CICLOTRONE COMPATTO AD ALTA INTENSITA' PER L'ESPERIMENTO

ISODAR

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ISODAR → ISOtope Decay-At-Rest

MIT proposal for high sensitive *sterile neutrino* search

IsoDAR is Phase II of the DAEδALUS neutrino source development program

Academic institutions participating:

- Amherst College
- Cockcroft Institute for Accelerator Science & the University of Manchester
- Columbia University
- Duke University
- Imperial College London
- Lawrence Livermore National Laboratory
- Laboratori Nazionali del Sud – INFN
- Los Alamos National Laboratory
- Massachusetts Institute of Technology
- Michigan State University
- New Mexico State University
- Paul Scherrer Institut
- RIKEN
- Tohoku University
- University of California, Berkeley
- University of California, Irvine
- University of California, Los Angeles
- University of Maryland
- University of Tennessee
- University of Hudderseld

Commercial companies participating:

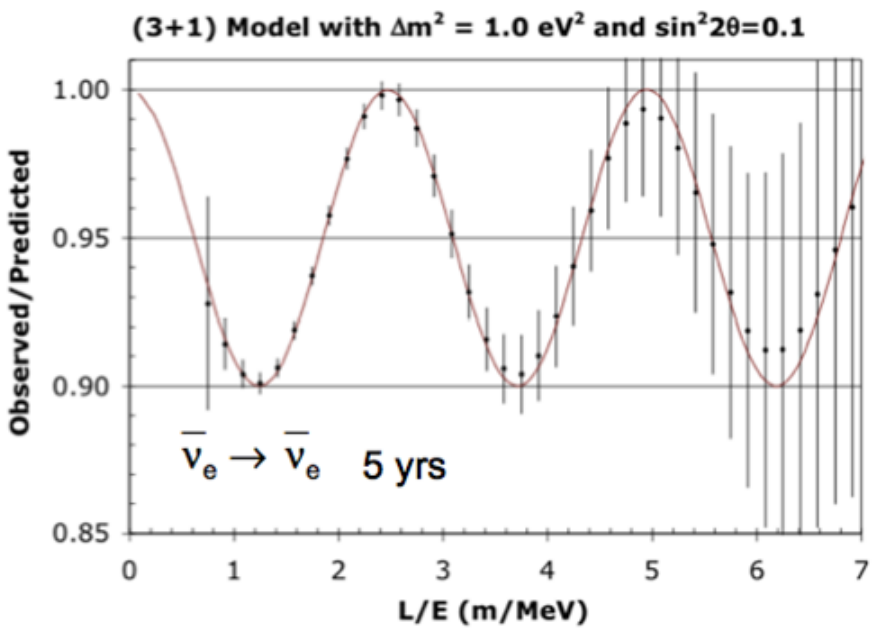
- Bartoszek Engineering
- Best Cyclotron Systems, Inc.
- IBA (Ion Beam Applications S.A.)

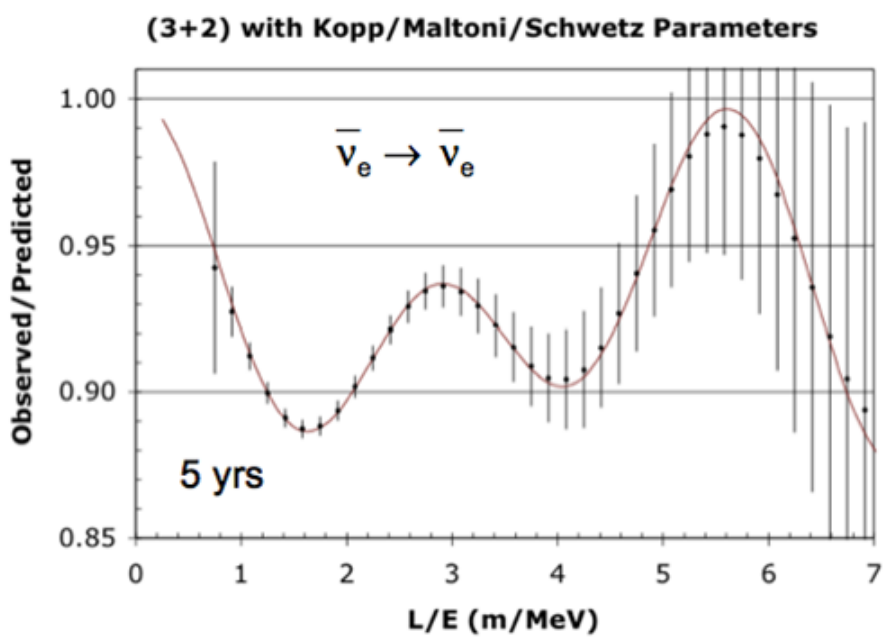
ISODAR : the aim

$\bar{\nu}_e$ disappearance due to oscillations → Δm^2 anomalies

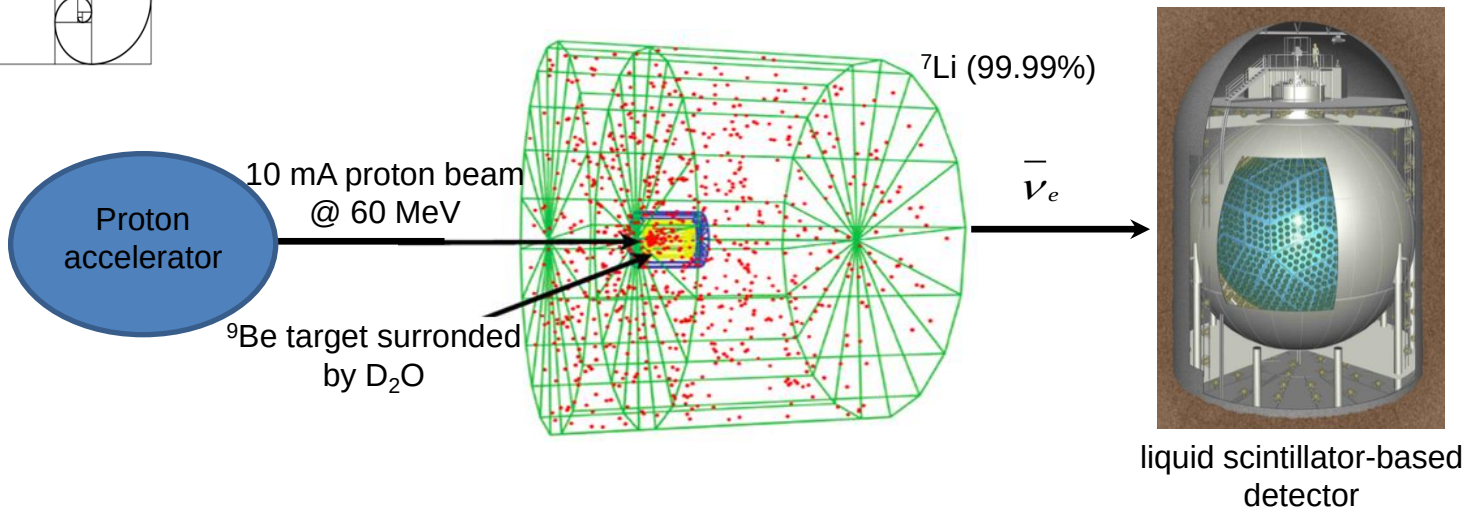
Sterile neutrinos: (3+1) and (3+2) models can solve the problem

Oscillation L/E waves in IsoDAR → High statistic and good L/E resolution





ISODAR : the experiment



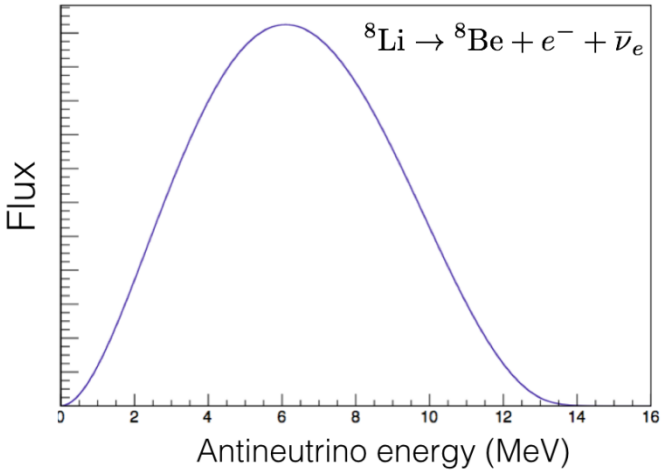
Not in scale!

- Proton beam into neutron-producing target

  $p + {}^9Be \rightarrow {}^8Li + 2p + n$
- Secondary neutrons into ~50 kg pure ^{7}Li blanket

  $n + {}^7Li \rightarrow {}^8Li$
- ^{8}Li decay produces $\bar{\nu}_e$ with $\langle E_{\bar{\nu}_e} \rangle$ = 6.4 MeV

  ${}^8Li \rightarrow {}^8Be + e^- + \bar{\nu}_e$
- IBD in liquid scintillator-based detector



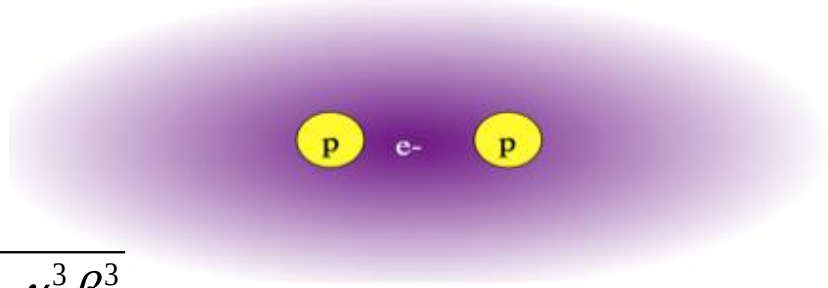
Requirements for the proton accelerator:

- ✓ a new record in intensity for 60 MeV/amu (600 kW!)
- ✓ compact cyclotron design to be placed underground

ISODAR : the H_2^+ cyclotron

Critical point concerning the proton source → **Space charge effects**

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

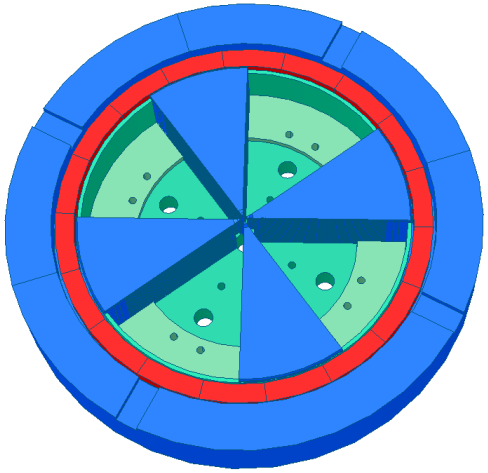


Generalized Perveance (Reiser's formula)

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

The perveance of 5 mA H_2^+ at 35 keV/amu is the same as 2 mA of 30 keV protons

✓ ***Commercial cyclotron (IBA, BEST Cyclotron Systems)***

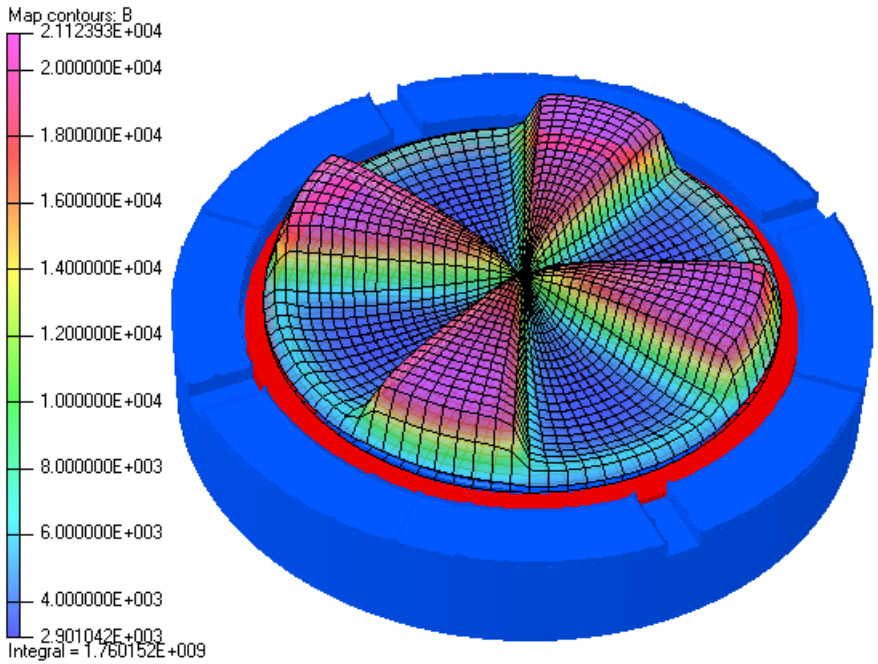


Same magnetic circuit of the DAEδALUS injector cyclotron

Compact, room temperature coils

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

ISODAR : the main cyclotron parameters



E_{inj}	35 keV/n	E_{max}	61.7 MeV/n
B_0	1.075 T	<B> at R_{ext}	1.166 T
$<R_{inj}>$	51.58 mm	$<R_{ext}>$	2000 mm
N. Sectors	4	Hill width	25.5° ÷ 36.5°
Valley gap	1800 mm	Hill gap	100 mm
Diameter	6240 mm	Full height	2700 mm
N. Cavities	4	Cavities λ/2	Double gap
RF Harmonic	4th	RF frequency	32.8 MHz
Acc. Voltage	70 ÷ 250 kV	Power cavity	<160 kW
Coil size	200x250 mm^2	Current density	3.17 A/mm^2

- Beam extraction by using electrostatic deflector
- Axial beam injection by using spiral inflector

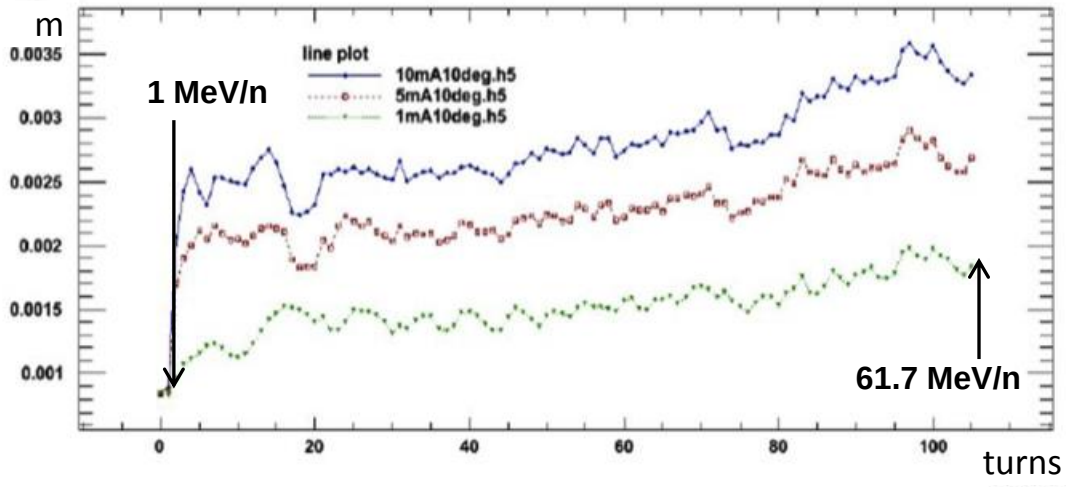
→ **Main critical issues**

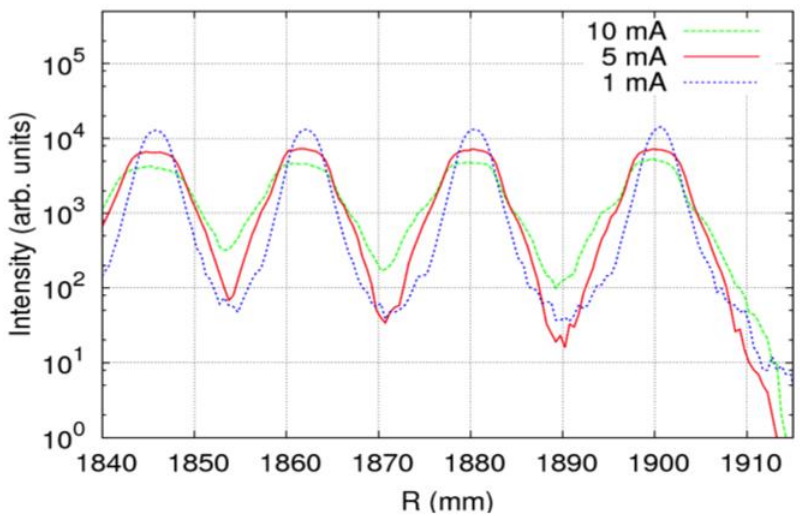
ISODAR : beam dynamics

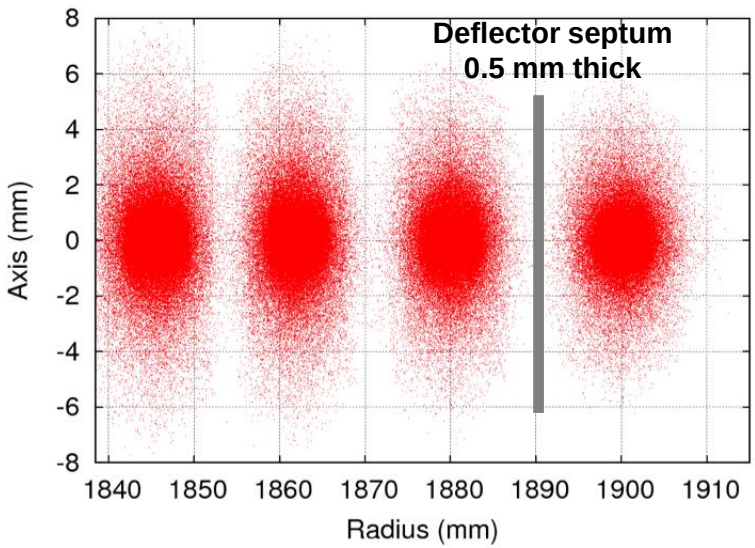
Beam dynamics simulations made @ PSI by using OPAL code

- ✓ Beam size acceptable!
- ✓ Extraction efficiency 99.98% if the beam power is 600 kW, only 120 W on the septum

Vertical beam size vs. number of turns for different beam currents



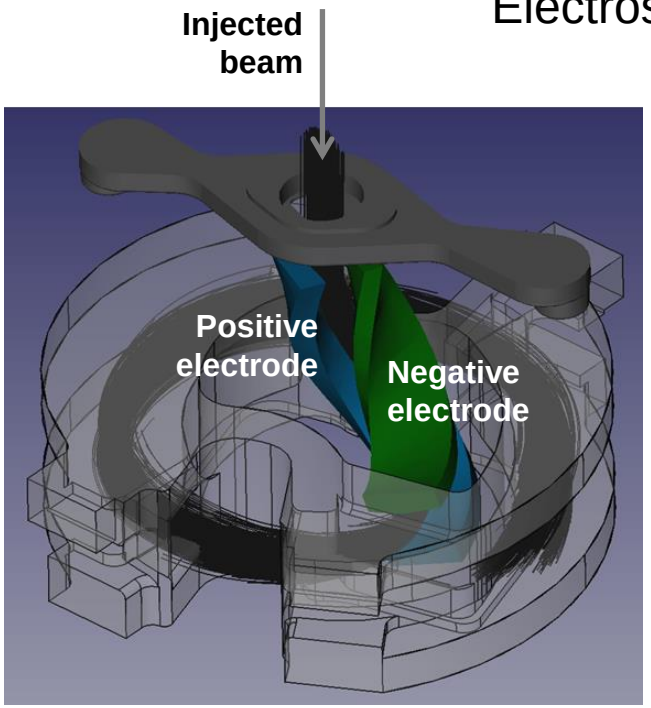




ISODAR : beam injection

The spiral inflector bends the particle beam from the axial line to the cyclotron median plane → Does it work for high intensity beams?

Electrostatic device → applied voltage ≈ ±10 KV - ±13 KV



Injection feasibility tests:

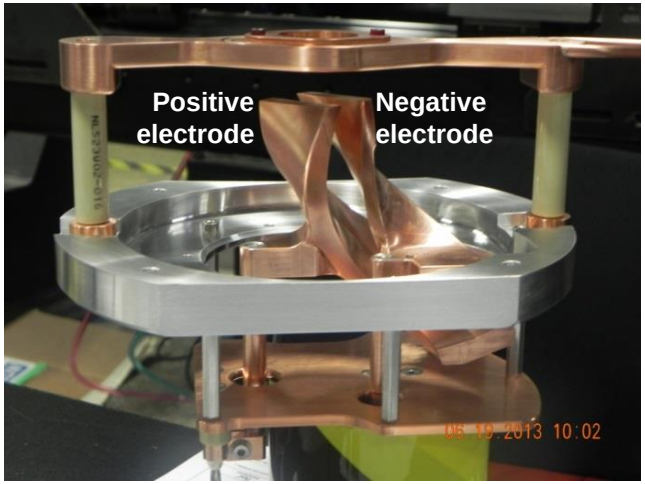
- in collaboration with MIT, INFN and BEST Cyclotron Systems, in Vancouver → in progress (next slide)
- use of a new small cyclotron as prototype of the IsoDAR cyclotron central region*

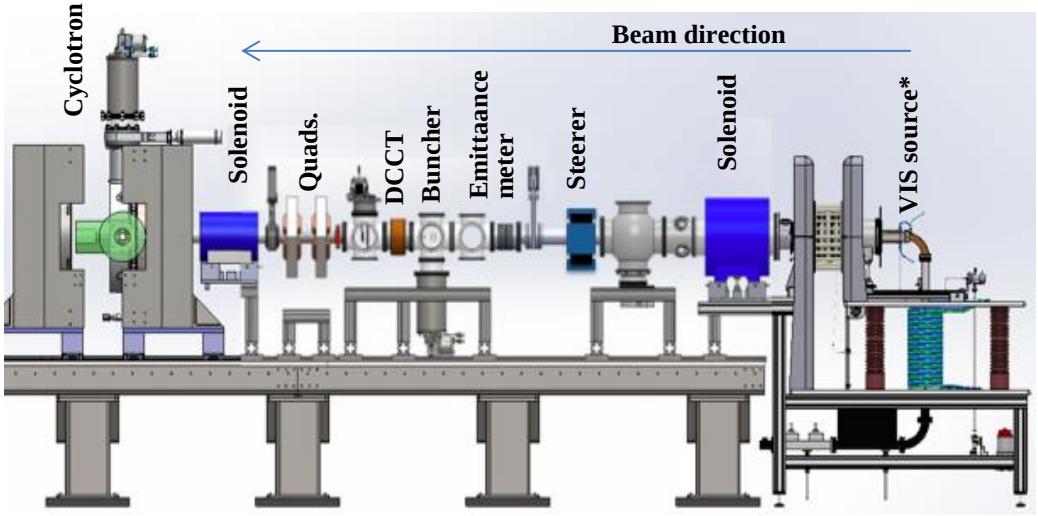
Innovative solution:

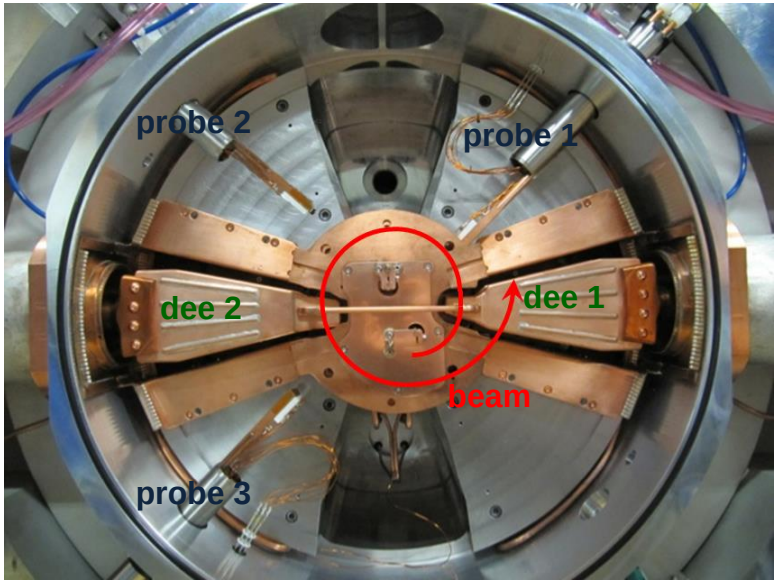
- inflector based on permanent magnets

(*) «Ciclotroni per fasci di ioni ad alta potenza e relative applicazioni», A.Calanna et Al., *this conference*

ISODAR : injection test in progress







CAPEN
(Ciclotroni Alta Potenza per Esperimenti sui Neutrini)
CSN 5 – INFN/LNS

Preliminary result

beam trasmission through the spiral inflector ≈ 85%

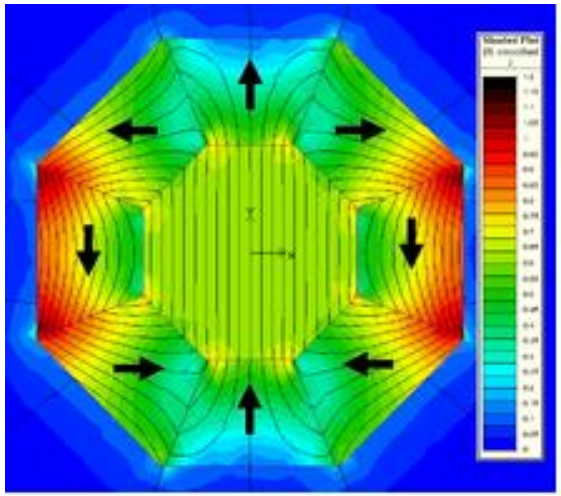
→ 7.2 mA!

(*) «Generazione di intensi fasci di H_2^+ per mezzo della sorgente VIS (Versatile Ion Source) nell'ambito dell'esperimento ISODAR», G.Castro, *this conference*

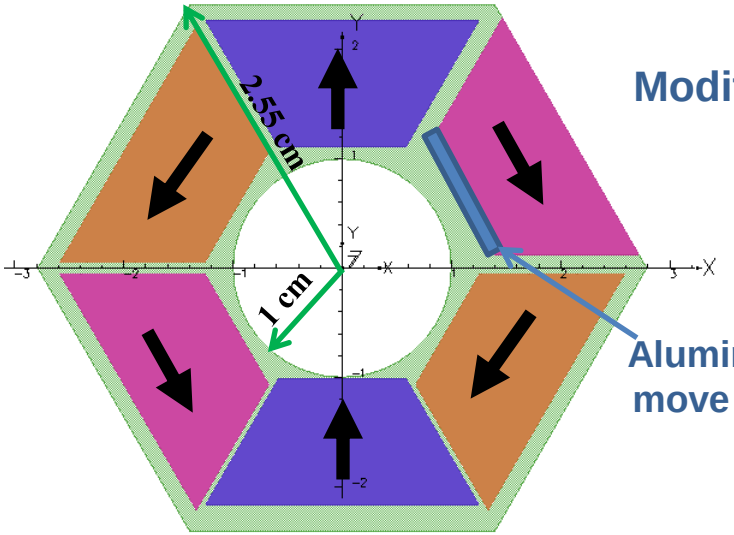
ISODAR : magnetic inflector

«Halbach ring»

array of permanent magnets (PM) produce $\vec{B}||\vec{y}$ in the PM median plane

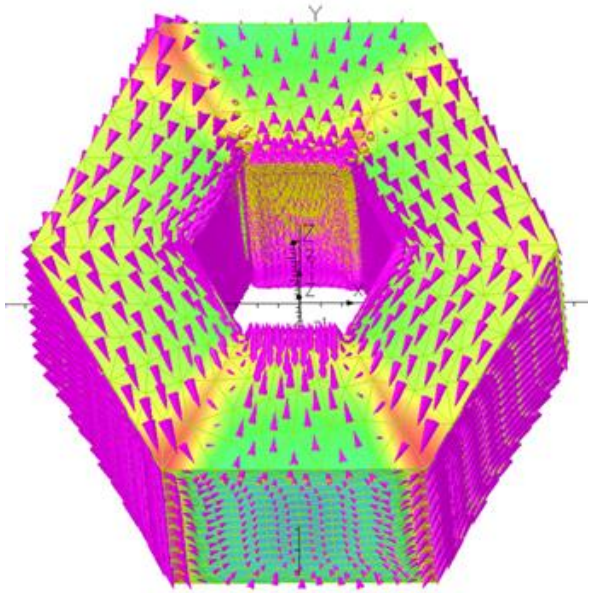


L. Calabretta's idea → set of 6 Halbach rings to drive the beam into the cyclotron median plane



Modified Halbach ring (MHR)

Aluminum sheet to move the PM back

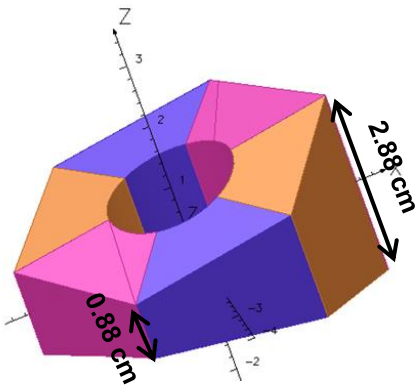


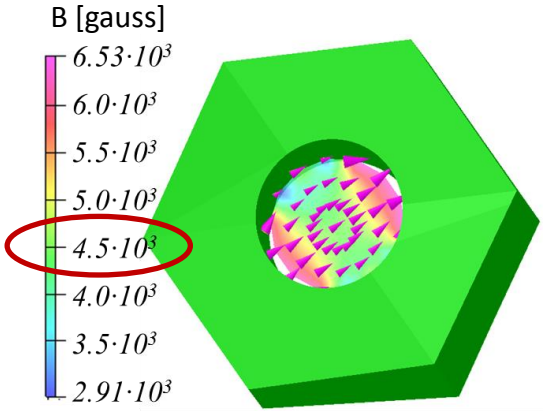
Technical solution for the fine tuning of the h-ring (0.2 – 0.3%)

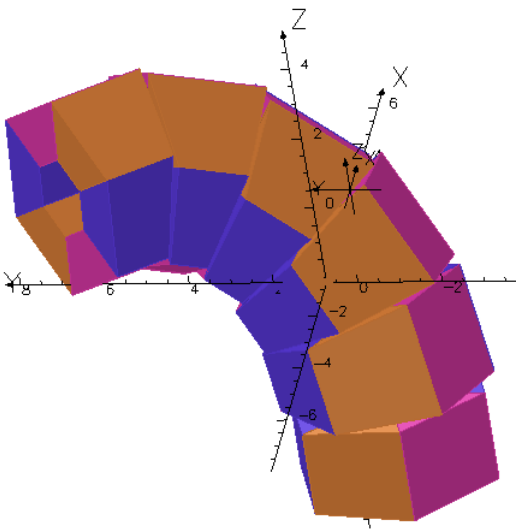
Calabretta @ kyma-undulators (Trieste, Italy)

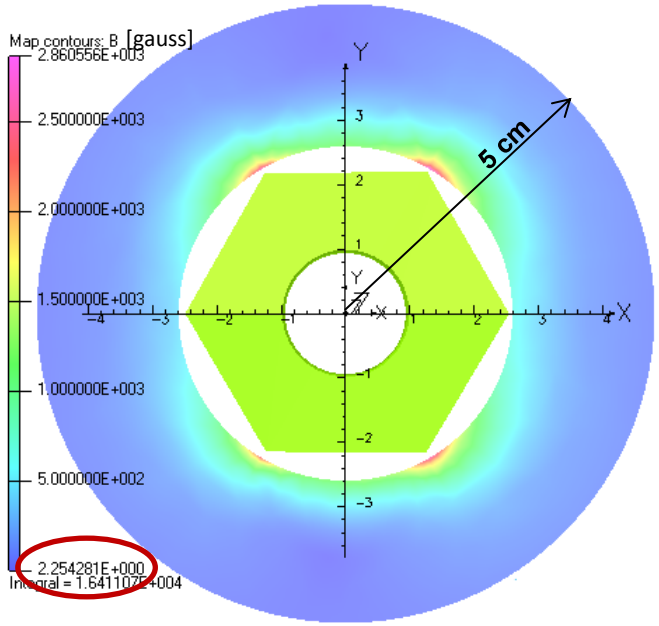
ISODAR : Modified Halbach Ring (MHR)

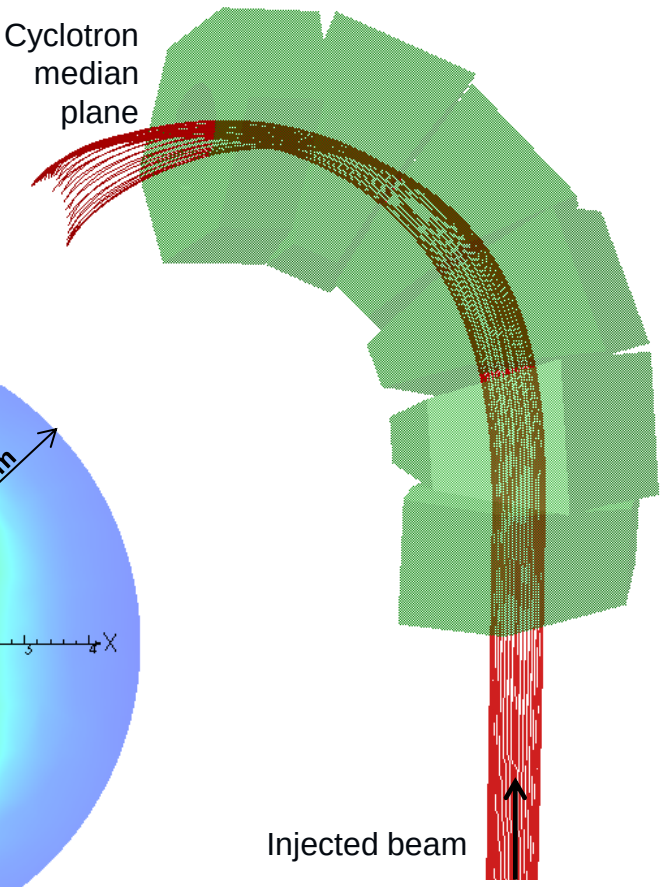
Optimized to transport H_2^+ molecules @ 30 keV/amu in a cyclotron magnetic field of 1 tesla, as the spiral inflector of the injection test in progress at BEST Cyclotron Systems





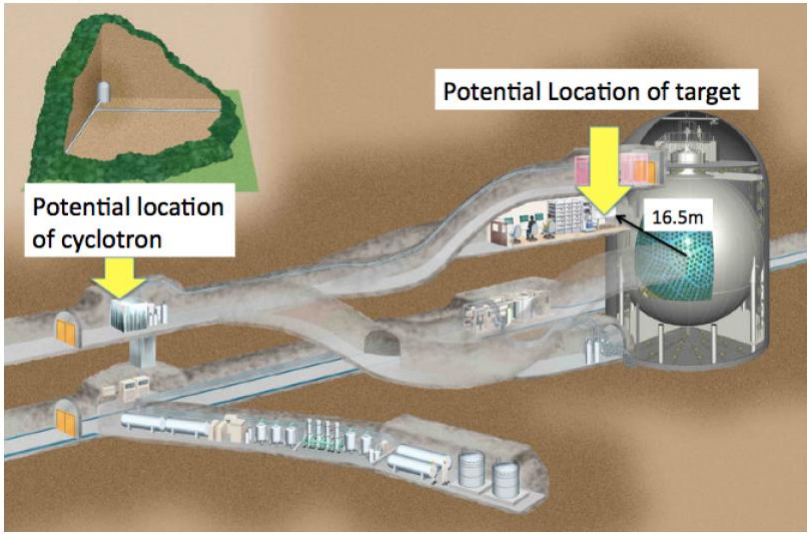


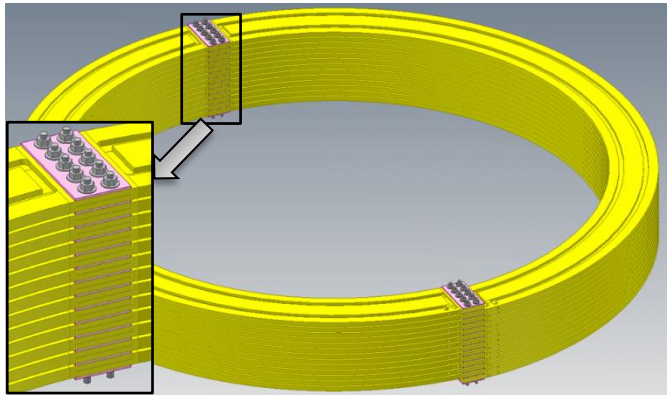




ISODAR : "cut-in-pieces" cyclotron

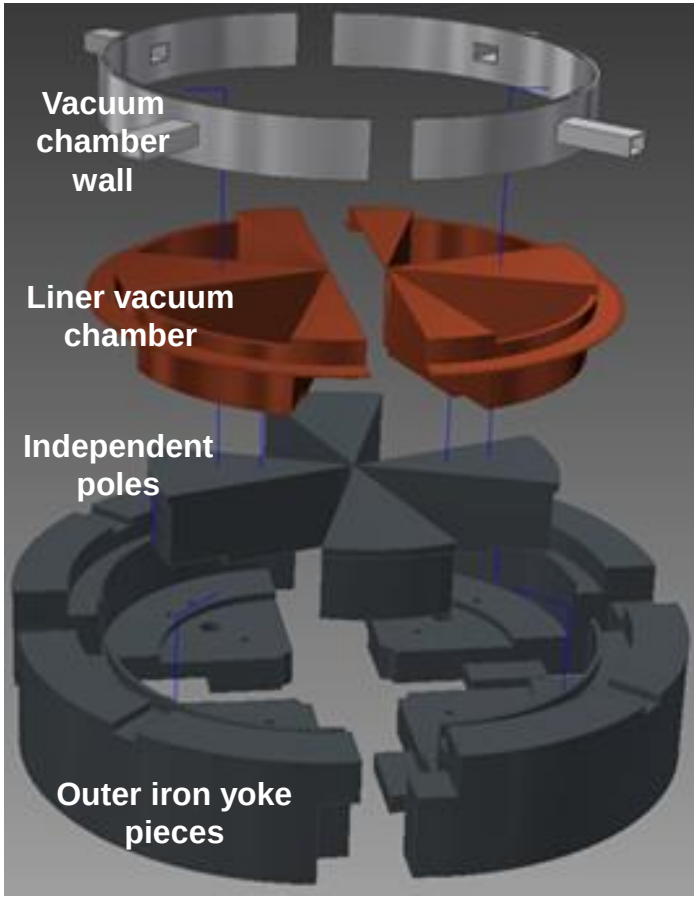
Possible ISODAR site → KamLand, underground site with small access





Coil → 13 aluminium plates parallel to the median plane

IsoDAR cyclotron requires assembly technical solutions



ISODAR : summary

- ✓ H_2^+ ions can be a key to high-power cyclotrons for many applications.
- ✓ Compactness and relative lower cost of cyclotrons could open doors to several important neutrino experiments.
- ✓ New ambitious goal in terms of technical solutions.
- ✓ Preliminary feasibility test in progress.