The LHC Final Alignment

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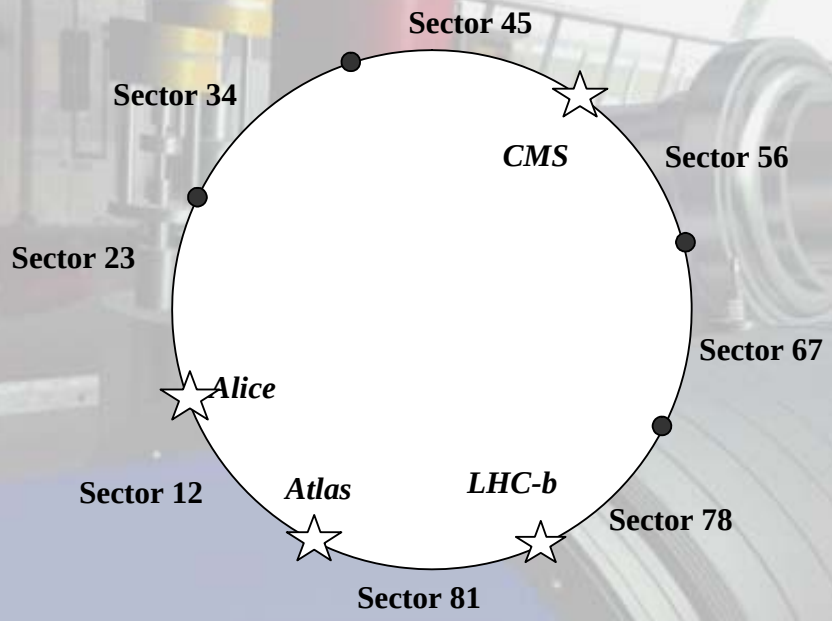
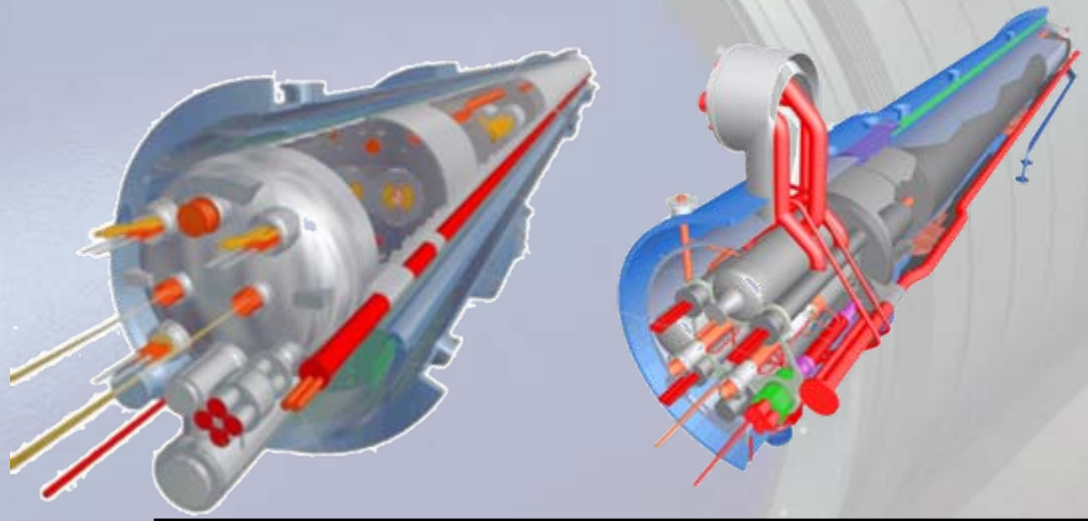
Overview

- Introduction to the LHC Project
- the initial alignment
- The final alignment
- The measurements
- The PLANE software
- Conclusions

The LHC Project



- **LHC**
  - ✓ 27 km proton-proton collider
  - ✓ ~2000 cold components
  - ✓ Two beams in two different cold bore tubes
  - ✓ 4 interaction points
  - ✓ Divided in 8 sectors which are cooled down one by one
  - ✓ **First beam in may 2008**

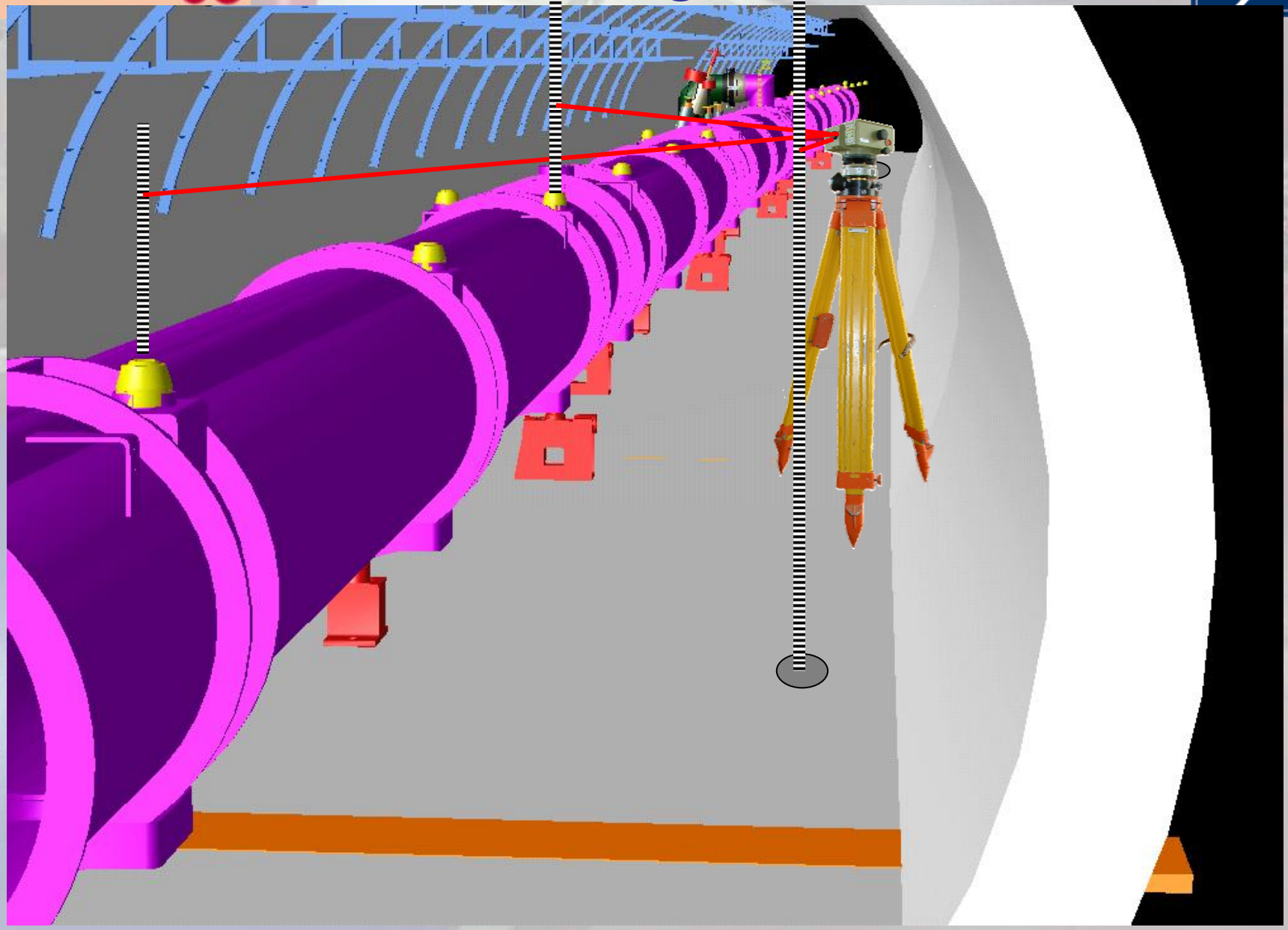



CERN
Where the web was born...

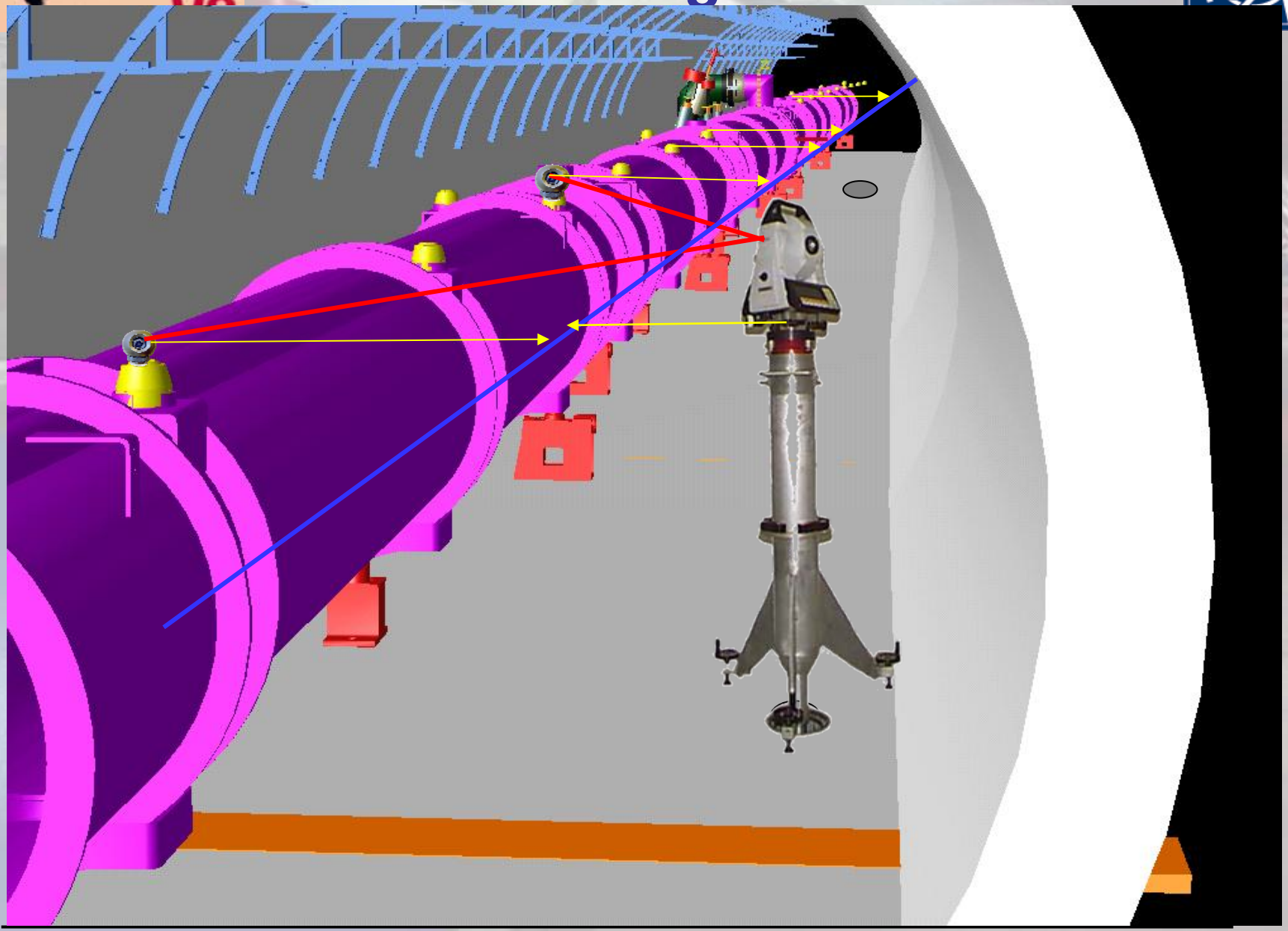
The First Alignment

- **From the geodetic network**
  - ✓ measured from the position of the LEP collider main quadrupoles
  - ✓ Using levelling, horizontal angles, Mekometer distances, gyroscopic orientations and offset measurements
- **How**
  - ✓ Using optical level NA2, TDA5005 distances, offset measurements
  - ✓ Local horizontal smoothing
- **Accuracy**
  - ✓ In order to obtain the best absolute position
  - ✓ A relative position of
    - 0.15 mm at 1 σ in z
    - 0.25 mm at 1 σ in x and y

The First Alignment



The First Alignment



The Final Alignment

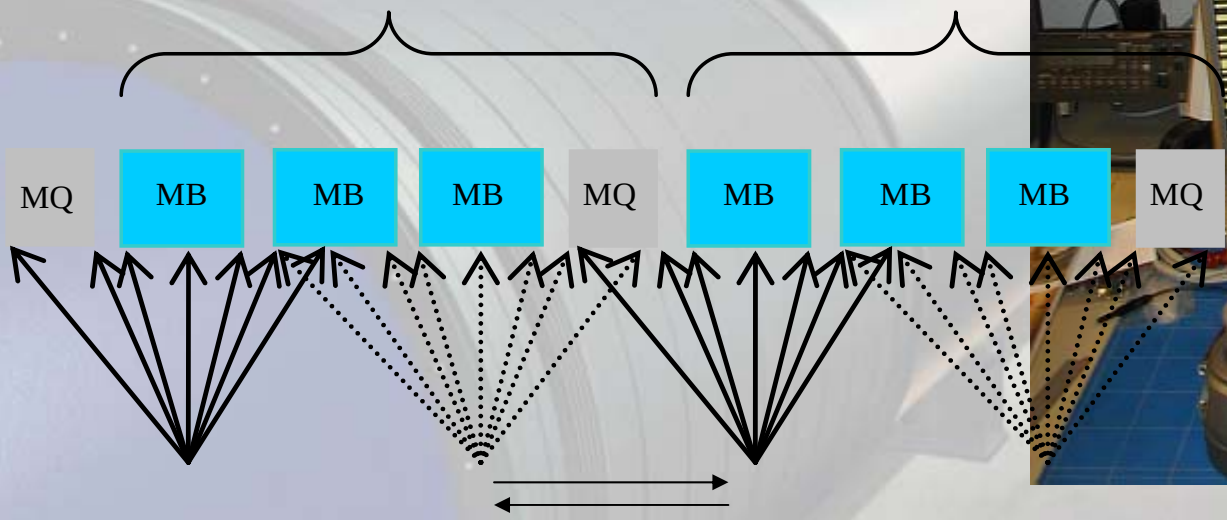
- **Operation that**
  - ✓ Suppress the steps which pertubates the particle beams
  - ✓ Improve the relative accuracy of the components
  - ✓ Has to take place when the magnets are « cold », i.e. all the constraints have occured
- **What magnets**
  - ✓ All cryo-magnets not only the MQs
  - ✓ To prevent the shearing off the tubes in the interconnect
- **Accuracy**
  - ✓ Deviation to a smooth line not exceeding of 0.15mm at 1 s
- **Steps**
  - ✓ Roll angle, Vertical and Horizontal measurements
  - ✓ Calculation of the smooth line with « PLANE »
  - ✓ Displacement of the magnets out of tolerance

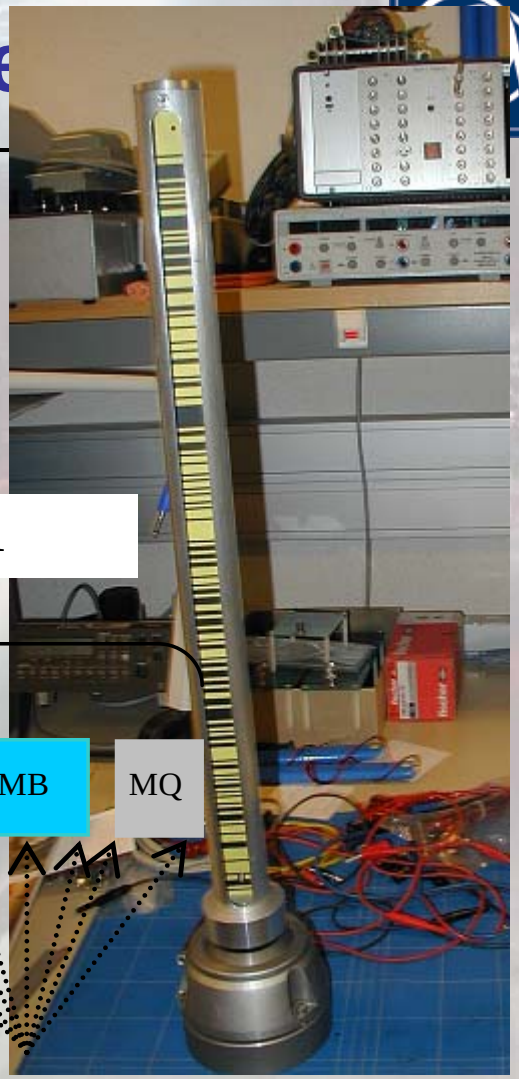
Roll angle measurement

- With a special instrumentation installed on two fiducials
- No important mo
- Slight degradati
- Per sector, 3 da team of 2 perso measurements corrections

Vertical measureme

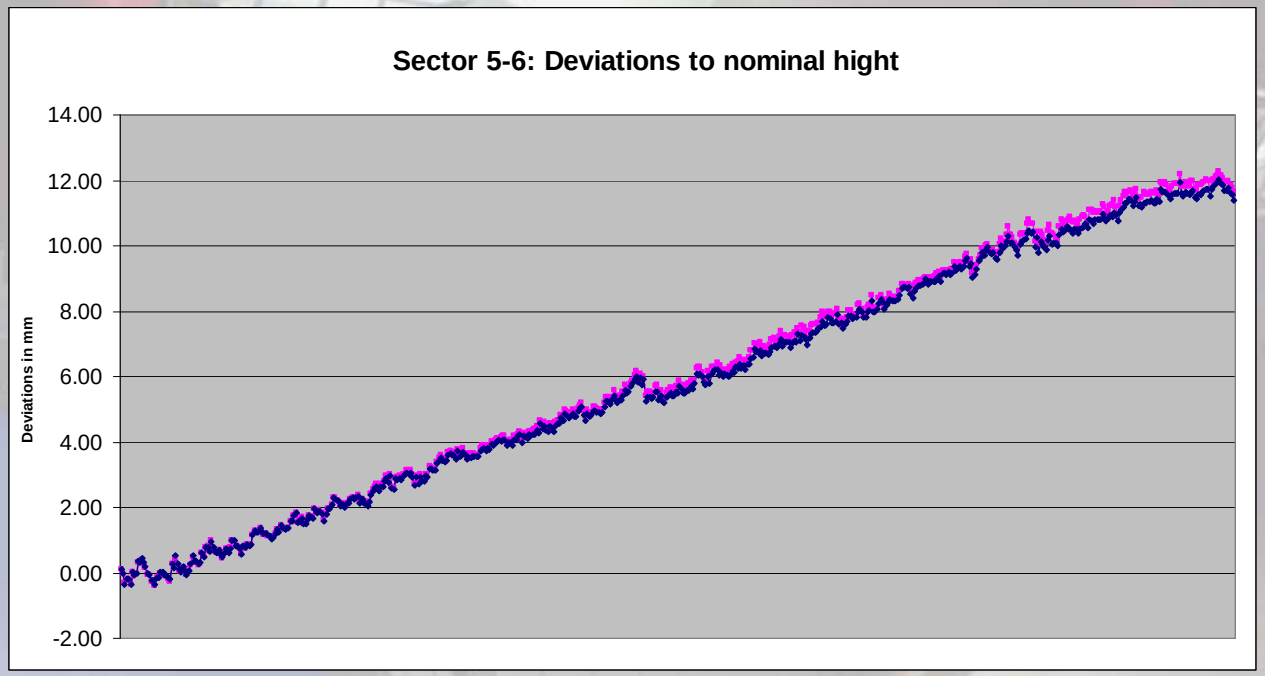
- **Instruments**
  - ✓ Digital levels DNA03
  - ✓ Illuminated staff
- **Measurement sequences**





- **Advantage**
  - ✓ Regular sequence
- **Drawback**
  - ✓ Inequality of distances

Vertical measurement

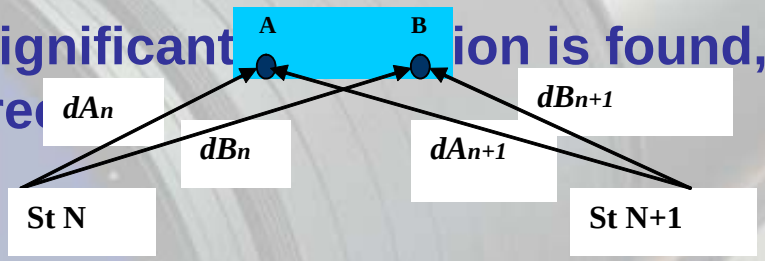


- **Scale factor**
  - ✓ a staff problem which was too tight by 0.2mm on 800mm
  - ✓ Measurements corrected by 1.00025

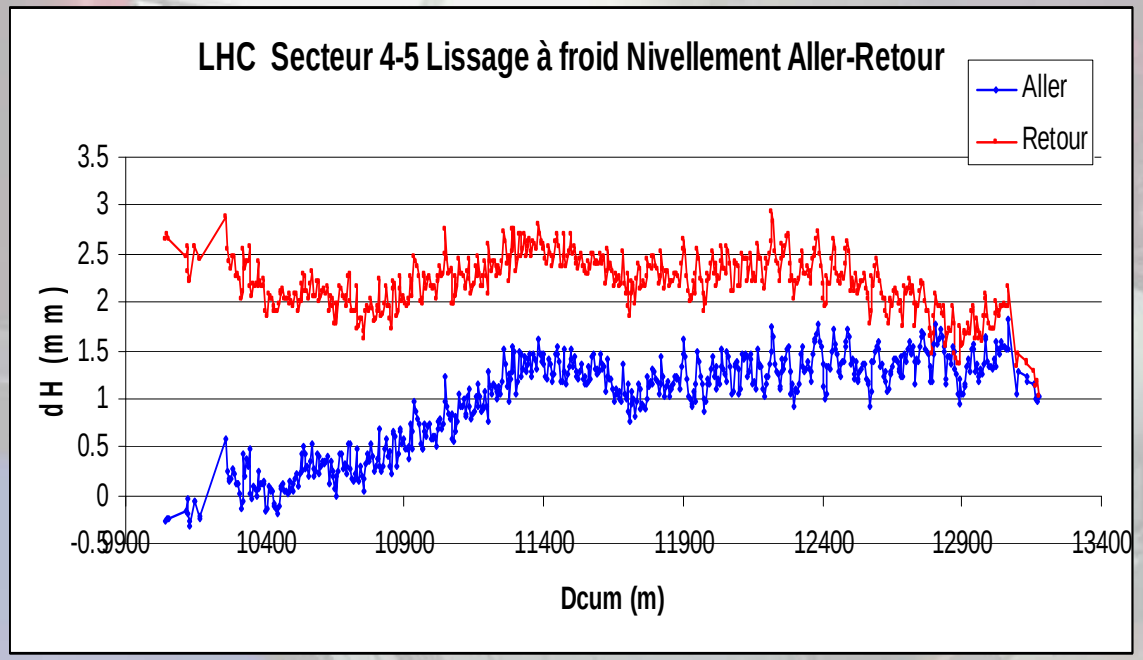
Vertical measurement

- **Collimation problem**
  - ✓ Check-and-adjust was giving surprising values day from the other
  - ✓ The difference of heights of the turning points was not the same from station N and station N+1
    - ✓ the difference of distances between Stations is ~11m

- **When a significant ion is found, measurements were corre**

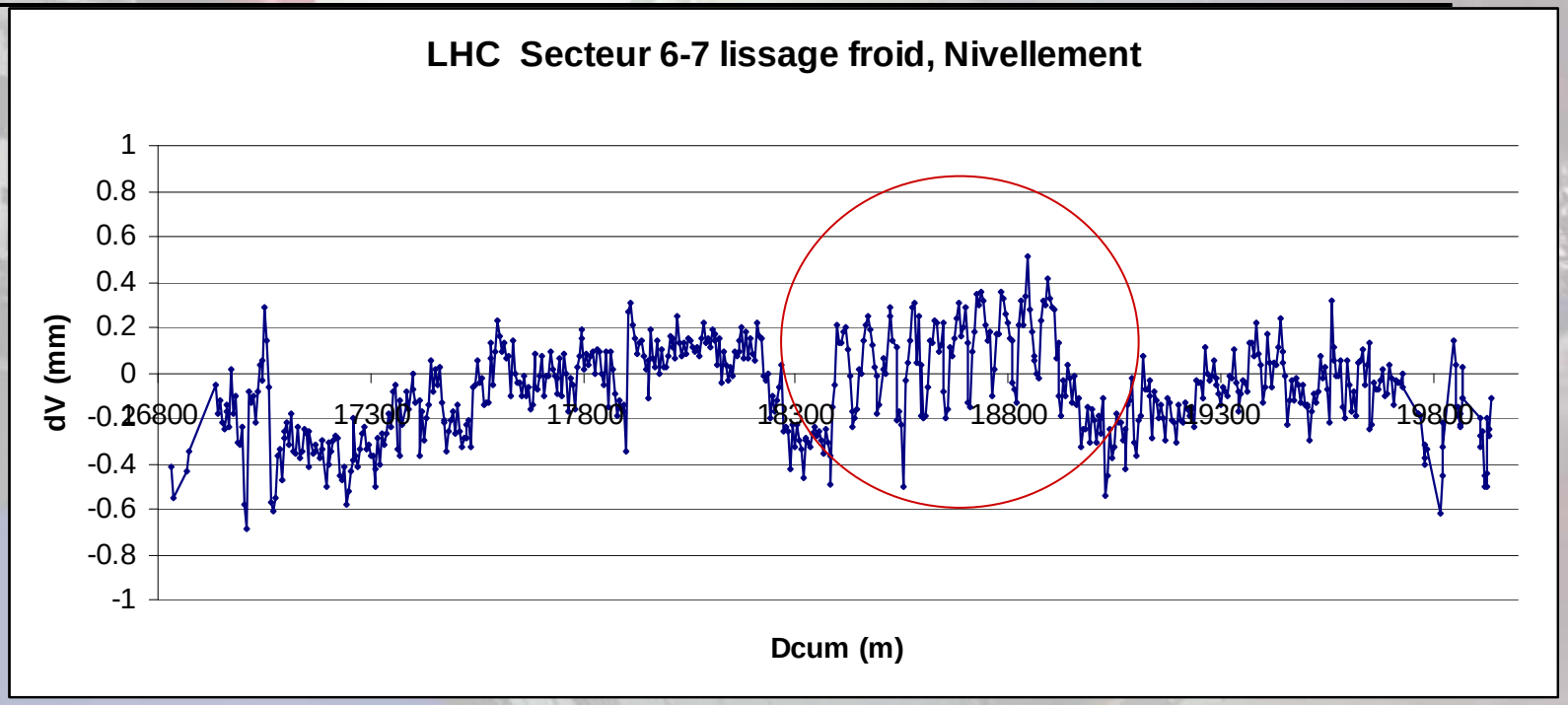


Vertical measurement



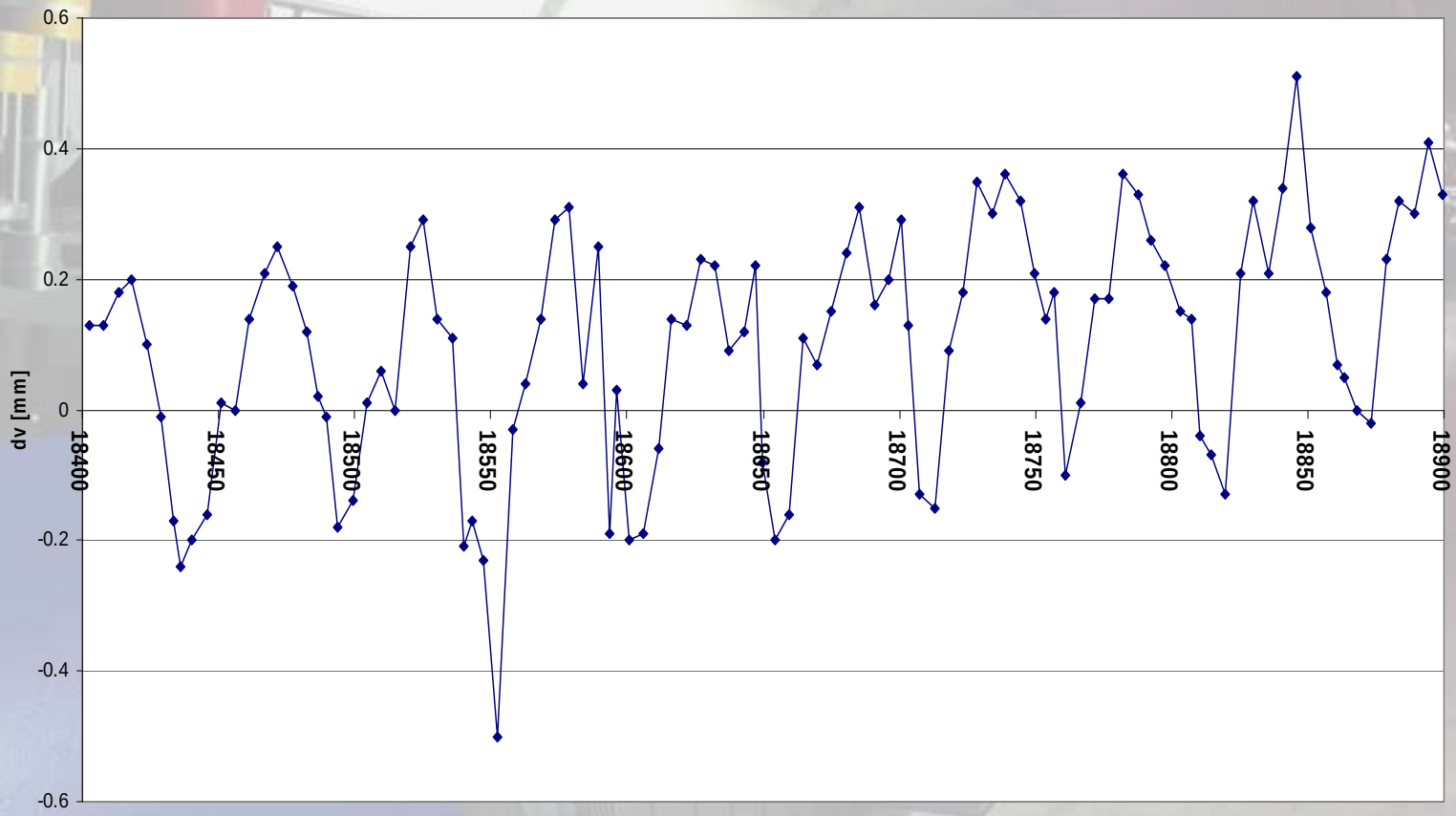
- Discrepancies between both runs
- No influence on the relative position of magnets
- Still to be investigated

Vertical measurement



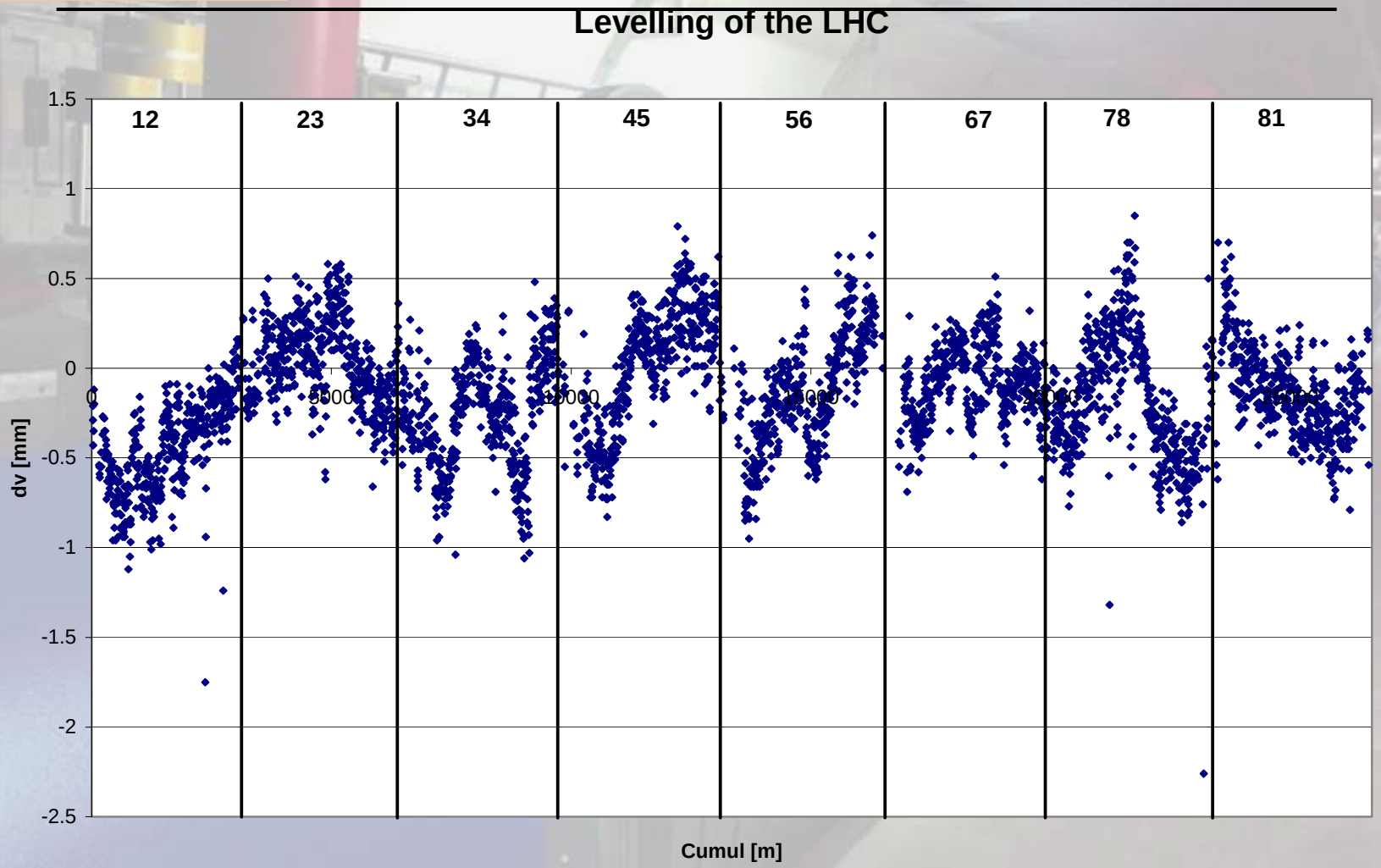
- Levelling blocked at each side of the sector on deep references
- No big deviations
- Points to be moved calculated by plane (later in this talk)
- Saw tooth phenomena visible for most of the sectors

Vertical measurement



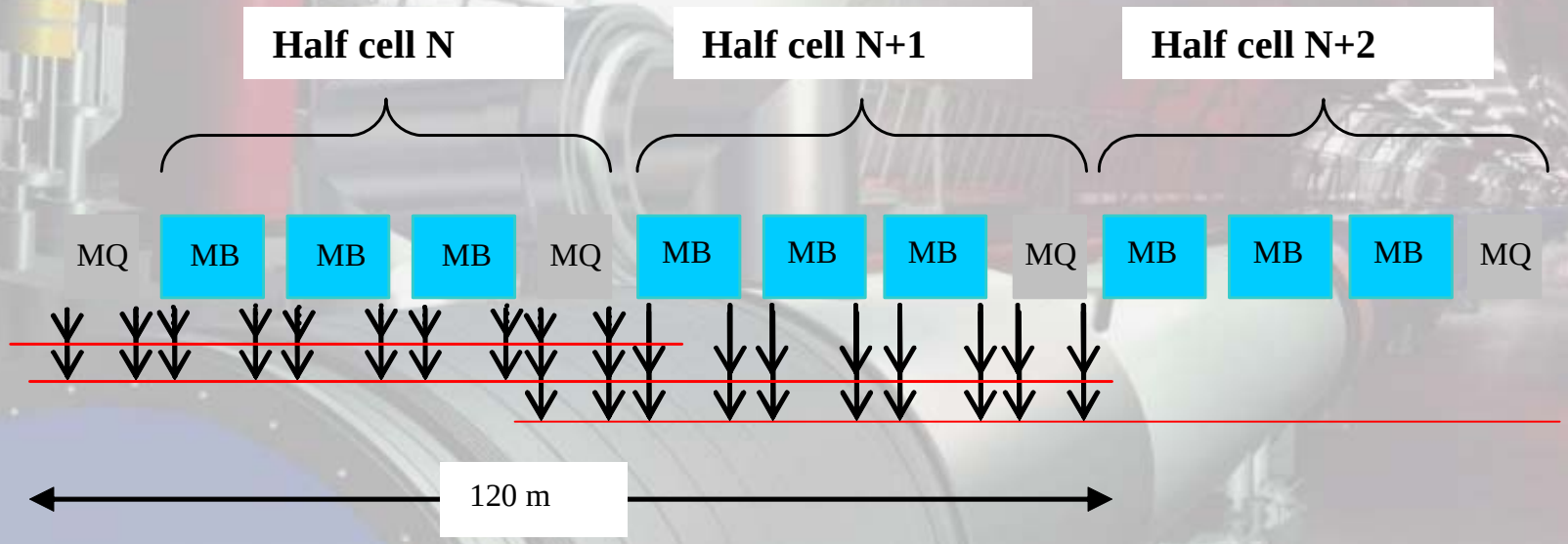
- Length of the wave is a half cell length ~53 m
- Probably due to a collimation error of the NA2 used during the initial alignment (unstability of the optical axis)
- Large Influence when no equality of distances

Vertical measurement



- Levelling has been blocked on all the deep references
- No large deviations

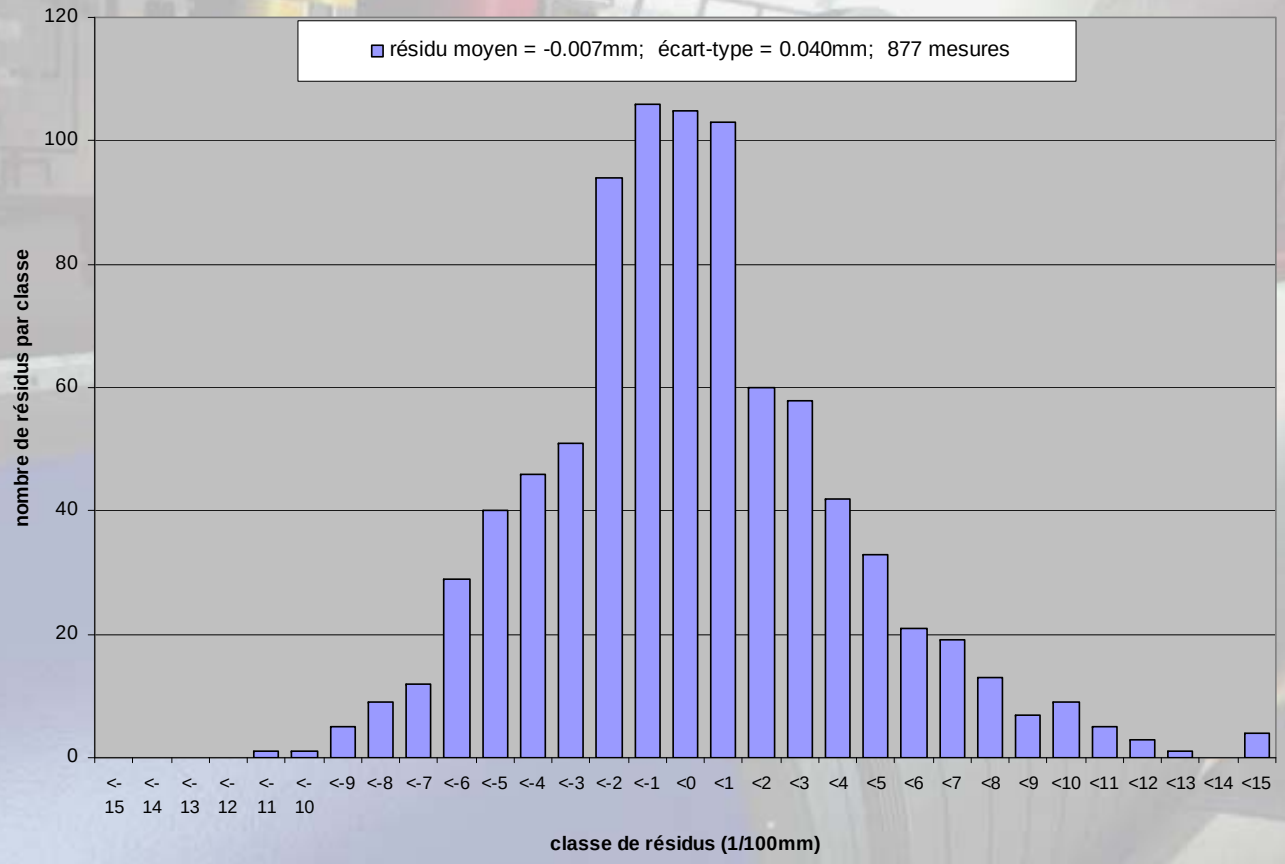
Horizontal measurement



- Offset = Distance to a Stretch wire
- Redundancy of 3 for MQs and 2 for MBs
- Protection inside a tube
- 2 weeks per sector for a team of 3 persons

Offset measurement

Offset measurements (results)

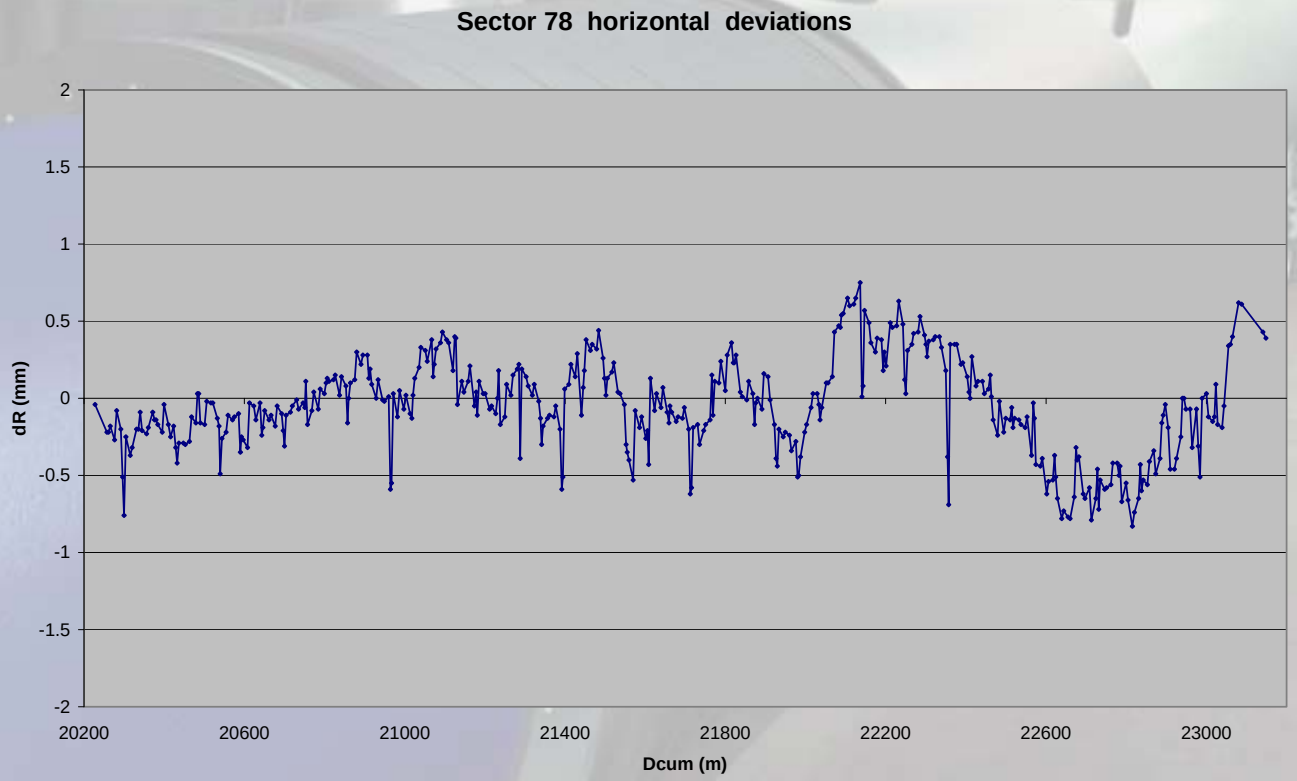


Sector	Number of measurements	r.m.s (mm)	Average (mm)
45	920	0.051	0.009
78	877	0.040	-0.007

- Sectors 78 and 45 measured at cold
- Very good quality of the measurements

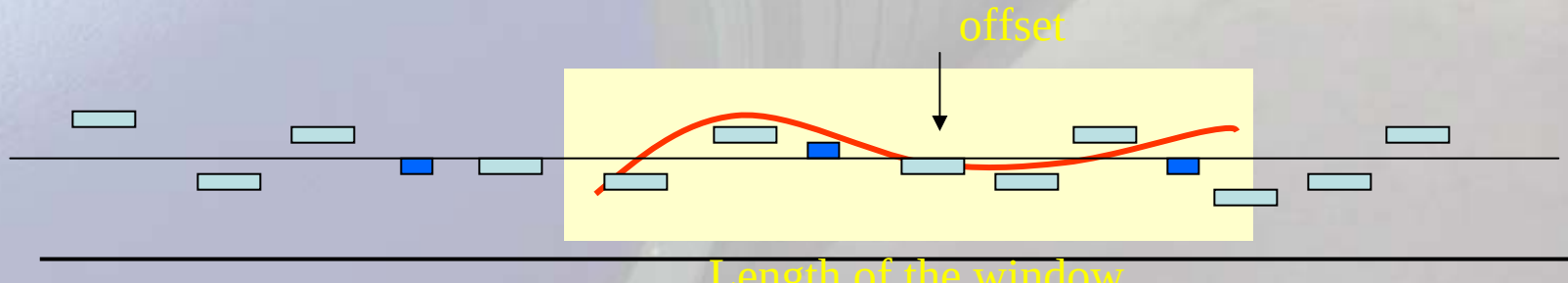
Horizontal Measurement

- For each sector, compensation avec 1 fixed pt, and orientation pt and radial constraints
- No big relative deviations
- Points to be moved calculated by « Plane »



Smoothing with “Plane”

- **What is Plane ?**
  - ✓Software to calculate a smooth line and the points to be displaced
  - ✓Principles : windows and polynomials
  - ✓Parameters : size of the window and Tol above which the points are rejected
  - ✓Works in vertical and horizontal plane



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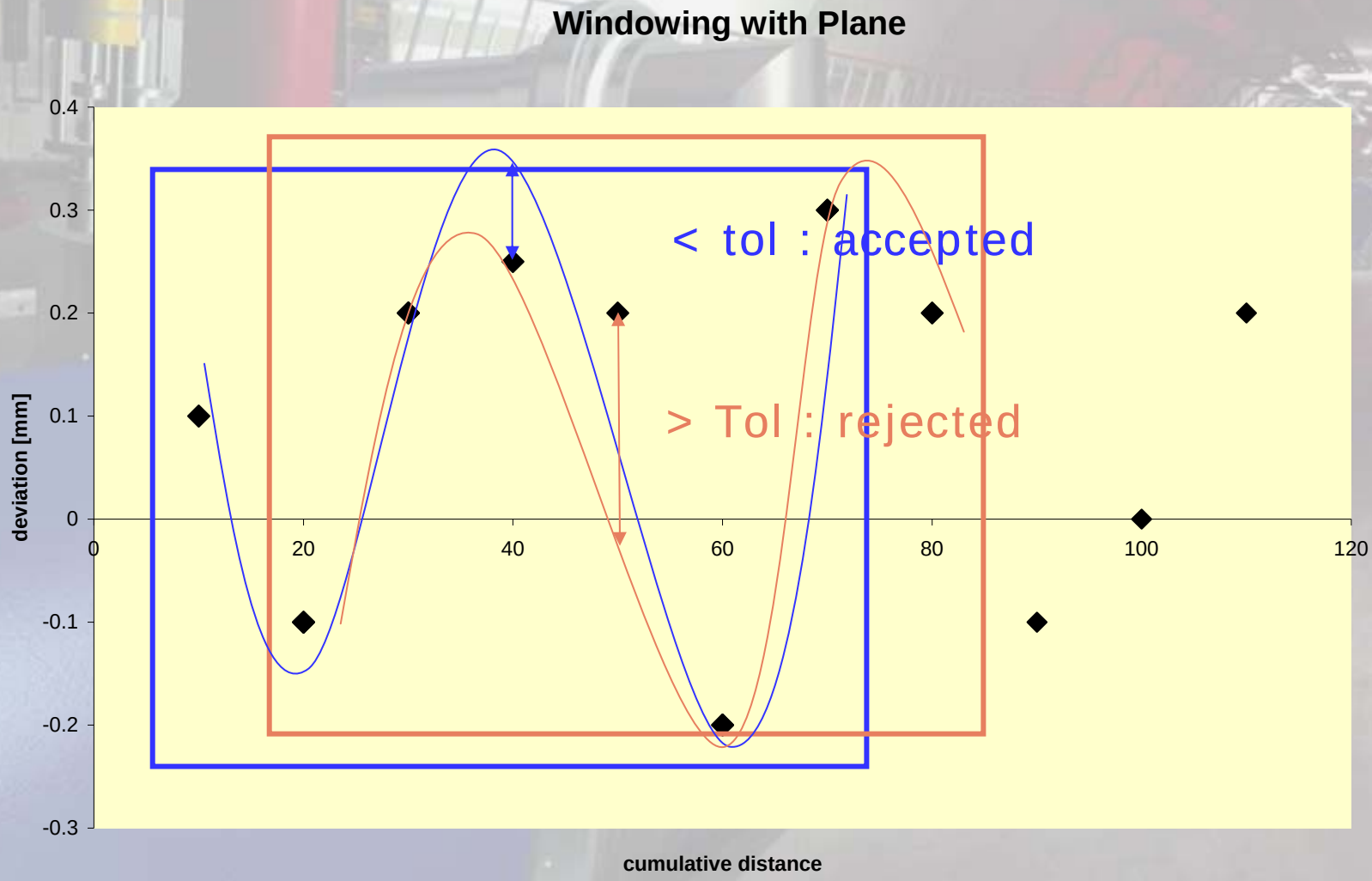
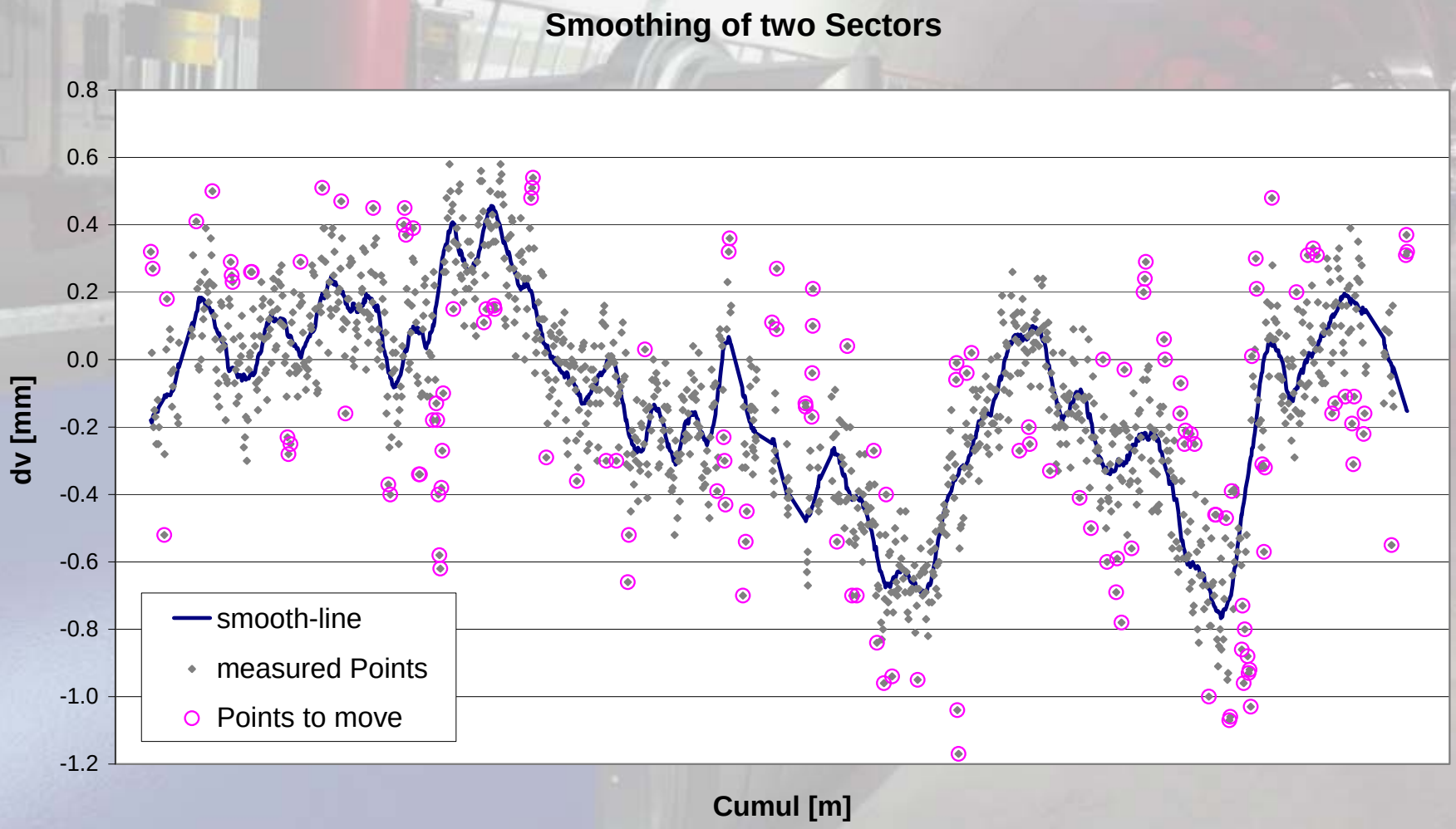


Smoothing with “Plane”



Smoothing with “Plane”

❑ Vertical

Sector	Stdev before smoothing (mm)	Stdev after smoothing (mm)	Points to be moved
1-2	0.16	0.10	41
2-3	0.17	0.12	63
3-4	0.18	0.11	84
4-5	0.15	0.11	45
5-6	0.15	0.10	49
6-7	0.13	0.10	20
7-8	0.19	0.11	53
8-1	0.16	0.11	67

❑ Horizontal

Sector	Stdev before smoothing (mm)	Stdev after smoothing (mm)	Points to be moved
4-5	0.19	0.11	65
7-8	0.17	0.11	41

- ❑ 53 magnets moved/23%
- ❑ Good improvement of the smoothing process
- ❑ in both directions, the specification of 0.15 mm is reached
- ❑ Same accuracy in vertical and horizontal

Conclusions

- **The final alignment smoothing is very important**
  - ✓ For detection of big errors or movements
  - ✓ to improve the quality of the relative position of magnets just before a physics run
- **Instrumentation and methodology**
  - ✓ Very good quality of the offset measurements
  - ✓ Still difficult to have good levelling measurements
- **The results for LHC**
  - ✓ All sectors smoothed for the roll angles and in vertical plane, only two sectors in the horizontal under cold conditions
  - ✓ In both planes no important relative deviations
  - ✓ ~53 Magnets moved/sector
  - ✓ deviations under 0.15 mm rms as specified