



International Workshop on Acceleration and Applications of Heavy Ions

Acceleration of heavy ions and beam transport

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

Major types of accelerators:

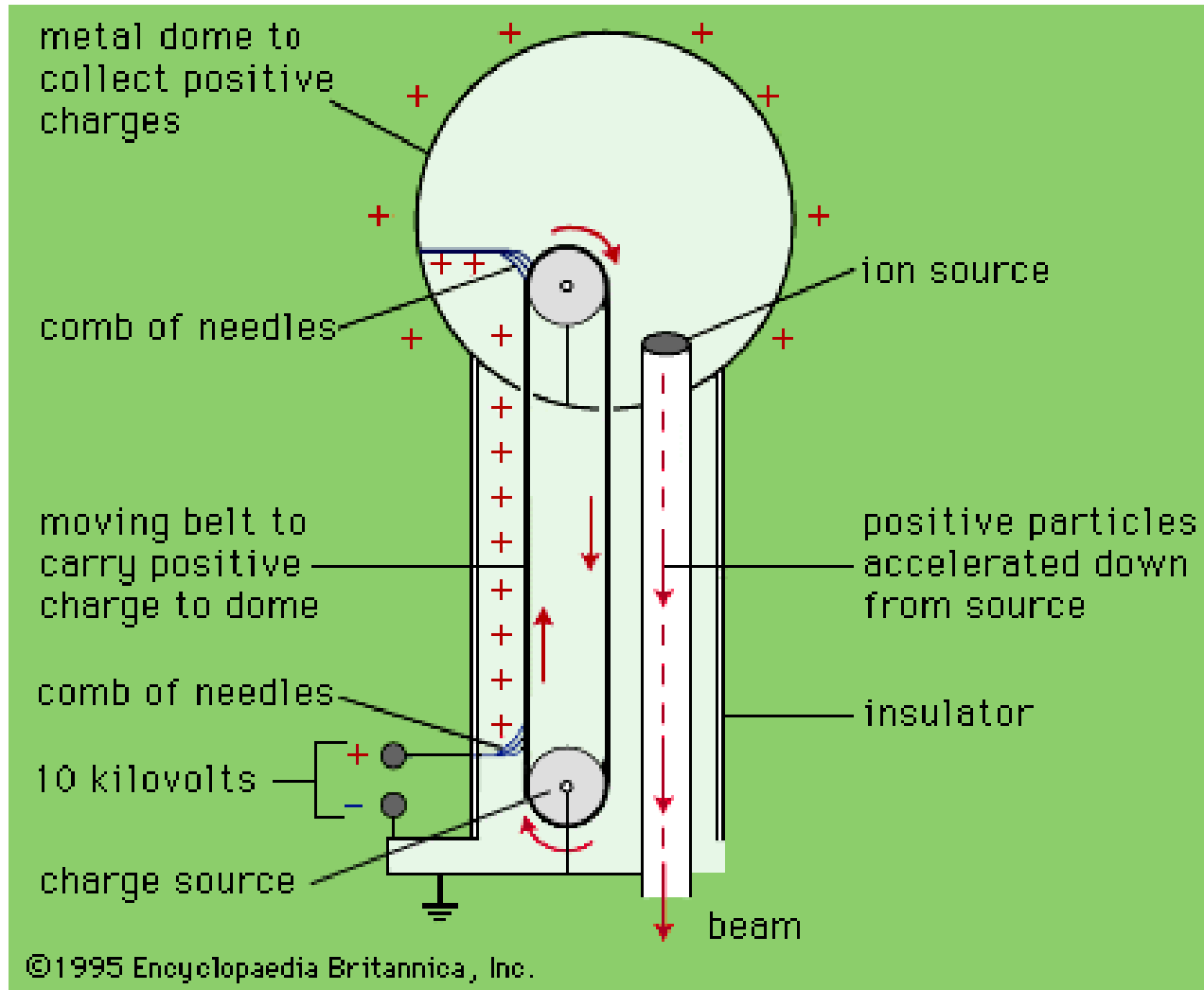
a) linear:

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

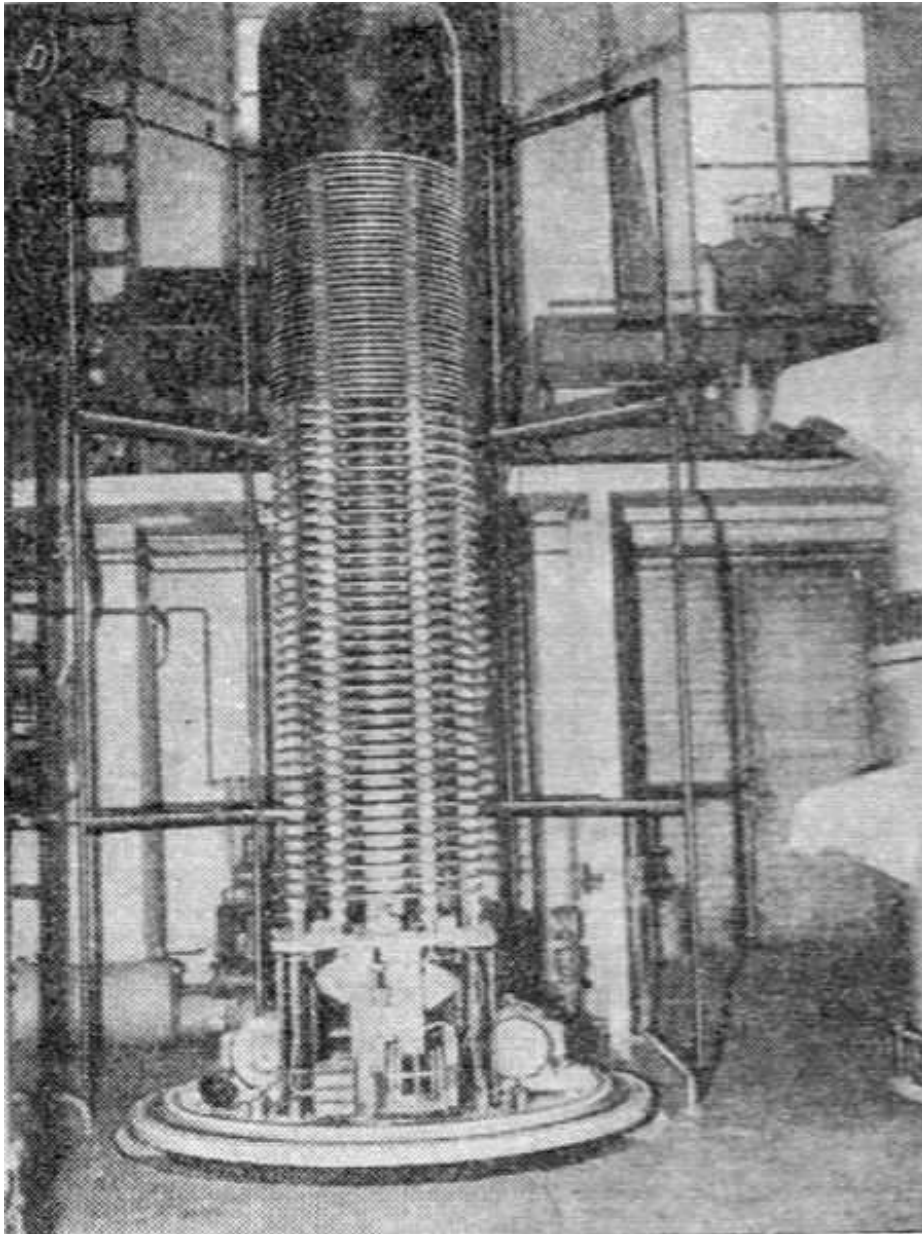
a) circular:

- 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)

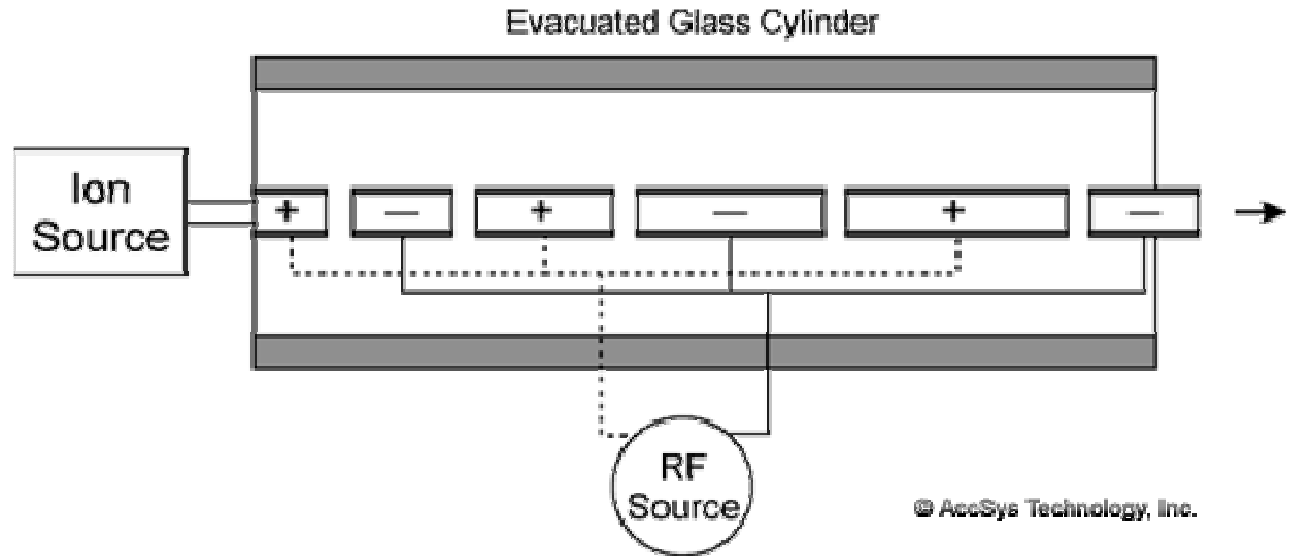
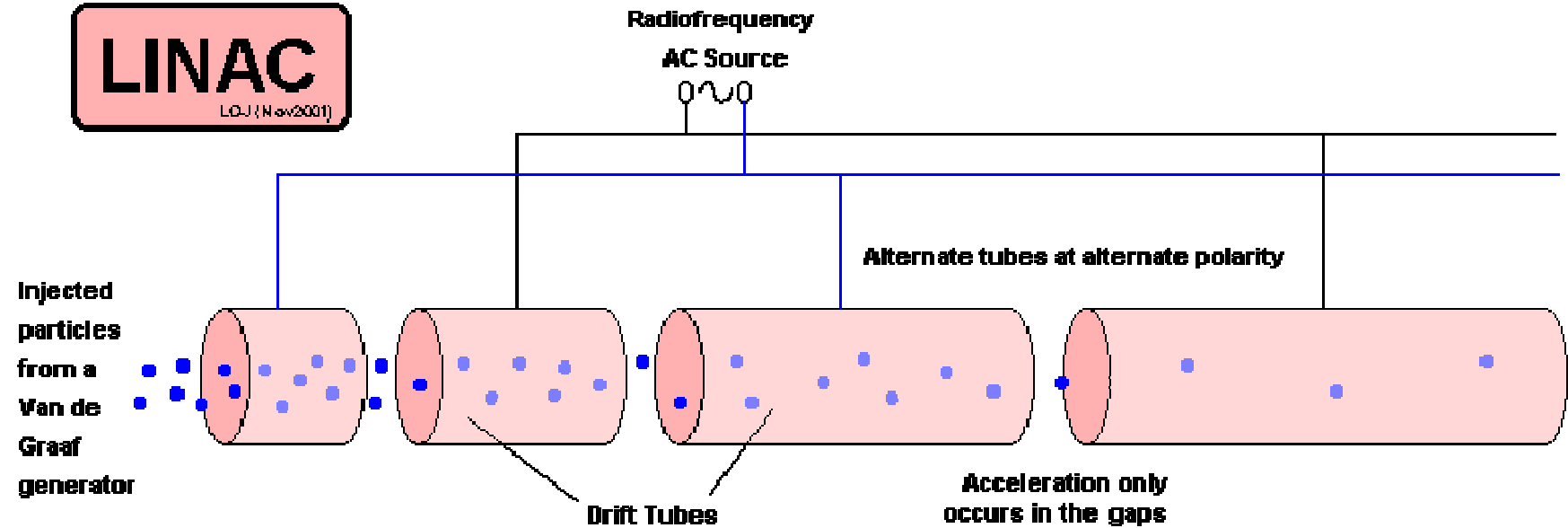


Electrostatic accelerator (van de Graaff)

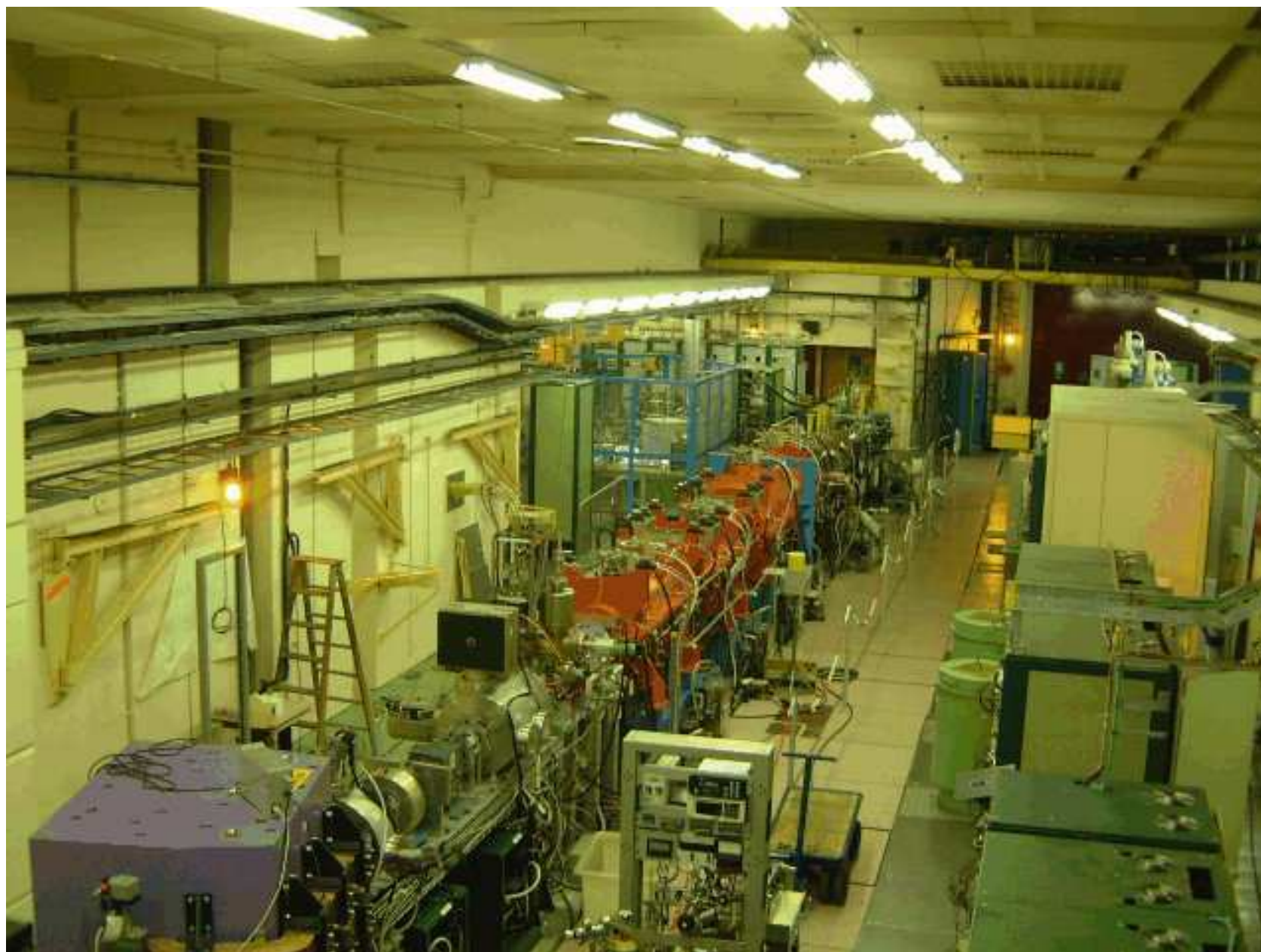


LINAC

LINAC
LOJ / Nov 2001



LINAC



CYCLOTRON

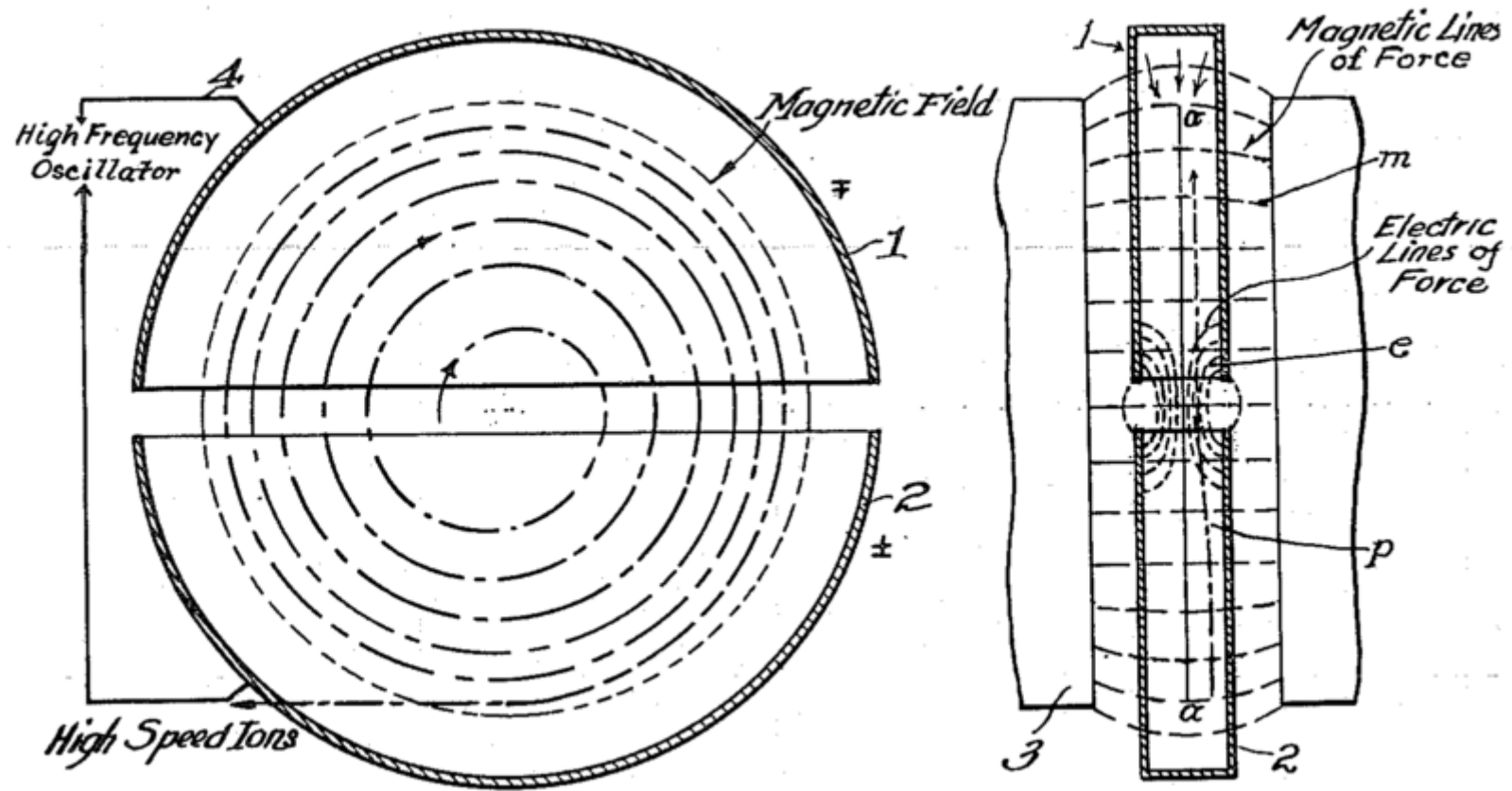
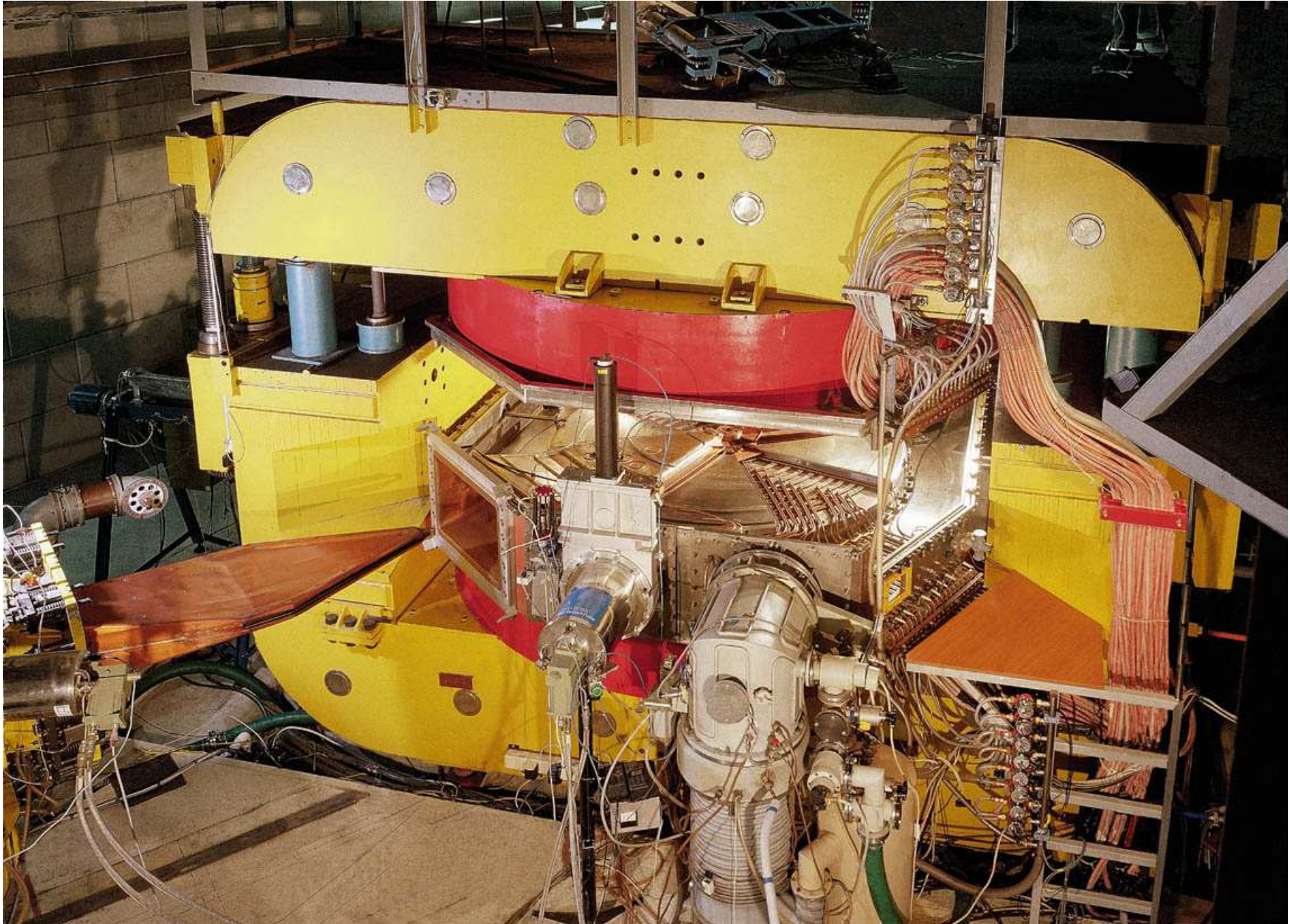
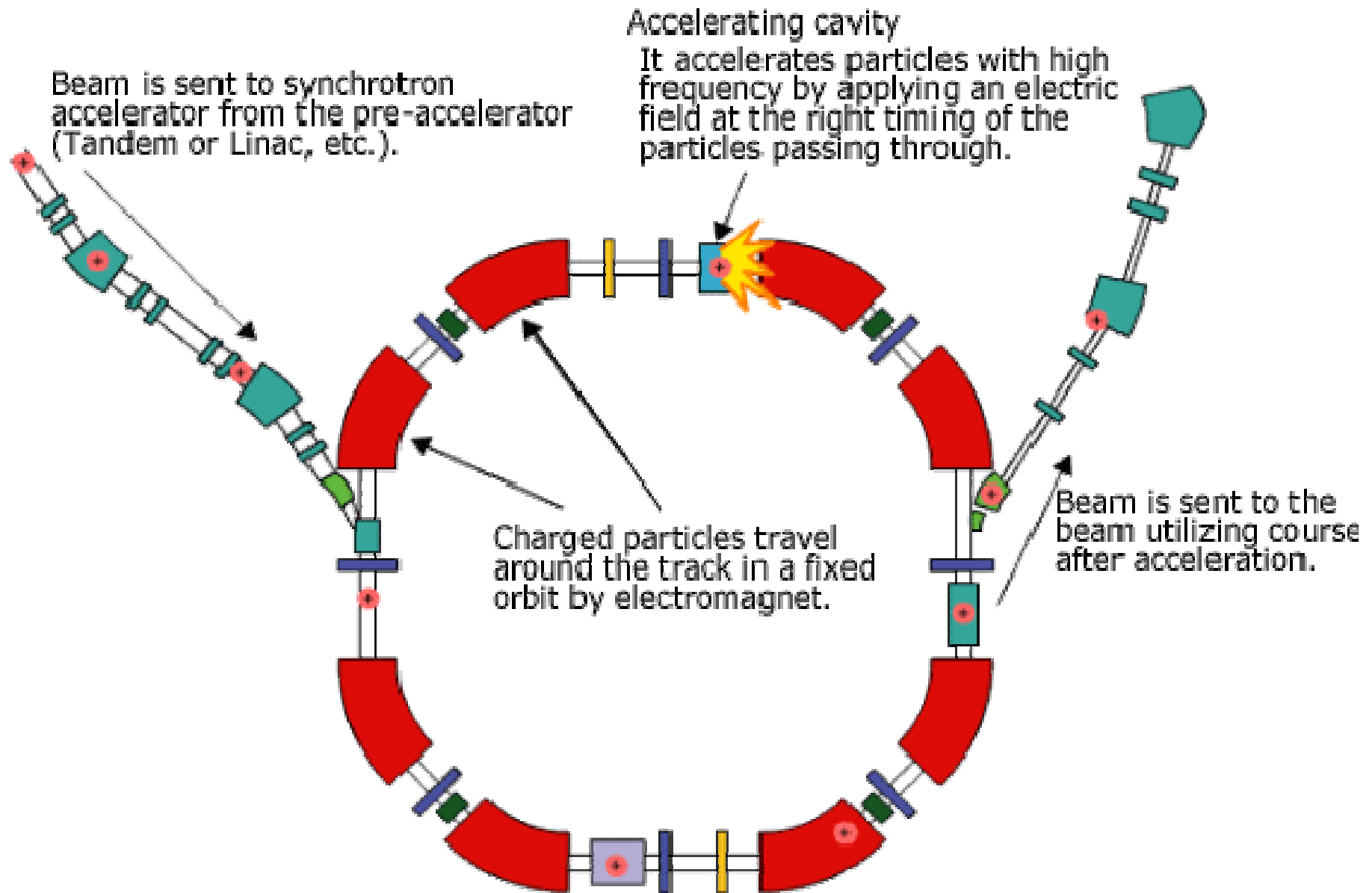


Diagram of cyclotron operation from Lawrence's 1934 patent
(Ernest Lawrence, 1931)

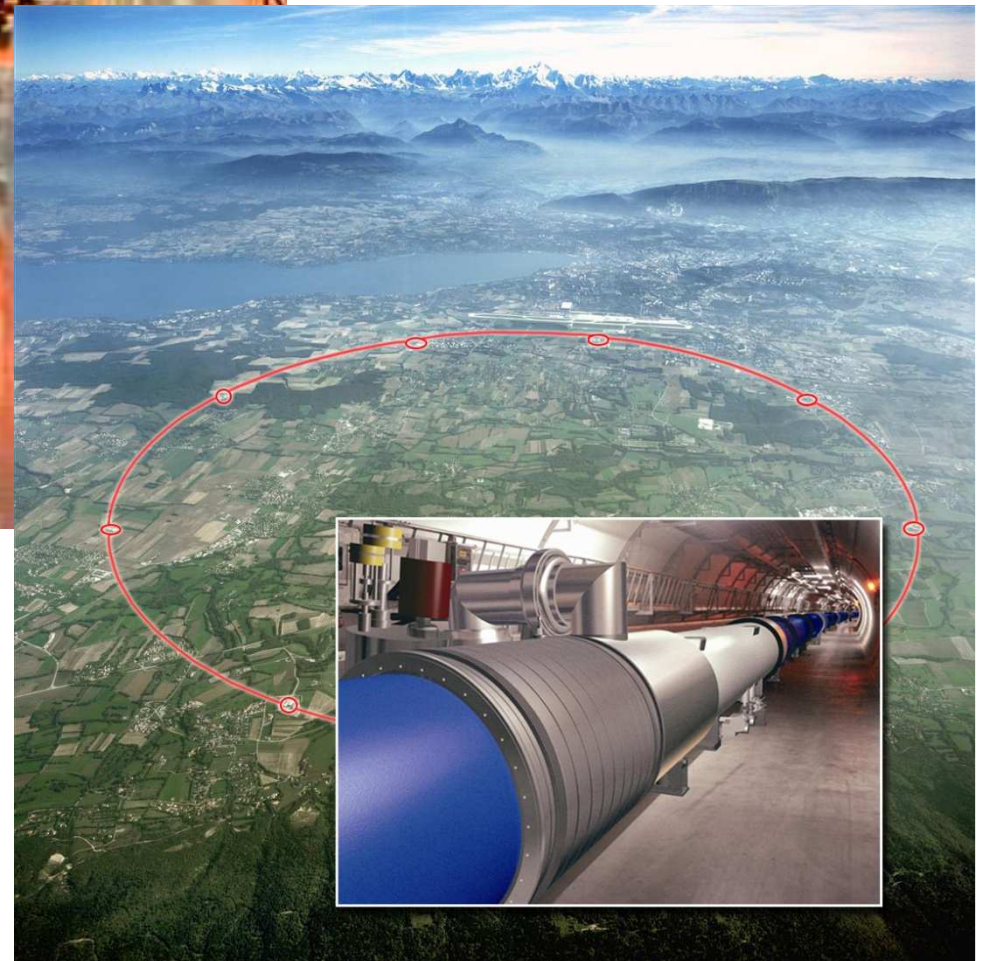
CYCLOTRON



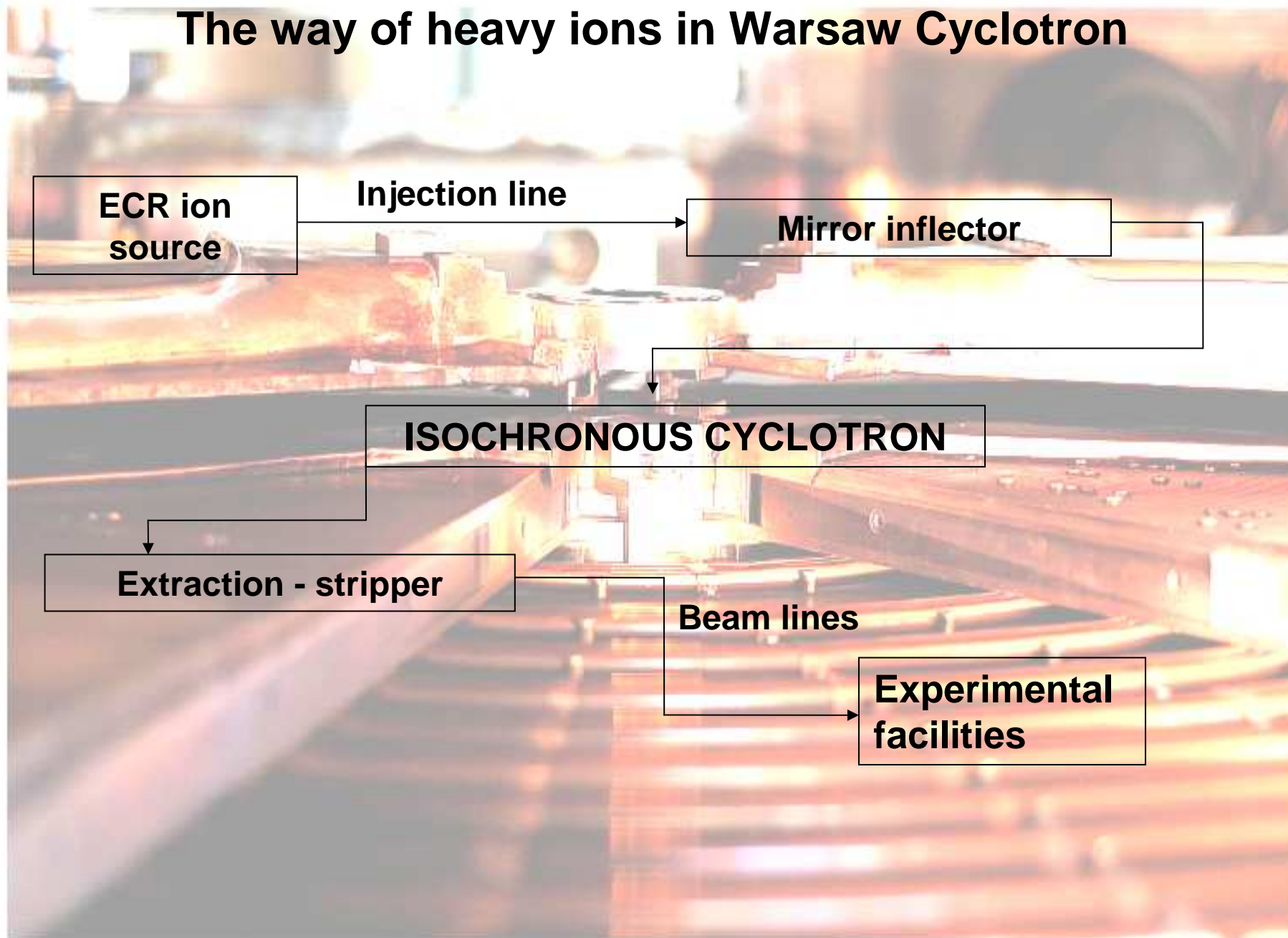
SYNCHROTRON



SYNCHROTRON



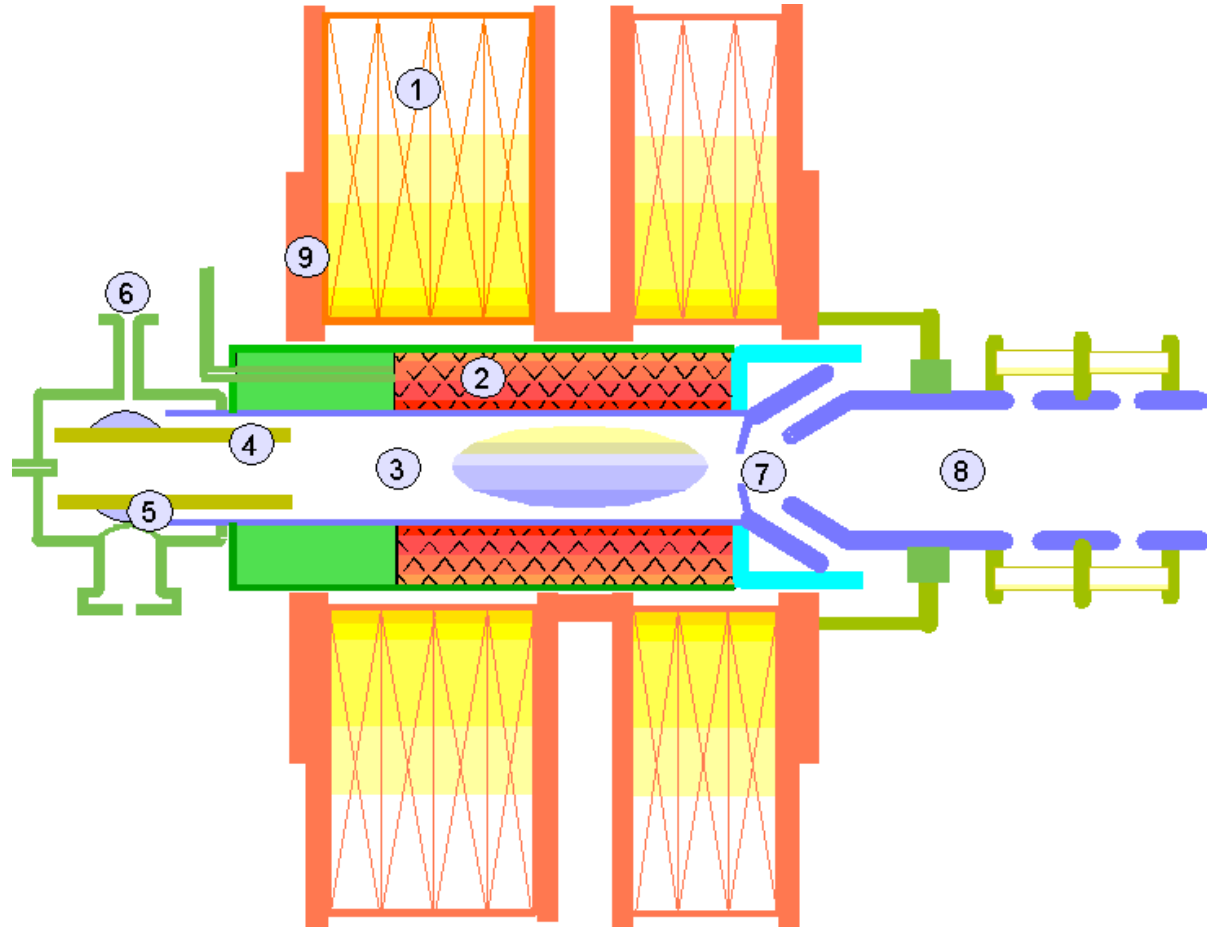
The way of heavy ions in Warsaw Cyclotron



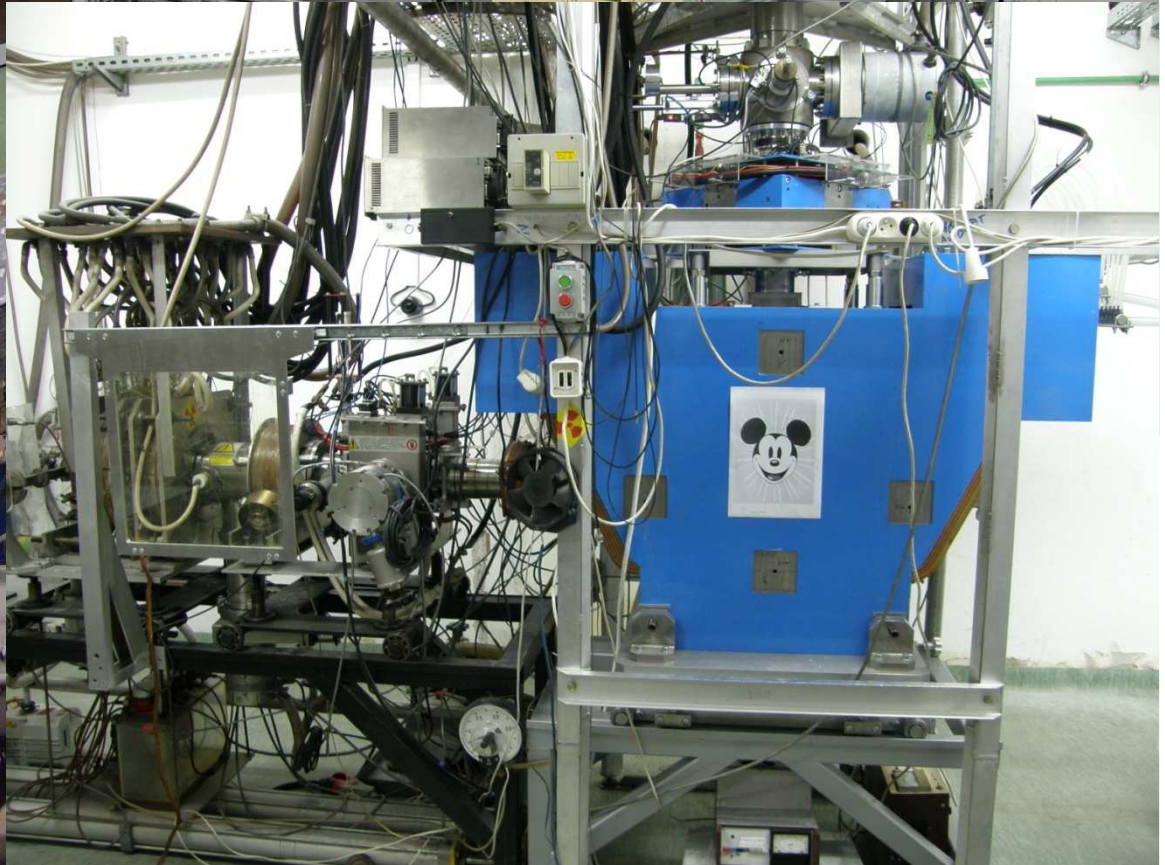
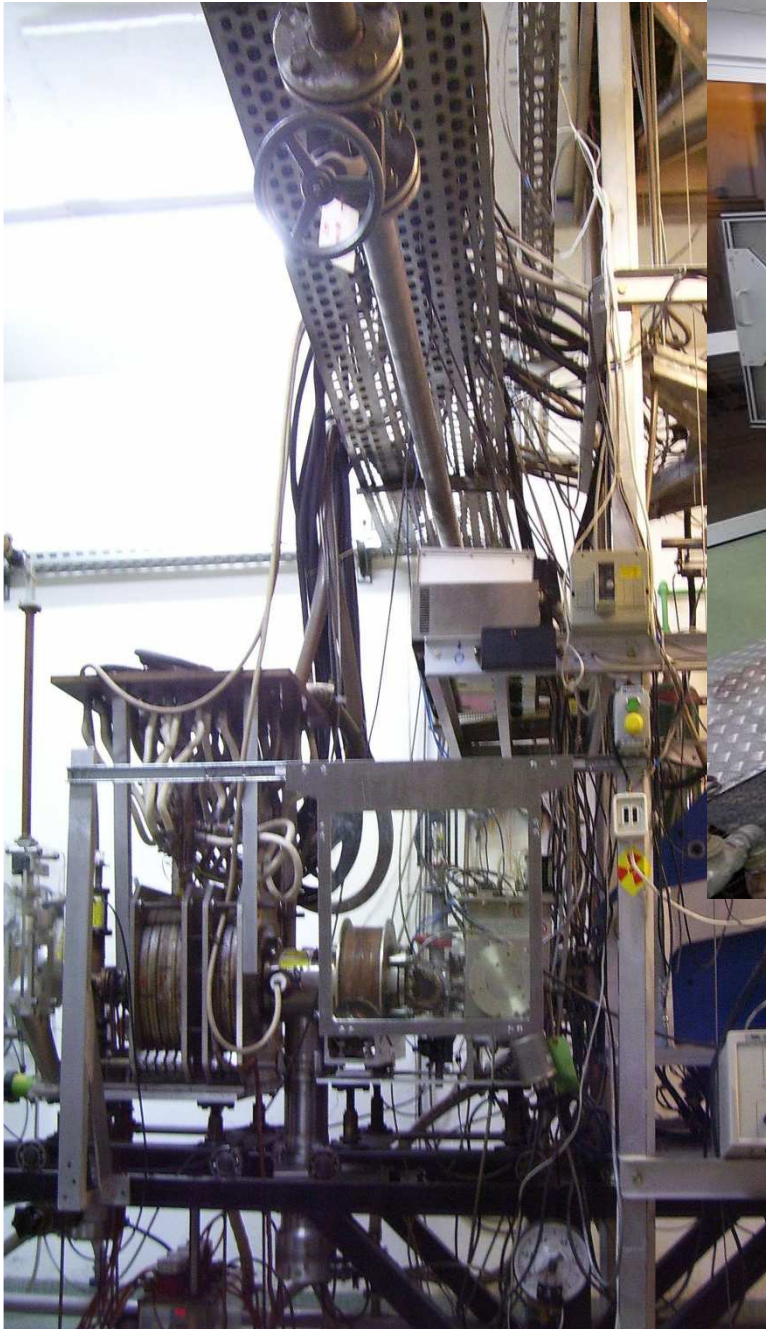
ECR ion source

(Electron Cyclotron Resonance)

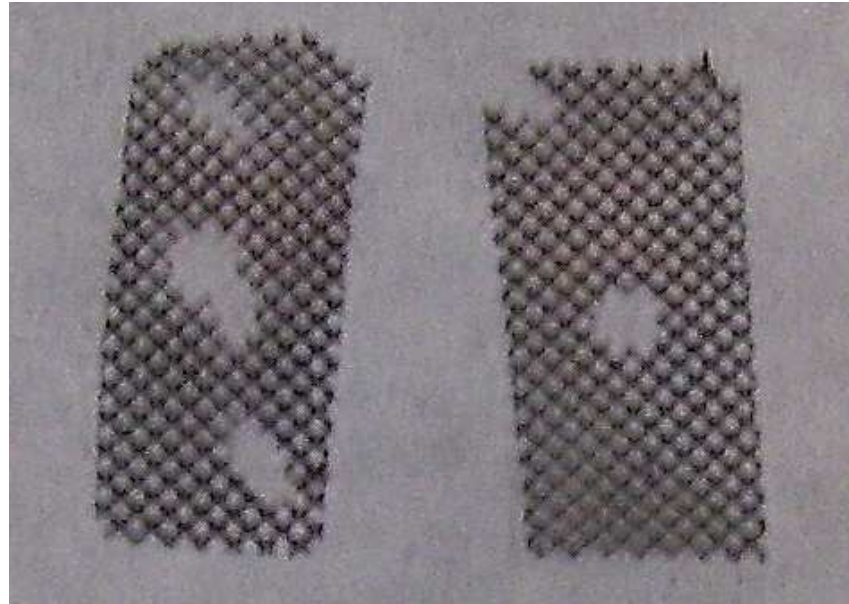
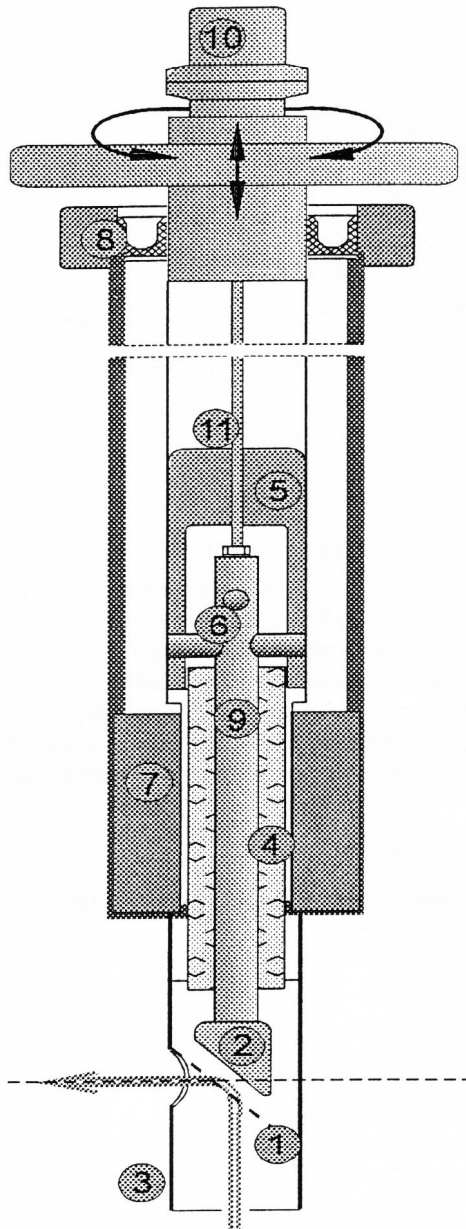
- 1. coils
- 2. hexapol
- 3. plasma chamber
- 4. coaxial line
- 5. tuner
- 6. RF injection
- 7. exit hole
- 8. Einzel lens
- 9. yoke



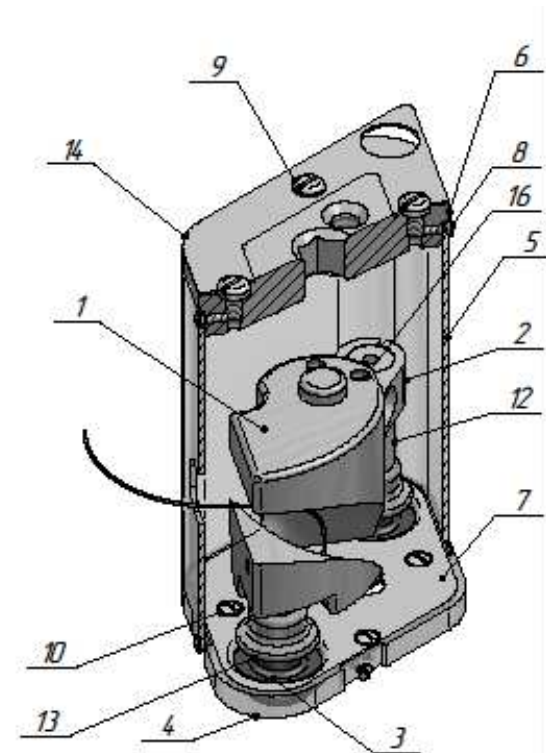
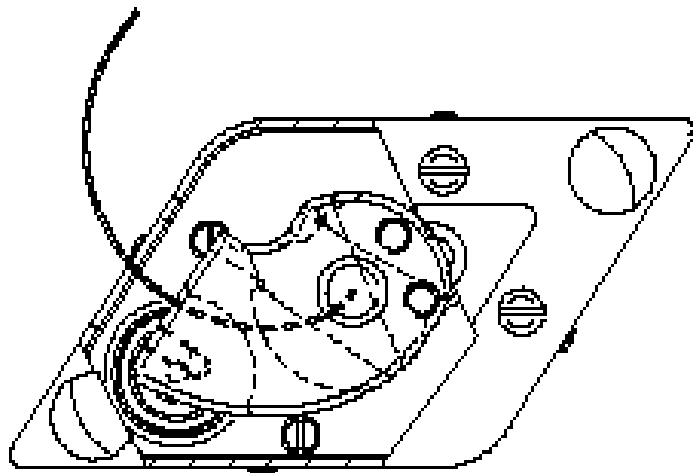
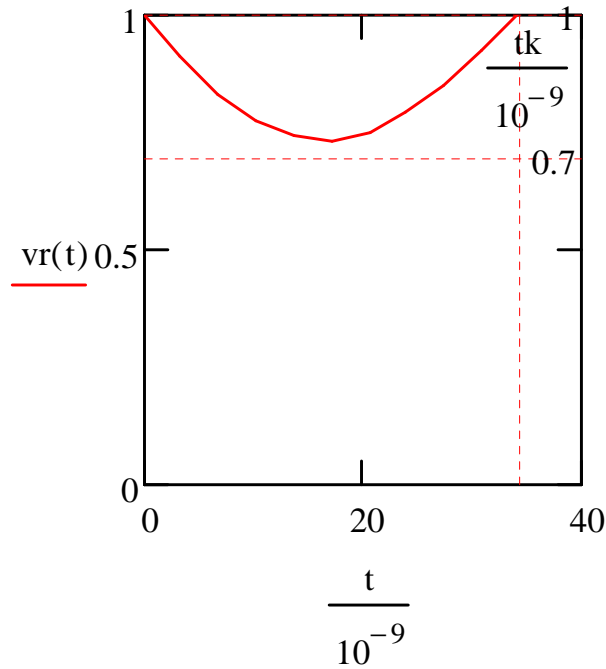
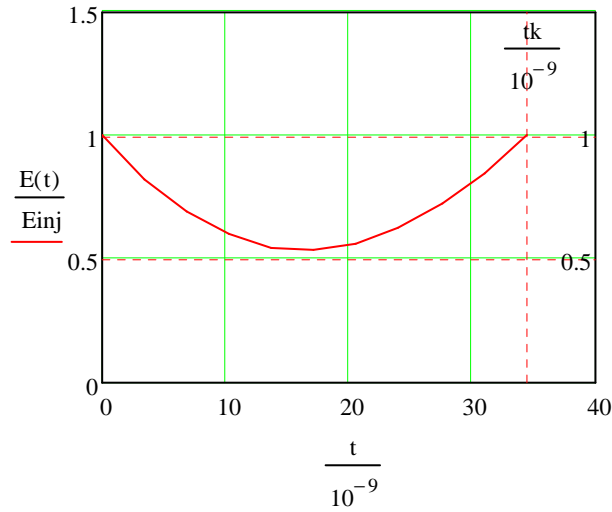
Our ion sources and injection line



Mirror inflector



Spiral inflector



				2990.02.00.00 Ошибка: Нет ссылки		
№	Изм.	№ докум.	Изд.	Дата	Изм.	Исполн.
Исполн.	Созд.	Созд.	Созд.	Созд.	0	2-1
Исполн.	Созд.	Созд.	Созд.	Созд.		
Исполн.	Созд.	Созд.	Созд.	Созд.		

Isochronous cyclotron

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

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

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

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

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

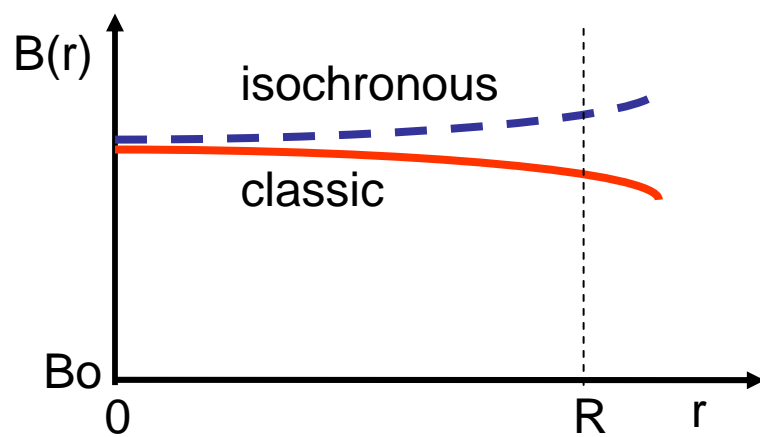
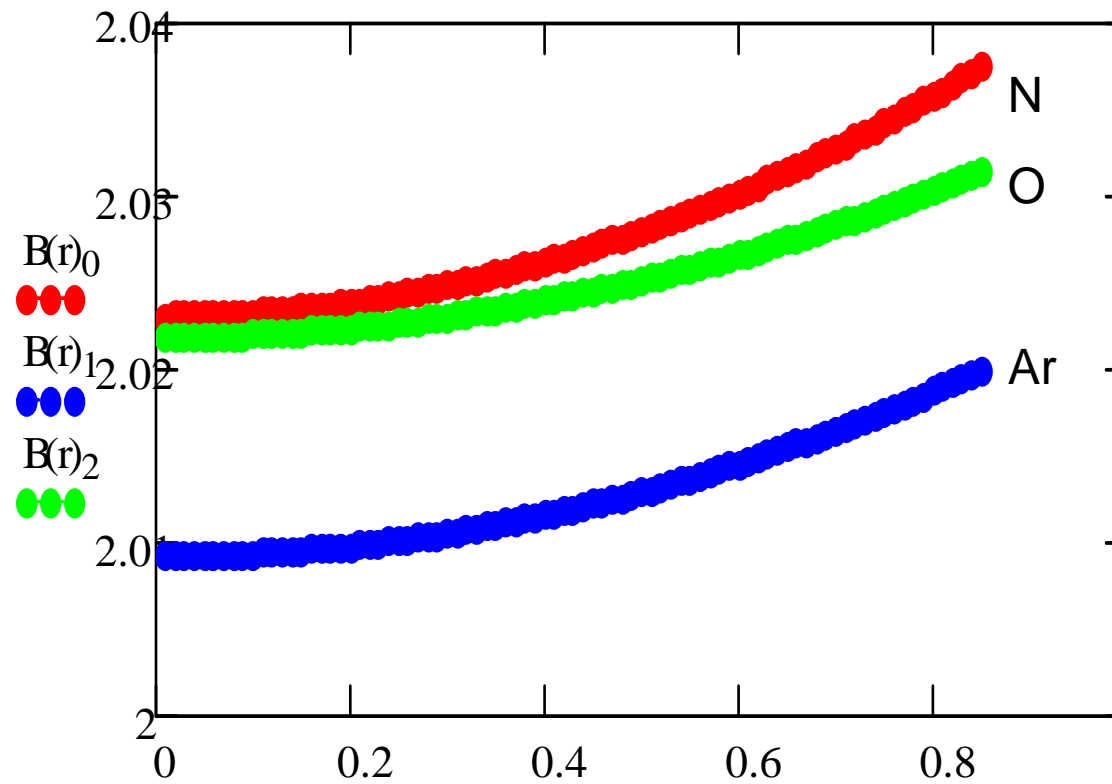
$$\gamma(r) = \frac{1}{\sqrt{1 - \left(\frac{v(r)}{c}\right)^2}} = \frac{1}{\sqrt{1 - \left(\frac{r \cdot \omega_c}{c}\right)^2}}$$

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

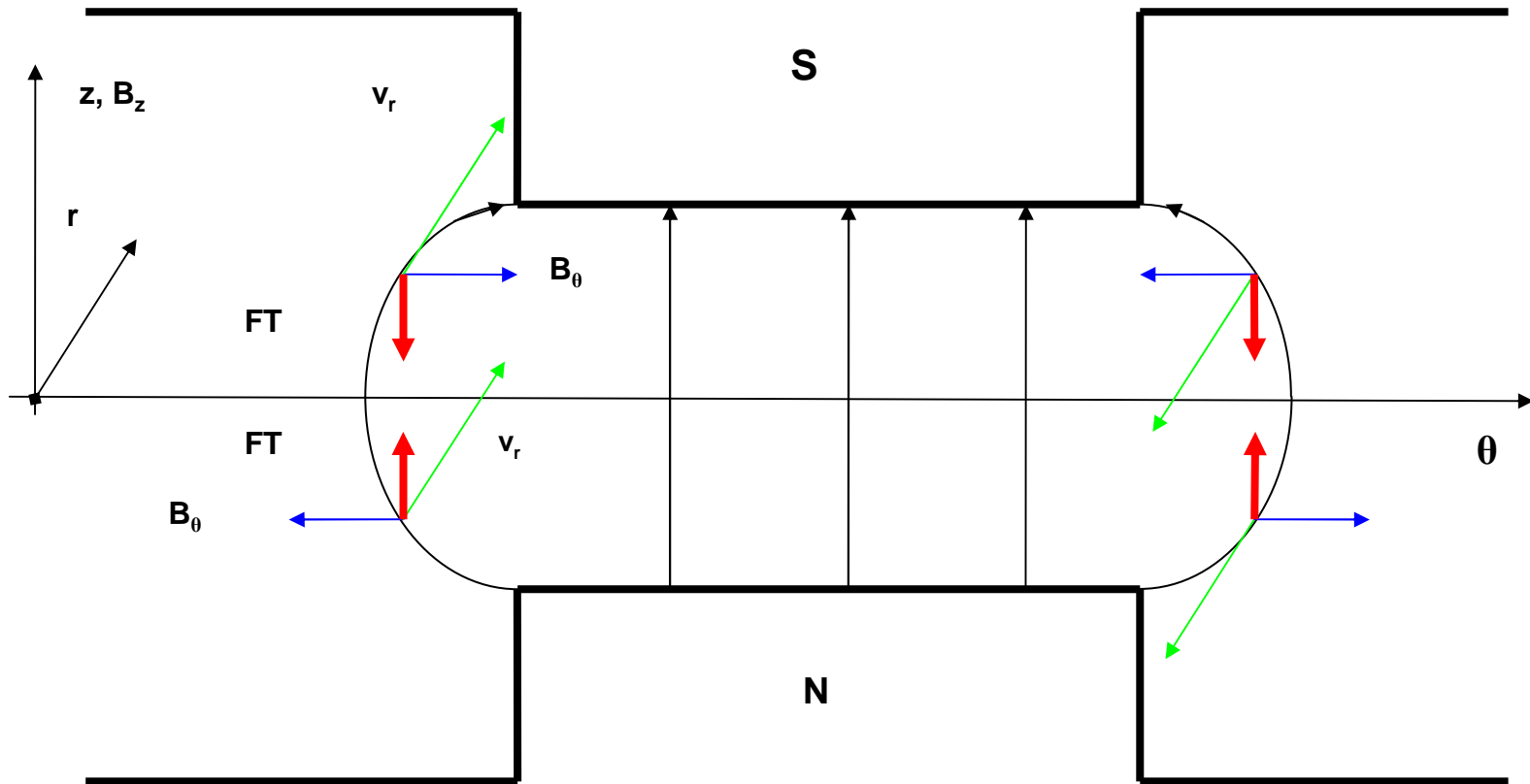
$$B(r) = \gamma(r) \cdot B_0$$

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

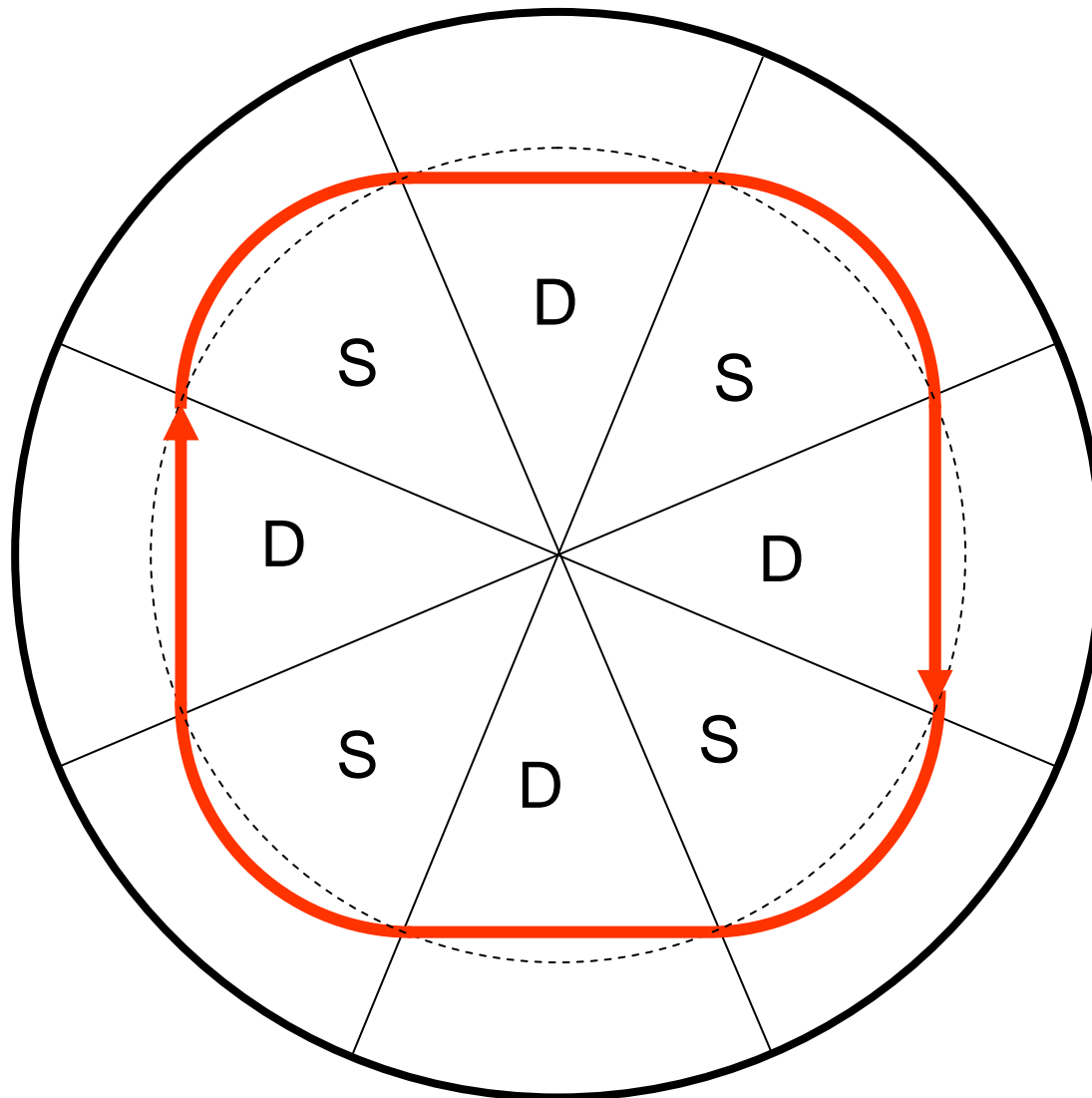
Isochronous cyclotron



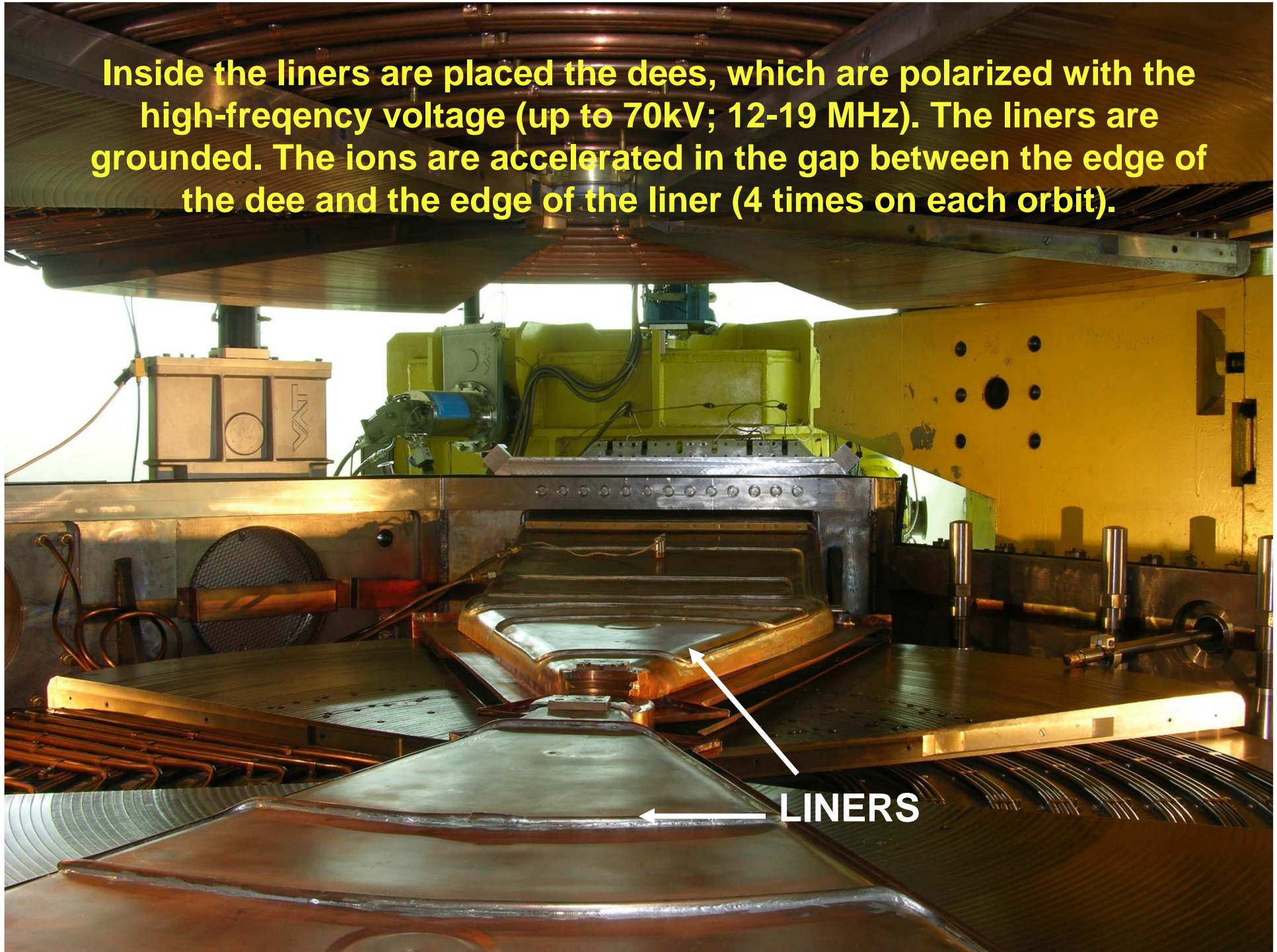
Thomas force

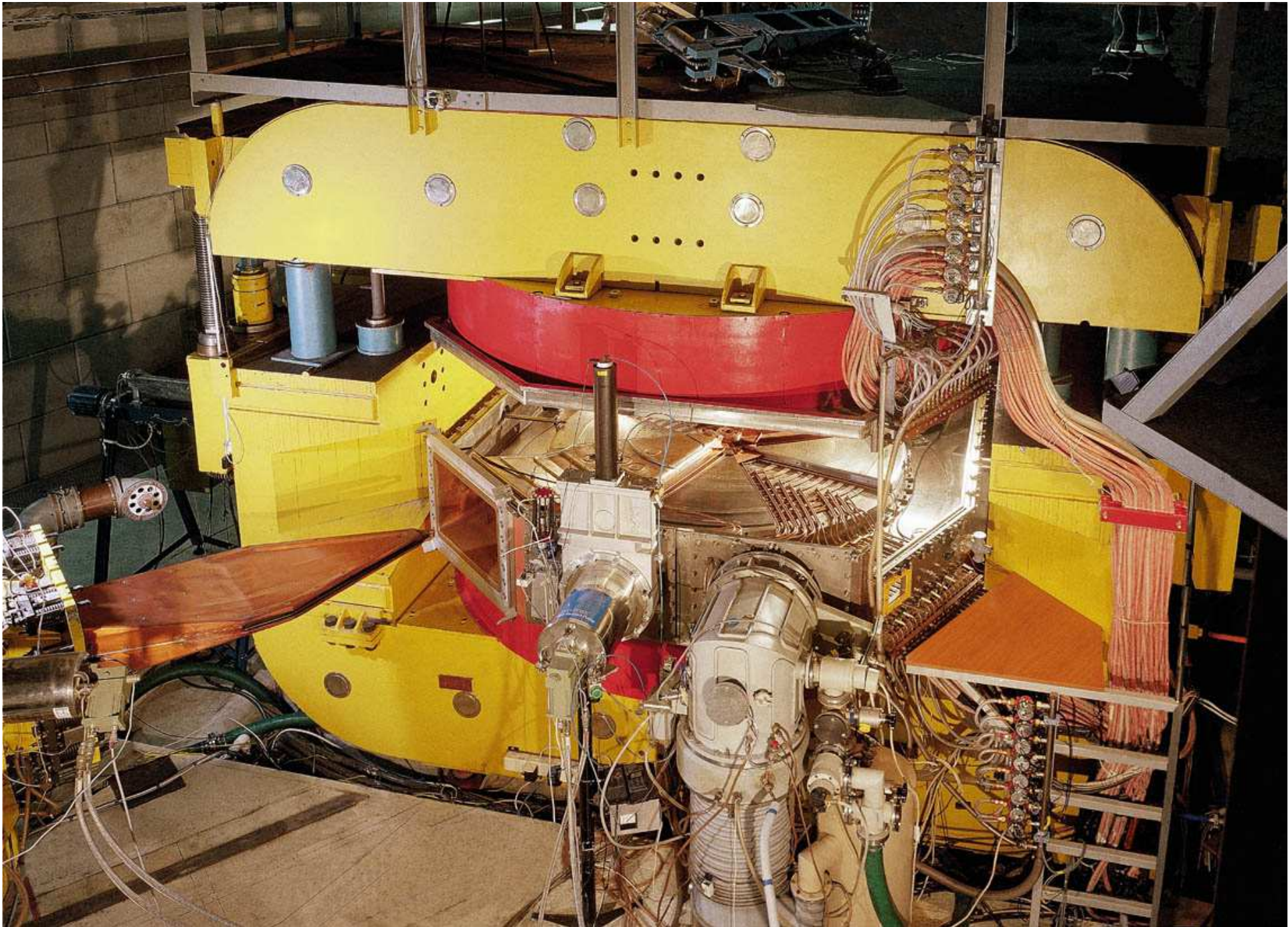


Thomas force

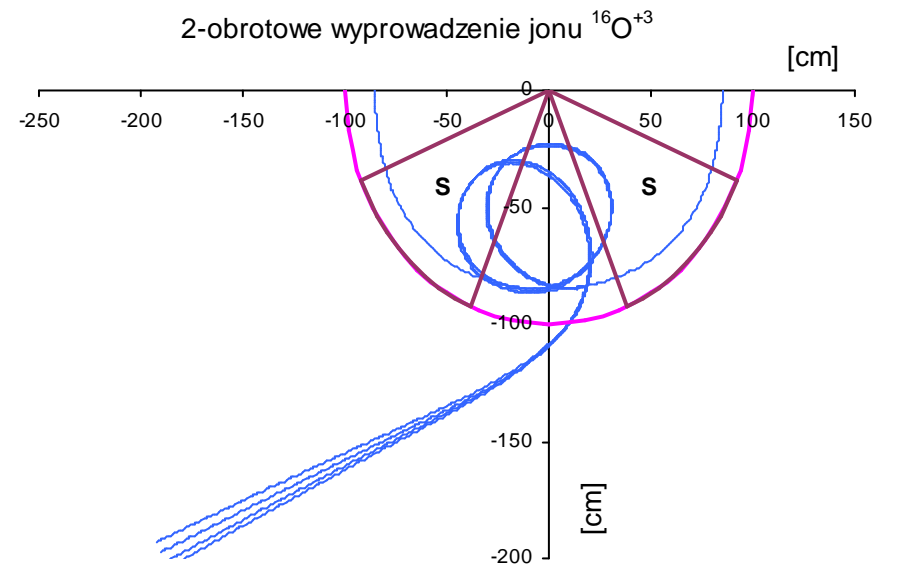
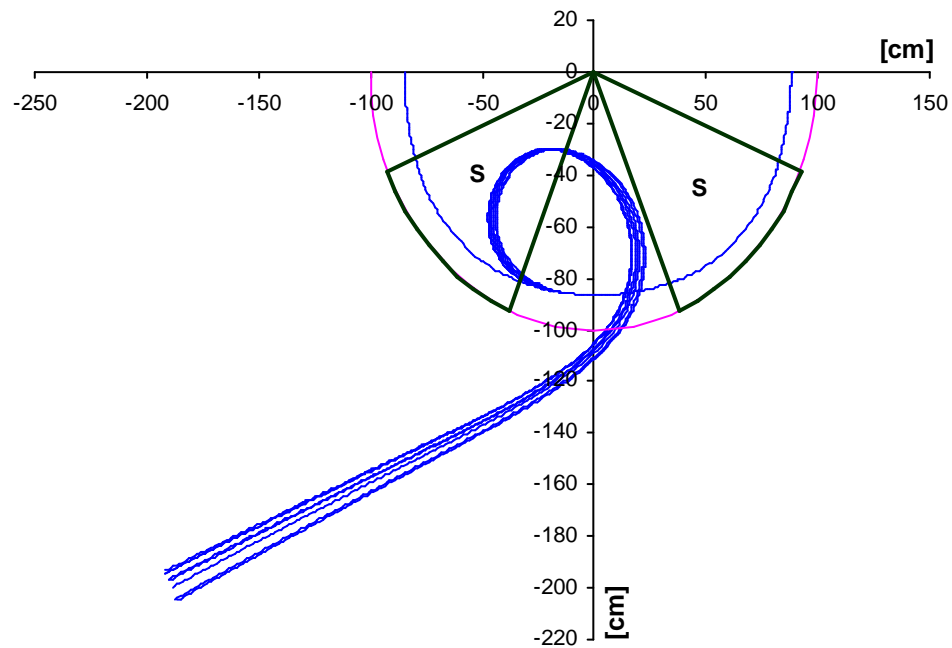


Inside the liners are placed the dees, which are polarized with the high-frequency voltage (up to 70kV; 12-19 MHz). The liners are grounded. The ions are accelerated in the gap between the edge of the dee and the edge of the liner (4 times on each orbit).

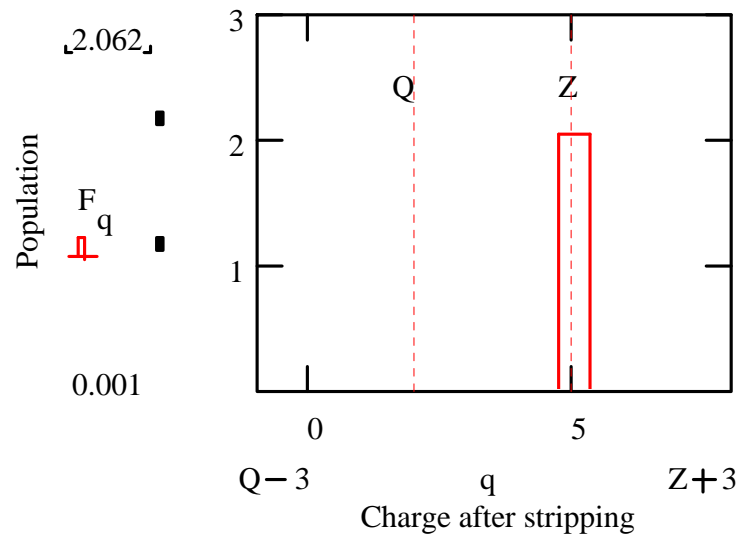




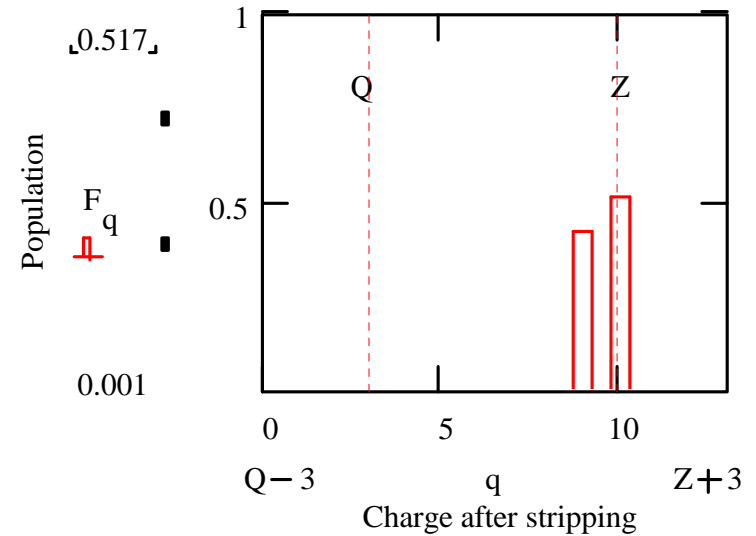
Extraction – stripper



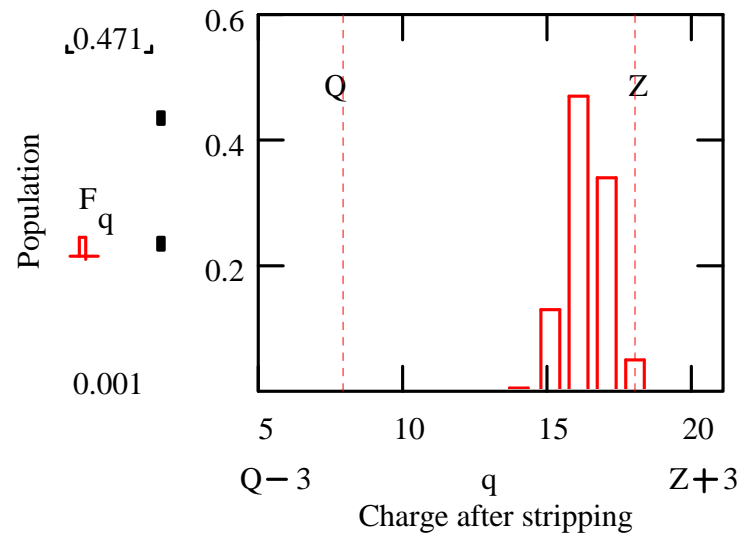
Dependence of the charge state population after stripping on the ion mass number A



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

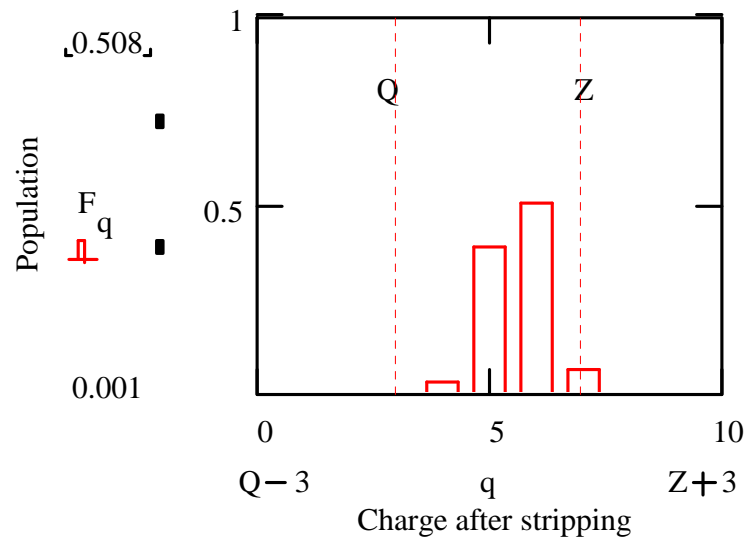


$A=20, Z=10, Q=3,$
 $E=5 \text{ MeV/A}$

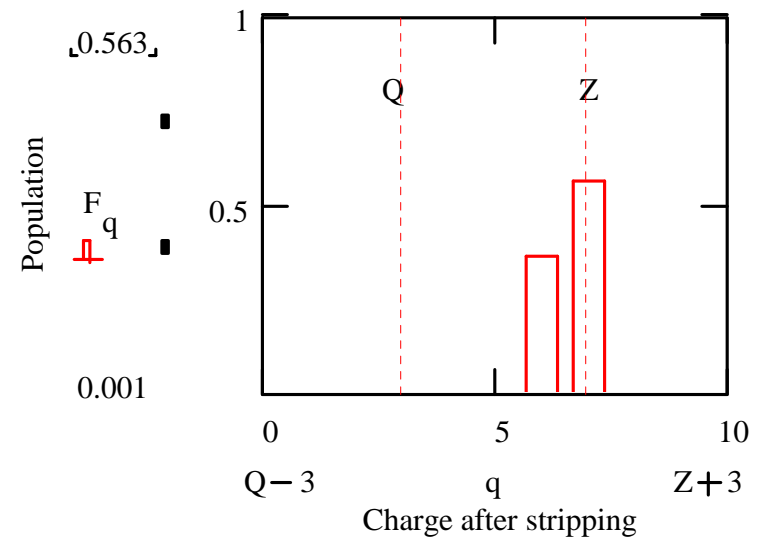


$A=40, Z=18, Q=8,$
 $E=5 \text{ MeV/A}$

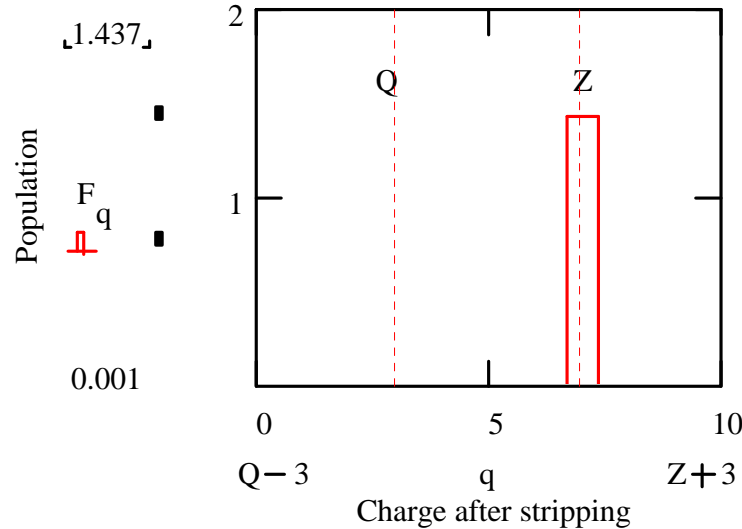
Dependence of the charge state population after stripping on the ion energy



$A=14, Z=7, Q=3,$
 $E=1 \text{ MeV/A}$

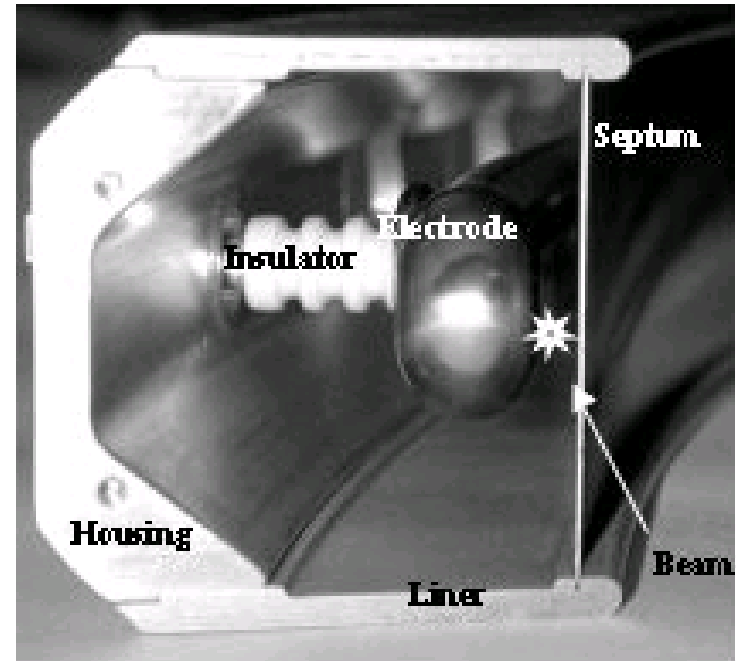
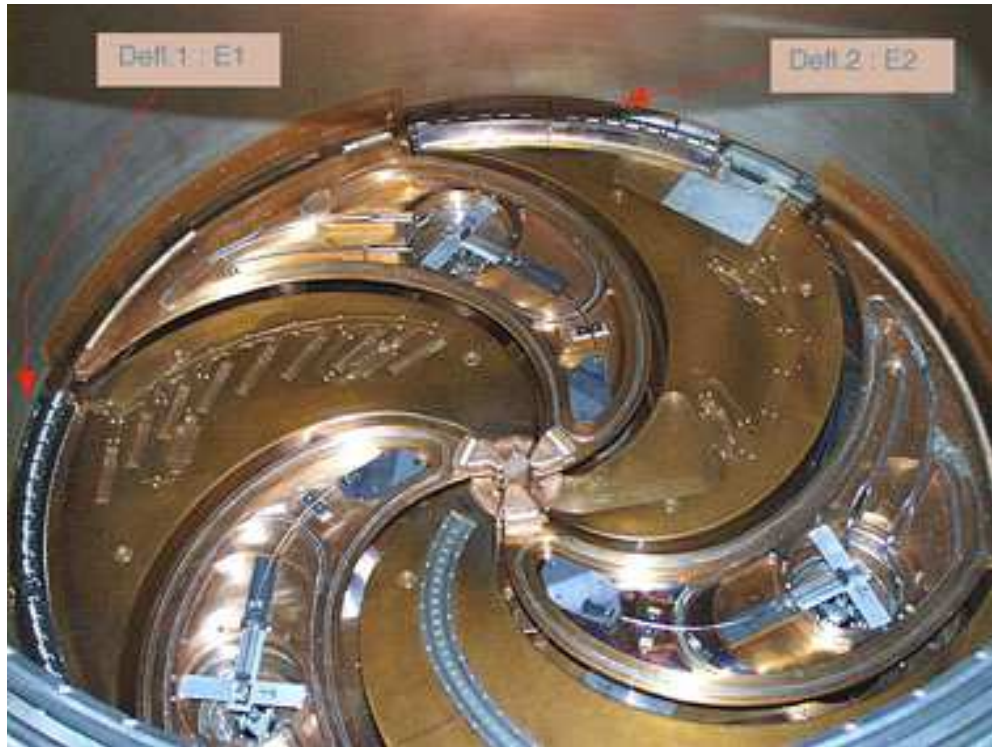


$A=14, Z=7, Q=3,$
 $E=3 \text{ MeV/A}$



$A=14, Z=7, Q=3,$
 $E=6 \text{ MeV/A}$

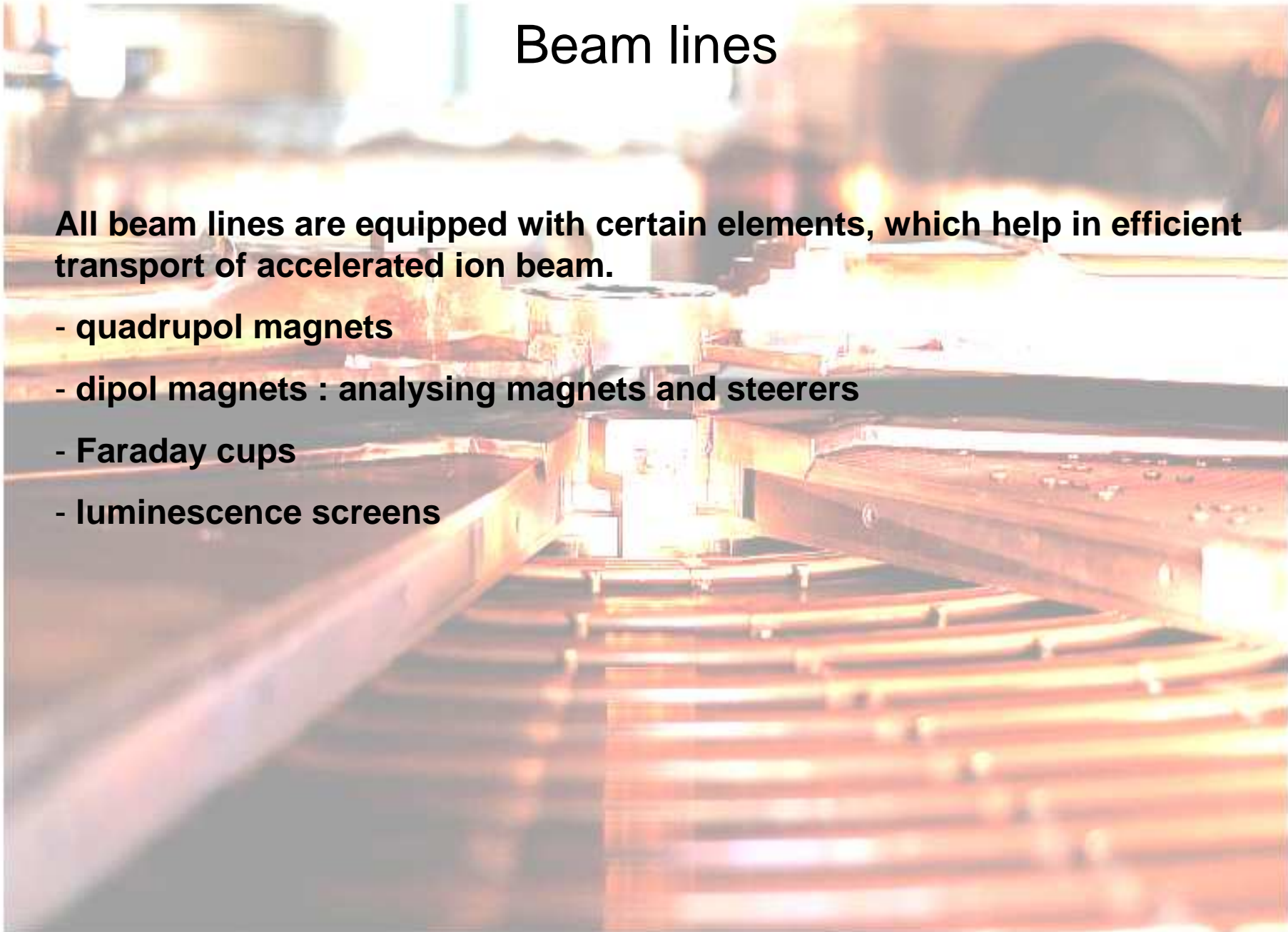
Extraction – electrostatic deflector



Beam lines

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

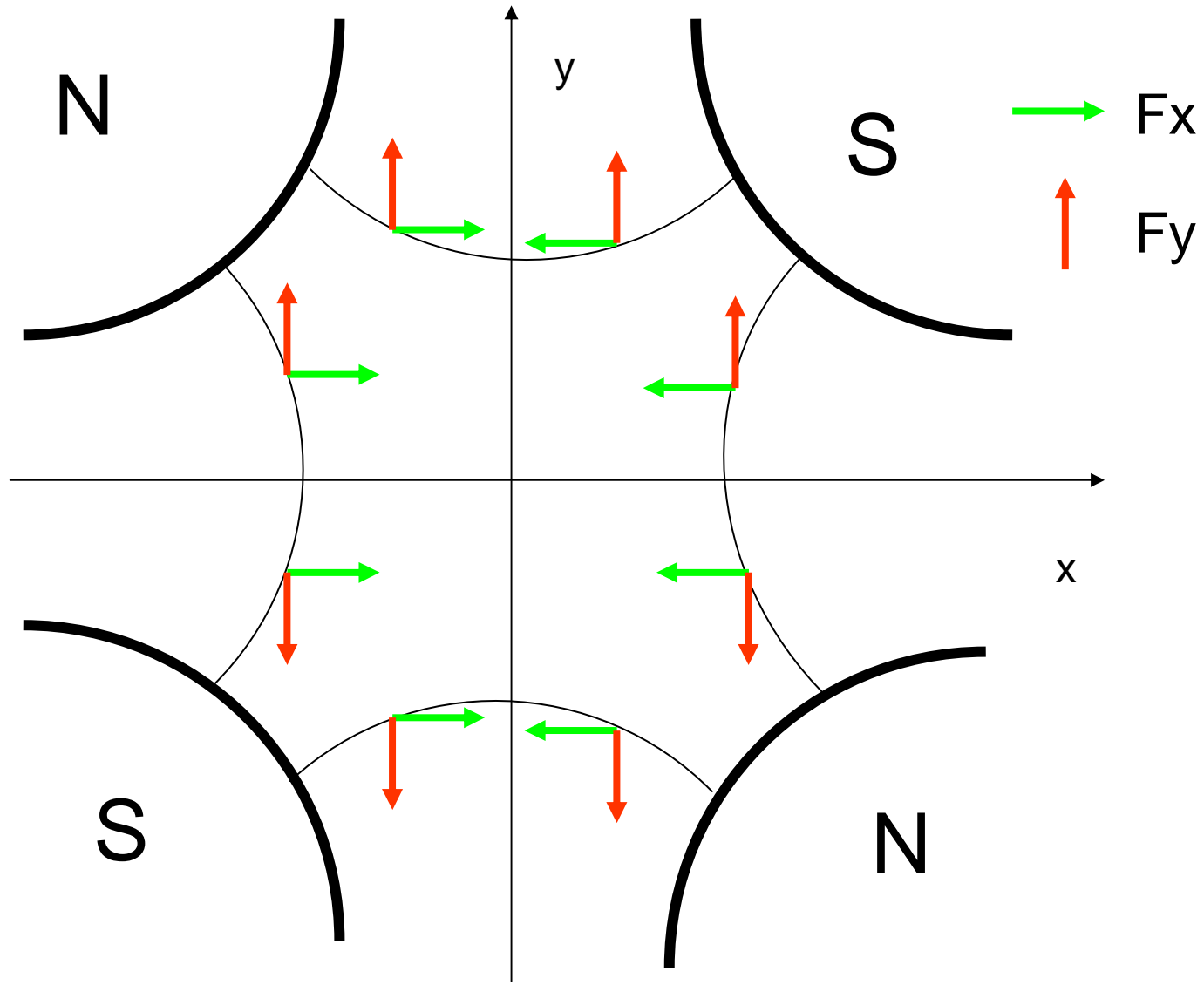
- quadrupol magnets
- dipol magnets : analysing magnets and steerers
- Faraday cups
- luminescence screens



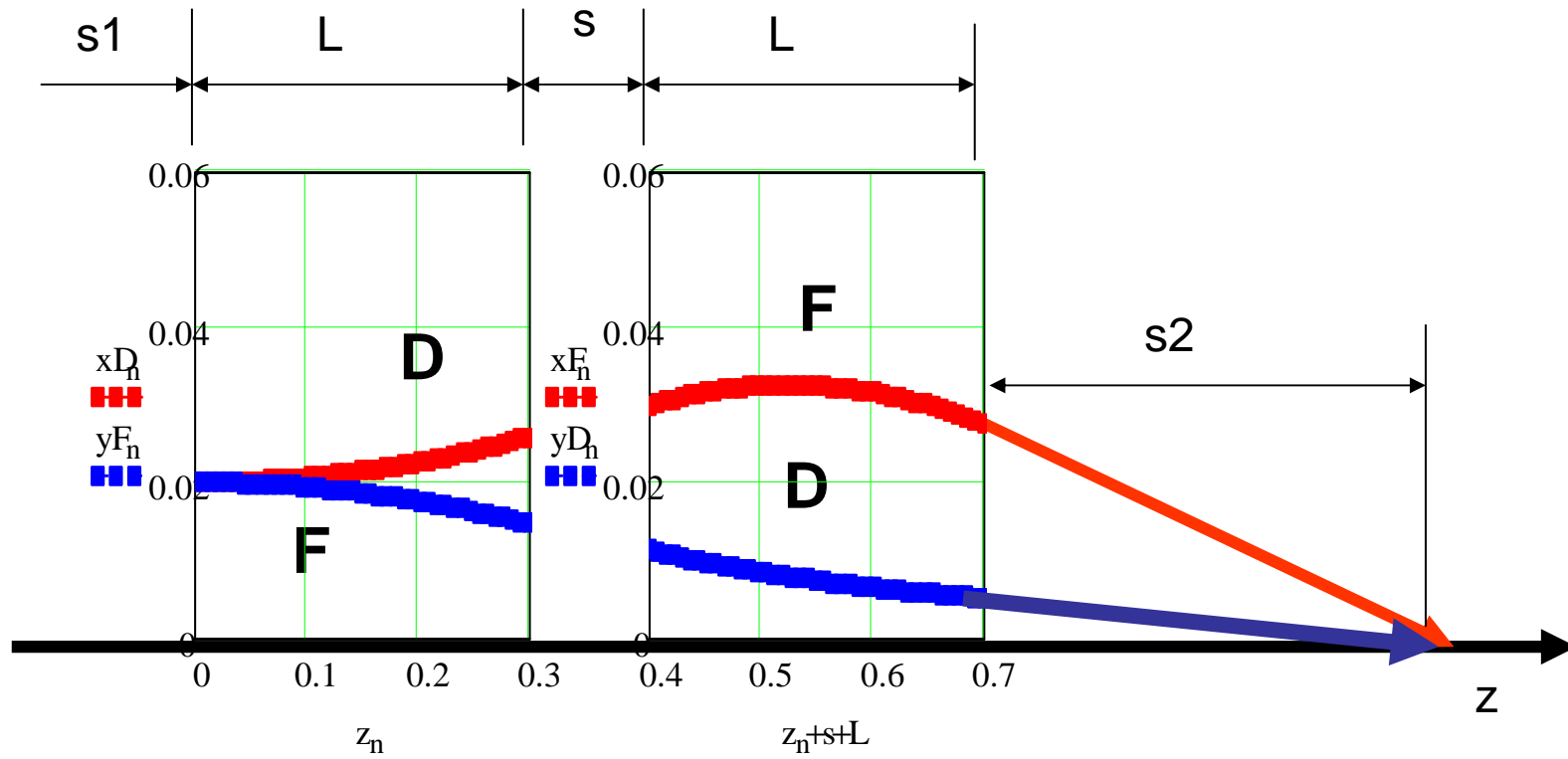
Quadrupol magnet



Quadrupol magnet



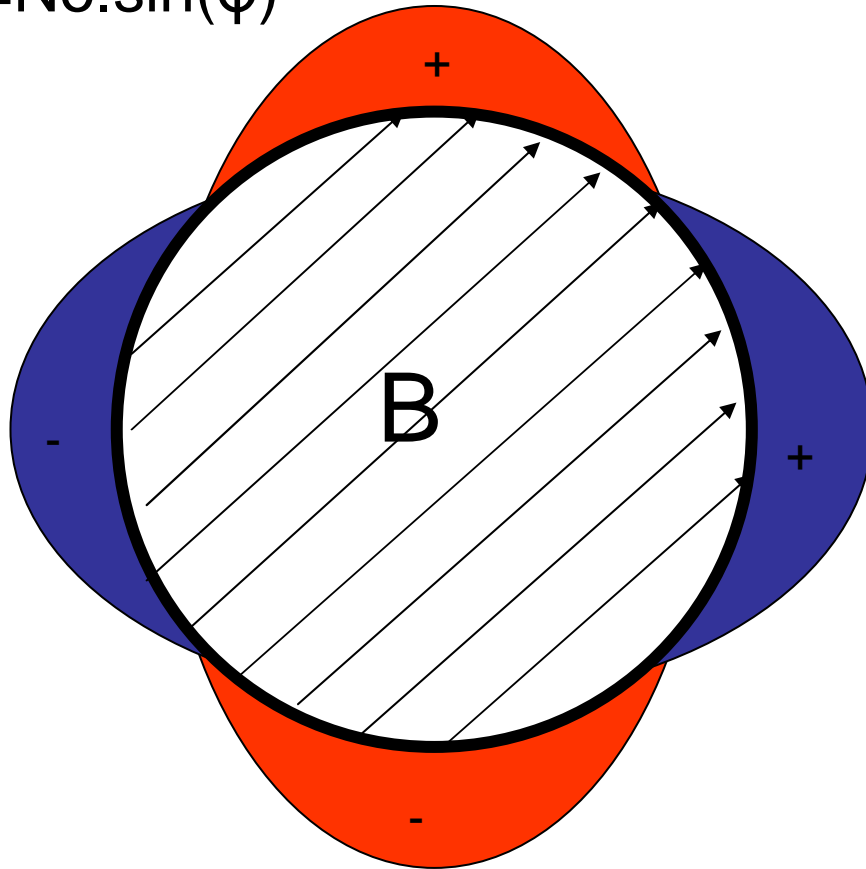
Quadrupol magnet



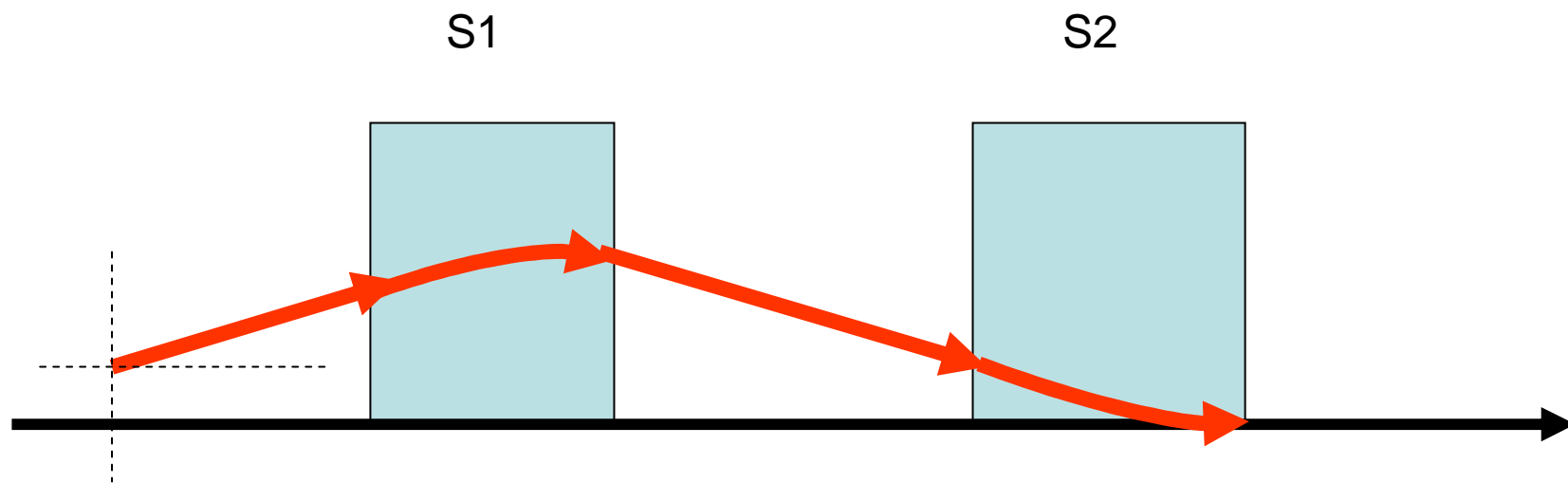
Dipol magnet - steerer

$$N1 = N_0 \cdot \cos(\varphi)$$

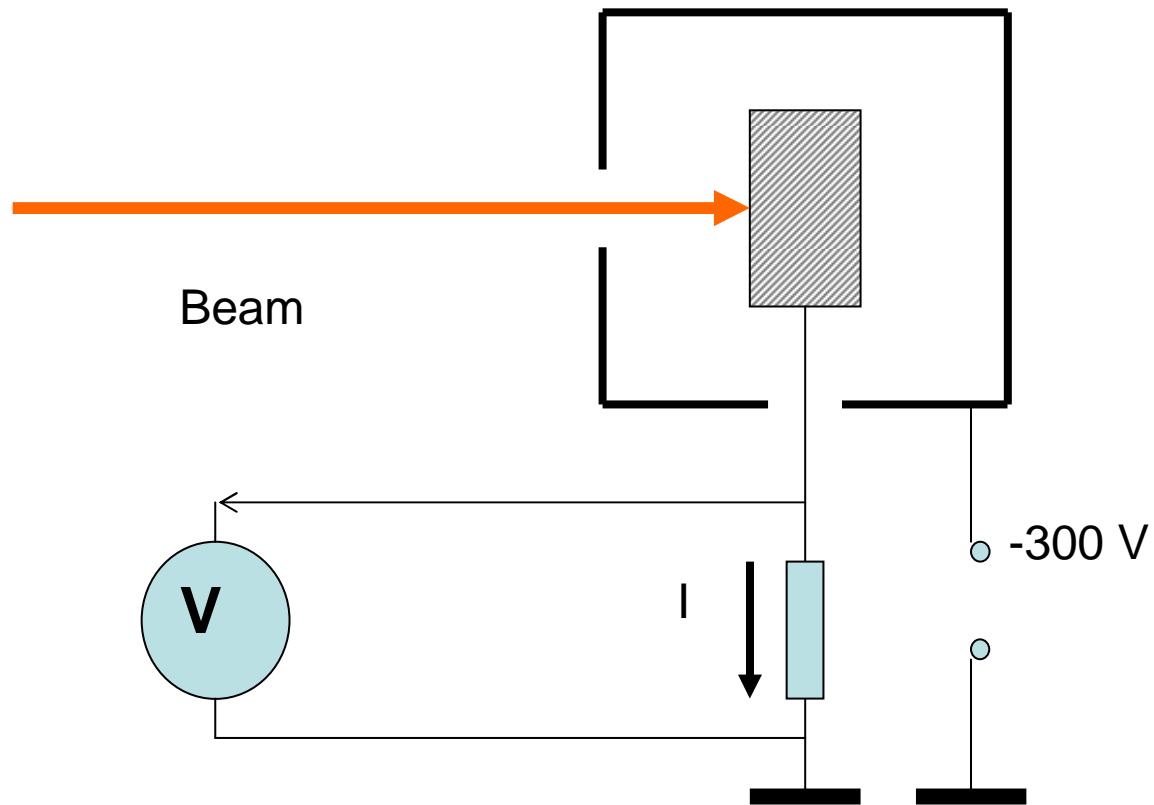
$$N2 = N_0 \cdot \sin(\varphi)$$



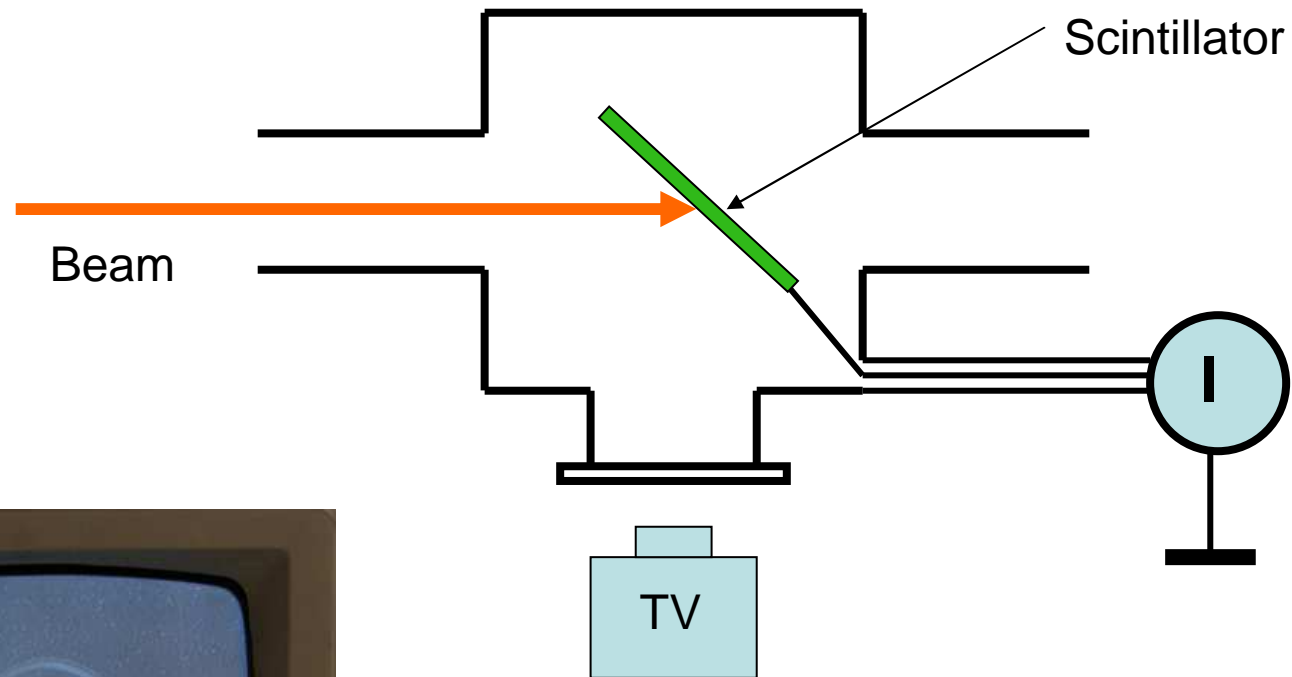
Dipol magnet - steerer

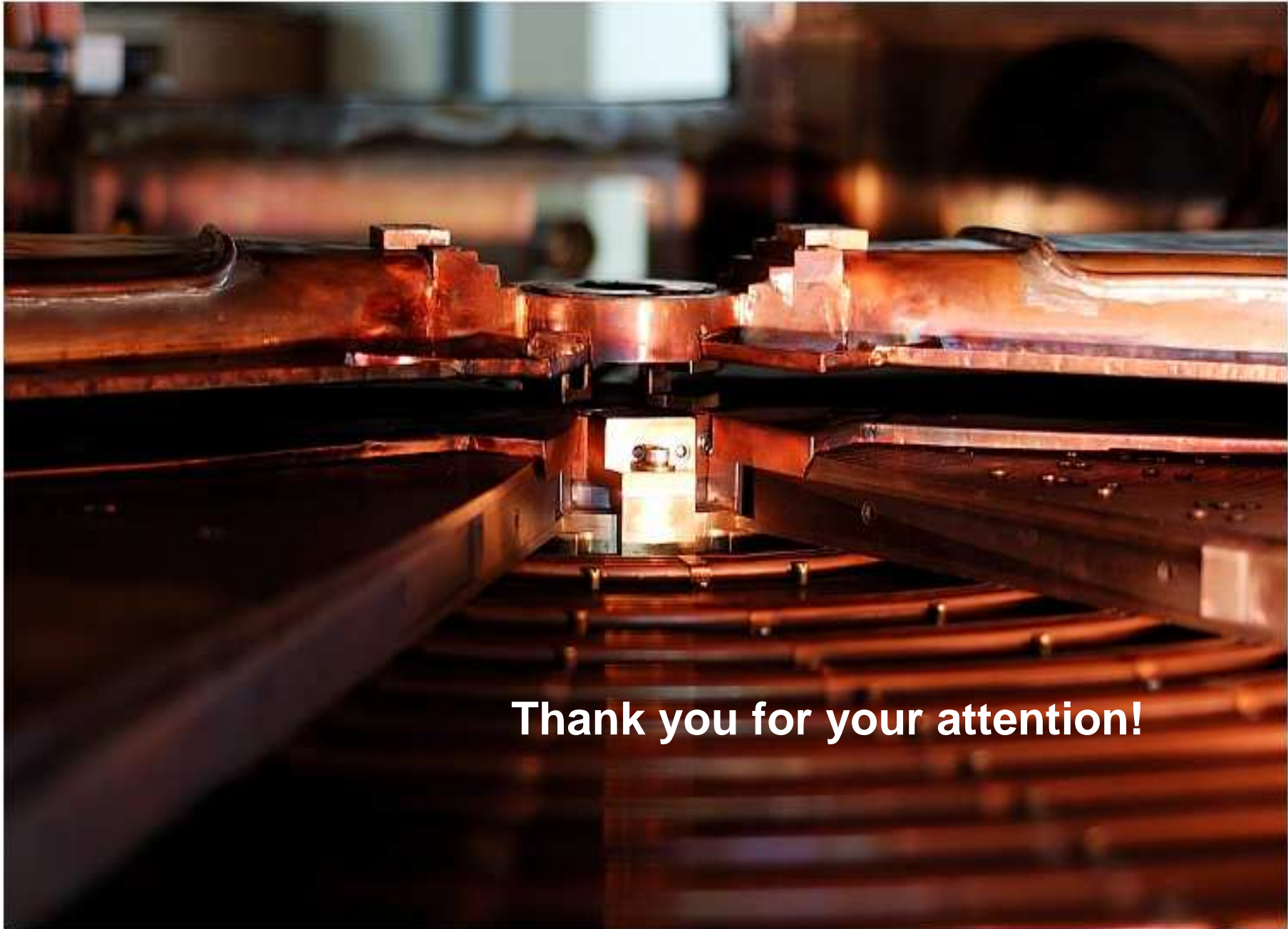


Beam diagnostic – Faraday cup



Beam diagnostic - „luminescence”





Thank you for your attention!