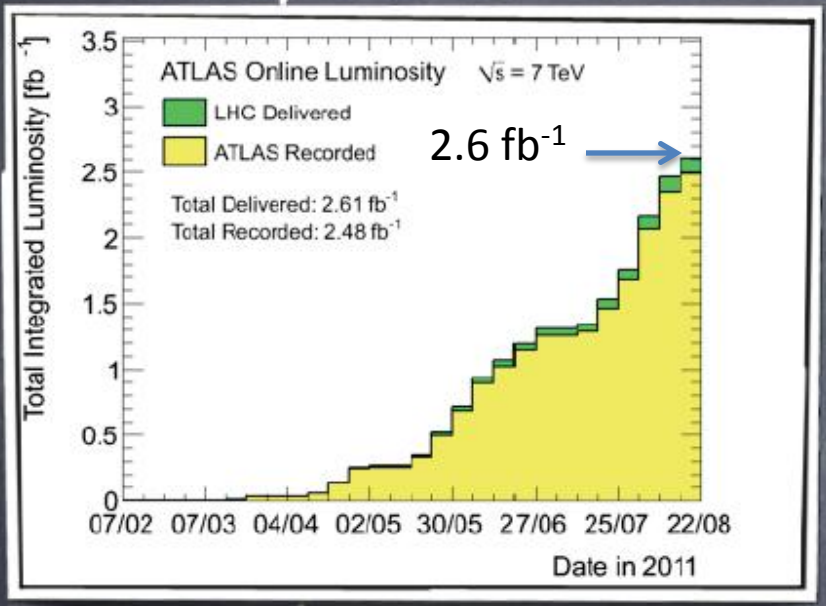
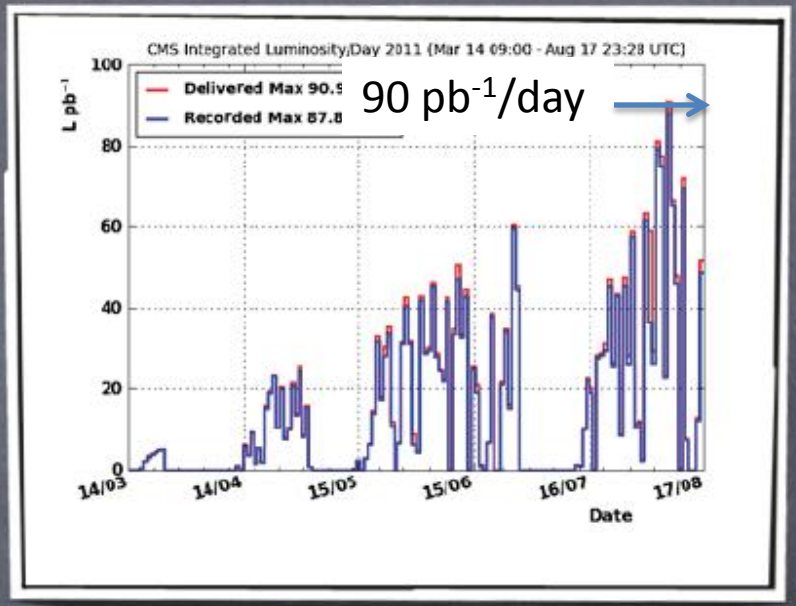
LHC Performance & Main Limitations

Mike Lamont for the LHC team

2011 - Oh What a Year

- The new thumb rule:
  ~500 pb^{-1}/week and more to come





- 50 ns bunch trains with 6-8 interactions/crossing
- The analyses presented here are based on 1-2.3 fb^{-1}/experiment

Beam from injectors

Excellent performance
Higher than nominal bunch intensity
Smaller than nominal emittance

Bunch spacing	From Booster	Np/bunch	Emittance H&V [mm.mrad]
150	Single batch	1.1×10^{11}	1.6
75	Single batch	1.2×10^{11}	2.0
50	Single batch	1.45×10^{11}	3.5
50	Double batch	1.6×10^{11}	2.0
25	Double batch	1.2×10^{11}	2.7

Best in 2011: ~1.45×10^{11}ppb,
Less than 2 microns from SPS
~2.3 microns into collision

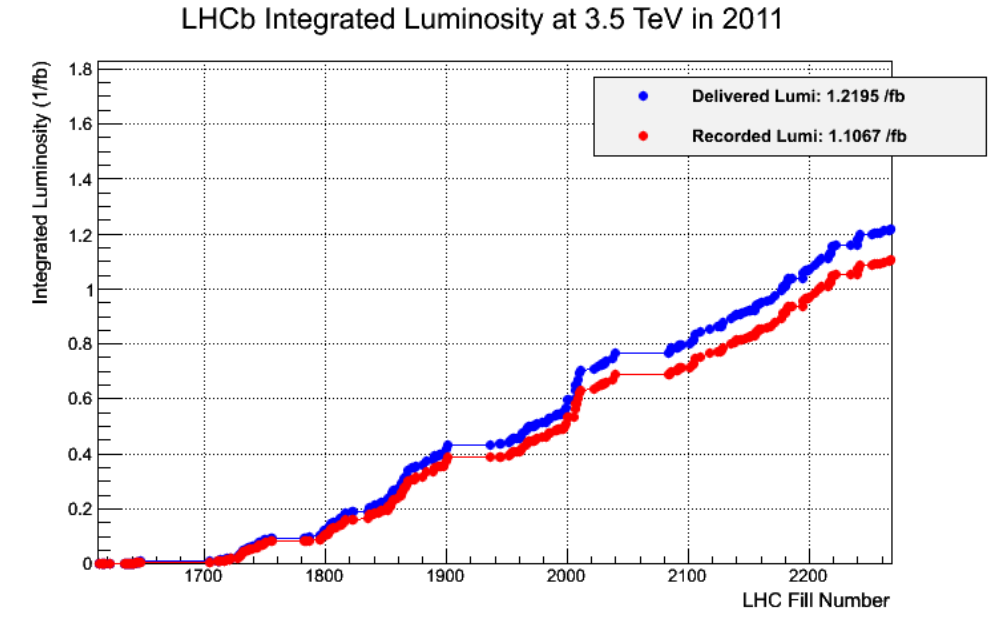
2011 parameters

Energy [TeV]	3.5
Beta* [m]	1.0, 10, 1.0, 3.0 m
Normalized emittance [microns]	**~2.3 start of fill**
Maximum bunch intensity	**1.45e11**
Number of bunches	**1380** 1331 collisions/IP1&5
Bunch spacing [ns]	50
Stored energy [MJ]	~110
Peak luminosity [$cm^{-2}s^{-1}$]	3.6e33
Beam-beam tune shift (start fill)	~0.020

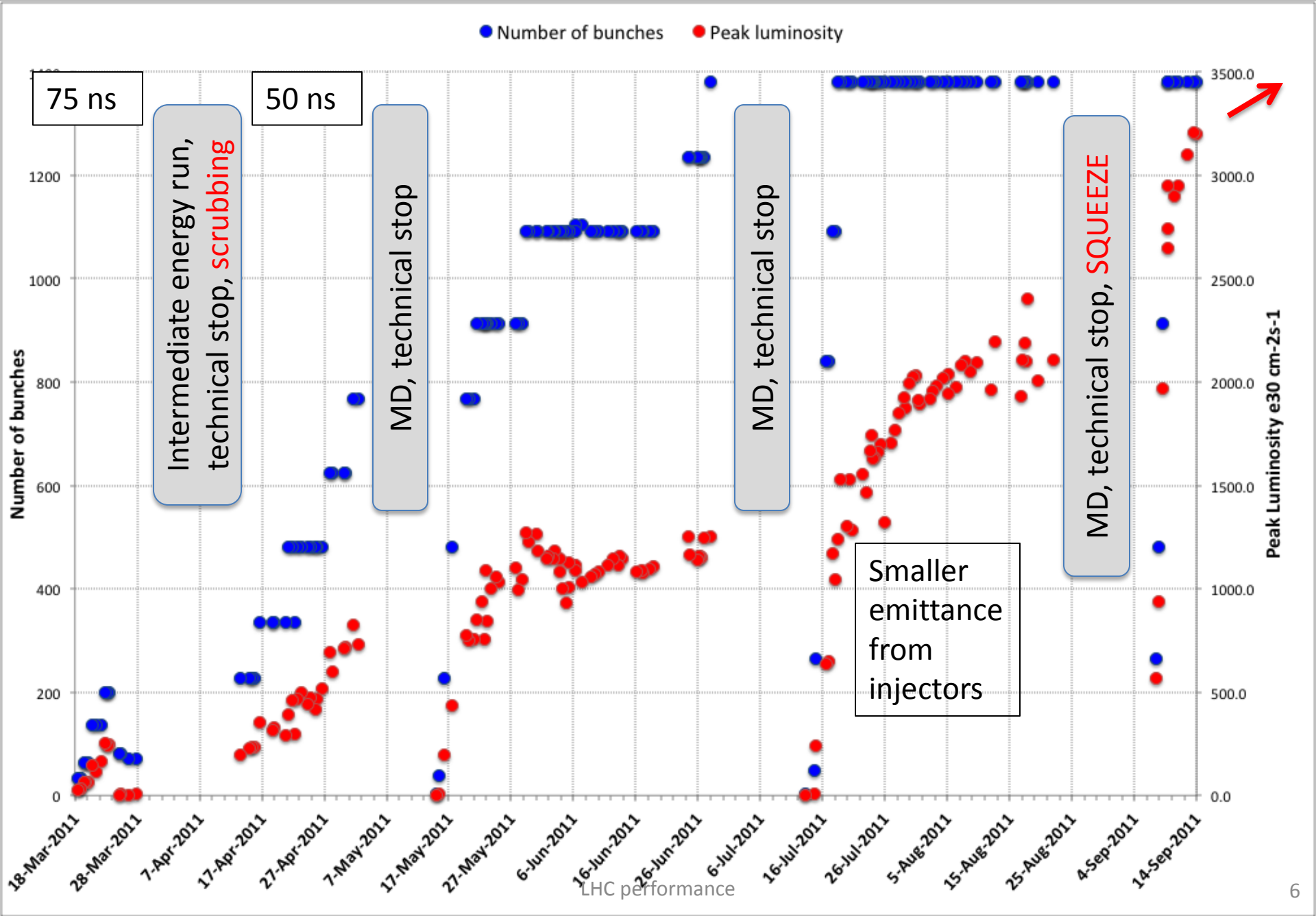
2011: (c/o Atlas & LHCb)

Peak stable luminosity	3.65 x 10^{33} $cm^{-2}s^{-1}$
Max. luminosity in one fill	122 pb^{-1}
Max. luminosity delivered in 7 days	584 pb^{-1}
Longest time in stable beams	26.0 hours
Longest time in stable beams for 7 days	107 hours (64%)
Fastest turnaround	2 hours 7 minutes

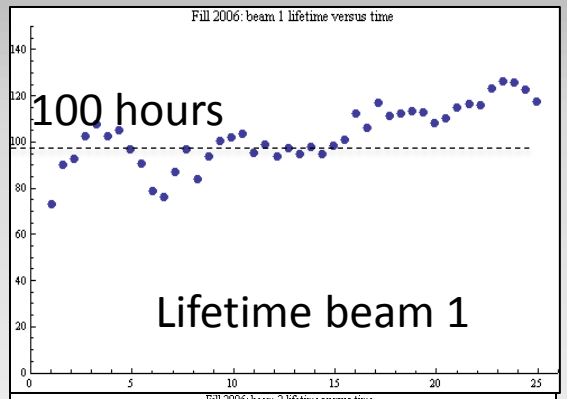
36% of design luminosity:
- half design energy
- nominal bunch intensity++
- ~half nominal emittance
- beta* = 1.0 m (design 0.55 m)
- half nominal number of bunches

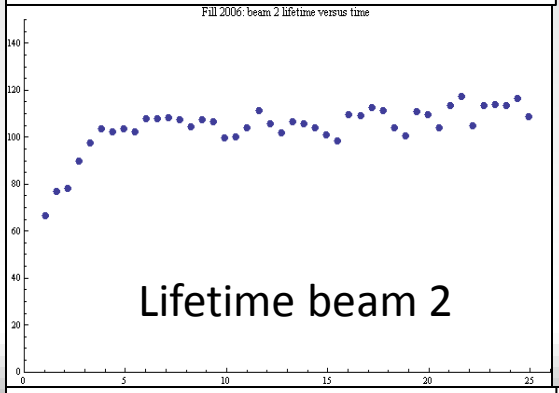


2011

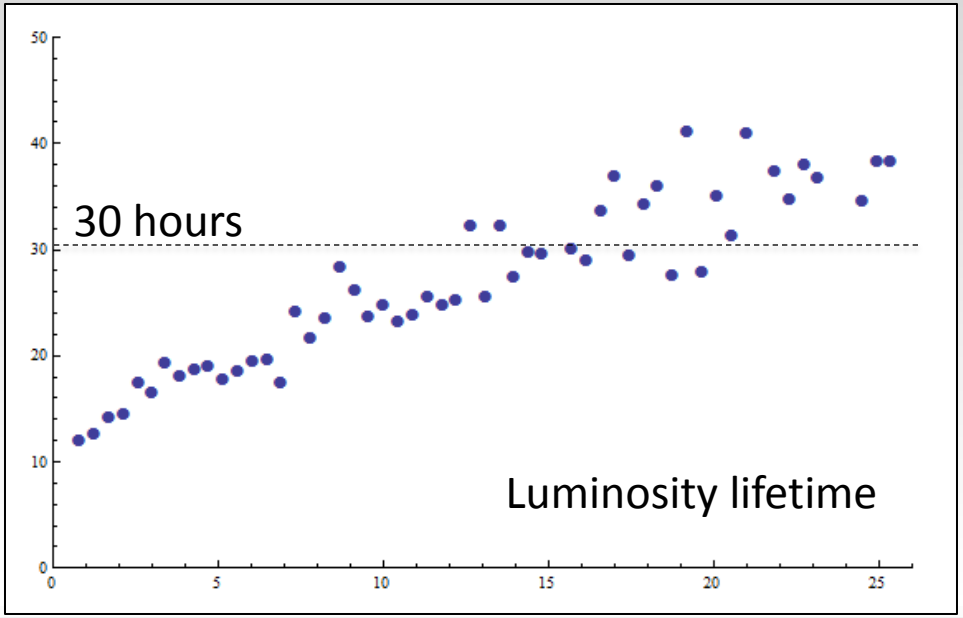

Number of bunches
Peak luminosity
75 ns
50 ns
Intermediate energy run, technical stop, scrubbing
MD, technical stop
MD, technical stop
MD, technical stop, SQUEEZE
Smaller emittance from injectors
Number of bunches
Peak Luminosity e30 cm-2s-1
0
200
400
600
800
1000
1200
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
18-Mar-2011
28-Mar-2011
7-Apr-2011
17-Apr-2011
27-Apr-2011
7-May-2011
17-May-2011
27-May-2011
6-Jun-2011
16-Jun-2011
26-Jun-2011
6-Jul-2011
16-Jul-2011
26-Jul-2011
5-Aug-2011
15-Aug-2011
25-Aug-2011
4-Sep-2011
14-Sep-2011

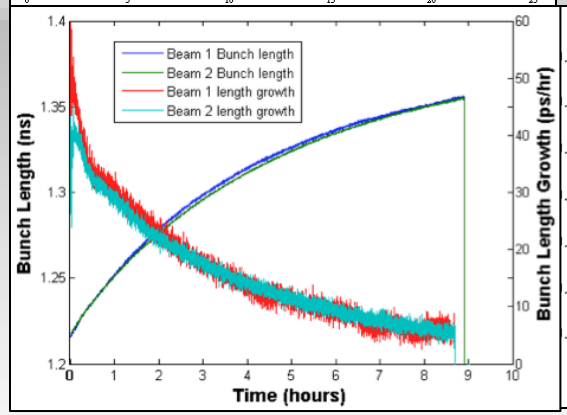
Fill 2006: Luminosity lifetime

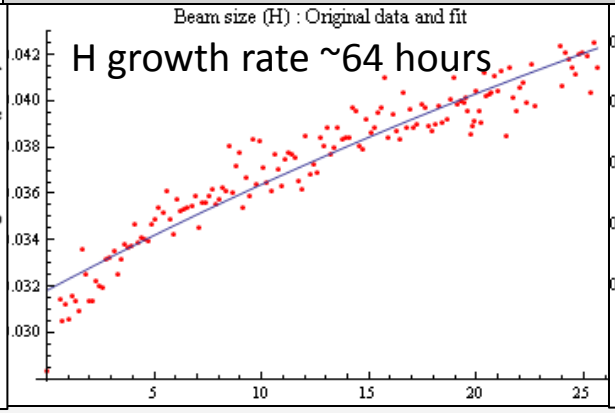


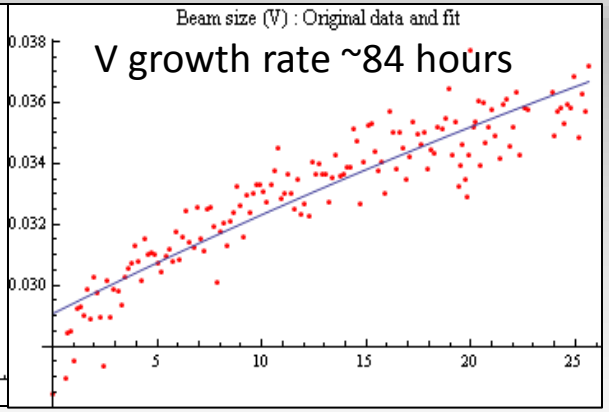


A “typical” fill that lasted 26 hours and delivered 100 pb^{-1}

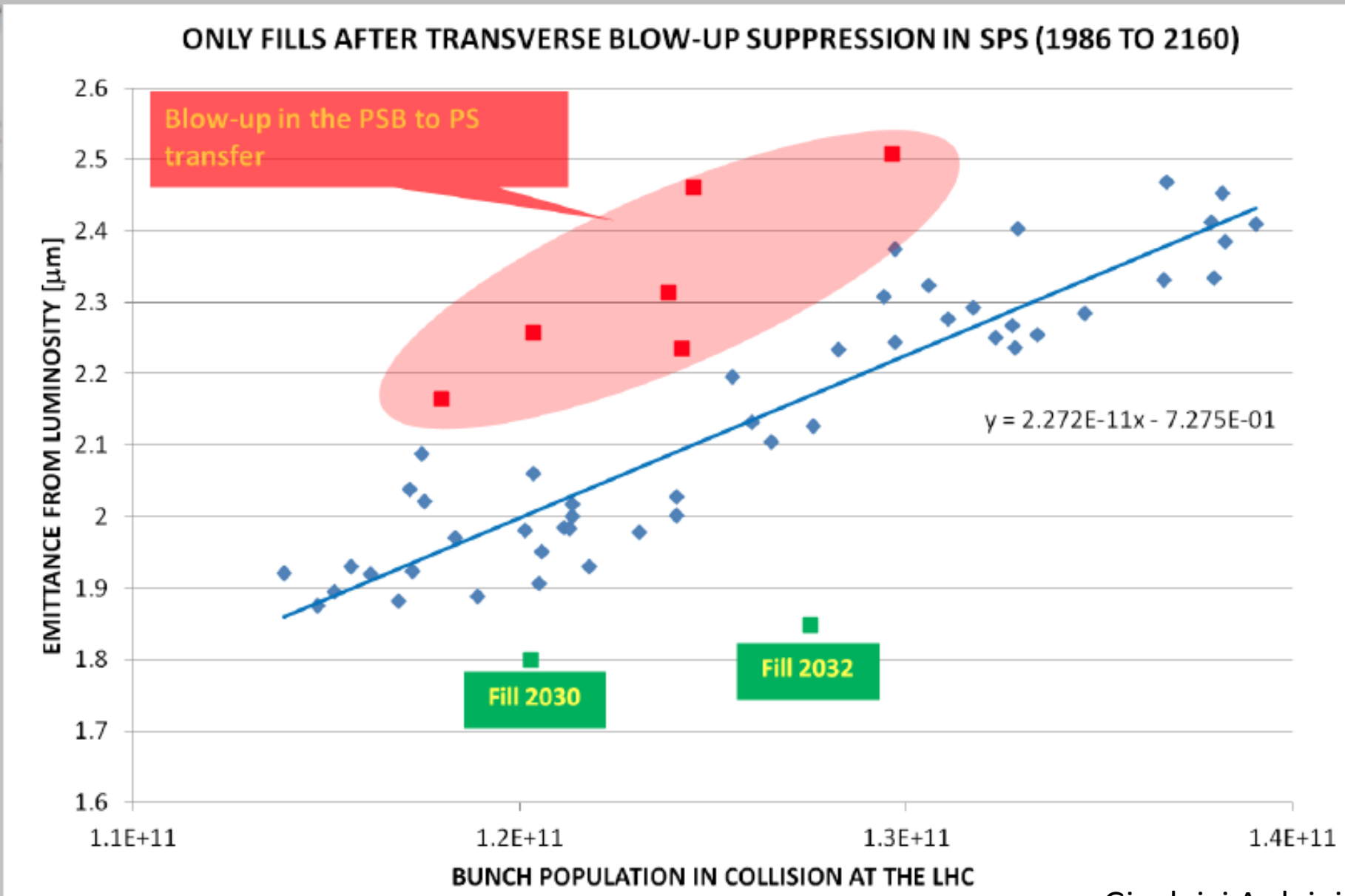








Emittance into physics



Gianluigi Arduini

Summing up

- Bunch current
  - instabilities under control via Landau damping and transverse feedback
  - Beam-beam – not an issue with present configuration
- Number of bunches
  - Total energy – excellent performance of machine protection and collimation
  - Issues include: vacuum, heating, UFOs, SEEs
- Bunch spacing
  - Effective scrubbing for 50 ns, encouraging for 25 ns
- Beta*
  - Aperture close to design, collimation (stability, efficiency)
- Beam size from injectors makes life a lot easier

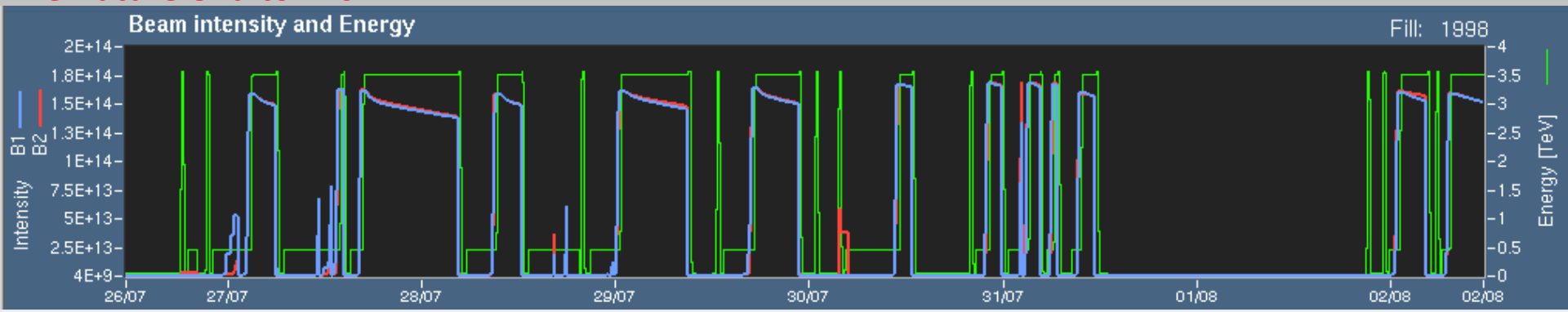
In general

- Excellent single beam lifetime – vacuum
- Linear optics: remarkably close to model, beating good and corrected to excellent
- At injection dynamic aperture greater than aperture defined by collimators
  - Excellent field quality, correction of non-linearities
  - Low tune modulation, low power converter ripple
- Low RF noise

Beam-beam

- Can collide well over nominal bunch intensity with smaller that nominal emittances
- Head-on: no problem up to ~0.0075, ~0.02 total tune shift with offset collisions in LHCb and Alice
- Long-range:
  - Low diffusion from < 5.7 sigma (if we do have a diffusive aperture it's greater than this)
  - However: have 50 ns – half nominal number of long range encounters, not fully squeezed, low emittances

Premature end to fills



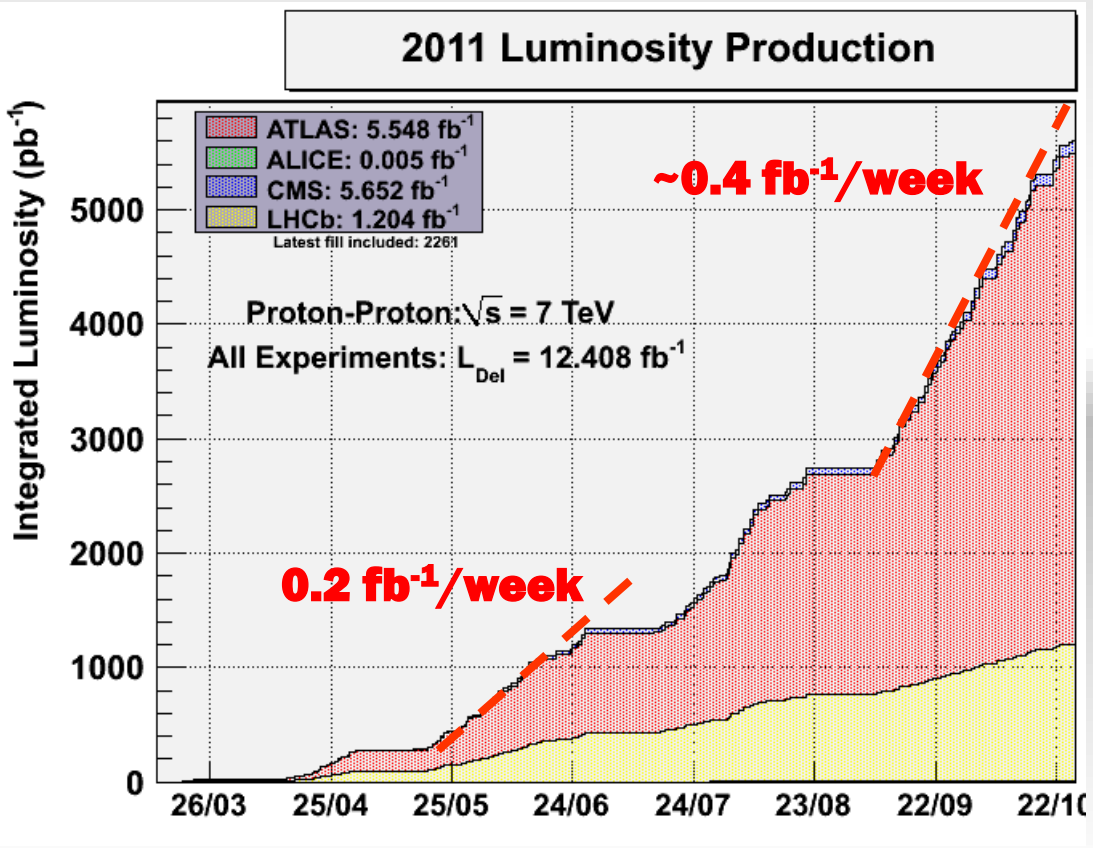
Peak and integrated potential is excellent

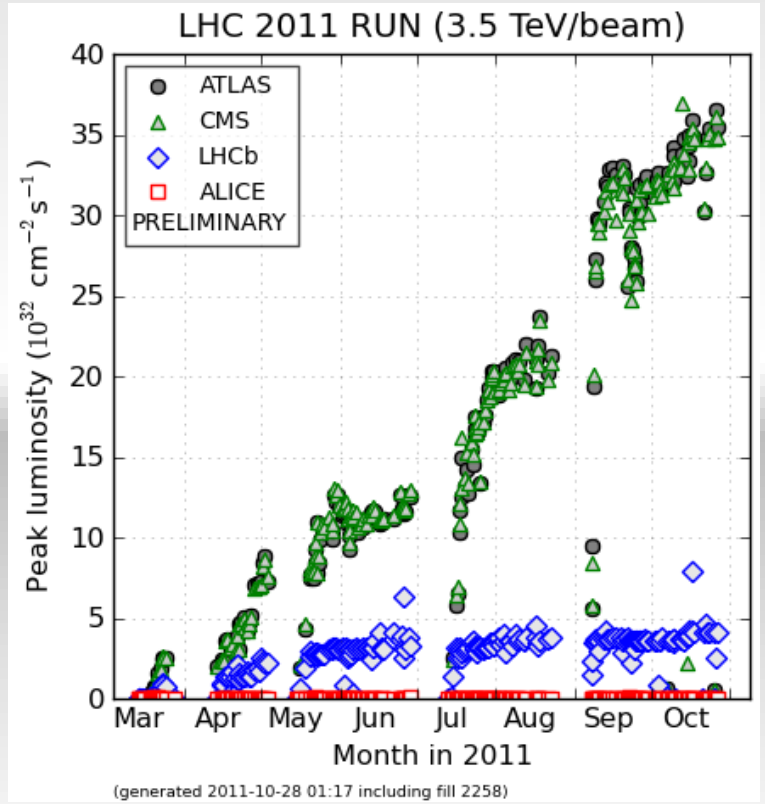
AVAILABILITY - EFFICIENCY

Integrated Luminosity 2011

- ATLAS/CMS > 5.5 fb^{-1}
- LHCb 1.2 fb^{-1}
- ALICE ≈ 5 pb^{-1}

Do not transform the gain in **peak** luminosity into gain in **integrated** luminosity

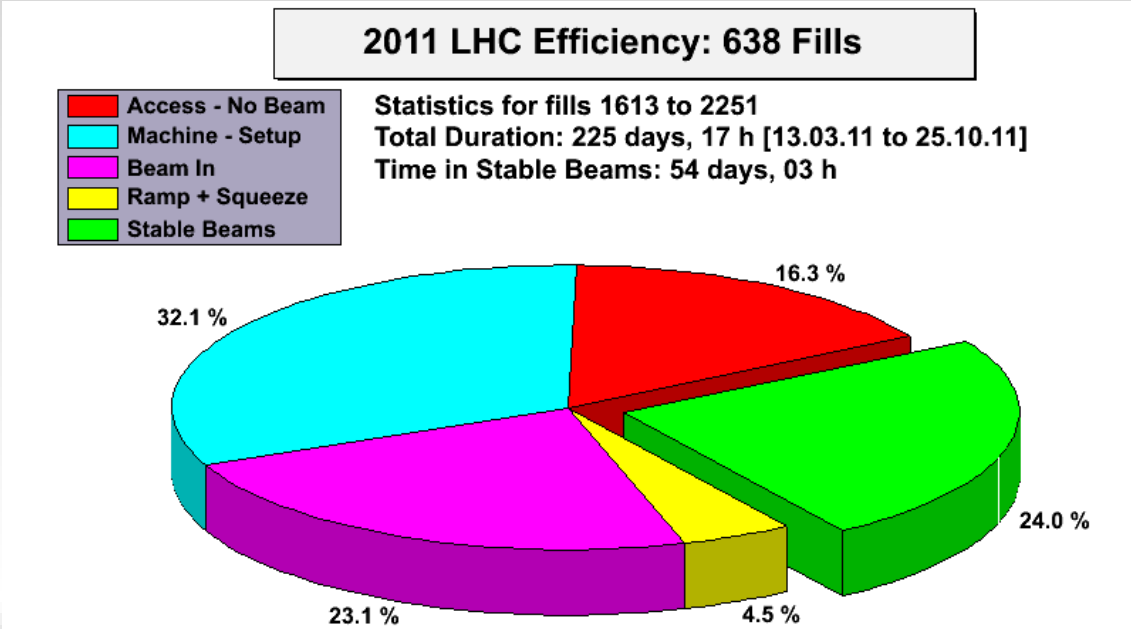




Efficiency

- **30% efficiency** for stable beams during **180 days for physics** (54 days in stable beams)

- Other scheduled periods:
  - 18 days technical stops
  - 10 days scrubbing run
  - ~17 days of MD

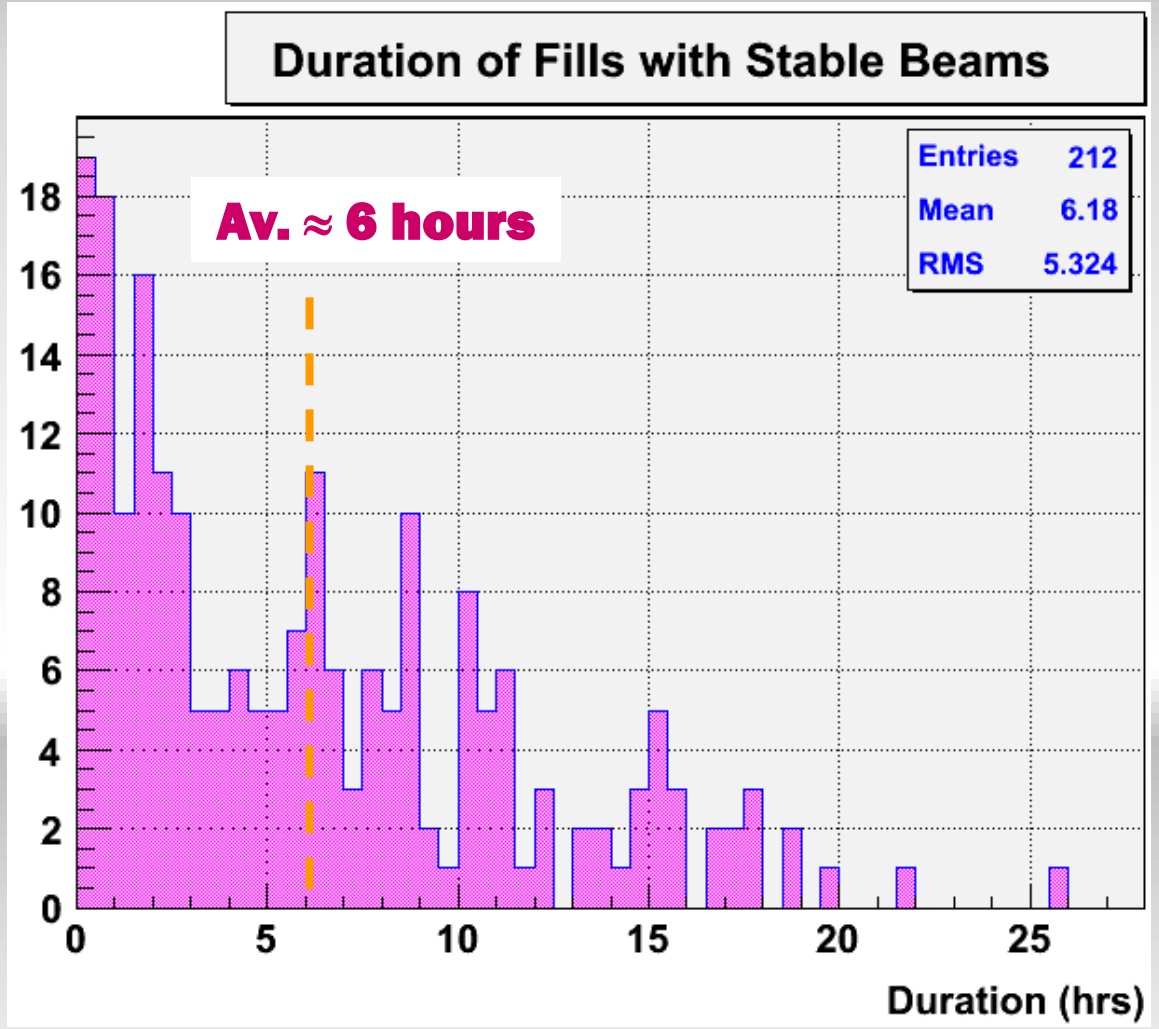


*Lost ~ **12** days due to cryogenics issues (frequently knock on from another issue, like electric network glitch) between July and September*

Fill Length

- Calculated optimum fill length ≈ 12-15 hours, but beams frequently dumped earlier
- Ideally, could produce up to ≈ 800 pb^{-1}/week

  record is 580 pb^{-1}



Premature dumps for a number of reasons…

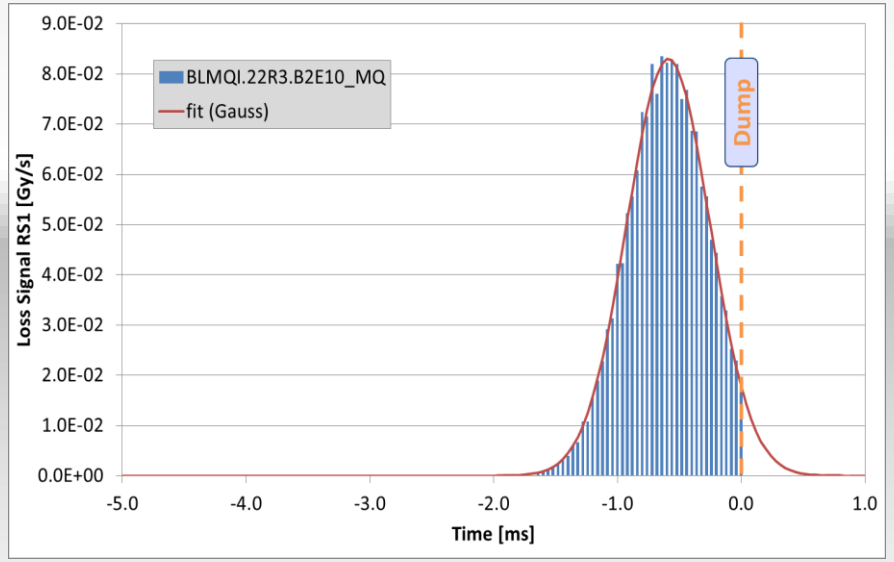
Beam Aborts due to UFOs

- Fast and localized losses all around the ring believed to be caused by macro particles interacting with the beam
- 'UFO': Unidentified Falling Objects

- Most UFOs far below dump threshold
- Number of UFOs is decreasing with time

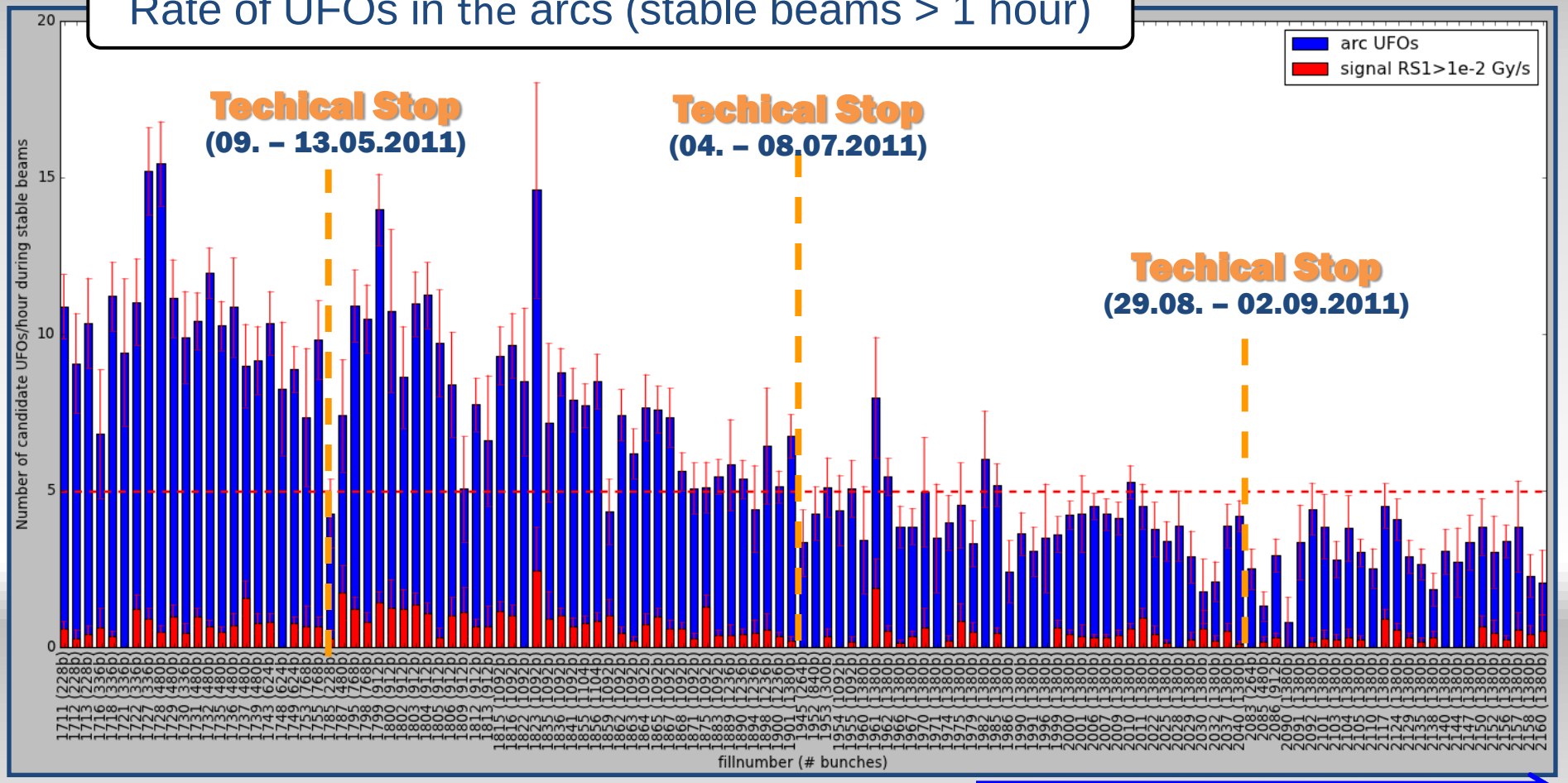
- Worry for 7 TeV: lower magnet quench thresholds and higher deposited energy

UFO Beam Aborts	35
of which:	
2010	17
2011	18
Around injection kickers (MKI)	13
Experiments	6
At 450 GeV	1



Monitoring Below-Threshold UFOs

Rate of UFOs in the arcs (stable beams > 1 hour)



UFO Rate ~ slowly decreasing to ~ 3-4 / hour

Single Event Effects

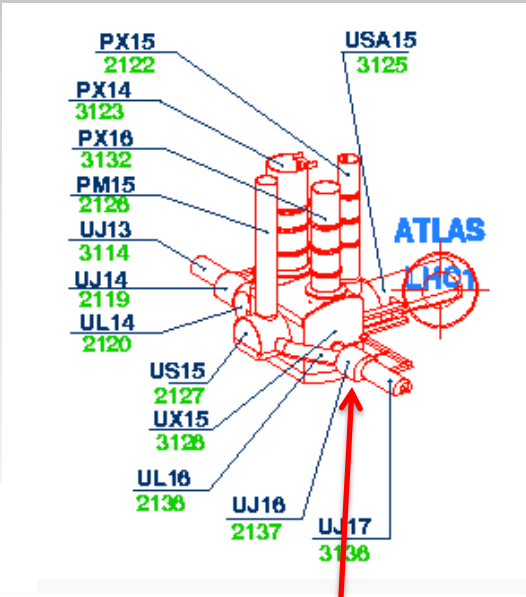
UJs	shielded areas HEH (cm-2/w26)	HEH (cm-2/2011)	tun HEH (cm-2/w26)
14 (13, tun)	3.3E+06	5.7E+07	9.8E+09
16 (17, tun)	2.3E+06	4.0E+07	7.7E+08
22	N/A	N/A	5.2E+07
23	<1.0E+6	<1.0E+6	8.6E+06
32	N/A	N/A	1.0E+6
33	<1.0E+6	<1.0E+6	<1.0E+6
56	<1.0E+6	9.3E+06	8.8E+08
76	<1.0E+6	<1.0E+6	8.8E+08
87	<1.0E+6	1.1E+06	1.5E+08
88	N/A	N/A	1.5E+08

Luminosity Dominant

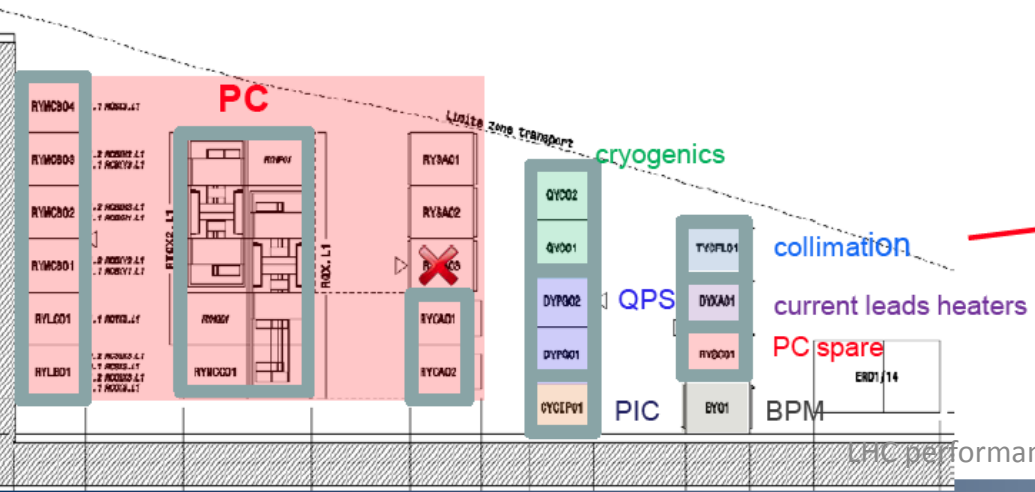
Intensity Dominant

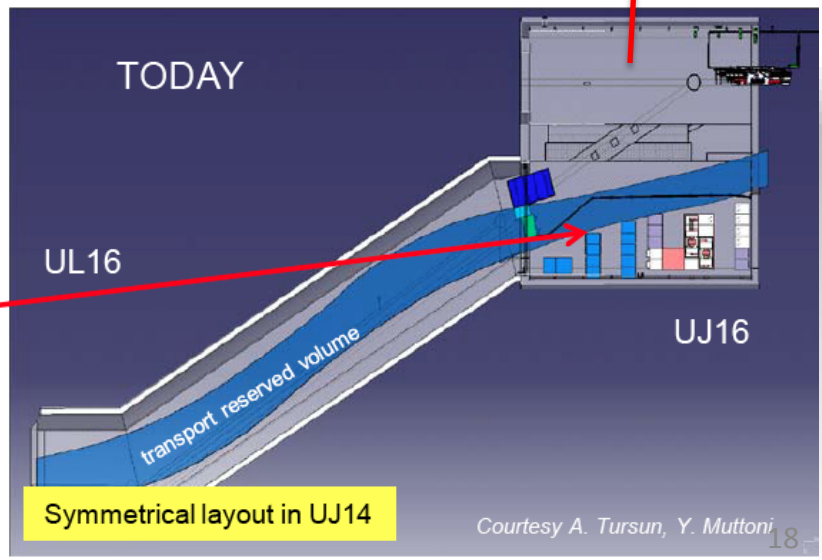
Luminosity Dominant

Intensity Dominant



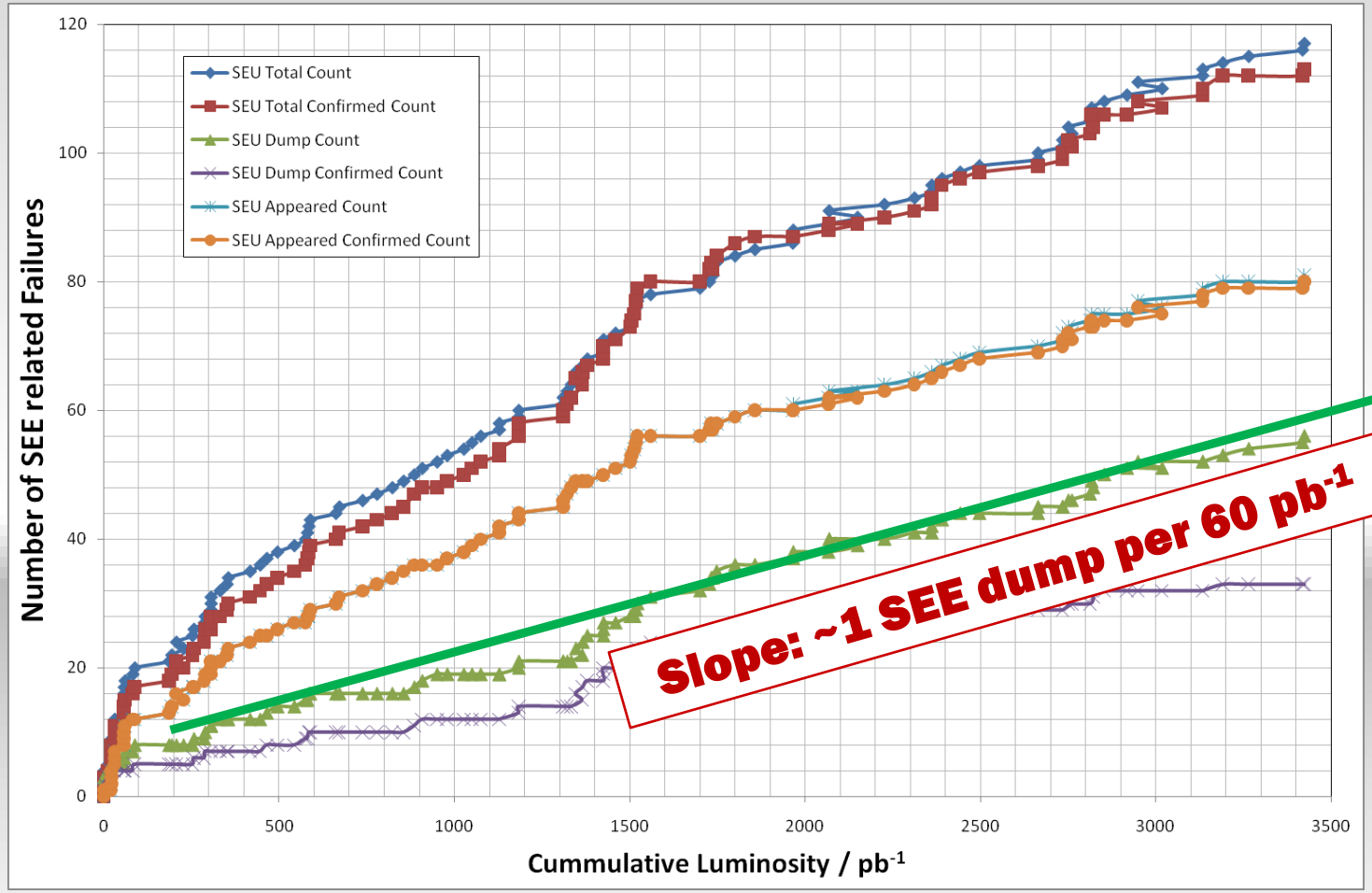
Major campaign ongoing: shield and relocate





Radiation to Electronics (R2E)

With the increasing luminosity: tunnel electronics starts to suffer from the (expected) SEE (Single Event Effects)



R2E

- 2011 operation:
  - Most critical systems: **Quench Protection Systems (QPS) and cry**ogenics
  - **Mitigation measures**: more robust firmware (QPS), special reset procedures (cryo), signal filtering (RF) etc.
- 2011/12 Christmas Break (and Technical Stops):
  - **Relocation**
  - **Additional shielding**
  - **The QPS equipment will remain exposed in 2012** despite firmware and electronics improvements – in particular in the area at the entrance of the arcs in Pt1 and Pt5

Vacuum

- **Beam scrubbing and vacuum conditioning** is observed during the year

- Pressure in MKI areas is limiting performances during 25 ns MD but not during 50 ns operation
- Origin is electron cloud at 25 ns
- **Solenoids at intermodule** could be added during Xmas break (will **not solve** the pressure increase inside MKI itself)

- **TDI** must be parked at **55 mm** to keep pressure below 10^{-8} mbar

- **ALICE** background is dominated by pressure in LSS2 between D1 and D2.
- The origin is **not identified**
- More **solenoids** and **upgrade** of pumping is foreseen during Xmas break

- **CMS** background is dominated from time to time by pressure level at 18 m, right side
- The origin is **not identified**
- **Re-commissioning** of the station is foreseen at Xmas break to multiply the available pumping speed by a factor 2

- **Pressure spikes** at D1 in LSS2 and LSS8 have their **origin in TCTVB-TCLI/TCDD areas**
- Pumping speed will be upgrade during Xmas break in LSS2

- **IT** have significant quantities of gas accumulated in the cold system
- **Propose to evacuate this gas** during Xmas while the cryogenic system will be warmed up

Vincent Baglin

X-rays the 7-11-2011, DCUM 3259.3524

Left side

Side view (xray from corridor to QRL)

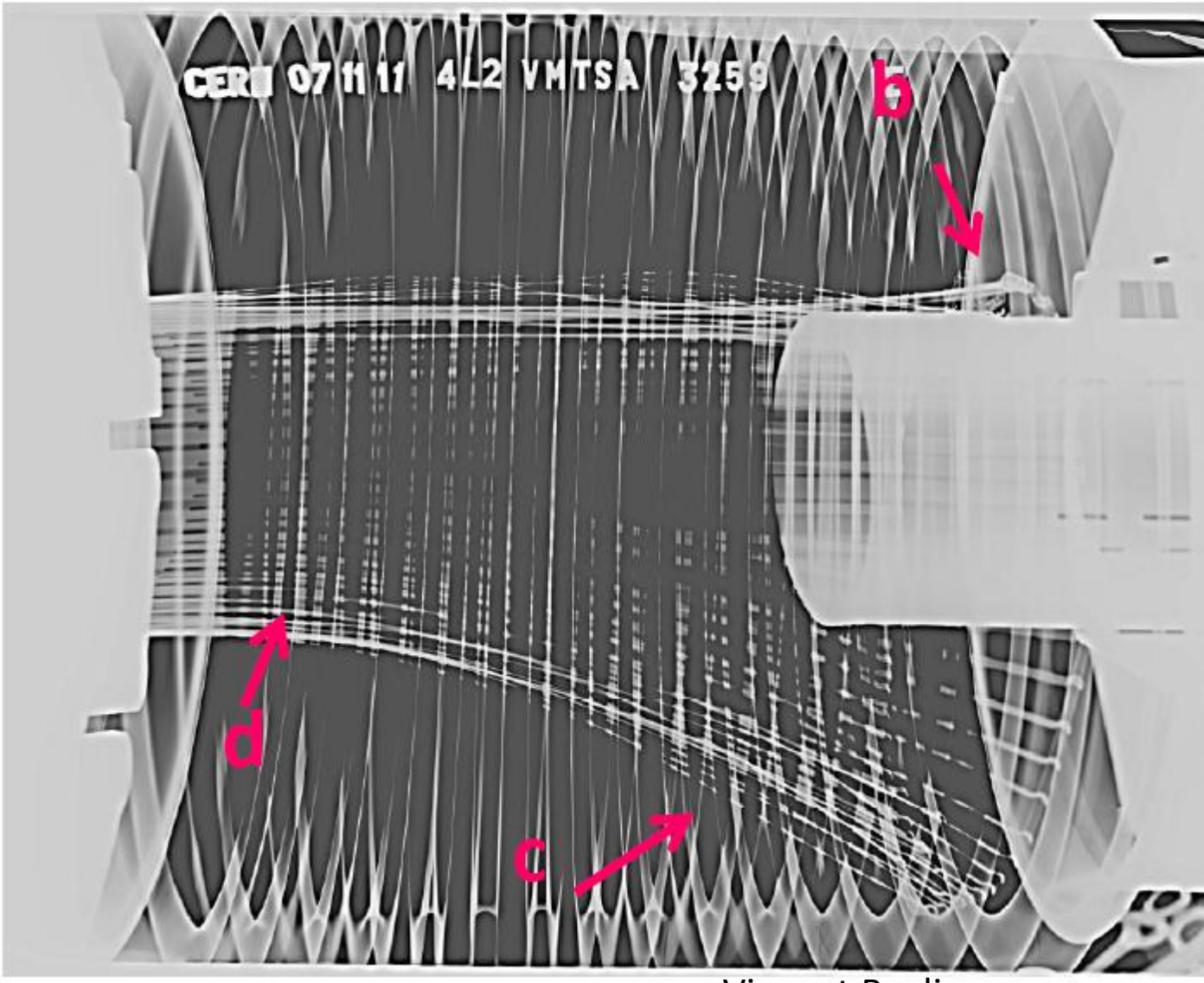
b) Metallic noise due to loose spring when hitting vacuum chamber

c) RF fingers falling due to broken spring

d) aperture reduced ?

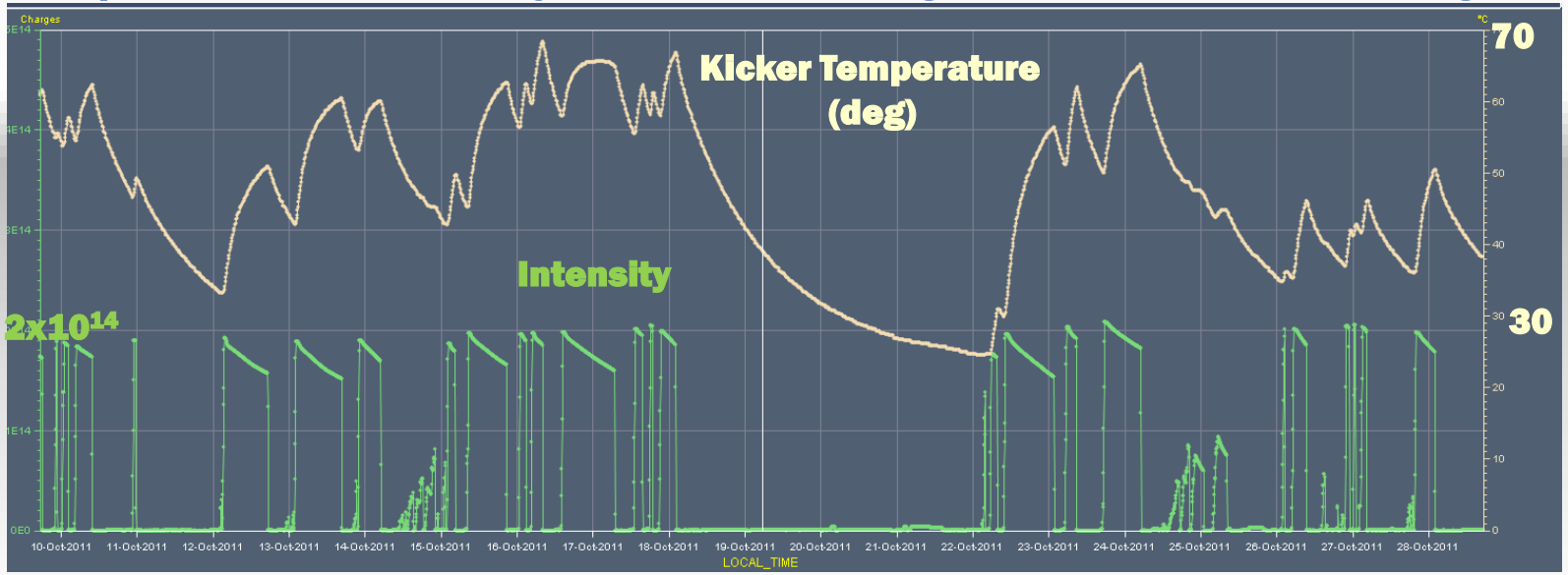
Non Conform

Spring was broken between May and November 2011

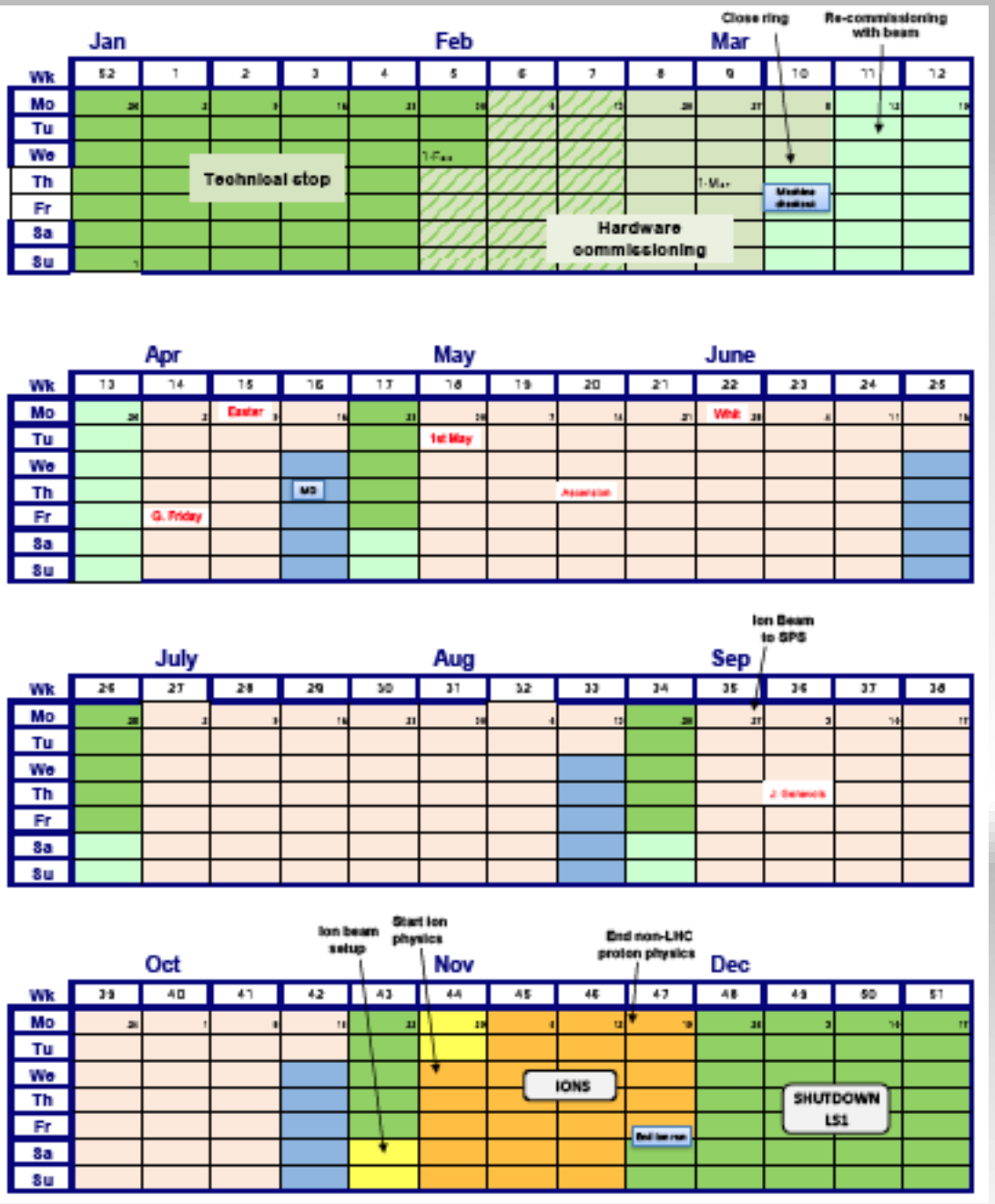


Beam Induced Heating

- High intensity bunches have led to heating of:
  - Collimators and absorbers
  - Injection kickers
  - Beam screens
- So far the situation is under control. Possible improvement by increasing the bunch length



2012 - draft



	Days
Commissioning	23
MD	22
Technical stops	20
Recovery & ramp-up	16
Initial ramp-up	16
Scrubbing for 25 ns	5
Proton running	~124
Special runs	~8
Ion setup	4
Ion run	24

Performance comparison

Bunch spacing	No. of bunches	Energy [TeV]	Beta* [m]	Normalized emittance [micron]	Protons per bunch [e11]	Peak lumi [cm-2s-1]	Peak mean mu
50 ns	1380	3.5	1.0	2.0	1.3	3.37	16.4
50 ns	1380	3.5	1.0	2.3	1.6	4.49	21.8
50 ns	1380	4.0	0.7	2.0	1.3	4.9	24.1
50 ns	1380	4.0	0.7	2.3	1.6	6.7	32.4
25 ns	2760	3.5	1.0	2.8	1.2	4.1	10.0
25 ns	2760	4.0	1.0	2.8	1.2	4.6	11.2

125 days at reasonable efficiency – might hope to push towards 10 fb^{-1}

Conclusions

- Excellent performance:
  - Beam from injectors
  - Exploiting well behaved beam dynamics – lifetimes, beam-beam, stability
  - Exploiting good system performance (collimation, instrumentation, machine protection…)
  - Good operational robustness (turn around, ramp, squeeze, collide) and reproducibility
- Availability OK despite a number of issues related to operations with high intensity beams
- Should be able squeeze out a little more next year