LHC Injectors Upgrade

Ion sources, Linac3, LEIR

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Special acknowledgements to C.Carli & D.Küchler

List of actions and planning of implementation
Studies
Impact on other users
Performance for LHC and other users in the different scenarios
Potential risks

Scope

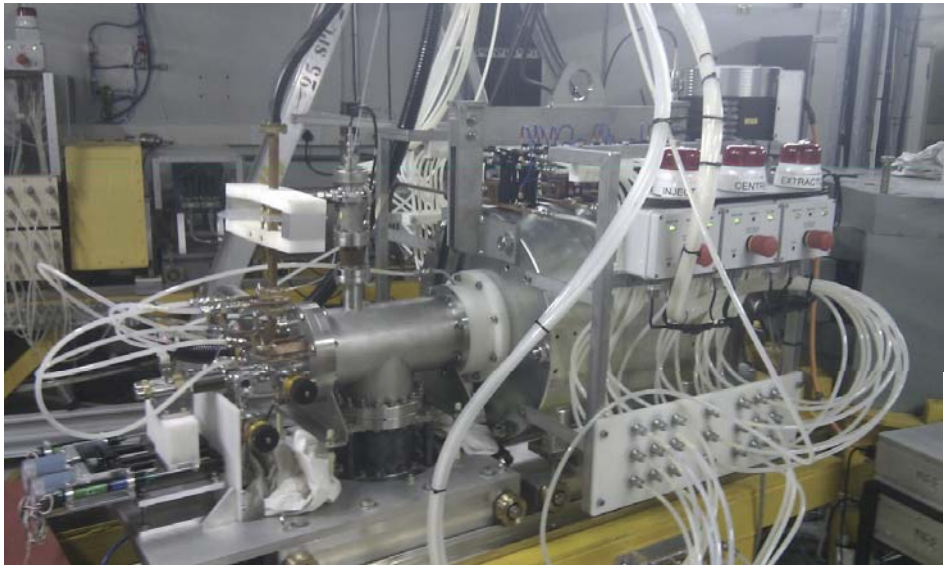
- Studies and upgrades needed in Linac3 and LEIR, in view of the LHC and SPS fixed target programmes:
  - Ar and Xe
  - HL Pb-Pb
- Medical ions only mentioned

	LHC	SPS fixed target
2012	Pb-p	Be (fragmented Pb)
2013	LS1	
2014		Primary Ar
2015	Pb-Pb	Primary Xe
2016	Pb-Pb	Primary Pb
2017	Pb-p	"
2018	LS2	
2019	Pb-Pb	Primary Pb
2020	Pb-p	"
2021	Ar-Ar	"
2022	LS3	
2023	HL Pb-Pb (& d-Pb?)	???

Possible route to 50ns

- Design current from Linac 3 (~50μA)
- LEIR
  - Produce 2 bunches of ~10^9 Pb^{54+} in same emittance (i.e. twice today)
- PS gymnastics
  - Batch compression to 100ns h = 16 -> 18 -> 21
    (no need for new cavities, 10MHz system exists)
  - Splitting h = 21 -> 42
    (20MHz system exists but V_{RF} acceptance to be checked)
  - 4 bunches > 1.4 x10^8 Pb^{82+} into SPS
- 12 SPS injections spaced by 50ns
  - Similar bunch quality as present beam
  - 48 bunches of ~1.4x10^8 Pb^{82+}
  - Transverse emittances ~0.85μm
  - But with 50ns spacing and hopefully less spread in bunch population
  - Note: longer LHC injection time

ECR ion source: studies of Ar and Xe



- Since 2010: Collaboration with iThemba laboratory (South Africa)
  - Identical ECR source preparing Ar and Xe
  - Expect results by end 2012
  - Training expert from iThemba on “afterglow mode” at CERN in 2012, will provide additional manpower during ion run
- 2013: asked for “derogation” from LS1
  - Source + RFQ + Linac will run for 2x13 weeks to prepare Ar and Xe at CERN, explore parameter space, and generally get operational confidence in new species
- 2014: Ar run alone for SPS
- 2015: Xe run before LHC Pb run
- Currently no schedule for other species

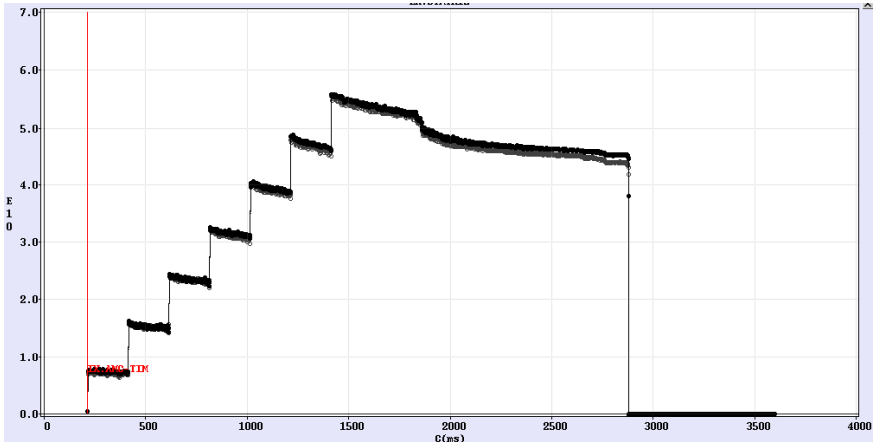
ECR ion source

- Design current out of Linac3 (50μA) needed for HL-LHC after LS3…source?
- All improvements of 2011 (new connection of intermediate electrode, new gas feedback loop, new oven filling scheme) towards better reliability, stability, and shorter filling time. Future improvements should aim at increasing the intensity without sacrificing the stability.
- Plasma chamber coating
  - Aluminium chambers gave a high intensity but a terrible beam stability, while the stainless steel chamber delivers a much better beam stability, hence the idea of coating a stainless steel chamber with Al, combining the advantages of both chamber types.
  - Will need time for testing the chamber
- 18GHz tests
  - Did not give expected (150%) results, conversion into spare for 14.5GHz

Linac 3

- Design current out of Linac3 (50μA) needed for HL-LHC after LS3
  - Is Linac3 the bottleneck? Can it transmit a higher intensity from the source?
- Multiple charge acceleration
  - RFQ/Linac can in principle accelerate Pb^{28+} and Pb^{30+} in addition to Pb^{29+}, then strip to Pb^{54+}
  - First (limited) tests at CERN date from 2001-2003 (transmission of Pb^{28+} through Linac3 tuned to Pb^{27+} acceleration)
- Faster Linac repetition rate
  - Currently 5Hz but 10Hz design (no HW limitation in principle)
  - ECR source is already pulsing at 10Hz
  - Possibility to double rep rate, and thus number of injections, but cooling in LEIR has to follow

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
- … a lot of studies with beam

LEIR Instrumentation & operation

- SEMs with electronics to see the injected beam
  - matching and emittance measurements of the injected beam
- Scrapers for emittance measurements
  - Need refurbishing of controls hardware, and writng an emittance measurement application
- Make BIPM measurements Operational
  - Still a specialist tool for the moment
- Modify security chain
  - Allow injection of ions into LEIR even during PS access
- Increase ECOOL's electron current
  - to compensate increased LINAC3 repetition rate

LEIR: other ion species

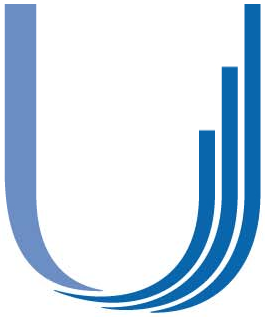
- Proposal by JINR (I. Meskov) for recombination tests with lower Pb charge states
  - Help us understanding recombination process
- Ar and Xe to provide beams for SPS fixed target (and LHC in 2021)
  - Program different magnetic cycles (started in 2011)
- Ions of interest for medical studies (C, O)
  - significantly higher energies per nucleon in case of fully stripped ions at the end of Linac3 (up to 430 MeV/nucleon with a new main power supply) Radio-protection issues to be studied. (Concrete ceiling?)
  - Reimplementation of a slow ejection
  - New ejection channel in section 40
  - Note: Higher electron currents would also be beneficial for light ions (Slower cooling time for lower charge)

The four options for deuterons

- ALICE will tell by the end of 2012 if d-Pb is requested after LS3
- Option 1: New source, LEBT and RFQ; re-use Linac3 IH for final energy
- Option 2: New source, LEBT and RFQ, which goes to final energy
- Option 3: Completely new linac (5?)
- Option 4: Cyclotron

Conclusions

- LHC and SPS fixed target programmes, as currently defined until LS3 are manageable with a single source
- Ar and Xe will be available after LS1
- Present performance needs at least doubling for HL-LHC
  - Although 10 years from now, no guaranteed route exists
- No current schedule for medical ions
  - Scheduling problem especially with a single source
  - Study of medical ions in injector chain would make them available for fixed target SPS experiments (but currently no request for O, C…)
- Deuterons would need a large investment



LHC Injectors Upgrade

THANK YOU FOR YOUR ATTENTION!

The four options for deuterons

- ALICE will tell by the end of 2012 if d-Pb is desirable after LS3
- Option 1: New source, LEBT and RFQ; re-use Linac3 IH for final energy
  - re-use of existing hardware
  - RFQ needs to go only to 250keV
  - switchyard needed to combine the two low beam lines in front of the IH structure
  - space very limited in the Linac3 hall for new hardware
  - ion current limitation due to space charge limit of the IH structure
  - new radioprotection policy needed due to possible activation at final energy
  - installation and commissioning only during period when Linac3 does not deliver beam

The four options for deuterons

- Option 2: New source, LEBT and RFQ, which goes to final energy
  - no limitation due to IH structure
  - higher intensities possible
  - deuterons and heavy ions can run in parallel
  - RFQ becomes very long and expensive
  - New location needed
  - No use of existing hardware

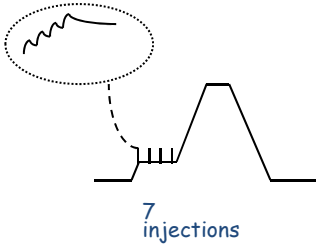
The four options for deuterons

- Option 3: Completely new linac (5?)
  - no limitations due to IH structure
  - higher intensities possible
  - design can be optimized for intensity and also for the injection energy into LEIR
  - deuterons and heavy ions can run in parallel
  - no use of existing hardware
  - new location needed

The four options for deuterons

- Option 4: Cyclotron
  - no limitations due to IH structure
  - design can be optimized for intensity and also for the injection energy into LEIR
  - a cyclotron for this energy range is very compact
  - could be placed near to LEIR injection
  - deuterons and heavy ions can run in parallel
  - no use of existing hardware
  - new location needed
  - new technology not common at CERN

Possible scheme for 2015

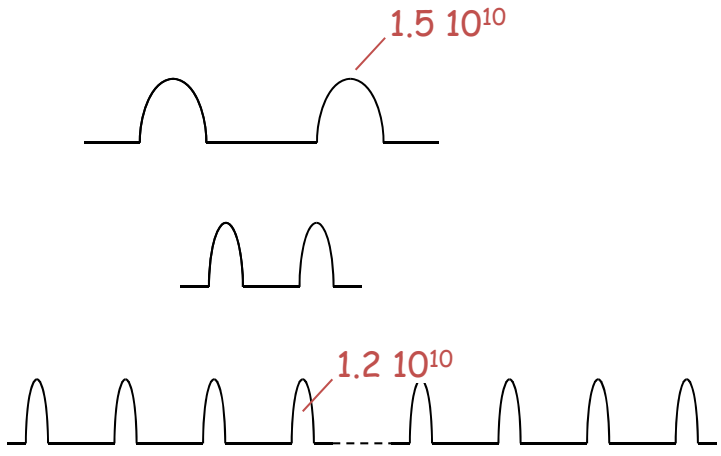


	Nb of bunches	Pb ions / (future) LHC bunch	Harmonic number / Frequency
LEIR (9 10^8 Pb ions / 3.6 s)	2		2
PS batch compression bunch spacing = 100ns	2		16-18-21 -169
SPS at extraction, after 12 transfers from PS, Batch spacing = 200 ns (resp 150ns)	24	1.4 10^8	200 MHz
LHC at injection, after 19 (resp 22) transfers from SPS	~460 (530)	1.2 10^8	400 MHz

β^* = 0.5 m -> L = 2.5x10^{27} cm^{-2} s^{-1}
(resp L= 3.0x10^{27} cm^{-2} s^{-1})

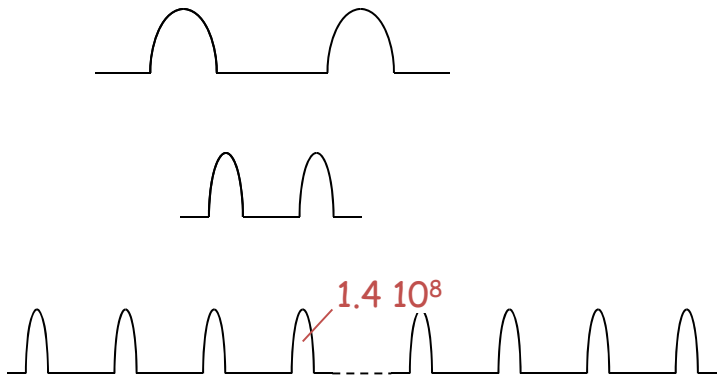
p-Pb 200ns scheme in 2012

	Nb of bunches		Harmonic number / Frequency
PSB (3 10^{10} protons)	2	1.5 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	1.2 10^{10}	200 MHz

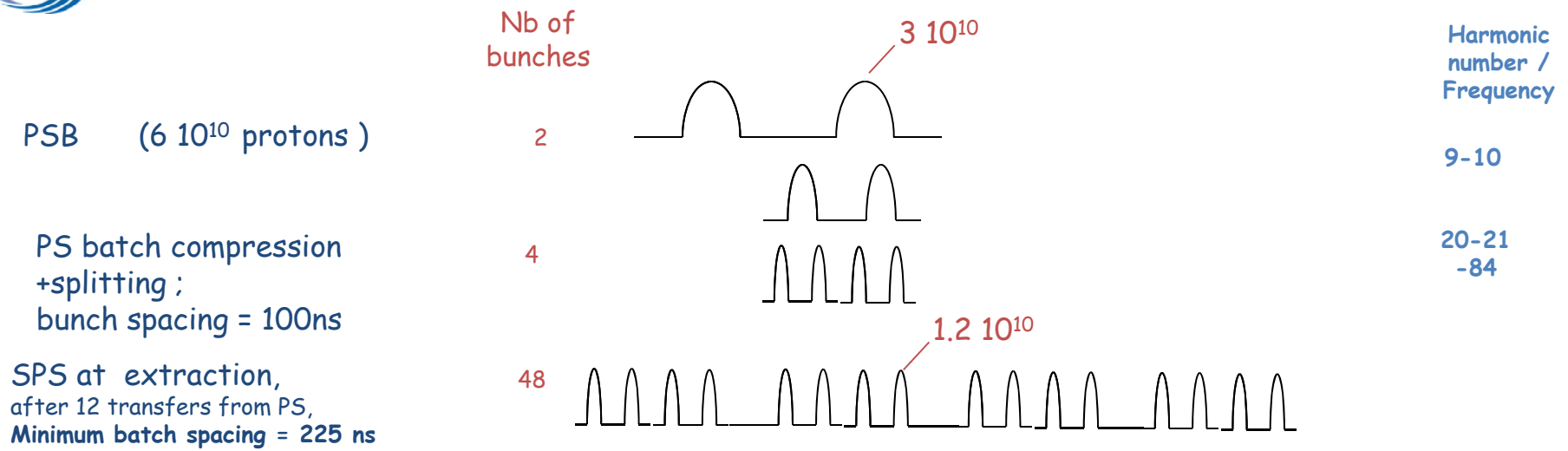


note: minimum batch spacing of 225ns dictated by protons injection at 26GeV/c

	Nb of bunches		Harmonic number / Frequency
LEIR (9 10^{8} 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	1.4 10^{8}	200 MHz



p-Pb 100ns scheme in 2012



Note: minimum batch spacing of 225ns dictated by protons injection at 26GeV/c