DAEδALUS
IsoDAR

Research and development for the IsoDAR experiment

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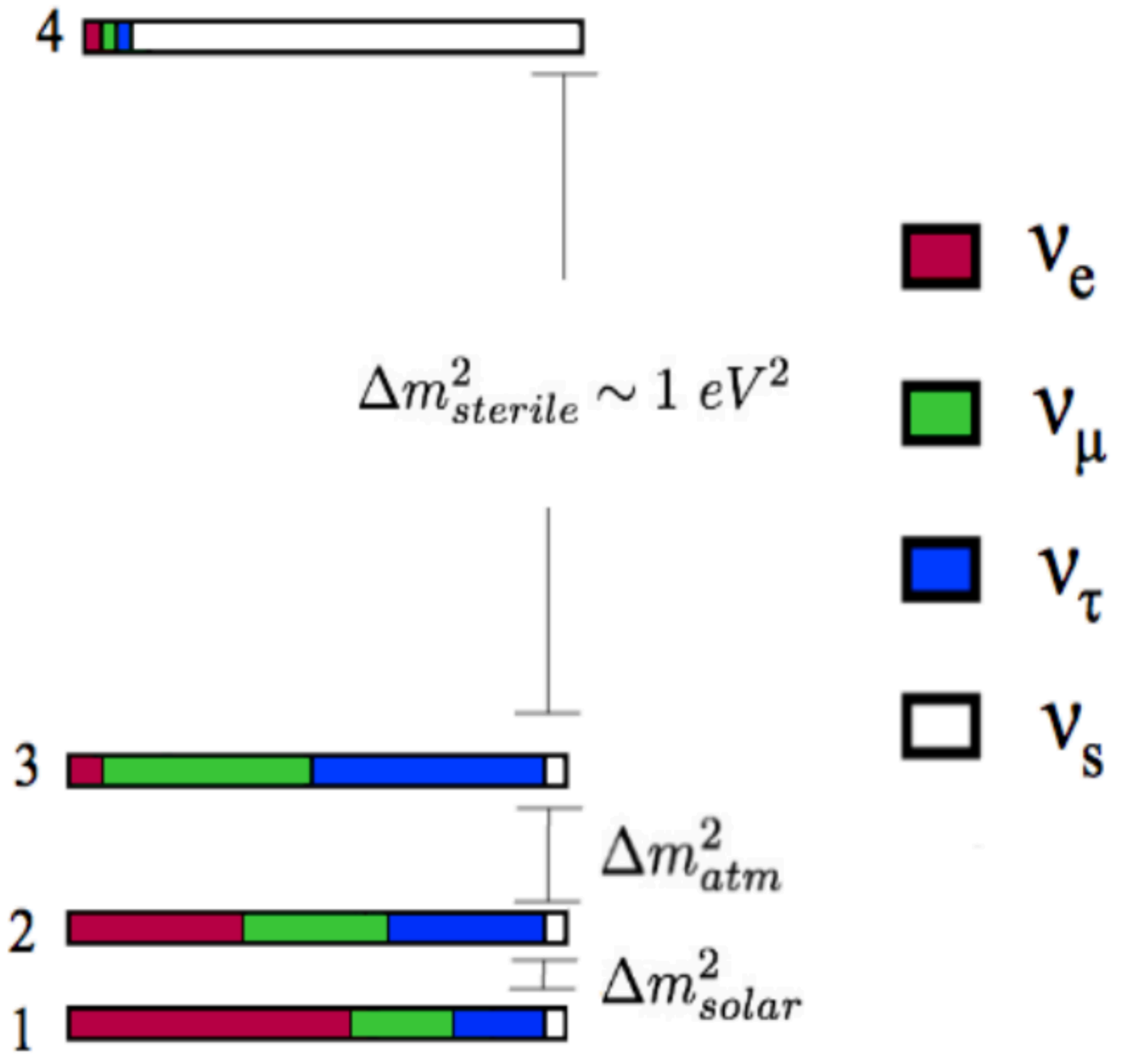
On behalf of the IsoDAR collaboration

Sterile neutrino overview

Modern searches for ~1 eV scale light sterile neutrinos are motivated by a set of observed anomalies.

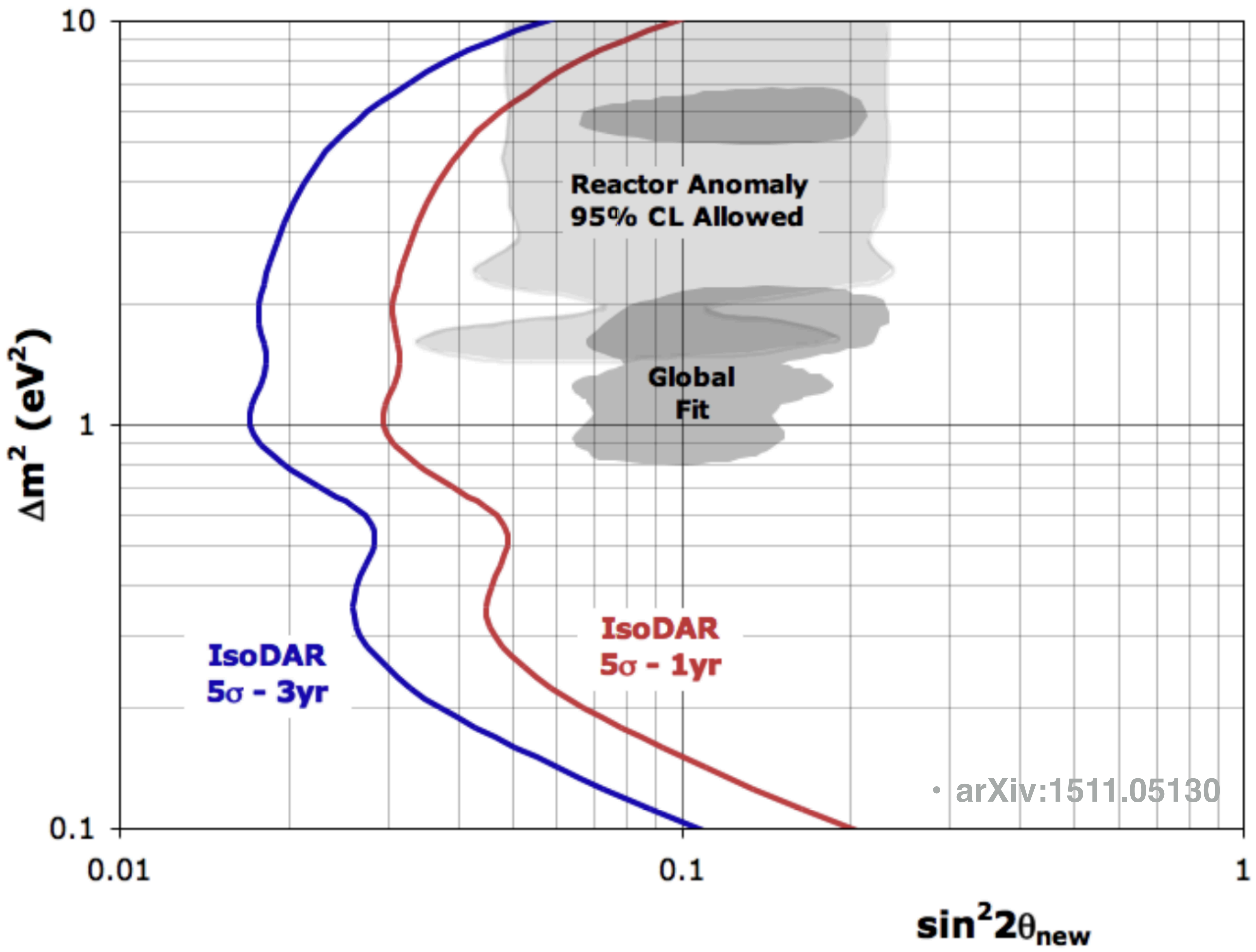
Oscillation Channel	Class	Anomalous signals (>2σ)	Sub-set of null results
ν_e disappearance $P(\nu_e \to \nu_e)$	Reactor/Source Experiments	GALLEX ($\bar{\nu}$) SAGE ($\bar{\nu}$) {Global Reactors}	KARMEN Daya Bay Bugey-3
ν_μ disappearance $P(\nu_\mu \to \nu_\mu)$	Long/Short Baseline Experiments	none	MiNOS CC CCFR84 IceCube
ν_e appearance $P(\nu_\mu \to \nu_e)$	Short Baseline Experiments	LSND ($\bar{\nu}$) MiniBooNE ($\bar{\nu}$, ν)	NOMAD KARMEN



Many of the proposed experiments to test the light sterile neutrino hypothesis do not have sufficient sensitivity to make a definitive >5σ statement.

Motivation for the IsoDAR experiment

The IsoDAR (Isotope Decay-A-Rest) experiment, paired with a kiloton detector like KamLAND, will be able to make a definitive statement about the existence of light sterile neutrinos.



- Rule out 3+1 global allowed region:
  - 20σ in 5 years
  - 5σ in 4 months
- The high statistics allow us to distinguish between a 3+1 and 3+2 sterile neutrino model.
- Collect the worlds largest sample of a low energy $\bar{\nu}_e$-electron elastic scattering events.
- Beyond this, we also make innovations in:
  - Ion source development
  - Beam transport and injection
  - High current cyclotrons

Motivation for the IsoDAR experiment

High Statistics:
- 8.2×10^5 IBD events in 5 years
- 2600 $\bar{\nu}_e$ -electron ES events

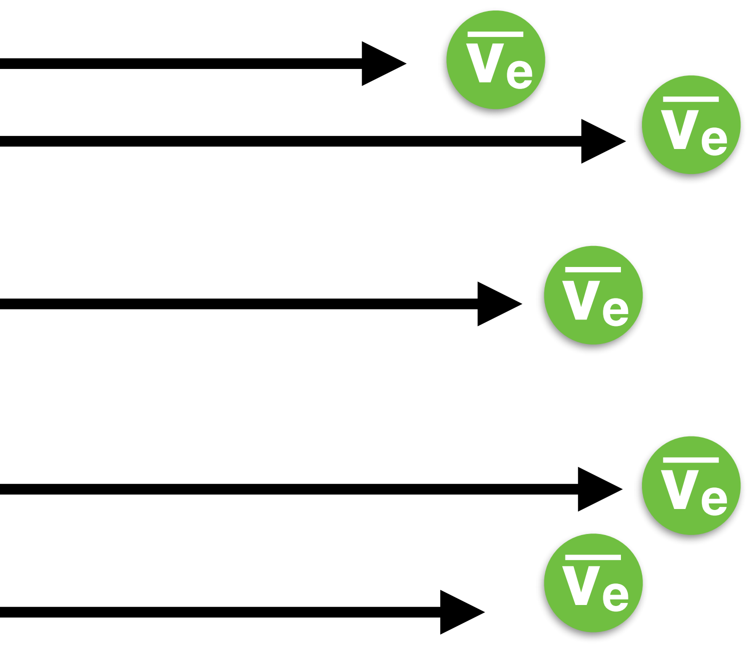
Well understood flux:
- ^8Li β decay-at-rest source
- Cross-section uncertainty 0.2%

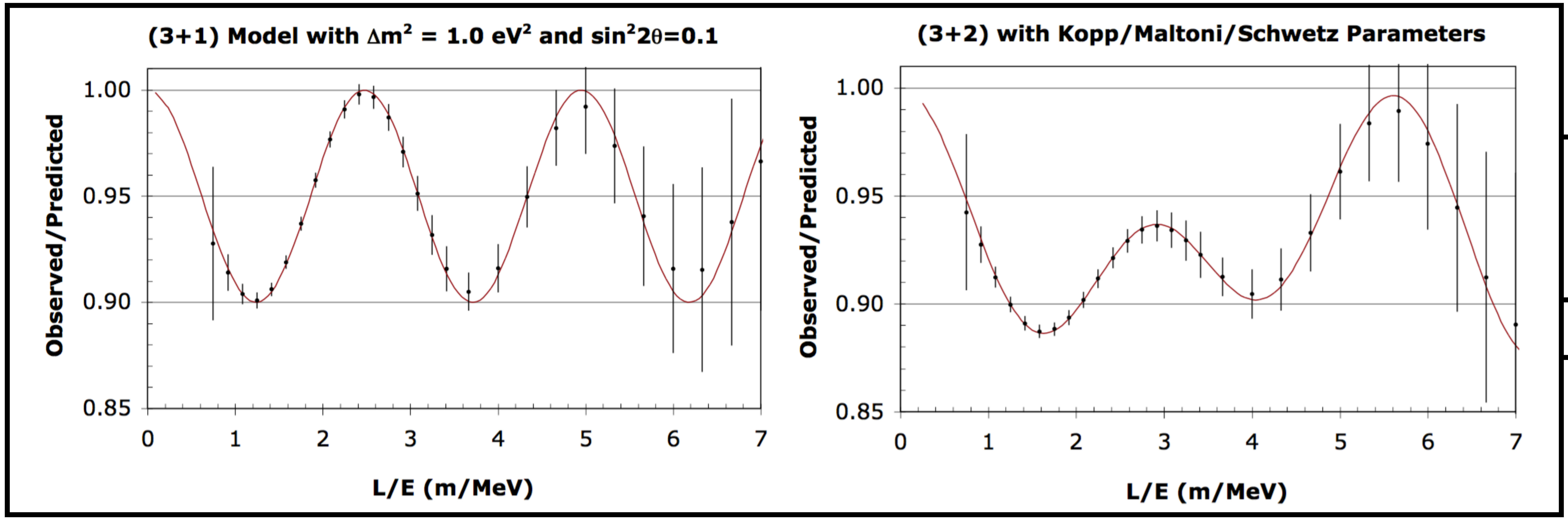
IsoDAR @ KamLAND

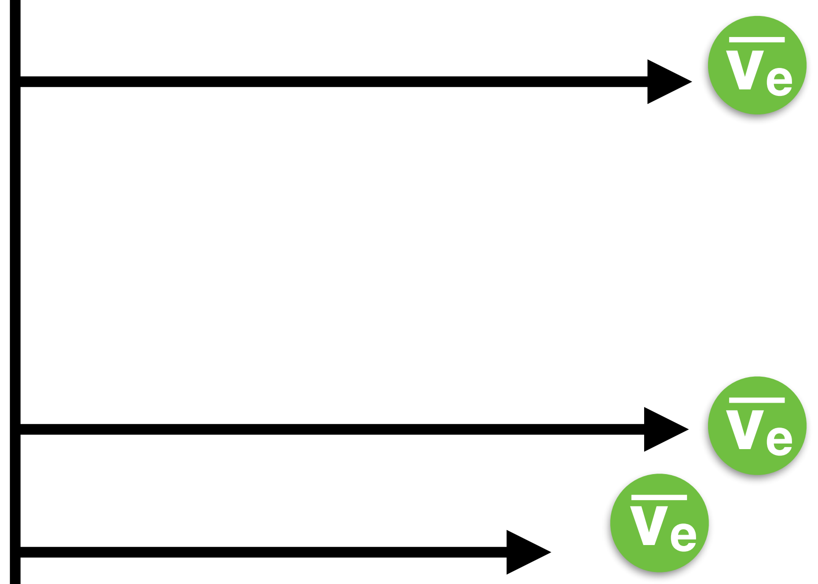
Low backgrounds:
- 2700 m.w.e overburden
- $\bar{\nu}_e$ energy above radiogenic (>3MeV)
- IBD ($\bar{\nu}_e + p \rightarrow e^+ + n$)

Event reconstruction (KamLAND):
- Vertex: ~5cm @ 6.4MeV
- Energy: ~3% @ 6.4MeV
- 92% detection efficiency for IBD events

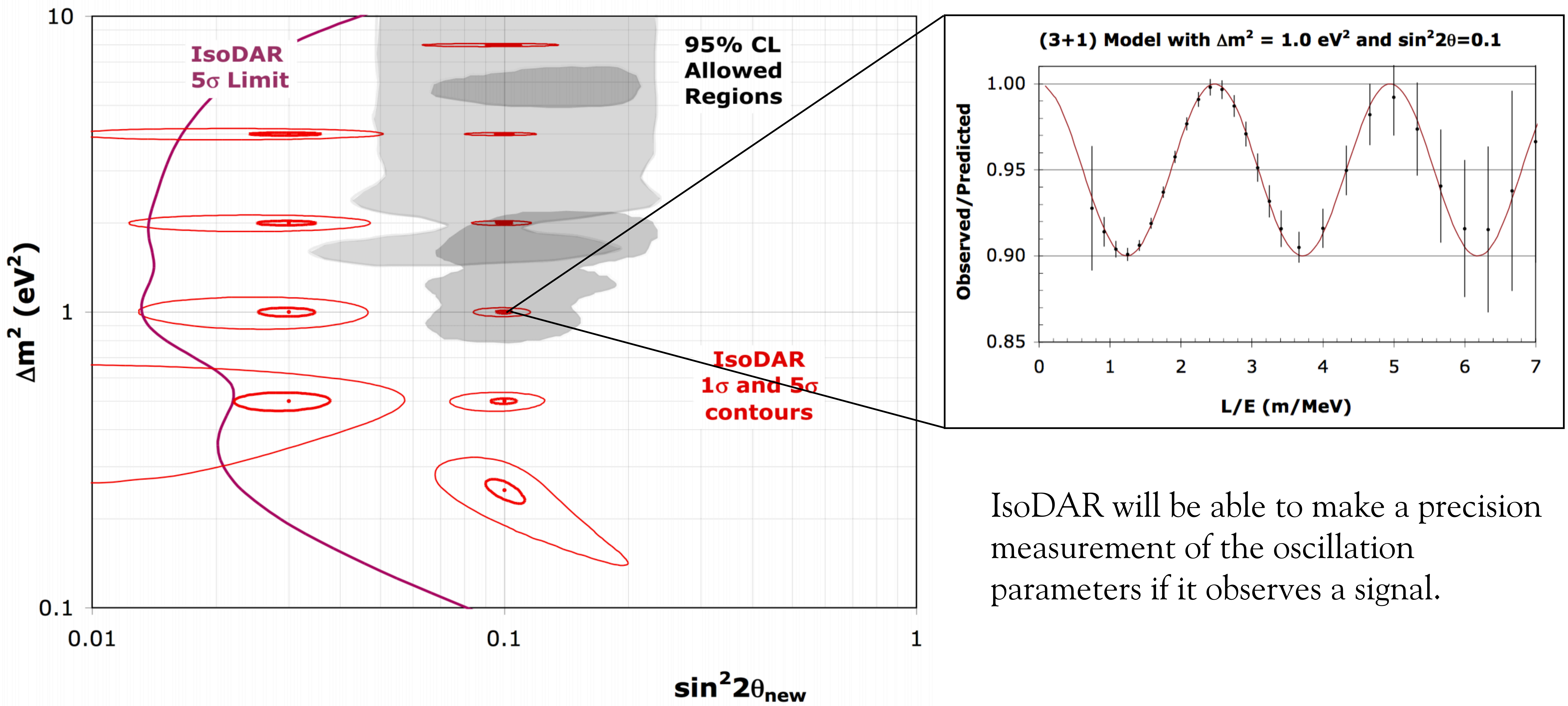
IsoDAR will search for sterile neutrinos by accurately mapping out the short baseline oscillations through a single detector, over an L/E of 0.6 to 7 m/MeV.





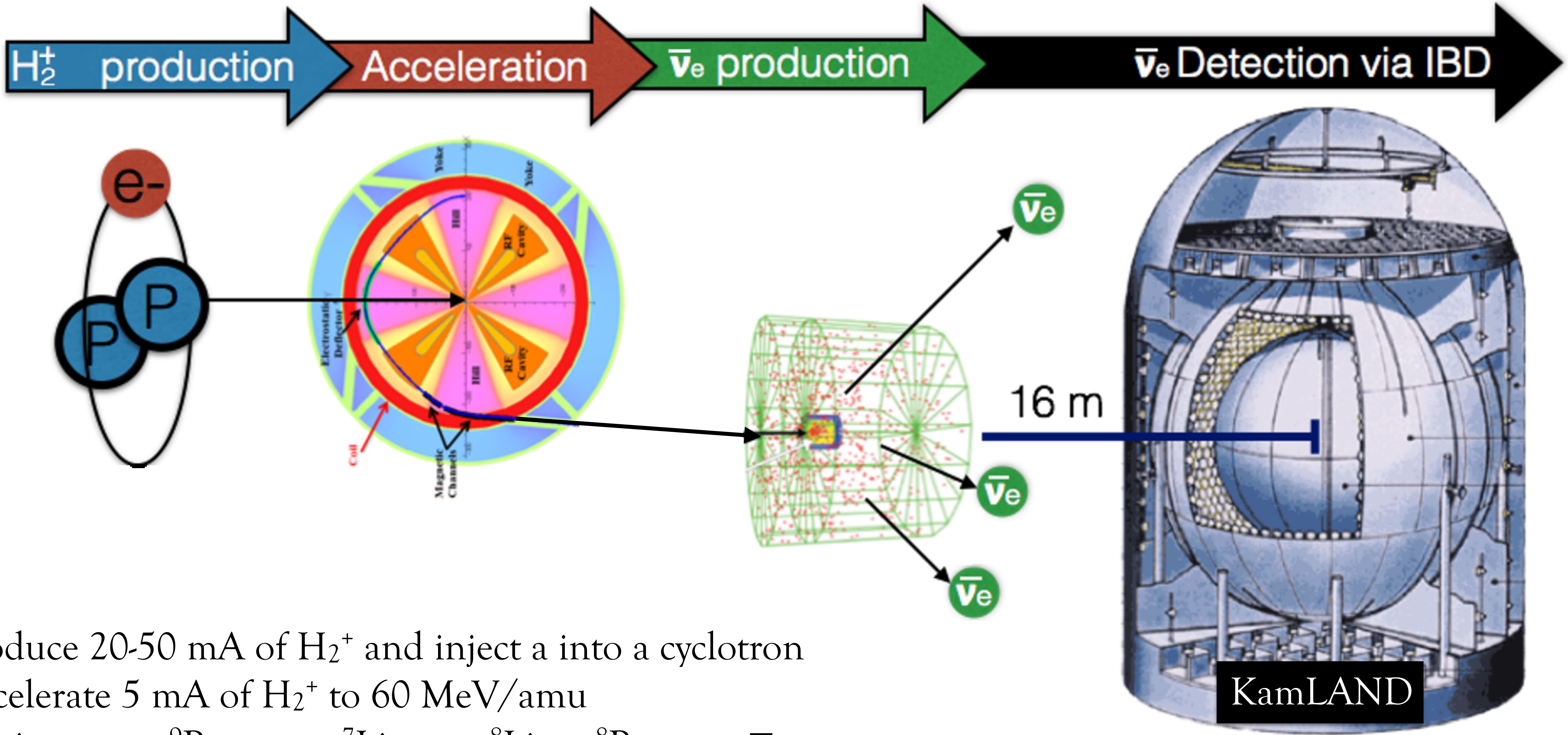


Motivation for the IsoDAR experiment



IsoDAR will be able to make a precision measurement of the oscillation parameters if it observes a signal.

Operation principles of IsoDAR

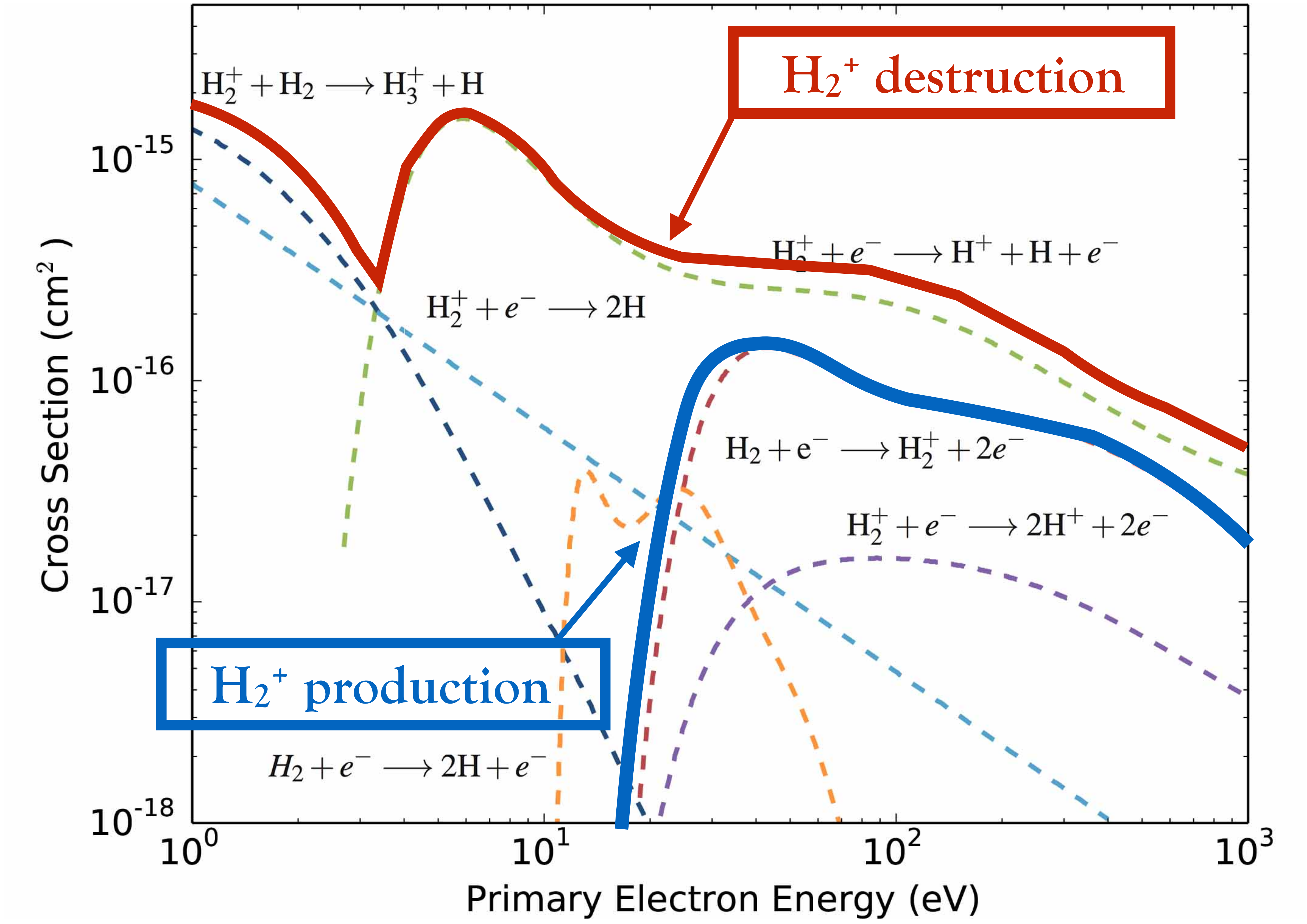


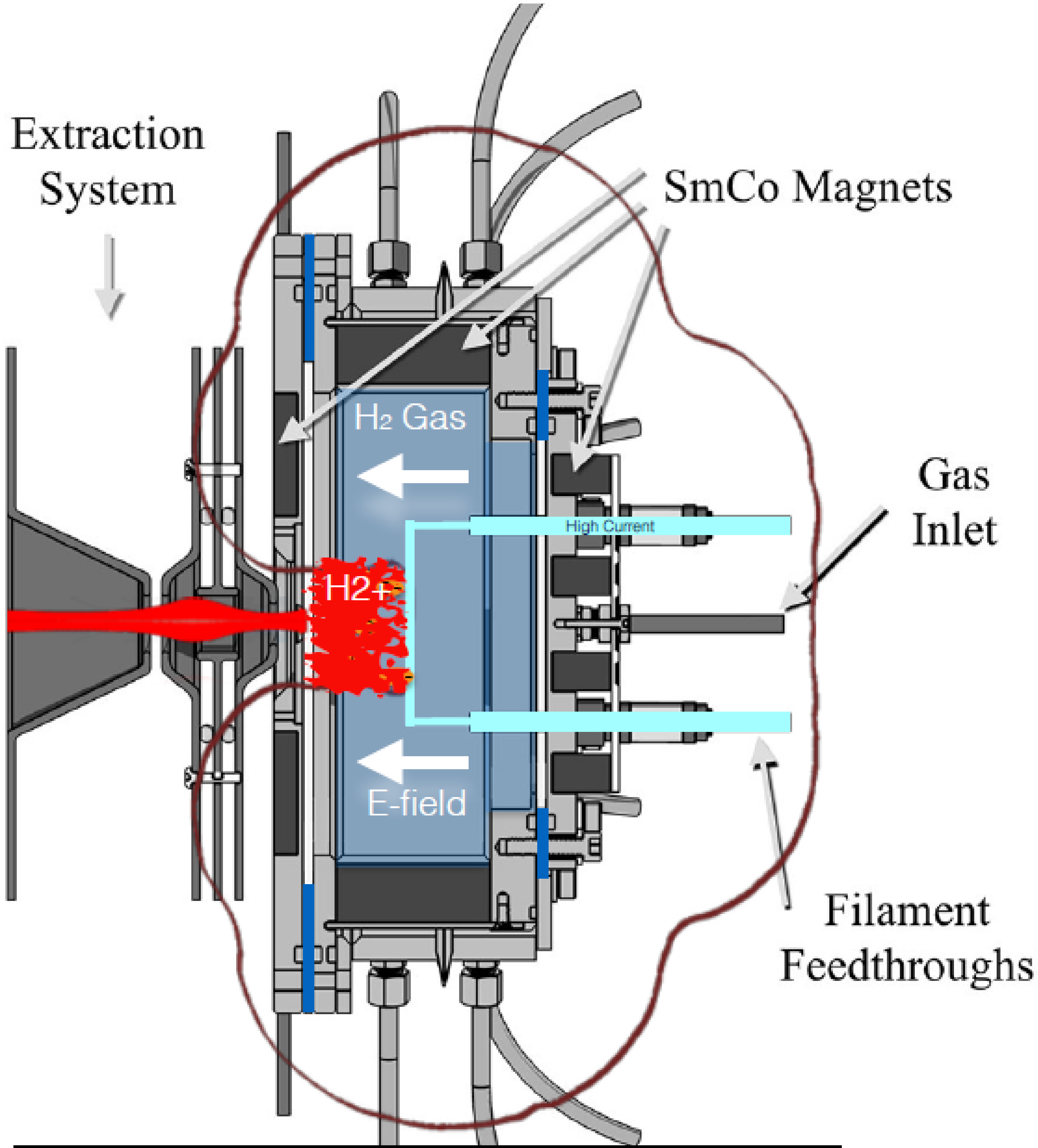
1. Produce 20-50 mA of H_2^+ and inject a into a cyclotron
2. Accelerate 5 mA of H_2^+ to 60 MeV/amu
3. Impinge on a ^{9}Be target. $^7Li + n \rightarrow {}^8Li \rightarrow {}^8Be + e^- + \bar{\nu}_e$
4. Map out oscillation in anti-electron neutrino disappearance within a kiloton scale detector like KamLAND

H_2^+ production: our new multi-cusp ion source, MIST-1

Key design choices:

- Short plasma chamber* (primary innovation in H_2^+ sources)
- Modular design
- Extraction plate cooling

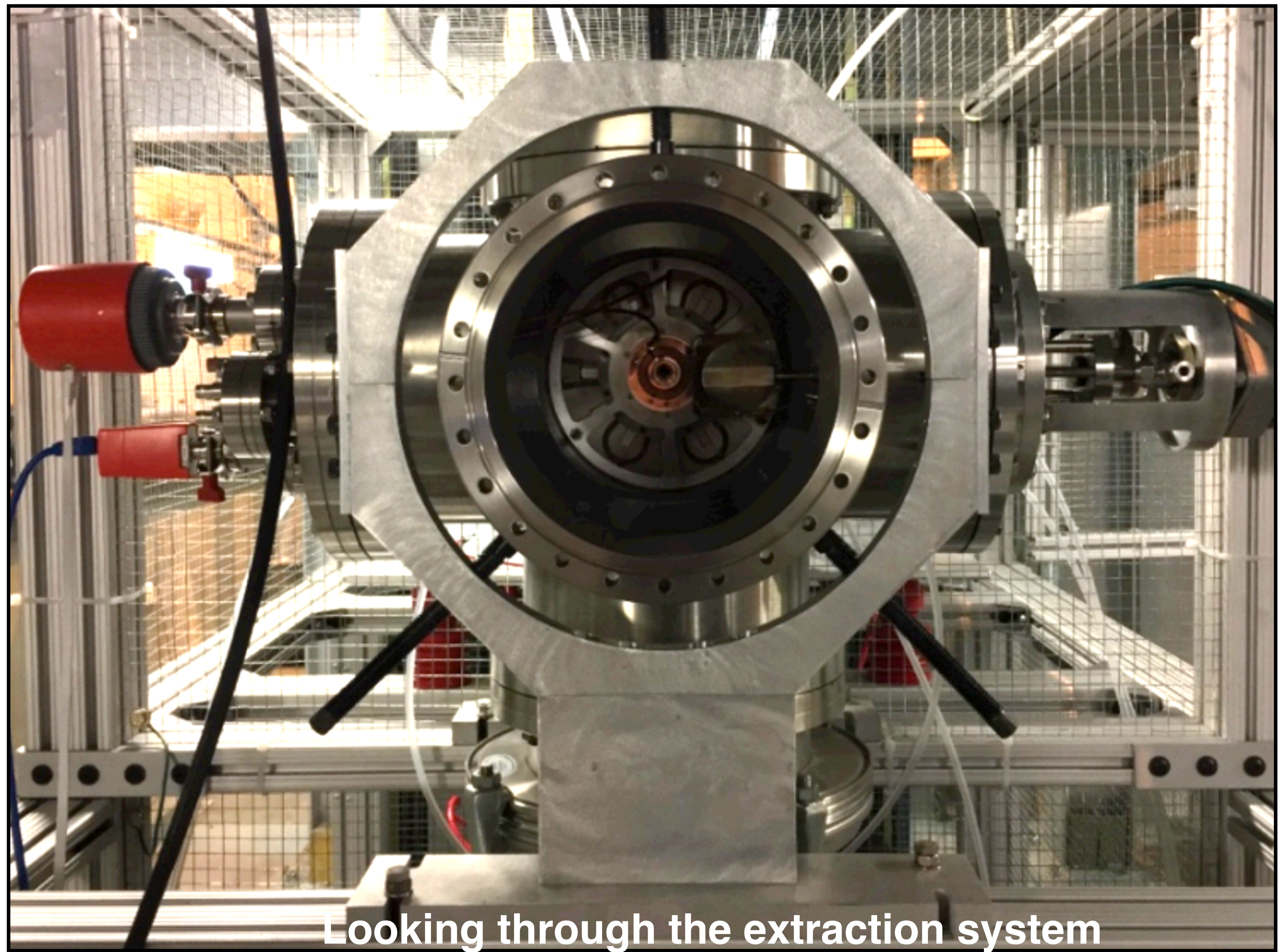


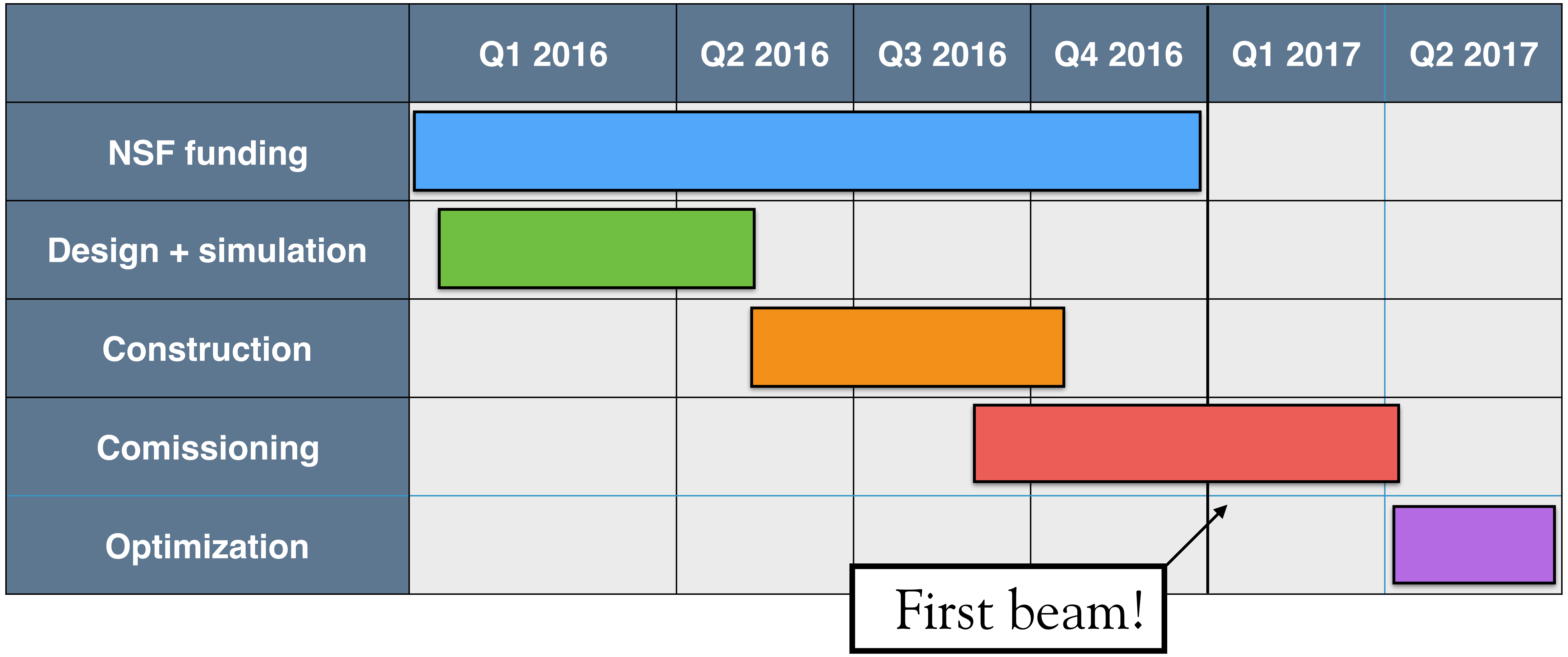


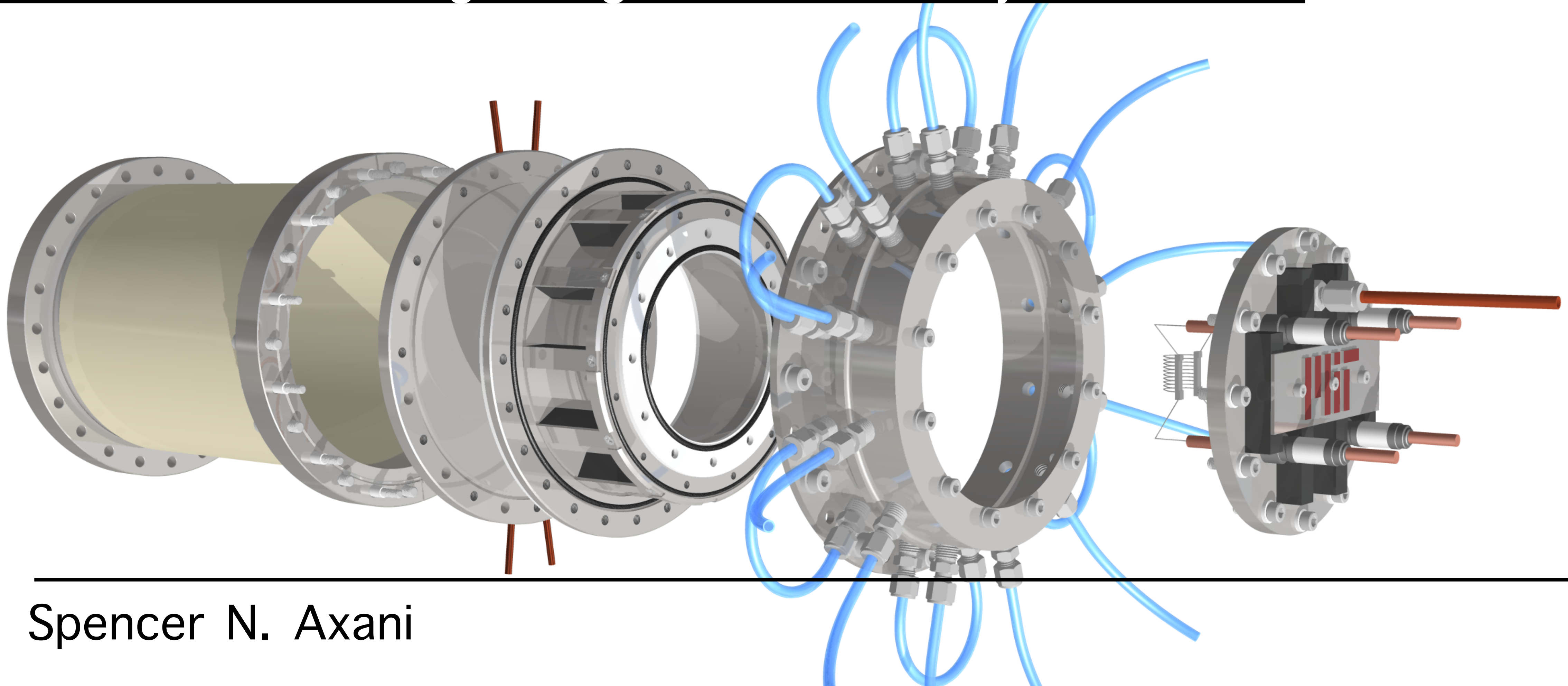
MIST-1
The Multicusp Ion Source at MIT

- *Rev. Sci. Inst. 54.6, 677-680 (1983)

H_2^+ production: our new multi-cusp ion source, MIST-1







- The development of a new multi-cusp ion source, MIST-1, was funded in 2016 by NSF.
- Commissioning recently concluded and first beam was achieved in early 2017.
- MIST-1 optimization currently in-progress and we expect to have results soon.

- Rev. Sci. Inst. 87.2 (2016): 02B704.

Pre-acceleration: RFQ injection into the cyclotron

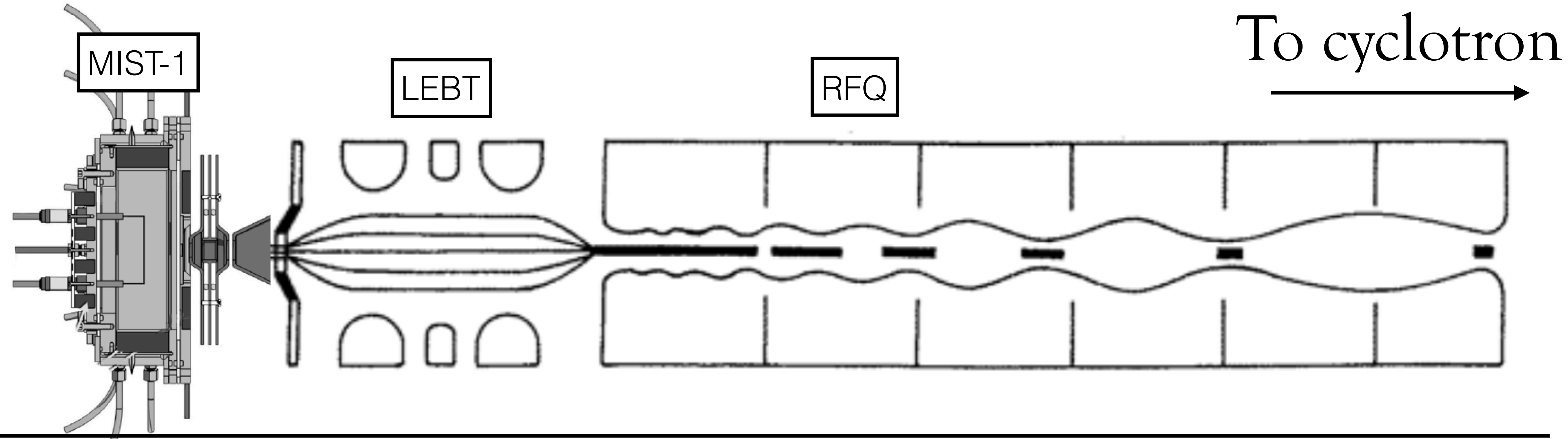
Radio-Frequency Quadrupole (RFQ)

A single device that is able to both efficiently accelerate and bunch a high-current beam.

- great for accelerating low-energy ions
- very small emittance growth
- accelerates and focuses with a single field
- separates our ion species

Modern technology, and becoming pervasive in intensity frontier complexes like Fermilab.

As of yet, using an RFQ as a buncher for axial injection into cyclotron has not been realized.

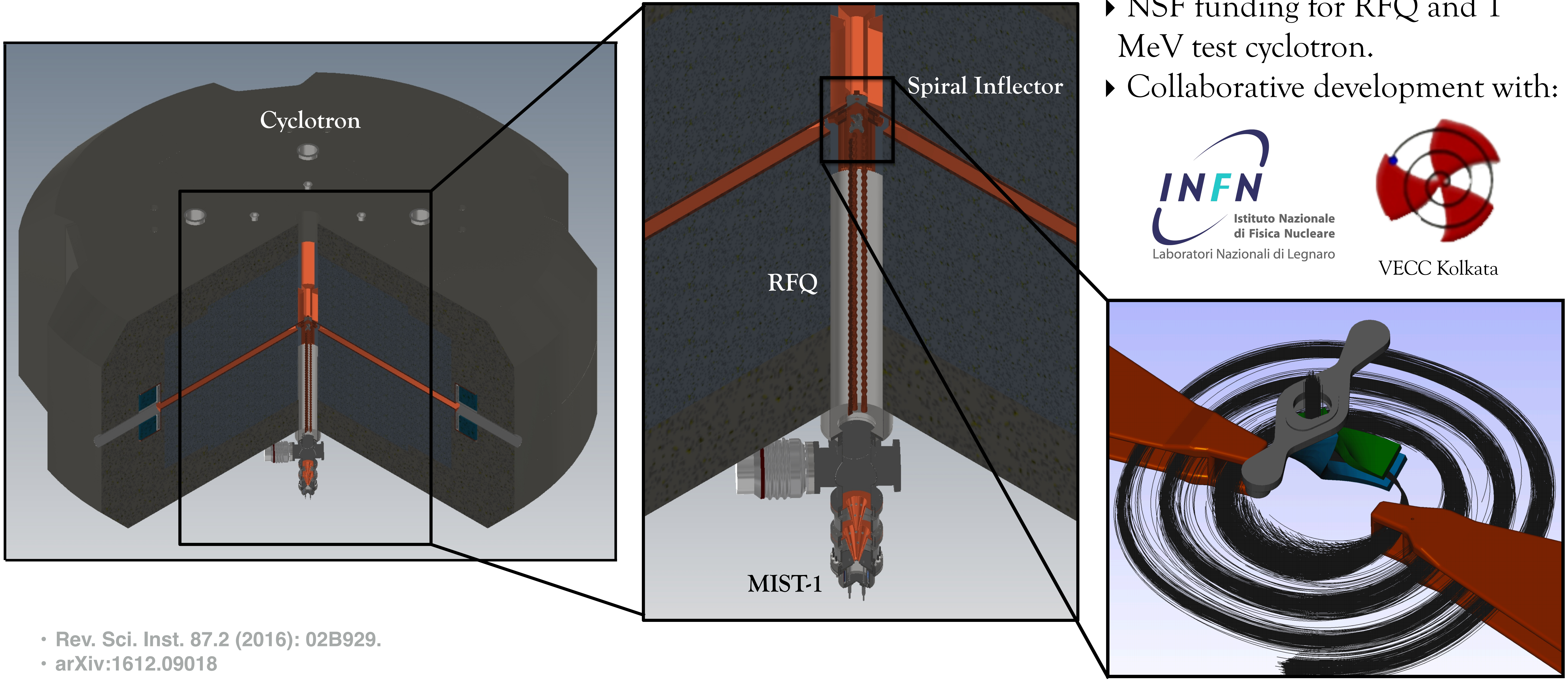


Pre-acceleration: RFQ injection into the cyclotron

- NSF funding for RFQ and 1 MeV test cyclotron.
- Collaborative development with:

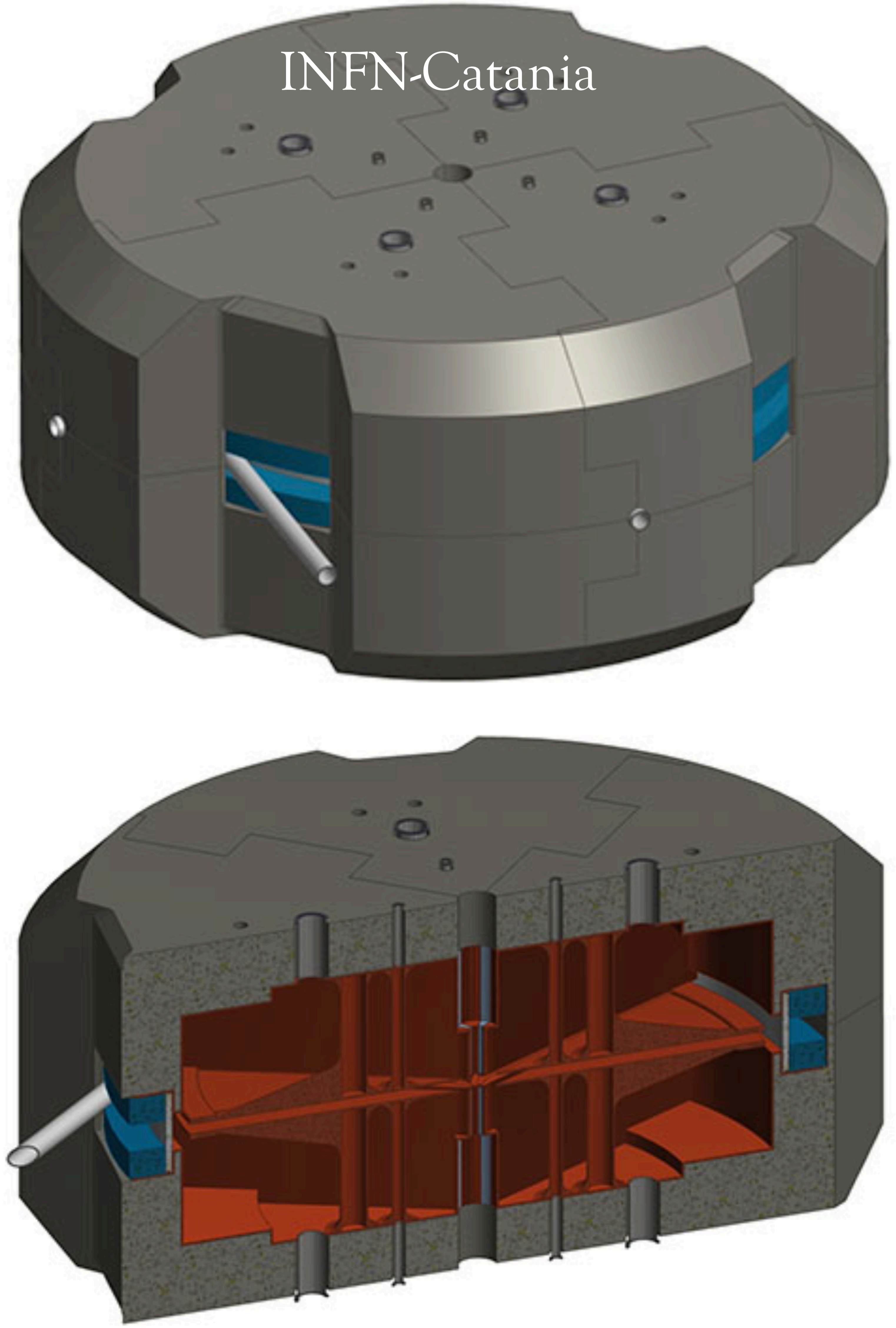
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

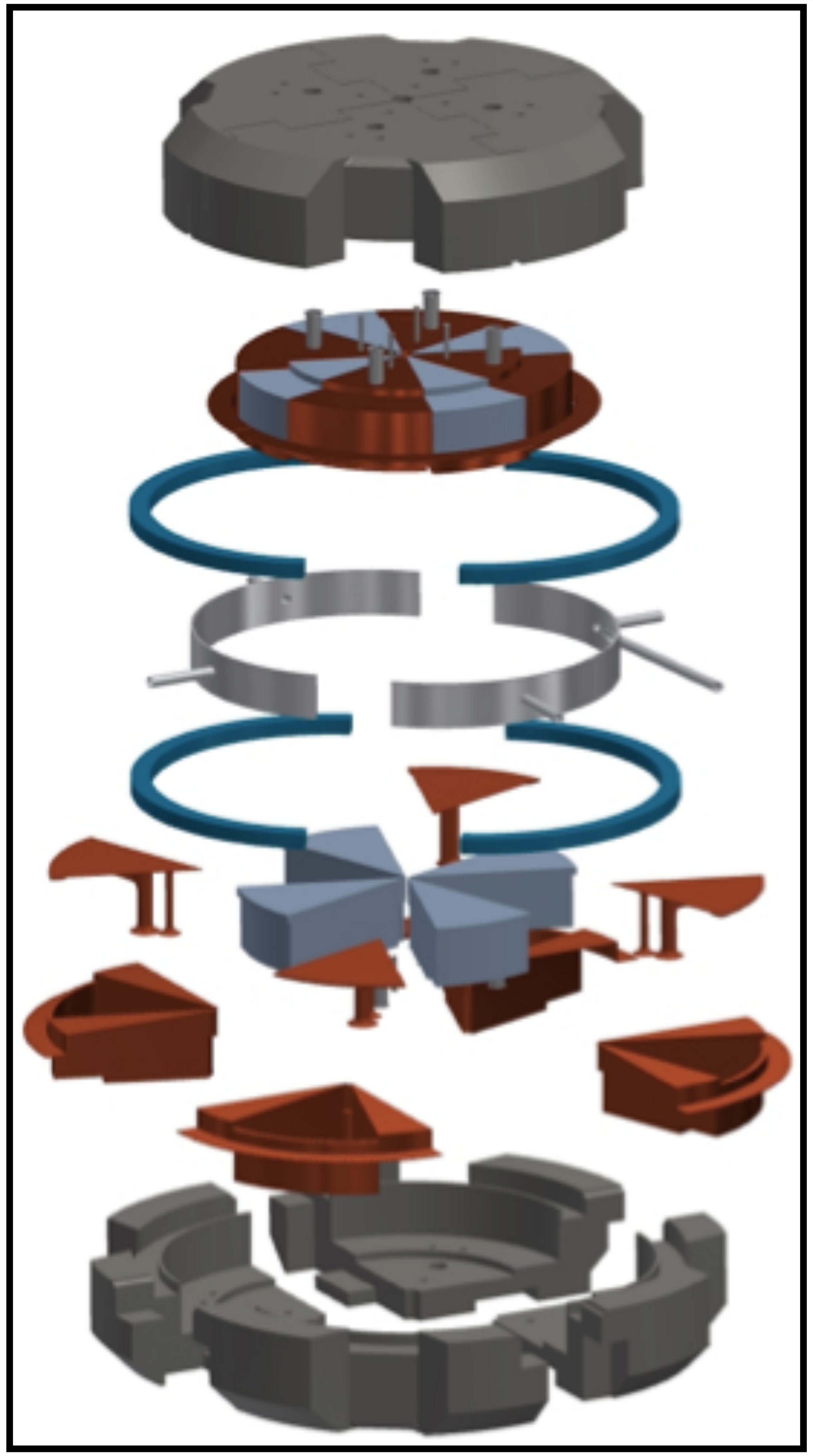
VECC Kolkata



- Rev. Sci. Inst. 87.2 (2016): 02B929.
- arXiv:1612.09018

H_2^+ Accelerator design





Energy at extraction	60 MeV/amu
Injected energy	35 keV/amu
Radius at extraction	1.99 m
Iron weight	450 tons
Harmonic	4th

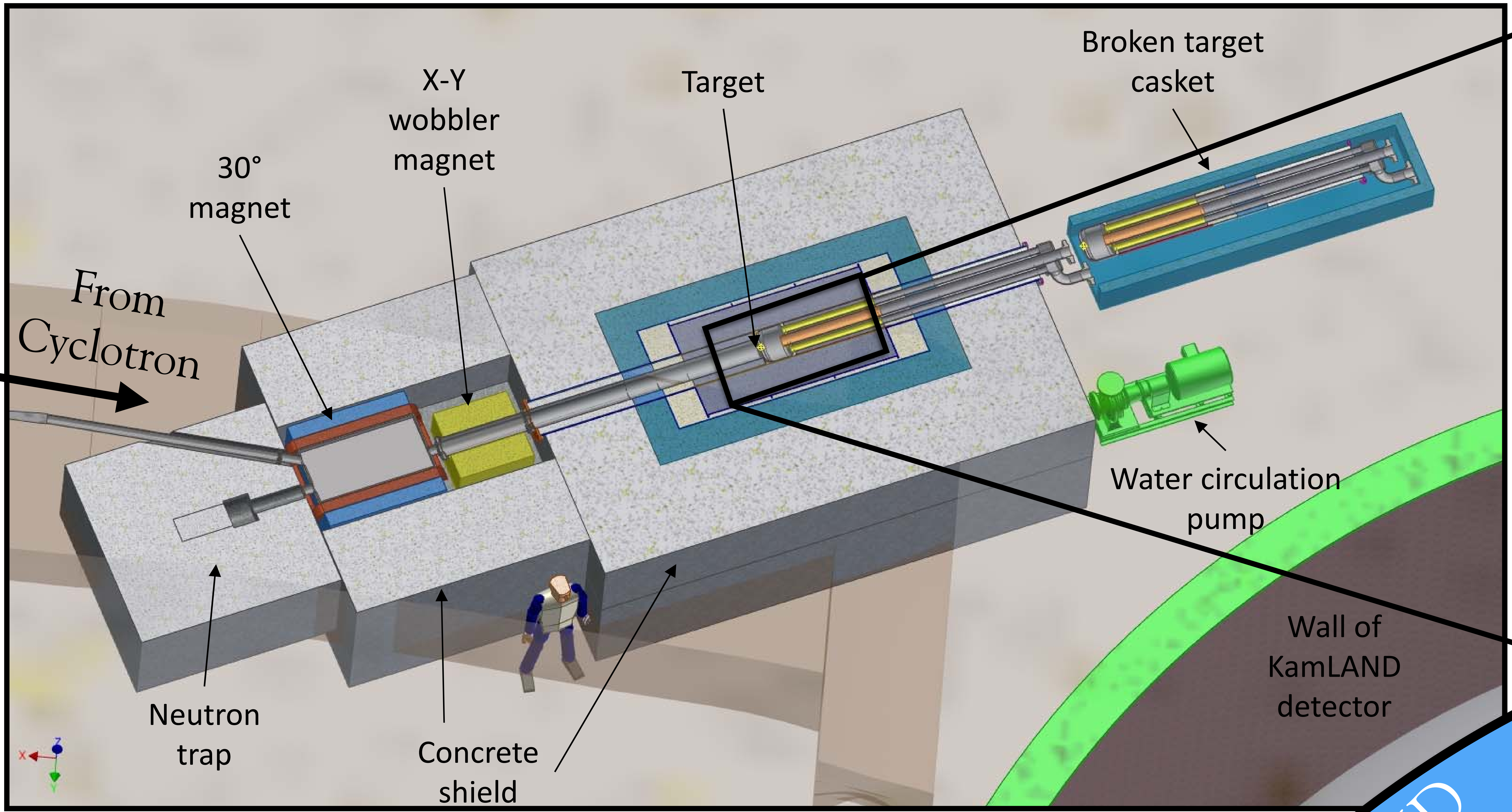
Requirements:

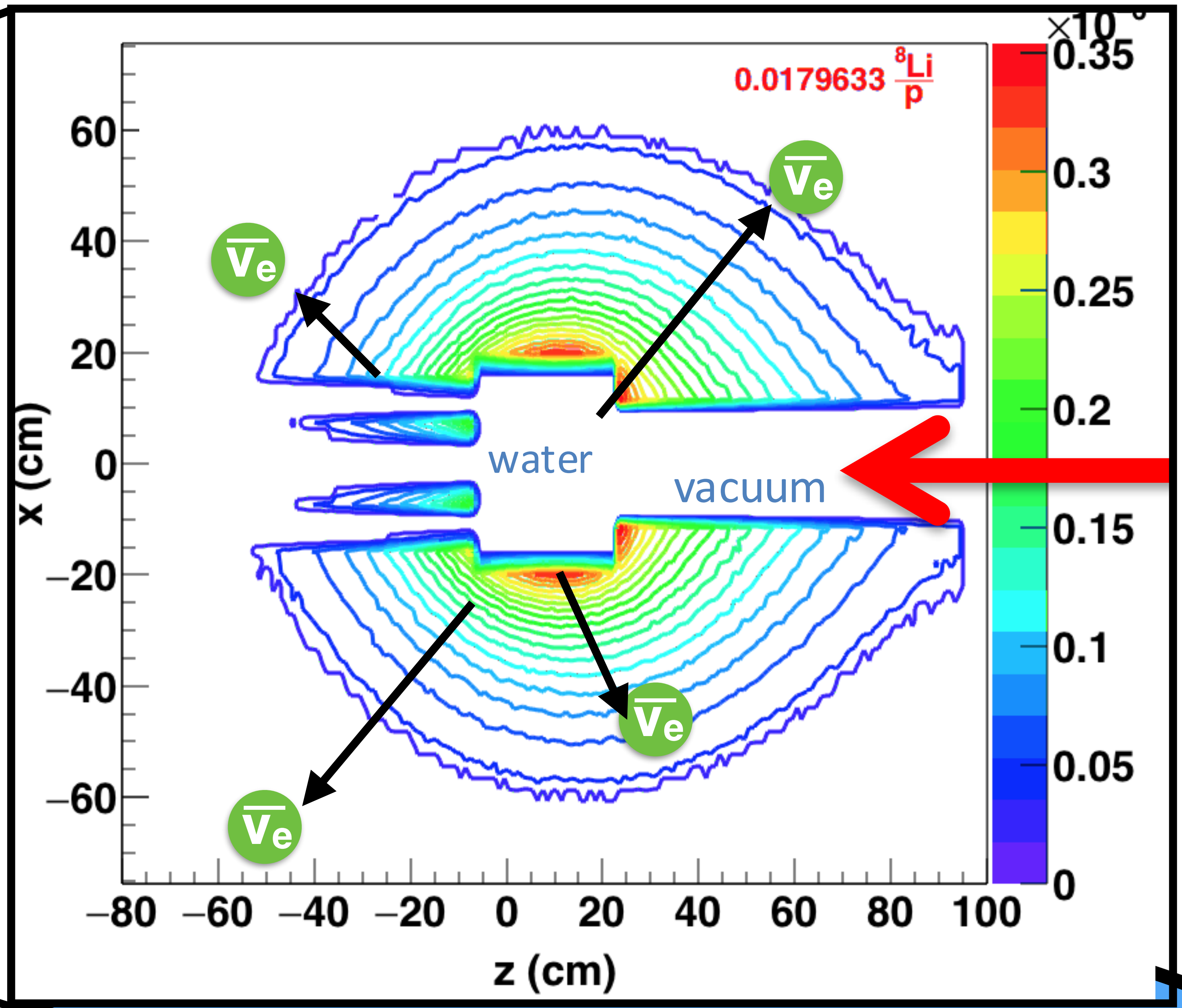
- A compact accelerator that can fit into the Kamioka observatory. Mine entrance size restriction and weight limits.
- Extract 10 mA @ 60 MeV protons

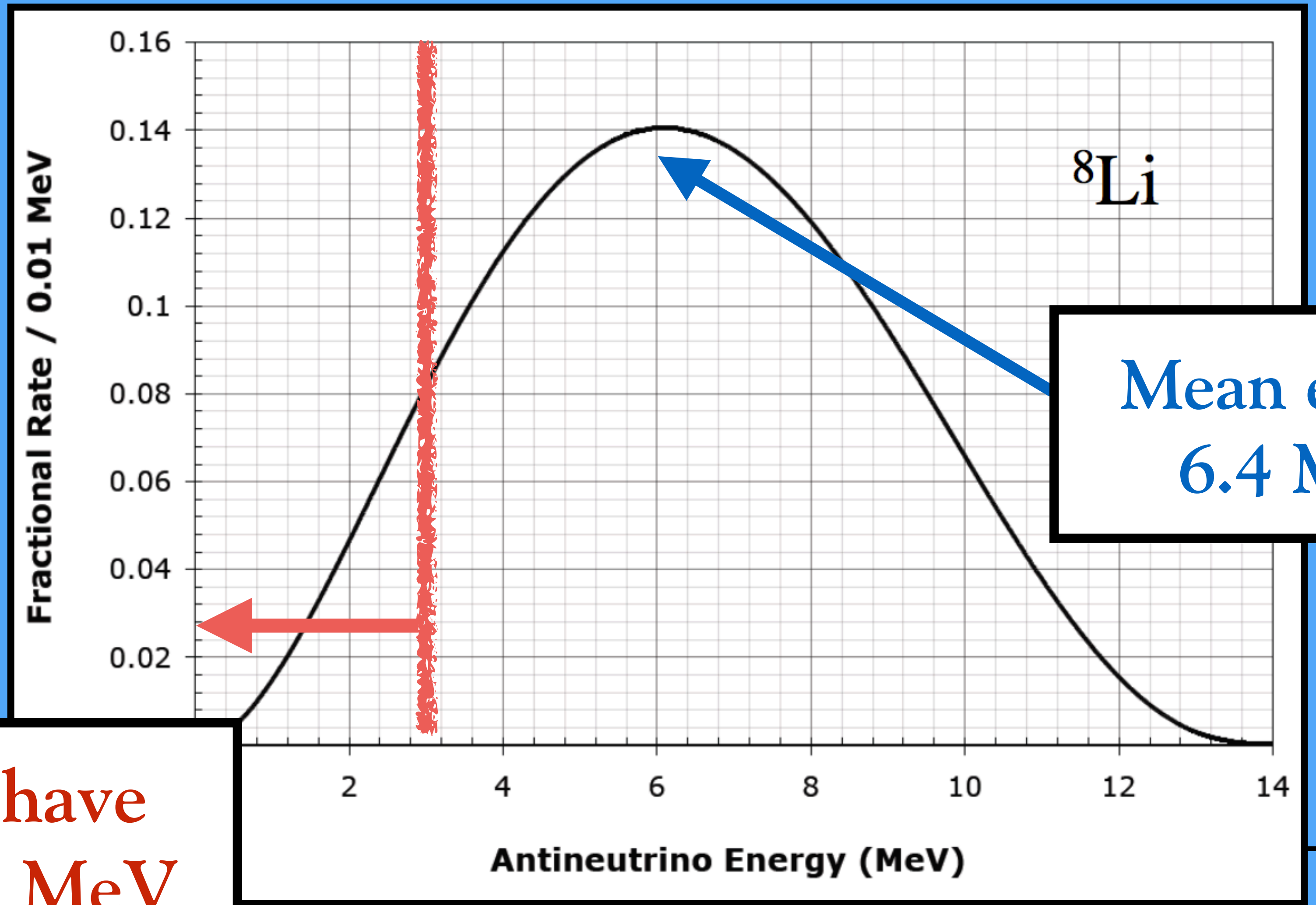
Innovations:

- Usage of H_2^+:
  - decrease the space charge effects
  - 2 protons per ion
  - eliminates the problem of Lorentz stripping
- Inject highly bunched beam from an intense ion source.

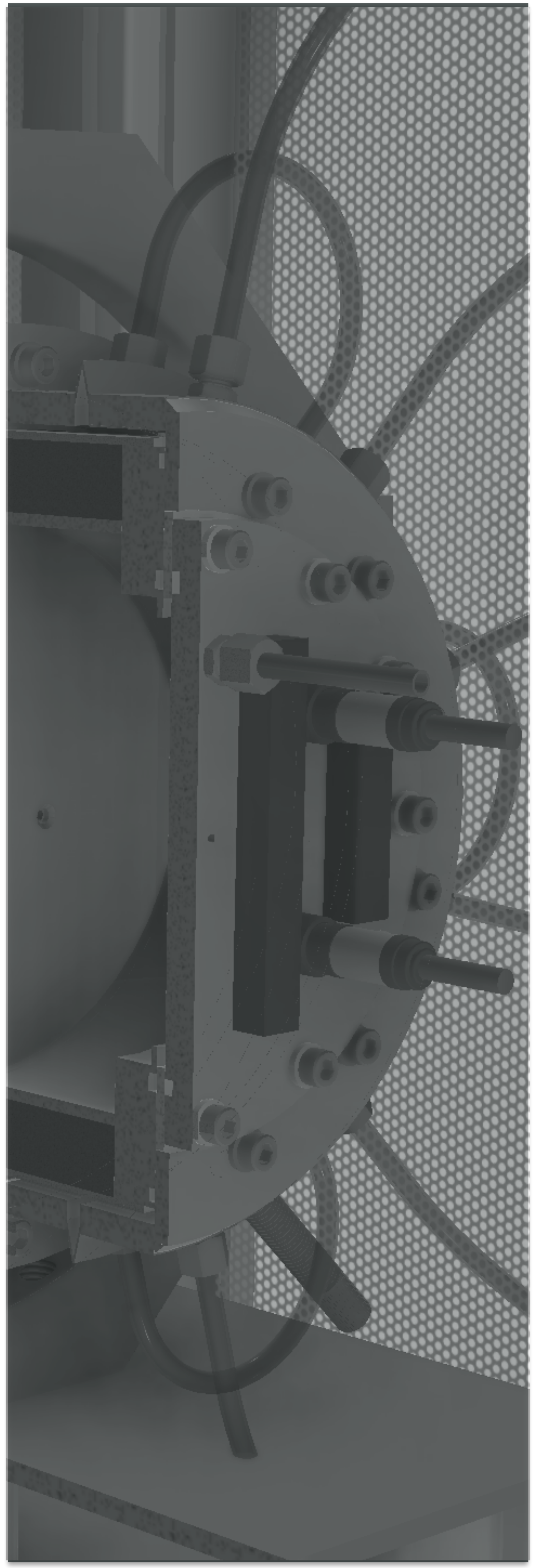
$\bar{\nu}_e$ production: the target design







- **Wobbler**: distribute beam over target face
- **Target**: replaceable ^{9}Be target. Counter-flow cooling
- **Sleeve**: 99.99% pure ^{7}Li
- **Shielding**: minimize activation of the mine



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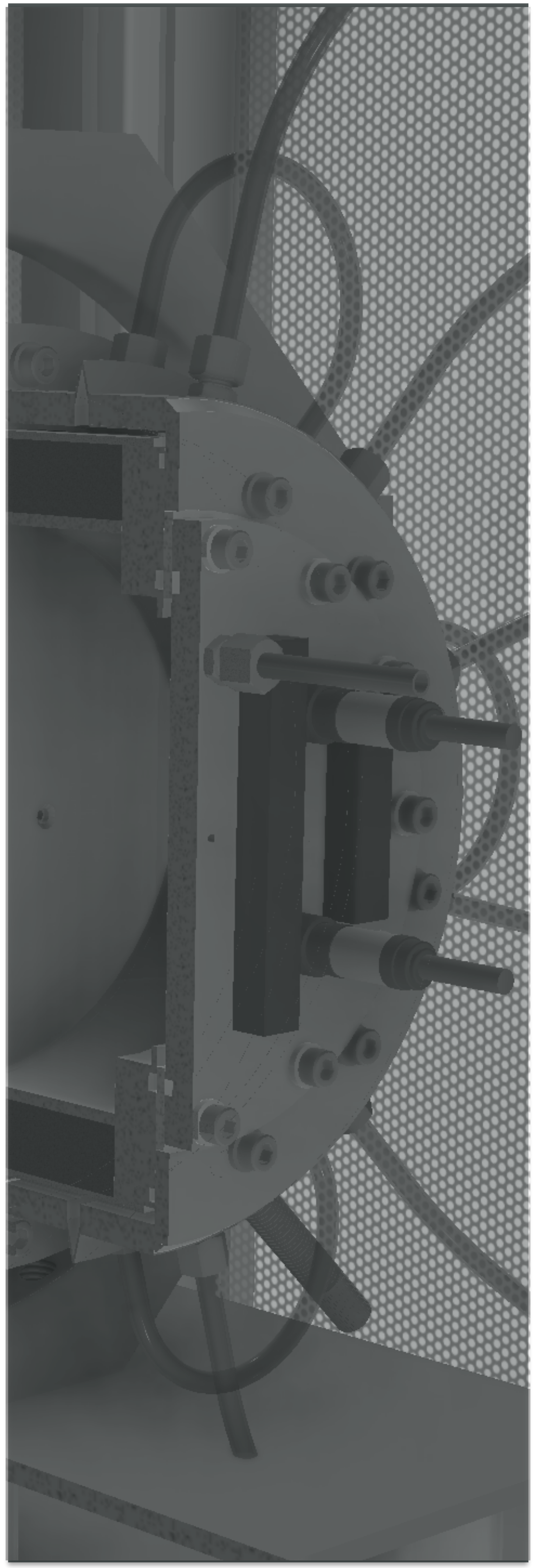
Summary

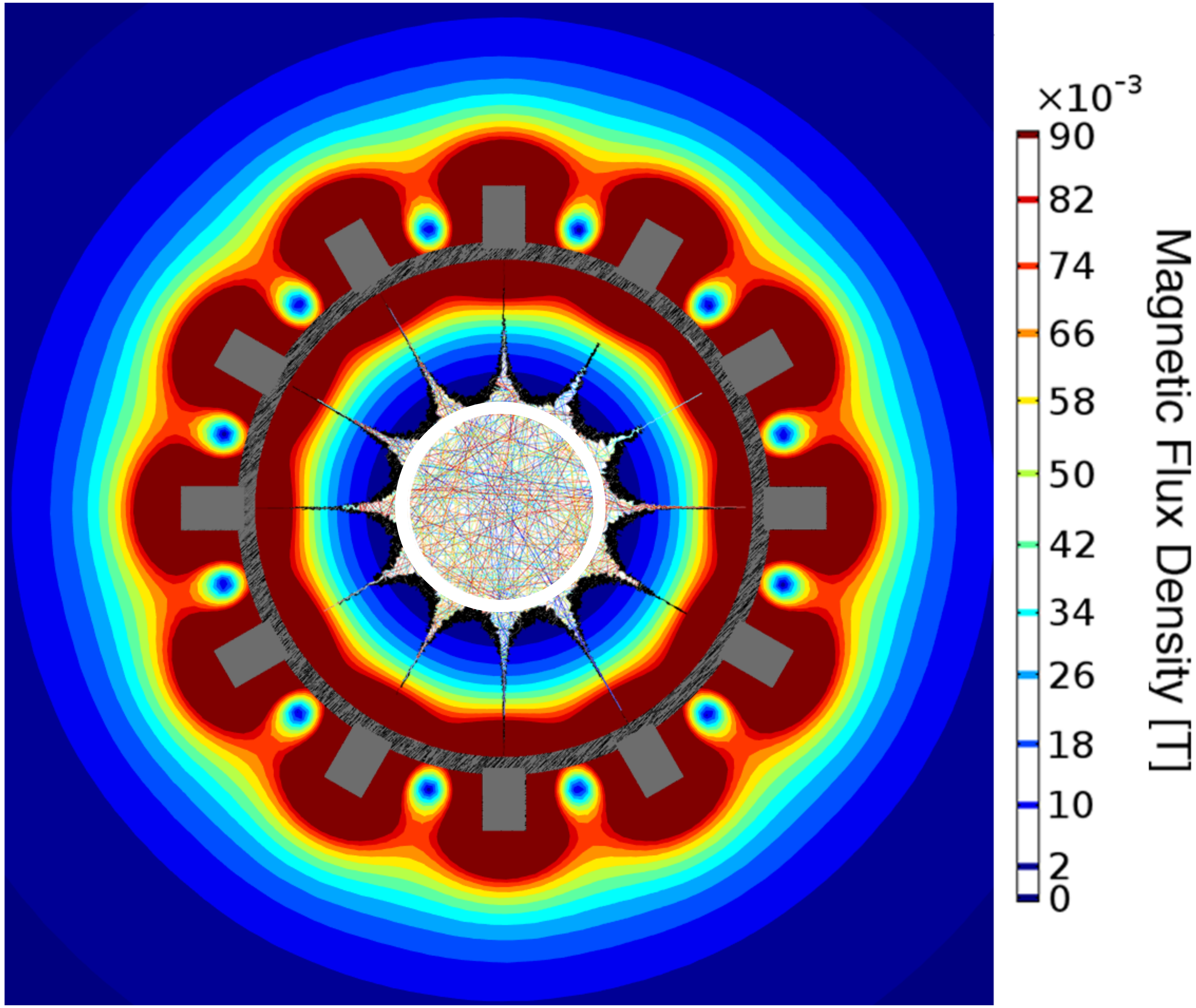
- IsoDAR is capable of making a definitive statement about light sterile neutrinos.
- In just 4 months of running, we can cover the global best fit allowed regions to 5σ.
- Accurately mapping out the oscillation wave will allow us to distinguish between a 3+1 and 3+2 sterile neutrino model.
- The development of IsoDAR innovates on several key technologies:
  - H_2^+ ion sources
  - RFQ axial injection
  - High-current cyclotrons

THANKS FOR YOUR ATTENTION!



Particle trajectory and magnetic field simulation

Backup

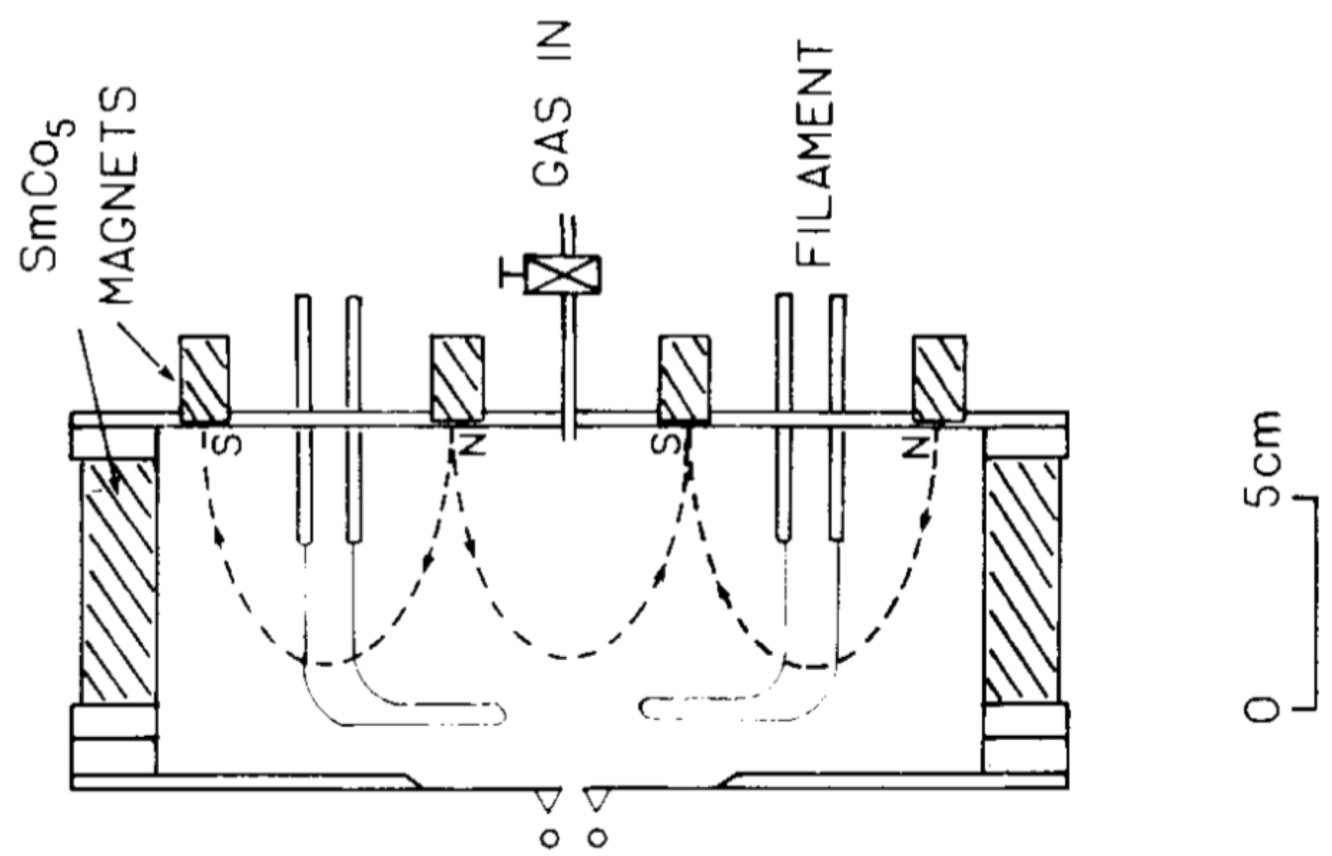


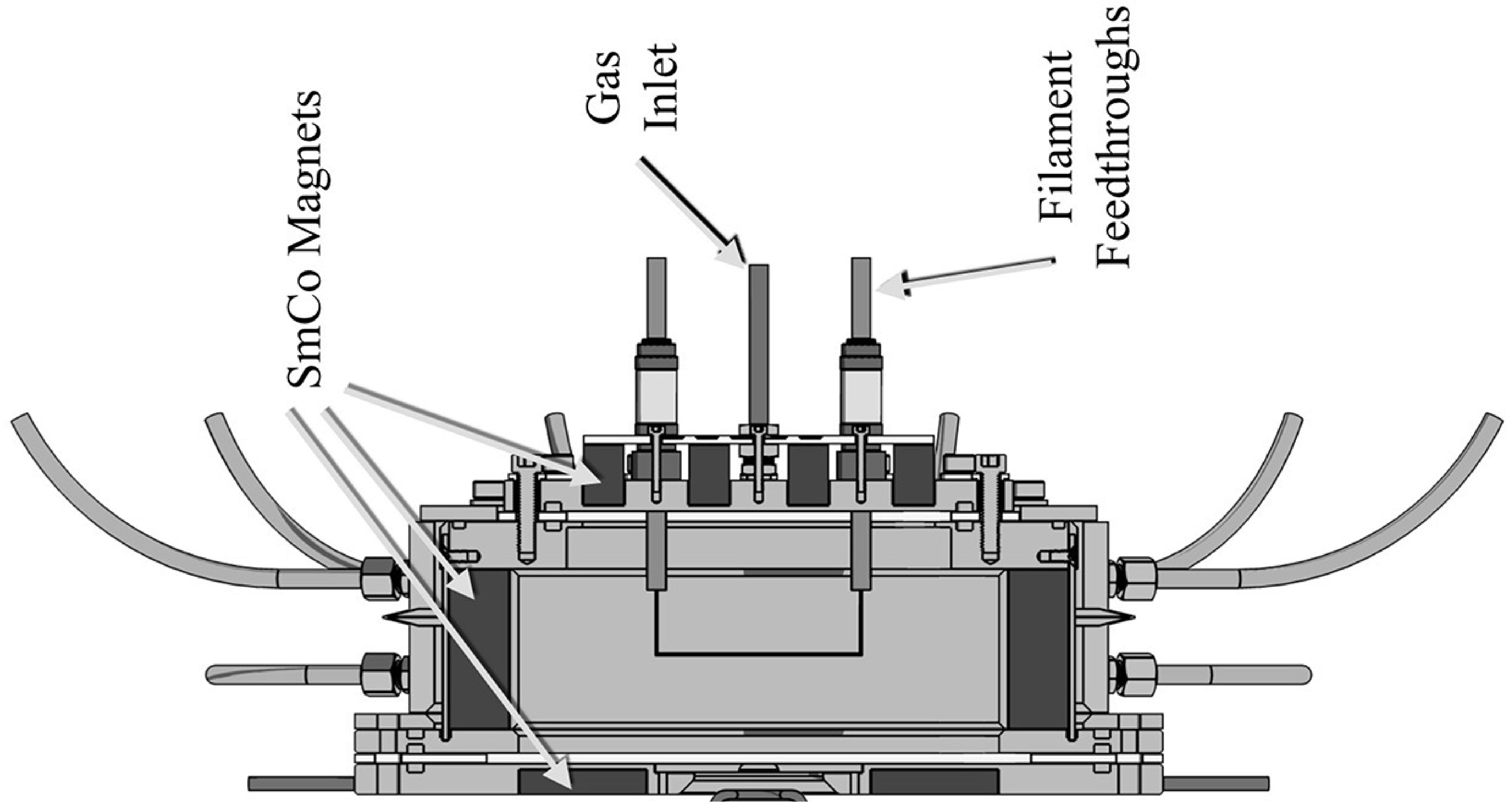
- 40-80 eV electrons were injected into the multi-cusp field.
- Electrons were found to be contained primarily in the sub-20 Gauss region (white circle).
- The multi-cusp field "reflects" the mobile charged particles back into the center of the ion source.

Innovations: MIST-v1

Backup

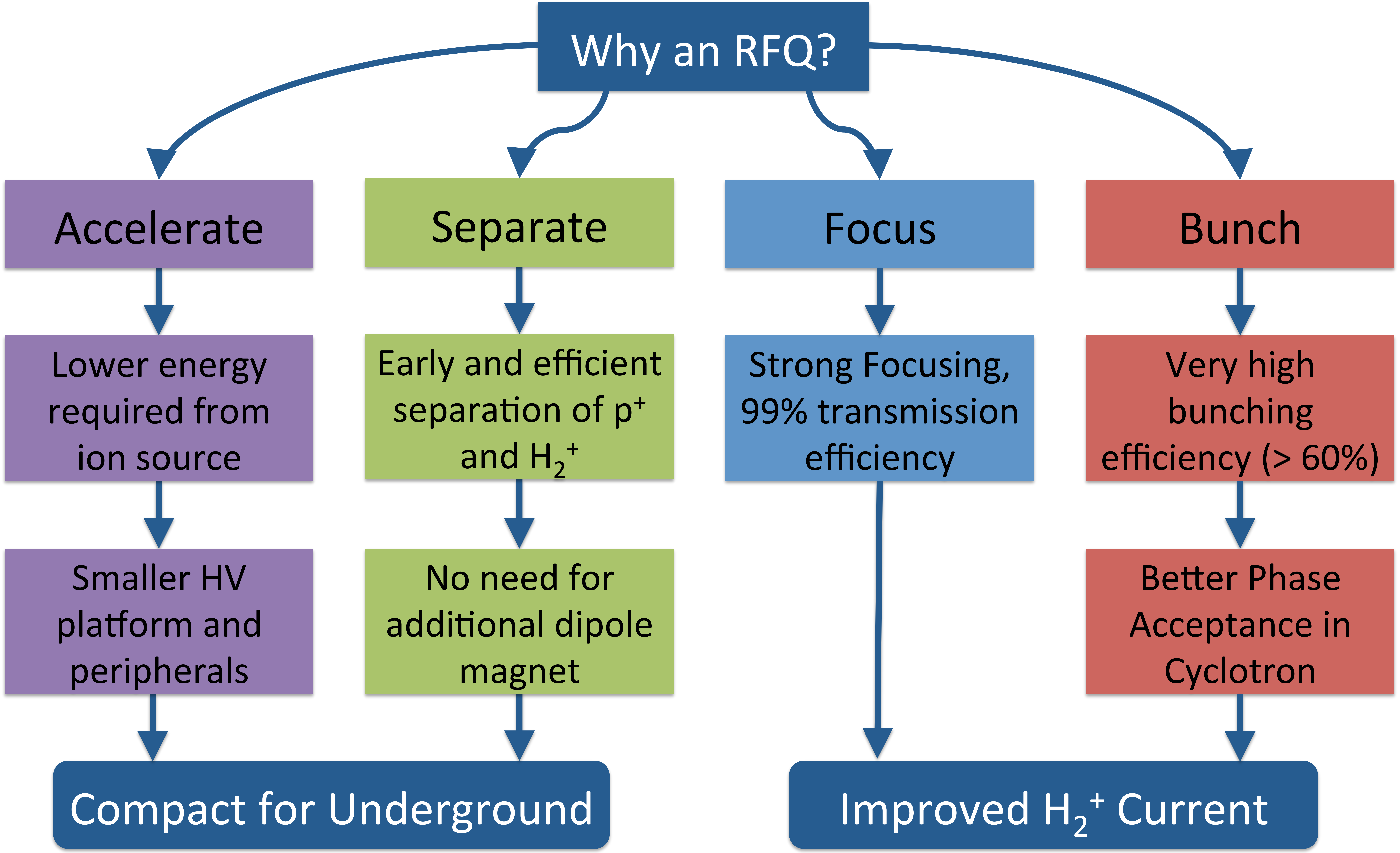
Ehlers and Leung's LBL Source	MIST-v1
10 column of SmCo magnets	12 columns of SmCo magnets
10 cm radius by 9 cm length	7.5 cm radius by 7 cm length
Axial plasma volume length: 2.0, 4.5 cm	Axial plasma volume length: 1.5 - 5.0 cm
Not water cooled.	Front plate and plasma chamber is water cooled
Back plate biasing (observed a 30% increase in extracted current)	Back plate biasing and plasma chamber biasing
Magnetic configuration: plasma chamber/back plate	Magnetic configuration: plasma chamber/back plate/front plate





IsoDAR's interest in RFQs

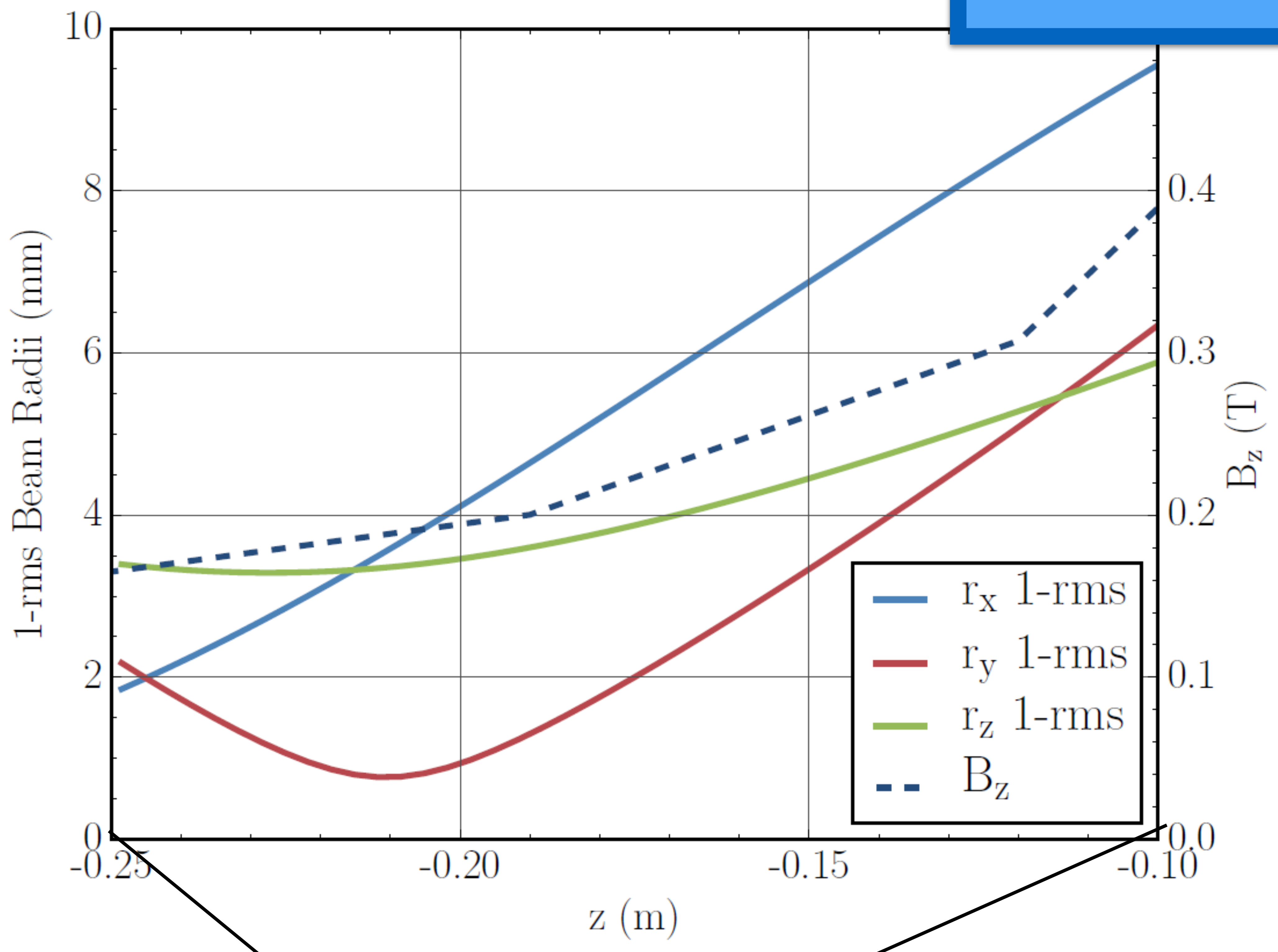
Backup

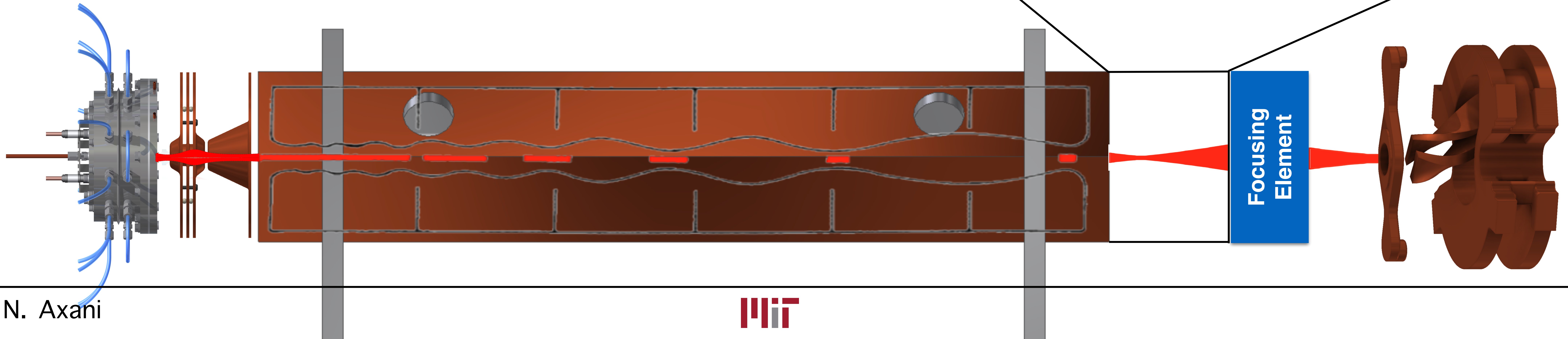


IsoDAR's interest in RFQs

Backup

- The design now needs to be optimized.
- We can see that at the exit of the RFQ, the beam is highly divergent.
- 15 cm from the exit, the 10 mA beam has increased from 3mm to 8 mm, nearing the limitations of our spiral inflector entrance aperture.

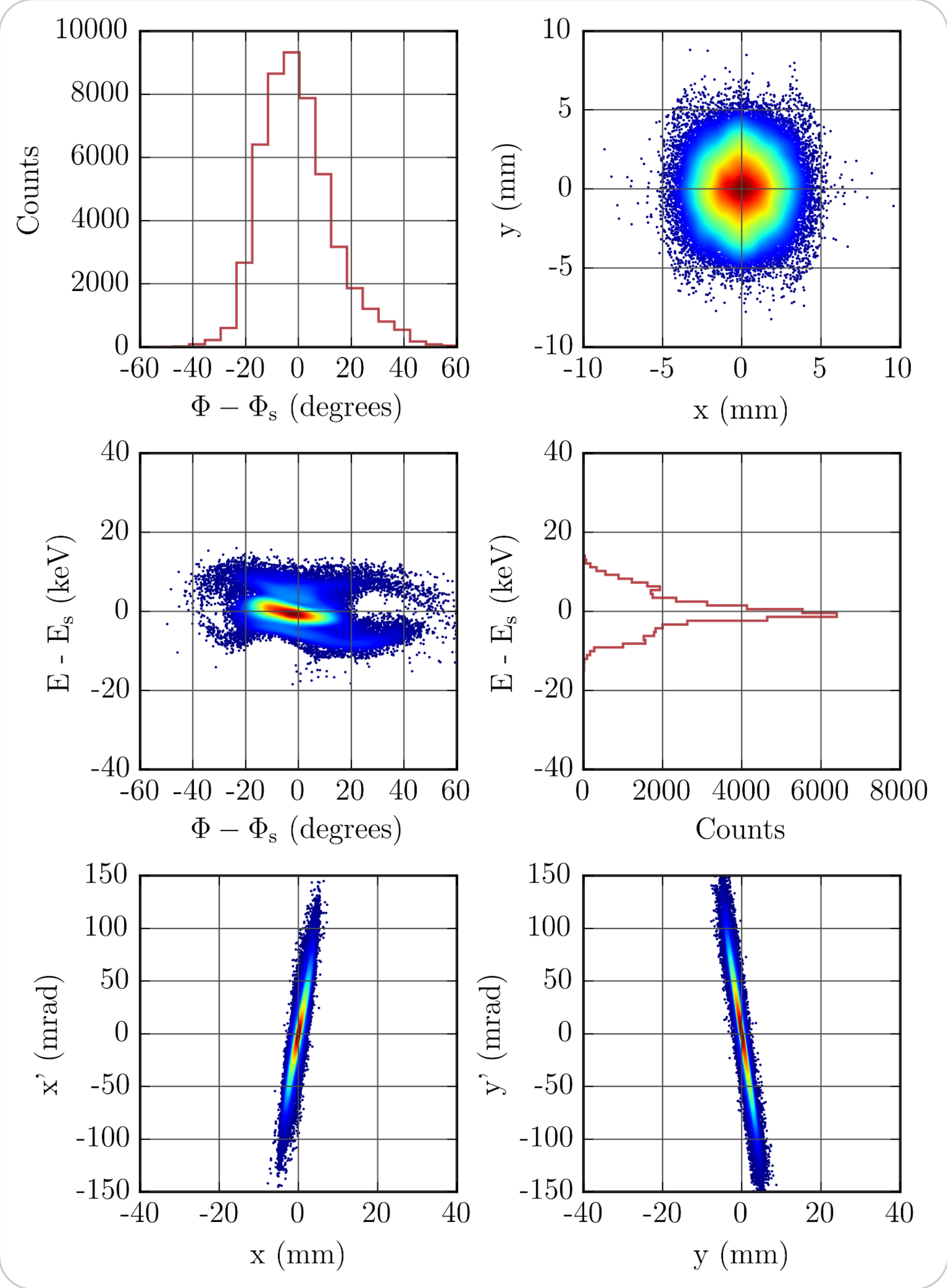




IsoDAR's interest in RFQs

Backup

The phase spread of each particle. 60% of the particles are contained within +/- 10 degrees of the synchronous phase



The beam at the exit of the RFQ is fairly round.
Roughly 3 mm in radius.

Energy versus particle phase

Energy distribution centered around the design energy (80 keV). 60% contained within +/- 2 keV

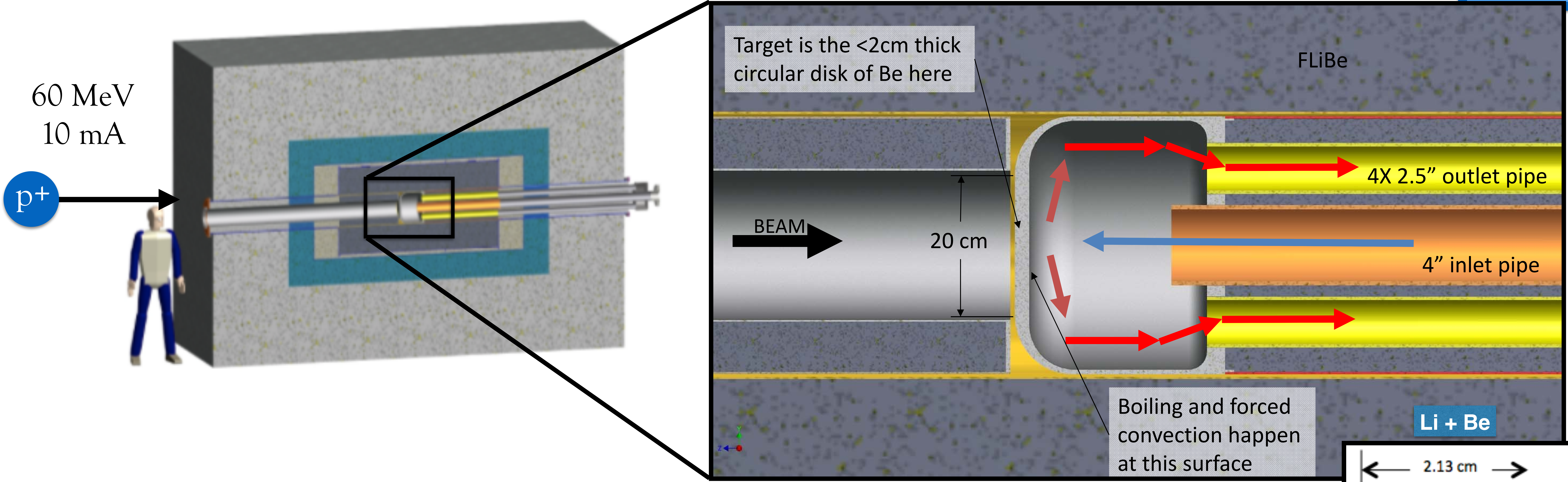
Horizontal phase space. We see it is diverging.

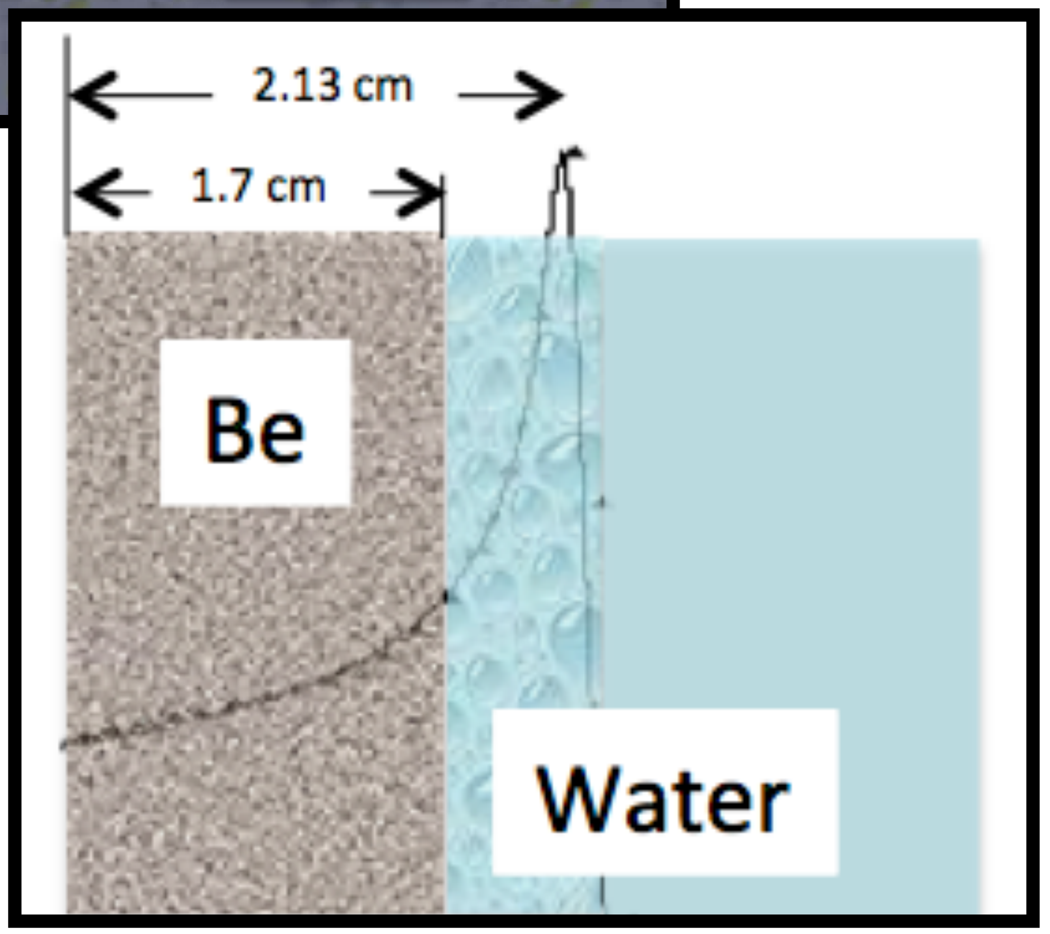
Vertical phase space. We see it is converging.

Target design and cooling

Backup

60 MeV
10 mA





Beam: 600kW
NSF proposal to make a beryllium prototype target
+ simulation + CFD
Test cooling design.

Location in the mine