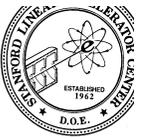


Why Does the LEP Tunnel Move the Way it Moves

Rainer Pitthan
SLAC



Why Does the LEP Tunnel Move the Way it Moves



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The 22nd Advanced ICFA Beam Dynamics Workshop
on Ground Motion in Future Accelerators
SLAC, Stanford University, November 6-9, 2000

LEP, containing the world's **largest** precision underground geodetic networks, is found to move vertically predominantly in a **systematic fashion**.

This study is only concerned with **yearly and longer** movements and does not help with vibrational problems.

What is it which result in such a strange behavior?

For updates: www.slac.stanford.edu/~rainer/GroundMotion/LEPHow&Why

Tuesday November 7, 2000



Thanks



Many people have contributed over 9 years to the idea of "systematic tunnel movements". Maybe the idea was spawned by Gerry Fischer always muttering about PEP: "**The hill is there for a reason**".

The PEP data came from Fred Linker, HERA data from Franz Löffler, LEP data from Michel Hublin, Michel Mayoud and Jean-Pierre Quesnel. Modern analysis was furnished by Fengxiang Jin whom I thank for giving me a deeper understanding of analysis and interpretation of leveling survey of large networks. The subject matter is alien to physicists because of the particular way errors propagate.

Gerry Fischer pestered me to the last week of his life: where is your write-up! I dedicate this talk to his memory.

This presentation has two parts:

The **second** part, dealing with the systematic motion of LEP, was prepared before the workshop started.

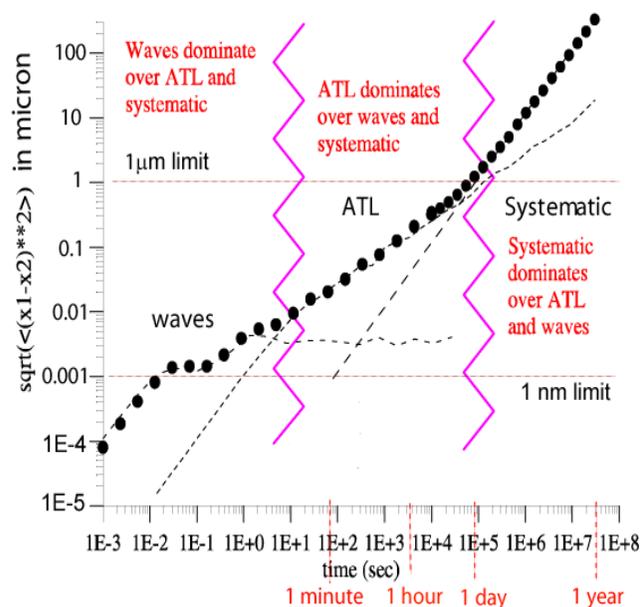
The **first** part was **added** as a consequence of what I have learned yesterday in the work shop, in particular what questions and results puzzled people. In particular I want to stress how important the random movements of the accelerator in the **1-hour-frame** are. Naturally this is **independent of the source of the motion** (geological ground motion through the tunnel floor, cultural noise from the outside, machine motion produced noise through water and ventilation, and others).

The SLAC (Ground) Motion Model (Seryi)

The SLAC motion model is based on wire measurements in the FFTB tunnel, short-term measurements in the SLAC tunnel using various instruments, and the 17-year long-term measurement of **rebound and settling** in the 2-mile tunnel using the laser and Fresnel lens system (for comparison, see **D. Martin's talk**).

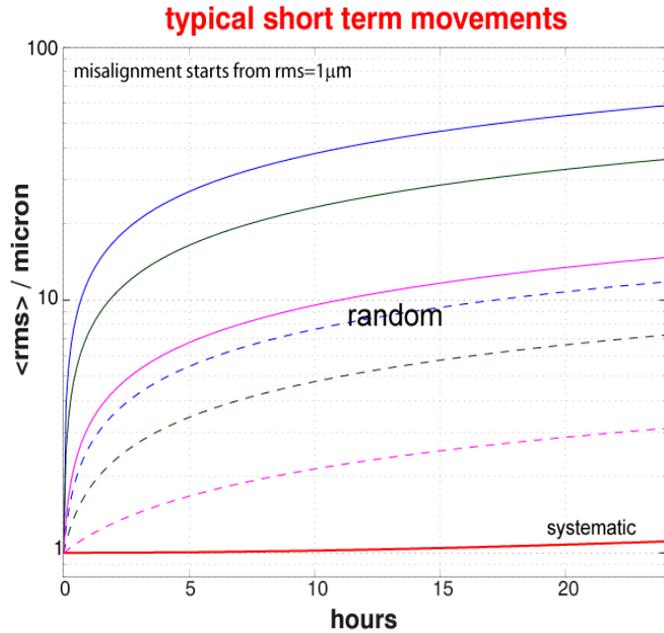
Since many measurements were based on the motion of equipment, it is not a "true" ground motion model (see talk by A. Seryi). I want to emphasize the importance of getting a clear **quantitative** picture of the **minute to hour** movements of accelerator components, because these will **make or brake operation** of a linear collider.

Sery's SLAC Motion Model (based on $\Delta L=30m$?)



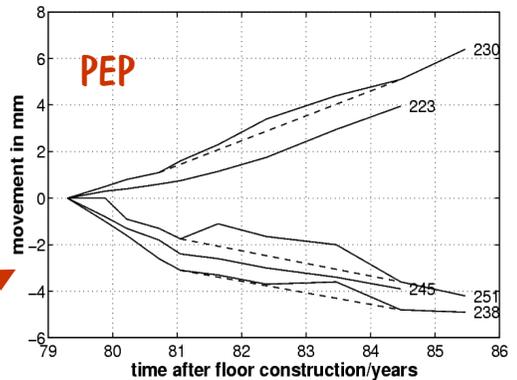
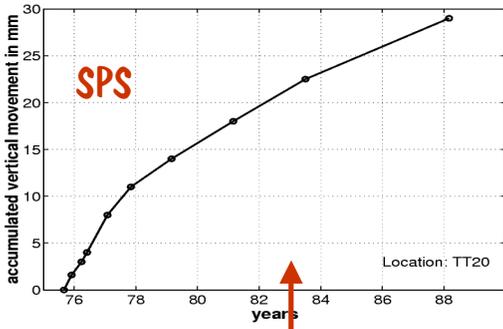
The importance of determining precisely where the random regime ends, and where the systematic movement regime starts, is demonstrated with the graph on the right: Random movements are $\sim\sqrt{\text{time}}$, while systematic movements are linear with time (different curves in the plot make different assumptions about the length parameter L in random movements, SLAC-PUB-8286).

Since mis-alignment tolerances are a few microns at best, random movements force re-alignment on a short time scale.



How Did We Get There?

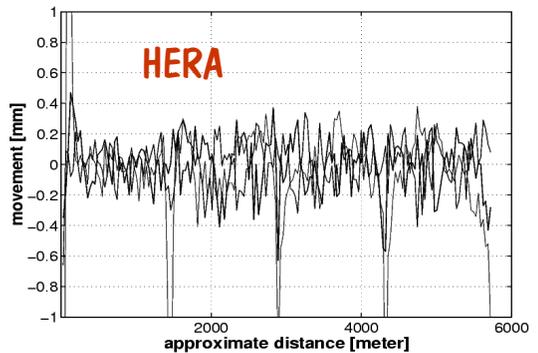
Once upon a time it was observed



...that many points in accelerators move unidirectional!

Oops →

HERA has no discernible long-term movements. It is different because built in sand and not in a solid geological strata! The price to pay is in the larger sensitivity to vibrations.





Quantitatively: How LEP has Moved Vertically

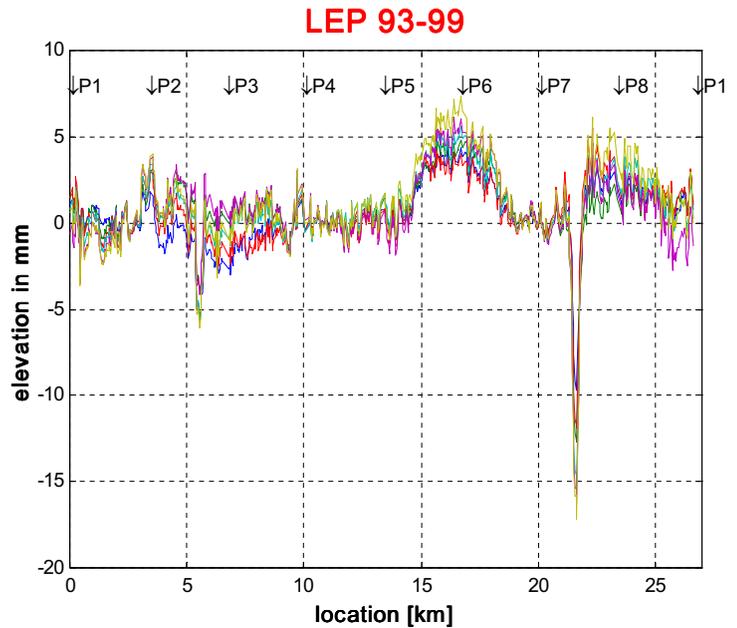


Global (and literal) interpretation of the data is tricky and can be dangerous (see talks by F. Jin and M. Mayoud). Elevations meander around, without apparent underlying motion. Need independent monitoring system.

Interpretation not done here, but see SLAC-PUB-8286.

Focus later will be on particular localized movements in

P1 (Injection) P2.7 (Sergy)
P3.8 (Allondon) P7.5 (Ferney)
and non-movement in P4-P5.



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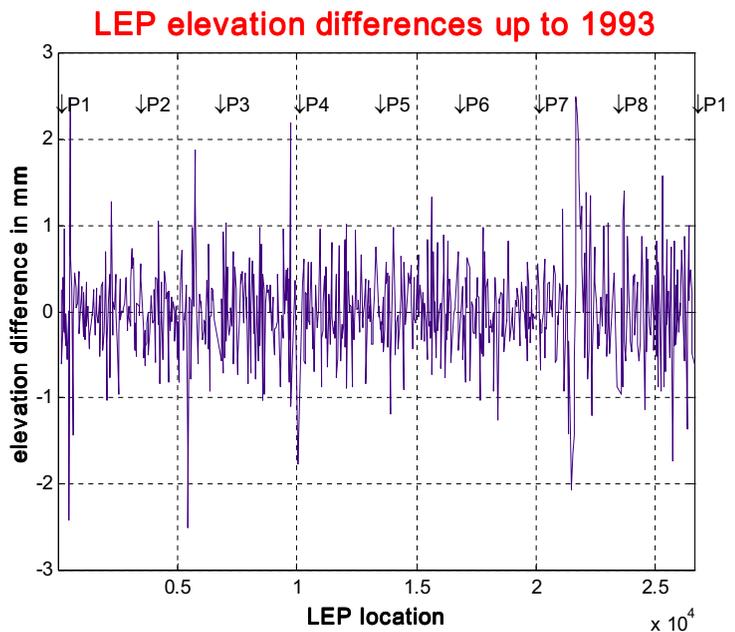


Actually More Useful: Differential Movements



Using differences avoid model dependencies. It is a better representation of the non-smoothness of the movement. It is also identical to the original measurements.

It is the most important quantity for LHC with the limited range in movements of super conducting vacuum connections between cryostats.



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- LEP long-term accelerator floor movements do not follow one quantitative rule. Quadrupole rms-differences vary from 0.05 mm/year to 0.2 mm/year, regionally different.
 - Although qualitatively each point with a clearly discernable movement seems to be moving in one, and one only, direction over time (that is, systematic), the direction and its magnitude depend on the locality.
 - So the future accelerator builder has to go through the messy process of investigating the built accelerator, its construction, geology, hydrology, etc., to extract possible lessons to apply.
 - To boot, vibrational issues might also be different in different locations.
- Good Luck!

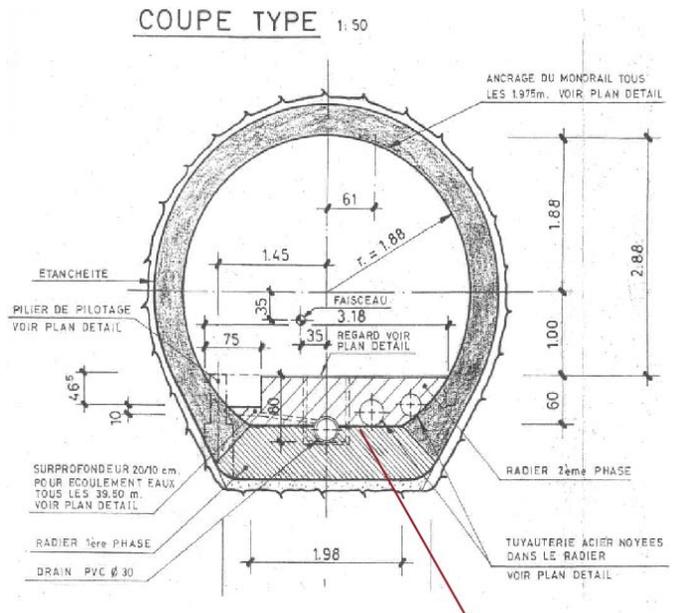
Differential floor movements are small (smaller than at SLC).

Rms (not rms²) movements range from ≈ 60 μm/year for region P4-P5 to ≈ 175 μm/year for region P1.

Contributing to stability is the very elaborate concrete floor:

two layers of 60 cm each (4 times as thick as the floor in the SLC arc tunnels).

However: no rebar. No ties between floor sections.



4 feet thick tunnel floor, poured in two layers

What I will talk about further:

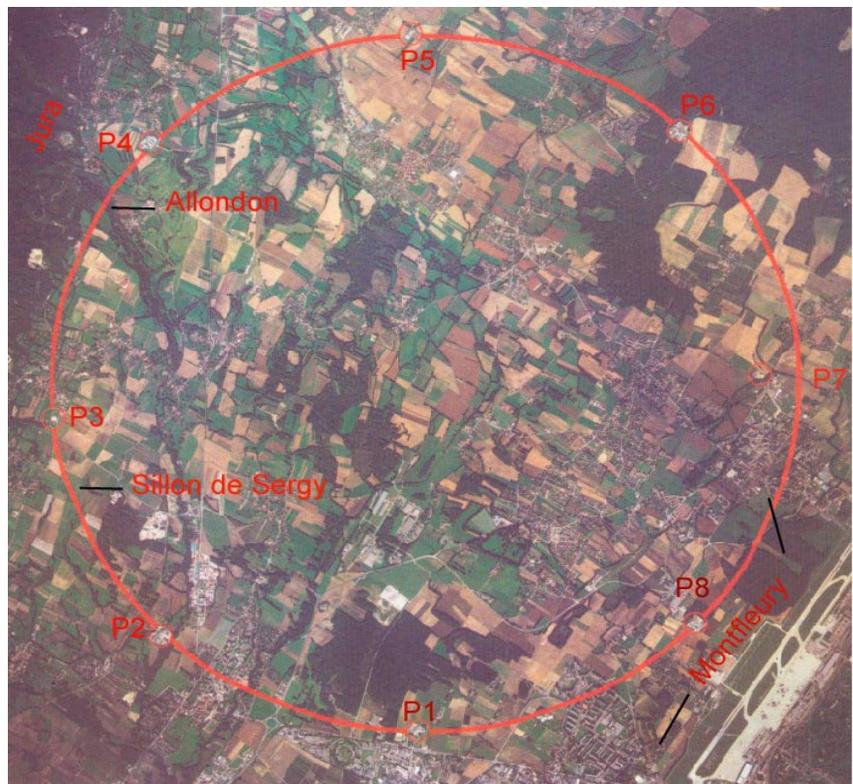
- **Global** view of the area LEP is situated in, the **Pay de Gex**, situated between the Jura Mountain and Lake Geneva (Lac Lemman).
- **Tectonically active** area.
- **Loose Ice Age** deposits (Moraines) on top of **compacted sand stone** (Molasse, not unlike the stone most of the SLC arcs are build in). Composition of Molasse very uneven – many inclusions of other material.
- 24km of LEP are bored in this sand stone, 3km in the lime stone of the Jura. Both are separated by an **evil layer of clay** (Gompholite = Butano at SLAC).
- Lively **underground water activity**, in conjunction with many fault lines
- Focus on **particular locations** in LEP which have large movements and can be explained by the above.

The Apparent Environment: Topology of the Pay de Gex

Large movements of the LEP tunnel floor happened and:

- Were **expected** at the **Allondon Fault** and maybe at **P1** (Injection Tunnels joining LEP in sections with different cross sections).
- Were **not expected** next to the **Airport** at the **Sillon de Montfleury** and at the **Sillon de Sergy**.

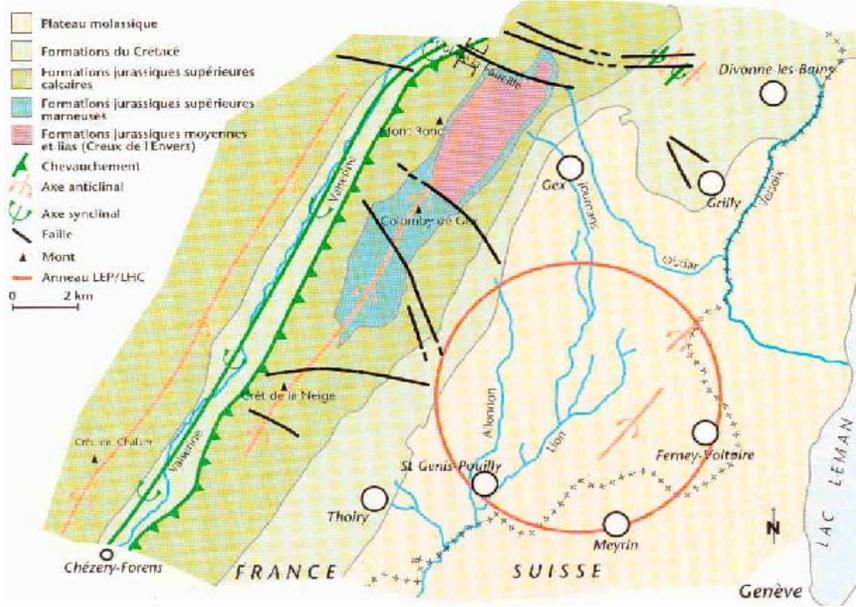
Sillon \approx **Underground Valley**, maybe **Aquifer**.



Drainage mostly from N->S toward the Rhone.

There is a hill (synclinal) west of Ferney and between Ferney and Lake Geneva. And a water channel is going from Ferney to Meyrin (**Avril de Nantes**).

2 Fault lines cross LEP around P2.7, and one at P3.8 (Allondon).

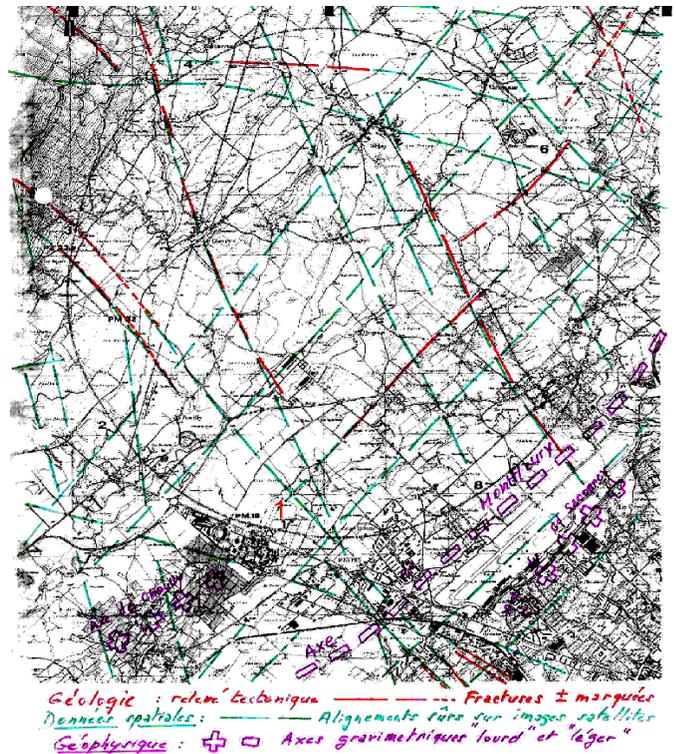


Red Lines faults determined through classical geology.

Green Lines faults found with Radar Satellite through GEOSAT.

Map courtesy of Michel Hublin.

Note the mark-up of "Montfleury" next to the Airport.



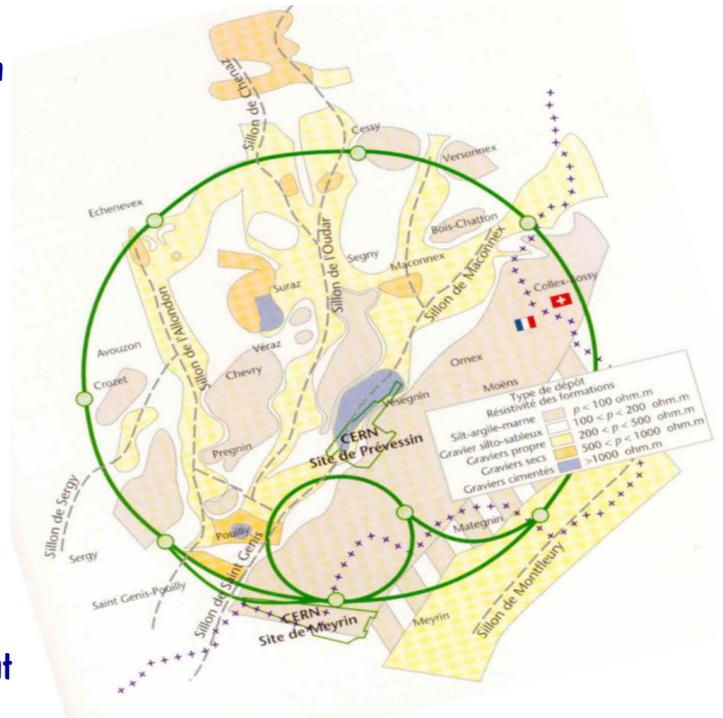
Underground **drainage** in the Pay de Gex is mostly (but not exclusively) from North to South (Rhône).

LEP itself is **tilted 1° West (high) to East (low)**.

The aquifers in the north have no apparent impact on LEP because of the good north-south drainage.

But the two in the south (Sergy, Montfleury) coincide with large movements.

Montfleury is also close to the lowest point of LEP, where the water would collect.



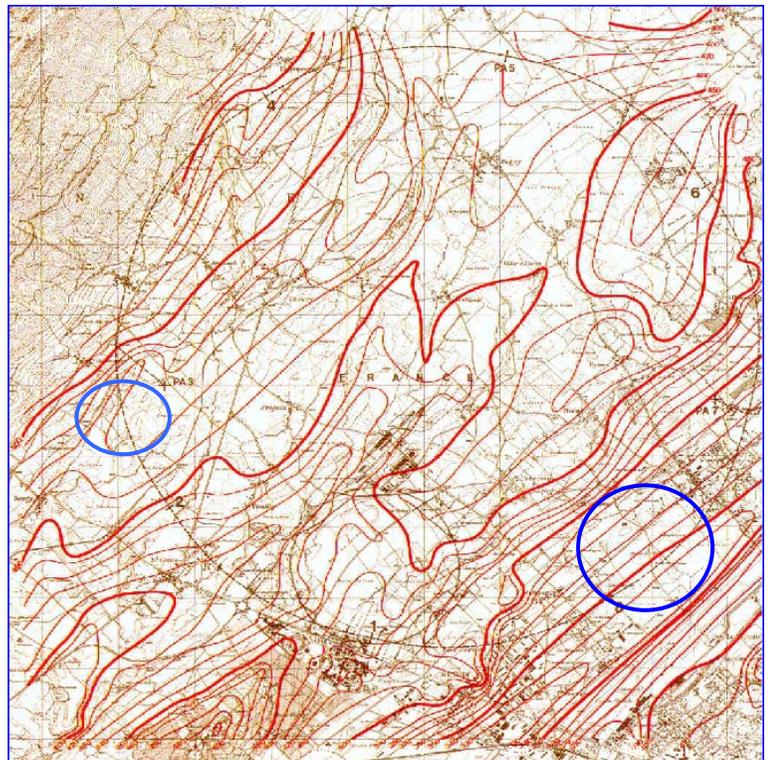
Clue to large movements:

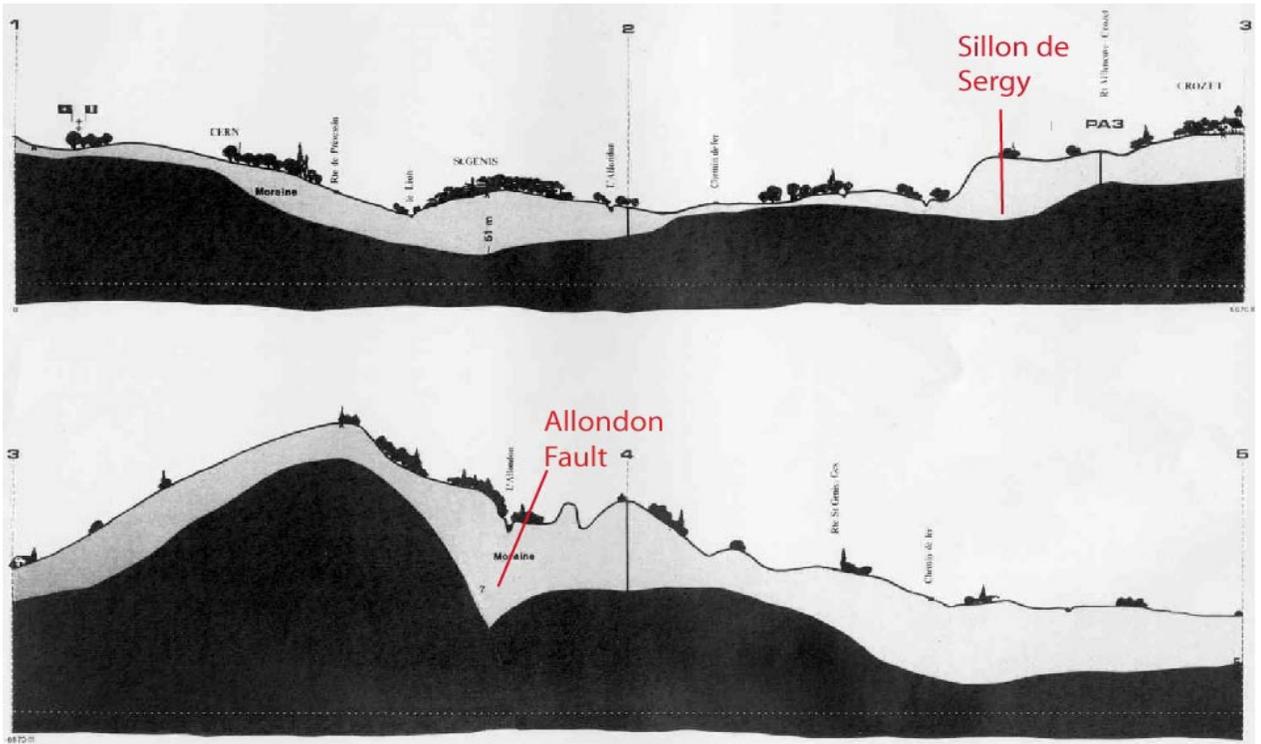
water puddles on top of the sand stone (blue rings):

Existing faults
+ water
≈> movements.

Faults maybe new or old?
dormant or active? known from geology or visible from satellite radar?

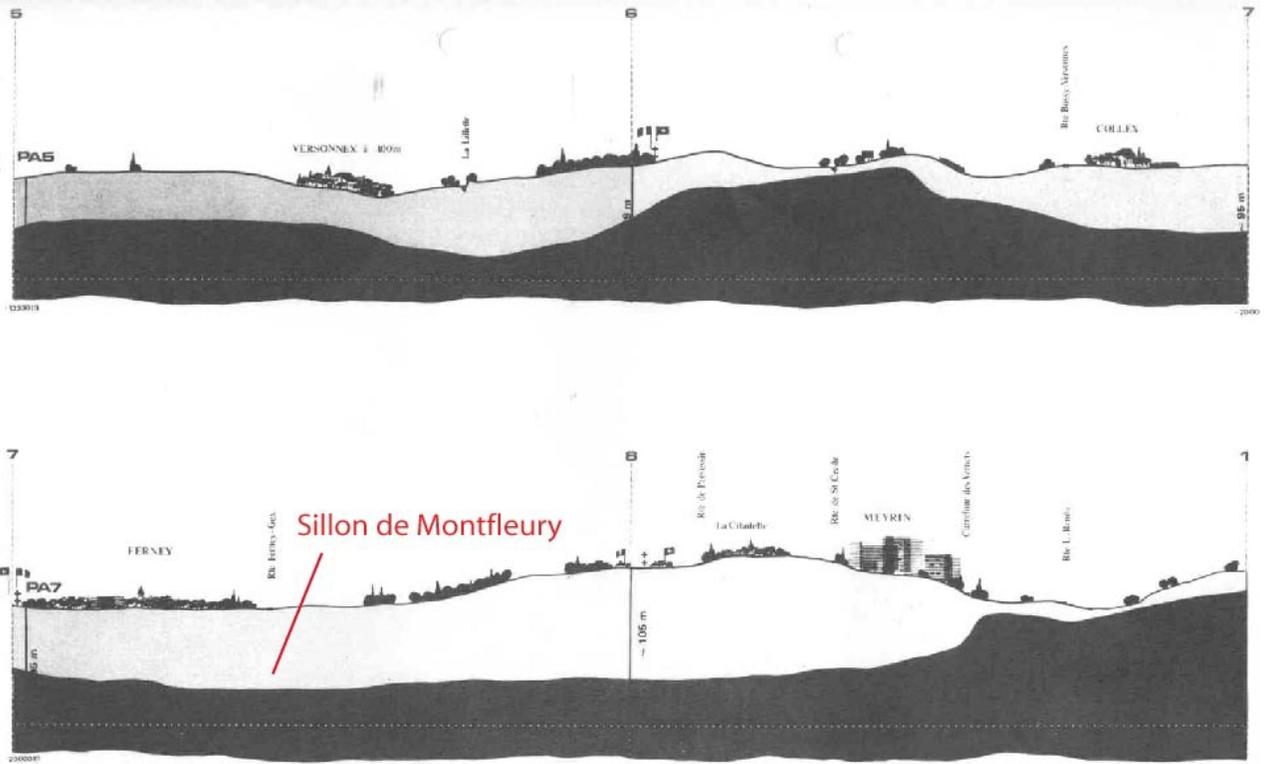
Not clear if the existence of water, or the drainage of water, is the culprit after construction?!





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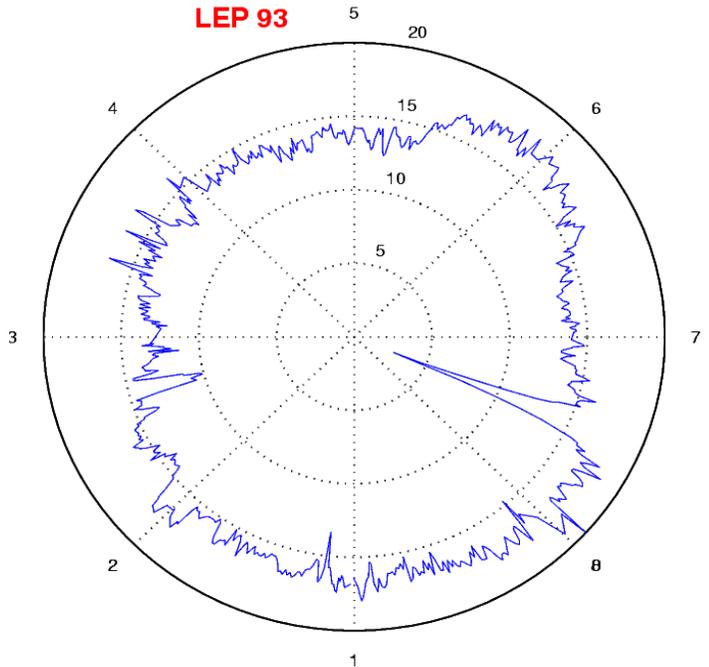


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Nominal zero: set to 17 mm.

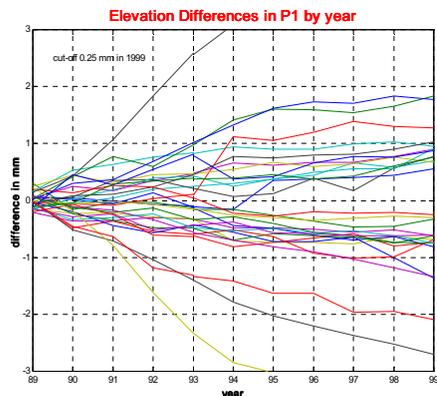
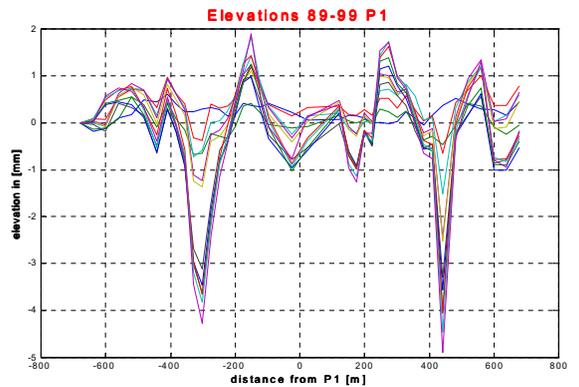
1. **Best documented:** P1 (Injection)
2. **Most quiet:** P4 to P5
3. **Largest settling:** near Ferney at P7.5, at the Sillon de Montfleury
4. **Most ragged:** under the Jura between P3 and P4 (the Allondon is at P3.8)
5. **Also noticeable:** at the Sillon de Sergy at P2.7



Note: Data for the larger movements seem to fall into **2 groups**, 88-94 and 94 -99.

Reasons not clear. Any or all of the possibilities are:

- Earthquake (in '94, after survey, before alignment)
- bookkeeping
- change of smoothing algorithm
- Begin of preventive misalignment (Running with the Wind).



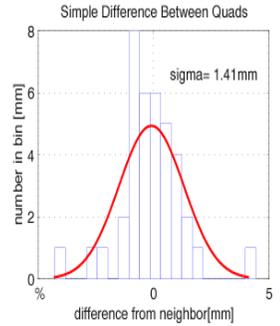
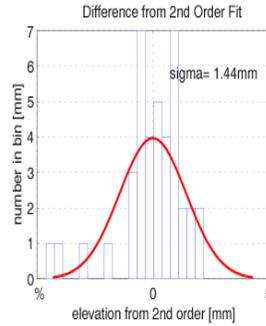
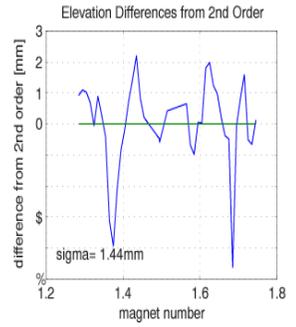
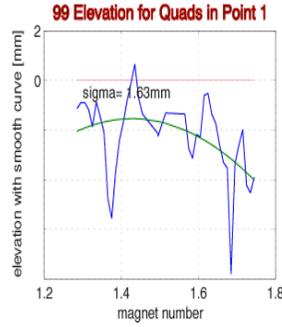
If $rms^2 = ATL$ would be valid, rms^2 for elevation vs. elevation differences should be different by a factor of $L1/L2 = 17$. The rms' itself should be different by $\sqrt{17} = 4$.

The factor of 17 comes from using $L_{elev} = 680$ m for calculating the elevation-rms, and $L_{diff} = 40$ m in calculating the difference-rms.

But the rms, 1.44 mm and 1.41 mm, respectively, are identical within errors.

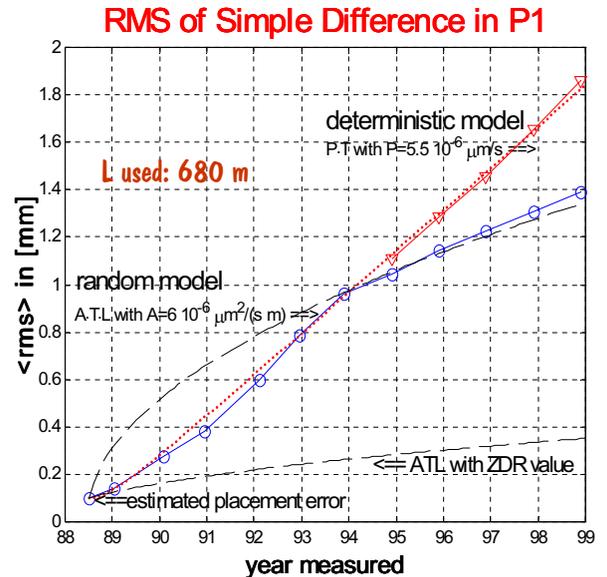
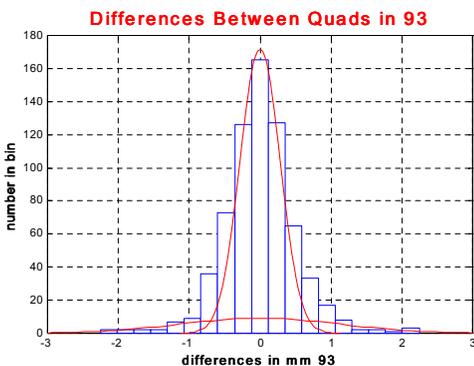
ATL can not be valid here. Since it is obvious that there is a dependence on T, the dependence on L must be wrong.

I am thanking V. Shiltsev of making me aware of this contradiction and conclusion.

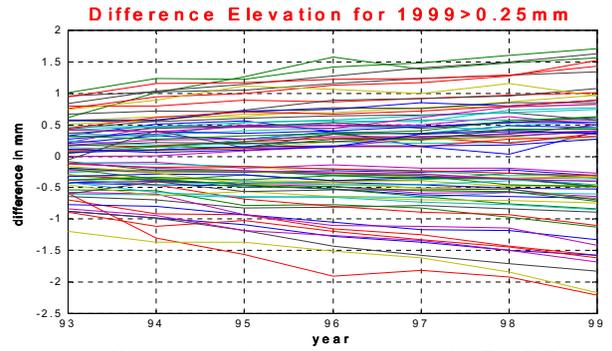
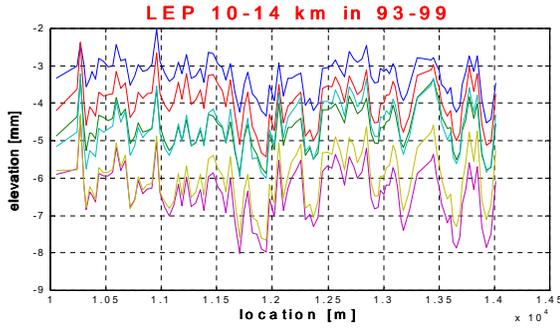


P1: $\langle rms \rangle(T) = 0.17$ mm/year
3 times the low typical movements (wide vs. narrow curve below).

Not the only place in LEP with that order of movement, but higher than most.



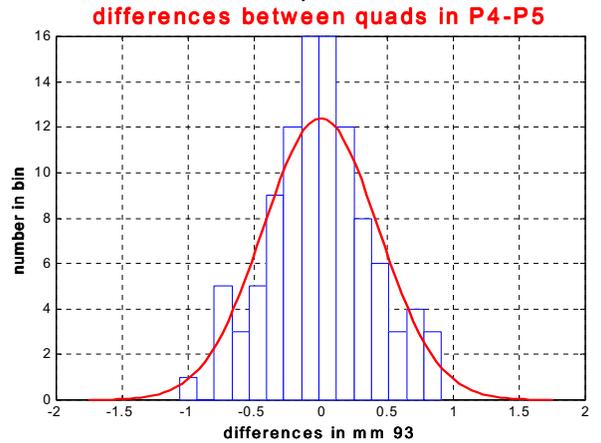
Difficult to decide which L to use for ATL curves? Previous slide shows either 40m or 680m are OK, conceptually at least. Naturally, only one can give the right answer.



Smallest movements: **0.06 mm/year !**
But why so regular?

Perfect systematic and/or random movement overall.

Explanation: construction of LEP Tunnel!

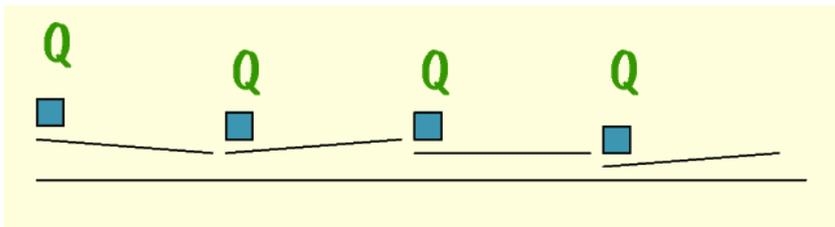


Unbeknownst to the Machine Physicists:

The Civil Engineers **matched** the floor and wall construction length to the Quadrupole (betatron) pattern of the arcs: 39.5 m for the floor, 39.5/4 for the wall sections.

That means if **one** floor section moves, **one** Quadrupole moves with it. Floor sections are **not** connected.

Movement is 60 μm/year in the best "normal" case.

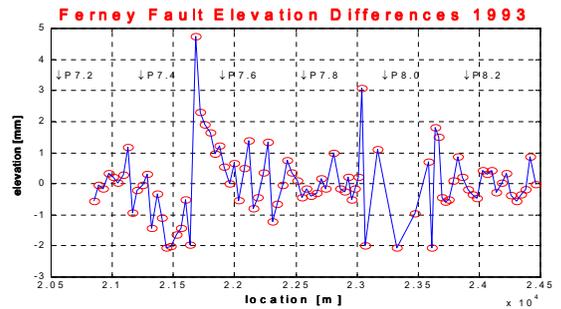
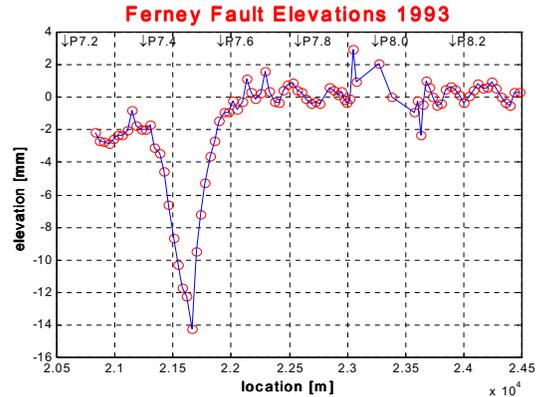


Longitudinal cut shows **nothing special** above or below ground in P7.5.

But: both geological and Satellite data show **fault line(s)**. Sillon de Montfleury was an aquifer known; no concern was raised.

No survey data between 88 and 93. LEP management did not want to spend the money. Detrimental effects on machine operation not apparent until ~93.

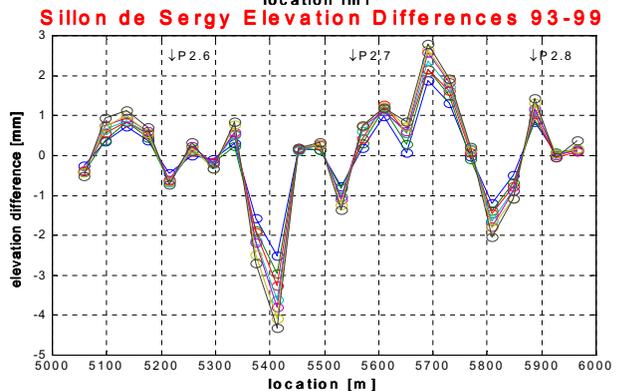
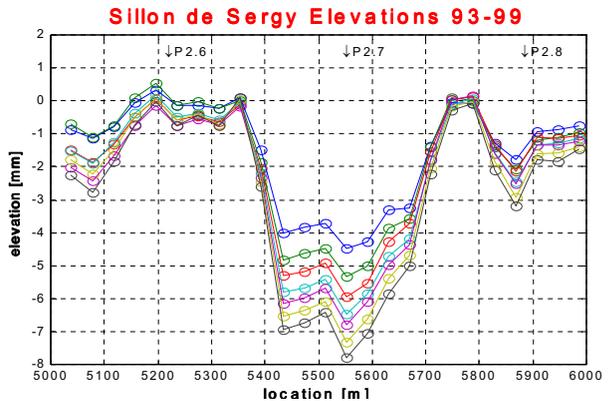
Difference plot could be interpreted as **plot of pitch** (change of slope) between adjacent magnets.



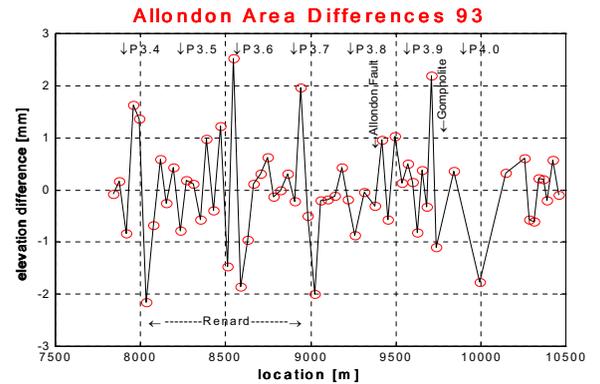
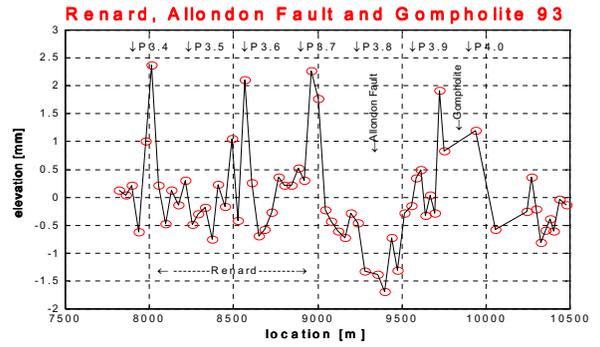
LEP Environmental Impact Report mentioned (but no alarm signal):

Two fault lines from the Jura (Calame, Tremblaine) cross LEP here + important underground water drainage area (**Sillon de Sergy**).

The **width** of the measured LEP movement (300m) identical with the known **width** of the underground valley.



1. Flagged in the LEP Design Report as a potential trouble spot because of the **Allondon fault**.
2. Vicinity: during tunneling water was hit (**Le Rénard**). Upward movements happened for many years until they stopped. Not clear if pumping of **grout** or **self-healing** of lime stone responsible.
3. The boundary between the Molasse and the lime stone is a **clay layer** (**Gompholite**). **Swells when wet** → upwards movement (**Butano at SLAC** does the same).



Conclusions

Not very satisfying: **There is no cure-all, no explain-all. However, the "Fischer Principle" has been verified": Every Ground Motion has a Definite Explanation.**

The **long-term motions are systematic** (deterministic) in time. There is no indication of any L-dependence in space, beyond what can be explained by the **leveling error**.

Result intellectually satisfying, even nice, but **doesn't help** with the vibrations which will kill us with the Multi-TeV Colliders. **Helps though** with proper design of range of supports.

Good tunnel floor engineering important. Learn from LEP. **Rebar! Good drainage** -neither too much nor too little - also important. Maybe **humidity of soil** needs to be monitored and kept constant? **Vibrational properties** probably also will be different in different parts of the tunnel?

Recommendations:

- Design monolithic floor, as done in modern synchrotron sources.
- Just right drainage **drainage** – neither too much nor too little – is important.
- Monitor **humidity of soil** and keep constant?
- Don't try to find a **one-fits-all** theory. Think globally, measure locally!
- **Survey early** after beneficial occupancy – determine motions – plan girder adjustments accordingly.
- **Do not abandon monuments** while going to smoothing methods. Monuments are necessary to track **deformations of the tunnels themselves**.
- Make provisions for measurement of **straightness independent of beam**, as with the **SLAC Laser Alignment System**, or the **CLIC Wire System**.

