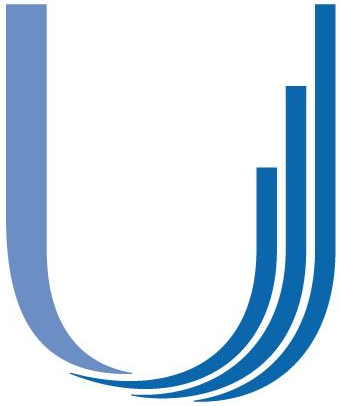

LHC Injectors Upgrade

LHC Injectors Upgrade

80 bunches schemes plus comments on BCMS and 8b+4e

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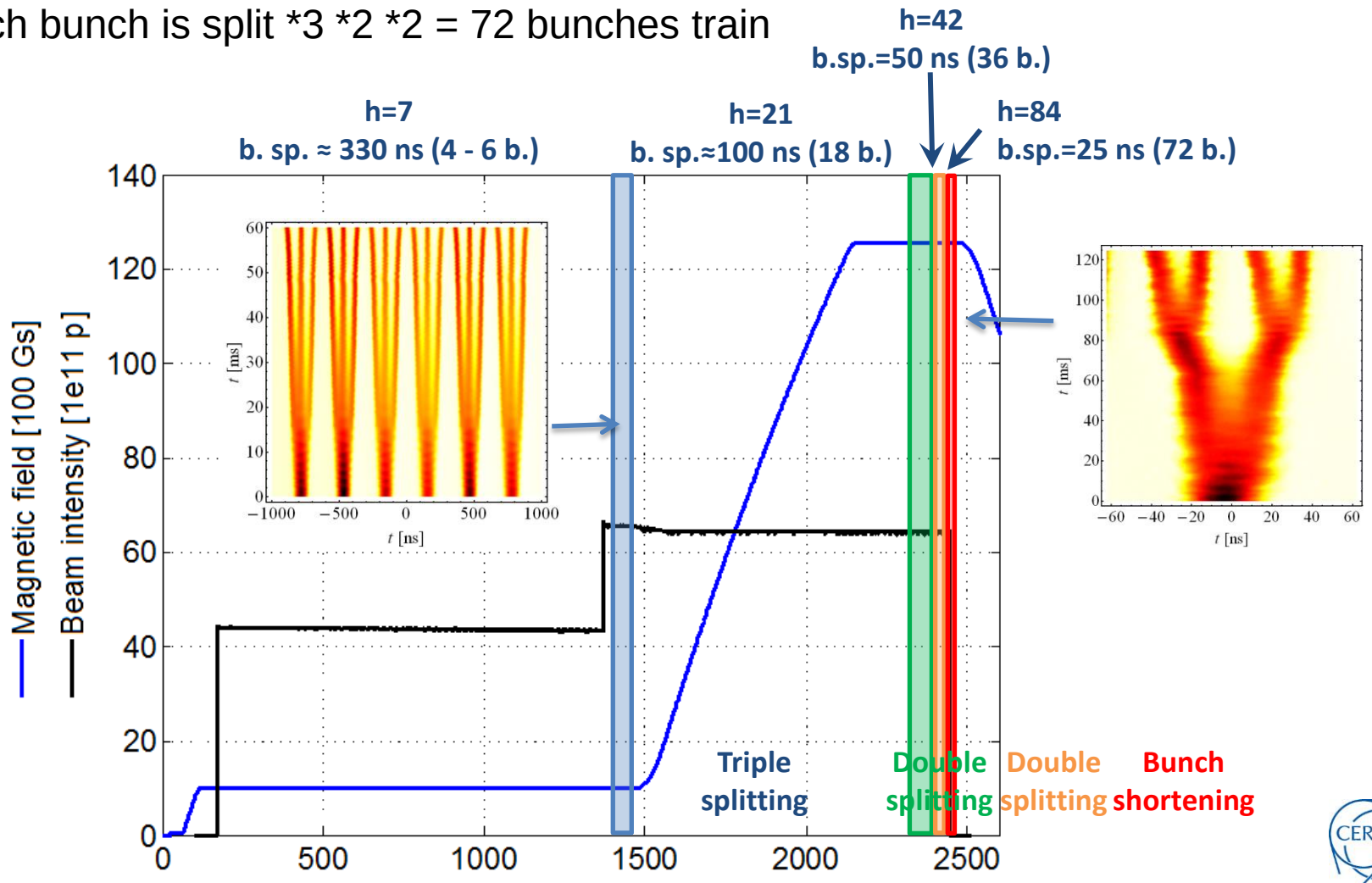
In collaboration with: H. Bartosik, H. Damerau, B. Goddard, V. Kain, G. Rumolo, G. Sterbini

CERN

25ns LHC production scheme in the PS

Standard scheme (72 bunches) :

- inject 6 bunches on h=7
- Each bunch is split *3 *2 *2 = 72 bunches train



LIU parameter table (standard 25 ns beam)

PS injection (double injection, 4 + 2 bunches or **4 + 3 bunches**)

	N (10^{11} p)	$\varepsilon_{\xi,y}$ (μm)	E_{kin} (GeV)	ε_z (eVs)	τ (ns)	$\delta p/p_0$ (10^{-3})	$\Delta Q_{x,y}$
Achieved	16.8	2.2	1.4	1.2	180	0.9	(0.24,0.31)
LIU	28.1	1.6	2.0	3.0	205	1.5	(0.16,0.28)
HL-LHC	32.5	1.8	2.0	3.0	205	1.5	(0.18,0.30)

PS extraction – 72 or **80 bunches**

	N (10^{11} p)	$\varepsilon_{\xi,y}$ (μm)	p_0 (GeV/c)	ε_z (eVs)	τ (ns)
Achieved	1.3	2.4	26	0.35	4
LIU	2.2	1.7	26	0.35	4
HL-LHC	2.6	1.9	26	0.35	4

Beam parameters mildly depend on the number of bunches:

- Electron cloud
- PS coupled bunch instab.

80 bunch-train production scheme: selective elimination of bunches using Transverse Damper

Production scheme in PS (25 ns) :

- Inject 7 bunches in 7 buckets (full machine)
- Triple splitting: 7*3 = 21 bunches
- Eliminate 1 bunch @ 2.5 GeV with T-damper: 20 bunches accelerated to 26 GeV
- Two times double splittings: 20*2*2 = 80 bunches to SPS

Observation:

- The PS harmonics corresponding to 25 ns is 84 :
  not possible in any case to cleanly extract more **80** nominal bunches due to extraction kicker rise time.
- 21 bunches regularly accelerated to study coupled bunch instabilities but only extracted on h=21
- 82 done in the past by killing two bunches on the extraction kicker rise time with impact on the rest of the train
- Only multiples of 4 bunches can be eliminated with this method :
  76 bunches would be of any use?

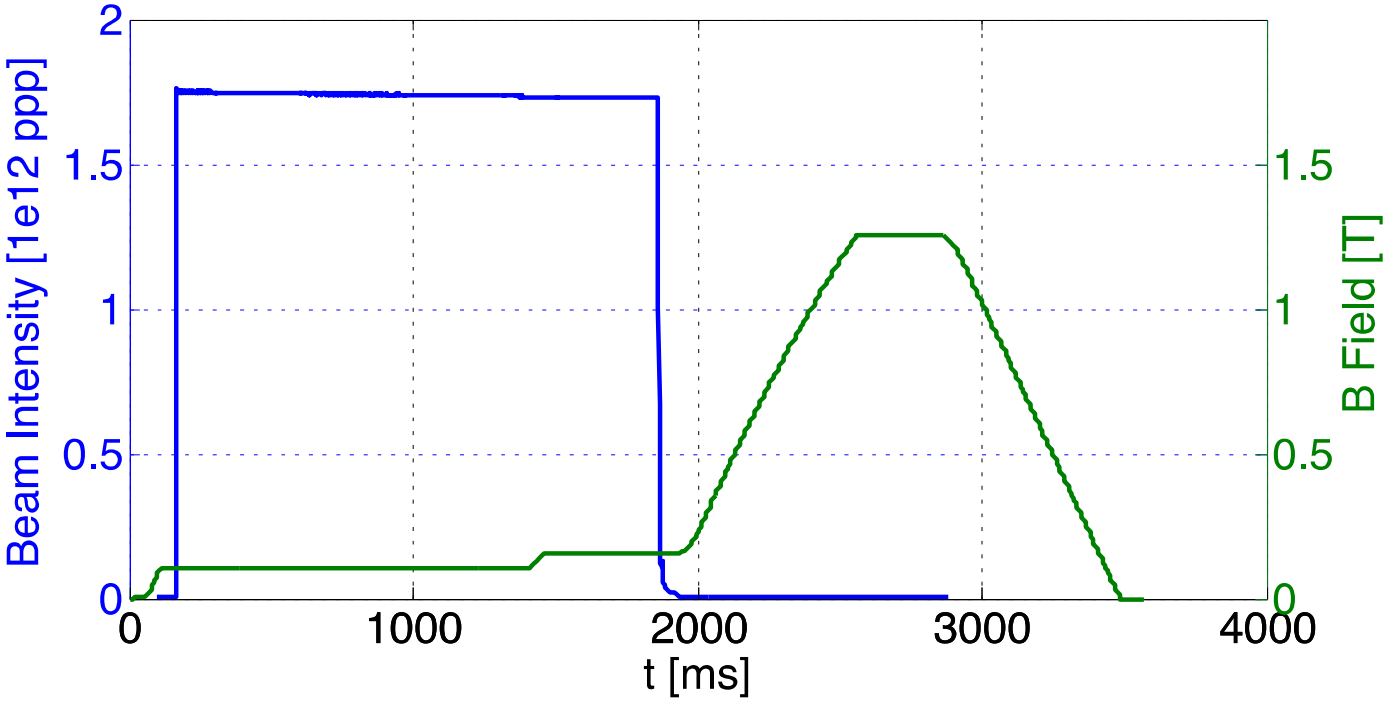
Status:

- Not possible today to use selective bunch excitation, due to limitation of transverse damper firmware. Upgrade being implemented (test this week).
  MDs planned as soon as new firmware ready.
- First single-bunch elimination test proved to be successful

80 bunches from PS: single bunch 2014 test

Very promising first experimental tests on **single bunch beam** @2.5GeV

- Excitation with the transverse damper (with low and corrected chromaticity)
- Extracted beam shows a 95% extinction efficiency



See Chamonix 2014 proceedings: H. Bartosik et al.,
OTHER MEANS TO INCREASE THE SPS 25 ns PERFORMANCE
– TRANSVERSE PLANE

Plans for 2015

- Validate elimination of single bunch out of a train when tagging firmware ready
- Losses localization:
  - Try to concentrate losses in PS well shielded regions like close to the internal beam dumps or to the dummy septum (non-active element used to shield extraction septum during extraction)
- Check for ghost and badly-injected bunches in the SPS
  - Validate the bunch extinction efficiency
  - Check kicker rise times and synchronisation
- Impact on e-cloud and longitudinal stability in PS and SPS
- Injection of 1-2 80b trains into LHC
  - Check effect of kicker ripple, ecloud, ghost bunches, damper, BI, losses

Other possible limitations

Possible other limitations to be quantified:

- Protection devices which could see full beam (TPSG in SPS extraction, TCDI in TLs, TDI in LHC…)
- SPS RF total power (slightly longer fraction of ring occupied by beam)
- SPS and LHC Wirescanners
- Impedance heating in SPS and LHC
- Whether ~8.8 us really OK for MKI and MKE6 (pulse length will be input for planned MKE4 changes)
- LHC beam dump TDE load (TCDS/TCDQ unchanged)

- Note: even if some of these prove insurmountable, 3x80b per transfer to LHC (giving same number of colliding bunches as nominal scheme) could be very interesting as fall back option if unexpected limitations with total p+ in SPS…
  - Or if SPS single bunch intensity could reach 288/240 x HL-LHC spec!

Beam transfer from SPS to LHC

Key issue is performance of protection devices TPSG, TCDI and TDI(S)

- With present beam of 1.2e11 p+ in 2.6 um, existing TCDIs with 320b injected will be above the design criteria for LHC protection (with 288b of 1.7e11 in 3.5 um), by about 6%
  - Should just be OK for slightly reduced intensity of about 1.1e11 p+ in same emittance
- For HL-LHC it is already very difficult to design these devices to reach the specification of 288x2.3e11 p+ in 2.1 um emittance
- 320b is 11% higher intensity again: will be even more difficult to reach this specification
  - These designs are in progress and (for TCDI) at stage of engineering specification
  - Change of design parameters now could result in delay for LIU and likelihood of not installing in LS2 - production needs to be launched in 2015
  - LIU-SPS and WP14 propose to make explicit evaluation of this beam (320b with nominal 25 ns parameters), to find real limits. Will not be top priority compared to finishing design for nominal parameters.

Why we cannot increase number of bunches for BCMS ?

BCMS Production scheme:

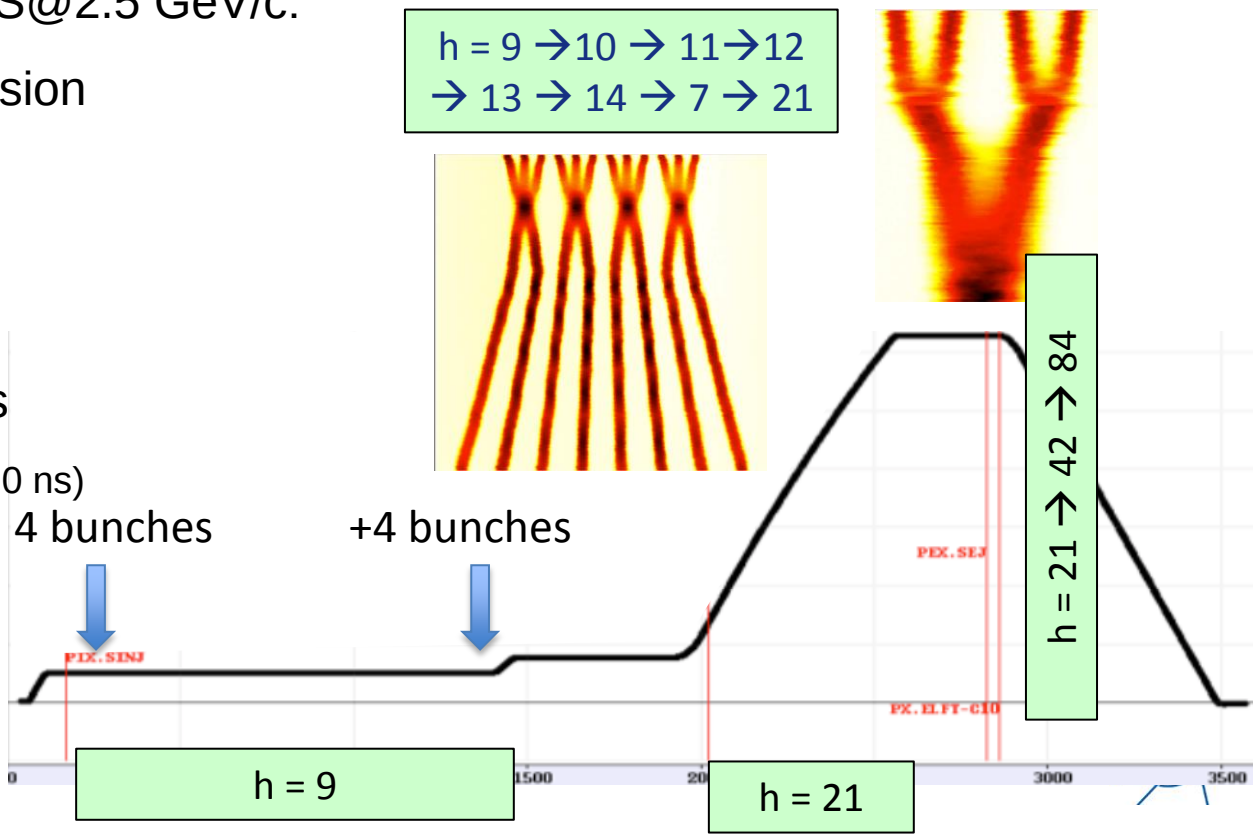
a) Double batch injection from PSB (**4 + 4 bunches, 8 bunches for PS at h=9**)

b) Up to 5 batches of **48 bunches** each transferred to the SPS (240 bunches)

Transverse emittance produced in the PSB, longitudinal in the PS

- Multiturn proton injection in PSB with **shaving**
- RF gymnastics in PS@2.5 GeV/c:
  - Batch compression
  - Bunch merging
  - Triple splitting
- Acceleration
- 2 x Double splittings

  (1 Double splitting for 50 ns)
- Bunch rotation



Why we cannot increase number of bunches for BCMS ?

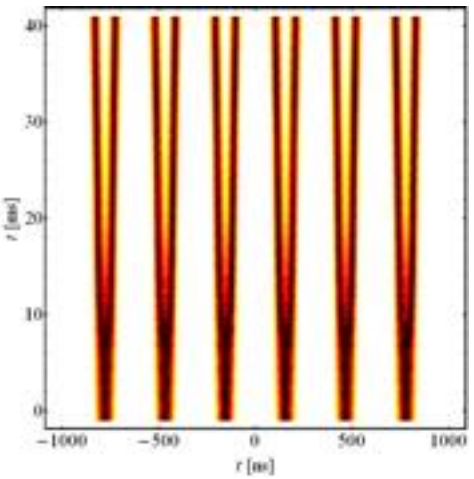
Why not adding > one bunch from the PSB

- Longer injection cycles at PS injection
  - 4 rings are already injected twice
  - Cycles will become 1.2 s longer
  - SPS flat-bottom which effectively becomes longer by 3.6 s (for 240 bunches) or 7.2 s (for 288 bunches) compared to the nominal scheme
- 2 more rings should be injected because we need merging
  - **But injection of 10 bunches of h=9.**
    No space for one more bunch

8b+4e → from 48 to 56 bunches

Nominal 8b+4e scheme:

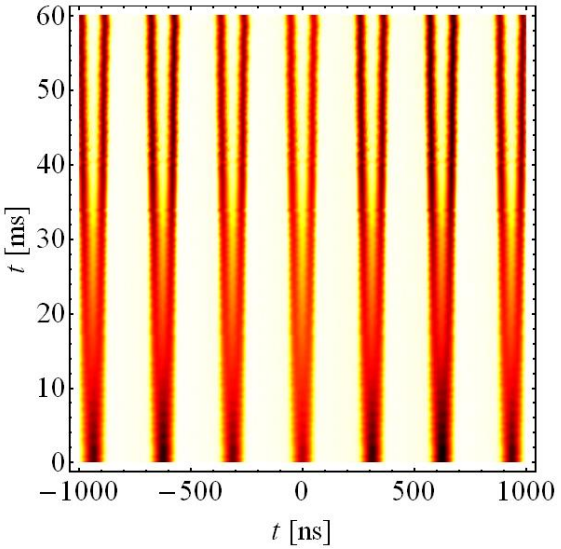
- **6 bunches injection on h=7**
- double split at low energy
- Two double splittings at high energy
- **Batches of 48 bunches**
- 5 Gaps of 4 bunch positions



Full machine 8b+4e (already extracted):

- **7 bunches injection on h=7**
- double split at low energy
- Two double splittings at high energy
- **Batches of 56 bunches**
- 6 Gaps of 4 bunch positions
- No injected in the SPS yet

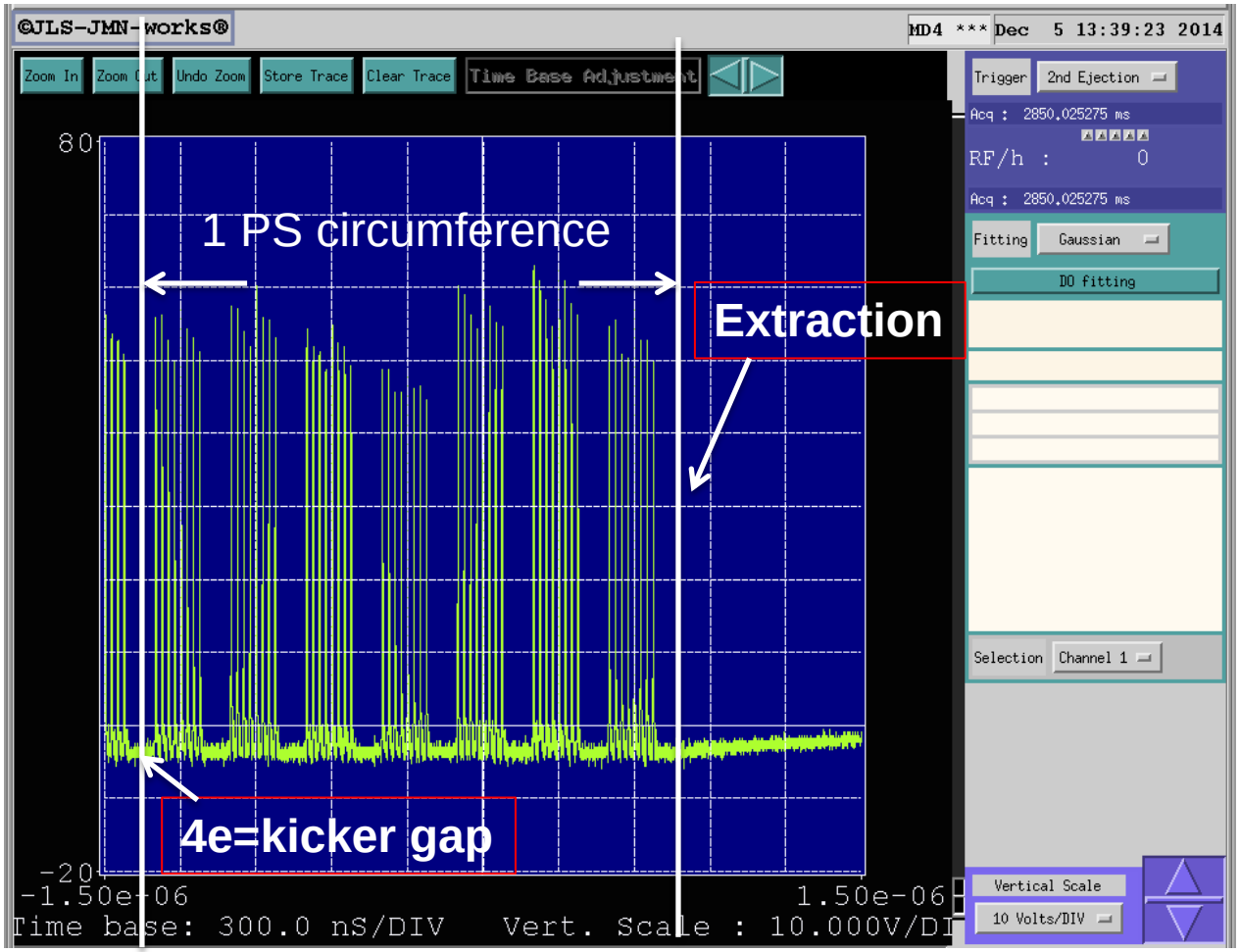
Measured



No need of bunch extinction, extraction kicker gap already present

8b+4e 56 bunches at PS extraction

7 groups of 8 bunches = 56 bunches



- **Good extraction of 8b+4e proves that 80 bunches extraction can work since empty gap for kicker rise time is the same**
- **Should check the result in the SPS.**

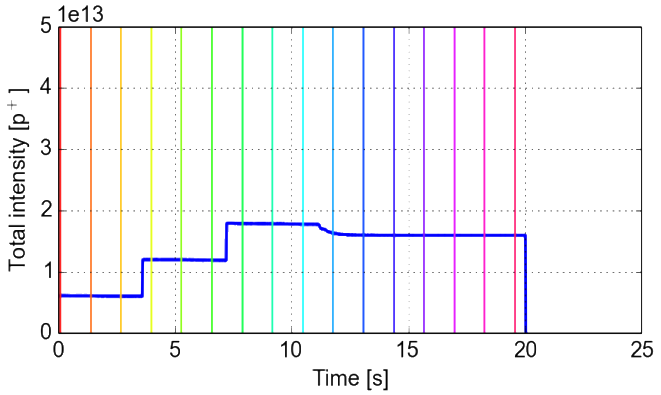
8b+4e- 48 bunches in SPS during scrubbing run

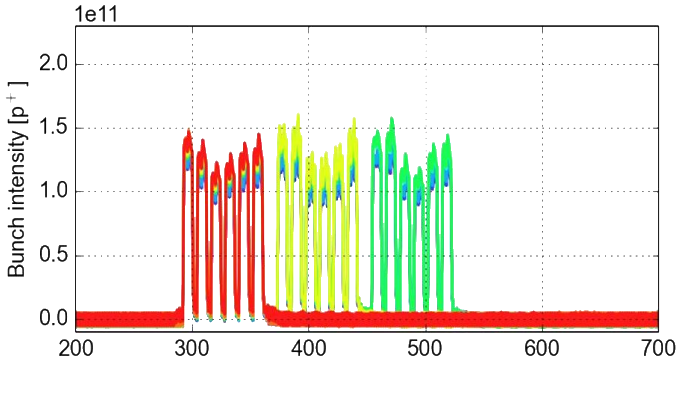
8b+4e (low e-cloud scheme)

From G. Iadarola presentation
LIU SPS intermediate scrubbing review
23 February, 2015

- Injected up to **~1.7 x 10^{11} p/b**
- Accelerated up to **~1.4 x 10^{11} p/b (3 x 48 b.)**
  - Limited by **sparking in the electrostatic septa (ZS)** → conditioning observed
- No visible e-cloud degradation, good lifetime at 26 GeV/c
- Losses at the beginning of acceleration → setup to be refined

Beam type	Bunch intensity (injected)	Number of bunches	Transverse emittances (at 26 GeV)	Beam lifetime after each injection
25 ns Standard	~1.25 x 10^{11} p/b	288 (4 x 72)	$\varepsilon_{H,V}$ ≈ ~. 6 μm	~200 s, ~210 s, ~180 s
8b+4e (at 26 GeV)	~1.7 x 10^{11} p/b	144 (3 x 48)	ε_H ≈ ~2.6 μm ε_V ≈ ~. 9 μm	~250 s, ~240 s, ~260 s





Conclusion

- **80 bunches scheme as interesting option for several reasons:**
  - Potential to get 5% more LHC lumi with same events per crossing
  - Possible enhanced scrubbing beam
  - Possible mitigation if SPS total intensity limited
  - Path to using higher intensity per bunch in SPS, within current design envelope for protection devices
- **MD plans well establish to validate the production schemes**
- **Potential limitations need careful evaluation:**
  - Main ones identified are in SPS to LHC beam transfer.
  - **Can evaluate performance reach but late for re-specification and re-design, as production to start in 2015 to be ready for LS2**
- **Also other schemes re-evaluated to increase number of bunches**