Beams in the injectors

H. Bartosik, G. Rumolo

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Evian workshop, June 2014

Outline

- Single bunch beams
- 25 ns and 50 ns physics beams
- Doublet scrubbing beam
- 8b+4e beam
- SPS scrubbing run and milestones for LHC beam commissioning in 2014
- Conclusions

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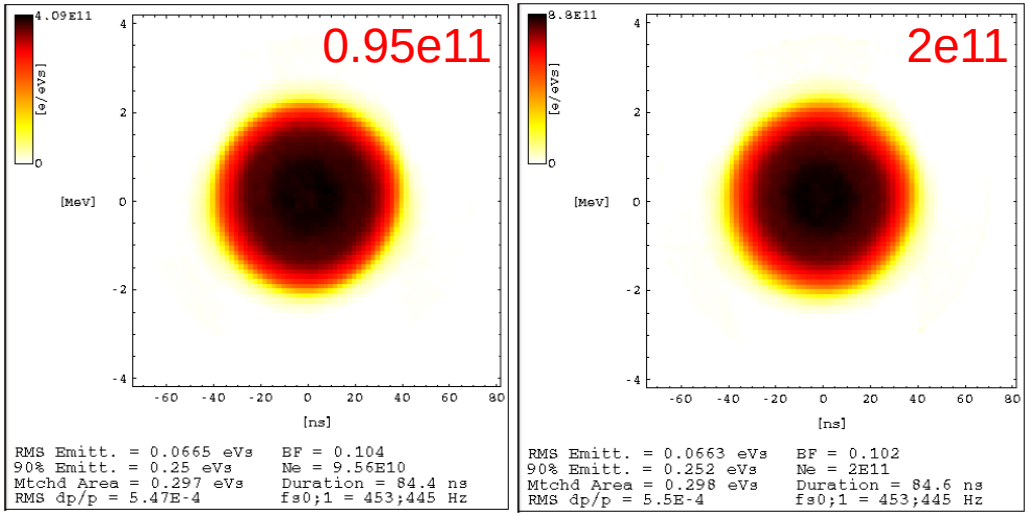
LHCPROBE & LHCINDIV – specs @LHC injection

- Since 2013, new production mechanism in the PSB to cover wide parameter range for LHCPROBE and LHCINDIV (S. Hancock, **CERN-ATS-Note-2013-040 MD**)



- Longitudinal blow up (C16) during the first part of the PSB cycle for intensity control
- Excellent shot-to-shot reproducibility wrt intensity
- Preserving the 6D phase space volume for different intensity values

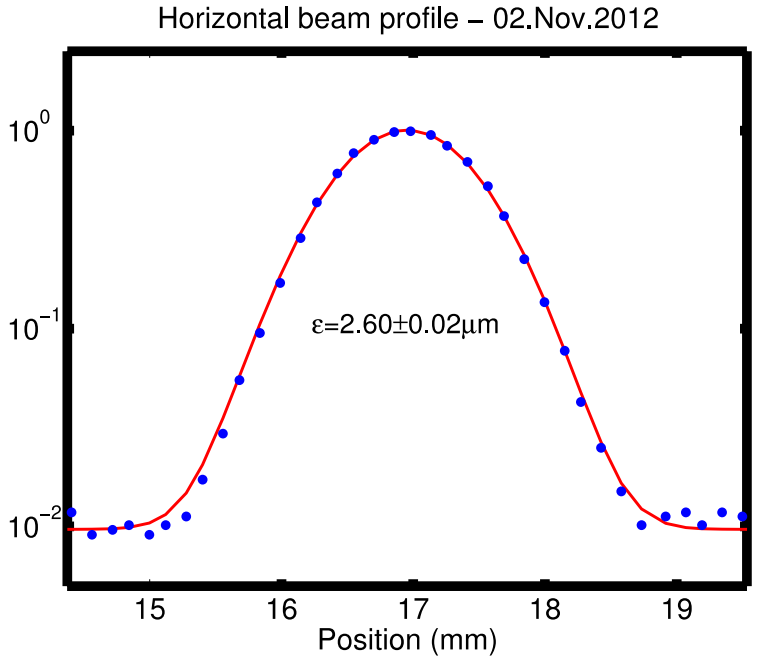
	LHCPROBE	LHCINDIV
Intensity [p/b]	$5 \times 10^9 – 2 \times 10^{10}$	$2 \times 10^{10} – 3 \times 10^{11}$
Transverse emittance, 1s [μm]	1	< 2.5
Longitudinal emittance [eVs]	0.35	0.35 – 0.5

LHCINDIV Van der Meer

Single bunch beam parameters	
Intensity [p/b]	7 – 9 x 10^{10}
Transverse emittance, 1s [μm]	≥ 2.5
Transverse distribution	**Gaussian**

To be reproduced in 2014/15 …

- In 2012, a new single Gaussian bunch was produced for Van der Meer scans (H. Bartosik and G. Rumolo, **CERN-ACC-NOTE-2013-0008 MD**)
  - Based on longitudinal AND transverse shaving in the PSB to obtain “large” emittance single bunches with less than Gaussian tails
  - Provides Gaussian bunches with the desired intensities in the SPS after scraping



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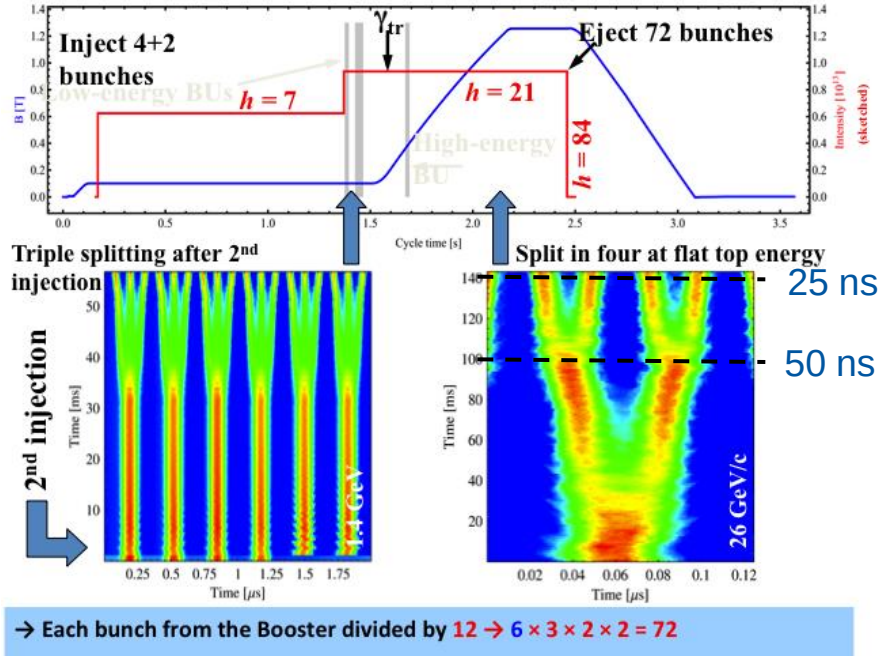
LHC25 and LHC50 (std & BCMS) – 2012/13

Std scheme:

(maximum number of bunches in LHC)

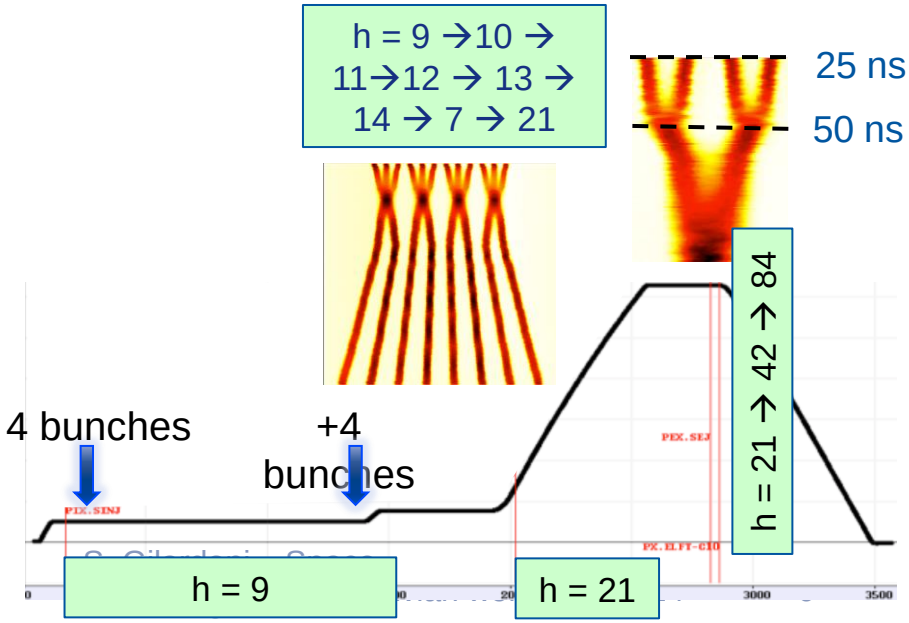


PS batches with 72 (36) bunches for 25ns (50ns)

Triple splitting up to now at 1.4 GeV (will be moved to 2.5 GeV after LS1)

BCMS scheme:

(less bunches in LHC but higher brightness)

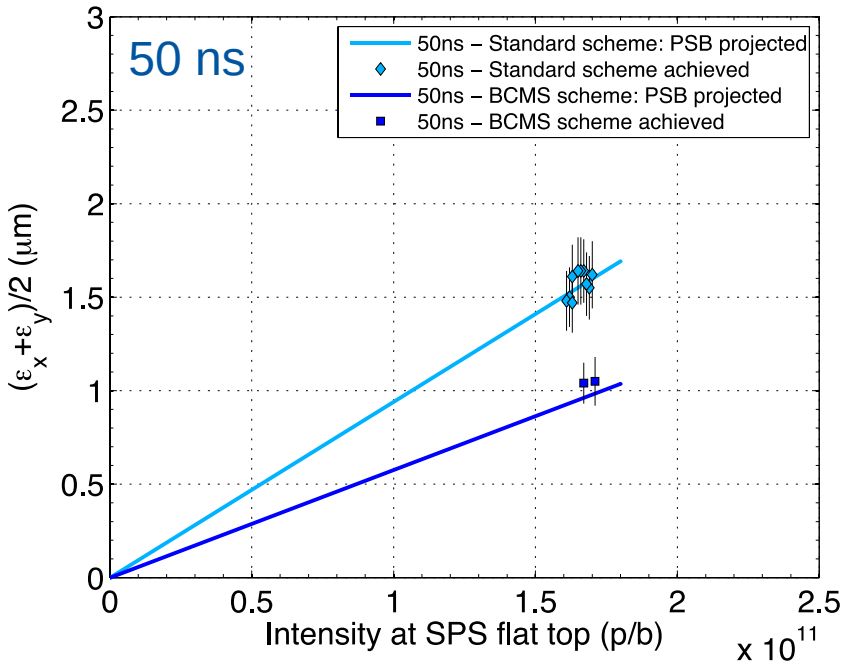


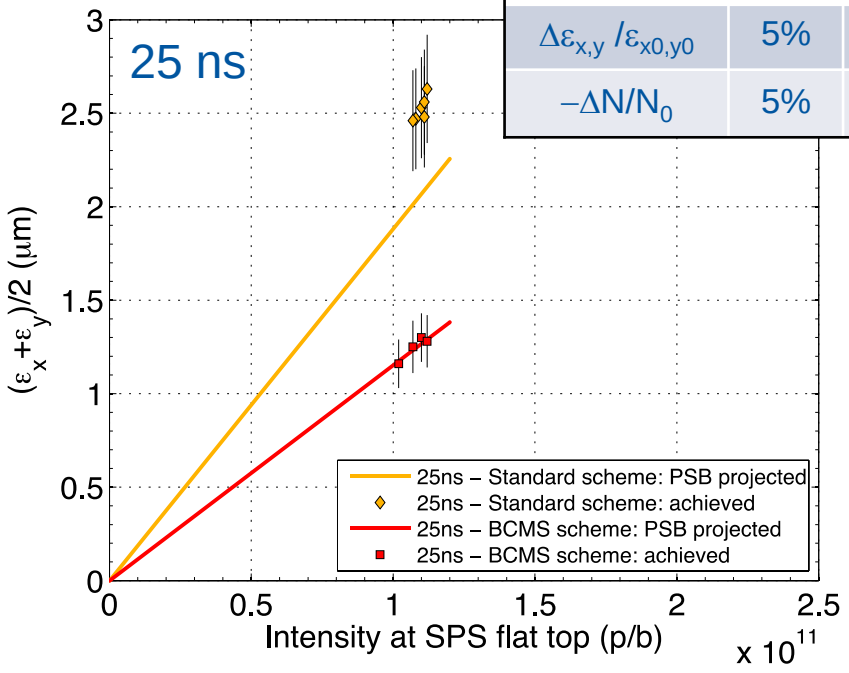
PS batches with 48 (24) bunches for 25ns (50ns)

LHC25 and LHC50 (std & BCMS) – 2012/13

- 50 ns and 25 ns beam at SPS extraction in late 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: beam production after LS1

- Recover 2012 performance
  - Machines exposed to air, electron cloud → SPS scrubbing run
  - RF manipulations in the PS will now be performed at 2.5 GeV instead of 1.4 GeV in all LHC cycles (was regularly used already with BCMS beams in 2012)
    - increases available bucket area
    - tuning groups of cavities have changed → allows for further increase of bucket area
- Potential for higher bunch intensity
  - Possible benefits in the PS from
    - upgraded 1-turn delay feedback for 10 MHz cavities (available at start-up 2014)
    - upgraded longitudinal coupled-bunch feedback (commissioning starting in 2014)
  - 25 ns up to 1.3 x 10^{11} p/b at SPS extraction as during 2012 MDs (limited by RF power and longitudinal instabilities in the SPS)
- Potential for higher brightness (as from RLIUP workshop)
  - PS: Alleviate space charge by longer bunches and larger momentum spread
    - need longitudinal blow-up on the PSB ramp to produce required emittance
    - use of h1+2 in phase at PSB extraction to keep these larger longitudinal emittance bunches within a certain length (recombination kicker rise time constraint)
  - SPS : further working point optimization for 50 ns BCMS beam

Beam parameters at LHC injection after LS1

2012 performance

25 ns	Intensity (p/b)	Emittance (μm)
Standard	1.2×10^{11}	2.6
BCMS	1.15×10^{11}	1.4

50 ns	Intensity (p/b)	Emittance (μm)
Standard	1.7×10^{11}	1.7
BCMS	1.7×10^{11}	1.1

- Assuming transport in the PS and SPS within budgets like in 2012
- **Requires successful SPS scrubbing !**
- All beams to be prepared in 2014!

Beam parameters at LHC injection after LS1

	2012 performance		with potential improvements from optimized PSB-PS transfer and intensity increase in SPS	
25 ns	**Intensity (p/b)**	**Emittance (μm)**	**Intensity (p/b)**	**Emittance (μm)**
Standard	1.2×10^{11}	2.6	1.3×10^{11}	2.4
BCMS	1.15×10^{11}	1.4	1.3×10^{11}	1.3
50 ns	**Intensity (p/b)**	**Emittance (μm)**	**Intensity (p/b)**	**Emittance (μm)**
Standard	1.7×10^{11}	1.7	1.7×10^{11}	1.6
BCMS	1.7×10^{11}	1.1	1.7×10^{11}	1.1

- Assuming transport in the PS and SPS within budgets like in 2012
- **Requires successful SPS scrubbing !**
- All beams to be prepared in 2014!

- Setup of longitudinal blow-up along PSB ramp and h1+2 transfer to the PS during commissioning and MDs
- Push SPS to intensity limit for 25 ns beams

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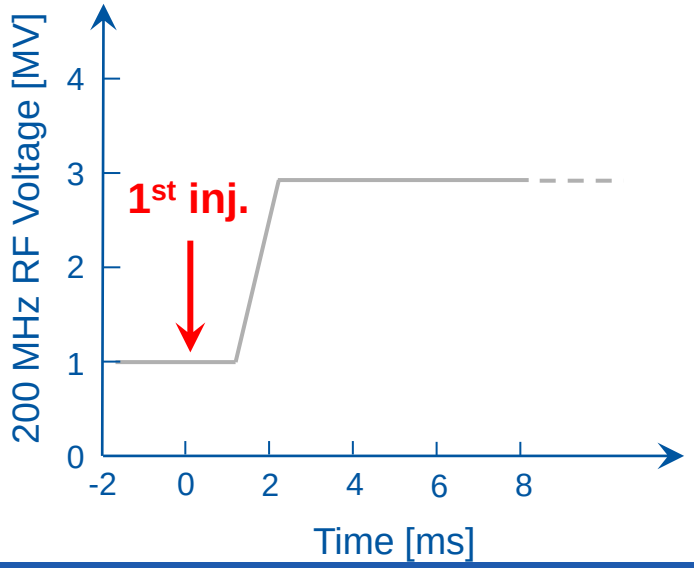
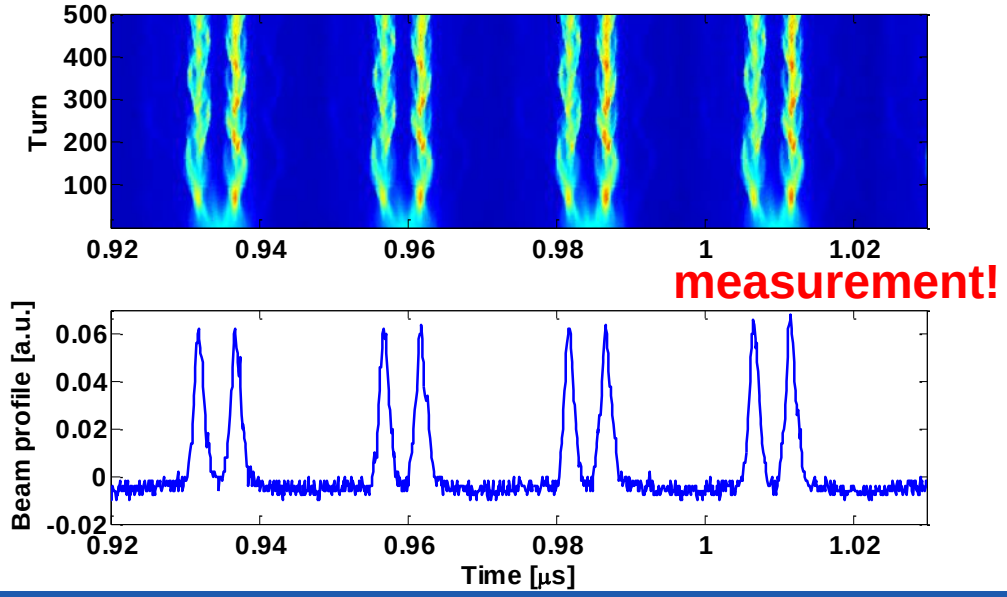
Doublet beam

- Injection of trains of 72 x 10 ns long bunches with 1.7e11 p/b on unstable phase and capture in two neighboring buckets in the SPS
  → **successfully tested (no acceleration to 450 GeV)**
  → **e-cloud enhancement observed in the SPS**





Doublet beam

- Injection of trains of 72 x 10 ns long bunches with 1.7e11 p/b on unstable phase and capture in two neighboring buckets in the SPS
  → successfully tested (no acceleration to 450 GeV)
  → e-cloud enhancement observed in the SPS
- New SPS transverse feedback will be capable of working during the splitting (pickups for LHC beams to be installed despite vacuum issues) **→ to be setup**
- Acceleration of 1.6e11 p/doublet as requested for LHC scrubbing
  - need 3x slower ramp due to beam loading and required RF voltage
  - possible beam quality degradation e.g. longer bunches, unbalanced doublet intensity, blow-up from e-cloud, …

→ lots of SPS MD time required

Twice the intensity per batch compared to 50 ns beam in 2012 !!!

	Intensity (p/doublet)	Emittance (mm)
Doublets	1.6×10^{11}	> 3.0

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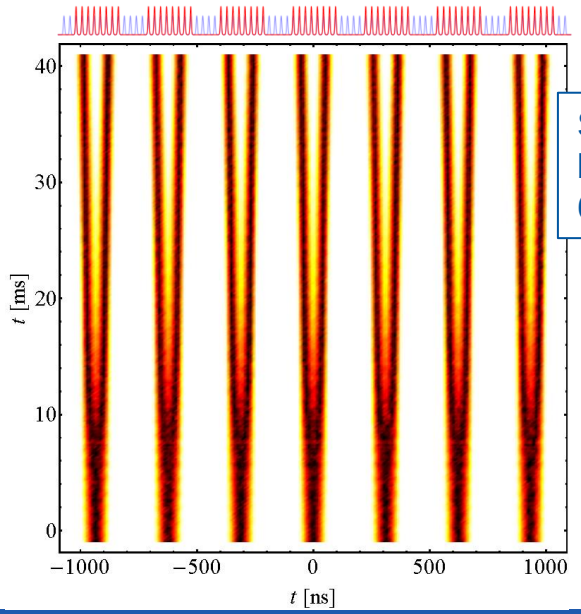
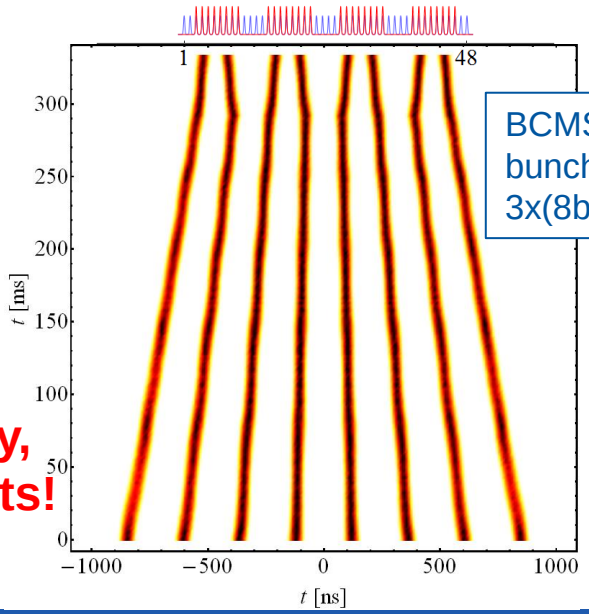
8b+4e scheme

- Trains with 4 missing bunches every 8 bunches (H. Damerau, RLIUP)
  - Allows for larger intensity per bunch
  - Expected to reduce e-cloud effects (→ to be checked in measurements)
- Production
  - Std. scheme: h = 7 → 21 double split + empty bucket
  - BCMS: merging and triple splitting suppressed but h = 14 → 21 batch compression



Standard scheme bunch pattern: 6x(8b+4e) + 8b

simulations only, no measurements!

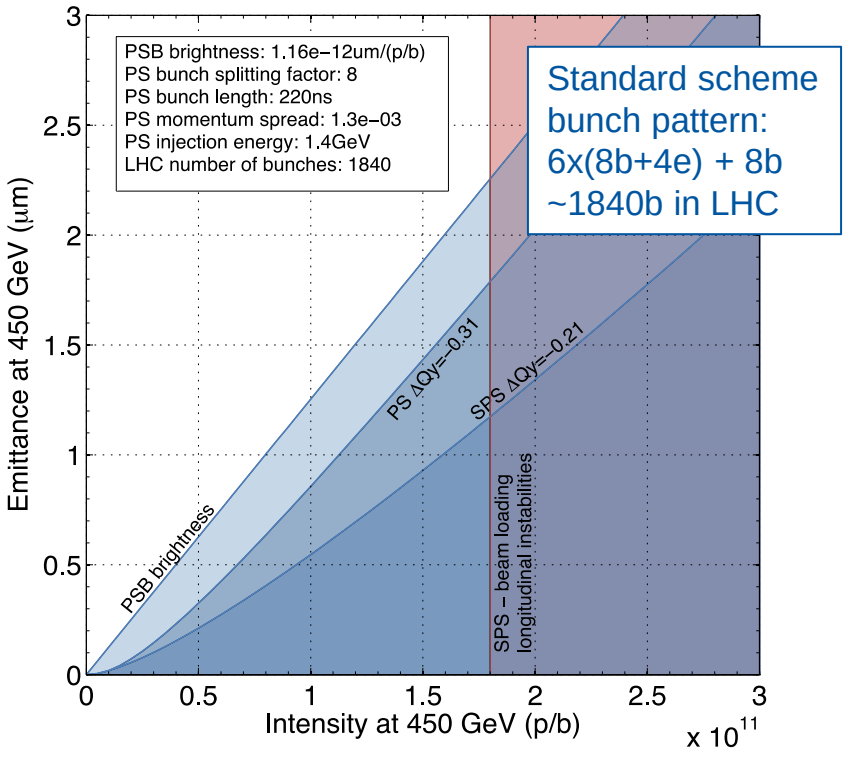


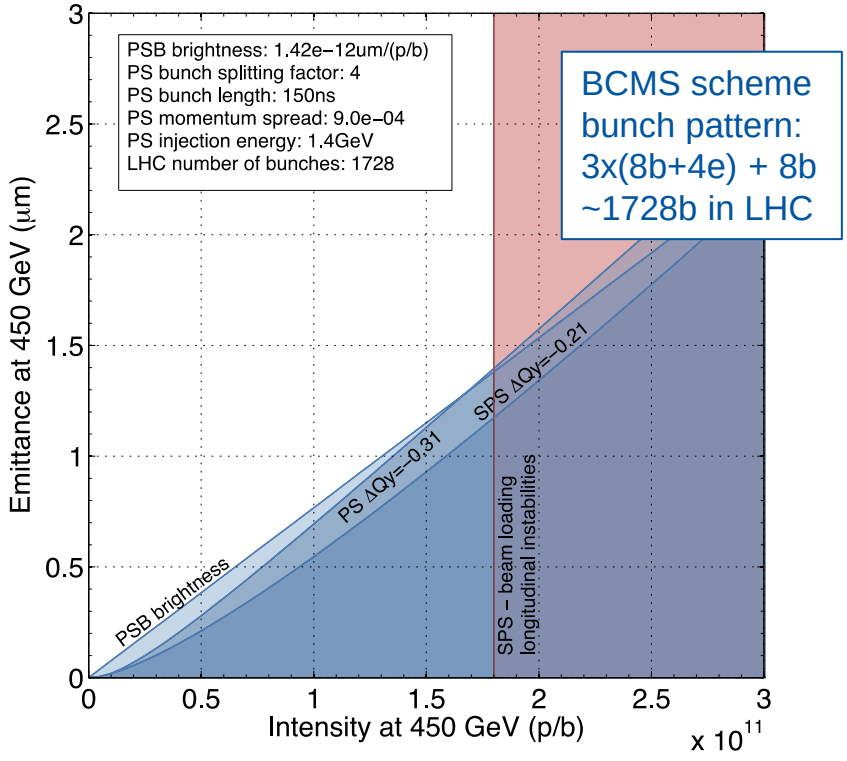
BCMS scheme bunch pattern: 3x(8b+4e) + 8b

8b+4e scheme

- Expected to be limited to 1.8 x 10^{11} p/b because of SPS longitudinal instabilities
- Brightness limit from PSB for standard scheme
- No outstanding bottleneck for BCMS

to be tested in MD studies in 2015 …





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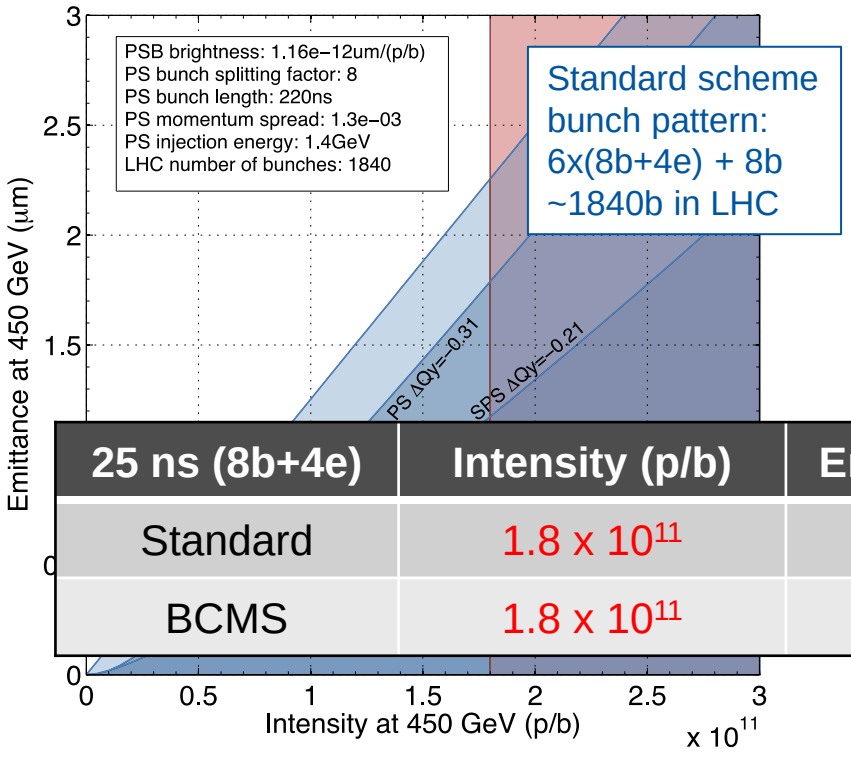
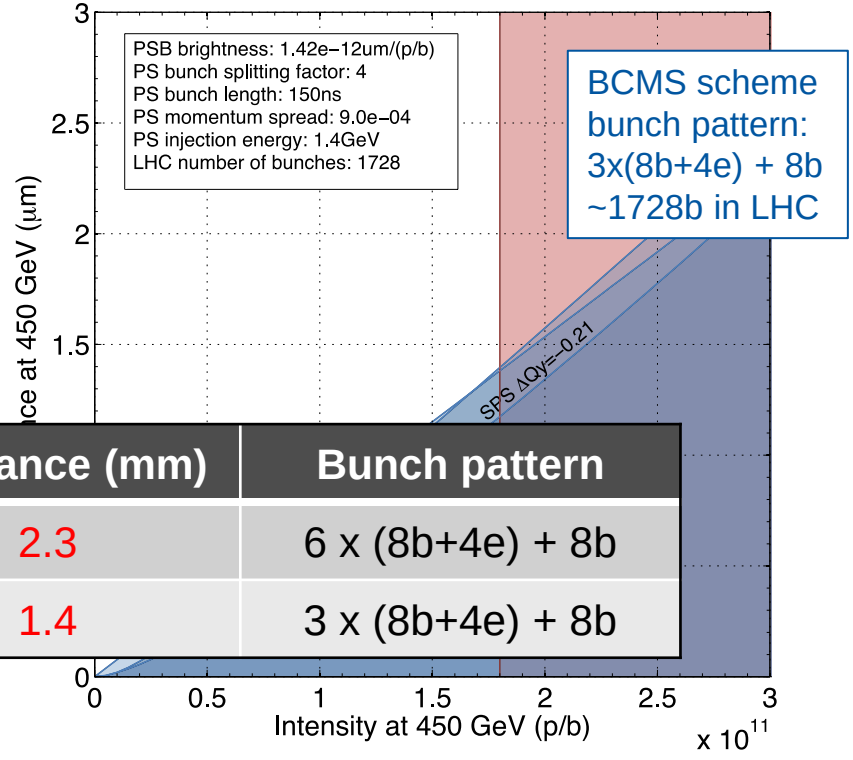


Standard scheme bunch pattern: 6x(8b+4e) + 8b ~1840b in LHC



BCMS scheme bunch pattern: 3x(8b+4e) + 8b ~1728b in LHC

25 ns (8b+4e)	Intensity (p/b)	Emittance (mm)	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

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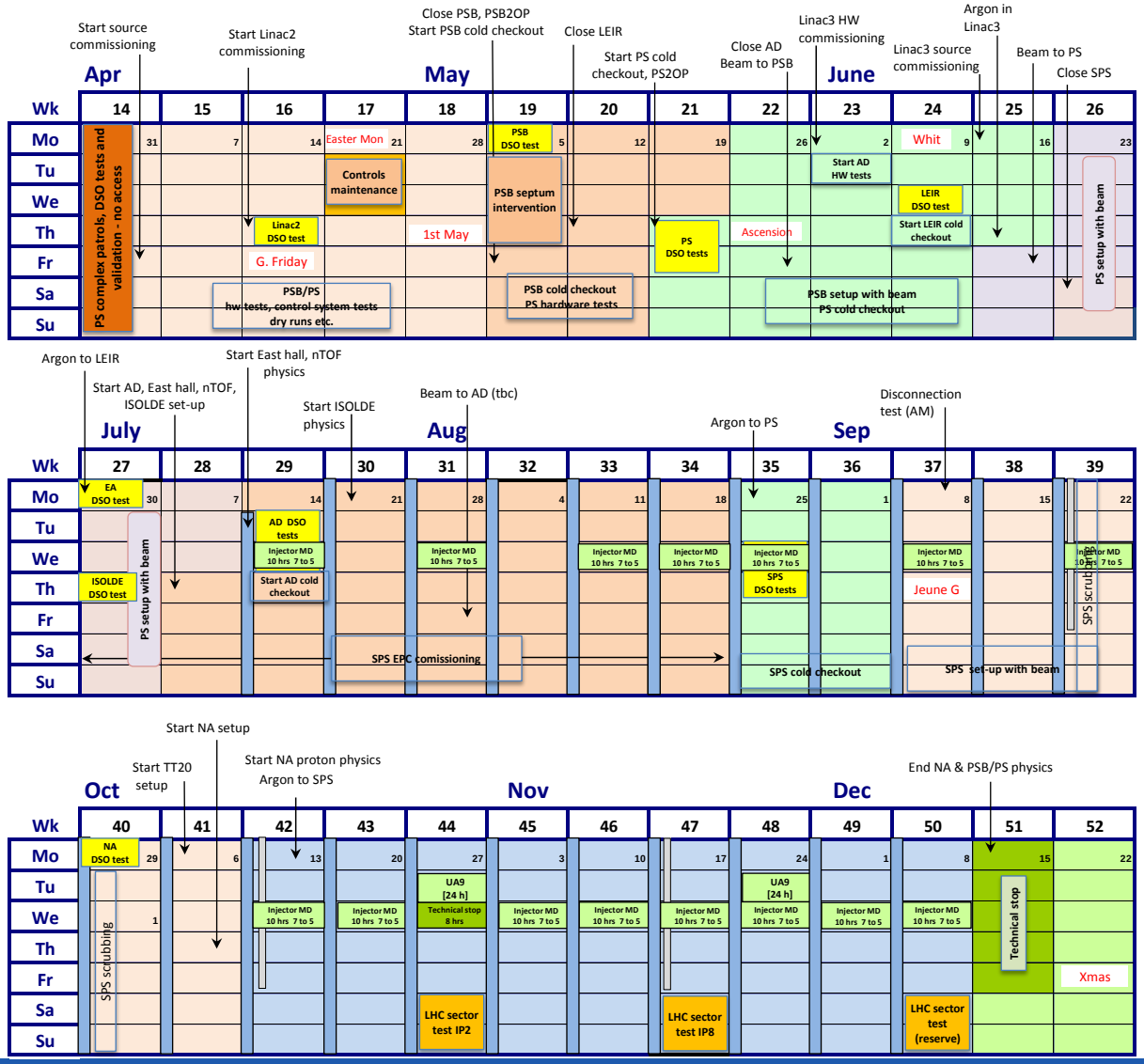
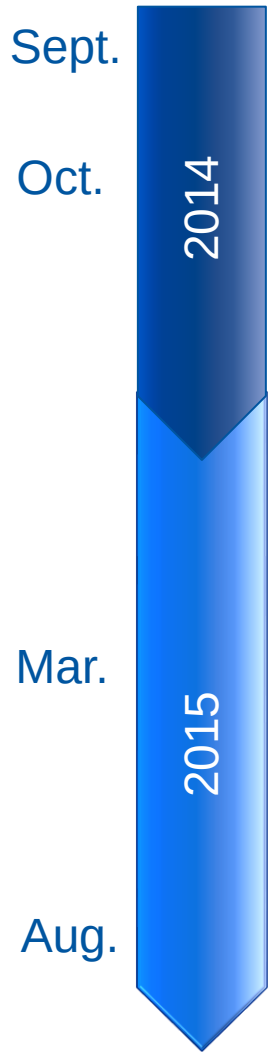
Injector schedule 2014



Milestones (I): SPS scrubbing



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 for scrubbing

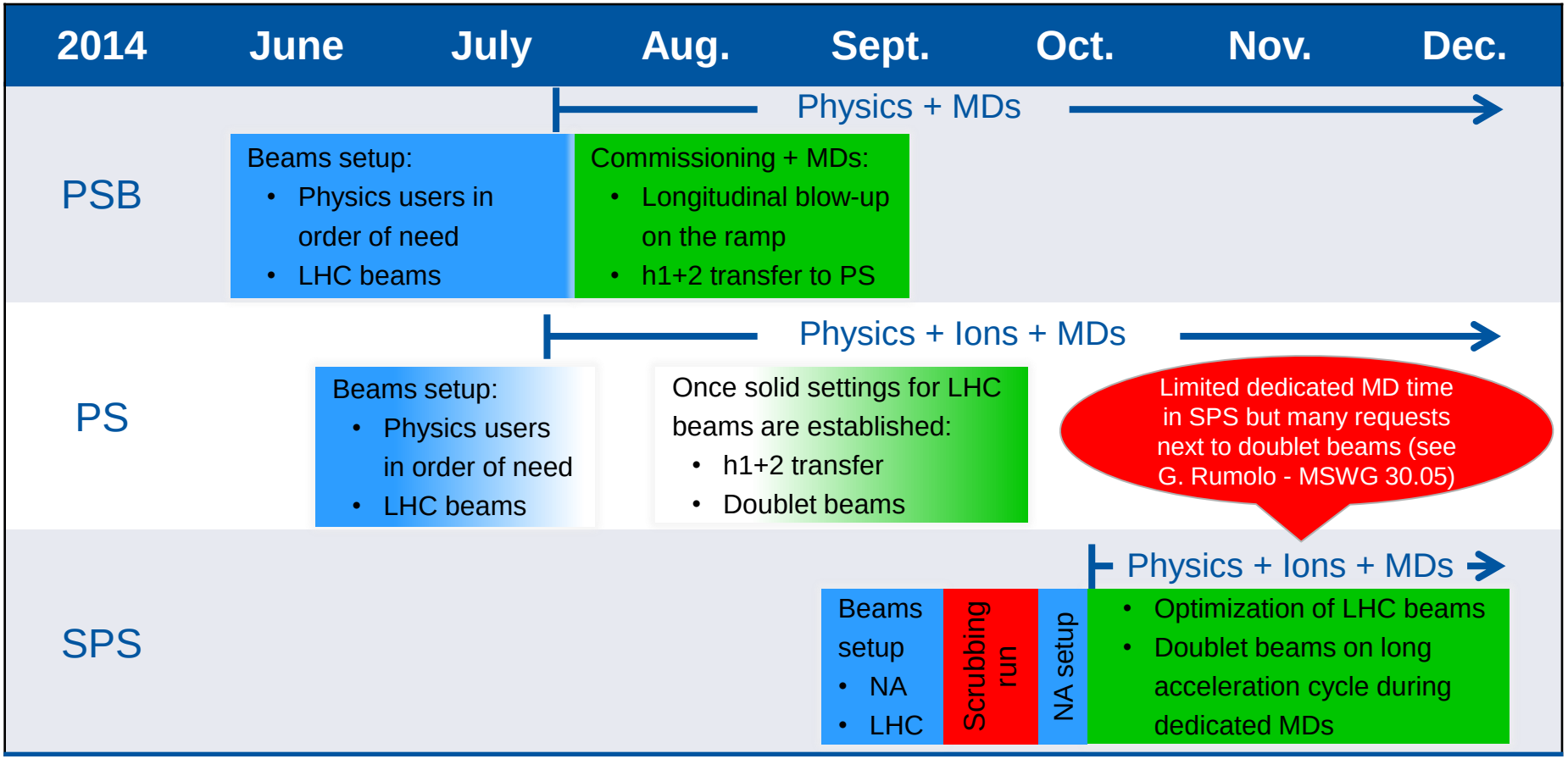
- Set up the doublet beam with acceleration + test of the LHC BPMs in the SPS with doublets (critical for LHC scrubbing!)
- Push intensity of the 25 ns beam

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?

Milestones (II): New LHC beam production schemes



- Ion beams (Ar) have to be ready in January 2015 for NA physics … setup will also take lots of time!
- Hopefully able to demonstrate doublet production scheme in 2014 (limited dedicated SPS MD time!)
- 8b+4e beams to be done in 2015 (maybe first tests advanced to 2014) …

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Conclusions

- Single bunch beams
  - New production scheme for better control of intensity and longitudinal emittance
- 25 ns and 50 ns beams
  - Recovering the 2012 performance relies on successful scrubbing of the SPS
  - Implementation of new beam production schemes for higher brightness as part of the LHC beams commissioning in PSB and PS and higher intensity in SPS
  - Second SPS scrubbing run in 2015 to decide if coating is needed to reach higher beam intensity
- Doublet beam for LHC (and SPS) scrubbing
  - Setup of the SPS cycle with acceleration
  - Reaching target intensity (1.6e11 p/doublet) challenging

} lots of SPS MD time with very long cycle needed !!

- 8b+4e beam as low e-cloud option
  - First tests in the SPS most likely not before 2015 due to limited MD time
- 2014 will be very busy for injectors: physics beams, LHC beams (old and new schemes!), ion beams in preparation for 2015, MDs …

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

Longitudinal emittance per bunch at PS injection should not exceed

- [Total Split Factor x 0.35 eVs]/1.1 (includes 10% margin for blow-up)
- About 3 eVs (h=7) and 2 eVs (h=9) for RF manipulations at E_{kin}=2.5 GeV
- [FB Split Factor x 1 eVs] for transition crossing in h=21
- Matched value in the PSB (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

Longitudinal emittance per bunch at PS injection should not exceed

- [Total Split Factor x 0.35 eVs]/1.1 (includes 10% margin for blow-up)
- About 3 eVs (h=7) and 2 eVs (h=
- [FB Split Factor x 1 eVs] for tran
- Matched value in the PSB (h1+2

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