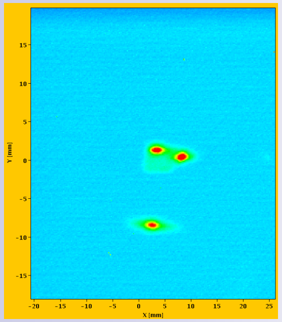
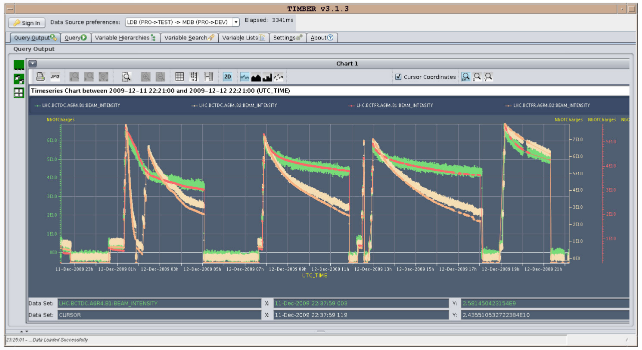
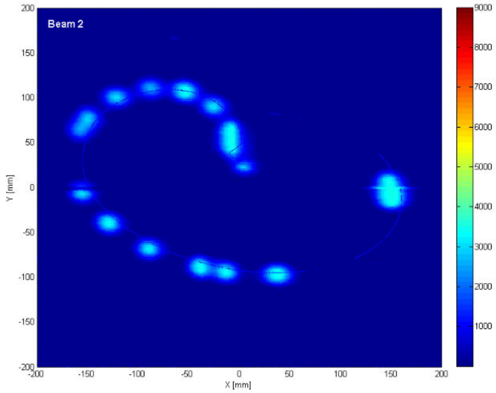
LHC Commissioning 2009

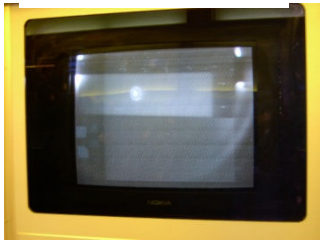




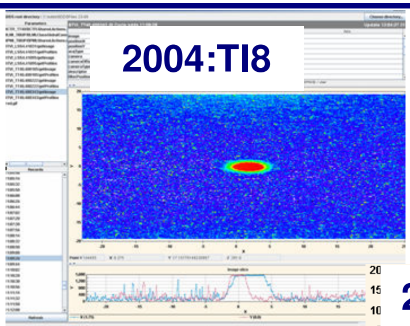


Prep: beam tests through the years

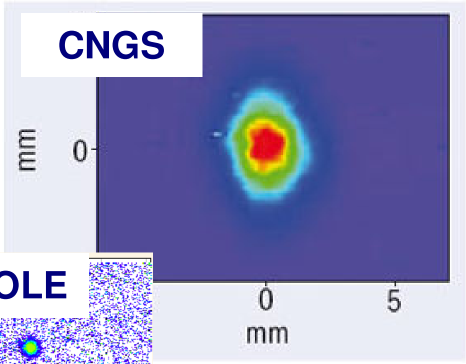
2003:TT40



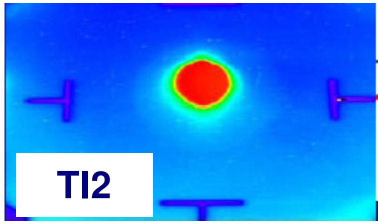
2004:TI8



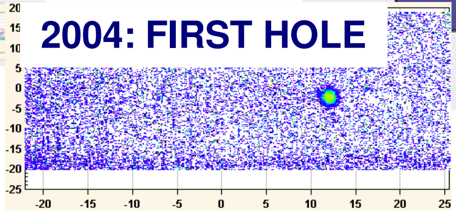
CNGS



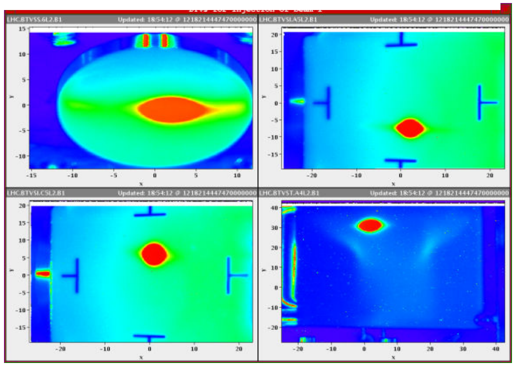
TI2



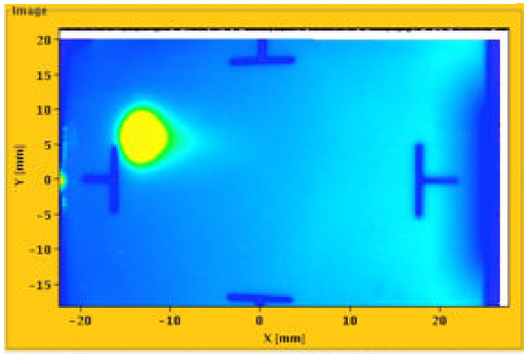
2004: FIRST HOLE



2008: FIRST BEAM TO LHC

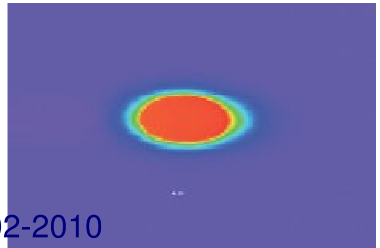


2008: FIRST BEAM TO IR3

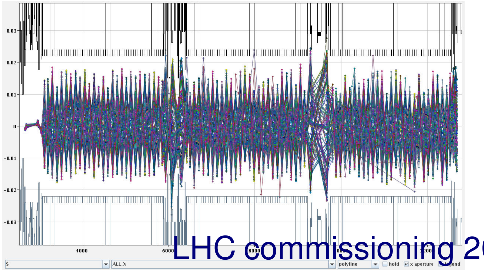


2008: SEPT 10

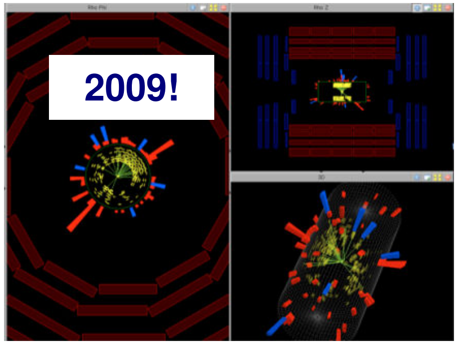
2009: FIRST IONS TO LHC



2009: Sector test

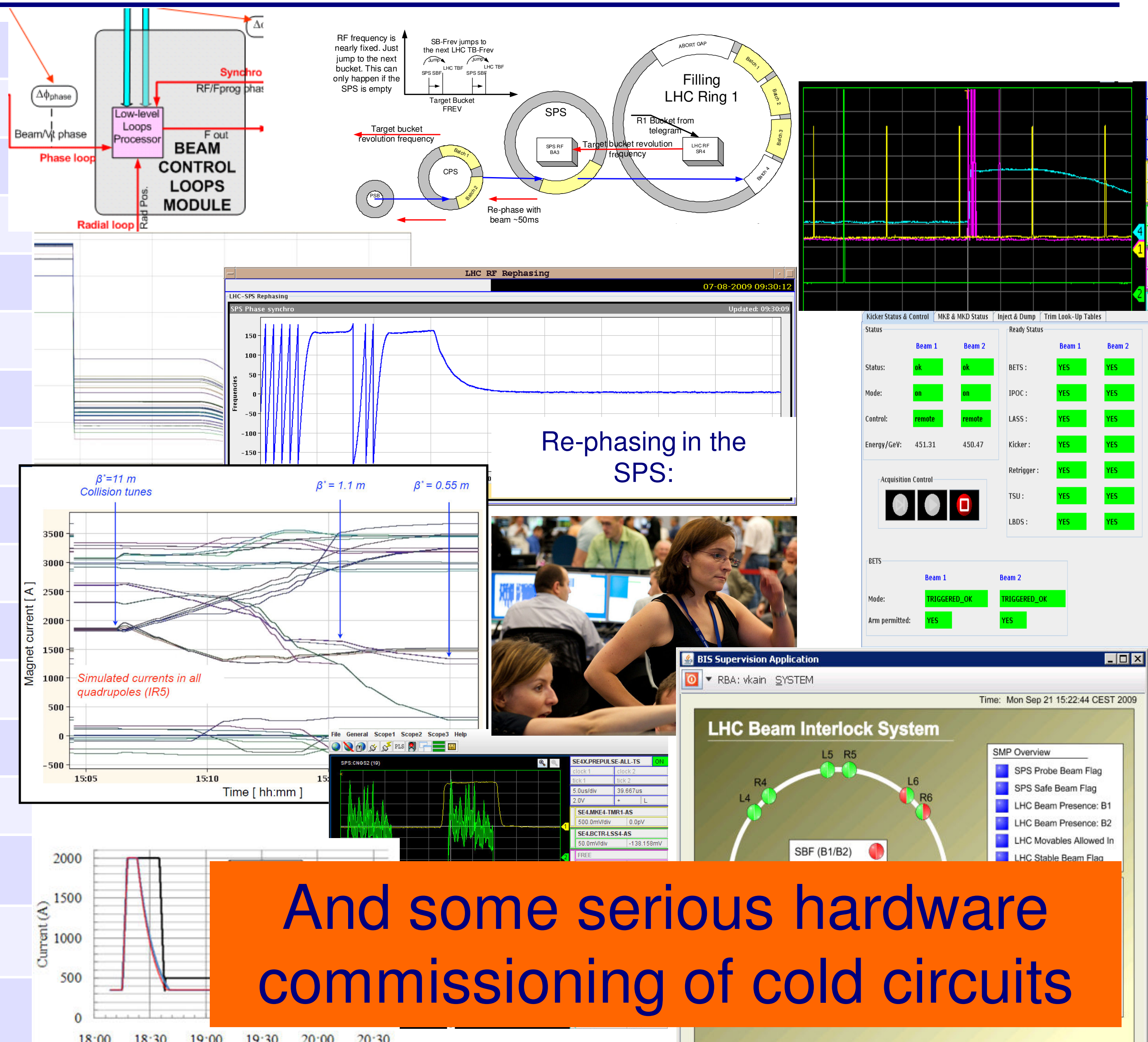


2009!



Prep: dry runs and machine checkout

- **Extraction**
- **Transfer lines**
- **Injection**
- **RF, injection sequence**
- **Timing System**
- **Beam Interlock System**
- **Collimators**
- **Vacuum**
- **Interlocks, SIS**
- **BLMs, BPMs**
- **BTV, BCT**
- **Beam dump**
- **PGCs**
- **Magnet model**
- **Sequencer, alarms**
- **Controls, logging, DBs**
- **LSA, optics model, YASP**



And some serious hardware commissioning of cold circuits

Beam milestones 2009 1/2

20th Nov	injection of both beam – rough RF capture
21st Nov	Beam 1 circulating
22nd Nov	Beam 2 circulating
23rd Nov	First pilot collisions at 450 GeV First trial ramp
26th Nov	Pre-cycle established – excellent reproducibility Energy matching
29th Nov	Ramp to 1.08 TeV and then 1.18 TeV
30th Nov	Solenoids on
1st – 6th Dec	Protection qualified at 450 GeV to allow "stable beams"
6th Dec	Stable beam @ 450 GeV
8th Dec	Ramp 2 beams to 1.18 TeV – first collisions
11th Dec	Stable beam collisions at 450 GeV with high bunch intensities: 4 x 2 10^10 per beam

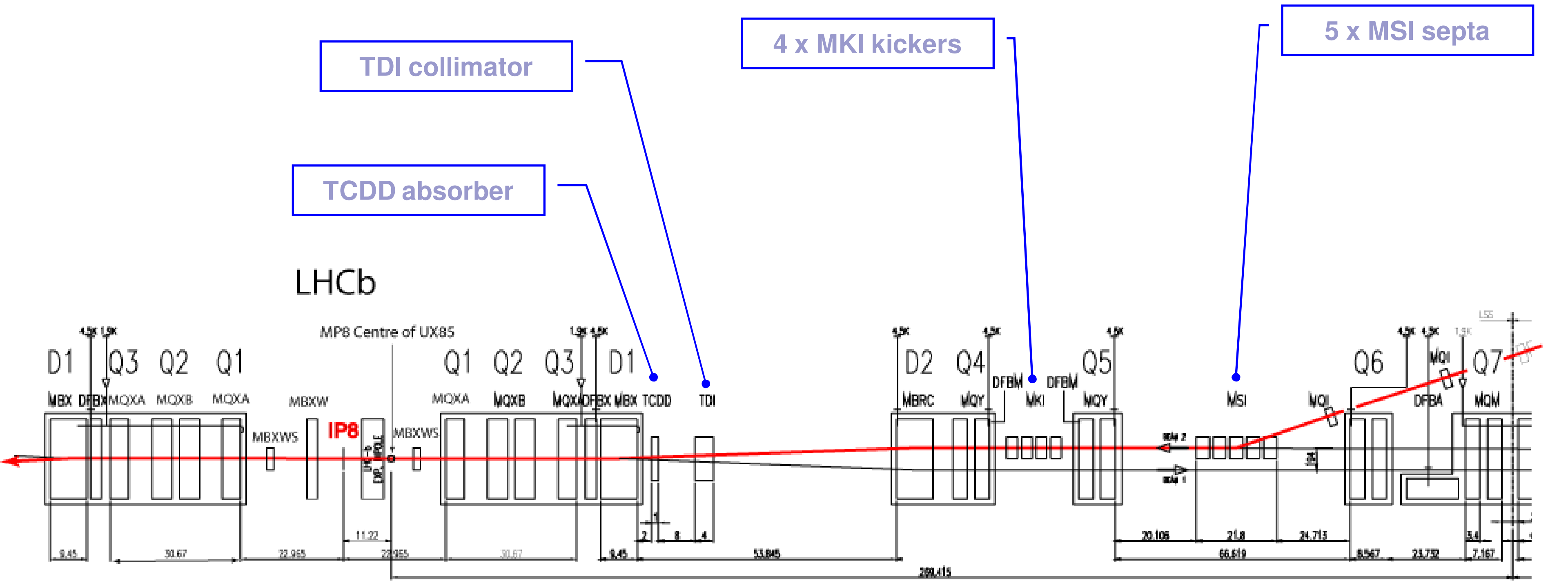
Milestones 2/2

14th Dec	Ramp 2 on 2 to 1.18 TeV - quiet beams - collisions in all four experiments
14th Dec	16 on 16 at 450 GeV - stable beams
16th Dec	Ramped 4 on 4 to 1.18 TeV - squeezed to 7 m in IR5 - collisions in all four experiments
16th Dec	End of run

- 3 days - first collisions at 450 GeV
- 9 days - first ramp to 1.2 TeV
- 16 days - stable beams at 450 GeV
- 18 days - two beams to 1.2 GeV, first collisions

Injection - reminder

Layout (point 8)



Nominal batch from the SPS: 288 bunches of 1.15 e11 protons at 450 GeV

We did a single bunch of 2 e10

Injection

- Delicate process
  - We will sling around a lot of beam during this process
  - Complex dance of hardware, timing, RF, interlocks etc.
  - Have to carefully position collimators and other protection devices to make sure we catch any losses

- Full program of beam based checks performed
  - injection protection (TDI etc), transfer line collimators, TDI positioning, aperture, kicker waveform etc.

- WORK TO DO

Injection

- Issues with BLMs triggering the beam interlock system due to fast losses during the injection process
  - Even at these low intensities (one bunch 2 e10)
  - BLMs set for circulating beam not injected – problem being addressed

- Generally impressive, clearly benefits from experience gained during injection tests.

- However, for the moment one would worry about routinely injecting unsafe beam.

TT40 Damage during 2004 High Intensity SPS Extraction / Goddard, B ; Kain, V ; Mertens, V ; Uythoven, J ; Wenninger, J

Or what you can do with 2.9 MJ

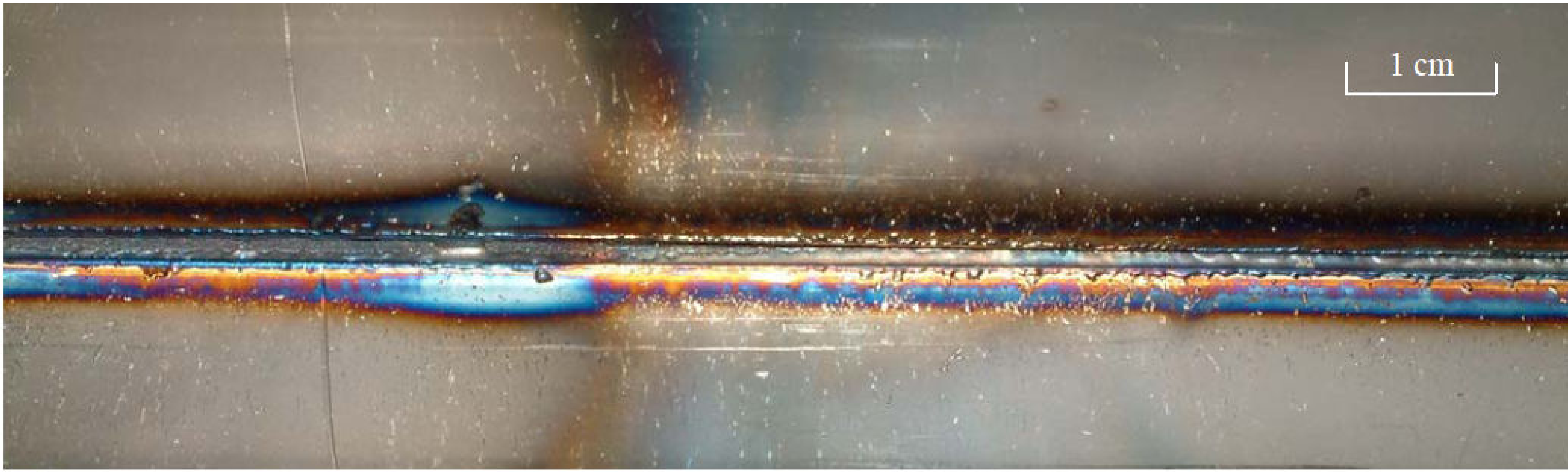


Figure 4. Damage observed on the inside of the vacuum chamber, on the beam impact side. A groove approximately 110 cm long due to removed material was clearly visible, starting at about 30 cm from the entrance.

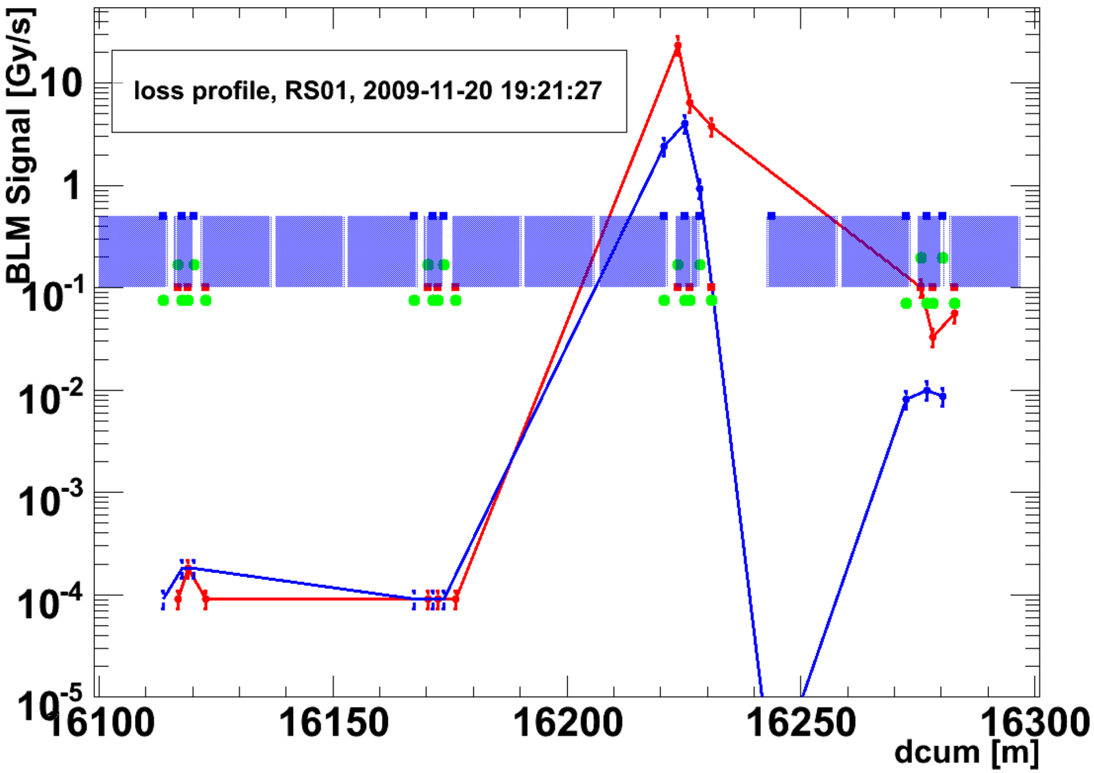
During high intensity extraction on 25/10/04 an incident occurred in which the vacuum chamber of the TT40 magnet QTRF4002 was badly damaged.

The beam was a 450 GeV full LHC injection batch of 3.4 10^{13} p+ in 288 bunches, and was extracted from SPS LSS4 with the wrong trajectory

= 4.4 e12 at 3.5 TeV

Injection

- We can still cause quenchinos with very little beam



by mistake…

For future reference – note low quench level of around 2 e9 at 450 GeV - in line with predictions

450 GeV

Full set of instrumentation and associated hardware and software commissioned and operational (more-or-less)

- Measurement and control of key beam parameters
  - Orbit, tune, chromaticity, coupling, dispersion
  - Beam loss
  - Beam size
  - Lifetime optimization: tune, chromaticity, orbit
  - Energy matching
  - Full program of aperture checks performed covering arcs and insertions

Availability of hardware, instrumentation and software impressive

Good preparation – fast problem resolution

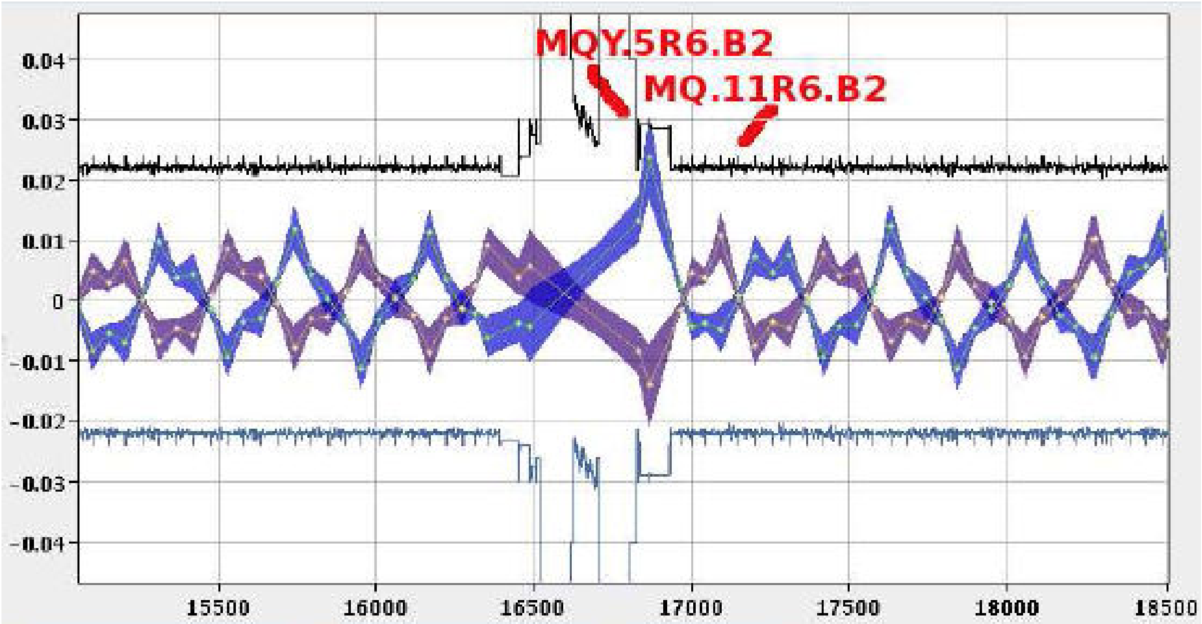
450 GeV

- Experiments’ magnets
  - Solenoids – brought on without fuss and corrected
  - Alice & LHCb dipoles – brought on at 450 GeV – issues with transfer functions
- Two beam operation both with and without bumps
- Optics checks
  - beating & correction
- Full program of polarity checks of correctors and BPMs

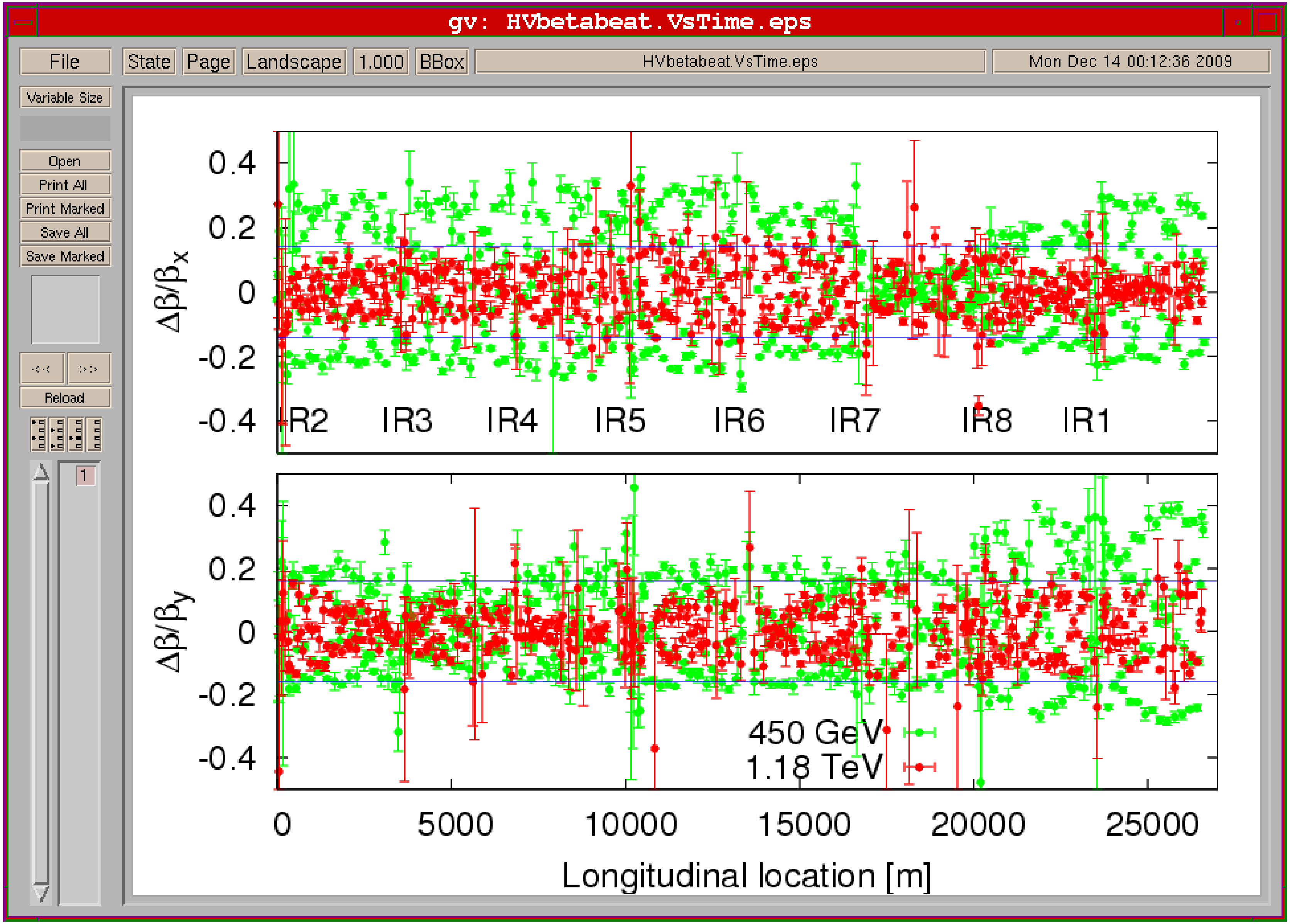
Aperture

Rogelio Tomás et al

- Beam clearance seems to be OK, above or equal to 7.
- Some measured bottlenecks agree with model predictions using measured functions.
- Aperture is out of budget due to the large-beating
  - N1 < 7 even reducing the closed orbit budget to the measured 3.2 mm peak closed orbit
- Correcting beta beating seems mandatory at 450 GeV



Beating: 450 & 1180 GeV

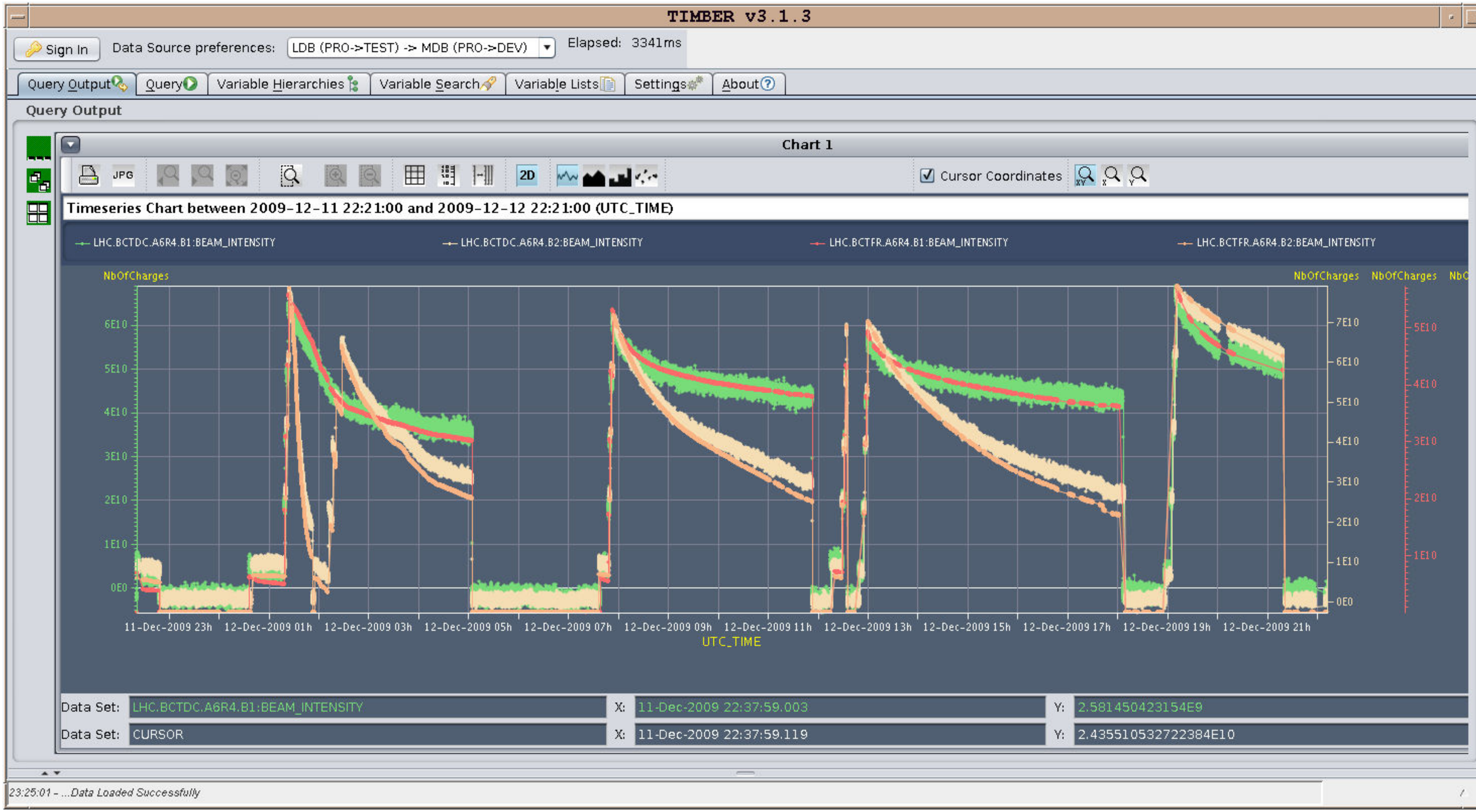


Collisions at 450 GeV

- Man was never meant to do collisions at 450 GeV (in the LHC at least)
- Full program of machine protection, collimation, aperture and LBDS checks allowed “stable beams” to be declared.
- Multi-bunch and higher intensities achieved
  - 16 bunches – total 1.85 x 10^{11}
- “Lumi scans” tested successfully
- Lots of events collected
  - 6 reasonably happy experiments

- Clear issue here for the machine was the activity in the vertical tune spectra and vertical emittance blow-up

Collisions at 450 GeV



After 20 days commissioning this smells faintly of showing off

Tune@450 GeV - issues

- Residual micron amplitude tune oscillations:
  - PRO: beneficial for the FFT-based systems!
  - CON: bad for beam life-time and Q-PLL operation

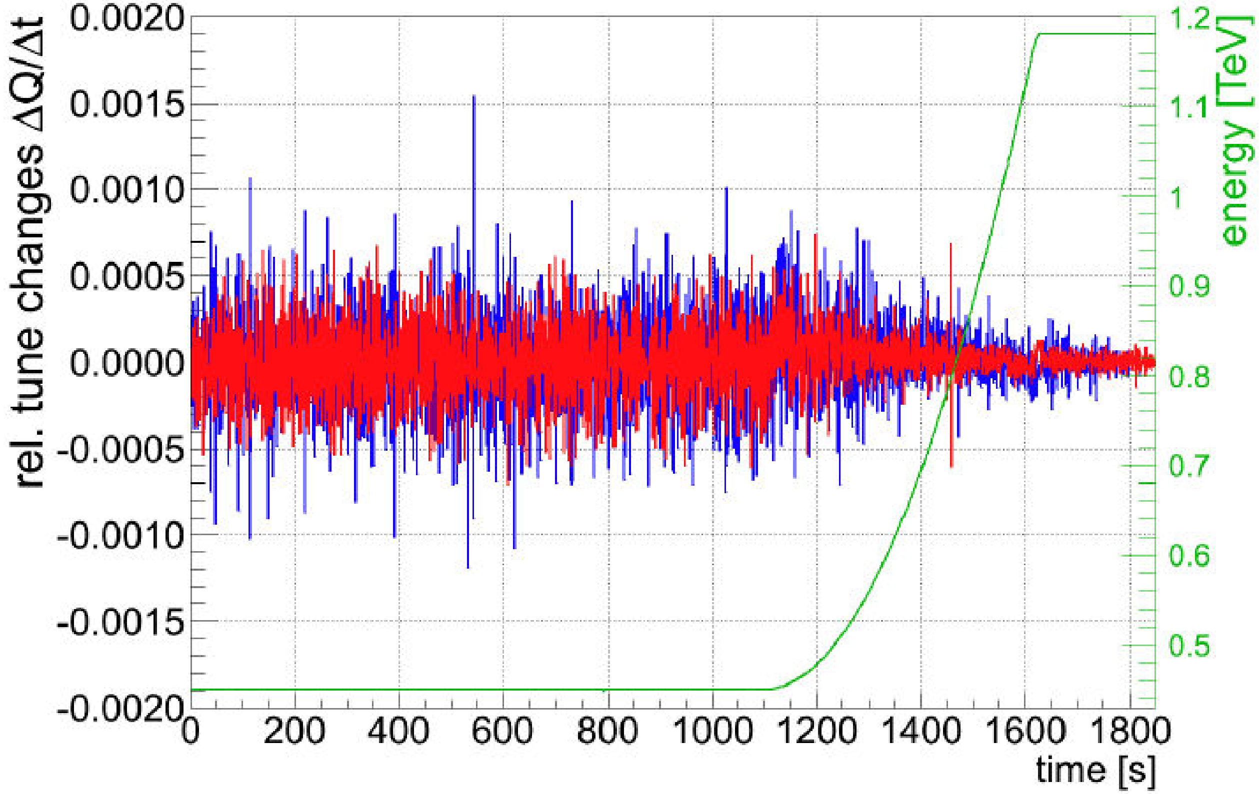
- 8 kHz line, broad frequency “hump”, and other spectra perturbations:
  - Reduction of beam life-time, emittance blow-up, …
  - Potential to perturb FFT-based Q-Tracker

Maybe not of direct relevance to this audience but this sort of thing can give you a real headache

Residual tune stability

Ralph Steinhagen

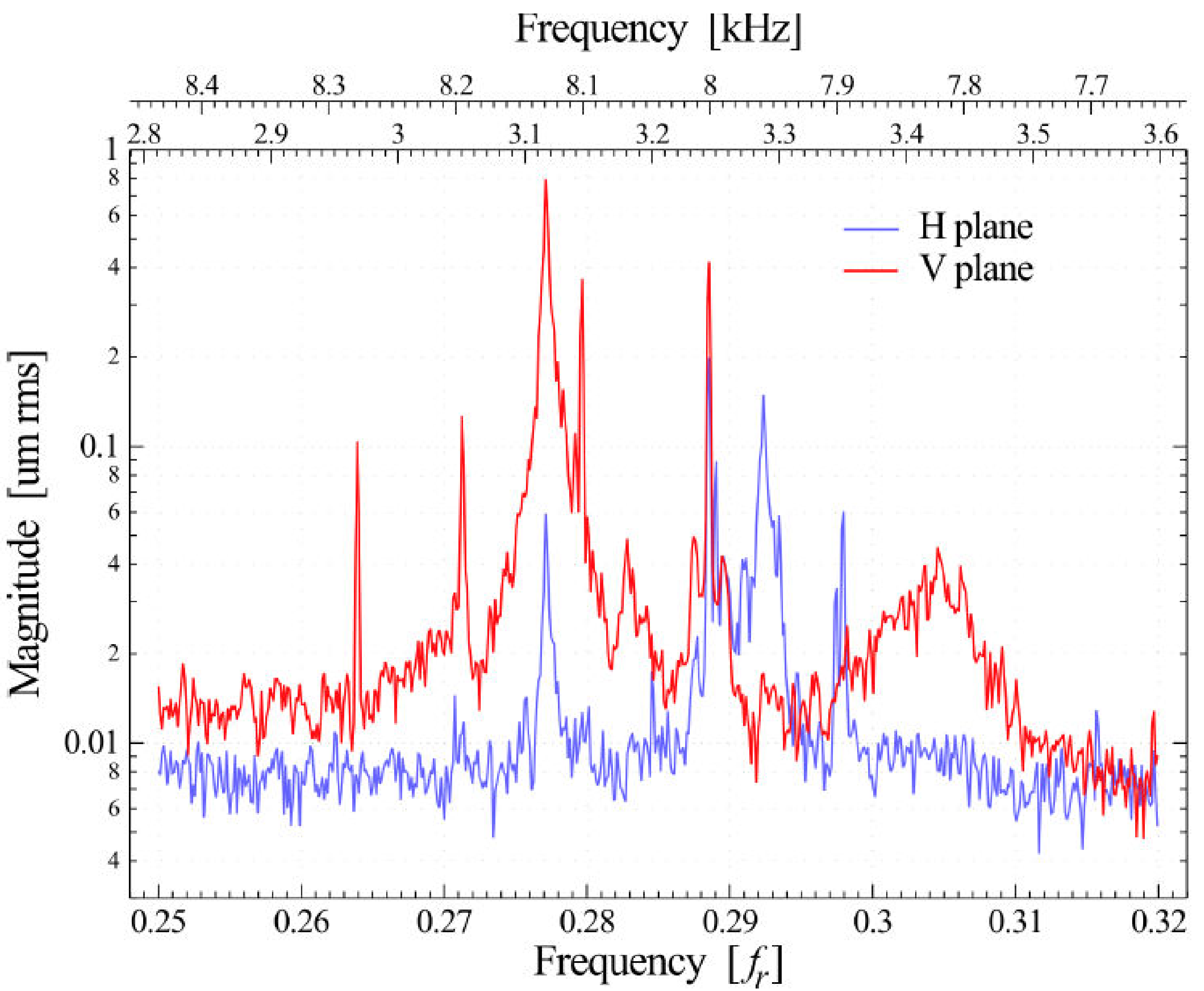
- Example (3. ramp 2009-11-30 @00:15):



– Residual tune stability $\Delta Q \approx 5 \cdot 10^{-4}$
  - no particular frequency dependence → 'white noise'
  - Little/no Q' but energy dependence → power converter noise?

Possible source candidates under examination

8 kHz & the hump



Nominal cycle: ramp

Walter Venturini

	Date	Beam	Energy [GeV]	Comment
1	24/11/09	1	560	Tunes
2	29/11/09	1	1043	1/3 integer
3	30/11/09	1/2	1180	No full precycle No feedback
4	8/12/09	1/2	1180	B1 lost after 3 minutes at top energy. Feedback on B2
5	13/12/09	1/2	800	Feedback on both beams from here Lost B2 – BPM interlock
6	14/12/09	1/2	1180	1 hour “quiet beams” – collisions in all 4 experiments
7	15/12/09	1/2	1180	Beam lost to rogue real-time packet
8	16/12/09	1/2	1180	Squeeze/collisions

Seriously impressive

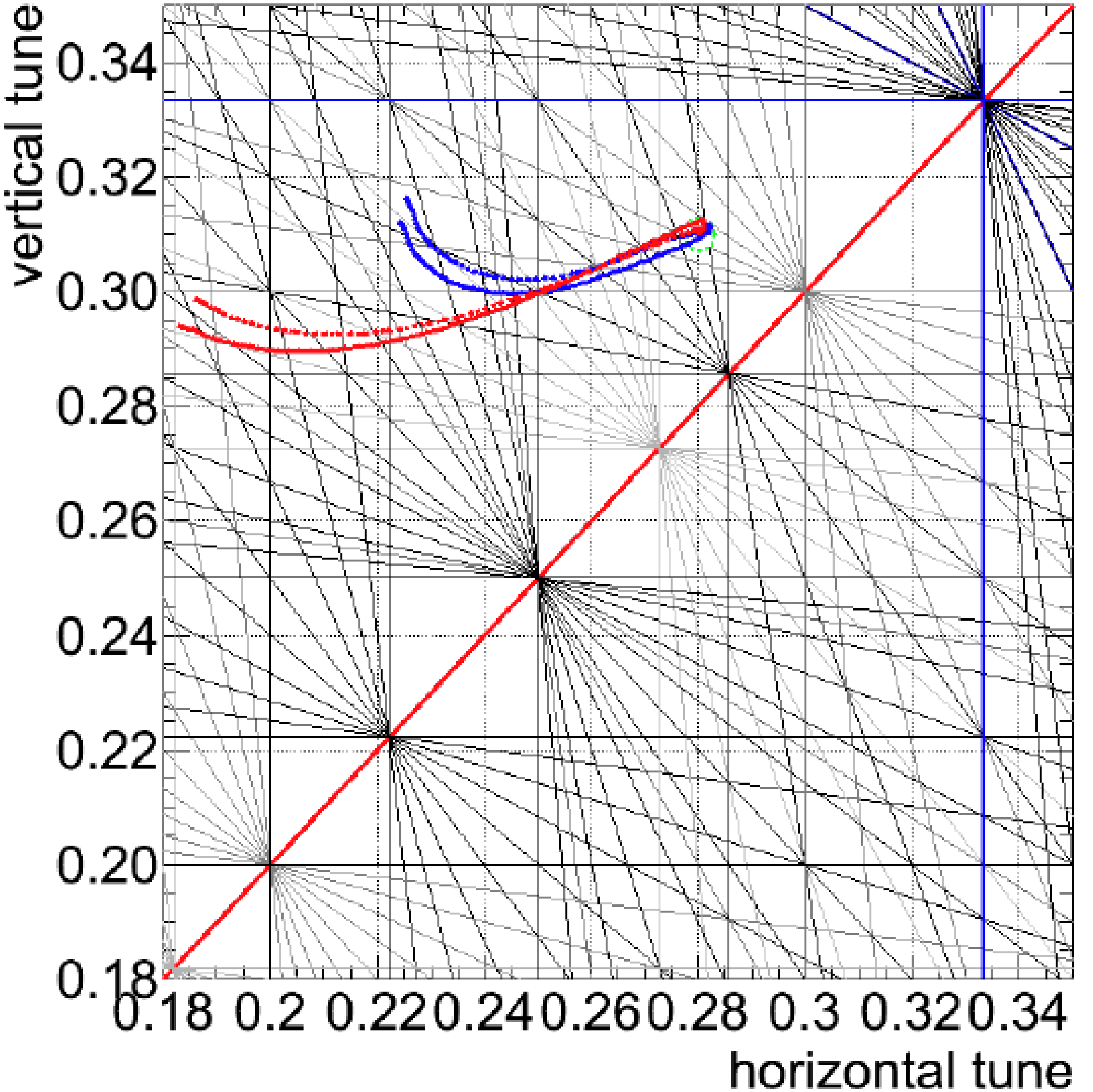
Ramp - issues

Ramp looked good (<u>and reproducible</u>)

Both tune feedback and feed-forward operational

- Tune evolution not understood (in particular the differences between beams)
- Fidel corrections to be updated with best estimate for snapback correction
- Orbit – need feedback (and perhaps feed-forward)
- Need on-line chromaticity measurement
- Appropriate incorporation of 450 GeV trims
- RF: commissioning of emittance blow up
- Ramp with separation bumps

Ramp 7 & 8 – bare tunes



Not understood

Squeeze

- **First beam tests of betatron squeeze were successful!**
  - Mechanics of the squeeze works well.
  - good agreement with the expected beta values.
- **Some issues were identified and are being addressed**
  - Improve further LSA implementation (incorporation, BP handling)
  - New functionalities: change of optics matrices for orbit feedback;
  - Handle stop points for critical properties (collimators).
- **Feedbacks (preliminary):**
  - Orbit feedback would be highly appreciated, as expected!
  - If simulations are confirmed, tune feedback seem less critical.

FIDEL

Ezio Todesco

- The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning
- Huge parameter space, mistakes made, lessons learnt etc but…
- Tunes, energy matching, optics close to the model already
- Some discrepancies being hunted down (450 GeV particularly)
- Bodes very well for the future.

Magnet model

- Largest momentum offsets by sector:
  - -0.27 permill in sector 56 / beam1
  - +0.32 permill in sector 78 / beam2

Beam	Parameter	Meas	trim
1	QH	0.28	-0.023
1	QV	0.31	0.049
2	QH	0.28	-0.089
2	QV	0.31	0.015
1	QPH	5	-16
1	QPV	7	2
2	QPH	9	-15
2	QPV	8	2

and check out the beta beating at 1.2 TeV

FIDEL - precycle

- Fully deployed with precyling prescriptions in place for nearly all circuits
- ~One hour long with all magnet circuits being put through a magnetic ringer.
- Very good reproducibility when re-injecting
  - this will save us.

Precycle

Monitoring application. Currently monitoring : LHC - [1 subscription]
LHC
RBA: lhcop
[Display the graphs on 1 column(s) for 5,150 points | Minimum graph width 150 px - height 150 px | show legend | smooth graphs | show points]
monitoring SUB_51 for 180 devices : RPMBA.RR57.RQTL11.R5B1/SUB_51 ...
Fixed Graph
Close
3500
3000
2500
2000
1500
1000
500
0
-500
06:10
06:15
06:20
06:25
06:30
06:35
06:40
06:45

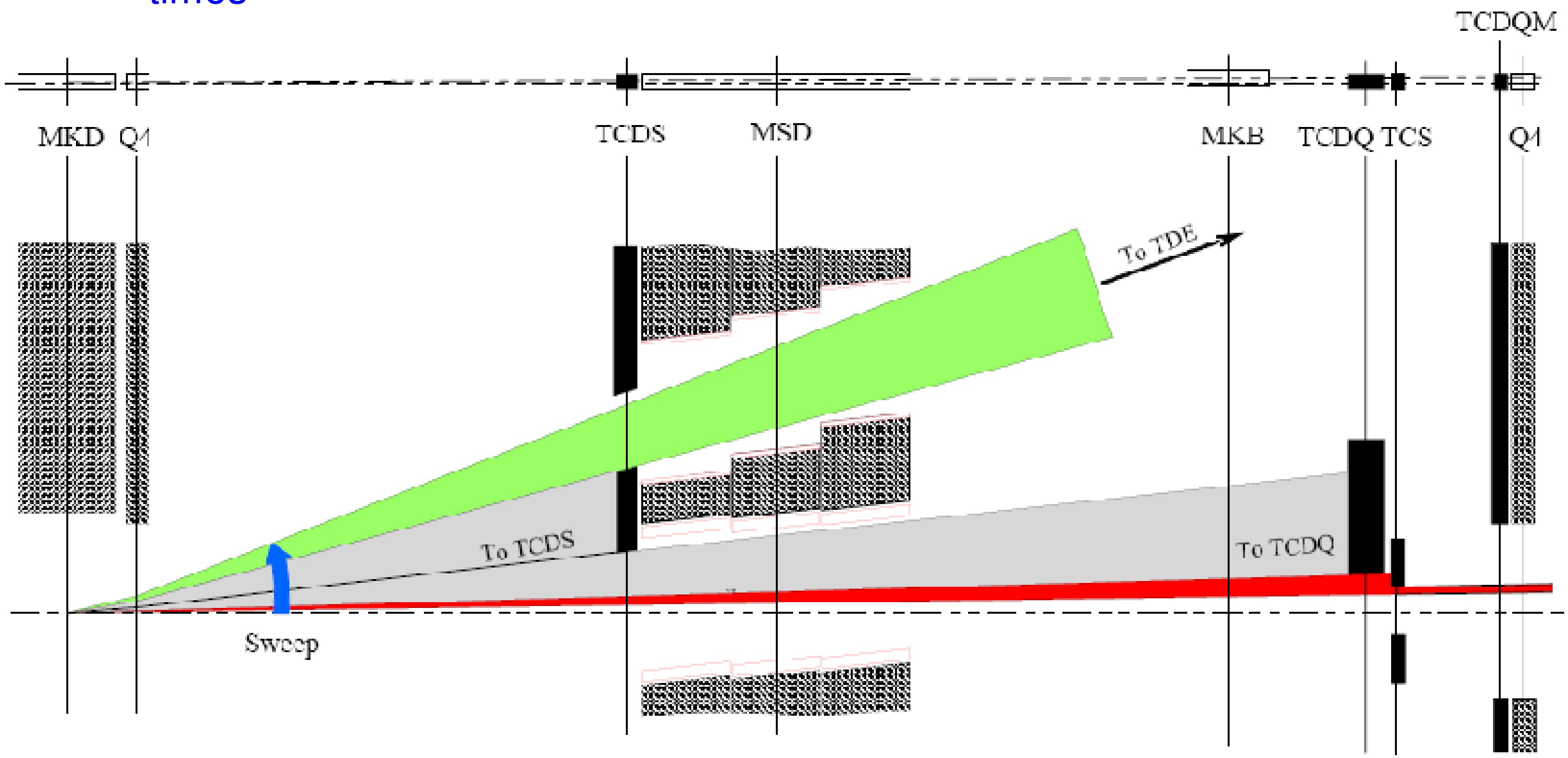
Beam Dump - briefly

Wolfgang Bartmann

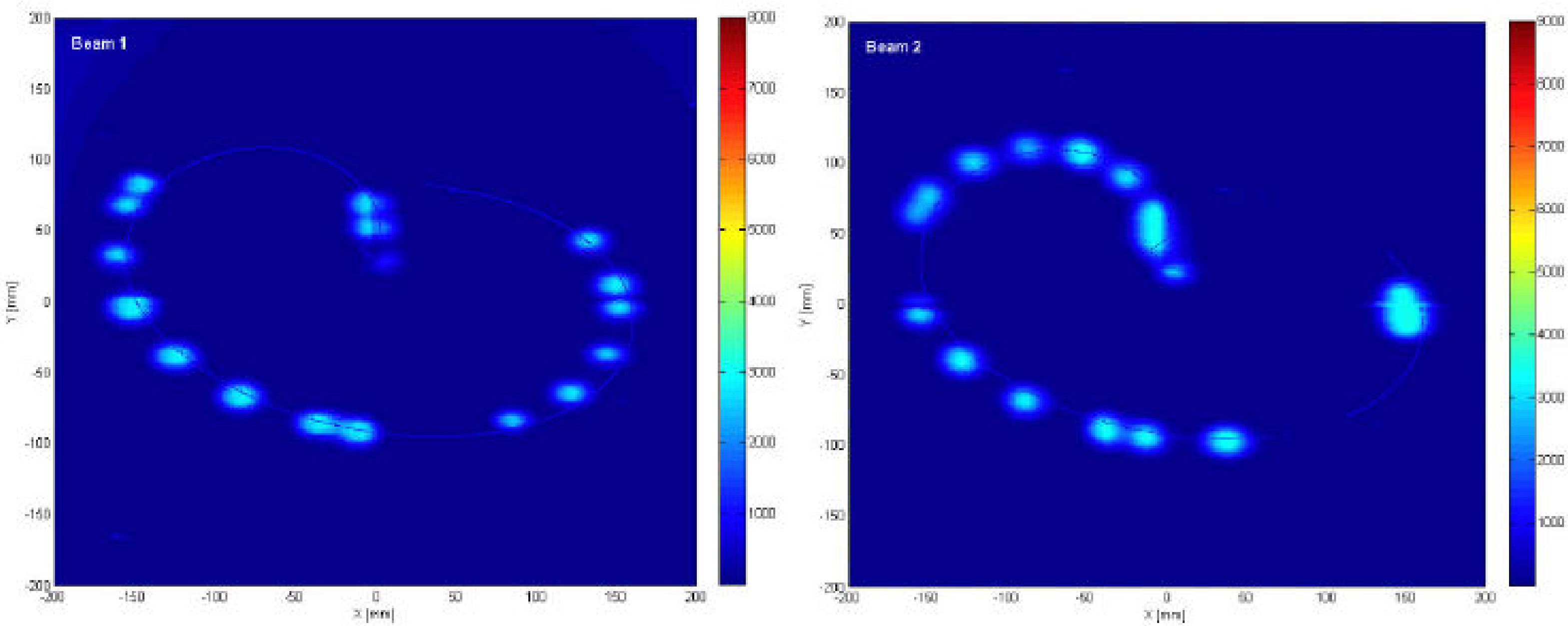
TCDQ/TCSG protects Q4 and downstream elements

…in case of asynchronous beam dump or asynch. firing of MKD kickers where part of beam is not absorbed by TCDS

- TCDS (fixed) – 6 m long diluter protects extraction septum
- TCDQ/TCS (mobile) – 7 m long diluter kept at about 7-8 σ from the beam, at all times



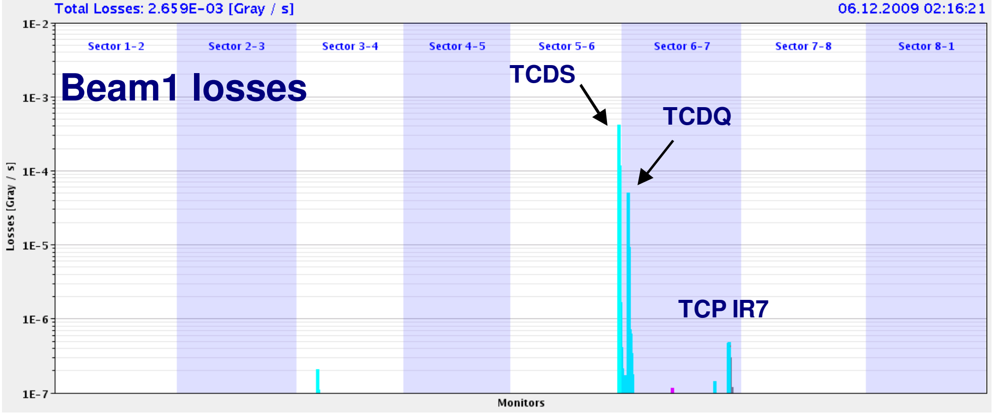
Beams for physics dumped, at the right place! 450 GeV

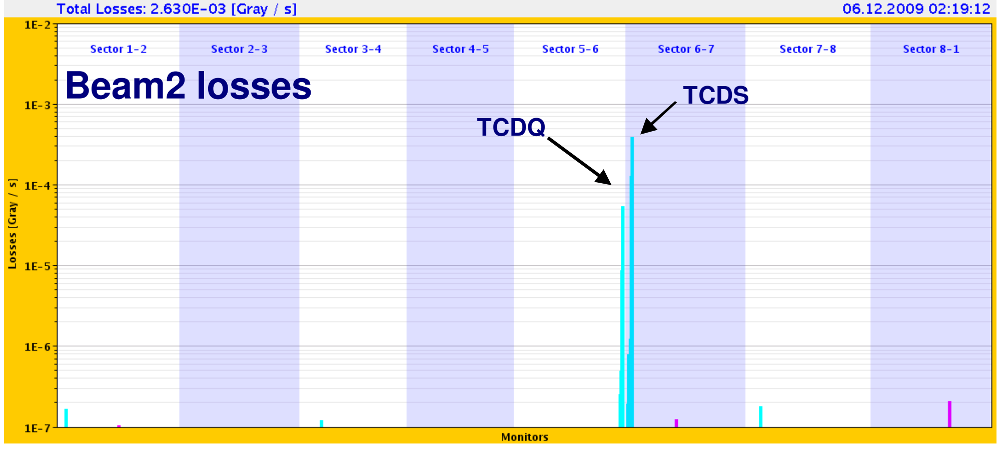


Beam dumps, 16 bunches + pilot, 14/12/09 around 21:00
BTVDD image = position on beam dump block TDE
Comparison with calculated positions from measured kicker magnet waveforms.

TCDQ/TCSG set-up

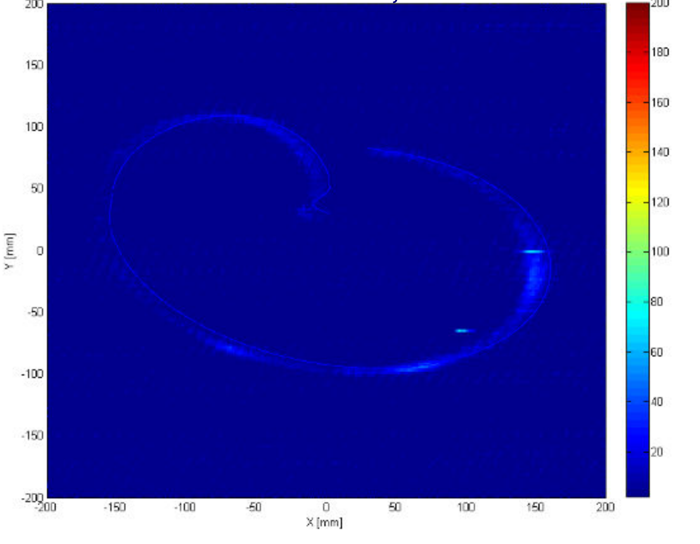
- Check of TCDQ protection (dump of debunched beam):
  - Losses concentrated on dump protection devices, with 0.1% on collimators





Asynchronous dump tests:

4 bunches, B2



Sweep shape on BTVDD as expected

Beam dump – are we ready for higher energies?

- The beam dumping systems worked very well and the XPOC and IPOC systems caught all failures
  - Only real failures were the Synchronous-Asynchronous dumps: solved after TSU firmware upgrade

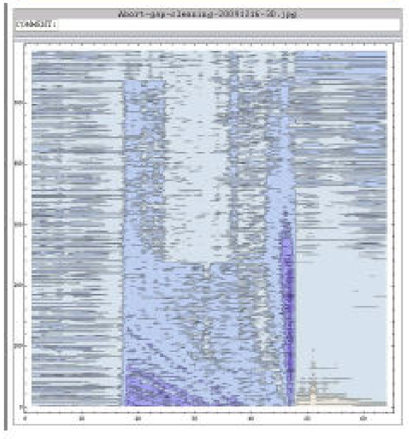
- Many tests with beam outstanding
  - Dump at intermediate energies
  - Positioning of protection devices
  - Follow commissioning procedures for increasing energy and intensity

Abort gap cleaning tests

Jan Uythoven

- Undulator and synchrotron light monitor successfully commissioned for beam 2
- Beam 1 remains to be commissioned
- Abort Gap Cleaning “works” already during first tests!
  - But needs to be further optimized to clean over the full 3 μs while limiting the losses outside the abort gap
  - About 10 % of the beam was left in the gap
- Need to commission the **Abort Gap Monitoring Interlock**

BSRA data show gap partially cleaned



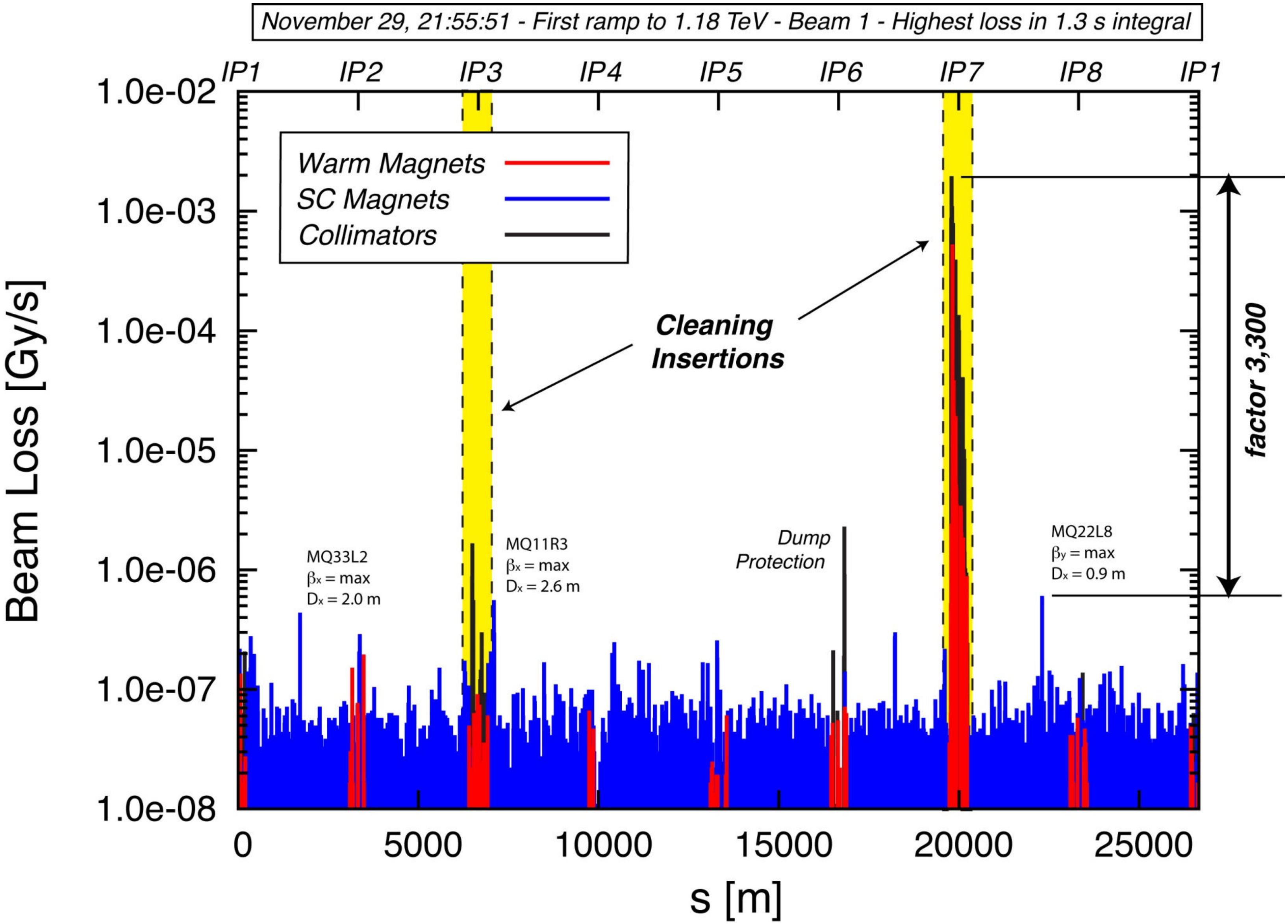
Collimation

Chiara Bracco

Excellent initial beam based commissioning following careful preparation and tests

- Full program of beam based positioning
- System works as designed. Expected cleaning and leakage processes seen.
- Possible to verify passive protection: losses at primary collimators.
- Hierarchy established and respected in tests
- Collimation setup remained valid over 6 days, relying on orbit reproducibility and optics stability
- Even the Roman pots got a run out

Collimation



Ralph Assmann

Machine Protection

- Mission critical backbone
  - Beam Interlock System
  - Safe Machine Parameter
  - Plus inputs to/from other systems (e.g. timing, BCT)
- A large multitude of user inputs
- The beam driving a subtle interplay of:
  - LBDS, Collimation, protection devices, RF…
  - Instrumentation (BLMs, BCT, BPMs…)
  - Aperture
  - Optics

Careful testing before beam

Full set of beam based tests

Clearly the critical path

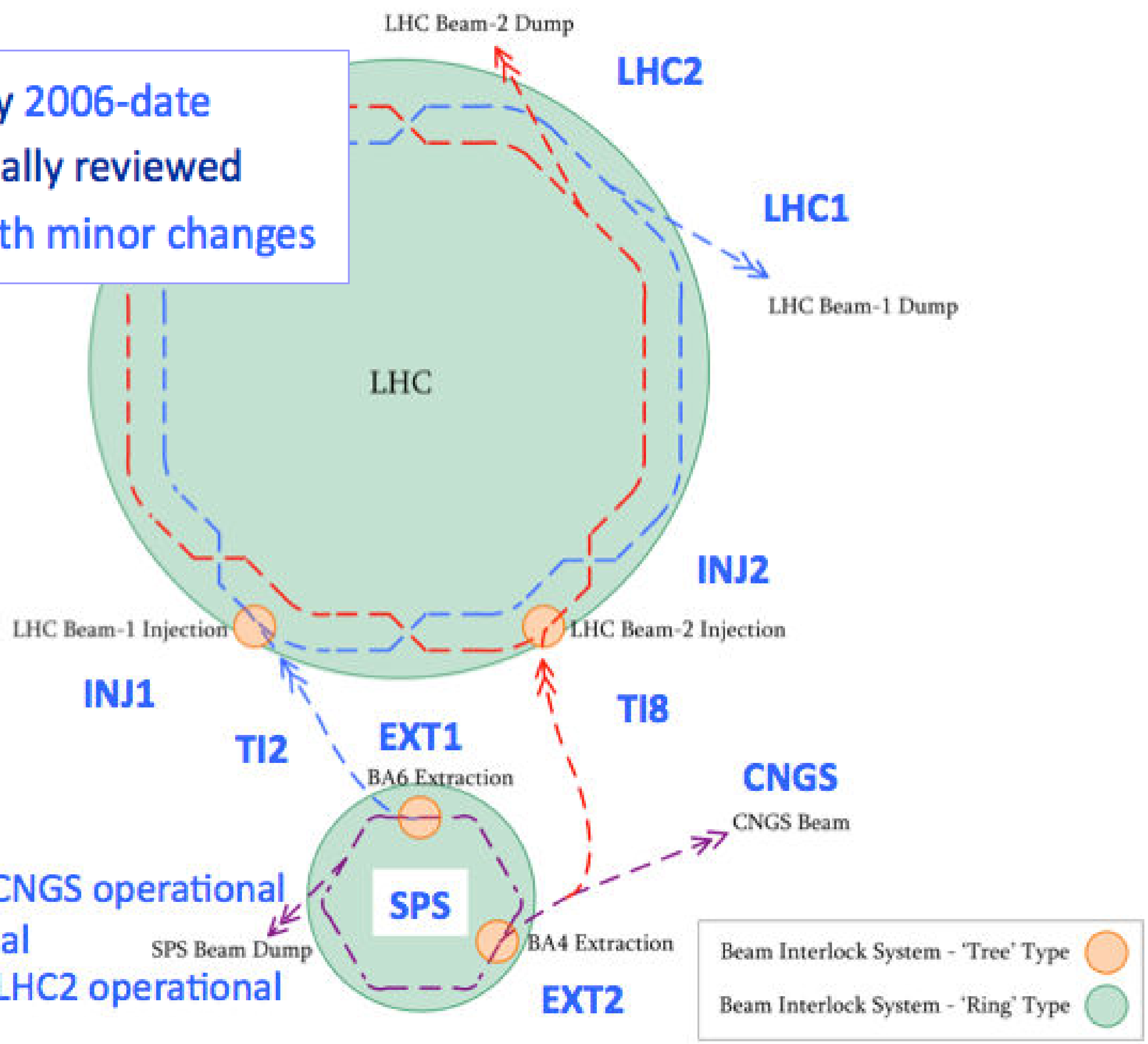
BIS-BIC-SMP

Ben Todd

99.996% availability 2006-date

Internally and externally reviewed

will be ready for 2010 with minor changes



2006: SPS, EXT1, EXT2, CNGS operational

2007: TI2, TI8 operational

2008: INJ1, INJ2, LHC1, LHC2 operational

Machine protection – user input

			R1	L2	R2	U3	S3	L4	R4	L5	R5	L6	R6	U7	S7	L8	R8	L1	CCC	Inj1	Inj2	Σ
UNmaskable	1	**Vacuum** (Sector valves)		♦b♦r	♦b♦r	♦b♦r		♦b♦r	♦b♦r	♦b♦r		♦b♦r	♦b♦r	♦b♦r		♦b♦r	♦b♦r	♦b♦r				30
		("X valves")	♦p	♦p	♦p						♦p					♦p	♦p					
	2	**PIC** (for essential circuits)	♦p	♦p	♦p	♦p♦p		♦p	♦p	♦p	♦p	♦p	♦p	♦p♦p		♦p	♦p	♦p				16
	3	**BLM** (at aperture limitations)		♦p			♦p	♦p		♦p		♦p			♦p	♦p		♦p				8
	4	**Warm magnets (WIC)**		♦p		♦p			♦p	♦p		♦p		♦p		♦p		♦p				8
	5	**Beam Dumping system**										♦b	♦r							♦b	♦r	4
	6	**Injection Kicker**			♦b												♦r			♦b	♦r	4
	7	**Access** (LASS + E.I.S.)				♦p		♦p	♦p										♦p			4
	8	**Operator Buttons** (CCC)																	♦p	♦b	♦r	3
	9	**Programmed Beam Dump**																	♦b♦r			2
	10	**Safe Machine Parameters sys**																	♦b♦r			2
	11	***ATLAS*** (Detector part)	♦p																	♦b	♦r	3
	12	" " (Movable device)	♦b♦r (yellow)																			2
	13	***ALICE*** (Detector part)			♦p															♦b	♦r	3
	14	***CMS*** (Detector part)									♦p♦p									♦b	♦r	4
	15	***LHCb*** (Detector part)															♦p			♦b	♦r	3
	16	" " (Movable device)															♦p					1
	17	***LHCF***	♦p																			1
	18	***TOTEM***									♦b♦r									♦b	♦r	4
Maskable	19	**Collimation** (Env. Param.)	♦b♦r	♦b♦r	♦b♦r	♦b♦r				♦b♦r	♦b♦r	♦b♦r		♦b♦r		♦b♦r	♦b♦r			♦b♦b	♦r♦r	24
	20	**Collimation** (Motor pos.)	♦b♦r	♦b♦r	♦b♦r	♦b♦r				♦b♦r	♦b♦r	♦b♦r		♦b♦r		♦b♦r	♦b♦r	♦b♦r		♦b♦b	♦r♦r	26
	21	**PIC** (for auxiliary circuits)	♦p	♦p	♦p	♦p♦p		♦p	♦p	♦p	♦p	♦p	♦p	♦p♦p		♦p	♦p	♦p				16
	22	**BLM** (in the arcs)		♦p			♦p	♦p		♦p		♦p			♦p	♦p		♦p				8
	23	**Screens**		♦b		♦b♦r			♦b♦r				♦b♦r	♦r			♦r					9
	24	**Fast Magnet Current ch. Mon**			♦p♦p		♦p♦p♦p				♦p		♦b♦r		♦p♦p♦p			♦p		♦b♦b	♦r♦r	16
	25	**RF & Transverse Damper**						♦b♦r (yellow)	♦b♦r													4
	26	**Beam Aperture Kicker**						♦b♦r														2
	27	**TCDQ**										♦b♦r										2
	28	**Fast BCT** (di/dt)							♦b♦r													2
	29	**Beam excursion (BPM)**											♦b♦r		♦b♦r (yellow)							4
	30	**MSI Power Conv.** (sum fault)																		♦b	♦r	2
	31	***Experimental Magnets***	♦p		♦p						♦p (yellow)						♦p					4
	32	***ALICE-ZDC***																		♦b		1

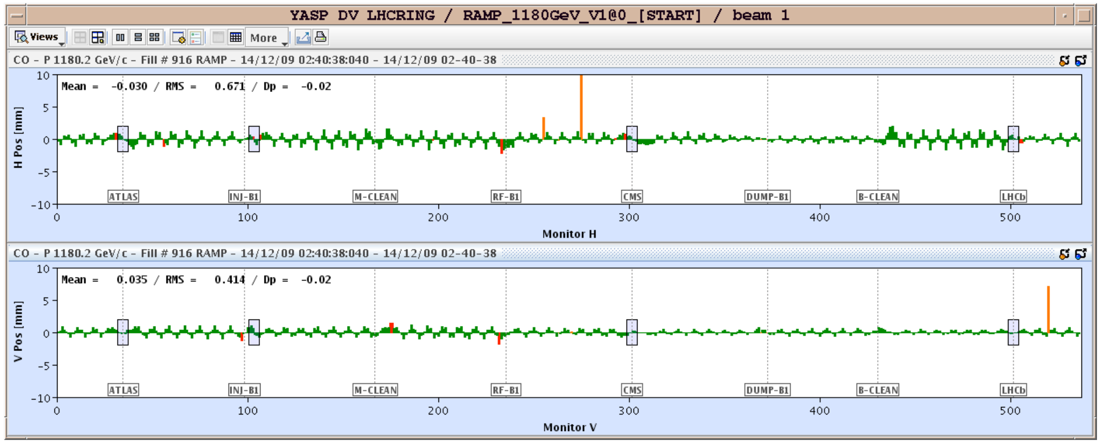
♦b♦r : **Individual Beam connections** ♦p : Both Beams connections *Not connected* (yellow) **Total: 216**

BEAM INSTRUMENTATION

Orbit

- Excellent performance of BPM system
- Very stable orbit (V drift ~ 15µm/h)
  - Better correction possible.
  - Should spend some time to establish a better global correction (and avoid strong local corrections) before setting up collimators.

- Orbit feedback
  - Basically operational, time needed for testing
  - Essential for ramp and squeeze



BLMs

Christos Zamantza
s

- BLMs correctly removes the BEAM PERMIT signal if measurements are over threshold. No reliability issues observed.
- System is well understood since it has been up and running for more than a year. VERY IMPRESSIVE.

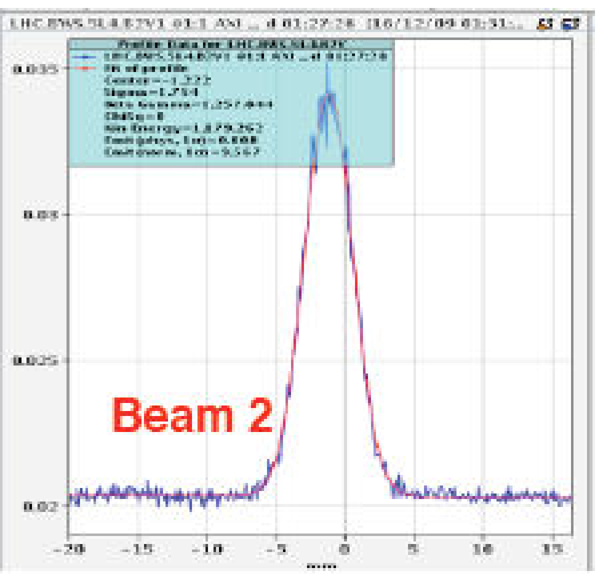
- Some availability issues (false dumps) at energies higher than the injection are to be expected if thresholds don't change in some regions.
- Continuous monitoring of noise is required.
- Sequencer initiated tests will be enforced to be run regularly.

- More tests to verify and adjust the threshold values are needed.
- Investigation of spurious signals from the SEMs are ongoing and first corrections are being implemented.

Profile monitors

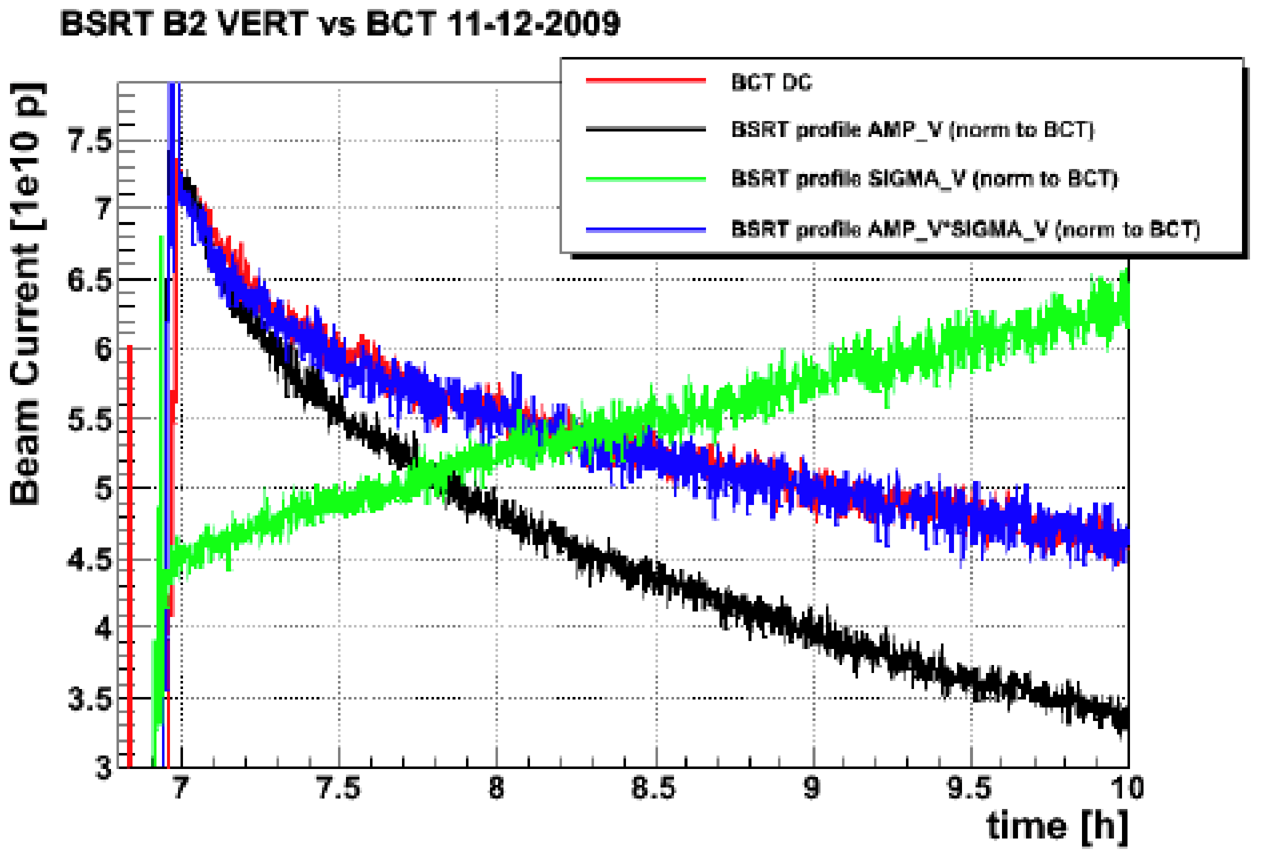
Thibaut Lefevre

- **BTVs and Wire scanners** works quite reliably – still few bugs to be fixed
- **Synchrotron Light Monitors**
  - Systems worked basically as designed - need the other undulator on
  - Deeper analysis of performances on going
  - Cross calibration with respect to Fast BCTs and Wire scanners needed



Synchrotron light monitor

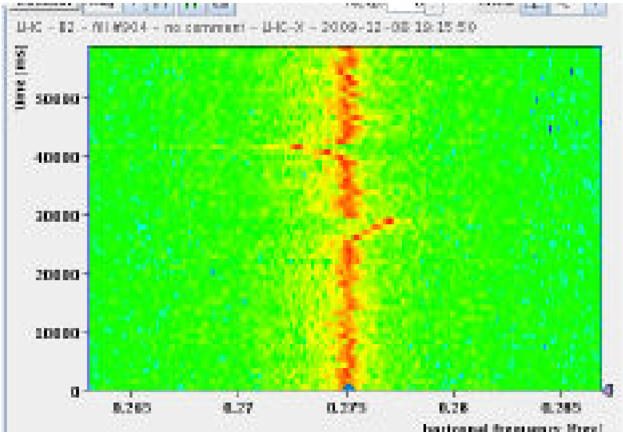
Vertical emittance blow-up – beam 2



Tune

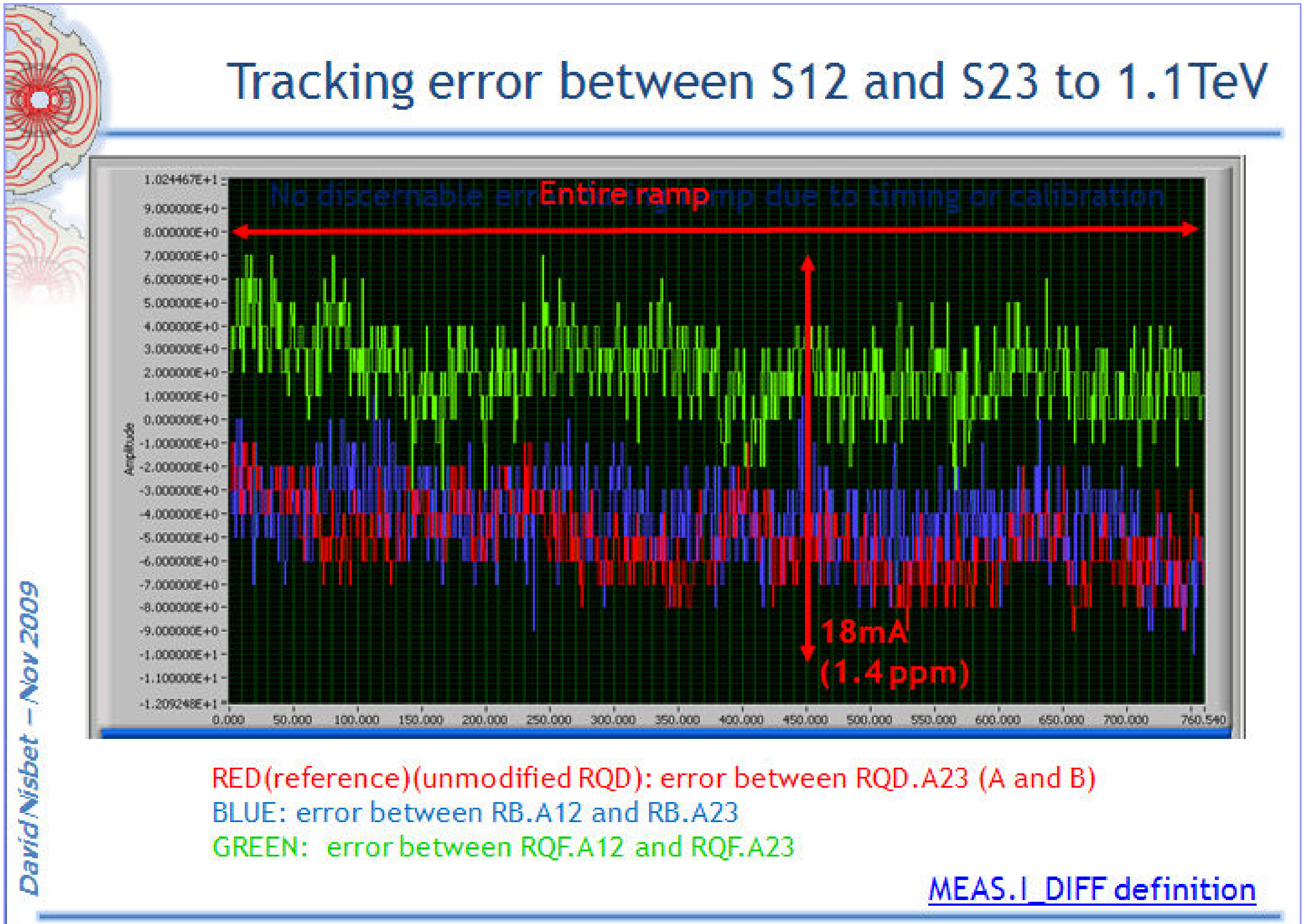
Ralph Steinhagen

- The Base-Band-Tune (BBQ) system was work horse from LHC day one
  - No hardware, minimal software and only a few beam related issues
  - Most measurements were done with residual beam excitation
  - Q measurements resolution in the range of 10^{-4} … 10^{-5}
- PLL – partially deployed – to be fully commissioned
- Feedback operational via BBQ continuous FFT



Power converters

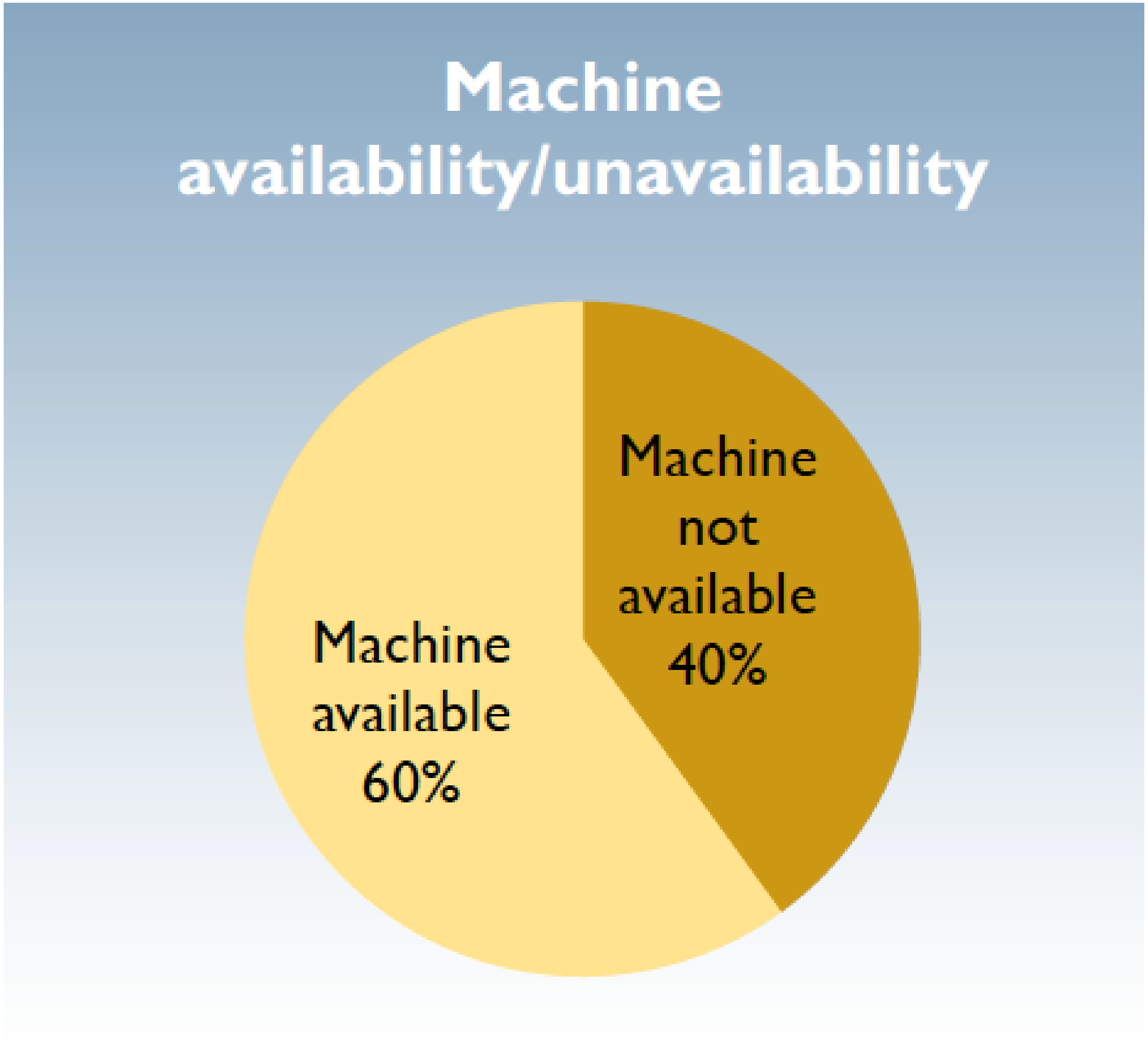
- Unmentioned because brilliant



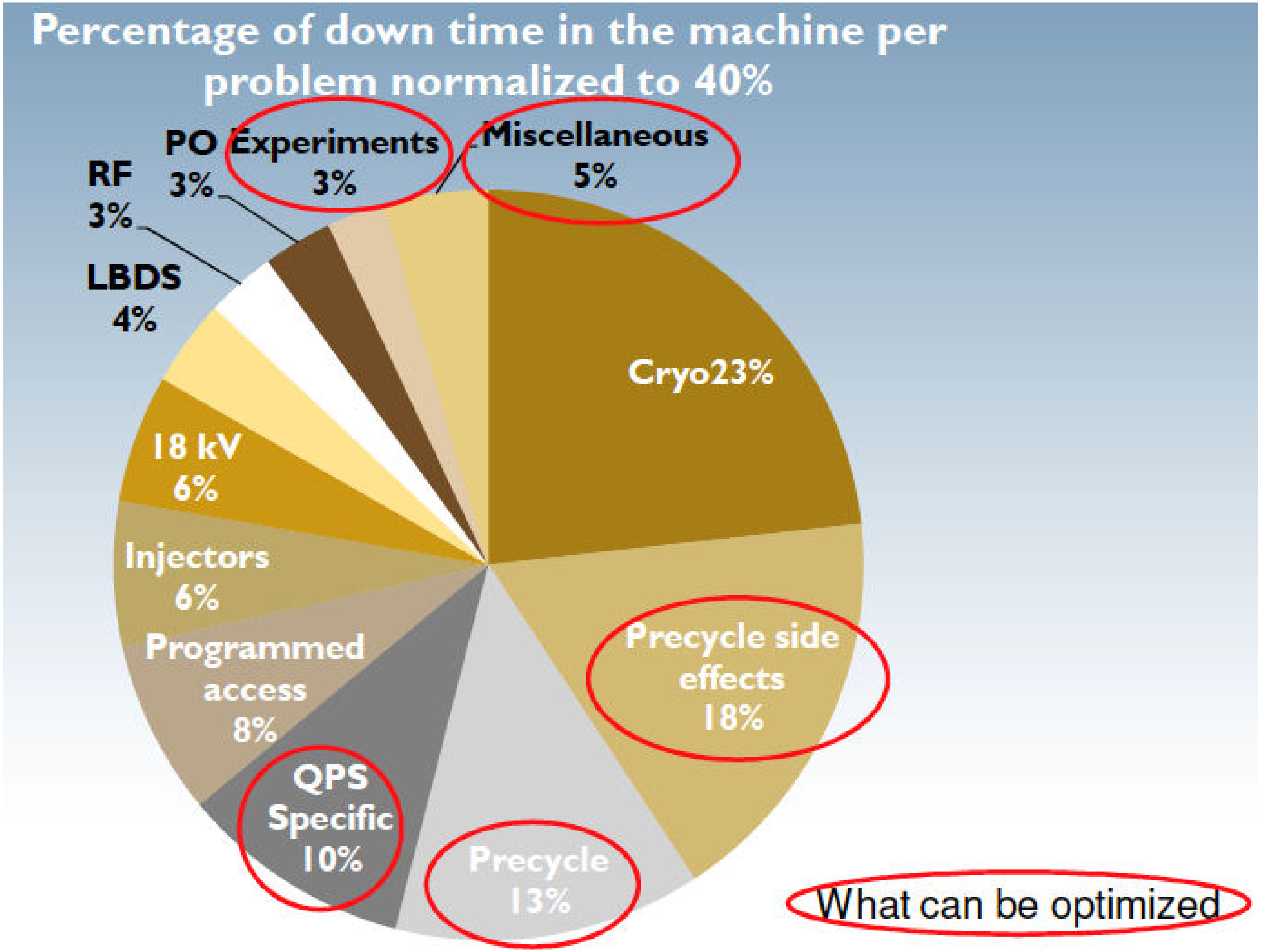
This will also save us…

Availability

Reyes Alemany



Unavailability

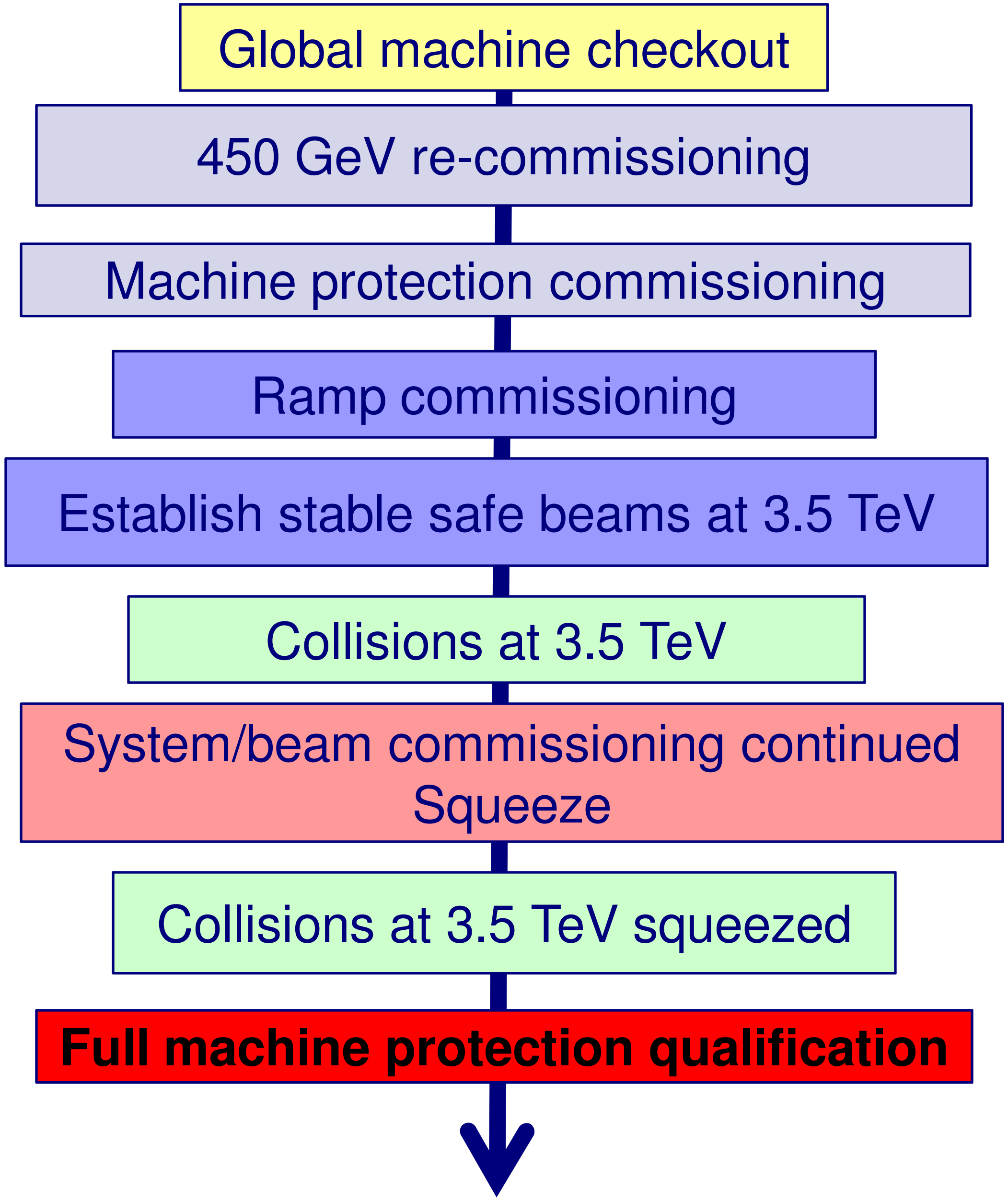


2010

2010 overview

- Beam commissioning continued
  - Through to colliding, safe, stable, squeezed beams
- Consolidation & physics
- Increased intensity phase 1 & associated machine protection qualification
  - Establish secure and reproducible operations and fully field test
- Consolidation & physics
- Increased intensity phase 2 & associated machine protection qualification
- Etc.

Beam commissioning strategy 2010



2010 – parameters

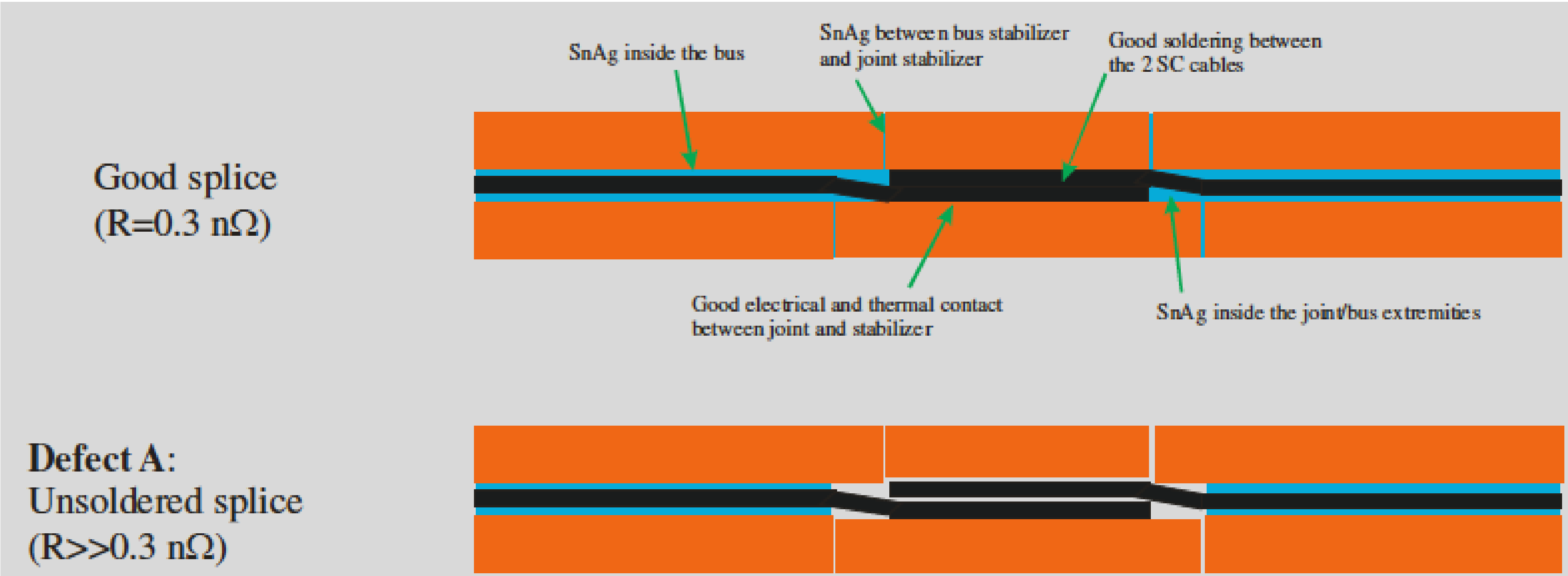
Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	5×10^{10}	11 / 10 / 11 / 10	Weeks
2	3.5	2x2	$2 - 5 \times 10^{10}$	11 / 10 / 11 / 10	
3	3.5	2x2*	$2 - 5 \times 10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	5×10^{10}	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	5×10^{10}	2 / 10 / 2 / 2	
6	3.5	156x156	9×10^{10}	2 / 10 / 2 / 2	Months
7	3.5	50 ns - 144**	7×10^{10}	2.5 / 3 / 2.5 / 3	
8	3.5	50 ns - 288	7×10^{10}	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	7×10^{10}	2.5 / 3 / 2.5 / 3	Months

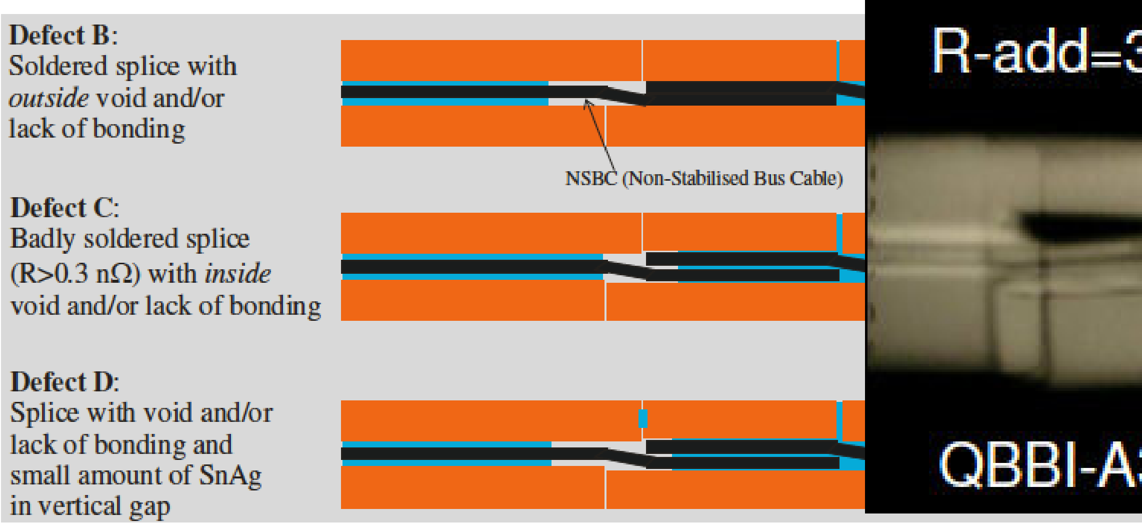
* Turn on crossing angle at IP1.

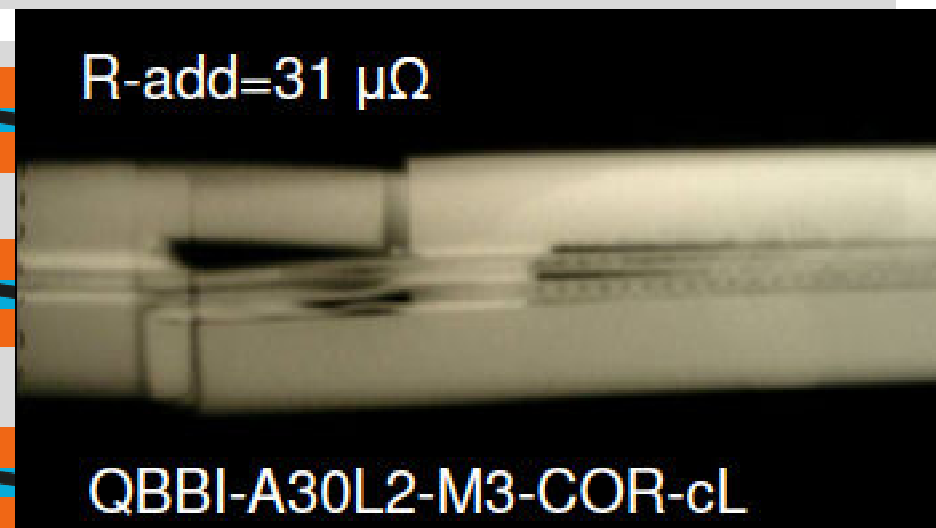
**Turn on crossing angle at all IPs.

- Bring on the crossing angle sooner rather that later and don't waste too much time with 156 bunches per beam
- Explore higher bunch intensities early.
- ~200 pb^{-1} if things go well

Splices – we still have a problem







3.5 TeV requirements

Michael Koratzinos

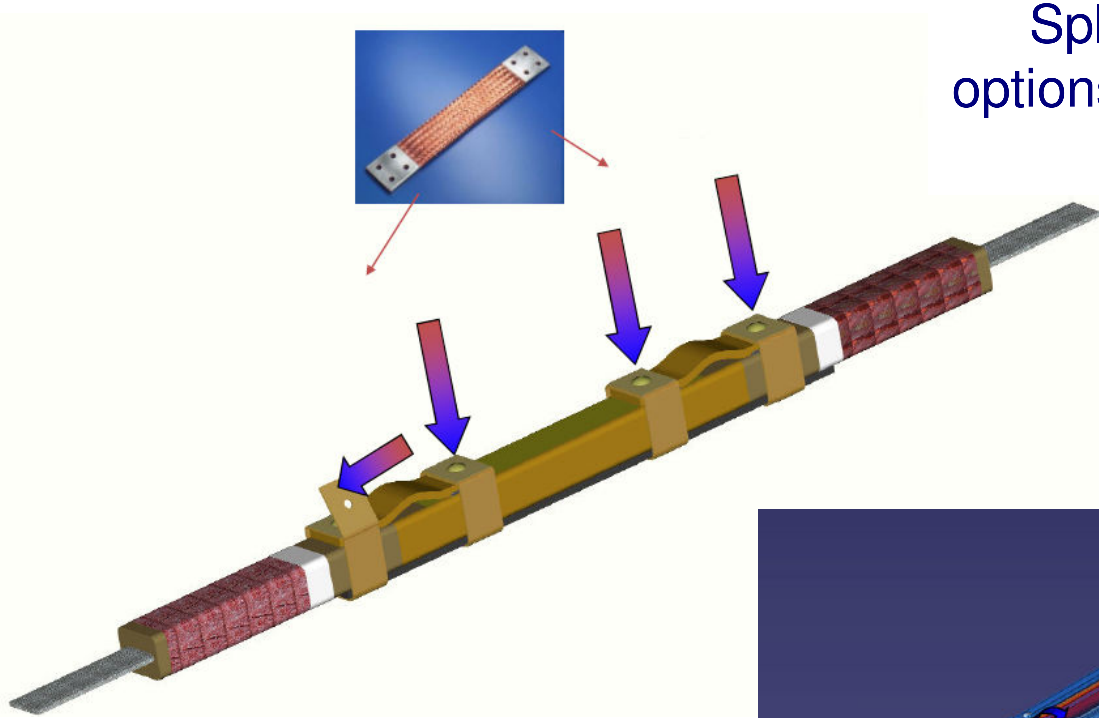
circuit	τ [s]	Condition	Max R_{addit} for RRR_{bus}=100	Max R_{addit} for RRR_{bus}=160
RB	50	~~GHe with t_{prop}=10 s~~	~~80~~	~~87~~
		GHe with t_{prop}=20 s	>100	>100
		LHe without He cooling	58	65
		LHe with He cooling	76	83
RQ	10	~~GHe with t_{prop}=10 s~~	~~>150~~	~~>150~~
		GHe with t_{prop}=20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

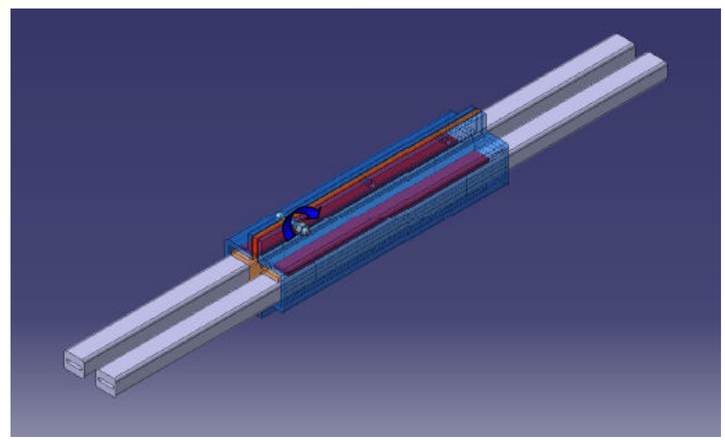
Essential message is that we can't, with any confidence, go above 3.5 TeV in 2010

To go to 7 TeV

Paolo Fessia

Splice consolidation options under examination





Everywhere

Near future looks like being…

- Run 2010 at 3.5 TeV
  - Estimate integrated luminosity 100 - 200 pb^{-1}
- Short winter stop
  - Carry on running at 3.5 TeV with the aim of delivering at least 1 fb^{-1}
- Long shutdown (~1 year)
  - Fix all splices properly – LHC good for 7 TeV (give or take some dipole re-training).
  - 6.5 TeV should be relatively easy
- Head for nominal performance

NB: hot off the Chamonix press

Conclusions 1/2

- A lot of hard work over the years has enable a truly impressive period of initial commissioning with beam.
- Initial indications are that the LHC:
  - **is reproducible;**
  - **magnetically well understood;**
  - **optically in good shape;**
  - **is armed with a mighty set of instrumentation, software, and hardware systems.**
- Lots still to sort out, in particular…
- Operations, controls, instrumentation etc. have the capability to unnecessarily stress the machine protection system – issues must be resolved.

Long way to go before we are ready to go much beyond the safe beam limit

Conclusions 2/2

- 2010 ~4 weeks to establish stable, safe beams at 3.5 TeV
- Extended running period around the safe beam limit
  - With blocked MD periods as required
- Formal review process of machine protection before starting a stepwise increase in intensity
  - Each step up in intensity to be followed by an extended running period
- Heading for 10^{32} $cm^{-2}s^{-1}$ in 2010 and hopefully between 100 – 200 pb^{-1}