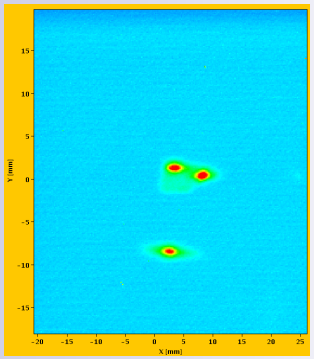
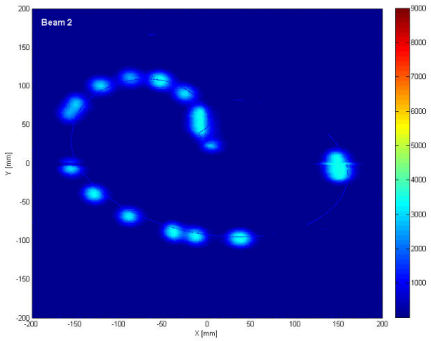
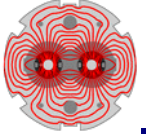
LHC beam commissioning workshop Evian January 2010

The good, the bad, and the not very pretty







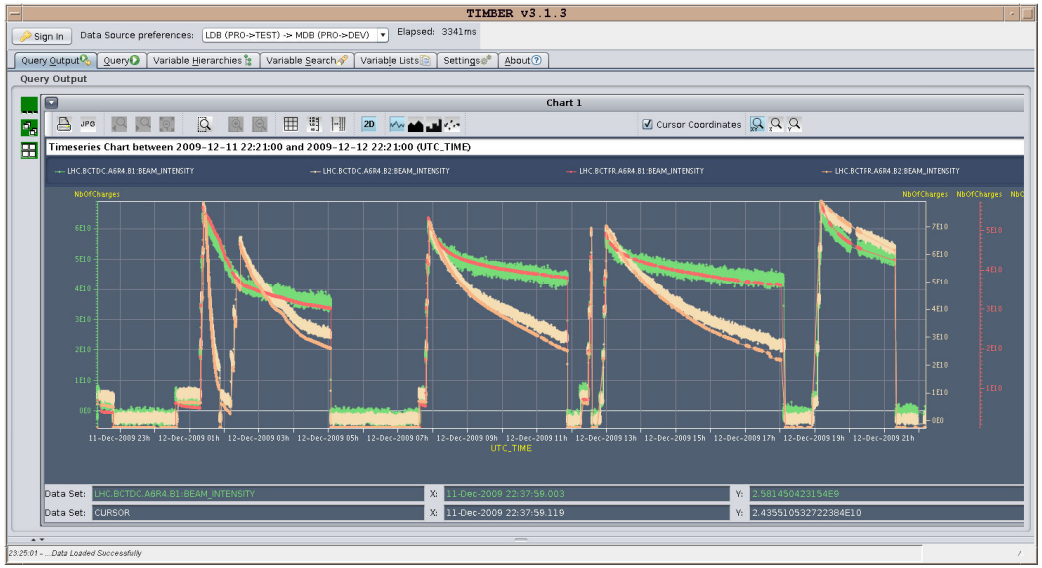
Evian 2010

- Sessions on
  - Review of 2009 LHC beam operation and models
  - Beam diagnostics
  - Injection & Ramp & Squeeze & Adjust & Stable beam
  - Machine protection
  - Controls and operational aspects: going from commissioning to operational regime
  - 2010 operation
- Speakers ask bury Caesar not to praise him

Beam commissioning 2009

- 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

General agreement that this wasn't bad



Injection

Malika Meddahi

Complex dance of hardware, timing, RF, interlocks etc.

- Transfer lines in good shape after big effort.
- Re-phasing, synchronization & transfer & capture
  - Excellent – some RF controls and OP procedural issues
- Injection sequencing:
  - injection schemes, multi-bunch, two beams, collision scheduling
- Kicker Soft Start - now part of the process
- Injection Quality Check operational (new arrival!)
- Abort gap keeper commissioned
- Full program of beam based checks
  - injection protection (TDI etc), transfer line collimators, TDI positioning, aperture, kicker waveform etc.

Injection - problems

Wolfgang Bartmann

- Over injection
  - Losses at the LHC TDI and exceeding thresholds at the MQXA
  - Various solutions under examination
- TCDI set up:
  - losses in the ring already close to BLM interlock limit for pilot bunch… needed to scrape in the SPS
  - Ratio of one pilot bunch to one nominal SPS batch: 6.4e3
  - BLM saturation and dump thresholds for fastest integration time scale – general issue for fast loss
  - BLM crosstalk while set-up
- TDI asymmetry
  - – 2mm offset in P8, to be understood, tank opening required

Lots still to sort out
Not yet ready for higher intensities

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, controls & software in general very impressive

Good preparation – fast problem resolution

450 GeV

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

One main issue at 450 GeV was the activity in the vertical tune spectra and associated vertical emittance blow-up

Tune@450 GeV - issues

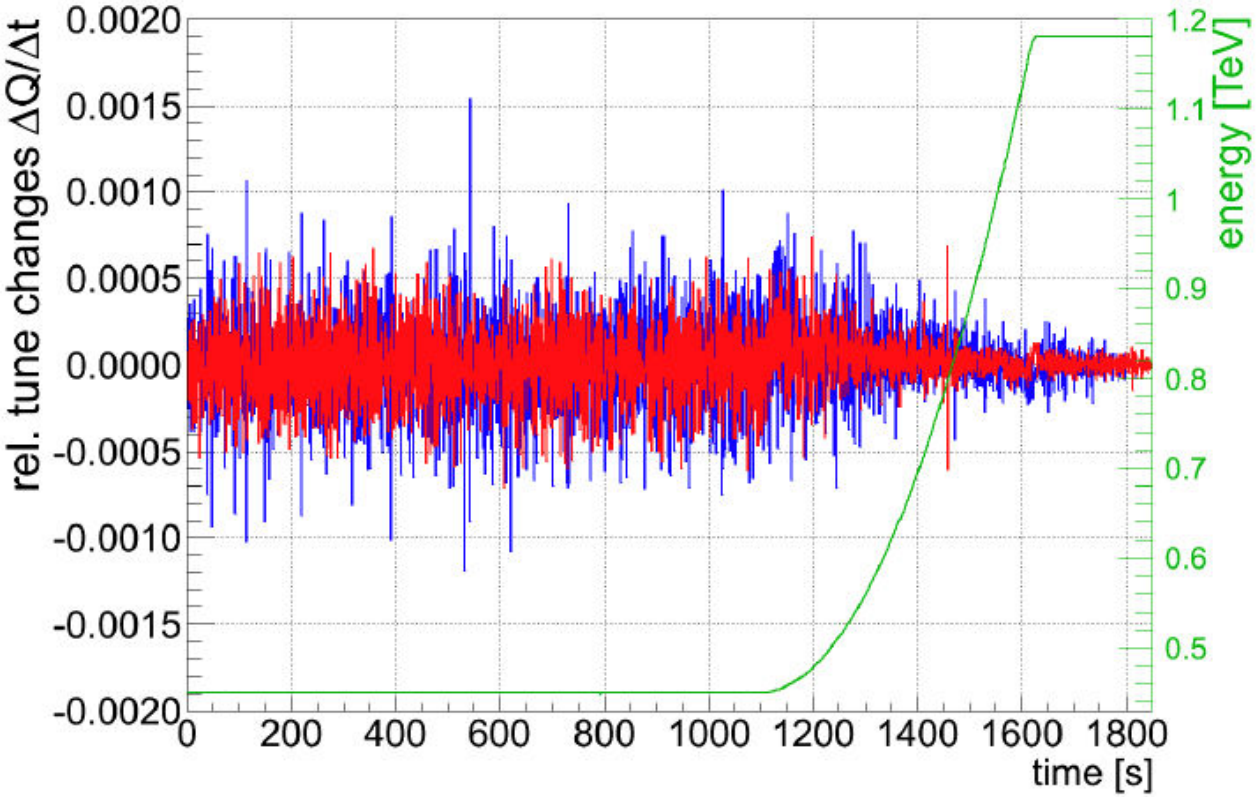
- Residual micron amplitude tune oscillations:
  - PRO: beneficial for the FFT-based systems!
  - CON: bad for beam life-time and Q-PLL operation

- 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

Ralph Steinhagen

Residual tune stability

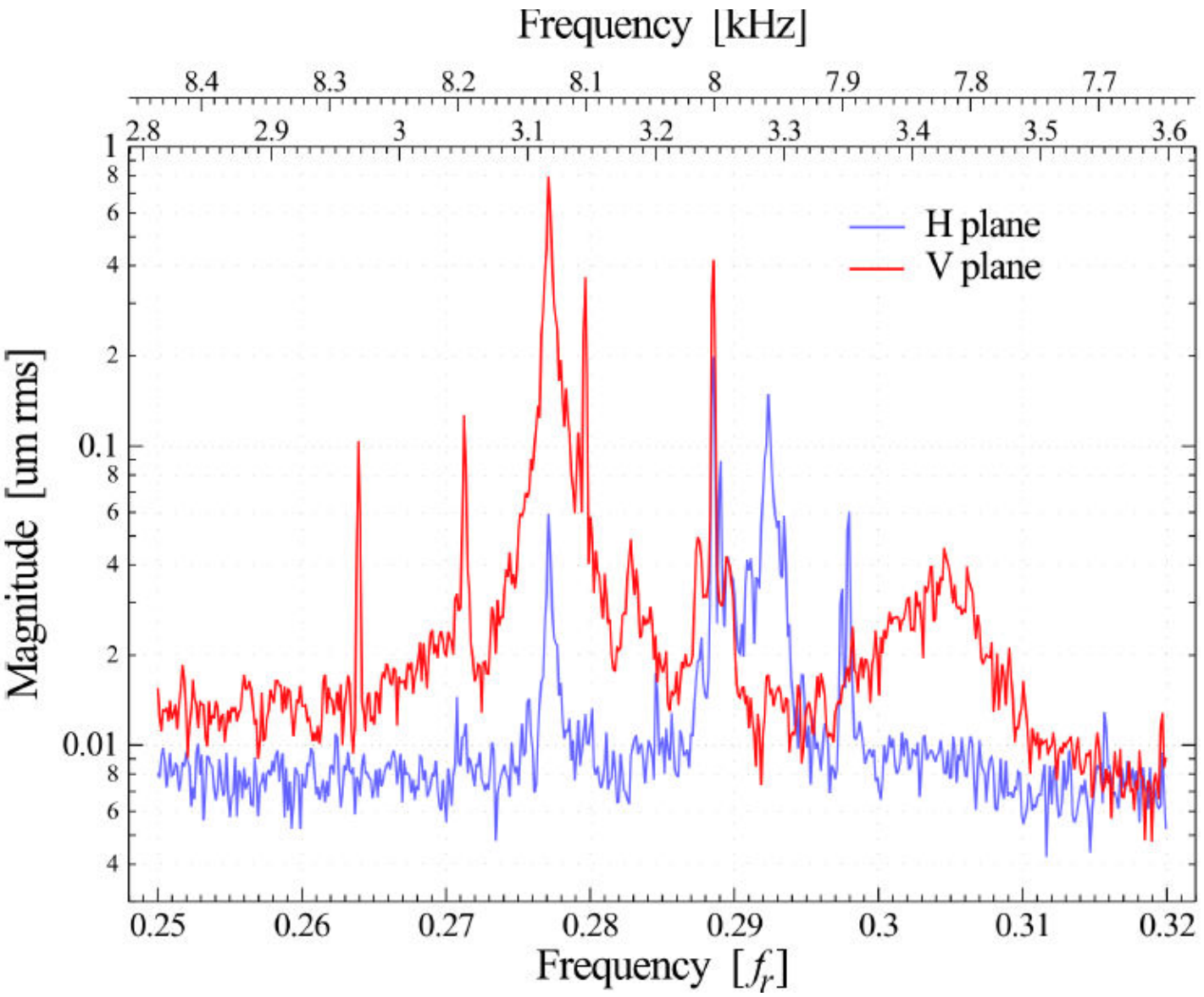
- Example (3. ramp 2009-11-30 @00:15):



  - 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

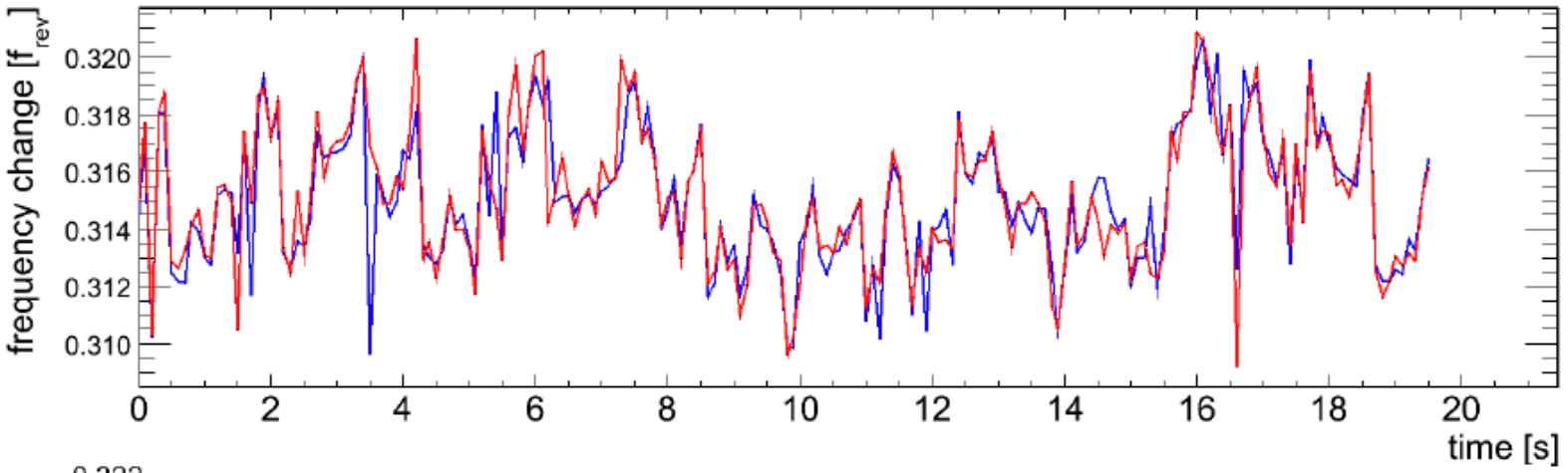


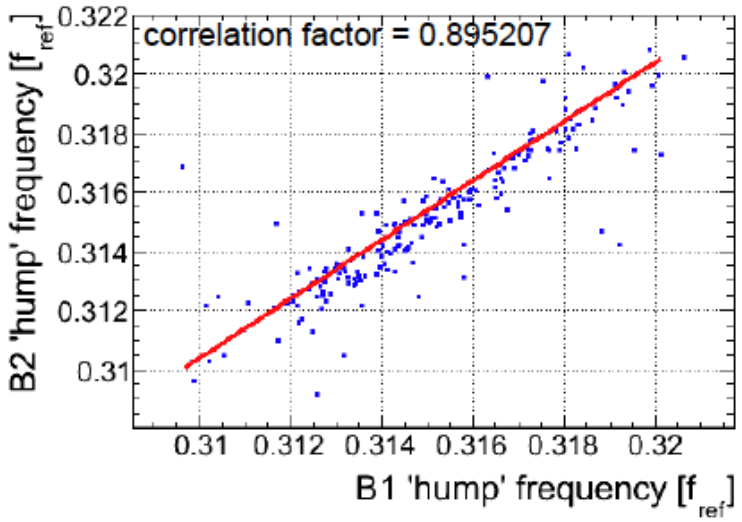
Tune@450 GeV

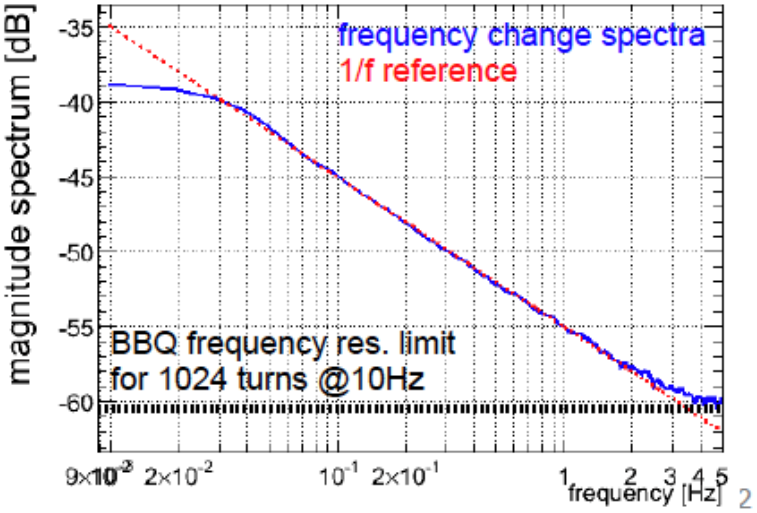
- Residual 8 kHz confirmed to be due to the UPS
  - Damper 200W driver output spectrum, UPS 'on' vs. 'off' (courtesy W. Hofle):
- The 'hump' seemed to become more apparent during commissioning:
  - Predominantly seen in vertical plane
  - Beam gets resonantly excited if tune in the vicinity of this frequency
  - Emittance blow-up nicely seen by sync light monitor
- Amplitude seems to approximately scale with energy
- Actually a fast frequency shifting oscillation with the mean drifting slowly between 0.25...0.32 frev

The hump

- Hump on Beam 1 is correlated with the one in Beam 2:





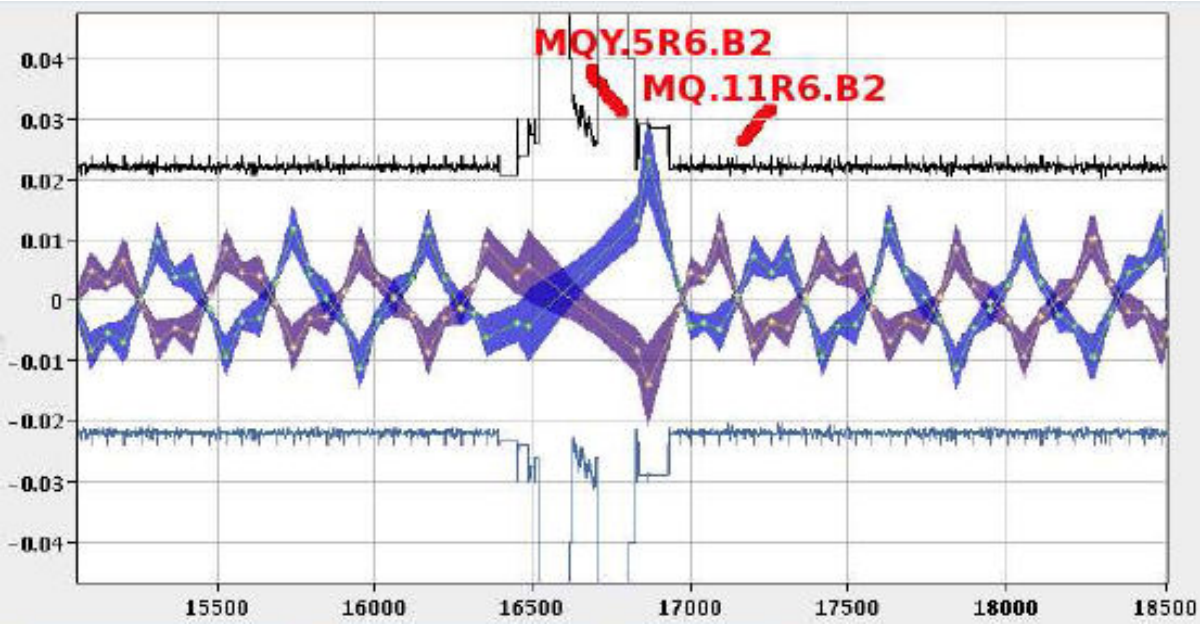


Hunting the hump – a priority for 2010

Aperture

Rogelio Tomás,

- 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

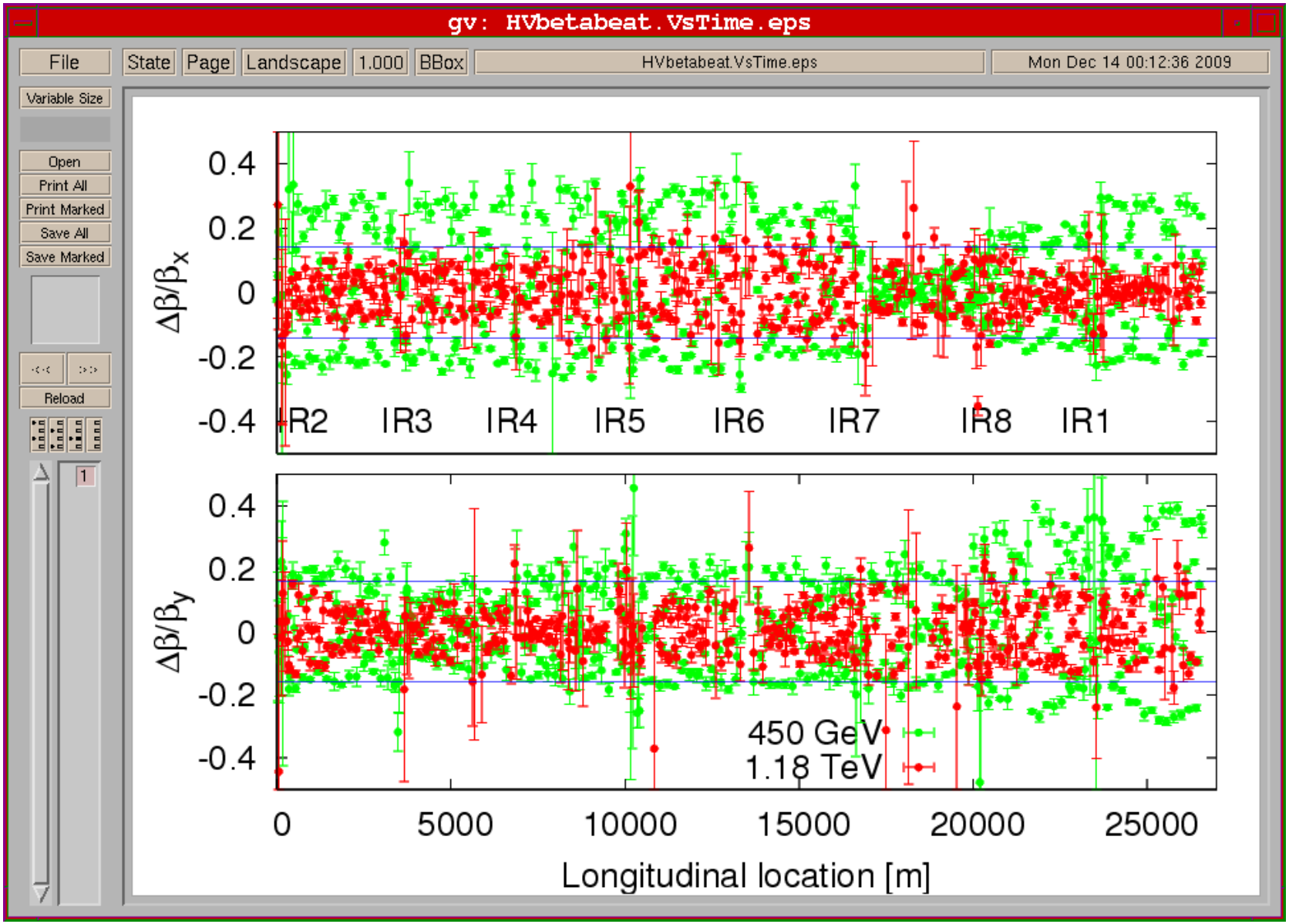


Beta beating

Rogelio Tomás,

- Important to get this corrected early on
  - Otherwise we have to re-visit MP and other optimization afterwards.
- Beta Beating actually not that bad.
- Important to understand the sources, possible candidates include:
- IR3 and IR7
  - Q6 not pre-cycled … should be
  - Can largely correct β-beat with 3% change in warm quads ????
- IR2 & IR8
  - 50 units on Q2 (IR2) – rather large
  - Is it reasonable to just tweak individual IT quads???

Beating: 450 & 1180 GeV



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 RT packet
8	16/12/09	1/2	1180	Squeeze/collisions

Seriously impressive

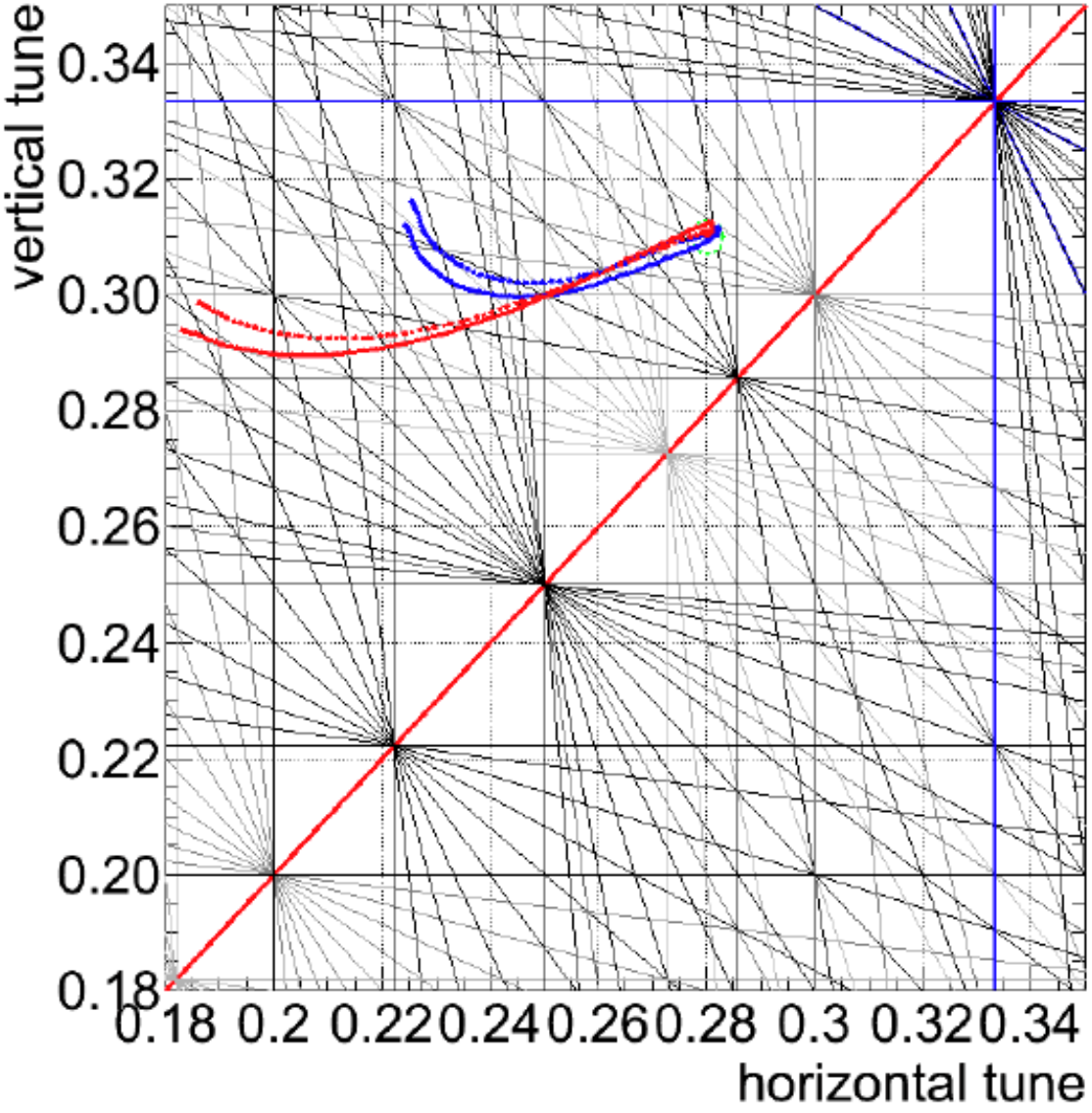
Ramp - issues

Ramp looked good (and reproducible)

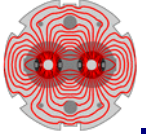
Both tune feedback and feed-forward operational

- 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

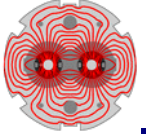


Not understood



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

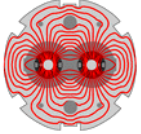
Ezio Todesco

- 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
- Future priorities
  - Origin of beta beating
  - Spectrometers/compensators transfer functions
  - Correction of the snapback at 6 kA – new equations
  - Tune drift during ramp: origin?
  - Better understand tune and Q' trims used at injection
  - Implement hysteresis in LSA
  - Continue measurements on dipoles to characterize them at 3.5 and 5 TeV precycle
- Cross-check, cross-check, cross-check ...

THE LHC IS NOT A LEPTON MACHINE!

- Working point was chosen for flattest region in the aperture. At high energy collisions bb effects are leading the dynamics and indeed it is foreseen to change the tune in collisions, to stay away from the high order resonances.
- WP at injection was meant for separated beams!
- If bad lifetime is observed, it might be due to IBS!
- Emittance fluctuation is an important parameter, and time should be sent to correct the unbalanced beam sizes
- Hump must be cleared as it will appear in both beams through collisions and any tune modulation will be a killer.
- Visible bb effects expected at injection. If emittance smaller than nominal then tune spread is worst!

Beam-beam effects already clearly seen

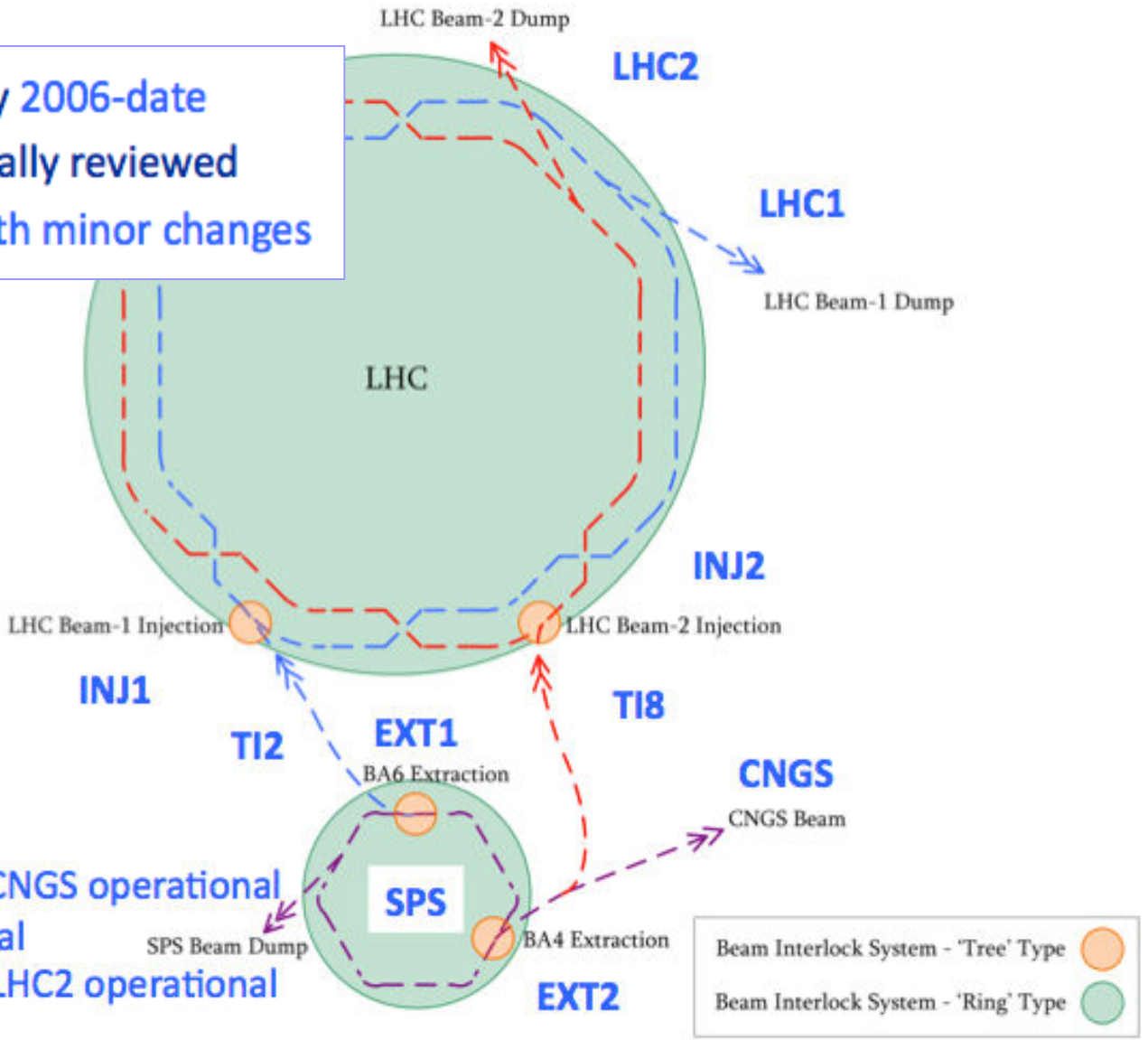


MACHINE PROTECTION

BIS-BIC-SMP

Dr. 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

Safe Machine Parameters (SMP)

- There are known limitations with the 2009 implementation
- Reinforce the 2009 system for 2010 over the next 4 weeks
- NB: The final LHC SMP system to be ready in 2011 for nominal energy and intensity

Note: SMP is only as strong as its dependencies:

- Intensity Information – Beam Current Transformer
  Dependability (safety, reliability, availability) must be clarified
- Transmission medium – General Machine Timing
  Various methods and solutions for cross-checking must be investigated

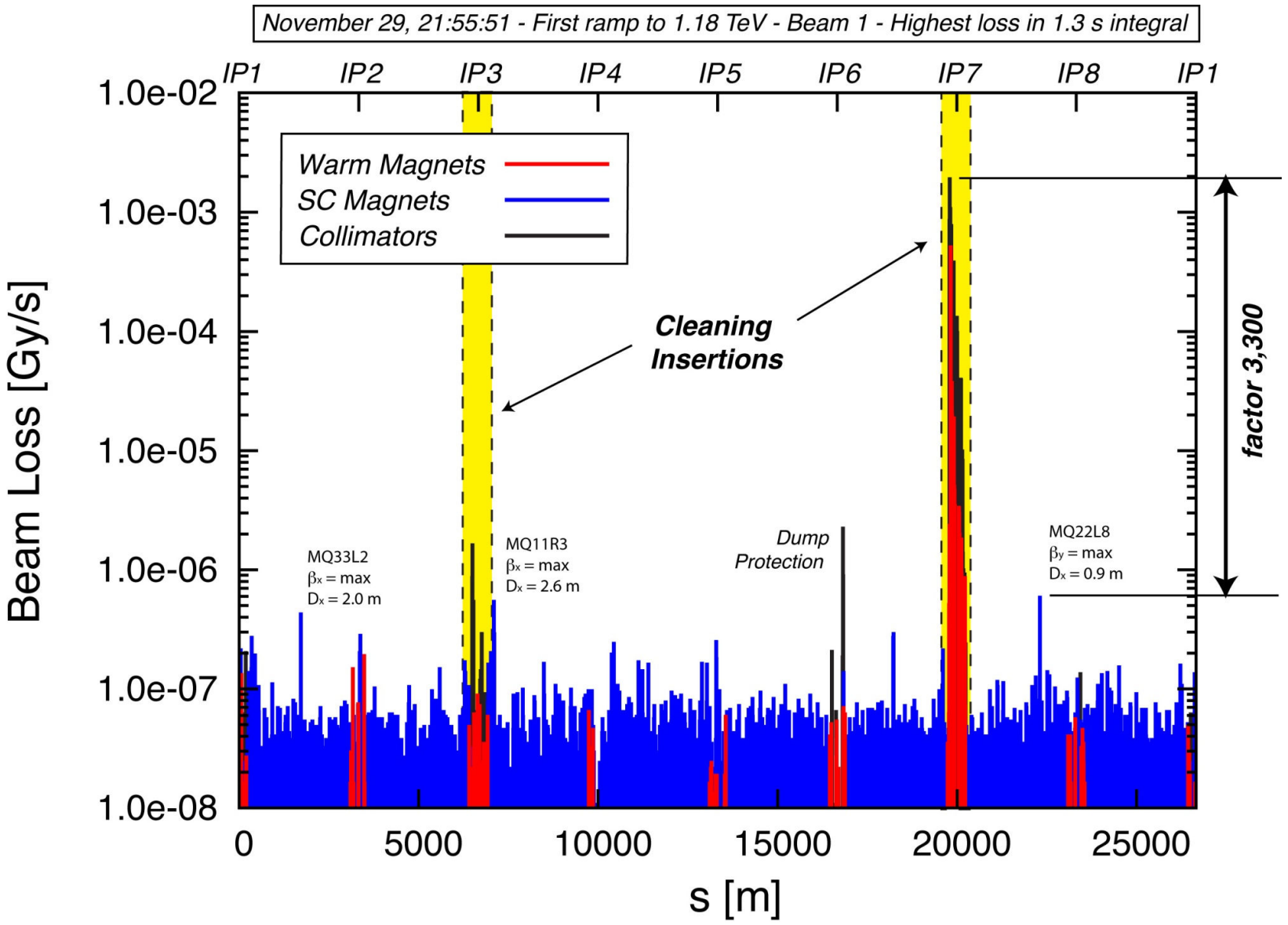
Collimation

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

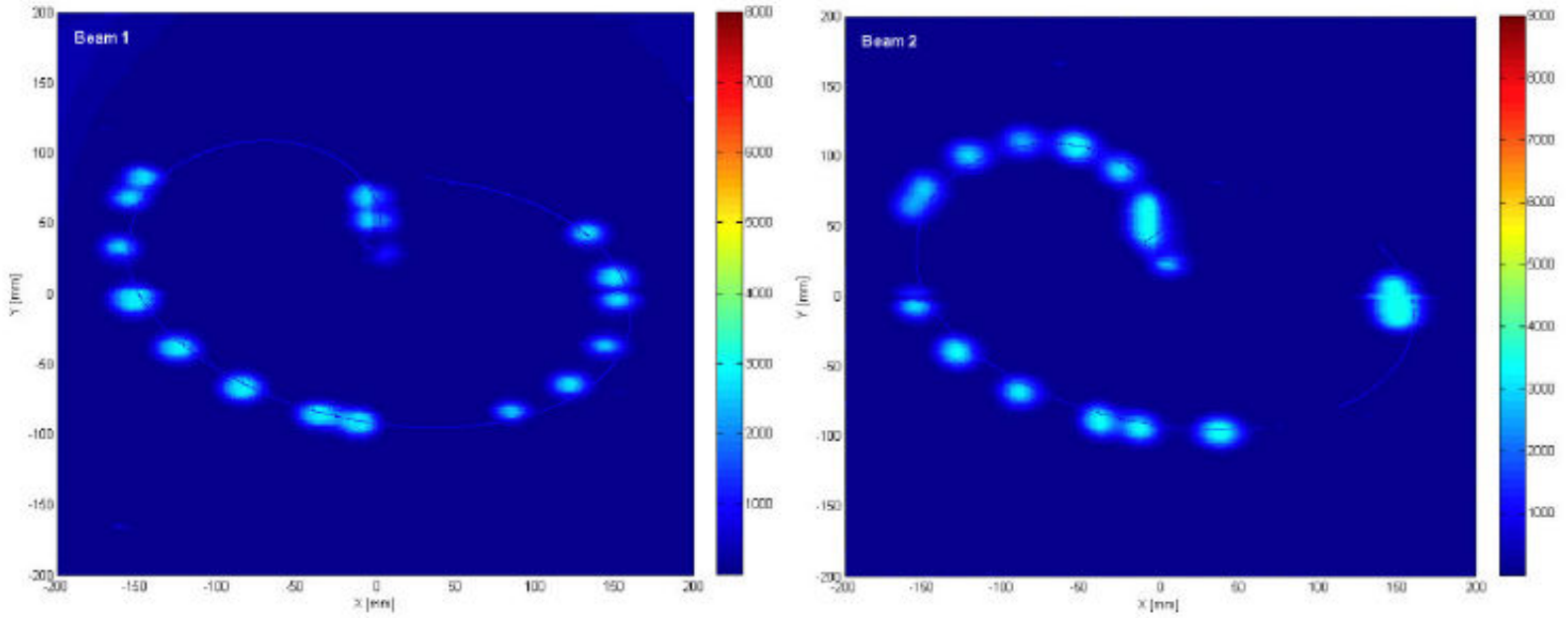


Collimation - issues

- Beam-based settings different from theoretical:
  - why? Need to understand in more detail. More beam time.
- Wrong sequence -> collimators parking -> interlocks.
  - Safe but not nice. Follow logical & debugged sequence is essential. Cannot set up by hand.
- Abnormal losses in right dispersion suppressor of IR3:
  - why? Leftover alignment error from 3-4 incident? Needs to be understood.
- Power cut: all collimators could be reset by STI piquet quite fast (~2h). This is a feature, as controls is on UPS, not the high power drivers.
- Need faster analysis for loss maps, collimator movements, interlocks, …

Plenty of time still required for further commissioning

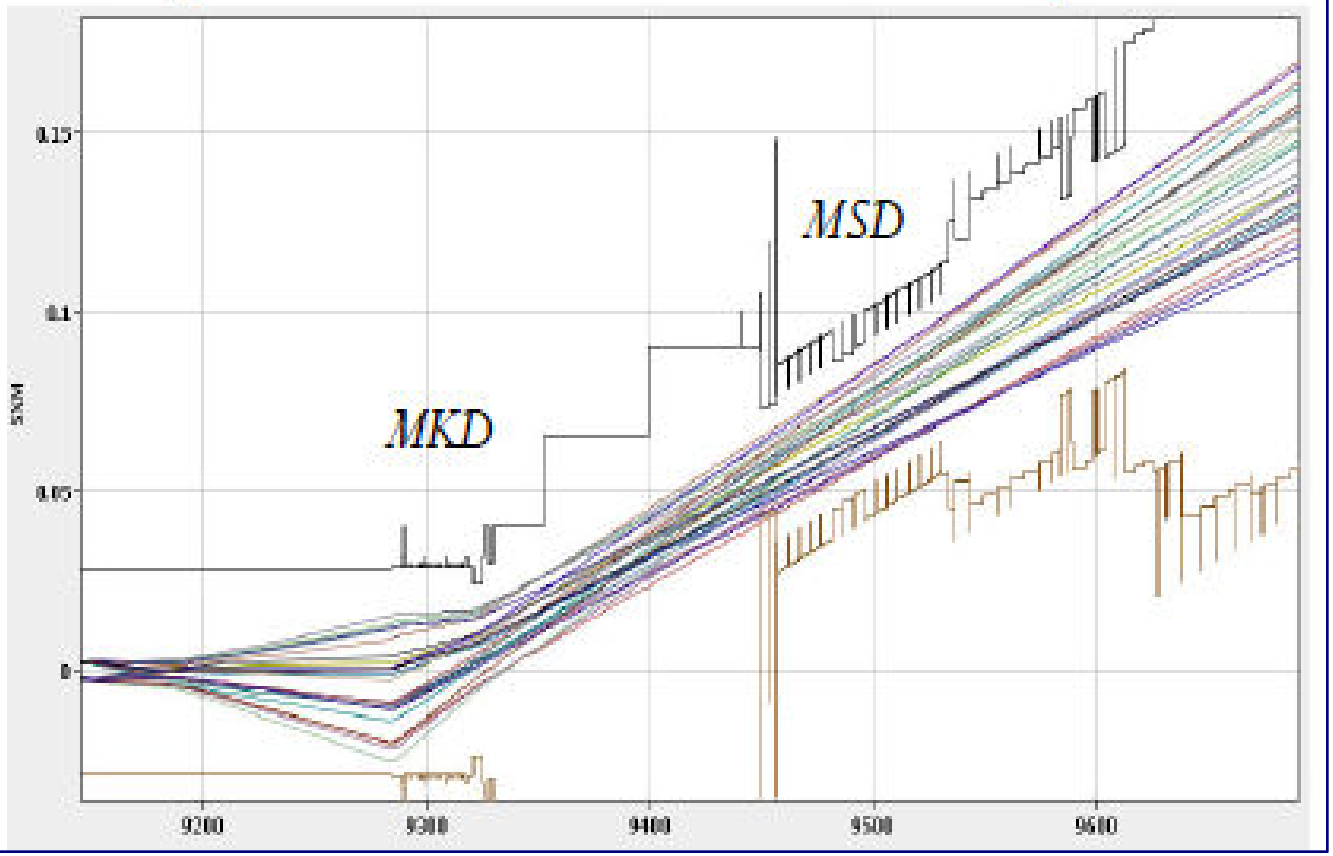
Beams for physics dumped, at the right place! 450 GeV



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.

LBDS – full program of beam based tests

Aperture limits measured with all phases in H and V plane for B1 and B2 → as expected



Beam dump – are we ready for higher energies?

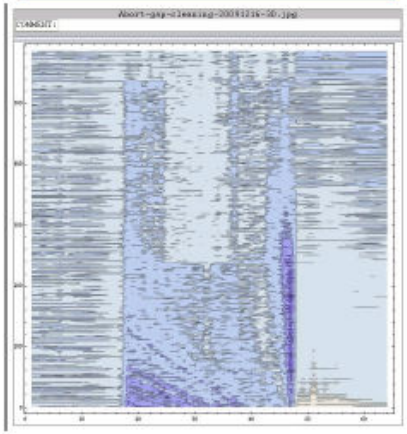
- The beam dumping systems worked very well and the XPOC and IPOC systems caught all failures
  - Only real failures were the Synchronous-Asynchronous dumps: solved after TSU firmware upgrade
- Many tests with beam outstanding
  - Dump at intermediate energies
  - Positioning of protection devices
  - Follow commissioning procedures for increasing energy and intensity
- Need to converge to a more standard way of running sequences

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



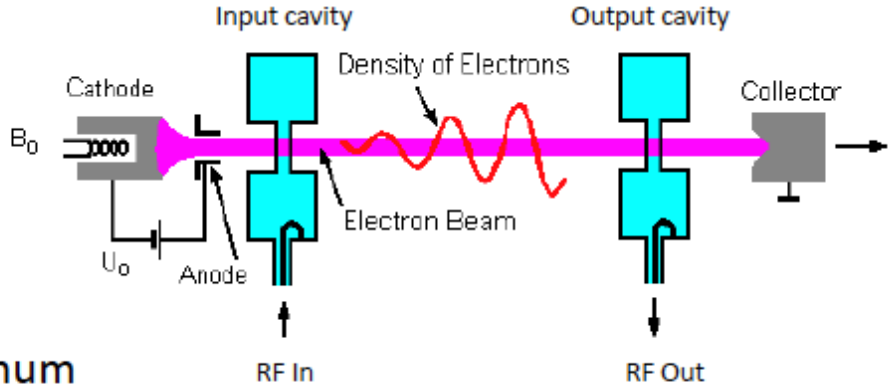
RF

Andy Butterworth

- Power system:
  - minor hardware problems understood and addressed
  - possible concern over klystron collectors – limited to around 80% of nominal power – collector design fault
- Time needed to commission variable cavity Q
- Controls & software:
  - major operational problems solved
- Low level & synchro:
  - various causes for synchronisation problems understood and resolved
- Readiness for unsafe beam:
  - addition of interlocks on cavity sum, frequency and synchro
- To do…
  - Q change, 1T feedback, longitudinal feedback, emittance blowup...

Klystron Collector Power

$$P_{collector} = P_{DC} - P_{RFout}$$



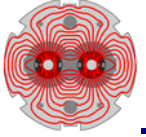
→ $P_{collector}$ close to rated maximum

Collector opened 15/01/10

Potential concern - under investigation.

Transverse Damper (ADT)

- Commissioning with beam started, need dedicated time 2010 for commissioning!
- Noise spectra need attention, remove ground loops by common mode chokes
  - improved ground between surface and underground areas necessary ?
- Two pick-up cables (7/8”) will be replaced during the technical stop,
  - performance for multi-bunch operation to be checked (residual ripple from cable)
- Abort gap cleaning promising, but pulse shape optimization required



BEAM INSTRUMENTATION

BPM and COD polarity checks

Kajetan Fuschberger

BPMs:

	total	checked	ok	%checked	% ok
Beam 1	1076	1076	1050	**100,00%**	**97.58%**
Beam 2	1076	1076	1058	**100,00%**	**98.33%**

Work on all BPM issues already ongoing by BI

CODs (without MCBX):

	total	checked	ok	%checked	% ok
Beam 1	508	483	483	**95,08%**	**100,00%**
Beam 2	508	371	371	**73,03%**	**100,00%**

Also MCBX should be systematically checked.

(At least one of them seemed to be inverted)

Orbit

- Very stable (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.
- Open issues:
  - Drifts between Pt7 and Pt1 (maybe also temperature?)
  - Vertical offsets in arcs 23,34,45. Proposal: check with aperture if orbit is centered or not.
  - Switch of BPM high/low sensitivity: Check resulting orbit change. When/how to switch?
- Orbit feedback
  - Basically operational, time needed for testing
  - Essential for ramp and squeeze

BLMs

Christos Zamantzas

- 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.

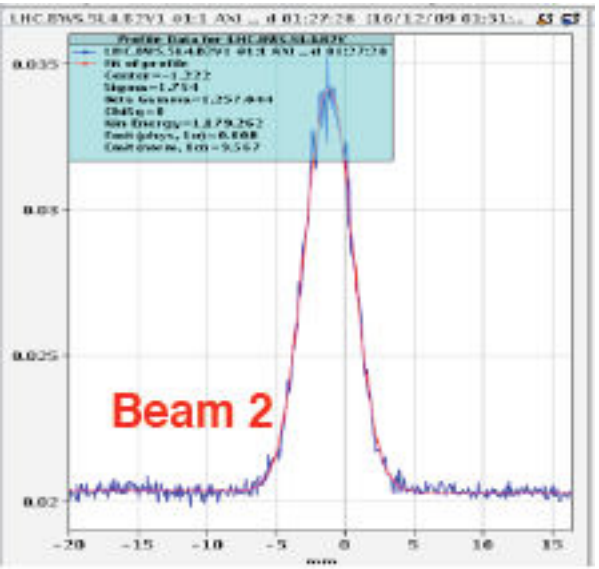
- Some availability issues (false dumps) at energies higher than the injection are to be expected if thresholds don't change in some regions.
- Continuous monitoring of noise is required.
- Sequencer initiated tests will be enforced to be run regularly.

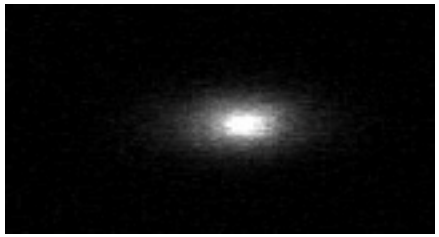
- More tests to verify and adjust the threshold values are needed.
- Investigation of spurious signals from the SEMs are ongoing and first corrections are being implemented.

Profile monitors

Thibaut Lefevre

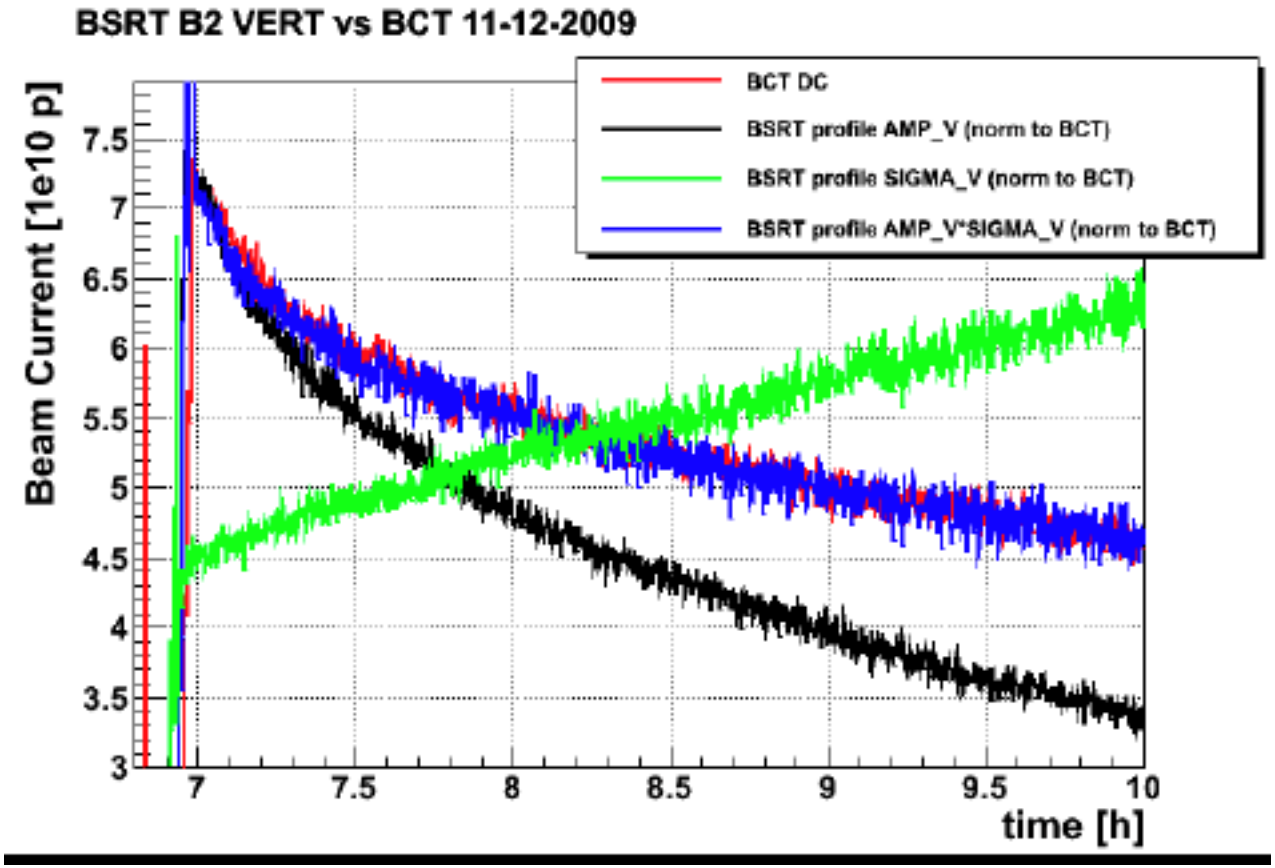
- **BTVs and Wire scanners** works quite reliably – still few bugs to be fixed
- **Synchrotron Light Monitors**
  - Systems worked basically as designed - need the other undulator on
  - Deeper analysis of performances on going
  - Cross calibration with respect to Fast BCTs and Wire scanners needed





Synchrotron light monitor

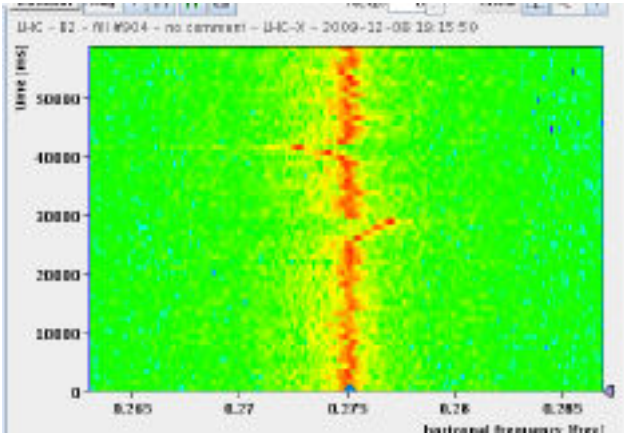
Vertical emittance blow-up – beam 2

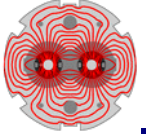


Tune

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





CONTROLS & OPERATIONS

Controls

Wojtek Sliwinski

A number of issues exposed by the hammering commissioning gave the system…

- Infrastructure – disk space, consoles, …
- CMW – proxies, subscriptions, …
- FESA – front-end instabilities
- RBAC – introduction of STRICT policy
- JMS – data publishing
- BE-CO Development Process

Our dedicated team of professionals are working hard to resolve all these issues.

Weak points of operation?

Some important ones from a long list

- Frequent accidental over-injection
- Injection and circulate for many turns with screens IN
- Tacit acceptance of unofficial ‘quiet beam’ mode
- Playing wrong sequence at a bad time
- Wrong timing tables loaded for given sequence/mode
- Parallelism (beam 1/beam 2, and ‘parasitic) in studies
- (Too) easy to disable ‘required’ functionalities
- Collimator/protection device threshold management
- LBDS internal trigger latency to BIS
- Inputs to SMP need to be rock-solid
- No enforced PM analysis or systematic offline dump analysis

Captain Brennan “Blackheart” Goddard

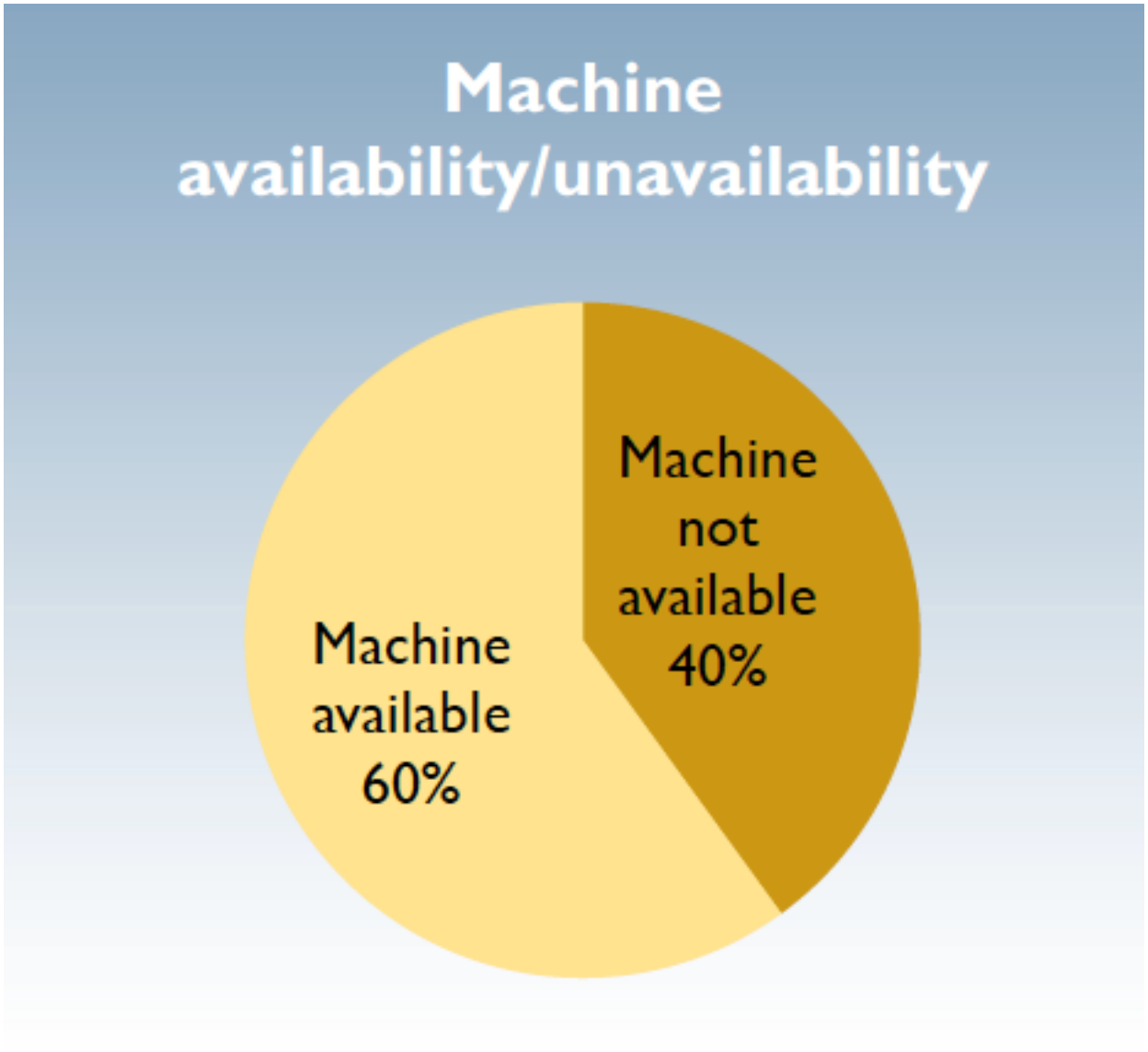
Weak points of operation?

- **There are many, many strong points of LHC operation – honest**
  - Expertise, motivation, dedication, preparation, communication, coordination, teamwork, experience, support, controls, ….
- **After just having learnt to walk, our baby will soon be running with scissors**
- ***We will require much more discipline* when we go above safe beam limit**

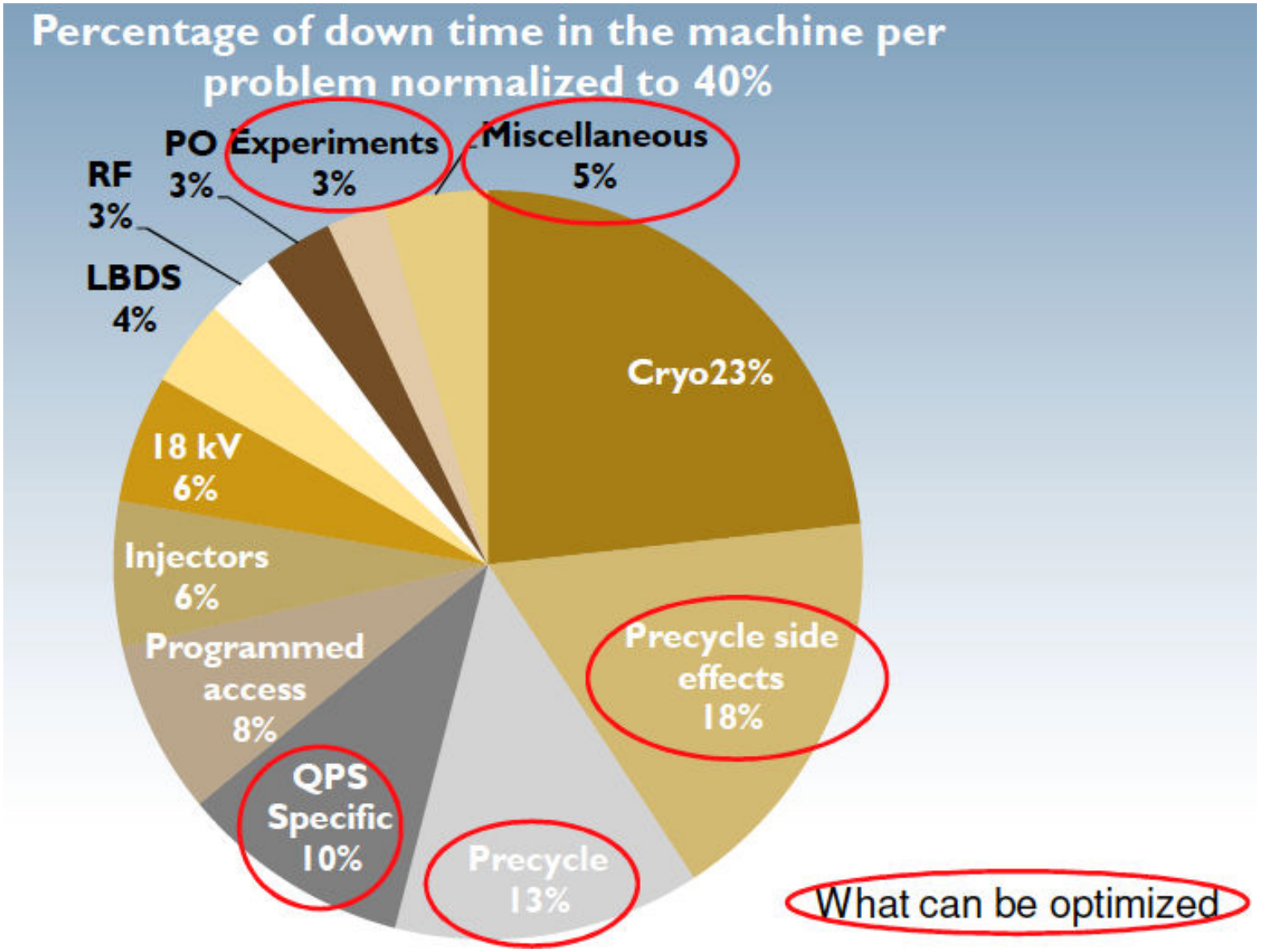
Brennan “We are not at home to Mr. Cockup” Goddard

Availability

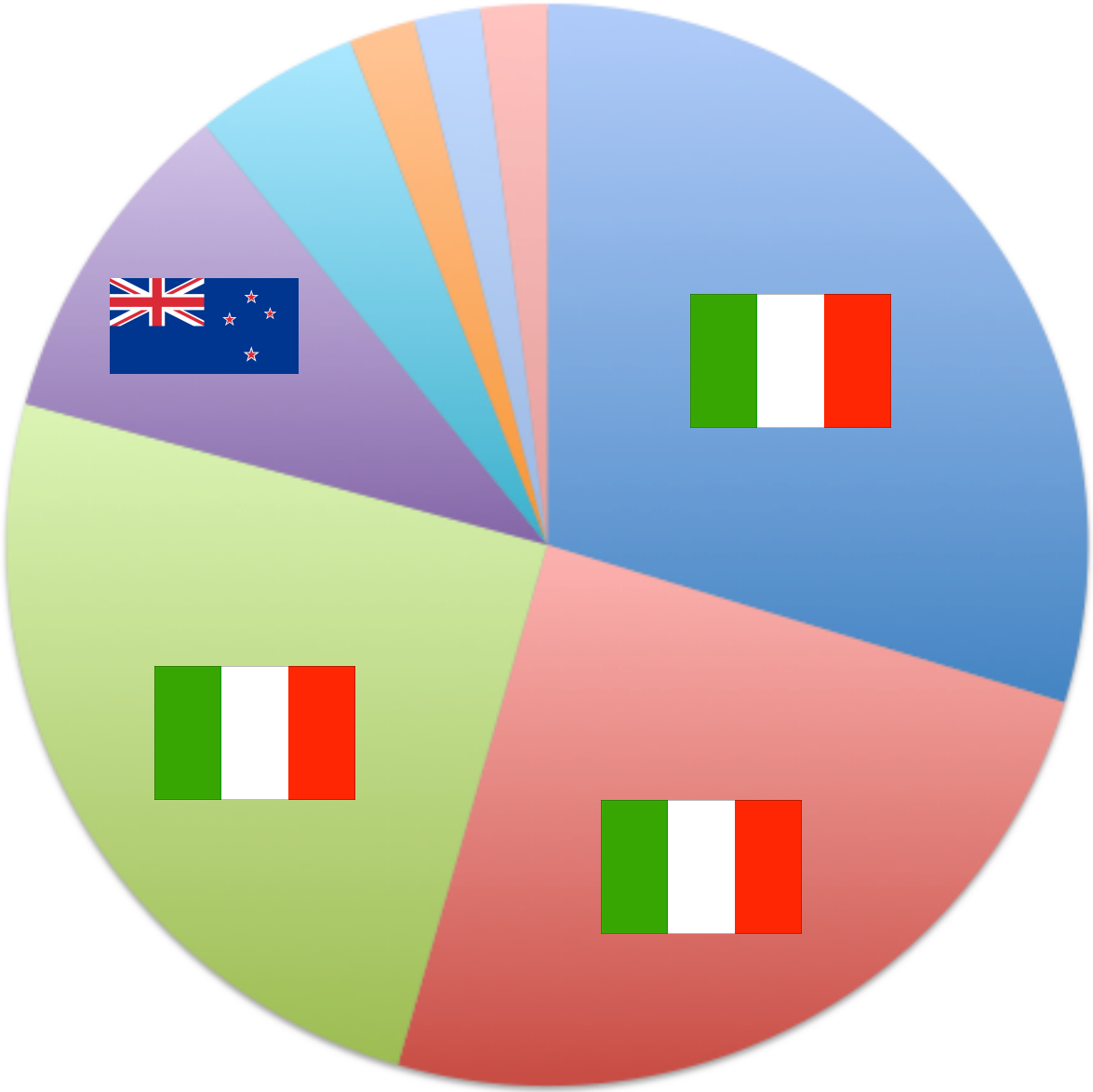
Reyes Alemany



Unavailability



Unavailability by EIC



2010

Chosen not to summarize Massi's summary of the LPC/LBS meeting and his list of experiments' requirements

2010 – parameters

Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	$5x10^{10}$	11 / 10 / 11 / 10	Weeks
2	3.5	2x2	$2 - 5x10^{10}$	11 / 10 / 11 / 10	
3	3.5	2x2*	$2 - 5x10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	$5x10^{10}$	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	$5x10^{10}$	2 / 10 / 2 / 2	
6	3.5	156x156	$9x10^{10}$	2 / 10 / 2 / 2	Months
7	3.5	50 ns - 144**	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
8	3.5	50 ns - 288	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	$7x10^{10}$	2.5 / 3 / 2.5 / 3	Months

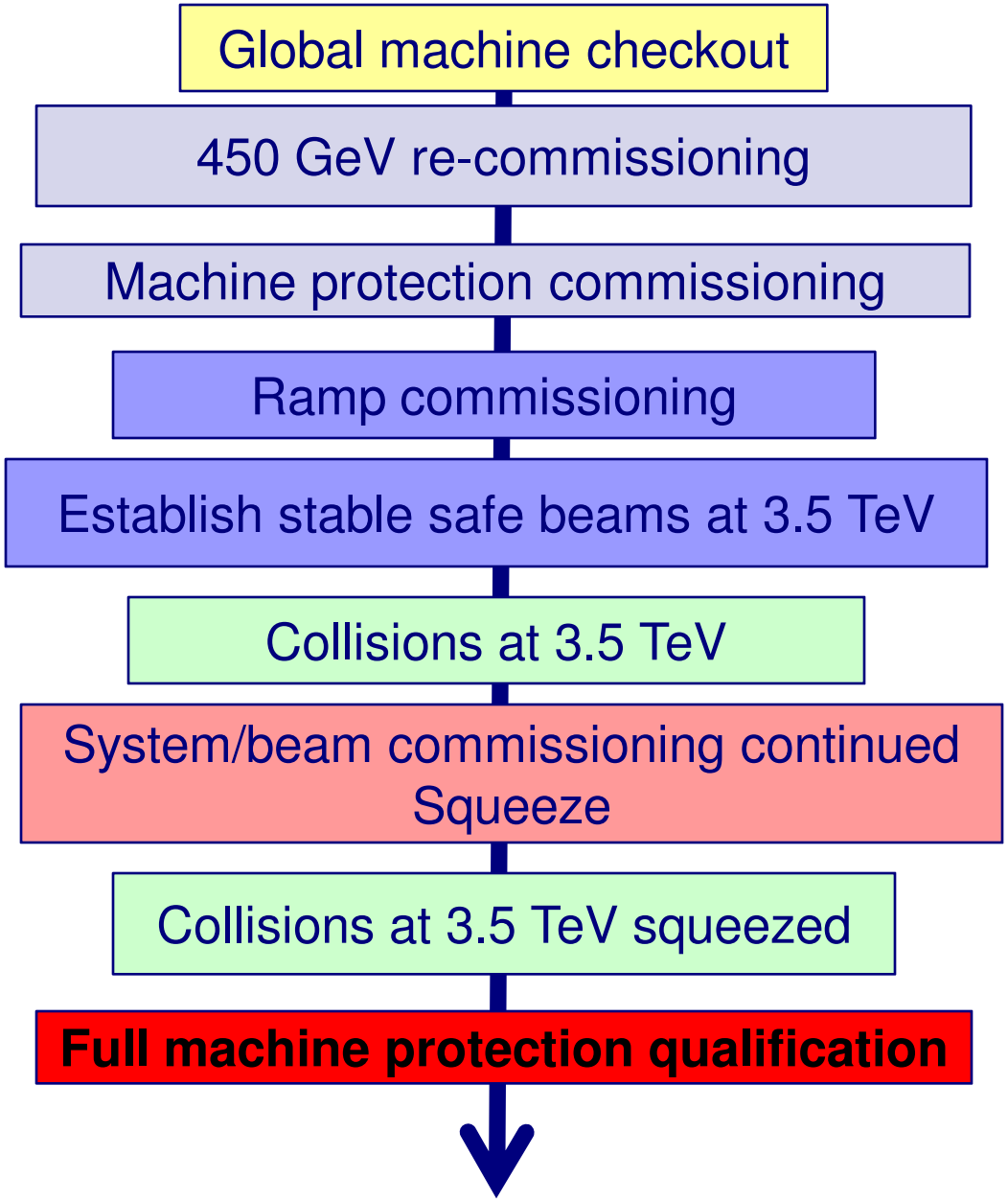
* Turn on crossing angle at IP1.

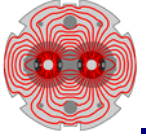
**Turn on crossing angle at all IPs.

- 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

Massimo Gionvannozzi
Werner Herr

Beam commissioning strategy 2010





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

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