The IsoDAR cyclotron design

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SCK· CEN

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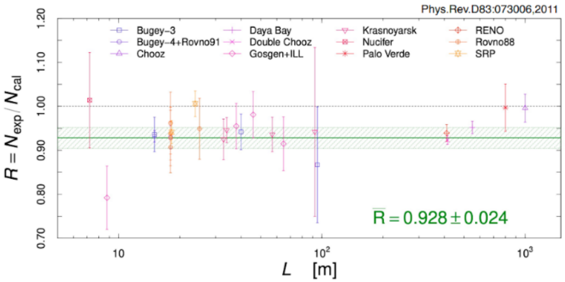
Neutrino Physics

Outstanding puzzles

- LSND anomaly: Excess of $\overline{\nu}_\mu \to \overline{\nu}_e$ oscillations
- MiniBoone anomaly: Excess of $\nu_\mu \to \nu_e$ oscillations - at lowest energies

- The Reactor anomaly: too few ν_e seen at short distances from reactors



- The Gallium anomaly: Gallex and SAGE calibrations using ν_e sources from electron capture see only $87 \pm 5\%$ of expected rates

Could imply further 'sterile' neutrino(s)? Seems shocking, but neutrinos have given shocks in the past.

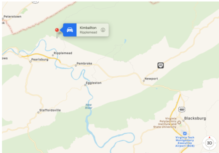
IsoDAR

To provide a definitive answer

1. 60 MeV protons on ^{9}Be target - generates intense flux of neutrons
2. neutrons interact in ^{7}Li sleeve giving ^{8}Li
3. ^{8}Li isotope beta decays (half-life 0.8 sec) at rest giving $\overline{\nu}_e$
4. Large neutrino detector detects through inverse beta decay: $\overline{\nu}_e p \rightarrow n e^+$. Very clean signal - scintillation + neutron capture gamma
5. Measure E_{ν_e} and path length - so can follow oscillations with L/E
6. 820,000 events in 5 years would really establish or reject sterile neutrino models

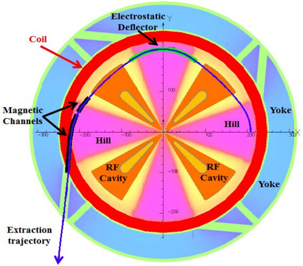
Possible detectors + sites: Kamland at Kamioka and Chandler at Kimbalton

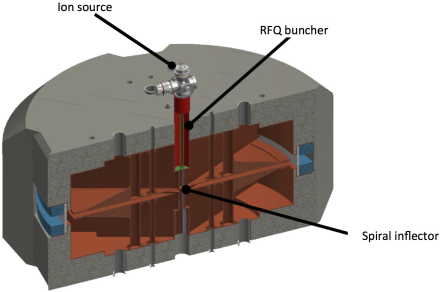
IsoDAR at KamLAND



The IsoDAR cyclotron

The IsoDAR cyclotron needs provide 10 mA of 60 MeV protons: $\sim 10\times$ more power than state of the art (e.g. IBA Cyclone70 1 mA at 70 MeV)





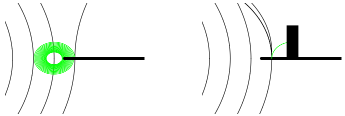
3 innovations/advances

- Use of H_2^+
- Early-stage RFQ
- Detailed simulation of the cyclotron especially central region

H_2^+ and the accelerated ion

Modern cyclotrons use H^- rather than H^+ for extraction by stripping
Increasing interest in H_2^+ as an alternative

1. Binding energy is 2.8 eV as opposed to 0.7 eV, so more robust under strong electric (RF) and magnetic (Lorentz stripping) field
2. Space charge effects (important at low energies) are reduced because the mass is doubled. Characterised by Generalised Perveance $K = \frac{qI}{2\pi\epsilon_0 m_0 c^3\beta^3\gamma^3}$
3. Extraction can be done without the convoy electrons damaging the stripping foil

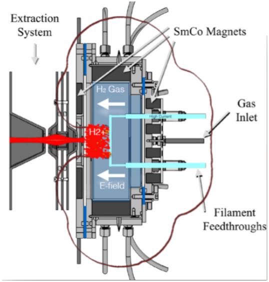


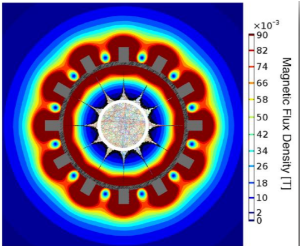
Incidentally can also accelerate D^+, He^{2+}, C^{6+}

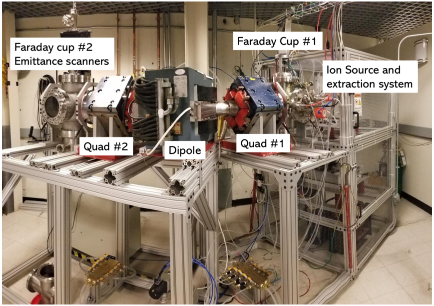
Ion Source Status

Multicusp Ion source MIST-1 optimised for H_2^+

SmCo permanent magnets to confine plasma







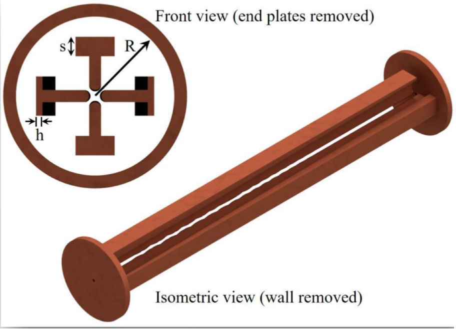
Very early days

5mA current achieved with large H_2^+ component

$40 mA/cm^2$

H and V emittances acceptable (but working on improving them)

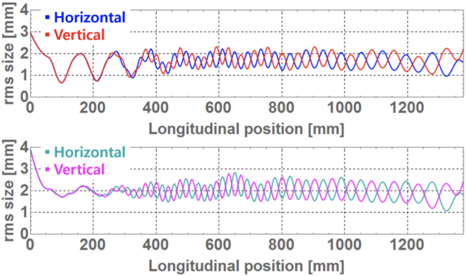
Advantages of an RFQ



Conventional ion source is DC. On injection, particles entering within 10° of the correct RF phase are accelerated. All others are lost.
Buncher may give factor ~ 2 improvement,
Not treated as a problem as energies are low. But means 50 mA source needed for 5 mA beam current
Solution: use RFQ as LEBT. Focuses+bunches+accelerates

RFQ status

4 rod split-coaxial design. 1.4m long, operates at 32.8 MHz (very low frequency!)
Consumes modest 12.25 kW
Accelerates from 15 keV to 70 keV
Collection efficiency 97%. with longitudinal re-buncher at the end
Encouraging simulations (using TRACK code: 10 mA and 20 mA shown)



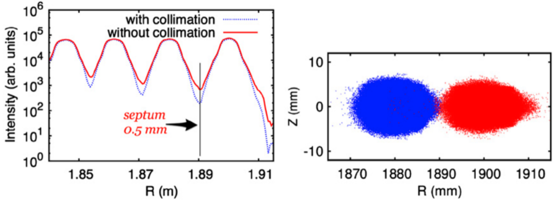
Design being finalised. Construction approved.

Cyclotron Design

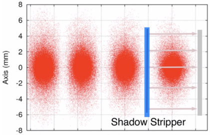
Modern simulation software (OPAL) gives understanding of bunch dynamics in cyclotrons (space charge repulsion, field inhomogeneities, inter bunch effects,..) including spiral inflector

Established by use in PSI injector II and other machines. Shows 'vortex motion' mixing T and L emittance, driven by space charge.

Central collimators give clean beam separation for high energy orbits.



Control losses and enable shielded septum between outermost bunch orbits



Timeline

Injector funded (NSF) :

Ion Source running and being studied

RFQ design nearly done, construction soon

Working with Bevatech on construction of cyclotron prototype

Applications: Medical Isotopes

Highlighting these among many uses for such machine

Production of medical isotopes with (relatively) small cross sections:

60 MeV protons on natural Gallium target (^{69}Ga and ^{71}Ga) gives 50 Ci/week $^{68}\mathrm{Ge}$

$^{68}\mathrm{Ge}$ decays to $^{68}\mathrm{Ga}$ - a positron emitter

Like widely used Mo/Tc system used for imaging except

- PET not SPECT so better imaging
- Half life of $^{68}\mathrm{Ge}$ is 270 d so "cow" lasts for 1 year not few days
- $^{68}\mathrm{Ga}$ half life 68 min not 6 h: don't send patients home radioactive

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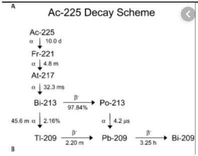


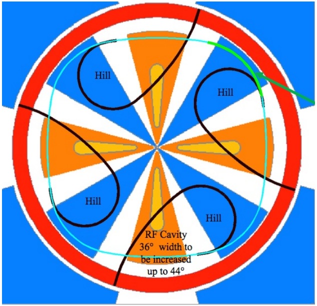
$^{225}\mathrm{Ac}$ radiotherapy α emitter

4 α particles, enormous LET, range 50 microns, so powerful targeted dose.

Make by 60 MeV protons on thorium. Estimate could get 200 mCi/hour so 5 hours gives as much as current world production

Conclusions

The IsoDAR design is a game changer
Increase the power of low energy cyclotrons by an order of magnitude.
Many applications - including ADSR injectors
(and solve the sterile neutrino question)



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