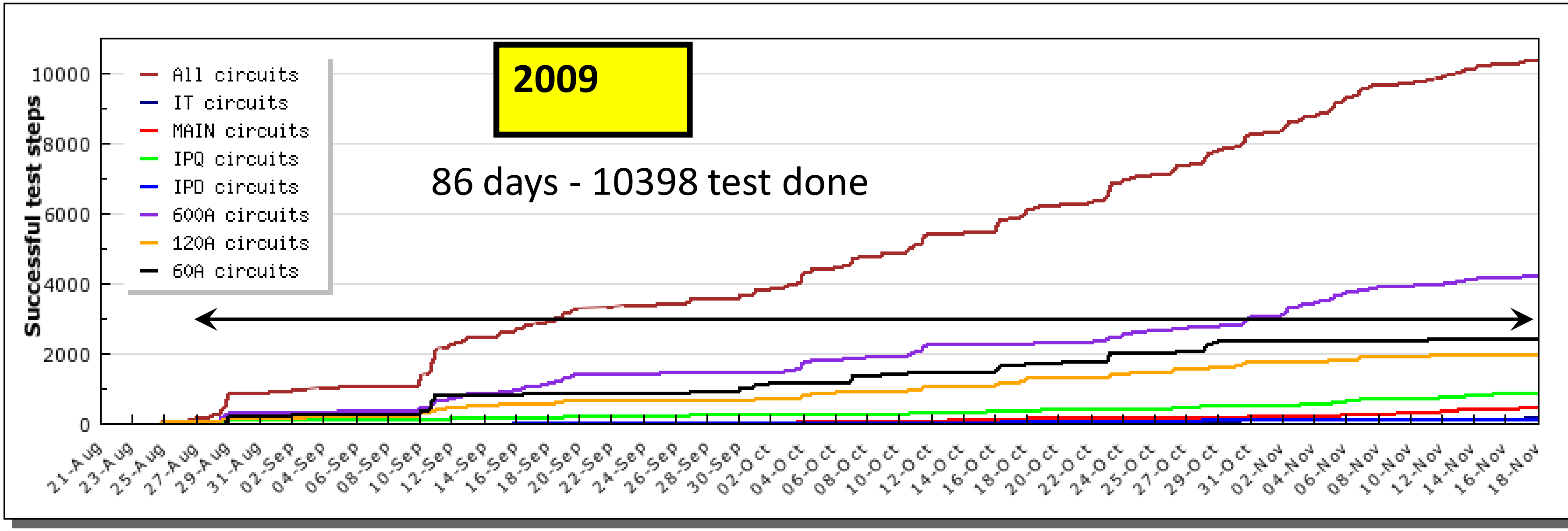
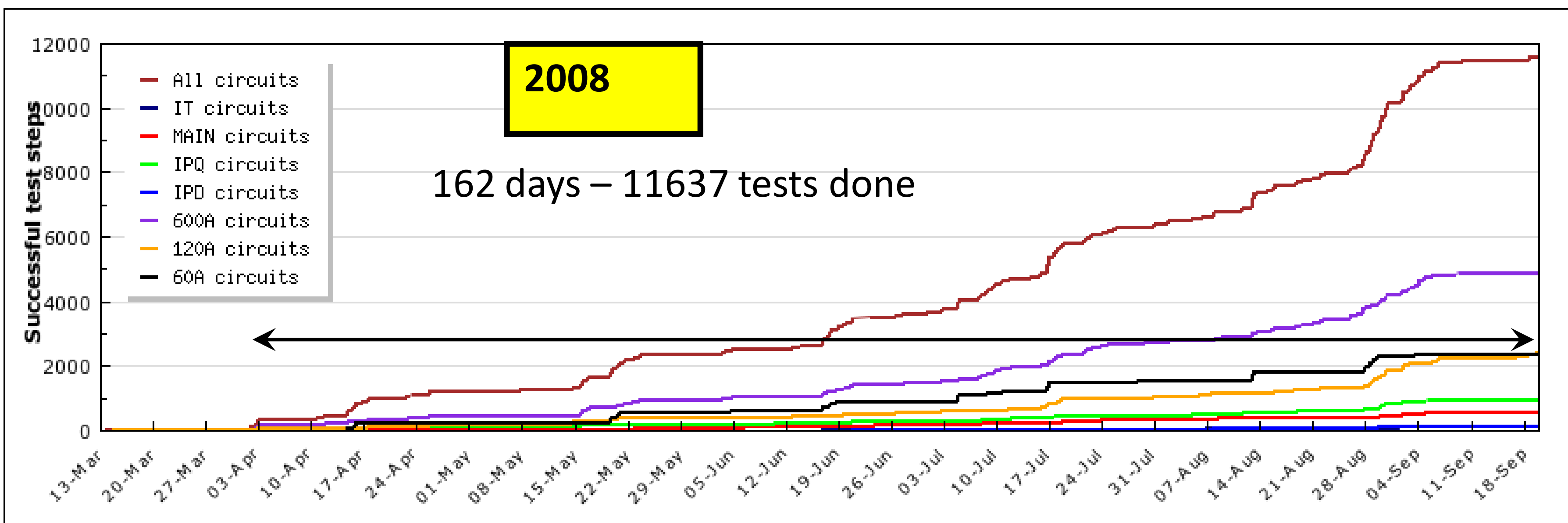
LHC Operation with Beam and Chamonix Outcome

(on behalf of the LHC team)

LHCC February 17, 2010

Powering Tests overview

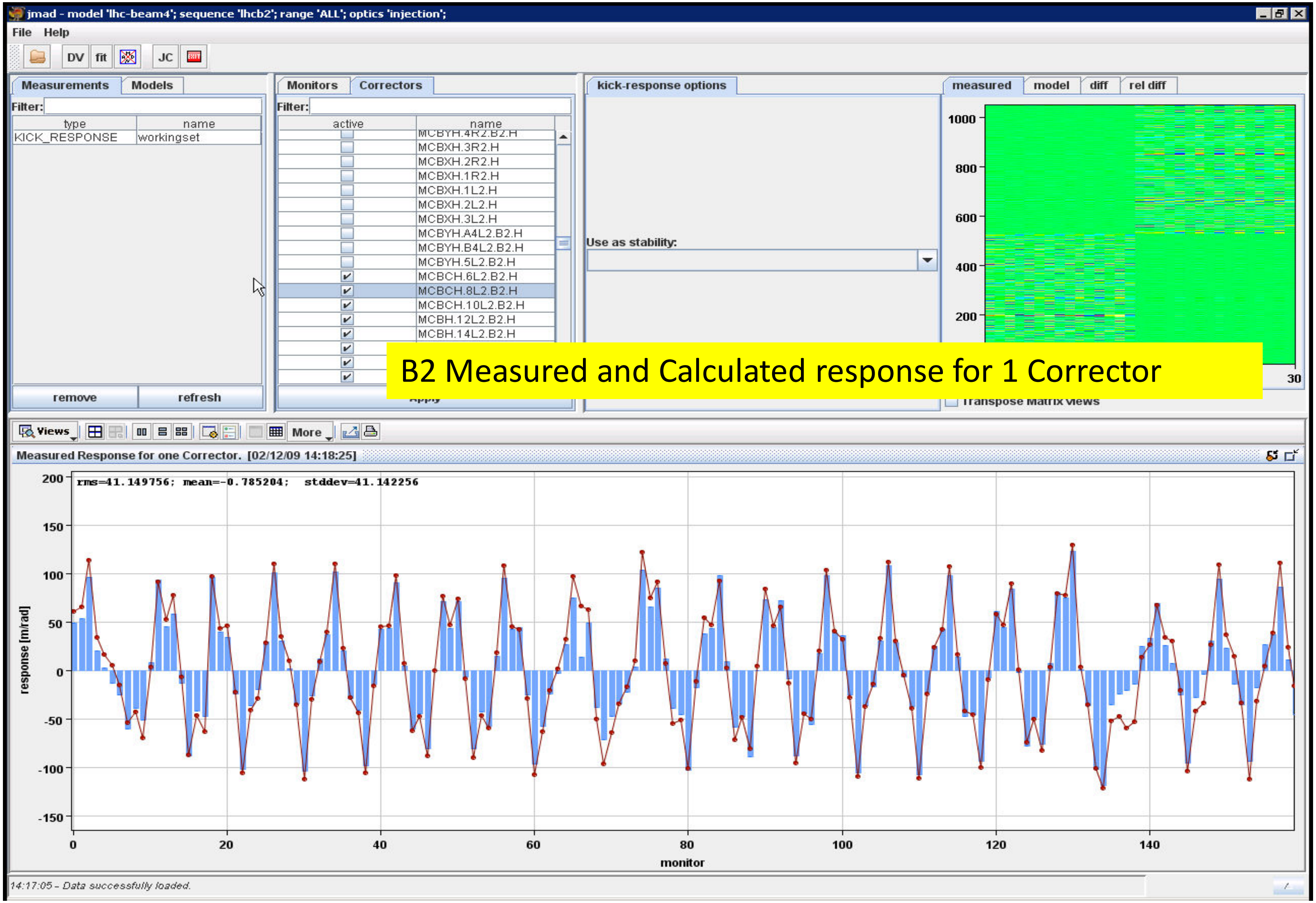




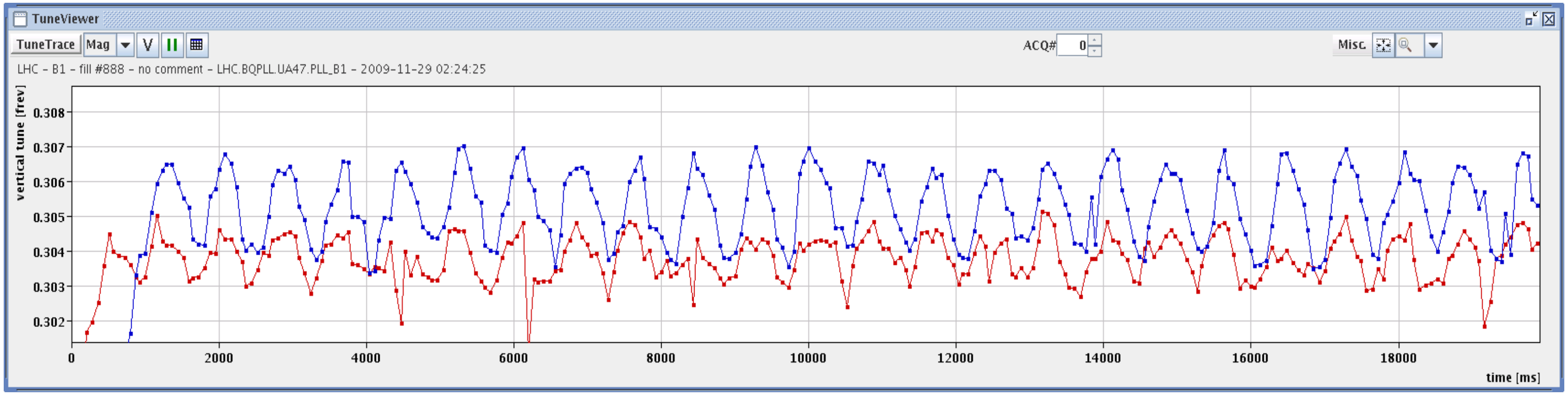
Milestones During the 26 days

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

Optics Checks (2nd Dec)

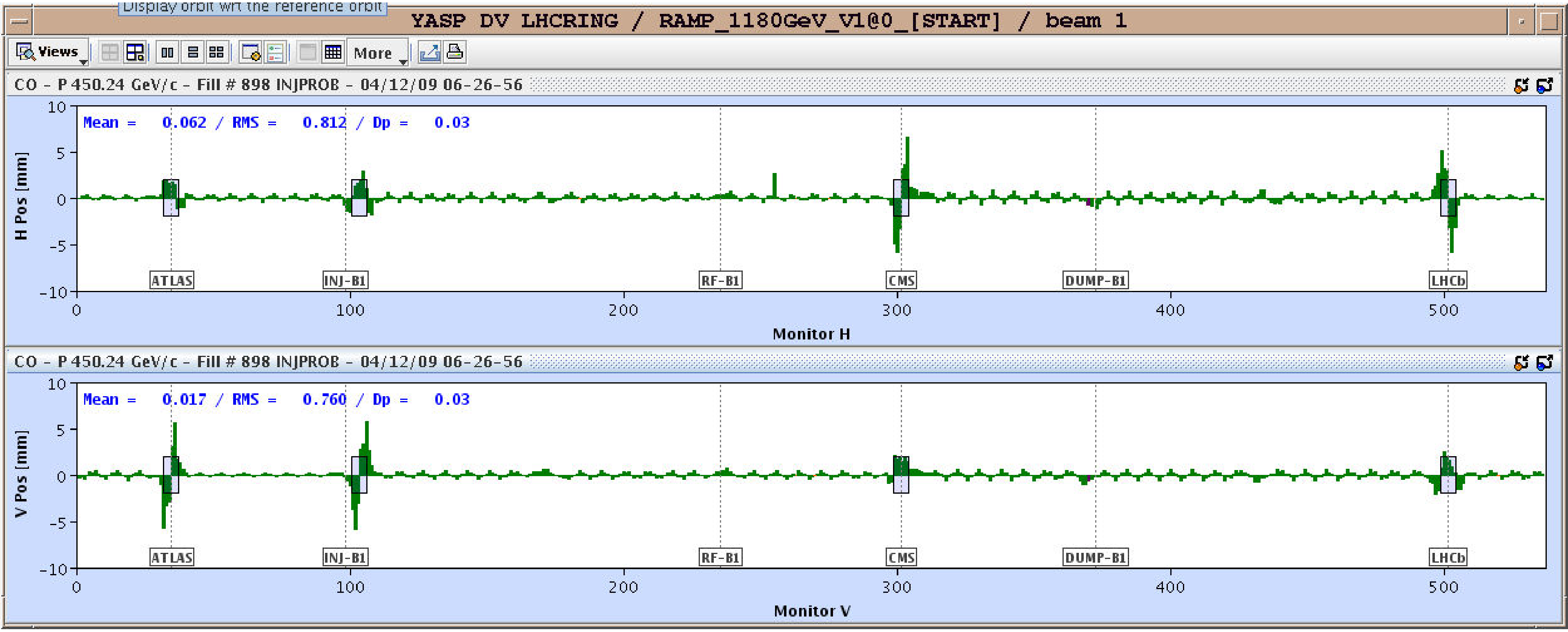


Chromaticity Measurement and Correction

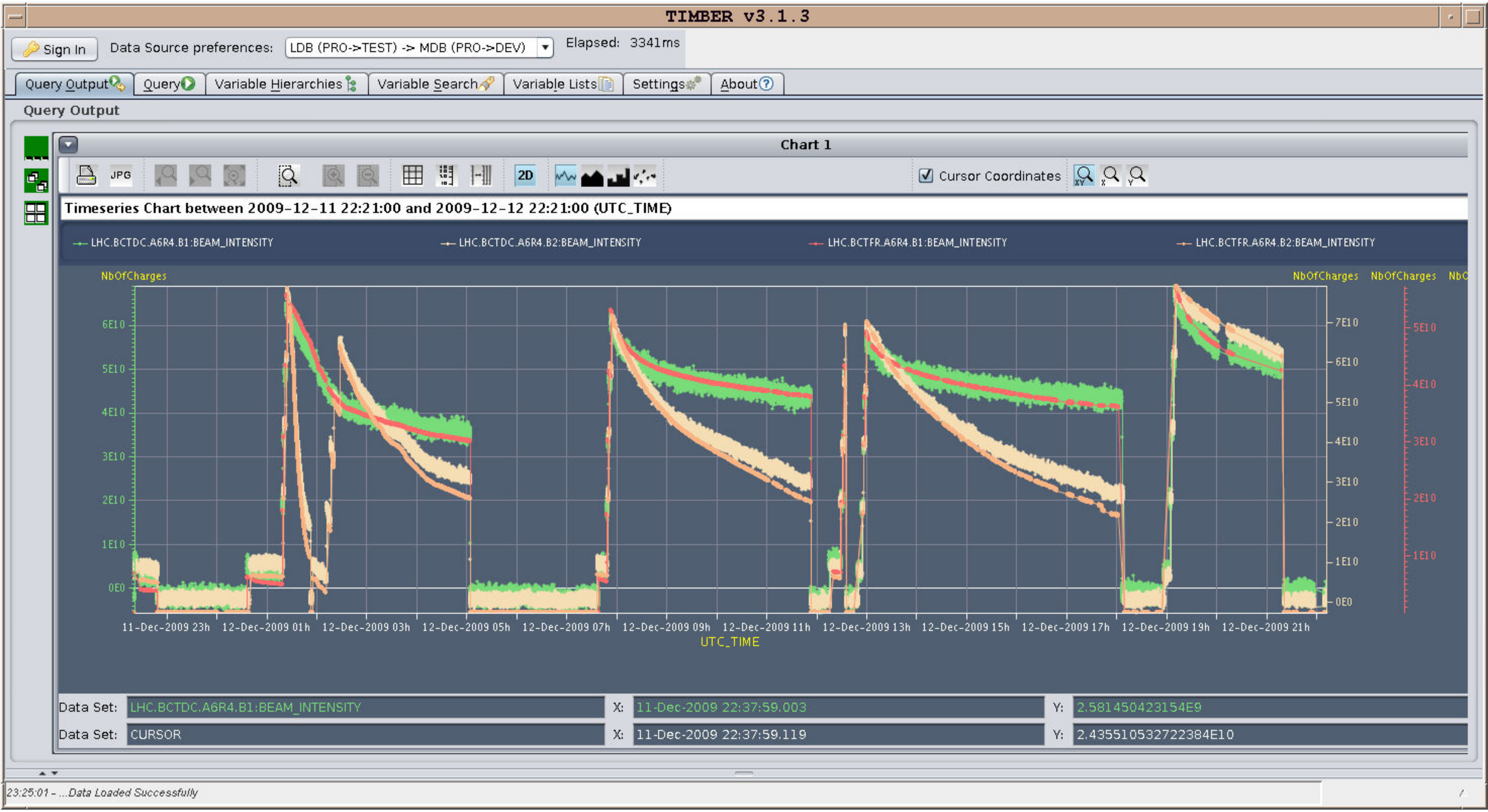


measured Q_v' = 15 using dp/p=1e-4 @2.5 Hz radial modulation,
damper amplitude 1e-3
with dQ_v' = -10 trim
'blue' trace before and 'red' after trim

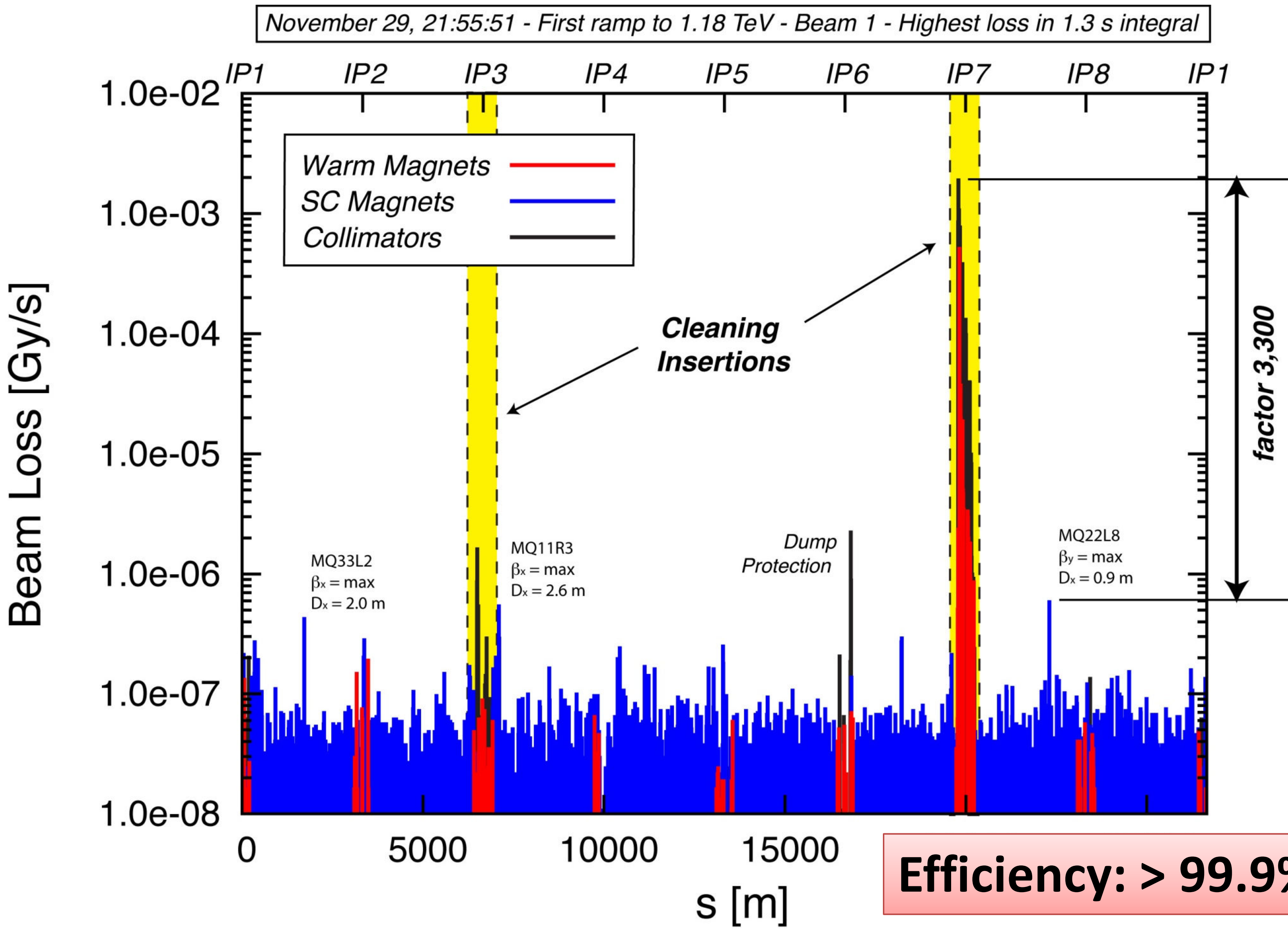
Separation bumps and crossing angle.



13.12.2009: 24 hours running - currents

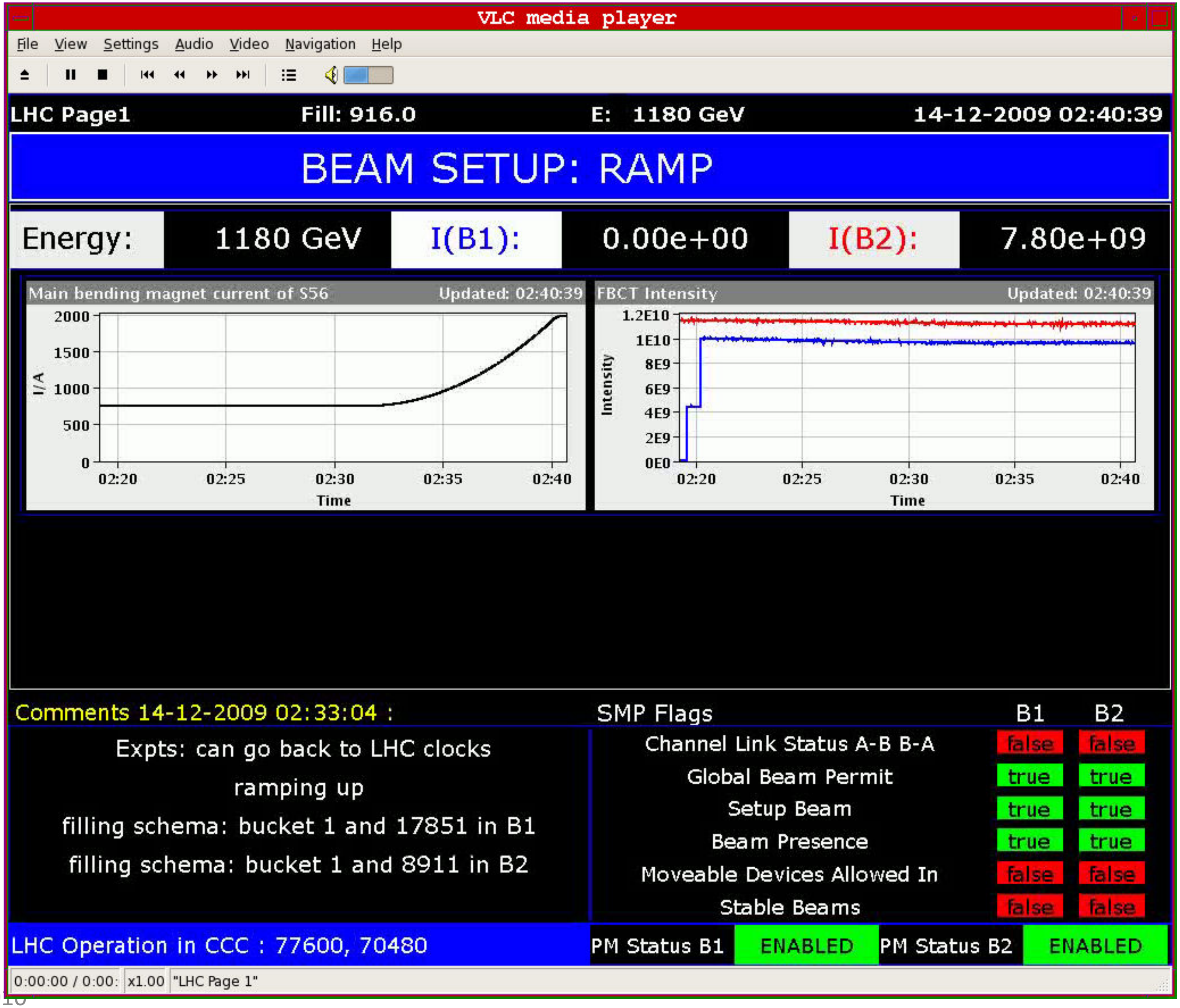


Collimation after beam based set up

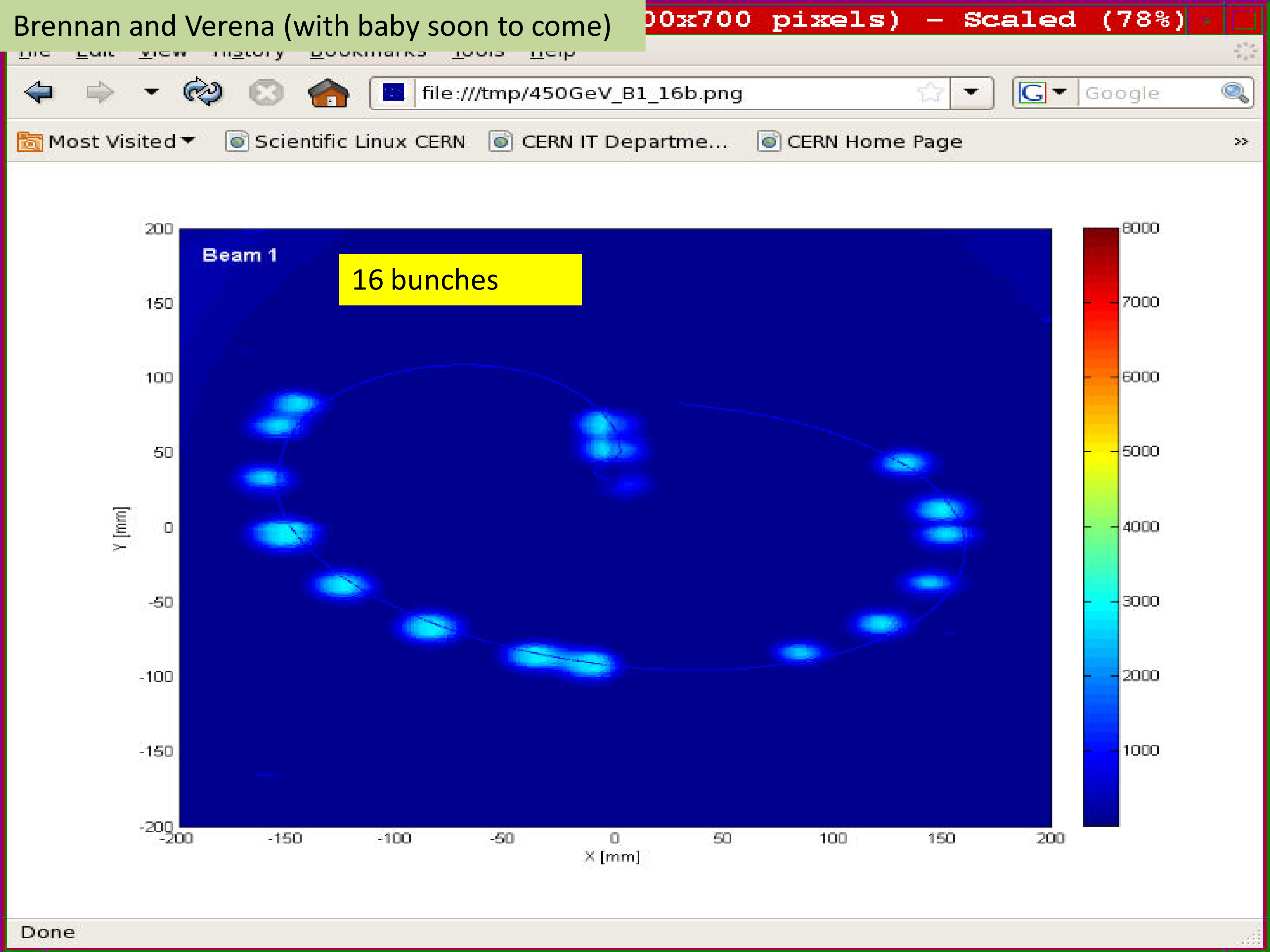


Efficiency: > 99.9%

Ramp 2 on 2 to 1.18 TeV



Brennan and Verena (with baby soon to come)



Summary

LHC is back on line!

26 days of highly successful beam commissioning due to

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

Technical Stop

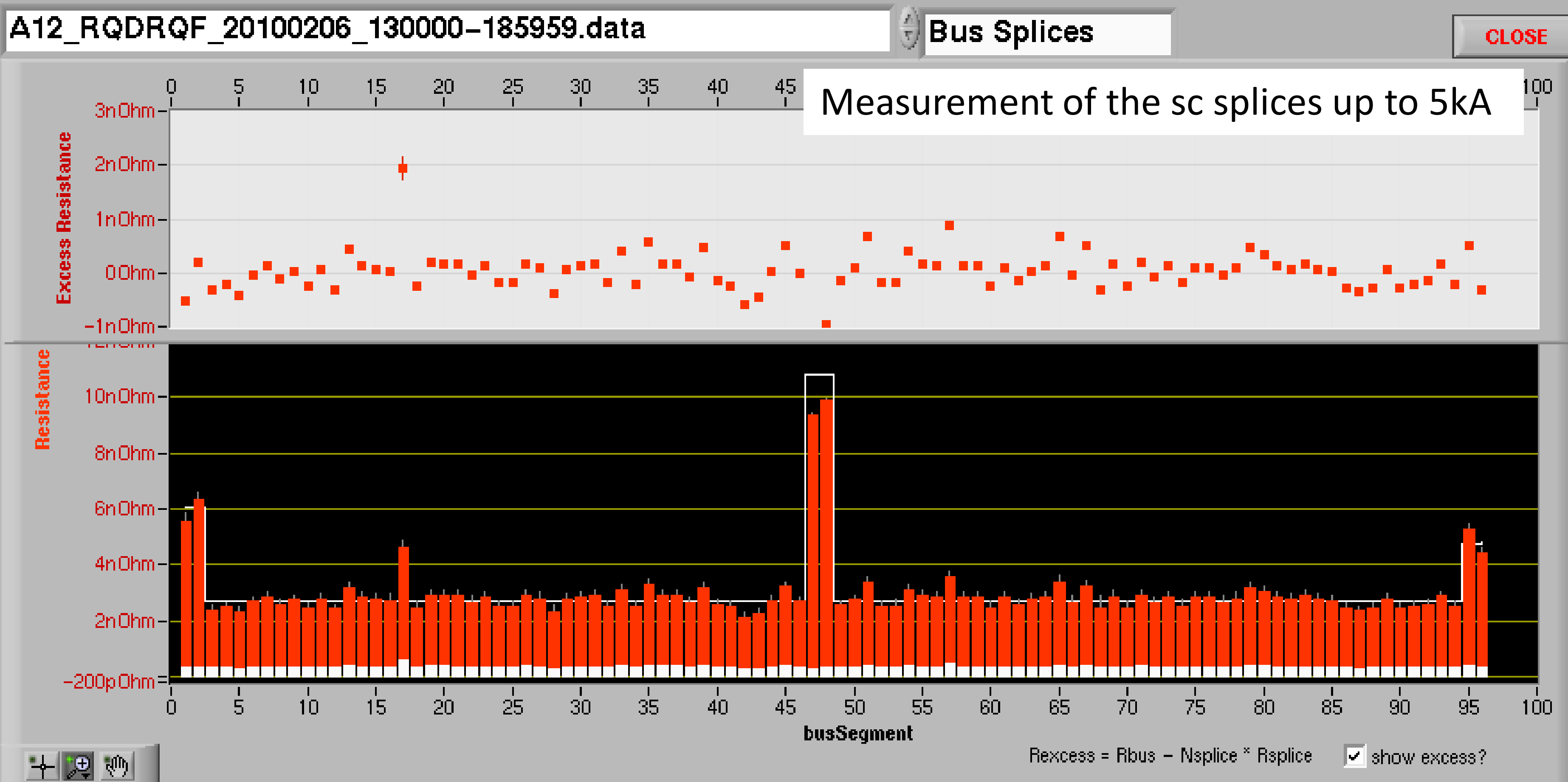
- nQPS connectors completed as schedule
- CMS repair of water cooling finished on time
- Hardware Commissioning on going band a few days late.
  - 3 sectors fully commissioned to 6kA
  - 3 sectors will be ready (6kA) within a few days
  - 2 sectors late (S78 and S81): oil leak on a transformer: will be ready in 1 week
- Collisions at 3.5TeV still foreseen around mid March
- BUT! A few scares

  CMS vacuum chamber

  Motor generator set

S12: RQF and RQD pyramids to 2kA and 5kA

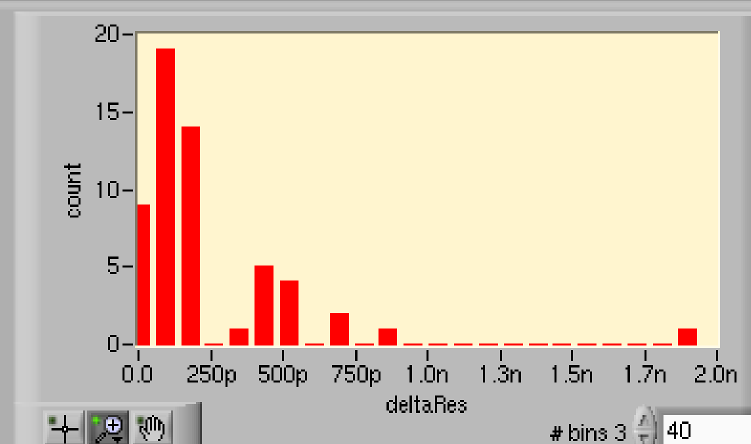
Measurement of the sc splices up to 5kA

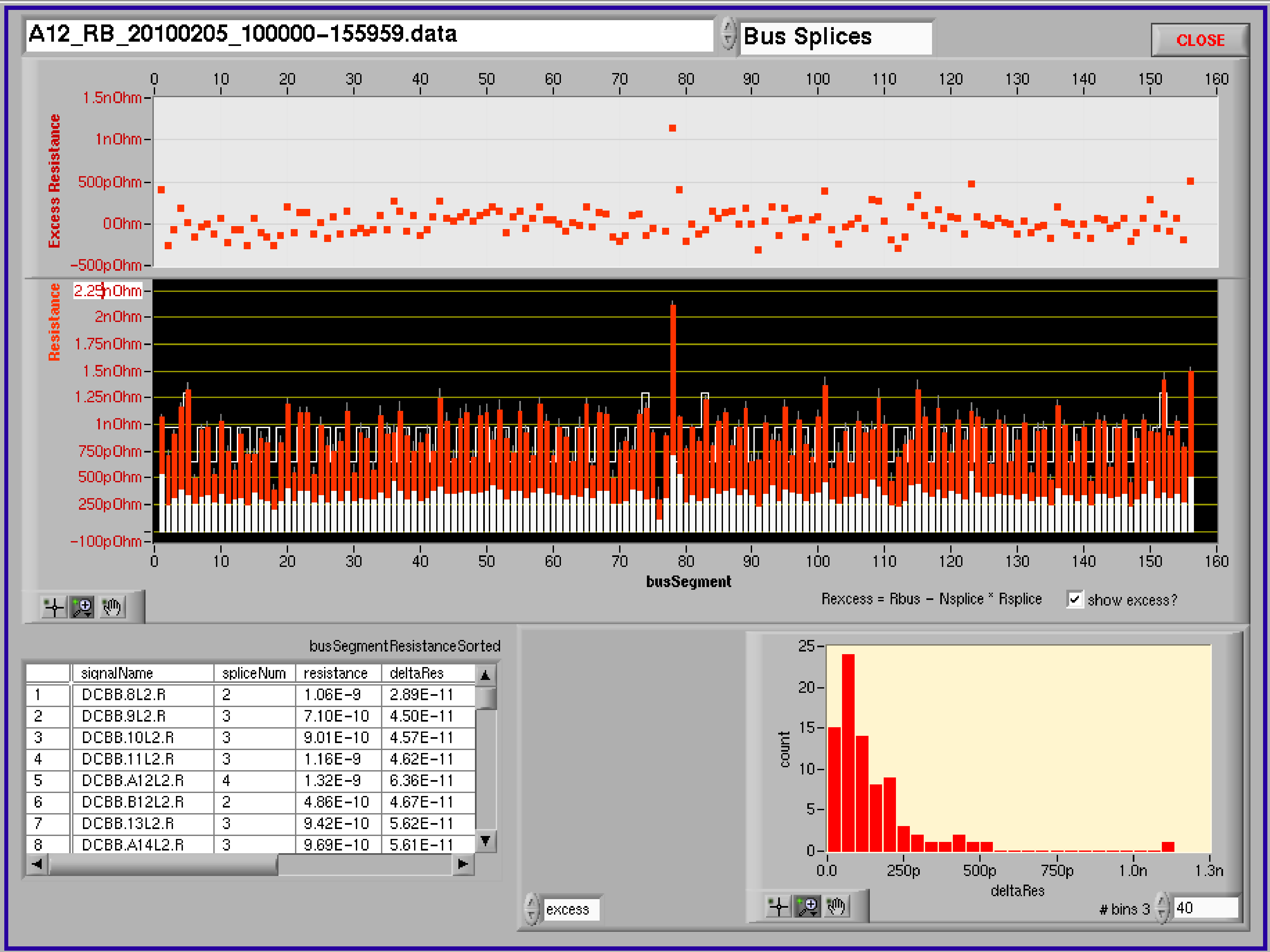


busSegmentResistanceSorted

	signalName	spliceNum	resistance	deltaRes
1	DCQDQ.12L2.R	18	5.57E-9	2.76E-10
2	DCQFQ.12L2.L	18	6.31E-9	2.81E-10
3	DCQDQ.14L2.R	8	2.38E-9	1.76E-10
4	DCQFQ.14L2.L	8	2.49E-9	1.80E-10
5	DCQDQ.16L2.R	8	2.30E-9	1.79E-10
6	DCQFQ.16L2.L	8	2.68E-9	1.89E-10
7	DCQDQ.18L2.R	8	2.84E-9	1.89E-10
8	DCQFQ.18L2.L	8	2.60E-9	1.80E-10

excess





	signalName	spliceNum	resistance	deltaRes
1	DCBB.8L2.R	2	1.06E-9	2.89E-11
2	DCBB.9L2.R	3	7.10E-10	4.50E-11
3	DCBB.10L2.R	3	9.01E-10	4.57E-11
4	DCBB.11L2.R	3	1.16E-9	4.62E-11
5	DCBB.A12L2.R	4	1.32E-9	6.36E-11
6	DCBB.B12L2.R	2	4.86E-10	4.67E-11
7	DCBB.13L2.R	3	9.42E-10	5.62E-11
8	DCBB.A14L2.R	3	9.69E-10	5.61E-11

Outcome of Chamonix 2010

- I will not give a summary of summaries but present selected. There are many more topics which are also very important but not as urgent. All will be followed up in the LMC
  1. Running scenarios for 2010-2011
  2. Upgrade of the Injector Chain
  3. Upgrade of the insertions (IT “phase 1”)
  4. Future Upgrade Plans

Running Scenarios for 2010-2011

Splices and Beam Energy: Statements

- Simulations for safe current used pessimistic input parameters (RRR......) but have no safety margins
- For 2010, 3.5 TeV is still OK
    - **Measure the RRR (asap) to confirm the safety margin for 3.5TeV/beam**
- Without repairing the copper stabilizers, **5 TeV is risky**
- For confident operation at 5TeV we would need
    - Repairs to the "outlier" splices
    - Better knowledge of the input parameters (RRR...)
    - With present input parameters the "limit" splice resistances are **43 μΩ (RB)** and **41 μΩ (RQ)**
      NOTE: these values are close to the limit of the resolution of our measurements made for the RBs at 300K

Splices and Beam Energy: Statements

- For confident operation at 14TeV we need
  - To replace all splices with new clamped shunted ones!

► F. Bertinelli, A. Verweij, P. Fessia (unaminous)

For safe running around 7 TeV/beam, a shunt has to be added on all 13 kA joints, also on those with small R_{addit}. Joints with high R_{addit} or joints with large visual defects should be resoldered and shunted.

A Cu-shunt with high RRR and a cross-section of 16x2 mm^2 is sufficient, if soldered at short distance from the gap. Experimental confirmation by means of a test in FRESCA should be foreseen.

3.5 TeV requirements

circuit	τ [s]	Condition	Max R_{addit} for RRR_{bus}=100	Max R_{addit} for RRR_{bus}=160
RB	50	GHe with t_{prop}=10 s	80	87
		GHe with t_{prop}=20 s	>100	>100
		LHe without He cooling	58	65
		LHe with He cooling	76	83
RQ	10	GHe with t_{prop}=10 s	>150	>150
		GHe with t_{prop}=20 s	>150	>150
		LHe without He cooling	74	80
		LHe with He cooling	80	84

5 TeV requirements

circuit	τ [s]	Condition	Max R_{addit} for RRR_{bus}=100	Max R_{addit} for RRR_{bus}=160
RB	75	GHe with t_{prop}=10 s	34	37
		GHe with t_{prop}=20 s	46	51
		LHe without He cooling	23	28
		LHe with He cooling	43	48
RQ	15	GHe with t_{prop}=10 s	71	75
		GHe with t_{prop}=20 s	>120	>120
		LHe without He cooling	35	40
		LHe with He cooling	41	47

Remark: better knowledge of RRR_{bus} may give another 10 μΩ margin.

13 kA requirements

circuit	τ [s]	Condition	Max R_{addit} for RRR_{bus}=100	Max R_{addit} for RRR_{bus}=160
RB	100	GHe with t_{prop}=10 s	**11**	12
		GHe with t_{prop}=20 s	13	14
		LHe without He cooling	8	9
		LHe with He cooling	15	21
RQ	20	GHe with t_{prop}=10 s	18	22
		GHe with t_{prop}=20 s	[illegible]	[illegible]
		LHe without He cooling	13	14
		LHe with He cooling	15	17

Conclusion: $R_{addit,RB}$<11 μΩ and $R_{addit,RQ}$<15 μΩ are required for operation around 7 TeV.

Better knowledge of RRR_{bus} will hardly increase these numbers

Two Possible Scenarios 2010-2011

1. Run at 3.5 TeV/beam up to a predefined integrated luminosity with a date limit. Then consolidate the whole machine for 7TeV/beam.
    - Need to determine the needs for the shutdown (resources, coactivity etc)

2. Run until second half 2010 then do minimum repair on splices to allow 5TeV/beam in 2011 (7TeV/beam comes much later)
    - ? Do DN200s at same time
    - ? Will we need to **warm** all sectors in order to re-measure (looks like yes to 7 RB octants from Mike's results, and 8 RQ)
    - ? How many splices will we need to repair to reach the "limit" copper stabilizer resistances (what about the RQs?)

Circuit/ Sector	Temperature spread (K)	Excess resistance spread	Highest remaining excess resistance	Excess resistance limit 90%CL
A12 RB	1.1	13	37	51
A34 RB	1.9	10	35	47
A45 RB	0.9	17	53	78
A56 RB	0.4	9	20	34
A67 RB	0.6	14	31	48

Comparison of Scenarios

- Scenario 1 (Minimum Risk)
  - Probably the more efficient over the LHC lifetime
    - **+ ALARA**
    - **determine the needs for the shutdown (resources, coactivity etc)**
    - **Re-design/testing of the splices; timing is "reasonable"**
- Scenario 2 (Higher Risk)
  - Reduced running in 2010, long shutdown 2010-2011, delays operation at the highest energy
    - **-- ALARA**
    - **-- Urgently needs a more accurate measurement of warm resistance (thermal amplifier) which has not yet been developed**
    - **? -- May need nearly as much shutdown time as scenario 1 and the repair is only good for 5TeV/beam**

What to do if we have an unforeseen stop e.g. S34 vacuum?

Upgrades: Foreword

New Studies have been launched about one year ago and are ongoing

- Performance Aim
  - To maximize the useful integrated luminosity over the lifetime of the LHC
- Targets set by the detectors are:

  3000fb^{-1} (on tape) by the end of the life of the LHC

  → 250-300fb^{-1} per year in the second decade of running the LHC
- Goals
  - Check the performance of the presently considered upgrades
  - Check their coherence wrt
    - » accelerator performance limitations,
    - » Detector needs,
    - » manpower resources,
    - » shutdown planning including detectors

Injector Upgrades

- Present Peak Performance Situation

Intensity Limitations (10^{11} protons per bunch)		
	Present	
Linac2/LINAC4	4.0	
PSB or SPL	3.6	
PS or PS2	1.7	
SPS	~1.2	
LHC	1.7-2.3?	

Conclusion 1: SPS is the bottleneck!

SPS Bottleneck

- Other injectors are limited by a fundamental limitation, the space charge effect (ΔQ_{sc} = 0.3)
- In the SPS at injection: ΔQ_{sc} = 0.07! (no fundamental limitation)
- Actual Intensity Limitation in SPS (mitigaton)
  - Electron cloud (vacuum chamber coating)
  - Transverse Mode Coupling Instability (Impedance reduction and/or transverse feedback)
  - RF effects such as beam loading etc (redesign of existing RF or build new system)

Immediately after Chamonix a task force has been set up to investigate the removal of this SPS bottleneck (led by Volker Mertens)

Injectors Performance (Availability)

- From the LINAC2 to the SPS we have ageing machines
  - We need consolidation or replacement
- Proposed scenario (White Paper, 2006) is to replace LINAC2, PSB and PS
  - LINAC4, SPL, and PS2
- Recent study shows time scale for operation of the PS2 is at earliest 2020 and likely 2022.
  - Conclusion 2: We need to aggressively consolidate the existing injector chain to allow reliable operation of the LHC until at least 2022.
  - Task force set up late last year. (Simon Baird)
- BUT: Resources needed for the consolidation of the existing injectors are in direct competition with those needed for the construction of SPL/PS2
- Question: What would be the LHC performance implications of not constructing SPL/PS2??

Summary of Intensity Limits

Intensity Limitations (10^{11} protons per bunch)			
	Present	SPL-PS2	
Linac2/LINAC4	4.0	4.0	
PSB or SPL	3.6	4.0	
PS or PS2	1.7	4.0	
SPS	1.2	>1.7?	
LHC	1.7-2.3?	1.7-2.3?	

It would be wonderful to be able to afford these additional margins and flexibility! Also an asset to CERN for future high intensity proton project proposals

Performance Limitations without SPL/PS2

- Alternative scenario to SPL/PS2
  - Consolidate existing injectors for the life of the LHC (2030)
  - During the same consolidation, improve the performance of PSB/PS as injectors for the LHC
- New "Idea"(Preliminary and needs to be verified)
  - Increase the extraction energy of the PSB which would allow an increase of the injection energy of the PS.
  - 2GeV injection energy in the PS allows ~$3x10^{11}$ ppb with the same space charge tune shift (preliminary study presented in Chamonix)

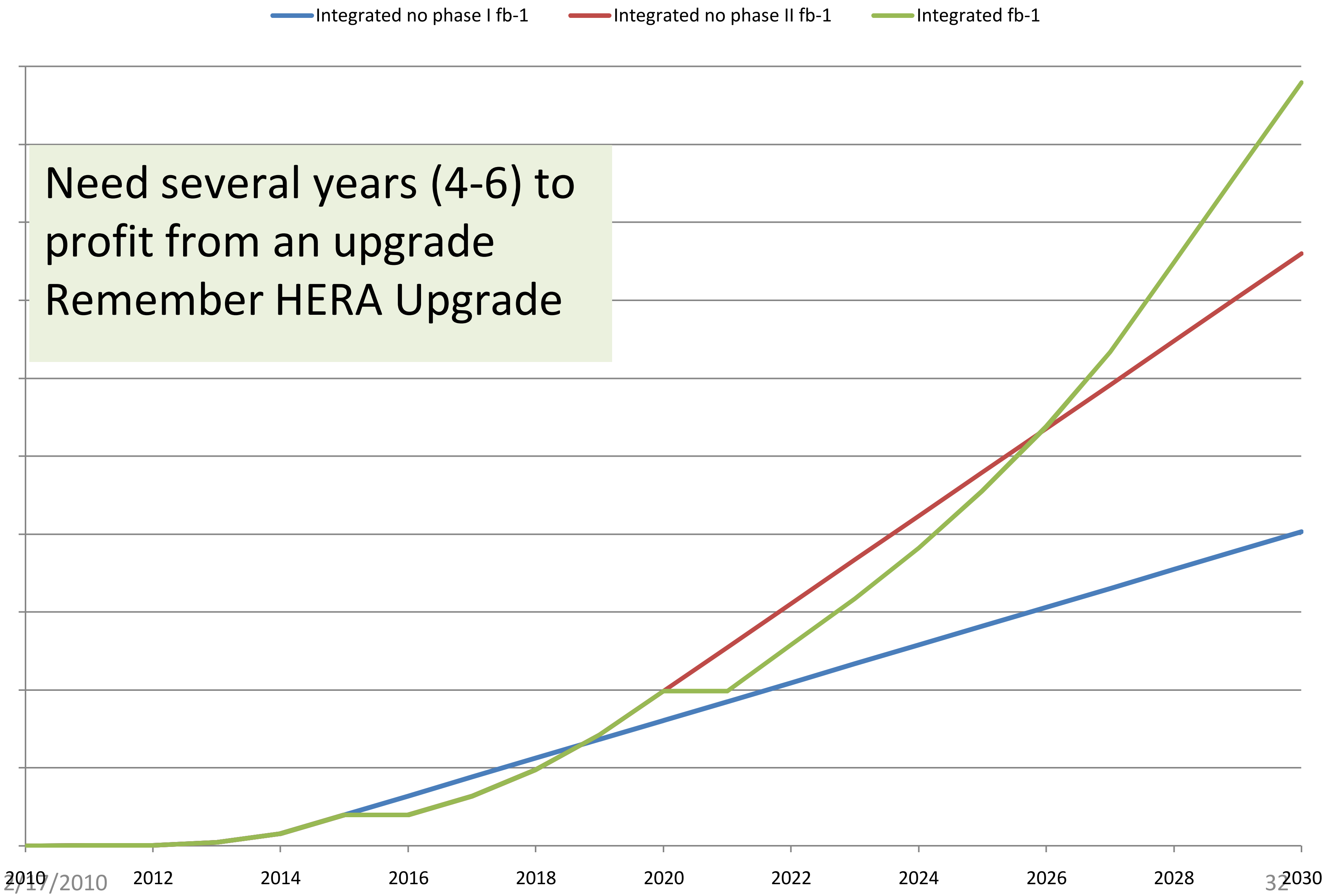
"Project" set up immediately after Chamonix

Intensity Limits

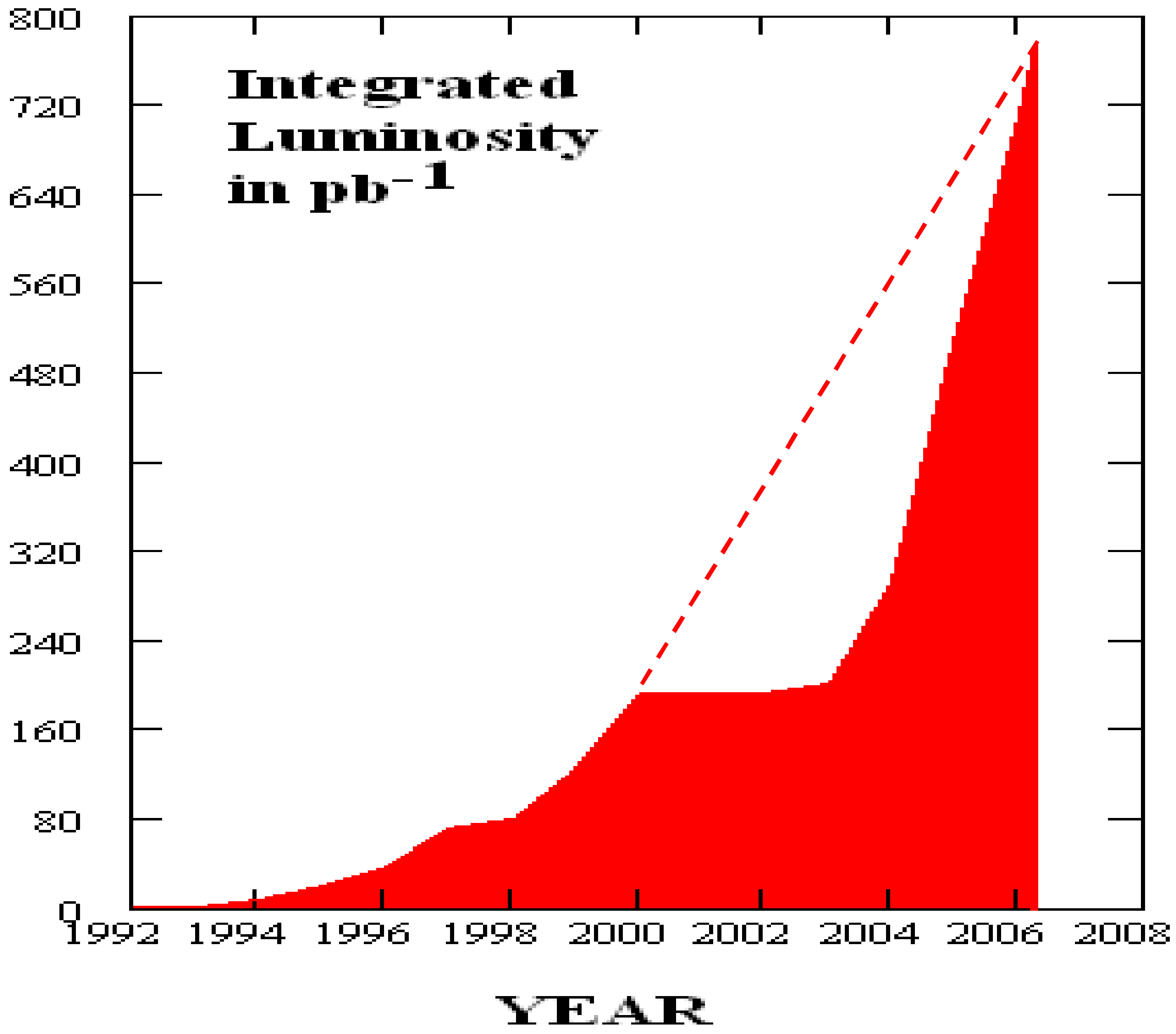
Intensity Limitations (10^{11} protons per bunch)

	Present	SPL-PS2	2GeV in PS
Linac2/LINAC4	4.0	4.0	4.0
PSB or SPL	3.6	4.0	3.6
PS or PS2	1.7	4.0	3.0
SPS	1.2	>1.7?	>1.7?
LHC	1.7-2.3?	1.7-2.3?	1.7-2.3?

IR/Optics Upgrade or not



HERA II



Integrated Luminosity in pb^{-1}
800
720
640
560
480
400
320
240
160
80
0
1992
1994
1996
1998
2000
2002
2004
2006
2008
YEAR

Insertion Upgrade Plans

- IT Upgrade "phase 1"
  - Goal: reliable operation at $2x10^{34}cm^{-2}s^{-1}$, intensity < ultimate and > nominal

Very similar to "ultimate"

Same resources are needed for splice consolidation!

Tough Questions:

1. Will the phase 1 upgrade produce an increase in useful integrated luminosity?
   - Installation time and recomissioning a new machine afterwards
2. Do we have the resources to complete on a time scale which is reasonable with respect to phase 2?

Task force set up immediately after Chamonix (Lucio Rossi) 4-5 weeks to answer above questions

Future Upgrade Scenarios "Phase 2"

- Luminosity Optimization and Levelling
  - For LHC high luminosities, the luminosity lifetime becomes comparable with the turn round time.. Low efficiency
  - Preliminary estimates show that the useful integrated luminosity is greater with
    - a peak luminosity of 5×10^{34} cm^{-2} s^{-1} and luminosity levelling
    - than with 10^{35} and a luminosity lifetime of a few hours
  - Luminosity Levelling by
    - Beta*, crossing angle, crab cavities, and bunch length

Detector people have also said that their detector upgrade would be much more complicated and expensive for a peak luminosity of 10^{35} due to

- Pile up events
- Radiation effects

Some additional Remarks

- Cryo Collimation scheme
- Radiation to Electronics

- We also need to study
  - How to give LHCb $5x10^{33}cm^{-2}s^{-1}$
  - Higher luminosity with lead collisions (ALICE)

Conclusions

- The Luminosity Targets set by the detectors are:
    - 3000fb^{-1} (on tape) by the end of the life of the LHC
    - → 250-300fb^{-1} per year in the second decade of running the LHC
- The Upgrades needed to attack these goals are

1. SPS performance improvements to remove the bottleneck
2. Aggressive consolidation of the existing injector chain for availability reasons
3. Performance improvement of the injector chain to allow phase 2 luminosities
4. a newly defined sLHC which involves
    - At least one major upgrade of the high luminosity insertions
    - luminosity levelling at ~5-6x $10^{34}cm^{-2}s^{-1}$ (crab cavities etc…)

Thank you for your attention

Spare Slides

Corrector polarity checks

Beam 1

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

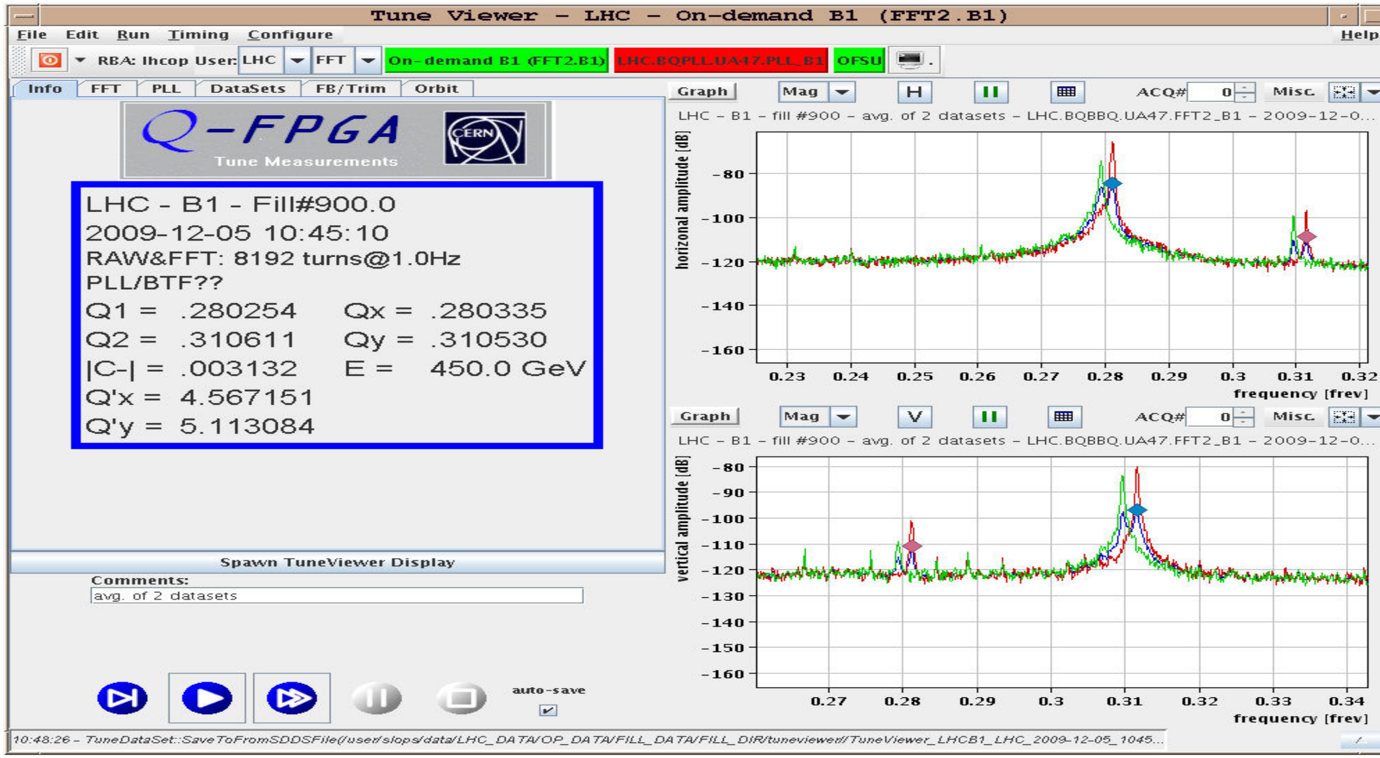
Beam 2:

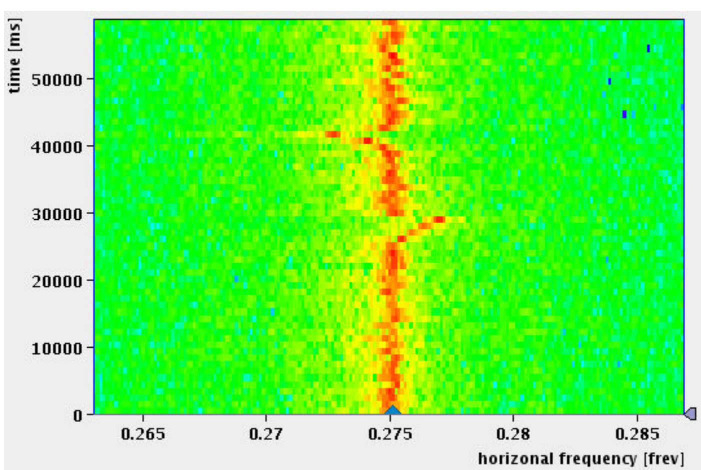
	total	checked	ok	checked ok?	% checked
L1	39	32	32	TRUE	82.05%
R1	38	30	30	TRUE	78.95%
L2	40	31	31	TRUE	77.50%
R2	37	31	31	TRUE	83.78%
L3	31	31	31	TRUE	100.00%
R3	30	29	29	TRUE	96.67%
L4	30	29	29	TRUE	96.67%
R4	29	27	27	TRUE	93.10%
L5	39	32	32	TRUE	82.05%
R5	38	32	32	TRUE	84.21%
L6	29	29	29	TRUE	100.00%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

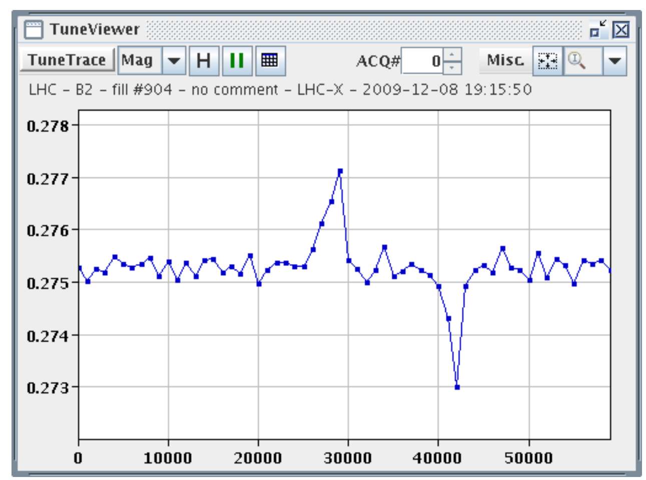
BPM polarity checks

	checked	ok	% ok
Beam 1	1076	1050	**97.58%**
Beam 2	1076	1058	**98.33%**

Q Q' C and Q loop

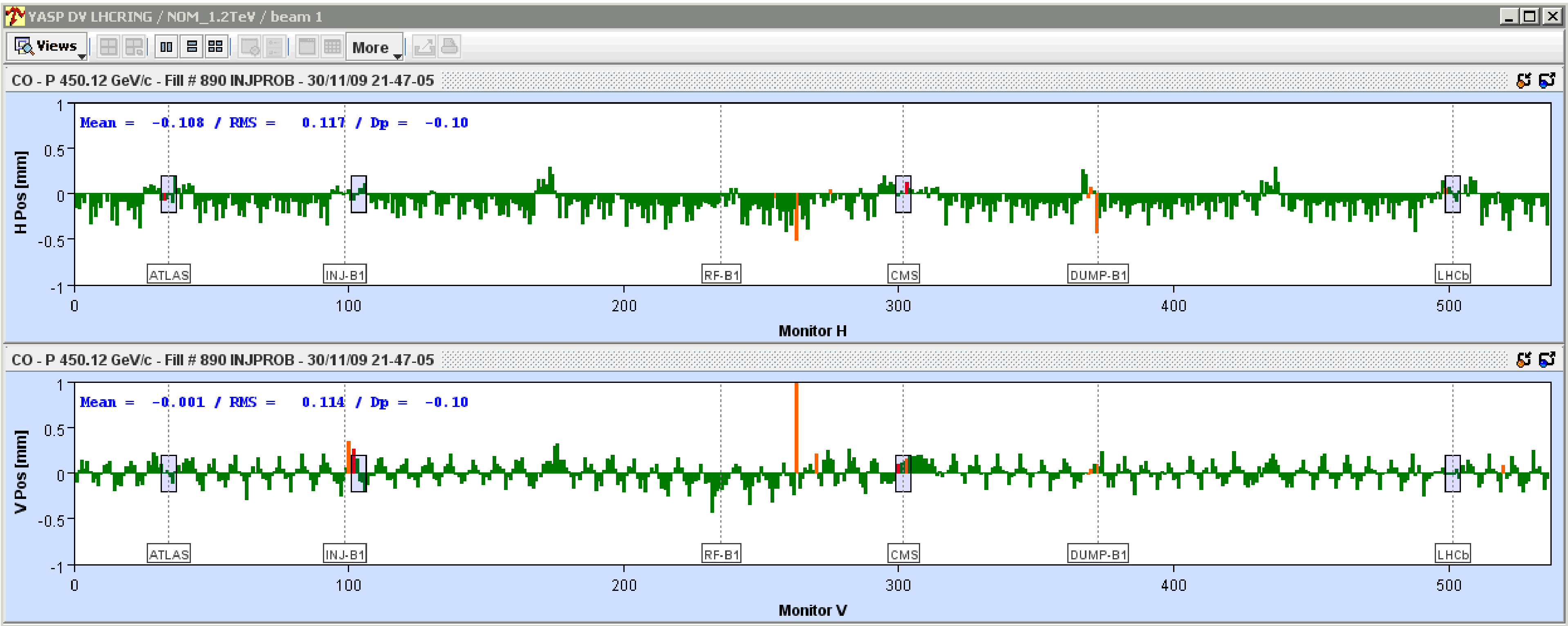






CMS solenoid ramp up

Orbit difference CMS ON – CMS OFF



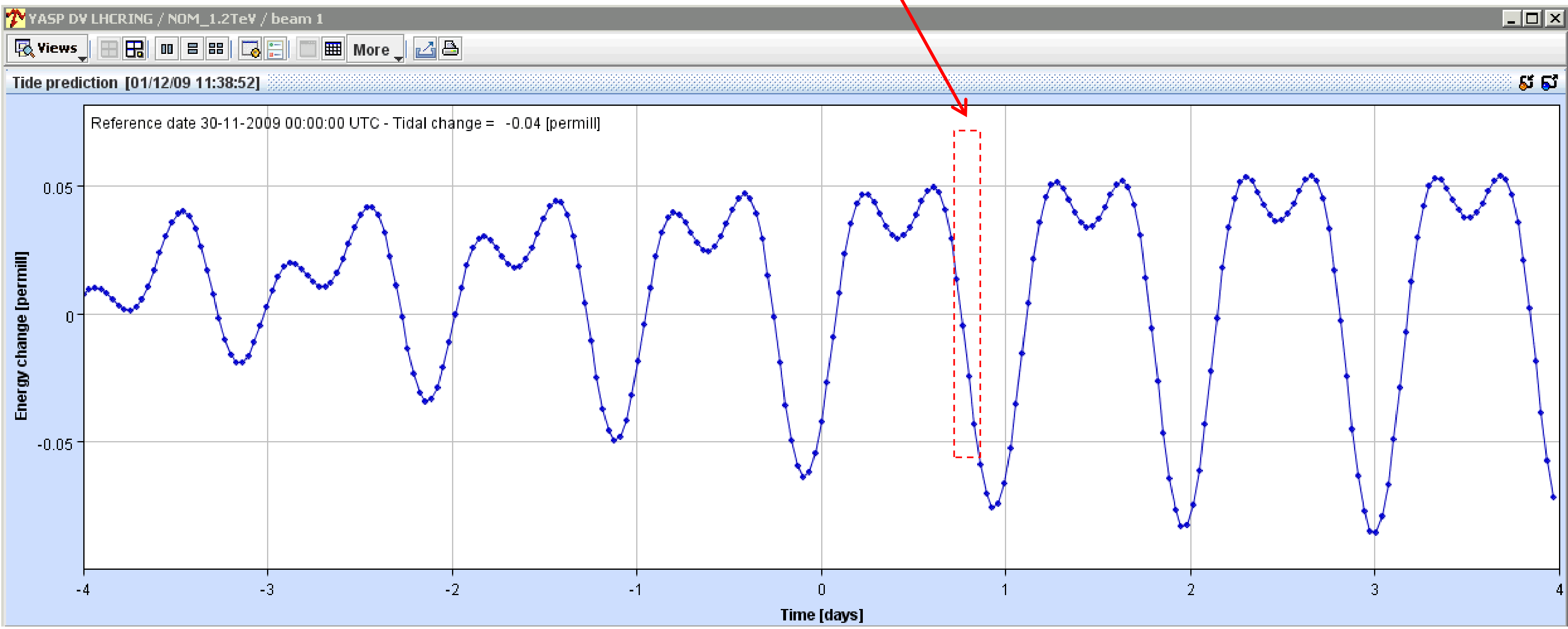
dp/p error change by ~ 0.1 per mill…

?? CMS solenoid changes the beam energy??

Joerg

NO! But Earth tides do!

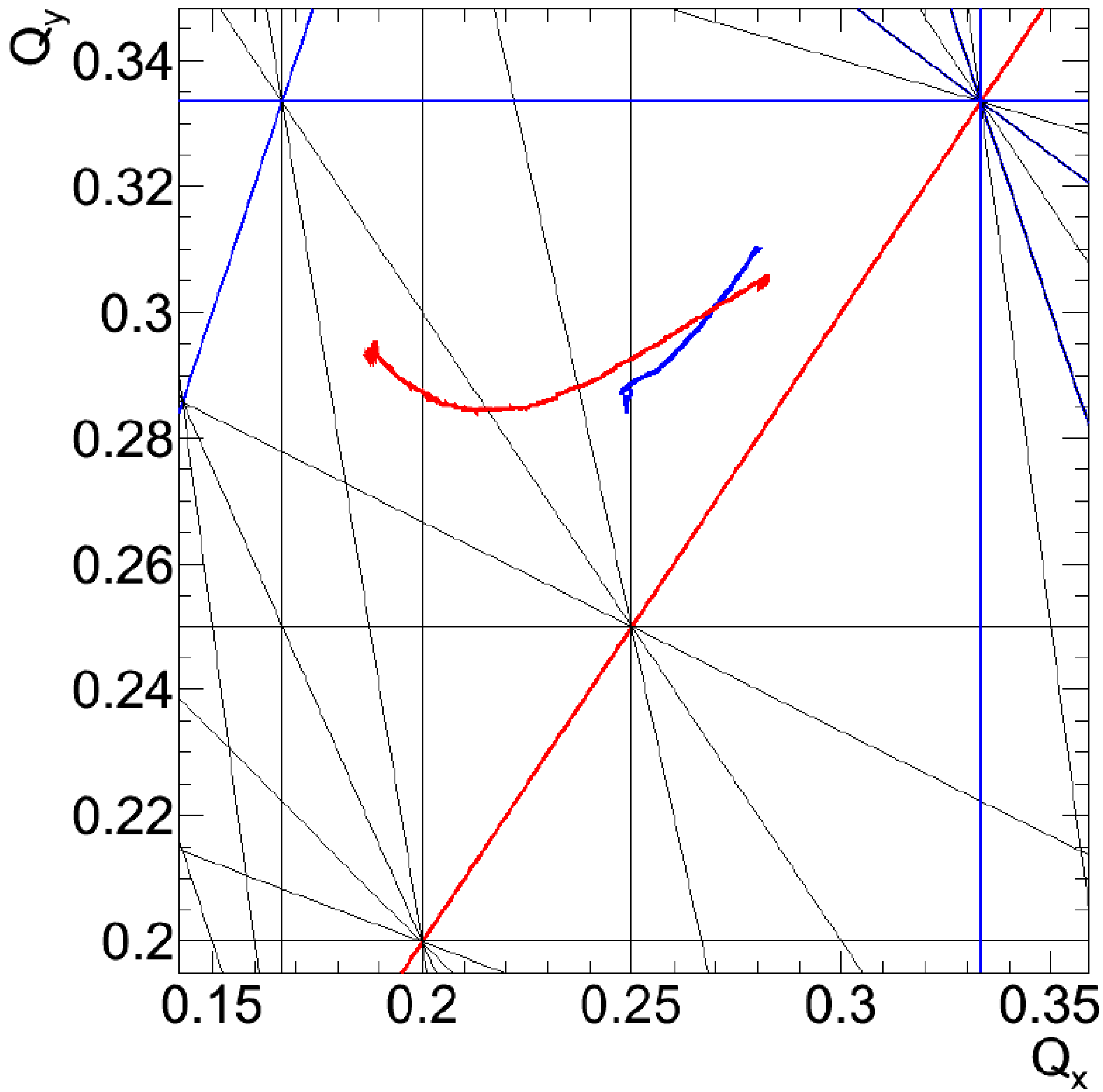
Ramp up coincided with large tidal change – good agreement !
Tidal swing corresponds to ~ 15 Hz.



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

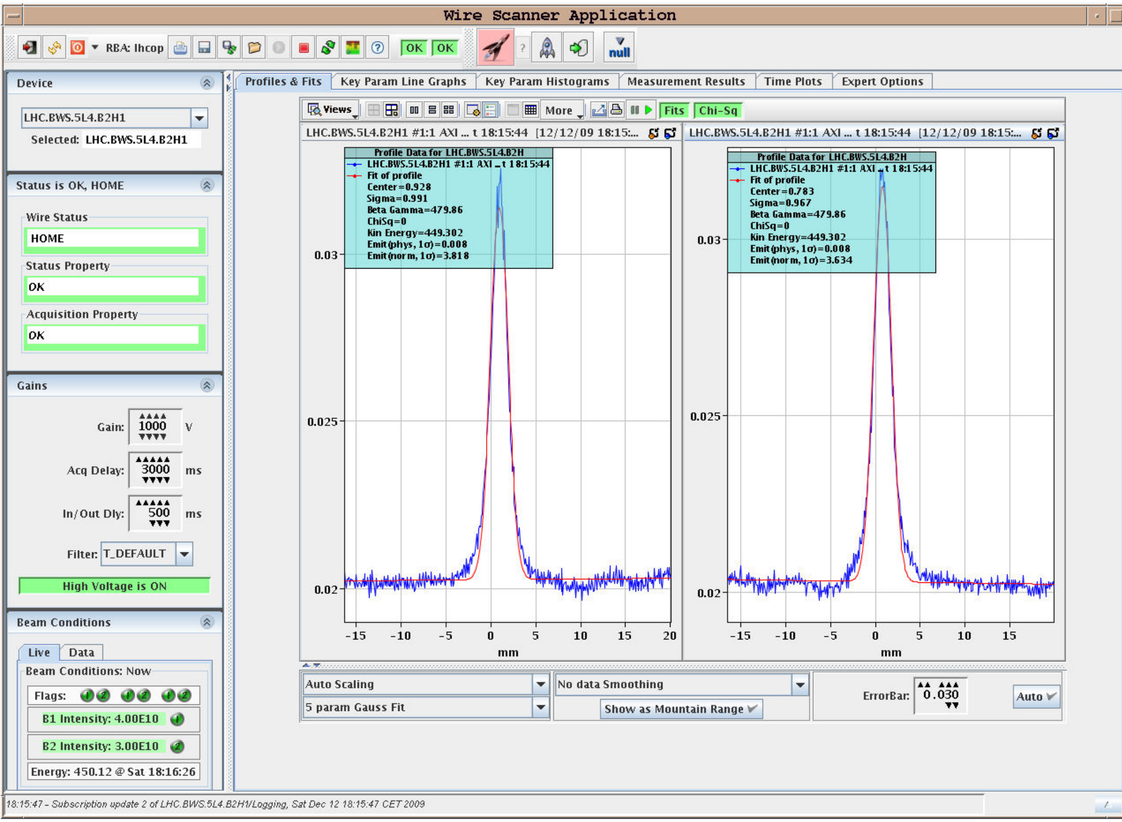
Third Ramp to 1.18 TeV

Tune variations during ramp
Beam 1
Beam 2

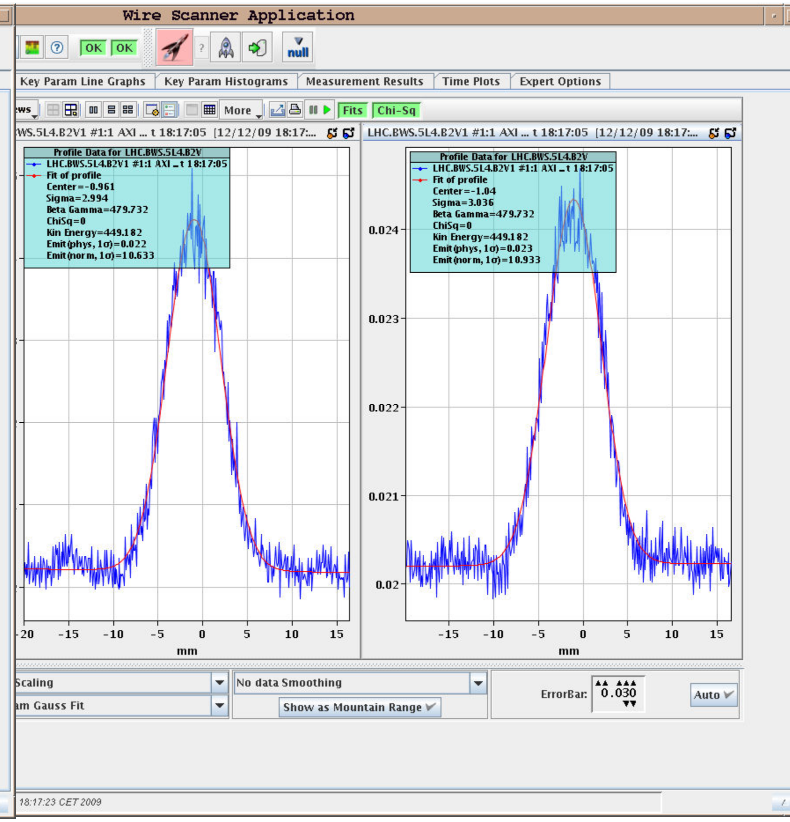


13.12.2009: Wire Scans During STABLE Beams

Beam2 horizontal:



Beam2 vertical

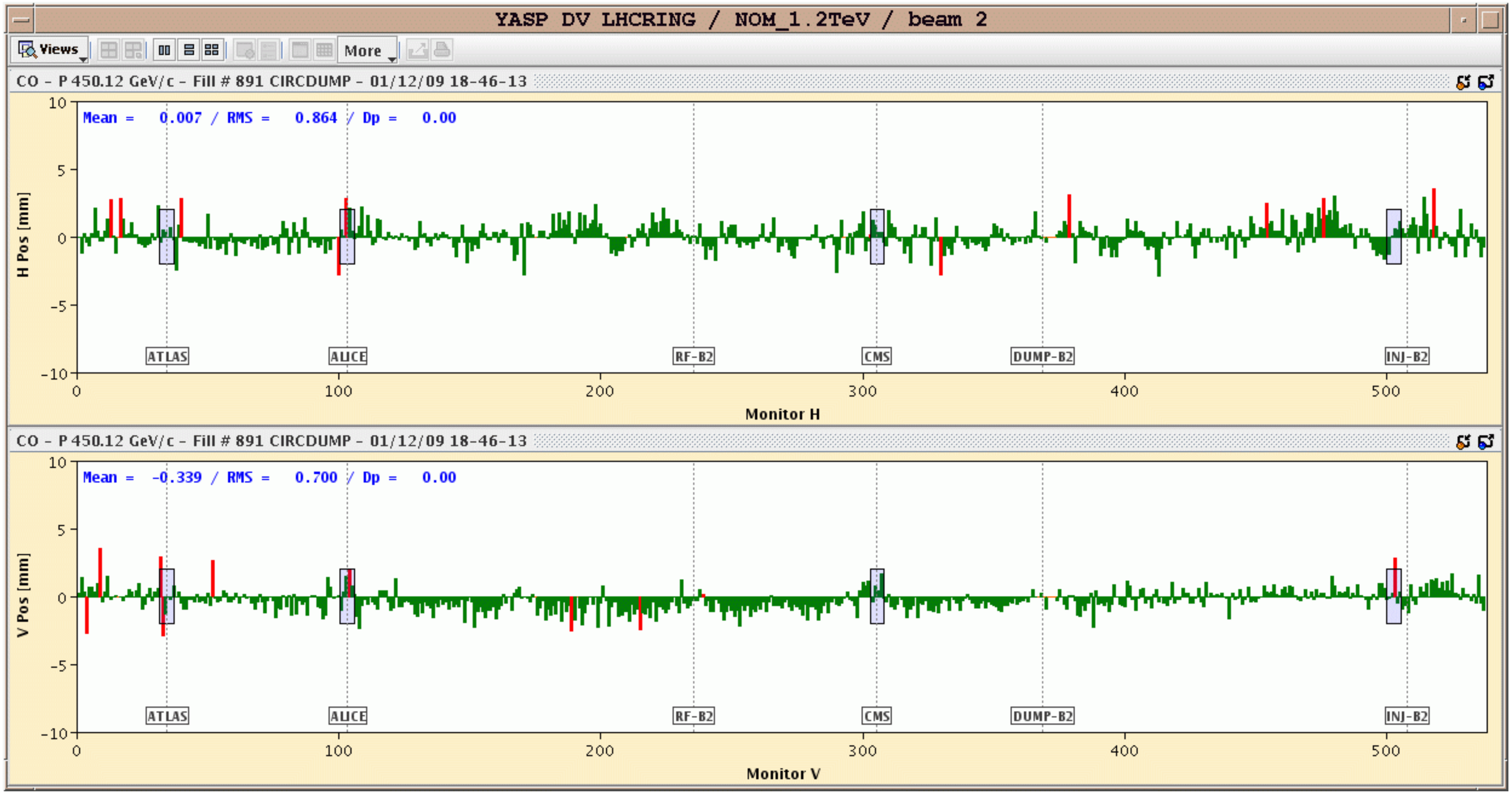


Comparing beam size from wire with synchrotron light monitor

Wire: σ_x = 0.98mm σ_y = 3.0mm

BSRT: σ_x = 1.10mm, σ_y = 2.7mm → ca factor 2 between σ_y and σ_x

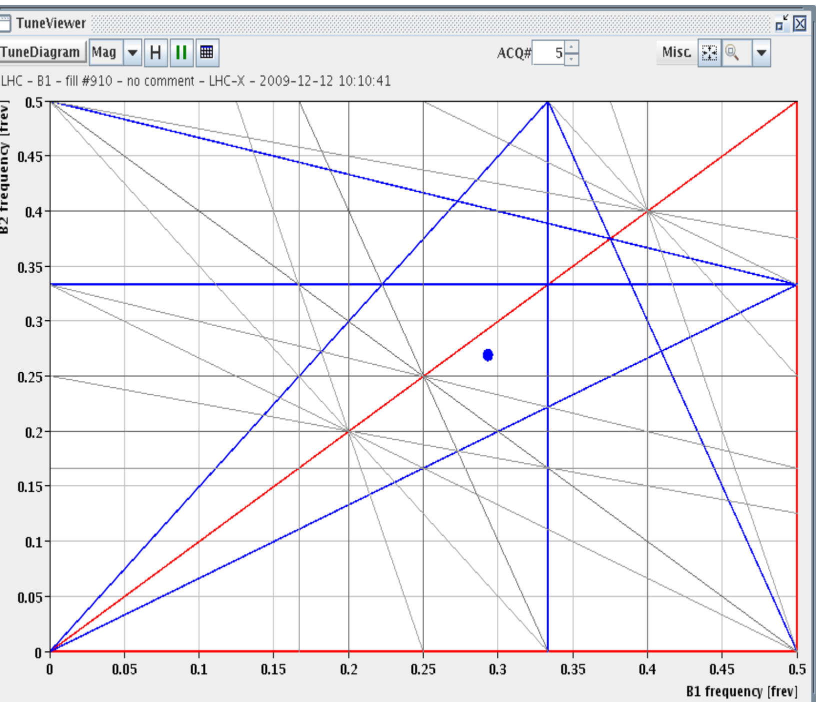
Orbits – golden “Santa Klaus”

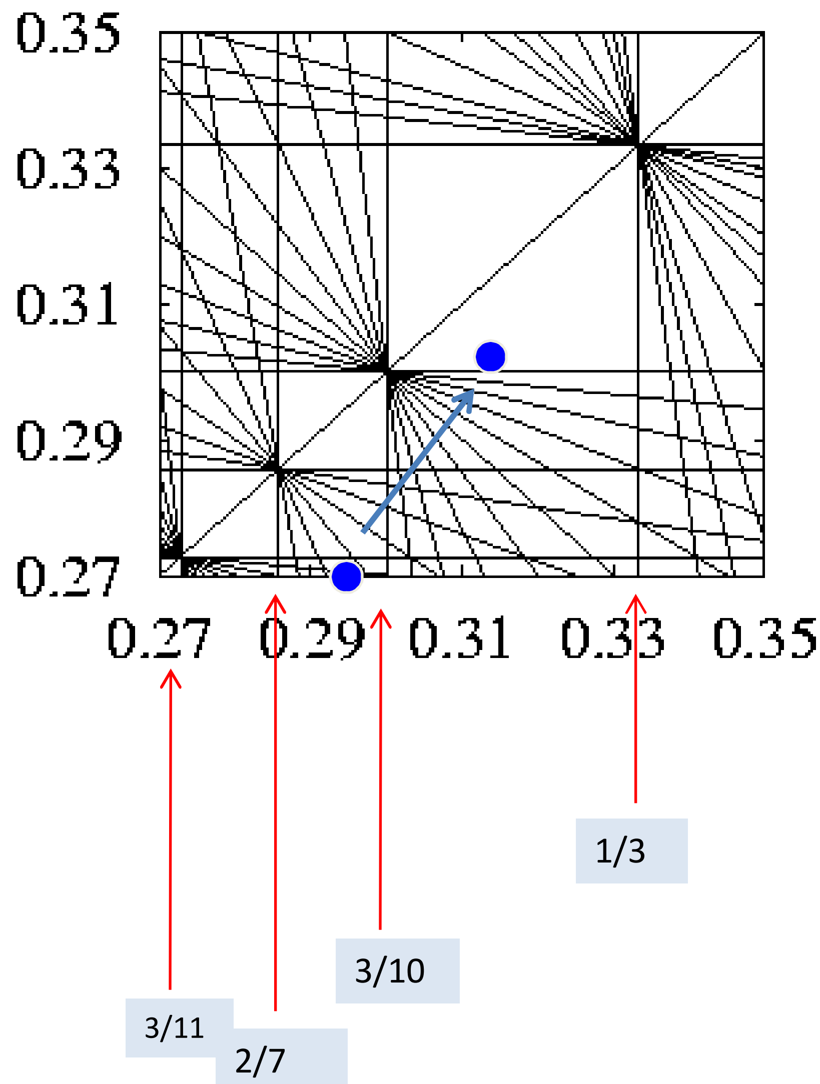


Oliver

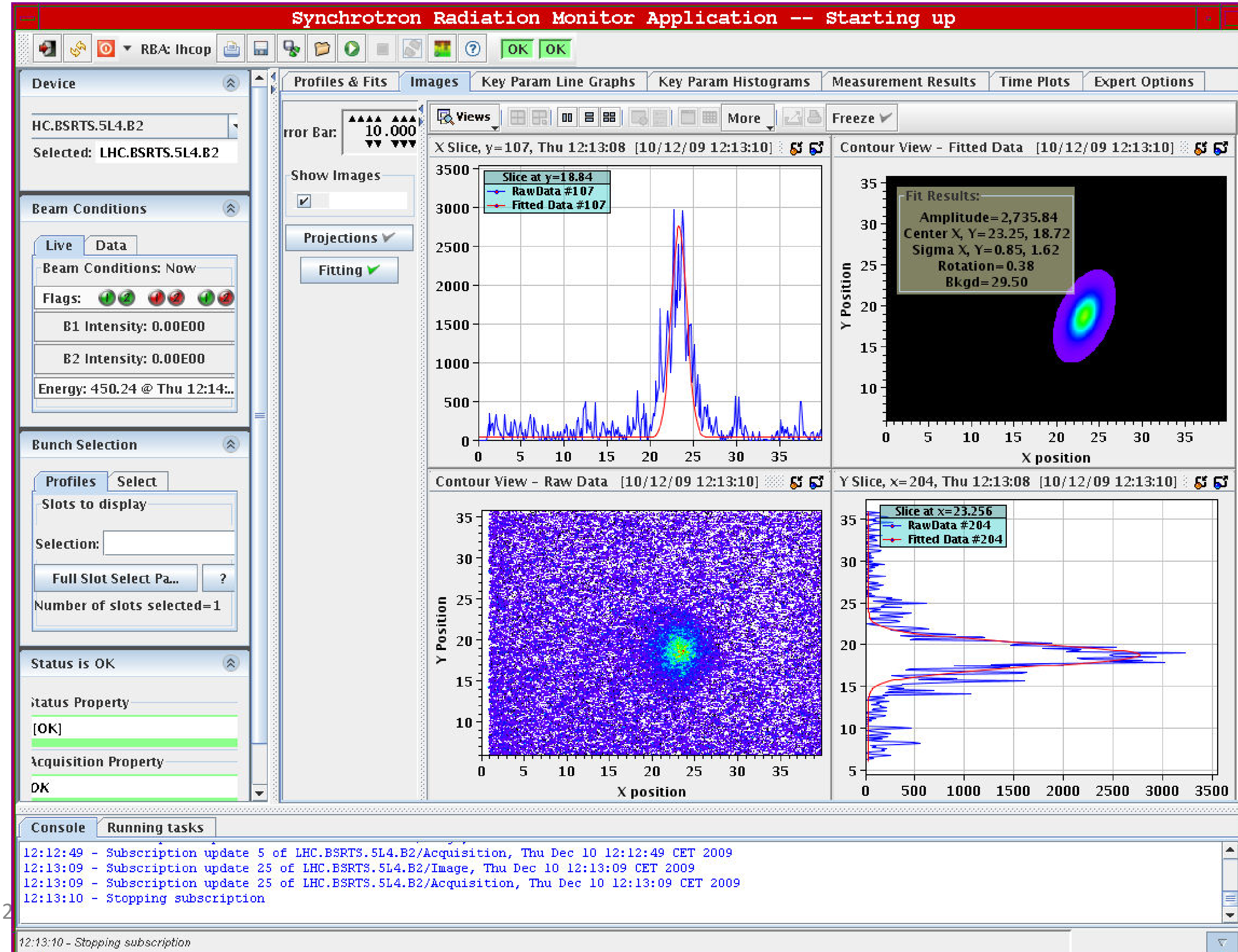
13.12.2009: Tune Adjustments for Beam2

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



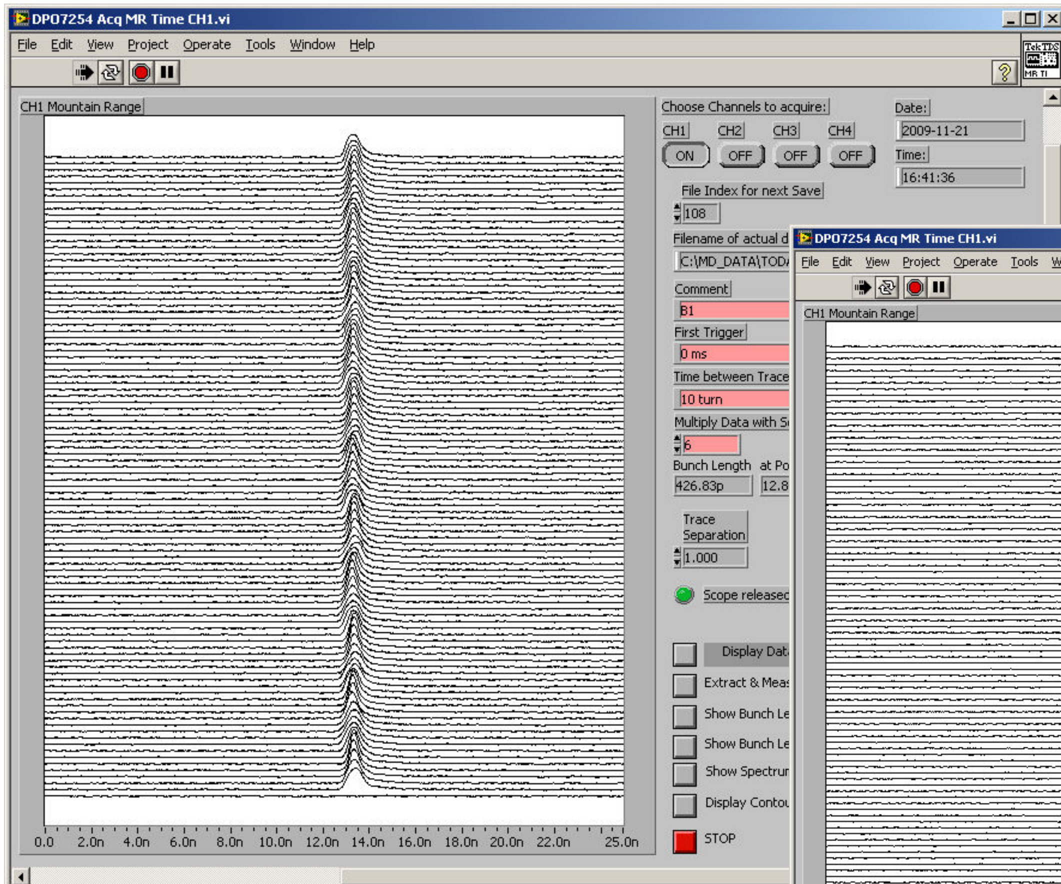


BSRT on beam 2

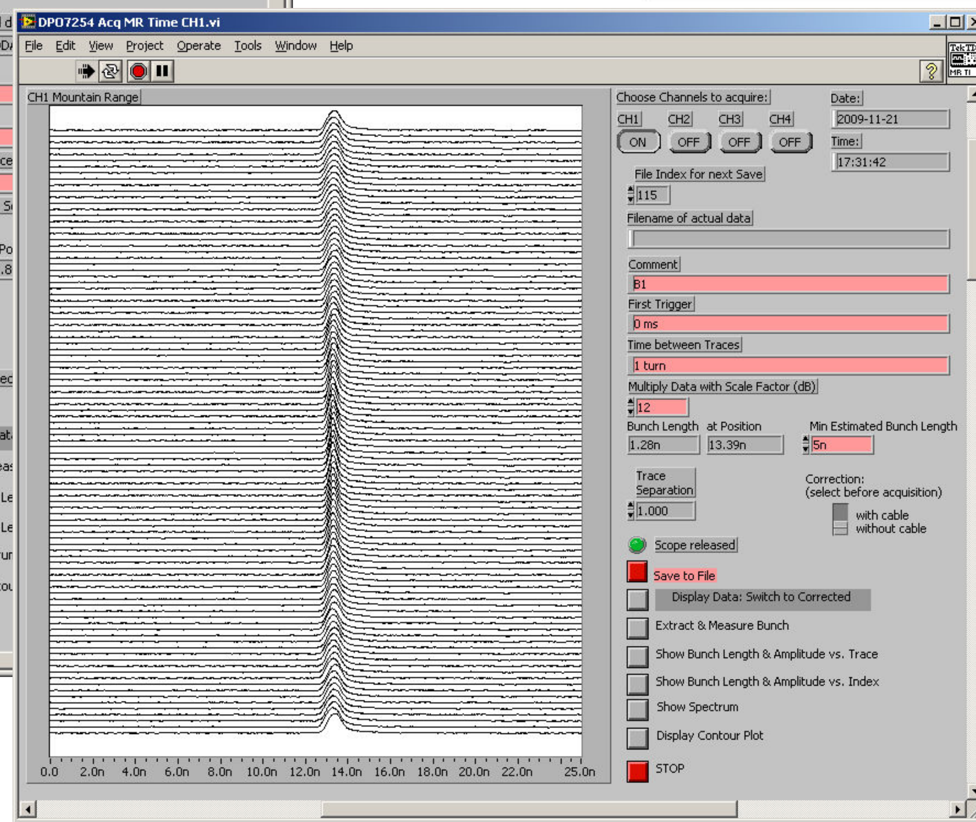


The “RF guys” (Ed and his merry men)

Screens showing two beams in the LHC

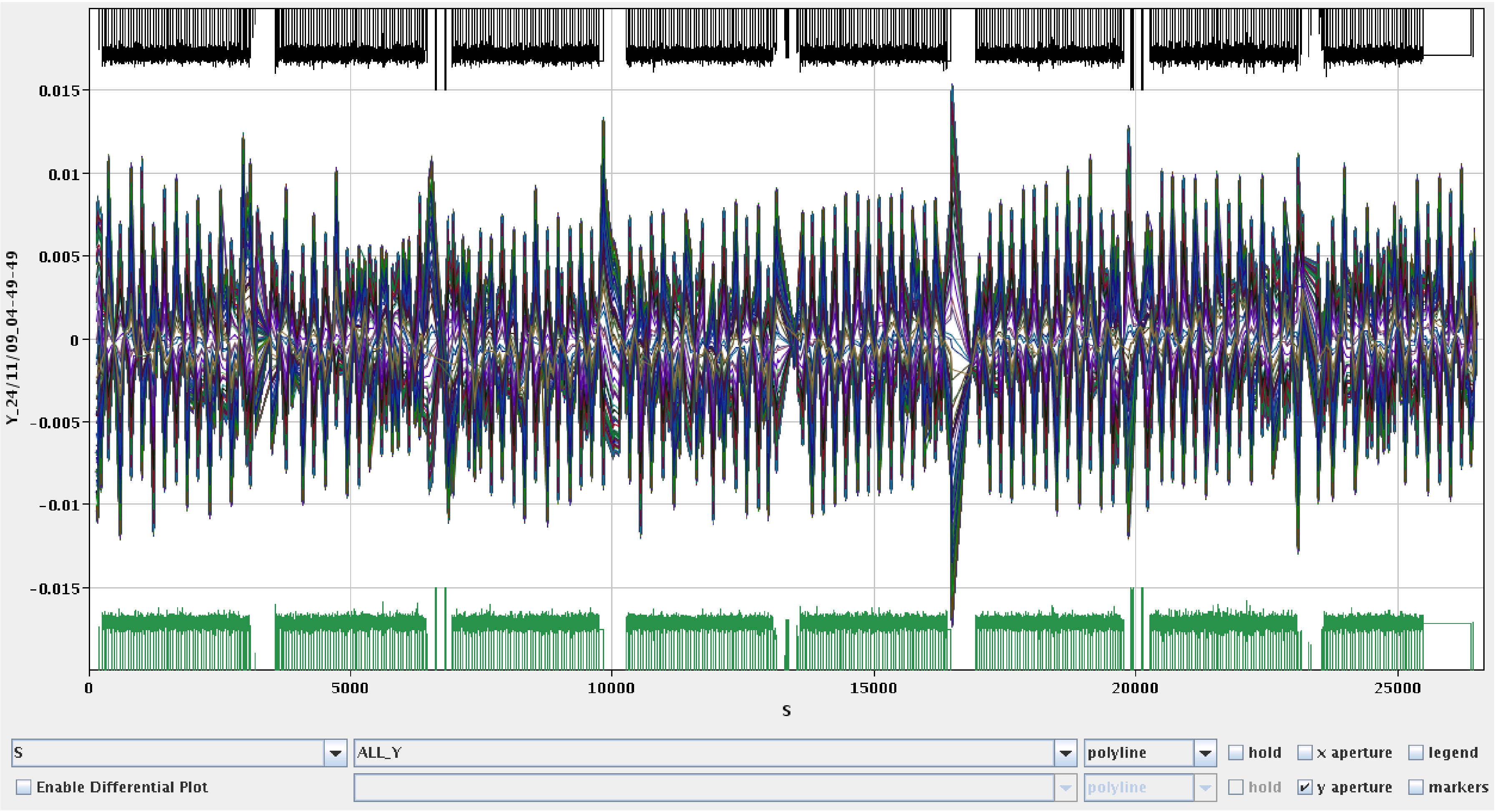


Phase loop Off



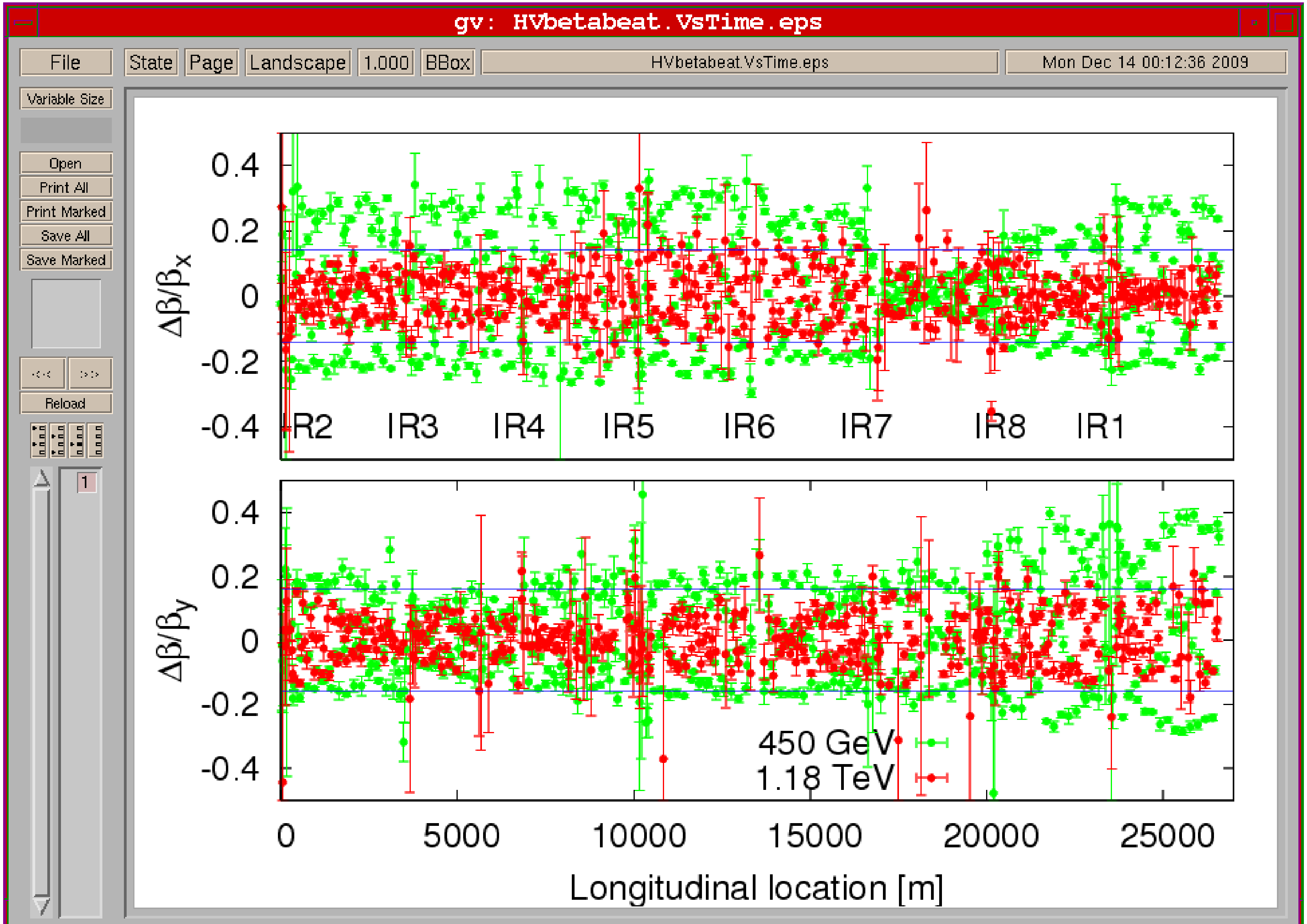
Phase Loop On

Aperture checks with free oscillation

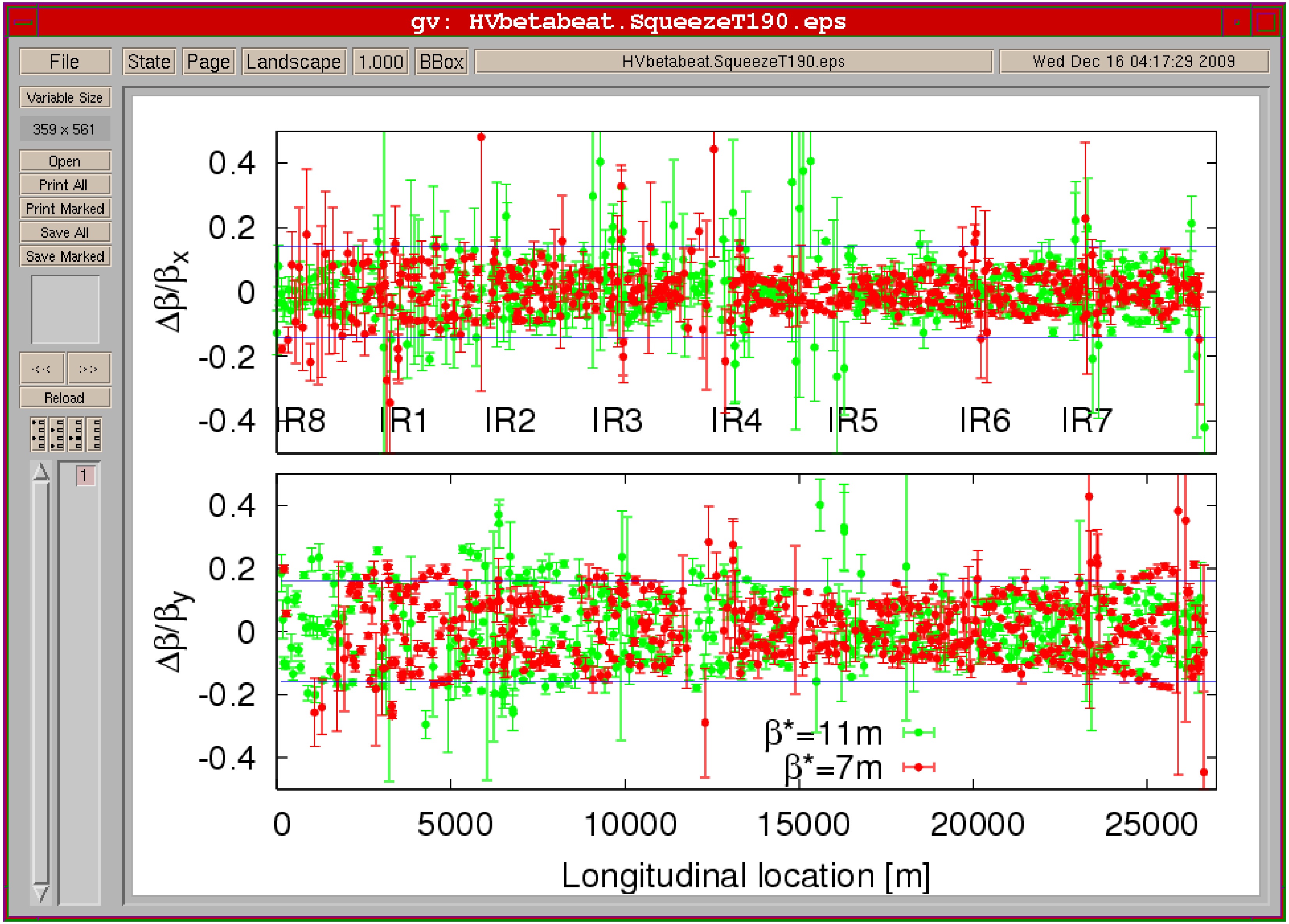


Dispersion…WoW

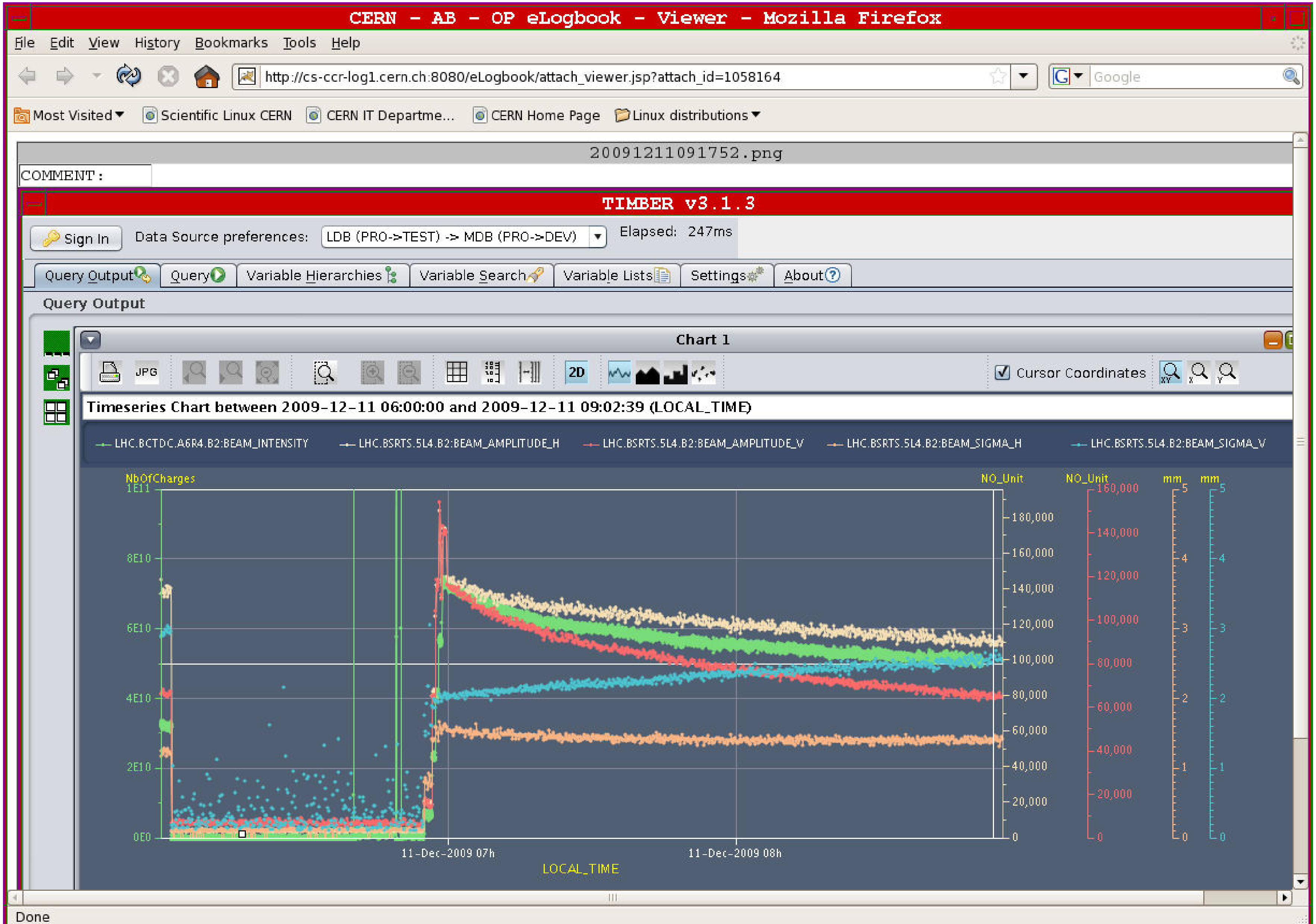
Beta-beat comparison 450 GeV and 1.18 TeV

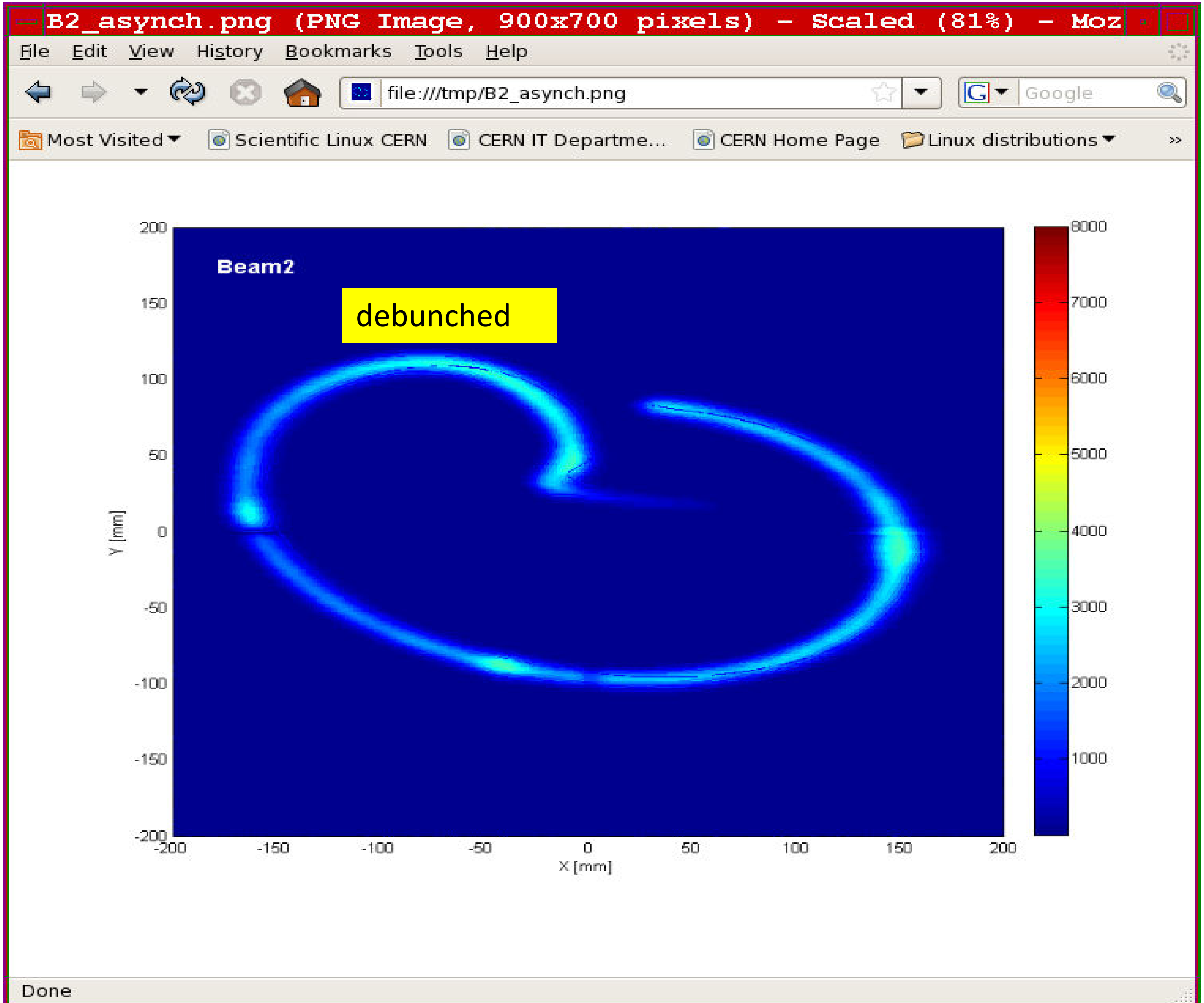


Beta-beat comparison 11m and 7m



Food for thought – V blow up of beam 2




B2_asynch.png (PNG Image, 900x700 pixels) - Scaled (81%) - Moz
File Edit View History Bookmarks Tools Help
file:///tmp/B2_asynch.png
Google
Most Visited
Scientific Linux CERN
CERN IT Departme...
CERN Home Page
Linux distributions
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Done

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!

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
…
…

Mike’s cunning plan

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

Global machine checkout

Essential 450 GeV commissioning ↔ Trial ramps

Machine protection commissioning 1

Experiments’ magnets at 450 GeV

450 GeV collisions

Ramp commissioning to 1.2 TeV

Xmas

All has been accomplished! +

System/beam commissioning | Machine protection commissioning 2

2010

3.5 TeV beam & first collisions

Full machine protection qualification

System/beam commissioning | Pilot physics