Geometry: analysis and trend.

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Acknowledgements*:*

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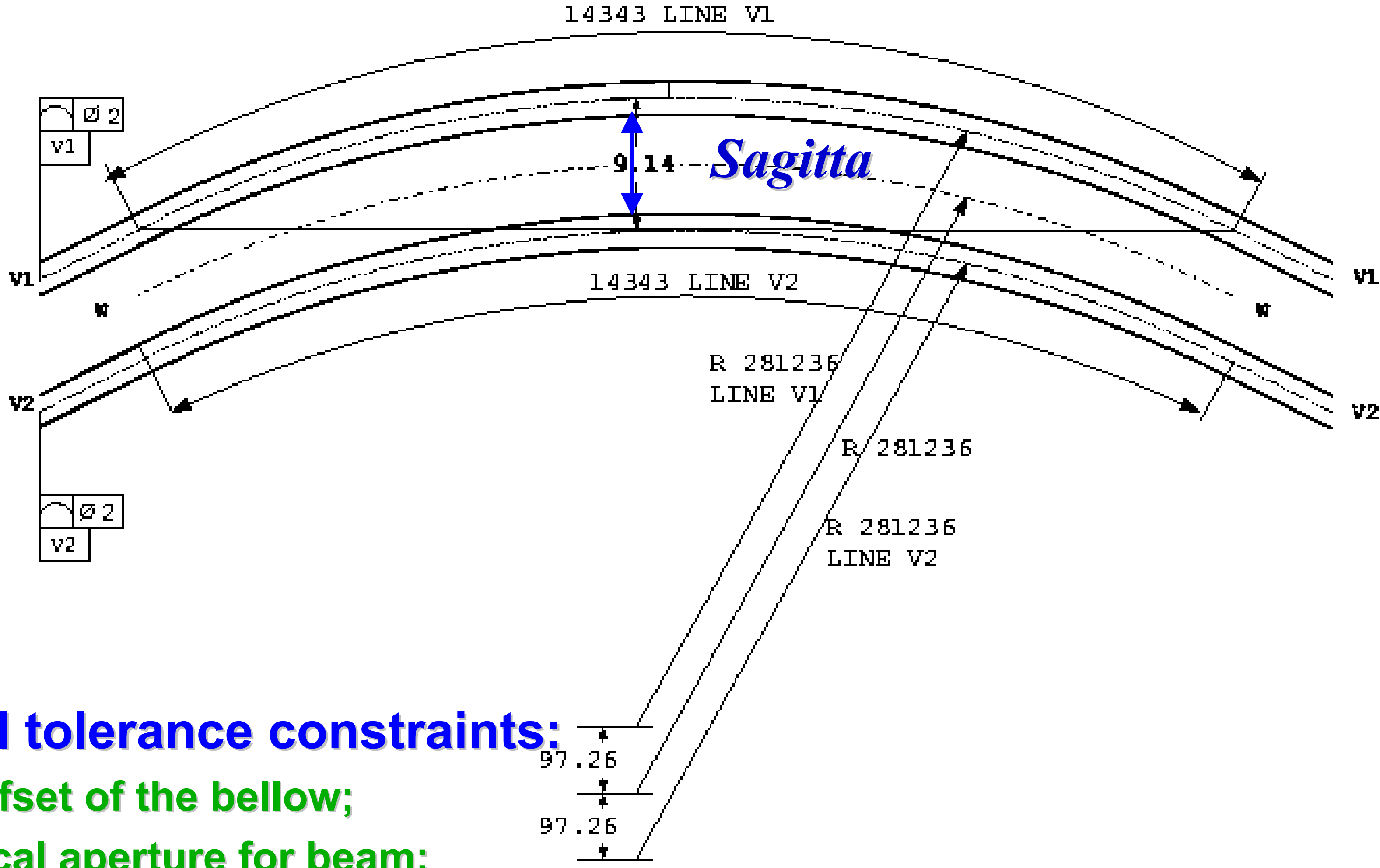
THEORETICAL SHAPE OF THE DIPOLE



Mechanical tolerance constraints:

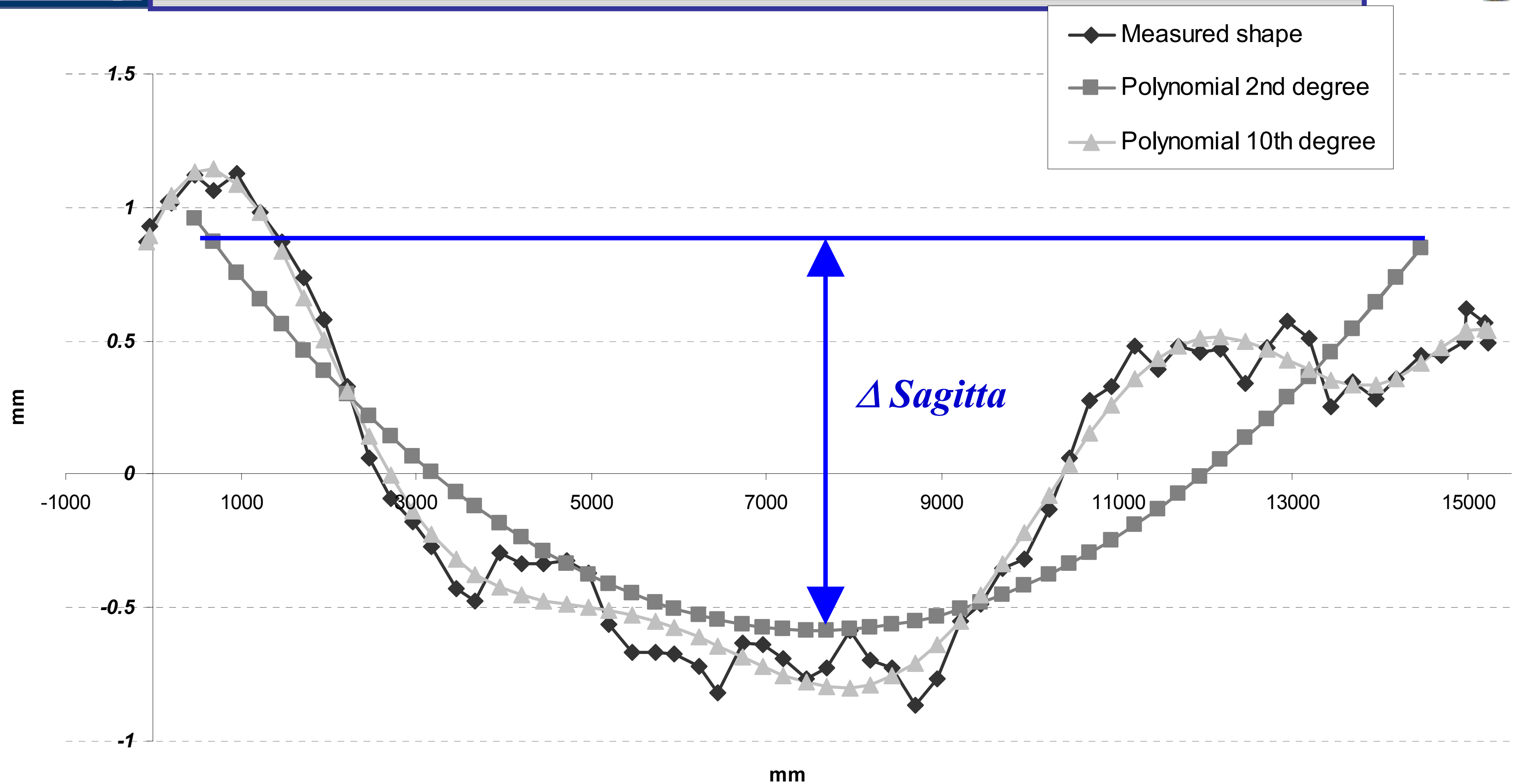
- Radial offset of the bellow;
- Mechanical aperture for beam;
- Radial displacement of the spool piece to prevent feed down

TOLERANCE TABLE

rms deviations (1σ) in mm	Core	Ends	Corrector
Cold Mass Assembly			
Identification of the 'bundled' referencial	0.07	0.07	
Geometric vs mechanical axes in the dipole	0.33	0.20	
Deformations induced by dynamic effects	0.20	0.20	
Magnetic vs mechanical axes in the dipole	0.10	0.10	
Geometric vs mechanical axes in the corrector			0.10
Magnetic vs mechanical axes in the correctors			0.10
Beam screen			
Beam screen axis vs dipole mechanical axis	0.30	0.30	
Cold Mass in the Cryostat			
Thermo-mechanical deformation of the cold-feet	0.10	0.10	0.10
Cryostat ovalisation and straightness error	0.10	0.10	0.10
Dipole geometric axis vs external survey target	0.10	0.10	0.10
Mispositionning of the dipole central foot	0.10	0.05	0.05
Positioning in the Tunnel			
Transportation nto the tunnel	0.15	0.15	0.15
Ideal position vs real position after one year run	0.28	0.50	0.50
Mechanical aperture restriction in the dipole	0.54	0.63	
Magnetic center of the corrector vs magnetic axis of the dipole			0.48

Tolerance at 3 σ in mm	Core	End		Ends round-off
Max at the manufacturers	1.01	0.64		0.6
Max at CERN reception	1.18	0.87		0.9
Max at CERN at storage	1.29	0.98		1.0
Max in the tunnel after one year	1.63	1.88		2.0
Max magnetic center of the corrector vs magnetic axis of the dipole			1.45	
Max radial offset of two consecutiveV-lines(including 1 mm margin)		3.66		4.0

SAGITTA

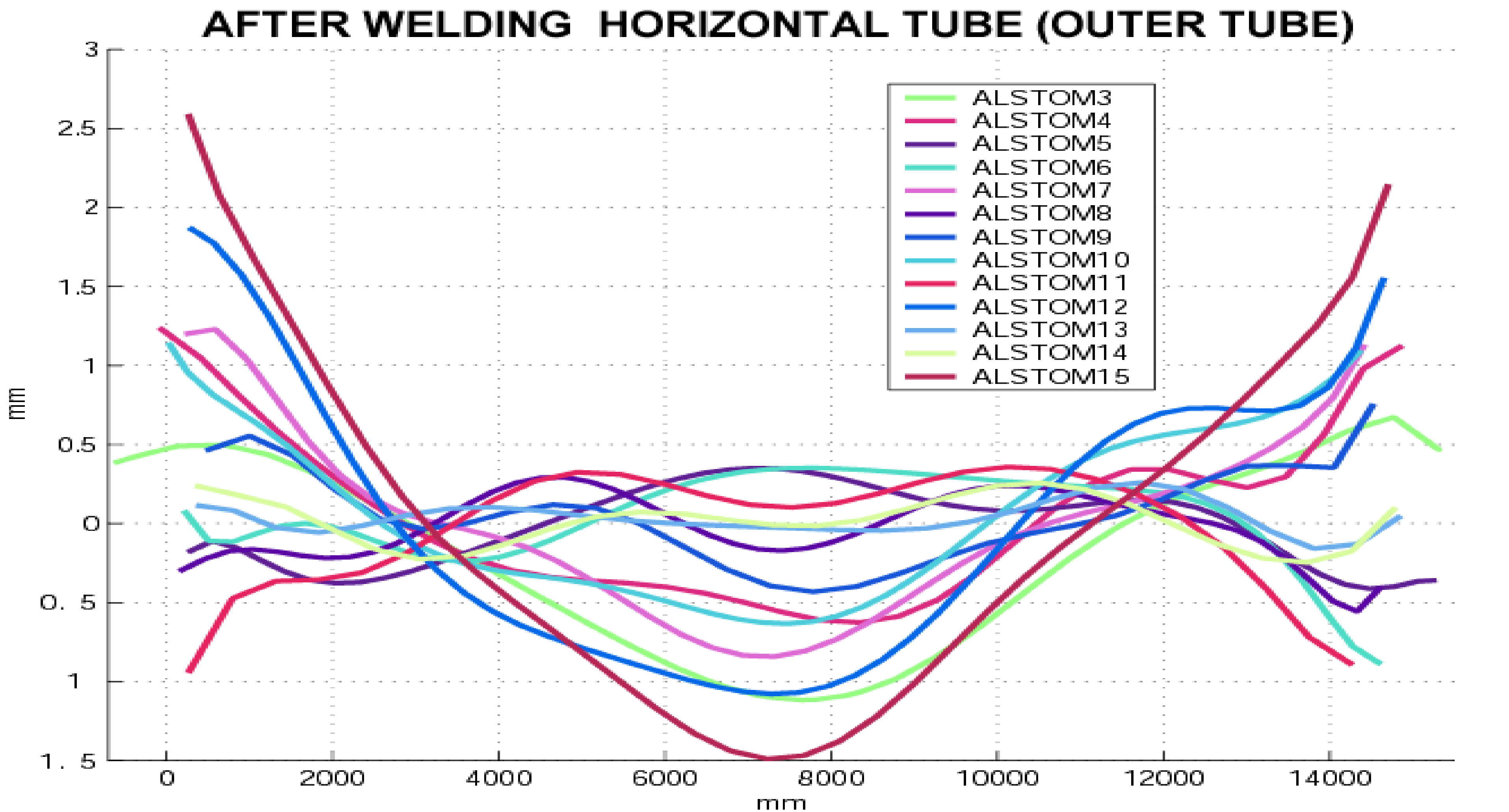


- **The change of sagitta is computed using the 2nd order polynomial interpolation.**

DATA COLLECTION AND INVOLVED DIPOLES

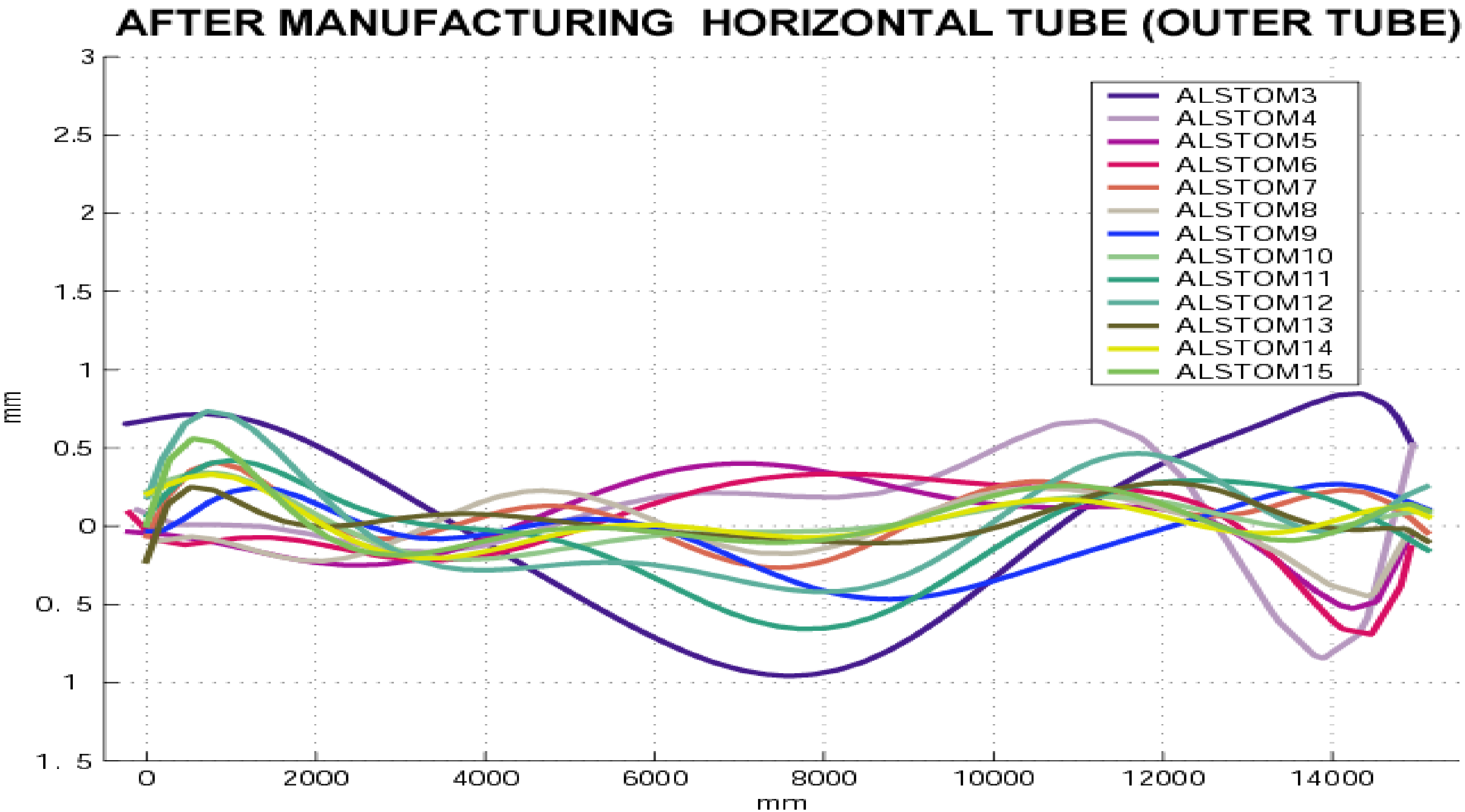
- **Measurement steps available:**
  - AfterWelding: without end cover and before reshaping
  - ITP20: measurements performed by manufactory
  - WP01: arrival @ CERN
  - WP03: after cryostating
  - WP08: after cold tests
- **Analyzed dipoles:**
  - Alstom3
  - Alstom6
  - Alstom7
  - Alstom8
  - Alstom9
  - Alstom10
  - Alstom11
  - Alstom12
  - Alstom14
- **Non Reshaped dipole:**
  - Alstom8
  - Alstom9
  - Alstom14
- **Geometrical analysis restricted to the horizontal plane.**

AFTER WELDING



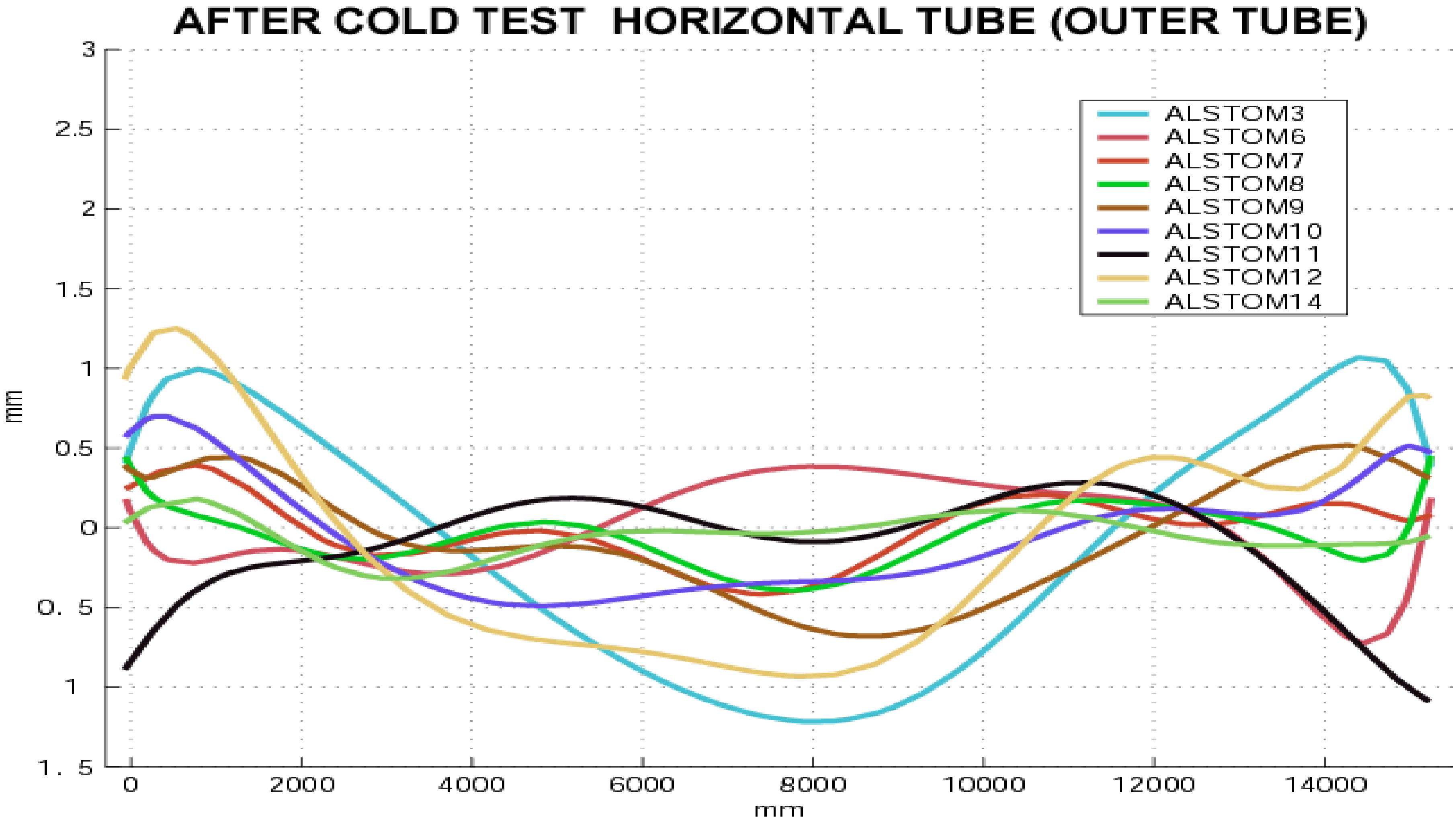
"AfterWelding" the shape varies from dipole to dipole.

AFTER MANUFACTURING



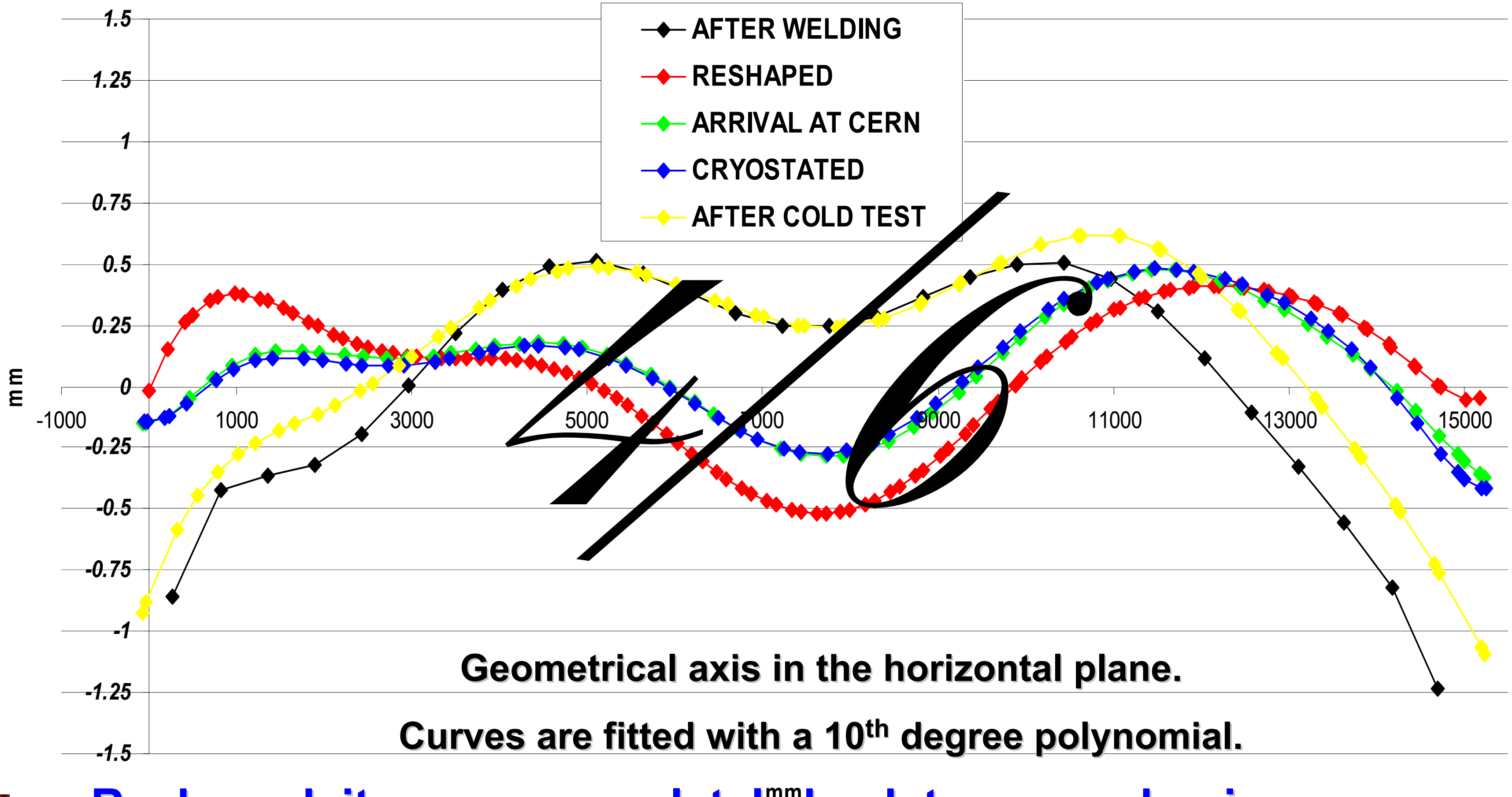
After manufacturing, shape variation is reduced.

AFTER COLD TEST



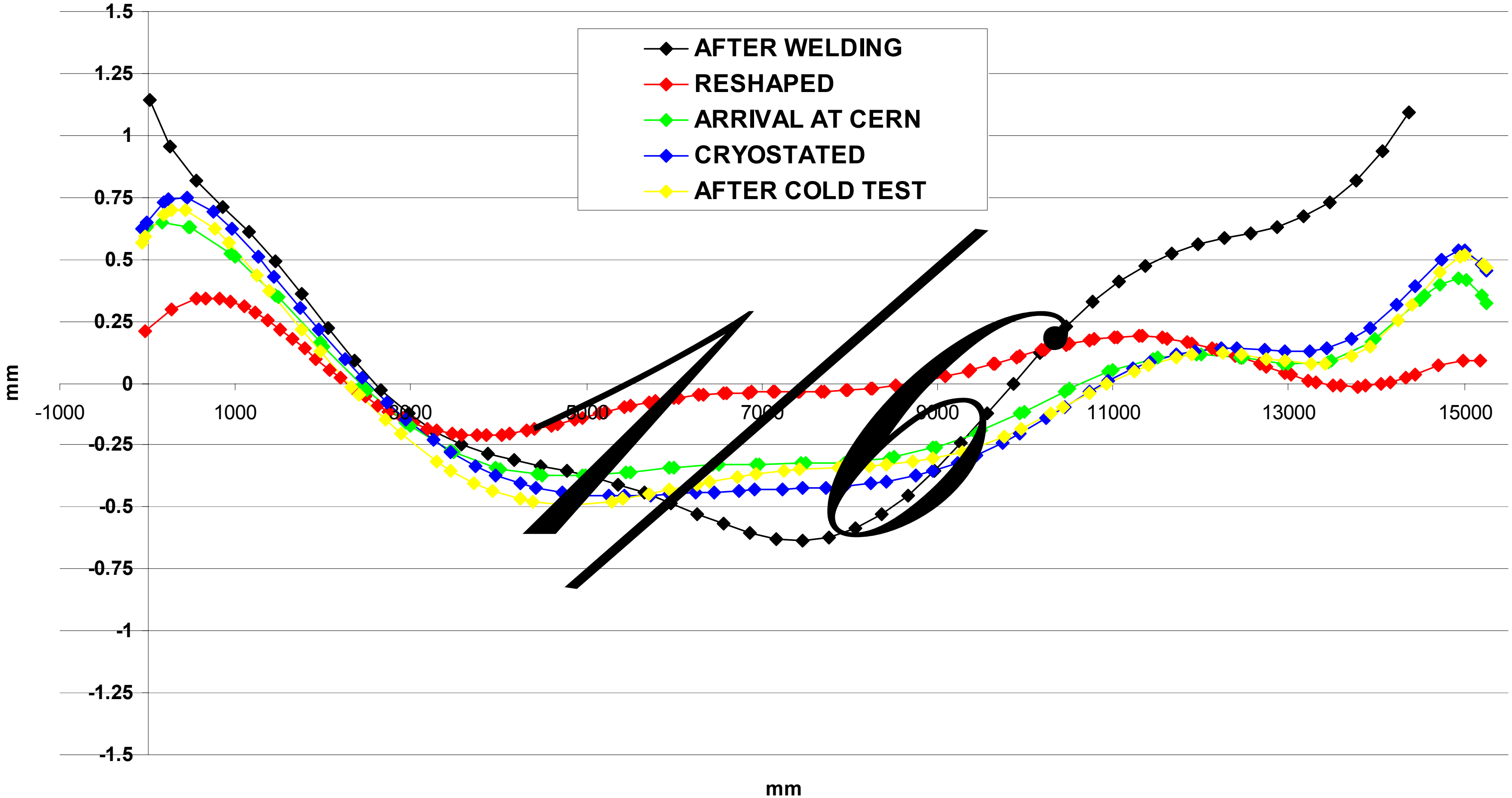
After cold test the shape variation increases again.

ALSTOM11



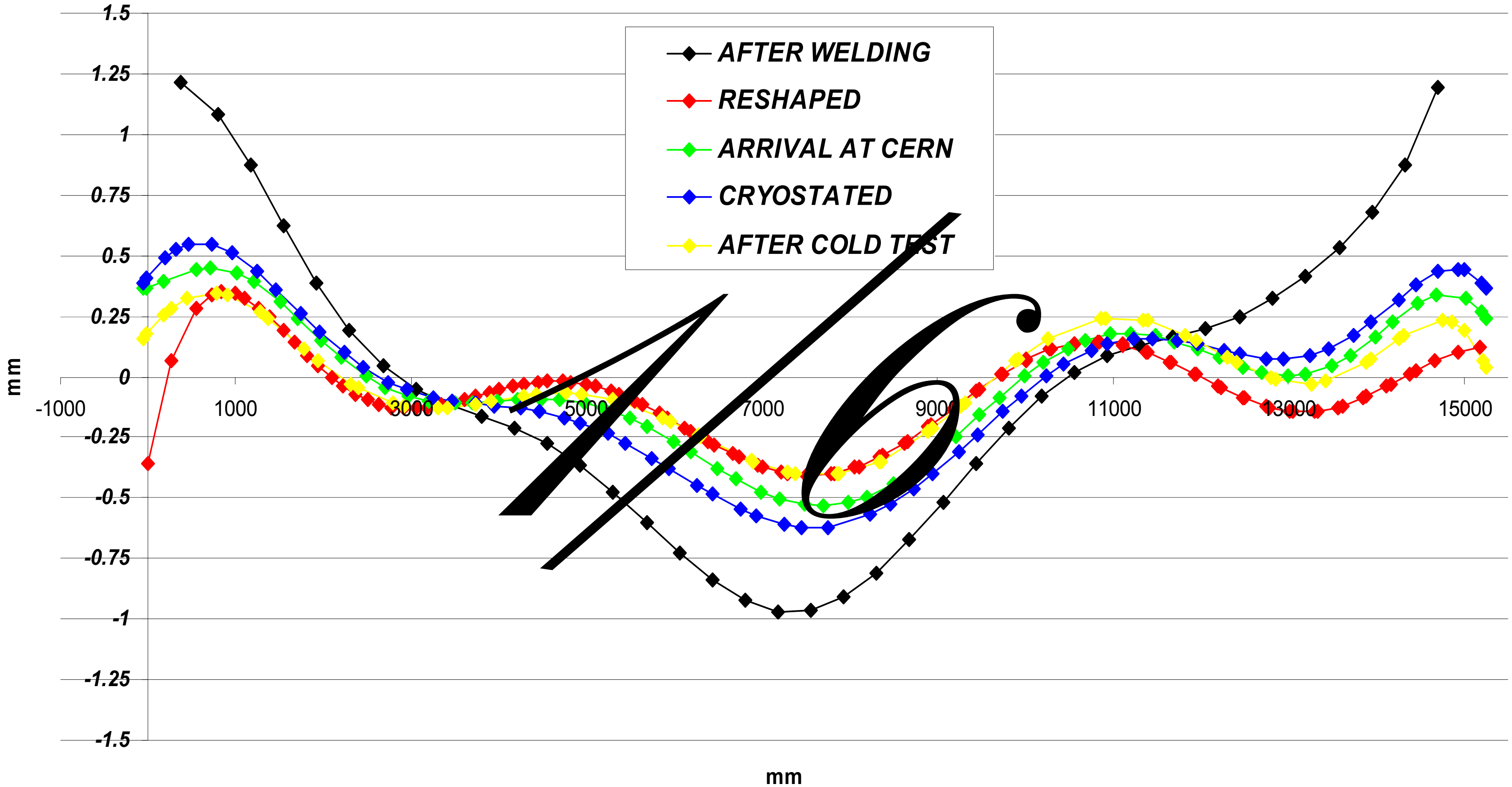
- **Reshaped, it comes completely back to pre-reshaping.**
- **Extremities present displacements.**
- **For Alstom3 the behavior is doubtful because of the large measuring errors.**

ALSTOM10



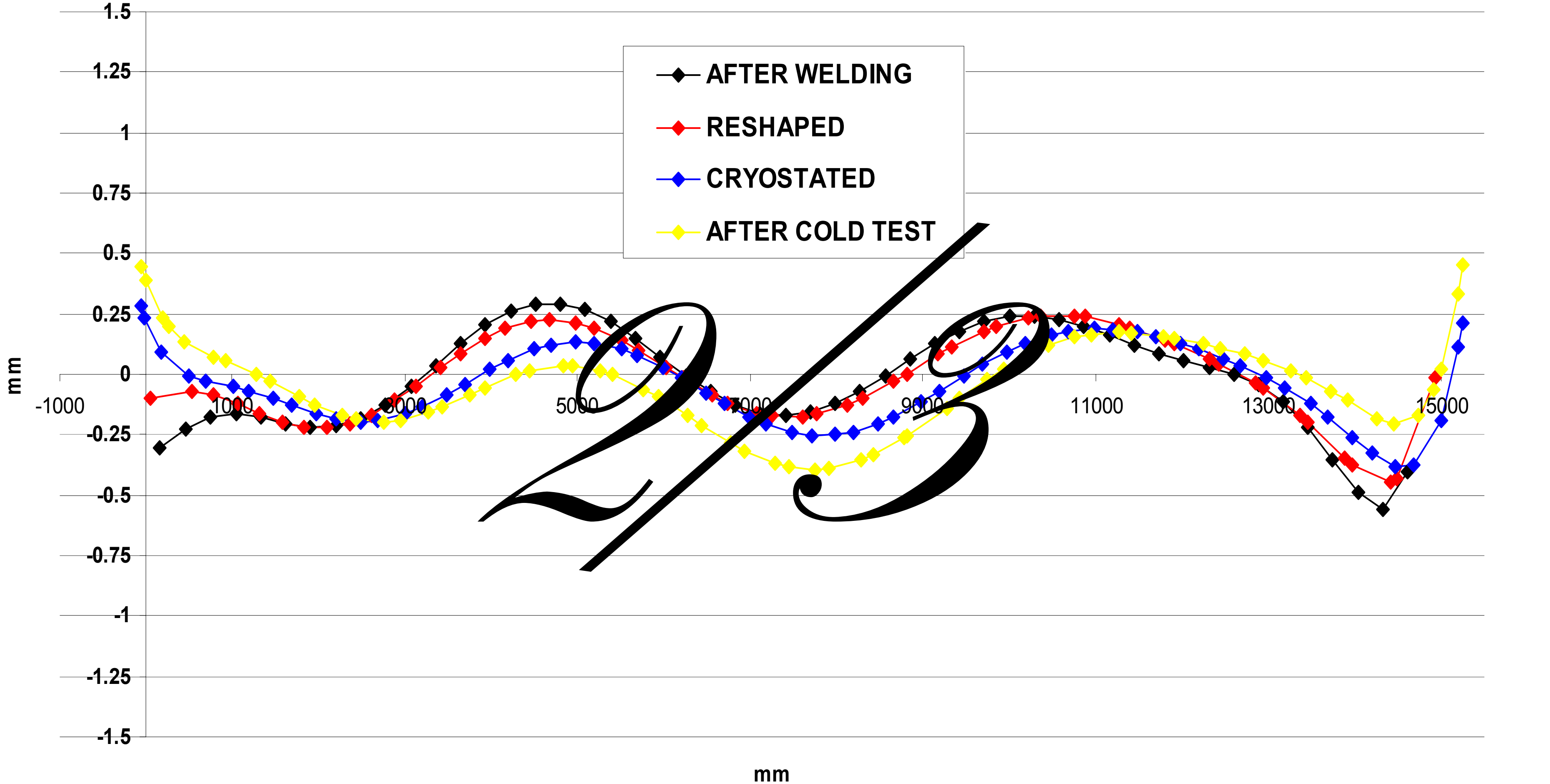
- Reshaped; after transportation, partial change towards "AfterWelding".
- No additional change induced by cold test.
- Non negligible displacements at the extremities.

ALSTOM7



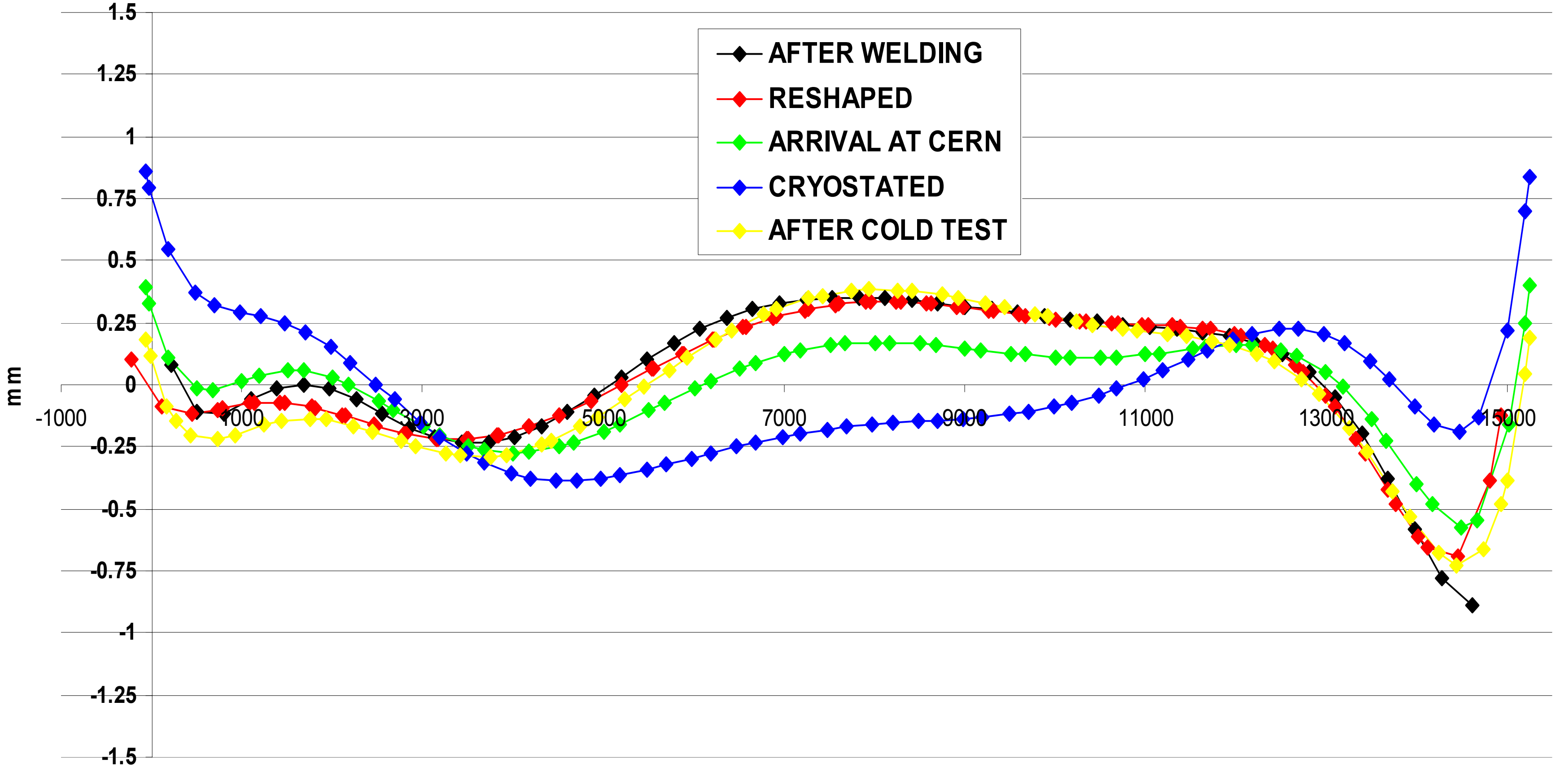
- Reshaped, after cold test same shape as after manufacturing.
- Extremities present non negligible displacements.

ALSTOM8



- **Non reshaped; a relaxation is visible in the curvature and in the extremities.**
- **Unexplained behavior in the Connection Side extremity.**

ALSTOM6



- Change of shape induced by an inappropriate cryostating procedure.
- The problem disappear after cold test.
- The cryostating procedure was improved afterwards.

SAGITTA VARIATION

- Sagitta variation at the end of cold test.

	Dipoles	Δ sagitta [mm] respect AfterWelding	Δ sagitta [mm] respect Reshaped
Reshaped	Alstom3	-0.47	-0.16
	Alstom6	-0.11	-0.12
	Alstom7	+1.48	-0.08
	Alstom10	+0.77	-0.78
	Alstom11	+0.04	+1.89
	Alstom12	+0.12	-1.06
Non reshaped	Alstom8	-0.69	-0.64
	Alstom9	+0.15	-0.42
	Alstom14	+0.11	+0.28

- After cold test 5/9 dipoles have the same sagitta as "AfterWelding"
- The other dipoles present erratic movements.

HEADS INSTABILITY

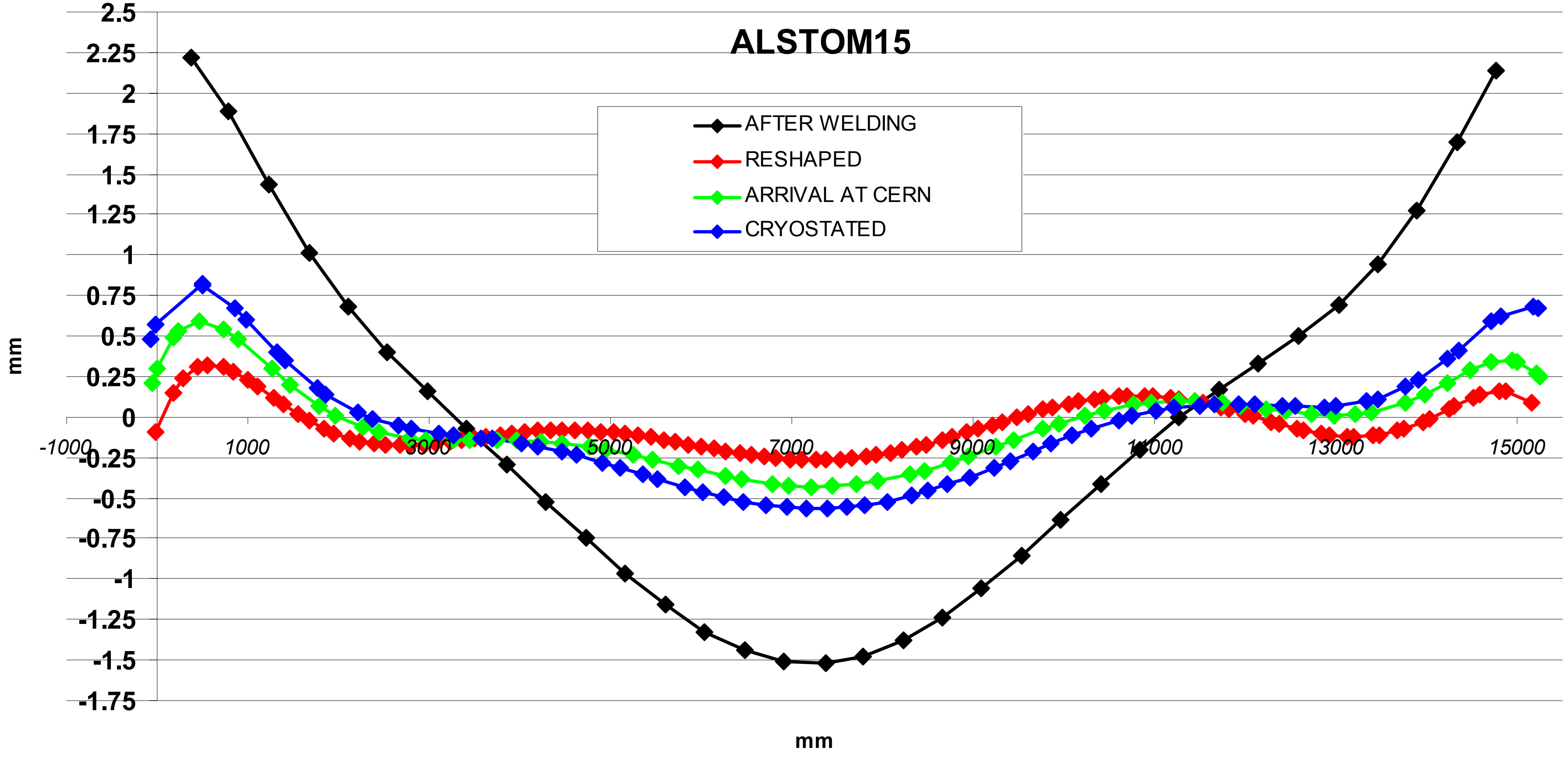
- **Variation of the heads after cold test:**

	Δ [mm]	Δ displacements respect AfterWelding	Δ displacements respect Reshaped	Δ sagitta respect AfterWelding
Reshaped	Alstom3	+0.25	+0.15	-0.47
	Alstom6	+0.10	-0.05	-0.11
	Alstom7	-0.91	+0.62	+1.48
	Alstom10	-0.65	+0.25	+0.77
	Alstom11	-0.02	-0.93	+0.04
	Alstom12	-1.02	+0.71	+0.12
Non Reshaped	Alstom8	+0.75	+0.55	-0.69
	Alstom9	+0.50	+0.45	+0.15
	Alstom14	-0.25	-0.25	+0.11

- **No evidence of systematic trends in head displacements.**
- **Large head displacements (5/9) respect to Reshaped (detrimental for mechanical aperture).**
- **Opposite sign in head shift respect to sagitta variation (8/9); possible cause: friction of the cold mass central post.**

ALSTOM 15

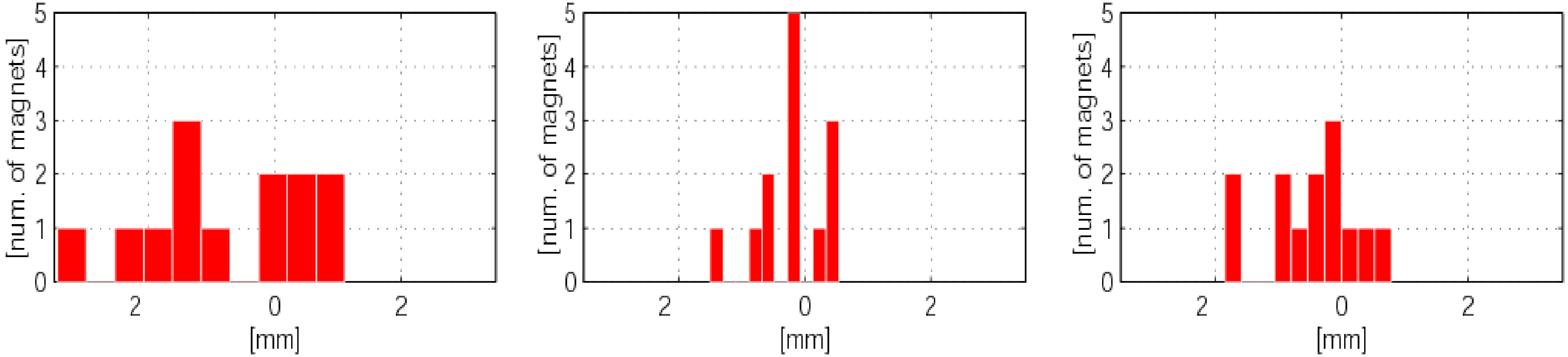
What will it happen to Alstom15, after cold test?



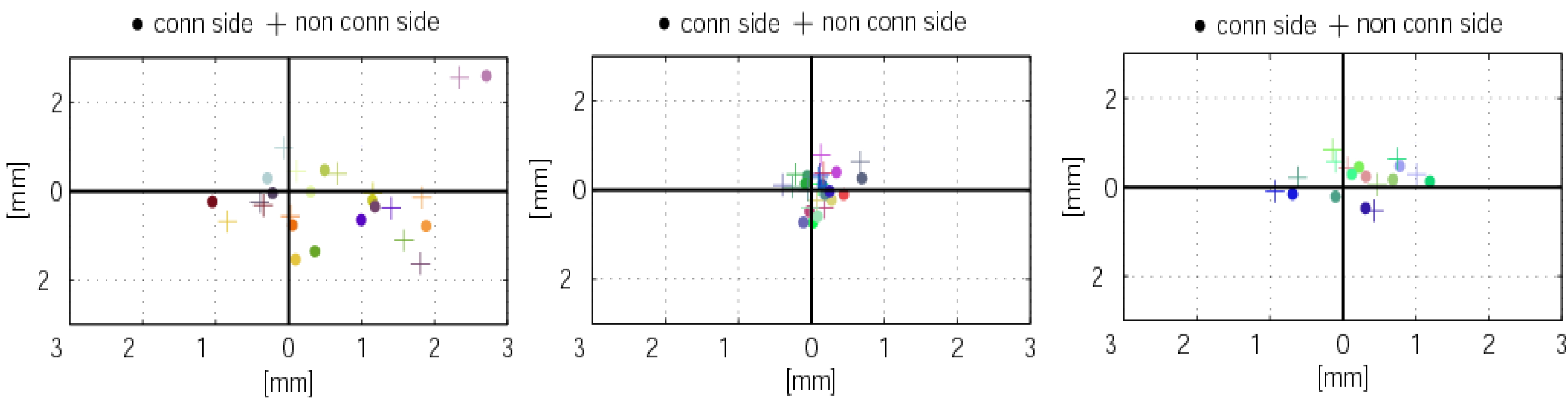
SAGITTA AND HEAD DISTRIBUTIONS

AFTER WELDING | AFTER COMPLETE MANUFACTURING | AFTER COLD TESTS

SAGITTA DISTRIBUTION



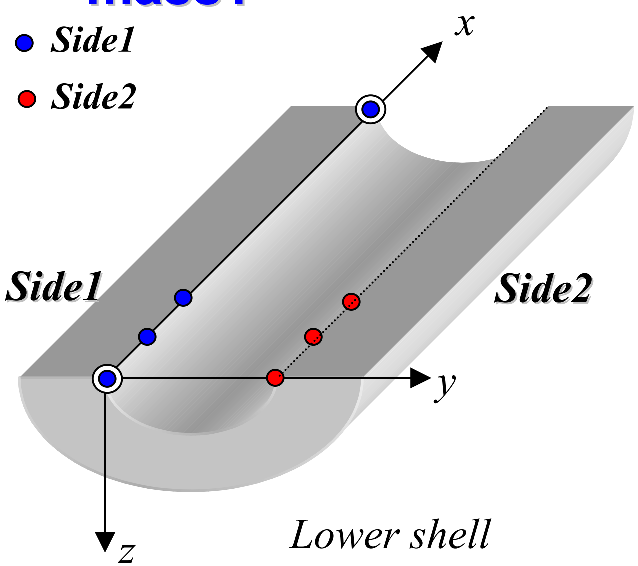
EXTREMITY POSITIONS

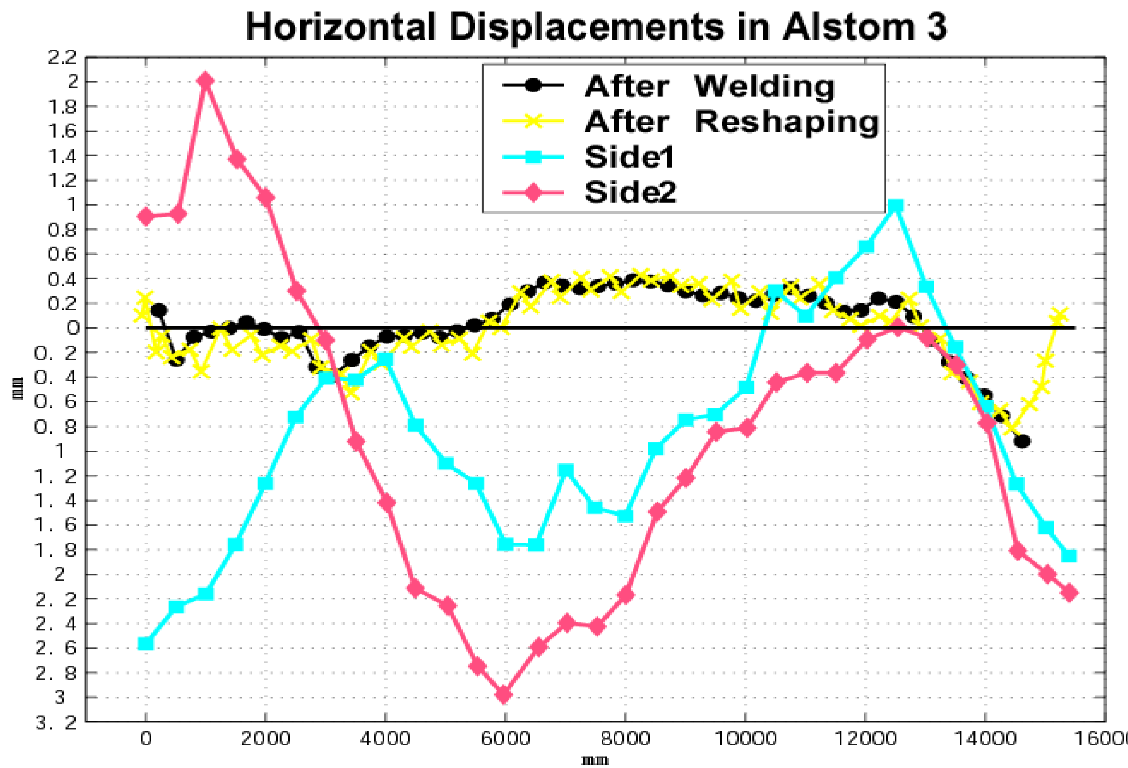


SHELL-SHAPE CORRELATION

AT-MAS

- The shells determine the inertia of cold mass
- Is there any correlation between the shape of the shell and that of cold mass?

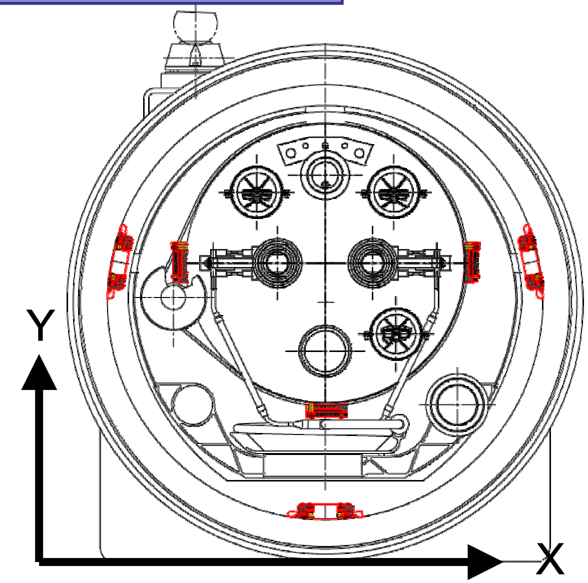




- Comparison between curvature shells and after cold test and “AfterWelding” measurements of horizontal plane.
  - Seen a very good correlation in Alstom12 (8/9).
  - But no correlation in all the other cases

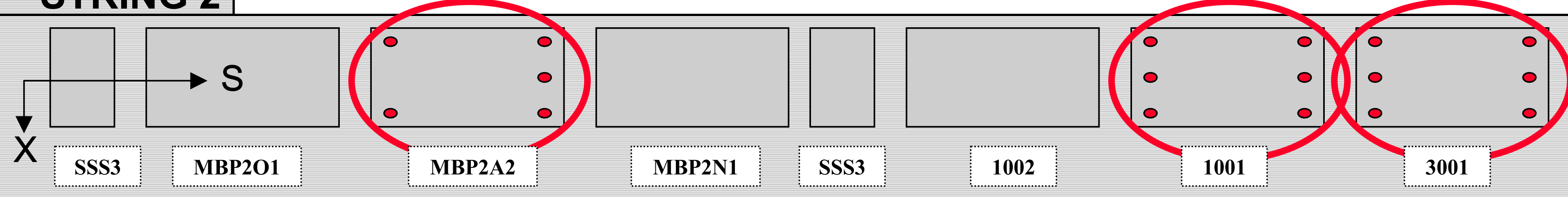
Cold mass displacements in the test string2 second run

- Both extremities have been monitored in three dipoles by mean of a low coherence interferometer
- Displacement in X and Y directions have been detected during and after tests



	COOL DOWN		QUENCH			Full th. cycle (1001)	
	ΔX [mm] 6	ΔY [mm] 2	ΔX [mm] 23	ΔY [mm] 5	rec time [hours] 28	ΔX [mm]	ΔY[mm]
mean	0.19	-1.025	-0.072	-0.24	3.7	0.2	-0.1
std dev	0.14	0.11	0.015	0.026	0.7	--	--

STRING 2



CONCLUSIONS

- **AFTER THE COLD TEST**
  - 4/6 reshaped dipoles tend to assume the "AfterWelding"shape.
  - 1/6 reshaped dipole only partially shifted towards "AfterWelding" shape.
  - 1/6 reshaped dipole preserves its shape.
  - The non reshaped dipoles have stable sagitta but instable heads.
  - All type of dipoles may have some residual sagitta (5/9). In this case they have opposite sign in head offset respect to sagitta variation.
- **There is no correlation between shell curvature and dipole shape at any stage.**
- **In the pre-series dipoles, the cold mass displacements induced by cool down or by quenches may reach few tenth of millimeter, as shown both in String2 and in the test benches.**