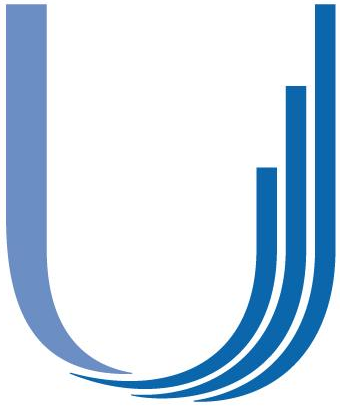
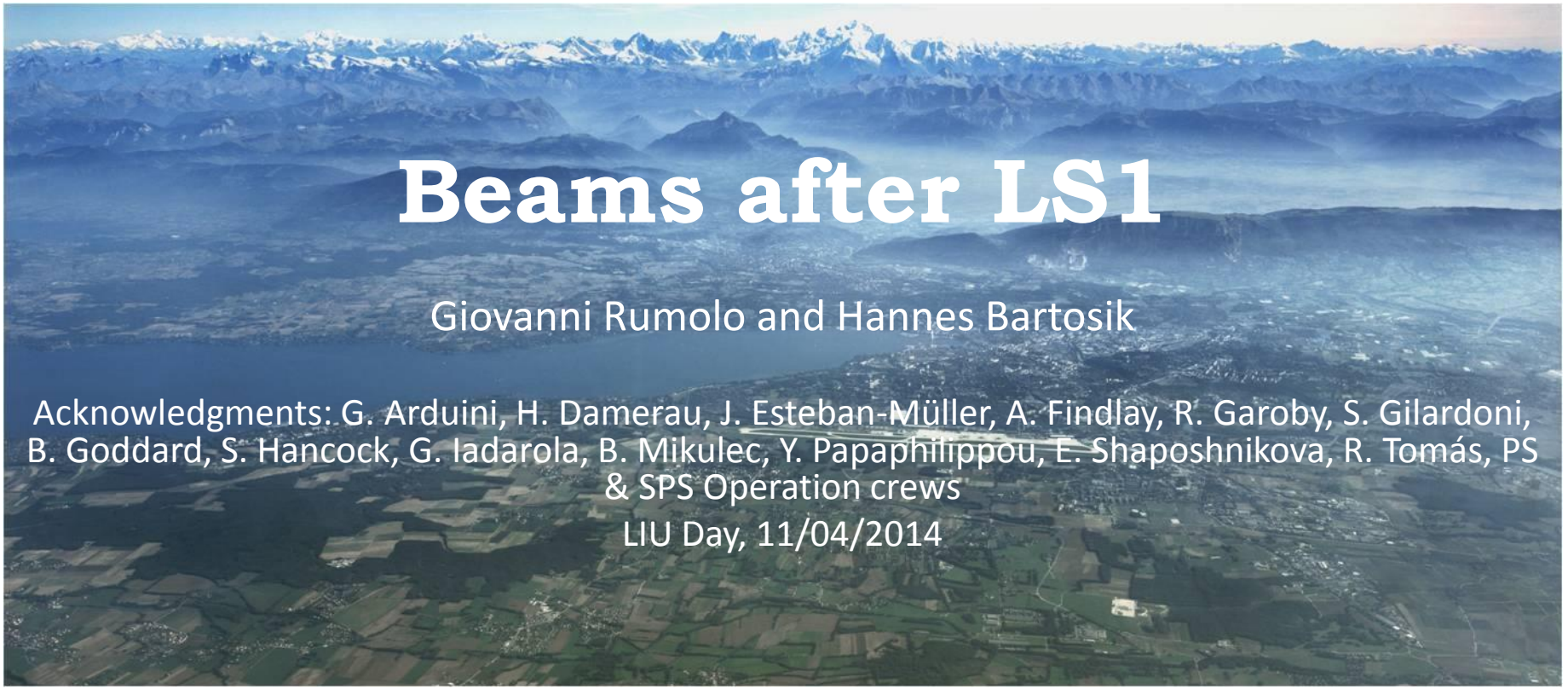


# LHC Injectors Upgrade



LHC Injectors Upgrade

# Beams after LS1

Giovanni Rumolo and Hannes Bartosik

Acknowledgments: G. Arduini, H. Damerau, J. Esteban-Müller, A. Findlay, R. Garoby, S. Gilardoni, B. Goddard, S. Hancock, G. Iadarola, B. Mikulec, Y. Papaphilippou, E. Shaposhnikova, R. Tomás, PS & SPS Operation crews

LIU Day, 11/04/2014

CERN

# Outline

- The LHC beams
  - Single bunches (probe and indiv)
  - 50 and 25 ns beams (standard and BCMS)
  - Doublet beam (scrubbing)
  - 8b+4e (low e-cloud)

- Summary

- The LHC beams
  - Single bunches (probe and indiv)
    → Achieved performance in 2013
  - 50 and 25 ns beams (standard and BCMS)
  - Doublet beam (scrubbing)
  - 8b+4e (low e-cloud)

- Summary

# LHCPROBE & LHCINDIV – specs @LHC injection

| | LHCPROBE | LHCINDIV |
|---|---|---|
| Intensity [p/b] | $5 \times 10^9 – 2 \times 10^{10}$ | $2 \times 10^{10} – 3 \times 10^{11}$ |
| Transverse emittance, $1\sigma$ [$\mu$m] | 1 | < 2.5 |
| Longitudinal emittance [eVs] | 0.35 | 0.35 – 0.5 |

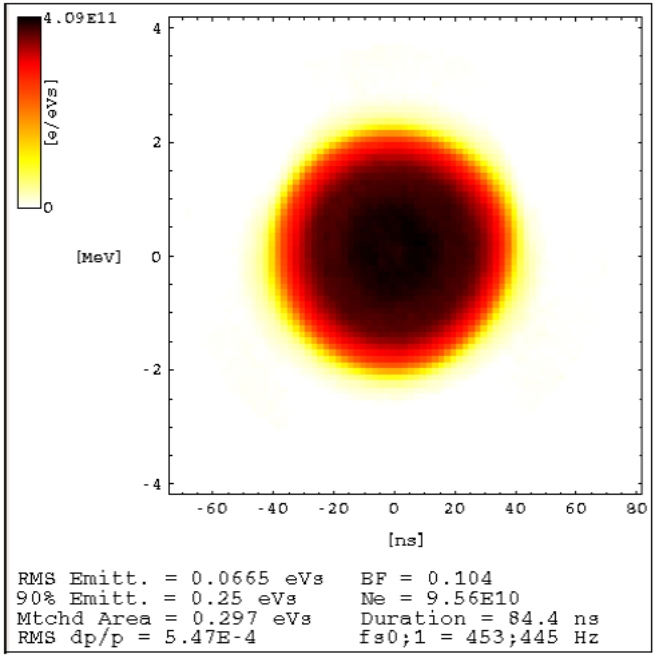
- LHCPROBE usually below or about $10^{10}$ p/b, transverse emittance not critical
- LHCINDIV parameter range also extended in MDs to produce single bunches with up to $4.5 \times 10^{11}$ p/b and/or with lower longitudinal emittances (down to 0.15 eVs) at SPS injection
  - Accelerate and extract high intensity variants for possible impedance or beam-beam studies ?

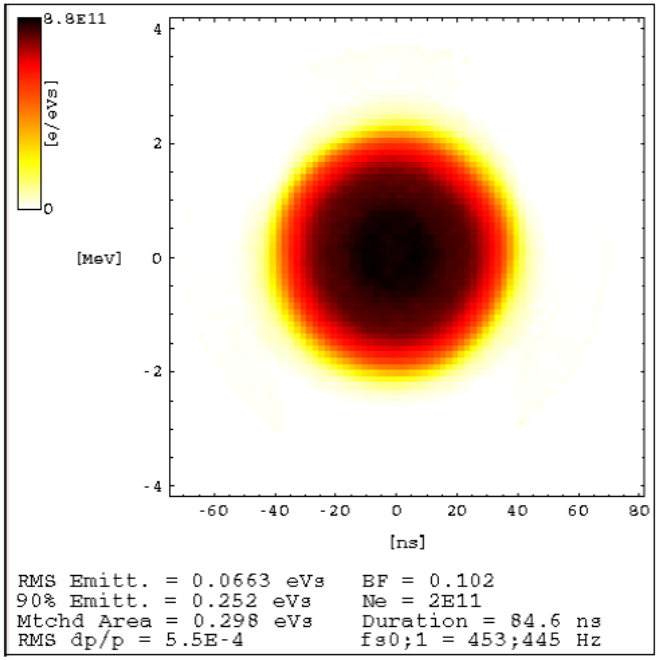
# LHCPROBE & LHCINDIV – 2013 status

Since 2013, new production mechanism in the PSB to cover parameter range for both these beams (S. Hancock, **CERN-ATS-Note-2013-040 MD**)

- Based on longitudinal blow up (C16 voltage) during the first part of the cycle for intensity setting
- Excellent intensity shot-to-shot reproducibility preserving the 6D phase space unchanged for different intensity values

→ **Baseline for post-LS1**



- The LHC beams
  - Single bunches (probe and indiv)
  - 50 and 25 ns beams (standard and BCMS)
    - → Achieved performance in 2012
    - → Expected performance after LS1
  - Doublet beam (scrubbing)
  - 8b+4e (low e-cloud)

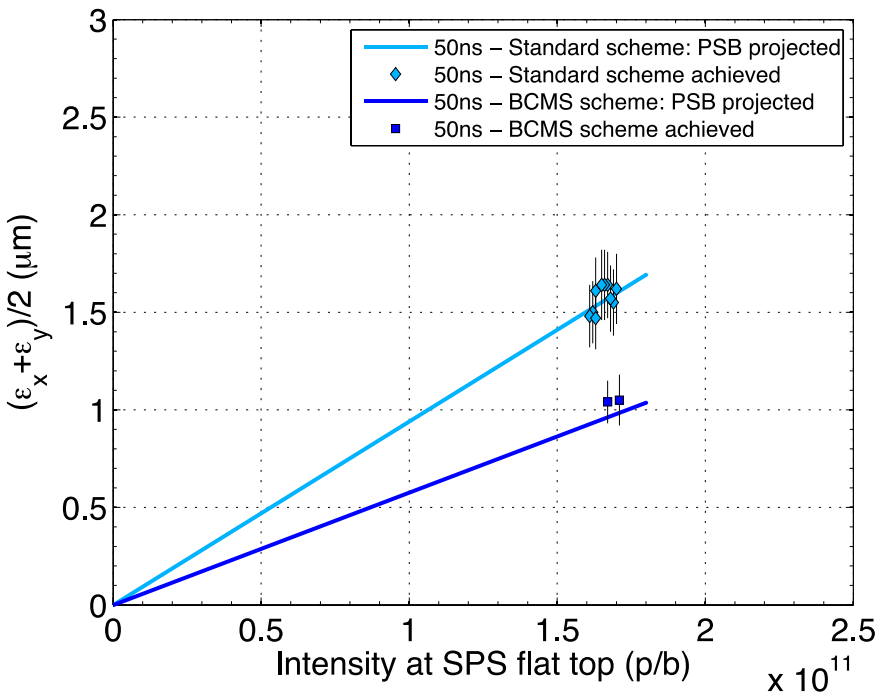
- Summary

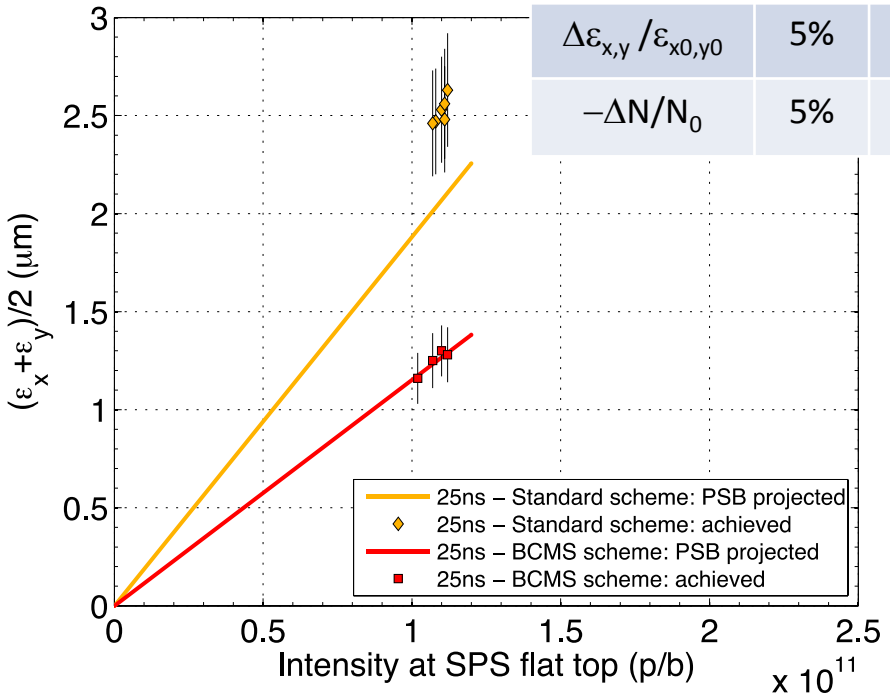
# LHC25 and LHC50 (std & BCMS) – pre-LS1 status

50 ns and 25 ns beam at the SPS extraction in 2012 (Q20)

- ✓ Combined wire-scans at end of SPS flat bottom (values cross-checked with LHC) and intensity measured at SPS flat top after scraping
- ✓ Transport through PS/SPS nearly within intensity loss and emittance blow up budgets (except for LHC25 std)

| Budget | PS | SPS |
|---|---|---|
| $\Delta\varepsilon_{x,y}/\varepsilon_{x0,y0}$ | 5% | 10% |
| $-\Delta N/N_0$ | 5% | 10% |



# LHC25 and LHC50 Post-LS1: Expected performance

- **Recover 2012 performance**
  - Machines exposed to air, electron cloud

- **Potential for higher bunch intensity**
  - → Possibly extended reach thanks to the upgraded longitudinal feedback in the PS
  - → 25 ns up to 1.3 x $10^{11}$ p/b at the SPS extraction (limited by RF power and longitudinal instabilities)

- **Potential for higher brightness**
  - → Move RF manipulations in the PS to 2.5 GeV (instead of 1.4 GeV)
    - ⊙ Larger longitudinal emittance from the PSB
      - ☑ Possible thanks to PSB control of longitudinal parameters along the cycle and at extraction
    - ⊙ Space charge alleviated by both longer bunches and larger momentum spread
  - → Improve SPS space charge limit (for 50 ns BCMS)
    - ⊙ Working point optimization for high brightness beams

# SPS scrubbing in 2014/15

Sept.

Nov.

Mar.

Aug.

2014

2015

SCRUBBING RUN I (weeks 39 & 40)
Beam → Standard 25 ns

Main goals:
1. Qualify scrubbing after long shut-down (efficiency and duration)
2. Recover 2012 performance

SPS MDs
- Set up the doublet beam with acceleration (long cycle)
- Push the intensity to higher values for 25 ns beam

SCRUBBING RUN II (2 weeks)
Beams → High intensity 25 ns, scrubbing beam (doublet)

Main goal:
Determine whether scrubbing also works for high intensity

**LIU-SPS Review**

Scrubbing or coating?

# Beam parameters at LHC injection after LS1

Assuming:

- Transport in the PS and SPS within budgets
- Benefits from reviewed longitudinal parameters in the PSB – PS transfer
- Successful SPS scrubbing after exposure to air during LS1

**Summary tables**

| 25 ns | Intensity (p/b) | Emittance (μm) |
|---|---|---|
| Standard | $1.3 \times 10^{11}$ | 2.4 |
| BCMS | $1.3 \times 10^{11}$ | 1.3 |

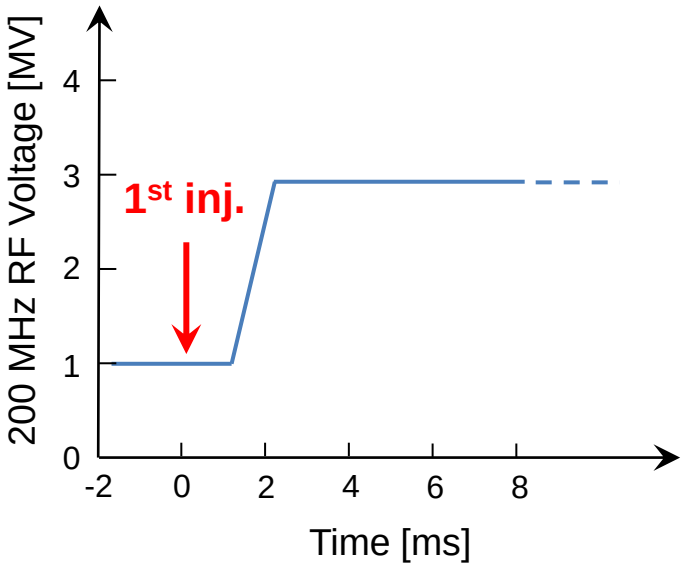
| 50 ns | Intensity (p/b) | Emittance (μm) |
|---|---|---|
| Standard | $1.7 \times 10^{11}$ | 1.6 |
| BCMS | $1.7 \times 10^{11}$ | 1.1 |

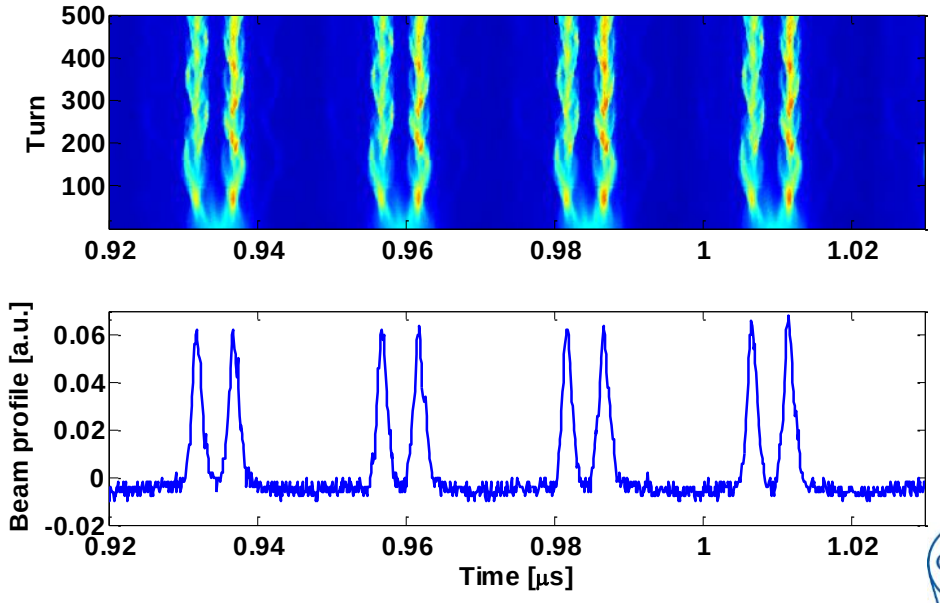
- The LHC beams
  - Single bunches (probe and indiv)
  - 50 and 25 ns beams (standard and BCMS)
  - Doublet beam (scrubbing)
    - → Achieved performance in 2012/13
    - → Expected performance after LS1
  - 8b+4e (low e-cloud)

- Summary

# Doublet beam

- Machine tests in the SPS at the end of 2012-13 run
  - ✓ Doublet production scheme at SPS injection validated
  - ✓ E-cloud enhancement experimentally demonstrated
- Production scheme
  - Injection of trains of 72 x 10ns long bunches with 1.7e11 p/doublet on unstable phase and capture in two neighboring buckets in the SPS (done)
  - Acceleration on slower ramp and extraction to LHC of 1.6e11 p/doublet (to be set up, possible beam quality degradation)
  - Should be fine in LHC → only interlocked BPMs to be checked with doublets



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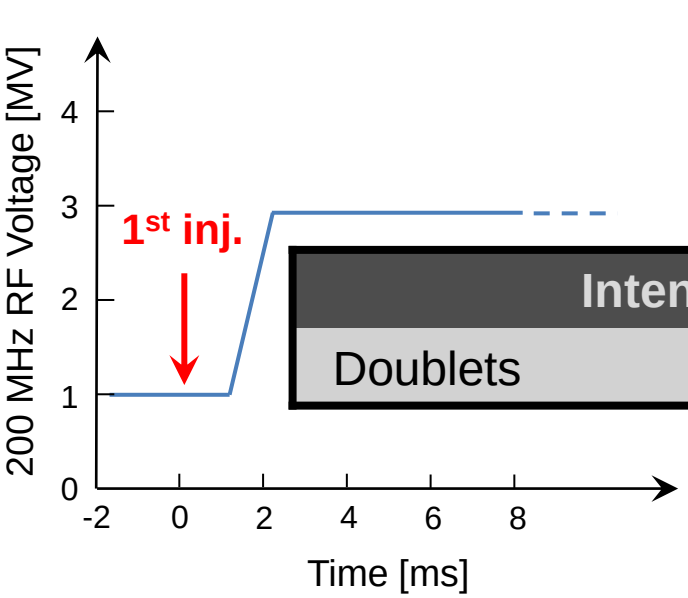
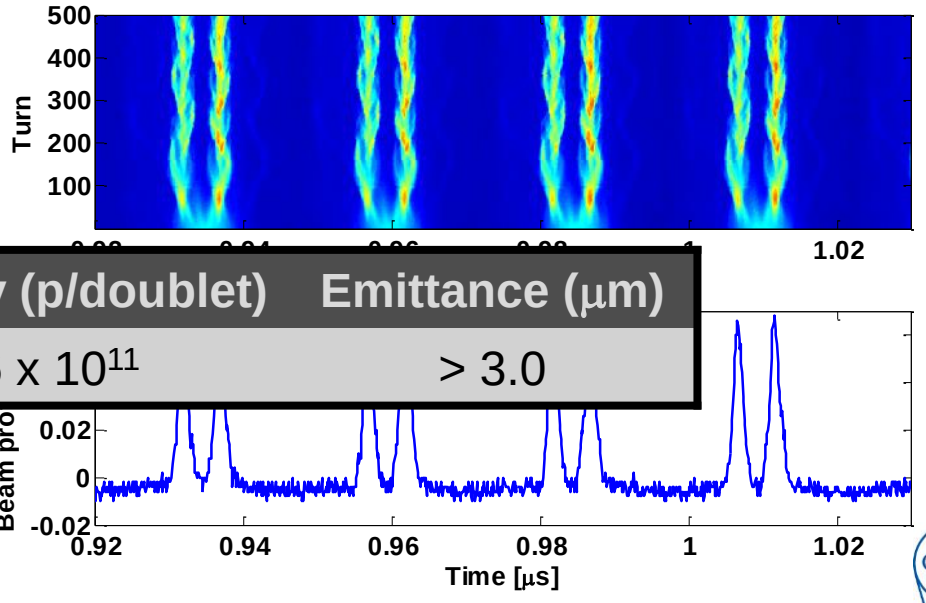



| | Intensity (p/doublet) | Emittance (μm) |
|---|---|---|
| Doublets | 1.6 x $10^{11}$ | > 3.0 |

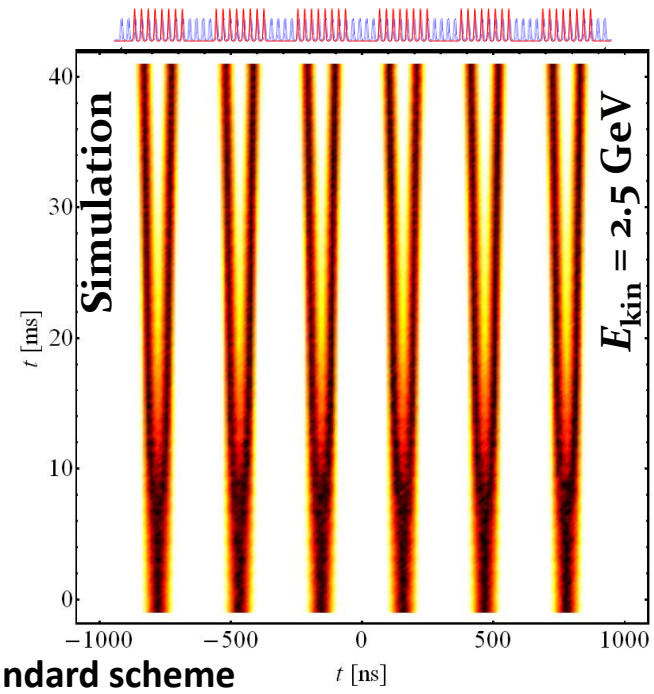
- The LHC beams
  - Single bunches (probe and indiv)
  - 50 and 25 ns beams (standard and BCMS)
  - Doublet beam (scrubbing)
  - 8b+4e (low e-cloud)

    → Expected performance after LS1

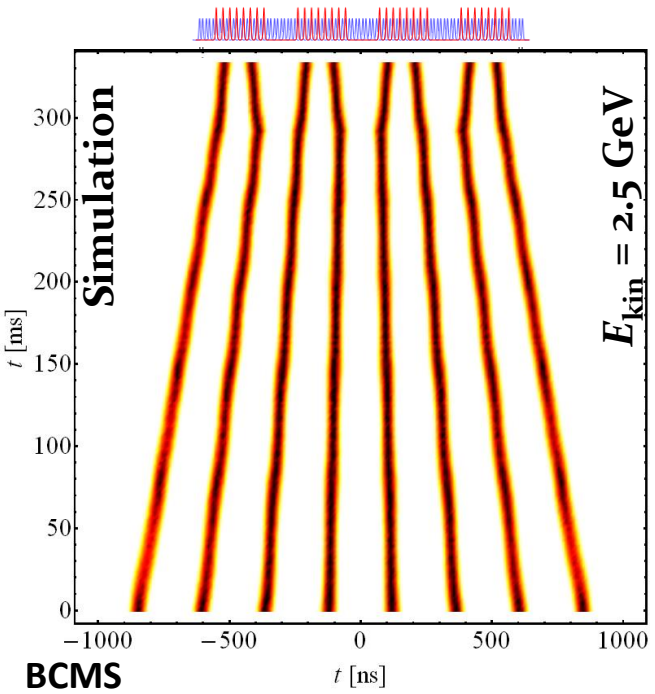
- Summary

# 8b+4e scheme

- Trains with 4 missing bunches every 8 bunches (H. Damerau, RLIUP)
  - Allows for larger intensity per bunch
  - Is expected to reduce e-cloud effects
- Production
  - Std scheme → Unbalance h = 7 → 21 triple split into a double split, leaving empty bucket – bunch pattern 6x(8b+4e) + 8b
  - BCMS → merging and triple splitting suppressed – bunch pattern 3x(8b+4e) + 8b



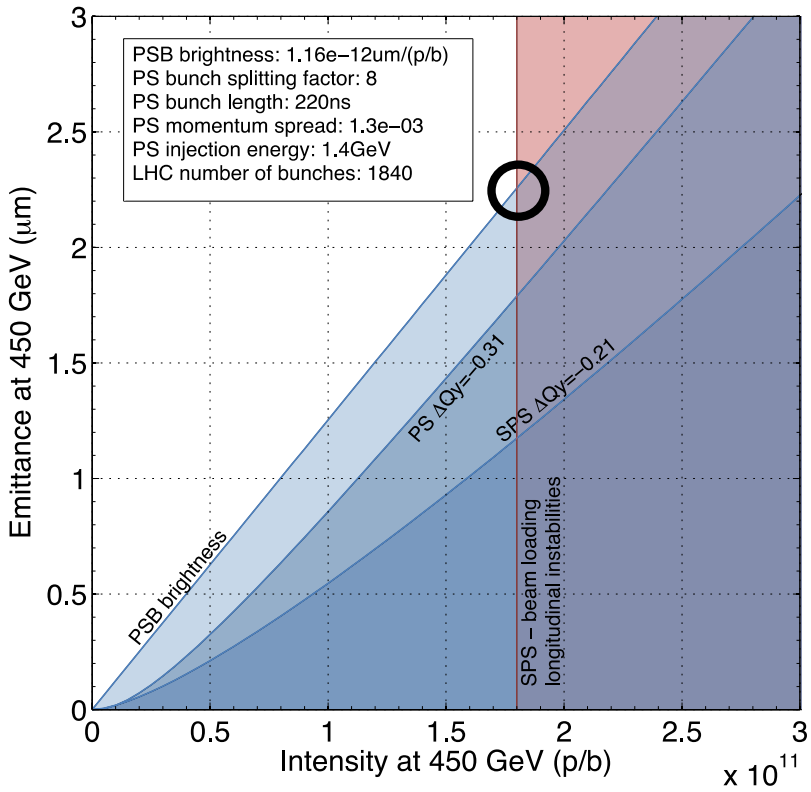

**Standard scheme**



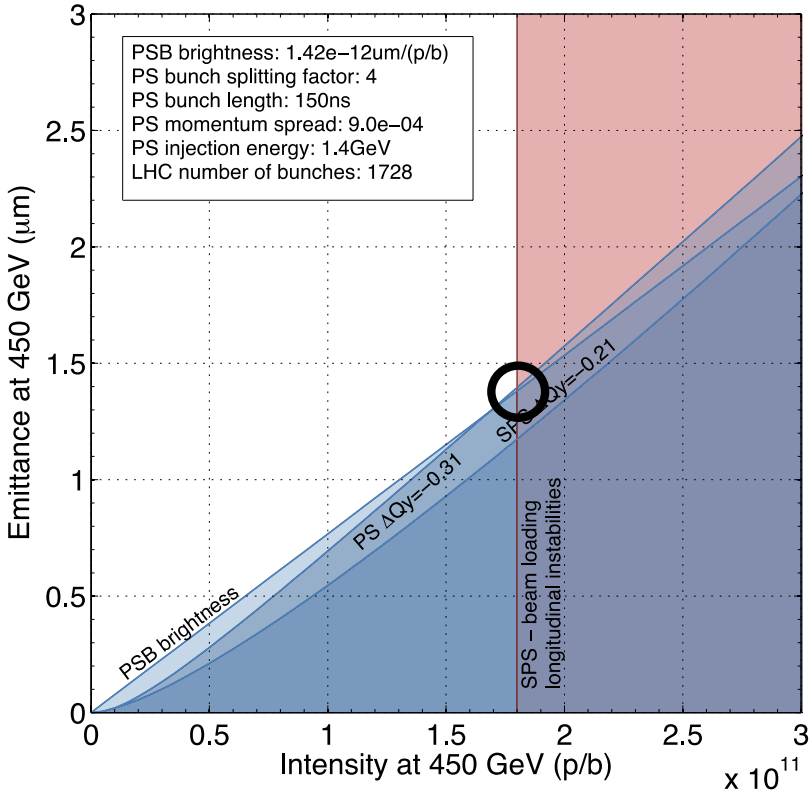

**BCMS**

# 8b+4e scheme

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




**Standard scheme**




**BCMS**

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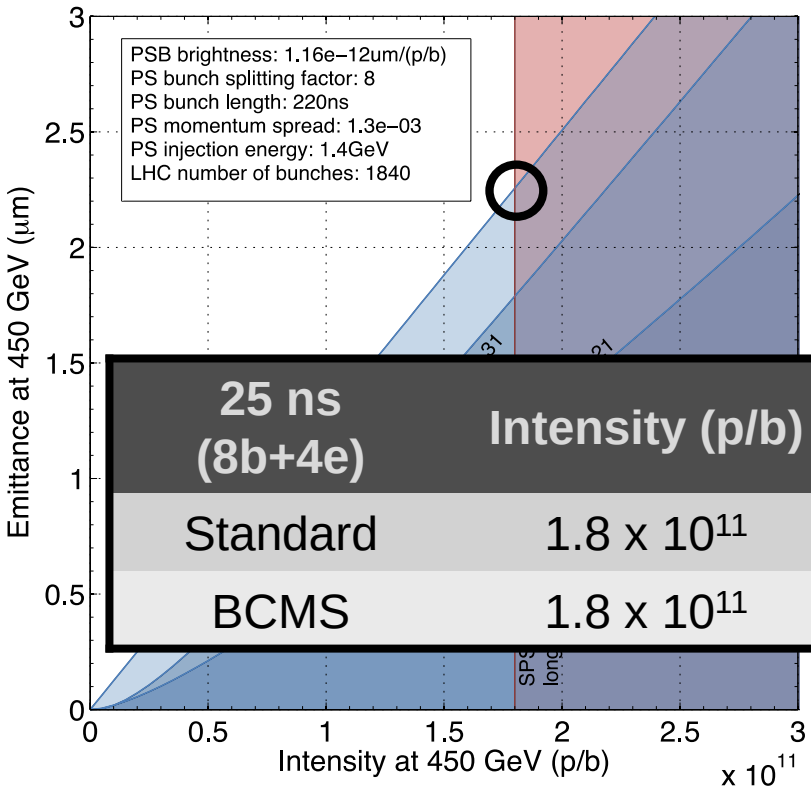
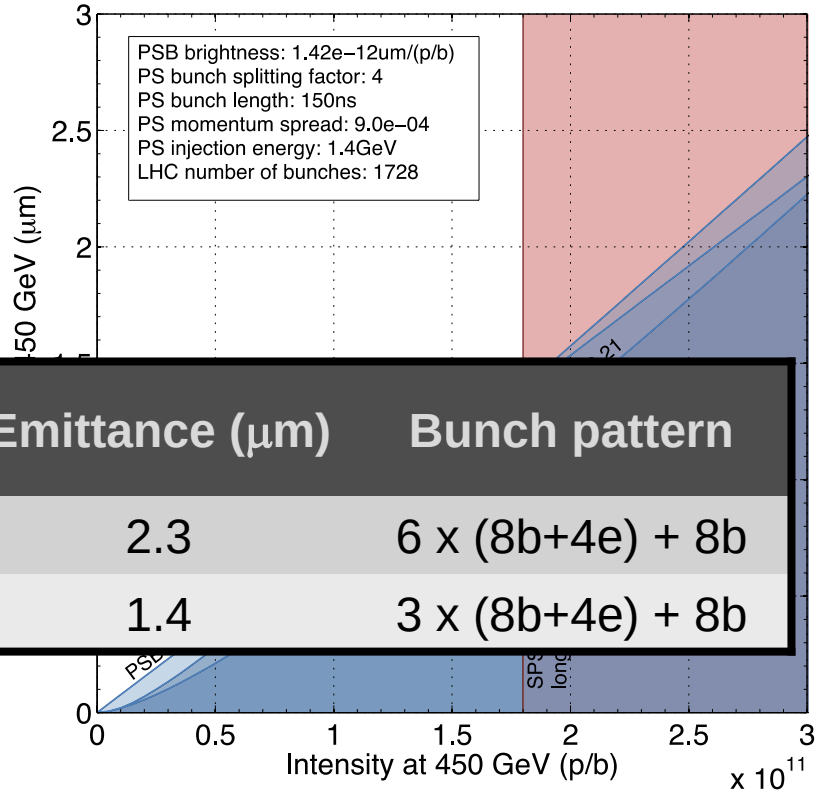



| 25 ns (8b+4e) | Intensity (p/b) | Emittance (μm) | Bunch pattern |
|---|---|---|---|
| Standard | 1.8 x $10^{11}$ | 2.3 | 6 x (8b+4e) + 8b |
| BCMS | 1.8 x $10^{11}$ | 1.4 | 3 x (8b+4e) + 8b |

**Standard scheme** **BCMS**

- The LHC beams
  - Single bunches (probe and indiv)
  - 50 and 25 ns beams (standard and BCMS)
  - Doublet beam (scrubbing)
  - 8b+4e (low e-cloud)

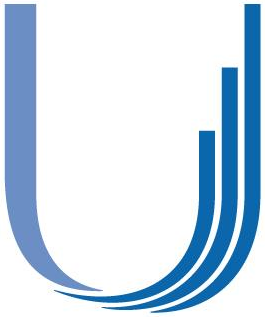
- Summary

# Summary

- **Lots of MD time needed** to produce “old” beams with new schemes and “new” beams

- **LHC start up and scrubbing**
  - LHCPROBE and LHCINDIV with new production mechanism in the PSB
  - LHC50 standard
    - Up to 1.7 x $10^{11}$ p/b with $\varepsilon_{x,y}$=1.6 μm
  - LHC25 standard
    - Up to 1.3 x $10^{11}$ p/b with $\varepsilon_{x,y}$=2.4 μm
  - LHC25 doublet
    - Up to 1.6 x $10^{11}$ p/doublet with $\varepsilon_{x,y}$> 3.0 μm

- **Physics**
  - LHC50 (standard or BCMS)
    - BCMS up to 1.7 x $10^{11}$ p/b with $\varepsilon_{x,y}$=1.1 μm
  - LHC25 BCMS
    - Up to 1.3 x $10^{11}$ p/b with $\varepsilon_{x,y}$=1.3 μm
  - 8b+4e as alternative if LHC scrubbing is not enough to run with LHC25 BCMS
    - Up to 1.8 x $10^{11}$ p/b with $\varepsilon_{x,y}$=2.3/1.4 μm (std/BCMS)



# LHC Injectors Upgrade

**THANK YOU FOR YOUR ATTENTION!**

# Post-LS1: PSB – PS transfer

Recombination kicker rise time:

| Kinetic energy, $E_{kin}$ | Rise time |
|---|---|
| 1.4 GeV | **105 ns** |

| | $E_{kin}$ | Bucket length | Max bunch length |
|---|---|---|---|
| **h=7 (std)** | 1.4 GeV | 327 ns | 220 ns |
| **h=9 (BCMS)** | 1.4 GeV | 255 ns | 150 ns |

**Constraints on longitudinal emittance per bunch** at PS injection

- Bunches to the SPS with $\varepsilon_z$=0.35 eVs
- Quality of RF manipulations at $E_{kin}$=2.5 GeV
- Bunches crossing transition on h=21 with $\varepsilon_z$<1 eVs
- PSB available voltage (h1+2) to obtain the above bunch lengths

# Post-LS1: PSB – PS transfer

Recombination kicker rise time:

| Kinetic energy, $E_{kin}$ | Rise time |
|---|---|
| 1.4 GeV | **105 ns** |

| | $E_{kin}$ | Bucket length | Max bunch length | Bunch length (pre-LS1) |
|---|---|---|---|---|
| **h=7 (std)** | 1.4 GeV | 327 ns | 220 ns | 180 ns |
| **h=9 (BCMS)** | 1.4 GeV | 255 ns | 150 ns | 150 ns |

**Constraints on longitudinal emittance per bunch** at PS injection

- Bunches to the SPS with $\varepsilon_z$=0.35 eVs
- Quality of RF manipulations at $E_{kin}$=2.5 GeV
- Bunches crossing tra
- PSB available voltag

| RF Manipulation: | @1.4 GeV | @2.5 GeV |
|---|---|---|
| 50 ns (Std/BCMS) | 1.2/0.9 eVs | 1.9/0.9 eVs |
| 25 ns (Std/BCMS) | 1.2/0.9 eVs | 2.8/1.5 eVs |