Oak Ridge and Neutrinos

eHarmony forms another perfect couple

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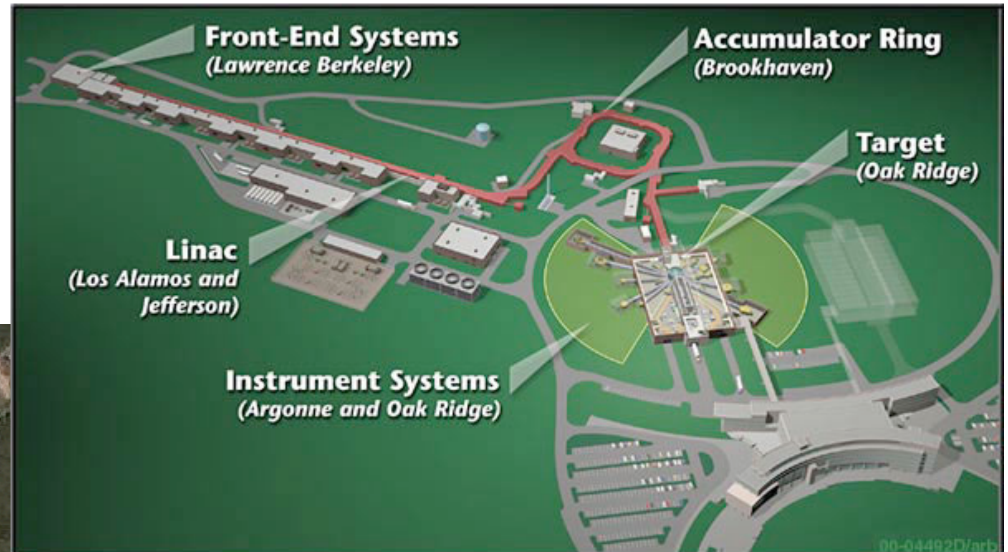
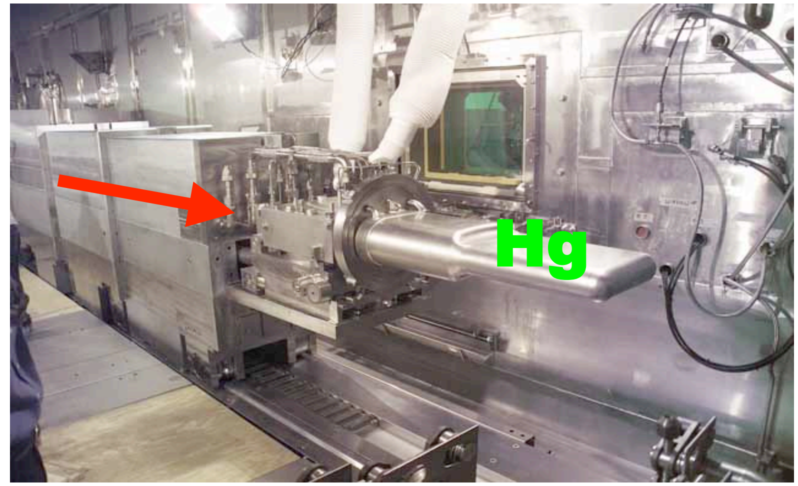
Spallation Neutron Source



Accelerator based neutron source in Oak Ridge, TN

The Spallation Neutron Source

- World's most intense pulsed accelerator-based neutron source
- 1 GeV protons
- Liquid Mercury target



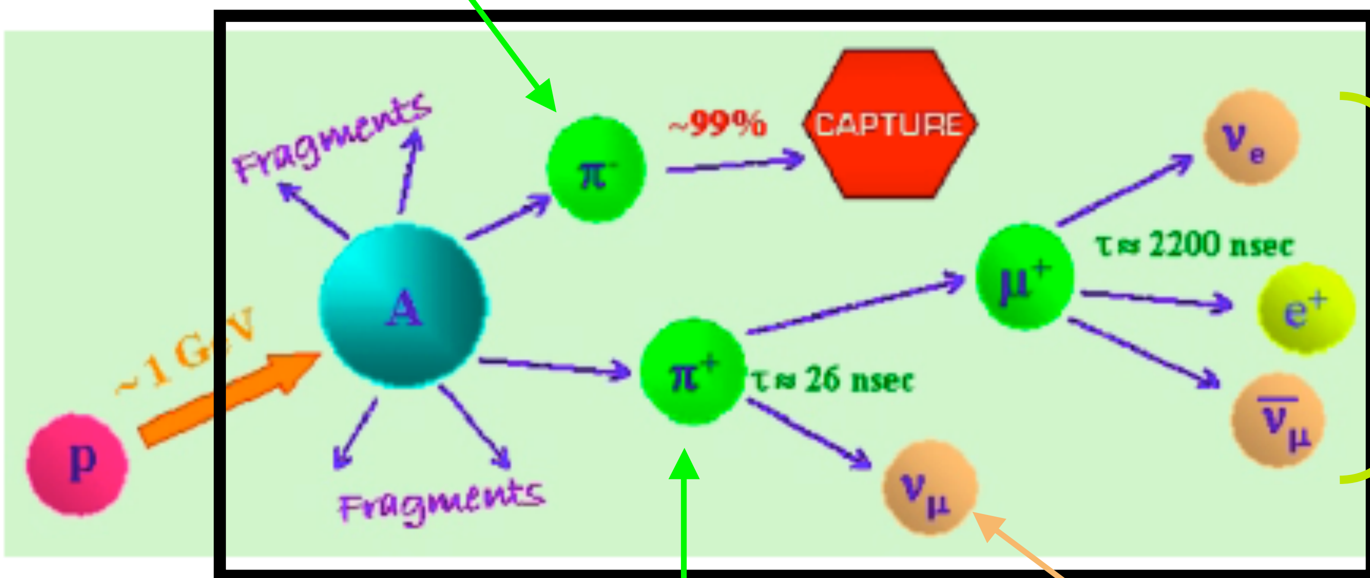
- 1.4 MW of beam at full power
  - @~400 kW. Expect ~800 by end of summer
- 60 bunches/second (9 x 10^{15} p/sec)
- Pulses 695 ns wide
  - LAMPF = 600 μs wide,
  - FNAL = 1600 ns wide
  - Latest = < 500 ns wide!

Neutrinos come for free!

The Spallation Neutron Source

Accelerator based Decay at Rest

π^- absorbed by target



E range up to 52.8 MeV

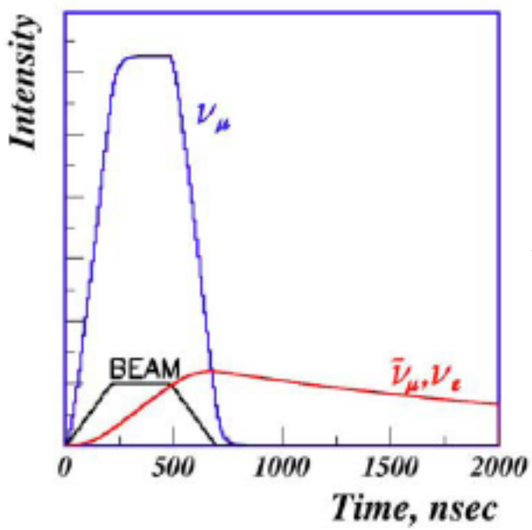
Target Area

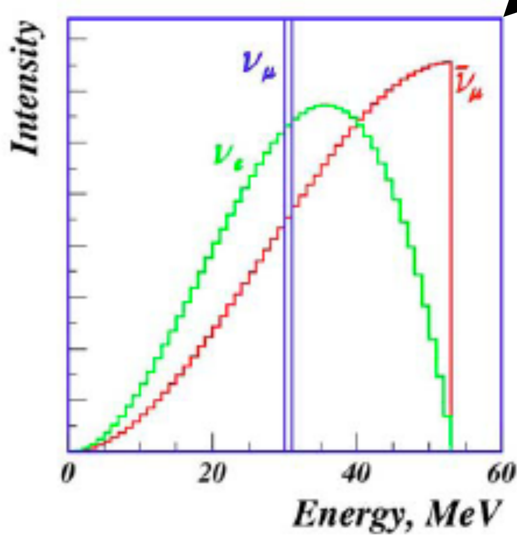
π^+ DAR

Mono-Energetic!
ν_μ = 29.8 MeV

Liquid Mercury (Hg+) target

Decay At Rest





- Advantage = Know timing of beam, lifetime of particles, use to greatly suppress cosmic ray background, isolate ~pure mono-energetic ν_μ sample

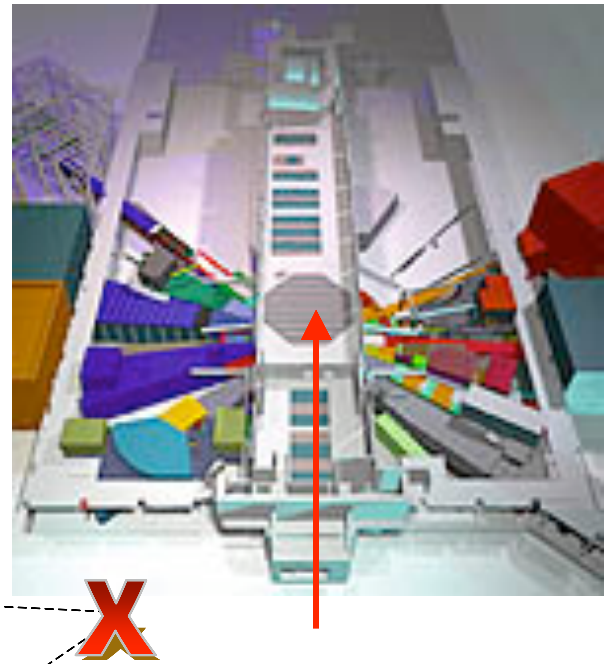
- Advantage = extremely well defined flux

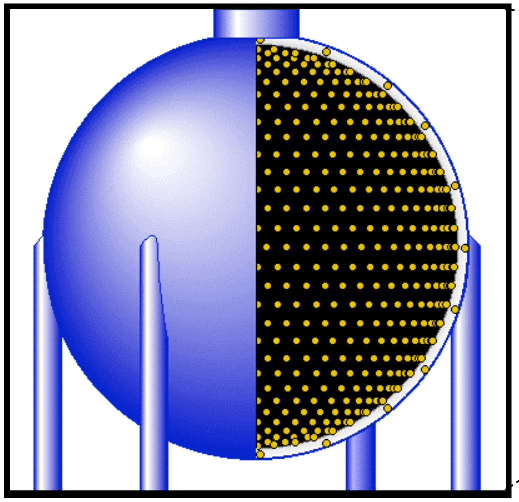
- Potential disadvantage = Low E limits choices of neutrino interactions

- Potential disadvantage = Beam is isotropic - no directionality
  - Hard to make an intense ν beam

The Osc-SNS Experiment

- ~60-100 m upstream of the beam dump/target
  - Removes DIF bgd
- Homogeneous liquid scintillator detector (~800 tons)
- Mineral oil + scintillator
  - Increase light of low-E particles produced in ν interactions





- Flexible-arm deployment system for calibration sources (1-50 MeV)
  - Cosmic ray μ (decay e- endpt 52.8 MeV)
  - ^{16}N produces a beta tagged 6.1 MeV gamma
  - ^{8}Li produces electron E spectrum up to 15 MeV
  - ^{252}Cf produces fission neutrons

Osc-SNS Physics Plan

- Neutrino oscillations
  - 3 appearance
  - 2 disappearance ν_μ, ν_e
    - Test disappearance to 6% by measuring ratio of elastic scattering on electrons (ν_μ / ν_e + anti-ν_μ)
    - $\mu_{\nu\mu}$ best limit from LSND ($< 6.8 \times 10^{-10}$)
- Search for sterile neutrinos
  - Range of interest to astro/cosmology
- Cross Section measurements
- Test LSND/MB excess

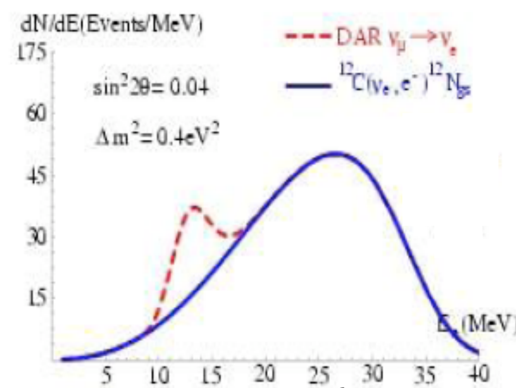
Bread and Butter

- CP Violation
- World's largest sample of ν_μ NC events for xsec measurement
- Test μ-e universality
  - $R_1 = \sigma_{NC}(\nu_e + \text{anti-}\nu_\mu)/\ \sigma_{NC}(\nu_\mu)$
  - $R_2 = \sigma_{NC}(\nu_e + \text{anti-}\nu_\mu)/\ \sigma_{CC}(\nu_e)$
  - Improve KARMEN results by order of mag.
    - $R_2 = 1.17 \pm 0.11 \pm 0.012$, calculated values are 1.08, 1.13, 1.27

Appearance Analyses

- Oscillation searches at SNS can be performed with CCQE interactions
- Probes lower Δm^2 (.001 to 10 eV^2), low $\sin^2 2\theta$ (0.00001 to 0.01), impact SN/BBN physics

- Appearance : anti-$\nu_\mu \rightarrow$ anti-ν_e
  - anti-ν_e + p $\rightarrow$ e^+ + n, n + p $\rightarrow$ d + 2.2 MeV γ
  - Time separation = 186 μs
  - No background from intrinsic ν_e



E of e^- (MeV)

- Appearance : $\nu_\mu \rightarrow \nu_e$
  - ν_e + ^{12}C $\rightarrow$ e^- (~13 MeV) + $^{12}N_{gs}$
  - $^{12}N_{gs}$ $\rightarrow$ ^{12}C + e^+ (~8 MeV) + ν_e
  - Mono-energetic ν_μ = classic bump on a background
  - Time separation within 50 ms

Sterile Neutrinos

- Sterile neutrinos = RH neutrinos, don't interact with other matter (LH = SM, Weak)

- Use super-allowed NC interactions to search for sterile neutrinos (Disappearance)
  - $\nu_x + C \rightarrow \nu_x + C^*$
  - $C^* \rightarrow C +$ 15.11 MeV photon

- KARMEN measured NC xsec rate consistent with theory, 20% total error, half due to stats!
  - $3.2 \pm 0.5 \pm 0.4 \times 10^{-42}$ cm^2, Phys. Lett. B 423 (1998)
- SNS = 100x KARMEN stats for this measurement, smaller systematic errors

Osc-SNS Detector Rates / Year

$\nu_e\ ^{12}C \rightarrow e^-\ ^{12}N_{gs}$	6940
$\nu_e\ ^{12}C \rightarrow e^-\ ^{12}N^*$	3178
Total $\nu_e\ ^{12}C \rightarrow e^-\ X$	**10,118**

$\nu_\mu\ ^{12}C \rightarrow \nu_\mu\ ^{12}C^*_{15.11}$	2740
anti-$\nu_\mu\ ^{12}C \rightarrow$ anti-$\nu_\mu\ ^{12}C^*_{15.11}$	5553
$\nu_e\ ^{12}C \rightarrow \nu_e\ ^{12}C^*_{15.11}$	4578
Total $\nu\ ^{12}C \rightarrow \nu\ ^{12}C^*_{15.11}$	**12,871**

800 ton detector @ 60 m, 50% eff

Why the Osc-SNS?

- Multi-faceted physics program
  - Perform several high stat low syst measurements
- Accelerator/source already funded & built!
  - Need 10-15M for detector
- Neutrino experiment is strictly symbiotic!
- Beam structure allows excellent and simultaneous measurements in neutrino, anti-neutrino modes
- Well known E spectrum to allow precise measurements

Backup Slides

SNS Production Statistics

- 23% p produce π^+
- 85% π^+ decay
  - 0.7% DIF
- 100% μ+ decay
  - ~100% DAR

- 13.7% p produce π^-
- 0.5 % π^- decay
  - 100% DIF
- 25 % μ^- decay
  - ~100% DAR

- For 9×10^{15} p/sec on target get
  - 1.76×10^{15} of each flavor ν_μ, anti-ν_μ, ν_e
  - 6.17×10^{12} of anti-ν_μ, 1.54×10^{12} of ν_μ, anti-ν_e
- anti-ν_e / anti-$\nu_\mu < 9 \times 10^{-4}$
  - expect x10 reduction as MC becomes more advanced
- Flux @ 60 m from target = $3.9 \times 10^6\ s^{-1}\ cm^{-2}$ of π^+ ν_μ, anti-ν_μ, ν_e

3M POT : 1 GeV protons, 60 Hz, 1.4 MW beam

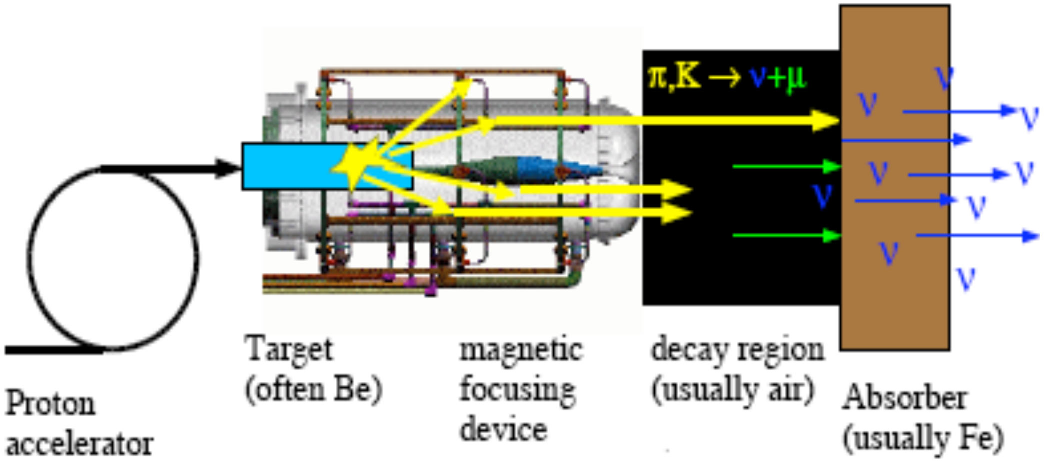
Osc-SNS Collaborators

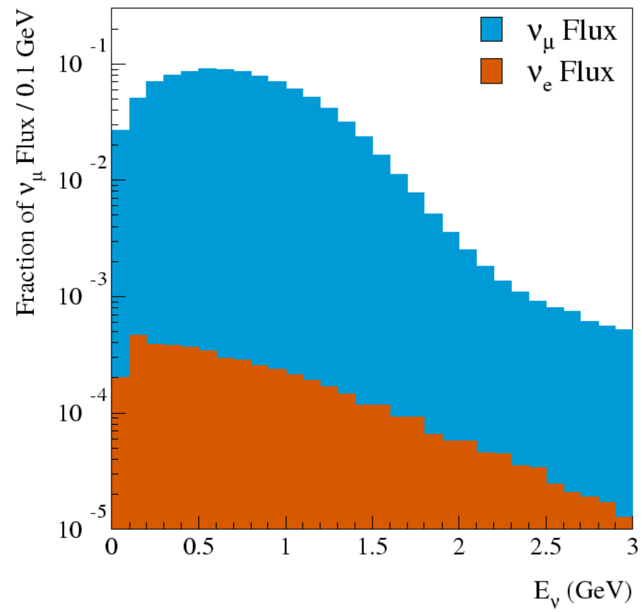
- U. Alabama, U. Florida, Indiana U, LANL, Indiana State U, U Michigan, Perdue U Calumet, U South Carolina, ORNL/U Tennessee

Neutrino Masses

- Electron neutrino < ~2 eV
  - Tritium beta decay experiments
- Muon neutrino < few MeV
- Tau neutrino < few MeV

Decay In Flight





- Advantage : more intense beam because mesons are focused (not isotropic)
- Advantage : can select neutrino, anti-nu beam
- Disadvantage : difficult to understand the flux (in content and in E)!

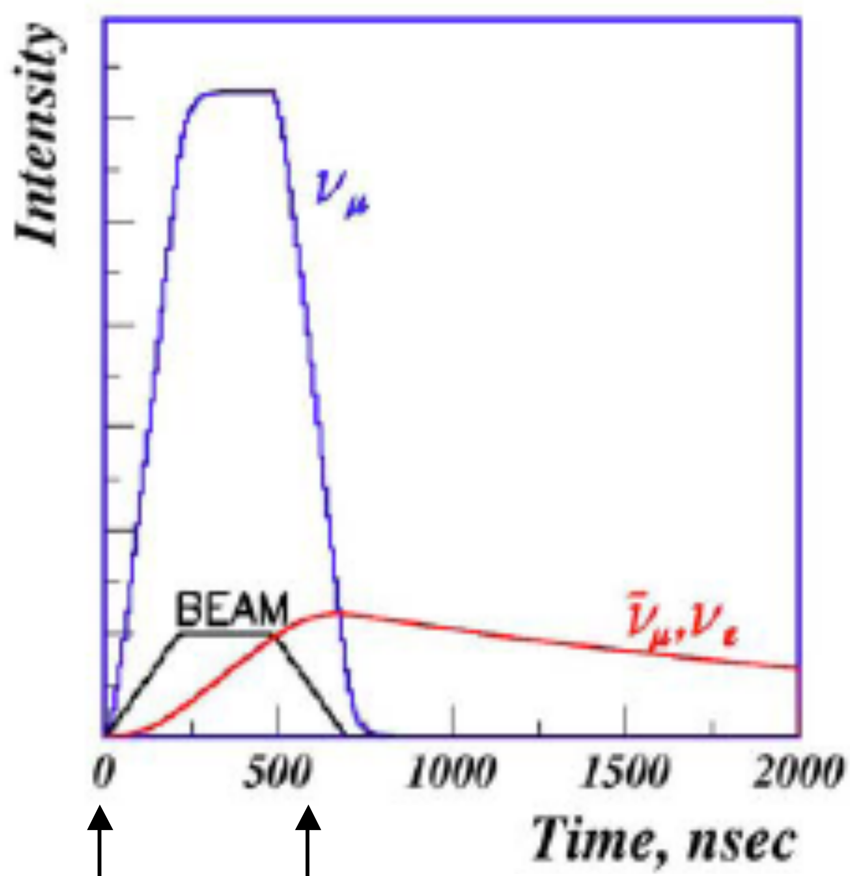
Spallation

- Spallation describes the break-up or disintegration of a nucleus into several parts
- This process typically occurs when the nucleus is bombarded with a high energy particle

The Spallation Neutron Source

- $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - τ = 26 ns
- $\mu^+ \rightarrow e^+ + \text{anti-}\nu_\mu + \nu_e$
  - τ = 2.2 μs

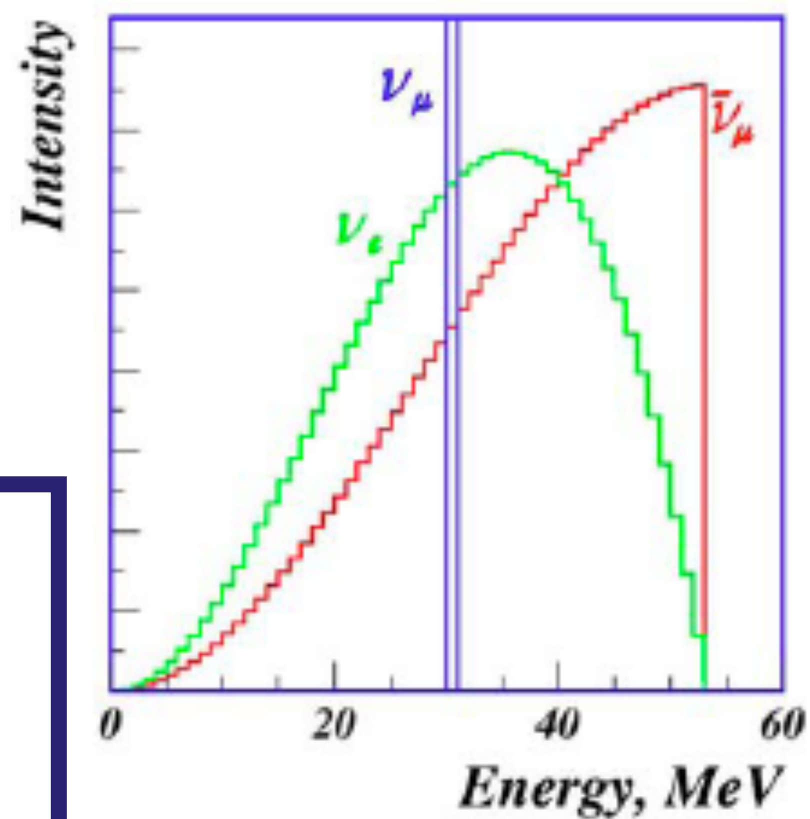
- Pulse timing, beam width, lifetime of particles = excellent separation of neutrino types



Simple cut on beam timing = 72% pure ν_μ

The Spallation Neutron Source

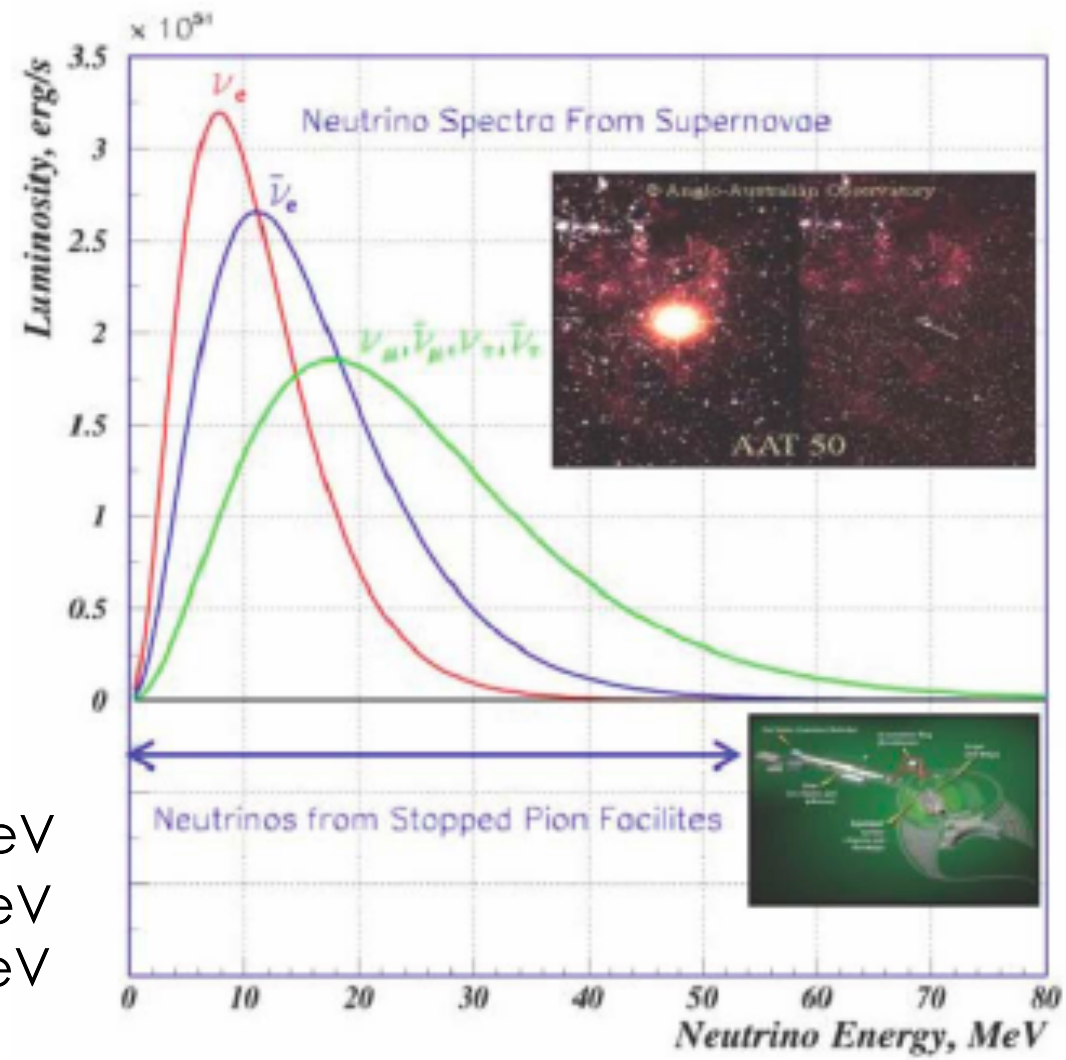
- $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - τ = 26 ns
- $\mu^+ \rightarrow e^+ + \text{anti-}\nu_\mu + \nu_e$
  - τ = 2.2 μs



- Mono-energetic ν_μ
  - E = 29.8 MeV
- anti-ν_μ, ν_e = known distributions
  - end-point E = 52.8 MeV

The Spallation Neutron Source

Neutrino spectrum in range relevant to astrophysics / supernova predictions



ν_e = ~10 - 13 MeV

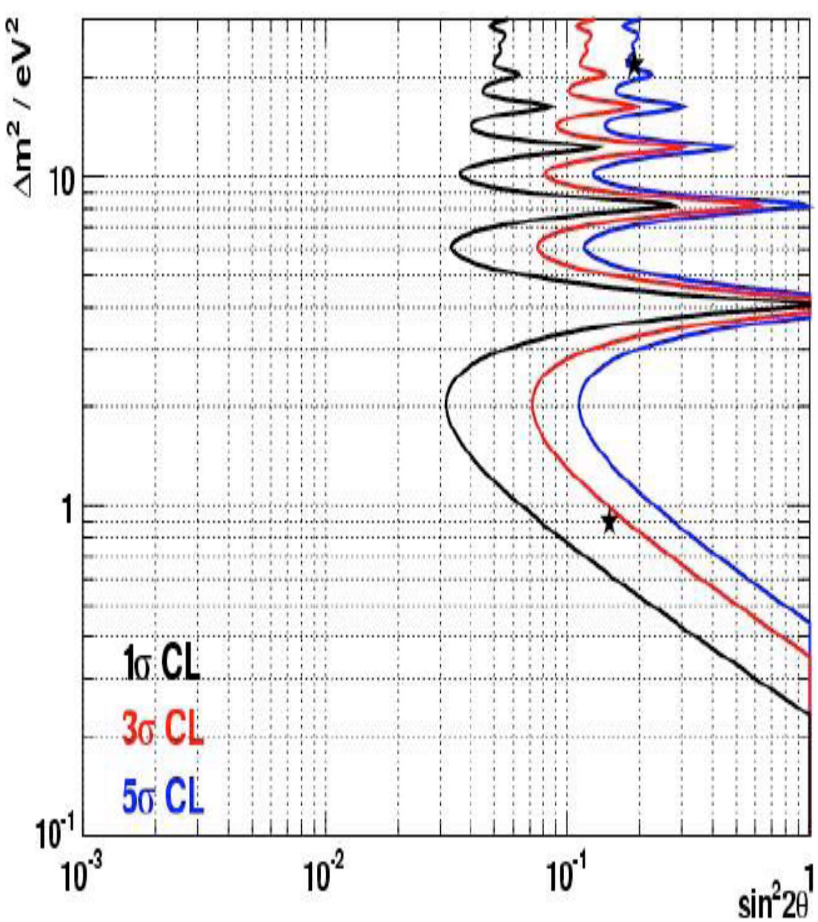
anti-ν_e = ~14 - 17 MeV

$\nu_{\mu,\tau}$, anti-$\nu_{\mu,\tau}$ = ~23 - 27 MeV

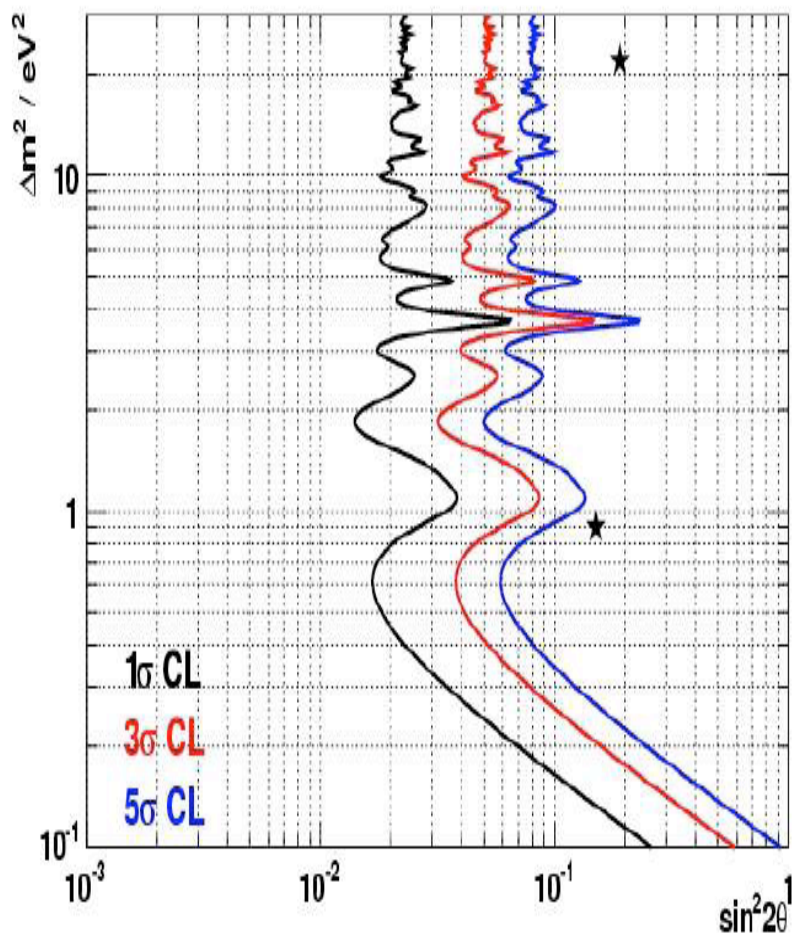
Neutron Background

- No active shielding, timing cuts, veto, PID, have ~10^8 cosmic-ray muon events, ~10^6 cosmic ray neutron events, and ~10^9 machine events per day
- Active veto, shielding reduce cosmic ray bgds to negligible amount
- Machine neutron bgds greatly suppressed for t > ~1100 ns after proton pulse
- anti-ν_μ, ν_e production governed by μ lifetime (~2.2 μs)

Sterile Neutrinos



Near Detector only



Near + Far Detector

Why the SNS?

	Beam Width	S:B	Osc. Candidates
LSND anti-$\nu_\mu \rightarrow$ anti-ν_e	600 μs	1:1	35 total (observed R > 10)
FNAL $\nu_\mu \rightarrow \nu_e$	1600 ns	1:3	~400 total
SNS anti-$\nu_\mu \rightarrow$ anti-ν_e	695 ns	5:1	~448/year

Maybe < 500 ns!

Expected for LSND best fit point of $\sin^2 2\theta = 0.004$ $dm^2 = 1$

Sterile Neutrinos

- R-process nucleosynthesis
  - Balantekin and Fuller, Astropart. Phys. **18**, 433 (2003)
- Pulsar kicks
  - Kusenko, Int. J. Mod. Phys. D **13**, 2065 (2004)
- Dark matter
  - Asaka, Blanchet, Shaposhnikov, Phys. Lett. B **631**, 151 (2005)
- Formation of supermassive black holes
  - Munyaneza, Biermann, Astron and Astrophys., 436, 805 (2005)
- Play impt. role in Big Bang nucleosynthesis
  - Smith, Fuller, Kishimoto, Abazajian, astro-ph/0608377