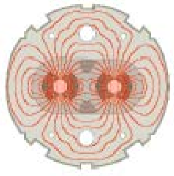


The LHC : Performance and Plans

BLOIS 2010

Lucio Rossi

Magnet and Superconductor Group Leader

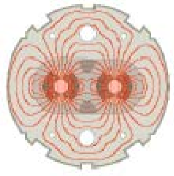
CERN Geneva

Topics

- The LHC(reminder)
- The last 18 months (rapidly)
  - The Accident, Repair and Consolidation
  - Initial Commissioning with Beam
- Plans
  - Near future (2010-2011)
  - Medium future (2012-16) Nominal LHC
  - Far future (2014-2020?) HL-LHC
  - Very far future (2030??) HE-LHC

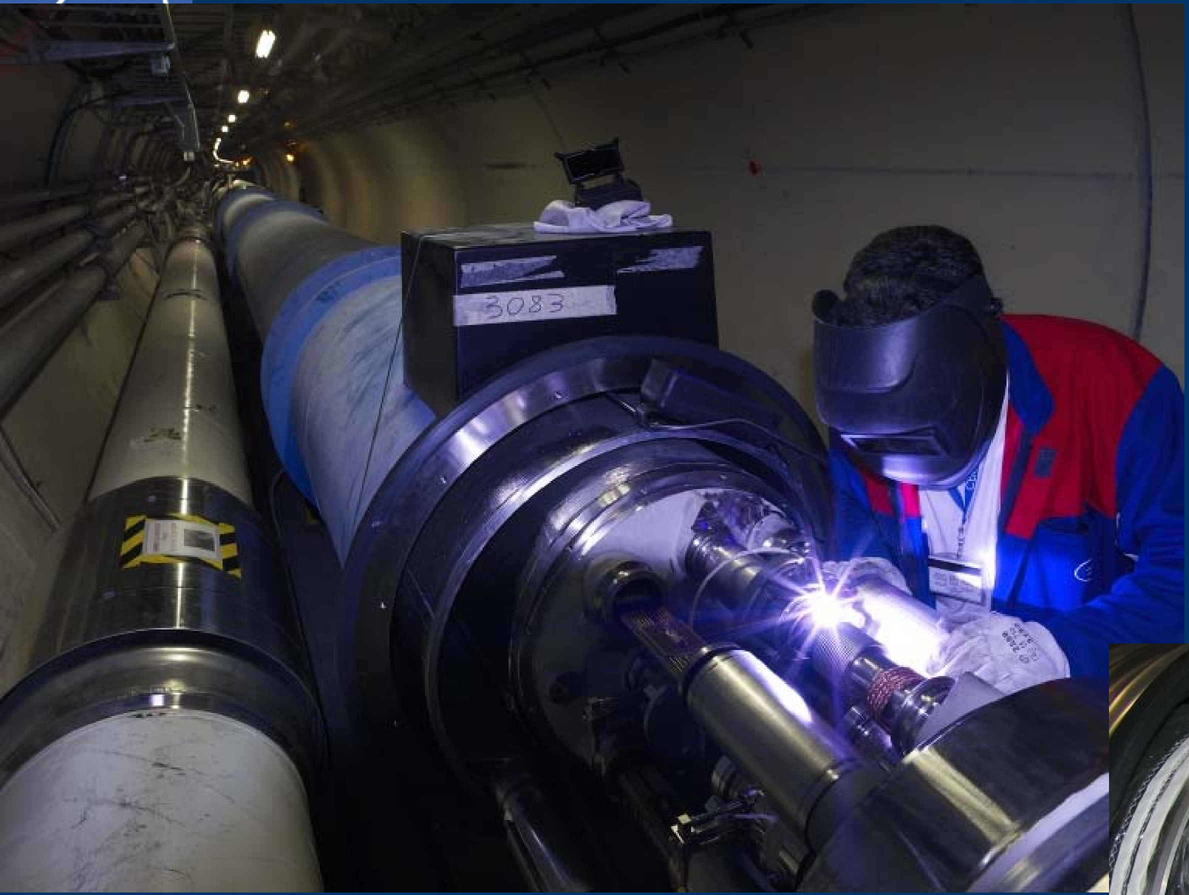
Superconducting Proton Accelerator and Collider
installed in a 27km circumference underground tunnel (tunnel cross-section diameter 4m) at CERN
Tunnel was built for LEP collider in 1985

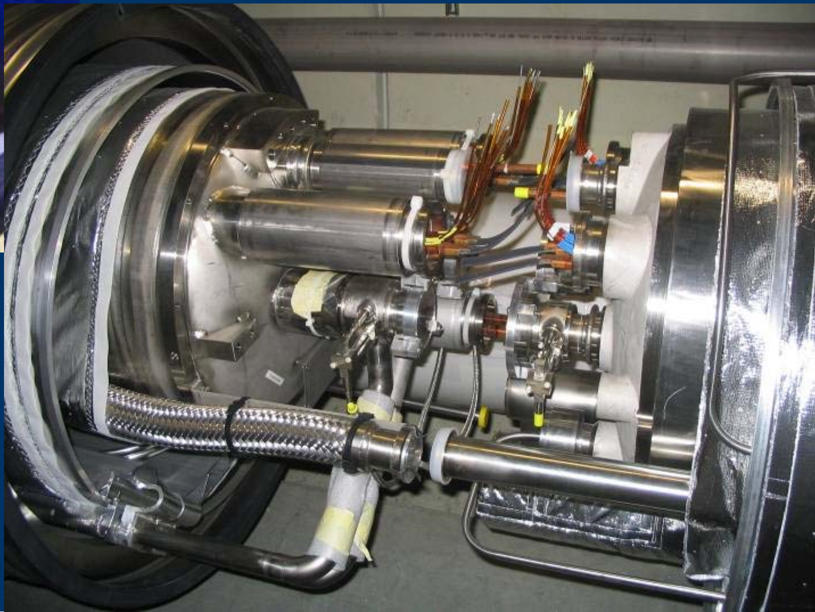
LHC: Some Technical Challenges



Circumference (km)	26.7	100-150m underground
Number of superconducting twin-bore Dipoles	1232	Cable Nb-Ti, cold mass 37million kg
Length of Dipole (m)	14.3	
Dipole Field Strength (Tesla)	8.3	Results from the high beam energy needed
Operating Temperature (K) (cryogenics system)	1.9	Superconducting magnets needed for the high magnetic field Super-fluid helium
Current in dipole sc coils (A)	11850	Results from the high magnetic field 1ppm resolution
Beam Intensity (A)	0.5	$2.2.10^{-6}$ loss causes quench
Beam Stored Energy (MJoules)	362	Results from high beam energy and high beam current 1MJ melts 1.5kg Cu
Magnet Stored Energy (MJoules)/octant	1100	Results from the high magnetic field
Sector Powering Circuit	8	1612 different electrical circuits

Interconnections





During cool-down of the LHC the machine contracts by 80 metres, 10m per octant

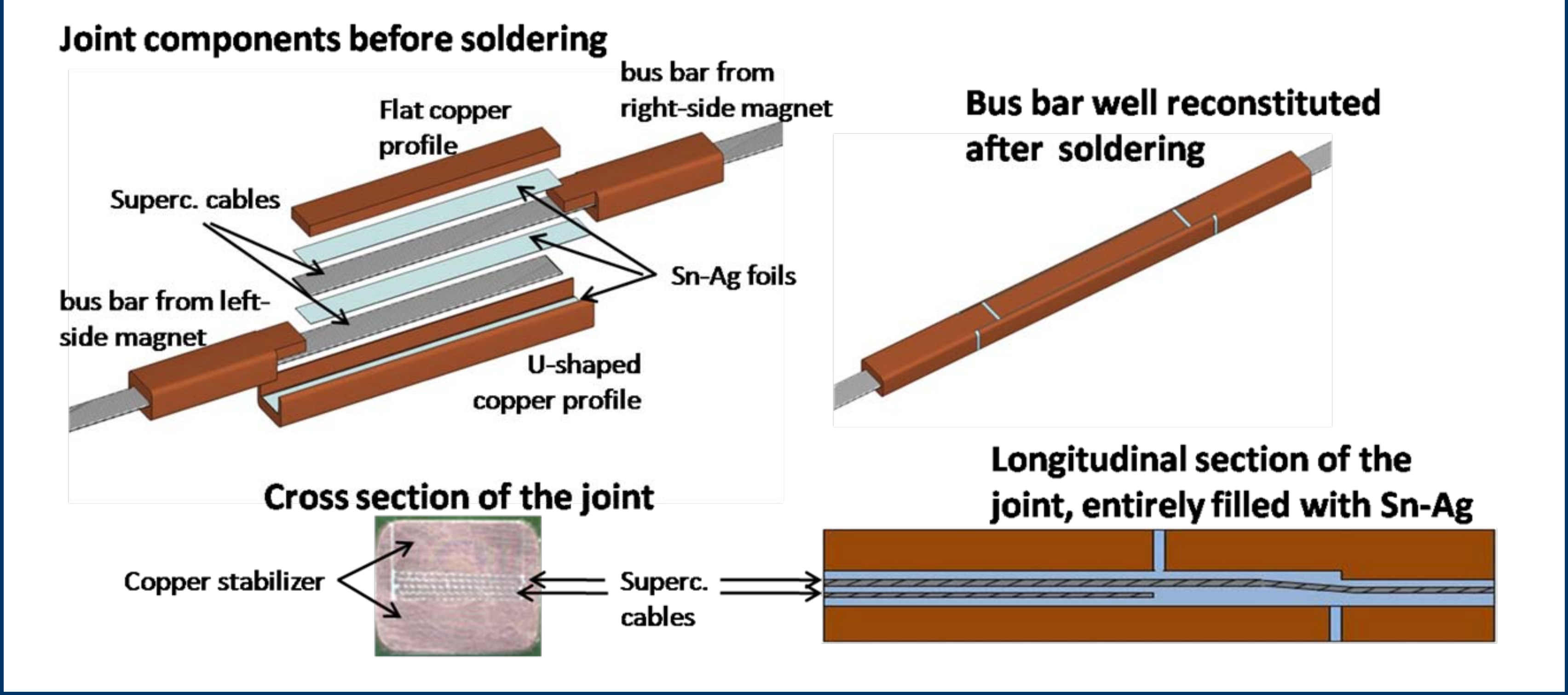
- Vacuum continuity
- Electrical connections

Accident of September 19th 2008

- Following a very impressive start-up with beam on September 10, 2008

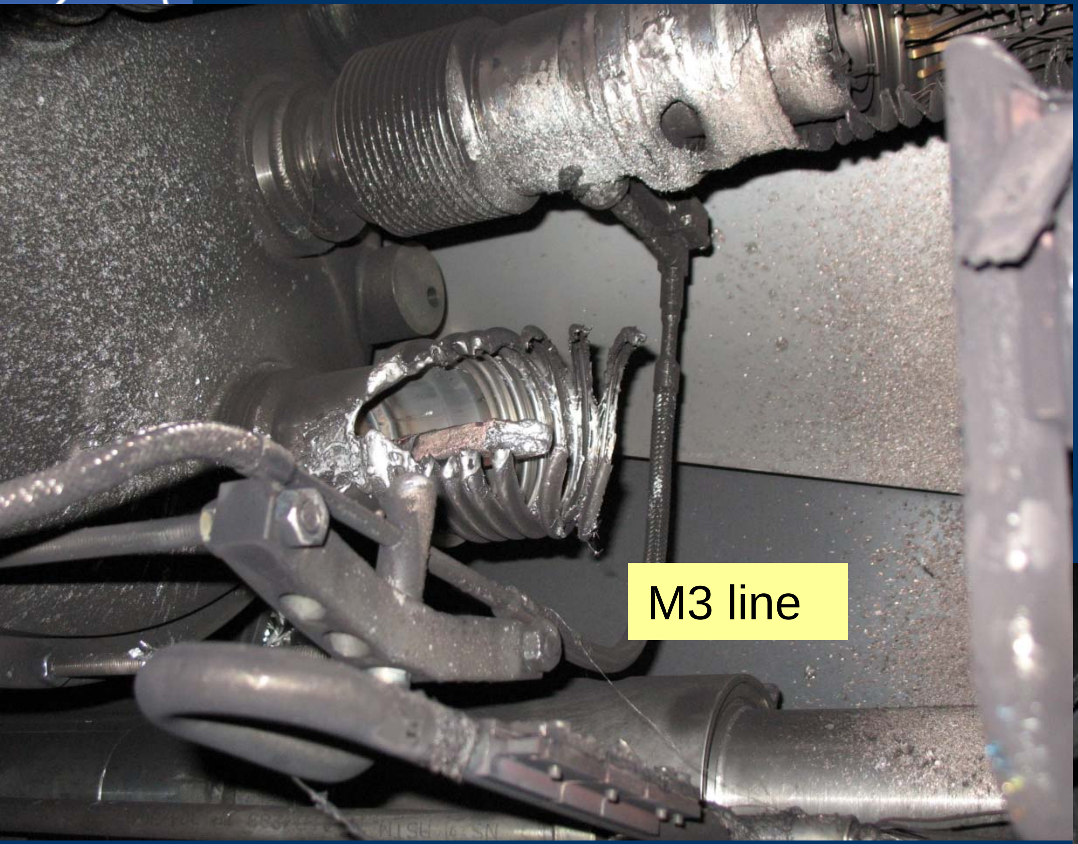
  - During a few days period without beam
  - Making the last step of dipole circuit in sector 34, to 9.3kA
  - At 8.7kA, development of resistive zone in the dipole bus bar splice between Q24 R3 and the neighbouring dipole
  - Electrical arc developed which punctured the helium enclosure

Bus bar splice



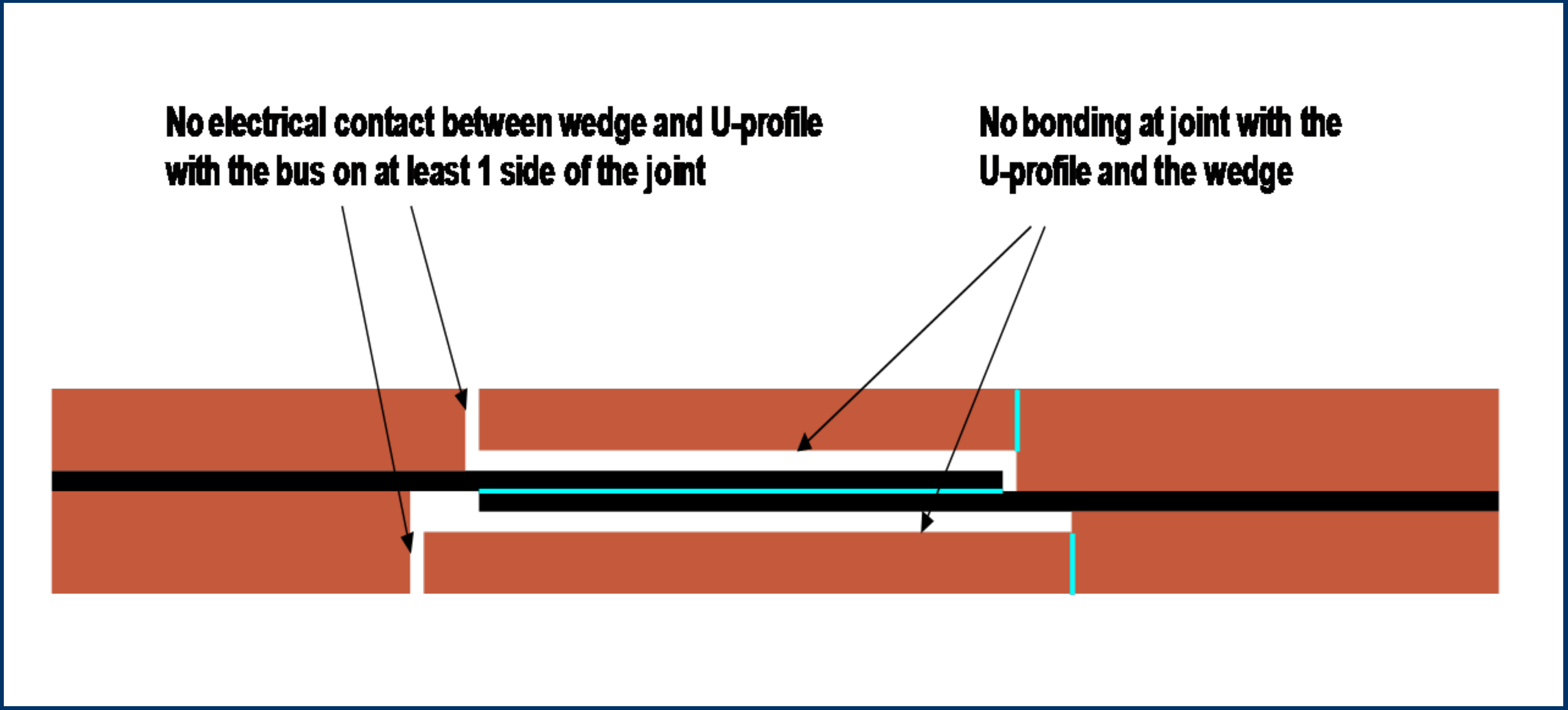
Consequences

Electrical arc between C24 and Q24



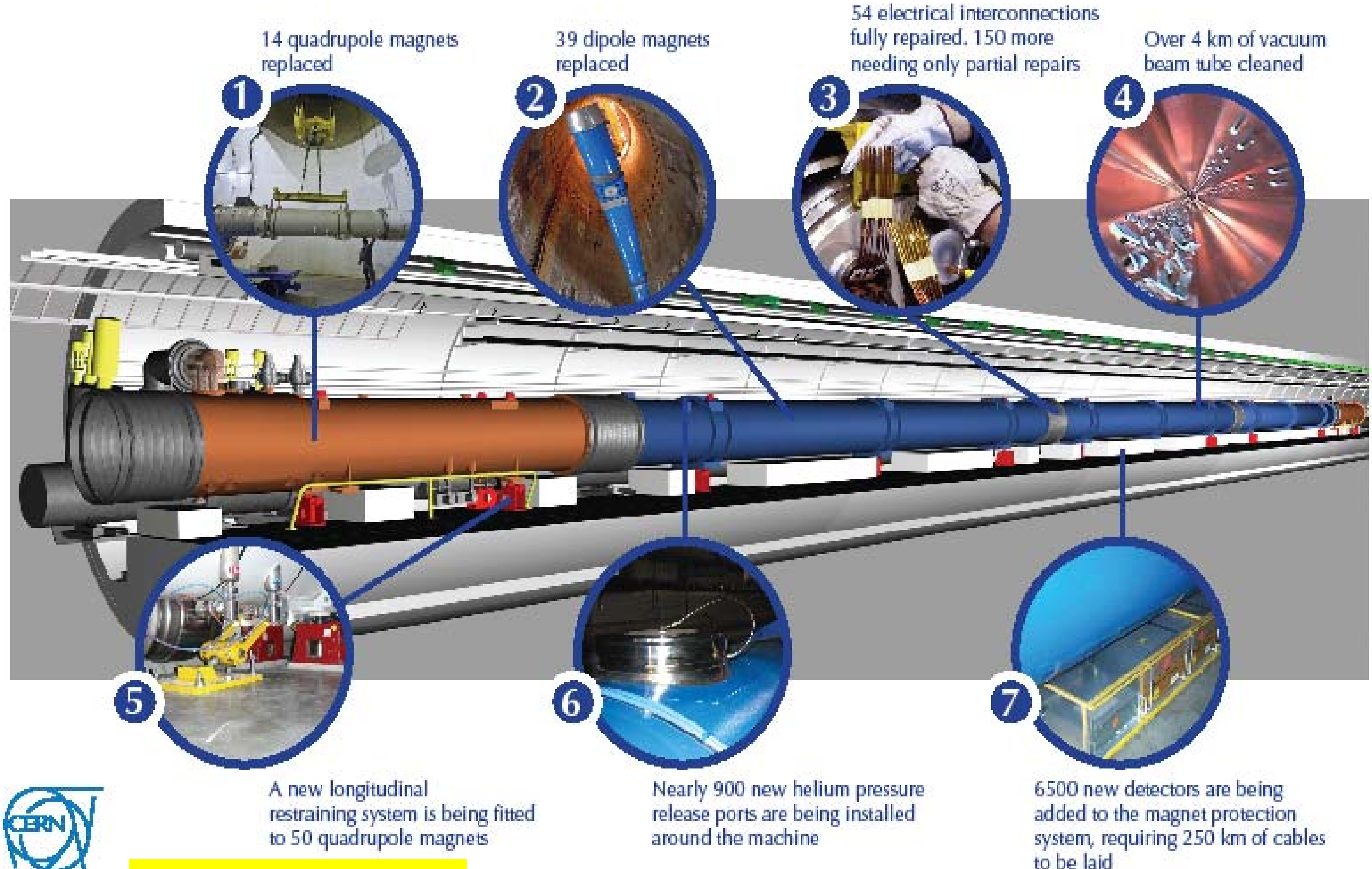
V lines

The cause (bad splice)

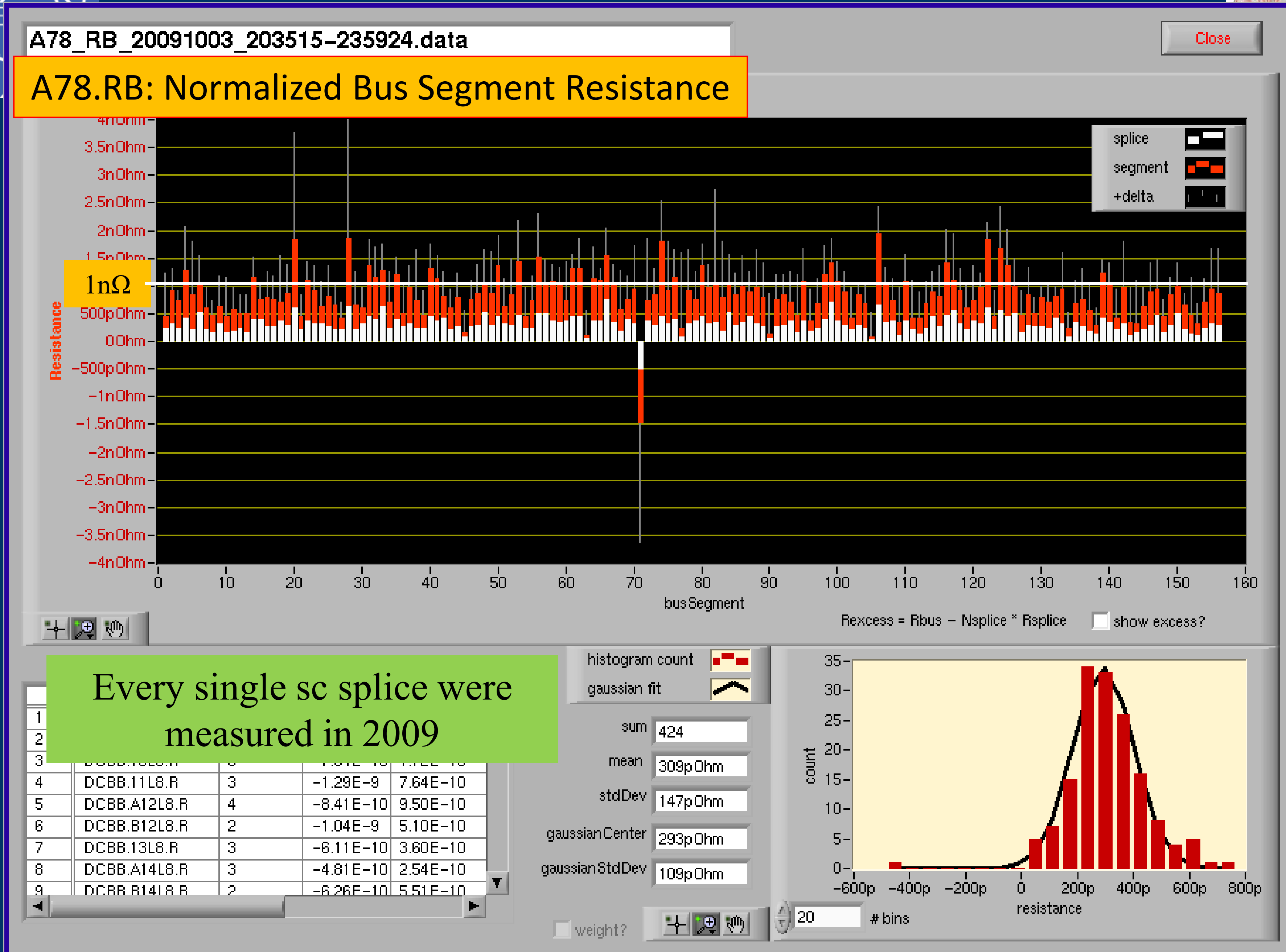


Phase 1 +2

The LHC repairs in detail



\+ 8 cryogenics!



A78_RB_20091003_203515-235924.data
Close
A78.RB: Normalized Bus Segment Resistance
1nΩ
Resistance
3.5nOhm
3nOhm
2.5nOhm
2nOhm
500pOhm
0Ohm
-500pOhm
-1nOhm
-1.5nOhm
-2nOhm
-2.5nOhm
-3nOhm
-3.5nOhm
-4nOhm
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
busSegment
splice
segment
+delta
Rexcess = Rbus - Nsplice * Rsplice
show excess?
Every single sc splice were measured in 2009
4 DCBB.11L8.R 3 -1.29E-9 7.64E-10
5 DCBB.A12L8.R 4 -8.41E-10 9.50E-10
6 DCBB.B12L8.R 2 -1.04E-9 5.10E-10
7 DCBB.13L8.R 3 -6.11E-10 3.60E-10
8 DCBB.A14L8.R 3 -4.81E-10 2.54E-10
histogram count
gaussian fit
sum 424
mean 309pOhm
stdDev 147pOhm
gaussianCenter 293pOhm
gaussianStdDev 109pOhm
weight?
count
35 30 25 20 15 10 5 0
-600p -400p -200p 0 200p 400p 600p 800p
resistance
20 # bins

The near future: Decided Scenario 2010-2011

- Run at 3.5 TeV/beam up to a integrated luminosity of around $1fb^{-1}$.
- Then consolidate the whole machine for 7TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

Why are we limiting the beam energy to 3.5TeV in 2010-2011?

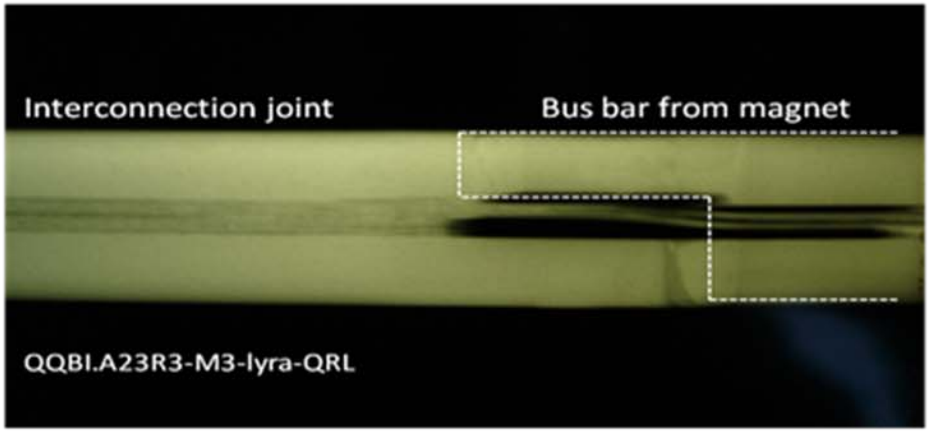
All the work we have done since November 2008 makes us certain that a repeat of September 19 can NEVER happen.

The offending connector in this incident had an estimated resistance of 220nΩ. We have measured all 10,000 inter-magnet connectors and the maximum resistance we have seen is 2.8nΩ.

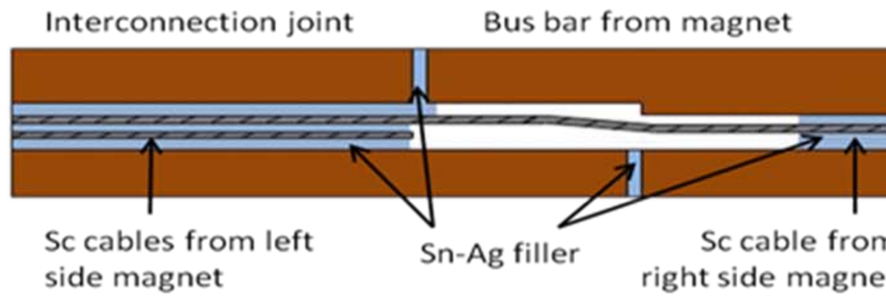
BUT in April 2009, we have uncovered a different possible failure scenario which could under certain circumstances produce again a thermal runaway in the magnet interconnects:

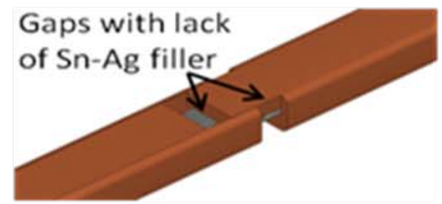
The lack of continuity in the stabilizer

This is much more subtle enemy



Defective interconnetion-bus bar transition
γ-ray picture (left) and scheme (right)





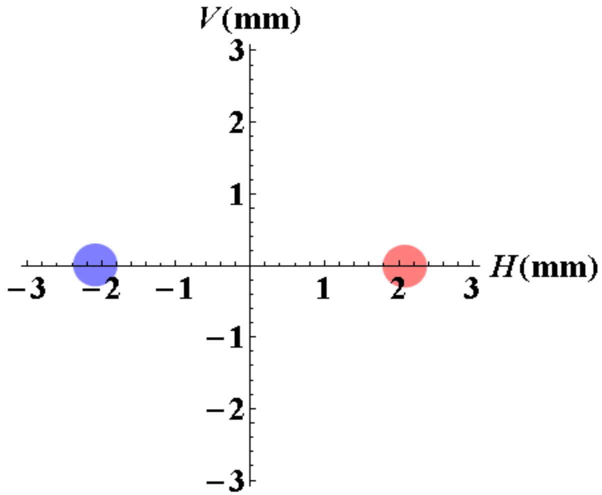
A joint between bus bar can quench even if the splice is well done.
When a magnet quenches, the warm helium wave makes the SS cable in the joint to quench in about 10-20 s. Since the decay time of the current is 104 s in the bas bar (and so in the joint) , cable will becomem resitive and the stabilizing copper is there just to avoid overheating by diluting the current density.
If the curren thas to pass through the SC cable only, above e certain lenght it burns. We know we have thsis situation: then we limit the dipole current to 6 kA (4.2 T → 3.5 TeV/beam)

First Collisions at 7TeV cm
March 30, 2010

March 30 2010

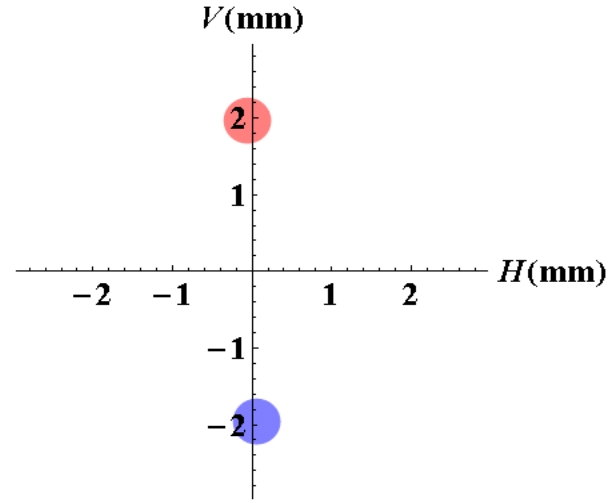
ATLAS IP Separation

H = 4.173 mm : V = 0.035 mm

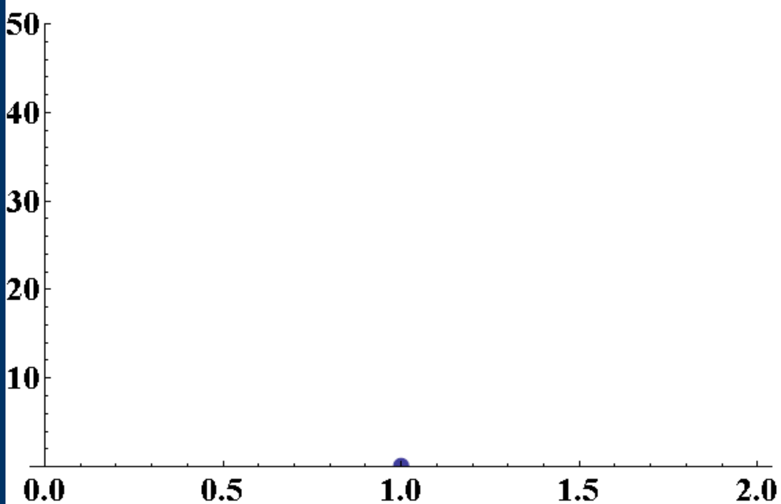


CMS IP Separation

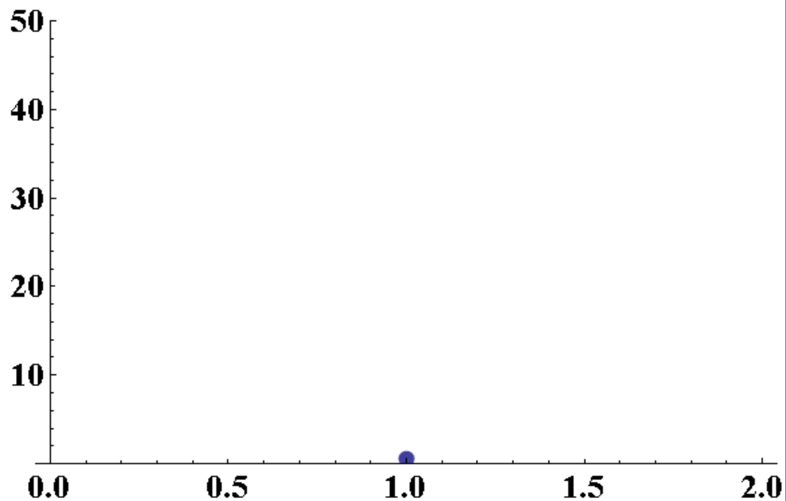
H = 0.130 mm : V = 3.925 mm



ATLAS Coll Rate Evol



CMS Coll Rate Evol



30/3/2010

11:15 injected again
12:38 : At 3.5 TeV

OP Vistars - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://op-webtools.web.cern.ch/op-webtools/vistar/vistars.php?usr=LHC1

Most Visited | Scientific Linux CERN | CERN IT Departme... | CERN Home Page | Linux distributions

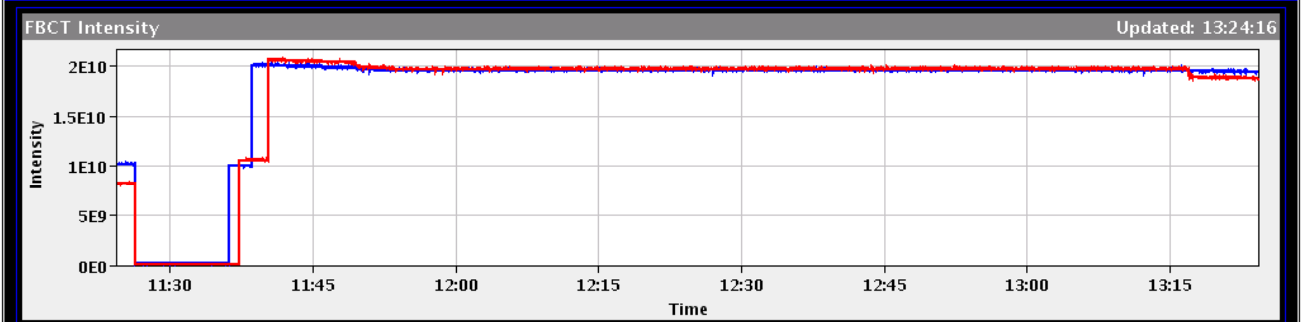
CERN - AB - OP eLogbook - Vi... | CERN - AB - OP eLogbook - Vi... | CERN - AB - OP eLogbook - Vi... | CERN - AB - OP eLogbook - Vi... | OP Vistars

LHC1 — OP Vistars

LHC Page1	Fill: 1005	E: 3500 GeV	30-03-2010 13:24:16

PROTON PHYSICS: STABLE BEAMS

Energy:	3500 GeV	I(B1):	1.88e+10	I(B2):	1.68e+10



Comments 30-03-2010 13:22:57 :

Stable beams!

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	true	true
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

LHC Operation in CCC : 77600, 70480 — PM Status B1 ENABLED — PM Status B2 ENABLED

Done

Soon after the first Collisions

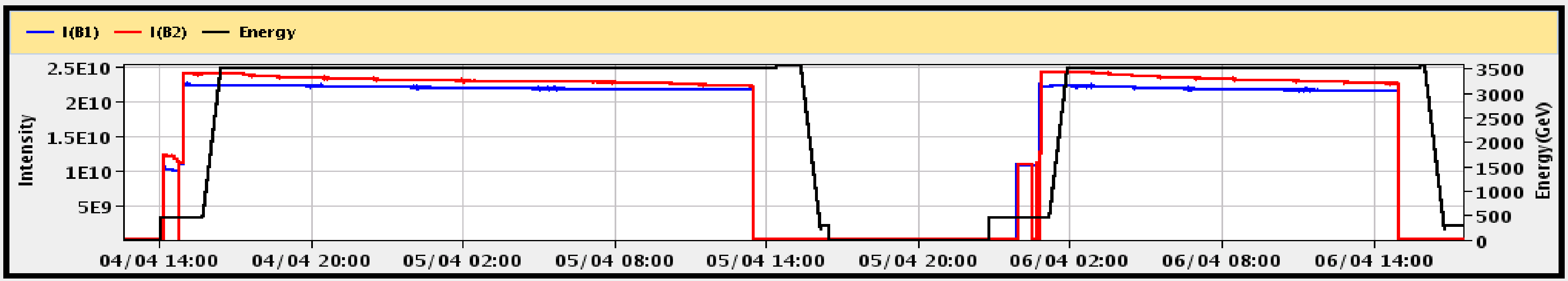
A very good 48 hour period!

06-Apr-2010 17:27:13 Fill #: 1023 Energy: 297.4 GeV I(B1): 1.55e+08 I(B2): 7.01e+07

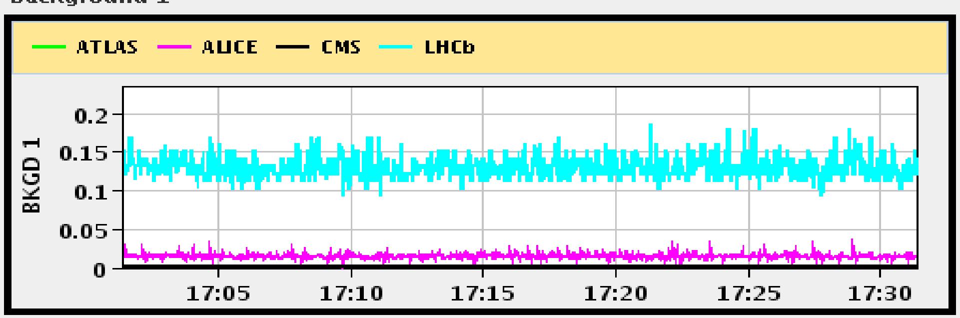
	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	NOT READY	STANDBY	STANDBY
Instantaneous Luminosity	0.000e+00	0.000e+00	0.000e+00	8.989e-04
BRAN Count Rate	3.229e-07	4.059e-32	2.086e-11	1.635e-32
BKGD 1	0.002	0.014	0.002	0.131
BKGD 2	0.000	0.000	0.002	0.002
BKGD 3	0.000	0.005	0.003	0.037

LHCf STANDBY Count(Hz): 0.000 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: CALIBRATION

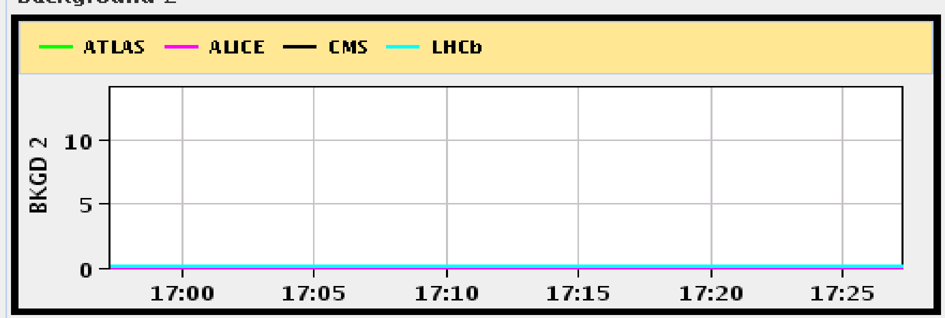
Performance over the last 12 Hrs



Background 1

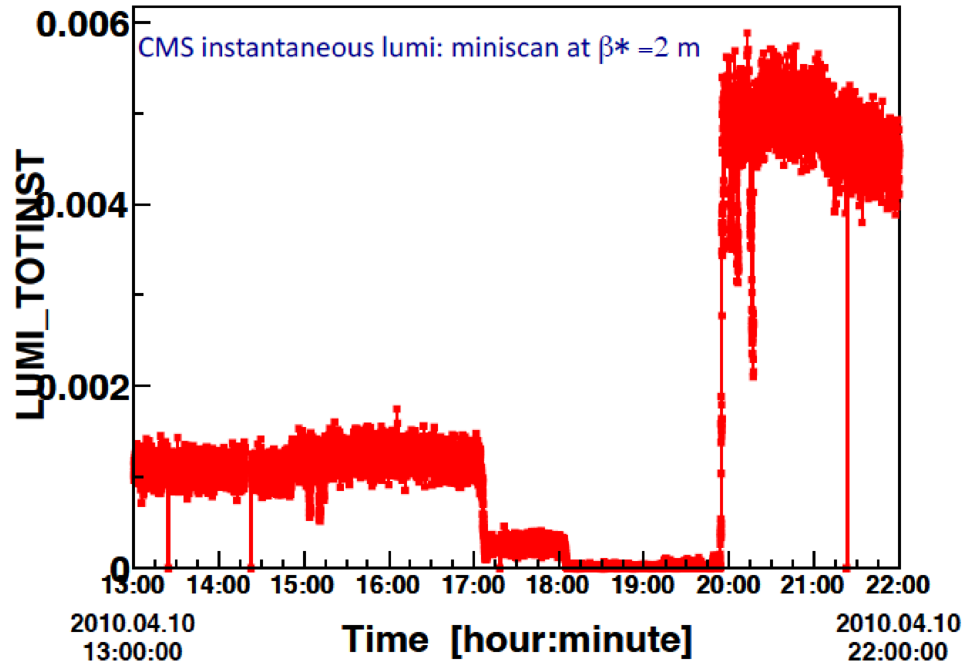


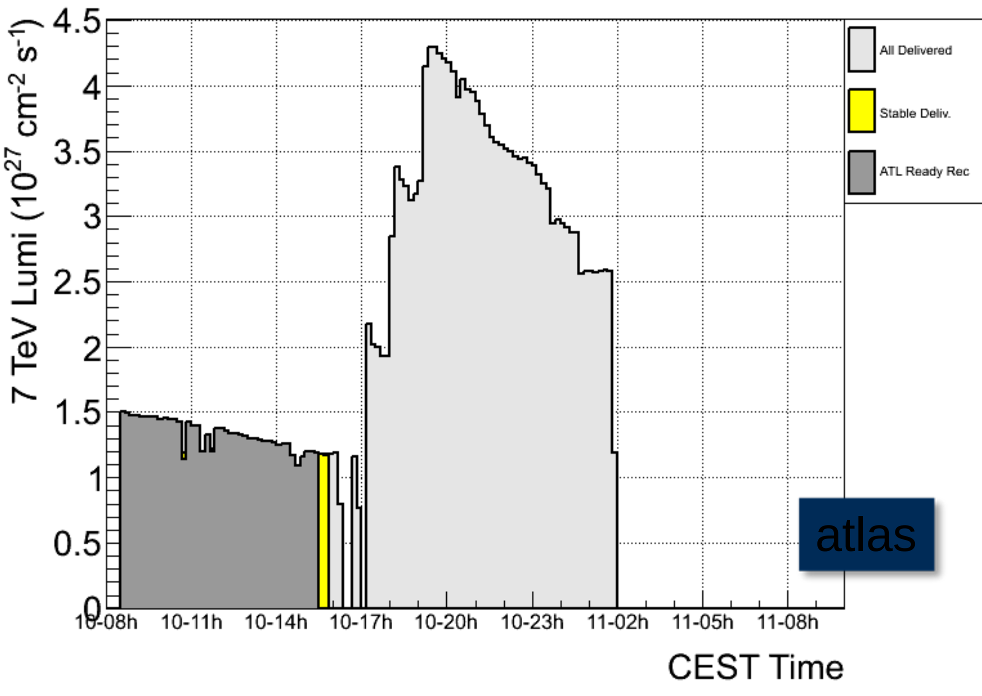
Background 2



IP1&5 lumi vs squeeze

- Raw (online) lumi plots on 10 apr 2010, during the squeeze to 2m in IP1 and IP5
- Factor gained (raw numbers):
  - ~4.5 in Pt5 (after min scan)
  - ~4 in Pt1
- Not corrected for lumi decay over the ~5h of squeeze and mini scans



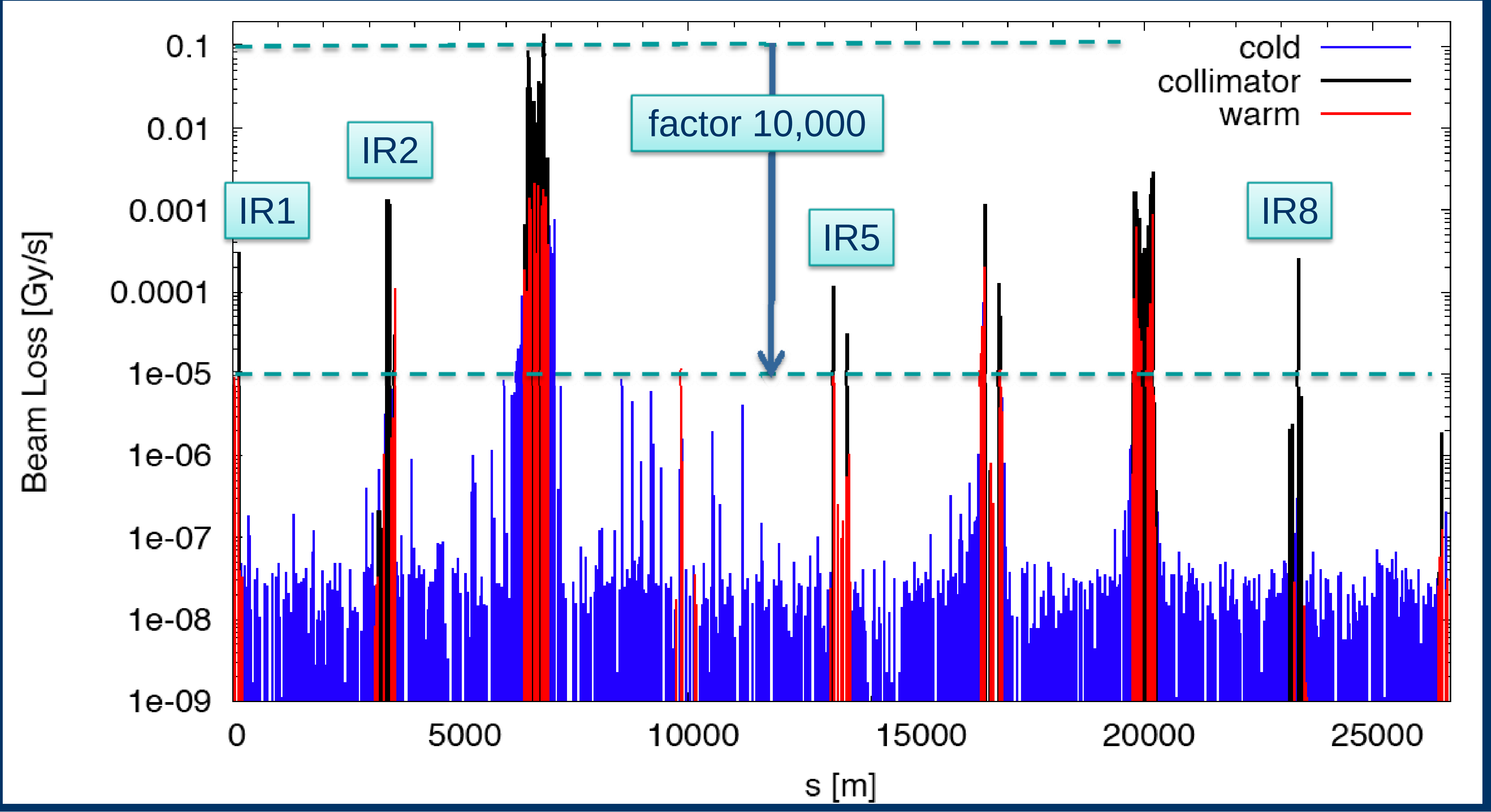


LHC Design Bunch Intensity: Thursday 15.4.2010

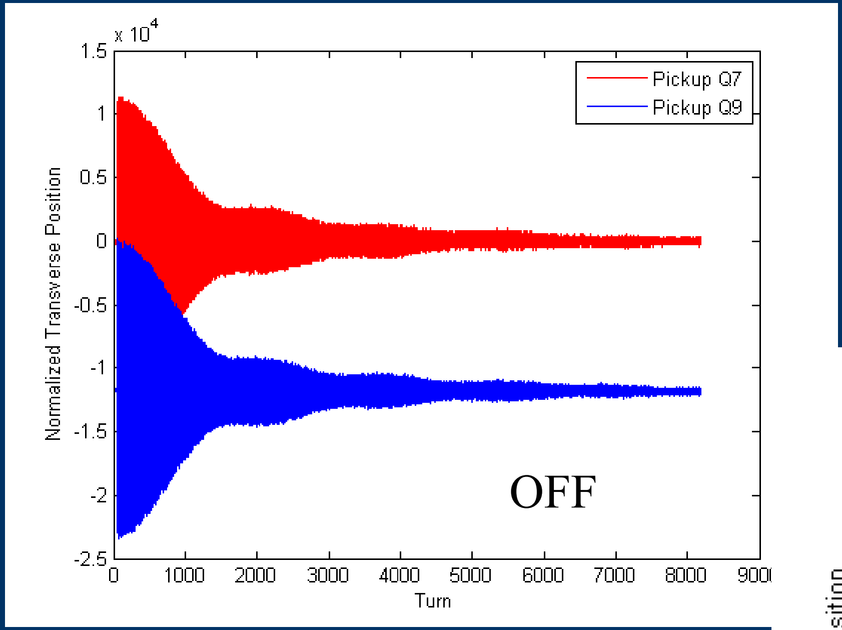
- Higher intensity
  - Over-injection working well
  - Over-injected 1.1E11, with collimators at nominal 4.5 sigma settings.
  - Emittance at 1E11: 2.5 um H, 2,3 um V.

Qualification: Off-momentum collimation

Loss map for off-momentum error. All OK. See expected low leakage to experimental IR's. OK for stable beams from coll.

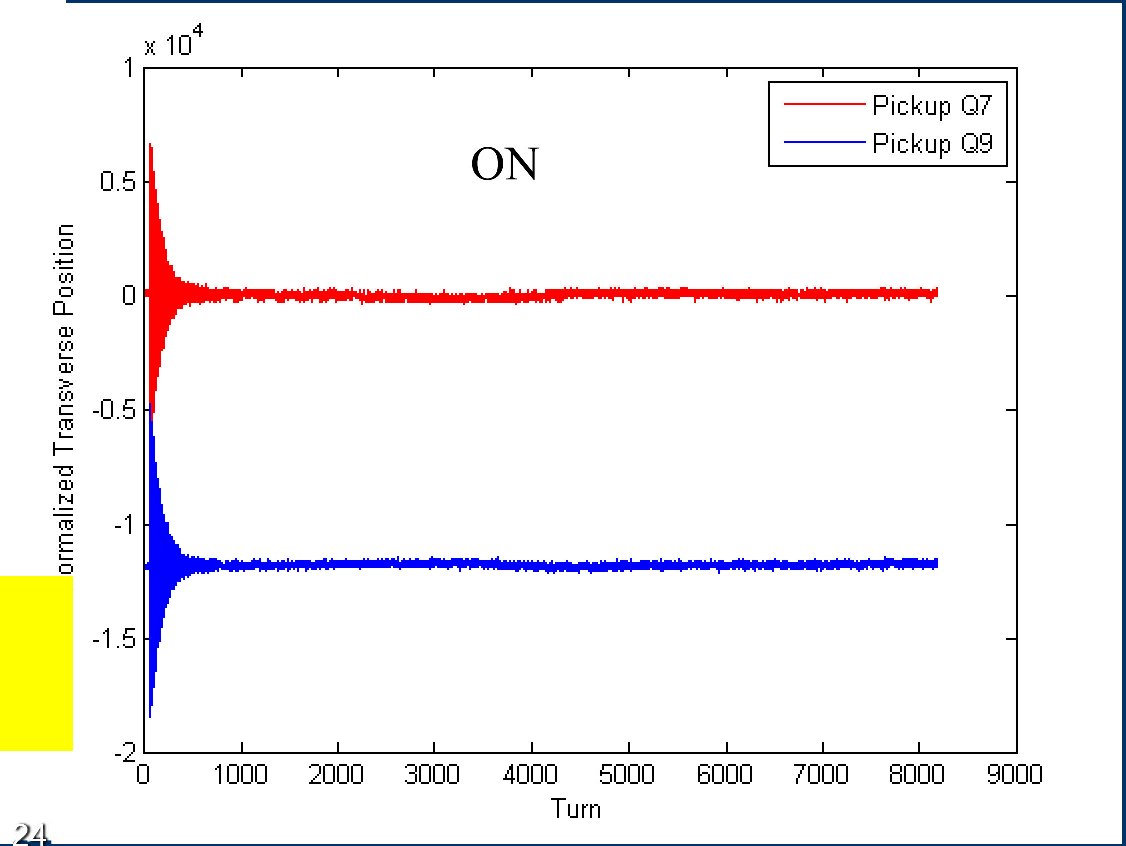


Transverse Damper: Damping Beam Excitations



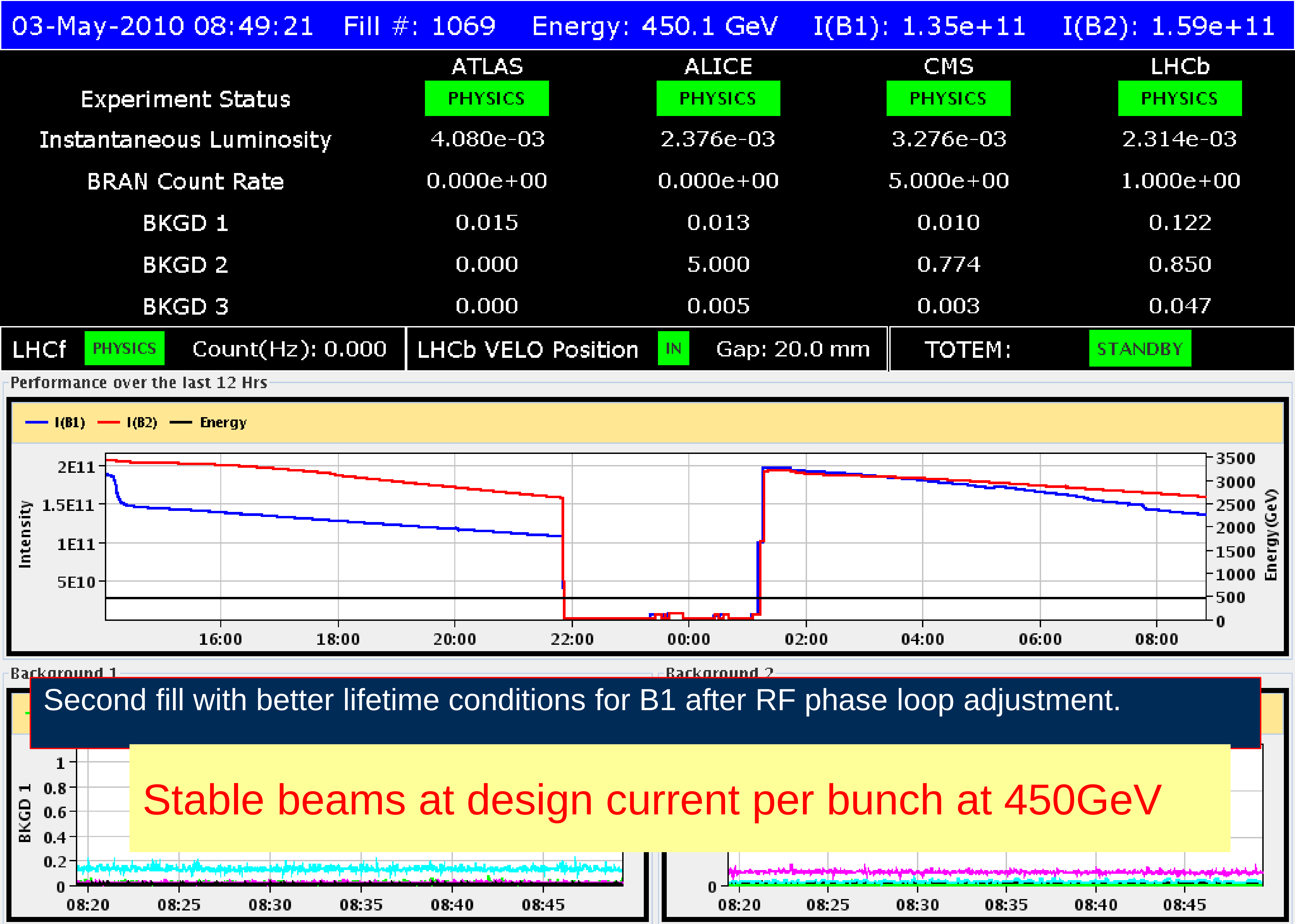
Crucial device to keep emittance growth under control!

Wolfgang Hoefle et al



Transverse Damper will stabilize against the Hump

Collisions with design current at 450GeV


03-May-2010 08:49:21 Fill #: 1069 Energy: 450.1 GeV I(B1): 1.35e+11 I(B2): 1.59e+11

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Luminosity	4.080e-03	2.376e-03	3.276e-03	2.314e-03
BRAN Count Rate	0.000e+00	0.000e+00	5.000e+00	1.000e+00
BKGD 1	0.015	0.013	0.010	0.122
BKGD 2	0.000	5.000	0.774	0.850
BKGD 3	0.000	0.005	0.003	0.047

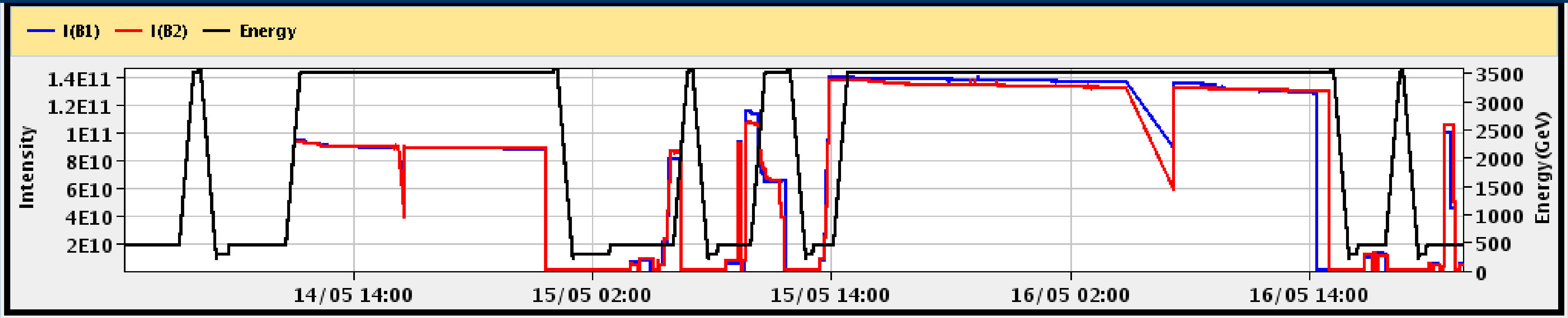
LHCf PHYSICS Count(Hz): 0.000 | LHCb VELO Position IN Gap: 20.0 mm | TOTEM: STANDBY

Second fill with better lifetime conditions for B1 after RF phase loop adjustment.

Stable beams at design current per bunch at 450GeV

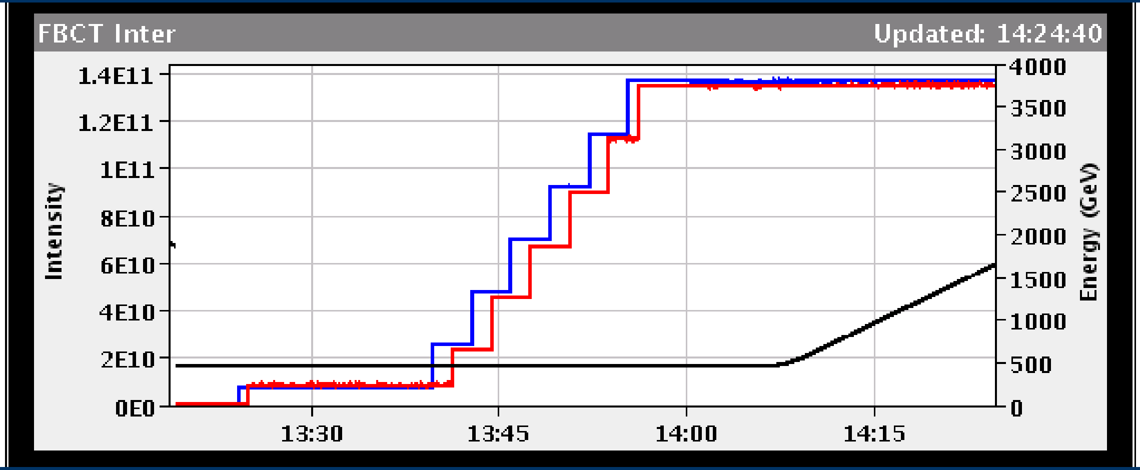
Pushing Number of 2e10 Bunches

2 x 2e10 ➔ **4 x 2e10** **6 x 2e10** per beam

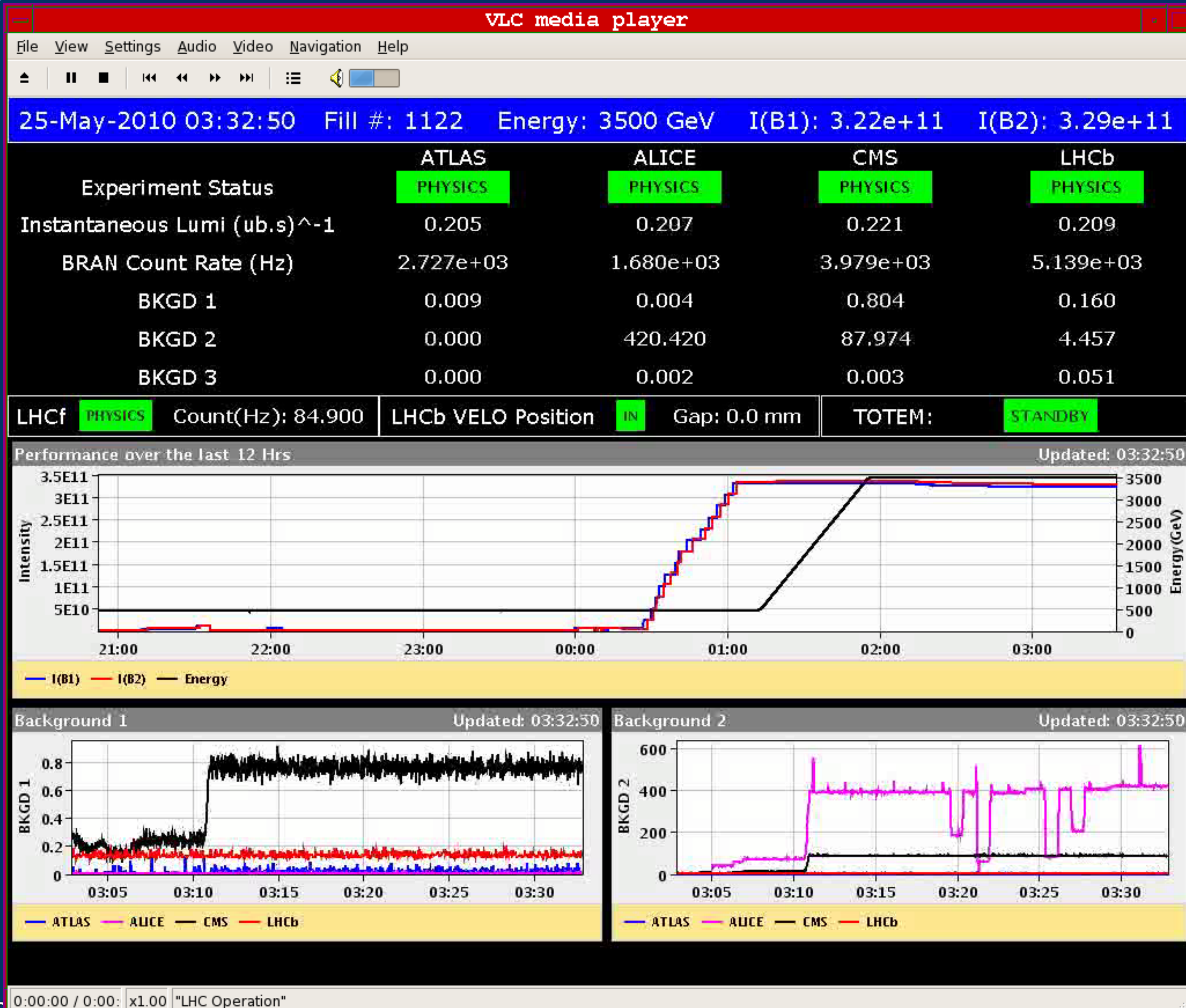


48 hours

Allowed doubling the integrated luminosity for 2010 within 48 hours!



13 bunches: $3x10^{29}$!!

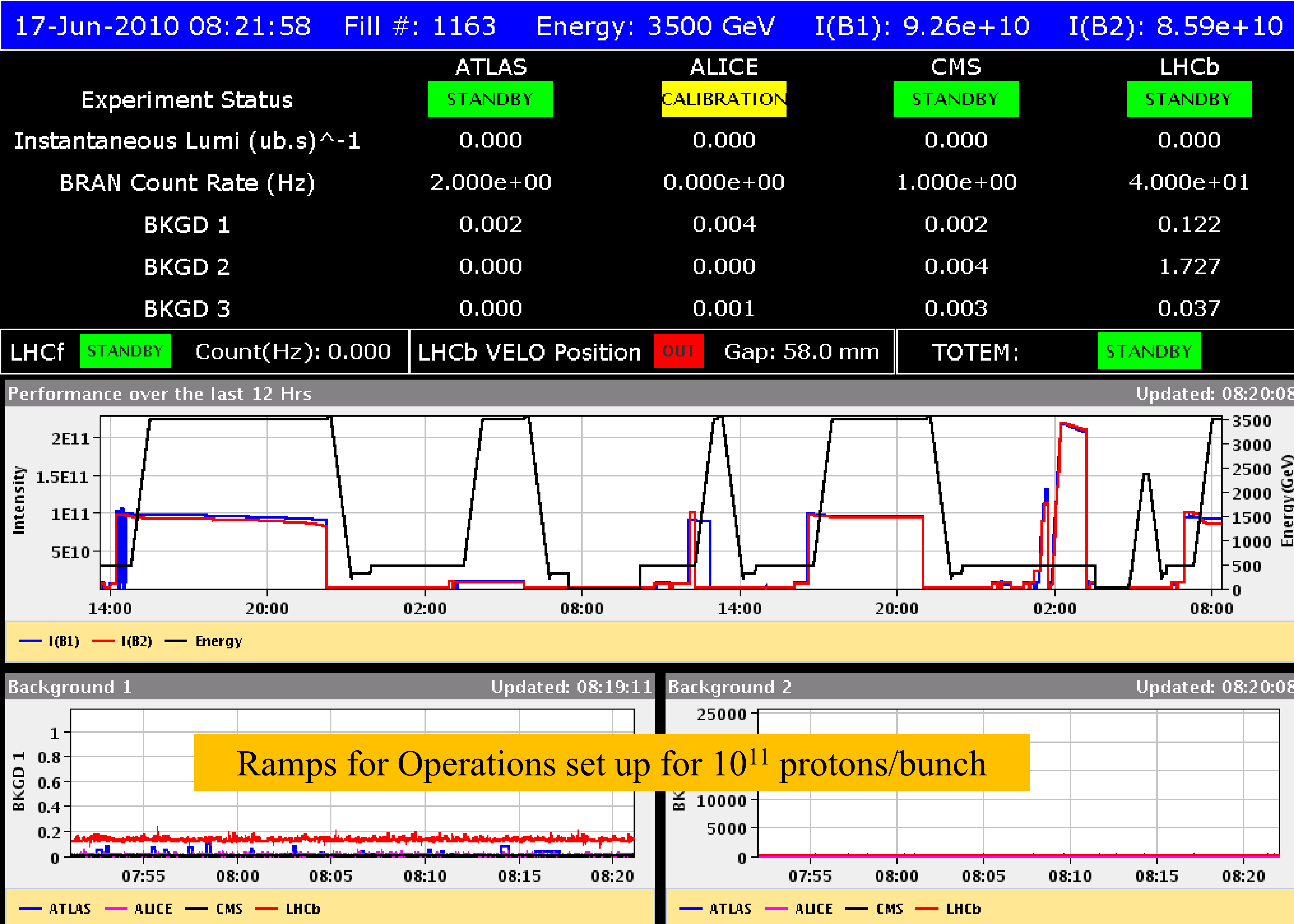


Getting to Stable beams at 1.1×10^{11}.

Instabilities in Collision at 3.5TeV/beam

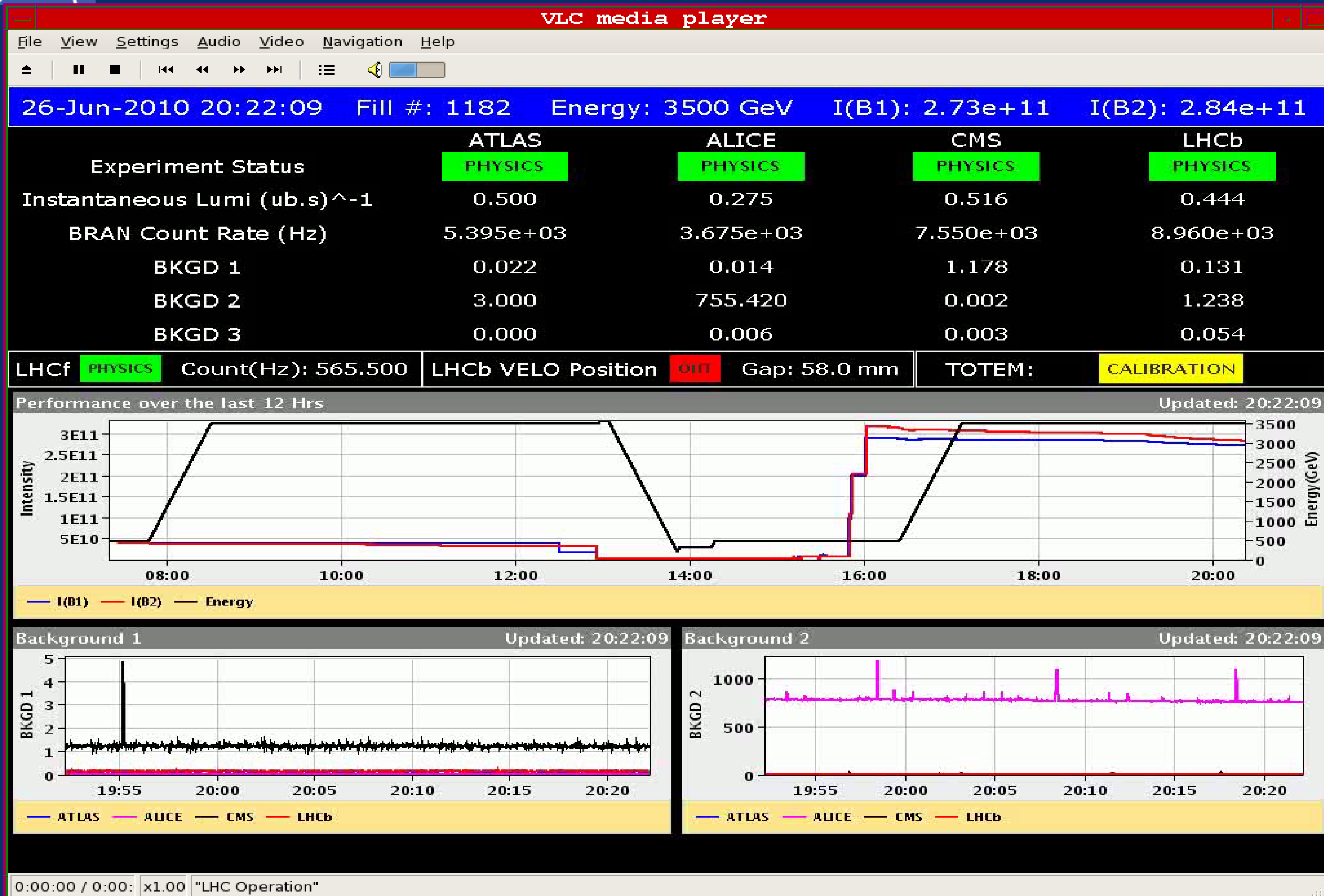
- longitudinal emittance control
  - In the SPS
  - During the ramp in the LHC
- Transverse damper working
- Collimators set up
- Injection set up for new high intensity
- Beam dump set up for higher intensity

- Started physics data taking under these conditions on Saturday 26th June

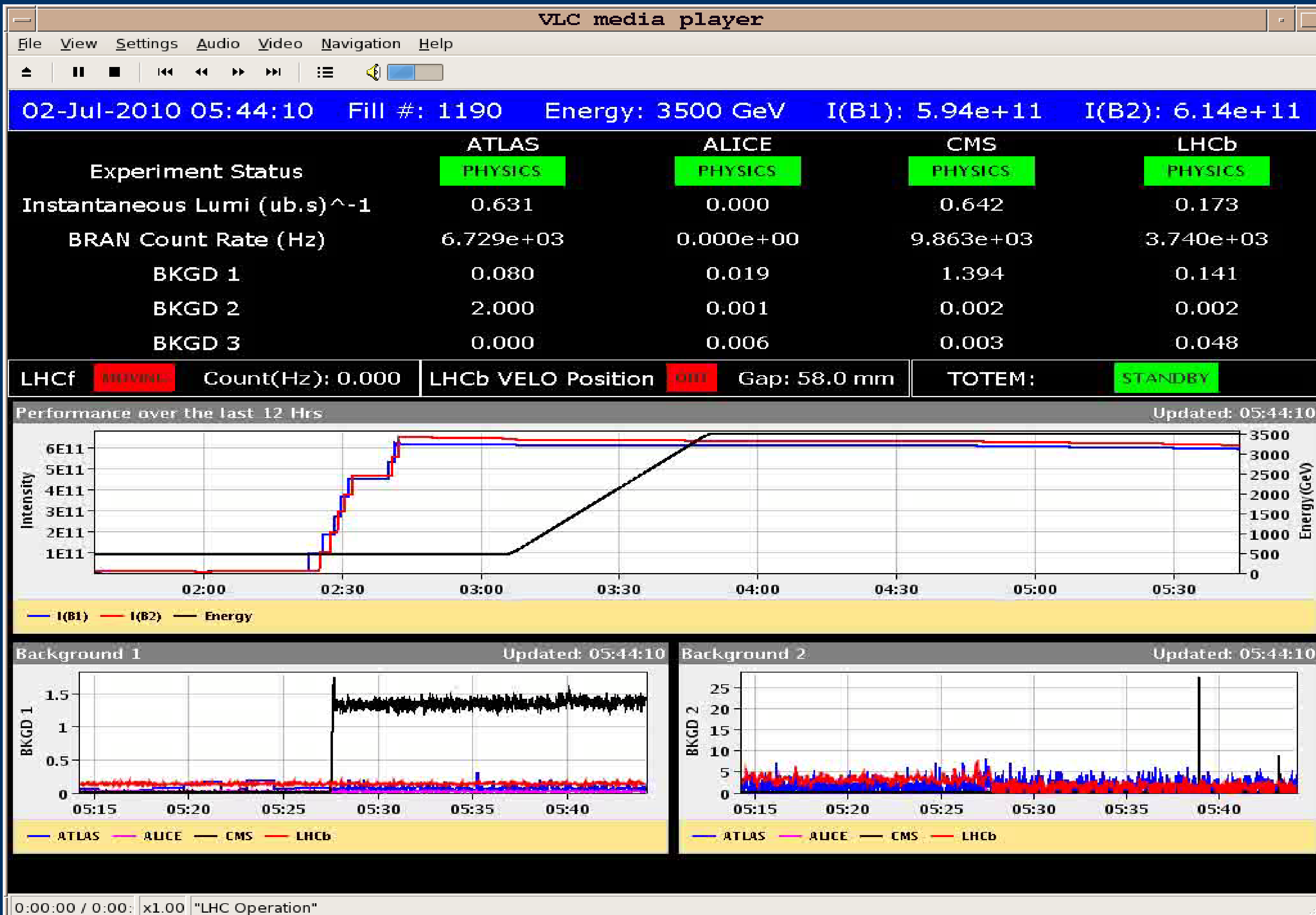


Ramps for Operations set up for 10^{11} protons/bunch

26th June: 5×10^{29} with 3 bunches/beam; 10^{11}/b



2^{nd} July: Colliding 6 bunches per beam; 10^{11}/b

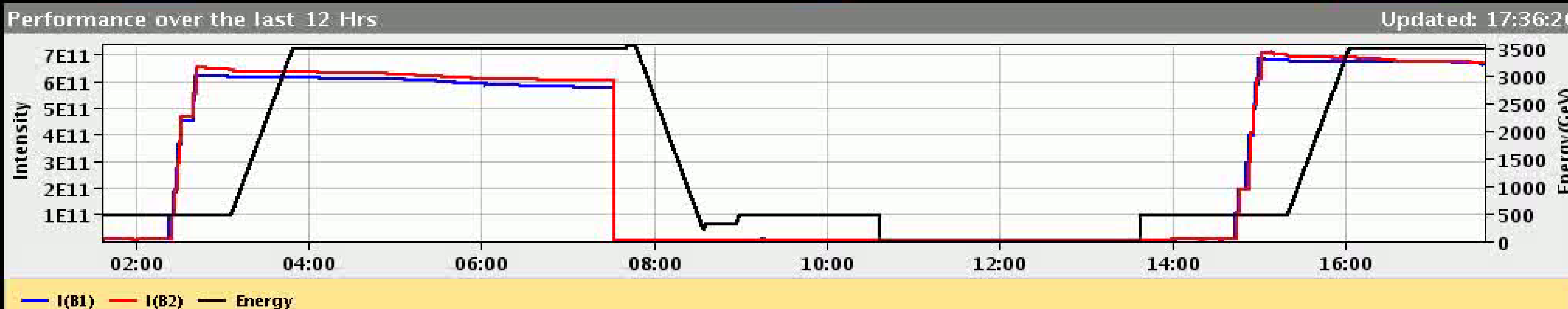


6 bunches/beam New Record Lumi > 1e30 $cm^{-2}s^{-1}$

02-Jul-2010 17:36:21 Fill #: 1192 Energy: 3500 GeV I(B1): 6.65e+11 I(B2): 6.70e+11

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi (ub.s)^-1	1.054	0.004	1.172	1.047
BRAN Count Rate (Hz)	1.098e+04	3.100e+01	1.657e+04	2.124e+04
BKGD 1	0.028	0.016	2.416	0.169
BKGD 2	0.000	0.008	0.002	1.974
BKGD 3	0.000	0.005	0.003	0.060

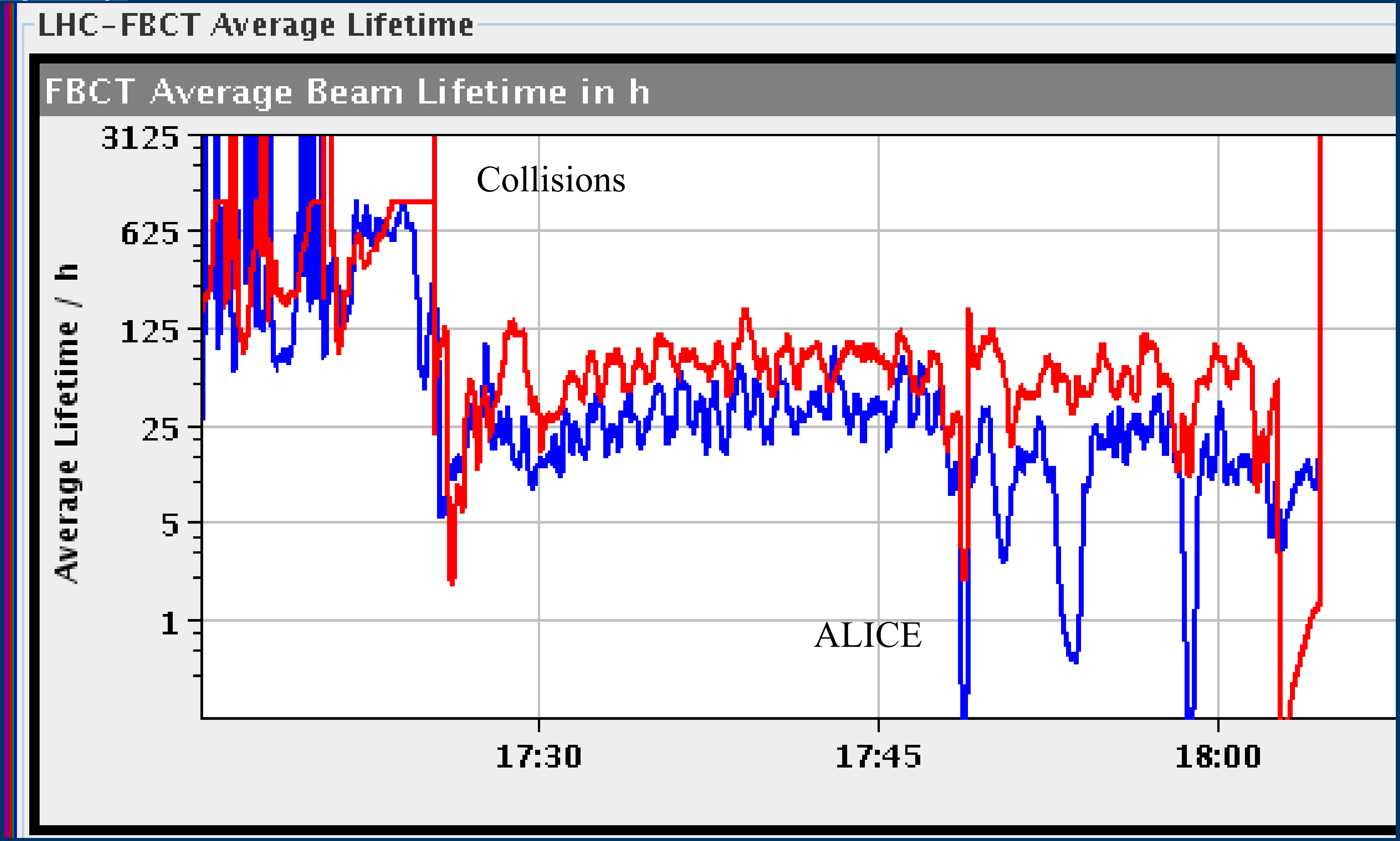
LHCf MOVING Count(Hz): 0.114 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: STANDBY



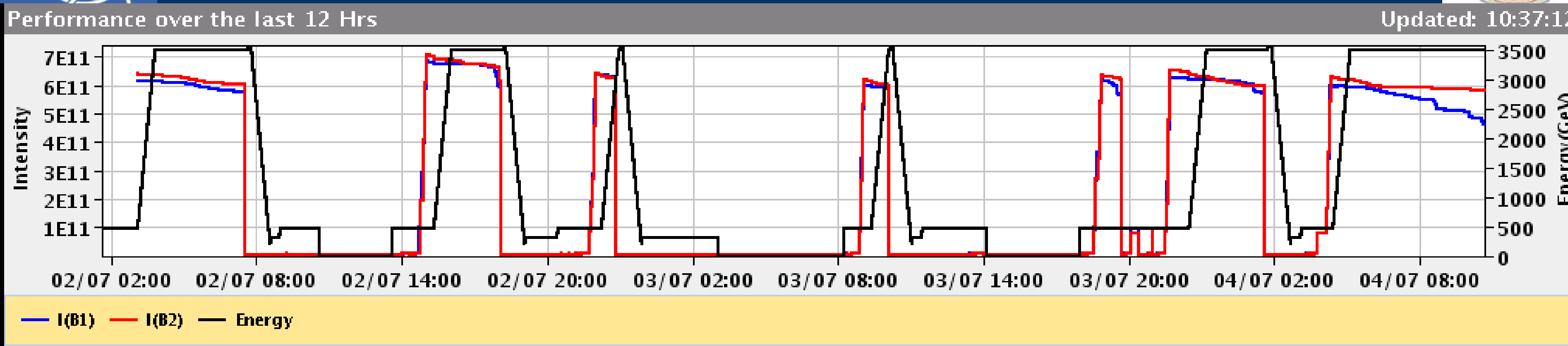

```
Emittances before ramp :
B1 H: 2.5
B1 V: 2.5
B2 H: 2.5
B2 V: 3.0 (measure not so good)
```

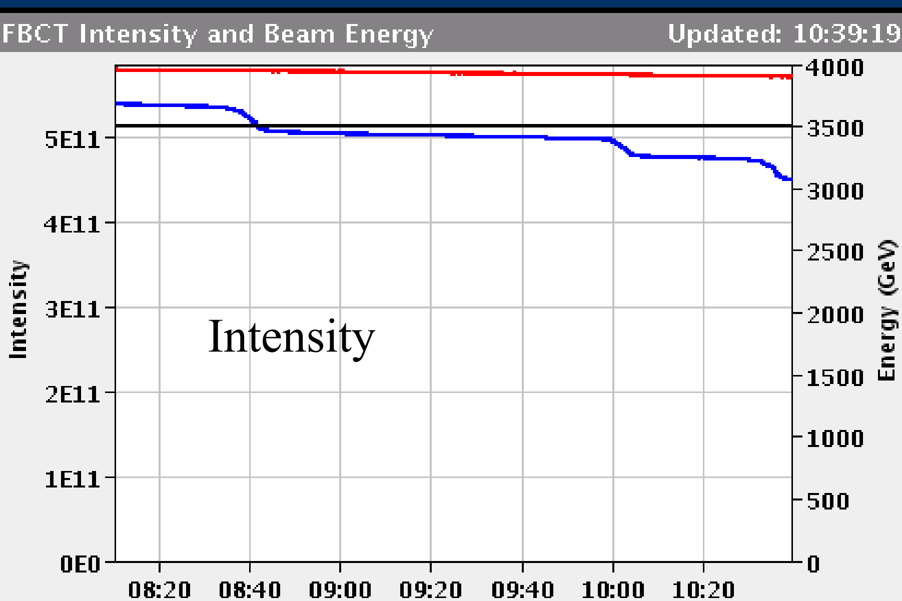
```
Emittances meas during the ramp
B1 H:4.2
B1 V:5.1

B2 H:2.3
B2 V:2.9
```

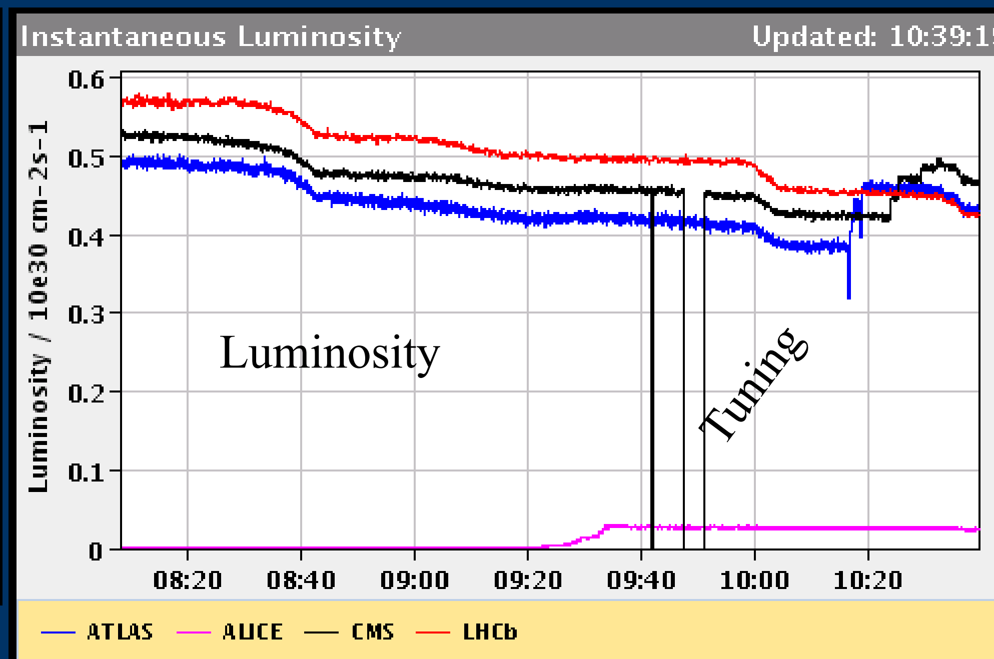
Beam Lifetime



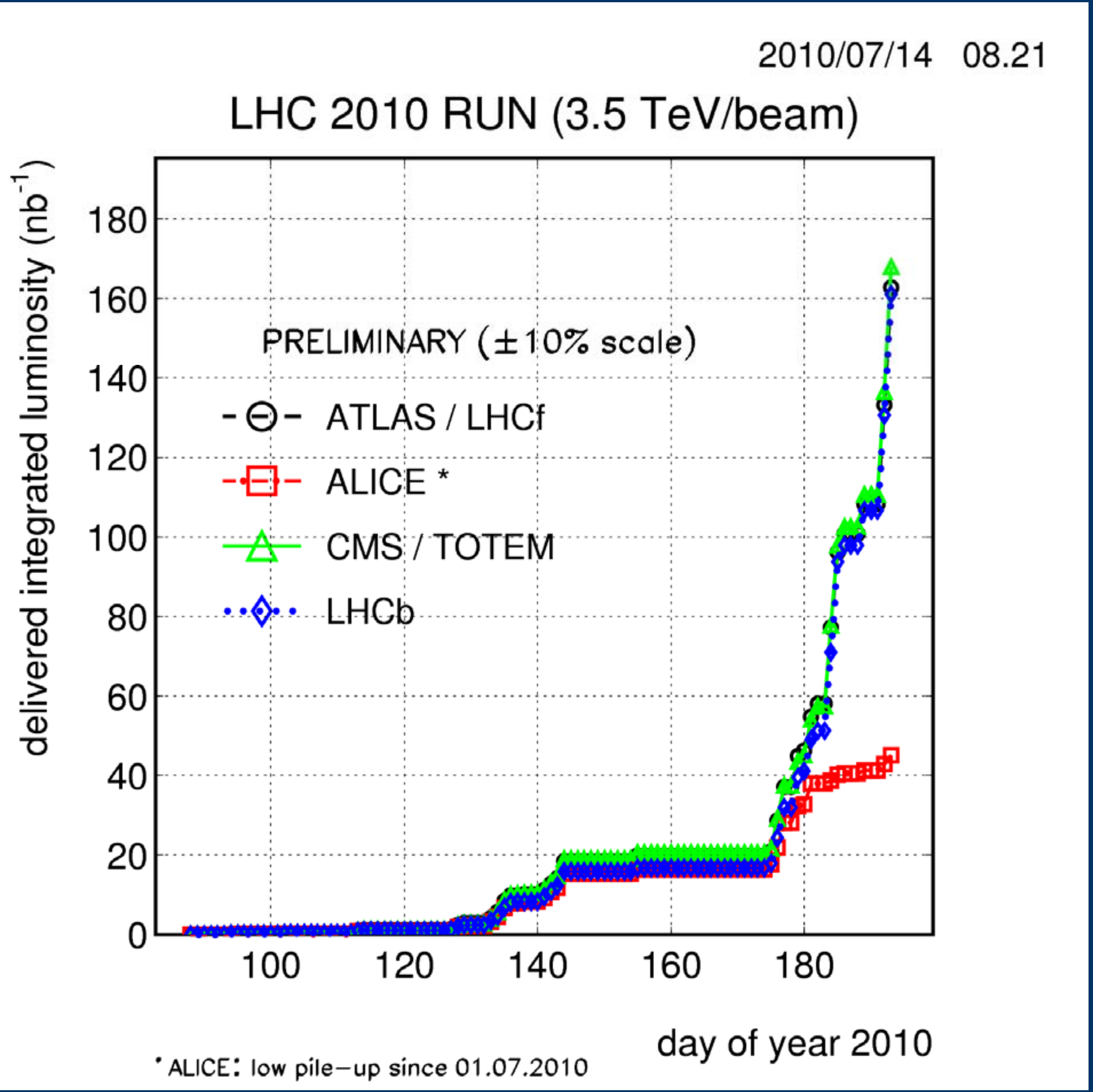
Better but not perfect stability…



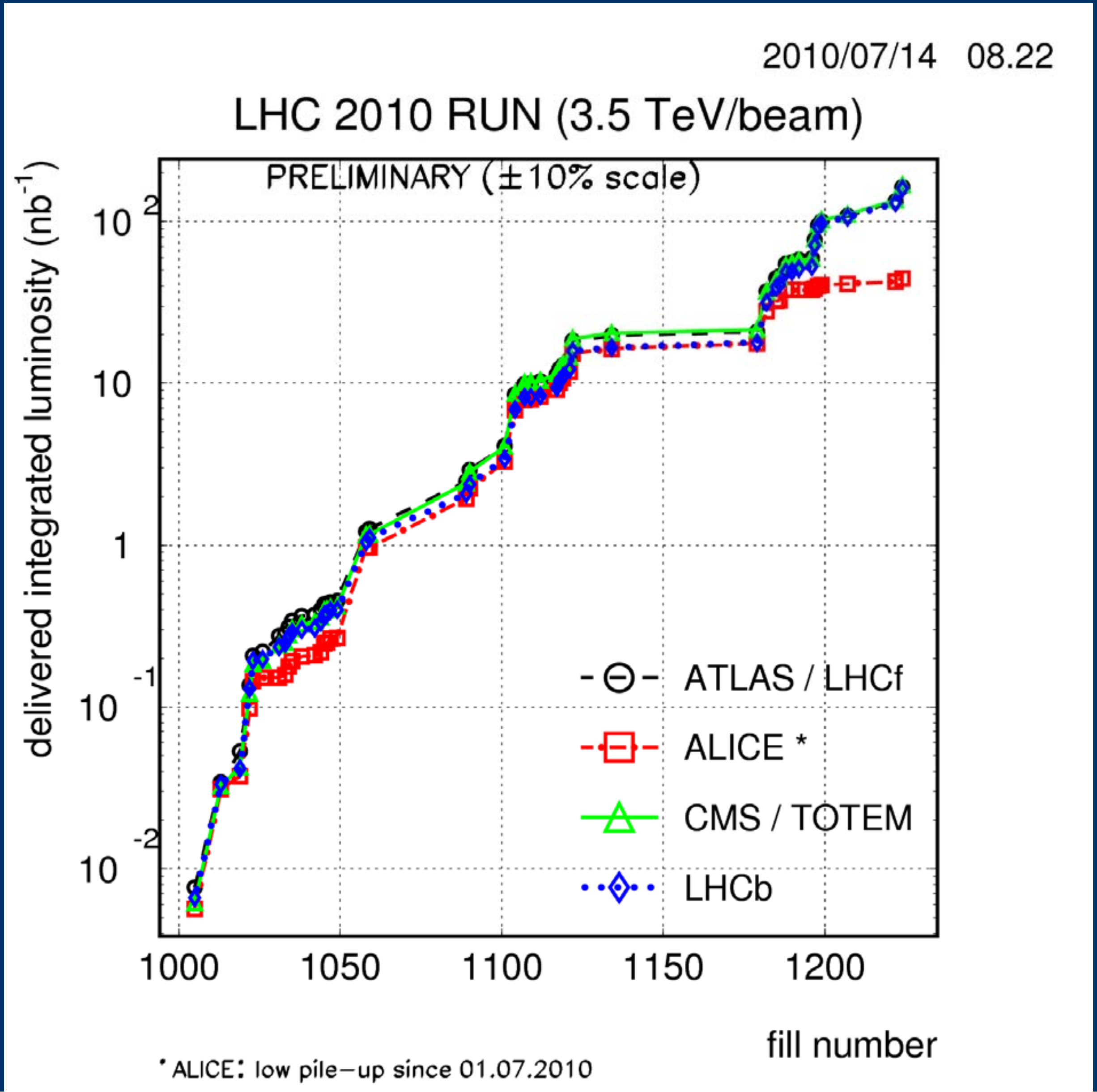




Integrated Luminosity on 14th July

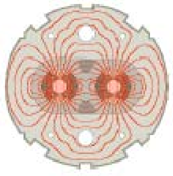


The same vs fill number in log graph



Summary of Milestones thus far

- 30 March: first collisions at 3.5TeV/beam
- 19 April: order of magnitude increase in luminosity
  - doubling the number of particles/bunch
  - β * from 11 to 2m (4b/beam) L ~2x1028.
  - Beam lifetimes of ~1000 hours
- 22 May another order of magnitude:
  - 13 bunches in each beam (L~ $3x10^{29}$)
- 26 May: Design intensity bunches were brought into collision at 3.5TeV/beam.
- 2nd July peak luminosity of $10^{30} cm^{-2}s^{-1}$.
- Half July: 1.4 $10^{30} cm^{-2}s^{-1}$ consolidated, aiming at more
- By August : bunch train



Presently

- From experience so far
  - No fundamental issue for 1e30 luminosity
  - Further equalize beam parameters (emittance, intensity, …) while delivering luminosity. Try to get nominal beam and bunch parameters, including variations.
  - As stability is improved, push up again on luminosity
- In addition:
  - Cross calibrate emittance measurement devices.
  - Push transverse damper into full operation in collision, however, possibly needs noise reduction.

Aim is for 10^{32} before the end of 2010 which is needed for an integrated luminosity of **1fb-1 before end of 2011**

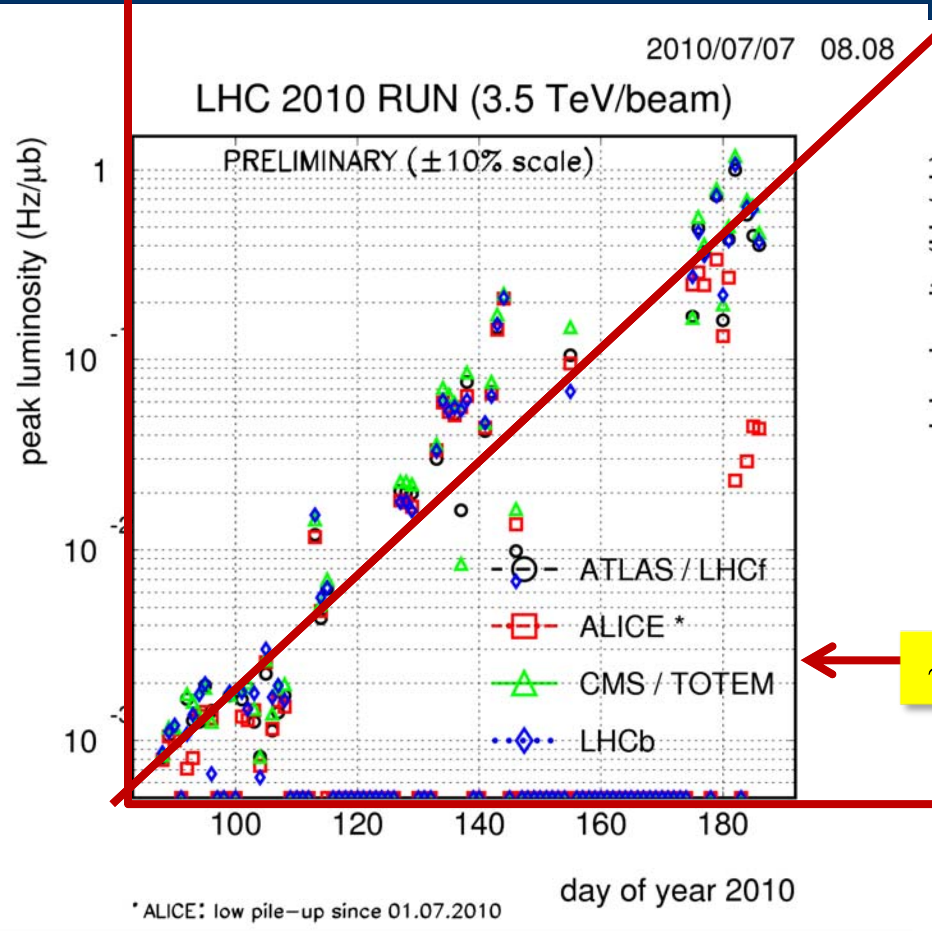
At 7 Tev c.o.m. energy

10^{32} how far we are ?

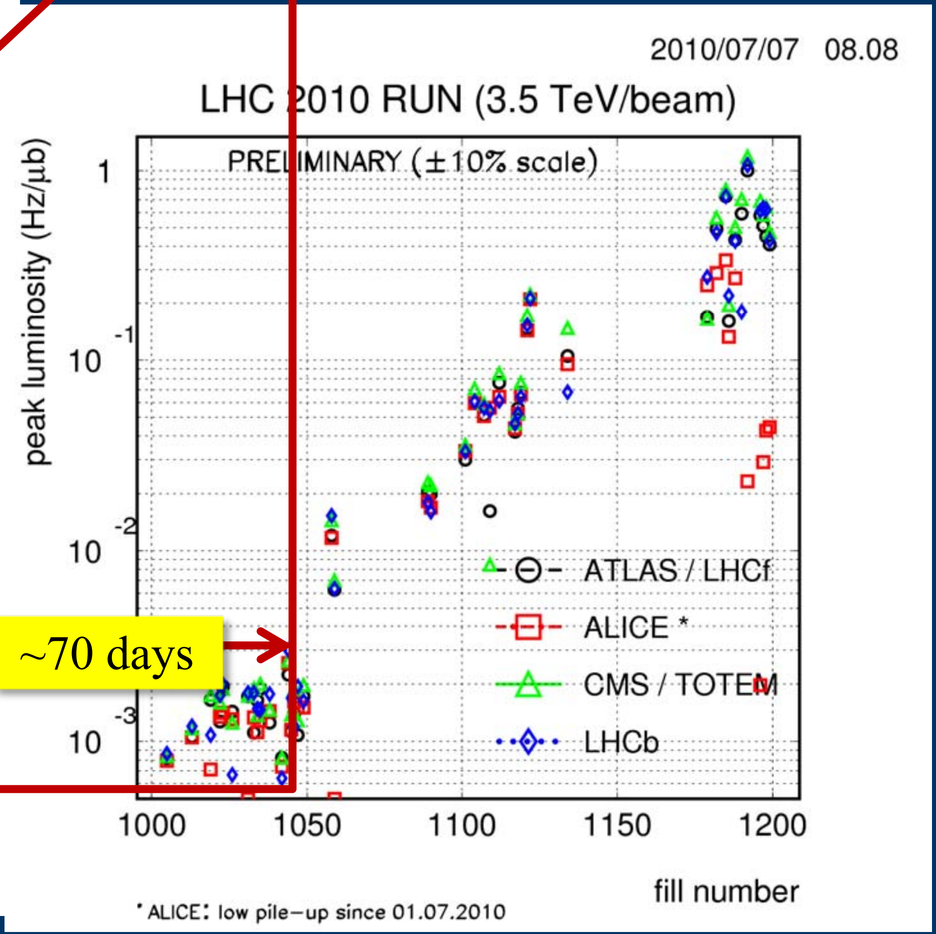
(modulo some possible luminometers down time...)

1e32 !!

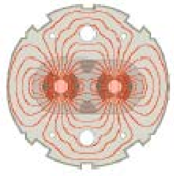
Fills 1005-1199



~70 days

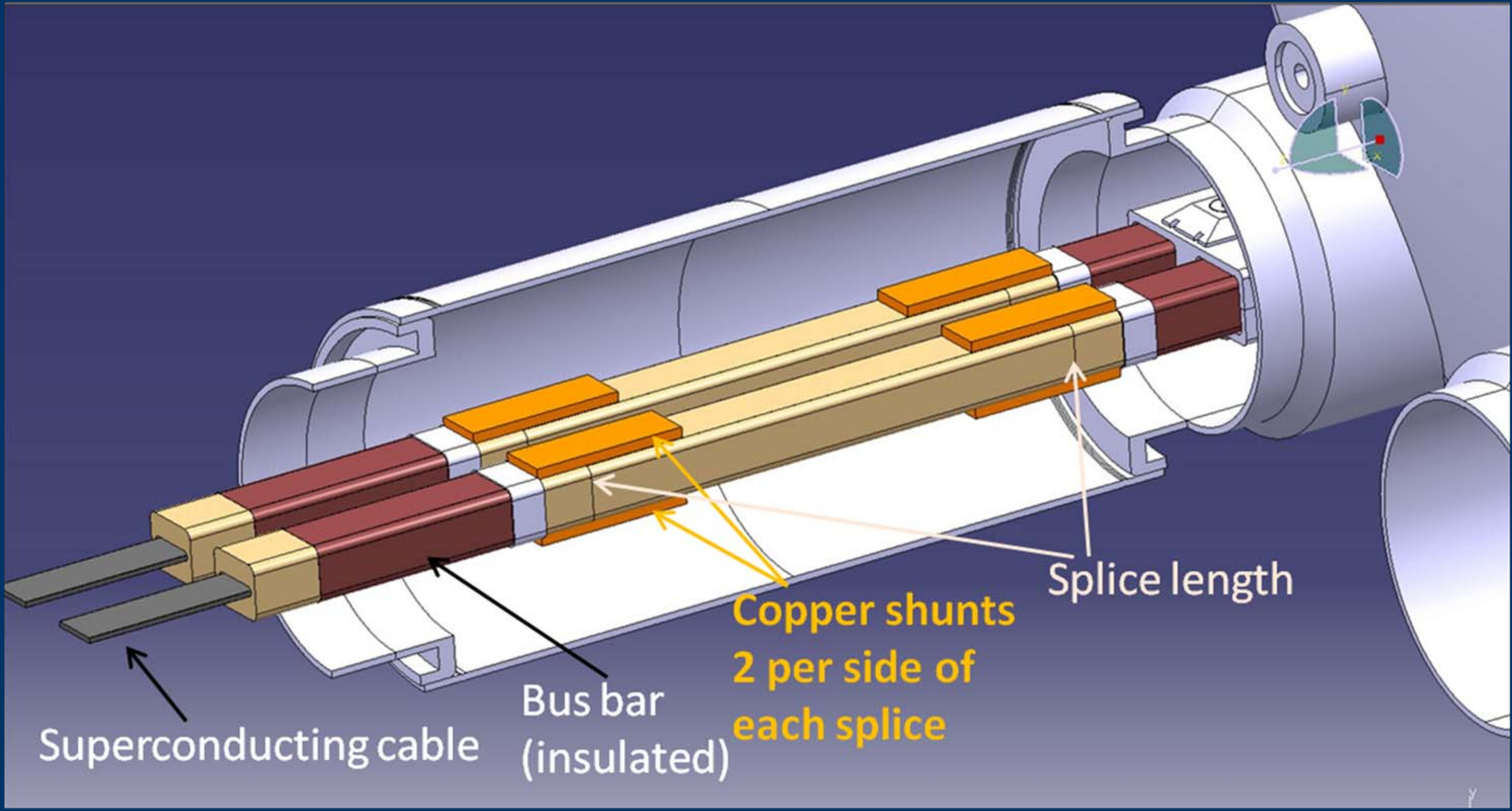


Medium future : 2012-13 shutdown

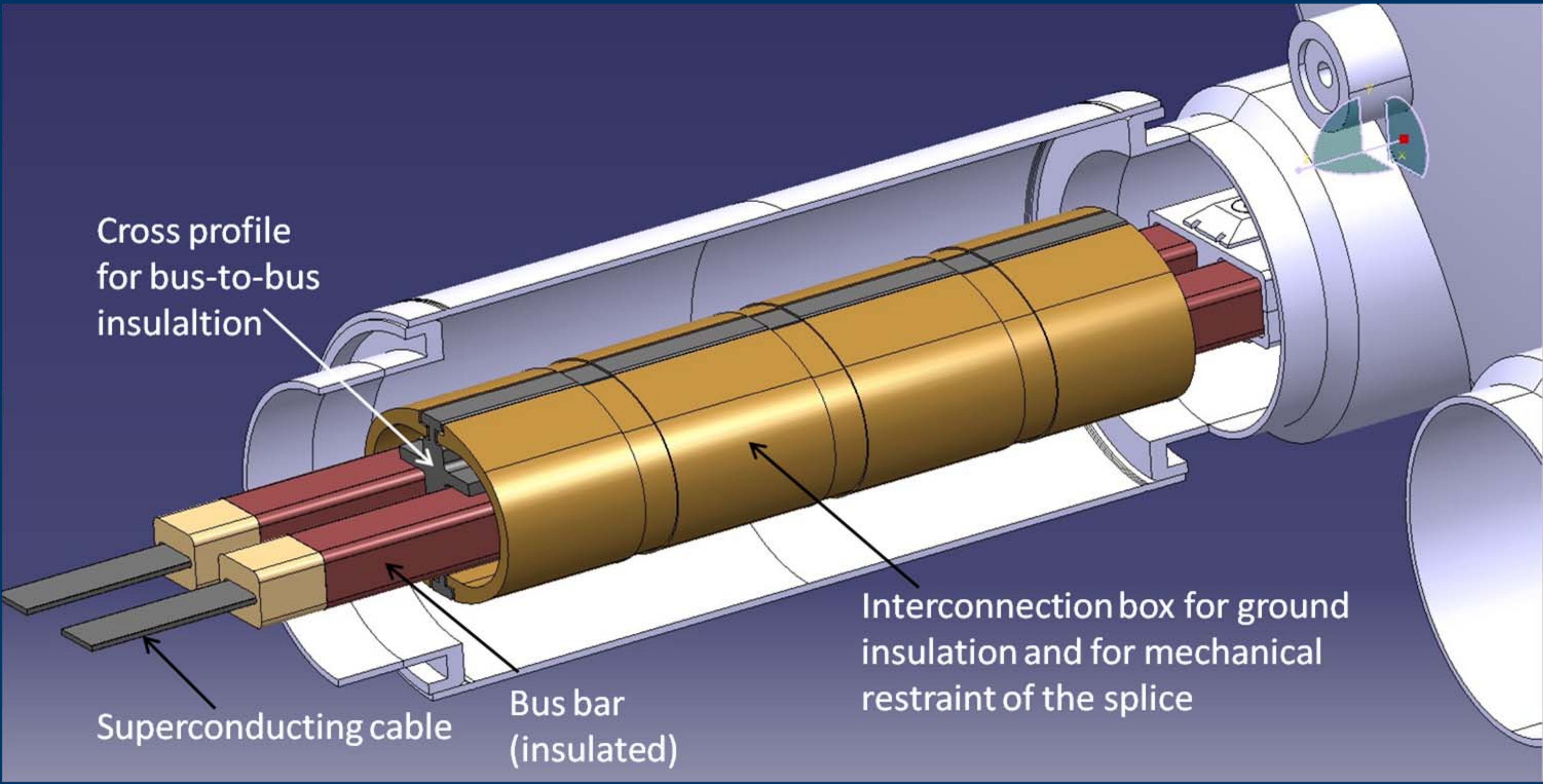


- Splice consolidation for nominal energy 13-14 TeV c.o.m.
  - All sectors to be warmed up
  - All Interconnects to be opened (about 2000), and 5000 helium enclosure - pipes with flanges and bellow - cut and opened
  - All 10,000 joints inspected, some 15% expected to be repaired and ALL to be consolidated with a copper shunt
  - Some 5 magnets to be replaced for electric or vacuum defectsand 10-15 for n.c. internal (inside magnets) splice.
- Completion of collimation system for nominal luminosity
  - (we think we will be limited at 2-20% of nominal luminosity by lack of complete collimation)
  - This requires to remove to surface 24 main magnets (+ 4 cryostats) and to reinstall in displaced position in order to fit:
  - NEW 4 cold-warm-cold transitions to place 4 collimators in the DS zone of P3 (in addition to six more normal collimator s still missing)

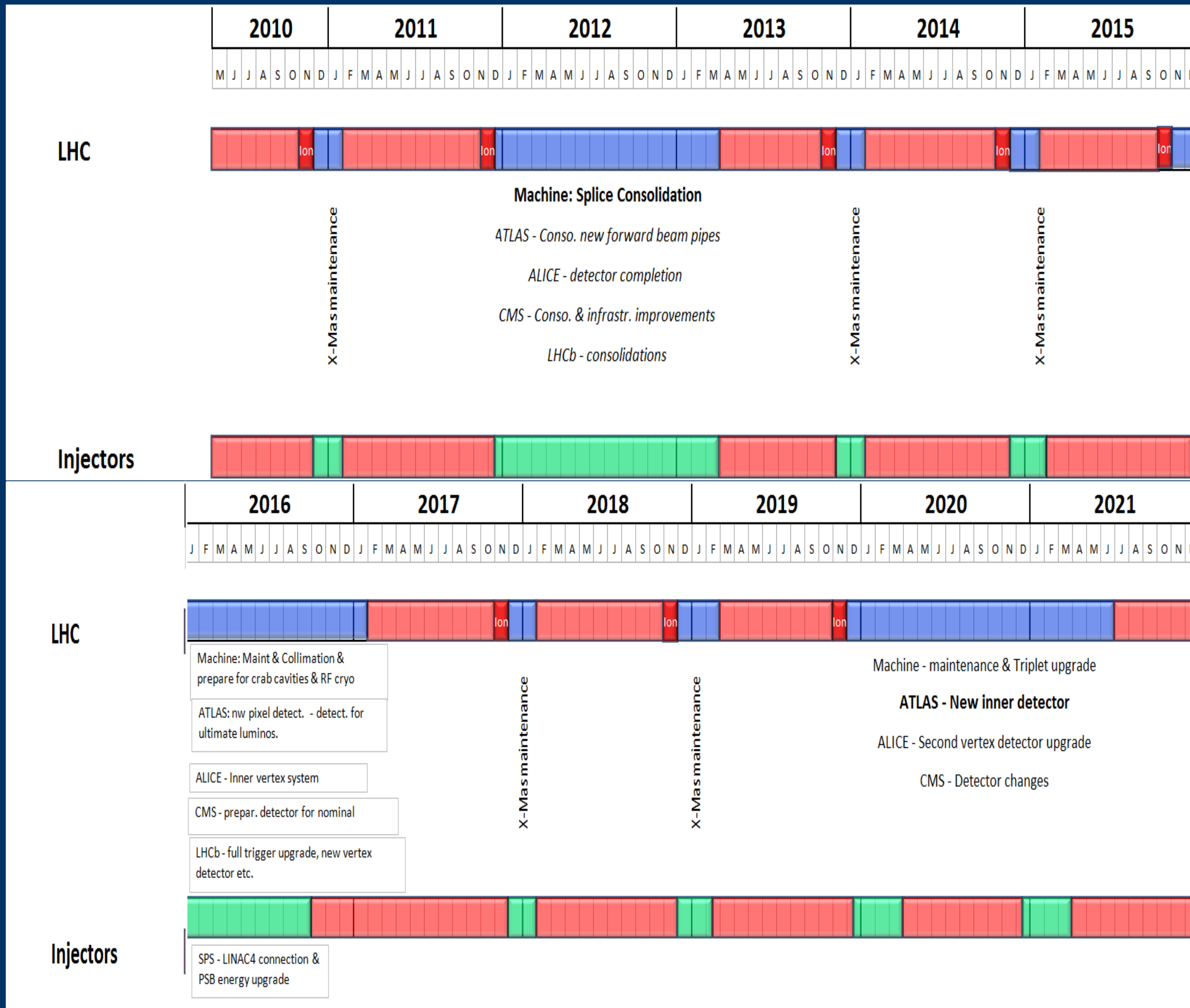
Sketch of the copper shunt



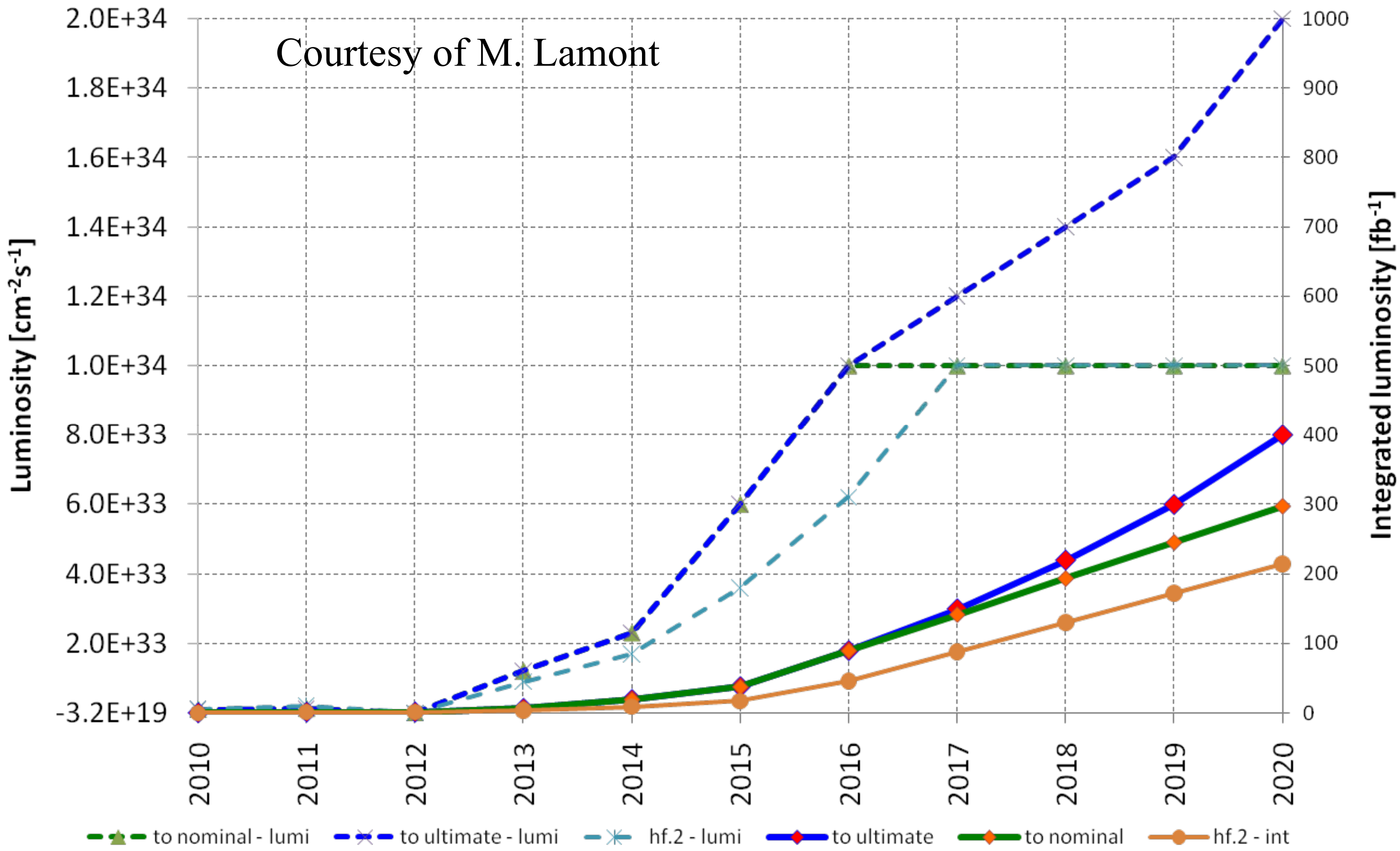
Sketch of the restraining box



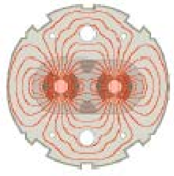
A possible schedule for the next decade ….



A look to a possible – possible!!! – lumi evolution



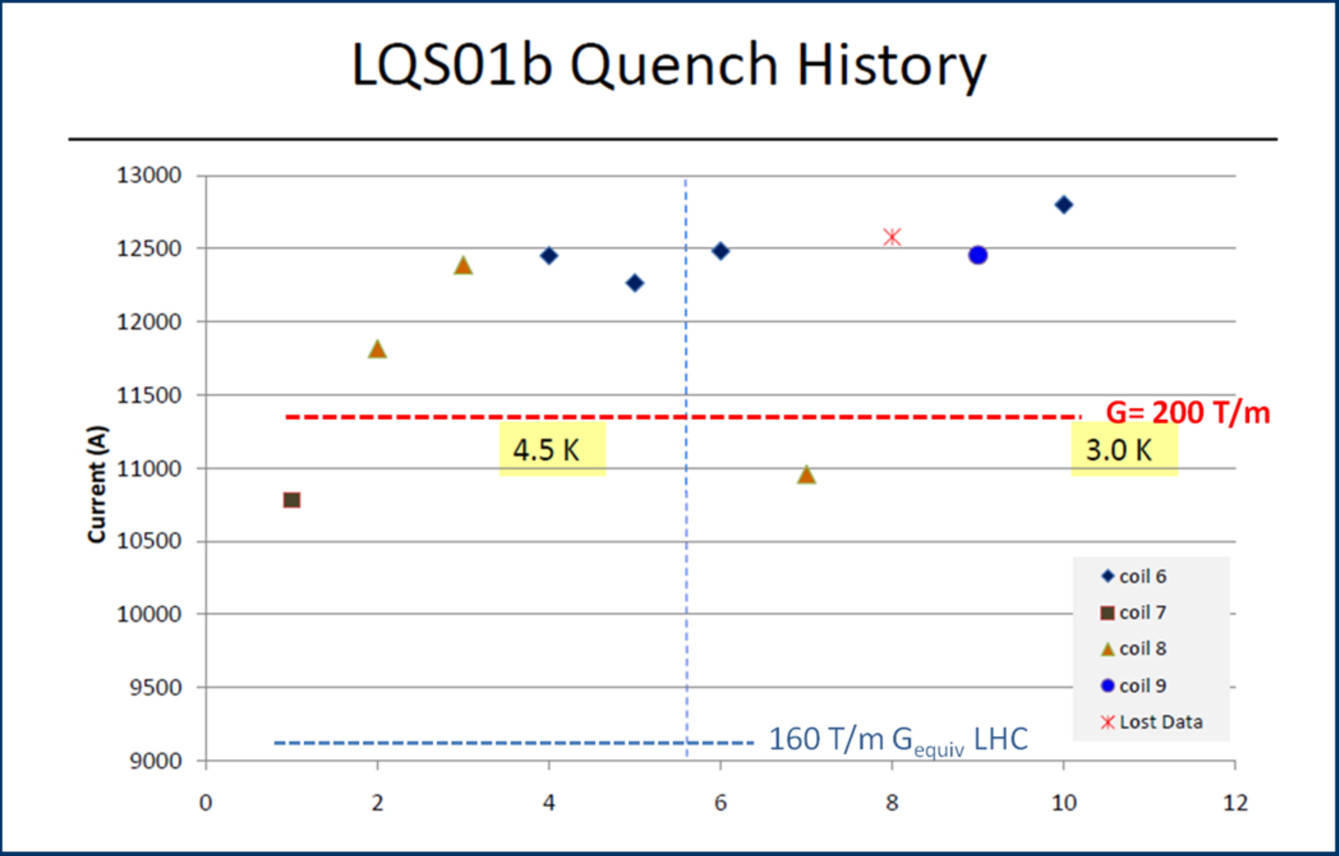
Far Future - High Luminosity LHC : aim at 5 10^{34} with leveling



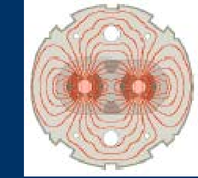
- **New Hardware**
  - 13 T magnets, 16 high grad low beta quandrupoles for ATLAS & CMS and 4 large aperture dipoles
  - New IR magent layout with also new cryo-plants
  - New SC crab cavities to rotate the beam and make effective the gain of the low beta quads
  - New magnets inthe Matching sections with larger apertures
  - New Sc links to remove Power Supply on surface (R2E problem)
  - Further collimation system in the DS of P7, IP2 (IP1 and IP5?) requiring special 11 T LHC like dipoles
  - New collimation system and absorber in the IR to protect magnets.
- **What is the time scale ?**
  - The Study and R&D takes 5 years
  - In 2013-14 we are ready for a decision, then 5 year to built and test
  - Installation from 2020… some 1500-2000 fb-1 by 2030…

Atre we ready with this new technology? Almost…

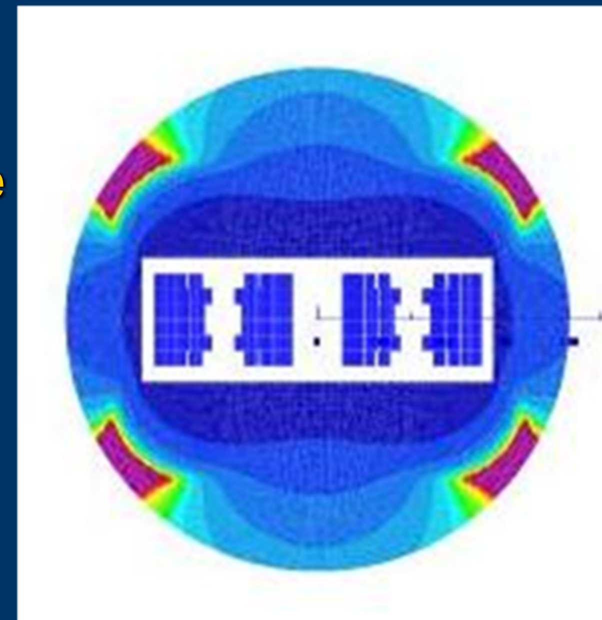
US – LARP (DOE program) is developing Nb3Sn SC magnets
LQS is a 3.6 m coil length quandrupole with **90 mm aperture**. Its goal is 200 T/m, as LHC @ 70 mm and 1.9 K!

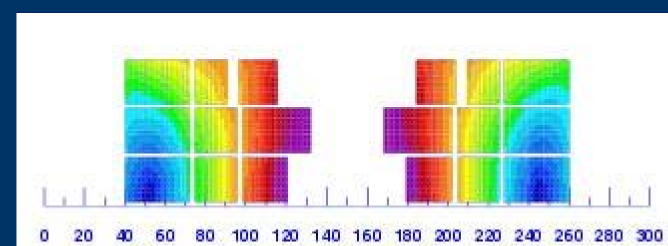


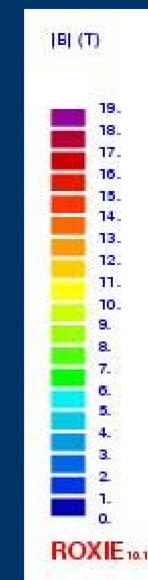
Very Far Future - High Energy LHC : aim at 28-33 TeV c.o.m.



- New Hardware
  - 17-20 T main dipole magnets!
  - Synchrotron radiation also a big issue
  - But it looks possible…
  - Sketch of a 20 T dual dipole with 40 mm bore with Nb-Ti (LHC), Nb_3Sn (HL-LHC) and HTS.
  - Working group lead by S. Meyers is – slowing – taking momentum
  - Taking profit form HL-LHC R&D







- What is the time scale ?
  - The Study, R&D, industrialization will take 10 years
  - Construction further 10 years
  - Installation from 2030… or later

Conclusions

- LHC is finally there !
  - 1 fb^{-1} @ 7 TeV c.o.m. by 2011
  - 14 TeV and 50-100 fb^{-1} by 2016,
  - 200-400 fb^{-1} by 2020.
- HL-LHC
  - aiming @ 5 10^{34} cm^{-2} s^{-1} average, 1500-2000 fb^{-1} by 2030
  - decision in 2014 for installation in 2020
  - cost : 500 Millions
- HE-LHC
  - Aim at 28-33 TeV c.o.m by 2030…
  - Cost : 5000 Millions + …
  - I don't know if physics requires such accelerator…
  - If we can afford a linear collider, we can certainly afford HE-LHC !