A Test Site for High Power Cyclotrons

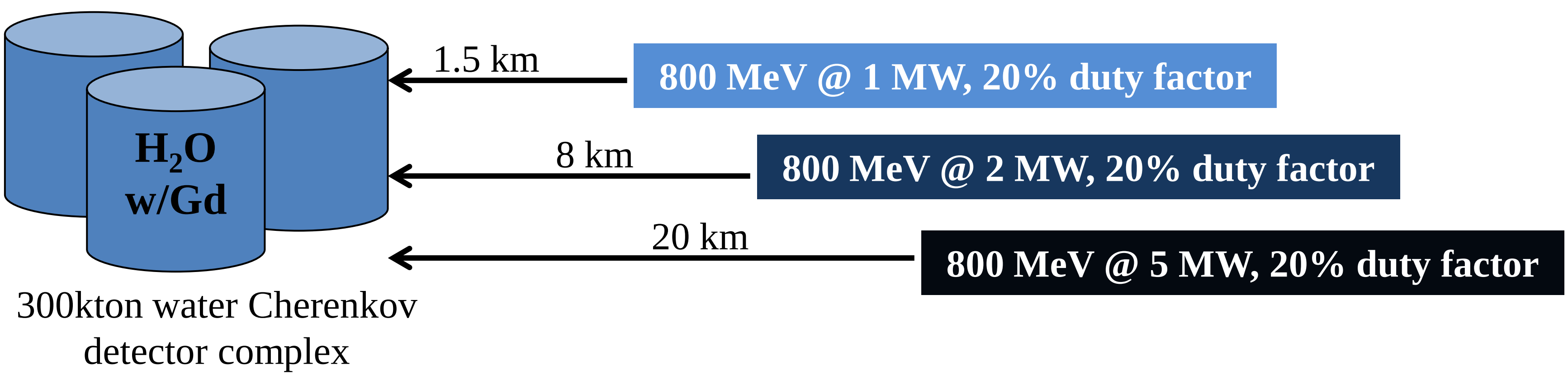
for Fundamental Physics and Radioisotope Production

By Luciano Calabretta, INFN-LNS

LNS User Meeting, Catania 6 December 2013

DAEδALUS

Decay **A**t rest **E**xperiment for $\boldsymbol{\delta_{cp}}$ studies **A**t the **L**aboratory for **U**nderground **S**cience

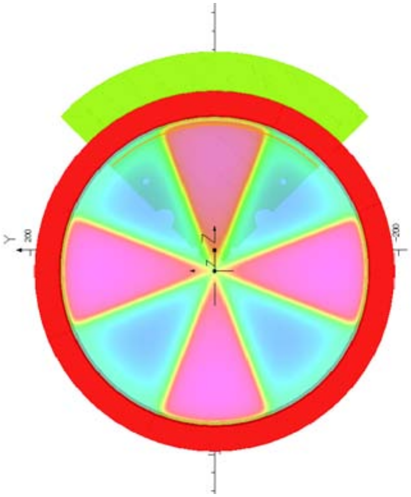


<2 MW> with a peak power of 10 MW or higher

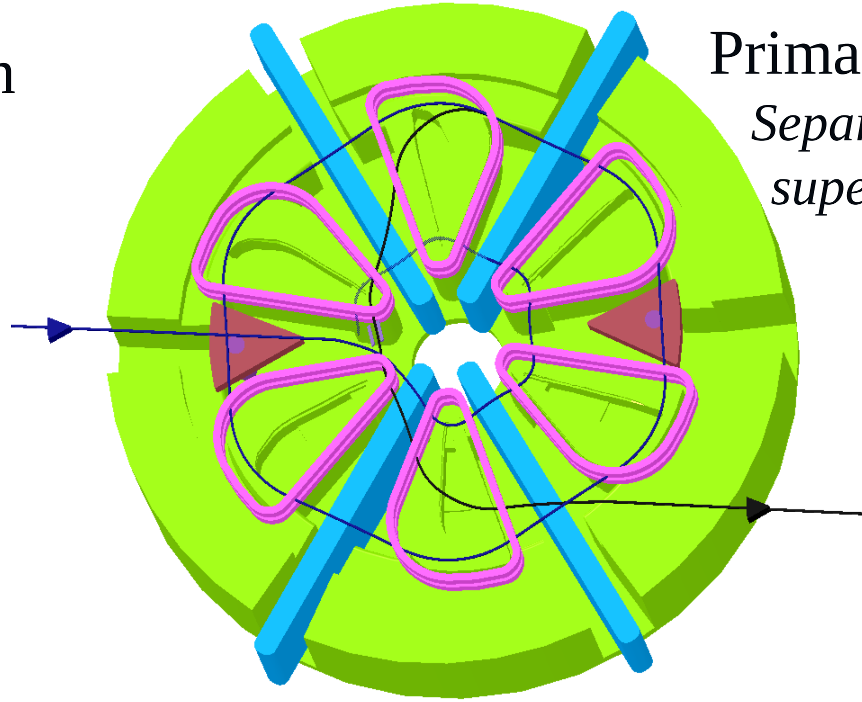
DAEδALUS base module features

Injector Cyclotron

compact, resistive



- < 1 mA> H_2^+ 60 MeV/n
- Peak current 5mA of H_2^+
- Average power 120 kW
- Peak power 600 kW

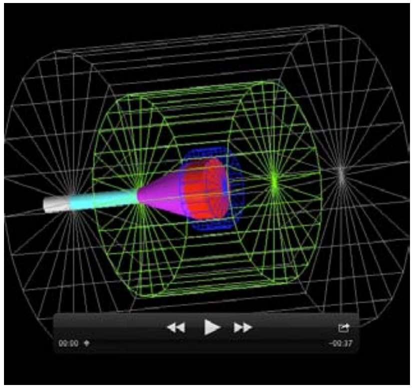


Primary Cyclotron

Separated sectors, superconducting

- <1 mA> H_2^+ 800 MeV/n
- Peak Power 10 MW,
- Average power 2 MW
- Beam losses < 200 W!
- Stripping extraction

Target/shielding



arXiv.org > physics > arXiv:1207.4895

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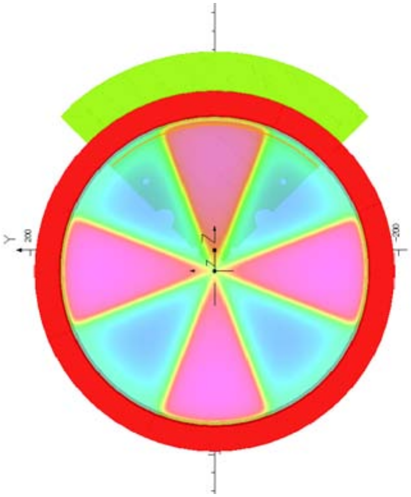

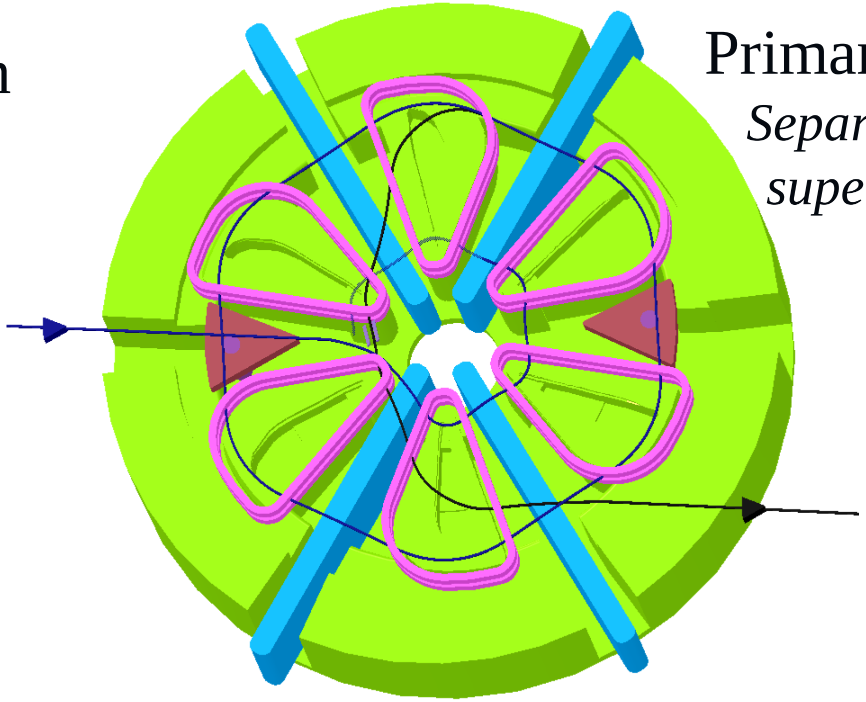

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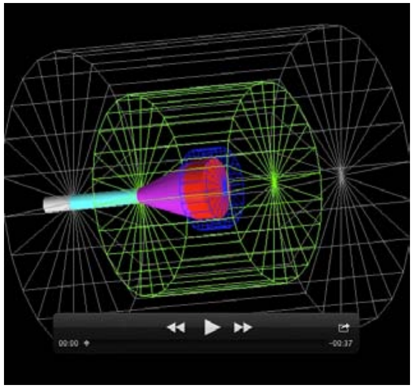

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❖Space Charge effects
❖Electrostatic Deflectors

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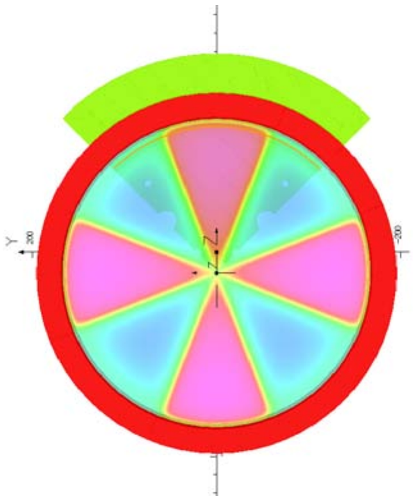

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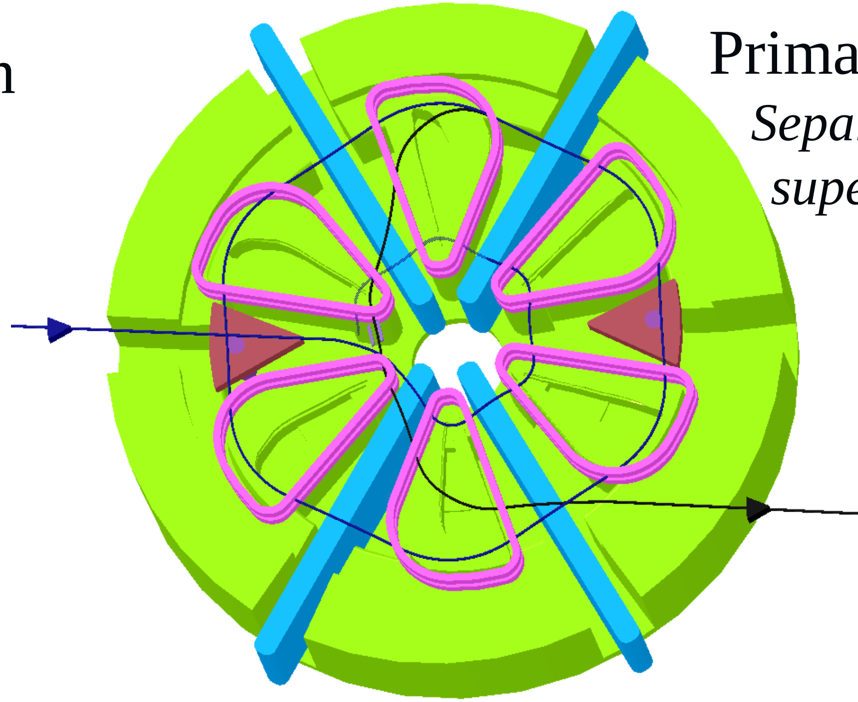
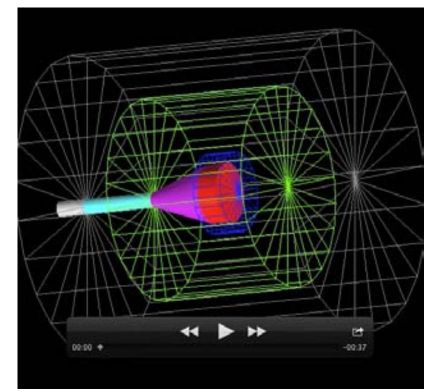


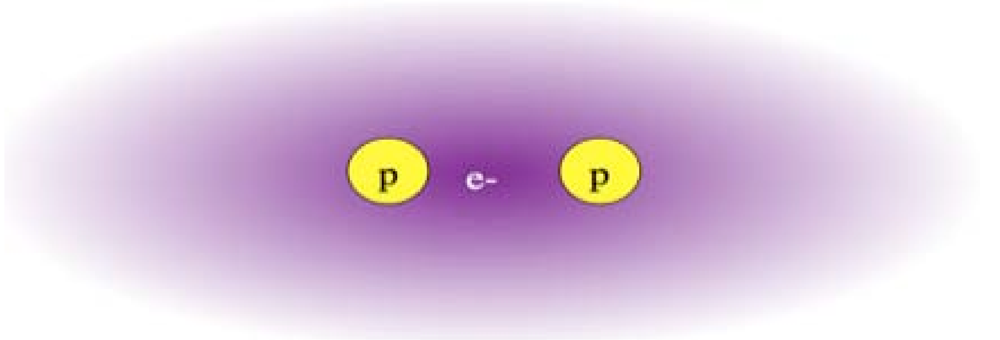
- <1 mA> H_2^+ 800 MeV/n
- Peak Power 10 MW,
- Average power 2 MW
- Beam losses < 200 W!
- Stripping extraction

❖Superconducting Coils
❖Losses due to residual gas
❖Electromagnetic stripping

Target/shielding



Acceleration of H_2^+ ions to produce high intensity proton beam



- ✓ Two protons for every ion (1 emA = 2 pmA)

The Generalized Perveance measures the space charge effect and it is defined by the Reiser's formula:

$$K = \frac{qI}{2 \cdot \pi \cdot \varepsilon_o \cdot m \cdot \gamma^3 \beta^3}$$

Perveance of 5 emA H_2^+ at 35 keV/amu same as 2 emA of 30 keV protons

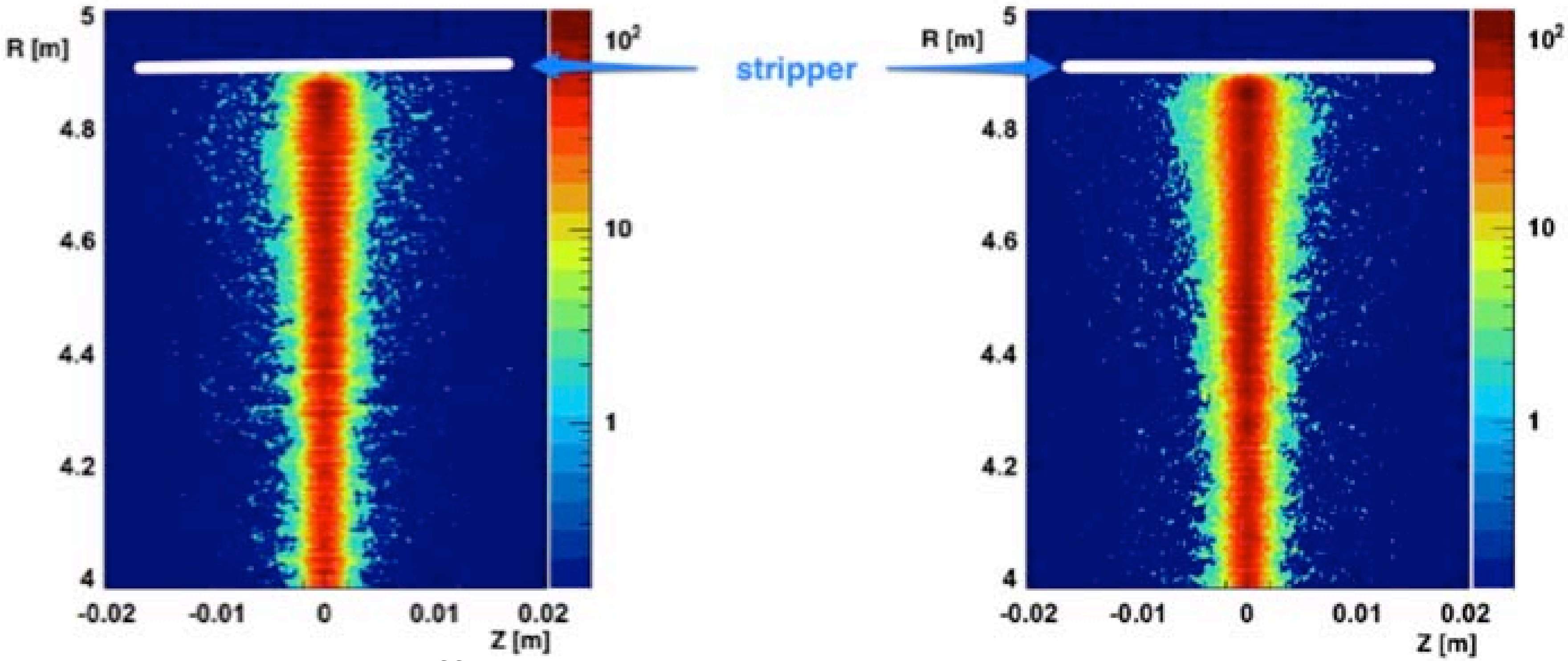
- ✓ axial injection of 2 emA protons at 30 keV is established

- ✓ Extraction with stripping foil, because it requires a high-acceptance extraction channel and not a clean turn separation

DAEδALUS Superconducting Ring Cyclotron

Vertical beam size along the acceleration in the radial range from 4 to 4.9 m, snapshot at 0° azimuth.

Simulation made by J. Yang and A. Adelman @ PSI, using OPAL code.



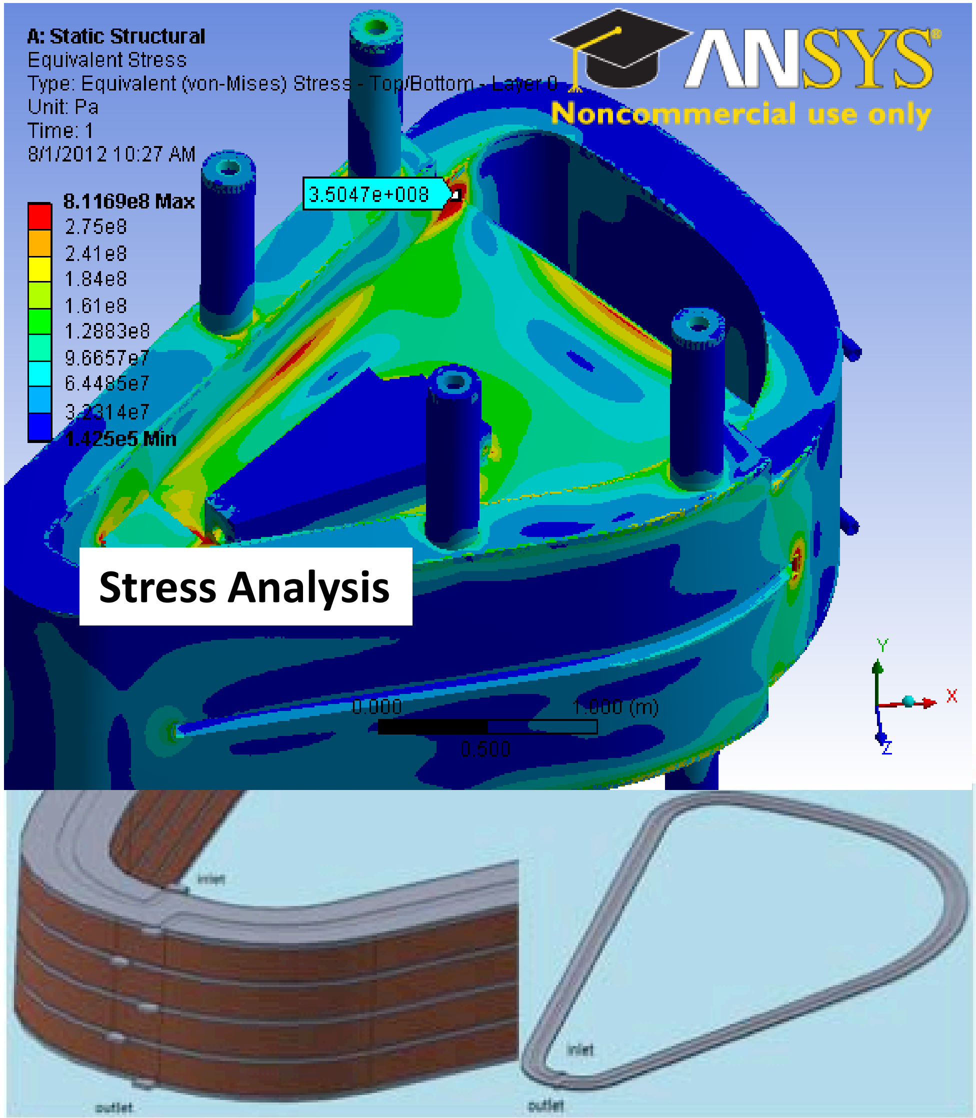
no charge space effects

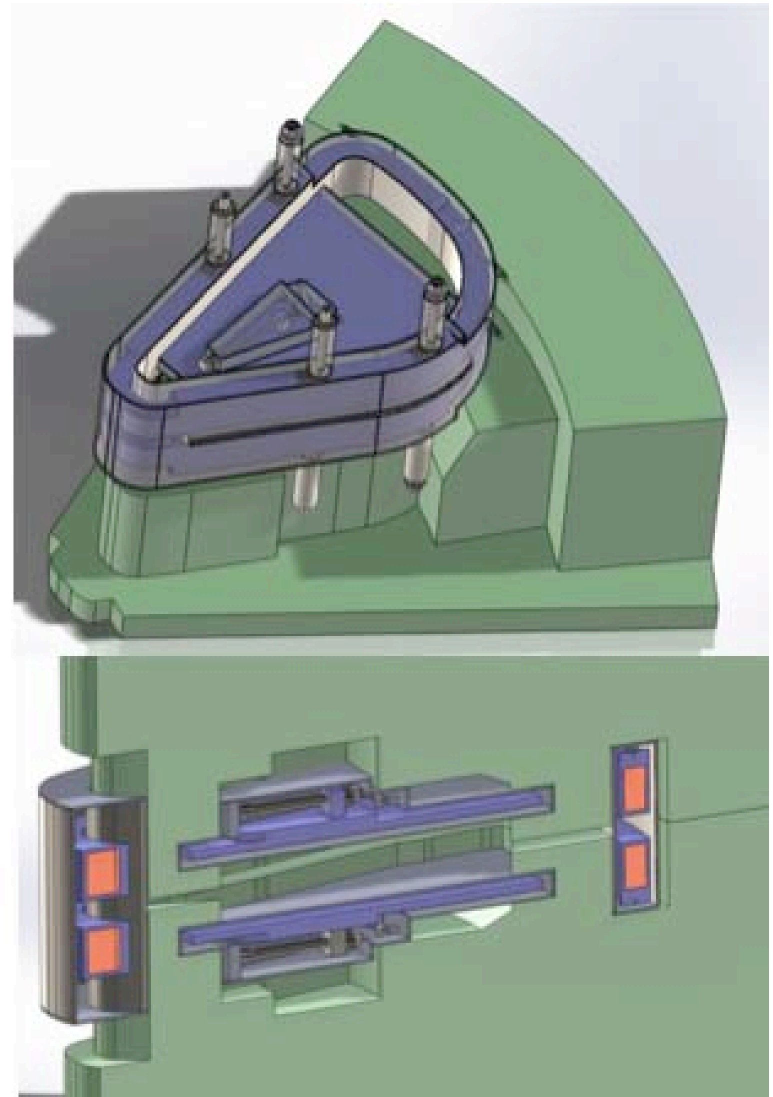
5 mA beam H_2^+ current

Space charge produces negligible effects during acceleration!

Preliminary study of the cryostat

Design made by J. Minervini Group @ MIT-PSFC

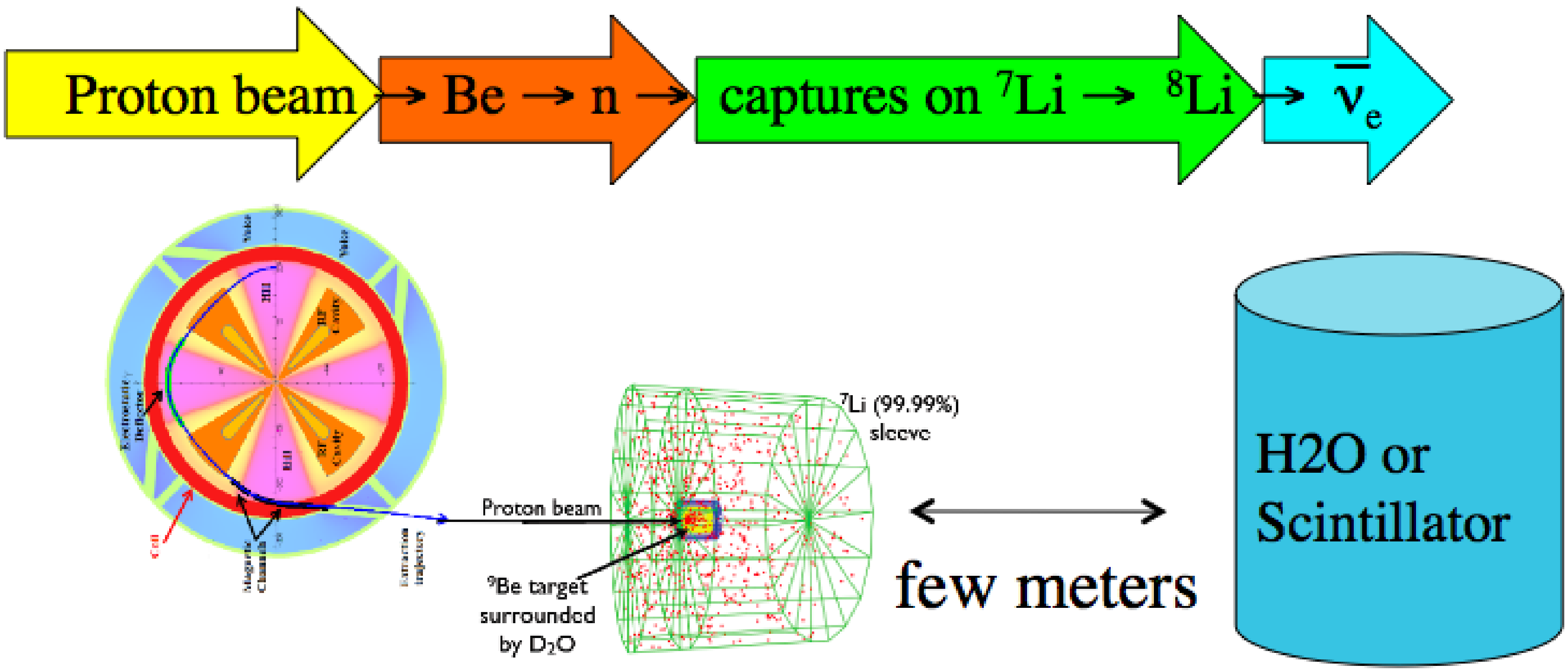




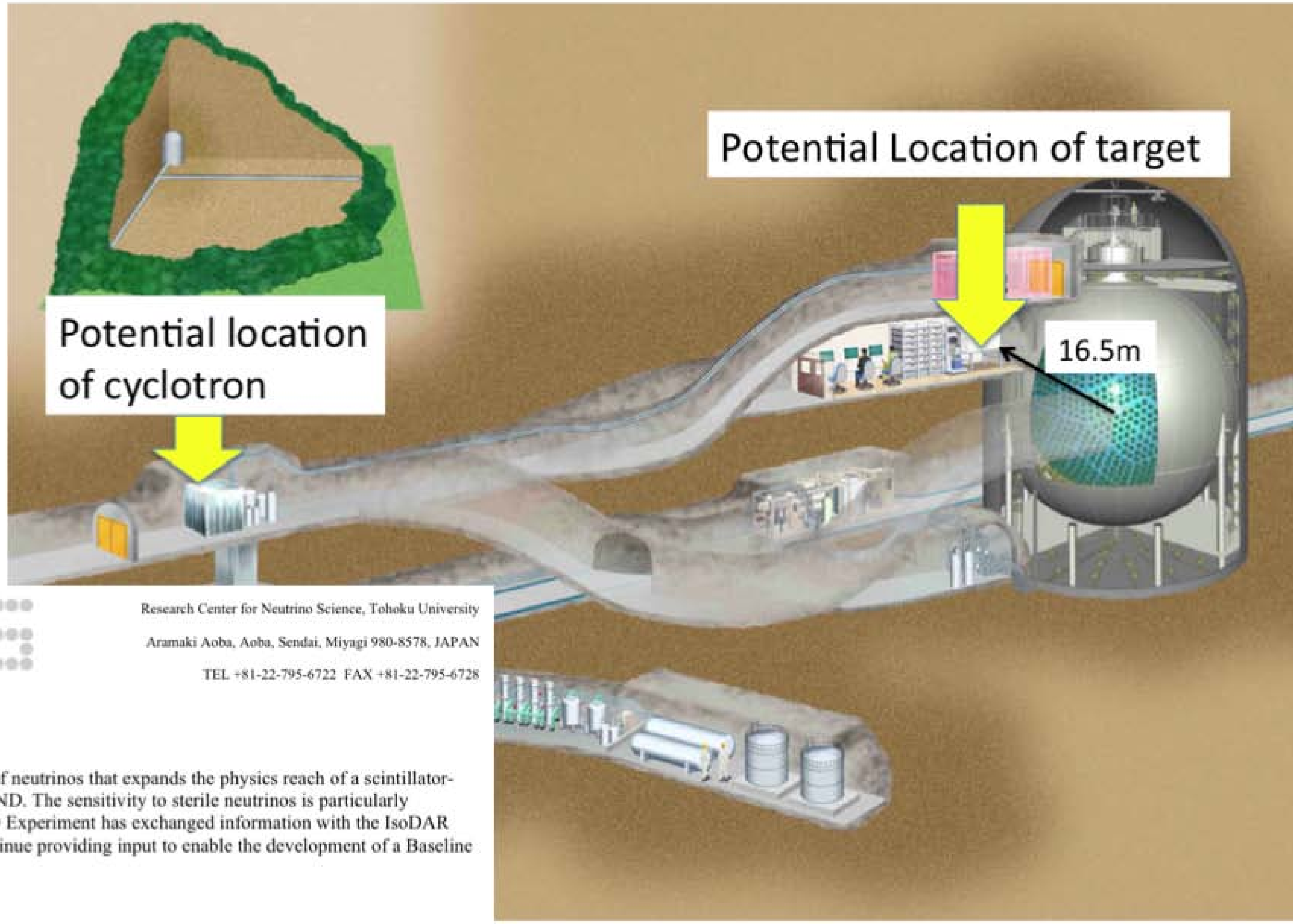
arXiv.org > physics > arXiv:1209.4886

DAEδALUS phase 1!

IsoDAR Experiment: Search for Sterile Neutrino



IsoDAR at Kamland



Research Center for Neutrino Science, Tohoku University
Aramaki Aoba, Aoba, Sendai, Miyagi 980-8578, JAPAN
TEL +81-22-795-6722 FAX +81-22-795-6728

Letter of Collaboration

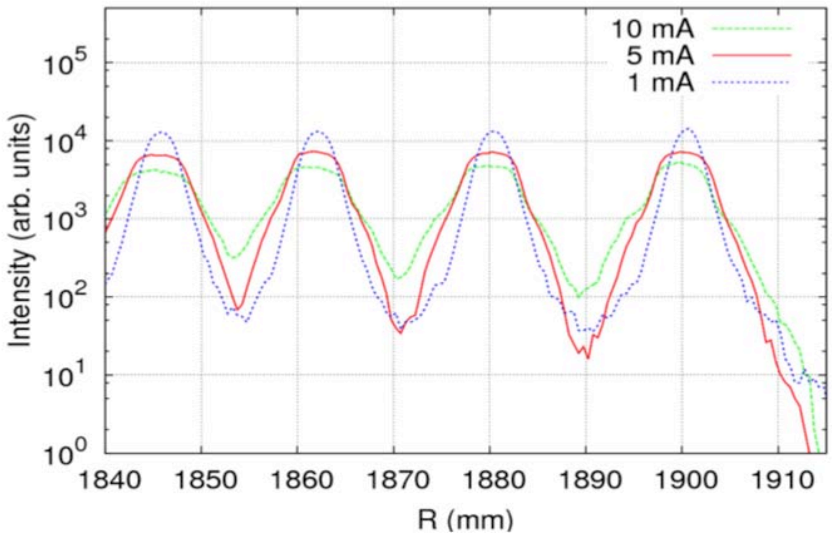
IsoDAR provides a source of neutrinos that expands the physics reach of a scintillator-based detector like KamLAND. The sensitivity to sterile neutrinos is particularly motivating. The KamLAND Experiment has exchanged information with the IsoDAR group already, and will continue providing input to enable the development of a Baseline Design Report.

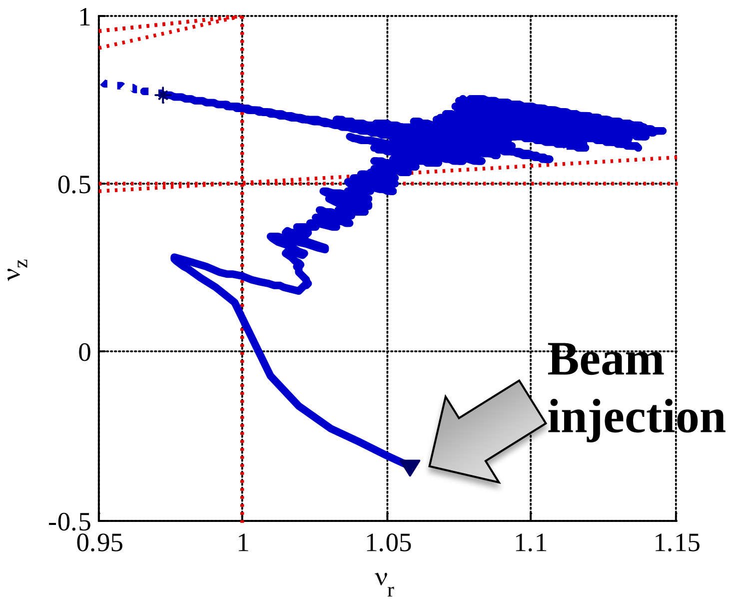
Sincerely,

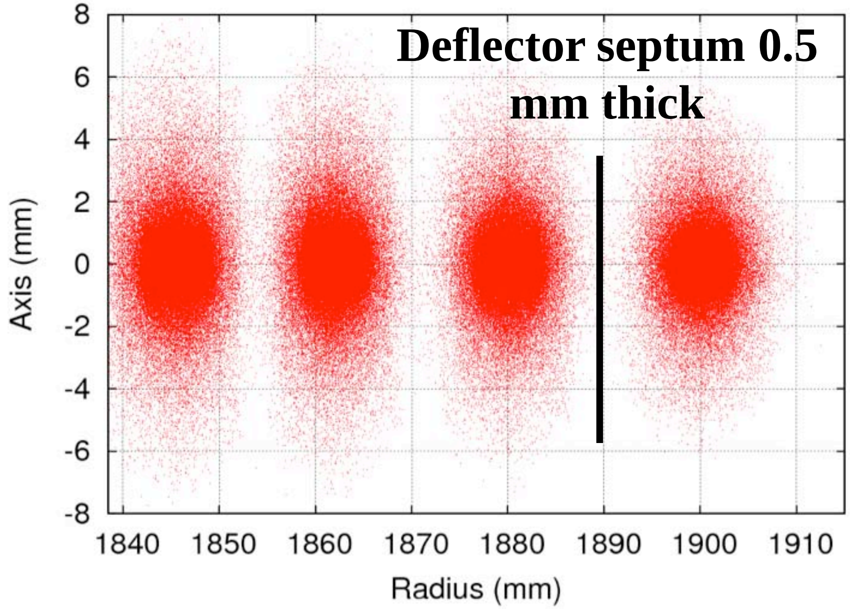
Kunio Inoue

Kunio Inoue
Research Center for Neutrino Science,
Tohoku University

Beam dynamics in DAEδALUS Injector Cyclotron, well fixed!

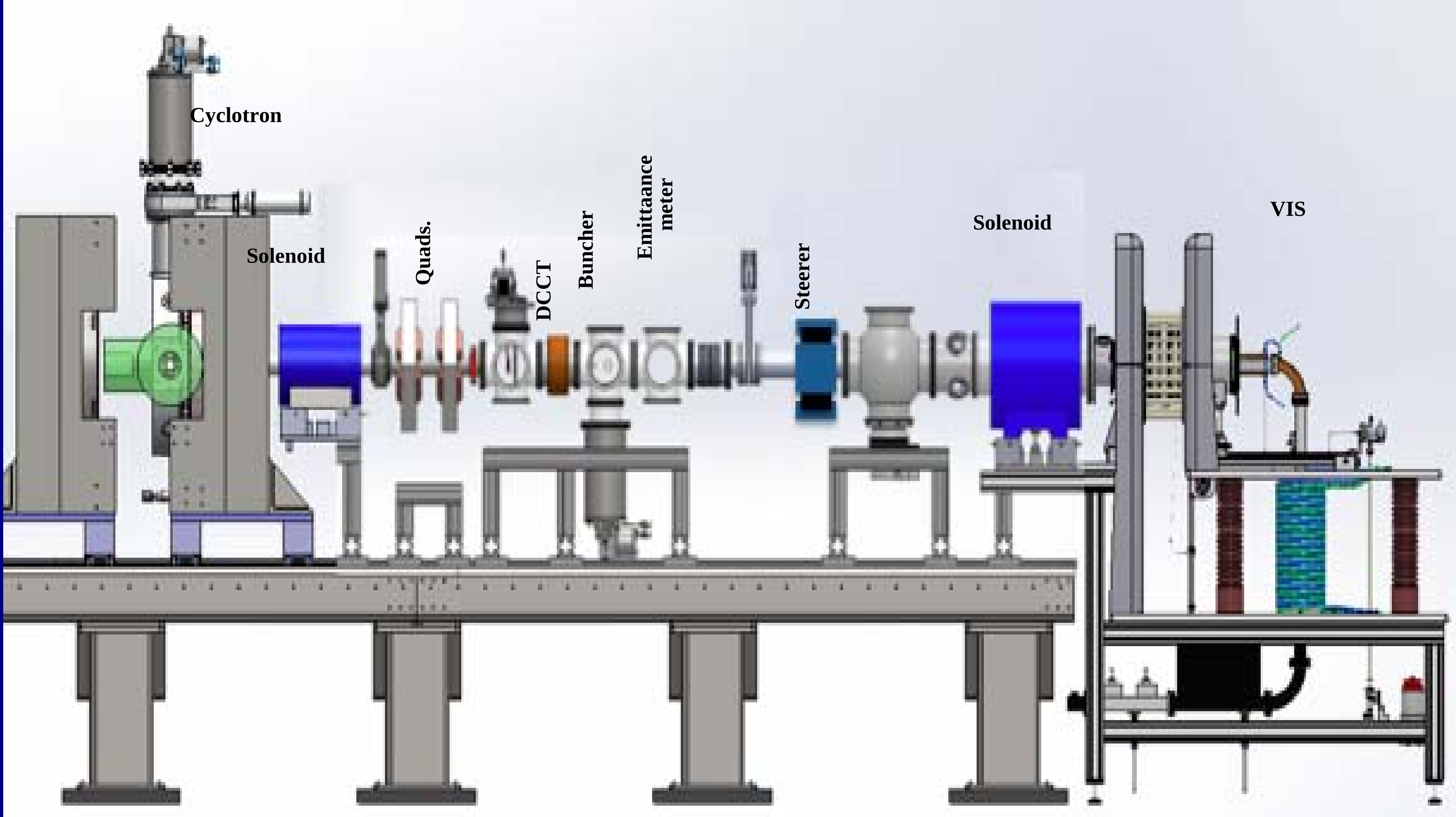




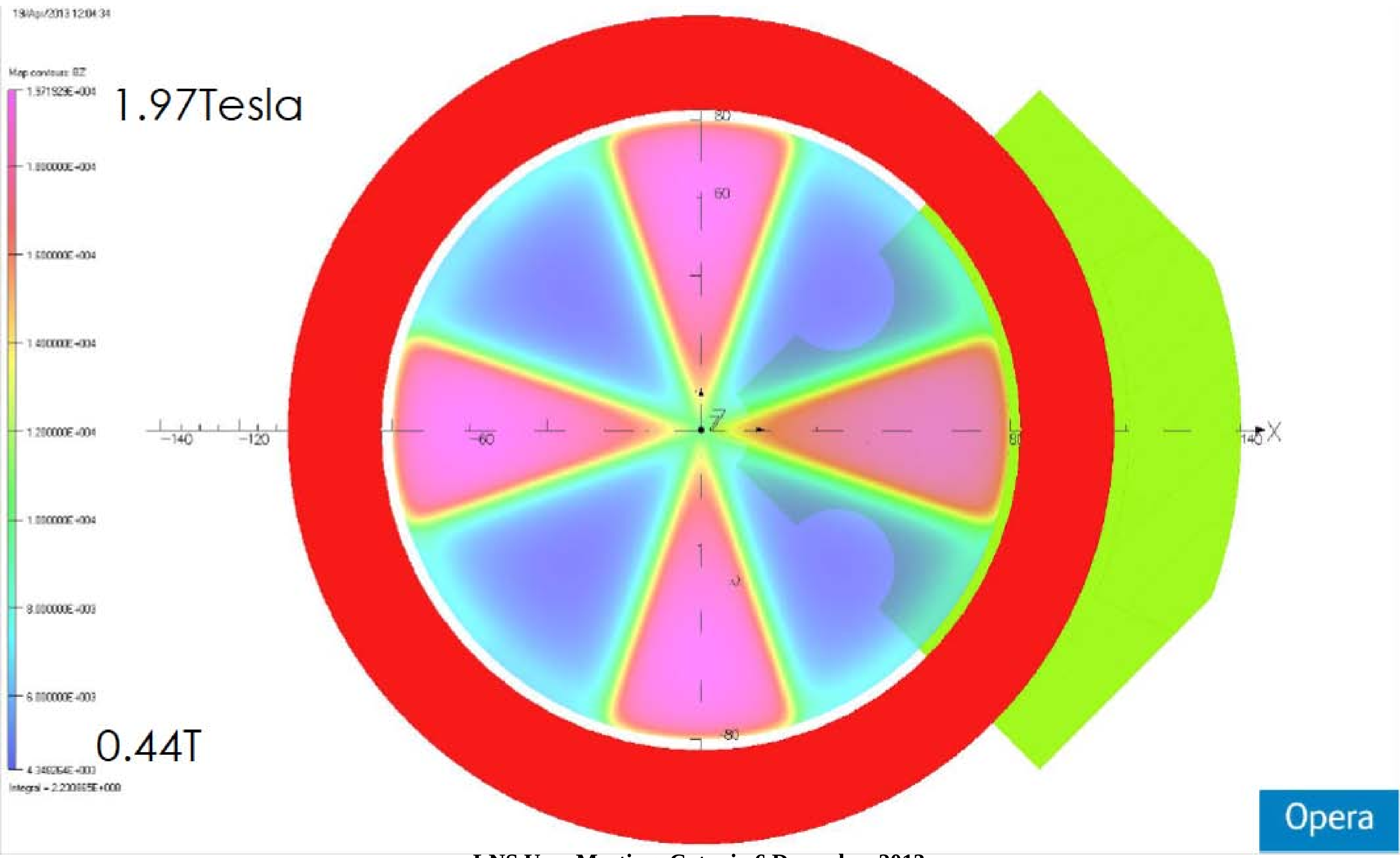


Extraction efficiency 99.98%, if beam power is 600 kW on the septum 120 W!

Injection of 5 mA of H2+ is challenging!
Simulations studies are not reliable!
Test in Vancouver are planned to check the simulation code!



PROPOSAL FOR HIGH POWER CYCLOTRONS TESTS SITE IN CATANIA



Cyclotron parameters

R axial hole	29 mm	R pole	800 mm
N. Sectors	4	Hill width	30° ÷ 36°
Valley gap	1400 [mm]	Pole gap	60 [mm]
Diameter	2800 [mm]	Full height	1800 [mm]
Total weight	52 [tons]	Vacuum	10^{-5} Pa
Cavities λ/2	Double gap	Acc. Voltage	70 [kV]
Main Coil size	200x240 [mm^2]	2nd Coil size	30x240 [mm^2]
Parameters for ions with q/A=0.5, H_2^+, He^{++}			
E_{inj}	70 [keV]	E_{max}	7 [MeV/amu]
B_0	1.08 [T]	Bmax	1.90 [T]
RF Harmonic	4th	Freq.	32.5 [MHz]
Main coil curr. density	2.8 [A/mm^2]	2nd coil curr. density	-1.1 [A/mm^2]
Parameters for proton beam			
E_{inj}	40 [keV]	E_{max}	28 [MeV]
B_0	1.12 [T]	Bmax	2.0 [T]
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Cur. density Main coil	2.3 [A/mm^2]	Cur. density 2nd coil	4 [A/mm^2]

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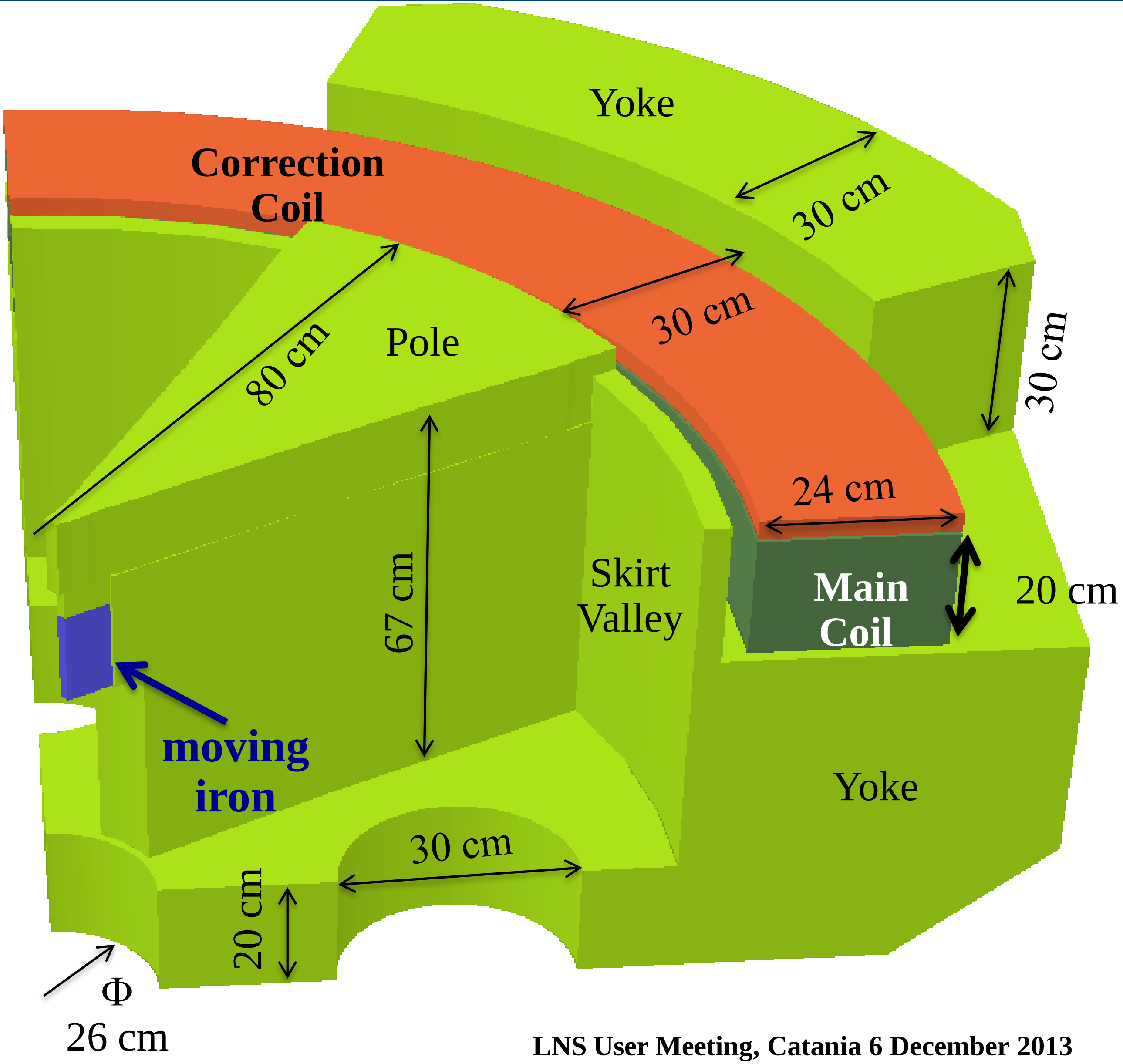
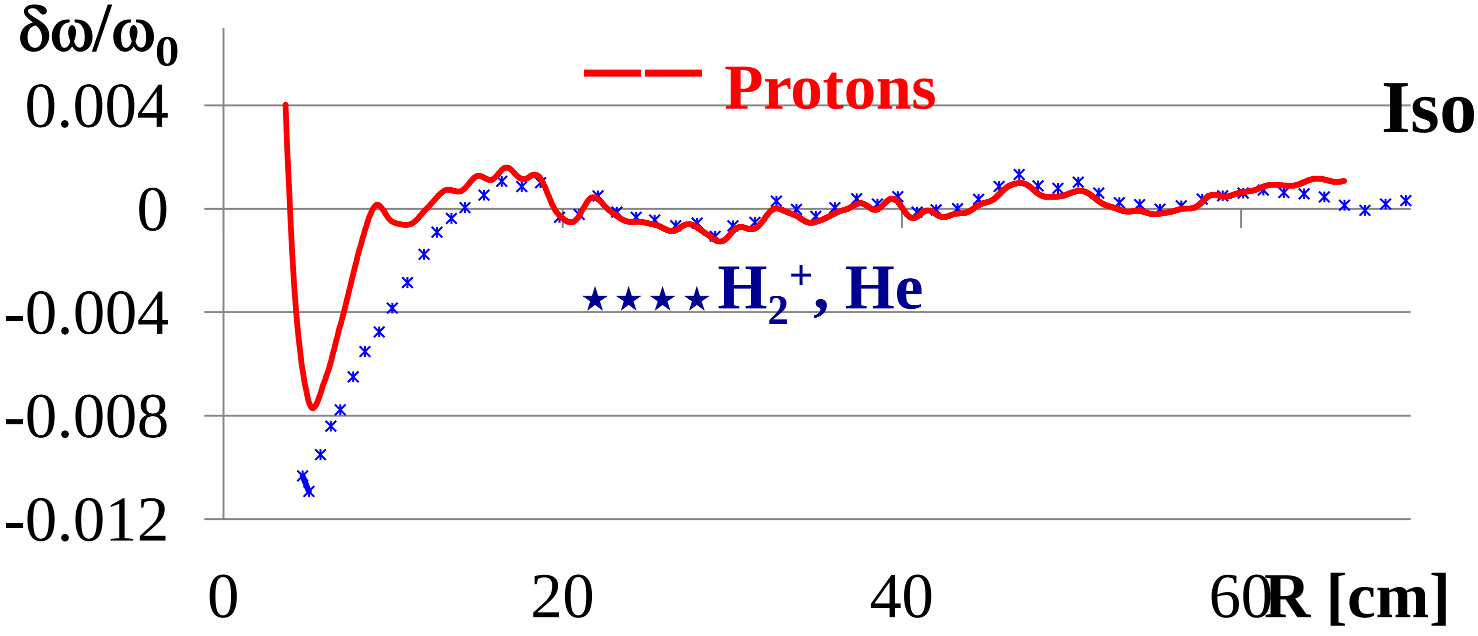


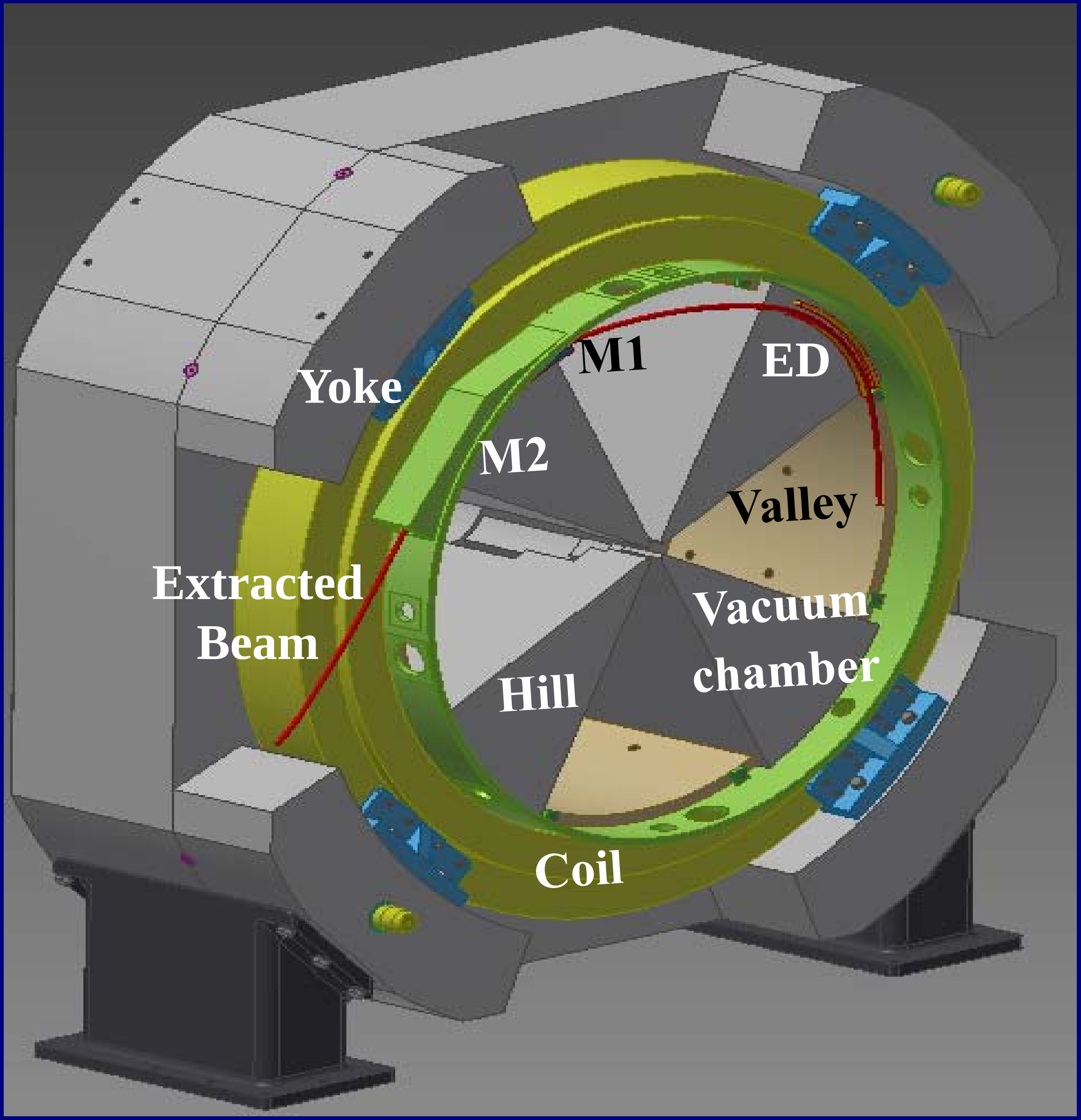
H-, Proton Beam
@28 MeV

H_2^+, He^{++}
@7 MeV/amu

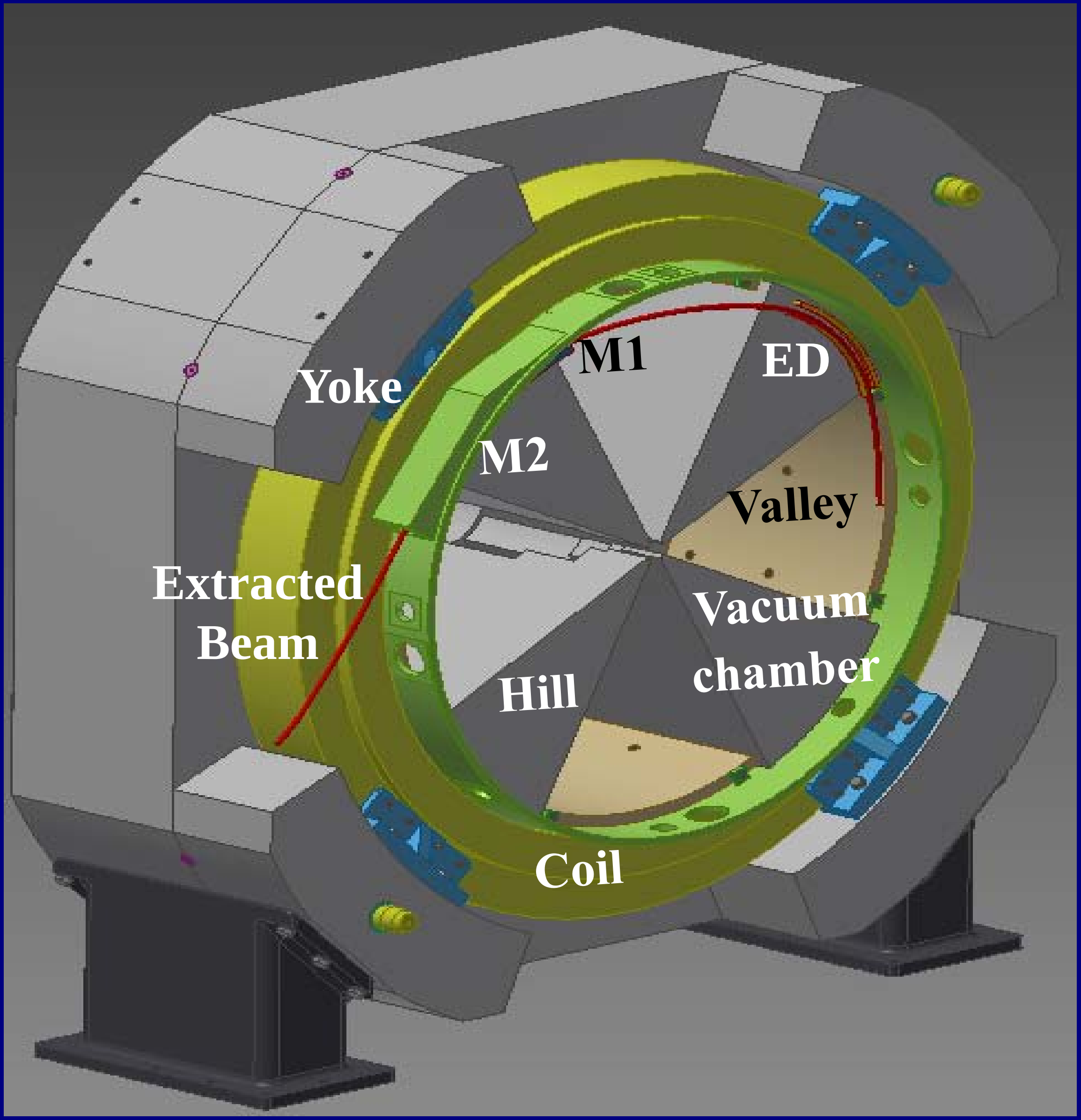
Average field [T]



Isochronism plot

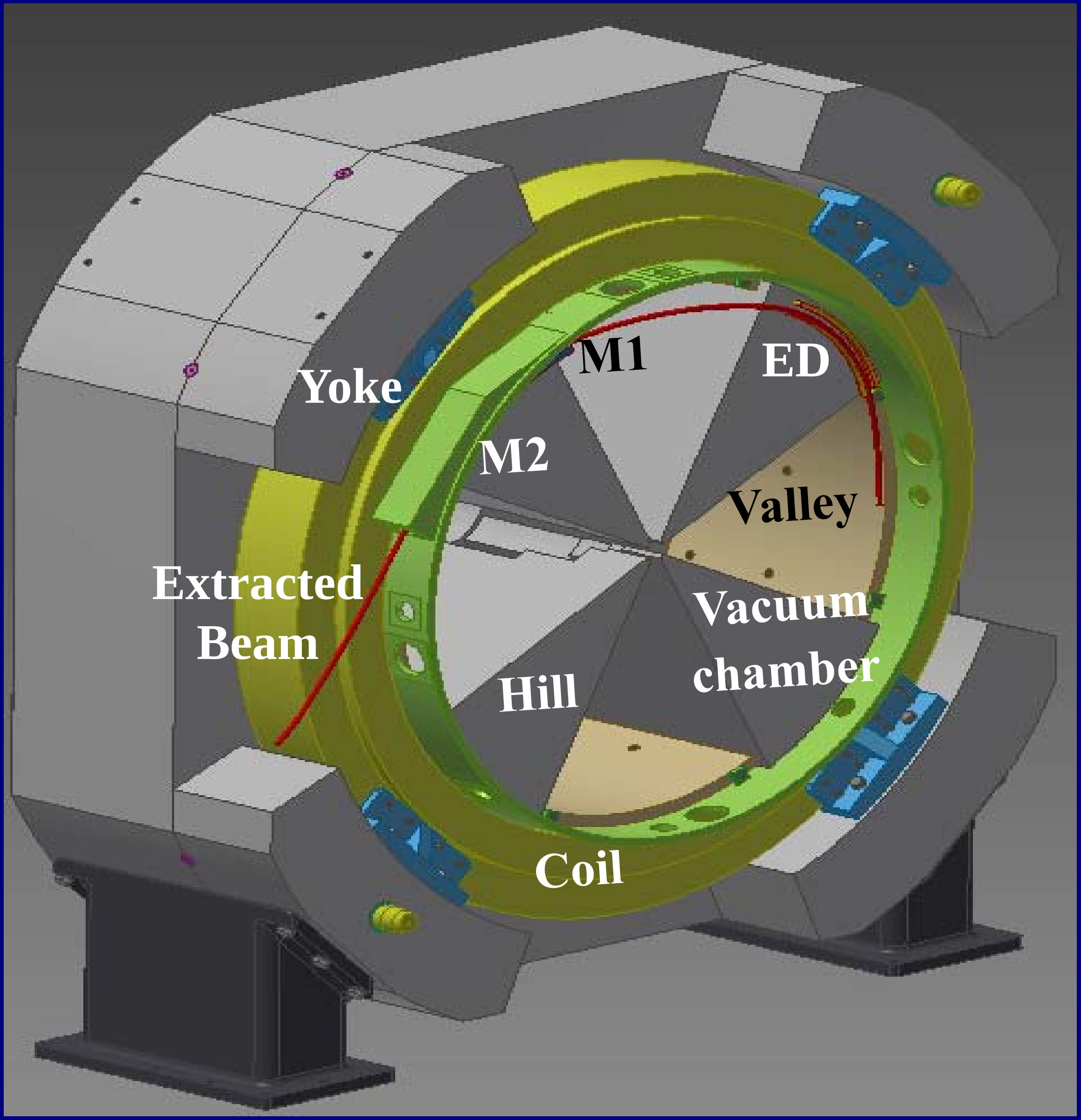


Cyclotron view with extraction trajectory for H2+ and He++



Cyclotron view with extraction trajectory for H2+ and He++

Stripper extraction (proton beam) is not yet fully studied



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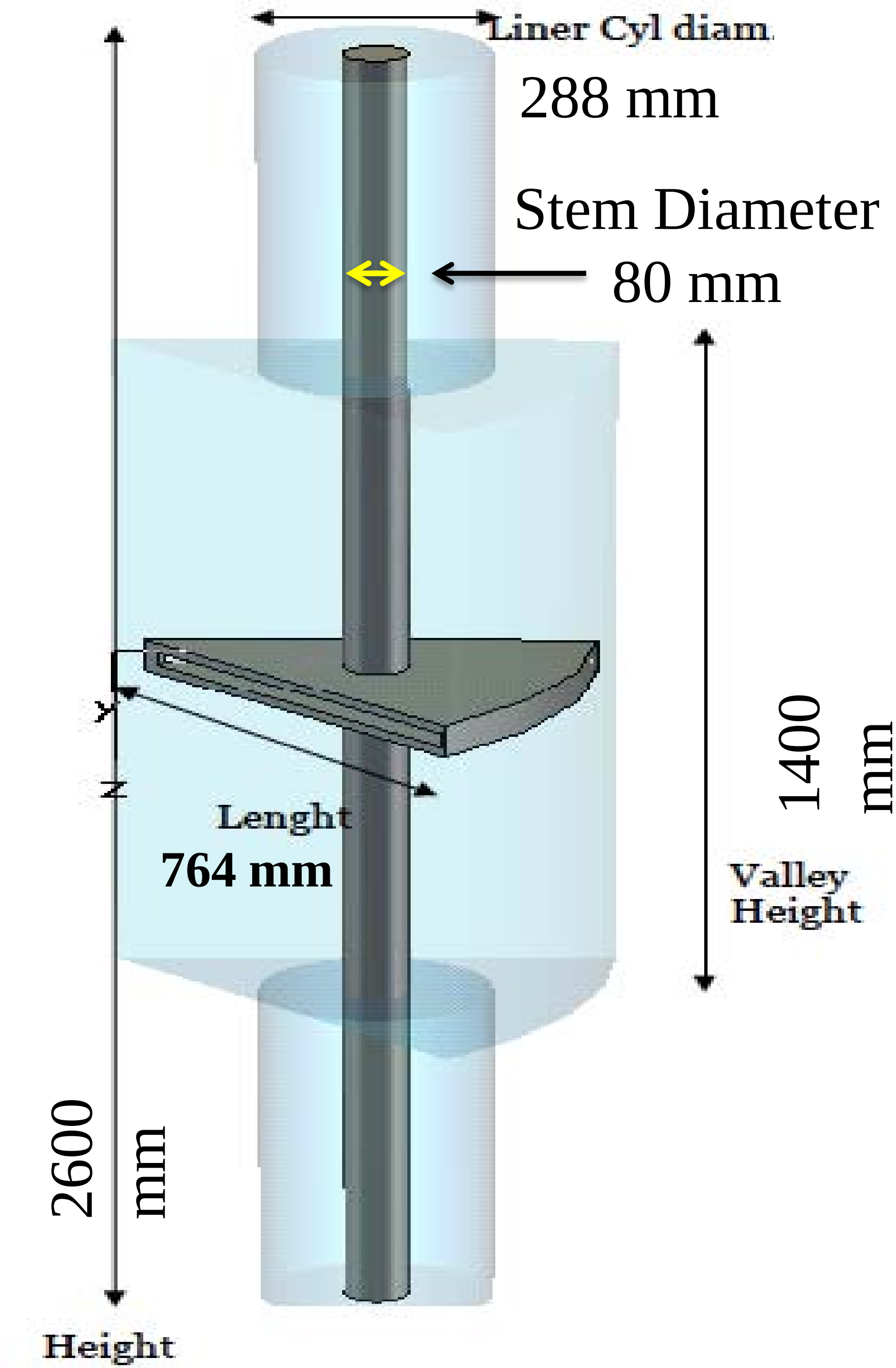
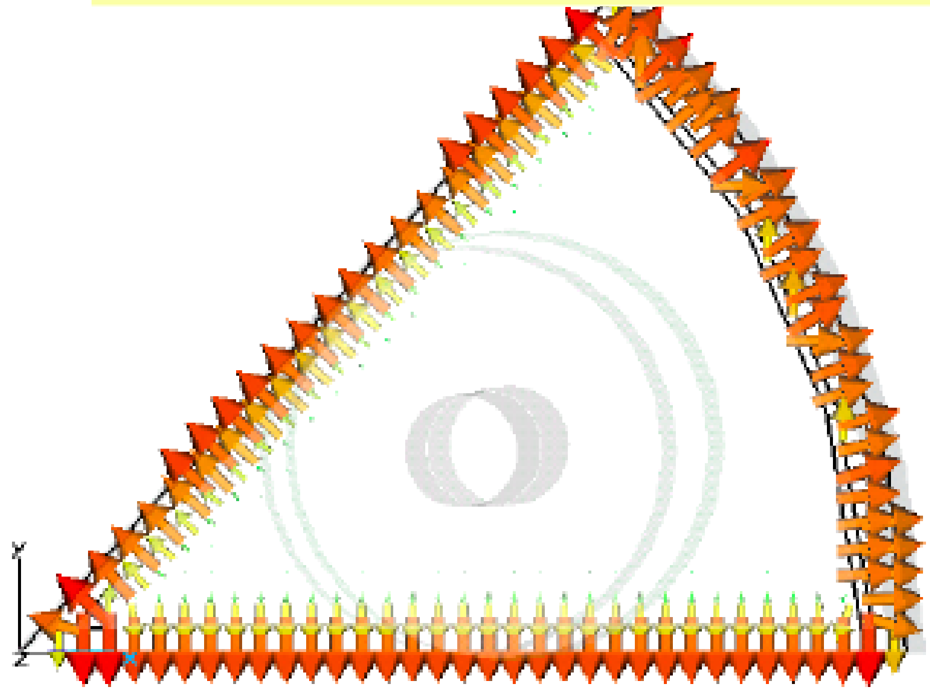
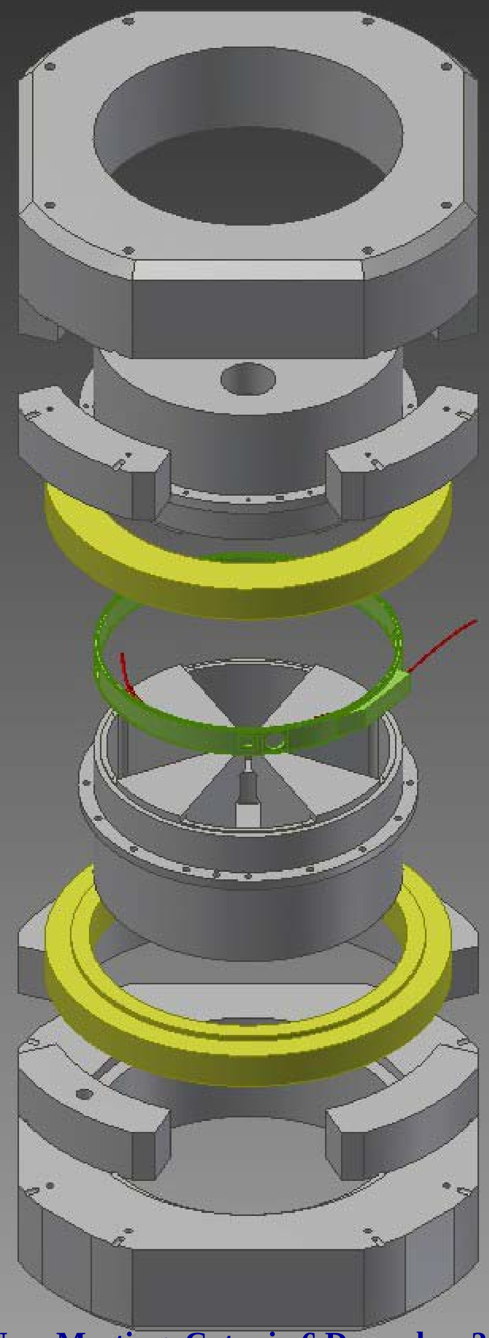
Layout of vacuum chamber with holes for vacuum pumps, RF tuning and trimmer capacitors, diagnostic probes



B28 Cavity Performances	
Resonant Frequency	≈ 31.7 MHz
Quality Factor	≈ 6'869
Power dissipation	≈ 10.58 kW
Max Surface Current	≈ 49 A/cm
Max Electric Field	≈ 5 MV/m
Voltage Distribution on a gap	≈ 70-70 kV
Dee Radial Extension (Length)	= 735 mm
Stem Diameter/Liner Cyl Diameter	= 80/288 mm
Dee Gap	= 30 mm



Preliminary layout of cyclotron assembling



Upper Yoke

Upper Pole

Upper Coil

Vacuum Chamber

Lower Pole

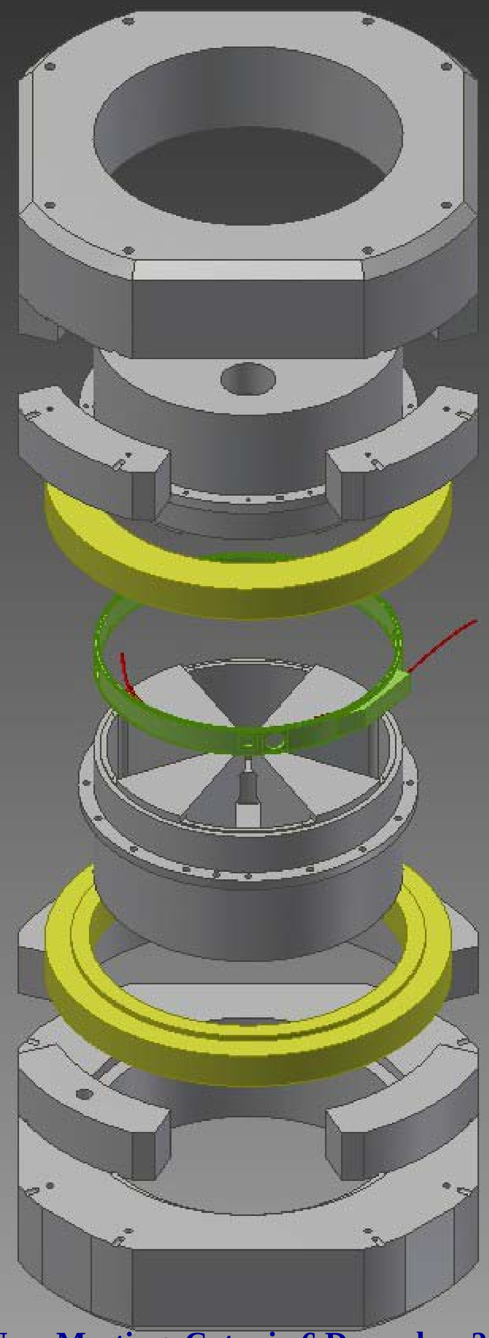
Lower Coil

4 additional pieces of yoke

Lower yoke

Preliminary layout of cyclotron assembling

A new simplified and cost optimized design is in progress!



Preliminary layout of cyclotron assembling

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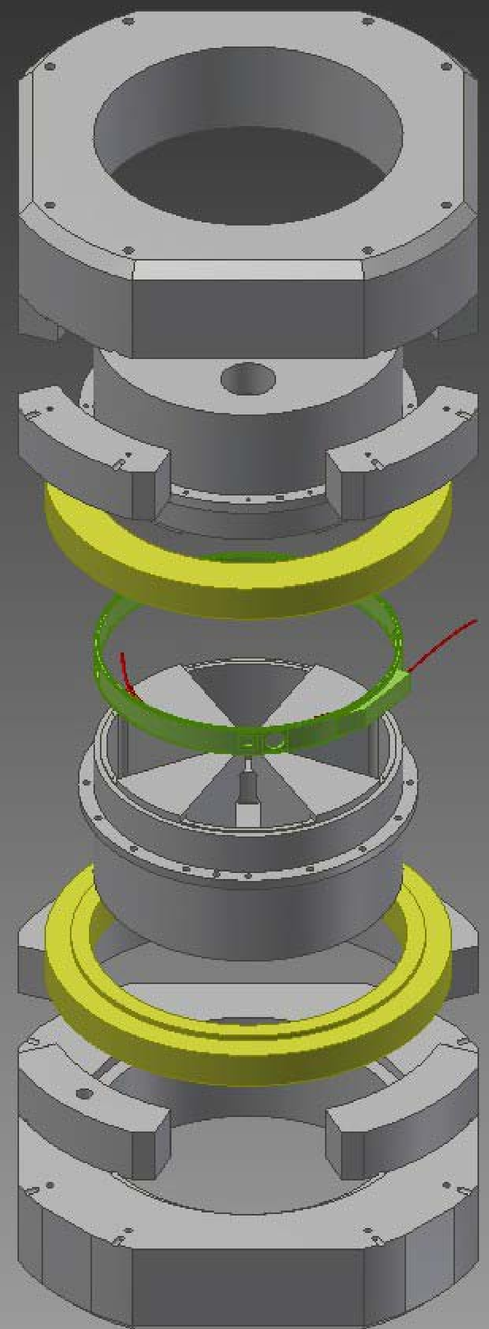
The cyclotron now is not a true dual particle!

But to accelerate H- or H2+ it is mandatory to replace central region and the pole shimming!



Upper Yoke

Upper Pole

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Lower Pole

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4 additional pieces of yoke

Lower yoke

MEMORANDUM OF UNDERSTANDING

RECITALS

- BTL is a specialized engineering, manufacturer and distributor of particle accelerators and cyclotron and conducts research and development activities in this field. In particular Best is interested in the realization of a 28MeV Negative hydrogen ion (H-) Cyclotron that accelerates 400uA-1.000uA of beam current to produce radioisotopes of medical interest;

- INFN is an Italian Governmental Agency responsible for the Italian government's research in the fields of sub-nuclear, nuclear, and astro-particles physics and, in this capacity, promotes the necessary research and development activities in such fields and in particle accelerators. In particular INFN has developed a physical design of a cyclotron able to accelerate H2+ up to 7MeV/amu, moreover this cyclotron with a small change in the setting parameters and in the magnetic configuration is also able to accelerate H- beam up to 28 MeV.

- BTL and INFN have entered into discussions regarding the establishment of a collaboration, to start a joint activity to offer to the worldwide market a cyclotron accelerator able to deliver a high current proton beam in the range of 1-5 mA. Specifically, the Participants plan to conduct research and development in the cyclotron field to achieve this ambitious goal. Appendix A describe the details of the work to be performed, the allocation of responsibilities between the Participants, and a general timeframe for performance. ("Memorandum").

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The goals of the project are:

- Acceleration and extraction by stripping up to 1 mA of H- at energy of 28 MeV;
- Injection and acceleration up to 5 mA of H2+ at energy of about 7 MeV/amu.

Our Scientific Goal is to accelerate an H_2^+ beam with a current of 5 mA

To achieve this goal we use our present existing Versatile Ion Source with some upgrading to deliver a beam current of about 50 mA

A new injection beam line, including a RF buncher, will be build by MIT

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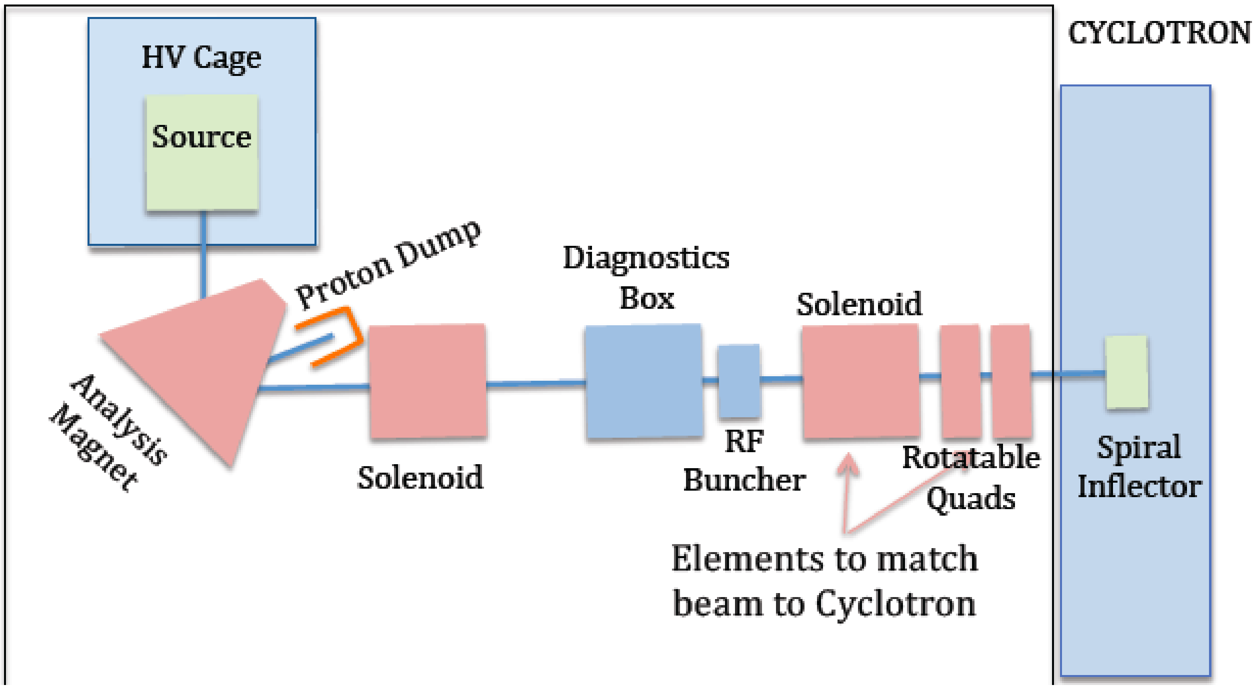
The cyclotron is designed by INFN but will be built and paid by BEST Cyclotron Inc. System, agreements are in progress

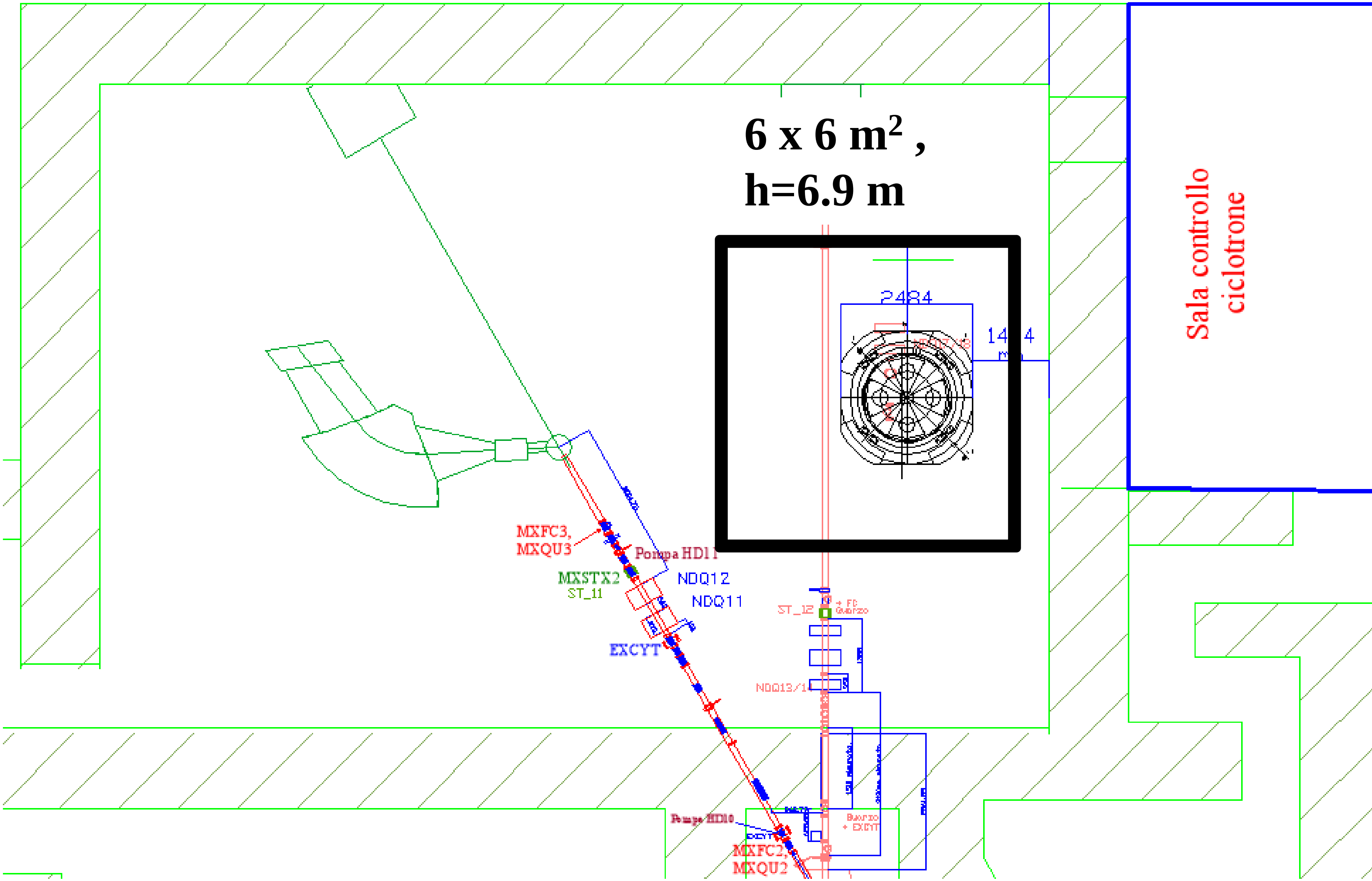
The new injection beam line for H2+, including a RF buncher Will be build by MIT



MIT will supply also scientific manpower during commissioning

1 post Doc, 1 PhD student and 1 graduate

The Cyclotron will be installed near the MAGNEX spectrometer



Tentative Schedule

- BEST Cyclotrons plan to order the Iron on January!
- On June we expect to start the machining of the iron.
- The poles, coils, Power supplies should arrive in Catania on December 2014 - March 2015
- Assembling January - June 2015
- July-November 2015 commissioning proton 28 MeV
- January 2016 Commissioning H2+
- June – September 2016 disassembly of cyclotron and delivery to the custom! Or…

How we could use this cyclotron, after accelerator research?

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The cyclotron will be able to supply

Proton beam 1 mA @ 28 MeV

and/or Deuteron beam @ 14 MeV, Helium beam @28 MeV

current intensity depends from the central region

and from the ion sources

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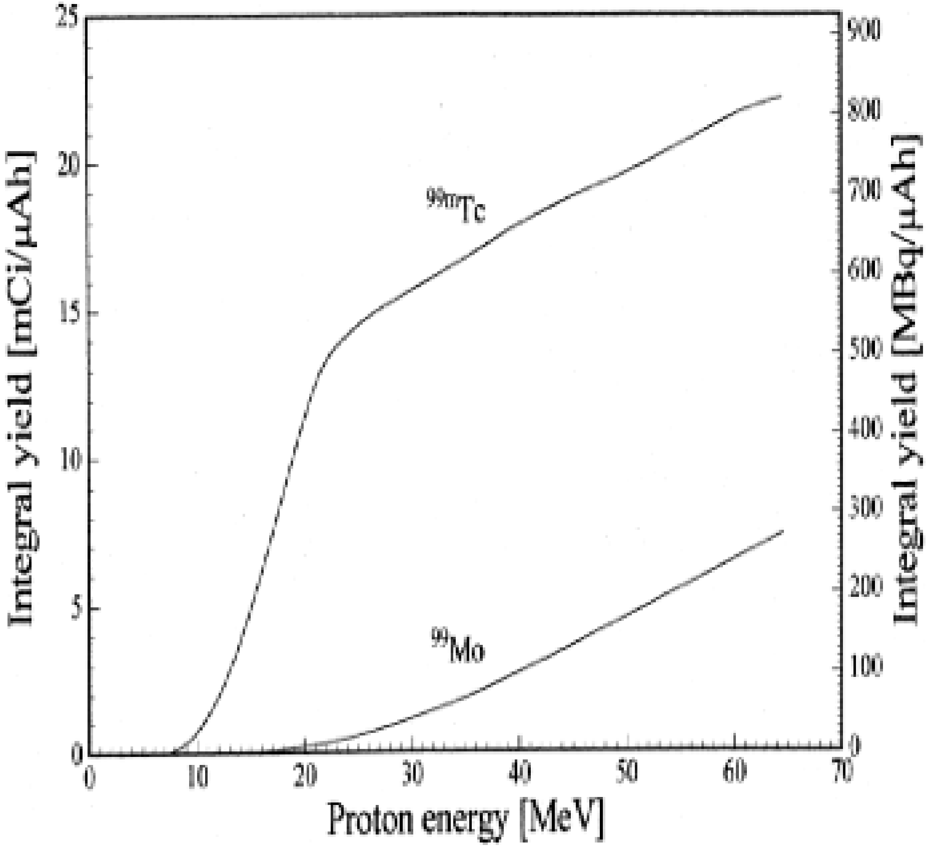
Physics Department of Catania University is interested to develop a laboratory for radioisotope purification

Cyclotron produced Tc^{99m}

- The supply of Tc99m for Nuclear Medicine procedures has been interrupted several times recently and this has prompted the development of accelerator techniques for the production of Tc99m. The figure below indicates the production yields for the process p +Mo100 ->Tc99m+2n.



IS POSSIBLE SATISFIES THE NEEDS OF ITALY WITH JUST 6 DEDICATED CYCLOTRONS LIKE OUR OR ALSO USING EXISTING COMMERCIAL CYCLOTRONS, BUT …

DISTRIBUTION MUST BE DAILY BASED FOR 99TC

WHILE THE PRESENT ^{99}MO DISTRIBUTION IS WEEKLY BASED

ADDITIONAL COSTS AND A LOT OF RADIOACTIVITY MATERIAL HAS TO BE TRANSPORTED THROUGH THE COUNTRY

99TC IS A NEW DRUG! YOU NEED NEW PERMISSION

Could a high current alpha accelerator be useful?

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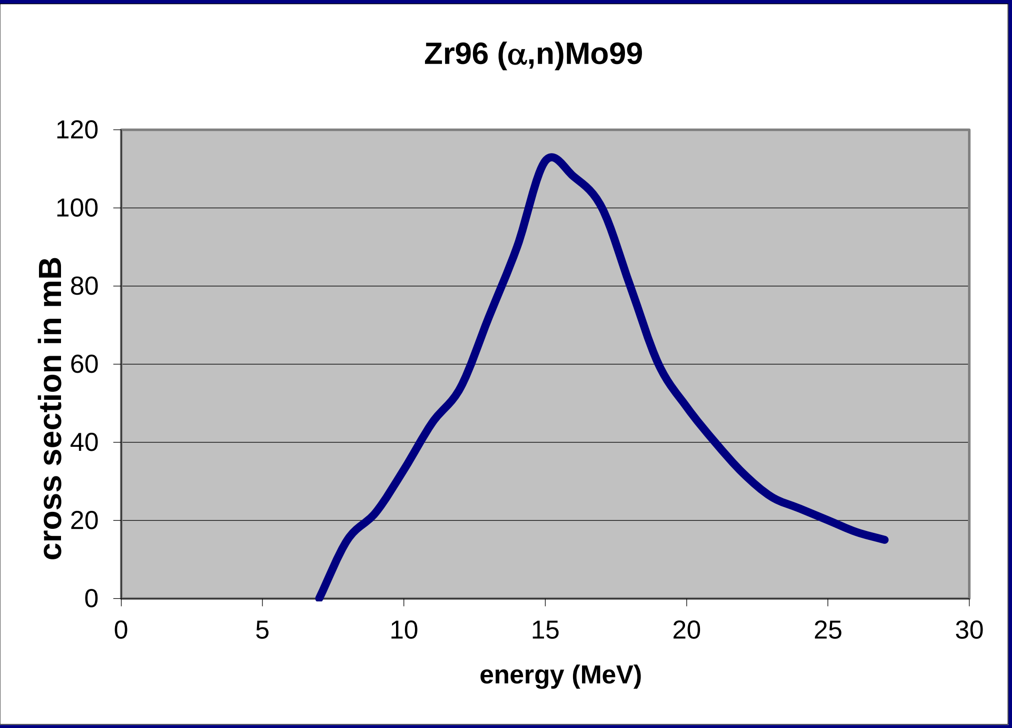

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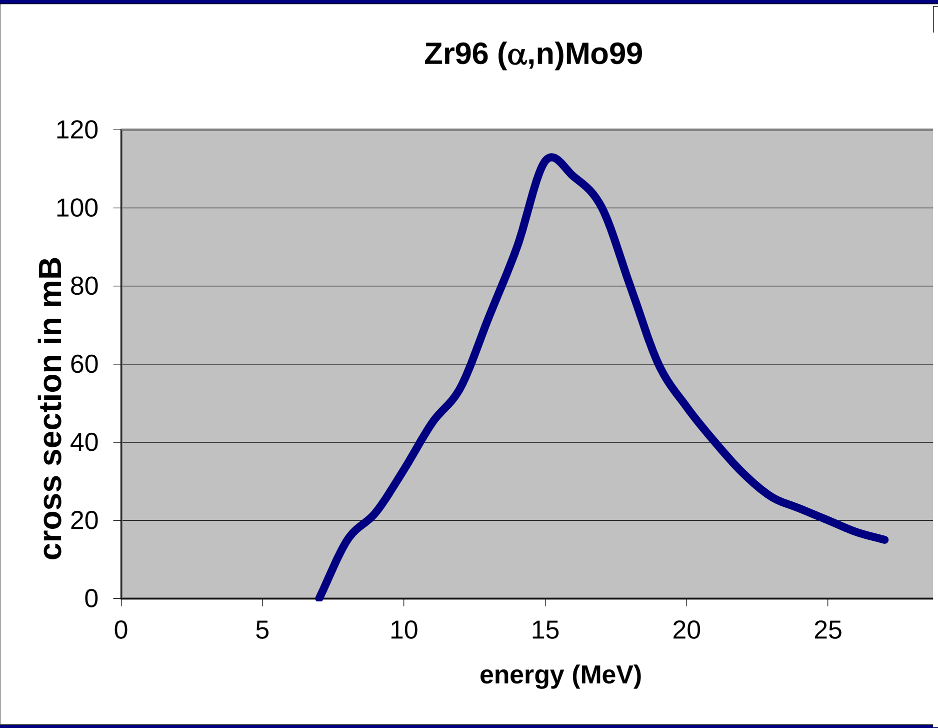

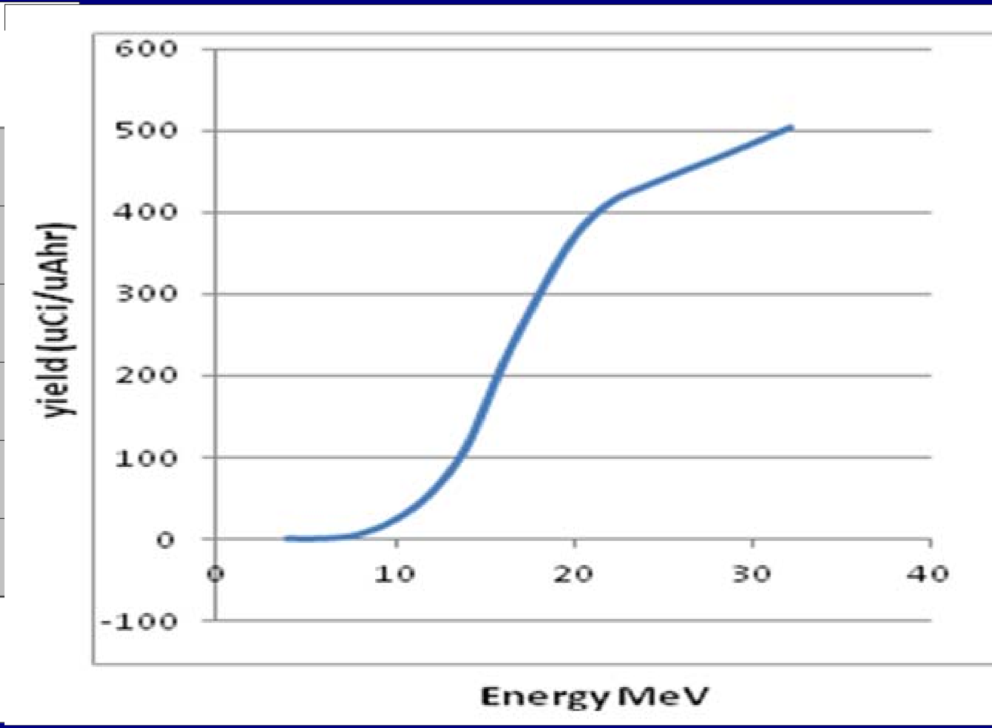

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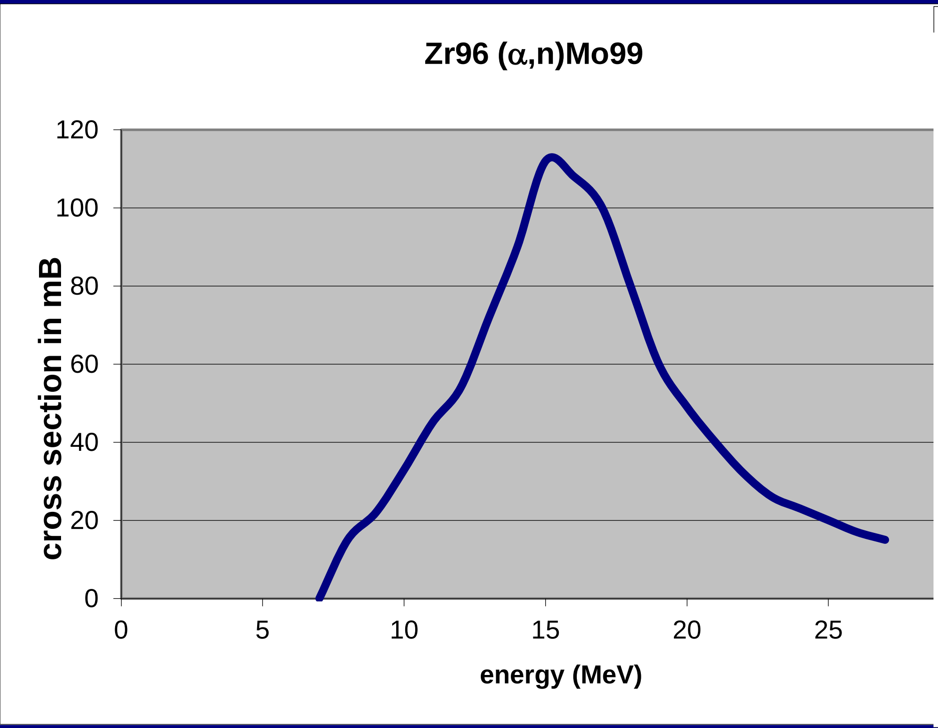
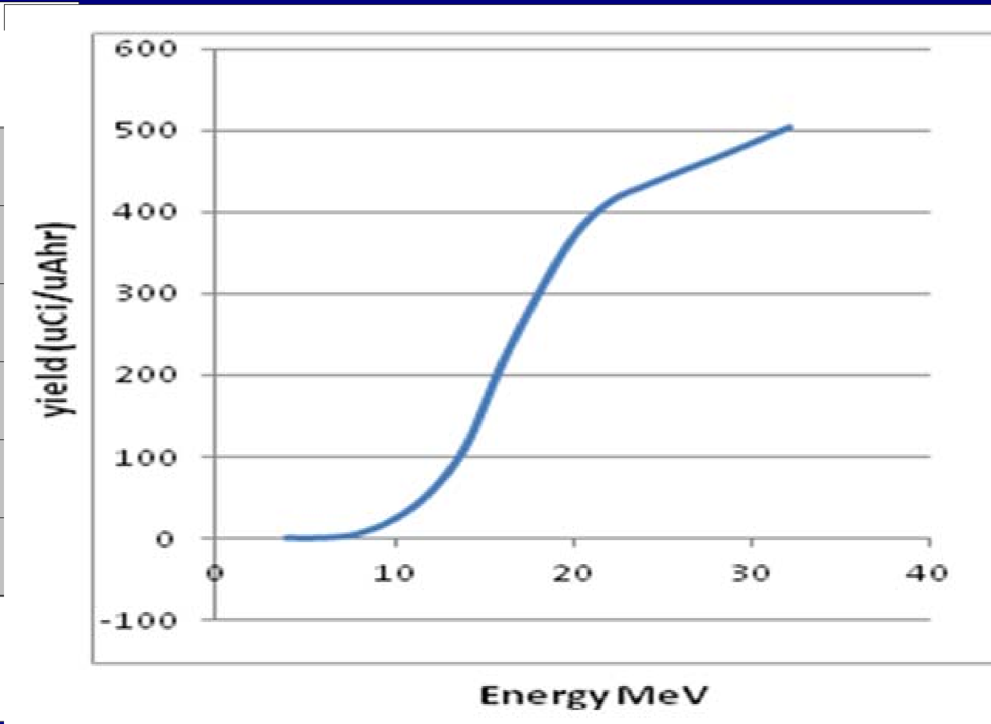




A 1 mA of He beam can produce a dose of 80 Ci/week

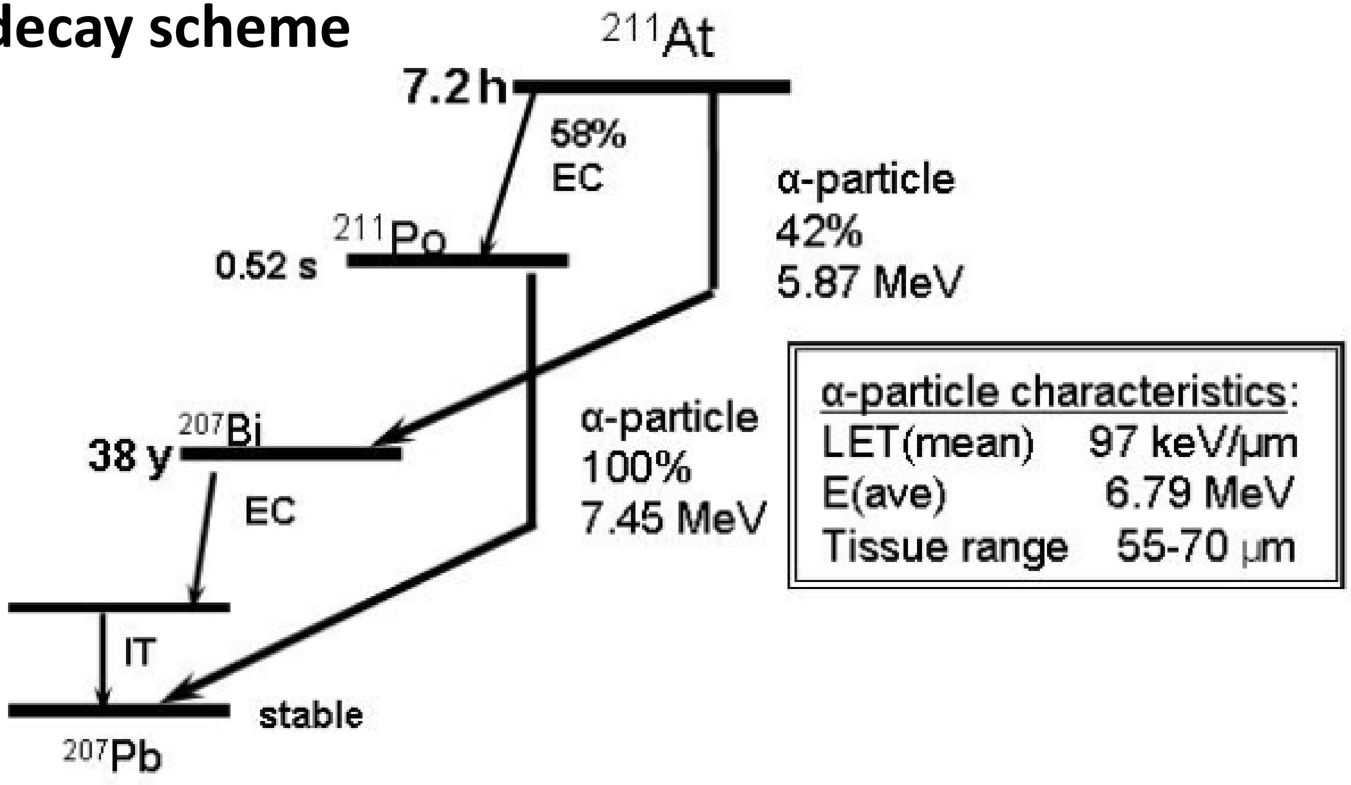
Hospital generators needs a recharge of 0.5÷10 Ci/week

We could supply 160÷8 generators per week

DISTRIBUTION CAN BE DONE WEEKLY!

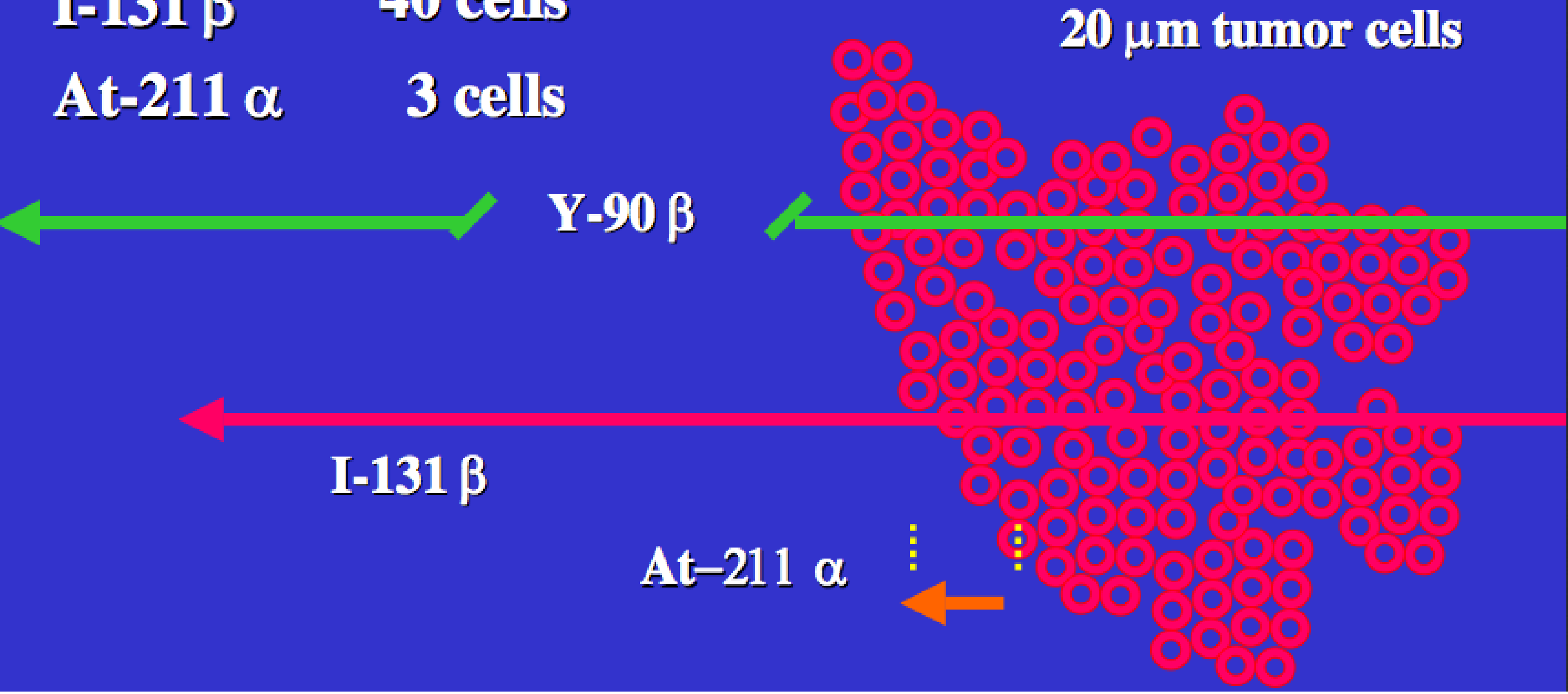
A further interesting reaction is Bi 209 (alpha, 2n) At 211

At 211 decay scheme



Range of α- and β-Particles

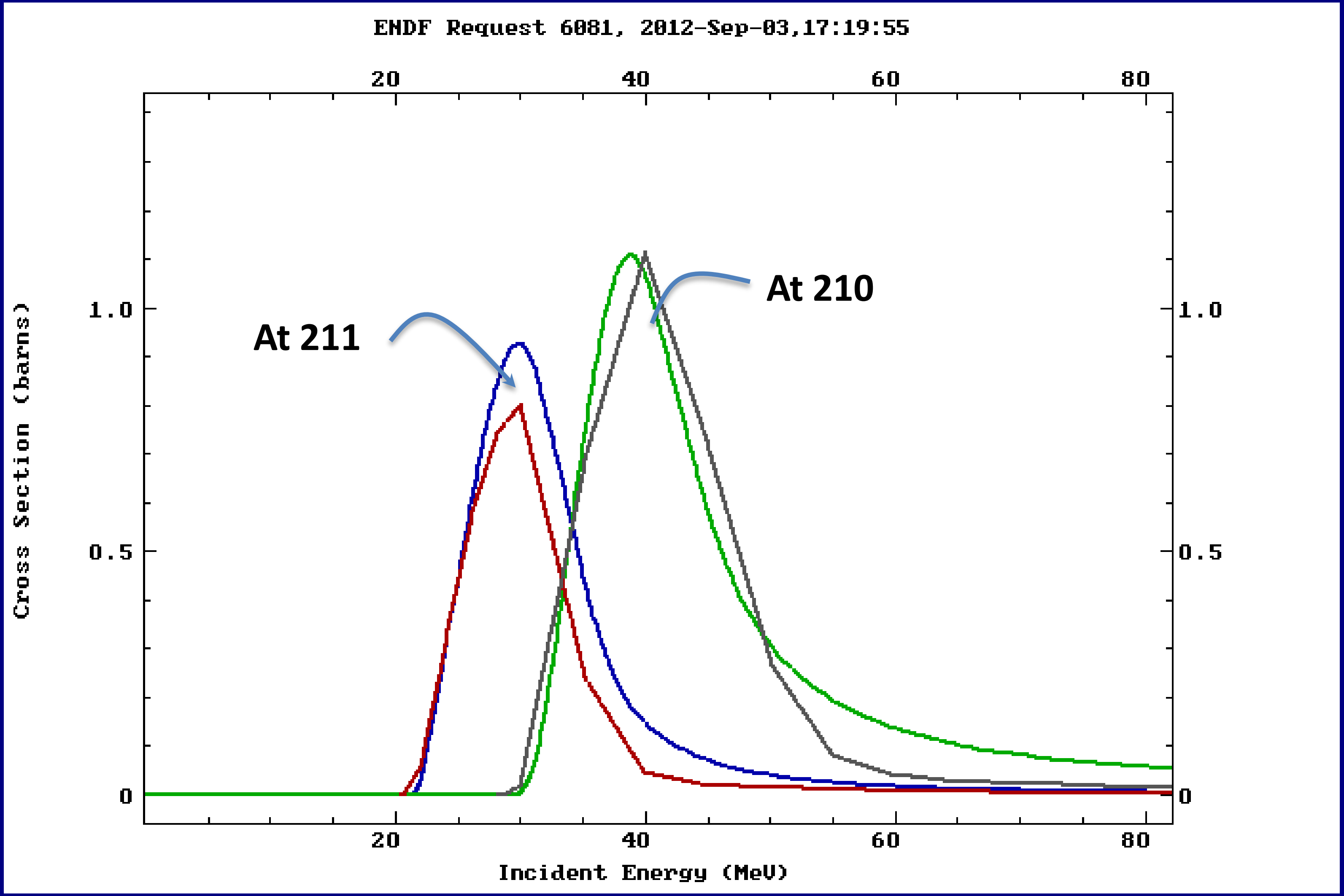
	Mean range
Y-90 β	215 cells
I-131 β	40 cells
At-211 α	3 cells

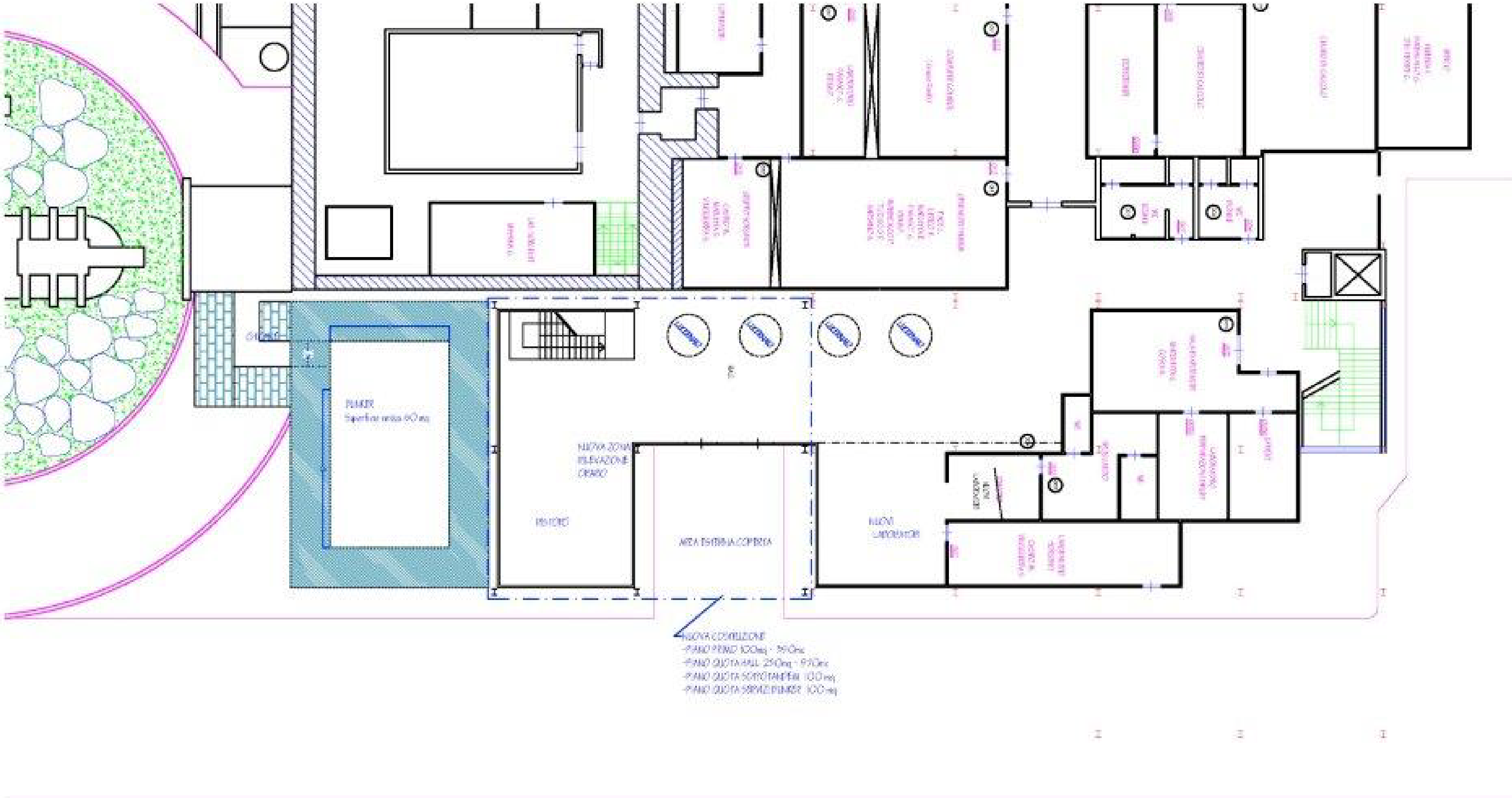


Potential Applications of α-Particle Therapy

- Micrometastases
- Tumors of Circulation
  - -Lymphoma
  - -Leukemia
- Compartmental Tumors
  - -Cystic
  - -Ovarian
  - -Neoplastic Meningitis

^{210}At contaminant beta decay to ^{210}Po. $T_{1/2}$ 138 days
Energy range limited below 30 MeV to avoid this problem





...And thats all folks!

Thanks for your attention!