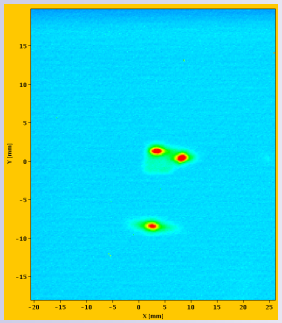
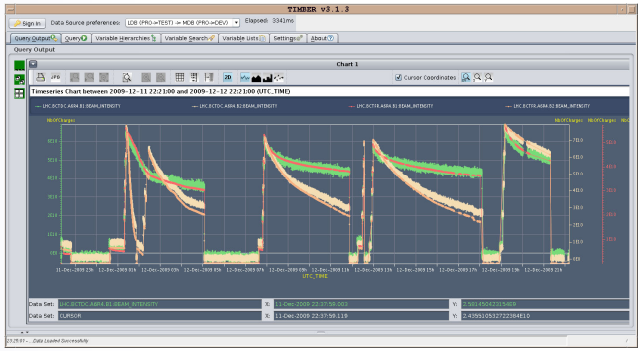
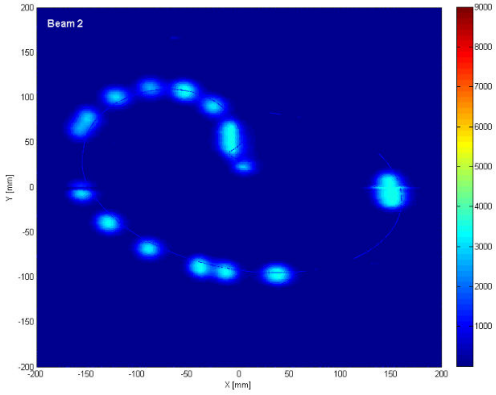
LHC Commissioning 2009

The good, the bad, and the not very pretty

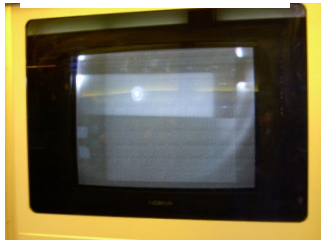


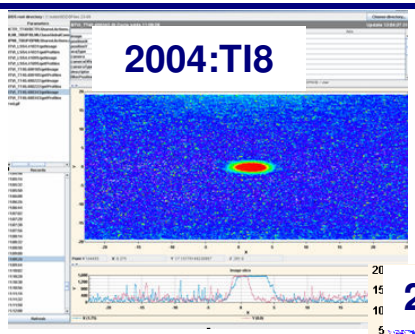


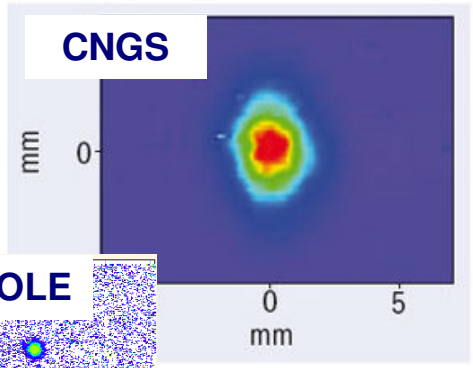


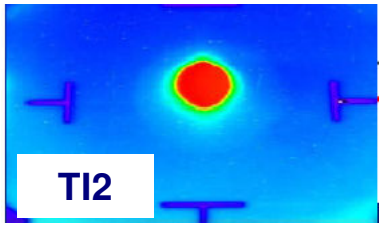
Prep: beam tests through the years

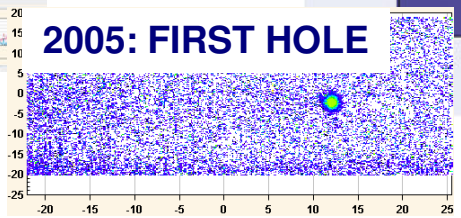
2003:TT40



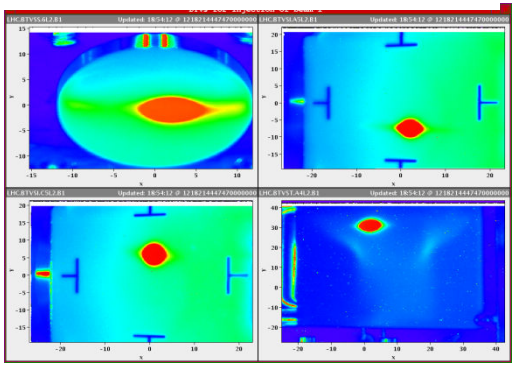




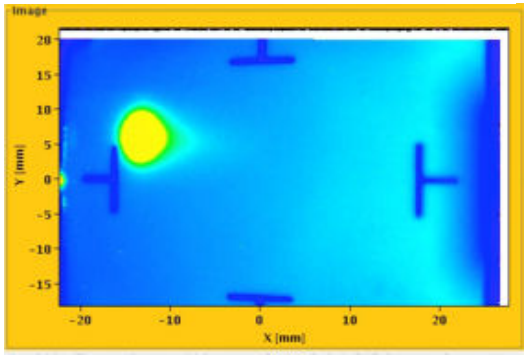




2008: FIRST BEAM TO LHC

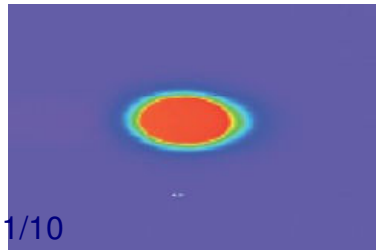


2008: FIRST BEAM TO IR3

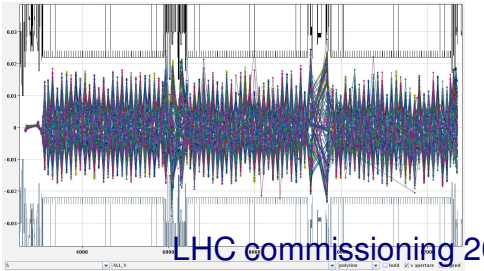


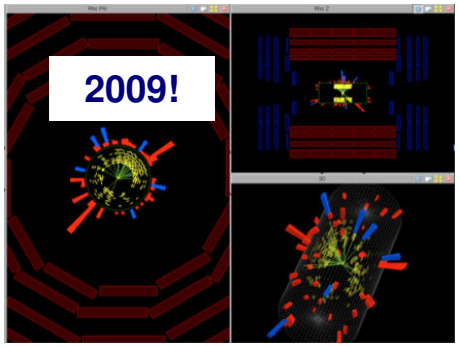
2008: SEPT 10

2009: FIRST IONS TO LHC



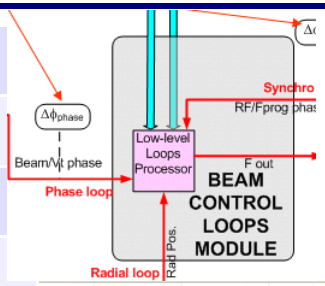
2009: Sector test

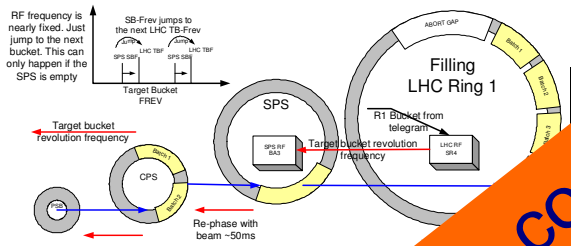


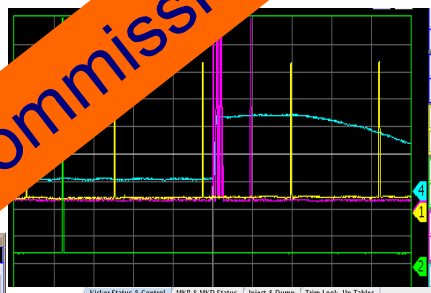


Prep: dry runs and machine checkout

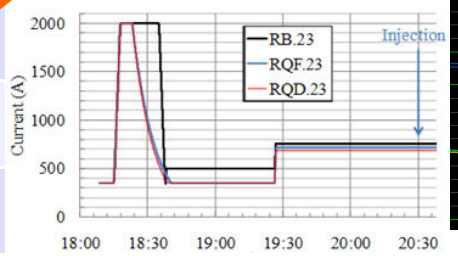
- Extraction
- Transfer lines
- Injection
- RF, injection sequence
- Timing System
- Beam Interlock System
- Collimators
- Vacuum
- Interlocks, SIS
- BLMs, BPMs
- BTV, BCT
- Beam dump
- PGCs
- Magnet model
- Sequencer, alarm
- Controls, logging, DBs
- LSA, optics model, YASP

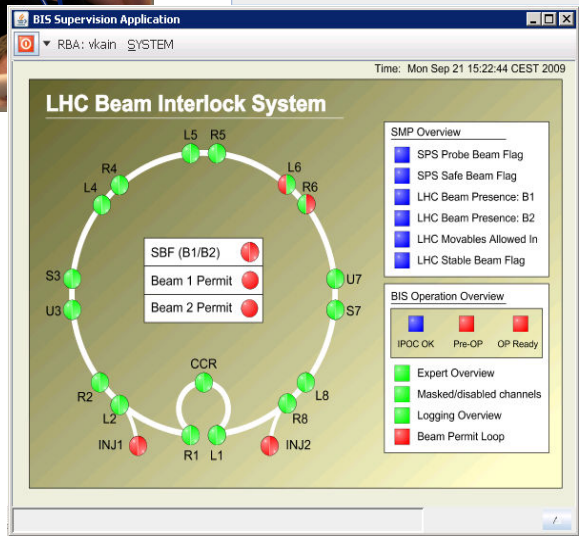






Re-phasing in the SPS:





And, of course, some serious hardware commissioning

Milestones 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 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

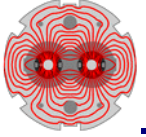
Milestones 2/2

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

Overview

- All in all – rather impressive
- Got seriously operational on most beam based systems
- Managed to start to master control of a hugely complex system
- Operations very much in commissioning mode: this phase part of a necessary learning process
- Furious amount of problem resolution and debugging going on.



Via the nominal cycle, some key areas if importance, beam instrumentation, controls

THE GOOD

Nominal cycle: precycle

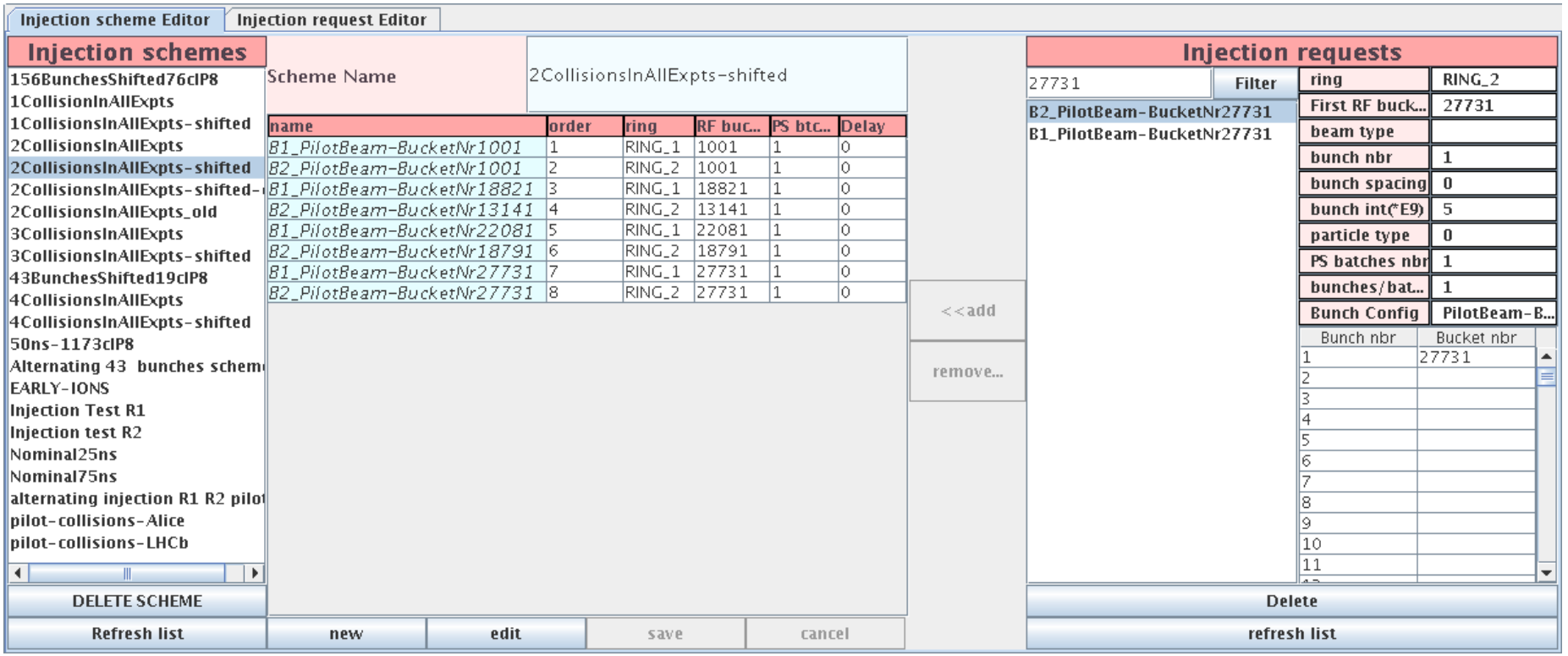
- Fully deployed with precyling prescriptions in place for nearly all circuits
- Very good reproducibility
- Handful of circuits still missing
  - Q6, compensators…
- Some optimization of total length possible
- Stressed QPS/power converters – frequent trips during the process

Nominal cycle: injection

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

- Re-phasing, synchronization & transfer & capture
  - Excellent – some RF controls and 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.
- Issues: over-injection, beam dump with beam on TDI, aperture, injection kicker not firing

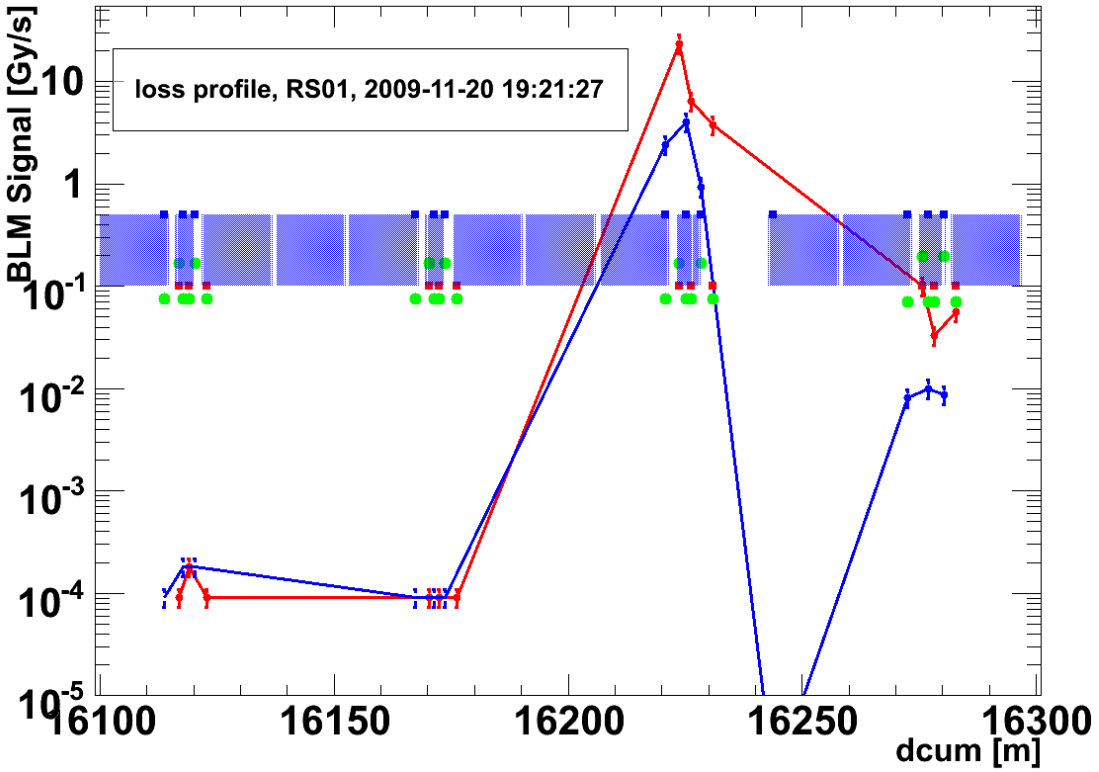
Nominal cycle: injection



Generally very impressive, clearly benefits from experience gained during injection tests. For the moment one would worry about routinely injecting unsafe beam.

Nominal cycle: injection

- We can still cause quenchinos with very little beam



by mistake…

Nominal cycle: 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 (some issues)

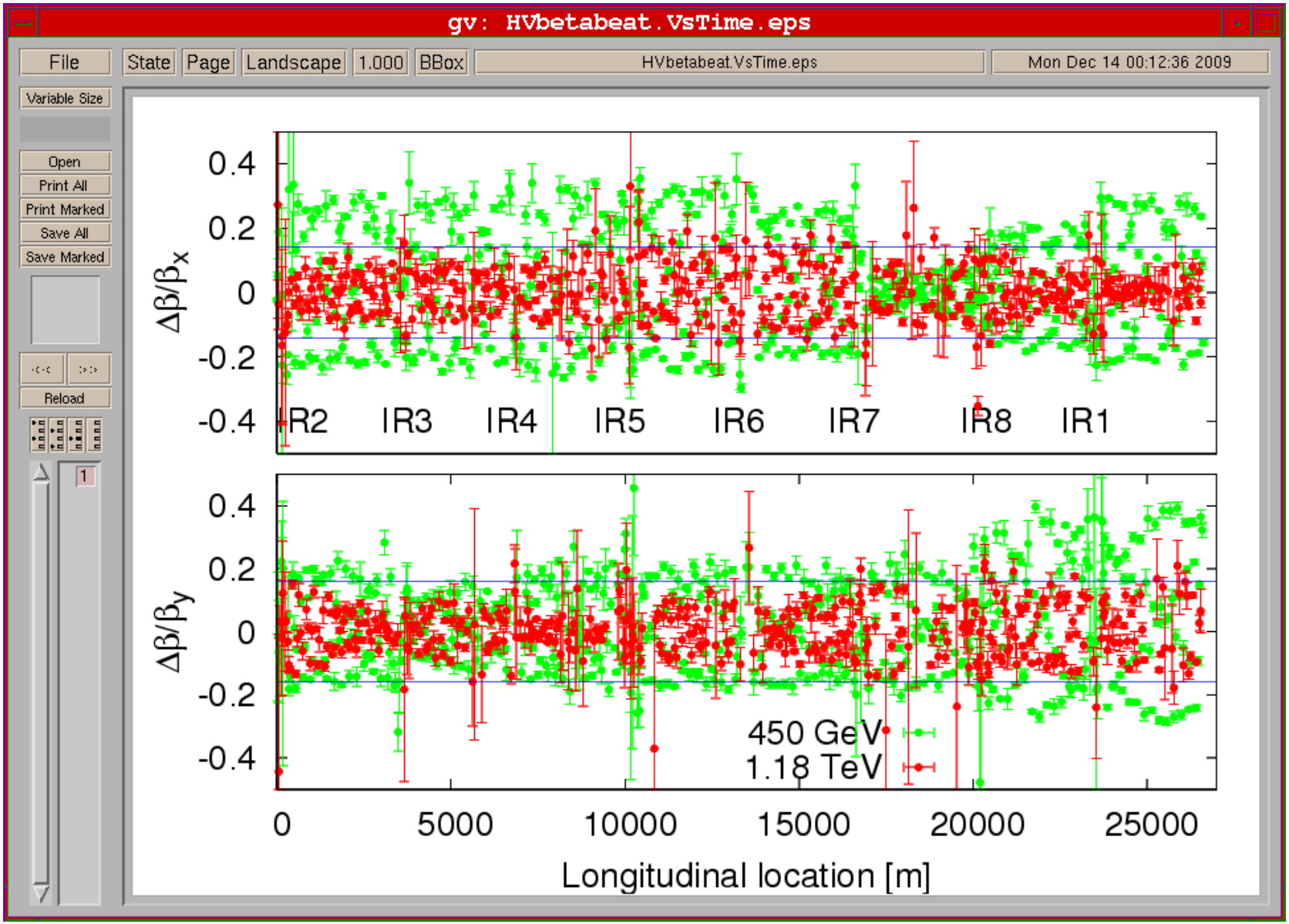
Availability of hardware, instrumentation and software
very, very impressive

Good preparation – fast problem resolution – leveraging C21st technology

Nominal cycle: 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 & correction
- Full program of polarity checks of correctors and BPMs

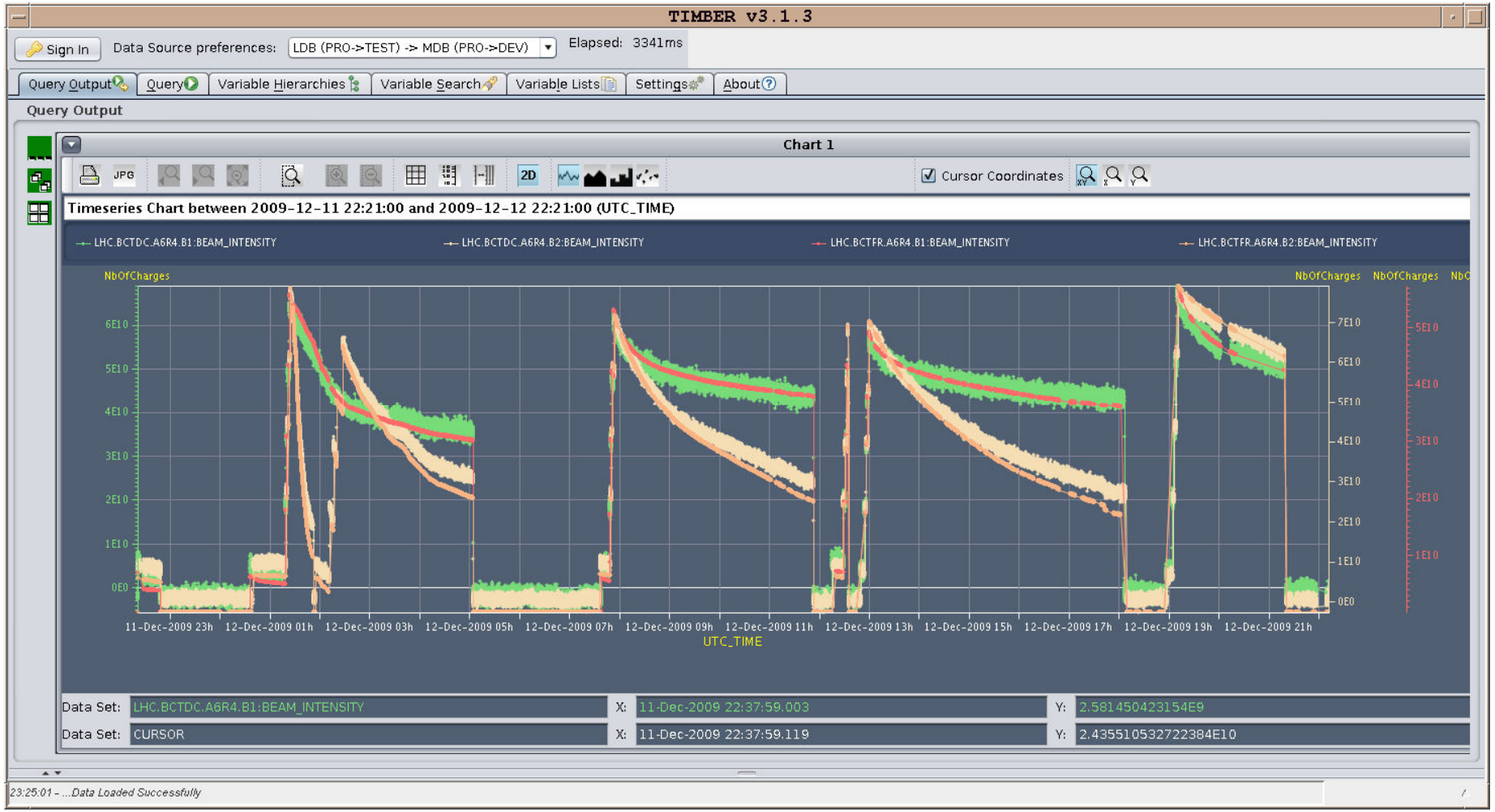
Beating: 450 & 1180 GeV



Collisions at 450 GeV

- Man was never meant to do collisions at 450 GeV
- 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
- Hundreds and hundreds of thousands of events collected
  - 6 happy experiments
- Clear issue here 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

Nominal cycle: ramp

	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 beam 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

This is definitely showing off

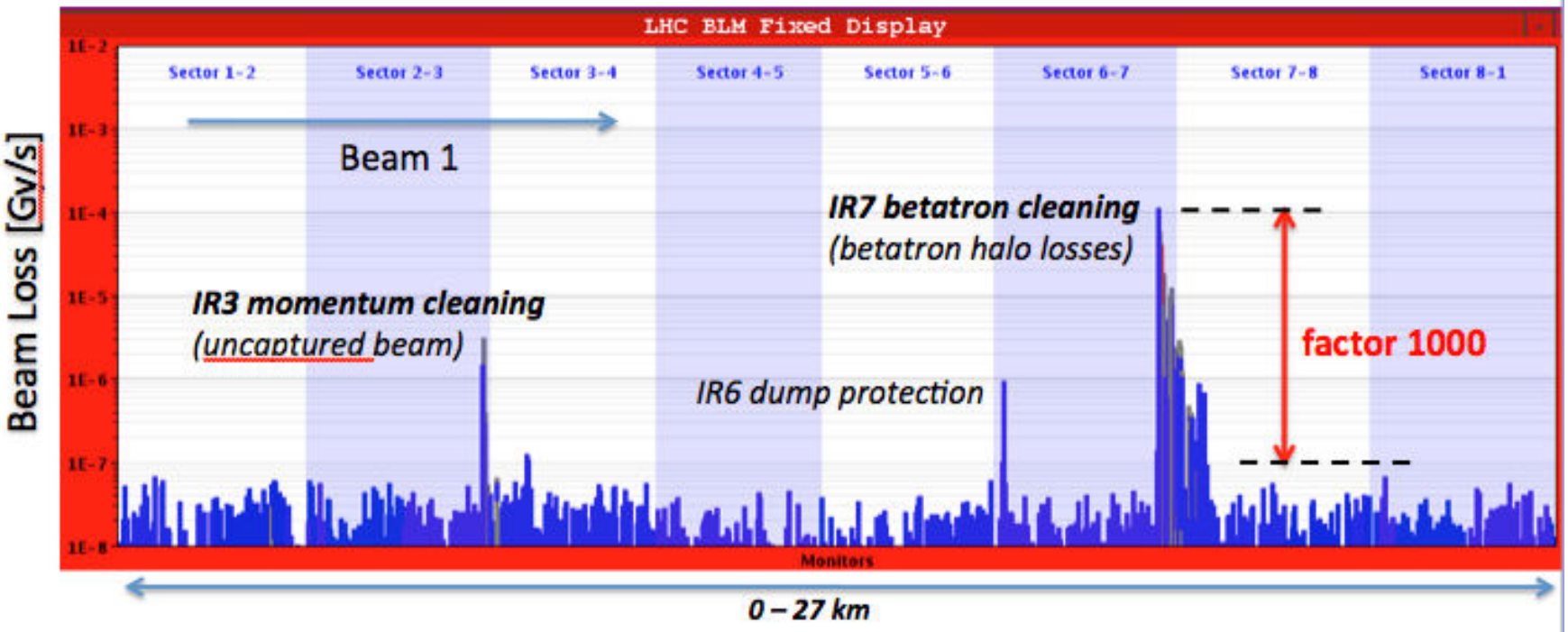
Ramp

- Settings – a fully consistent set
  - Fidel – all main transfer functions, harmonics etc.
  - RF – complicated parameter space in place
- Tune feed-forward
  - Reproducibility looks very good
- Tune feedback
  - Pretty miraculous
- Orbit
  - RT acquisition immediately available
  - Feed-forward strategy?
- Issues
  - Tune swing to be understood
  - Appropriate incorporation methods to be deployed.

First Multi-Stage Betatron and Momentum Collimation

21/100 coll. beam-based aligned to nominal settings for trial ramp 24.11.2009 (others coarse).

IR7	Primary:	5.7 σ	Secondary:	~10 σ	Tungsten absorber:	10 σ
IR3	Primary:	8.0 σ	Secondary:	~10 σ	Tungsten absorber:	10 σ
IR6	TCS:	~7.0 σ	TCDQ:	~8.0 σ		



- No unexpected losses in arcs, experimental insertions, …
- Initial cleaning efficiency: > 99 %

Nominal cycle: squeeze

- One successfully if not smooth attempt:
  1. shift to collision tunes,
  2. 11 to 9 m.
  3. 9 to 7 m.
- Some work required here but impressive nonetheless
  - Settings strategy worked and respected the need
    - for smooth round-off at intermediate optics
    - Single quadrant power converter limitations
  - Tunes, beating, dispersion etc at intermediate points
- Lots more incoming from Stefano

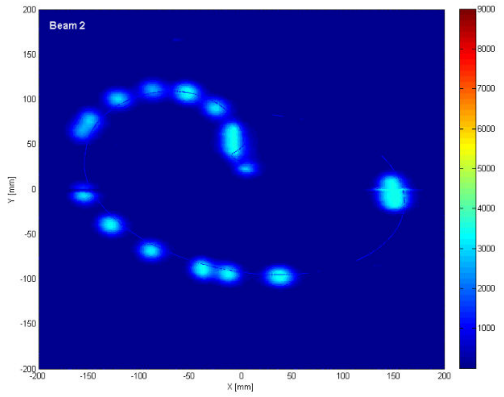
For a first attempt – no so much showing off but flaunting it

LHC Beam Dump System

Rigorous and vigorous commissioning program

- Extensive program of tests with beam
  - Beam based alignment of TCDQ and TCS
  - Aperture scans
  - Extraction tests
  - Asynchronous beam dump tests with de-bunched beam
- BETS, XPOC, IPOC, timing, synchronization, abort gap, inject & dump, circulate & dump, TSU etc. etc.
- Asynchronous dumps

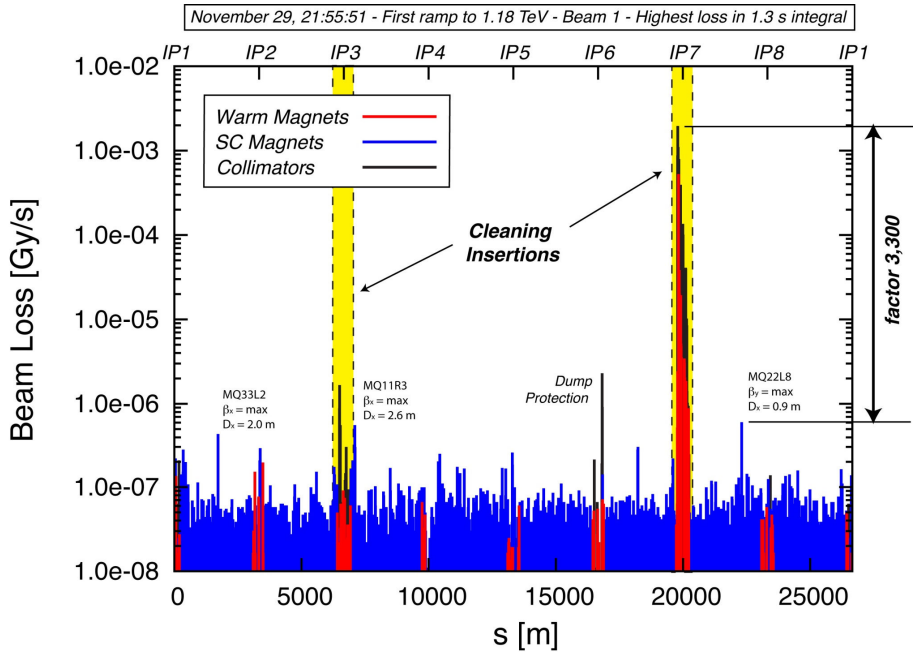
Lots more tomorrow…

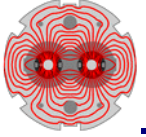


Collimation

Again excellent initial beam based commissioning following careful preparation and tests

- Full program of beam based positioning,
- 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





Machine Protection

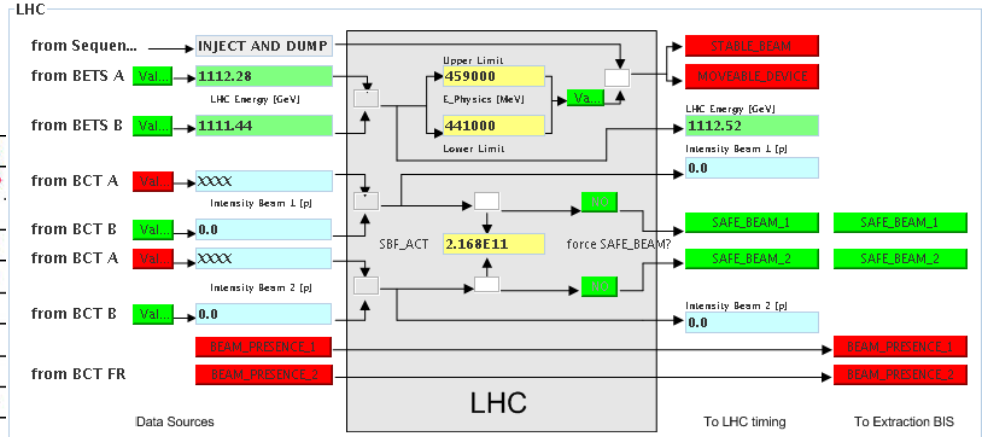
- Mission critical backbone
  - Beam Interlock System
  - Safe Machine Parameter
  - Plus inputs to/from other systems (e.g. timing, BCT)
- A large multitude of user inputs
- The beam driving a subtle interplay of:
  - LBDS, Collimation, protection devices, RF…
  - Instrumentation (BLMs, BCT, BPMs…)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

Careful testing before beam

Full set of beam based tests

Clearly the critical path

Machine protection



			R1	L2	R2	U3	S3	L4													
UNmaskable	1	**Vacuum** (Sector valves)		♦♦	♦♦	♦♦		♦♦													
		("X valves")	♦	♦	♦																
	2	**PIC** (for essential circuits)	♦	♦	♦	♦♦		♦													
	3	**BLM** (at aperture limitations)		♦			♦	♦													
	4	**Warm magnets (WIC)**		♦		♦															
	5	**Beam Dumping system**																			
	6	**Injection Kicker**			♦																
	7	**Access** (LASS + E.I.S.)				♦		♦													
	8	**Operator Buttons** (CCC)																			
	9	**Programmed Beam Dump**																♦♦			2
	10	**Safe Machine Parameters sys**																♦♦			2
	11	***ATLAS*** (Detector part)	♦																♦	♦	3
	12	" " (Movable device)	♦♦																		2
	13	***ALICE*** (Detector part)			♦														♦	♦	3
	14	***CMS*** (Detector part)									♦♦								♦	♦	4
	15	***LHCb*** (Detector part)														♦			♦	♦	3
	16	" " (Movable device)														♦					1
	17	***LHCF***	♦																		1
	18	***TOTEM***									♦♦								♦	♦	4
Maskable	19	**Collimation** (Env. Param.)	♦♦	♦♦	♦♦	♦♦				♦♦	♦♦	♦♦		♦♦		♦♦	♦♦		♦♦	♦♦	24
	20	**Collimation** (Motor pos.)	♦♦	♦♦	♦♦	♦♦				♦♦	♦♦	♦♦		♦♦		♦♦	♦♦	♦♦	♦♦	♦♦	26
	21	**PIC** (for auxiliary circuits)	♦	♦	♦	♦♦		♦	♦	♦	♦	♦	♦	♦♦		♦	♦	♦			16
	22	**BLM** (in the arcs)		♦			♦	♦		♦		♦			♦	♦		♦			8
	23	**Screens**		♦		♦♦			♦♦				♦♦	♦			♦				9
	24	**Fast Magnet Current ch. Mon**			♦♦		♦♦♦				♦		♦♦		♦♦♦			♦		♦♦	♦♦	16
	25	**RF & Transverse Damper**						♦♦	♦♦												4
	26	**Beam Aperture Kicker**						♦♦													2
	27	**TCDQ**										♦♦									2
	28	**Fast BCT** (di/dt)							♦♦												2
	29	**Beam excursion (BPM)**											♦♦		♦♦						4
	30	**MSI Power Conv.** (sum fault)																	♦	♦	2
	31	***Experimental Magnets***	♦		♦						♦					♦					4
	32	***ALICE-ZDC***																	♦		1
			♦♦ : Individual Beam connections							♦ : Both Beams connections						*Not connected*			Total: 216		

Overview: beam instrumentation 1/3

- BPMs
  - looking very good, FIFO as per injection tests
  - capture mode commissioned – enabling multi-turn acquisition and analysis
- BLMs
  - magnificent following full deployment during injection tests – a close to fully operational tool
  - issues with SEMs, some thresholds to be adjusted, some still masked
- DBCT, FBCT, lifetime
  - commissioned and operational
  - Calibration & controls issues

Overview: beam instrumentation 2/3

- BTVs
  - operational
- Wire scanners
  - operational, calibrated and giving reasonable numbers
- Abort Gap Monitor
  - giving sensible results
- Synchrotron light monitor
  - B2: undulator commissioned, SLM operational at 450 GeV and 1.2 TeV
  - B1: undulator not commissioned, SLM operational at 1.2 TeV

Overview: beam instrumentation 3/3

- Tune
  - BBQ FFT from day 1 – used in feedback during ramp
    - the work horse – tune, coupling, sometimes chromaticity
  - MKQA tune kickers operational
  - PLL – good progress, feedback to be tested
  - radial modulation tested
  - (issues with the hump, tune stability, 8 kHz)
- Coupling
  - measured and corrected
- Chromaticity
  - Standard delta RF method
  - Semi-automatic BBQ peak analysis
  - Radial modulation

Controls/Operations 1/2

- LSA++
- Logging
- YASP
- Sequencer
- On-line model
- Critical settings
- Alarms
- Timing
- Oasis
- Post mortem
- (Un) Fixed displays

Deployed and tested in good time.

In general pretty good

Some issues – see later

Controls/Operations 2/2

- Injection Quality Check
- RBAC
- DIP/Handshakes etc.
  - some squeals
- Middleware
  - FESA/subscription/proxies
  - Re-boot wars
- Concentrators
  - BLMs, BPMs

- eLogbook – special mention

Magnet model

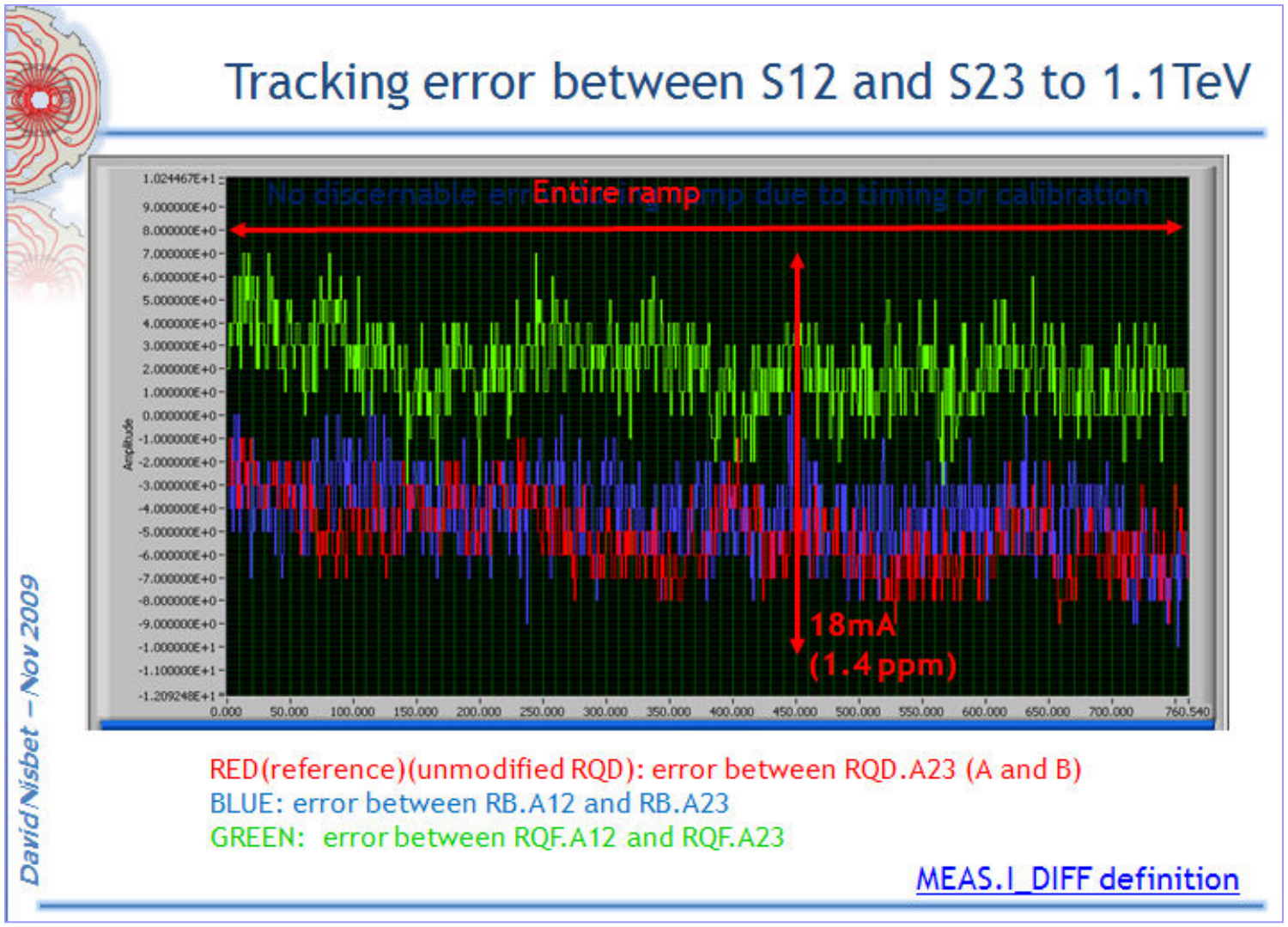
- Are they not Gods?
- Largest momentum offsets by sector:
  - -0.27 permill in sector 56 / beam1
  - +0.32 permill in sector 78 / beam2

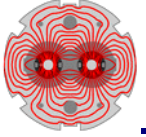
Beam	Parameter	Meas	trim
1	QH	0.28	-0.023
1	QV	0.31	0.049
2	QH	0.28	-0.089
2	QV	0.31	0.015
1	QPH	5	-16
1	QPV	7	2
2	QPH	9	-15
2	QPV	8	2

and check out the beta beating at 1.2 TeV

Power converters

- Are these not Gods as well?





THE NOT SO PRETTY

Advice from PIXAR

Ed Catmull, Academy Award-winning computer scientist and current president of Walt Disney Animation Studios and Pixar Animation Studios.

DON'T LET SUCCESS MASK YOUR PROBLEMS

Post mortem - do a deep analysis

He also has something to say on Cassandra:
the real curse is people who don't listen.

Controls & Operations

From a Machine protection review 2005

It should be noted that control systems for equipment under control which are not safety related as defined above may also contribute to safety and should be properly designed, operated and maintained.

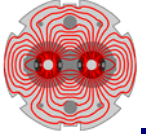
Where their failure can raise the demand rate on the safety related system, and hence increase the overall probability of failure of the safety related system to perform its safety function, then the failure rates and failure modes of the non-safety systems should have been considered in the design, and they should be independent and separate from the safety related system.

We don't rely on the control system for machine protection (networks, front-ends, software, databases, timing system etc.)

However…

A lightning strike on 24 July 1994 contributed to causing a gigantic explosion that rocked the Texaco oil refinery in Milford Haven. The explosion was followed by a fierce blaze, with flames soaring 100 ft into the air.

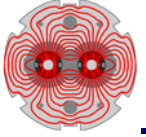
However the direct cause of the explosion that occurred some five hours later was a combination of failures in management, equipment and control systems during the plant upset



Explosion at the Texaco Refinery, Milford Haven. 24th July 1994

Failures in Technical Measures

- A control valve being shut when the control system indicated it was open. Inadequate maintenance of plant and instrumentation.
  - Control Systems: actuator/valve, sensors
  - Maintenance Procedures: maintenance systems
- Modification of the plant which had been carried out without an assessment of the potential consequences.
  - Plant Modification / Change Procedures
- Control panel graphics did not provide necessary process overviews. Excessive number of alarms in emergency situation reduced effectiveness of operator response.
  - Control Room Design: plant layout, human factors/ergonomic issues
- Attempts to keep the unit running when it should have been shut down.
  - Emergency Response / Spill Control: emergency operating procedures/training



Controls/operations can help

- Reduce the load on machine protection
  - catch errors, enforce procedures
  - catch problems – surveillance, software interlocks
  - impose limits, secure settings
- Diagnostics
  - Post-mortem, logging, alarms
- Monitoring
  - Status of MPS, critical components
- Ensure reliability
  - XPOC
  - Checks: test sequences
  - Standards
- Simulations
  - Tests of acquisition system, system response etc.

Controls/operations can hinder

- Availability
  - time lost to problem resolution
- Reliability
  - Loss of diagnostics
- Failures
  - gateways, networks (band width, response), servers, databases, timing
  - loss of critical signals, displays, functionality etc
- Source of false manipulations
  - bugs
  - poor ergonomics
  - mis-conceived sequencing
  - mis-behaving feedback loops
  - …

Miscellaneous collection 1/3

- Beam Presence Flag - 1 was stuck at false in the input to the Safe Machine Parameters Controller.
  - Suspect cable has been identified, and has been repaired. A new cable will be installed in due course, when a better design is found.
- Lost RQTF and RQTD circuits of beam 2 in all the machine.
  - N.B. these were used by the tune feedback and the RT input not been set to zero before the ramp-down
- Page 1 stuck again
- Message from Christos:
  - after a reboot the MCS should be ran twice, this is known bug that will be fixed.

Miscellaneous collection 2/3

- ATLAS is reporting PROBLEM over DIP the whole night
- Andy is trying to re-establish the communication to the front end server on cfc-ccr-cgplrf
- Dip problem. Solved by restarting process dipGwOper on cs-ccr-cmw1. Was causing a SIS from LHCf and the handshake fixed display was stucked.
- The synchronization between the SPS and the LHC was not correct
  - In normal operation we should always run BEAM CONTROL RESYNCHRONIZATION sequence from now on for robustness AND safety

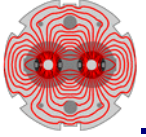
Note: controls problem also can bad English cause

Miscellaneous collection 3/3

- Had a look at the dump of the physics beam at 06:58 this morning:
  - No data from BTVDD (the cameras were off when the beam was dumped
  - BPMD data for B1 not usable data (no sensible reading for this extraction for B1 – to understand with BI)
  - BLM post mortem has only a handful of monitors, for IR 3,4 & 7. Nothing for P6.
  - BLM data history shows some small losses on TCDS.B1 for this dump. Normally there are small losses on TSCG/TCDQ.

BG,JU

Marge: Homer there's someone here to help.
Homer: Is it Batman?
Marge: No, a scientist
Homer: Batman's a scientist.
Marge: It's not Batman!



Conclusions

- 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.
- The devil's in the details and we've still considerable detail to sort out.

- Still a long way to go before we are ready for unsafe beam.