LHC Status and Plans

Gianluigi Arduini

Accelerator and Beam Physics Group

Beams Department

CERN

Acknowledgements: LHC Machine teams & Experiments for the constructive collaboration

Outline

- Lessons learned from 2010 run and achievements:
  - Protons
  - Ions
- Present proton performance, i.e.:
  - How did we get to 10^{33} $cm^{-2}s^{-1}$?
- Perspectives for 2011
  - Protons
  - Ions
- Summary

2010 achievements (protons)

	2010	Nominal
Energy [TeV]	3.5	7
β* [m]	3.5, 3.5, 3.5, 3.5	0.55, 10, 0.55, 10
Emittance [μm]	2.0 – 3.5 start of fill	3.75
Transverse beam size at IP [μm]	60	16.7
Bunch population	1.2×10^{11} p	1.15×10^{11} p
Number of bunches	368 348 collisions/IP	2808
Stored energy [MJ]	28	360
Peak luminosity [$cm^{-2}s^{-1}$]	2×10^{32}	1×10^{34}

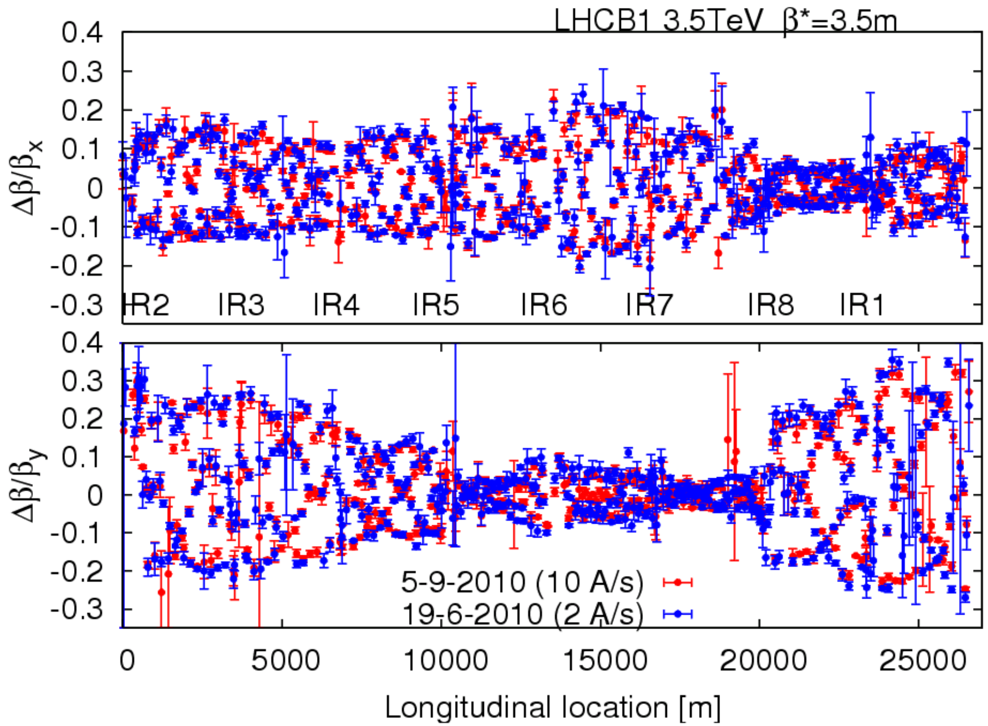
LHC 2010 – lessons learned

- Excellent single beam lifetime
- Ramp & squeeze essentially without loss
  - No quenches with beam above 450 GeV
  - Excellent performance of Machine Protection
- Magnet sorting + very good alignment tolerances ➔ aperture better than expected
- Better than nominal beam from injectors (>50% larger brightness)
  - Emittances, bunch intensity
- Beam-beam: can collide nominal bunch currents
  - With smaller that nominal emittances

➔ ability to exceed the luminosity target from Chamonix 2010

And surprisingly good availability…

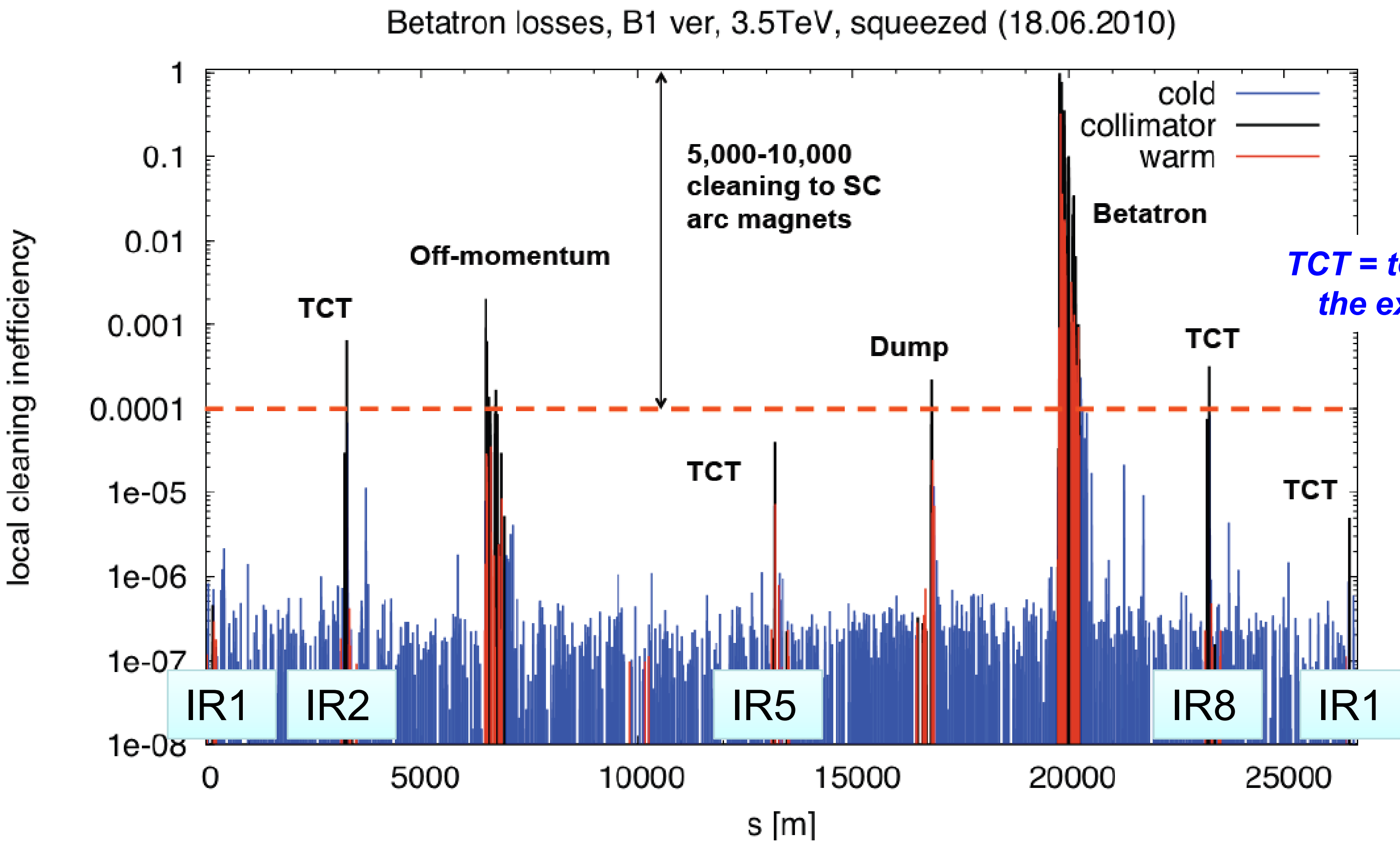
Optics & magnetic machine



- Machine magnetically and optically well understood
  - Excellent agreement with model and machine
- Magnetically reproducible
  - Important because set-up remains valid from fill to fill

Collimation

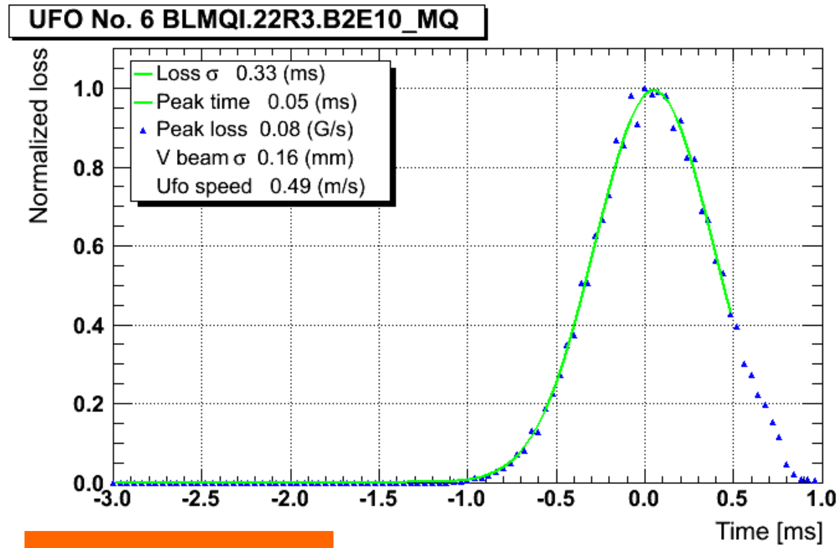
Beam cleaning efficiencies ≥ 99.98% ~ as designed



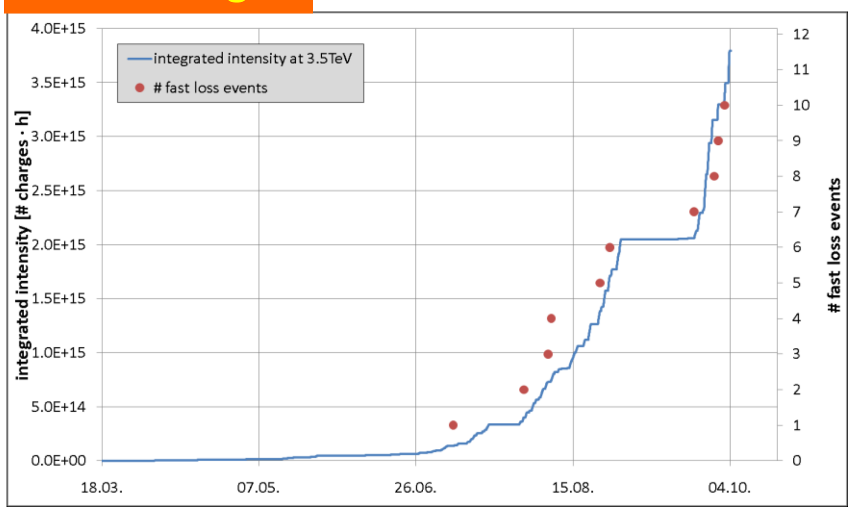
TCT = tertiary coll. at the experiments.

UFOs - Unidentified Falling Objects

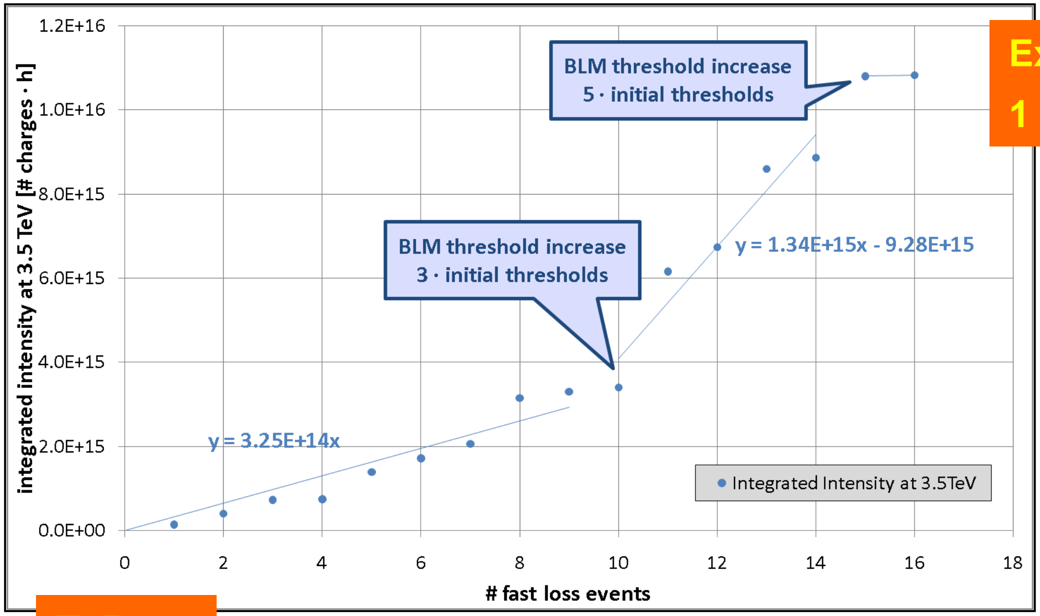
- Sudden fast local losses recorded: most likely: dust (10's μm) particles falling into beam creating losses propagating downstream
- **18 beam dumps** due to UFOs
- 113 UFOs below threshold found in logging database in 2010
- UFO rate proportional to intensity
- No dependency of peak signal on intensity
- Loss duration (~ms) has tendency to become faster with higher intensity.



J. Wenninger



UFOs - Unidentified Falling Objects

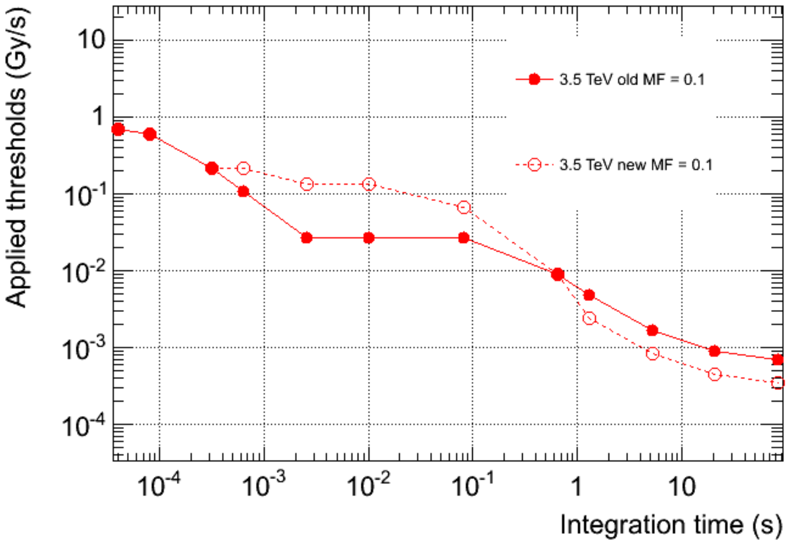


Extrapolation to 2011 (900 bunches):
1 UFO dump /10 hours

- In 2010 the quench thresholds were probed by experiments and by actual loss events. From this experience

T. Baer

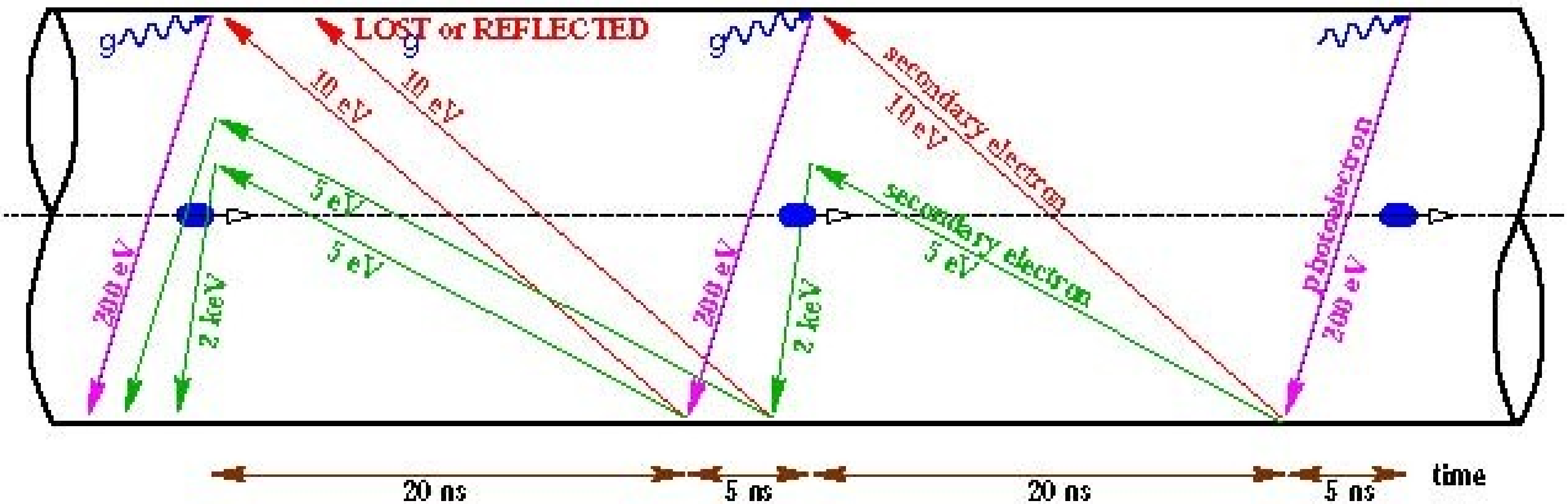
After the increase of the BLM Monitor Factor by a factor of 3 there were about **4.1 times fewer UFO related beam dumps.**



Electron cloud

Reflection

F. Ruggiero



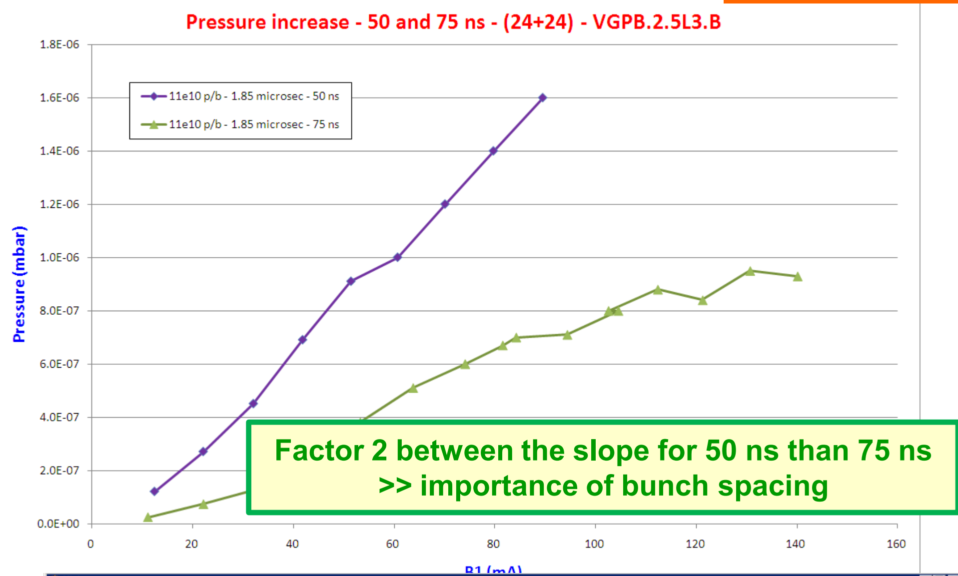
Secondary emission yield [SEY]

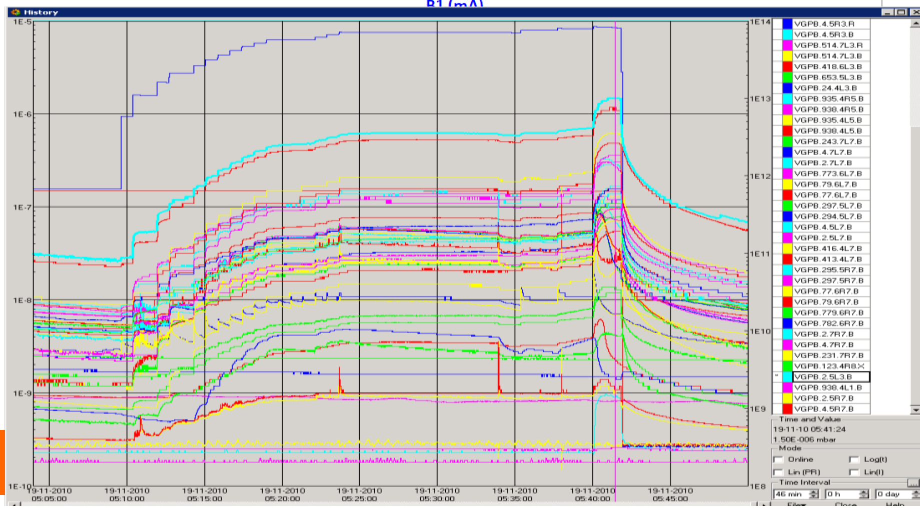
- Electron cloud effects occur **both in the warm and cold regions**
  - Vacuum pressure rise (interlock levels,
  - Single-bunch and multi-bunch instabilities
  - Incoherent emittance growth
  - Heat load in the arcs beam screens

Electron cloud

V. Baglin

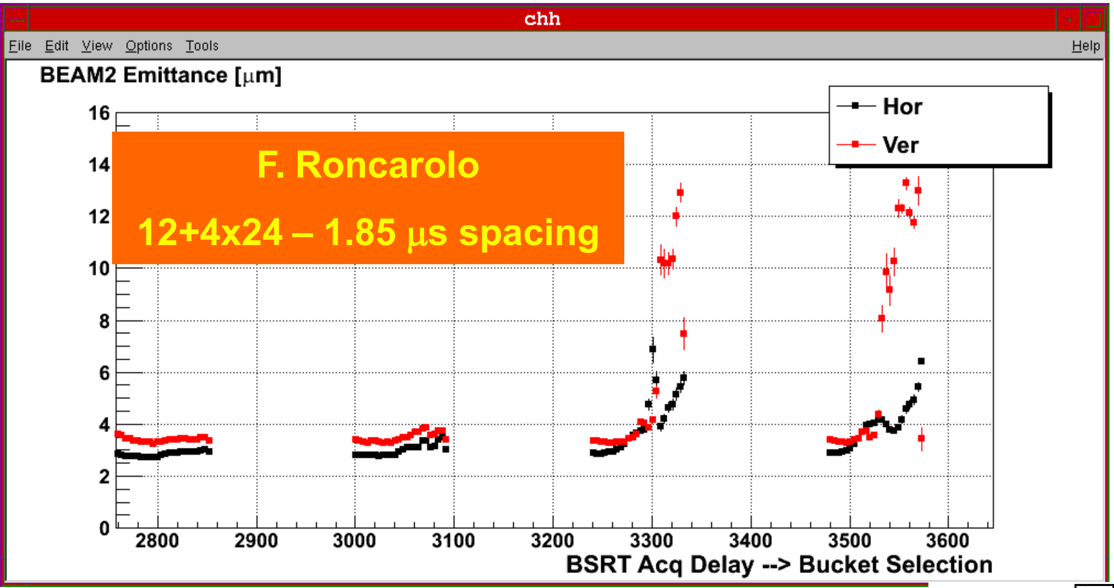
- Vacuum activity started off in common beam pipe with 150 ns spacing
- Tried 50 ns bunch spacing
  - High vacuum activity in warm regions (single beam pipe)
  - Significant heat load in cold regions
  - Instabilities and beam size growth observed
  - Surface conditioning ('scrubbing') observed in warm and cold regions
- Situation cleaner with 75 ns but:
  - incoherent effects seen – emittance blow-up
  - Not possible to ramp more than 200-300 bunches with no scrubbing



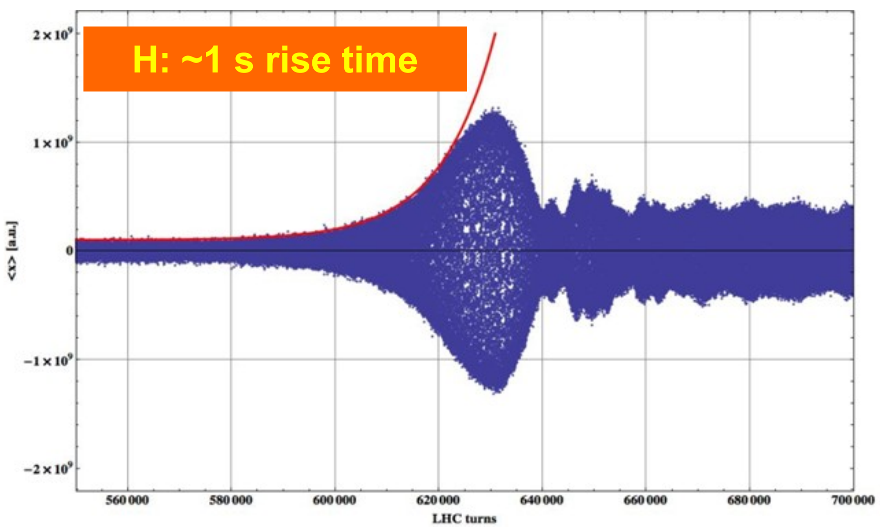


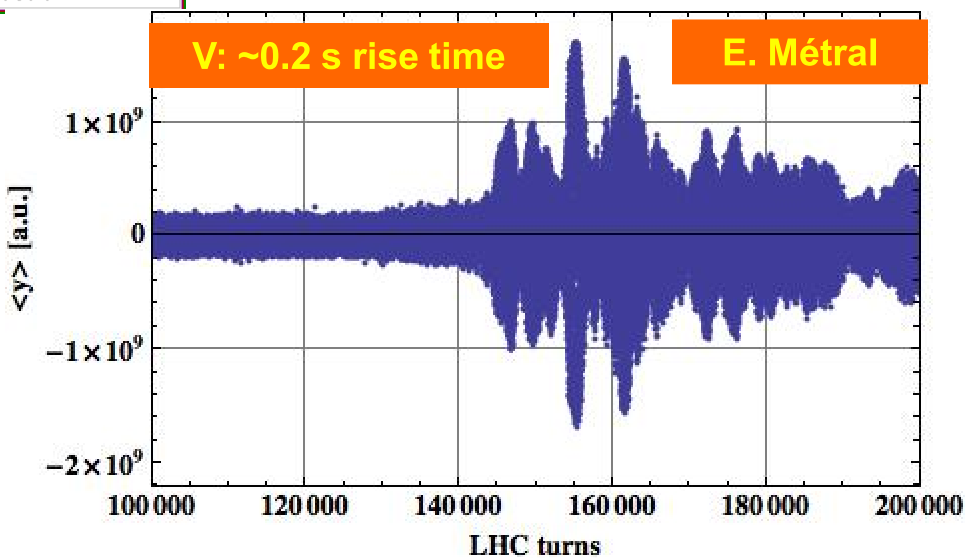
824 bunches – 75 ns

Beam instabilities

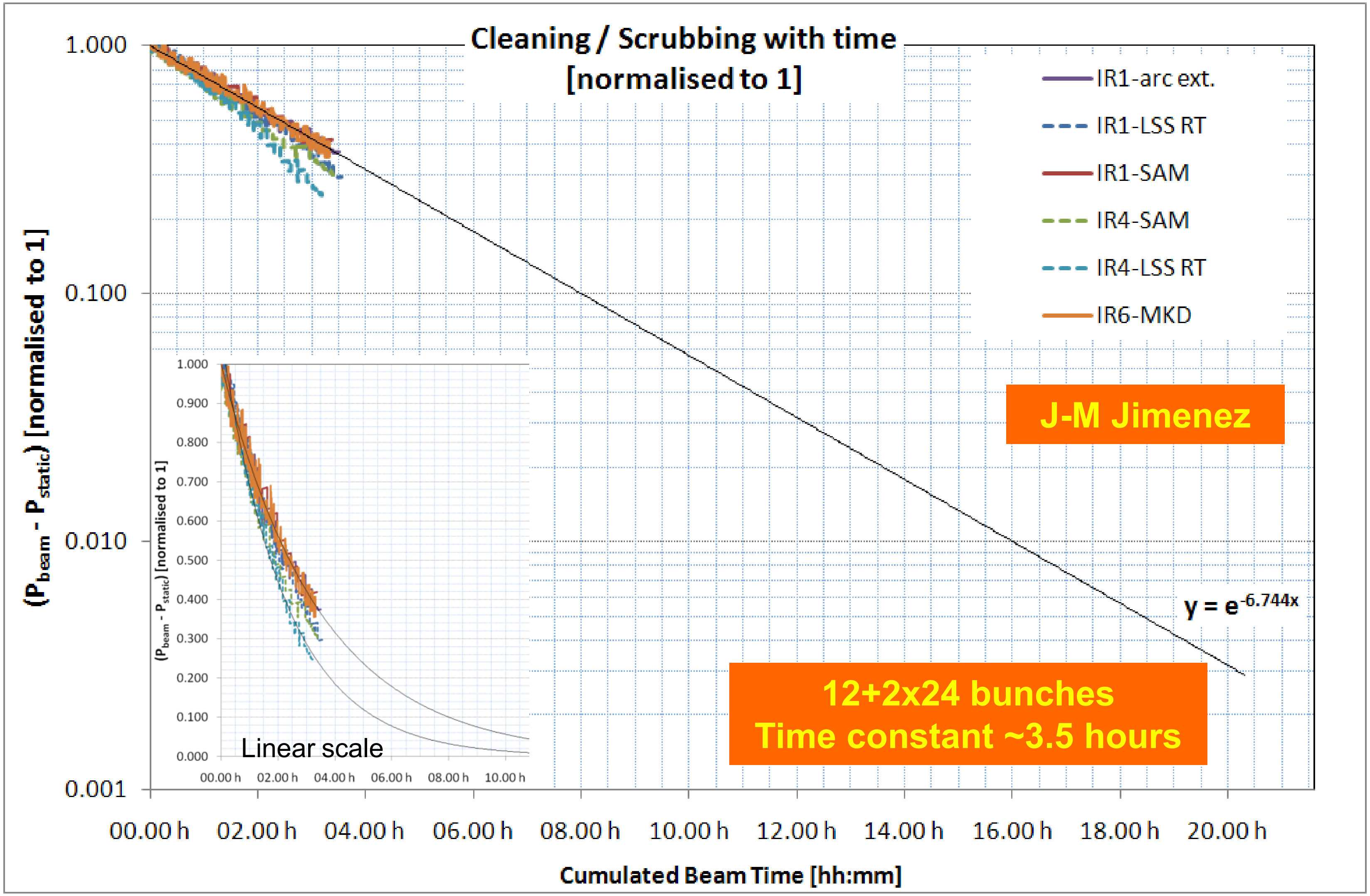


- Build-up of the electron cloud over more than one train leading to instabilities and emittance blow-up along the trains.
- Compatible with electron cloud instability



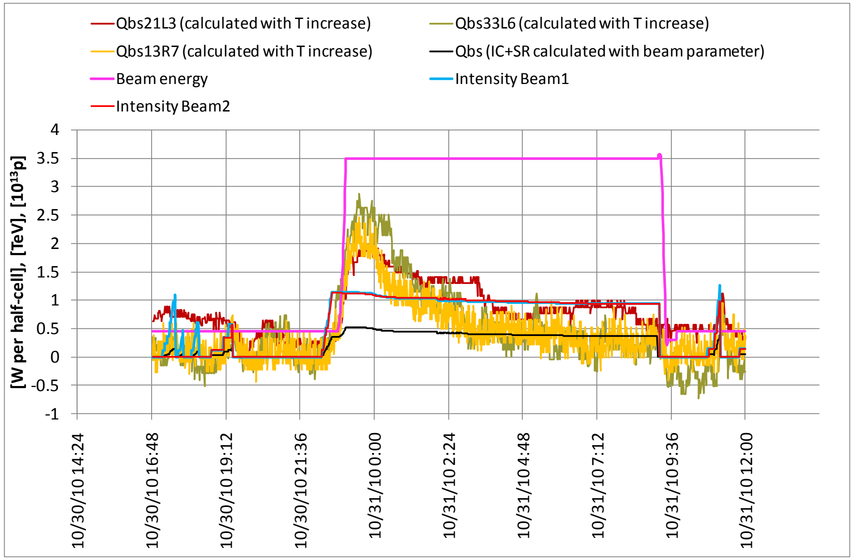


Cleaning + Scrubbing

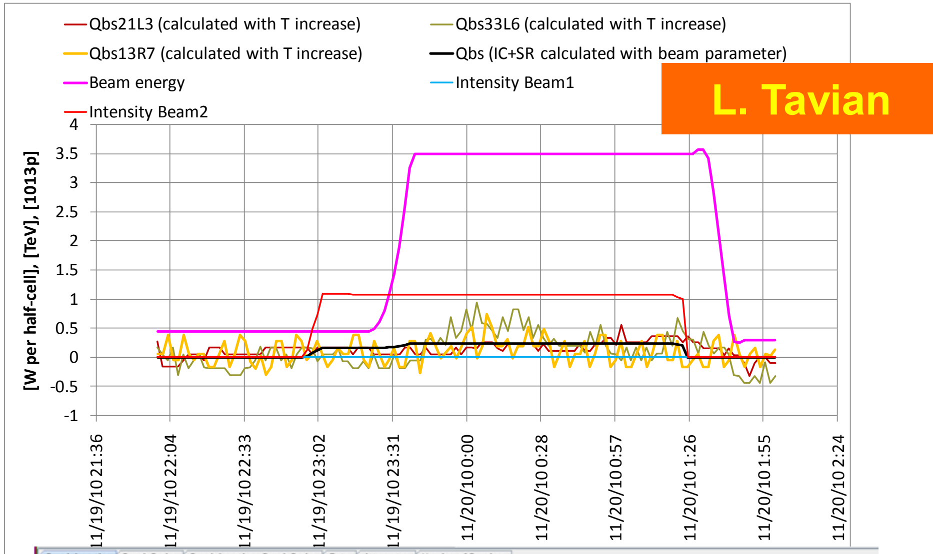


Effect of scrubbing (50 ns)

- Before scrubbing (30/10): Heat load ~20 mW/m/beam



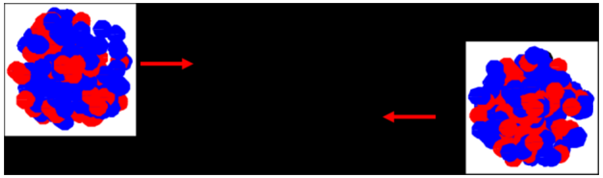
- After scrubbing (19/11): heat load <10 mW/m/beam. Only B2

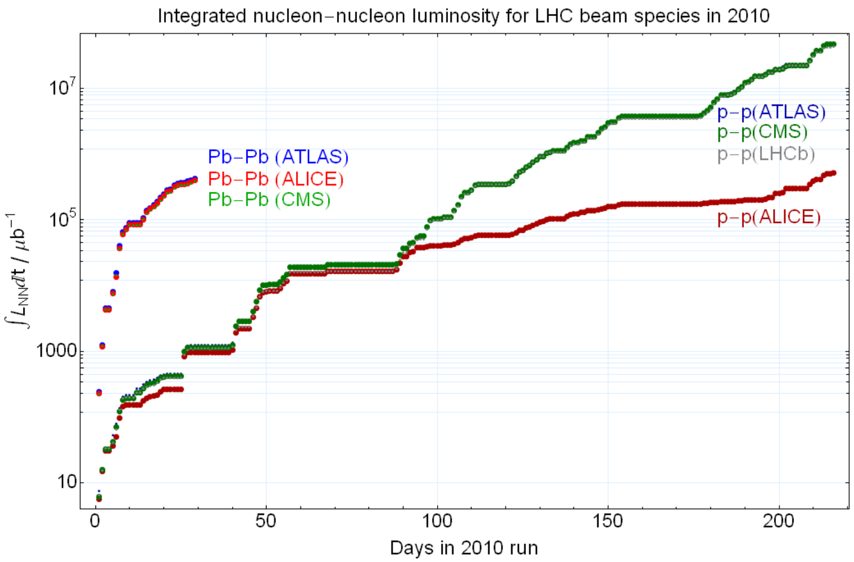


Same filling pattern (9x12 b) and bunch population (~10^{11} p). Scrubbing at 450 GeV effective also for 3.5 TeV in the arcs

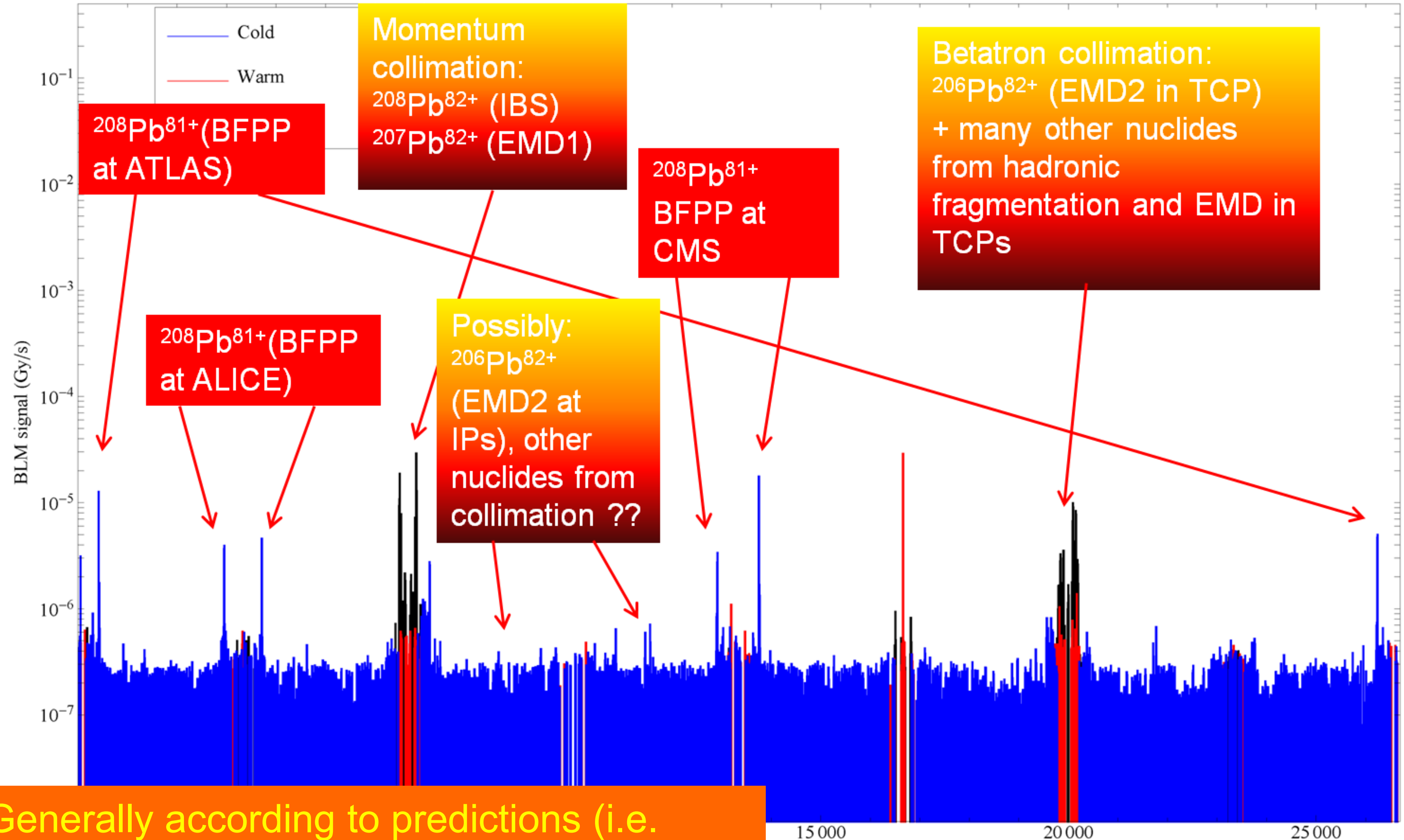
Pb run 2010

- Very fast commissioning plan worked:
  - Collisions within 50 hours of first injection
  - Profited of the experience of the proton run
  - Stable beams within 4 days (… and physics)
  - Rapid progression in number of bunches
- The LHC worked with Pb beams
  - No rapidly decaying, invisible beams
  - No quenches
- Rich/novel beam physics, much as predicted
  - Some new losses and radiation problems
  - Emittance blow-up still to be fully understood





Pb run 2010: Collimation

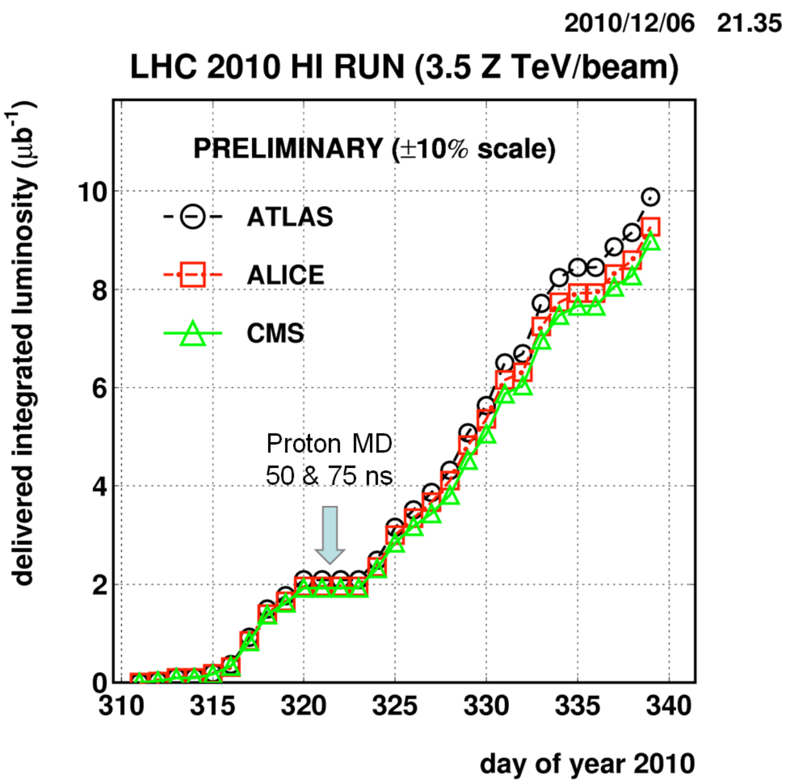


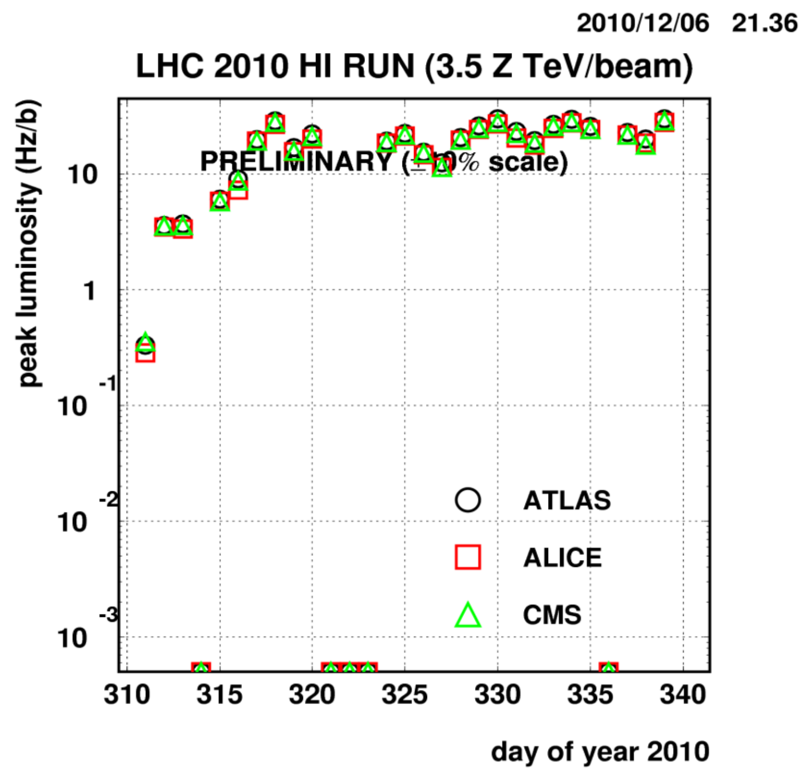
Generally according to predictions (i.e. efficiency is a factor 100-500 worse than p).

J. Jowett

Pb run 2010 - Achievements

Integrated Luminosity	10 μb^{-1}
Peak Stable Luminosity Delivered	3.04×10^{25} $cm^{-2}s^{-1}$
Maximum number of bunches in collision	137
Average bunch population	1.2×10^{8} ions (>60% above nominal)





Strategy for 2011 - protons

- **Reduction of β^* to from 3.5 m to 1.5 m**. This is possible because there is more aperture thanks to better orbit control and alignment.

  Gain = 2.3

  NB : Applies only to ATLAS/CMS, LHCb luminosity limited to ~2-3x10^{32} $cm^{-2}s^{-1}$ (β^* = 3 m for LHCb, if needed offsets at the collision point).

- **Increase number of bunches** using 75 ns (900 b) or 50 ns (1400 b) spacing.

  Gain = 2.5 to 3.8

- **Increase bunch charge N to 1.4×10^{11}** or higher if possible.

  Gain ≥ 1.4 *depends also on emittance...*

→ **$L > 10^{33}$ $cm^{-2}s^{-1}$**

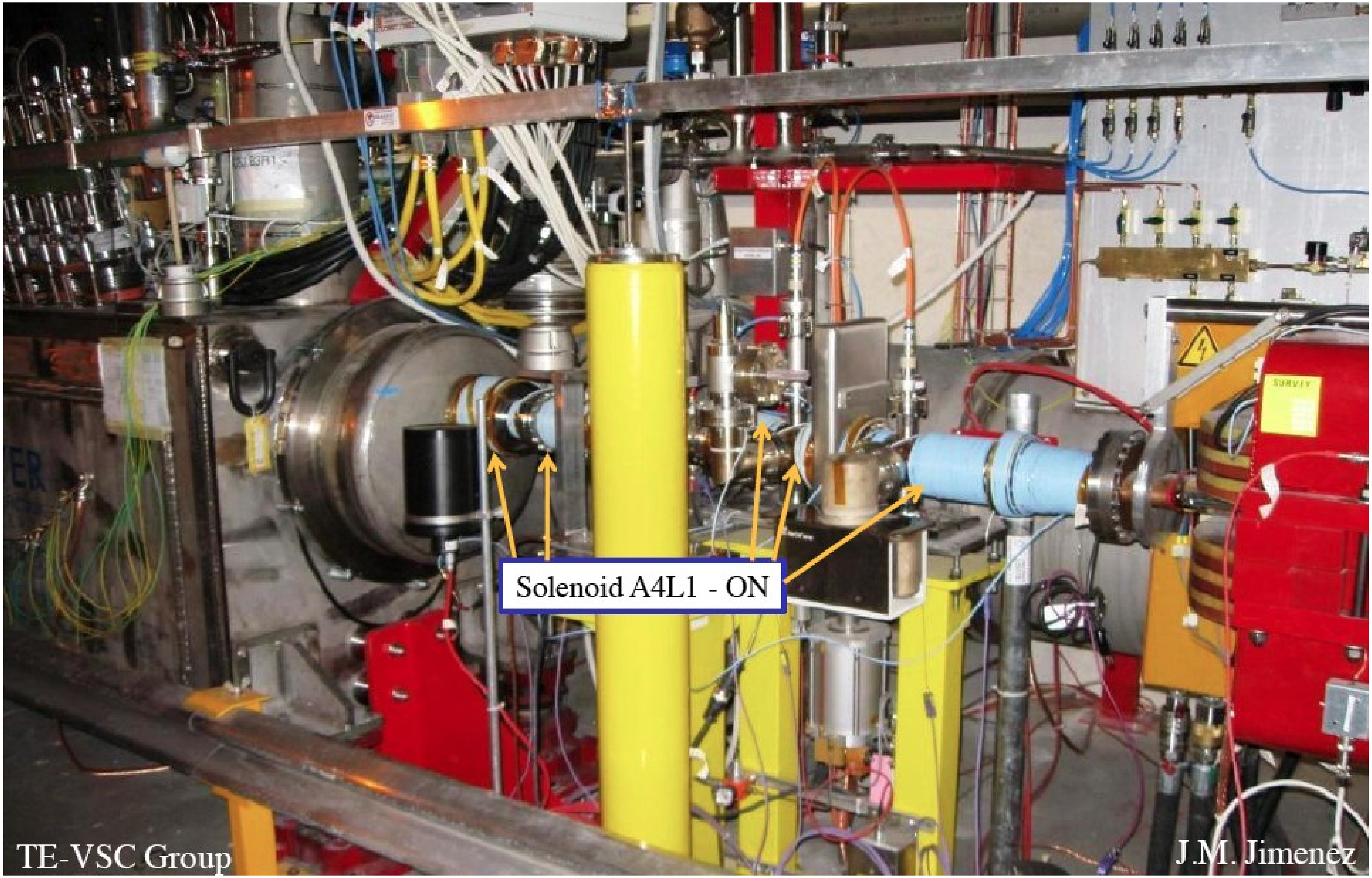
Baseline scenario

- Beam commissioning: 3 weeks
  - Exit - stable beams with low number of bunches
- Ramp-up to ~200-300 bunches (75 ns): 2 weeks
  - Multi-bunch injection commissioning continued
  - Stable beams
- Scrubbing run: 10 days including 50 ns injection comm.
- Decide on 50 vs 75 ns operation
  - 50/75 ns operation and increase bunch number
  - MP and OP qualification
- Physics operation 50/75 ns – 936/1404 b

Scrubbing strategy for 2011

- 2010 observations consistent with initial SEY ~2.5
- Expect to be able to reach 200-300 b with 75 ns without scrubbing
- Scrubbing with large emittance (>3.5 μm), high intensity (>1.2×10^{11}), 144 (4x36) bunches of 50 ns beam
- Time:
  - 2-3 days needed to setup 50 ns at injection
  - 7 days of scrubbing
  - 1 day for validation and scrubbing result evaluation
- Solenoids wrapped around warm sections close to IP1/2/5/8 during the 2010-11 Christmas stop

Solenoids between DFBX and D1 in IR1L



Estimates (early 2011)

- 125 days of high intensity operation
- Efficiency ~25% (fraction time with collisions within the 125 days).

Spacing	k_b	N_b	ε (μm)	L (Hz/cm²)	Stored E (MJ)	L int (pb⁻¹)
75 ns	930	1.10E+11	2.5	1.1E+33	65.5	2360
75 ns	930	1.40E+11	3.5	1.3E+33	83.3	2730
50 ns	1400	1.10E+11	2.5	1.6E+33	98.6	3552
50 ns	1400	1.40E+11	3.5	1.9E+33	125.4	4110

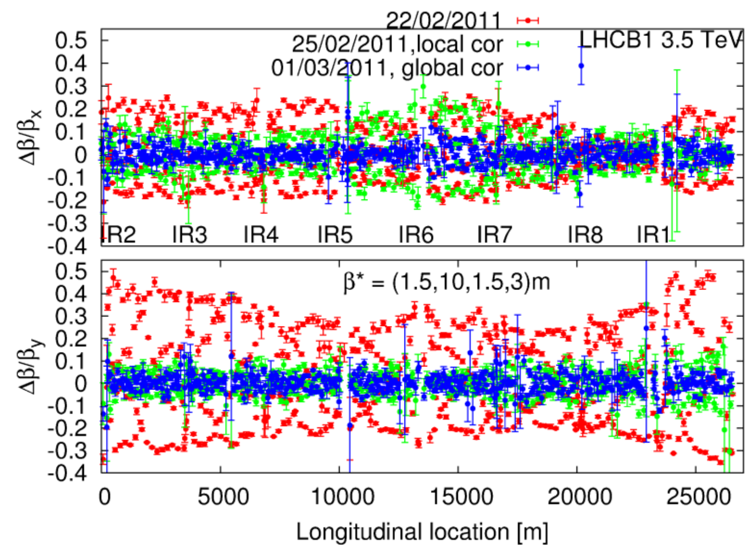
- Main goal: 1 fb^{-1} delivered to each of IP1, IP5 and IP8 at 3.5 TeV. Alice pp run: 5×10^{29} to 5×10^{30} $cm^{-2}\,s^{-1}$
  - Can probably do better for IP1 and IP5
- It will be a challenge to deliver 1 fb^{-1} to IP8
  - Maximum luminosity : from 2×10^{32} to 3×10^{32} $cm^{-2}\,s^{-1}$
  - Luminosity leveling via separation required to get close

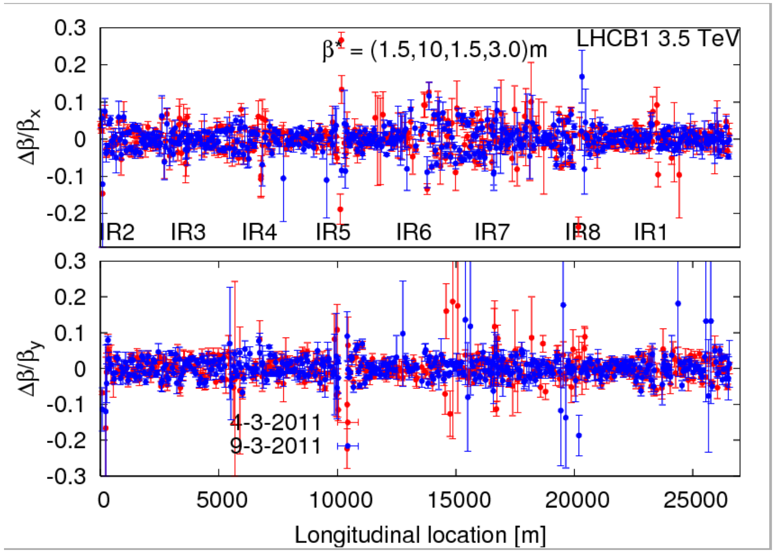
Re-commissioning with beam

- Beta beating corrected down to 5-10%!!
- Confirmed stability of the optics
- 'Final' β* values from K-modulation:

Beam/plane	IR5	IR1
B1H	1.50	1.53
B2H	1.48	1.57
B1V	1.52	1.50
B2V	1.52	1.57

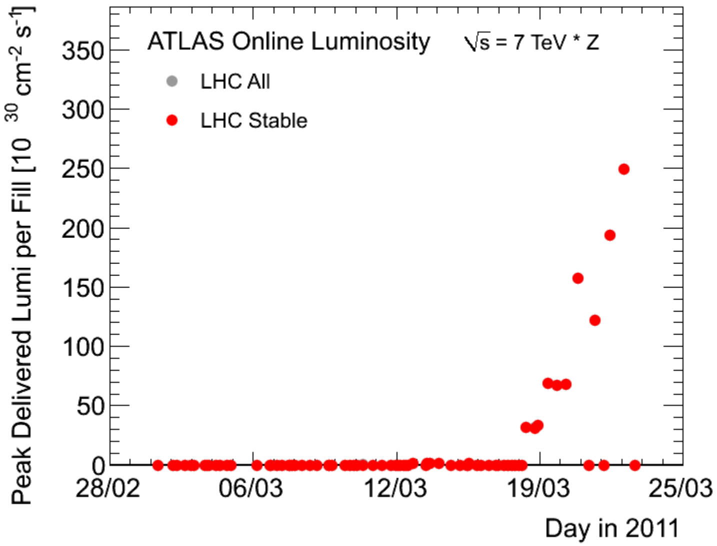
- Errors around 4-10%
- Aperture: global > 12 σ, triplet > 14.5 σ





Re-commissioning with beam

- Transfer line and multi bunch injection setup:
  - Transfer line trajectories more reproducible then in previous year
  - establish injection with up-to 24 bunches per injection & operation with 200 bunches with 75 ns bunch spacing
- Collimation system setup:
  - achieved setup time of ca. 25min / collimator tank
  - Leakage to cold elements of ~10^{-4} at 3.5 TeV
- Performance achievement:
  - ε = 2.5 μm in collision @ 1.2 10^{11} ppb
  - 15 MJ stored beam energy
  - L = 2.5 10^{32} cm^{-2} sec^{-1} with 194 colliding bunches



After 10 days of physics!!

Scrubbing run

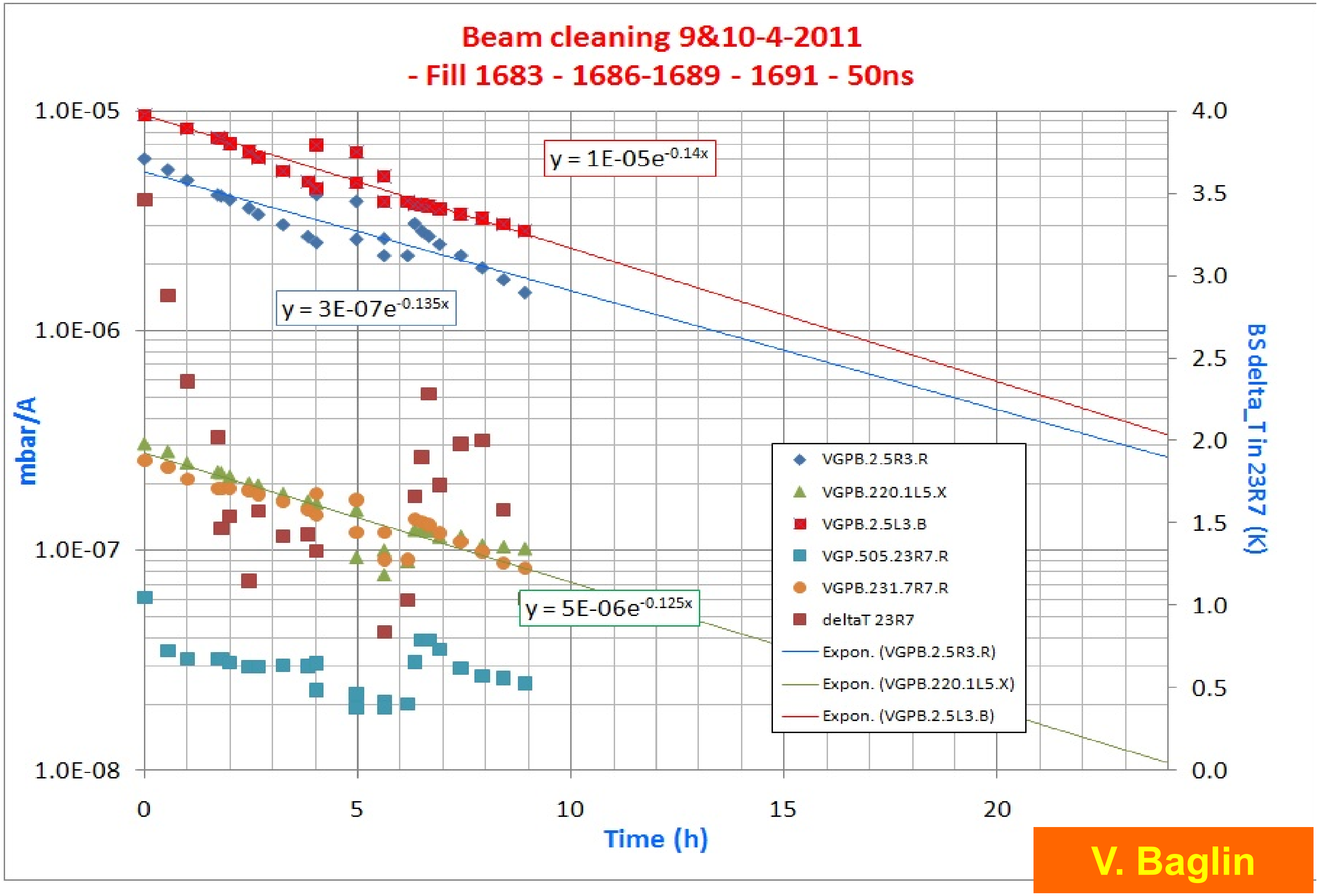
- Impressive progression in spite of several technical problems not related to the scrubbing (> 3 days lost).
- 5 days of scrubbing
- All solenoid off (experiments and vacuum solenoids at warm sections)

Date	Bunches B1+B2
Tue 5th April	300+300
Wed 6th April	408+336
Sat 8th April	588+588
Sun 9th April	804+804
Mon 10th April	1020+1020

- Careful increase in intensity (in steps of 200 bunches) monitoring cryogenics, vacuum, machine protection and particularly RF
- Limited to 72 bunches/train by injection performance
- reached 1020 bunches per beam at the end of the scrubbing run ➔ more than 10^{14} protons per ring

Scrubbing: vacuum evolution

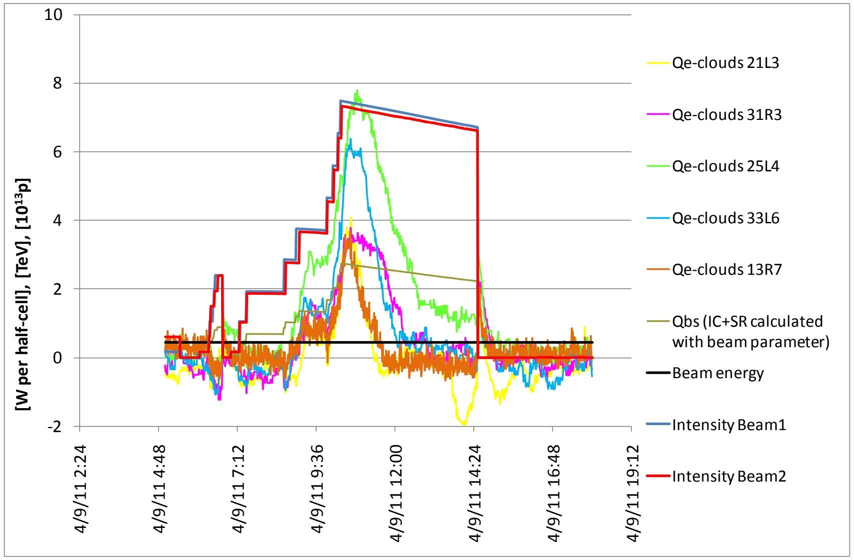
- Time constant of ~ 4 hours. Consistent with 2010 observations

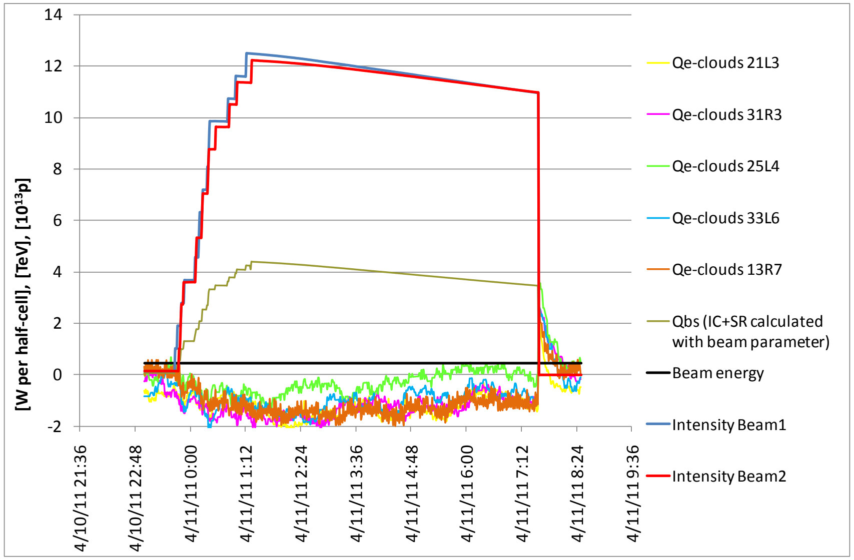


V. Baglin

Scrubbing: Heat-loads in the arcs

- Impressive reduction of the heat load in few hours: results consistent with SEY reduction from 2.5 to <1.8

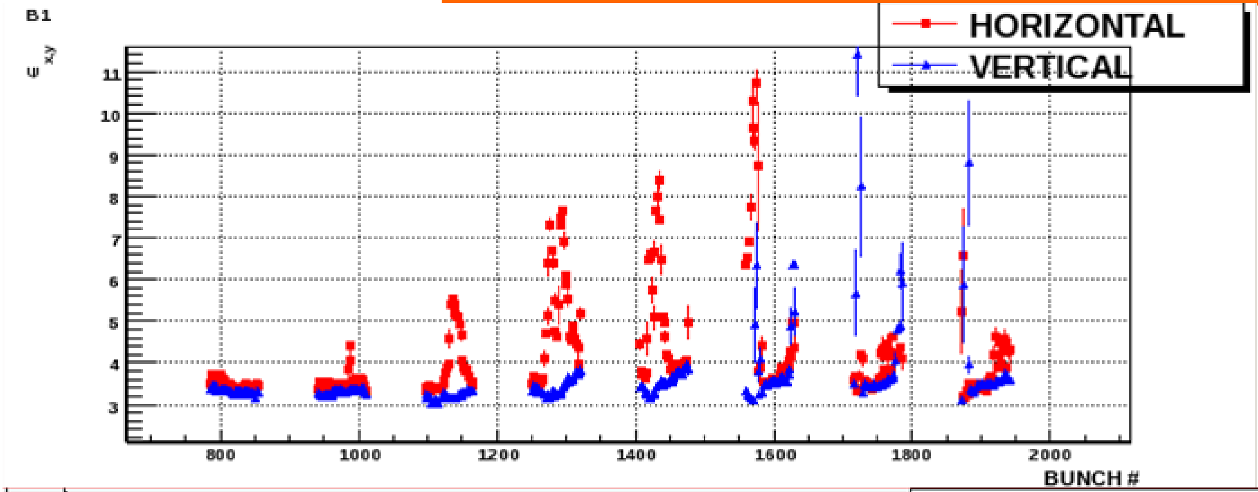


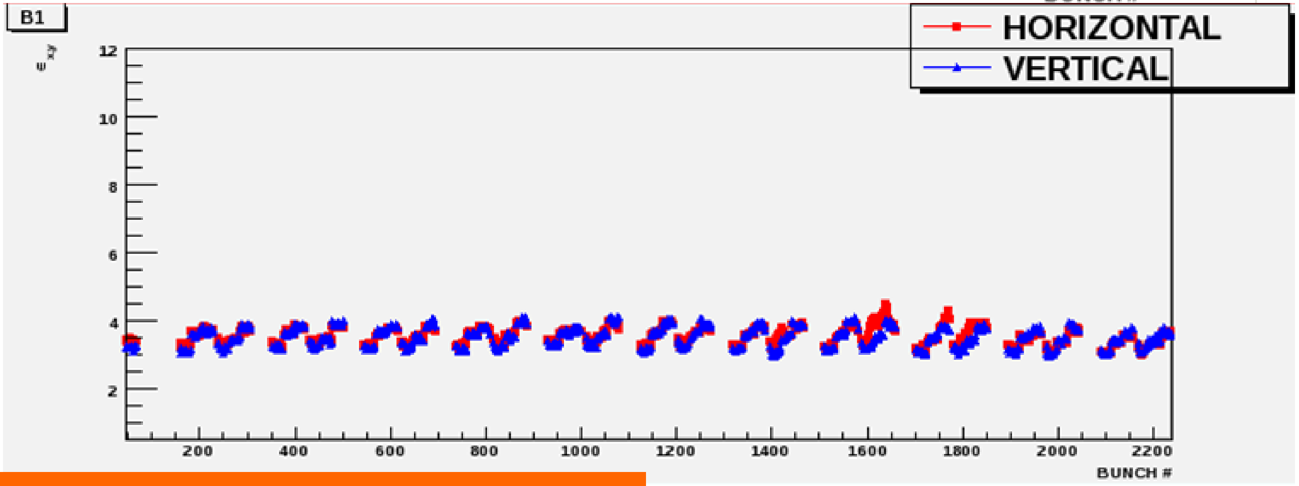


L. Tavian

Scrubbing: effect on beam

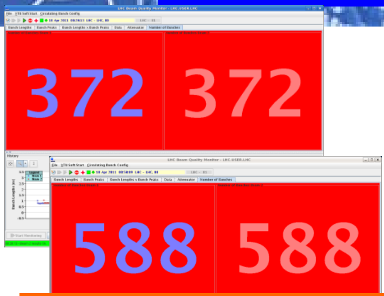
We started like that – 300 bunches

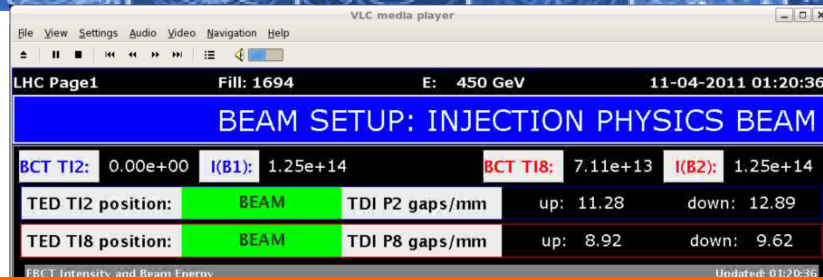


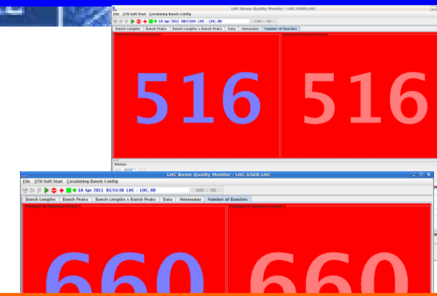


804 bunches some hours of scrubbing

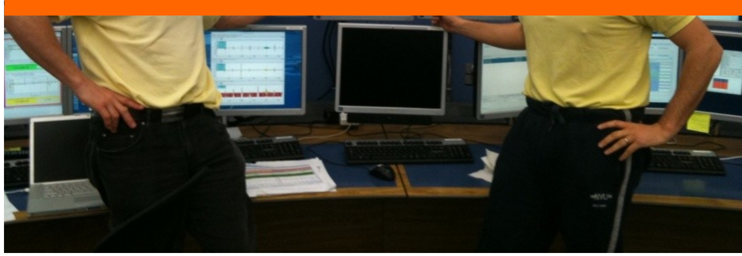
Progression

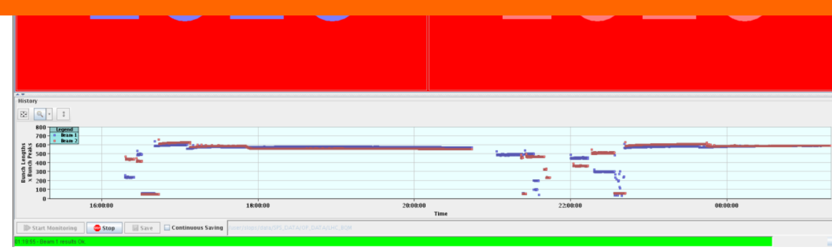






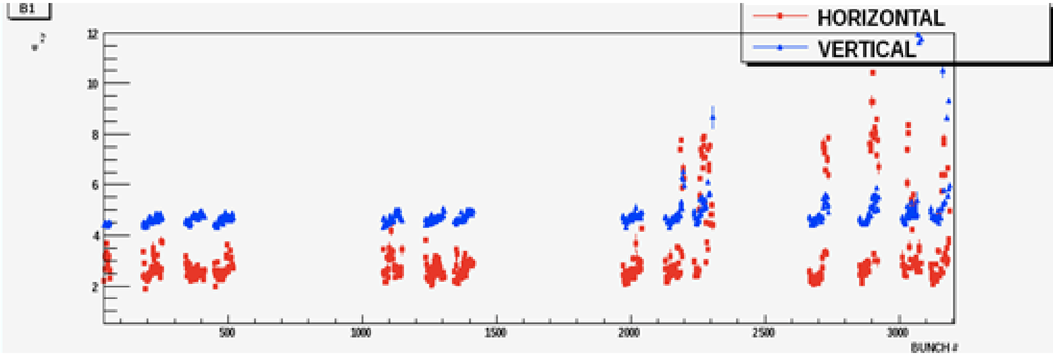
Decision: continue physics with 50 ns beams given the positive results and the higher potential of 50 ns vs. 75 ns beam

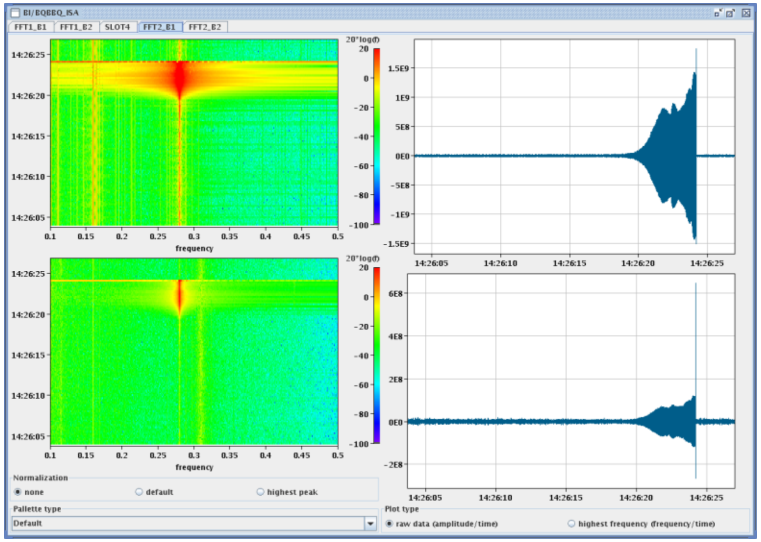




High intensity effects: beam stability

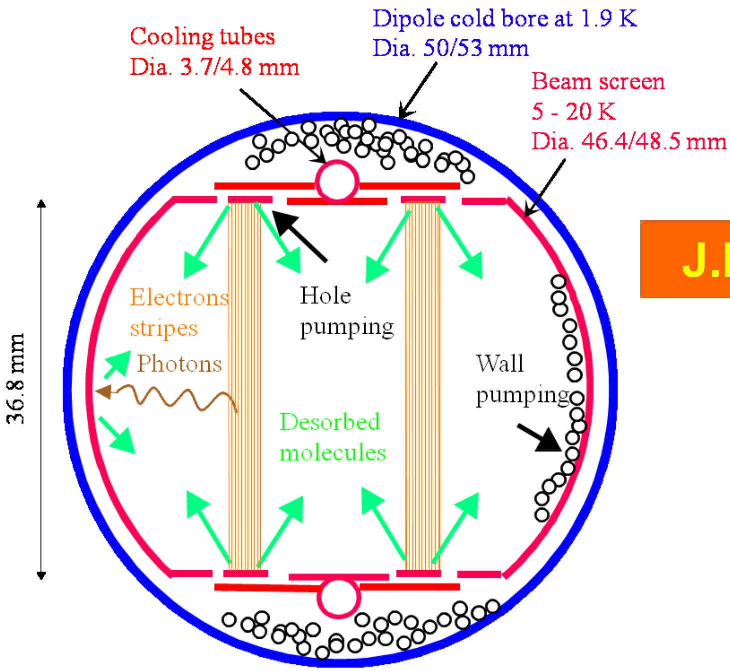
- Need tight control of the machine parameters at injection (chromaticity at ~1 unit) to avoid instabilities due to machine impedance ➔ Improvement with the implementation of the on-line magnetic model corrections (FiDeL)

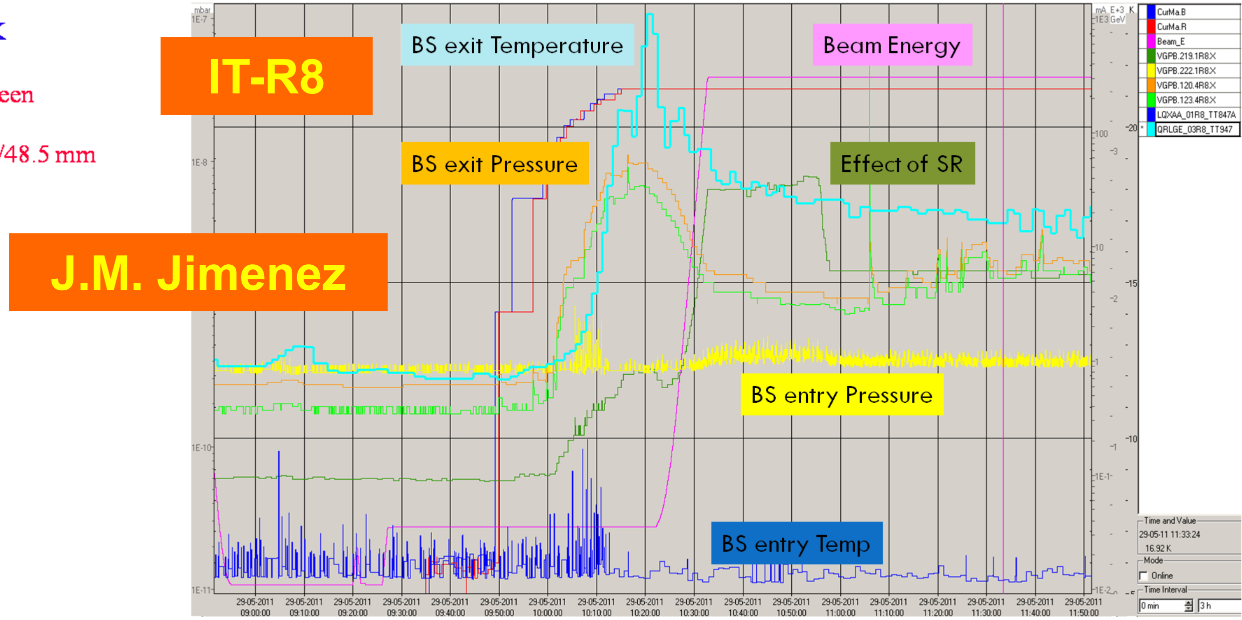


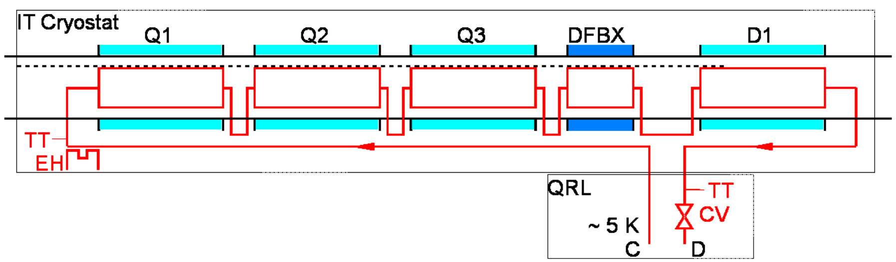


- ....and in in all phases (ramp, squeeze, collision) ➔ expected and it can be done!!

High intensity effects: vacuum & cryogenics



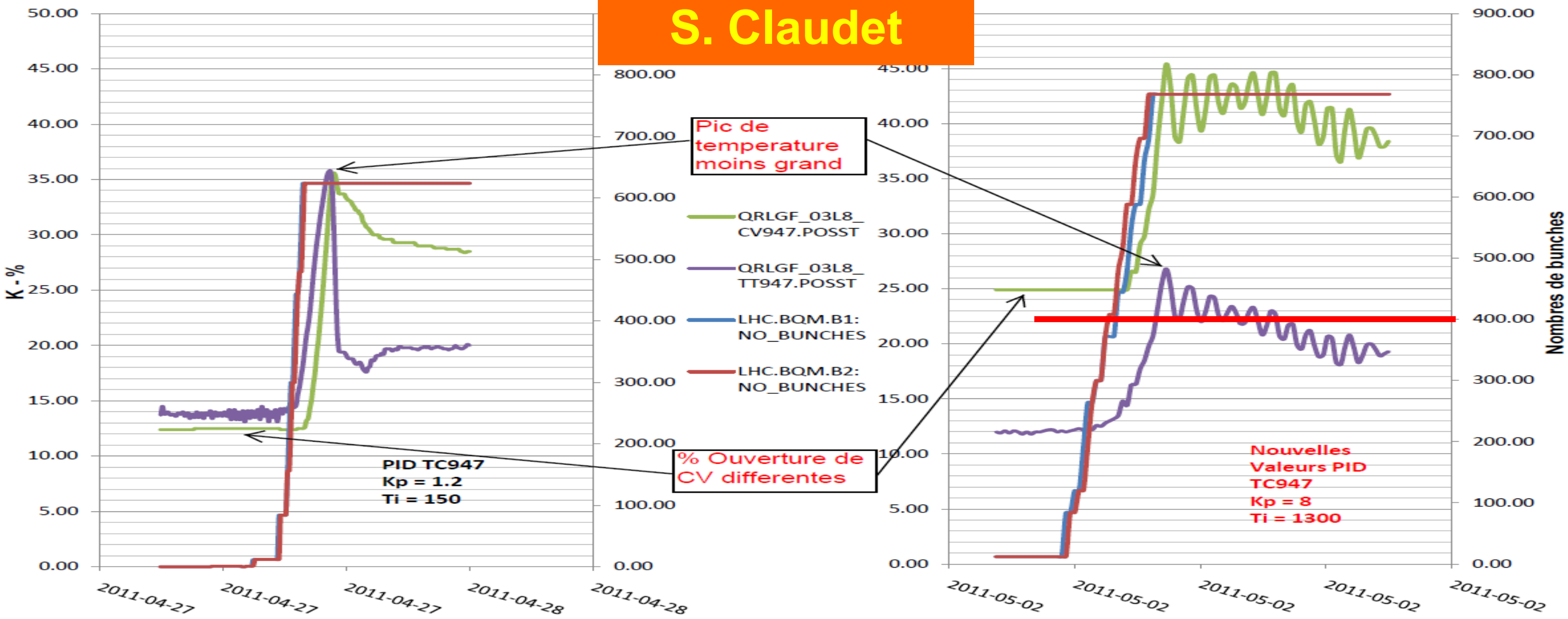




- Interplay between Beam Screen temperature and vacuum. Too large temperature excursions (resulting from injection of high intensity) lead to pressure rise and beam dumps due to vacuum or beam losses

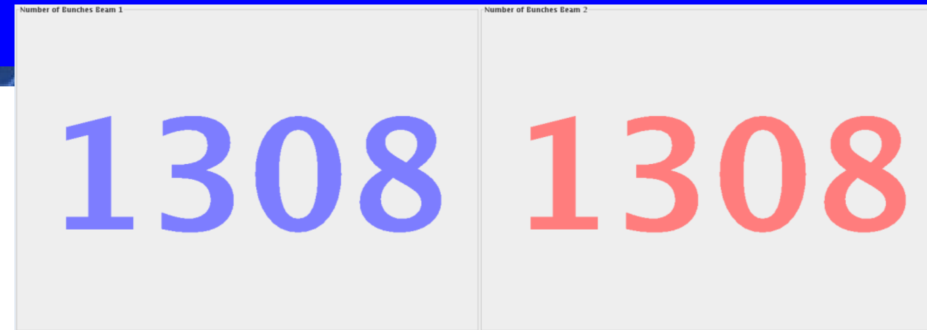
High intensity effects: vacuum & cryogenics

S. Claudet



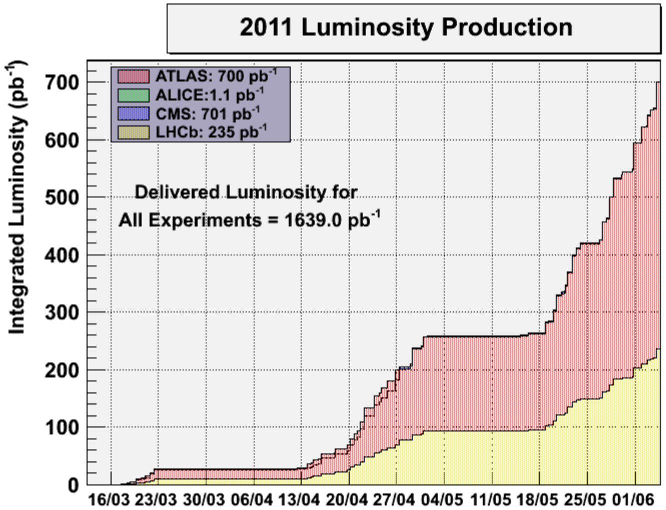
- New BS temperature regulation implemented in May to minimize peak at injection (25K max.) and get 17K during beam operation
- Cryo bake-out tested in point 8 to transfer condensed gas (H_2 and CO) from beam screen to cold bore
- No more issues related to vacuum observed!!

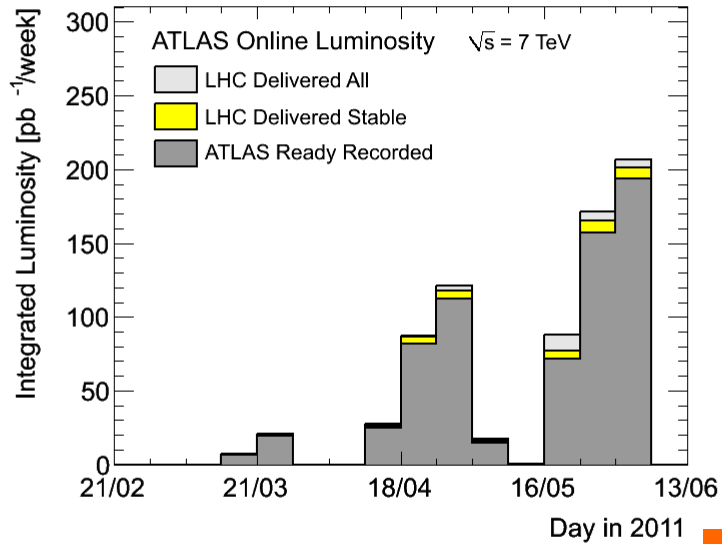
Achievements



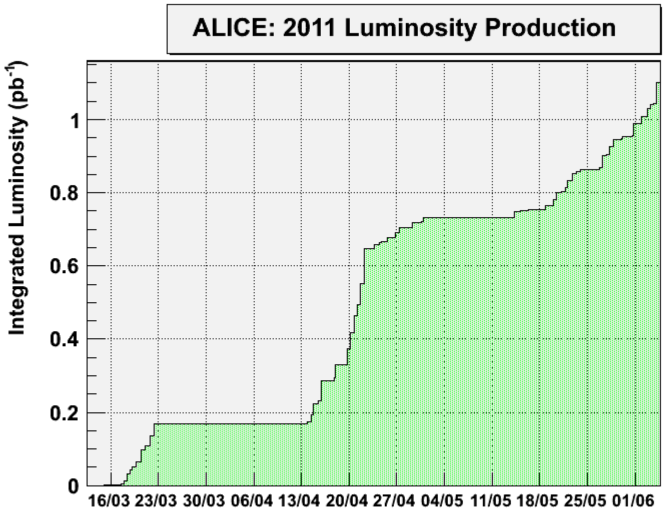
Integrated Luminosity to date (IR1-5/IR8)	0.7 fb^{-1}/0.24 fb^{-1}
Peak Stable Luminosity Delivered	1.26×10^{33} $cm^{-2}s^{-1}$
Maximum number of bunches at 450 GeV/c	1308
Maximum number of bunches in collision	1092
Maximum intensity in collision at 450 GeV/c	1.5×10^{14} p/beam
Maximum intensity in collision	1.3×10^{14} p/beam
Maximum stored energy	73 MJ/beam
Average bunch population	1.2×10^{11} p
Emittance in collision	2.5 μm
Maximum Luminosity Delivered in one day	46 pb^{-1}
Maximum Luminosity Delivered in one week	200 pb^{-1}

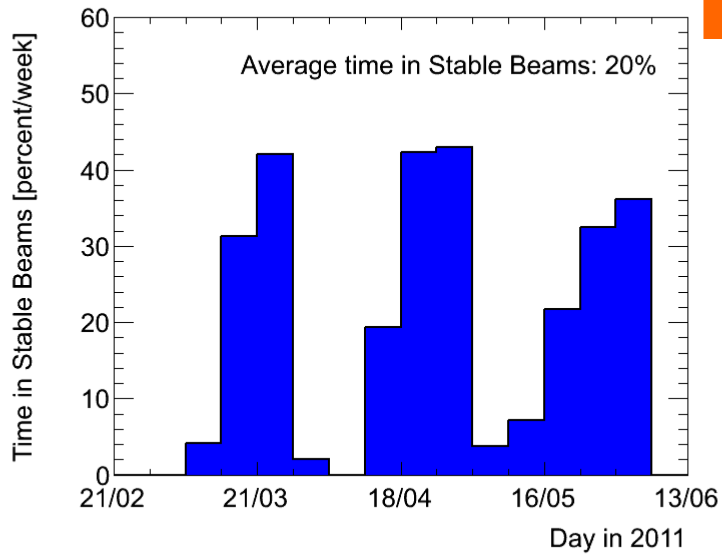
Achievements





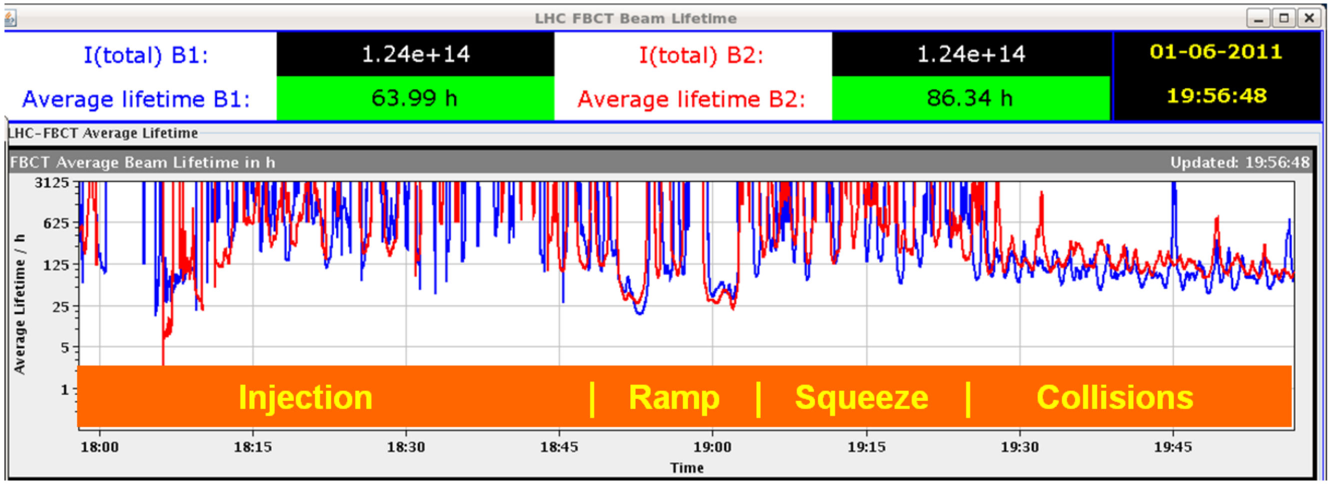
c/o ATLAS



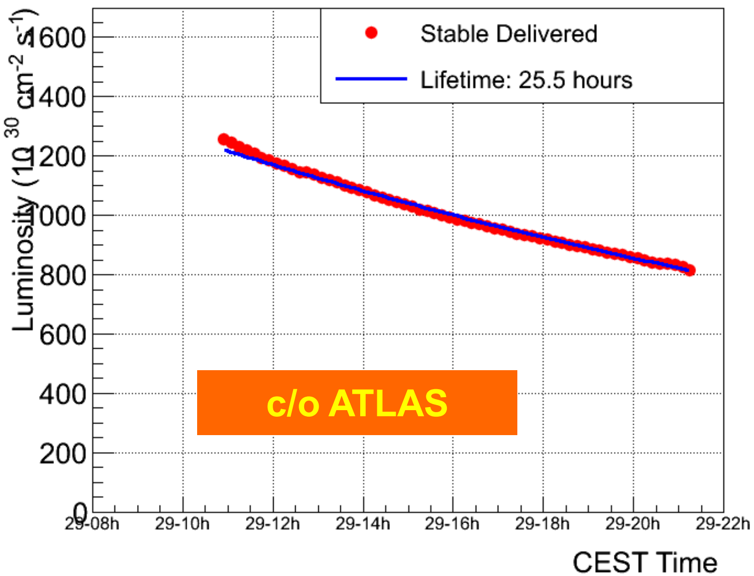


Lifetimes during a fill (1092 bunches)

- Very good lifetime during the whole process
- Hardly visible when we go in collision

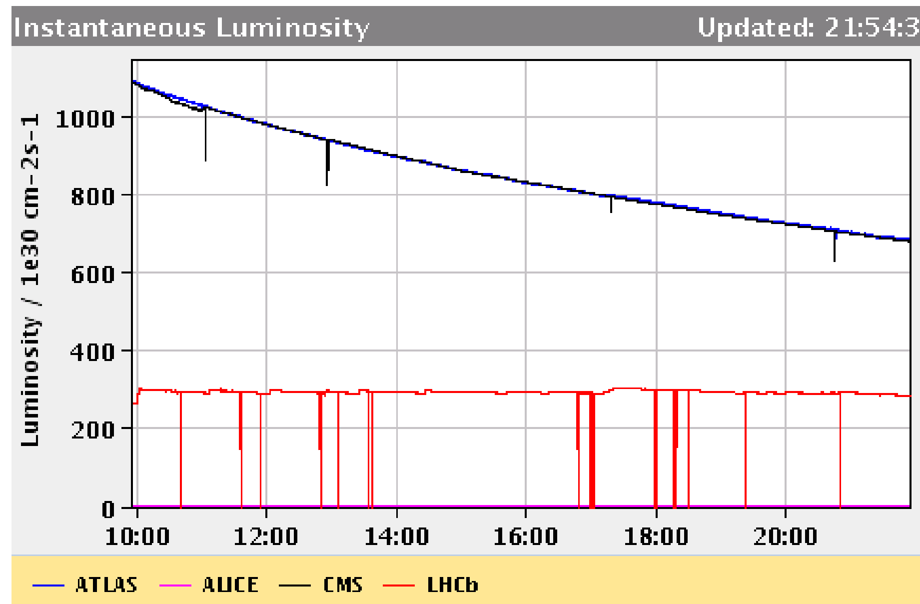


- Luminosity lifetime > 20 hours



IP8 Luminosity leveling operational

- Absolutely needed to get to 1 fb^{-1} in LHCb given the limit in peak luminosity



Outlook for 2011 (protons)

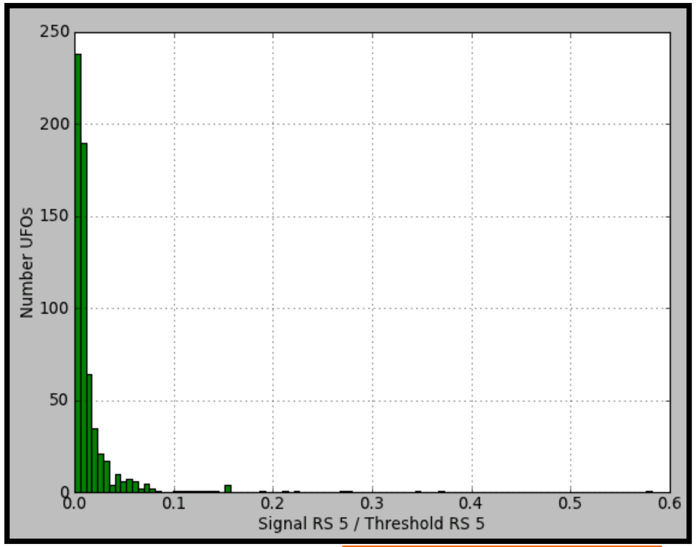
- From the beam dynamics point of view no show-stoppers are in view to increase number of bunches or bunch intensity to the previously mentioned values and peak luminosities of 2×10^{33} $cm^{-2}s^{-1}$ are within reach. Recent MDs have provided promising results in that respect.

- Possible 'Threats' for further performance progression
  - UFO
  - Radiation induced Single Event Upset in tunnel electronics

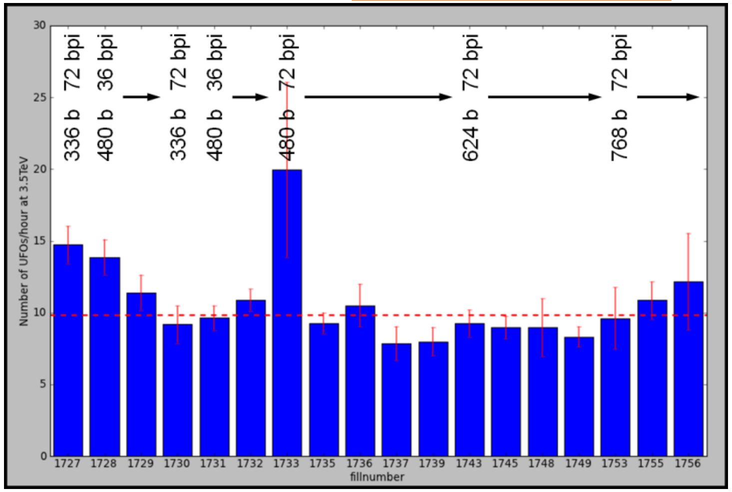
- We are presently working on understanding and finding solutions to them → stabilize very good performance achieved so far before next steps

Potential performance limitations: UFOs

- Most UFOs are much below threshold (<0.1 %)
- But 8 cases above dump: 6 of which in the last 2 weeks with > 912 bunches. 4 of which located at MKIs.
- So far:
  - no dependence of loss level on total intensity had been observed. Outliers?
  - No evidence of a dependence of the UFO rate on intensity and number of bunches/SPS train.
  - No evidence of a cleaning either (unless cleaning and intensity ramp-up compensate exactly…)

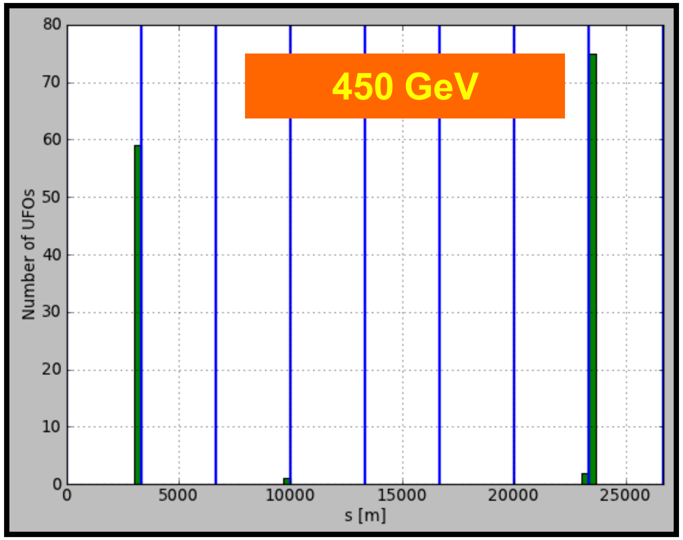


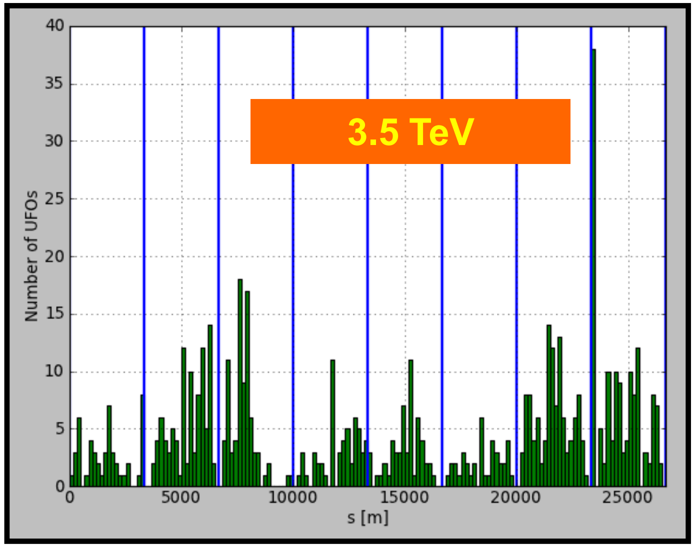
T. Baer



Potential performance limitations: UFOs

- At 450GeV: only at MKIs
- At 3.5 TeV:
  - at MKI ➔ MKI in point 8 is sticking out. Concentration around MKI is likely key for understanding this phenomenon.
  - in all sectors, peaking in the middle of the arcs. No UFOs left of IP4.



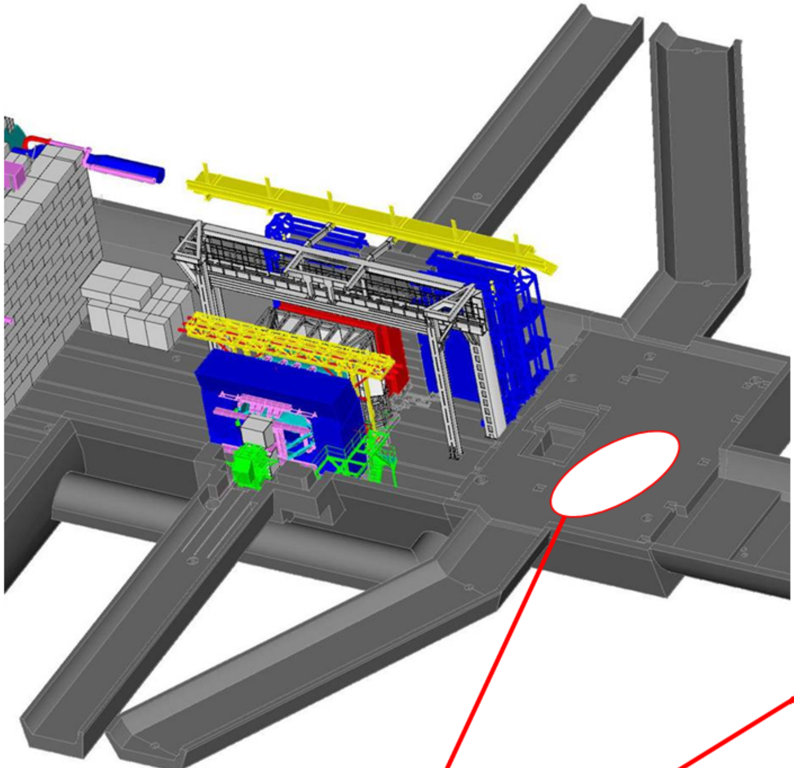


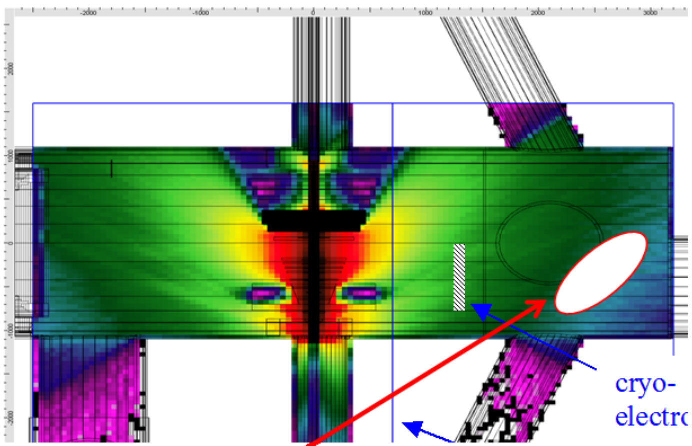
- BLM thresholds still conservative: no beam induced quench observed at high energy ➔ increased BLM threshold by a factor 2 close to MKI (4/6) following a step-wise cautious approach.

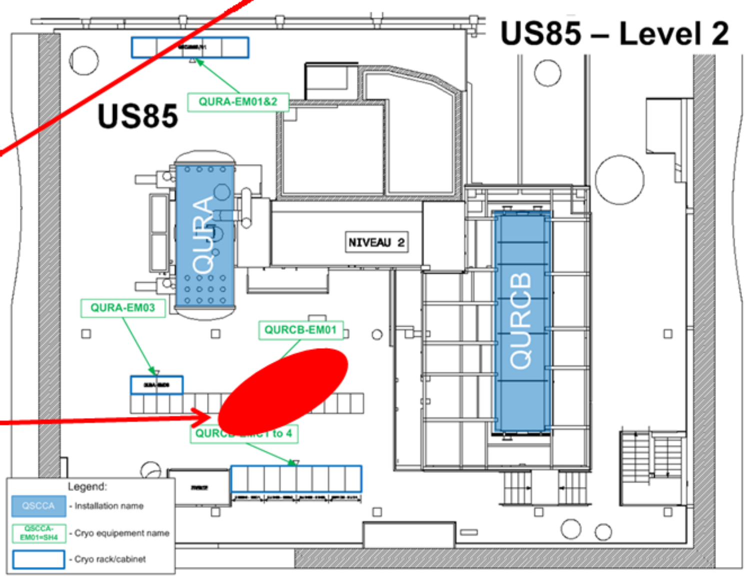
Potential performance limitations: R2E

- Point 1 (related to luminosity):
  - Collimation Control UJs@P1 (**confirmed**) ➔ Shielding (Christmas stop 2011-12). Reduction of fluence by factor 10
  - Cryogenics UJ14 (**confirmed**) ➔ idem
  - QPS Control UJ14/16 (**2x, corrector circuits**) ➔ Firmware update (being prepared)
- Point 5 (related to luminosity):
  - RR57 + ? Power-Supply (**2-3?**)
  - UPS UJ56/US85?(**unlikely, but possible**)
- Point 8 (related to luminosity):
  - US85 PLCs (Cryo, **3x, likely**) ➔ Relocation of critical CPU during next technical stop
- Distributed :
  - QPS ISO-150 (**multiple, tunnel & shielded areas**) [**Soft + New Develop.**]
  - uFIP as used in QPS/Cryo (**few times, tunnel**) [**Soft + New Develop.**]
- Careful monitoring ongoing (statistics is still – luckily – low) Contingency plan for the critical equipments in preparation

Potential performance limitations: R2E



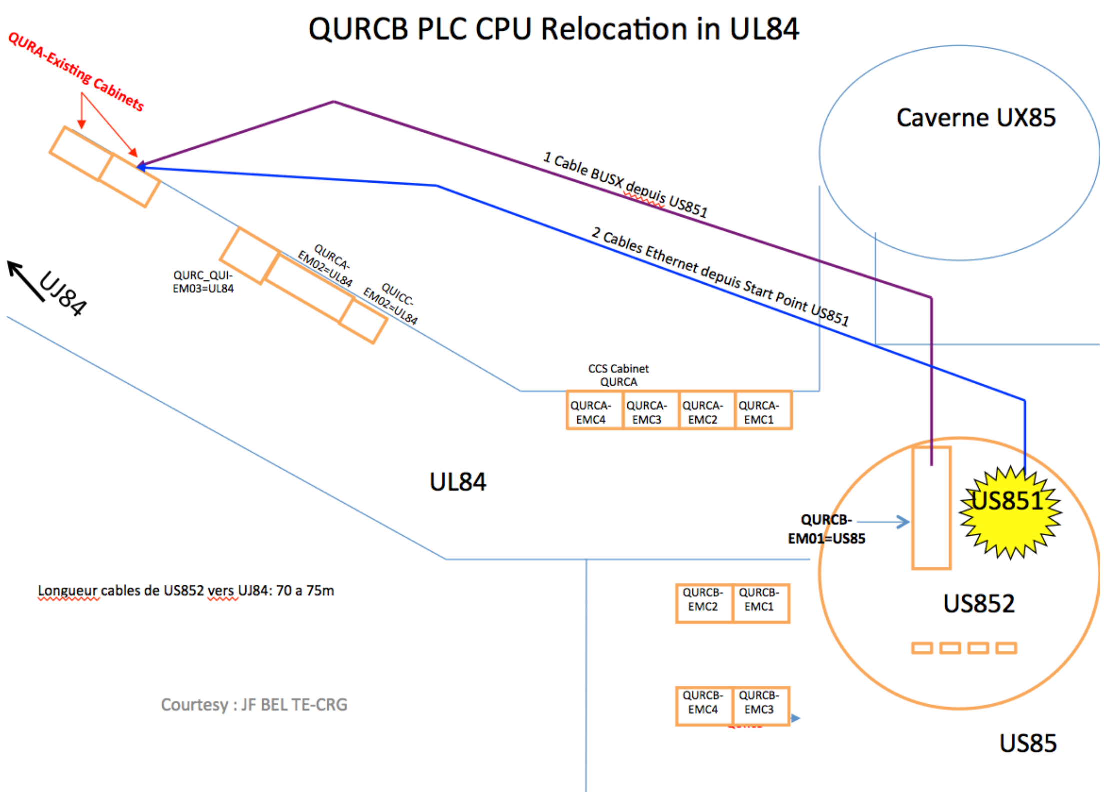




QURCB PLC localization

Potential performance limitations: R2E

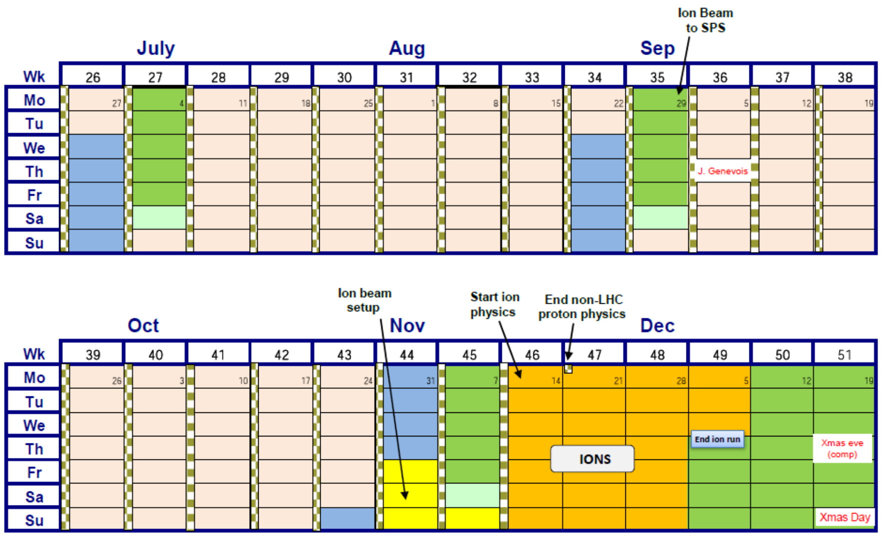
- Technically Feasible
- Low risk:
  - No change in logic,
  - Limited PLC reconfiguration
- Can be done in July TS
  - Cable and connector at CERN
  - Additional components ordered, action taken toward Schneider to receive them next week



Ph. Gayet

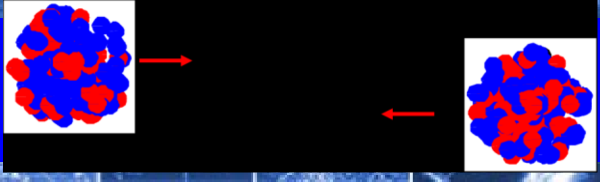
Outlook for 2011 (protons)

- Length and frequency of the technical stops optimized to maximize periods of steady production
- 115 days at >10^{33} $cm^{-2}s^{-1}$ and an efficiency for Physics (Hubner factor) of 0.2 gives >2.3 fb^{-1}
- Main unknown: UFOs and SEU but we are working on that!



- 25 ns studies to come during MDs (to sort out injection and beam stability issues) and possibly an operational development period to validate scrubbing and future operation scenarii

Outlook for 2011 (Pb)



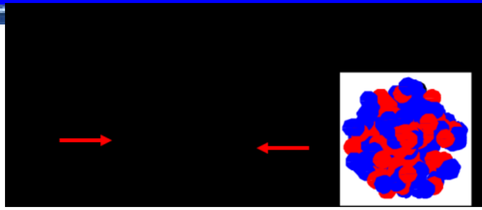
- Number of bunches vs. Bunch population
  - Possibility to reach 540 bunches but likely limited to nominal bunch population
  - Injectors, Early or Nominal (not yet fully tested in SPS) with a possible intermediate scenario

- Optics
  - Take over ATLAS and CMS β* from pp
    - Possibly reduce crossing angles ? Quick in 2010.
  - Squeeze ALICE to same value β*= 1.5 m
    - 2 days setup, unless done previously with protons

- Could reach peak luminosities in the range of 1-1.4 $\times 10^{26}$ $cm^{-2}s^{-1}$ and integrate 30 to 50 μb^{-1}

- Short run more sensitive to any prolonged machine stop

Testing p-Pb in 2011



- Important to resolve uncertainties regarding feasibility, Pb intensity limit from unequal revolution frequencies at injection, ramp
  - Modulation of long-range beam-beam, excitation of overlap knock-out resonances, transverse feedback, tune-control …
- Crucial questions are related to injection and ramping
  - Effects of protons (say 10% of nominal) on one Pb bunch
  - Inject few Pb bunches against some convenient p filling scheme
  - Possible in 2011 (small LLRF upgrade needed to collide, OK in 2012)
  - Detailed planning of MD being worked out

Summary

- Experience 2010 and re-start 2011:
  - Injection, ramp and squeeze fully operational
  - LHC magnetic model & optics excellent
  - Beam instrumentation in good shape.
  - Beam cleaning and collimation works reliably with predicted efficiency.
  - Machine protection excellent performance
  - Machine aperture looks good

We have a beautiful machine on our hands both for protons and ions!

- The machine can work with high specific luminosity, good beam and luminosity lifetime, low losses with 50 ns beam

Summary

- High intensity was known to require more careful control of the machine parameters and systems:
  - initial difficulties related to instabilities and vacuum/cryogenics interplay solved).

- 50 ns has proven to be a good choice ➔ more potential

- 1 fb^{-1} is well within reach for ATLAS and CMS (very challenging for LHCb). How higher we can go for ATLAS and CMS will depend on extent of:
  - UFOs
  - Radiation to electronics

….but we are attacking them and optimizing our strategy…

Summary (Ions)

- Substantial factor in luminosity possible for 2011:
  - Different options for filling are possible pending results form injector commissioning, we count on experiments flexibility

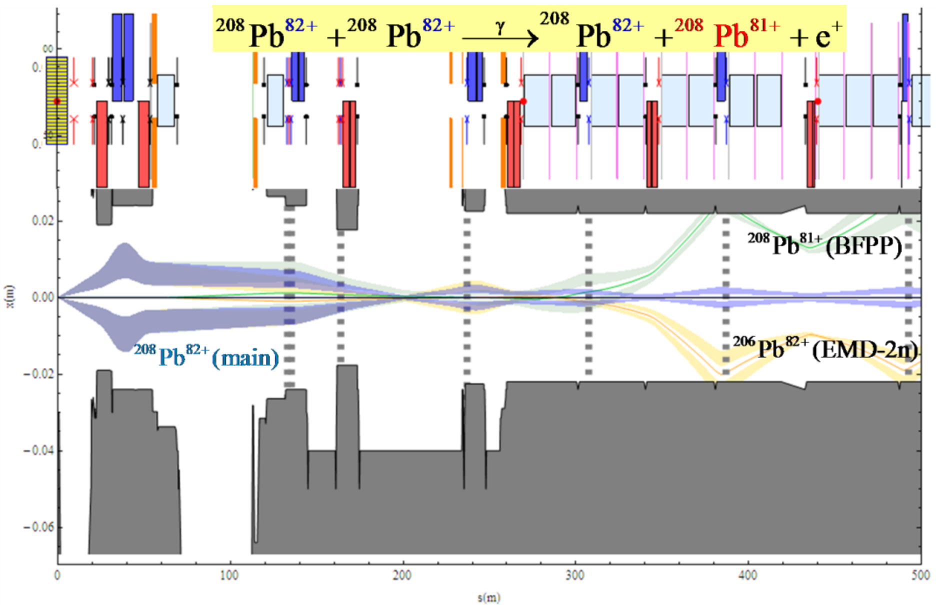
- By the end of 2011 we should have a better idea on issues for the operation p-Pb and on the feasibility of the p-Pb run in 2012.

Thank you for your attention !!!

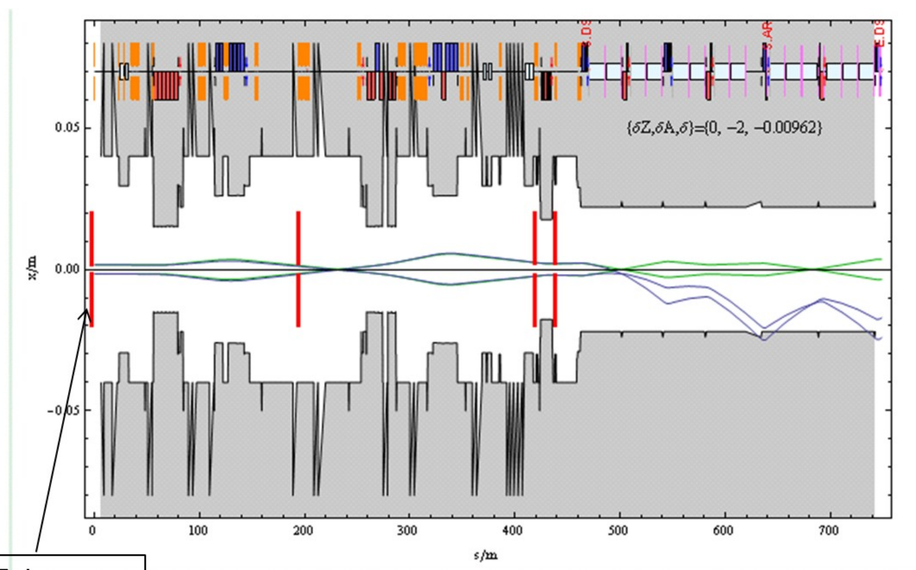
Collimation

G. Bellodi, R. Bruce, J. Jowett

BFPP at IP2. This might pose the tighter constraint in luminosity



EM Dissociation at collimator in IR7



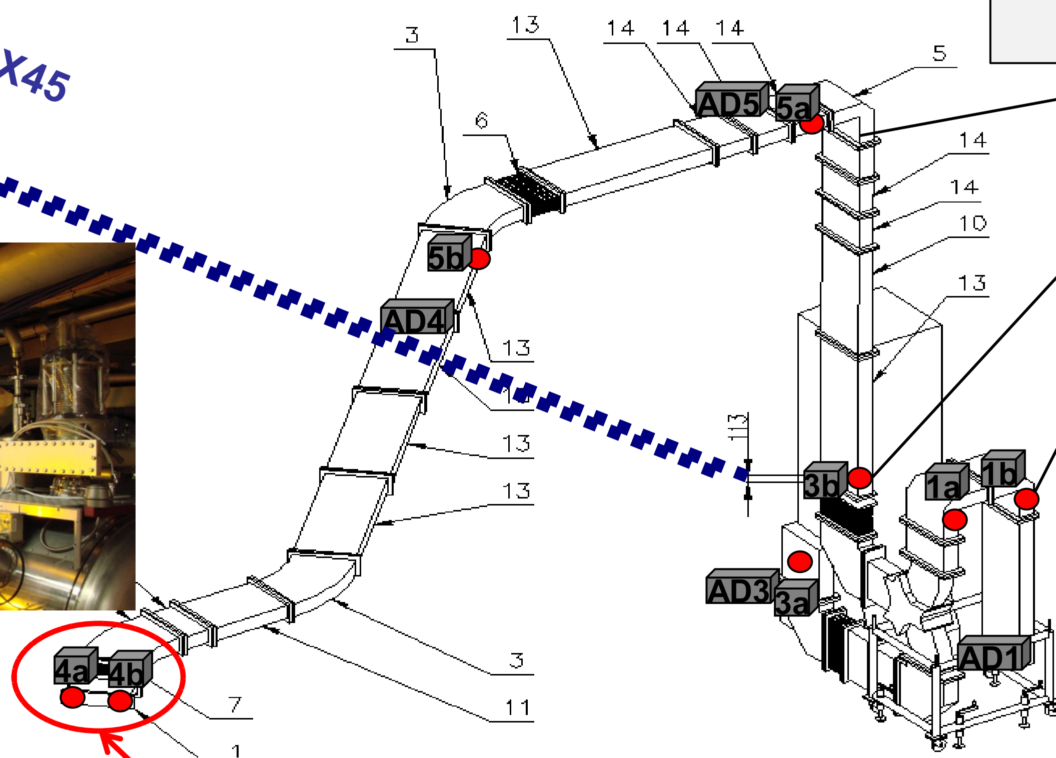
Primary collimator

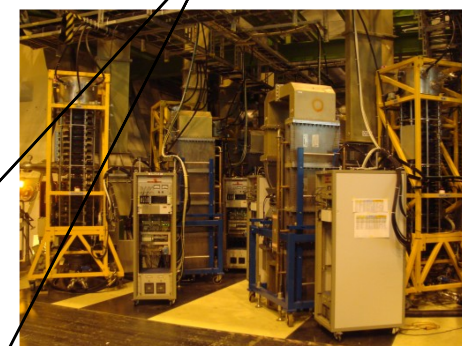
Spurious RF arc detection triggers

Each power station is equipped with eight arc detectors

- Klystron output couplers – circulators – RF loads – WG – cavity power couplers

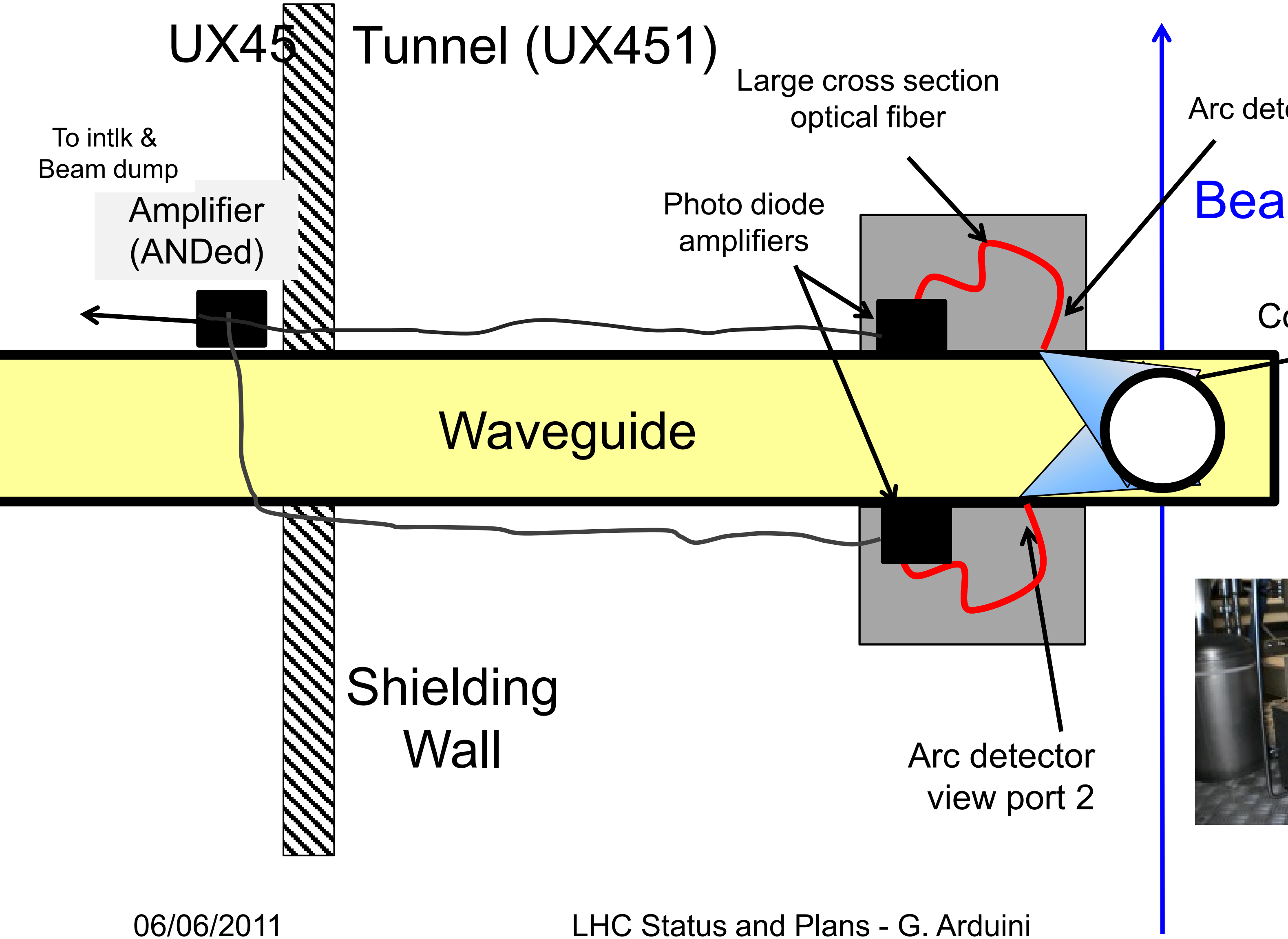
Arc detectors waveguide
Cut the RF





Arc detector power coupler (cavity window)
Dumps the beam (since last "scrubbing run")

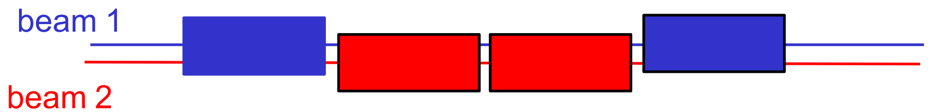
Spurious RF arc detection triggers



Spurious RF arc detection triggers

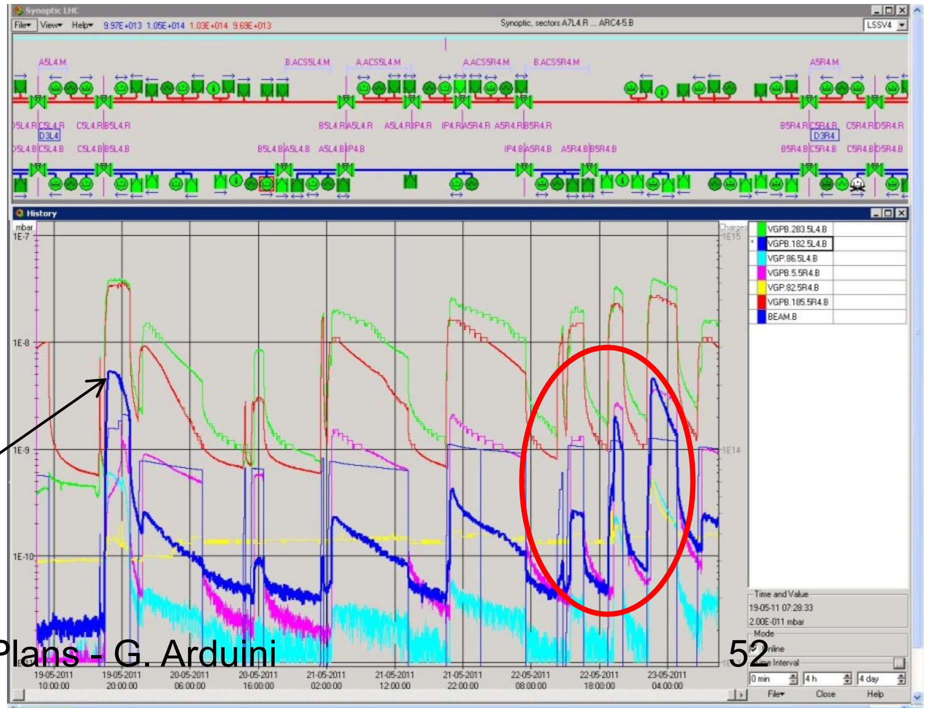
Observations:

- Only cavities of B1 have been affected (so far) => closer to warm sectors where uncoated instrumentation exists



- Consistent with radiation induced spurious signals resulting with higher background vacuum

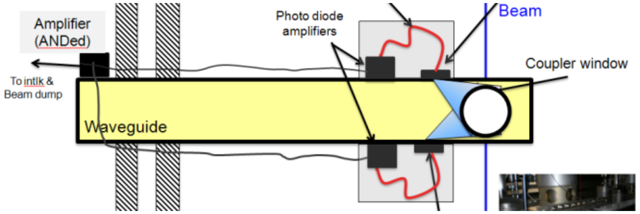
912 bunches



1308 bunches @ 450 GeV

Spurious RF arc detection triggers - cures

- Move the amplifiers further away from the WG holes (done)



- Possibility to move the detectors outside the tunnel
- Newly designed amplifier boards installed
  - Differences between spurious and real arc signals studied and electronics modifications being prepared ➔ next few weeks
- Continue development tests with real arcs to learn whether the gain and the speed of the photodiode pre-amplifier could be reduced
- Install solenoids in the RF instruments and damper kicker to minimize pressure rise (if e-cloud is present)

2010/2011/2012 Radiation Levels

	FLUKA & Operation		MEASUREMENTs		FORECAST			
	2010 using 2009 estimations	2010 with actual operation	2010 with RadMON (FLUKA r)	2010 with RadMON (TLD r)	2011	2012	NOMIN	ULTIM
UJ14 UJ16	2.5E+06	1.3E+06	1.6E+05	1.1E+06	7.2E+07	1.2E+08	2.1E+09	4.2E+09
RR13 RR17	5.0E+05	2.5E+05	1.0E+05	6.2E+05	4.3E+07	7.1E+07	1.2E+09	2.5E+09
UJ56	2.5E+06	1.3E+06	2.1E+05		1.7E+07	2.9E+07	5.0E+08	1.0E+09
RR53 RR57	5.0E+05	2.5E+05	1.0E+05	6.2E+05	4.3E+07	7.1E+07	1.2E+09	2.5E+09
UJ76	6.9E+06	1.1E+06	5.9E+05	2.1E+06	4.7E+07	8.0E+07	7.4E+08	8.3E+08
RR73 RR77	3.4E+06	5.7E+05	2.1E+05	3.1E+06	6.9E+07	1.2E+08	1.1E+09	1.2E+09
UX85b	1.0E+07	1.3E+07	4.8E+07	1.0E+07	9.4E+07	1.9E+08	3.3E+08	3.3E+09
US85	5.0E+06	6.3E+06	3.6E+06	2.9E+06	2.7E+07	5.4E+07	9.4E+07	9.4E+08

!!! Amazing !!! **Close to 'Threshold'** **Critical** **Dramatic**

Current Radiation Levels

2011 Operation up to Week 21 (2010 excluded): -> 400pb-1 (nominal: x125)

RRs	shielded areas HEH (cm-2/w20)	shielded areas HEH (cm-2/2011)		tunnel HEH (cm-2/w17)	tunnel HEH (cm-2/2011)	tunnel BLM dose (mGy/week)
13	<1.0E+6	1.1E+06	Luminosity	3.5E+06	4.0E+07	<10
17	<1.0E+6	1.2E+06		3.5E+06	3.8E+07	<10
53	<1.0E+6	1.4E+06		6.9E+06	3.8E+07	<10
57	<1.0E+6	1.3E+06		8.6E+06	4.5E+07	<10
73	<1.0E+6	1.7E+06	Intensity	<1.0E+6	<1.0E+6	<10
77	<1.0E+6	1.9E+06		1.7E+07	4.7E+07	<10

UJs	shielded areas HEH (cm-2/w20)	shielded areas HEH (cm-2/2011)		tunnel HEH (cm-2/w17)	tunnel HEH (cm-2/2011)	tunnel BLM dose (mGy/week)
14 (13, tun)	6.6E+06	2.2E+07	Luminosity	1.3E+10	2.4E+10	<10
16 (17, tun)	4.9E+06	1.6E+07		3.1E+09		<10
22	N/A	N/A	Intensity	4.5E+07	6.4E+08	<10
23	<1.0E+6	<1.0E+6		1.7E+07	7.1E+07	<10
32	N/A	N/A		<1.0E+6	<1.0E+6	1393
33	<1.0E+6	<1.0E+6		<1.0E+6	<1.0E+6	N/A
56	<1.0E+6	5.0E+06	Luminosity	[illegible]	6.4E+09	<10
76	<1.0E+6	<1.0E+6	Intensity	5.7E+08	3.6E+09	<10
87	<1.0E+6	<1.0E+6		[illegible]	1.2E+09	<10
88	N/A	N/A		3.1E+07	4.8E+08	<10

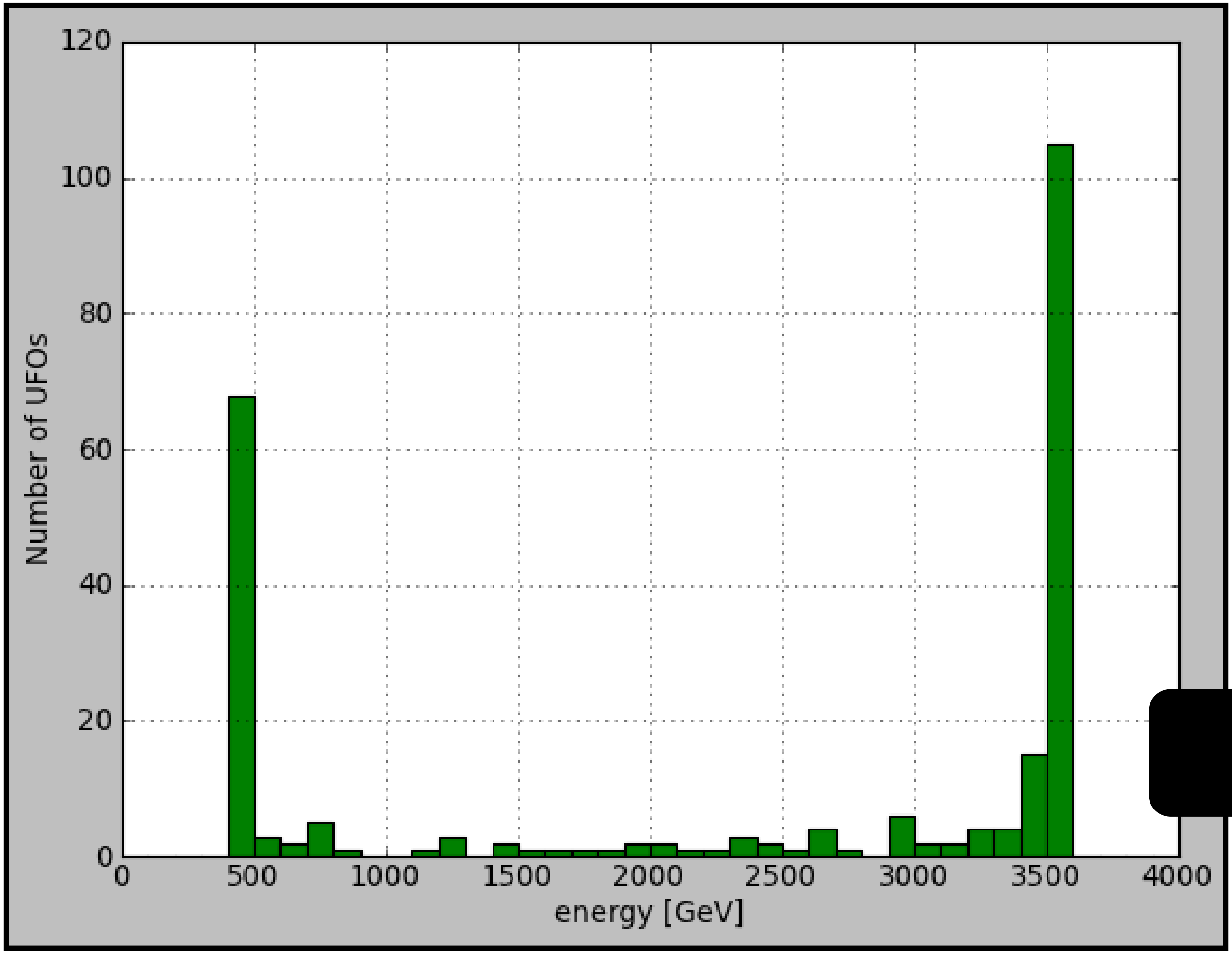
US85/UX85	cavern US85 HEH (cm-2/w20)	cavern US85 HEH (cm-2/2011)		cavern UX85 HEH (cm-2/w17)	cavern UX85 HEH (cm-2/2011)
	1.7E+06	6.3E+06	Luminosity	7.6E+06	4.5E+07

- **Fairly consistent with expectations**

Mitigation Actions Already Done

- **Shielding installed:**
  - RR73/77 **(gain ~factor 10**)
  - UJ76 (**gain ~factor 10 for safe-room, 2-3 for upper floor**)
  - Ducts in P6 (RA63/UA63 and RA67/UA67) (**gain ~factor 5-10**)
  - UJ22/23 and UJ88/87 (**gain ~factor 10**)
  - US85 Safe-Room (**gain ~factor 10**)
- **Cryo-relocations/valve replacement in UX85**
- **Relocation of UPS from UJ76 (safety critical at that time!)**
- **Relocation of fire control racks (possible impact on safety):**
  - UJ76, US85, UJ56,
- **Relocation of fire detectors (possible impact on safety):**
  - US85 (other points prepared)
- **Relocation of EN/EL control equipment**
  - RTU safe rooms UJ56 and UJ76
- **Cabling preparations: P1, P7, P8**

Energy Distribution of MKI UFOs



[redacted]

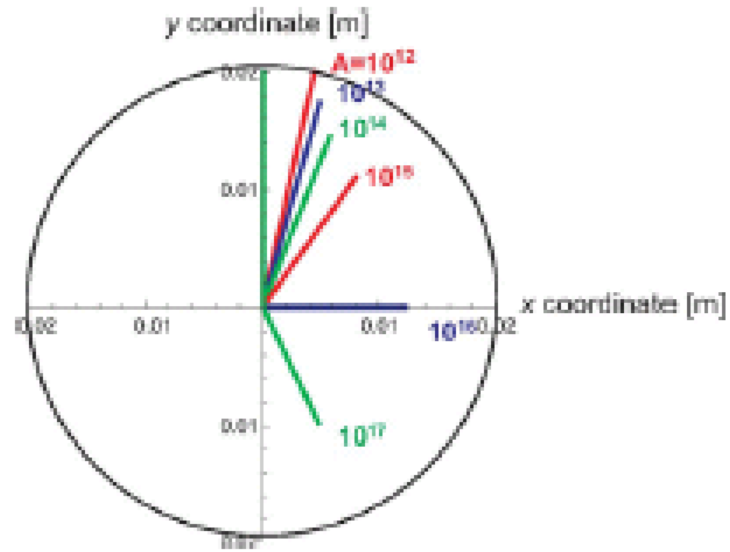
Many events at 450 GeV.

Dynamics of Dust Particles

From **simulations**:

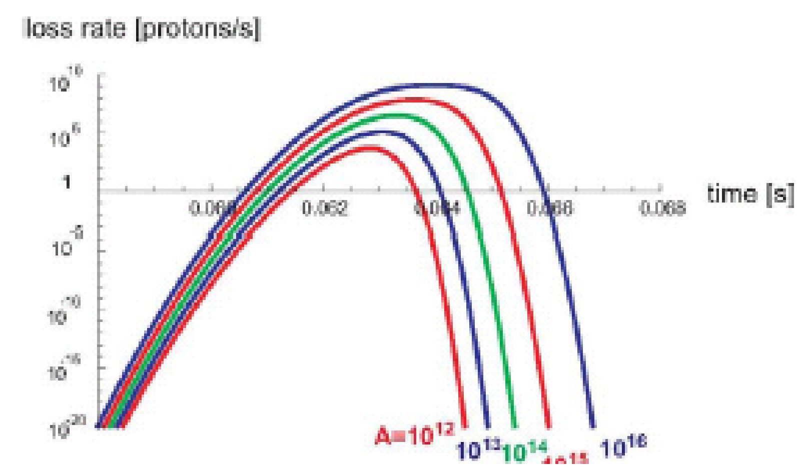
- Dust particle will be positively ionized and be repelled from the beam.

  Beam intensity: $2.3 \cdot 10^{12}$ protons, Al object.



- Loss duration of a few ms.

  Losses become shorter for larger beam intensities.



courtesy of
F. Zimmermann

Some highlight …

MDs prove excellent performance potential of LHC:

- No head-on beam-beam limit encountered with 3 times nominal brightness. Total tune shift: 0.03 with ATLAS/CMS collisions.
- ATS injection optics with different integer tunes fine to 3.5 TeV.
- Collimation system reached tighter settings with better cleaning efficiency.
- Impedance and instabilities under control.

Operational improvements:

- 90m optics for ALFA and TOTEM works fine.

Beam-beam limit

43% of design

50% above design

- Collided high intensity beams (1.7 E11) and small emittances (smaller than 1.5 um) in IP1 and IP5.
- First attempt achieved tune shifts 0.01 per IP, vertical blowup of emittance.
  - Blowup most likely due to 10th order resonance.
- In final attempt reduced vertical tune to end up below 10th order after putting beams in collision. No more blowup observed, tune shifts per IP in excess of 0.015 (with initial emittance below 1.2

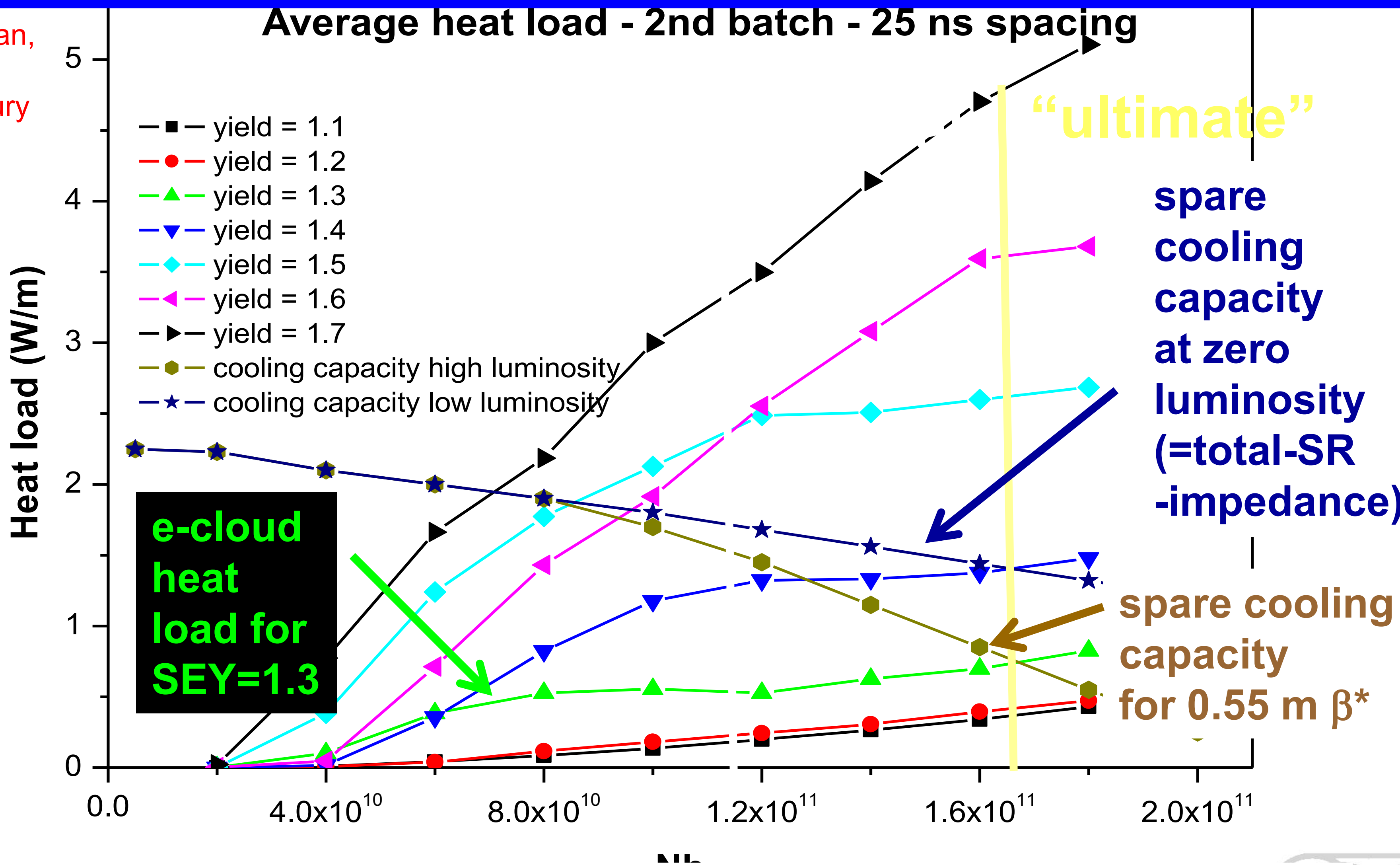
Factor of 4.5 above design

- Collisions in IP1 and IP5, optimized and no more blowup.
- No limit found for head-on beam-beam effects for the intensities investigated so far (no long range yet).

cooling & e- heat for 25 ns spacing

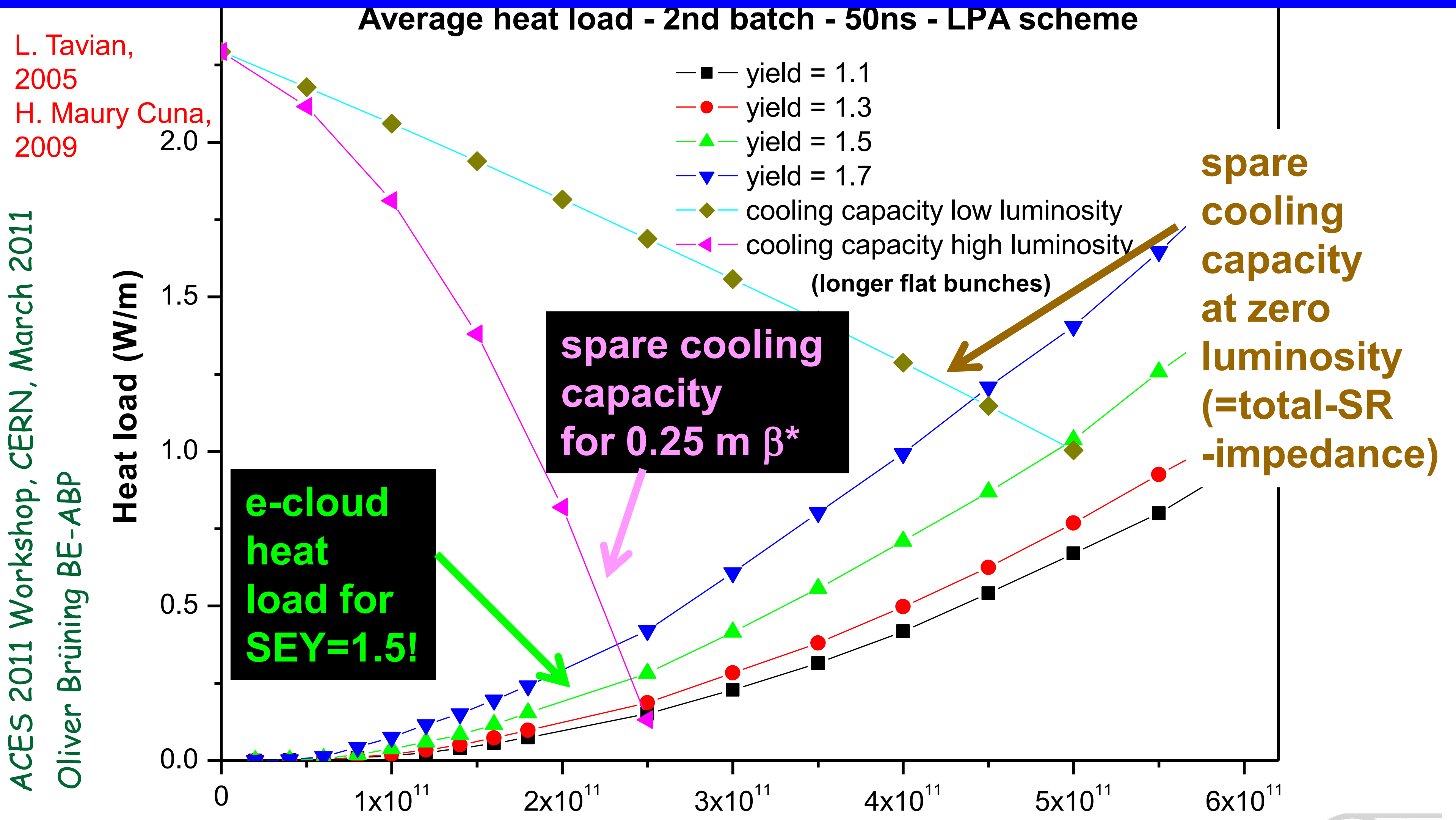
L. Tavian, 2005
H. Maury Cuna, 2009

ACES 2011 Workshop, CERN, March 2011
Oliver Brüning BE-ABP



going above N_b=1.7x10^{11} & ultimate luminosity requires dedicated IR cryo plants; limit then becomes N_b~2.3x10^{11}

cooling & e- heat for 50 ns spacing

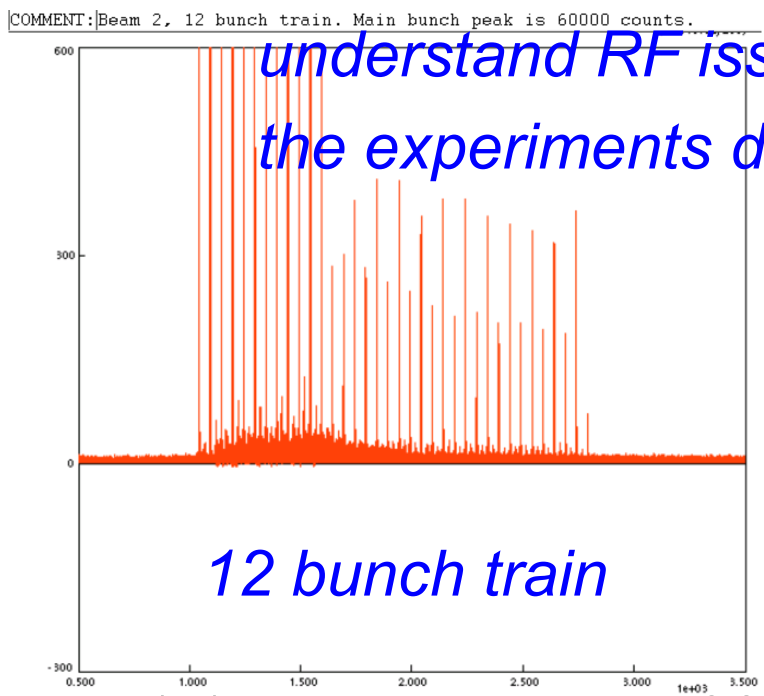


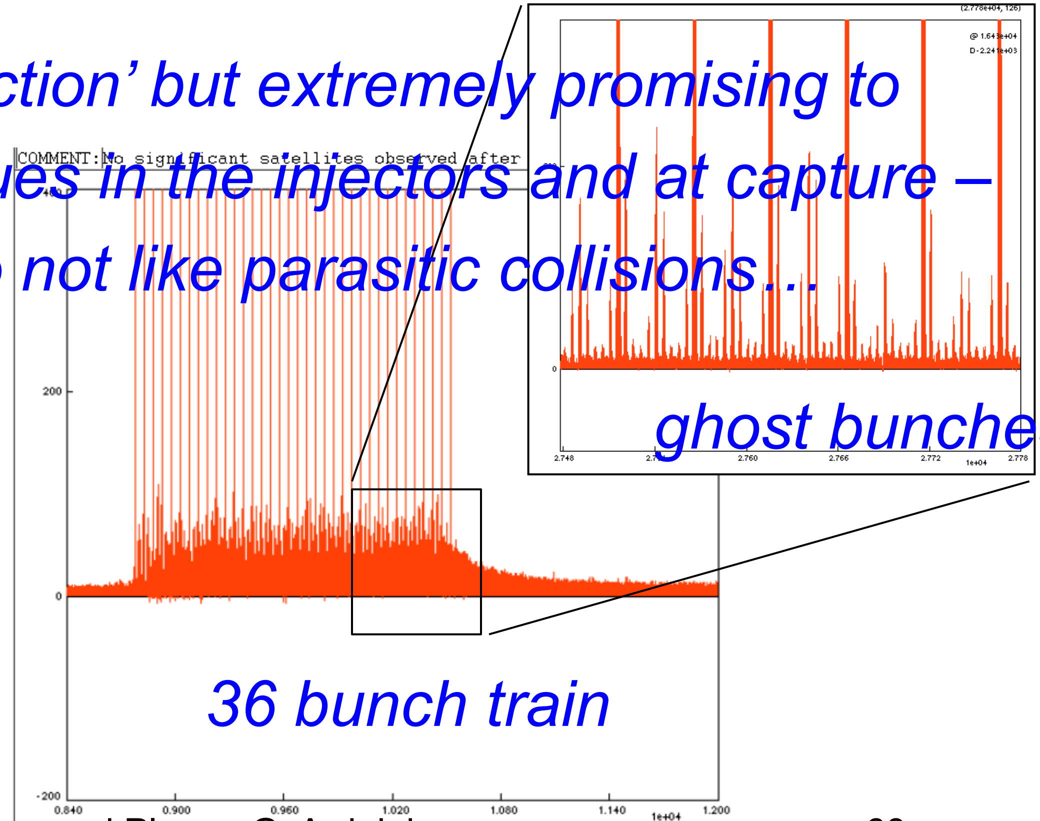
going above N_b=2.3x10^{11} & ultimate luminosity requires dedicated IR cryo plants; limit then becomes N_b~5.0x10^{11}

Longitudinal Density Monitor

A longitudinal profile monitor based on photon counting (same source as synchrotron light monitor) is beginning to provide high resolution data of the longitudinal structure of the beams !

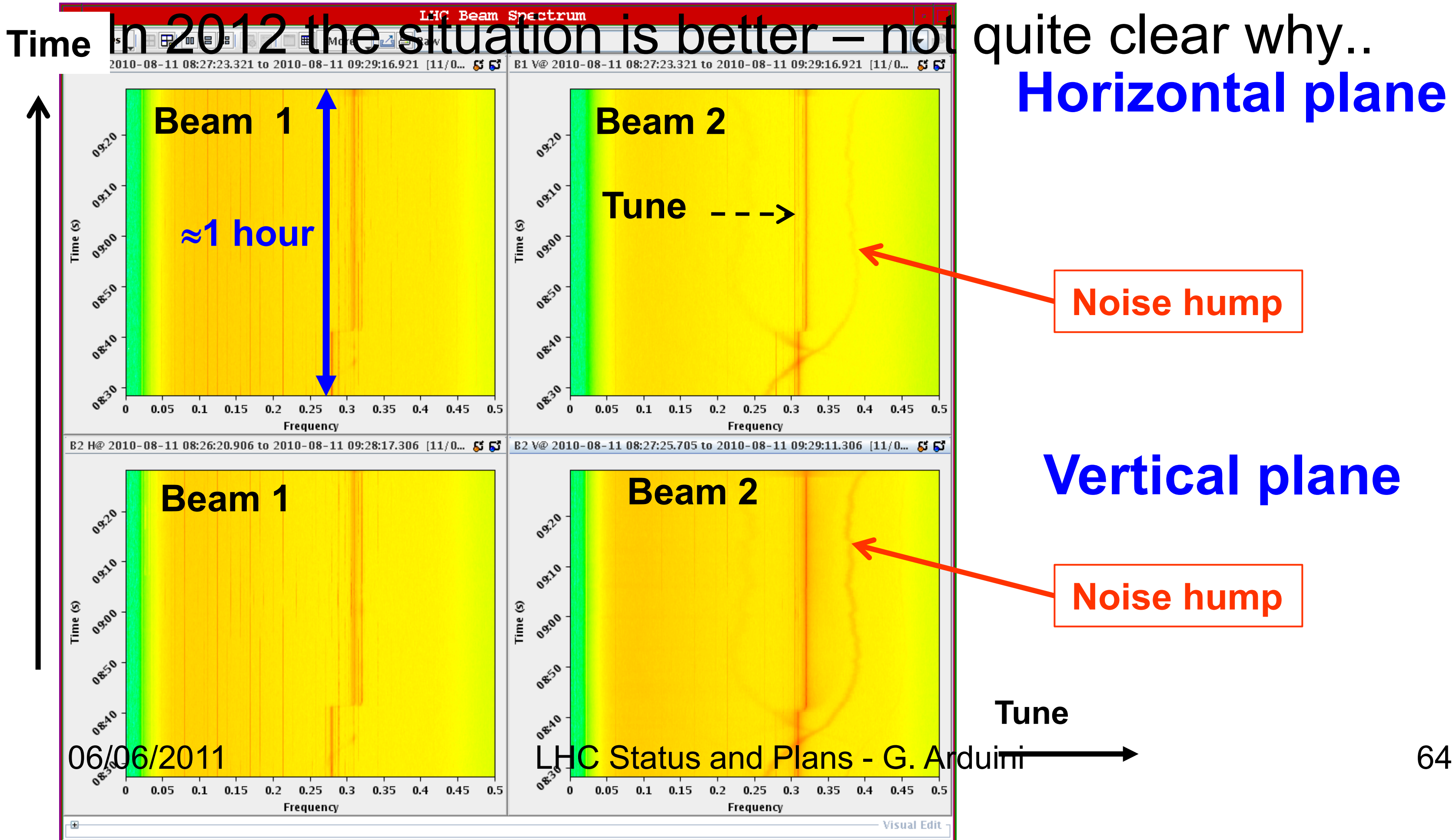
- *Still 'under construction' but extremely promising to understand RF issues in the injectors and at capture – the experiments do not like parasitic collisions…*





Noise on the beam

- In 2009 & 2010 the beams were periodically excited by an unknown noise source ('hump') of varying frequency – affected mostly beam2 in vertical plane.
  - *Amplitude ~ μm → emittance growth.*
- In 2012 the situation is better – not quite clear why..



Event of 7th April

Thursday afternoon (7th April) all powering was stopped in the LHC following the discovery of a worrying cabling problem affecting the QPS system protecting the HTS current leads.

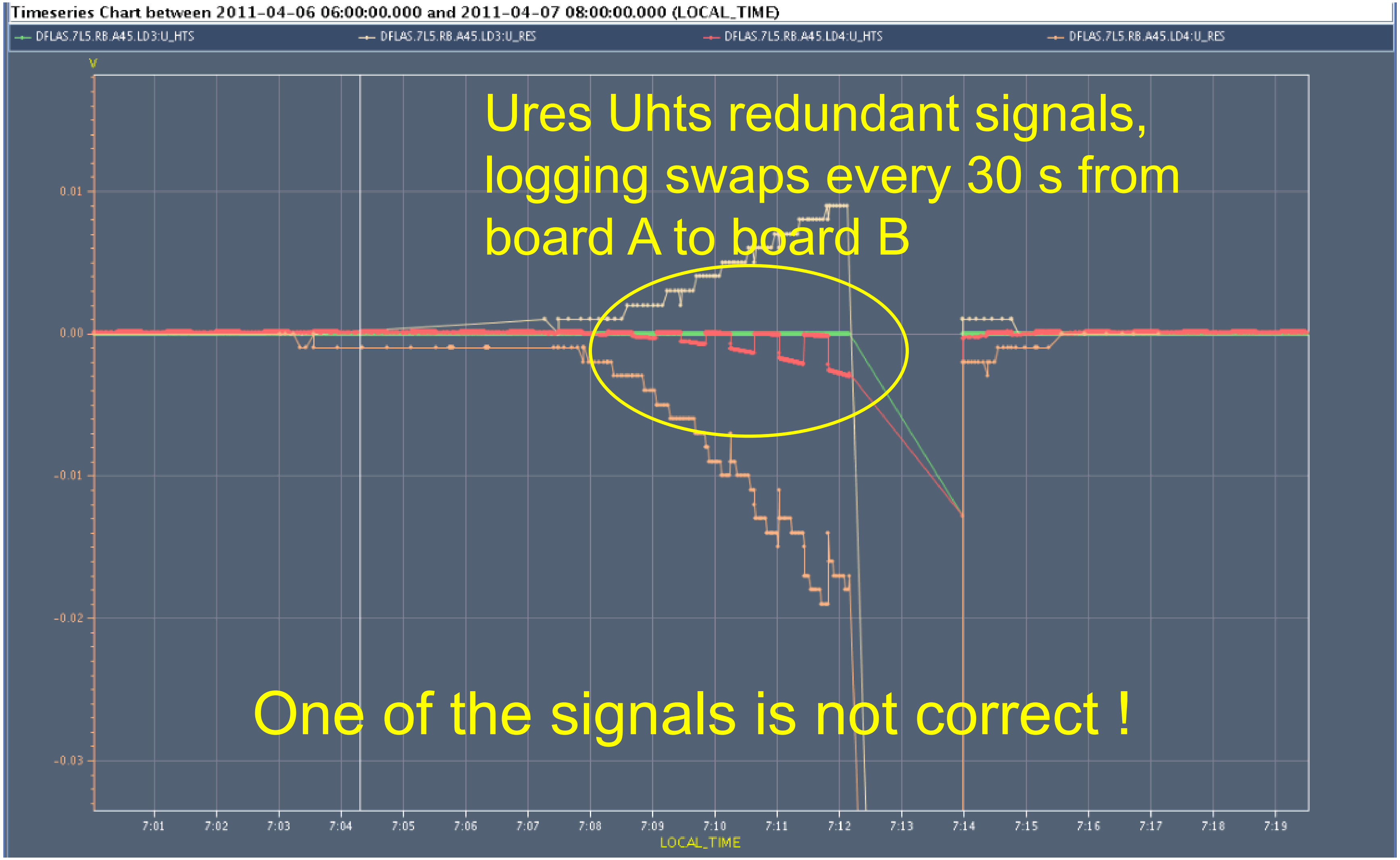
Followed by an extensive verification campaign.

Lost about 2 days.

HTS quench (sc link)- what happened

- QPS tripped the RB circuit in sector 45 on Thursday around 07:00. *First time ever quench of HTS current lead*
- The HTS quenched due to a lack of cooling in the DFB
  - Faulty electronics board corrupted the temperature feedback loop
- Protection by the QPS monitoring the current leads.
  - Logging of the two HTS signals showed that only one of the two measurements was correct, the other was measuring a short circuit
- An identical fault on the redundant signal would have left the system unprotected and could lead to beyond repair damage to the DFB. No spares
- **Decided to stop powering magnets**
  - To validate other circuits

QPS signals monitoring the HTS

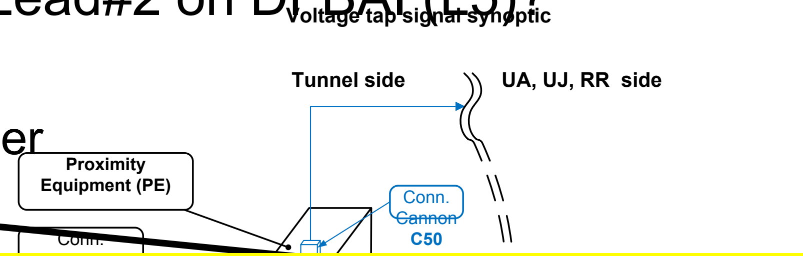


What was swapped…?

What was found swapped in RB.A45, Lead#2 on DFBAI (L5)?

EE22 (pin 15) and **EE42** (pin16)

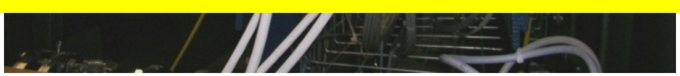
of cable between PE and QPS controller

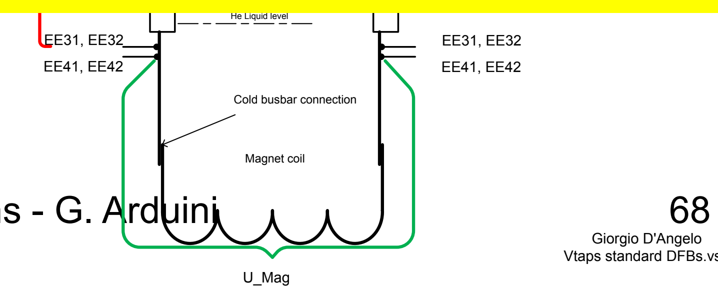


This connection had been like this since 2005

Are all connections like this?

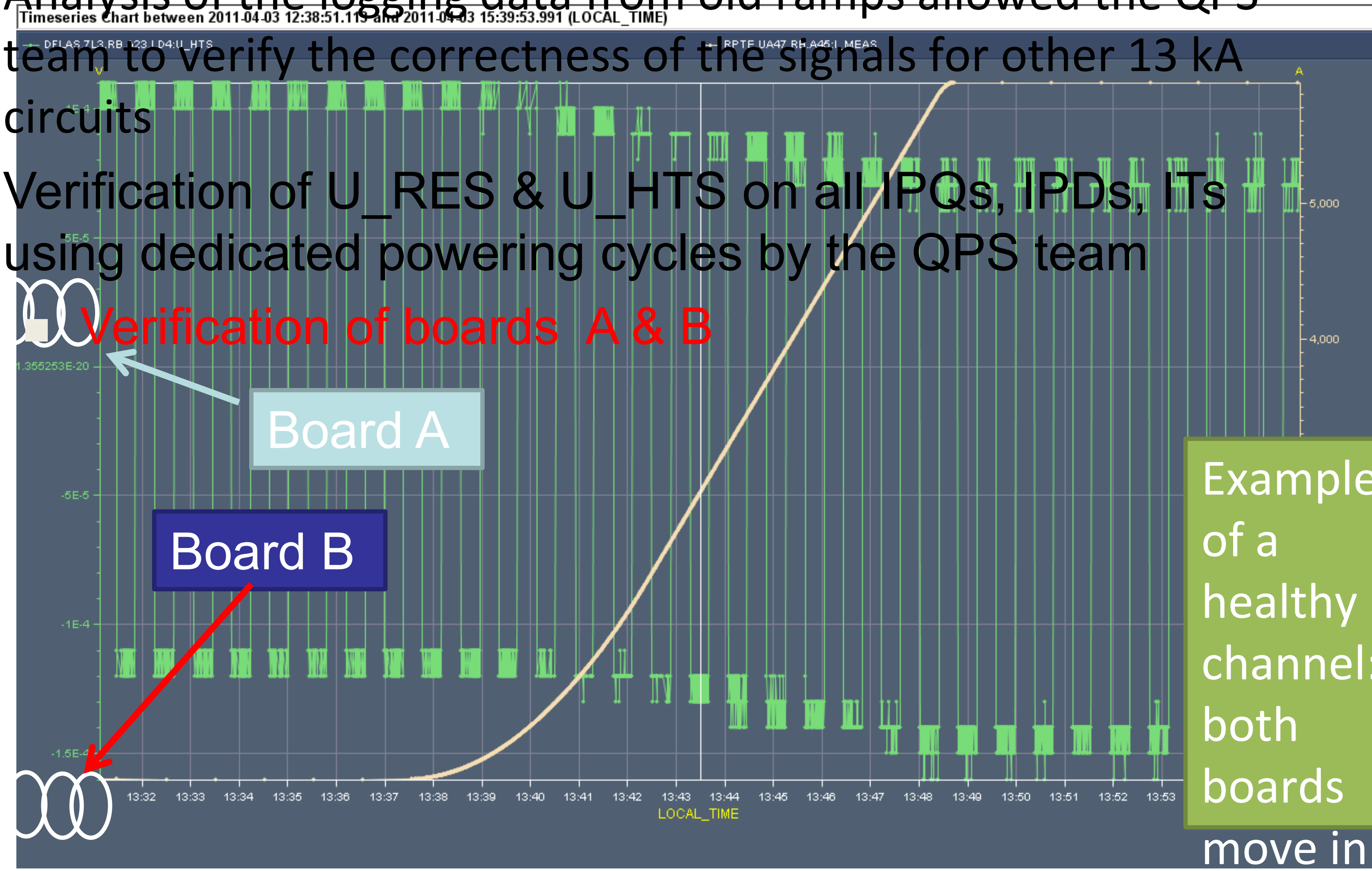
Stop operation until all connections are verified





From the logging

- Analysis of the logging data from old ramps allowed the QPS team to verify the correctness of the signals for other 13 kA circuits
- Verification of U_RES & U_HTS on all IPQs, IPDs, ITs using dedicated powering cycles by the QPS team
  - Verification of boards A & B



Example of a healthy channel: both boards move in

Verification - Friday 8th April

In the late afternoon all high current circuits except the 600 A circuits had been checked.

- Acceptable risk for 600 A circuits.

All tests showed the presence of the expected signals.

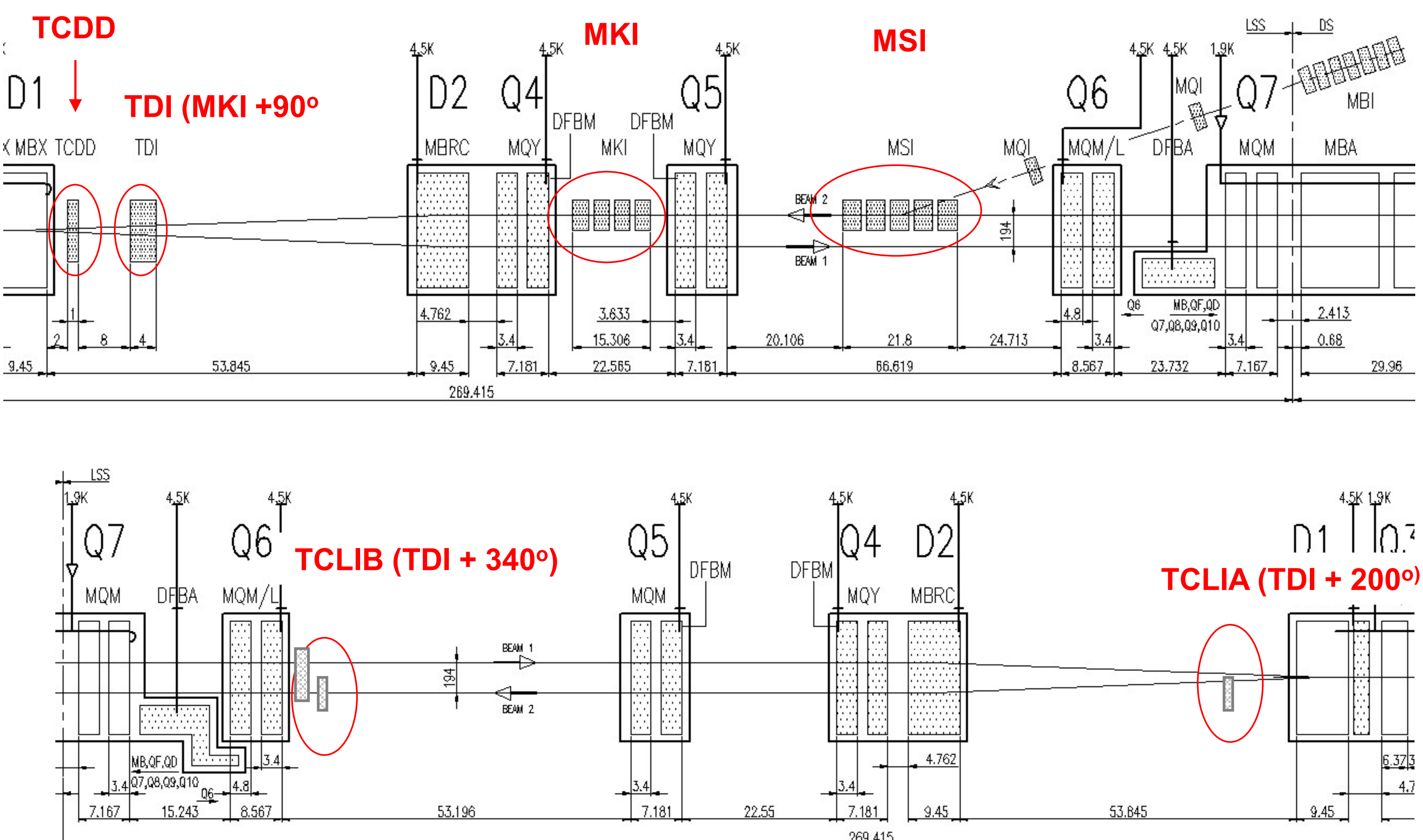
Green light for powering from TE/MPE in the evening.

Among all the high current circuits we happen to quench exactly the one circuit with a cabling problem !!

Event of 18th April

- Flashover (high voltage breakdown) on B2 MKI magnet D (first one seen by the beam) while injecting 72b
- Extensive beam losses through P8 and arc 78: result
  - Kicker interlocked off
  - Quench heaters fired on 11 magnets
  - Vacuum valves closed
  - Several very anxious hours....

Overview of injection region (IR8)



Measures proposed and taken

- New SIS to prevent injection if MKI pressure >1e-9 (will have to get some experience with this)
- Checked carefully TDI alignments in P2 and P8, especially with respect to TCLI openings
  - No anomalies found
- New Fixed Display in CCC with MKI pressures
- Vacuum sublimation made on MKI2 and MKI8
- Production of 2nd spare MKI speeded up

Conclusion

- Had a real breakdown in MKI8.D, between two 36b trains in a 72b batch
- 36b overkicked and grazed lower jaw of TDI/TCLI
  - About half of this intensity was transmitted into LHC (2e12)
- Known worst case scenario for injection protection
  - Showers caused quenches and LHCb trips
  - No damage (magnets, MKI, LHCb, TDI)
  - Protection works – factor 8 to go to real worst-case
  - Setting up and positioning of these devices critical
  - BLMs need more dynamic range
- Production of 2nd new spare MKI accelerated

Next years

Physics data-taking until end of 2012

- Start taking advantage of the performance possibilities arising from the machine studies (July 2011 performance review, following MD2)
    - beam beam, aperture, emittance, intensity (pile-up)
- Following measurements of the copper stabilizers during the Christmas stop we will re-evaluate the maximum energy for 2012 (Chamonix 2012)

Long Shutdown in 2013

- repair/upgrade the magnet interconnects for operation at 6.5-7 TeV/beam
- install new collimation system in DS zone?

Nominal collimation, single b tune shift (Coll, Imp.)

Initial blow-up tests with transverse damper.

Injection scraping during short delay from injectors.

Nominal 3.5 TeV collimation settings achieved for b1 &b2:

- TCP = 5.7 sigma (nom), TCSG = 6.7 sigma (nom)
- TCLA = 9.7 sigma (nom), IP6 = 7.2/7.7 sigma (nom)

Octupoles trimmed to 350A for beam 1.

For b1 moved towards nominal 7 TeV settings. Limited by TCSG losses close to IP7. Valid setup reached:

- TCP = 4.0 sigma (nom), TCSG = 6.0 sigma (nom)
- TCLA = 8.0 sigma (nom), IP6 = 7.0/7.5 sigma (nom)
- Smallest gap: 2.2 mm
- Beam lifetime: > 100 hours
- Tune shift measured: ~2e-4
- Efficiency measured: 3e-5 – 1e-4

- Two ovens operational
- The first oven filling lasts for around two weeks, the second for only one week (due to plasma heating of the oven)
- Oven refill takes around 36 hours
- In 2010 only the first oven was used, the second one was used as hot spare in case of problems
- In principle one can extend the period between two oven refills to three weeks, but the third week may suffer from instabilities and intensity fluctuations
- The switch between the two ovens is normally transparent to the operation, it takes several