View from CERN

- Finalization of existing deliverables :

  ➔ Installation of LHC luminosity monitors for 2009 run
  ➔ Prototype of rotatable collimators
  ➔ Nb_3Sn magnet R&D with long prototype by 2010

  Success of the above deliverables is vital for successful launch of new production projects!

View from CERN

- New initiatives at CERN:

  ➔ Studies at CERN lack resources and offer interesting areas for US contributions.

  ➔ Help is desired in form of studies (USLARP) and hardware production and prototyping (APL)

LHC Upgrade Plans and New Initiatives

CERN New Initiatives

LHC Insertion:

➔LHC IR Upgrade –Phase I project lead by Ranko Ostojic

LHC collimation:

➔Phase 2 collimation project lead by Ralph Assmann

LHC injector complex:

➔ LINAC4 project lead by Maurizio Vretenar

➔ PS2 design study lead by Michael Benedikt

➔ LSPL design study lead by Roland Garoby

➔ SPS upgrade study team lead by Elena Shaposhnikova

Goals for the LHC Phase 1 IR Upgrade

- Main milestones (Lyn):
  - ➔ develop short Nb-Ti magnet prototype by middle 2009.
  - ➔ full length prototype by 2010.
  - ➔ installation by 2013
    - ➔ requires proposal for Phase 1 upgrade magnets by 2008
    - ➔ July review at CERN:

      -120mm diameter with 120 T/m gradient.

      -Modular design with equal magnet length.

      -Cold D1 magnets.

      -No other modifications of the existing matching sections.
    - ➔ Phase I IR upgrade will be implemented in parallel with the LINAC4 startup (availability of higher beam brightness).

Goals for the LHC Phase 2 IR Upgrade

Phase II

Identify new IR layouts and magnet technologies that allow a ten fold increase in the nominal LHC luminosity:

➔ Prepare a solution that can withstand the radiation for operation with $L = 10^{35}\ cm^{-2}\ sec^{-1}$

➔ The Phase II upgrade should be implemented once the Phase I solution reaches the end of the magnet lifetime (700 fb^{-1} for Nb-Ti) ➔ after 4 to 5 years of the Phase I upgrade operation assuming the Phase I operation reaches $L = 3\ 10^{34} cm^{-2} sec^{-1}$

➔ earliest installation by 2017 ➔ requires substantial R&D

➔ There are currently 2 options under study:

➔ 25 ns option using integrated 'slim magnets' inside the detectors

➔ 50ns option using above 'ultimate' beam intensities

General Upgrade Study Topics

- There are several beam dynamic studies that could be beneficial for all upgrade Phases:
  - ➔ Long range beam-beam wire compensation.
  - ➔ Electron lenses for head-on beam-beam compensation.
  - ➔ CRAB cavities and CRAB waist operation.
  - ➔ Studies related to absorbers and magnet protection.
  - ➔ Studies related to the suppression of the electron cloud effect.
  - ➔ Upgrade studies for the LHC injector complex (e.g. space charge limitations).
  - ➔ Studies related to understanding the beam-beam effects and limits.
  - ➔ Studies related to understanding limits imposed by chromatic aberrations.
  - ➔ Studies of diffusion and loss mechanisms and their impact on collimation
  - ➔ LHC impedance and beam stability

Priorities for New Production Projects

- Priority guidelines:

➔ Priority 1: New initiatives production projects (IR upgrade & LINAC4) with clear deadlines and specifications

(e.g. magnets for Phase 1 IR upgrade)

➔ Priority 2: Injector upgrades and studies for LHC IR upgrades that go beyond Phase 1 IR upgrade goals and where parameter specifications are well advanced (e.g. SPS upgrades; PS2)

➔ Priority 3: future upgrade plans where parameters have not yet been well defined (e.g. Phase 2 collimators) or where still substantial R&D efforts are required (e.g. CRAB cavities and LHC electron lens)

View from CERN: new initiatives

- New initiatives at CERN:

  ➔ Studies at CERN lack resources and offer interesting areas for US contributions.

  ➔ Seek synergies between studies where possible (e.g. e-cloud simulations and e-cloud feedback studies).

  Role of JIRS and interface with team at CERN!!!

Potential US contributions for Phase I upgrade

- APL:
  - ➔ cold D1
  - ➔ feedbox with cryogenic link
  - ➔ collimators

- USLARP (JIRS?):
  - ➔ DA, field quality specifications and tracking
  - ➔ collimator efficiency
  - ➔ heat deposition studies
  - ➔ lattice tunability studies

Potential USLARP activities for PSII

- APL:
  - ➔ 40 MHz RF system
  - ➔ Laser H^- ion stripping

- USLARP:
  - ➔ 40 MHz RF system (still requires R&D)
  - ➔ Lattice design (review planned for 2009)
  - ➔ Non-linear dynamics and MTE
  - ➔ Collimation system design and efficiency studies
  - ➔ Impedance and instabilities

Potential USLARP activities for other New Initiatives

- Phase II upgrade:
  → CRAB cavity design / production (USLARP & APL)
  → Rotatable collimators (USLARP / APL)
  → e-cloud feedback system (USLARP / APL)
  → electron-lens (USLARP / APL)
- LINAC4:
  → Laser profile monitor (APL)
- SPL:
  → high power vector modulator (APL)
  → 700 MHz super conducting RF modules (APL)

Status of the LHC Machine ‘2008 Agenda and Events’

A Very Eventful First Year!

O. Brüning
CERN, Geneva, Switzerland

On Behalf of the whole LHC Commissioning Team

ContentsLHC Layout

- Synchronization tests in August and September
- Beam Commissioning in September
- Events at the End of September and implications on 2009 operation.

Status at the Beginning of 2008

- Installation: 2002 to 2008

- Issues related to QRL installation:

  → required partial re-installation of installed QRL line in 78

- Issues related to the triplet magnets:

  → decision to cool arc without triplets (arc 78 and 45) implied a warm up at later stage

- Hardware commissioning identified weak elements in arc 78:

  → one dipole limited to 2kA and QF/QD limited to 6.5kA

  → implied an intervention (warm up) at later stage

- Deformation of the RF fingers in the interconnects

- Successful transfer line commissioning

Main Events in 2008

- First magnet powering in the tunnel: quench tests with large ‘string’; synchronous powering of complete arc system; de-training
- Machine cool down: 22. August - all sectors simultaneously at 1.8K;
  30. August first cryo OK for complete machine
- Tunnel closure: 5. September - LHC access control enters operational phase
- ‘Synchronization tests’ with beam:

  first beam steering in injection area; first beam induced quench; inject & dump test
- Commissioning with beam:

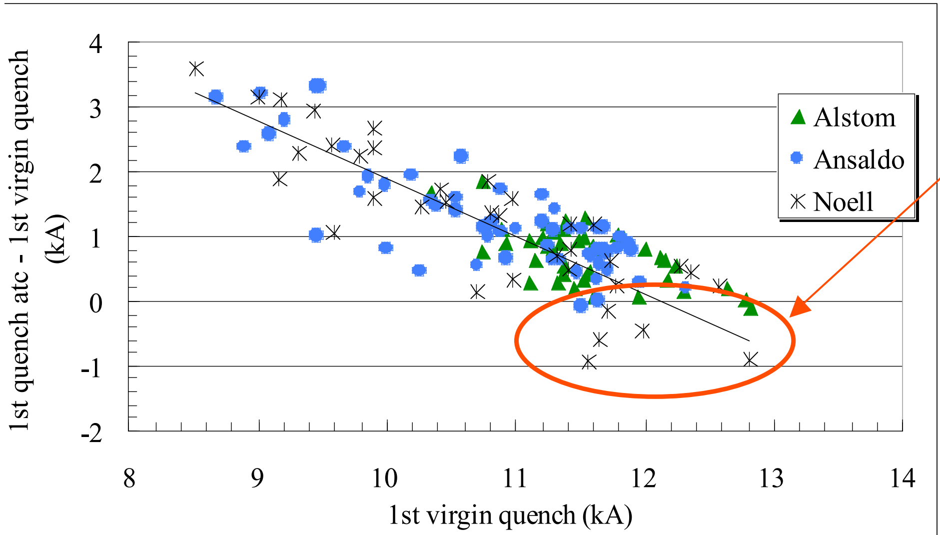
  first turn; orbit correction; aperture verification; tune measurements; optics checks; RF capture with 20 min+ beam life time
- 19. September

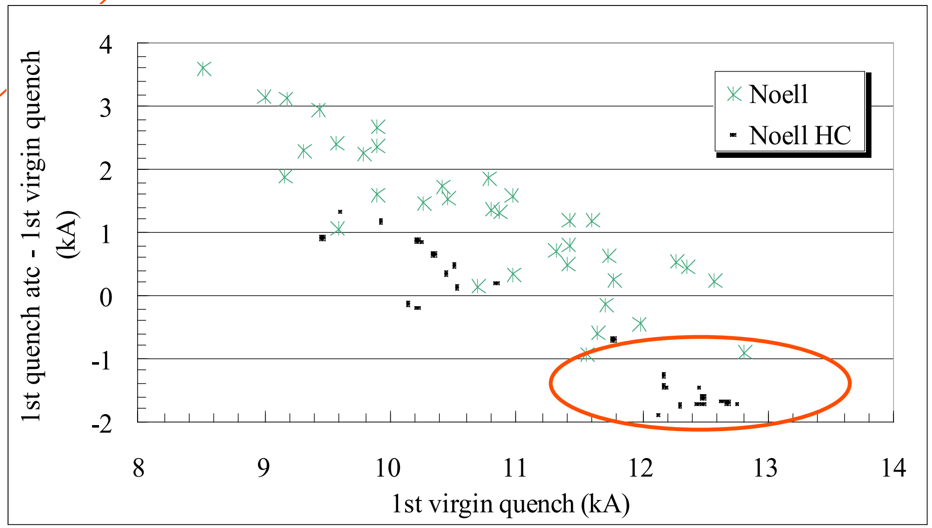
De-Training Effect for Quench Levels

- The LHC magnets have a higher quench level after thermal cycle as compared to 1st virgin quench
  - The gain is the larger the lower the 1st virgin quench

A. Siemko at MAC 23

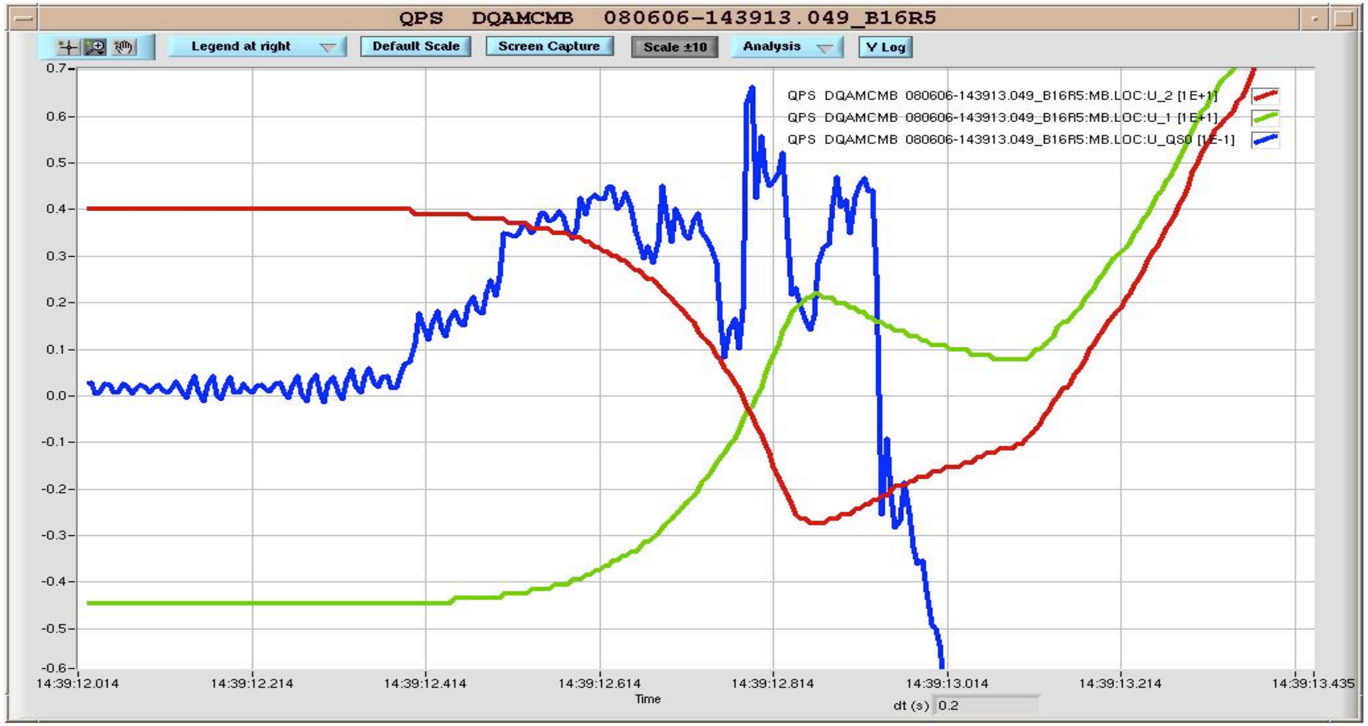
- However, Noell magnets shows some anomalous behavior





- Detraining looks worse for the Sector 56 data
- ➔ decision to perform hardware commissioning in 2008 to 5.5 TeV

Phenomenon of Symmetric Quenches

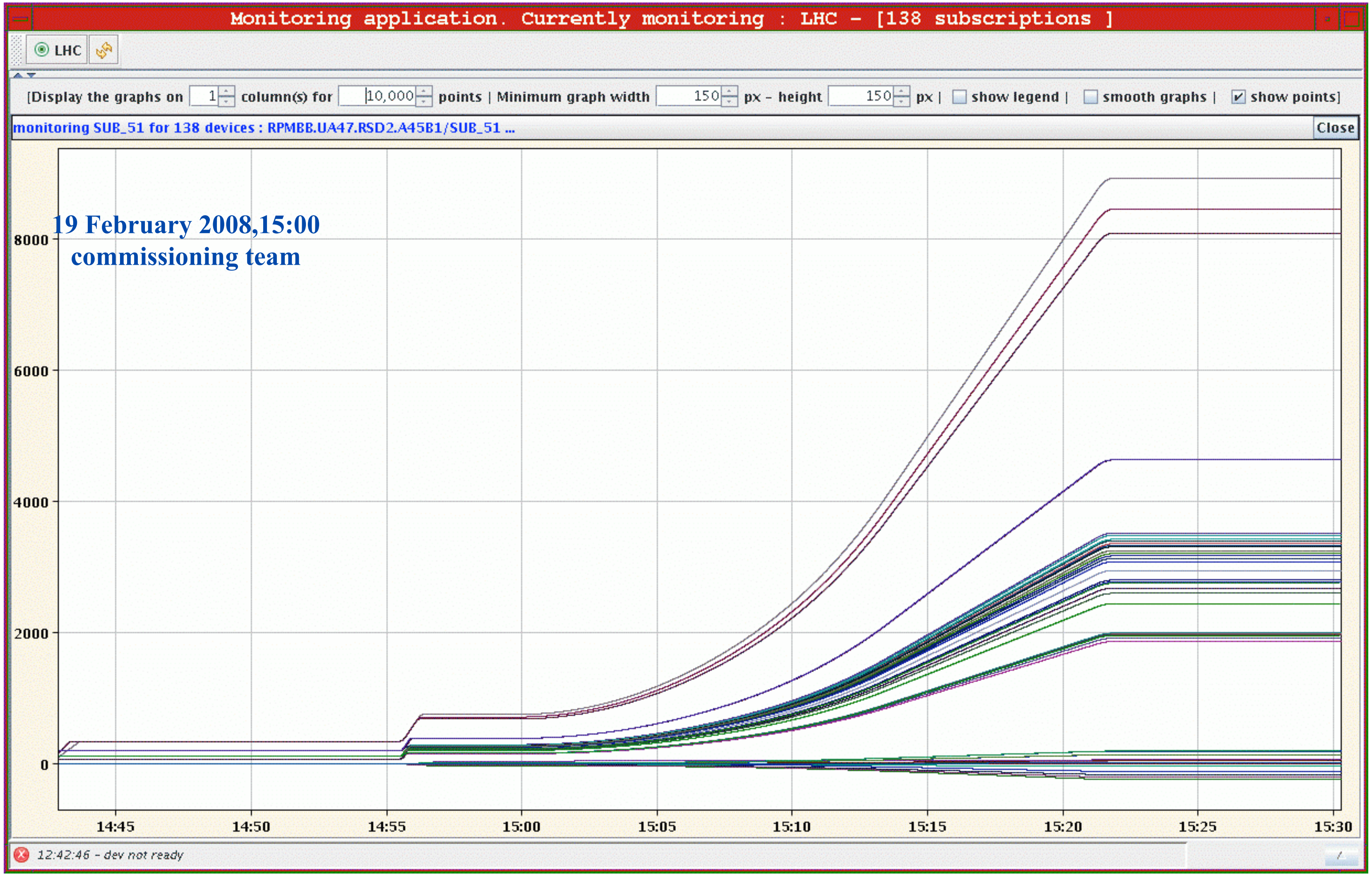


A. Siemko at
B. MAC 23

- In sector 5-6 five symmetric quenches were observed after quench propagation caused by a thermo-hydraulic wave
  - One quench (in B16.R5 at ~7.4 kA) has developed the high “MIITs” and resulting high hot spot temperature
- ➔ required modifications to the quench protection system!

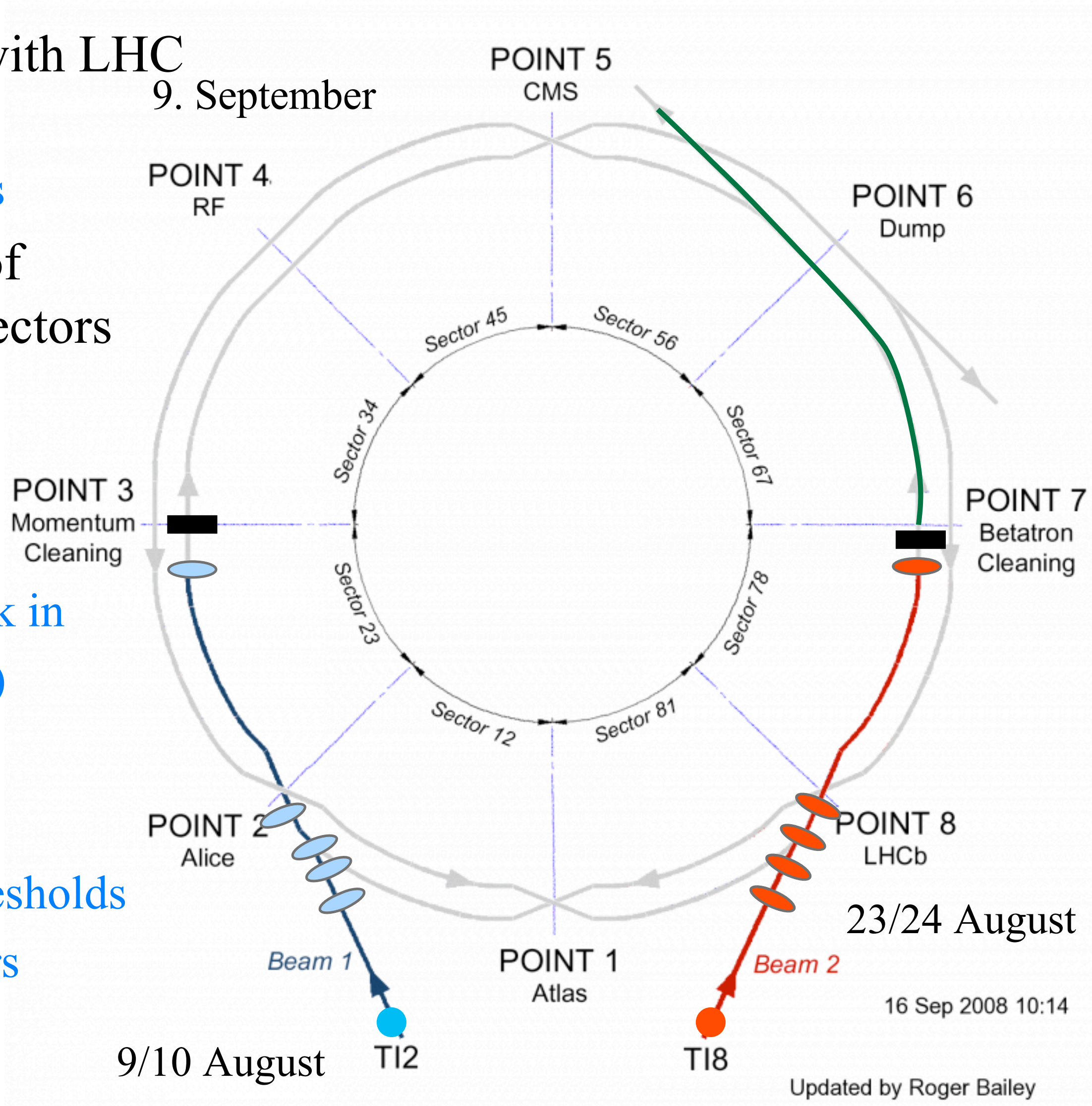
Ramp of 138 power converters to a current equivalent to 5.3 TeV

(including all high current magnets realistic LHC optics)



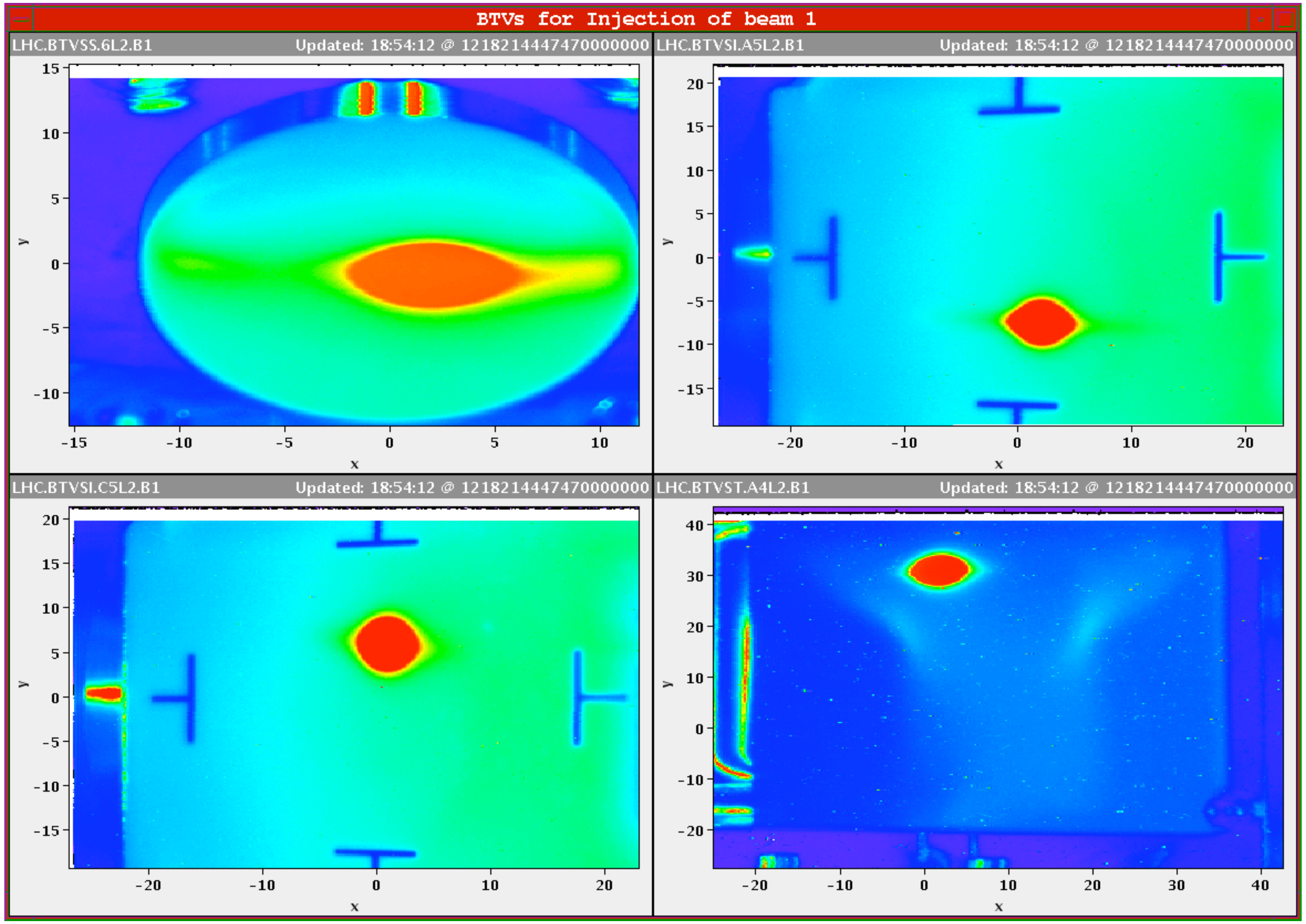
Synchronization Tests With Beam

- Synchronize SPS extraction with LHC injection kickers
  - Adaptation of timing controls
- Magnet polarity verification of injection line and first LHC sectors
  - Sorted out several polarity errors (data base)
- Aperture scans
  - Identified aperture bottle neck in injection area (vacuum valve)
  - First beam induced quench
- BPM & BLM verification
  - Concentrators, data base, thresholds
  - Sorted out several BPM errors
- Inject & dump mode
  - Dump kicker timing



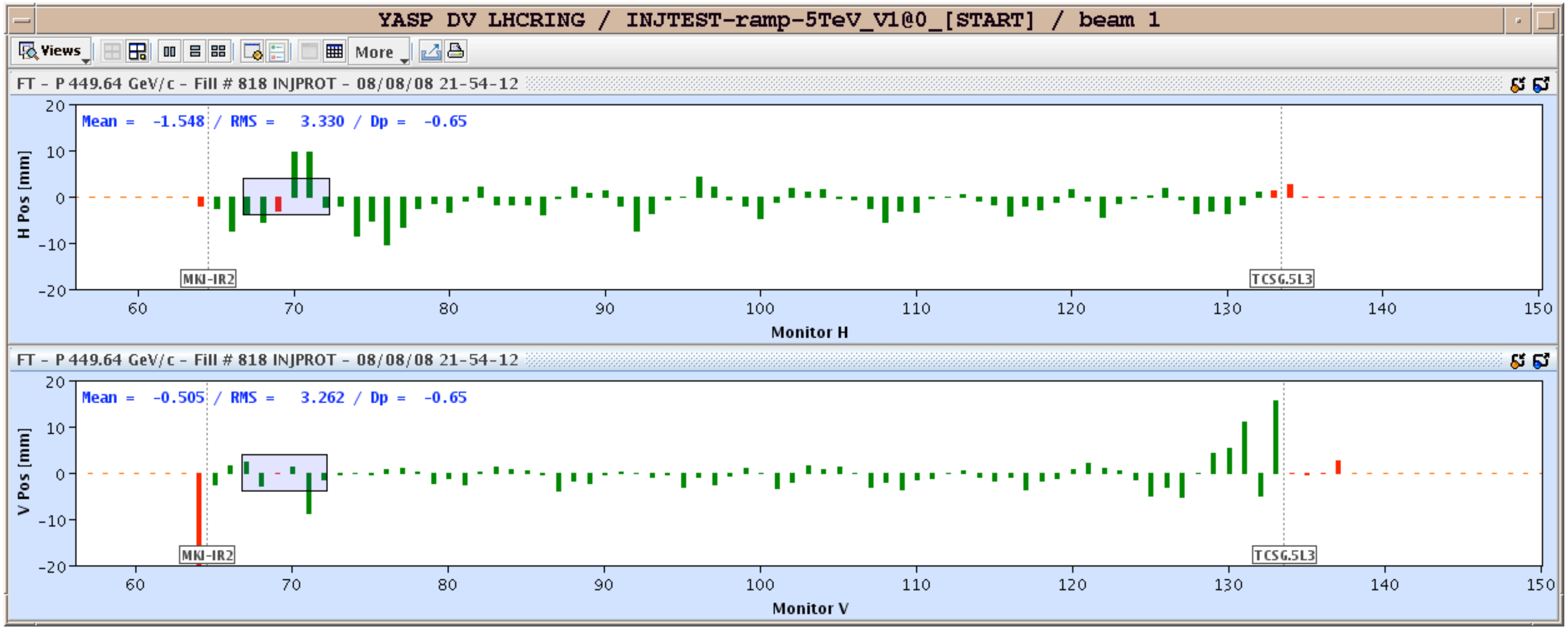
Synchronization Tests With Beam

- First Beam in the LHC: Injection area (Sept, kicker and TDI)



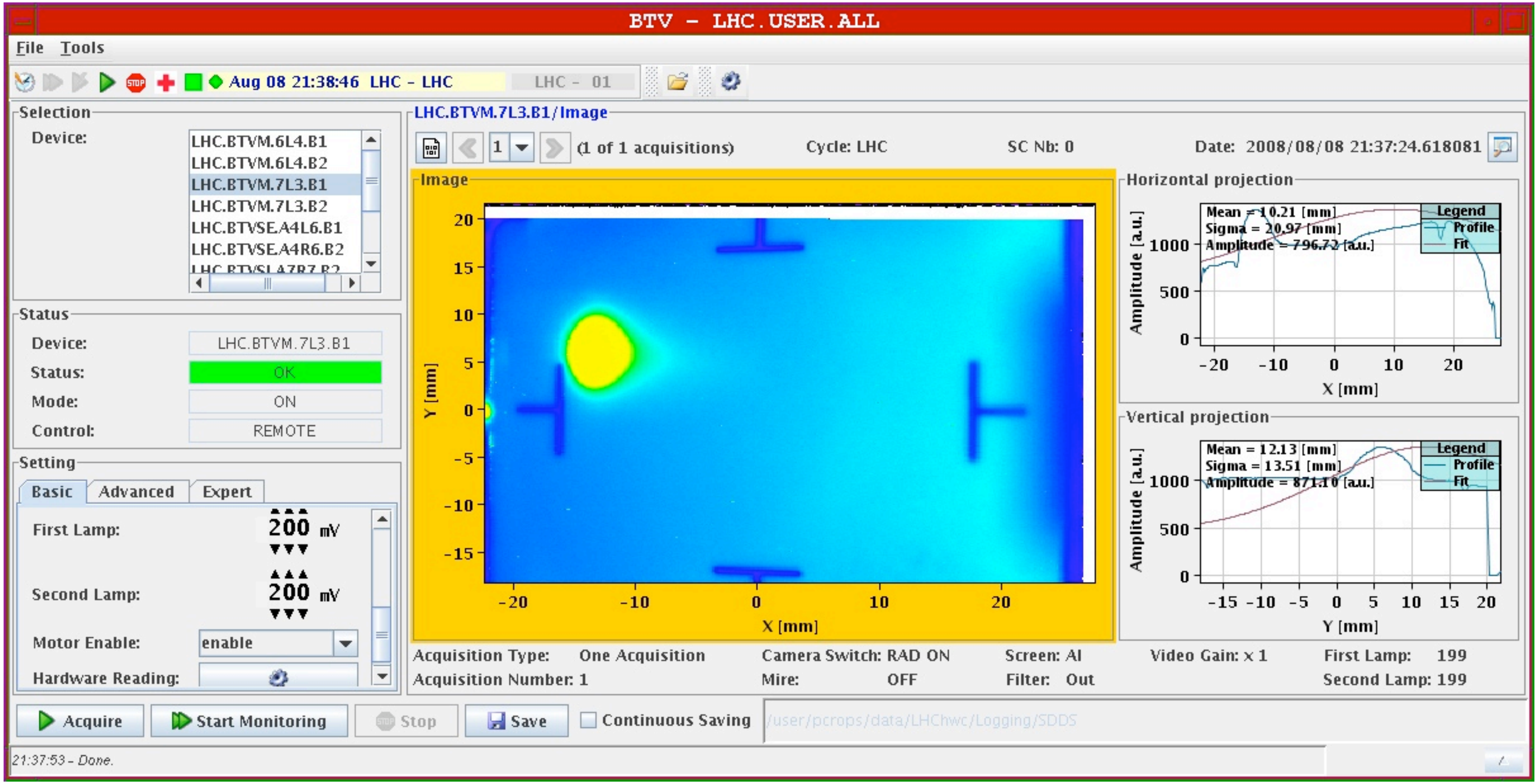
Synchronization Tests With Beam

- First Beam to IR3: First trajectory steering onto collimator in IR3



Synchronization Tests With Beam

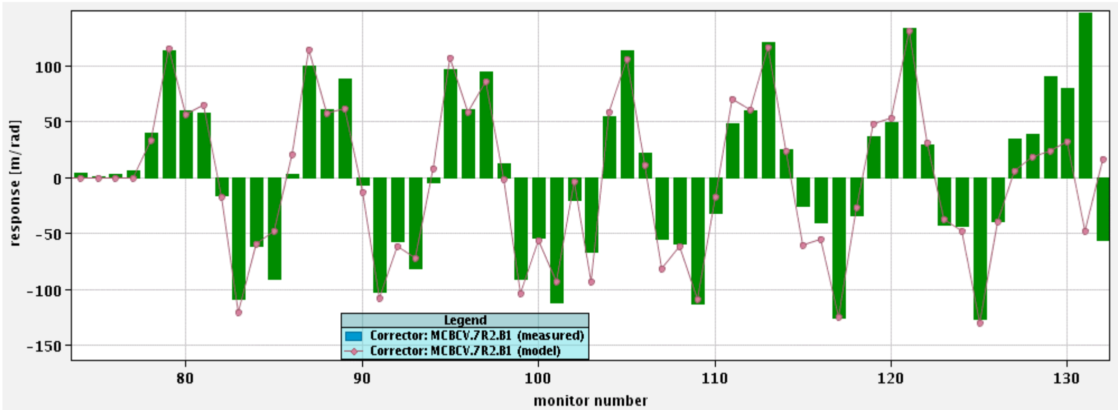
- First Beam to IR3: Beam stopped on collimator jaw



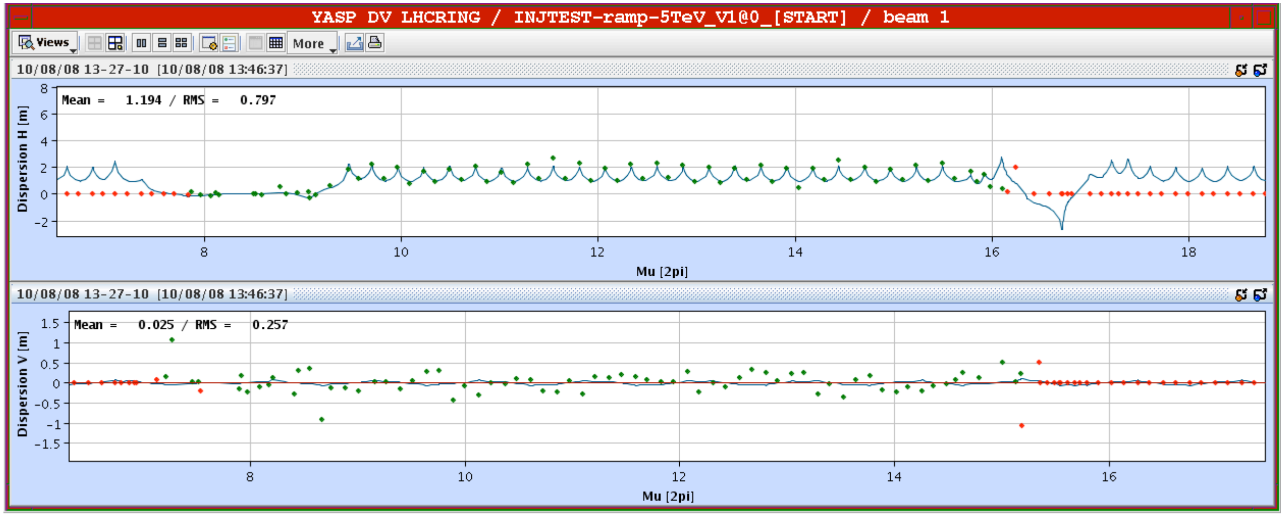
Synchronization Tests With Beam

- First Beam to IR3: Kick response ➔ excellent fitting tools!

V. Kain
J. Wenninger



- First Beam to IR3: Dispersion orbit measurement ➔ polarity errors

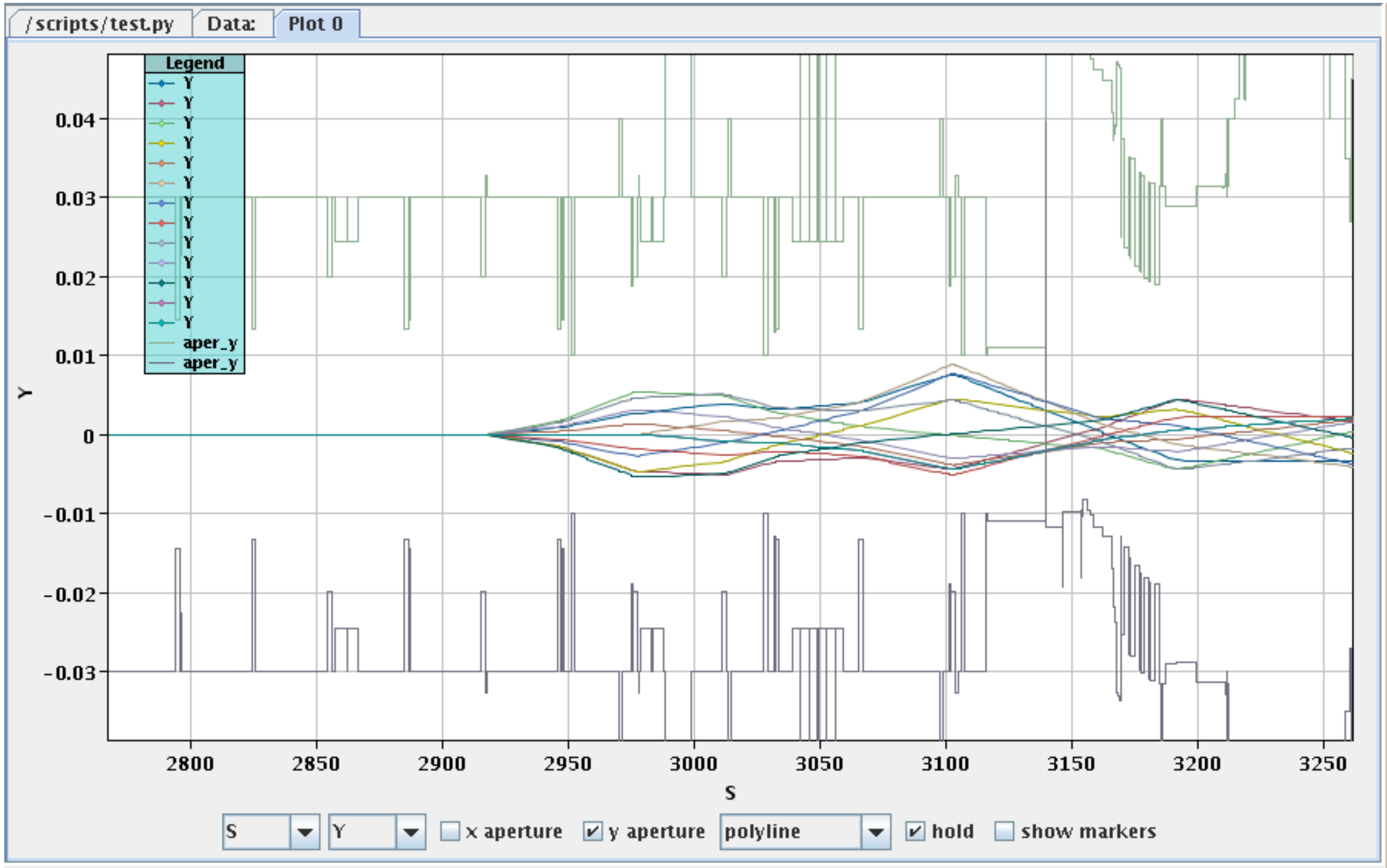


V. Kain
J. Wenninger

Synchronization Tests With Beam

- Injection region aperture verification: Aperture limitation due to vacuum valve

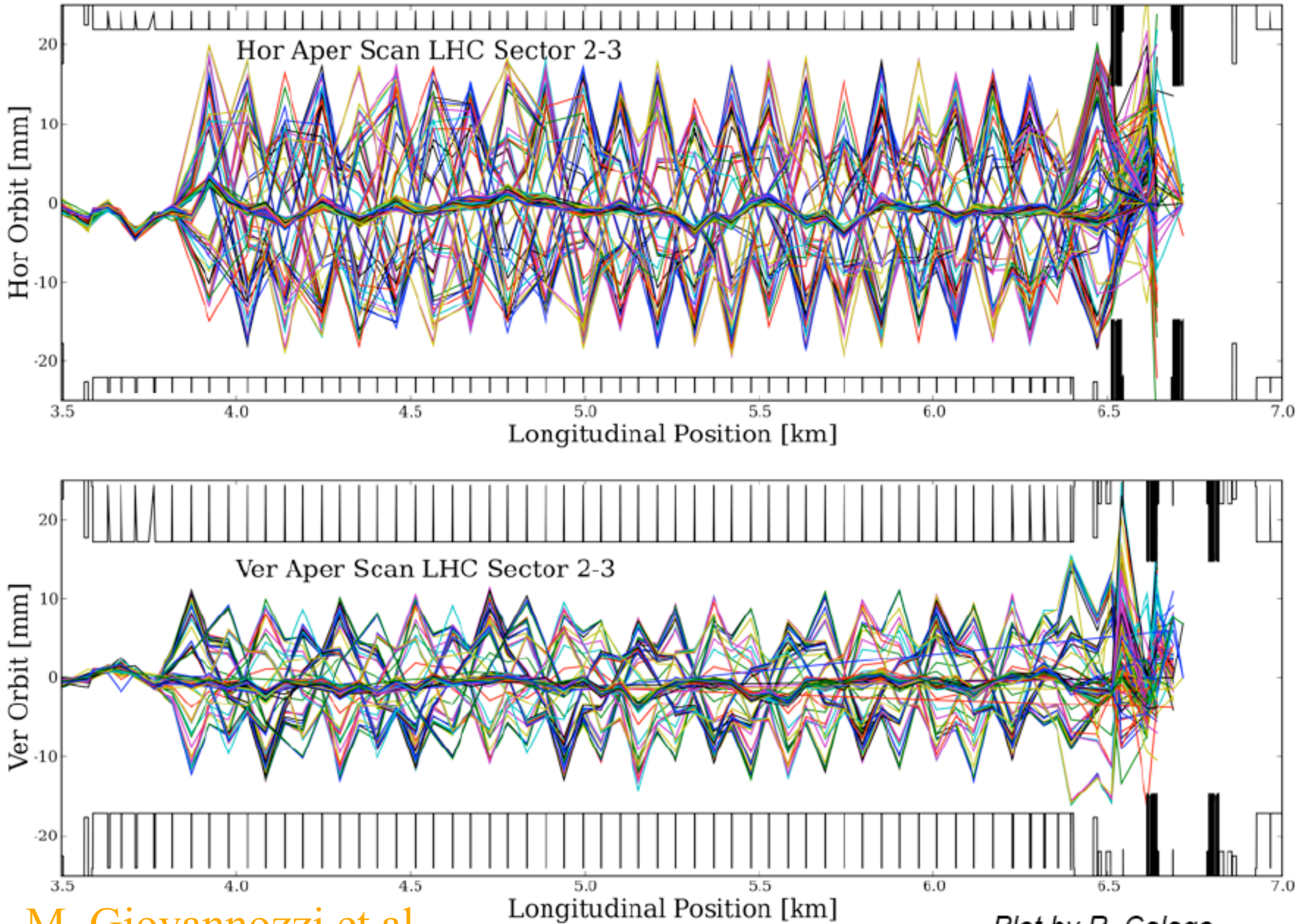
B. Goddard



- MADX online model Ilia Agapov

Synchronization Tests With Beam

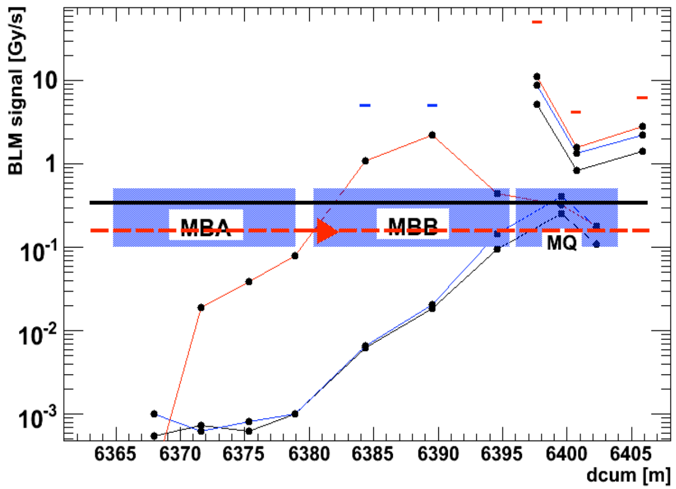
- Arc aperture verification: Kick measurements ➔ aperture and coupling

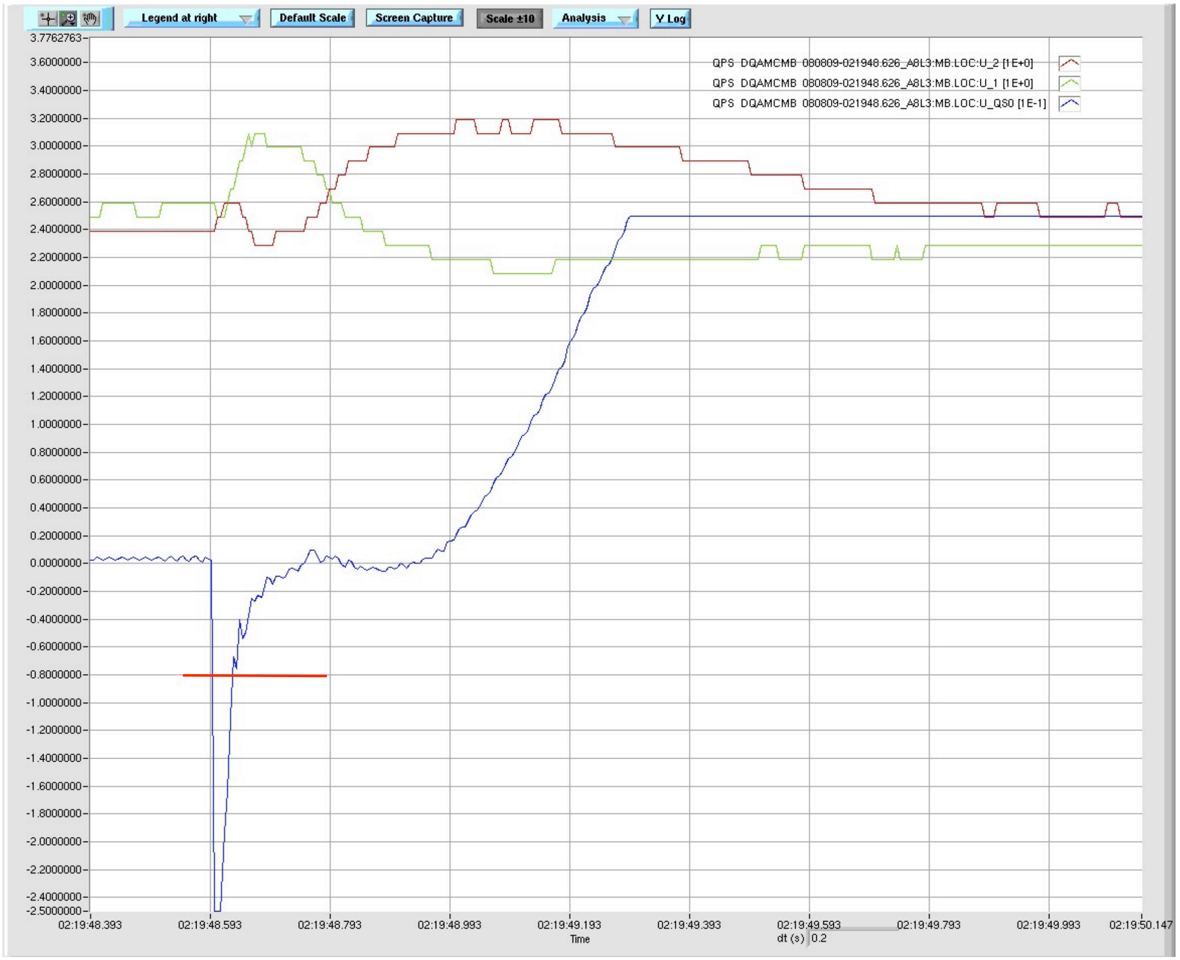


R. Callaga, M. Giovannozzi et al.

Synchronization Tests With Beam

- First Beam to IR3: First trajectory corrections and beam induced quench:





Summary Synchronization Tests

- Extremely useful exercise: last minute fixes to software (timing), powering data base (polarities), functionality checks (BPM and BLM), Removal of aperture bottle necks (vacuum valve alignment)
- First beam induced quench: BLM calibration!, verification of 'safe beam' intensities
- Tools: extremely useful due to availability of excellent analysis tools (YASP, MADX online model; fitting tools for kick response & BPM data analysis); successful validation of LSA
- Procedures: validation of key procedures (synchronous powering of circuits and collimators); access system and beam interlock system

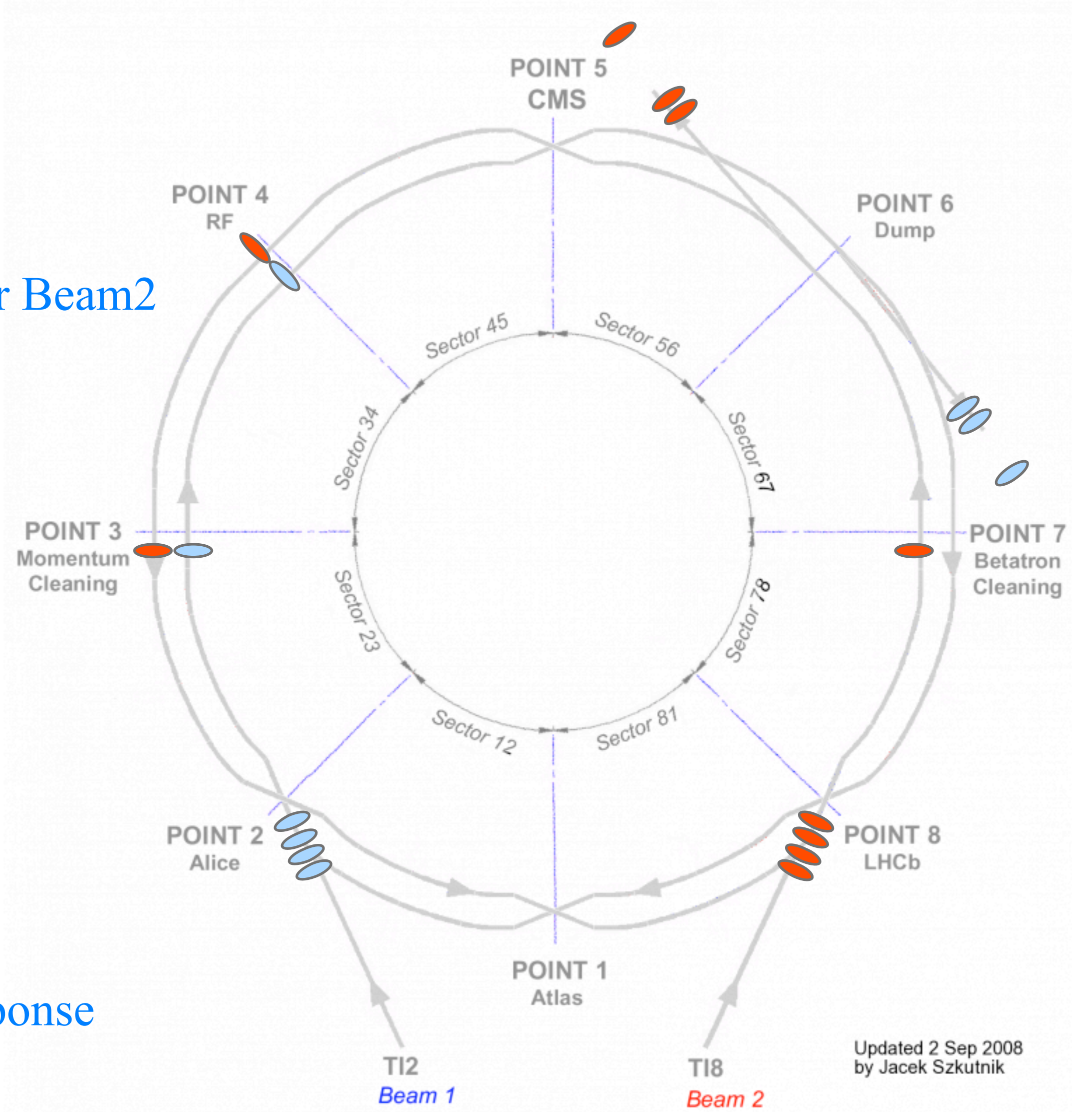
LHC Startup 10. September

LHC Beam Commissioning:

- 10. September:
  - Established 1. Turn for Beam 1
  - Established 1. Turn for Beam 2
  - Established circulating beam for Beam2

- Following days:
  - RF capture Beam 2;
  - Klystron based RF system!
  - Noise + feedback loops

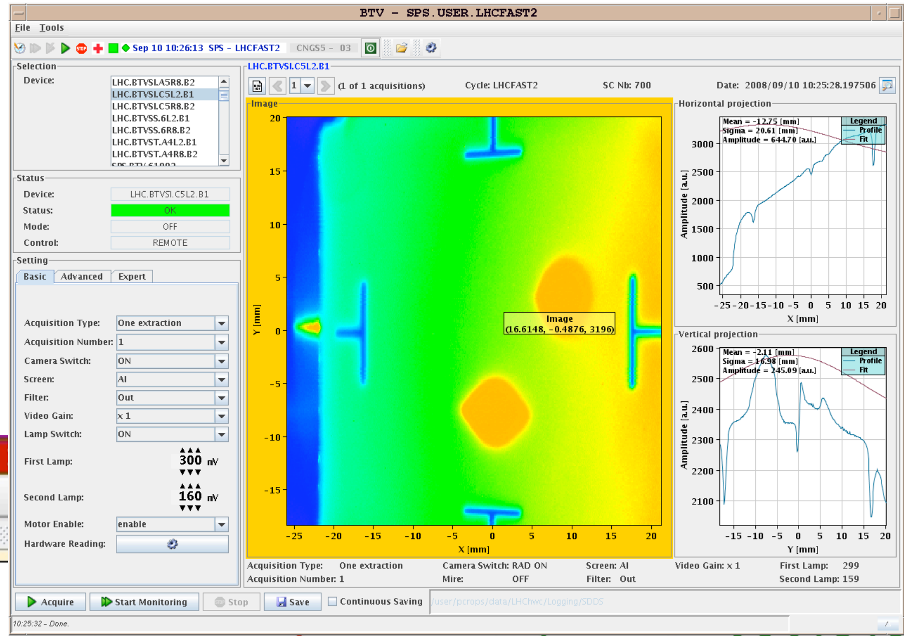
- First beam measurements
  - Orbit correction
  - Tune & coupling measurement
  - Optics verification via kick-response

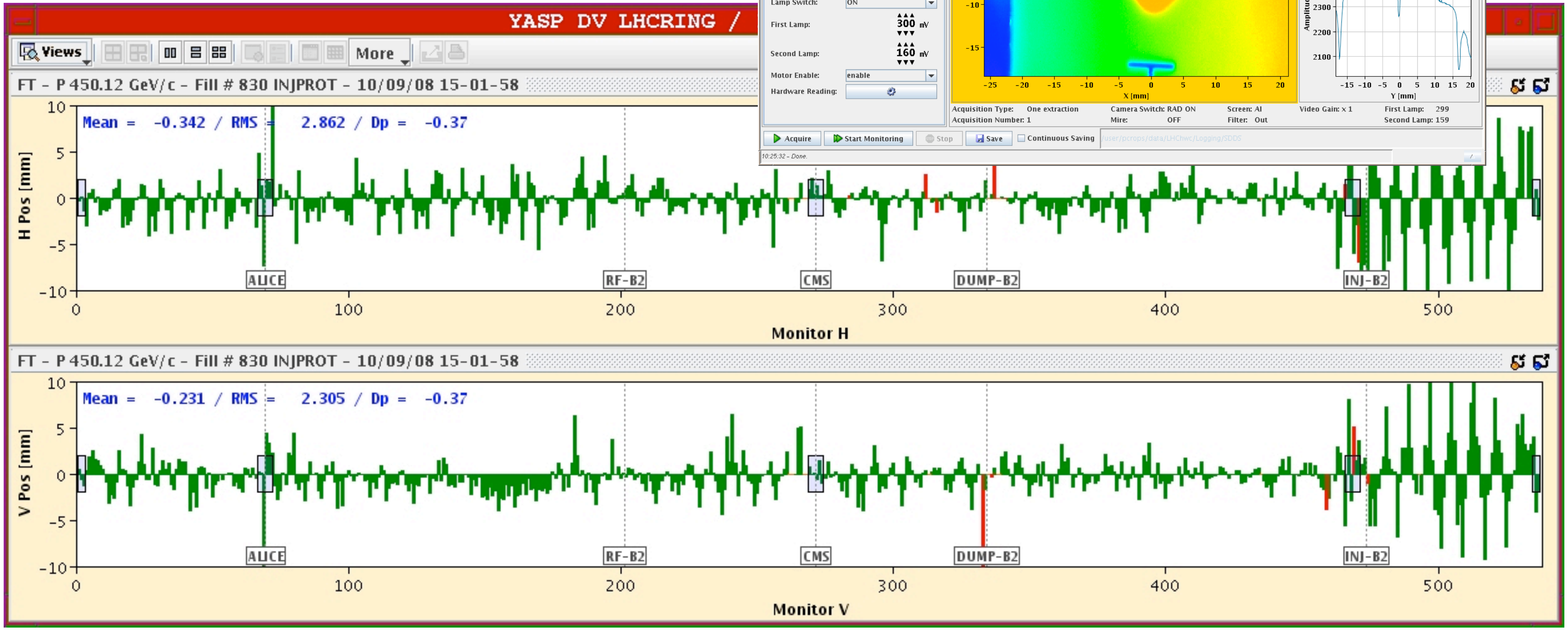


First Turn

- First & Second Turn on screen
- First Turn on BPM system

Jörg Weninger
Courtesy of Roger Bailey





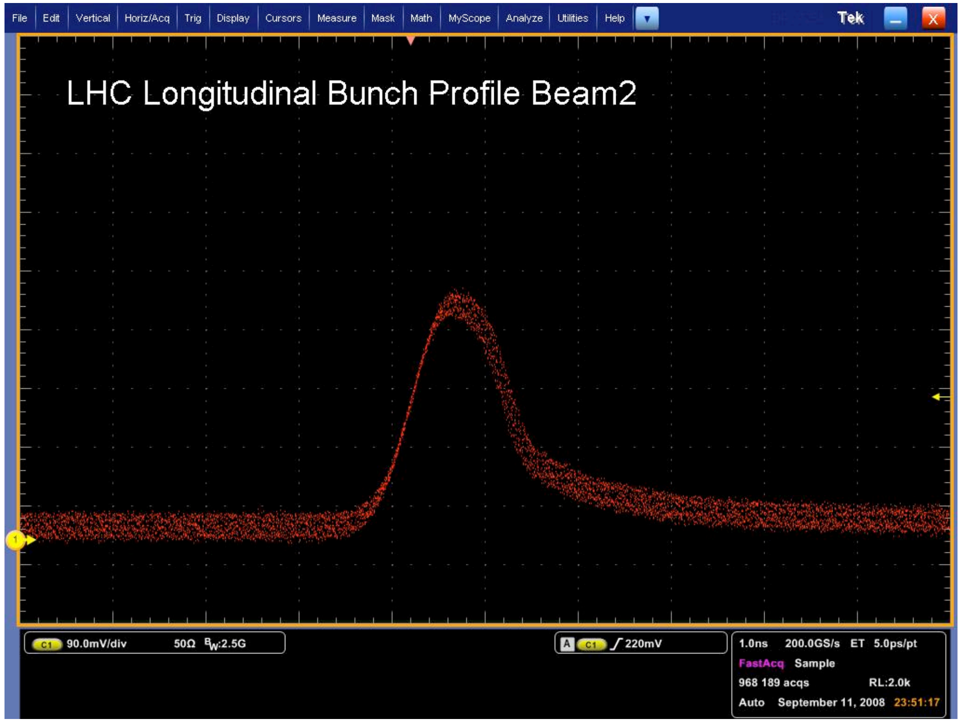
Closed Orbit and Kick Response for Full Machine

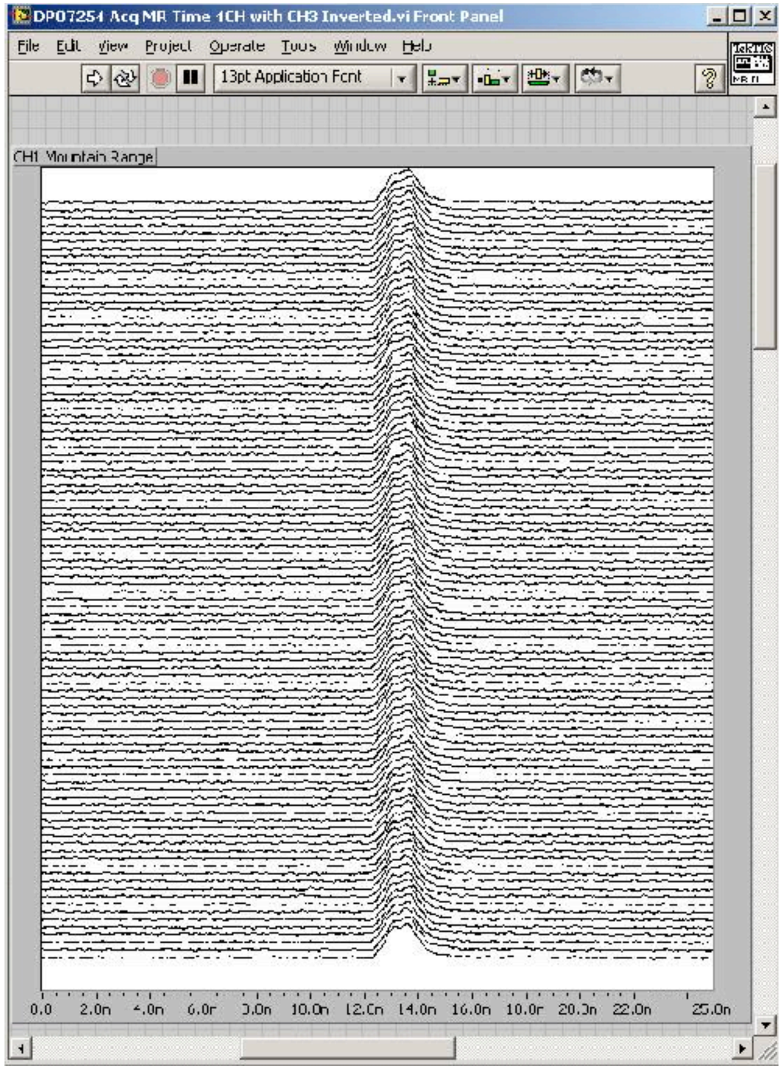
YASP by
Jörg Weninger

RF Capture:

- Captured Beam Current
- Mountain Range display

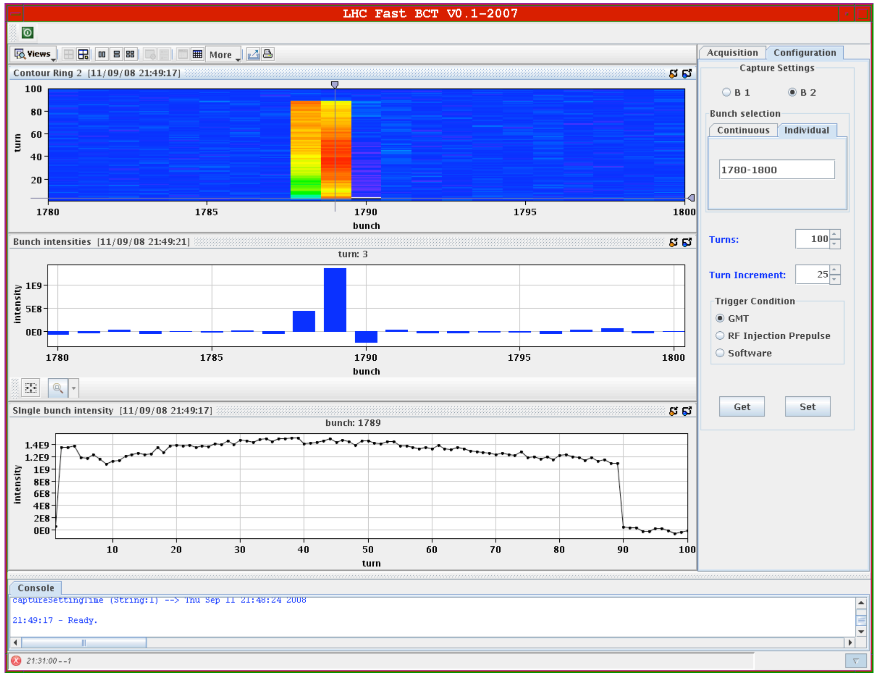
Ed Chiapal

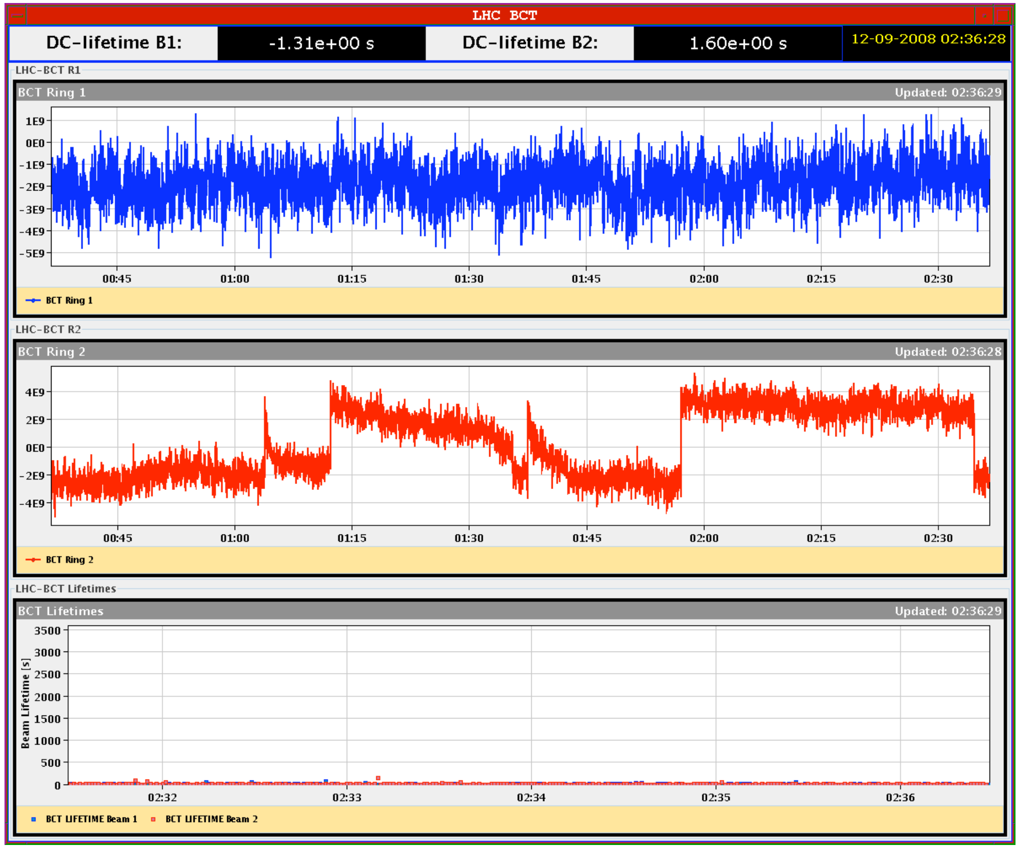




Beam Current Transformer and Beam Lifetime:

- BCT versus bunch number and time: ca. ½ h beam lifetime!



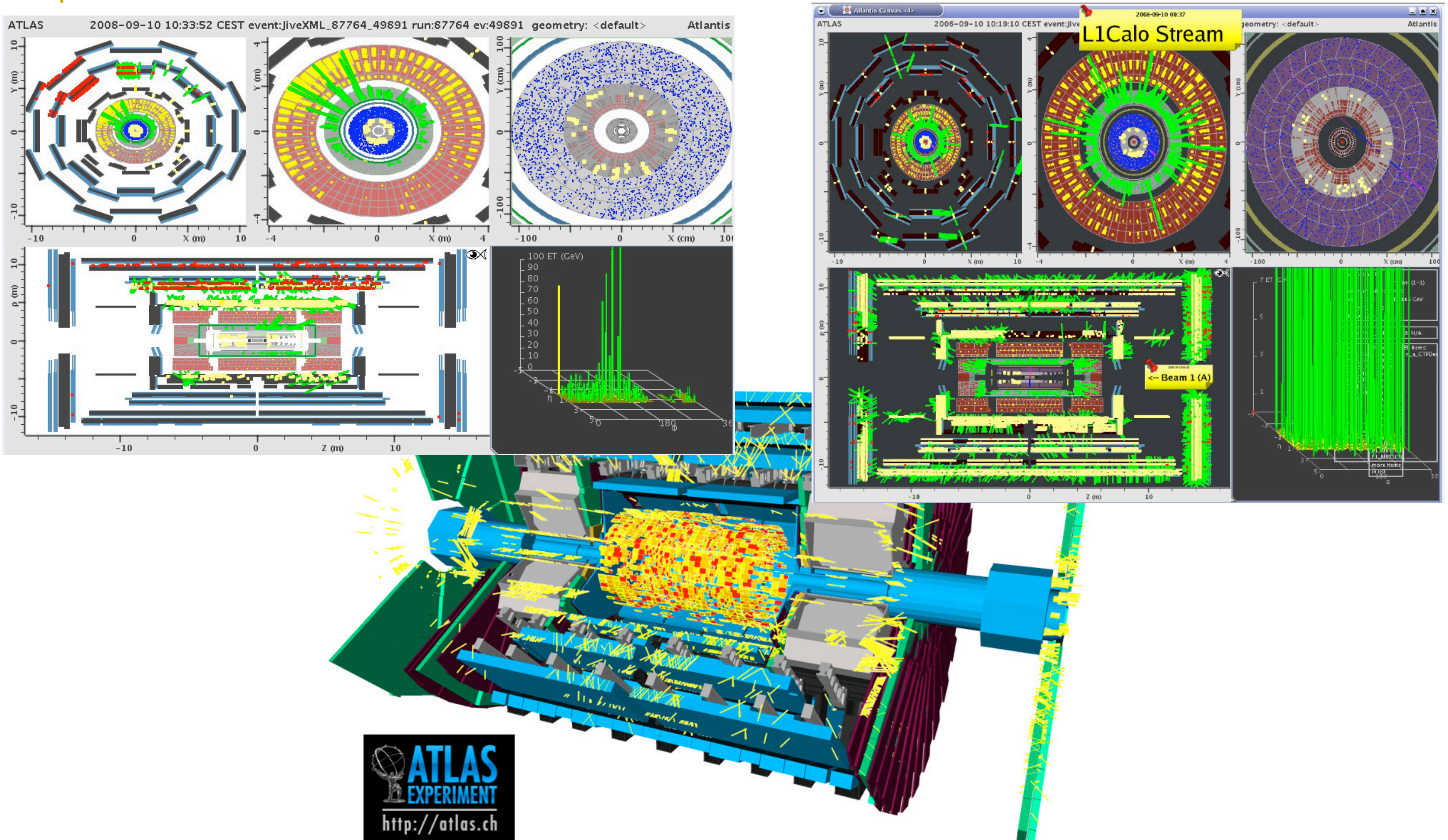


Tune and β-beat:

Jörg Weninger
R. Steinhagen

R. Thomas

First Beam Seen by the Experiments



first beam event seen in ATLAS

Summary Beam Commissioning

- Extremely successful start-up!! Made possible by:
  - Meticulous preparation
  - Accurate magnetic model
  - Dry runs (parallel 'operation' and hardware commissioning)
  - Synchronization tests
  - Powerful control system and tools and
  - a highly motivated team!!!

- Beam Commissioning stopped on Friday 12. September:
  - Transformer failure on Friday evening (12 MVA)
  - Loss of cryogenics in point 8 (➔Arcs 78 and 81)
  - Replacement could be found in CMS installation
  - Several days of access in LHC site
  - Ready for beam by 18. September (started injection tests for Beam 1)

LHC Incident in Sector 34

- CERN Press Release from 20.9.2008:
  Geneva, 20 September 2008. During commissioning without beam of the final LHC sector (Sector 34) at high current for operation at 5 TeV, an incident occurred at mid-day on Friday 19 September resulting in a large helium leak into the tunnel. Preliminary investigations indicate that the most likely cause of the problem was a faulty electrical connection between two magnets which probably melted at high current leading to mechanical failure. CERN's strict safety regulations ensured that at no time was there any risk to people.

- CERN Press Release from 23.9.2008:
  Investigations at CERN following a large helium leak into sector 3-4 of the Large Hadron Collider (LHC) tunnel have indicated that the most likely cause of the incident was a faulty electrical connection between two of the accelerator's magnets. Before a full understanding of the incident can be established, however, the sector has to be brought to room temperature and the magnets involved opened up for inspection. This will take three to four weeks. Full details of this investigation will be made available once it is complete.

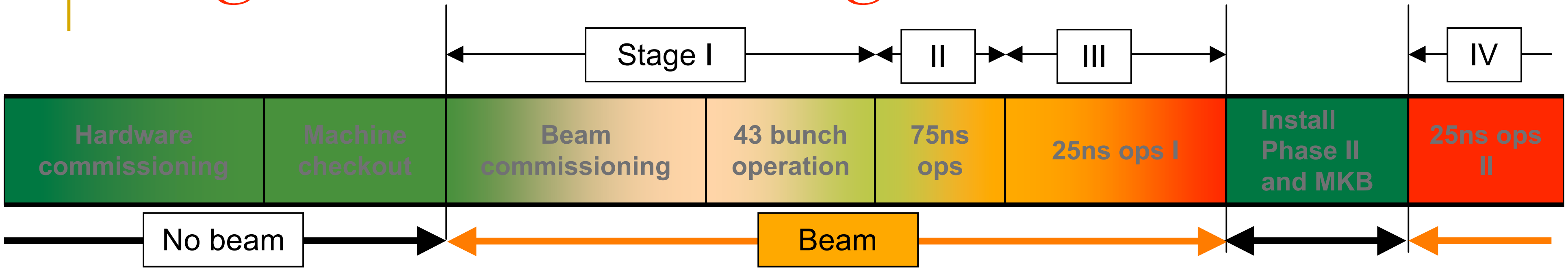
LHC Incident in Sector 34

- Assessment as of October 2008:
  - ➔ Loss of ca. 6T of He inventory (ca.½ of the arc inventory).
  - ➔ Ca. 250 MJ of stored electromagnetic energy was 'missing' in the dump resistors and diodes of the quench protection system
  - ➔ 4 short straight sections (unit of a quadrupole + corrector magnets) are affected by the incident and need to be repaired on surface
  - ➔ Of the order of 10 dipole magnets might be affected by the incident and need to be inspected on the surface.
  - ➔ Most likely cause was a bad splice between magnets
  - ➔ Means for detecting similar problems in the future are currently under study

- Impact on Operation Schedule:
  - ➔ LHC operation stopped 3 month before planned operation stop.
  - ➔ General shutdown work at CERN was advanced by 2 month (early October).
  - ➔ Start-up in 2009 advanced to 1. May instead of 1. June.
  - ➔ Net loss of ca. 2 month of LHC operation due to September incident.

Spare Transparencies

Staged Commissioning Plan for Protons



Pilot physics run

- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance (156 bunches, partial squeeze in 1 and 5 ➔ $L \approx 10^{31}$ cm^{-2} sec^{-1})

75ns operation

- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle ➔ $L \approx 10^{33}$ cm^{-2} sec^{-1} (event pile up rate)

25ns operation I

- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal ➔ $L \approx 2\ 10^{33}$ cm^{-2} sec^{-1}

25ns operation II

- Push towards nominal performance

Courtesy of Roger Bailey

Parameter evolution and rates

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

All values for nominal emittance, 10m β* in points 2 and 8

All values for 936 or 2808 bunches colliding in 2 and 8 (not quite right)

	Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
	k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
5 TeV	43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	1.4	$8.0\ 10^{29}$	<< 1	Depend on the configuration of collision pattern	
	43	$4\ 10^{10}$	3	$1.7\ 10^{12}$	1.4	$2.9\ 10^{30}$	0.36		
	156	$4\ 10^{10}$	3	$6.2\ 10^{12}$	5	$1.0\ 10^{31}$	0.36		
	156	$9\ 10^{10}$	3	$1.4\ 10^{13}$	11	$5.4\ 10^{31}$	1.8		
7 TeV	936	$4\ 10^{10}$	11	$3.7\ 10^{13}$	42	$2.4\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
	936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
	936	$6\ 10^{10}$	2	$5.6\ 10^{13}$	63	$2.9\ 10^{32}$	1.6	$6.0\ 10^{31}$	0.34
	936	$9\ 10^{10}$	1	$8.4\ 10^{13}$	94	$1.2\ 10^{33}$	7	$1.3\ 10^{32}$	0.76
	2808	$4\ 10^{10}$	11	$1.1\ 10^{14}$	126	$7.2\ 10^{31}$	<< 1	$7.9\ 10^{31}$	0.15
	2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
	2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24
	2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6	$1.2\ 10^{32}$	0.24

Low-beta squeeze (15 independent quadrupole circuits)