The great adventure of LHC

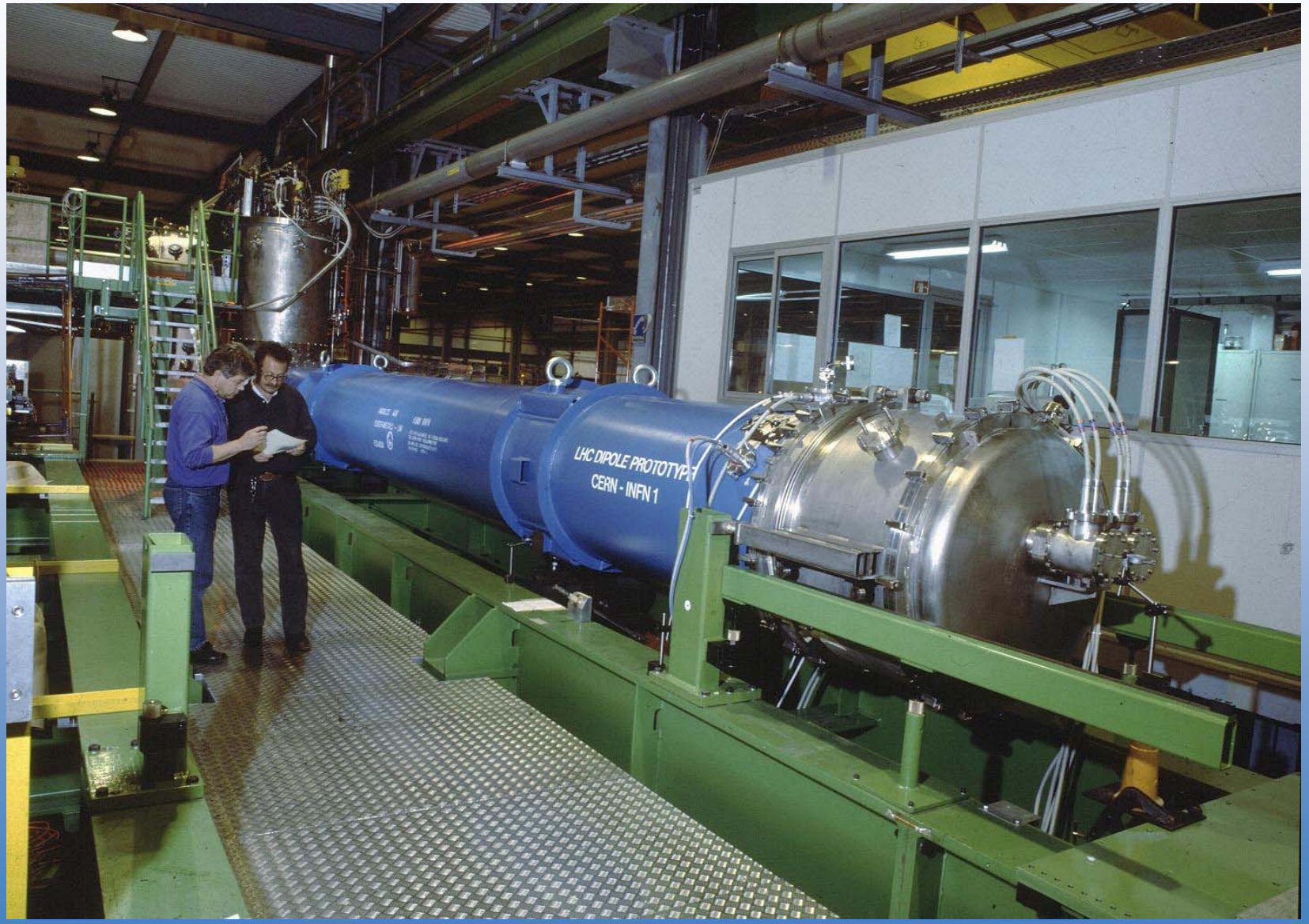
Lyn Evans

The Legacy of Edoardo Amaldi in science and society

Rome - 24 October 2008

Chamonix workshop - 1993

The 10 metre long prototype bending magnet for LHC, which has reached a field of 8,73 Tesla on 14 April 1994



SM18 control room - 1994

Finance Committee April 1994

Message de J.P. Gourber et R. Perin

à L. Evans

- on a atteint 8,73 tesla
  100 quench

16 December 1994

The CERN Council approves the construction of the LHC. To achieve the project without enlarging CERN's budget, it is decided to build the accelerator in two stages.

Japan becomes an Observer – June 1995

Japan becomes an Observer of CERN and announces a financial contribution to the LHC.

The Japanese Minister for Education, Sciences and Culture offers a Daruma doll to CERN's Director-General. According to Japanese tradition, an eye is painted on the doll to mark the beginning of the LHC project and the second eye must be drawn at the time of its completion.

Japan makes two other major financial contributions to the LHC project in 1996 and 1998.

1996

March

- India makes a financial contribution to the construction of the LHC.
- And in June, Russia announces a financial contribution to the project.

December

- Canada announces a financial contribution for the LHC, while a protocol of co-operation is defined for participation of the United States.

Thanks to the contribution of non-Member States of CERN, the Council decides to construct the LHC in only one stage.

United States contribution - December 1997

The United States signs an agreement to take part in the LHC, in particular by providing superconducting magnets for the accelerator.

About 1300 American physicists are users of CERN today.

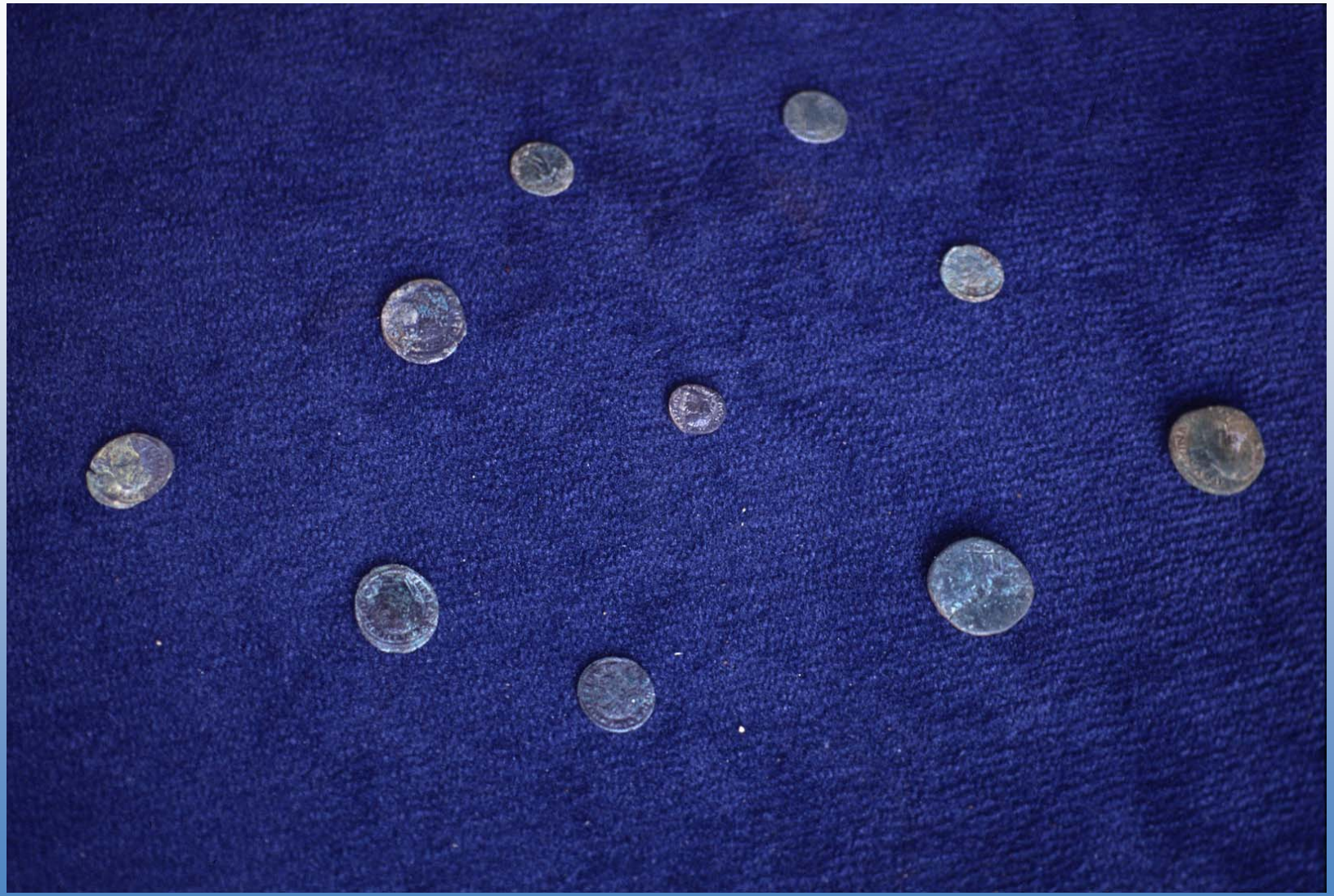
April 1998

Civil engineering work begins for the ATLAS experiment.

Projects include: the excavation of two shafts, the digging of two caverns –one of which is the largest in the world dug in molasse-type rock– and the construction of buildings on the surface.

Aerial view of Point 5. Gallo-roman vestiges 1998

Roman coins found during archeological excavations at Point 5



Point 1 - UX15 vault demolition of central pillar - September 20, 2000 - CERN ST-CE

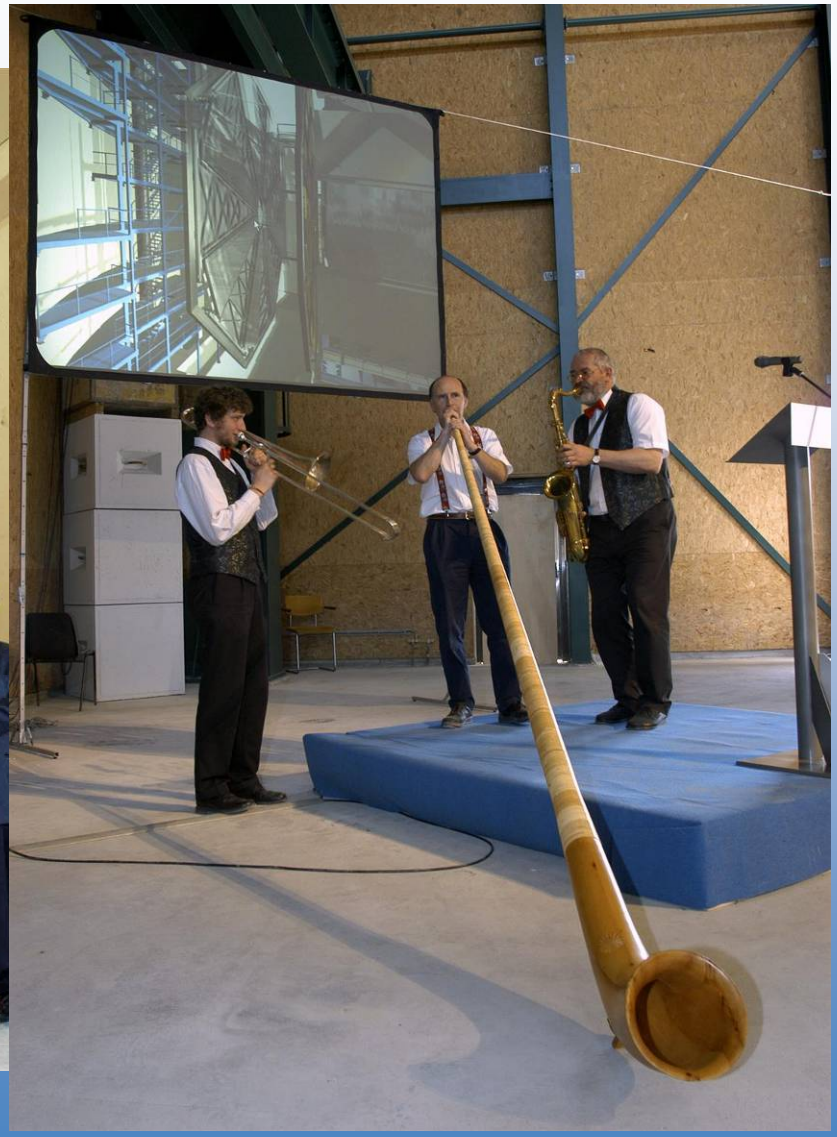
Point 1 - UX15 cavern - Concreting of vault panel n°2 - April 10, 2001 - CERN ST-CE

LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE

Point 5 -Excavation commencement of PM54 shaft - July 09, 1999 - CERN ST-CE

Point 5 - UXC55 cavern excavation - LEP demolition - January 23, 2002 - CERN ST-CE

ATLAS cavern inauguration 2003



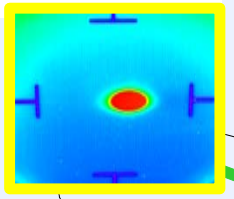
QRL crisis June 2004

QRL team

General situation

13:39 → beam at the end of TI 8, some 2.5 km away, at first attempt

- **length of newly tested part ~ 2.5 km**
- **over 400 magnets**



beam tests
23./24.10.04
6./7.11.04

TI8 - MBIT

Magnet storage

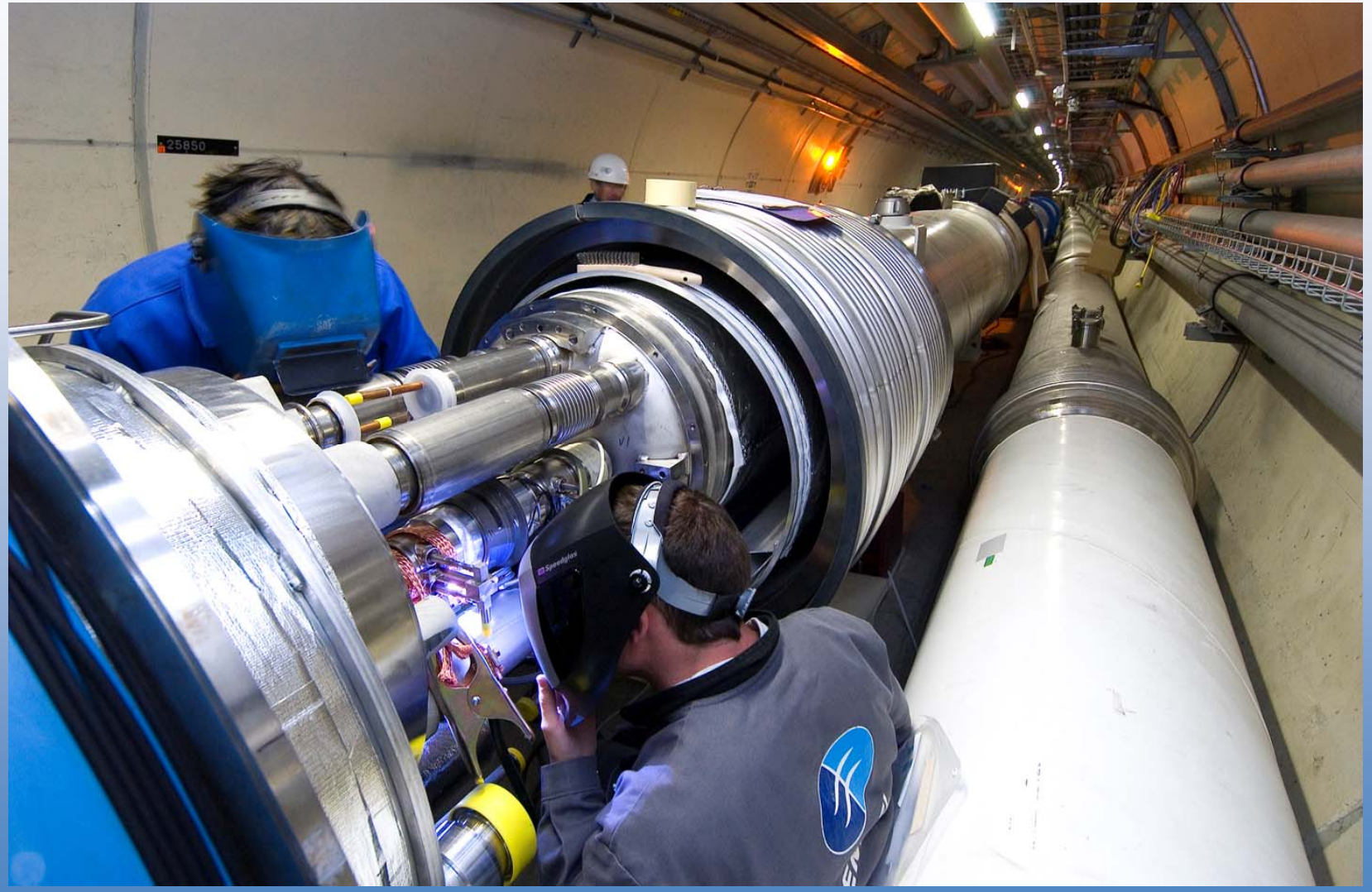
End of civil engineering works in Point 5 (1st February 2005)

First cryodipole lowered on 7 March 2005

Transport in the tunnel with an optical guided vehicle

Transfer on jacks

Interconnects



Electrical quality control in the tunnel

Quarks and Photons: The Strangest Little Things in Nature

FOX NEWS.COM, THURSDAY, NOVEMBER 09, 2006

AP

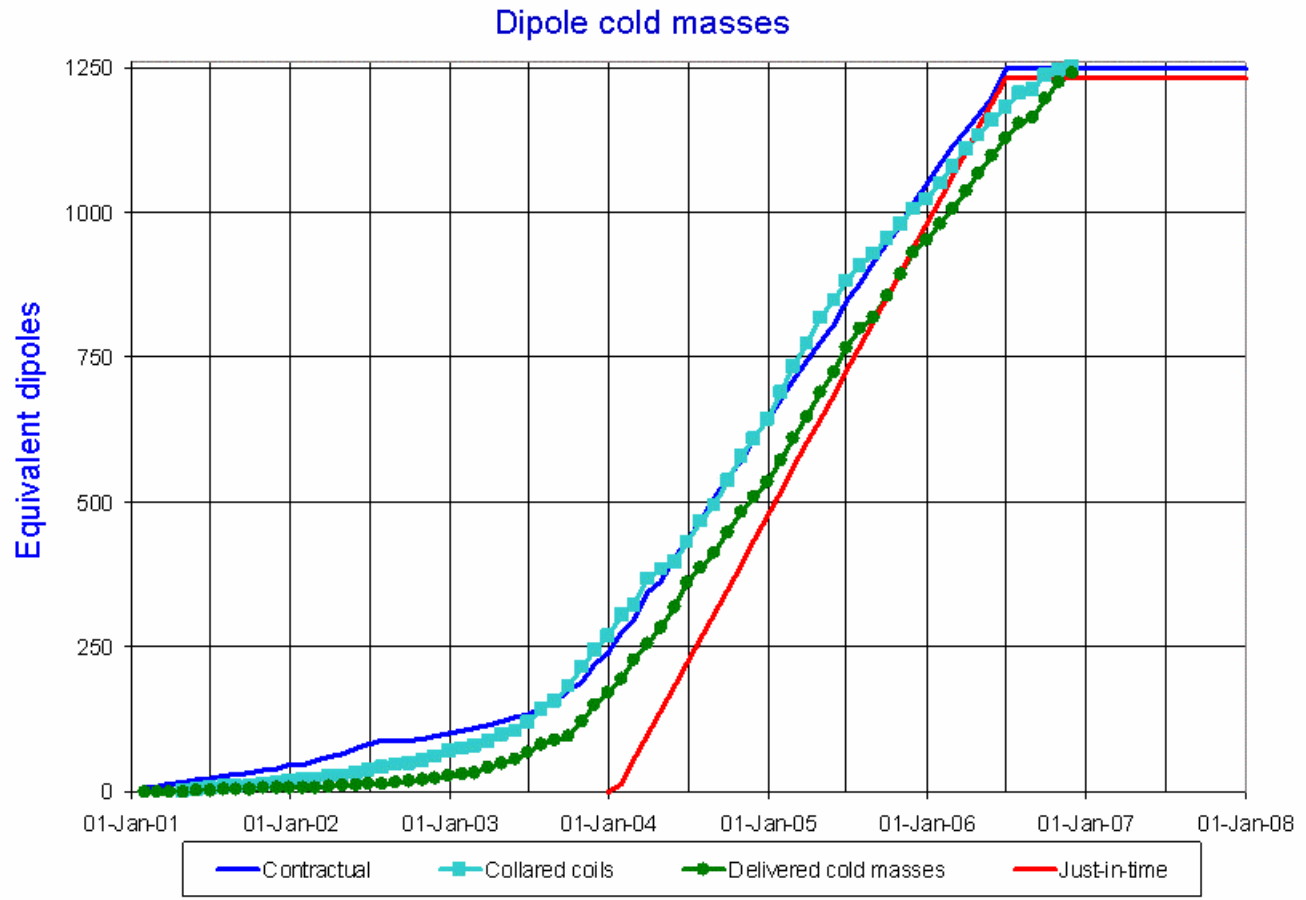
The CERN Large Hadron Collider in Geneva, Switzerland, which will be the world's largest particle accelerator when it enters full operation in 2008.

Last delivered dipole, 27 November 2006

Dipole cold masses

LHC Progress Dashboard

Accelerator Technology Department

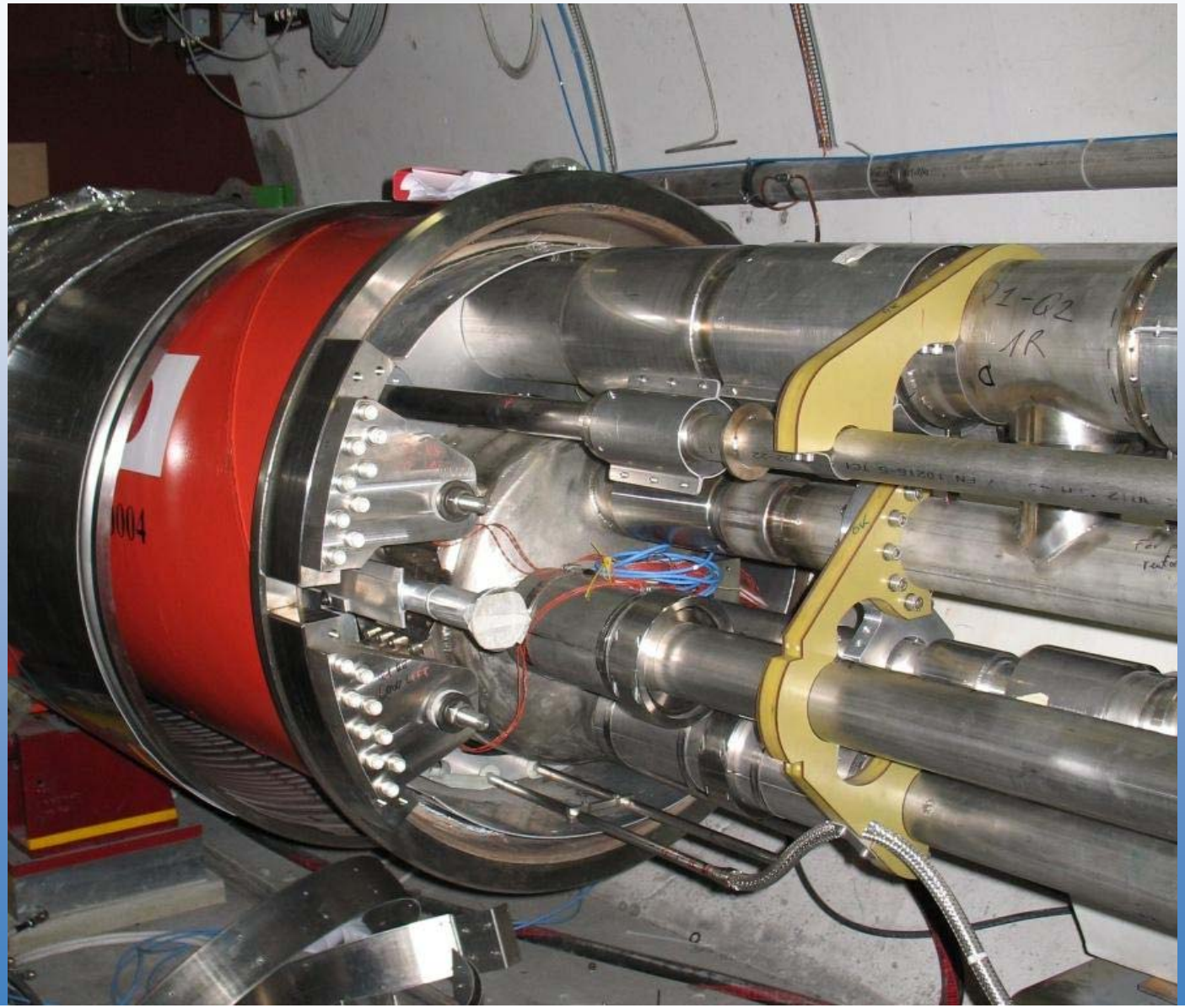


Updated 30 Nov 2006 Data provided by G. de Rijk AT-MCS

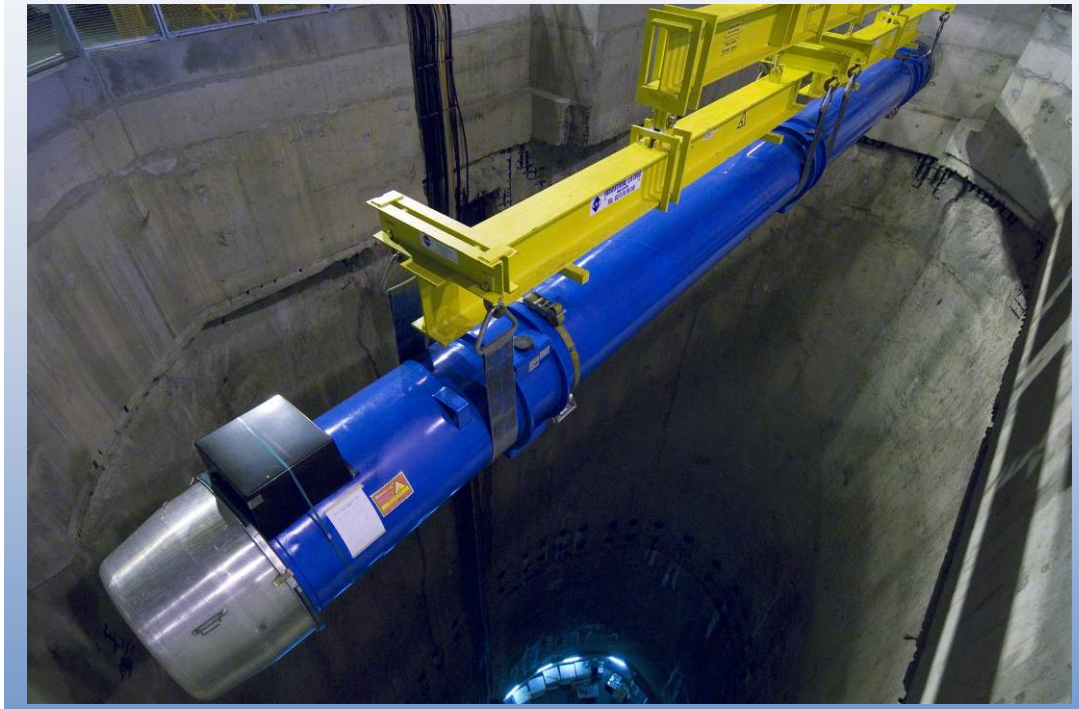
Completion of magnet cryostating & tests
1 March 2007

Cryostating	425 FTE.years
Cold tests	640 FTE.years

Inner triplet crisis February 2007



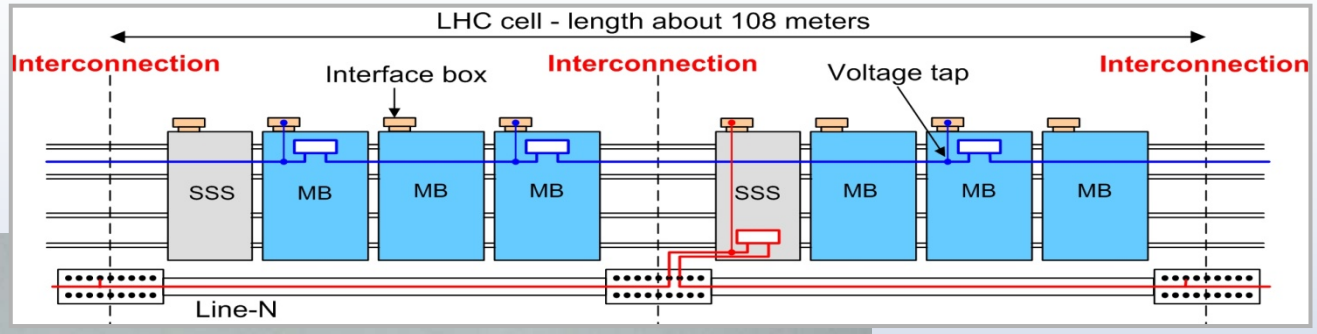
Descent of the last magnet, 26 April 2007

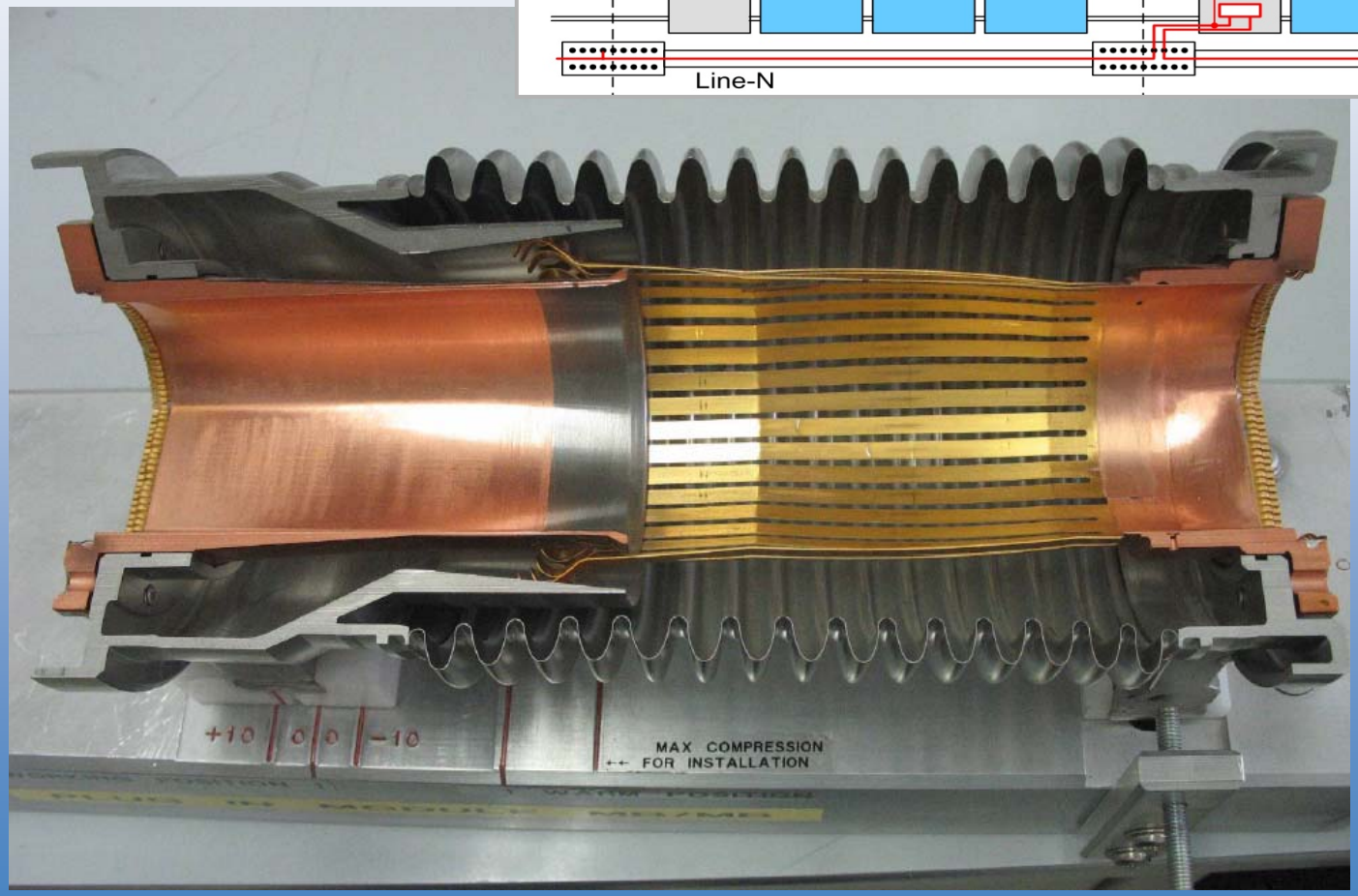


30’000 km underground at 2 km/h!

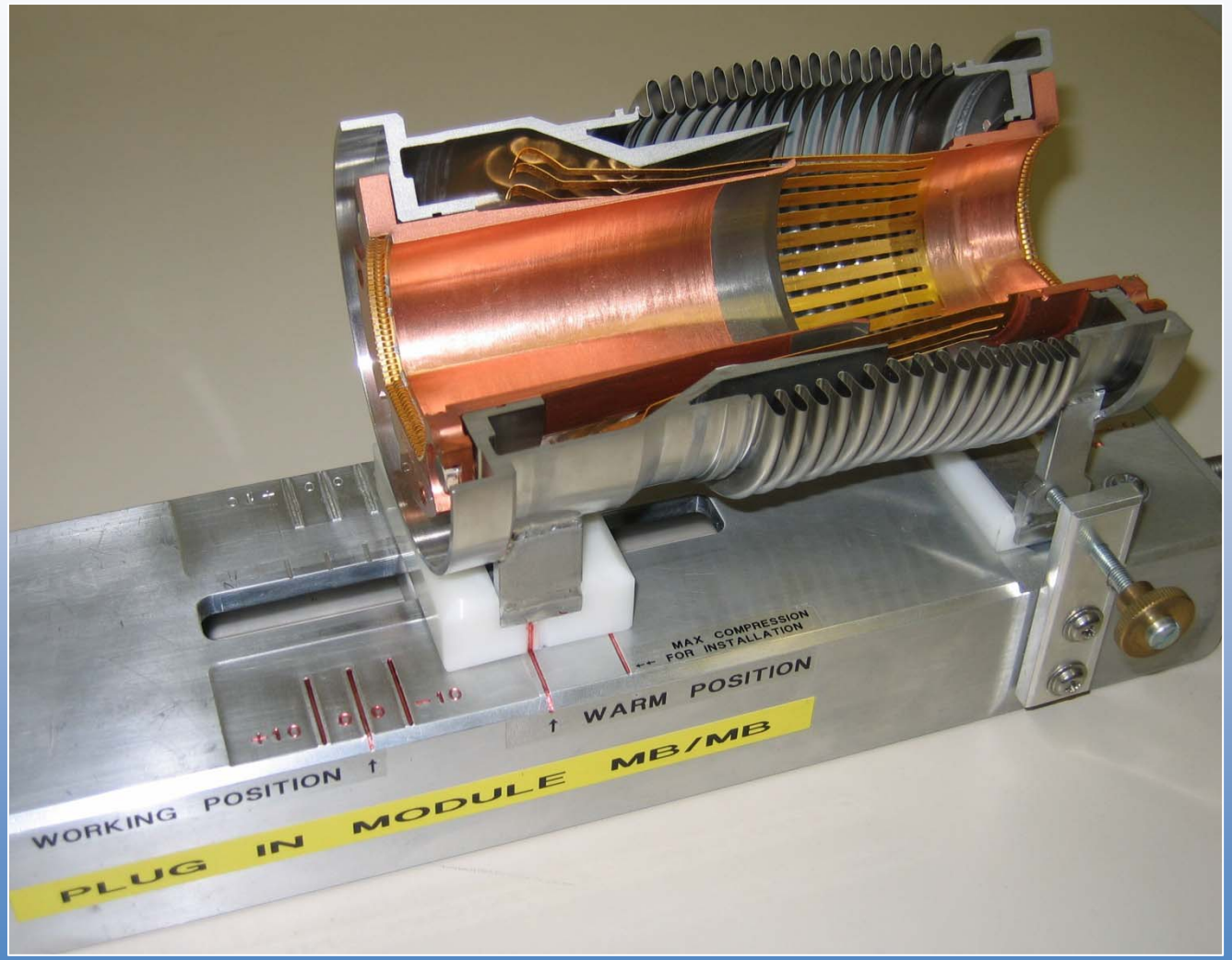
Closure of continuous cryostat - November 2007

The crisis of the PIM's

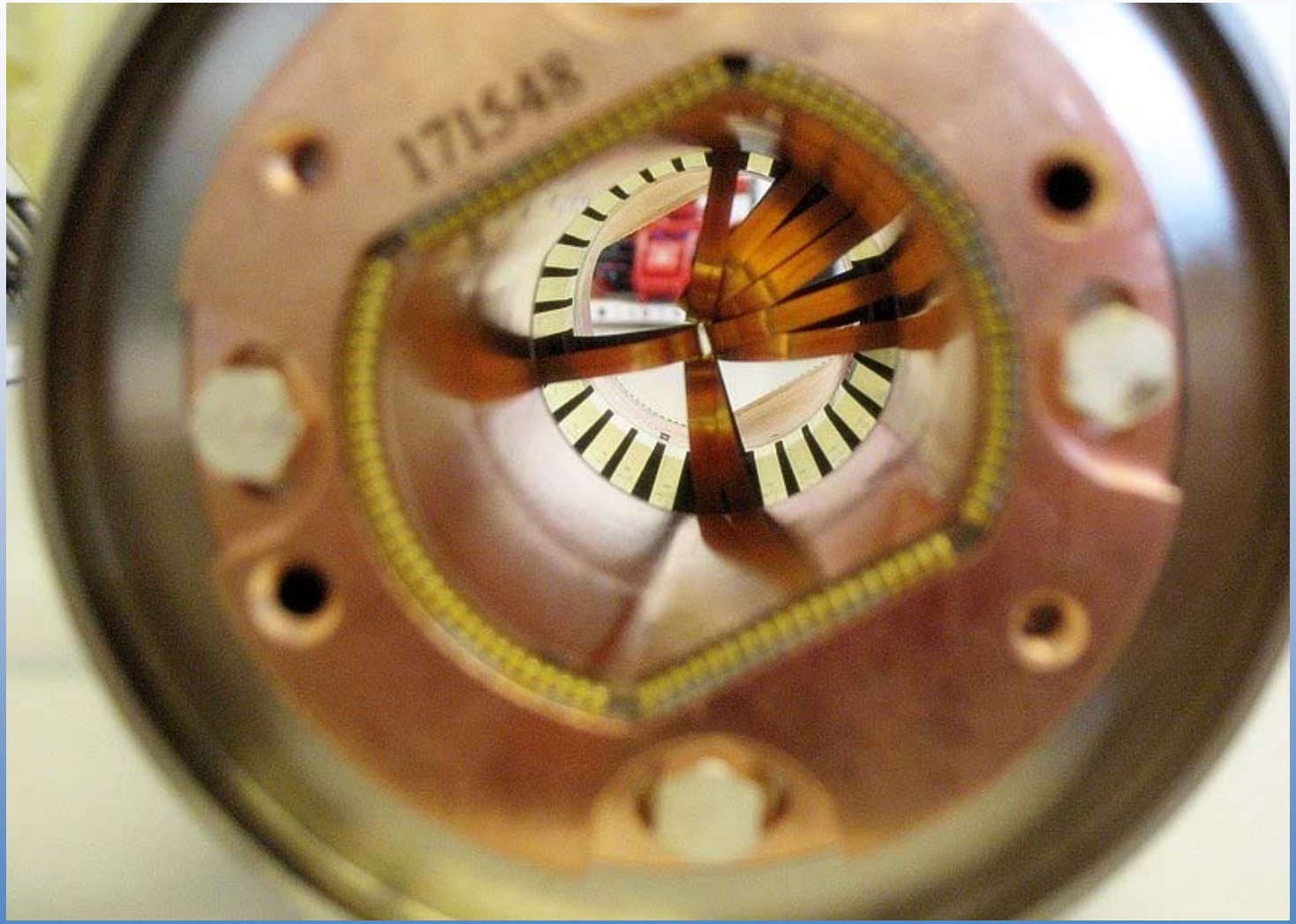




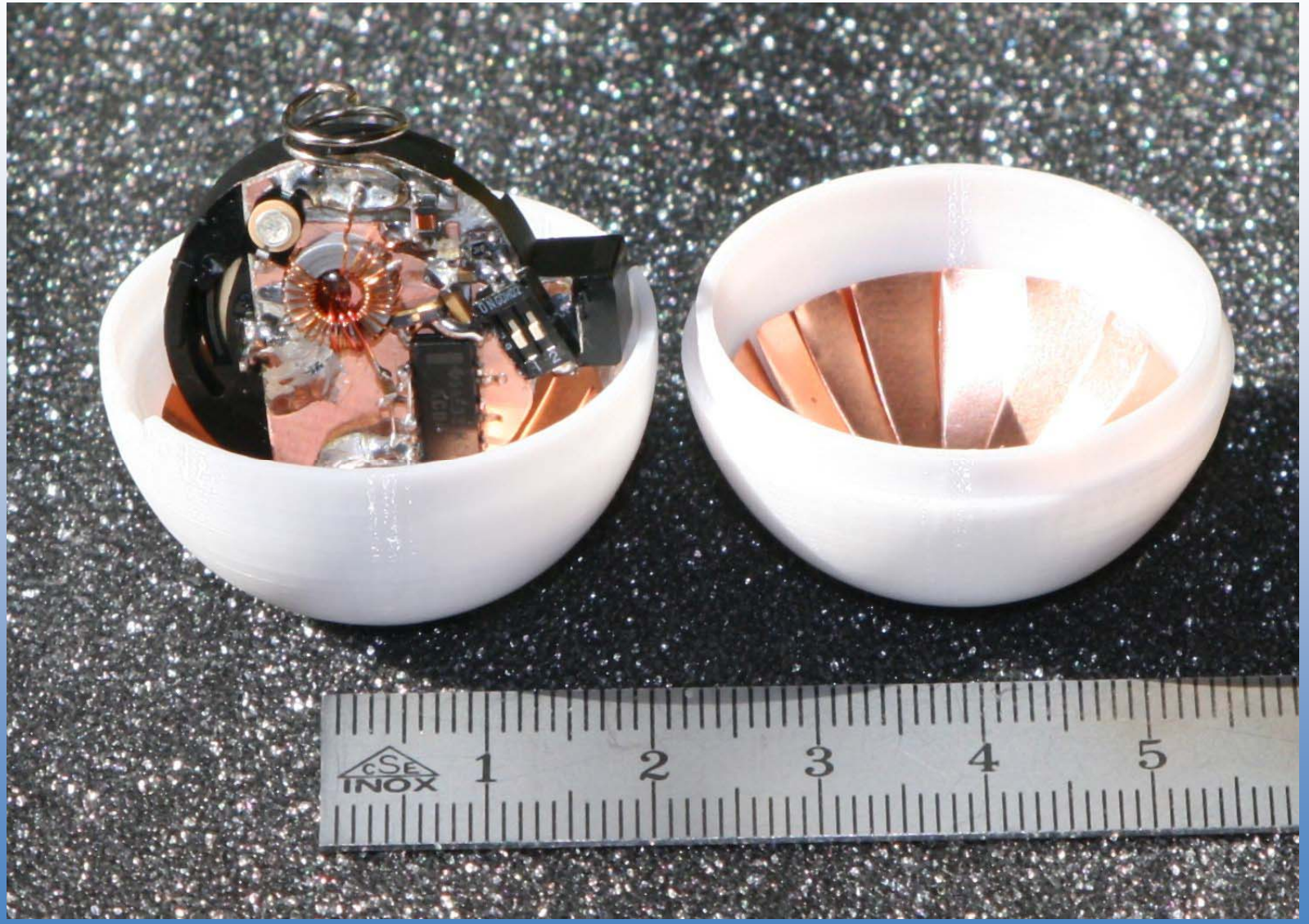
Arc plug-in module at warm temperature



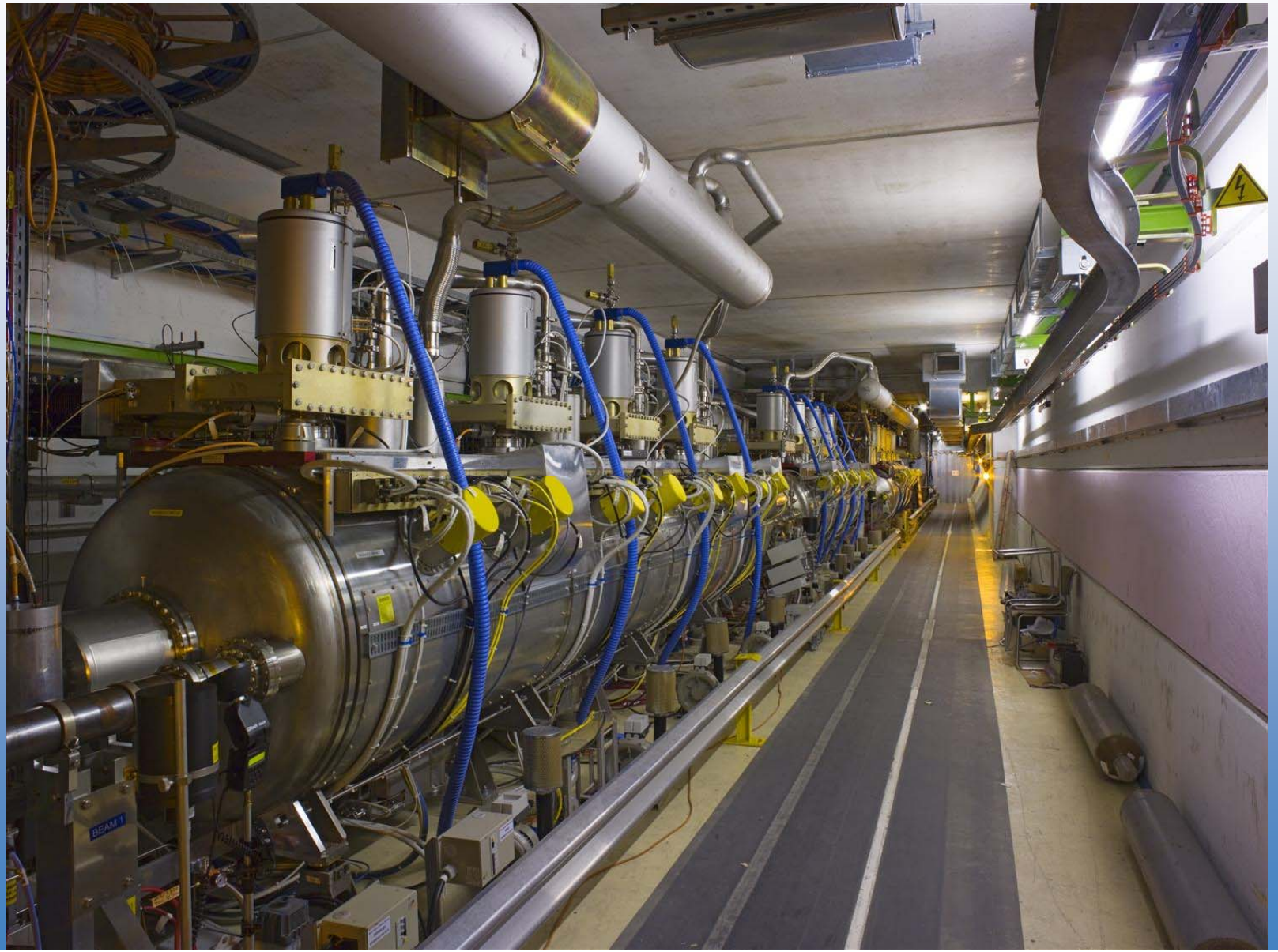
Arc plug-in module with damaged fingers



Transmitter ball



RF cavities



Cooldown of Sector 7-8

- From RT to 80K precooling with LN2. 1200 tons of LN2 (64 trucks of 20 tons). Three weeks for the first sector.
- From 80K to 4.5K. Cooldown with refrigerator. Three weeks for the first sector. 4700 tons of material to be cooled.
- From 4.2K to 1.9K. Cold compressors at 15 mbar. Four days for the first sector.

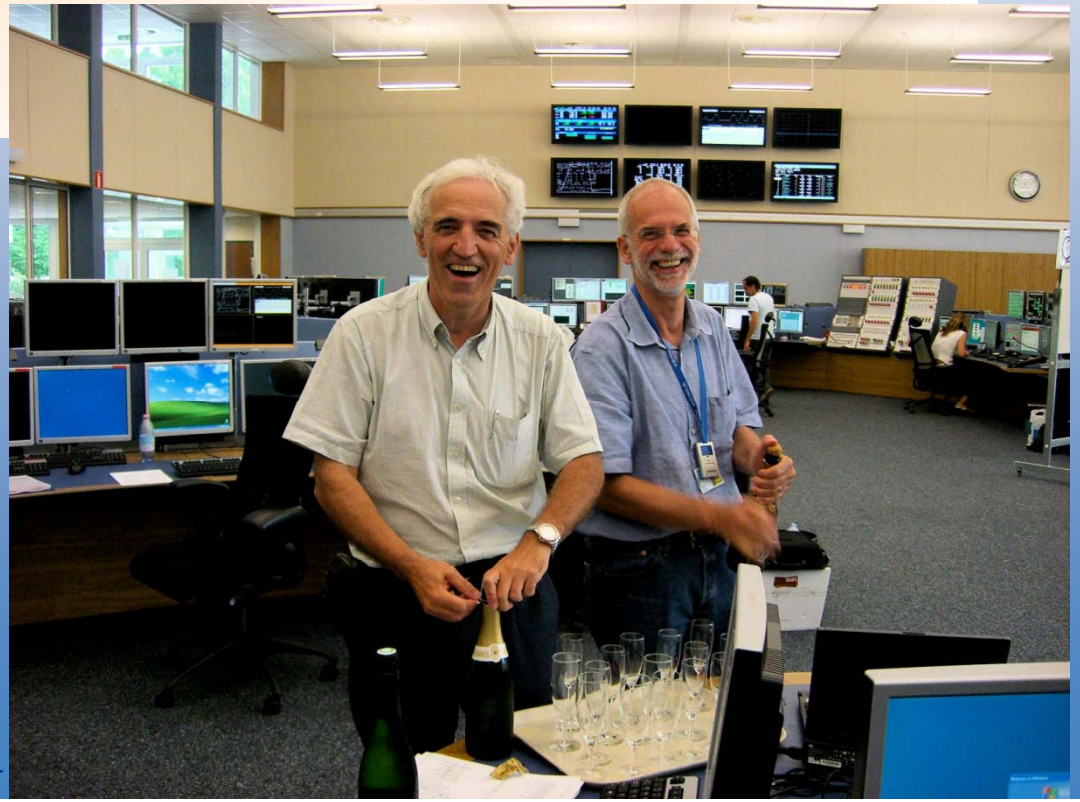
Large helium refrigerator for cooling down to 4.5 K

33 kW @ 50 K to 75 K
23 kW @ 4.6 K to 20 K
41 g/s liquefaction

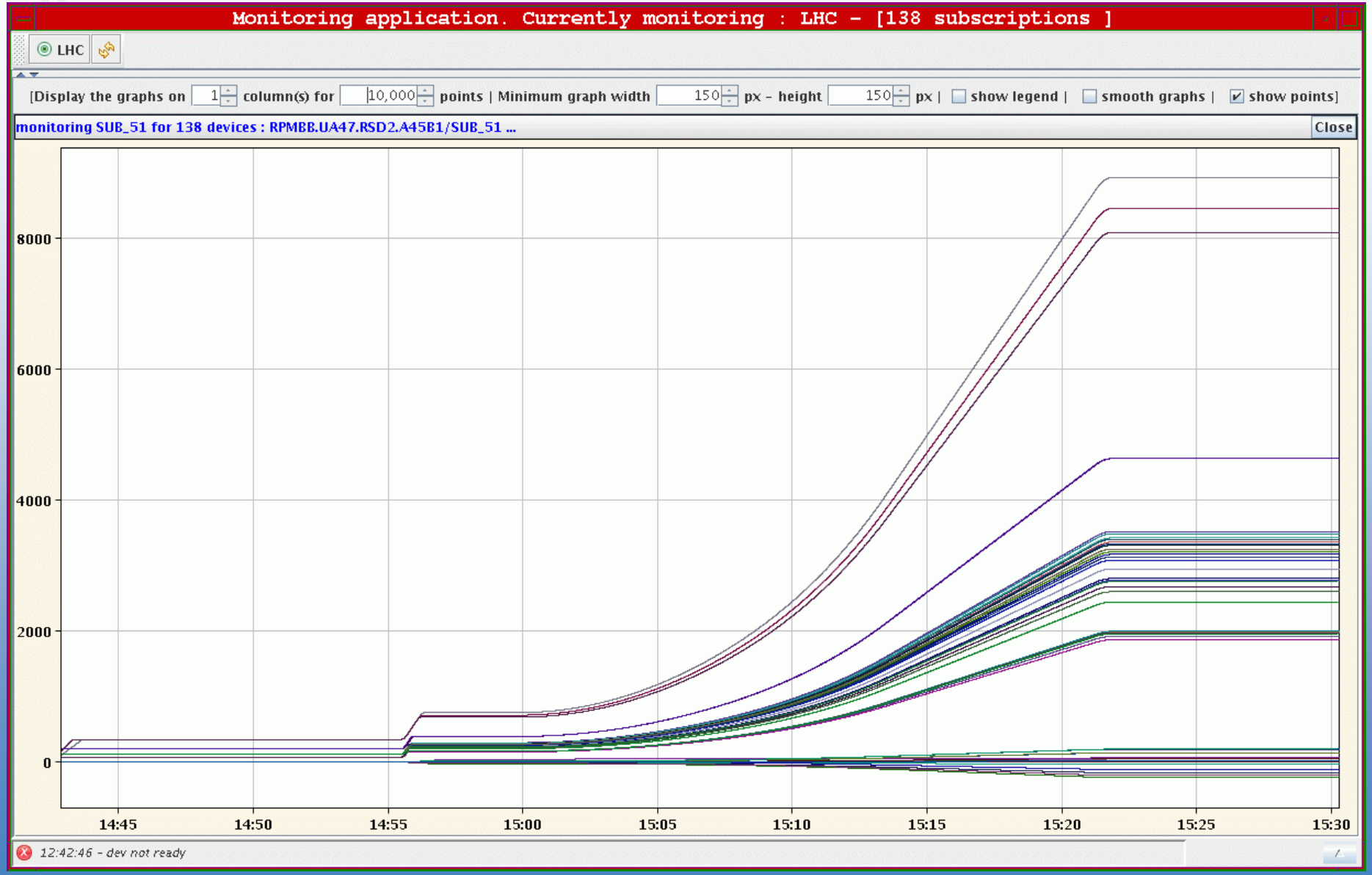
600 kW precooling to 80 K
with LN2 (up to ~5 tons/h)

June 2007

- A complete LHC sector 3.3 km-long and cooled at –271°C is powered up for the first time..
- Several thousands of amps circulate in the superconducting magnets installed in the tunnel. Members of the groups involved celebrated with champagne.

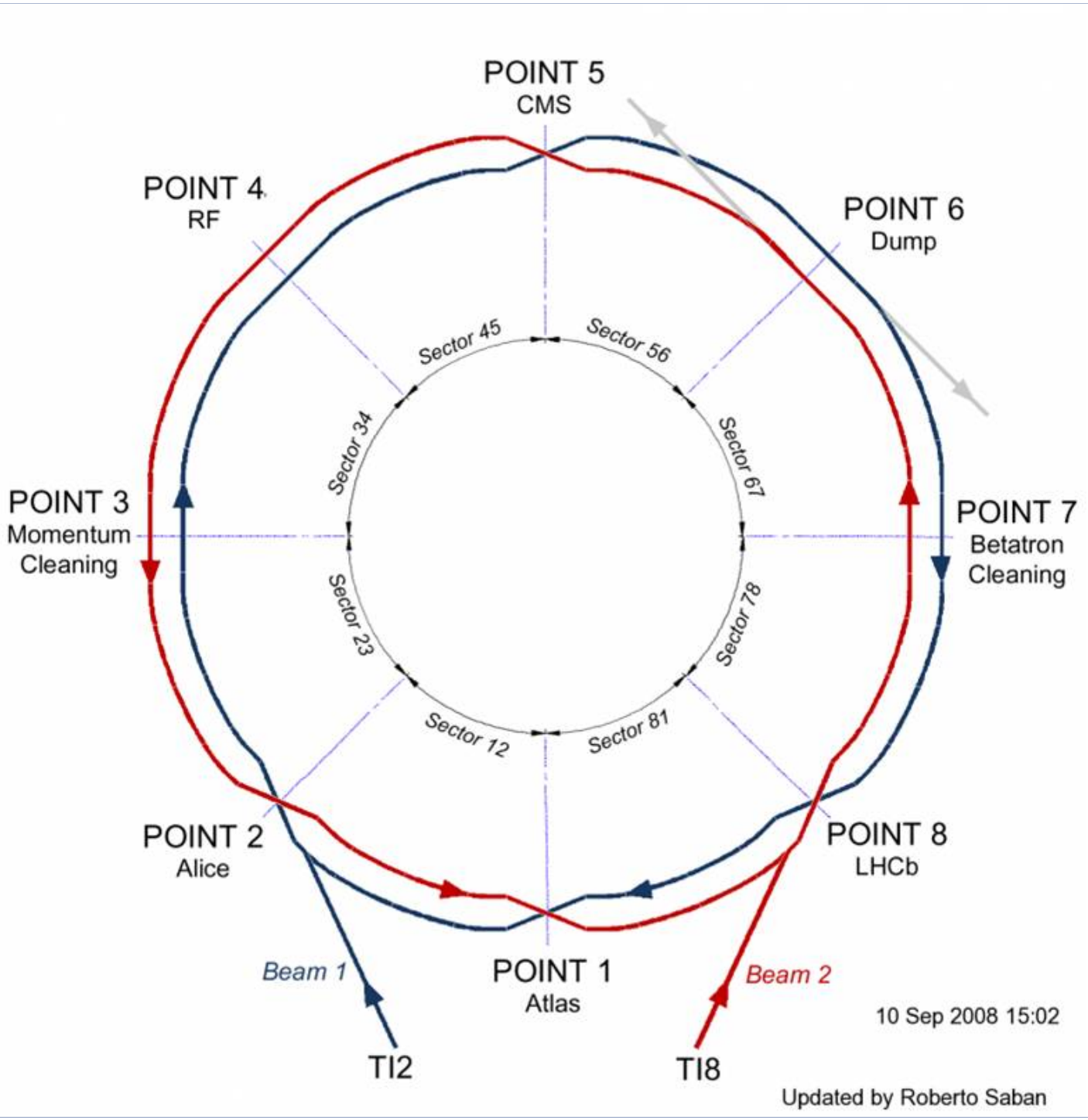


Ramp of 138 power converters to a current equivalent to 5.3 TeV (including all high current magnets realistic LHC optics)

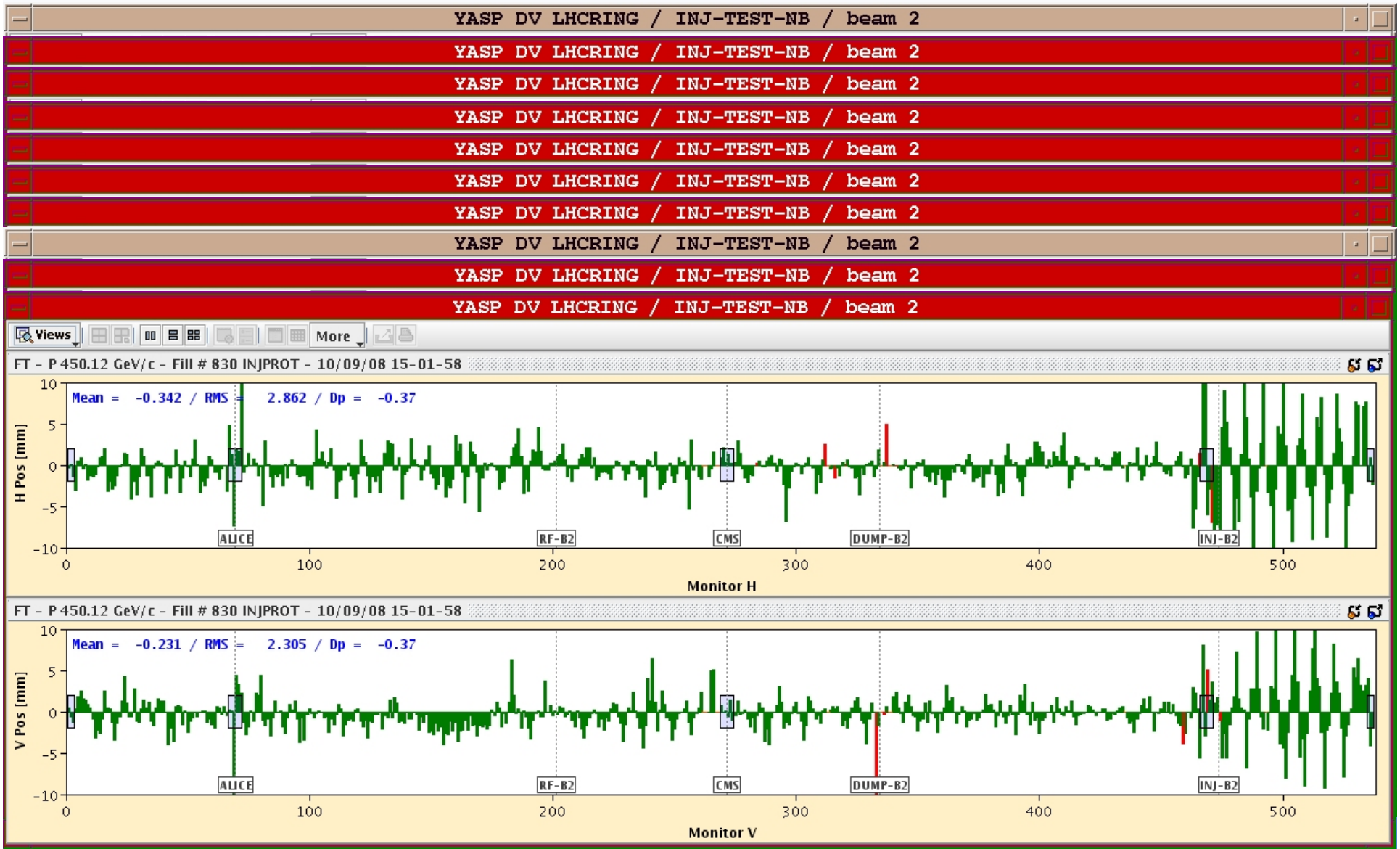


Situation on 10th September

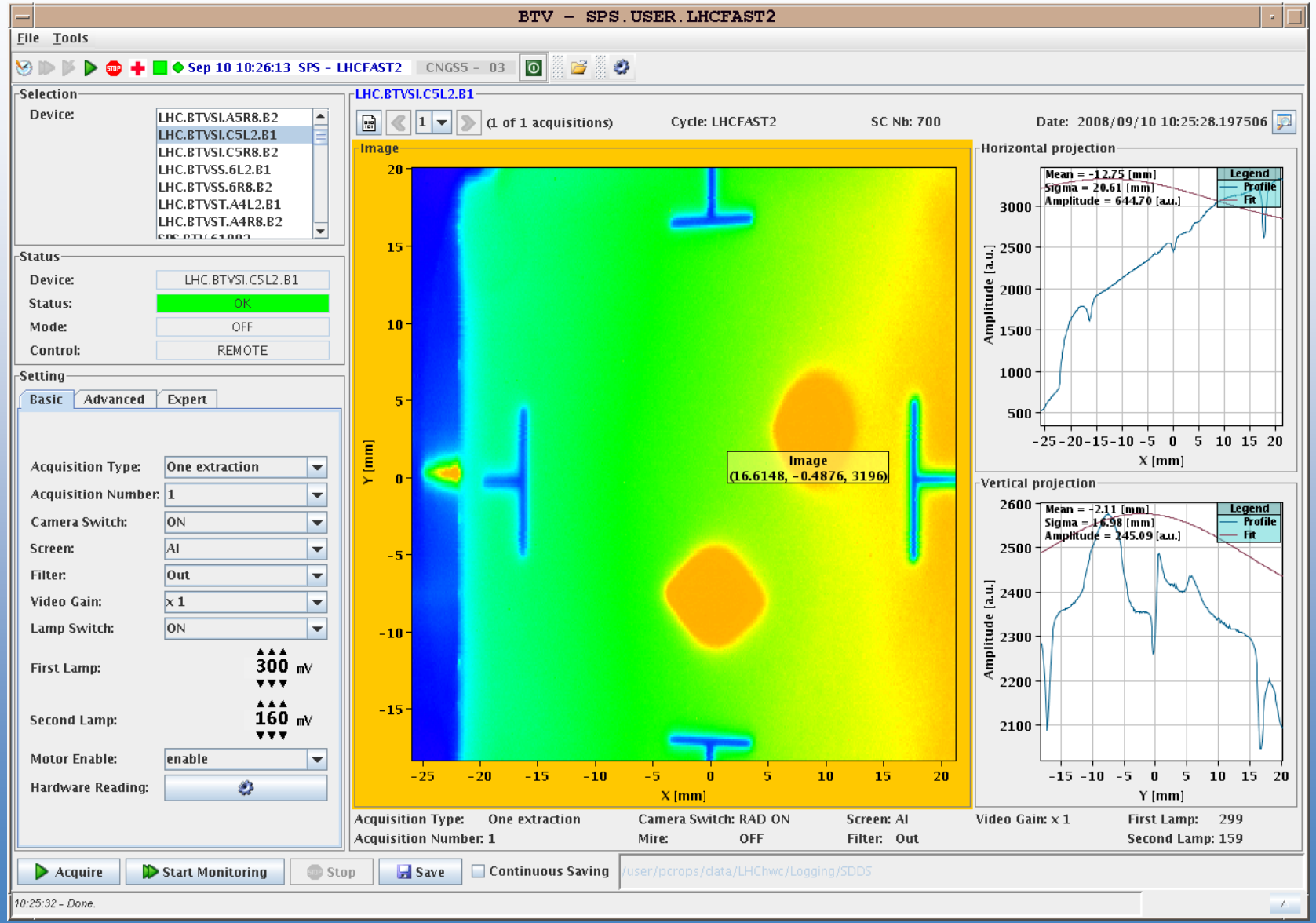
- 7 out of 8 sectors fully commissioned for 5 TeV operation and 1 sector (3-4) commissioned up to 1 TeV.


POINT 5
CMS
POINT 4
RF
POINT 6
Dump
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
POINT 2
Alice
POINT 8
LHCb
POINT 1
Atlas
Sector 45
Sector 56
Sector 34
Sector 67
Sector 23
Sector 78
Sector 12
Sector 81
Beam 1
Beam 2
TI2
TI8
10 Sep 2008 15:02
Updated by Roberto Saban

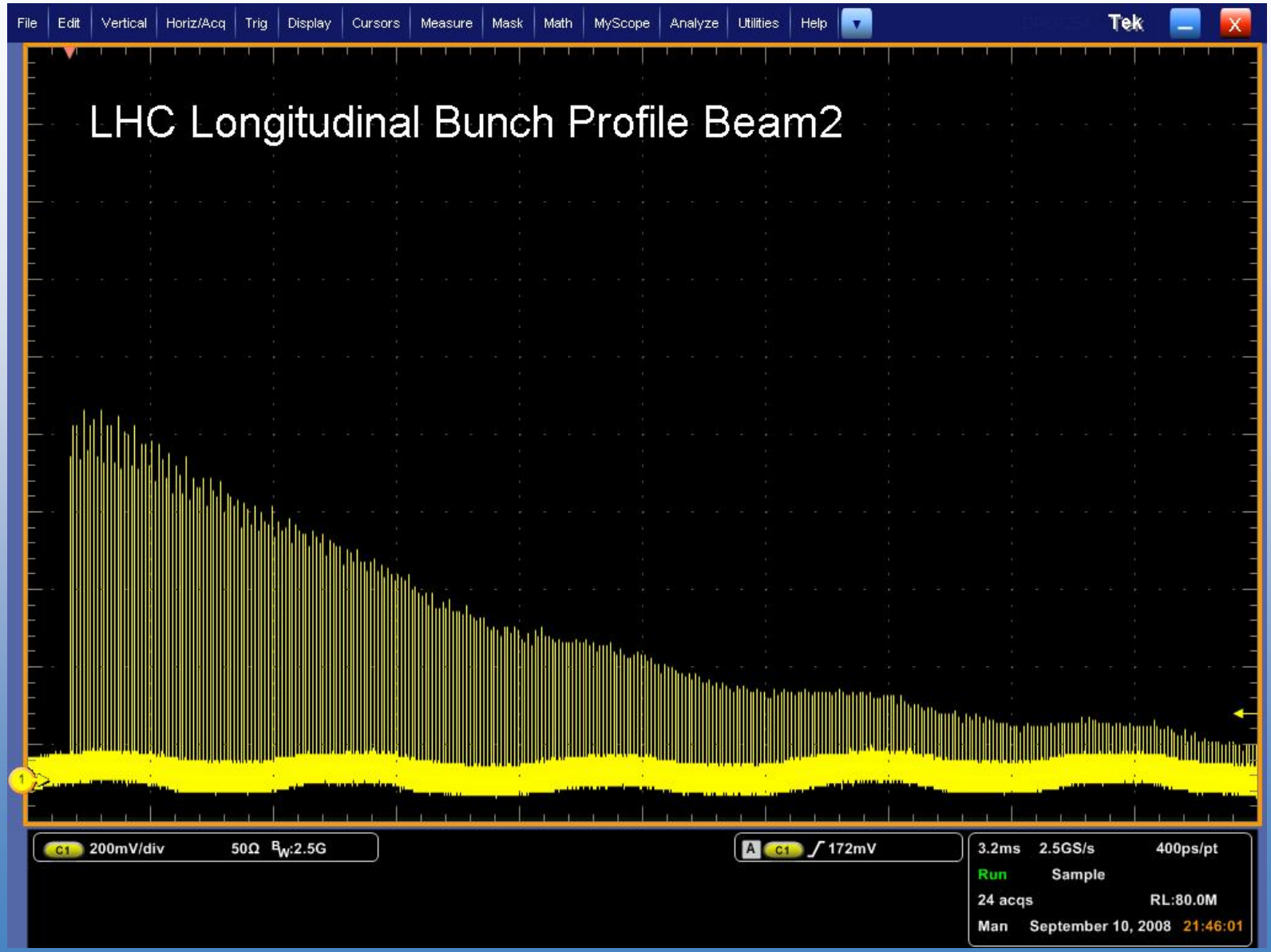
Beam 2 first beam – D-Day



Beam on turns 1 and 2

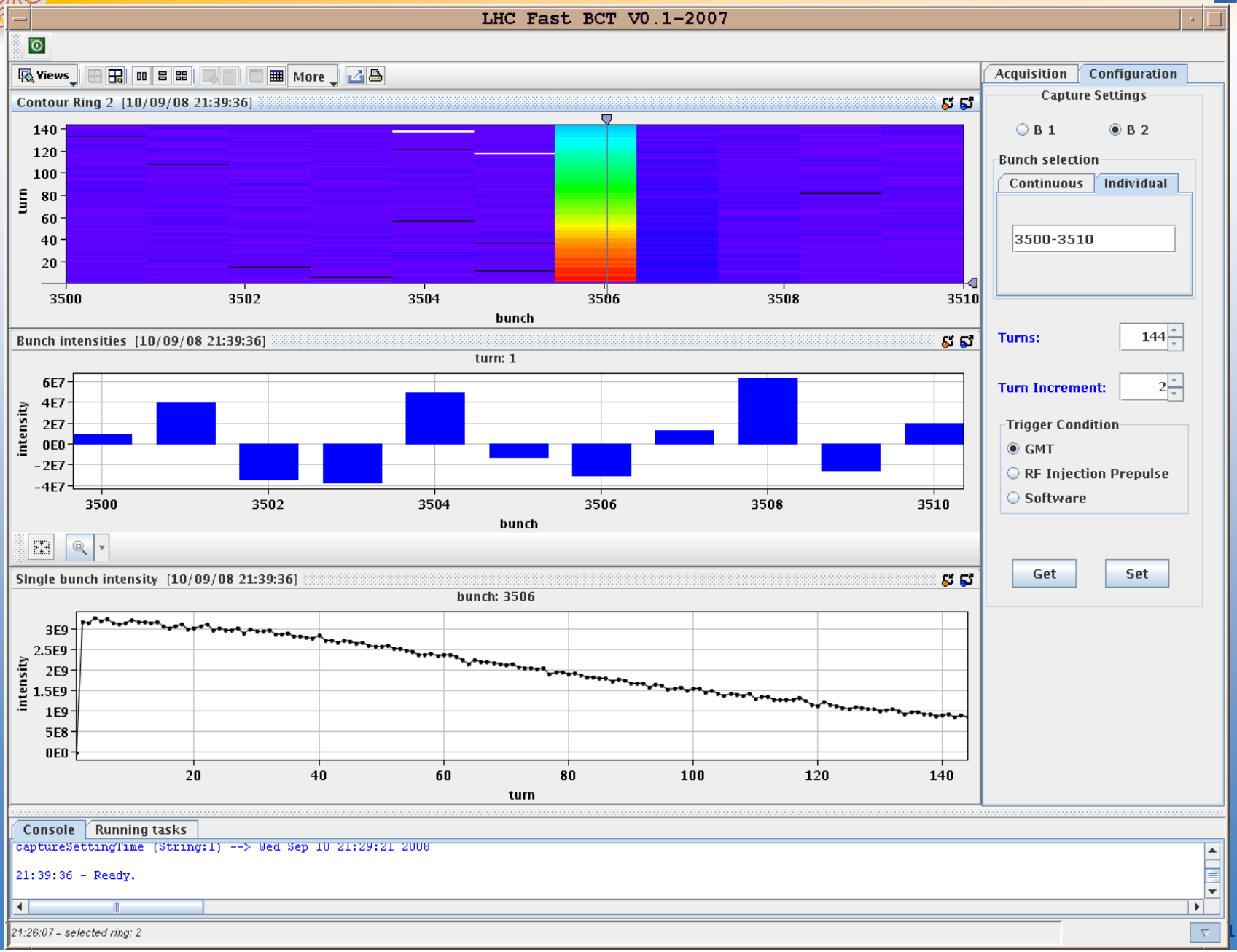


Few 100 turns

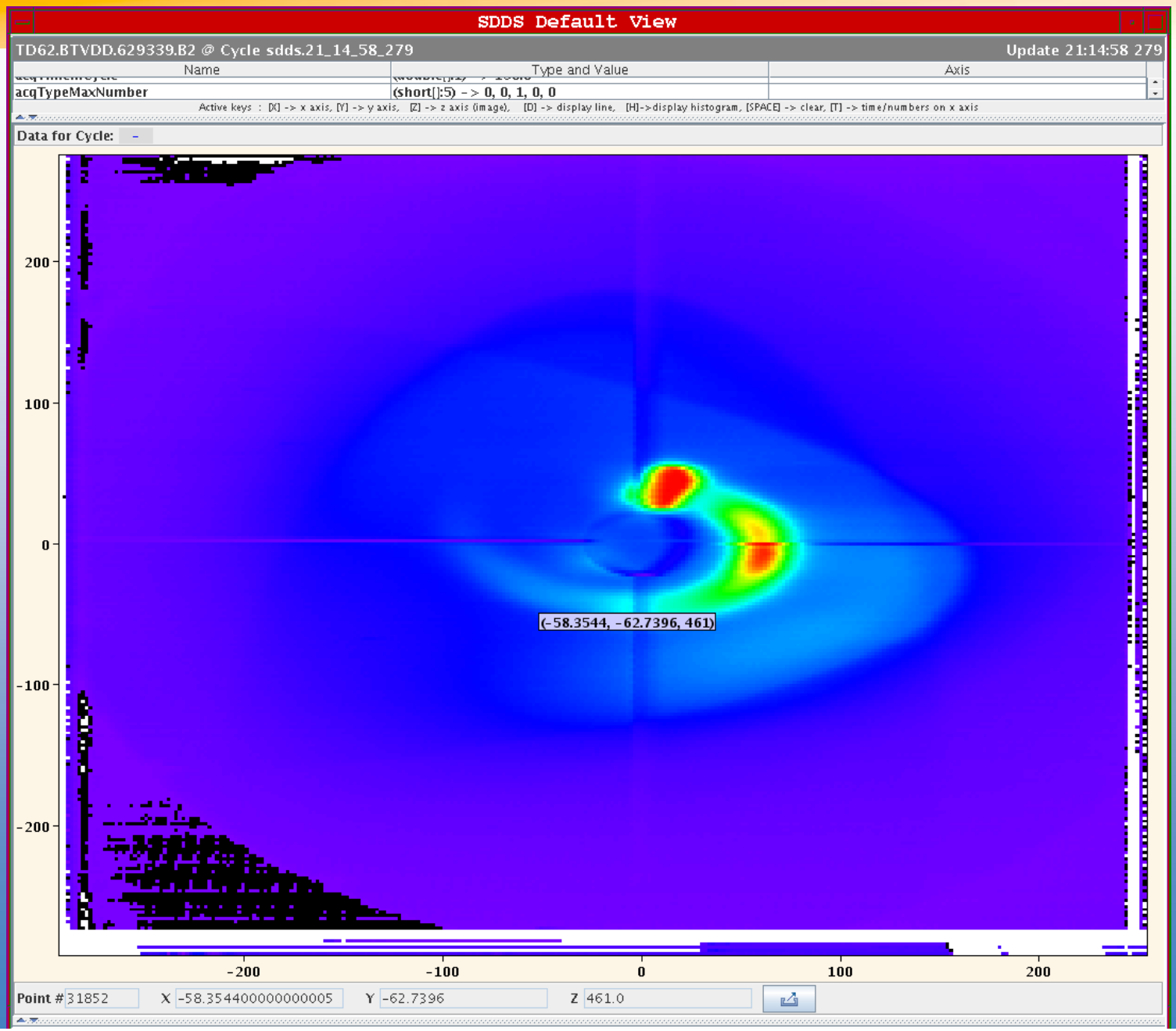


Courtesy R. Bailey

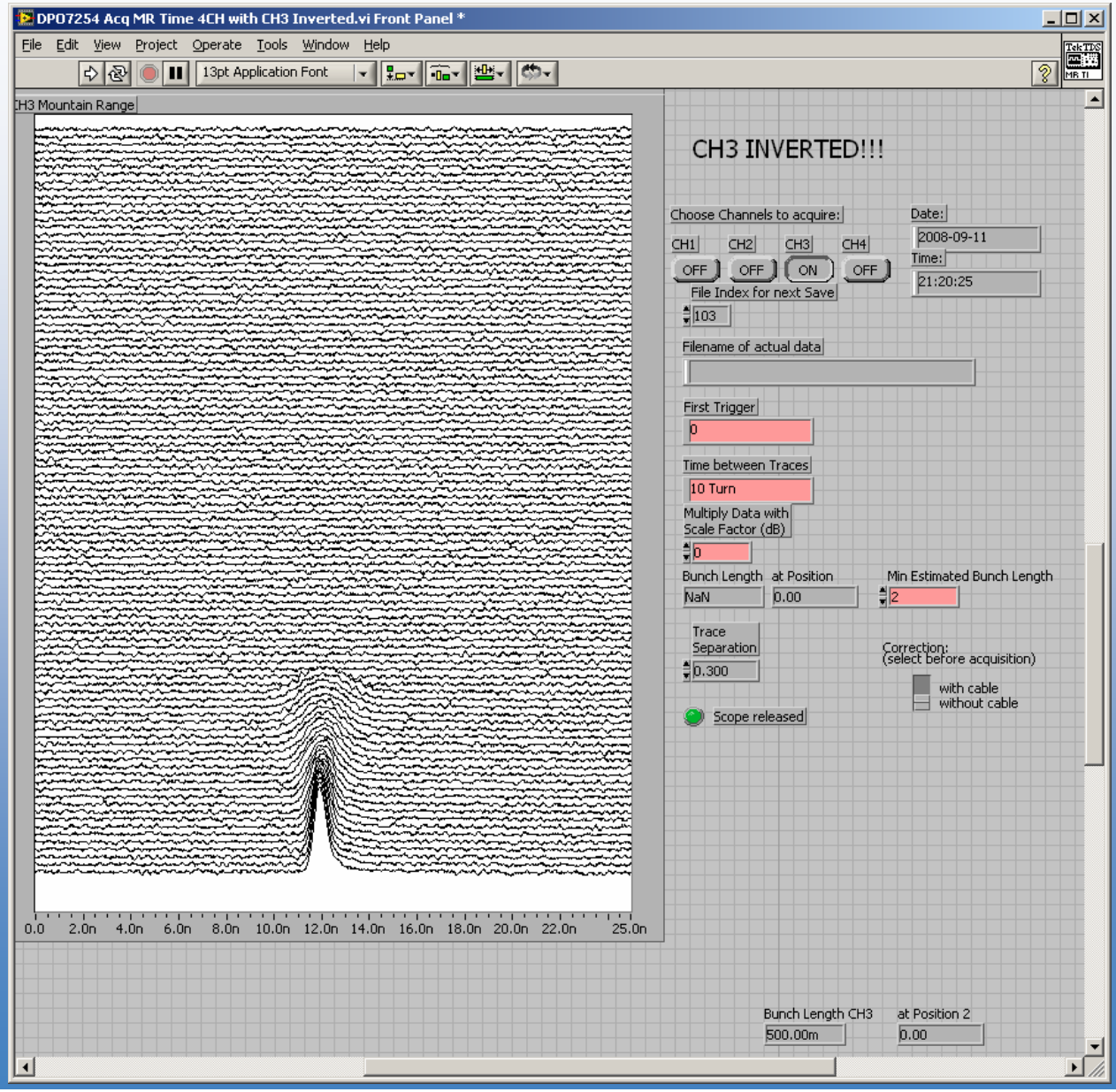
Fast BCT


LHC Fast BCT V0.1-2007
Views
More
Contour Ring 2 [10/09/08 21:39:36]
turn
bunch
Bunch intensities [10/09/08 21:39:36]
turn: 1
intensity
bunch
Single bunch intensity [10/09/08 21:39:36]
bunch: 3506
intensity
turn
Acquisition
Configuration
Capture Settings
B 1
B 2
Bunch selection
Continuous
Individual
3500-3510
Turns:
144
Turn Increment:
2
Trigger Condition
GMT
RF Injection Prepulse
Software
Get
Set
Console
Running tasks
captureSettingTime (String:1) --> Wed Sep 10 21:29:21 2008
21:39:36 - Ready.
21:26:07 - selected ring: 2

Dump dilution sweep

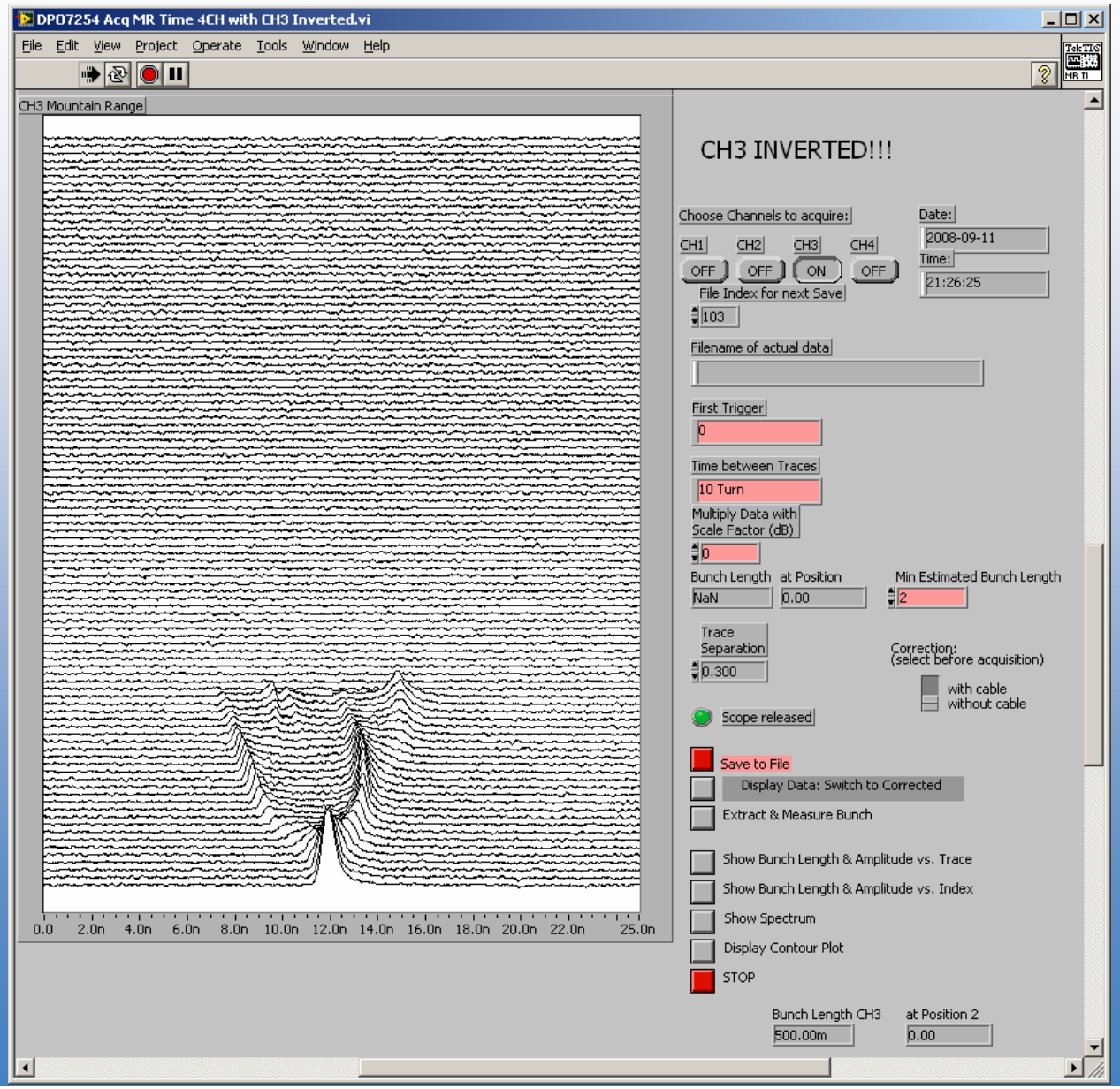


No RF, debunching in ~ 25*10 turns, i.e. roughly 25 mS



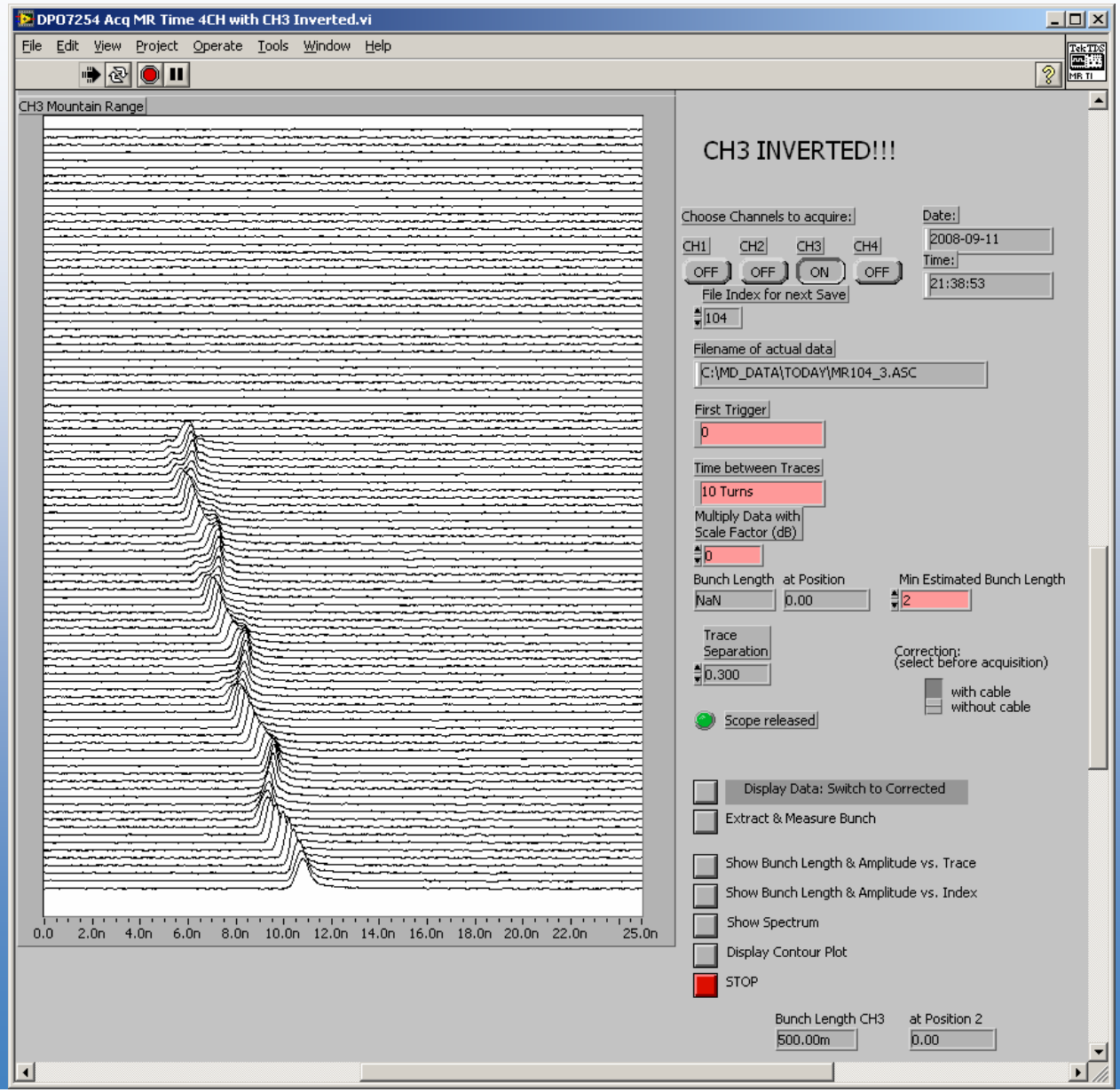
Courtesy E. Ciapala

First attempt at capture, at exactly the wrong injection phase…



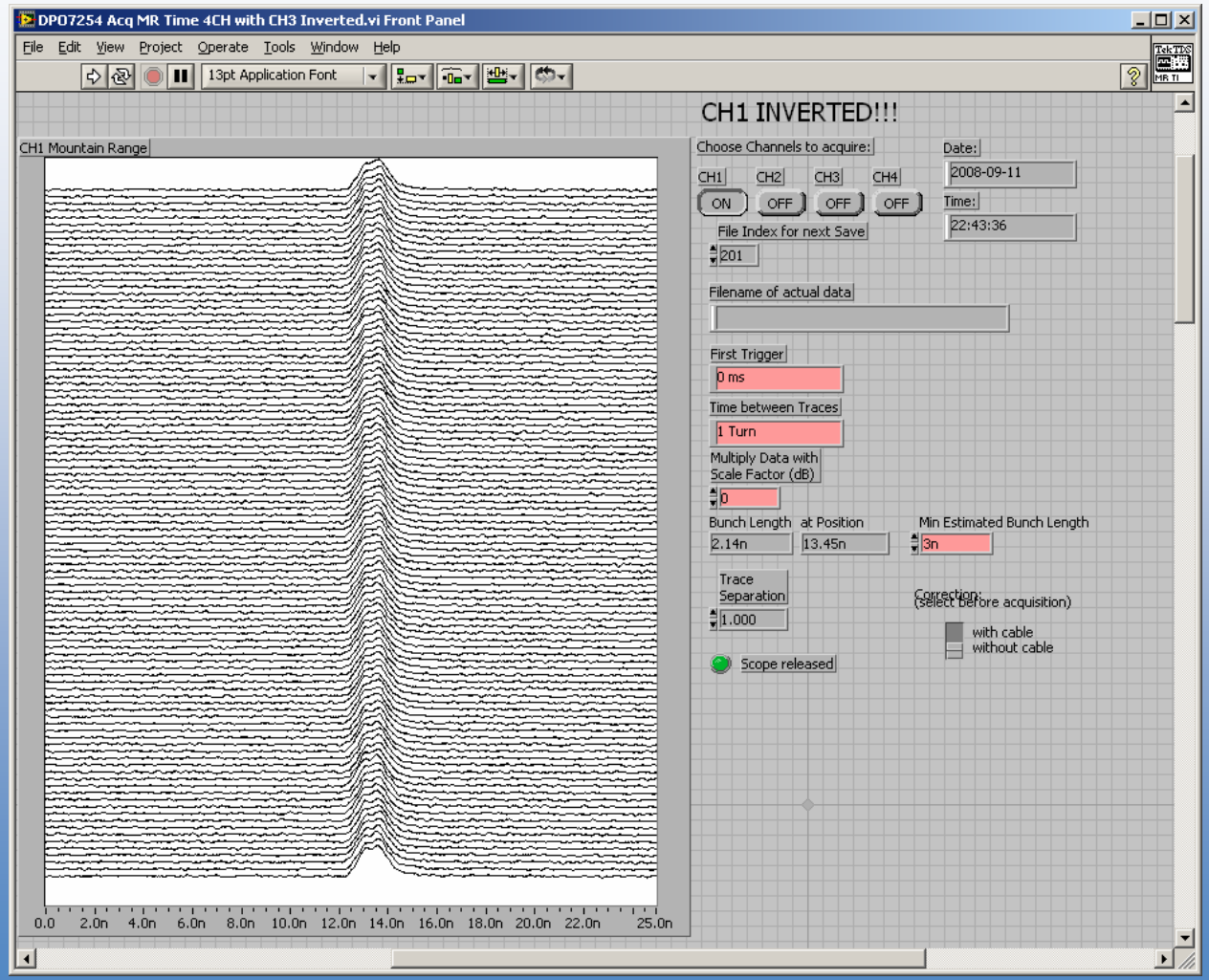
Courtesy E. Ciapala

Capture with corrected injection phasing



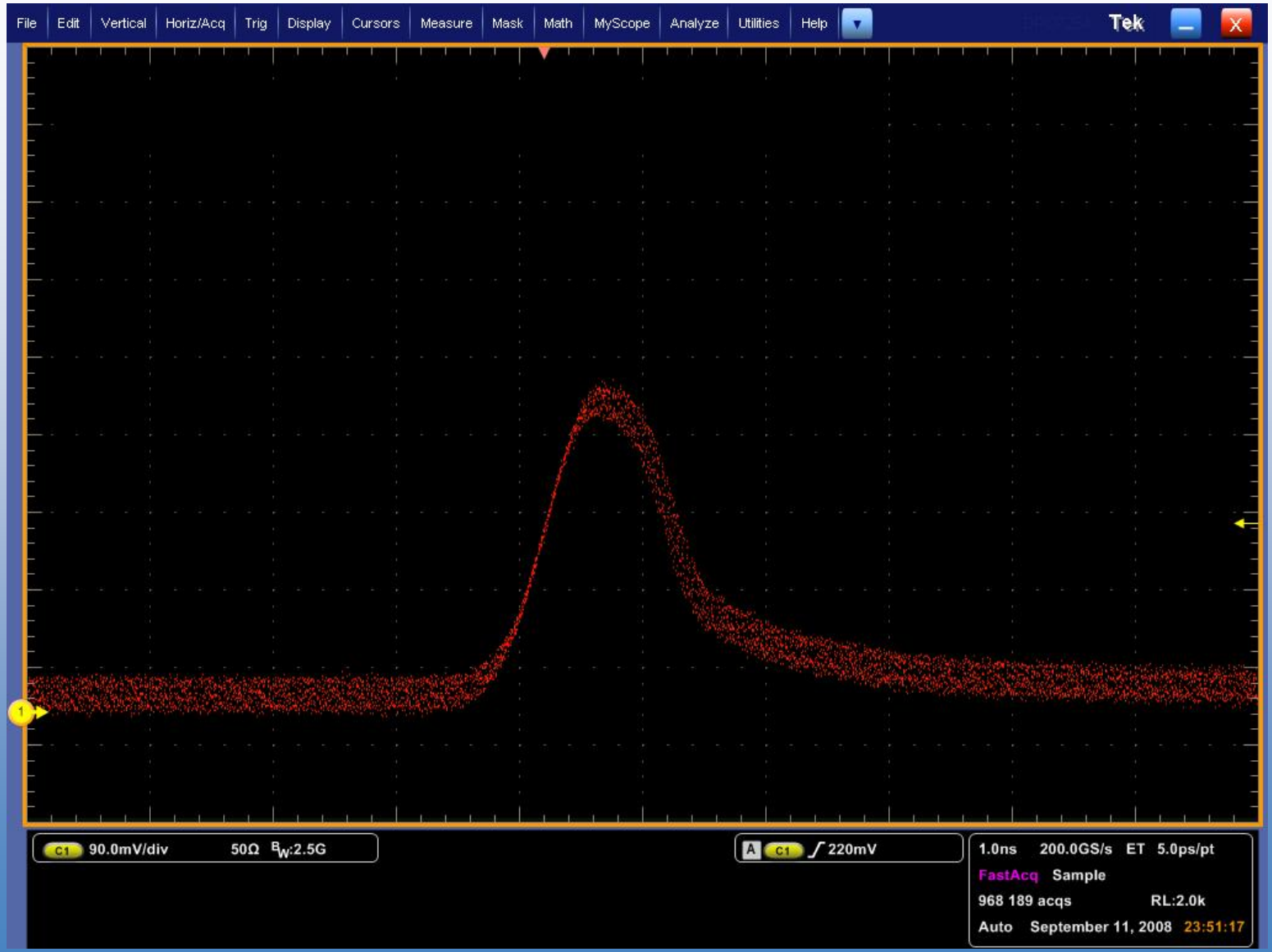
Courtesy E. Ciapala

Capture with optimum injection phasing, correct reference

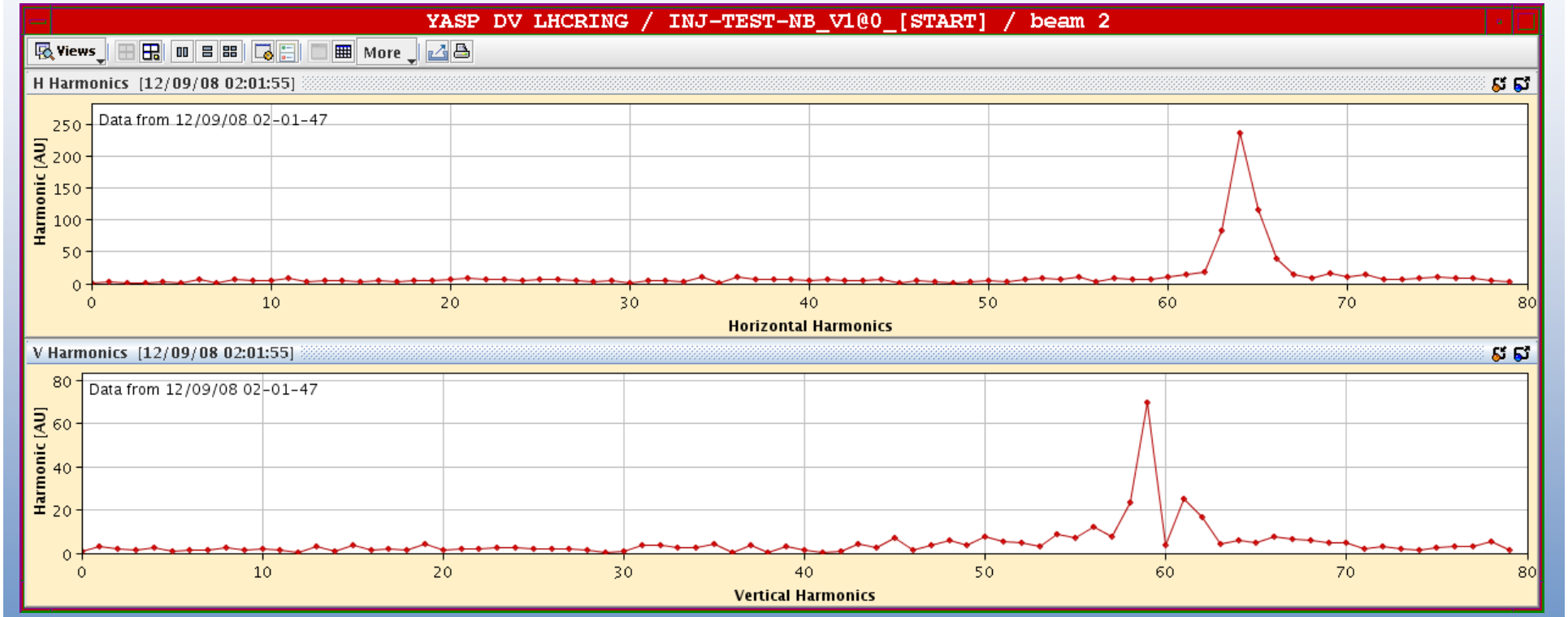


Courtesy E. Ciapala

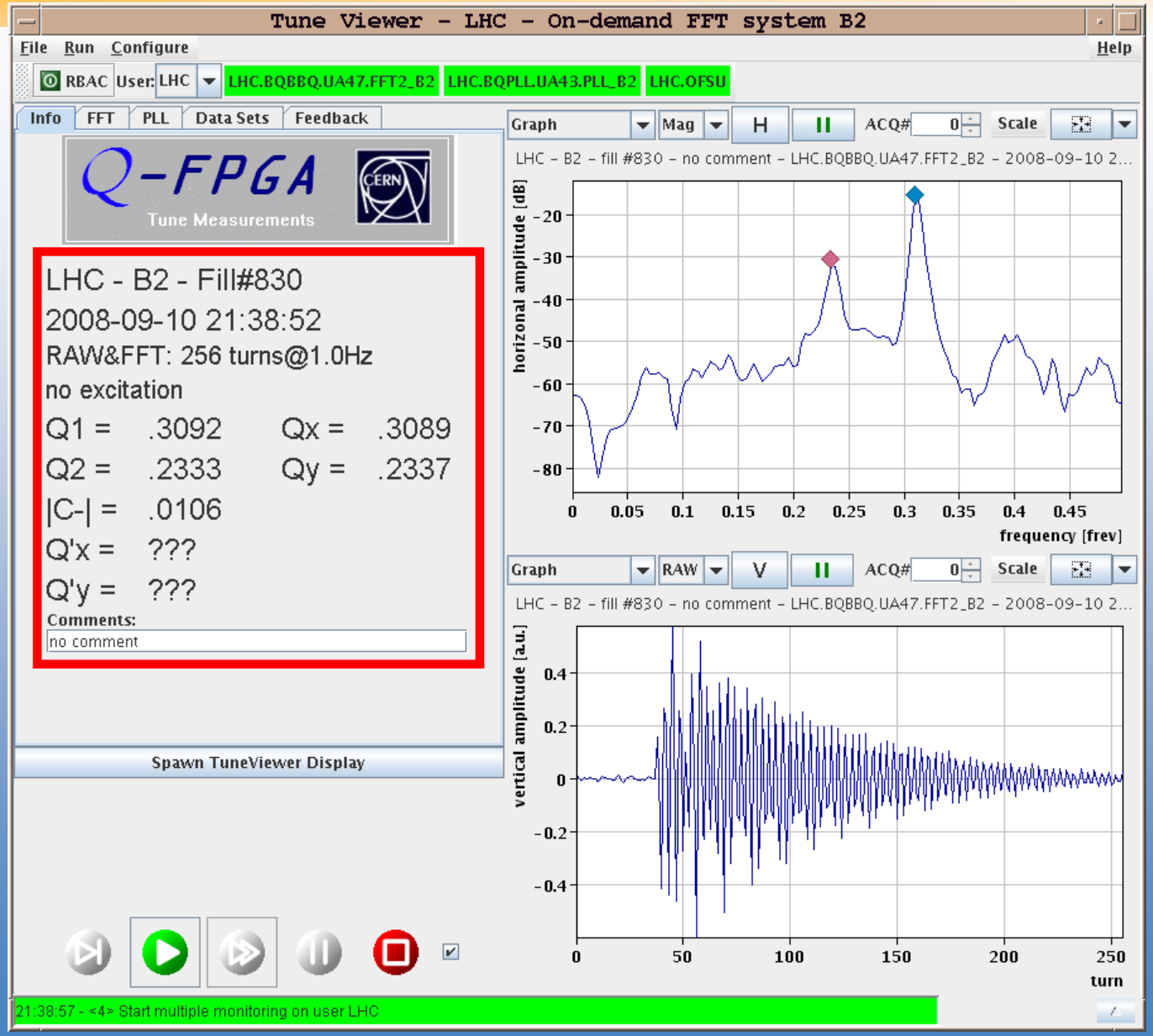
LHC longitudinal bunch profile Beam 2



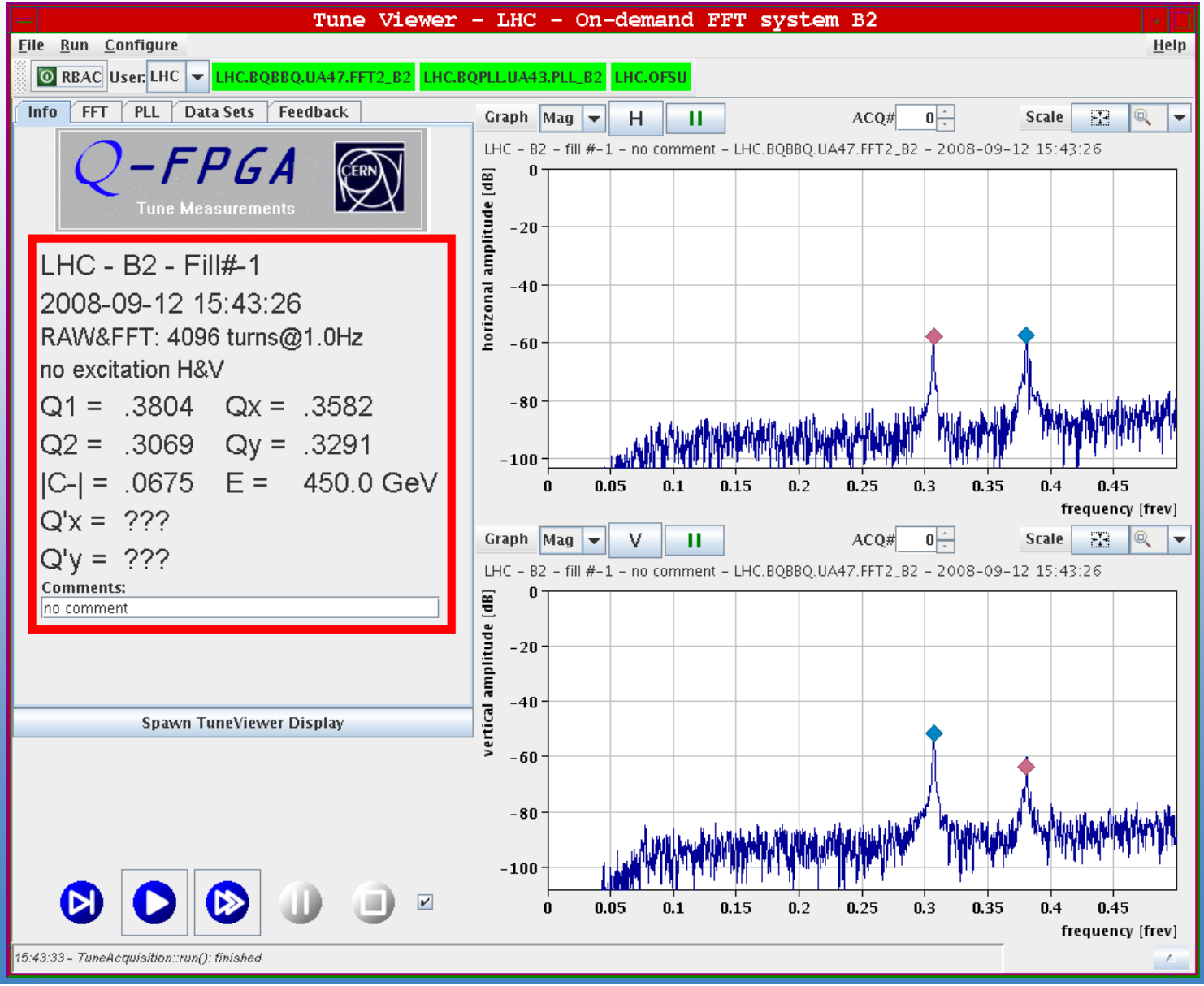
Integer tunes



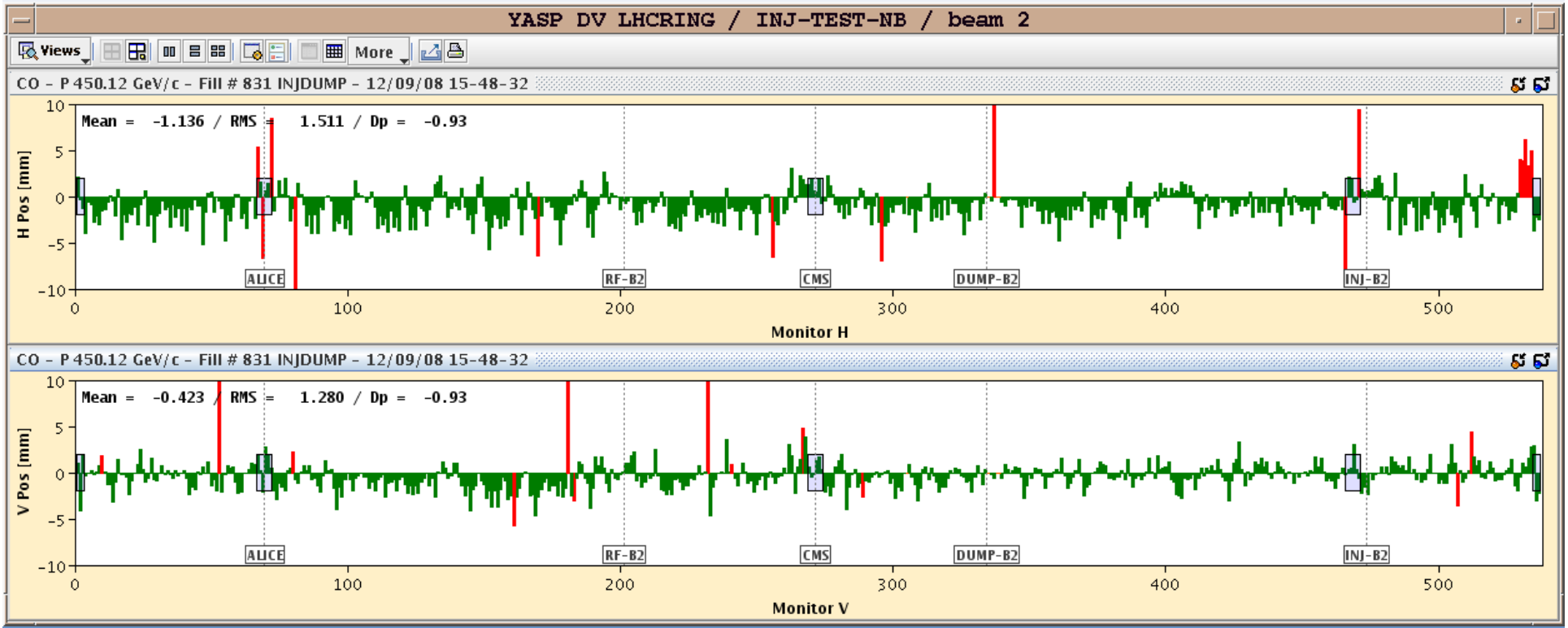
Tune measurements



Fractional tune spectrum H & V (Beam2) – closest Q approach ~ 0.06 due to coupling

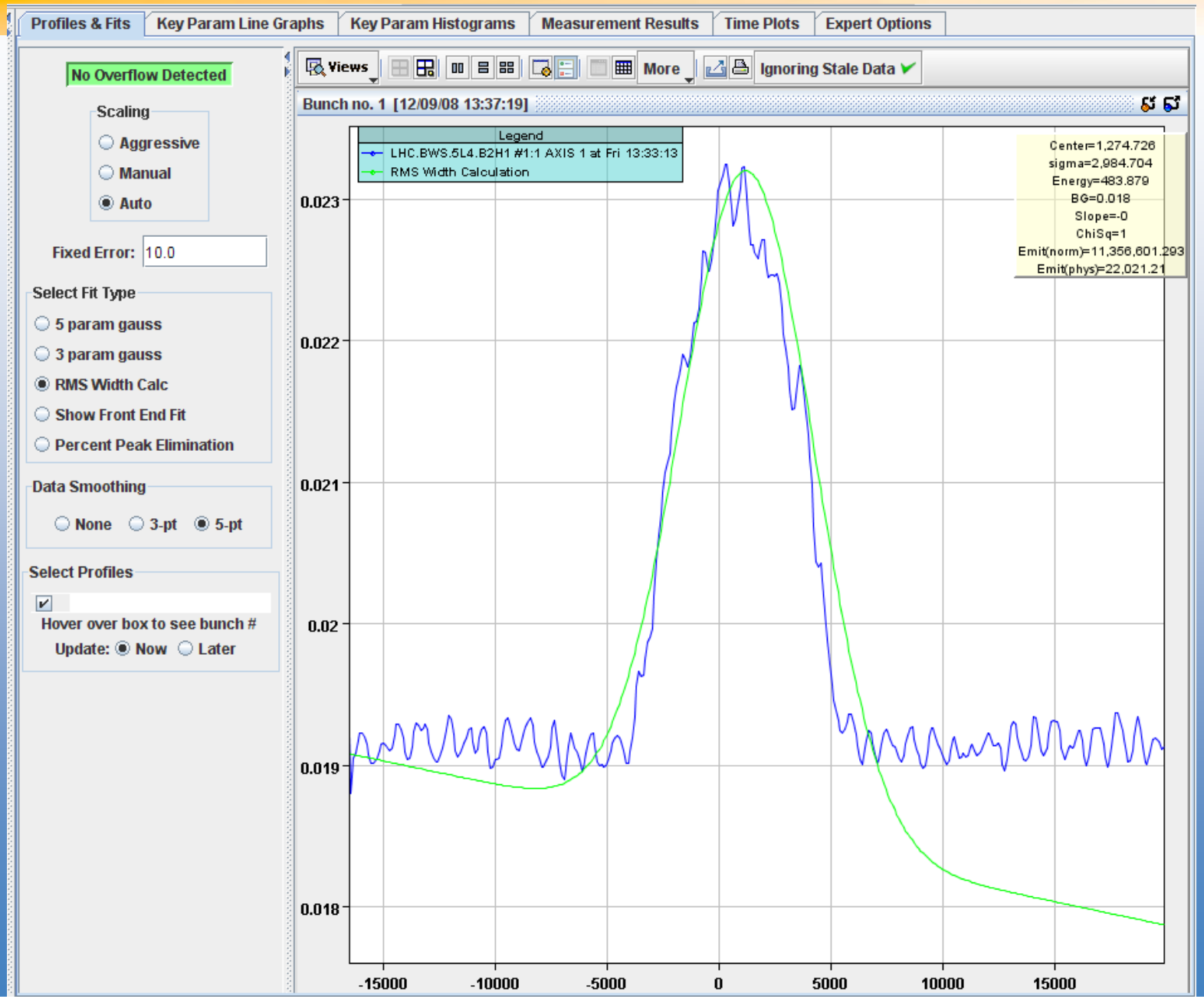


Corrected closed orbit on B2.
Energy offset of ~ -0.9 permill due to the capture frequency.

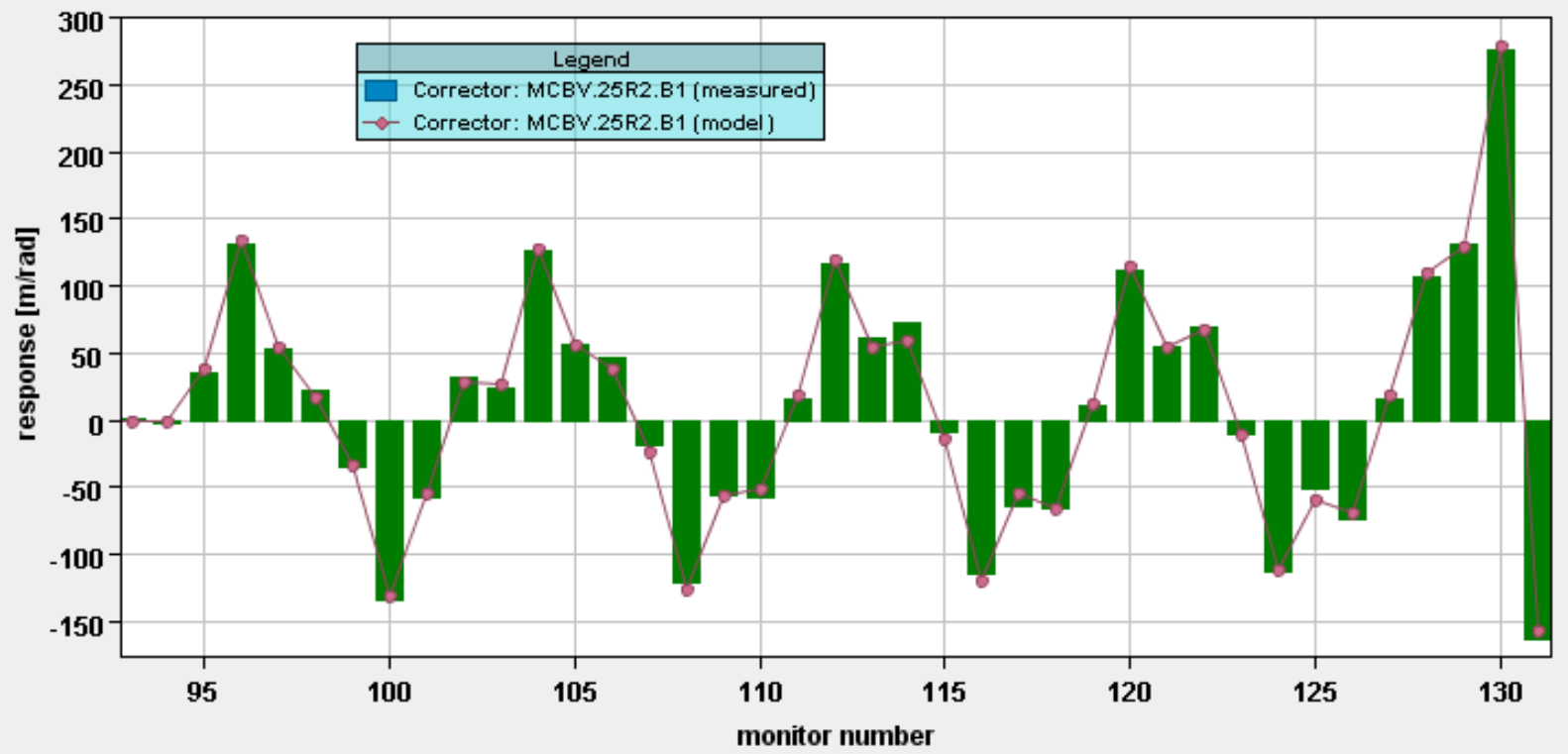


Courtesy J. Wenninger

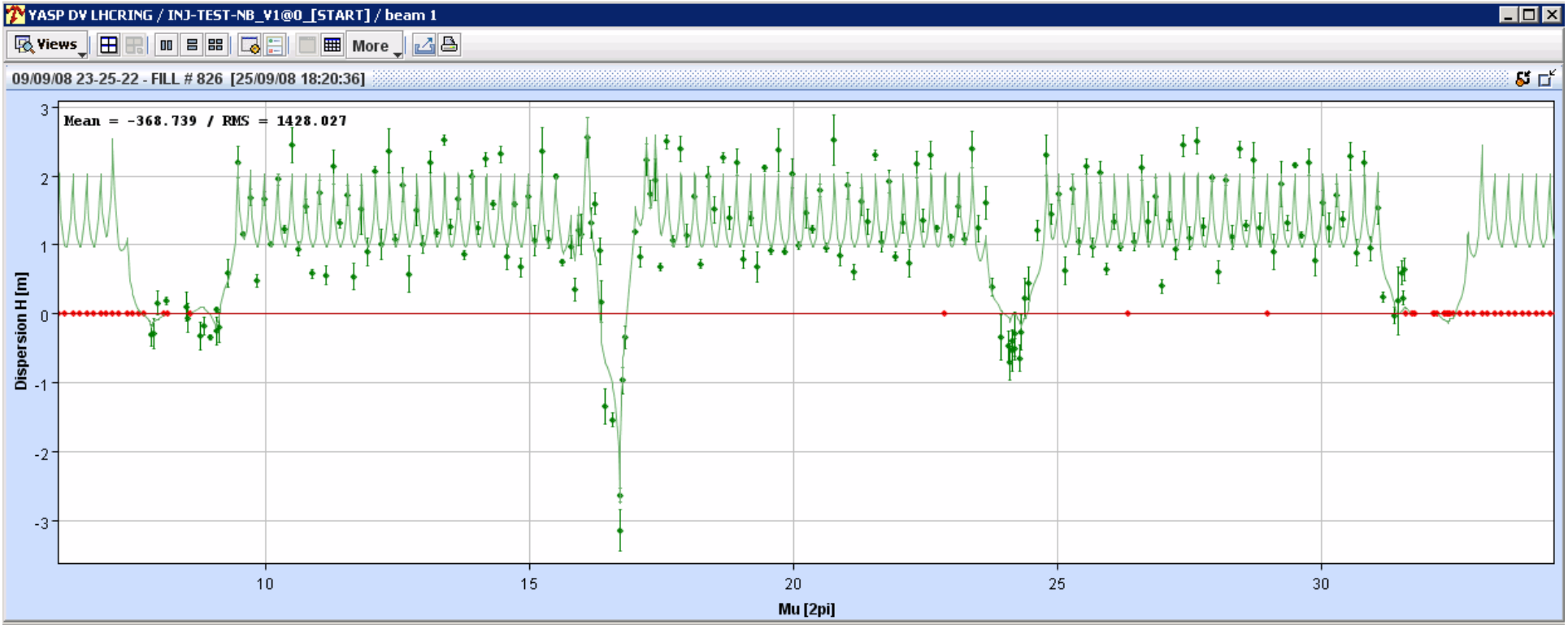
H wire scan


Profiles & Fits
Key Param Line Graphs
Key Param Histograms
Measurement Results
Time Plots
Expert Options
No Overflow Detected
Scaling
Aggressive
Manual
Auto
Fixed Error: 10.0
Select Fit Type
5 param gauss
3 param gauss
RMS Width Calc
Show Front End Fit
Percent Peak Elimination
Data Smoothing
None
3-pt
5-pt
Select Profiles
Hover over box to see bunch #
Update: Now Later
Views
More
Ignoring Stale Data
Bunch no. 1 [12/09/08 13:37:19]
Legend
LHC.BWS.5L4.B2H1 #1:1 AXIS 1 at Fri 13:33:13
RMS Width Calculation
Center=1,274.726
sigma=2,984.704
Energy=483.879
BG=0.018
Slope=-0
ChiSq=1
Emit(norm)=11,356,601.293
Emit(phys)=22,021.21
0.023
0.022
0.021
0.02
0.019
0.018
-15000
-10000
-5000
0
5000
10000
15000

Kick response compared with theoretical optics



Beam 1 H dispersion on first turn
Injection to beam dump



Courtesy J. Wenninger

Incident on 19th September

- During commissioning of the last main bend circuit to 5 TeV an incident occurred resulting in the triggering of quench heaters of about 100 magnets and a large He discharge into the tunnel.
- The most probable cause is a faulty electrical connection between two magnets. The sector is being brought to room temperature for repair.
- The time needed for warmup, repair and cooldown precludes a restart before CERN's obligatory winter shutdown.
- The shutdown schedule is being modified to gain ~ 1 month of LHC operation in 2009.

Incident during powering

The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008. For the main dipole circuit, this meant a powering in stages up to a current of 9.3 kA. The dipole circuit of sector 3-4, the last one to be commissioned, had only been powered to 7 kA prior to 10 September 2008. After the successful injection and circulation of the first beams at 0.45 TeV, commissioning of this sector up to the 5.5 TeV beam energy level was resumed as planned and according to established procedures.

On 19 September 2008 morning, the current was being ramped up to 9.3 kA in the main dipole circuit at the nominal rate of 10 A/s, when at a value of 8.7 kA, a resistive zone developed in the electrical bus in the region between dipole C24 and quadrupole Q24. The first evidence was the appearance of a voltage of 300 mV detected in the circuit above the noise level: the time was 11:18:36 CEST. No resistive voltage appeared on the dipoles of the circuit, individually equipped with quench detectors with a detection sensitivity of 100 mV each, so that the quench of any magnet can be excluded as initial event. After 0.39 s, the resistive voltage had grown to 1 V and the power converter, unable to maintain the current ramp, tripped off at 0.46 s (slow discharge mode). The current started to decrease in the circuit and at 0.86 s, the energy discharge switch opened, inserting dump resistors in the circuit to produce a fast power abort. In this sequence of events, the quench detection, power converter and energy discharge systems behaved as expected.

Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the “jumper” connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.

Inspection and diagnostics

The number of magnets to be repaired is at maximum of 5 quadrupoles (in Short Straight Sections) and 24 dipoles, but it is likely that more will have to be removed from the tunnel for cleaning and exchange of multilayer insulation. The exact numbers will be known once the ongoing inspections are completed. Spare magnets and spare components appear to be available in adequate types and sufficient quantities for allowing replacement of the damaged ones during the forthcoming shutdown. The extent of contamination to the beam vacuum pipes is not yet fully mapped, but known to be limited; in situ cleaning is being considered to keep to a minimum the number of magnets to be removed. The plan for removing/reinstallation, transport and repair of magnets in sector 3-4 is being established and integrated with the maintenance and consolidation work to be performed during the winter shutdown. The corresponding manpower resources have been secured.

Preliminary recommendations

Recommendations made by the task force aim at two different goals, namely to prevent any other occurrence of this type of initial event, and to mitigate its consequences should it however reproduce accidentally. Possible precursors of the incident in sector 3-4 are being scrutinized in the electrical and calorimetric data recorded on all sectors, in order to spot any other problem of the same nature in the machine. An improvement of the quench detection system is under way, to generate both early warnings and interlocks, and to encompass magnets, bus bars and interconnects. The relief devices on the cryostat vacuum vessels will be increased in discharge capacity and in number, so as to contain a possible pressure rise to below 0.15 MPa absolute even in presence of an electrical arc. The external anchoring of the cryostats at the locations of the vacuum barriers will be reinforced to guarantee mechanical stability. The personnel access rules during powering will also be reexamined, to further exclude human presence not only in the machine tunnel, but also in the neighboring caverns and technical areas underground.