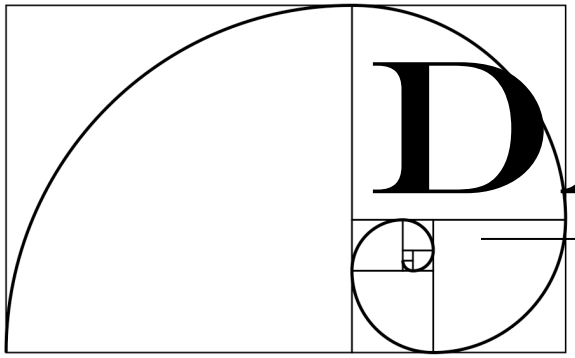
Accelerator Concepts and Challenges of the



DAEδALUS

Experiment

Jose Alonso
MIT

Accelerator Collaborators and Participants*

- Collaboration Spokespersons:
  - Janet Conrad, MIT
  - Mike Shaevitz, Columbia
- Collaborating Laboratories (Support: Internal and MIT contracts)
  - Laboratori Nazionali del Sud (INFN-LNS), Catania, Italy
    - Luciano Calabretta, Alessandra Calanna, Daniela Campo, Luigi Celona, Santo Gammino, …
  - Paul Scherrer Institute, Villigen, Switzerland
    - Andreas Adelmann, Jianjun Yang, Marco Schippers, …
  - RIKEN, Wako, Saitama, Japan
    - Hiroki Okuno
- Industries (Support: Internal)
  - Best Cyclotron Systems, Vancouver BC
    - Bruce Milton, Todd Mawhinney, Francis Labecque, …
  - IBA, Louvain la Neuve, Belgium
    - Yves Jongen, Willem Kleeven, Michel Abs, …
  - AIMA, Nice, France
    - Pierre Mandrillon, Gerome Mandrillon

* Principal funding provided by NSF through MIT

Topics

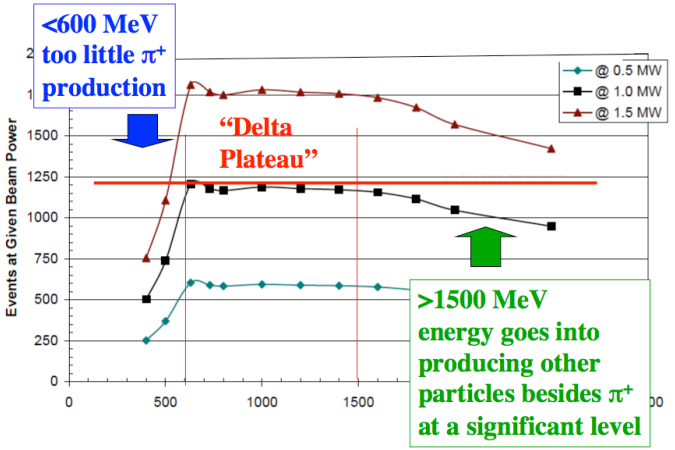
- Decay-At-Rest neutrino experiments
- Accelerator concepts: H_2^+
- Requirements and challenges
- Progress, Plans and R&D needs

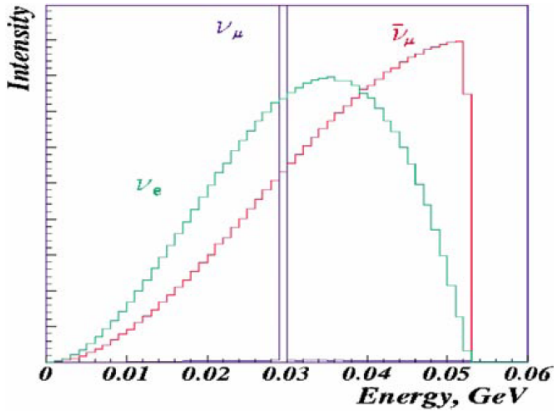
Decay-At-Rest Experiments: 1: Pions from 800 MeV Protons

- Energy comfortably above threshold
- Pions produced at low enough energy to stop before decaying
- π^- absorbed prior to decay
- Well-defined neutrino spectrum
- Mostly devoid of $\bar{\nu}_e$
  - $\bar{\nu}_e$ in primary beam $\sim 10^{-4}$
- Sensitive to appearance of $\bar{\nu}_e$
  - … oscillation from $\bar{\nu}_\mu$
- Detection: Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

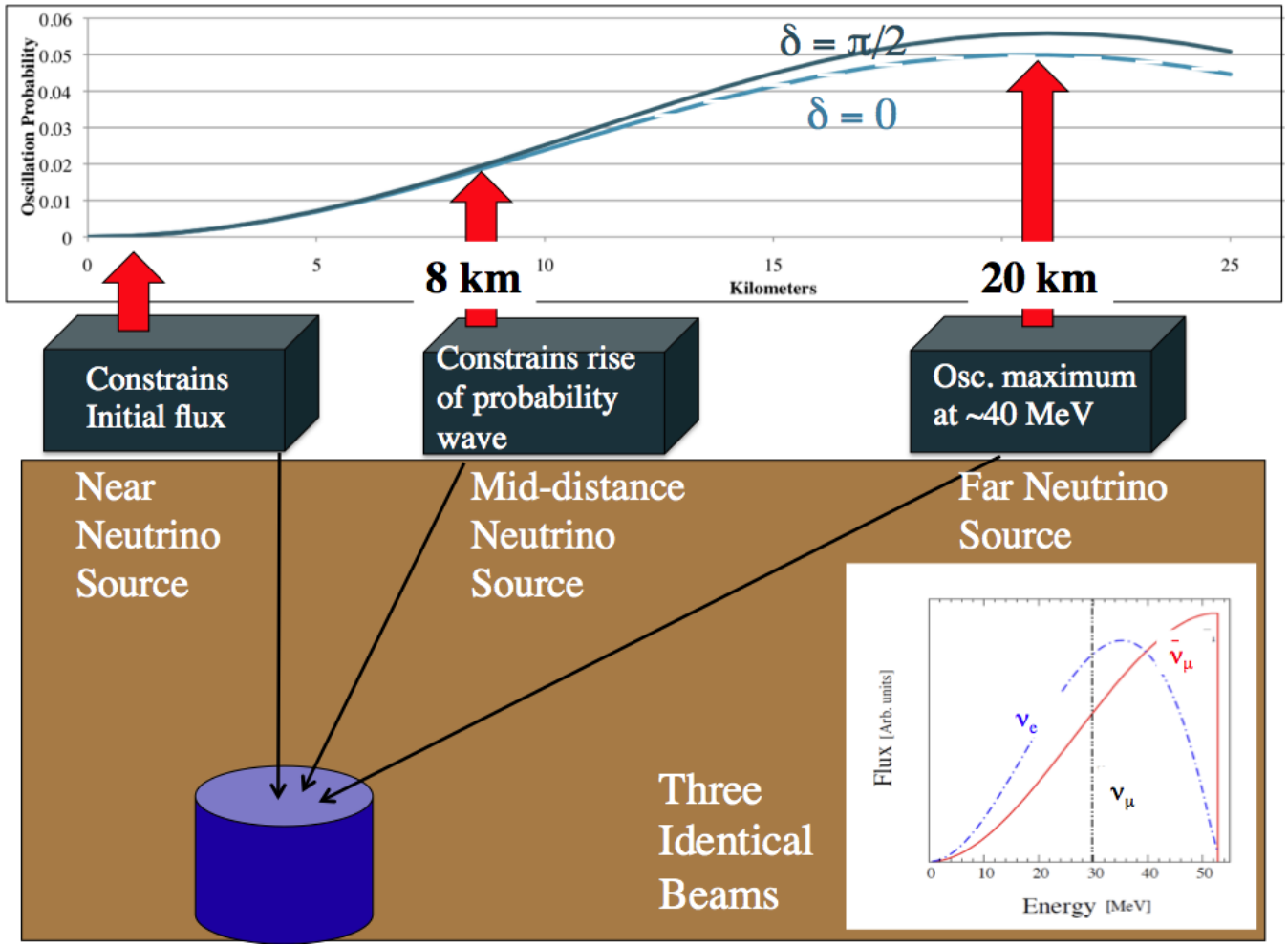
  - (need detector with high fraction of free protons: water or liquid scintillator)





DAEδALUS Configuration

Good sensitivity to
CP violation δ



Neutrino Oscillation:
$\lambda/E \approx 1/\Delta m^2$

1000 km / 2 GeV
(LBNE)
20 km / ~ 40 MeV
(DAEδALUS)

Complementarity!

LBNE in ν mode
DAEδALUS in $\bar{\nu}$

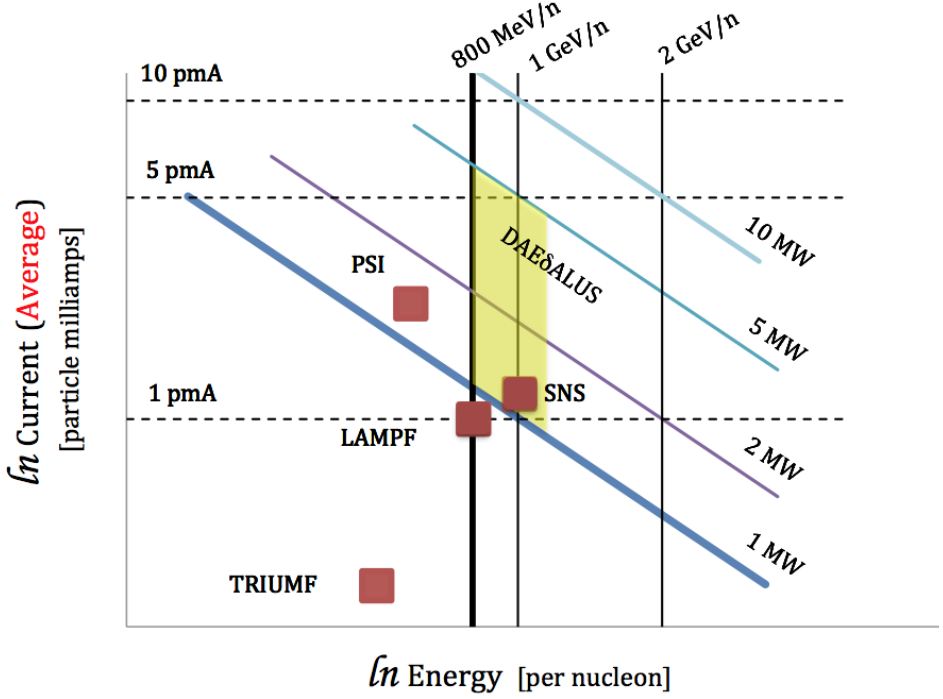
Great improvement
In statistics

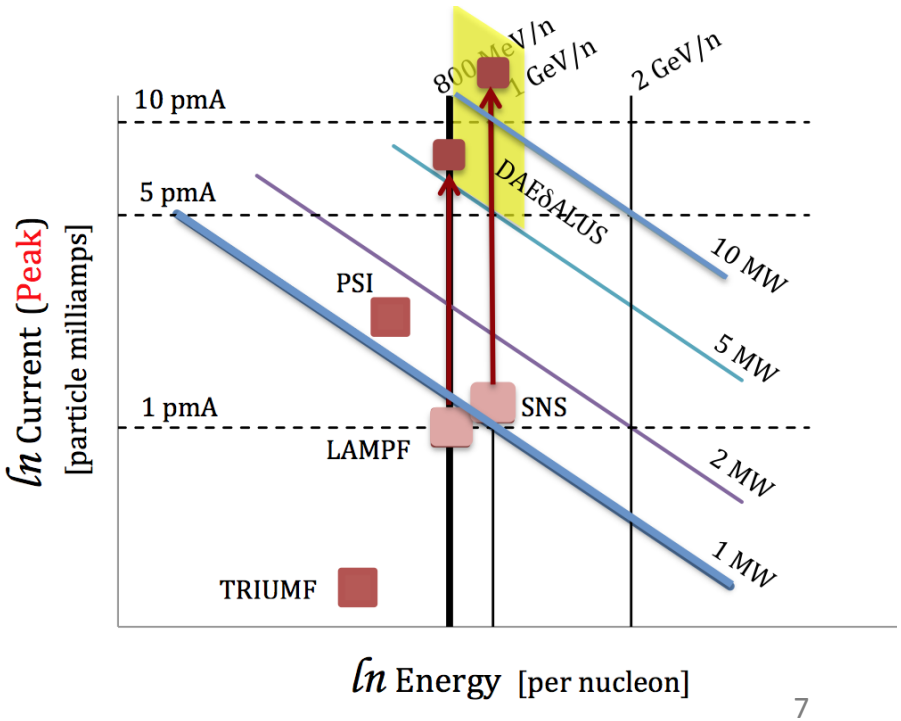
Accelerator Requirements

- Three "identical" sources
  - 800 MeV protons on target
  - Isotropic neutrino spectra requires greater flux at longer baselines
    - Not quite $\{r^2\}$, due to increased signal strength
  - Proton power on target (average):
    - Near site 1 MW
    - Mid site 2 MW
    - Far site 5 MW
      - Based on matching data rates from LBNE, and statistics for a ~10 year experiment
  - Peak current: ~10 mA
  - Size and costs must be kept as low as possible!

Implications of Timing Constraints

- Typical duty factor for each station: 20%
  - Only one machine operating at a time
  - Need time off for calibration, background

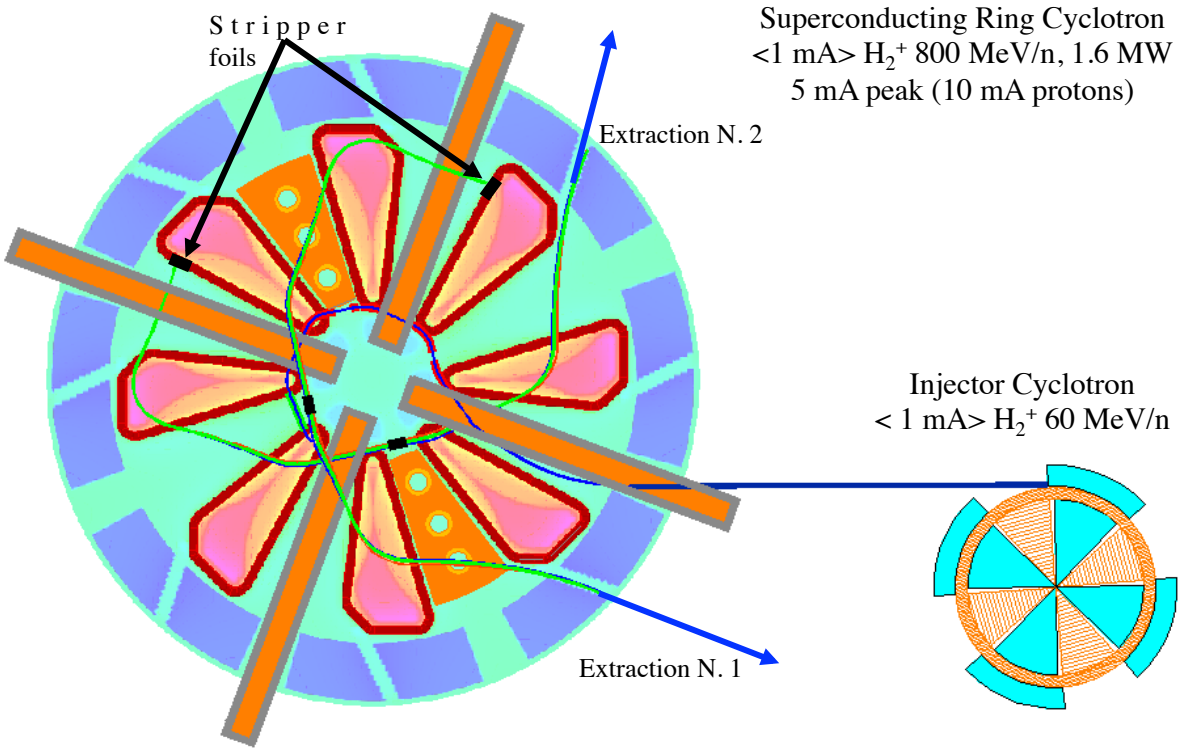




Concept: H_2^+ Cyclotrons

- Luciano Calabretta: INFN-Catania
- arXiv: 1107:0652

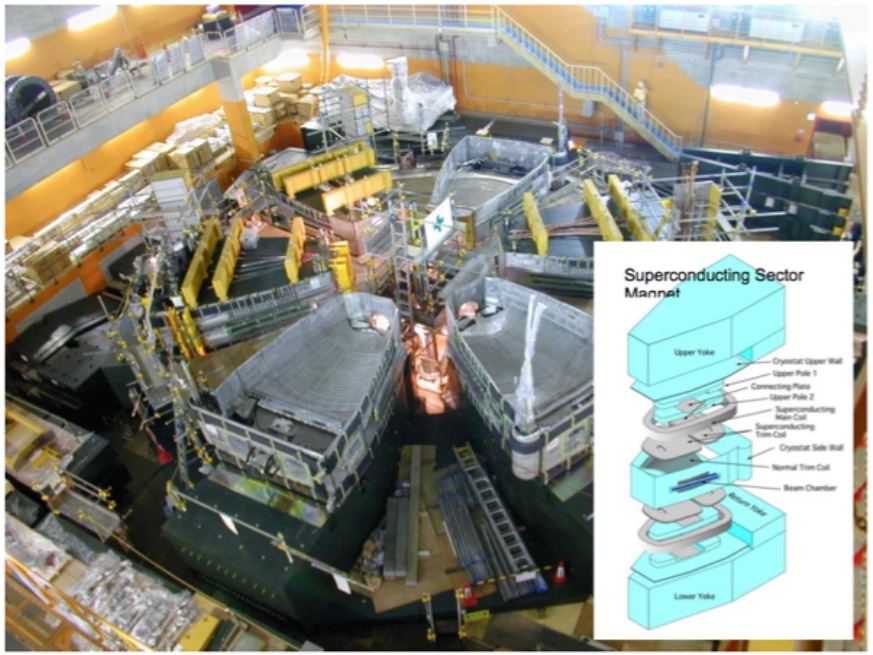
H_2^+ advantages:
- Lower space charge at injection
- Stripping extraction



Status of SRC Concept

RIKEN SRC:
Engineering Existence Proof!

RIKEN K2600 SUPERCONDUCTING RING CYCLOTRON

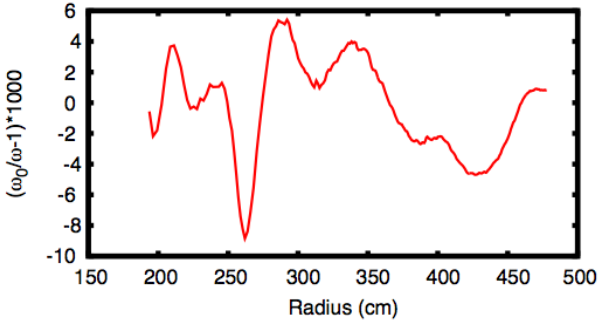


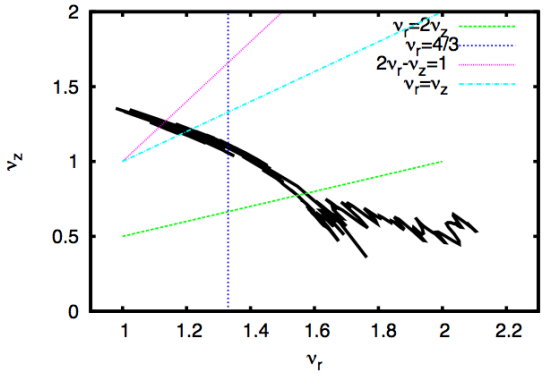
Completed November 2005 – the 140-ton cold mass cooled to 4.5K.

SRC Status

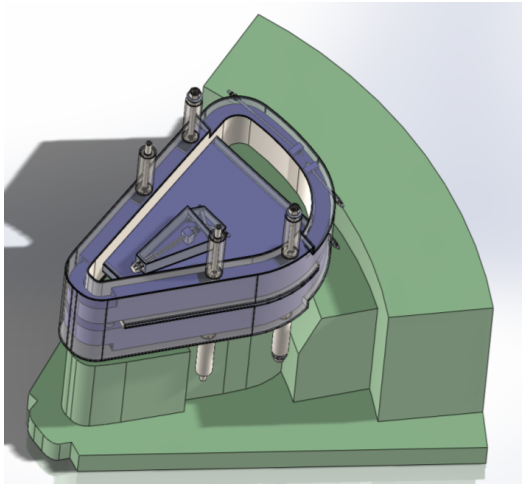
Beam Dynamics

Isochronicity (±0.4%)





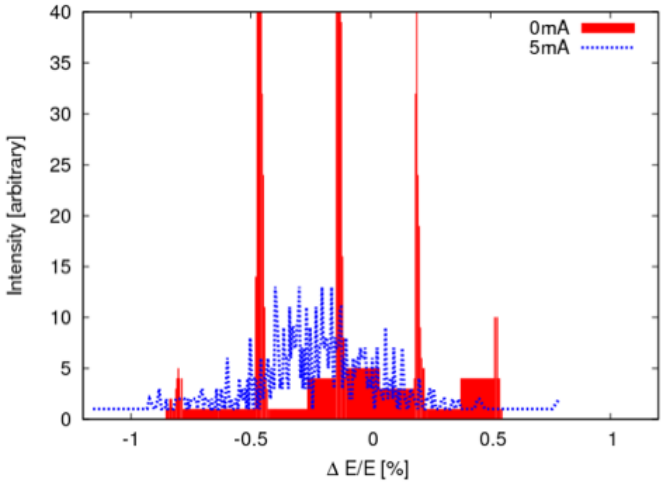
Tune diagram

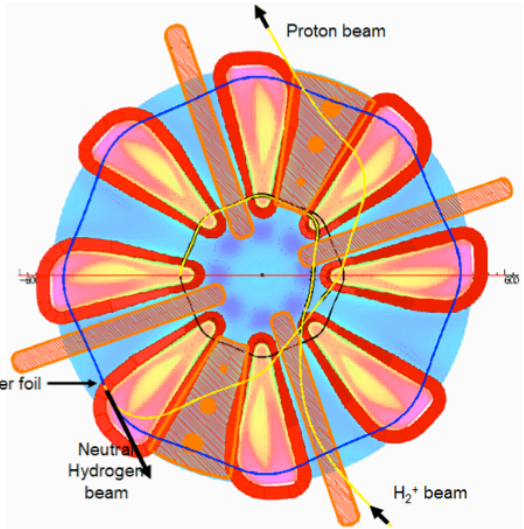


Engineering study of coil/cryostat assembly
MIT (Minervini et al)
Nov 2012

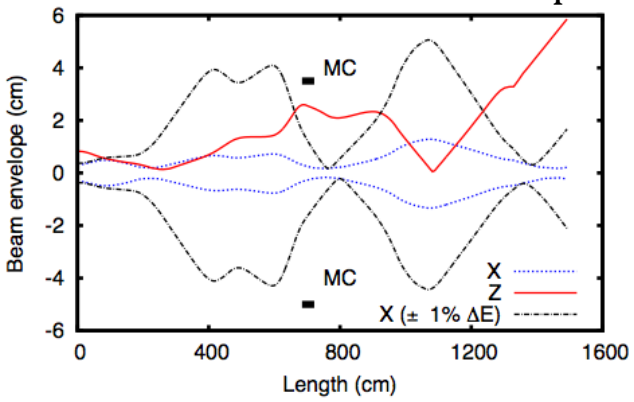
EXTRACTION

Energy spread on stripper





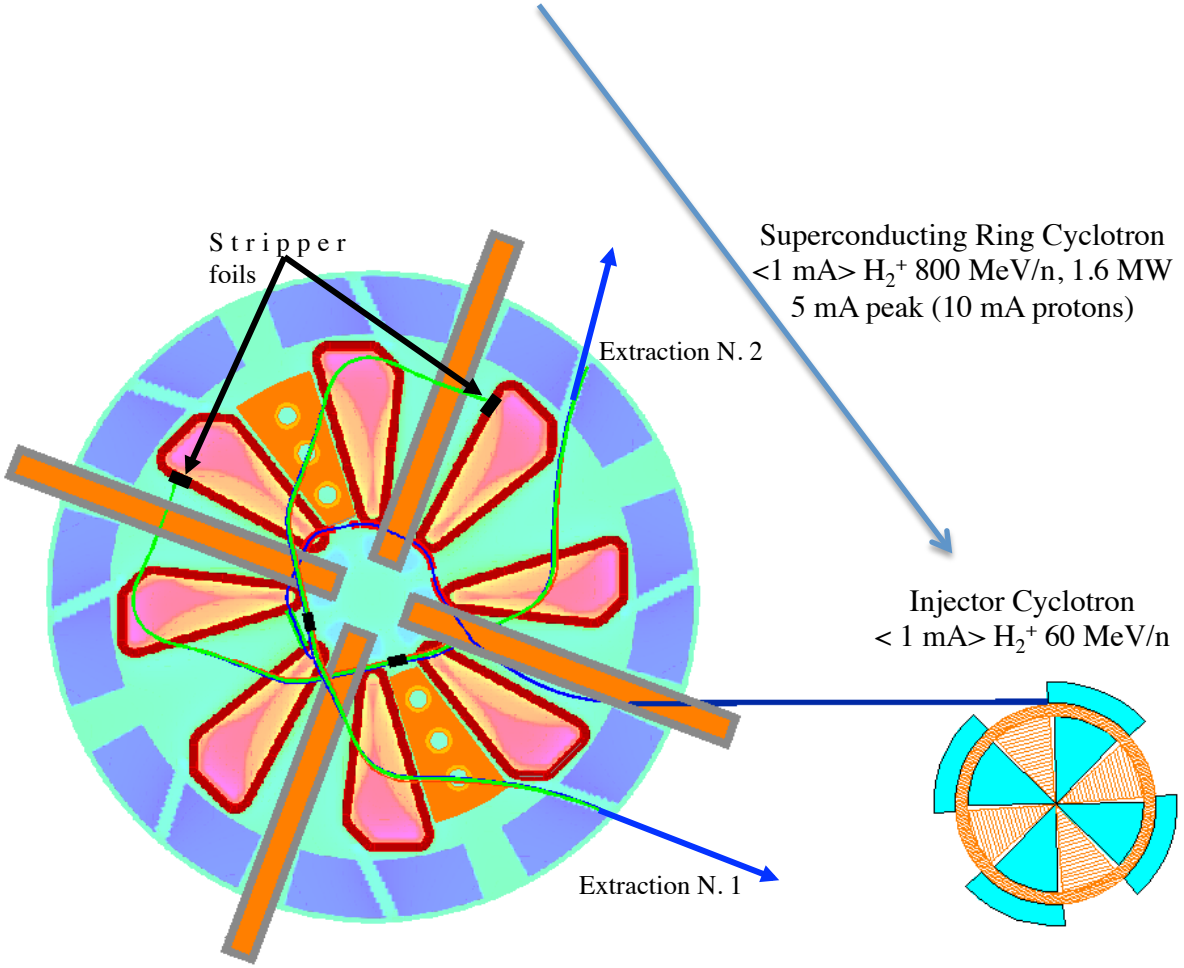
Extraction channel envelopes



Project Staging: Build Injector First

H_2^+ advantages:

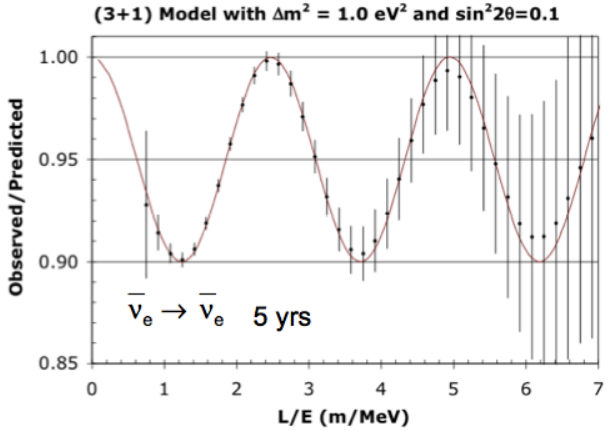
- Lower space charge at injection
- Stripping extraction

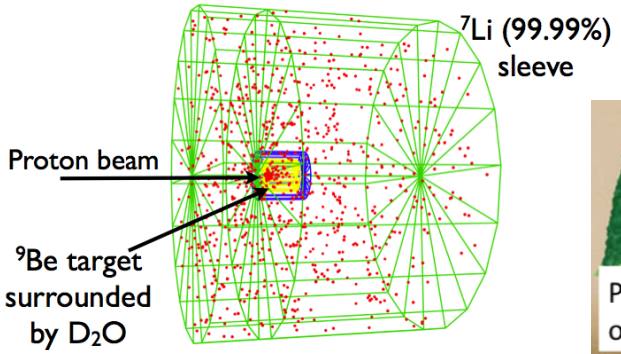


Injector Cyclotron: Basis for IsoDAR

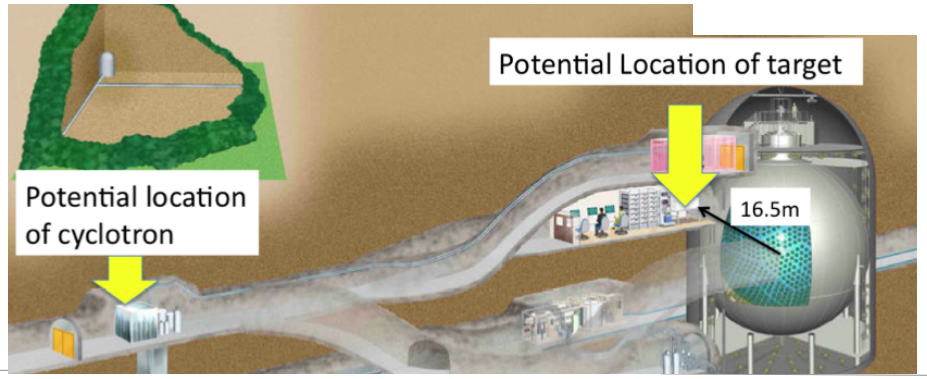
Decay-At-Rest Experiments:
2. Beta decay of ^{8}Li from 60 MeV protons

- $\bar{\nu}_e$ oscillation experiment at very short baseline
- Sterile neutrino search
  - $\Delta m^2 \sim 1$ eV^2, $\lambda < 10$ meters
    - Can see oscillations *within* detector!





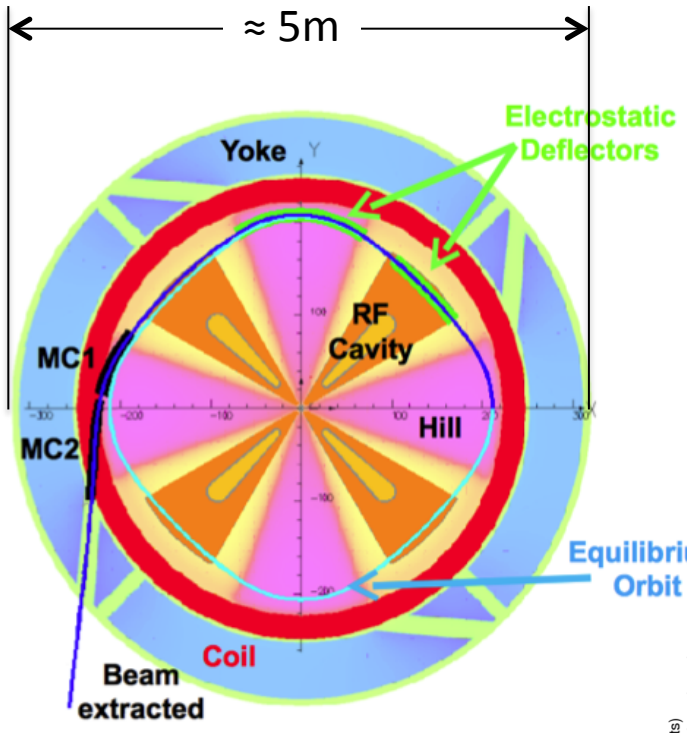
Neutrons generated in Be target, ^{8}Li produced in very pure ^{7}Li blanket

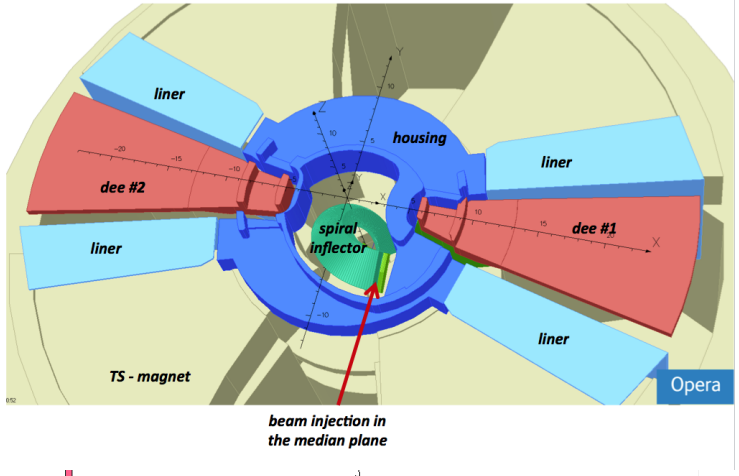


IsoDAR at KamLAND

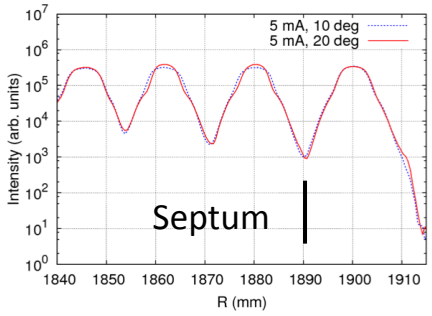
Injector Cyclotron Configuration

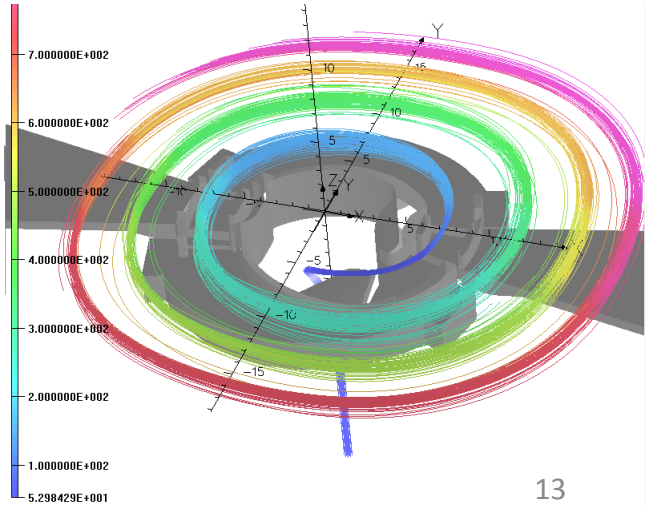
- Compact, axially-injected, septum extracted





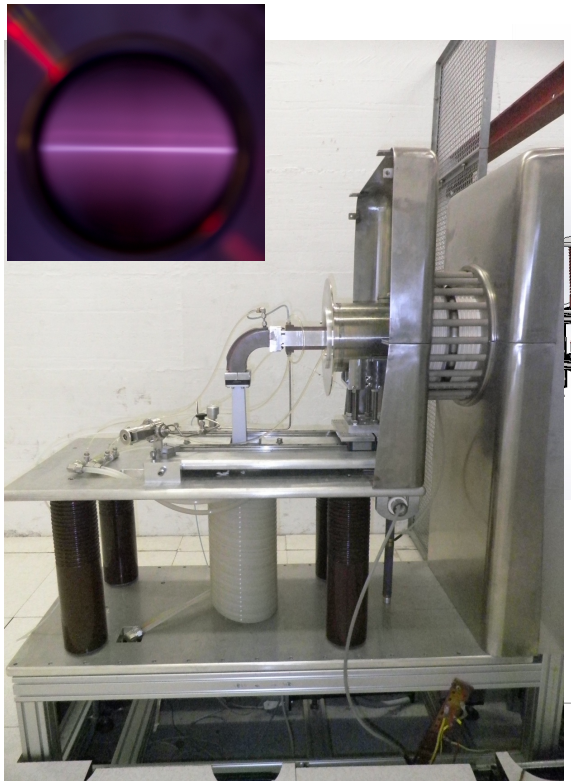
Turn separation at extraction

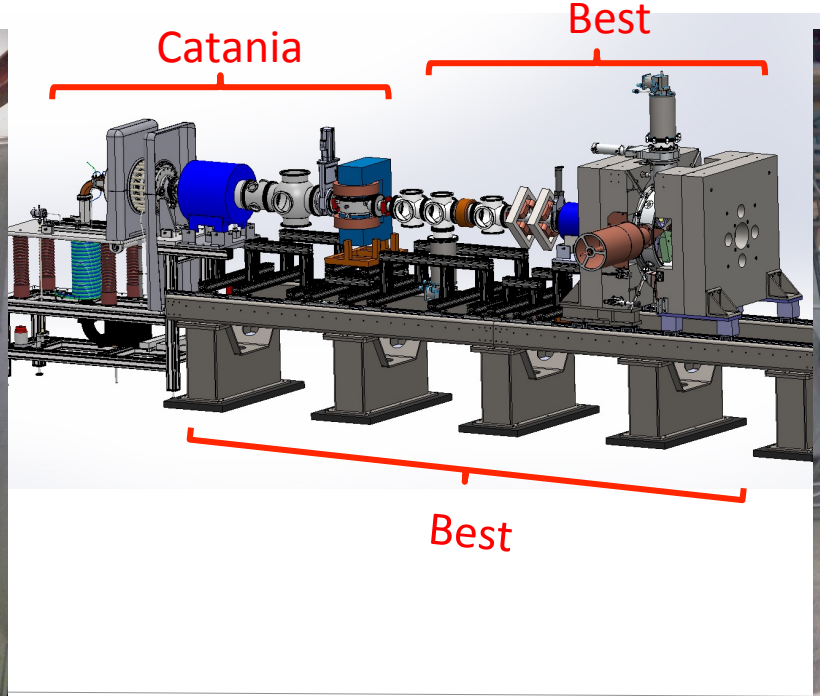


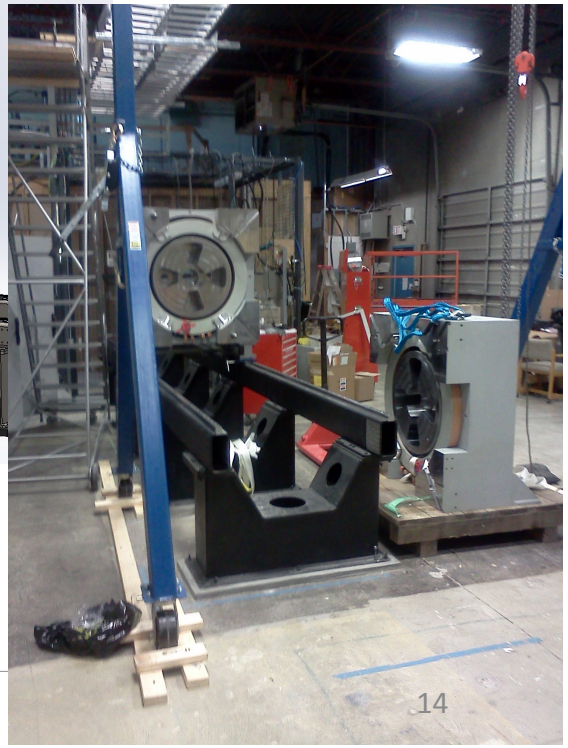


Challenges

- Space charge at axial injection
  - Being addressed this summer at Best Cyclotron Systems, Vancouver BC

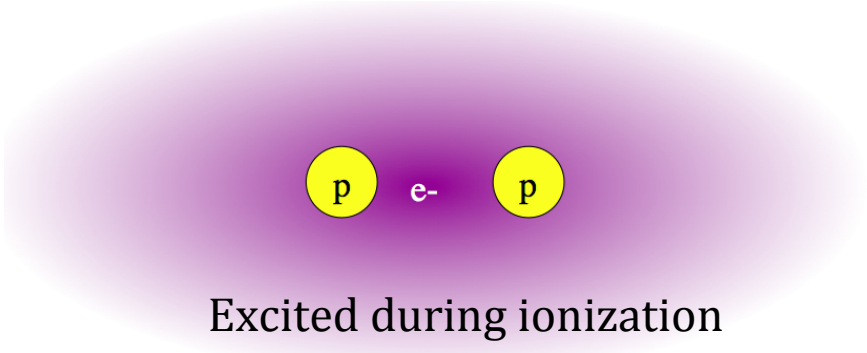




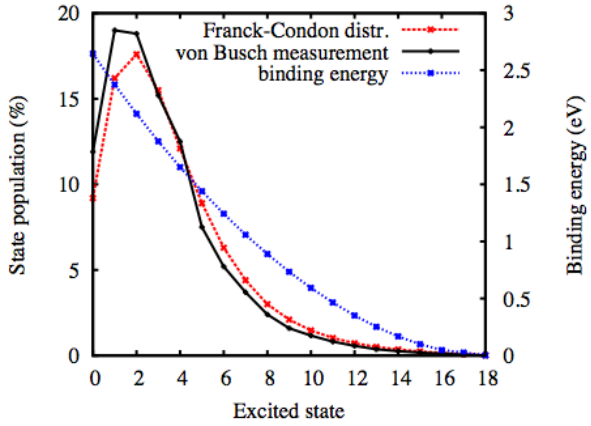


Challenges

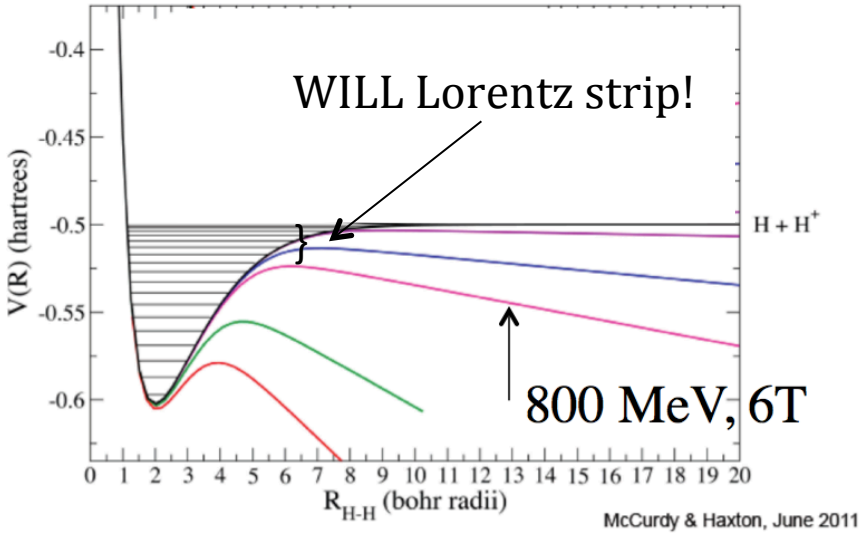
- H_2^+ Ion source: quenching vibrational states



Excited during ionization
by different proton spacing for H_2 and H_2^+



NOT a problem for IsoDAR



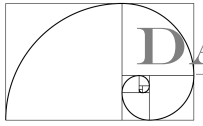
Collaborating with ORNL Atomic Physics
BUT: Test Stand, connected to Holifield is being shut down

Summary (1): Observations

- H_2^+ cyclotrons can be effective neutrino sources
  - Compact, cost-effective, modular
  - Other applications: Isotopes, ADS
- Best available beam-dynamics simulations indicate no show-stoppers
- Engineering studies and field experiences are encouraging

Summary (2): Roadmap

- Axial Injection Line and Central Region development
  - Tests in Vancouver, Spring/summer 2013
  - MIT/Catania/Best collaboration
  - Point to final design of Injector central region
- Injector Cyclotron: Unit #1
  - Deployment of IsoDAR experiment
  - Requires further simulations, engineering studies
  - Looking for collaboration with private industry
  - … producing world-class physics!
- Ring Cyclotron development
  - Need further simulations, engineering studies
  - Need prototyping of sector magnet
  - Studies of beam-loss mitigation (vacuum, injection, extraction)
- H_2^+ ion source development
  - Achieving required current levels of H_2^+ (~40-50 mA CW)
  - Quenching of vibrational states (ORNL has capabilities that may disappear!)



Extra Slides

- Note: Bibliography of DAEδALUS publications:

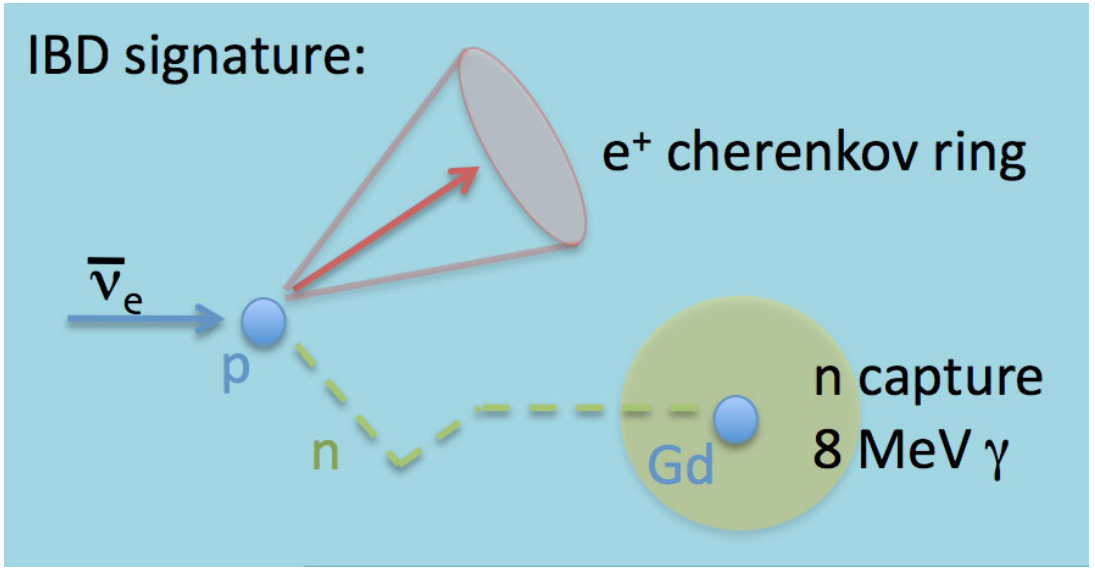
http://www.nevis.columbia.edu/daedalus/docs/publications.html

Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

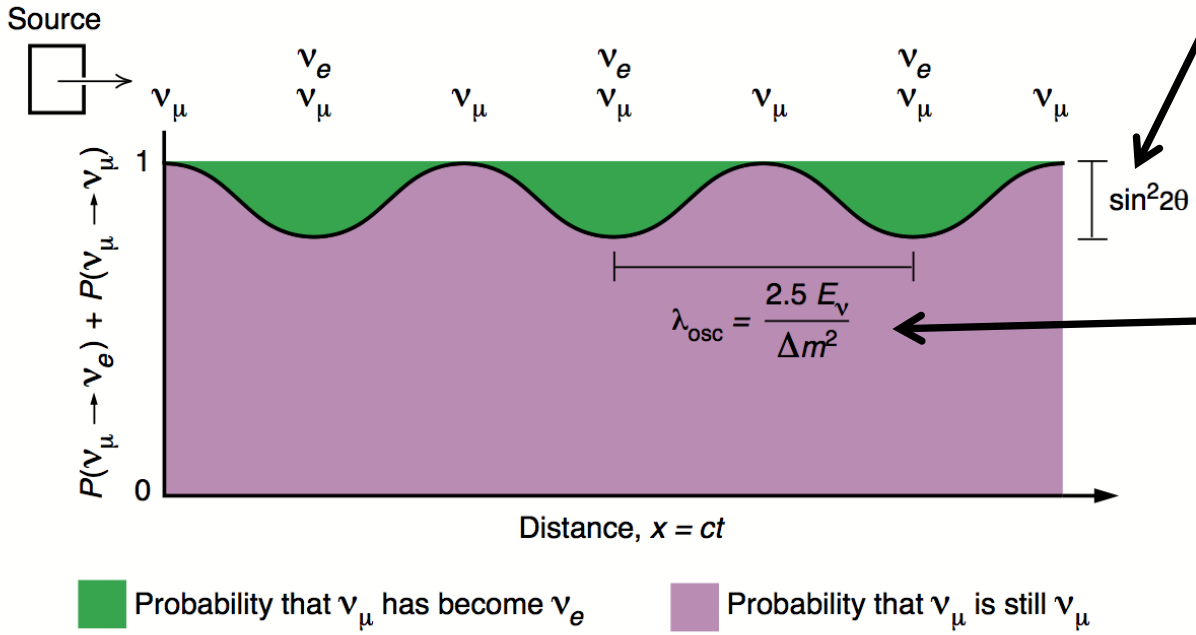
- (Relatively) high cross section
- Delayed coincidence provides excellent background suppression

~ 2 μs time to neutron capture (helps if detector is Gd doped)



Oscillations of Neutrinos

θ = mixing angle



λ = oscillation frequency

NOTE: $\lambda/E \sim 1/\Delta m^2$