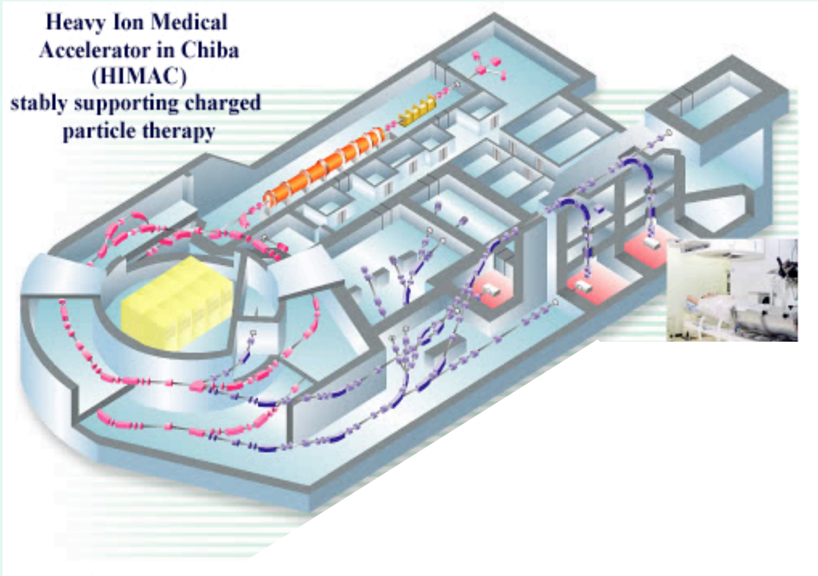
PAUL SCHERRER INSTITUT

A novel design of a **cyclotron based** accelerator system for multi-ion-therapy

Marco Schippers, Andreas Adelmann, Werner Joho, Marco Negrazus (PSI)
Heinrich Homeyer (Hahn Meitner Inst.)

Demand for “heavy” ion therapy



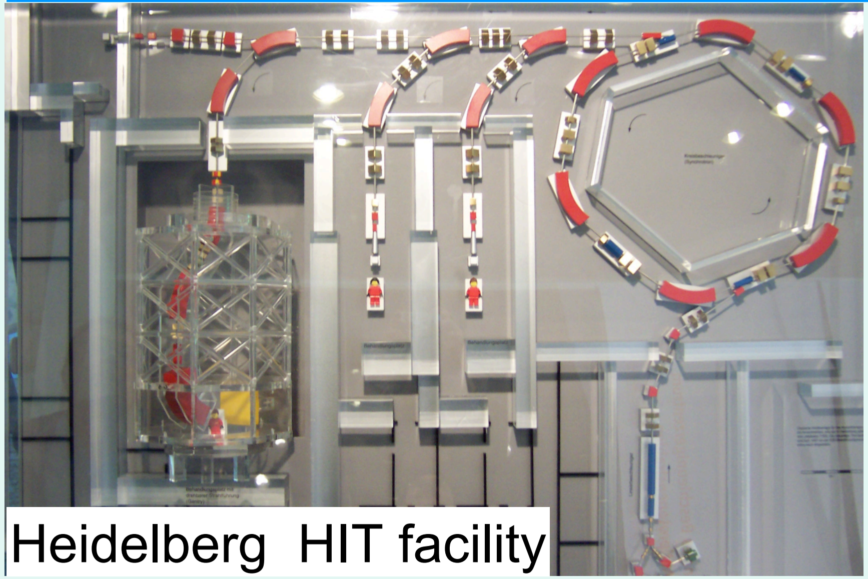
<u>Present facilities:</u>

(Berkeley)

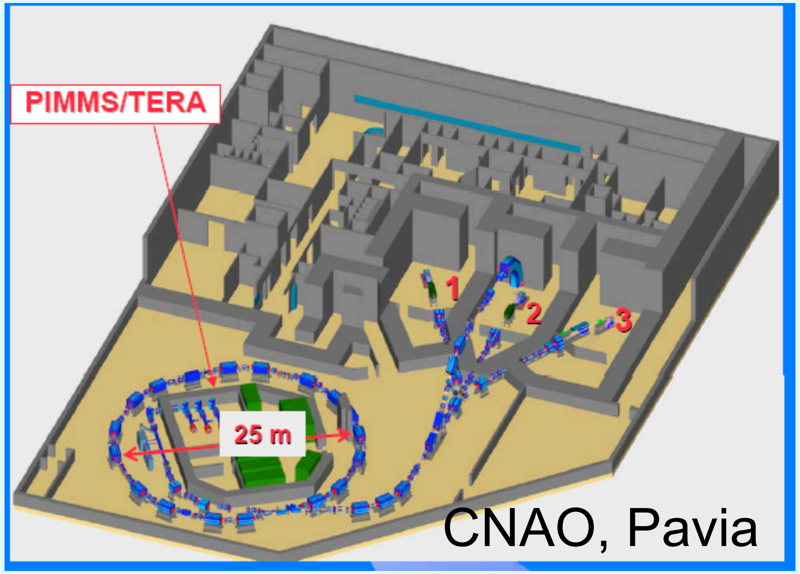
Himac

GSI

Currently: synchrotron facilities



Heidelberg HIT facility



CNAO, Pavia

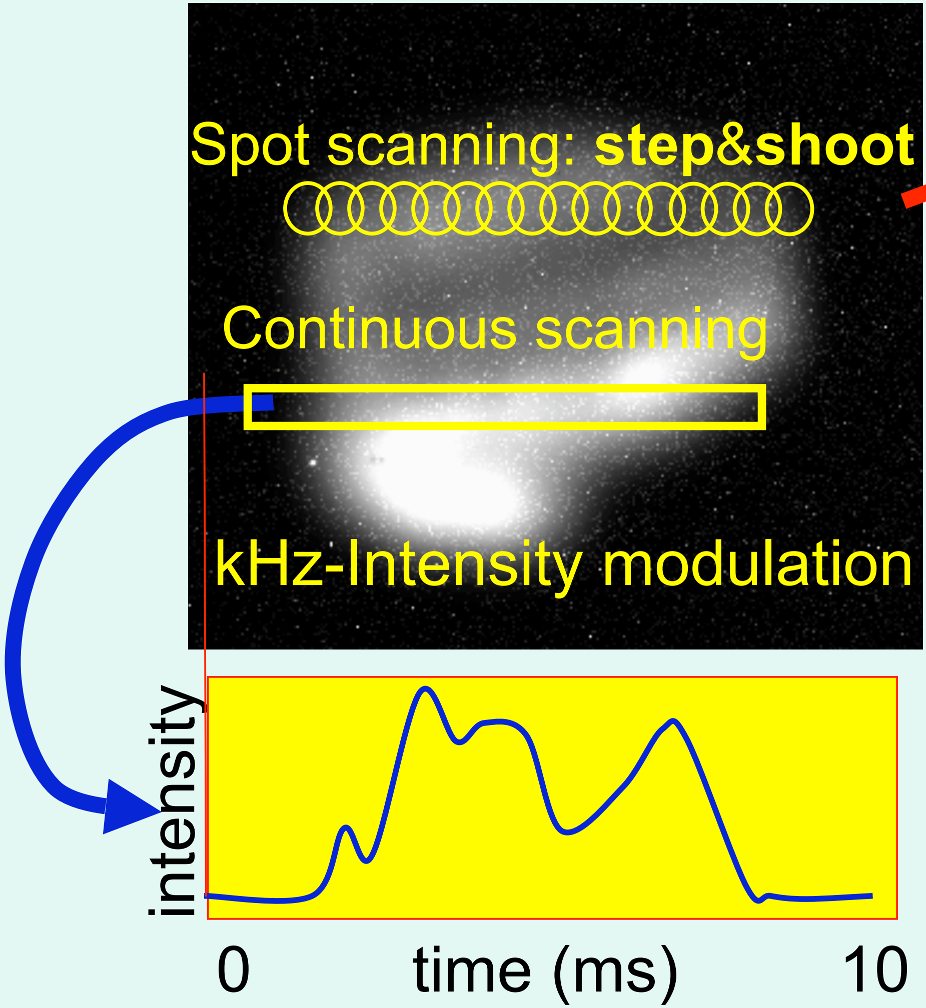
Coming up:

HIT, Japan, Pavia, Kiel, Marburg

Vendors are offering (often in collaboration with laboratories):

- synchrotron (Siemens, PIMS, NIRS)
- cyclotron 250, 300, 400 MeV/nucl (IBA, Catania, JINR)

PSI: Pencil beam scanning



Requirements for accelerator:

- stable beam position:

=> any accelerator is OK

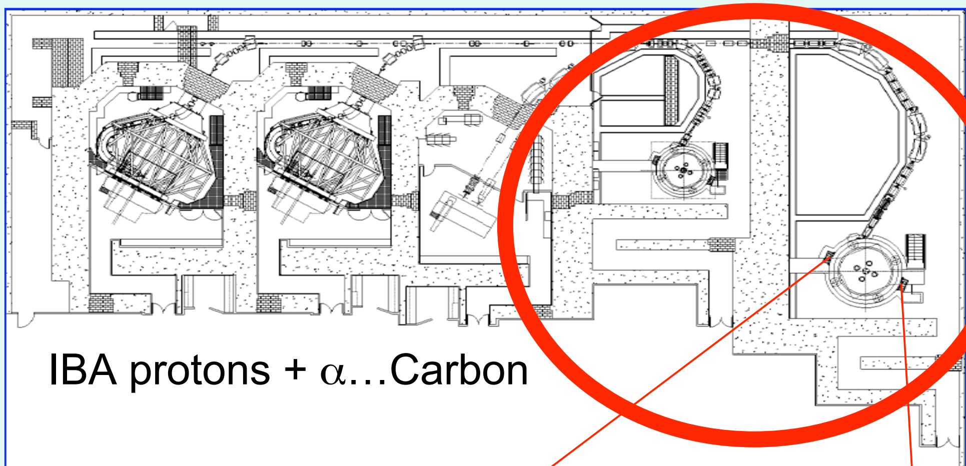
allows fast target **repainting**:
15-30 scans / 2 min.

Requirements for accelerator:

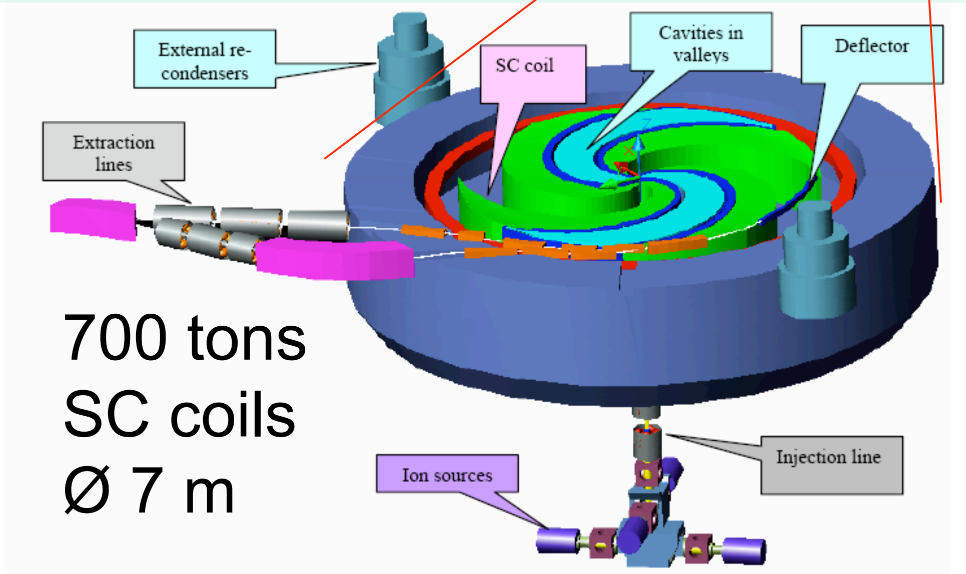
- stable beam position
- **continuous** and **stable** beam
- **fast adjustable** beam **intensity**
- **fast adjustable** beam **energy**

=> Cyclotron is optimal choice

Cyclotron facility



IBA protons + α…Carbon



700 tons
SC coils
Ø 7 m

Figure 1: Artist's view of the median plane in the 400 MeV/amu Carbon/Proton superconducting cyclotron.

Observations:

- Protons are "proven work tools" (also covered by insurances)
- Carbon is interesting
- Carbon offers research possibilities
- One prefers to start with protons

=> Often two-phases desired

Int. Conf. Cyclotron and appl, Tokyo 2004

IBA C400 CYCLOTRON PROJECT FOR HADRON THERAPY

Y. Jongen, M. Abs, W. Beeckman, A. Blondin, W. Kleeven, D. Vandeplassche, S. Zaremba, IBA, Belgium
V. Aleksandrov, A. Glazov, S. Gurskiy, G. Karamysheva, N. Kazarinov, S. Kostromin, N. Morozov, E. Samsonov, V. Shevtsov, G. Shirkov, E. Syresin, A. Tuzikov, JINR, Russia.

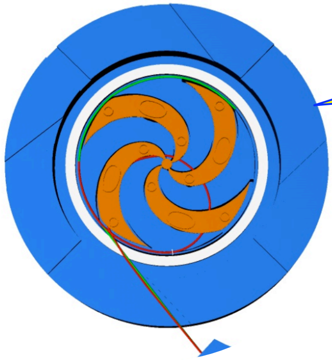
A novel idea:

Two steps: injector and booster

AND: injector also provides (limited) carbon beams

	Beams from injector cyclotron: 250 MeV/nucl. (4.86 Tm)			From Booster (6. 83 Tm)
	Proton (**H_2^+ ions**)	Helium 2+ (α)	Carbon 6+	Carbon 6+ 450 MeV/n
Range in water (cm)	38.3	38.3	12.7	33.3

First concept

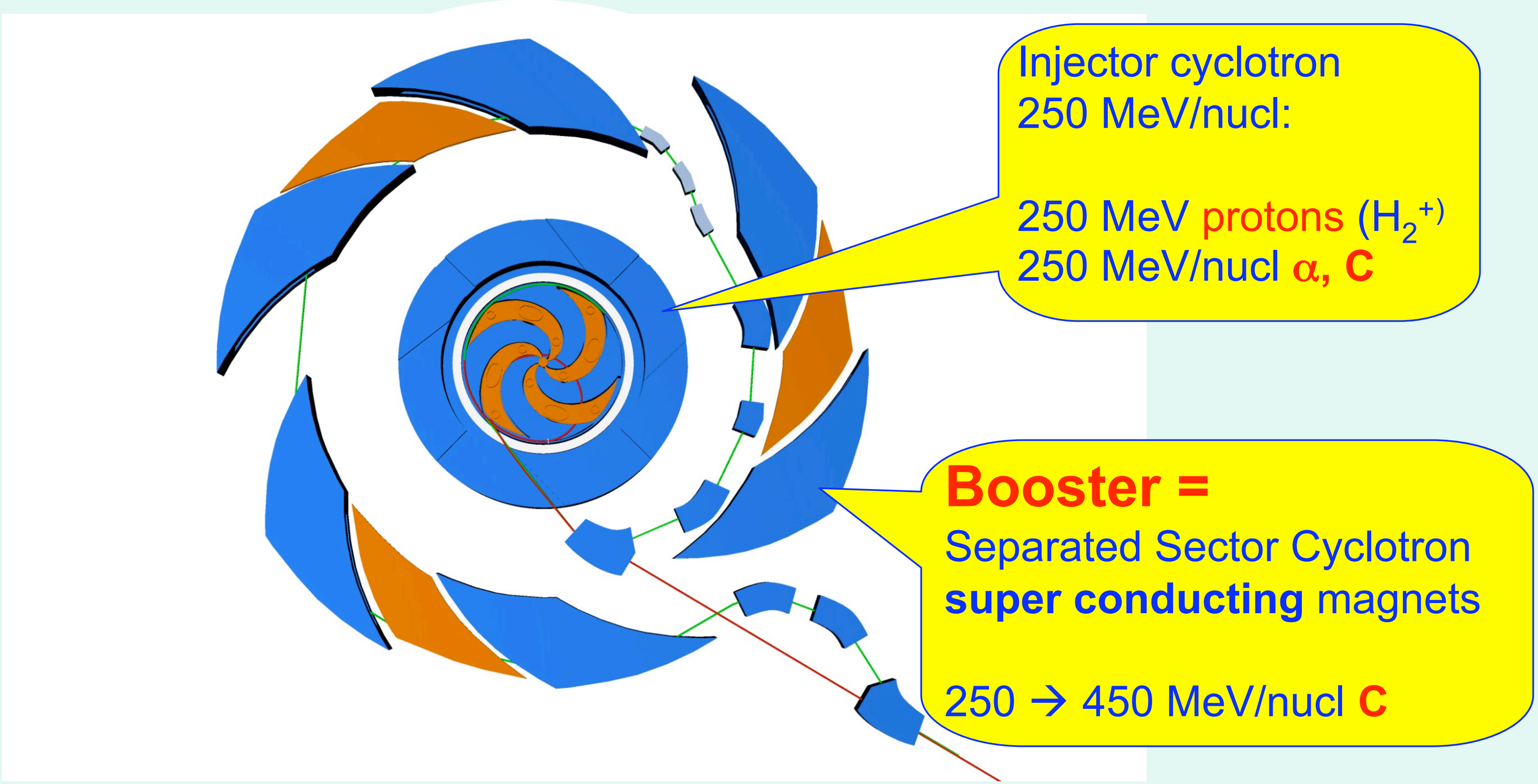


Injector cyclotron
250 MeV/nucl:

250 MeV protons (H_2^+)
250 MeV/nucl α, C

(Heinz Homeyer, HMI, at European cyclotron workshop in Nice)

First concept



(Heinz Homeyer, HMI, at European cyclotron workshop in Nice)

A possible injection cyclotron:

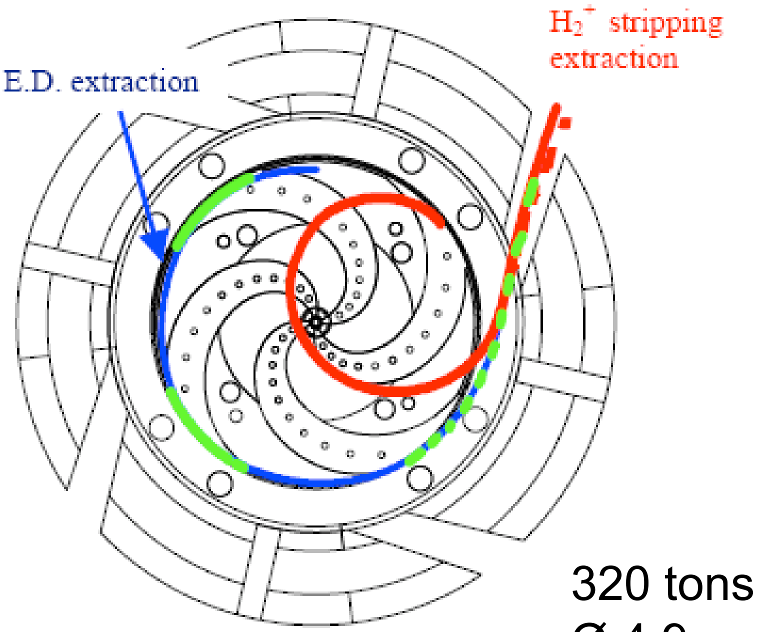


Figure 3: Layout of the cyclotron with overdrawn the extraction trajectories by E.D. and by stripper. The E.D. and the M.C. positions are also shown.

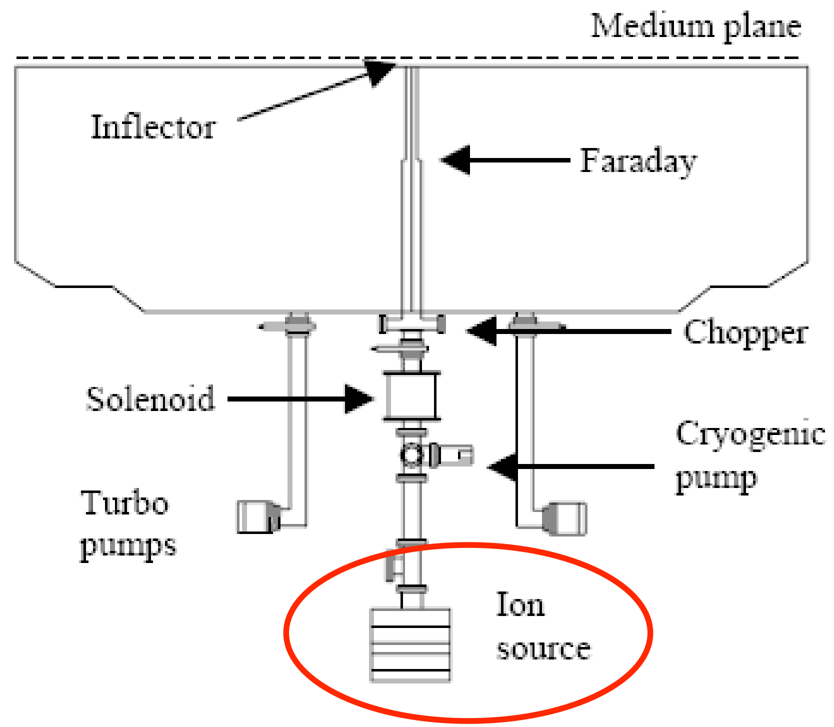


Figure 4: Layout of the axial injection line and part of vacuum plant

LNS CATANIA PROJECT FOR THERAPY AND RADIOISOTOPE PRODUCTION

L.Calabretta, G. Cuttone, M. Re, D. Rifuggiato, LNS-INFN, Catania, Italy
M.Maggiore, University of Catania, LNS-INFN, Italy

Cyclotron conference, Tokyo 2004

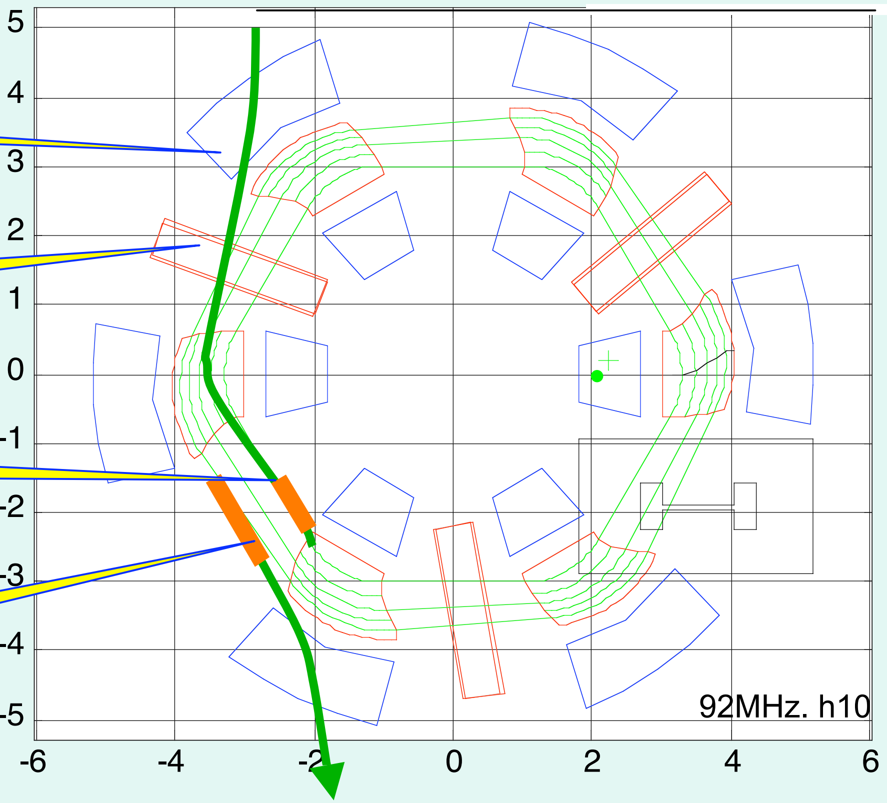
current ideas for a novel 450 MeV/nucl sep. sector cyclotron

Magnet **yokes too large** for original idea.

Separate locations of injector and booster more advantageous.

Magnets with **super conducting** coils.

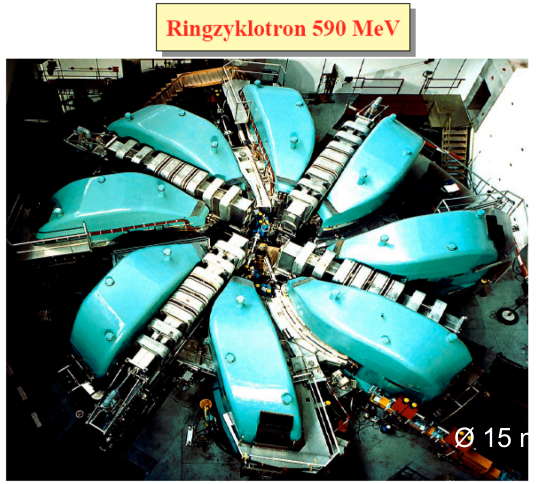
⇒ **H-magnets** possible.



Advantages

- 2 phase approach possible (first protons)
- in first phase already α and (up to 12.5 cm) Carbon
- Booster should be **simpler** than single cyclotron

- Use of proven **well established techniques**:
  - Injector: **existing similar SC** cyclotrons (ACCEL/PSI, Groningen, Catania, East Lansing)
  - Booster: extremely **reliable ring** cyclotrons at PSI (injector 2 + ring cyclotron for neutron source)

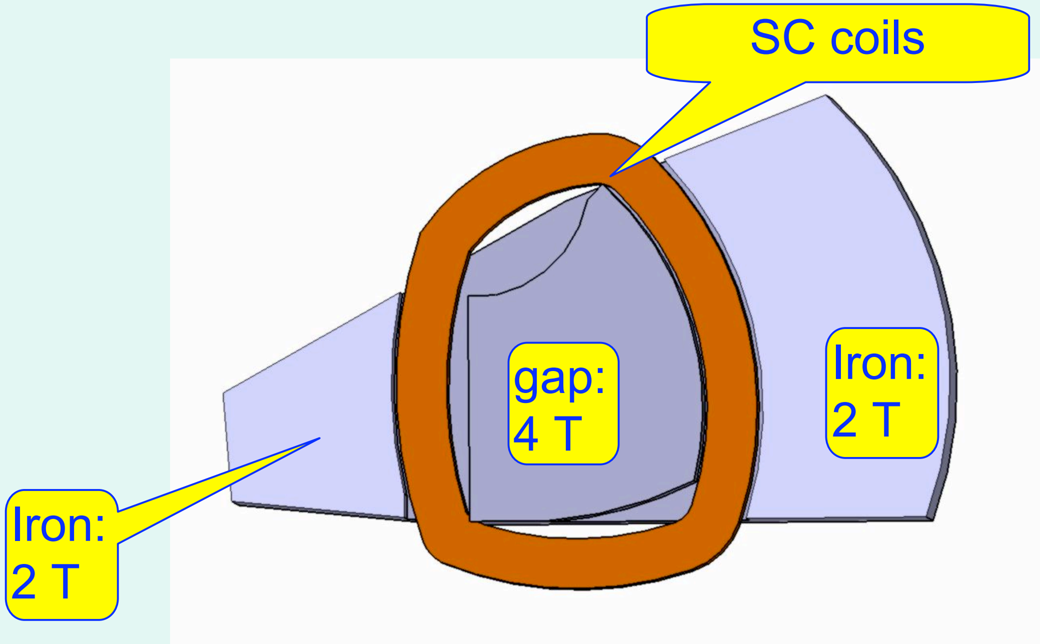


- High fields in magnets: **stable and reproducible**
- **Low power** of SC magnets
- Beam dynamics in Booster **“relaxed” and robust:**
  - no problems with resonances
  - still many degrees of freedom to design
  - strong vertical focusing
  - large orbit separation => high extraction efficiency

- Option: when employing both Carbon-energies: **2 simple degraders**, one at each cyclotron

parameters of sep. sector cyclotron

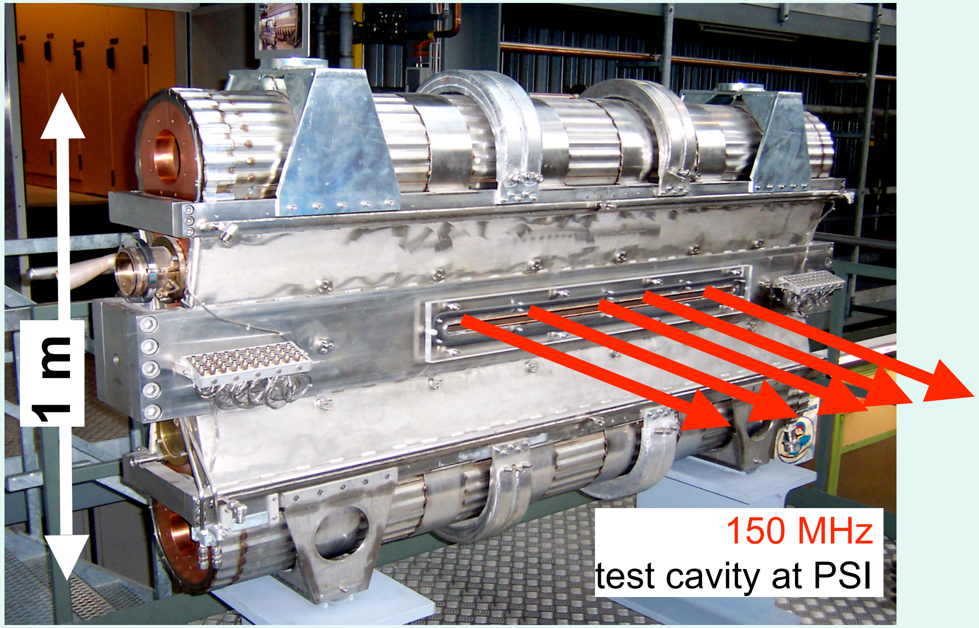
Magnet types	H-magnets , superconducting coils
Magnetic field	4 Tesla



parameters of sep. sector cyclotron

RF frequency	92 MHz; 3 single gap cavities, 600 kV
ΔE per turn	~ 0.8 MeV/nucl

Advantages of single gap :
- high ΔE per turn: **600 kV**
- less space azimuthally
- smallest vacuum volume

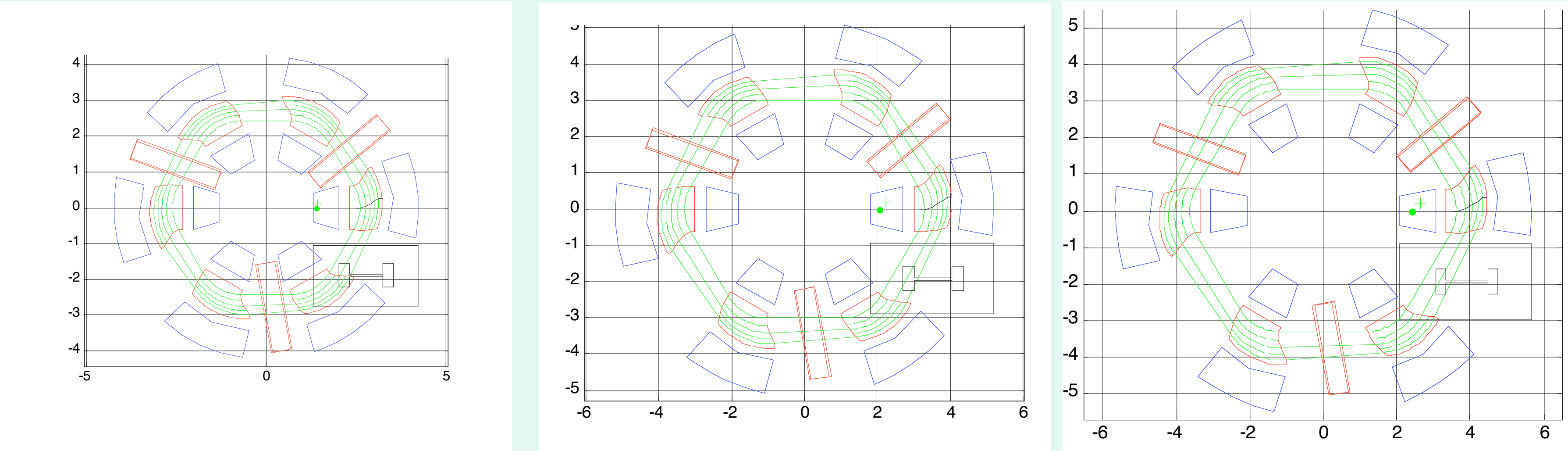


"Scaled 150 MHz test cavity":
Height 1.0 m→1.5 m

=> high injection and extraction efficiencies are expected

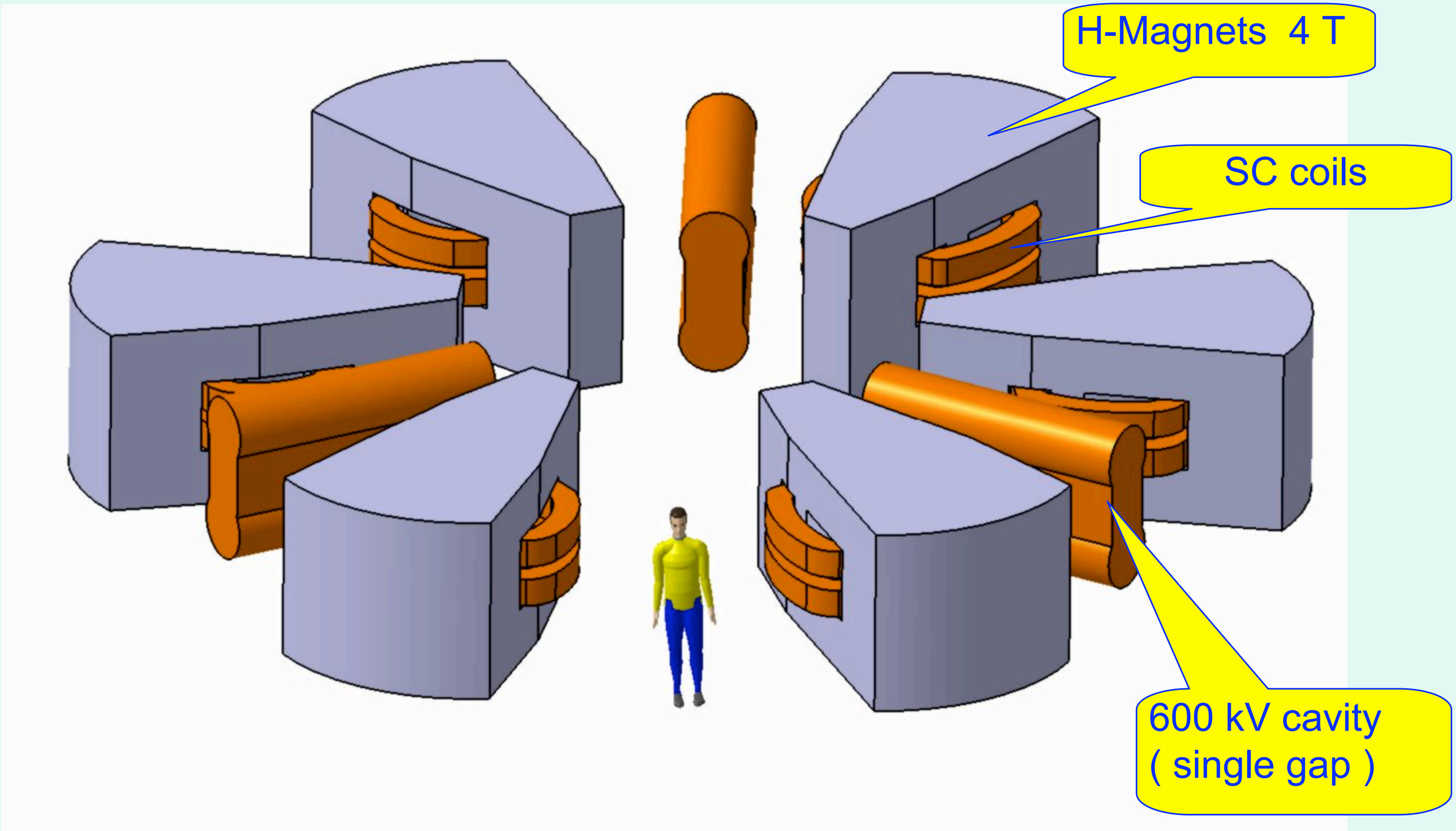
3 options, depending on h ($=f_{RF}/f_{particles}$)

	design options		
Harmonic nr ($f_{RF}/f_{particles}$)	8	10	12
Weight (tons)	360	420	480
Size ∅ (m)	9	10	11

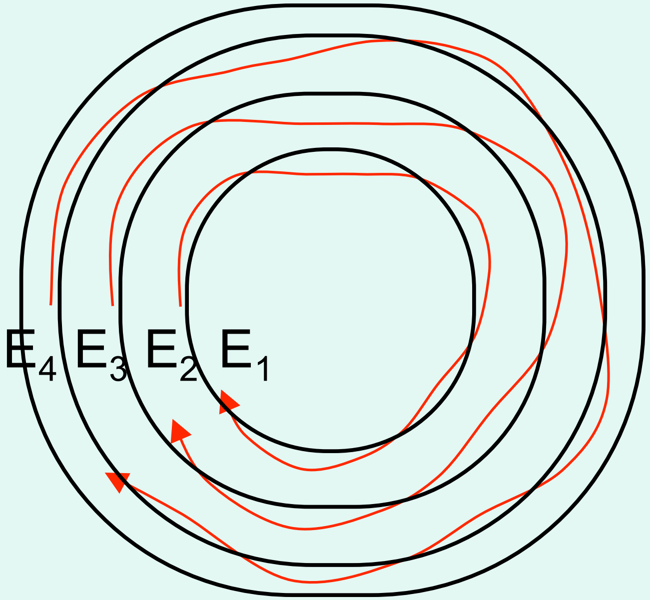


spreadsheet designs 92h8 92h10 92h12

Possible 450 MeV/nucl sep.sect. cyclotron



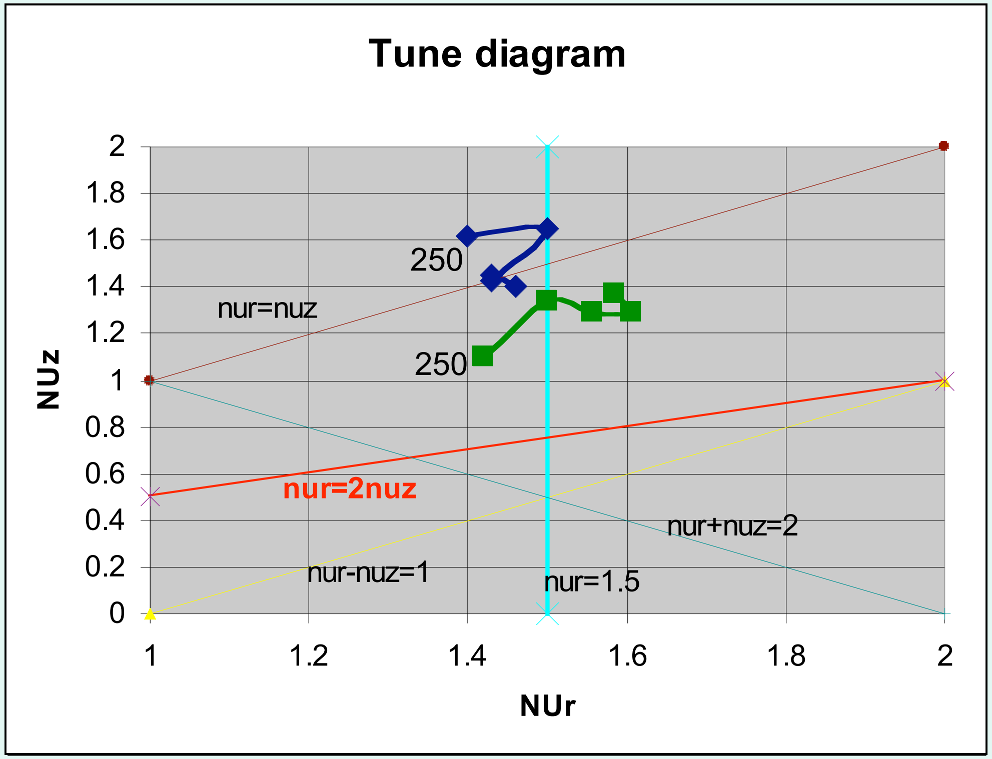
Preliminary beam dynamics



$\nu_r(E)$ and $\nu_z(E)$

=> *focusing strength ($\sim\nu^2$)*

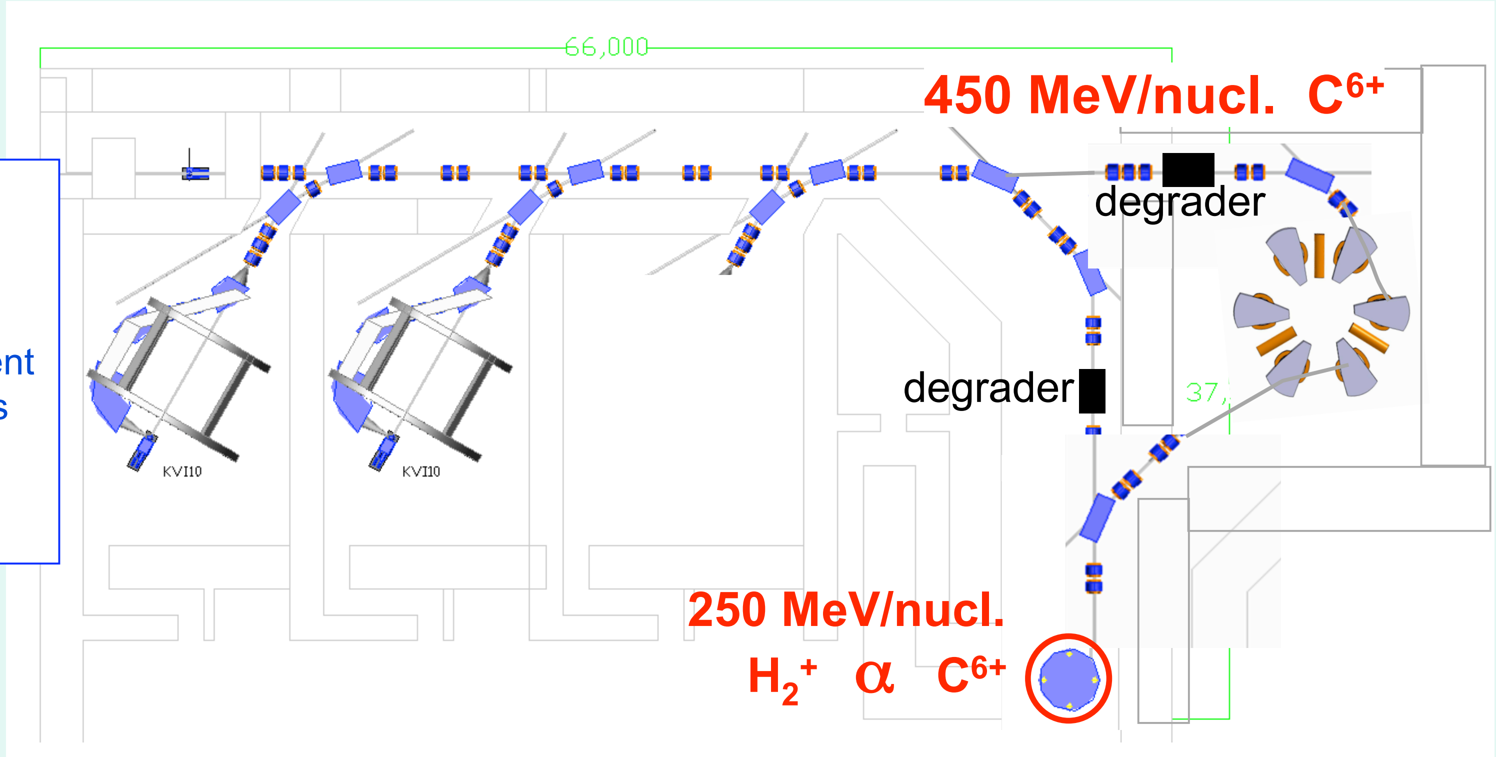
=> *avoid (or use!) resonances*



⇒ far away from dangerous resonances

⇒ ν_r=1.5 could be used for extraction

Possible system layout



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New Treatment Rooms

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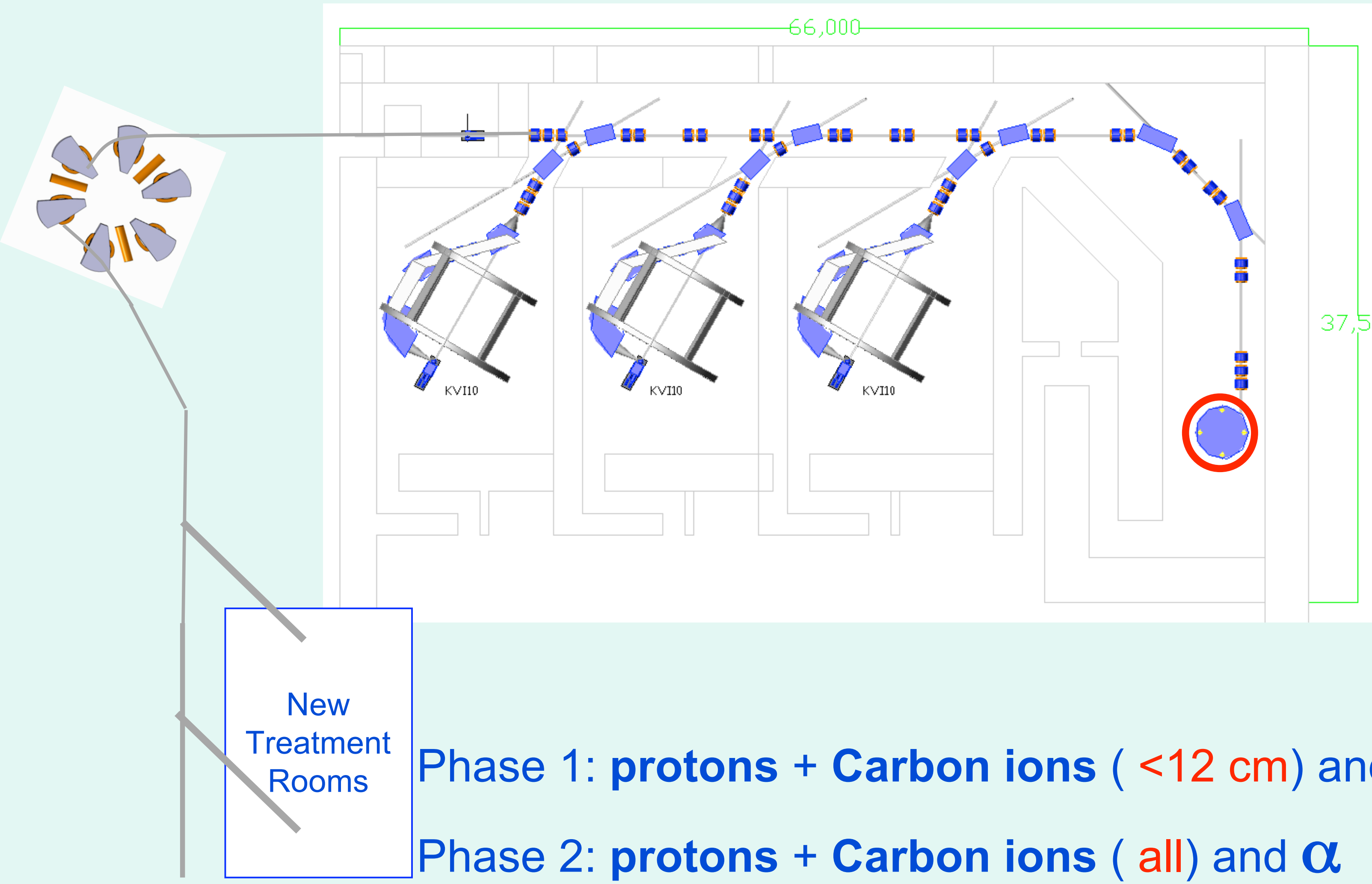
Phase 1: **protons** + **Carbon ions** (<12 cm) and **α**

Phase 2: **protons** + **Carbon ions** (all) and **α**

alternative system layout



Phase 1: **protons** + **Carbon ions** (<12 cm) and α

Phase 2: **protons** + **Carbon ions** (all) and α

Next to do:

- (parameters of) Injector Cyclotron
- optimize field and sector shape
- magnet design; minimize iron;
- injection and extraction
- cost estimate
- partner (industry and/or lab)

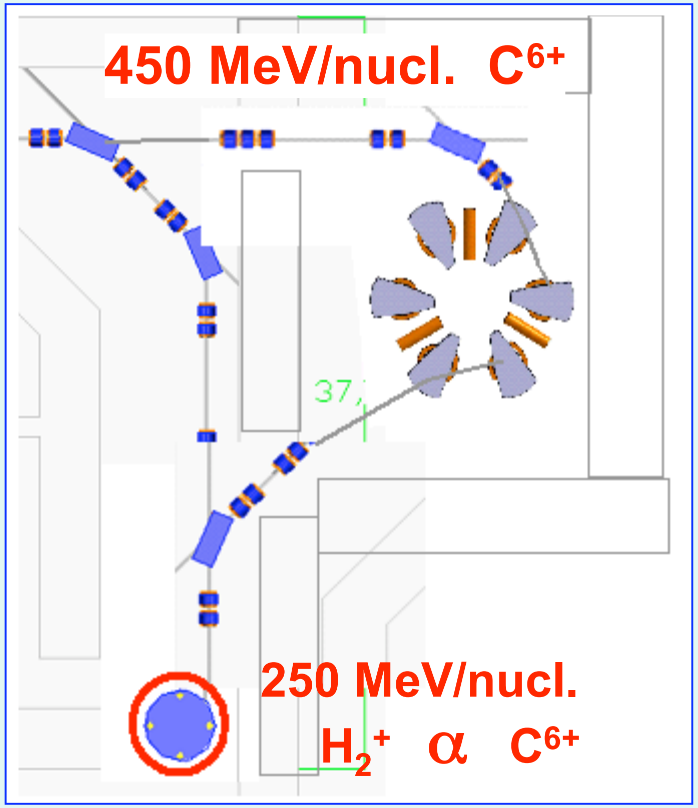
summary

A novel idea for a **2 step approach** of **multi-particle** therapy:

- Start with protons AND
- α + (up to 12.5 cm:) Carbon
- Second step: also 450 MeV/nucl Carbon

- Use of **well established techniques**
- Design of Booster is **"relaxed" and robust**
- Many **options**: phasing, layout, degrader

- For next project phase: **partner(s) wanted**

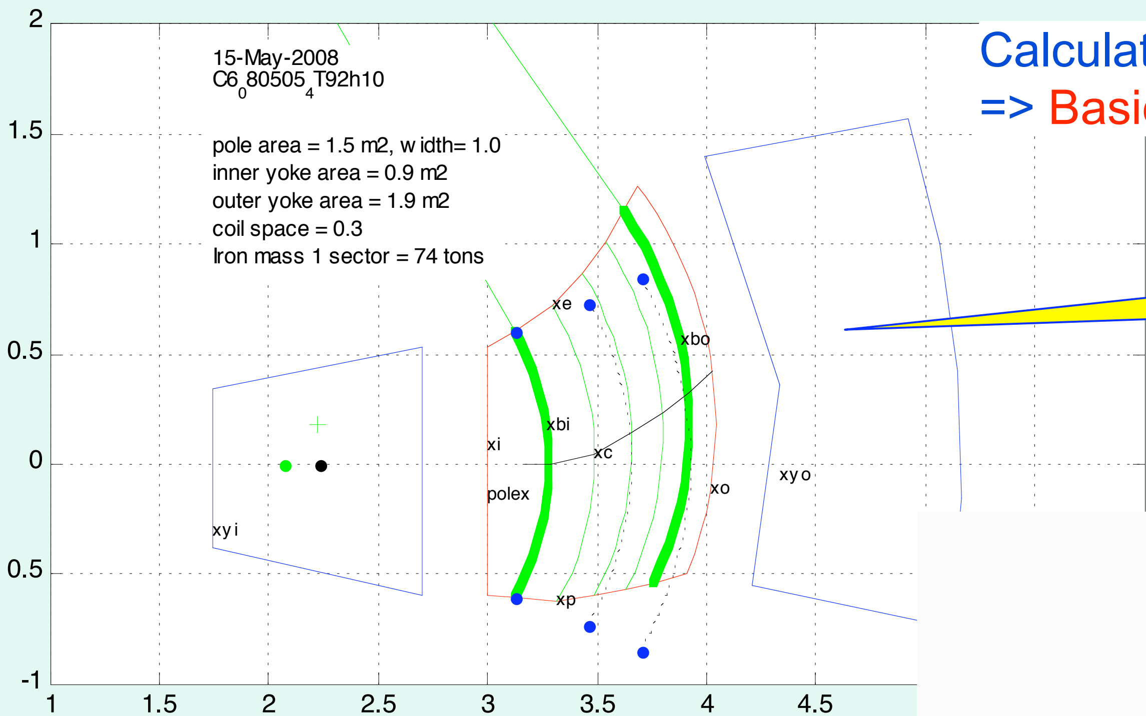


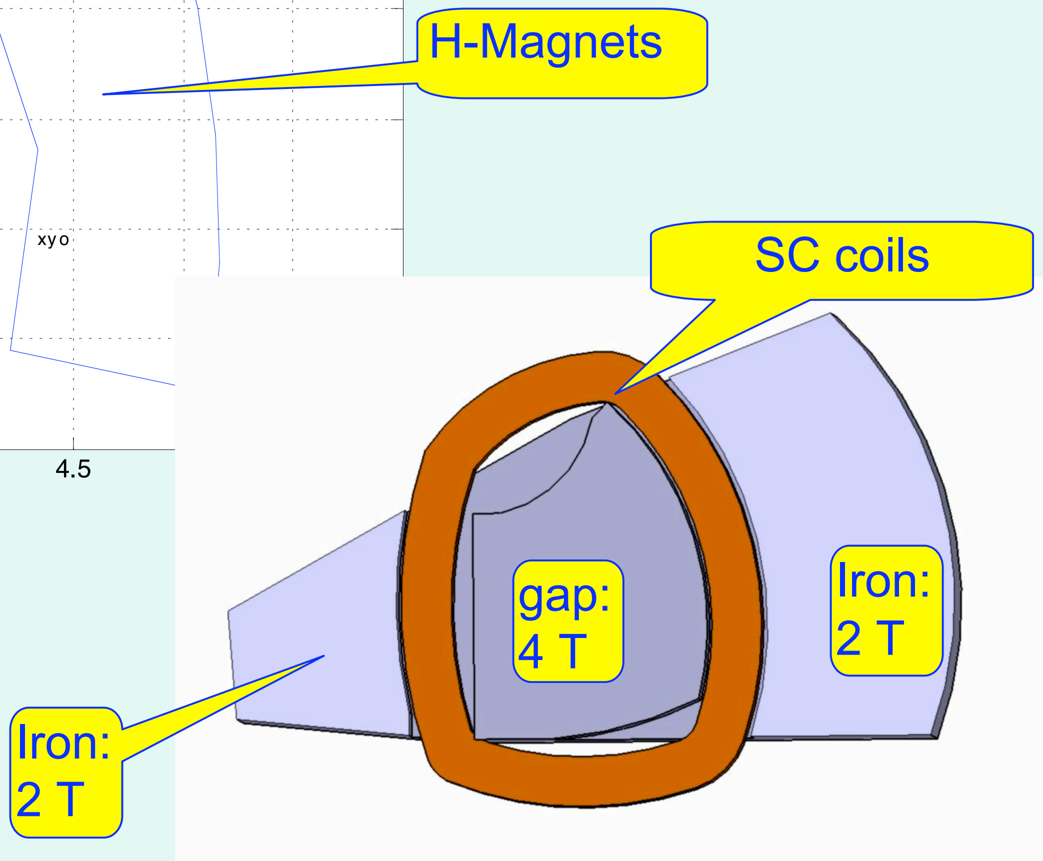
The long road still to go…..

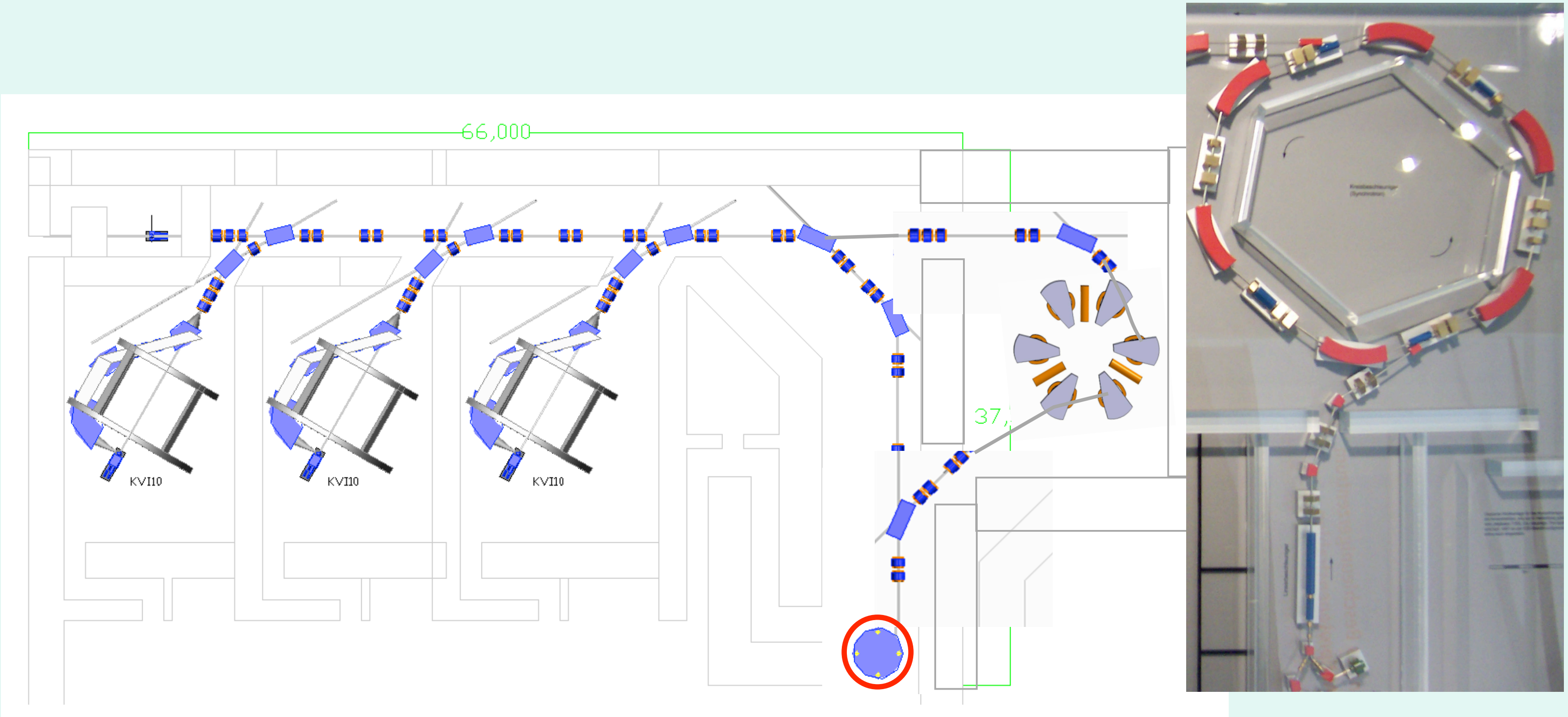
Reserve slides and images

Details of sector magnet

Calculation of closed orbit parameters
=> Basic magnet shape



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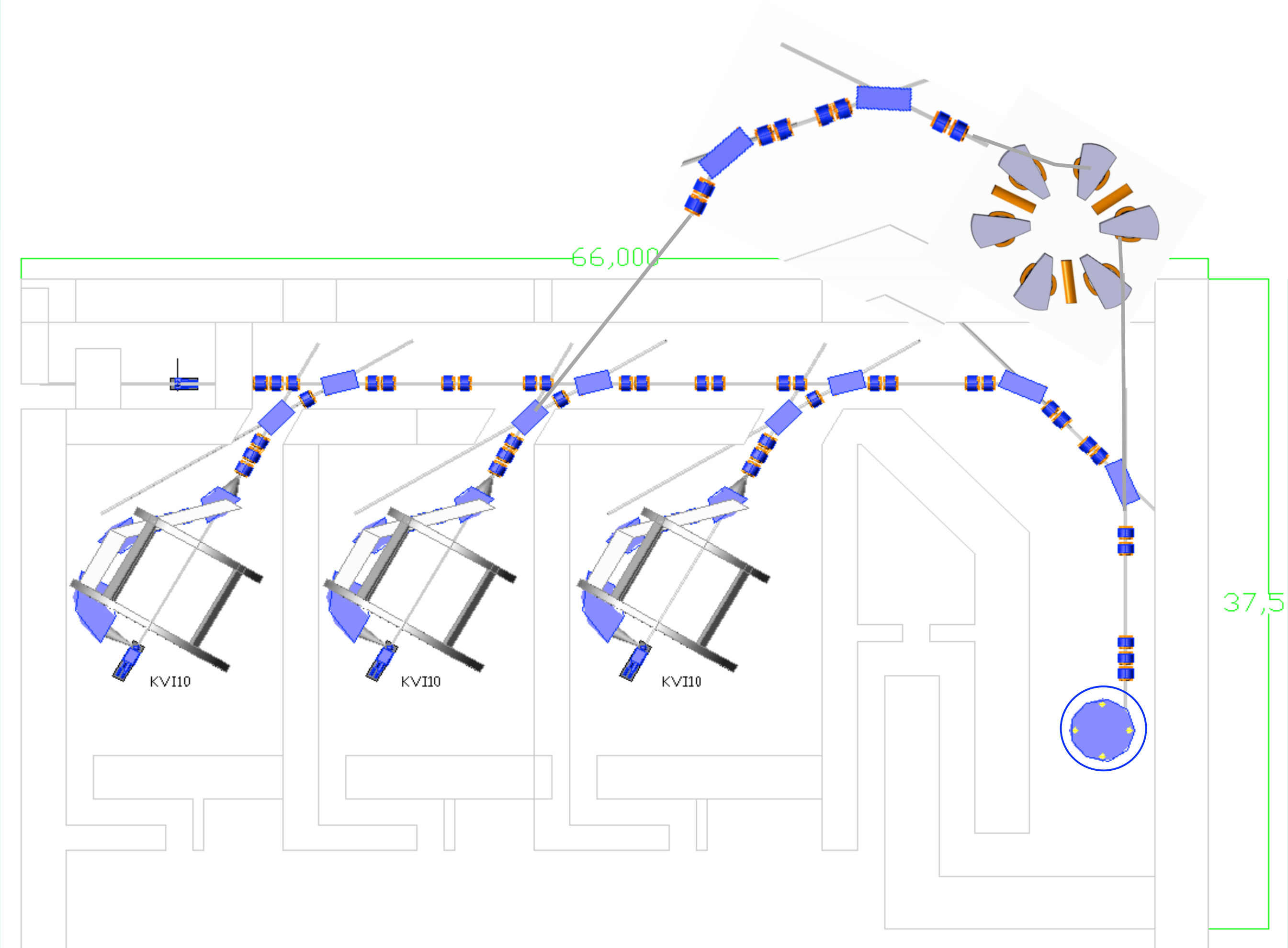
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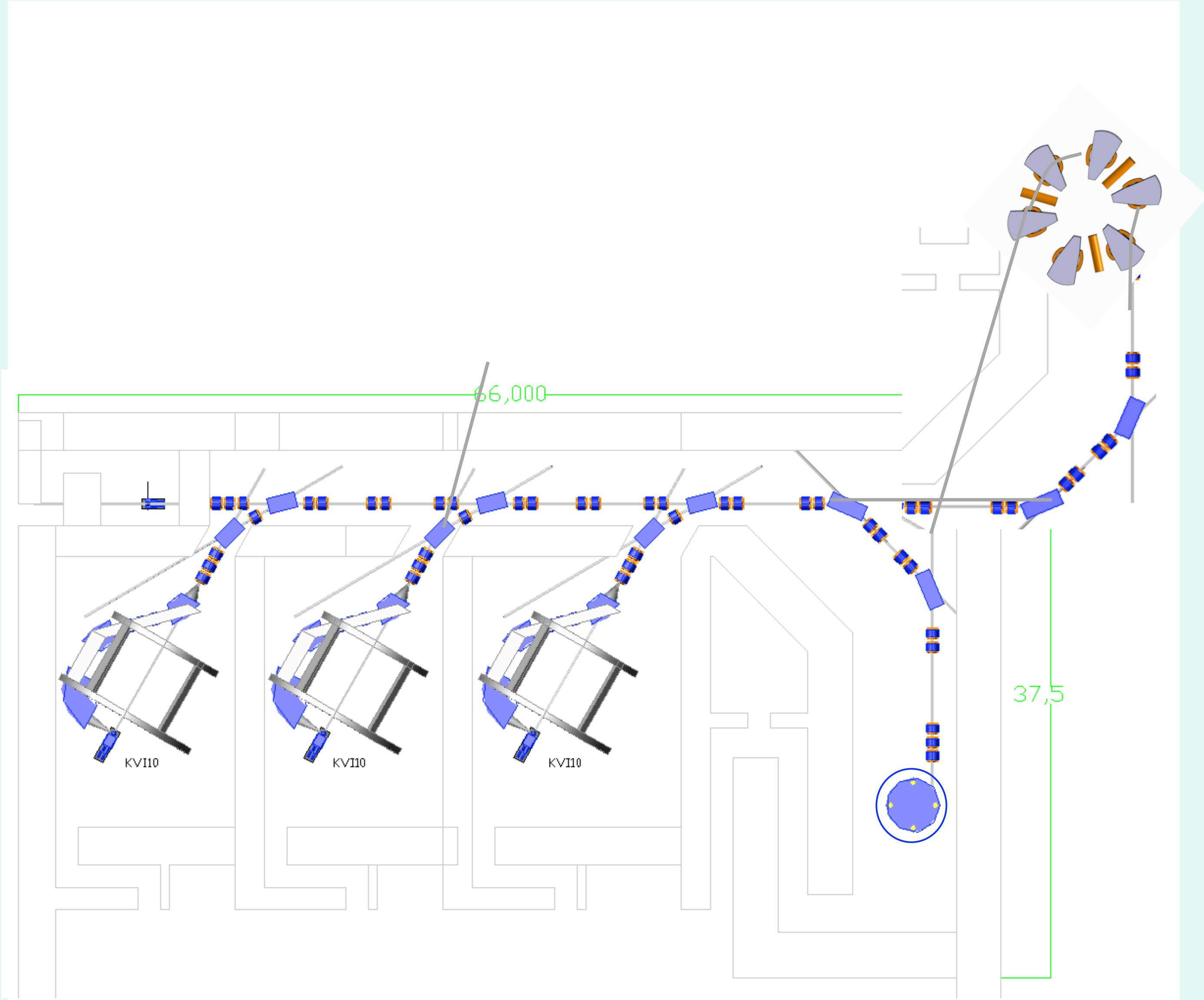
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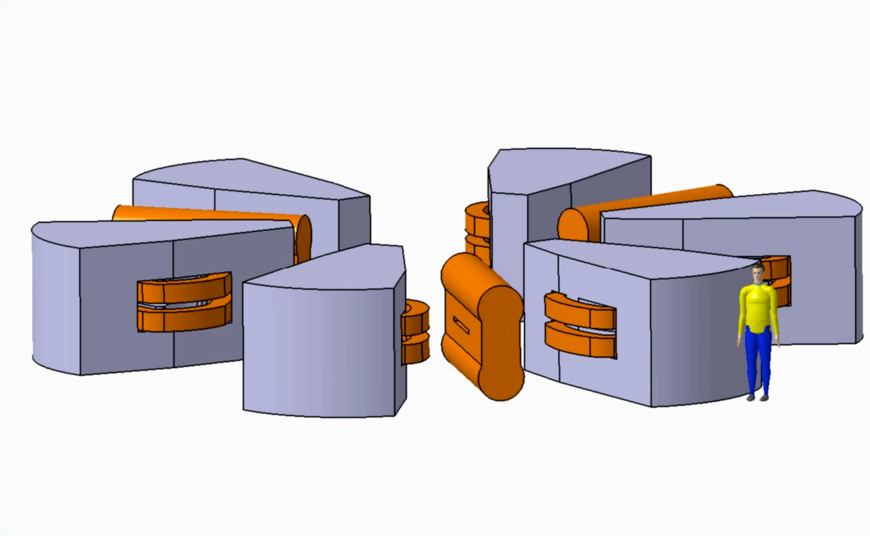
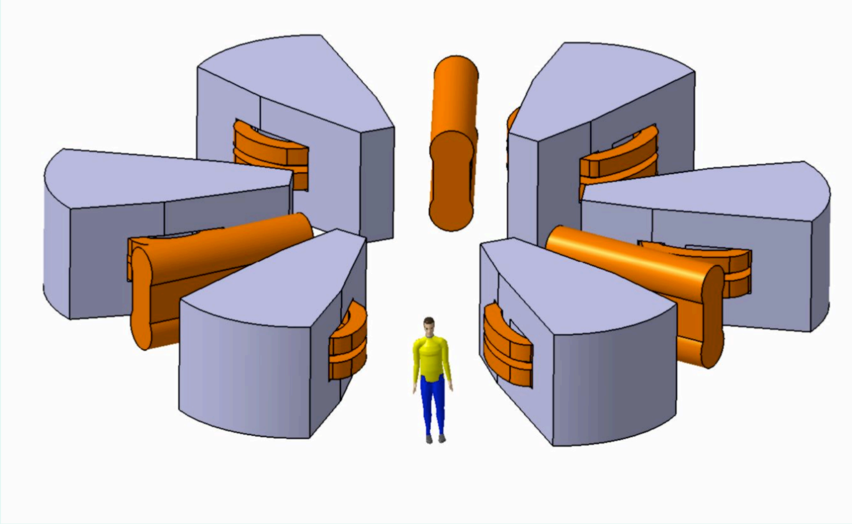
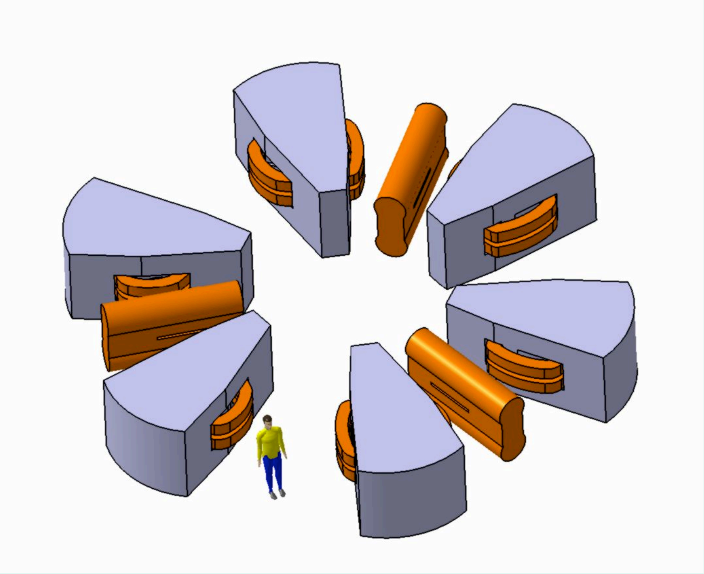
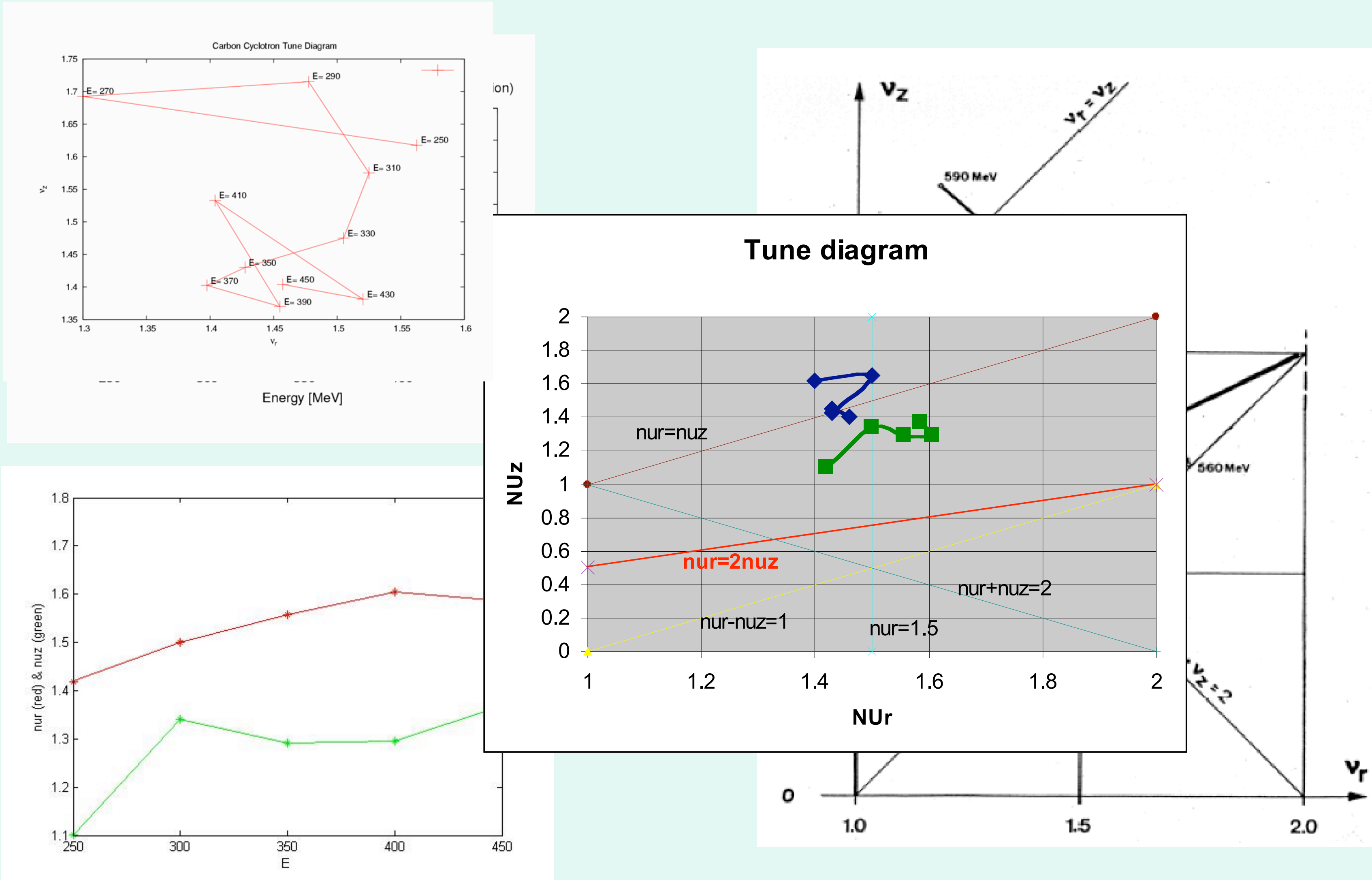
Ideas for the 450 MeV/n. ring cyclotron







Preliminary beam dynamics



A novel idea:

Two steps: injector and booster

BUT: injector also provides (limited) carbon beams

	Beams from injector cyclotron: 250 MeV/nucl			From separated sector cyclotron
	Proton 250 MeV/n (**H_2^+ ions**)	Helium 2+ (α) 250 MeV/n	Carbon 6+ 250 MeV/n	Carbon 6+ 450 MeV/n
Magnetic rigidity (Tm)	2.43 **4.86**	4.86	4.86	6.83
Range in water (cm)	38.3	38.3	12.7	33.3

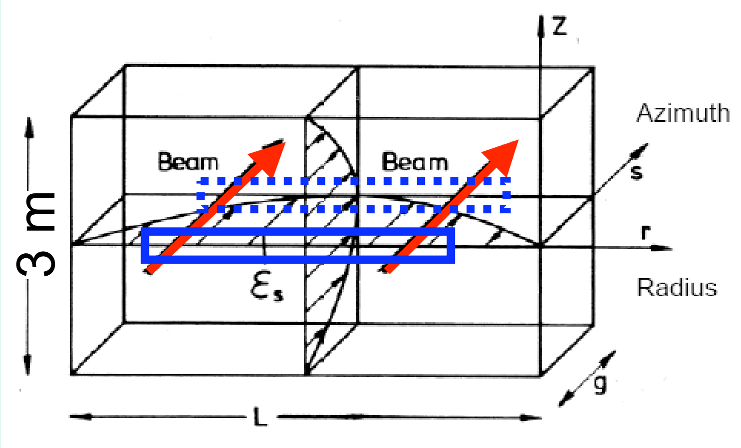
parameters of sep. sector cyclotron

Magnet types	H-magnets , superconducting coils		
Magnetic field	4 Tesla		
RF frequency	92 MHz; 3 single gap cavities 600 kV		
ΔE per turn	~ 0.8 MeV/nucl		
	design options		
Harmonic nr ($f_{RF}/f_{particles}$)	8	10	12
Weight (tons)	360	420	480
Size ∅ (m)	9	10	11
Orbit separ. inj (mm)	2.6	3.1	3.3
Orbit separ. extr (mm)	1.8	2.3	2.5
Good field width (m)	0.5	0.65	0.7

Details of RF cavity

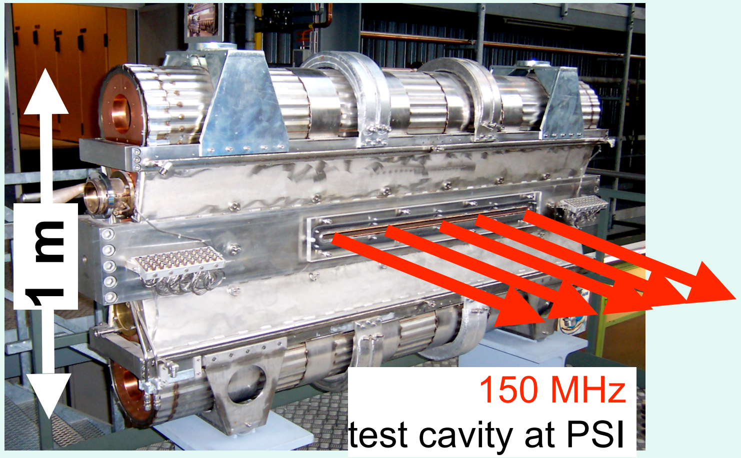
92 MHz (= f "Catania")
Single gap cavity

Advantages of single gap :
- high ΔE per turn: **600 kV**
- less space azimuthally
- smaller vacuum volume

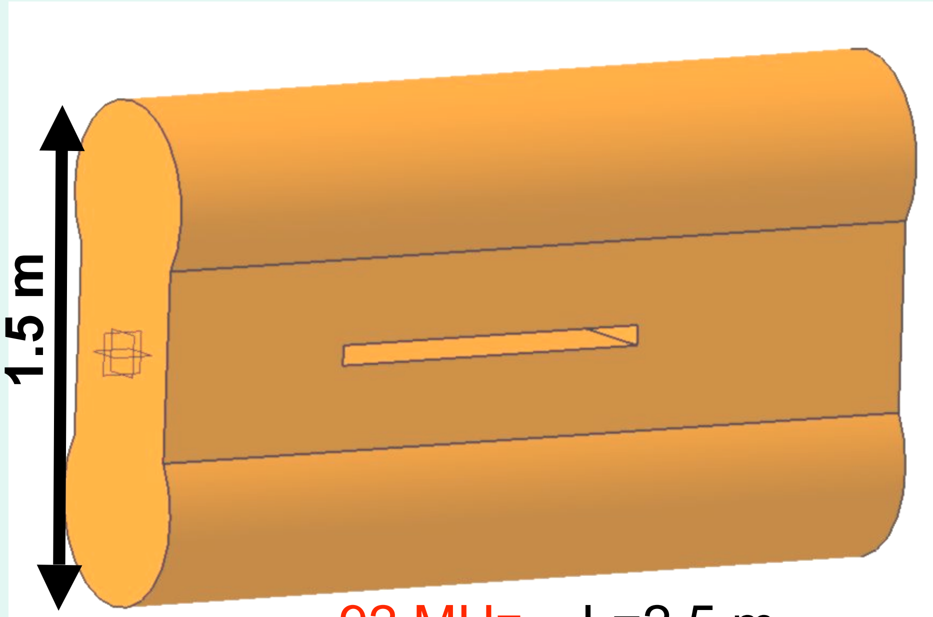


PSI-ring cavity: 50 MHz, 1MV, 500 kW

"Scaled 150 MHz test cavity"



150 MHz
test cavity at PSI



92 MHz, L=2.5 m