International Workshop on Acceleration and Applications of Heavy Ions

Acceleration of heavy ions and beam transport

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Warsaw, 03.07.2012

Accelerator – a device that uses electromagnetic fields to propel charged particles

Major types of accelerators:

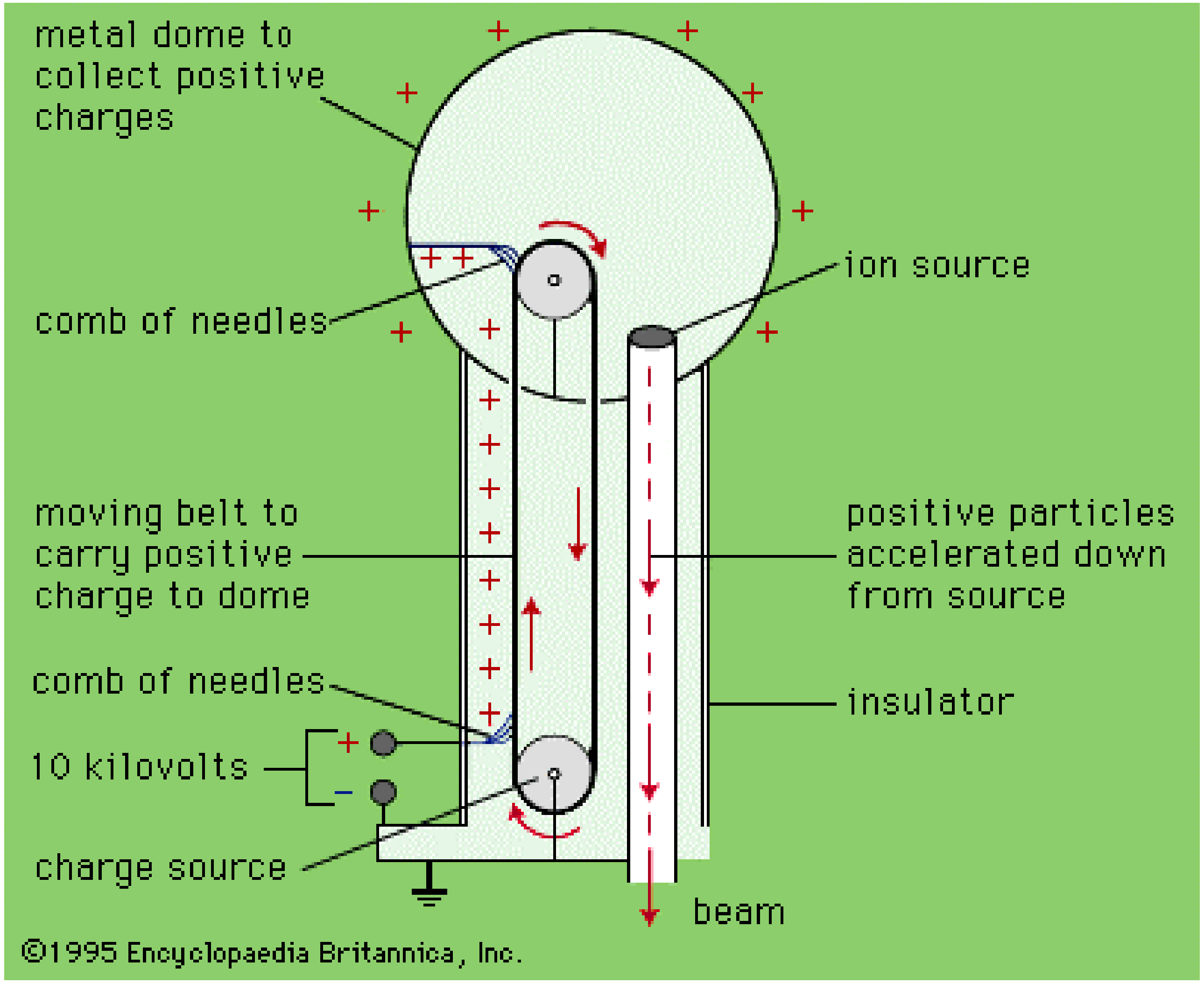
a) **linear:**

- **van de Graaff accelerator : Lech (IBJ, Warsaw, Poland)**
- **Linac (CERN, Geneva, Switzerland)**

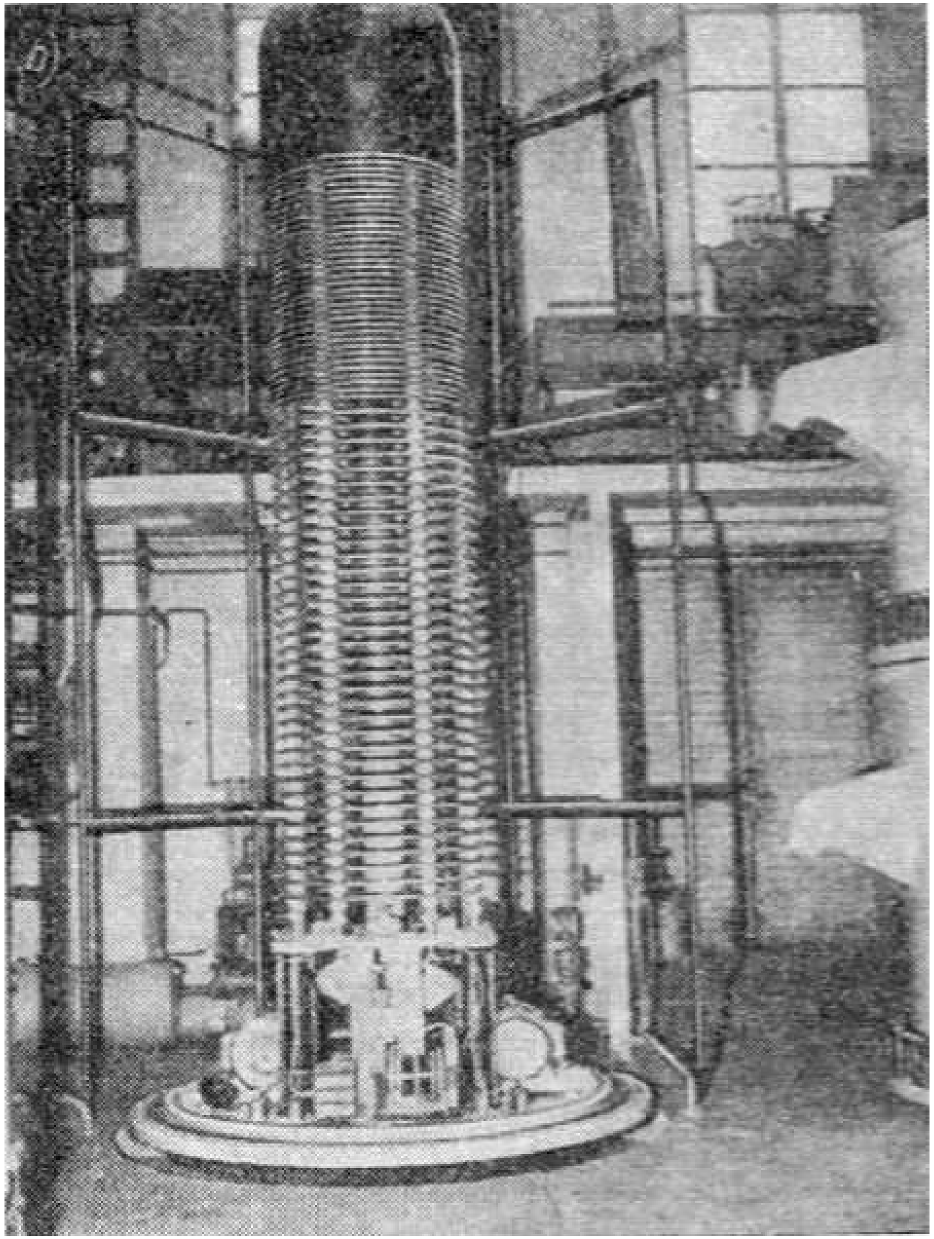
a) **circular:**

- **cyclotron: U200-P (HIL, Warsaw, Poland), K130 (JYFL, Jyväskylä, Finland), K800 (INFN LNS, Catania, Italy), U400 and U400M (JINR, Dubna, Russia)**
- **synchrotron: LHC (CERN, Geneva, Switzerland)**

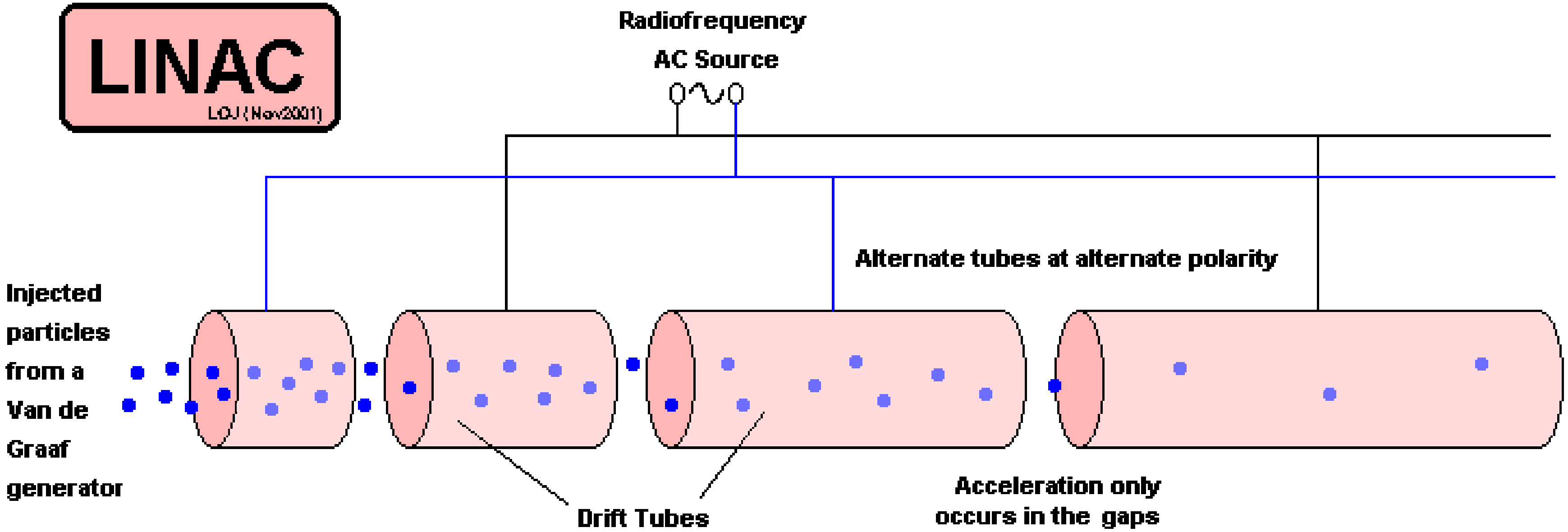
Electrostatic accelerator (van de Graaff)

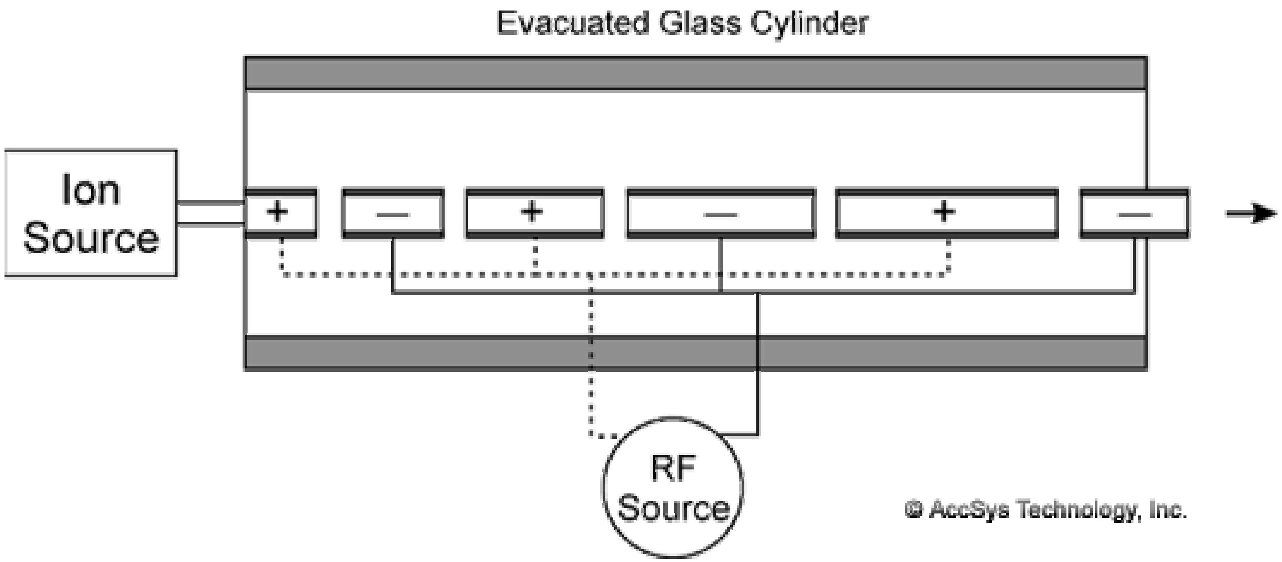


Electrostatic accelerator (van de Graaff)

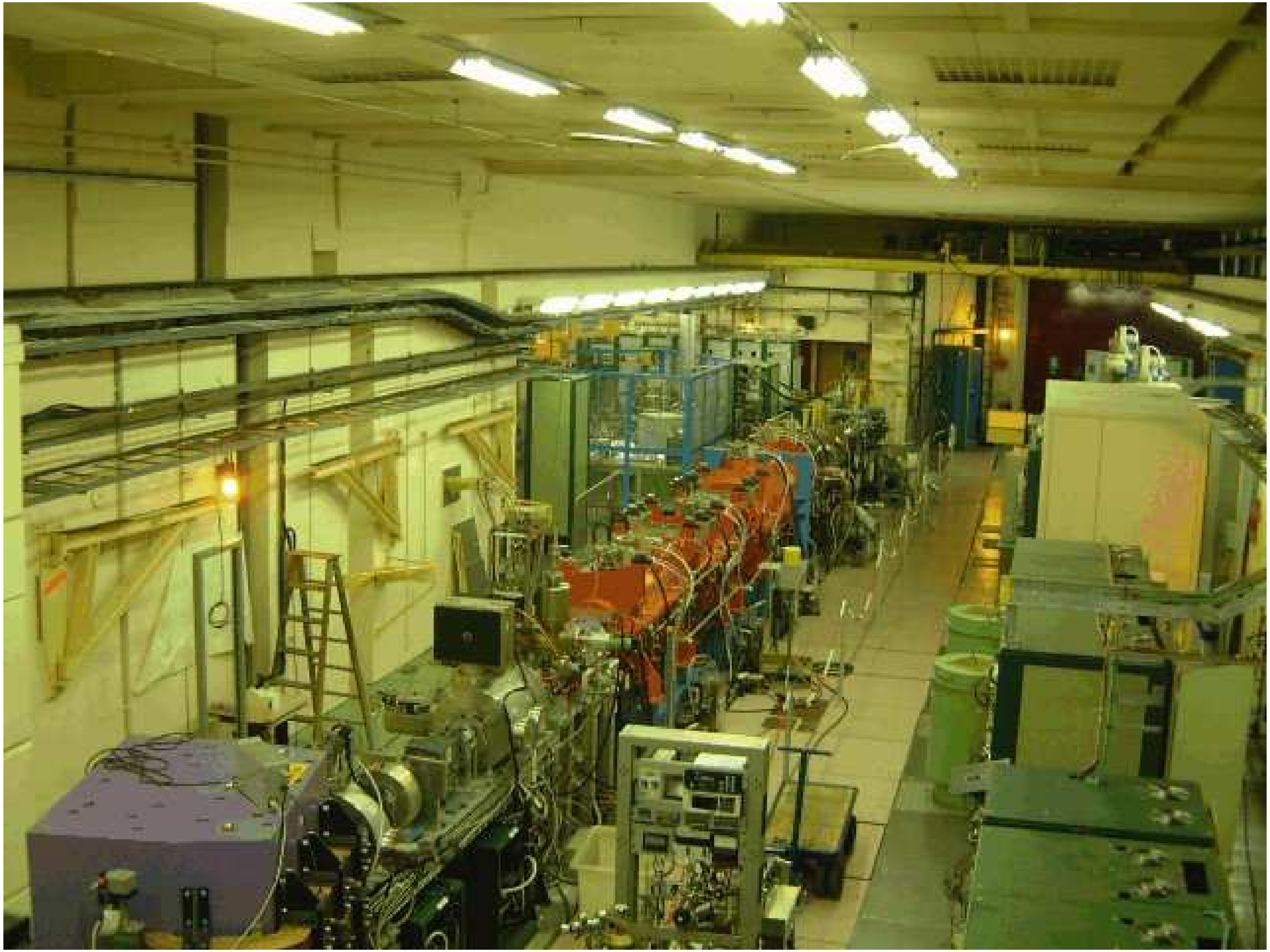


LINAC


LINAC
LOJ (Nov2001)
Radiofrequency
AC Source
Alternate tubes at alternate polarity
Injected
particles
from a
Van de
Graaf
generator
Drift Tubes
Acceleration only
occurs in the gaps


Evacuated Glass Cylinder
Ion
Source
+
—
+
—
+
—
RF
Source
© AccSys Technology, Inc.

LINAC



CYCLOTRON

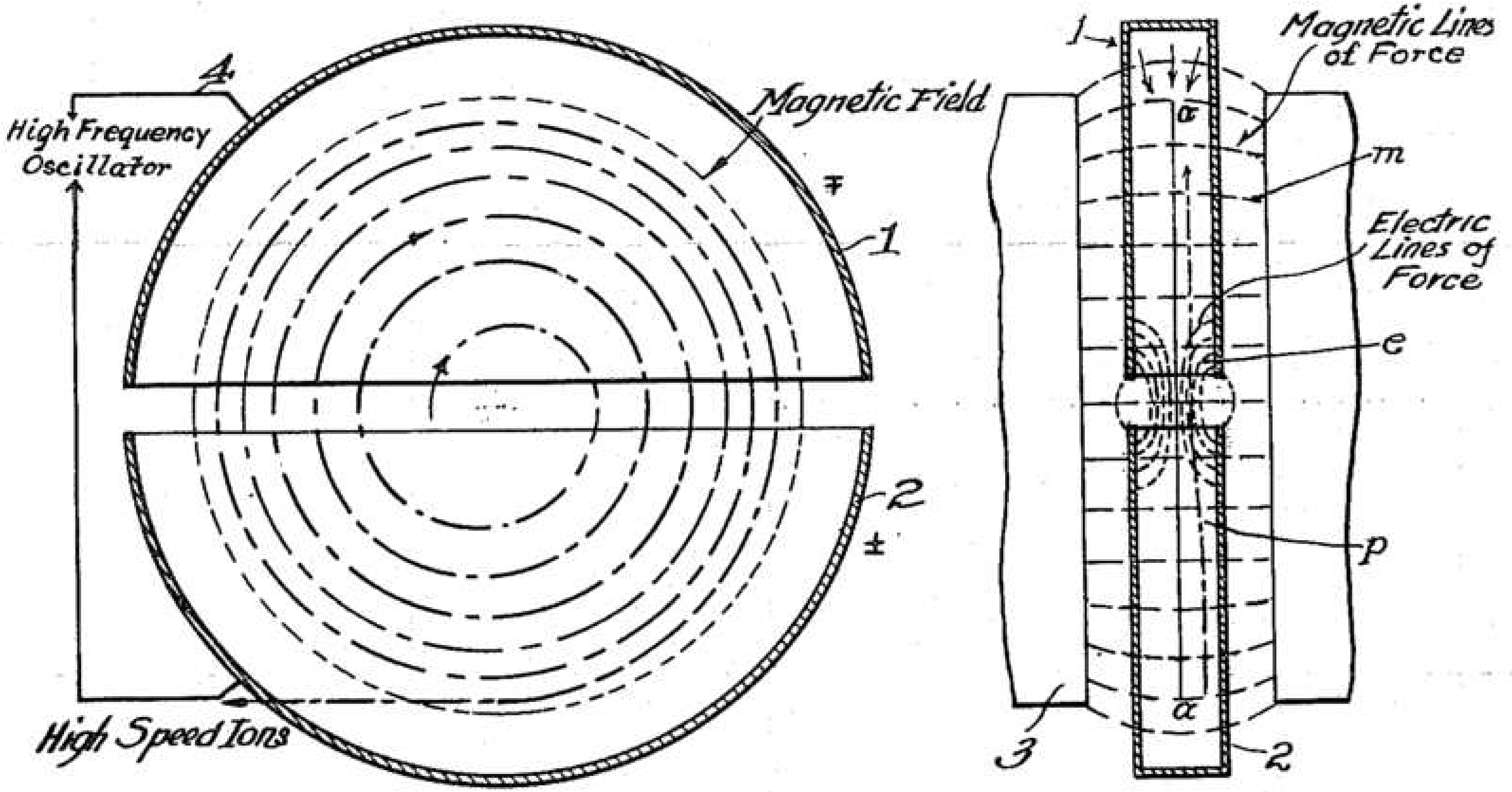
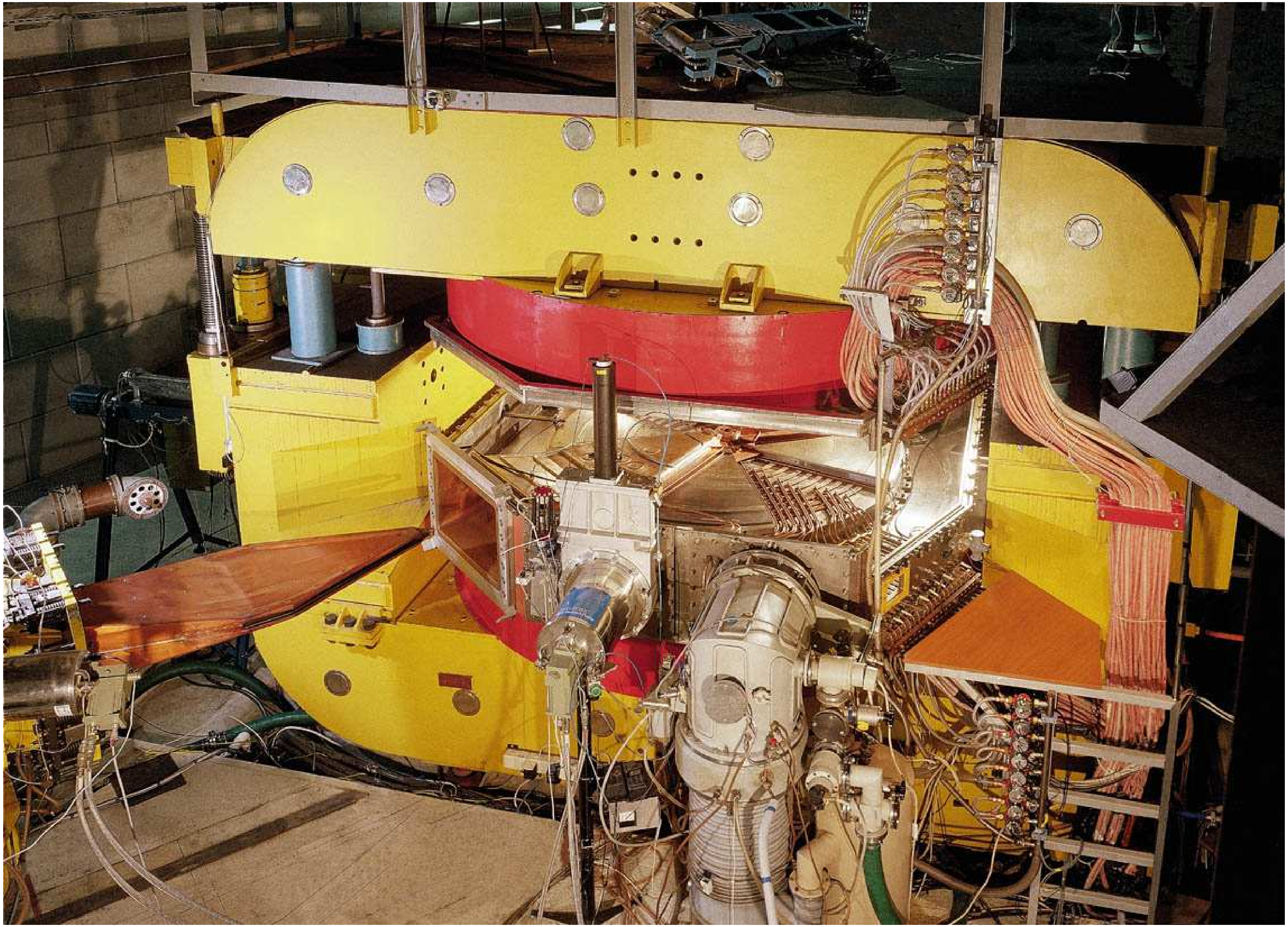


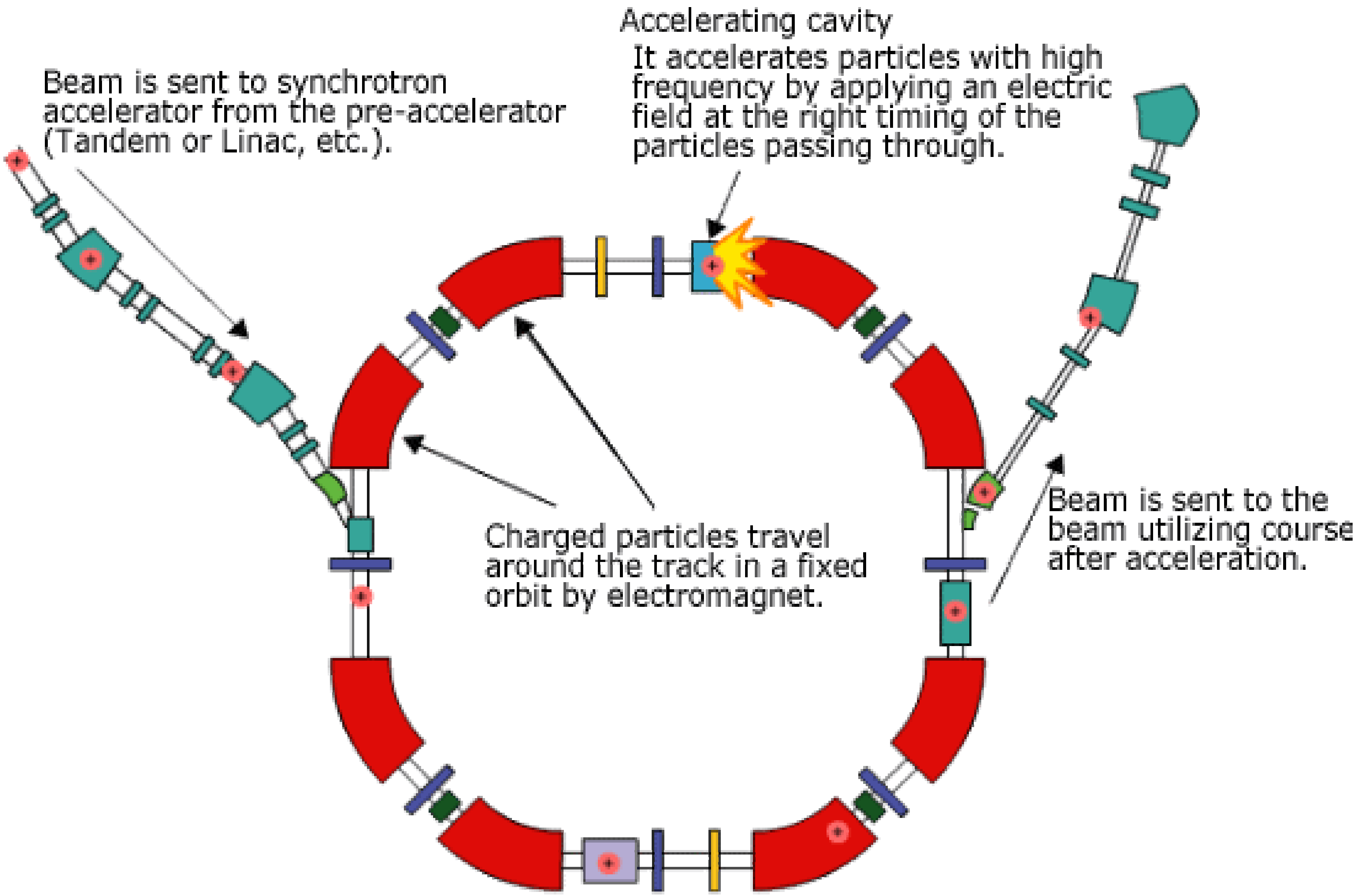
Diagram of cyclotron operation from Lawrence’s 1934 patent

(Ernest Lawrence, 1931)

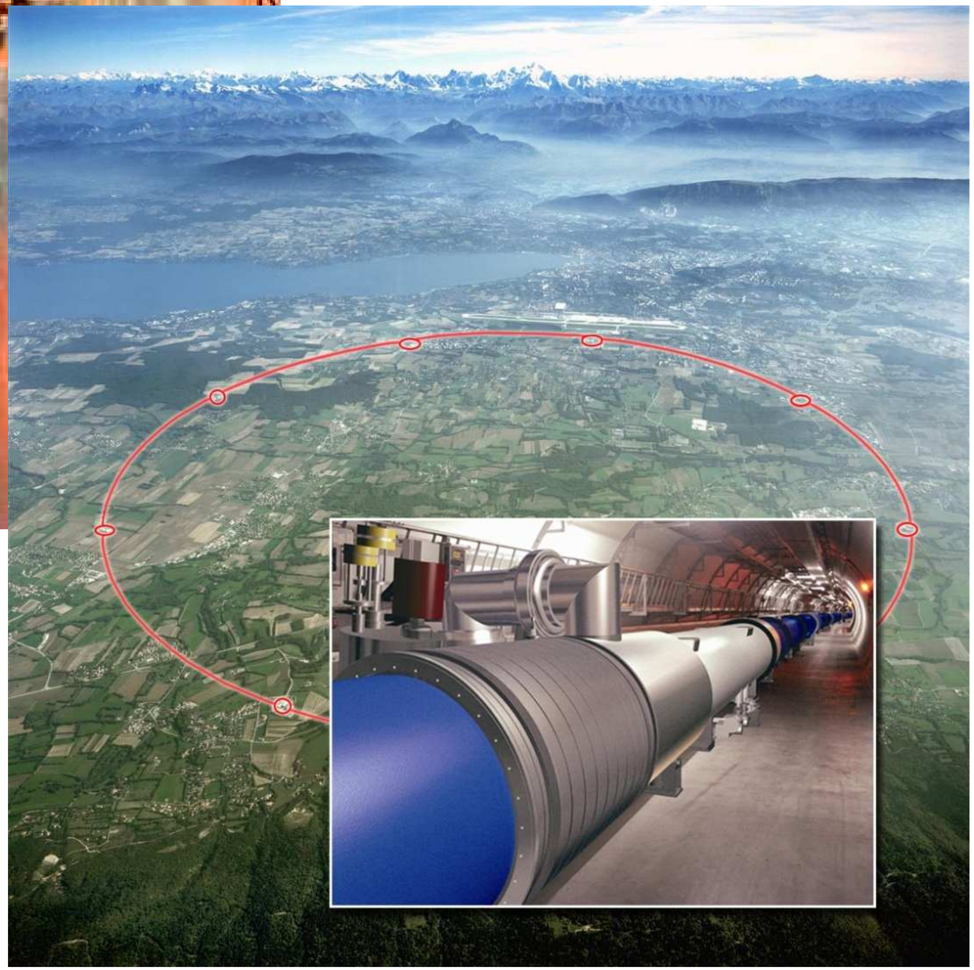
CYCLOTRON



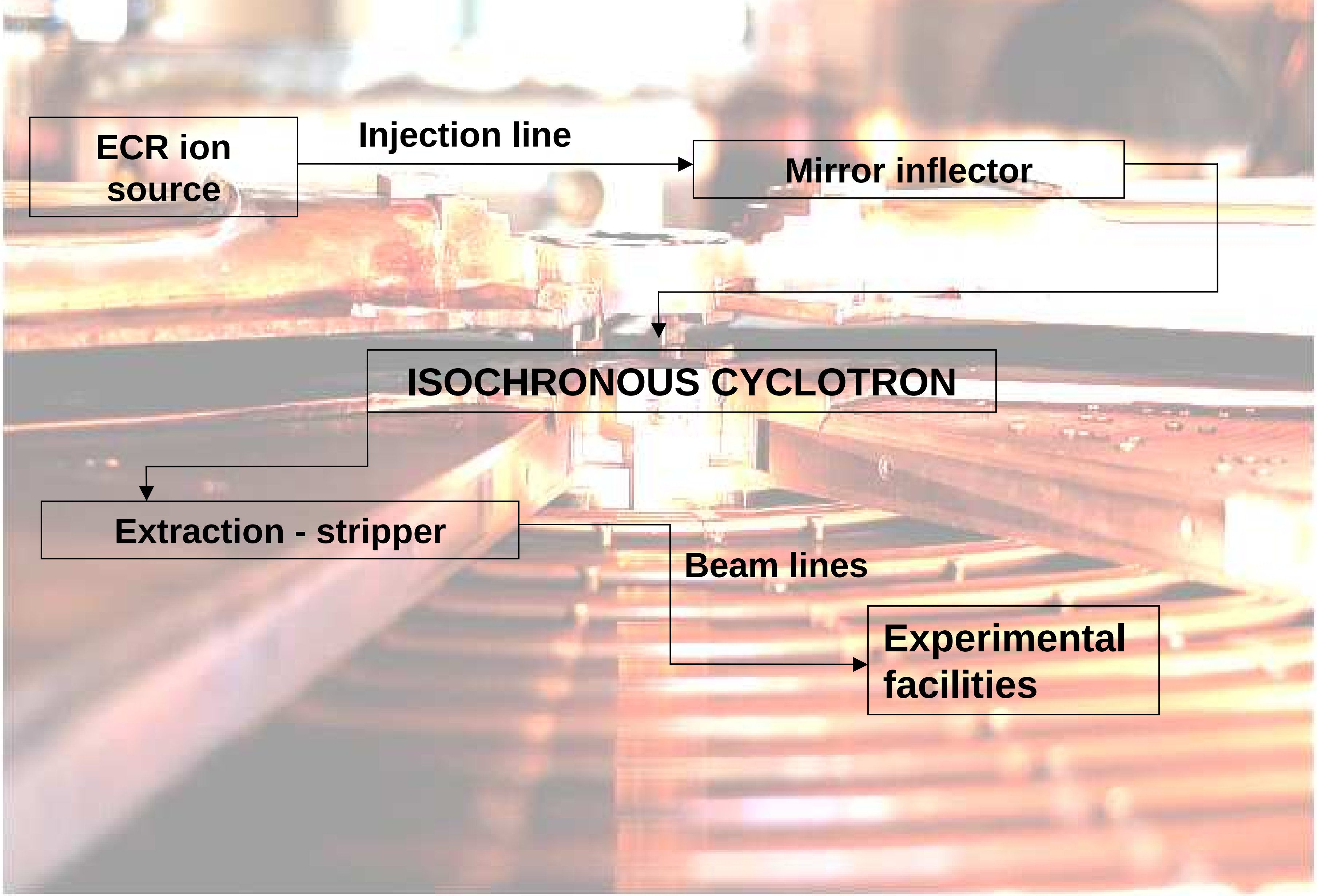
SYNCHROTRON



SYNCHROTRON



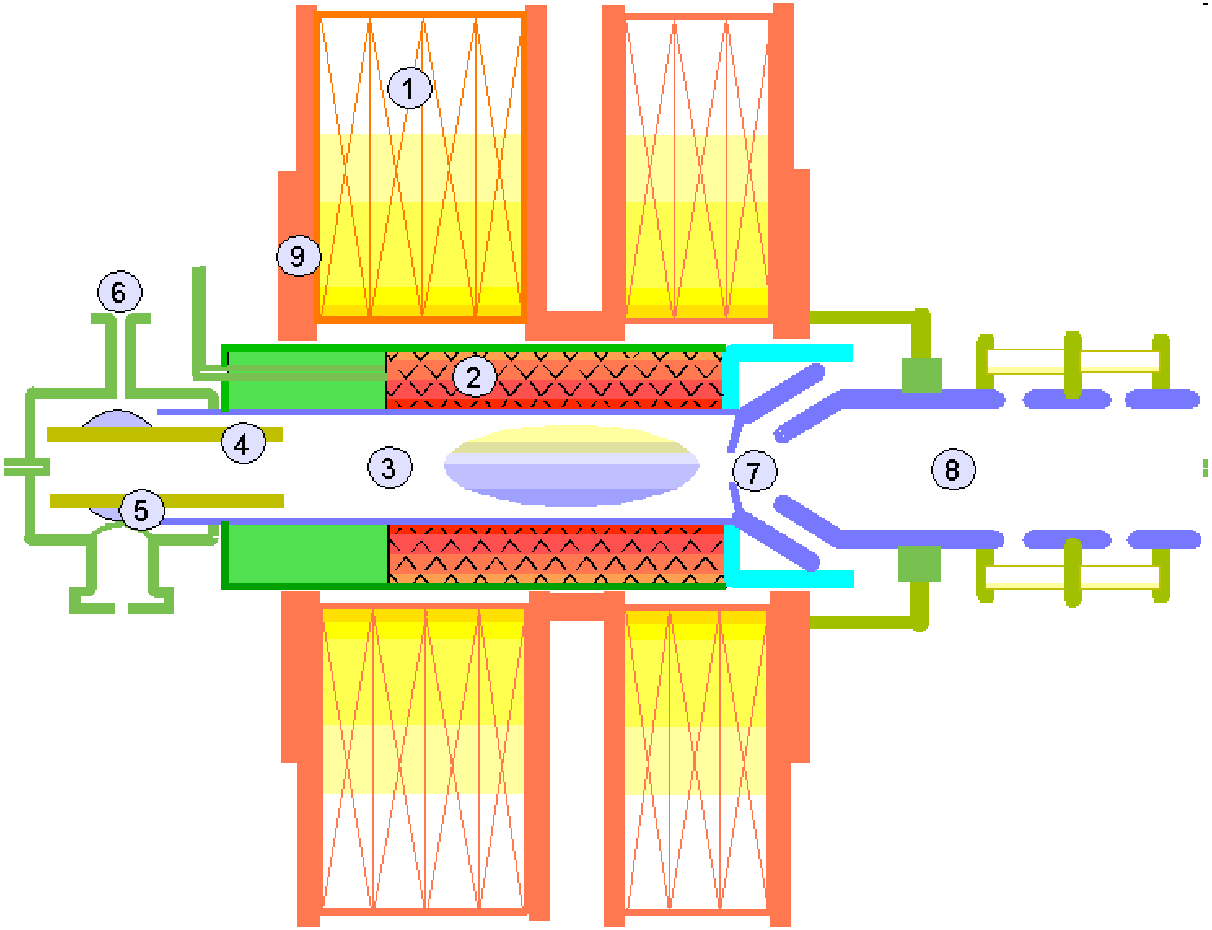
The way of heavy ions in Warsaw Cyclotron



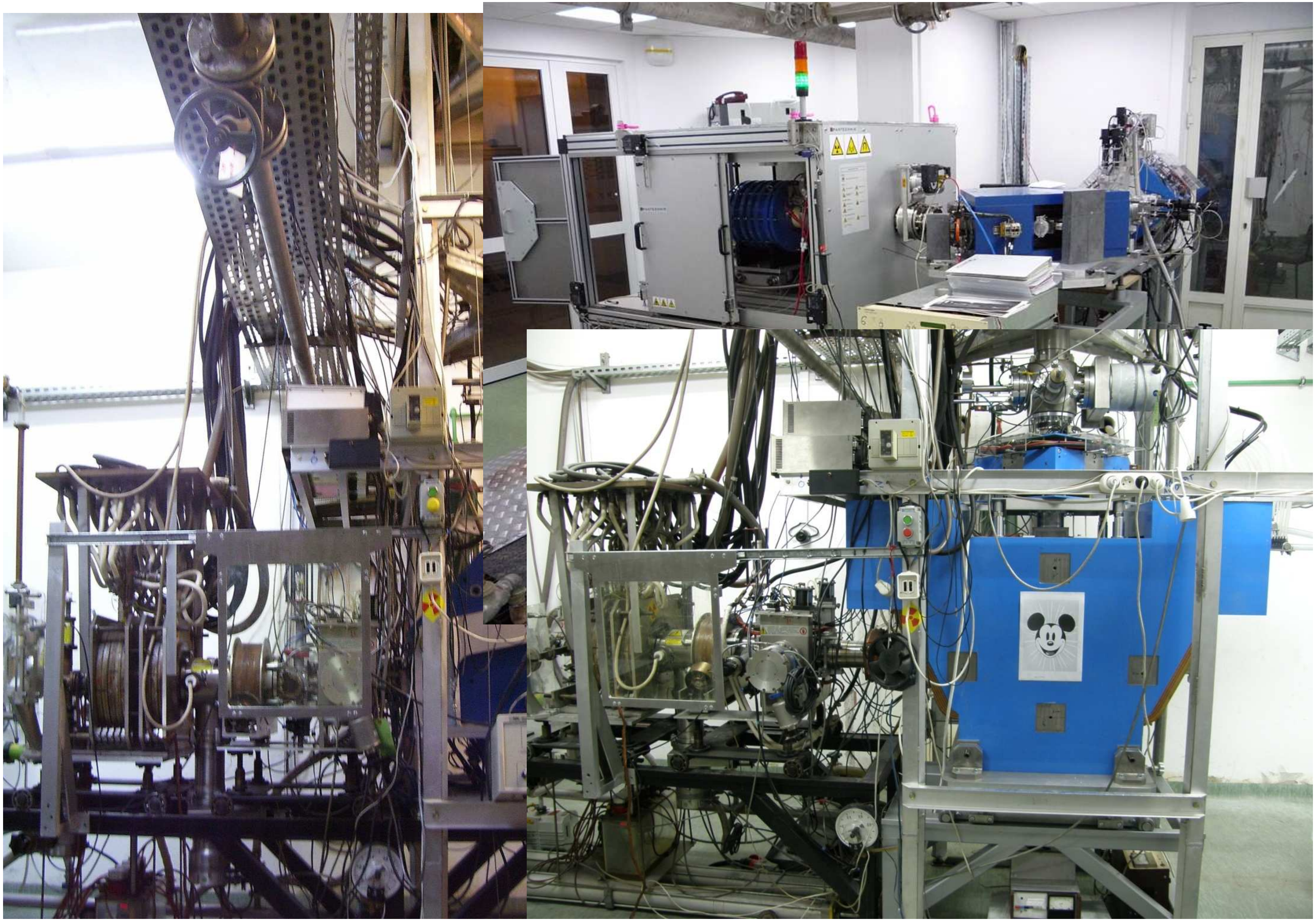
ECR ion source

(Electron Cyclotron Resonance)

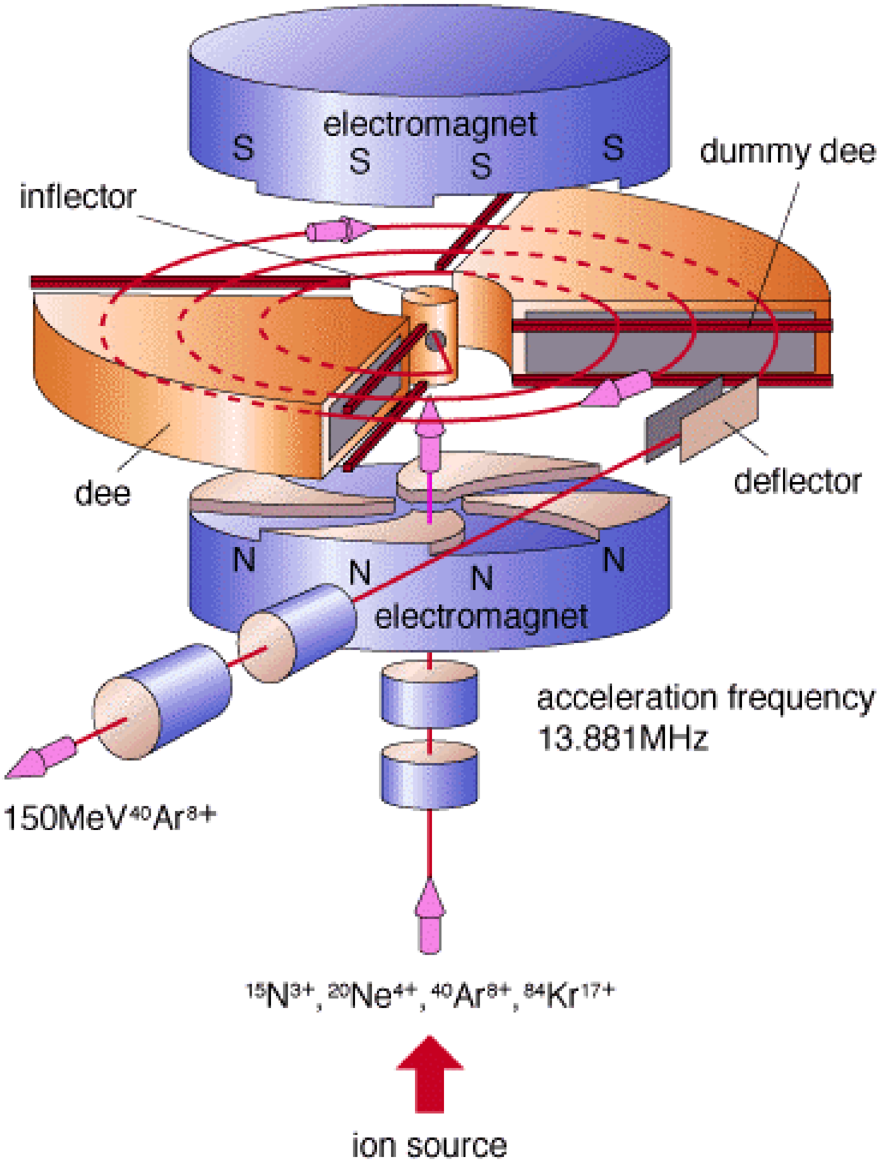
1. coils 2. hexapol
3. plasma chamber
4. coaxial line 5. tuner
6. RF injection 7. exit hole
8. Einzel lens 9. yoke



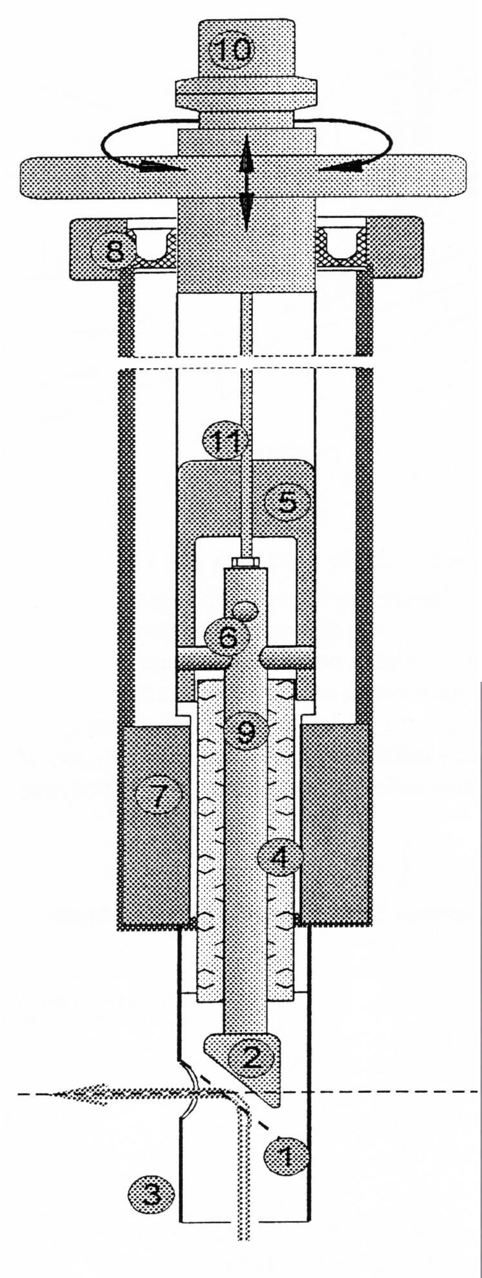
Our ion sources and injection line

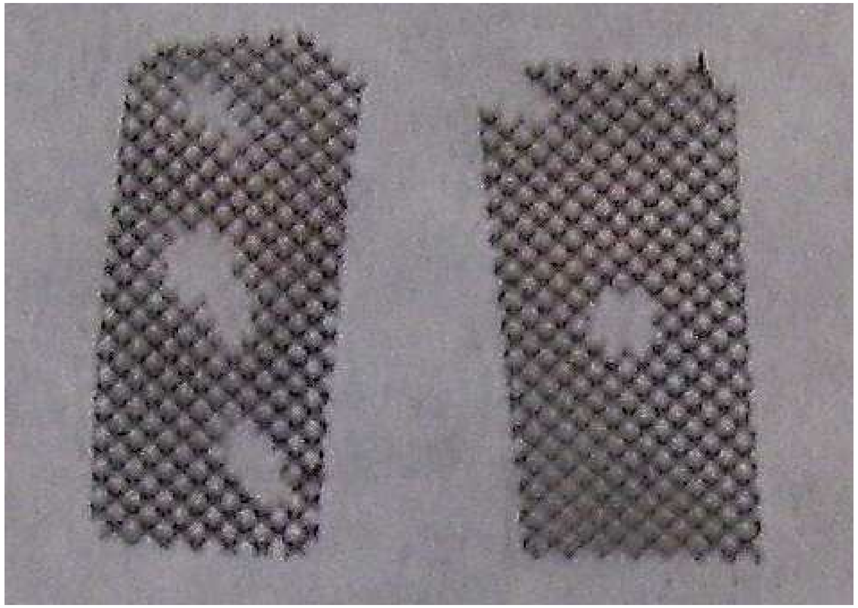


Mirror inflector

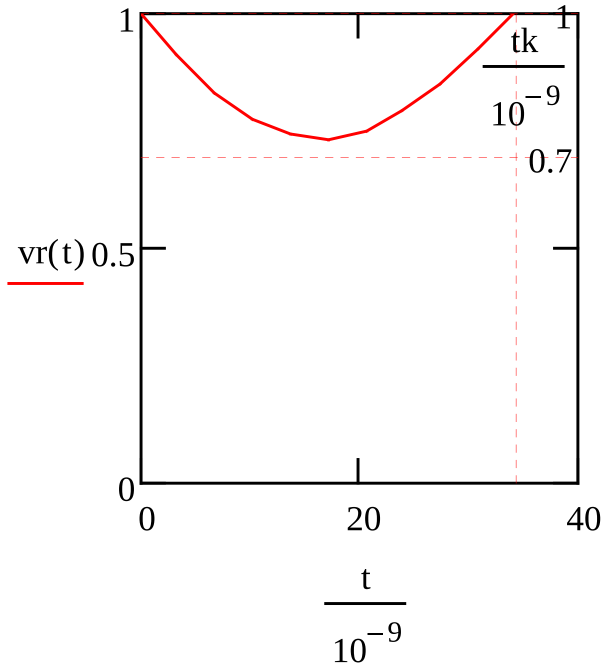


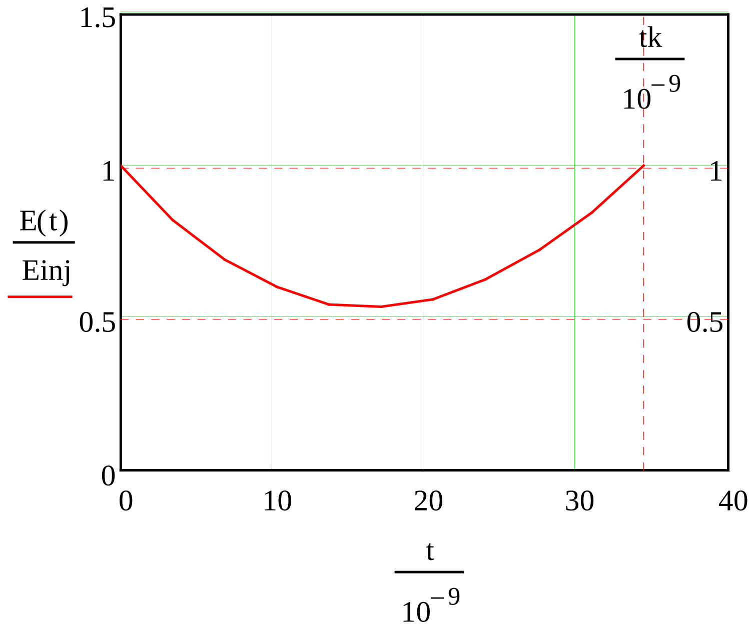
Mirror inflector

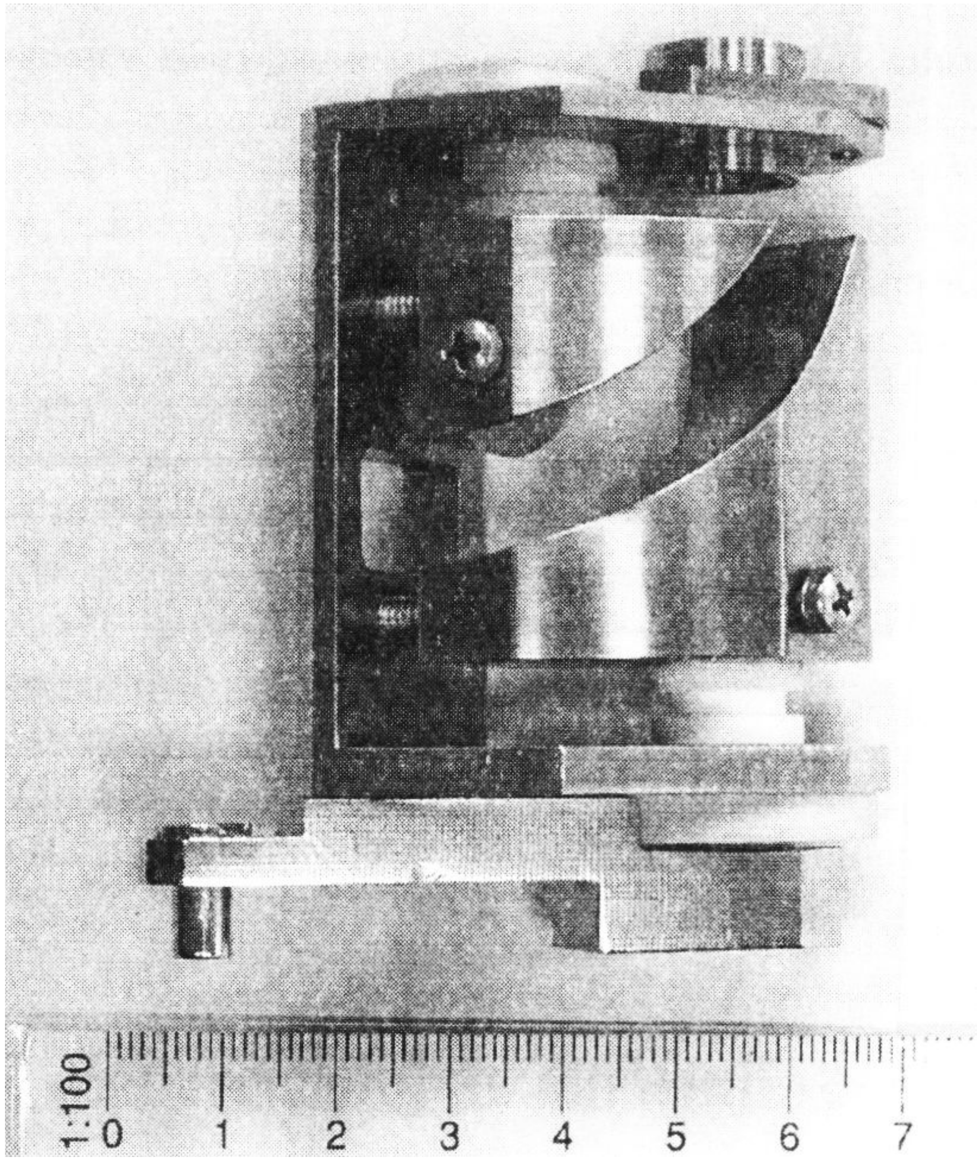




Spiral inflector







Isochronous cyclotron

$$\frac{m \cdot v^2}{\rho} = q \cdot v \cdot B$$

$$B \cdot \rho = \frac{m \cdot v}{q} = \frac{p}{q}$$

$$\omega_c = \frac{q}{m} \cdot B$$

$$\omega_{RF} = h \cdot \omega_c$$

$$m_r = m_0 \gamma = \frac{m_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

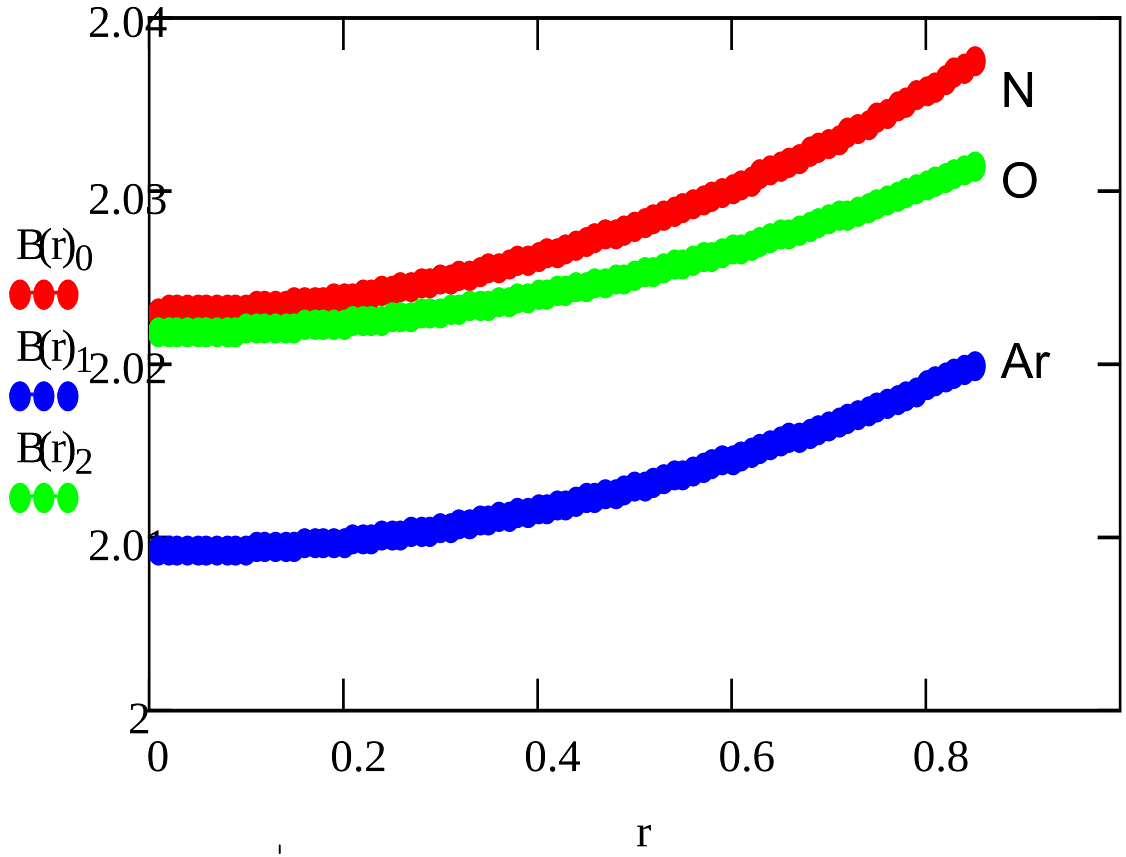
$$\gamma(r) = \frac{1}{\sqrt{1 - \left(\frac{v(r)}{c}\right)^2}} = \frac{1}{\sqrt{1 - \left(\frac{r \cdot \omega_c}{c}\right)^2}}$$

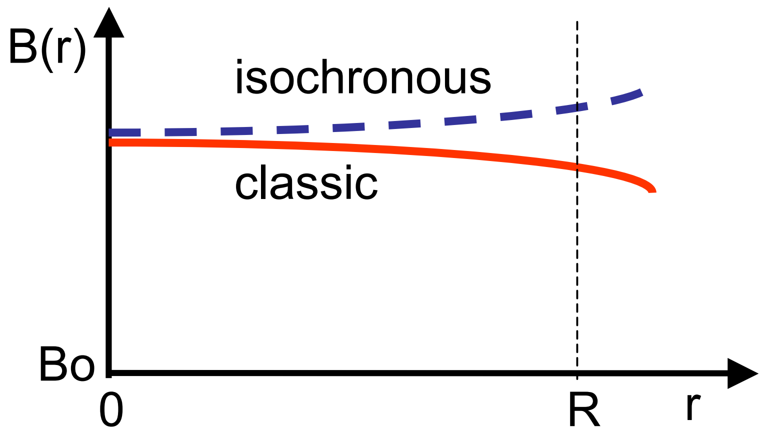
$$\omega_c = \frac{Bq}{m}$$

$$B(r) = \gamma(r) \cdot B_0$$

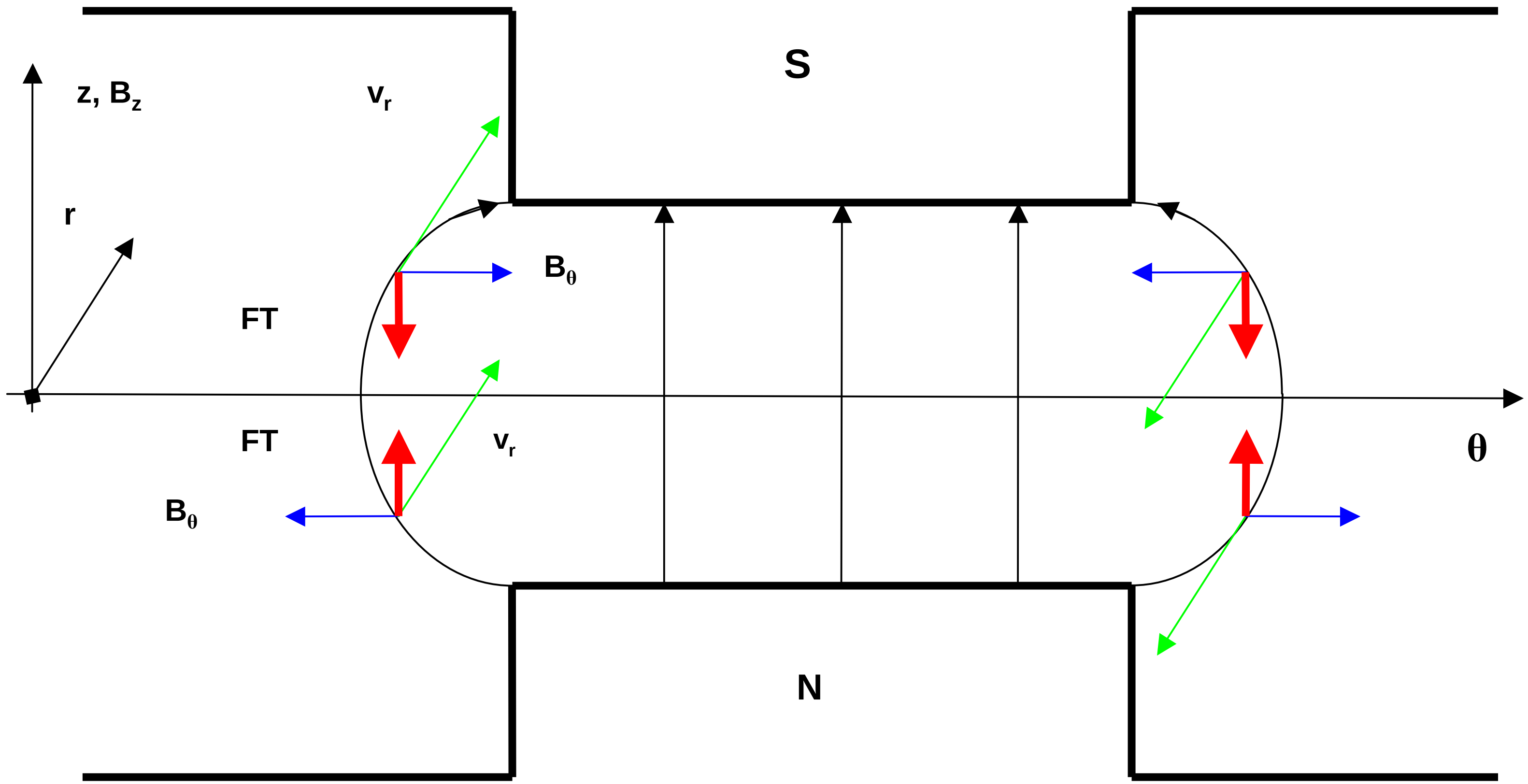
$$B(r) = \frac{B_0}{\sqrt{1 - \left(\frac{v(r)}{c}\right)^2}} = \frac{B_0}{\sqrt{1 - \left(\frac{r \cdot \omega_c}{c}\right)^2}}$$

Isochronous cyclotron

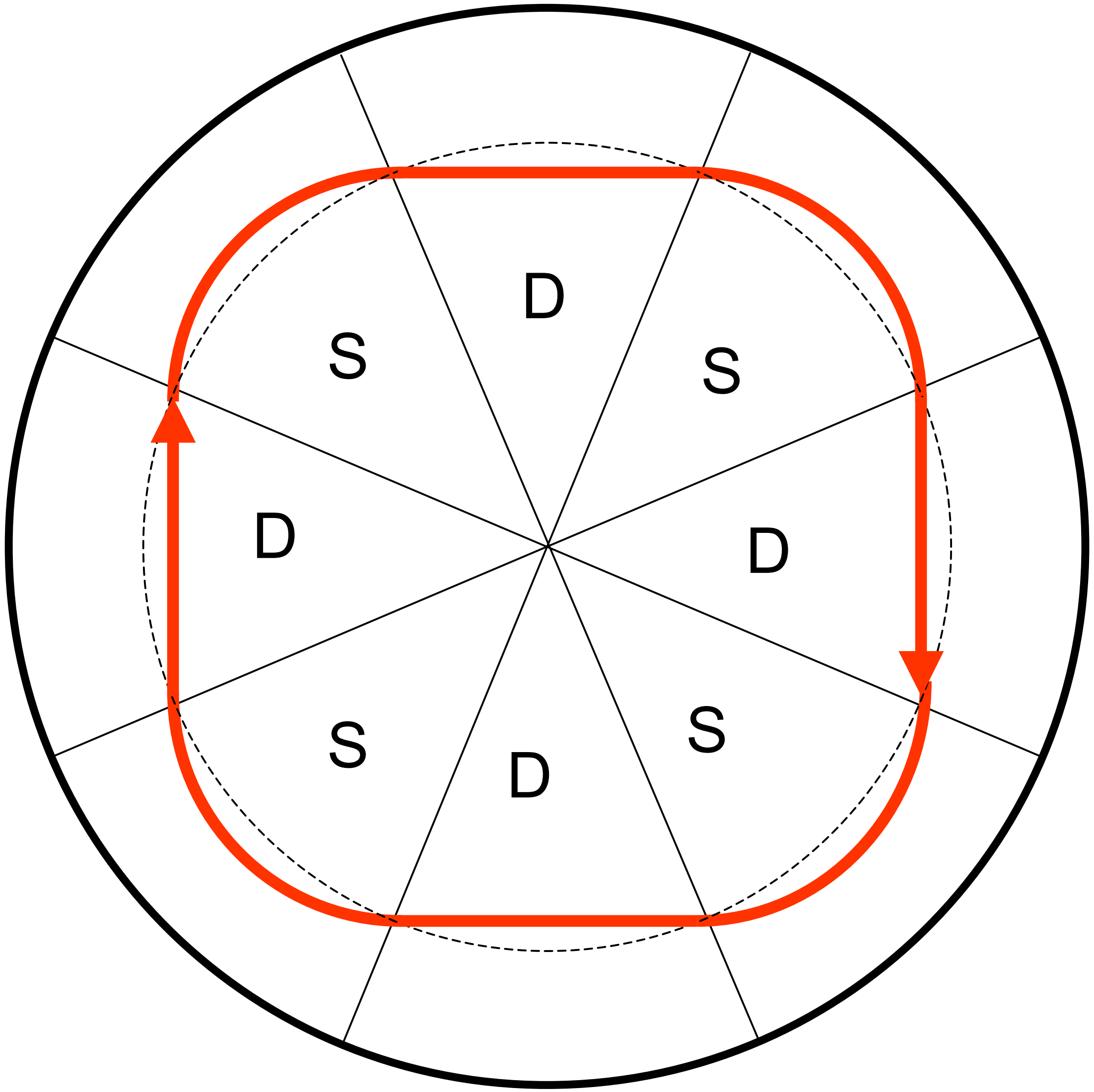


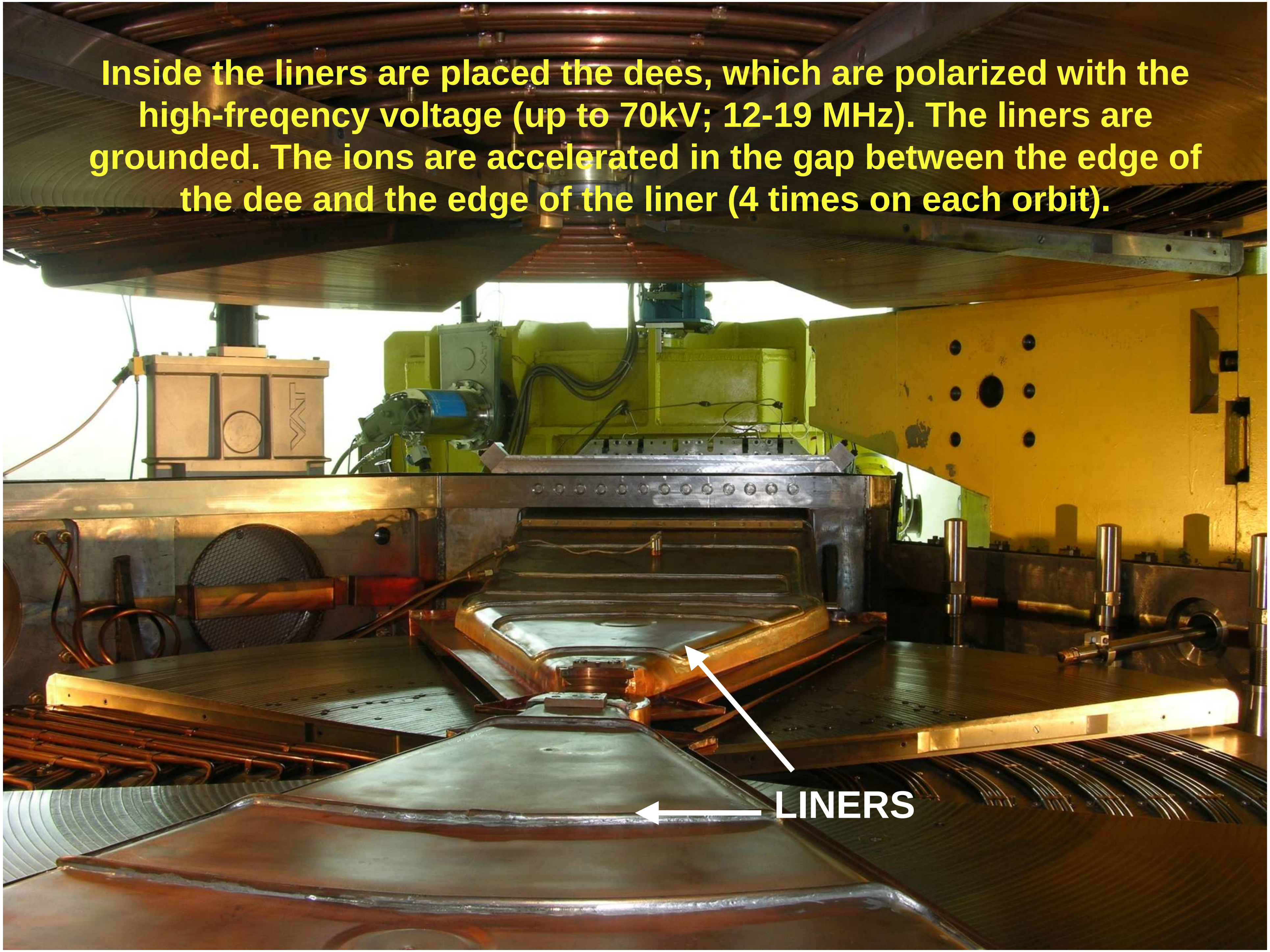


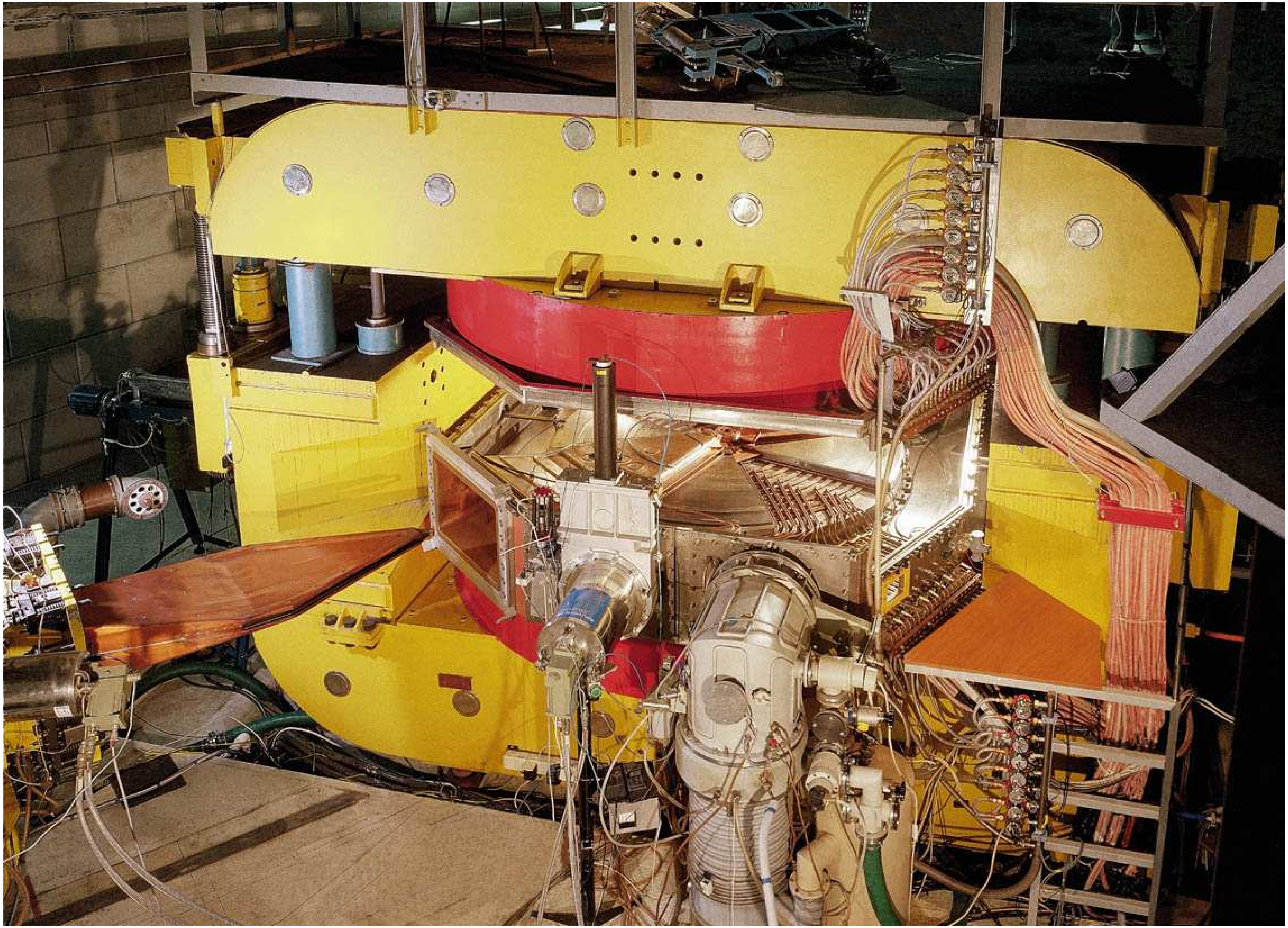
Thomas force



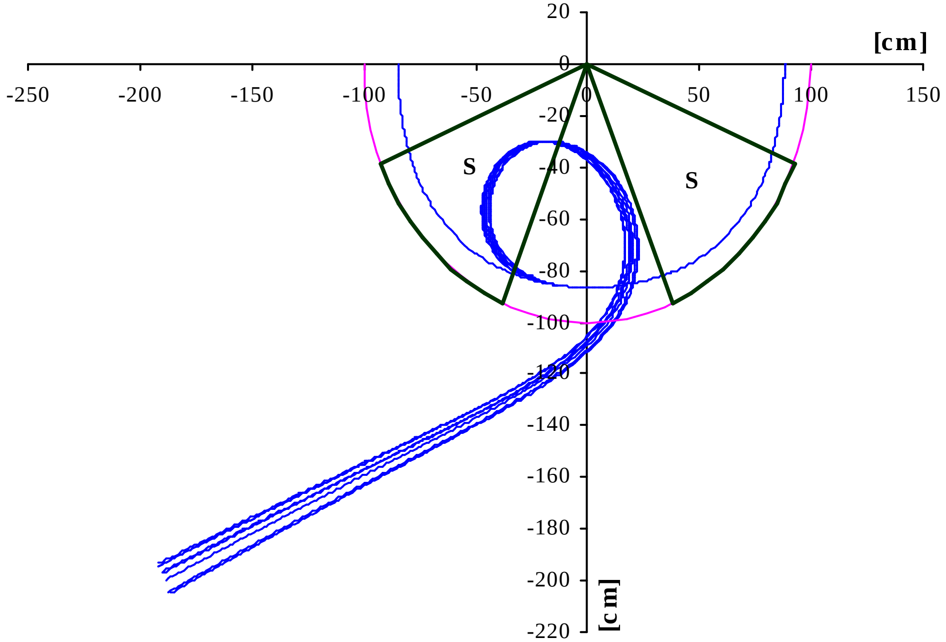
Thomas force

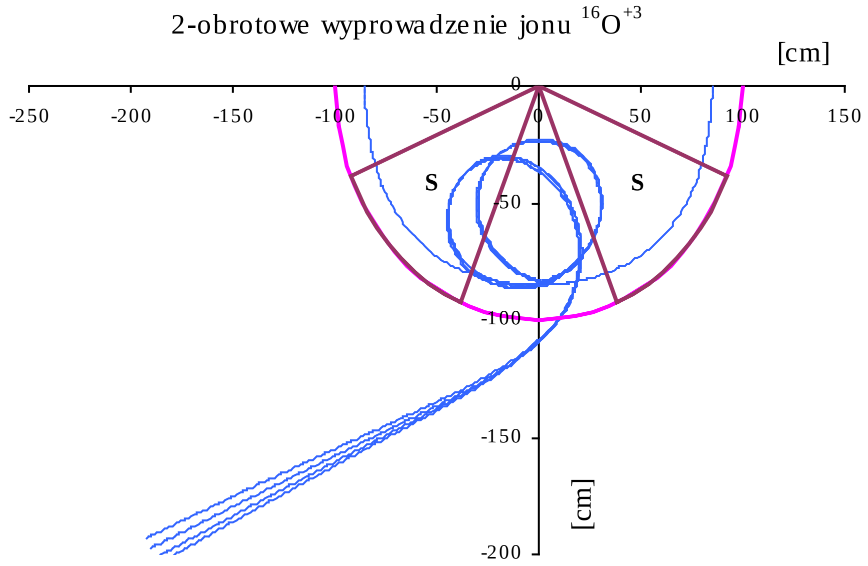



Inside the liners are placed the dees, which are polarized with the high-freqency voltage (up to 70kV; 12-19 MHz). The liners are grounded. The ions are accelerated in the gap between the edge of the dee and the edge of the liner (4 times on each orbit).
LINERS

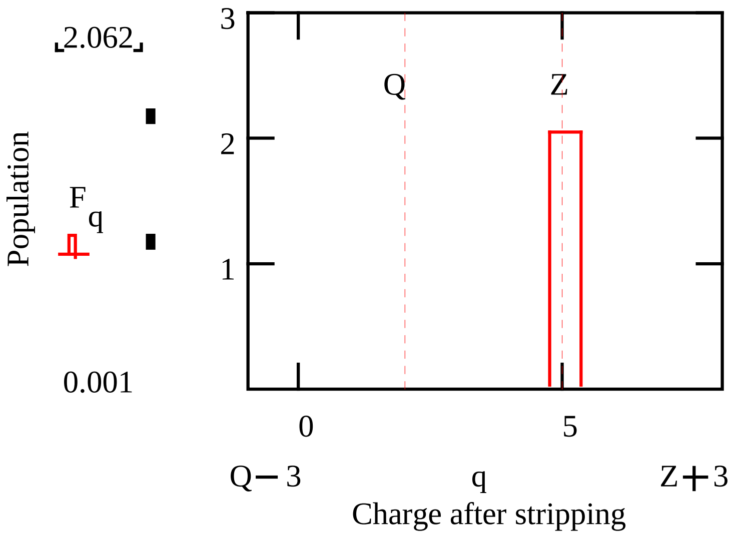


Extraction – stripper

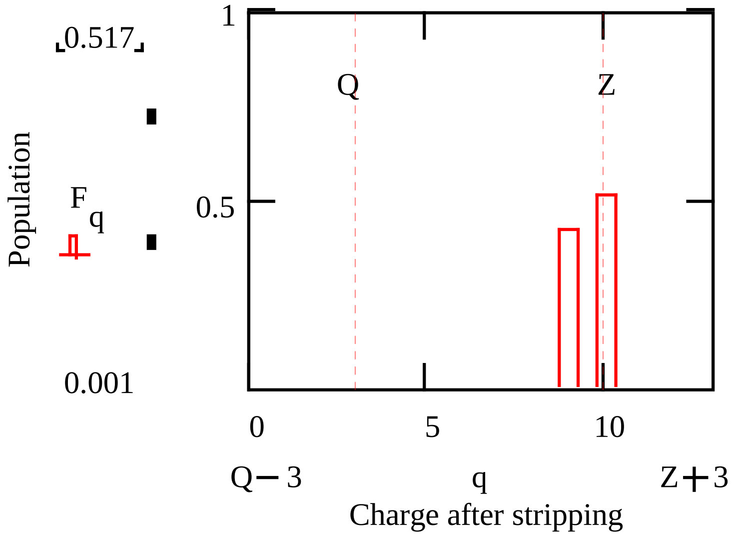




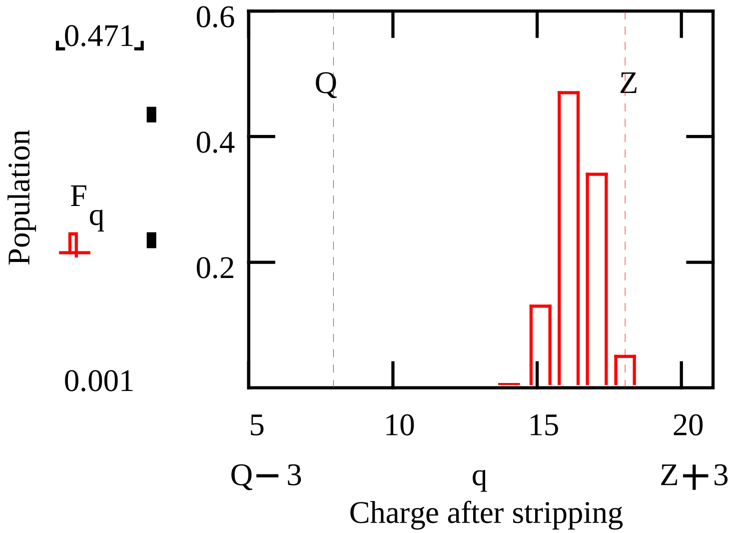
Dependence of the charge state population after stripping on the ion mass number A



A=10, Z=5, Q=2,
E=5 MeV/A

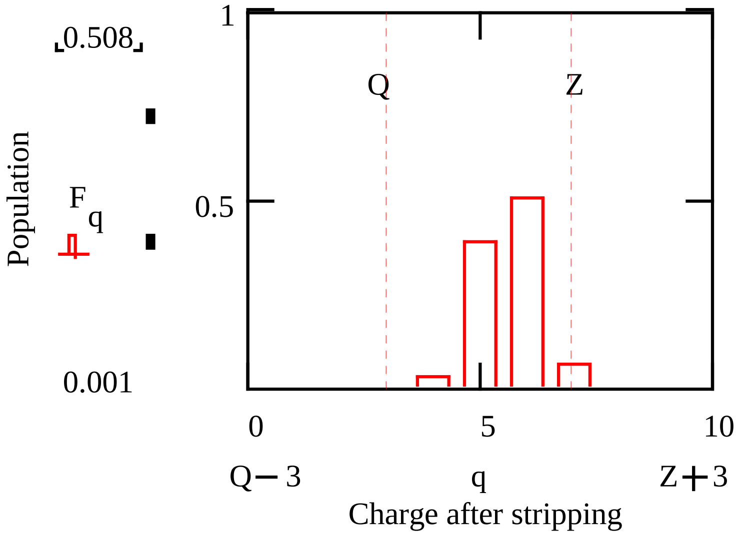


A=20, Z=10, Q=3,
E=5 MeV/A

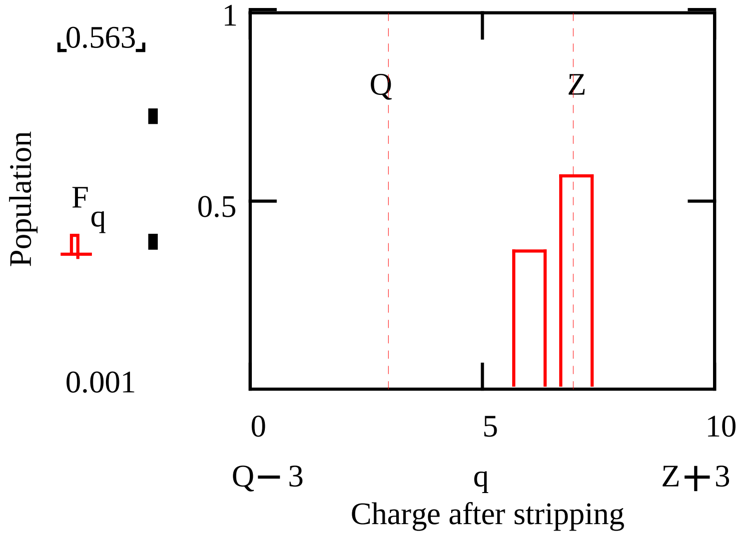


A=40, Z=18, Q=8,
E=5 MeV/A

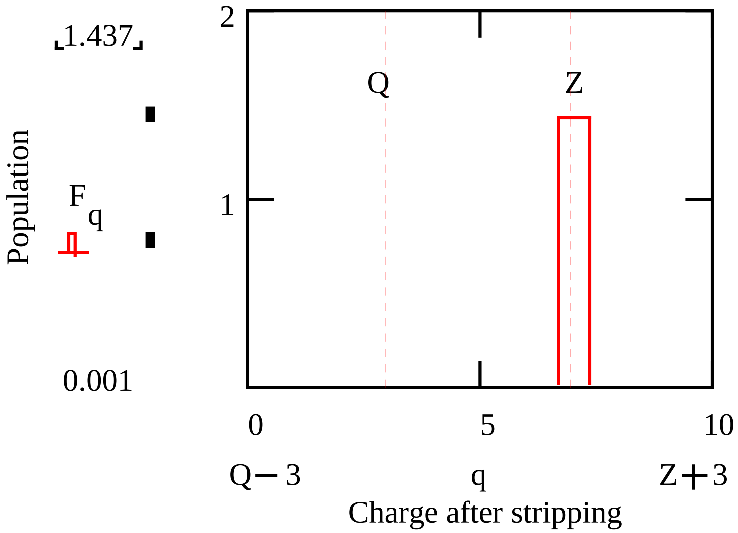
Dependence of the charge state population after stripping on the ion energy



A=14, Z=7, Q=3,
E=1 MeV/A

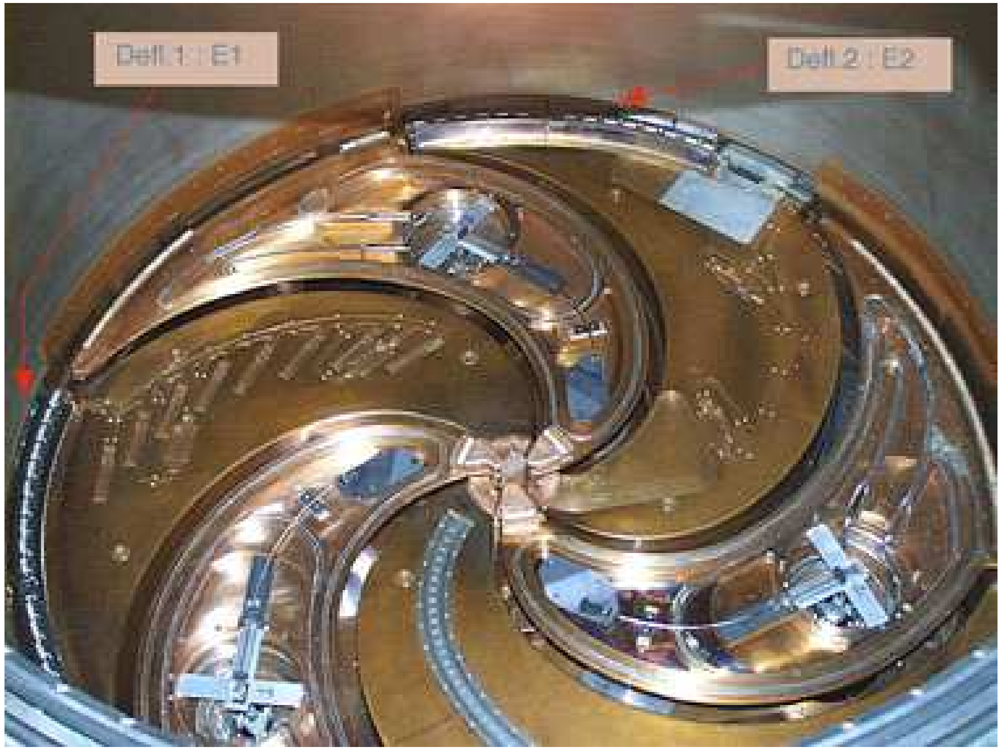


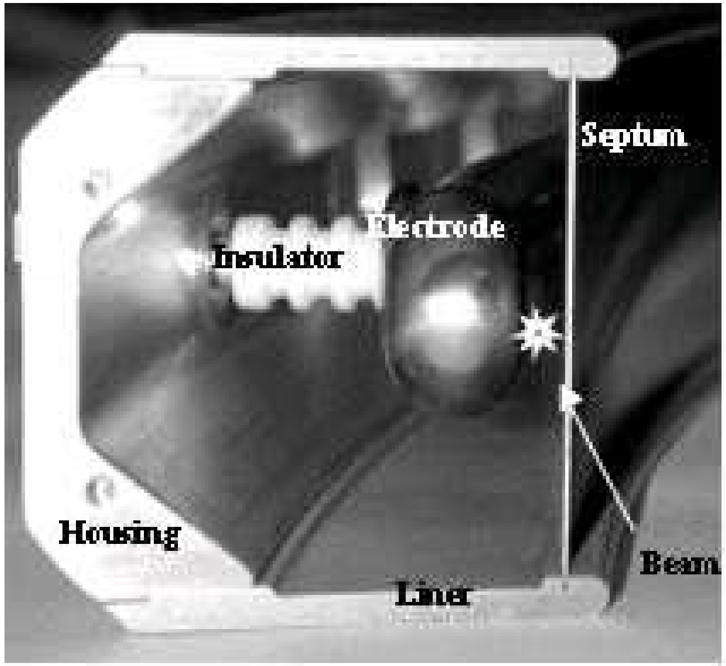
A=14, Z=7, Q=3,
E=3 MeV/A



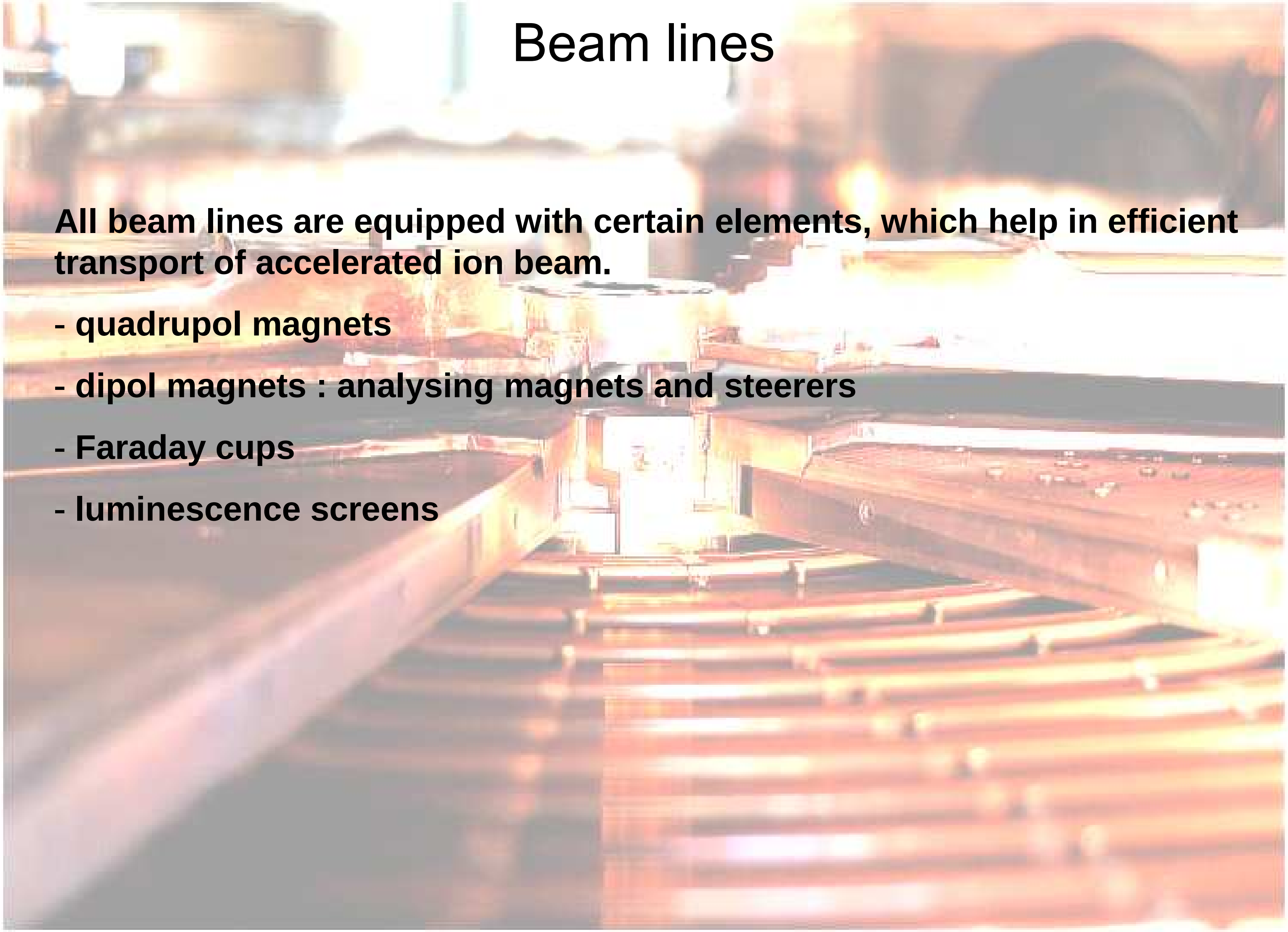
A=14, Z=7, Q=3,
E=6 MeV/A

Extraction – electrostatic deflector





Beam lines



All beam lines are equipped with certain elements, which help in efficient transport of accelerated ion beam.

- quadrupol magnets

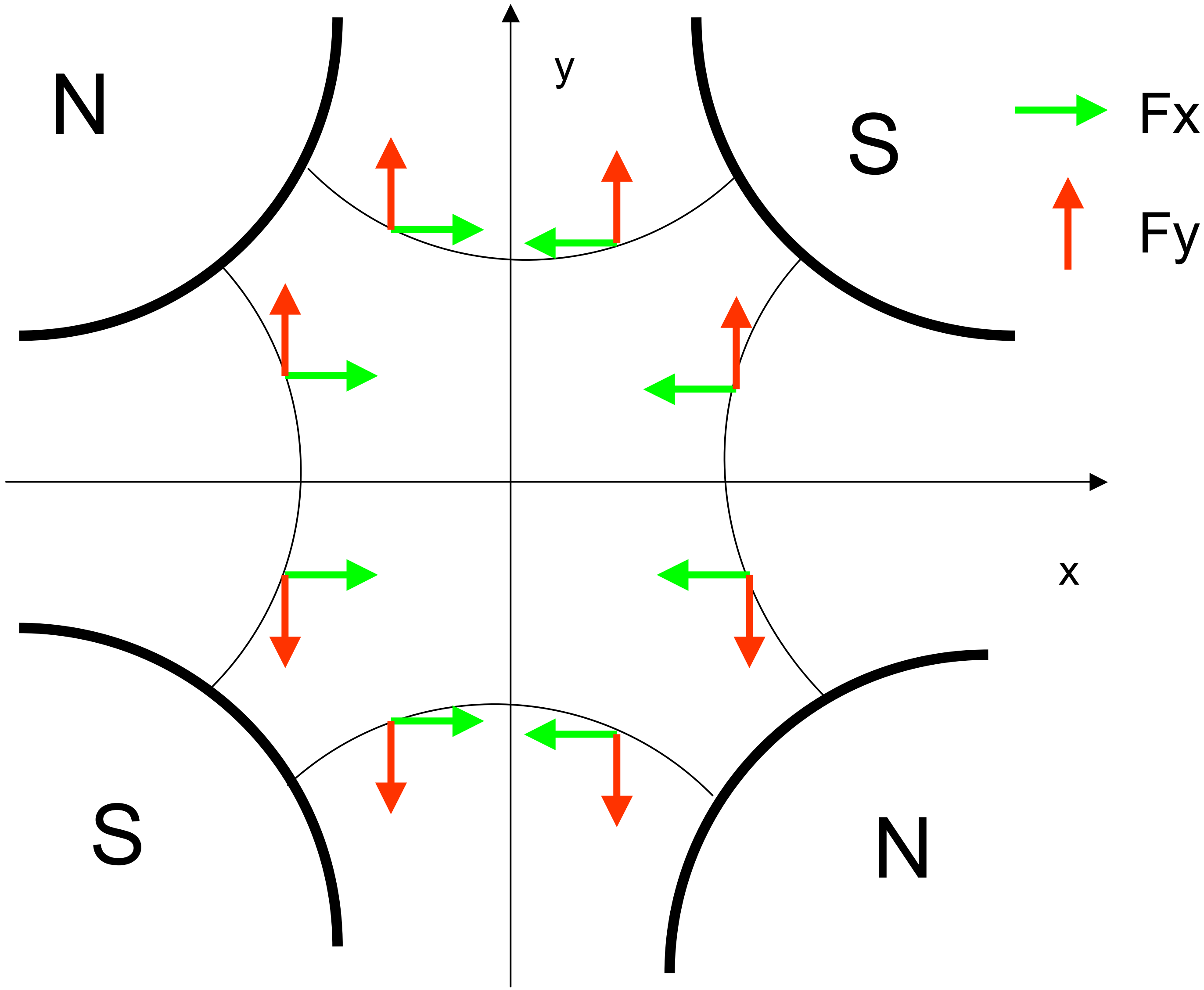
- dipol magnets : analysing magnets and steerers

- Faraday cups

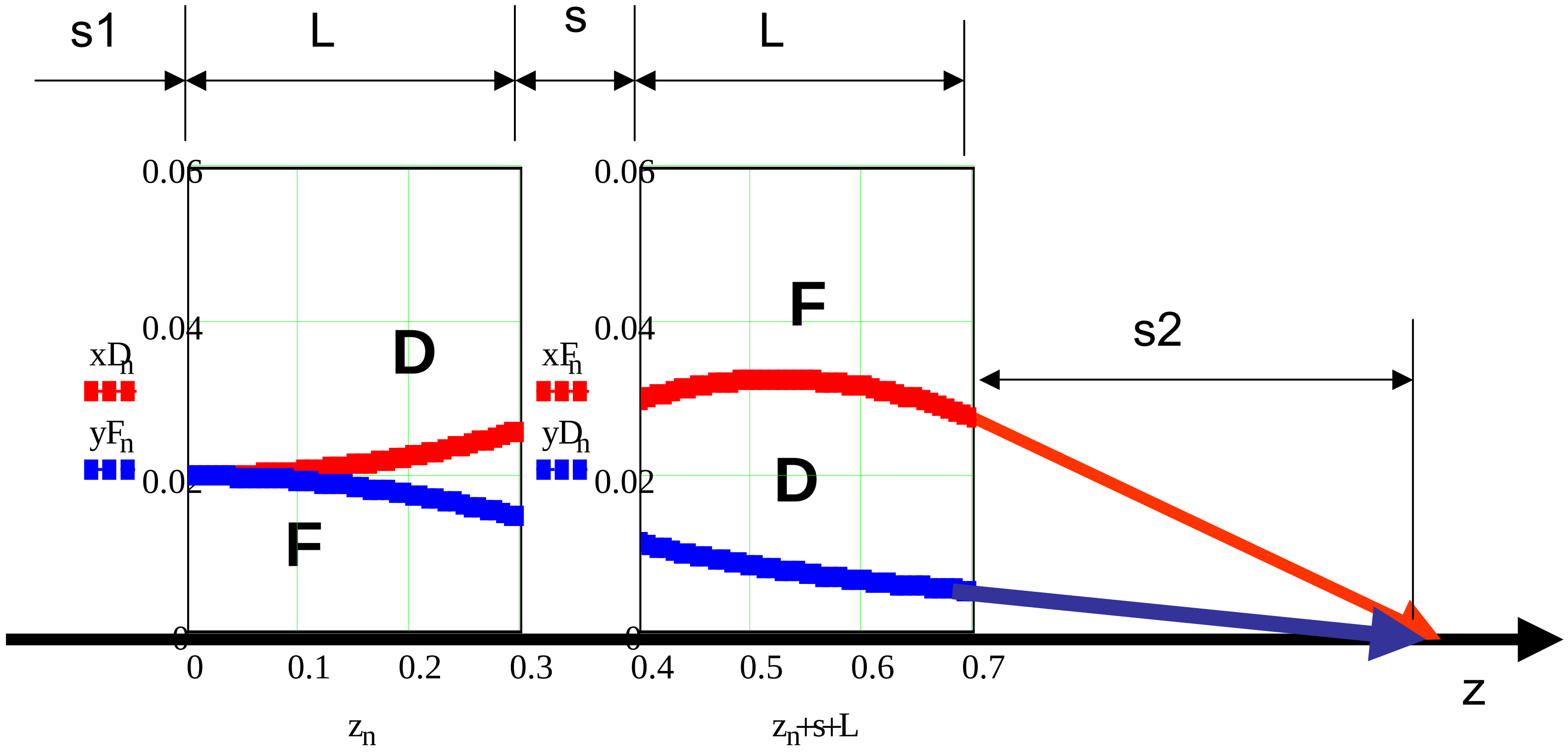
- luminescence screens

Quadrupol magnet

Quadrupol magnet



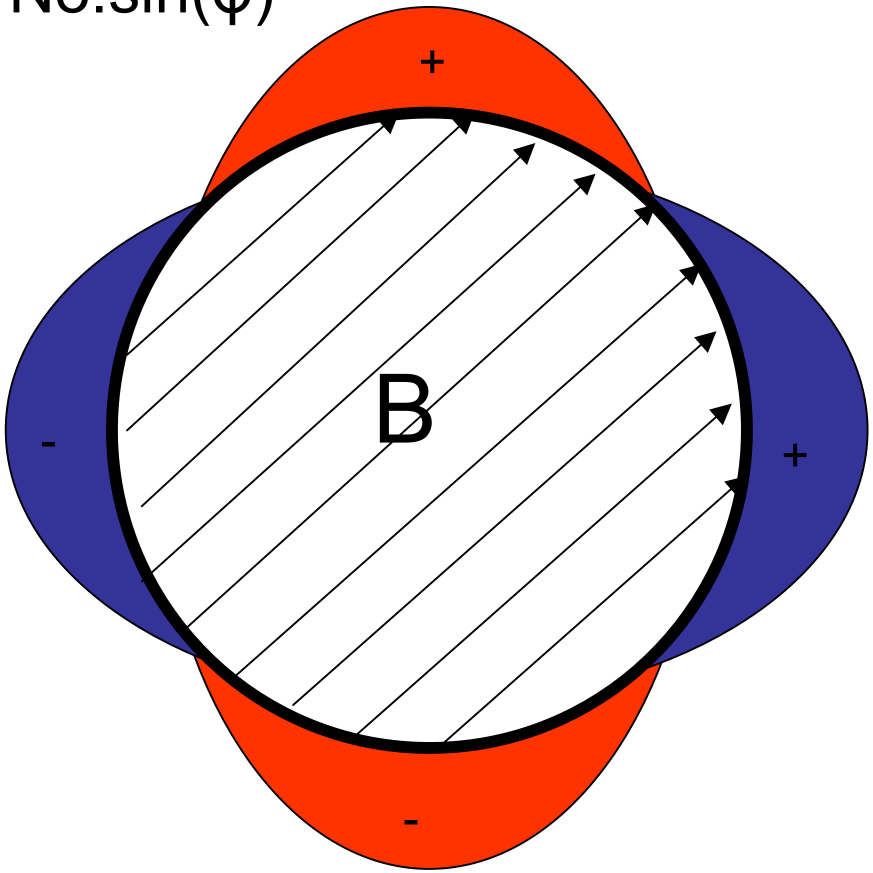
Quadrupol magnet



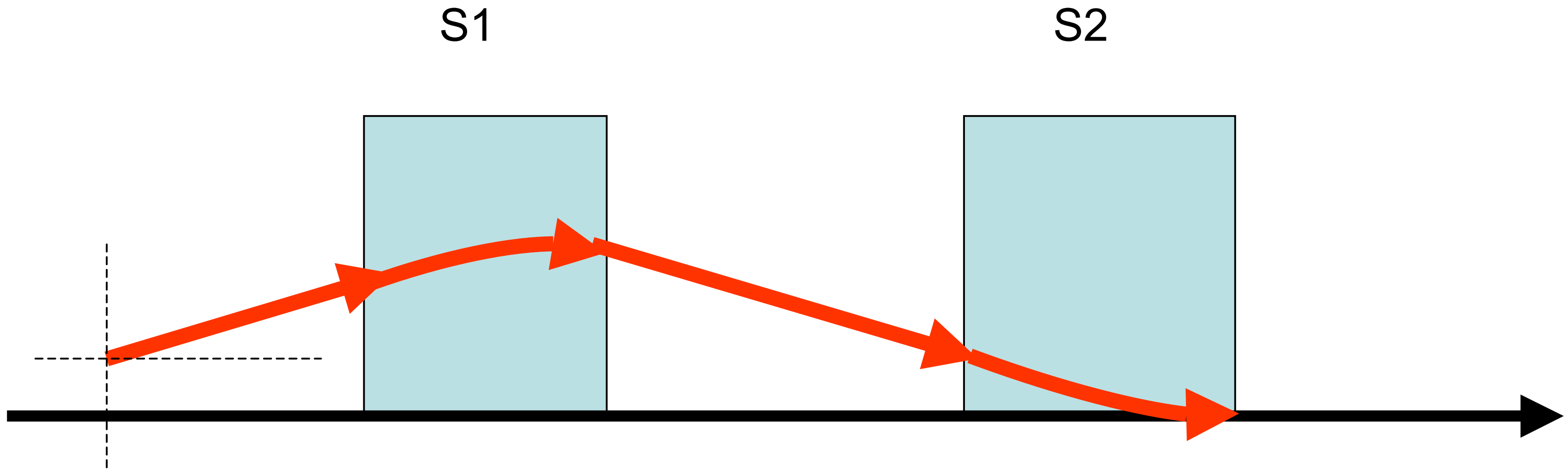
Dipol magnet - steerer

N1=No.COS(φ)

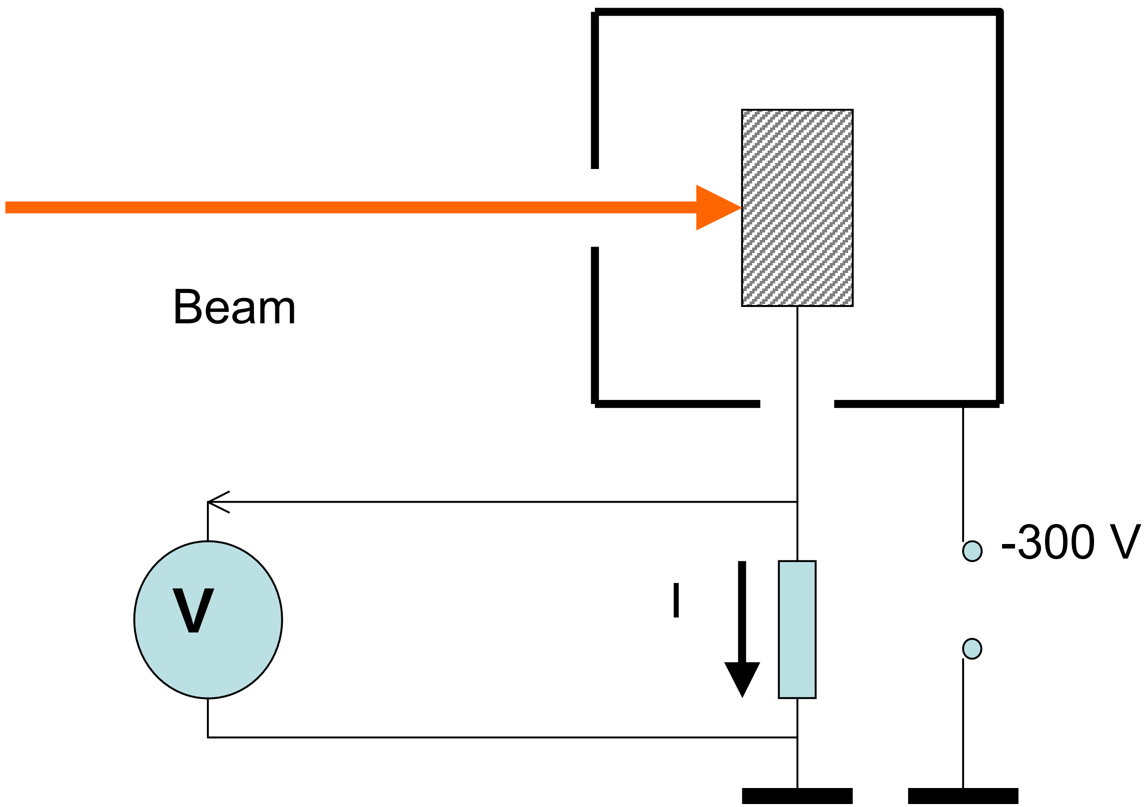
N2=No.sin(φ)



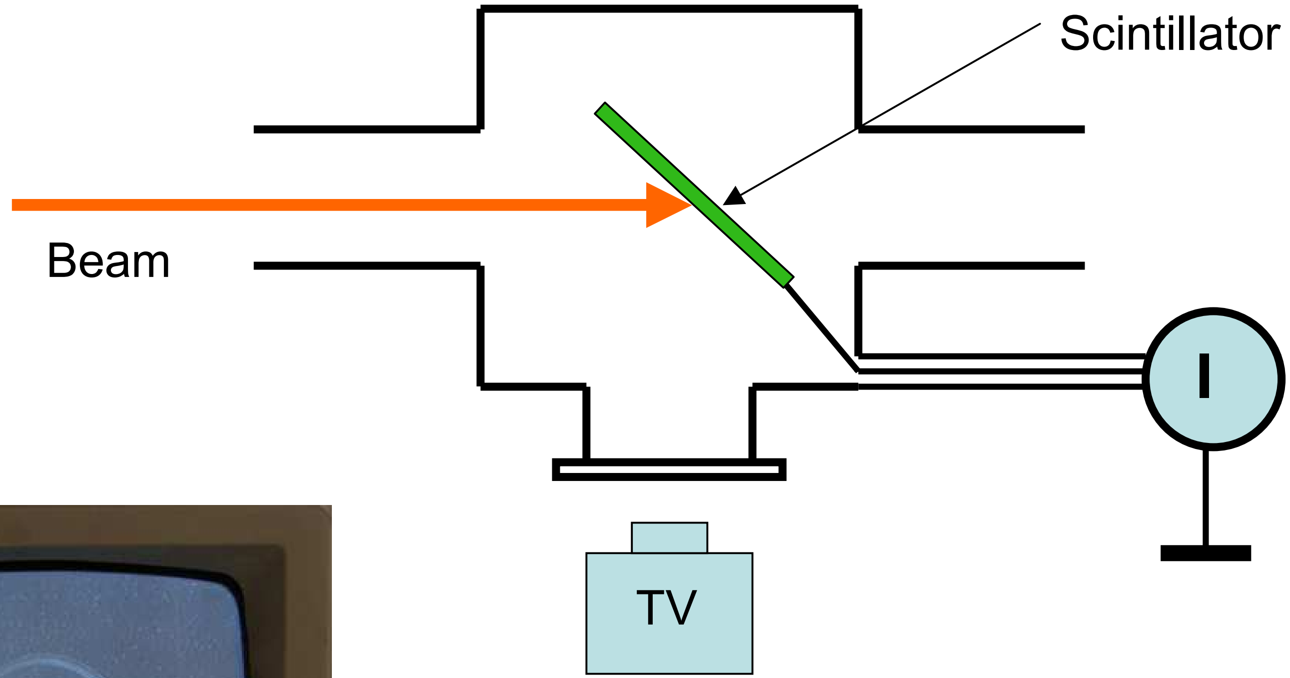
Dipol magnet - steerer

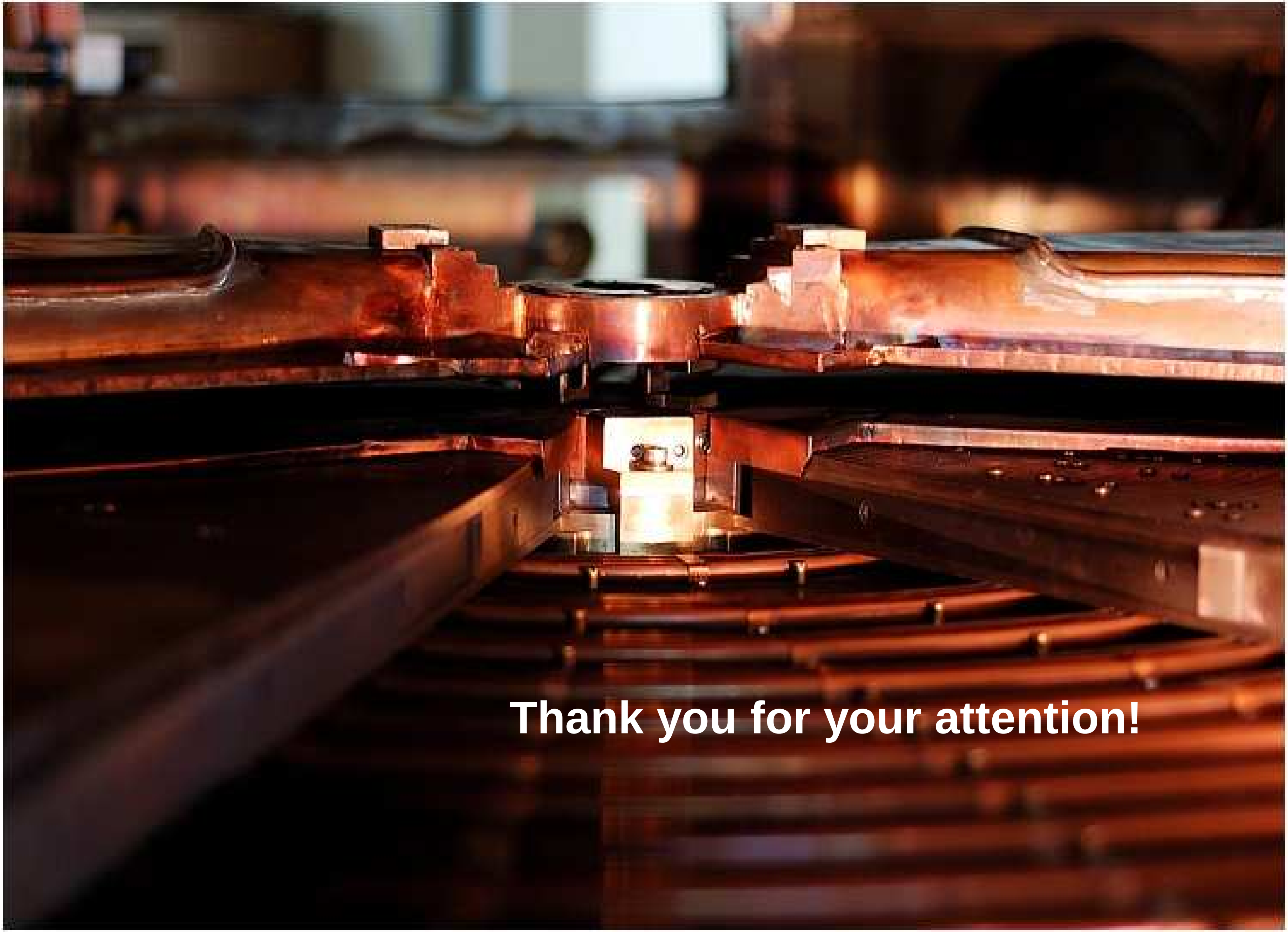


Beam diagnostic – Faraday cup



Beam diagnostic - „luminescence”




Thank you for your attention!