Brief summary of:

LHC Commissioning with Beam

Tuesday September 10th - Friday 12th

&

LHC Performance Workshop

Monday February 2nd - Friday February 6th

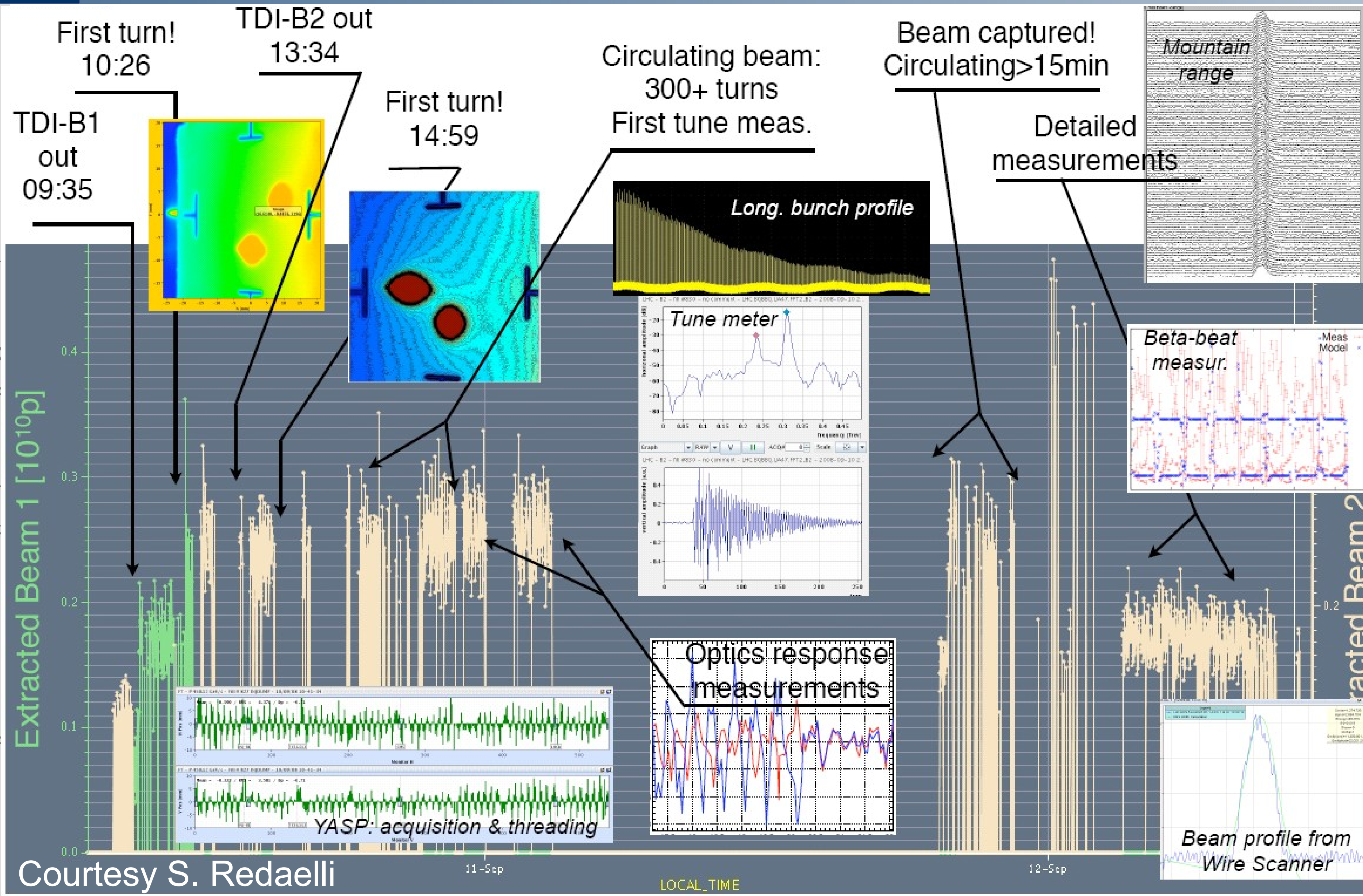
R.J. Steinhagen, BE Department, CERN

Special thanks to: T. Bohl, L. Bottura, M. Gasior, R. Jones, V. Kain, M. Lamont, S. Redaelli, J. Wenninger

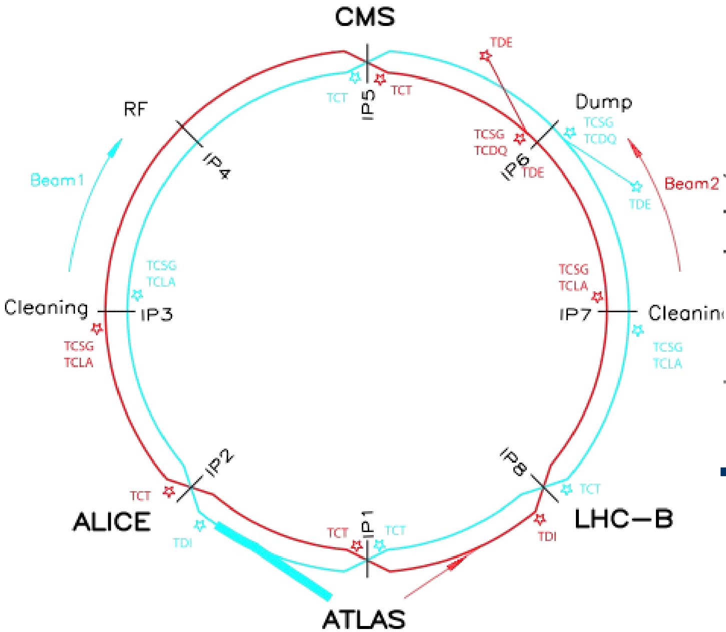
Overview

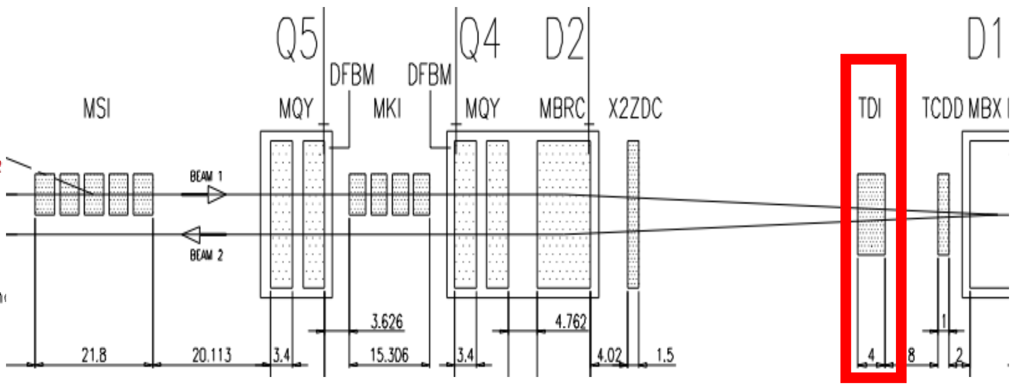
- Part I - LHC Commissioning with Circulating Beam
  – Milestones of 60 hours of LHC Beam
  – Lessons learned, performance of accelerator and beam diagnostics
- Part II - 'The September 19th Incident in LHC Sector 34'
- Part III – LHC Performance Workshop, Chamonix 2009
  – repair, prevention and mitigation of future MCI
  – Implications on the 2009 schedule run

Milestones of 50 Hours of LHC Beam Operation



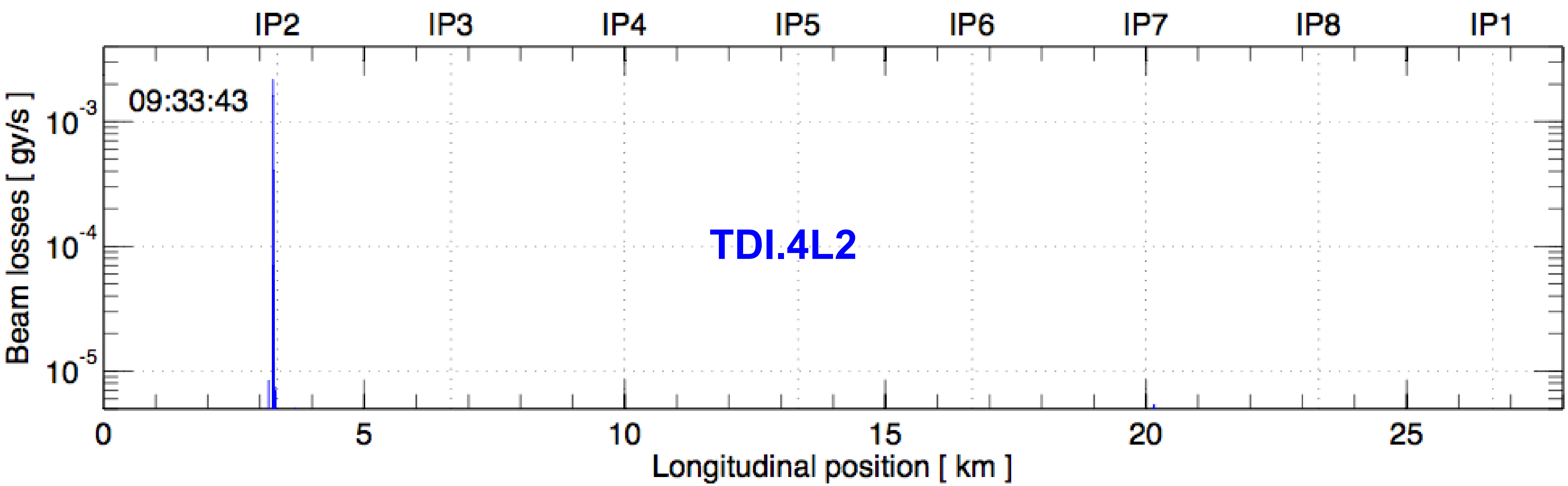
First Turn - Beam 1 on TDI (IR2)



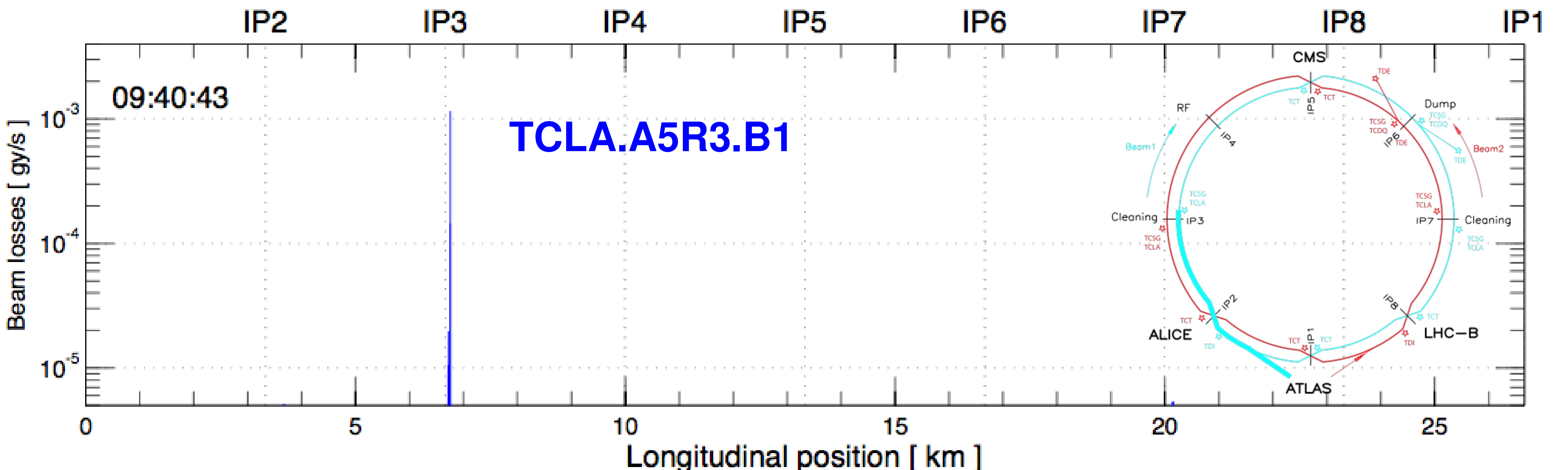


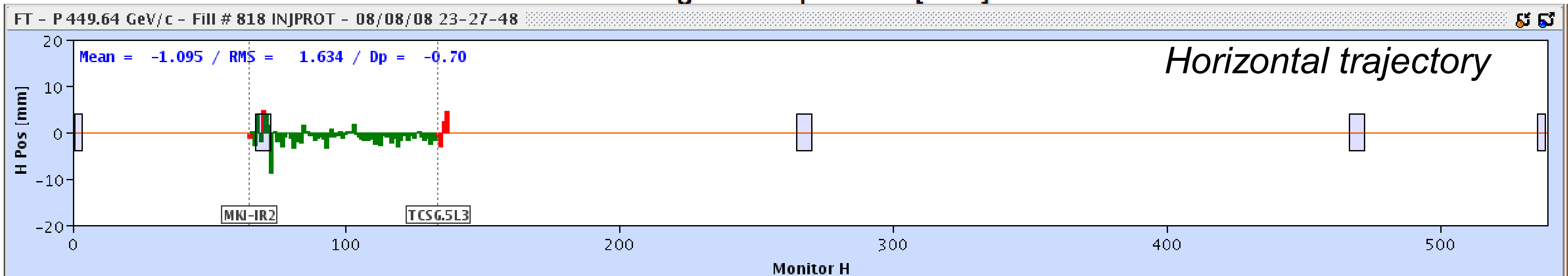
➔Collimators were used to stop the beam:

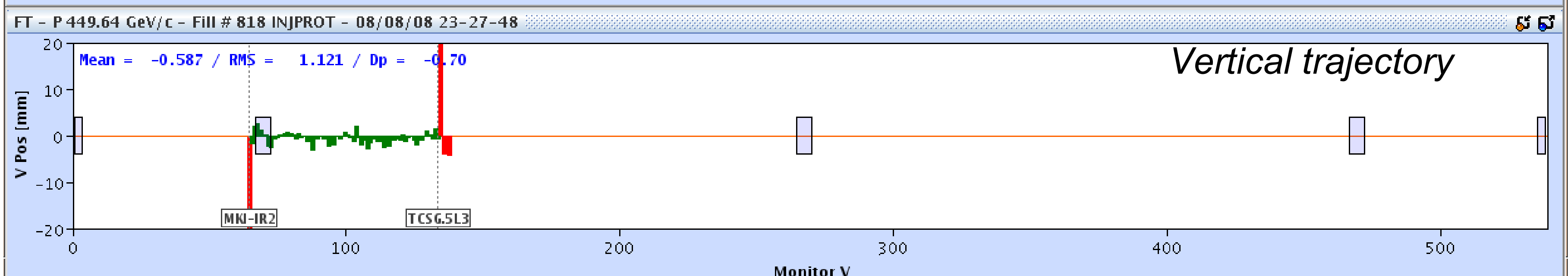
– optimise trajectory before going into next sector
– improve the show!



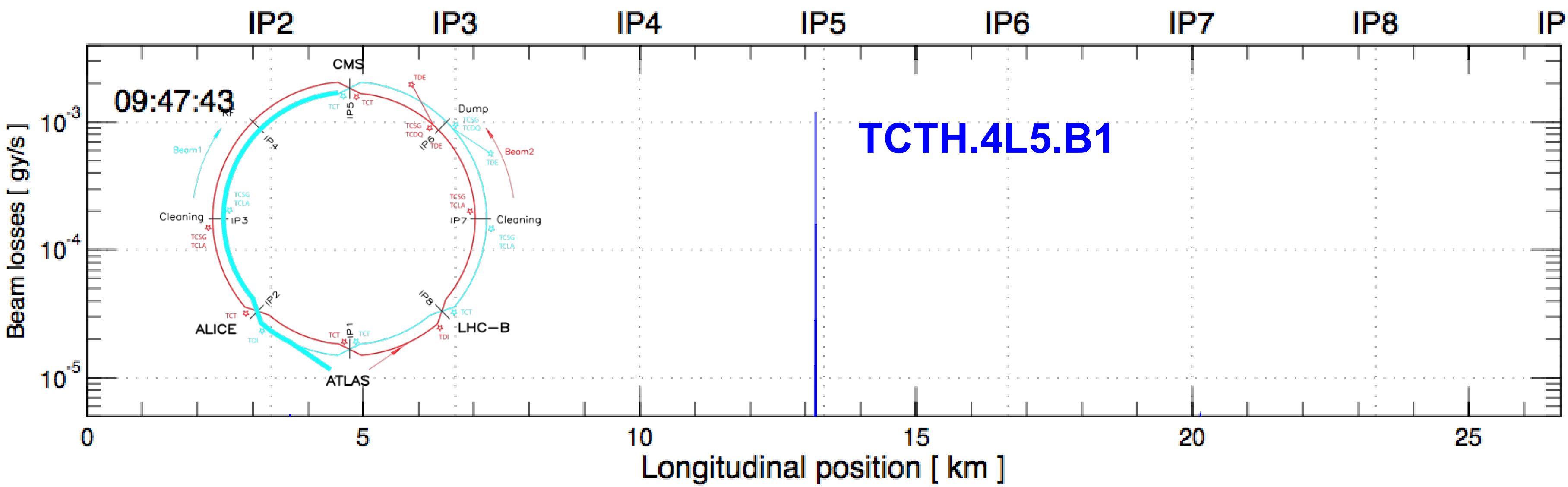
First Turn - Beam 1 to IR3

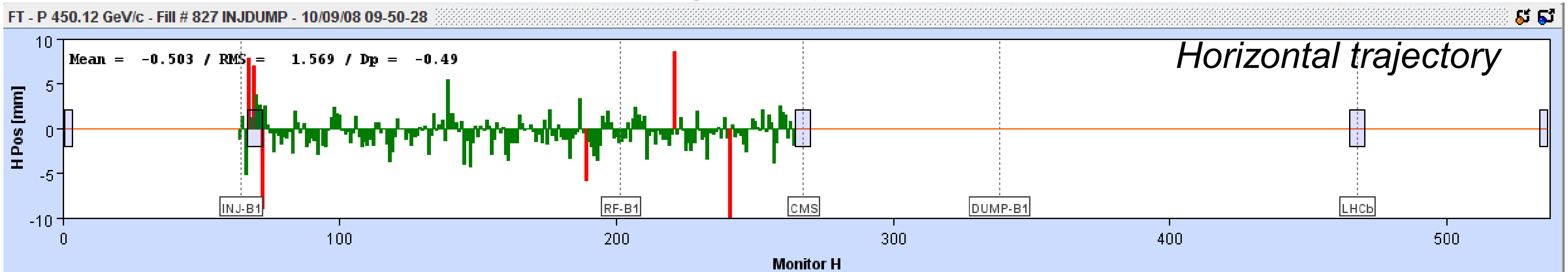


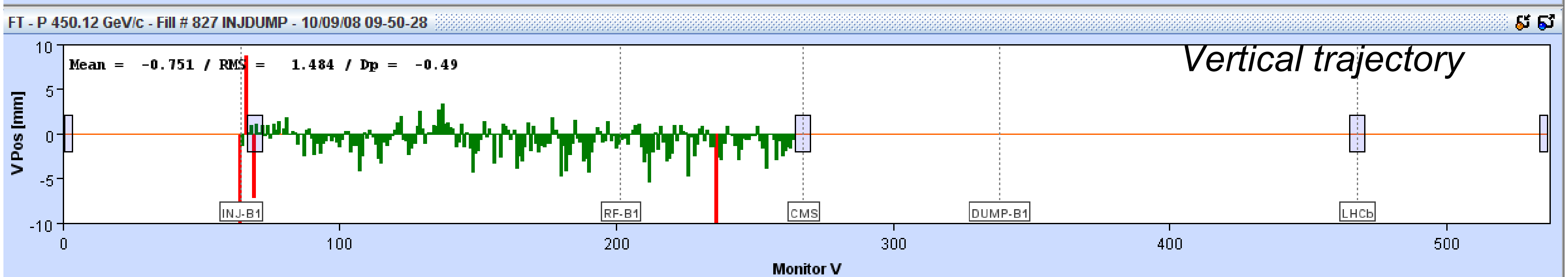




First Turn - Beam 1 to IR5 (CMS)

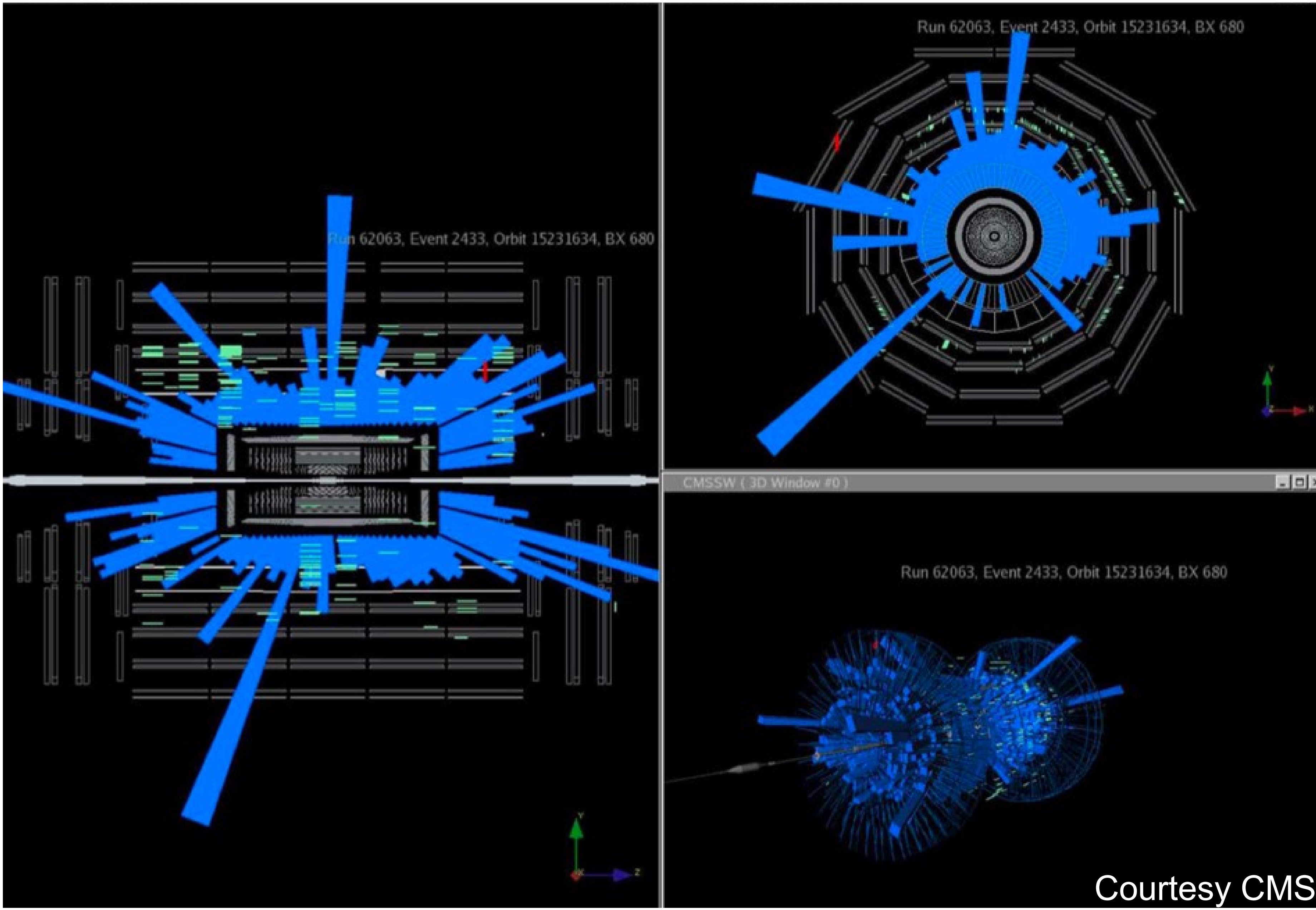




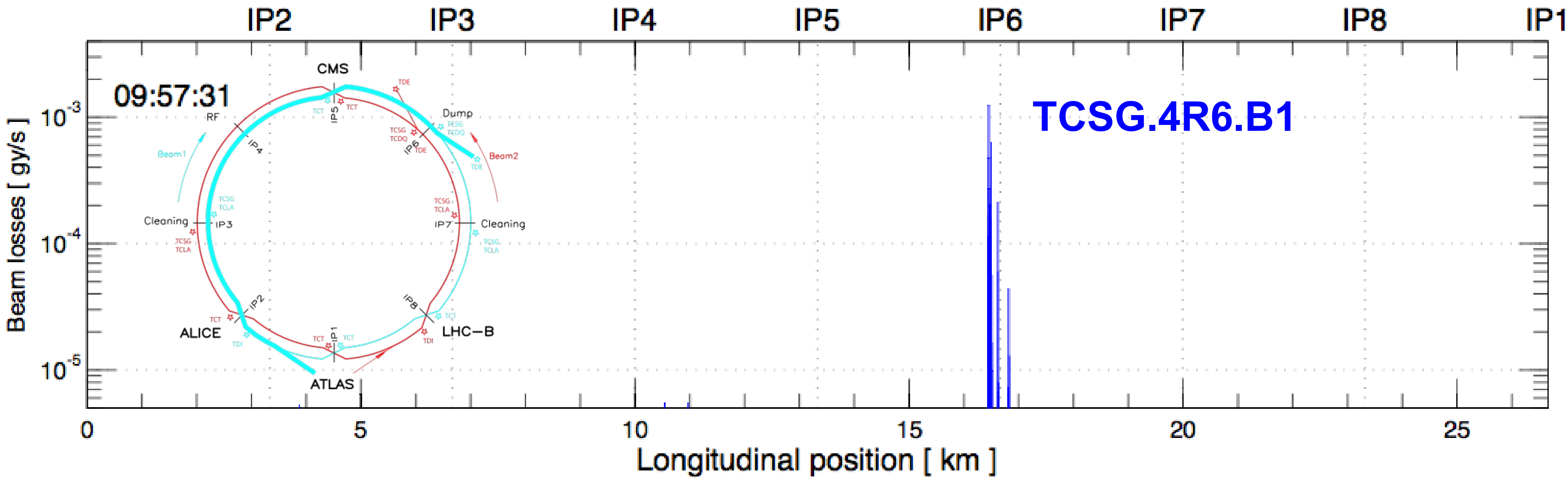


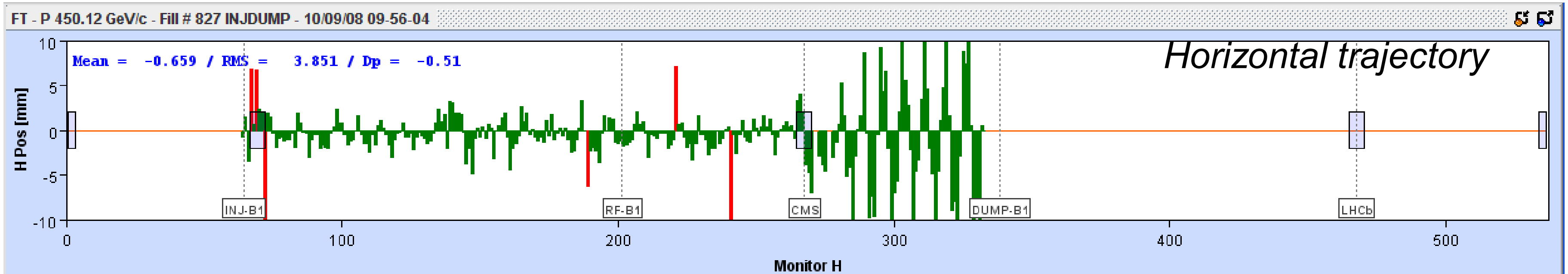
LHC Commissioning/Chamonix'09 Summary, Ralph.Steinhagen@CERN.ch, 2009-03-20

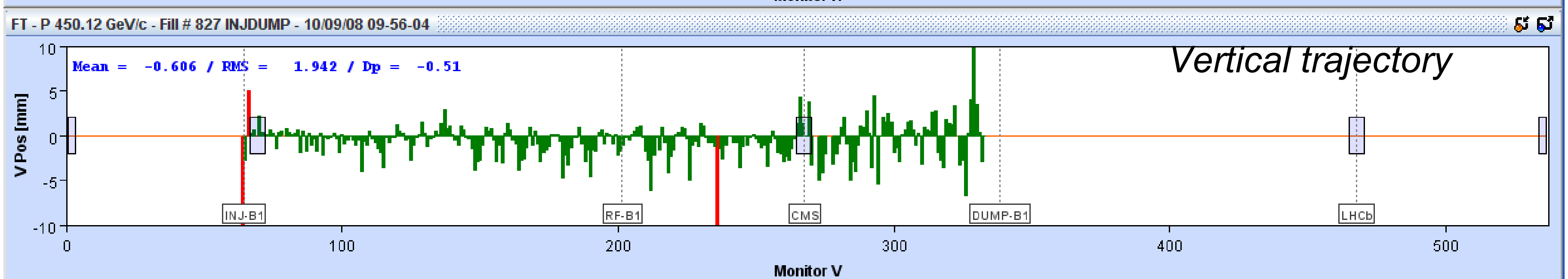
First Beam Event in CMS



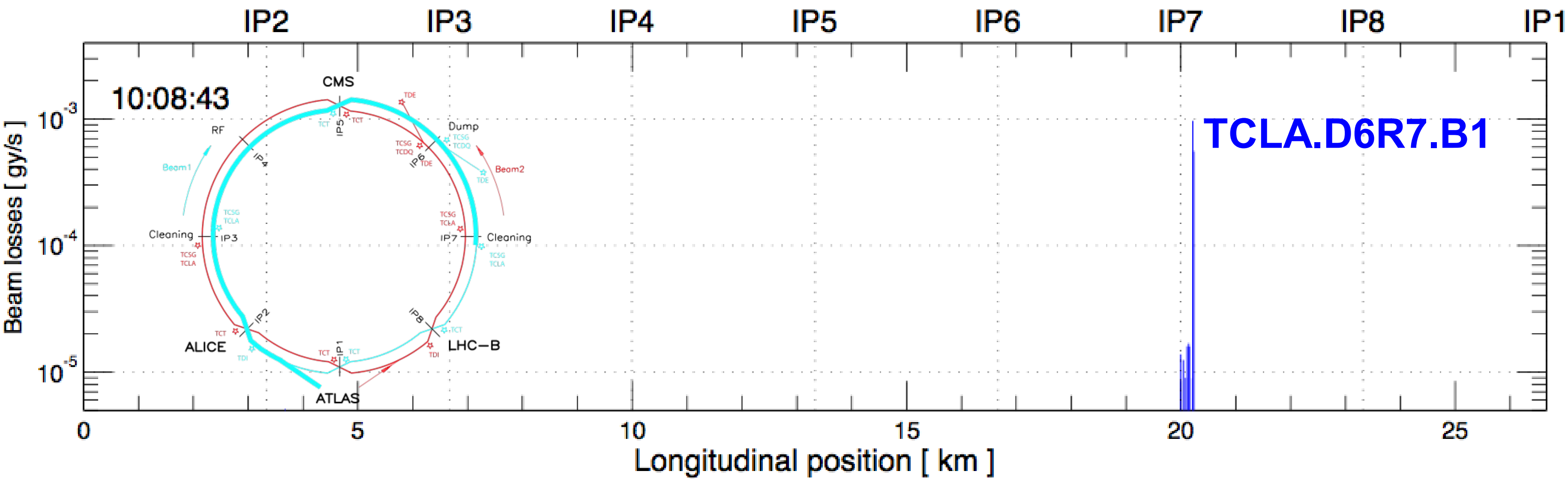
First Turn - Beam 1 to IR6 (Beam Dump)

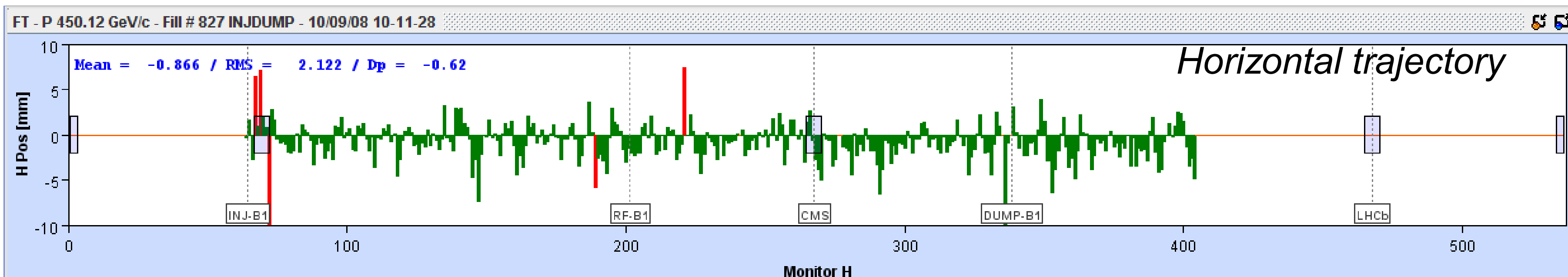


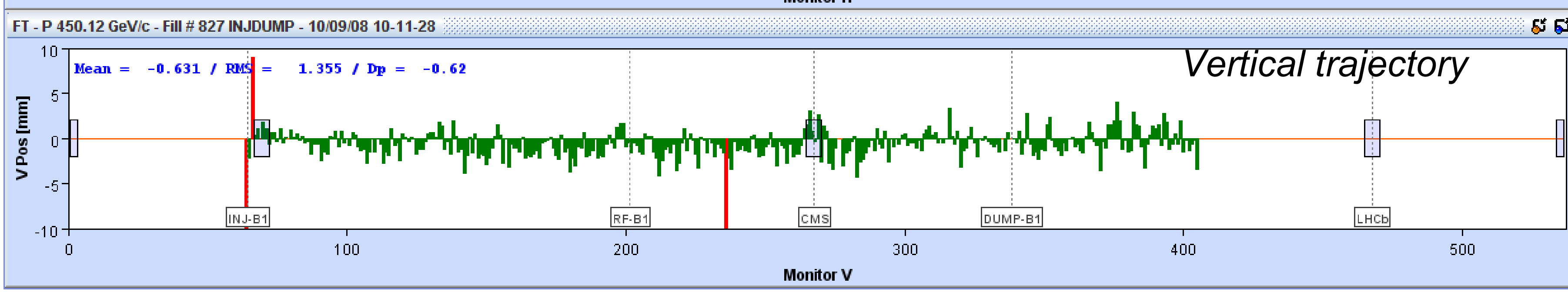




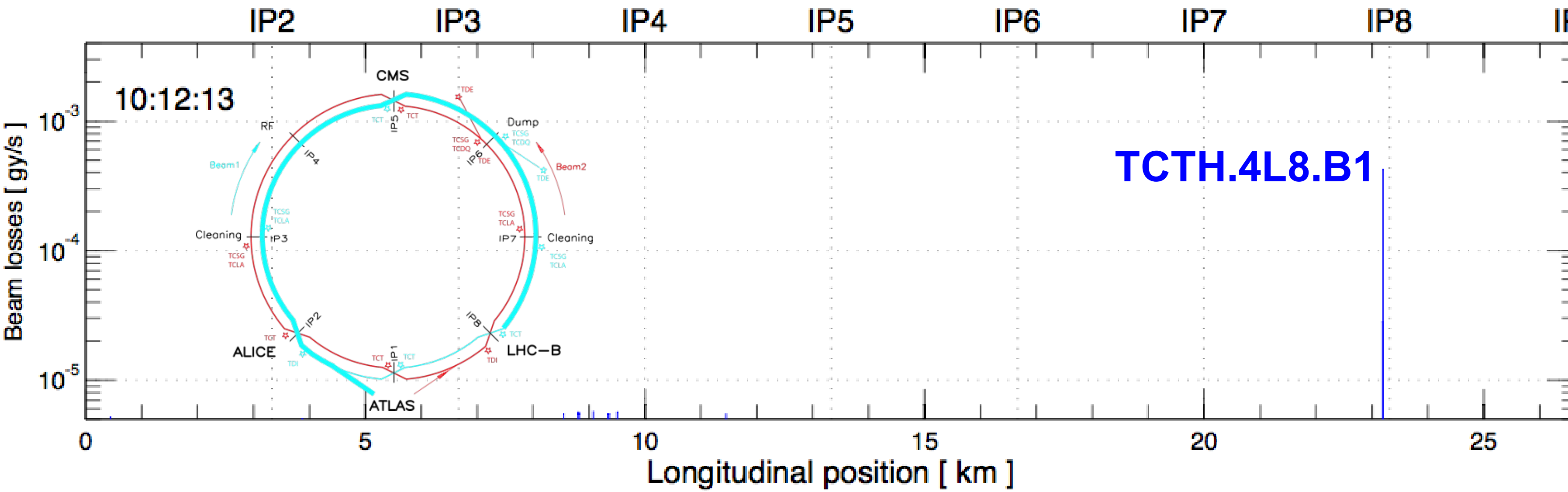
First Turn - Beam 1 to IR7 (Betatron Cleaning)

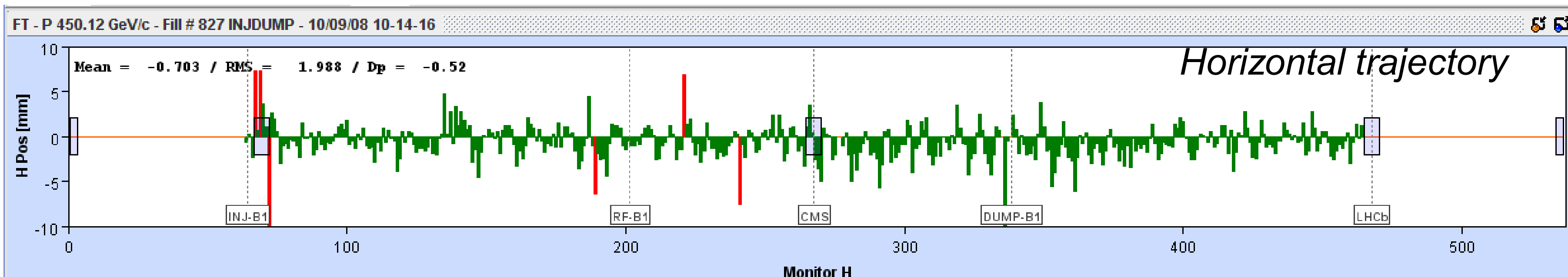


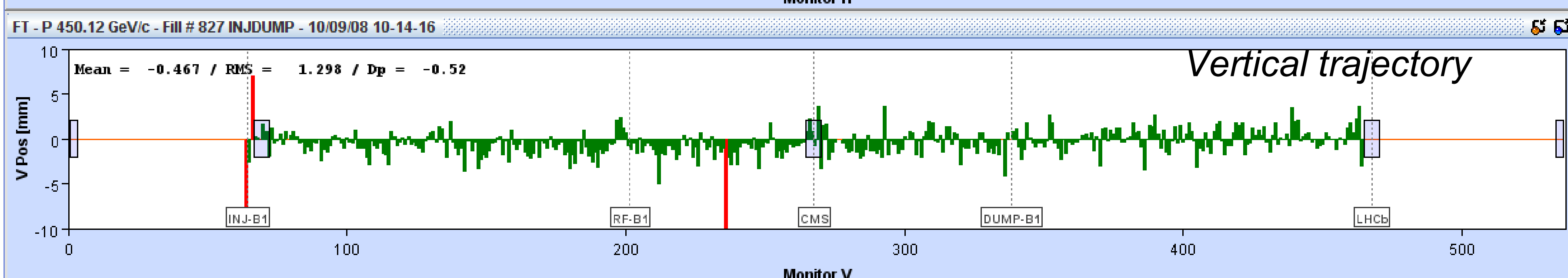




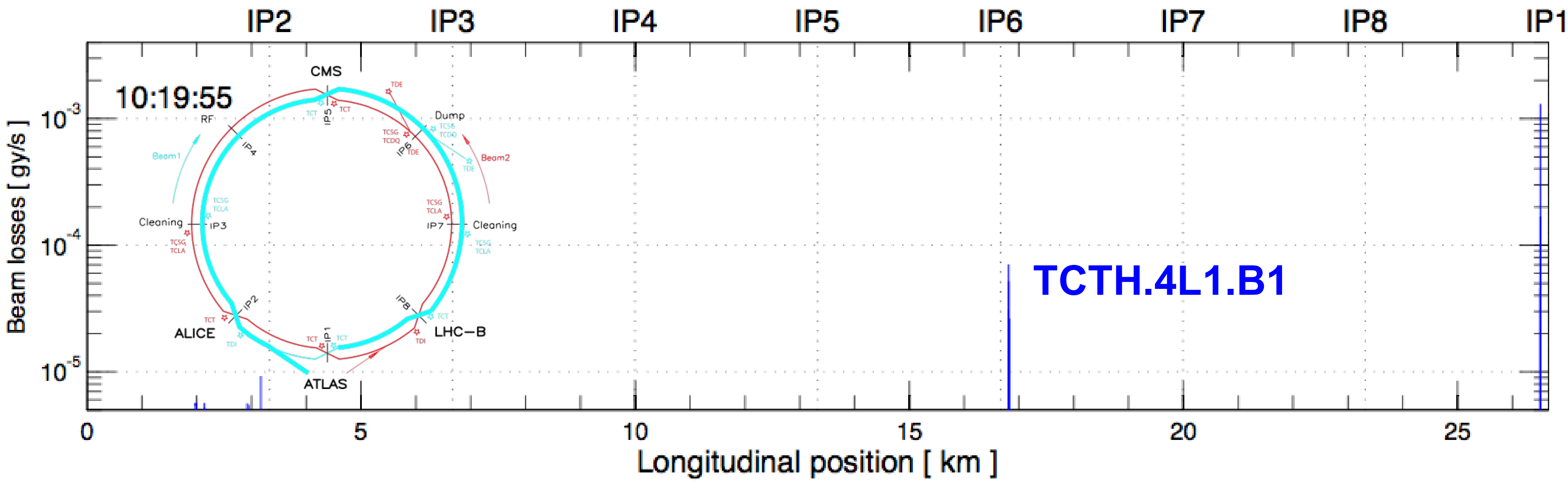
First Turn - Beam 1 to IR8 (LHCb)

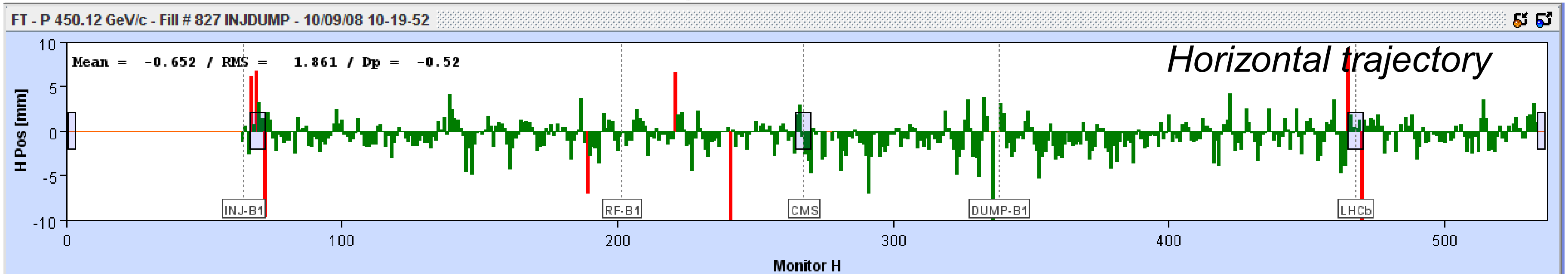


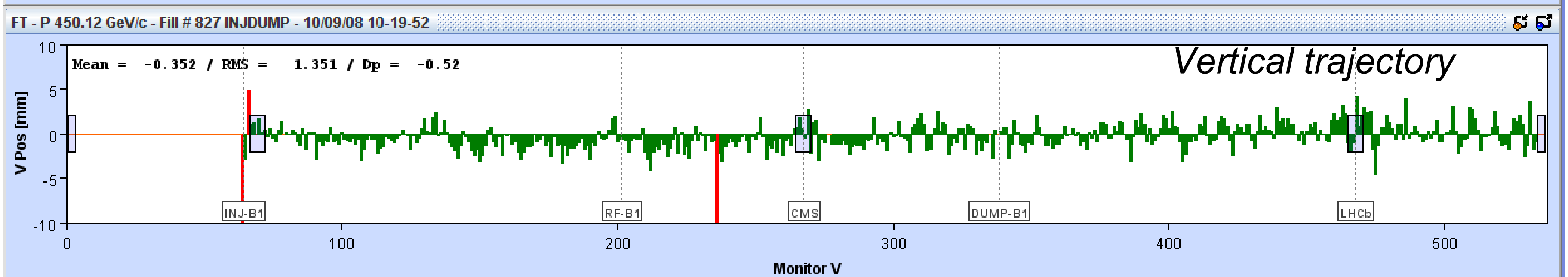




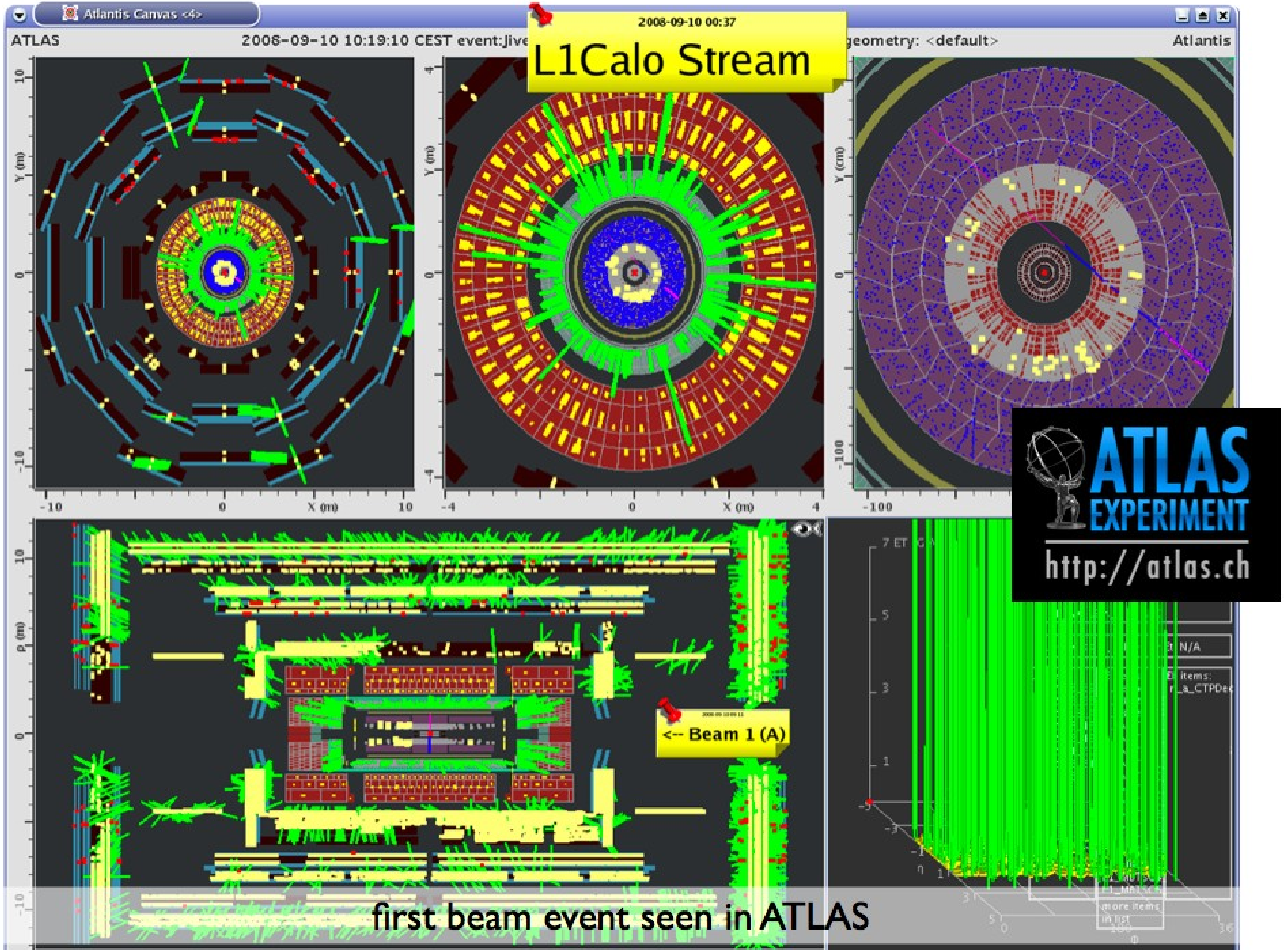
First Turn - Beam 1 to IR1 (ATLAS)





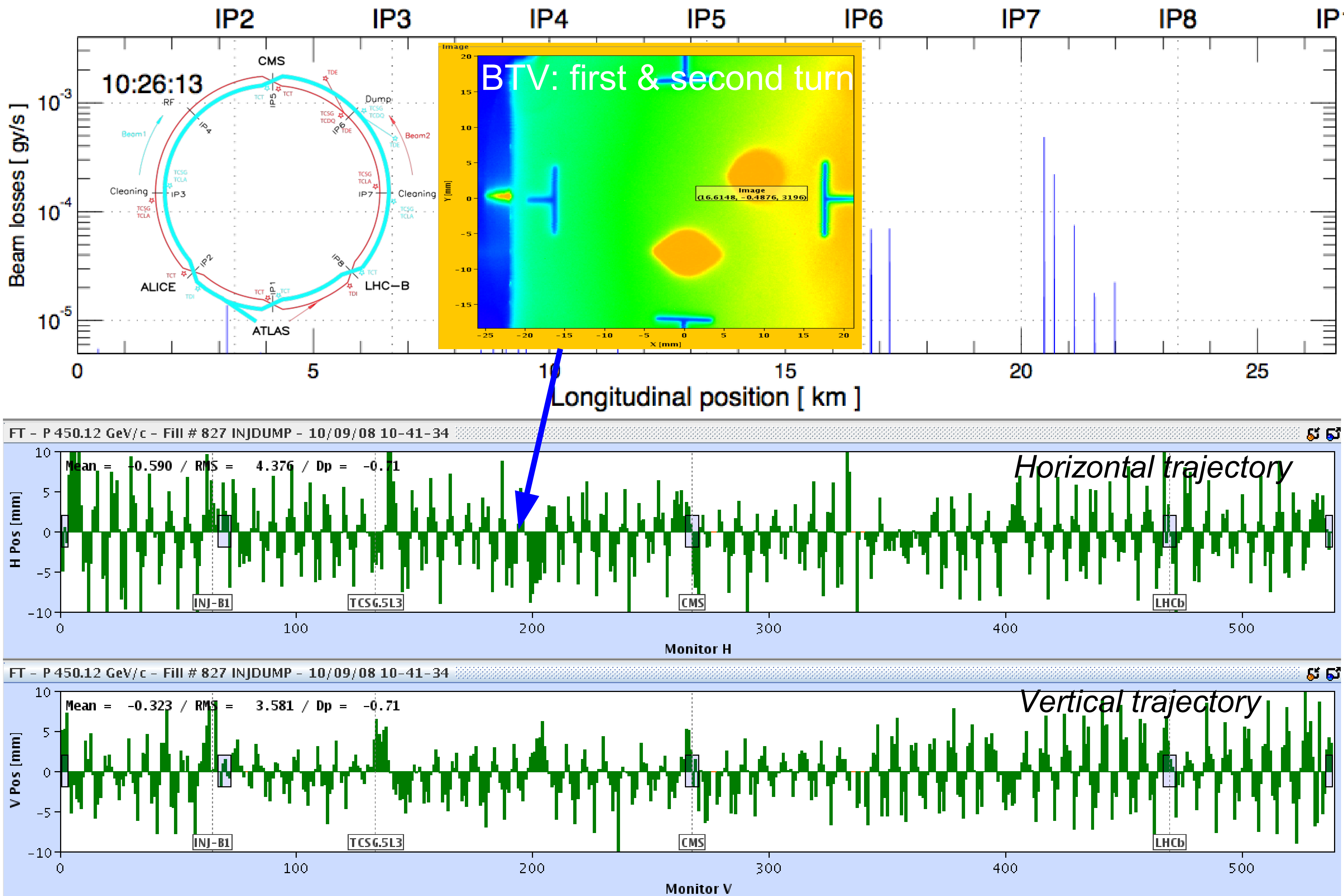


First Turn - Beam 1 to IR1 (ATLAS)

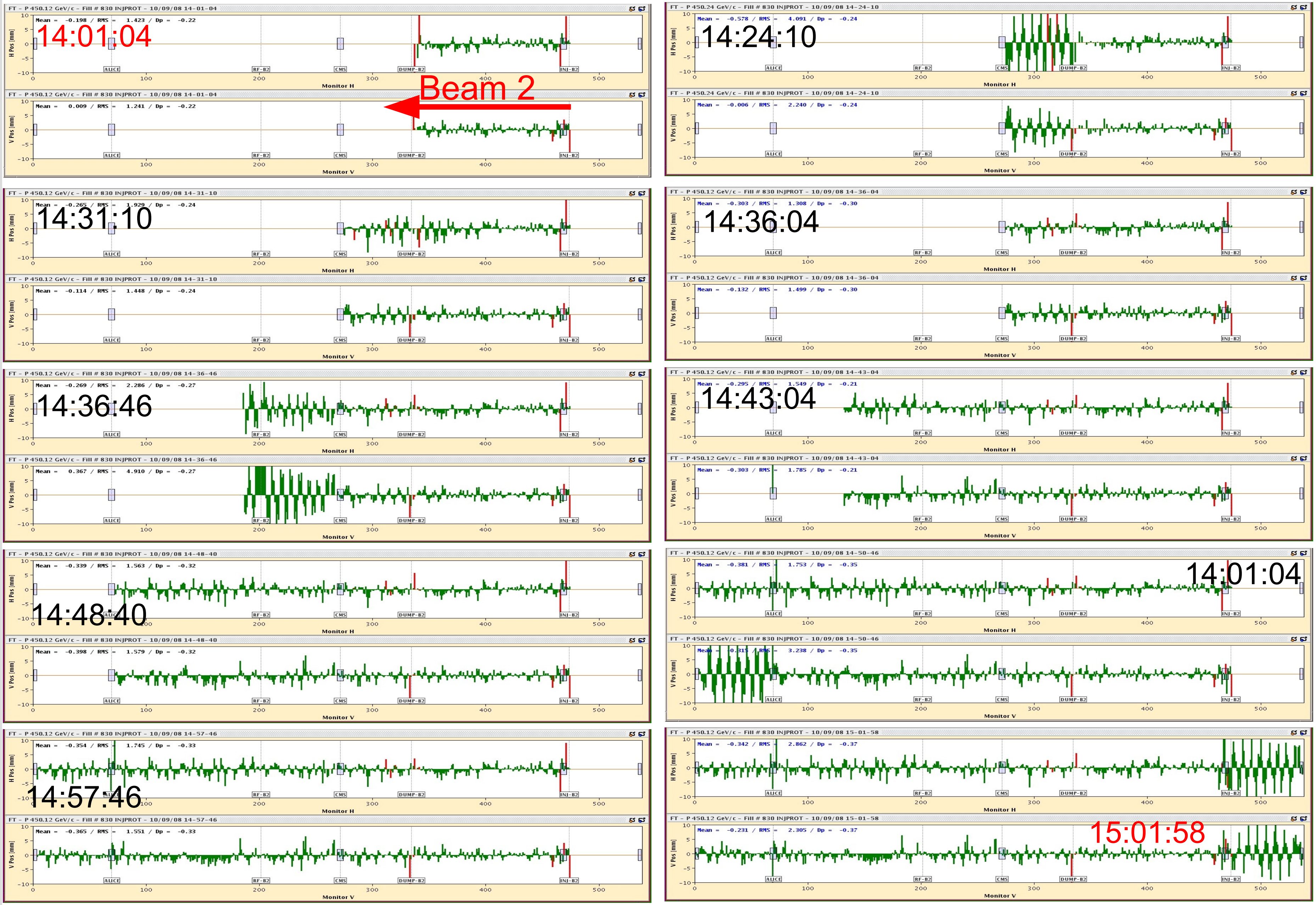


Courtesy of T. Wengler for the ATLAS team

First Complete Turn – Beam 1



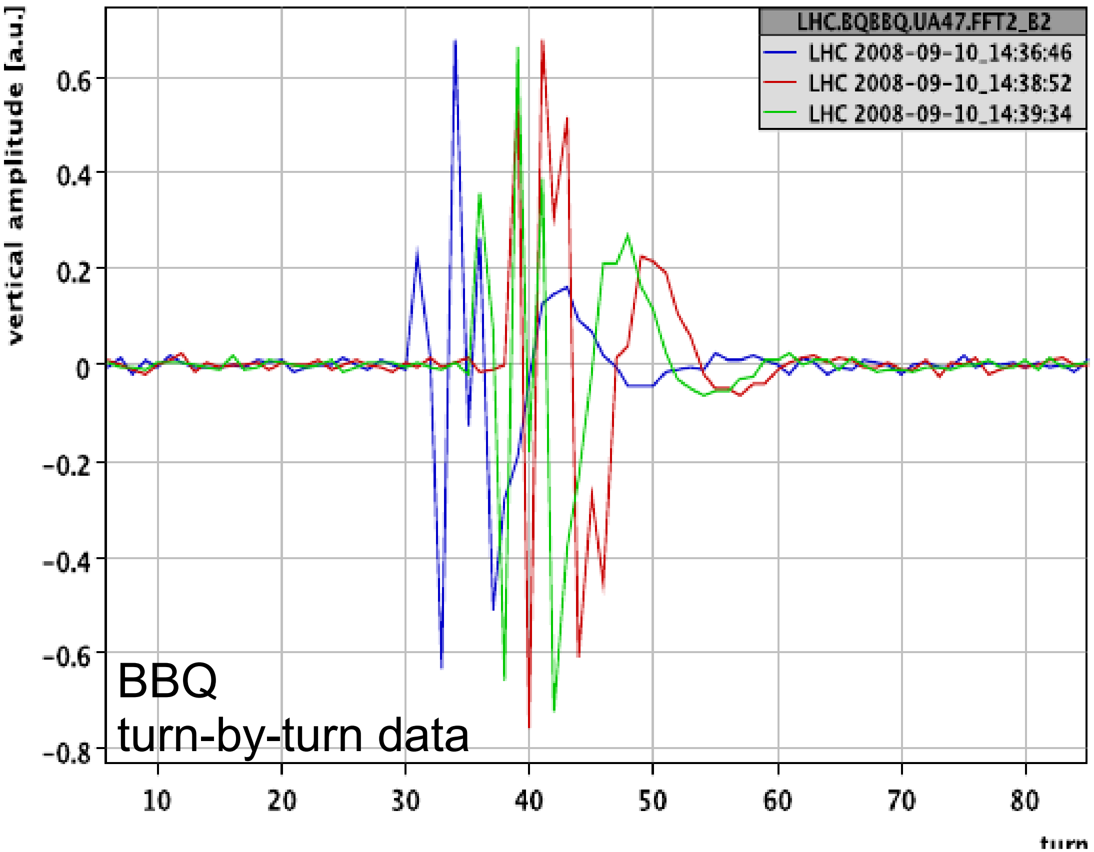
First Complete Turn – Beam 2



10th of September

September 10th
Beam 2 – On the Way to Circulating Beam

- During the late, after the crowd, artists and TV cameras left...
- Closing and establishing circulating beam was hampered by fast beam loss after a few number of turns.
  - Same orbit every second turn … (similarly already seen for B1)

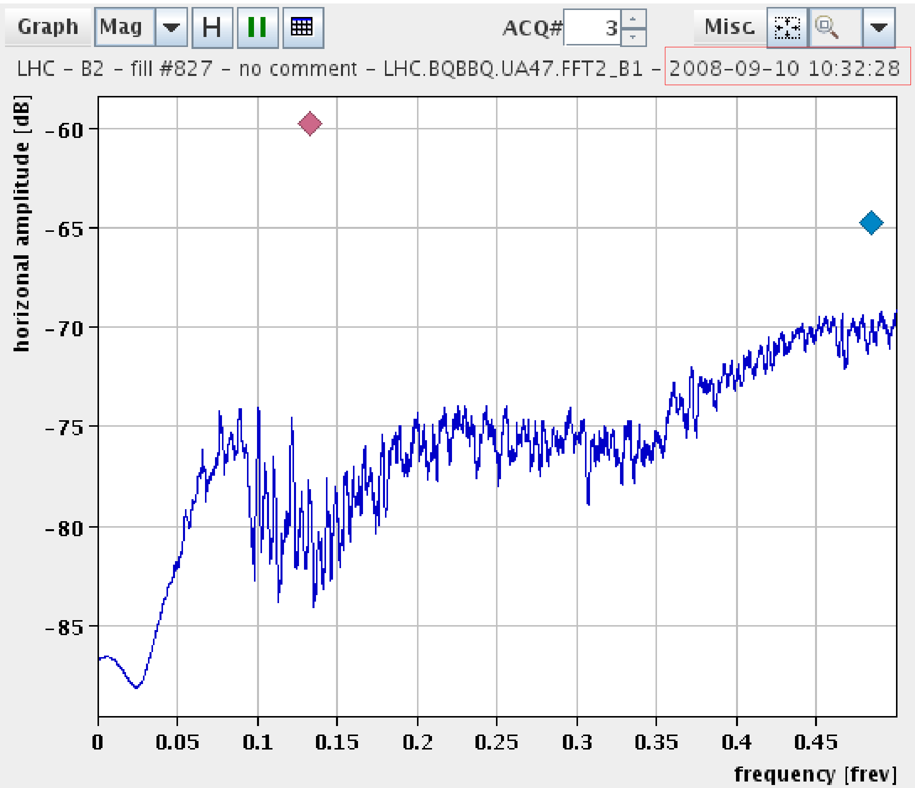


Could it be ... ?

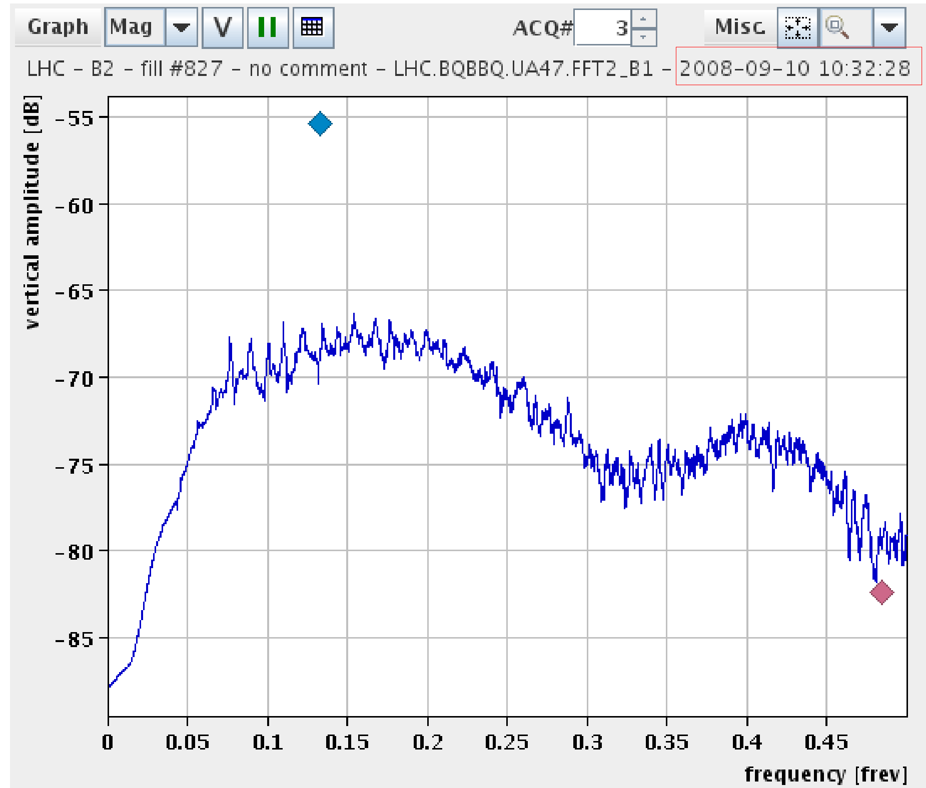
Injection Tune

- People in the control room (now less than 12) were very sceptic …

horizontal BBQ spectrum



vertical BBQ spectrum

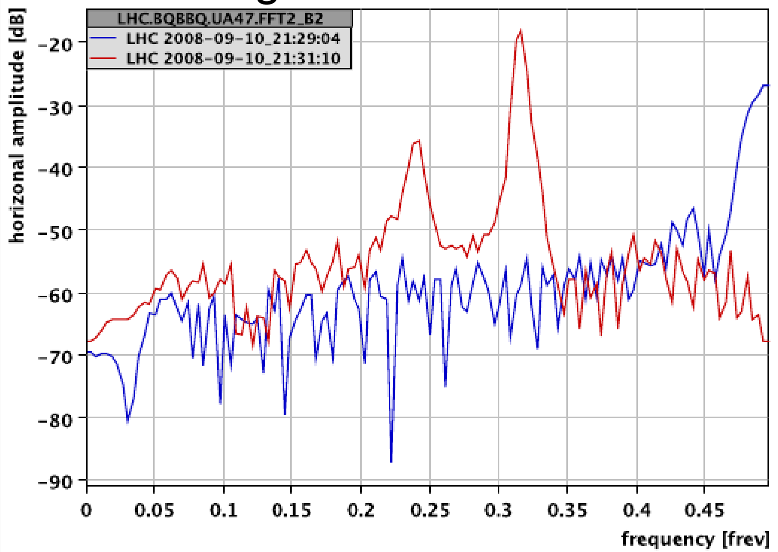


- N.B. We (Marek and myself) were quite surprised that the BBQ could resolve something without the diode-RC peak-detector being charged.

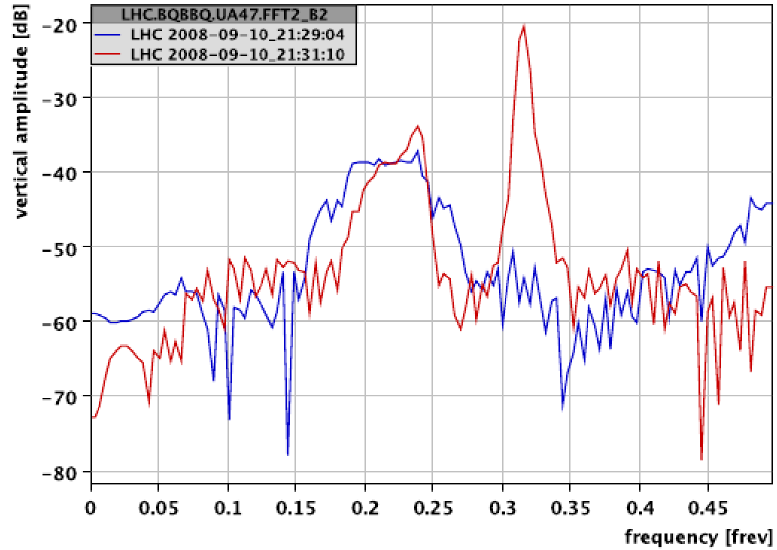
→ first tune trim experiments

Initial Tune Correction

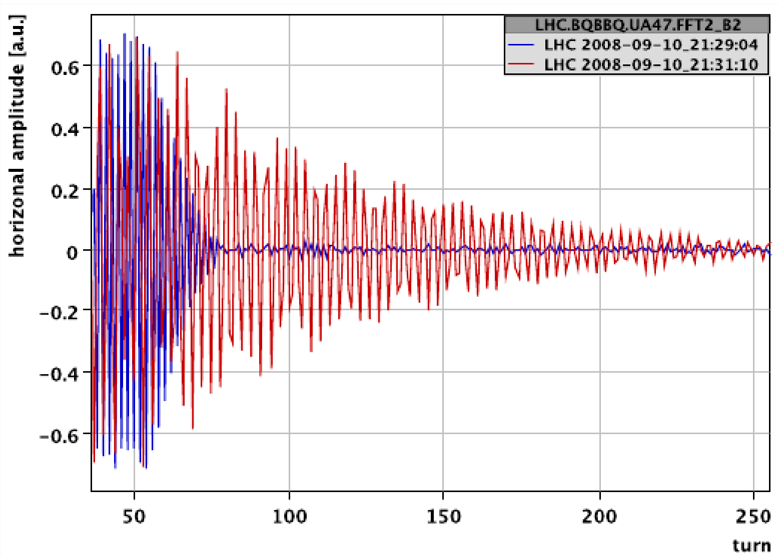
- … assuring that the BBQ indeed measures the tunes: before → after

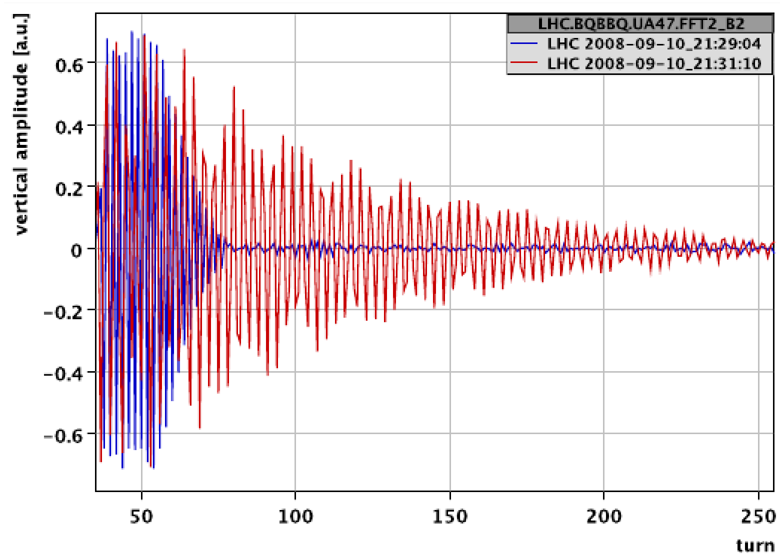


(a) Horizontal Spectra B2



(b) Vertical Spectra B2

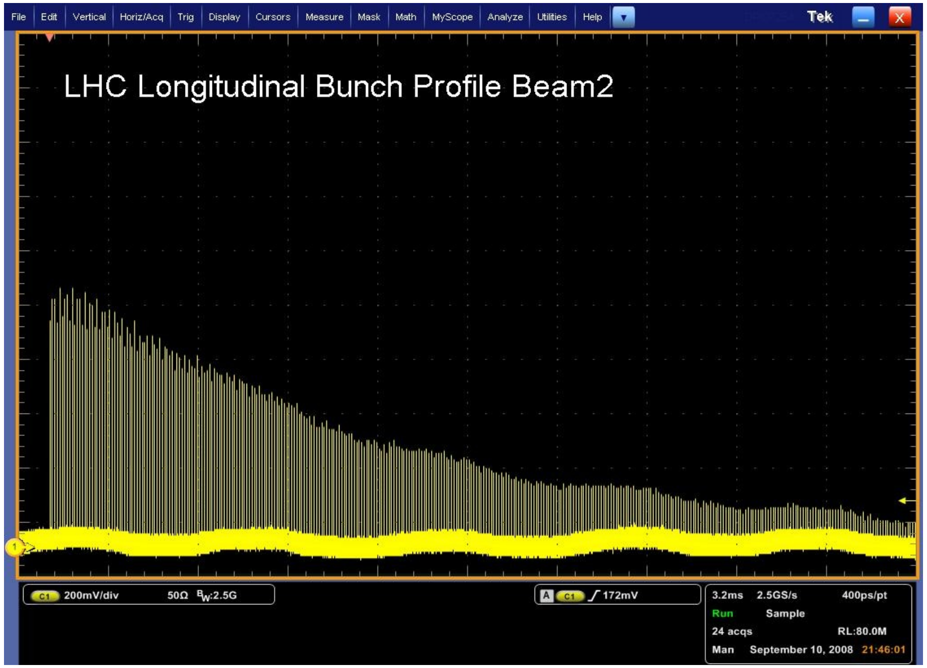


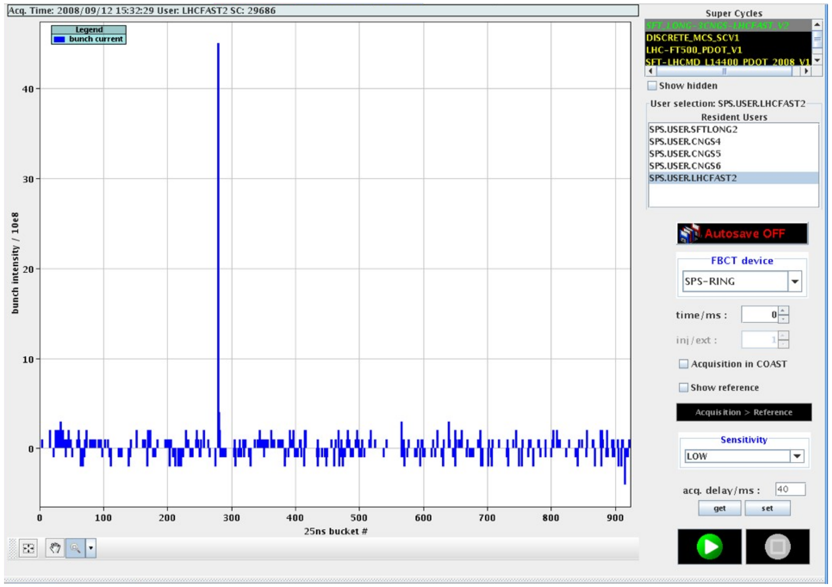


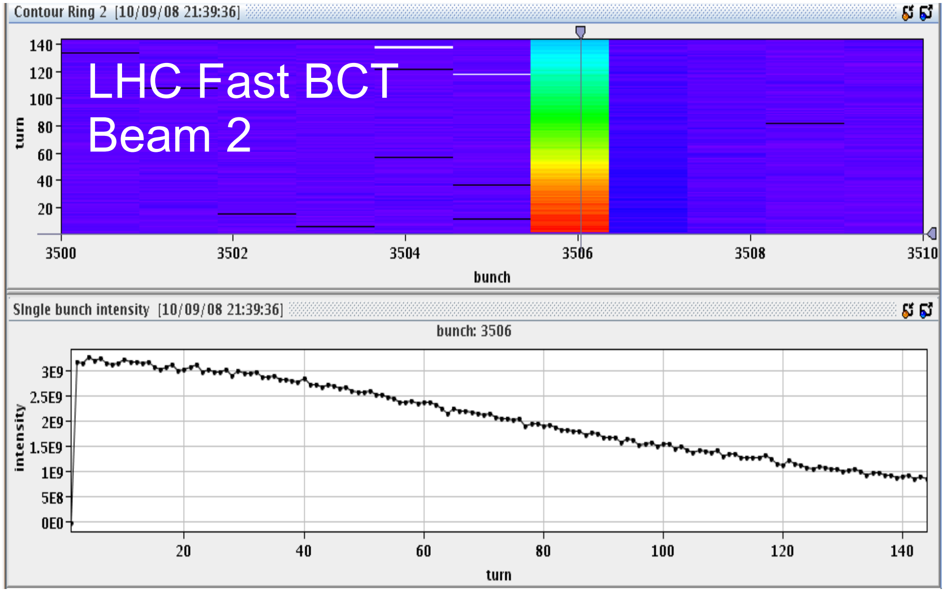
21:31 - Beam 2 Circulating!

→ beam circulates for a few hundreds of turns (RF off), once the tune was corrected! (N.B. decreasing signal due to debunching / filamentation)

- Further inj. Q and closed orbit optimisation
- … response matrix measurements.

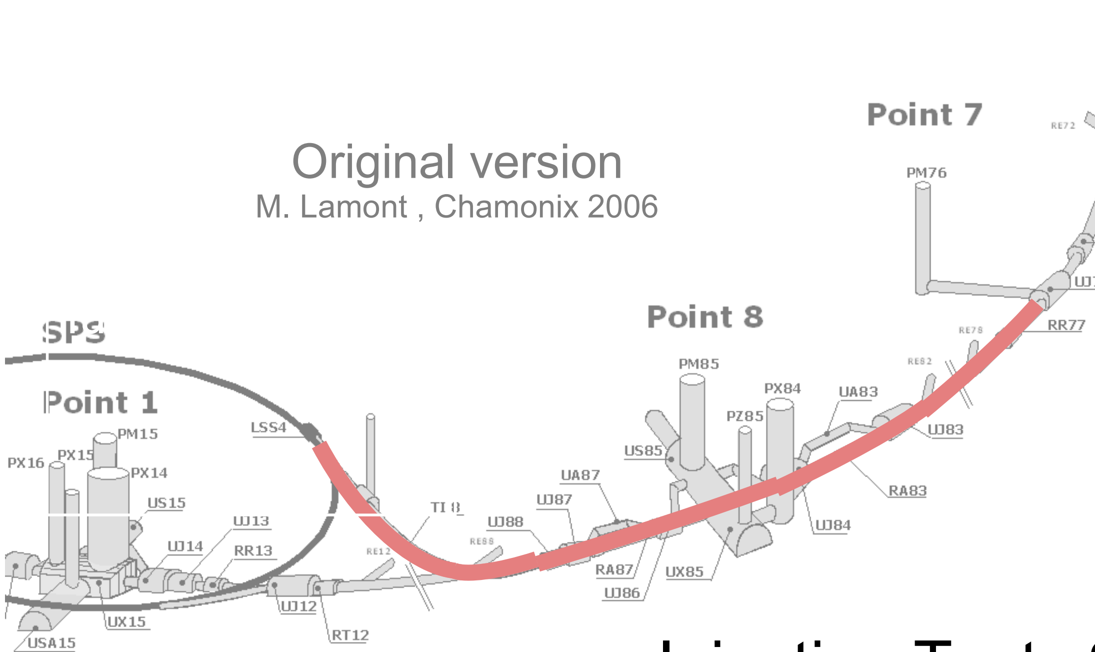


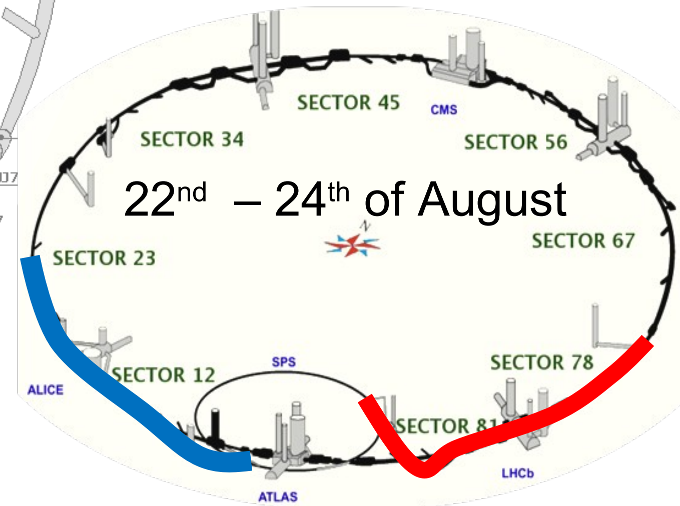




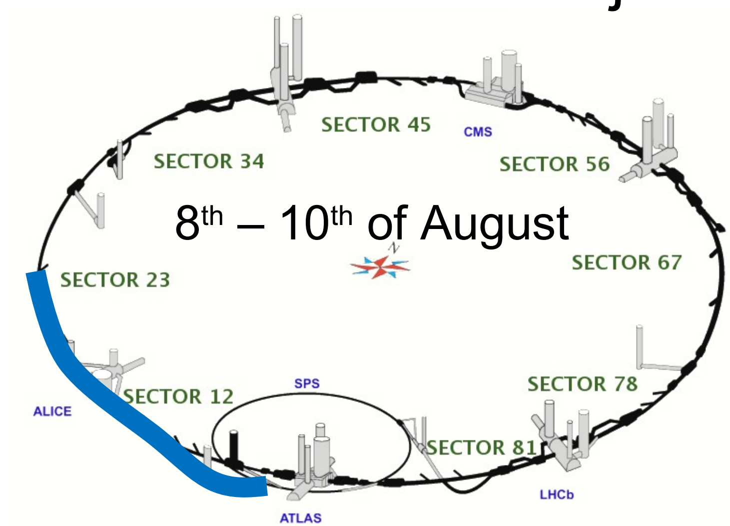
Success was no Accident: LHC Injection Tests

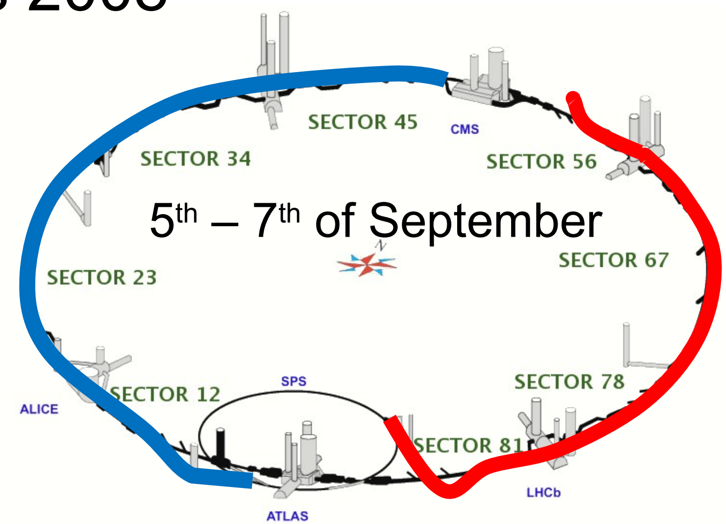
Original version
M. Lamont , Chamonix 2006





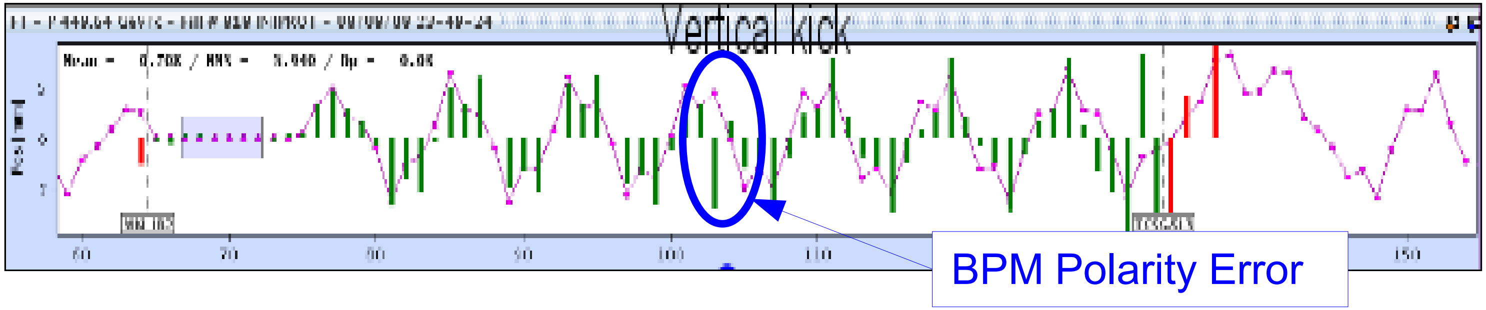
Injection Tests 2008

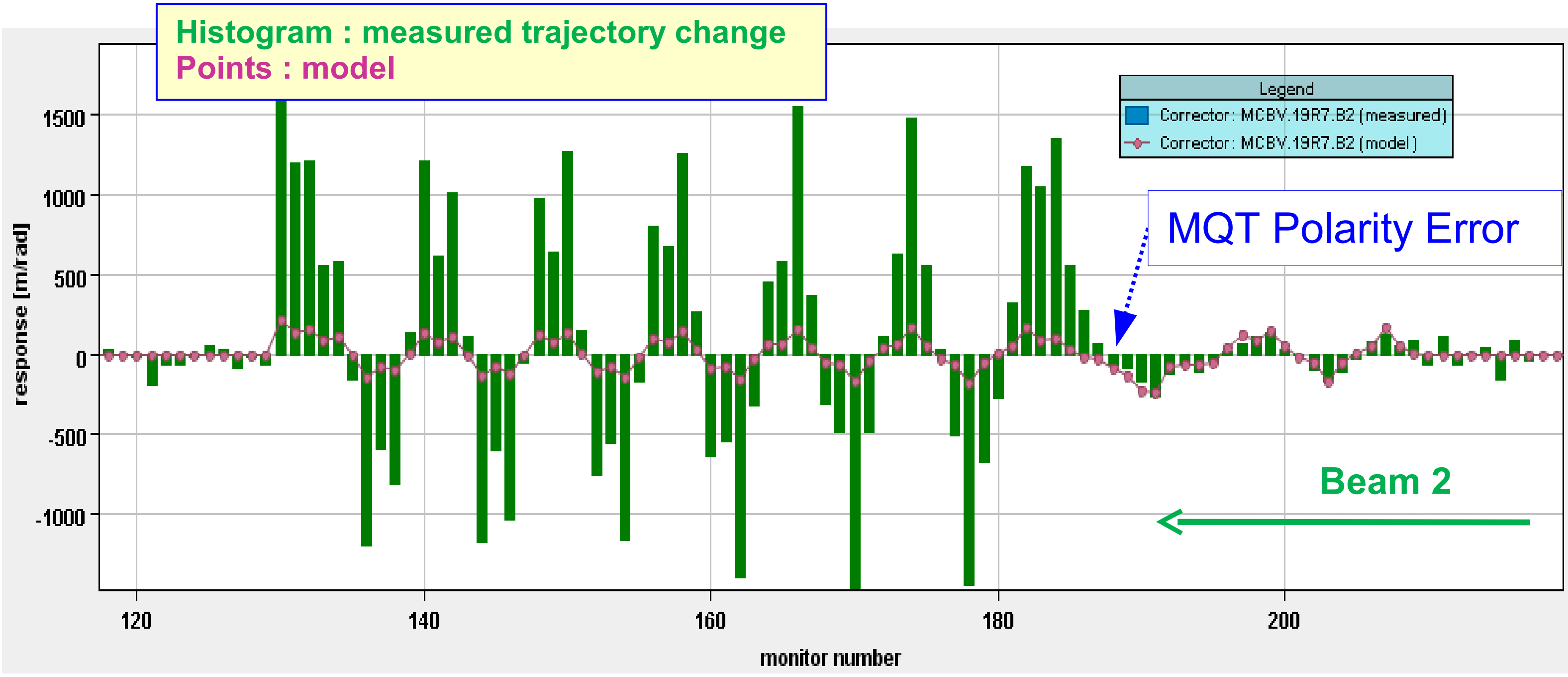




Magnet Polarity and BPM Cabling Errors

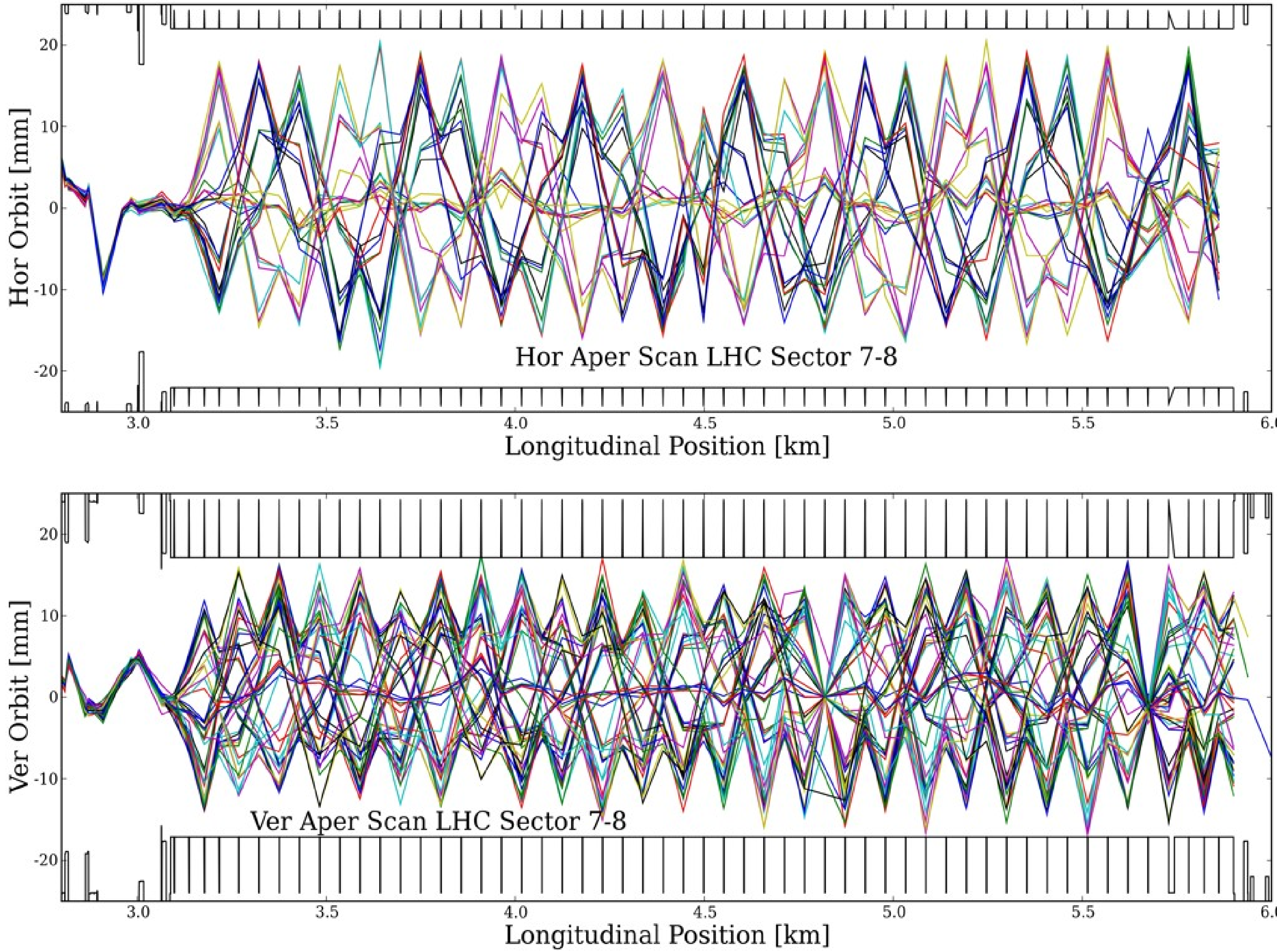
- Most of the 'obvious' BPM, COD and optic errors have been resolved during the sector tests!





Available Aperture – Beam 2 Injection Tests

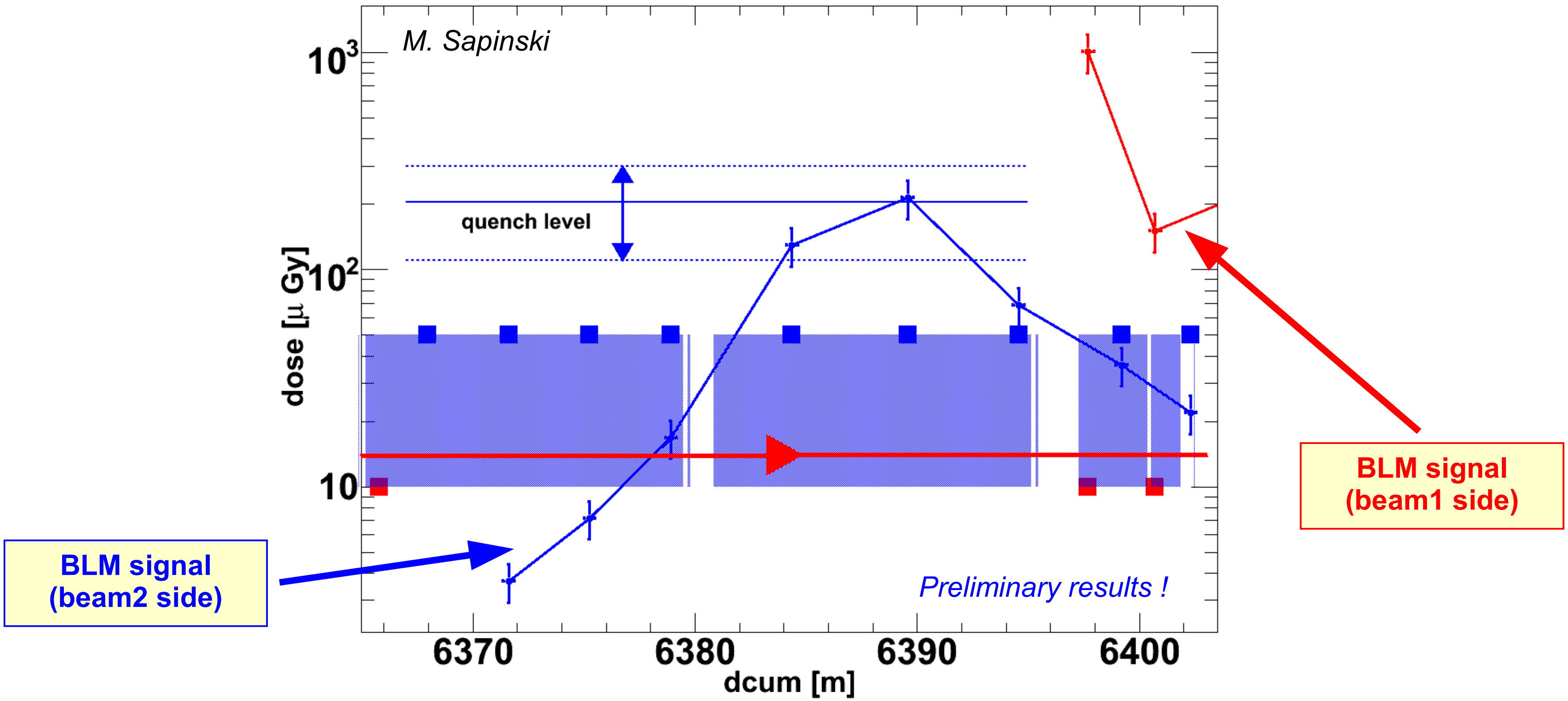
- A great relief : the aperture was very good – no buckled bellows & Co.



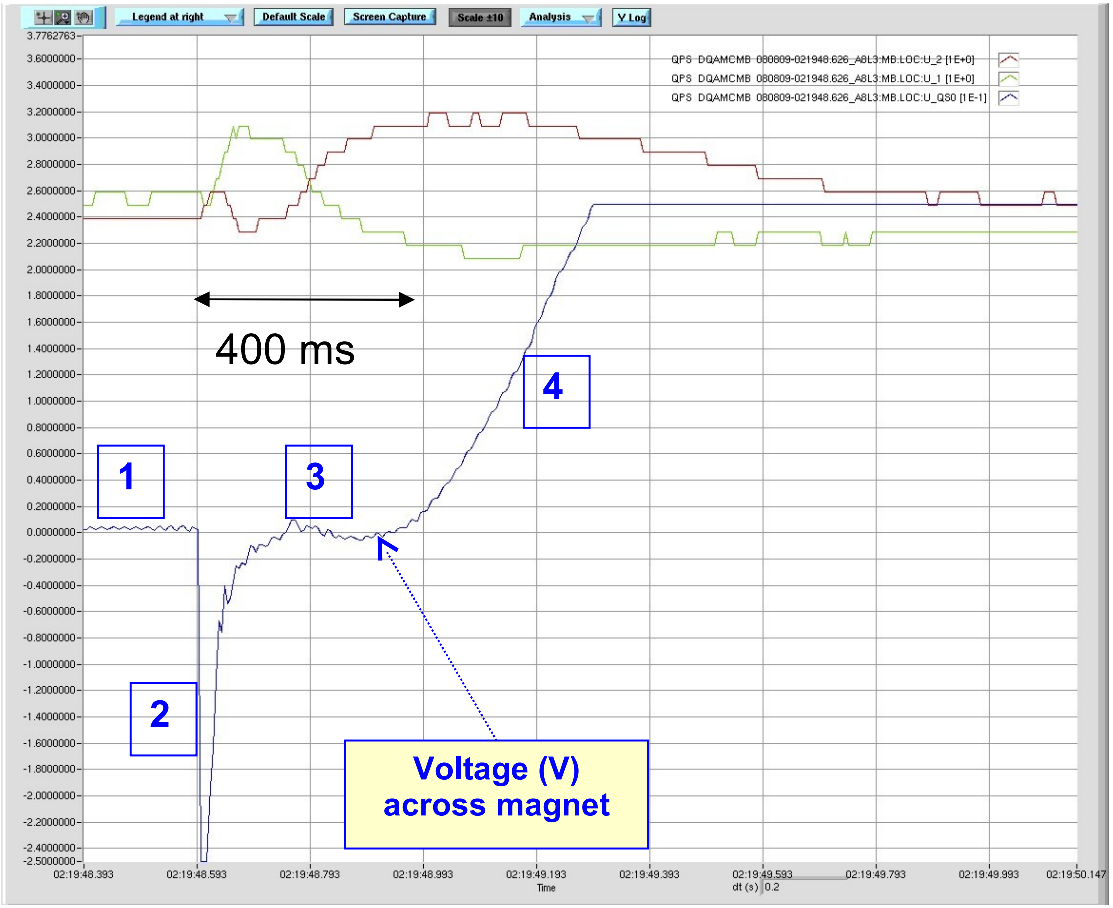
Courtesy R. Calaga

OUR FIRST QUENCH
– A Beam Instrumentation Perspective

- Bunch intensity ~4 10^9 p, which is within the expected range
  → reduced the commissioning intensity 2..3·10^9 p.
- Prior to 10th, a test revealed that even with ~2·10^9 p one can quench
  - but very unlikely in normal operation due to the large impact angle.



OUR FIRST QUENCH – A Magnet Perspective



1. Voltage = 0: → no resistance
2. Beam impact, Voltage != 0 → resistive area in the magnet
3. Voltage back to 0 → magnet recovered (very little energy deposition!)
4. Voltage != 0: QPS enters the game and force-quench the magnet etc…

Intermediate Conclusions

- Despite the presence of an unbelievable crowd of people :
  - 10:30 : Beam 1 around the ring (in ~ 1.5 hour). Beam makes ~ 3 turns.
  - 15:00 : Beam 2 around the ring (in ~ 1.0 hour), beam makes 3-4 turns.
  - 22:00 : Beam 2 circulates for hundreds of turns…
- Most essential Beam 2 instrumentation and acc. systems commissioned
- … and no Black Holes.

Feedback

We got overwhelmed with positive BI related feedback!

A very big thank you!

This success was not an accident,
but a result of a combined, high-quality, and meticulous preparation prior to the 10th of September.

BNL played an important part in the LHC commissioning with RHIC being the cradle of many LHC system for which we want to express our sincere thanks!

LHC Day II

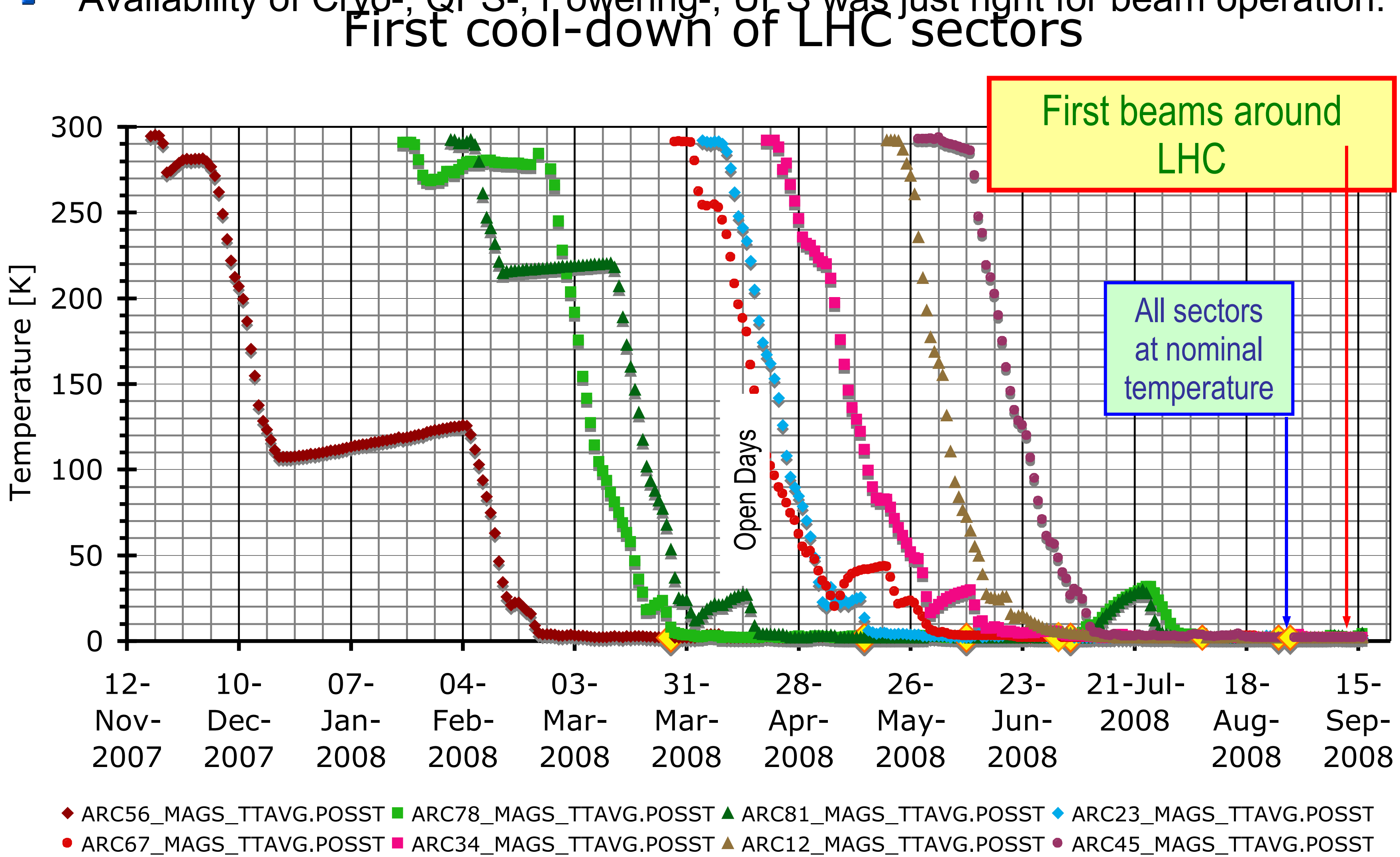
or

The day we realised how lucky we were...

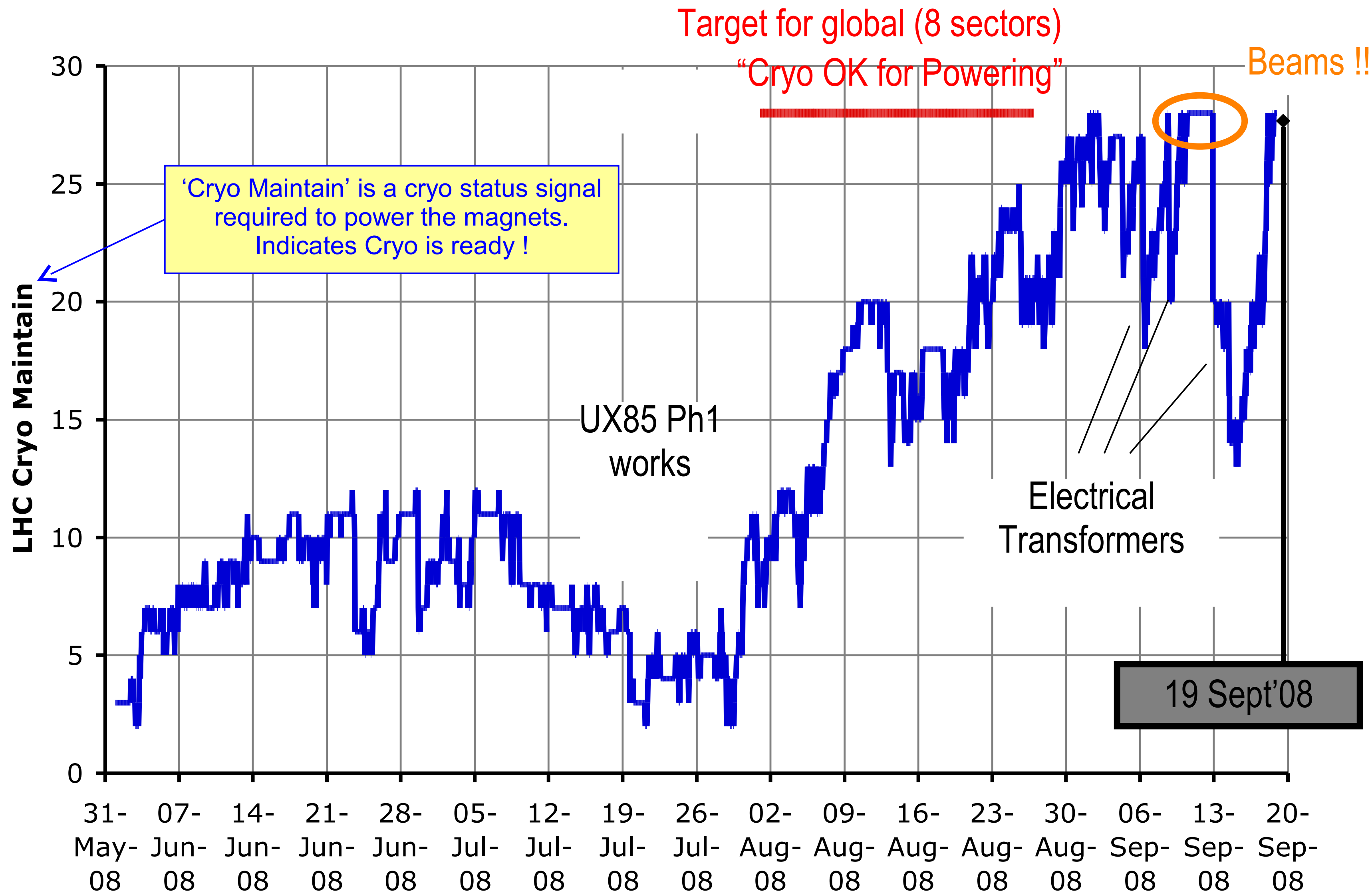
First cool-down of LHC I/II
- Cool-Down Time ~ 4-6 Weeks/Sector

...fortune was on our side!

- Availability of Cryo-, QPS-, Powering-, UPS was just right for beam operation:



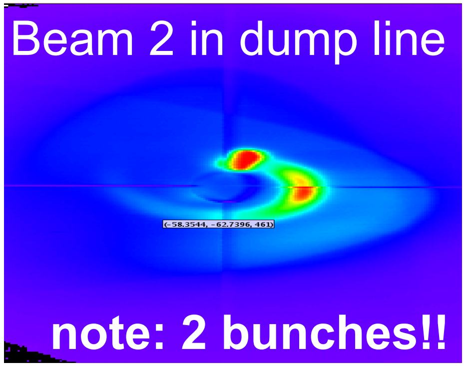
First cool-down of LHC I/II
- LHC cryogenics towards beam

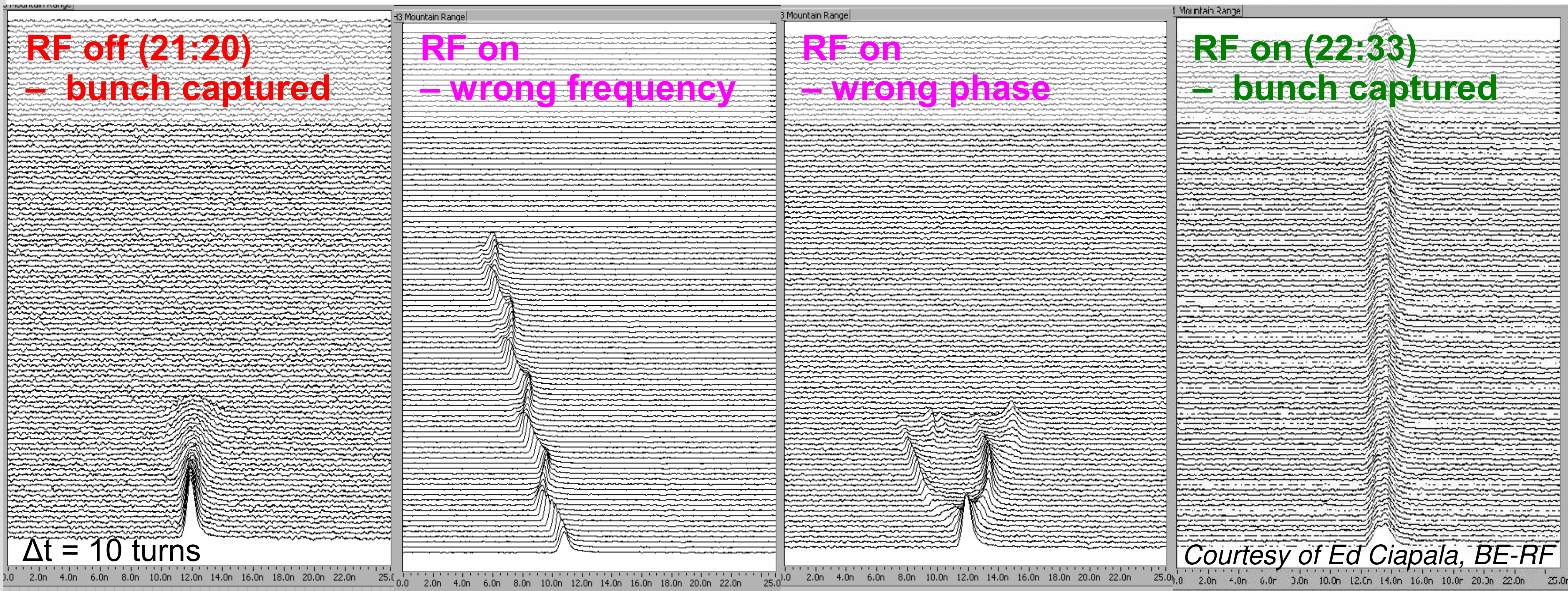


Beam 2 - RF Capture
Thursday 11th – Late Evening

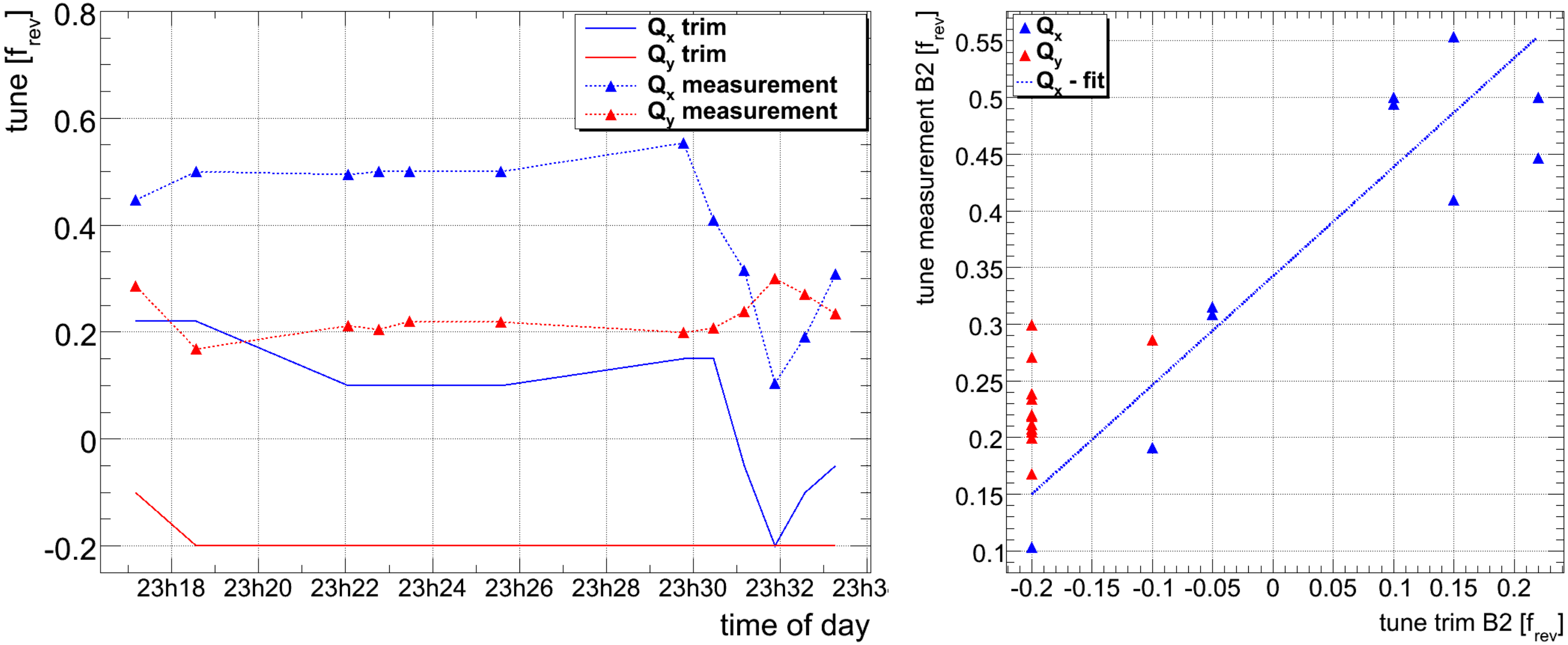
once QPS, cryo and power systems have been fixed:

- Re-cycled LHC, re-corrected tune, orbit, …, switched on RF
- Beam circulated for more than 10 minutes (life-time > 1 h)
  - forced beam abort → first emergency beam dump test
- Commissioning driven by RF team from SR4.
  - CCC could only watch the longitudinal profile monitor!





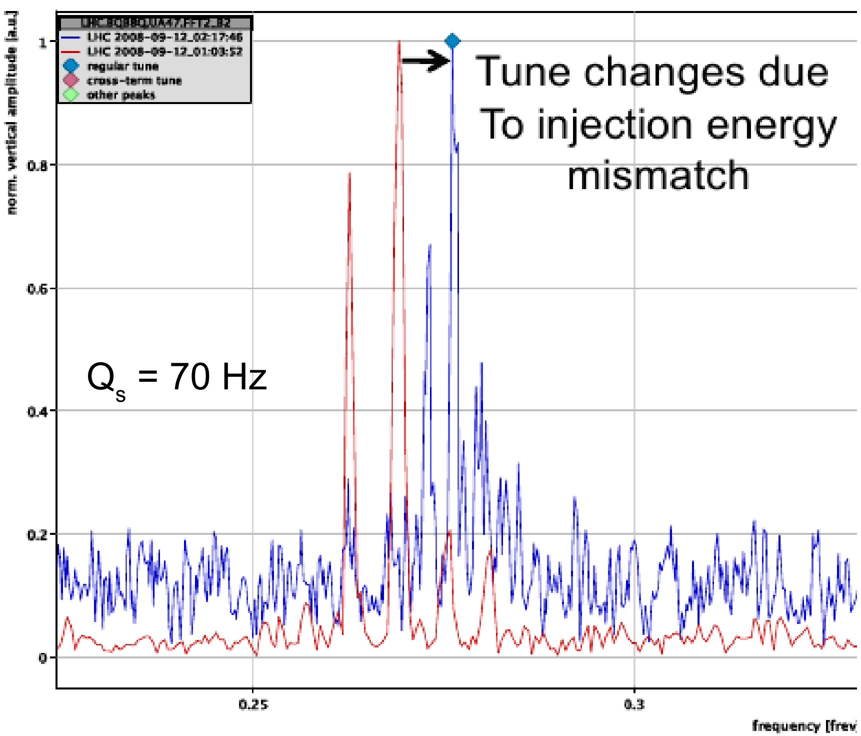
Beam 2 Injection Tune vs. Trim History

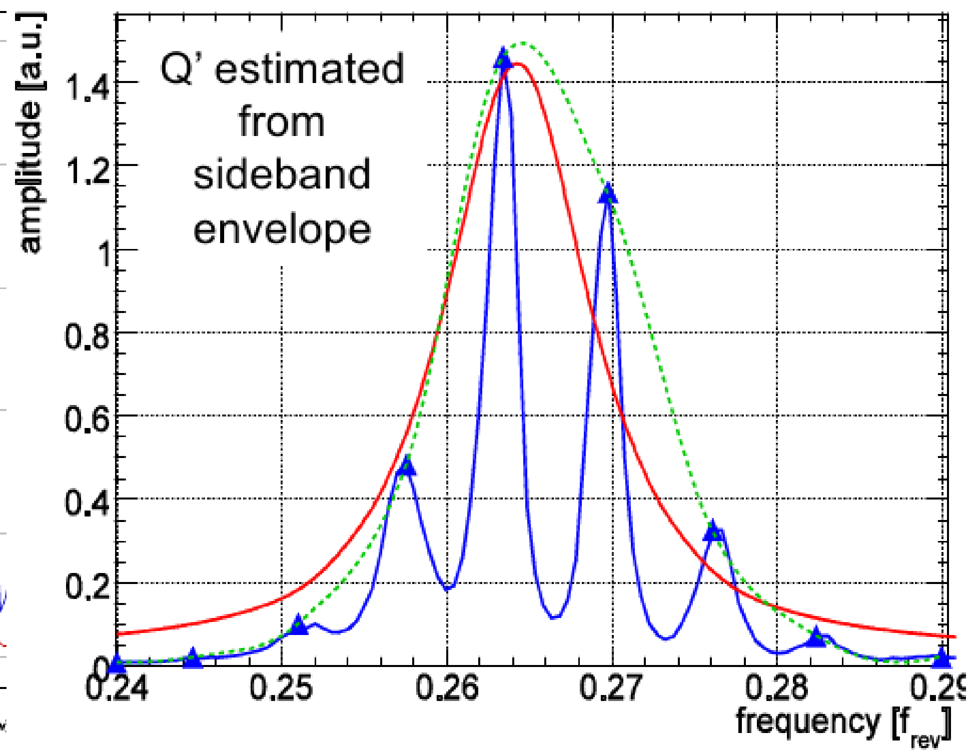


- Tune trim vs. measurement fits (w.r.t. Q_x=0.32 & Q_y=0.28):
  - Horizontal correlation: $\Delta Q_x = (0.96 \pm 0.16)\cdot Q_x(\text{trim}) + (0.03 \pm 0.03)$
  - Vertical correlation: $\Delta Q_y \approx X\cdot Q_x(\text{trim}) + 0.16$
    - Scaling 'X' off due to QD polarity error (fixed by Mike the same day)
- Compared to the LHC magnetic field description (FIDEL, L. Bottura):
  - outermost range but still within the possible magnet model error
  - biggest uncertainties due to unknown pre-cycling (limited time....)

- Tune shift due to injection momentum offset
  - Comparison of injection tunes to circulating beam tunes
    → Inconclusive as no systematic logging of momentum mismatch (Q' > 0)
- Estimates from tune to synchrotron side-band amplitude ratio
  - Measured chromaticity $Q_H' \approx Q_V' \approx 32$

$$S_n(Q') = J_n\left(\frac{Q'}{\omega_s}\frac{\Delta p}{p}\right)$$

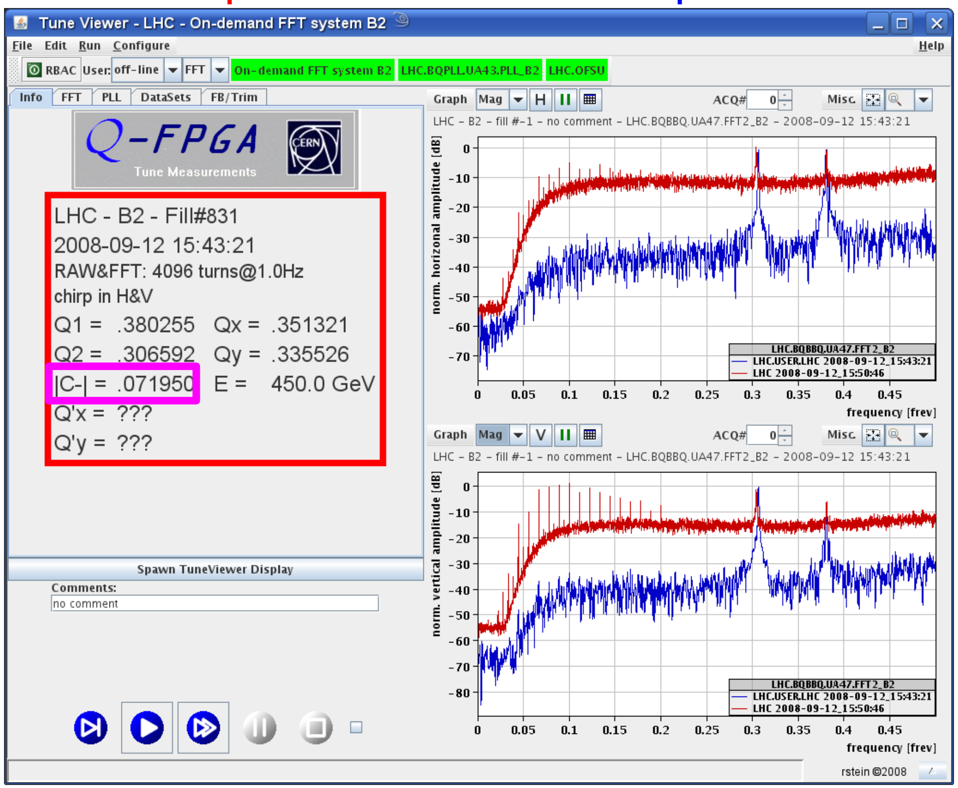


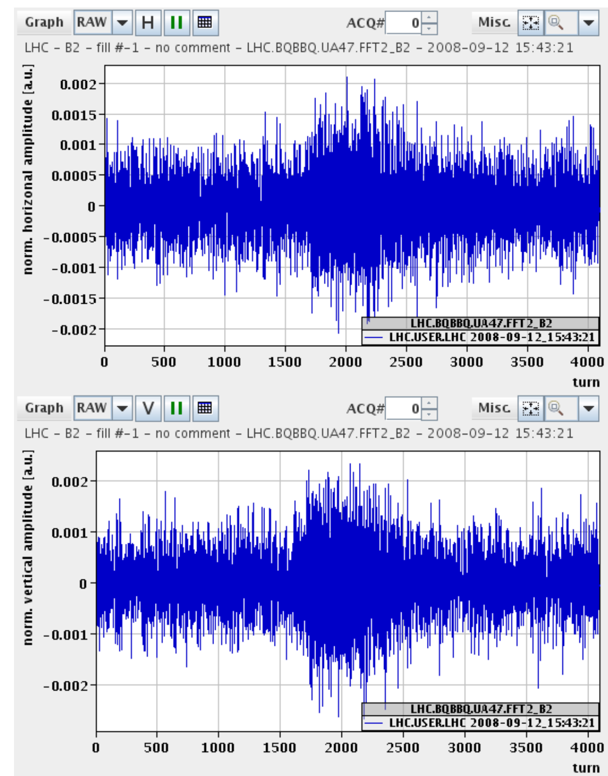


Initial Tune, Chromaticity and Coupling Studies III/III

- Spectra sufficient for tune diagnostics without any further explicit excitation
- BBQ Tune On-Demand system commissioned
  - Chirp excitation using transverse damper (2.5% of max. Strength)
- First coupling estimate: |C-| ≈ 0.07

residual spectrum vs. excited spectrum



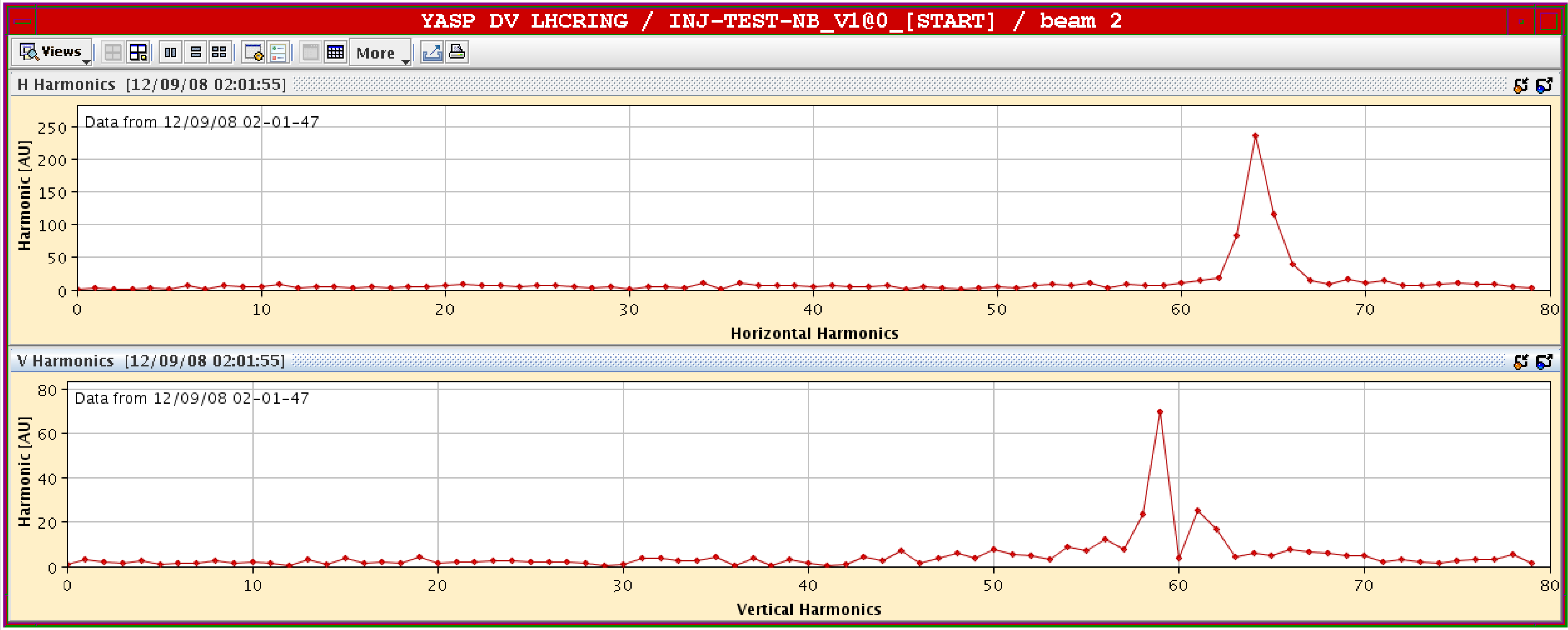


LHC Day III

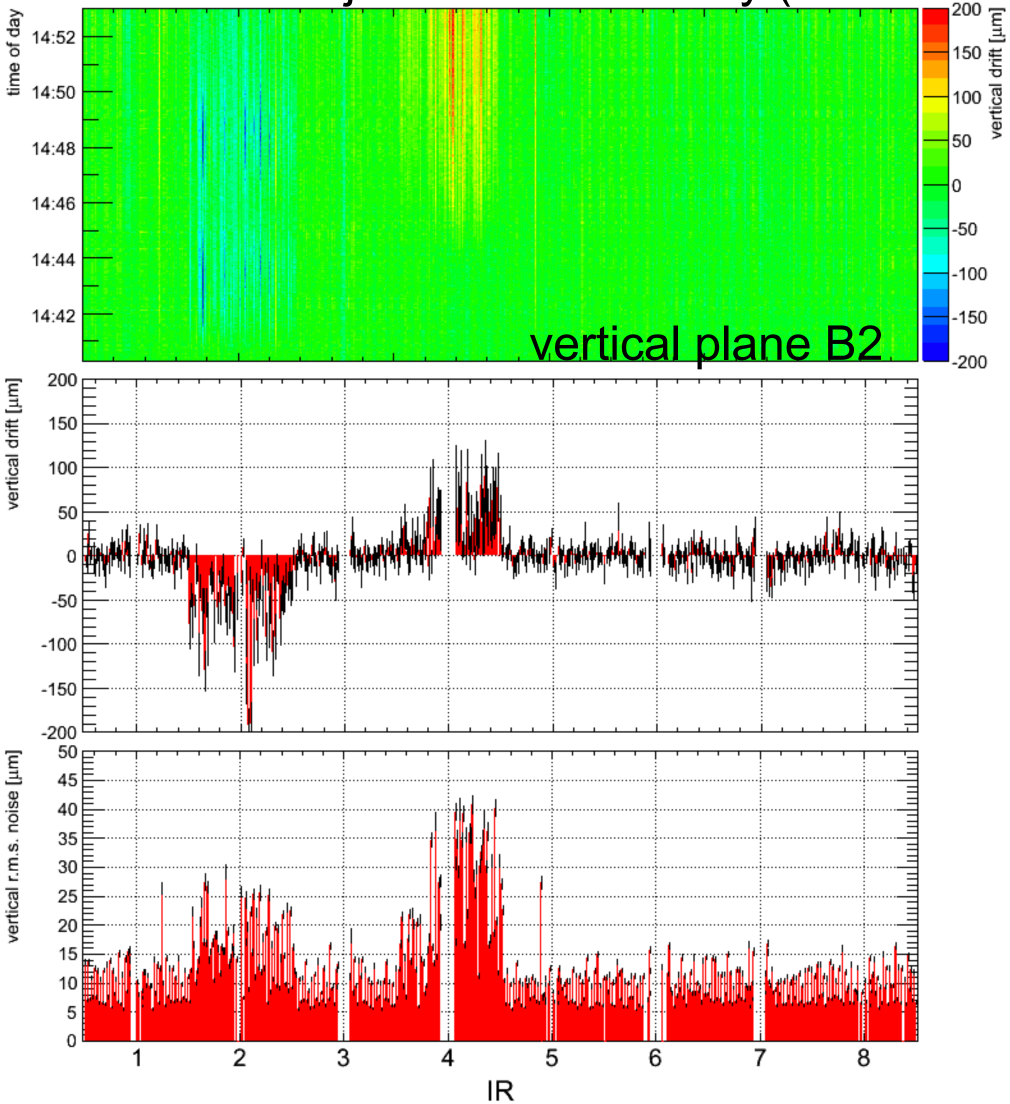
20++ years of simulations meet the ultimate challenge:
experiments with real beam in the machine

Integer Tunes

- Something probably measured only rarely during an accelerator's life-time:
  - Integer tunes:
    - $Q_x = 64$
    - $Q_y = 59$



- Residual injection orbit stability (orbit feedback/radial loop off)



no obvious time structure
(with exception of IR2 & 4)

→ dominated by 'white noise' floor of the BPM acquisition electronics

Systematic drift in IR2 and IR4
Effect known (next slide)

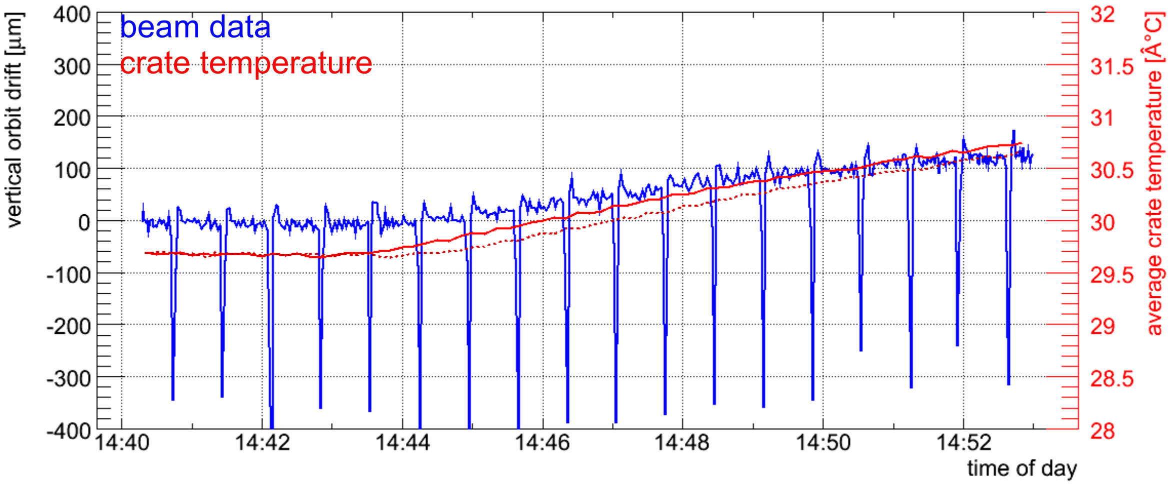
r.m.s. noise: ≈ 5-10 µm

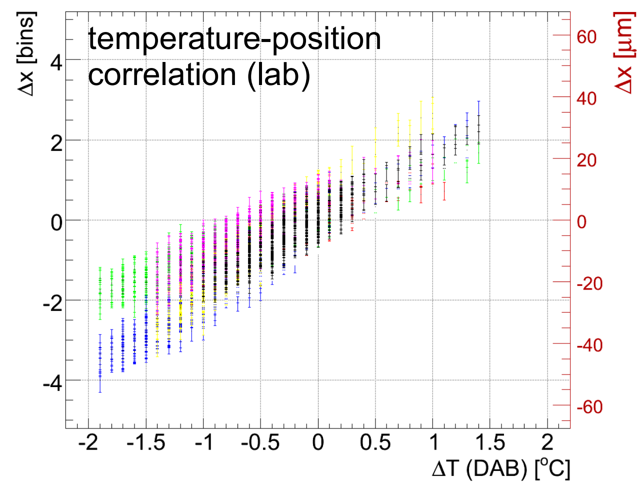
expected from lab and electronic design for the given intensity ($2 \cdot 10^9$ protons/bunch)

- Found 2 (B1)/ 12(B2) polarity/mapping errors – fixed immediately once spotted
  - no additional erroneous BPMs found with circulating beam (injection test paid off)

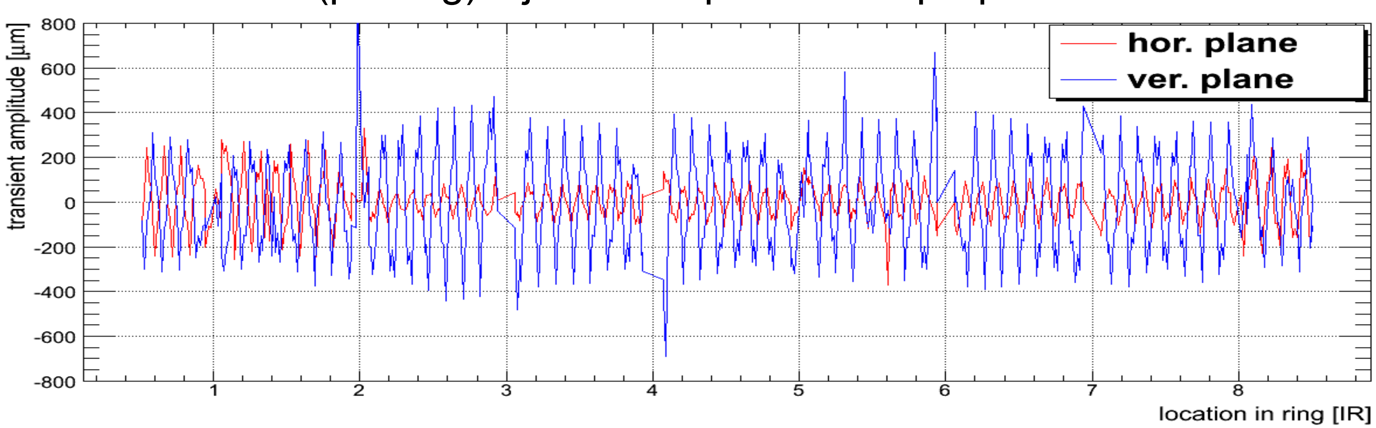
LHC Orbit Stability Beam 2 II/III - Residual Noise Sources

- Effective LHC B2 orbit stability about 6 μm, two known sources:
  1. turn-by-turn noise predicition → orbit r.m.s.: ≈ 6 μm (150-200μm, 1024 turns average)
  2. Residual noise of the COD power supplies, expectation: 5-10 μm orbit r.m.s.
- Small drifts in point 2 and 4 → thermal drifts (switched off SX4 climatisation)
  - Fix: 'somebody' gets a scarf for Christmas & local crate temperature control

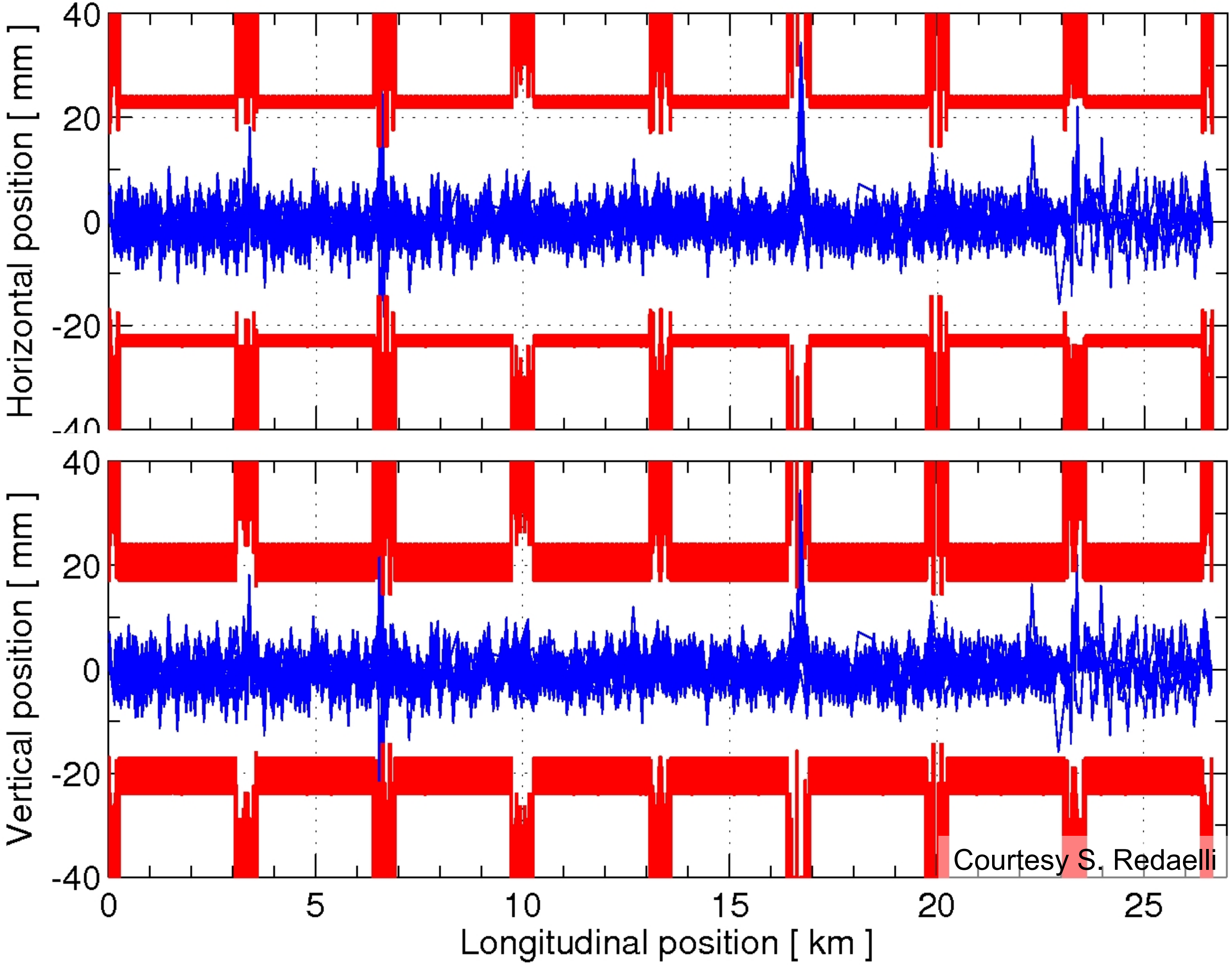




- Transient orbit due to (pulsing) injection septa MSI → proposed solution: DC operation

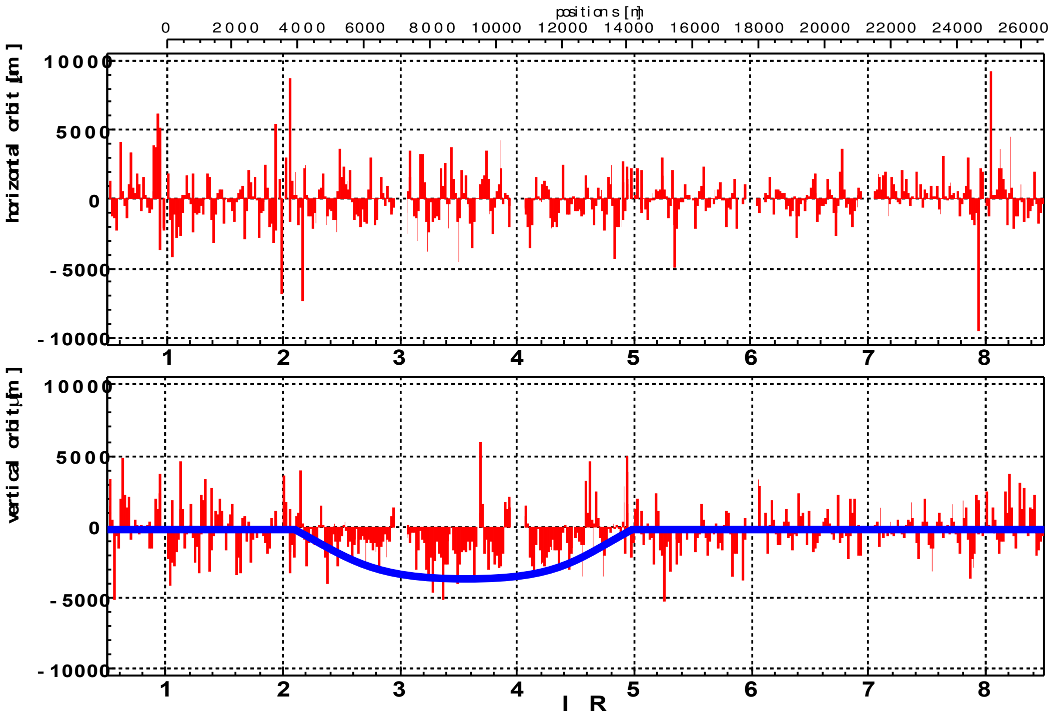


Available Aperture – Circulating Beam 2



LHC Orbit Stability Beam 2 III/III - Machine Alignment Estimate

- LHC alignment estimates were quite good: 200 - 500µm rms (globally)
  - r.m.s. quad-to-orbit propagation & orbit corrections using quad-shifts are consistent



"Analysis of Ground Motion at SPS and LEP - Implications for the LHC", CERN-AB-2005-087

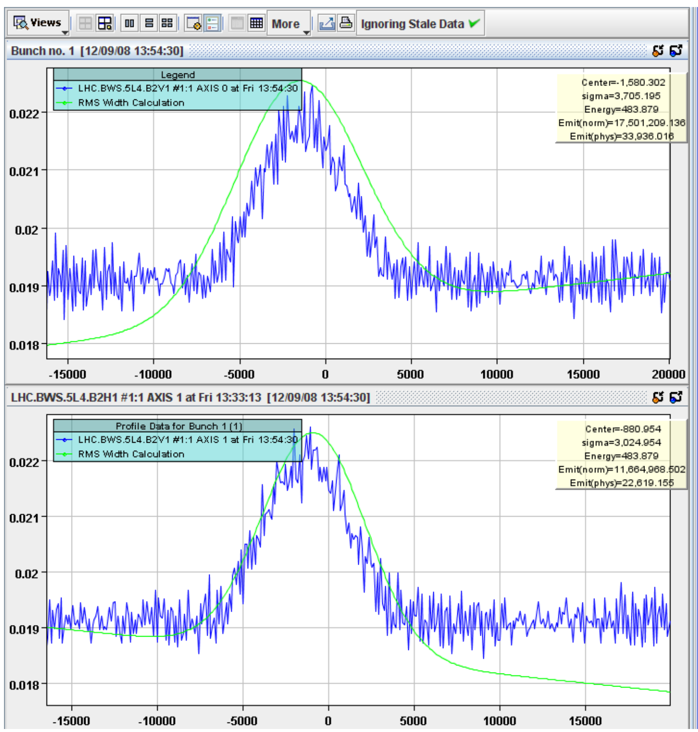
	horizontal		vertical	
	κ	$\bar{\kappa}$	κ	$\bar{\kappa}$
SPS	40.6 ± 19.3	3.1 ± 1.4	30.1 ± 13.3	4.1 ± 2.0
LEP coll	34.3 ± 13.7	5.0 ± 2.0	119.5 ± 65.7	11.2 ± 6.1
LEP coll*	34.3 ± 13.7	5.0 ± 2.0	58.6 ± 25.9	5.6 ± 2.4
LHC inj	30.5 ± 11.5	3.2 ± 0.8	29.6 ± 9.0	3.0 ± 0.7
LHC coll	63.3 ± 32.5	5.2 ± 2.0	62.1 ± 25.5	4.9 ± 1.9
TI8 TED	19.5 ± 14.6	1.8 ± 1.3	10.6 ± 8.0	1.6 ± 1.2
CNGS target	4.2 ± 3.2	1.3 ± 1.0	4.9 ± 3.6	1.1 ± 0.8

orbit r.m.s. ≈ κ · quad. r.m.s.

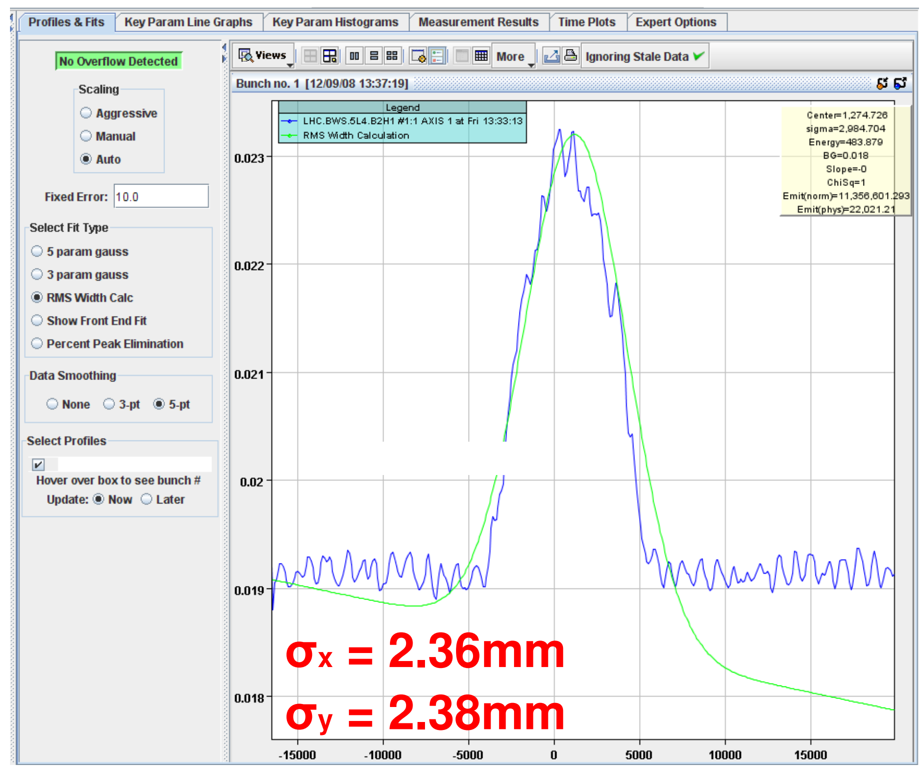
- Systematic vertical offset from IR2 to IR5 is visible
  - Source not yet understood & no obvious explanation
  - Systematic misalignment or thermal drift of BPMs unlikely
  - Machine optics or magnet imperfections (b1 to a1 tilt) unlikely
  - Machine alignment – no obvious explanation according to alignment group

- B2 System Commissioned
  - Low intensity single bunch gives expected noisy signals
  - Beam size seems to be a bit large
    - Calibration verified & looks to be OK → likely candidate beta-beat

Vertical In / Out Scan on B2

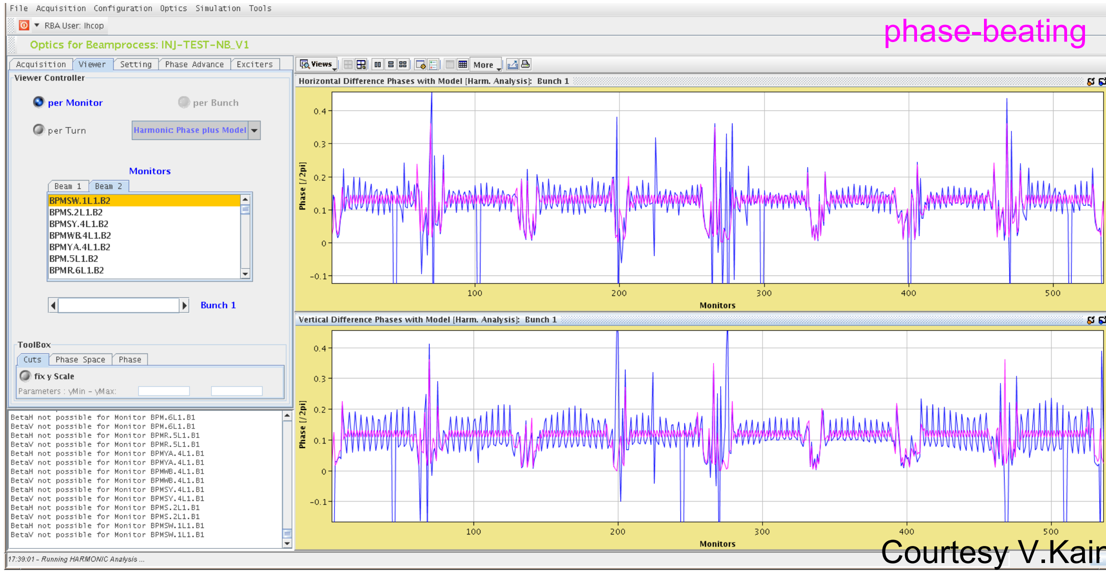


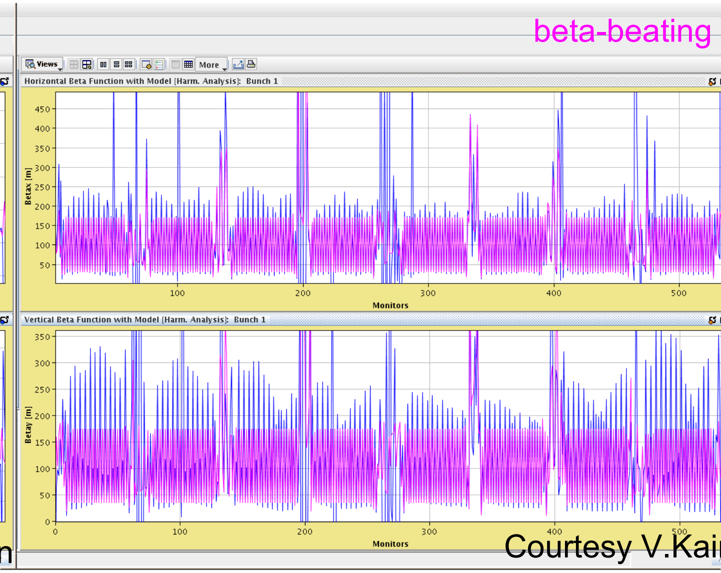
Horizontal Scan on B2



The LHC BPM System at It's Best I/II
Preliminary LHC Optic Estimates cont.

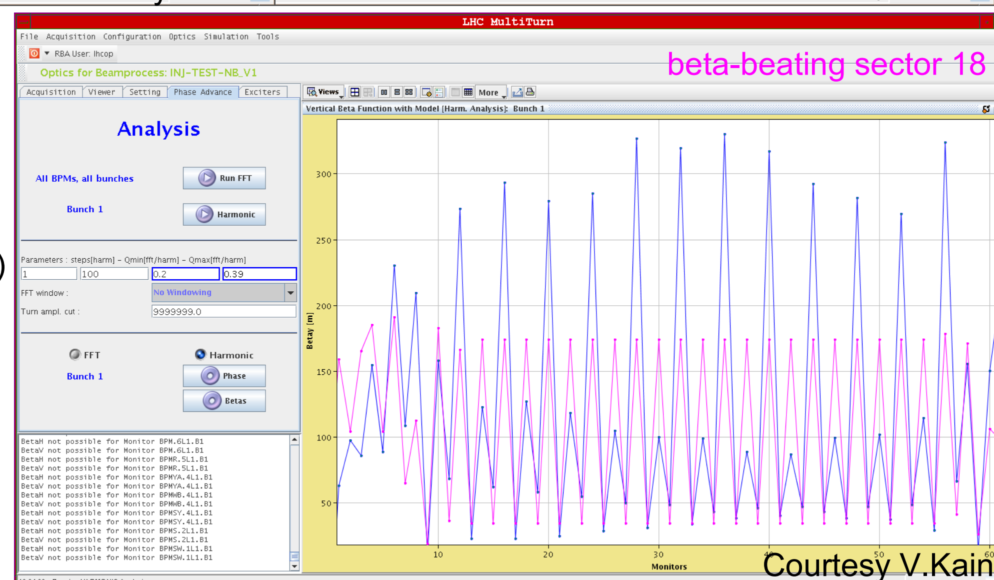
- Could reconstruct LHC B1 optic on the few 10% level using only 50-90 turns





- Nearly all BPM triggered and gave useful readings

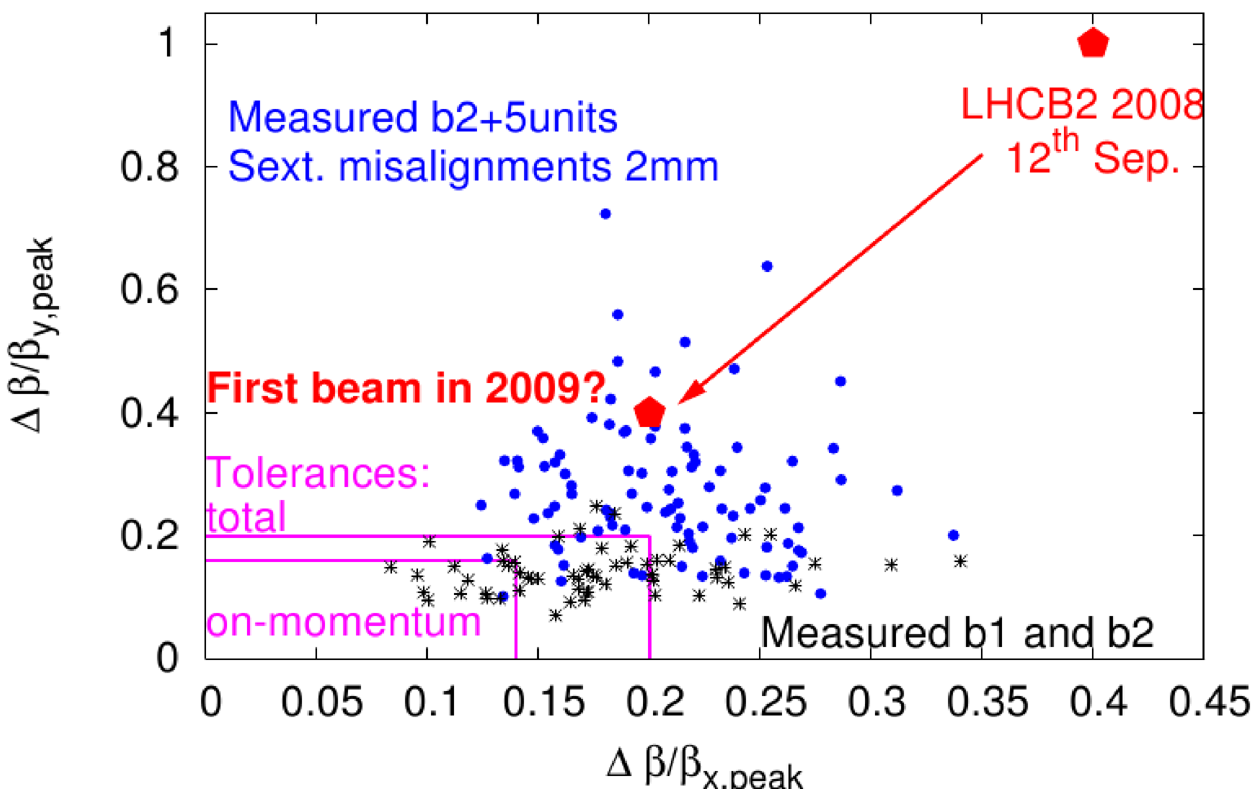
- Vertical beta-beat (blue) vs. model (pink)
  - Surprisingly large: 100%
  - further analysis/correction proposal pending (R. Tomas)



The LHC BPM System at It's Best II/II
Preliminary LHC Optic Estimates cont.

- Known errors in dispersion suppressors (MQTL) may contribute to the effect but do not fully explain the observed magnitude
  - IMHO: some parts may be due to b_1 drifts during injection (source unknown)
  - Further analysis inconclusive → tests with beam pending

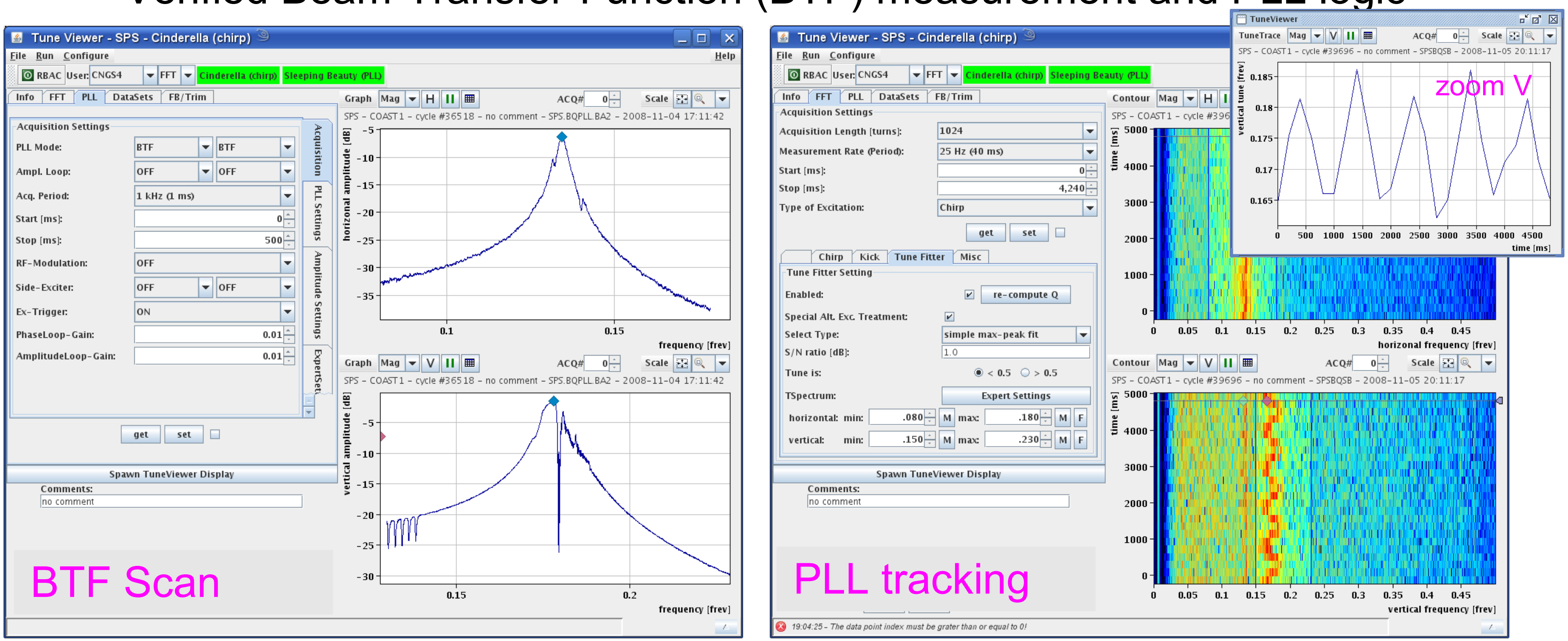
Target vs. Simulation vs. Initial Measurements



Courtesy R. Tomas

Present Commissioning State
... Tune Phase-Locked-Loop Commissioning

- … made the best of the absence of beam in the LHC → used the LHC-PLL installation in the SPS for further tests
  - same interfaces/controls/server/operational GUI as LHC
  - Verified Beam-Transfer-Function (BTF) measurement and PLL logic



- To be tested: real-time display for PLL, LHC-RF interfaces (radial modulation)
- Since BBQ HW is fine for B2 (B1) and that the logic is correct (SPS test): remaining PLL commissioning should take less than one shift/beam.

Part II

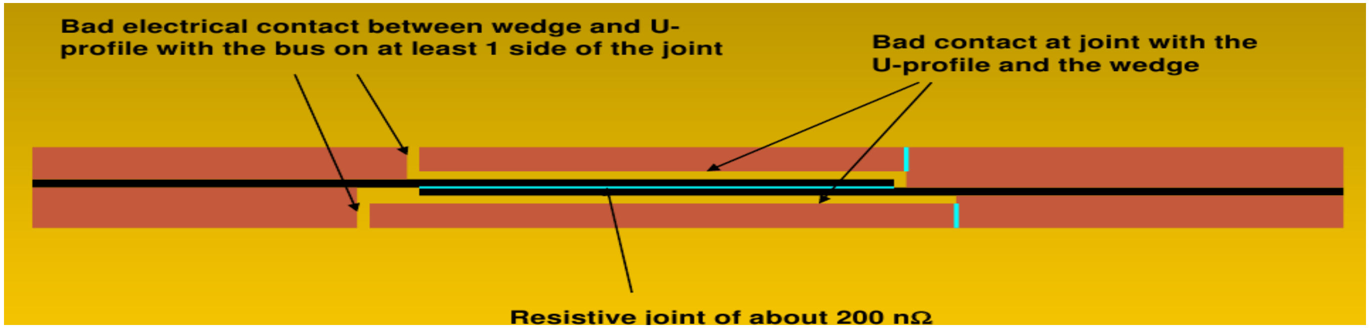
September 19th 11:18 – S34 Incident

or

…what you can do with 200 MJ

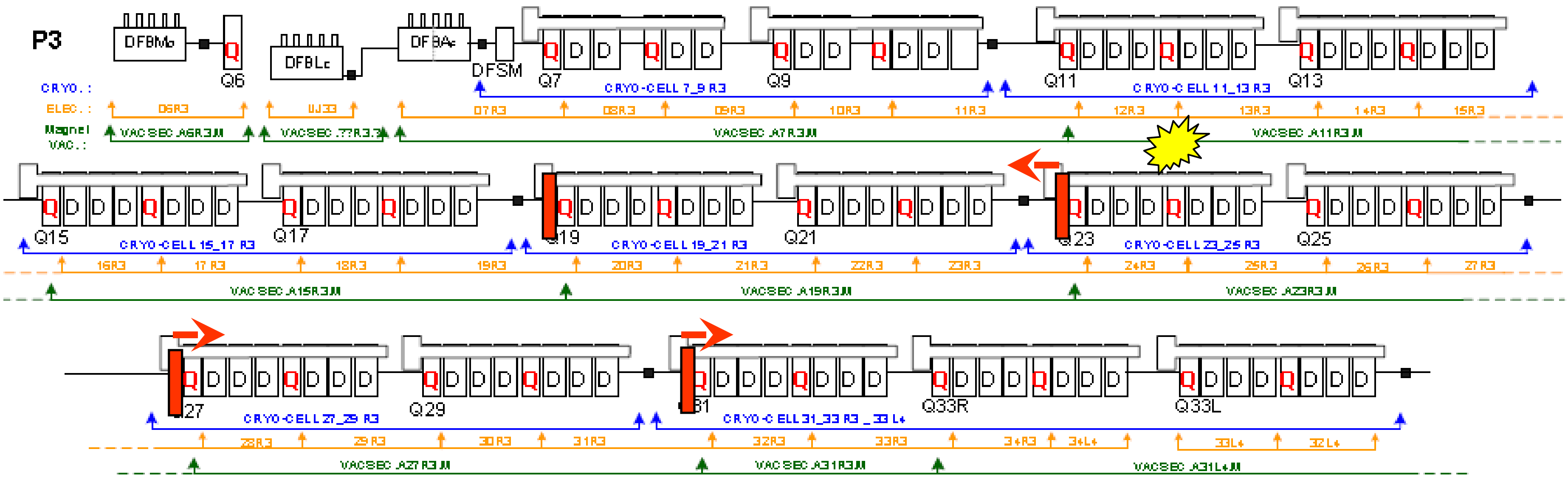
.. last commissioning step of main dipole circuit in sector 34 to 9.3kA!

- The mechanic/facts:
  1. Estimated power of 10.7 ± 2.1 W at 7 kA → 175-260 nΩ
  2. Maximum current of 8715 A.
  3. Fast voltage increase during incident: ~0 to 1 V in about 1 sec
  4. possible small voltage increase (~ 10 mV) during 30 sec before incident.
  5. Bus-bar QPS threshold reached before any voltage increase on the magnets.
  6. Origin probably in or near bus-bar joint
- Most likely scenario:



  - electrical arc developed which punctured the helium enclosure.
  - Large amounts of He were released into the insulating vacuum
  - Rapid pressure rise inside the LHC magnets
    - Large pressure wave travelled along the accelerator both ways,
    - Self actuating relief valves opened but could not handle all,
    - ...

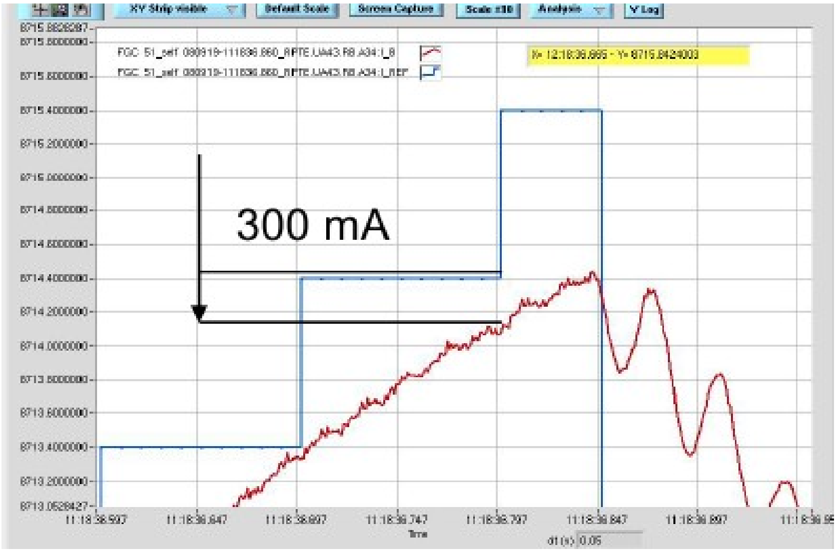
Mechanics of the incident on 19th September II/III
From D - Days to D(amage) - Regions

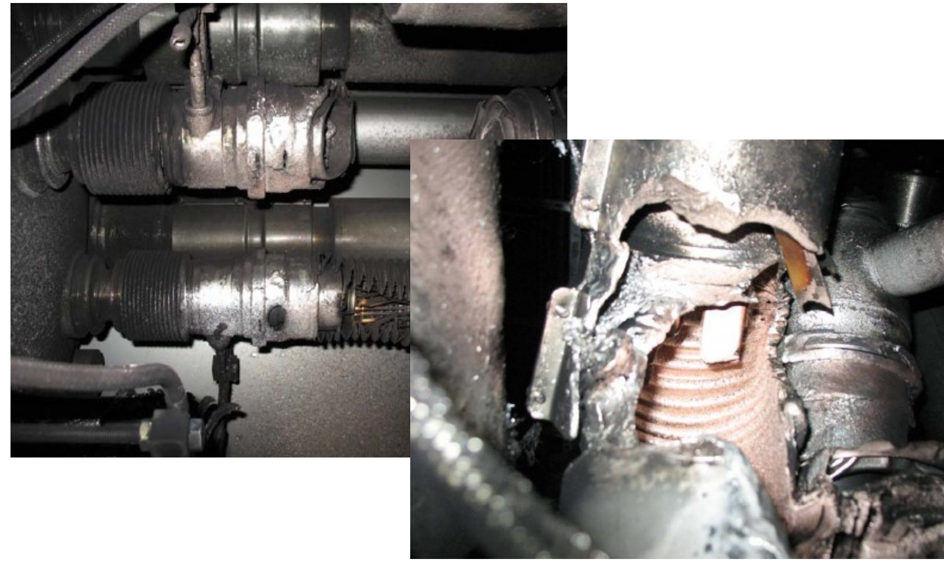


Insulating vacuum barrier every 2 cells in the arc → **Some moved**

- Large forces exerted on the vacuum barriers located every 2 cells.
  - forces displaced several quadrupoles by up to ~50 cm.
- Considerable collateral damage over few hundred metres
- Contamination by soot and debris (magnetic !) of vacuum chambers
  - extends beyond mechanical damage zone.
- Damage to super-insulation blankets
- Large release of helium into the tunnel (6 of 15 tons)

- Some of the observables....





QQBI.27R3

- Agreed conclusion:

The original design 1 V QPS threshold was much too high to safely protect the dipole busbars..

Two possible origins of the incident are identified, that fulfill the observed facts (about 11 W @ 7 kA, Imax=8.7 kA, Dt_runaway≅1 s), namely:

1) Resistive joint with very bad bonding to wedge and U-profile, and longitudinal discontinuity of the copper (bus).

2) Resistive cable with bad contact to bus at the start of the joint, and longitudinal discontinuity of the copper (bus). The cable can be resistive due to strongly reduced critical current or due to mechanical movement below 7 kA.

Both origins would have been detected with a QPS threshold voltage <1 mV long before the start of the thermal runaway.

A QPS threshold of 0.3 mV is needed to protect the RB bus and the joints in all imaginable conditions.

Fast thermal run-aways resulting from sudden transient disturbances (without intermediate stable heating) are unprotectable by any QPS system (whatever the threshold).

To avoid such fast thermal runaways one needs to assure a good thermal contact between joint and U-profile/wedge (by means of clamping) or to assure a good electrical and thermal contact between bus and joint (perfect soldering between bus and joint).

A. Verweij,

Part III

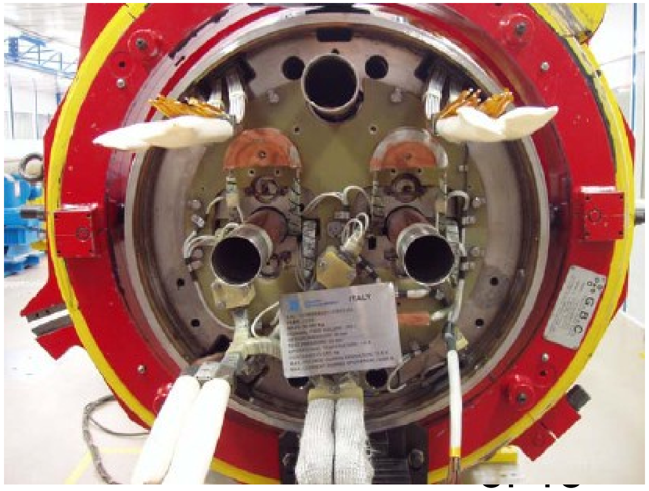
LHC Performance Workshop - Chamonix 2009

- The good 'ol Chamonix Performance Workshop is back:
  - Old DG: vetoed one → R. Heuer: charged S. Myers the organise one

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	Session 1	Session 3	Session 5	Session 7	Session 9 Summary
Evening	Session 2	Session 4	Session 6	Session 8	

- Brief programme:
  - Session 1 - What did we learn without beam in 2008
  - Session 2 - Safety
  - Session 3 - Repair of 34
  - Session 4 - Consolidation to avoid incident and limit collateral damage
  - Session 5 - Shutdown Modifications 2008/9 and Future shutdowns
  - Session 6 - What else can go wrong
  - Session 7 - What did we learn with beam in 2008
  - Session 8 - What we will do for beam preparation in 2009
  - Session 9 - What will we do with beam in 2009/10

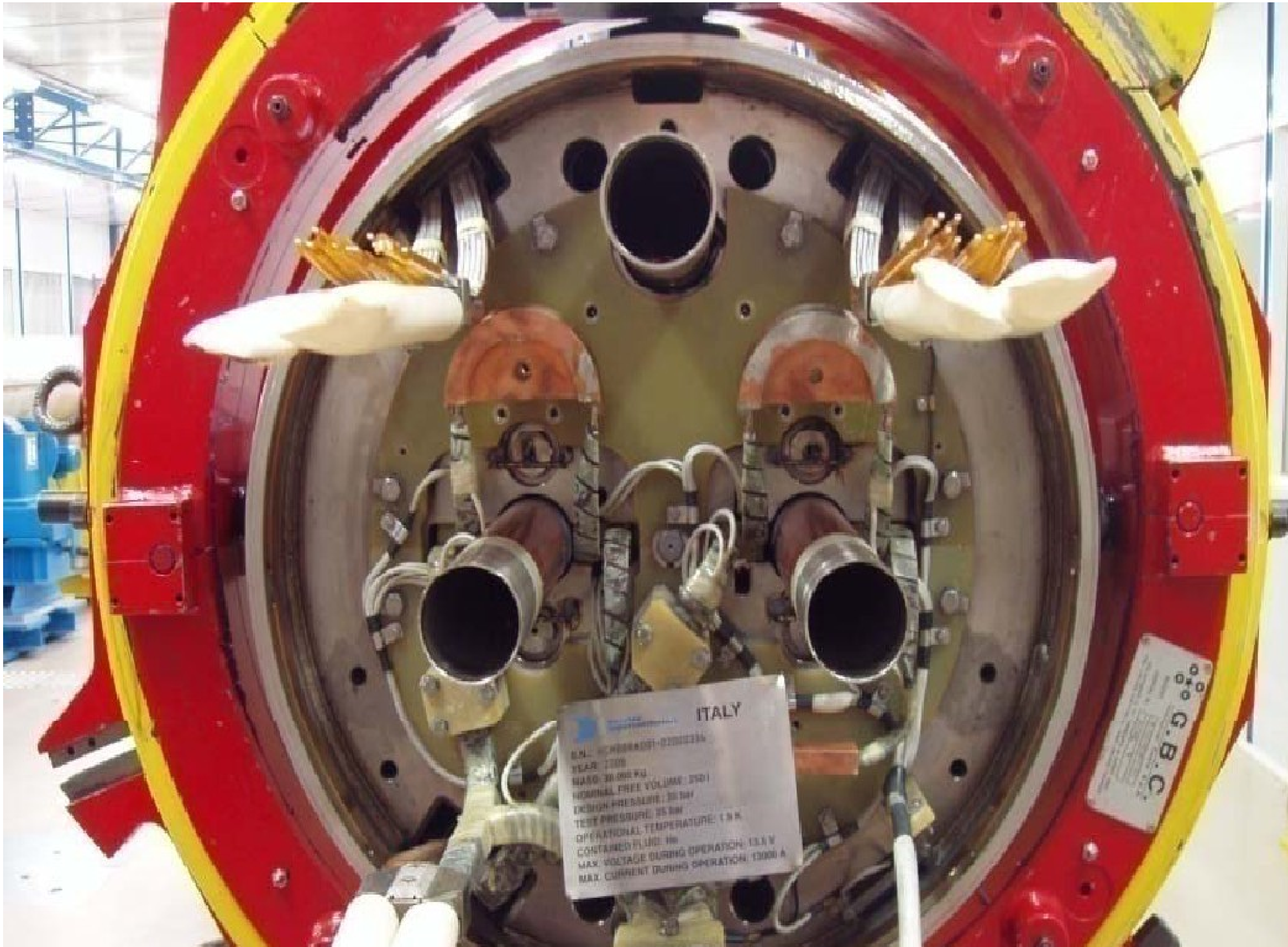
Minimisation of Maximum Credible Incidents (MCI) I/II - Quality Assurance



- Additional splice quality control measures:
  - Visual inspection of each splice by member QC team prior to soldering operation and soldering operation (before insulation)
  - Dimensional measurement of finished splice
  - Systematic ultrasonic testing of 13 kA splices
  - Record temperature cycles during soldering kA splices
  - … and don't be blind to other potential problems …

- Calorimetric measurements using the cryo-system temperature increases
  - used as indication, final verification using the QPS

Minimisation of Maximum Credible Incidents (MCI) I/II - Quality Assurance: Visual Inspection

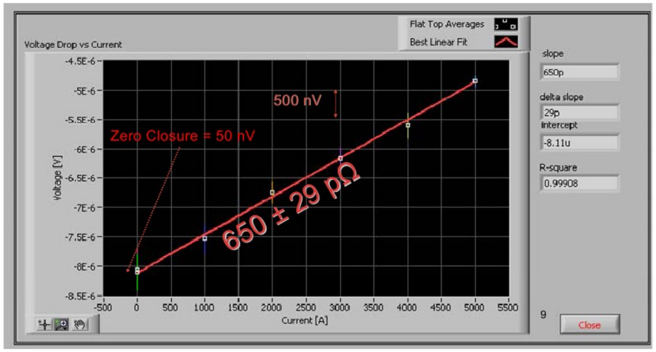


Minimisation of Maximum Credible Incidents (MCI) II/II - QPS Upgrade

- R. Denz: “QPS Upgrade and Re-commissioning”, Session 4
  – Feasibility tests with prototype units in sector 12:

325 ± 15 pΩ / Splice

Results from Measurements Performed on 30 Oct. at 5000 ADC with DQQDC Detector



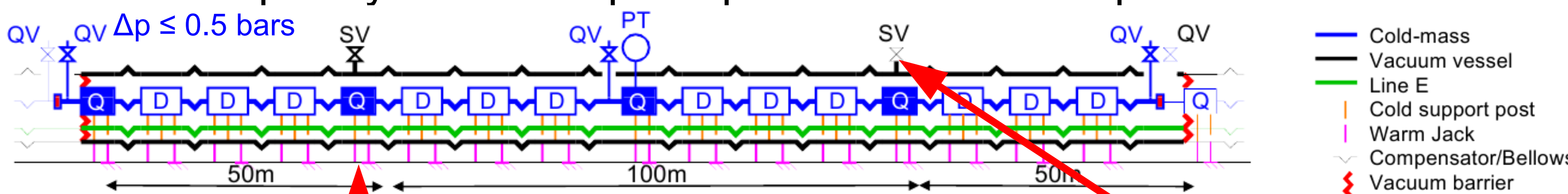
Z. Charifoulline, B. Flora

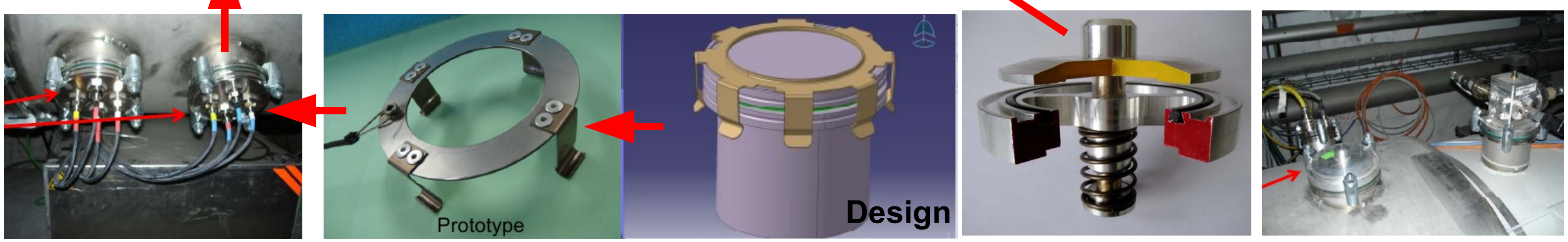
  – Detection threshold reduced from 1 V to ≤ 0.3 mV!
  – Local, rather than global fault detection.
  – Implemented with “symmetric quench” detection system.
  – Proposed to perform regular (weekly?) verification without beam.

- Important: further measures mitigate but do not remove the risk
  – Steve's conclusion:
    - enforce QPS upgrade (~ recommended/mandatory)
    - Implement mitigations compatible with QPS installation schedule

Mitigation of MCI consequences: Pressure Wave → additional Valves

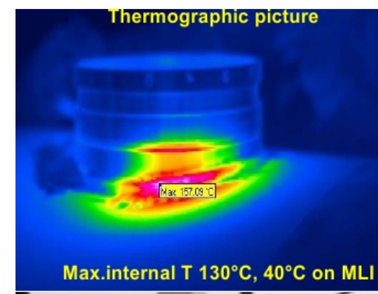
- Present temporary solution: open up DN100 and BPM ports



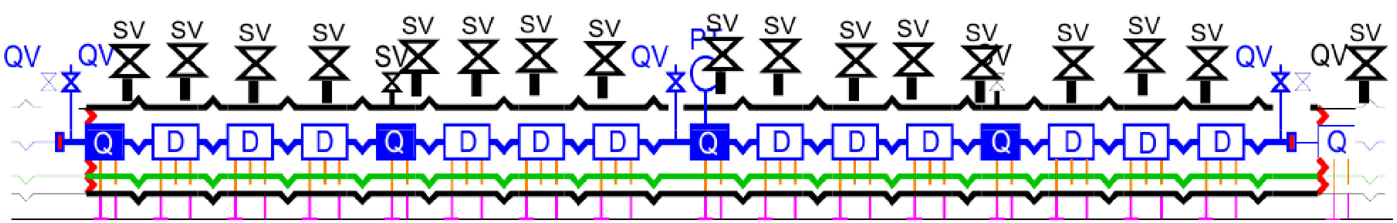


→ Cross-section: x10

V.Parma: "Use of instrumentation ports should be temporary, until warming up of sectors" (Obvious implication: BPM/BLM re-cabling!?!)



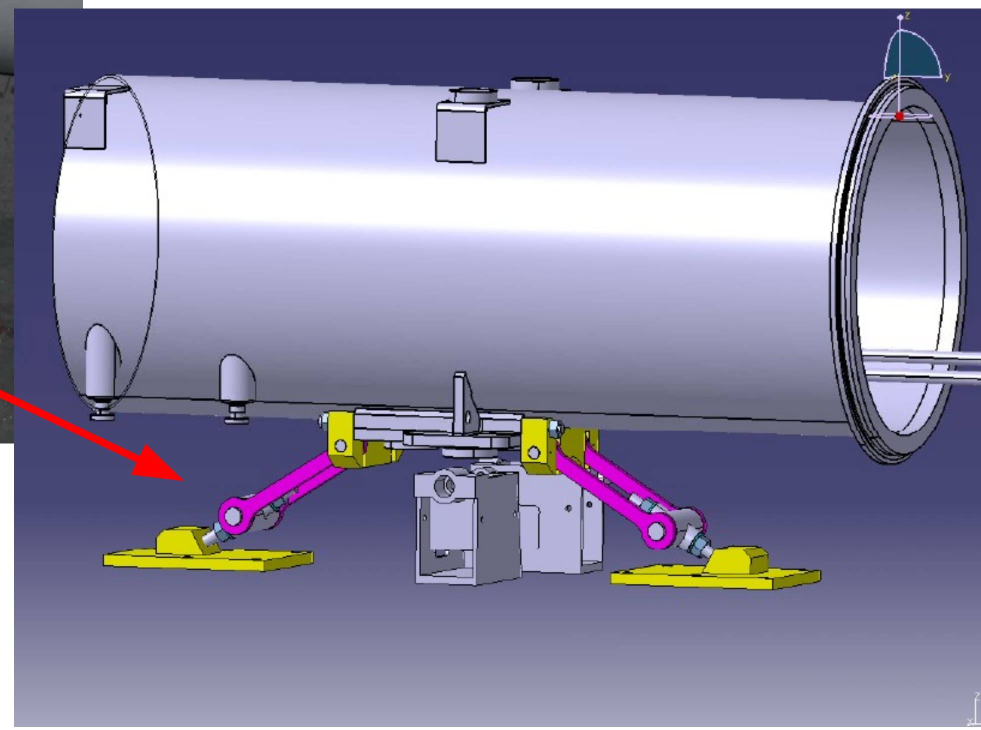
- Base-line: one DN200 port per dipole
  - parts ordered and tb installed in warmed-up sectors



Cross-section: x 33

Mitigation of MCI consequences:
Magnet Movement → Reinforcement of Magnet Jacks

- O. Capatina: Incident on 19th of September 2008 -> failure of some supports of SSS in sector 3-4 due to longitudinal loads

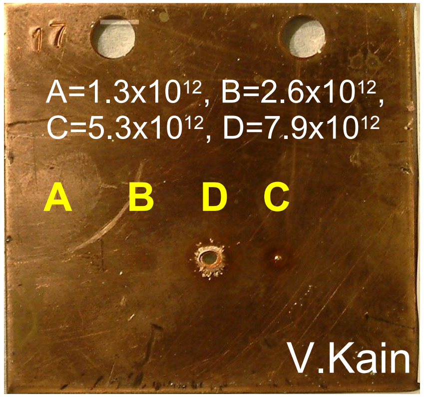


- Proposed solution
  - Withstands 240 kN
  - ~ 2 weeks/sector

- Important consideration: probable next “weak point” – DFBA... ?

Session 6 - What else can go wrong?

- The word of the week: '**M**aximum **C**redible **I**ncident' (MCI)
- Beam induced damage: 350 MJ/beam nominal
  - Most 'primary' effects affecting machine protection are believed to be identified and secured against
  - What remains:
    - secondary effects, collateral damage (e.g. thermal shock, …)
    - handling of multiple failure scenarios (e.g. "bad orbit" + "kick")



'Safe Beam' = "set-up" intensity, **not** intensity which can be safely lost **under all conditions**!

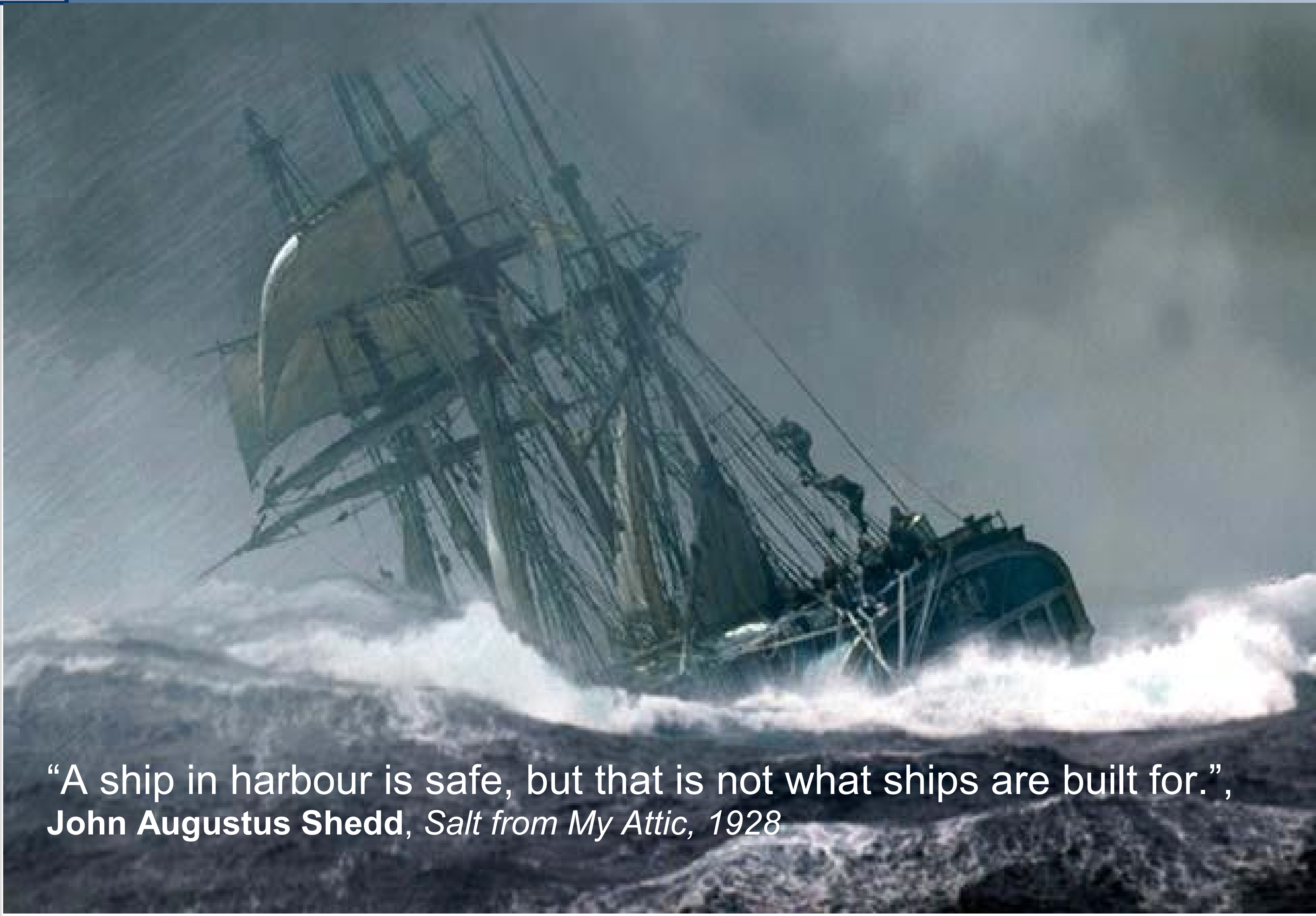
- Biggest risks comes from magnet operation itself: 1.2 GJ/arc
  - Most damages are "collateral" effects due to He pressure waves
    - Critical candidate: DS, DFBA, inner triplet, …

- Main outcome: We should neither be careless nor blinded by fear of "what else could go wrong" - Risks are known, we should learn and not repeat them.

- Jim Strait quoting Franklin Delano Roosevelt (First Inaugural Address, 1933):

"We have nothing to fear but fear itself."

What else can go Wrong?
– Intermediate Conclusion – Steve Myer's reply:



"A ship in harbour is safe, but that is not what ships are built for.",
John Augustus Shedd, *Salt from My Attic, 1928*

Road Map 2009/2010

- Physics Discovery Potential (S. Myers)

$$D_p \approx \eta_{LHC}(E) \cdot L_{avg.}(E) \cdot T_{run} \cdot F(E)$$

  - η_{LHC}(E): operational efficiency
  - L_{avg}: average luminosity during the physics run
  - F(E): given by the cross-section of the process being studies

→ S. Myers: "T_{run} is the scheduled running time [..] and should be maximised"

- With Strictly No running of the machines in the winter months
  - Repair schedule has no contingency
  - Any slip of >1 month will delay first LHC physics till Aug./Sep. 2010!

→ S. Myers: "Must have the possibility of running during winter months"

Proposed Schedule 2009/2010

- Proposed preliminary Schedule (will be confirmed by March)

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base'	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									

high electricity prices

- Impacts of running during winter months:
  - Electricity: + 8MEuros (+ 8% contingency)
    - Considered a 2nd order issue → back-up by R. Heuer (DG)
  - Need to further evaluate impact on
    - injector schedule and shut-down work
    - necessary maintenance
      - Cooling towers, electrical network
      - …

Pressure Relief Valves in Arcs

A: install 4 sectors (09-10) + 4 sectors (10-11)
+ present schedule allows calorimetry measurements in 23, 45 much sooner
+ first physics sooner: detectors debugging.. earlier warning
+ first beam sooner: ramp, squeeze, .. Sooner... earlier warning
+ focuses attention of repair teams

B: Installation 8 sectors (09-10)

+ reduced amount of collateral damage in event of a splice problem in 2010
+ reduced additional electricity bill
+ reduced overall shutdown time
+ reduced ALARA problems (2nd order)

- Enhanced Quench Protection (Detection)
  - Busbar Detection (Protection)
  - “Symmetric” quench protection

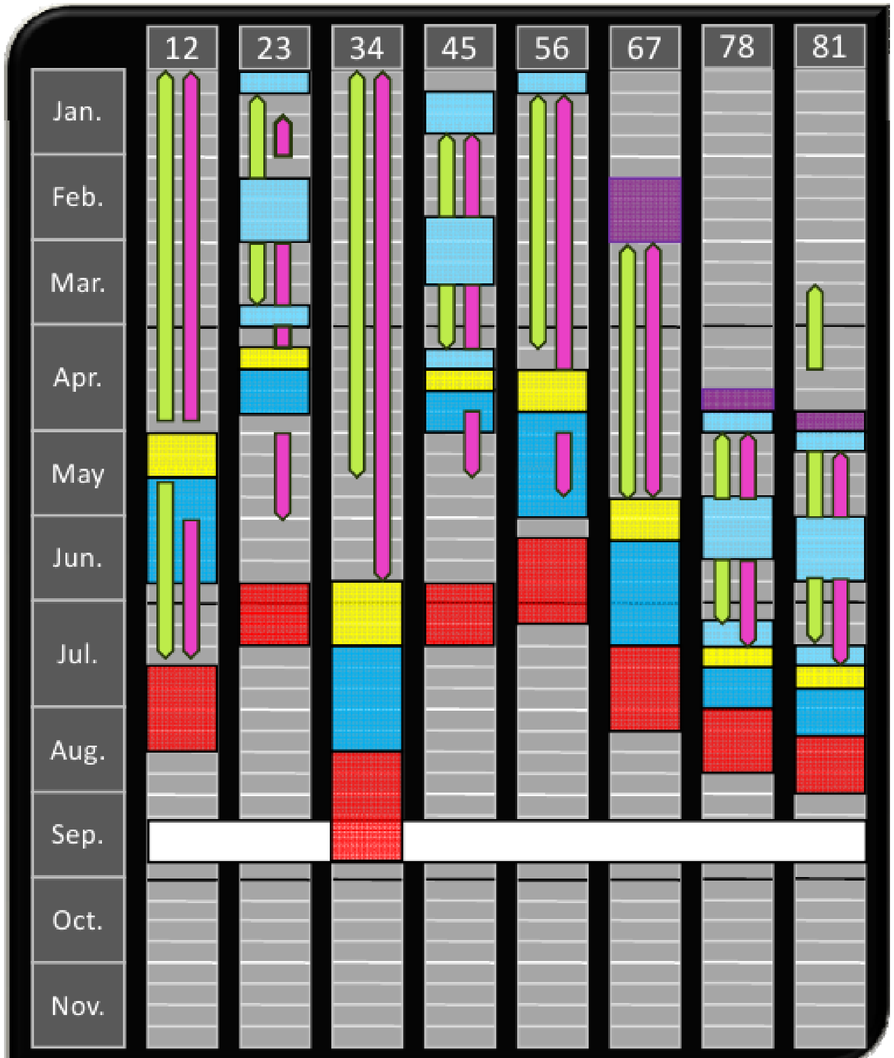
LHC should not be operated unless the FULL Quench System is tested and operational (my opinion, but open for discussion)

S. Myers, Summary

- Decision on 'A' or 'B' will be taken this March

Repair Scenario II/II

- Possible slip of 5 weeks
  - "Blowing Off" Helium in 78/81 gains 2 weeks and would cost 1.2MCHF



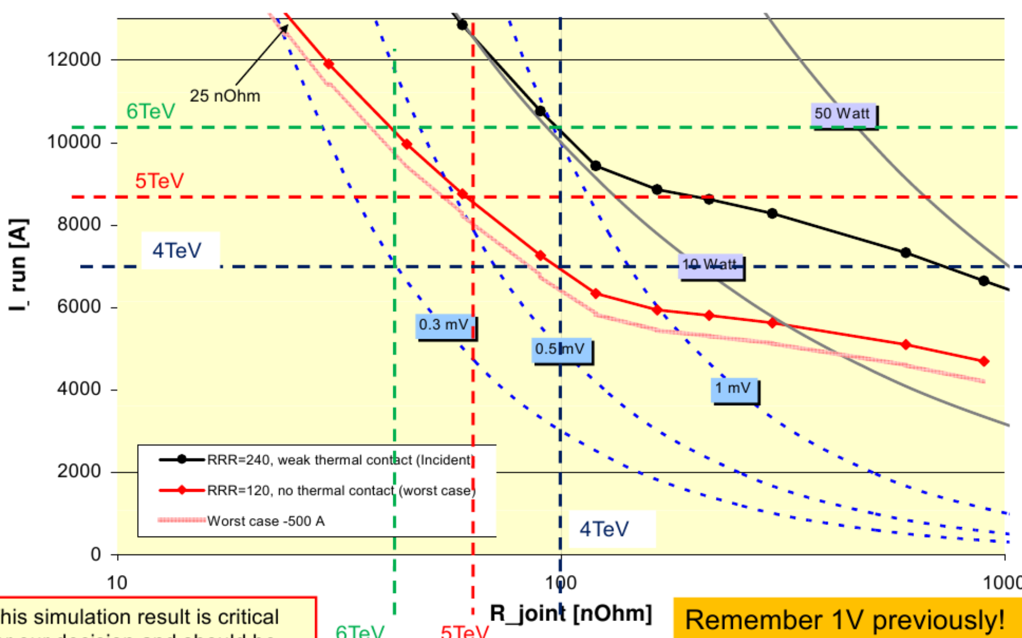
- Intermediate cool-down & QRL warm-up (Stand Alone)
- Activities
  - Arc
  - LSS
- Flushing & ELQA at warm
- Cool-down
- Powering tests
- Cold check-out

K. Foraz

Which Energy Level for Operation?
- An Accelerator and Physics Perspective

- Dipole field which can be reached → 5 TeV seem to feasible
- Risks associated with operating at field → see QPS plot
  - Splices stability (thermal runaway…), poor splice detection, new beam effects
- Operational efficiency of other systems
  - cryo recovery time: ~ 3h @ 5TeV vs. >6h @ 7TeV)
- Useful (Competitive) LHC-HEP requires 2-3 TeV

- Physics: favours collisions > 2-3 TeV

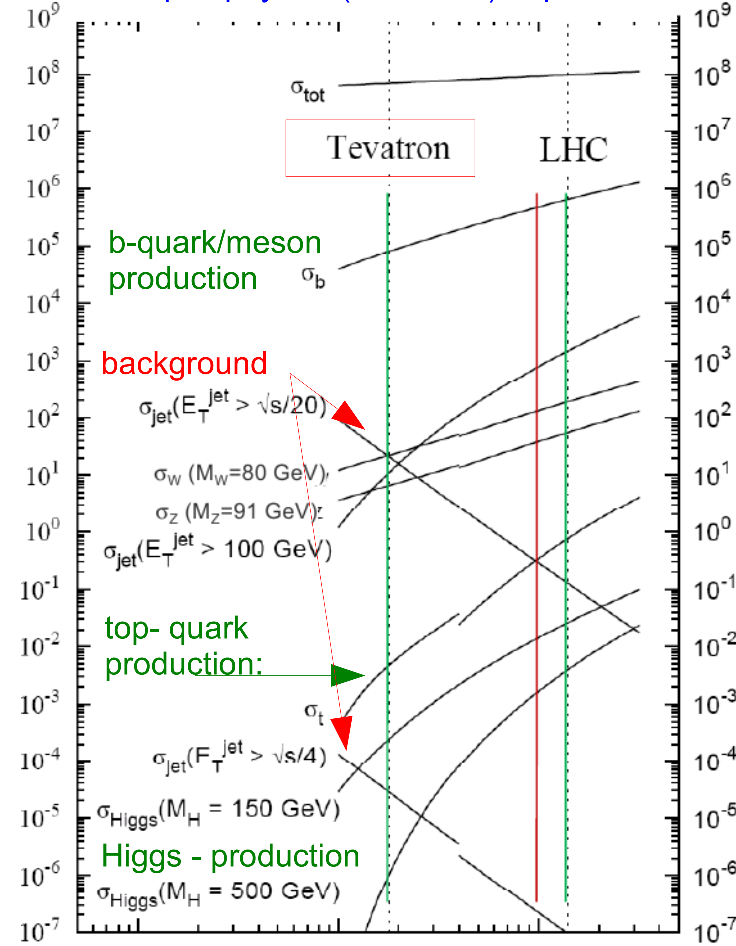


This simulation result is critical for our decision and should be independently confirmed

Remember 1V previously!

A. Verweij

Example: physics (cross-sec) dep. on E



Conclusions and Targets for 2009

Main outcomes:

- Risk of magnet induced and collateral damage has been intensively evaluated
  - Risk minimisation: QPS++ system (protection against slow thermal runaway), clamping of splices (protection against sudden opening of bus bar joints)
  - Collateral damage mitigation: pressure relief valves (DN100, DN200), ...
- Fixed shut-down policy would reduce LHC availability for physics by 20 weeks → planned to run the machine throughout the winter (if necessary)

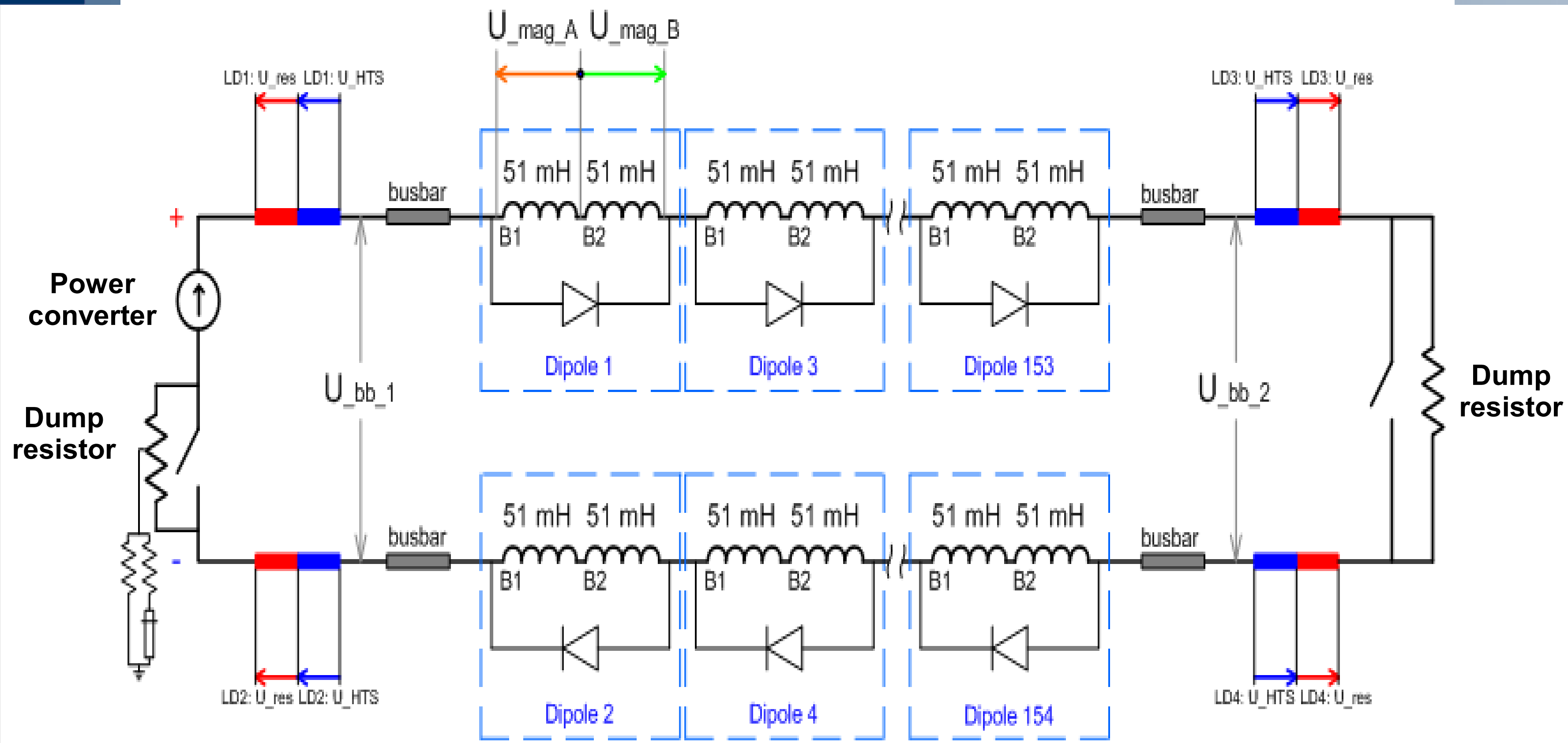
LHC accelerator physics goals:

- Best/feasible/rel. safe energy option (S. Myers): 5 TeV
- Estimated [targeted] integrated luminosity (S. Myers):
  - During first 100 days of operation ≈ 100 pb^{-1}
  - During next 100 days of operation ≈ 200 pb^{-1}??

} ↔ 156x156 scheme!

Reserve Slides

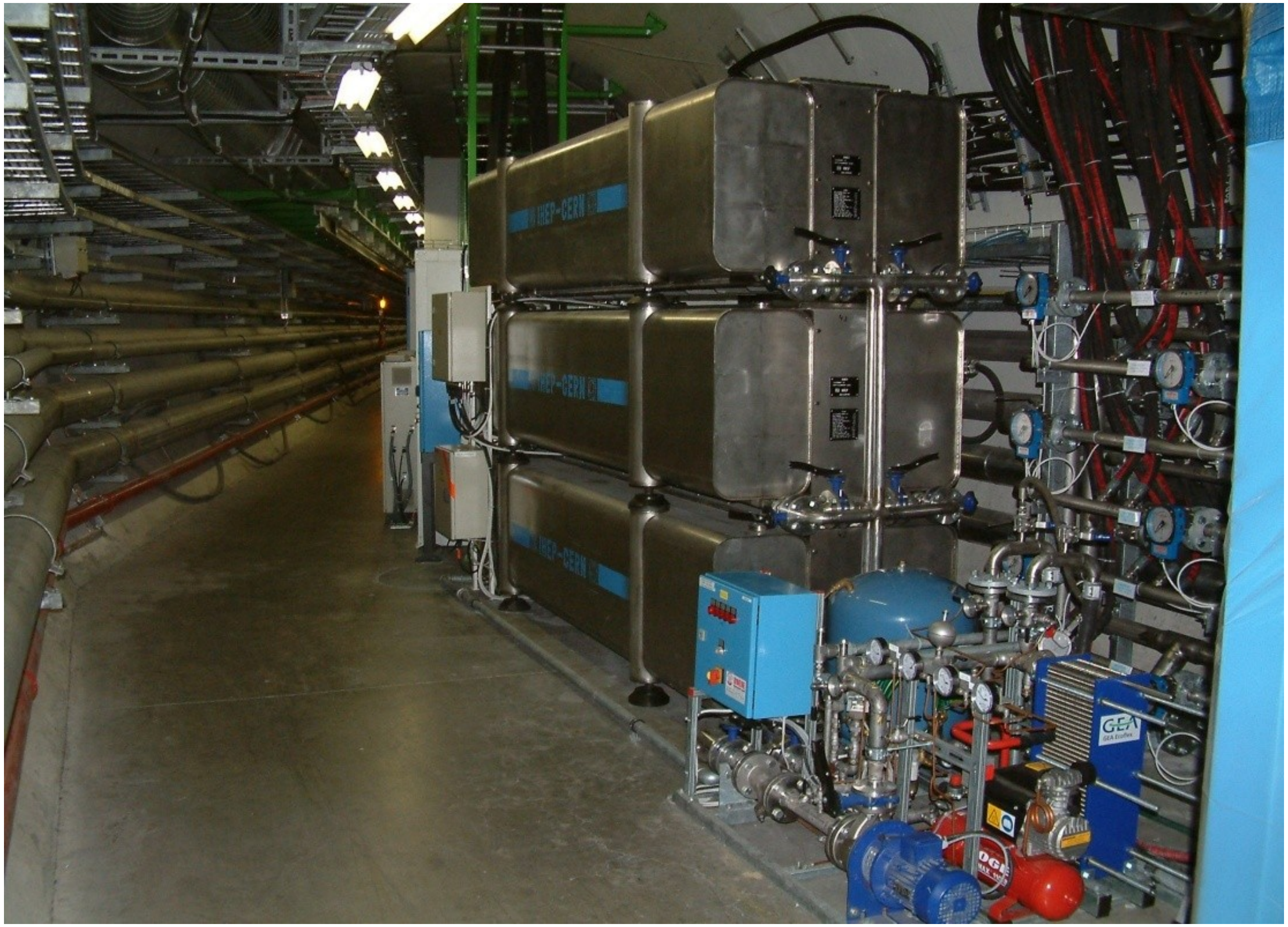
Quench Detection and Energy Discharge



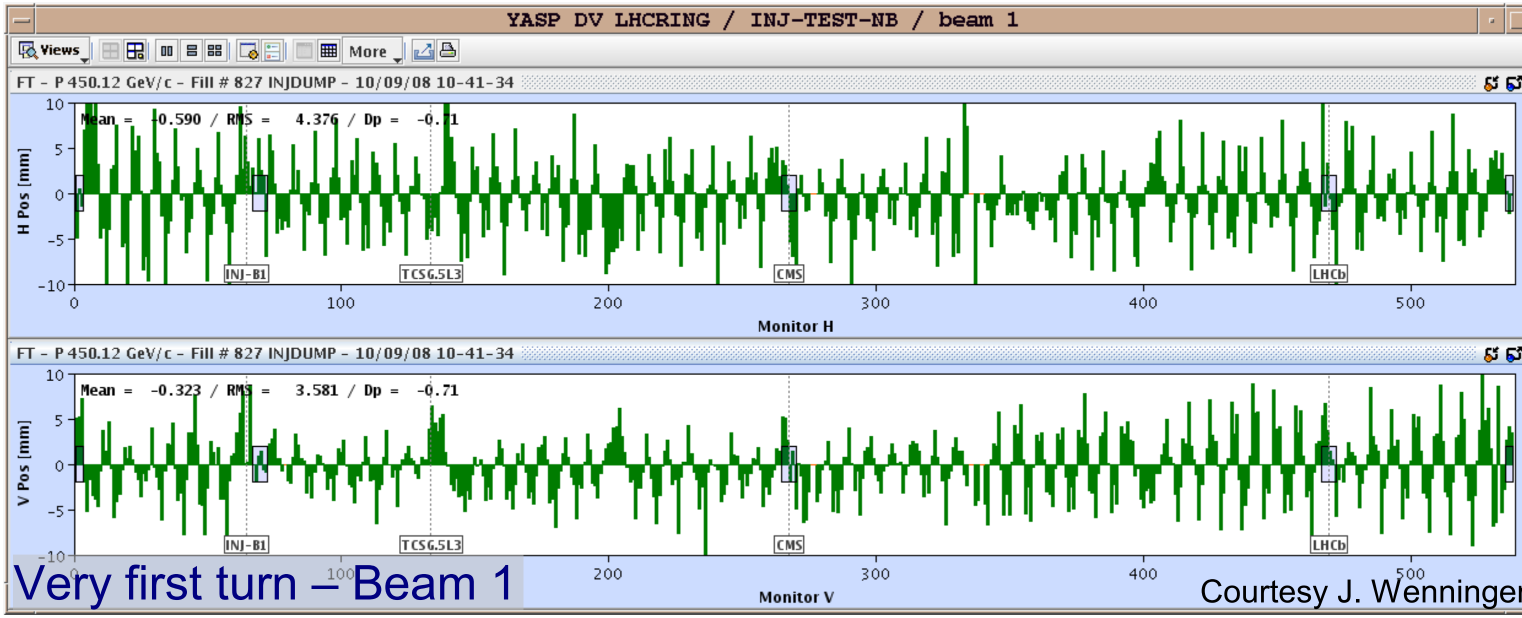
1. **The quench is detected based on voltage measurements over the coils (U_mag_A, U_mag_B).**
2. **The energy is distributed over the entire magnet by force-quenching with quench heaters.**
3. **The power converter is switched off.**
4. **The current within the quenched magnet decays in < 200 ms, circuit current now flows through the ‚bypass' diode that can stand the current for 100-200 s.**
5. **The circuit current/energy is discharged into the dump resistors.**

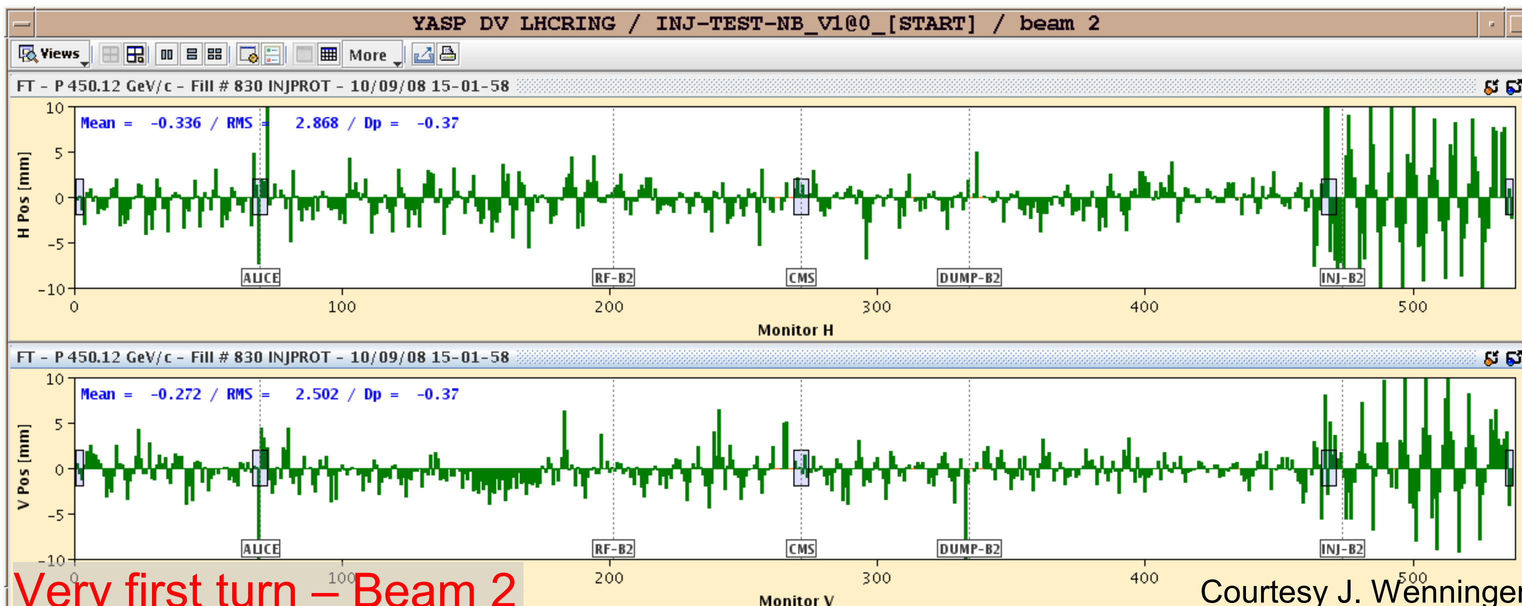
Dump Resistors

- Those large air-cooled resistors can absorb the 1 GJ stored in a dipole magnet circuit (they heat up to few hundred degrees Celsius).



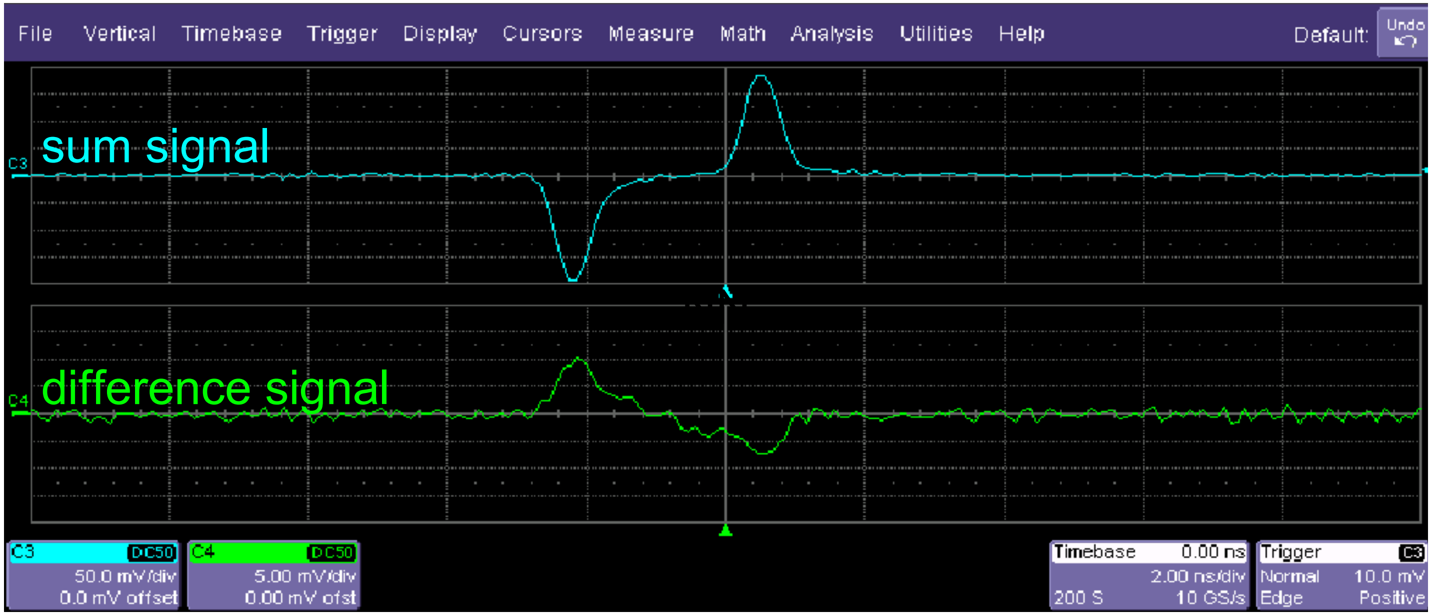
LHC Beam Position Monitor – LHC Day 1
The LHC BPM System at It's Best I/II





BI's Wall-Current and Head-Tail Monitor

- Tested that detectors are alive and trigger on given timing event
  - Some software tests/adjustments pending
    - one full acquisition presently results in about 1.5 GByte of data
    - optimisations in the pipe-line
      - optimised memory usage (Java/JDataViewer)
      - optimised/simplified GUI for the WCM
    - Otherwise: same functionality/state as SPS Head-Tail system (bunch length, intensities, HT modes, chroma estimates, ...)



Chromaticity via Tune Resonance Width I/II

- Some comments on Q', modulation index and tune width of the BTF
  - Turn-by-turn oscillations can be approximated by (n: turn)

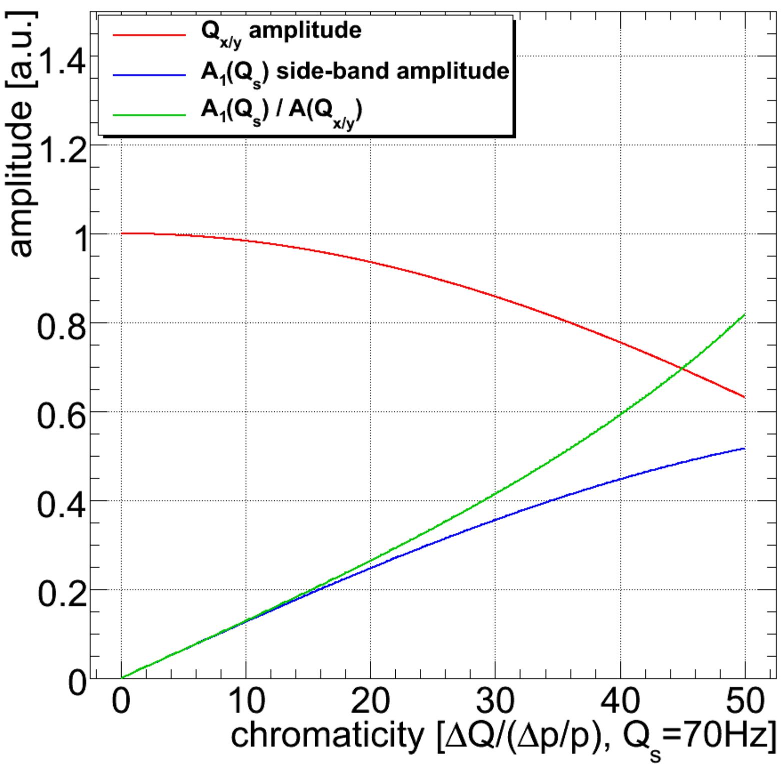
$$\Delta z(n) = z_0 \cdot \sin\left(2\pi \cdot \left[Q_0 \cdot n + \frac{Q'}{\omega_s}\frac{\Delta p}{p} \cdot \sin(\omega_s n)\right] + \varphi_\beta\right)$$

$$\cos(\omega_c t + B \sin(\omega_m t)) = \sum_{n=-\infty}^{+\infty} J_n(B) \cdot \cos((\omega_c + n\,\omega_m) t)$$

- Tune/Qs side-band amplitude (J_n: Bessel f.):

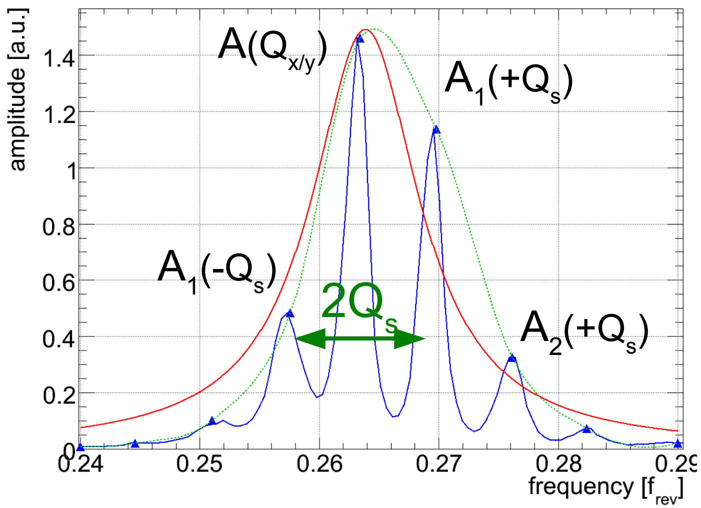
$$S_n(Q') = J_n\left(\frac{Q'}{\omega_s}\frac{\Delta p}{p}\right)$$

  - linear over a wide range of Q'
  - However: Q_s not always visible
    → only upper limits in this case
  - Simple estimates for non-linearities
    - ω_s: direct spectra observable
    - $\Delta p/p \approx 10^{-3}$: from bunch RF length (courtesy T.Bohl)

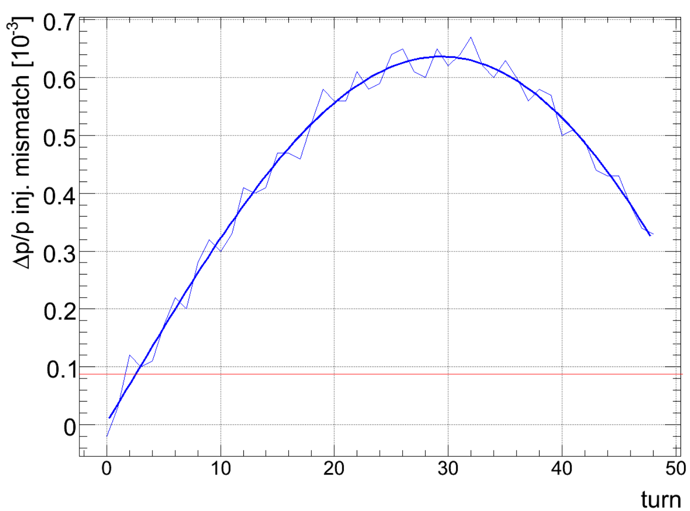


Chromaticity via Tune Resonance Width II/II

- 2008-09-12 (01:03++)
  - Q_s = 70 ± 2 Hz (f_{rev} = 400.788963 Mhz, U_T = 8 MV)
  - Estimates: $Q'_H \approx Q'_V \approx 32$
    - Settings: $Q'_H = 2.0$, $Q'_V = -30$
    - Asymmetry due to amplitude detuning
      - anti-symmetric (left/right avg.)
  - ~ consistent over several injections
  - N.B. AB-RF found Q_s to be 60 Hz (difference unclear, same spectra)
- changed drastically from Thursday to Friday (machine was magnetically recycled)



- Injection mismatch fit:
  - Injection mismatch is likely < 10^{-4}
  - Compatible with above Q' estimates and observed tune shifts (previous slides)
  - further analysis pending (SDDS data)



First Turn and Closed Orbi

- b1 & b2 FT dp/p offsets on Sept 10th are consistent / show no significant difference.
  - dp/p = -4 units

    $f_{RF,LHC}$ = 400'788'790 Hz
- b2 CO dp/p offsets on Sept 12th :
  - dp/p = -9.4 units
  - FT seems well centered on CO, i.e. similar shift as CO within 1 unit.

    $f_{RF,LHC}$ = 400'788'963 Hz

>> The RF frequency difference of 173 Hz (wrt 10) explains a shift of the FT of -2.2 units due to the energy change in the SPS. Is the remaining shift of -2 to -3 units due to LHC ?

>> A shift of <u>**-119 Hz**</u> is required to center b2 on the CO:

$f_{RF,LHC}$ = 400'788'884 Hz

>> The SPS field must be increased by