Ions for LHC: Sources, Linac3

A Glimpse on the LHC injector chain
- Nominal lead beam in LHC

ECR Source, Linac3 issues
- Intensity in allowed emittance

Lighter Ions
- Estimated yields from source, Linac, stripper
- Possible improvements

Low Energy Ion Ring (LEIR) or Laser Ion Source (LIS)?
Acknowledgements

Charles Hill and Richard Scrivens for providing source and Linac data as well as drawings

Daniel Brandt, Michel Chanel, Carlo Wyss for welcome suggestions

Cost estimates of the LIS route by Stephan Maury
The LHC Injector Chain

LHC 7 TeV p-p
2.8 TeV/n Pb-Pb

177 GeV/n Pb

SPS 450 GeV

BOOSTER 1.4 GeV

PS 25 GeV

6 GeV/n Pb

ION ACCUMULATOR

LEIR 72 MeV/n Pb

LINACs

P 50 MeV

Pb 4.2 MeV/n

PROTONS

IONS
Lead Ions in LHC and Injectors - Nominal

LHC Pb Luminosity = $1 \times 10^{27}$ cm$^{-2}$ s$^{-1}$

<table>
<thead>
<tr>
<th>LINAC3</th>
<th>LEIR</th>
<th>PS</th>
<th>SPS</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV/n]</td>
<td>0.0042</td>
<td>0.072</td>
<td>6</td>
<td>177</td>
</tr>
<tr>
<td>Pb charge state</td>
<td>54+</td>
<td>54+</td>
<td>54+</td>
<td>82+</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>95, 5</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>ions/LHC bunch</td>
<td>$6 \times 10^8$ (20 μA)</td>
<td>$2.25 \times 10^8$</td>
<td>$1.2 \times 10^8$</td>
<td>$9 \times 10^7$</td>
</tr>
<tr>
<td>$\varepsilon^* \left( = (\beta\gamma)\sigma^2/\beta \right)$</td>
<td>0.3</td>
<td>0.7</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td># bunches</td>
<td>2</td>
<td>4 pairs</td>
<td>~52</td>
<td>592/ring (2)</td>
</tr>
<tr>
<td>pulses to fill downstream machine</td>
<td>5 (up to 5 Hz)</td>
<td>1</td>
<td>~13</td>
<td>12</td>
</tr>
</tbody>
</table>

(1) Same physical emittance as protons, with the same tight emittance budget
(2) 891 bunch places per ring
The CERN Ion Linac 3
Electron Cyclotron Resonance (ECR) Source
## ECR Source and Linac3: Speculations on Lighter Ions

<table>
<thead>
<tr>
<th></th>
<th>$^{208}$Pb(82)</th>
<th>$^{115}$In(49)</th>
<th>$^{84}$Kr(36)</th>
<th>$^{40}$Ar(18)</th>
<th>$^{16}$O(8)</th>
<th>$^{4}$He(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>charge state ion source</td>
<td>27+</td>
<td>21+</td>
<td>11+</td>
<td>8+</td>
<td>2+</td>
<td>1+</td>
</tr>
<tr>
<td>current source ($\mu$A$_c$) estim.</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>stripped to (after Linac)</td>
<td>53 (54)+</td>
<td>37+</td>
<td>29+</td>
<td>16+</td>
<td>8+</td>
<td>1+</td>
</tr>
<tr>
<td>current ($\mu$A$_c$), 14 GHz source</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>75</td>
<td>170</td>
<td>160</td>
</tr>
<tr>
<td>$18$ GHz source $4.2$ MeV/u</td>
<td>41-44</td>
<td>44-49</td>
<td></td>
<td>132</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$28$ GHz source(I) $4.2$ MeV/u</td>
<td>100-108</td>
<td>108-120</td>
<td></td>
<td>320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#ions injected LEIR per Linac pulse ECR 14 GHz, 50 “effective” turns</td>
<td>$4 \times 10^8$</td>
<td>$6.5 \times 10^8$</td>
<td>$9 \times 10^8$</td>
<td>$4.3 \times 10^9$</td>
<td>$1.8 \times 10^{10}$</td>
<td>$1.4 \times 10^{11}$</td>
</tr>
<tr>
<td>#ions from LEIR per LHC bunch (with 5 Linac3 pulses)</td>
<td>$3 \times 10^8$</td>
<td>$5 \times 10^8$</td>
<td>$6.8 \times 10^8$</td>
<td>$3.2 \times 10^9$</td>
<td>$1.4 \times 10^{10}$</td>
<td>$1.0 \times 10^{11}$</td>
</tr>
<tr>
<td>$\eta$ LHC collision/LEIR ejection</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Source vs other limitations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># ions/bunch, 2.8 TeV/u, source</td>
<td>$9 \times 10^7$</td>
<td>$2.6 \times 10^8$</td>
<td>$3.4 \times 10^8$</td>
<td>$1.6 \times 10^9$</td>
<td>$8.1 \times 10^9$</td>
<td>$6.3 \times 10^{10}$</td>
</tr>
<tr>
<td># ions/bunch, 2.8 TeV/u, other limits</td>
<td>$7 \times 10^7$</td>
<td>$2.2 \times 10^8$</td>
<td>$3.3 \times 10^8$</td>
<td>$5.5 \times 10^8$</td>
<td>$1 \times 10^9$</td>
<td>$5.2 \times 10^9$</td>
</tr>
<tr>
<td>marginal</td>
<td>marginal</td>
<td>marginal</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
<td></td>
</tr>
</tbody>
</table>

(1) fewer Linac pulses required
Laser Ion Source (LIS) – an Alternative?

CERN - High Current Laser Ion Source

CO$_2$ Amplifier
100 J, 1Hz, 15ns

CO$_2$ Oscillator
150 mJ, 3Hz

Target

Expanding plasma

Extraction system 120 kV

LEBT : Grided Electrostatic Lenses

Double aperture simulating the RFQ acceptance

Current

Current Emittance

Emittance

Current Charge State Distribution

Measurements

Bldg 363

Bldg 236

Pierrick Fournier-2001

28. June 2002 LHCC Ion Workshop, K.Schindl, CERN
LIS Power Laser and Source

The Russian 100 J, 1 Hz CO₂ Laser Amplifier in building 363 (“Farady Cage”), being commissioned

The prototype Laser Ion Source in building 236 on a HV platform (~100 kV) to decrease space charge

28. June 2002 LHCC Ion Workshop, K.Schindl, CERN
Could we go the LIS Route? It’s still R&D!

With Pb$^{25+}$ from LIS, one could use the PS Booster instead of LEIR if:

- Current > 5mA during ~ 5μs
- Norm. transverse rms emittance $\varepsilon_{\text{rms}}^* < 0.15 \mu m$
- Source stable, reliable, small jitter….

Needs other major investments

- Make an operational laser (spare parts…) + installation in Linac 3;
- A new RFQ;
- Upgrading of PSB injection and vacuum systems;
- (list not exhaustive) summing up to 10…14 MCHF

😊 A few millions cheaper than LEIR
😊 Much less exploitation cost compared to LEIR

😉 Laser will (hopefully) work this summer, but then R&D starts!
😉 We cannot afford to go the LEIR and LIS routes in parallel
😉 Even if conclusive results by end 2002, Pb to LHC not before 2009
😉 Lighter ions: speculations, needs more R&D (e.g. for gaseous elements)
Conclusions on Sources and Linac 3

ECR Sources:
- The present 14 GHz source could (just) do the job for Pb, In, Kr, and easily do it for Ar, O, He. Due to uncertainty of extrapolation, an upgrading to
- 18 GHz (+ proportional field increase) is envisaged: potential increase of ~1.5
- Collaboration with outside labs to achieve 28 GHz (a factor > 4 in intensity?)
- Even a factor 10 increase would not be sufficient for the PS Booster route

Laser Ion Source:
- Still a prototype in the R&D phase
- Implementation of an operational source and other hardware would cost at least 10 MCHF, but would save resources for exploitation of LEIR
- Lighter ions? Much more R&D needed (which also costs scarce resources)
- Pb ions not ready for LHC before 2009

Conclusion: If we want to have Pb ions ready for LHC in 2008 with a reasonable confidence level, decide NOW for LEIR + (upgraded) ECR source