SMOOTHING THE LHC DURING LS1

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Outline

- Introduction
- The strategy
- The «quick levelling»
- Smoothing the LSSs
- Smoothing the Arcs
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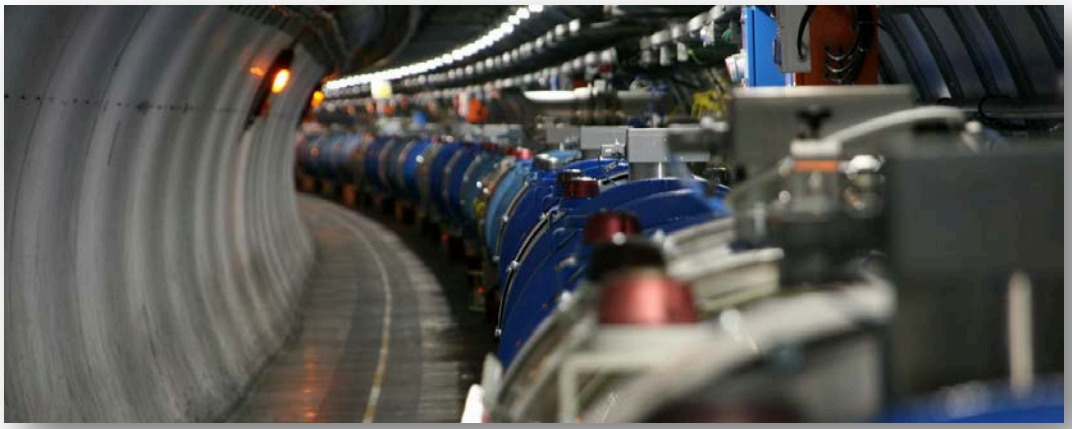
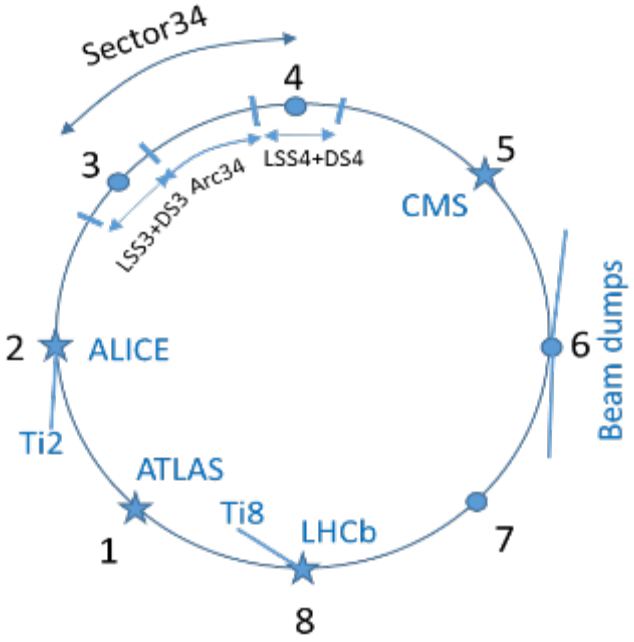
- Conclusion

Introduction

- The LHC is a 27km long machine
  - 8 LSS(cold and warm components)
  - 8 Arcs (only super-conducting magnets operating 1.9K)





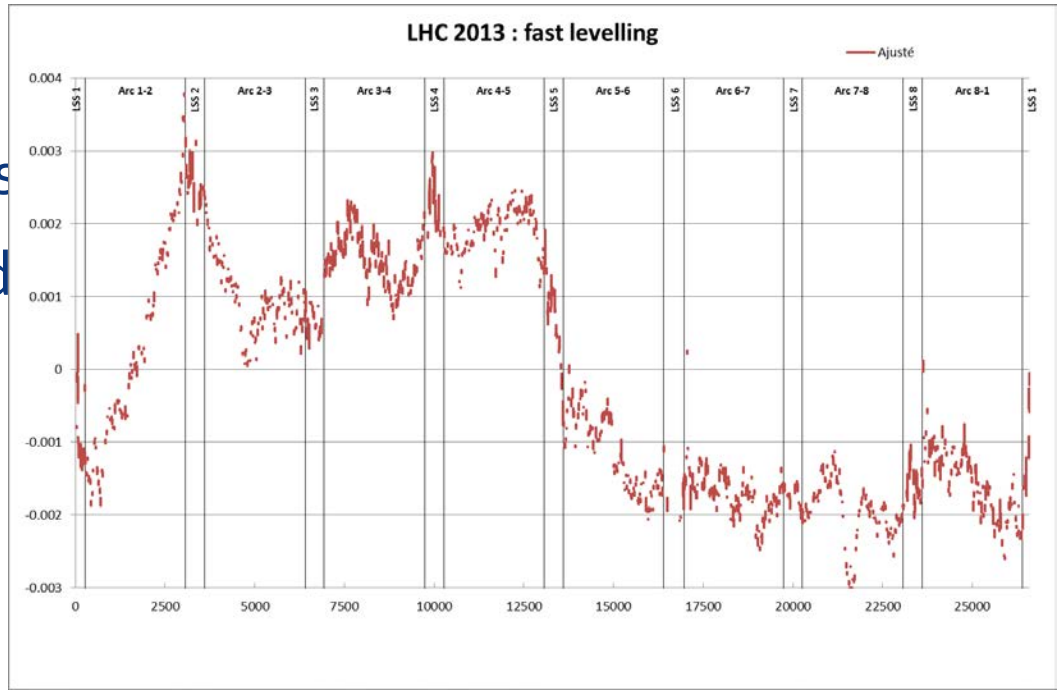
- The Long Shut-down 1
  - 24 month SD period

The strategy

- Considerations
  - The absolute position in vertical was not very well known
  - Measurements at the begin of the SD before opening
    - for statistics gathering
  - Realignment at the end of the SD under cold conditions (below 100K)
    - Necessity for a better position during the run
- =>
  - Quick levelling in 2013 to get an absolute shape
  - Measurement/realignment of
    - the LSSs at warm t° in 2013
    - The Arcs at cold t° in 2014

The quick levelling

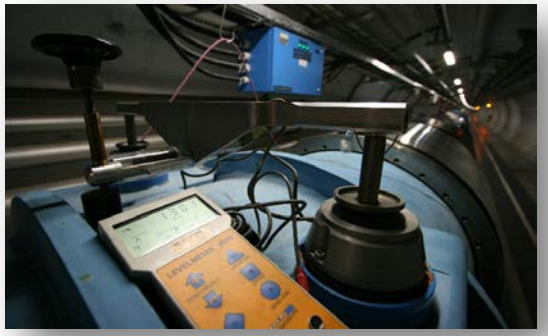
- Methodology
  - 1 magnet over two meas
  - Cholevsky, Outward and



- Results
  - Closure below 5 mm
  - New «absolute» shape of the LHC magnets after 3.5 years of run

Smoothing the LSS

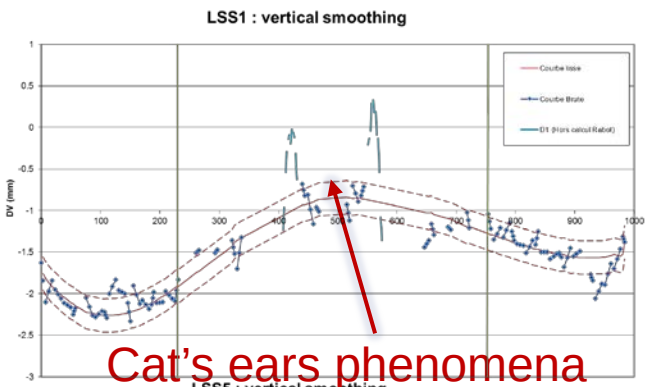
- Roll angle
  - 42% of magnets realigned
  - For almost all the LSS, the average below 0.1 mrad
  - Tendancy to sink towards the same direction (outside LHC) except LSS3
  - LSS1, 4 (Accelerating cavities), 5 and 6 (CE works done in 2000) are quite pertubated
  - 2, 3 and 7 are the most stable

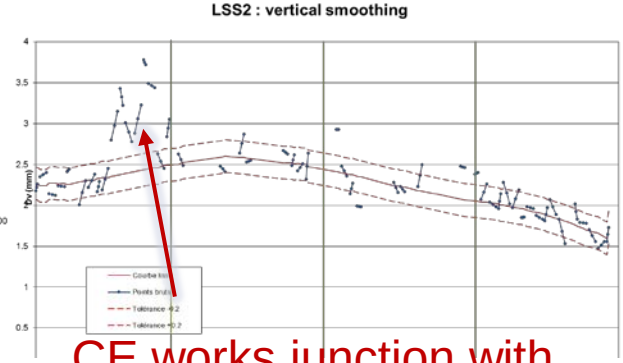


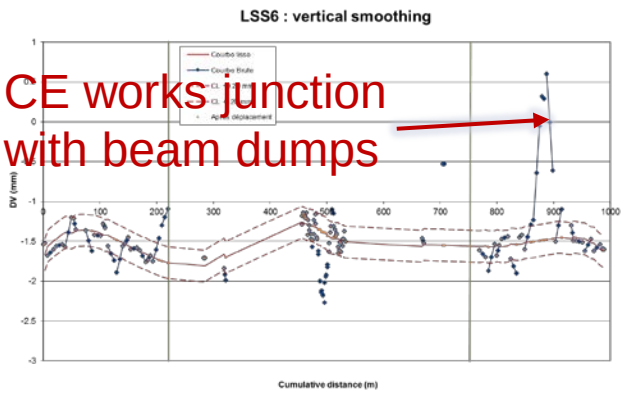
LSS	Deviation to theoretical roll angle (mrad)				Realigned magnets
	Avg	Rms	Min	Max	%
1	0.04	0.16	-.48	0.53	34
2	0.04	0.11	-.18	0.34	35
3	-.09	0.08	-.23	0.06	40
4	0.13	0.36	-.49	1.77	44
5	0.09	0.15	-.14	0.45	43
6	0.07	0.30	-.90	1.24	64
7	0.06	0.08	-.21	0.24	29
8	0.07	0.11	-.28	0.33	48
All					42

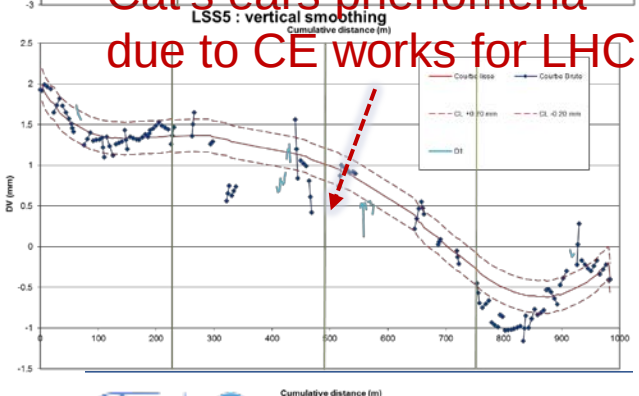
Smoothing the LSS

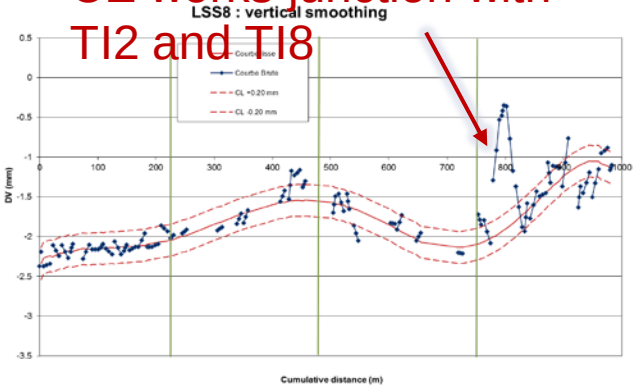
- Vertical
  - Between Q11Ln to Q11Rn, optical level Na2
  - Calculation fixed on the results of the quick levelling
  - Smoothed curve calculated with the PLANE software







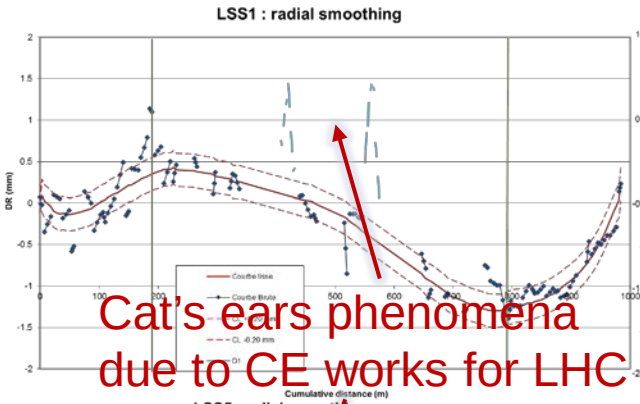


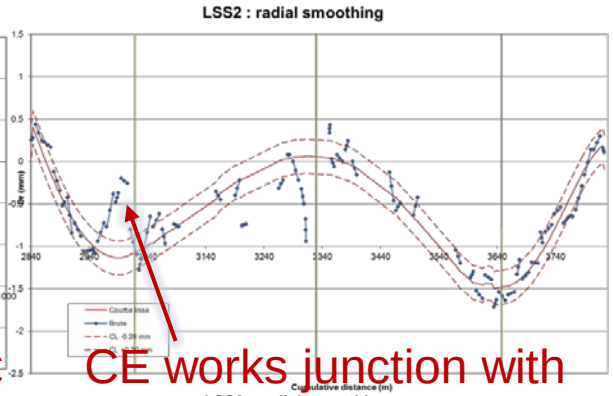


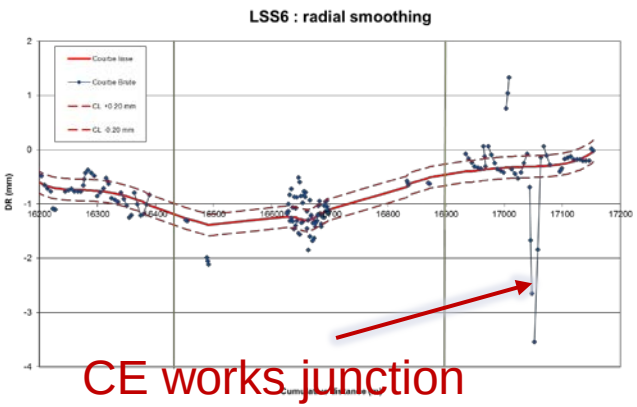
- LSS3, 4 and 7 quite stable

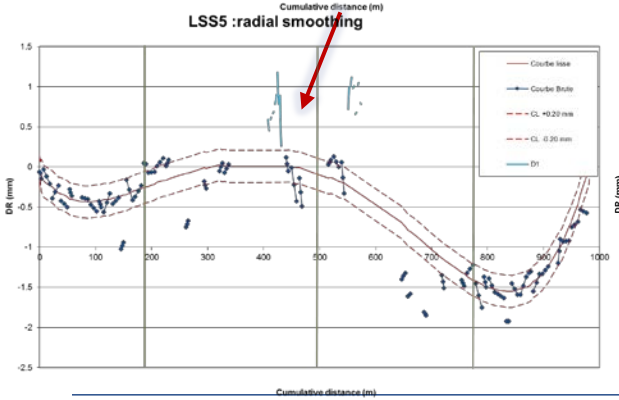
Smoothing the LSS

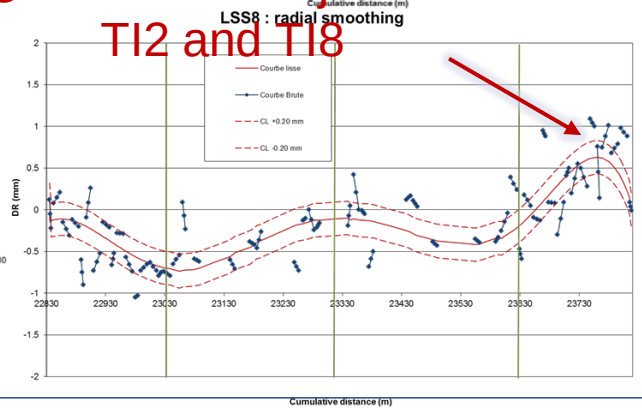
- Radial
  - Between Q12Ln to Q12Rn, offsets w.r.t a stretched wire
  - Calculation fixed on the Q2s and with a radial constraint









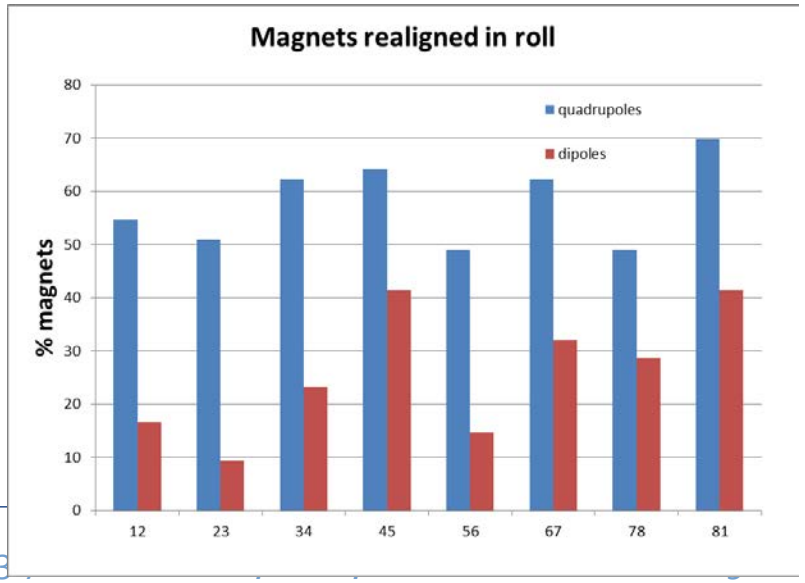


- LSS3, 4 and 7 quite stable also

Smoothing the Arcs

- Roll angle
  - Average below 0.1 mrad
  - Small degradation rms < 0.22
  - Tendancy to sink towards the same direction (outside LHC) except arc34
  - Arc 34, 45 and 81 are the most unstable
  - 34% magnets realigned, twice more quads than dipoles

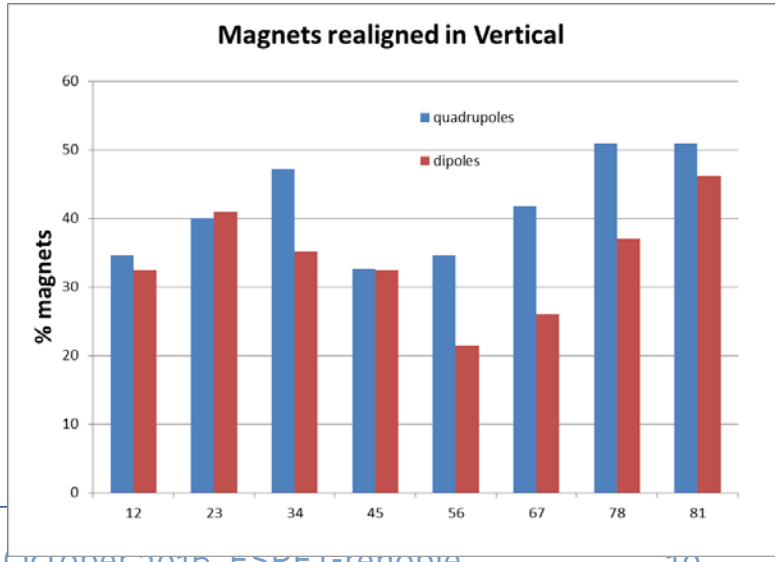
Arc	Deviation to theoretical roll angle (mrad)				Realigned magnets	
	Avg	Rms	Min	Max	%	Nb>1mrad
12	0.06	0.12	-.38	0.57	26	0
23	0.02	0.14	-.76	0.69	20	0
34	-.05	0.22	-1.5	0.77	33	3
45	.07	0.15	-.83	0.72	46	0
56	.01	0.17	-.91	0.64	23	0
67	.06	0.16	-1.12	0.43	39	1
78	.06	0.15	-.90	1.19	33	1
81	.07	0.22	-.65	1.16	48	1
all					34	6



Smoothing the Arcs

- Vertical
  - DNA03, Cholevsky, Outward and Return
  - Calculation fixed on the deep references, smoothing with PLANE
  - 34% magnets realigned
  - Very small degradation of the rms except Arc81
  - No big difference between quads and dipoles

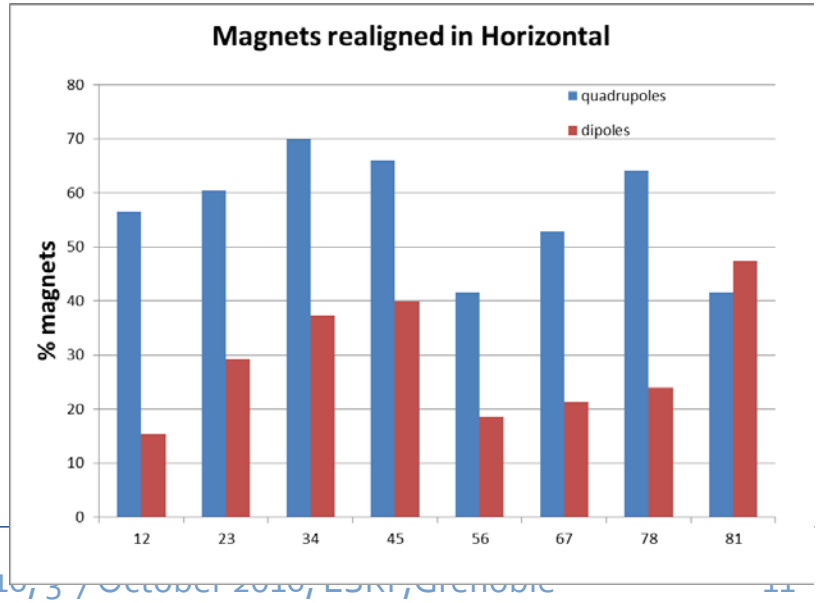
Arc	Deviation wrt the smooth curve (mm)			Realigned magnets	
	Rms	Min	Max	%	Nb>1mm
12	0.15	-.74	0.55	31	0
23	0.16	-.46	0.52	39	0
34	0.16	-.55	0.68	36	0
45	0.15	-.65	0.47	31	0
56	0.13	-.55	0.55	24	0
67	0.12	-.37	0.38	29	0
78	0.13	-.76	1.03	39	1
81	0.21	-.89	1.38	45	1
all				34	2



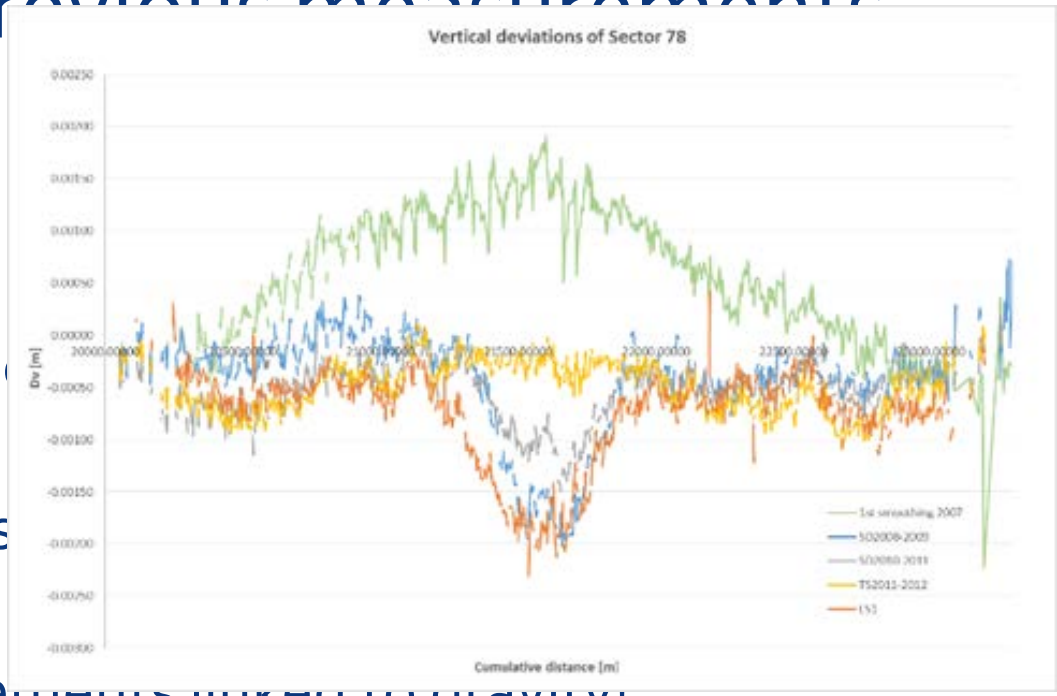
Smoothing the Arcs

- Radial
  - Offsets wrt a stretched wire, between $Q8R_n$ to $Q8L_{n+1}$
  - Calculation fixed on Q8s, radial constraint, smoothing with PLANE
  - Quite important degradation of the r.m.s, especially in Arc 34 and 81
  - 36% magnets realigned, 36 magnets by more than 1mm
  - twice more quads than dipoles

Arc	Deviation wrt the smooth curve (mm)			Realigned magnets	
	Rms	Min	Max	%	Nb>1mm
12	0.21	-.86	1.01	26	1
23	0.28	-1.88	1.20	37	5
34	0.35	-2.09	1.39	45	8
45	0.26	-1.71	0.96	46	2
56	0.25	-1.39	1.12	24	4
67	0.23	-1.53	0.78	29	3
78	0.27	-2.04	1.22	34	4
81	0.38	-.1.61	1.65	45	9
all				36	36



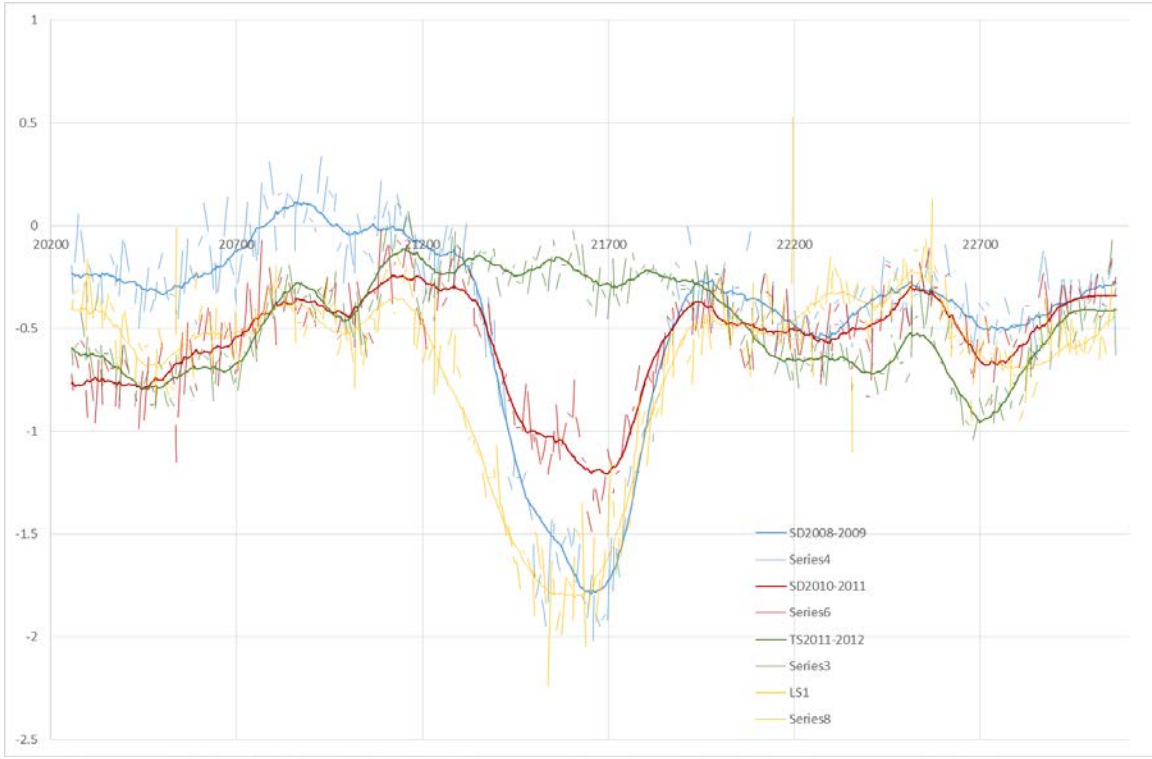
Comparison with previous measurements



- It is not easy because
  - Long size of the traverse
  - Movements have same ord errors
  - Parameters of post-process «absolute» position
- Even for the vertical measurements linked to gravity!
- We have to find a way to compare «locally» the shapes
- Two methods have been tested :
  - The offsets to the smooth curve at different epochs (M. Callassi, master thesis 2015)
  - The inclinations and deformations method (Post-doc th.,FenXiang Jin,1999)

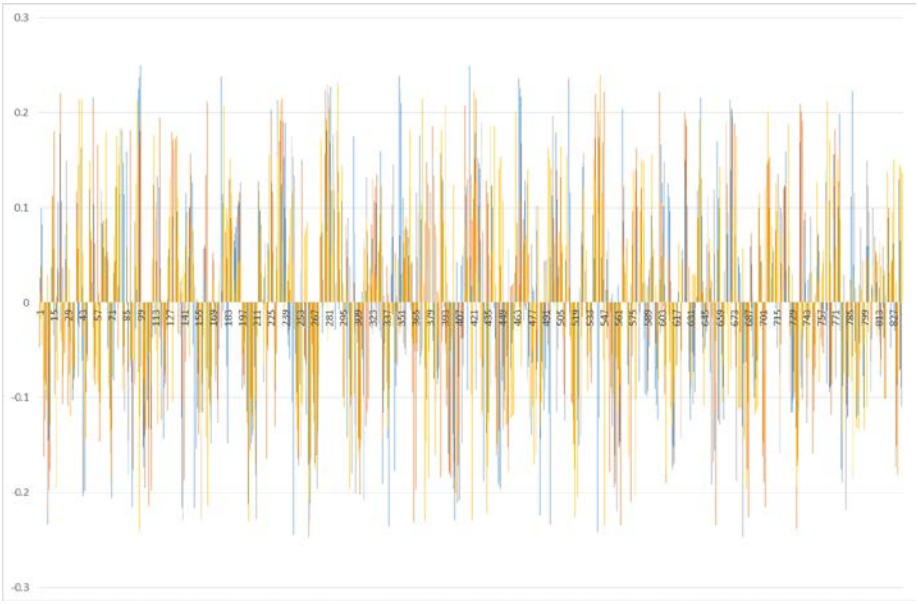
Comparison of the smooth curves at different epochs

- Was done on vertical measurements of Arc 78 at four different epochs
- The study shows that the magnets have the tendancy to stay on the same side of the smooth curves (even if they are not the same) all along the years

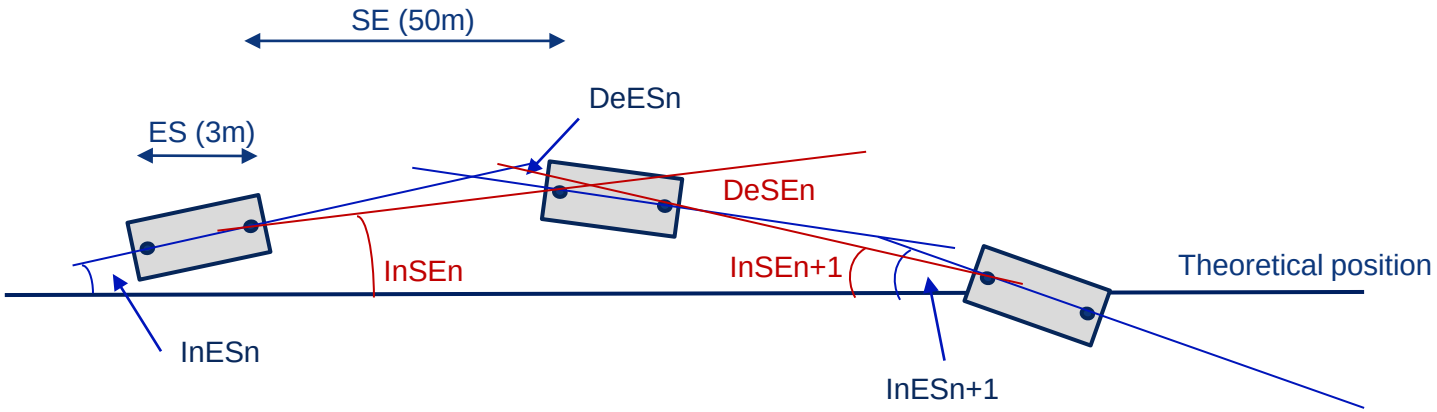


Comparison of the smooth curves at different epochs

- There is no systematism for realignment :
  - Some magnets had been realigned once and then never again
  - Some others had been realigned in one durection during one campaign and in the opposite direction during the next one



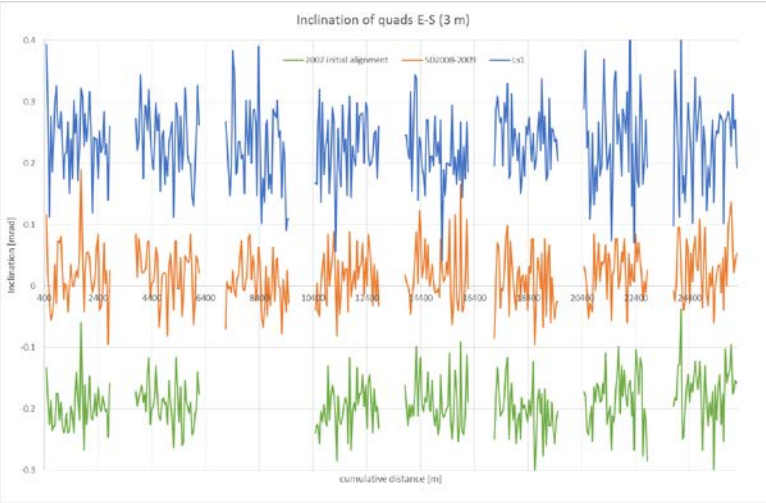
Inclinations and Deformations

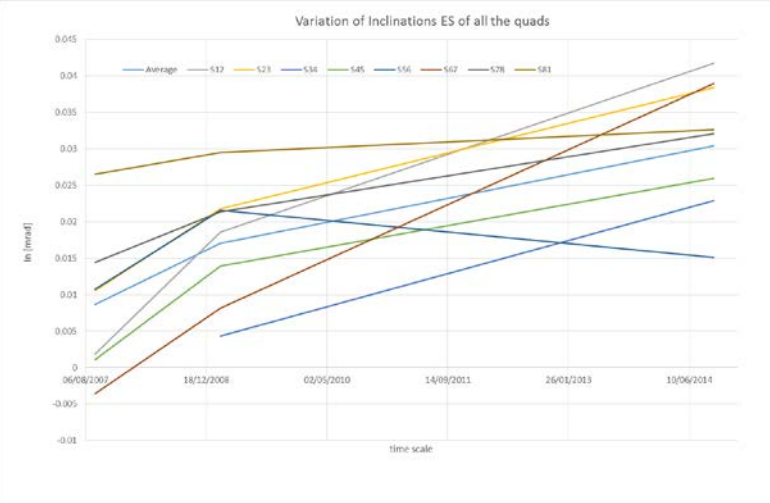


- Two quadrupoles inclinations (difference of vertical slope wrt theoretical position) are considered
  - between E and S of the same $quad_n$ (3 m) : $InES_n$
  - between the S of $quad_n$ and E of $quad_{n+1}$ (50 m):$InSE_n$
- Deformation is the difference between two consecutive Inclinations
  - $DeESn = InES_{n+1} – InES_n$
  - $DeSEn = InSE_{n+1} – InSE_n$

Inclinations

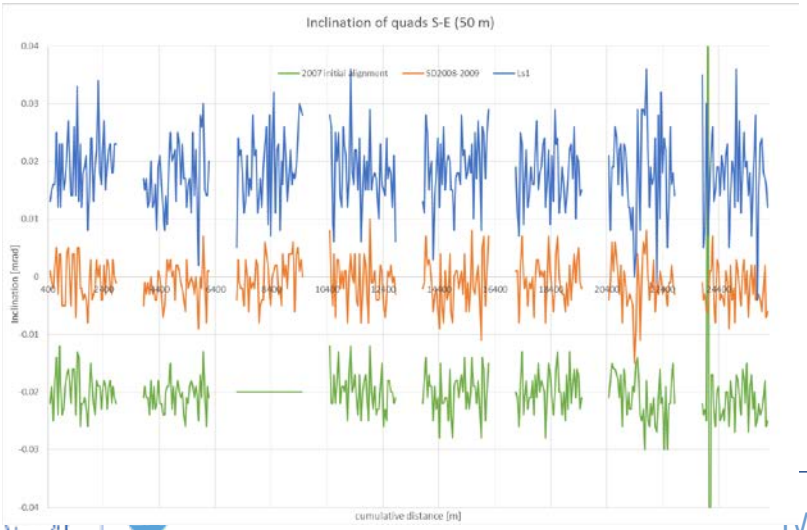
- 2007-2008 (initial alignment), SD2008-2009, LS1(2014)
- The measurements of LS1 were corrected with the displacements done during SD2008-2009
- The inclination ES is increasing with time (if no realignment is done)
- Positive ES variation with a change of speed in 2009 (except for 56)
- Average is +0.003 mrad/year (it was 0.008 mrad in the 90's at the LEP era)

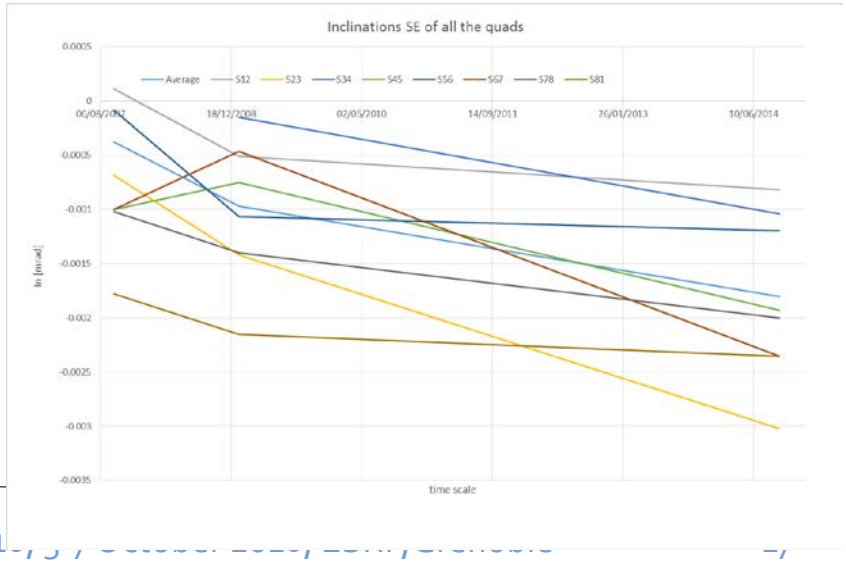




Inclinations

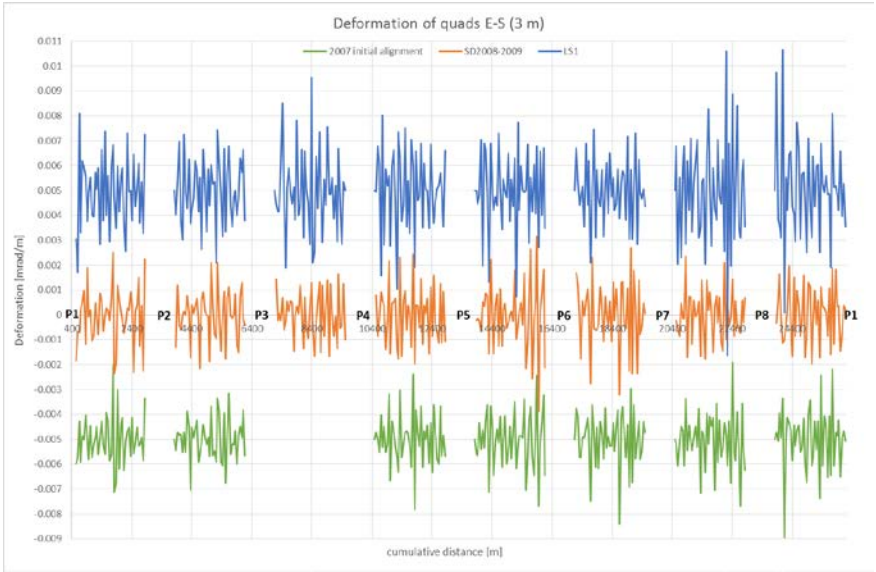
- The inclination SE is also increasing with time (if no realignment is done)
- Negative SE variation with a change of speed in 2009 (except for 67)
- Average is -0.0002 mrad/year (0.001 mrad at the LEP era)
- E fiducial is going down ? or S is going up ? unique jack sinking effect ?
- «Hole» of arc 78 and perturbation of 81

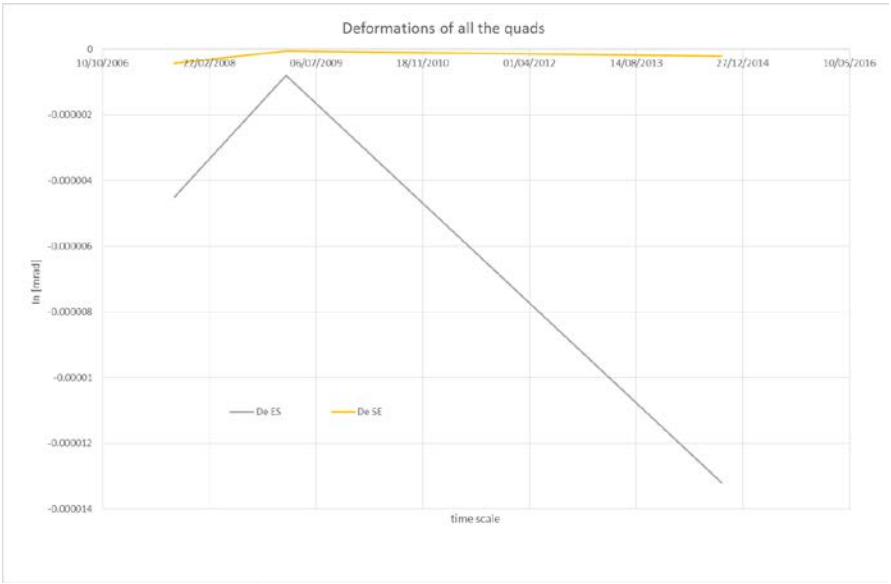




Deformations

- For the ES deformation, 78, 81 and 45 are the most active
- Both deformation are changing direction in 2009
- Both deformation much smaller than at the LEP era





Conclusion

- The most unstable areas have been identified
  - For the LSSs : visual techniques and CE inputs
  - For the Arcs : statistics of displaced magnets
- The comparison of deviations wrt the smooth curves didn't give any satisfying results
- The Inclination/deformation statistical analyzis showed
  - a decrease of vertical movement speed wrt LEP era
  - a possible problem with the unique jack
- Predictions are quite difficult to do but if it is linear, we will have the same amount of magnets to realign in LS2 (2019-2020)

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Thanks a lot