LHC Injectors Upgrade

Results and plans for Lead ions

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with the help of LIU-Ions team

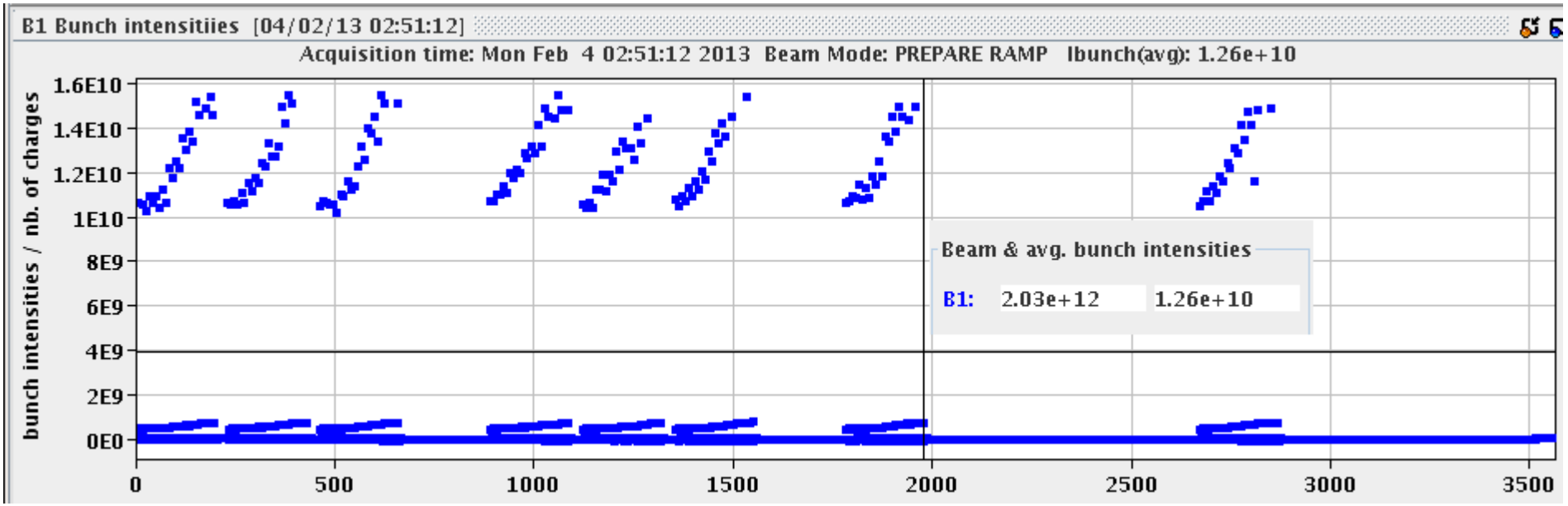
CERN

Current schedule

	LHC	SPS fixed target (NA61/SHINE)
2013	p-Pb followed by LS1	
2014	LS1	Preparation of Ar in injectors
2015	Pb-Pb (100/225 ns)	Primary Ar run
2016	Pb-Pb	Preparation of Xe in injectors
2017	Pb-p or Pb-Pb	Primary Xe run
2018	LS2	
2019	Pb-Pb	Primary Pb run
2020	Pb-Pb (100/50 ns)	“
2021	Pb-Pb? Pb-p? Ar-Ar?	“
2022	LS3	
2023	Pb-Pb	

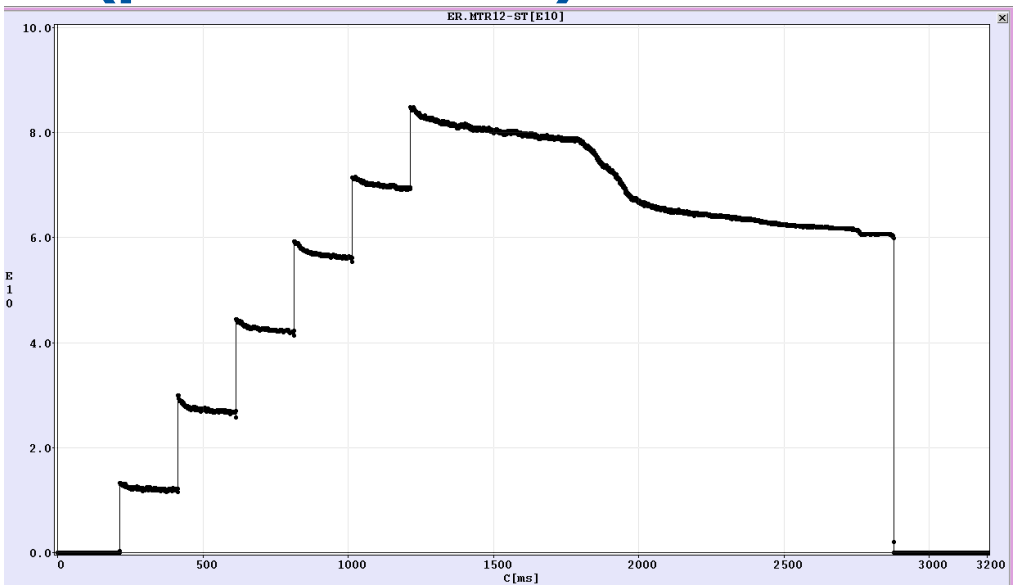
2013 improvements on SPS flat bottom

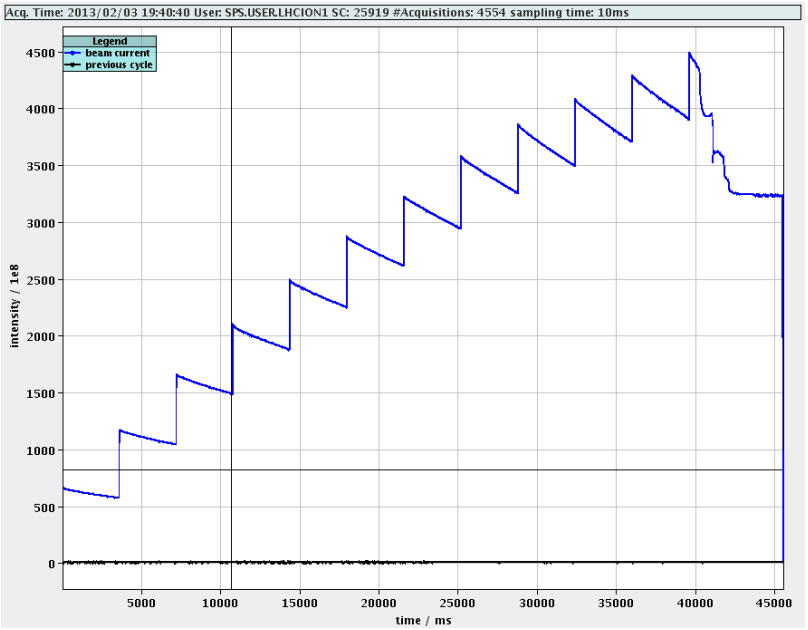
- First batch suffers 40 more seconds on flat bottom (RF Noise, IBS & ΔQ): lower intensity/bunch, transverse emittance blowup
  - Q20 :larger beam sizes, smaller IBS & ΔQ (Y.Papaphilippou, H.Bartosik)
  - RF Noise decreased (T.Bohl)
  - The bunch intensity ratio in the LHC max/min was >2, now ~1.5 average 1.53x10^{8} Pb^{82+} ions/bunch (design 7x10^{7} Pb^{82+} ions/bunch)



Present performance (p-Pb in 2013)

- Linac3
  - 200μs pulse Pb^{29+} stripped to Pb^{54+} (~22μA)
- LEIR
  - 6 multiturn injections
  - 2 bunches of ~$5.5x10^8$ Pb^{54+}
- PS
  - Batch expansion h = 16 -> 14 -> 12
  - Rebucketing h = 12 -> 24
  - Batch expansion h = 24 ->21
  - Rebucketing h = 21 -> 169
  - After stripping, 2 bunches of ~$3x10^8$ Pb^{82+} bunch spacing 200 ns
- SPS
  - 12 injections of PS batches, batch spacing 225 ns
  - 24 bunches of ~$1.7x10^8$ Pb^{82+} ($0.9x10^8$ design)
  - Transverse emittances ~0.85μm (1.2 design)
- LHC
  - 15 injections -> 338 bunches / ring
  - Average $1.53x10^8$ Pb^{82+} ions/bunch

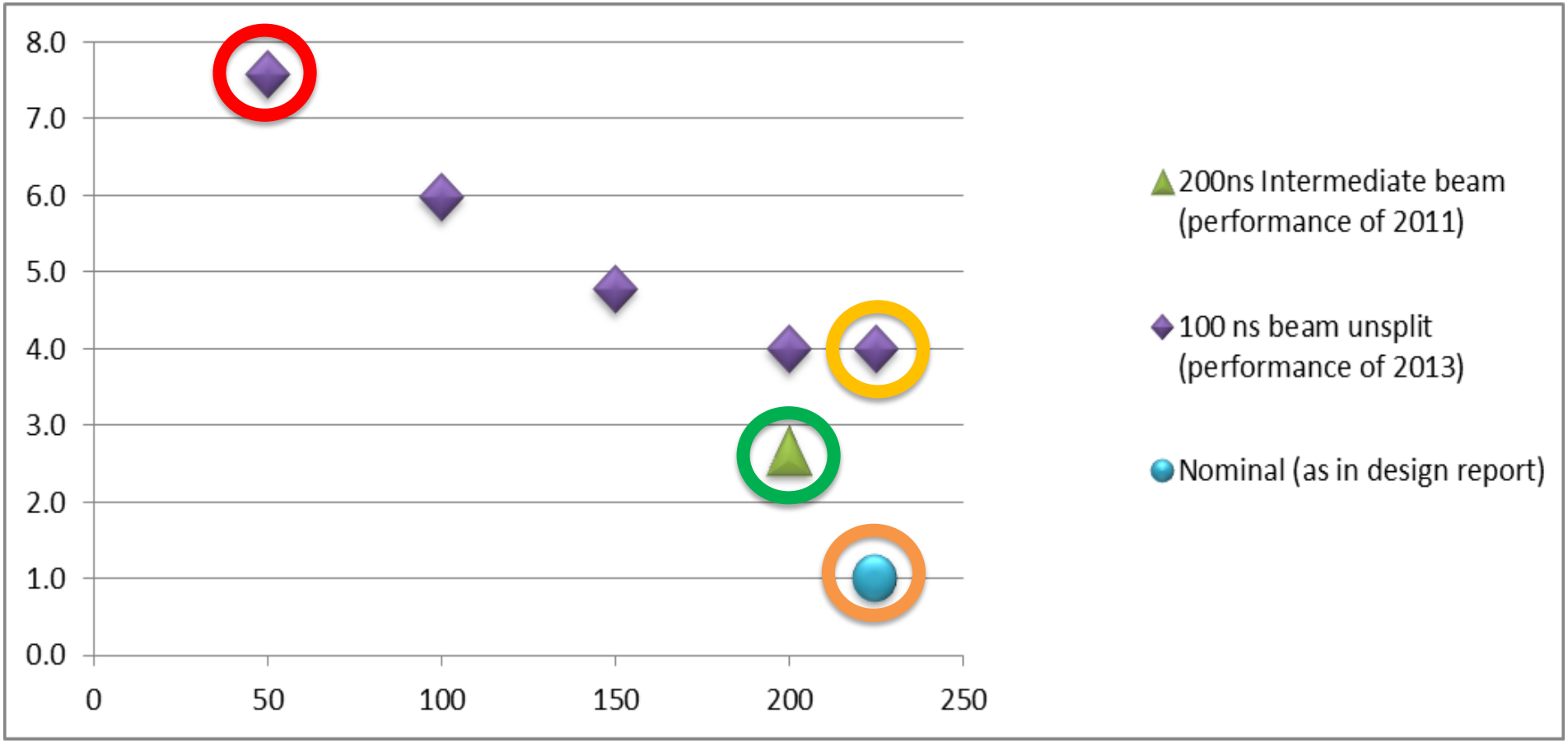




Peak luminosity increase

- Performance obtained in 2013 for p-Pb would correspond to ~3×10^{27} cm^{-2} s^{-1} at 7ZTev with β^*=0.4m
- Number of bunches
(x 2.4 by reducing spacing to 100/50ns)
  - Influence of LHC injection kicker (0.9μs) & abort gap (3μs)
  - Increase nr of injections in SPS to 24
(until LS1, 2 limits: 12 for ROCS, 15 for RF software)
- One can shoot for $L > 7 \times 10^{27} cm^{-2}.s^{-1}$

Scaling ($N_B x n_B^2$) with 24 PS injections versus MKP rise time (ns)



100/50ns beam design

- LEIR
  - Produce 2 bunches of ~6x10^{8} Pb^{54+}
- PS gymnastics
  - Batch compression to 100ns h = 16 -> 18 -> 21 (demonstrated in 2012 by H.Damerau & S.Hancock)
  - 2 bunches ~ 4x10^{8} Pb^{82+} ,
- 24 SPS injections spaced by 50ns
  - Similar bunch quality as present beam
  - 48 bunches of ~1.9x10^{8} Pb^{82+} , 19 such trains / LHC -> 912 bunches /ring (factor 2.4)
  - Long LHC injection time (~1h)
- Any improvement upstream brings additional benefits
  - Linac 3 current
  - LEIR transmission
  - Preservation of emittances and intensity on SPS flat bottom

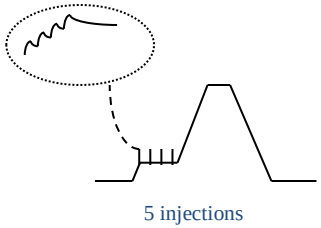
Studies/upgrades

- Linac 3
  - RFQ transmission (rematching study started: A.Lombardi)
  - Multiple charge acceleration (to be revived)
  - Increase Linac repetition rate to 10Hz
    (study started: D.Bodart, JM.Cravero)
- LEIR
  - Loss at acceleration/limits to be understood
  - Needs better diagnostics
- PS
  - RF gymnastics for 100ns (demonstrated in 2012)
- SPS
  - Q20 on flat bottom (done in 2012: Y.Papaphilippou, H.Bartosik)
  - RF noise (improved in 2012: Th.Bohl)
  - New Pb ion injection system (study started: B.Goddard)
  - Increase nr of injections to 24
    (already part of LS1 improvements: A.Rey)

Main resources

- Time
  - To be ready for installation in a shutdown earliest 1 year after end of LS2, top priority has to be assigned for SPS injection studies, design, procurement, installation, testing…
  - Linac3 & LEIR already busy
    - Preparation and operation of fixed target Ar & Xe
    - Pb LHC programme
    - Medical applications?
  - MD time in the whole chain, ECR-RFQ-Linac3-LEIR-PS-SPS, to set up and study those cycles and beams, with availability of specialists (OP, ABP, RF, …)
- Manpower
  - 1.5 M.Y for Linac/RFQ studies
  - 19.3 M.Y. for new SPS injection (to be found)
- Money
  - 8 MCHF for new SPS injection (to be found)
  - 0.5MCHF for Linac 10Hz (partly already in consolidation)

Possible scheme for 2015: alternating 100/225 ns



LEIR (10^9 Pb ions / 3.6 s)

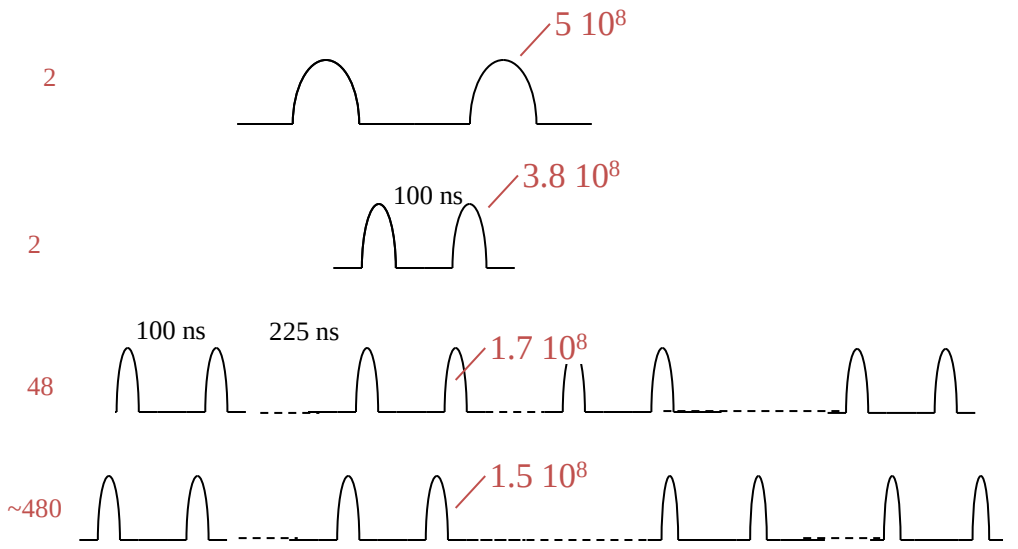
PS batch compression
bunch spacing = 100ns

SPS at extraction,
after 24 transfers from PS,
Batch spacing = 225 ns

LHC at injection,
after 10 transfers from SPS

Nb of bunches

Pb ions / (future) LHC bunch



Harmonic number / Frequency

2

16–18-21

-169

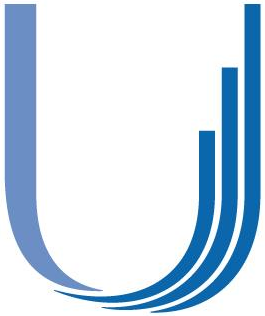
200 MHz

400 MHz

L = 4x10^{27} cm^{-2} s^{-1}

Conclusions

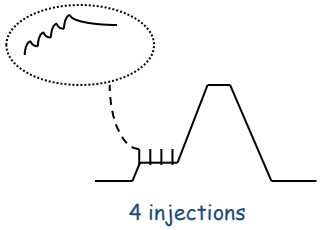
- The most feasible scheme to upgrade the luminosity for Pb-Pb experiments is proposed.
  - A peak luminosity of $L=7x10^{27}cm^{-2}.s^{-1}$ is within reach at the cost of several upgrades in each of the machines of the injector chain
  - Without a new SPS injection system, factor 1.5-2 still missing but principle can be tested in 2015 ($L=4x10^{27}cm^{-2}.s^{-1}$)
  - Up to the LHC to level it to decrease burn-off and optimise the integrated luminosity
  - It can only be ready for installation in a shutdown earliest 1 year after end of LS2.
- Shall we proceed with investigating the implementation?
- How shall we deal with the impact on other activities? (mainly medical ions & Fixed Target in North Area….)



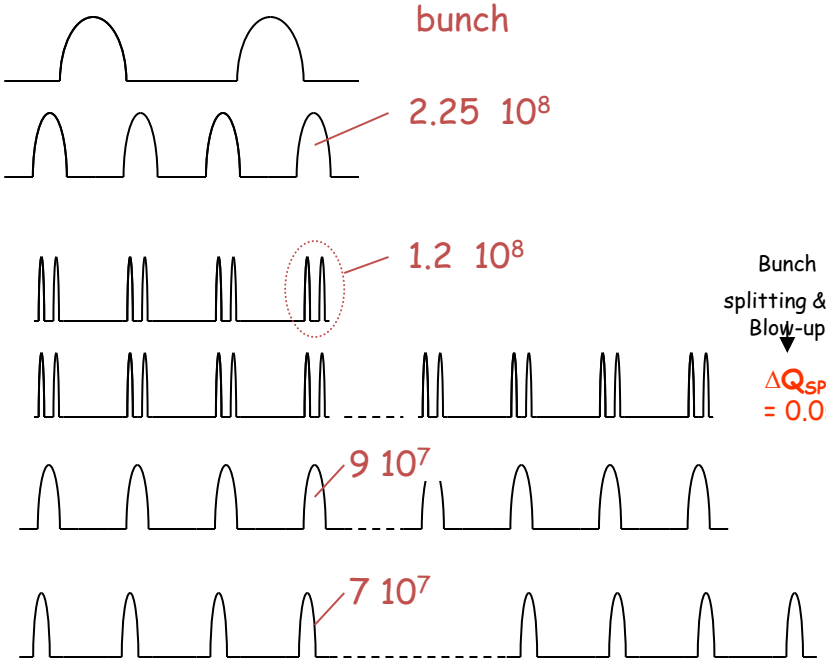
LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

Nominal scheme



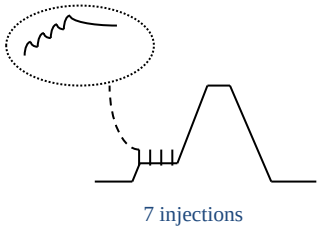
	Nb of bunches	Pb ions / (future) LHC bunch	Harmonic number / Frequency
LEIR (9 10^8 Pb ions / 3.6 s)	2		2
PS after 1st splitting	4	2.25 10^8	16-14-12-24
PS after 2nd splitting	4 pairs	1.2 10^8	24-21 -169-423
SPS at injection (43.2 s flat-bot) after 13 (12, 8) transfers from PS	52 (32, 8) pairs	Bunch splitting & ε_l Blow-up; ΔQ_{SPS} = 0.05	200 MHz
SPS at extraction	52 (32, 8)	9 10^7	100 MHz + 200 MHz
LHC at injection, after 12 transfers from SPS	592	7 10^7	400 MHz



β^* = 0.5 m -> L = 10^{27} cm^{-2} s^{-1}

Proposed scheme for HL-LHC: 100/50 ns

- Bunch spacing 100ns out of PS
- 24 PS batches into SPS, spacing 50ns
- 912 bunches in each LHC ring (~1h filling time!)

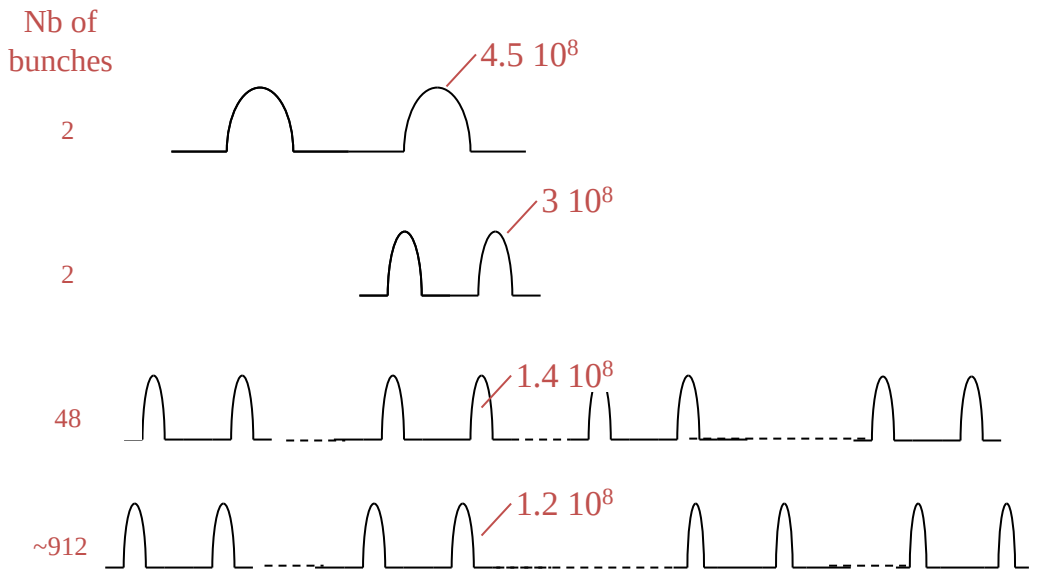


LEIR ($9\ 10^8$ Pb ions / 3.6 s)

PS batch compression
bunch spacing = 100ns

SPS at extraction,
after 24 transfers from PS,
Batch spacing = 50 ns

LHC at injection,
after 19 transfers from SPS



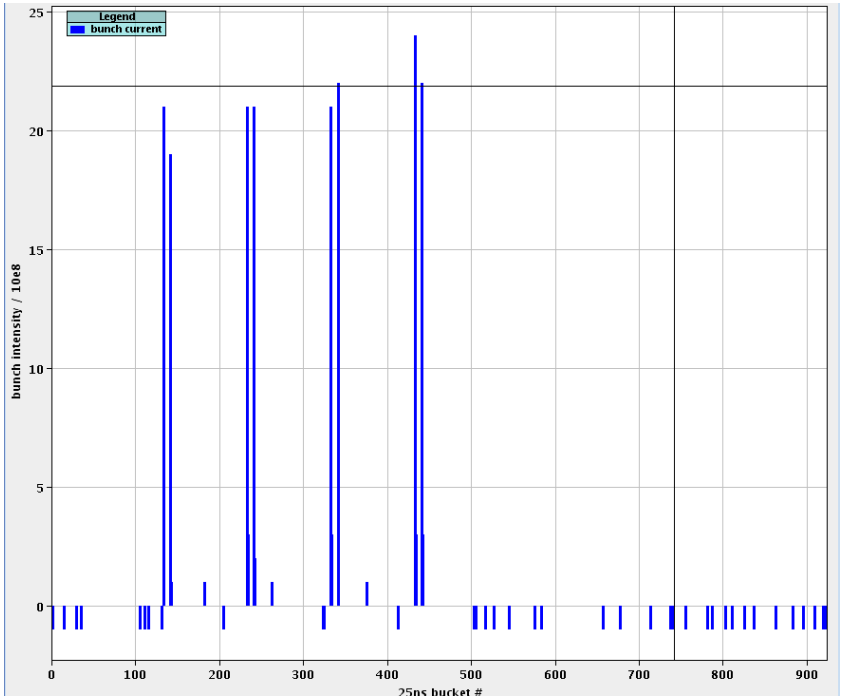
p-Pb 200/225 ns scheme in 2013

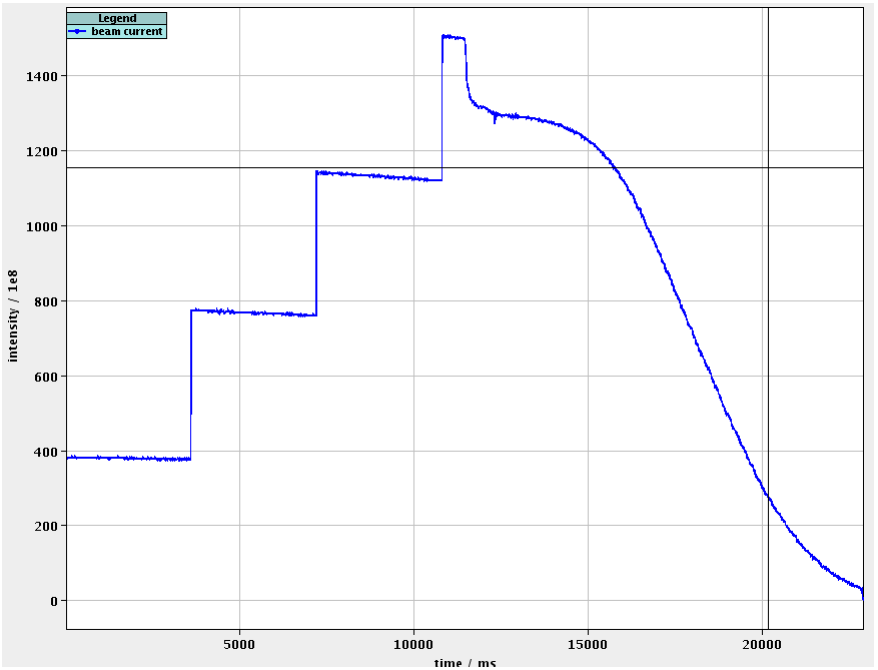
	Nb of bunches		Harmonic number / Frequency
PSB (3.2 10^{10} protons)	2 (1/ring)	1.6 10^{10}	2+1
PS batch compression bunch spacing = 200ns	2		9-10 20-21 -84
SPS at extraction, after 12 transfers from PS, **Batch spacing = 225 ns minimum**	24	1.5 10^{10}	200 MHz

Minimum batch spacing of 225ns for ions dictated by MKP with 4 generators

	Nb of bunches		Harmonic number / Frequency
LEIR (1.1 10^{9} Pb ions / 3.6 s)	2		2
PS batch expansion bunch spacing = 200ns	2		16-14-12-24 24-21 -169
SPS at extraction, after 12 transfers from PS, **Batch spacing = 225 ns minimum**	24	1.7 10^{8}	200 MHz

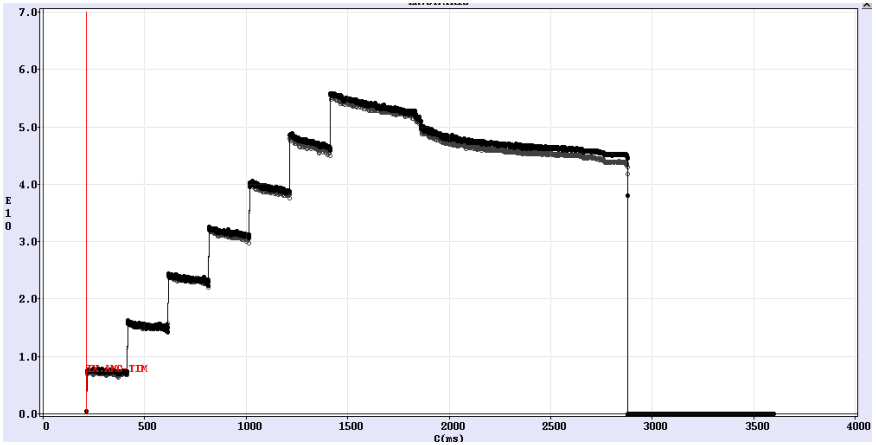
RF noise improvements on SPS flat bottom





- Principle demonstrated in 2012 MDs
- Operational in 2013 p-Pb run

LEIR loss at the beginning of the ramp



- Limitations due to direct space charge?
  - limit with irregular lattice lower than expected
- How small are emittances after cooling?
  - should we make them larger?
- Impact of Bdot
  - should we accelerate faster to decrease time spent with bunched beams at low energy?
  - or slower to reduce dynamic effects?
- Instabilities?
  - probably not an issue with present intensities
- Large measurement campaign started (M.Bodendorfer)

Beam performance comparison

Beam	PS bunches	Bunch spacing	SPS Kicker	Bunches in SPS	SPS train length	SPS > LHC	bunches in LHC	bunch intensity	Lth (e27)
100 ns nominal	4	100	225	96	12375	6	576	0.7	1.00
200 ns no split 200ns kick	2	200	200	48	9400	8	384	1.4	2.67
100 ns no split 200ns kick	2	100	200	48	7000	10	480	1.53	3.98
100 ns no split 225ns kick	2	100	225	48	7575	10	480	1.53	3.98
100 ns no split 150ns kick	2	100	150	48	5850	12	576	1.53	4.78
100 ns no split 100ns kick	2	100	100	48	4700	15	720	1.53	5.97
100 ns no split 50ns kick	2	100	50	48	3550	19	912	1.53	7.56
EARLY	1	100	1000	4	3000	21	84	1.4	0.58

- Early, nominal, and 200ns computed with design intensities, as achieved in 2011
- 100ns beam computed with increased performance as achieved in 2013