PSI's **SC cyclotron "COMET"** for proton therapy

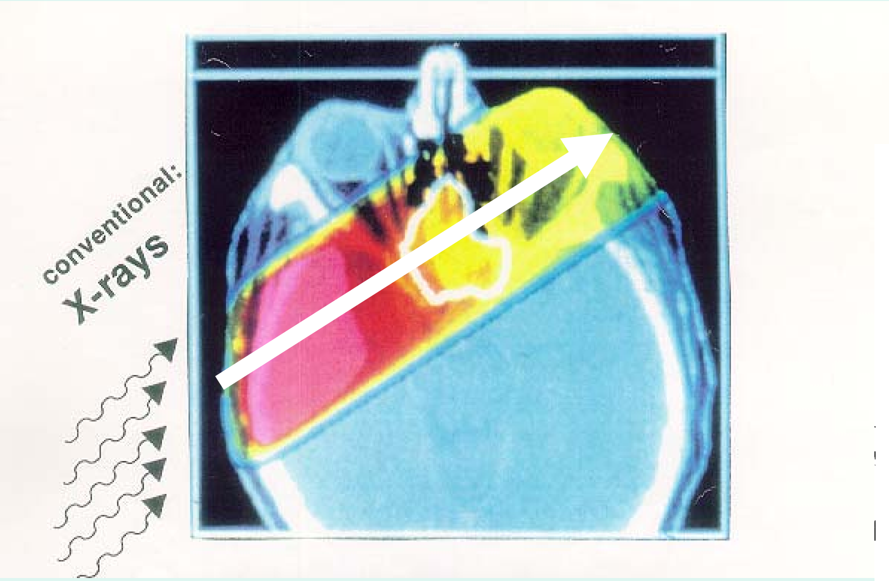
Marco Schippers

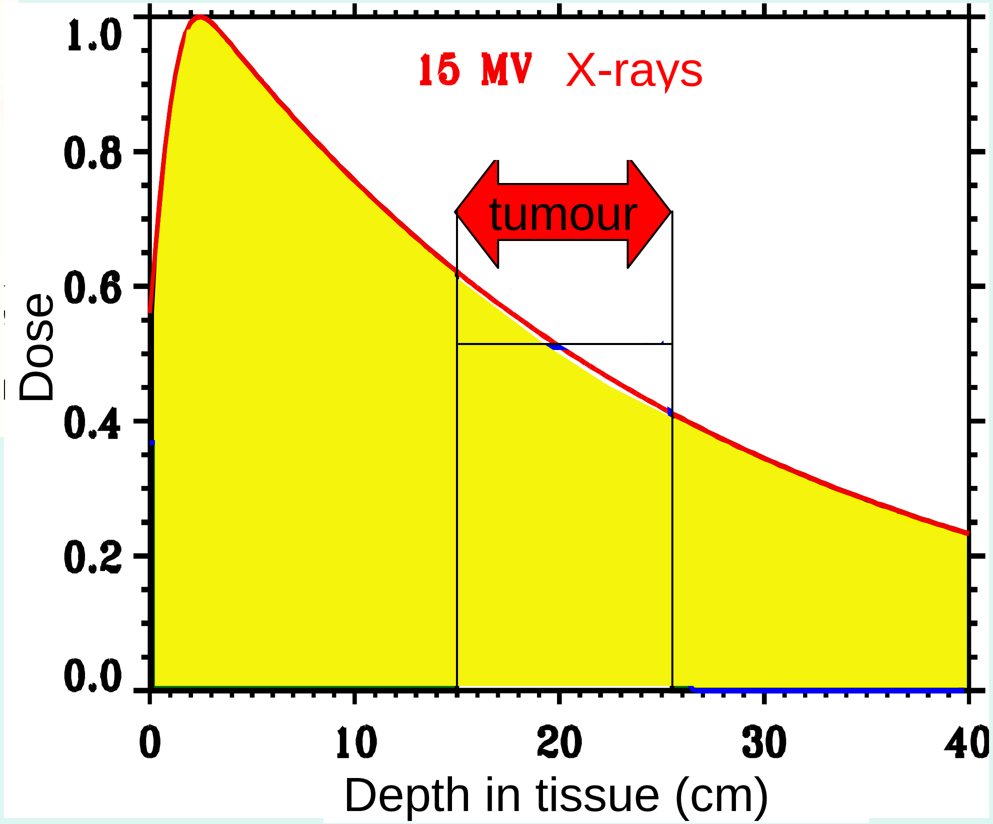
PAUL SCHERRER INSTITUT

Contents

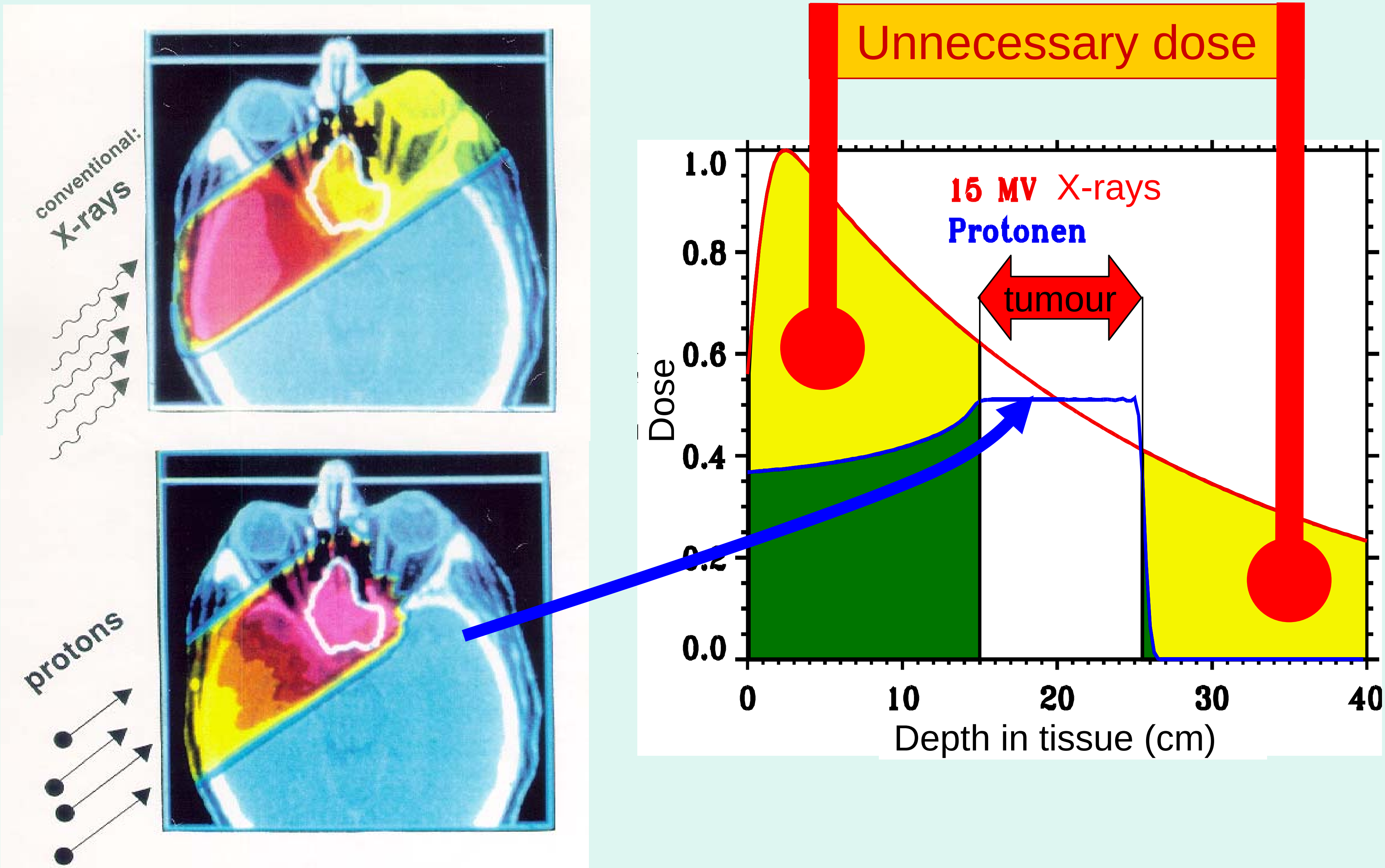
- **Proton therapy**
- **Dose delivery techniques**
- **Cyclotron**

X-rays vs. Protons





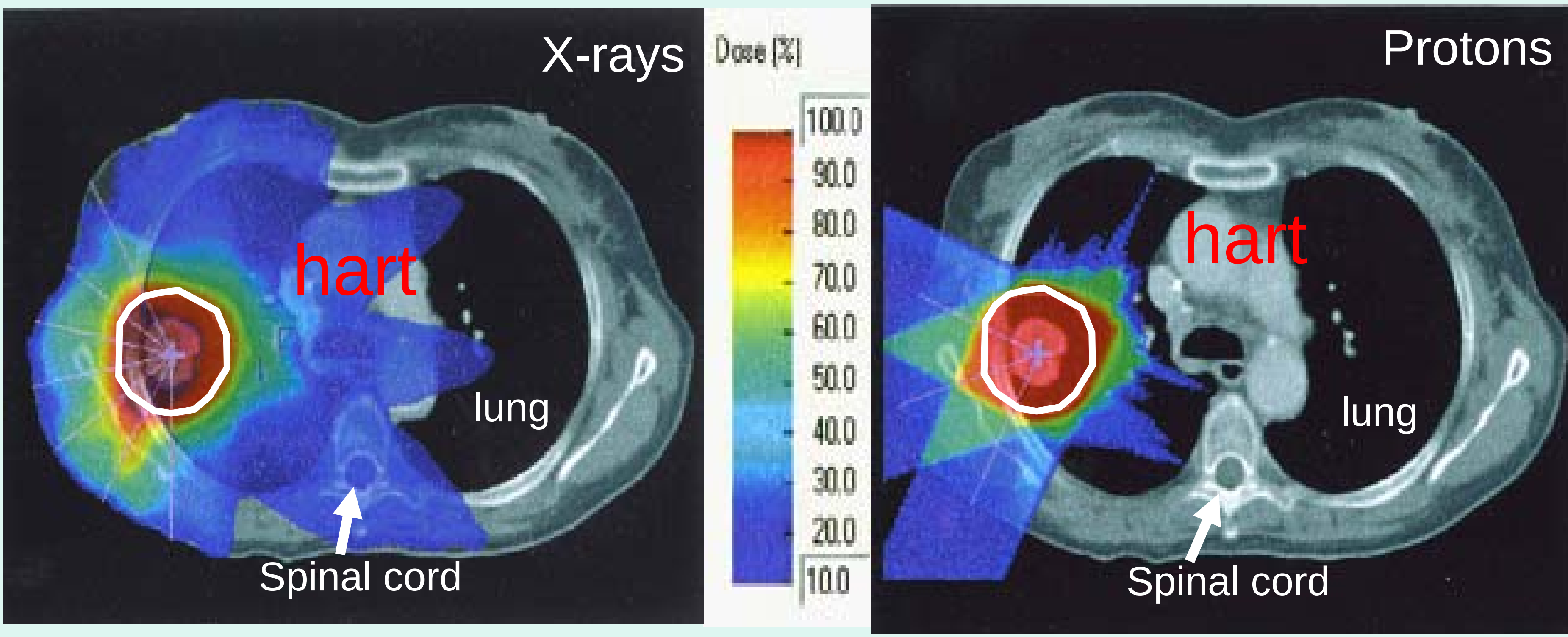
X-rays vs. Protons



X-rays vs. Protons

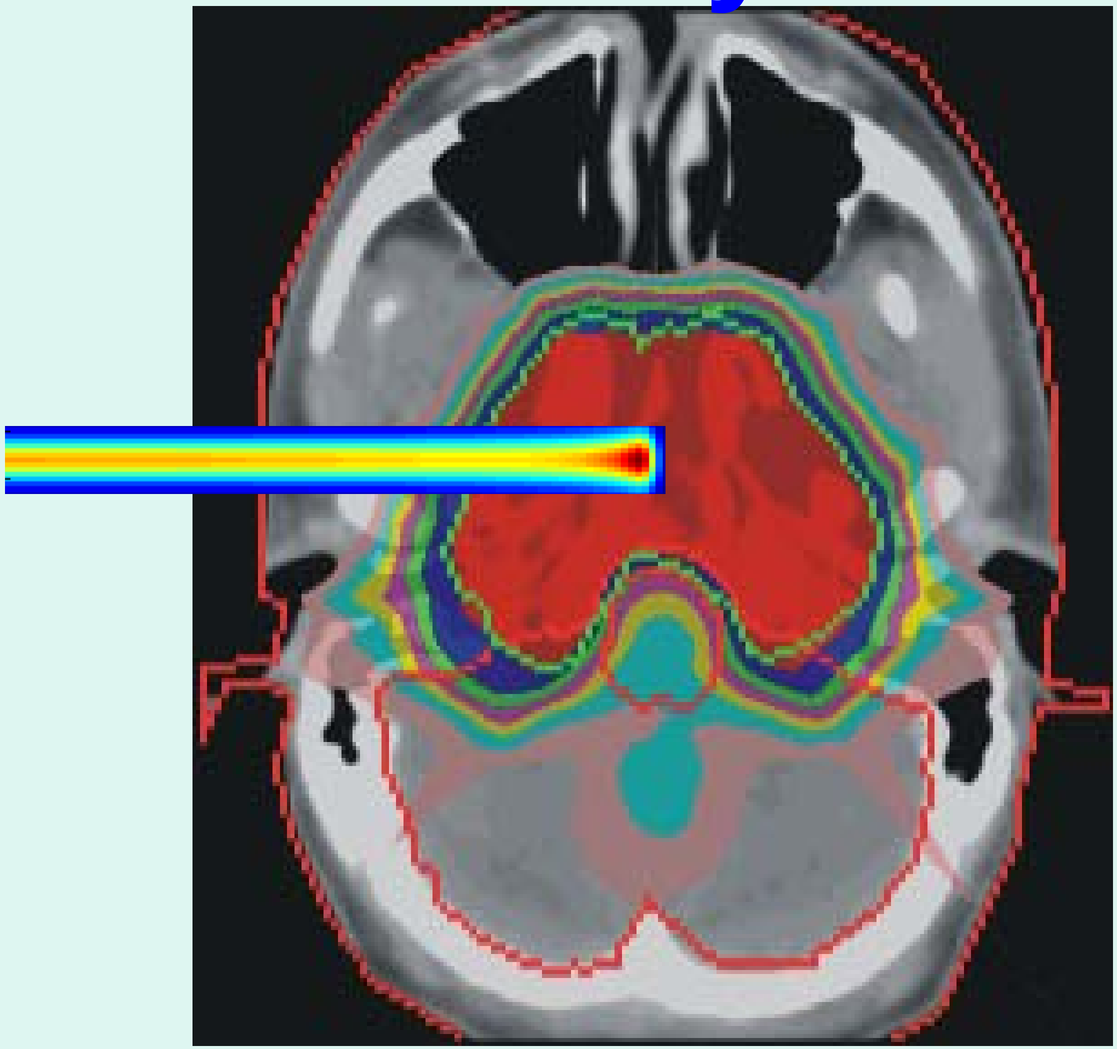
X-ray beams (IMRT)
from 7 directions

Proton beams
from 3 directions

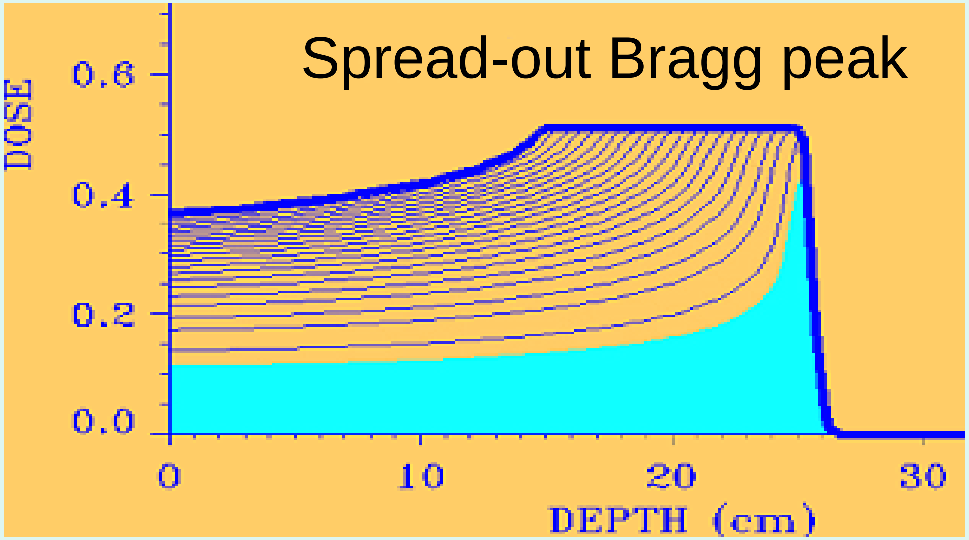


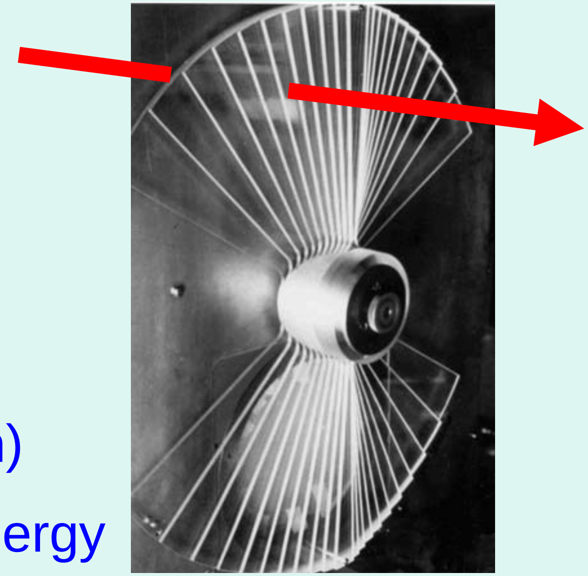
pictures: Medaustron

Dose delivery techniques



Dose delivery techniques: **Depth**





Methods to control depth:

1) Vary energy in accelerator (**synchrotron**)

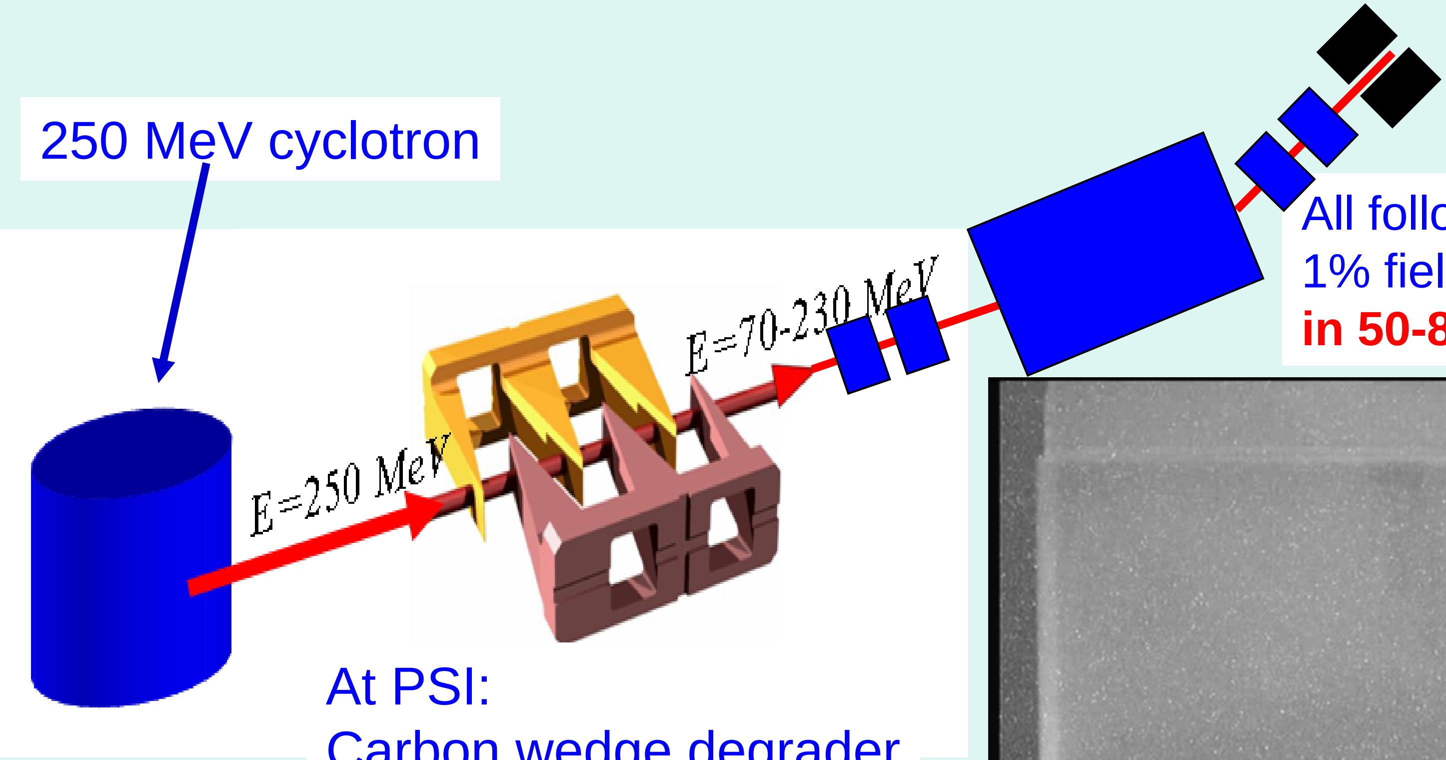
2) Slow down from a fixed to the desired energy

   - modulate "just" before patient (in "nozzle")

   - at start of beam transport **(cyclotron)**

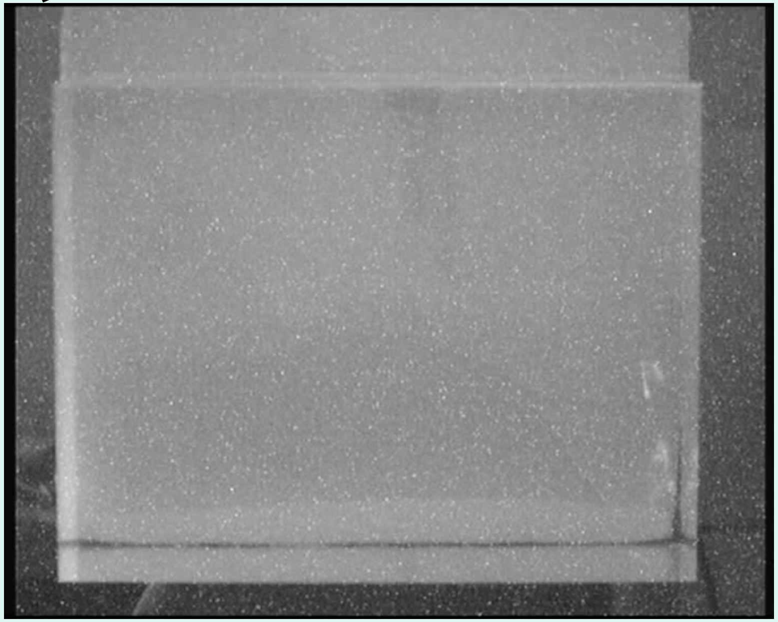
Dose delivery techniques: **Depth**

250 MeV cyclotron



At PSI:
Carbon wedge degrader
238-70 MeV

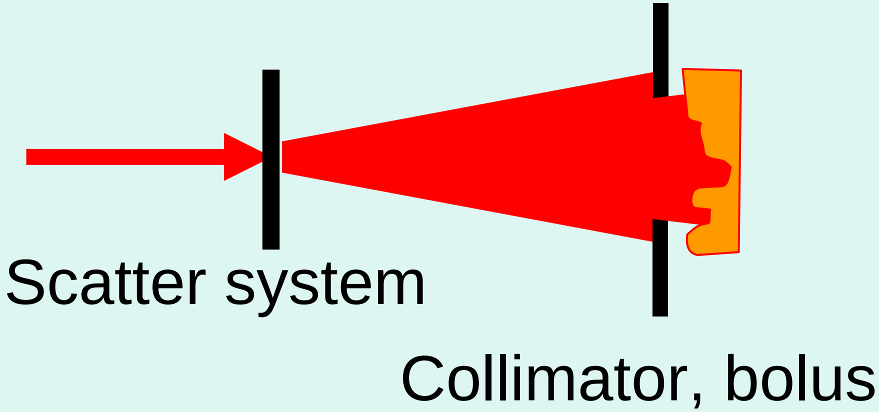
All following magnets:
1% field change
in 50-80 ms

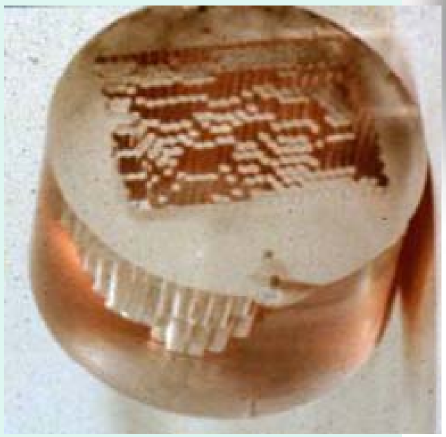


→ fast treatment
→ fast room switching

Dose delivery techniques: **lateral**

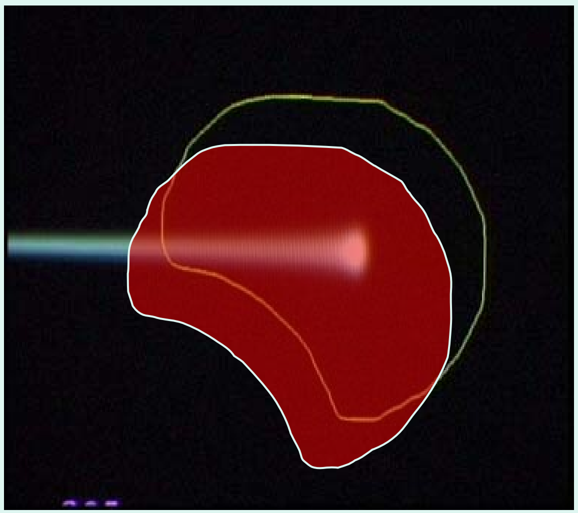
Scatter technique



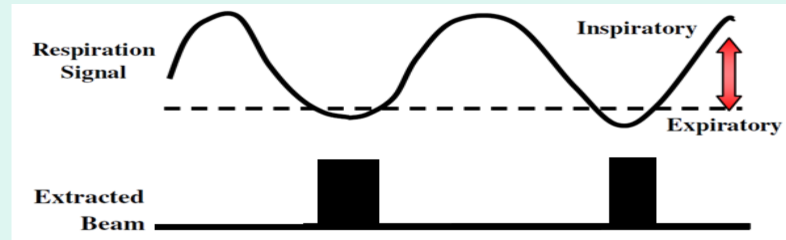


Possible solutions:

Organ motion

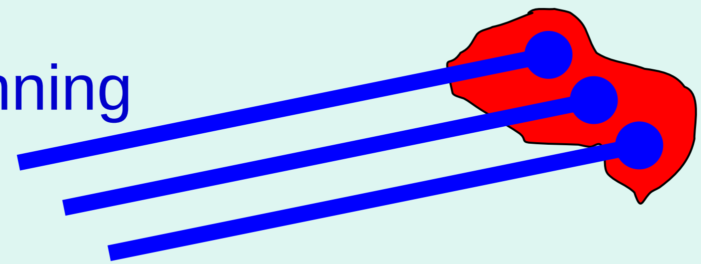


- Gating

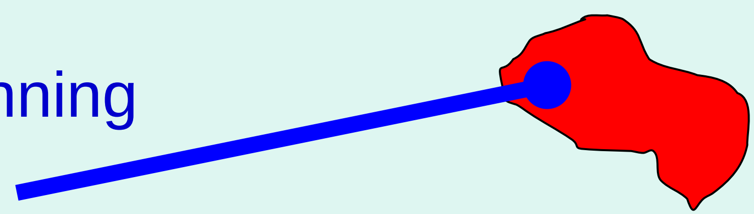


- Adaptive scanning

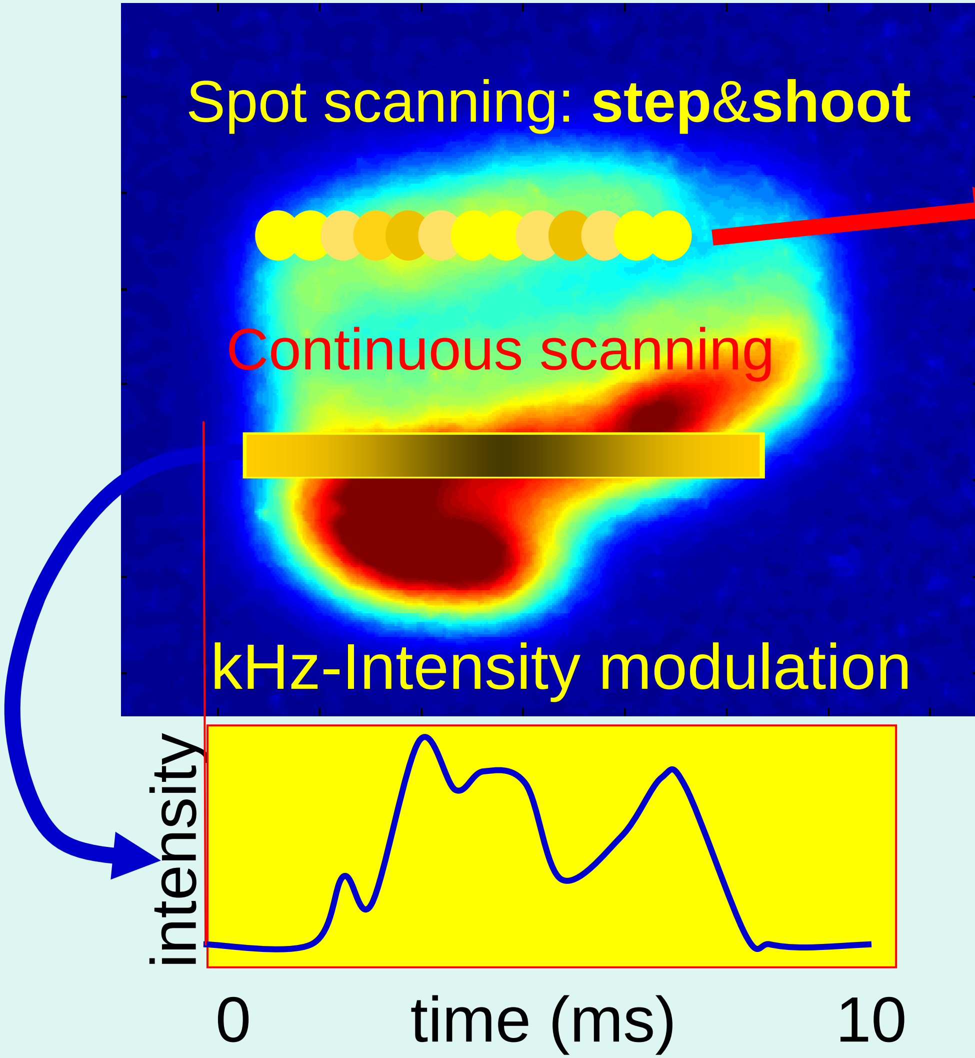
  (tumor tracking)



- Fast rescanning



Pencil beam scanning



Requirements for accelerator:

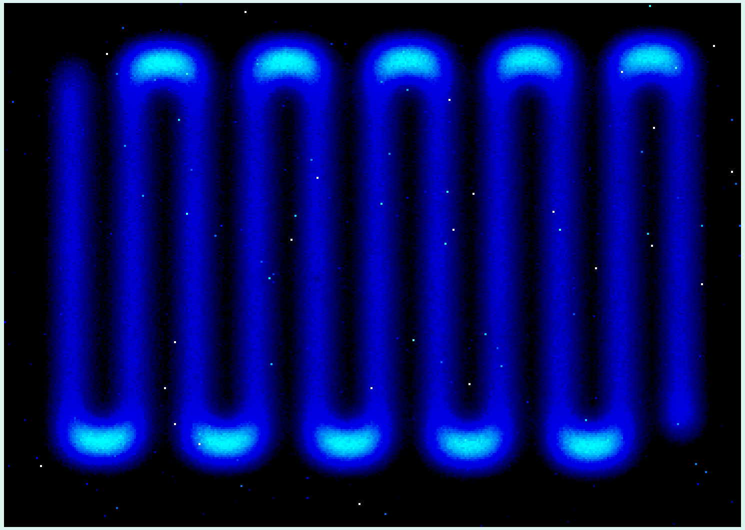
- stable beam position

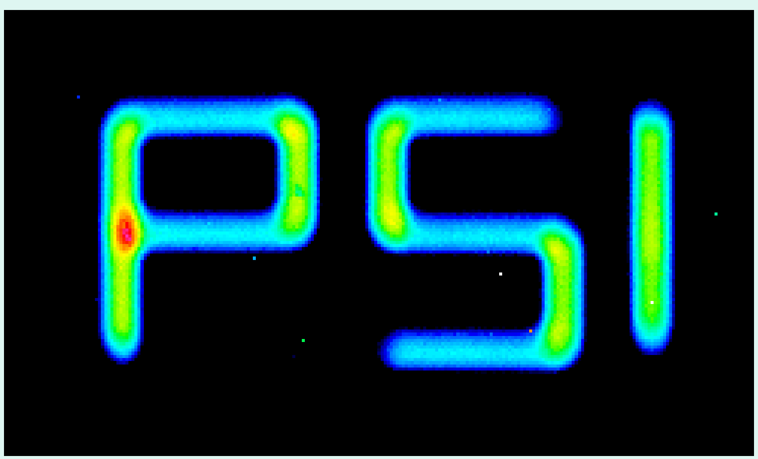
allows fast target **repainting**:
15-30 scans / 2 min.

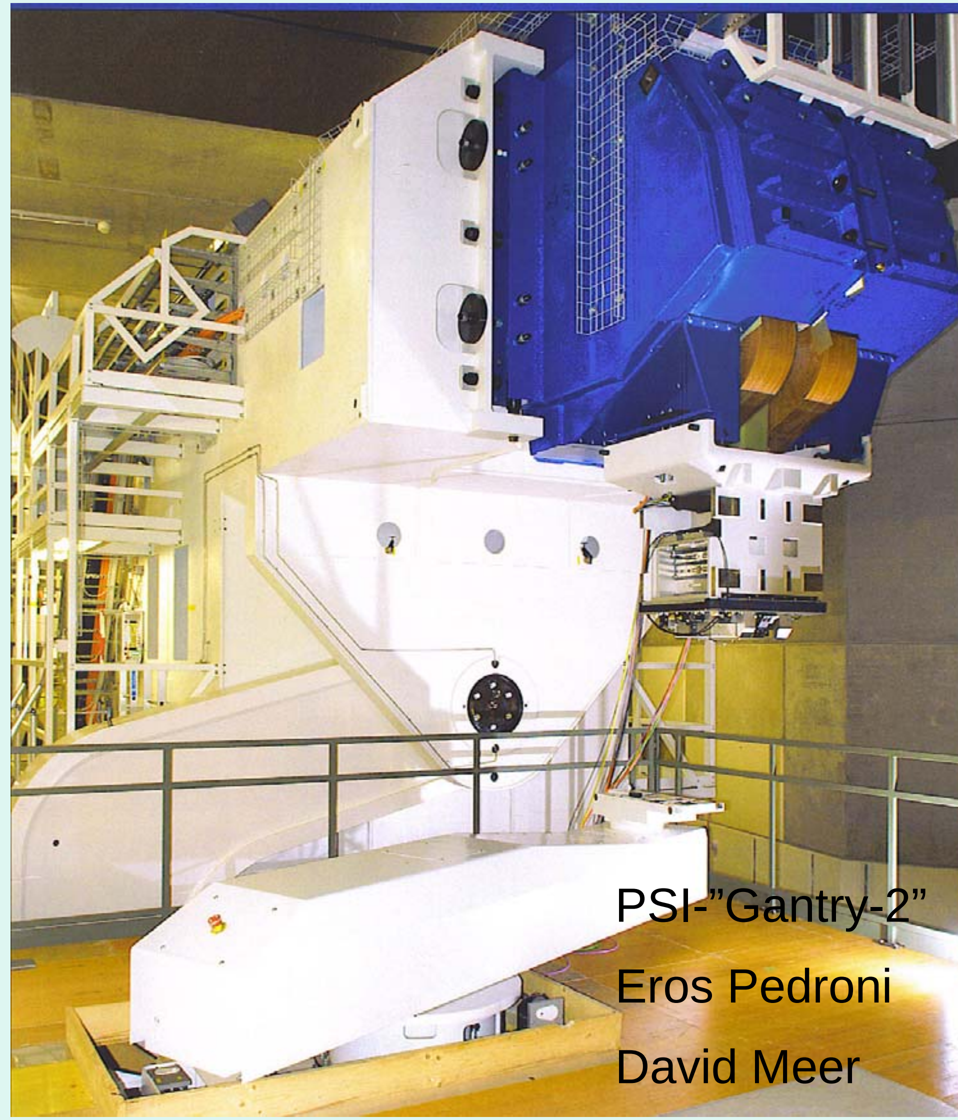
Requirements for accelerator:

- stable beam position
- continuous and stable beam
- fast adjustable beam intensity
- fast adjustable beam energy

PSI Gantry-2: fast 3D scanning

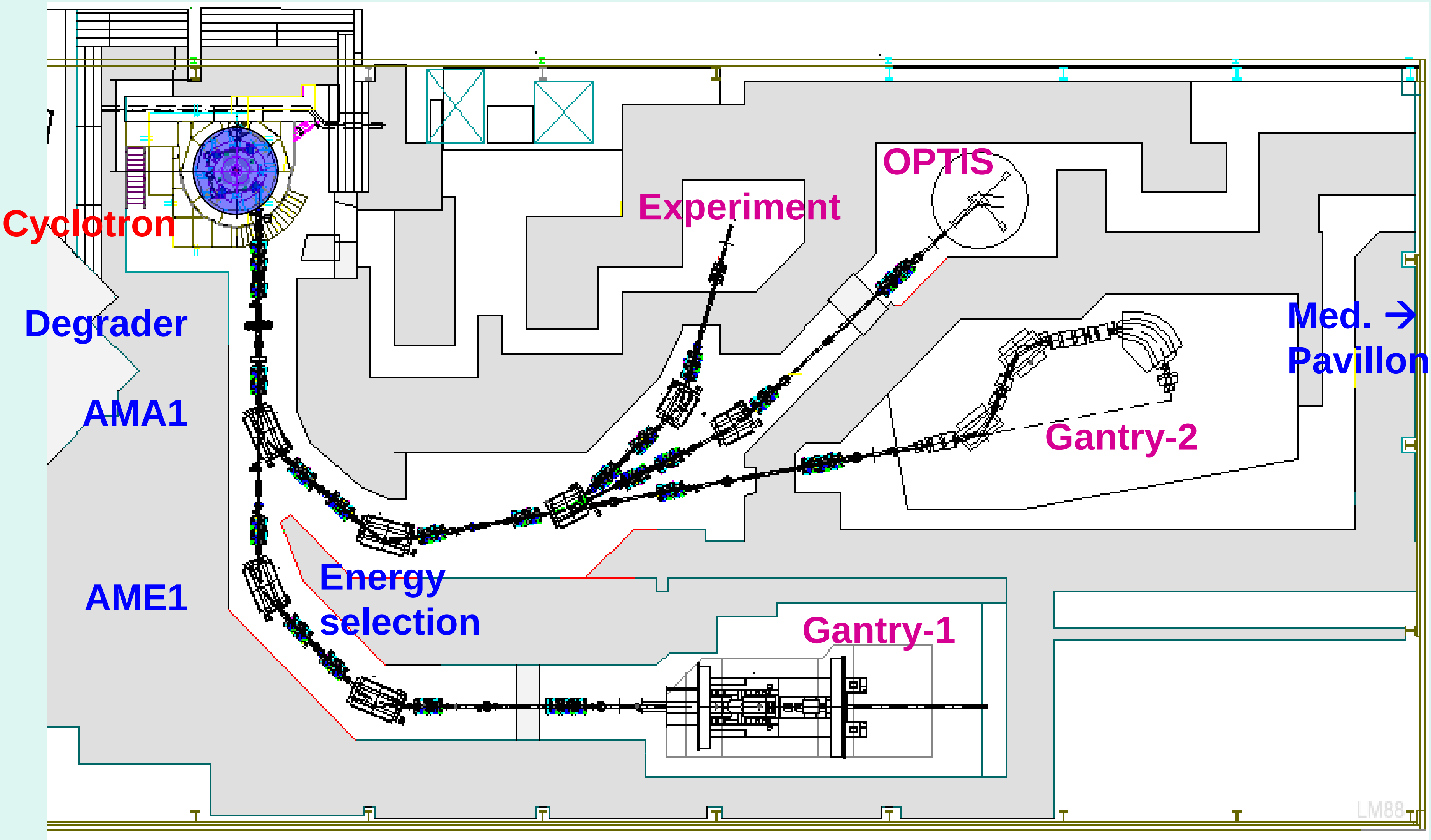




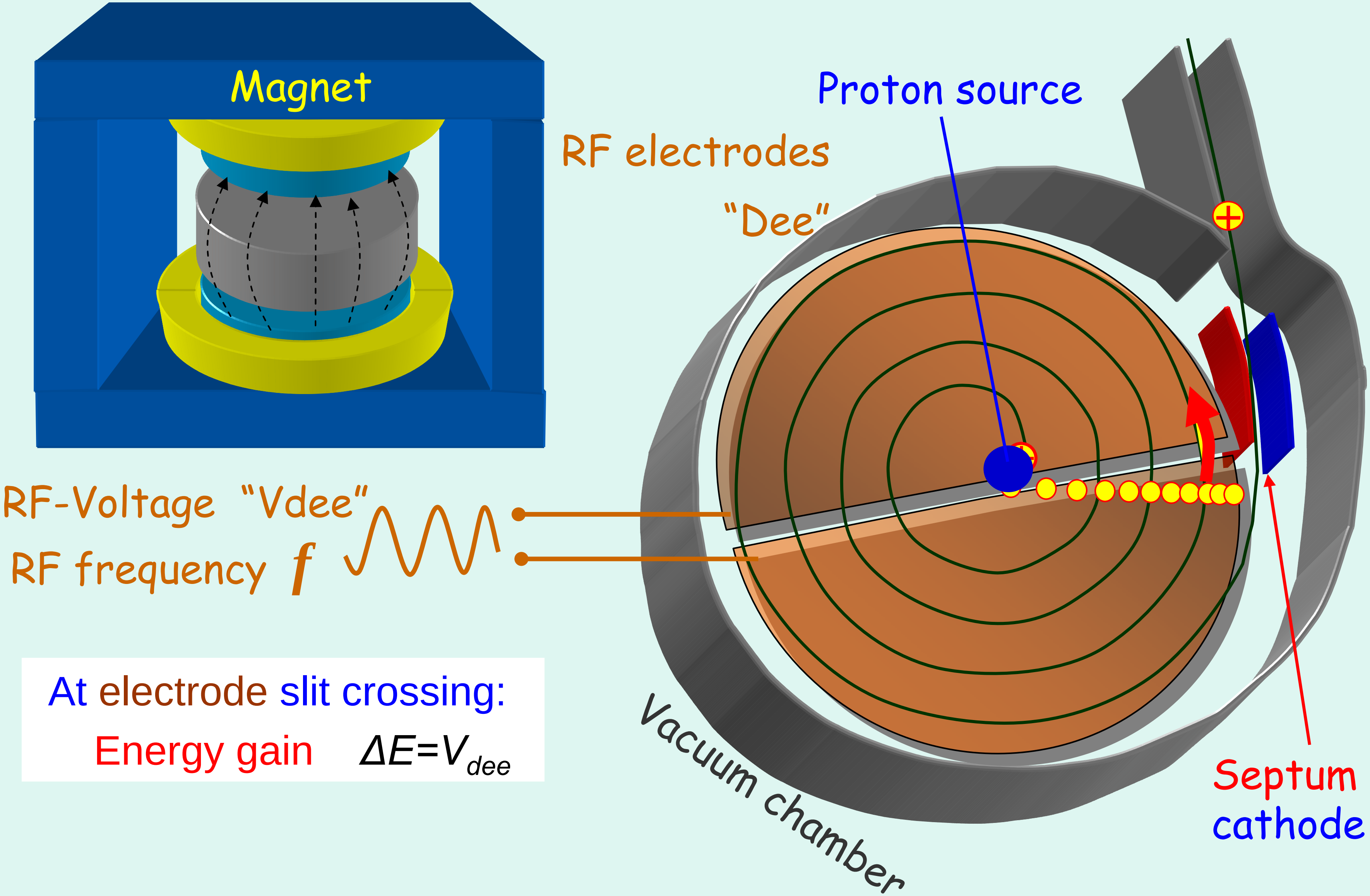


The SC cyclotron at PSI

the PROSCAN facility



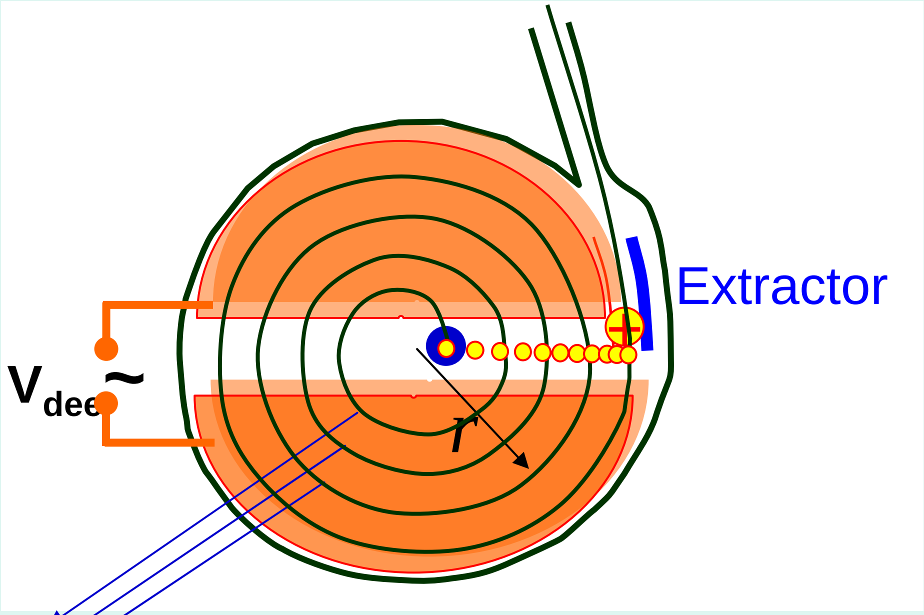
Cyclotron (1930)



At electrode slit crossing:

Energy gain $\Delta E = V_{dee}$

Cyclotron



Circular orbits:

Centripetal force = Magnetic force $$\frac{mv^2}{r} = Bqv$$

=> $T_{circle} = \frac{2\pi.r}{v} = \frac{2\pi.m}{Bq}$

=> T_{circle} independent from orbit radius r

m = mass

v = speed

r = orbit radius

B = magnetic field

q = charge

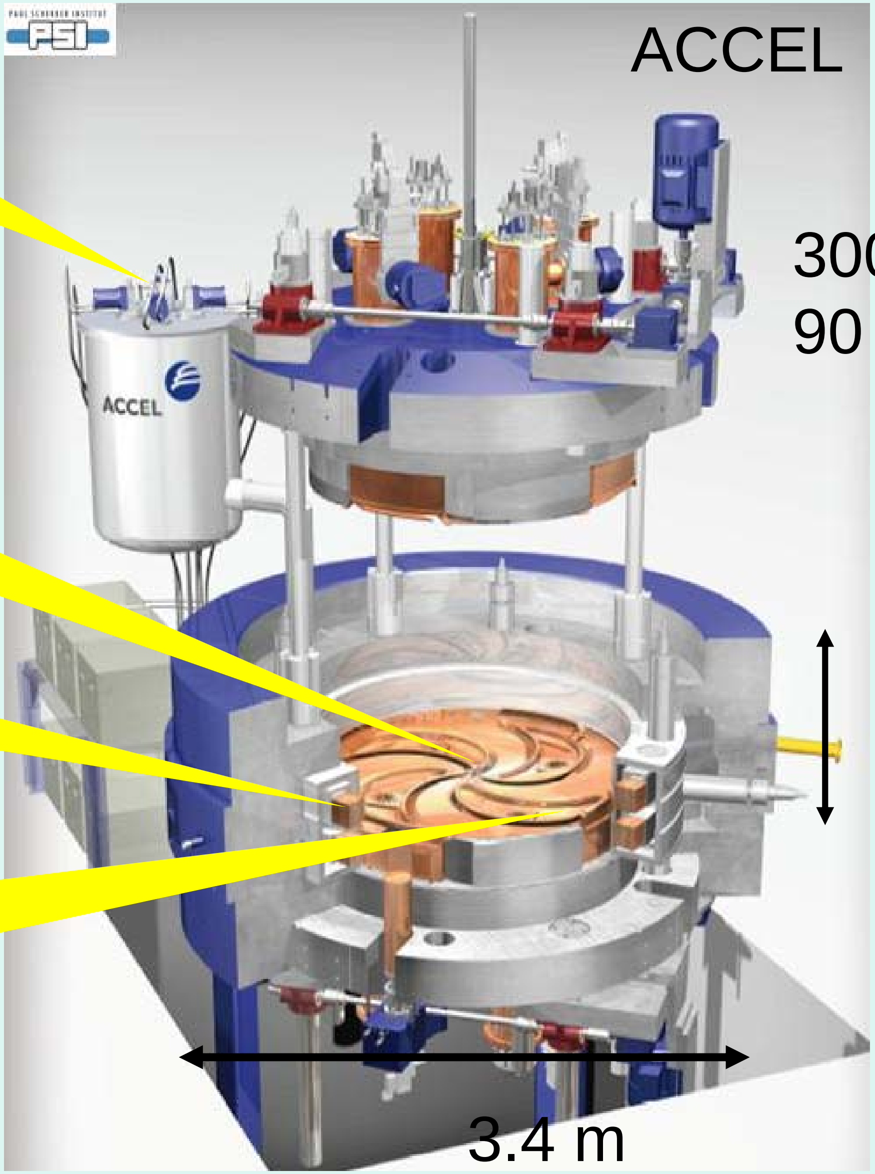
250 MeV proton cyclotron (ACCEL/Varian)

Closed He system
4 x 1.5 W @4K

Proton source

superconducting
coils => 2.4 – 3.8 T

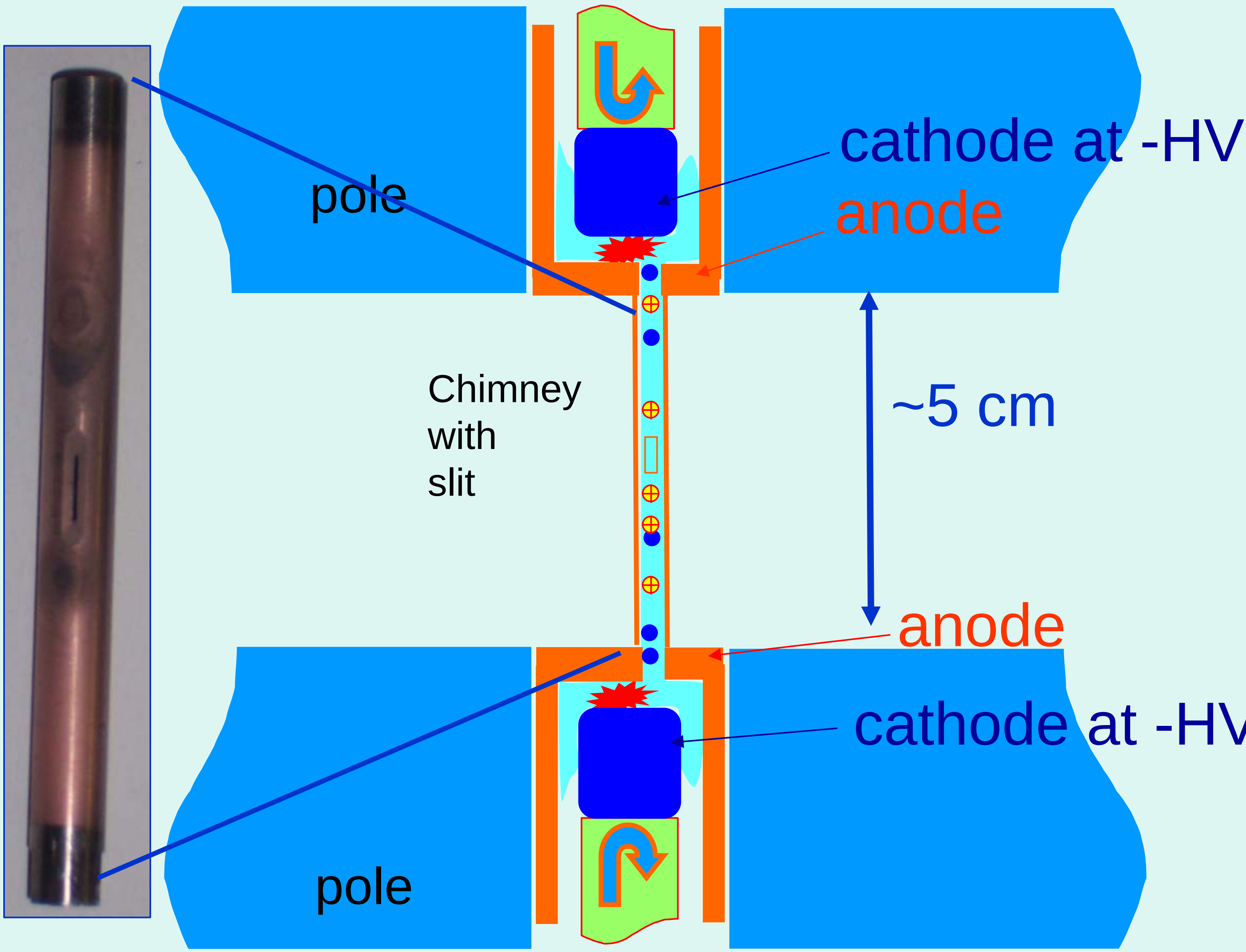
4 RF-cavities:
72 MHz (h=2)
~80 kV



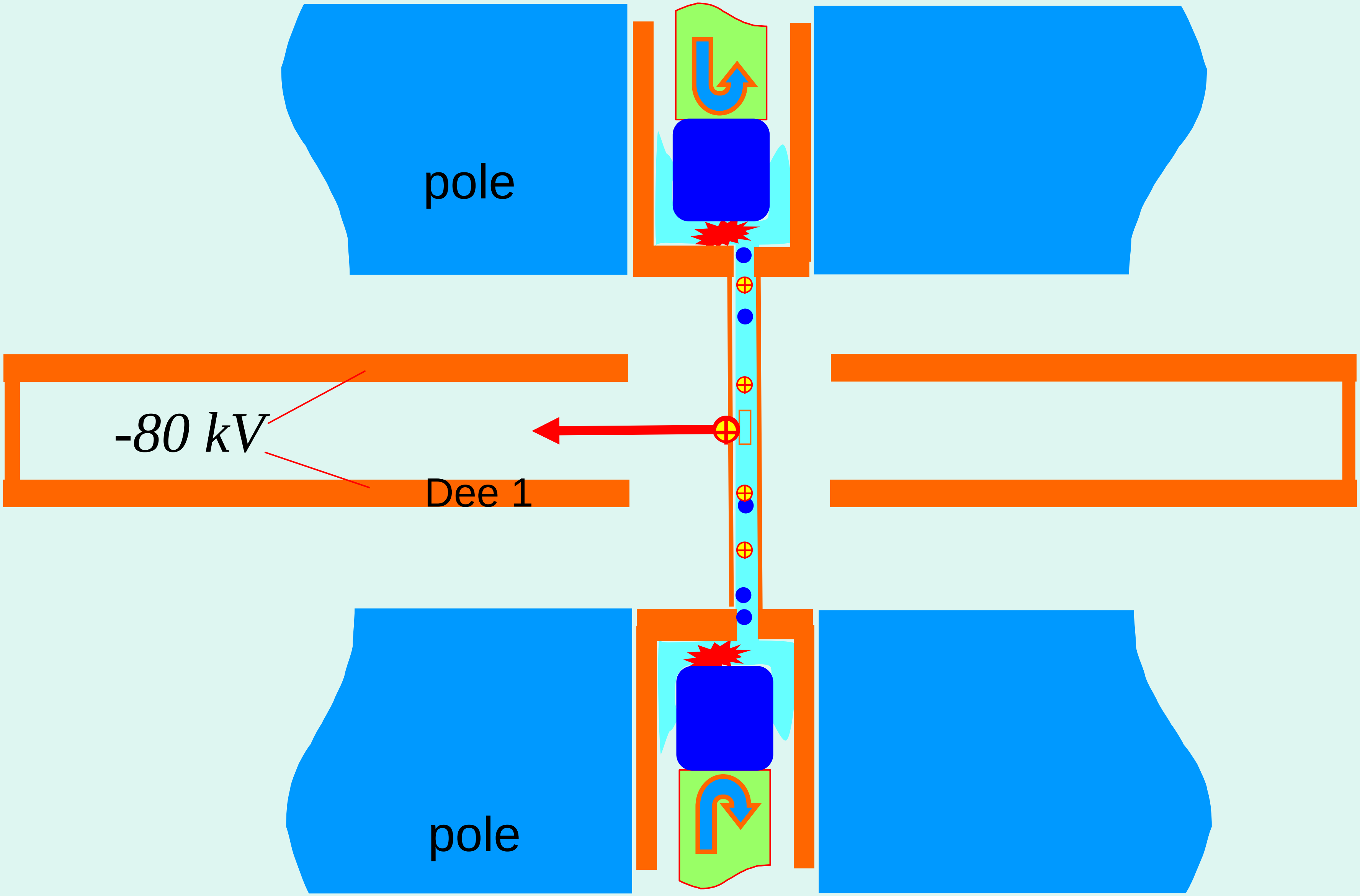
300 kW
90 tons

1.4 m

Internal proton source

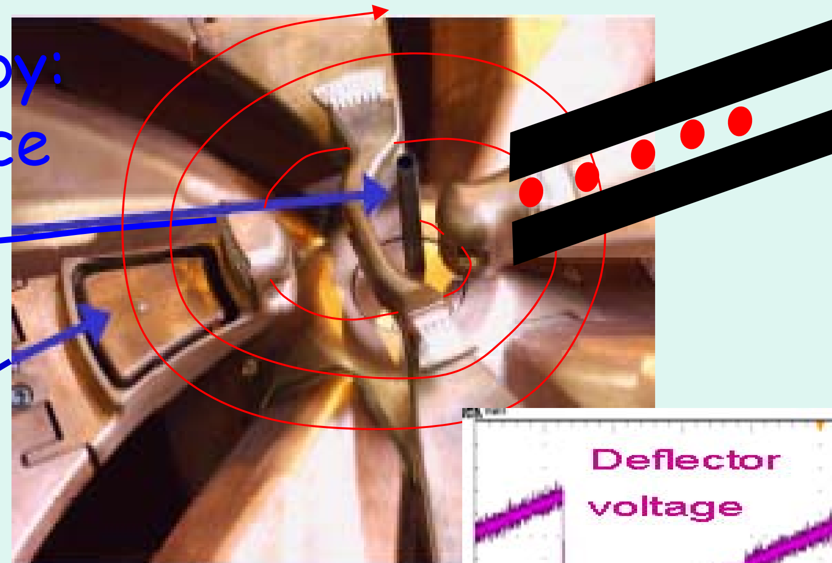


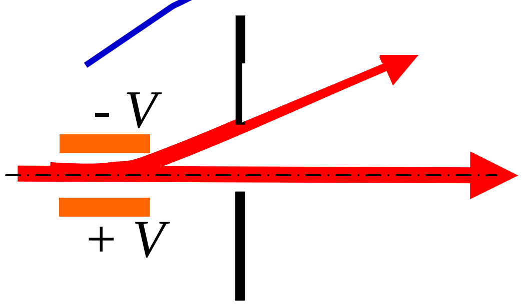
Internal proton source



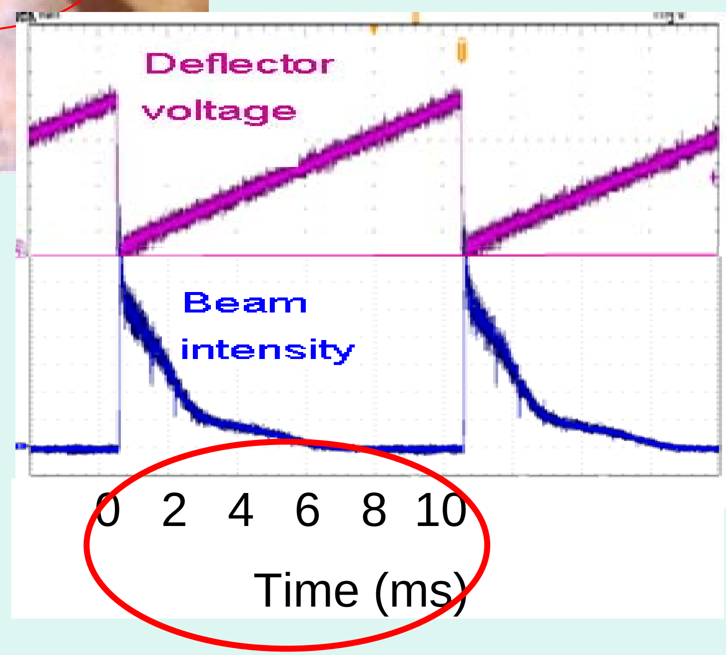
intensity control

Max. intensity set by:
proton source



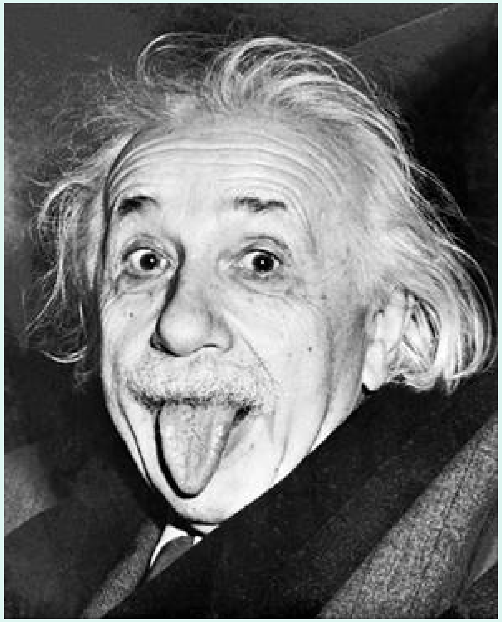


Deflector plate:
sets intensity
- within 50 μs
- 3% accuracy



Relativity in high-E cyclotrons

Cyclotron essential: $T_{circle} = \dfrac{2\pi.m}{Bq}$ => T_{circle} constant for all radii



However, when $v \rightarrow c$: $m = \dfrac{m_0}{\sqrt{1-v^2/c^2}} = \gamma \cdot m_0$

e.g: *10 MeV p: v/c=0.14 => m=**1.01** m_0*

*250 MeV p: v/c=0.61 => m=**1.27** m_0*

=> T_{circle} increases with radius => **particles lose pace with RF**.

Relativity in high-E cyclotrons

$$T_{circle} = \frac{2\pi . m}{q . B}$$

$$m = \frac{1}{\sqrt{1 - v^2/c^2}} . m_0$$

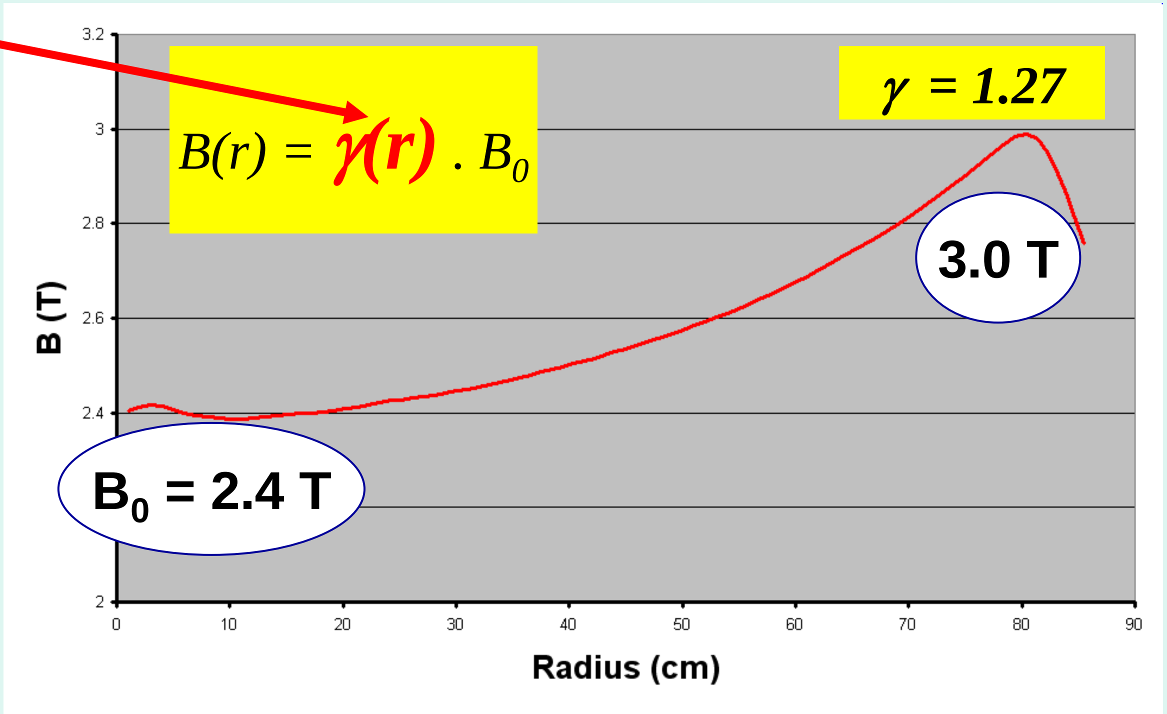
$\gamma(r)$

Remedies when T_{circle} increases with radius:

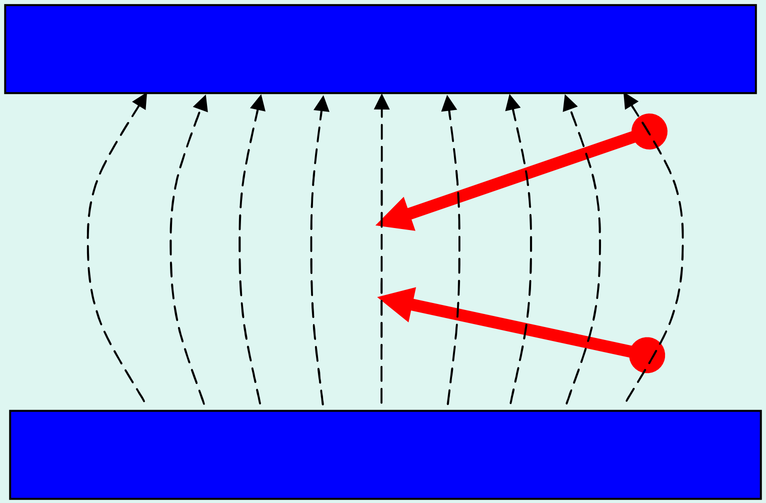
1) decrease f_{RF} with radius.

   (*synchro-cyclotron;* pulsed)

2) **increase B with radius**



Relativity in high-E cyclotrons



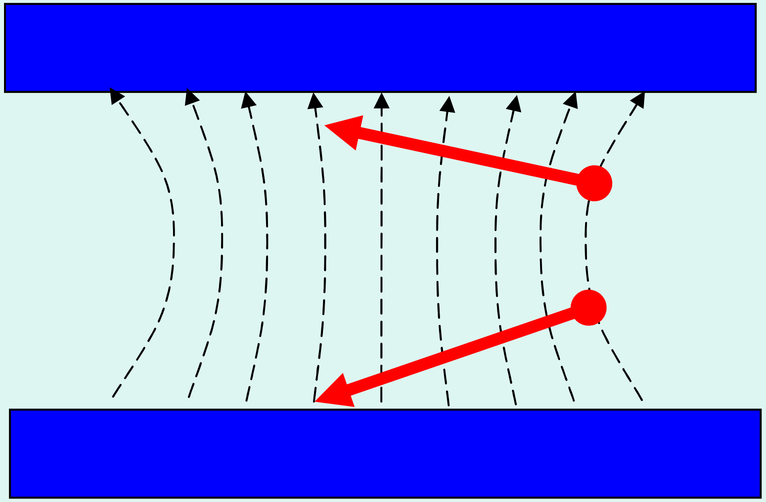
Radial variation of field (field index):

$$n(R) = -[R/B(R)]\ [dB(R)/dR]$$

$n>0\ :\ dB/dr<0$

When B **decreases** with radius:

Automatic **vertical stability**



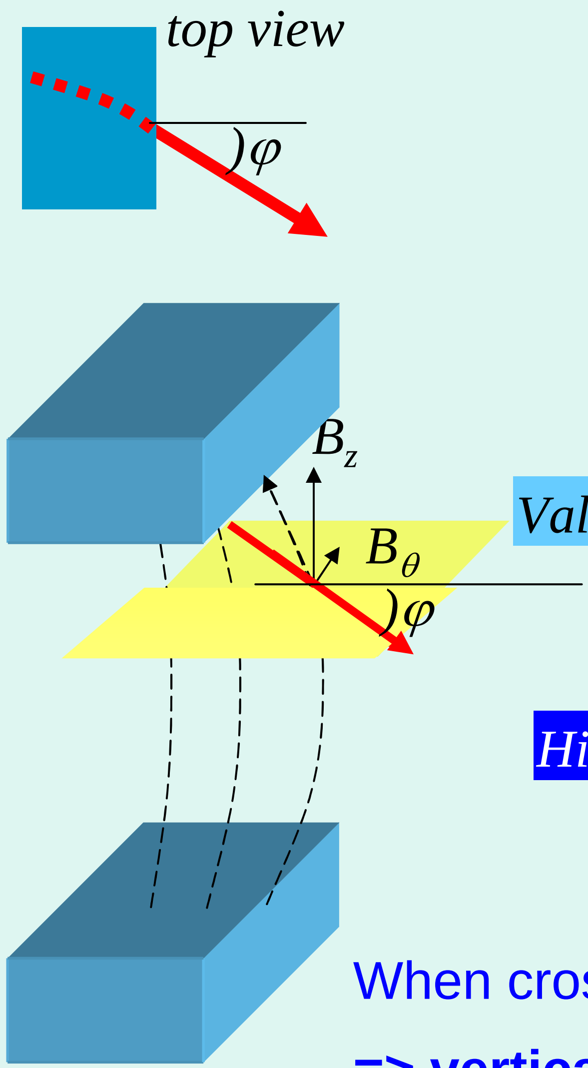
When B **increases** with radius:

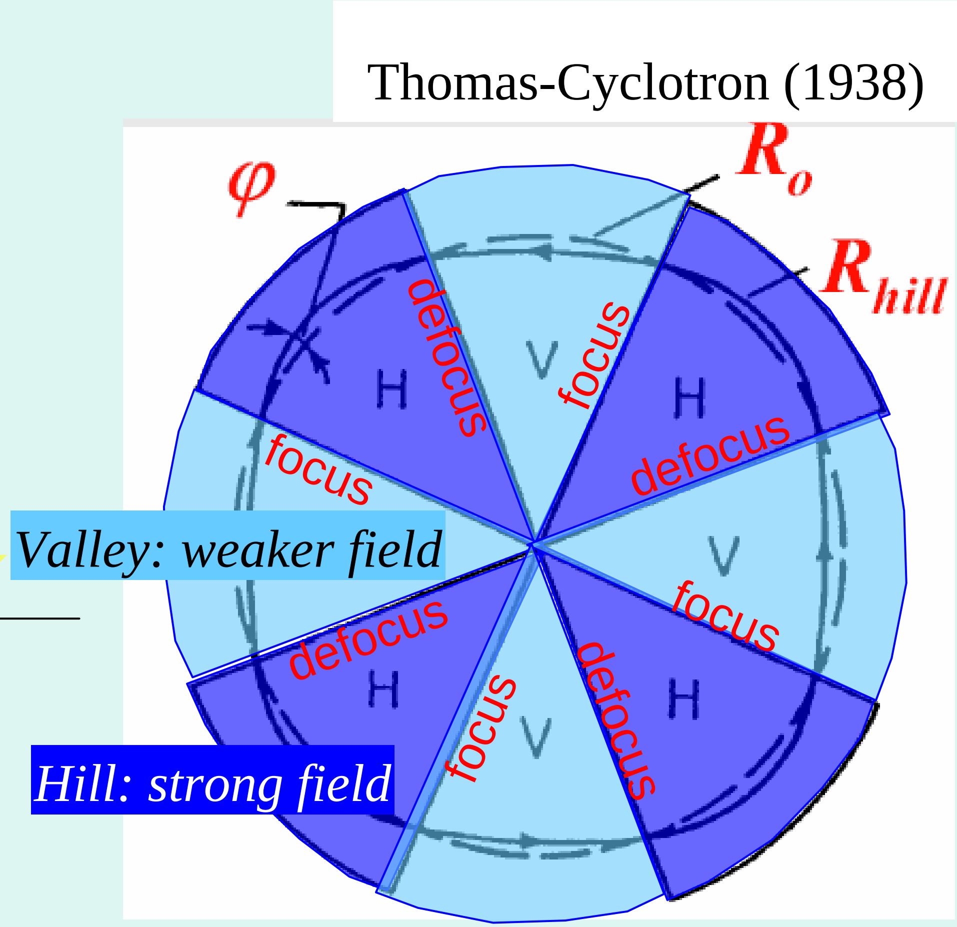
No **vertical stability**

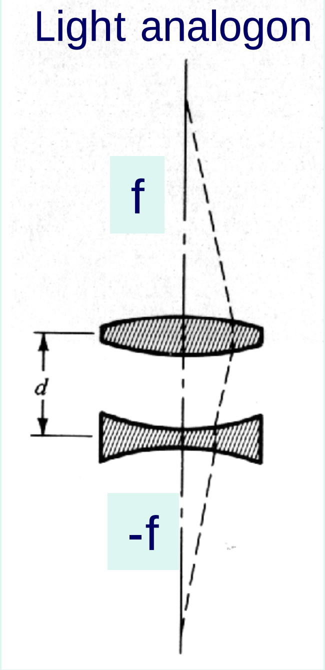
$n<0\ :\ dB/dr>0$

$$n(R) = -[R/B(R)]\ [dB(R)/dR] = -(\gamma^2-1)$$

Vertical focussing: **A**zimuthally **V**arying **F**ield





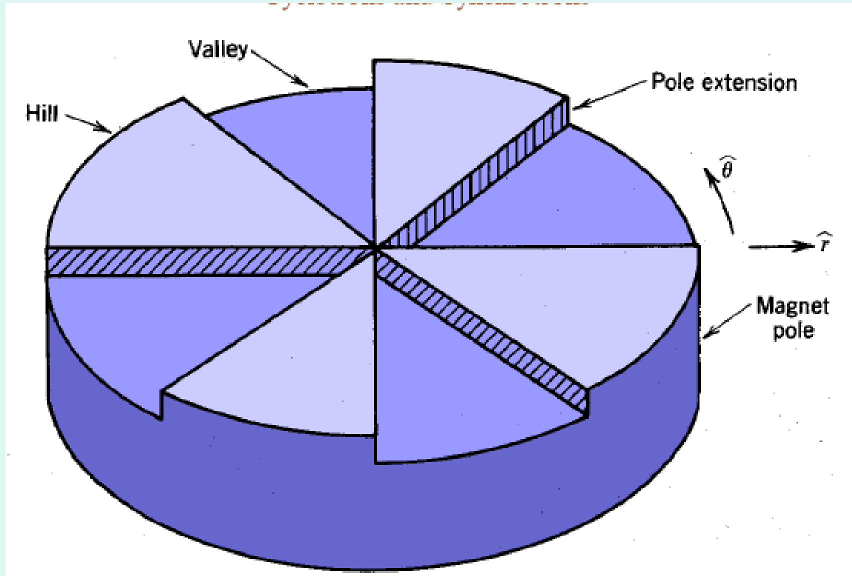


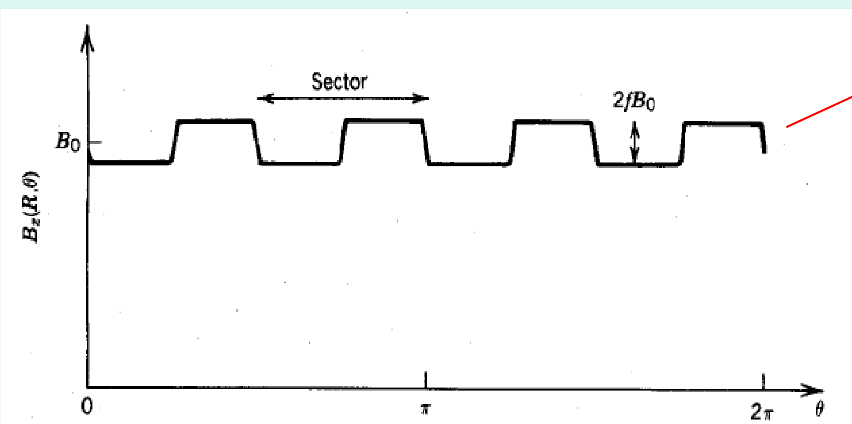
$\mathbf{f_{comb} = f^2 / d}$

When crossing B change **not** ⊥

=> vertical force from $B_\theta \times v$

Vertical focussing: **A**zimuthally **V**arying **F**ield





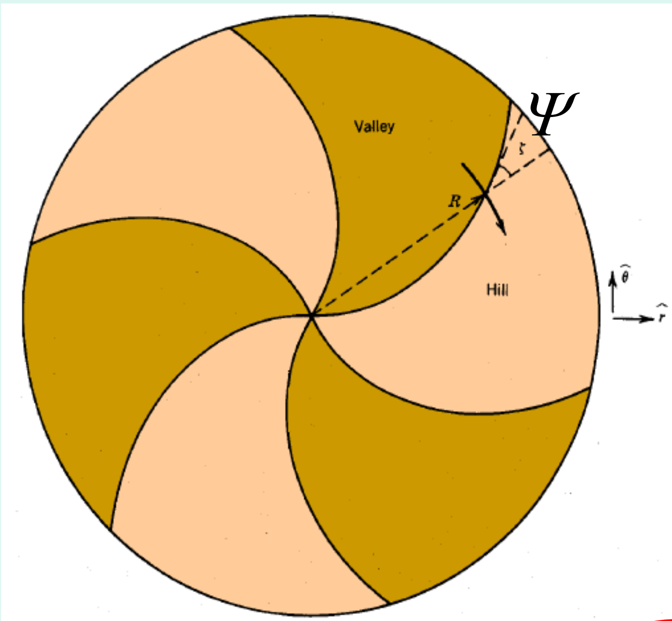
Flutter function

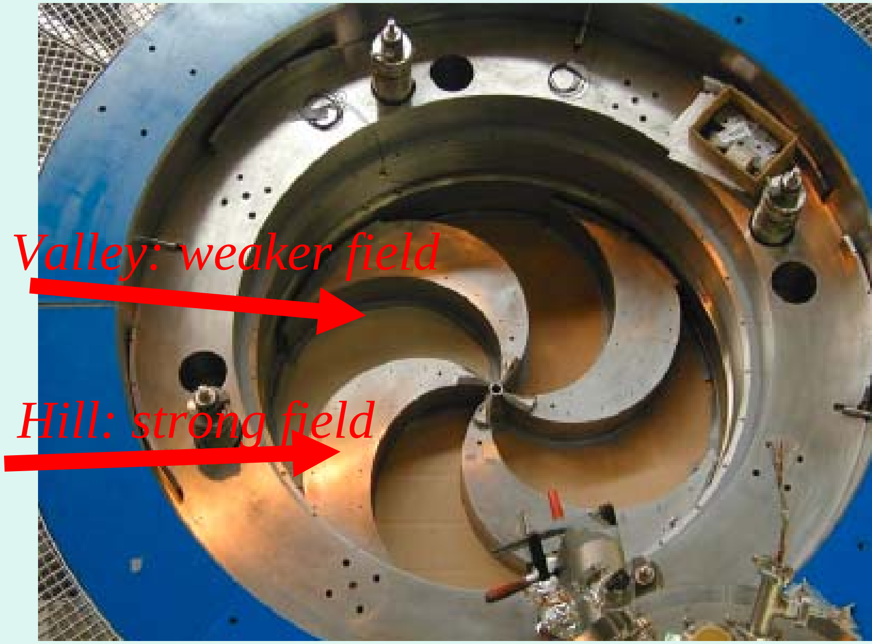
$$F(R) = \overline{[(B_z(R,\theta) - B_o(R))/B_o(R)]^2}$$

Thomas focusing: $\nu_z^2(R)=n(R)+F(R)$

Vertical focussing

Azimuthally Varying Field cyclotron





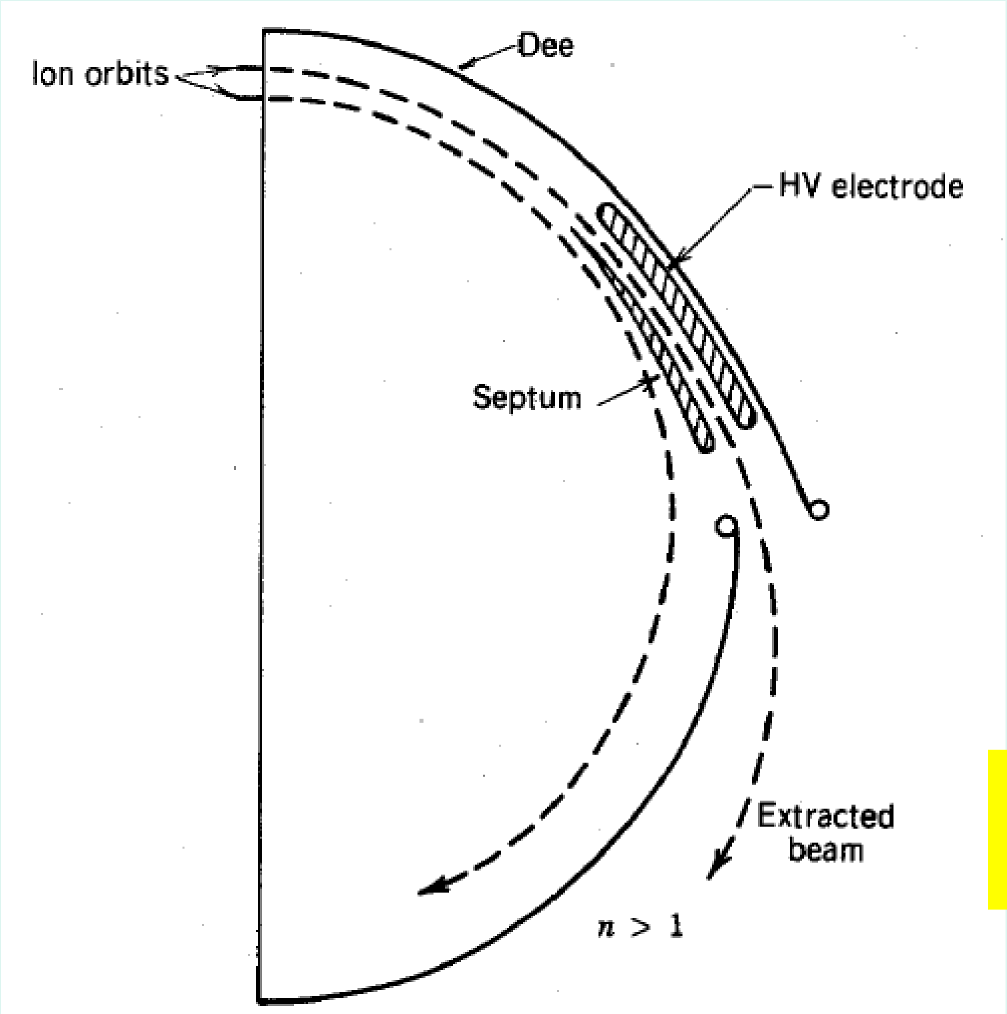
$$\upsilon_z^2(R) = n(R) + F(R).(1 + 2\tan(\psi(R)))$$

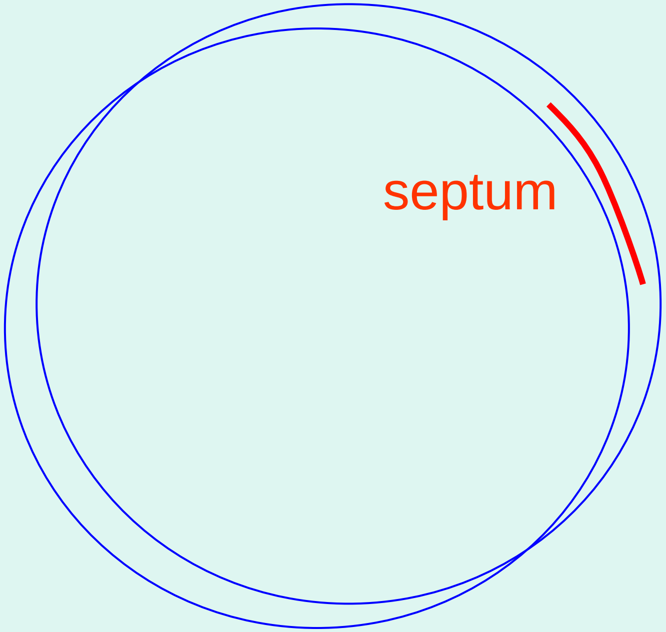
to **compensate** :

- increasing $B\rho$
- Increasing defocussing by main field

=> increase angle Ψ with radius => **spiral shape**

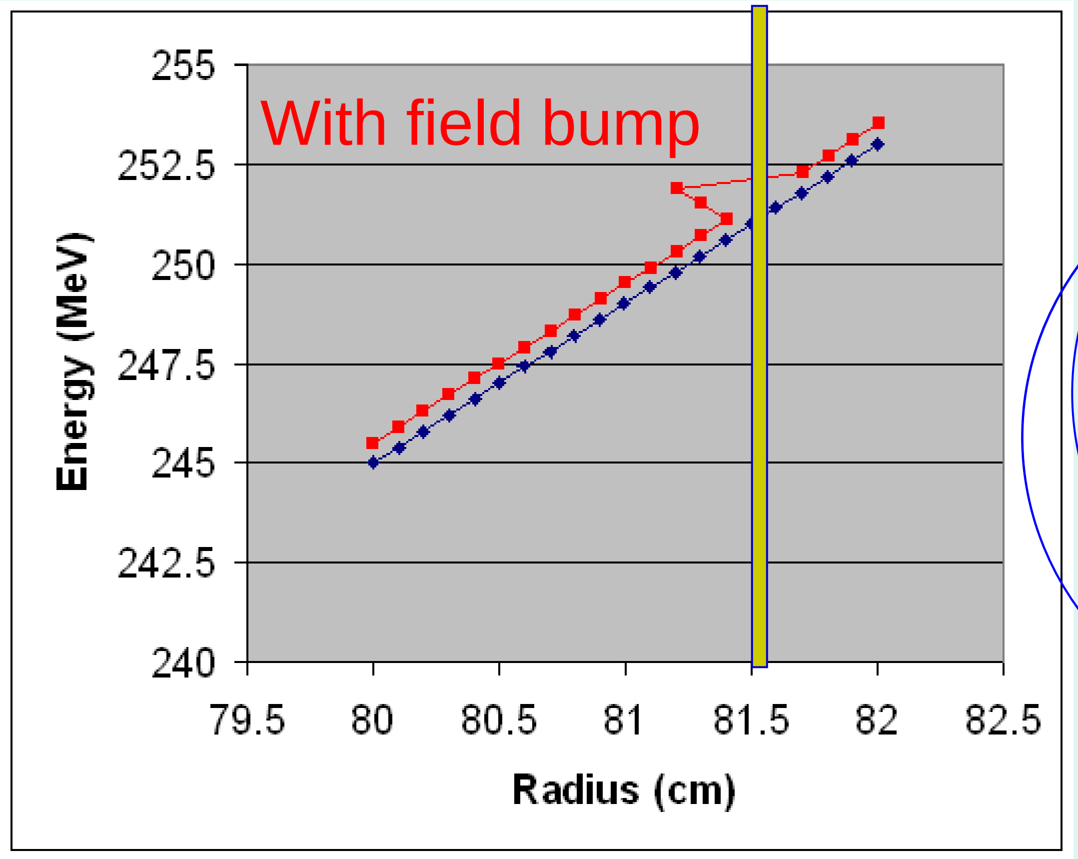
Extraction from cyclotron

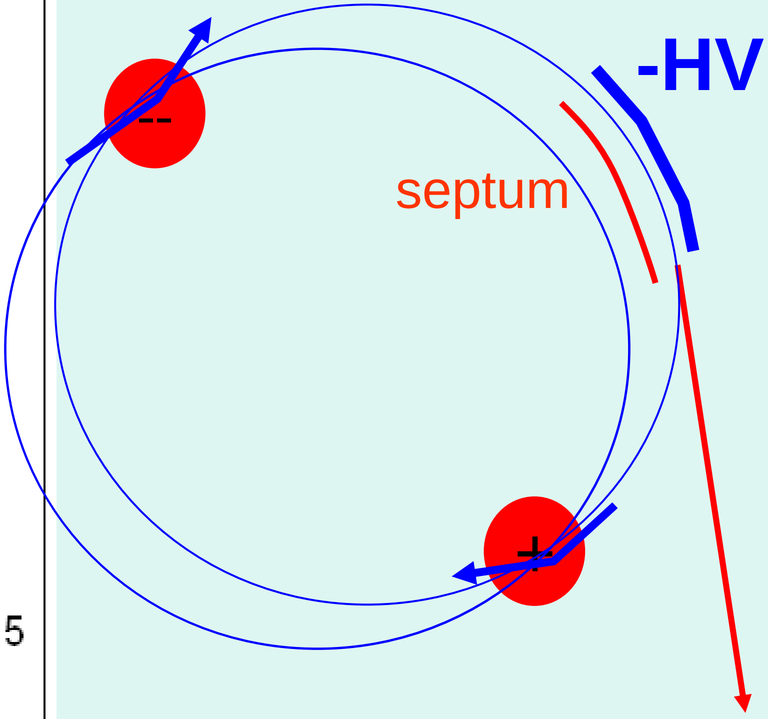




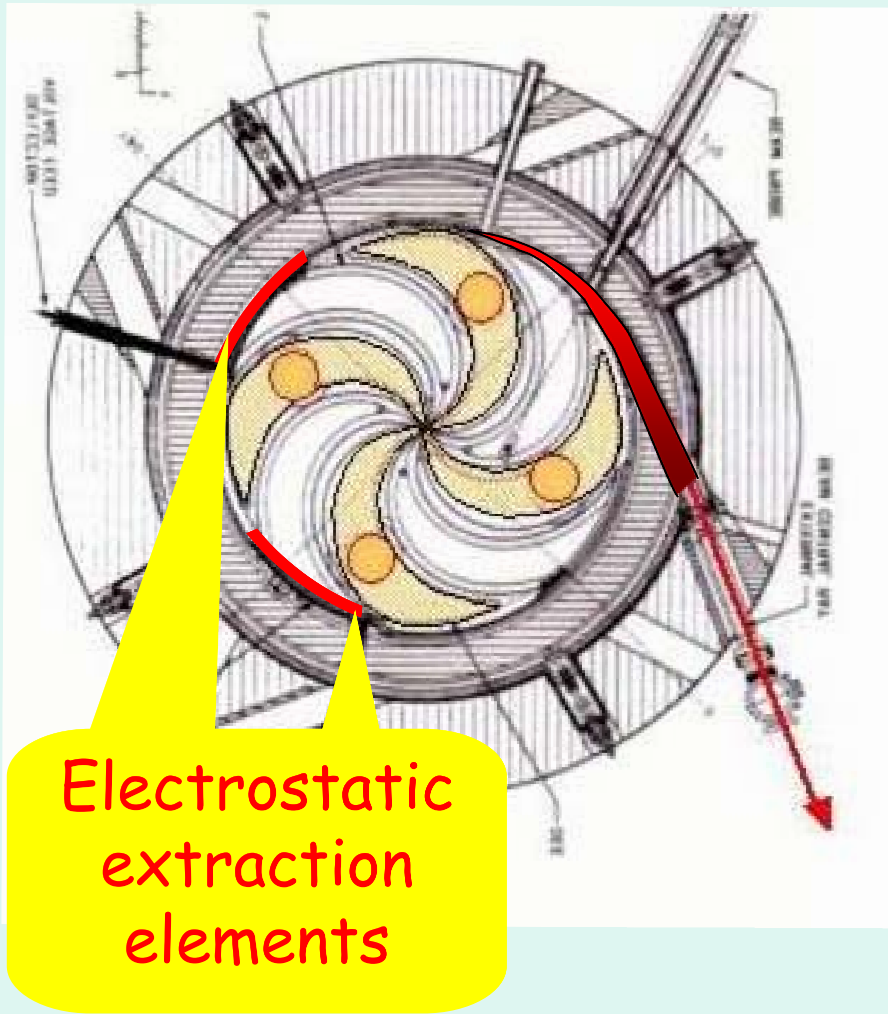
Resonant extraction: use ν_r=1

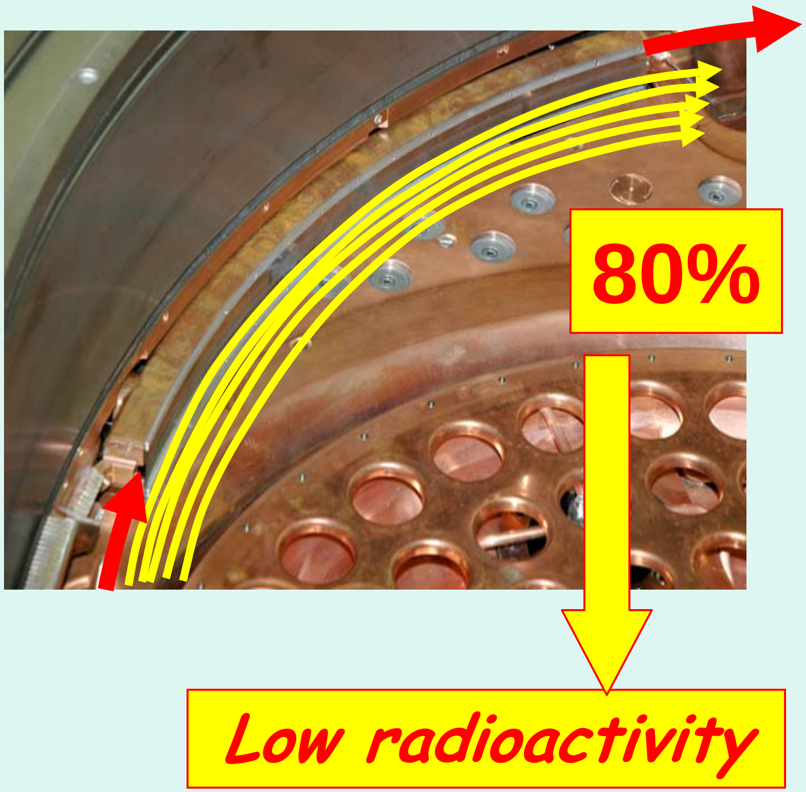
resonant extraction





Extraction from cyclotron





(ACCEL / Varian)

Advantages of a cyclotron

=> a cyclotron provides:

- continuous beam
- any intensity
- very fast adjustable intensity
- accurate intensity control
- great reliability

\+ range change of 5 mm < 50 ms

(with fast degrader and good magnets + power supplies)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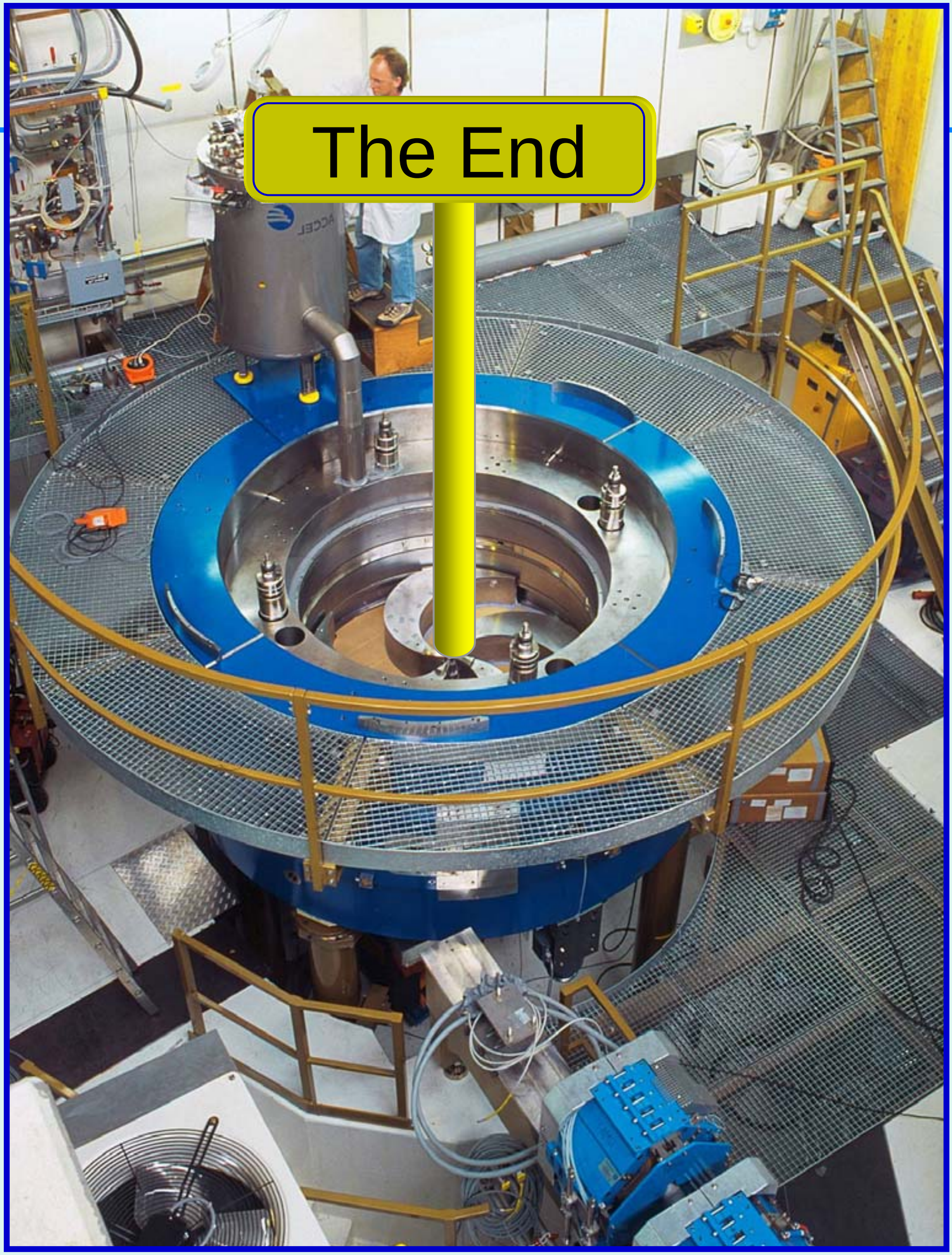
The End