LHC Injectors Upgrade

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Protons: Baseline and Alternatives, Studies Plan

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CERN

Outline

- Introduction: Goals and means of the LIU project
- Impact of the foreseen LIU improvements on performance of LHC injector synchrotrons and studies required in Run 2
  - PSB
  - PS
  - SPS
- Parameter reach at LHC injection for LIU beams
  - New beams after LS1: pure batch compression (PBC), 8b+4e, doublet
  - LHC beams after the full upgrade (LS2)
- Conclusions

- Introduction: Goals and means of the LIU project

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Goals and means of the LIU project

Boost performance of the injectors to match HL-LHC requirements

Increase brightness and intensity

⇒ Inject H^- into the PSB at 160 MeV (replace Linac2 with Linac4, re-design injection into PSB)

⇒ Raise injection energy in the PS to 2 GeV (increase field in the PSB magnets, replace main power supply, change transfer equipment, re-design PS injection)

⇒ Upgrade PSB, PS and SPS to make them capable to accelerate and manipulate higher intensity beams (RF upgrade, impedance reduction, electron cloud mitigation, feedbacks, etc.)

Increase injectors' reliability and lifetime to cover HL-LHC run (until ~2035!) (closely related to consolidation)

⇒ Upgrade/replace ageing equipment (power supplies, magnets, RF…)

⇒ Improve radioprotection measures (shielding, ventilation…)

Linac4 beam parameters determine beam parameters at PSB injection

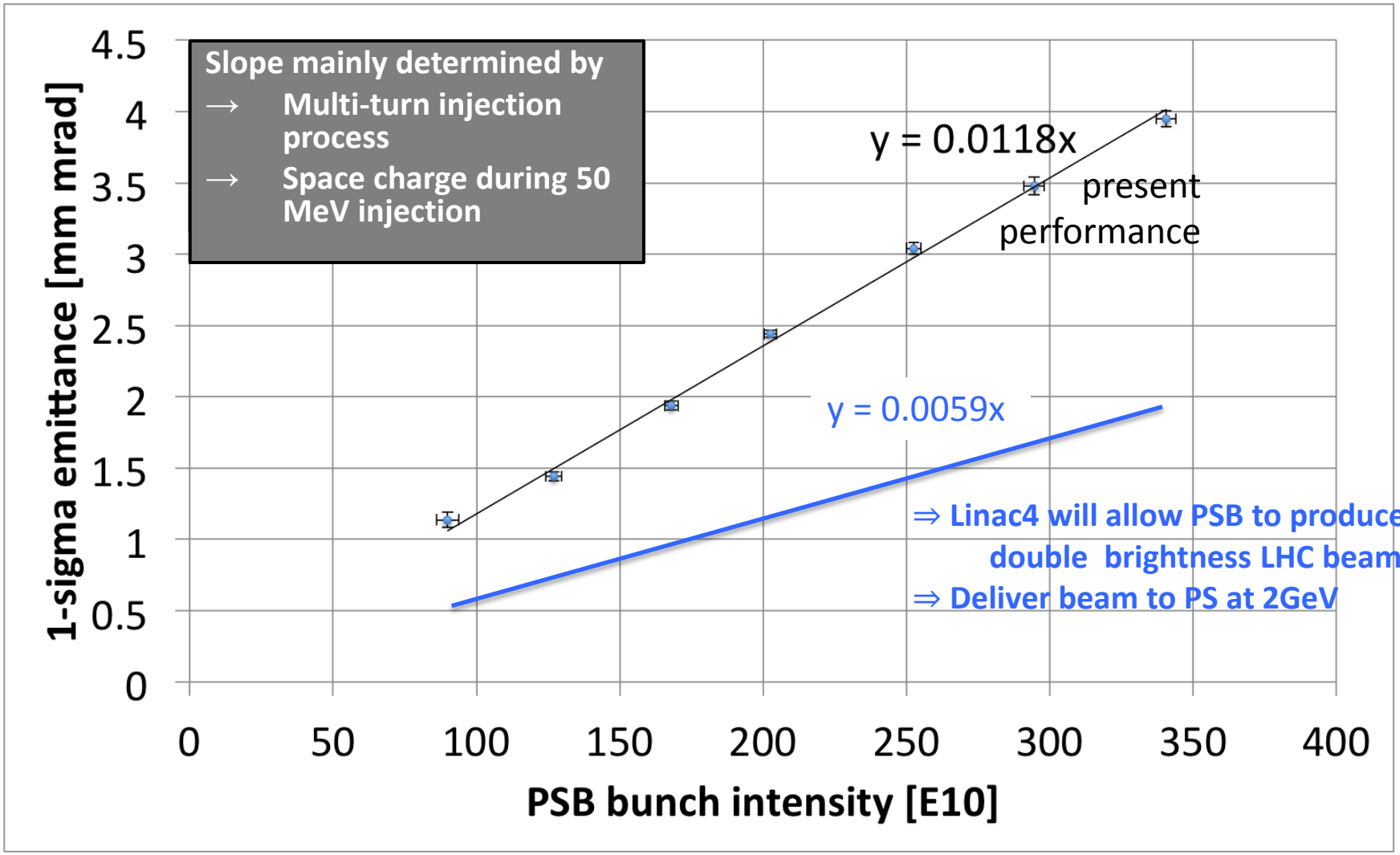
Details in A. Lombardi's talk

Ion species	H^-
Output Energy	160 MeV
Bunch Frequency	352.2 MHz
Max. Rep. Frequency	2 Hz
Max. Beam Pulse Length	0.4 ms
Max. Beam Duty Cycle	0.08 %
Chopper Beam-on Factor	65 %
Chopping scheme:	222 transmitted /133 empty buckets
Source current	80 mA
RFQ output current	70 mA
Linac pulse current	40 mA
Transverse emittance	0.4 π µm

Maximum repetition frequency of accelerating structures 50 Hz

- HL-LHC goal:
  ~28 turns → 3.4 10^{12} p/Ring in 1.7 µm
- High intensity ISOLDE
  ~100 turns → 14 10^{12} p/Ring

PSB performance
(LHC beam parameters @PSB extraction)



Key dates for LIU-PSB before LS2

Subject	Action	Date
Upgrade of main RF systems	New Finemet-based systems or upgrade of existing C02+C04 systems	Decision by end 2015
New H^- injection at 160 MeV from Linac 4	Mechanical mock-up. Half-sector test + stripping foil test	Scheduled mid 2016

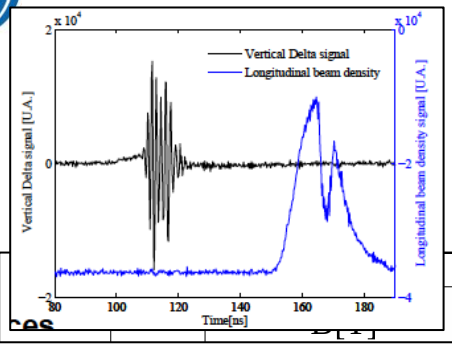
In terms of machine studies:

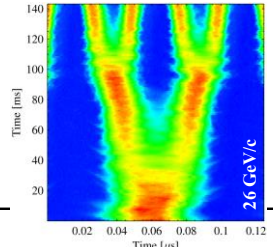
- 5 Finemet modules system successfully tested with beam in Ring 4 during Run 1
- 5 additional modules installed in PSB during LS1. Will be used for beam test throughout Run 2
- First review (with external reviewers) on 09/09/2014

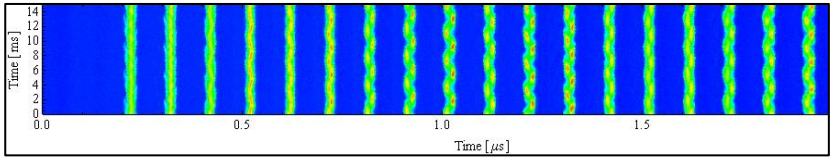
In terms of modelling:

- Simulations of injection into PSB from Linac4 to produce new brightness curve for LHC beams as well as study injection losses for high intensity beams
- Improve the optics model of the machine (linear and nonlinear)
- Improve the impedance model of the machine to study stability of future beams

PS brightness limitations overview

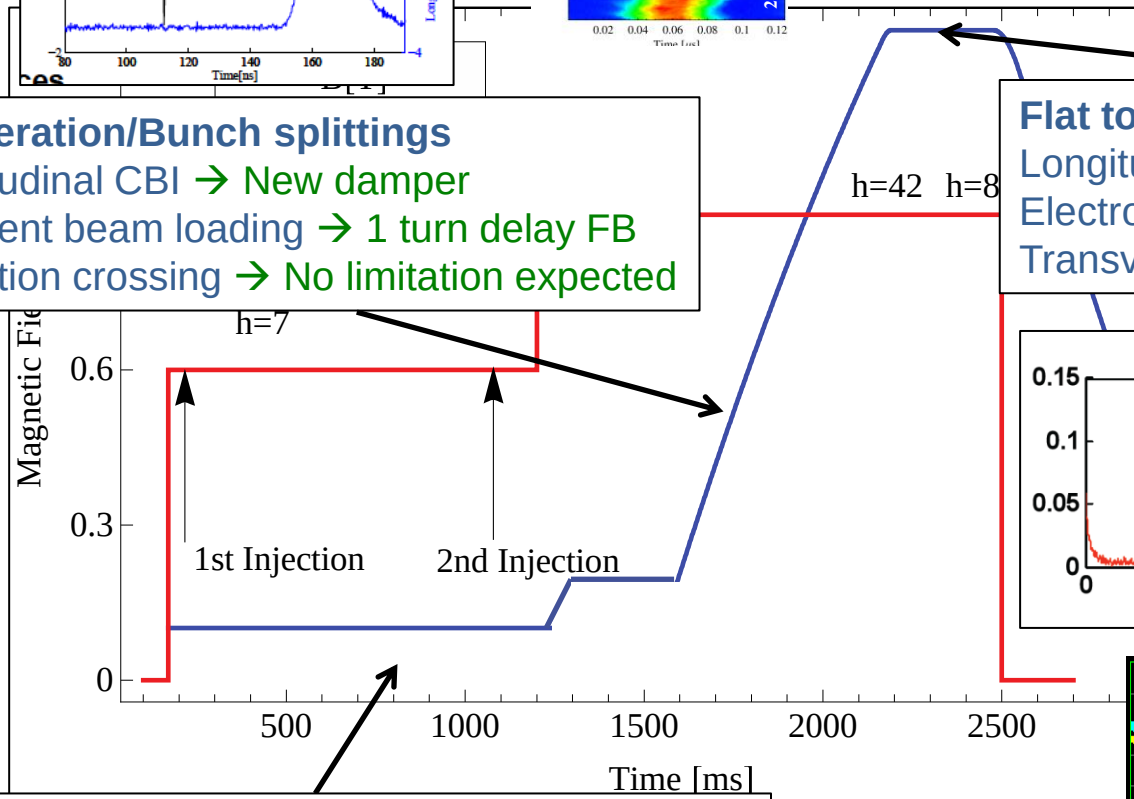


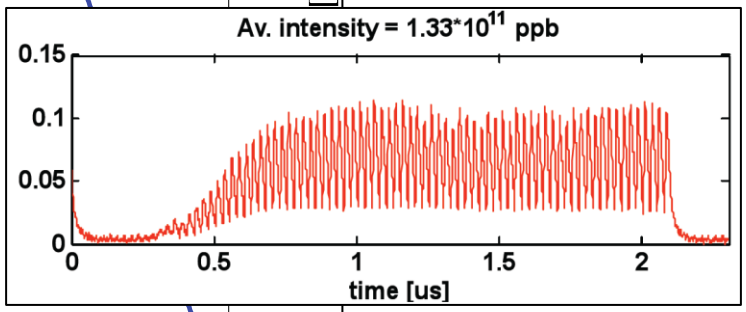


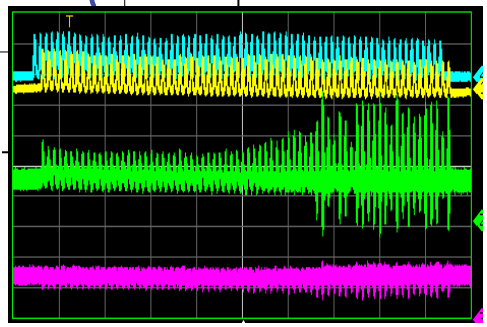


Acceleration/Bunch splittings
Longitudinal CBI → New damper
Transient beam loading → 1 turn delay FB
Transition crossing → No limitation expected

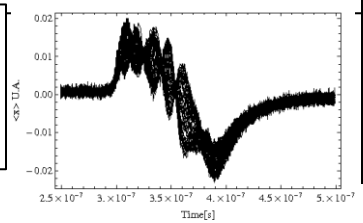
Flat top:
Longitudinal CBI → New damper
Electron cloud → Transverse FB
Transverse instabilities → Transverse FB



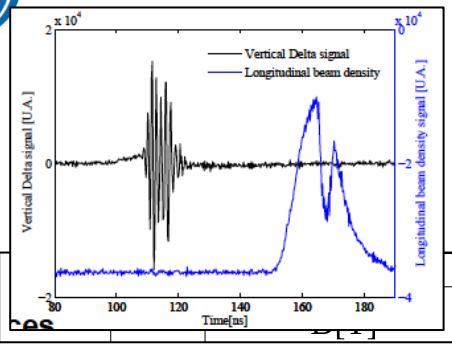


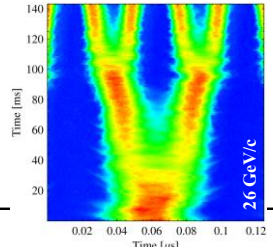


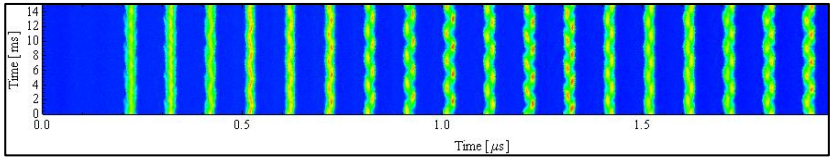
Injection flat bottom:
Space charge → Injection @2GeV
Headtail instability → Transverse FB



PS brightness limitations overview





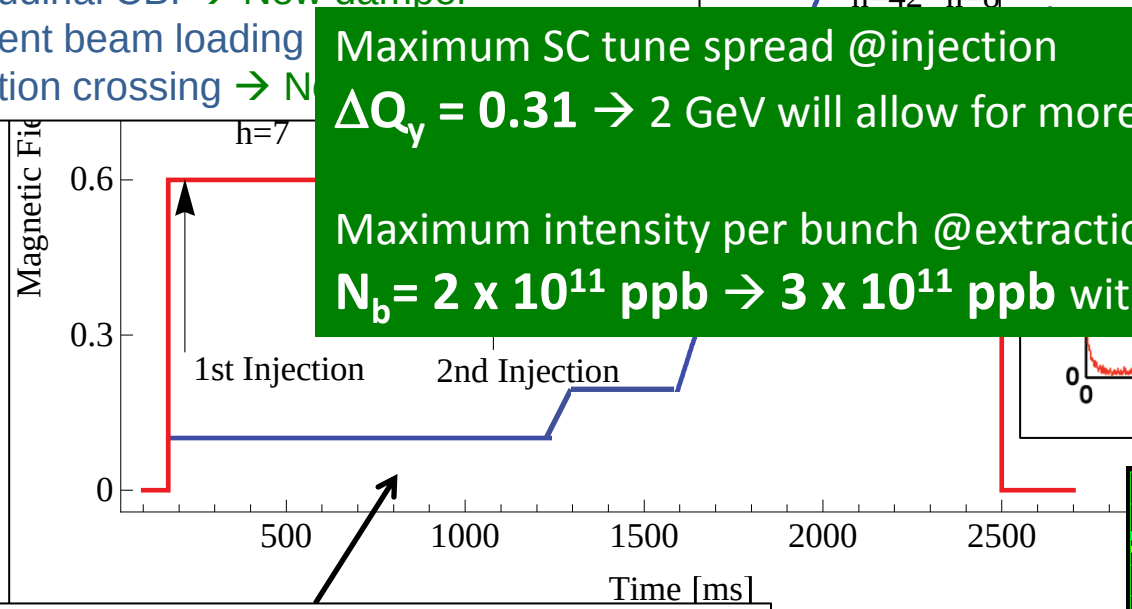


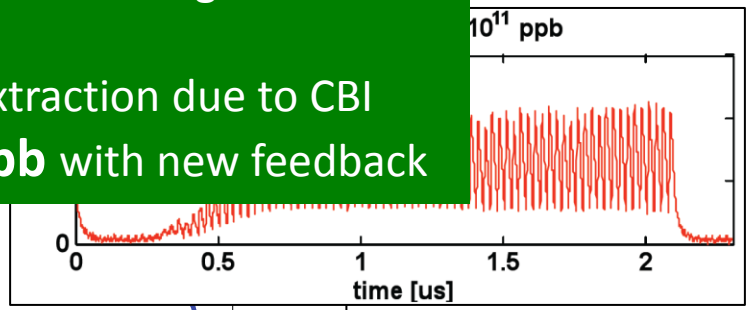
Acceleration/Bunch splittings
Longitudinal CBI → New damper
Transient beam loading
Transition crossing → N

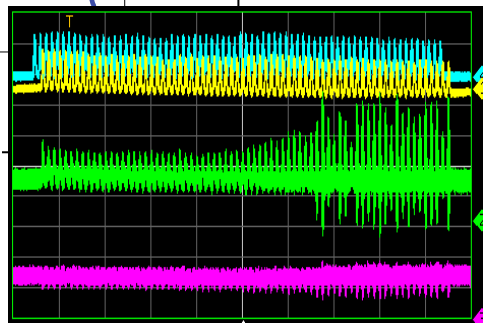
Flat top:
Longitudinal CBI → New damper
rse FB
Transverse FB

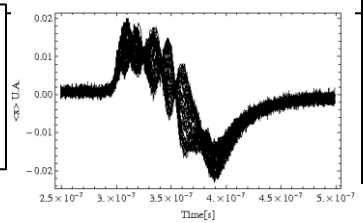
Maximum SC tune spread @injection
ΔQ_y = 0.31 → 2 GeV will allow for more brightness

Maximum intensity per bunch @extraction due to CBI
N_b= 2 x 10^{11} ppb → 3 x 10^{11} ppb with new feedback









Injection flat bottom:
Space charge → Injection @2GeV
Headtail instability → Transverse FB

Pending decisions for LIU-PS

Subject	Action	Decision date
Resonance compensation	New skew sextupoles and octupoles	Q4-2014
Increase of 40/80 MHz voltage for better capture in SPS	New C40 (C80) system	Q4-2014
Upgrade of main RF systems (beam loading performance)	New power amplifiers for C10 systems	Q1-2015

In terms of machine studies (and from LHC beam operation):

- Systematic study with re-installed octupoles will be done in 2014 (simulations predict that 4th order resonance is structure resonance)
- C40 (C80): Test to increase the power and voltage capability of existing cavities by installing new power supplies and changing the coupling
- C10: Studies to optimize feedbacks and beam loading behaviour of the existing systems (+ new one-turn delay feedback)
- Finemet cavity as wide-band kicker for longitudinal feedback already installed in the PS → Decisive tests on its potential will be conducted during Run 2

More PS machines studies in Run 2

In terms of machine studies and LHC beam operation:

- Operational development
  - ⟶ New production scheme for LHC beams (longer bunches, larger longitudinal emittances from PSB) → covered in **Y. Papaphilippou's talk**
  - ⟶ New RF manipulation schemes, i.e. pure batch compression (PBC) and 8b+4e
  - ⟶ 80+ bunch scheme (production/extraction schemes)
- Nonlinear optics model of the machine
- Space charge
  - ⟶ Special high dispersion optics
  - ⟶ Fully coupled optics
  - ⟶ Hollow bunches (together with PSB)
- TMCI at transition
- Electron cloud:
  - ⟶ Parameter studies with new electron cloud monitors (direct observation)
  - ⟶ Beam instability for larger bunch currents
  - ⟶ Effect of uniformly filled machine (80+ bunch transfer scheme)
- Impedance model via dedicated beam measurements

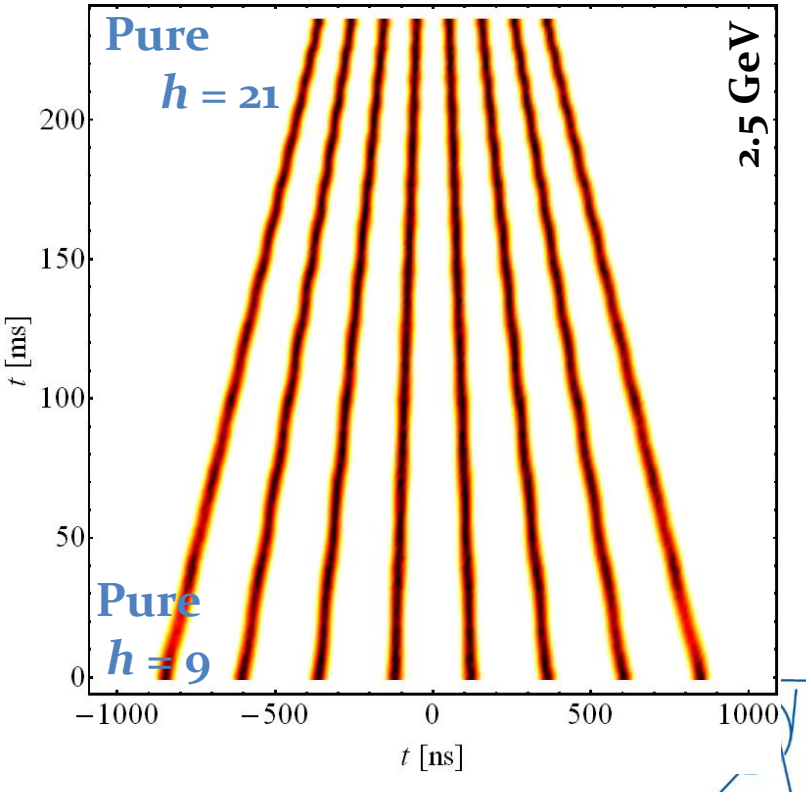
Pure batch compression (PBC) scheme

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 (11% lower # of bunches in LHC)
→ Trains of 16 bunches of 50 ns beams can also be produced

Potential production of ultra-bright 25 ns (and 50 ns) beams

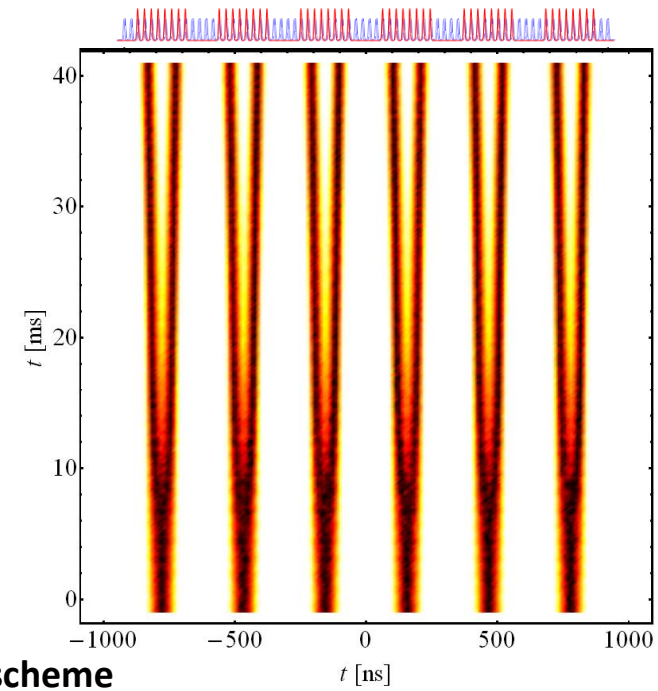
→ Relaxed electron cloud in downstream machines (due to short trains)
→ Interesting for space charge studies in SPS
→ Studies on transport of sub-µm emittances through injection chain



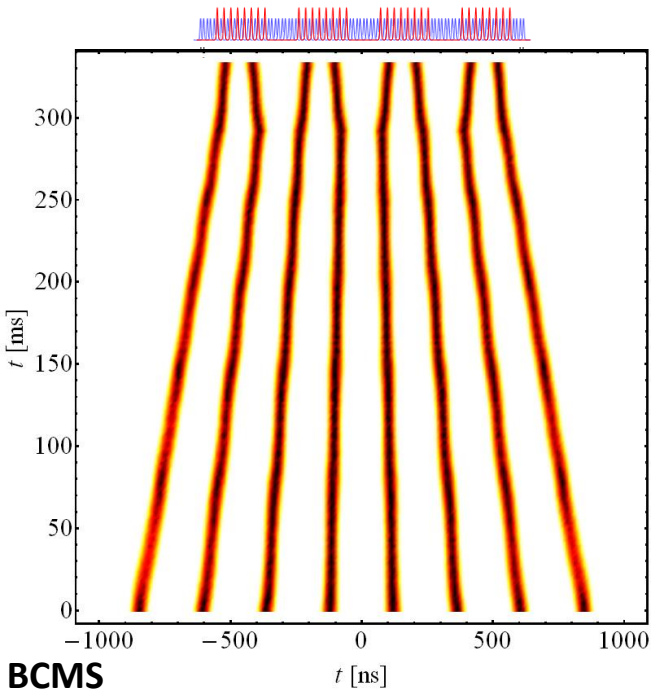
8b+4e scheme

- Creates trains with 4 missing bunches every 8 bunches (H. Damerau, RLIUP)
  - Allows accelerating higher intensity bunches in the SPS
  - Is expected to reduce e-cloud effects

  - Standard scheme → Double split from h= 7 to h= 21, leaving empty bucket – bunch pattern 6x(8b+4e) + 8b. This beam has been produced at the PS (H. Damerau, 2014)
  - BCMS → merging and triple splitting suppressed – bunch pattern 3x(8b+4e) + 8b

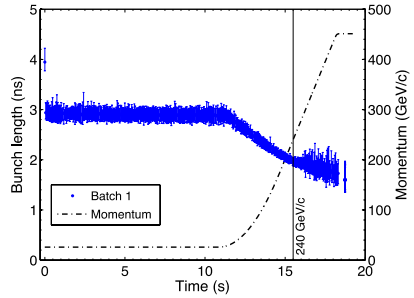


Standard scheme

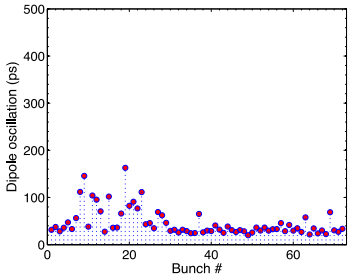


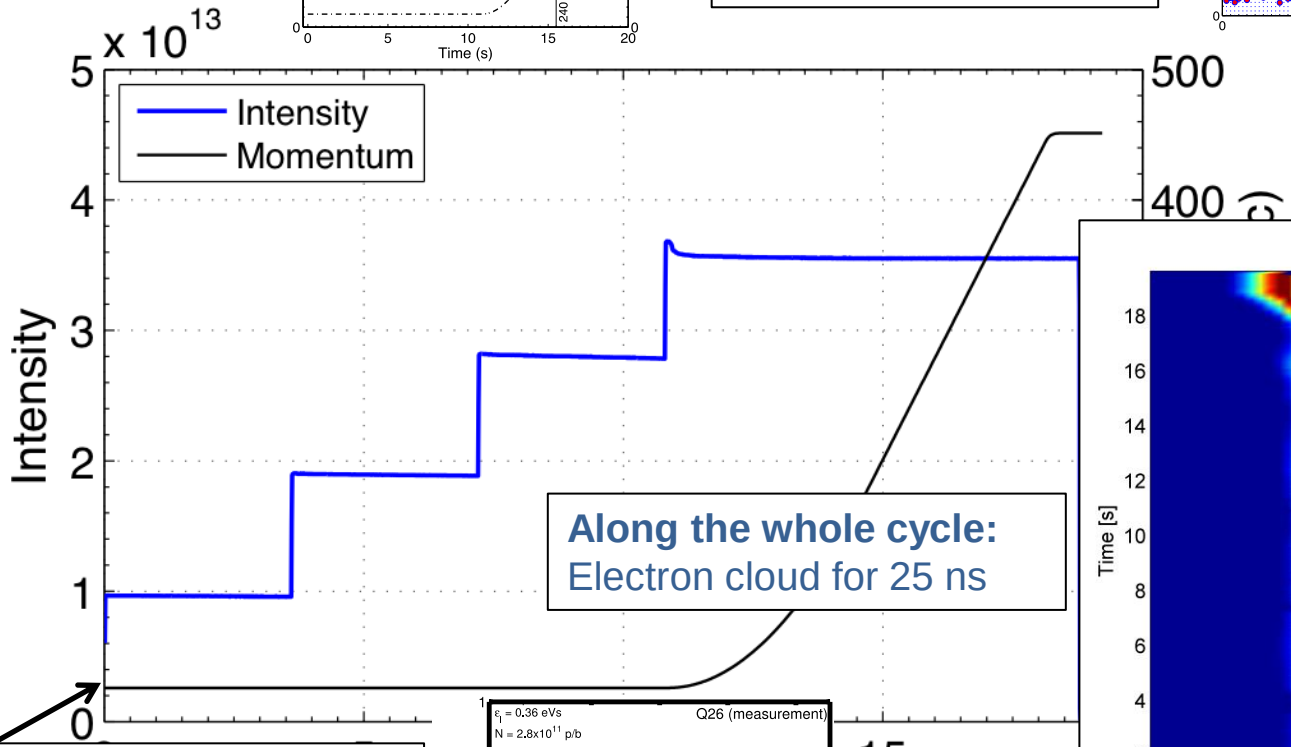
BCMS

SPS limitations overview

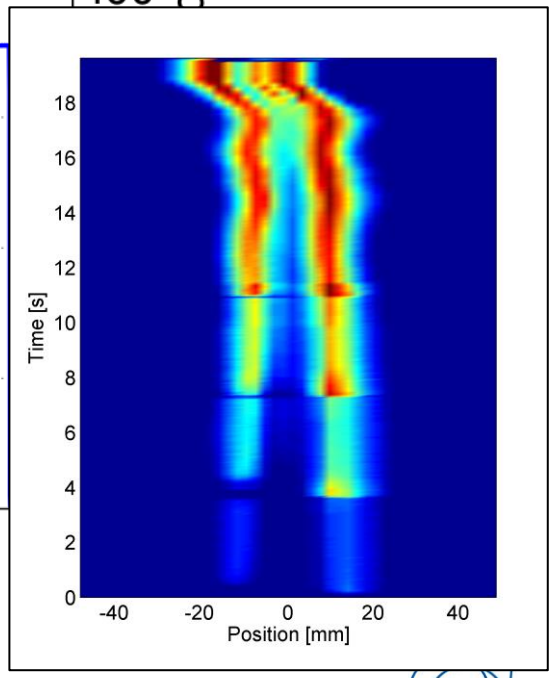


Ramp and flat top:
Longitudinal instability
Beam loading
RF power

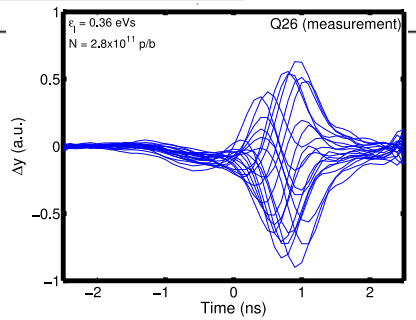




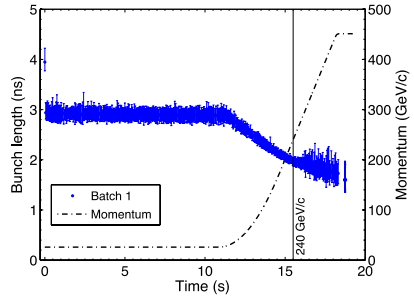
Along the whole cycle:
Electron cloud for 25 ns



Injection flat bottom:
Capture losses, incoherent losses
Space charge
TMCI



SPS limitations overview



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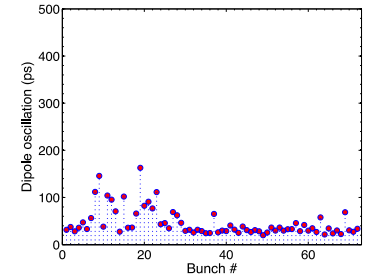
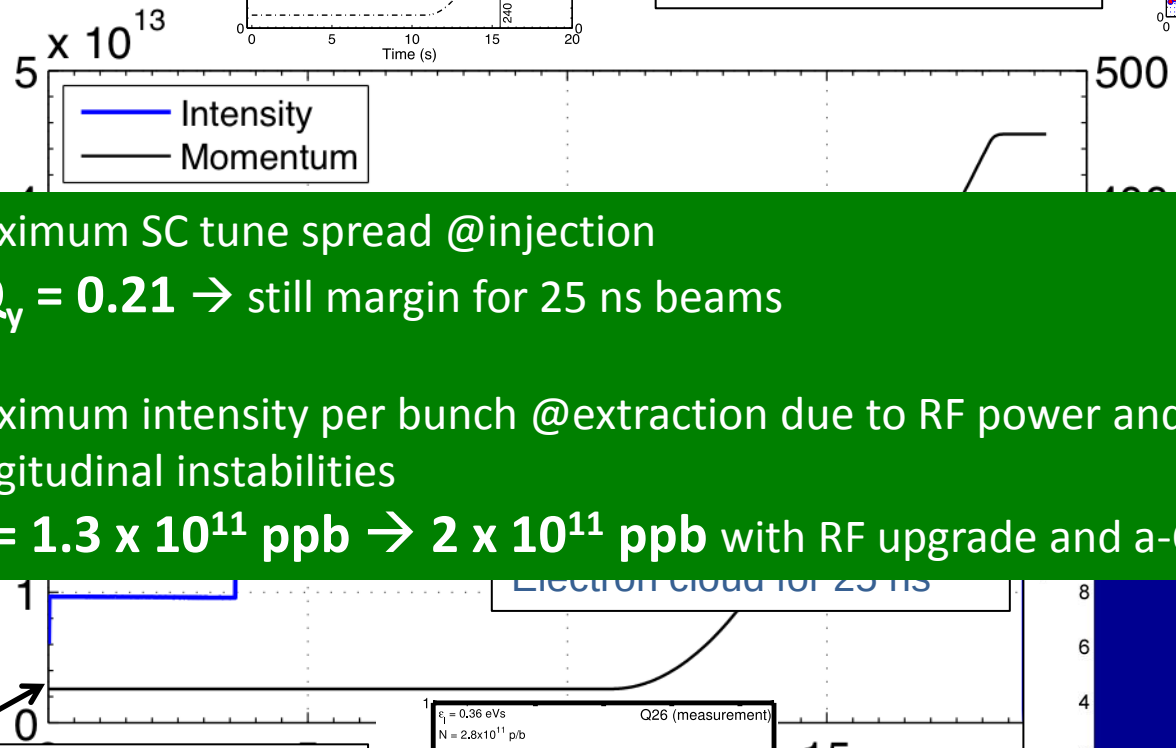
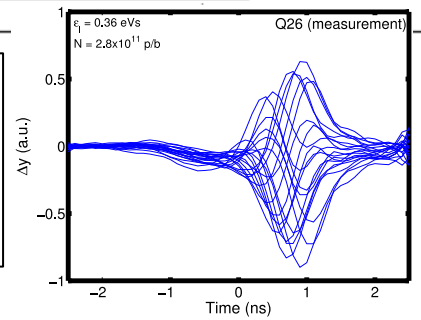
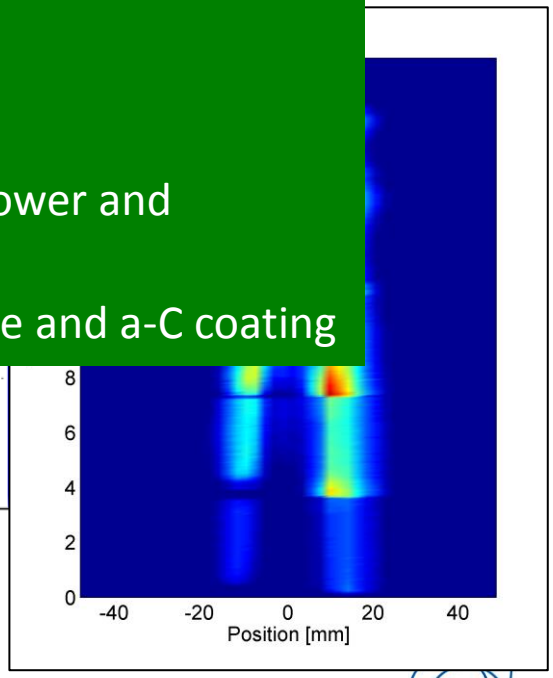




Maximum SC tune spread @injection
ΔQ_y = 0.21 → still margin for 25 ns beams

Maximum intensity per bunch @extraction due to RF power and longitudinal instabilities
N_b= 1.3 x 10^{11} ppb → 2 x 10^{11} ppb with RF upgrade and a-C coating





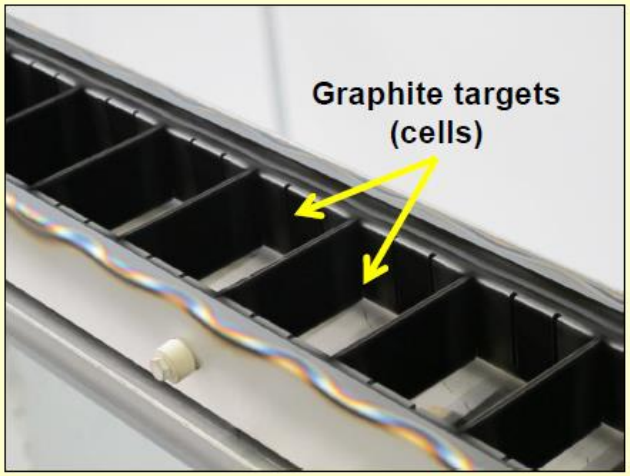
Injection flat bottom:
Capture losses, incoherent losses
Space charge
TMCI

Key dates for LIU-SPS before LS2

Subject	Action	Decision date
Electron cloud mitigation	a-C coating of vacuum chambers	Mid 2015 (with external reviewers)
Damping of intra-bunch instabilities	New Wide-band (GHz) transverse damper	End 2016 (CERN/LARP review with external experts)
Machine impedance reduction	Improved shielding of ZS, pumping modules , etc. Shielding/mode damping/redesigning vacuum flanges. Kicker design.	End 2015
Improvement of operation/reduction of irradiation	New external (high energy) beam dump	Q4-2014 to start civil engineering for LS2

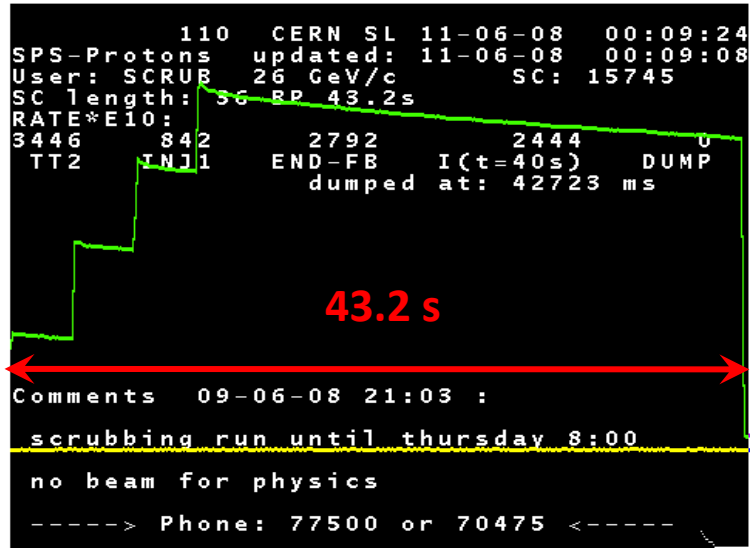
E-cloud mitigation (a-C coating)

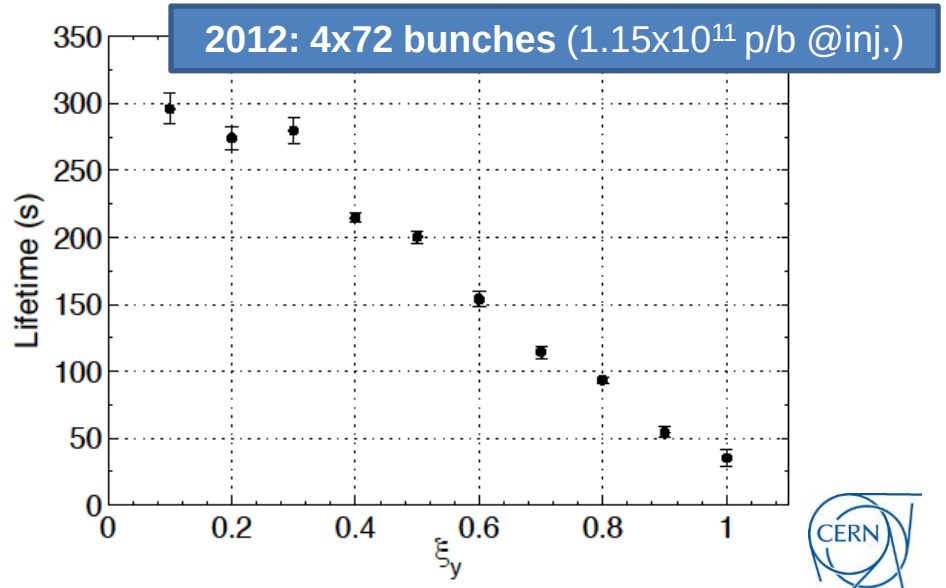
- Thin film of a-C provides intrinsically low Secondary Electron Yield
  - Suppression of e-cloud in prototype chambers demonstrated with beam in SPS
  - 4 SPS half cells (including quadrupoles) with a-C coating ready for the startup in 2014 → further tests with beam



E-cloud mitigation (scrubbing)

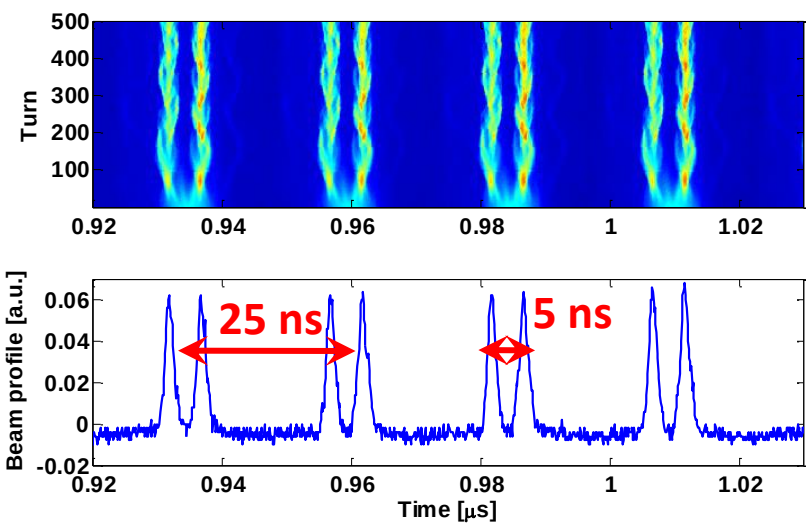
- Thin film of a-C provides intrinsically low Secondary Electron Yield
  - Suppression of e-cloud in prototype chambers demonstrated with beam in SPS
  - 4 SPS half cells (including quadrupoles) with a-C coating ready for the startup in 2014 → further tests with beam
- Scrubbing lowers SEY with accumulated dose (machine time)
  - Dedicated runs (1 to 2 weeks) performed at 26 GeV in cycling mode (~40 s cycle length) – about 40 days integrated time from 2002 (see talk on SPS scrubbing run)
  - Additional scrubbing accumulated during 25 ns MDs
  - 25 ns beam preserved "within budgets" in the SPS from 2011 onwards

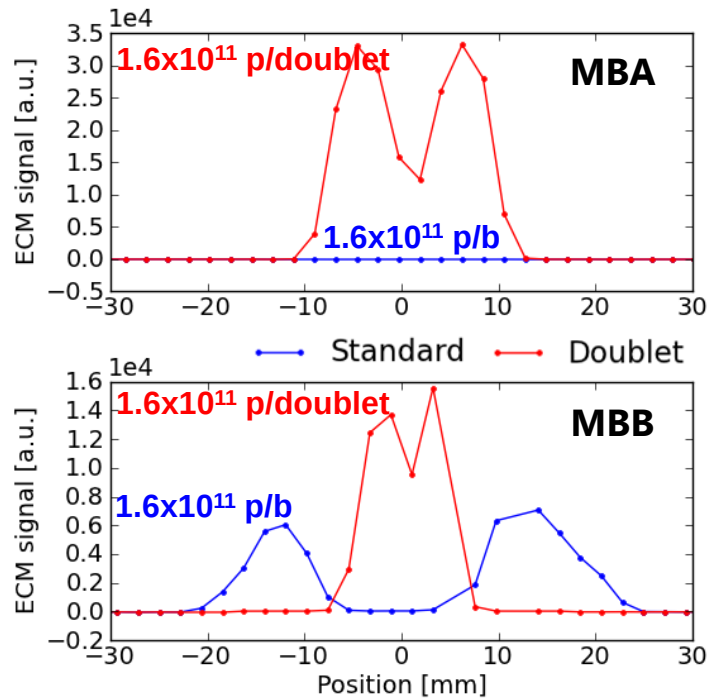




Doublet beam: a possible boost to scrubbing

- Injection of long bunches into SPS (with 25 ns spacing)
- Capturing each bunch in 2 neighboring 200 MHz buckets
- **Successfully tested in MDs** at the end of 2012/13 run with 1.6×10^{11} p/doublet
- Clear enhancement on **e-cloud detectors** compared to standard 25 ns beam measured





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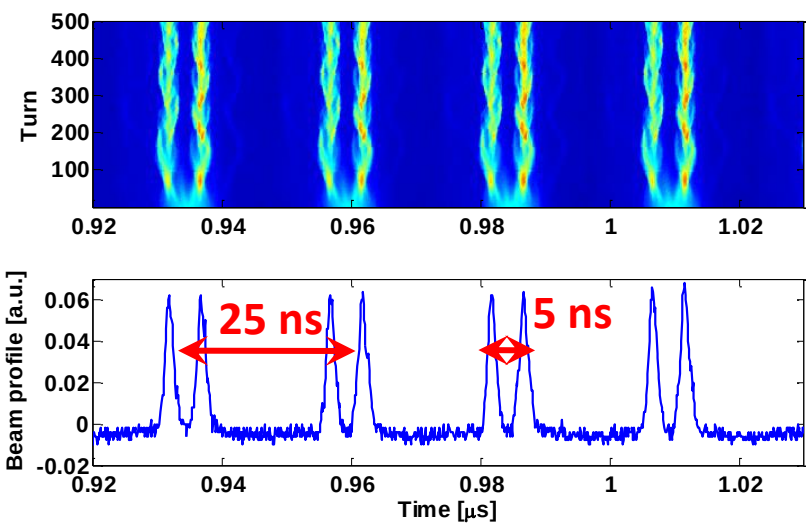
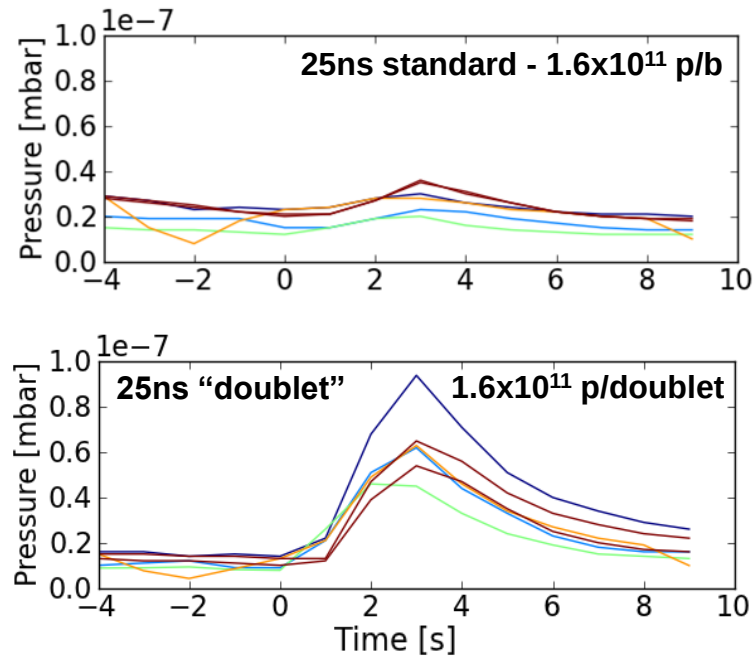
- Clear enhancement on **e-cloud detectors** compared to standard 25 ns beam measured
- Enhanced **pressure rise compared to standard 25 ns beam measured in the arcs**





Scrubbing or coating? A possible strategy …

Nov.

Dec.

2014

Mar.

2015

Jun.

SCRUBBING RUN I (1 week + 2 days)
beams: nominal intensity
Goal: recover the 2012 performance and test doublet beam

SCRUBBING RUN II (2 weeks)
Gradually increase intensity up to 2e11 p/b
Scrubbing successful for high intensity?

YES

NO

LIU-SPS Review: coating?
(after data analysis!)

a-C coating (during LS2)

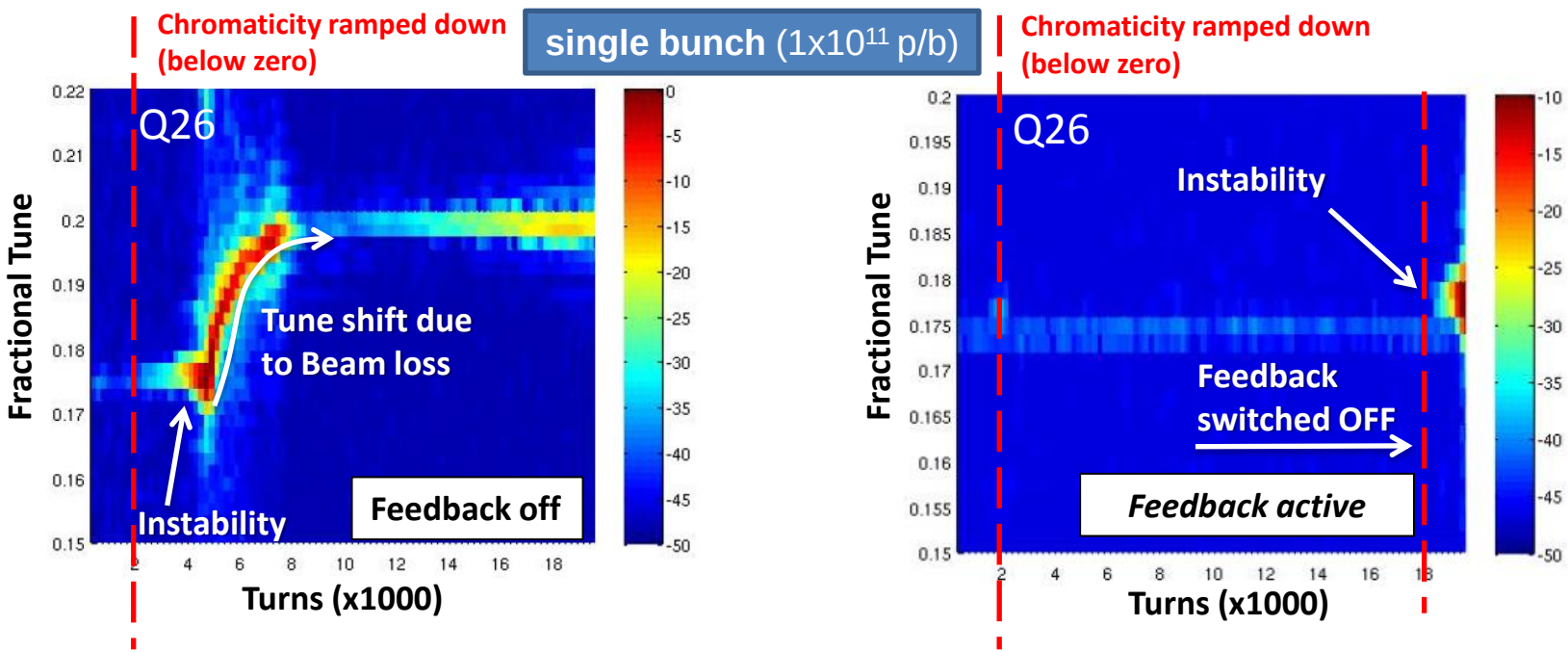
- **Scrubbing qualification**: No degradation for 2e11 p/b with 4x72 bunches and 5x48 bunches
- Results from the **4 coated half cells**
- Simulations for **higher brightness beams** (from Linac4)

High bandwidth transverse feedback (CERN/LARP)

see also LIU SPS High Bandwidth Feedback review

- High bandwidth (intra-bunch) feedback
  - It can suppress electron cloud induced coherent motion
    - Make scrubbing more efficient → Improve beam quality and stabilize pi-mode in doublets
    - Avoid running with high chromaticity settings → better beam lifetime and emittances
  - Was shown to work for dipole mode in 2012/2013 machine studies

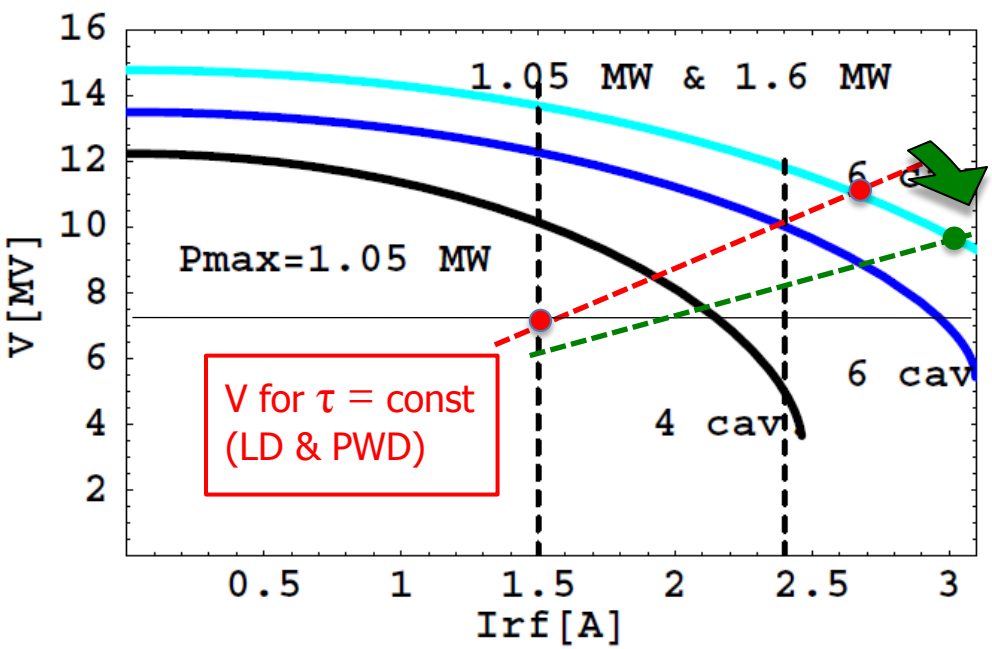
- LARP support to be defined for the future
  - 2014 – 2015: Hardware upgrade for demo system, operation of wideband stripline kicker with two R&K amplifiers and support for machine studies during Run 2 (people, MD analysis tools)
  - Resources for electromagnetic design of slotline kicker are being clarified



Impedance reduction

- Longitudinal plane
  - After full RF upgrade: 4 cavities with 1.05 MW & 2 cavities with 1.6 MW → 2.0×10^{11} p/b (scaling to preserve bunch length at extraction based on present understanding)
  - Identifying and reducing longitudinal impedance would allow for larger accelerated intensity → **Big effort in machine studies + impedance modeling – ongoing**
- Transverse plane
  - Reduction of transverse impedance entails an increase of TMCI threshold @inj ➔ Makes possible use with larger γ_t optics loosening constraint on RF power

(see **talks by H. Bartosik and T. Argyropoulos**)



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- Impact of the foreseen LIU improvements on performance of LHC injector synchrotrons and studies required in Run 2
  - PSB
  - PS
  - SPS
- Parameter reach for LIU beams
  - New beams after LS1: pure batch compression (PBC), 8b+4e, doublet
  - LHC beams after the full upgrade (LS2)
- Conclusions

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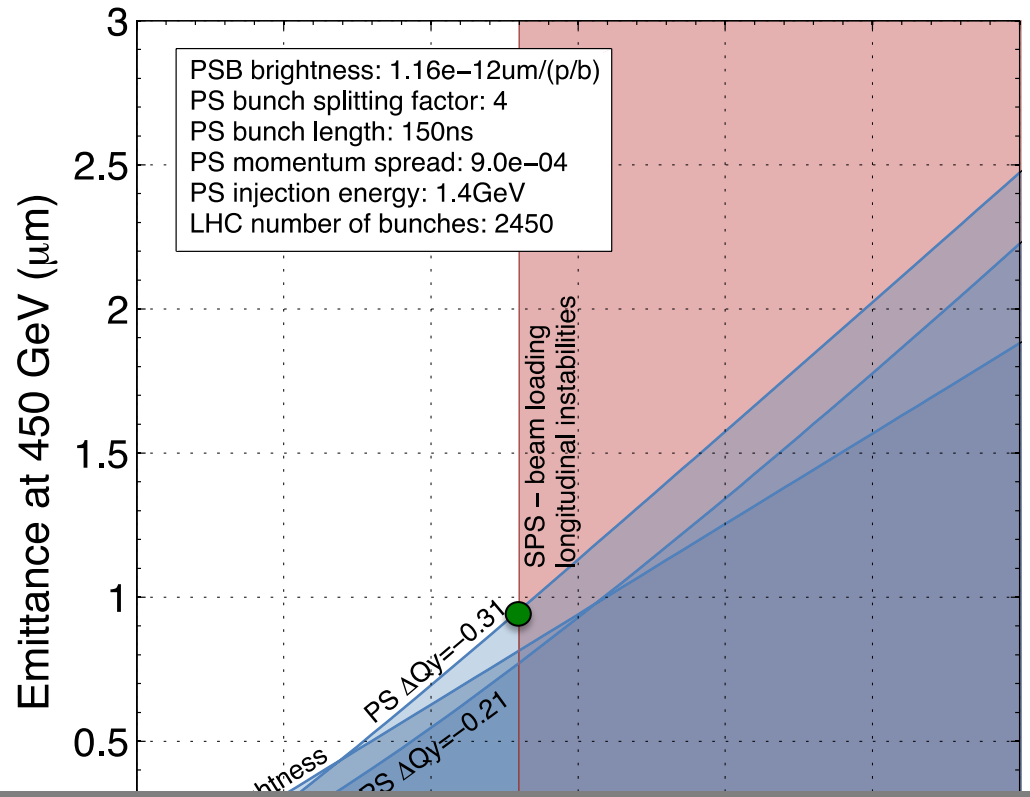
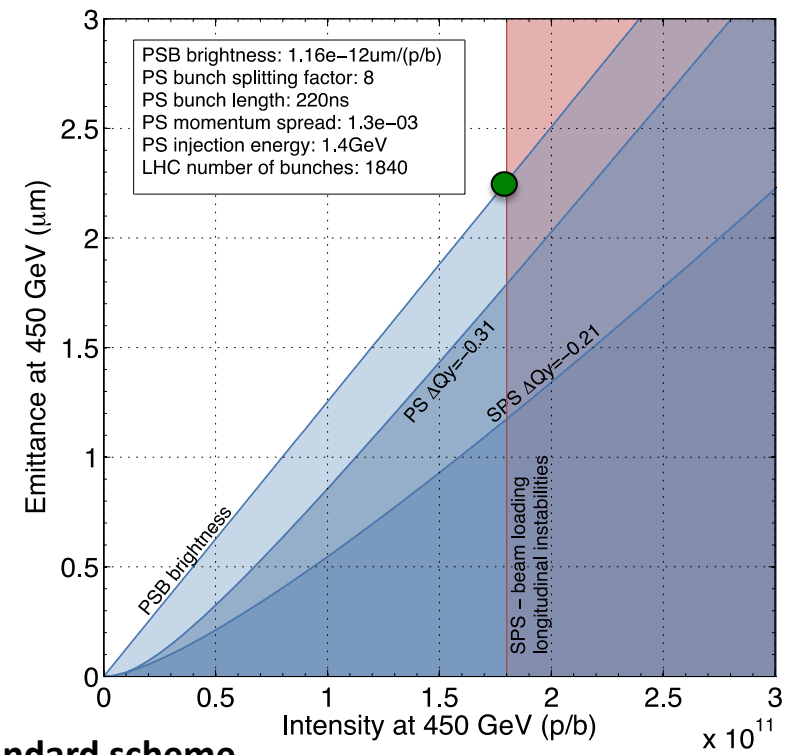
Pure batch compression (PBC) scheme



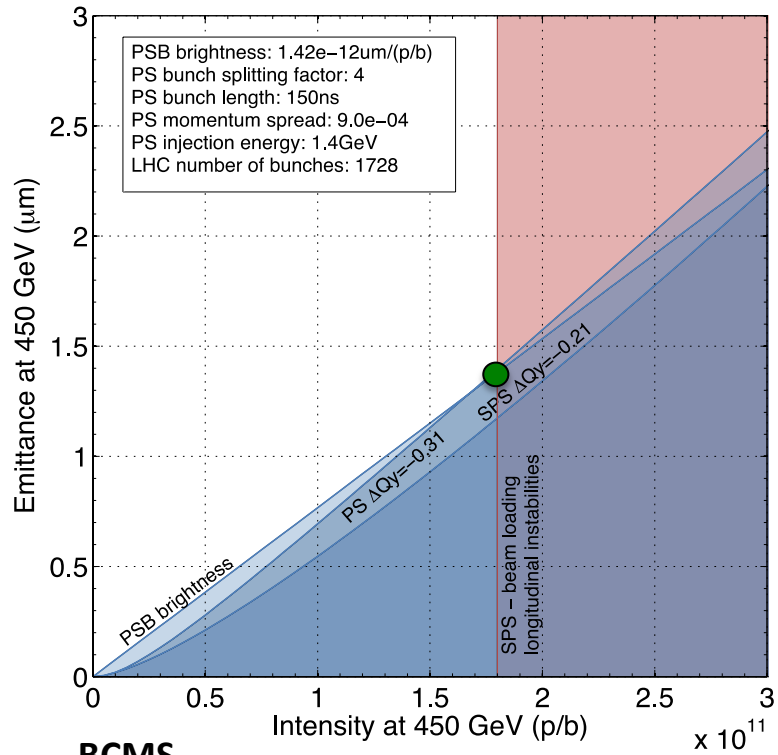
PBC	Intensity (p/b)	Emittance (μm)	Bunch pattern
25 ns	1.3×10^{11}	0.95	32b

8b+4e

- Limited to 1.8 x 10^{11} p/b in the SPS because of longitudinal instabilities
- Brightness limited by
  - → PSB brightness for standard scheme
  - → No outstanding bottleneck for BCMS



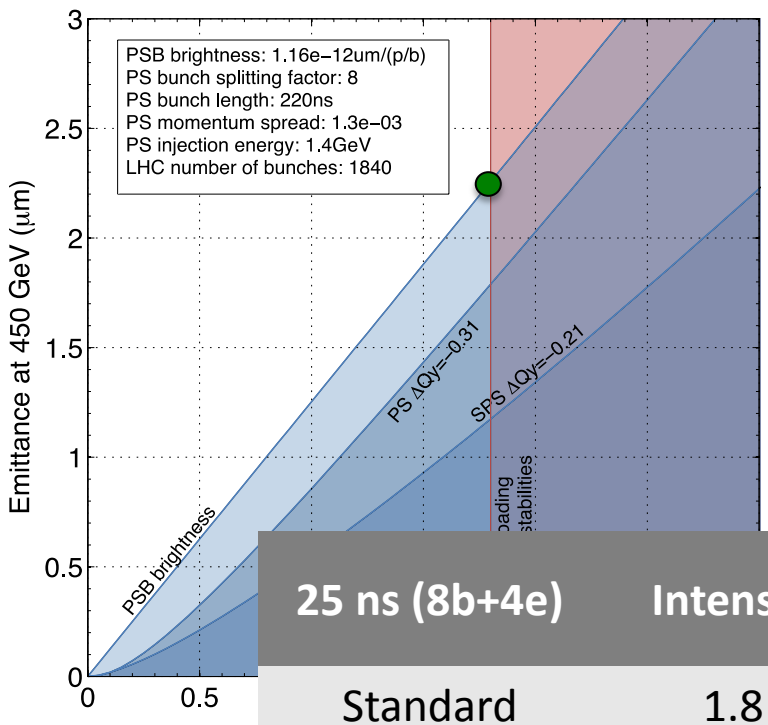
Standard scheme

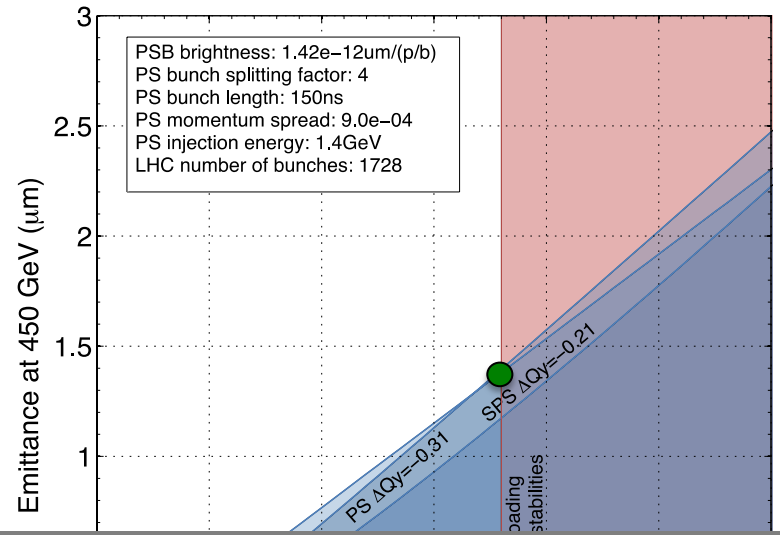


BCMS

8b+4e

- Limited to 1.8 x 10^{11} p/b in the SPS because of longitudinal instabilities
- Brightness limited by
  - → PSB brightness for standard scheme
  - → No outstanding bottleneck for BCMS

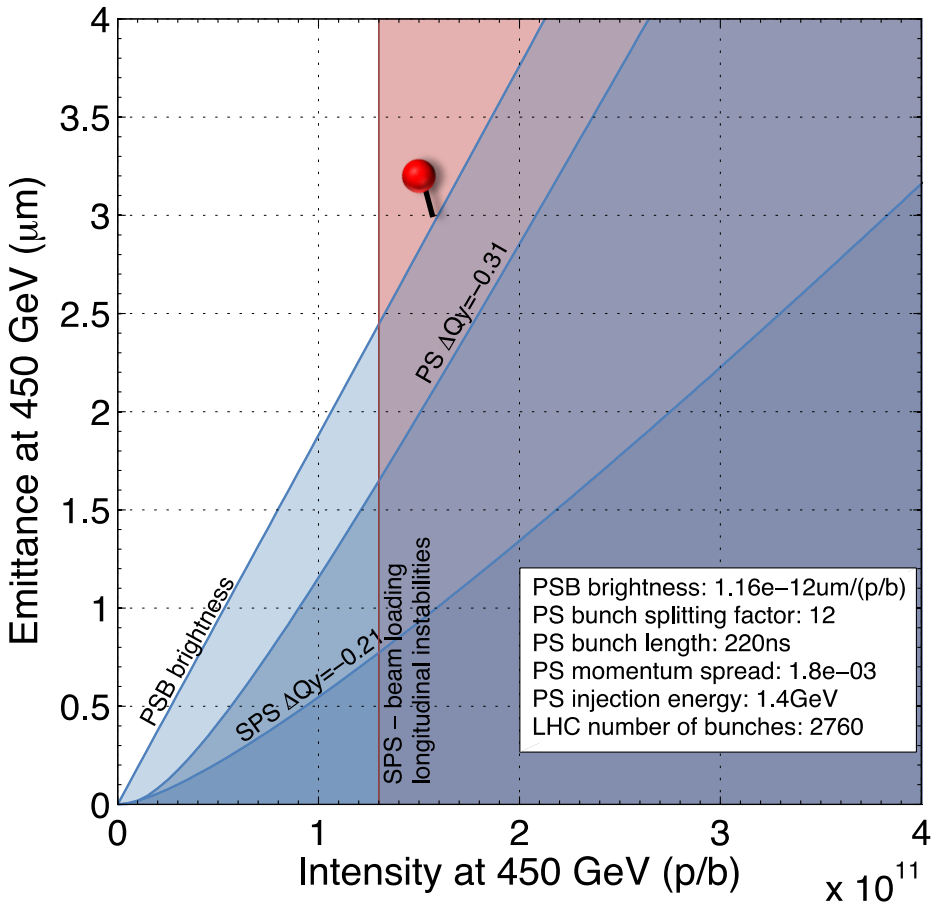




Standard scheme

25 ns (8b+4e)	Intensity (p/b)	Emittance (μm)	Bunch pattern
Standard	1.8 x 10^{11}	2.3	6x(8b+4e) + 8b
BCMS	1.8 x 10^{11}	1.4	3x(8b+4e) + 8b

Doublet beam



- We need to accelerate **1.6 x 10^{11} p/doublet** in the SPS
  - $\varepsilon_{x,y}$ ~3 μm at best at injection
  - RF power and longitudinal instability limitation in the SPS → intensity perhaps achievable with a 3x slower ramp rate, tentatively on Q20
  - Longitudinal emittance about 0.4 eVs at injection from simulations (J. Esteban-Müller)
  - Beam quality possibly degraded due to e-cloud and longitudinal limitations
- Need to gain experience in the SPS with dedicated MDs in 2014 for complete parameter list at flat top

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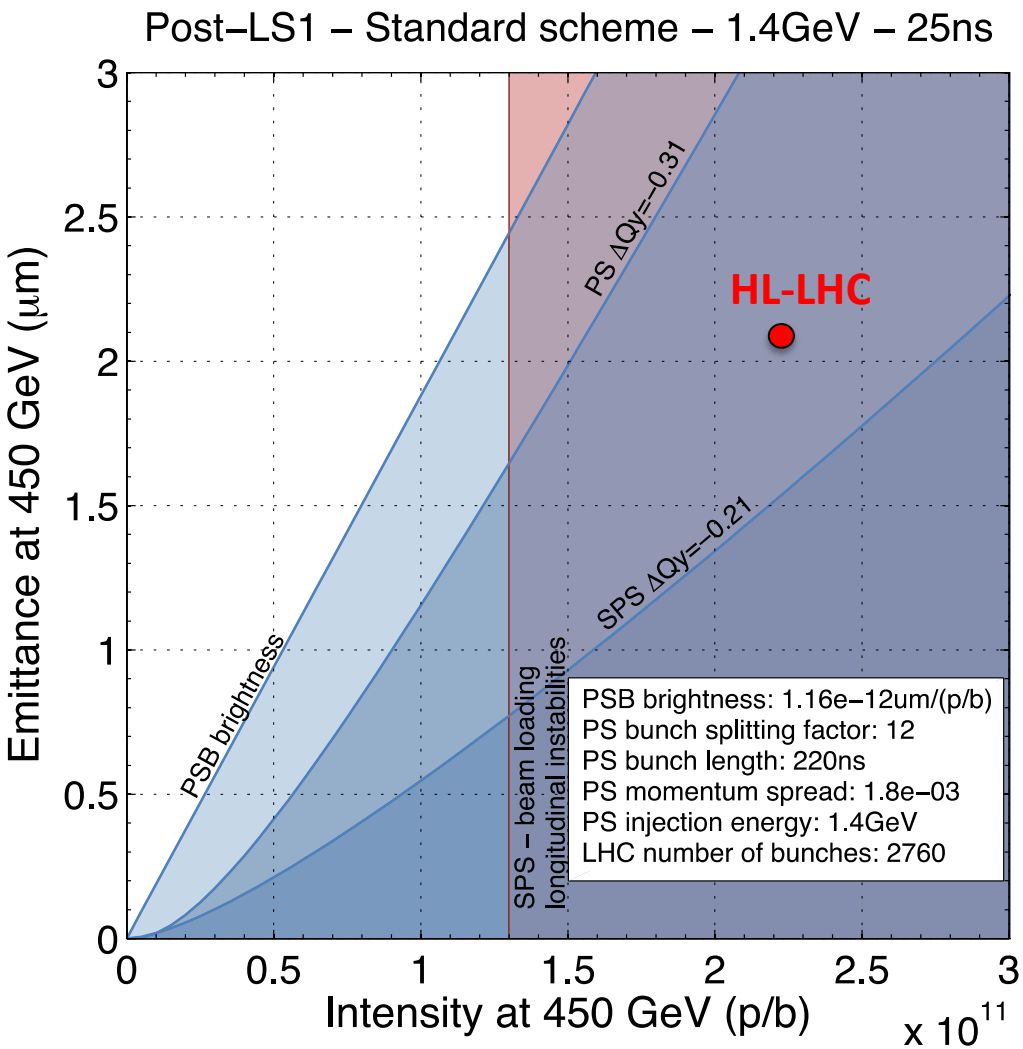
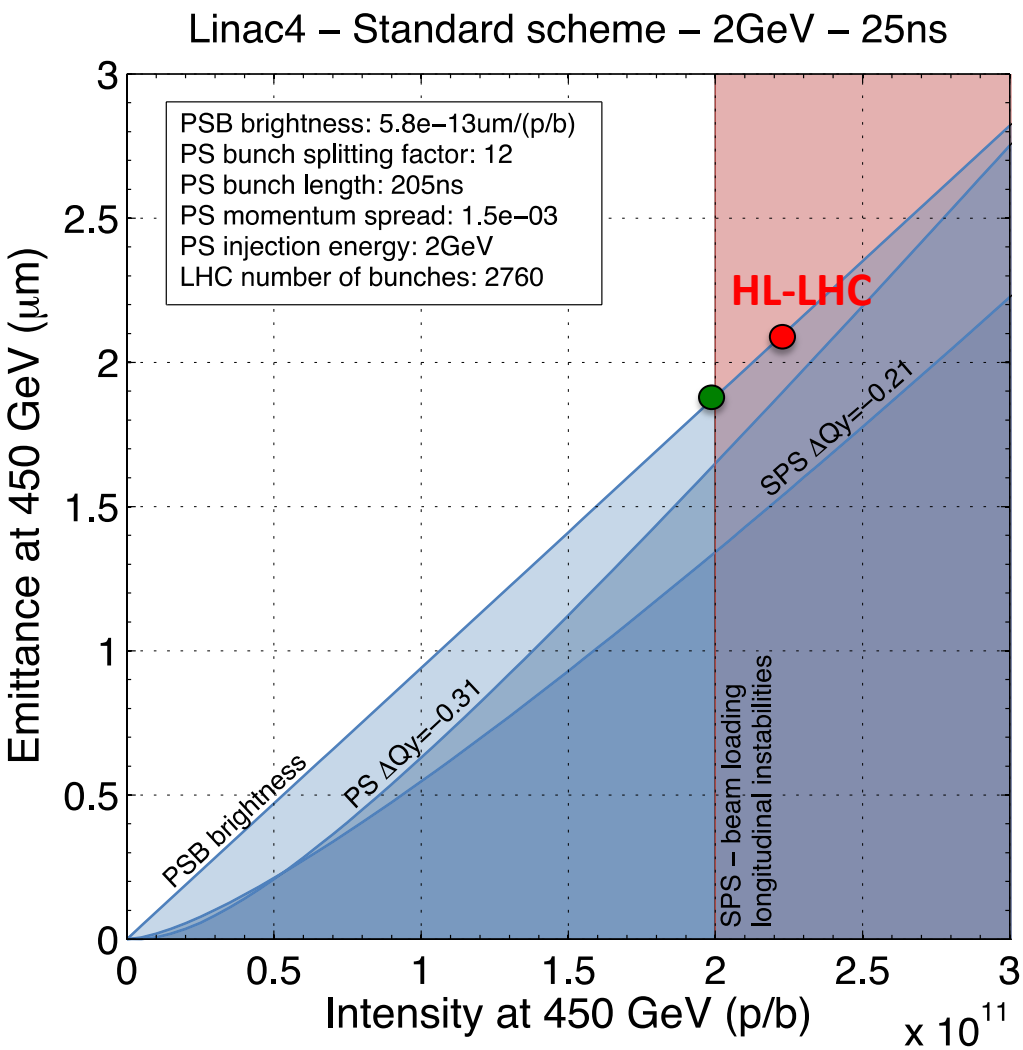
Standard scheme (72b trains) after LS2

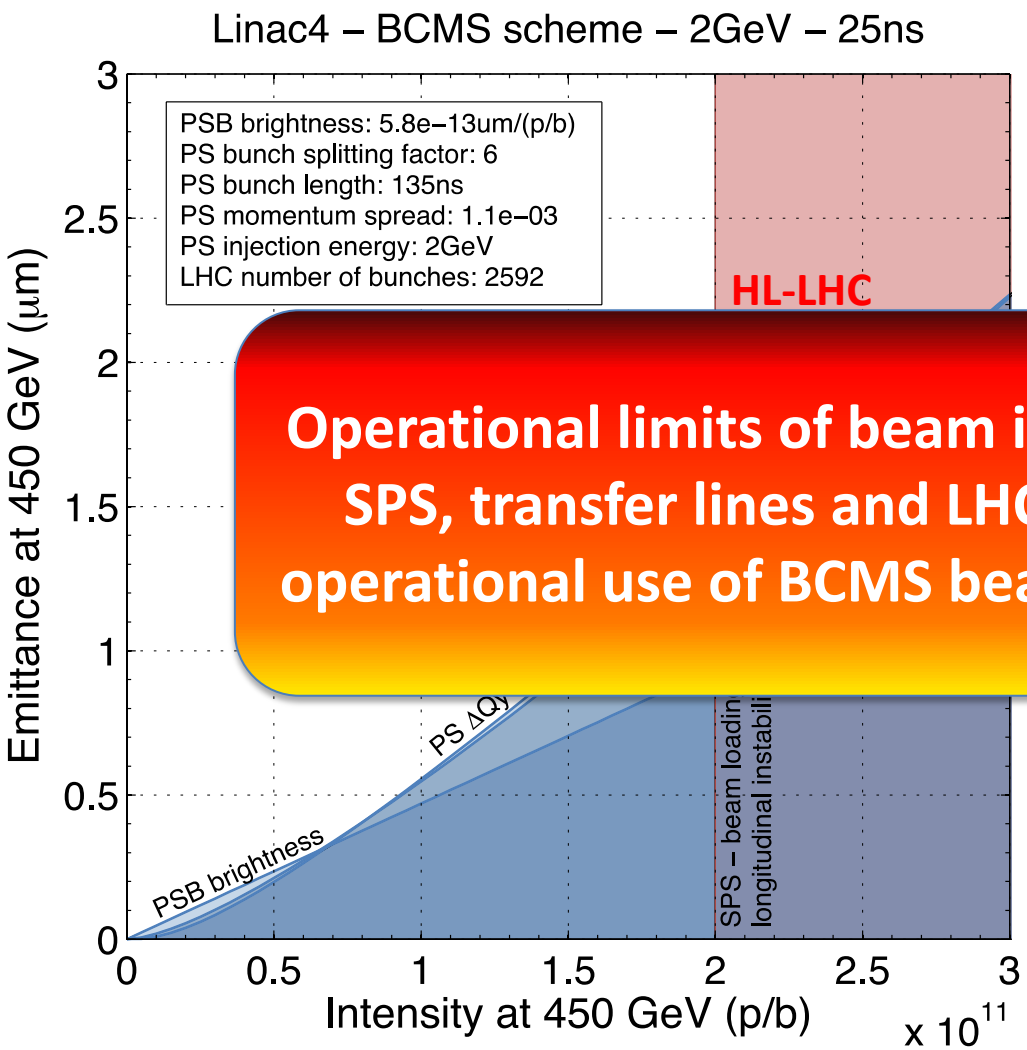


Standard scheme (72b trains) after LS2



- With Linac 4
- LIU upgrades
  - SPS 200 MHz upgrade
  - SPS e-cloud mitigation
  - PSB-PS transfer at 2 GeV
- Limitations standard scheme
  - SPS: longitudinal instabilities + beam loading
  - PSB: brightness
- Performance reach
  - 2.0×10^{11}p/b in 1.88μm (@ 450GeV)
  - 1.9×10^{11}p/b in 2.26μm (in collision)

BCMS scheme (48b trains) after LS2



- With Linac 4
- LIU upgrades
  - SPS 200 MHz upgrade
  - SPS e-cloud mitigation
  - 2 GeV

Operational limits of beam intercepting devices in SPS, transfer lines and LHC will determine the operational use of BCMS beams (see V. Kain's talk)

heme

nstabilities

- Performance reach
  - 2.0×10^{11} p/b in 1.37μm (@ 450GeV)
  - 1.9×10^{11} p/b in 1.65μm (in collision)

Overview on post LS2 LIU parameters

		PSB						
		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
LIU	Standard	29.55	1.55	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.55, 0.66)
	BCMS	14.77	1.13	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.35, 0.44)
HL-LHC		34.21	1.72	0.16	1.4	650	$1.8 \cdot 10^{-3}$	(0.58, 0.69)

		PS (double injection)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
LIU	Standard	28.07	1.63	2.0	3.00	205	$1.5 \cdot 10^{-3}$	(0.16, 0.28)
	BCMS	14.04	1.19	2.0	1.48	135	$1.1 \cdot 10^{-3}$	(0.19, 0.31)
HL-LHC		32.50	1.80	2.0	3.00	205	$1.5 \cdot 10^{-3}$	(0.18, 0.30)

		SPS (several injections)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
LIU	Standard	2.22	1.71	26	0.37	3.0	$1.5 \cdot 10^{-3}$	(0.09, 0.16)
	BCMS	2.22	1.25	26	0.37	3.0	$1.5 \cdot 10^{-3}$	(0.12, 0.21)
HL-LHC		2.57	1.89	26	0.37	3.0	$1.5 \cdot 10^{-3}$	(0.10, 0.17)

		LHC					
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)	bunches/train
LIU	Standard	2.00	1.88	450	0.60	1.65	72
	BCMS	2.00	1.37	450	0.60	1.65	48
HL-LHC		2.32	2.08	450	0.65	1.65	72

Parameter overview and main conclusions

LIU beams (during Run 2)	Intensity @SPS extraction	Normalized transverse emittance @SPS extraction
PBC (32 bunches/PS batch)	1.3×10^{11} p/b	0.95 µm
Standard 8b+4e (56 bunches/PS batch)	1.8×10^{11} p/b	2.3 µm
Doublet (72 doublets/PS batch)	1.6×10^{11} p/b	> 3 µm

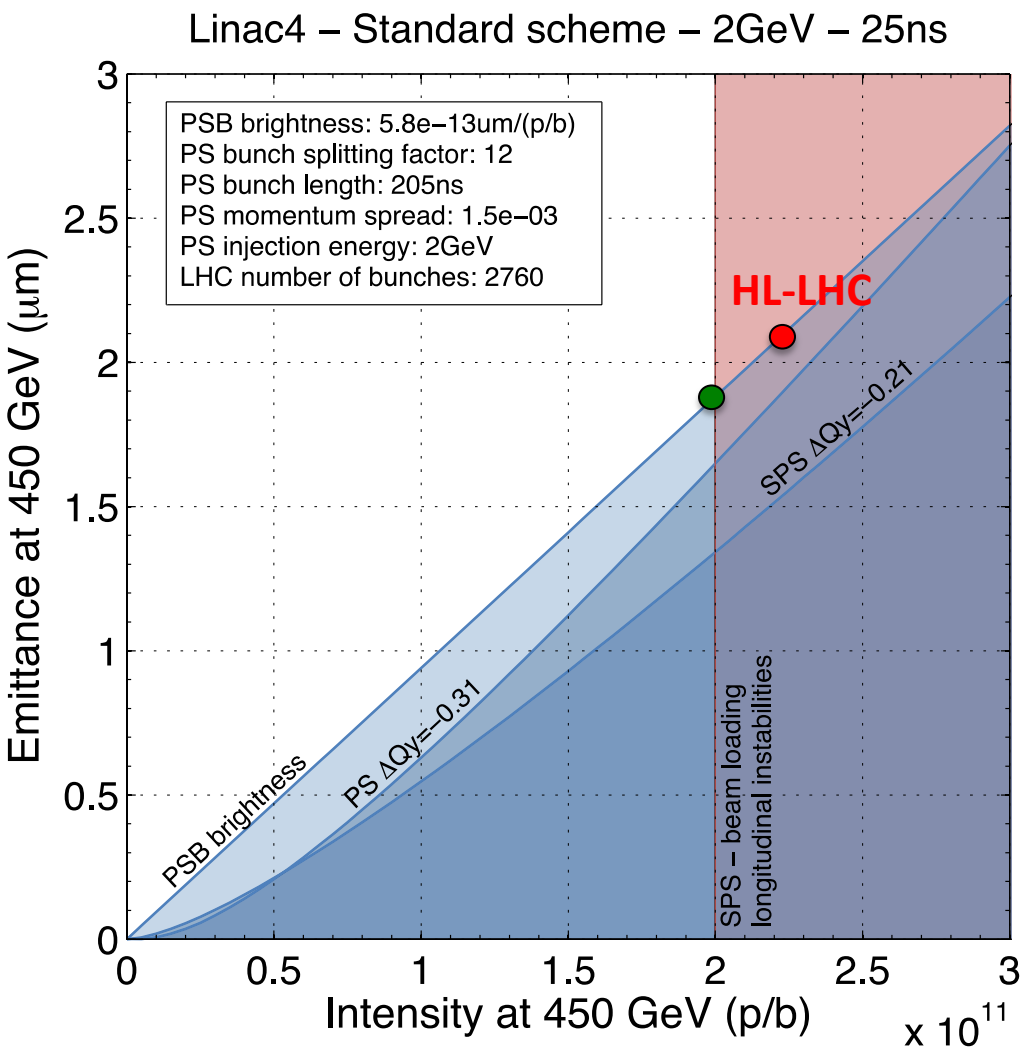
LIU beams (after LS2)	Intensity @SPS extraction	Normalized transverse emittance @SPS extraction
LIU - standard scheme (72 bunches/PS batch)	2×10^{11} p/b	1.88 µm
LIU - BCMS scheme (48 bunches/PS batch)	2×10^{11} p/b	1.37 µm

- LIU beams for studies identified and target parameters set
- Studies during Run 2 will be crucial to update parameter tables and steer some LIU related decisions → lots of MD time and resources needed!

LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

Standard scheme (72b trains) after LS2



- LIU upgrades
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Summary

1. **Present performance and post-LS1**

   → 25 ns beams from both standard and BCMS production schemes

   ✓ Perform about within budgets throughout the LHC injector chain

   ✓ Were used in 2012 for the LHC scrubbing and pilot physics runs

   → After LS1, an important margin for improvement comes from the relaxation of the longitudinal constraints at the PSB-PS transfer.

   ➜ The pure BC scheme holds great promise to produce ultra-bright 25 ns beams for the post-LS1 era with short trains (favorable against electron cloud)

2. **Only Linac4**

   → Standard 25 ns beams: 50% higher brightness is in reach (limited by PS space charge)

   → BCMS beams: no improvement with Linac4 because they are presently already at the limit for space charge in PS

   → Possible additional gains by creating hollow bunches or using alternative optics in the PS at injection

   → Single batch PSB-PS transfer could be used to reduce LHC filling time by 17%

Post-LS1 scenarios: summary

Post-LS1 25 ns beam options – October 1, 2013

		PSB						
		N (10^{11} p)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_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)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_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 (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)	$\delta p/p_0$	$\Delta Q_{x,y}$
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)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_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

2012 performance with standard production scheme: summary table

Standard Production Scheme – September 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)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	12.56	1.41	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.51, 0.61)
	25 ns	17.73	2.14	0.05	1.0	1100	$2.4 \cdot 10^{-3}$	(0.51, 0.59)

		PS (4+2 b/inj)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	11.93	1.48	1.4	1.2	180	$0.9 \cdot 10^{-3}$	(0.24, 0.31)
	25 ns	16.84	2.25	1.4	1.2	180	$0.9 \cdot 10^{-3}$	(0.25, 0.30)

		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)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	1.89	1.55	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.09, 0.15)
	25 ns	1.33	2.36	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.05, 0.07)

		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)
Achieved	50 ns	1.70	1.71	450	0.46	1.60
	25 ns	1.20	2.60	450	0.42	1.47

2012 performance with BCMS scheme: summary table

BCMS scheme – October 1, 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)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	6.28	0.89	0.05	0.9	1000	$2.2 \cdot 10^{-3}$	(0.41, 0.52)
	25 ns	8.48	1.15	0.05	0.9	1000	$2.2 \cdot 10^{-3}$	(0.46, 0.56)

		PS (4+4 b/inj)						
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	E (GeV)	ϵ_z (eVs/b)	B_l (ns)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	5.96	0.94	1.4	0.9	150	$0.8 \cdot 10^{-3}$	(0.21, 0.28)
	25 ns	8.05	1.20	1.4	0.9	150	$0.8 \cdot 10^{-3}$	(0.24, 0.31)

		SPS (max 3 × 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)	$\delta p/p_0$	$\Delta Q_{x,y}$
Achieved	50 ns	1.89	0.98	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.11, 0.21)
	25 ns	1.27	1.27	26	0.42	3.0	$1.5 \cdot 10^{-3}$	(0.07, 0.12)

		LHC (max 8 × 96 b/inj)				
		N (10^{11} p/b)	$\epsilon_{x,y}$ (μm)	p (GeV/c)	ϵ_z (eVs/b)	B_l (ns)
Achieved	50 ns	1.70	1.08	450	0.46	1.60
	25 ns	1.15	1.39	450	0.42	1.47