LHC: Machine Status and Prospects for the short, medium and long term.

EPS-HEP Conference,
Grenoble,
France

Tuesday 26th July 2011

Steve Myers **(for the LHC team and collaborators from around the world)**

Topics

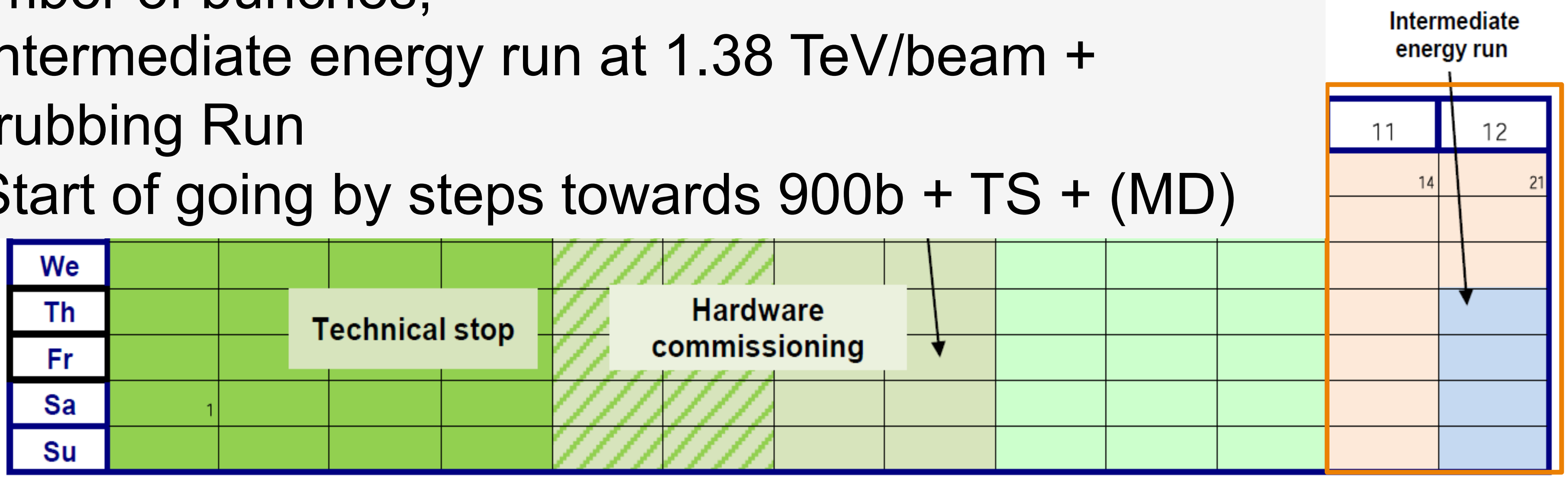
- LHC progress in 2011
- Prospects in the Short term (2011—2012)
- Mid Term Prospects (2014-2021)
- Long Term Prospects (2022--….)

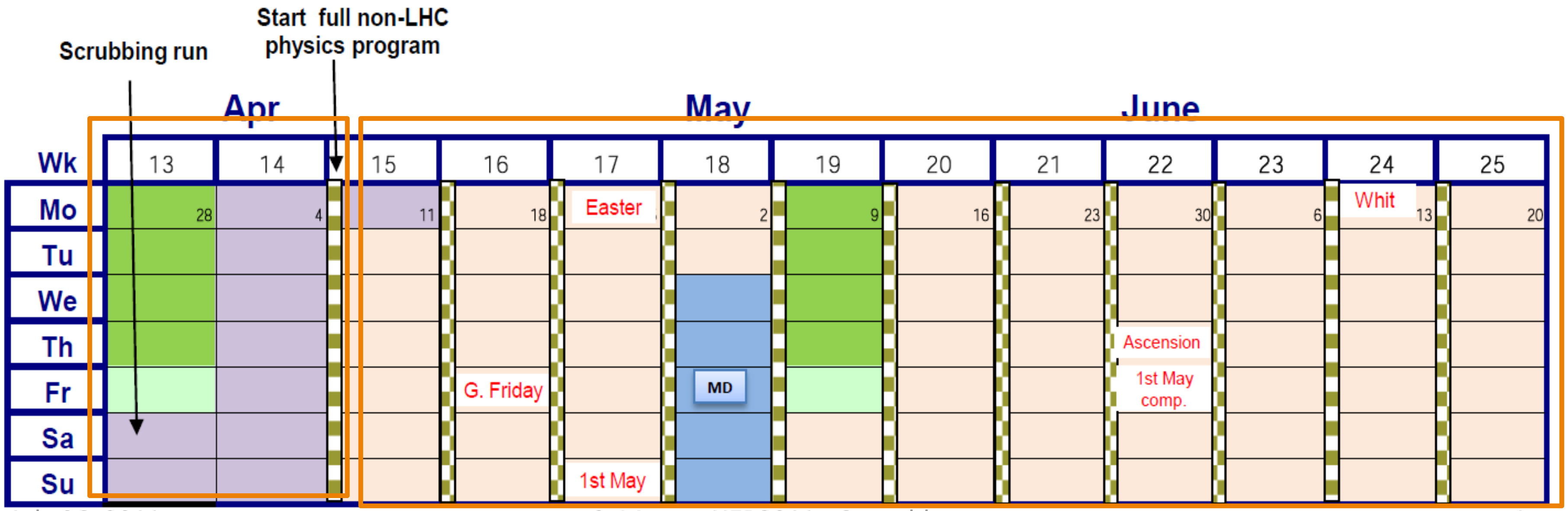
Topics

- LHC progress in first half of 2011
- Prospects in the Short term (2011—2012)
- Mid Term Prospects (2014-2021)
- Long Term Prospects (2022--….)

The 3 periods

1. Physics re-established with 75ns and increasing the number of bunches,
2. Intermediate energy run at 1.38 TeV/beam + Scrubbing Run
3. Start of going by steps towards 900b + TS + (MD)





Estimated Peak and Integrated Luminosity

March CERN Council

- Baseline is 2E32 Peak and 1fb-1 (integrated)
- But following 2010, we are confident we will do better

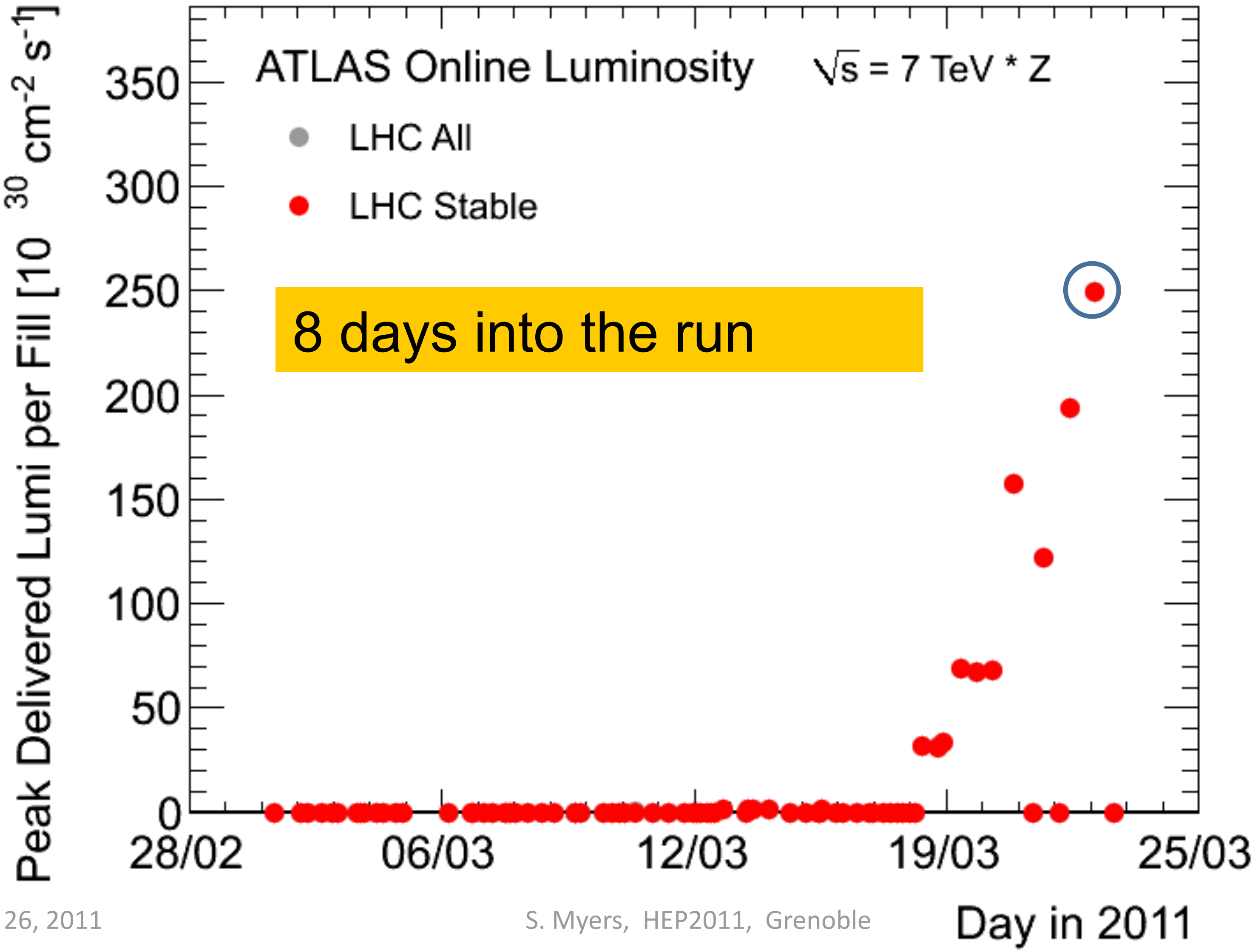
β* = 1.5m

days	H.F	Comm with	Fills with	kb	Nb e11	ε μm	ξ/IP	L Hz/cm²	Stored energy MJ	L Int fb^{-1} 4 TeV	L Int fb^{-1} 3.5 TeV
160	0.3	150 ns	150 ns	368	1.2	2.5	0.006	~5.2e32	~30	~2.1	~1.9
135	**0.2**	**75 ns**	**75 ns**	**936**	**1.2**	**2.5** **2** **1.8**	**0.006** **0.007** **0.008**	**~1.3e33** **~1.6e33** **~1.8e33**	**~75**	**~3** **~3.8** **~4.2**	**~2.7** **~3.3** **~3.7**
125	0.15	50 ns	50 ns	1404	1.2	2.5	0.006	~2e33	~110	~3.2	~2.8

Possible integrated Luminosity of 2-3 fb-1

First Record Fill of 2011 (on March 23)

Physics re-established with 75ns and increasing the number of bunches,



Summary of week 14 & part of 15

ubbing run

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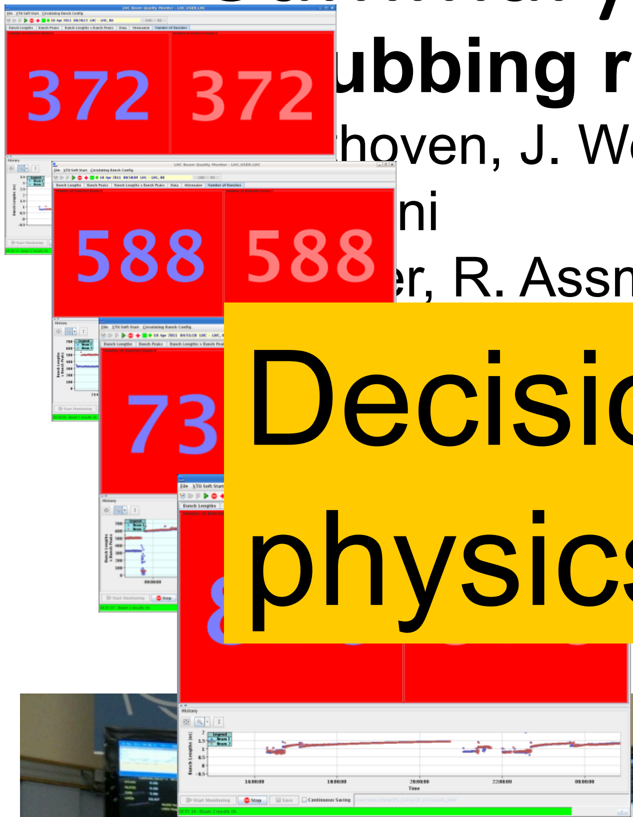
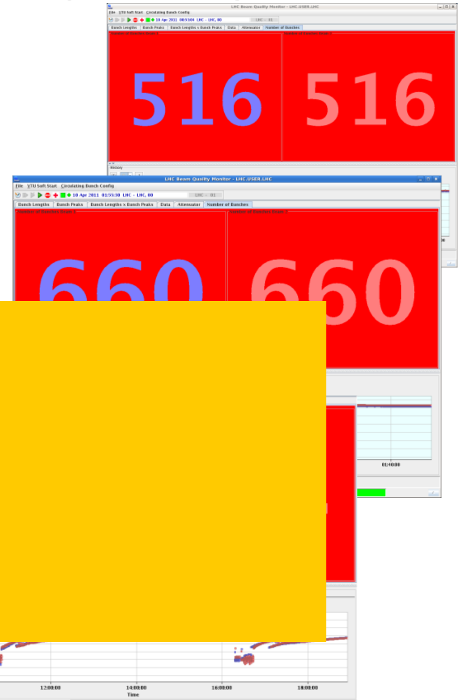
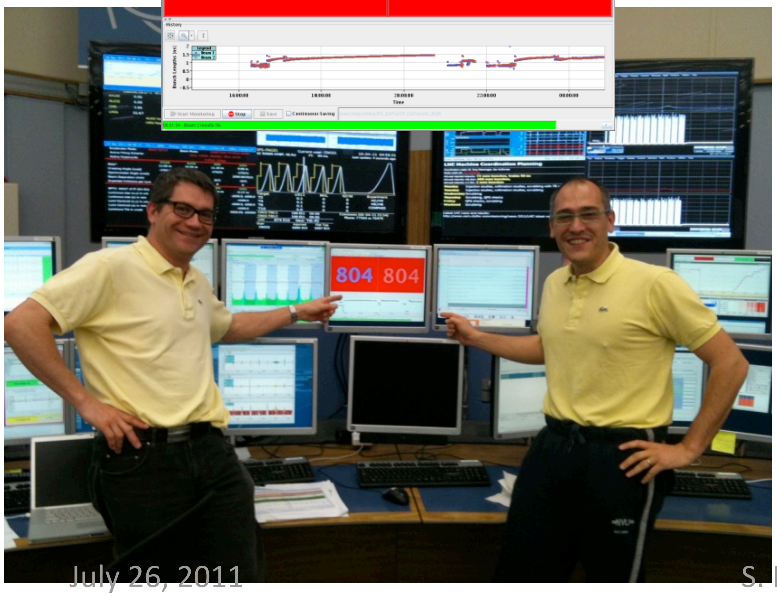
er, R. Assmann





Decision: Continue physics with 50ns



3rd Period: Goal to increase the number of bunches to 900

Issues encountered with Higher Intensities

- Requires much finer control of the beam parameters
  - Chromaticity, gain of feedback and use of Landau octupoles
  - Injection quality
- Many more UFOs: not yet serious

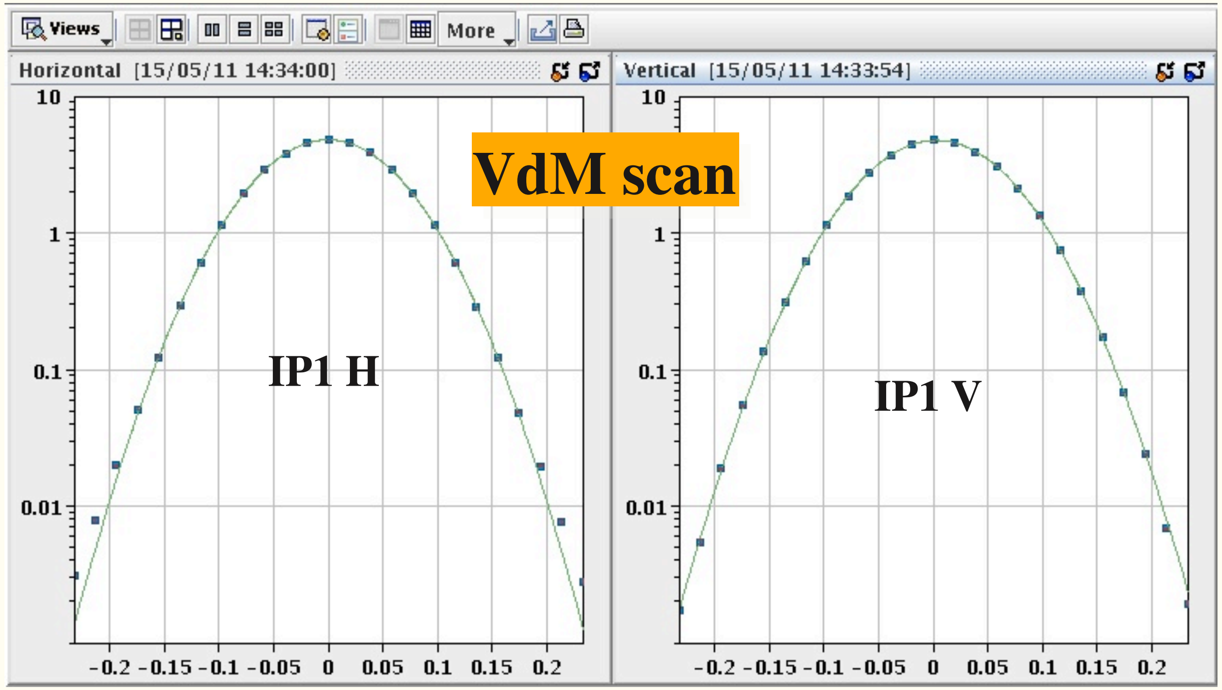
15th May 2011

LHC precision front

- absolute luminosity normalization

- low, well understood backgrounds

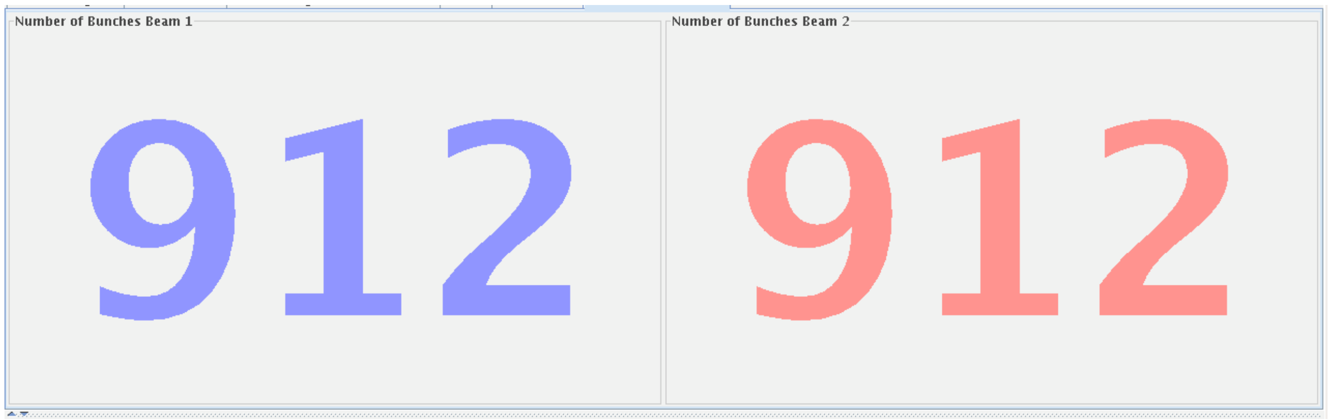
- precision optics for ATLAS-ALFA and TOTEM

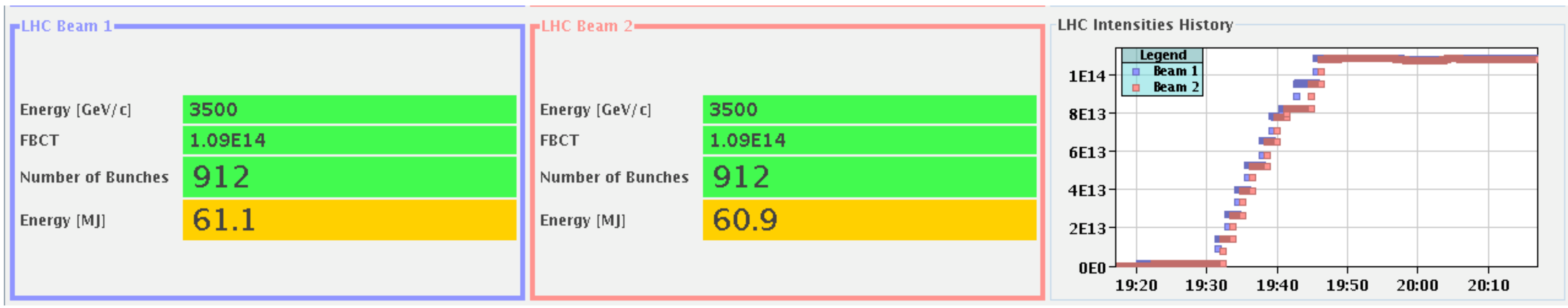


precise measurement of the luminous region + beam intensity --> absolute luminosity and cross section calibration

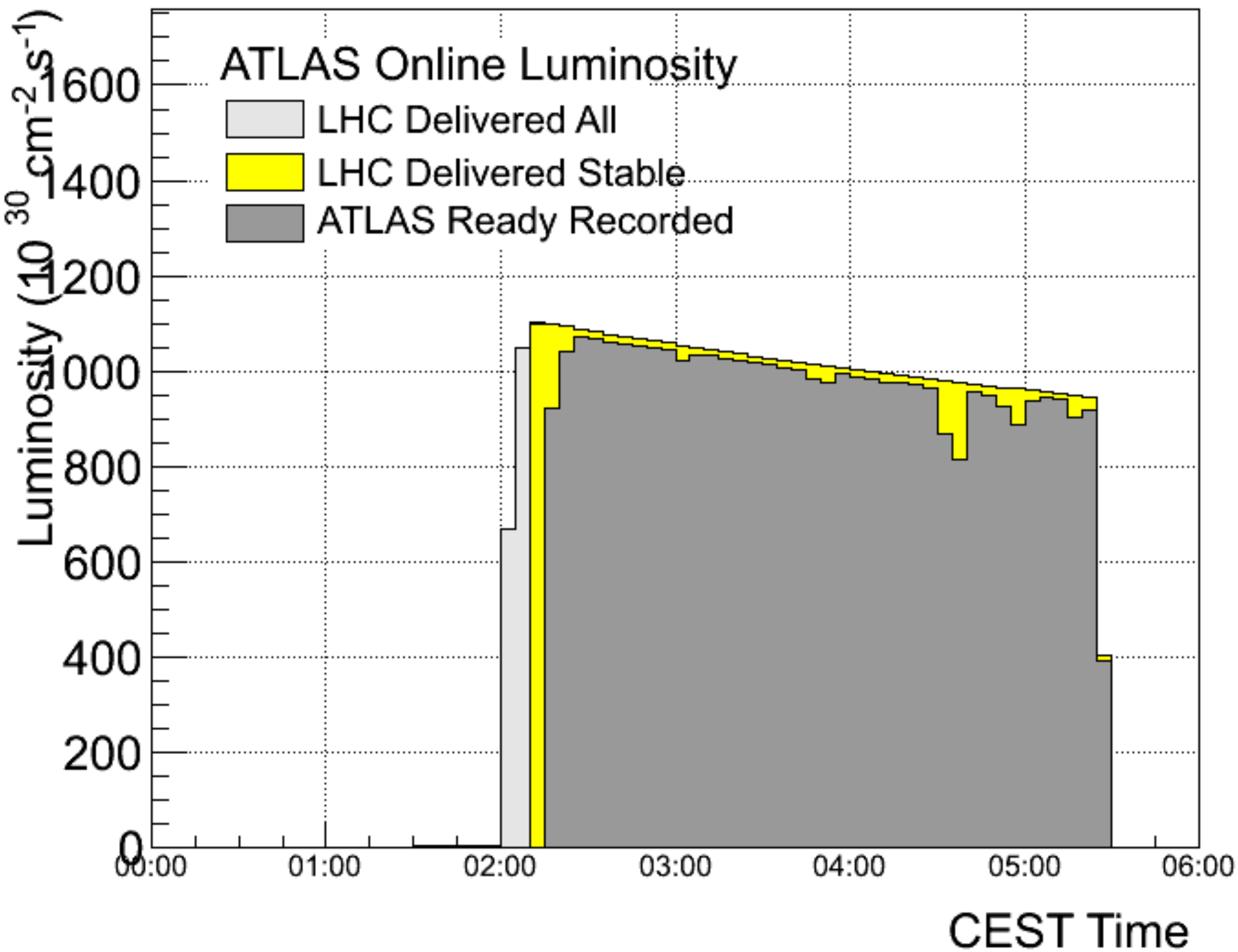
currently ~ 3.5 % level precision

21 May: 912 bunches at 3.5TeV



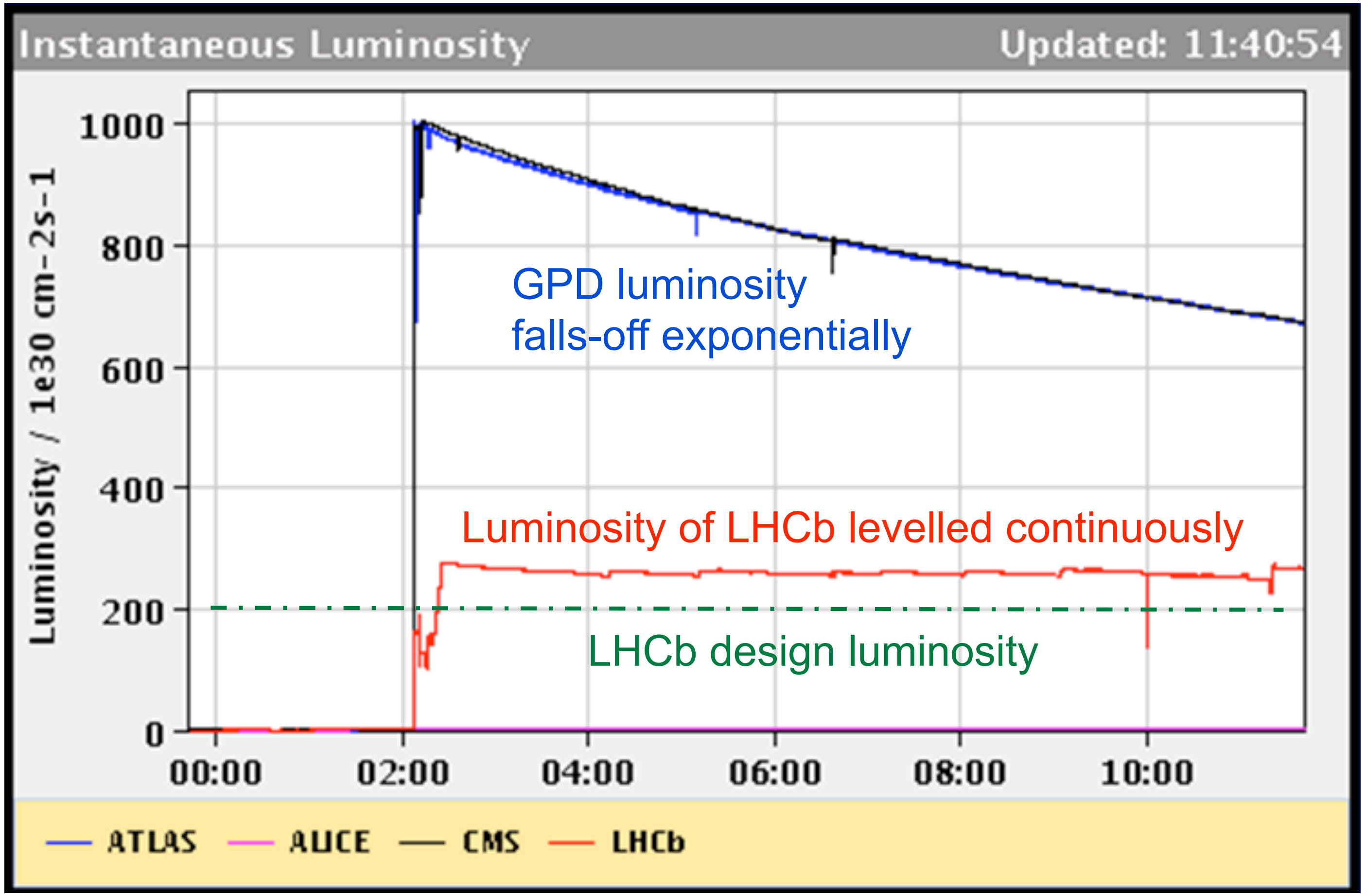


Sunday morning May 22: $1.1x10^{33}cm^{-2}s^{-1}$



Expected integrated luminosity for LHCb in 2011

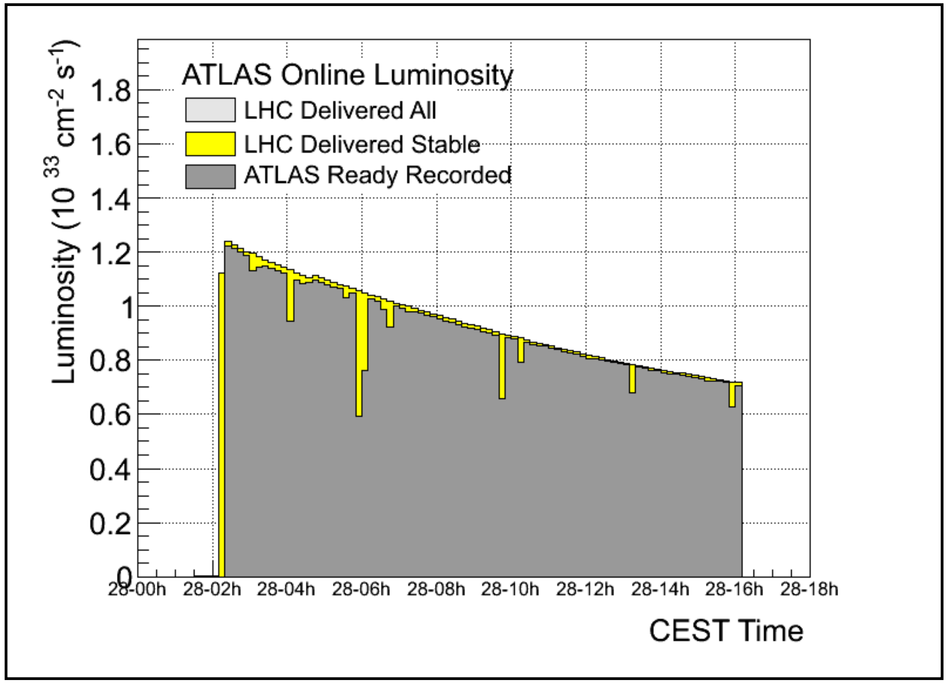
Introduced luminosity leveling for LHCb → can run at optimal μ and L_{max}

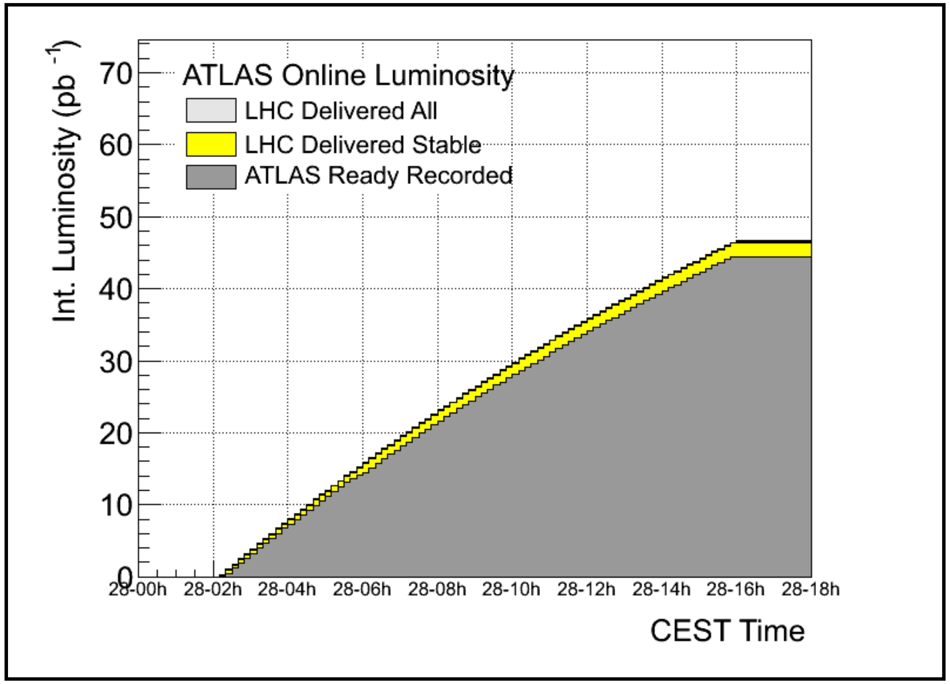


→ Since end of May running at constant $L \sim 3\cdot10^{32}$ $cm^{-2}s^{-1}$ with $\mu \sim 1.5$

Continue to 1380 Bunches

- Reached 1380 (max possible with 50ns) on 28 June fill 1901

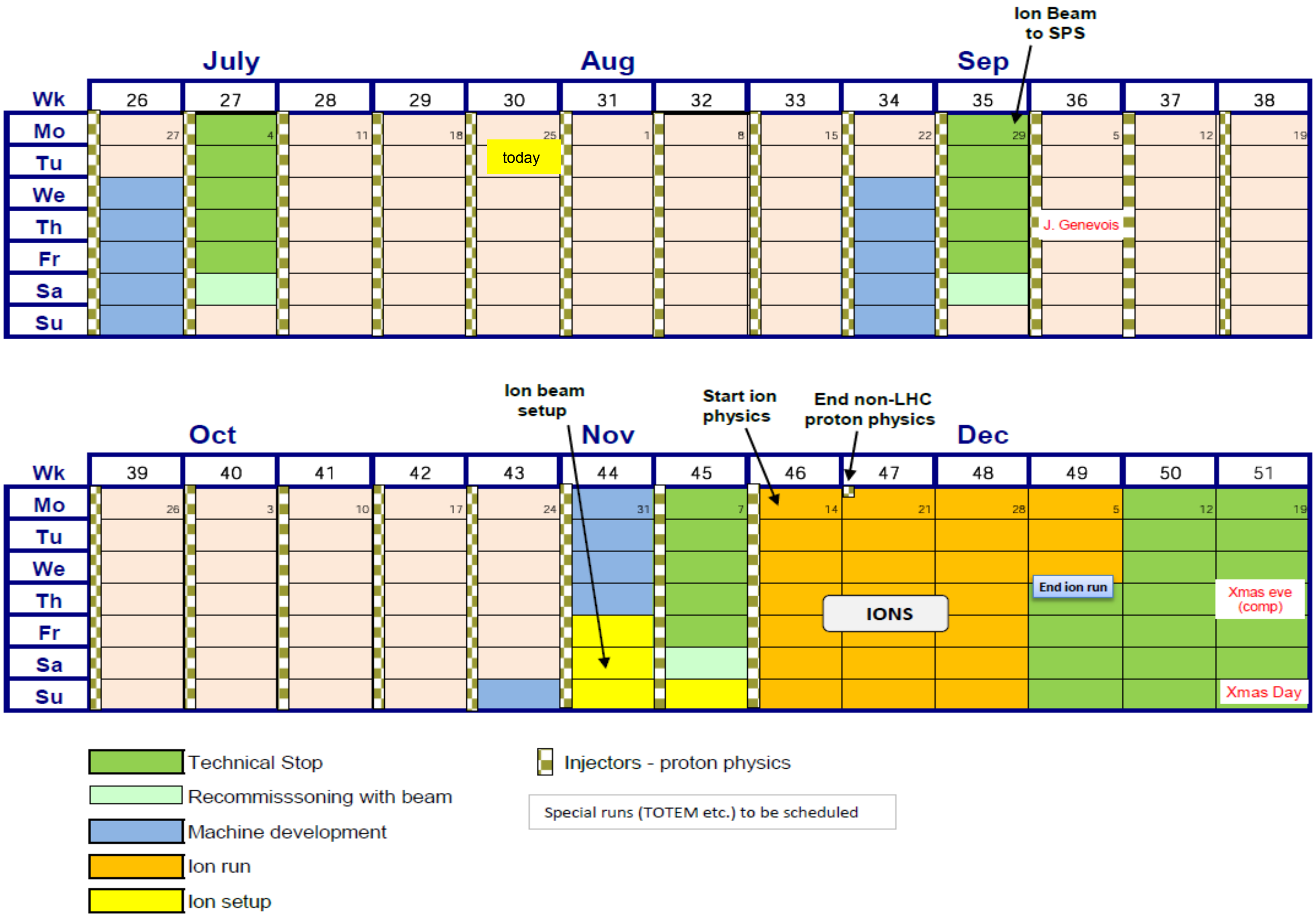




Topics

- LHC progress in 2011
- Prospects in the Short term (2nd half 2011)
- Mid Term Prospects (2014-2021)
- Long Term Prospects (2022--….)

Schedule: 2nd Half 2011



Mid Year performance Review "mini-Chamonix"

(July 15)

The workshop will examine the possible performance improvement options available during the rest of the LHC's 2011 proton run. It will also consider the experiments' requirements and potential limitations from hardware and beam related phenomena. **The principle aim to arrive at a strategy for maximizing the delivered luminosity by the end of the year.** The results from, and plans for, machine development will be considered where the knowledge gained might impact the above goal.

Discussion

Luminosity comparisons are wrt 1380 bunch operation with 1.1E11ppb, emittance 2.7um, beta* = 1.5, Lumi = 1.2E33

Parameter and Criteria	adiabatic?	Estimated Max Lumi Improvement Factor	Lost Time for physics (days)	Risk/ Reversibility	Pile-up	Cumulative Improvement factor (50ns)	Cumulative Improvement factor (25ns)
ppb	yes	2	0	0	higher	Yes	No
emittance	yes	1.35	0	0	higher	Yes	No
beta*	No	1.5	3	>0	higher	Yes	Yes
25ns	No	1.9	10	>0	same	No	Yes
				Luminosity Factor		4.1	2.9
				Pile Up		28	10
				Estimated Relative Integrated Luminosity		307	185
				Relative Integrated Luminosity if we do nothing		90	

$$L = \frac{n_b \cdot N_{bunch1} \cdot N_{bunch2} \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)$$

Conclusion

- Continue with 50ns
  - Operate with minimum emittance (2um)
  - Adiabatically increase the bunch intensity (max 1.55^{e}11)
  - ? Reduce beta* to 1m (LATER after next Technical Stop)

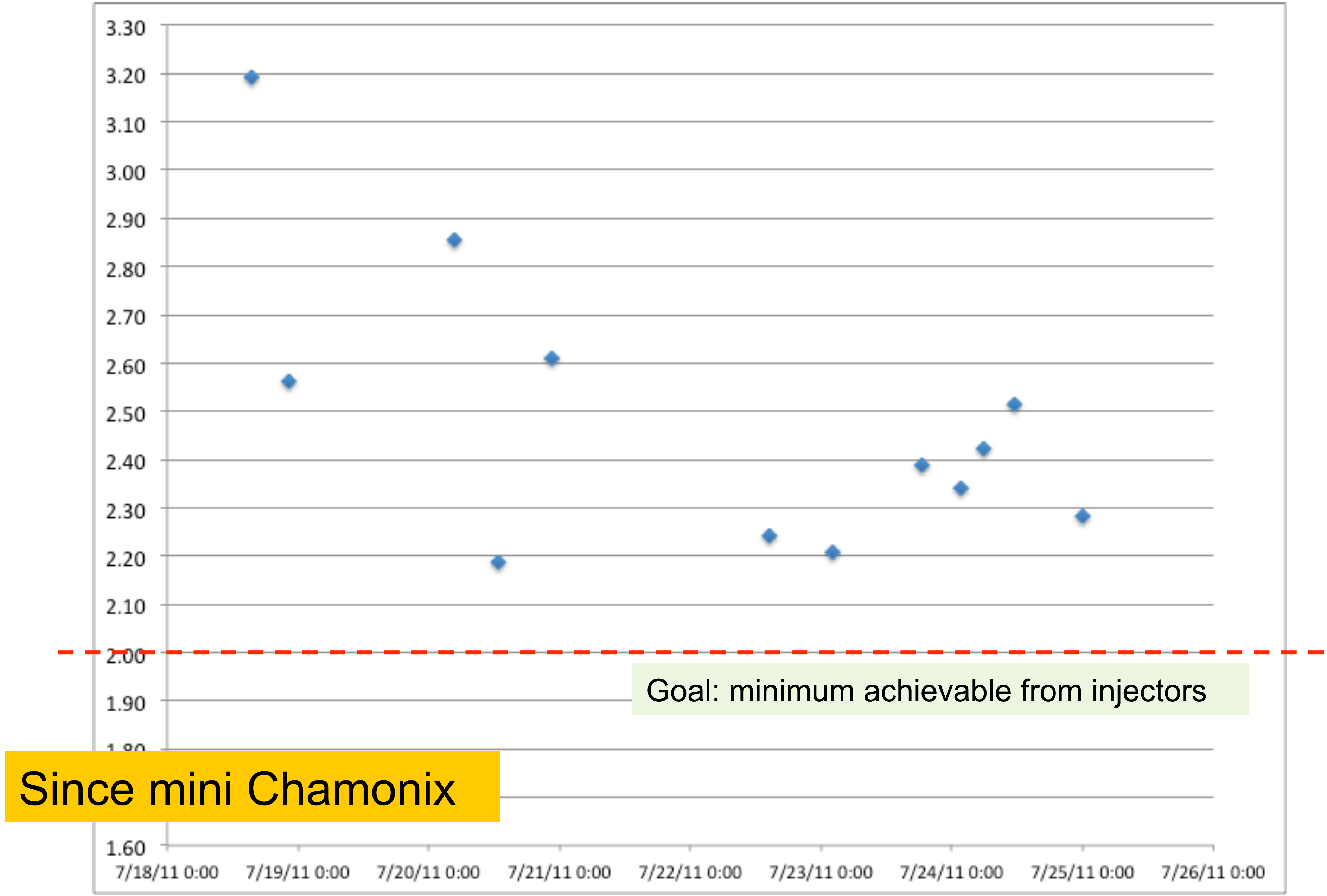
Discussion

Luminosity comparisons are wrt 1380 bunch operation with 1.1E11ppb, emittance 2.7um, beta* = 1.5, Lumi = 1.2E33

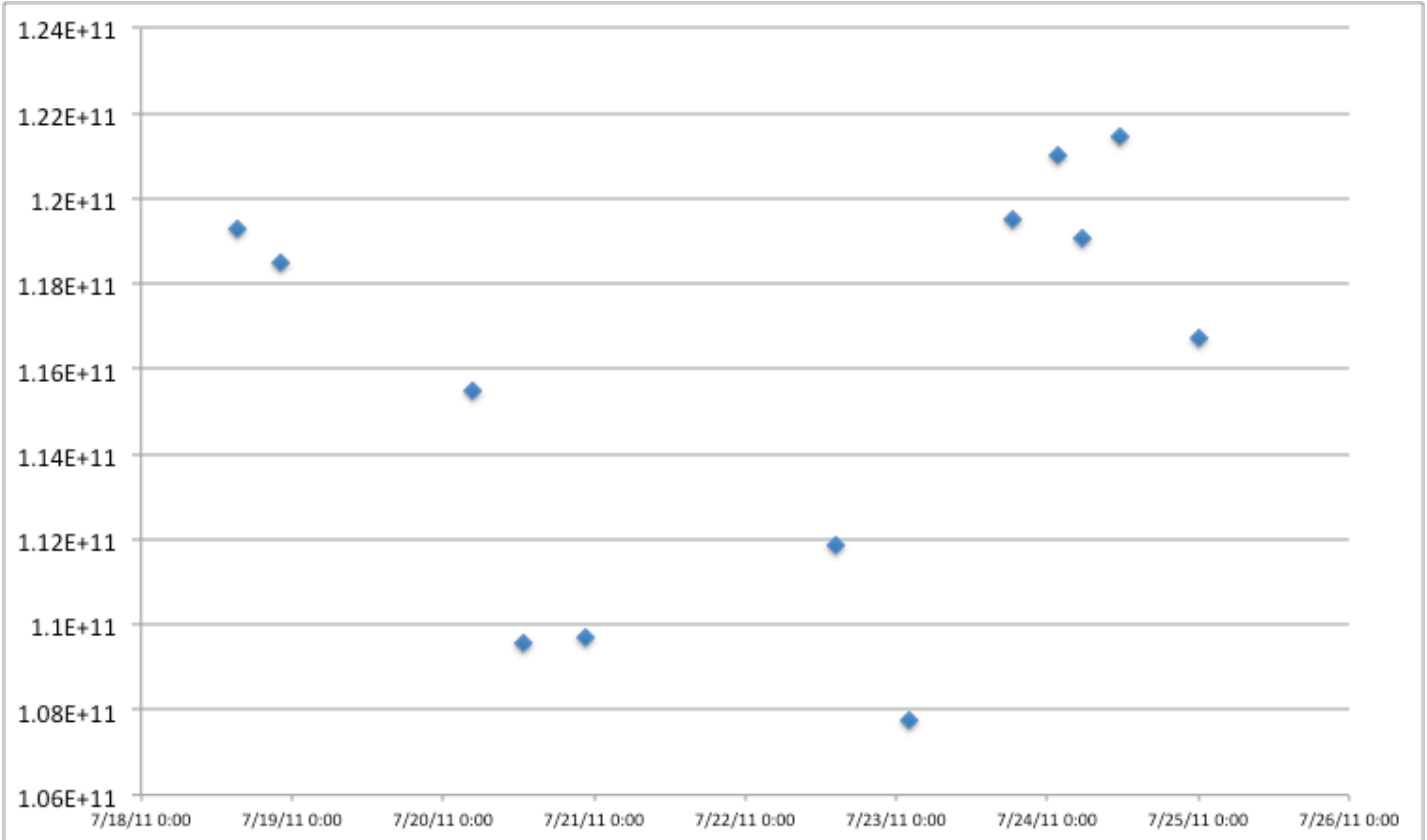
Parameter and Criteria	adiabatic?	Estimated Max Lumi Improvement Factor	Lost Time for physics (days)	Risk/ Reversibility	Pile-up	Available Improvement factor (50ns)	Available Improvement factor (25ns)
ppb	yes	2	0	0	higher	Yes	No
emittance	yes	1.35	0	0	higher	Yes	No
beta*	No	1	3	>0	higher	Yes	Yes
25ns	No	1.9	10	>0	same	No	Yes
				Luminosity Factor		2.7	1.9
				Pile Up		19	7
				Estimated Relative Integrated Luminosity		209	124
				Relative Integrated Luminosity if we do nothing		90	

$$L = \frac{n_b \cdot N_{bunch1} \cdot N_{bunch2} \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)$$

Emittances – start of fill

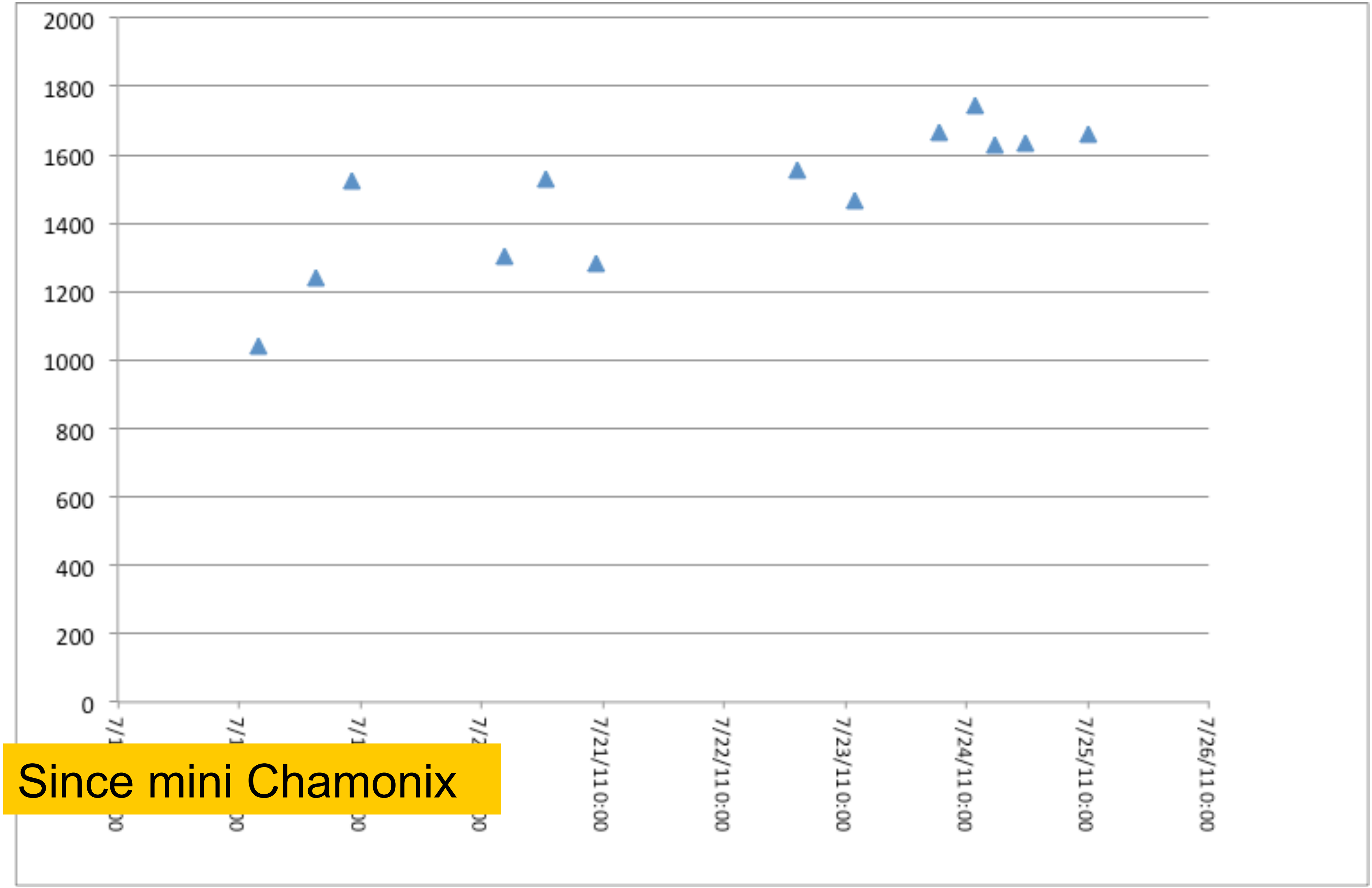


Bunch intensities



Since mini Chamonix

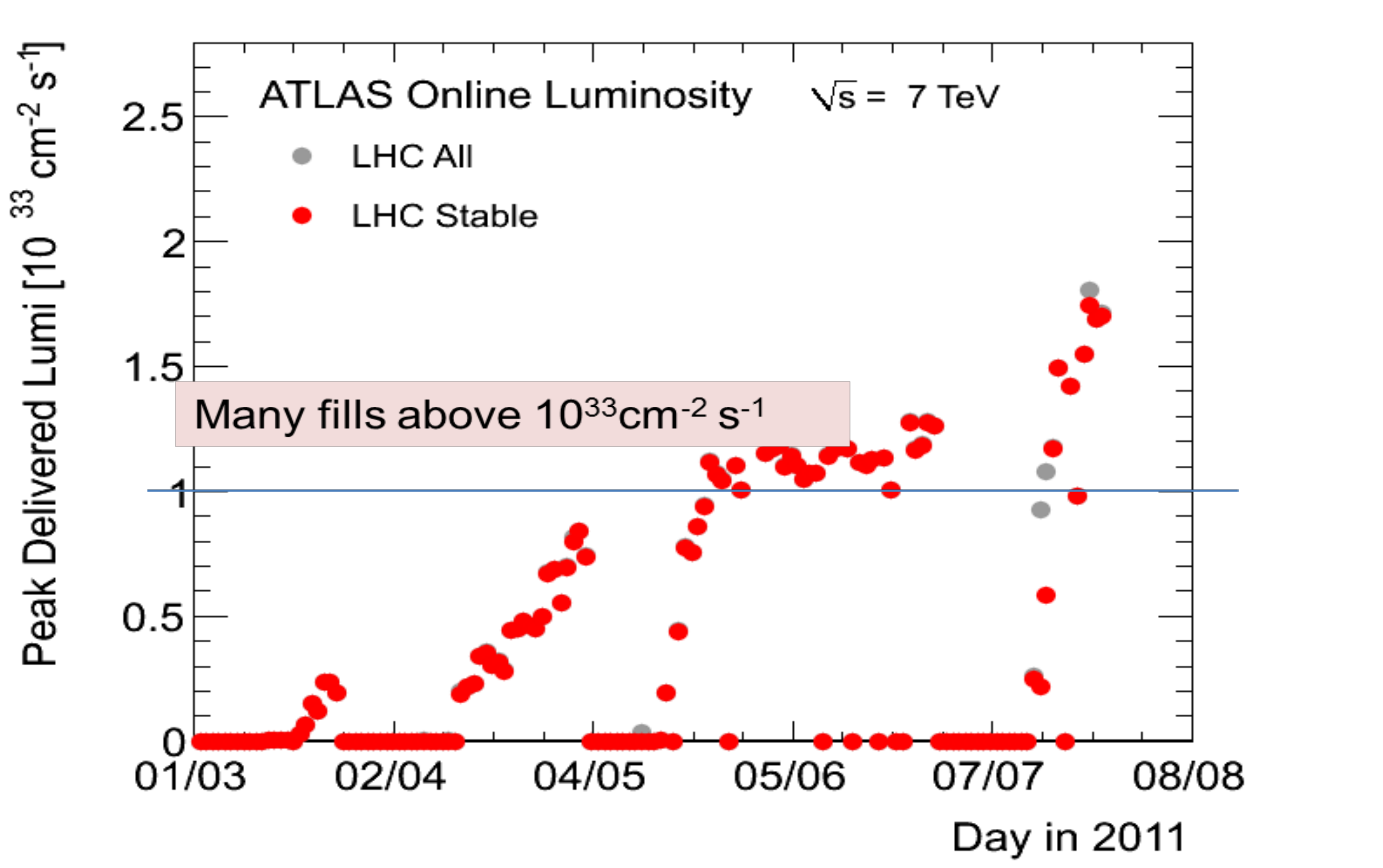
Peak luminosity



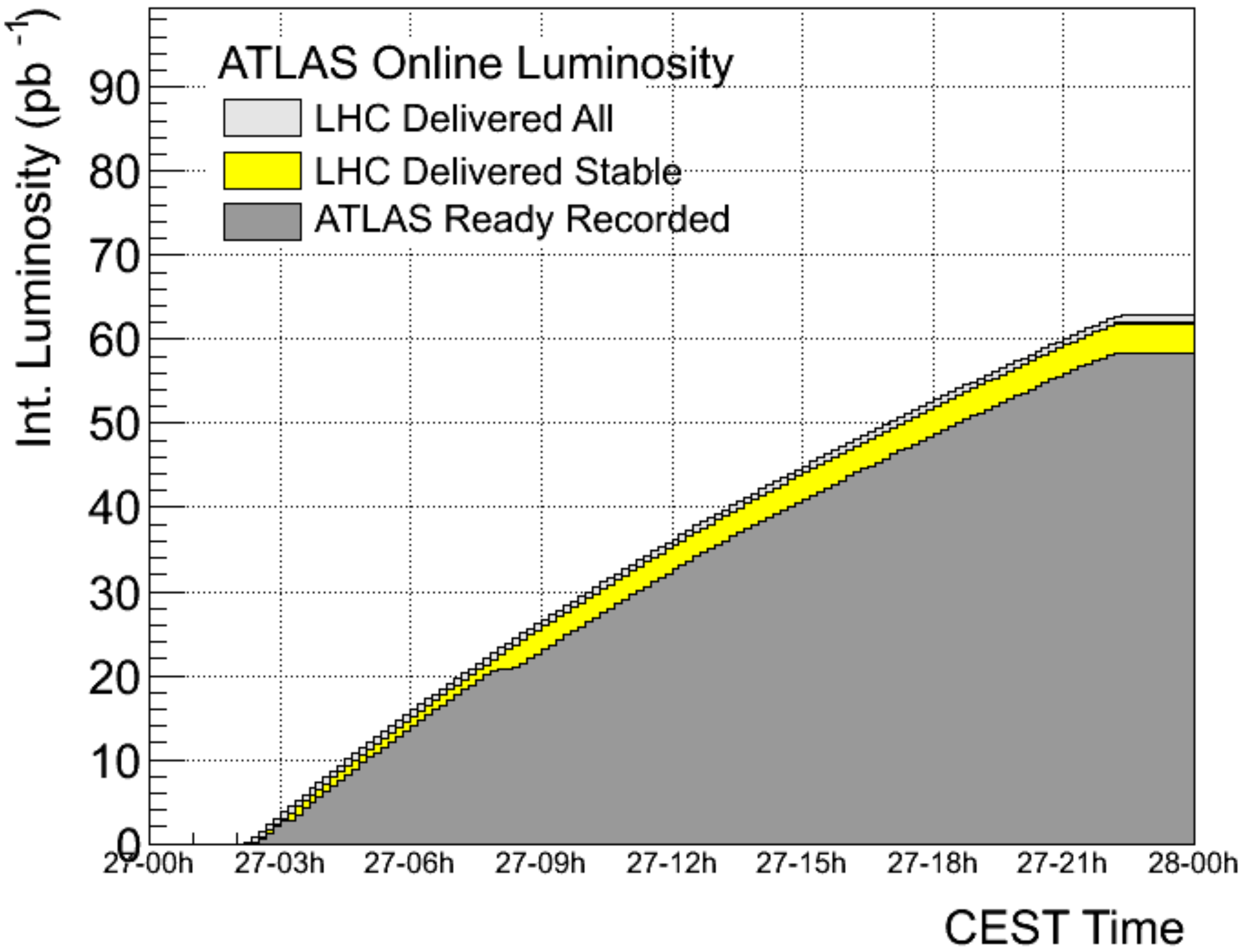
Since mini Chamonix

Up-to-Date Performance Plots

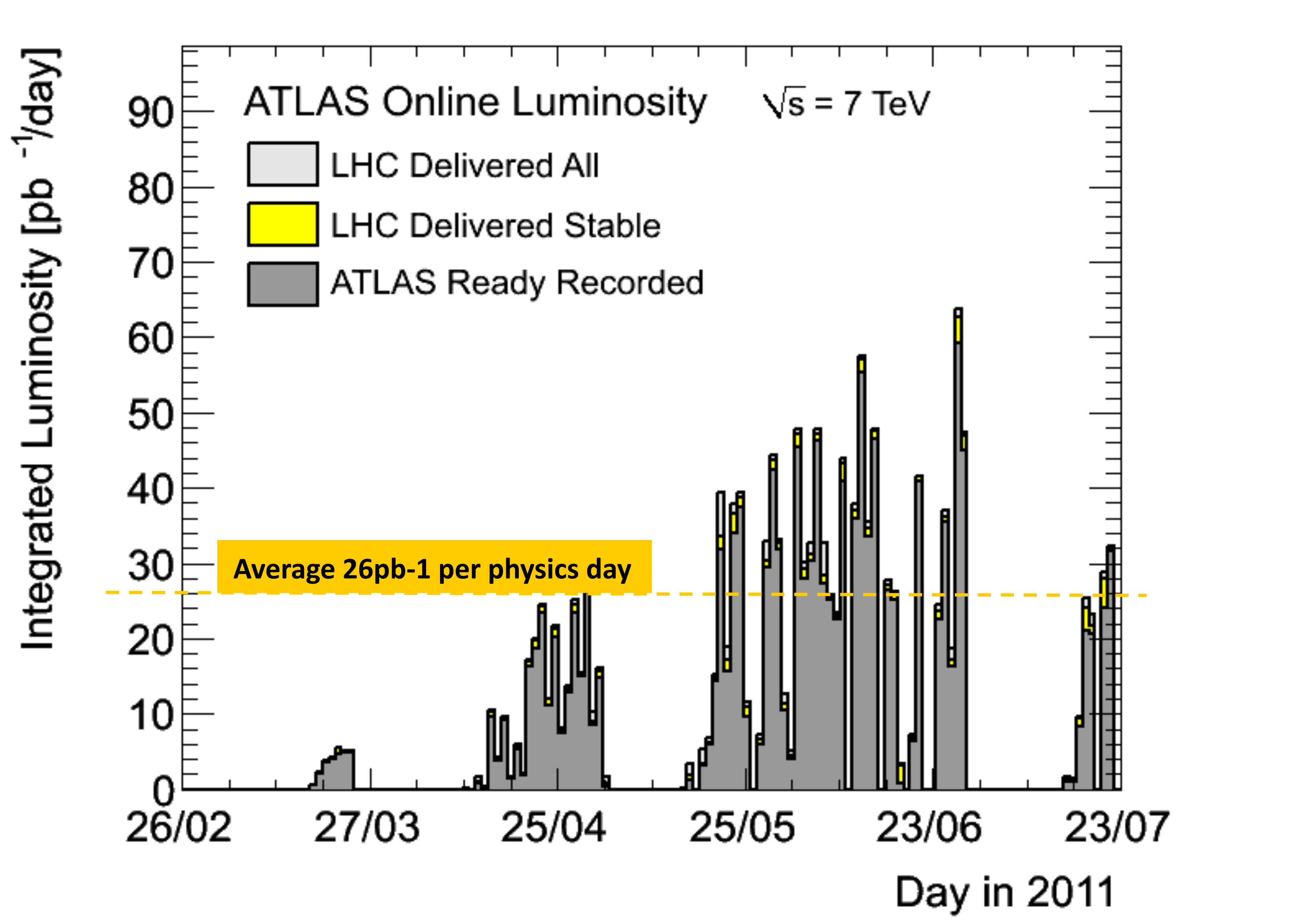
Peak Luminosity



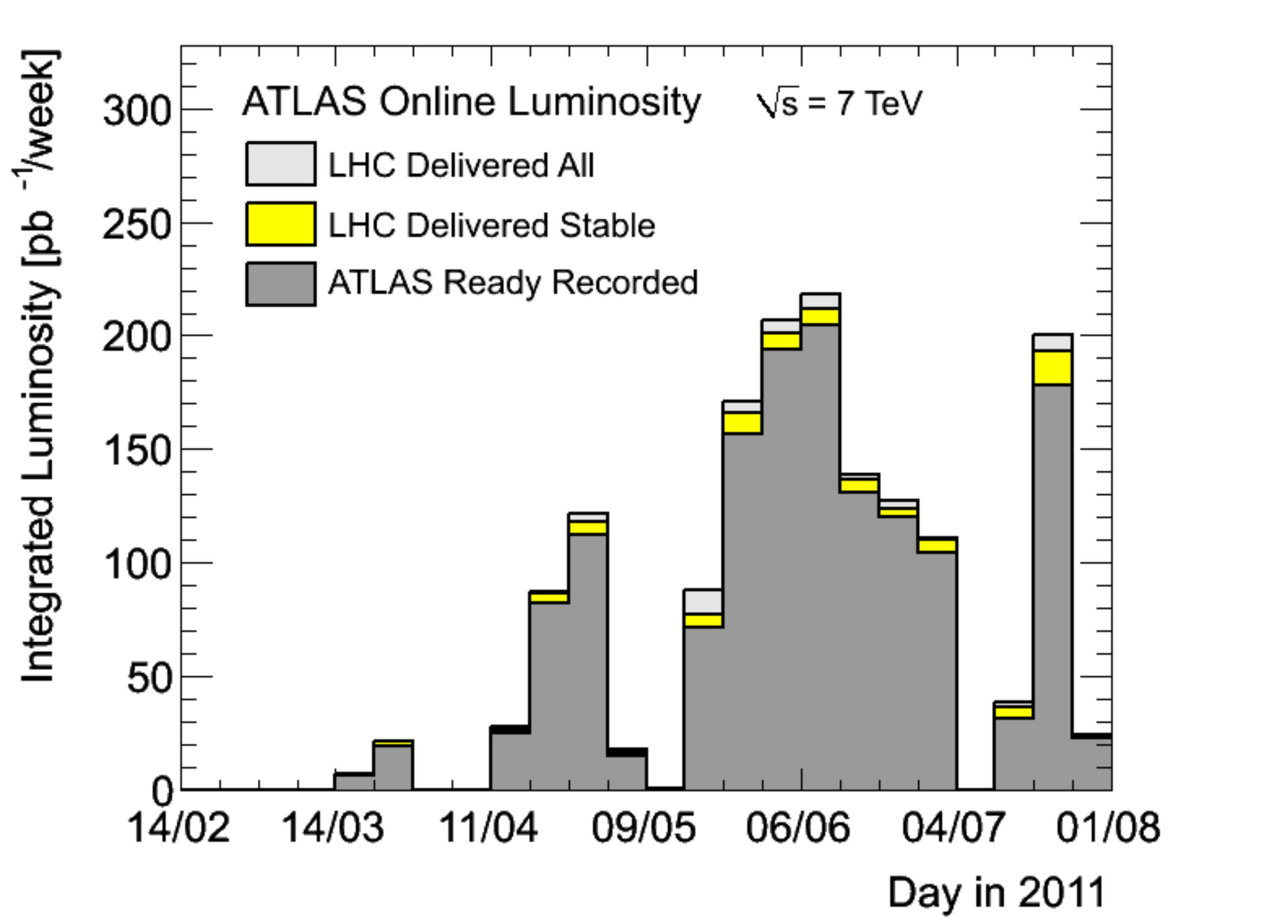
Best Fill


ATLAS Online Luminosity
LHC Delivered All
LHC Delivered Stable
ATLAS Ready Recorded
Int. Luminosity (pb $^{-1}$)
0
10
20
30
40
50
60
70
80
90
27-00h
27-03h
27-06h
27-09h
27-12h
27-15h
27-18h
27-21h
28-00h
CEST Time

Daily Integrated Luminosity (22/7)



Weekly Integrated Luminosity



Evolution of Peak Performances to date

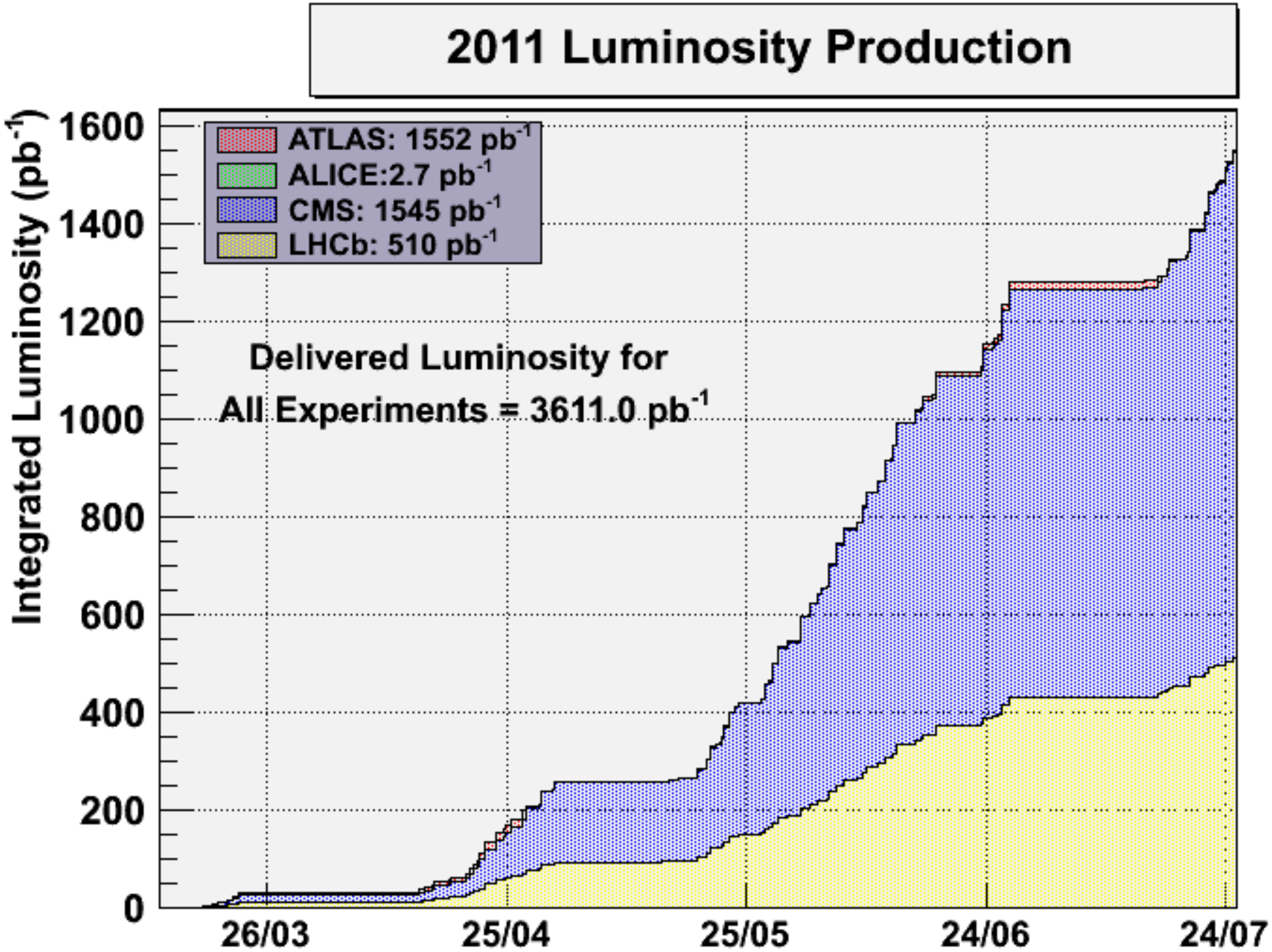
25th July 2011

Peak Performances					
Fill Number	Date	Bunch Spacing	Number of Bunches	Peak Luminosity ($10^{33}cm^{-2}s^{-1}$)	Total Number of protons per beam (10^{14})
1635	18 March 2011	75	32	0.03	0.04
1637	19 March 2011	75	64	0.06	0.07
1644	22 March 2011	75	136	0.17	0.16
1645	22 March 2011	75	200	0.25	0.24
1712	15 April 2011	50	228	0.24	0.29
1716	16 April 2011	50	336	0.35	0.42
1739	26 April 2011	50	480	0.51	0.58
1749	30 April 2011	50	624	0.72	0.76
1755	02 May 2011	50	768	0.83	0.93
1809	27 May 2011	50	912	1.10	1.15
1815	29 May 2011	50	1092	1.27	1.33
1901	27 June 2011	50	1236	1.25	1.64
1970	23 July 2011	50	1380	1.75	1.65

Records as of July 25

Peak Stable Luminosity Delivered	$1.75x10^{33}$	Fill 1970	11/07/23, 20:31
Maximum Luminosity Delivered in one fill	62.85 pb^{-1}	Fill 1900	11/06/26, 22:08
Maximum Luminosity Delivered in one day	62.85 pb^{-1}	Monday 27 June, 2011	
Maximum Luminosity Delivered in 7 days	242.32 pb^{-1}	Wednesday 08 June, 2011 - Tuesday 14 June, 2011	
Maximum Colliding Bunches	1331	Fill 1956	11/07/18, 08:00
Maximum Peak Events per Bunch Crossing	14.01	Fill 1732	11/04/23, 05:47
Maximum Average Events per Bunch Crossing	8.93	Fill 1644	11/03/22, 02:20
Longest Time in Stable Beams for one fill	19.2 hours	Fill 1900	11/06/27, 01:09
Longest Time in Stable Beams for one day	19.9 hours (82.9%)	Monday 27 June, 2011	
Longest Time in Stable Beams for 7 days	93.0 hours (55.4%)	Thursday 21 April, 2011 - Wednesday 27 April, 2011	
Fastest Turnaround to Stable Beams	2.4 hours	Fill 1718	11/04/16, 22:56

Integrated Luminosity (25/7)



Some Concerns with High Intensity

The Last Week 1/2

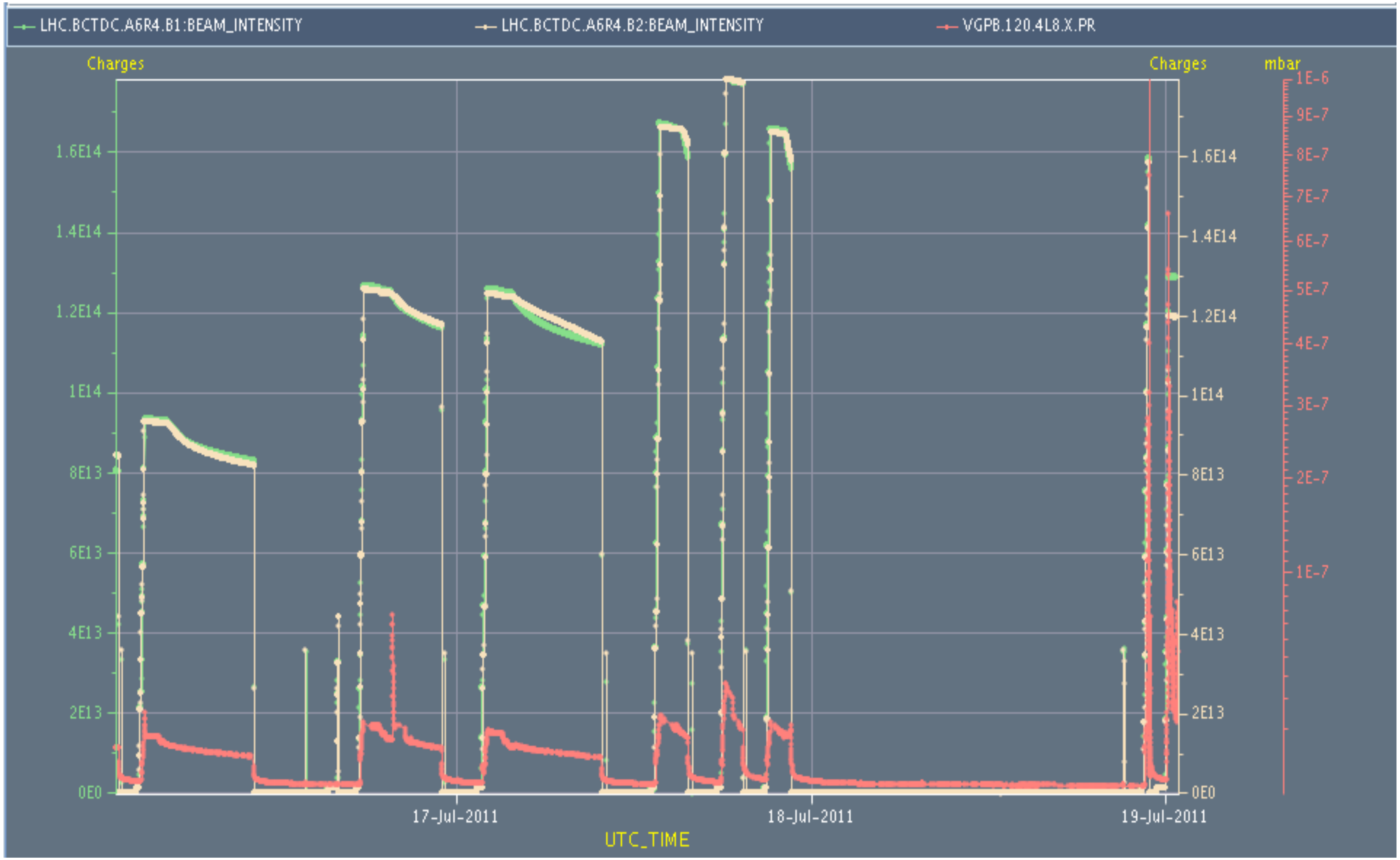
Date	Mode	Fill	SB	pb^{-1}	Cause of dump
MON 18	STABLE BEAMS	1955	6h8m	18.3	QPS trigger, trip of RQTL7.L7B1
MON 18	STABLE BEAMS	1956	17m	.4	Cryo lost S56, SEU on a thermometer at a current lead
MON 18	ADJUST	1957	0	0	Dumped by SW interlock on BLM HV channel (1.3e11/bunch)
MON 18	STABLE BEAMS	1958	21m	1.1	Loss of cryogenic conditions in Sector 34 – PLC crash
WEDS 20	STABLE BEAMS	1960	1h9m	5.2	Problem on valve on DFB in arc 8.1 Possible SEU
WEDS 20	STABLE BEAMS	1961	2h7m	8.2	QPS - blown fuse in WorldFIP repeater
THURS 21	STABLE BEAMS	1962	15h26	46.3	CMS BCM2
FRI 22	SQUEEZE	1963	0	0	QTF trip: QFB versus QPS
FRI 22	RAMP	1964	0	0	RCBXH.R1 tripped, PC changed
FRI 22	STABLE BEAMS	1966	8.56	34.6	CMS BCM2
SAT 23	STABLE BEAMS	1967	11.4	41.7	Valve controller IT.R1 – possible SEU

The Last Week 2/2

Date	Mode	Fill	SB	pb^{-1}	Cause of dump
Sat 23	STABLE BEAMS	1968	46m	4.0	Electrical network glitch
Sat 23	ADJUST	1969	0	1.8e33!	Vacuum spike 4L8
Sun 24	STABLE BEAMS	1970	1h37m	9.5	Vacuum spike 4L8
Sun 24	STABLE BEAMS	1971	1h8m	6.2	Controller IT5 Possible SEU
Sun 24	STABLE BEAMS	1972	46m	4.4	Cryo – R1 24V supply Possible SEU
Sun 24	FLAT TOP	1973	-	-	QPS communication problem
Sun 24	STABLE BEAMS	1974	5h15	25.5	Electrical network glitch

7 SEUs in one week, is becoming a serious issue.
Mostly luminosity dependant

Beam intensity and vacuum (4L8)



Present "Issues"

- SEUs (dependent on total intensity and luminosity)
- UFOs (not intensity dependent)
  - Not serious for the moment (at 3.5TeV/beam but…)
- HOM heating of Injection kickers, cryo, collimators.. (total intensity and bunch length dependence)
- Vacuum instabilities at very high bunch intensities (adiabatic) ? Proton losses causing heating and desorption
- Steering beams into collision (LHCb) often provoked serious reductions in beam lifetime (beam dumps)

Topics

- LHC progress in 2011
- Prospects in the Short term (2012)
    - Protons and ions
- Mid Term Prospects (2014-2021)
- Long Term Prospects (2022--….)

Short term (protons)

Physics data-taking until end of 2012

- 50ns or 25 ns
  - For peak luminosity, 50ns is still higher due to the better performance beams from the injectors. But…event pile-up?
  - Very high intensity operation at 50ns may need beam scrubbibng with 25ns
- beam energy
  - Following measurements of the copper stabilizers resistances during the Christmas stop, we will re-evaluate the maximum energy for 2012 (Chamonix 2012)

Short term (ions)

Lead-lead for 4-5 weeks at end of 2011 with increased number of bunches and luminosity

Feasibility Test end 2011 for protons-lead (possibly 2012)

If feasible protons-lead in 2012 otherwise continue with lead-lead. Can profit from any energy increase for the protons

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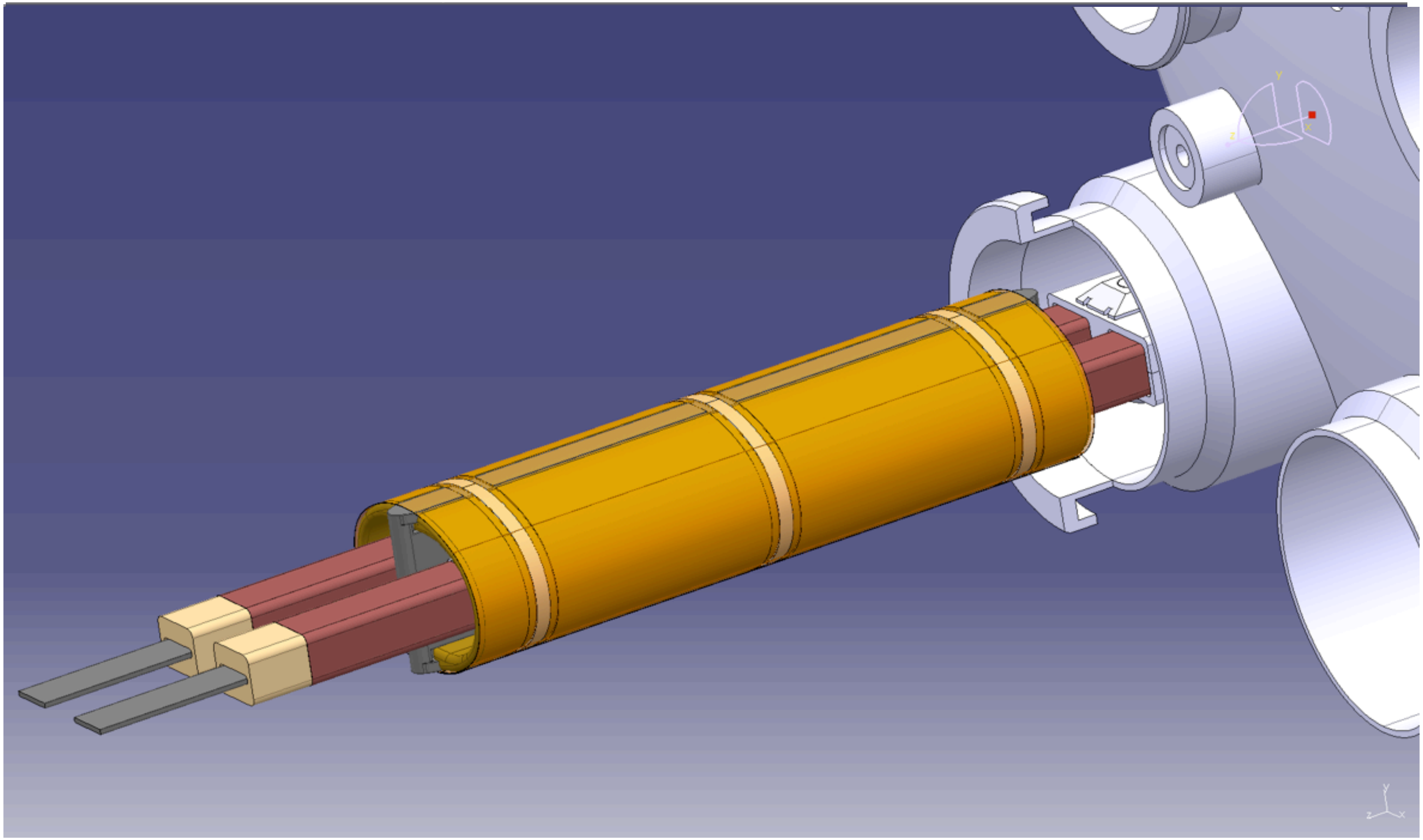
LS1 then operation around 7TeV/beam

LS1

- Repair defectuous interconnects
- Consolidate all interconnects with new design
- Finish off pressure release valves (DN200)
- Bring all necessary equipment up to the level needed for 7TeV/beam
- Not necessary to install the DS collimators in IR3
- Experiments consolidation/upgrades

LHC MB circuit splice consolidation proposal

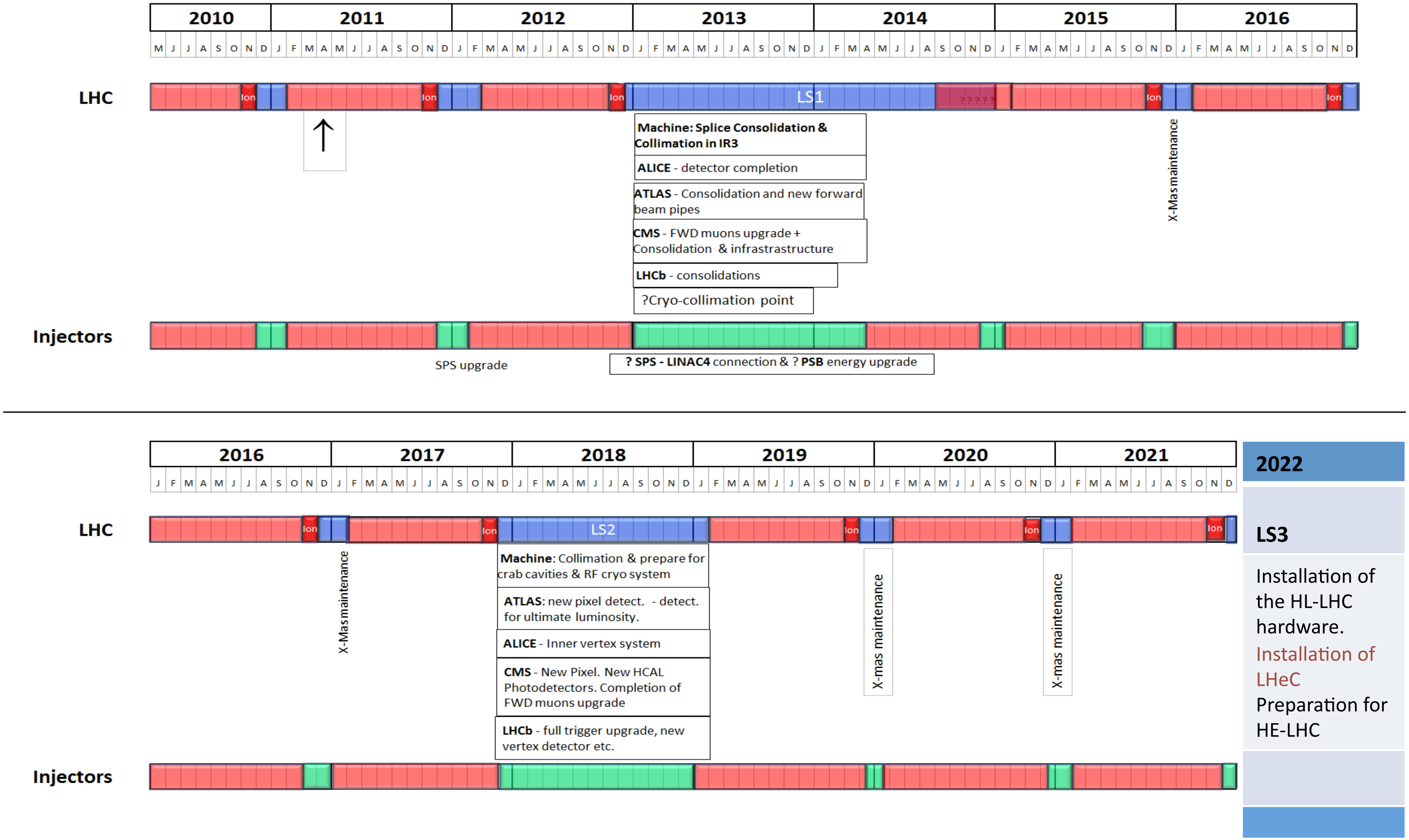


Phase III

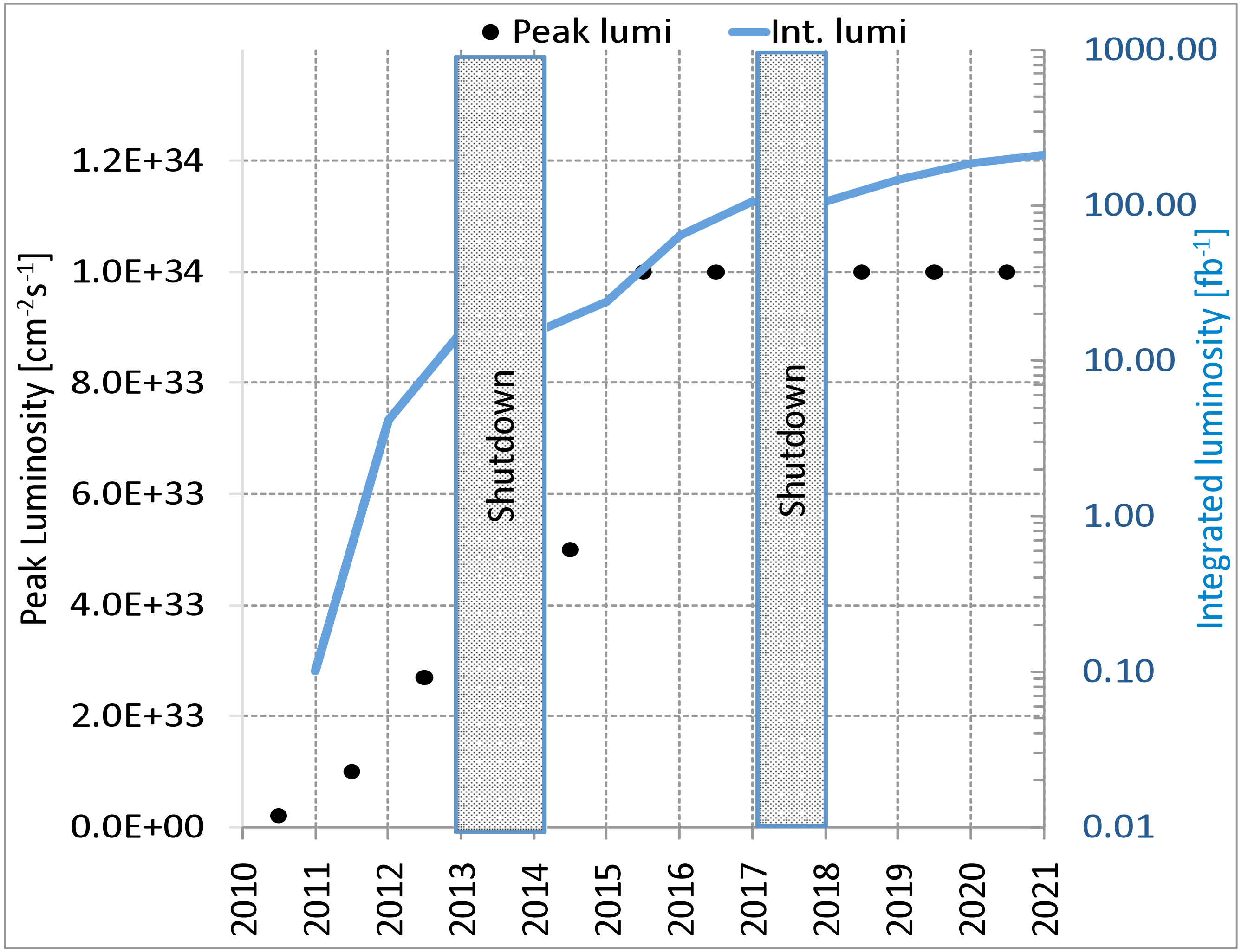
Insulation between bus bar and to ground, Lorentz force clamping

New rough draft 10 year plan

Not yet approved!



Possible Luminosity Evolution: optimistic to 2012, then prudent



Shown by Lucio Rossi last Saturday

Not yet validated by LMC or Directorate

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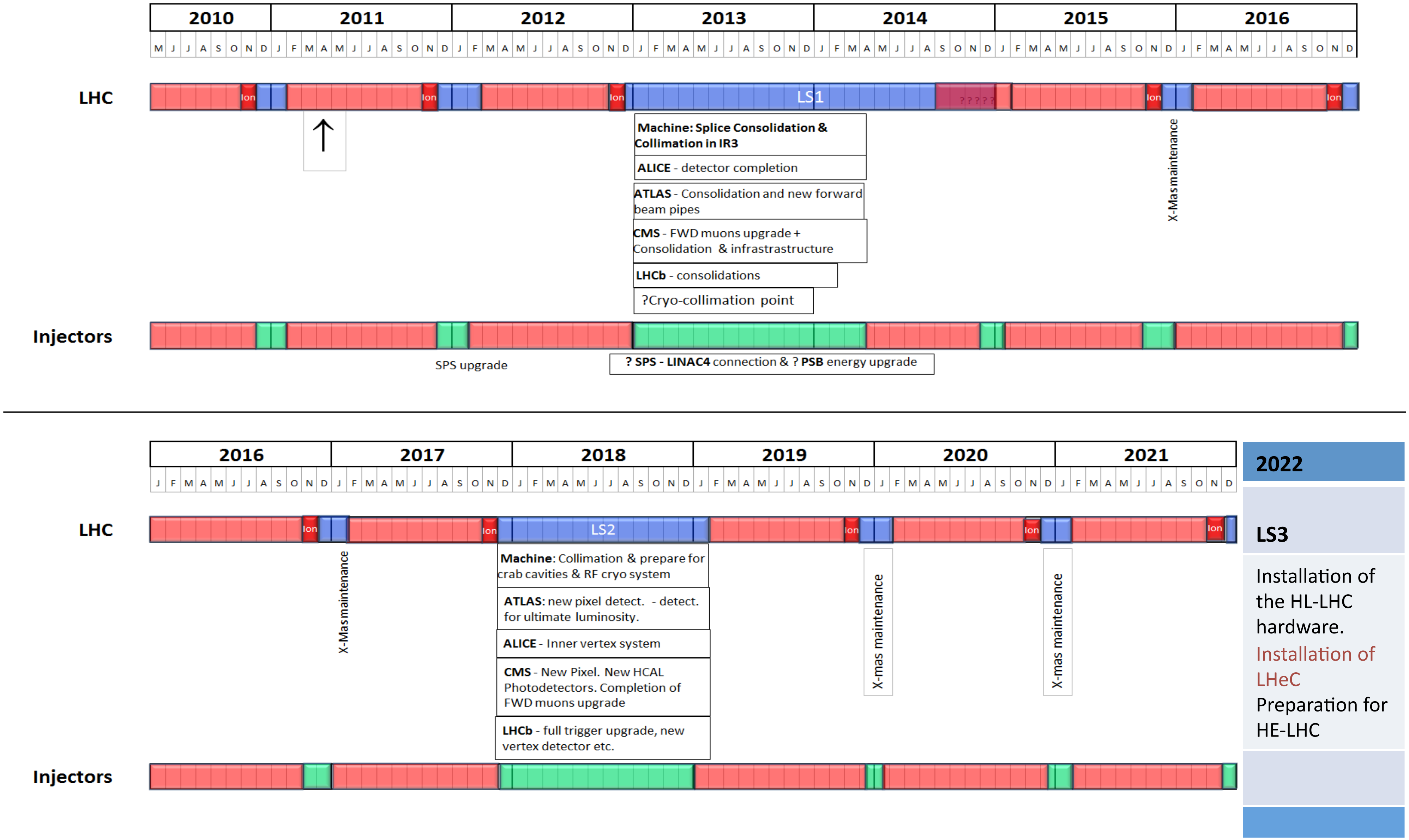


Longer Term

HL-LHC

LHeC

HE-LHC

HL-LHC

Luminosity Upgrade Scenario

- For LHC high luminosities, the luminosity lifetime becomes comparable with the turn round time ⇒ Low efficiency
- Preliminary estimates show that the useful integrated luminosity is greater with
  - a peak luminosity of $5x10^{34}$ cm^{-2} s^{-1} and a longer luminosity lifetime (by luminosity levelling)
  - than with 10^{35} and a luminosity lifetime of a few hours
- Luminosity Levelling by
  - Beta*, crossing angle, crab cavities, and bunch length
  - ??? Off steering
- Goal 200-300fb^{-1} per year

Hardware for the Upgrade

- New high field insertion quadrupoles
- Upgraded cryo system for IP1 and IP5
- Upgrade of the intensity in the Injector Chain (LIU)
- Crab Cavities to take advantage of the small beta*
- Single Event Upsets
  - SC links to allow power converters to be moved to surface
- Misc
  - Upgrade some correctors
  - Re-commissioning DS quads at higher gradient
  - Change of New Q5/Q4 (larger aperture), with new stronger corrector orbit, displacements of few magnets
  - Larger aperture D2

Draft Parameters HL-LHC

Results from Injectors Upgrades

Parameter	nominal	25ns	50ns
N	1.15E+11	2.0E+11	3.[illegible]+11
n_b	2808	2808	[illegible]
beam current [A]	0.58	1.02	[illegible]34
x-ing angle [μrad]	300	475	580
beam separation [σ]	10	10	10
β^* [m]	0.55	0.15	0.15
ε_n [μm]	3.75	2	3.75
ε_L [eVs]	2.51	[illegible]	2.5
energy spread	1.00E-04	1.0[illegible]	1.00E-04
bunch length [m]	7.50E-02	7[illegible]	7.50E-02
IBS horizontal [h]	80 -> 106	[illegible]5	37
IBS longitudinal [h]	61 -> 60	21	21
Piwinski parameter	0.68	2.5	2.5
geom. reduction	0.83	0.37	0.37
beam-beam / IP	3.10E-03	[illegible].9E-03	3.9E-03
Peak Luminosity	$1\ 10^{34}$	$7.4\ 10^{34}$	$6.8\ 10^{34}$

$5.6\ 10^{14}$ and $4.6\ 10^{14}$ p/beam

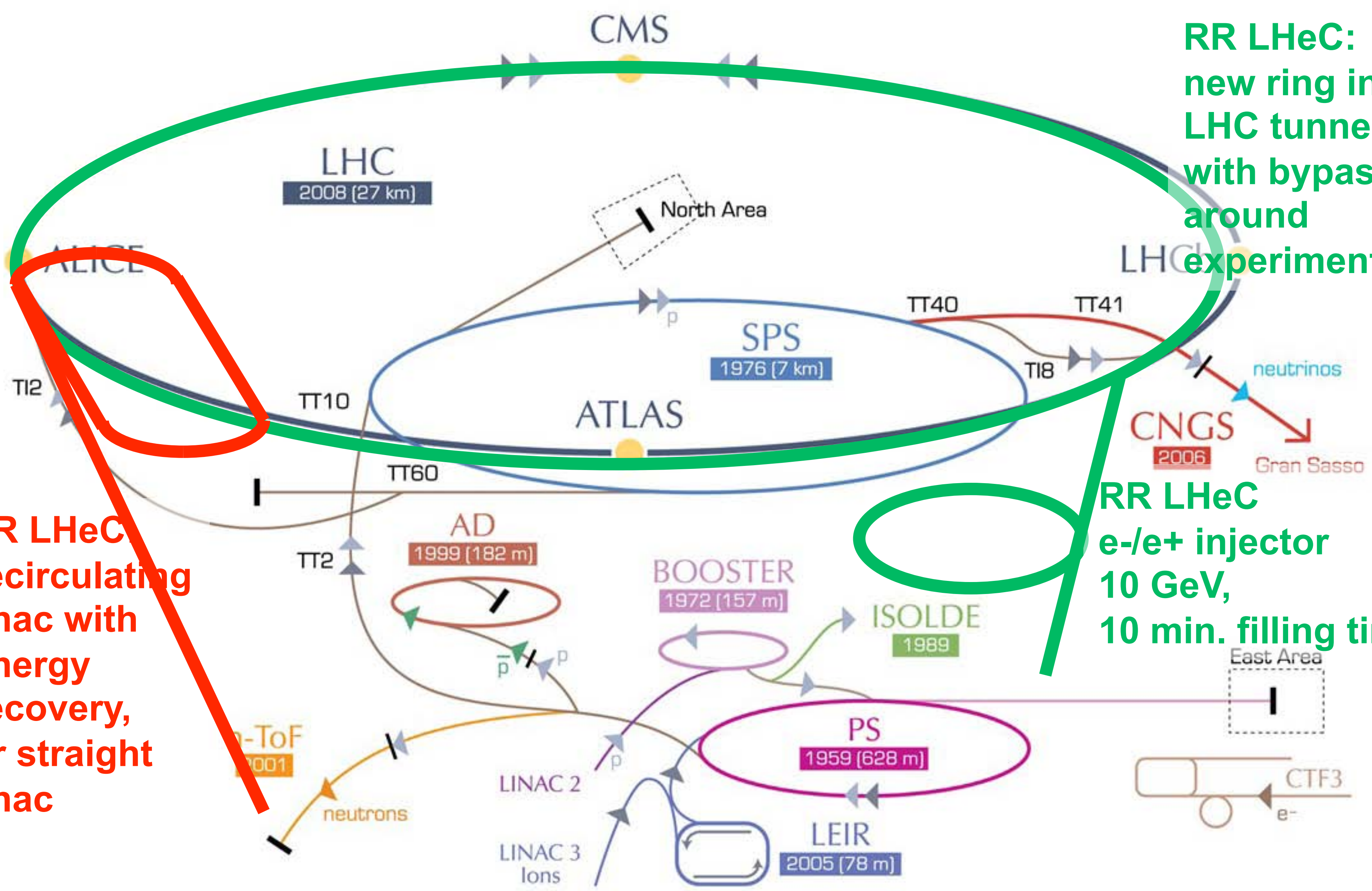
(Leveled to $5\ 10^{34}$ cm^{-2} s^{-1})

Events / crossing	19	141	257	95	190

OK for HL goals, if CRAB cavities are a viable option

LHeC

LHeC options: RR and LR



RR LHeC:
new ring in LHC tunnel, with bypasses around experiments

RR LHeC
e-/e+ injector
10 GeV,
10 min. filling time

LR LHeC:
recirculating linac with energy recovery, or straight linac

Design Parameters

electron beam	RR	LR	LR*
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17	10	0.44
polarization [%]	40	90	90
bunch population [10^9]	26	2.0	1.6
e- bunch length [mm]	10	0.3	0.3
bunch interval [ns]	25	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.58, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	30, 16	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.18, 0.10	0.12	0.14
full crossing angle [mrad]	0.93	0	0
geometric reduction H_{hg}	0.77	0.91	0.94
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	131	6.6	5.4
tot. wall plug power[MW]	100	100	100

*) pulsed, but high energy ERL not impossible

proton beam	RR	LR
bunch pop. [10^{11}]	1.7	1.7
tr.emit. $\gamma\varepsilon_{x,y}$ [μm]	3.75	3.75
spot size $\sigma_{x,y}$ [μm]	30, 16	7
$\beta^*_{x,y}$ [m]	1.8,0.5	0.1
bunch spacing [ns]	25	25

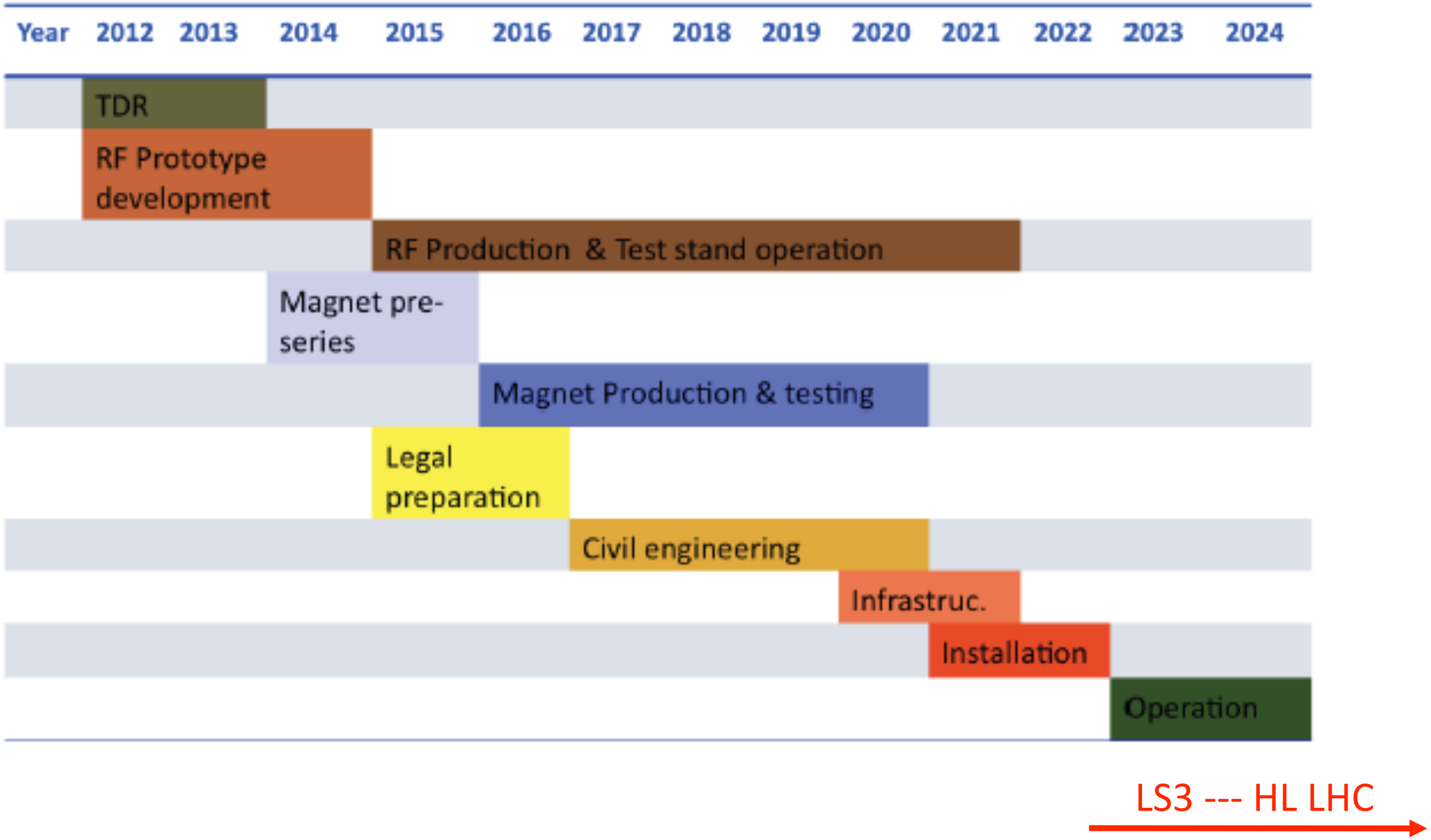
"ultimate p beam"
1.7 probably conservative

Design also for deuterons (new) and lead (exists)

RR= Ring – Ring
LR =Linac –Ring

Ring uses 1° as baseline : L/2
Linac: clearing gap: L*2/3

LHeC Tentative Time Schedule

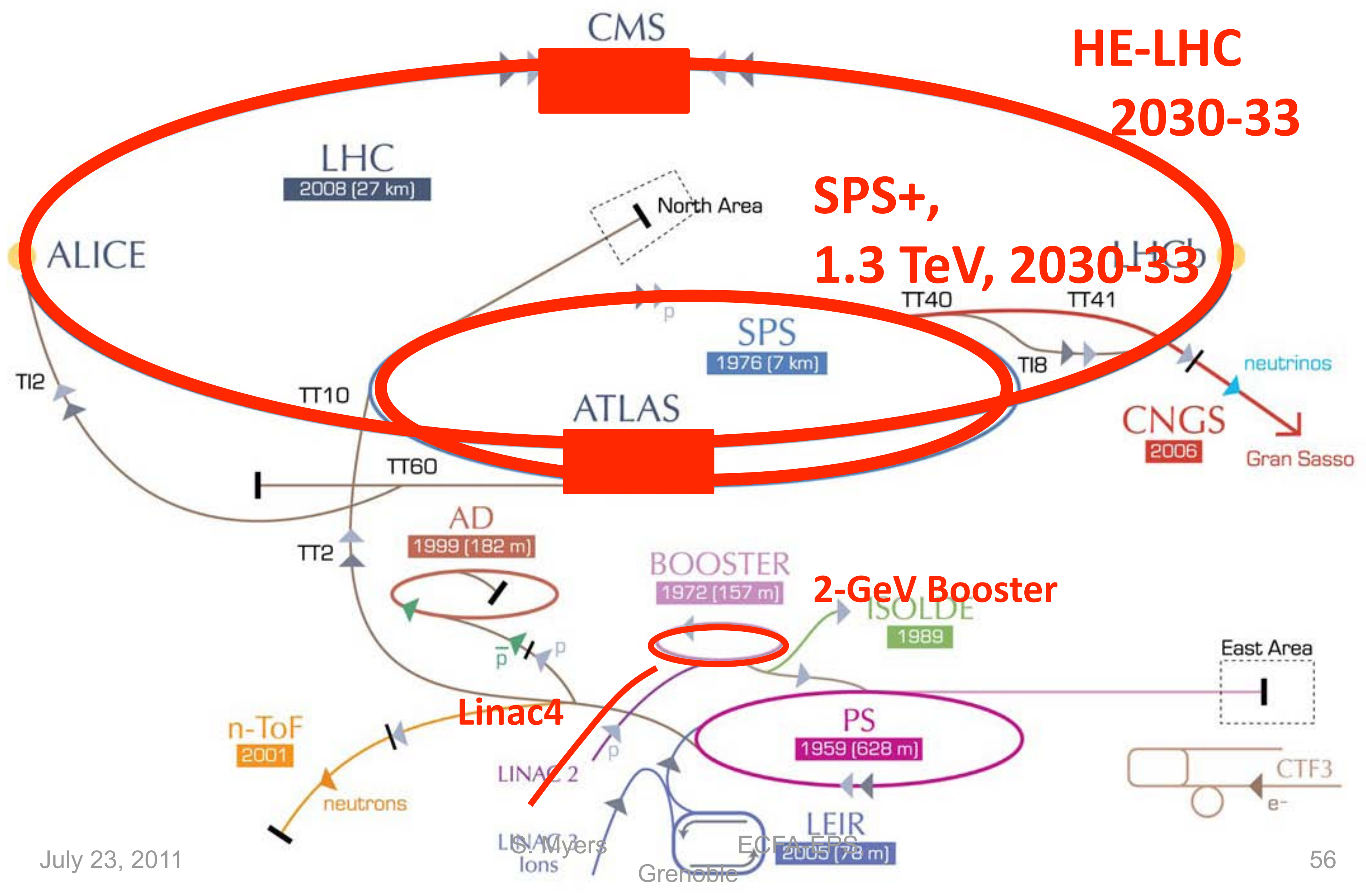


We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

HE-LHC

First Thoughts on an Energy Upgrade

HE-LHC – LHC modifications



Very Long Term Objectives: Higher Energy LHC

Preliminary HE-LHC - parameters

	nom…	HE-LHC
beam energy [TeV]	[illegible]	16.5
dipole field [T]	[illegible]	20
dipole coil aperture [mm]	[illegible]	40-45
#bunches / beam	[illegible]	1404
bunch population [10^{11}]	[illegible]	1.29
initial transverse normalized em… [μm]	[illegible]	3.75 (x), 1.84 (y)
number of IPs contributi…	3	2
maximum total bea…	0.01	0.01
IP beta function …	0.55	1.0 (x), 0.43 (y)
full crossing …	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})
stored b…	362	479
SR p…	3.6	62.3
longitu… …amping time [h]	12.9	0.98
events pe…	19	76
peak lumin… … $cm^{-2}s^{-1}$]	1.0	2.0
beam lifetime …]	46	13
integrated luminosity over 10 h [fb^{-1}]	0.3	0.5

Very preliminary with large error bars

HE-LHC – main issues and R&D

- ***high-field 20-T dipole*** *magnets based on Nb_3Sn, Nb_3Al, and HTS*
- ***high-gradient quadrupole magnets*** *for arc and IR*
- ***fast cycling SC magnets*** *for 1-TeV injector*
- ***emittance control*** *in regime of strong SR damping and IBS*
- *cryogenic handling of* ***SR heat load*** *(first analysis; looks manageable)*
- *dynamic* ***vacuum***

Summary on Future Prospects

- LHC Upgrades: 3 very interesting projects
  1. HL-LHC (approved) and needs LIU (approved)
  2. LHeC (CDR published, and will be reviewed by ECFA and CERN in October 2011)
  3. HE-LHC (project pre-study under way)
- Linear Colliders ILC/CLIC
- Proposal for next energy frontier project will be dependant on the physics output from the LHC until end 2012

LHC present status Summar

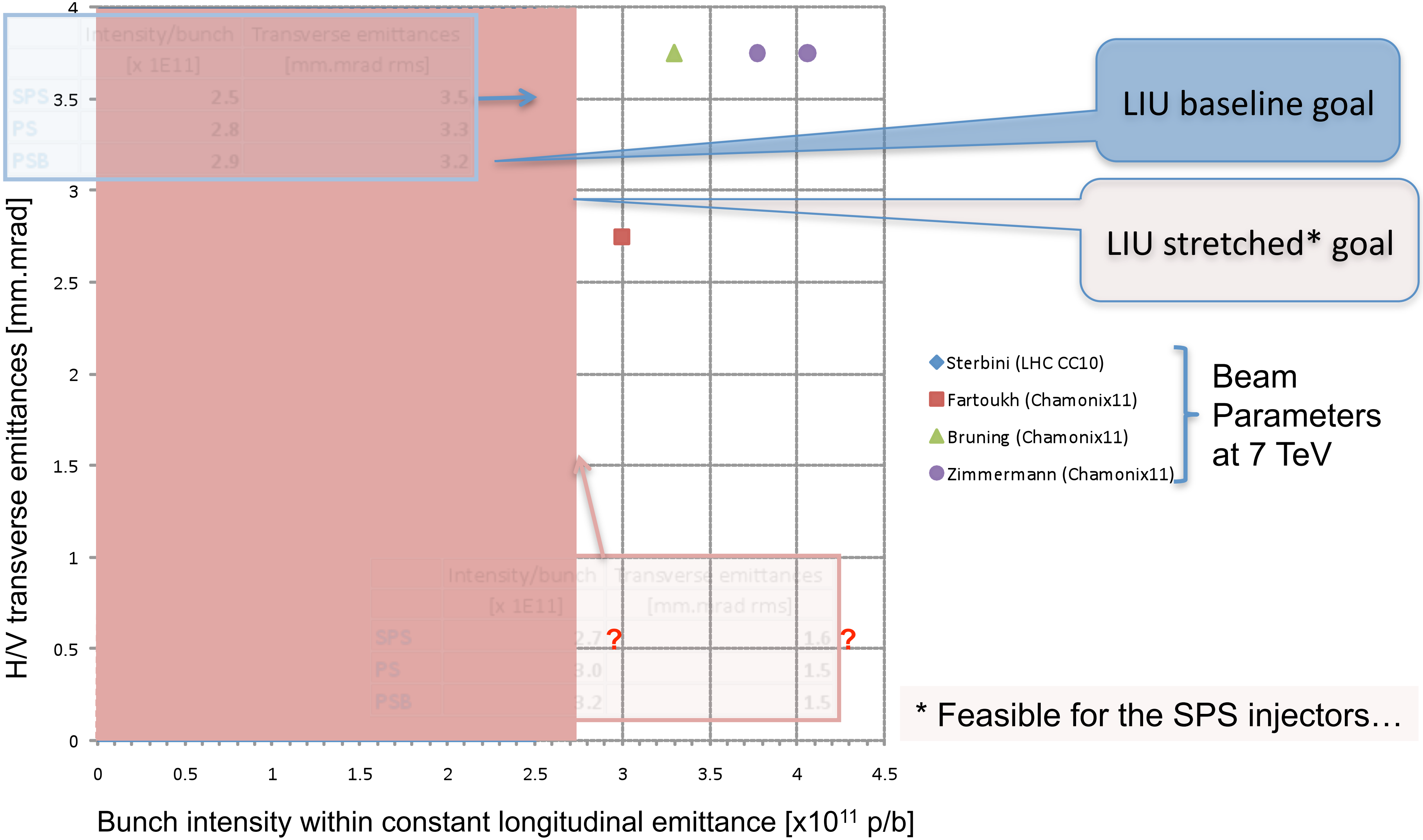
- Beam Intensity, peak and Integrated luminosity still g very (quite) rapidly
- Successfully implemented luminosity leveling for LHC luminosity calibration (vdM scans)
- We reached our 2011 target integrated luminosity, with ~16 weeks still to go, and will certainly produce more barring accidents
- However, progress from here on will be slower due to many simultaneous issues limiting the total intensity
- Conclusions. We are way ahead of the game, and the future is bright. But Euphoria is dangerous
- We must remain extremely vigilant with protection of the machine (100MJ of stored energy) and hope that th more old unexploded bombs in the hardware!!

Thanks to the dedication of the CERN staff and the many excellent collaborators from around the world who pulled together to make this performance possible.

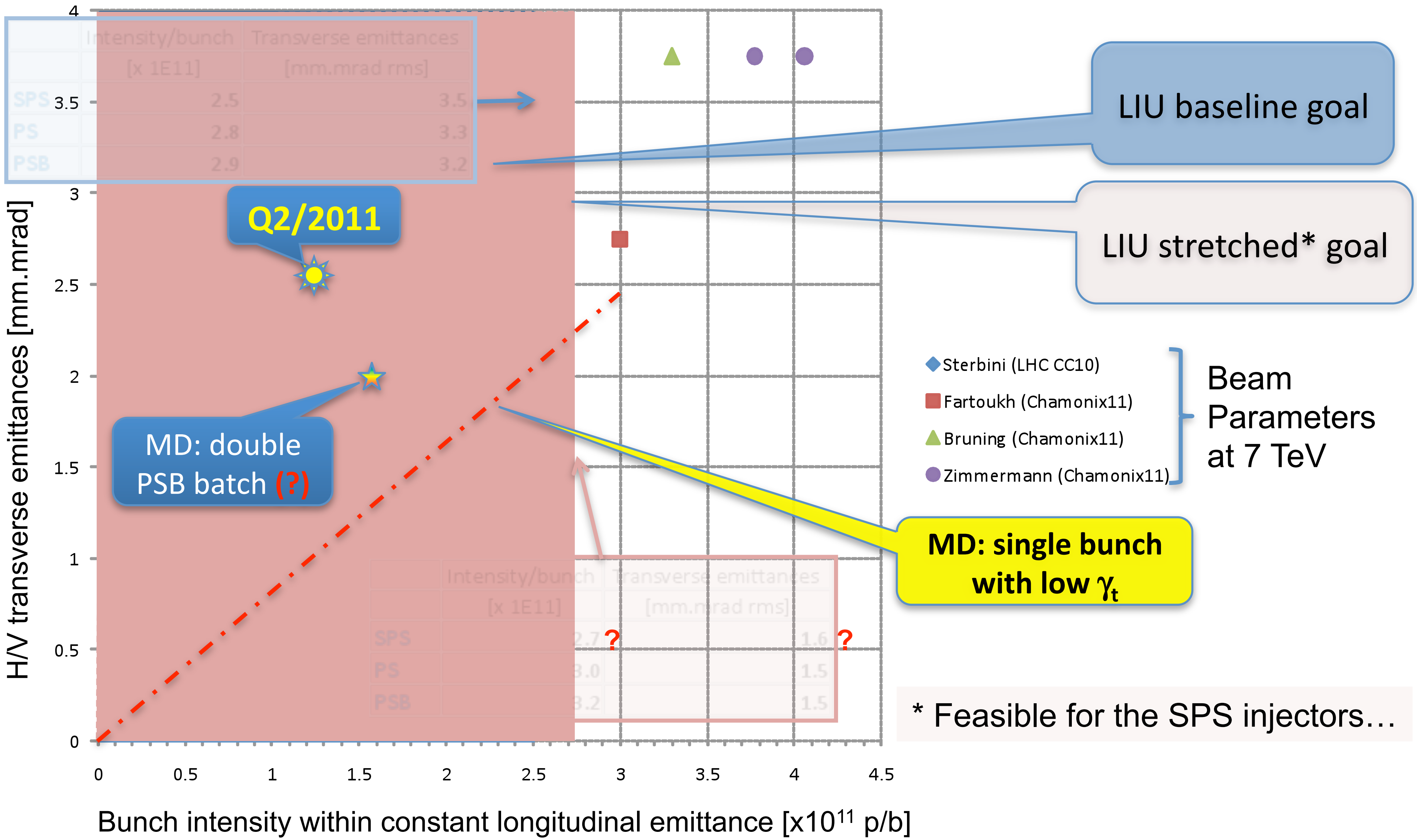
BRAVO!

LIU

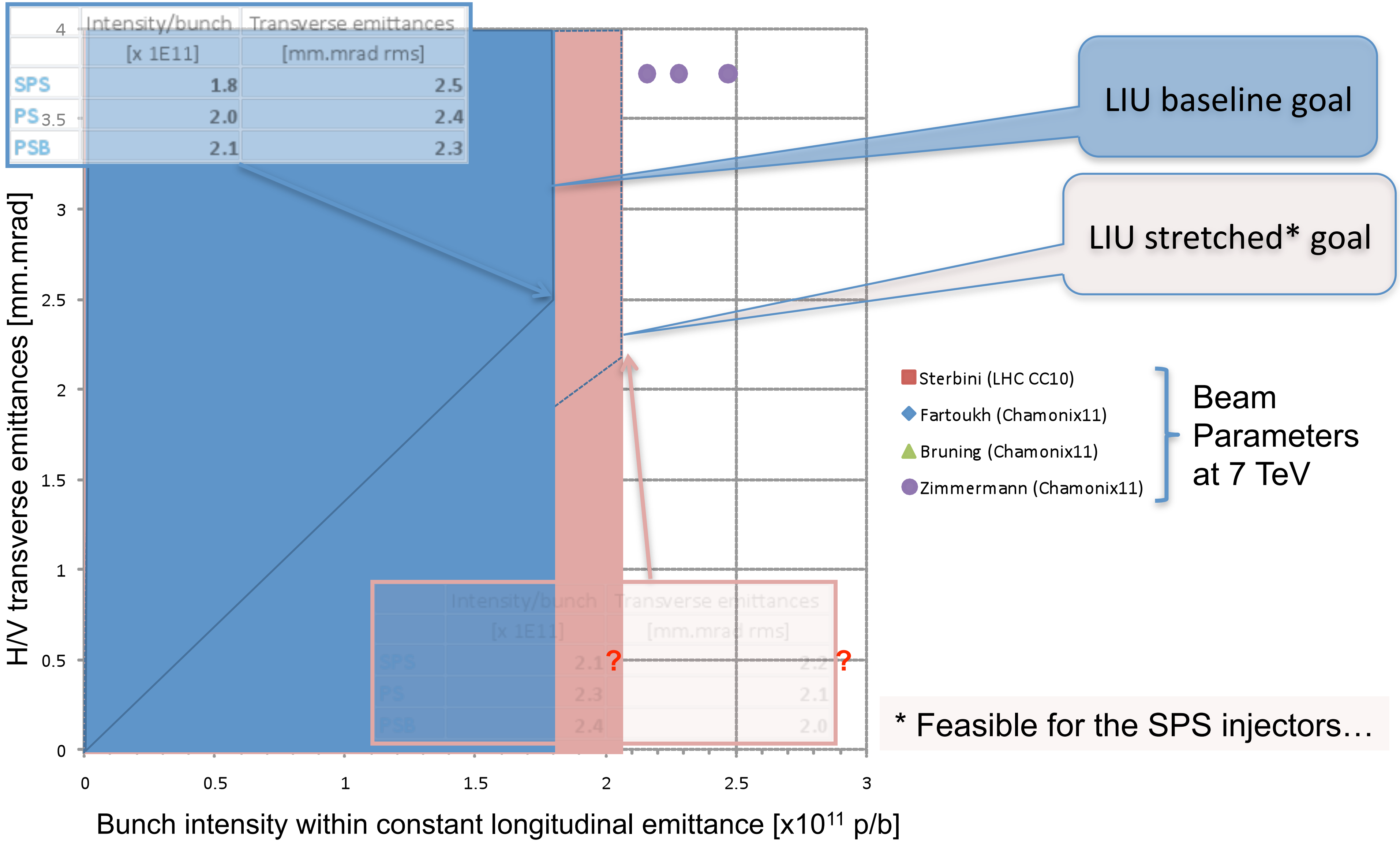
Beam parameters at LHC injection [50 ns]



Beam parameters at LHC injection [50 ns]



Beam parameters at LHC injection [25 ns]

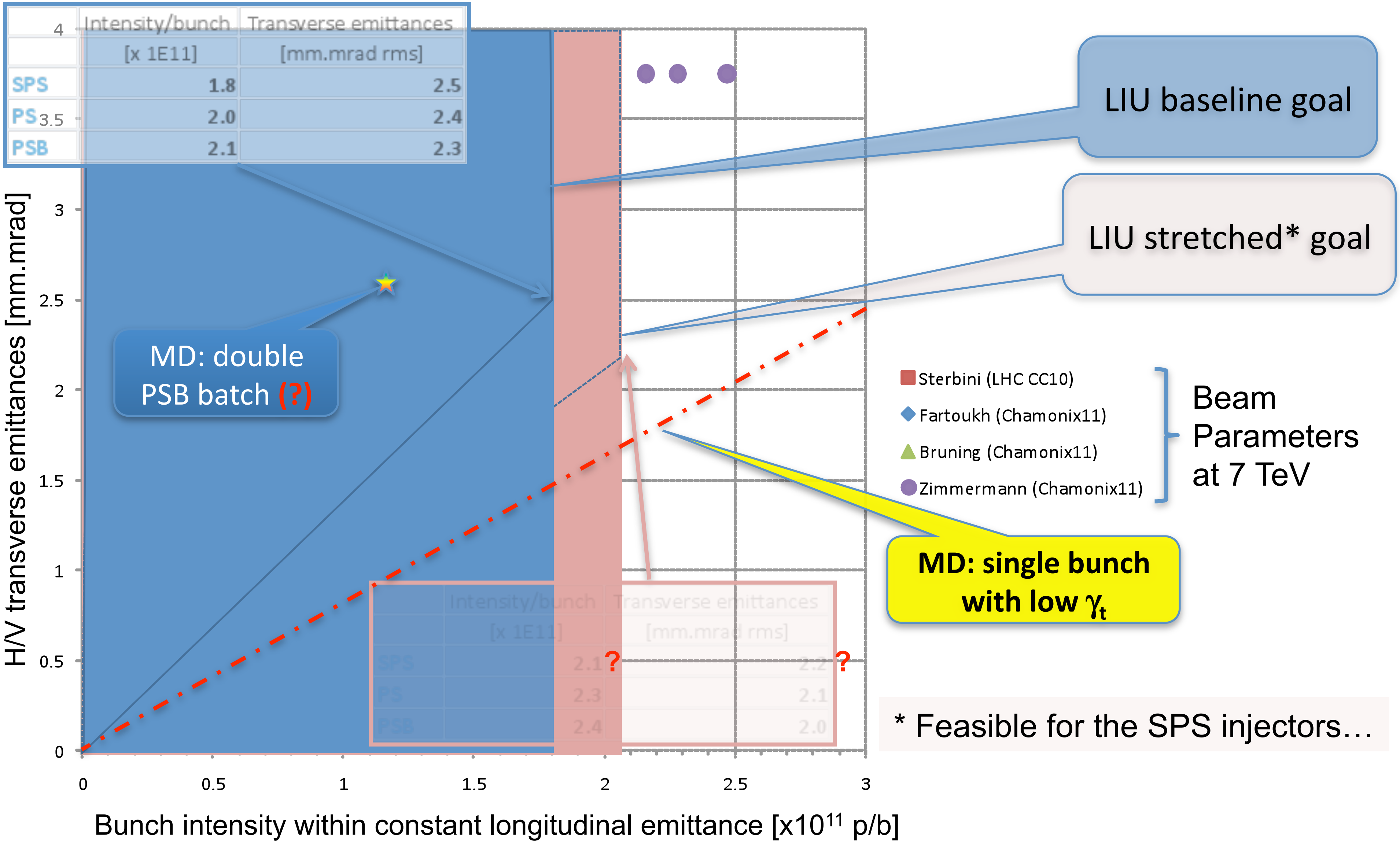


	Intensity/bunch [x 1E11]	Transverse emittances [mm.mrad rms]
SPS	1.8	2.5
PS	2.0	2.4
PSB	2.1	2.3

	Intensity/bunch [x 1E11]	Transverse emittances [mm.mrad rms]
SPS	2.1 ?	2.2 ?
PS	2.3	2.1
PSB	2.4	2.0

* Feasible for the SPS injectors…

Beam parameters at LHC injection [25 ns]



Performance optimization for the LHC

Luminosity (round beams):

$$L = \frac{n_b \cdot N_{bunch,1} \cdot N_{bunch,2} \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)$$

Event pileup & e-cloud

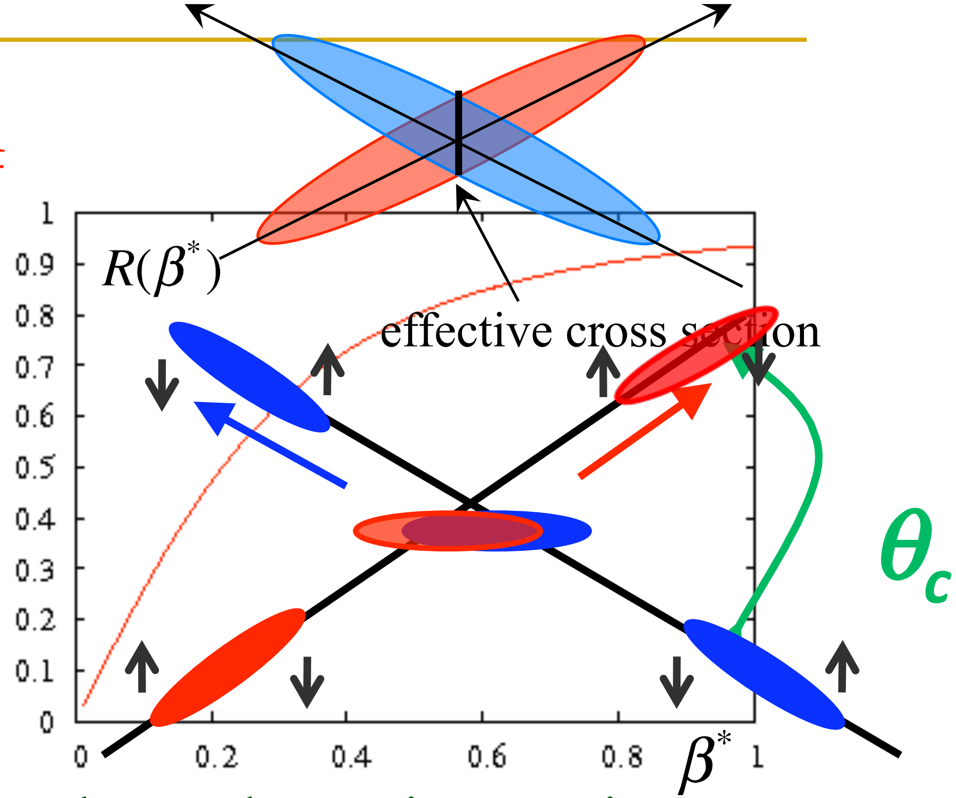
- ➔ 1) maximize bunch brightness [N_{bunch}/ε_n]
  beam-beam limit and injector complex performance
- ➔ 2) minimize beam size [β^*] (constant beam power)
- ➔ 3) maximize number of bunches (beam power limit)
- ➔ 4) compensate for 'R'

LHC Challenges: R

geometric luminosity reduction factor:

Piwinski angle

$$R_\theta = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

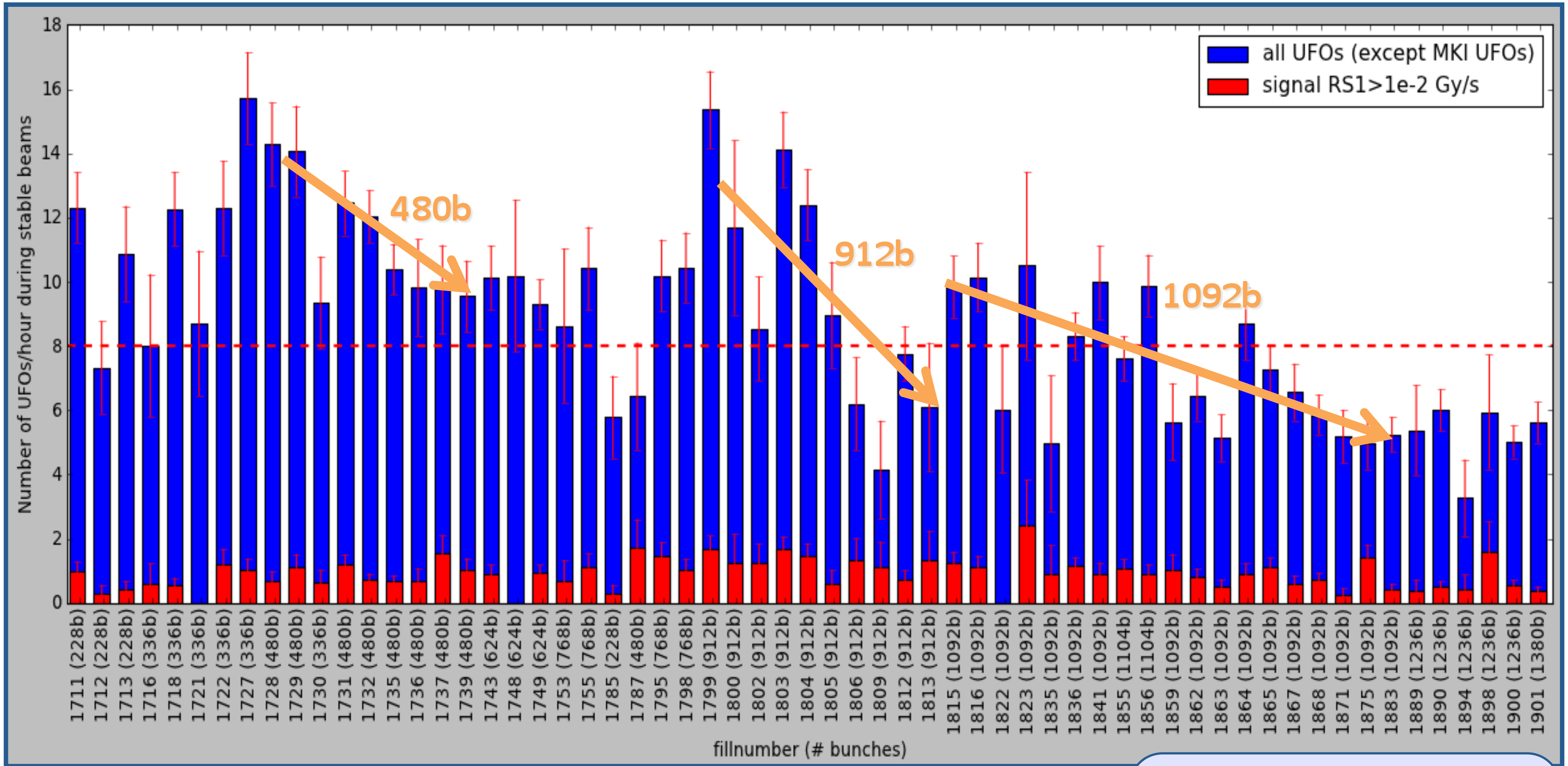


large crossing angle:

- ➔ reduction of long range beam-beam interactions
- ➔ reduction of head-on beam-beam parameter
- ➔ reduction of the mechanical aperture
- ➔ synchro-betatron resonances
- ➔ reduction of instantaneous luminosity
  - ➔ inefficient use of beam current
  - ➔ option for L leveling!

UFOs

UFO rate



2301 candidate UFOs (excluding MKI UFOs) during stable beams in fills with at least 1 hour stable beams. all UFOs: Signal RS05 > $2\cdot10^{-4}$ Gy/s. Data scaled with 1.85 (detection efficiency from reference data)

On average 8 UFOs/hour.
Is there a conditioning effect?

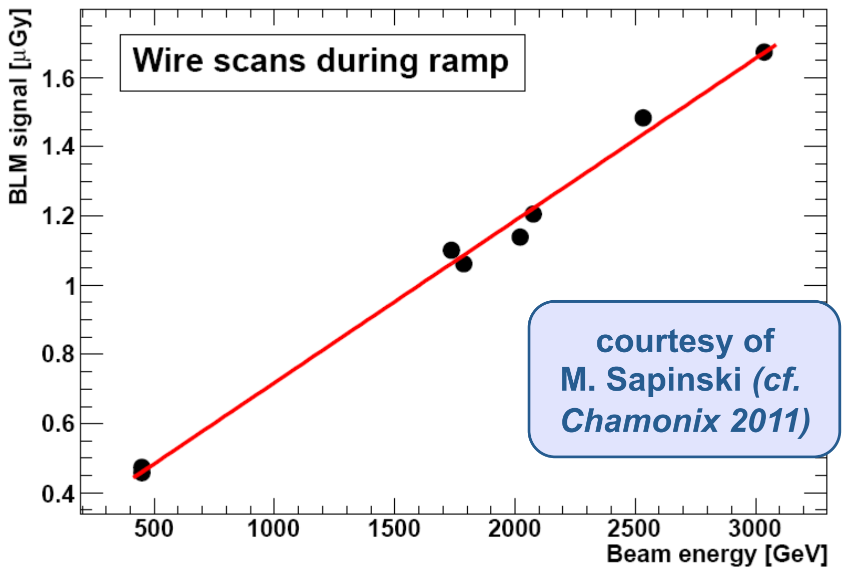
Energy Dependency

- **Ufo amplitude: Linear dependency** of BLM signal on beam energy observed (from wire scans).

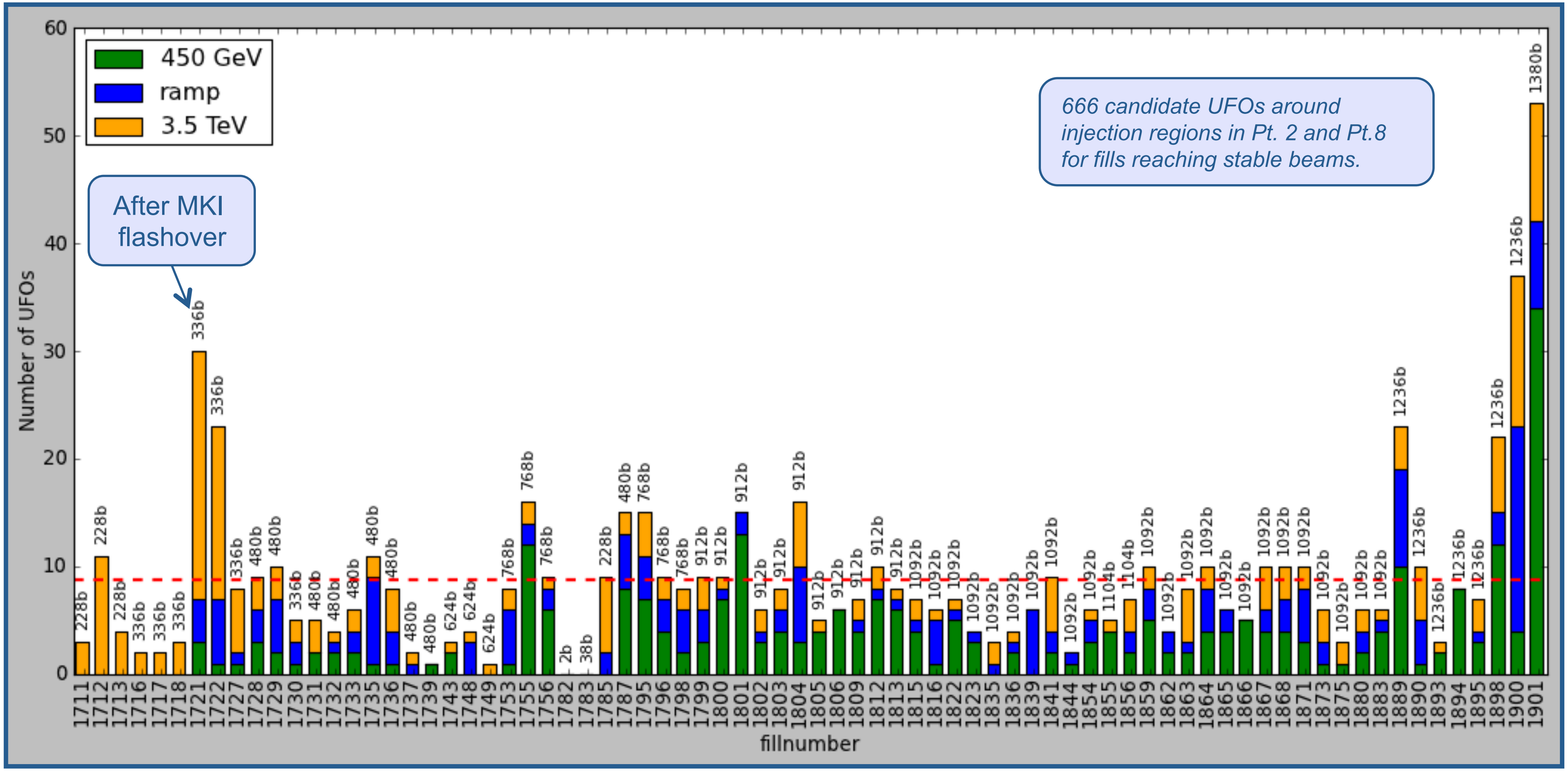
(cf. M. Sapinski at Chamonix 2011)

- **BLM Thresholds:** Arc Thresholds at 7 TeV are about a **factor 5 smaller** than at 3.5 TeV.

- **UFO rate:**
  - At 450 GeV: extremely rare.
  - During 1.38 TeV run: 3 UFOs in 36.5 h.
  - At 3.5 TeV: 8 UFOs/h.

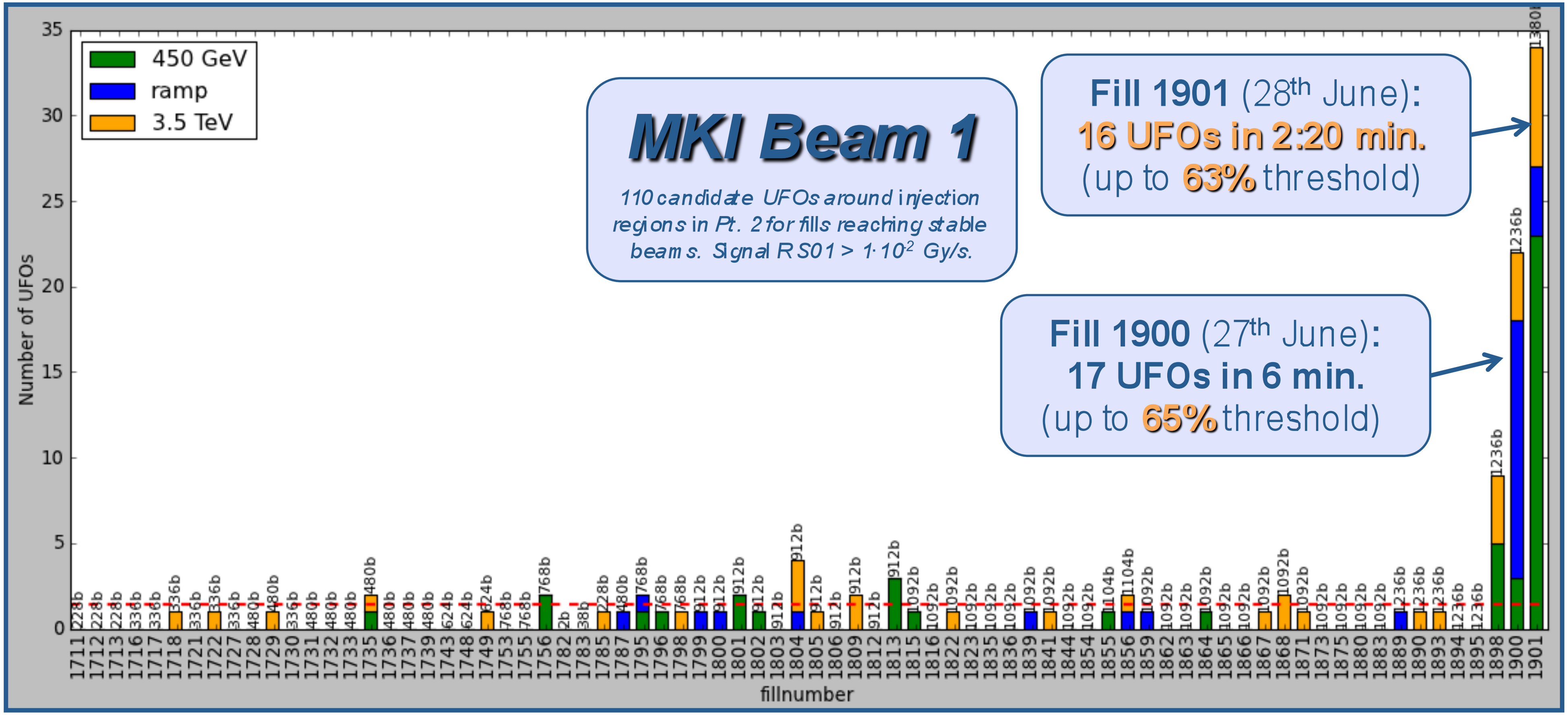


Number of MKI UFOs



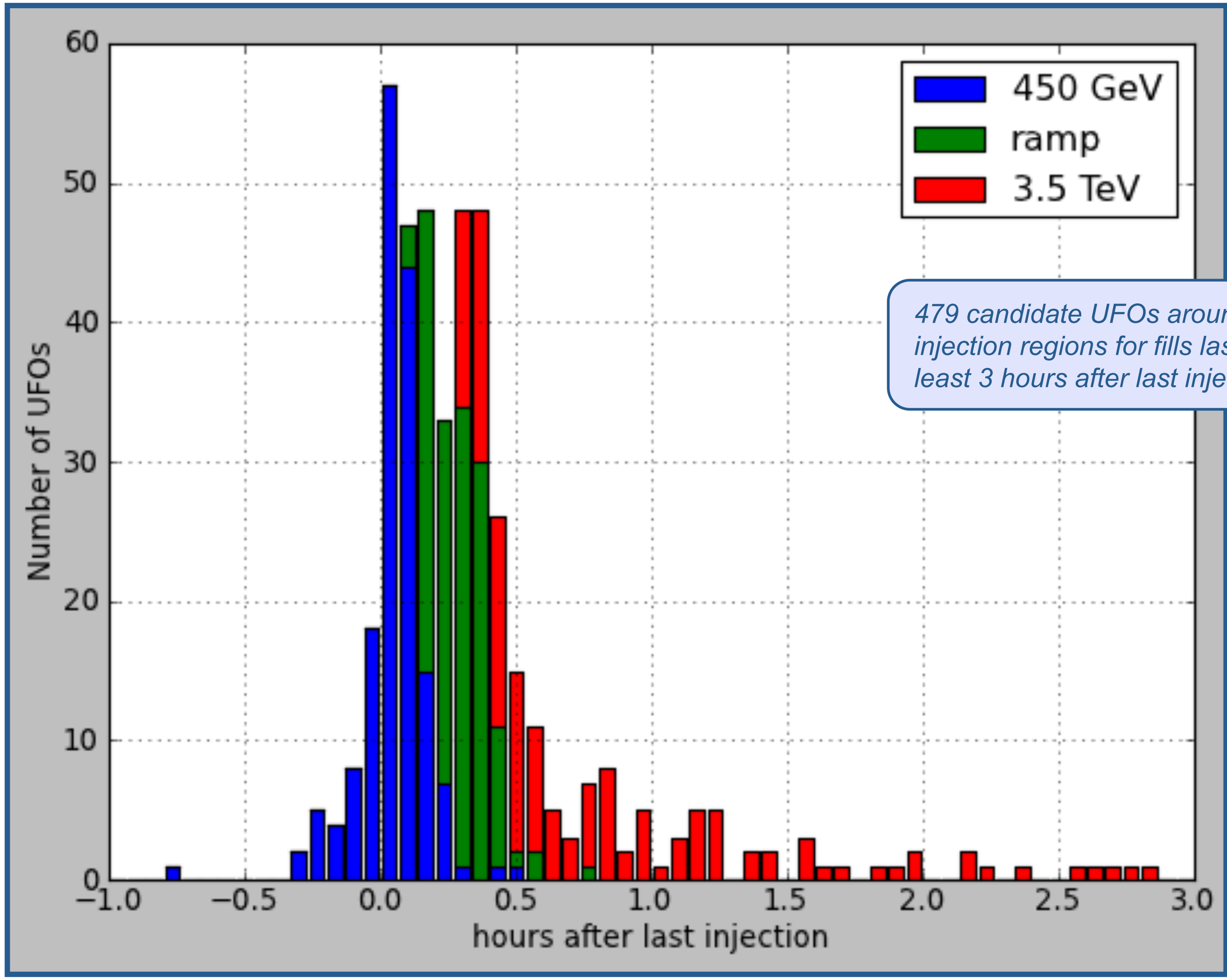
The number of MKI UFOs is much higher in Pt. 2 for the last few fills.

Number of Large MKI UFOs B1



In the last physics fills **many MKI UFOs** with **large amplitudes** occurred with a **high rate**. No obvious change found to explain this.

Time of MKI UFOs



479 candidate UFOs around injection regions for fills lasting at least 3 hours after last injection.

Most MKI UFOs occur shortly after the last injections.

UFO Detection

- For 2010: 113 UFOs below threshold found in logging database.

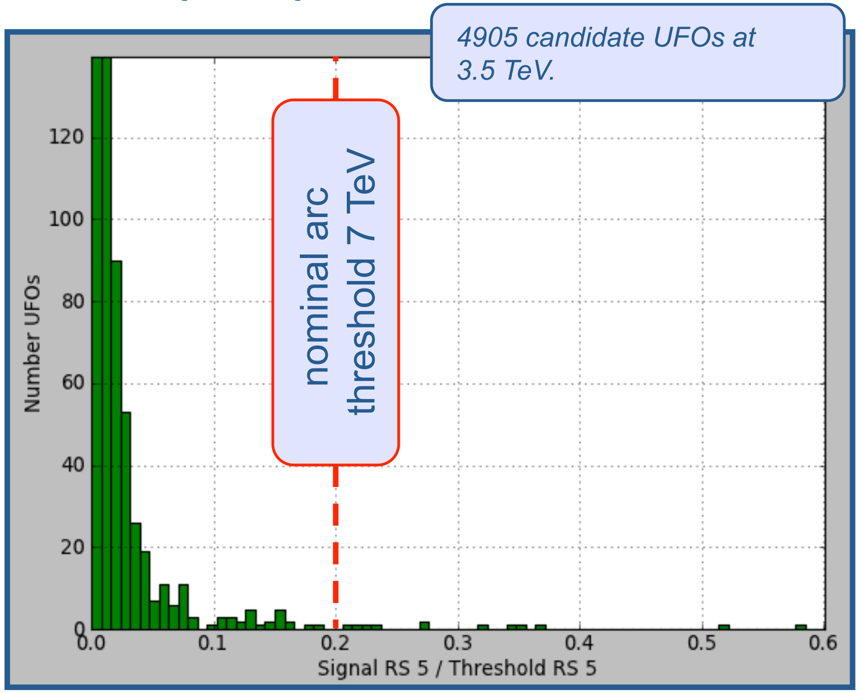
(E. Nebot)

- For 2011: Online UFO detection by **UFO Buster.**

Detects UFOs in BLM concentrator data (1Hz).

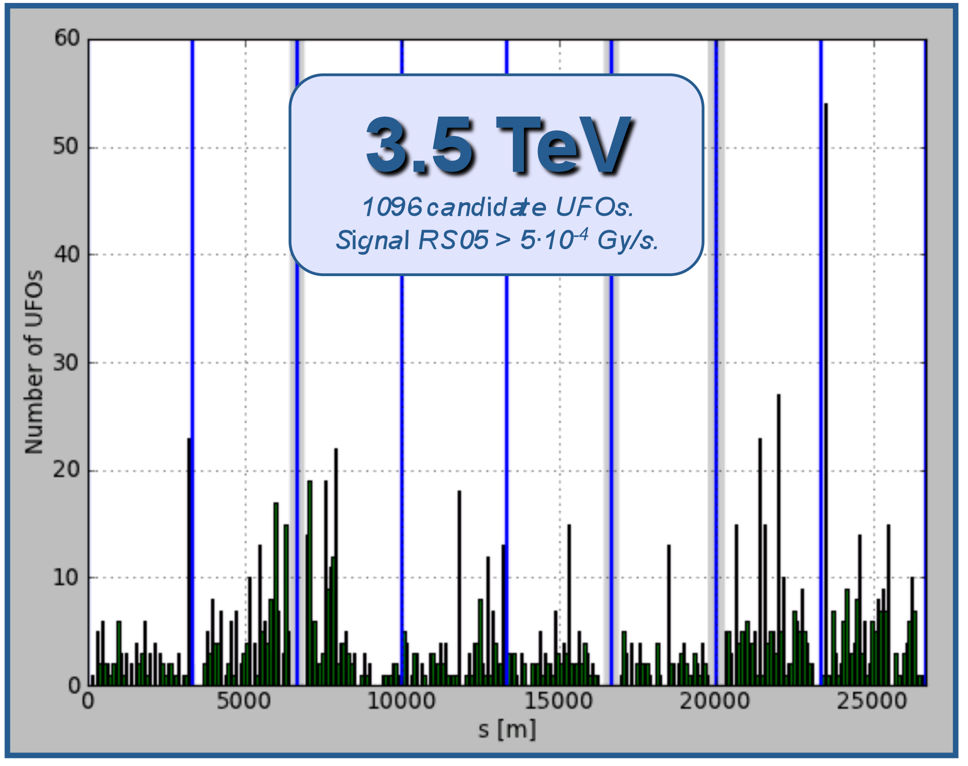
- **5000 UFOs** below threshold found so far.

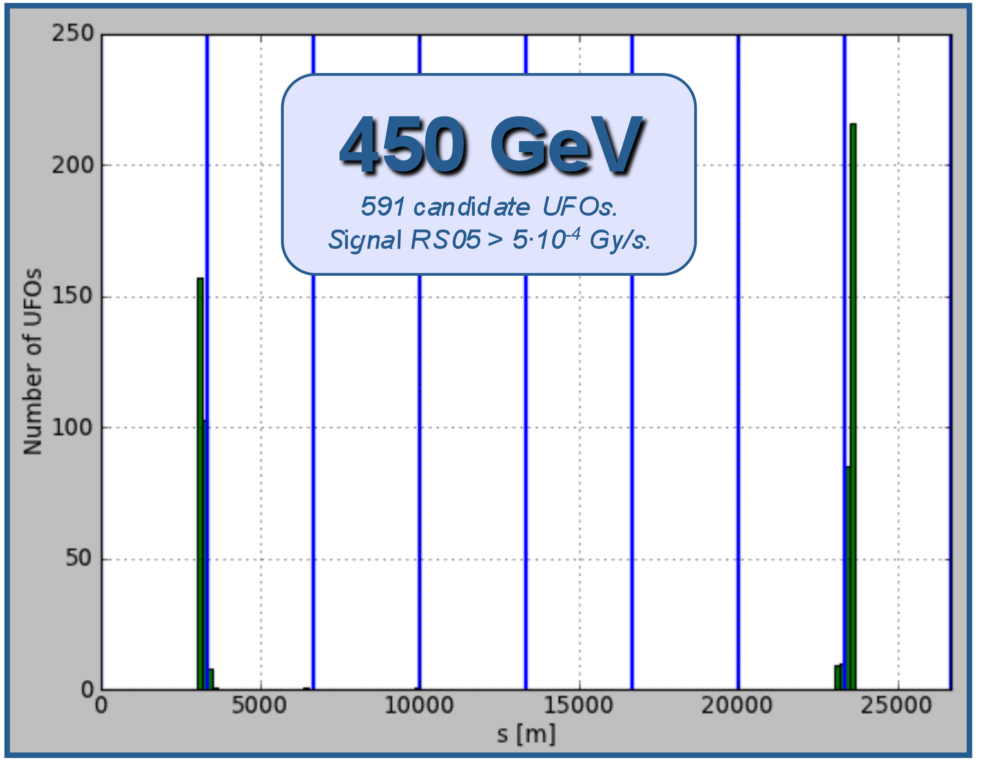
Most events are much below threshold.



"threshold" = lowest threshold in standard arc cell.

Spatial UFO Distribution





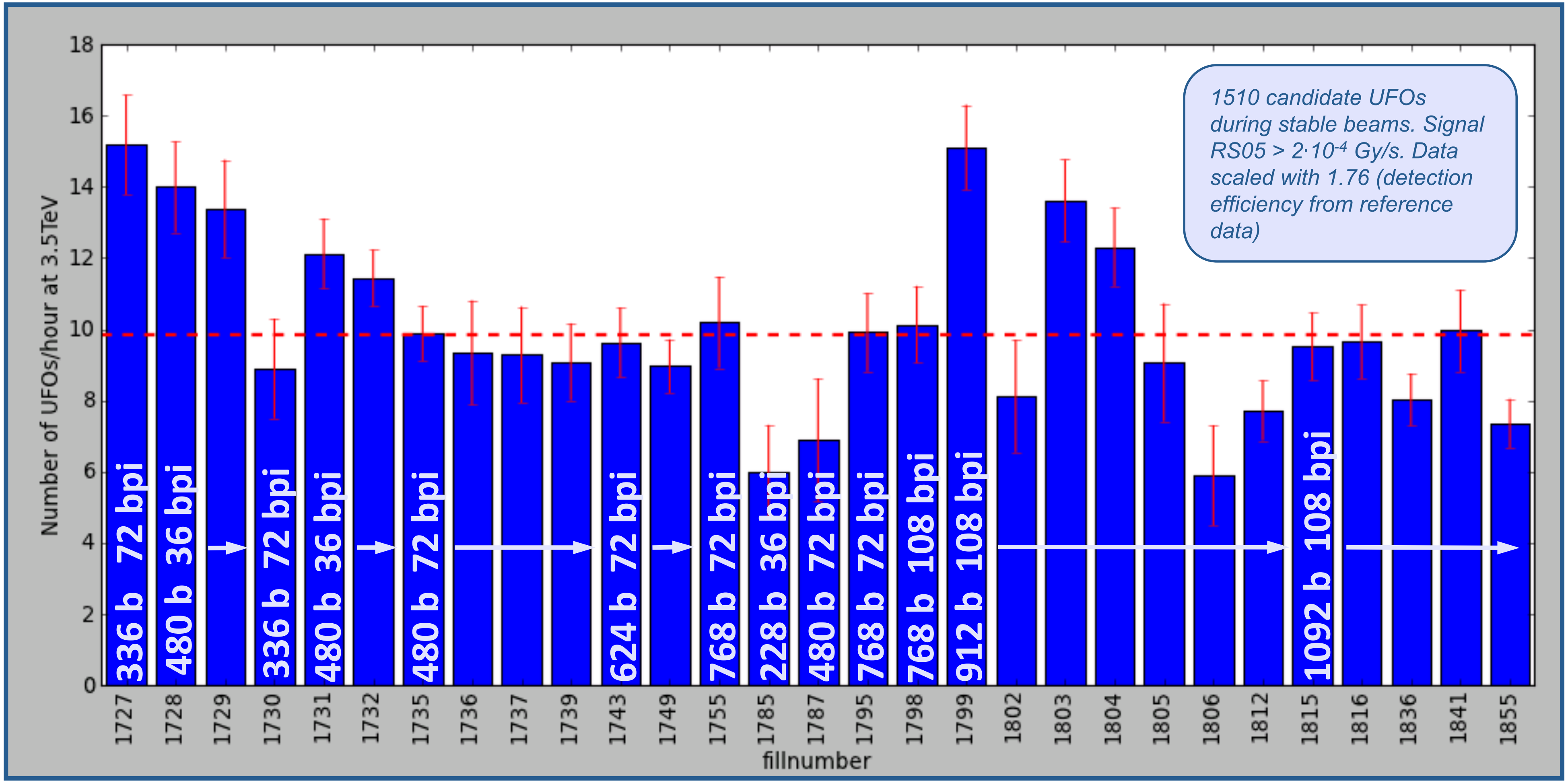
The UFOs are distributed all around the machine. About 7% of all UFOs are around the MKIs.

53 candidate UFOs at MKI for Beam 2.

gray areas around IRs are excluded from UFO detection.

Mainly UFOs around MKIs

UFO Rate in 2011

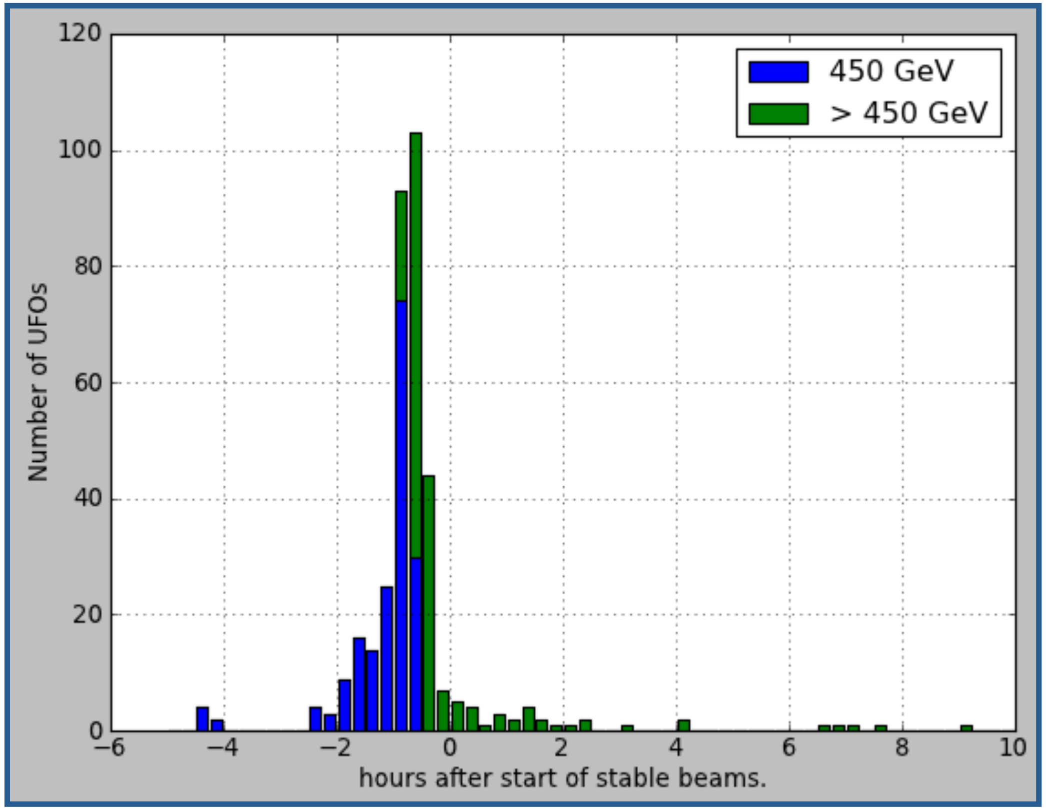


On average: **10 UFOs/hour**

UFOs around Injection Region

- **679 UFOs** around the MKIs caused **9 beam dumps.**

Most of the UFOs around the MKIs occur before going to stable beams.



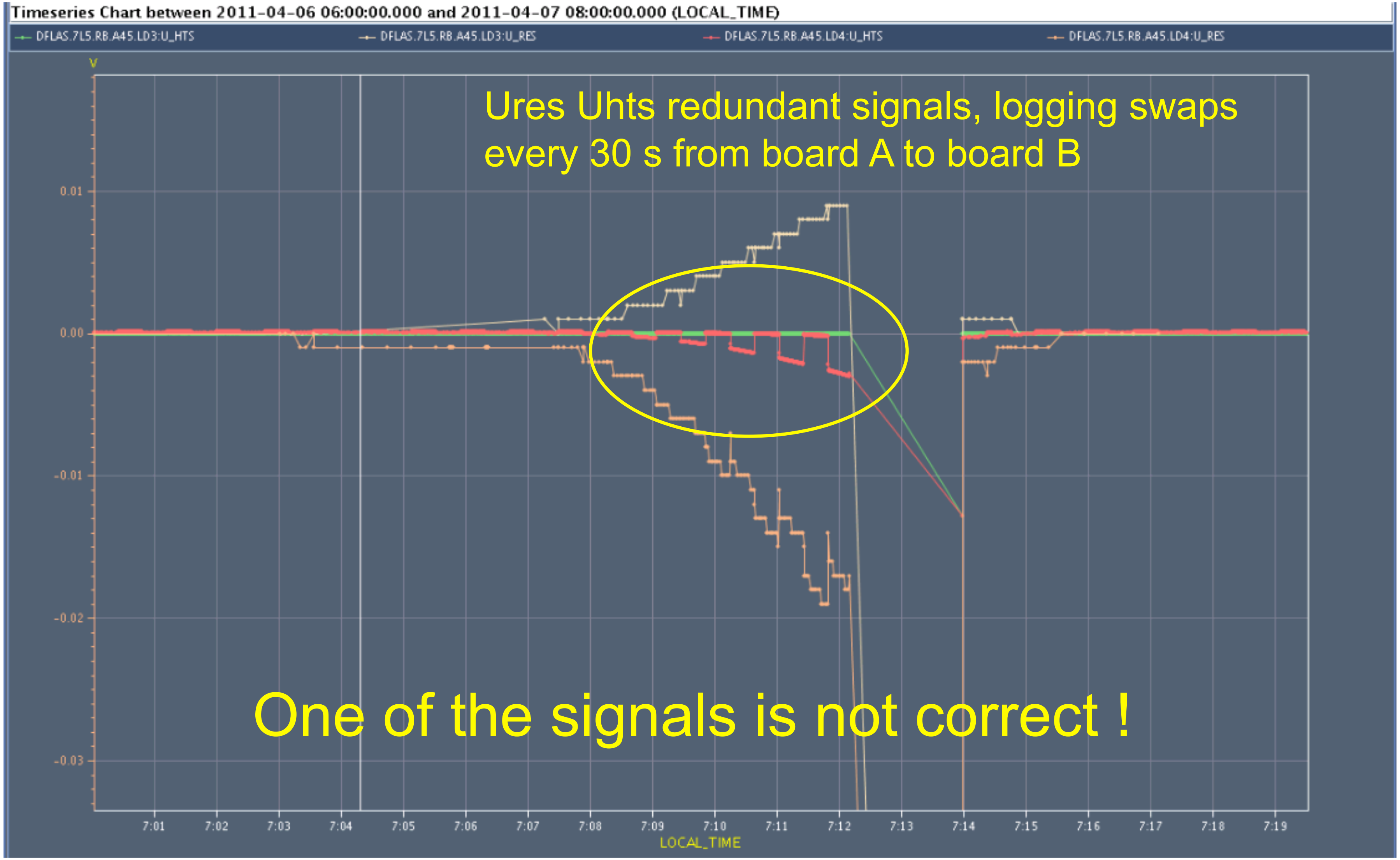
Event of 7th April

- **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

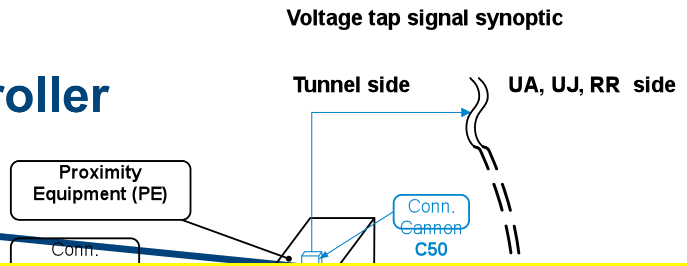


What was swapped…?

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

  EE22 (pin 15) and EE42 (pin16)

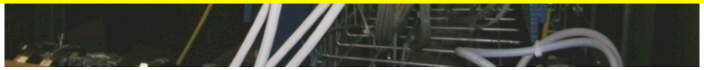
  of cable between PE and QPS controller

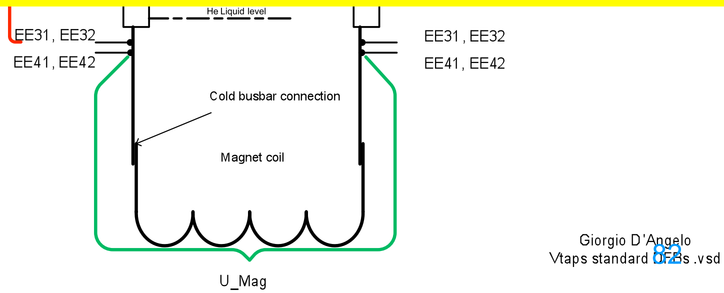


This connection had been like this since 2005

Are all connections like this?

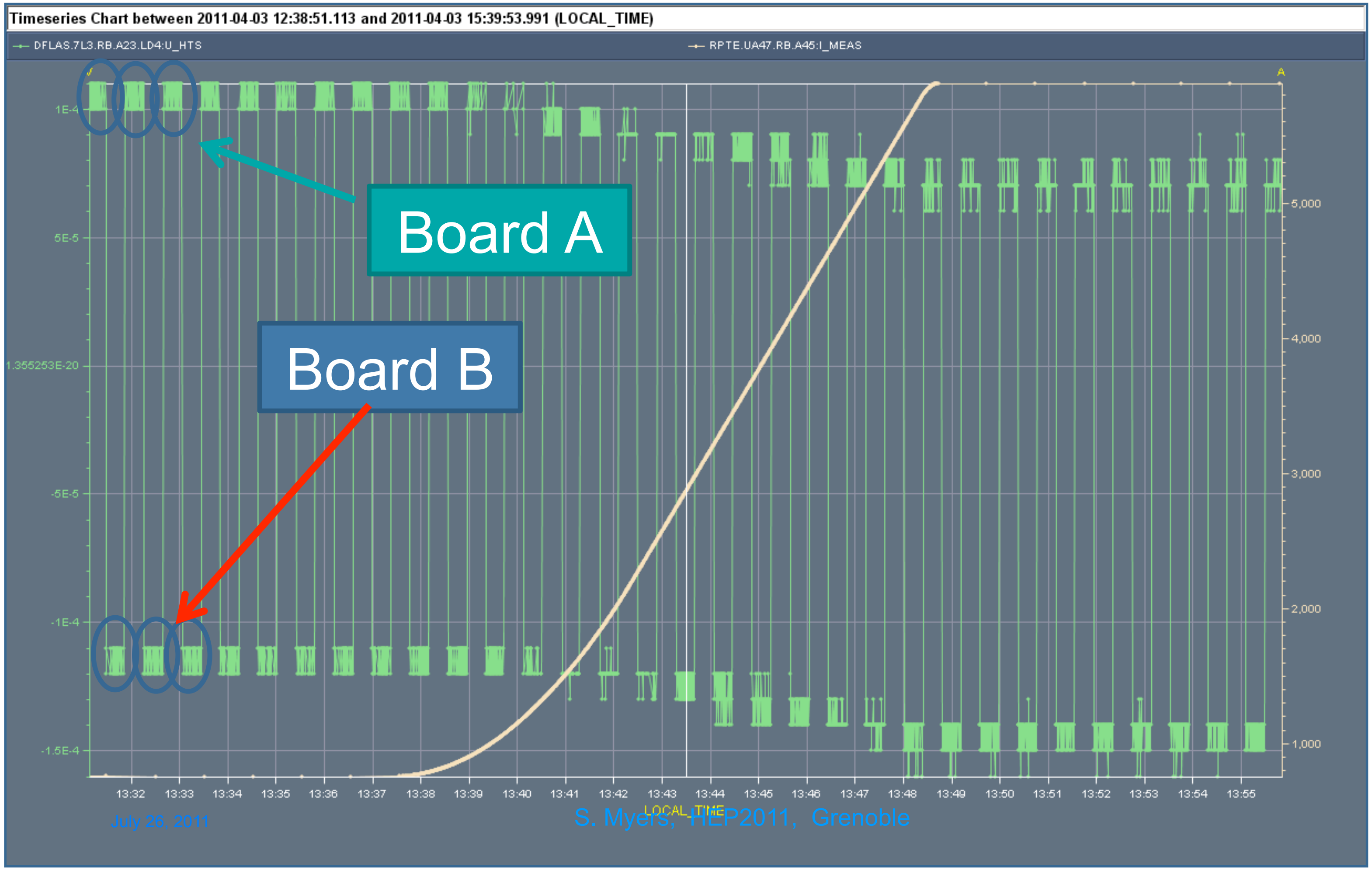
Stop operation until all connections are verified





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 unison during a ramp

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....

Beam Dumps at > 450 GeV – I

Date	Time	State	Reason
30/05	11h08	Stable beams	QPS trigger circuit detector of RCBXH2.L1. SEU?
	15h43	Adjust	New RF interlock not masked
	20h20	Adjust	FMCM. Electrical glitch
31/05	06h22	Stable beams	UFO IR2L
	10h38	Stable beams	Communication with DFBAJ. SEU?
	22h20	Squeeze	UFO IR2L
01/06	02h10	Squeeze	QPS trigger (Quench of Q9R5 ?)
	06h53	Adjust	RF trip (radiation-induced arc detector signal?)
	09h17	Ramp	Collimator temperature
	20h37	Stable beams	Collimation crate IR5R failure (PRS)
02/06	16h58	Beam dump	EIC
	21h50	Stable beams	UFO IR8
03/06	00h28	Squeeze	Trip of RQTF.A23B2
	13h30	Stable beams	Loss of I_meas reading
	18h24	Squeeze	UFO in IR8R
	21h17	Stable beams	Trip undulator IR4.

Beam Dumps at > 450 GeV – II

Date	Time	State	Reason
04/06	07:56	Stable beams	**QPS FIP communication lost, close to IR1.** S12 tripped.
	16:19	Stable beams	**Power converter fault.**
	20:20	Flat top	**UFO IR2L**
05/06	00:15	Stable beams	**RF trip**
	03:48	Adjust	**LHCb magnet trip**
	06:56	Stable beams	**UFO IR2L**
06/06	00:31	Stable beams	QPS trigger on RQTL11.R7B1.
	07:39	Stable beams	**PC failure of RQ6L2**.
07/06	07:28	Stable beams	**Bad current reading on RTQX2.R1**
08/06	09:22	Stable beams	**Alice dipole trip**

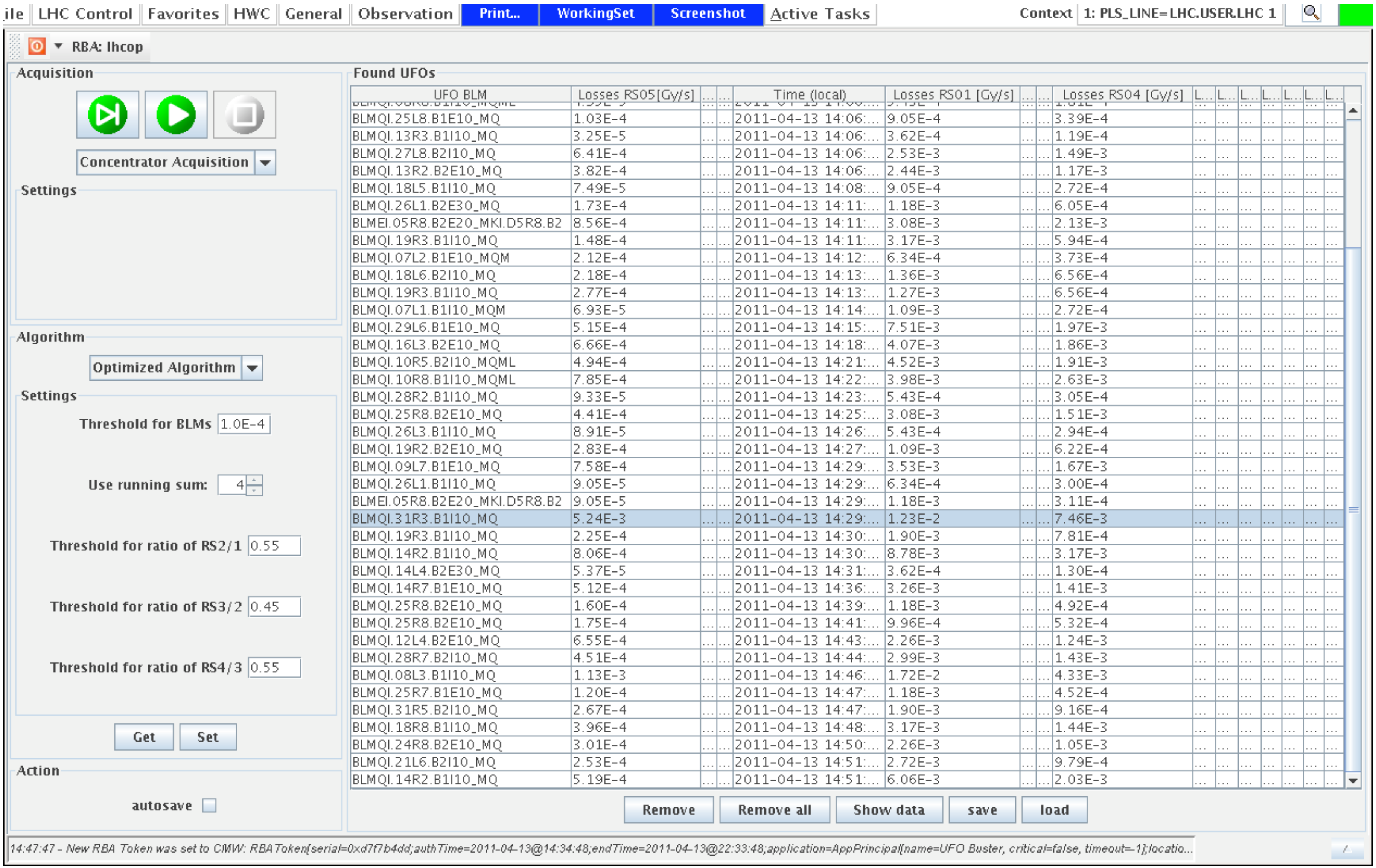
26 beam dumps at > 450 GeV, only one dumped by OP.

Increase of BLM dump threshold for Q4 (MQY) at MKI's by factor 2

Bunch length

- Important parameter for
  - Cryogenics stability
  - Collimator heating
  - Injection kicker heating
  - ...
- Work ongoing to improve blow-up control during the ramp by the RF-team
  - Better reproducible results -> test operation with longer bunches
  - Disadvantage is possibly more debunched beam when a cavity trips, but not an issue at the moment

UFO’s: 90 in 90 minutes



UFO BLM	Losses RS05[Gy/s]	...	...	Time (local)	Losses RS01 [Gy/s]	...	...	Losses RS04 [Gy/s]	L...	L...	L...	L...	L...	L...	L...
BLMQI.25L8.B1E10_MQ	1.03E-4	...	...	2011-04-13 14:06:...	9.05E-4	...	...	3.39E-4	...	...	...	...	...	...	...
BLMQI.13R3.B1I10_MQ	3.25E-5	...	...	2011-04-13 14:06:...	3.62E-4	...	...	1.19E-4	...	...	...	...	...	...	...
BLMQI.27L8.B2I10_MQ	6.41E-4	...	...	2011-04-13 14:06:...	2.53E-3	...	...	1.49E-3	...	...	...	...	...	...	...
BLMQI.13R2.B2E10_MQ	3.82E-4	...	...	2011-04-13 14:06:...	2.44E-3	...	...	1.17E-3	...	...	...	...	...	...	...
BLMQI.18L5.B1I10_MQ	7.49E-5	...	...	2011-04-13 14:08:...	9.05E-4	...	...	2.72E-4	...	...	...	...	...	...	...
BLMQI.26L1.B2E30_MQ	1.73E-4	...	...	2011-04-13 14:11:...	1.18E-3	...	...	6.05E-4	...	...	...	...	...	...	...
BLMEI.05R8.B2E20_MKI.D5R8.B2	8.56E-4	...	...	2011-04-13 14:11:...	3.08E-3	...	...	2.13E-3	...	...	...	...	...	...	...
BLMQI.19R3.B1I10_MQ	1.48E-4	...	...	2011-04-13 14:11:...	3.17E-3	...	...	5.94E-4	...	...	...	...	...	...	...
BLMQI.07L2.B1E10_MQM	2.12E-4	...	...	2011-04-13 14:12:...	6.34E-4	...	...	3.73E-4	...	...	...	...	...	...	...
BLMQI.18L6.B2I10_MQ	2.18E-4	...	...	2011-04-13 14:13:...	1.36E-3	...	...	6.56E-4	...	...	...	...	...	...	...
BLMQI.19R3.B1I10_MQ	2.77E-4	...	...	2011-04-13 14:13:...	1.27E-3	...	...	6.56E-4	...	...	...	...	...	...	...
BLMQI.07L1.B1I10_MQM	6.93E-5	...	...	2011-04-13 14:14:...	1.09E-3	...	...	2.72E-4	...	...	...	...	...	...	...
BLMQI.29L6.B1E10_MQ	5.15E-4	...	...	2011-04-13 14:15:...	7.51E-3	...	...	1.97E-3	...	...	...	...	...	...	...
BLMQI.16L3.B2E10_MQ	6.66E-4	...	...	2011-04-13 14:18:...	4.07E-3	...	...	1.86E-3	...	...	...	...	...	...	...
BLMQI.10R5.B2I10_MQML	4.94E-4	...	...	2011-04-13 14:21:...	4.52E-3	...	...	1.91E-3	...	...	...	...	...	...	...
BLMQI.10R8.B1I10_MQML	7.85E-4	...	...	2011-04-13 14:22:...	3.98E-3	...	...	2.63E-3	...	...	...	...	...	...	...
BLMQI.28R2.B1I10_MQ	9.33E-5	...	...	2011-04-13 14:23:...	5.43E-4	...	...	3.05E-4	...	...	...	...	...	...	...
BLMQI.25R8.B2E10_MQ	4.41E-4	...	...	2011-04-13 14:25:...	3.08E-3	...	...	1.51E-3	...	...	...	...	...	...	...
BLMQI.26L3.B1I10_MQ	8.91E-5	...	...	2011-04-13 14:26:...	5.43E-4	...	...	2.94E-4	...	...	...	...	...	...	...
BLMQI.19R2.B2E10_MQ	2.83E-4	...	...	2011-04-13 14:27:...	1.09E-3	...	...	6.22E-4	...	...	...	...	...	...	...
BLMQI.09L7.B1E10_MQ	7.58E-4	...	...	2011-04-13 14:29:...	3.53E-3	...	...	1.67E-3	...	...	...	...	...	...	...
BLMQI.26L1.B1I10_MQ	9.05E-5	...	...	2011-04-13 14:29:...	6.34E-4	...	...	3.00E-4	...	...	...	...	...	...	...
BLMEI.05R8.B2E20_MKI.D5R8.B2	9.05E-5	...	...	2011-04-13 14:29:...	1.18E-3	...	...	3.11E-4	...	...	...	...	...	...	...
BLMQI.31R3.B1I10_MQ	5.24E-3	...	...	2011-04-13 14:29:...	1.23E-2	...	...	7.46E-3	...	...	...	...	...	...	...
BLMQI.19R3.B1I10_MQ	2.25E-4	...	...	2011-04-13 14:30:...	1.90E-3	...	...	7.81E-4	...	...	...	...	...	...	...
BLMQI.14R2.B1I10_MQ	8.06E-4	...	...	2011-04-13 14:30:...	8.78E-3	...	...	3.17E-3	...	...	...	...	...	...	...
BLMQI.14L4.B2E30_MQ	5.37E-5	...	...	2011-04-13 14:31:...	3.62E-4	...	...	1.30E-4	...	...	...	...	...	...	...
BLMQI.14R7.B1E10_MQ	5.12E-4	...	...	2011-04-13 14:36:...	3.26E-3	...	...	1.41E-3	...	...	...	...	...	...	...
BLMQI.25R8.B2E10_MQ	1.60E-4	...	...	2011-04-13 14:39:...	1.18E-3	...	...	4.92E-4	...	...	...	...	...	...	...
BLMQI.25R8.B2E10_MQ	1.75E-4	...	...	2011-04-13 14:41:...	9.96E-4	...	...	5.32E-4	...	...	...	...	...	...	...
BLMQI.12L4.B2E10_MQ	6.55E-4	...	...	2011-04-13 14:43:...	2.26E-3	...	...	1.24E-3	...	...	...	...	...	...	...
BLMQI.28R7.B2I10_MQ	4.51E-4	...	...	2011-04-13 14:44:...	2.99E-3	...	...	1.43E-3	...	...	...	...	...	...	...
BLMQI.08L3.B1I10_MQ	1.13E-3	...	...	2011-04-13 14:46:...	1.72E-2	...	...	4.33E-3	...	...	...	...	...	...	...
BLMQI.25R7.B1E10_MQ	1.20E-4	...	...	2011-04-13 14:47:...	1.18E-3	...	...	4.52E-4	...	...	...	...	...	...	...
BLMQI.31R5.B2I10_MQ	2.67E-4	...	...	2011-04-13 14:47:...	1.90E-3	...	...	9.16E-4	...	...	...	...	...	...	...
BLMQI.18R8.B1I10_MQ	3.96E-4	...	...	2011-04-13 14:48:...	3.17E-3	...	...	1.44E-3	...	...	...	...	...	...	...
BLMQI.24R8.B2E10_MQ	3.01E-4	...	...	2011-04-13 14:50:...	2.26E-3	...	...	1.05E-3	...	...	...	...	...	...	...
BLMQI.21L6.B2I10_MQ	2.53E-4	...	...	2011-04-13 14:51:...	2.72E-3	...	...	9.79E-4	...	...	...	...	...	...	...
BLMQI.14R2.B1I10_MQ	5.19E-4	...	...	2011-04-13 14:51:...	6.06E-3	...	...	2.03E-3	...	...	...	...	...	...	...

Presently 10 per hour on average

3rd Period: Increasing number of bunches to 900

Issues with Machine Protection

1. Collimation loss of hierarchy at 450 GeV
   – Due to order in which the loss maps were performed
2. 72 (108/144) bunches
   – Last bunch of previous injection got kicked; low intensity and higher emittance
   – BPMs position calibration is sensitive to bunch intensity
   – Dump interlock measures local position of all bunches
3. **HTS quench (7th April) quench of 11 sc magnets**
4. **Injection Kicker Flashover (18th April)**

MD1

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.
  - New ATS injection optics with different integer tunes tested to 3.5 TeV. Next MD test squeeze
  - Collimation system reached tighter settings with better cleaning efficiency. (results crucial for decision on "cryo collimator system)
- 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.
- 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 um).

Factor of 4.5 above design

- No limit found for head-on beam-beam effects for the intensities investigated so far (no long range yet).

Integrated Luminosity

- Assumptions
  - 90 days left
  - 50ns: 3 days of machine studies followed by 30 days linear increase from present luminosity to max luminosity
  - 25ns: 10 (3+7) days of machine studies followed by 30 days linear increase from zero to max luminosity