Neutrino Studies at the SNS
Workshop, Aug. 28−29, 2003

Oscillations and Cross Sections at the SNS with a Large Cerenkov Detector

Gordon J. VanDalen
Research Professor

Department of Physics
Embry−Riddle Aeronautical University
Prescott, Arizona 86301

- Introduction
- Oscillation signature for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- Proposed 250ton Detector
- Fluxes and Backgrounds
- Rates for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ at 60m in a 250ton Detector
- Other Event Rates in Mineral Oil
- Other Liquids and Cross Sections − D, N, O, Cl, Br, I, etc.
- Conclusions

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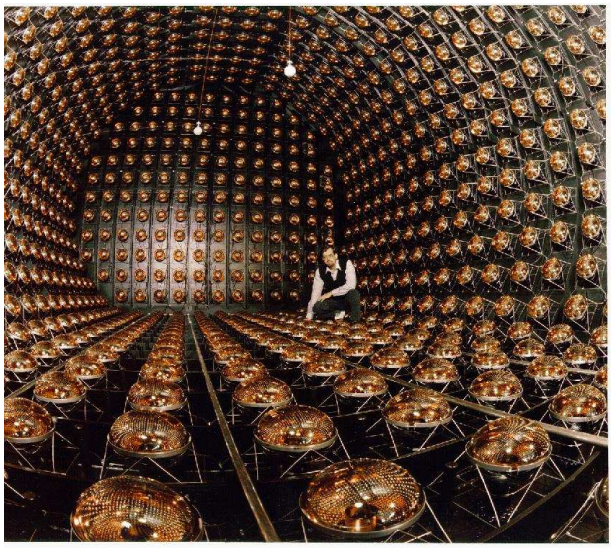
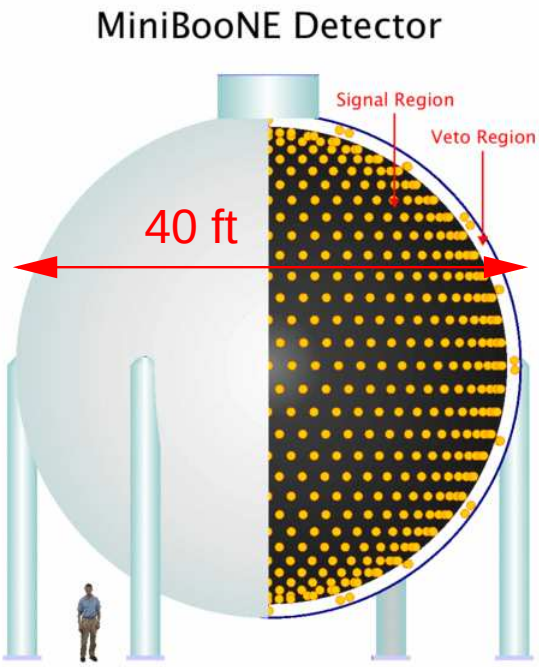
Introduction

The LSND and MiniBooNE are successful imaging Cerenkov detectors which are NOT located deep underground





LSND Oscillation Signal

DAR in beam stop	Oscillation	in Detector	observe these
$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\bar{\nu}_e\, p \rightarrow e^+ n$	after ~180 μs
		$n\ p \rightarrow d + \gamma$ (2.2 MeV)	

Neutrino Cross Sections

$\nu_e\, {}^A_Z X \rightarrow {}^A_{Z+1} Y\ e^-$ possibly followed by β's or γ's or n's

$\nu\, {}^A_Z X \rightarrow \nu\, {}^A_Z X^*$ and decay β's or γ's or n's

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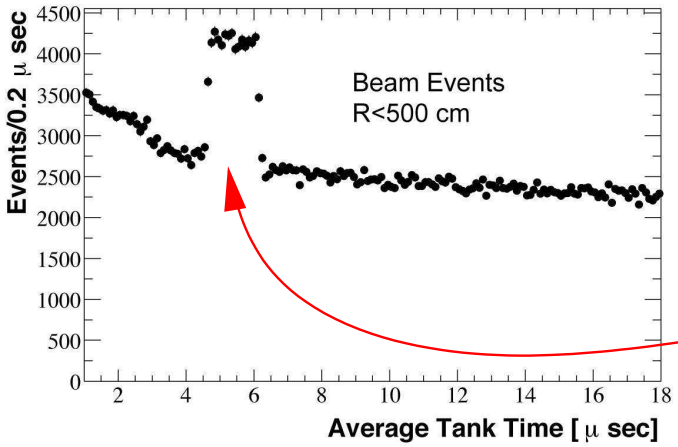
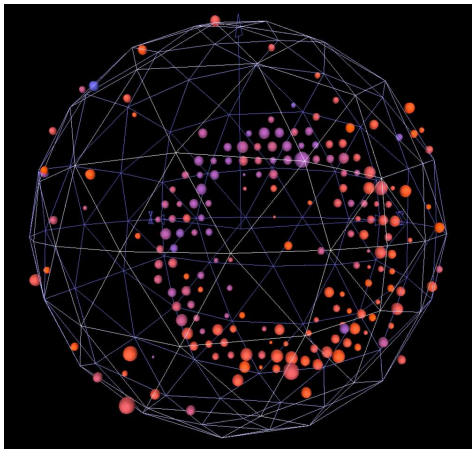
MiniBooNE Beam Data

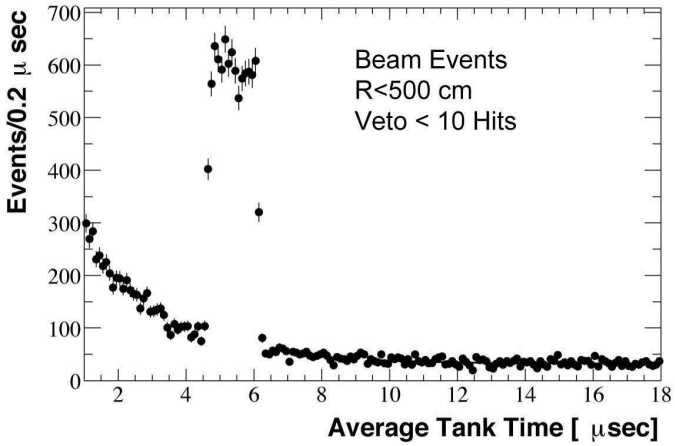
http://www−boone.fnal.gov/public/plots/biglist.html

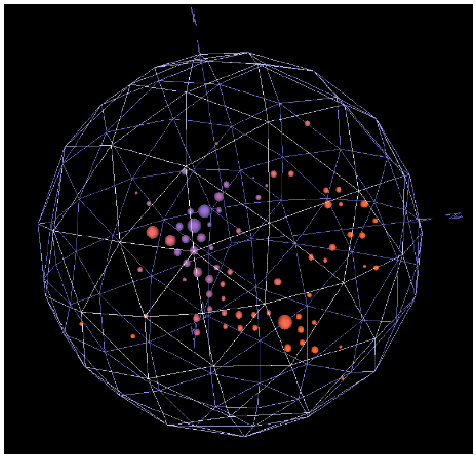


Beam spill

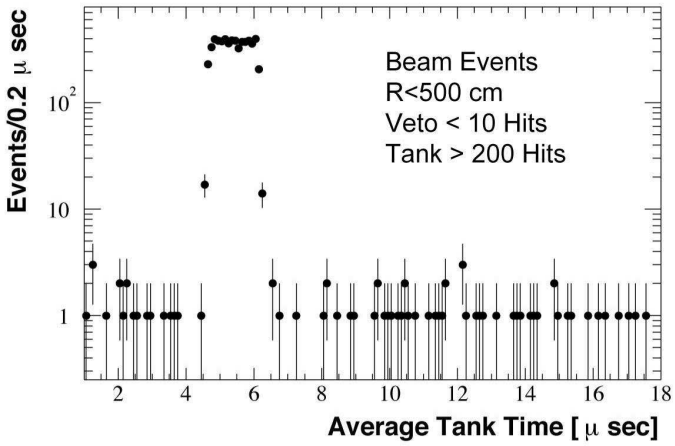


ν_μ Charged Current





michel e from μ decay



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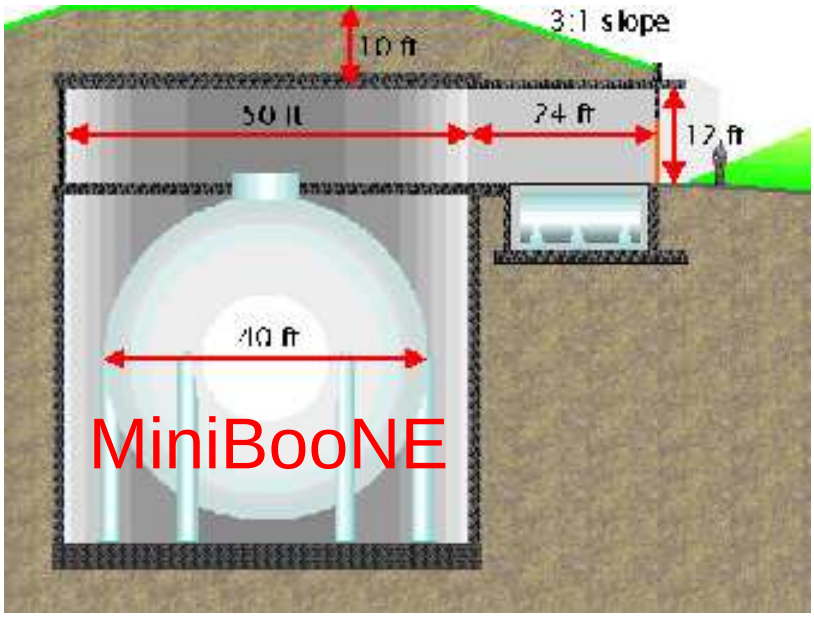
Proposed detector for SNS

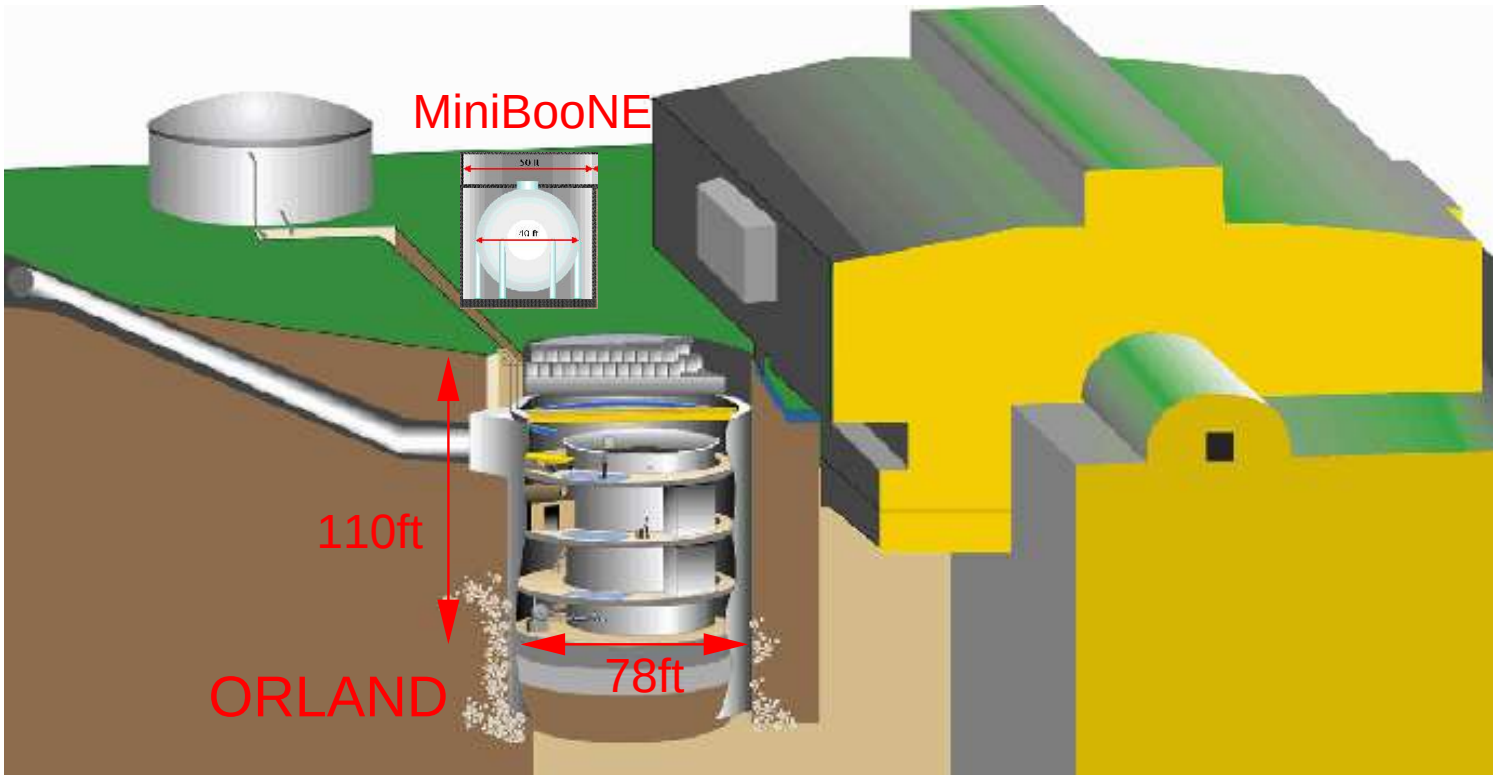
like MiniBooNE

500ton fiducial mass of mineral oil C_nH_{2n+2} n ~ 20

but smaller at 250tons fiducial mass of mineral oil

This is NOT the same as CoNDOR / ORLaND





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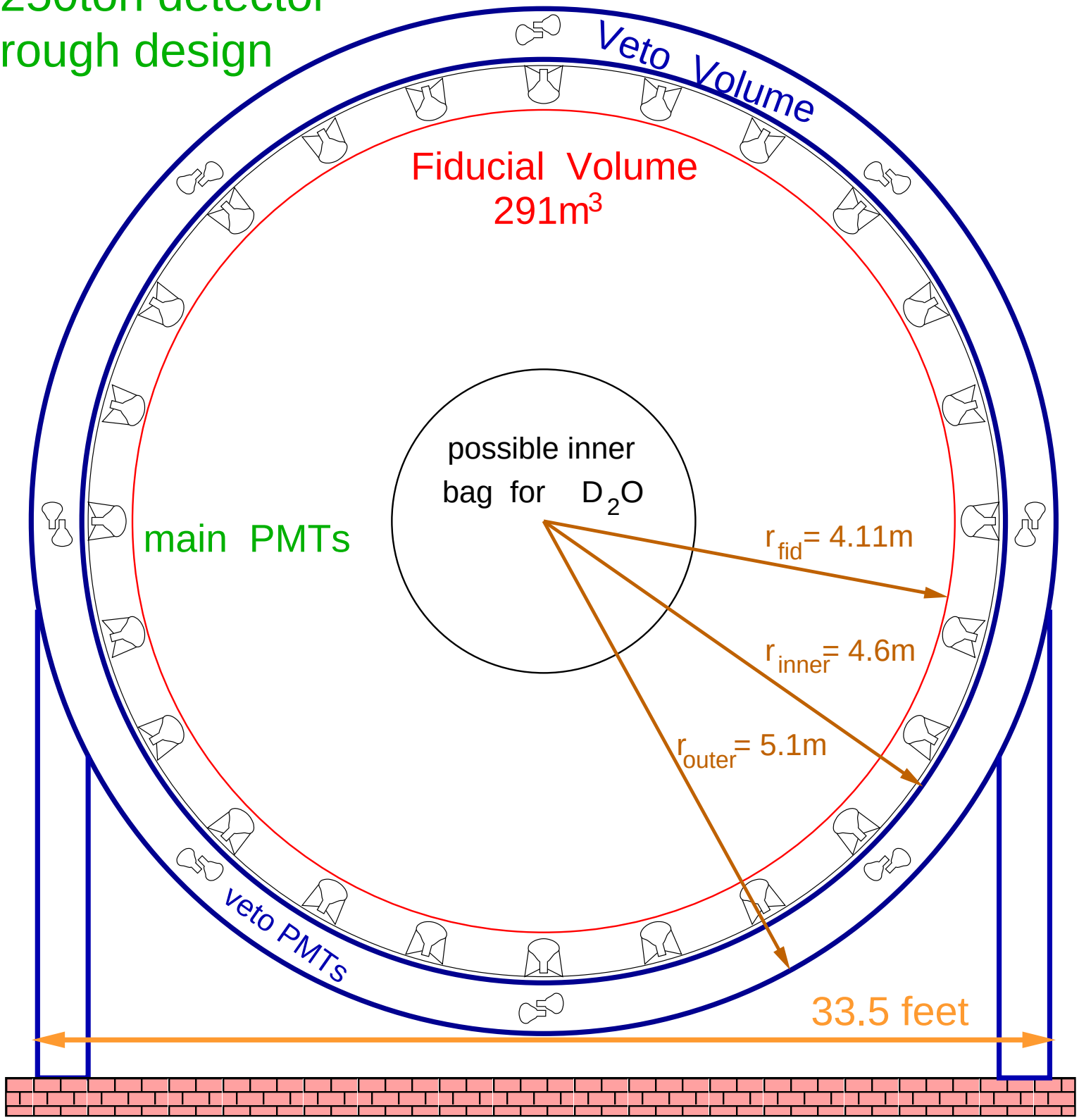
250ton detector rough design



Needs concrete enclosure 44 feet diameter and 40 feet deep. This is ~12% of ORLaND volume.

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Candidate Hamamatsu Photomultipliers

	R5912	R8055
height	290 nm	332 nm
diameter	202 mm	332 mm
effective diameter	190 mm	325 mm
quantum efficiency at 390nm	22%	20%
spectral response	300 to 650 nm	
peak sensitivity	420 nm	
typical HV for 10^7 gain	1500 volts	
transit time spread − FWHM	2.4 ns	2.8ns
Number for 20% photocathode coverage	1564	535

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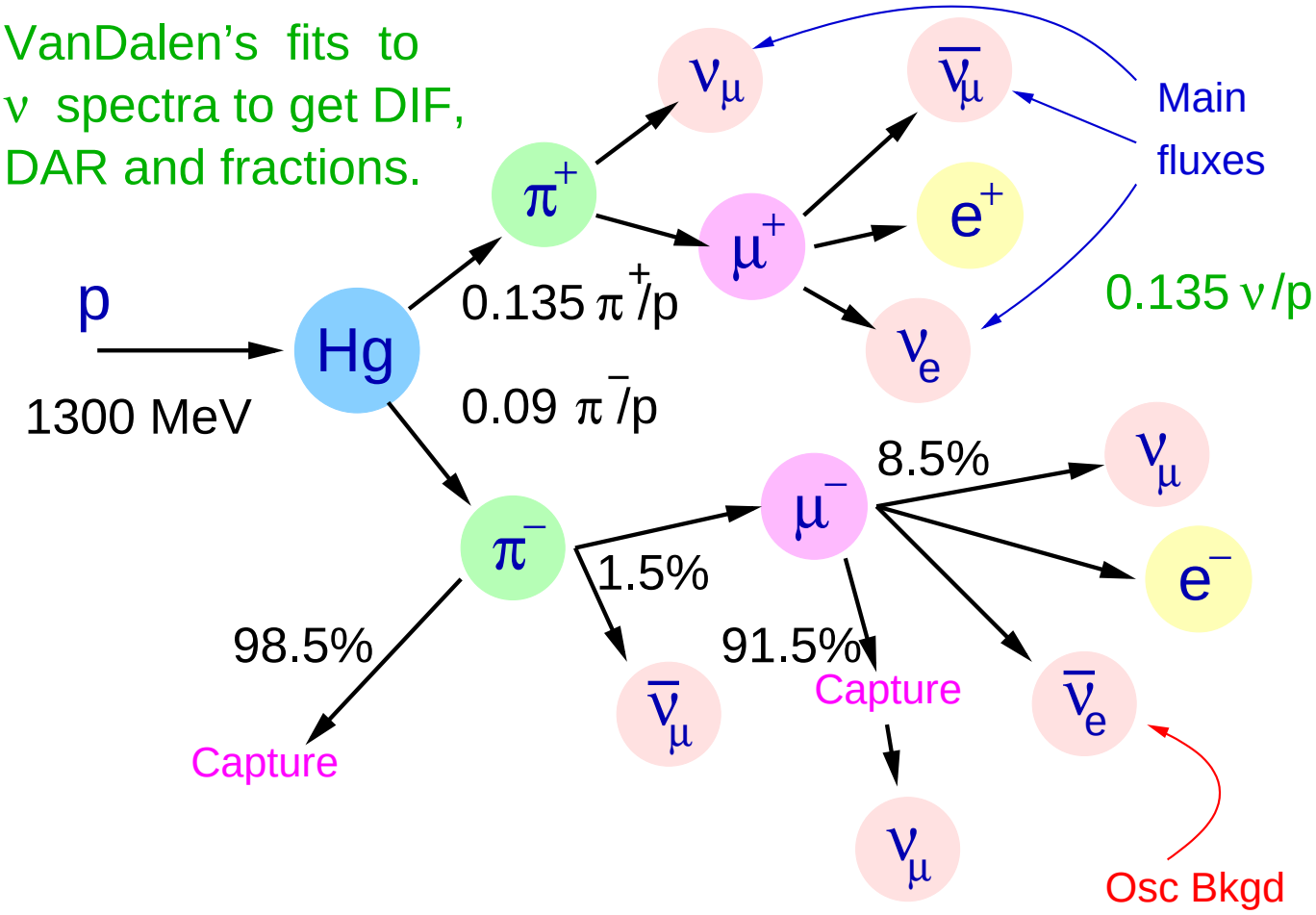
Neutrino Fluxes and Backgrounds

Yuri Efremenko at NuFact'03 June 10, 2003

VanDalen's fits to ν spectra to get DIF, DAR and fractions.



$$(\pi^-/\pi^+)(\pi^- \text{decay})(\mu^- \text{decay}) = \bar{\nu}_e/\bar{\nu}_\mu$$

$$(0.09/0.135)(0.015)(0.085) = 0.00085$$

$\bar{\nu}_e$ is 0.085% of $\bar{\nu}_\mu$ from μ^+ DAR

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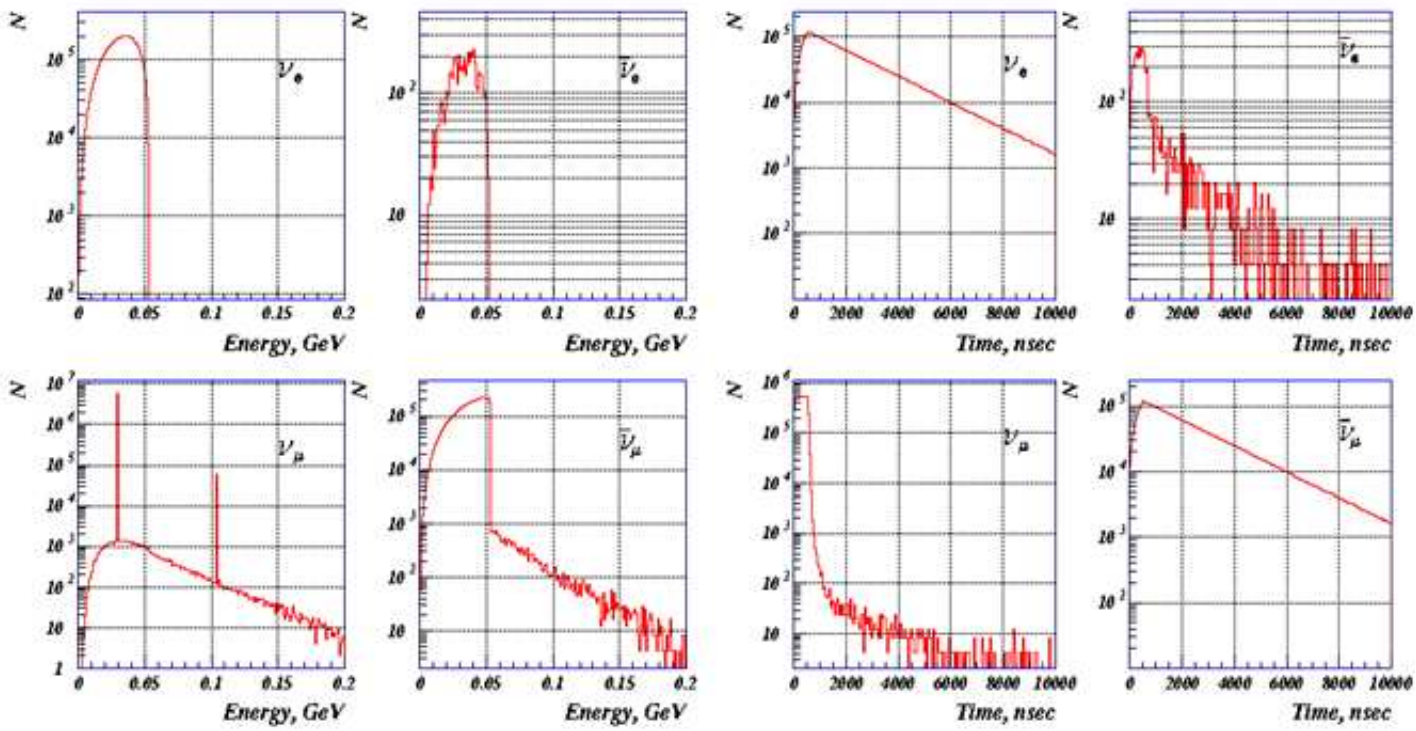
Yuri Efremenko at NuFact'03 June 10, 2003

Actual spectra of neutrinos from SNS

Energy **Time**



Short pulses with the energy similar to SN neutrino spectra

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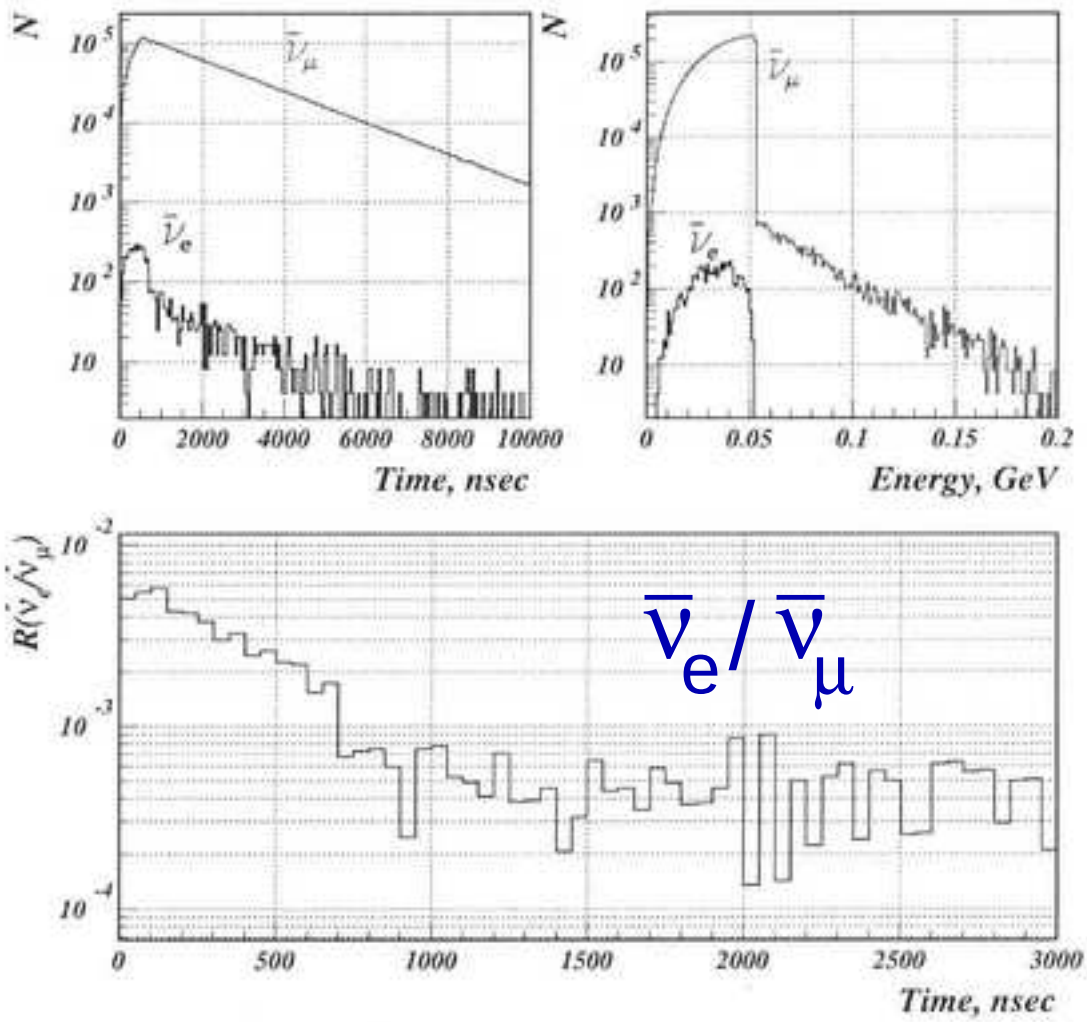

$\bar{\nu}_e$ background in the beam comes from

π^- / π^+	is 2/3
$\pi^- \rightarrow \mu^- \bar{\nu}_\mu$	1.5% of the π^- DIF before capture
$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$	8.5% of the μ^- DAR before capture with a 76.2ns life time

Overall background is 0.085% 8.5×10^{-4}

After the spill 0.695μs → 5μs it is 0.024% 2.4×10^{-4}

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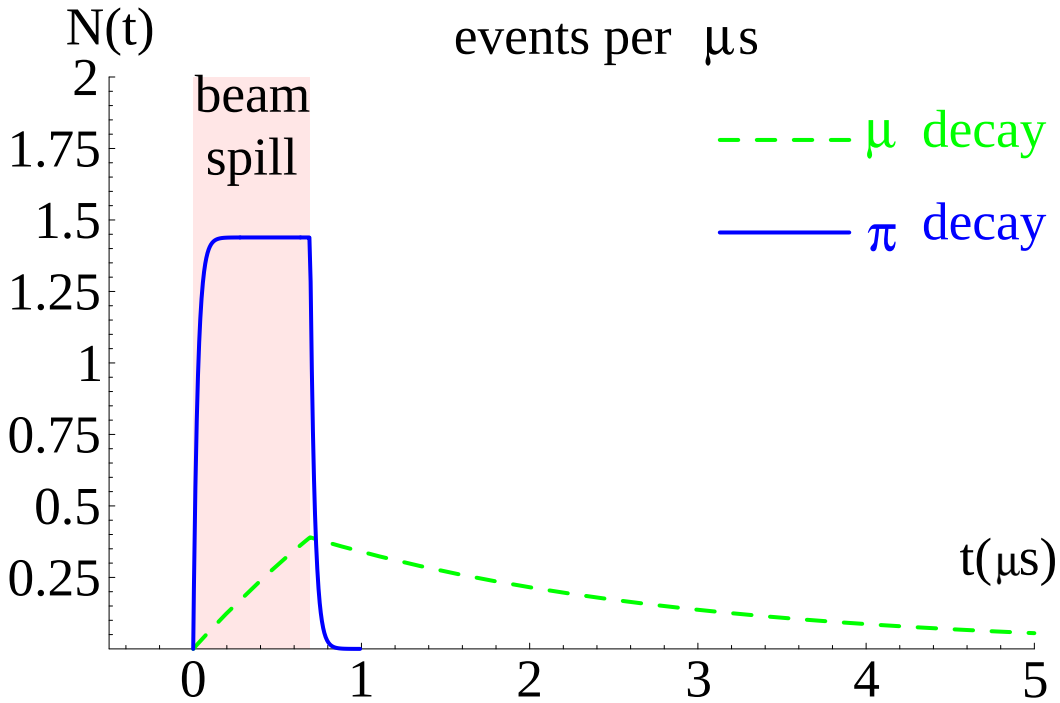

	0 → 0.695μs	0.695μs → 5μs	>5μs
π decays including π^+ decay at rest to ν_μ $\pi^\pm$ decay in flight μ^- capture (76.2 ns)	96.3%	3.7%	0
μ decays to $\bar{\nu}_\mu$ and ν_e and oscillation candidates	14.3%	73.6%	12.1%

(yes, an overall time fit can do better)

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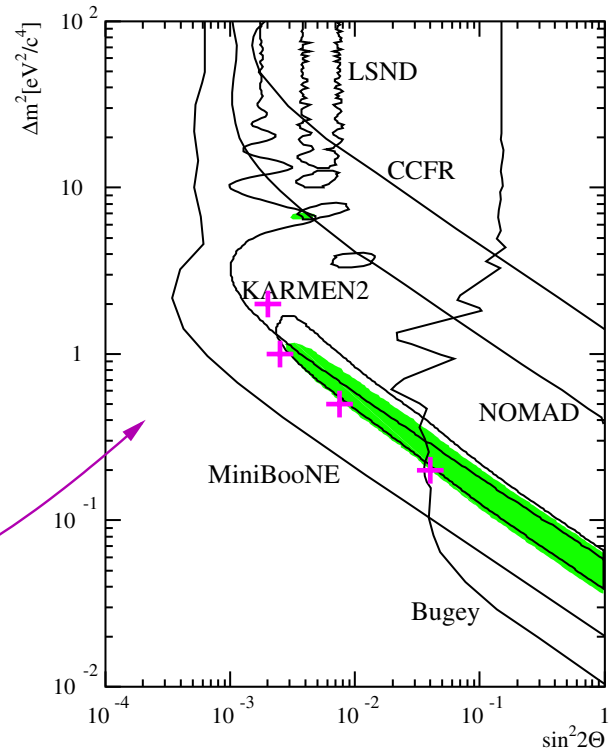
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Rates at 60m into 250tons of Mineral Oil

Use conservative mixing values

Figure from E. Church et al. "Statistical analysis of different $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ searches", PRD 66, 13001 (2002) (Combined LSND and KARMEN fit)

$\sin^2 2\theta$	Δm^2
0.002	2.0 eV^2
0.0025	1.0 eV^2
0.0075	0.5 eV^2
0.040	0.2 eV^2

crosses on graph



$\sin^2 2\theta$	Δm^2	σ for E_e > 20 MeV	events / year
0.002	2.0 eV^2	0.049×10^{-42} cm^2	69 ε_{rec}
0.0025	1.0 eV^2	0.191×10^{-42} cm^2	266 ε_{rec}
0.0075	0.5 eV^2	0.428×10^{-42} cm^2	592 ε_{rec}
0.040	0.2 eV^2	0.500×10^{-42} cm^2	693 ε_{rec}

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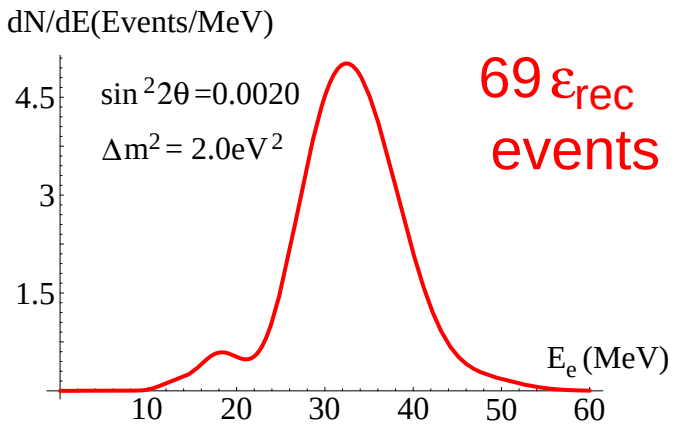
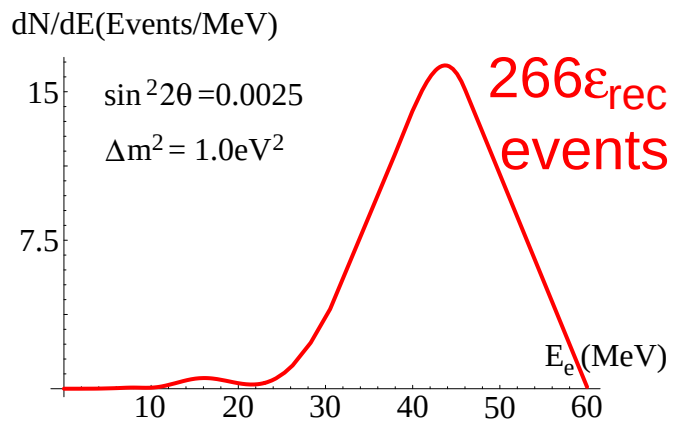
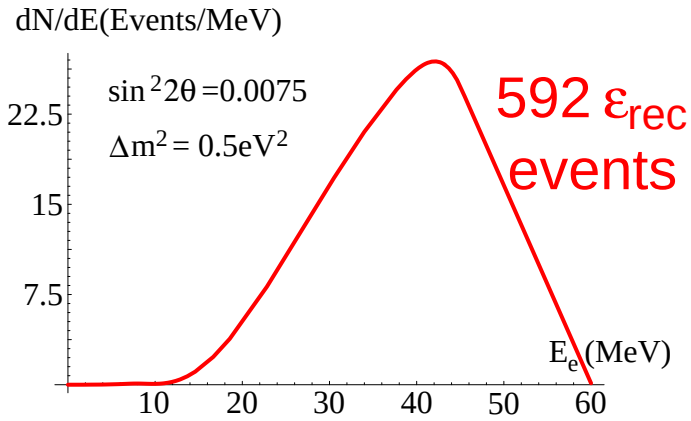
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillation Event Energy Distributions



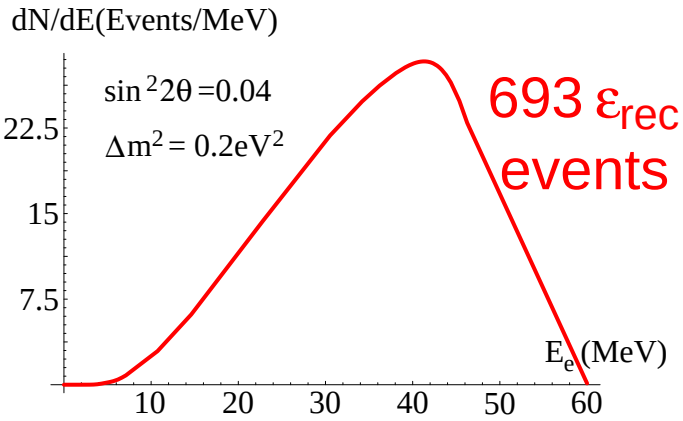
$\sin^2 2\theta = 0.002 \quad \Delta m^2 = 2.0\ eV^2$



$\sin^2 2\theta = 0.0025\ \Delta m^2 = 1.0\ eV^2$



$\sin^2 2\theta = 0.0075\ \Delta m^2 = 0.5\ eV^2$



$\sin^2 2\theta = 0.04 \quad \Delta m^2 = 0.2\ eV^2$

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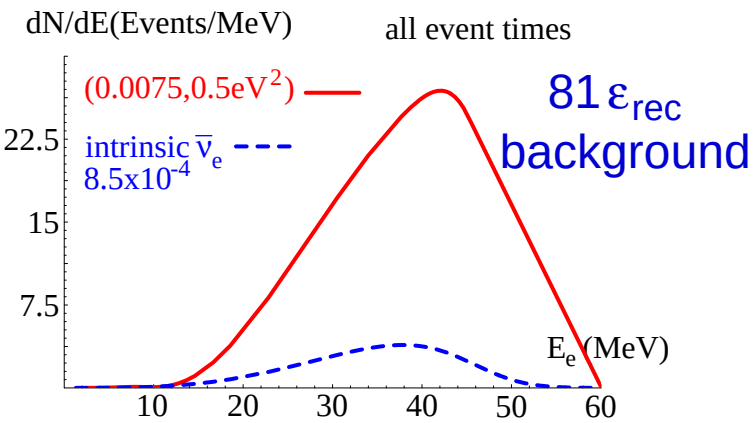
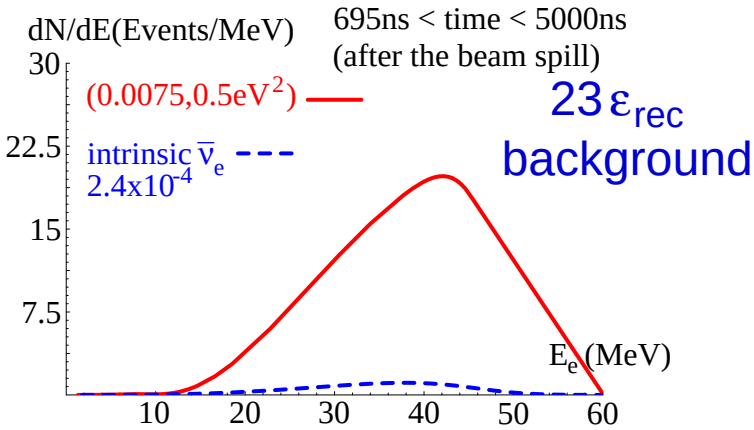
$\bar{\nu}_e$ Beam Related Backgrounds

Intrinsic $\bar{\nu}_e$

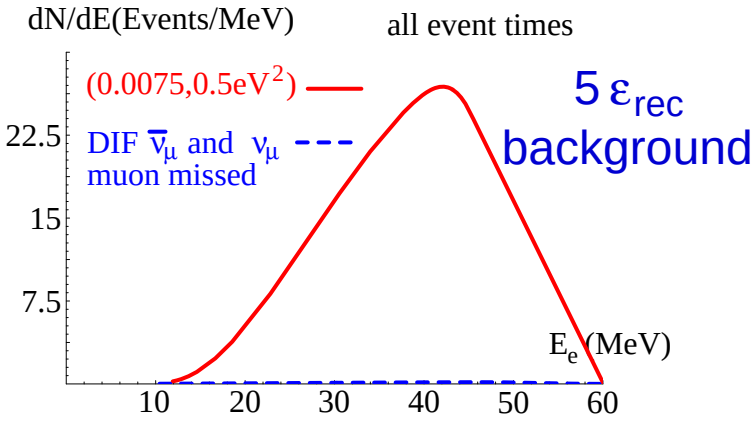


All Event Times



695ns → 5000ns

Decay−in−Flight ν_μ and $\bar{\nu}_\mu$ with T_μ < 3MeV



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Other Event rates in 250tons of Mineral Oil

Process	Neutrino Source	ν Source Lifetime	Events per year
ν_μ e elastic	π^+ DAR	26ns	69 ε_{rec}
$\bar{\nu}_\mu$ e elastic	μ^+ DAR	2197ns	99 ε_{rec}
ν_e e elastic	μ^+ DAR	2197ns	630 ε_{rec}
all ν e elastic $T_e > 20$MeV			798 ε_{rec}
$\nu_e\,{}^{12}C \rightarrow e^-\,{}^{12}N_{g.s.}$	μ^+ DAR	2197ns	4689ε_{rec}
$\nu_e\,{}^{12}C \rightarrow e^-\,{}^{12}N^*$	μ^+ DAR	2197ns	2147ε_{rec}
$\nu_e\,{}^{13}C \rightarrow e^-\,{}^{13}X$	μ^+ DAR	2197ns	308ε_{rec}
all ν_e C charged current $T_e > 20$MeV			7144ε_{rec}
$\nu_\mu\,{}^{12}C \rightarrow \nu_\mu\,{}^{12}C^*_{15.11}$	π^+ DAR	26ns	1851ε_{rec}
$\bar{\nu}_\mu\,{}^{12}C \rightarrow \bar{\nu}_\mu\,{}^{12}C^*_{15.11}$	μ^+ DAR	2197ns	3752ε_{rec}
$\nu_e\,{}^{12}C \rightarrow \nu_e\,{}^{12}C^*_{15.11}$	μ^+ DAR	2197ns	3093ε_{rec}
all $\nu\,{}^{12}C$ neutral current			8696ε_{rec}

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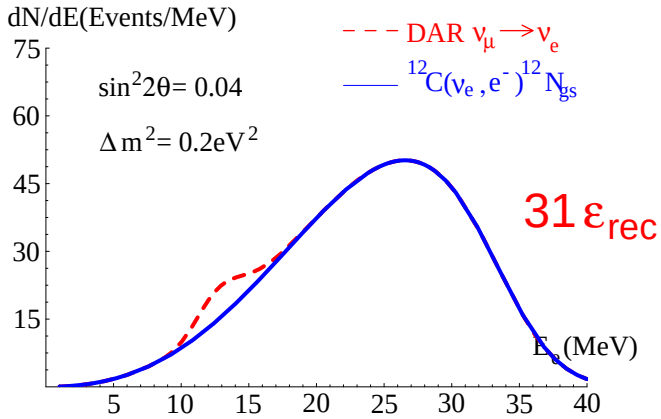
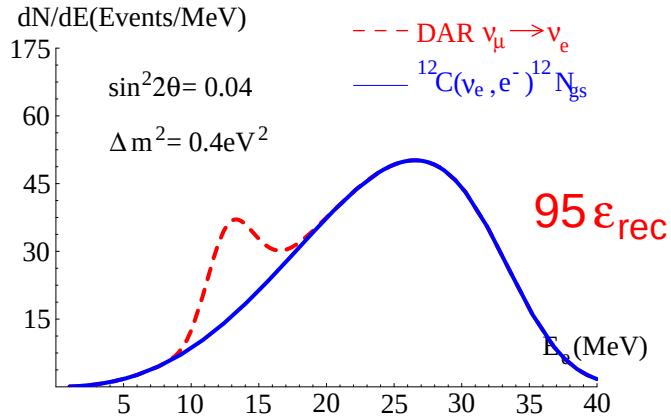
Decay at Rest $\nu_\mu \longrightarrow \nu_e$ ν_μ all at 29.8MeV

Detect using $\nu_e\ {}^{12}C \longrightarrow e^-\ {}^{12}N_{gs}$ ${}^{12}N_{gs} \longrightarrow {}^{12}C\ e^+\ \nu_e$





"best" of 4 parameter sets more optimistic set

Backgrounds

- $\nu_e\ {}^{12}C \longrightarrow e^-\ {}^{12}N^*_{gs}$

  shown in figs. above ~15/MeV

- $\nu\ {}^{12}C$ neutral current

  in beam window

  with accidental beta (0.5%)

  about 15 events at 15.11MeV

KARMEN data

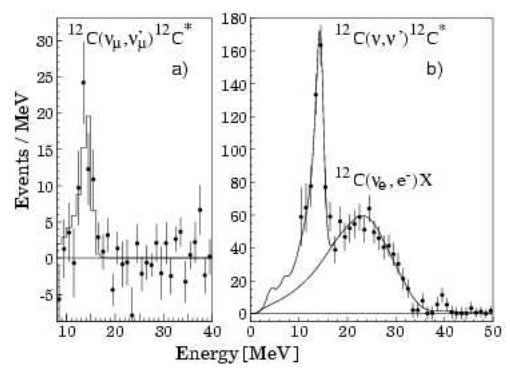


Figure 4. Visible energies of ν-induced isolated events, background subtracted.

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Other Liquids and Cross Sections

Look for clear liquids containing H and/or C, and at most one other element of interest

physics	stuff	chemical	density	n	properties
ν_eC CC ν C NC	mineral oil	C_nH_{2n+2} n ~ 20	860kg/m^3	1.47	 butyl−PBD for n's
ν_eO CC ν O NC	water	H_2O	1000kg/m^3	1.33	b.p. 100°C Gd for n's
ν_eN CC	ammonia	NH_3	771kg/m^3	1.33	b.p. −33°C
ν N NC	ammonia + water	90g ammonia to 100g water			liquid at 10°C
ν Cl	tetrachlorethene	C_2Cl_4	1505kg/m^3	1.51	used by R. Davis
ν Br	tribromoethene	$C_2H_3Br_3$	2708kg/m^3	1.604	b.p. 163°C
ν Br	methyene bromide	CH_2Br_2	2497kg/m^3	1.542	b.p. 97°C
ν I	ethylene iodide	$C_2H_4I_2$	2179kg/m^3	1.534	b.p. 131°C
ν I	methylene iodide	CH_2I_2	3325kg/m^3	1.742	b.p. 182°C
ν_eD	heavy water	D_2O	1105kg/m^3	1.34	in clear bag

plus others ??

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$\nu_e\ {}^{127}I \longrightarrow e^{-}\ {}^{127}Xe$ Cross Section using CH_2I_2

fiducial mass is $(291 m^3)(3325 kg/m^3) = 967{,}000$ kg

967 tons of methylene iodide ("250 tons" for mineral oil only!)

2.17×10^{30} molecules 4.35×10^{30} iodine−127 atoms

1) the only stable isotope of iodine is number 127
2) the threshold for electron neutrino interactions is 789keV
3) above 8MeV excitation energy Xe−127 is unstable to neutron emission. The proposed detector can associate subsequent neutron captures.
4) calculations and mesurement for this process are excitations to Xe−127 states which return to the ground state. This state has a 36.4−day half−life EC, extracted radio−chemically.

Engel, Pittel, Vogel, Phys Rev C50 (1994) 1702 $(2.1 - 3.1)\times 10^{-40} cm^2$

Distel et al, (LANSCE) nucl−ex:0208012v1 $(2.75+0.85+0.24)\times 10^{-40} cm^2$

One year at the SNS with methylene iodide gives the event totals

$\boxed{77{,}200\ \nu_e\ {}^{127}I}$ $1{,}630\ \nu_e C$ CC $1{,}980\ \nu\ {}^{12}C$ NC

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Conclusions

- The SNS is the ideal decay−at−reat neutrino source
  High neutrino flux, low backgrounds,
  small duty factor, good $\nu_\mu / \nu_e \; \bar{\nu}_\mu$ separation
- A several hundred cubic−meter imaging Cerenkov detector can be built in a modest excavation away from the target hall foundation
- Confirm or refute the LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation result in about one year with mineral oil
  (MiniBooNE is checking $\nu_\mu \rightarrow \nu_e$)
- Other liquids for D, N, O, Cl, Br, I, and more
  80k $\nu_e {}^{127}\mathrm{I}$ in methylene iodide in one year
- This program can be done, so should be considered

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