ISODAR

Progress on the Neutrino Source

Janet Conrad,
IsoDAR Physics Workshop, January 2018

PURPOSE OF THIS TALK:

CONVINCE YOU WE KNOW HOW TO BUILD ISODAR

1. GENERAL PLAN
2. THE ACCELERATOR
3. THE TARGET

1. General Plan
2. The Accelerator
3. The Target

We are proposing to construct a new neutrino source

The steps involved in producing the flux are:

"Proton" beam $\rightarrow$ Be $\rightarrow$ n $\rightarrow$ captures on ^{7}Li $\rightarrow$ ^{8}Li $\rightarrow$ $\bar{\nu}_e$

These map to the following pieces of apparatus:

Each has its own challenges.
I'll discuss how we have addressed these.

"The Technical Facility"

Ion source Low energy transport to cyclotron Injection Cyclotron Extraction region
Medium energy beam transport
Target Sleeve

Details about the design:

arXiv.org > physics > arXiv:1511.05130

Search or Artic

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Physics > Accelerator Physics

IsoDAR@KamLAND: A Conceptual Design Report for the Technical Facility

M. Abs, A. Adelmann, J.R Alonso, S. Axani, W.A. Barletta, R. Barlow, L. Bartoszek, A. Bungau, L. Calabretta, A. Calanna, D. Campo, G. Castro, L. Celona, G.H. Collin, J.M. Conrad, S. Gammino, R. Johnson, G. Karagiorgi, S. Kayser, W. Kleeven, A. Kolano, F. Labrecque, W.A. Loinaz, J. Minervini, M.H. Moulai, H. Okuno, H. Owen, V. Papavassiliou, M.H. Shaevitz, I. Shimizu, T.M. Shokair, K.F. Sorensen, J. Spitz, M. Toups, M. Vagins, K. Van Bibber, M.O. Wascko, D. Winklehner, L.A Winslow, J.J. Yang

(Submitted on 16 Nov 2015)

This conceptual design report describes the technical facility for the IsoDAR electron-antineutrino source at KamLAND. The IsoDAR source will allow an impressive program of neutrino oscillation and electroweak physics to be performed at KamLAND. This report provides information on the physics case, the conceptual design for the subsystems, alternative designs considered, specifics of installation at KamLAND, and identified needs for future development. We discuss the risks we have identified and our approach to mitigating those risks with this design. A substantial portion of the conceptual design is based on three years of experimental efforts and on industry experience. This report also includes information on the conventional facilities.

Subjects: **Accelerator Physics (physics.acc-ph)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:1511.05130 **[physics.acc-ph]**
(or arXiv:1511.05130v1 **[physics.acc-ph]** for this version)

Details about the design:

arXiv.org > physics > arXiv:1710.09325

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Physics > Instrumentation and Detectors

IsoDAR@KamLAND:A Conceptual Design Report for the Conventional Facilities

Jose R. Alonso, K. Nakamura for the IsoDAR Collaboration

(Submitted on 25 Oct 2017)

This document describes requirements for the caverns to house the cyclotron, beam transport line, and target systems; issues associated with transport and assembly of components on the site; electrical power, cooling and ventilation; as well as issues associated with radiation protection of the environment and staff of KamLAND who will be interfacing with IsoDAR during its operational phases. Specifics of IsoDAR operations at the KamLAND site are not addressed. Recent developments in planning for deployment of IsoDAR include the identification of a potential new site for the experiment, where the target can be placed directly on the equatorial plane of the KamLAND detector, and also, an upgrade of the detector resolution to 3\%/$\sqrt{E(MeV)}$. The option of the new site might allow, depending on the results of shielding and background evaluations in KamLAND, for an increase in event rate by about a factor of 1.6 owing to increased solid angle for the detector, improving the physics reach for a same period of the experiment. Alternatively, it raises the option of reducing technical risk and cost by reducing beam intensity to maintain the originally planned event rates. This new siting option is described, and aspects the physics reach of the sterile neutrino search are updated to reflect this second option, as well as the higher resolution of the experiment. A full update of the physics capability given the new site and resolution is beyond the scope of this CDR and will be published later.

Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:1710.09325 **[physics.ins-det]**
(or arXiv:1710.09325v1 **[physics.ins-det]** for this version)

About 5 years of design work has gone into this.
Many groups have contributed!

[1]Amherst College, Amherst MA, US
[2]Bartoszek Engineering, Aurora IL, US
[3]Best Cyclotron System, Inc., Springfiled VA, US
[4]University of California, Berkeley, CA, US
[5]University of California, Los Angeles, CA, US
[6]University of California, Irvine, CA, US
[7]China Institute of Atomic Energy, Beijing CN
[8]The Cockcroft Institute Daresbury Laboratory, Daresbury, UK
[9]Columbia University, New York NY, US
[10] FLIBE Energy Inc., Huntsville AL, US
[11]University of Huddersfield, Huddersfield, UK
[12] Imperial College London, London, UK
[13] Ion Beam Applications, S.A., Ottignies-Louvain-la-Neuve, BE
[14]INFN Laboratori Nazionale del Sud, Catania, IT
[15] Lawrence Livermore National Laboratory, Tracy CA, US
[16]Massachusetts Institute of Technology, Cambridge MA, US
[17] University of Manchester, Manchester UK
[18] University of Michigan, Ann Arbor MI, US
[19]New Mexico State University, Las Cruces NM, US
[20]Paul Scherrer Institute, Villigen, CH
[21]RIKEN Nishina Center for Accelerator-based Science, Wako, JP
[22]Tohoku University, Sendai, JP

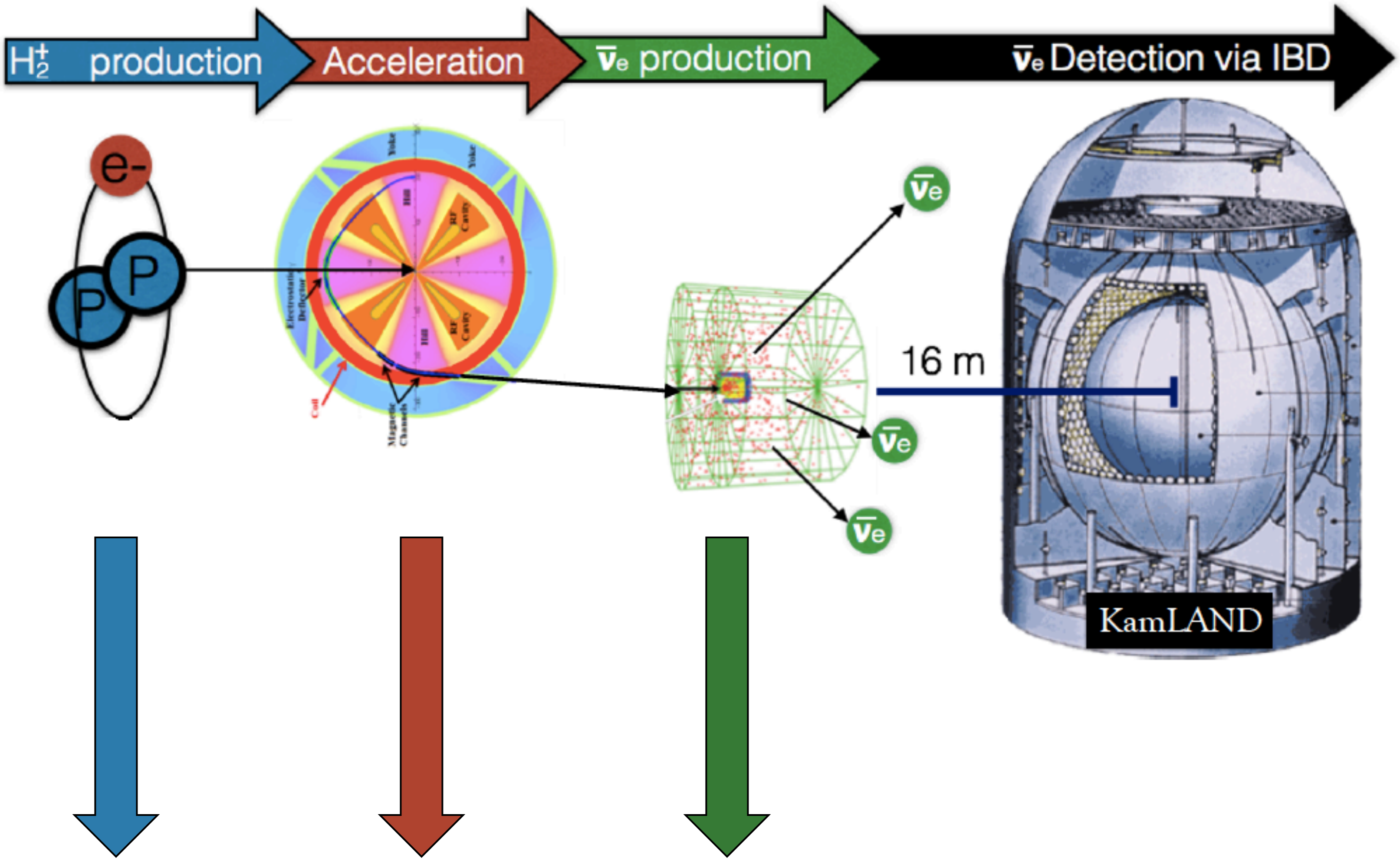
This work could not have been done without:

Input from Accelerator Laboratories, especially:
INFN –Catania, INFN-Legnaro, Paul Scherrer Institut, RIKEN

Input from Cyclotron Companies, especially:
AIMA, Best Cyclotron Systems, IBA RadioPharma Solutions

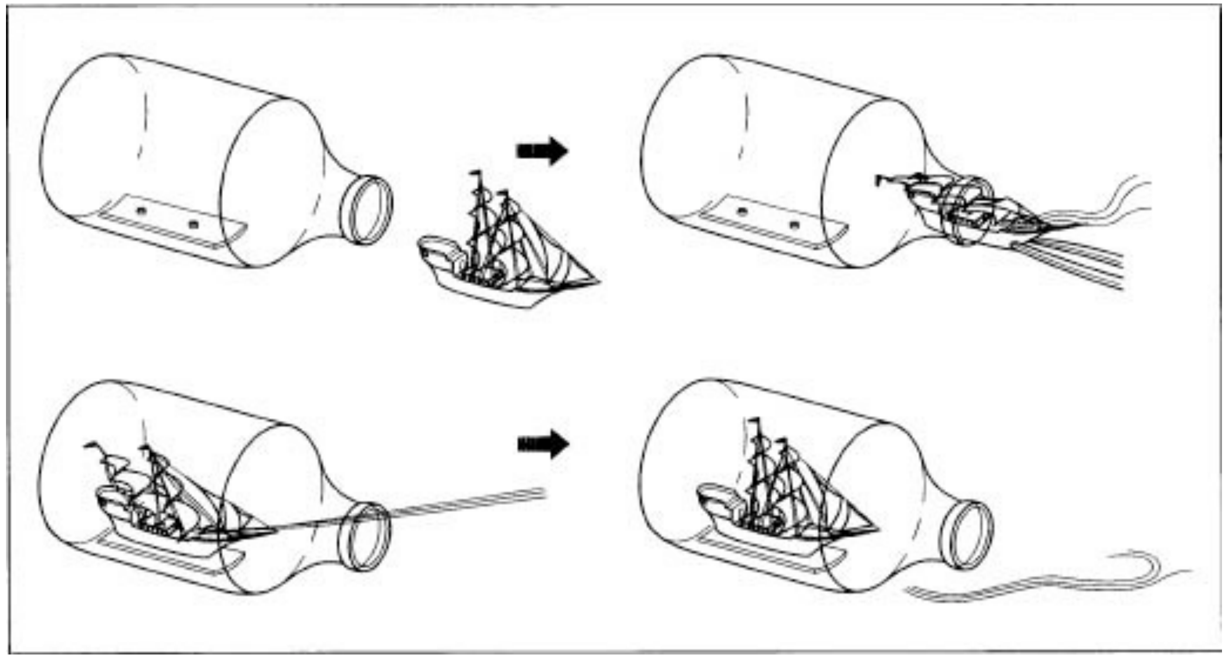
Substantial funding for R&D costs from:
NSF, MIT and foundations: Bose, Heising-Simons.

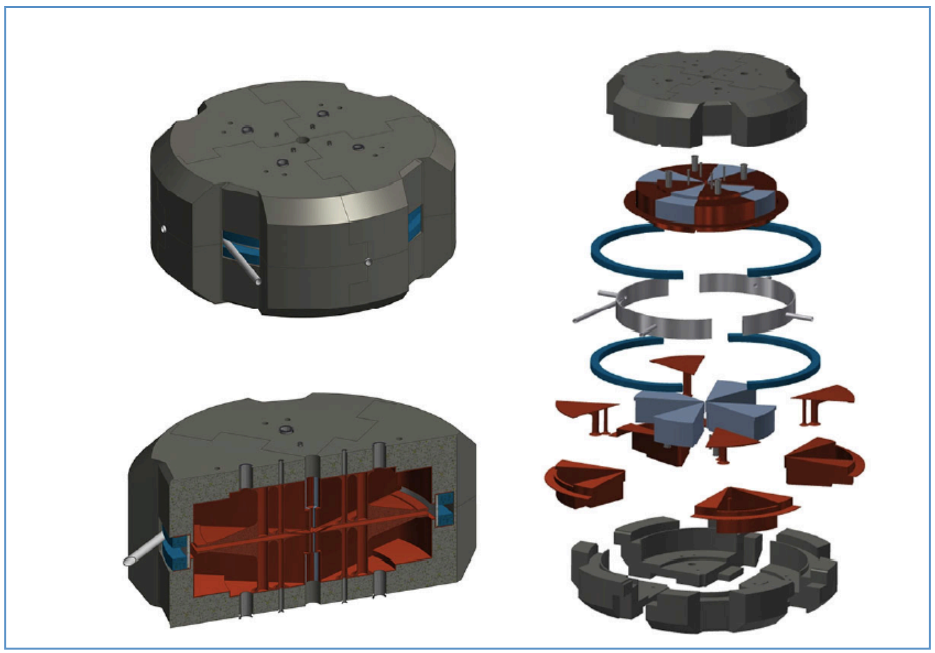
Next funding step:
We are planning to submit a proposal to cover the neutrino source to the NSF midscale program.

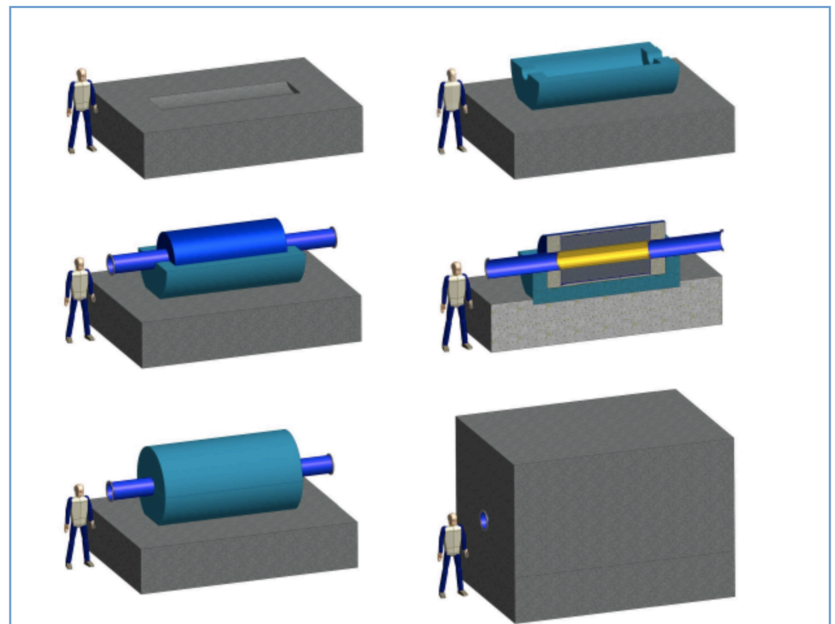


Each of these three steps has had interesting challenges.
At this point, we have good, practical solutions!

An additional complication:



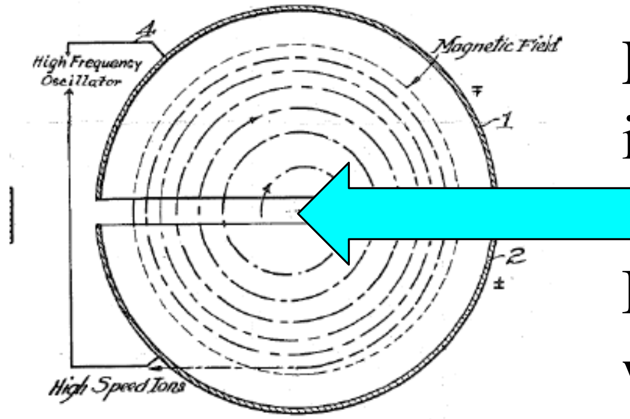




Laser scans of the Kamioka halls…

1. GENERAL PLAN
2. THE ACCELERATOR
3. THE TARGET

H_2^+ production ... Why?



Present machines inject p or H^-

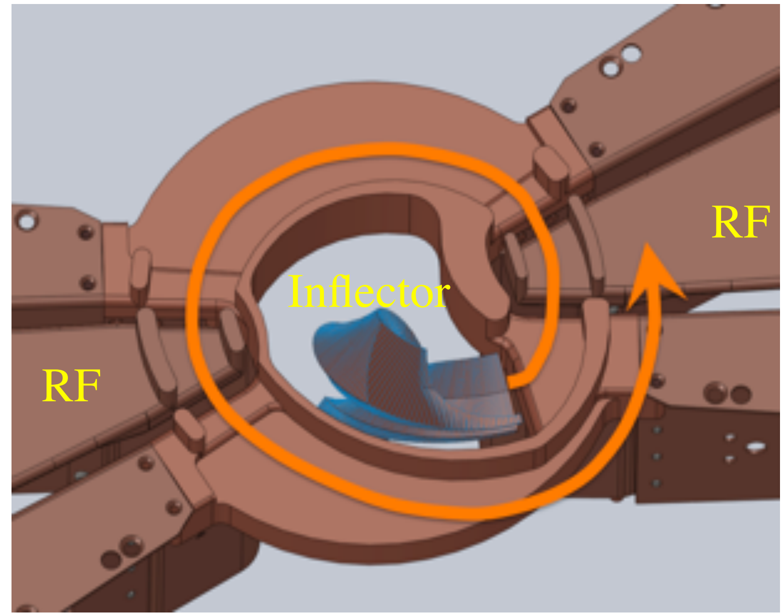
Instead, we inject H_2^+

This is reduces the total electric charge of an injected bunch, while accelerating the same number of protons.

For 5 mA of H_2^+ accelerated,
we can have 10 mA of protons downstream,
once the electron is stripped off.

H_2^+ production ... What's needed?

In present injection designs, you lose between 80% and 90% of the ions



Most ions are lost in the first "turn" of the cyclotron because they hit material. (Phase acceptance 20-30 degrees)

To capture 5 mA with a conventional bunching system we will need between 35 and 50 mA injected.

We can do that!

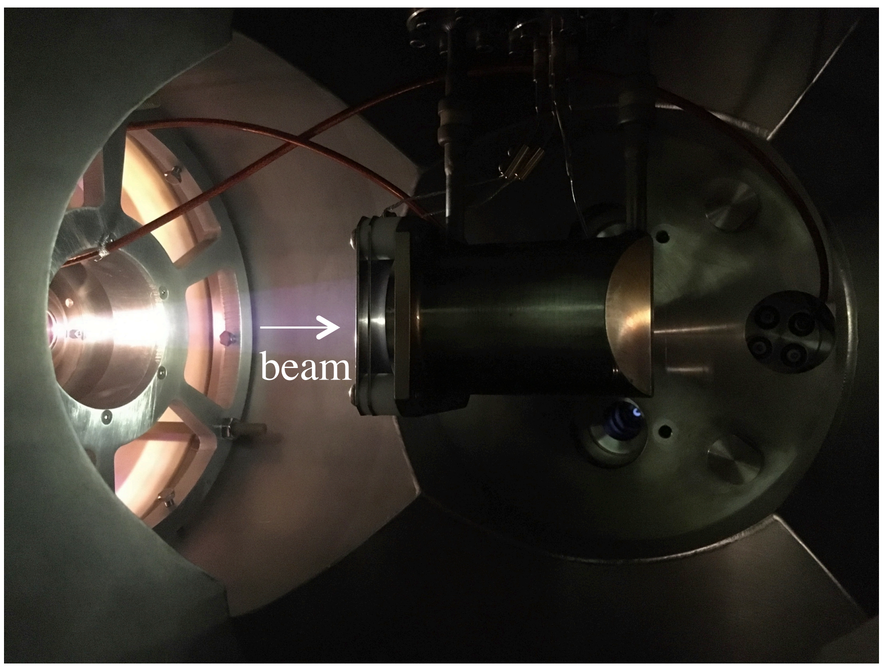
There is an existence proof of an H_2^+ ion source of sufficient intensity

Testing of a H_2^+-enriched ion source for deuterium simulation

M. D. Williams and K. N. Leung
Lawrence Berkeley Laboratory, Berkeley, California 94720
G. M. Brennen and D. R. Burns
McDonnell Douglas Astronautics Co., St. Louis, Missouri 63166

(Presented on 12 July 1989)

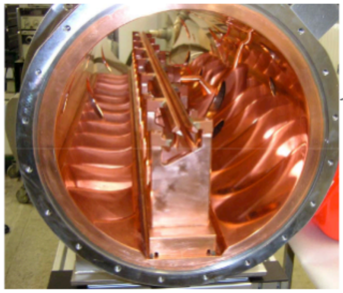
We have tested a McDonnell Douglas short milticusp plasma generator, designed to generate a positive hydrogen ion beam which is enriched with H_2^+ ions. Initial testing shows that the prototype source is capable of producing a positive hydrogen ion beam with H_2^+ percentage greater than 85%. The total ion-current density was 56 mA/cm^2. For a higher current density of 110 mA/cm^2, the percentage of H_2^+ ions is approximately 73% as measured by a magnetic deflection spectrometer. A comparison between tungsten and lanthanum hexaboride cathodes shows that tungsten filaments can provide better performance.

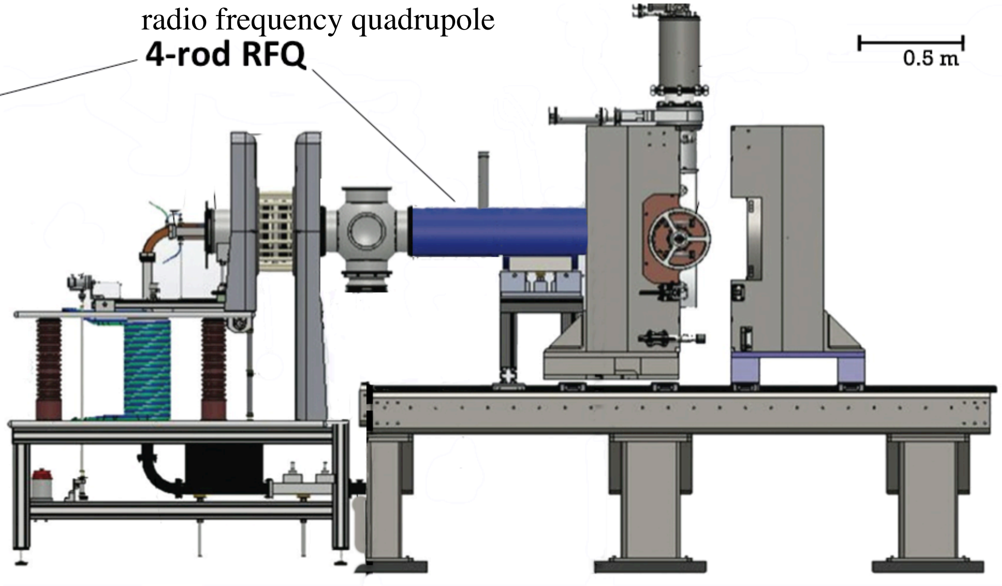


We have built a similar source with some improvements, using funding from NSF.

You can visit the ion source this afternoon, if you like!
(We won't turn it on)

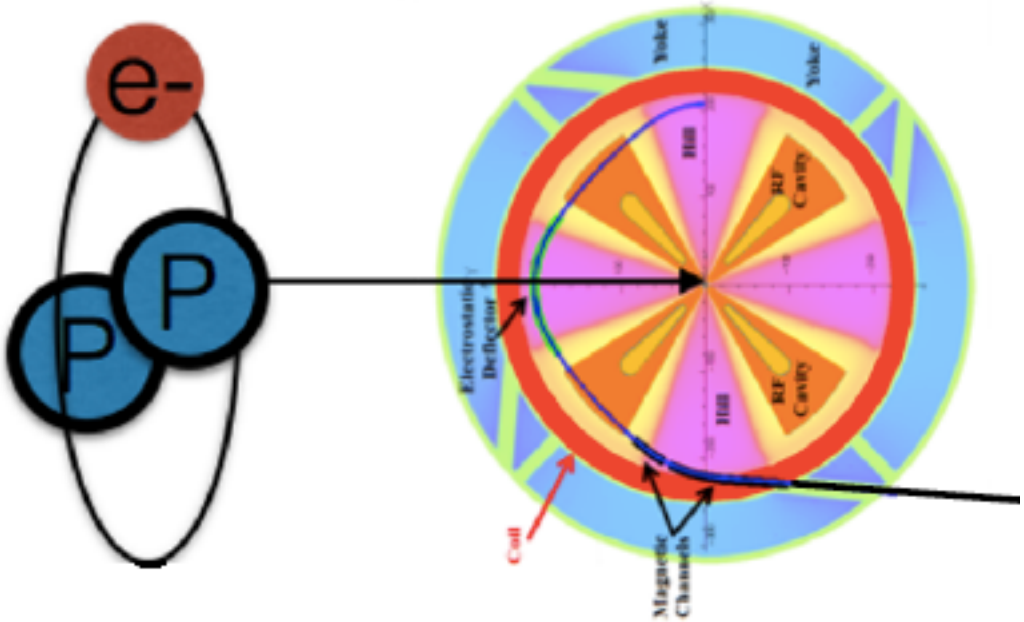
Also, we have a new approach to the transport that gives >90% efficiency for capture through RFQ-bunching



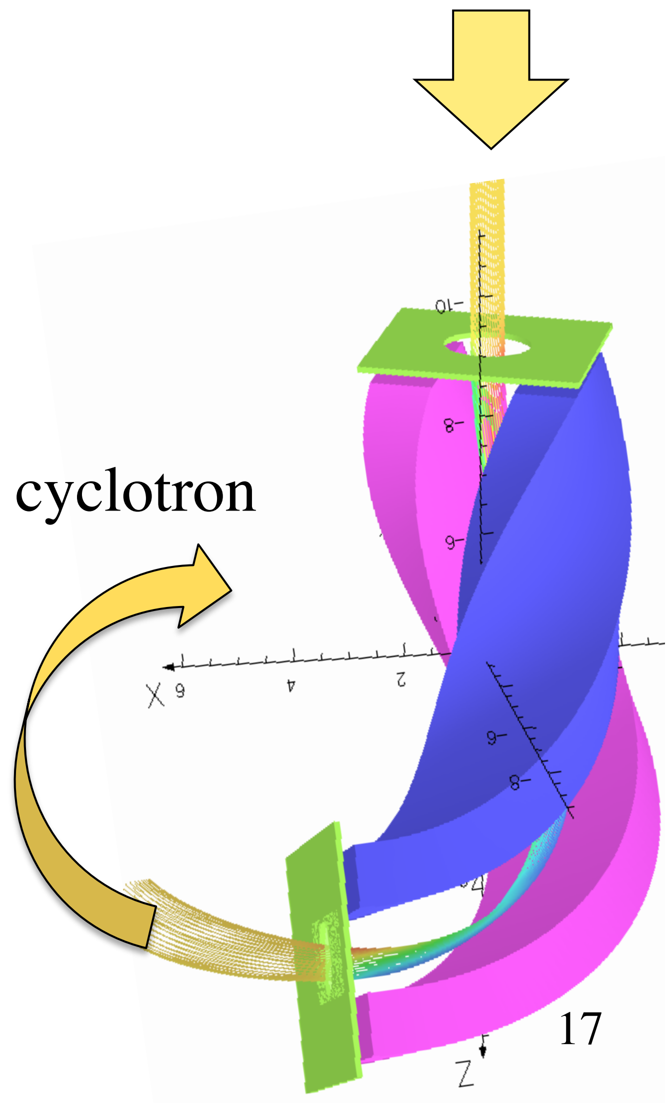


This was funded as an NSF MRI. We will initally run the RFQ at AIMA for studies.

Old idea (paper in 1981) waiting to happen.
It required some recent developments with RFQs
Ours will be the first RFQ axial injection into a compact cyclotron!

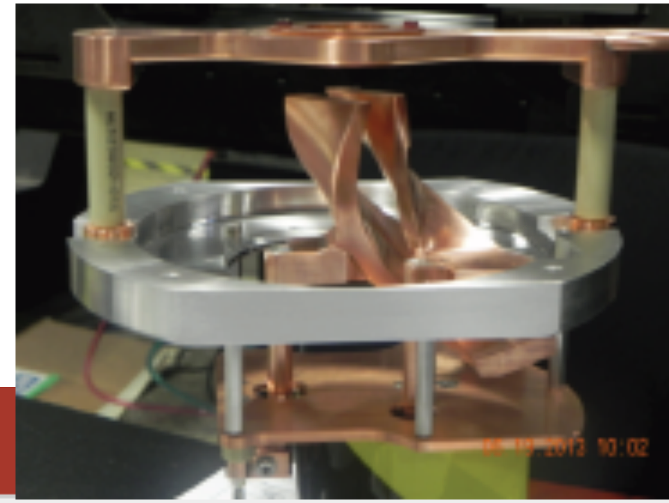


The ion source injects into RFQ.
The RFQ injects into a “spiral inflector” in the cyclotron (takes beam from vertical to horizontal plane)



Ours is unusual:
Large size due to rigidity of H_2^+

We built one and ran it at Best Cyclotron Systems, funded by NSF EAGER.



arXiv.org > physics > arXiv:1508.03850

Physics > Accelerator Physics

The IsoDAR High Intensity H_2^+ Transport and Injection Tests

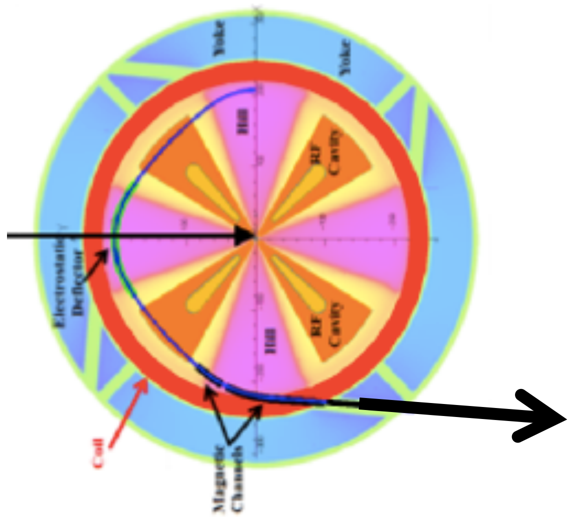
Jose Alonso, Spencer Axani, Luciano Calabretta, Daniela Campo, Luigi Celona, Janet M. Conrad, Alexandra Day, Giuseppe Castro, Francis Labrecque, Daniel Winklehner

Parameter	Value
Species	H_2^+
Beam Energy	60.0 keV
Solenoids 1/2	340 A/240 A
Cyclotron Magnet	223 A
Spiral Inflector Upper/Lower Electrode	-10 kV/+10 kV
Beam Stop Current (halo+beam)	7.5 $\pm$ 0.8 mA
Spiral Inflector Aperture Current (halo)	1.3 $\pm$ 0.5 mA
Paddle Probe Current	5.8 $\pm$ 0.4 mA

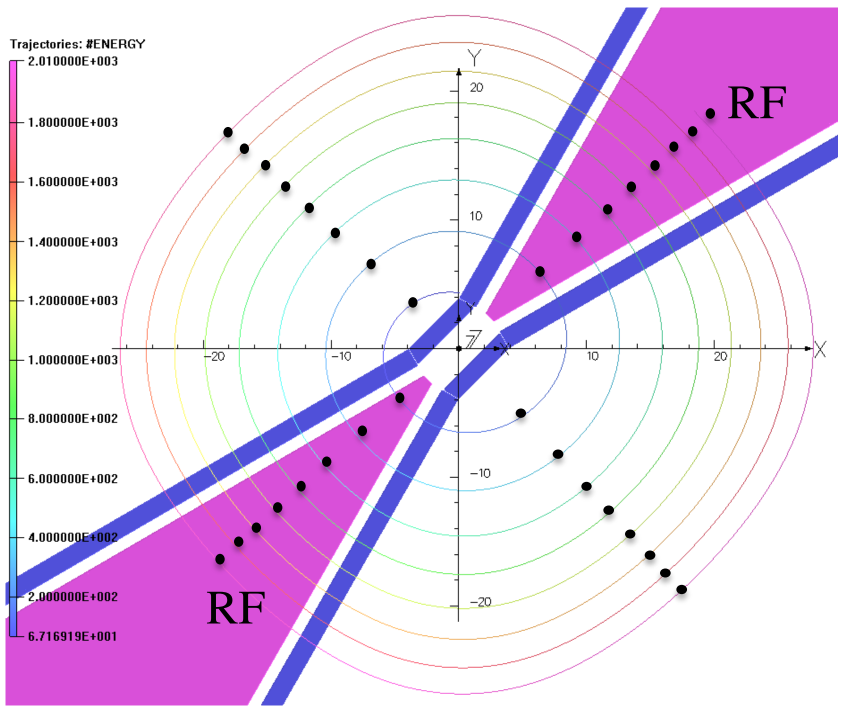
} 6.2 mA

5.8/6.2 = 93.5% transmission

With Ion source + RFQ + spiral inflector, we capture enough beam!

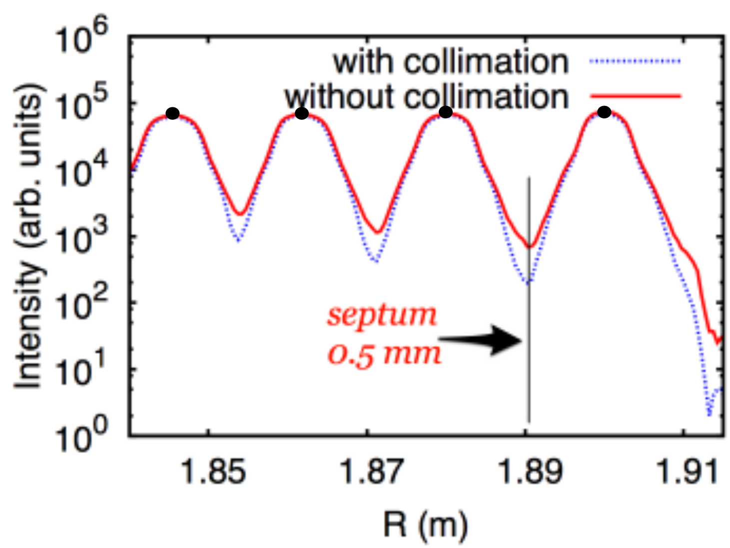


Avoid beam losses on the electrostatic extraction septum (protecting with a stripper foil, removing 50 μA of beam)



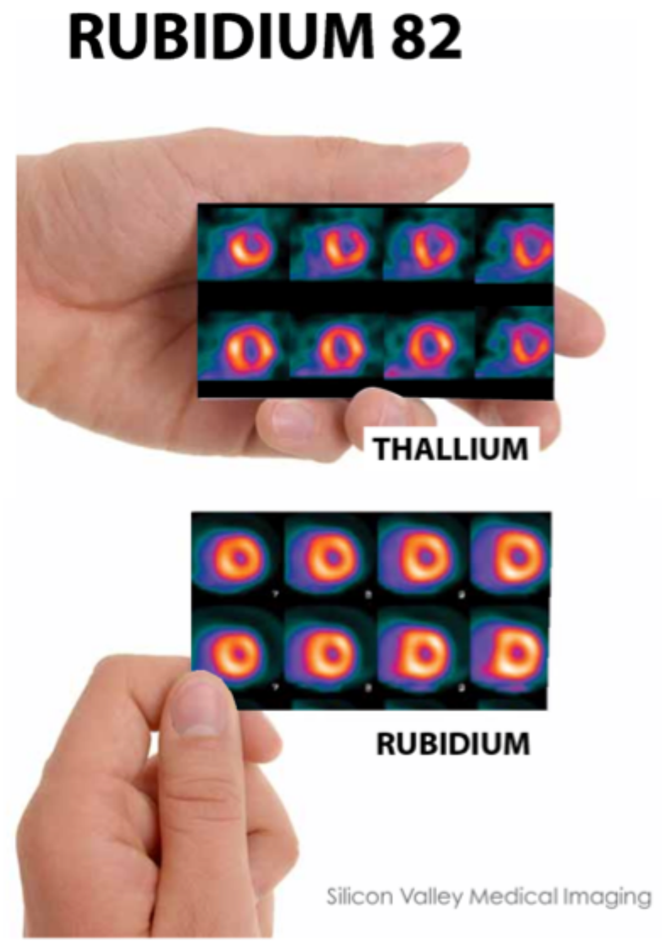
Without the foil:

Intensity vs. position in final 4 turns:



The 50 μA of extracted beam from the foil can be used…

This is the beam energy and intensity that pharmaceutical companies need to produce $^{82}Sr \rightarrow {}^{82}Rb$.

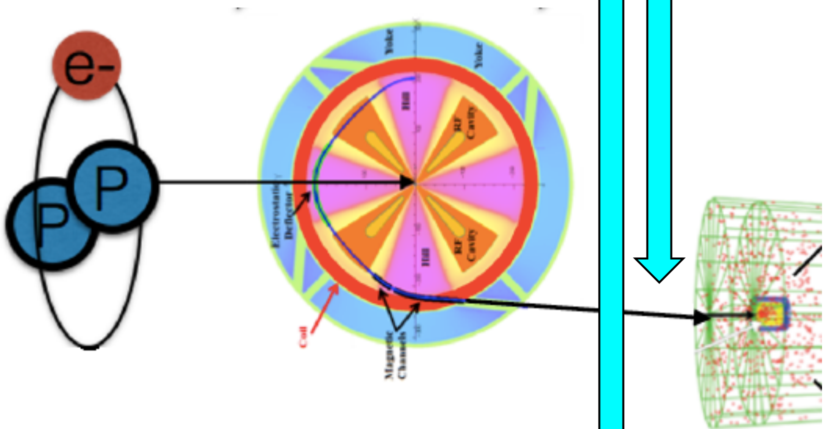


Can we offset some cost of running, by collaborating with a company on producing ^{82}Sr?

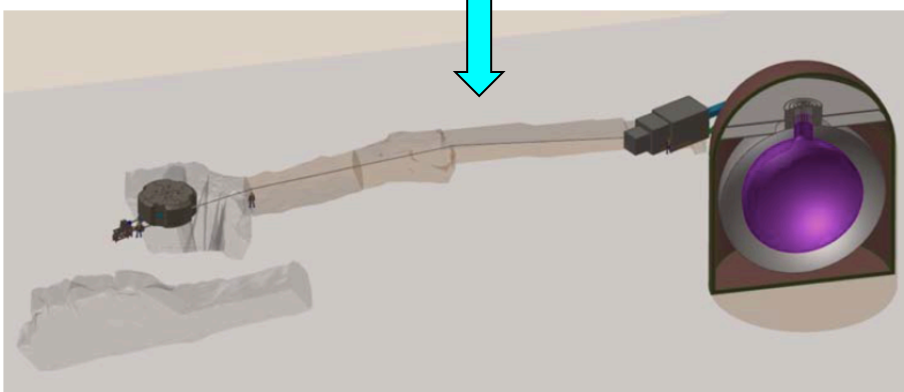
We are working on a white-paper on self-funding operations

1. General Plan
2. The Accelerator
3. The Target

Now we are here.

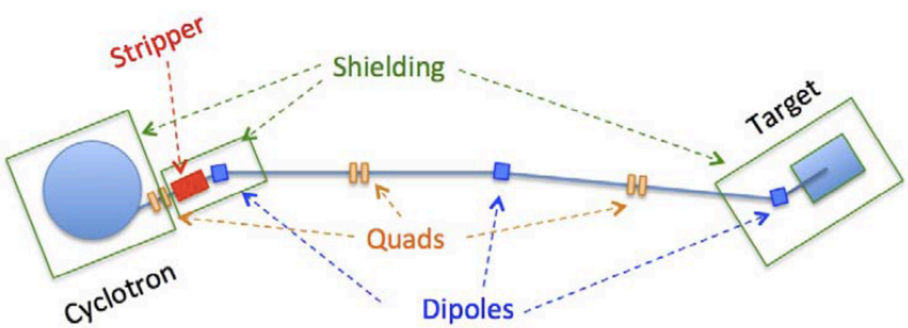


We must take the beam
from the cyclotron
to the target @ 60 MeV.

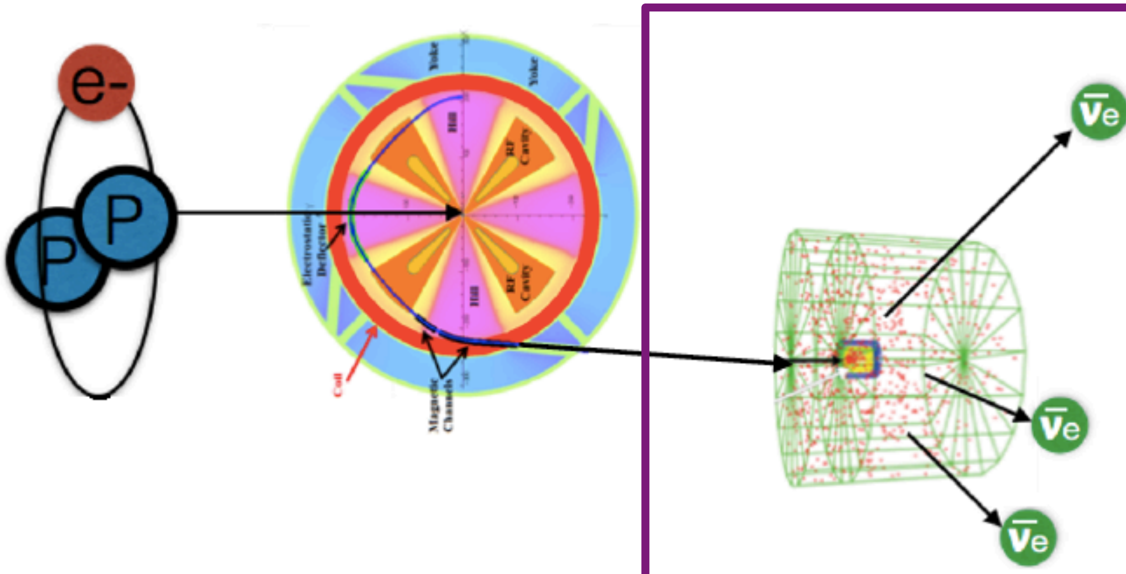


This will use a classic "Medium Energy Beam Transport."

Details will depend on the layout in the caverns.



10 mA of protons at 60 MeV will reach...



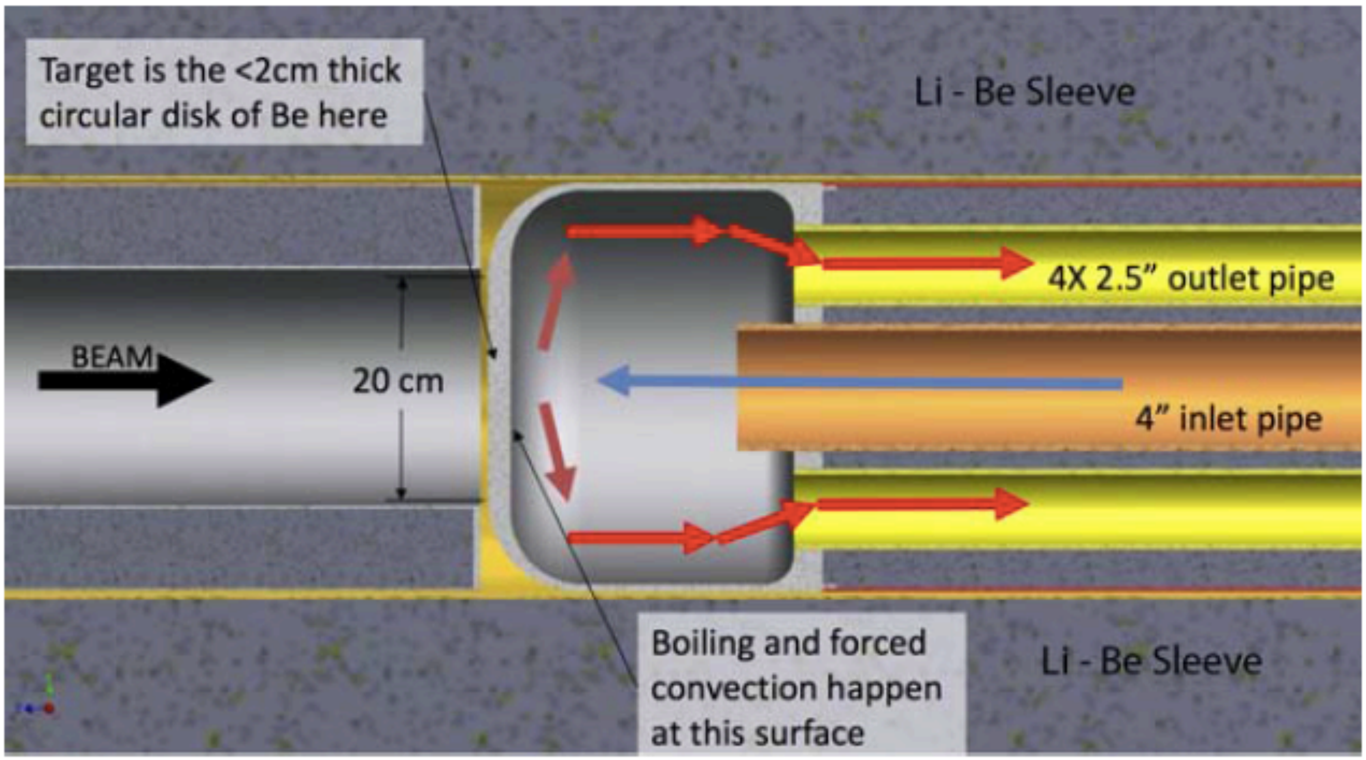
Where the neutrinos are produced:

a ^{9}Be target within a ^{7}Li sleeve

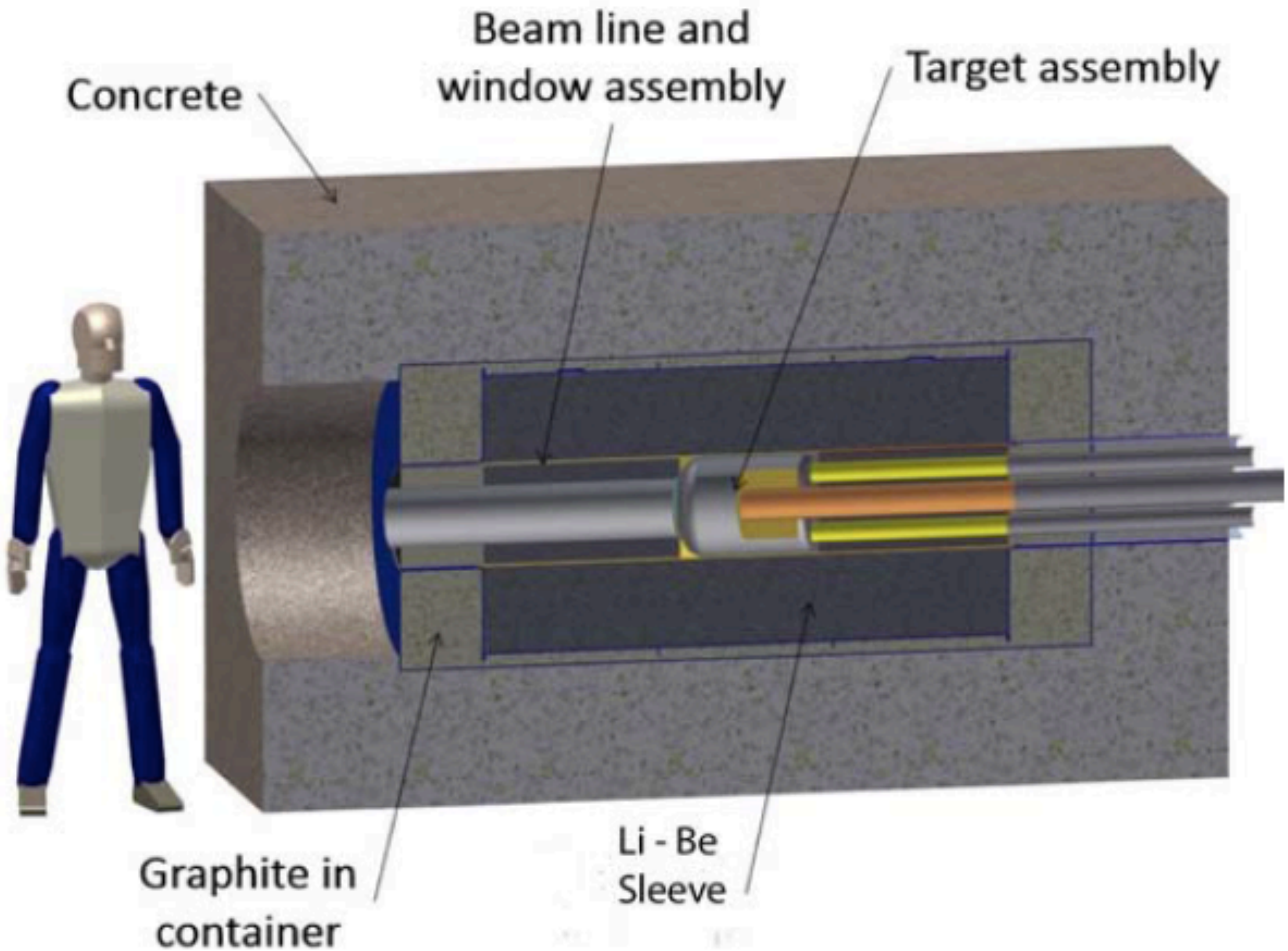
Important sources of expertise: Bartoszek Engineering, RIKEN

The beryllium target:

600 kW painted across face ~ 16 cm diameter (~3 kW/cm^2)



We have an NSF grant to study target cooling.



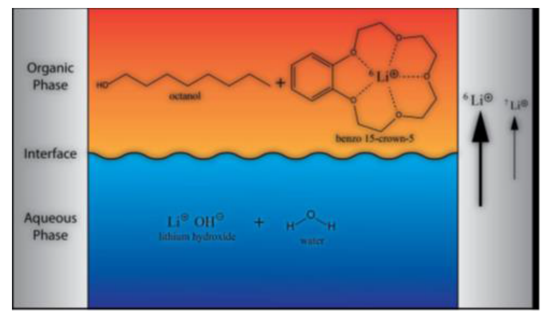
We save considerable money with a new sleeve design
consisting of embedded Be balls in the ^{7}Li.
(instead of opting for higher statistics, we opt for savings)

Obtaining ~0.3 tons of ^{7}Li

We can obtain the required 7Li from Russia via IsoFlex

But we are also coordinating with DOE as a potential source…

The requirement for a 1 GWe commercial reactor is estimated to be about 25000 kg of 99.995% enriched ^{7}Li. New processes need to be developed and proven to address such large-quantity and high-enrichment needs in an environmentally responsible fashion.



- Environmentally friendly Li-7 production based upon crown-ether solvent extraction and/or chromatography – R&D to support ability to meet specifications for industry

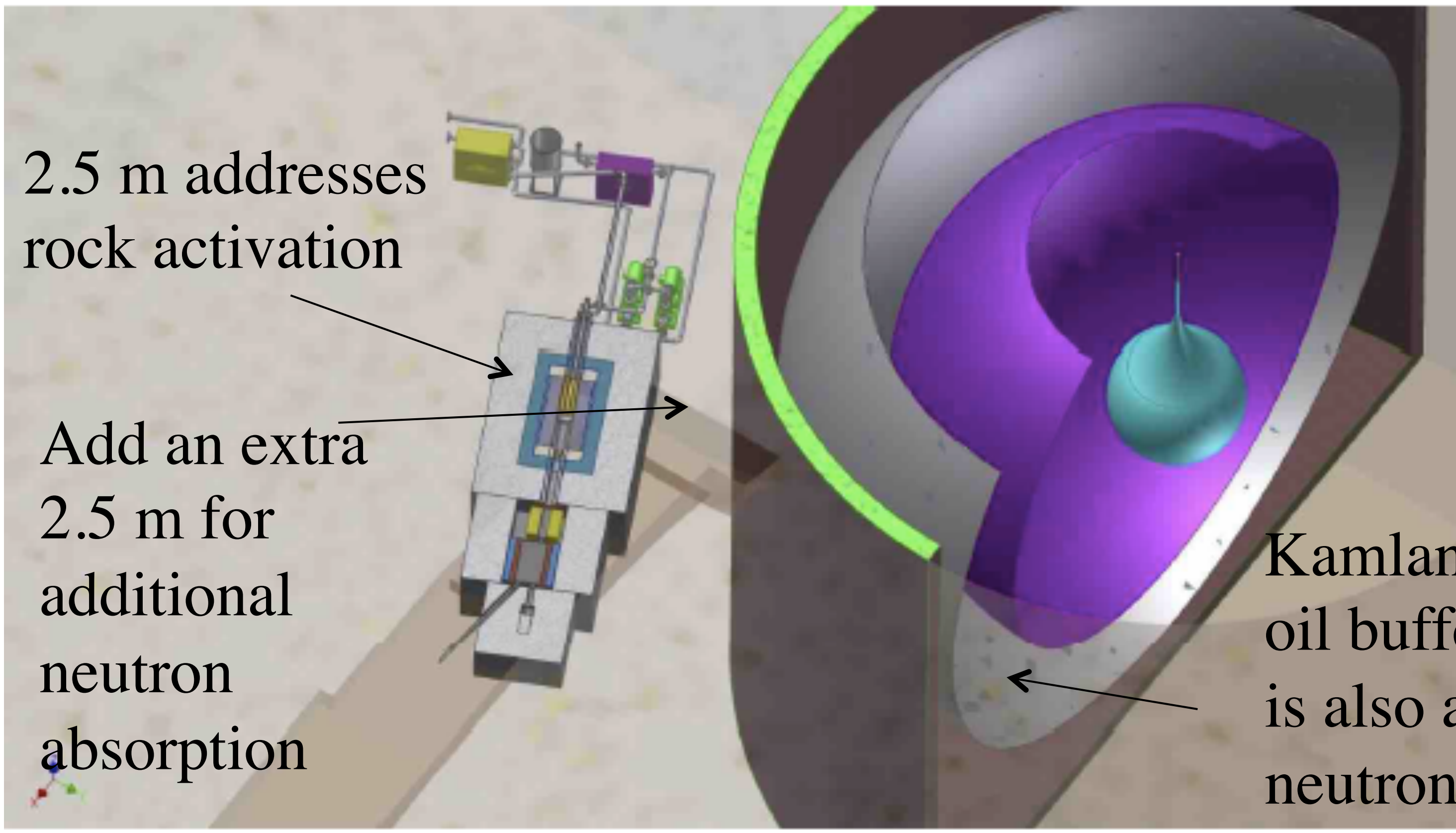
From the FY18 DOE Budget:

Recent research results have also demonstrated technical feasibility of a potential new production route for lithium-7, an isotope used as a coolant reagent in pressurized water nuclear power plants. Currently, the U.S. is dependent upon foreign supplies of lithium-7 which are not always reliable; this successful research could provide a path for re-establishing domestic production of lithium-7.

Shielding for 2 reasons:

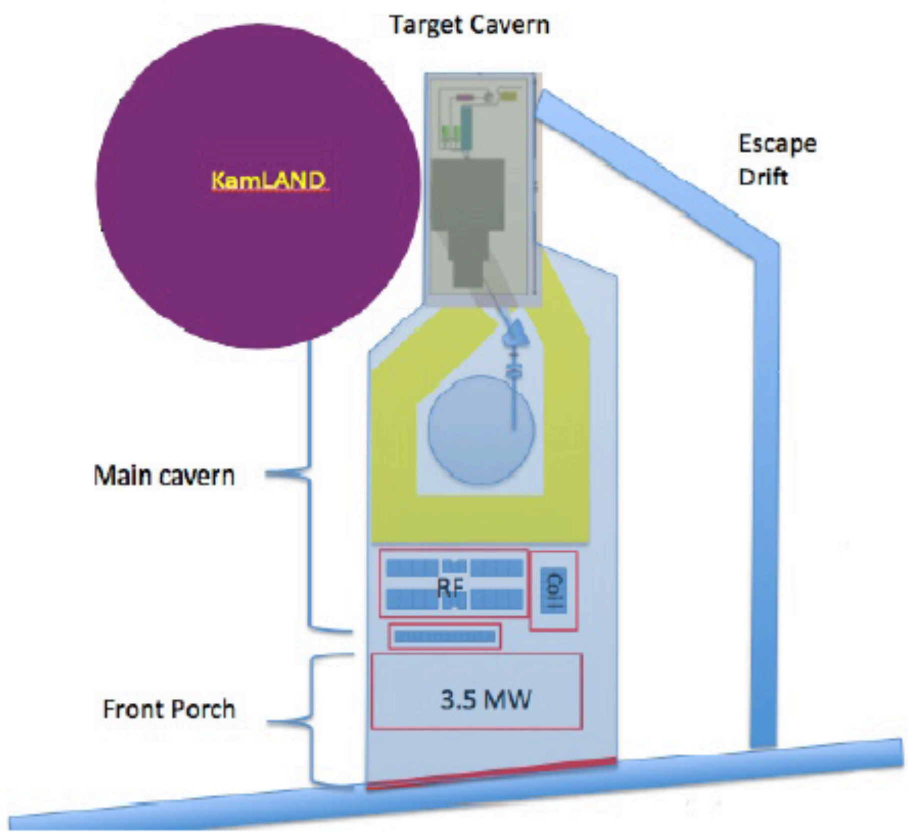
#1 Don't activate the mine!

#2 No neutron background in the detector!



We are proposing to work with Draper Labs to find less thick shielding material.

We have several options for sites,
here is our preferred layout – a new cavern at the midpoint,
off of an existing tunnel.



(This does not involve blasting. It uses an expanding grout to crack rock. This is a common method.)

The actual placement of target-to-detector is not quite fixed. Assume 16.0 m for now.

CONCLUSIONS

Conclusions about the design

We have a very solid design for a novel cyclotron
that will produce 10 times the beam of commercial cyclotrons
and 3 times the beam of PSI.*

We pair this machine with a unique target/sleeve to produce
20% of a mole of pure electron antineutrinos in 5 years.
Combined with KamLAND we produce ~1M IBD events.

This is a completely new opportunity for neutrino physics.
This also changes the game for research cyclotrons,
for isotope production and for ADS technology.

We have a few "To-Do's" but...,
We will be ready to apply for engineering/construction funds in 2018

**PSI has beam quality requirements that we do not have because they must make high-quality secondary beams. Thus our machine is not applicable to their purpose.*

BACKUP SLIDES

Choosing H_2^+ as vs. p or H^- reduces space charge effects at injection:

A measure of the strength of space charge is the generalized perveance:

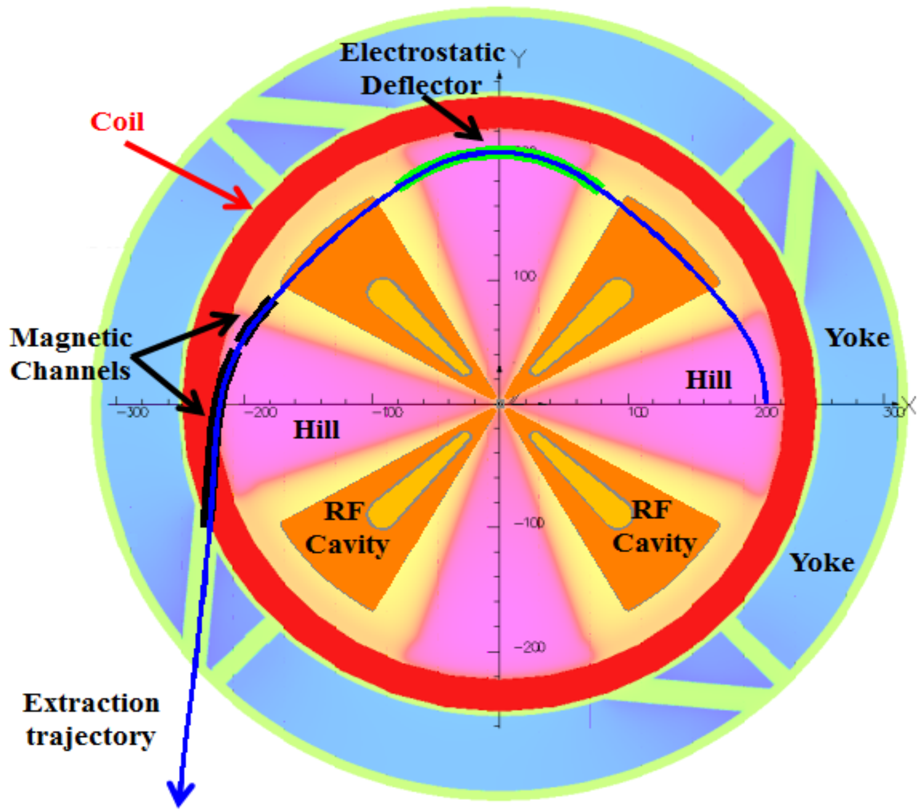
$$K = \frac{qI}{2\pi\varepsilon_0 m\gamma^3\beta^3}$$

Higher perveance = more problems at injection
This depends in charge, *q*, and on energy at injection.

Our perveance at injection matches what has been achieved:
5 mA, 70 keV of H_2^+ = 2 mA, 30 keV of p
(used in commercial cyclotrons)

i.e., design solutions already exist if we use H_2^+ and inject at higher energy.

The cyclotron driver…

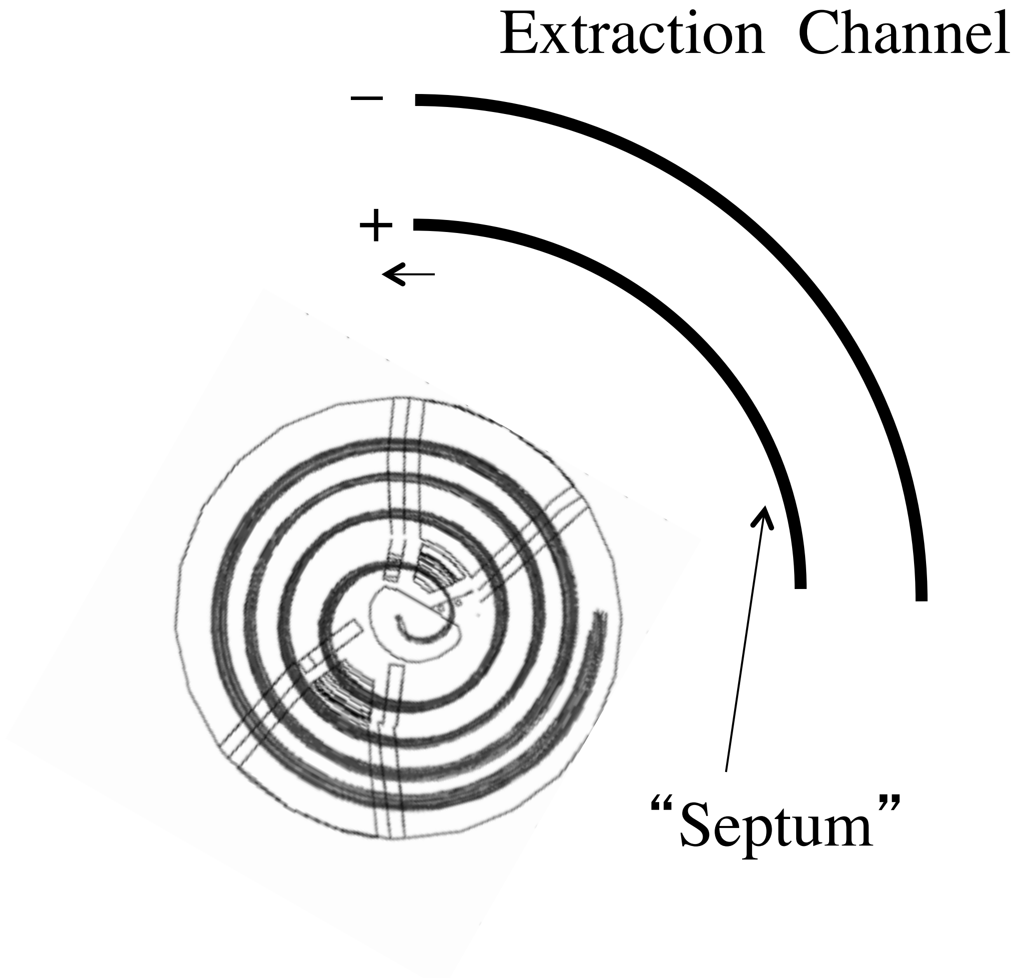


E_{max}	60 MeV/amu
E_{inj}	35 keV/amu
R_{ext}	1.99 m
R_{inj}	55 mm
$< B >$ @ R_{ext}	1.16 T
$< B >$ @ R_{inj}	0.97 T
Sectors	4
Hill width	28 - 40 deg
Valley gap	1800 mm
Pole gap	100 mm
Outer Diameter	6.2 m
Full height	2.7 m
Cavities	4
Cavity type	$\lambda/2$, double gap
Harmonic	4th
rf frequency	32.8 MHz
Acc. Voltage	70 - 240 kV
Power/cavity	310 kW
ΔE/turn	1.3 MeV
Turns	95
ΔR /turn @ R_{ext}	$>$ 14 mm
ΔR/turn @ R_{inj}	$>$ 56 mm
Coil size	200x250 mm^2
Current density	3.1 A/mm^2
Iron weight	450 tons
Vacuum	$< 10^{-7}$ mbar

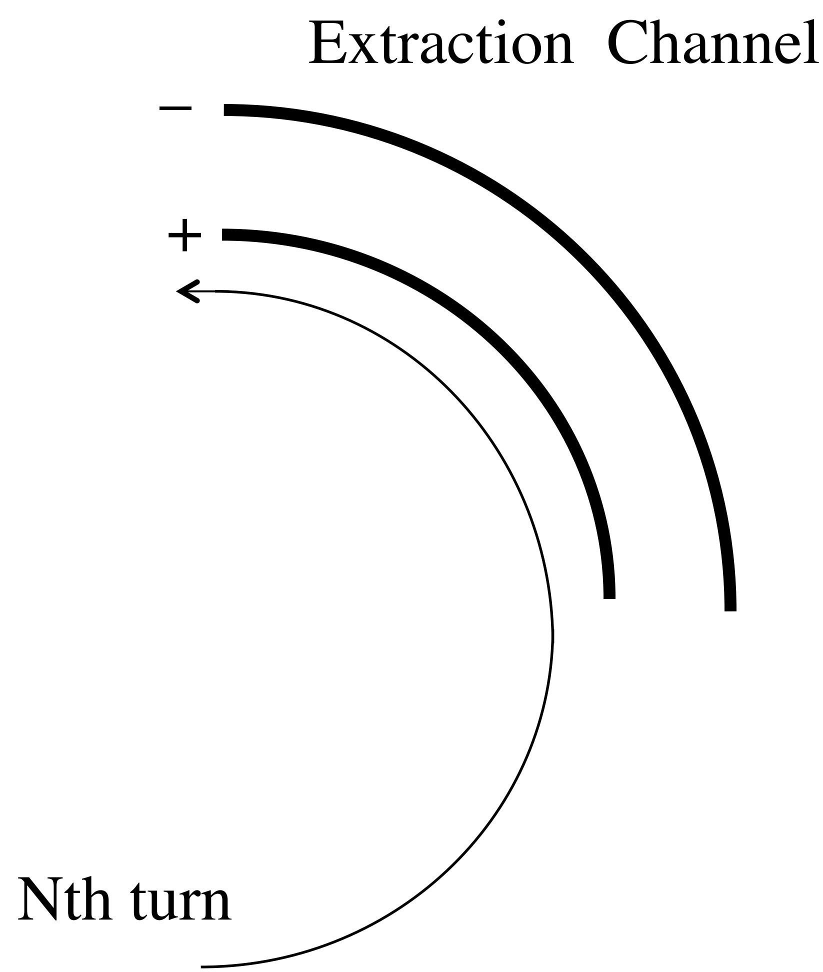
5 mA of H2+…
x10 total protons
of "on-market" machines
(x5 the electrical current)

How does the stripper foil help to protect the electrostatic septum?
(and what can you do with that beam?)

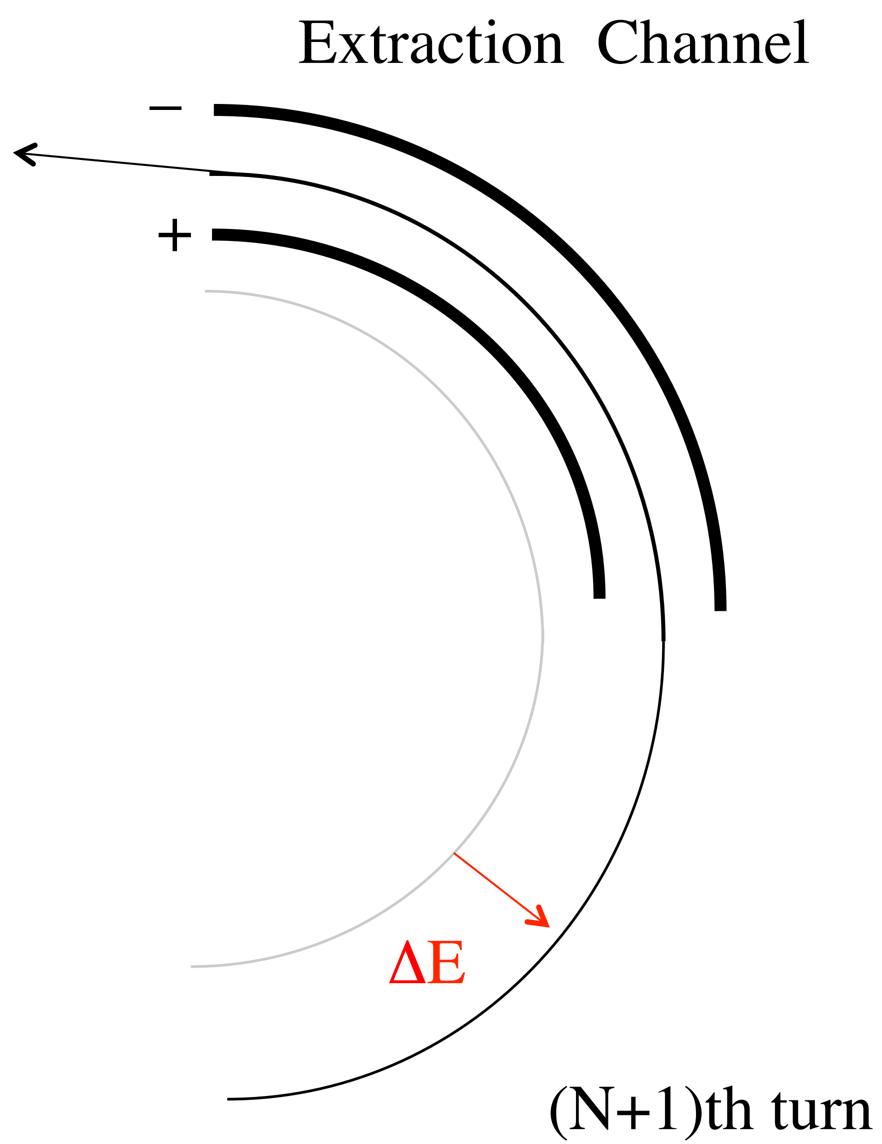
Extraction Process



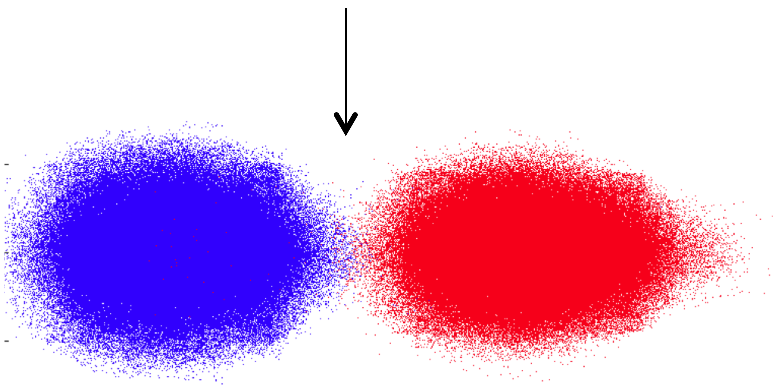
Extraction Process



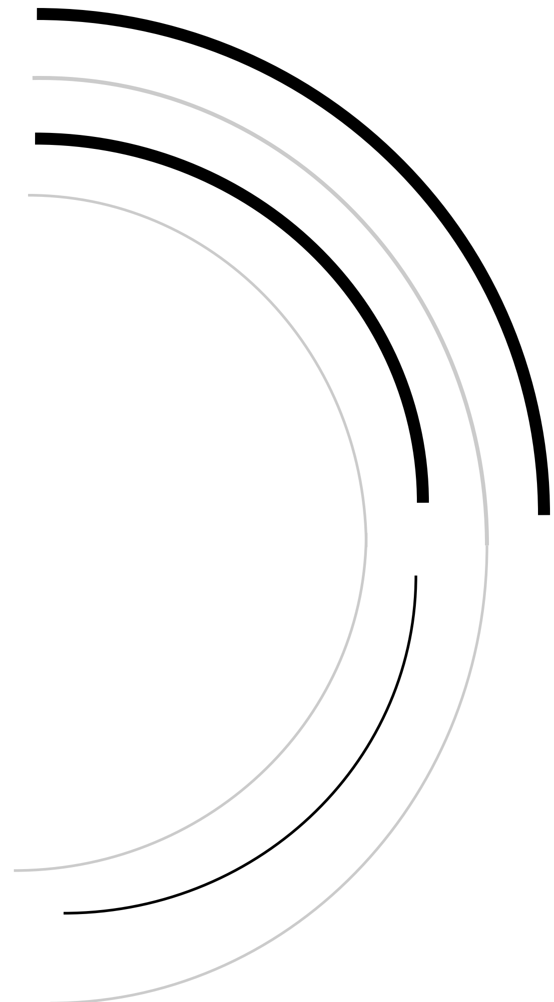
Extraction Process



Extraction Process



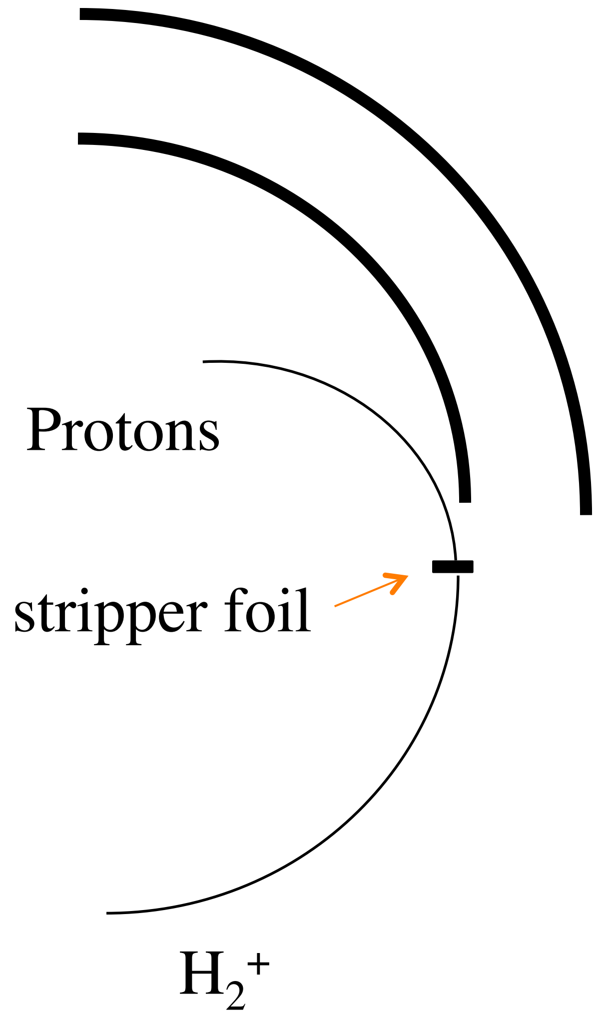
~.02% intercepted
on septum



“Problem”
(120 W max)

Extraction Process

Notice protons
cross the
cyclotron
to exit!
That's ok!



Isotope production while running may sound crazy, but it isn't…

Isotope production is the reason cyclotron companies want to work with us…

AIMA have also have expressed interest

Dear Professor Calabretta,

We have discussed the possibility of engaging in the research and development of a new cyclotron accelerator. Your original motivation for the device is for it to become the injector for a very high intensity neutrino source for pure science research (DAEδALUS). The same concepts that you have described have an immediate medical radioisotope application.

⋮

TeamBest is interested to collaborate in the development of such a design and build project since your technical objectives are so similar to ours. We would be prepared to contribute to the design in the areas of ion sources for protons, RF power, beam lines, Radioisotope production

⋮

The actual details of this ambitious project will need to be mapped out carefully so that we can accomplish our objectives in a timely fashion. I look forward to a successful collaboration.

Sincerely,

Krishnan Suthanthiran, President

BEST THERATRONICS,

BEST MEDICAL Italy

In fact, BEST requests to distribute isotopes produced using our 2nd generation test stand (7 MeV/n) to be built at INFN

Why haven't companies taken these steps before,
and already built 5 mA machines for isotope production?

→ They had missed the idea of using H_2^+ (Calabretta)

- 5 mA of protons or H- have significant space charge problems.
- A proton beam cannot be divided for easy targeting.

(the H- and H2+ can be split w/ offset stripping foils)

Cost-effective Design Options for IsoDAR

arxiv: 1210.4454

Are cyclotrons
Really the best
Option for
Isotope
Decay-at-Rest?

Assessment

- Good
- Moderate
- Bad

	60 MeV Compact Cyclotron	RFQ/Separated Sector Cyclotron	LINAC, 30 MeV, 40 mA	Modified Beta Beam Design	New Detector at Existing Beam
1. Cost	Good	Moderate	Bad	Moderate	Bad
2. $\bar{\nu}$e rate	Good	Good	Good	Bad	Good
3. Backgrounds low	Good	Good	Good	Good	Moderate
4. Technical risk	Moderate	Moderate	Moderate	Moderate	Good
5. Compactness	Good	Moderate	Bad	Good	Moderate
6. Simplicity u' ground	Good	Moderate	Moderate	Bad	Moderate
7. Reliability	Good	Good	Good	Bad	Good
8. Value to other exps	Good	Good	Good	Bad	Bad
9. Value to Industry	Good	Moderate	Moderate	Bad	Bad

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