

Limitations for Light and Heavy Ion Injectors

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Injector linacs for rings and accelerators are characterized by a low duty cycle ($\leq 10^{-3}$) and by high beam intensities. Relevant ion source developments were done during the last two decades. They can be characterized due to their $n_e \tau$ product and to the electron temperature, resulting in different mean charge states (Fig.1). Highest beam currents are gained from volume plasma sources, which are optimized to produce singly charged ions. Main disadvantages when using this type of ion source are the low beam velocity after passing the extraction and terminal voltages as well as the high accelerator voltages needed to reach a specified beam energy per nucleon. In case of high mass to charge ratio multi hole extraction allows to increase the beam current density: This results from the Child-Langmuir law and from the Kilpatrick-limit, respectively /1/.

To transport and match these beams with typical energies between 1 keV/u and 5 keV/u, beam currents up to 50 mA and normalized emittances around 0.3π mm mrad to the RFQ entrance, one has to rely on space charge compensation by electrons from the rest gas (Low Energy Beam Transport LEBT with vacuum pressures of several 10^{-6} hPa). An alternative design in case of very clean beams from the ion source is direct injection into the RFQ along a short (≤ 500 mm) LEBT.

Efficient synchrotron acceleration needs high ion charge states. The Electron Beam Ion Source EBIS can at present produce the highest charge states and breed into a selected charge state with relatively high abundance. All other high charge state producing sources like Electron Cyclotron Resonance Sources ECR or LASER-sources generate a wide charge state spectrum leading to a large extracted sum current and to a complicated LEBT.

So far no heavy ion synchrotron injector optimized for highest beam intensities has been realized. However, a 4.2 MeV/u injector based on an ECR source, an RFQ and an IH-DTL delivers Pb-beams to the CERN accelerator complex since 1994 with up to 4×10^8 Pb-ions per SPS-cycle (Fig. 2a). The injection energy of 4.2 MeV/u was given by the capabilities of the existing PSB transfer line and leads to high beam losses in the PSB (one order of magnitude) due to charge exchange reactions (Fig. 3). Another drastic reduction in ion number is caused by the stripping process $\text{Pb}^{27+} \rightarrow \text{Pb}^{53+}$ behind the linac (factor 5.5).

One scheme for the future to support the LHC with heavy ions was tested successfully (Fig. 2c):

The Low Energy Antiproton Ring LEAR is used as accumulator (via e^- cooling) and accelerator before injection into the PS. In that case beam decay rates are defined by the electron cooler current /2/.

Another option for LHC is a second preaccelerator into the IH-DTL (Fig. 2b) consisting of a LASER source and of an additional RFQ /3/.

BNL is developing a powerful EBIS type source /4/ and plans to inject that beam into the booster synchrotron without a stripping process. However, two beam stripping processes are foreseen before and after passing the AGS (Fig. 2d).

GSI has rebuilt the 1.4 MeV/u front end of the UNILAC recently to improve its capabilities as an injector for the synchrotron SIS 18 (Fig. 2e). The new 91 MV linac was designed for A/q-values up to 65 and for beam currents up to 10 mA $^{40}\text{Ar}^{+1}$ and 15 mA $^{238}\text{U}^{4+}$, respectively, at norm. 90 % emittance values around 0.5π mm mrad- The numbers were demonstrated successfully in 1999 for an Ar^{1+} -beam /5/.

Two stripping processes at 1.4 MeV/u and at 11.4 MeV/u reduce the beam particle current down to about 15 % of the original value in case of the most heavy ions like uranium.

An optimized high current injector for heavy ions using available technology might be characterized in the following way:

Use an intensive ion source for low charge states and accelerate this beam up to an energy, where you get a charge state by stripping (gas jet or plasma stripper) which is acceptable for injection into the first ring. Accelerate these ions up to an energy where charge exchange processes at ring injection energy do not considerably reduce the beam intensity (that means about 5 MeV/u Argon or 20 MeV/u Uranium at a ring vacuum pressure in the 10^{-10} hPa range).

- /1/ R.Keller in 'The Physics and Technology of Ion Sources', I.G. Brown (editor), John Wiley & Sons, N.Y., 1989
- /2/ S.Baird et al., Phys. Lett. B 361 (1995), p. 184
- /3/ H.D.Haseroth, Proc. of the LINAC 96, Geneve, p. 283
- /4/ E. Beebe et al., Rev. of Scient. Instr., Vol. 71 (2000) p. 893
- /5/ U.Ratzinger, Proc. of the EPAC 2000, Vienna, p. 98

Ion Sources

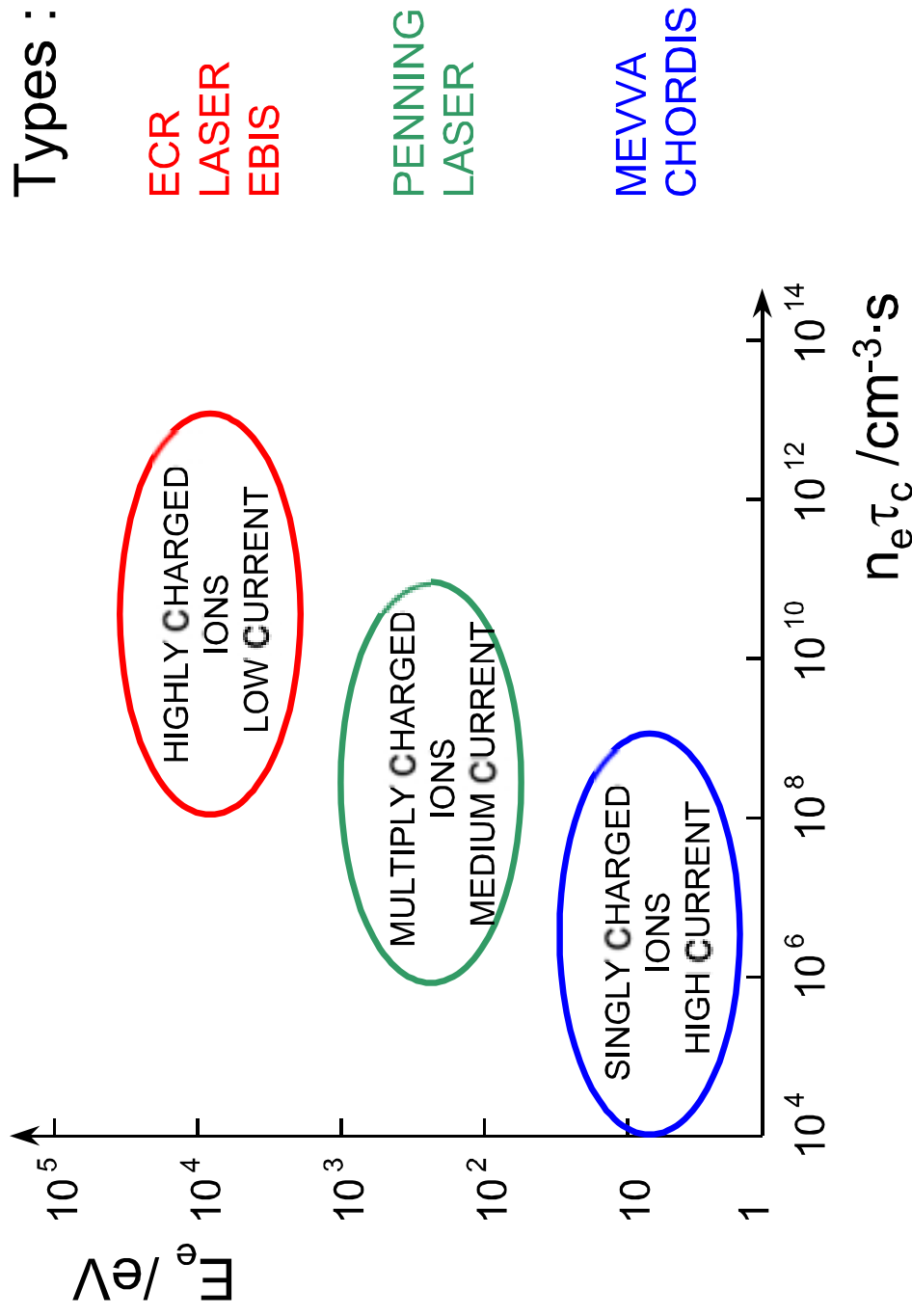
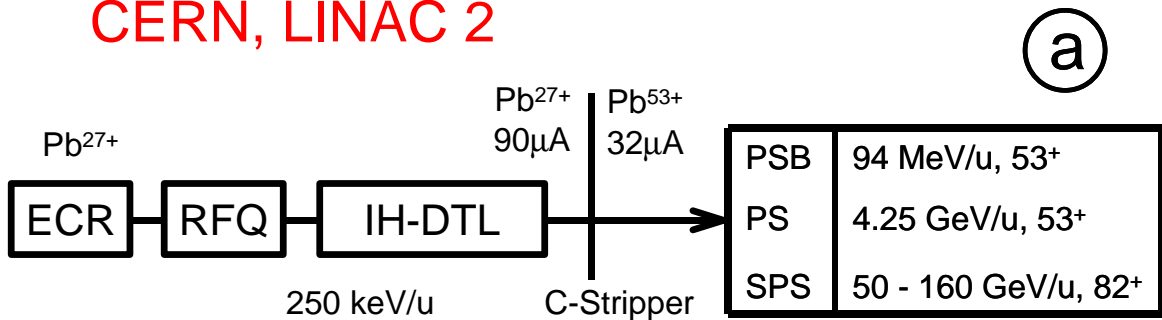


Fig.1 Classification of Ion Sources

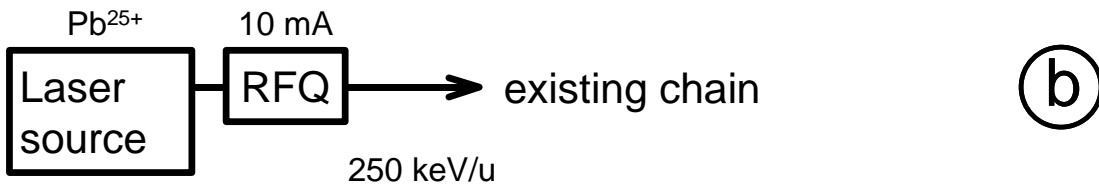
Fig. 2 : **Comparison of Designs**

CERN, LINAC 2



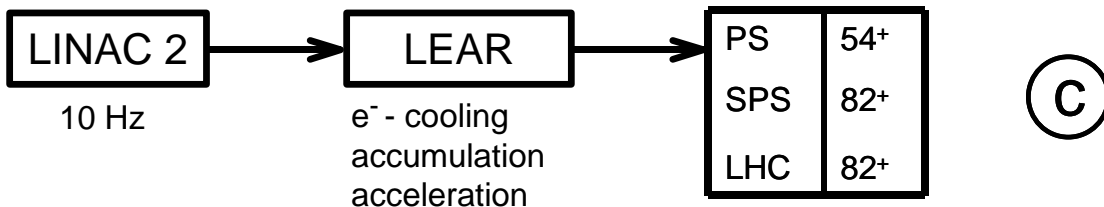
H.D.Haseroth, Linac 96, p.283

Additional High Current Injector for LINAC 2, under development :



H.D.Haseroth et al., Linac 96, p.570

Proposed Scheme for LHC Injection



e⁻ - cooler , beam decay rates:

S.Baird et al., Phys. Lett. B 361(1995) p.184

K.Blasche et al., EPAC 98, Stockholm, p.550

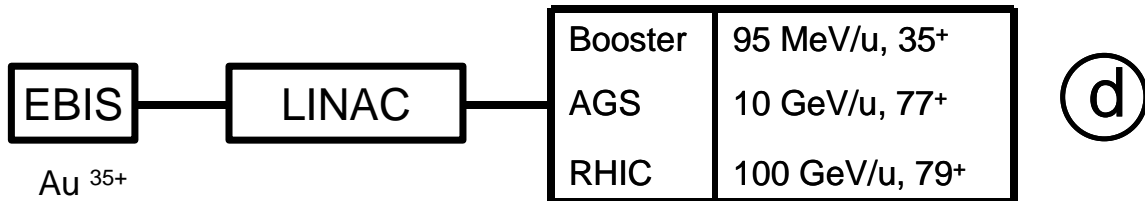
Injection scheme:

P.Lefevre and D.Möhl, CERN 94-03(1994) p.411

Fig. 2 : Comparison of Designs (2)

BNL, HI Injector for RHIC

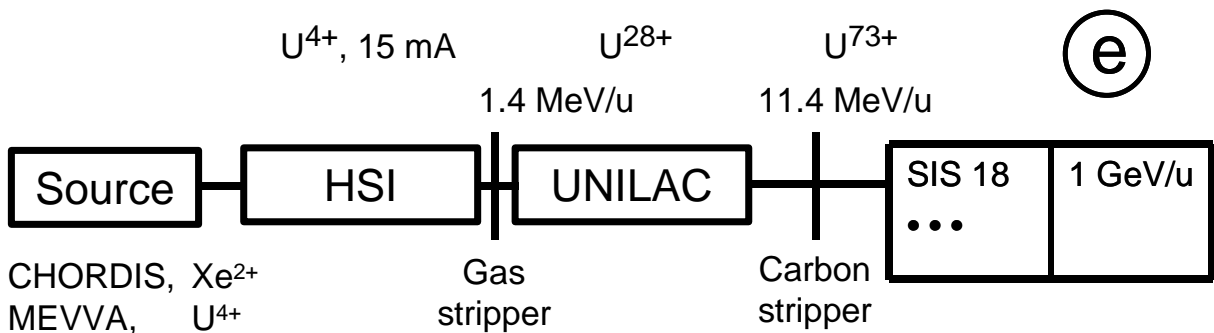
Under investigation



EBIS : E. Beebe et al., Rev. Of Scient. Instr.
Vol. 71(2000) p. 893

Scheme : S. Ozaki, Proc. of the PAC 2001, Chicago

GSI. HI Injector for SIS 18 ...



Filling of SIS 18 up to the space charge limit with
 $t_{inj} = 100 \mu s$ (~ 20 turns)

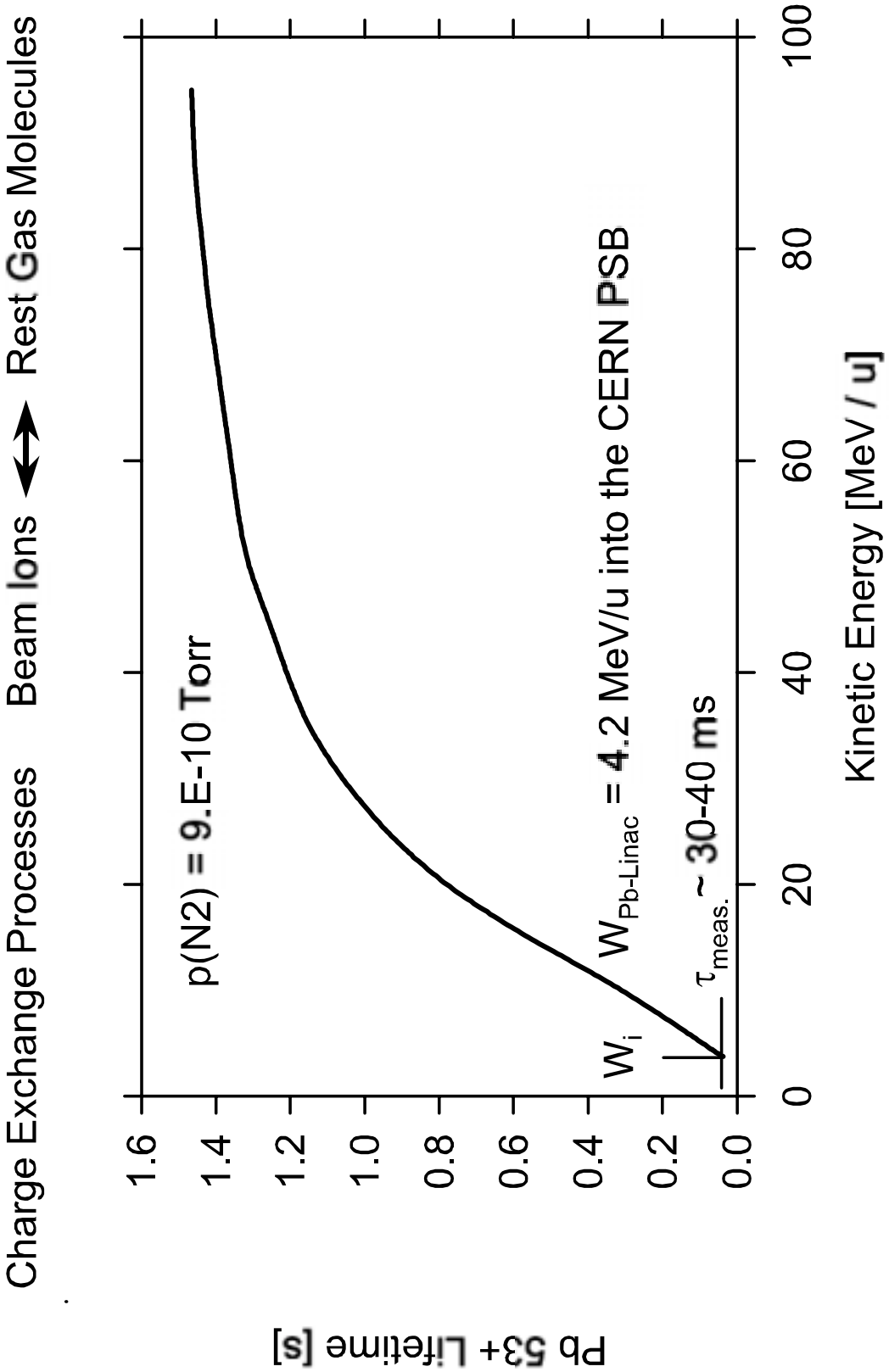


Fig. 3 Lifetime of Pb-ions in the CERN PSB