LHC Injectors Upgrade

SPS experience for LHC ion run

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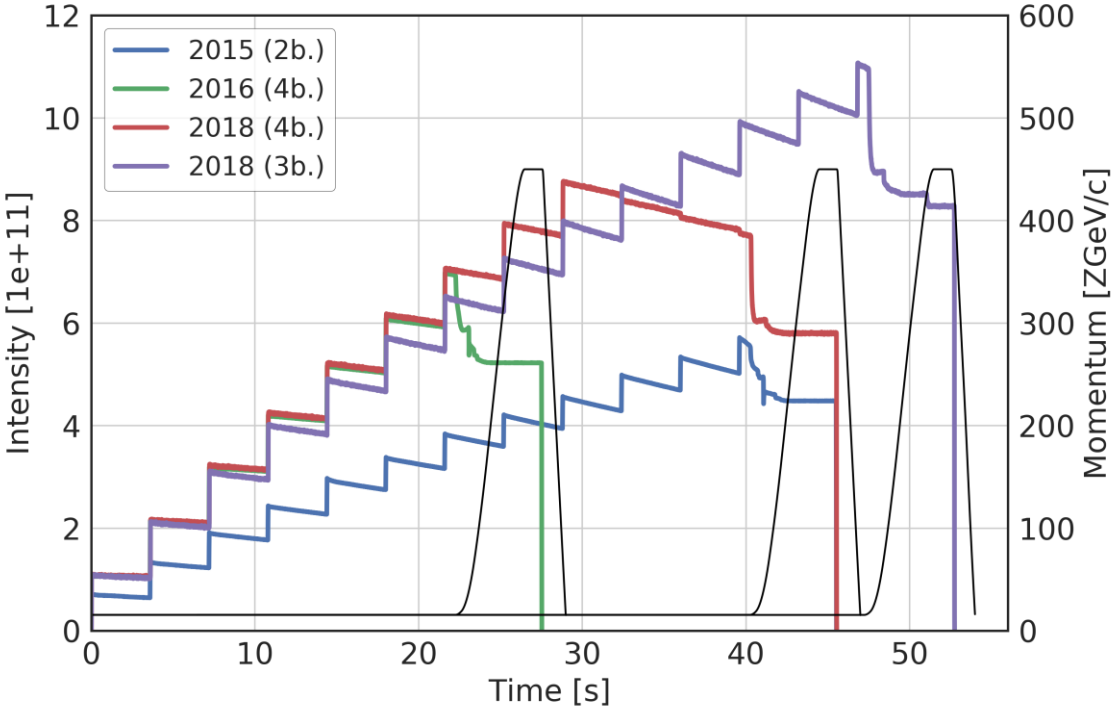
SPS & PS operators

LIU beam performance meeting, 13 December 2018

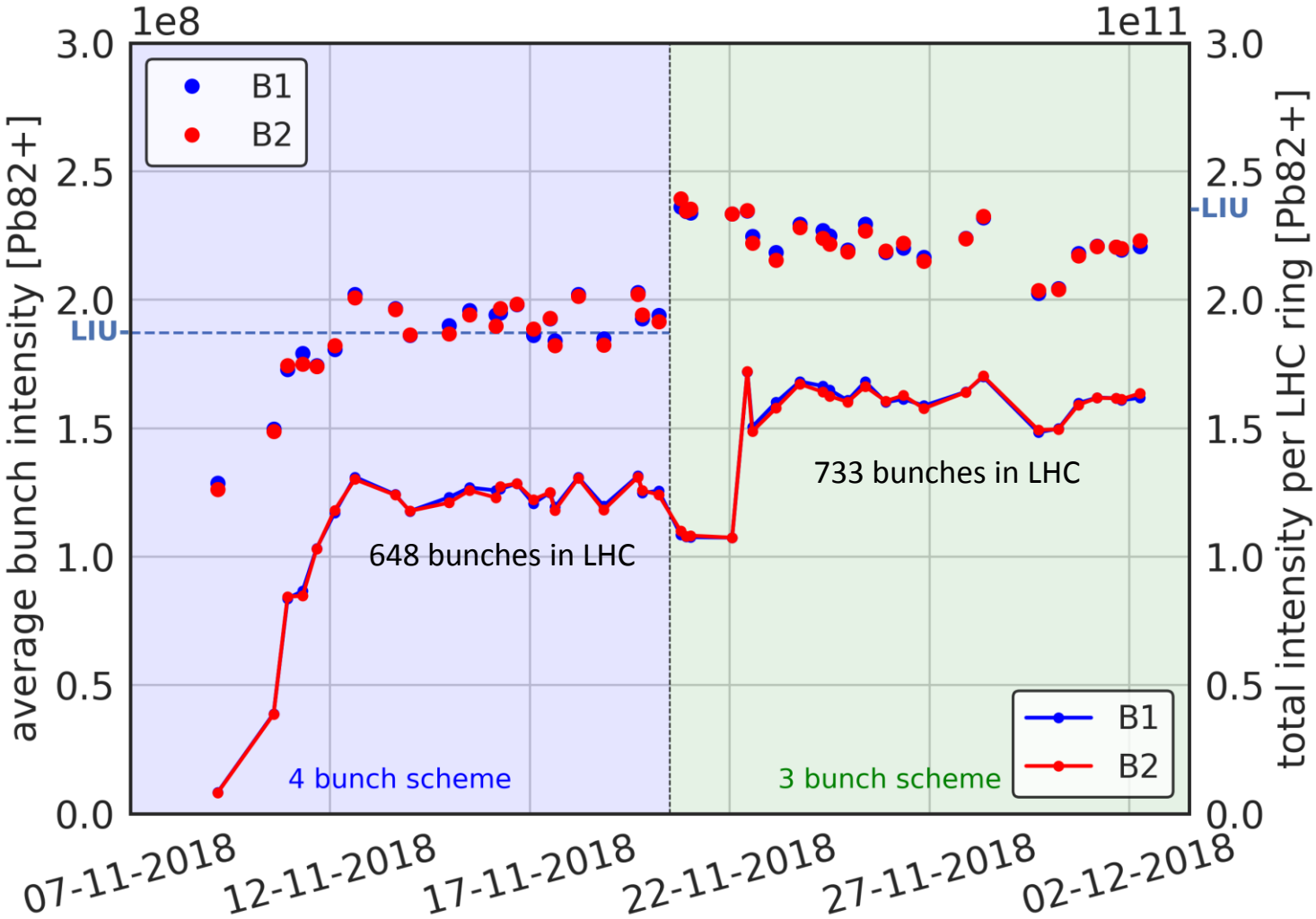
SPS cycles and beams used

- **First half of the 2018 run with 4 bunch (100 ns) scheme**
  - Cycle prepared for 12 injections – LHC took only 9 injections due to abort gap settings
  - Similar transmission in Q26 (2018) as in Q20 (2016)

- **Second half with 3 bunch (75 ns) scheme**
  - Cycle with up to 14 injections
  - Scraping had been requested by LHC



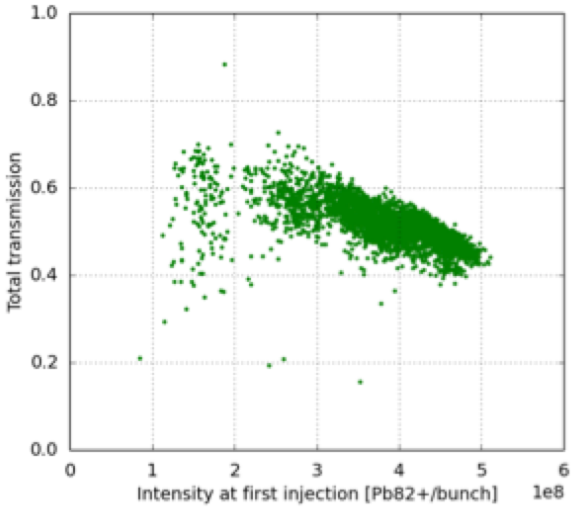
Intensity evolution LHC Pb-Pb run 2018



Performance target reach: risk & mitigation

- **Slip-stacking represents main performance risk**
  - **Without slip stacking only 58% of target** for same beam production scheme (losses in SPS remain the main bottleneck)
- **Progress on alternative beam production scenarios**
  - Option of 3 bunches spaced by 75 ns demonstrated with Xe-ions in LEIR & PS → **67% of target expected** (to be tested with Pb)
  - Further gain from reduced batch spacing in SPS → feasibility of 125 ns to be tested with beam in 2018

2015 data (12 SPS injections)

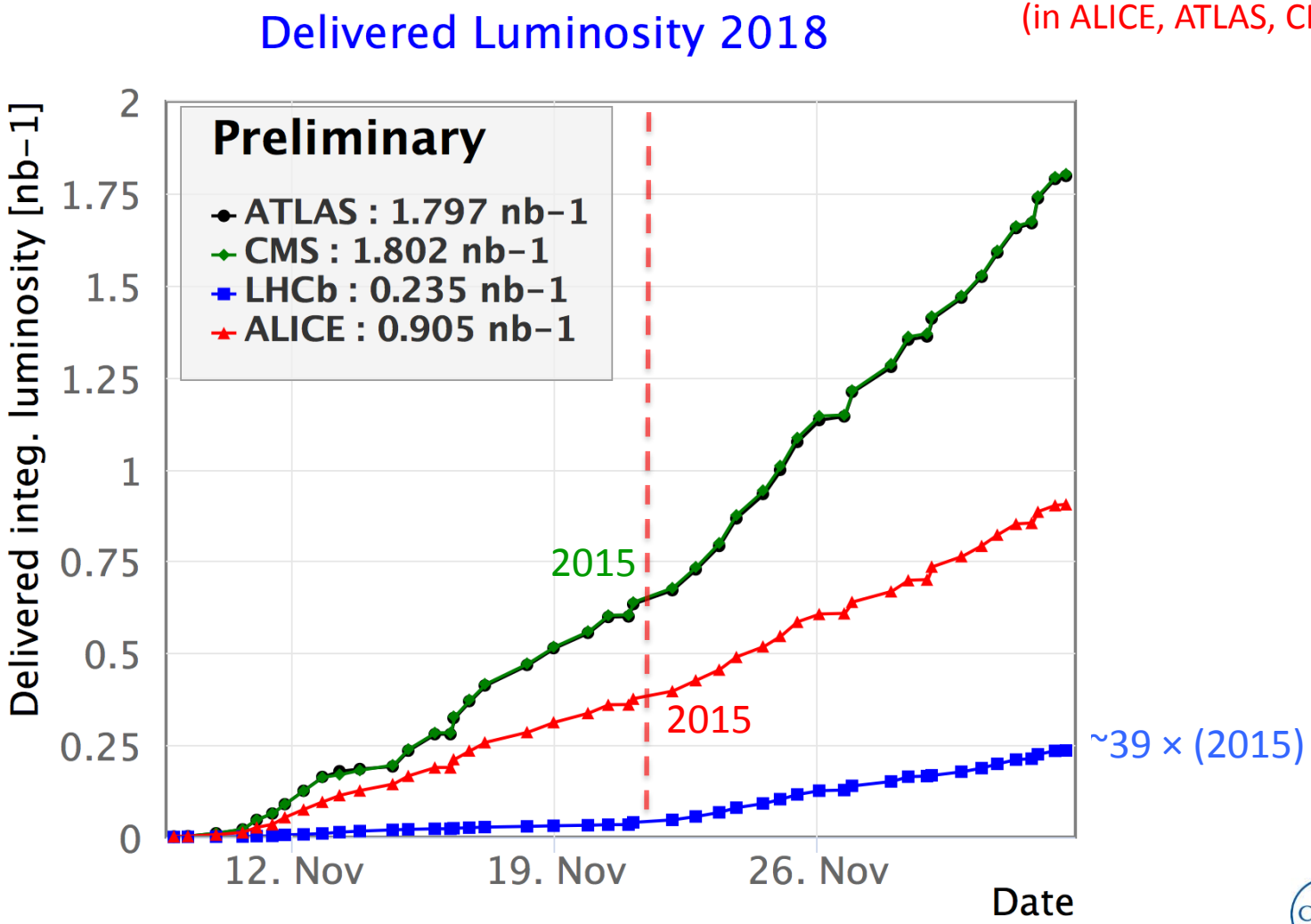


	Pb82+/b @SPS inj.	PS bunch spacing (ns)	bunches (from PS)	MKP gap (ns)	SPS slip stacking	LHC total bunches	expected SPS transmission	expected total Pb82+	total intensity relative to target
baseline	3.6e8	100	4	150	YES	1256	56%	2.35e11*	104%
4 bunches	3.6e8	100	4	150	NO	696	56%	1.40e11	58%
3 bunches	4.8e8	75	3	150	NO	750	45%	1.62e11	67%
3 bunches	4.8e8	75	3	125	NO	798	45%	1.72e11	71%

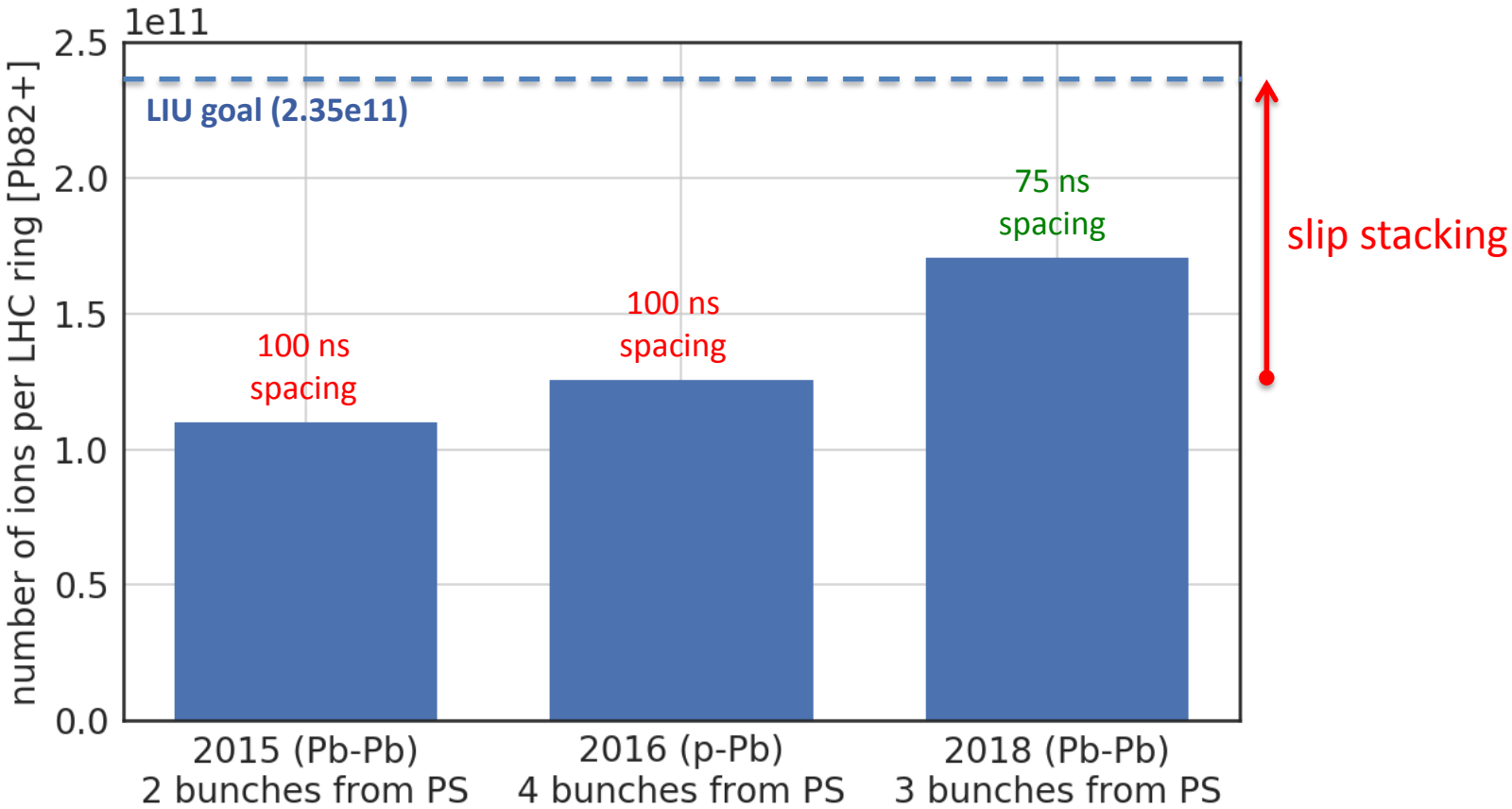
* including 5% losses for slip stacking

Integrated luminosity in LHC

HL-LHC goal: 2.85 nb^{-1}
(in ALICE, ATLAS, CMS)

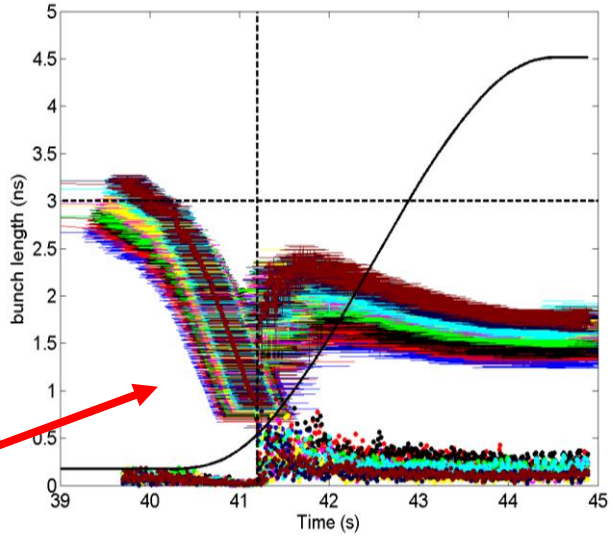


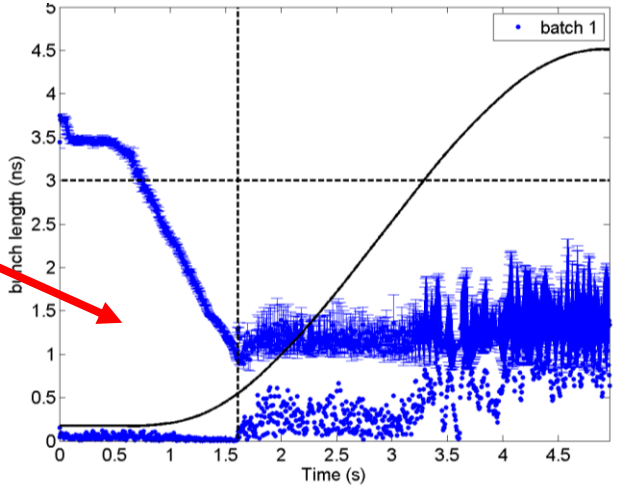
Pb-ion performance over the last years



Issues with longitudinal stability

- **Significant reduction of intensity and bunch length along the SPS batch at end of flat bottom**
  - leads to instability of the shortest (and less intense) bunches
- **Transition crossing**
  - Adjustments are done using many knobs (2 main: transition timing and radial beam displacement)
  - Instability and emittance blow-up during transition crossing lead to better beam stability later on
  - Will be improved after LS2 due to LLRF (phase discriminator) upgrade
- **But … bunches crossing transition without significant blow-up become unstable later**
- **Had to run with relaxed BQM settings**
  - bunch length tolerance 2.2 ns, …
  - No particular issue from LHC side!





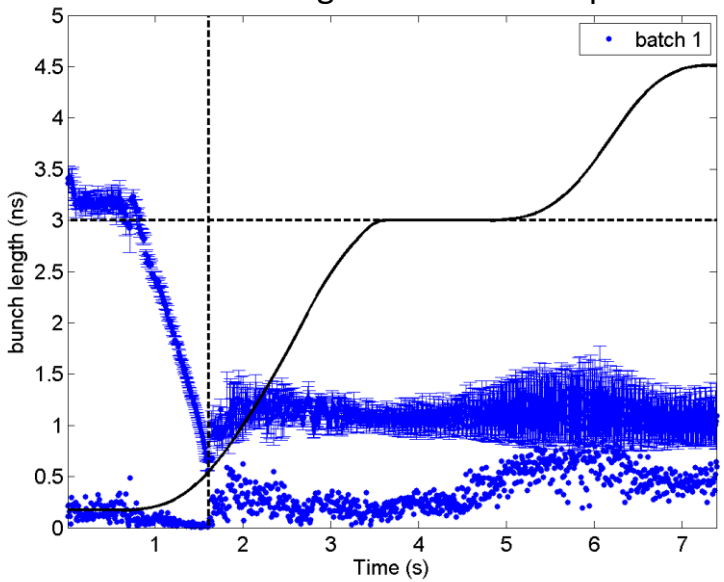
Observations during slip-stacking MD

- **Radial displacement at intermediate flat portion (20 mm) didn't lead to BCT losses**
  - maybe we can displace only one beam and simplify slip-stacking?

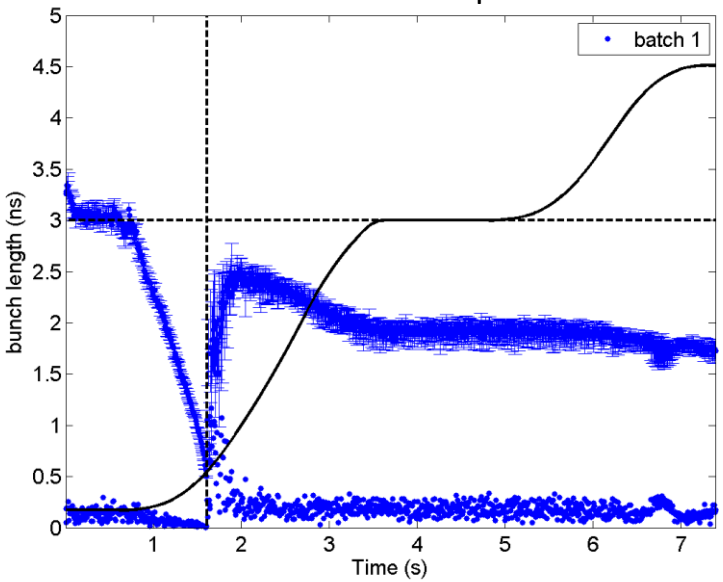
- **Instability is often starting at the plateau**
  - reduction in the synchrotron frequency spread?

- **Slip-stacking of unstable beam will be difficult and not reproducible**
  - Need to find mitigation measures for beam stabilisation before and during slip-stacking

Beam becoming unstable on flat portion



Beam stable after blow-up at transition



Possible stabilisation of the ion beam

- **800 MHz RF system was finally applied during one MD after deployment for ions**
  - relative phase was not specifically calibrated for ion operation
  - no effect on beam was observed
  - can be used only after transition crossing (too late?)
  - if used during slip-stacking – need separate control of each cavity (as 200 MHz) – not available
- **Controlled emittance blow-up**
  - very difficult in a single RF system due to small frequency spread
  - In double RF can be done only after transition crossing (too late?)
  - large bunch-by bunch variation in bunch length (> 50%) and then in synchrotron frequency shift
- **Feasibility of controlled blow-up needs to be studied during LS2 in simulations for realistic bunch-by-bunch particle distribution and SPS impedance model**
  - before transition crossing in a single RF
  - after transition in double RF with phase noise or phase modulation of 800 MHz

Summary & Outlook

- **Very successful ion run for the SPS and all injectors**
  - High intensity beam delivered by Linac3/LEIR and PS
  - No particular issue related to 75 ns beam
  - Q26 re-deployed with no big difference wrt. Q20 (Q26 required to avoid bunch rotation after slip stacking in the future!)
  - Reached expected total intensity in LHC (67% of LIU intensity) with 3 bunch 75 ns scheme
  - Longitudinal instabilities encountered after transition crossing (as with Q20)
  - MDs devoted to tune scans and tests in view of slip stacking (data analysis ongoing)
  - Test of 6 bunch scheme successful – option for slip stacking commisioning (low bunch intensity)

- **Outlook: slip stacking**
  - Reaching LIU goal requires slip stacking (in first run after LS2)
  - Achieving longitudinal stability of ion bunches is big challenge, but pre-requisite to slip stacking
  - Simulation studies during LS2 for achieving longitudinal stability and optimizing slip stacking manipulations
  - Will need commitment of all people involved to make it operational in first year after LS2