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## **RLIUP – Session 2**

# **Post LS1 scenarios without and with LINAC4**

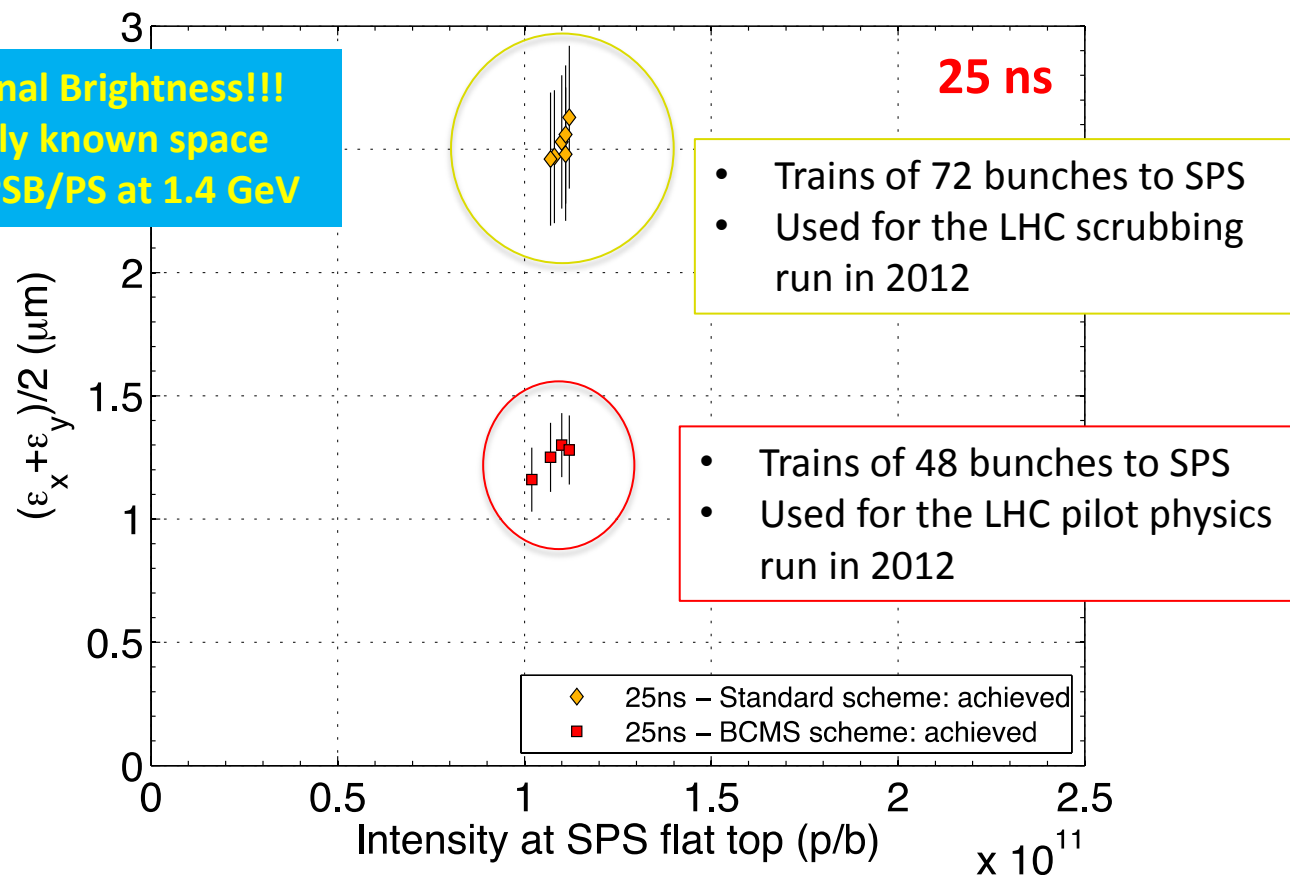
Acknowledgements: L. Bottura, K. Foraz, G. Rumolo, J. Wenninger

# Session 2

- Performance of the injectors and LHC peak and integrated luminosity if no major upgrade except the connection of LINAC4 and H-injection (**G. Rumolo and J. Wenninger**)
- Expected shut-down schedule (assuming only “winter stops” for regular maintenance) taking into account the lifetime of major accelerator components (**K. Foraz and L. Bottura**)

# 2012 injector performance (@SPS ext.)

Up to 3 x Nominal Brightness!!!  
At the presently known space  
charge limit of PSB/PS at 1.4 GeV



## Measurement points

- Emittances deduced from combined wire-scans at end of SPS flat bottom (values cross-checked with LHC)
- Error bars include spread from several measurements as well as systematic uncertainty (10%)
- Intensity measured at SPS flat top after scraping



## Expected Injector performance after LS1

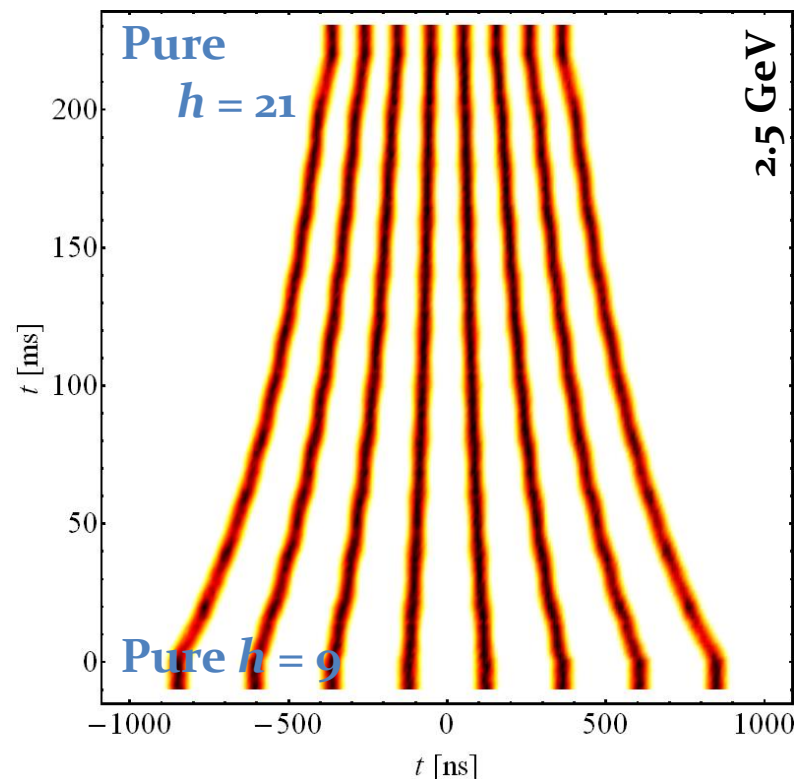
- 25 ns beam (both standard production and BCMS) already very close to the limits in injectors
- **Higher intensity (SPS RF power limit)**
  - **max  $1.3 \times 10^{11}$  ppb**
- **Higher brightness (PS space charge)**
  - RF manipulations in the PS @2.5 GeV (instead of 1.4 GeV)
  - PSB control of longitudinal parameters along the cycle



# Expected Injector performance after LS1

## Alternative production scheme for 25 ns beams

- **Pure batch compression** at 2.5 GeV (from  $h=9$  to  $h=21$ )
- Twice double splitting at FT
- Trains of 32 bunches to the SPS
  - promise to produce ultra-bright 25 ns beams for the post-LS1 era with short trains (favorable against electron cloud), at the price of 13% lower number of bunches in LHC



# Expected Injector performance after LS1

		PSB						
		$N$ ( $10^{11}$ p)	$\epsilon_{x,y}$ ( $\mu\text{m}$ )	$E$ (GeV)	$\epsilon_z$ (eVs)	$B_l$ (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Post-LS1	Standard	19.21	2.02	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.58, 0.67)
	BCMS	9.60	1.06	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.48, 0.61)
	Pure BC	6.40	0.78	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.40, 0.53)

		PS (double injection)						
		$N$ ( $10^{11}$ p/b)	$\epsilon_{x,y}$ ( $\mu\text{m}$ )	$E$ (GeV)	$\epsilon_z$ (eVs/b)	$B_l$ (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Post LS1	Standard	18.25	2.12	1.4	2.79	220	$1.8 \cdot 10^{-3}$	(0.14, 0.23)
	BCMS	9.12	1.11	1.4	1.48	150	$1.4 \cdot 10^{-3}$	(0.18, 0.31)
	Pure BC	6.08	0.72	1.4	1.0	150	$0.9 \cdot 10^{-3}$	(0.21, 0.31)

		SPS (several injections)						
					after filamentation ( $\epsilon_z=0.35$ eVs, $B_l=4$ ns @inj)			
		$N$ ( $10^{11}$ p/b)	$\epsilon_{x,y}$ ( $\mu\text{m}$ )	$p$ (GeV/c)	$\epsilon_z$ (eVs/b)	$B_l$ (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Post-LS1	Standard	1.44	2.22	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.05, 0.08)
	BCMS	1.44	1.16	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.08, 0.14)
	Pure BC	1.44	0.86	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.10, 0.18)

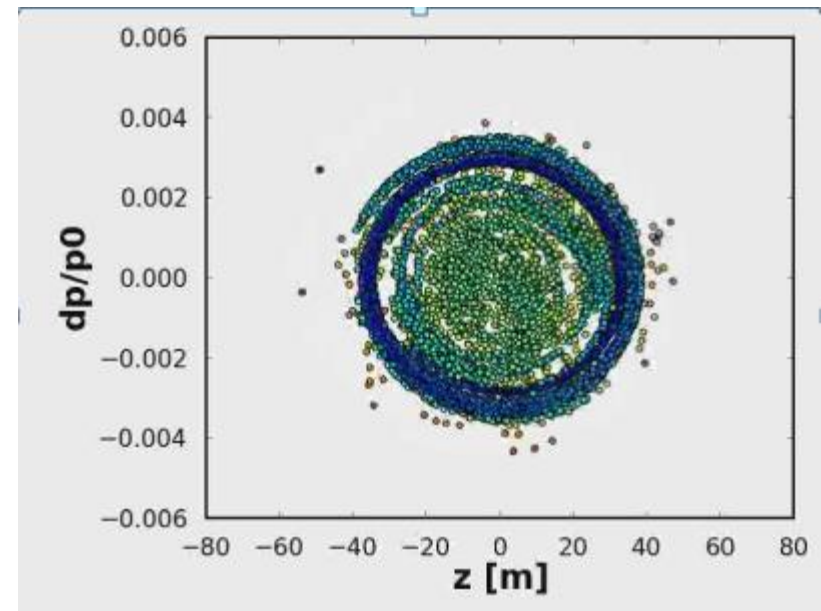
		LHC					
		$N$ ( $10^{11}$ p/b)	$\epsilon_{x,y}$ ( $\mu\text{m}$ )	$p$ (GeV/c)	$\epsilon_z$ (eVs/b)	$B_l$ (ns)	bunches/train
Post-LS1	Standard	1.30	2.44	450	0.47	1.63	72
	BCMS	1.30	1.28	450	0.47	1.63	48
	Pure BC	1.30	0.95	450	0.47	1.63	32

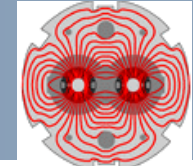
**Small emittances are more difficult to handle in the LHC: IBS, additive sources of blow-up, beam stability**

# Expected Injector performance after LS1

## Only Linac4

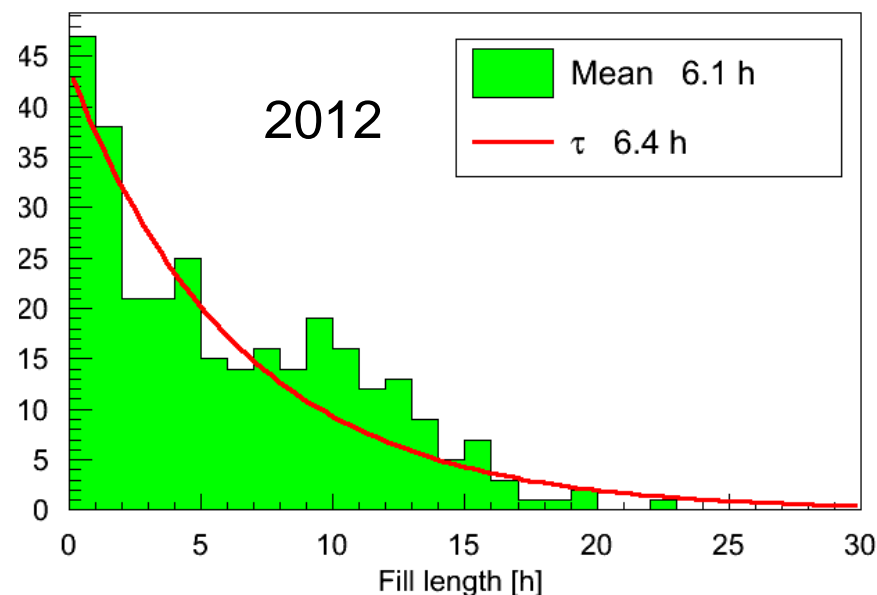
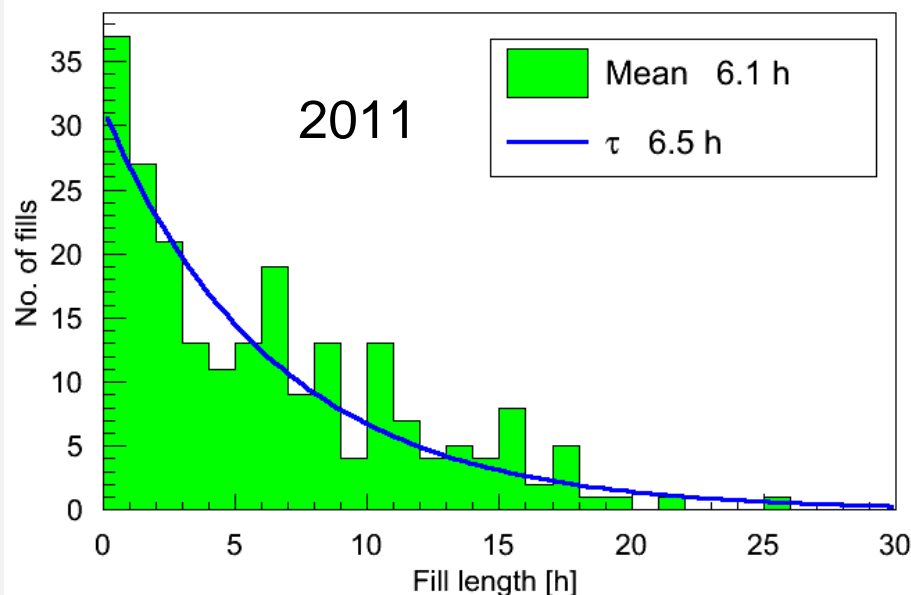
- Standard 25 ns beams: 50% higher brightness (limited by PS space charge) **but intensity limited by the SPS**
- BCMS beams: no improvement with Linac4 (space charge in PS)
- Possible additional gains by creating **hollow bunches** or **using alternative optics in the PS at injection** → need lots of MD time and full experimental validation!





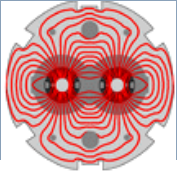
- Fill lengths in 2011 and 2012  $\approx$  exponentials.

- *$\sim 30\%$  of the fills are dumped by OP.*

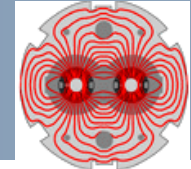


- An exponential fill length distribution is used for the performance figures quoted in the next slides.





- The expected integrated luminosity per year for 25 ns is in the range of **45-55 fb<sup>-1</sup>** for a 2012-like efficiency.
  - *For 5 ½ years of operation until LS3 → 250-300 fb<sup>-1</sup>.*
  - *Unknowns on limitations, emittance, efficiency – 10% level effects – situation will be clearer end 2015.*
  - *Peak luminosity close to / above expected triplet limitation (**~1.75 × 10<sup>34</sup> cm<sup>-2</sup>s<sup>-1</sup>** ±10-20%) !!!!*
  - *Pile-up limit in the experiments assumed to be ~45 events/crossing*
  
- With L4 the standard 25 ns beams and the BCMS beams have very similar performance.
  - *Bonus for standard 25 ns: lower pile-up (~10%).*
  - *The emittances that are eventually achieved may make the difference – easier for standard (larger ε) ?*



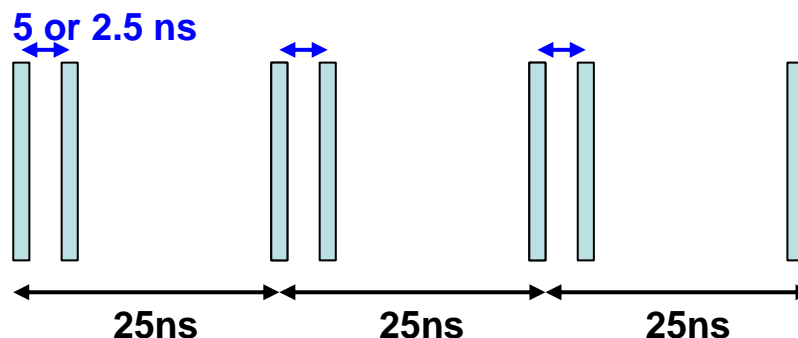
□ The intensity/brightness may be limited by instabilities.

- *E-cloud*
- *Instabilities*
- *heating*
- *UFOs.*

Enhance scrubbing at 450 GeV to remove e-cloud in the dipoles  
“completely” with dedicated scrubbing beam is essential

Use **doublet** beam : **5 – 20 ns or 2.5 – 22.5 ns spacing**

Implications and issues (BI, RF, ADT) under investigation.

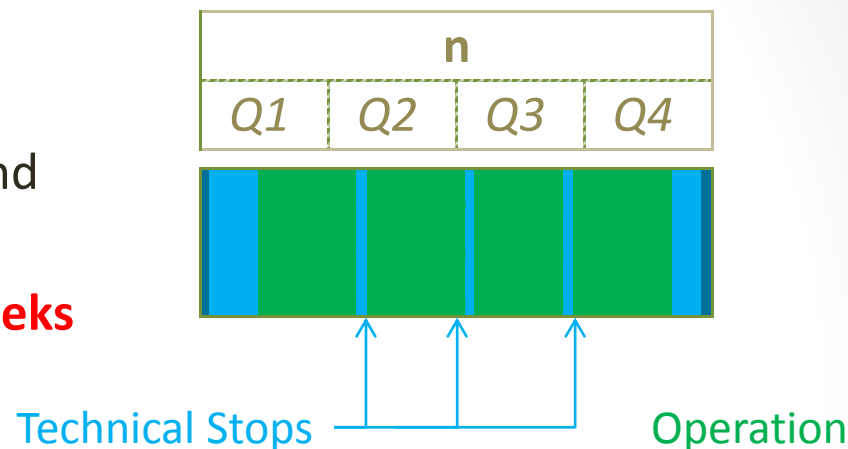


**Important to test and push bunch population for doublet scheme (20+5 ns) in 2014 to allow faster scrubbing in the SPS and LHC (essential for 25 ns!!!)**

# Shutdown schedule until 2035

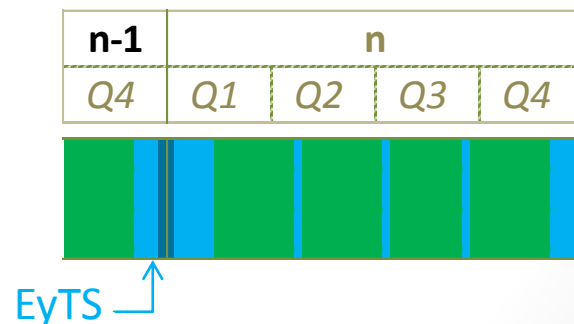
- Technical Stops:**

- In order to perform preventive and corrective maintenance
- Min. length = **5 days every 10 weeks**



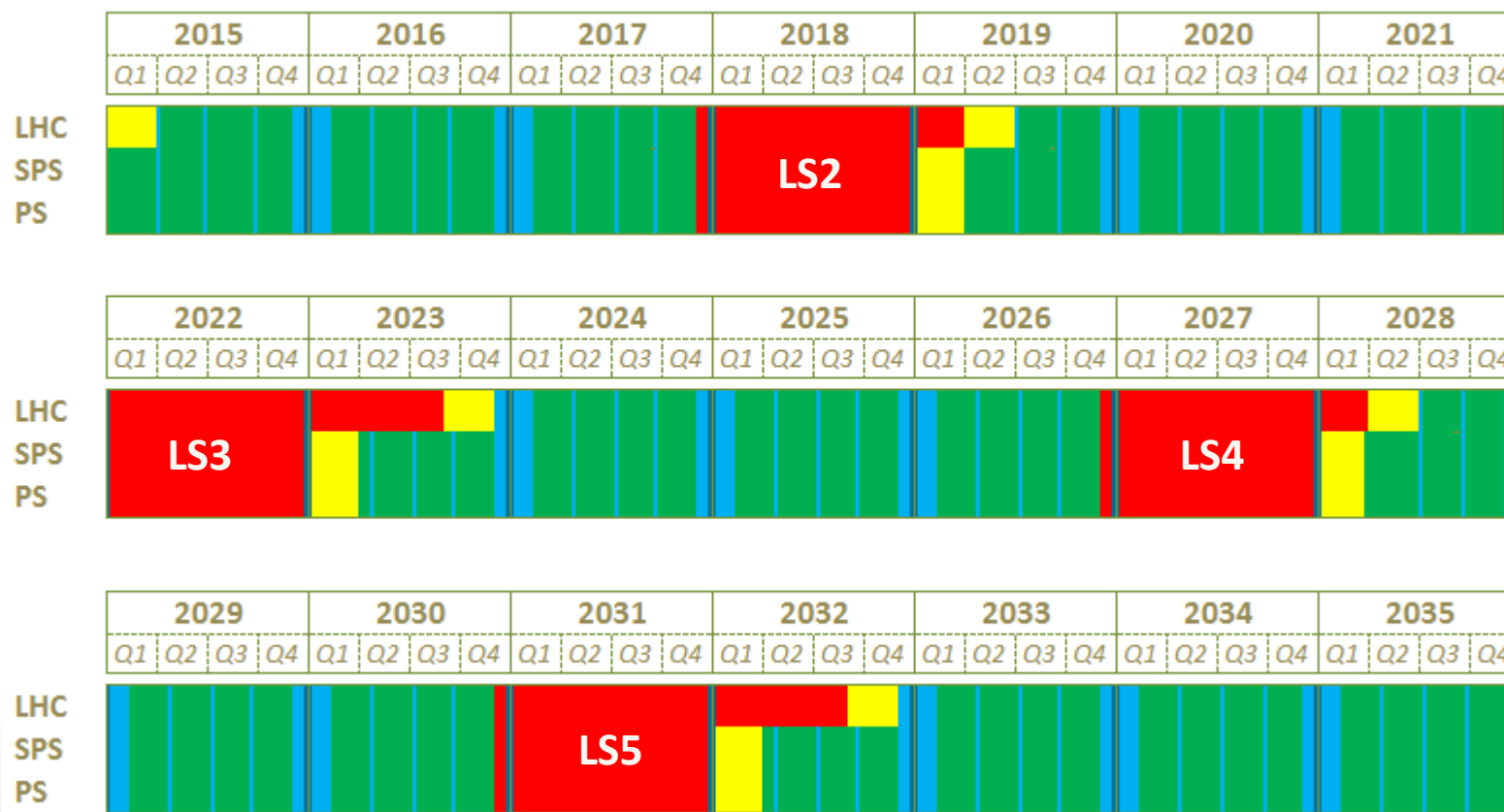
## End of Year Technical Stops:

- Assuming ion operation in LHC with no protons in the Injectors at the end of each year (cool-down time)*
- Min. length: **10 weeks** (incl. Xmas holidays)



# Shutdown schedule until 2035

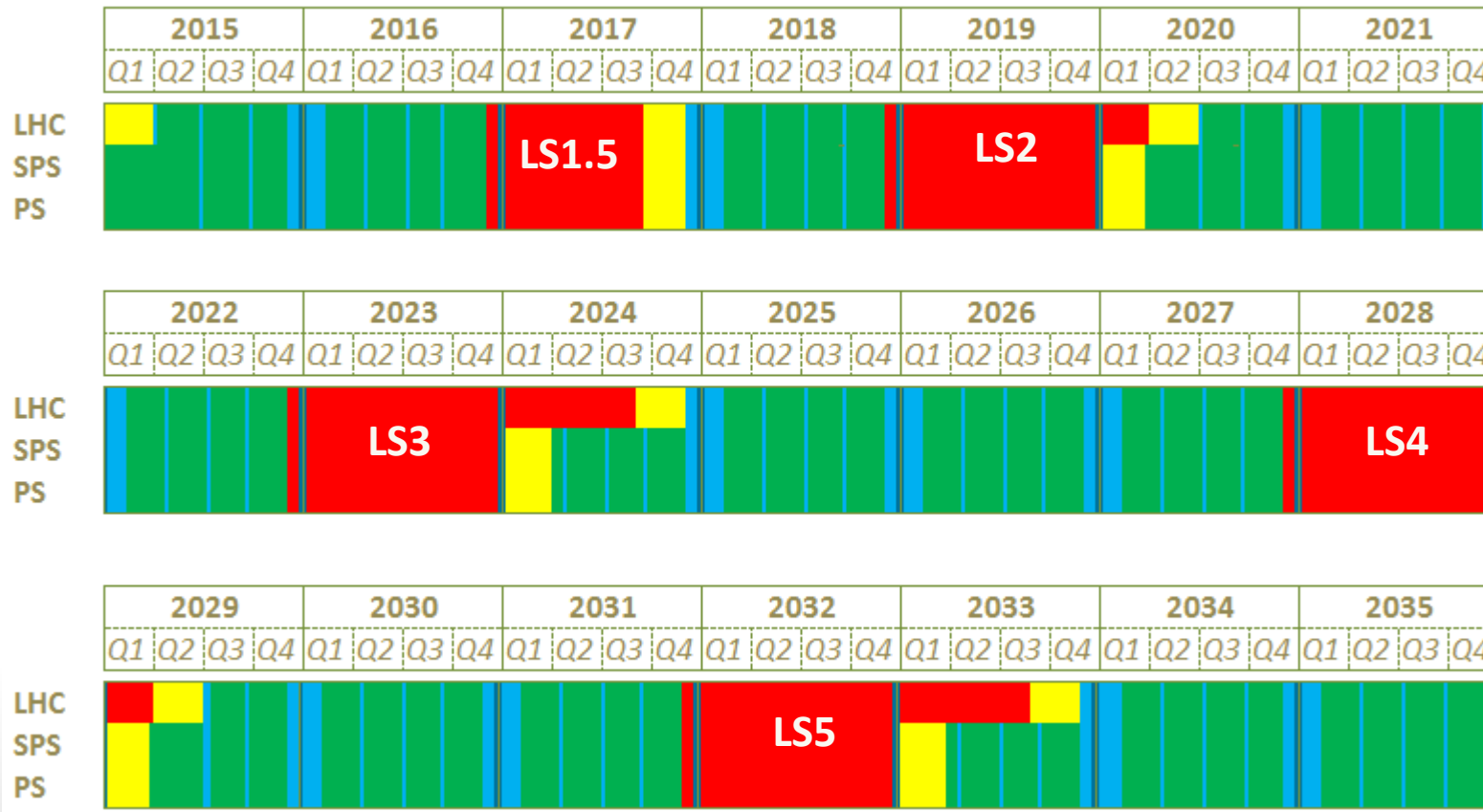
Scenario 1  
from 2015 to 2035: beam = 57%



# Shutdown schedule until 2035

Scenario 2

from 2015 to 2035: beam = 54 % of time



# Shutdown schedule until 2035

- Minimum shutdown lengths have been given
  - Leading to beam operation  **$\sim 3/5^{\text{th}}$  of the time from 2015 to 2035**
  - LS2: LHC 16 months (CV and Cryo), Injectors 12 months (CV and access)
  - LS3: LHC 20 months (**triplets**) , Injectors 12 months (CV)
  - LS4: LHC 16 months (CV+Cryo), Injectors 12 months (CV)
  - LS5: LHC 20 months (**triplets**), Injectors 12 months (CV)

**Significantly long stops are required even with no upgrades!**

- **Preference for scenario with LS1.5 (see Session 3 – B. Mikulec)**
  - Mitigate risk of Linac2 failure
  - Linac4 is not left idle
  - Reduce LS2 workload (mainly in Injectors) EL, GS, CV....
  - Reduced physics potential (  $\sim 4\%$  ) can be recuperated with one year of additional running in 2036

# What could stop us?

- Potential causes of mechanical failures of SC magnets
  - Mechanical fatigue on coil, structure, busses:
    - Powering cycles:  $10^4$  per magnet
    - Thermal cycles: a few for the LHC
  - Singular events and associated thermal and electrical stress:
    - Quenches: order of 10 per magnet
    - Heater discharges (triggers): order of 10 per magnet
  - Radiation and associated degradation of mechanical and electrical strength:
    - Magnet in the triplet region (Point 1 and Point 5)
    - Magnets in the collimators region (Point 7)

# What could stop us?

- Electromechanical failures:
  - An MTBF of 400...500 years has been estimated for the LHC superconducting magnets
  - This translates in approximately 3...4 magnet electrical NC's per year of operation, and at least 10...15 magnets exchanges every long shutdown → need to have tools to evaluate (on-line) effect of non-conformities
  - Given the estimated MTBF, the probability of electrical failure of one of the triplet magnets within the next 10 years of operation is 3 %, i.e. 1 magnet
- Questions:
  - Ageing?
  - Impact of number of cycles?
  - Experimental magnets

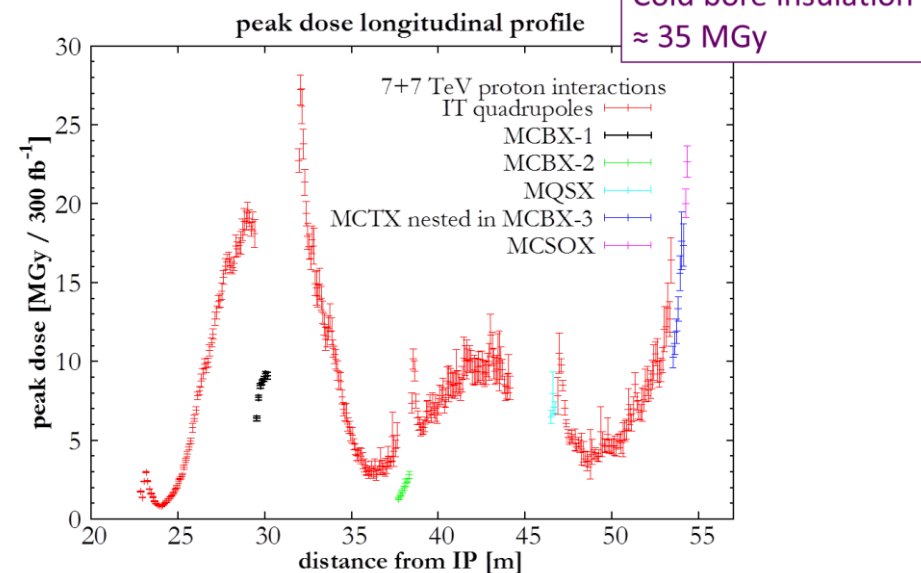


# What could stop us?

L. Bottura

- Radiation and Inner Triplets

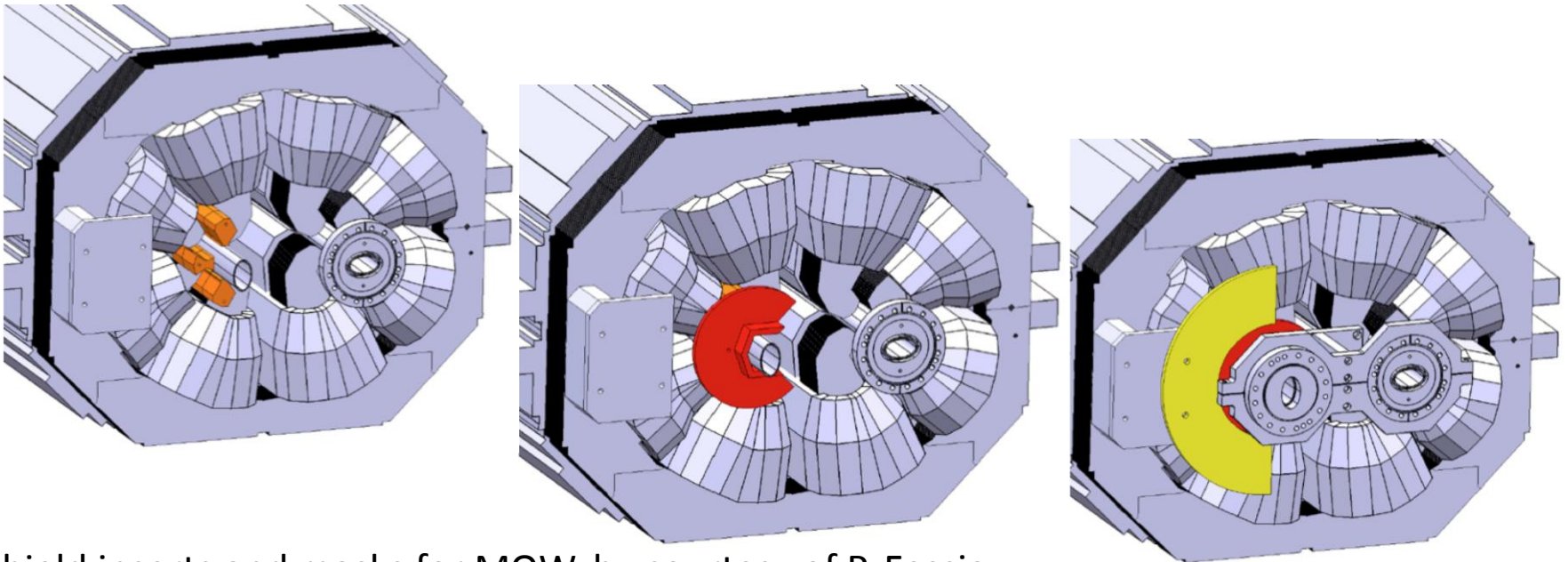
- Expected dose by LS3 ( $300 \text{ fb}^{-1}$ )
  - Range of 27 [18...40] MGy in the Q2
  - Range of 20 [13...30] MGy in the MCBX
- IT may experience mechanically-induced insulation failure in the range of  $300 \text{ fb}^{-1}$  ( $\text{LS3} \pm 1 \text{ year}$ ) consistent with previous analyses.
- Effects:
  - Premature quenches (cracks in end spacers)
  - Insulation degradation (monitor on line)
  - Mechanical failure (nested coils in MCBX)



# What could stop us?

L. Bottura

- Radiation on the warm magnets (collimation area)
- Expected dose by LS3 ( $300 \text{ fb}^{-1}$ )
  - Range of 80....90 MGy in the MBW and MQW
- Actions have been proposed and approved to avoid insulation failure in the period LS2 to LS3
- Starting in LS1



Shield inserts and masks for MQW, by courtesy of P. Fessia

# What could stop us?

- Point 1

- Point 5

**Radiation to the personnel**  
**The triplet will be a limited stay area**  
**Access and work in the triplet and**  
**collimator area will be subject to**  
**ALARA-level III rules**  
**Measures must be taken to reduce**  
**intervention time → in LS3 at the latest**

