

# Operating the LHC **with Beam**

(on behalf of the LHC team)

December 18, 2009

# Milestones

Date	Day	Achieved
Nov 20	1	Each beam circulating. Key beam instrumentation working.
Nov 23	4	<b>First collisions at 450 GeV. First ramp (reached 560 GeV).</b>
Nov 26	7	Magnetic cycling established (reproducibility).
Nov 27	8	Energy matching.
Nov 29	10	<b>Ramp to 1.18 TeV.</b>
Nov 30	11	Experiment solenoids on.
Dec 04	15	Aperture measurement campaign finished. LHCb and ALICE dipoles on.
Dec 05	16	<b>Machine protection (Injection, Beam dump, Collimators) ready for safe operation with pilots.</b>
Dec 06	17	First collisions with <b>STABLE BEAMS, 4 on 4 pilots at 450 GeV, rates around 1Hz.</b>
Dec 08	19	Ramp colliding bunches to 1.18 TeV
Dec 11	22	Collisions with <b>STABLE BEAMS, 4 on 4 at 450 GeV, &gt; 10<sup>10</sup> per bunch, rates around 10Hz.</b>
Dec 13	24	<b>Ramp 2 bunches per beam to 1.18 TeV. Collisions for 90mins.</b>
Dec 14	25	Collisions with <b>STABLE BEAMS, 16 on 16 at 450 GeV, &gt; 10<sup>10</sup> per bunch, rates around 50Hz.</b>
Dec 16	27	Ramp 4 on 4 to 1.18 TeV. <b>Squeeze to 7 m.</b>

# Corrector polarity checks

## Beam 1

	total	checked	ok	checked ok?	% checked
<b>L1</b>	39	32	32	TRUE	82.05%
<b>R1</b>	38	30	30	TRUE	78.95%
<b>L2</b>	40	33	33	TRUE	82.50%
<b>R2</b>	37	29	29	TRUE	78.38%
<b>L3</b>	31	31	29	FALSE	100.00%
<b>R3</b>	39	0	0	TRUE	0.00%
<b>L4</b>	30	29	29	TRUE	96.67%
<b>R4</b>	33	28	28	TRUE	84.85%
<b>L5</b>	39	32	32	TRUE	82.05%
<b>R5</b>	38	31	31	TRUE	81.58%
<b>L6</b>	29	29	29	TRUE	100.00%
<b>R6</b>	28	28	28	TRUE	100.00%
<b>L7</b>	31	31	29	FALSE	100.00%
<b>R7</b>	30	28	28	TRUE	93.33%
<b>L8</b>	40	34	34	TRUE	85.00%
<b>R8</b>	40	32	32	TRUE	80.00%
	562	457	453	FALSE	81.32%

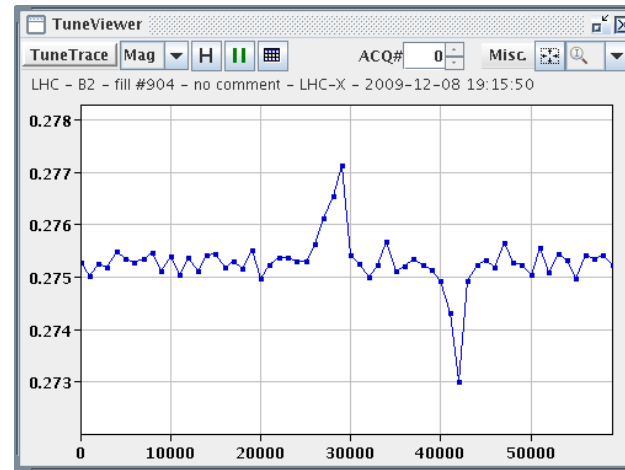
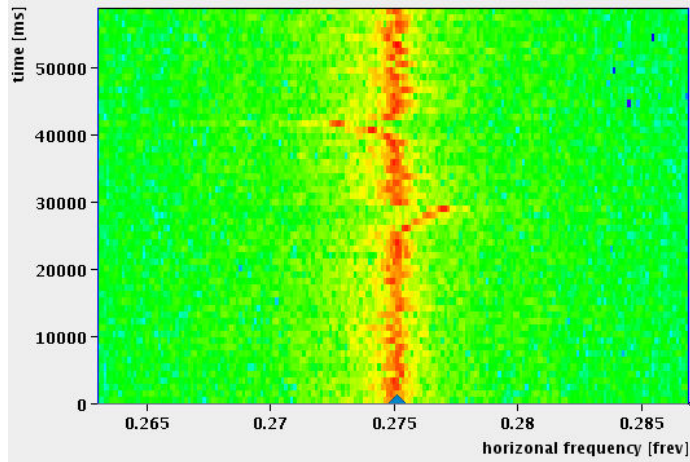
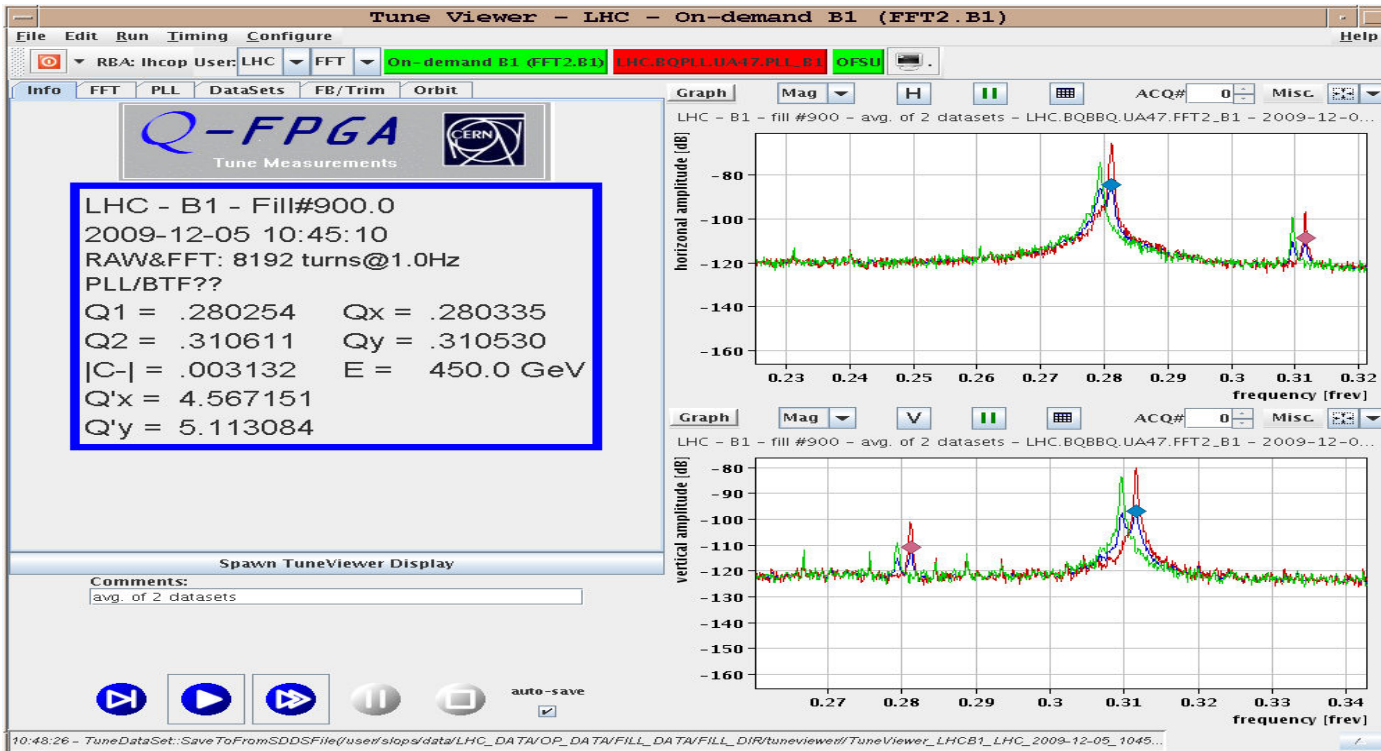
## Beam 2:

	total	checked	ok	checked ok?	% checked
<b>L1</b>	39	32	32	TRUE	82.05%
<b>R1</b>	38	30	30	TRUE	78.95%
<b>L2</b>	40	31	31	TRUE	77.50%
<b>R2</b>	37	31	31	TRUE	83.78%
<b>L3</b>	31	31	31	TRUE	100.00%
<b>R3</b>	30	29	29	TRUE	96.67%
<b>L4</b>	30	29	29	TRUE	96.67%
<b>R4</b>	29	27	27	TRUE	93.10%
<b>L5</b>	39	32	32	TRUE	82.05%
<b>R5</b>	38	32	32	TRUE	84.21%
<b>L6</b>	29	29	29	TRUE	100.00%
<b>R6</b>	28	28	28	TRUE	100.00%
<b>L7</b>	31	16	16	TRUE	51.61%
<b>R7</b>	30	15	15	TRUE	50.00%
<b>L8</b>	40	0	0	TRUE	0.00%
<b>R8</b>	40	0	0	TRUE	0.00%
	549	392	392	TRUE	71.40%

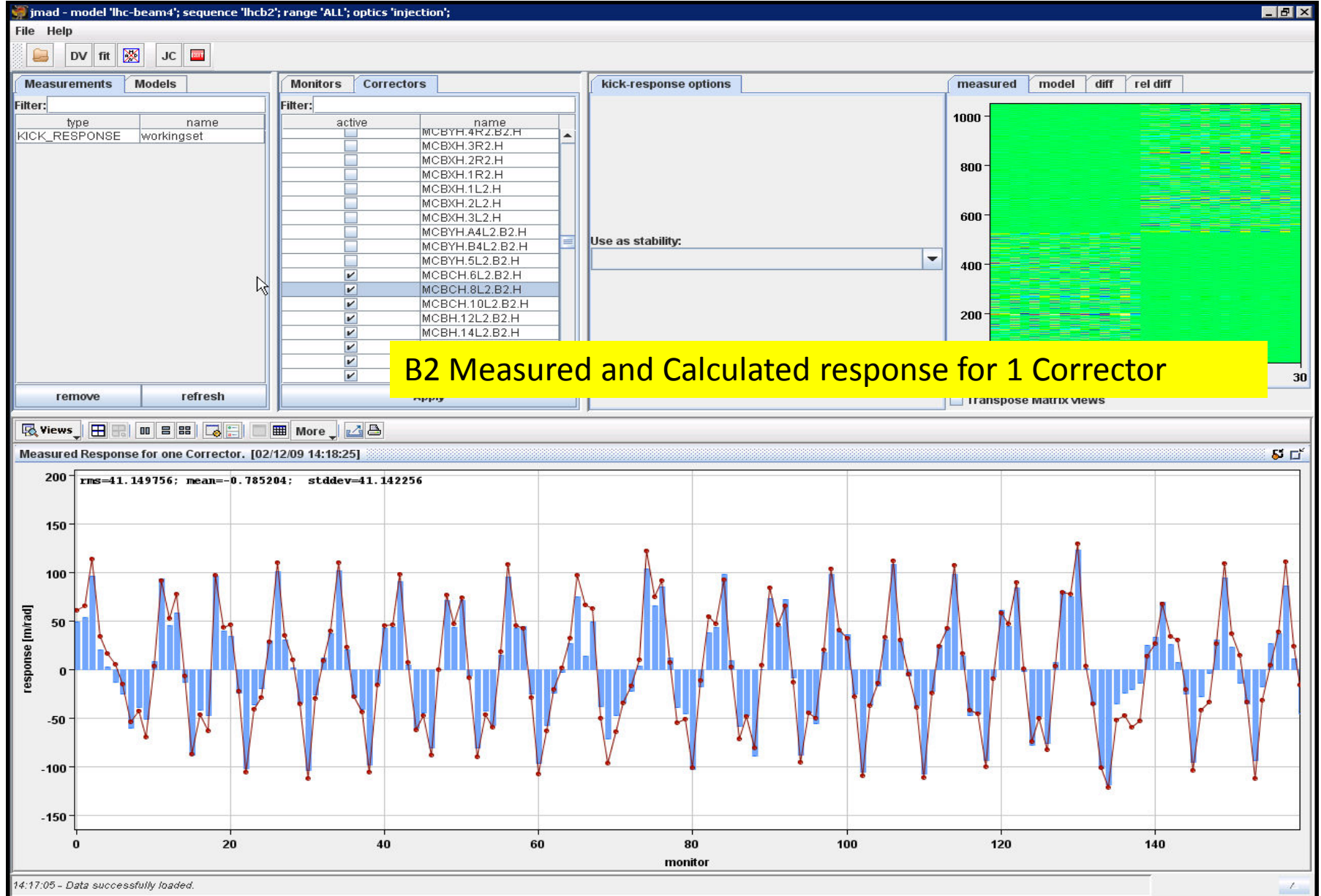
# BPM polarity checks

	checked	ok	% ok
Beam 1	1076	1050	<b>97.58%</b>
Beam 2	1076	1058	<b>98.33%</b>

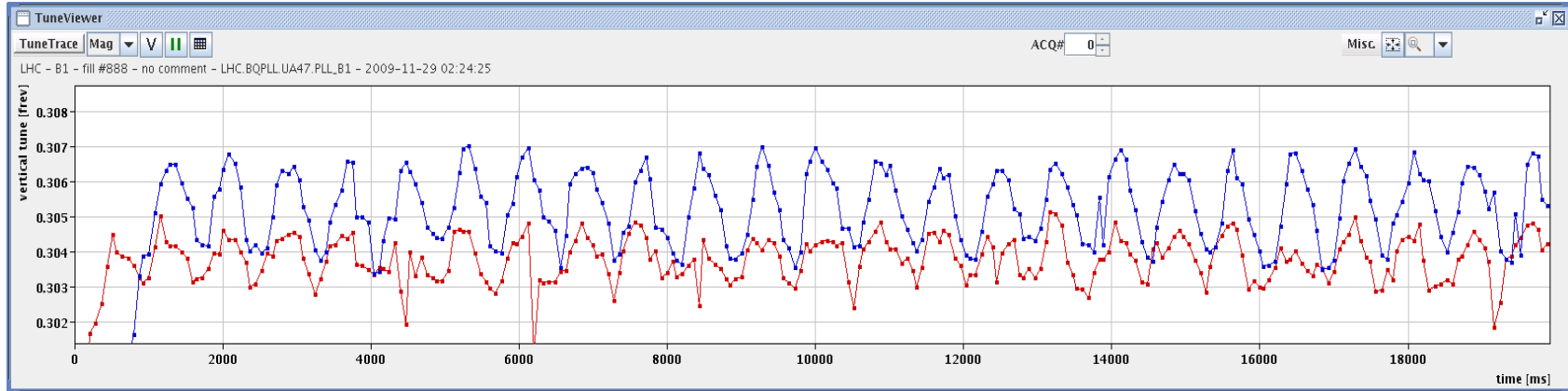
# Q Q' C and Q loop



# Optics Checks (2<sup>nd</sup> Dec)

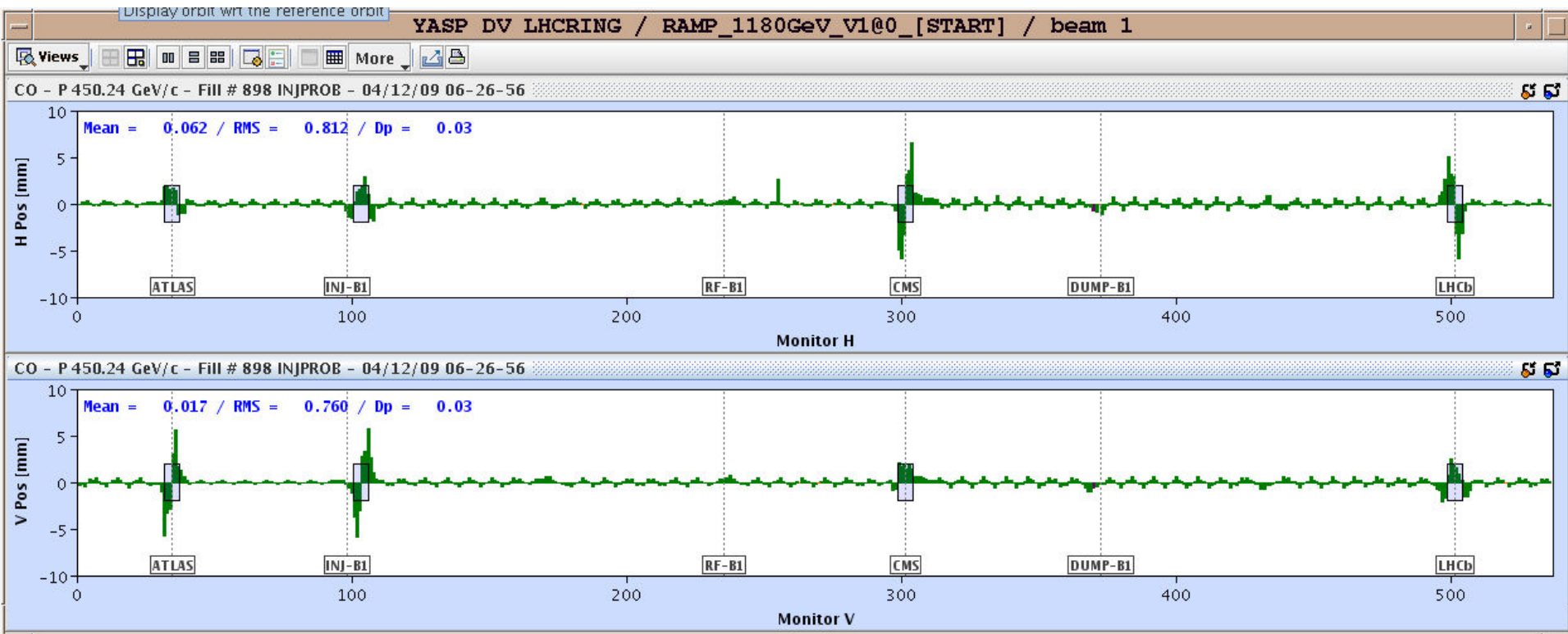


# Chromaticity Measurement and Correction



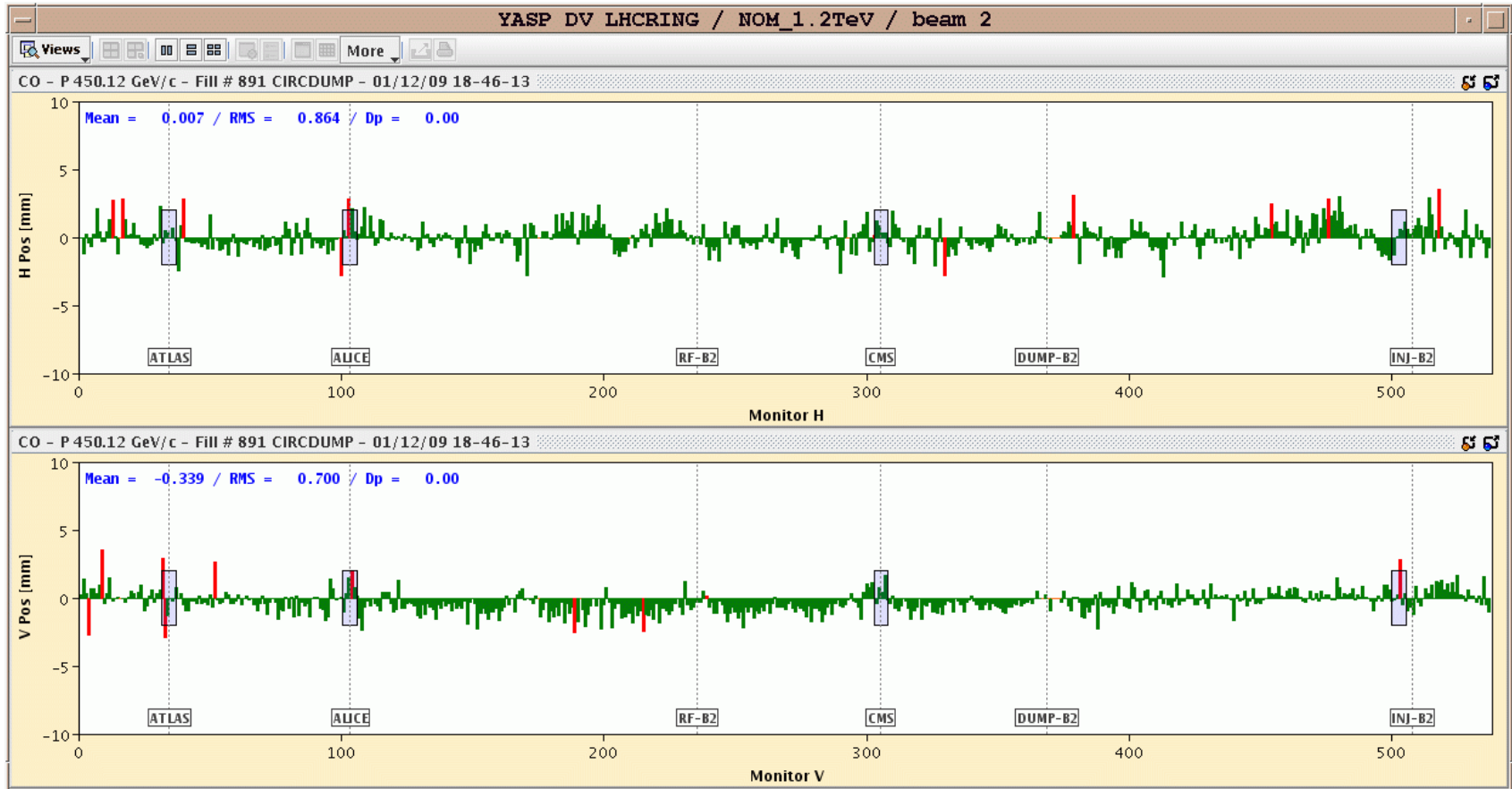
measured  $Q_v' = 15$  using  $dp/p=1e-4$  @2.5 Hz radial modulation,  
damper amplitude  $1e-3$   
with  $dQ_v' = -10$  trim  
'blue' trace before and 'red' after trim

# Separation bumps and crossing angle.



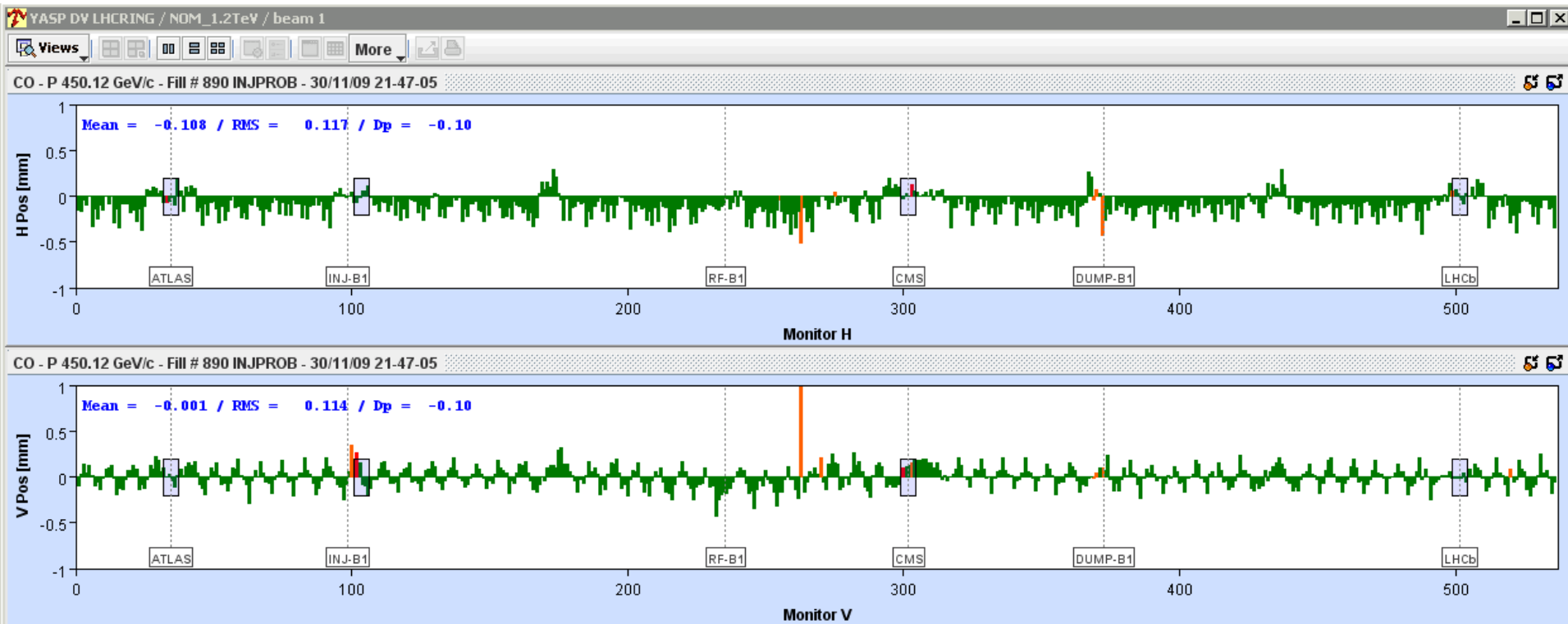


# Orbits – golden “Santa Klaus”



# CMS solenoid ramp up

Orbit difference CMS ON – CMS OFF

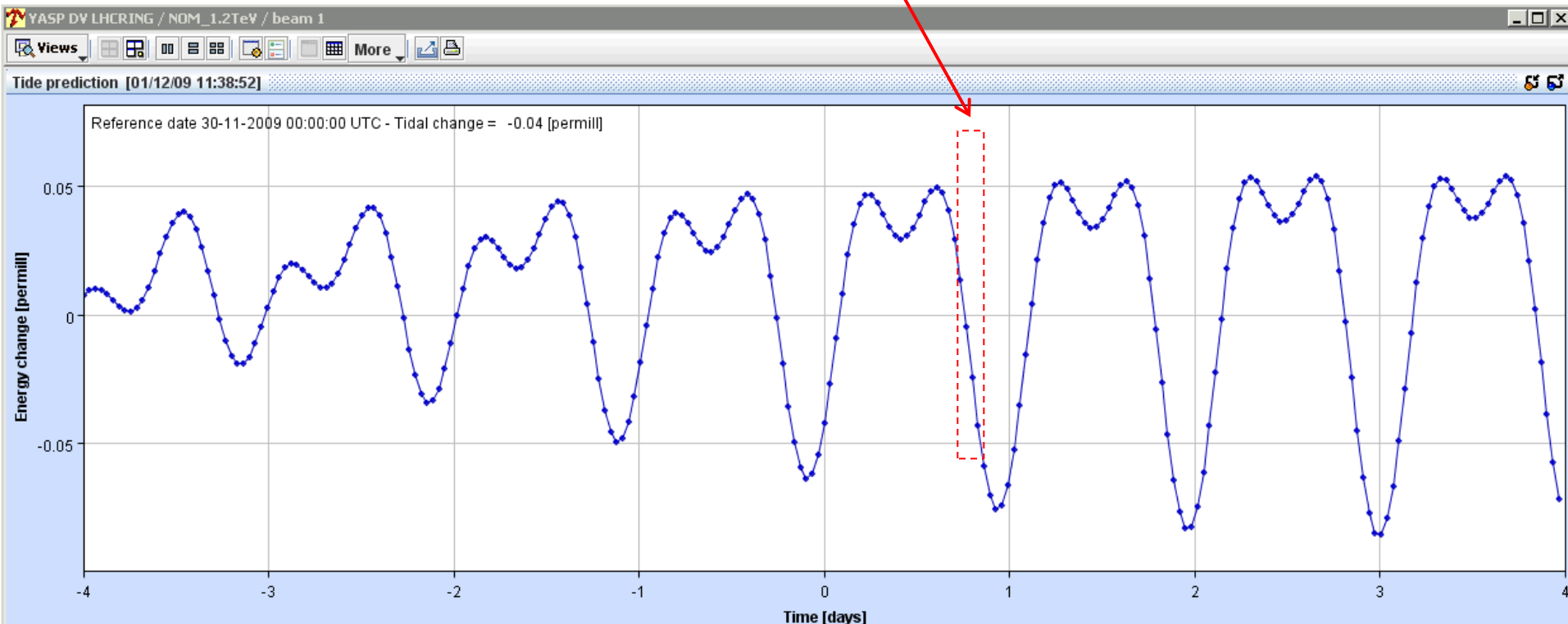


dp/p error change by  $\sim 0.1$  per mill...

?? CMS solenoid changes the beam energy??

# NO! But Earth tides do!

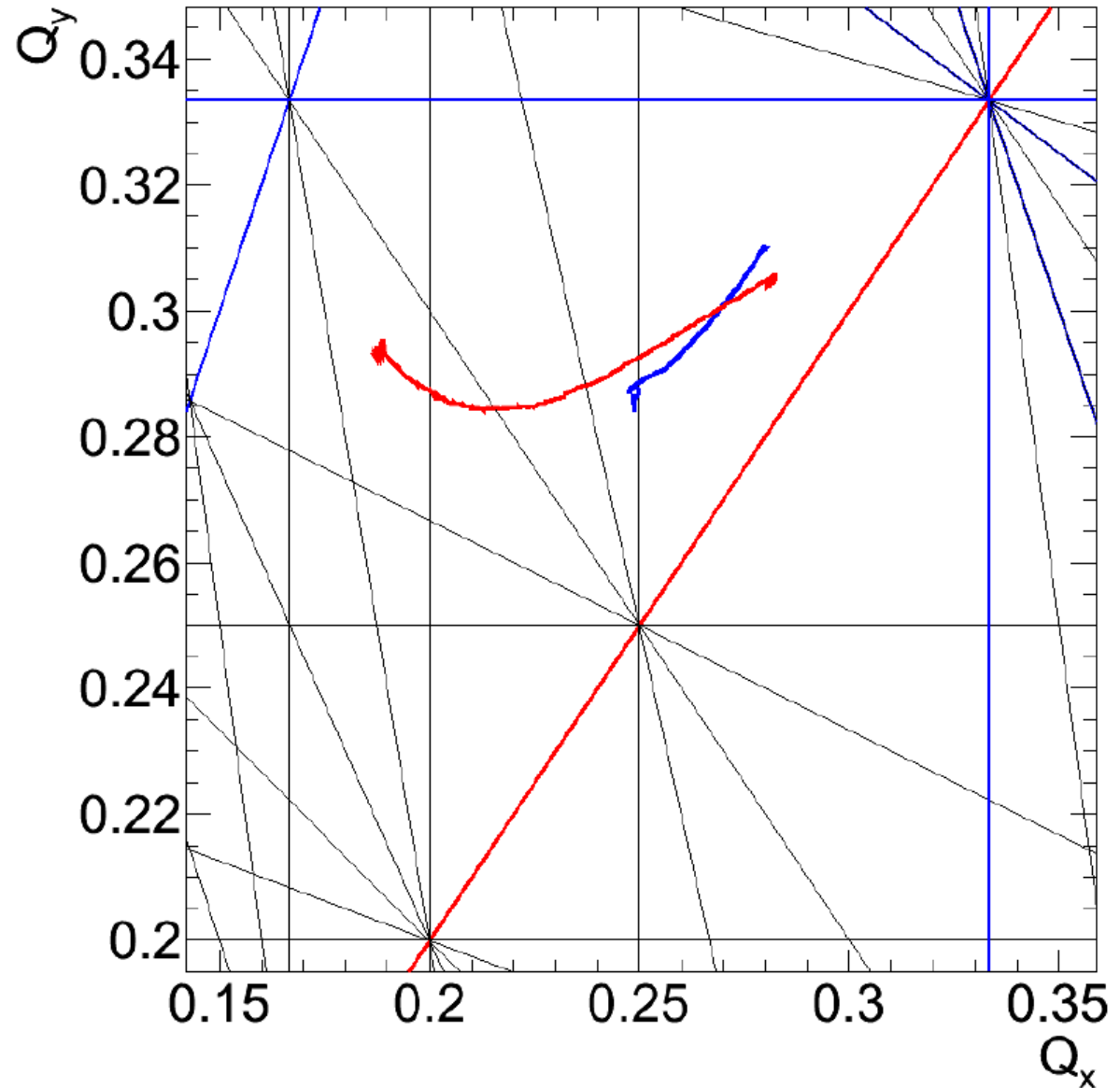
Ramp up coincided with large tidal change – good agreement!  
Tidal swing corresponds to  $\sim 15$  Hz.



LHC measures influence of tidal forces 10 days after 1st Beam!

# Third Ramp to 1.18 TeV

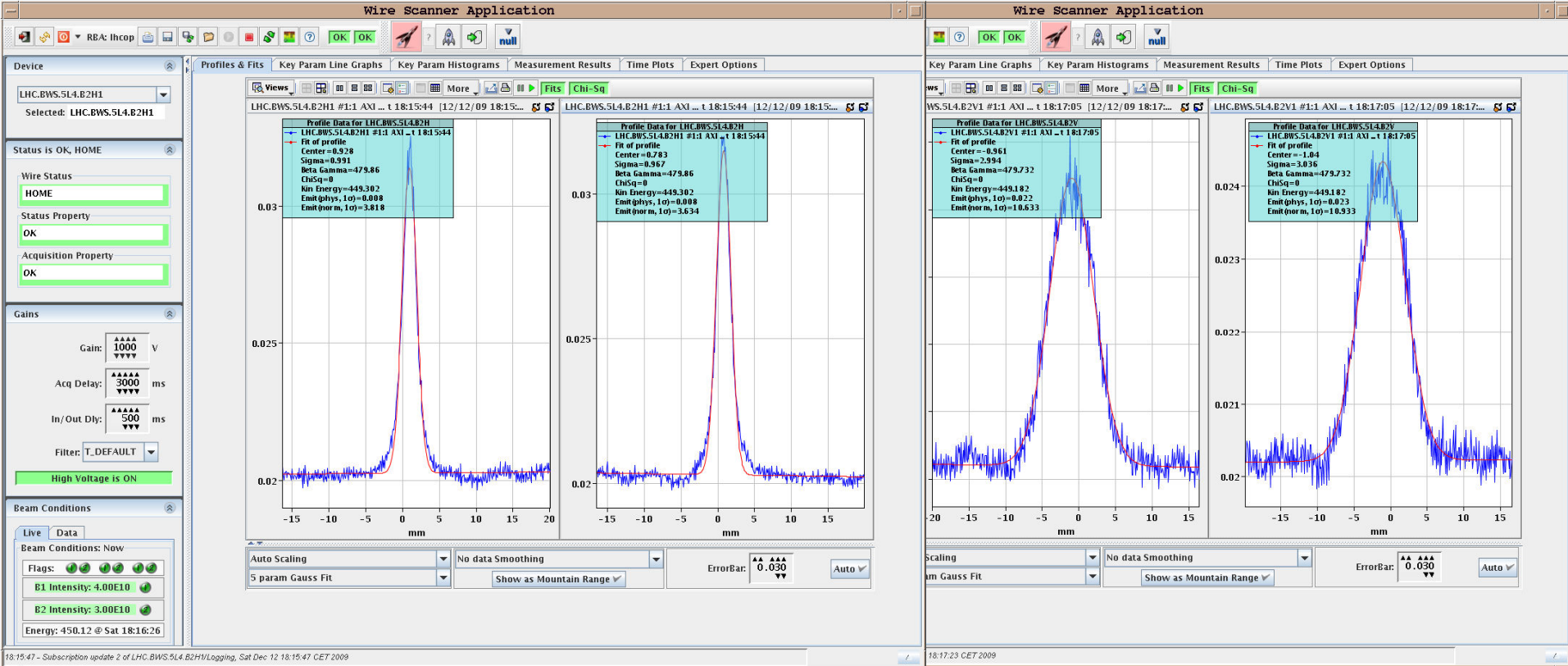
Tune variations  
during ramp  
Beam 1  
Beam 2



# 13.12.2009: Wire Scans During STABLE Beams

Beam2 horizontal:

Beam2 vertical



Comparing beam size from wire with synchrotron light monitor

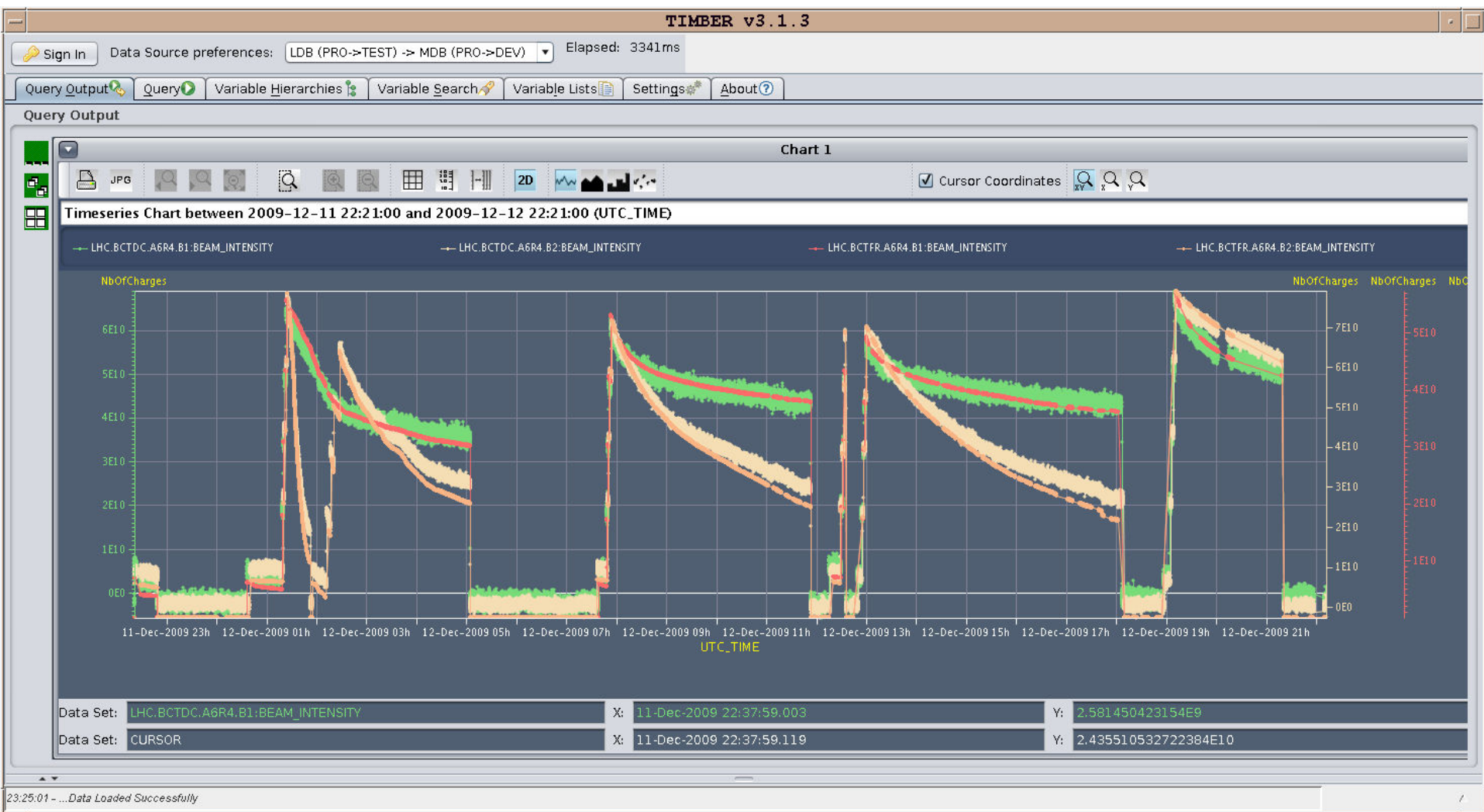
Wire:  $\sigma_x = 0.98\text{mm}$

$\sigma_y = 3.0\text{mm}$

BSRT:  $\sigma_x = 1.10\text{mm}$ ,

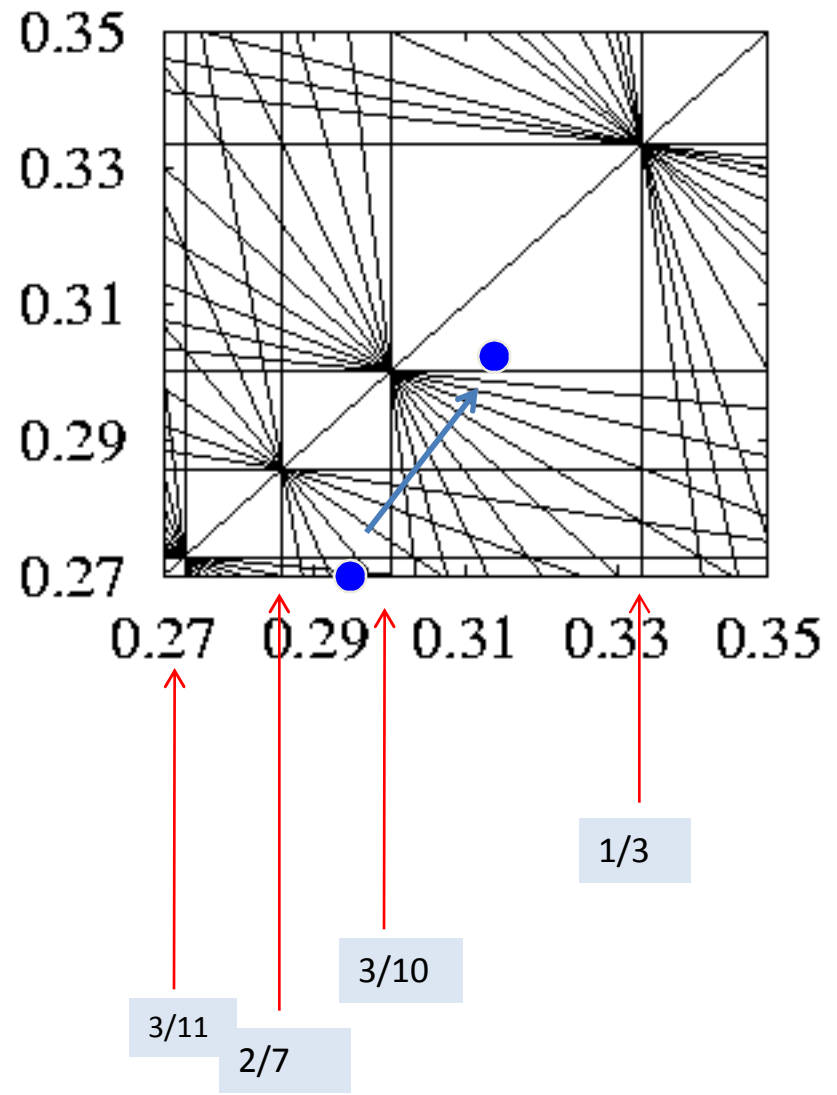
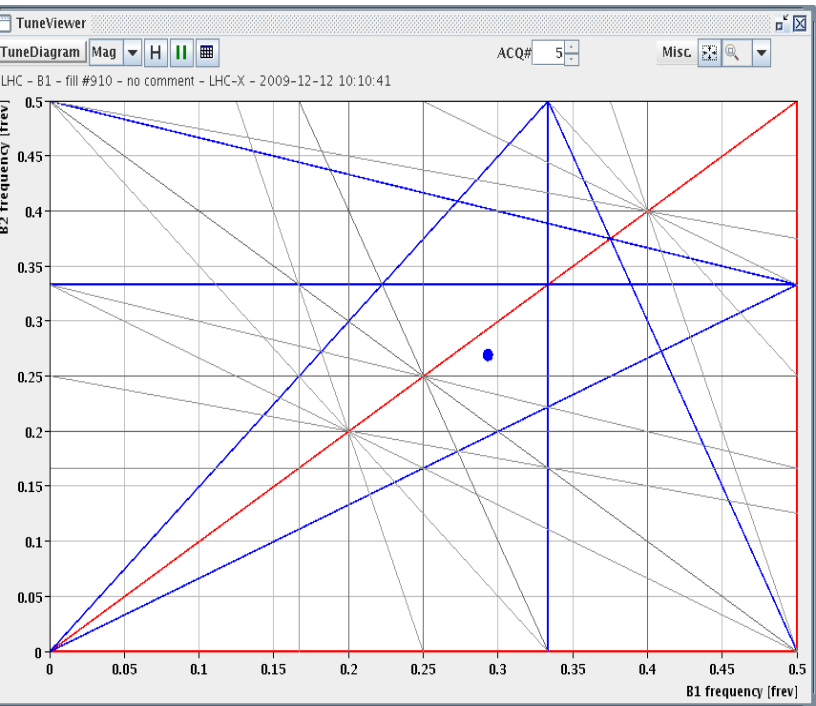
$\sigma_y = 2.7\text{mm} \rightarrow$  ca factor 2 between  $\sigma_y$  and  $\sigma_x$

# 13.12.2009: 24 hours running - currents

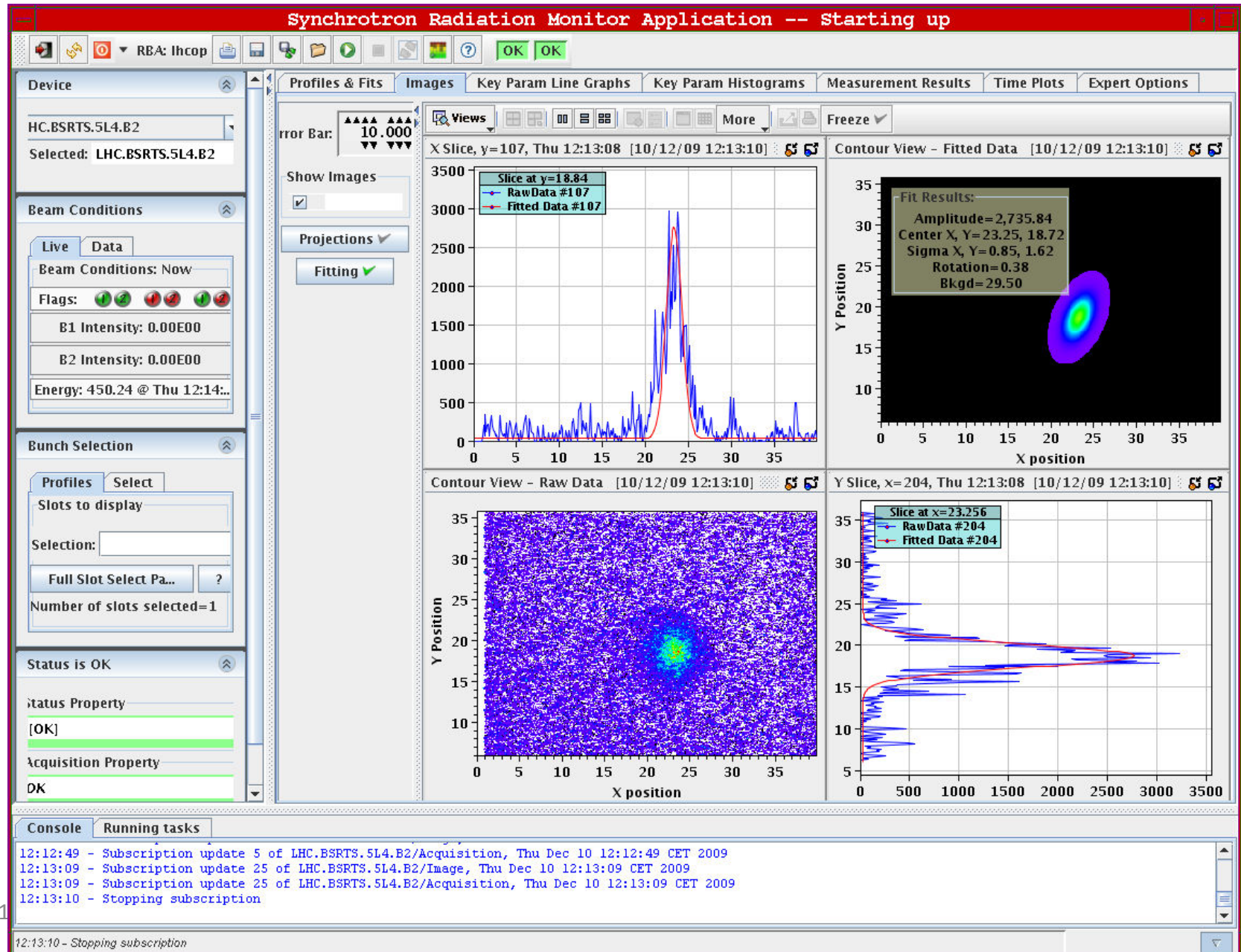


# 13.12.2009: Tune Adjustments for Beam2

- B1:  $Q_x = 0.293$ ,  $Q_y = 0.269$ ; lifetime = 26h
- B2:  $Q_x = 0.297$ ,  $Q_y = 0.267$ ; lifetime = 5h
- B1:  $Q_x = 0.293$ ,  $Q_y = 0.269$ ; lifetime = 25h
- B2:  $Q_x = 0.312$ ,  $Q_y = 0.305$ ; lifetime = 12h



# BSRT on beam 2

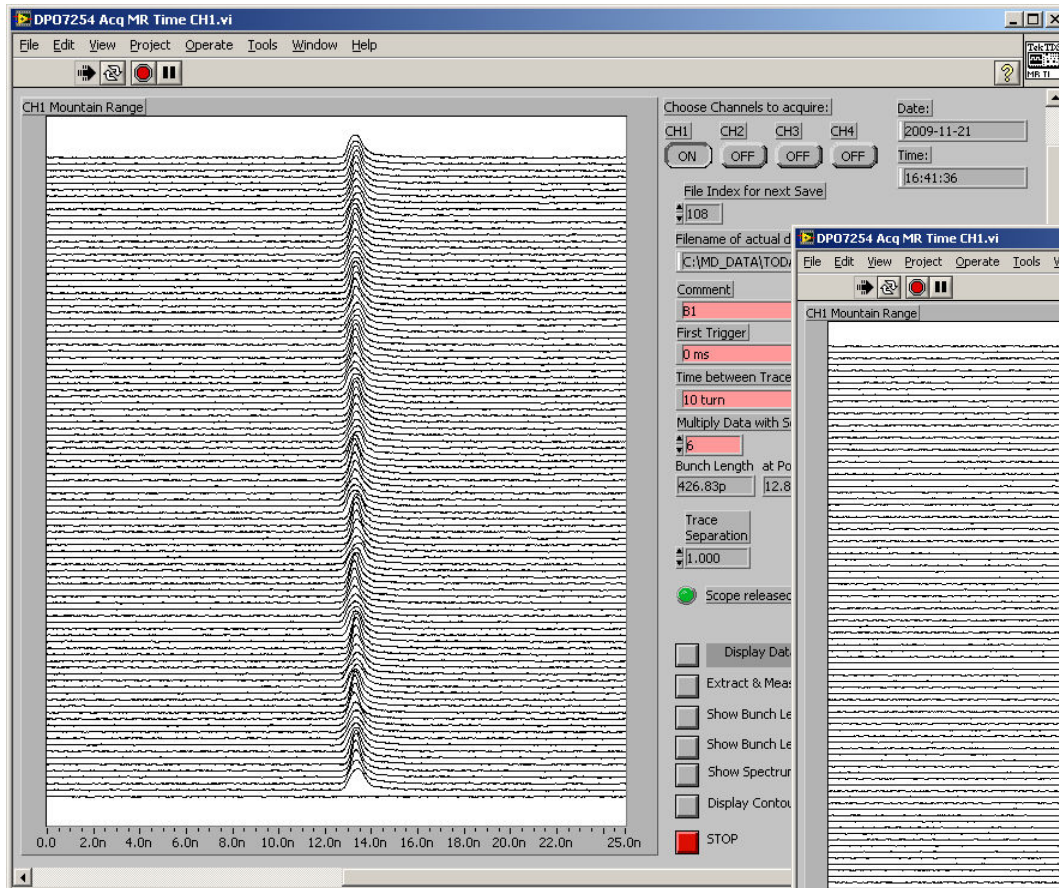




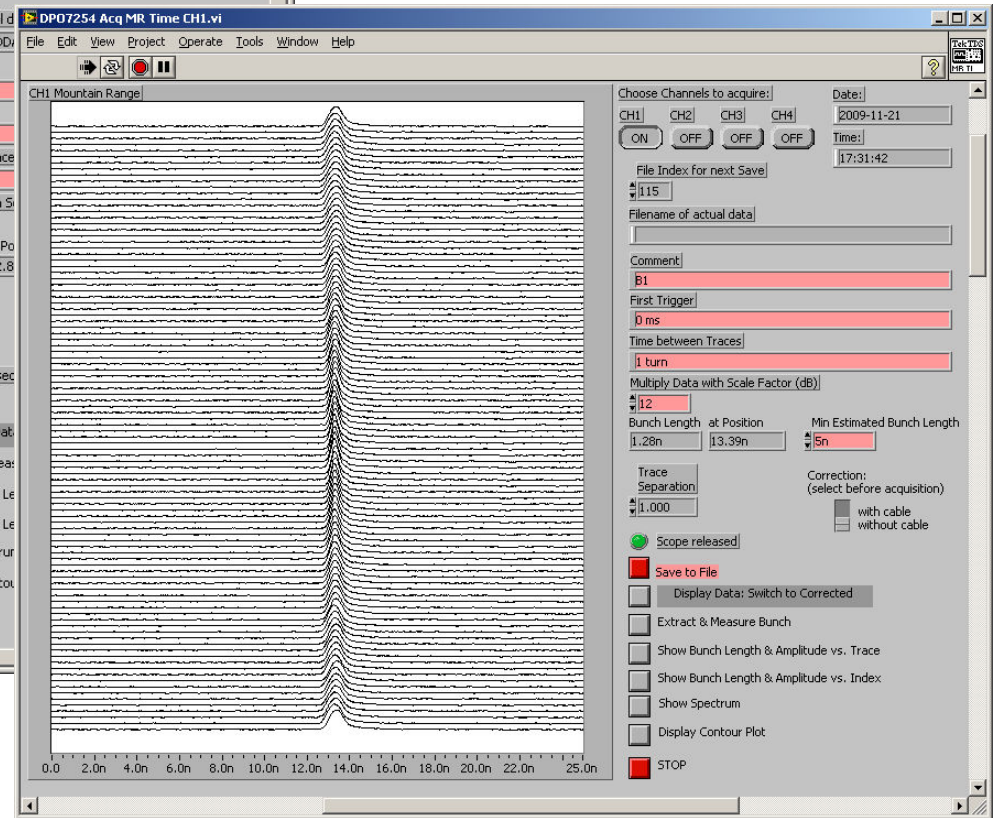
# The “RF guys” (Ed and his merry men)



Screens showing two beams in the LHC



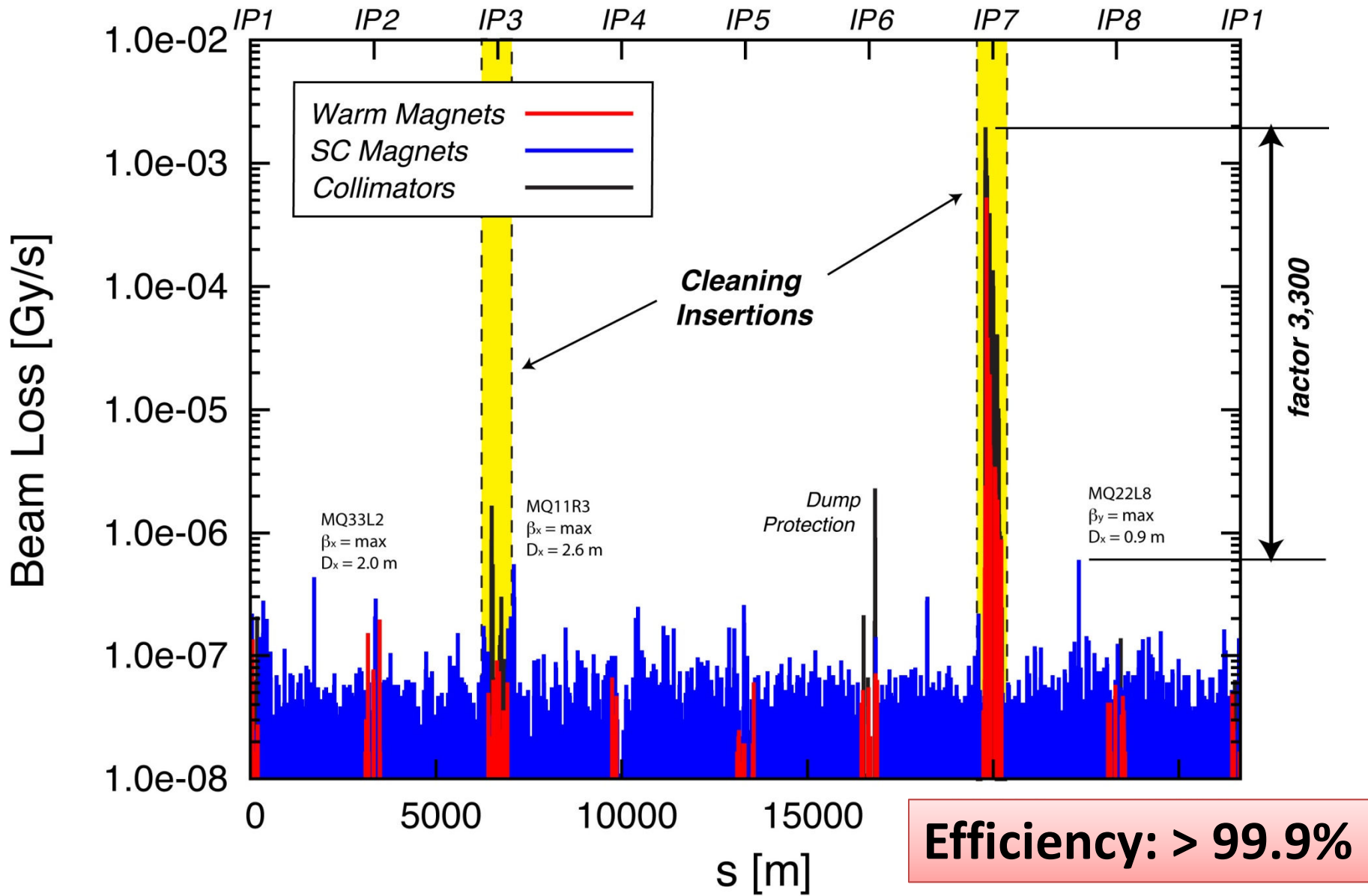
Phase loop Off



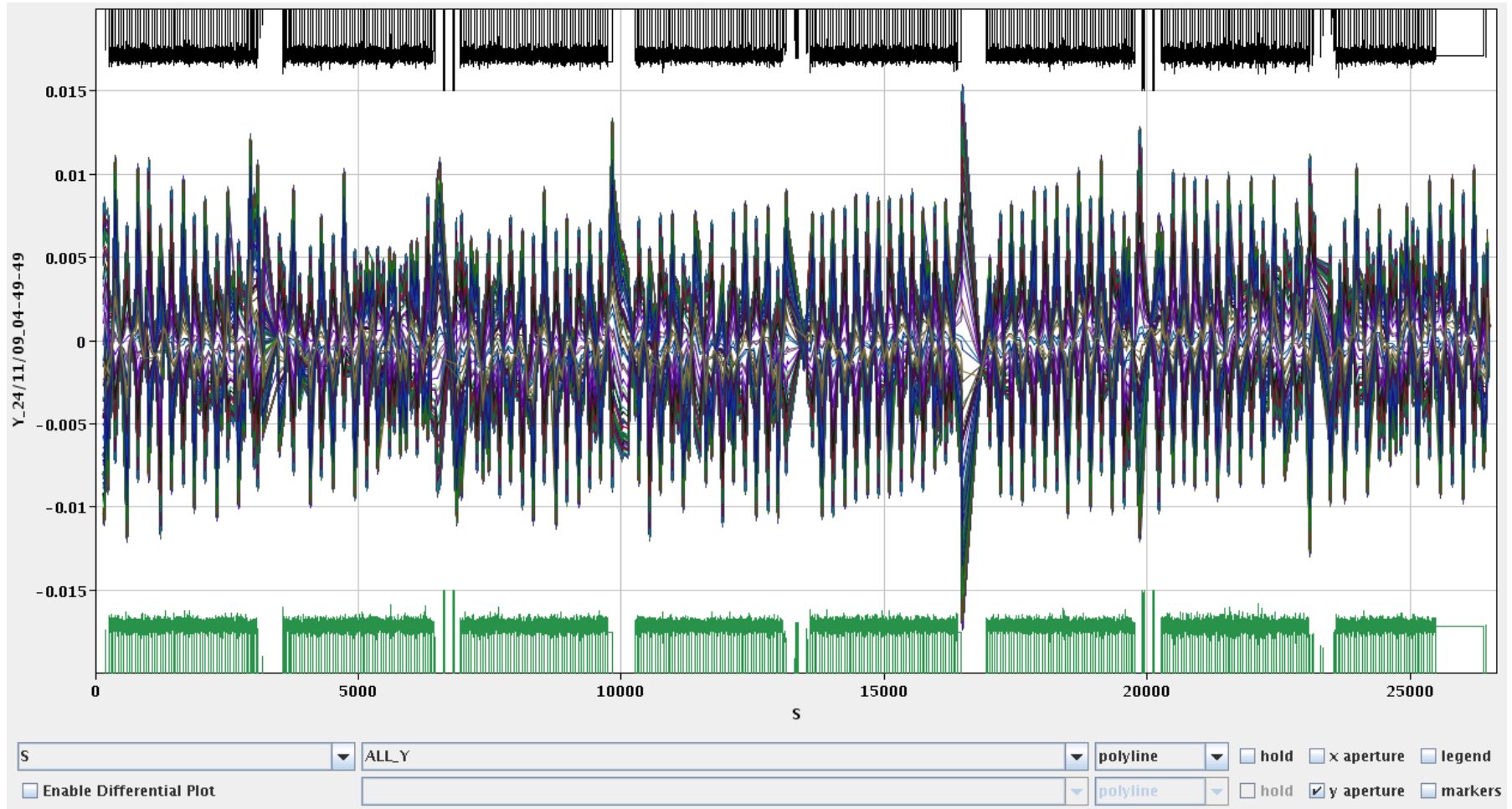
Phase Loop On

# Collimation after beam based set up

November 29, 21:55:51 - First ramp to 1.18 TeV - Beam 1 - Highest loss in 1.3 s integral

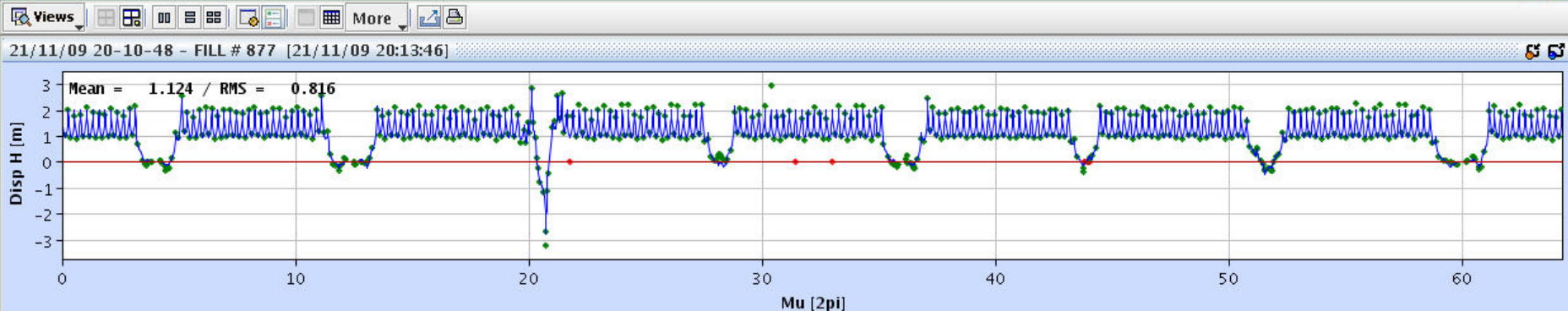


# Aperture checks with free oscillation



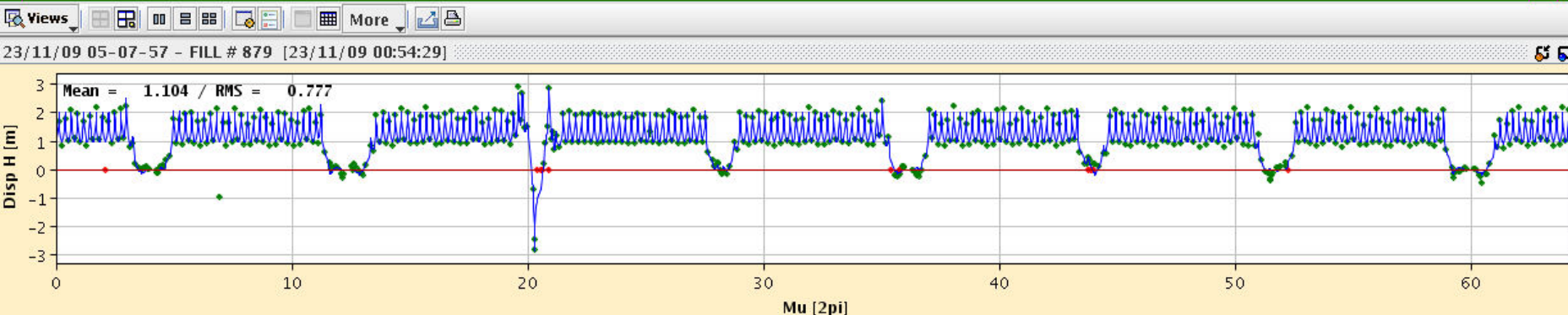
# Dispersion...WoW

YASP DV LHCRING / NOM\_1.2TeV / beam 1

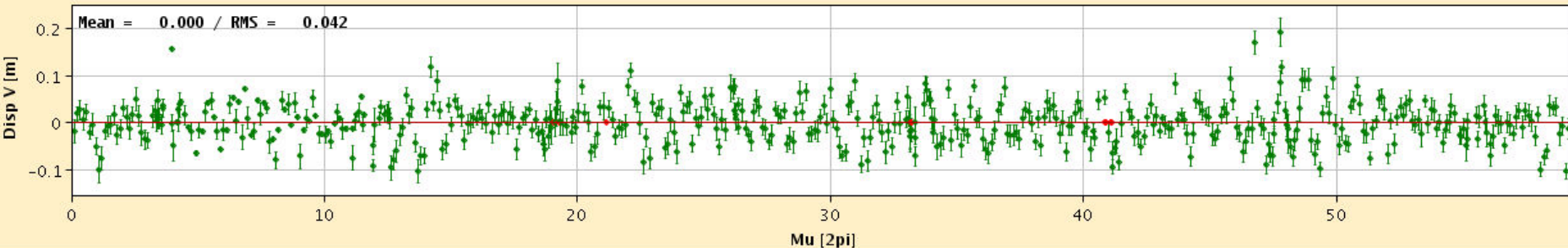


21/11/09 20-10-48 - FILL # 877 [21/11/09 20:13:46]

YASP DV LHCRING / NOM\_1.2TeV / beam 2



23/11/09 05-07-57 - FILL # 879 [23/11/09 00:54:29]



# Ramp 2 on 2 to 1.18 TeV

VLC media player

File View Settings Audio Video Navigation Help

LHC Page1      Fill: 916.0      E: 1180 GeV      14-12-2009 02:40:39

## BEAM SETUP: RAMP

<b>Energy:</b>	1180 GeV	<b>I(B1):</b>	0.00e+00	<b>I(B2):</b>	7.80e+09
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**Main bending magnet current of S56**      Updated: 02:40:39

**FBCT Intensity**      Updated: 02:40:39

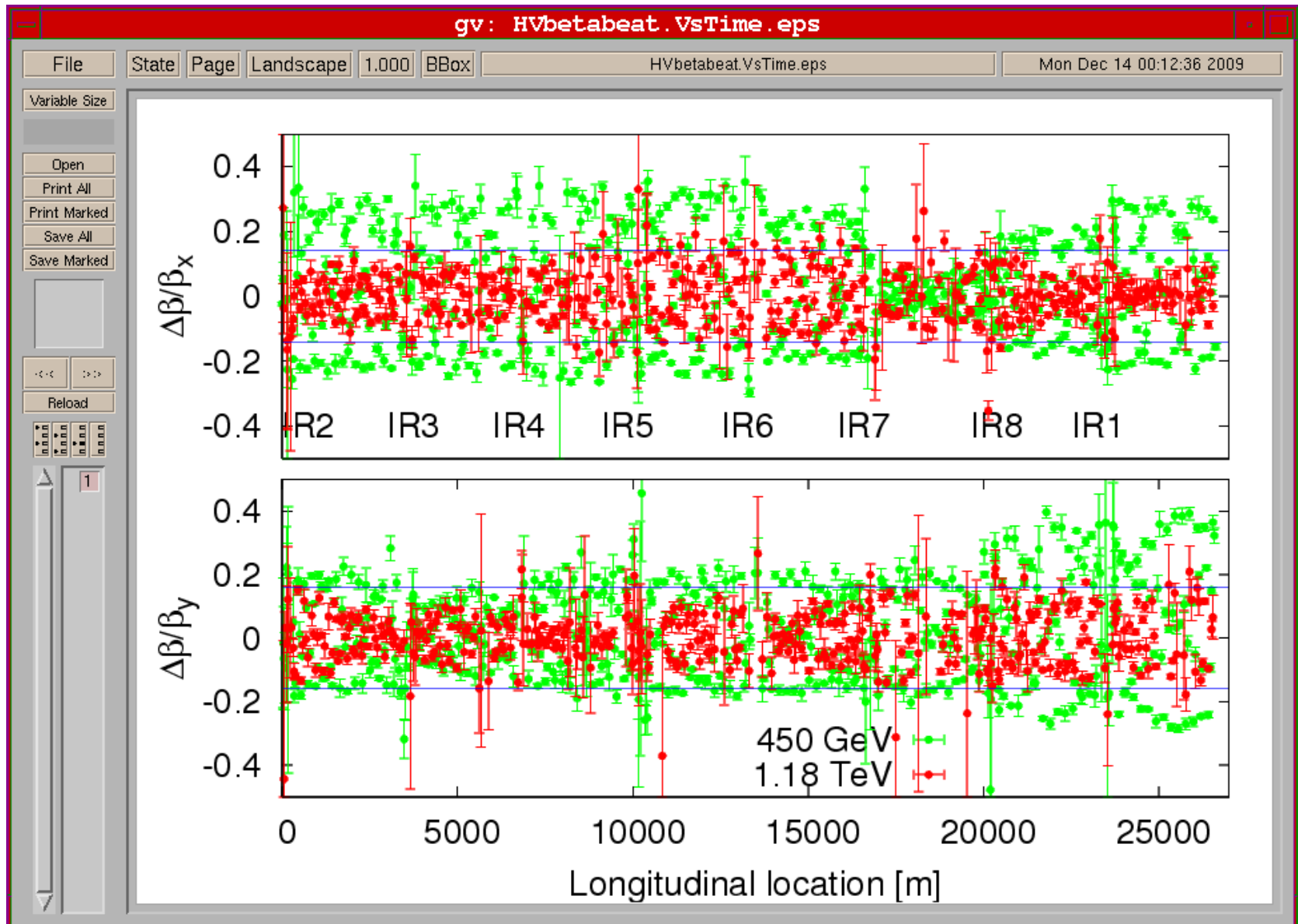
<p><b>Comments 14-12-2009 02:33:04 :</b></p> <p style="text-align: center;">Expts: can go back to LHC clocks ramping up</p> <p style="text-align: center;">filling schema: bucket 1 and 17851 in B1</p> <p style="text-align: center;">filling schema: bucket 1 and 8911 in B2</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left;">SMP Flags</th> <th style="text-align: center;">B1</th> <th style="text-align: center;">B2</th> </tr> </thead> <tbody> <tr> <td>Channel Link Status A-B B-A</td> <td style="text-align: center;">false</td> <td style="text-align: center;">false</td> </tr> <tr> <td>Global Beam Permit</td> <td style="text-align: center;">true</td> <td style="text-align: center;">true</td> </tr> <tr> <td>Setup Beam</td> <td style="text-align: center;">true</td> <td style="text-align: center;">true</td> </tr> <tr> <td>Beam Presence</td> <td style="text-align: center;">true</td> <td style="text-align: center;">true</td> </tr> <tr> <td>Moveable Devices Allowed In</td> <td style="text-align: center;">false</td> <td style="text-align: center;">false</td> </tr> <tr> <td>Stable Beams</td> <td style="text-align: center;">false</td> <td style="text-align: center;">false</td> </tr> </tbody> </table>	SMP Flags	B1	B2	Channel Link Status A-B B-A	false	false	Global Beam Permit	true	true	Setup Beam	true	true	Beam Presence	true	true	Moveable Devices Allowed In	false	false	Stable Beams	false	false
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Beam Presence	true	true																				
Moveable Devices Allowed In	false	false																				
Stable Beams	false	false																				

LHC Operation in CCC : 77600, 70480

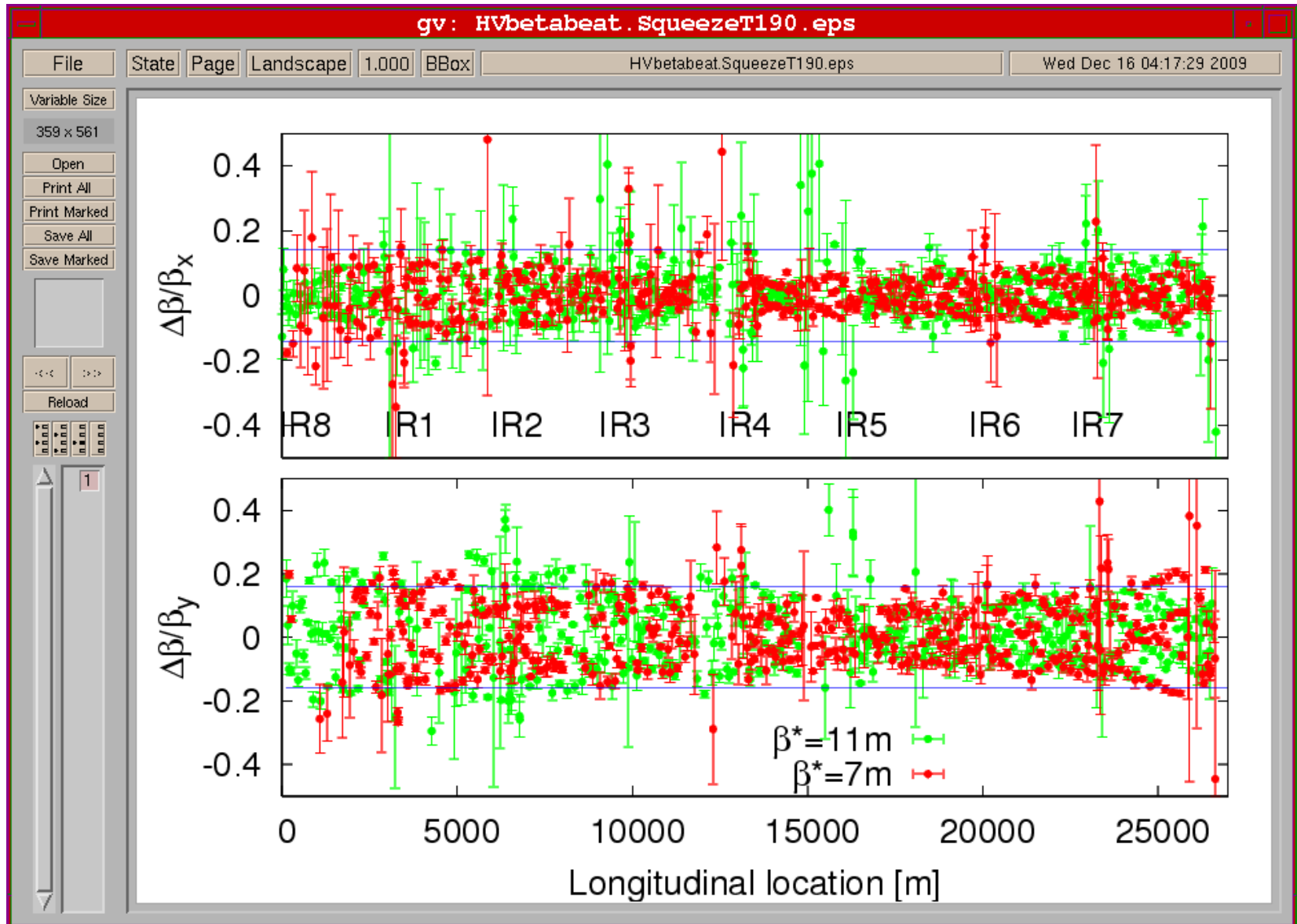
PM Status B1	ENABLED	PM Status B2	ENABLED
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0:00:00 / 0:00:00 | x1.00 | "LHC Page 1"

# Beta-beat comparison 450 GeV and 1.18 TeV



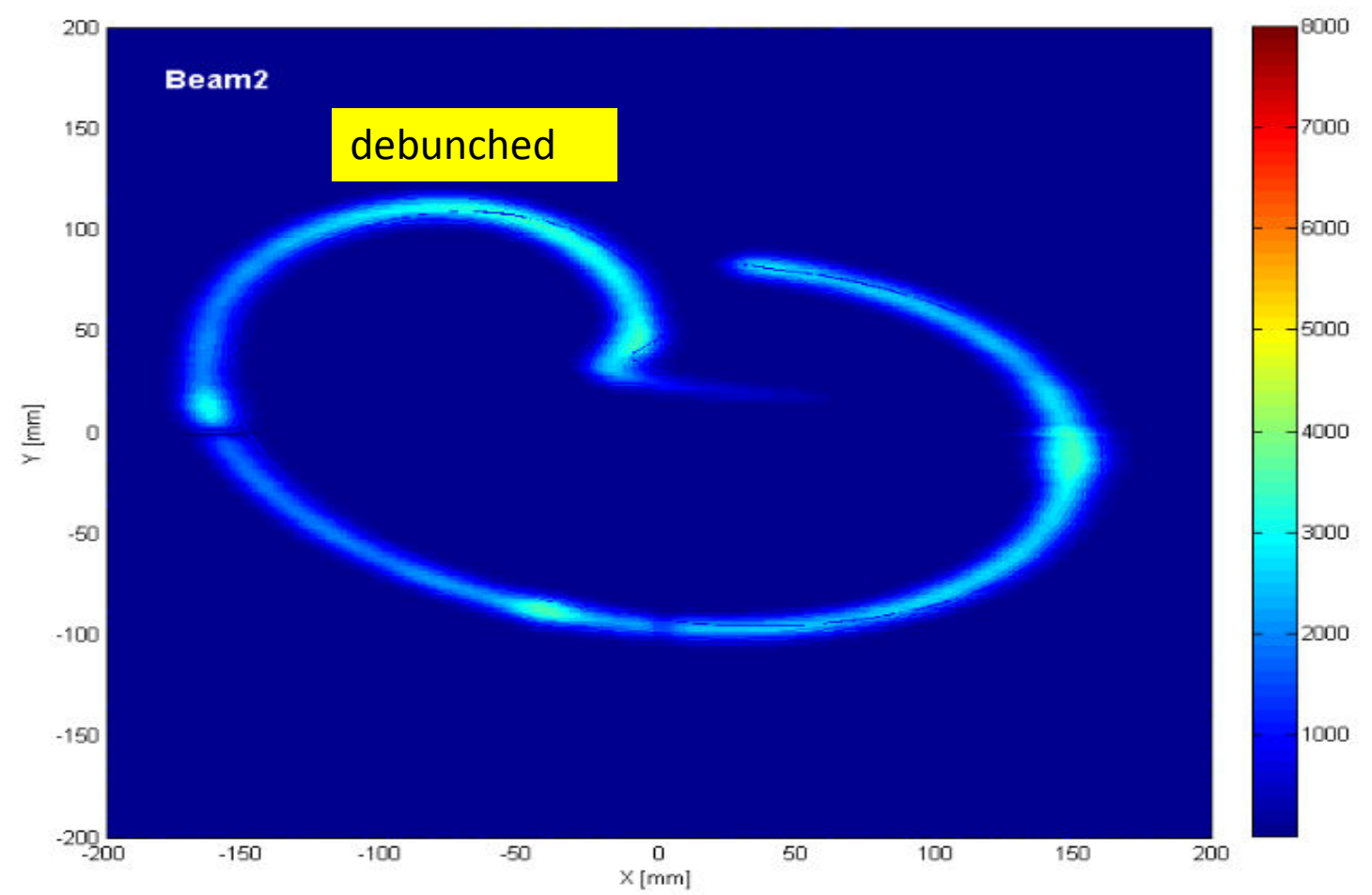
# Beta-beat comparison 11m and 7m

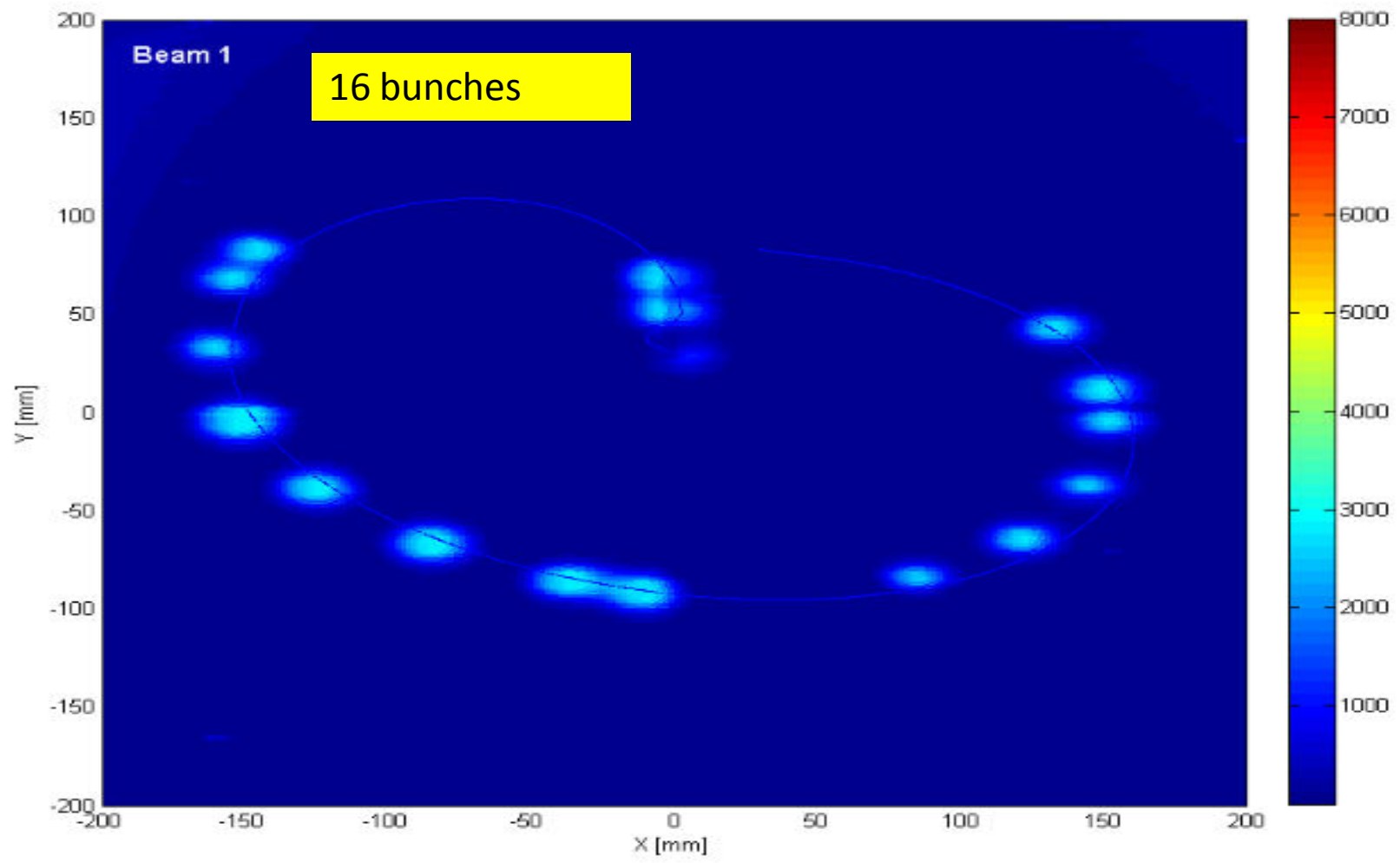


# Food for thought – V blow up of beam 2









# System commissioning

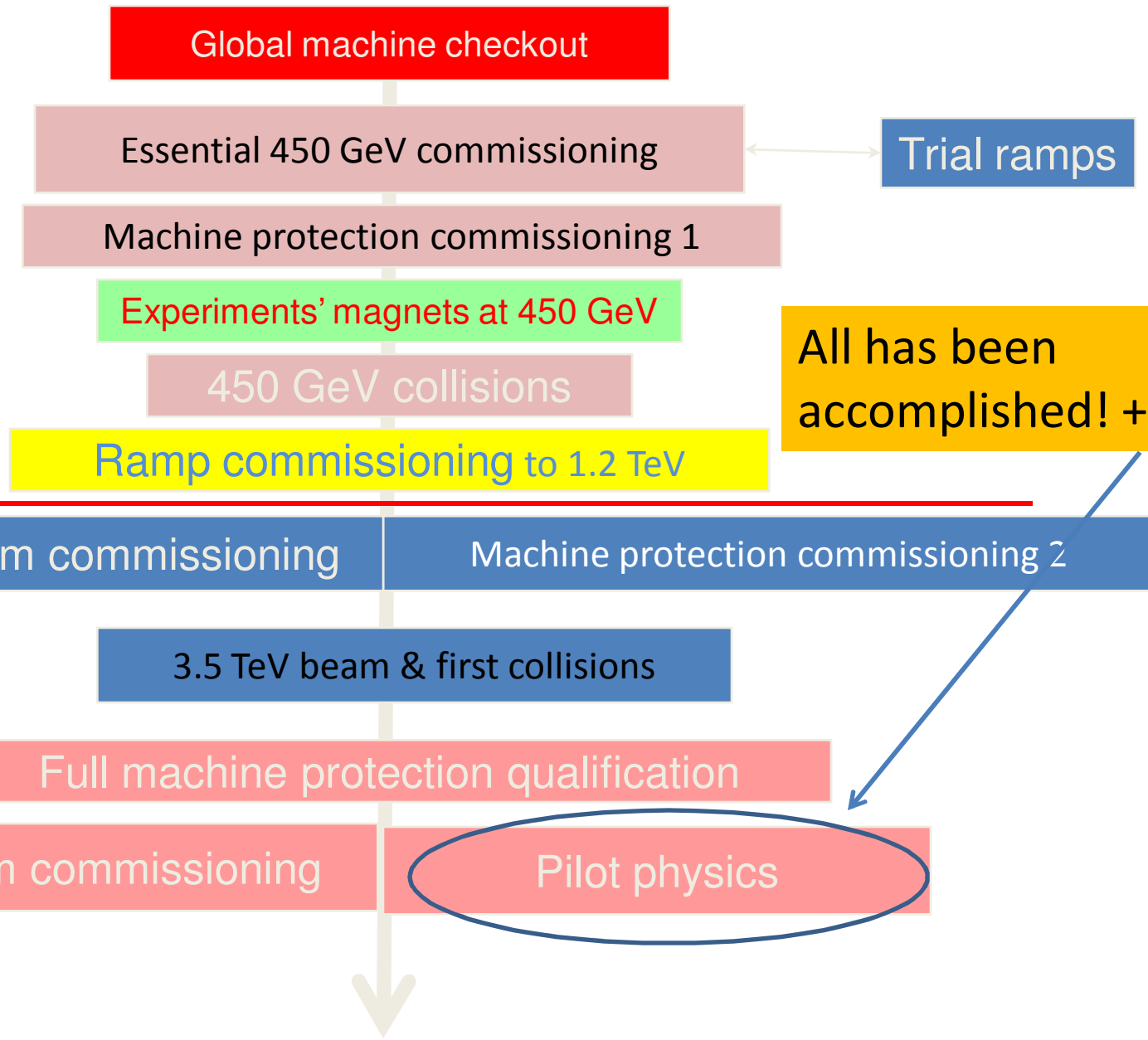
- Plenty of systems worked as needed on day 1
- Planning was adjusted on a daily basis for critical systems
  - Beam Instrumentation
  - Acceleration (RF)
  - Injection
  - Extraction
  - Collimation
  - Kick response campaign
  - Aperture measurement campaign
  - Optics measurements
  - Machine protection
  - Collisions
  - Ramp
  - Squeeze

and don't forget

- Magnets
- Power supplies
- Cryo
- vacuum
- Controls
- Electrical distribution
- Cooling
- Access
- nQPS
- ...
- ...

# Beam commissioning strategy

Energy	Safe	Very Safe
450	1 e12	1 e11
1 TeV	2.5 e11	2.5 e10
3.5 TeV	3.0 e10	probe



Xmas

Trial ramps

All has been accomplished! +

2010

Pilot physics

# Summary

## LHC is back!

26 days of highly successful beam commissioning due to

- meticulous planning
- High availability of all accelerator and detector components

# In conclusion

It has been a truly remarkable 24 days. Things have moved so quickly that it has been hard to keep up with the progress.

Many firsts for the LHC and the detectors

On the longer time scale, it has been a fantastic effort, with five impressive phases:

1) repair; 2) consolidation; 3) hardware commissioning; 4) preparation for beam; and 5) beam operation.

The final phase has been highly visible, and widely reported throughout the world, but would not have been possible without the other phases.

From the CERN management, we would like to express our sincere thanks and congratulations to all of you who have done such a great job in bringing the LHC BACK!

I wish you

- A good rest
- a great Christmas with your families
- A very happy new year



And please come back in 2010 fully recharged  
for the next phase

While waiting  
for  
Questions...  
A little black  
Christmas  
humour

