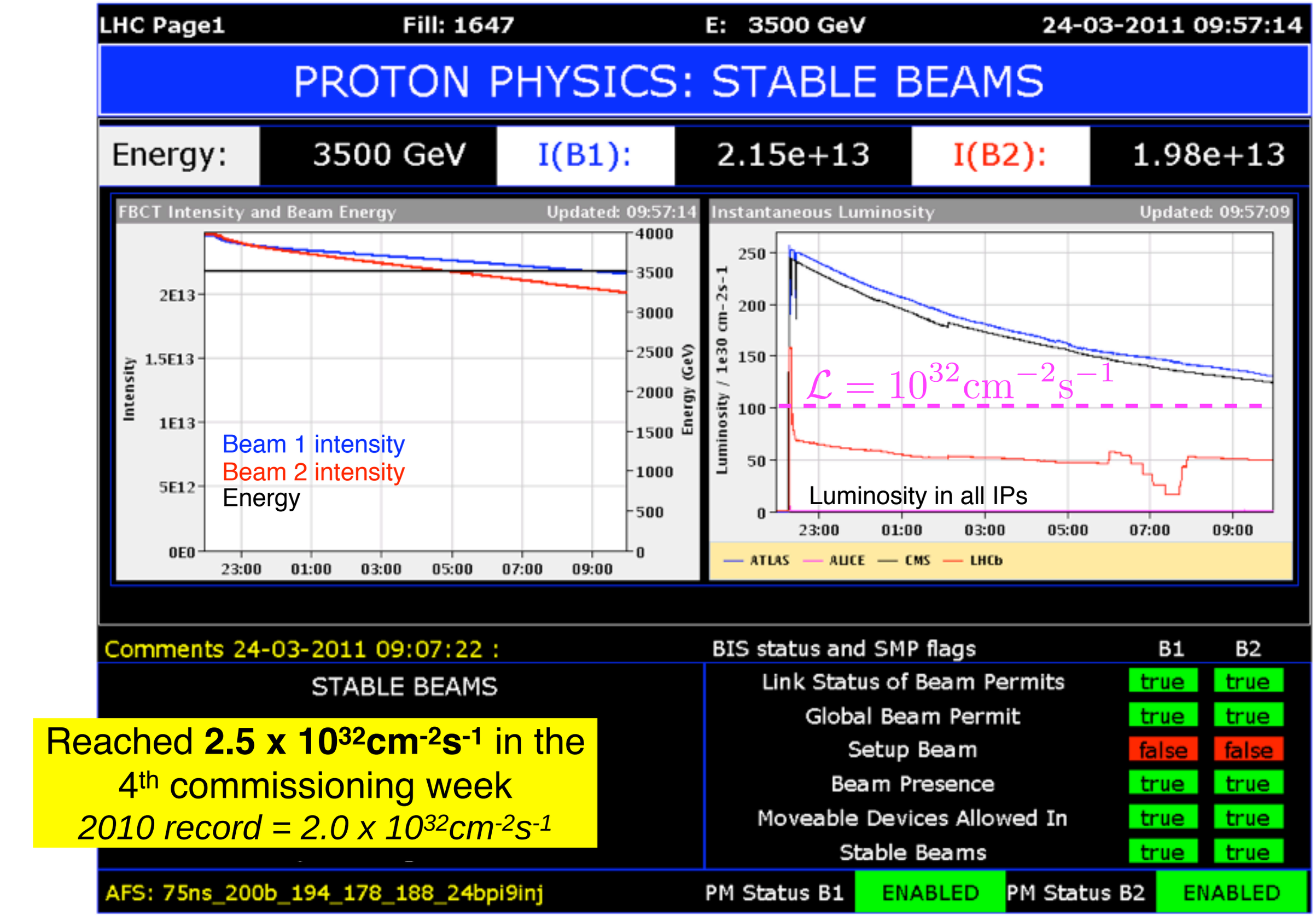
2010 Particle Accelerator Conference, PAC'11
March 28th - April 1st, 2010
Marriott Marquis Hotel, New York, U.S.A.

Status of LHC Operations and Physics Program

Stefano Redaelli on behalf of the LHC team
BE department - OP group
CERN Geneva (CH)

LHC page 1 a few days ago...



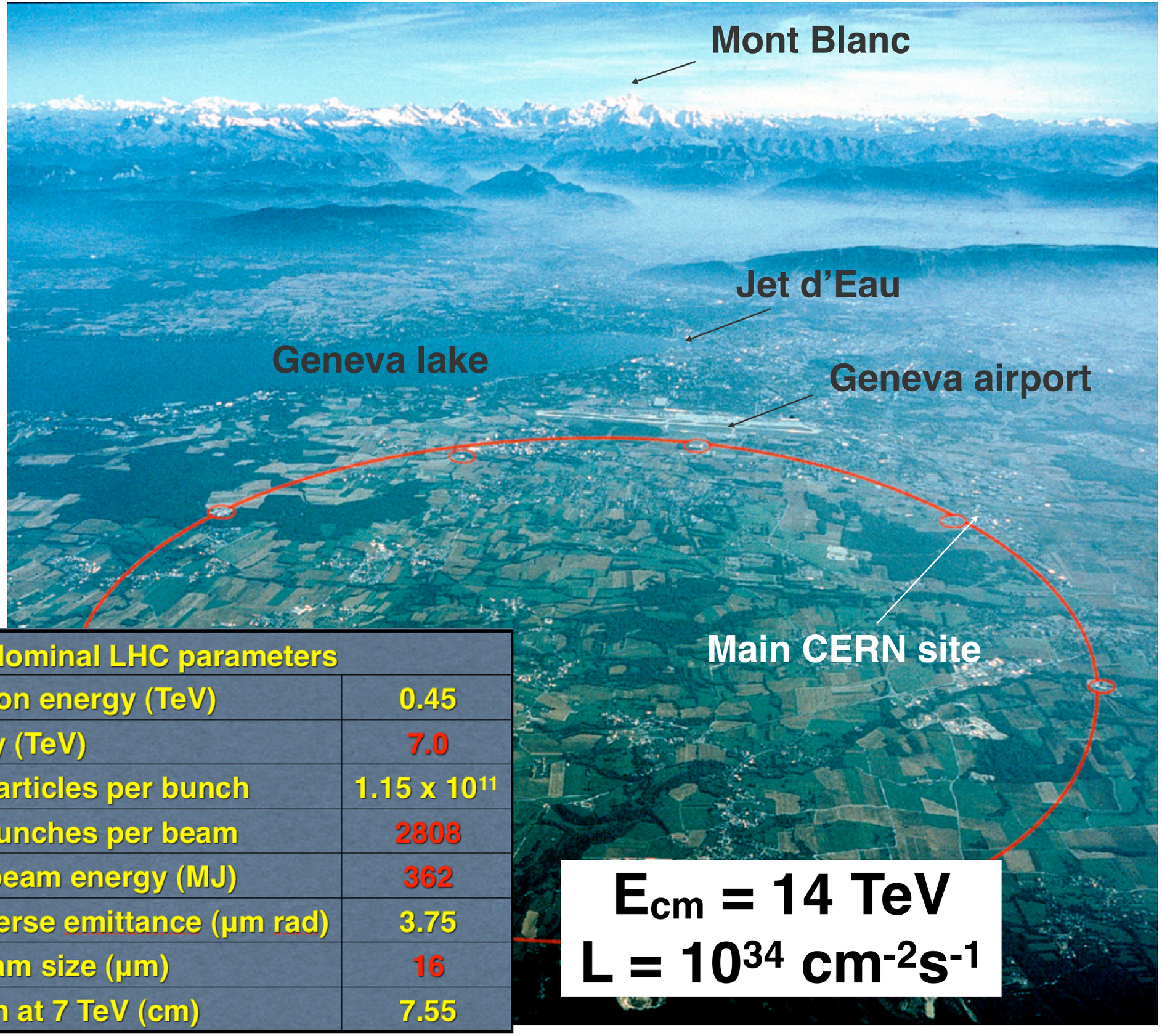
Reached **2.5 x 10^{32}cm^{-2}s^{-1}** in the 4th commissioning week

2010 record = 2.0 x 10^{32}cm^{-2}s^{-1}

Outline

- Introduction
- LHC layout
- Performance in 2010
- 2011 prospects
- Conclusions

The Large Hadron Collider



Nominal LHC parameters	
Beam injection energy (TeV)	0.45
Beam energy (TeV)	7.0
Number of particles per bunch	1.15 x 10^{11}
Number of bunches per beam	2808
Max stored beam energy (MJ)	362
Norm transverse emittance (μm rad)	3.75
Colliding beam size (μm)	16
Bunch length at 7 TeV (cm)	7.55

LHC energy target

All main magnets commissioned for 7TeV operation before installation

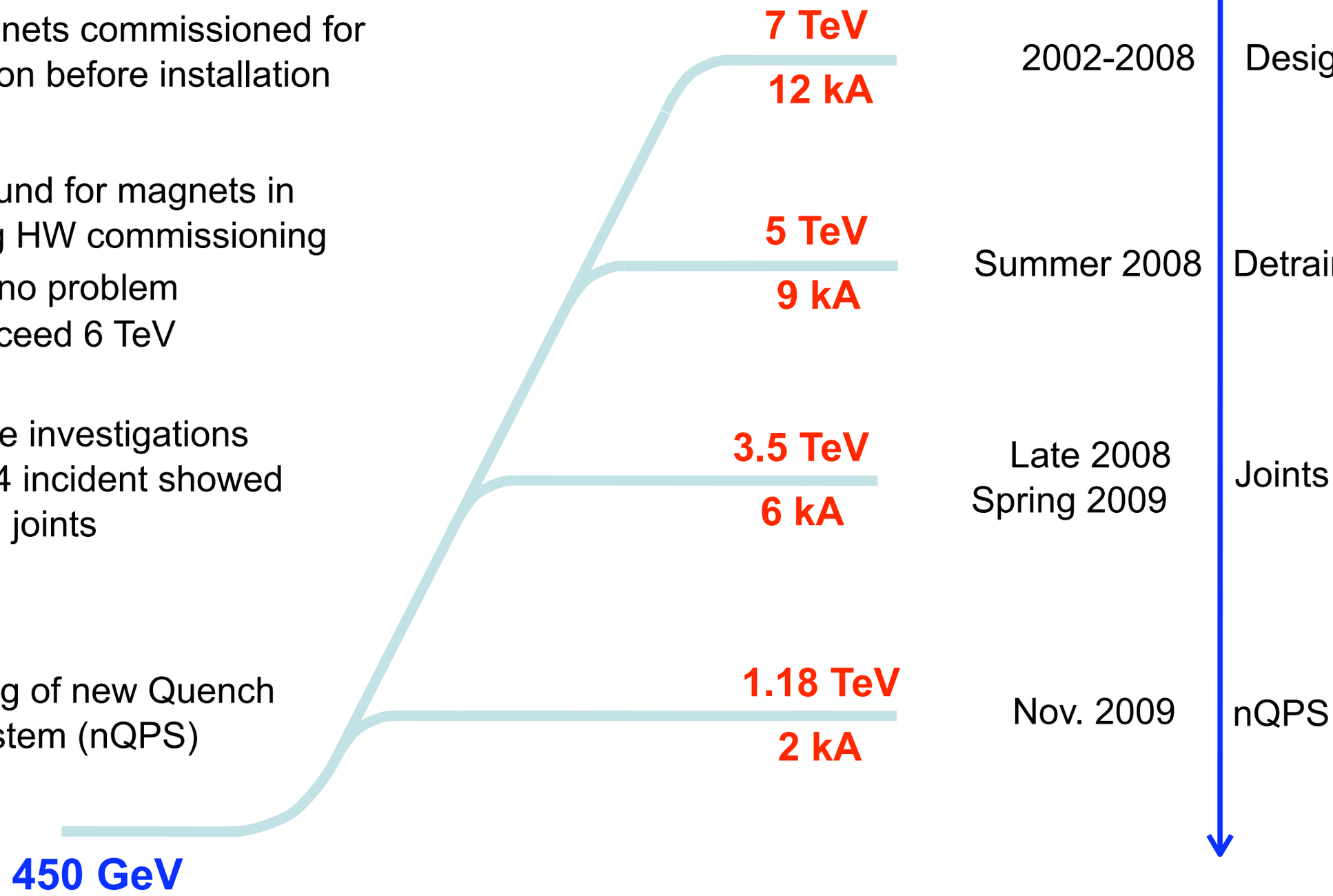
Detraining found for magnets in series, during HW commissioning

5 TeV poses no problem

Difficult to exceed 6 TeV

Machine wide investigations following S34 incident showed problem with joints

Commissioning of new Quench Protection System (nQPS)



When	Why
2002-2008	Design
Summer 2008	Detraining
Late 2008 Spring 2009	Joints
Nov. 2009	nQPS

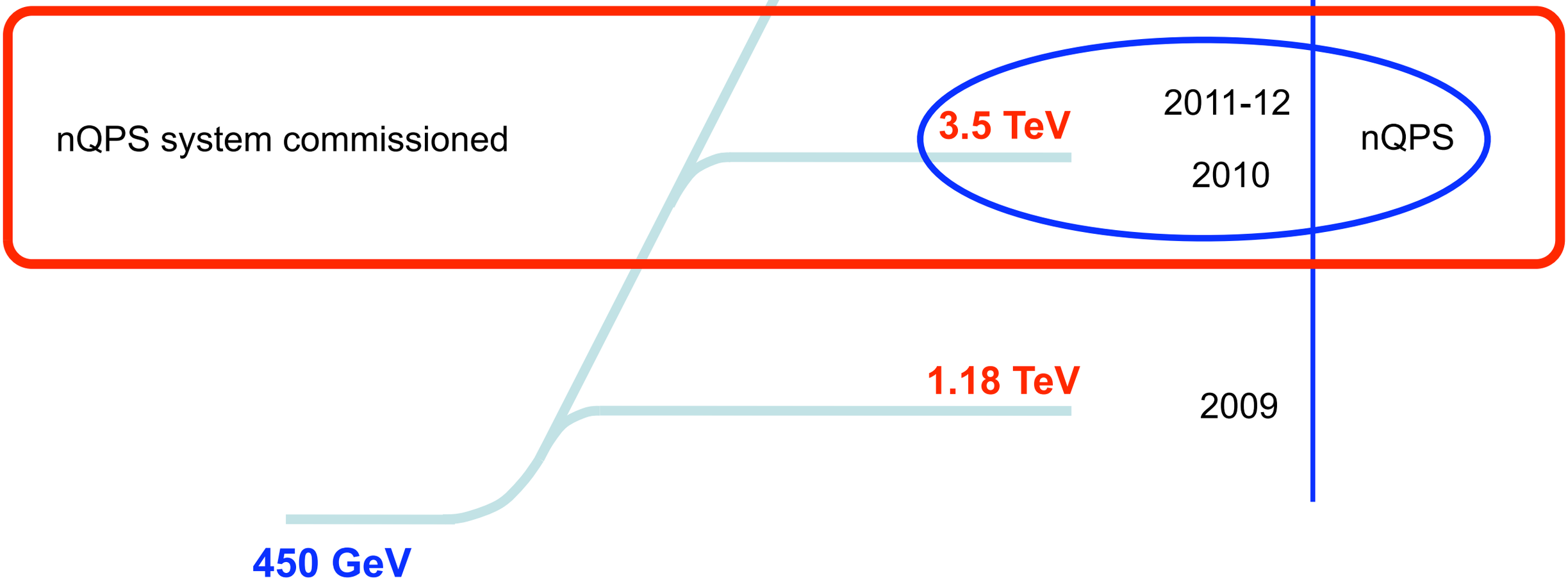
LHC energy target - the way up

Train the dipole magnets
- 6.5 TeV is within reach
- 7 TeV will take time

Repair joints

Complete pressure relief system

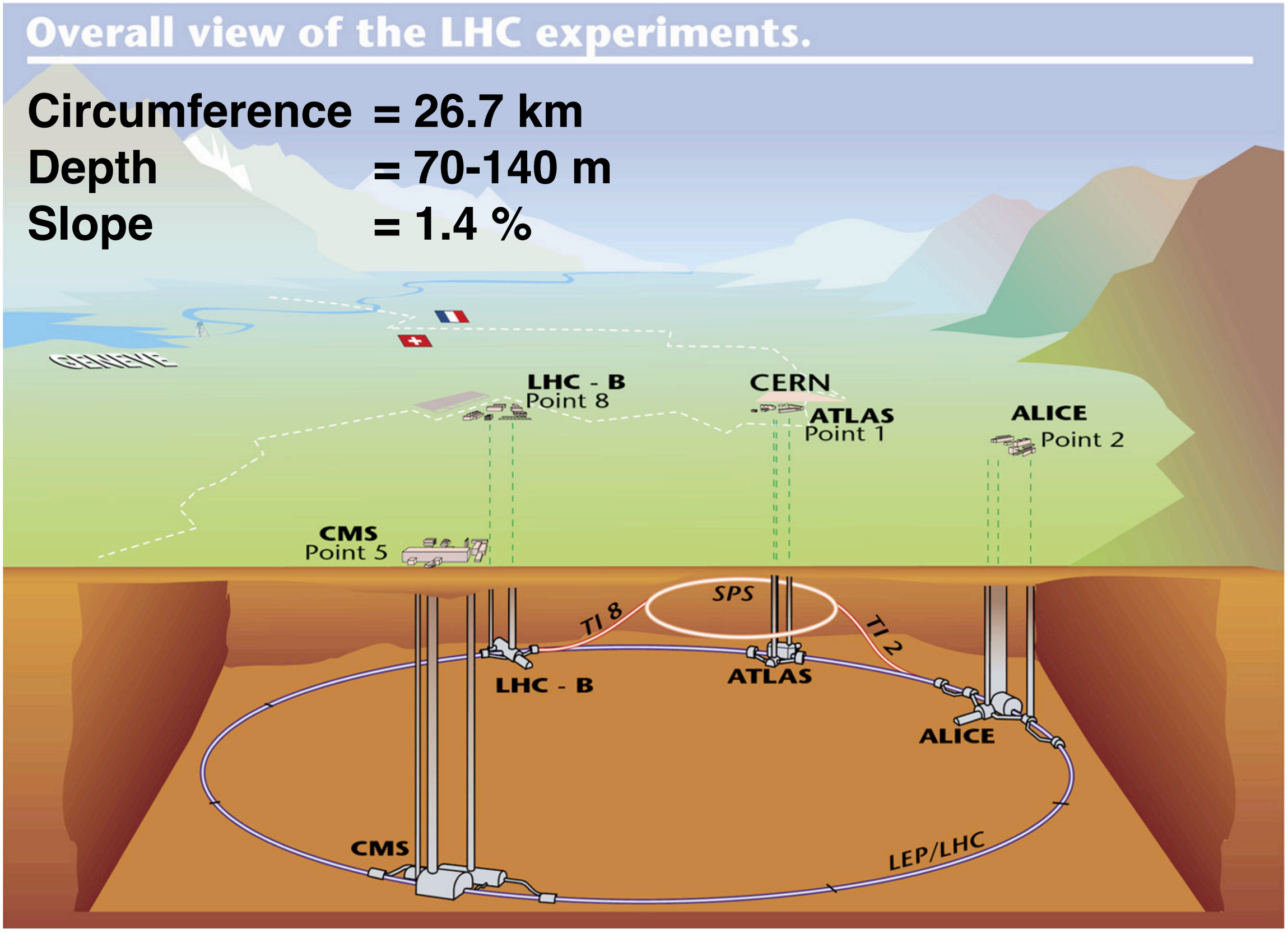
nQPS system commissioned



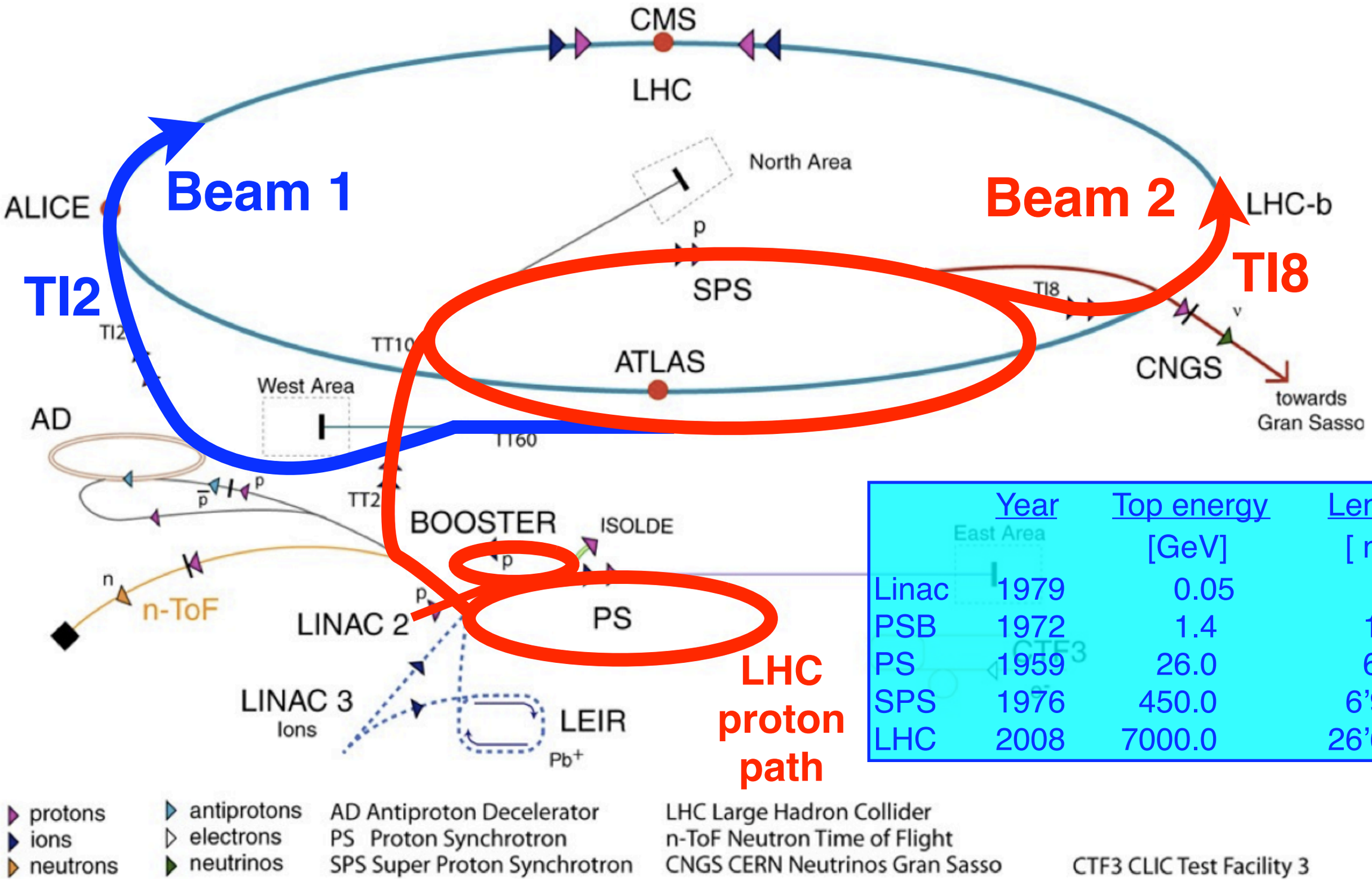
Outline

- Introduction
- **LHC layout**
  - **Tunnel layout**
  - **Accelerator systems**
- Performance in 2010
- 2011 prospects
- Conclusions

LHC tunnel


Overall view of the LHC experiments.
Circumference = 26.7 km
Depth = 70-140 m
Slope = 1.4 %
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

LHC injector complex



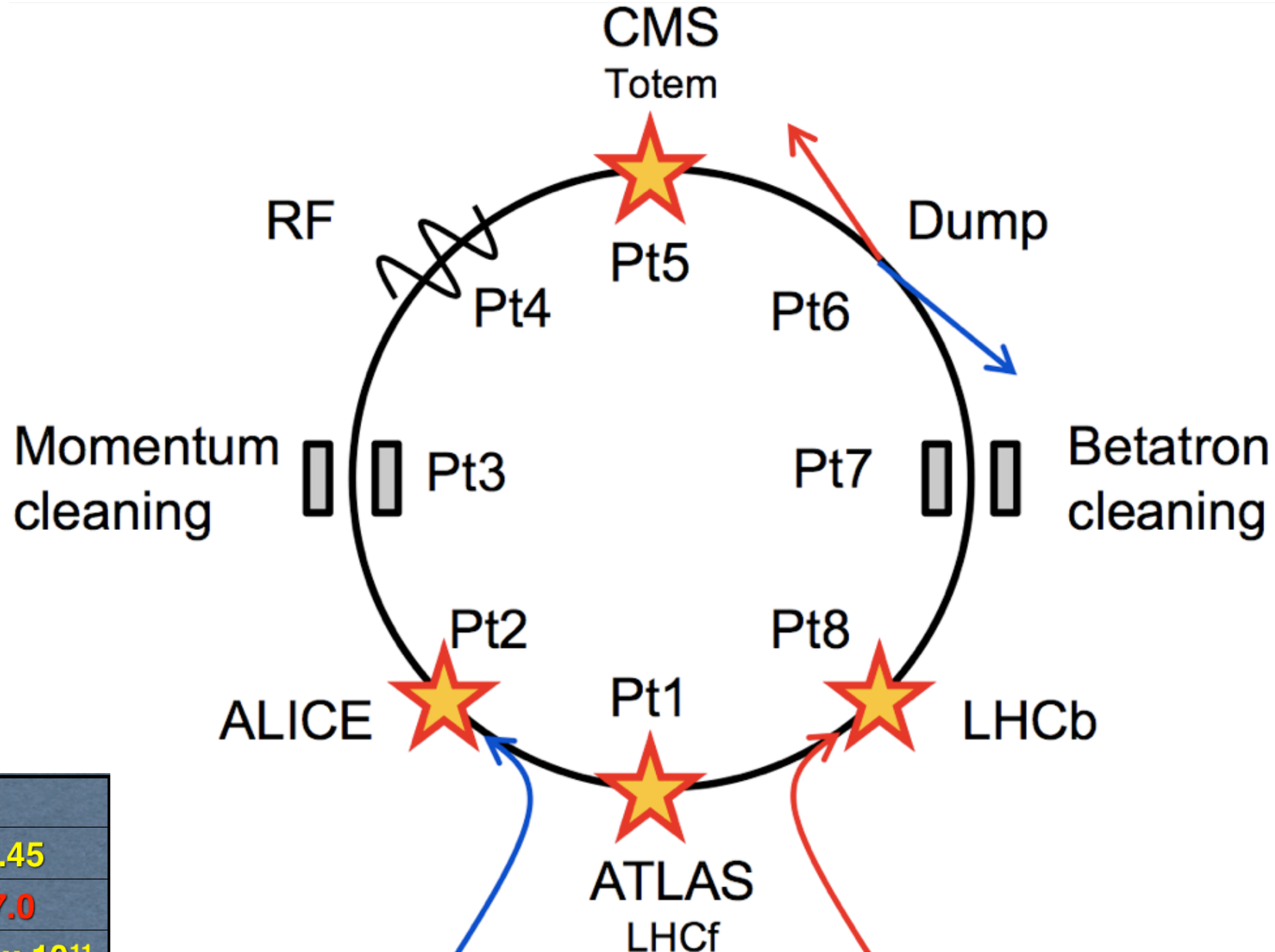
	Year	Top energy [GeV]	Length [m]
Linac	1979	0.05	30
PSB	1972	1.4	157
PS	1959	26.0	628
SPS	1976	450.0	6’911
LHC	2008	7000.0	26’657

Excellent performance of the accelerator complex in 2010!!

Layout and accelerator systems

LHC Layout

- 8 arcs (~3 km)
- 8 straight sections (~700 m).
- Two-in-one magnet design
- 4 interaction points (IPs):
  IP1, IP2, IP5, IP8
- IP2/IP8: beam injection
- IP6: beam dump region
- IP4: RF (acceleration)
- IP3/IP7: beam cleaning



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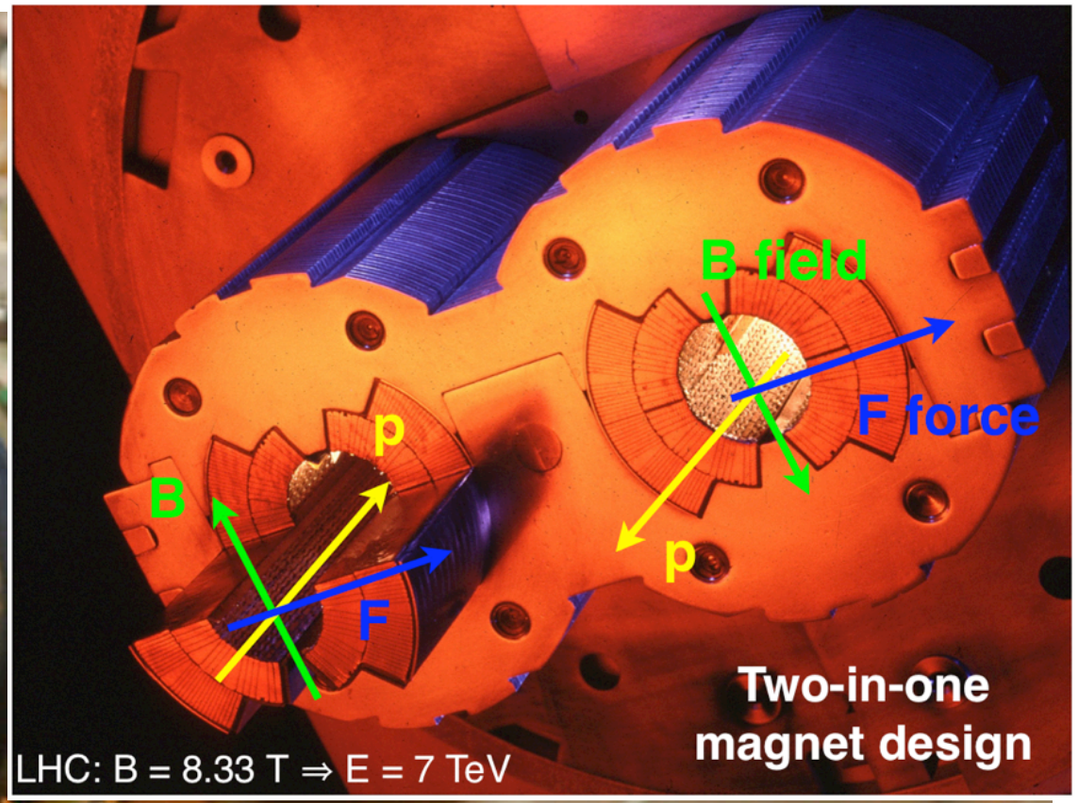
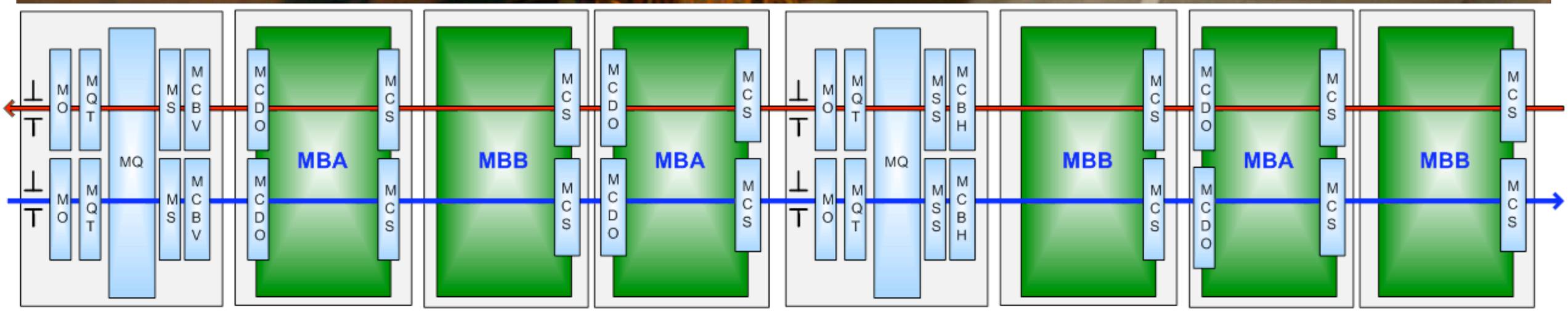
LHC arcs



1232 main dipoles + 3700 multipole corrector magnets

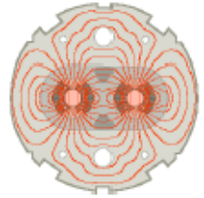
392 main quadrupoles + 2500 corrector magnets



Outline

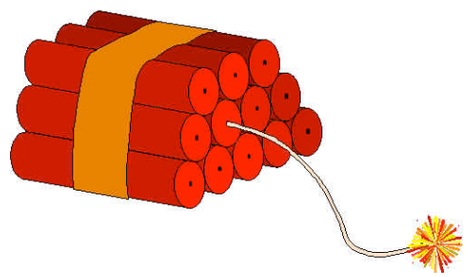
- Introduction
- LHC layout
- **Performance in 2010**
  - **Goals/Achievements**
  - **High-intensity issues**
  - **Ion operation**
- 2011 prospects
- Conclusions

Goals of 2010 LHC operation

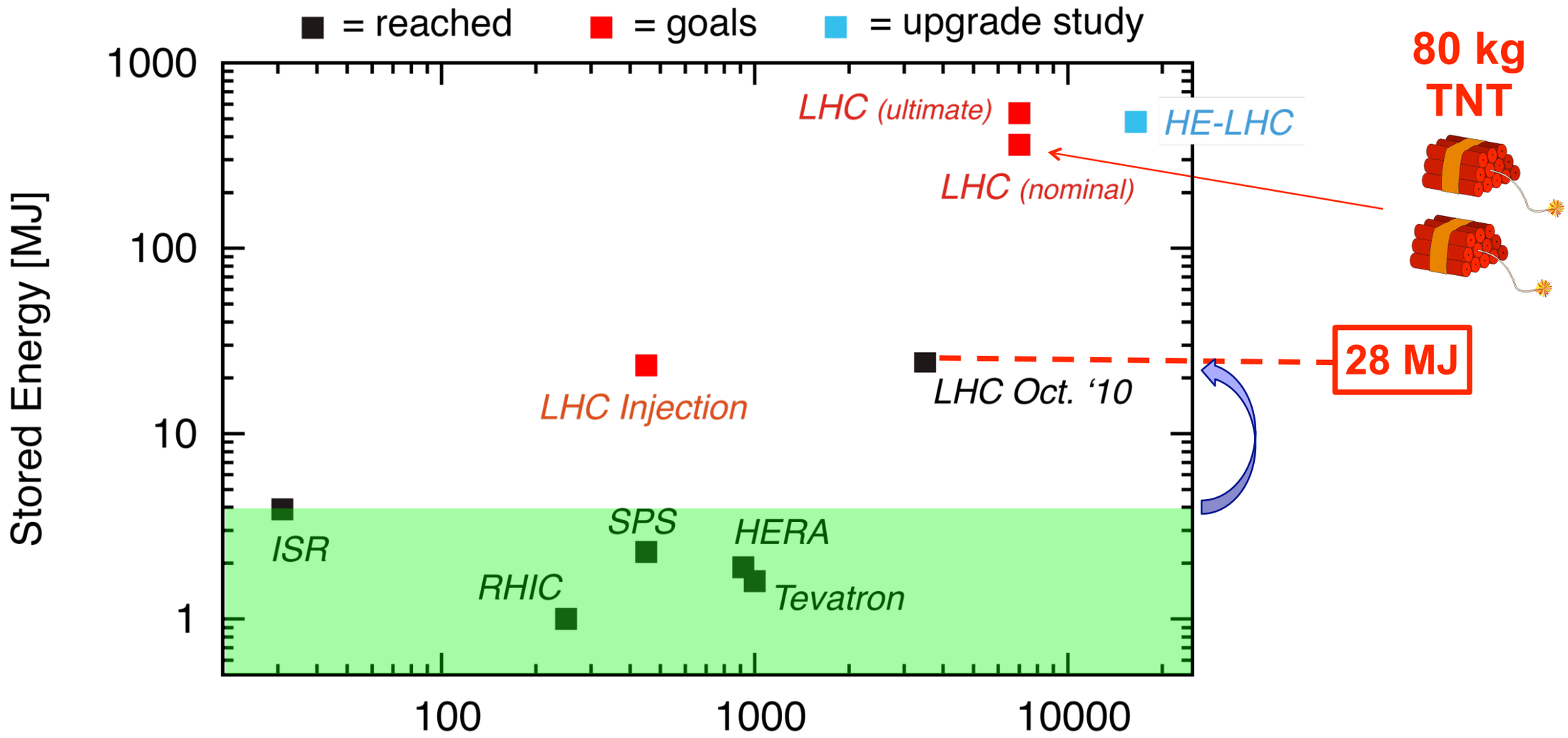


- ☑ Lay foundations for the 2011 goal of **1 fb^{-1}**. 2010 target: **peak luminosity = 10^{32} cm^{-2} s^{-1}.** ✓
- ☑ **Steady run around 1-2 MJ** for an extended period of time. ✓
- ☑ **Safe,** phased increase up to **~ 30 MJ.** ✓
- ☑ **Gain a solid operational experience on the critical machine phases** (injection, energy ramp, squeeze, collisions, ...). ✓

30 MJ is equivalent to ~7 kg of TNT



What does this means in practice?



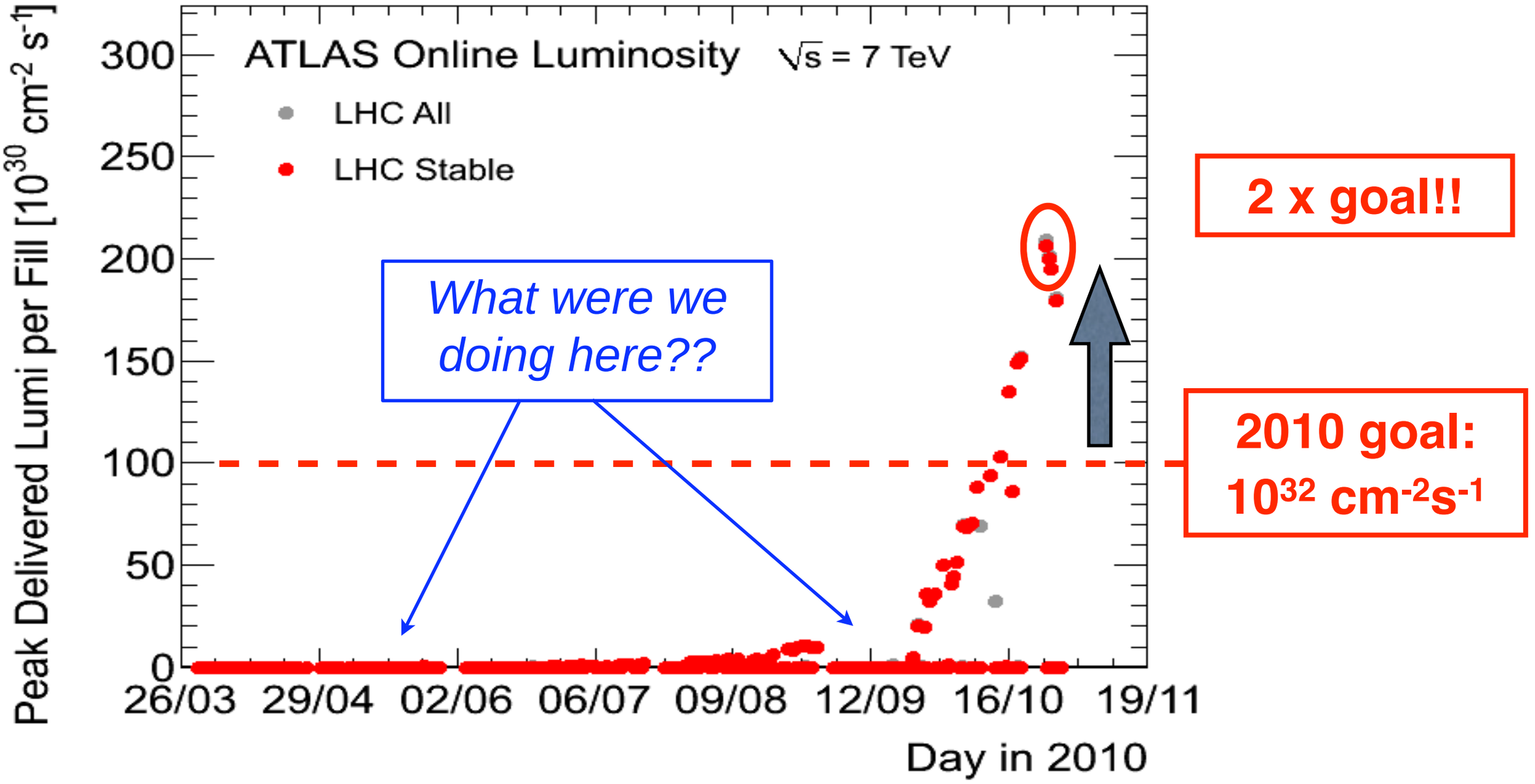
R. Assmann

In the first year of operation we needed to achieve:

Factor ~10 above state-of-the-art.

Factor ~15 above the Tevatron.

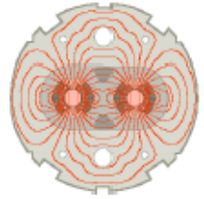
Peak luminosity performance

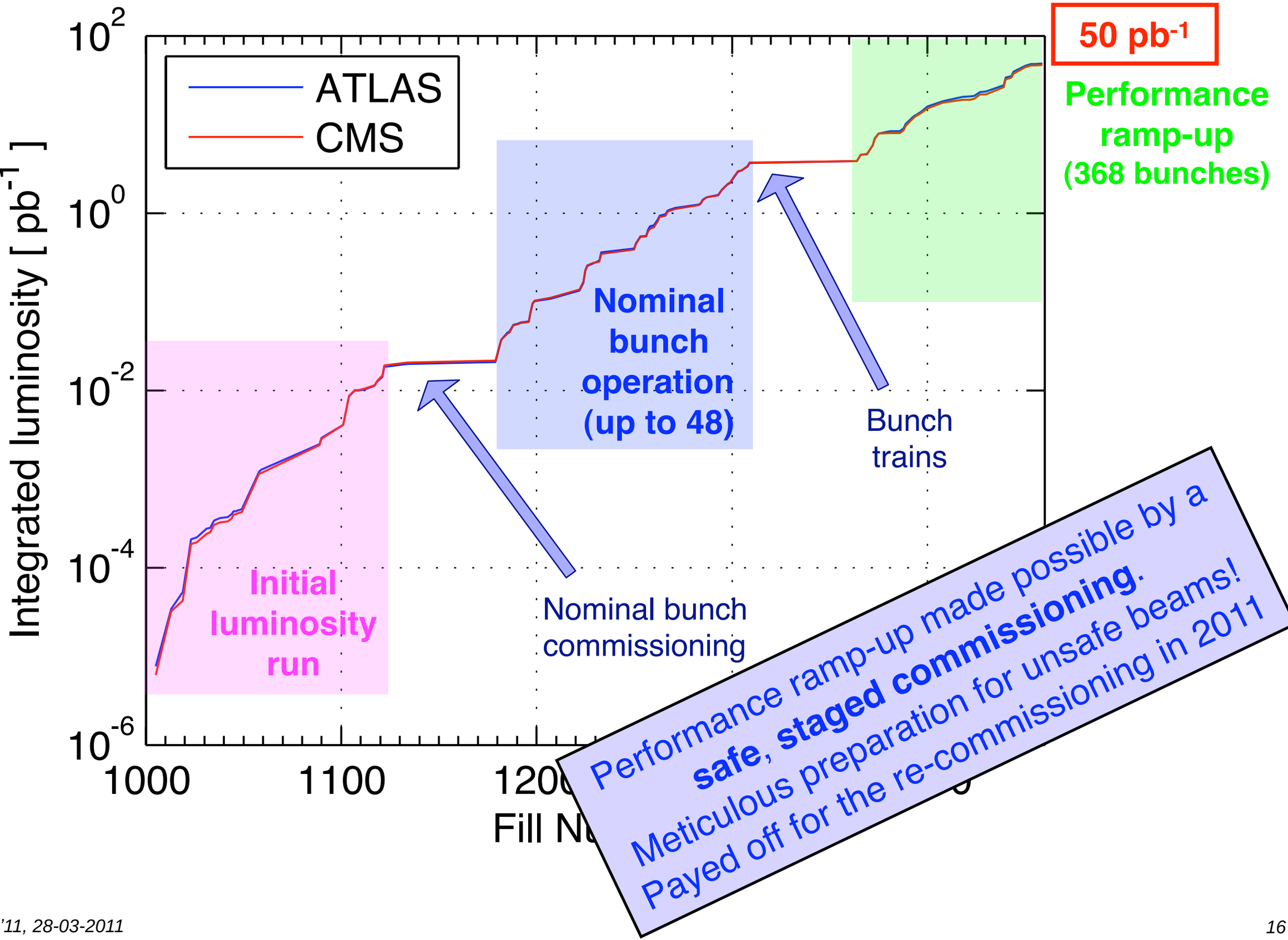


Achieved with 368 bunches of 1.2×10^{11} protons (~24 MJ).

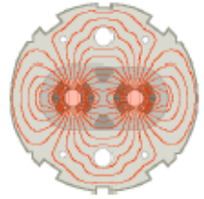
Colliding beam sizes = ~ 40 μm ($\beta^* = 3.5$ m, $\varepsilon^n_{\text{injected}} \sim 2.5$μm)

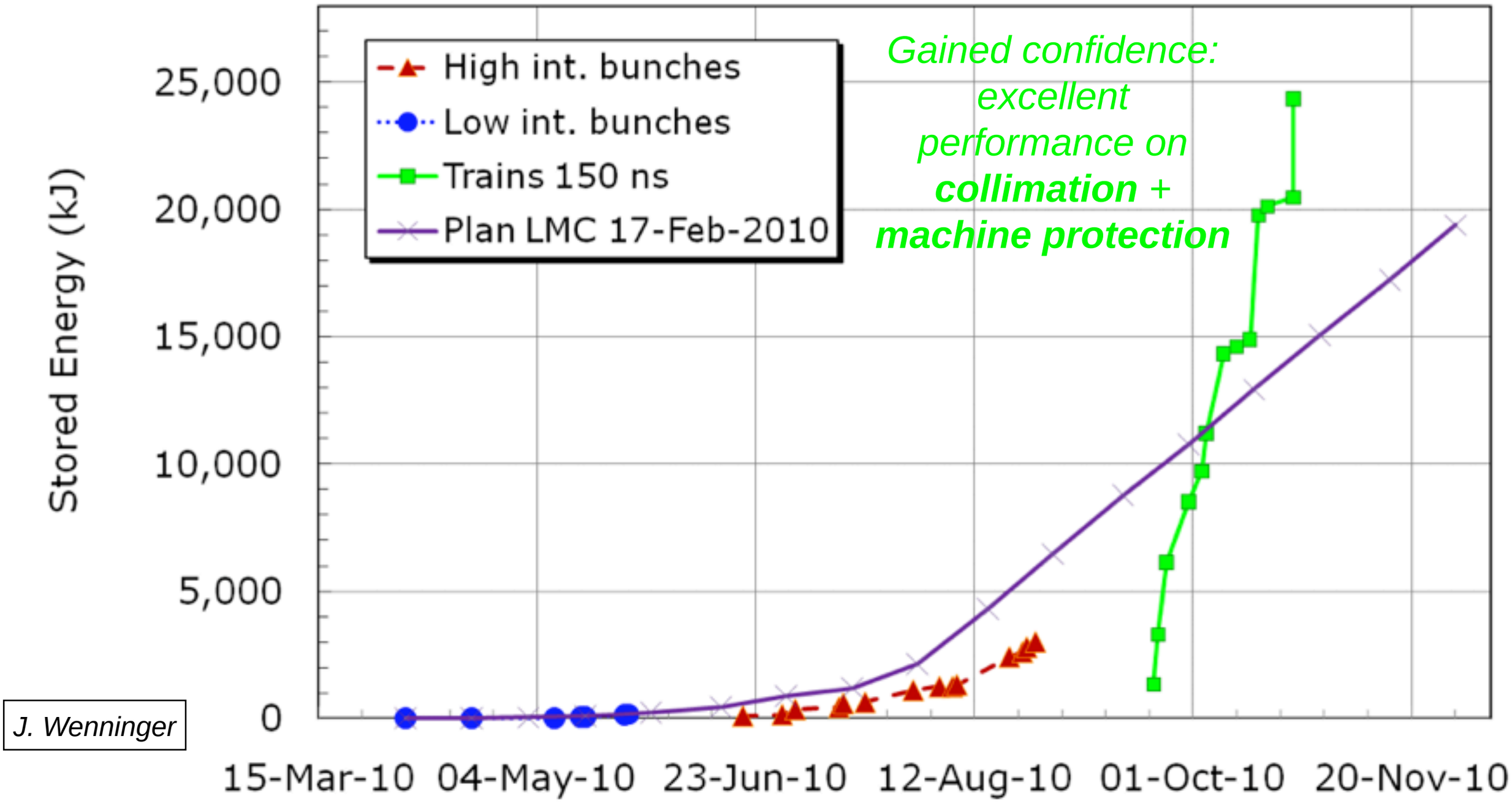
Luminosity: 3 running periods





E_{stored} challenge: achieved vs. predicted



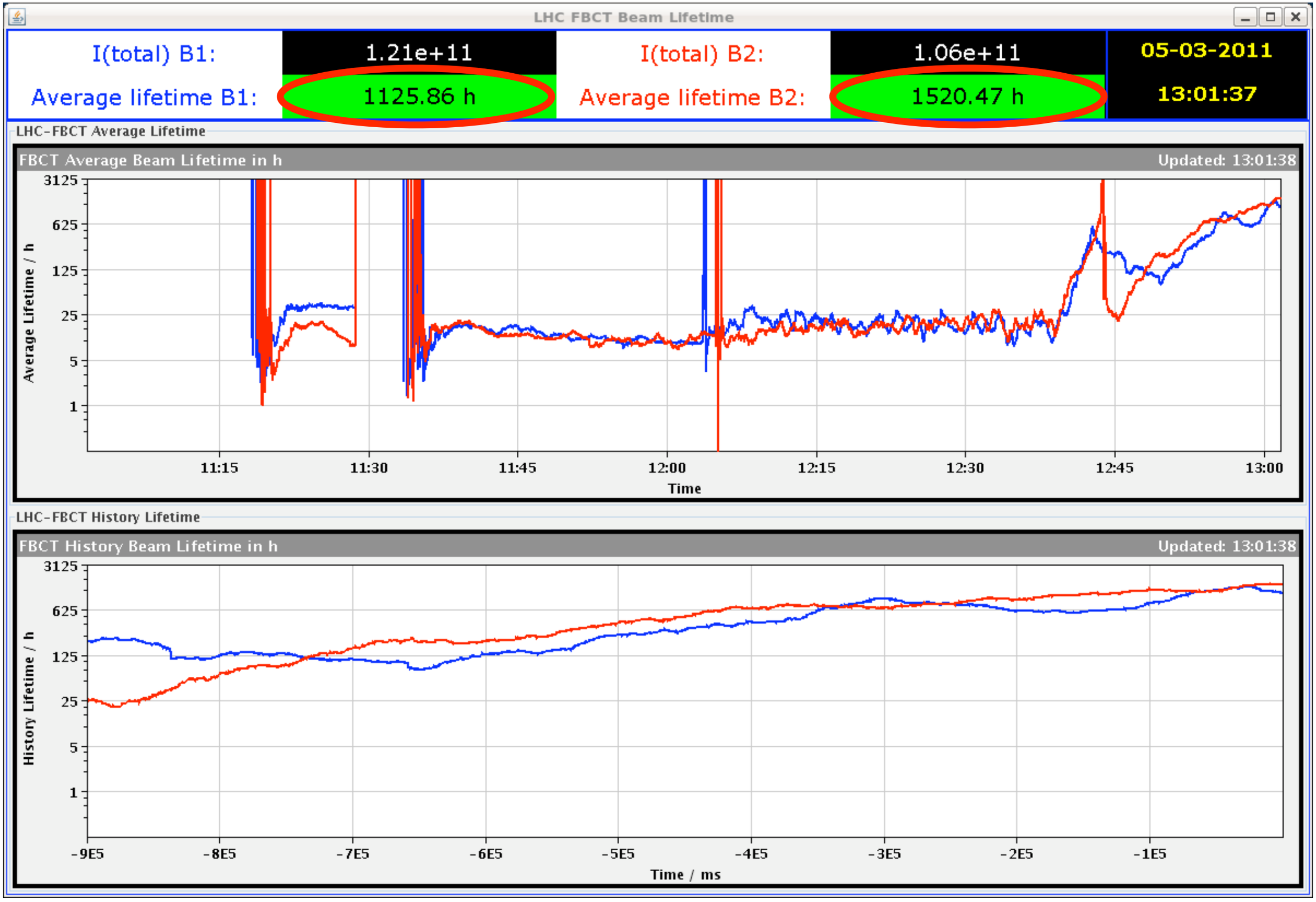


Gained confidence: excellent performance on ***collimation*** *+* ***machine protection***

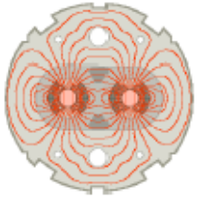
J. Wenninger

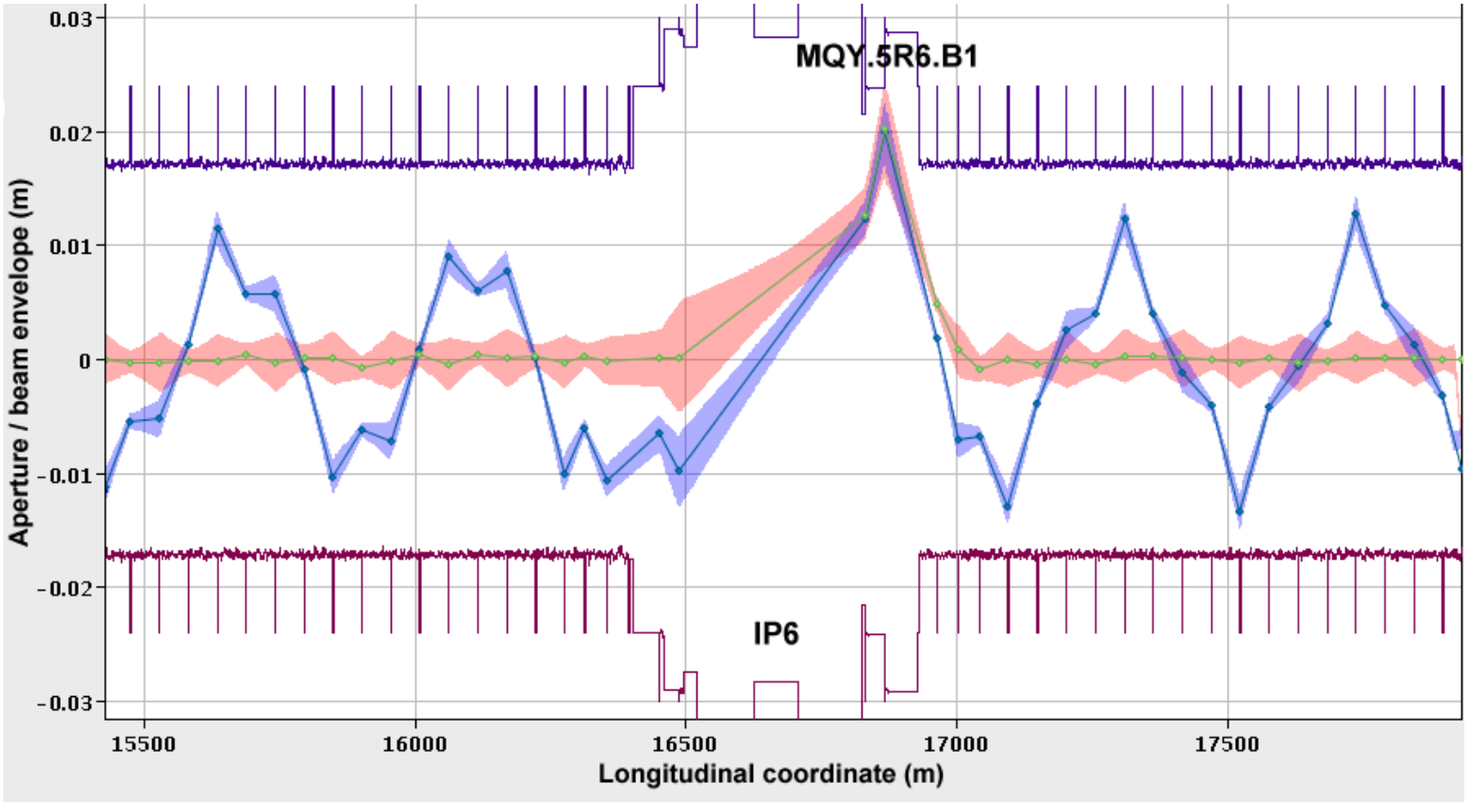
The performance increase was driven by machine protection constraints/requirements.

Amazing single-beam lifetime



Ring aperture: very good!

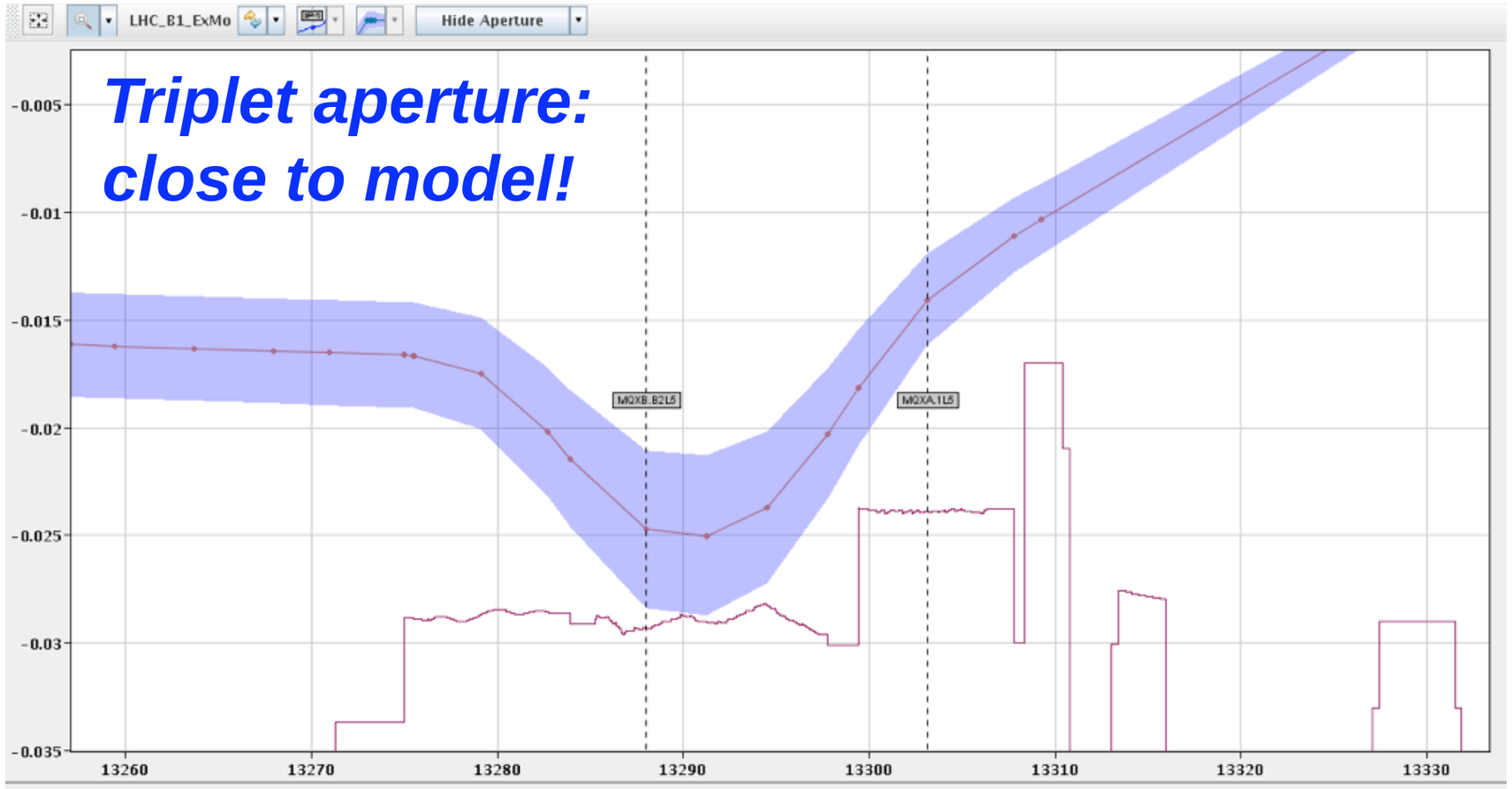




On-momentum aperture **bottlenecks**:

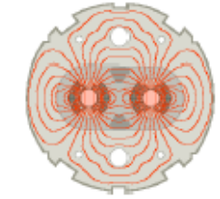
----- 2011 -------	--------2010------
B1H Q6R2 ~12.0 sigma	~12.5 sigma Q6R2
B1V Q4L6 ~13.0 sigma	~13.5 sigma Q4L6
B2H Q5R6 ~12.5 sigma	~14.0 sigma Q5R6
B2V Q4R6 ~13.0 sigma	~13.0 sigma Q4R6

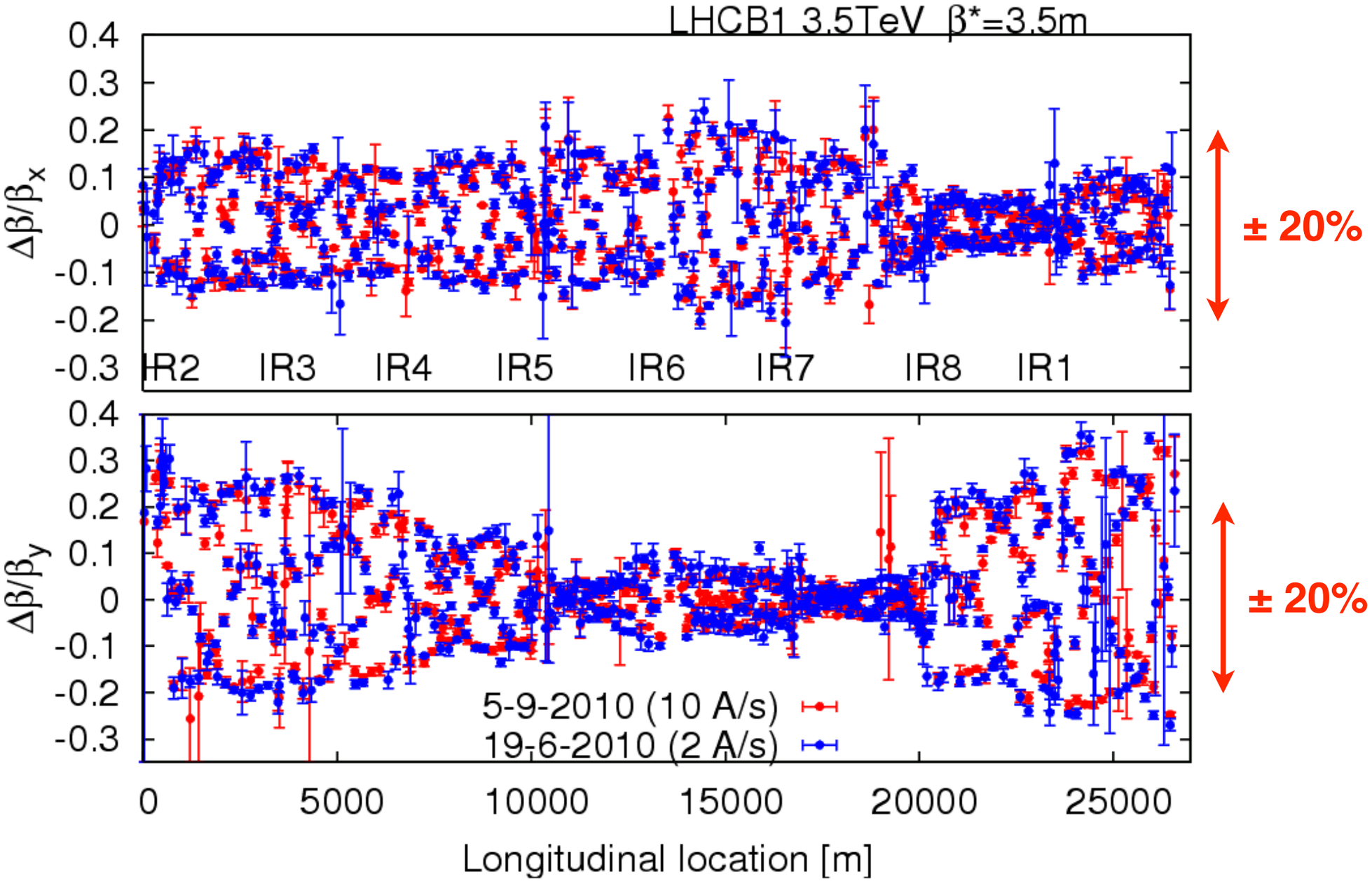
Design assumption at 450GeV: **~8.5-10sigma**



LHC online ApertureMeter by G. Müller

LHC optics: good, correctable, stable!



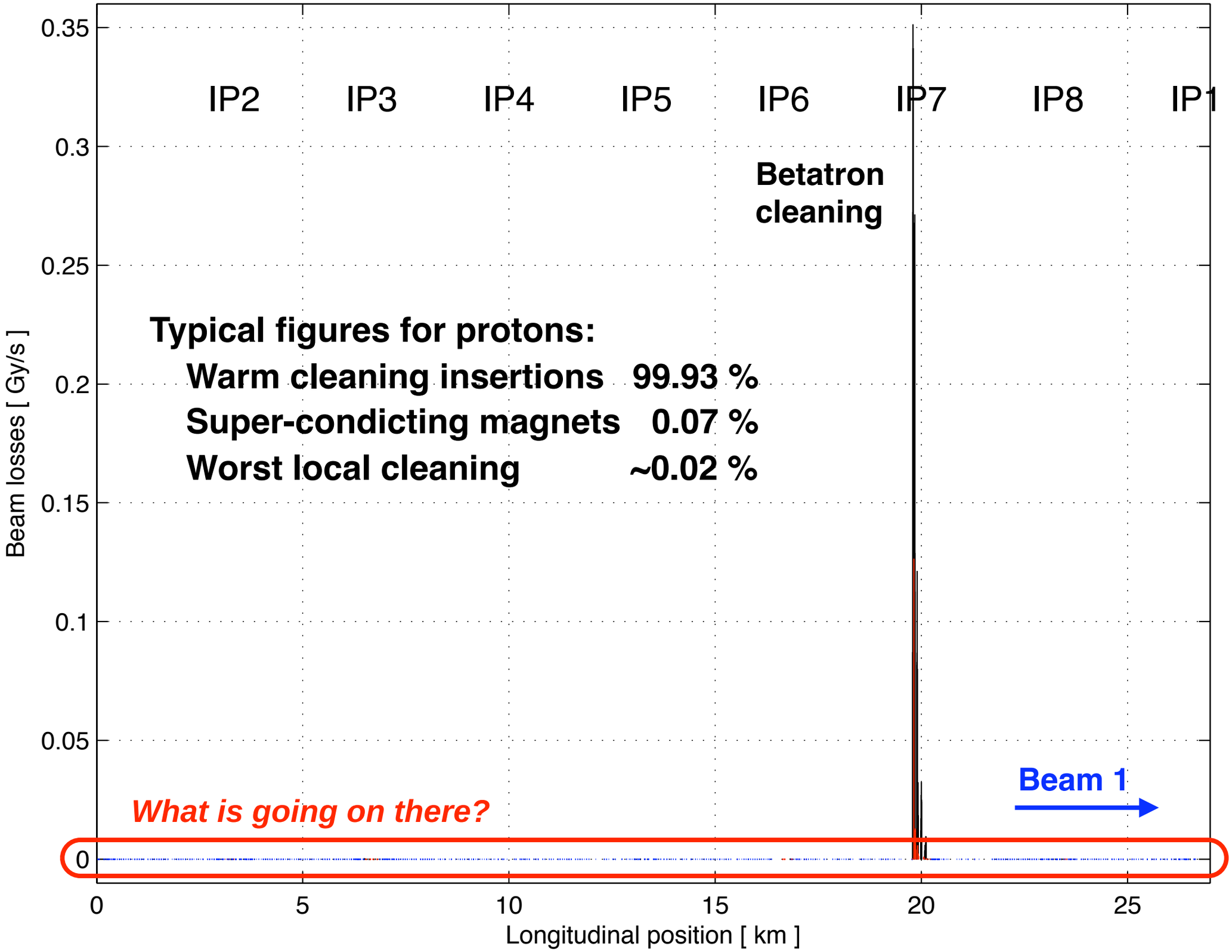


R, Tomàs for the beta-beat team.

- Optics stunningly stable! Correctable below 10 % error!
- 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 cleaning 3.5 TeV

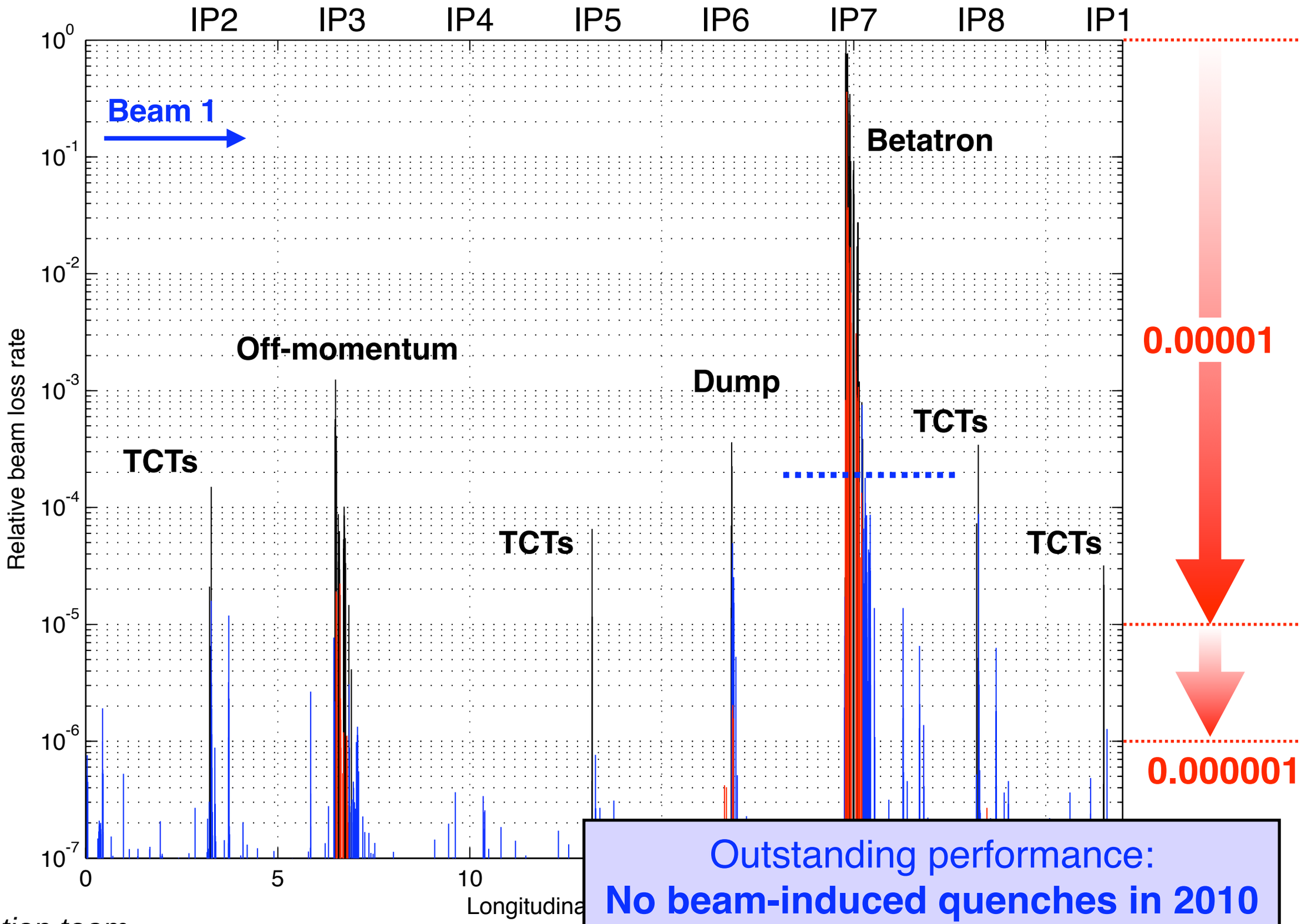
4000 beam loss monitors along 27 km



LHC collimation team

Collimation cleaning at 3.5 TeV (ii)

Generate higher loss rates: beam across the 3rd order resonance.



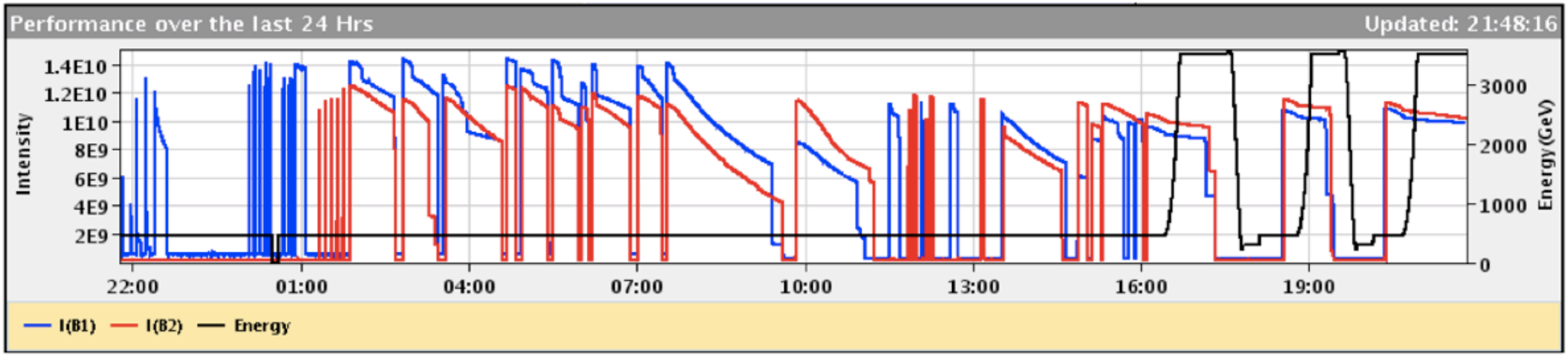
Legend:
Collimators
Cold losses
Warm losses

Outstanding performance:
No beam-induced quenches in 2010
No limitations expected for 2011-12 run

LHC collimation team

2010 Pb ion run - commissioning

1 day



Beam 1 Inj., Circ. & Capture

Beam 2 Inj., Circ. & Capture

Optics Checks
BI Checks
Collimation Checks

First Ramp
Collimation Checks
Squeeze

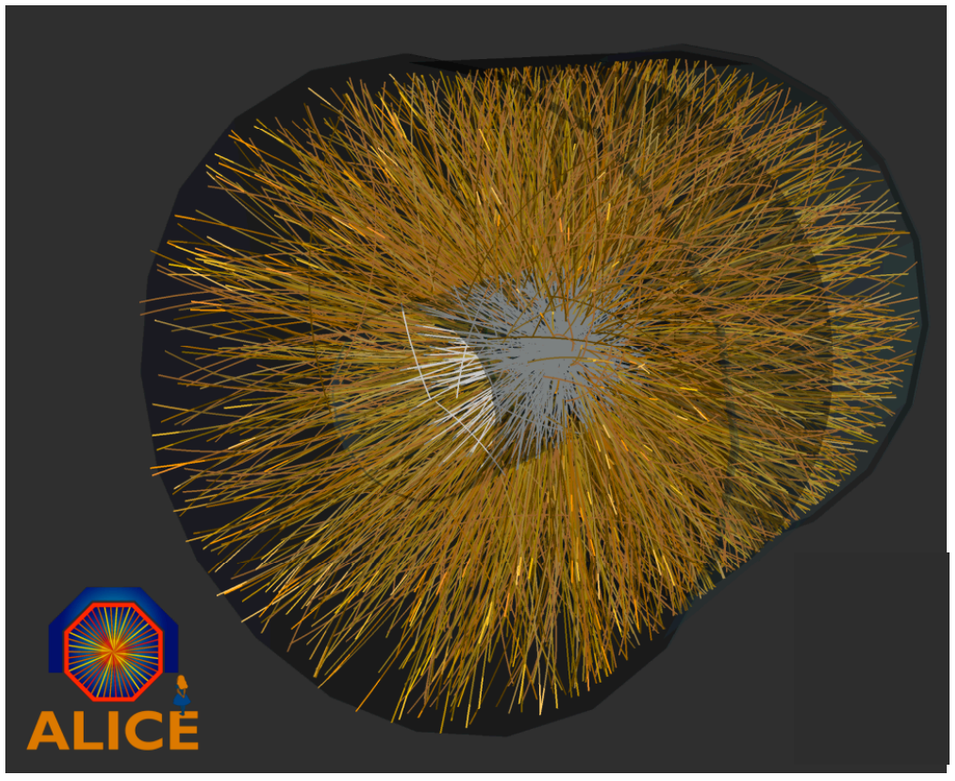
Achieved **ion collisions** after **54 hours** of commissioning!

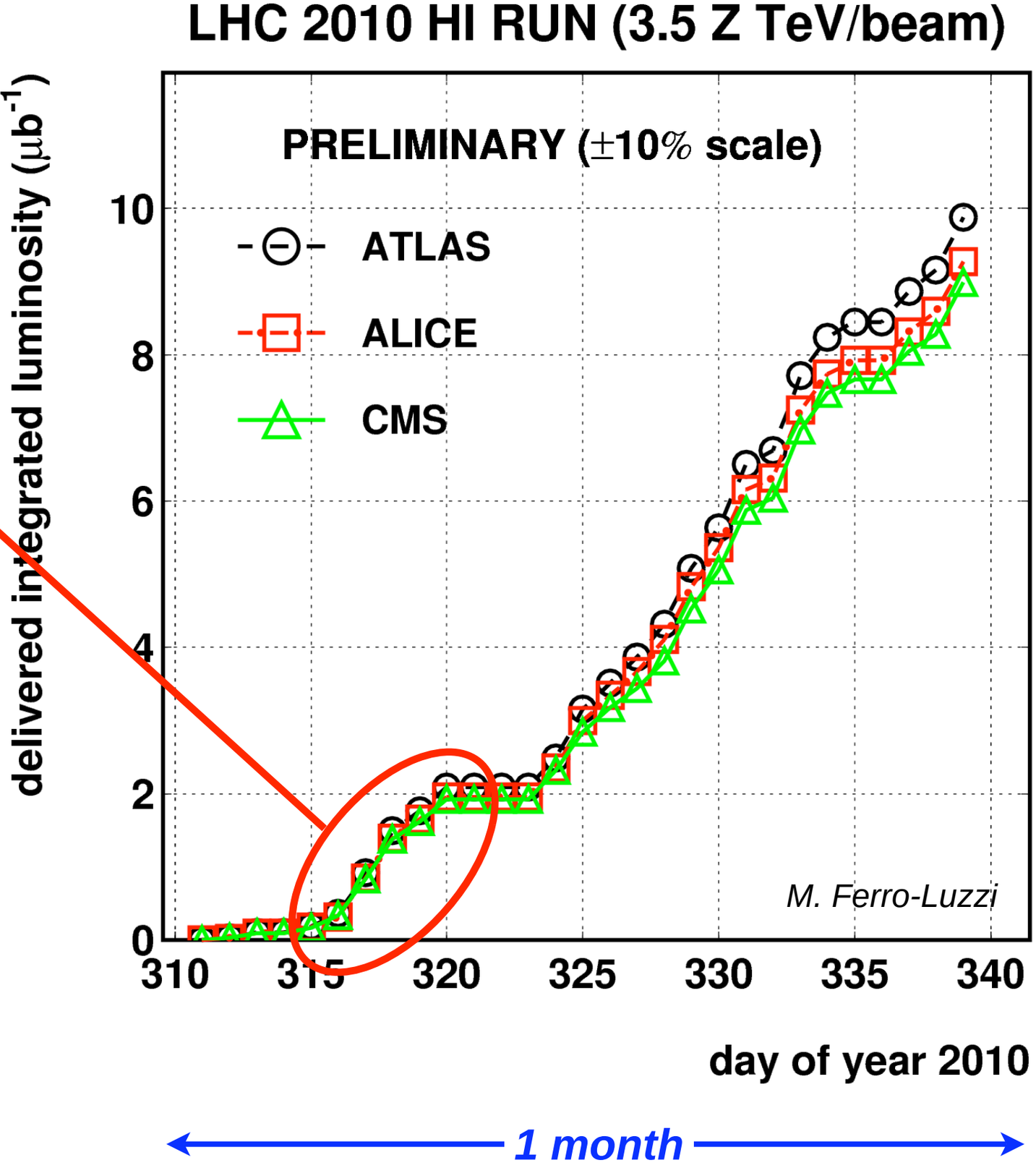
This indicates the remarkable maturity and performance of controls, instrumentation, operational experience.

Ion luminosity performance

Gained a factor 100 of peak luminosity in 6 days!

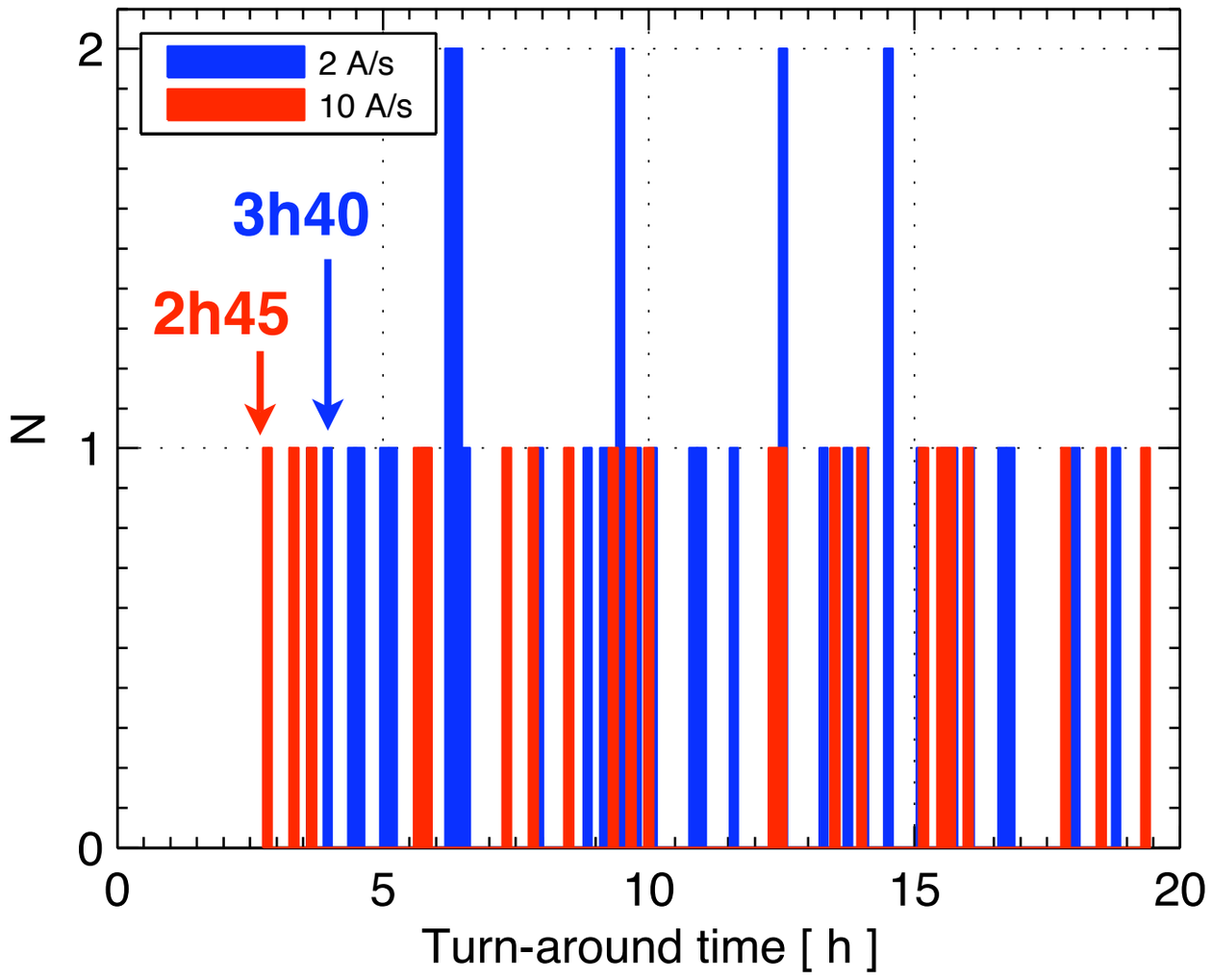
Some spectacular events out there...



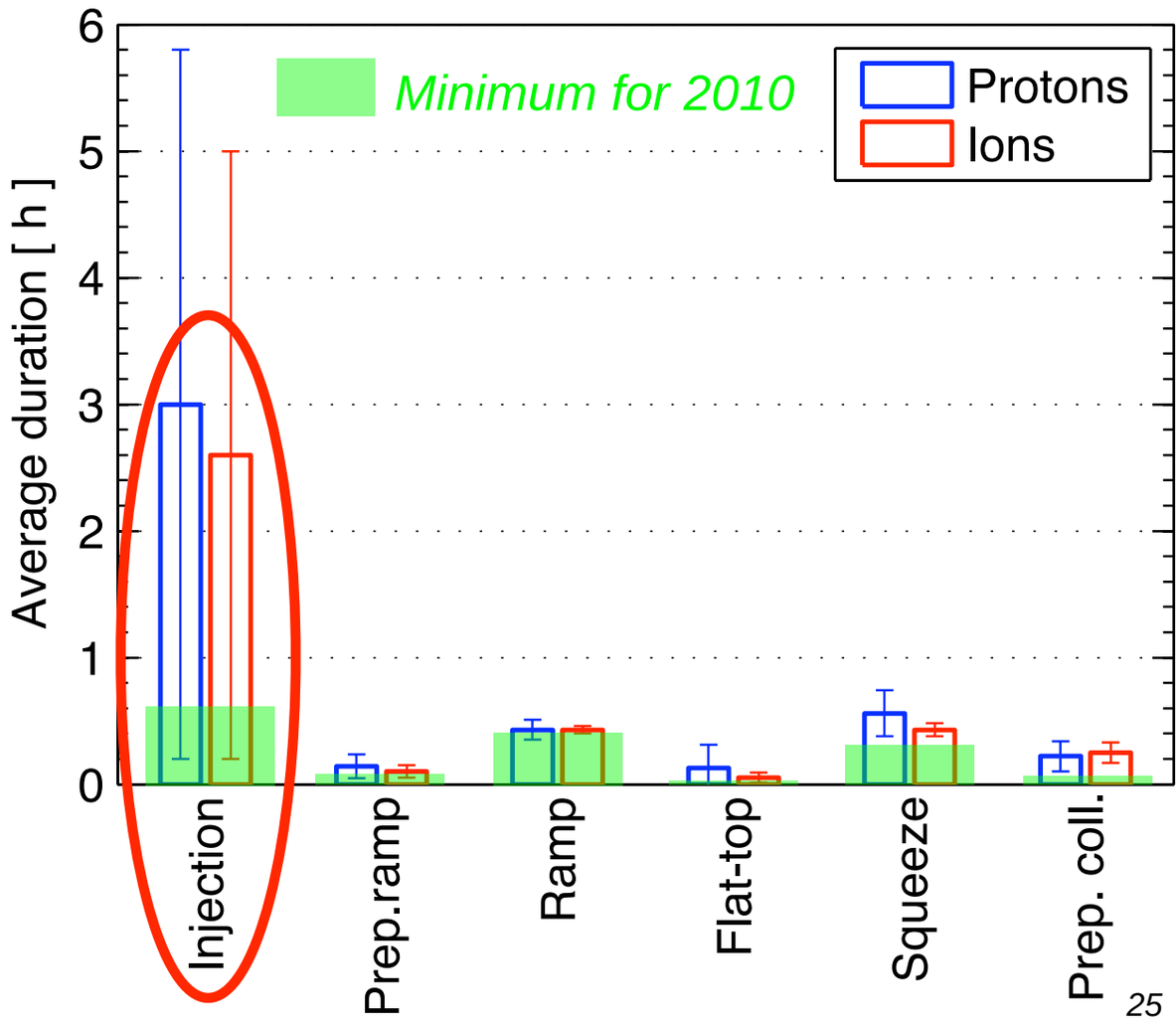


LHC turnaround in 2010

Dump to stable beam turn-around time

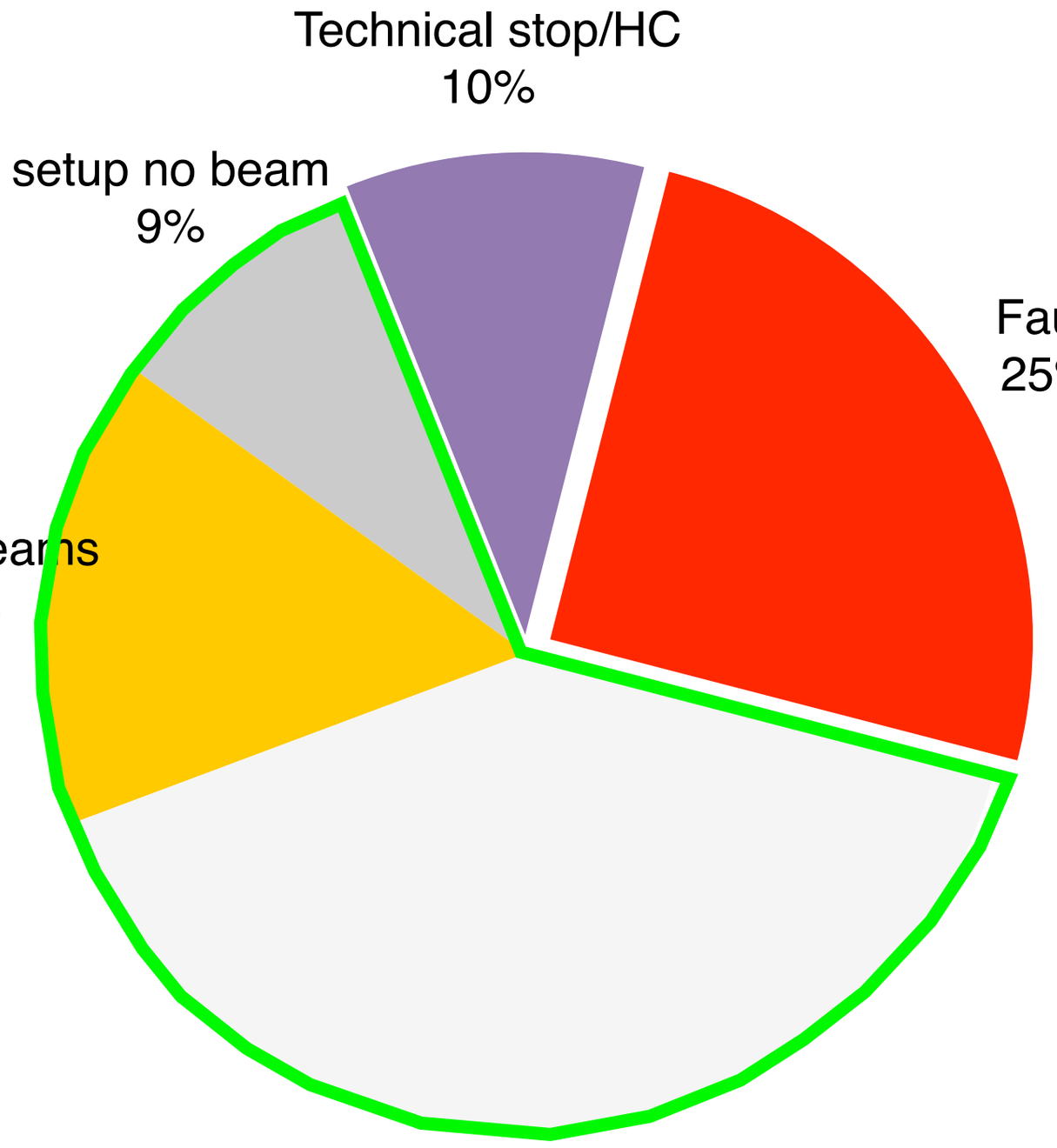


Machine phase	Proton run (3) Time [h]	Ions Time [h]
Injection	3.0 ± 2.8	2.6 ± 2.4
Prepare Ramp	0.14 ± 0.09	0.10 ± 0.05
Ramp	0.43 ± 0.08	0.43 ± 0.03
Flat top	0.13 ± 0.18	0.05 ± 0.04
Squeeze	0.56 ± 0.18	0.43 ± 0.05
Prepare collisions #	0.22 ± 0.12	0.25 ± 0.08



Theoretical minimum ~ 2h00
Achieved minimum: 2h45
Average: > 5h00
Will improve in 2011!

Overall LHC efficiency in 2010



65% availability!

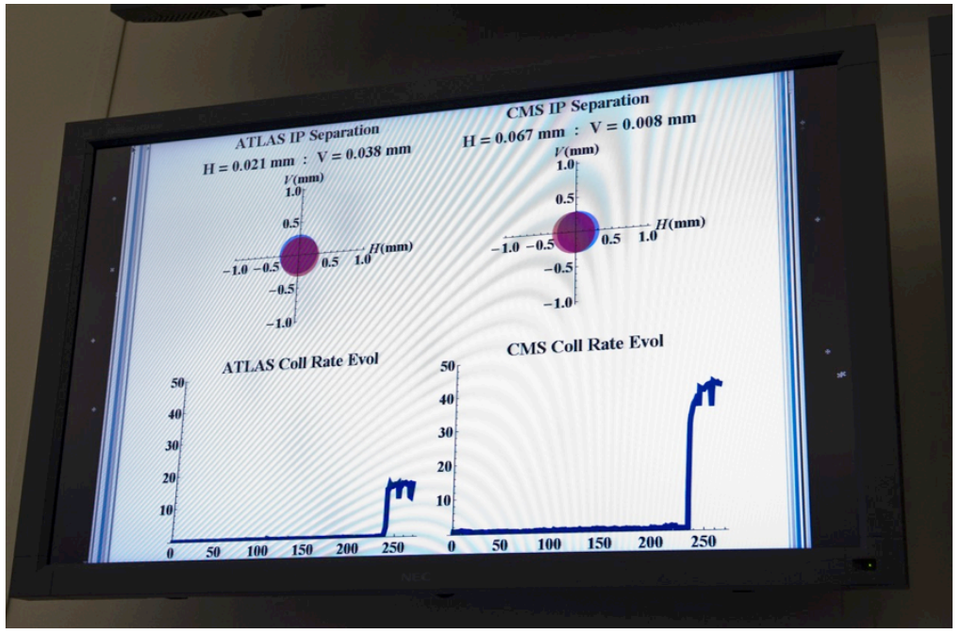
Best: 80% in November (26% physics)

Worst: 53% in March (1% physics!)

W. Venturini

First 7 TeV collisions (March 30th)

What was the 1% period of stable beams in March?



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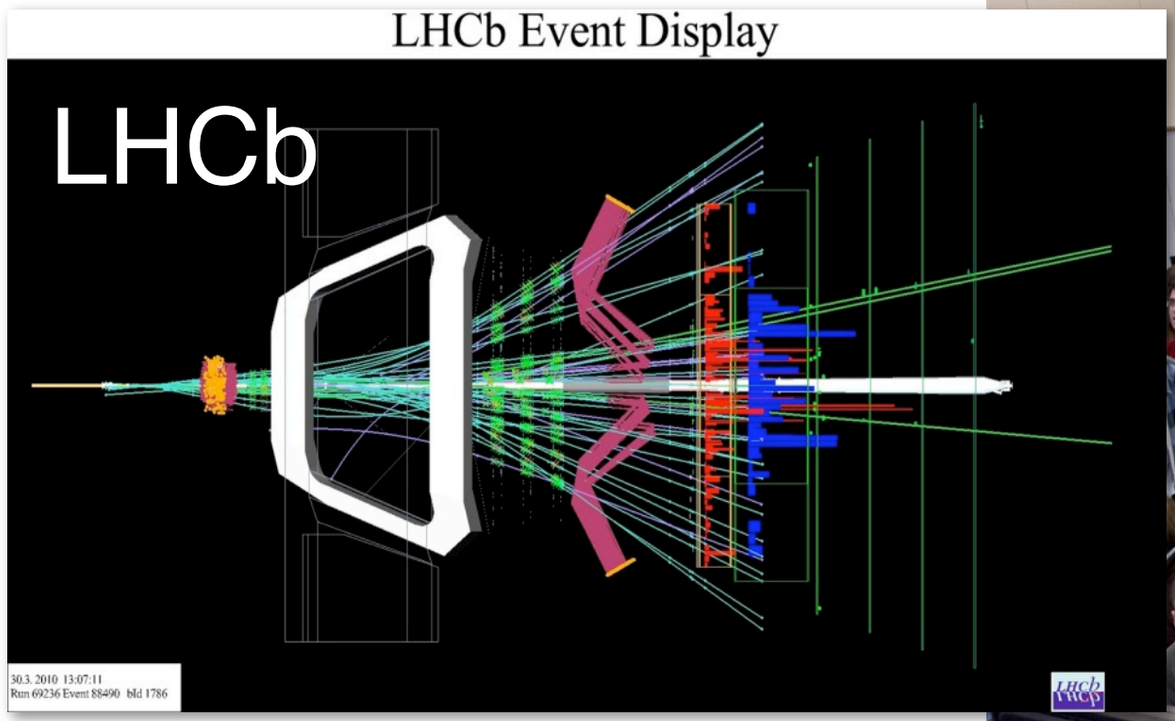
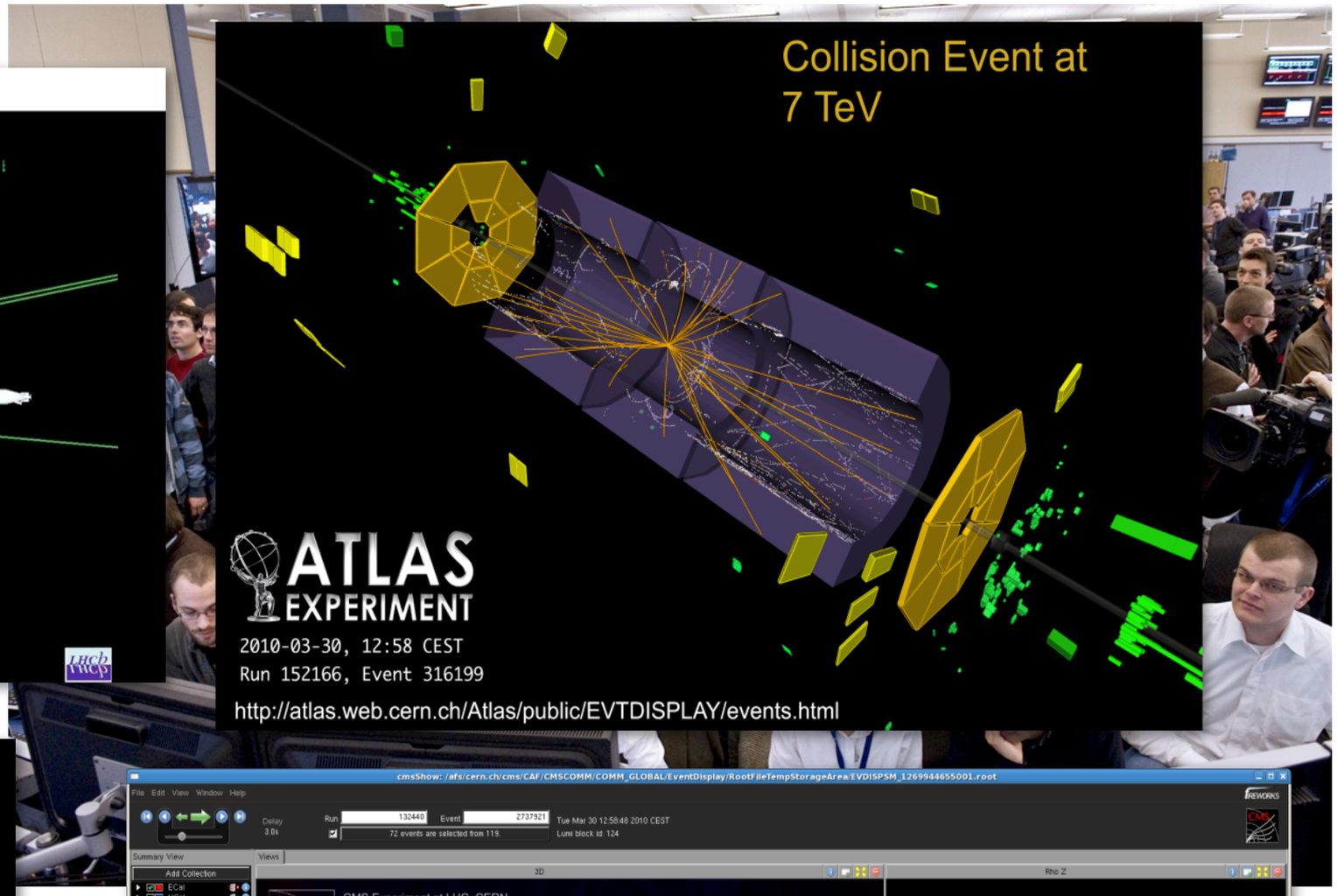
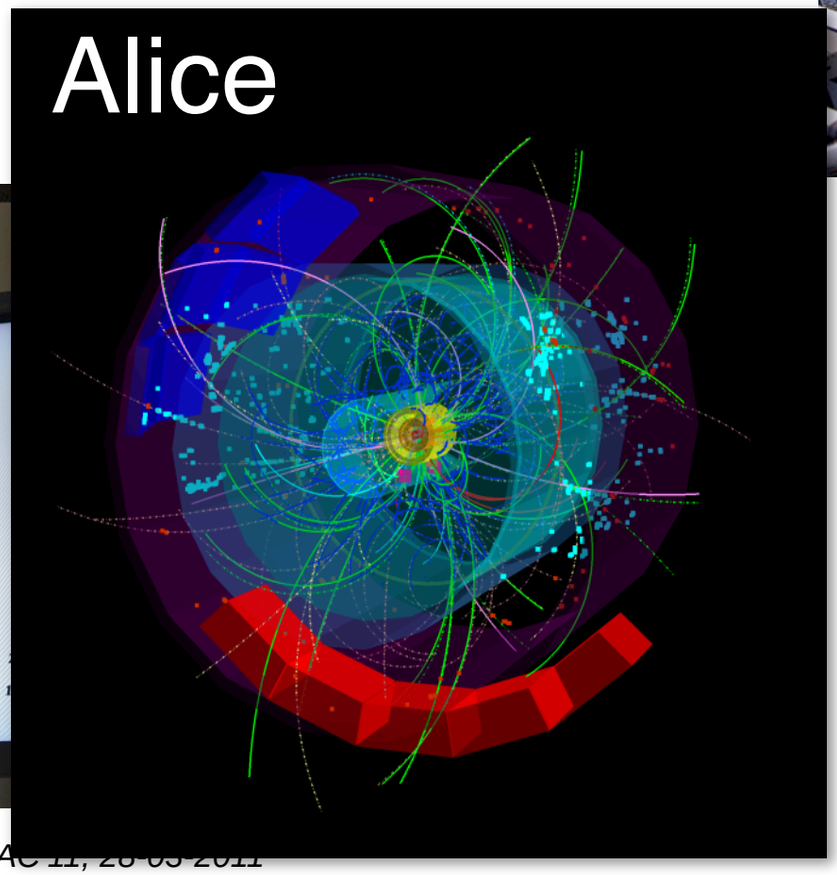
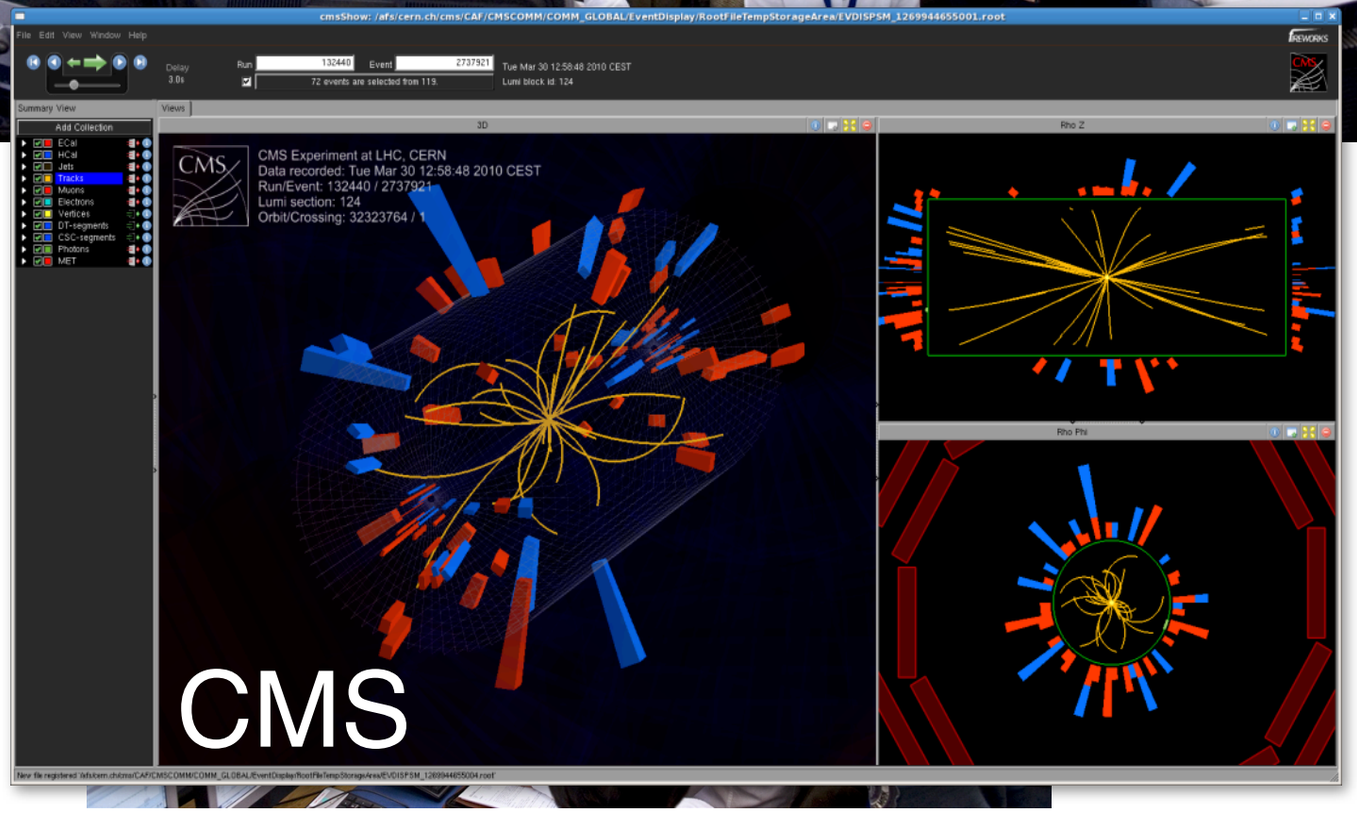
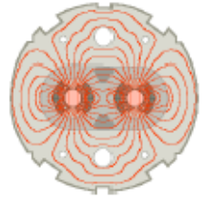


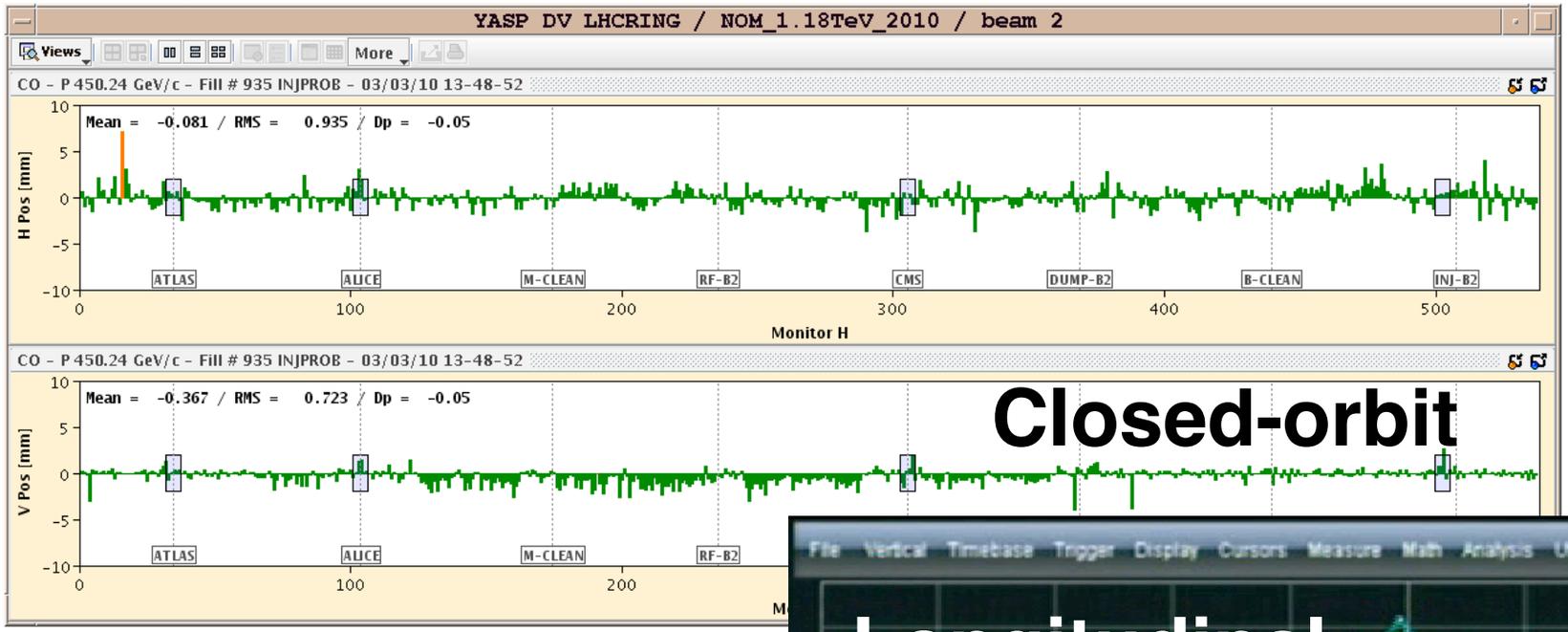


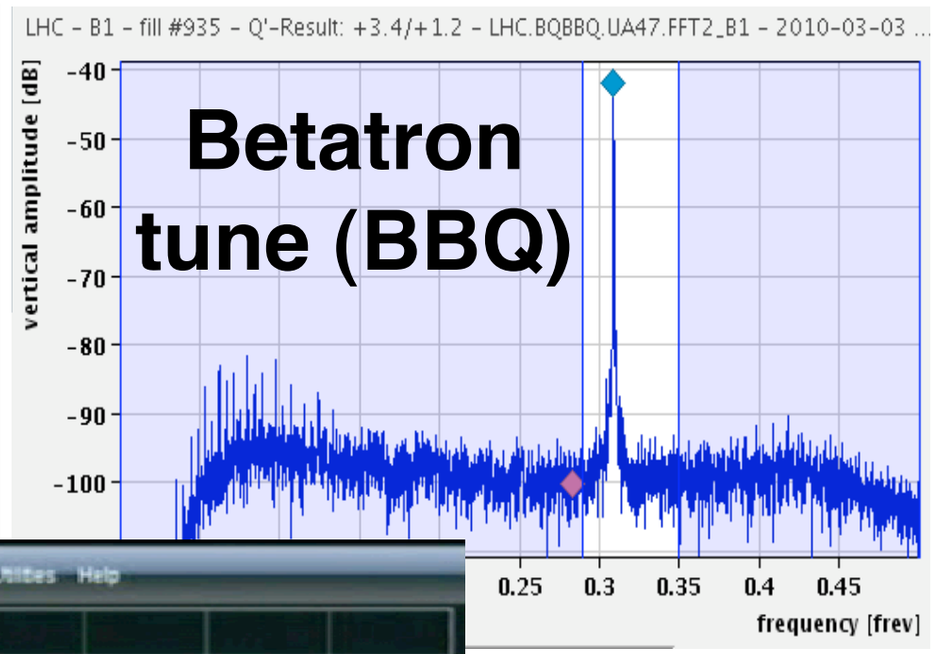


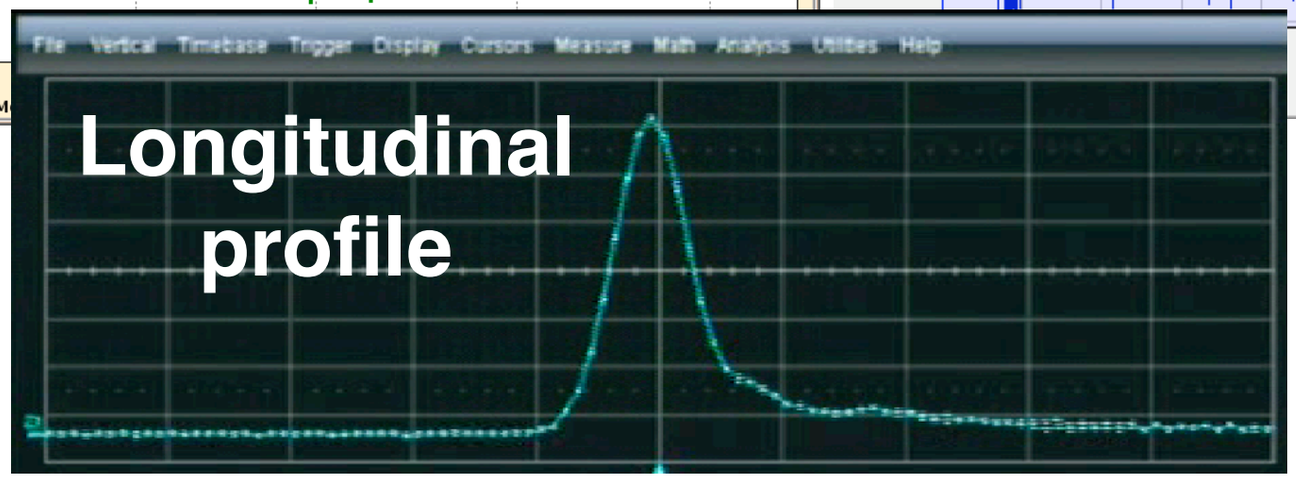


Excellent beam instrumentation!



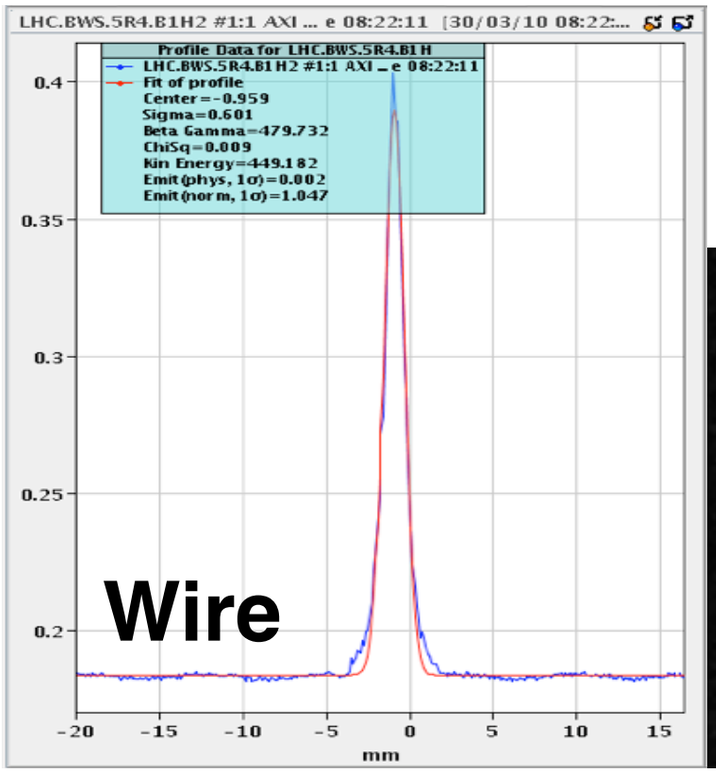


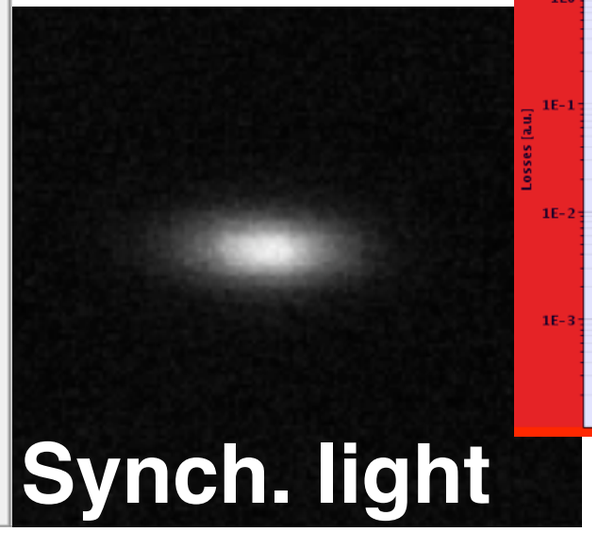


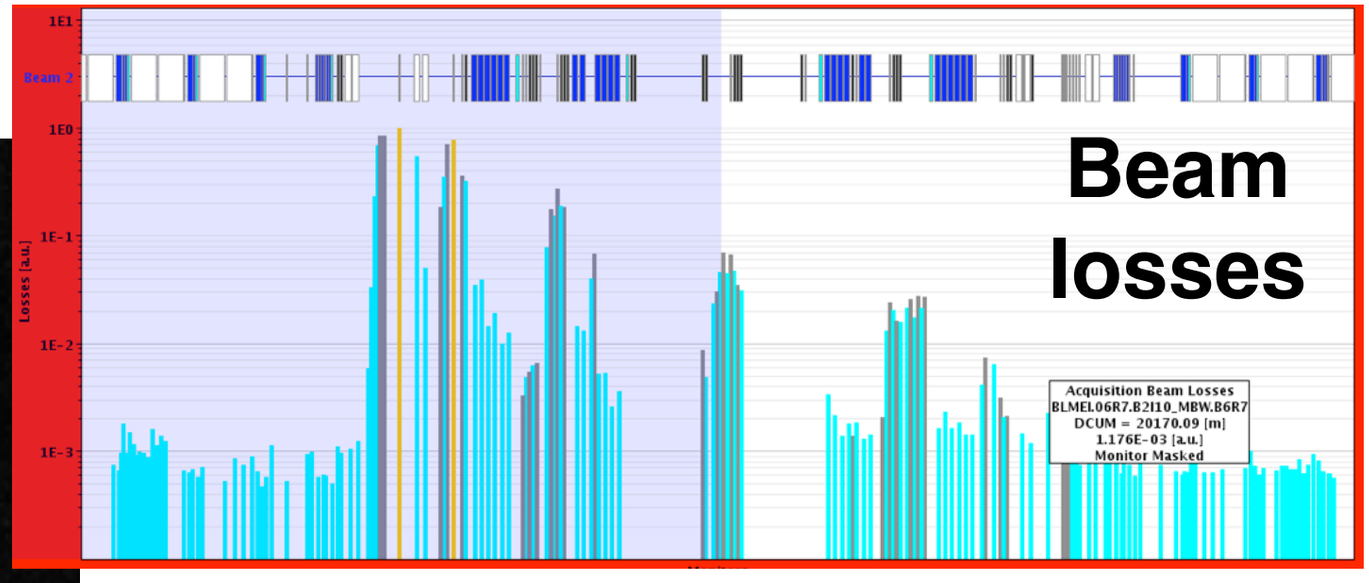


See also talk by R. Steinhagen

Transverse size







And much more...

Outstanding problems encountered

(only mention potential performance limits for 2011)

☑ UFOs - Unidentified FALLING objects

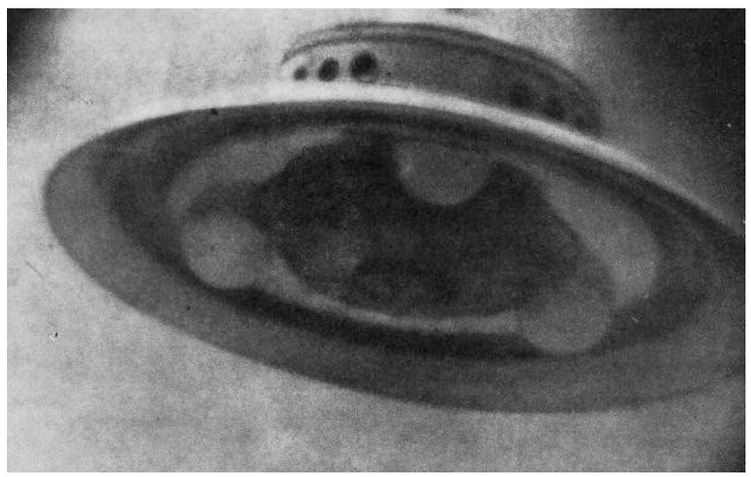
Sudden fast losses (t < 0.001s).

Potentially caused by falling (dust) particles.

No danger for the super-conducting magnets,

but trigger preventive beam dumps;

More frequent with larger beam intensities!



☑ Electron cloud

"Clouds" of electrons generated in the vacuum pipe if

the bunches are too close longitudinally.

Can limit the total intensity (bunch number):

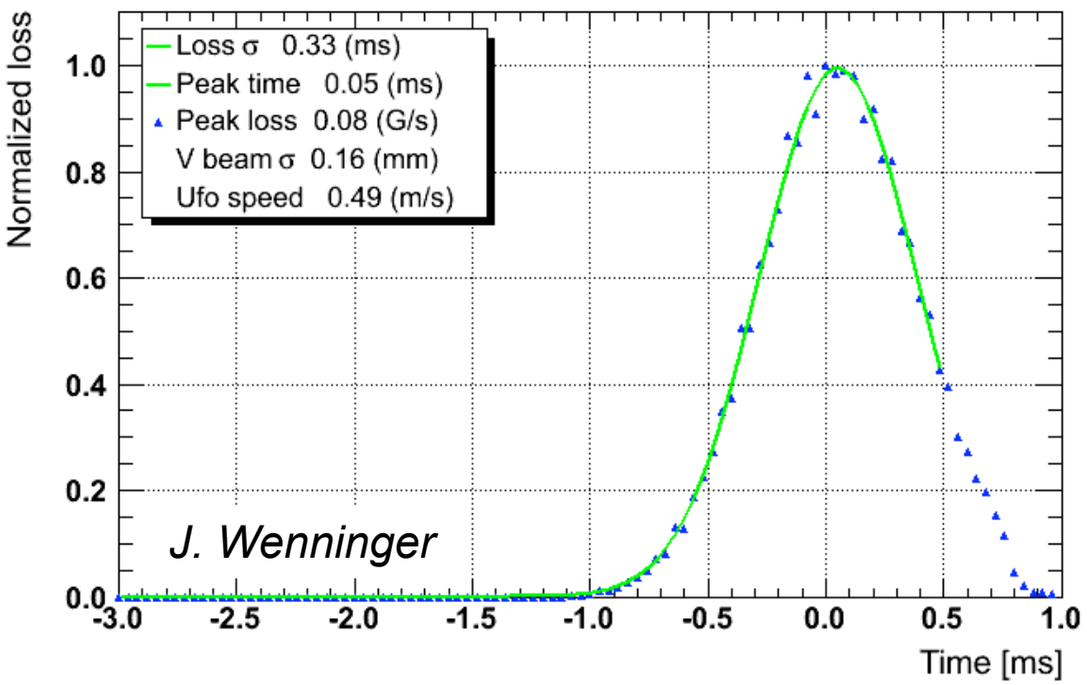
vacuum problems; instabilities;

growth of the beam size.

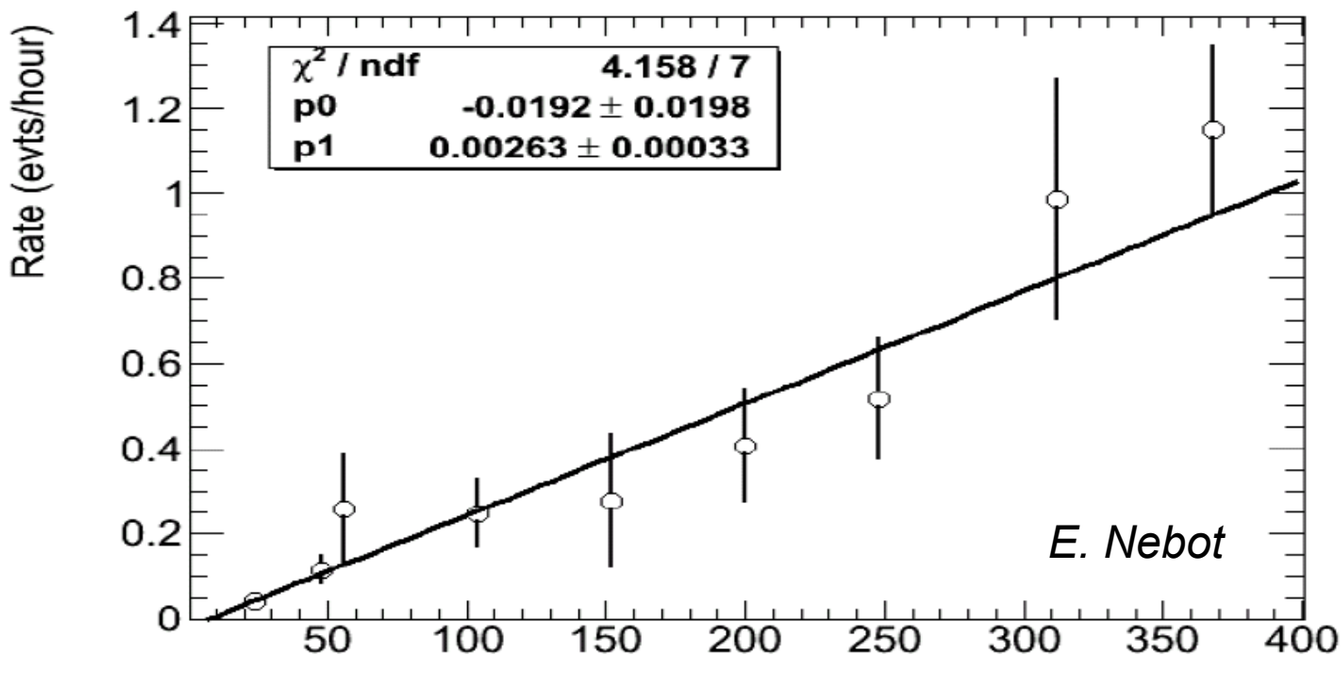
Can be cured by "scrubbing" the chamber.

UFO losses

Losses vs. time



Correlation vs intensity - worrisome!



Total of 18 beam dumps!

Signal amplitude does not increase with intensity, but rate does.

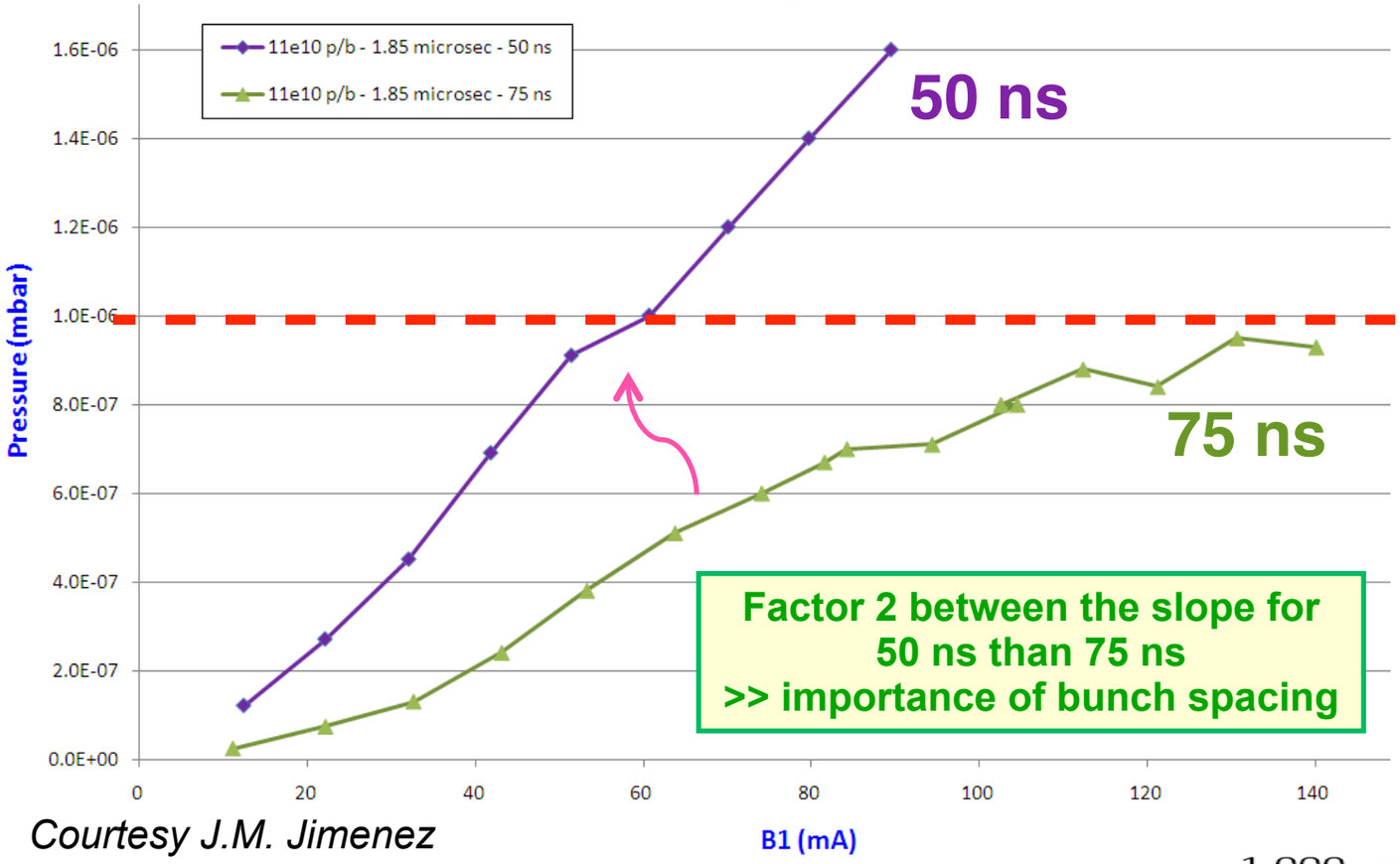
→ Relaxed BLM thresholds for fast losses

→ Improved diagnostics is ongoing

→ Monitor behaviour above ~200 bunches

e-cloud effects

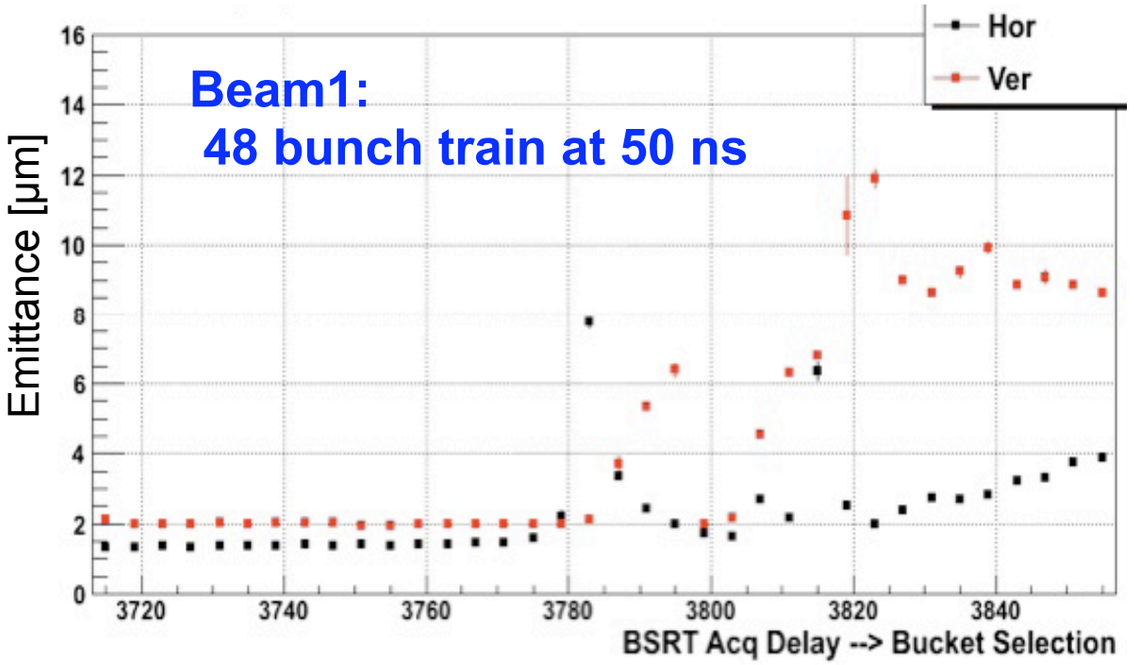
Vacuum pressure rise



Factor 2 between the slope for 50 ns than 75 ns
>> importance of bunch spacing

Courtesy J.M. Jimenez

Emittance blow-up

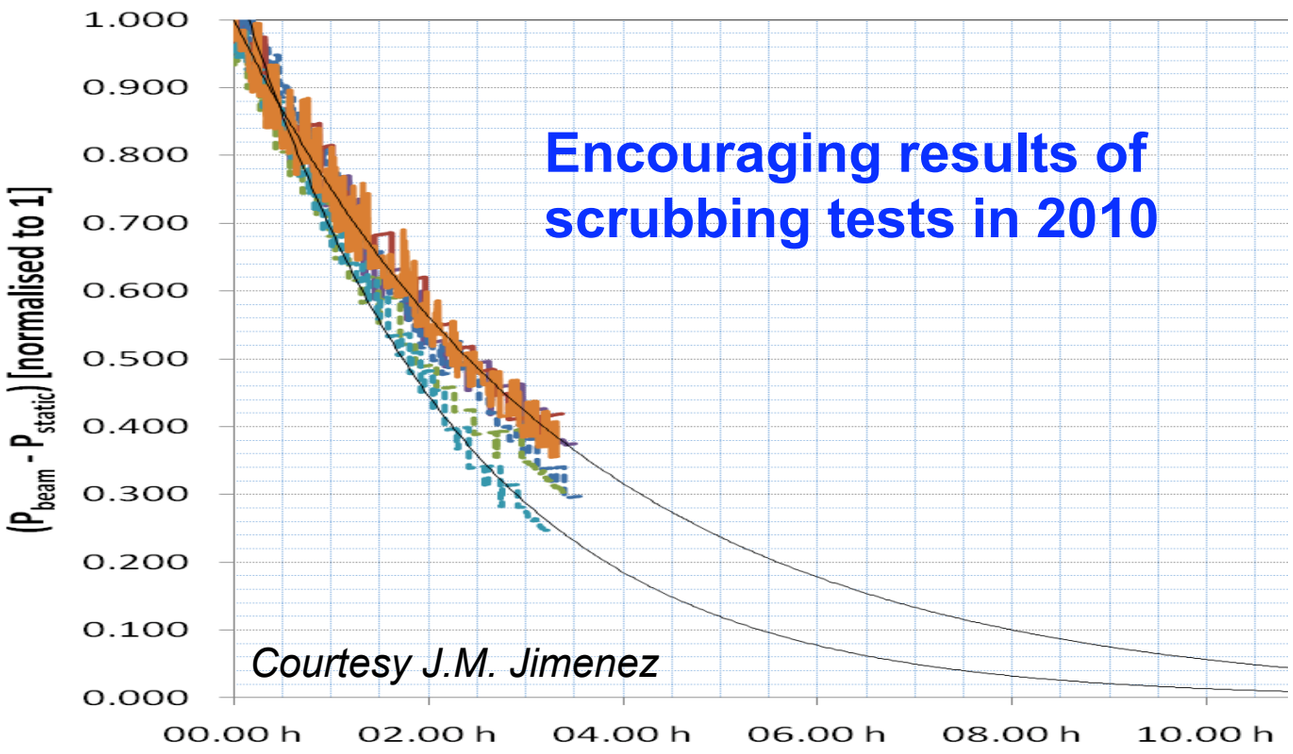


Courtesy F. Roncarolo

Possible cure: **SCRUBBING!**

We will start in 5 days for 1.5 week. Outcome will have an impact on the 2011 run configuration!

Also: additional solenoids.



Courtesy J.M. Jimenez

Outline

- Introduction
- Performance in 2010
- **2011 prospects**
  - **Goals and draft schedule**
  - **Performance reach**
- Conclusions

2011 prospects

- Outcome of Chamonix 2011 workshop:
  - (1) Operate at 3.5+3.5 TeV in 2011
  - (2) First long shutdown in 2013

- Goal for 2011: **integrated luminosity = 1 fb^{-1}!**

- Other **approved** physics programs:
  - *Intermediate physics at 1.38 TeV*
  - *Special runs at β^*=90m in IP1/5*
  - *Luminosity calibration runs*
  - *Special runs for Roman pots of TOTEM/ALFA*

Time estimate: ~ 10 days

- Dedicated Machine Development time : **11 x 2 days**

2011 parameter table

	Nominal	2010	2011
Energy [TeV]	7	3.5	3.5
beta* [m]	0.55/10/0.55/10	3.5/3.5/3.5/3.5	**1.5/10/1.5/3**
Emittance [μm]	3.75	**2.0 – 3.5**	**2.0 – 3.5**
IP beam size [μm]	16.7	~ 55	~ 35
Bunch current	1.15E+11	1.2E+11	1.2E+11
N_b	2808	368	~ 900
E_{stored} [MJ]	360	28	~ 70
L [$cm^{-2}s^{-1}$]	1E+34	**~2E+32**	**~1E+33**

Improvements for 2011

→ **Reduction of β* to from 3.5 m to 1.5 m** → **Gain = 2.2**

→ **Increase number of bunches** → **Gain = 2.5 to 3.8**

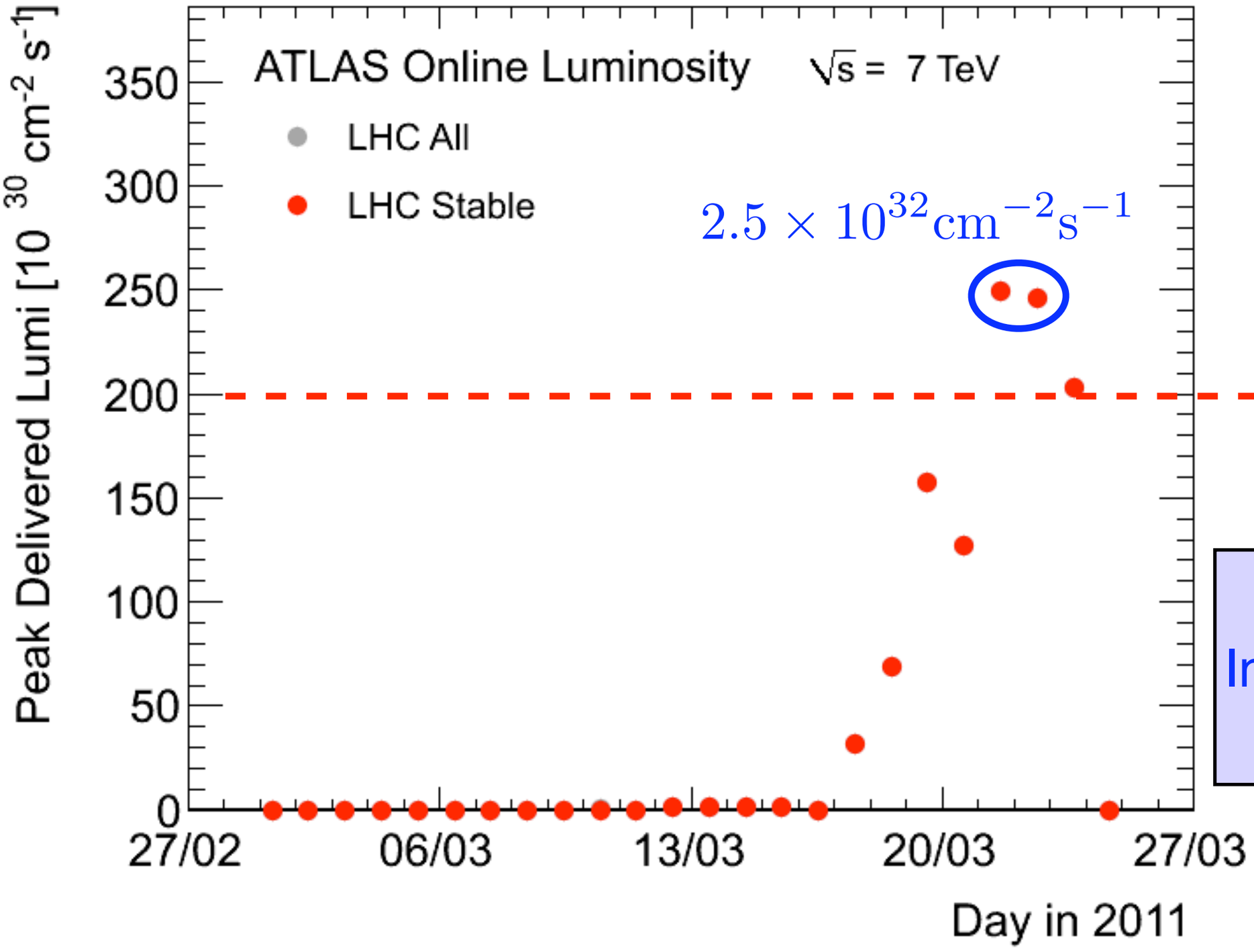
Using 75 ns (920 b) or 50 ns (1400 b) spacing

→ **Increase bunch charge to 1.4×10^{11}** → **Gain ≥ 1.5**

Depends on emittance and bunch spacing

→ **Significant improvement of turnaround time**

Where do we stand?



$N_b = 200$

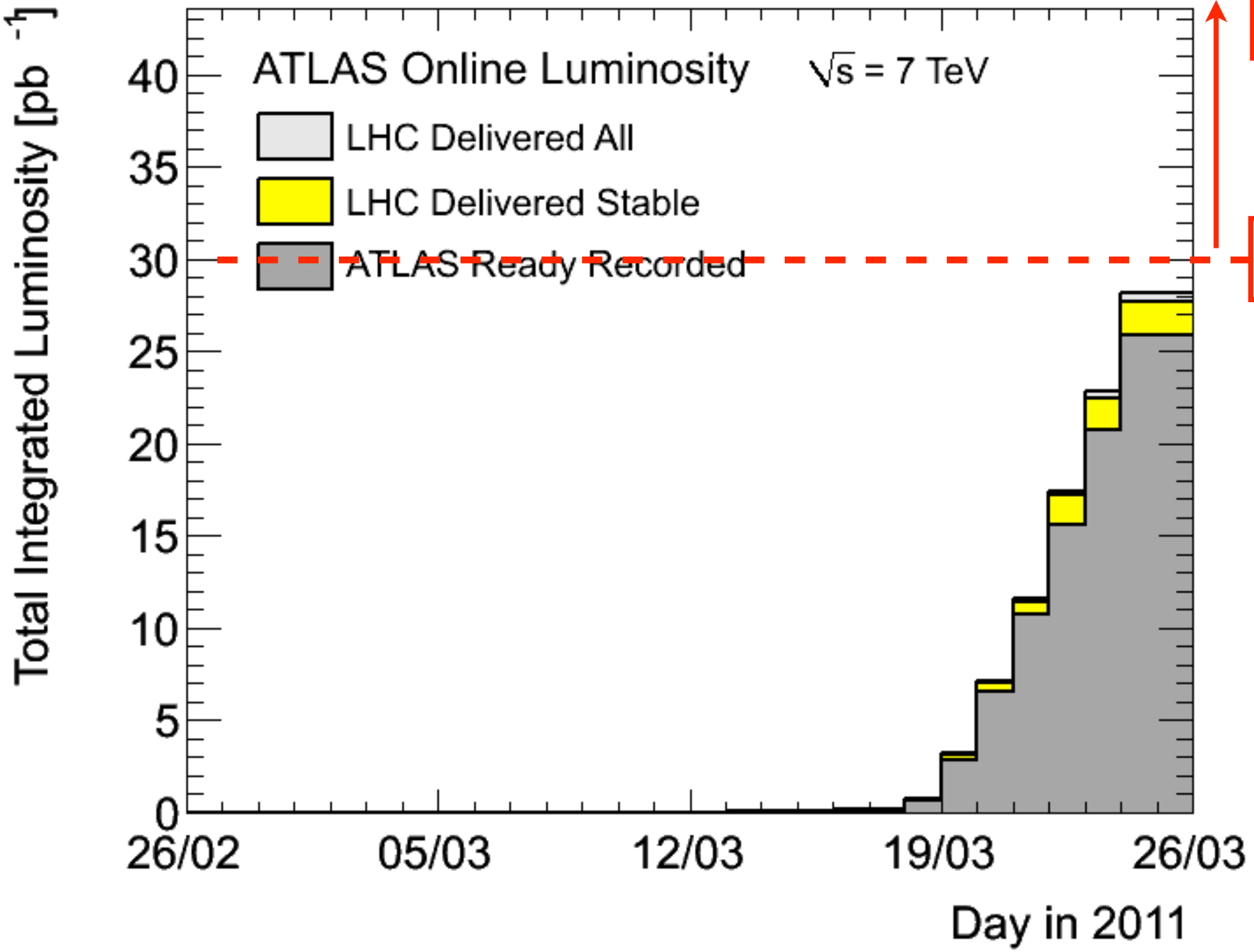
$\beta^* = 1.5$ m

$\varepsilon = 2.5$ µm

2010 record

Next step: Increase number of bunches!

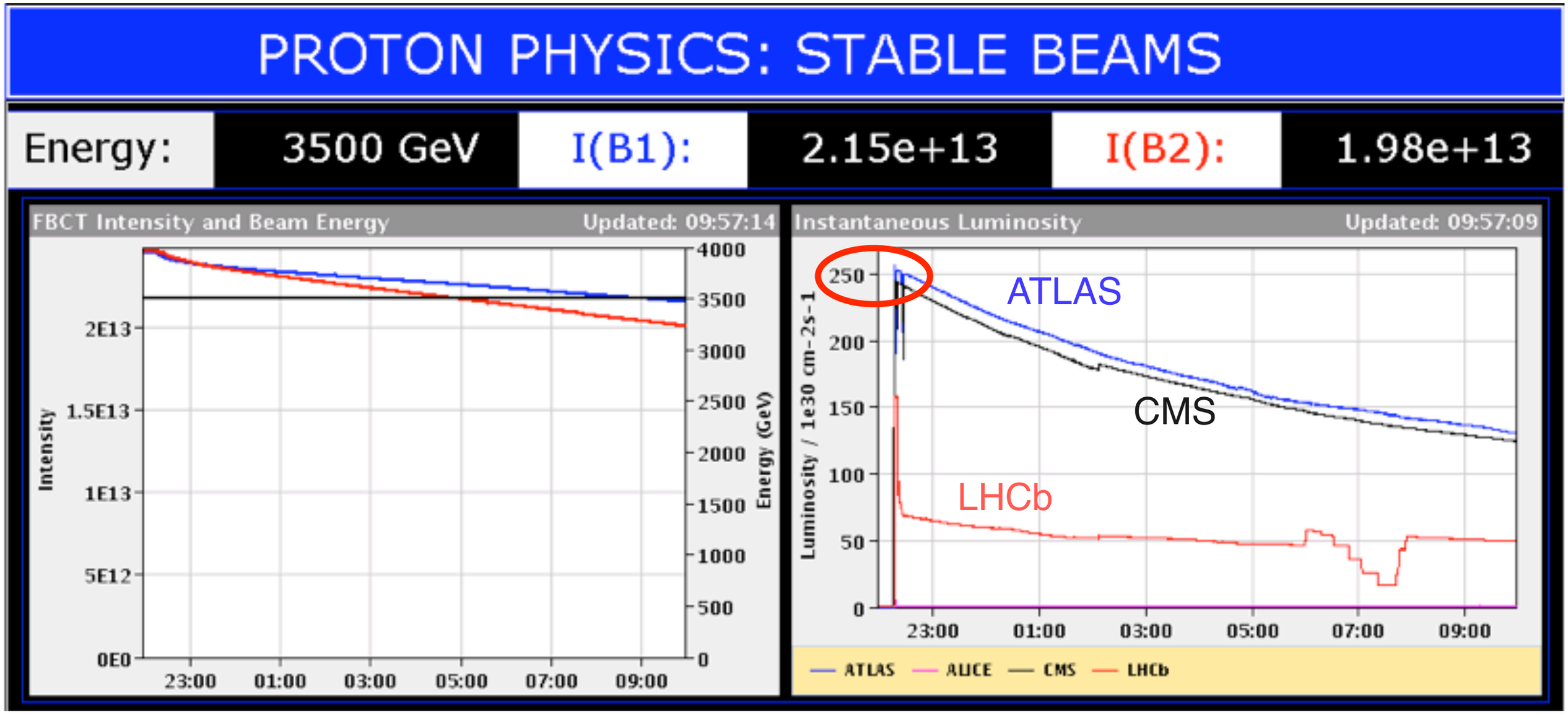
Integrated L at 3.5 + 3.5 TeV



Integrated 2011

30 pb^{-1}

Best fill so far



March 24th: ➔ ATLAS: 6.16 pb-1

➔ CMS: 6.25 pb-1

LHCb: tested luminosity leveling with offsets: ok!

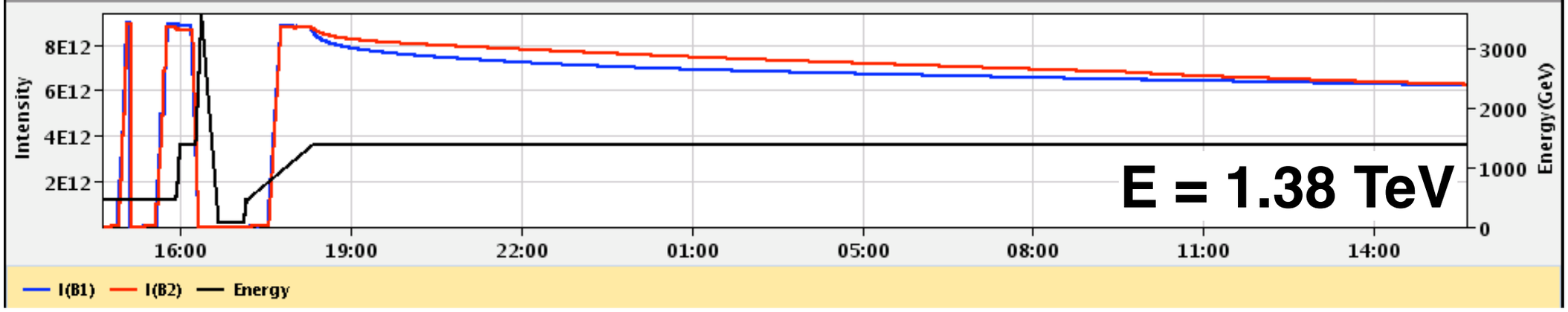
Completed yesterday: 1.38 TeV physics

27-Mar-2011 15:37:20 Fill #: 1653 Energy: 1380 GeV I(B1): 6.22e+12 I(B2): 6.27e+12

Experiment Status	ATLAS PHYSICS	ALICE PHYSICS	CMS PHYSICS	LHCb PHYSICS
Instantaneous Lumi (ub.s)^-1	0.105	0.376	1.693	2.162
BRAN Luminosity (ub.s)^-1	0.000	0.041	0.000	0.040
Fill Luminosity (nb)^-1	170.7	29.2	182.6	36.0
BKGD 1	0.005	0.326	0.060	0.131
BKGD 2	11.000	0.526	3.686	1.105
BKGD 3	0.000	4.476	0.146	0.053

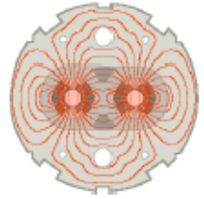
LHCb VELO Position IN Gap: 10.0 mm | STABLE BEAMS | TOTEM: STANDBY

Performance over the last 24 Hrs Updated: 15:37:15



Now:
Started first 2011 technical stop (5 days)
Followed by the scrubbing run (10 days).
Will then finalize the intensity increase strategy (150 ns, 75 ns or 50 ns?)

Conclusions



- **We have a beautiful machine in our hands!**
  - *Critical OP phases (injection, ramp, squeeze,...) under control.*
  - *Excellent BI, magnetic model, optics, aperture...*
  - *Collimation and machine protection work reliably!*
  - *Good efficiency (65% in 2010) and turnaround times.*
- **We have laid the foundation for the 2011 goal of 1fb^{-1}**
  - *Many improvements in the shutdown, fast re-commissioning.*
  - *2010 performance already exceed: $L_{peak} \sim 2.5 \times 10^{32} cm^{-2}s^{-1}$.*
  - *Expect to gain further, towards a $L_{peak} \sim 10^{33} cm^{-2}s^{-1}$.*
  - *$L_{integrated}$ between 1fb^{-1} and 3fb^{-1} seem within reach.*
- **A few very interesting months ahead of us!**
  - *Discover real intensity limits (UFOs, e-cloud, beam-beam).*
  - *Will determine the performance reach at 3.5 + 3.5 TeV.*
- **Two exciting year of operation at 3.5 TeV before long 2013 shutdown that will remove energy limits!**

Acknowledgments

Talk presented on behalf of the LHC commissioning team.

Results of the hard work of MANY people over SEVERAL years!

Material for these slides from:
M. Lamont, J. Wenninger, M. Ferro-Luzzi, S. Myers
+ plots from the experiments.