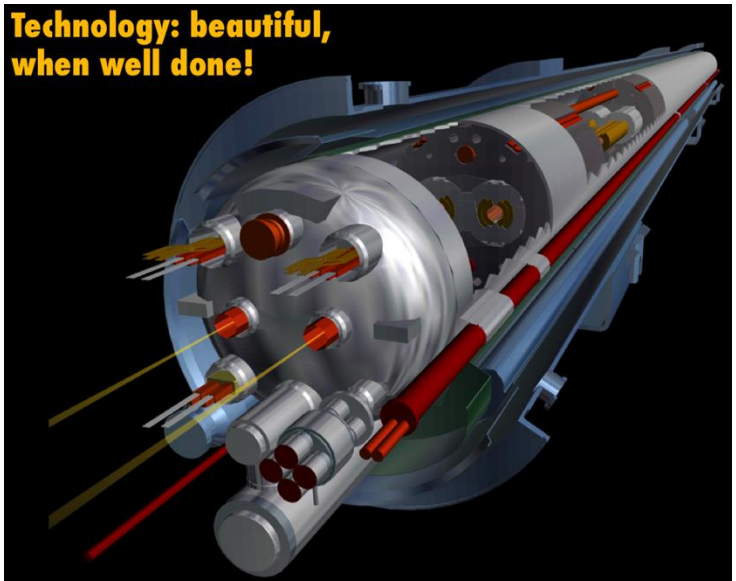
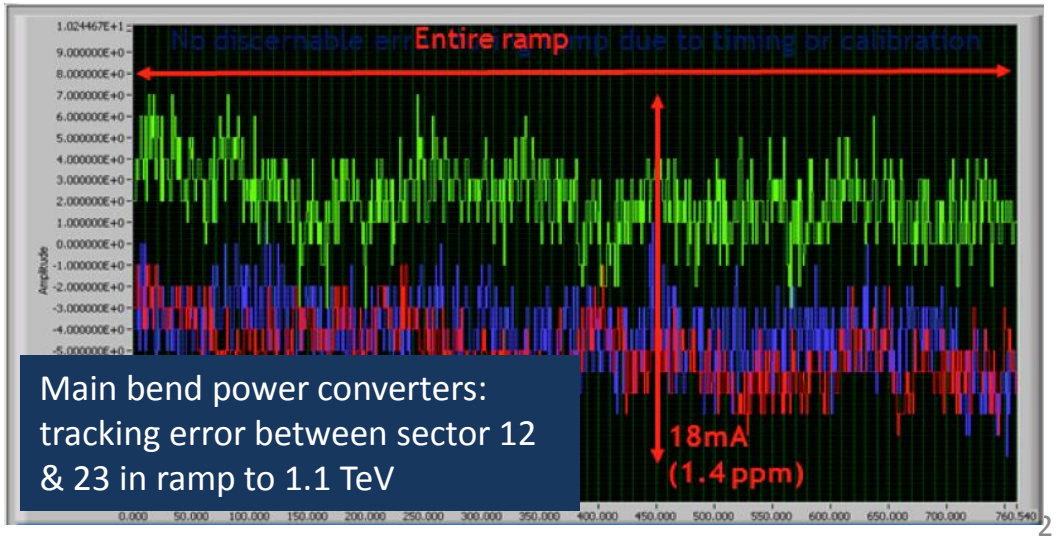
LHC Accelerator Performance

Mike Lamont
for the LHC team

Exit Run 1(2010 – 2012)

- Foundations well proven at 4 TeV
  - Magnets, vacuum, cryogenics, RF, powering, instrumentation, collimation, beam dumps etc.
- Huge amount of experience gained
  - Operations, optics, collimation…
- Healthy respect for machine protection





2013 - 2015

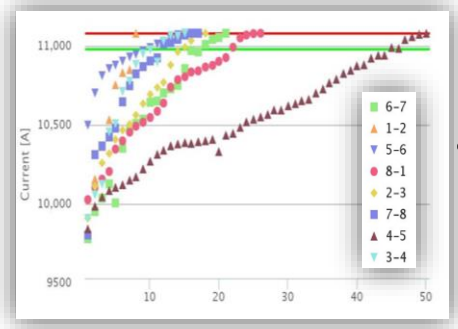
April ‘13 to Sep. ‘14

5th April

3rd June
First Stable Beams

28th October
Physics with record number of bunches
Peak luminosity 5 x 10^{33} $cm^{-2}s^{-1}$

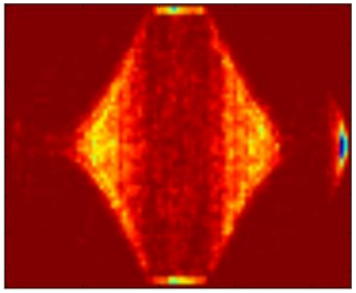
13-14	Aug 14-Apr 15	2015



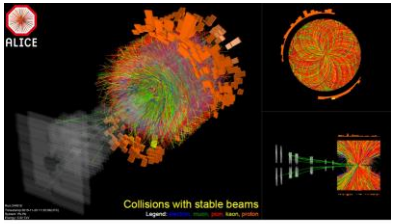
Dipole training campaign

10th April
Beam at 6.5 TeV

Struggle



IONS

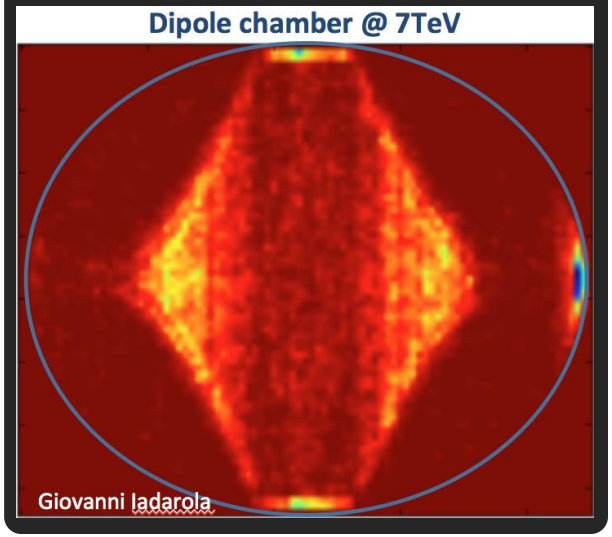


Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

2015: re-commissioning year, relaxed parameters, some issues…

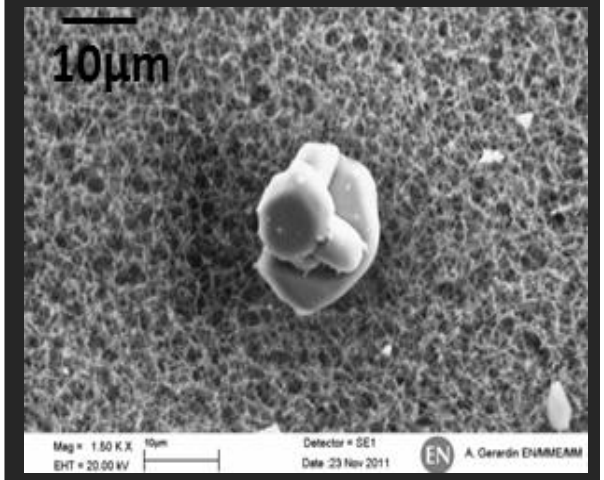
Electron cloud

- Anticipated
- Significant head load to cryogenics



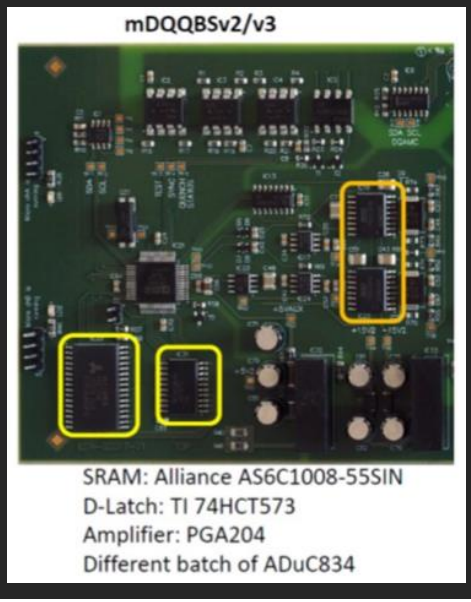
UFOs

- 8 UFO dumps within 2 weeks (Sep 20 to Oct 5)
- Conditioning observed



Radiation to electronics

- Mitigation measures (shielding, relocation…)
- Non-rad hard components used in LS1 upgrade



Exit 2015 with reasonable performance & hope for production in 2016

LHC 2016

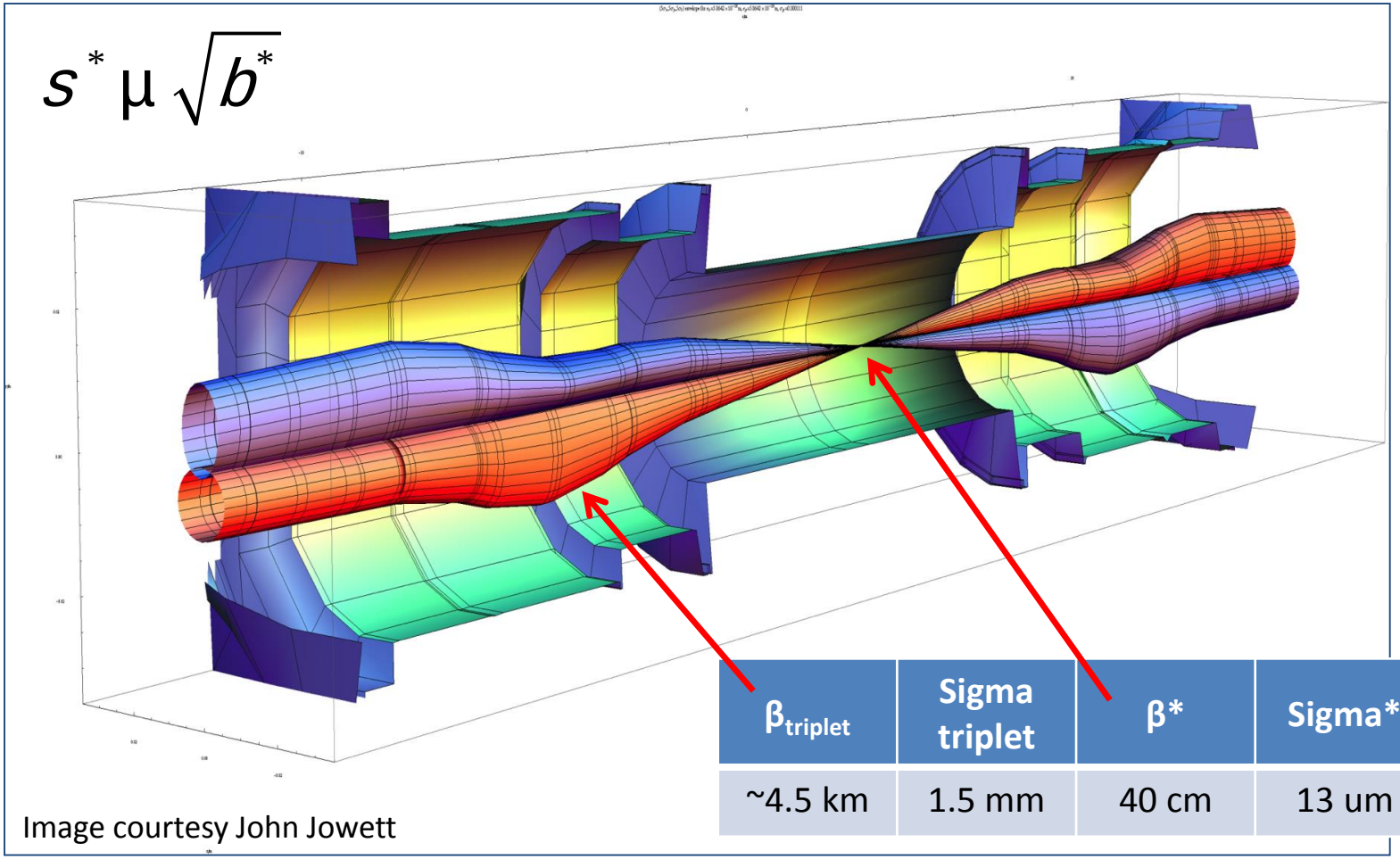
Choose a relatively bold set of operational parameters based on past experience

- Energy: 6.5 TeV
- 25 ns beam - nominal bunch population (~1.2e11)
- Low emittance from injectors – variations possible
- Squeeze harder in ATLAS and CMS
  - beta* = 40 cm
  - cf. 80 cm in 2015, 55 cm design

$$\mathcal{L} \propto \frac{1}{\beta^*}$$

Squeeze in ATLAS/CMS

- Lower beta* implies larger beams in the triplet magnets
- Larger beams implies a larger crossing angle
- Aperture concerns dictate caution – experience counts

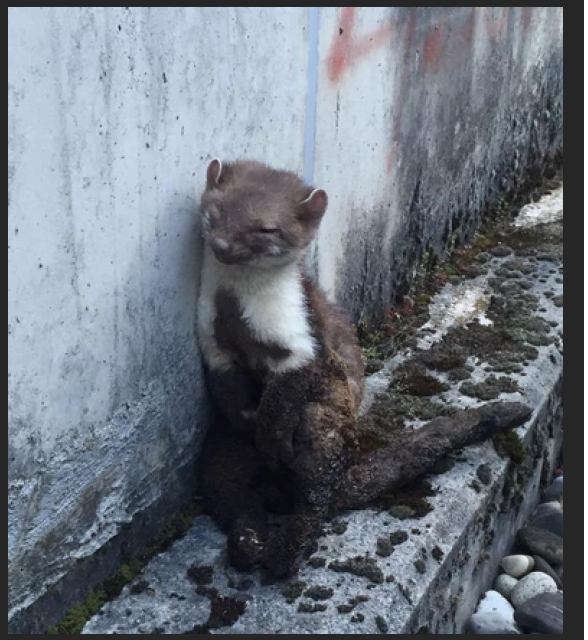


$\beta_{triplet}$	Sigma triplet	β*	Sigma*
~4.5 km	1.5 mm	40 cm	13 um

Image courtesy John Jowett

Overcome a few problems

WEASEL

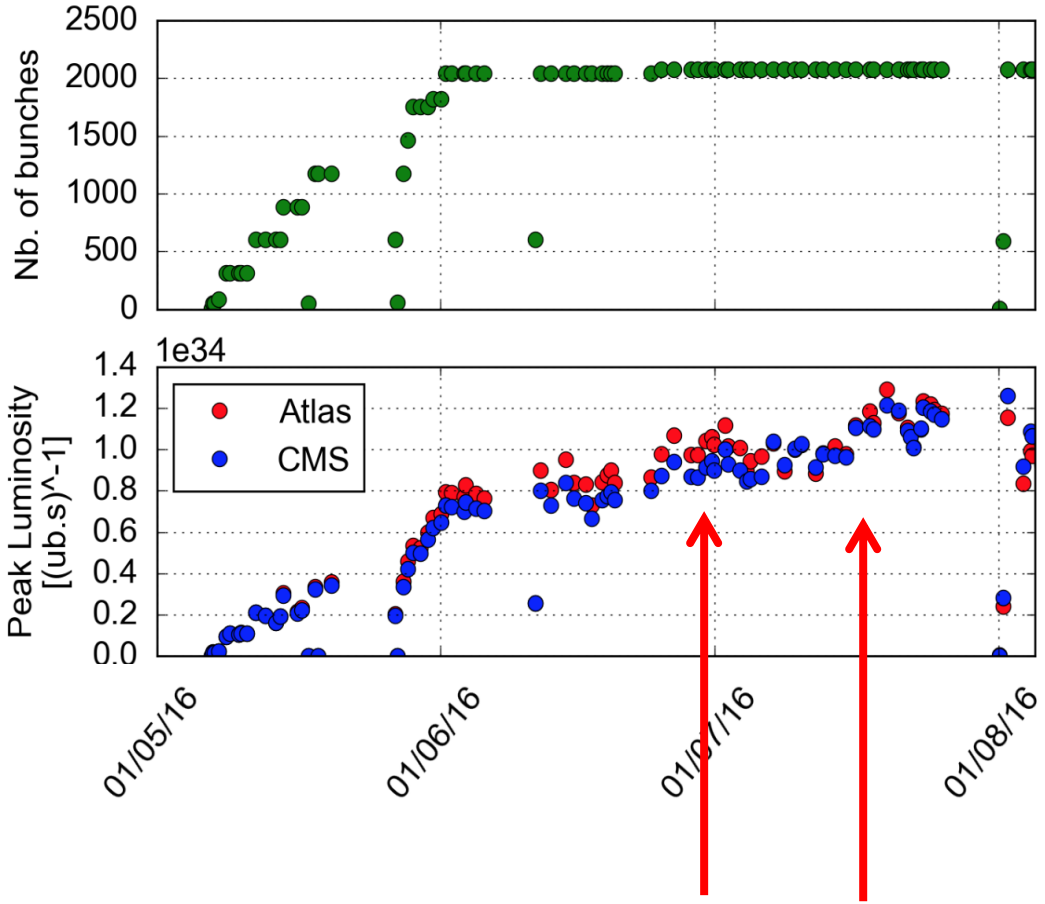


PS MAIN POWER SUPPLY

SPS BEAM DUMP

- **Limited to 96 bunches per injection**
- **2076 bunches per beam cf. 2750**

Peak luminosity



- Reasonably quick ramp-up in number of bunches
  - Limited by SPS beam dump to ~2100
  - Electron cloud still very much with us but effects under control

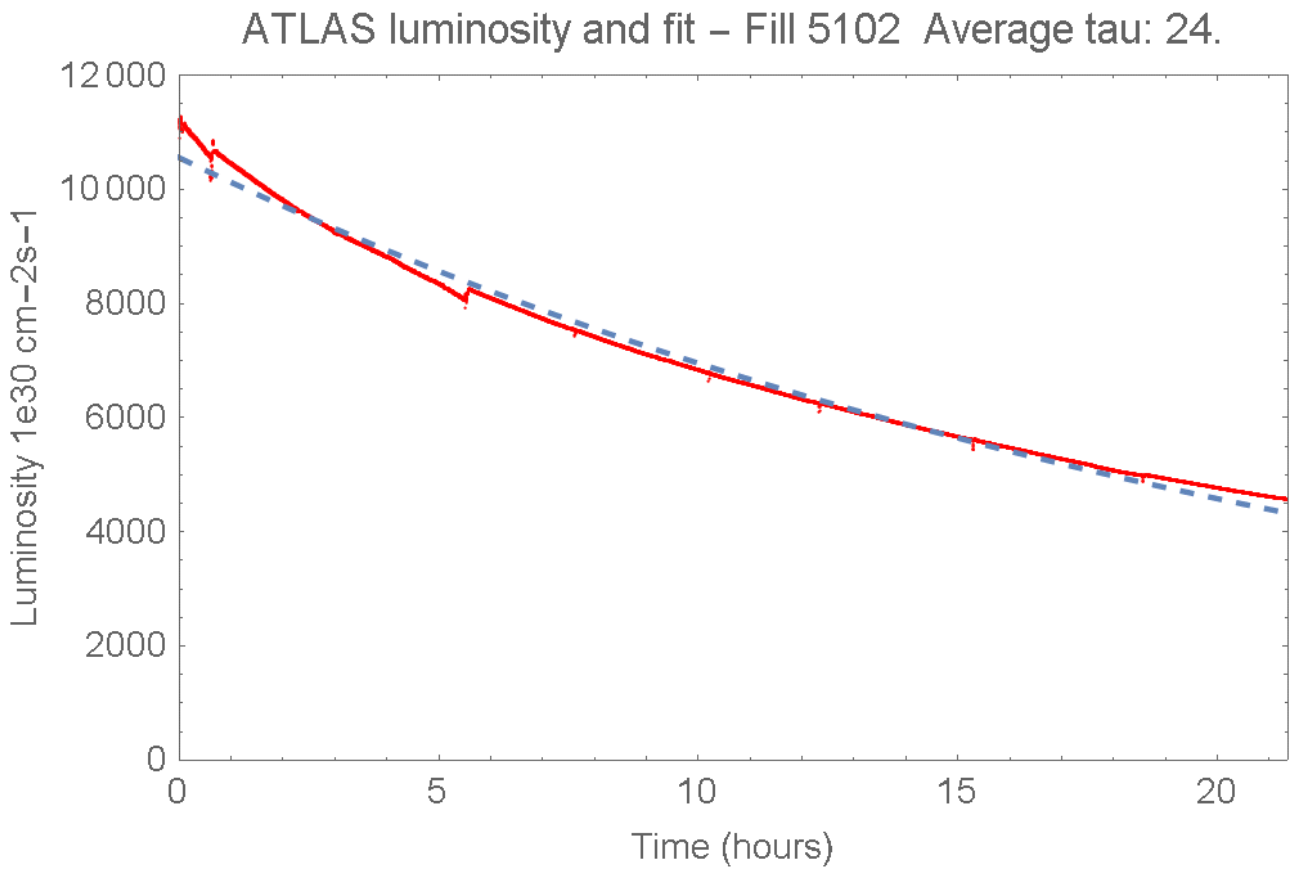
10^{34} **Lower emittance from injectors**

LHCb and ALICE: levelled operation at ~3×10^{32} and ~2×10^{30} $cm^{-2}s^{-1}$ respectively

Design luminosity reached

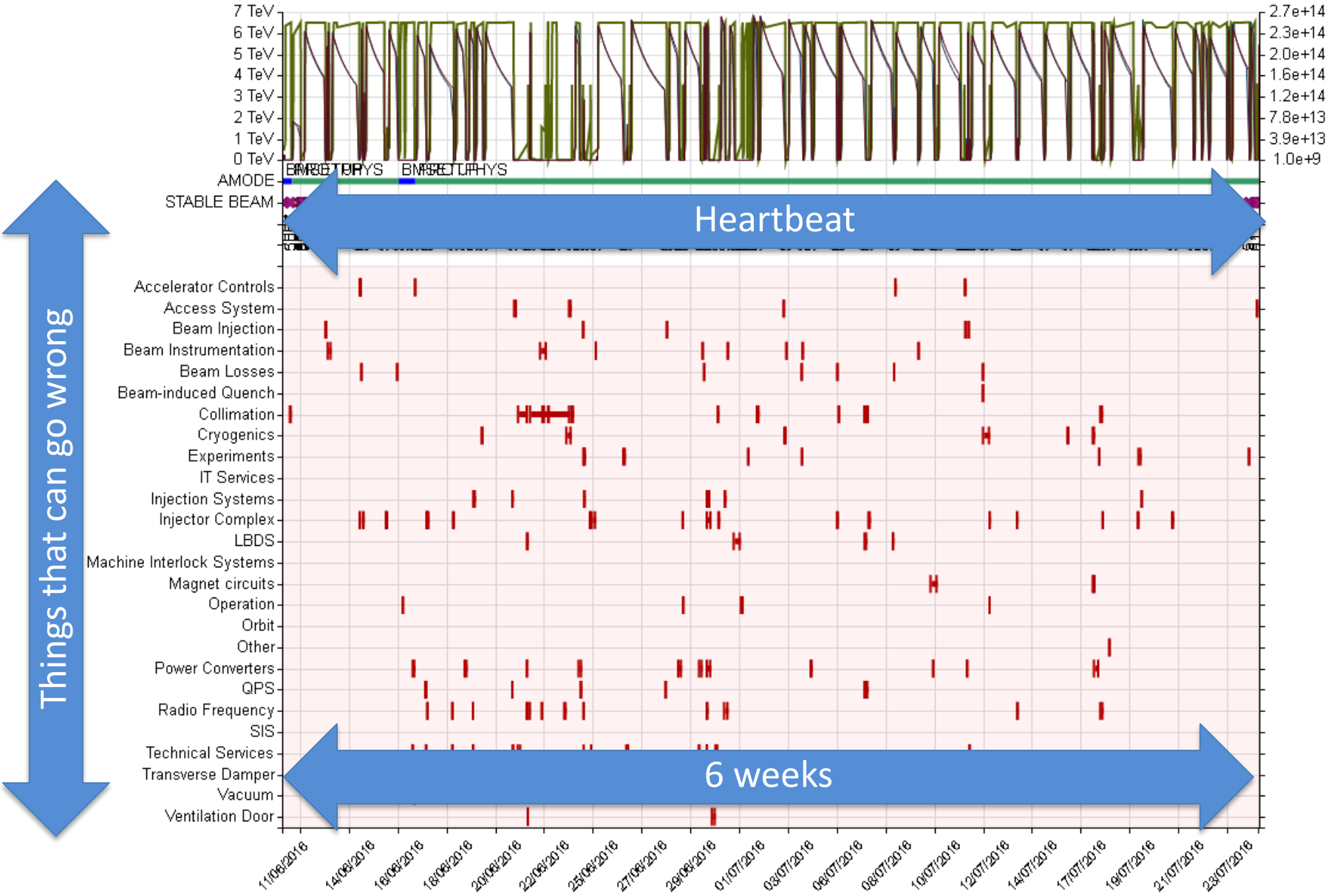
Reduced beta* and lower transverse beam sizes from the injectors compensating the lower number of bunches

Luminosity lifetime

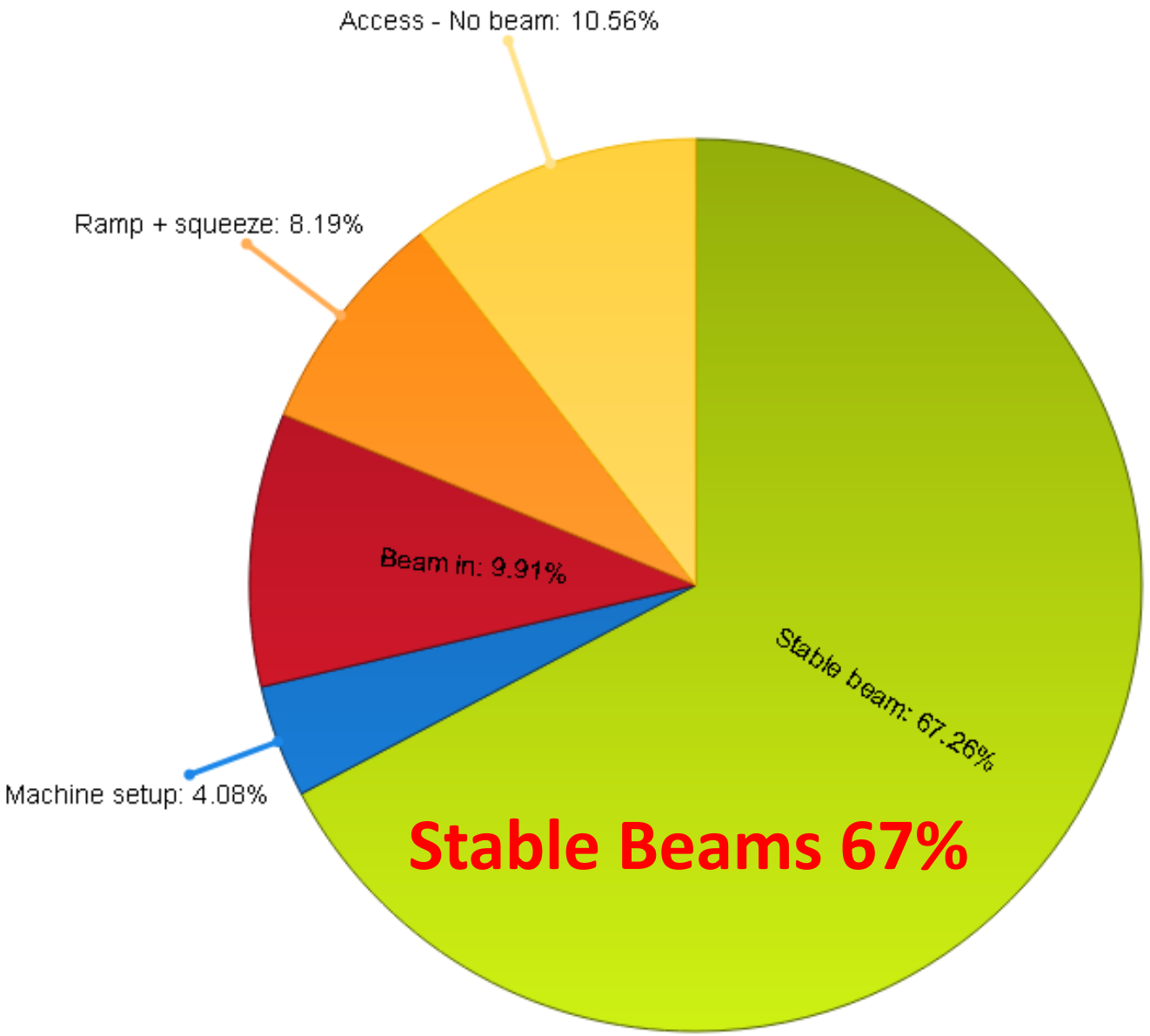


Excellent luminosity lifetime – main component - proton loss to inelastic collisions in ATLAS, CMS and LHCb

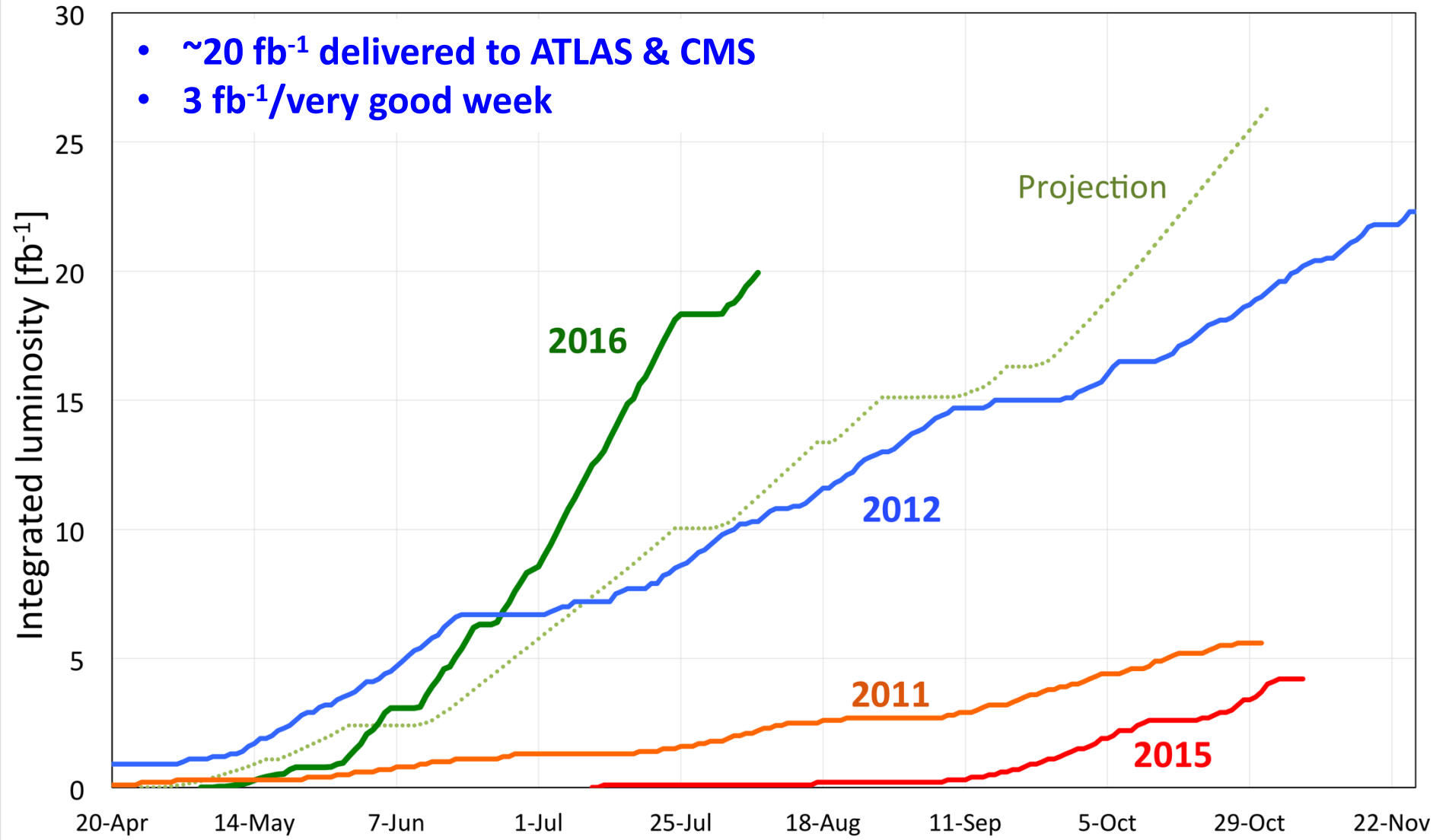
Then enjoy some remarkable availability



Availability: 11th June – 23rd July



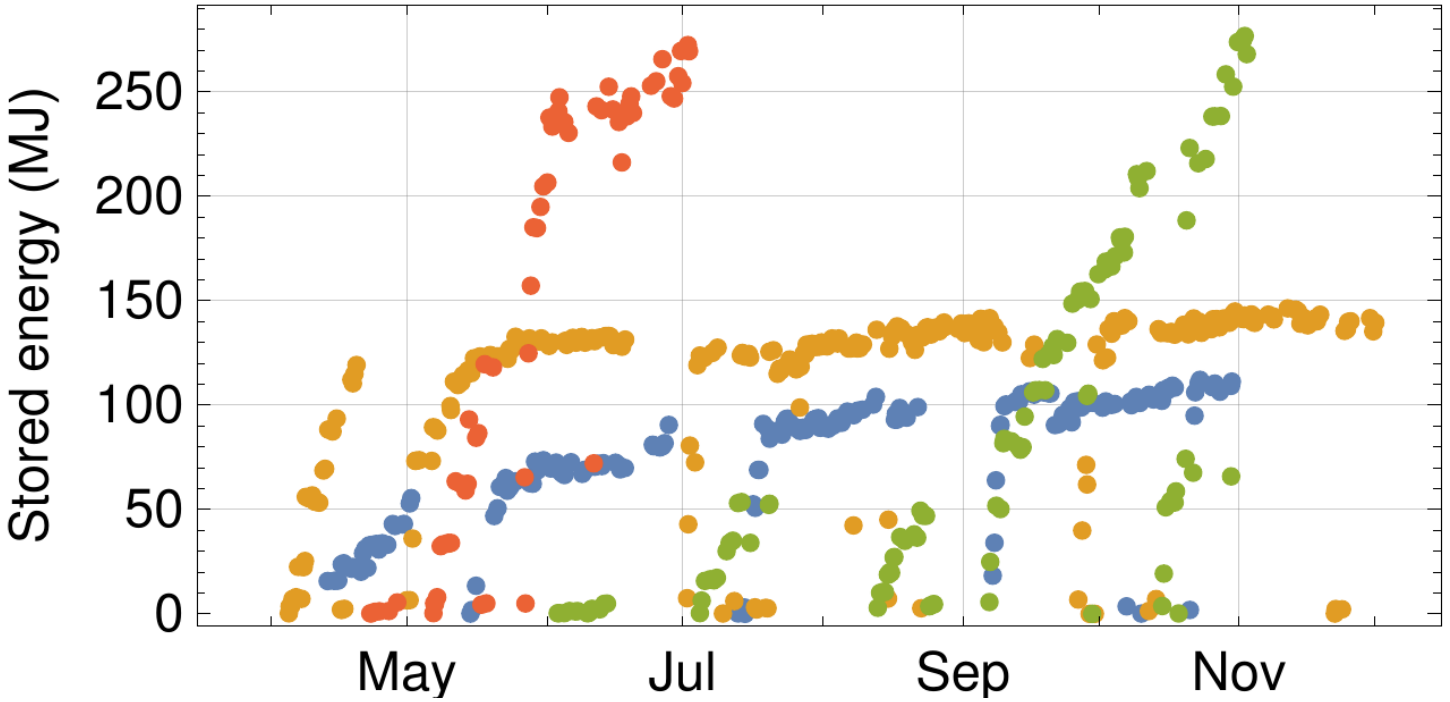
Integrated luminosity



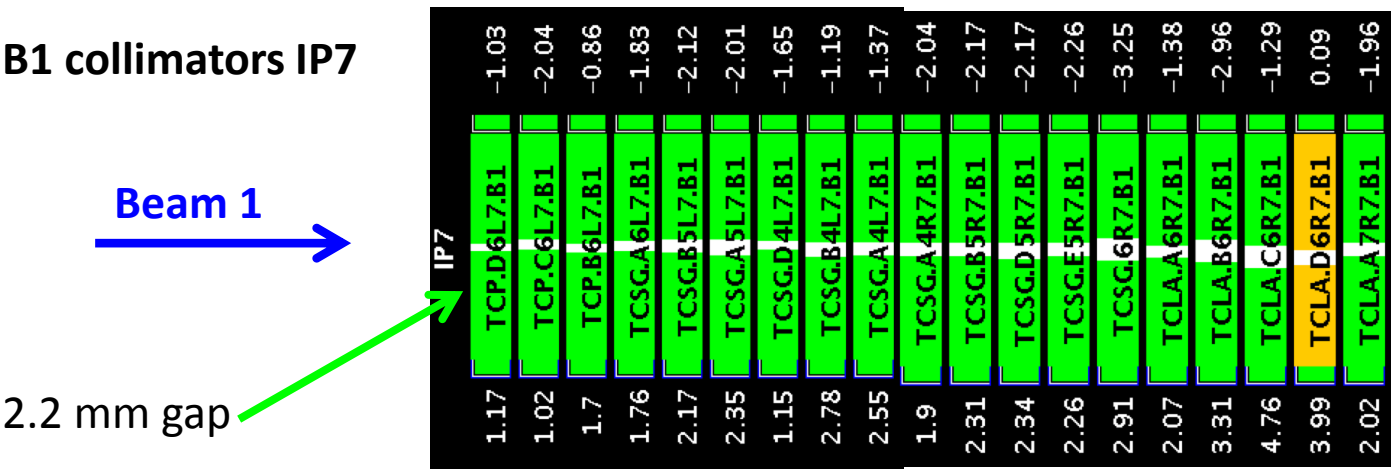
2016
No one is more surprised than we are

- Good peak luminosity, excellent luminosity lifetime
- Stunning availability
  - Sustained effort from hardware groups
- Few premature dumps – long fills
  - UFO rate down, radiation to electronics mitigated

Stored energy per beam



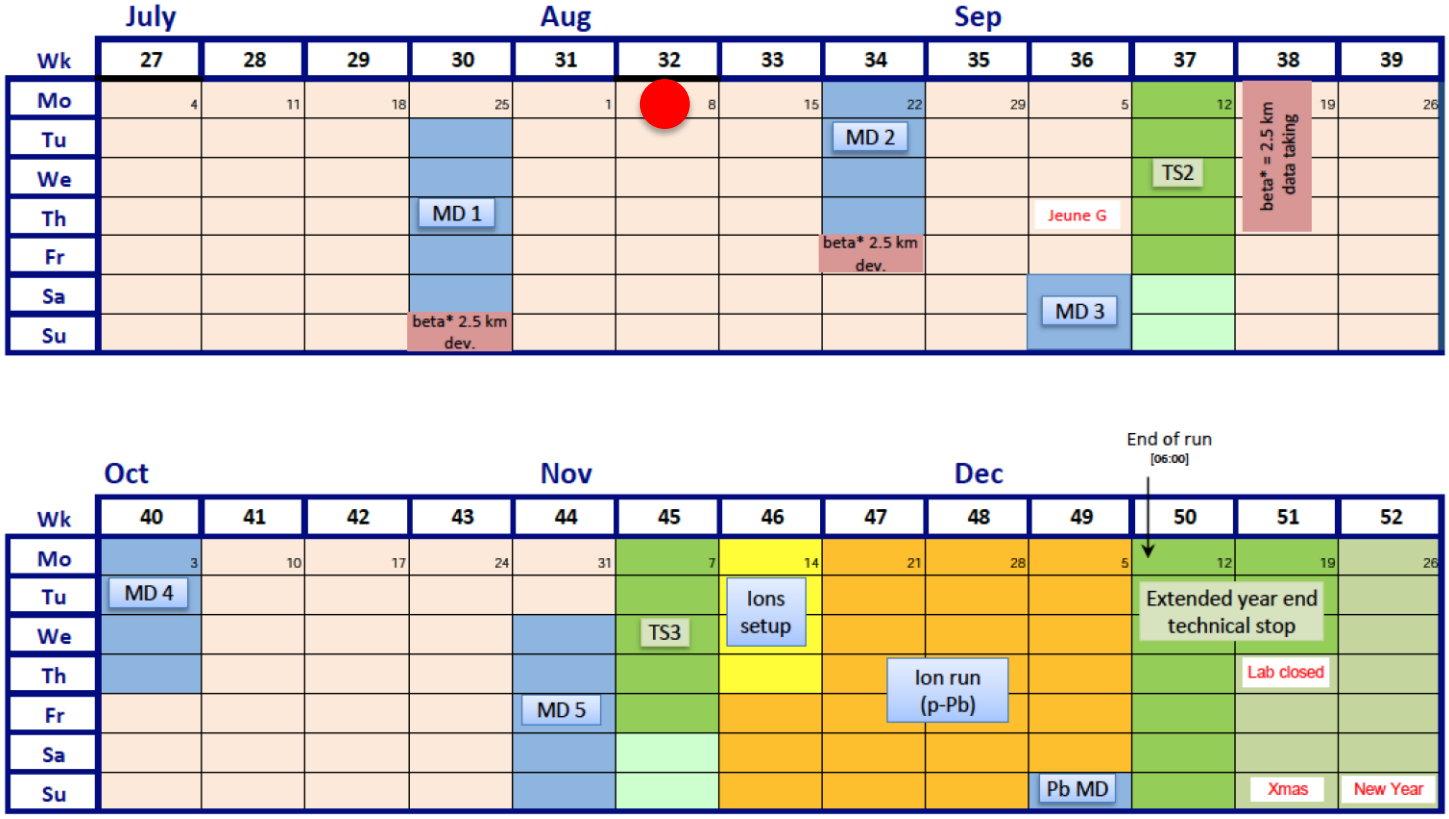
B1 collimators IP7



Machine status - summary

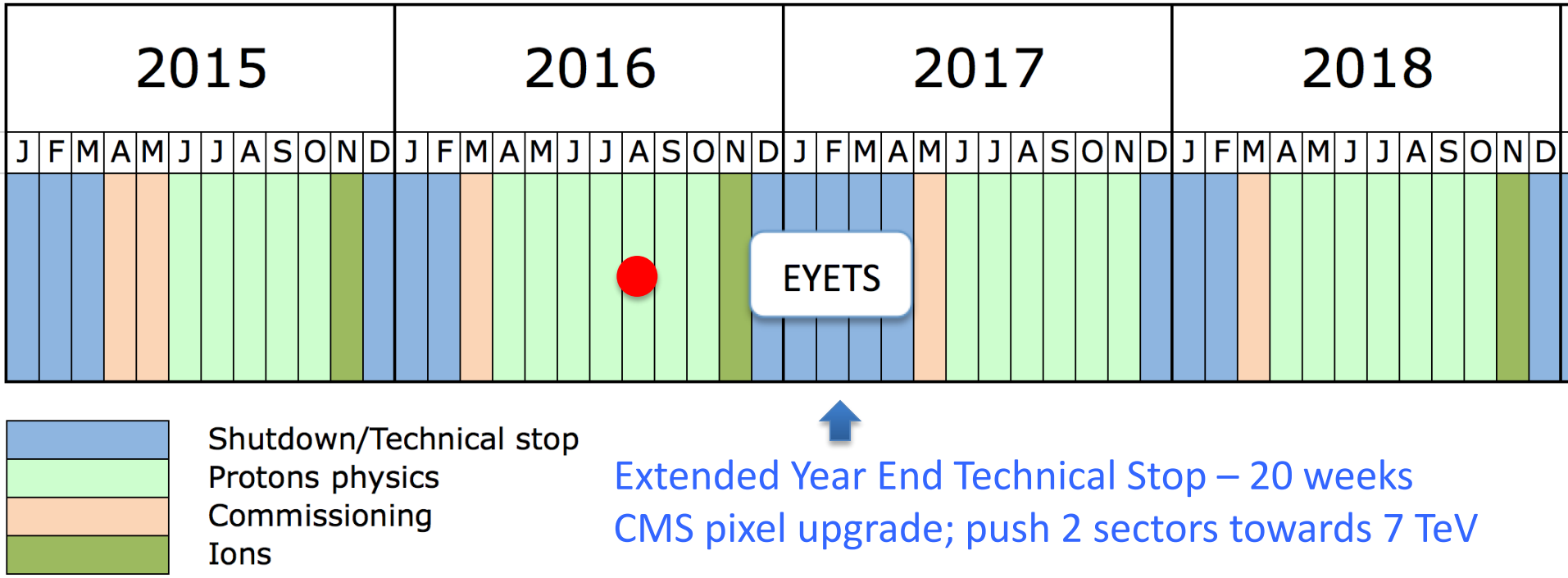
- Excellent and improved system performance
- Good beam lifetime through the cycle
- Operationally things well under control
- Magnetically reproducible as ever
- Optically good, corrected to excellent
- Aperture is fine and compatible with the collimation hierarchy.
- Magnets behaving well at 6.5 TeV

Incoming 2016



- ~9 weeks of proton physics left…
- Proton-lead run at $\sqrt{s_{NN}}$ of 5 and 8 TeV

Run 2



- Peak luminosity limited to ~1.7e34 by inner triplets
- ~40 fb^{-1}/year in 2017 and 2018
- Prepare for HL-LHC and post-LS2 LIU era
- Prepare for 7 TeV operation

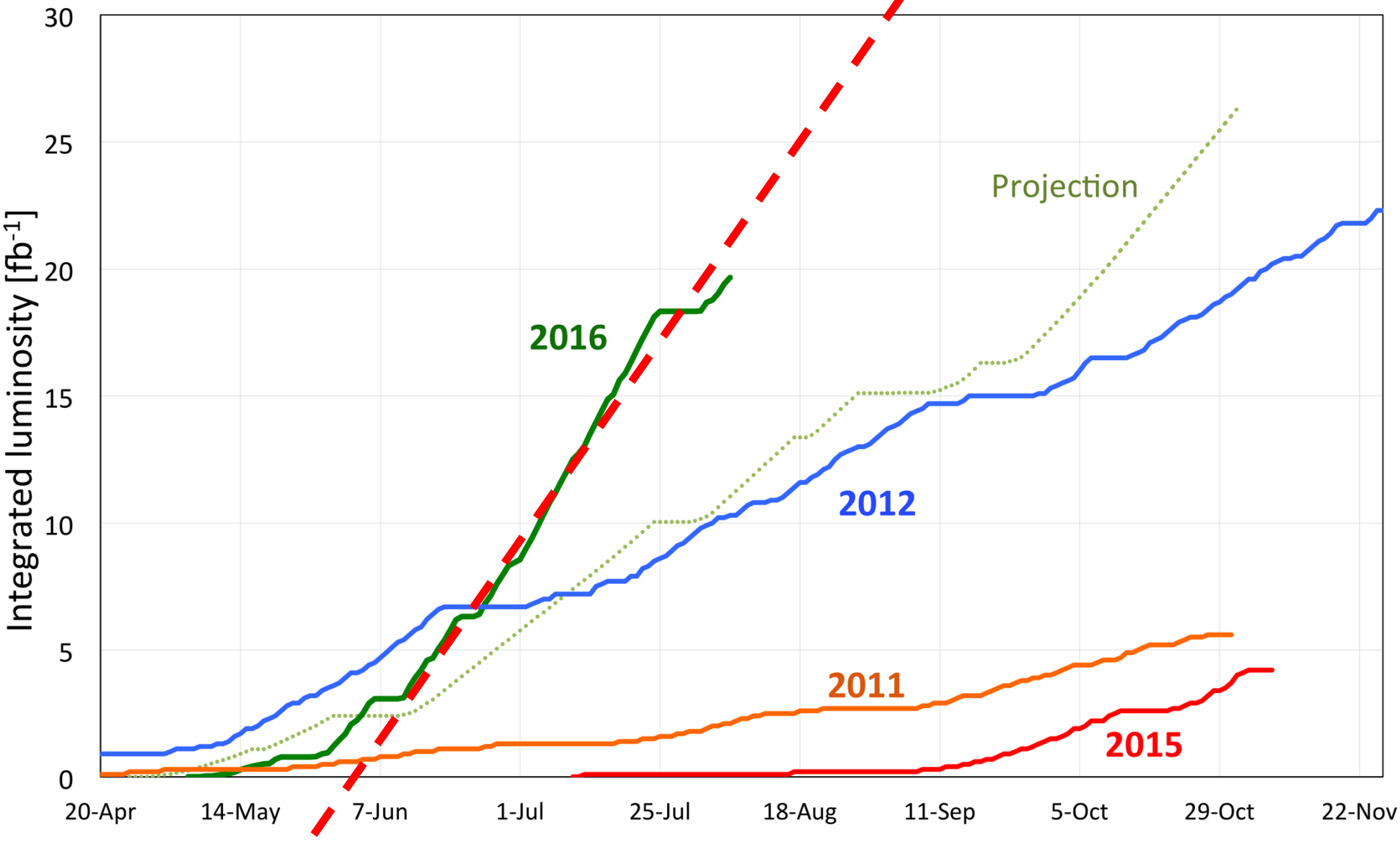
Conclusions (1/2)

- **Excellent peak performance**
  - Design luminosity (squeeze, beams from injectors)
  - Still margin for improvement in Run 2
- **Good integrated delivery**
  - Remarkable availability
  - Electron cloud conditioning slowly
  - Fortunate that UFOs have conditioned down

Conclusions 2/2

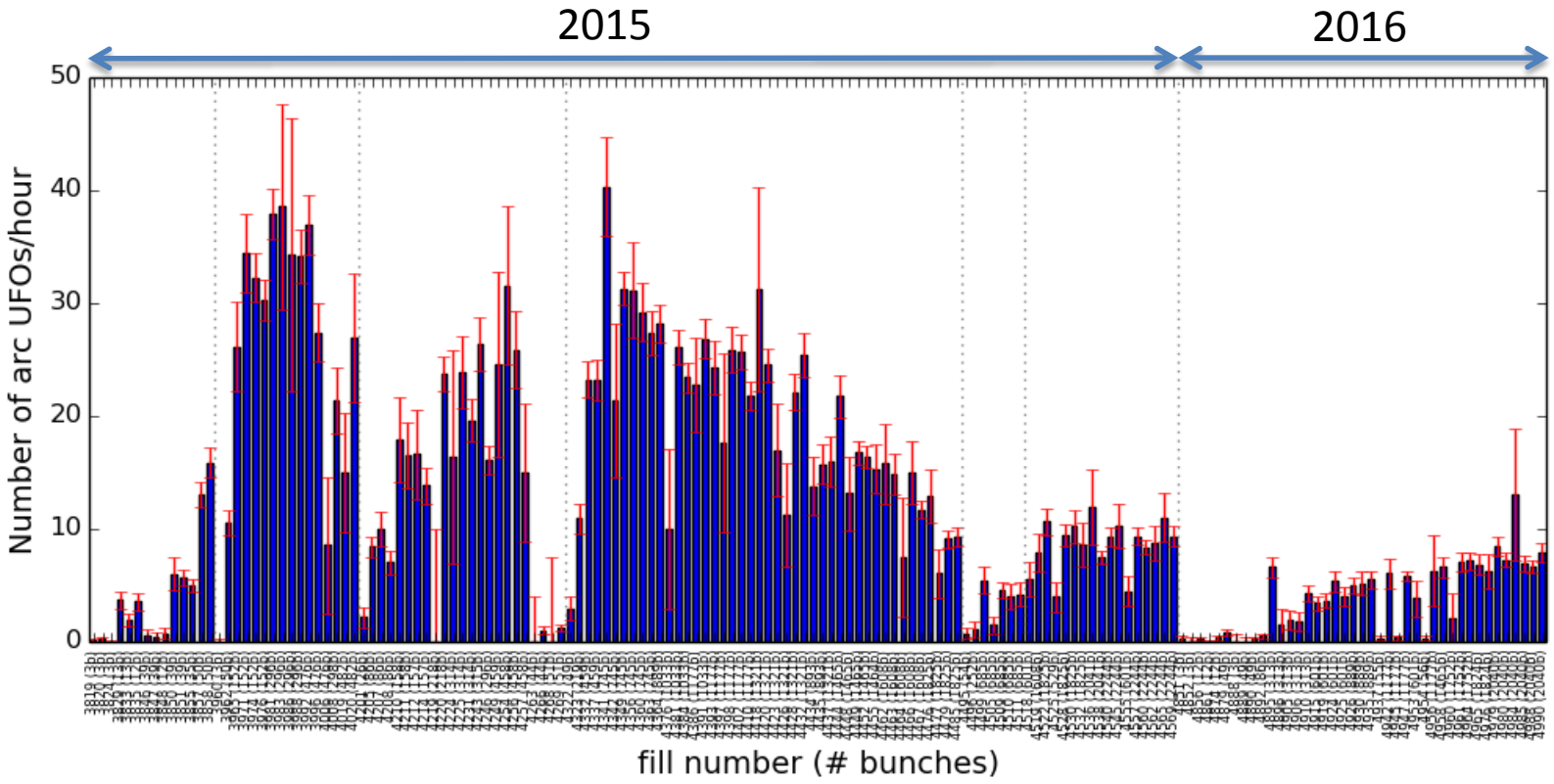
- Moved from commissioning to exploitation
- LHC is enjoying the benefits of the decades long international design, construction, installation effort – foundations are good
- Huge amount of experience & understanding gained and fed-forward
- Progress represents a phenomenal ongoing effort by all the teams involved.

Please don't do this!



BACKUP

UFOs: Run 2 so far

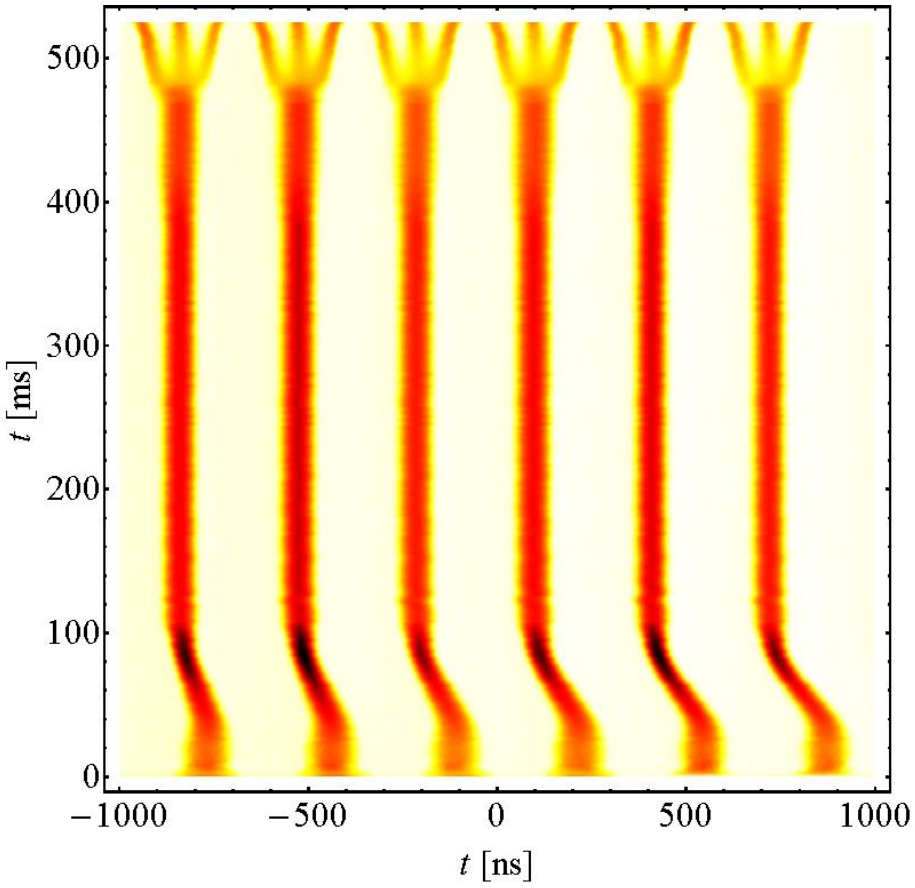


- arc UFOs (cell >11): rates similar to end of 2015
  - did not lose conditioning over the Xmas stop

Beam from injectors

Lower than nominal emittance taken a step further

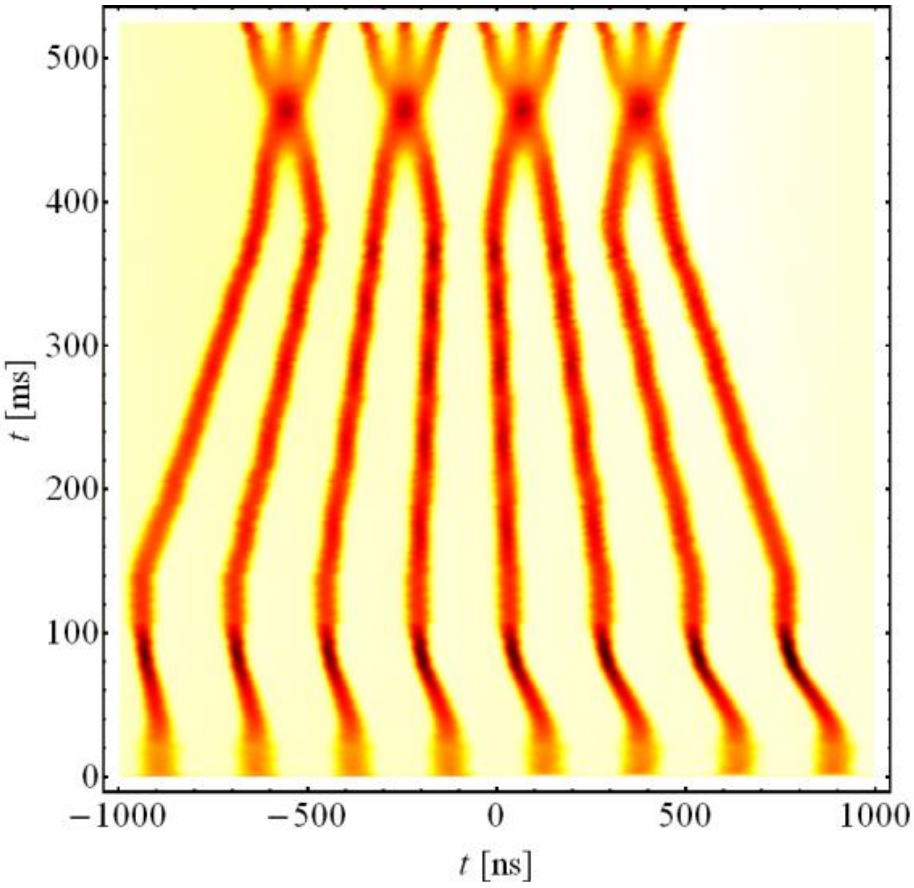
Standard 25 ns scheme



PS circumference

BCMS

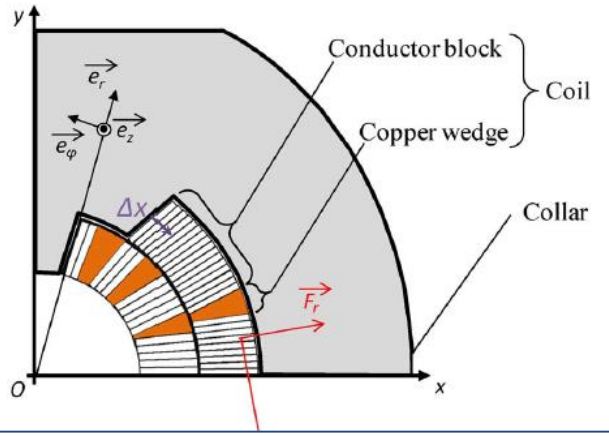
(**B**atch **C**ompression, **M**erging & **S**plitting)



Lower intensity, **smaller** bunches from PSB

Dipole training 2/2

Training: frictional energy released during conductor motion



Campaign summary

Training quenches during HWC 2014-2015 occurring until I_PNO+100 A has been reached for the first time									
Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total
RB.A12	11080 A reached	50	95	9	2	1	4	7	7
RB.A23	11080 A reached	56	58	40	0	1	15	16	16
RB.A34	11080 A reached	44	81	29	1	5	8	14	14
RB.A45	11080 A reached	48	44	62	0	3	48	51	49
RB.A56	11080 A reached	28	42	84	0	0	15	15	14
RB.A67	11080 A reached	57	36	61	0	1	20	21	20
RB.A78	11080 A reached	53	40	61	2	8	6	16	16
RB.A81	11080 A reached	64	24	66	0	3	26	29	26
	Total:	400	420	412	5	22	142	169	162

#M: Number of magnets in a sector.

#MQ: Number of magnet training quenches in a sector.

#CQ: Number of circuit quenches in a sector.

- All magnets have been trained to well over 7 TeV in SM18 before installation
- Extensive re-training in situ was not expected