

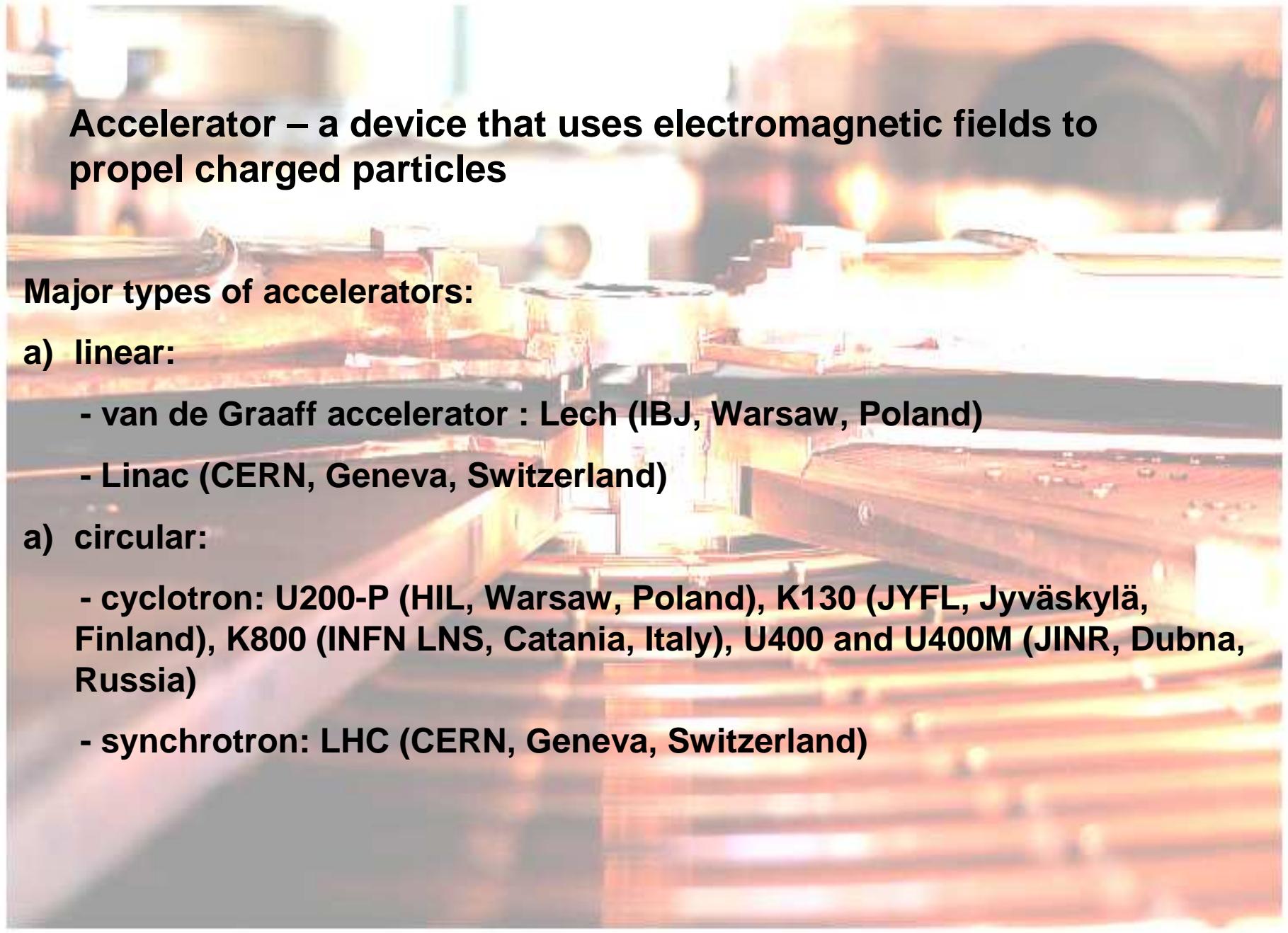


International Workshop on Acceleration and Applications of Heavy Ions

Acceleration of heavy ions and beam transport

Olga Steczkiewicz

Warsaw, 25.02.2013



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

Major types of accelerators:

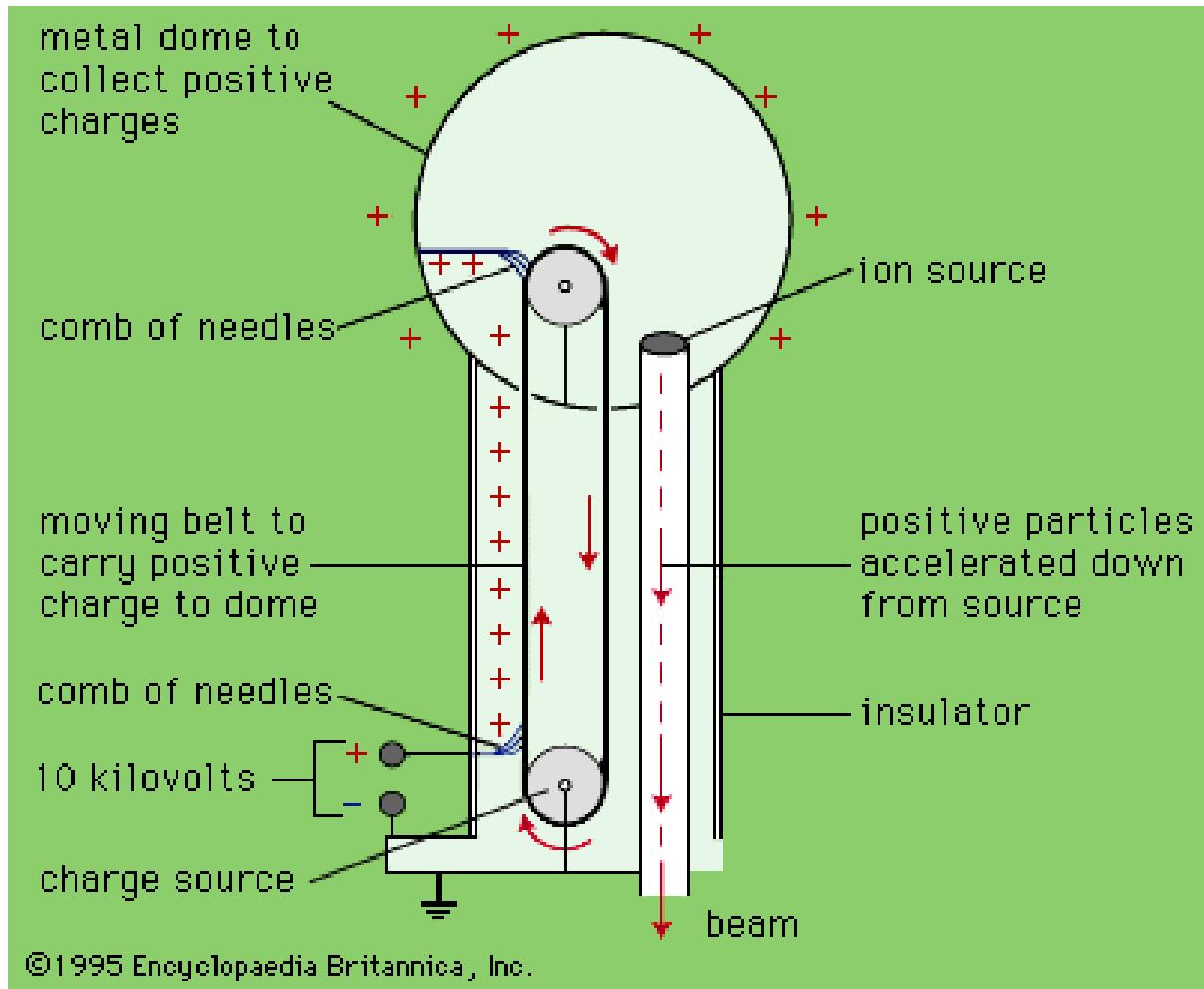
a) linear:

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

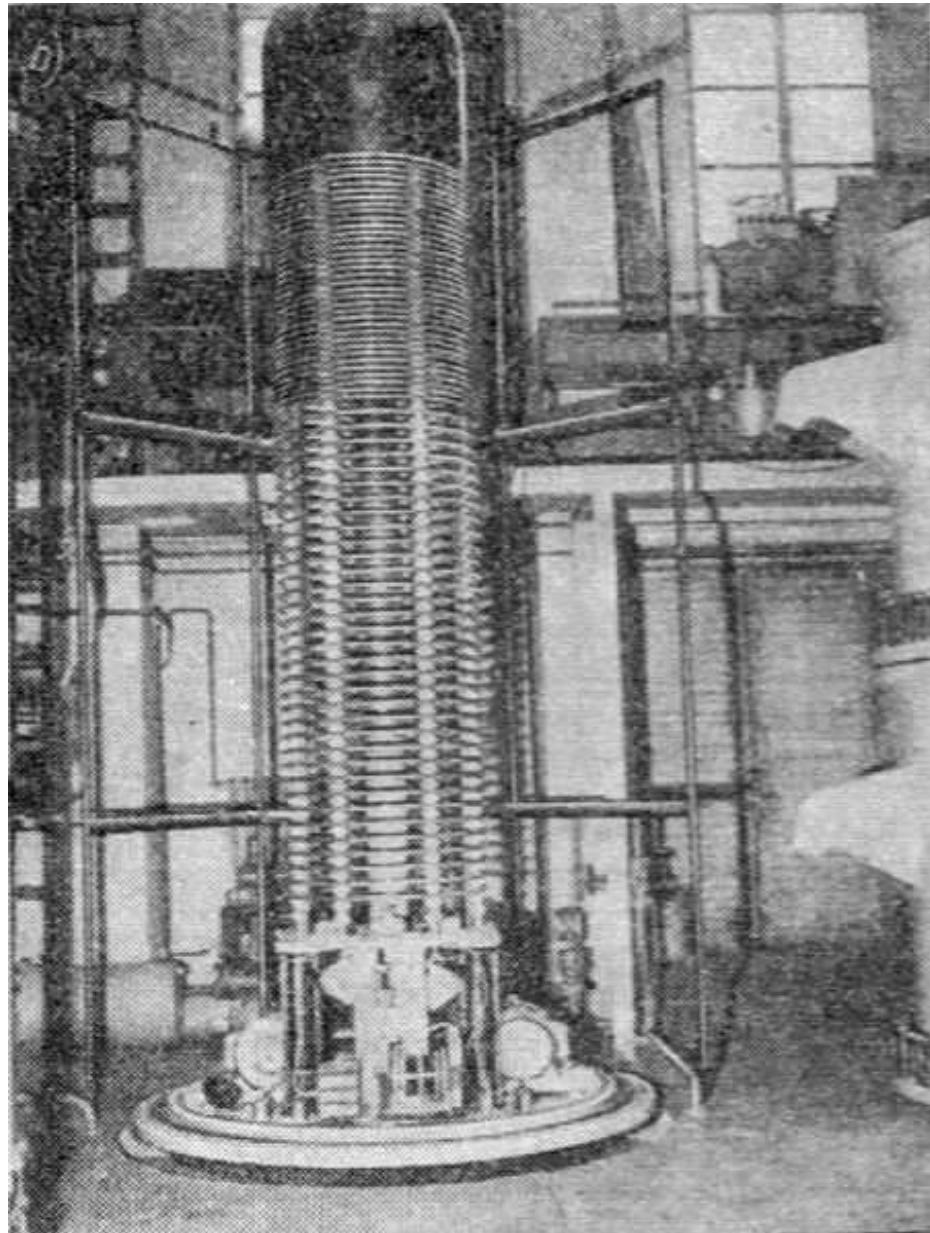
a) circular:

- 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)

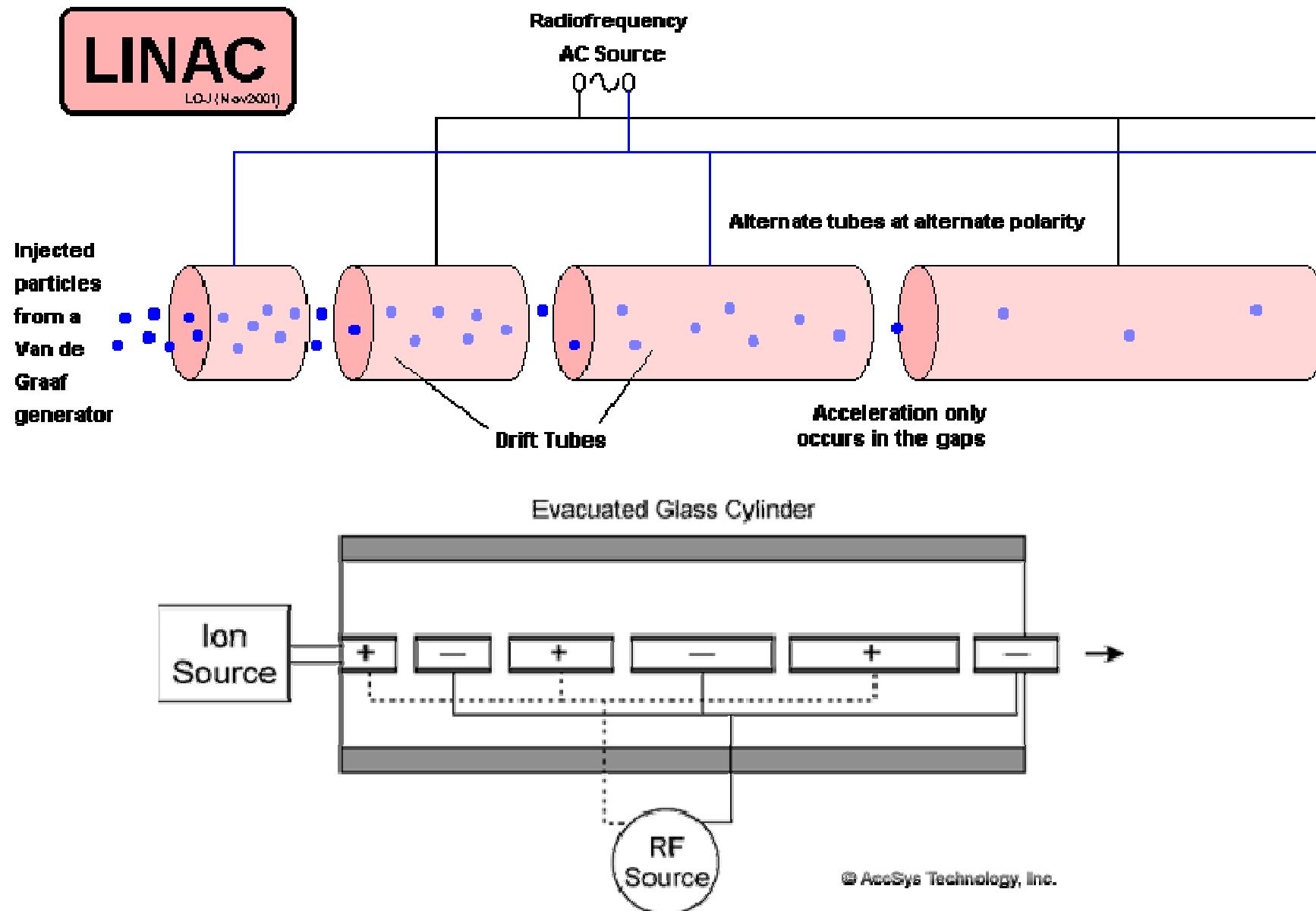
Electrostatic accelerator (van de Graaff)



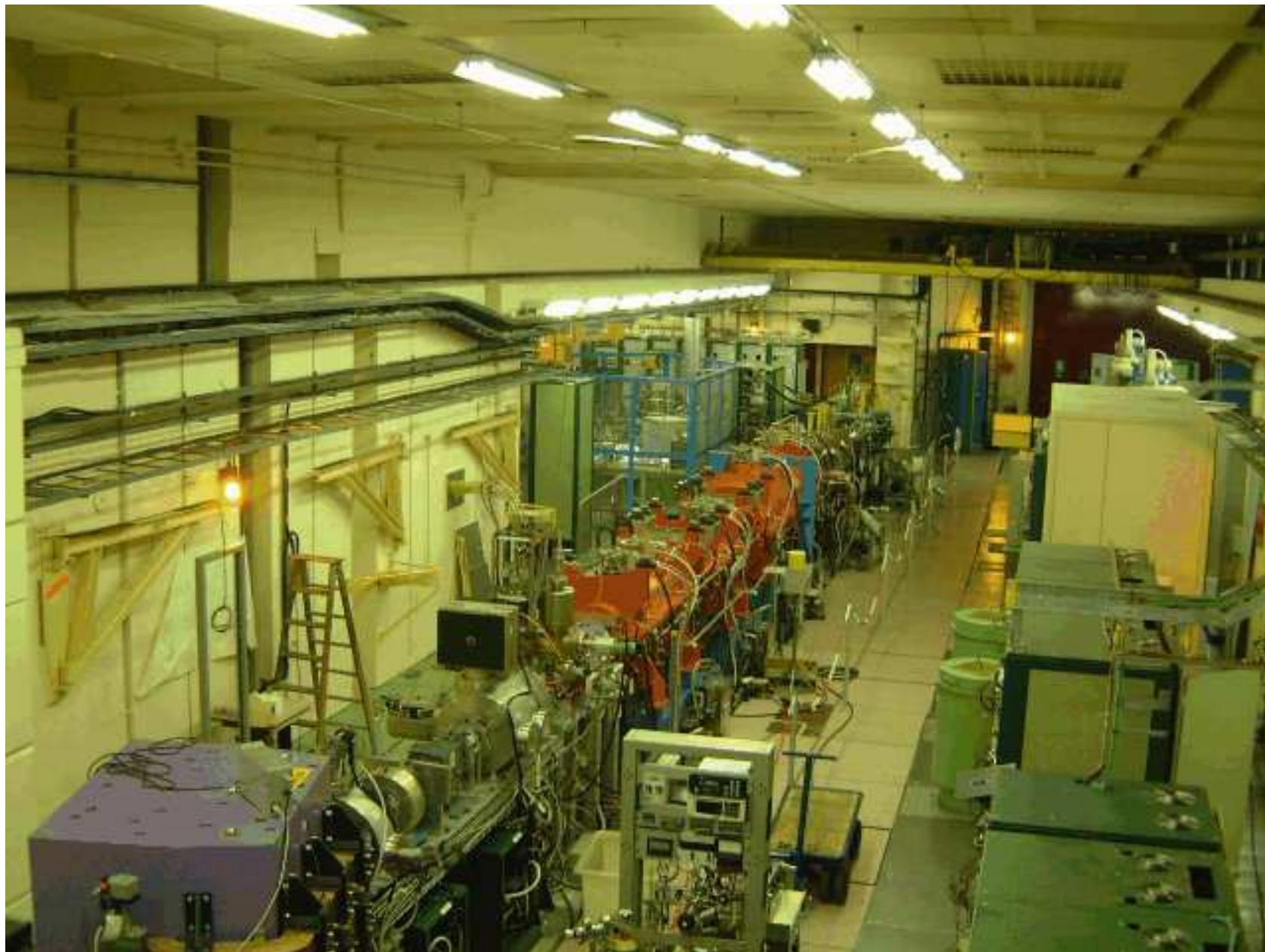
Electrostatic accelerator (van de Graaff)



LINAC



LINAC



CYCLOTRON

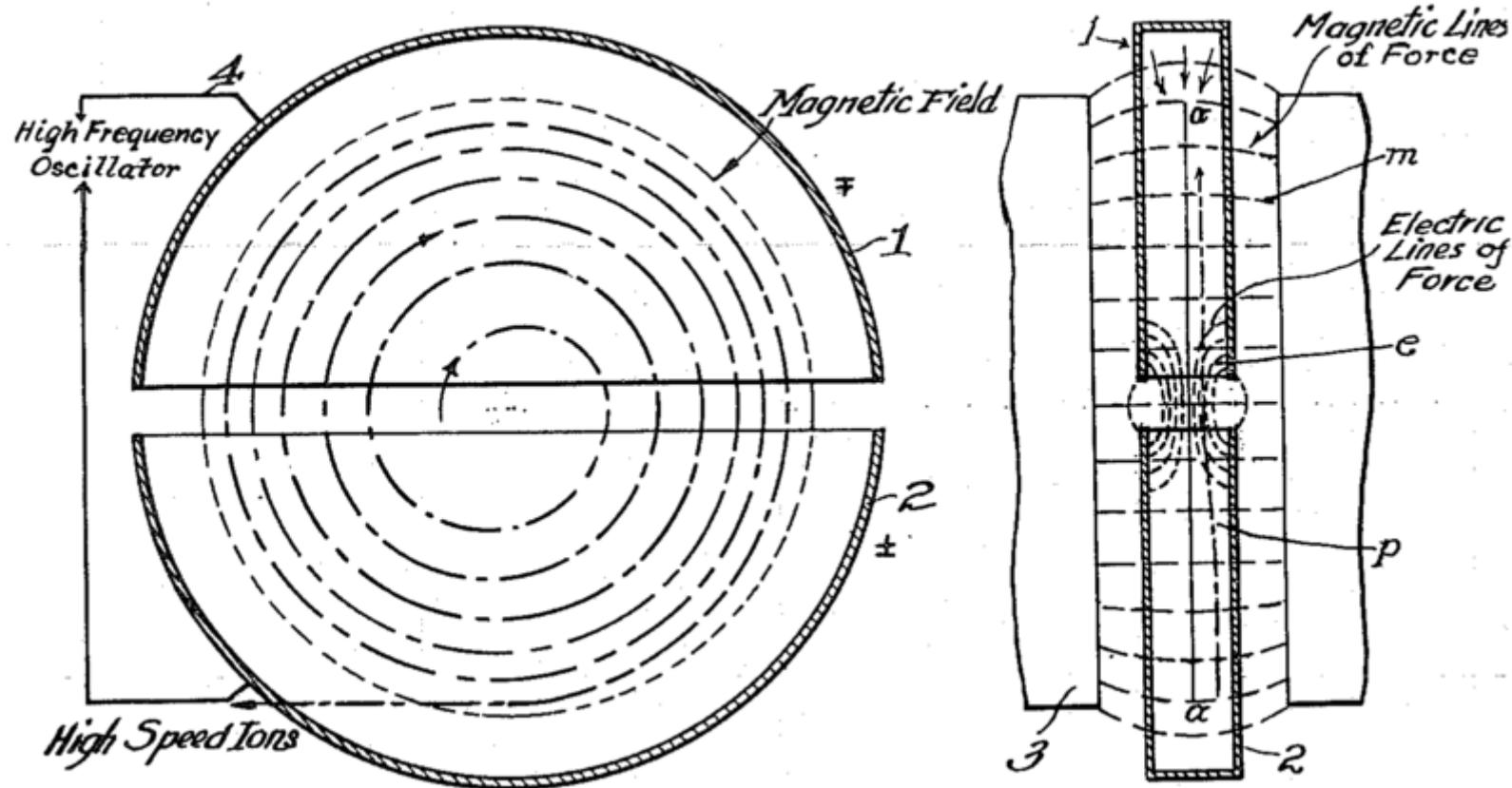
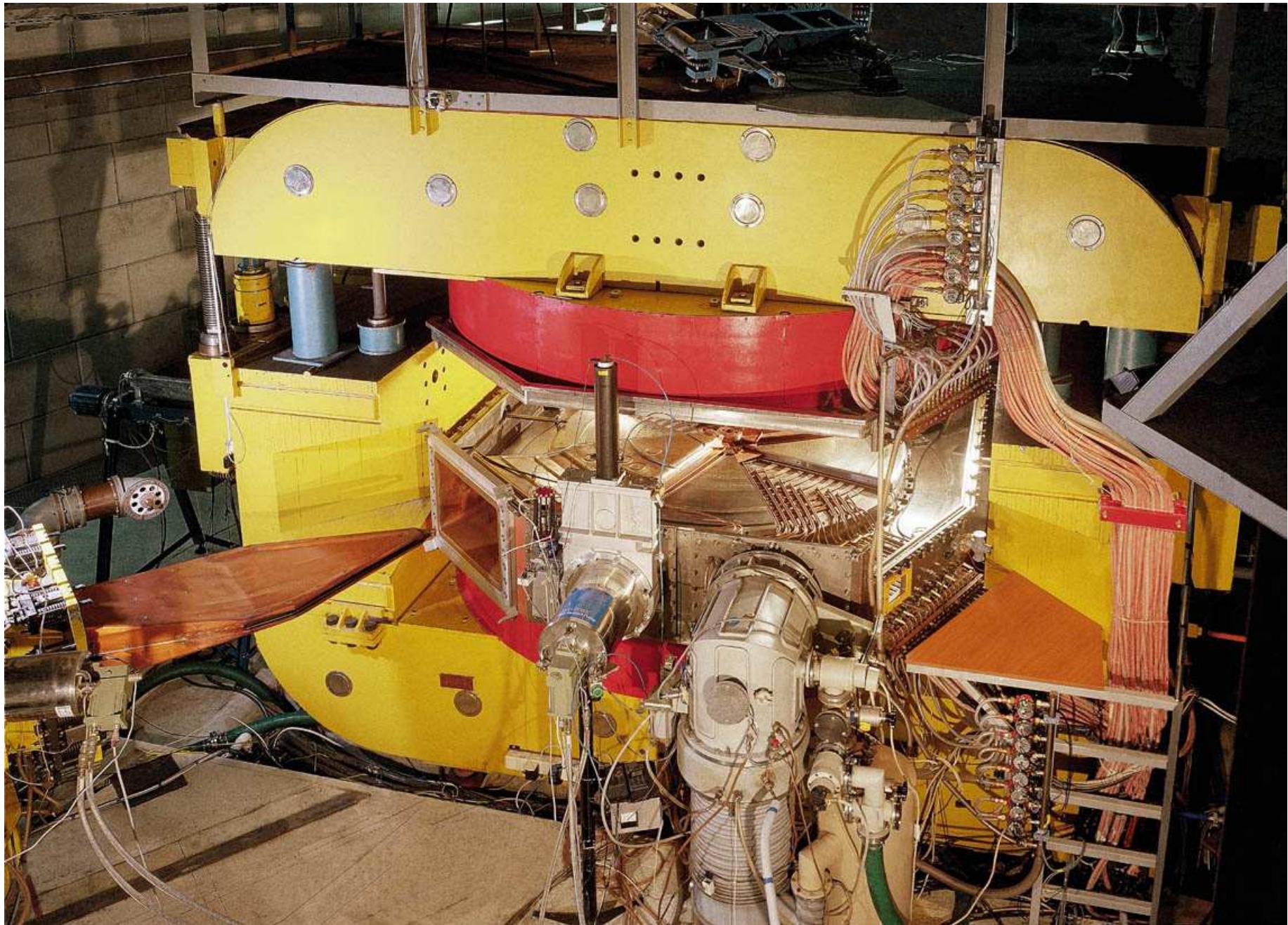


Diagram of cyclotron operation from Lawrence's 1934 patent
(Ernest Lawrence, 1931)

CYCLOTRON



SYNCHROTRON

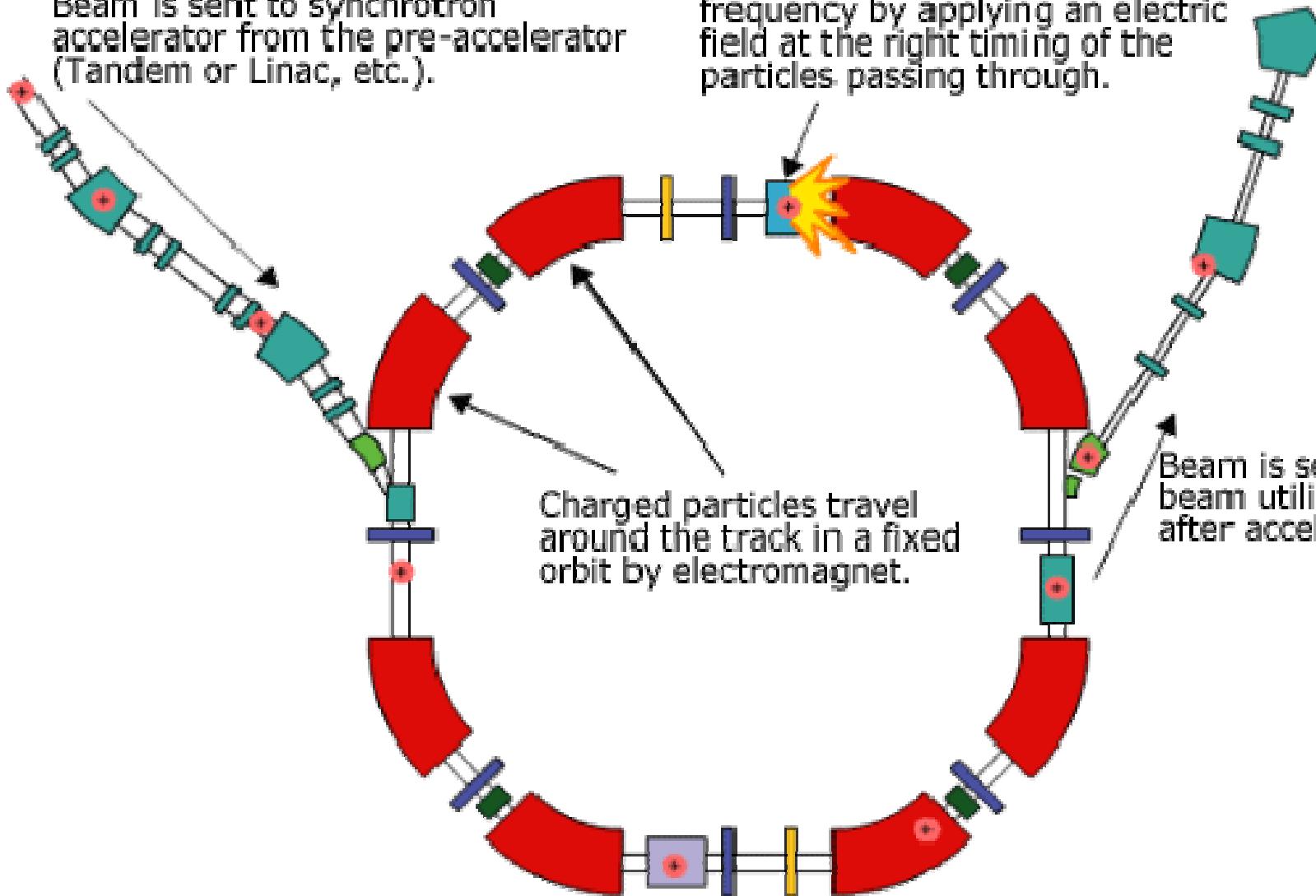
Beam is sent to synchrotron accelerator from the pre-accelerator (Tandem or Linac, etc.).

Accelerating cavity

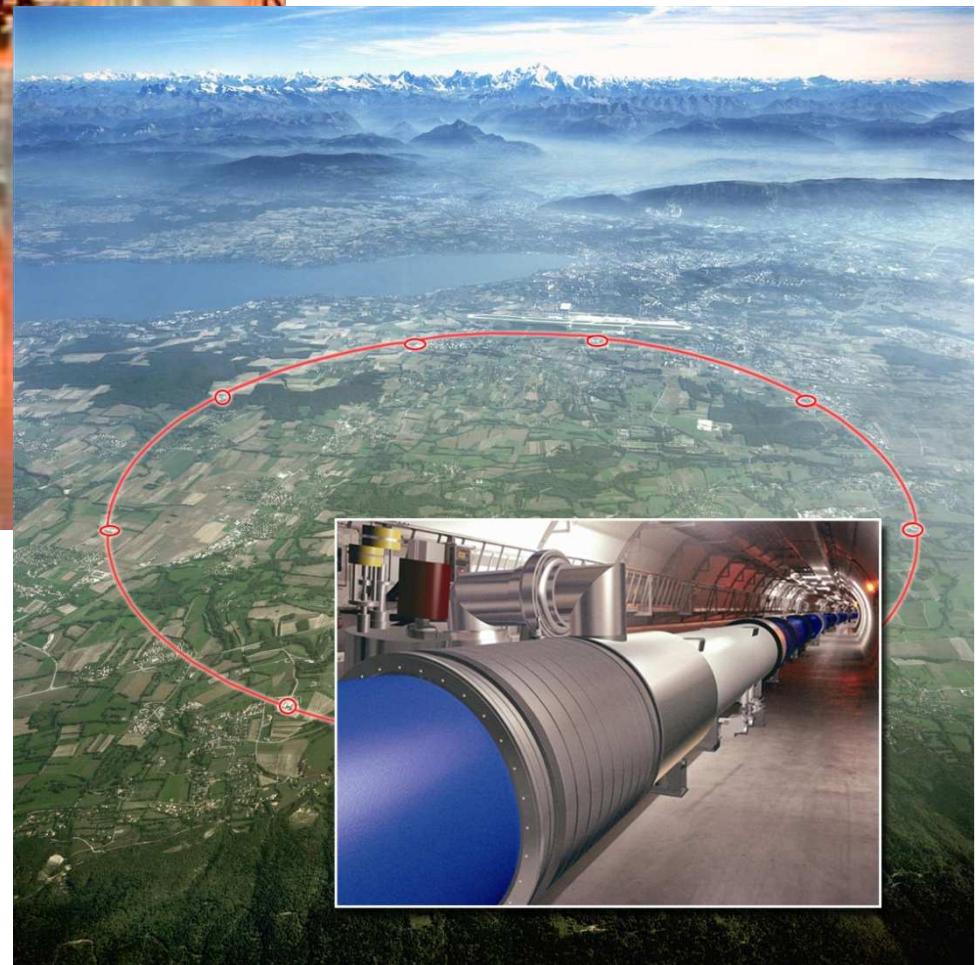
It accelerates particles with high frequency by applying an electric field at the right timing of the particles passing through.

Charged particles travel around the track in a fixed orbit by electromagnet.

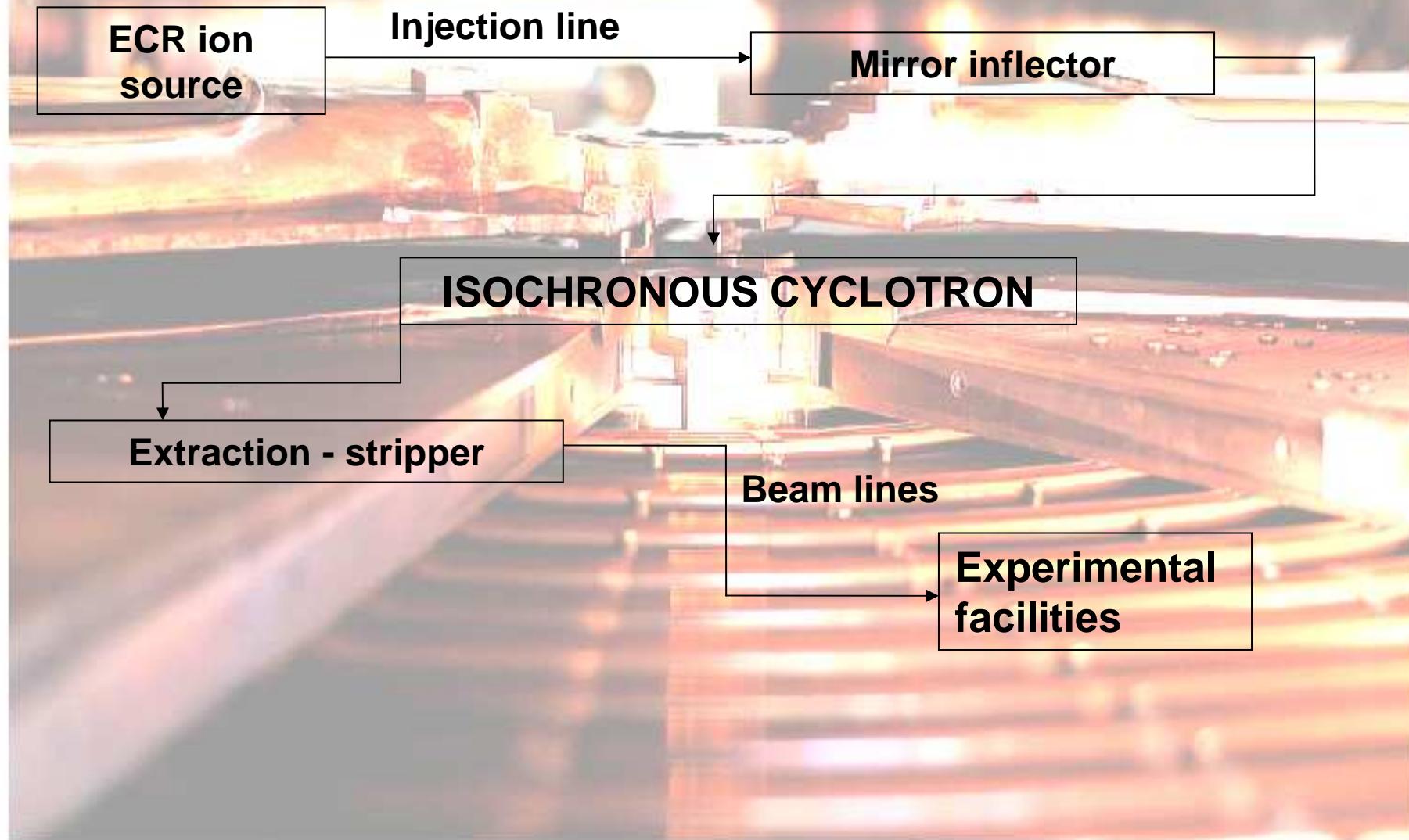
Beam is sent to the beam utilizing course after acceleration.



SYNCHROTRON



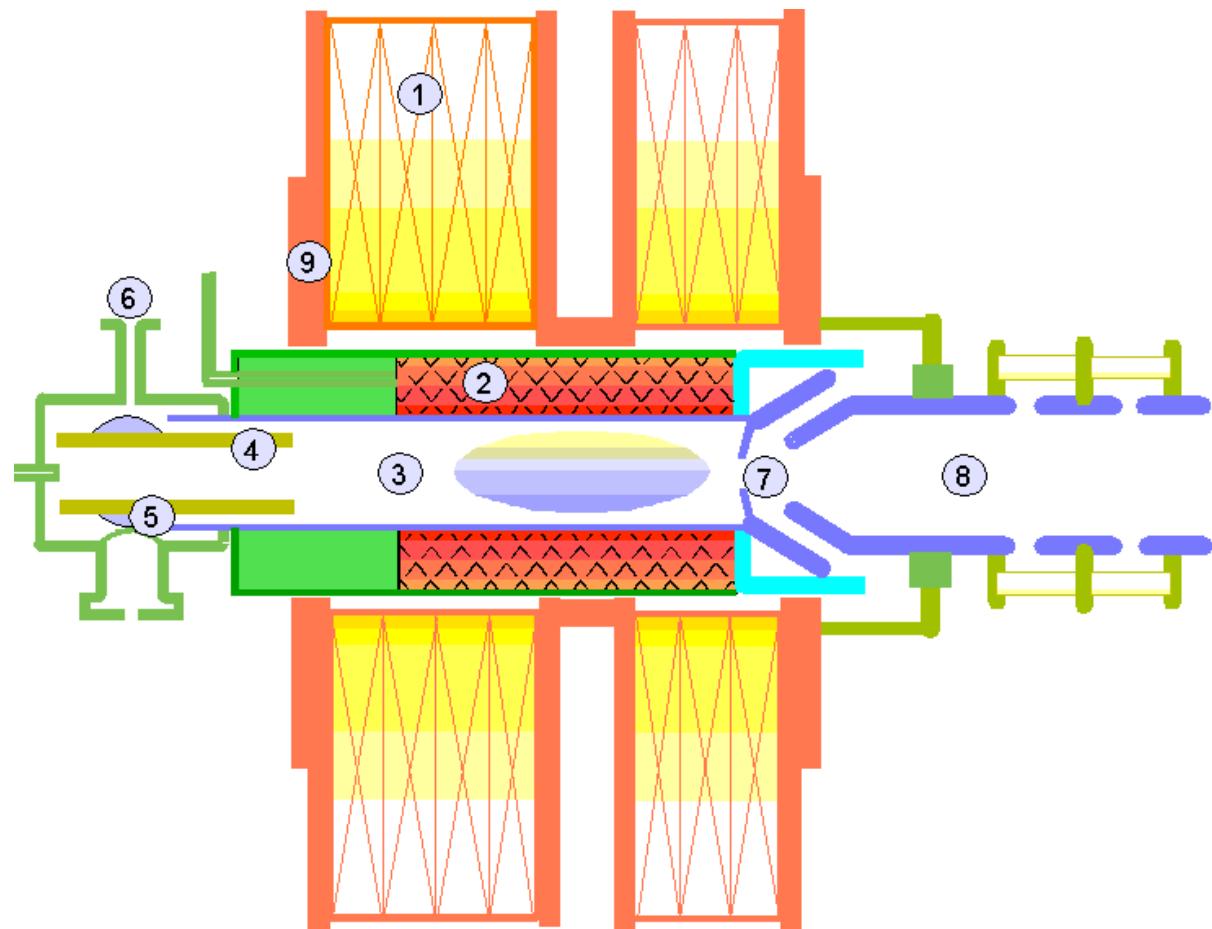
The way of heavy ions in Warsaw Cyclotron



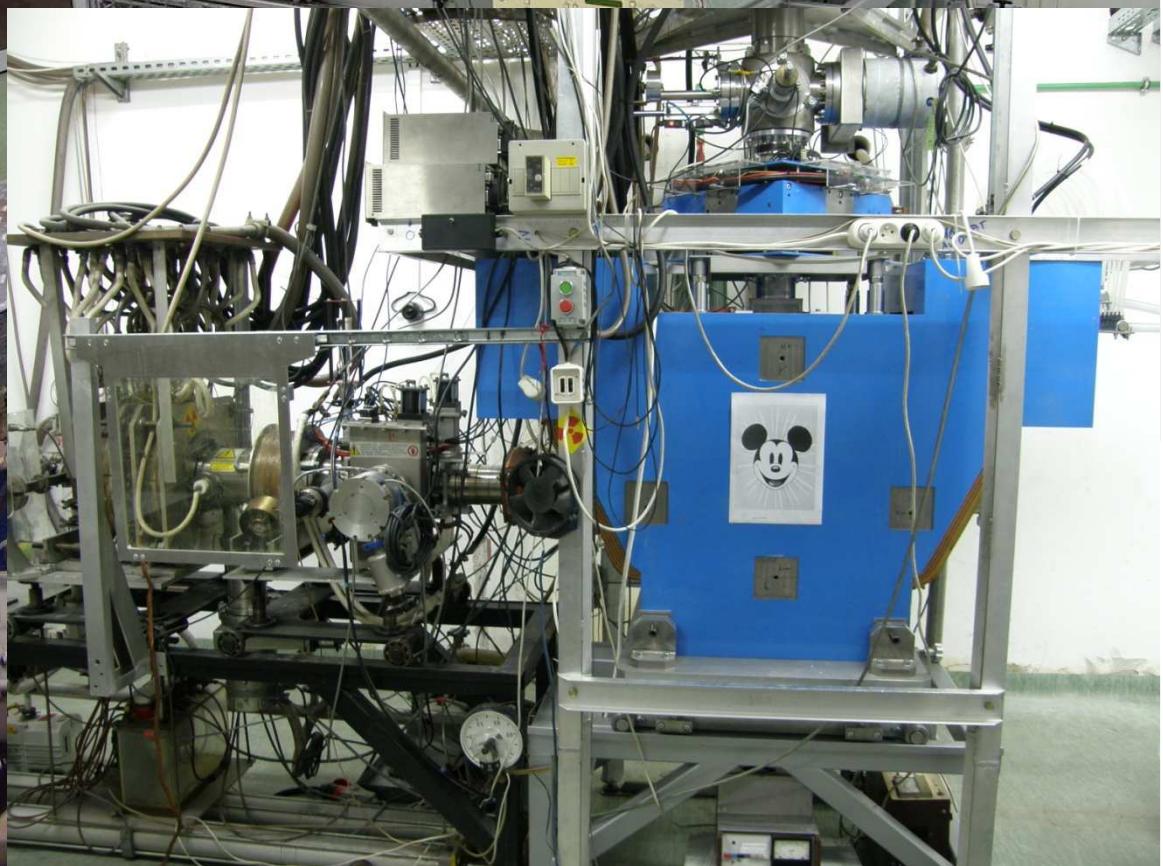
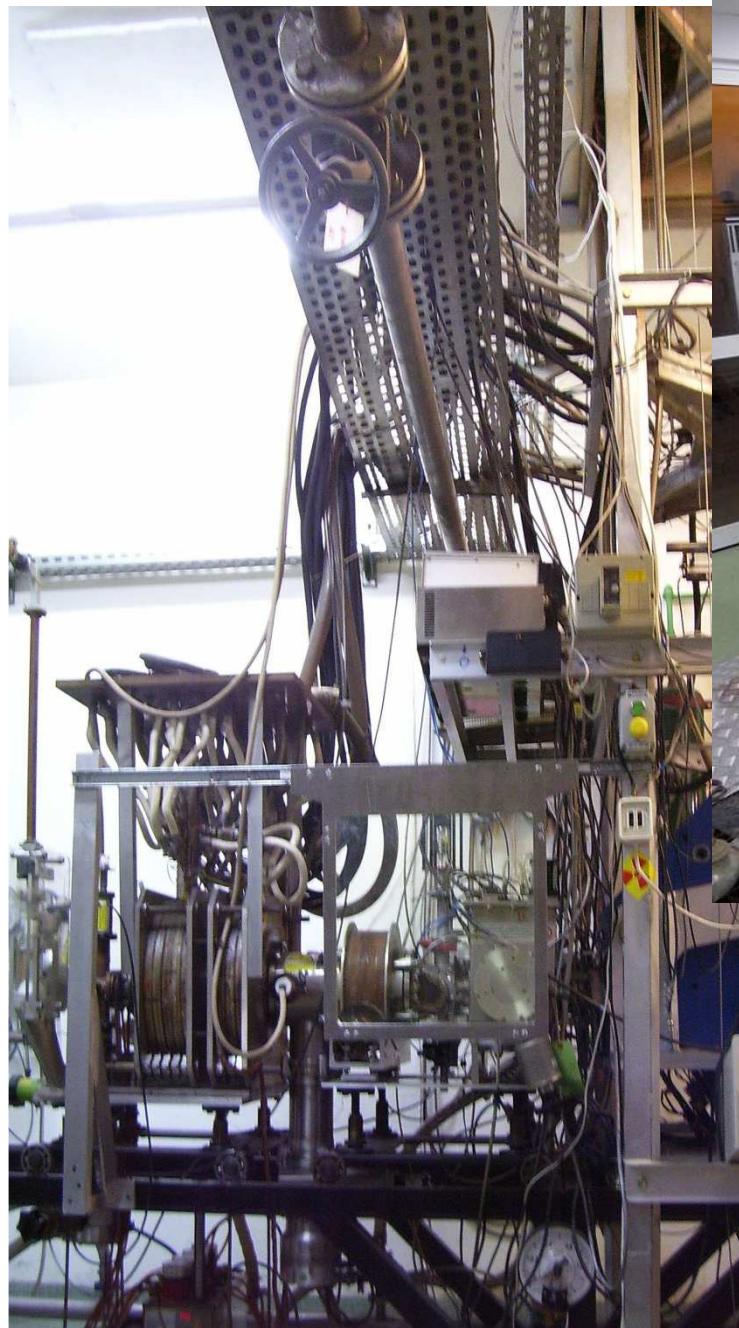
ECR ion source

(Electron Cyclotron Resonance)

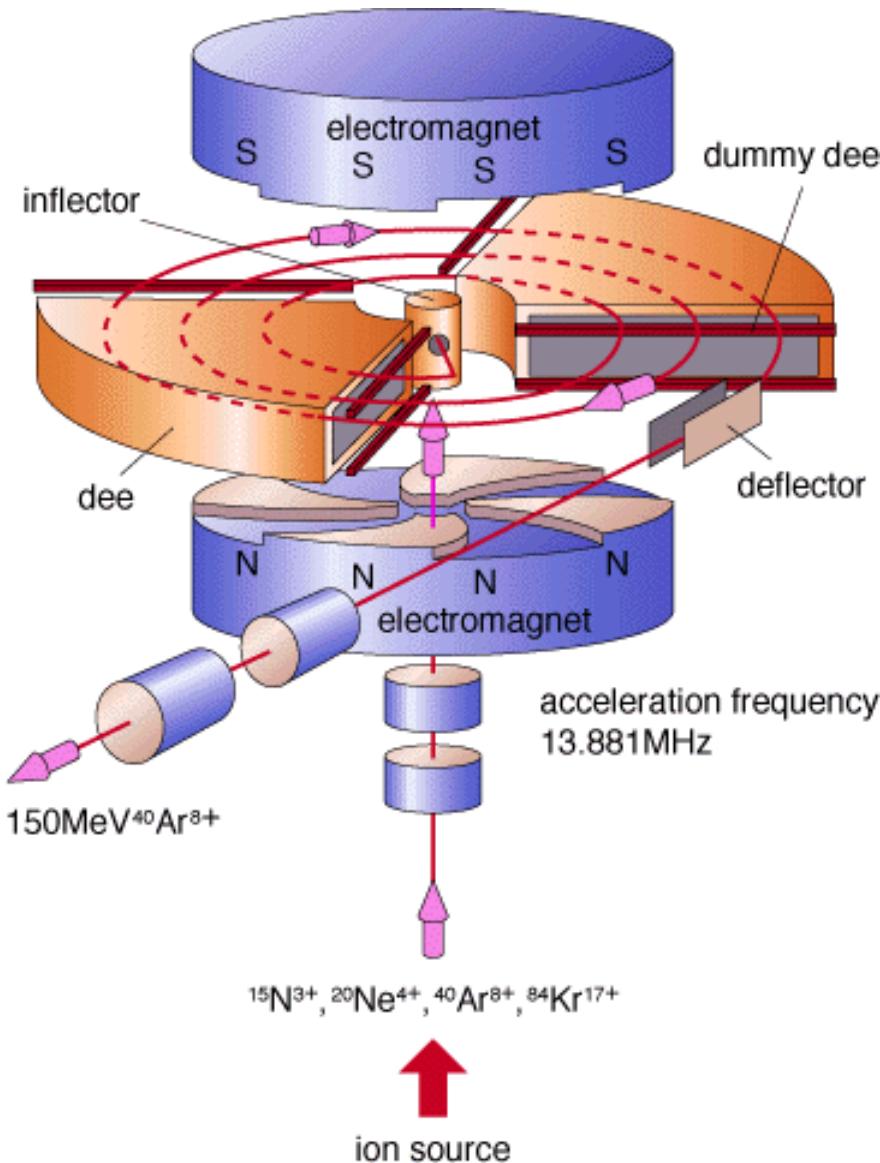
- 1. coils 2. hexapol
- 3. plasma chamber
- 4. coaxial line 5. tuner
- 6. RF injection 7. exit hole
- 8. Einzel lens 9. yoke



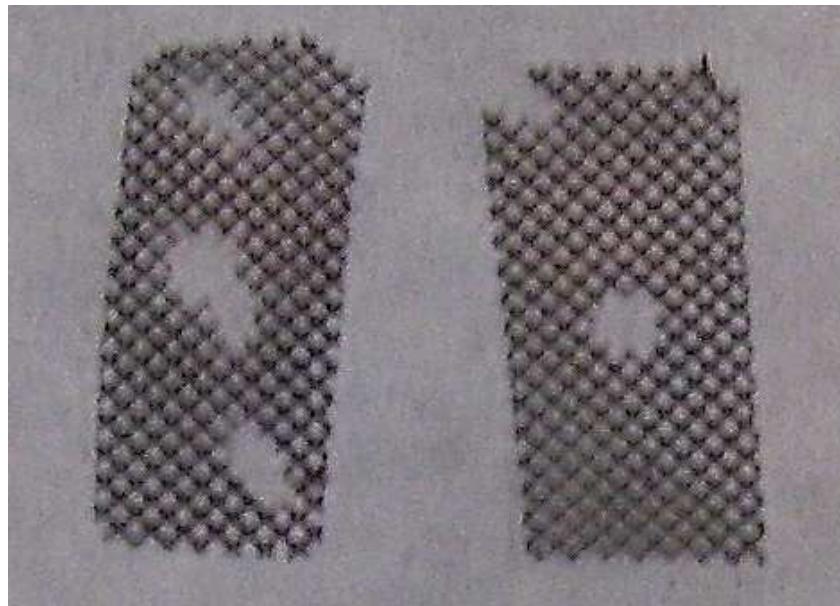
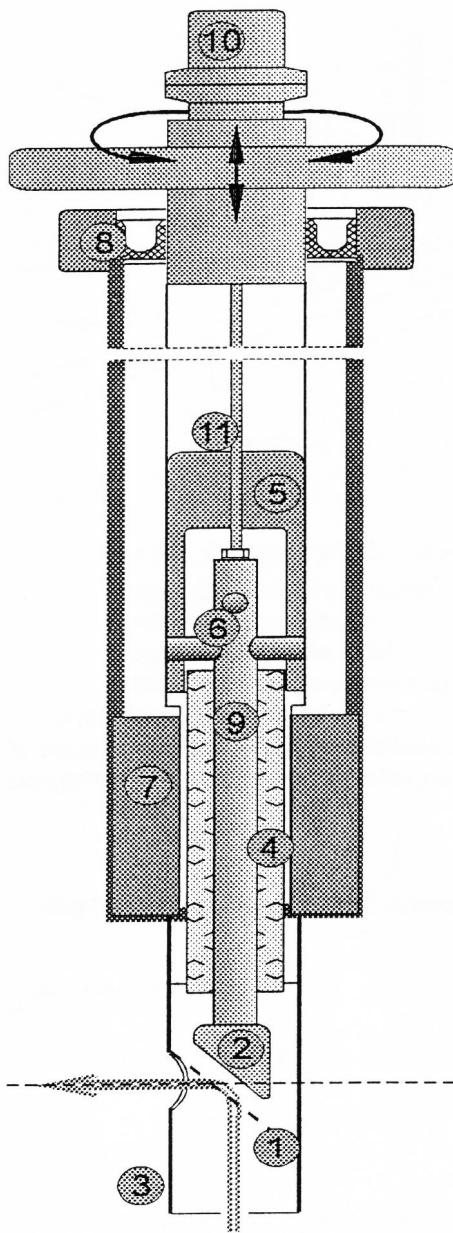
Our ion sources and injection line



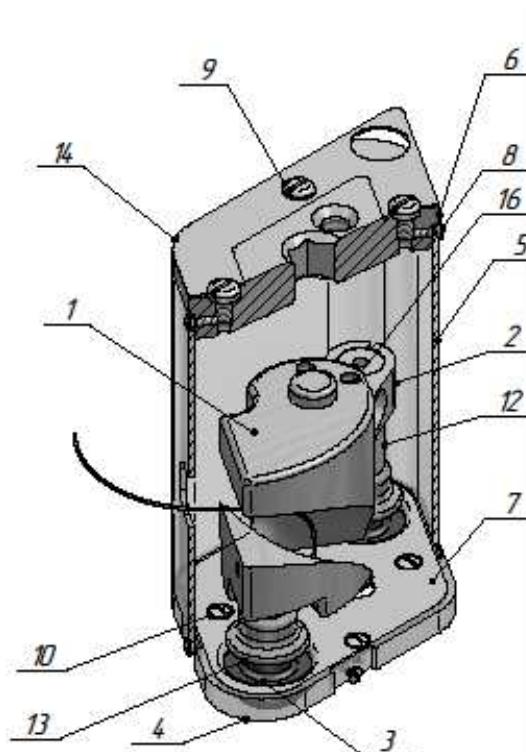
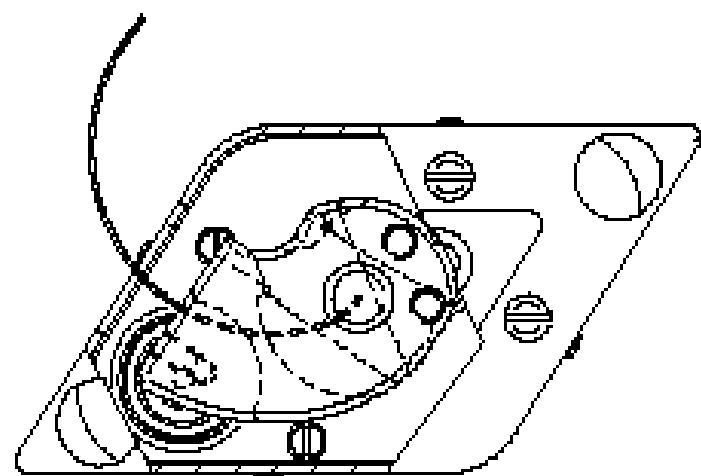
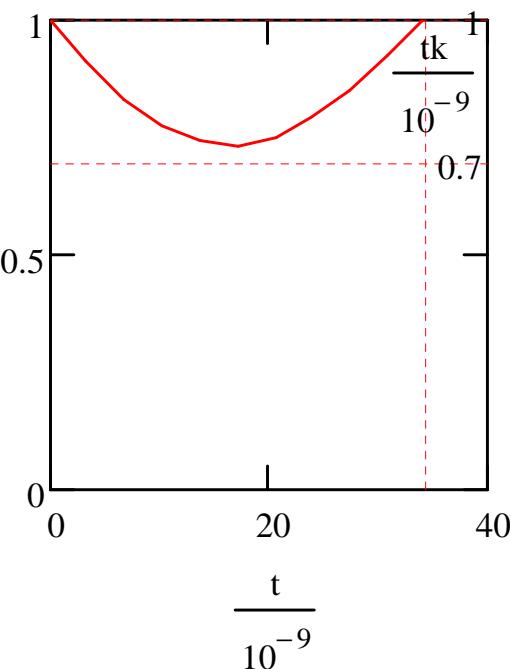
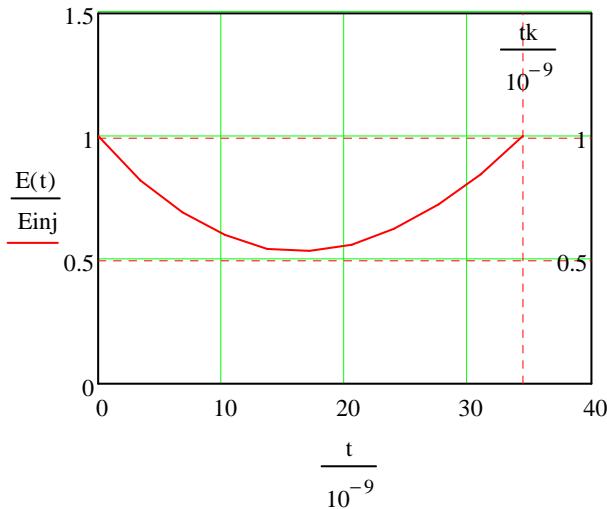
Mirror inflector



Mirror inflector



Spiral inflector



2990.02.00.00 Ошибка: Нет ссылки		
Ном. позн.	Нр. звезж.	Ном. звезд.
1	Блок спиральный	
2	Блок опорный	
3	Лапка	Лапка
4	Лапка	Лапка
5	Блок опорный	
6	Блок спиральный	
7	Лапка	Лапка
8	Лапка	Лапка
9	Лапка	Лапка
10	Лапка	Лапка
11	Лапка	Лапка
12	Лапка	Лапка
13	Лапка	Лапка
14	Лапка	Лапка
15	Лапка	Лапка
16	Лапка	Лапка

Инфлектор
Ошибка: Нет ссылки

Ант.	Масса	Номинал
0	2.1	
дим. 7	диаметр	7

Isochronous cyclotron

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

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

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

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

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

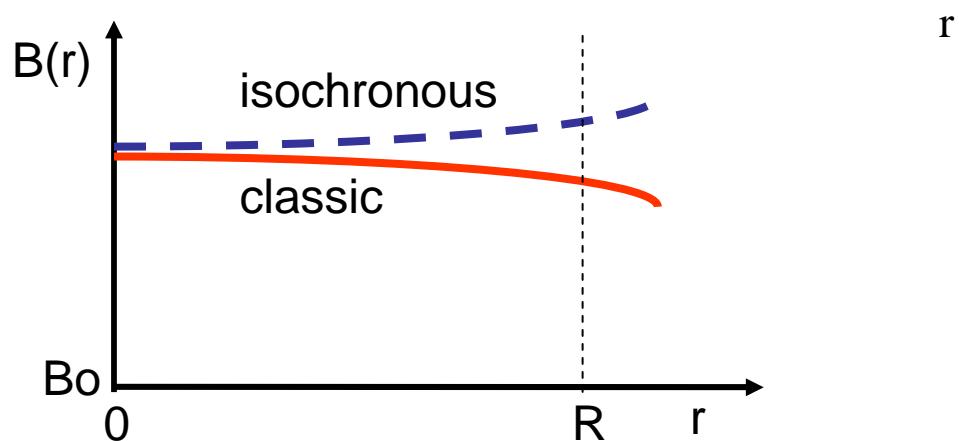
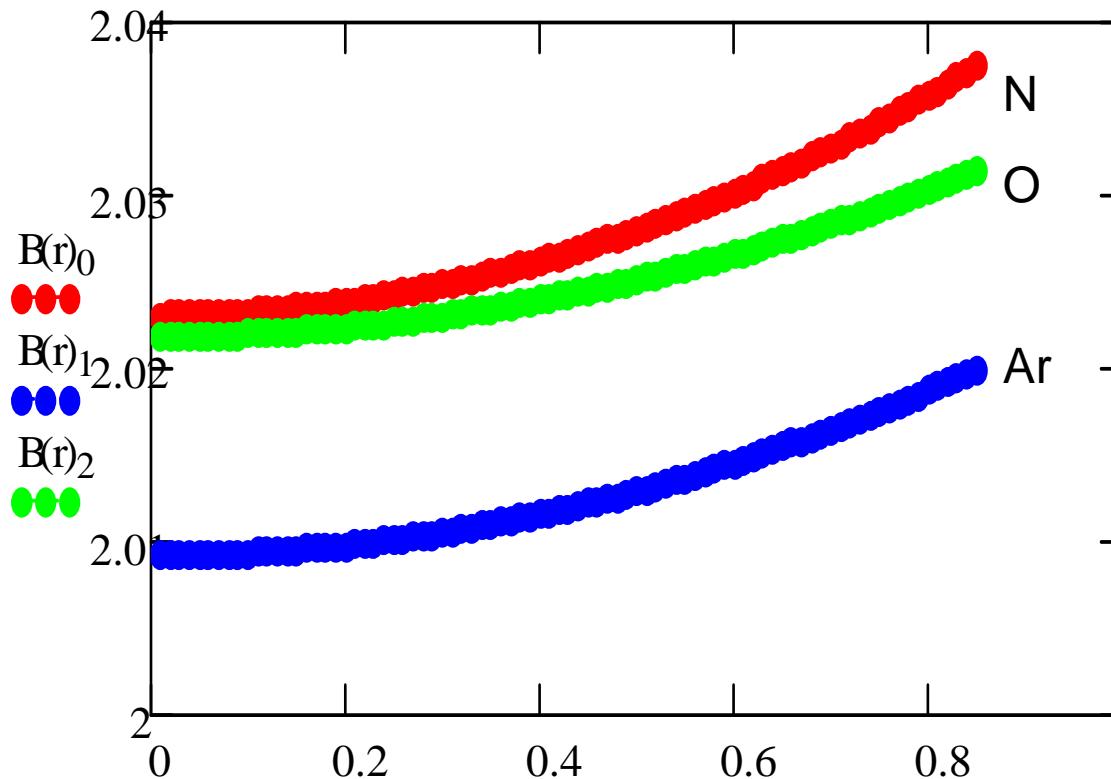
$$\gamma(r) = \frac{1}{\sqrt{1 - \left(\frac{v(r)}{c}\right)^2}} = \frac{1}{\sqrt{1 - \left(\frac{r \cdot \omega_c}{c}\right)^2}}$$

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

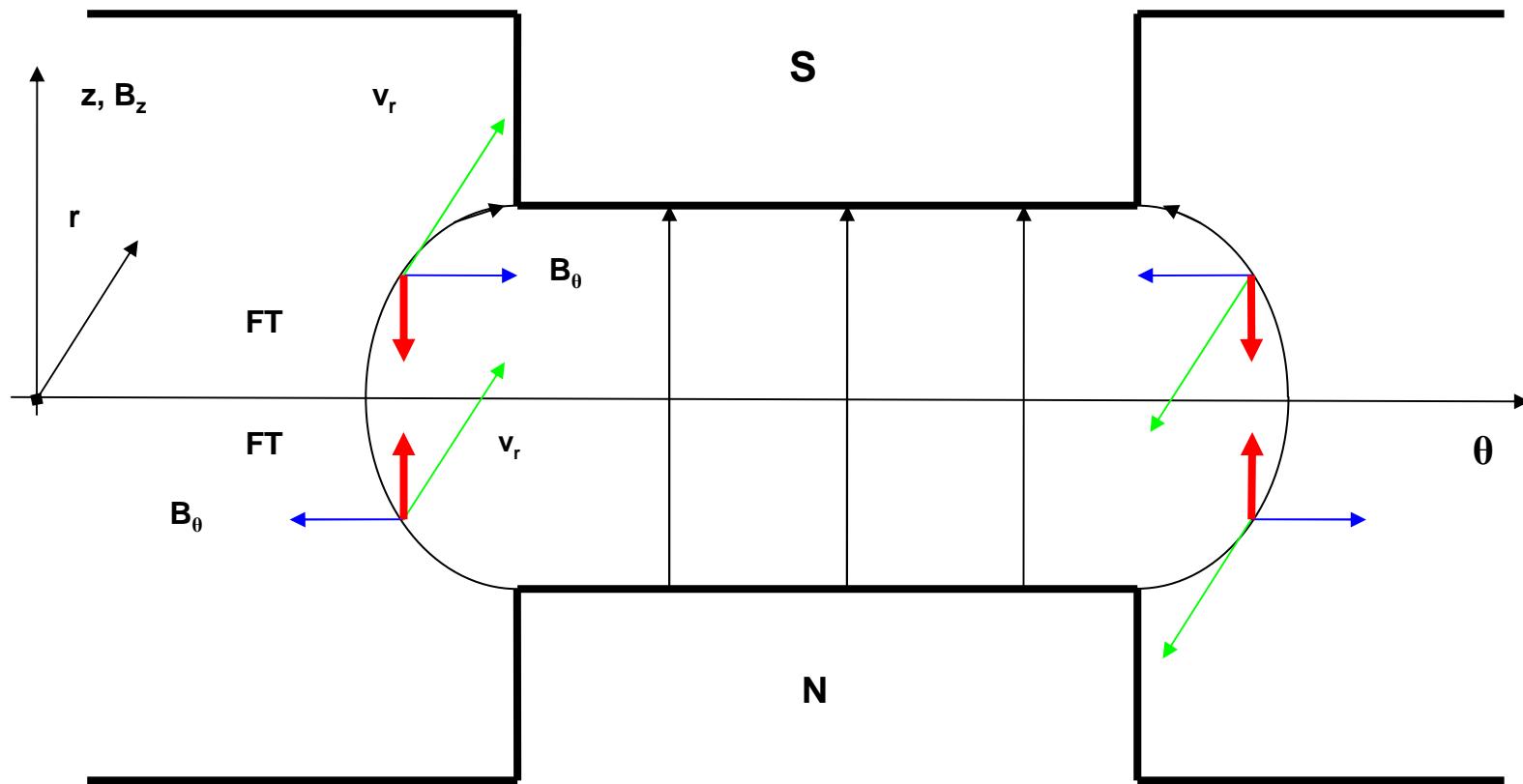
$$B(r) = \gamma(r) \cdot B_0$$

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

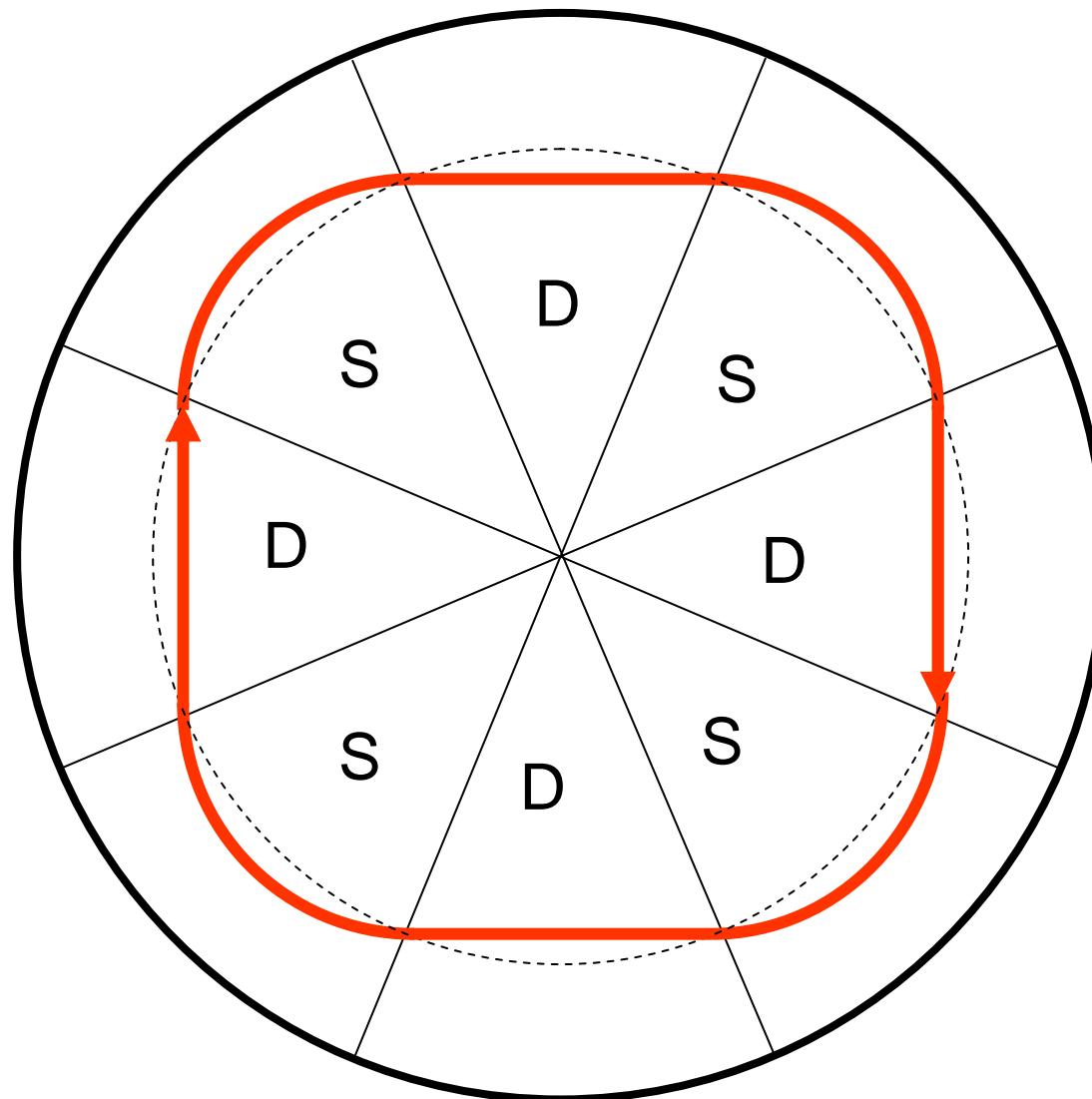
Isochronous cyclotron



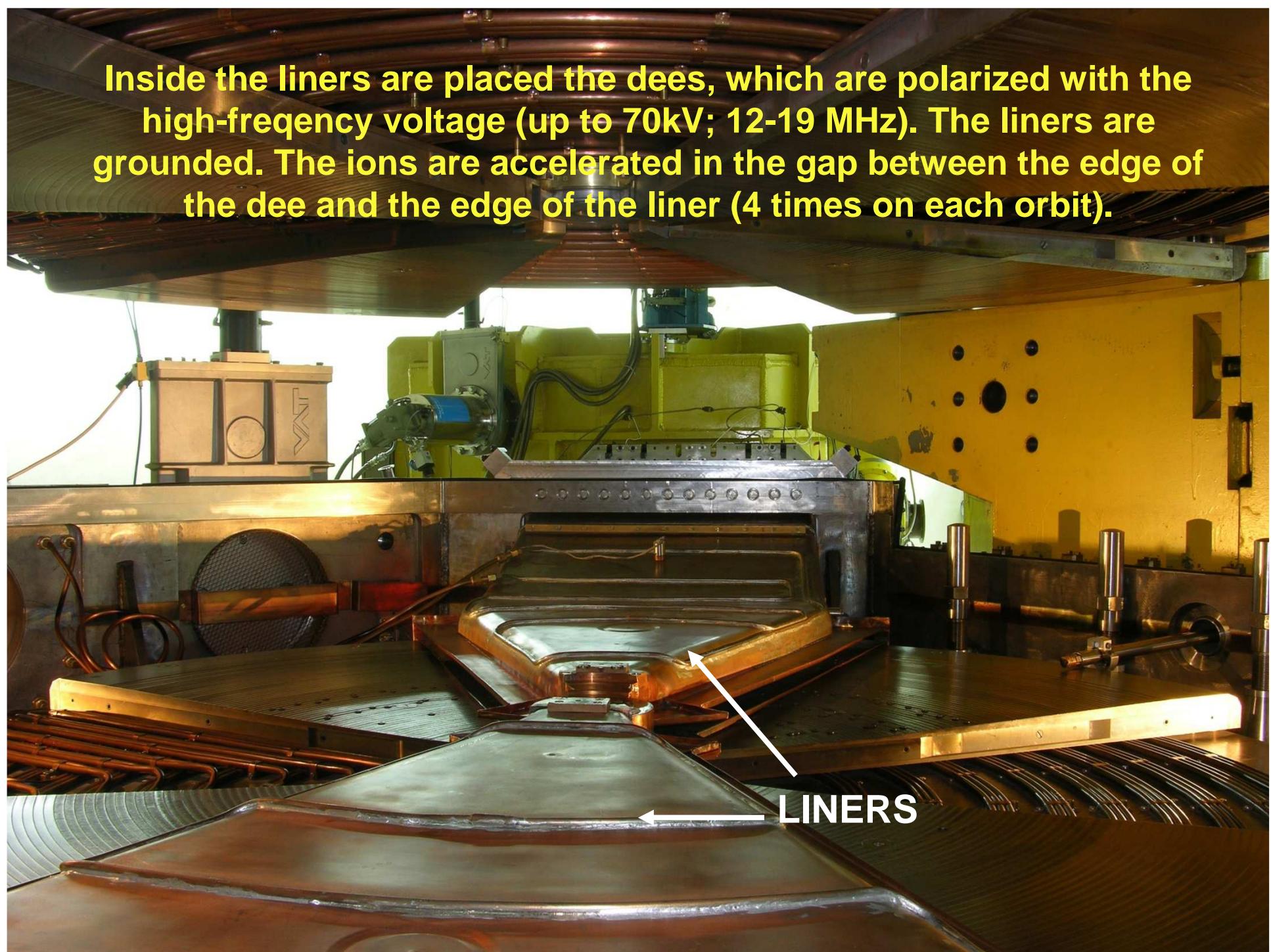
Thomas force

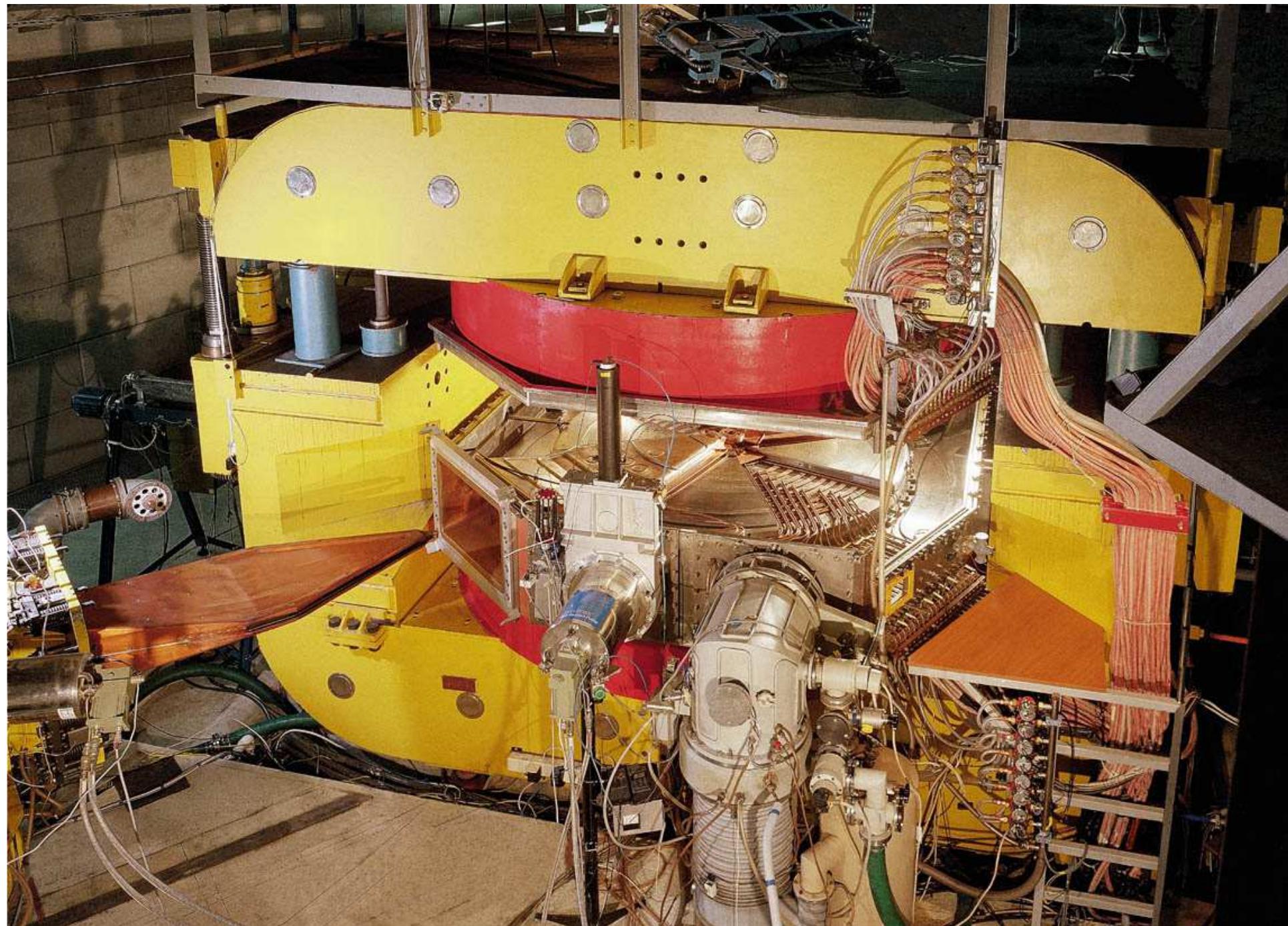


Thomas force

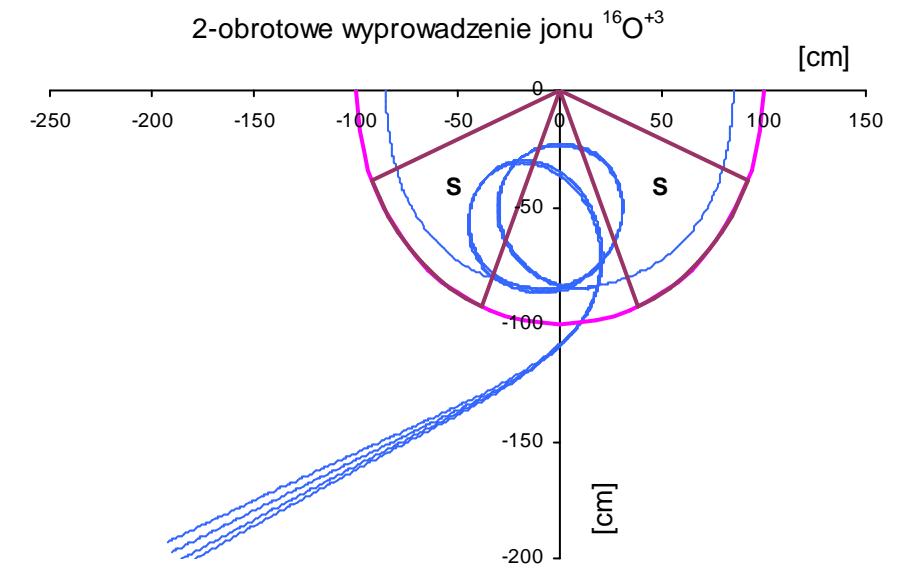
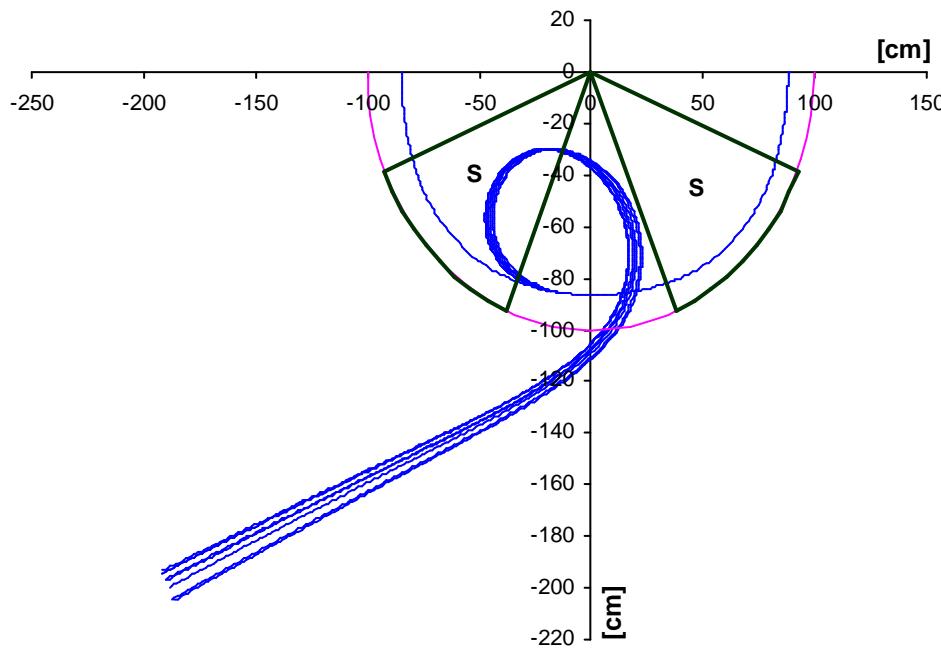


Inside the liners are placed the dees, which are polarized with the high-frequency voltage (up to 70kV; 12-19 MHz). The liners are grounded. The ions are accelerated in the gap between the edge of the dee and the edge of the liner (4 times on each orbit).

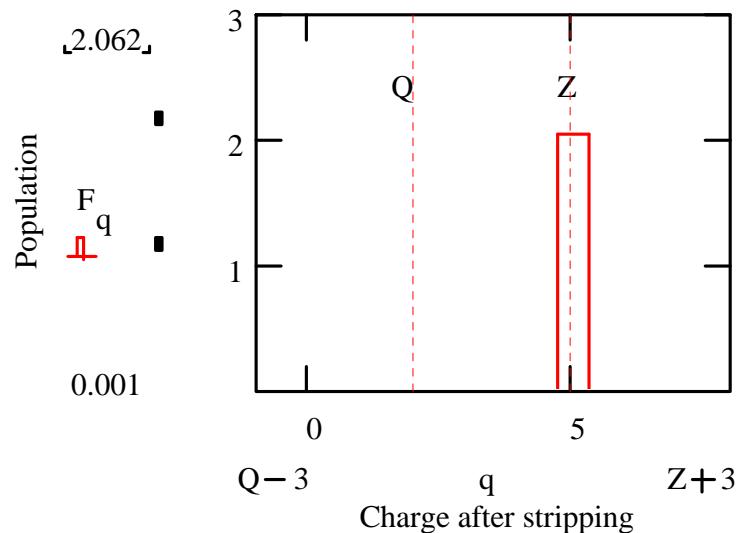




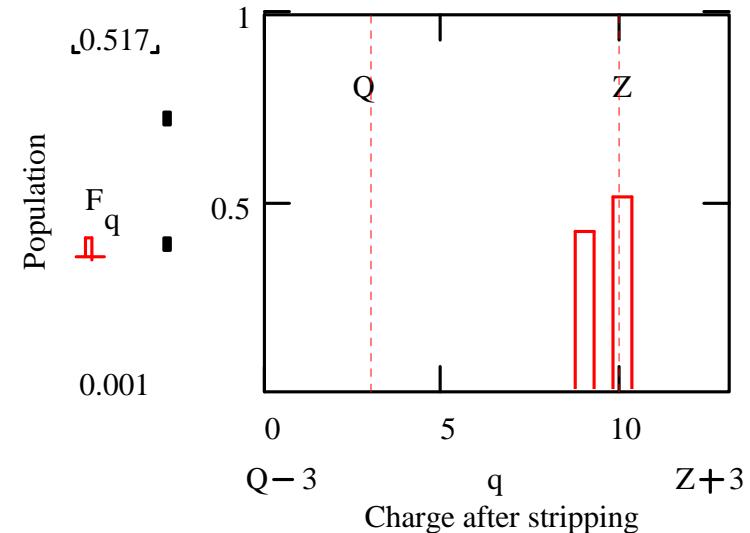
Extraction – stripper



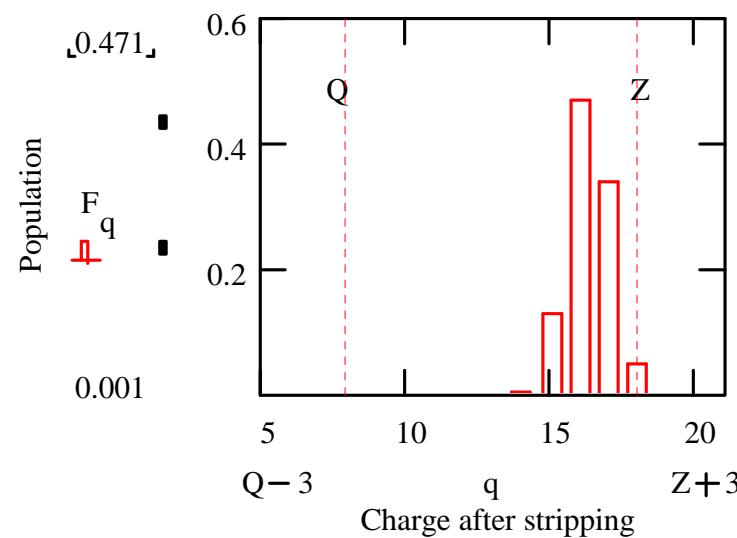
Dependence of the charge state population after stripping on the ion mass number A



$A=10, Z=5, Q=2,$
 $E=5 \text{ MeV}/A$

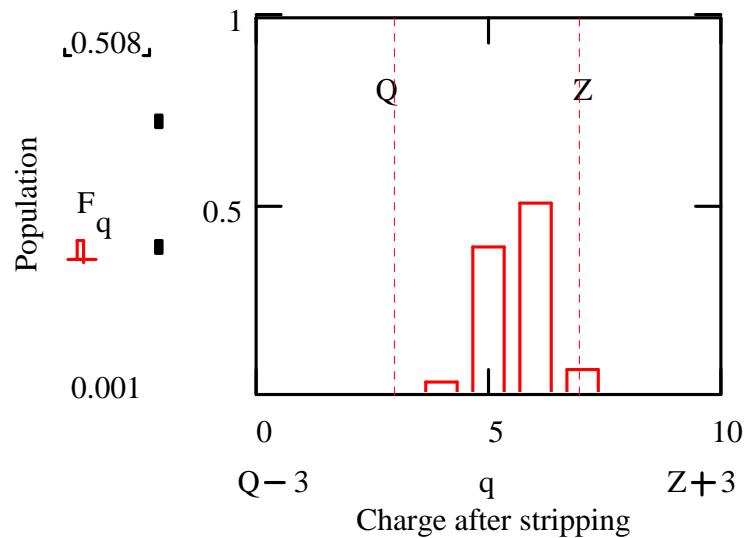


$A=20, Z=10, Q=3,$
 $E=5 \text{ MeV}/A$

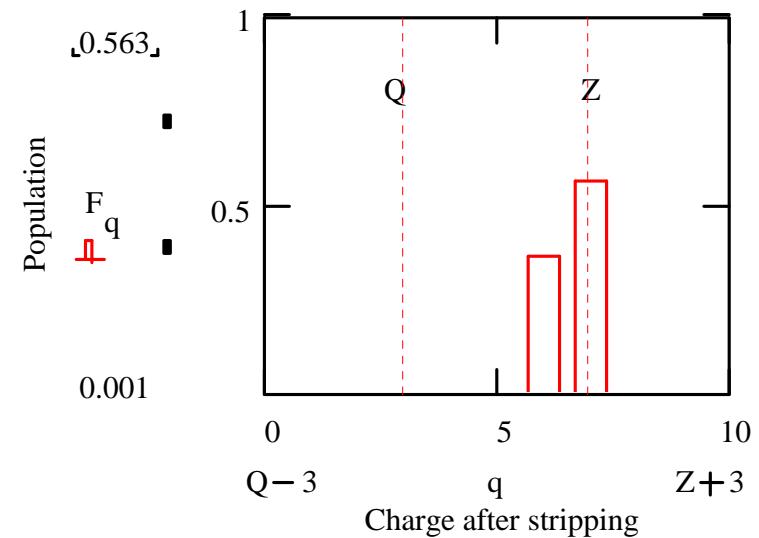


$A=40, Z=18, Q=8,$
 $E=5 \text{ MeV}/A$

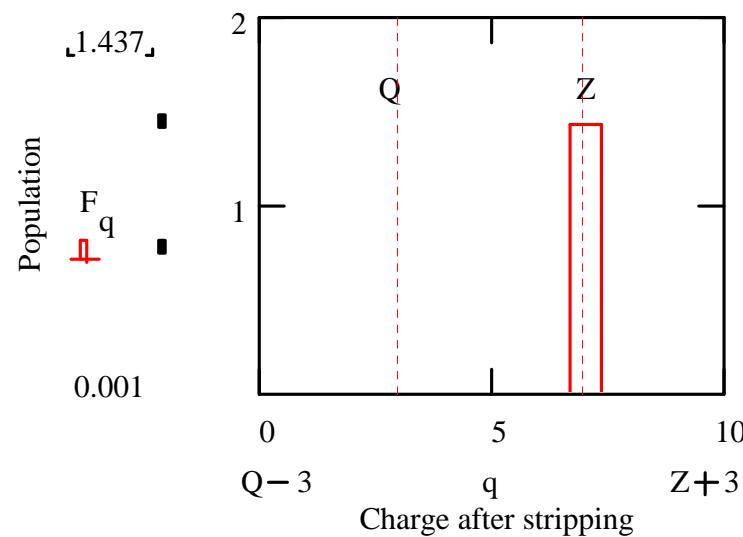
Dependence of the charge state population after stripping on the ion energy



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

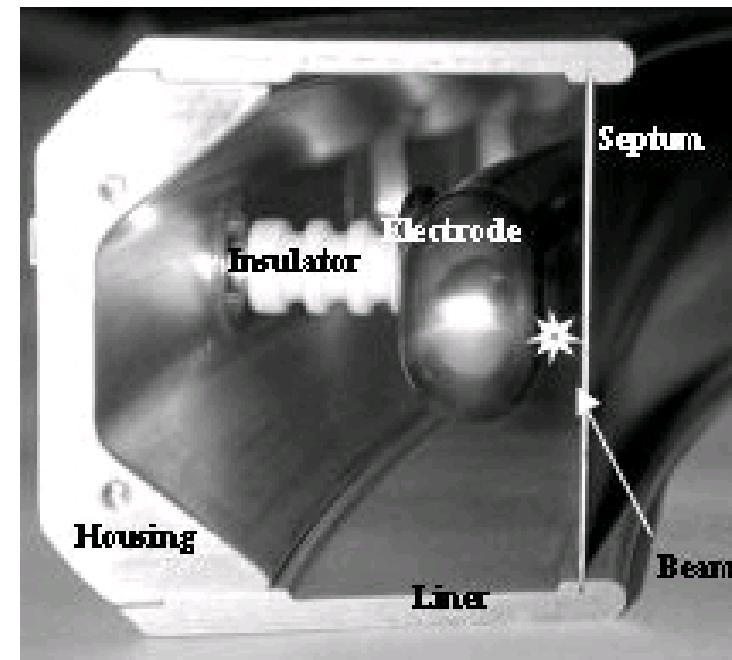


$A=14$, $Z=7$, $Q=3$,
 $E=3$ MeV/A



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

Extraction – electrostatic deflector



Beam lines

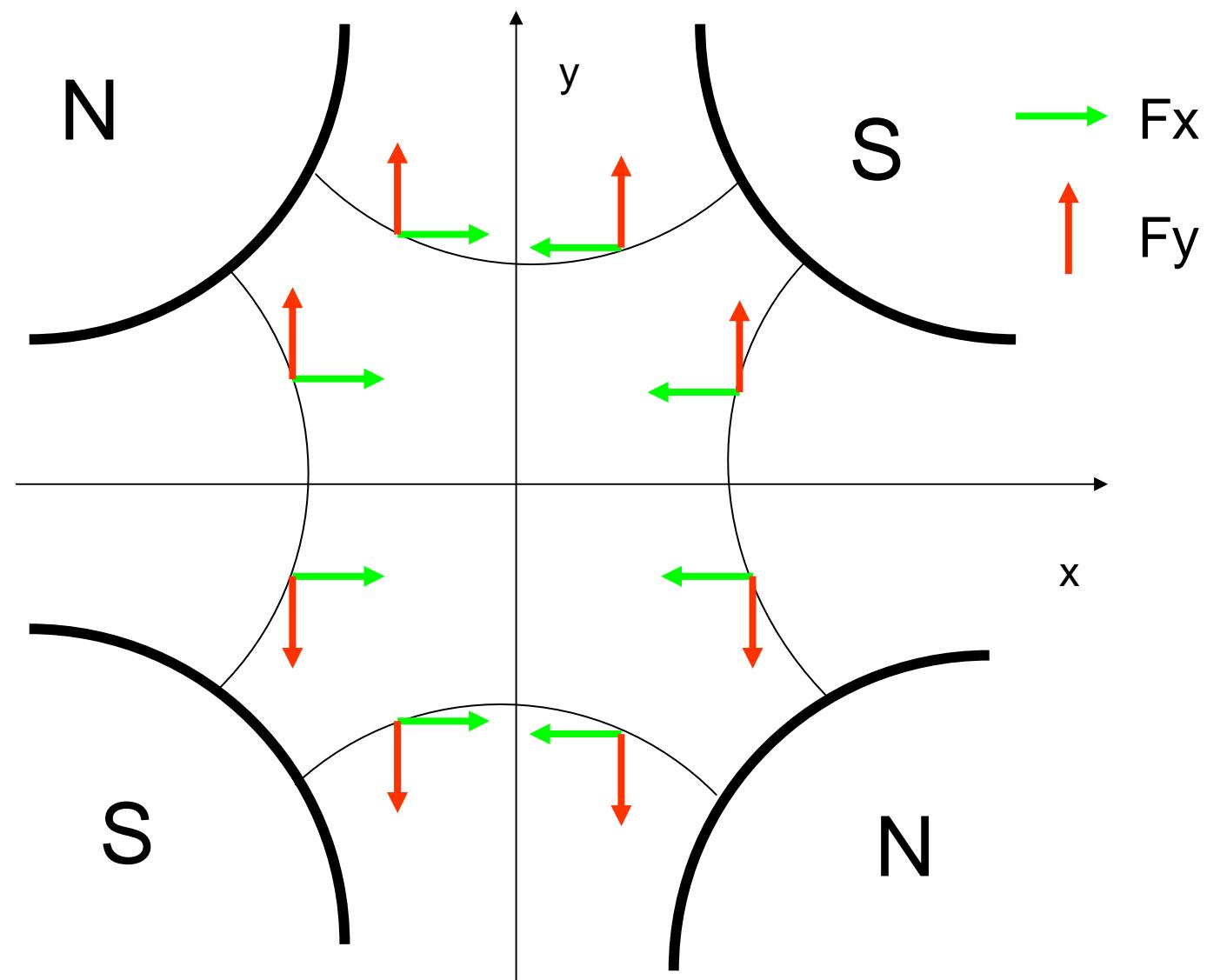
All beam lines are equipped with certain elements, which help in efficient transport of accelerated ion beam.

- quadrupol magnets
- dipol magnets : analysing magnets and steerers
- Faraday cups
- luminescence screens

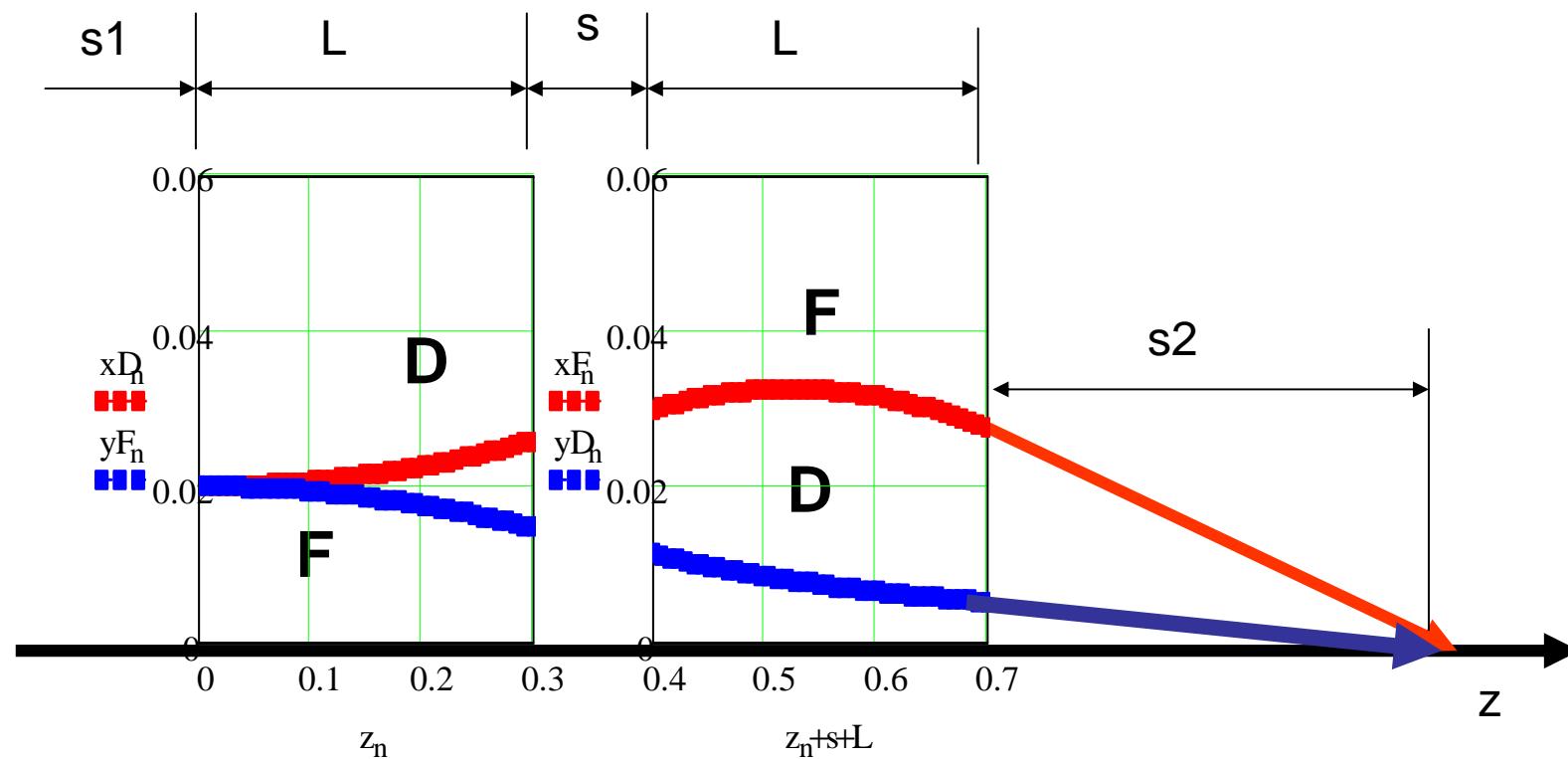
Quadrupol magnet



Quadrupol magnet



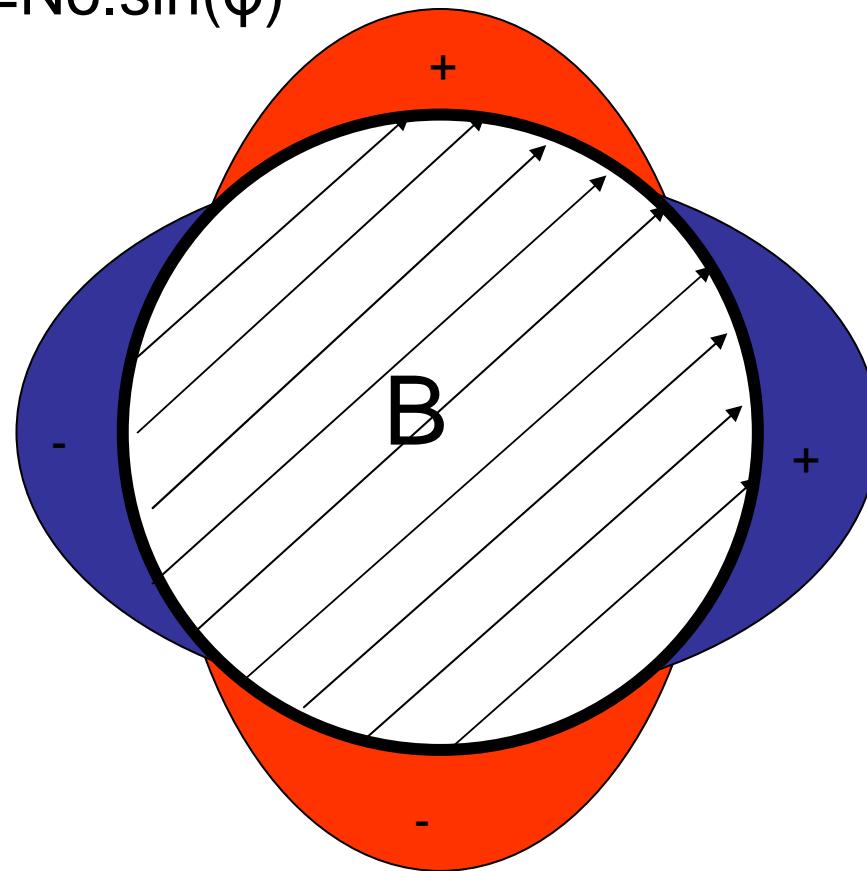
Quadrupol magnet



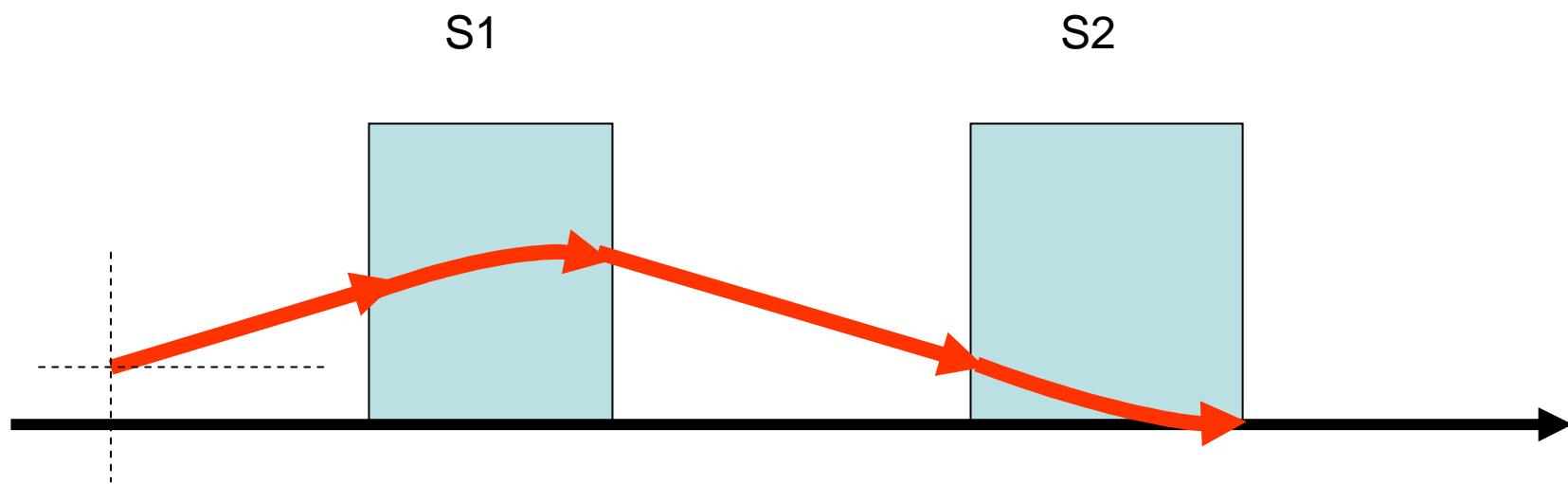
Dipol magnet - steerer

$$N_1 = N_o \cdot \cos(\varphi)$$

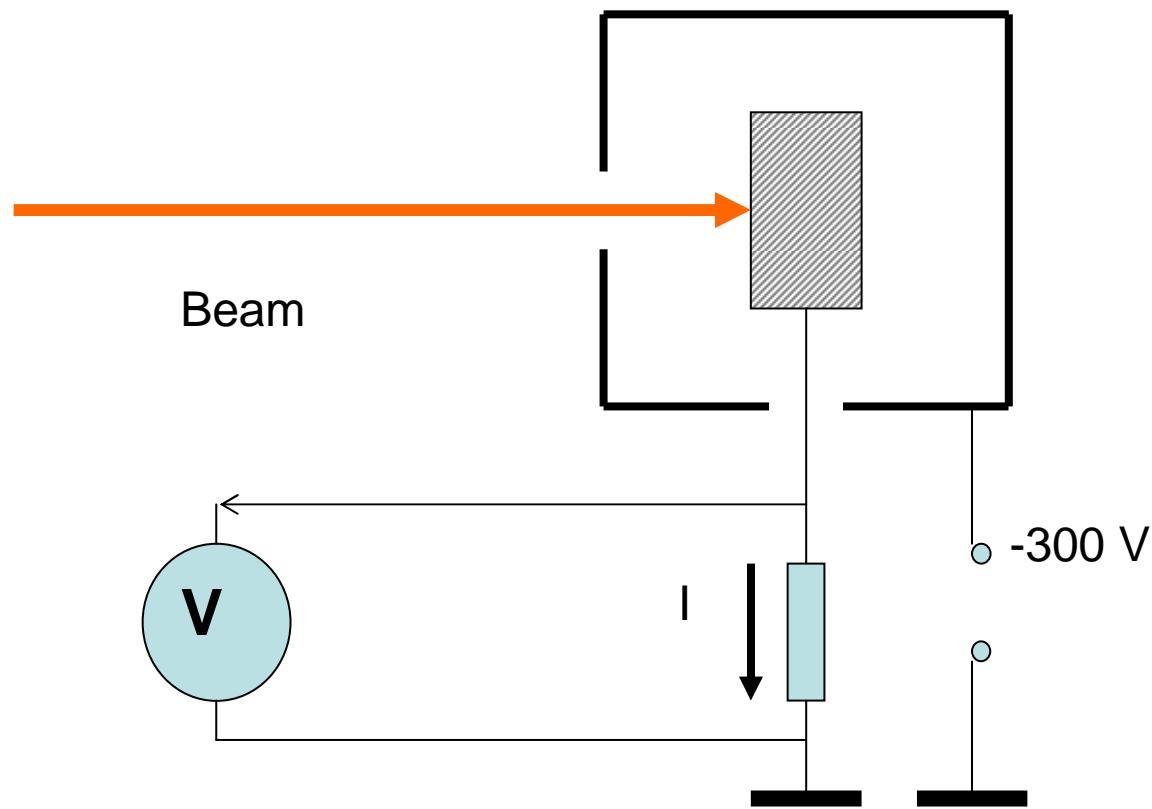
$$N_2 = N_o \cdot \sin(\varphi)$$



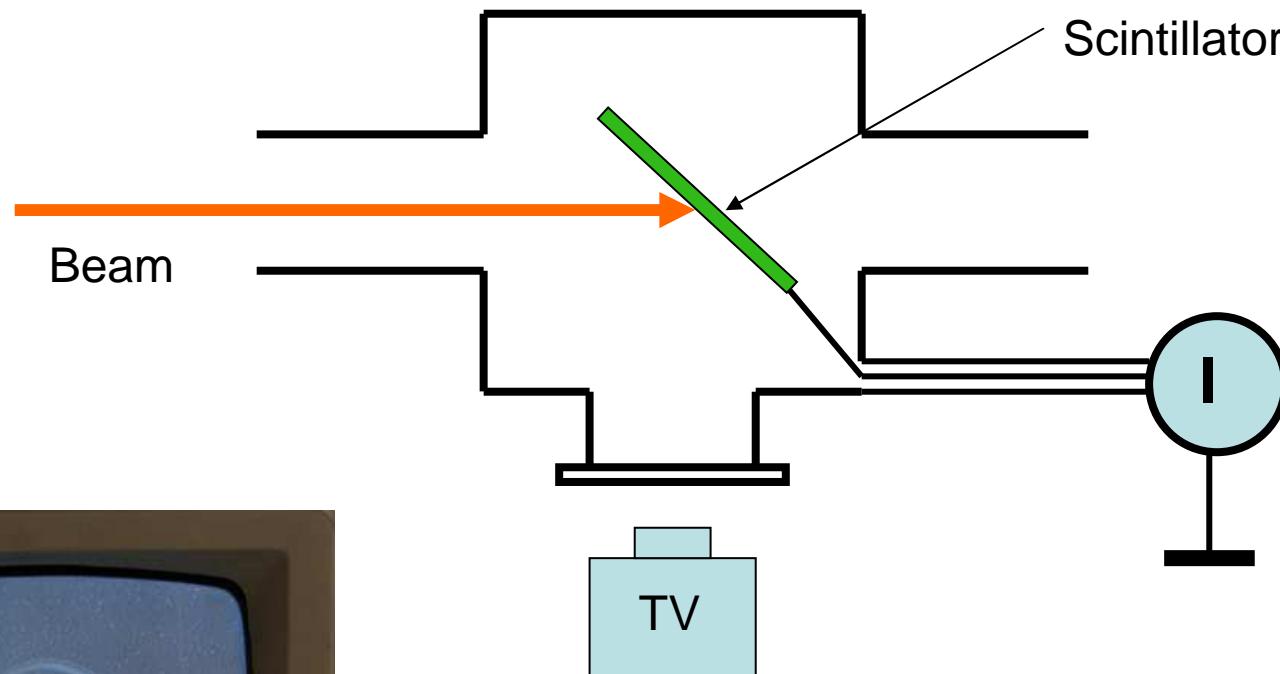
Dipol magnet - steerer

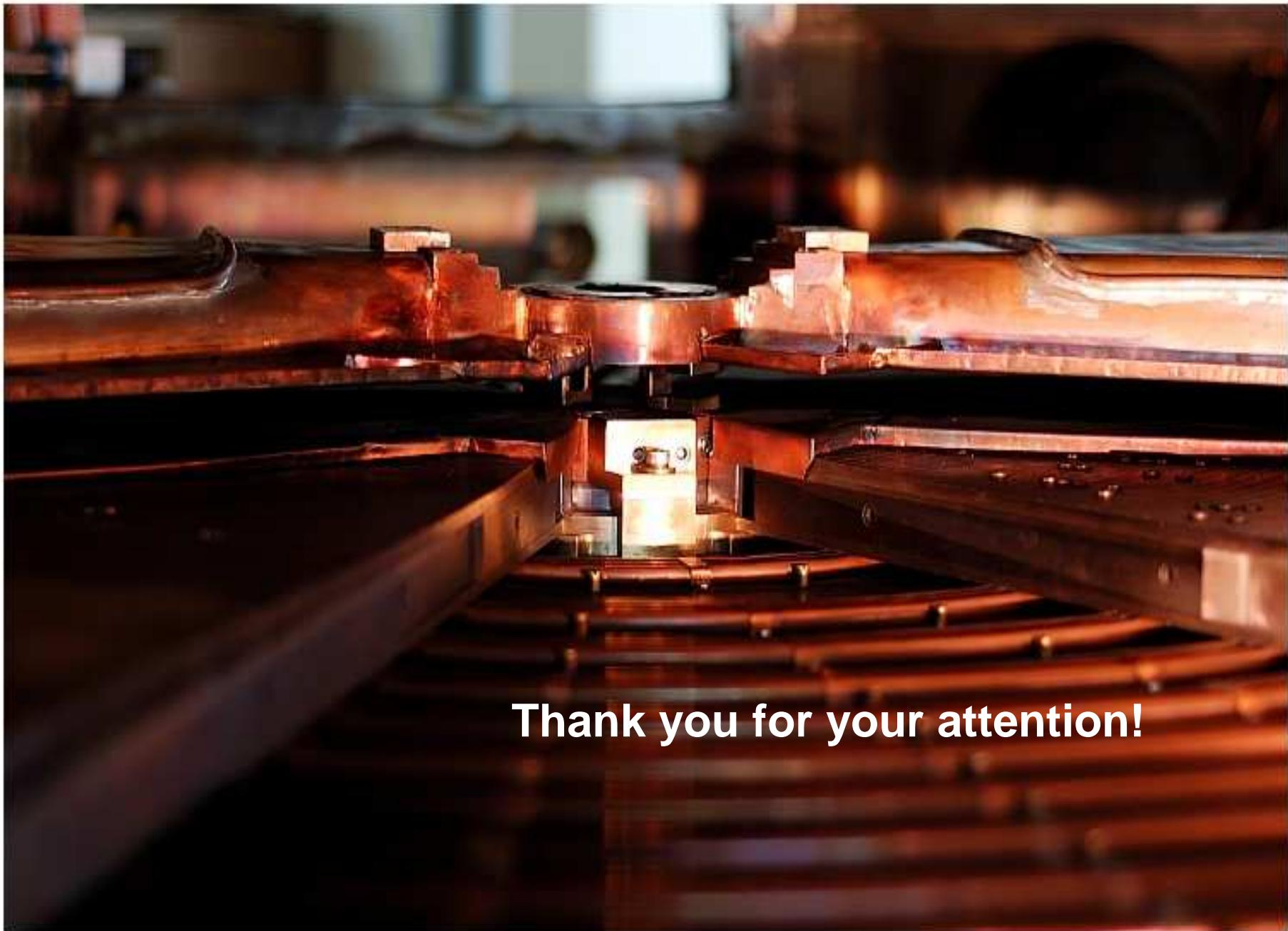


Beam diagnostic – Faraday cup



Beam diagnostic - „luminescence”





Thank you for your attention!