FIG Working Week 2004

Athens, 4-7 October 2004

Large Scale Metrology for Research and Industry

Application to Particle Accelerators and Recent Developments

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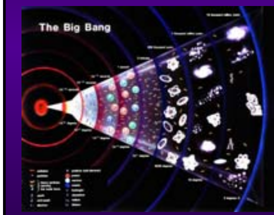
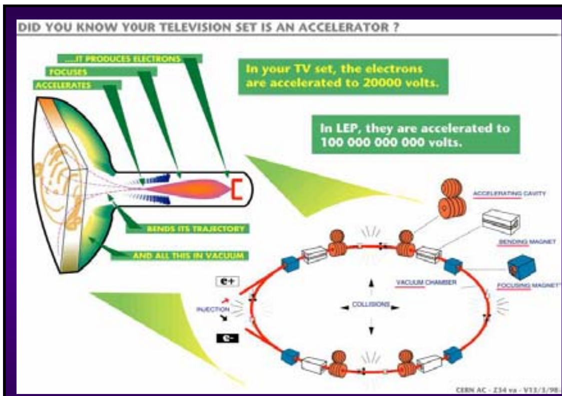
What is CERN? Why HEP research?

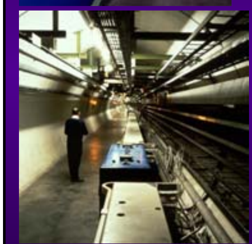
- European Organisation of 20 member-states + associates
- World's largest Laboratory for Particle Physics (9000 persons)
- Fundamental research in High Energy Physics

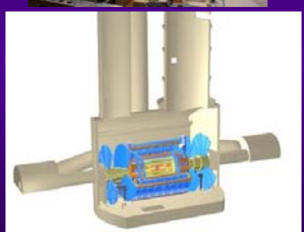


Why surveyors at CERN ?

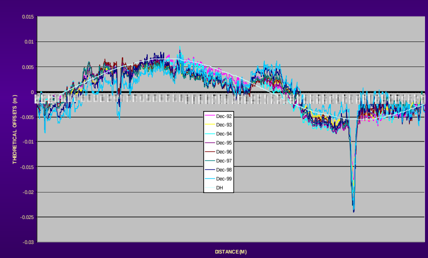
- 65 km of beam lines, >8500 elements "aligned" and surveyed
- High precision requirements on accelerators : 0.1 mm to a few µm
- Huge detectors on experimental areas and caverns, also capable of tracking particles within 0.1 mm to a few µm
- Ambitious projects and unusual challenges : focussing particle beams to a few nanometres and colliding them, or sending particles towards a detector at 732 km...







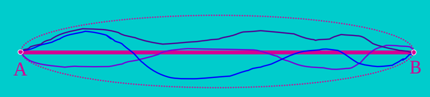
Stability of LEP (27 km) : annual levelling before realignments



Comparing successive surveys

Successive surveys of a perfectly rigid and stable object :
if random errors only, all "wrong" lines have the same likelihood to be true…

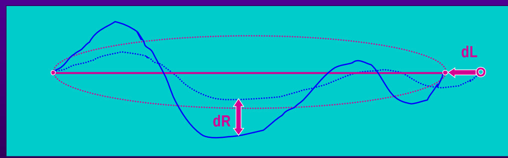
Stable traverse or arc AB of length L_{km}



No deformation signal there, only measurement noise (random errors);
Beware of biased conclusions…

Horizontal Surveys : combined effects

- The overall changes of curvature are induced by errors (random & systematic) in distances and/or in radial measurements, but also by those of control points;
- The general pattern - i.e. the polynomial order of the trend curve - depends on the scheme and quality of the measurements (redundancy, accuracy, overlaps);
- Local dispersion (smoothness) depends on resulting short range errors;

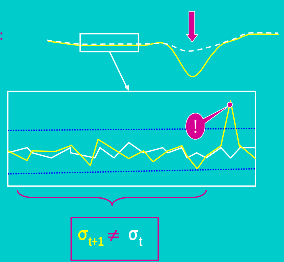


Comparing surveys : what is it looked for ?

Seeing & correcting true deformations :
"ad hoc" local comparisons

Restoring a functional alignment and correcting singular movements :
smoothing process

Assessing the alignment decay :
statistics on alignment changes

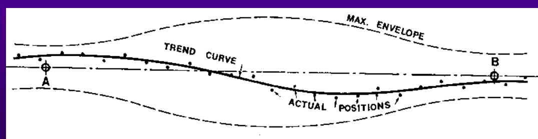


The smoothing concept

•The initial alignment consists in reducing the scattering to within the specification (0.10 to 0.15mm r.m.s) by moving selectively the misaligned components

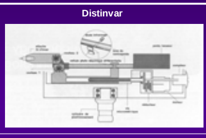
•Maintenance alignments aim to restore this situation at the optimum of functional values whenever needed

•Smoothing algorithms can be parametric or non parametric, and data processing is made in a sliding window - with an adjustable threshold which optimally selects, from local fits and statistics, the components to move back to a better position.

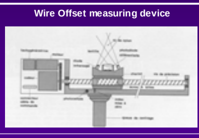


Past developments made at CERN for managing 0.1 mm accuracy

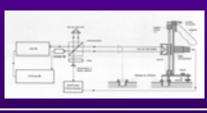
Distinvar



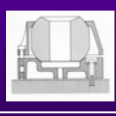
Wire Offset measuring device



In situ interferometry with self-aligning reflector



Force-centring reference socket



New developments for managing a few µm accuracy

Wire Positioning System (WPS)
One or two axes
Measurement range : ± 5mm
Resolution: 0.1 µm ; Repeatability: 1 µm
Bandwidth: 0-10 Hz

Hydrostatic Levelling System (HLS)
Measurement range : 5 mm
Resolution : 0.2 µm ; Repeatability : 1 µm
Bandwidth: 0-10 Hz

Tilt Meter System (TMS)
Biaxial measurement of tilt and acceleration
Measurement range : ± 10-2 radian
Resolution : 10-7 radian ; Repeatability : 10-6 radian
Bandwidth : 0 to 100 Hz

Actuators
Stepwise motorization
Length at mid course : 155mm
Diameter : 60mm ; Travel : ±4 mm
Resolution : 0.2 µm ; Repeatability : 1µm
Maximum load along the trust axis : 400 N

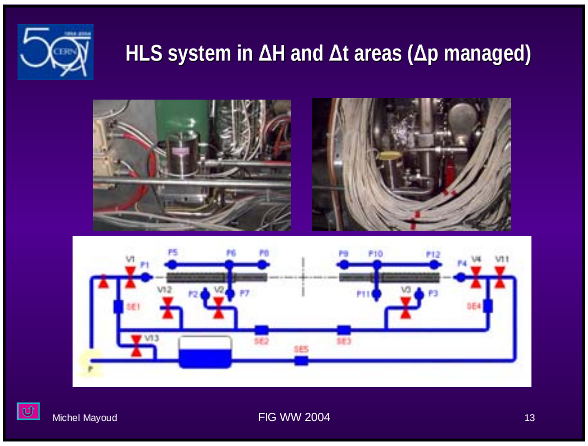

HLS system in ΔH and Δt areas (Δp managed)
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FIG WW 2004
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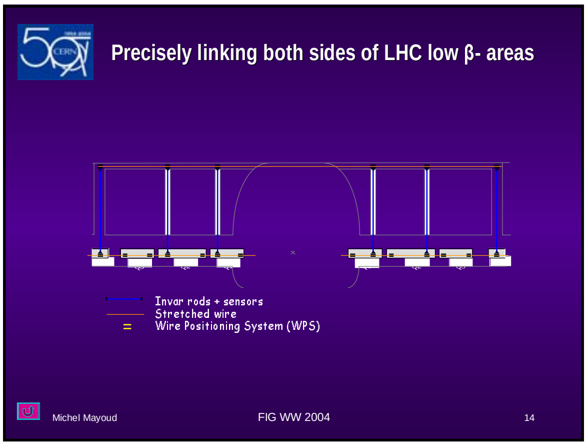
Precisely linking both sides of LHC low β- areas
Invar rods + sensors
Stretched wire
Wire Positioning System (WPS)
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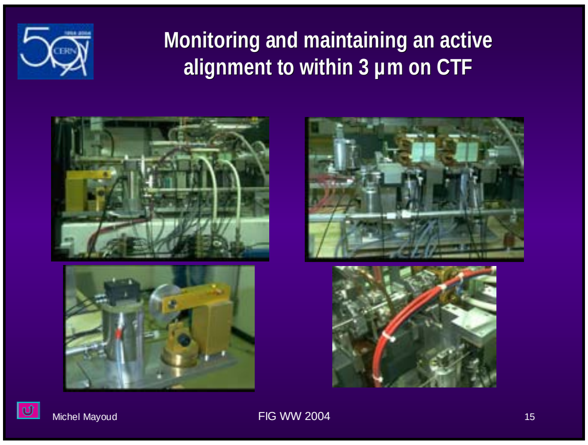
Monitoring and maintaining an active alignment to within 3 µm on CTF
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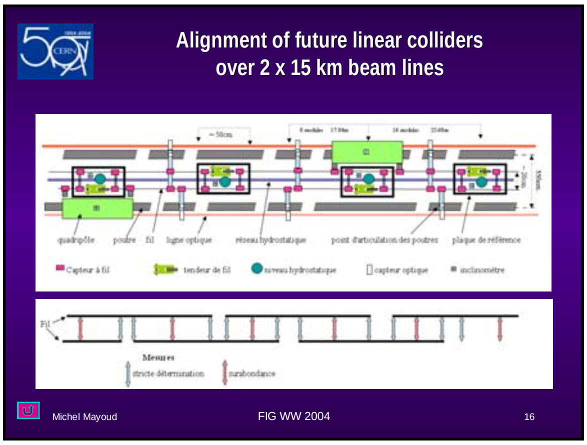
Alignment of future linear colliders over 2 x 15 km beam lines
quadrupôle
poutre
fil
ligne optique
réseau hydrostatique
point d'articulation des poutres
plaque de référence
Capteur à fil
tendeur de fil
niveau hydrostatique
capteur optique
inclinomètre
Mesures
stricte détermination
surabondance
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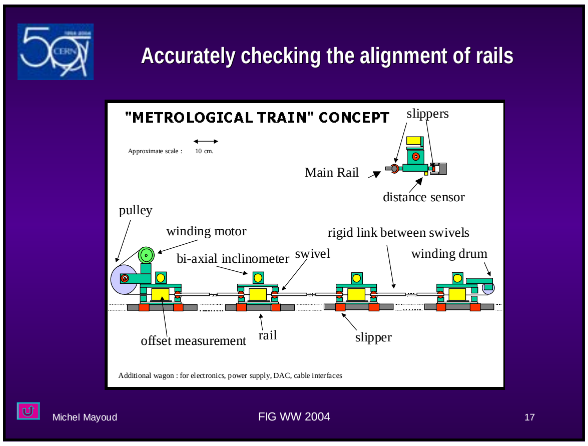
Accurately checking the alignment of rails
"METROLOGICAL TRAIN" CONCEPT
slippers
Main Rail
distance sensor
pulley
winding motor
rigid link between swivels
bi-axial inclinometer
swivel
winding drum
offset measurement
rail
slipper
Additional wagon : for electronics, power supply, DAC, cable interfaces
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CERN Calibration Facility :
The 50 m length and offset benches
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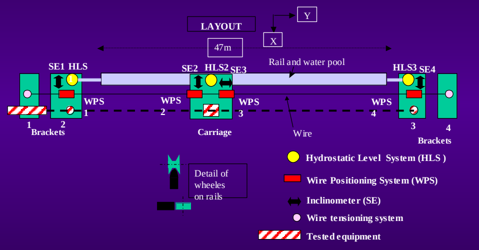
Main features of the calibration benches

- Calibration of lengths (interferometric bench) :
  - Reference : interferometer (σ<0.1 µm)
  - Carriage : manual or automatic mode
  - Calibrated instruments : invar wires, electro-optical distance-meters (for constant & cyclic errors), passive or active linear gauges, engraved tapes, scale bars, levelling staves
- Calibration of alignment systems (bi-axial offset bench) :
  - High precision capacitive sensors and inclinometers
  - Vertical reference line : hydrostatic levelling (σ=2 µm)
  - horizontal reference : stretched wire (σ=5 µm)
  - Carriage : manual, with all position parameters measured
  - Calibrated instruments and systems : wire or laser offset measuring devices, telescope & target alignment systems, optical polar systems (theodolites/total stations, laser trackers or scanners)

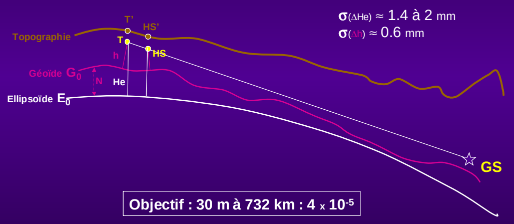
Layout of the bi-axial offset calibration bench



From large scale metrology to large scale geodesy : sending neutrino beams far away

The CNGS geodetic problem

$dN = [He_{(HS)} - He_{(T)}] - [h_{(HS)} - h_{(T)}] = [He_{(HS')} - He_{(T')}] - [h_{(HS')} - h_{(T')}] + \varepsilon$



Objectif : 30 m à 732 km : 4×10^{-5}

CONCLUSIONS

- Research has always been the most demanding for all applied sciences and technologies, in all professions
- Surveying for research works => research works for surveying
- It has to remain a surveyor's concern => multidisciplinary approach, collaboration with universities and industry