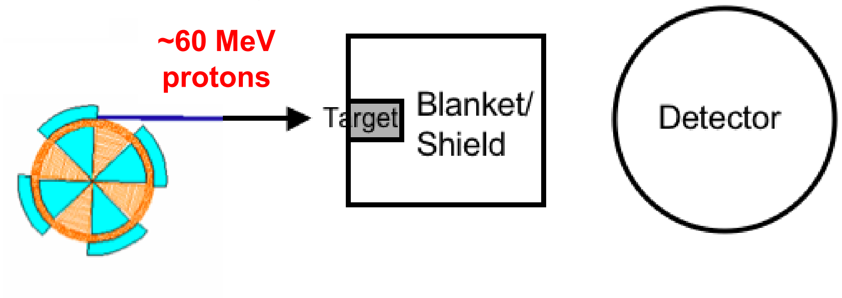
Daeδalus and IsoDAR Experiments

("Cyclotrons as Drivers for Precision Neutrino Measurements" - arXiv:1307.6465
Snowmass Whitepaper on the DAEdALUS Program - arXiv: 1307.2949)

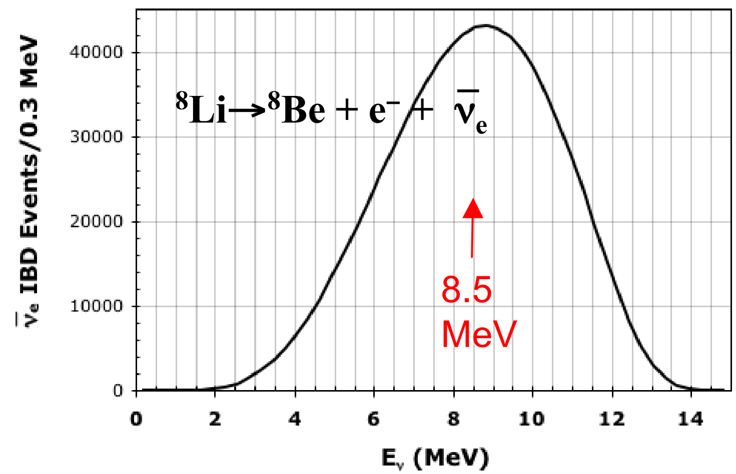
IsoDAR Setup:

Very short baseline search for sterile neutrinos

PRL 109, 141802 (2012)



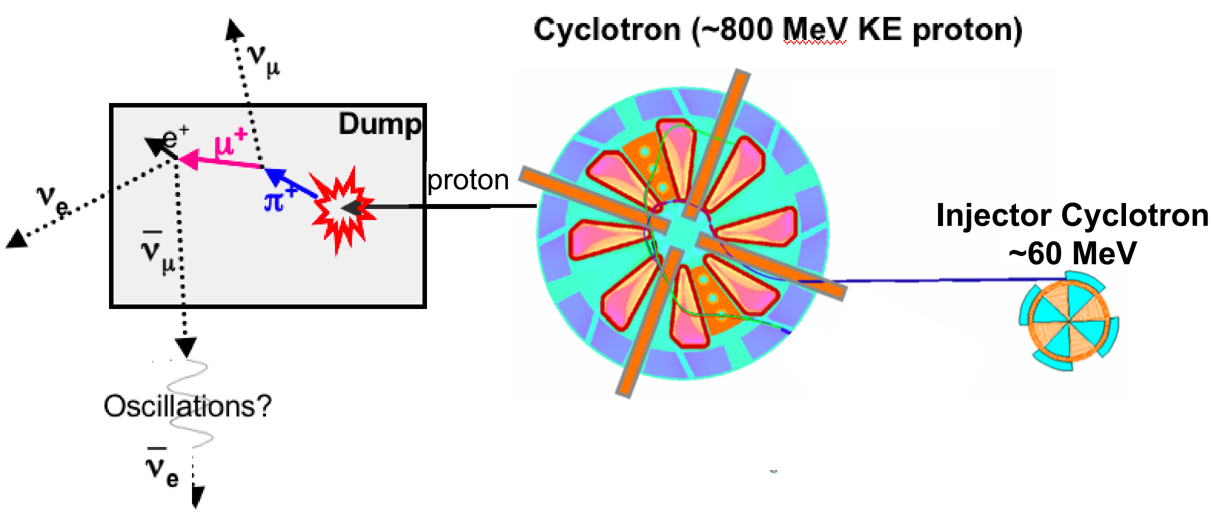
Isotope decay-at-rest



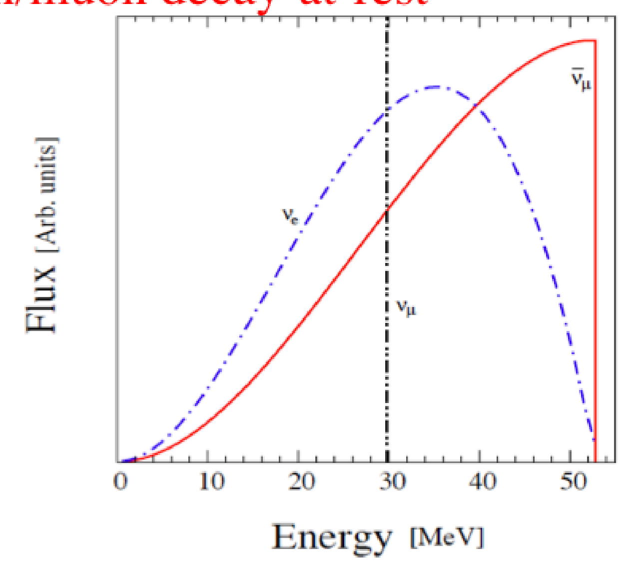
Daeδalus Setup:

A new way to search for CP violation in the ν-sector

PRL 104, 141802 (2010)



Pion/muon decay-at-rest

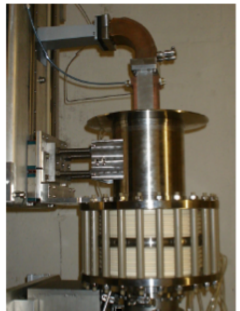


DAEδALUS / IsoDAR Summary

- DAEδALUS is a program to develop a new resource for Neutrino Physics.
  - The goal is to produce small sized and relatively inexpensive cyclotron-based decay-at-rest neutrino sources.
- This frees the program from being forced to match detectors to accelerator sites and opens up interesting new physics opportunities.
  - Therefore, the development of these new, smaller sources should be a priority for our field.
- This is a phased program with physics output at each stage
  - IsoDAR experiment is the second phase.
  - Full DAEδALUS for CP measurements as the final phase
- We request that P5 endorse our development program with the goal to move rapidly forward with a
  1. A first demonstration IsoDAR system built before the end of this decade
  2. A full DAEδALUS set-up potentially installed in the 2020's.

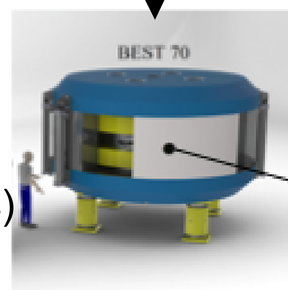
DAEδDALUS High Power (~1 MW) 800 MeV Cyclotron System (Under Development with Lab and Industrial Partners)

H_2^+ Ion Source

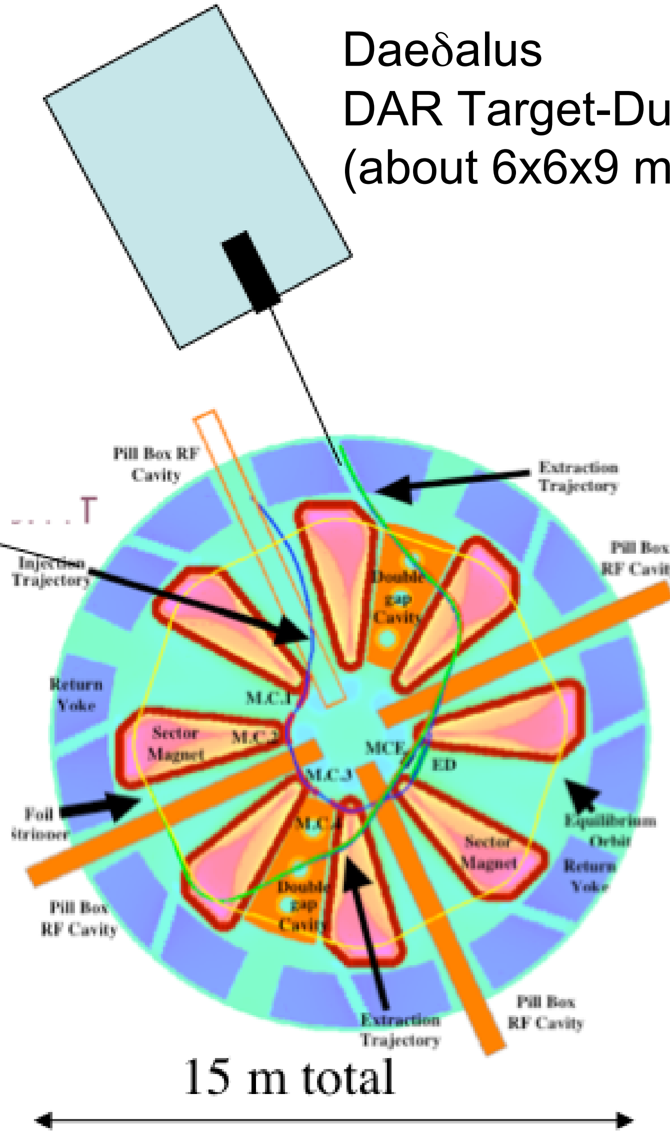


IsoDAR Cyclotron

Injector Cyclotron (Resistive Isochronous)



Daeδalus DAR Target-Dump (about 6x6x9 m³)



Multimegawat Daeδalus Cyclotron for Neutrino Physics

arXiv:1207.4895

Ring Cyclotron (Superconducting)

"Isochronous cyclotron" where mag. field changes with radius, but RF does not change with time. This can accelerate many bunches at once.

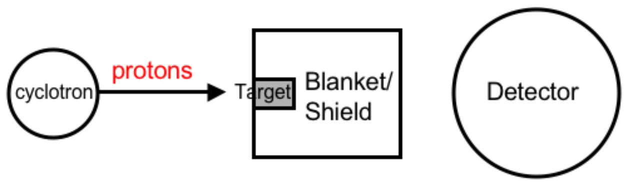
Question 1: “Notional Timeline” (Technically driven)

Phase				
I		Produce 50 mA H2+ source, inflect, capture 5 mA and accelerate	Best Inc. Teststand, Catania Experiment	**Accelerator Science** Physics: 2014-15
II	IsoDAR	Build the injector cyclotron, extract, produce antinu flux via 8Li	WATCHMAN, KamLAND, JUNO	**SBL $\bar{\nu}_e$ physics** Engineering, 2015 Start of run, 2018
III		Build the first SRC, Run this as a “near accel.” at existing large detector	NOvA, LENA, Super K	**SBL $\bar{\nu}_\mu$ physics** Engineering, 2017 Start of run 2021
IV	DAEδALUS	Build the high power SRC, Construct DAEδALUS	HyperK, LENA	**CP** Eng: 2020 Start 2025

We are here

IsoDAR $\bar{\nu}_e$ Disappearance Search

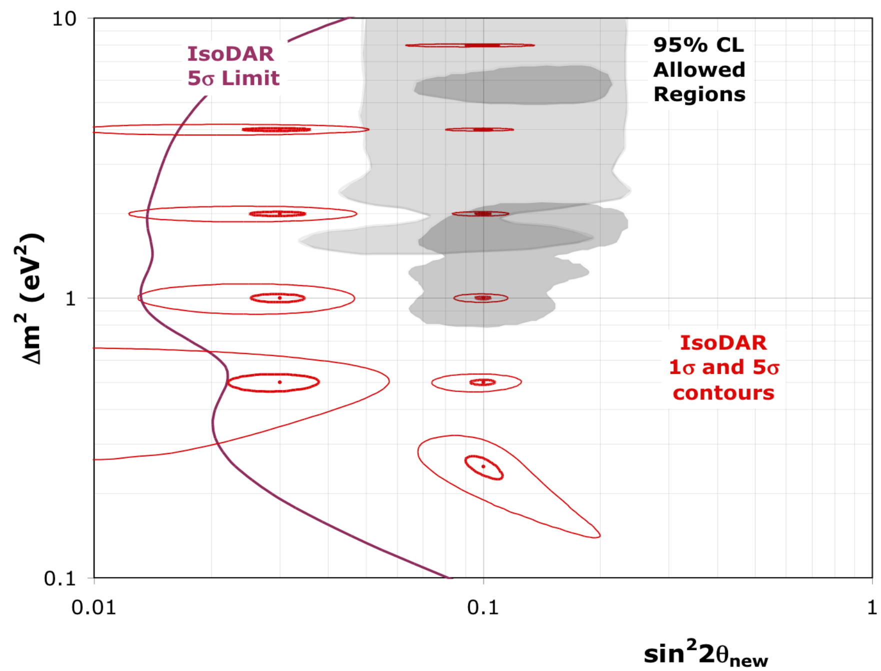
- IsoDAR: Isotope Decay-at-rest beam (high intensity $\bar{\nu}_e$ source)



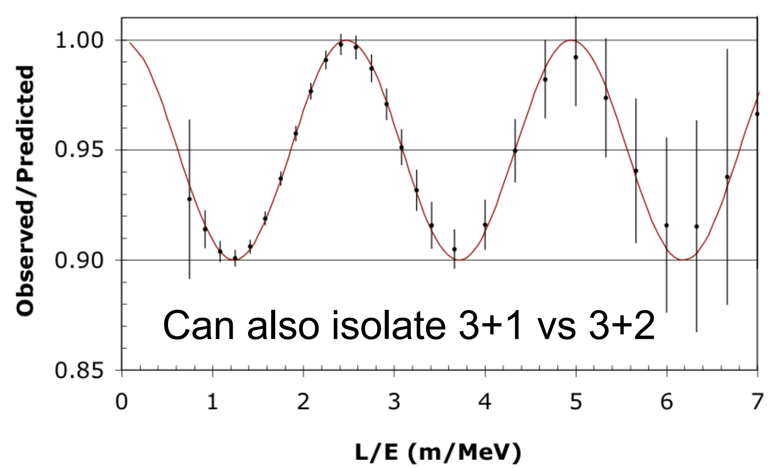
- p (60 MeV@10ma) into target $\rightarrow$ ^{8}Li
- ^{8}Li $\rightarrow$ ^{8}Be + e^- + $\bar{\nu}_e$
  - Known $\bar{\nu}_e$ energy spectrum (mean event energy of 8.5 MeV)
  - Use shape analysis with very small systematic uncertainties
  - Observe changes in the event rate as a function of L/E
  - ~160,000 IBD events / yr in 1kton

- Update options since Snowmass (see “Update on the IsoDAR Program For P5”)
  - Watchman 1kton Gd-doped water (or scintillator) detector in old IMB cavern
  - IsoDAR at JUNO (Daya Bay II) 20 kton liquid scintillator

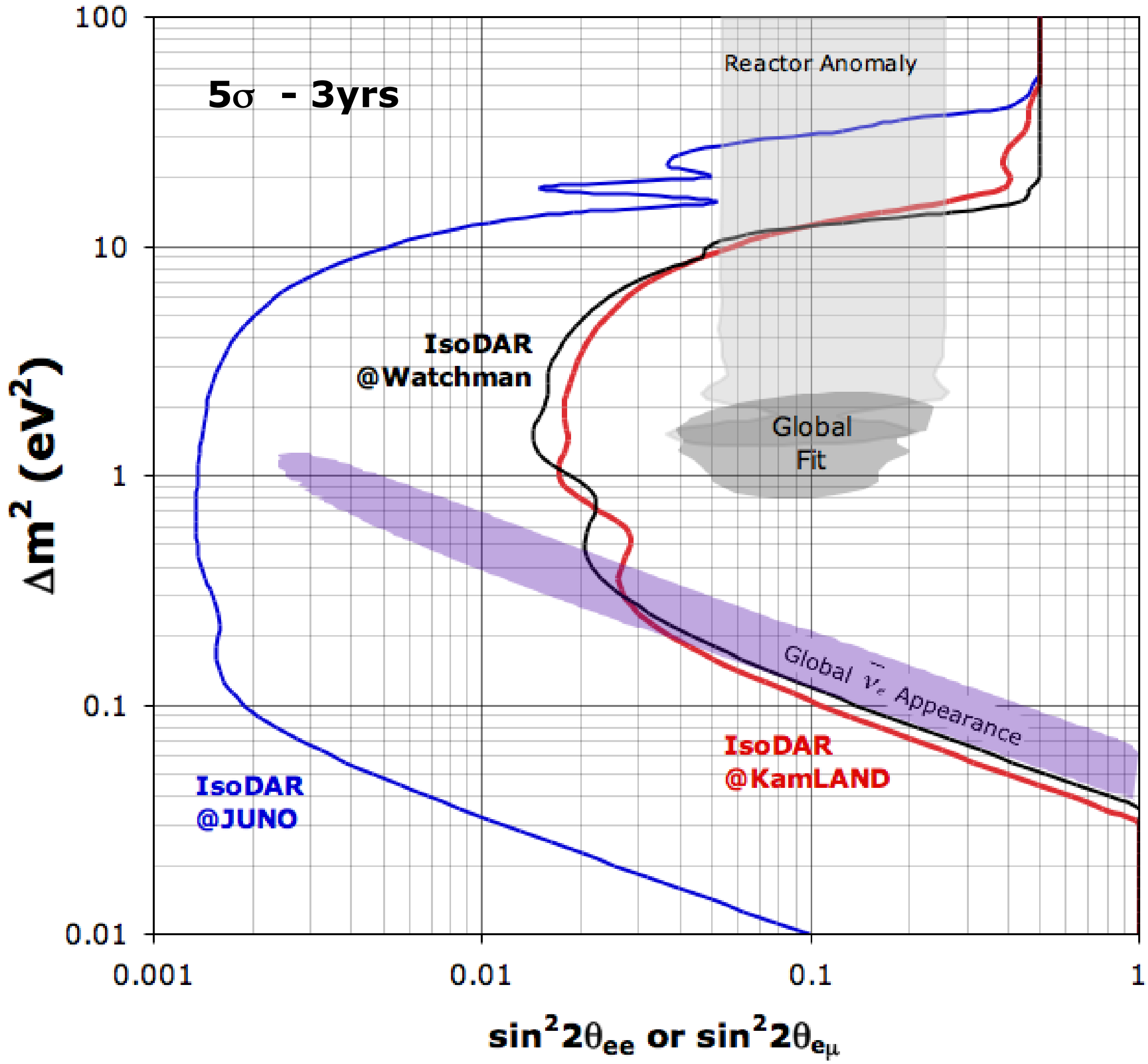
Measurement Sensitivity IsoDAR@Kamland



(3+1) Model with Δm^2 = 1.0 eV^2 and $\sin^2 2\theta$=0.1

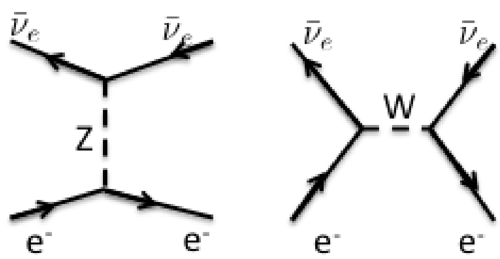


IsoDAR Combinations with Various Detectors



- IsoDAR @ **Watchman** or **KamLAND**
  - Full coverage of "Global Fit region" and "Reactor Anomaly" for $\Delta m^2 < 10 eV^2$
- IsoDAR @ **JUNO**
  - Full coverage of "Global $\bar{\nu}_e$ Appearance" region

IsoDAR Also Has Excellent Electroweak Measurement Sensivity ($\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$)



- Precision neutrino-electron scattering can also probe Non-Standard Interactions (NSI) since it is a well-understood Standard Model process

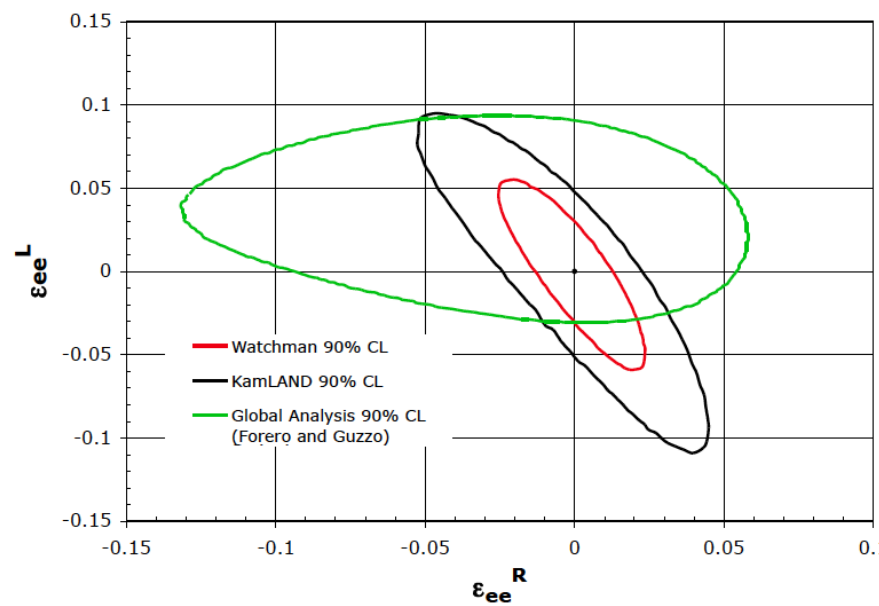
$$g_L \longrightarrow g_L + \epsilon_{ee}^{eL} \quad g_R \longrightarrow g_R + \epsilon_{ee}^{eR}$$

- 5yr data ⇒ ~7200 evts with E_{vis}>3MeV

⇒ IsoDAR@ Watchman:

$\delta\sin^2\theta_W$ = 0.0044 (~1.7%)

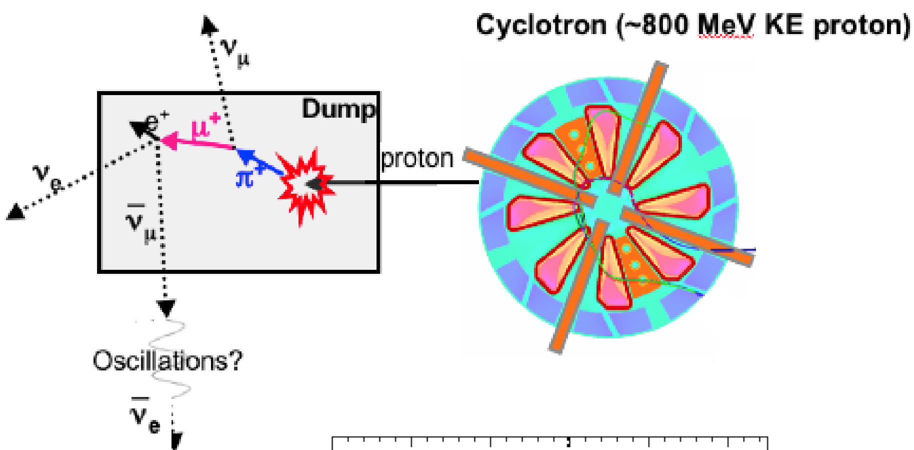
– Would be, by far, the world's best electron-flavor, pure leptonic measurement



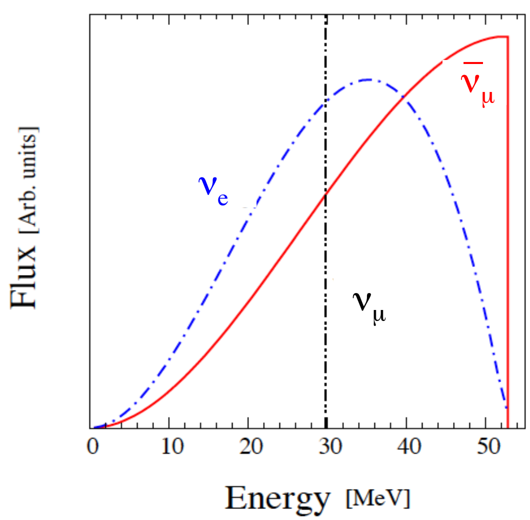
DAEδALUS Experiment

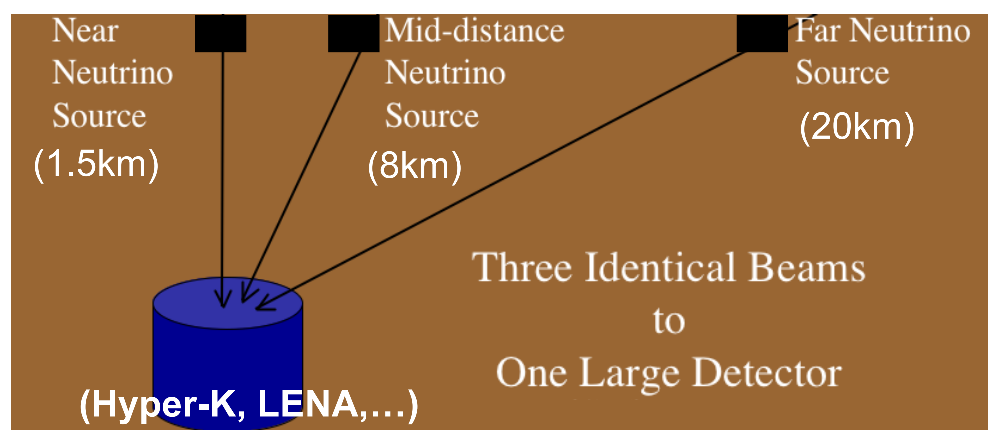
Search for CP Violation using $\bar{\nu}_e$ Appearance with a Pion Decay-at-Rest Neutrino Beam

- Pion decay-at-rest neutrino source produced by high-intensity 800 MeV cyclotron
  - Very high-intensity $\bar{\nu}_\mu$ source with known spectrum



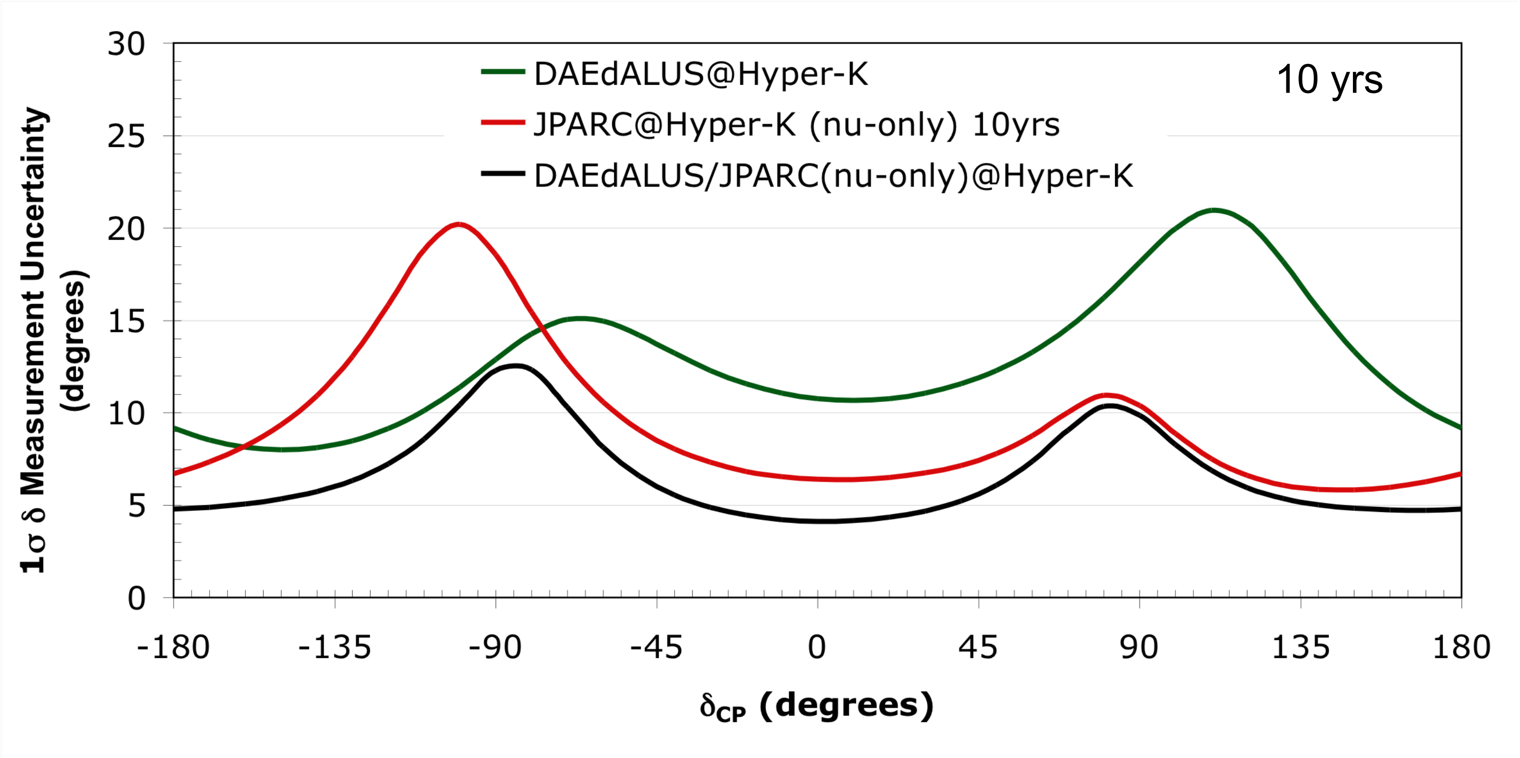
- Look for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- Single large water (with Gd) or scintillator
  - Need free hydrogen to use inverse-beta-decay (IBD) detection
- Neutrino sources at three different distances
  - Use IBD interactions to isolate a pure sample of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- Can combine DAEδALUS antineutrino data set with long baseline neutrino-only data for much improved CP violation search



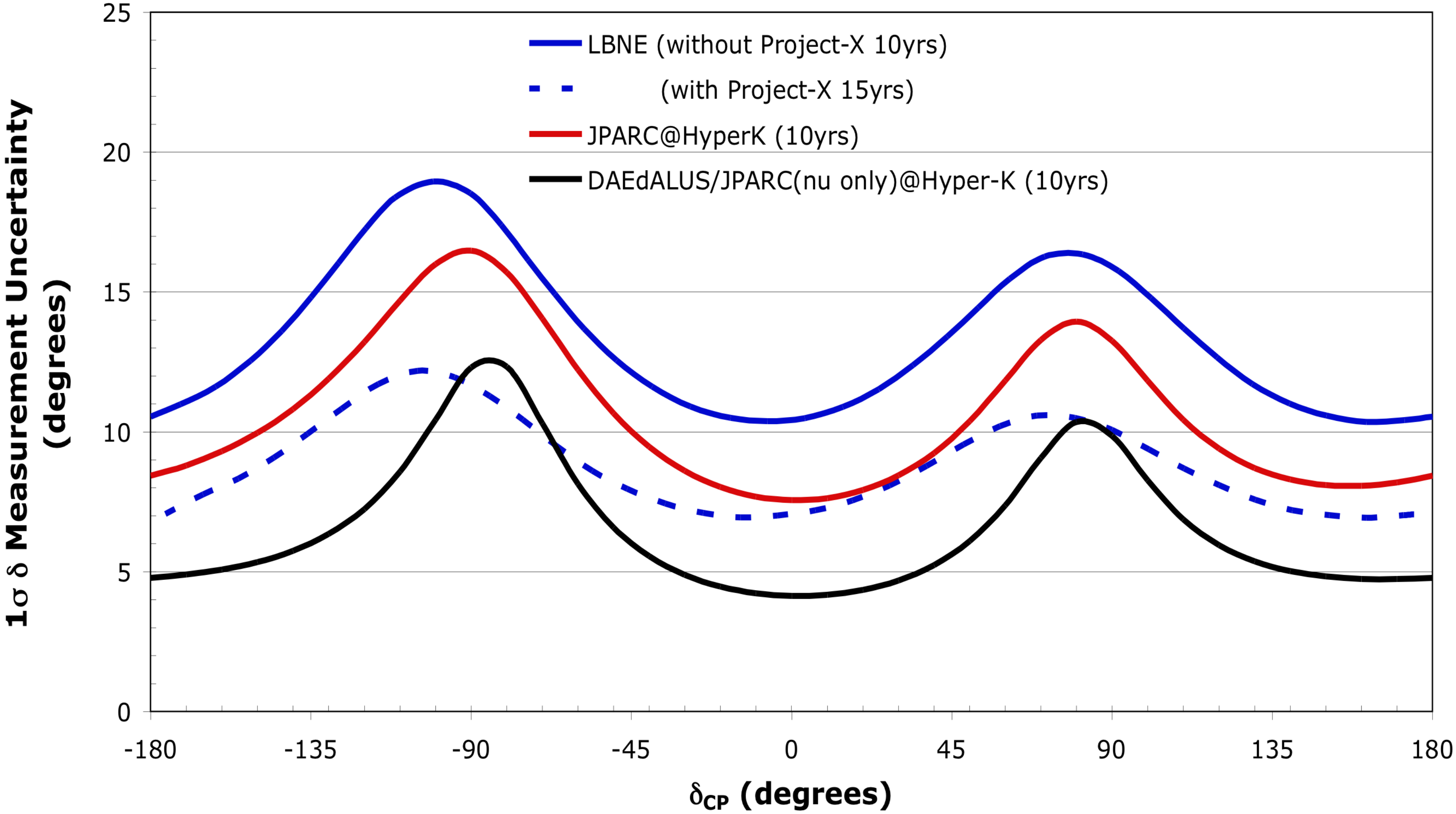


CP Violation Sensitivity

- Daeδalus has good CP sensitivity as a stand-alone experiment.
  - Small cross section, flux, and efficiency uncertainties
- Daeδalus can also be combined with long baseline ν-only data to give enhanced sensitivity, i.e. Hyper-K
  - Long baseline experiments have difficulty obtaining good statistics for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ which DAEδALUS can provide
  - Daeδalus has no matter effects and can help remove ambiguities.



δ_{CP} Sensitivity Compared to Others



Question 1: "What makes this program unique?"

These programs are quite different from all other proposals

IsoDAR

1. Known flux shape since single beta decay (unlike reactors)
2. Higher energy than sources or reactors (endpoint 13 MeV)
   - Well above the 3 MeV environmental backgrounds
   - Very low systematic uncertainties
   - High flux and low systematics allows precision $\bar{\nu}_e$ - e scattering
3. Flexible location
   - Can bring source to detector (unlike reactors)
   - Combined with higher energy gives better L/E coverage
4. Long runs are possible (unlike sources) with no interfacing with company or lab schedules

Question 1: "What makes this program unique?"

DAEδALUS

1. Tracing the oscillation wave is a unique approach to CP studies.
2. Beam energy and flavor content well defined
3. Very low $\bar{\nu}_e$ intinsic background
   - Due to compact target/dump design with little π^- decay-in-flight backgrounds
   - Energy implies no Kaon production
   - Better geometry than DAR setups at spallation facilities
4. Very short baseline $\Rightarrow$ no matter effects
   - No mass hierarchy dependence
   - Unaffected by propagation NSI effects
5. The complementary nature is what makes combining with conventional beam data so powerful

Questions 2 & 4: Collaborating Institutions and Labs

Very Active,
Ramping Up,
Low Level,
but interested

US

Amherst College
Bartoszek Engineering
Columbia University
Duke University
Lawrence Livermore National Lab.
Los Alamos National Laboratory
Massachusetts Institute of Technology*
Michigan State University*
New Mexico State University
UC Berkeley (Nuc. Eng.)*
UC Irvine
UCLA
University of Maryland*
University of Tennessee

Foreign

The Cockcroft Institute for Accelerator Science*
University of Huddersfield*
Imperial College London
University of Manchester*
Tohoku University*

Cyclotron Labs

LNS-INFN (Catania)*
Paul Scherrer Institut*
RIKEN*

* group includes experienced accelerator scientists

Questions 2 & 4: Collaboration Cyclotron Companies

Cyclotron Company	Location	Comment
AIMA	European	
Best Cyclotron Systems, Inc.	US & Worldwide	General interest
IBA	US & Worldwide	
Sumitomo Heavy Industries	Japan	Interest is in IsoDAR@KamLAND

So far the role of these companies has been as collaboration members, not as contractors.

Very Active,
Ramping Up,
Low Level,
but interested

Questions 3: IsoDAR Present Top Level Cost Estimates

Cost- effective Design Options for IsoDAR
A. Aldelmann et al. ; arxiv: 1210.4454

1st source constructed --
$30M base cost (2013 $)

recommended contingency
as of now: 50%
after 1st eng. design: 20%

If more sources are
constructed – ~$15M each.

We need funding for engineering to make improved cost estimates.

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

Questions 3: DAEδALUS Present Top Level Cost Estimates

DAEδALUS – \$130M near accelerator, \$450M for the 3 sites.

includes various contingency 20% to 50%.

Assumes component costs drop by 50% after prod. of 1st item.

Does not include site specific cost (buildings)

1. The SRC magnet is the cost driver. For this we have:

   Engineering Study for Daedalus Sector Magnet; Minervini, et al., arXiv:1209.4886

   (Minervini received the 2013 award for Continuing and Significant Contributions in the Field of Applied Superconductivity)

2. The RF is based on the PSI design, for which we have a cost.

3. The strong similarity to RIKEN allows a sanity check, and we have the costs for this.

4. All targets are ~1 MW (similar to existing targets), note each cyclotron can have more than one target to maintain the power level on each.

We need funding for engineering to make improved cost estimates.

Final Comment: Cyclotron Development as Value to Society

1. IsoDAR design would give enhanced medical isotope production - much industry interest

Isotope	Half-life	Use
^{52}Fe	8.3 h	The parent of the PET isotope ^{52}Mn and iron tracer for red-blood-cell formation and brain upt
^{122}Xe	20.1 h	The parent of PET isotope ^{122}I used to study brain bl
^{28}Mg	21 h	A tracer that can be used for bone studies, analogous to
^{128}Ba	2.43 d	The parent of positron emitter ^{128}Cs. As a potassium analog, this is used for heart and blood-fl
^{97}Ru	2.79 d	A γ-emitter used for spinal fluid and liver studie
^{117m}Sn	13.6 d	A γ-emitter potentially useful for bone studies
^{82}Sr	25.4 d	The parent of positron emitter ^{82}Rb, a potassium an This isotope is also directly used as a PET isotope for hea

COST / BENEFIT COMPARISON

FOR

45 MEV AND 70 MEV CYCLOTRONS

MAY 26, 2005

Conducted for:

U.S. Department of Energy
Office of Nuclear Energy, Science, and Technology
Office of Nuclear Facilities Management
19901 Germantown Road
Germantown, MD 20874

Conducted by:

JUPITER
Technical, Security, and Management Solutions

Suite 900, Westfield North
2730 University Boulevard West
Wheaton, MD 20902

2. DAEδALUS design applicable to Accelerator Driven Systems (ADS) Reactors

MW-CLASS 800 MeV/n H_2^+ SC-CYCLOTRON FOR ADS APPLICATION, DESIGN STUDY AND GOALS*

F. Méot, T. Roser, W. Weng, BNL, Upton, Long Island, New York, USA
L. Calabretta, INFN/LNS, Catania, Italy; A. Calanna, CSFNSM, Catania, Italy

Thorium reactor community interested in DAEδALUS development.

⇒ Cyclotrons are practical and cheap compared to linacs.

DAEδALUS / IsoDAR Summary

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  - The goal is to produce small sized and relatively inexpensive cyclotron-based decay-at-rest neutrino sources.

- This frees the program from being forced to match detectors to accelerator sites and opens up interesting new physics opportunities.
  - Therefore, the development of these new, smaller sources should be a priority for our field.

- This is a phased program with physics output at each stage
  - IsoDAR experiment is the second phase.
  - Full DAEδALUS for CP measurements as the final phase

- We request that P5 endorse our development program with the goal to move rapidly forward with a
  1. A first demonstration IsoDAR system built before the end of this decade
  2. A full DAEδALUS set-up potentially installed in the 2020's.

Backup Slides

Questions 3: Cost - Supporting docs for IsoDAR

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MAY 26, 2005

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U.S. Department of Energy
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19901 Germantown Road
Germantown, MD 20874

Conducted b

Suite 900, Westfi
2730 University E
Wheaton, MD 20

EXECUTIVE SUMMARY

A cost/benefit study was conducted by *JUPITER* Corporation to compare acquisition and operating costs for a 45 MeV and 70 MeV negative ion cyclotron to be used by the Department of Energy in the production of medical radioisotopes. The study utilized available information from Brookhaven National Laboratory (BNL) in New York and from the University of Nantes in France, since both organizations have proposed the acquisition of a 70 MeV cyclotron. Cost information obtained from a vendor, Advanced Cyclotron Systems, pertained only to their 30 MeV cyclotron. However, scaling factors were developed to enable a conversion of this information for generation of costs for the higher energy accelerators.

Two credible cyclotron vendors (IBA Technology Group in Belgium and Advanced Cyclotron Systems, Inc. In Canada) were identified that have both the interest and capability to produce a 45 MeV or 70 MeV cyclotron operating at a beam current of 2 mA (milliamperes).

The results of our analysis of design costs, cyclotron fabrication costs, and beamline costs (excluding building construction costs) resulted in total acquisition costs of:

- $14.8M for the 45 MeV cyclotron, and
- $17.0M for the 70 MeV cyclotron.

Ours will cost more because machine is larger, but this sets scale.

Obtaining ~3 tons of 99.99% pure 7Li -- molton salt reactor industry

Nuclear Engineering and Design

Volume 240, Issue 6, June 2010, Pages 1644–1656

Molten salt reactors: A new beginning for an old idea

David LeBlanc[a,b,*]

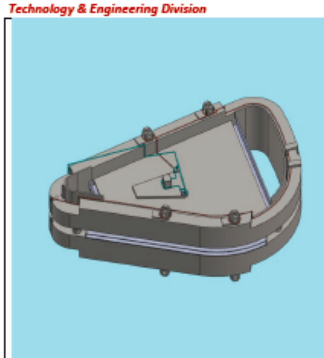
100 m^3 of flibe will contain about 30 tonnes of 99.995% ^{7}Li with previous cost estimates being from 120 to 800 $/kg. Even several

Questions 3: DAEδALUS - Supporting Docs

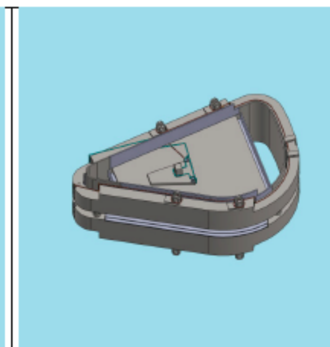
Engineering Study of SRC, arXiv: 1209.4886

Engineering design,
Assembly Plan,
Structural analysis,
Cryo system design

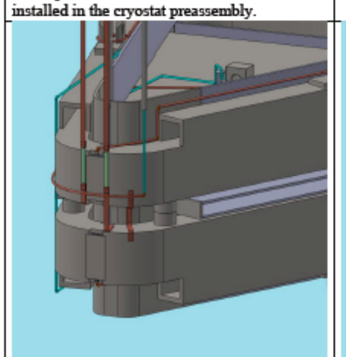
PSFC
Technology & Engineering Division



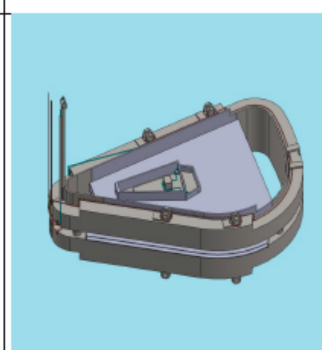
17. Top and bottom cold mass assemblies installed in the cryostat preassembly.



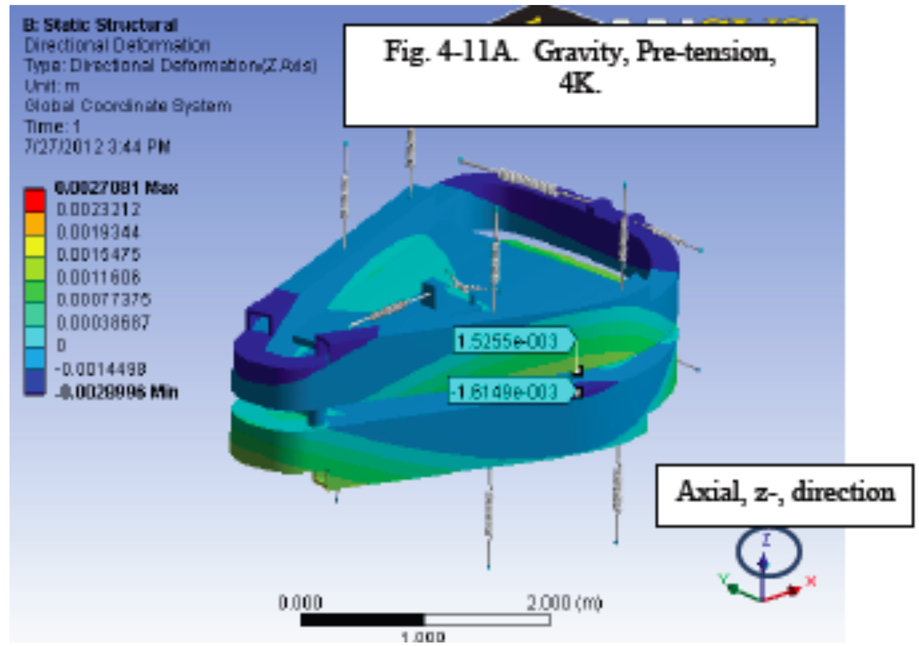
18. Inner cryostat wall cutout plates welded in.



19. Top and bottom coils He plumbing and cabling connected.



20 Cryostat top plate covering cold mass tie plate welded in.



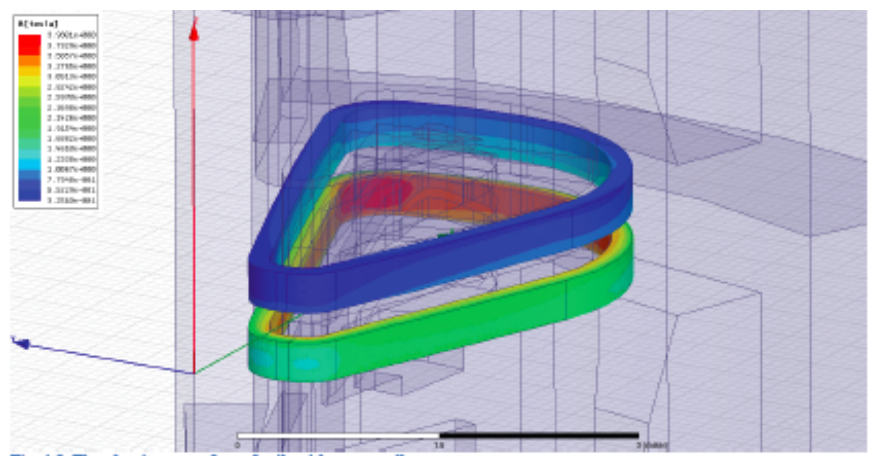
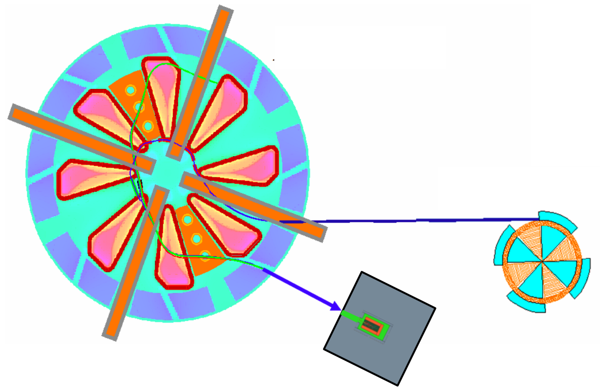
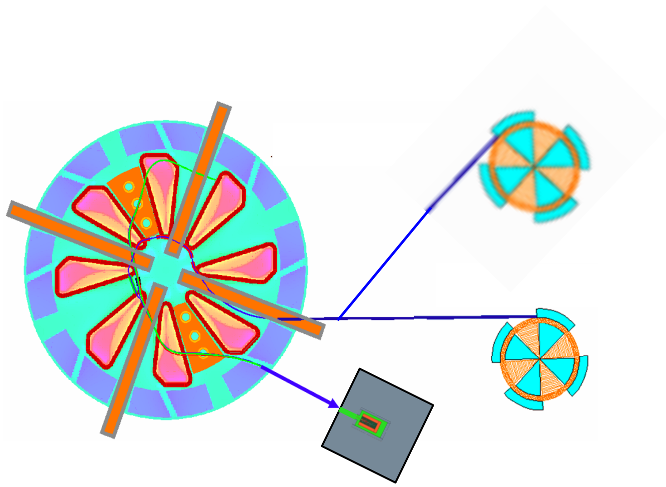


Fig. 4-9. Flux density on surface of coils with upper coil current zero.

Cyclotron Arrangements for DAEδALUS

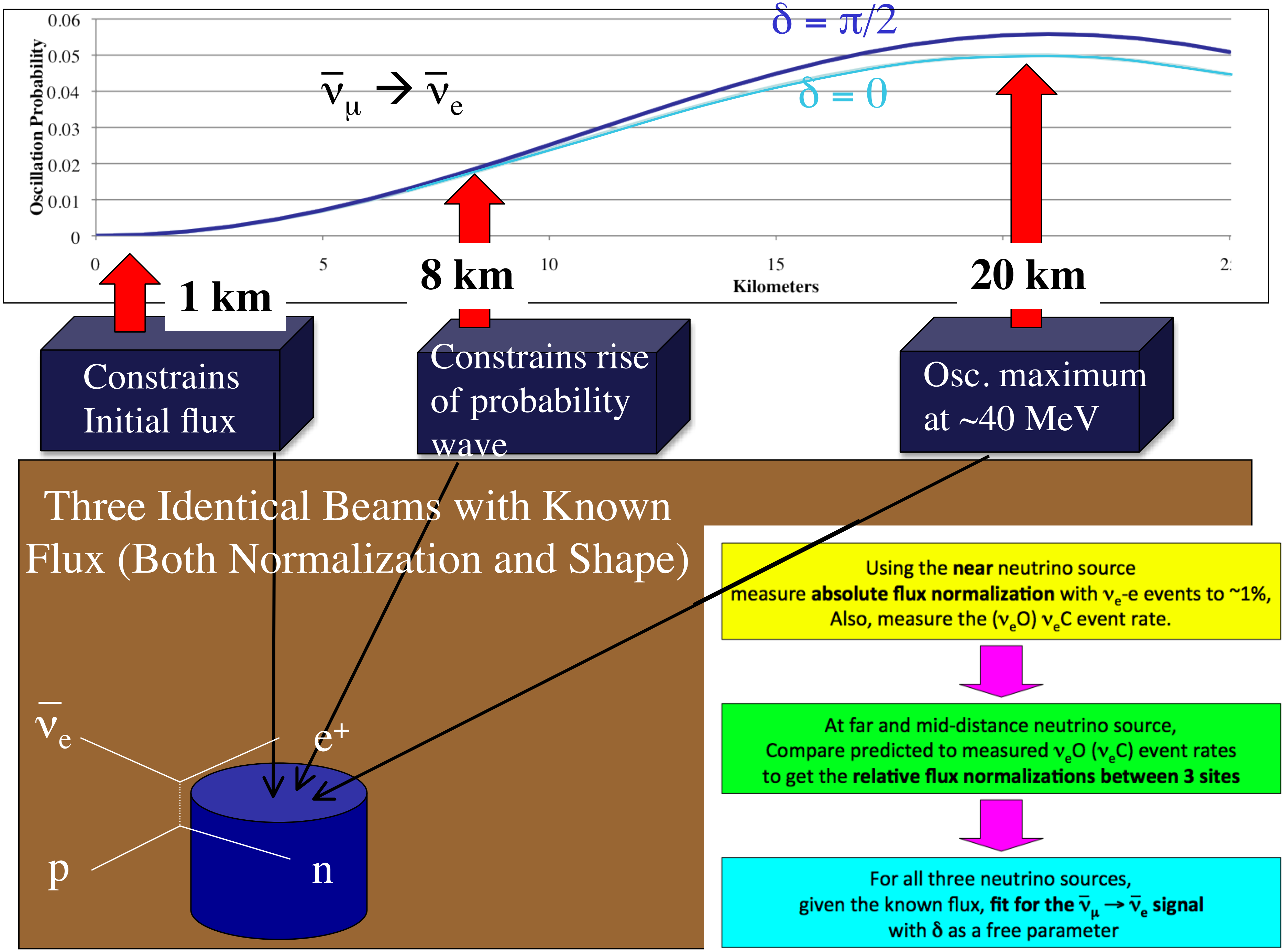


The “standard” system:
* 1 will run at near site,
DF ~ 13% ⇒ 10ma@0.8GeV*13%DF = 1MW
* 1 will run at midsite
DF ~ 25% ⇒ 10ma@0.8GeV*25%DF = 2MW



The “high power system”
* 2 will run at far site
DF~25% ⇒ 2 × 12.5ma@0.8GeV*25%DF = 5MW

Note: Cyclotrons can have multiple dumps. All dumps will be identical at 1 MW



δ = π/2
δ = 0
Oscillation Probability
0.06
0.05
0.04
0.03
0.02
0.01
0
0
5
10
15
Kilometers
ν̄μ → ν̄e
1 km
8 km
20 km
Constrains Initial flux
Constrains rise of probability wave
Osc. maximum at ~40 MeV
Three Identical Beams with Known Flux (Both Normalization and Shape)
ν̄e
e+
p
n
Using the **near** neutrino source measure **absolute flux normalization** with νe-e events to ~1%, Also, measure the (νeO) νeC event rate.
At far and mid-distance neutrino source, Compare predicted to measured νeO (νeC) event rates to get the **relative flux normalizations between 3 sites**
For all three neutrino sources, given the known flux, **fit for the ν̄μ → ν̄e signal** with δ as a free parameter

IsoDAR Compared to Existing Similar Cyclotrons

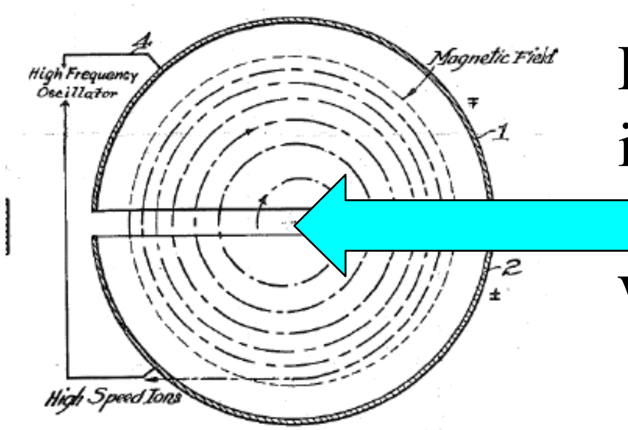
We claim we will be able to produce
~10 mA of protons @ 60 MeV
when commercial machines (IBA, Best) produce
~1 mA of protons @ 60 MeV

How do we achieve this?

Rather than one single order-of-magnitude improvement, there are four issues to solve…

1. Space Charge --- Solved by using H2+
2. Intensity of ion source -- Resolvable within 1 year
3. Inflection -- Resolvable within 2 years
4. Protection of the electrostatic septum -- solved with foil

1) Accelerate more particles for same level of space charge effects



Present machines inject p or H^-

We inject H_2^+

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

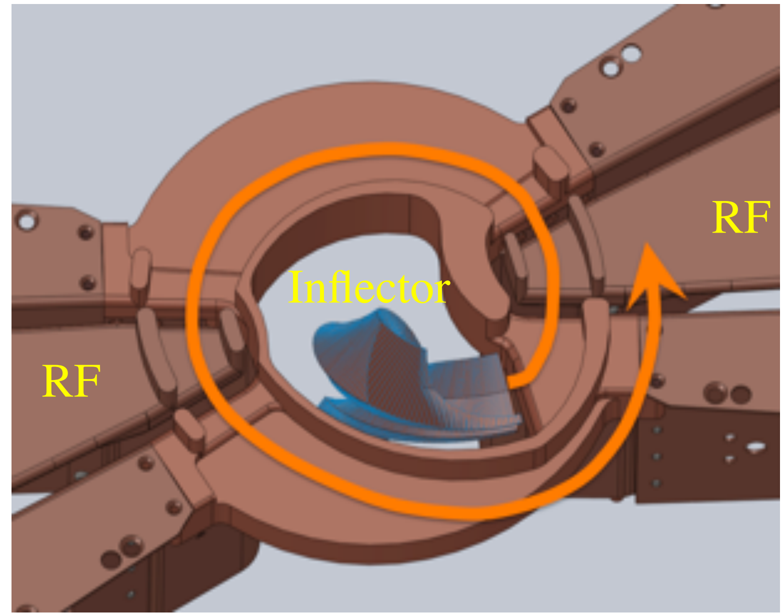
$$K = \frac{qI}{2\pi\varepsilon_0 m\gamma^3\beta^3}$$

Comparing perveance at injection:
5 mA, 35 keV/n of H2+ = 2 mA, 30 keV of p
(already achieved in commercial cyclotrons)

2) Push the envelope of H_2^+ intensities from ion sources

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

To capture 5 mA we will need between 35 and 50 mA injected.



This is not unusual for a p source, but is high for an H_2^+ source.
This is at the edge of what has been done…

Ion sources that are close to what is needed:

Proceedings of IPAC2013, Shanghai, China MOPFI035

PRELIMINARY RESULTS OF H_2^+ BEAM GENERATED BY A 2.45 GHZ PERMANENT MAGNET ECR ION SOURCE AT PKU*

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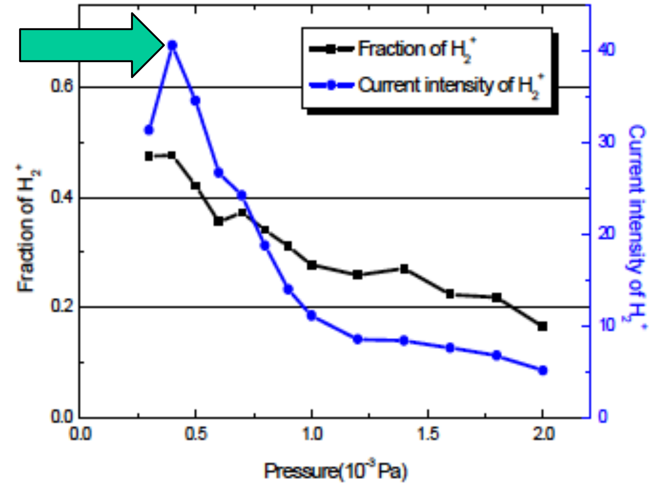
Can run 50 mA but is pulsed, not CW.
Interesting because design is similar to VIS source we have been using in our teststand.



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

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(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.

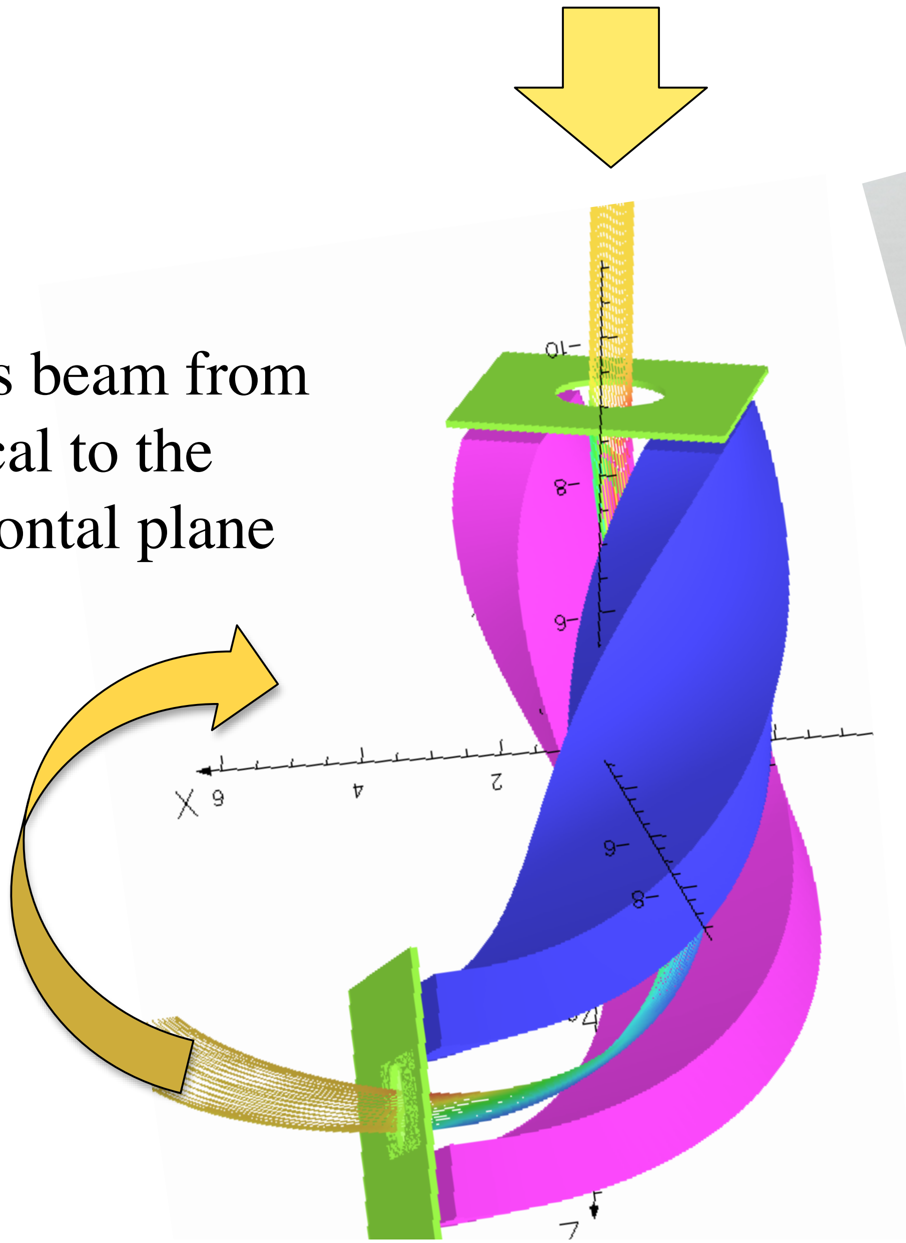
Most promising existing source?

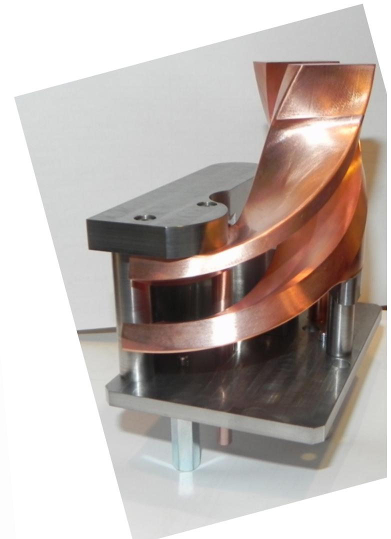
Under study!

3) Develop an unusually large spiral inflector (H_2^+ rigidity)

The beam enters axially, through a conducting "spiral inflector"

Takes beam from vertical to the horizontal plane





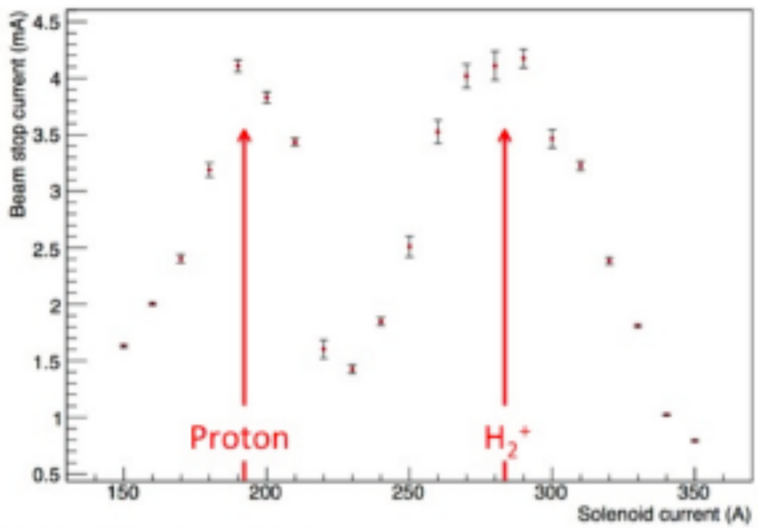
designed by MIT Postdoc Daniela Campo

Tricky to design:

- B field effects
- neutralization

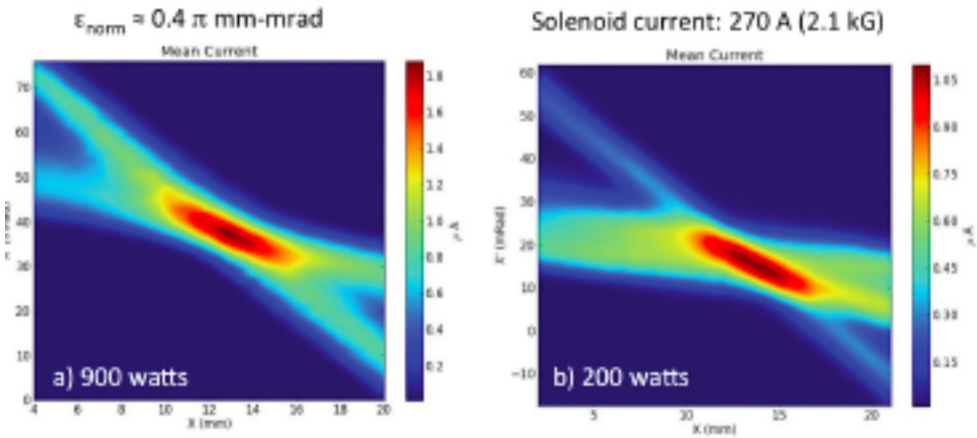
This is an iterative R&D process

Beam Stop (mA) vs Solenoid (A)



600 watts Microwave power
40 kV extraction potential

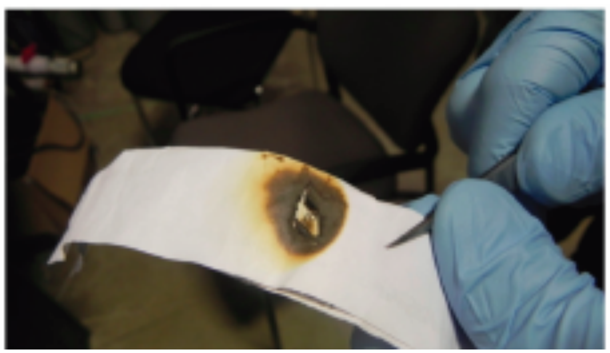
Emittance Plots

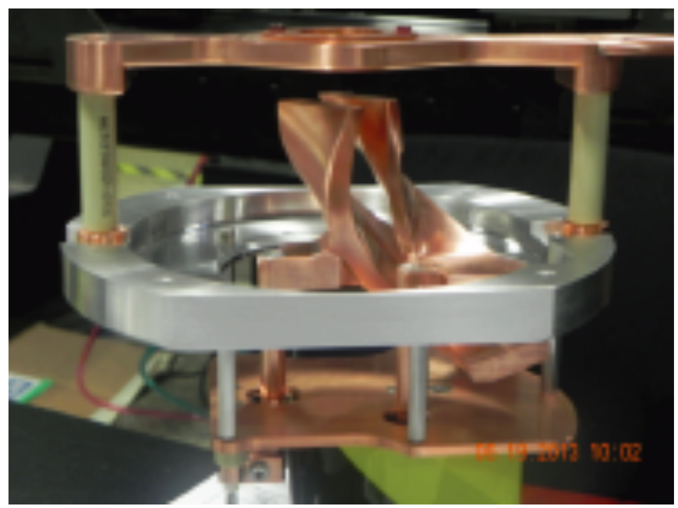


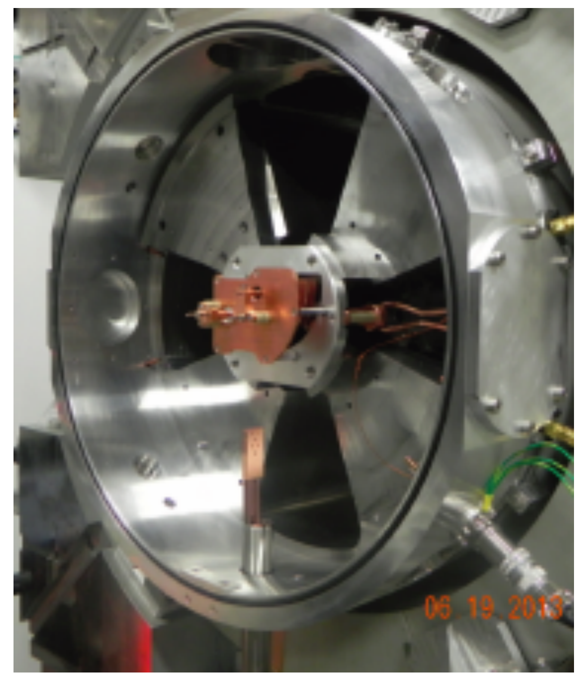
Note total current scale change

Note proton ellipse weaker

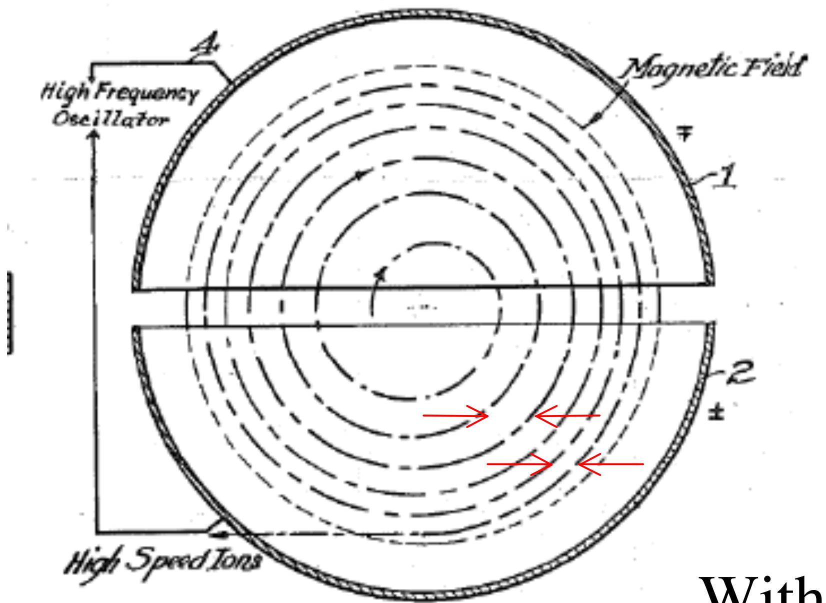
First Beam in Cyclotron!







Experiments ongoing now, and upgrades planned.

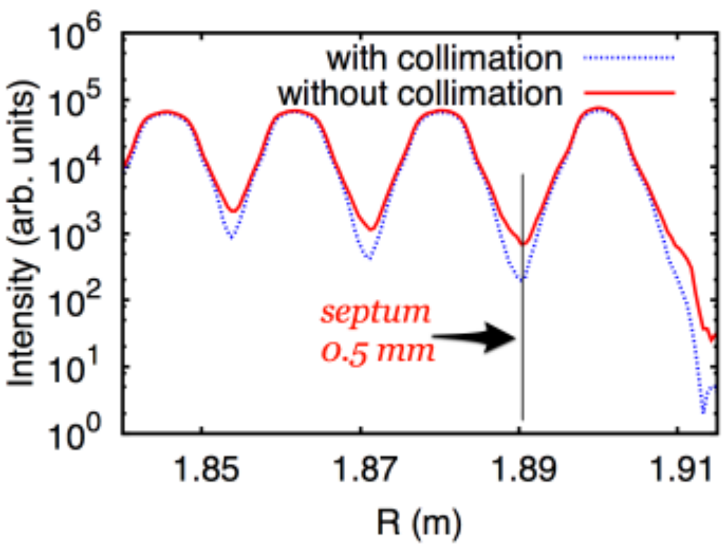


4) Avoid beam losses on the electrostatic extraction septum (protecting with a stripper foil, removing 5 μA of beam)

Without the foil:

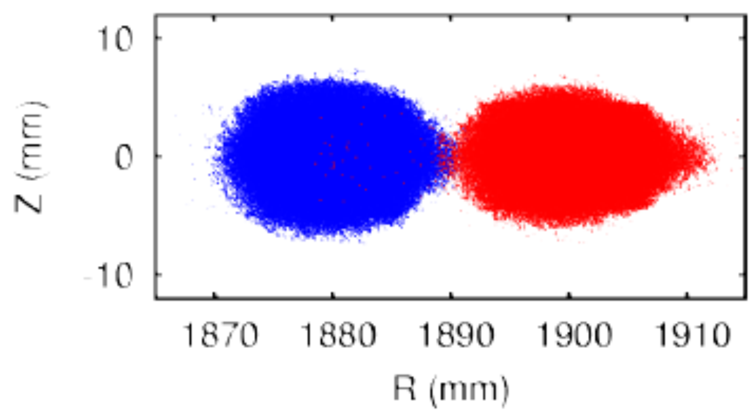
In the final four turns…

Intensity vs. position



In the final two turns…

Beam spot vs. position



What do communities outside of the Neutrino Frontier think?

From the Snowmass Accelerator Capabilities Executive Summary:

Our study heard exciting possibilities for capabilities of narrower experimental scope than Project X. The DAEδALUS collaboration proposes multiple sources of decay-at-rest anti-neutrinos for short baseline oscillation experiments. DAEδALUS would use three multi-MW H2+ cyclotrons and target stations located ~2-20km from a large hydrogenous detector to measure CP violation as a complement to the LBNE experiment. The first stage of DAEδALUS is IsoDAR, a compact 60 MeV cyclotron located only 15m from the KamLAND detector to make a definitive search for one or two sterile neutrinos. This international collaboration has engaged commercial industries to address the challenges of cost-optimization and reliable operation of multi-MW cyclotrons.

From Section 3 of the Accelerator Capability Report:

DAEdALUS [10] is a neutrino research program based on "decay-at-rest" sources. Pions are produced by interaction of 800 MeV protons on a suitable target. This energy is sufficiently above threshold for good pion yield, and low enough that pions will stop in the target before decaying. The DAEdALUS configuration consists of three sources of neutrinos as identical as possible. The highest power accelerator, located 20 km from the detector would provide 10 mA of protons at 800 MeV to the neutrino-generating targets. A current of 10 mA is approximately a factor of 5 over the highest achieved current at PSI, the world's leading high-power cyclotron today. Accelerating H2+ ions rather than protons has the potential for reducing space-charge issues at injection. Extraction of the beam at 800 MeV with a stripper foil minimizes the necessity for clean turn separation at the outer radii, only requiring an extraction channel (for the resulting protons) with sufficiently large momentum acceptance to allow for ions stripped from several overlapping turns. The use of H2+ acceleration represents a novel approach to reducing beam losses at extraction from the 800 MeV cyclotron.

To date, the DAEdALUS feasibility arguments are made by scaling from existing low-energy H- commercial cyclotrons as well as from the PSI high-power proton cyclotron. Since the high-power H2+ concept is quite novel, a systematic research is being conducted to address challenges of meeting the required performance. The most critical elements are 1) ion-source development to achieve very bright, vibrationally cold H2+ beams of at least 50 mA CW, 2) injection into cyclotrons with emphasis on bunching efficiency, space requirements and space-charge dynamics, 3) end-to-end simulations to evaluate beam stability and uncontrolled loss, and 4) atomic physics experiments of stripping and vacuum cross sections and possibly techniques for Lorentz dissociation of vibrational states in high-field (<25T) magnets in transport line between the injection and the second-stage cyclotrons. As is the case for Project X, target systems are challenging and will require sustained research.

The first phase of DAEdALUS is IsoDAR [11], a compact 600 kW cyclotron proposed to be located 15 m from the KamLAND detector for a 5 sigma search for one or two sterile neutrinos. The IsoDAR cyclotron would also be a prototypical injector for the superconducting ring cyclotron of DAEdALUS. Presently space charge effects at injection are being studied experimentally in collaboration with industrial partners.

From Accelerators for America's Future:

"The United States, which has traditionally led the development and application of accelerator technology, now lags behind other nations in many cases, and the gap is growing. To achieve the potential of particle accelerators to address national challenges will require sustained focus on developing transformative technological opportunities...."

This is quite true for cyclotrons!

From the Snowmass summary talk on Underground Capability:

…use of cyclotrons, intense sources or small modular reactors would increase the number of potential facilities for neutrino experiments in the U.S. and worldwide.

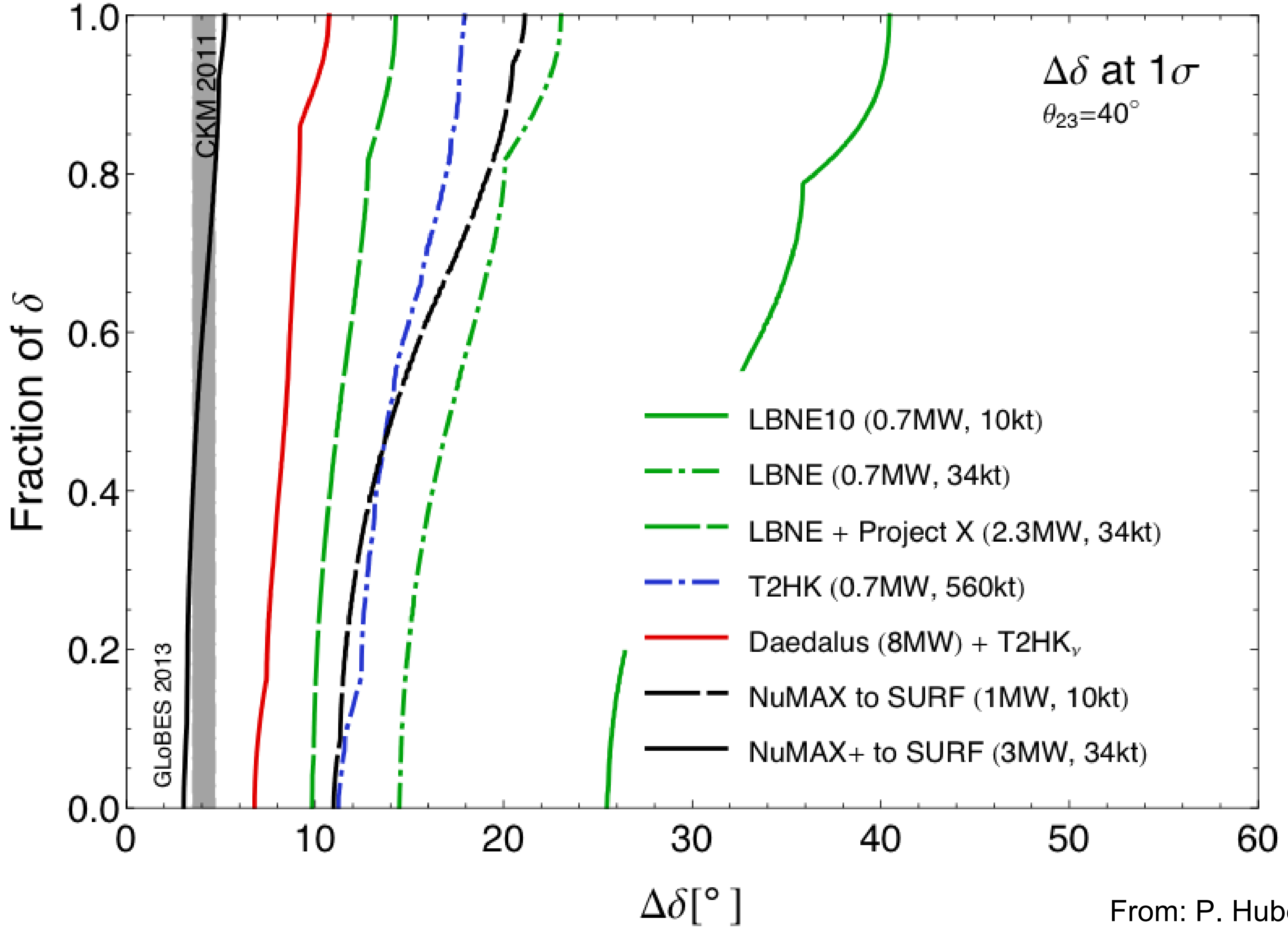
We can pair with other types of detectors…

e.g. Coherent Neutrino Scattering:

Coherent Neutrino Scattering in Dark Matter Detectors
arXiv: http://arxiv.org/abs/1103.4894 -- PRD

Measuring Active-to-Sterile Neutrino Oscillations with Neutral Current Coherent Neutrino-Nucleus Scattering
arXiv: http://arxiv.org/abs/1201.3805 -- PRD

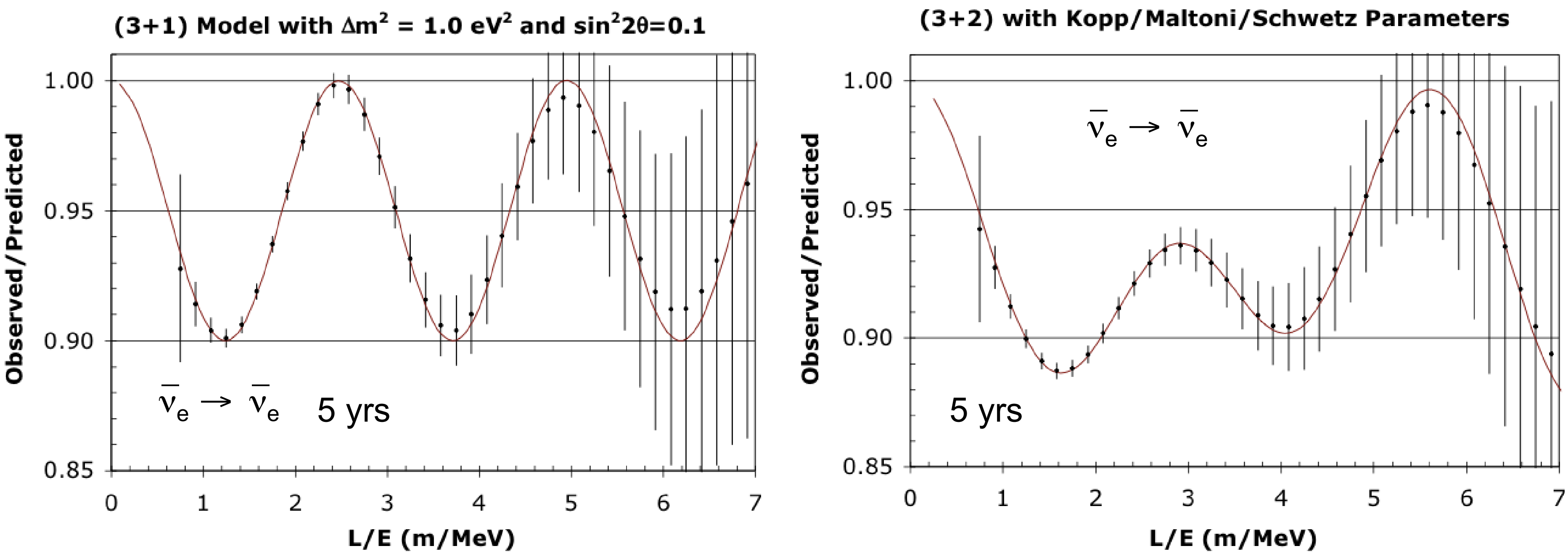
Comparison of δ_{CP} Measurement Uncertianties



From: P. Huber
Globes 2013

Oscillation L/E Waves in IsoDAR

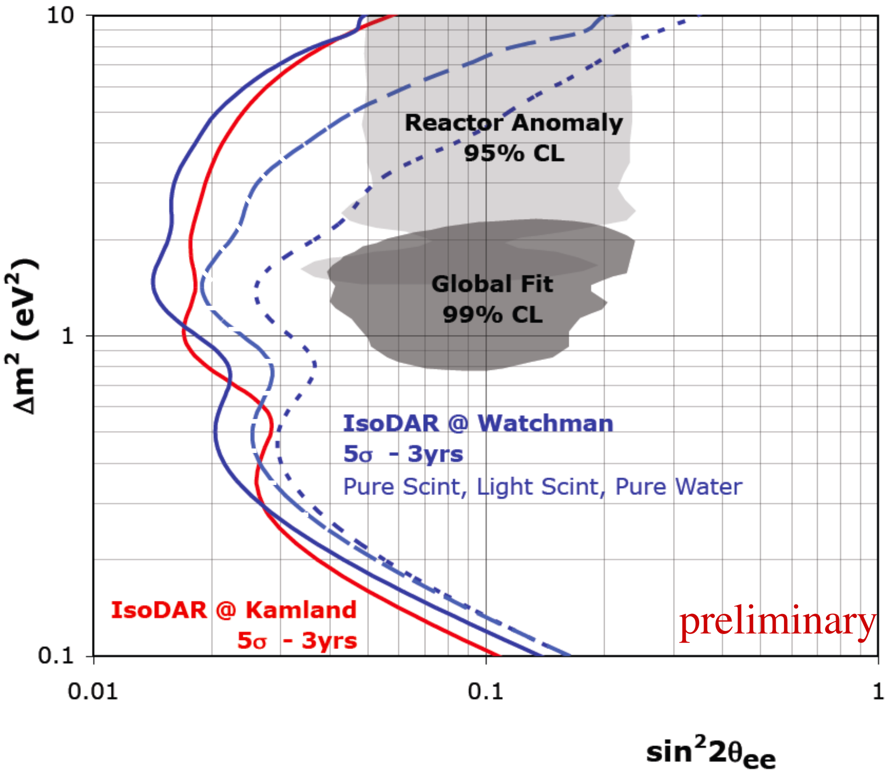
Observed/Predicted event ratio vs L/E including energy and position smearing

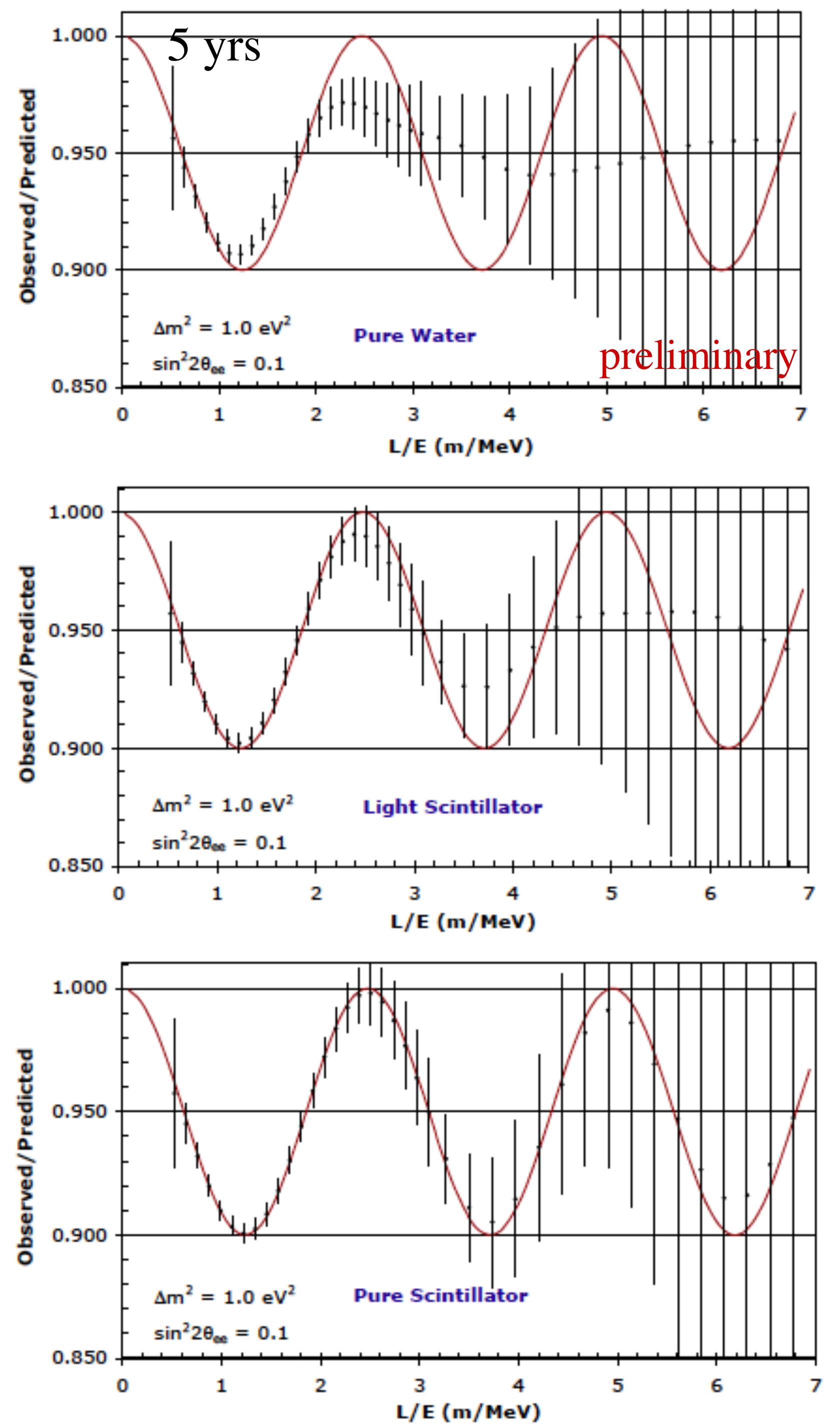


IsoDAR's high statistics and good L/E resolution has potential to distinguish (3+1) and (3+2) oscillation models

ISODAR@WATCHMAN

Sterile Neutrino Search





You want a convincing shape (L/E) analysis, not just rate.

Comparison of Future $\bar{\nu}_e$ Disappearance Proposals