Overview of the beams from the injectors

S. Albright, H. Bartosik, T. Bohl, H. Damerau, G. P. Di Giovanni, A. Findlay, A. Huschauer, V. Kain, A. Lasheen, G. Papotti, D. Quartullo, E. Shaposhnikova, M. Schwarz, F. Tecker, F. Velotti on behalf of all people involved in the injectors and with acknowledgements to the operators

Outline

- Introduction
- Beam production schemes
  - Standard beam LHC25
  - BCMS
  - 8b4e and BCS variant
- Summary of performance in 2017
- Expectations for 2018
- Conclusions

Introduction

- Two main objectives for the injectors

- Maximize beam brightness
  - Minimization of space charge effects
  - Emittance preservation (see talk F. Tecker)

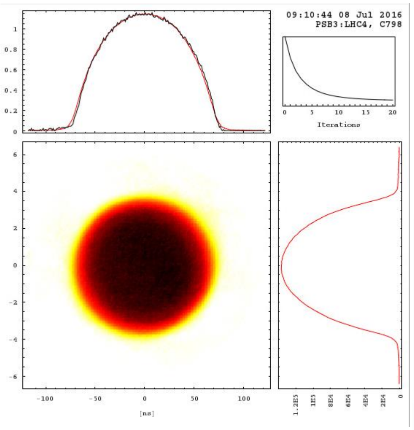
- Longitudinal distribution control
  - Bunch spacing definition
  - Batch spacing definition (see talk F. Velotti)

Reminder of main constraints

- Limit in brightness delivered by the PSB
  - The transverse emittance depends linearly on the intensity (brightness curve)
- Limit in longitudinal emittance extracted from PSB
  - Rise time of the recombination kickers
  - Blow-up observed at PS injection for large momentum spread
- Space charge on the PS flat bottom
  - Large tune spread, limited by resonances
  - Need to keep bunch intensity low to preserve brightness
- Longitudinal emittance at PS extraction set to 0.35 eVs
  - To keep losses small in the SPS and for longitudinal stability purposes

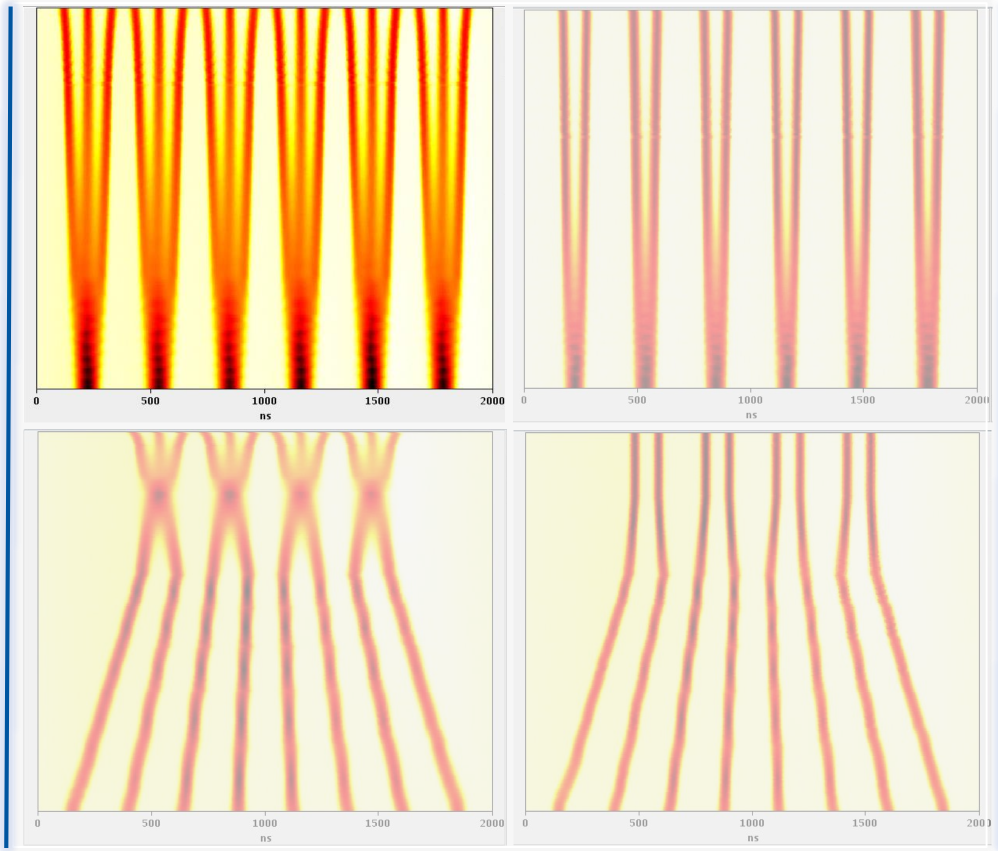
RF manipulations in PS

PSB 1.4 GeV → PS 2.5 GeV → PS 26 GeV



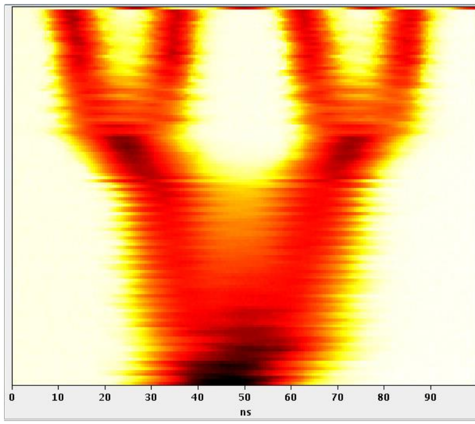
- **Standard LHC25:**

$\tau_L = 183$ ns
$\varepsilon_L = 1.27$ eVs
$\boldsymbol{N_b = 16.5 \times 10^{11}}$ **p/b**
bunches: 6



RF harmonics 7 -> 14 -> 21

25 ns spacing



RF harmonics
21 -> 42 -> 84

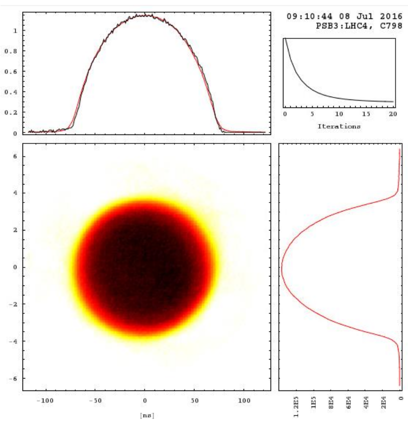
- Extracted:

$\varepsilon_L = 0.35$ eVs
$N_b = 1.3 \times 10^{11}$ p/b

- **Split factor: 12**
- # bunches: 72

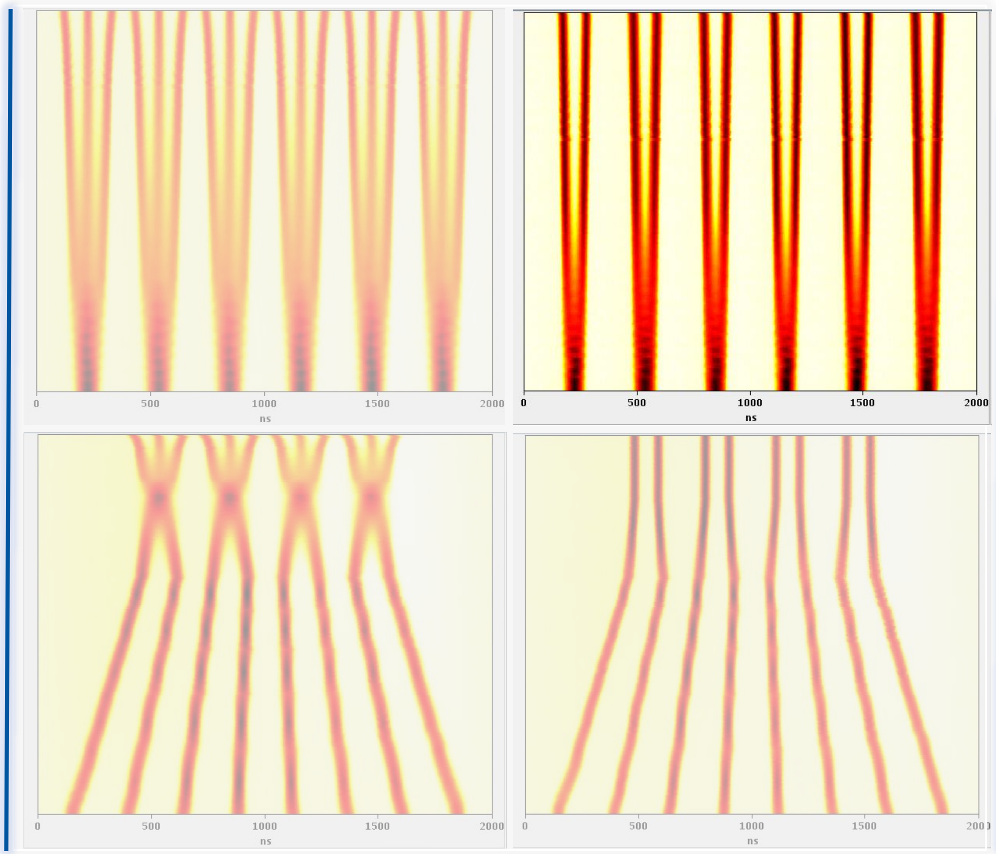
RF manipulations in PS

PSB 1.4 GeV → PS 2.5 GeV → PS 26 GeV



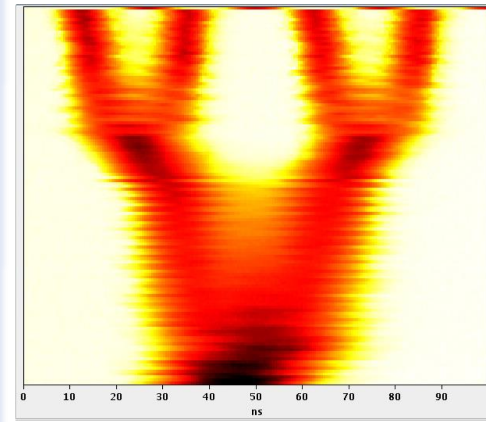
- **8b4e:**

$\tau_L = 179$ ns
$\varepsilon_L = 1.17$ eVs
$\boldsymbol{N_b = 10.6 \times 10^{11}}$ **p/b**
bunches: 7



RF harmonics 7 -> 21

25 ns spacing



RF harmonics
21 -> 42 -> 84

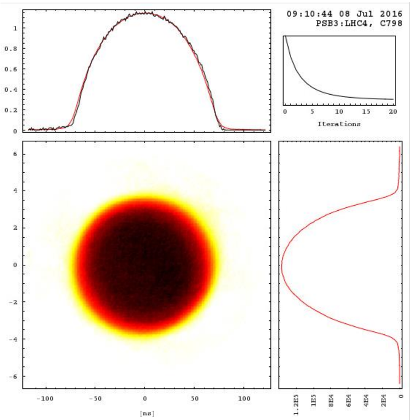
- Extracted:

$\varepsilon_L = 0.35$ eVs
$N_b = 1.3 \times 10^{11}$ p/b

- **Split factor: 8**
- # bunches: 56

RF manipulations in PS

PSB 1.4 GeV → PS 2.5 GeV → PS 26 GeV



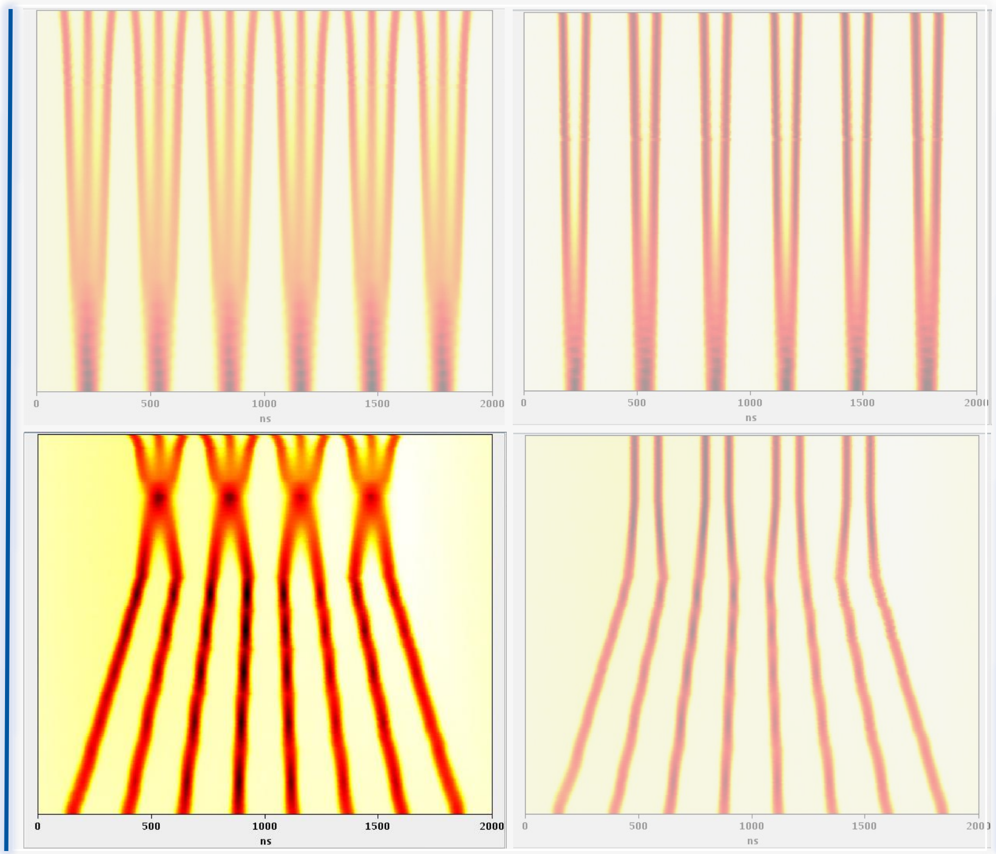
- **BCMS:**

$\tau_L = 150$ ns

$\varepsilon_L = 0.92$ eVs

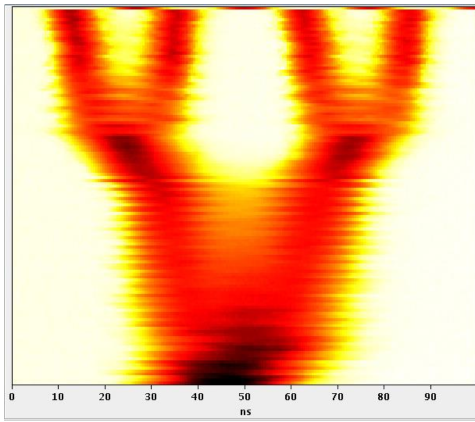
$\boldsymbol{N_b = 7.8 \times 10^{11}}$ **p/b**

\# bunches: 8



RF harmonics 9..14 -> 7 -> 21

25 ns spacing



RF harmonics
21 -> 42 -> 84

- Extracted:

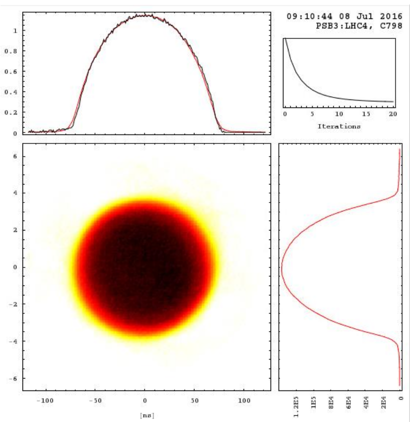
$\varepsilon_L = 0.35$ eVs

$N_b = 1.3 \times 10^{11}$ p/b

- **Split factor: 6**
- \# bunches: 48

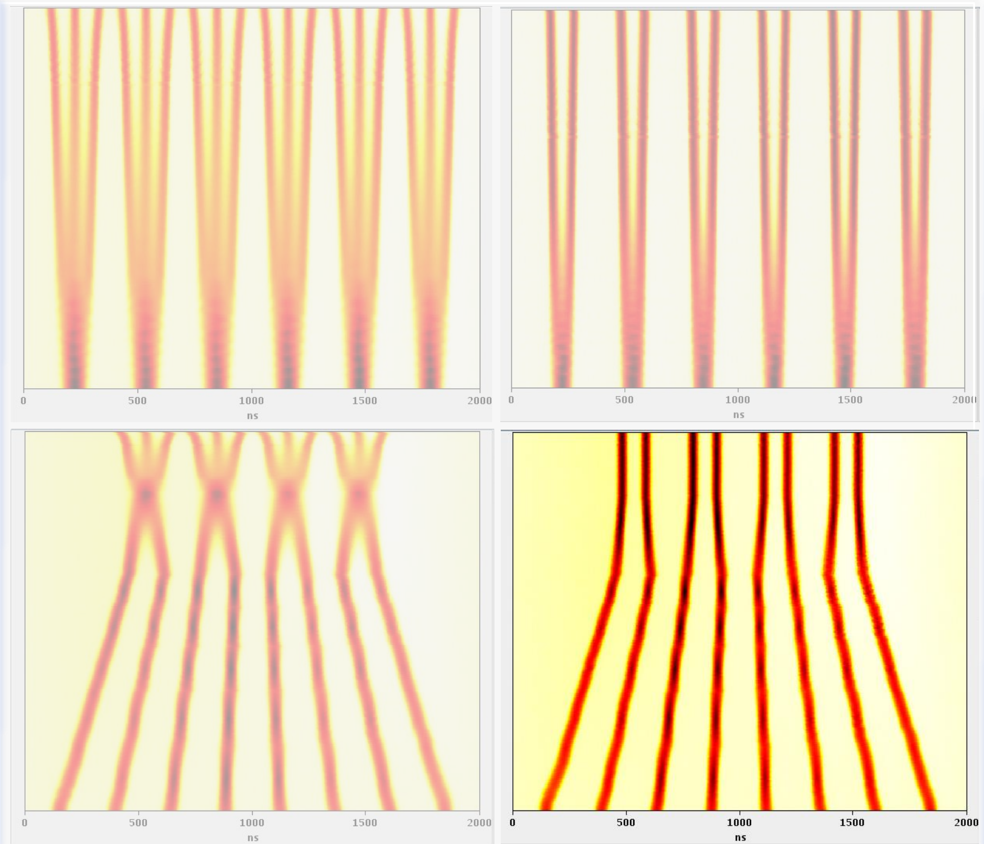
RF manipulations in PS

PSB 1.4 GeV → PS 2.5 GeV → PS 26 GeV



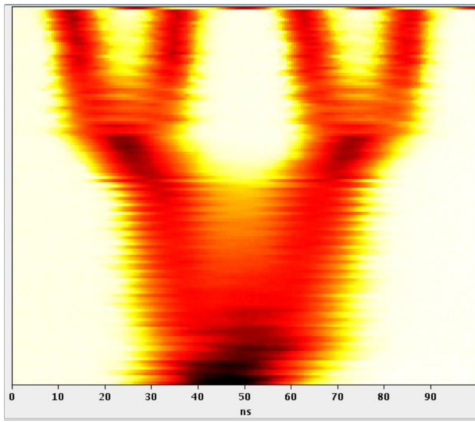
- **BCS 8b4e:**

$\tau_L = 142$ ns
$\varepsilon_L = 0.82$ eVs
$\boldsymbol{N_b = 5.3 \times 10^{11}}$ **p/b**
bunches: 8



RF harmonics 9..14..21

25 ns spacing



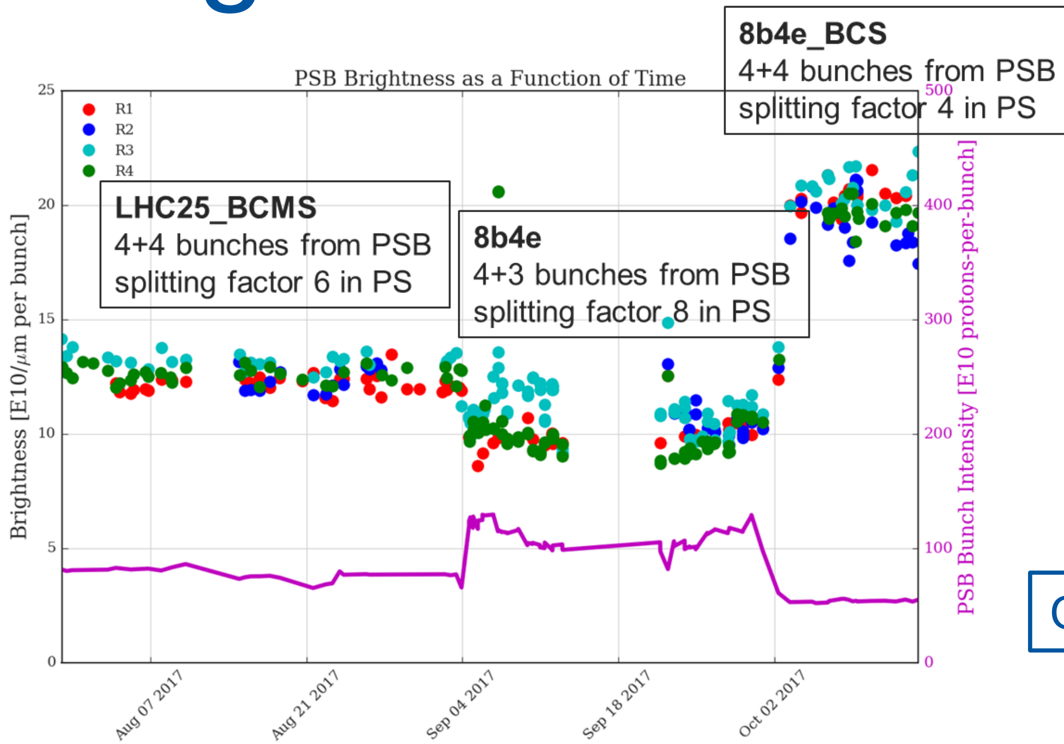
RF harmonics
21 -> 42 -> 84

- Extracted:

$\varepsilon_L = 0.35$ eVs
$N_b = 1.3 \times 10^{11}$ p/b

- **Split factor: 4**
- # bunches: 32

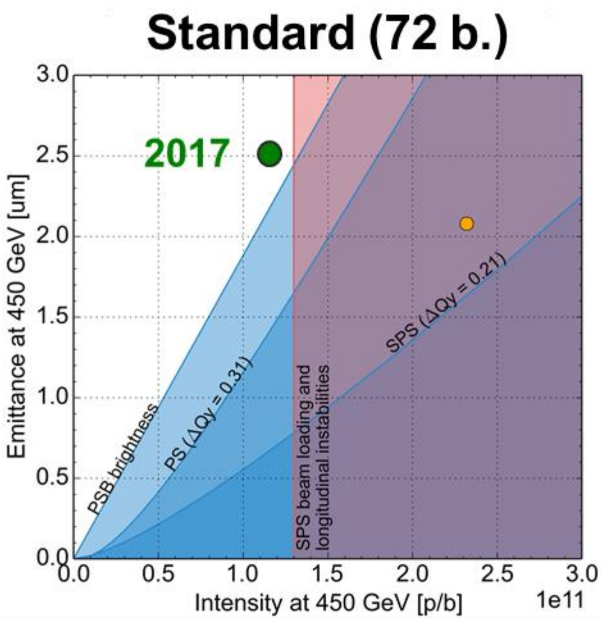
Beam brightness in PSB

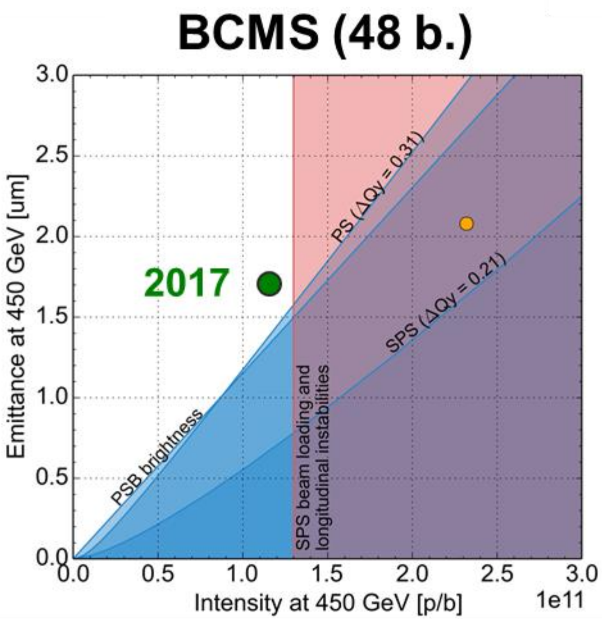


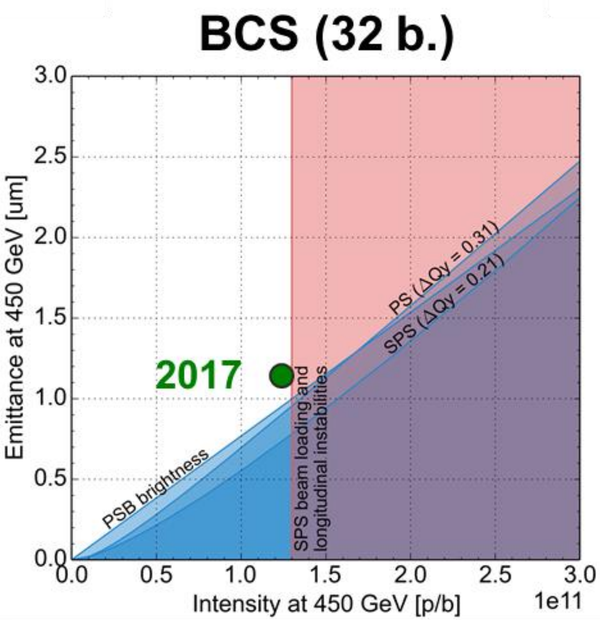
G. P. Di Giovanni

- Switch to 8b4e type beam to cope with LHC vacuum issues in 16L2, then switch to BCS 8b4e to maximize beam brightness
- Follows the expected brightness curve
- The intensity was varied in the range 105e10-130e10 for the 8b4e beam to find the right balance for the LHC

Limitation diagram for 2017 beams







1.15e11 / 2.5 um

1.15e11 / 1.7 um

1.25e11 / 1.15 um

H. Bartosik

- Performance in 2017 close to limitations
- The BCS type beam pushes the performance close to space charge limitations in SPS

Summary of 2017 performance

	Intensity [1e11 p/b]	Emittance [um]	pattern
25 ns standard (like 2017)	1.15	2.5 (2.4)	1-4 x 72 → 288
25 ns standard (high intensity)	1.30	2.8 (2.7)	1-4 x 72 → 288
25 ns BCMS (like 2017)	1.15	1.7 (1.4)	1-3 x 48 → 144
25 ns BCMS (high intensity)	1.30	1.9 (1.6)	1-3 x 48 → 144
8b4e standard (like 2017)	1.20	1.8 (1.6)	1-3 x 56 → 168
8b4e standard (high intensity)	1.60	2.4 (2.1)	1-3 x 56 → 168
8b4e BCS (like 2017)	1.25	1.15 (1.0)	1-4 x 32 → 128
8b4e BCS (high intensity)	1.60	1.55 (1.2)	1-4 x 32 → 128

H. Bartosik

- Blue: expected achievable emittance (see talk of F. Tecker on emittance preservation)
- The achievable intensity could be pushed to 1.4e11 in the SPS during MDs, but with degraded beam quality

Expectations for 2018

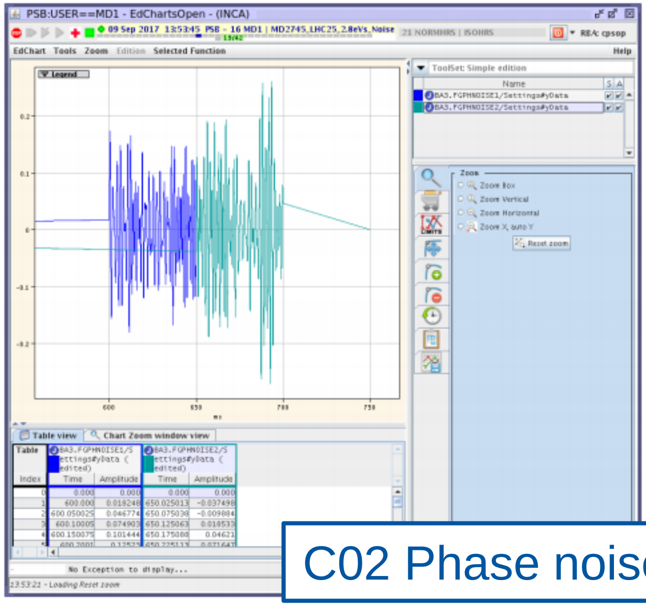
- Overall, the beam parameters for 2018 are expected to be comparable to the ones obtained in 2017. There is small margin for bunch intensity increase

- Another beam is available and could be considered for 2018
  - BCS, 25 ns variant

- Many studies were performed in 2017 in the framework of the LHC Injector Upgrade project. The results could contribute in improvement of the injector performance during the 2018 run

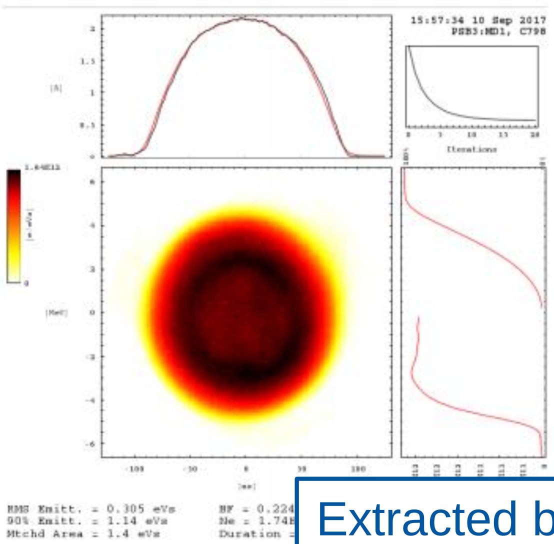
Longitudinal emittance blow-up in PSB

S. Albright, D. Quartullo – LIU-PSB BD WG meeting #1



C02 Phase noise

1.4 eVs

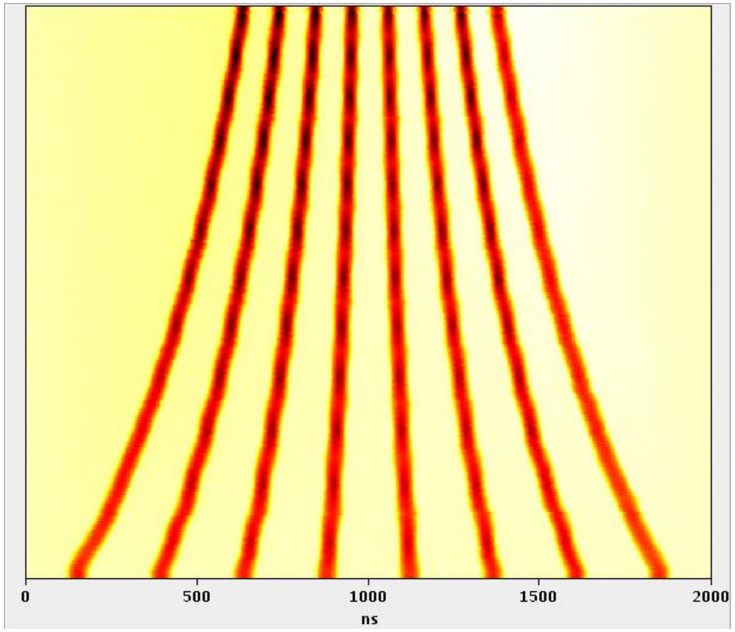


Extracted bunch

- Longitudinal emittance control is a key tool for space charge mitigation
- Phase noise injection in C02 for longitudinal emittance blow-up is under study as an alternative to present method using phase modulation in C16
- In 2017 method was successful used in tests to reach all required longitudinal emittances

BCS beam, 25 ns variant

H. Damerau, S. Hancock



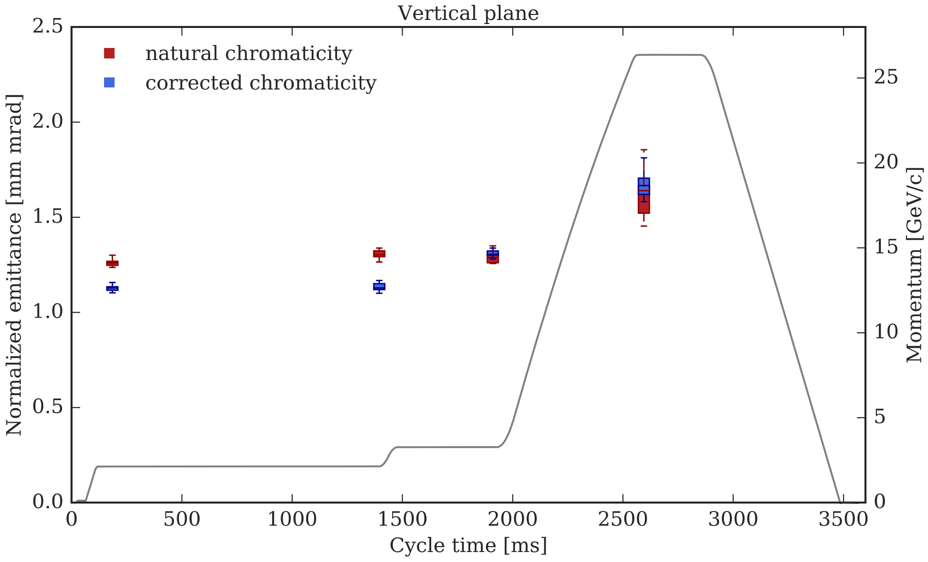
RF harmonics 9..21

- The BCS beam has the highest potential in brightness (PS splitting ratio: 4)
- A 25 ns variant is possible for this beam and was tested in 2017 (pure batch compression)
- This beam can be used in 2018 if found relevant (see talk of F. Velotti for batch spacing and V. Vlachodimitropoulos for hardware limitations)

	Intensity [1e11 p/b]	Emittance [um]	Pattern
25ns BCS (like 2017)	1.25	1.15 (1.0)	1-4 (3) x 32 → 128 (96)
25ns BCS (high intensity)	1.30	1.20 (1.0)	1-4 (3) x 32 → 128 (96)

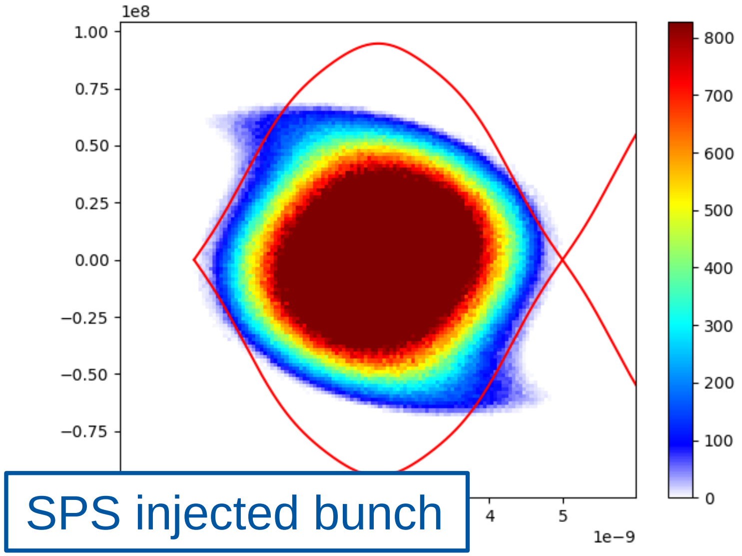
Low chromaticity and transverse feedback in PS

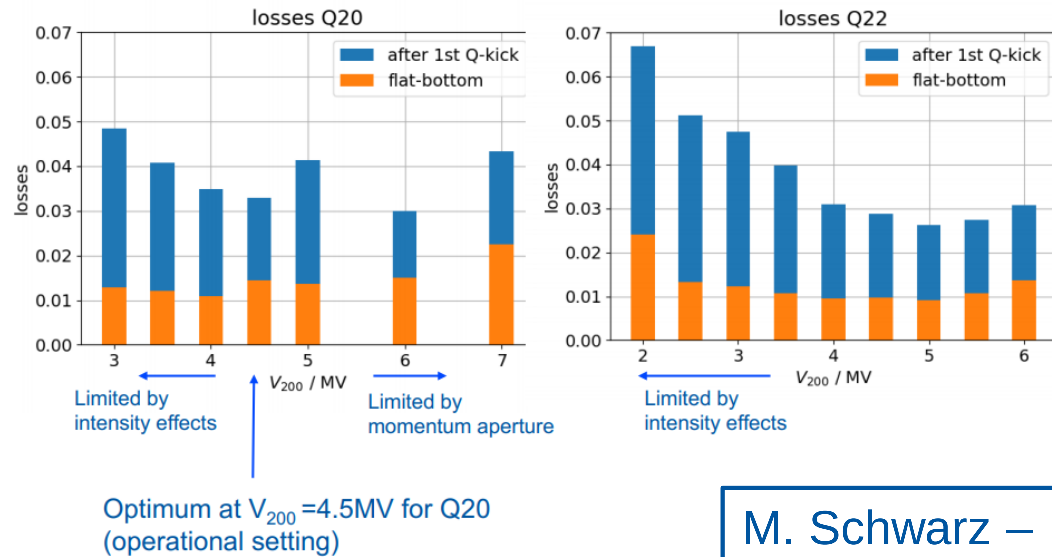
A. Huschauer – LIU-PS BD WG #6



- The transverse feedback can be used instead of linear coupling and high chromaticity to mitigate beam instability on the flat bottom
- Lower chromaticity gives more flexibility on the working point
- The horizontal emittance is unchanged (dominated by blow-up at injection), but the vertical emittance is reduced by 10-15% on the flat bottom

SPS injection losses





M. Schwarz – SPS injection losses review

- Identified reasons for capture losses in the SPS
  - Tails in the injected longitudinal particle distribution
  - Limited SPS momentum aperture
  - Beam loading in the 200 MHz RF system
- Studies in new optics (Q22): more bucket area available for the same RF voltage together with slightly larger momentum aperture
- Lower longitudinal emittance possible in PS and reduces losses in SPS, but
  - leads to longitudinal instability and issues with controlled emittance blow-up in SPS
- Post-acceleration in PS to shave the longitudinal tails (“controlled” losses)

Conclusions

- Various beams can be produced by the injectors to find a compromise between beam brightness and number of bunches extracted from the SPS.
- The injectors are flexible and were able in 2017 to cope with the requests from the LHC in (reasonably) small delay, while keeping the beam performance close to limitations
- The expected beam performance are expected to be similar in 2018, and it is reminded that the 25 ns BCS beam exist as a high brightness variant to the BCMS beam
- Studies performed during 2017 in the frame of the LIU project can slightly improve the injectors performance but may require more time to be applicable in operation

Menu for 2018

H. Bartosik

	Intensity [1e11 p/b]	Emittance [um]	pattern
25 ns standard (like 2017)	1.15	2.5 (2.4)	1-4 x 72 → 288
25 ns standard (high intensity)	1.30	2.8 (2.7)	1-4 x 72 → 288
8b4e standard (like 2017)	1.20	1.8 (1.6)	1-3 x 56 → 168
8b4e standard (high intensity)	1.60	2.4 (2.1)	1-3 x 56 → 168
25 ns BCMS (like 2017)	1.15	1.7 (1.4)	1-3 x 48 → 144
25 ns BCMS (high intensity)	1.30	1.9 (1.6)	1-3 x 48 → 144
25ns BCS (like 2017)	1.25	1.15 (1.0)	1-4 (3) x 32 → 128 (96)
25ns BCS (high intensity)	1.30	1.20 (1.0)	1-4 (3) x 32 → 128 (96)
8b4e BCS (like 2017)	1.25	1.15 (1.0)	1-4 (3) x 32 → 128 (96)
8b4e BCS (high intensity)	1.60	1.55 (1.2)	1-4 (3) x 32 → 128 (96)

- Blue: expected achievable emittance (see talk of F. Velotti for batch spacing and V. Vlachodimitropoulos for hardware limitations)
- The achievable intensity could be pushed to 1.4e11-1.45e11 in the SPS, but with degraded beam quality