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AE Budapest 2017

Laser – plasma interaction

J (W/cm2) = 10E12 – 10E14 W/cm2

The inverse Bremsstralung absorption coefficient is given by

$$K_{ab} = \frac{\upsilon_{ei}(n_{cr})L_h}{c}$$

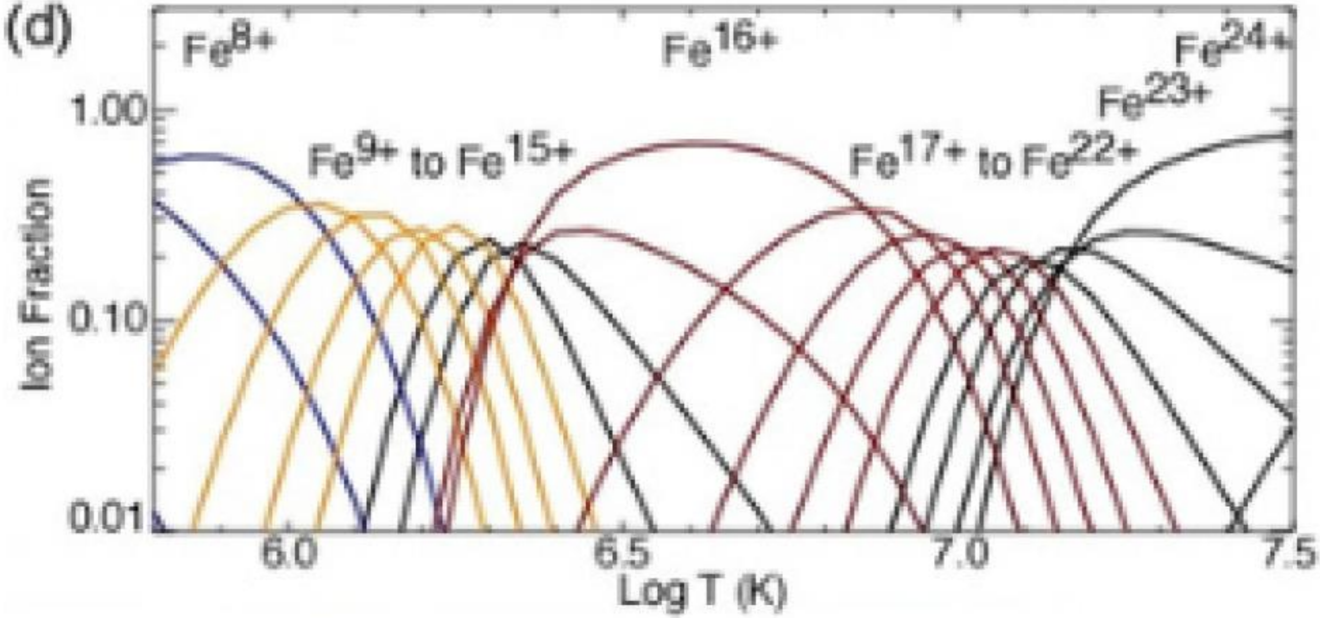
where

$$\upsilon_{ei}(n_{cr}) = \frac{4(2\pi)^{\frac{1}{2}}Ze^4\Lambda_{ei}n_{cr}}{3m_e^{\frac{1}{2}}(kT_e)^{\frac{3}{2}}}$$

is the electron-ion collision frequency , T_e is the temperature of the plasma electrons, Z is the ion charge state, e and m_e are the charge and mass of the electron, respectively. Λ_{ei} is the Coulomb logarithm (Λ_{ei} ≈ 8 - 10), $n_{cr} = \omega_L^2 m_e/4\pi e^2$ is the critical electron density, c is the speed of light, $L_h \approx \upsilon\tau_L$ is the scale length of the underdense plasma region, υ is the plasma velocity, and τ_L is the laser pulse duration.

Charge state distribution

Ion charge state as a function of temperature: Saha equation

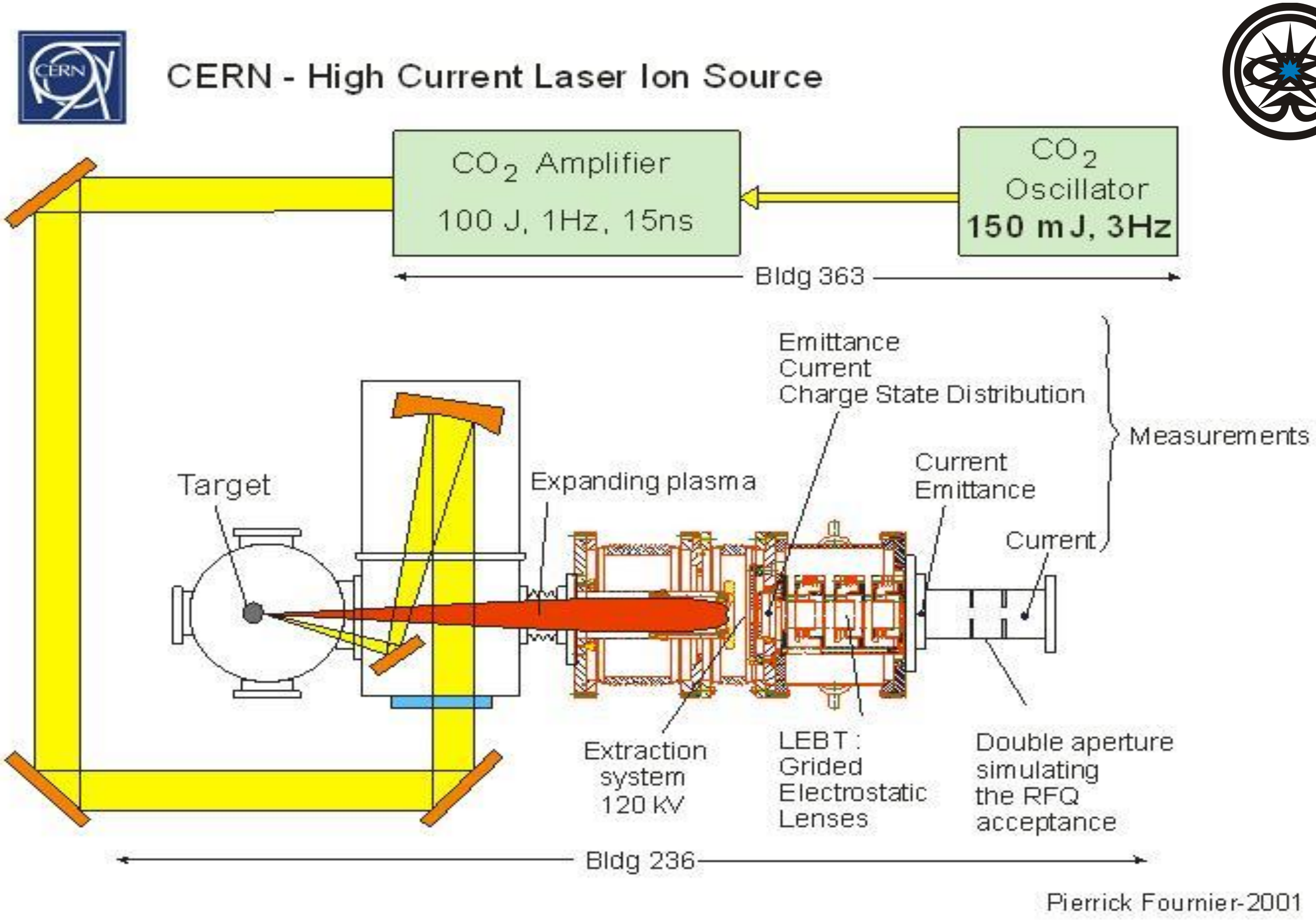


$$\frac{n_{z+1} n_e}{n_z} = \frac{g_{z+1}}{g_z} \cdot e^{-\frac{W_{iz}}{kT}} \cdot \frac{(2m_e^3)^{1/2}}{\pi^2 \hbar^3} \cdot \int_0^\infty \sqrt{E}\, e^{-\frac{E}{kT}} dE \quad = \frac{g_{z+1}}{g_z} \cdot \frac{2(2\pi m_e kT)^{3/2}}{h^3} e^{-\frac{W_{iz}}{kT}}$$

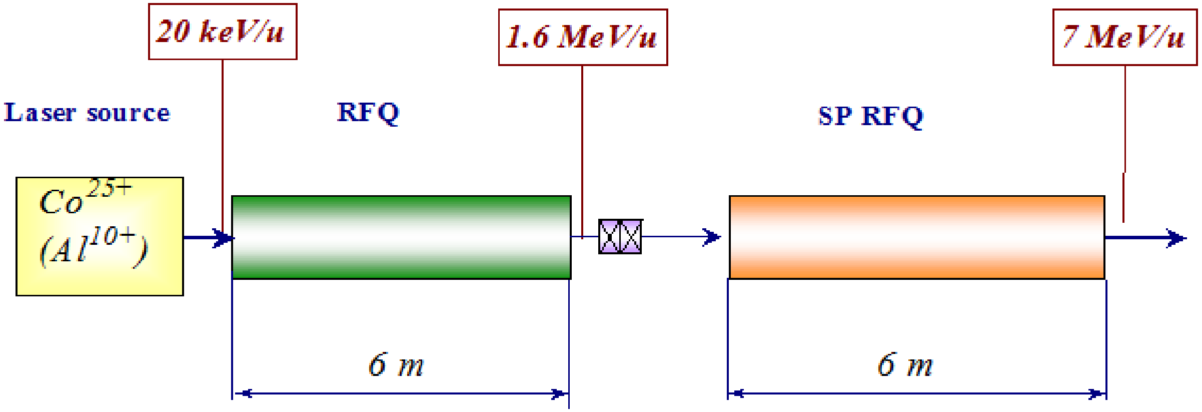
In the case of thermal equilibrium the Saha eqaution determines the relative abundance of charge states.

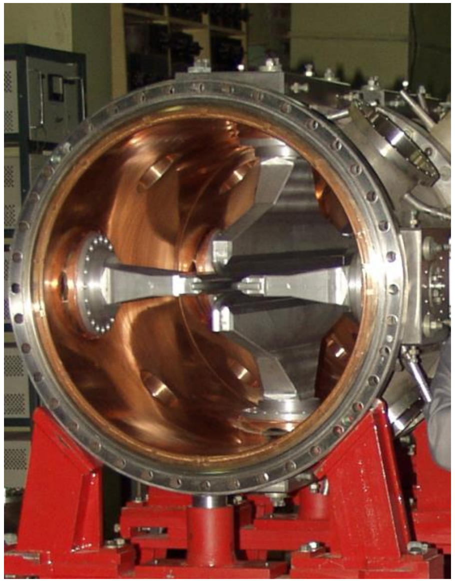
Laser Plasma Ion Source –at ITEP and at CERN

Capable of delivering Pb, In, Nb… ions with rep-rate 1 Hz
For Pb 25+ : 7,7 mA / 3.5 mks , 0.6 10 E10 ions measured
emittance – 0.2 mm mrad (normalized)



Current limitation in linear accelerators



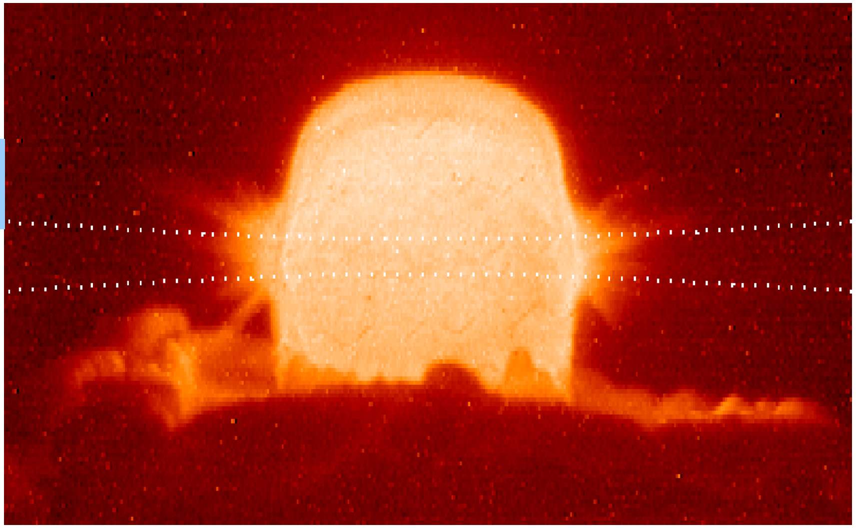


$$J[\mathrm{mA/cm^2}] \sim \mathrm{const}\,\frac{A}{Z}\,(\beta\gamma)^3$$

Alfred Maschke (BNL 1979) : ion current space charge limit for any quadrupole-focusing system

Intense beams of energetic heavy ions are an excellent tool to create and investigate extreme states of matter in reproducible experimental conditions

$$E_s = (1.6 \cdot 10^{-19}) \cdot \frac{dE/\rho dx}{\pi \cdot r^2} \cdot N \left[J/g \right]$$



$$dE/dx \sim -\rho \frac{Z^2_{эф}}{E_i} \ln \Lambda$$

Intense Heavy Ion Beams

large volume of sample (N mm3)
fairly uniform physical conditions
high entropy @ high densities
extended life time

HI : high entropy states of matter - without shocks !

Accumulation of an intense heavy-ion beam

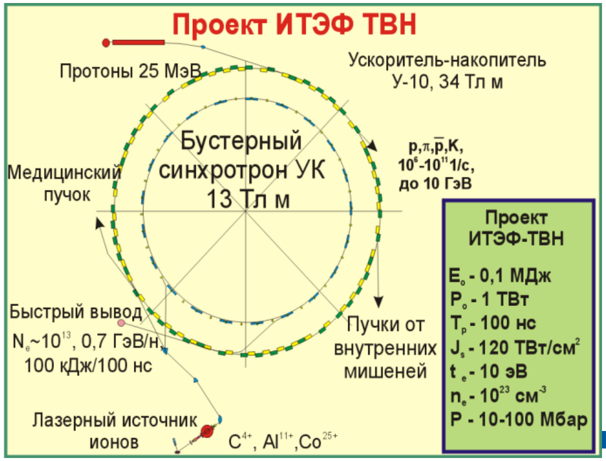
non-Liouvillian atomic or molecular processes could be used to enhance dramatically the final beam quality for driving a target.

The first possibility is the stacking of a beam <u>from a LINAC </u> into a <u>ring</u> (*either a storage ring or a synchrotron*).

Use of photoionization of Bi1+ at this stage was suggested by Carlo Rubbia, but would require high-power far-UV lasers.

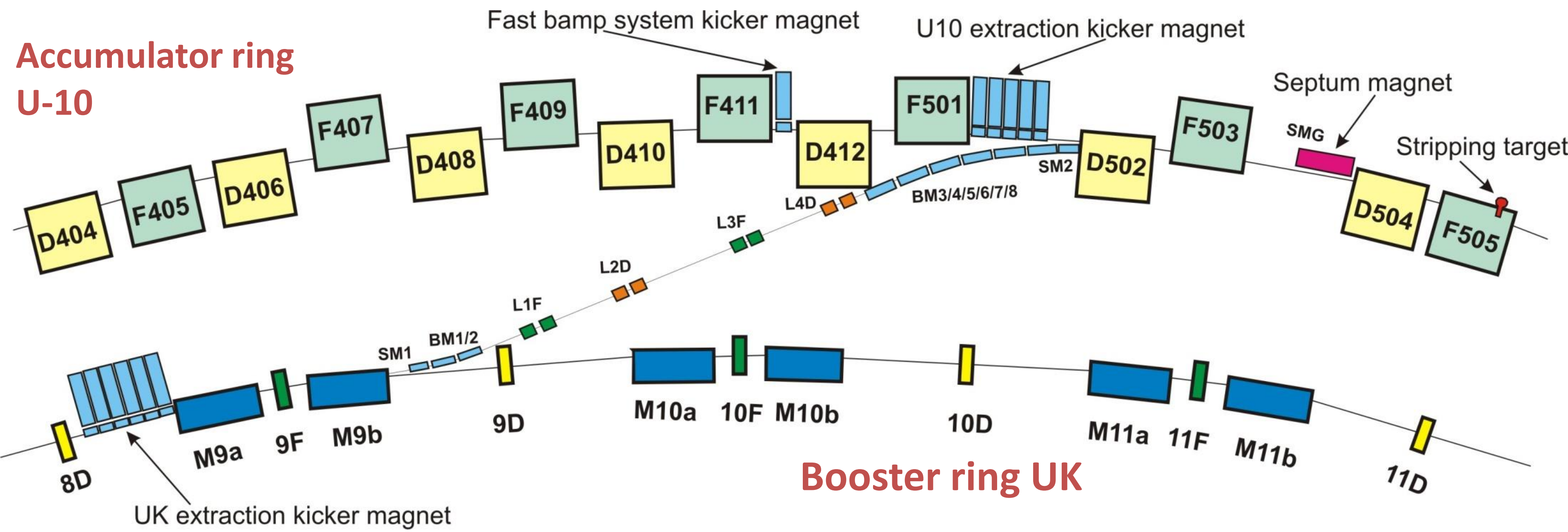
C. Rubbia, Nucl. Instr. and Meth. A 278 (1989) 253.

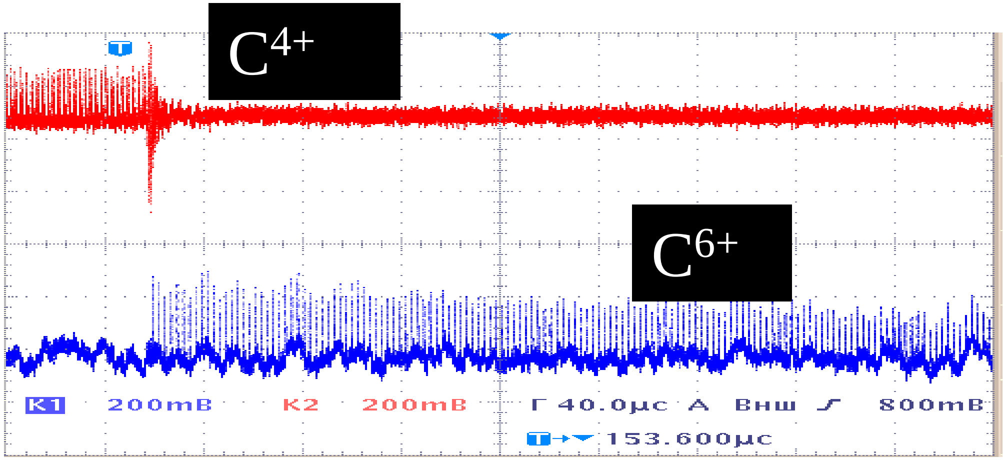
The second possibility is stacking of many pulses accelerated in a <u>synchrotron </u> into a <u>storage ring</u>.

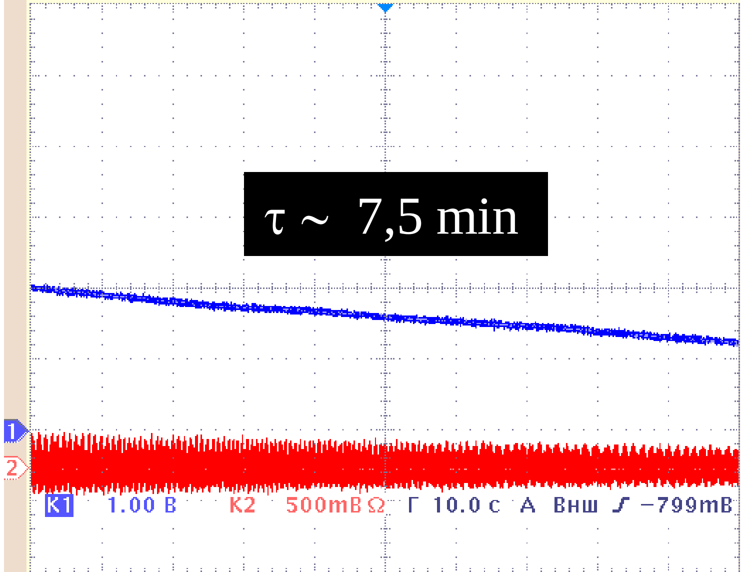


D.G. Koshkarev, B.Yu. Sharkov, R.C. Arnold - Nucl.Instr and Meth. in Physics Res. A 415 (1998) 296-304.

Non-Liouvillian Injection into the storage ring @ ITEP

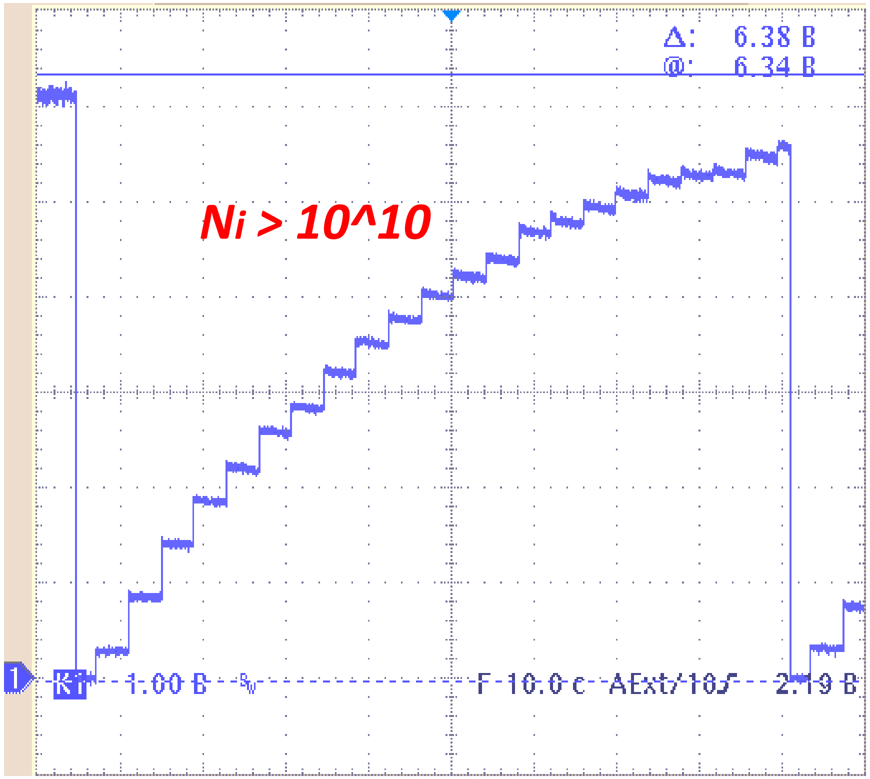






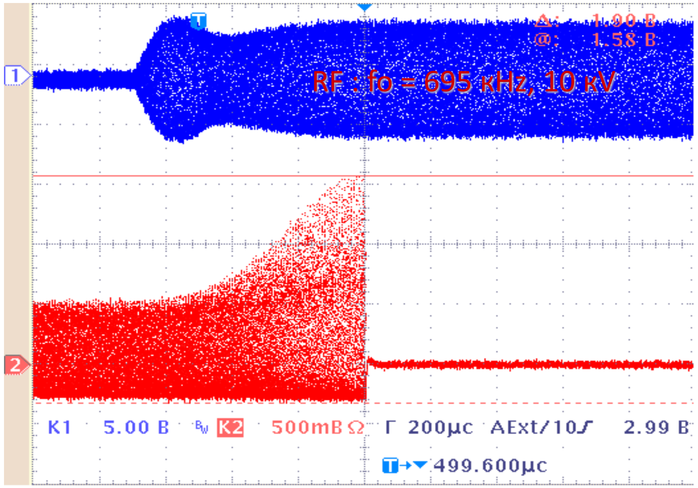
Non-Liouvillian stacking process

Stacking process for 213 MeV/u C6+

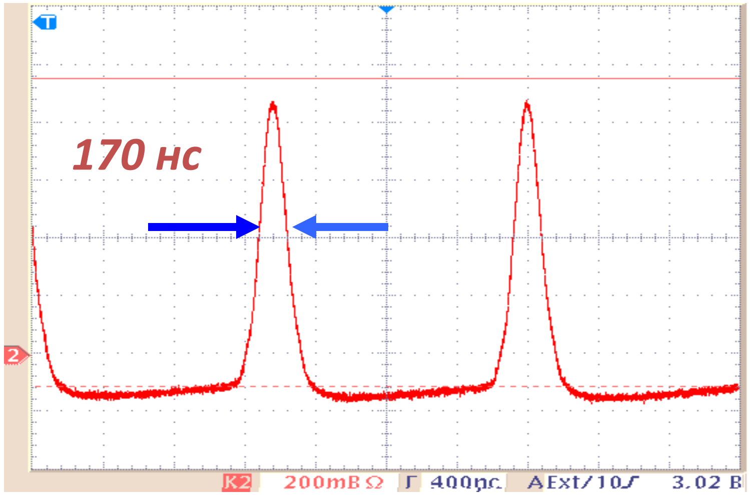


Ni > 10^10

RF bunch compression



RF : fo = 695 kHz, 10 kV

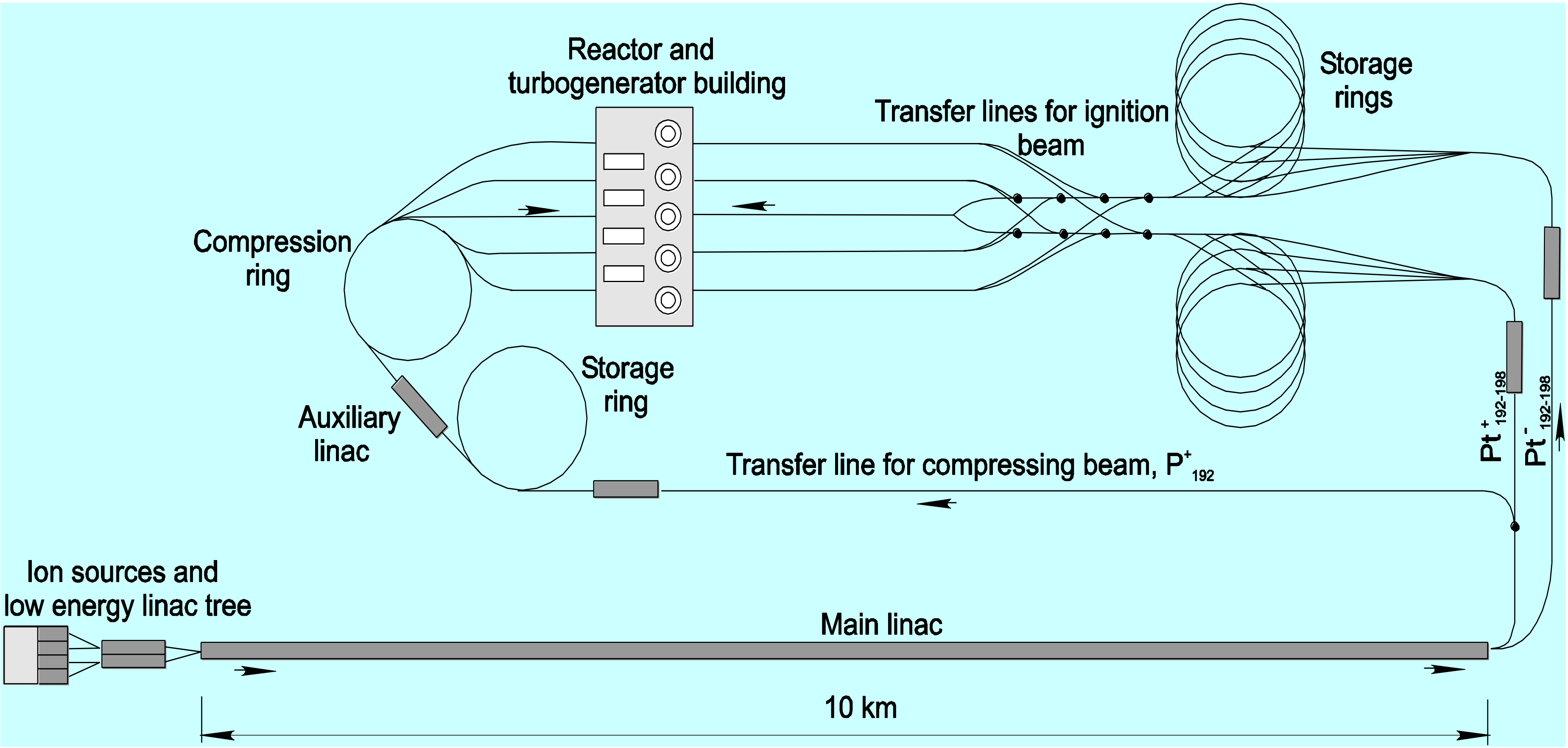


170 нс

HI IFE Concept

Ground plan for HIF power plant

B.Y. Sharkov BY, N.N. Alexeev, M.M. Basko et al., Nuclear Fusion 45(2005) S291-S297.

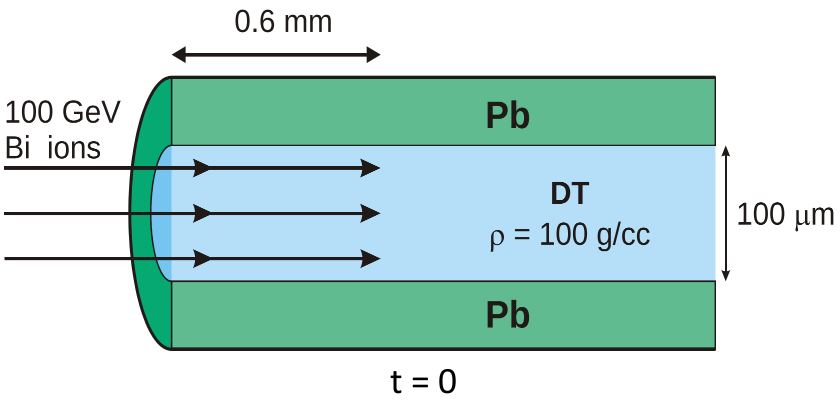


Slide № 3 Medin S.A. et al

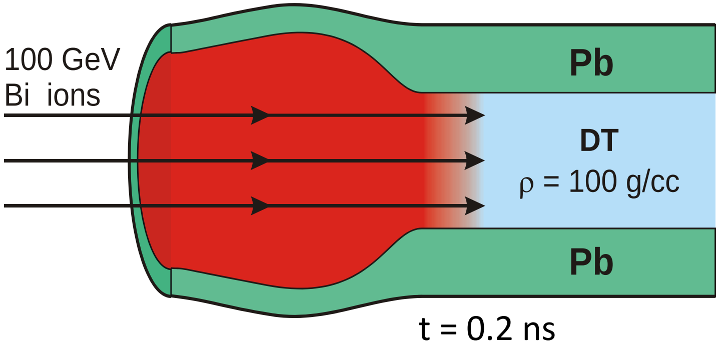
Fast ignition with heavy ions: assembled configuration

With a heavy ion energy ≥ 0.5 GeV/u, we are compelled to use cylindrical targets because of relatively long (≥ 6 g/cm^2) ranges of such ions in matter.

The 400 kJ ion pulse duration of 200 ps is still about a factor 4 longer than the envisioned laser ignitor pulse. For compensation, it is proposed to use a massive tamper of heavy metal around the compressed fuel:



Assembled configuration



Ignition and burn propagation

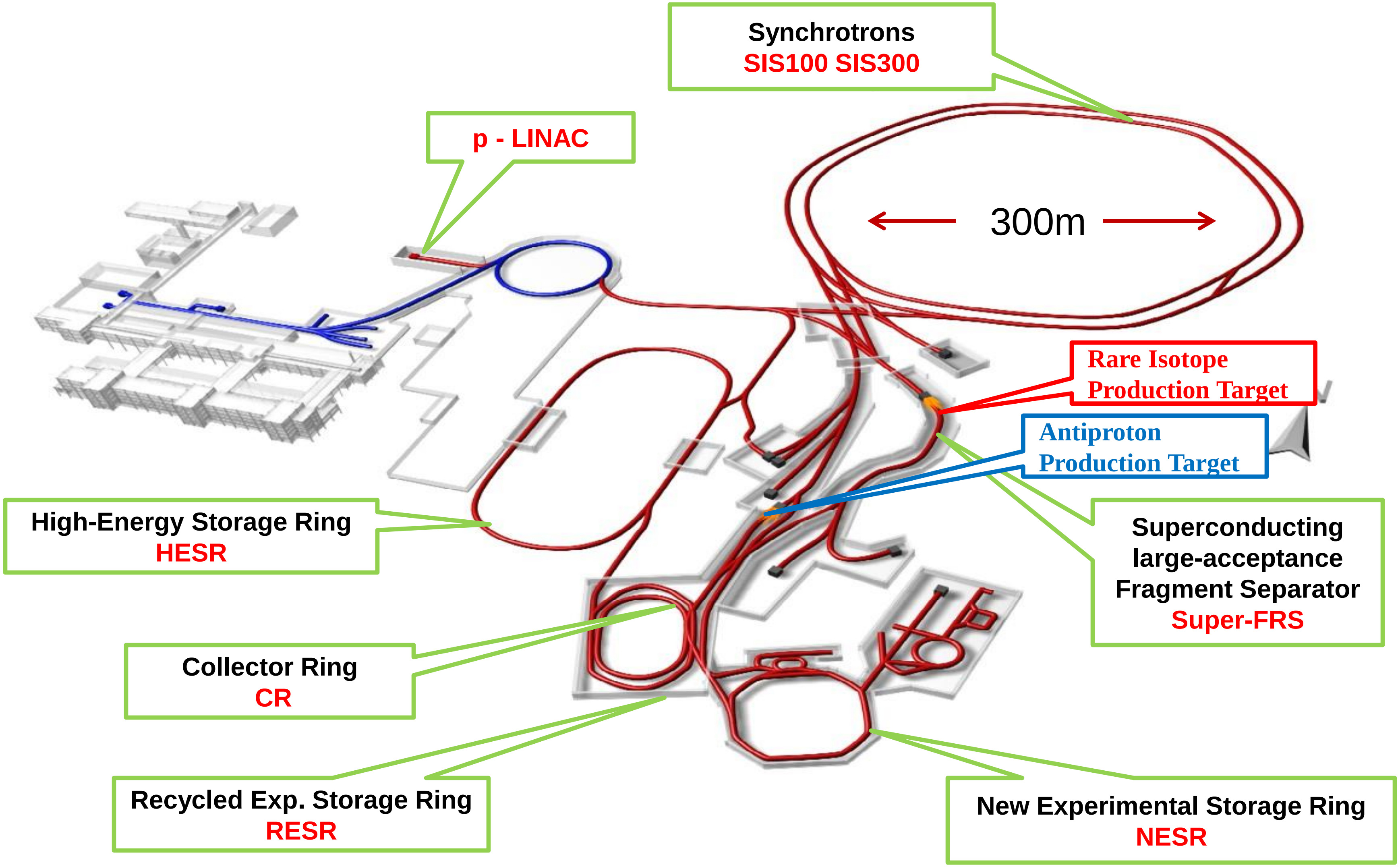
Fuel parameters in the assembled state: $\rho_{DT} = 100$ g/cc, $R_{DT} = 50$ μm, $(\rho R)_{DT} = 0.5$ g/cm^2.

2-D hydro simulations (ITEP + VNIIEF) have demonstrated that the above fuel configuration is ignited by the proposed ion pulse, and the burn wave does propagate along the DT cylinder.

B.Y. Sharkov BY, N.N. Alexeev, M.M. Basko et al., Nuclear Fusion 45(2005) S291-S297.

Facility for Antiproton and Ions Research –
the light tower of the ESFRI Roadmap

New accelerator systems entered the construction phase in Darmstadt



The 4 Scientific Pillars of FAIR

APPA: Atomic, **Plasma Physics** and Applications

CBM: Compressed Baryonic Matter

NUSTAR: Nuclear Structure, Astrophysics and Reactions

PANDA: Antiproton Annihilations at Darmstadt

In total: 2500 – 3000 Users
from 49 countries

Scientific program is competitive and world class

High Energy Density experiments of HEDgeHOB collaboration

HIHEX

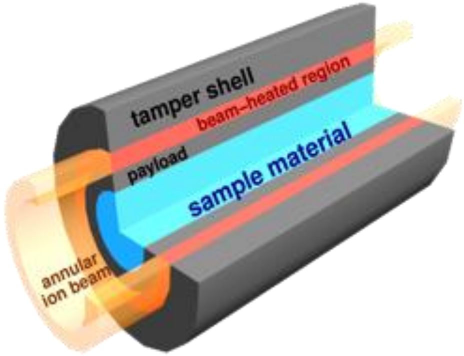
Heavy Ion Heating and Expansion

- uniform quasi-isochoric heating of a large-volume dense target, isentropic expansion in 1D plane or cylindrical geometry

Numerous high-entropy HED states:
EOS and transport properties of e.g., non-ideal plasmas, WDM and critical point regions for various materials

LAPLAS

Laboratory Planetary Sciences



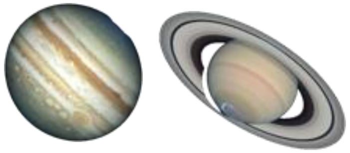
- hollow (ring-shaped) beam heats a heavy tamper shell cylindrical implosion and low-entropy compression

Mbar pressures @ moderate temperatures:
high-density HED states, e.g. hydrogen metallization problem, interior of Jupiter and Saturn

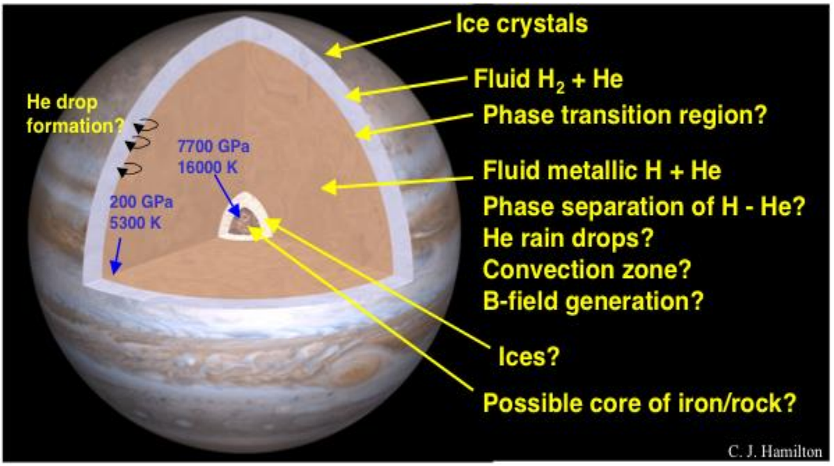
LAPLAS [LAboratory PLAnetary Sciences]

Experimental Scheme: Low entropy compression of a test material like H, D_2 or H_2O, in a multilayered cylindrical target

[Hydrogen Metallization , Planetary Interiors]



N.A. Tahir et al., PRE 64 (2001) 016202; High Energy Density Phsics 2 (2006) 21;
A.R. Piriz et al. PRE 66 (2002) 056403.



Au or Pb

Circular beam

Shock reverberates between the cylinder axis and the hydrogen-outer shell interface.

Very high densities, high pressure, higher temperature

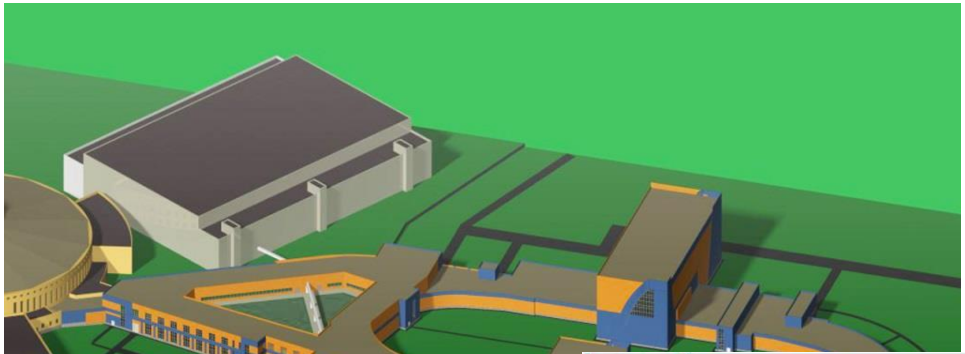
Very high ρ (23 g/cc), ultra high P (30Mbar) , low T (of the order of 10 kK).

ρ= 1.2 g/cc, P = 11 Mbar,
T = 5 ev

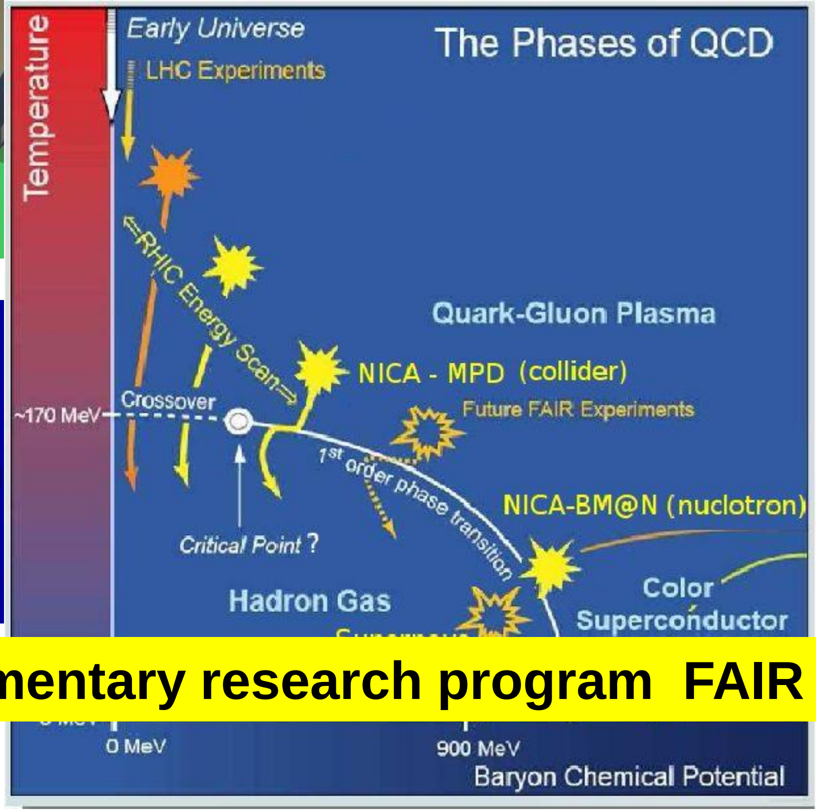
FAIR + NICA : extreme state of nuclear matter

JINR NICA/MPD

Nuclotron-based Ion Collider fAcility



FAIR/CBM



E_{lab} < 60 GeV/n

√sNN = 4 ÷ 11.0 GeV/n

Average luminosity
$10^{27} sm^{-2} s^{-1}$ Au x Au

E_{lab} ~ 34 GeV/n

√sNN = 8.5 GeV

Particle intensity
(for U) up to 10^{11} ppp

Complimentary research program FAIR - NICA

Thank you for attention !