Present/post-LS1

2012 Feb 2013 — **Long Shutdown 1 (LHC)** — Mid 2014 Beginning 2015

LHC operation with **25ns** beams!

N_b	**1.15 x 10^{11} ppb**
$\varepsilon_{x,y}$	**2.8 (1.4) μm**

Post-LS2

~ 2018 — **Long Shutdown 2 (LIU)** — ~ 2019

→Connection to Linac4
→2 GeV PSB upgrade
→Renovation of 200 MHz in SPS + coating (?)

- Towards **HL-LHC**-type beams in the injectors

LHC Injectors Upgrade

Description of the three stages

- **Present** performance (same as post-LS1)
  - Mainly based on values of intensity/transverse emittances measured in 2012/13 at the SPS extraction (or LHC injection). Longitudinal parameters measured in the different machines.
  - Transverse emittance/intensity values are transferred back to injection of the SPS – PS – PSB by using the budgets
    - → 10% intensity loss and emittance blow up in the SPS
    - → 5% intensity loss and emittance blow up in the PSB and PS
  - It turns out that
    I. Standard production scheme: the values match the PSB brightness lines for 50 ns beams, but 25 ns beams perform slightly worse.
    II. BCMS scheme: both 50 and 25 ns beams perform according to the budgets.

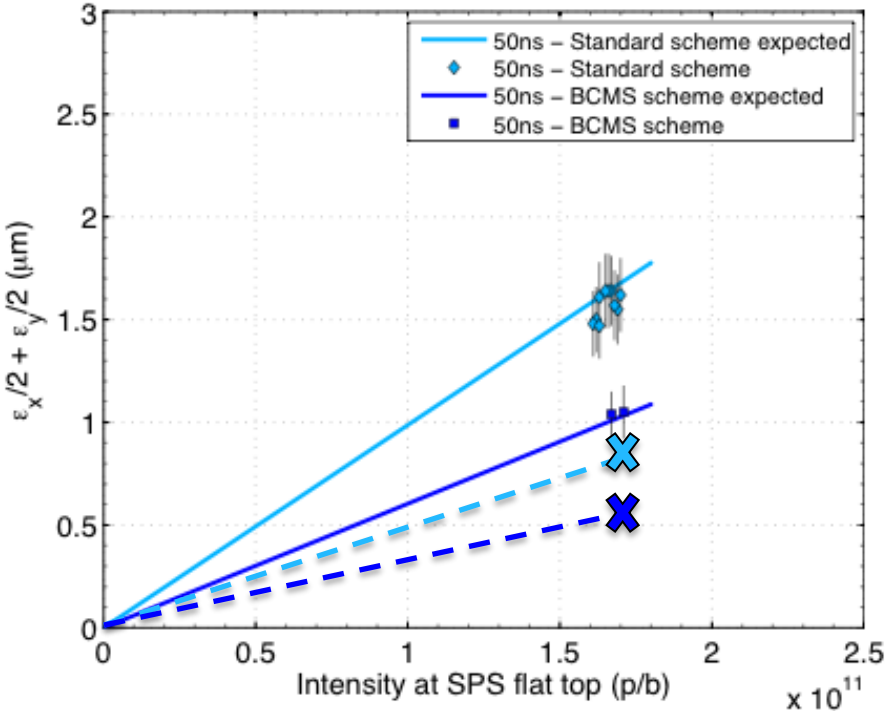
- Post-LS2 (**Linac4 + 2 GeV + SPS upgrade**)
  - Linac4 will provide beams with twice the brightness than those provided by Linac2, longitudinal parameters to be refined for different scenarios.
  - We can successfully transport along the injector chain **at least** the same intensity as before LS2 for the 50 ns beams and up to ultimate intensity for the 25 ns beam.

- **HL-LHC**
  - HL-LHC target values (given at the LHC collision, i.e. **3.5 x 10^{11} p/b in 3 μm for 50 ns** and **2.2 x 10^{11} p/b in 2.5 μm for 25 ns**) are translated into values at LHC injection assuming 5% intensity loss and 20% emittance blow up
  - Values in the SPS – PS – PSB are calculated back by using the standard budgets (above)

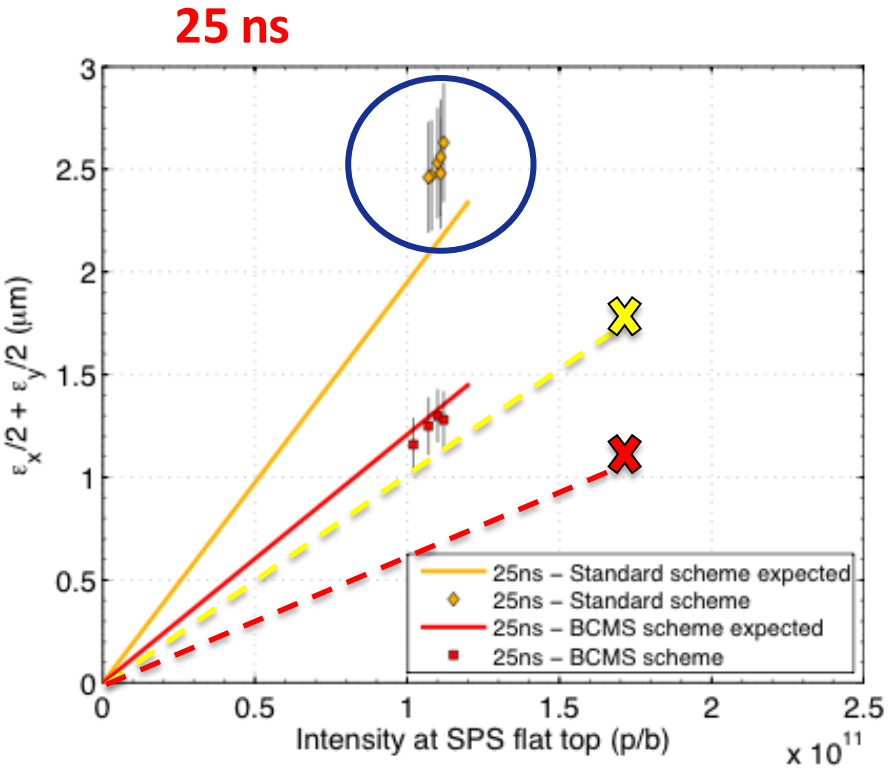
LHC Injectors Upgrade

Present performance

50 ns



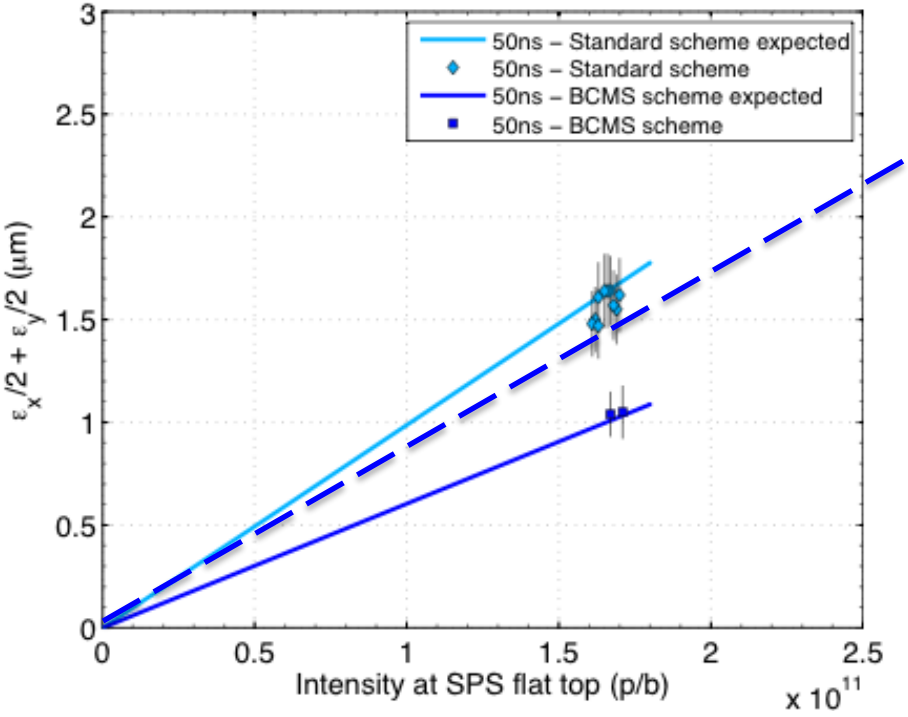
25 ns



LHC Injectors Upgrade

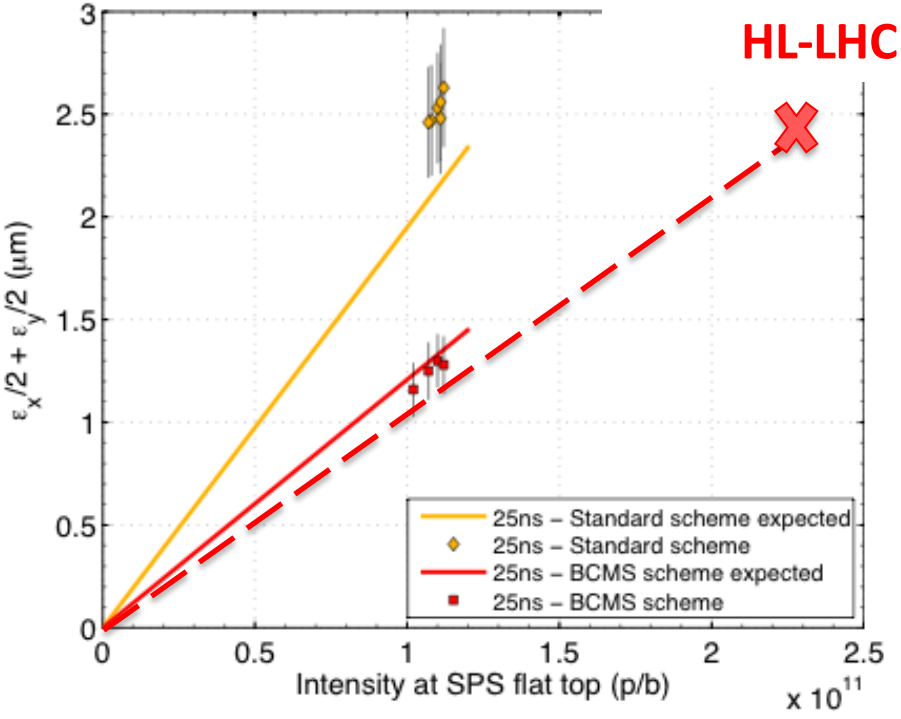
Present performance

50 ns



HL-LHC

25 ns



HL-LHC

LHC Injectors Upgrade

Standard Production scheme – May 30, 2013

		PSB (1 b after capture, c=285 ms)						
		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	12.56	1.41	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.18, 0.41)
	25 ns	17.73	2.14	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.21, 0.43)
Linac4 + 2 GeV + SPS upgrade	50 ns	12.56	0.71	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.10, 0.33)
	25 ns	25.12	1.41	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.17, 0.41)
HL-LHC	50 ns	27.21	2.06	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.16, 0.33)
	25 ns	34.21	1.72	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.22, 0.48)

		PS (4+2 b/inj)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	11.93	1.48	1.4	1.2	180	$1.1 \cdot 10^{-3}$	(0.21, 0.29)
	25 ns	16.84	2.25	1.4	1.2	180	$1.1 \cdot 10^{-3}$	(0.22, 0.29)
Linac4 + 2 GeV + SPS upgrade	50 ns	11.93	0.74	2	2.0	180	$1.2 \cdot 10^{-3}$	(0.14, 0.28)
	25 ns	23.86	1.48	2	2.0	180	$1.2 \cdot 10^{-3}$	(0.20, 0.32)
HL-LHC	50 ns	25.85	2.16	2	2.0	180	$1.2 \cdot 10^{-3}$	(0.18, 0.26)
	25 ns	32.50	1.80	2	2.0	180	$1.2 \cdot 10^{-3}$	(0.25, 0.38)

		SPS (4 × 36-72 b/inj)						
					after filamentation (ϵ_z=0.35 eVs, B_l=4 ns @inj)			
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	1.89	1.56	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.08, 0.14)
	25 ns	1.33	2.36	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.04, 0.07)
Linac4 + 2 GeV + SPS upgrade	50 ns	1.89	0.78	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.12, 0.24)
	25 ns	1.89	1.56	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.08, 0.14)
HL-LHC	50 ns	4.09	2.27	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.13, 0.22)
	25 ns	2.57	1.89	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.09, 0.16)

		LHC (n ×144-288 b/inj)				
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)
Present	50 ns	1.70	1.71	450	0.5	1.65
	25 ns	1.20	2.60	450	0.45	1.55
Linac4 + 2 GeV + SPS upgrade	50 ns	1.70	0.86	450	0.5	1.65
	25 ns	1.70	1.71	450	0.45	1.55
HL-LHC	50 ns	3.68	2.50	450	0.5	1.65
	25 ns	2.32	2.08	450	0.45	1.55

LHC Injectors Upgrade

BCMS scheme – May 30, 2013

		PSB (1 b after capture, c=285 ms)						
		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	6.28	0.90	0.05	0.9	1000	$2.2 \cdot 10^{-3}$	(0.12, 0.33)
	25 ns	8.48	1.12	0.05	0.9	1000	$2.2 \cdot 10^{-3}$	(0.16, 0.38)
Linac4 + 2 GeV + SPS upgrade	50 ns	6.28	0.45	0.16	1.1	–	–	–
	25 ns	12.56	0.90	0.16	1.4	–	–	–
HL-LHC	50 ns	13.61	2.06	0.16	1.1	–	–	–
	25 ns	17.11	1.72	0.16	1.4	–	–	–

		PS (4+4 b/inj)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	5.96	0.95	1.4	0.9	140	10^{-3}	(0.19, 0.28)
	25 ns	8.05	1.17	1.4	0.9	140	10^{-3}	(0.21, 0.31)
Linac4 + 2 GeV + SPS upgrade	50 ns	5.96	0.47	2	1.1	130	10^{-3}	(0.14, 0.30)
	25 ns	11.93	0.95	2	1.4	140	$1.2 \cdot 10^{-3}$	(0.16, 0.29)
HL-LHC	50 ns	12.93	2.16	2	1.1	130	10^{-3}	(0.14, 0.19)
	25 ns	16.25	1.80	2	1.4	140	$1.2 \cdot 10^{-3}$	(0.16, 0.24)

		SPS (5 × 24-48 b/inj)						
					after filamentation (ϵ_z=0.35 eVs, B_l=4 ns @inj)			
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Present	50 ns	1.89	1.00	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.10, 0.20)
	25 ns	1.27	1.23	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.06, 0.11)
Linac4 + 2 GeV + SPS upgrade	50 ns	1.89	0.5	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.16, 0.33)
	25 ns	1.89	1.00	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.10, 0.20)
HL-LHC	50 ns	4.09	2.27	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.13, 0.22)
	25 ns	2.57	1.89	26	0.42	3	$1.7 \cdot 10^{-3}$	(0.09, 0.16)

		LHC (n ×120-240 b/inj)				
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)
Present	50 ns	1.70	1.10	450	0.5	1.65
	25 ns	1.15	1.35	450	0.45	1.55
Linac4 + 2 GeV + SPS upgrade	50 ns	1.70	0.55	450	0.5	1.65
	25 ns	1.70	1.1	450	0.45	1.55
HL-LHC	50 ns	3.68	2.86	450	0.5	1.65
	25 ns	2.32	2.08	450	0.45	1.55

Present LHC beams – a schematic overview
Evolution of space charge ΔQ_y across the injector chain