

# 1<sup>st</sup> Beams in the LHC, Some Topics

I. Agapov, M. Aiba, G. Arduini, R. Bailey, O. Bruning, R. Calaga, P. Collier, S. Fartoukh, A. Franchi, K. Fuchsberger, M. Giovannozzi, B. Goddard, V. Kain, M. Lamont, L. Ponce, R. Steinhausen, Y. Sun, R. Tomas, G. Vanbavinckhove, W. Venturini-Delsolaro, F. Roncoralo, J. Wenninger, F. Zimmermann...

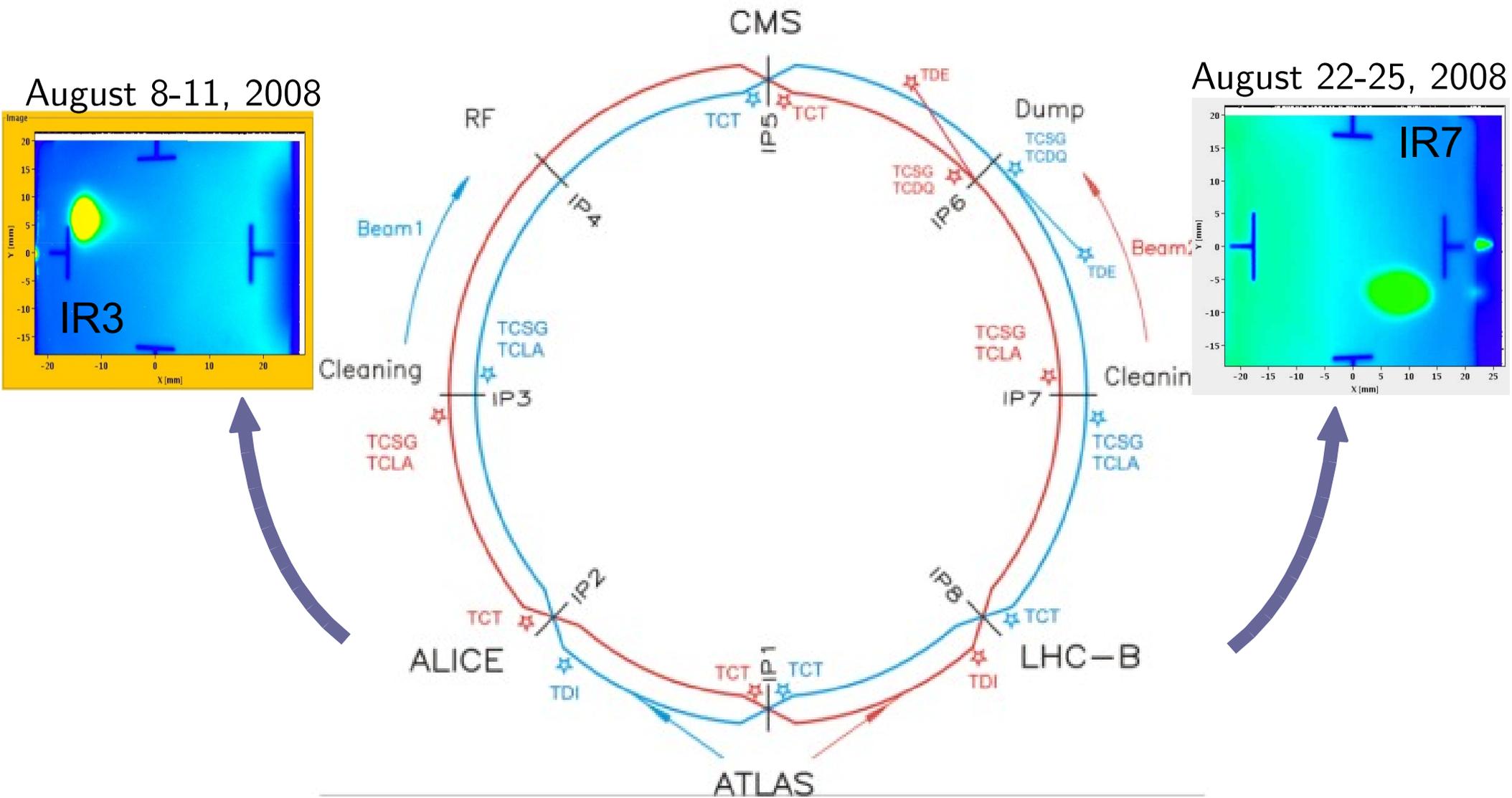
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ABP, OP, BI, CO

Note: Only contains subjects which I have contributed and some others that are relevant and are of interest

# Beams in the LHC

- August 8-11, 2008: Beam 1 thro' (Sector 2-3)
- August 22-25, 2008: Beam 2 thro' (Sector 7-8)
- September 5-8, 2008: Beam 2 (Sectors 78, 67) & Beam 1 (Sector 23, 34, 45)
- September 10, 2008: Beam 1 & 2 around the LHC



# Injection Aperture Scan

H Aper  $\sim \pm 8\sigma$

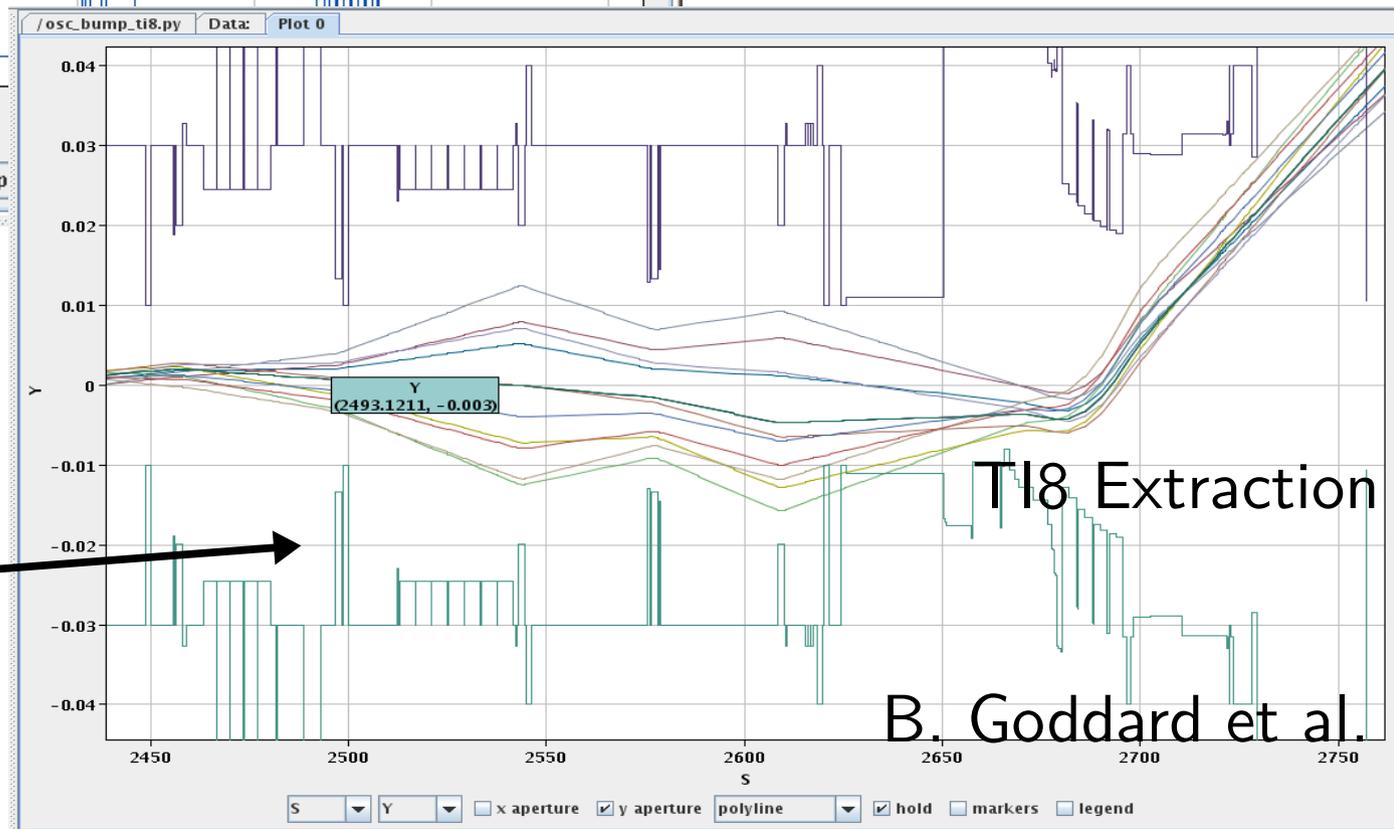
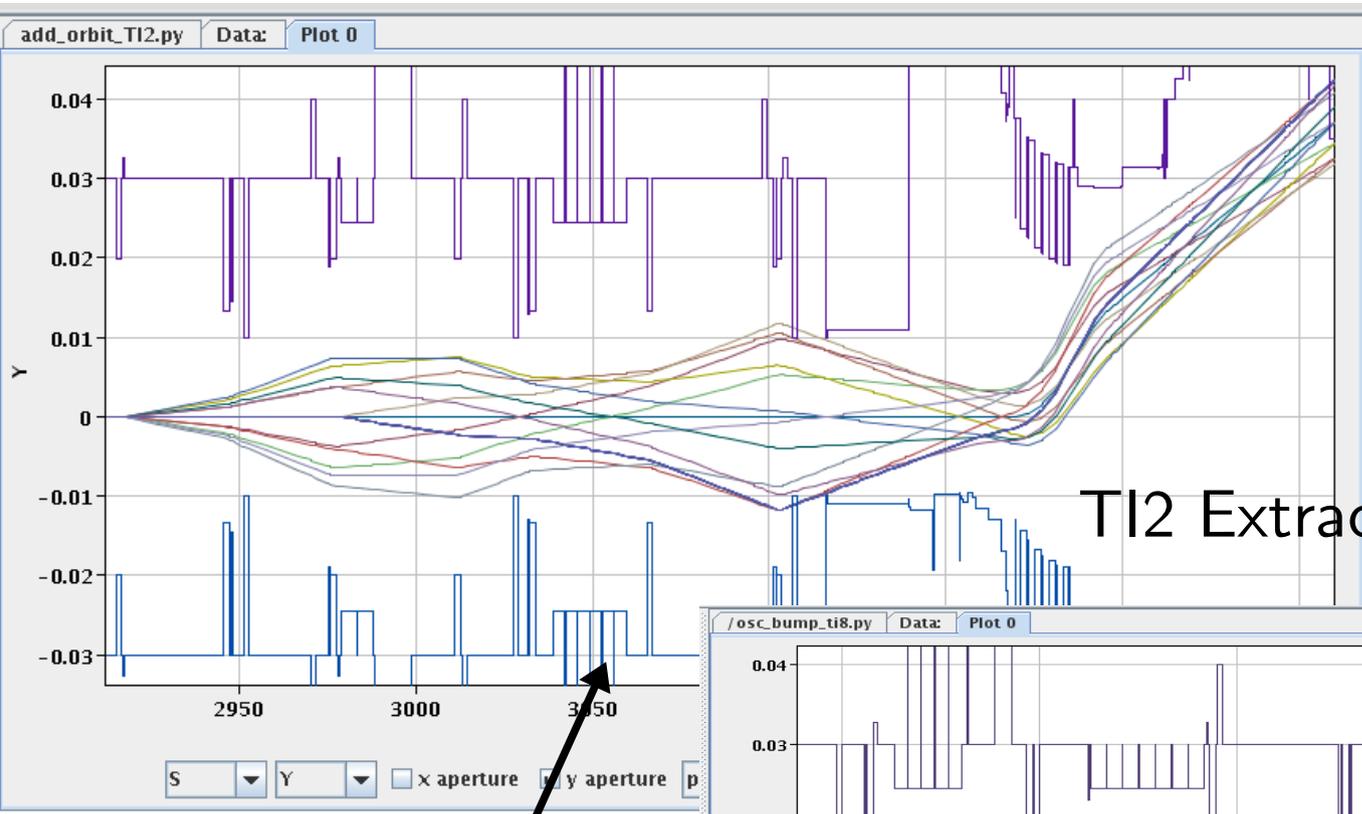
V Aper  $\sim \pm 6\sigma$

T12 Extraction

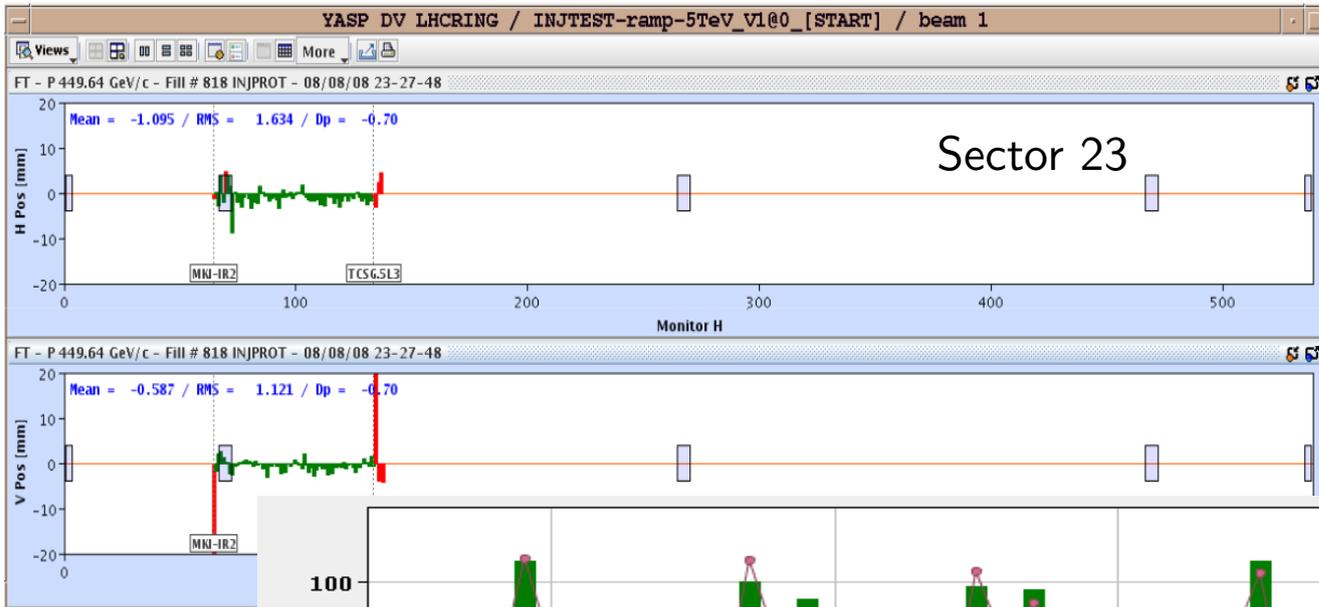
T18 Extraction

MAD-X Online Model

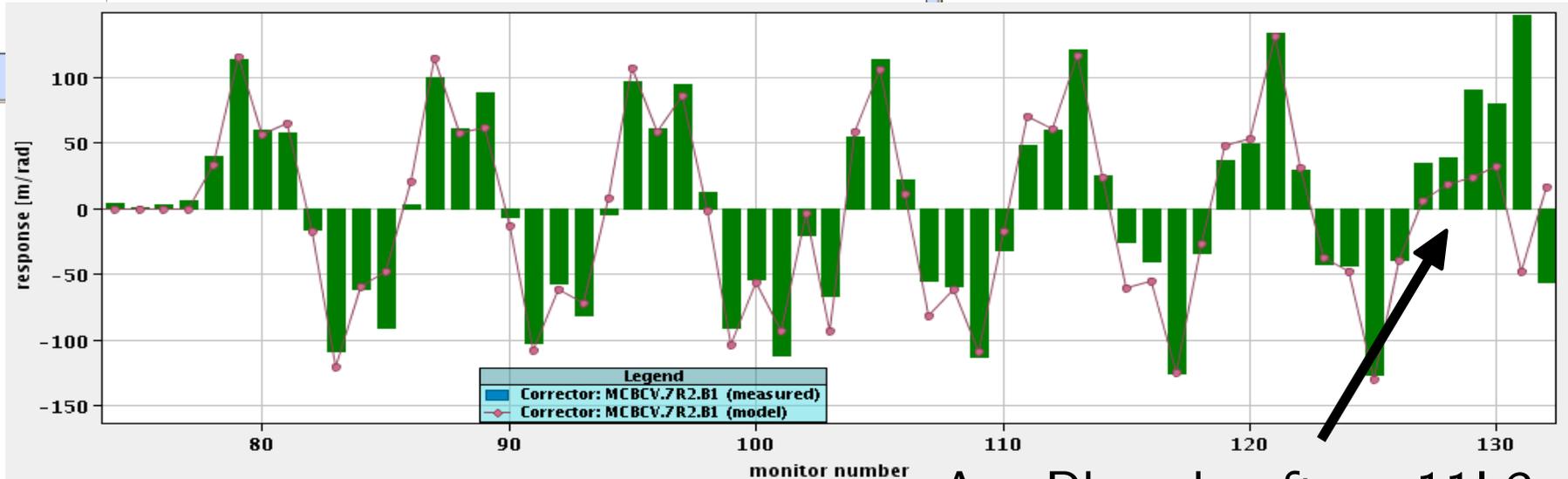
B. Goddard et al.



# Kick Reponse



Peak to peak  $\sim \pm 3\text{mm}$   
(design spec = 4mm)



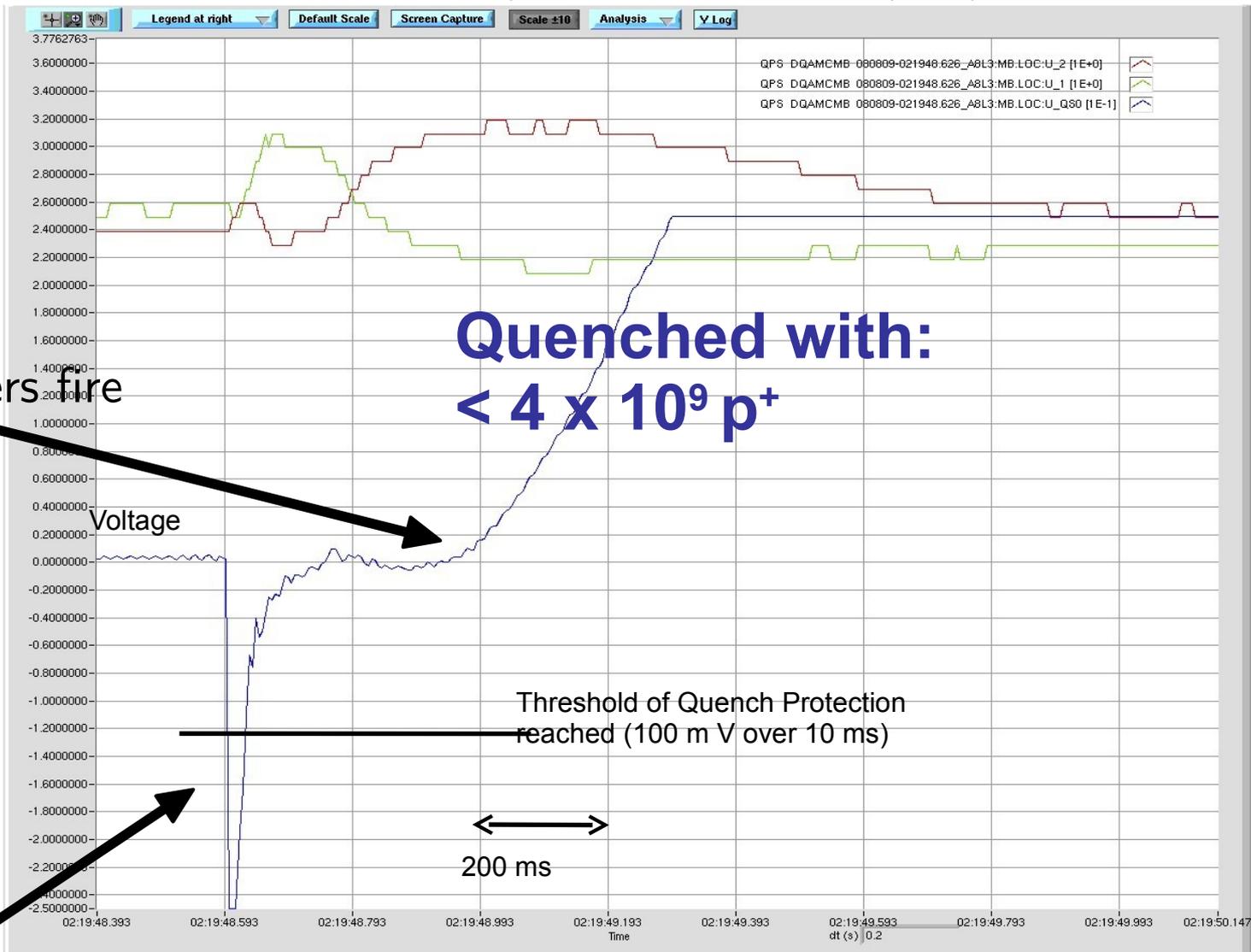
Arc Ph. adv after  $\sim 11L3$

Fit Par: BPM gains, Corrs, Main Quads  
(few BPM problems, kqf off by 1%)

- Candidate: MQTLI.11L3 (?)

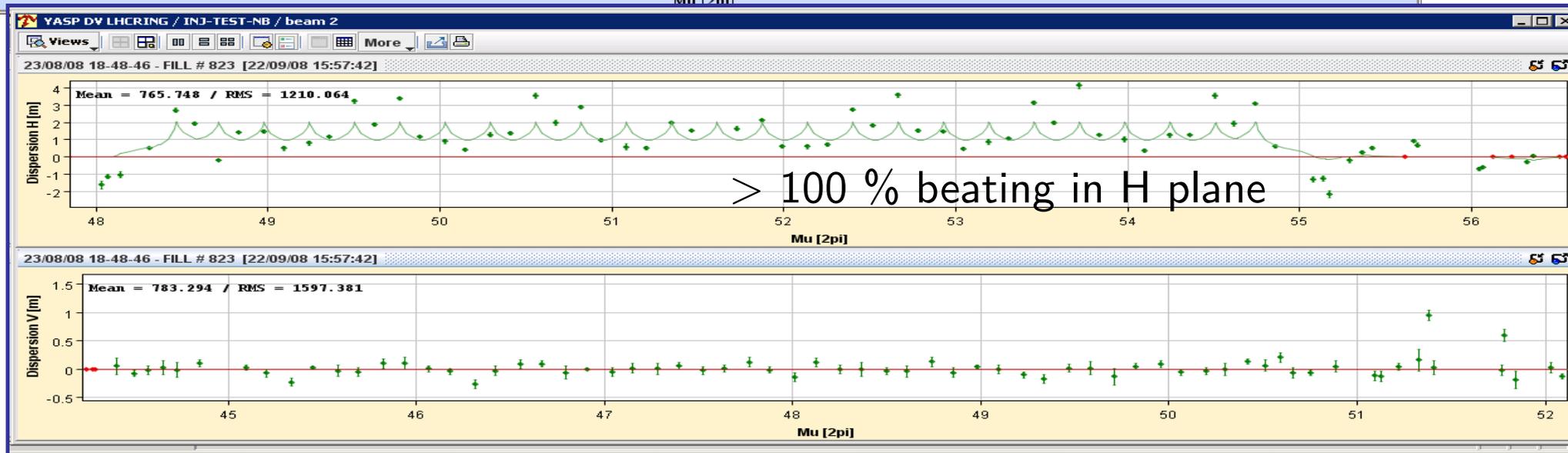
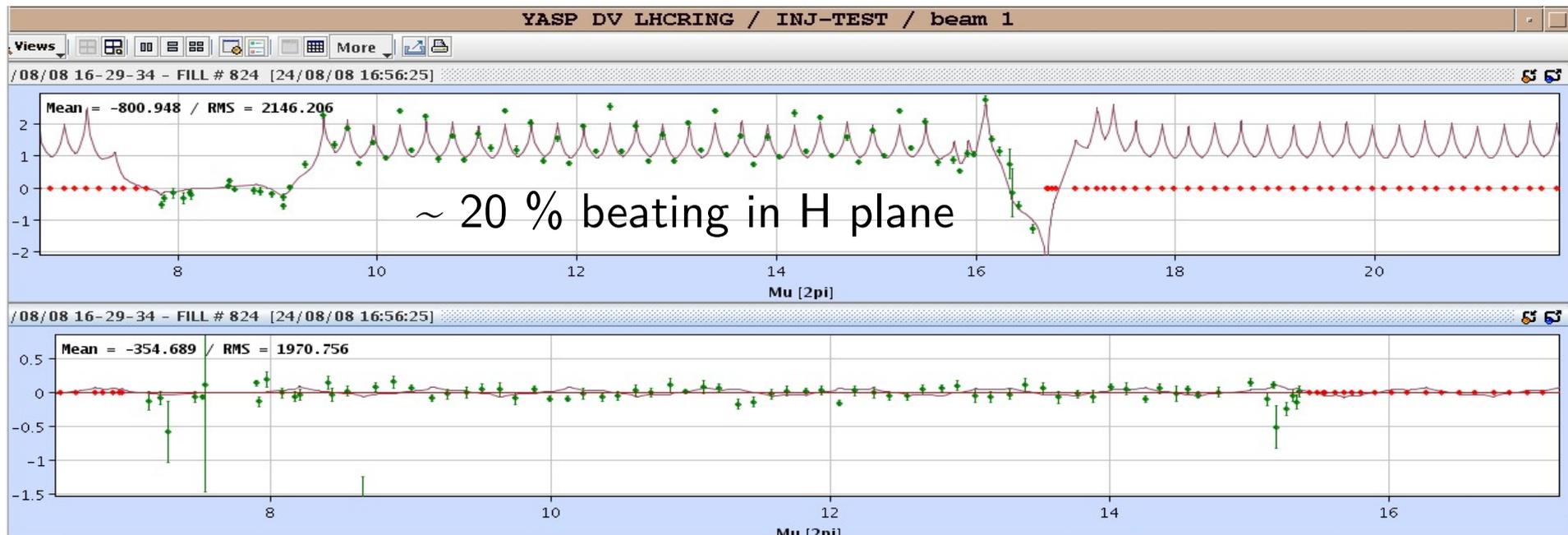
# Deliberate Quench

(LHC Project Report 44 (1996) predicted a threshold of  $3 \times 10^9$ )



Result of an orbit bump scan

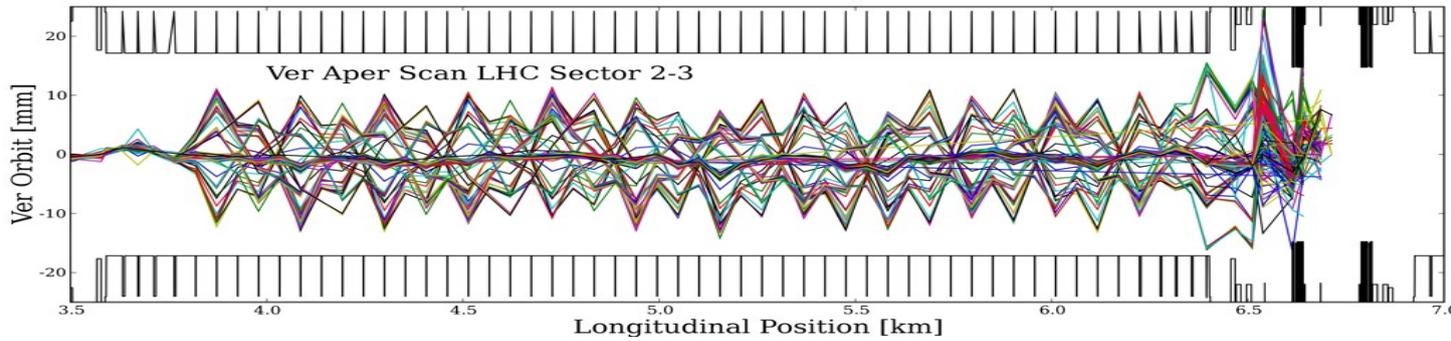
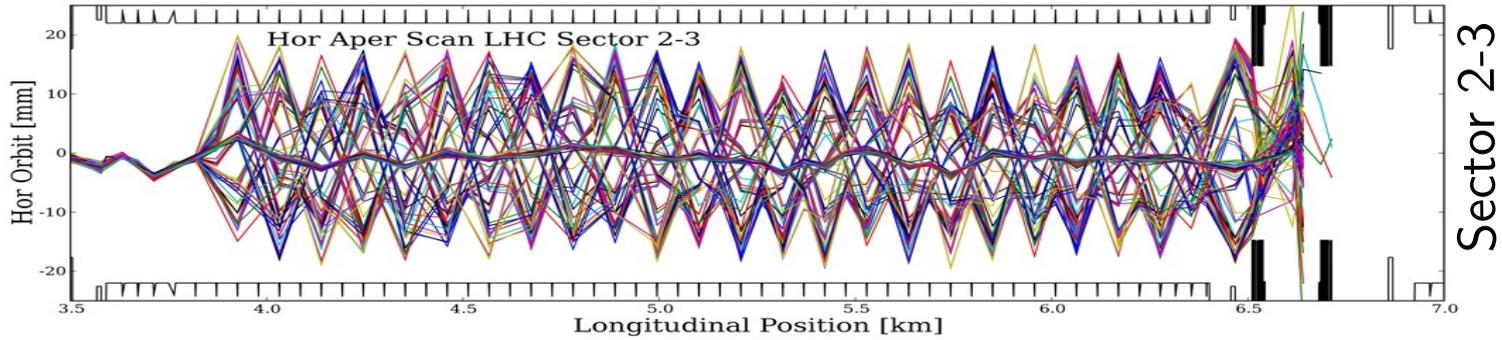
# Dispersion, Sector 23 & 78



Injection errors, polarities, unknown sources...

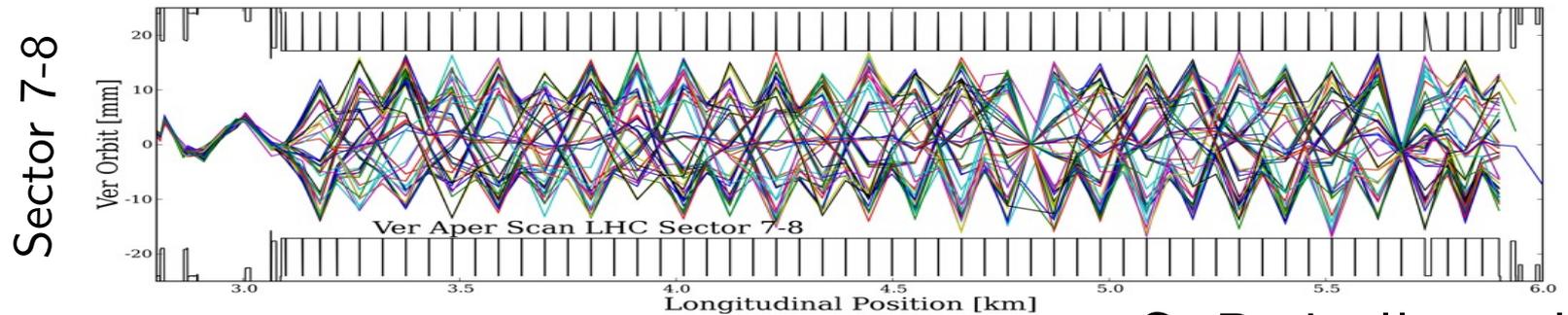
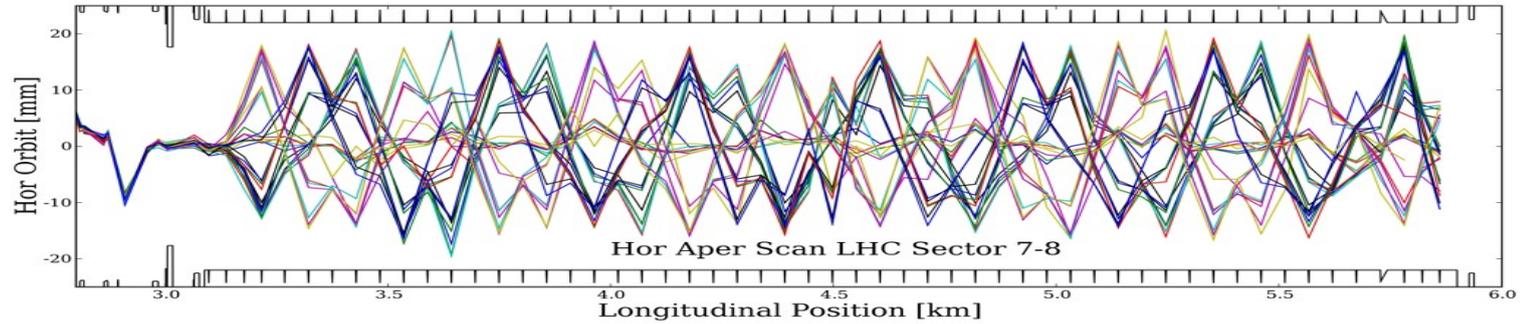
V. Kain, J.Wenninger et. al

# LHC Aperture

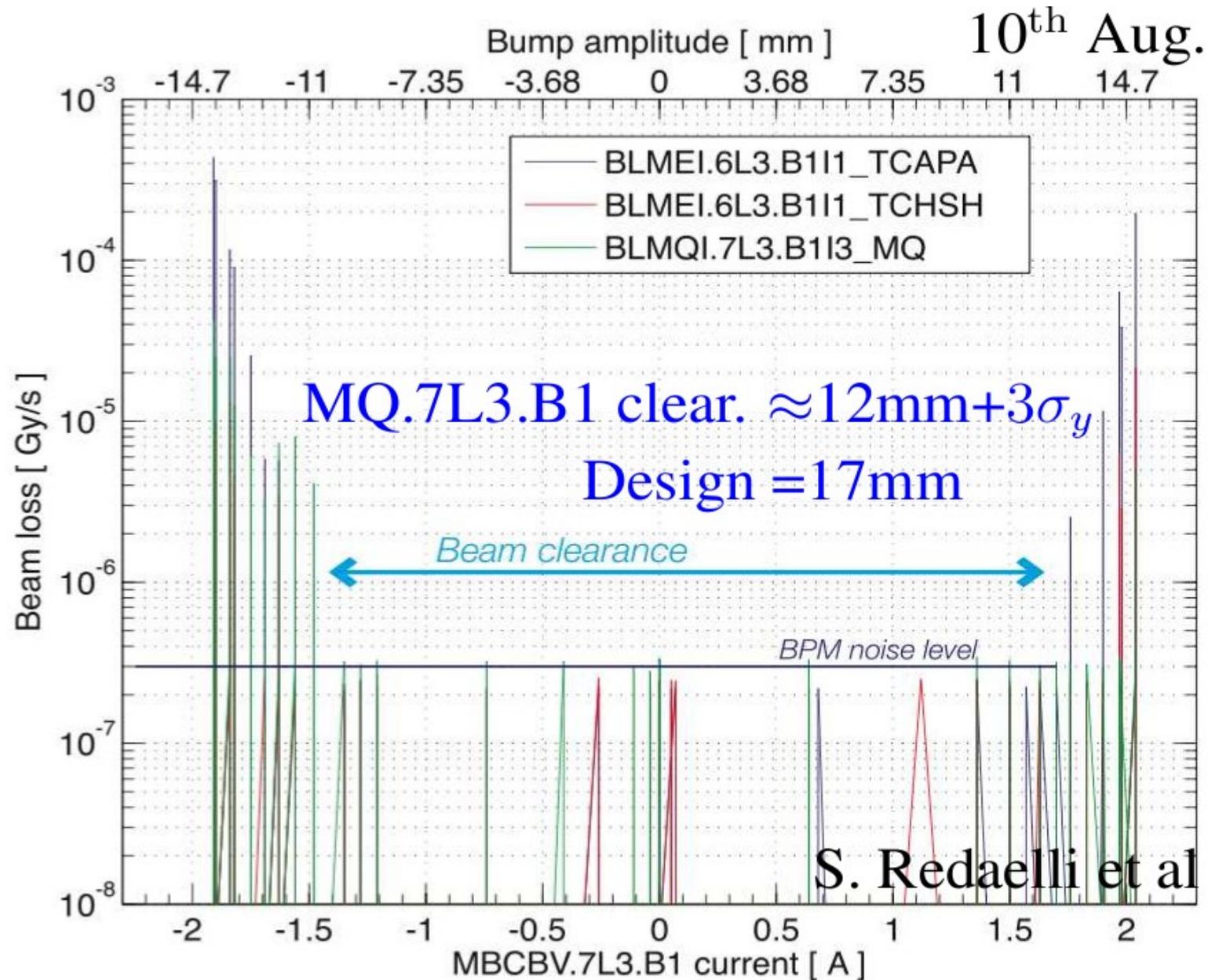


H/V free oscillations in the arc using 2 pairs of corrs  $\sim 90^\circ$  in phase

H Aper  $\sim \pm 18\text{mm}$   
V Aper  $\sim \pm 10\text{ mm}$

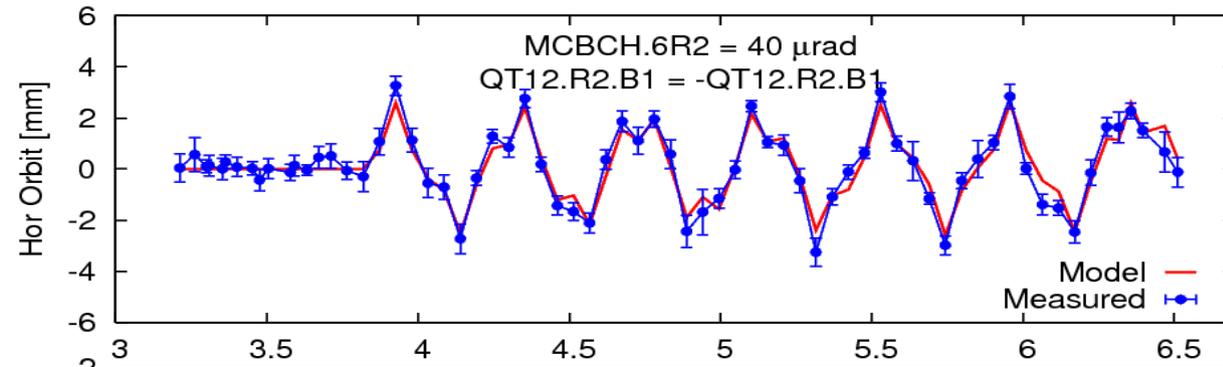


# LHC Aperture, Orbit Bump

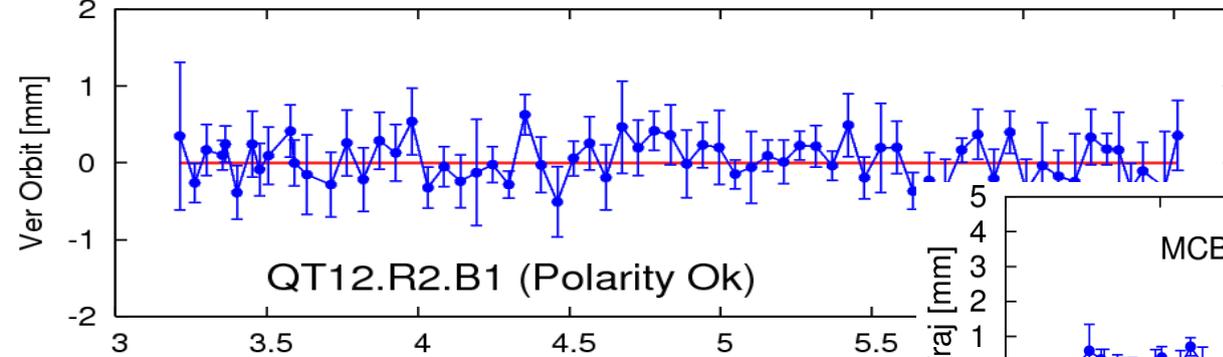


Need more precise optics & emittances for the discrepancy

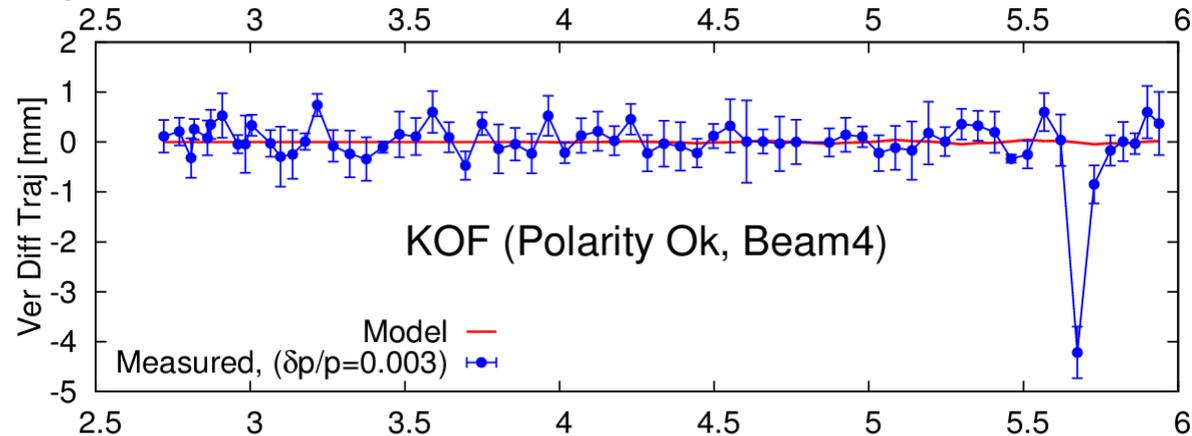
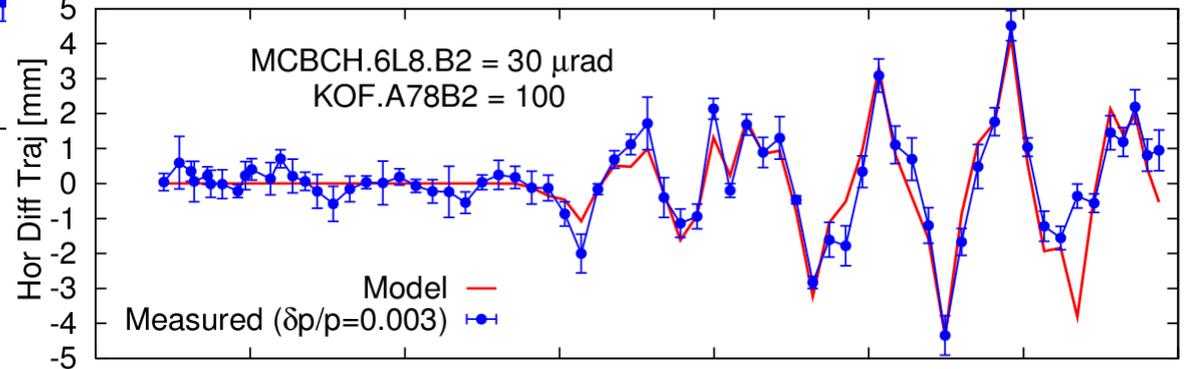
# Polarity Tests



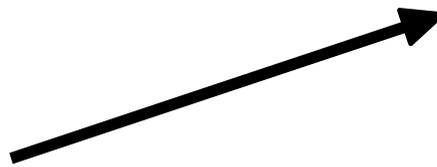
Trim Quadrupole  
Beam 1, QT12.R2



e.g. good polarity

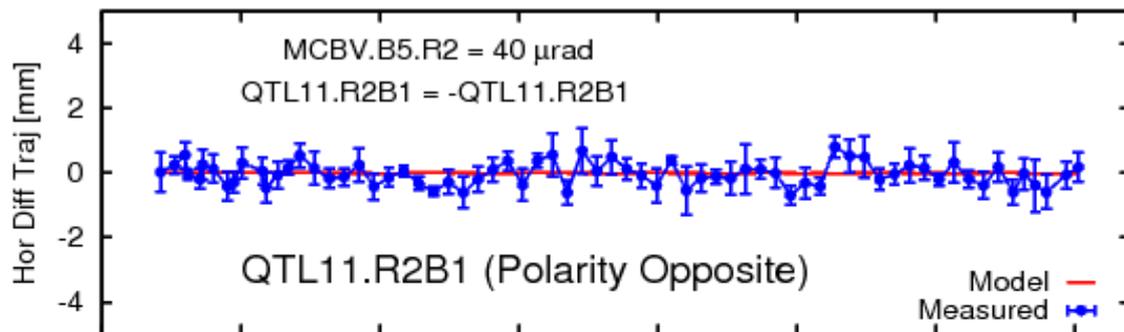


Octupoles



Beam 2(4), KOF -  $\delta p/p=0.003$

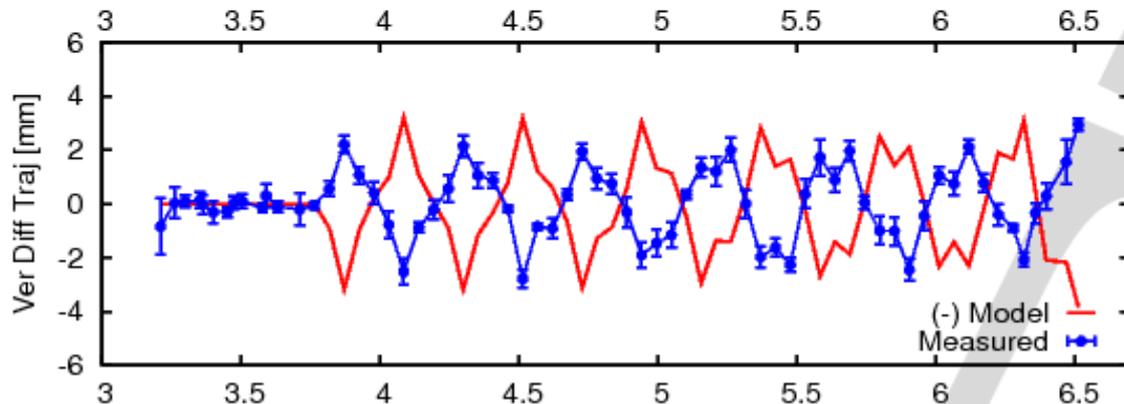
# Polarity Tests



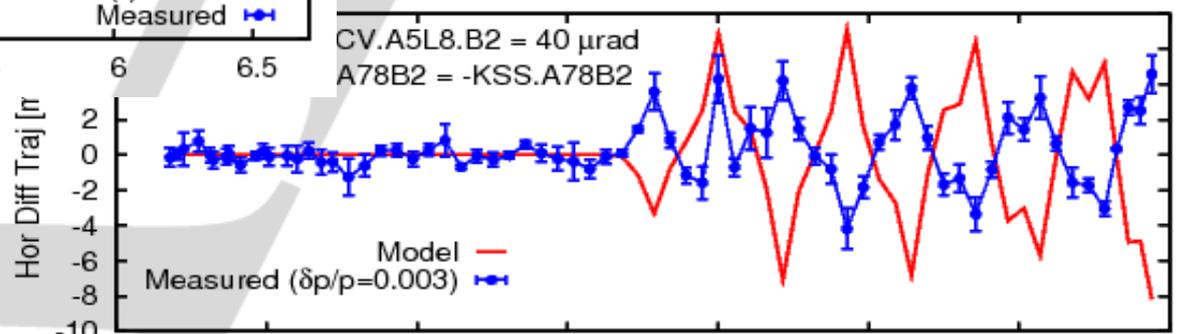
Trim Quadrupole  
Beam 1, QT11.R2B1



Fixed Before D-DAY !!

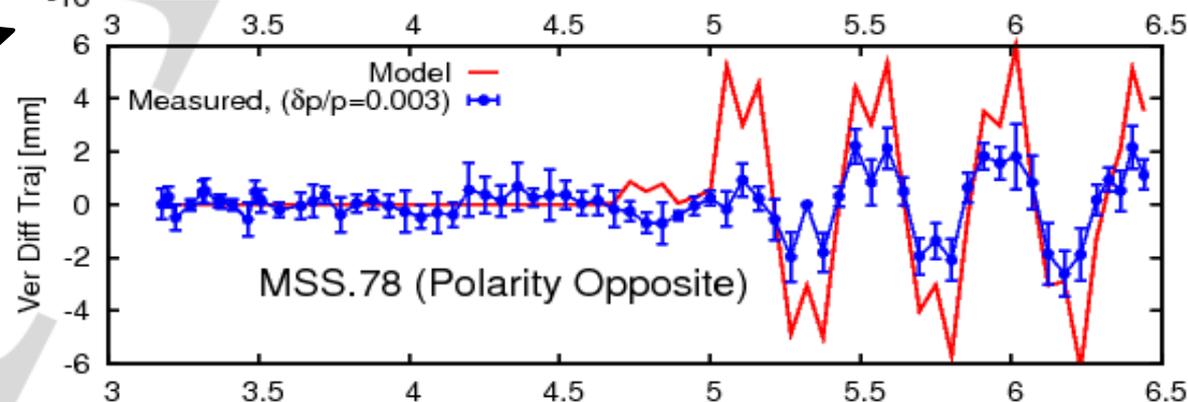
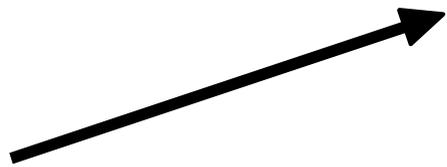


e.g. bad polarity



Skew Sextupoles

Beam 2(4), MSS -  $\delta p/p=0.003$



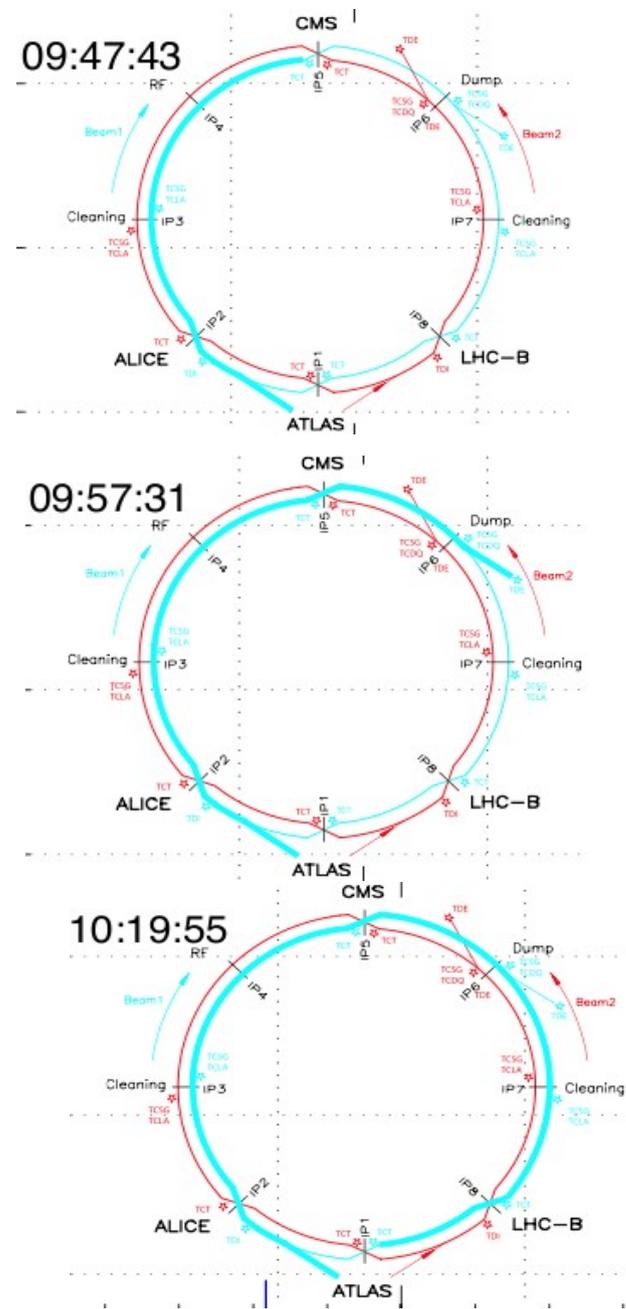
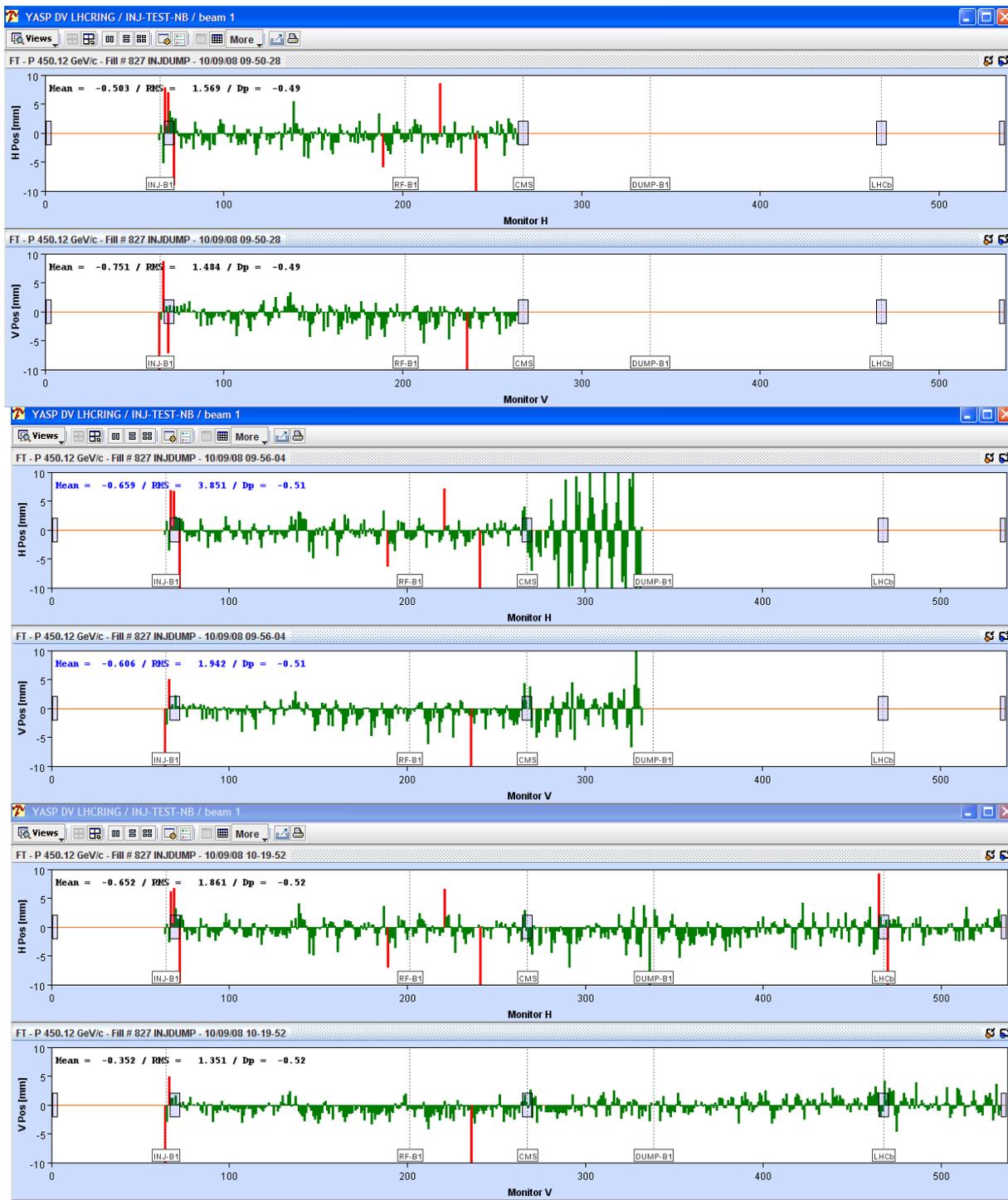
# Polarity Check, Summary

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- Very robust & clean signals from difference orbits to detect polarities of circuits
- Nominal lattice with reversed polarities & higher order circuits with  $dp/p$
- Orbit effect due to initial large offset for QT11.78 also found ([Y. Sun](#))
- Beam 1:
  - QT{11, 12, 13}, **MQS**
  - SF{1,2}, SD{1,2}, MSS
  - KOF, **KOD**
- Beam 2:
  - QT{11( $\delta x_{\text{initial}}$ ), 12, 13 (noisy)}, **MQS**
  - SF{1,2}, SD{1,2}, **MSS**, MCS
  - KOF, **KOD** ( $\delta p/p$  -or-  $D_{y, \text{initial}}$ )
- Future measurements with single passage -or- circulating beam

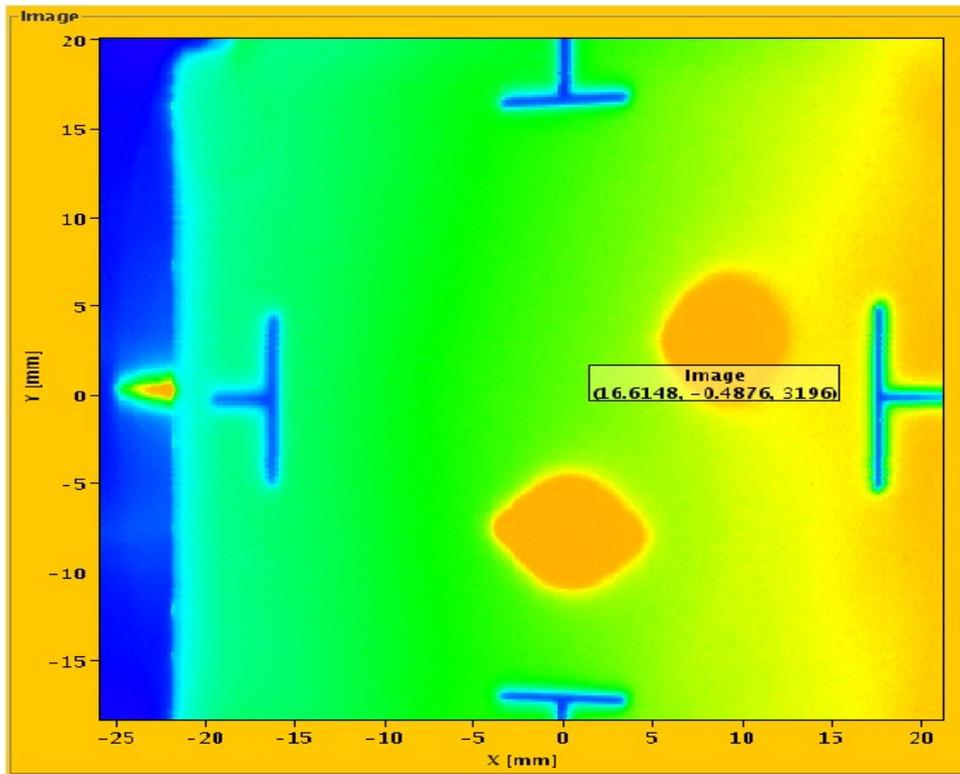
# September 10, D-Day

Start: 9:30 AM

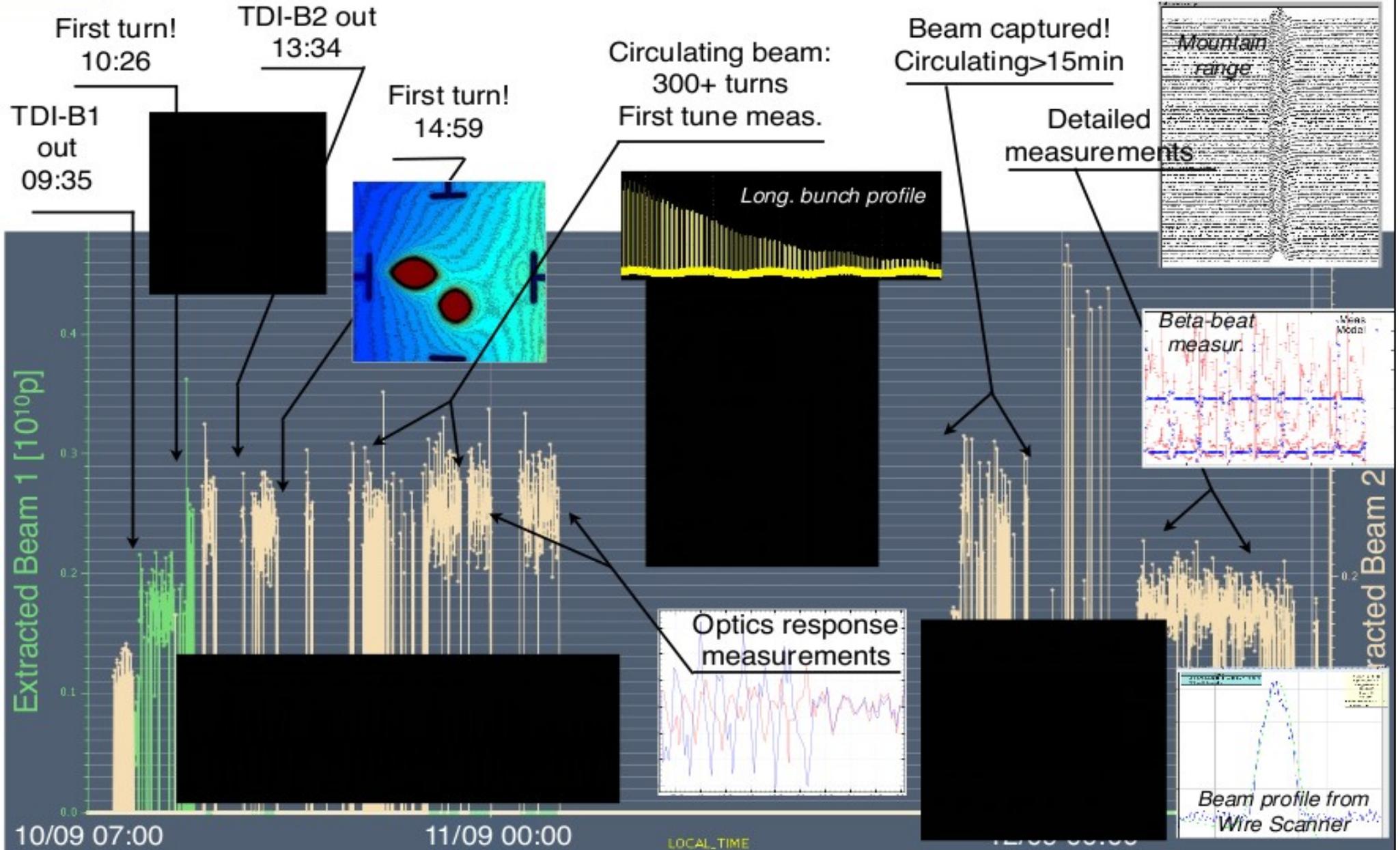


Courtesy, Operations Team

# First Full Turn !!

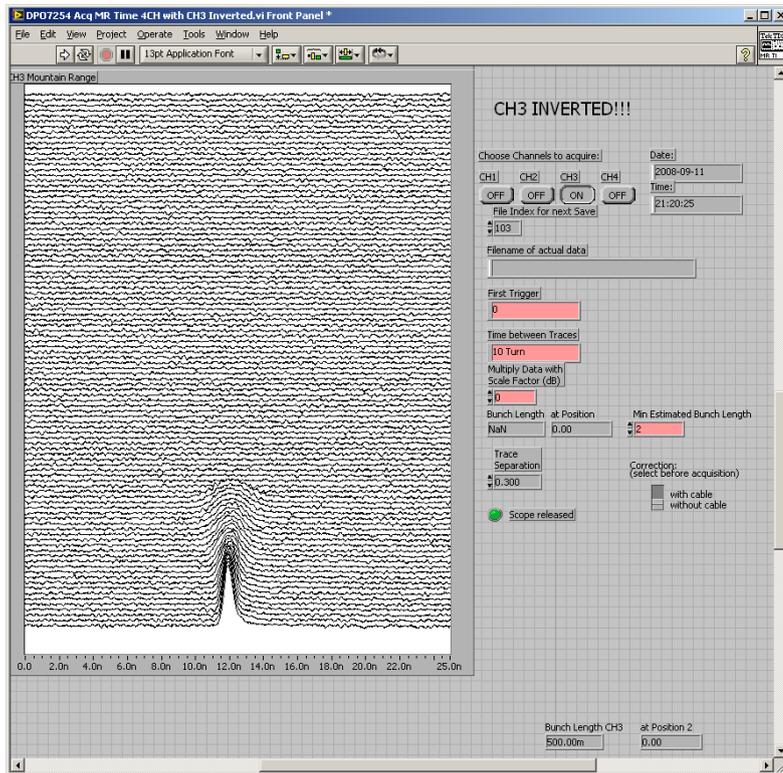


# 60 Hours of LHC Beam

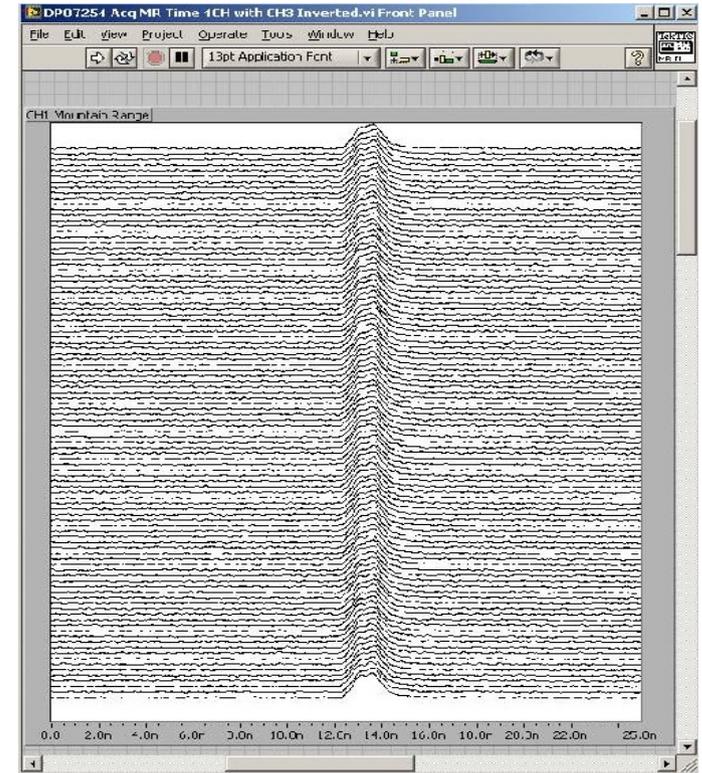


Courtesy, S. Redaelli

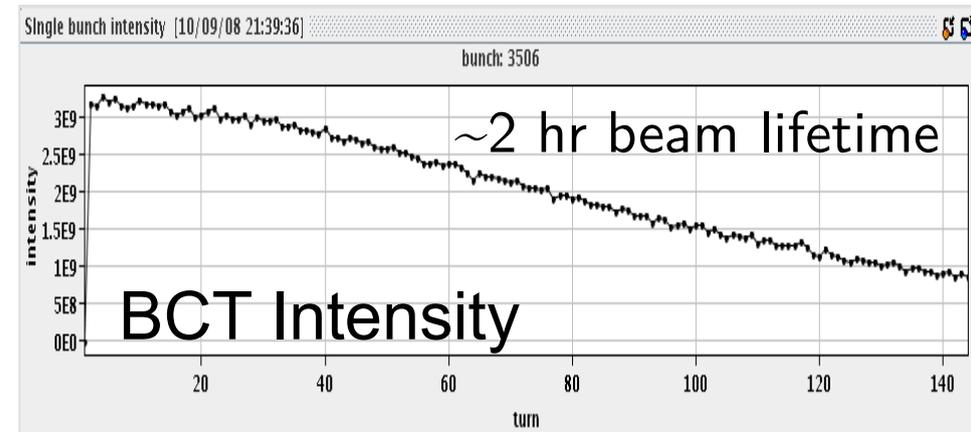
# RF Capture, Beam 2



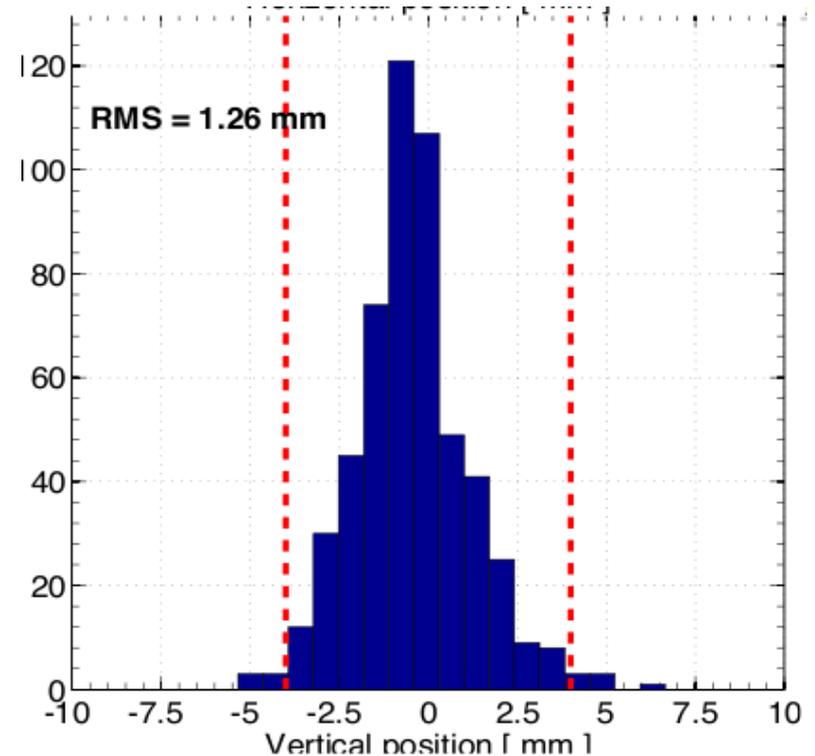
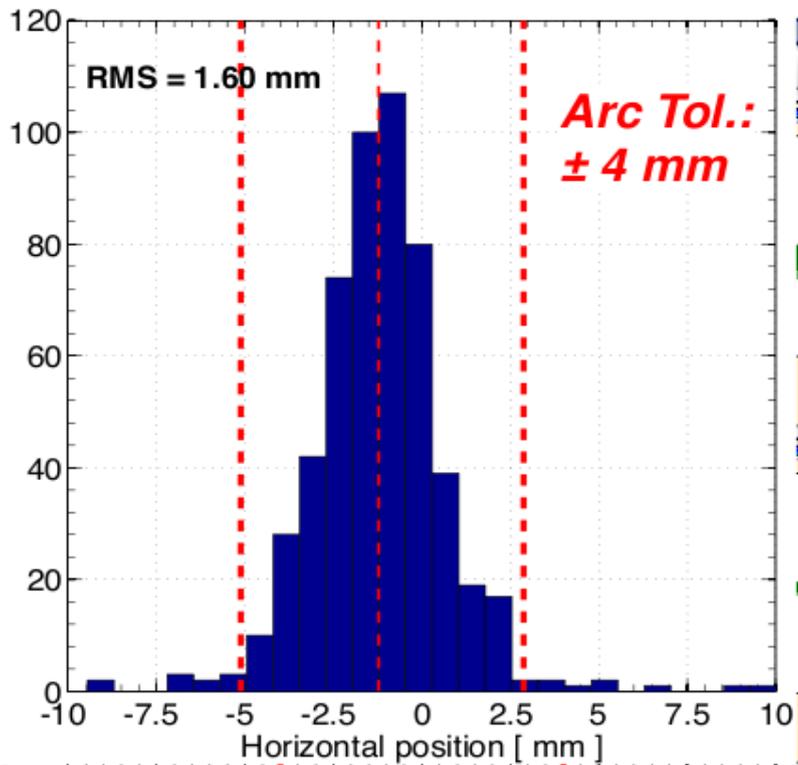
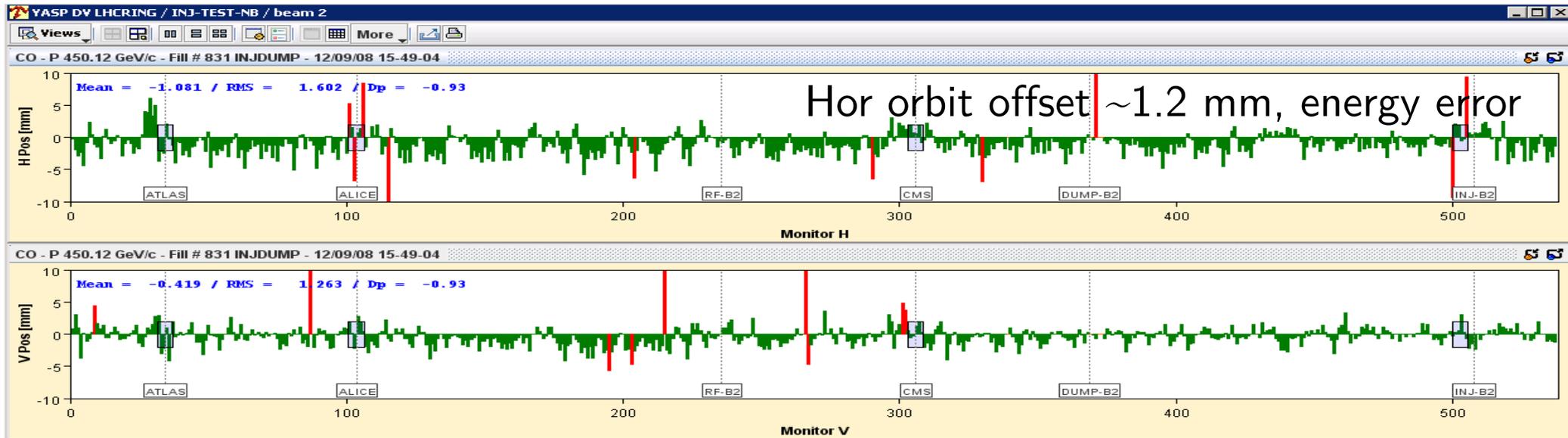
Sept 11, 2008



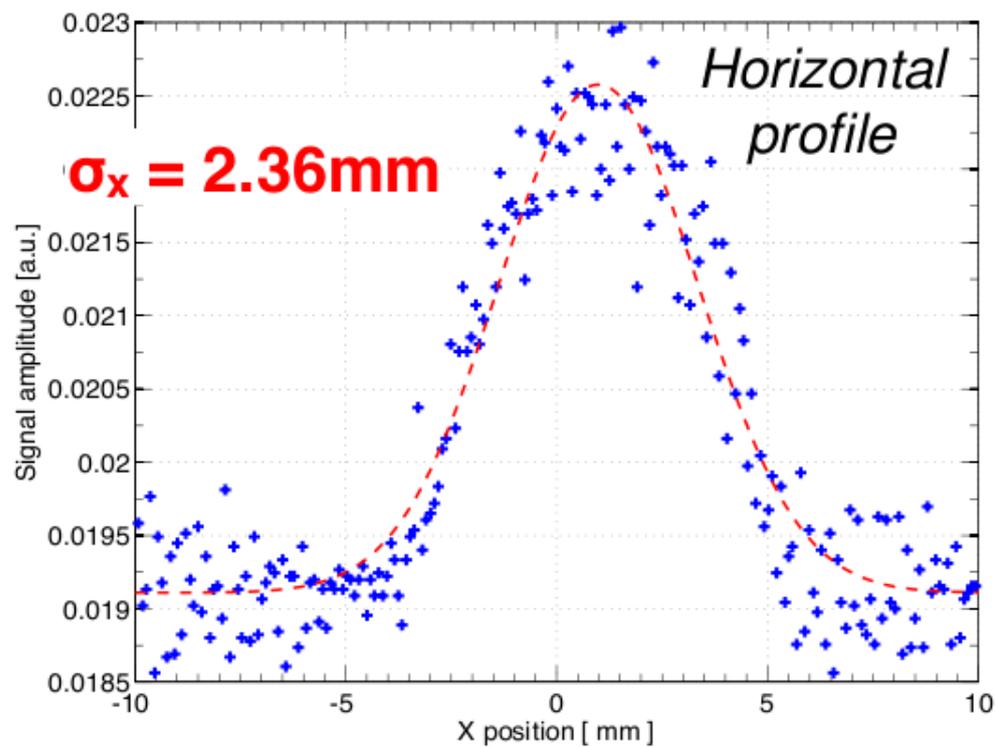
- 16 SRF Cavities, conditioned and nominal gradient, 16 ADT dampers commissioned
- Beam capture successful in beam 2
- Acceleration, collision & radial loop still needs testing



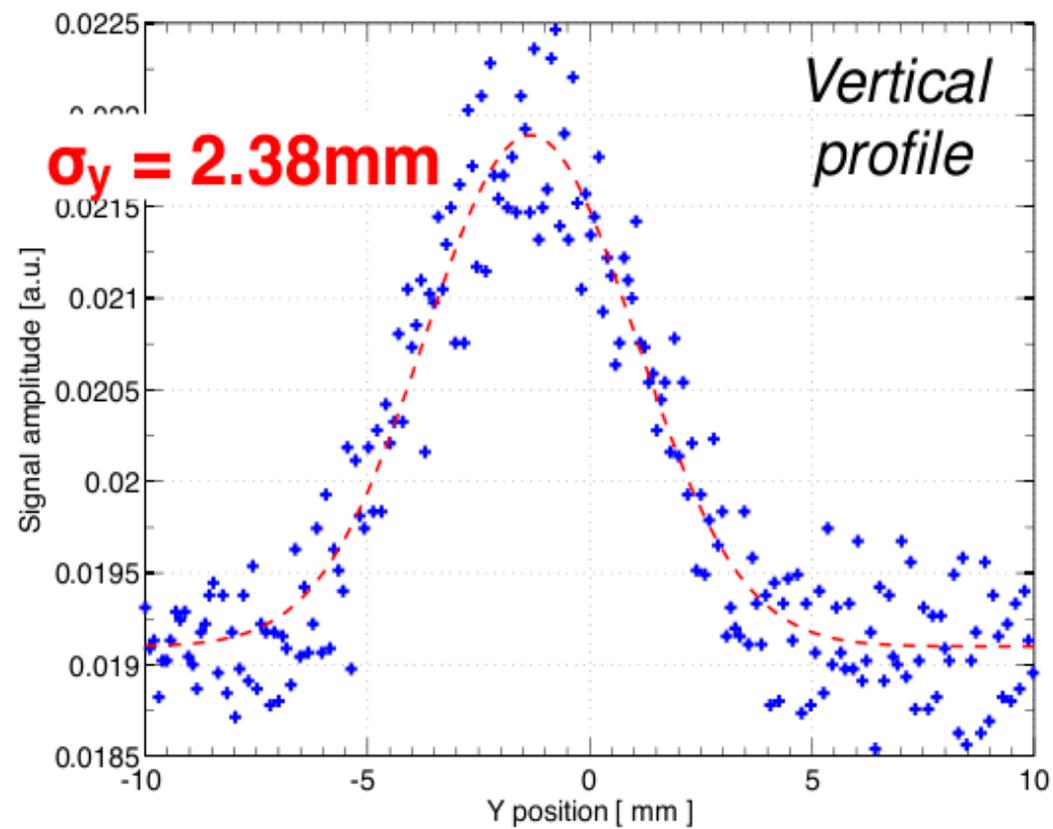
# Closed Orbit, Beam 2



# First Wire Scanners



September 12, 2009



Courtesy: BI, OP, S. Gilardoni

# Tunes & Chromaticity

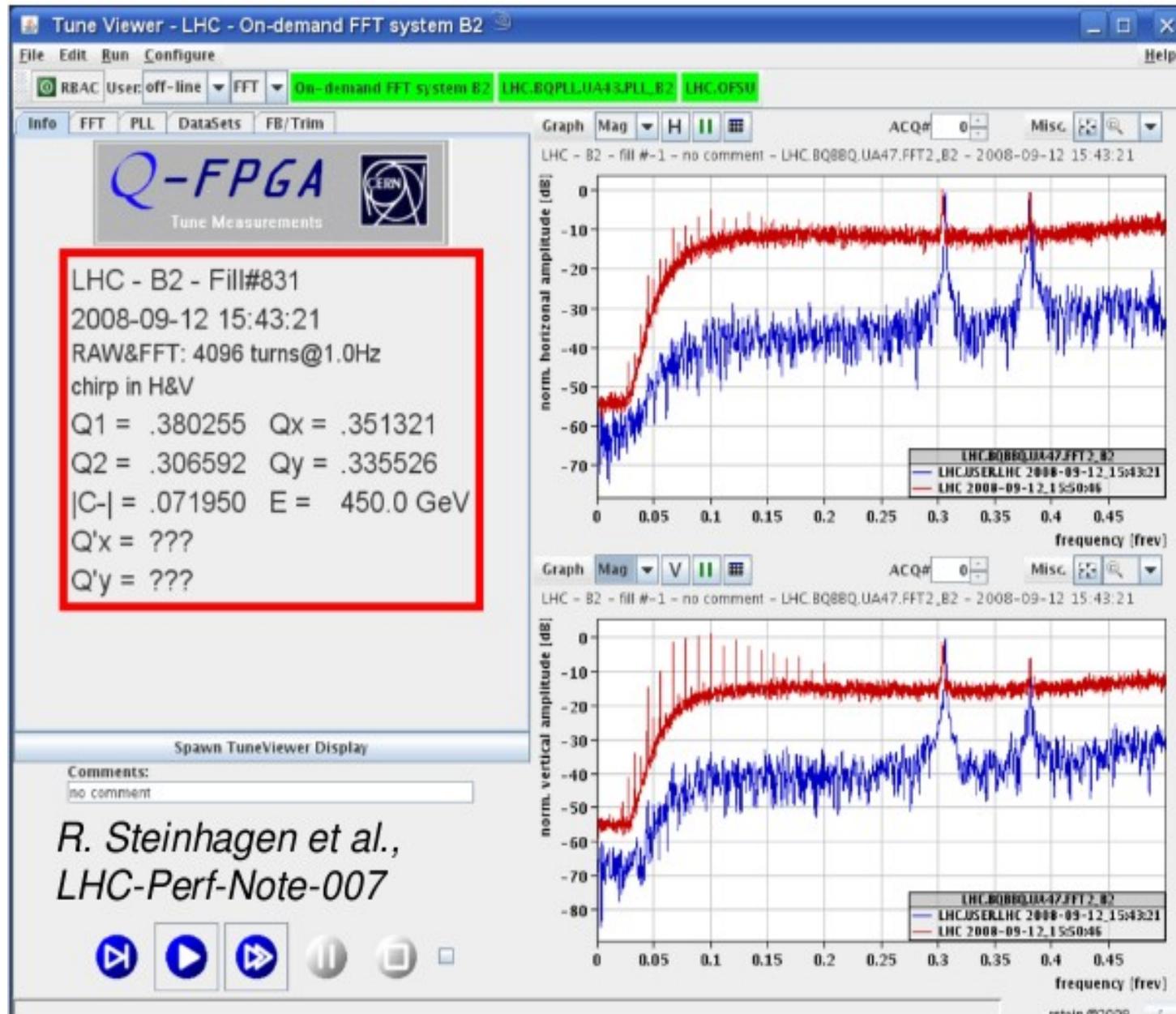
BBQ System:

$Q_x, Q_y: 0.35, 0.33$

$Q' \sim 30$  Units

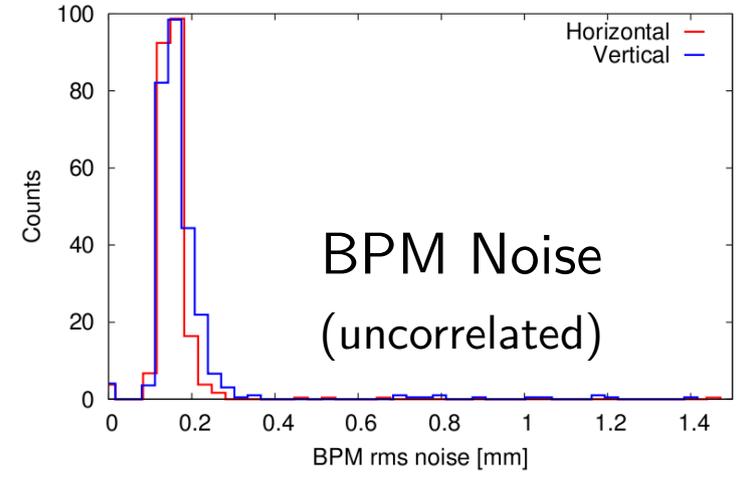
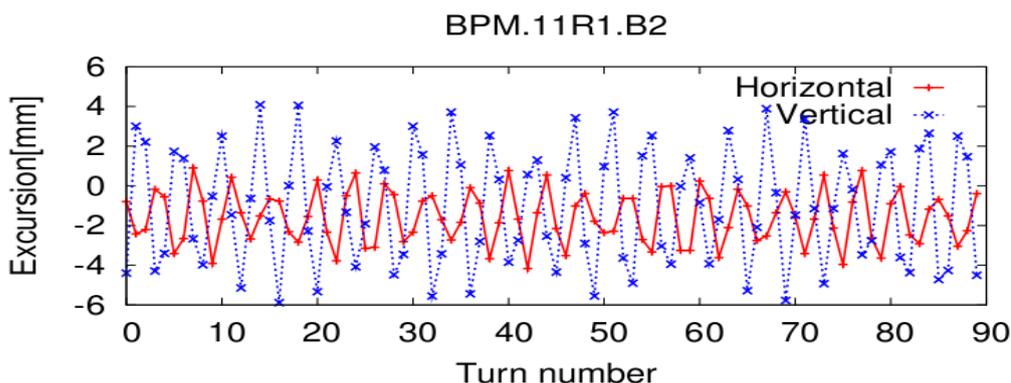
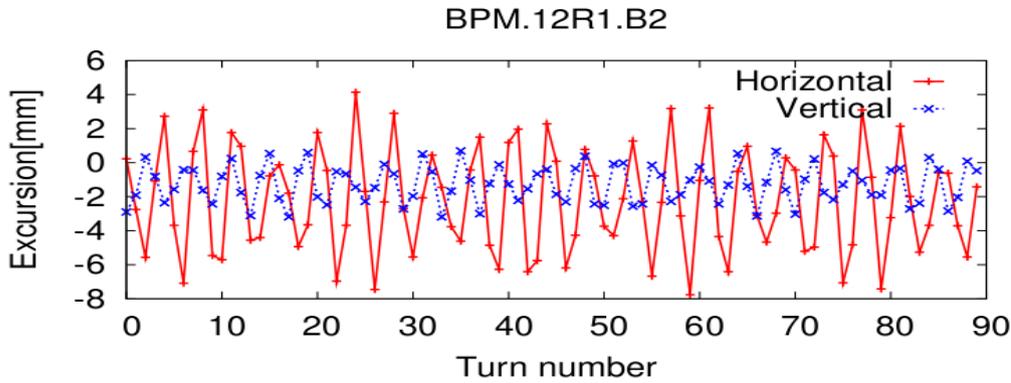
Coupling Significant

( $\Delta Q_{\min} \sim 0.06$ )

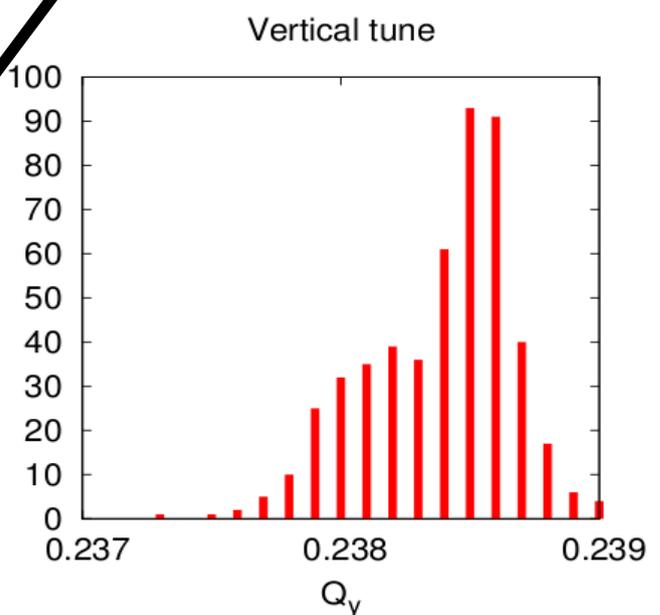
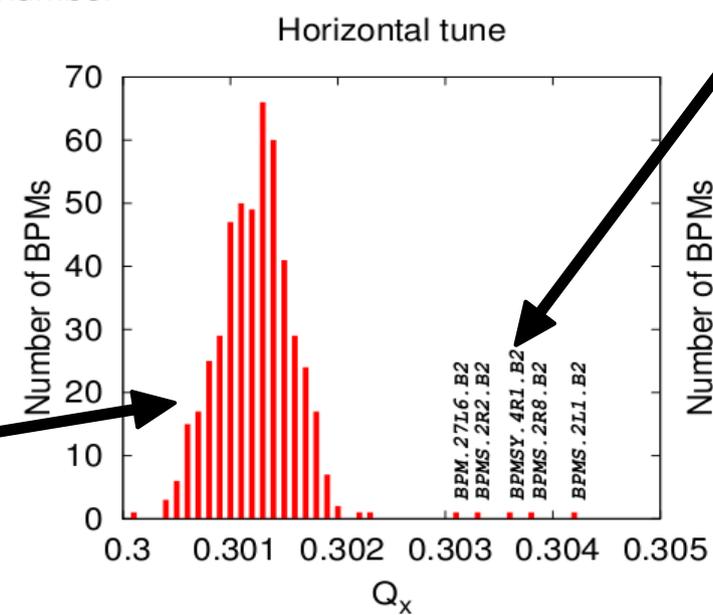


Courtesy: BI, R. Steinhagen

# LHC Optics, Beam 2



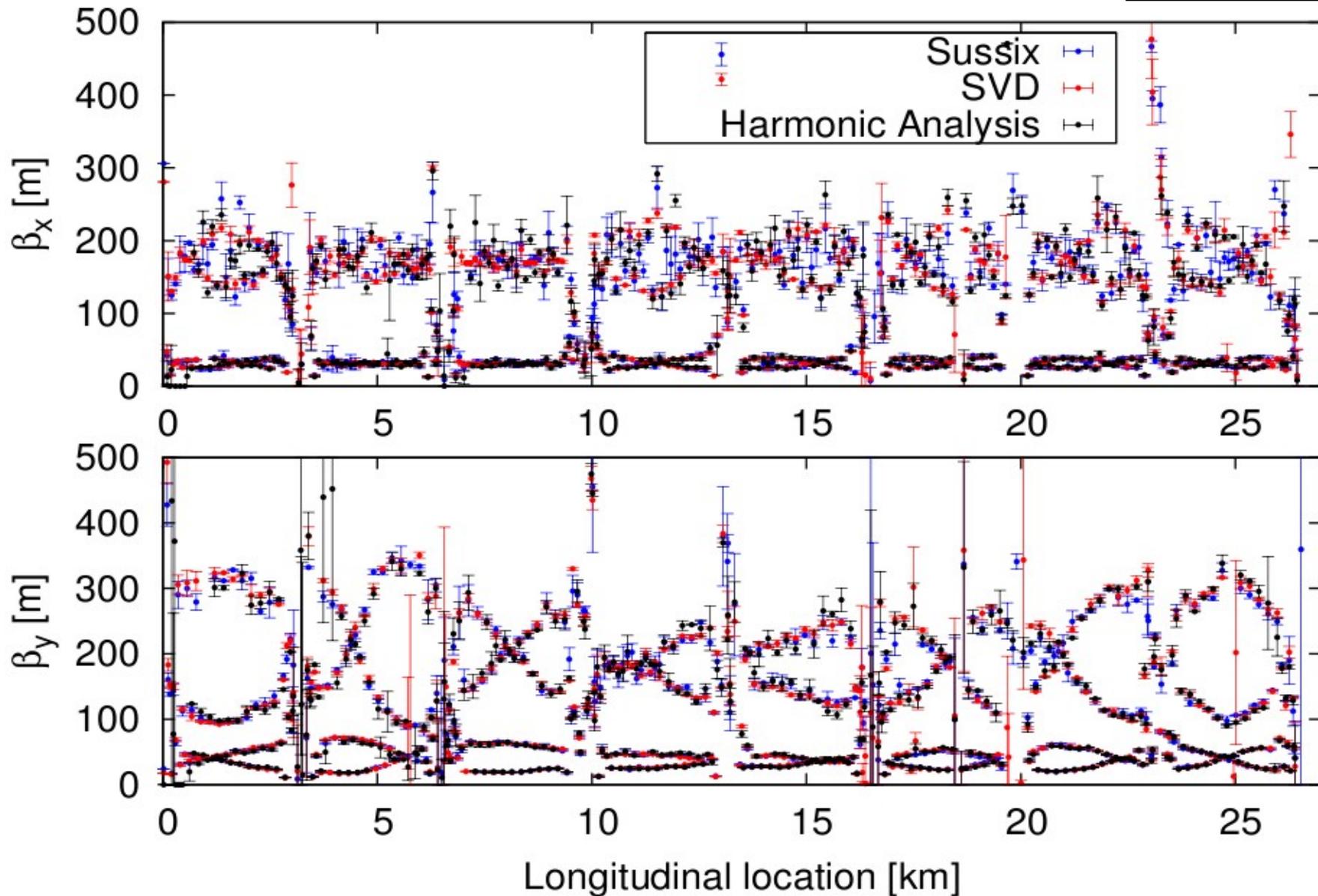
Possible faulty BPMs



Large tune spread  
(only 90 turns)

# LHC Optics, Beam 2

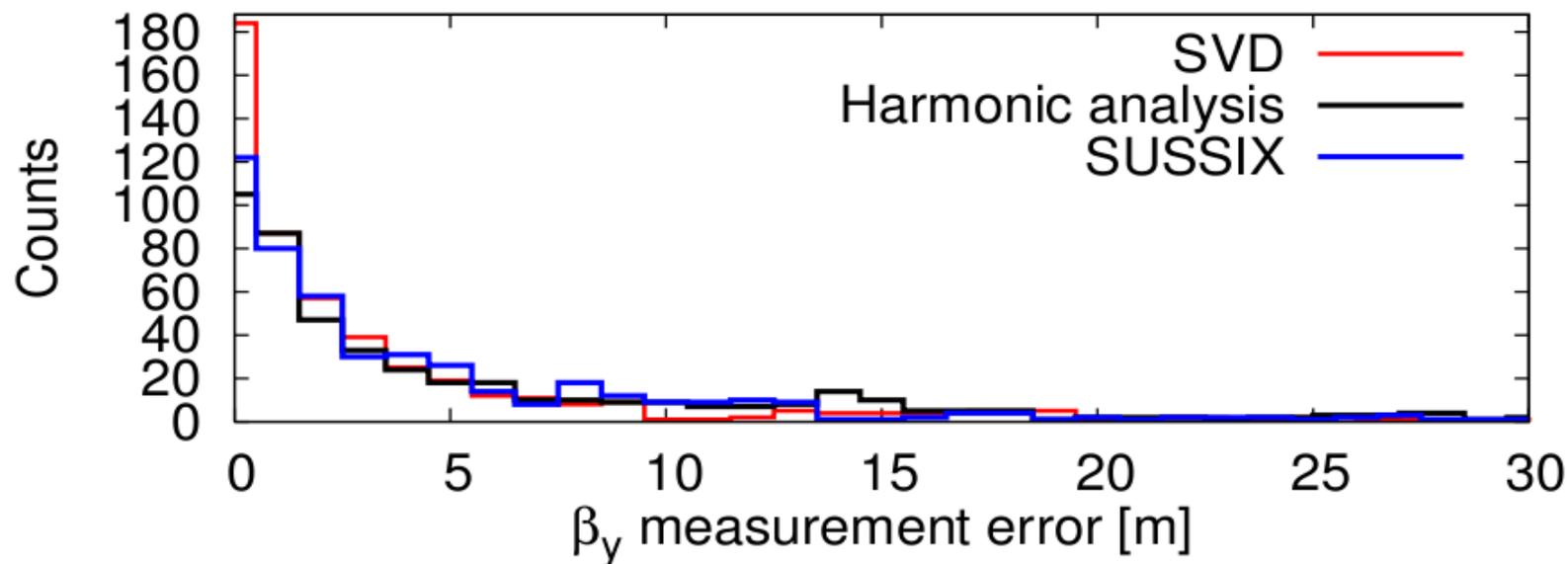
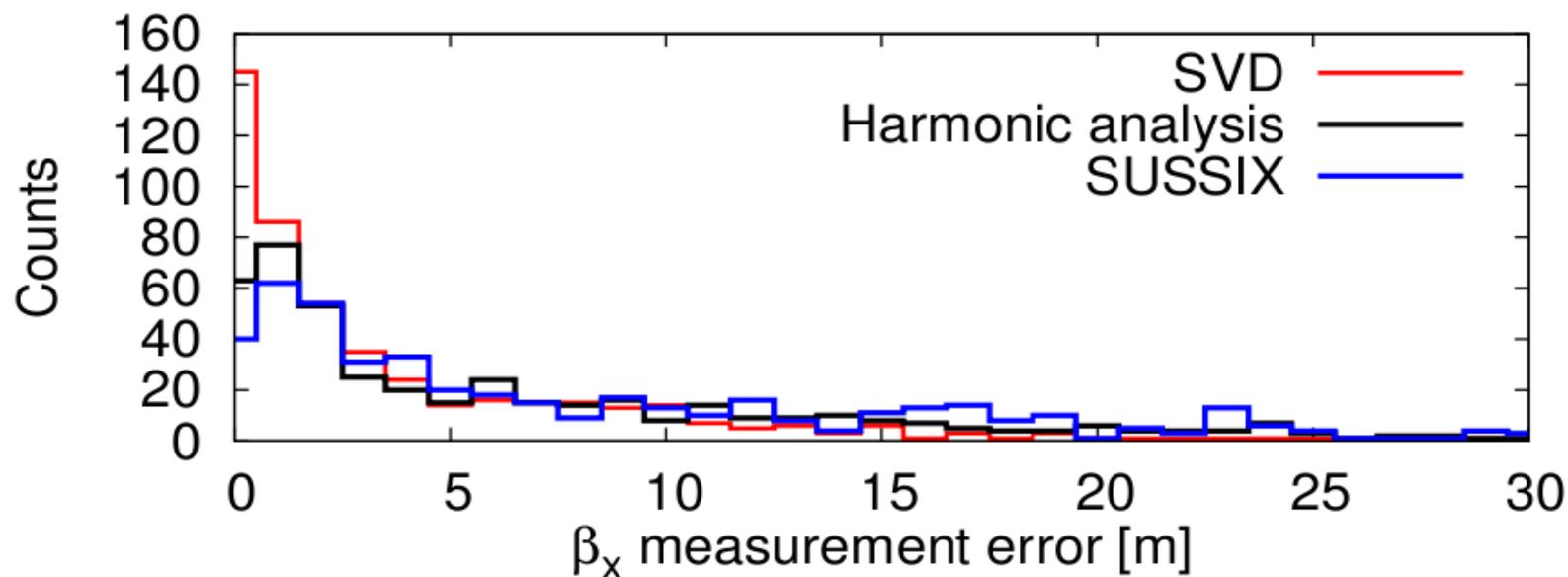
90 turns only



Beta's reconstructed from phase (1 data set!)

Statistical errors not known

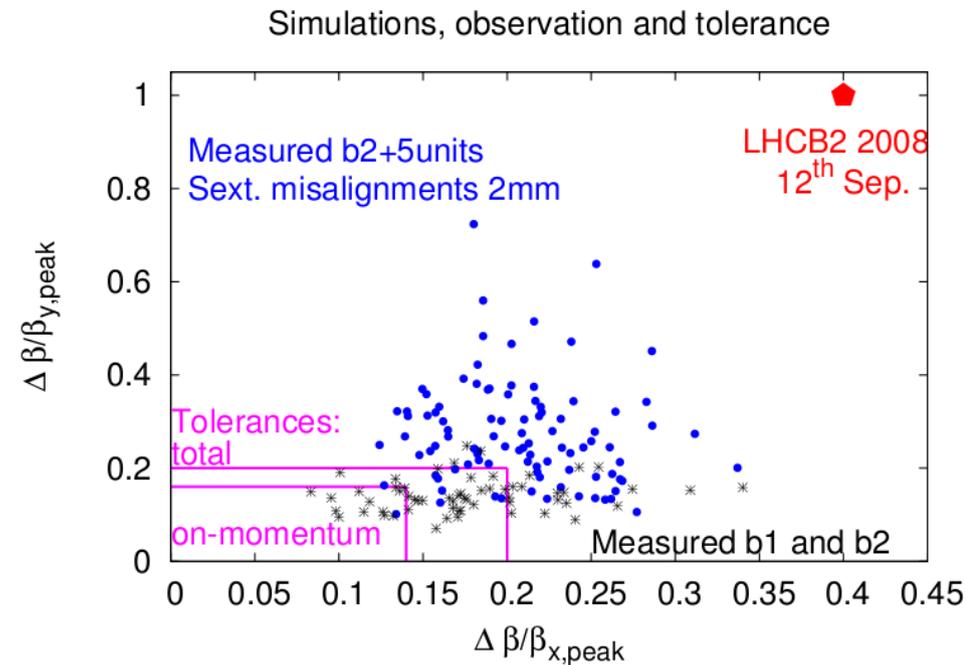
# Optics Measurement Errors



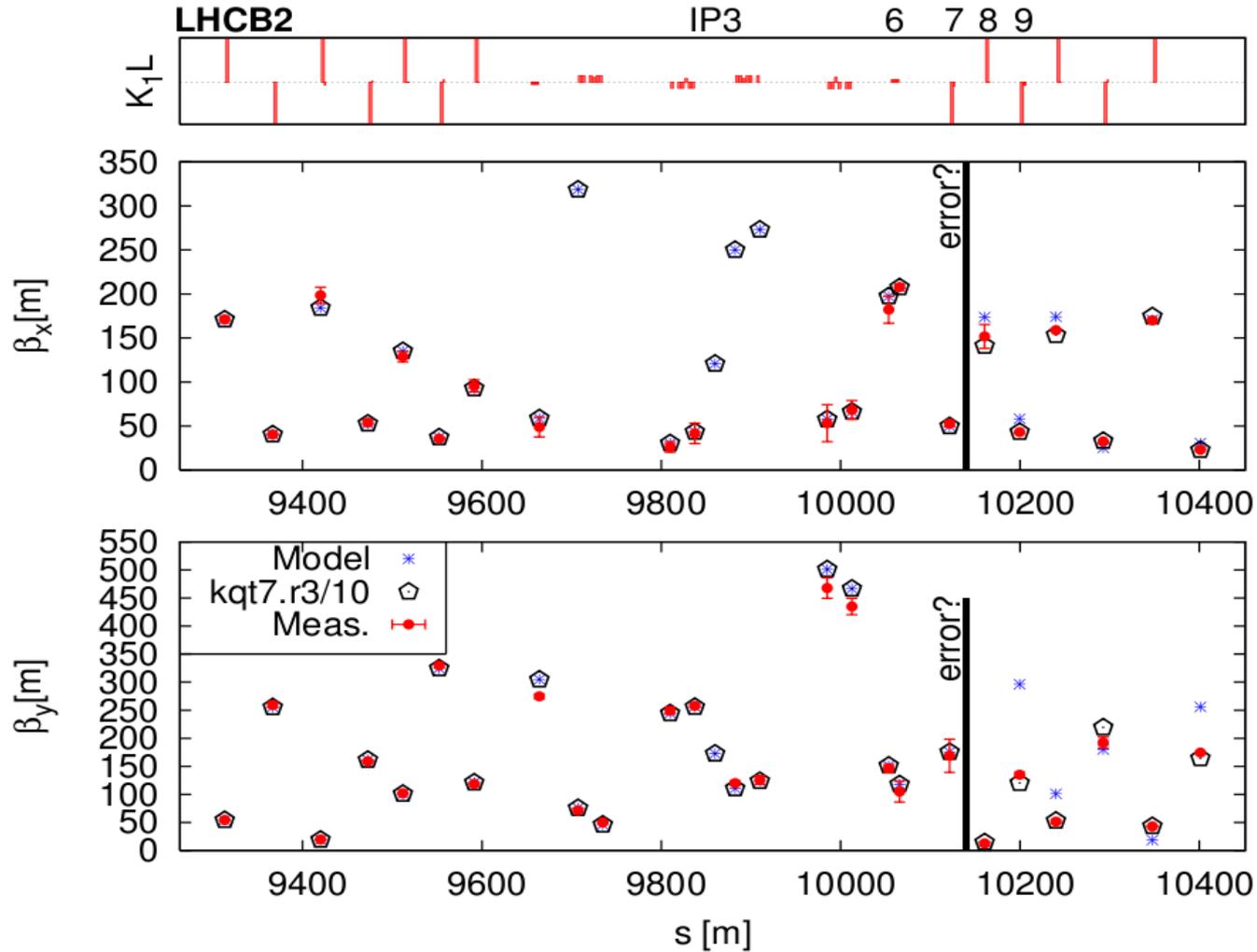
SVD provides smaller error (advantage of correlation of 500 BPMs)

# Model Reconstruction

- Excellent optics reconstruction despite **90 turns** and **single** data set
  - Reconstruction needs clear identification of **magnet polarity** mismatches & **BPM polarities**
  - Large uncorrected coupling makes it difficult
- 
- Conventional linear response matrix inversion (not applicable in this regime)
  - New [segment-by-segment](#) matching & iterative SVD inversion for final matching
  - Coupling errors more tricky to find



# Segment-by-segment Approach

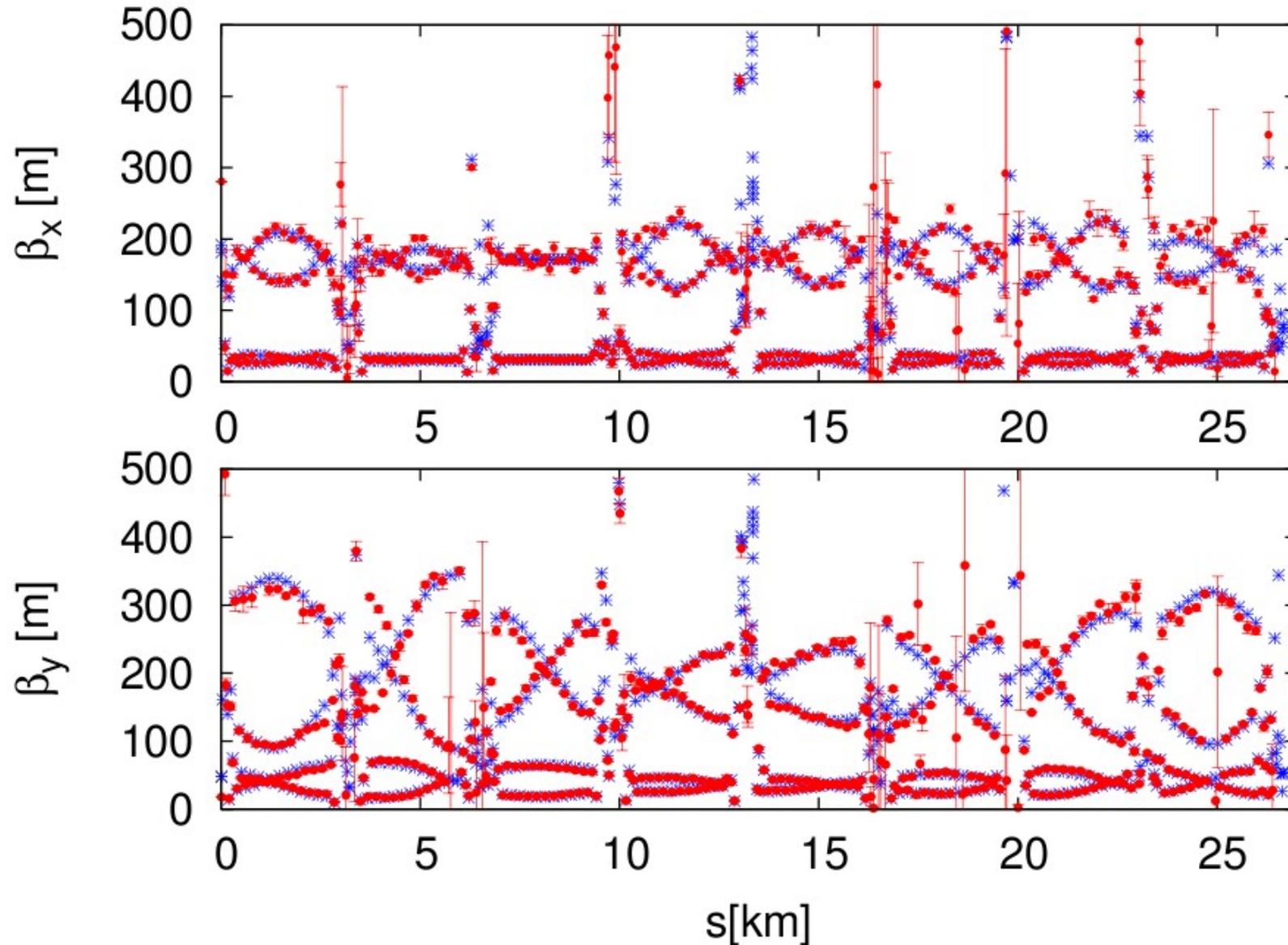


## Example: IR3

Suspected MQT.7R3 **off** ?? also confirmed by dispersion measurements and observed inversion of voltage taps during hardware tests

# Model Reconstruction

Segment-by-segment + 5 Iterations Global Matrix Inversion



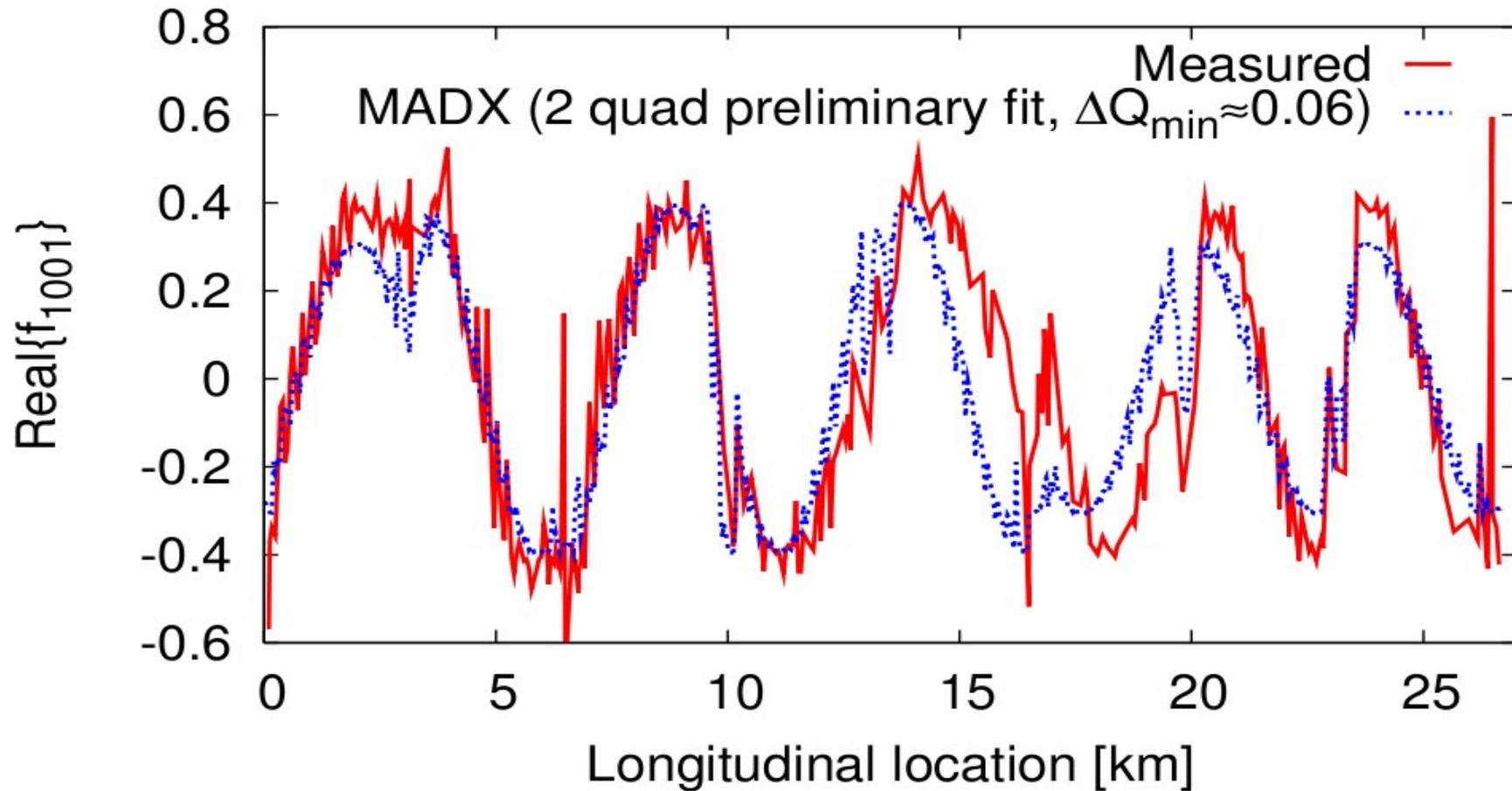
# Summary, All Irs & Arc 23

Segment	$\frac{\Delta\beta_x}{\beta_x}$ peak [%]	$\frac{\Delta\beta_y}{\beta_y}$ peak [%]	Source
IR3	17	54	mqtli7r3b2 (/10)
IR2	9	5	mqya4l2b2 (+14%)
IR7	6	6	mqt5[r1]7 ( $\times -2,3$ )
IR6	5	4	mq4l6b2 (+1%)
ARC23	0	3	mqd23 (+0.4%)

red: confirmed source, orange: not confirmed and “best fit”

# Transverse Coupling

Integer difference between horizontal & vertical tunes confirmed

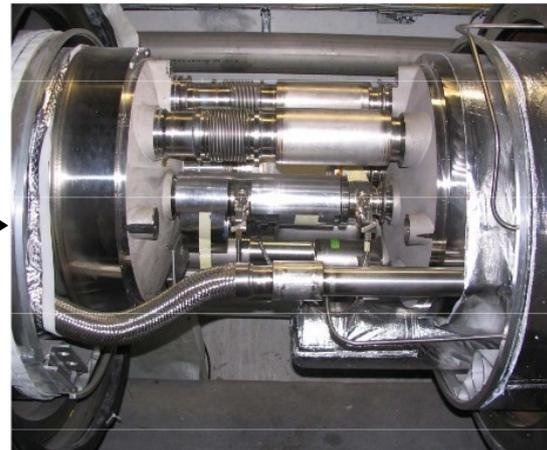
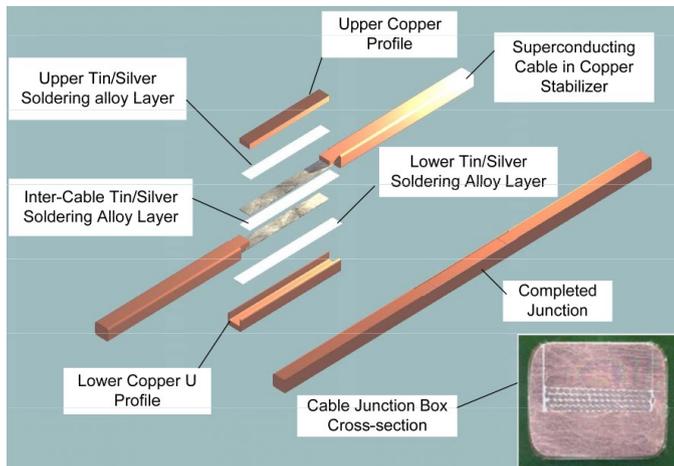


Easily corrected but exact source reconstruction non-trivial

# Incident

- Knowledge acquired with few injection tests & 60 hrs of beam is exceptional
  - Thanks to the excellent instrumentation and controls software driving them
- **However, party came to a fast stop !!**

## Electrical Arc Between Magnets



P. Lebrun at al.

Collateral damage



QQBI.27R3



# Longitudinal Displacements

## Displacements status in sector 3-4 (From Q17R3 to Q33R3) : P3 side

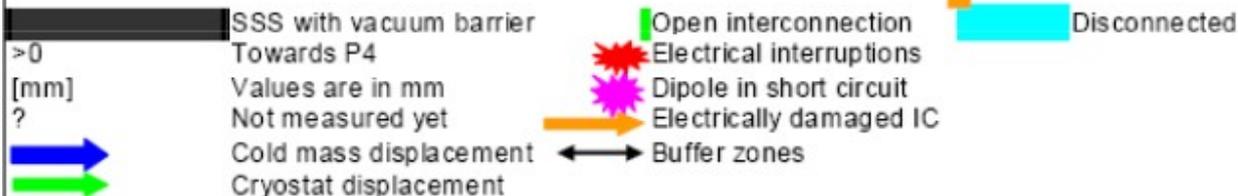
Based on measurements by TS-SU, TS-MME and AT-MCS

	Q17	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	?	?	?	?	?	?	?	?	?	?	<5	<5	<5	<5	<5	<5	<5

	Q21	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
Cryostat	<2	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	-25	-67	-102	-144	<5	-190	-130	-60	<5	<5	<5	<5	<5

	Q25	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	57	114	150?	-45	230	189	144	92?	50	35	<5	<5

	Q29	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	19	77	148	<5	140	105	62	18	<5	<5	<5	?



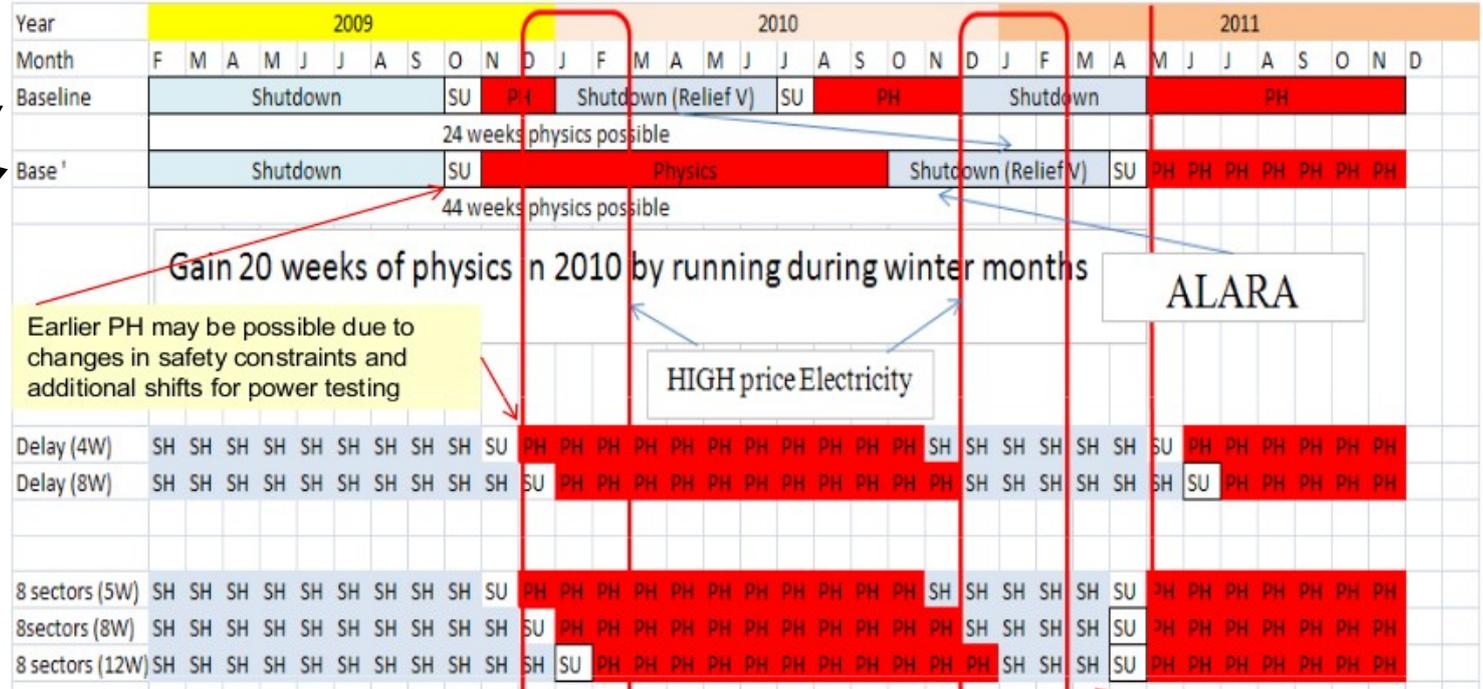
# Some Improvements

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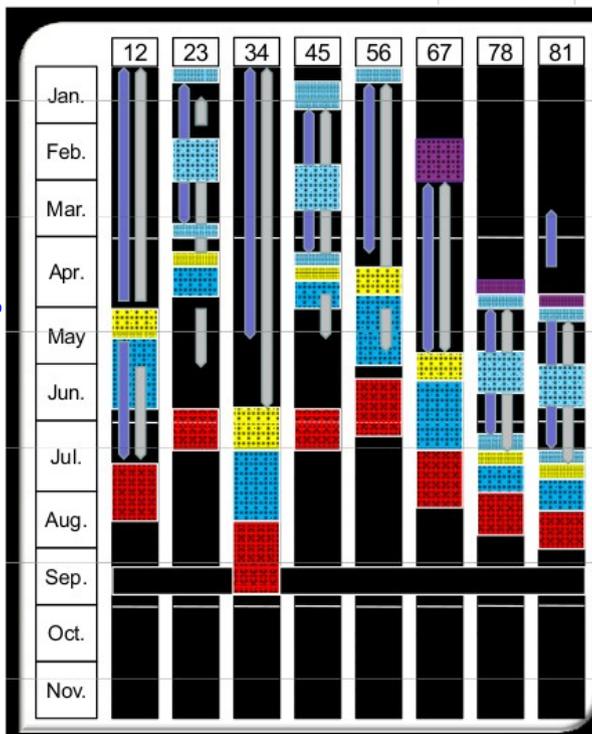
- Electrical measurements with higher sensitivity ( $< 0.3$  mV)
- Detailed calorimetric measurements and tracking of temperature
- Improve quench detection and include interconnects, bars
- Increase number/size of relief valves (3-4,1-2,6-7), mechanical clamps to protect from fast thermal run-away – future ?
- **Under investigation**
  - Exact nature of initial fault (resistive joint due to bad bonding -or- resistive cable with bad contact), long distance propagation & comprehensive extent of the damage
- Ultrasound and X-Ray (mid summer) testing of all splices
- Excluding Sector 34, all other have reached 5.3 TeV w/o quench (4-5 TeV operation safer)

# Possible Schedule

Two Scenarios  
(8-9M€ more for base')



Schedule for Physics in 2009



- Intermediate cool-down & QRL warm-up (Stand Alone)
- Activities
  - Arc
  - LSS
- Flushing & ELQA at warm
- Cool-down
- Powering tests
- Cold check-out

Presented at Chamonix09

S. Meyers

# Conclusions

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- Excellent preparation despite of the “stressful” Sept 10 deadline
- Instrumentation/controls were in an ideal state for rapid commissioning
- Tremendous amount of information with beam in just 60 hrs
- Rapid recovery in place for ~Sept2009 beam

It was a great pleasure to intimately participate during the first beams in the LHC