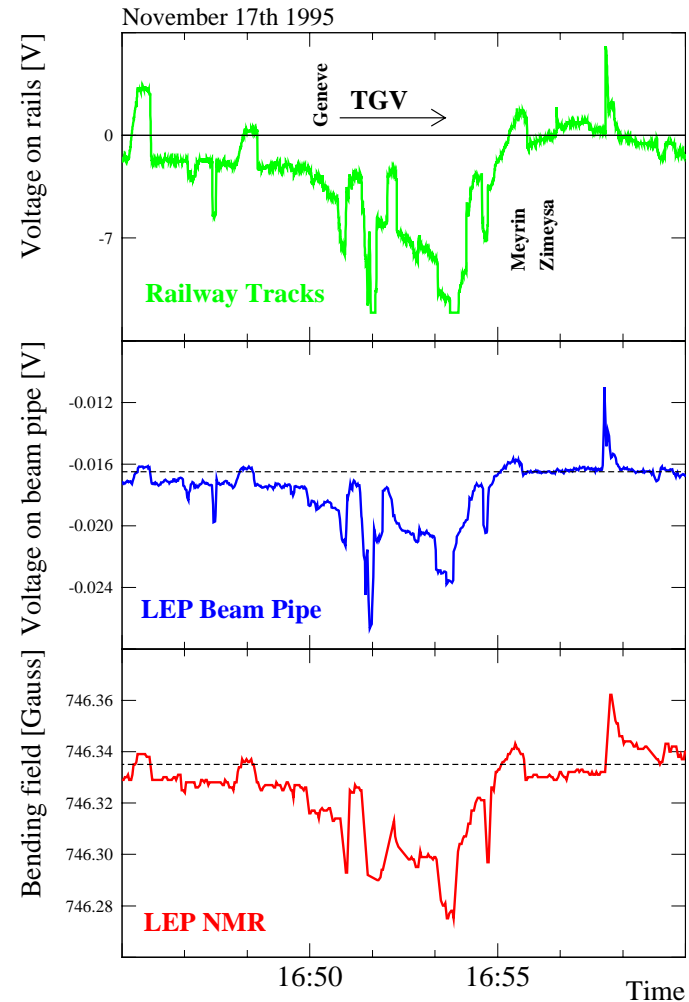
- The current on the railway tracks
- The current on the vacuum chamber
- The dipole field in a magnet

**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 !**



# 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  $\sim 1.5$  MeV to the total errors. Work is in progress on for the W mass...



# LEP Laser Polarimeter

