NEUTRINO TELESCOPES
and
The ORLAND Large Detector
at
The Oak Ridge Laboratory
for Neutrino Detectors

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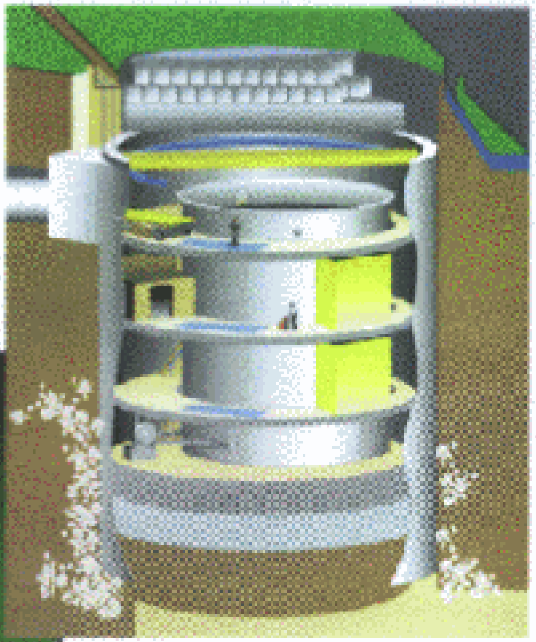
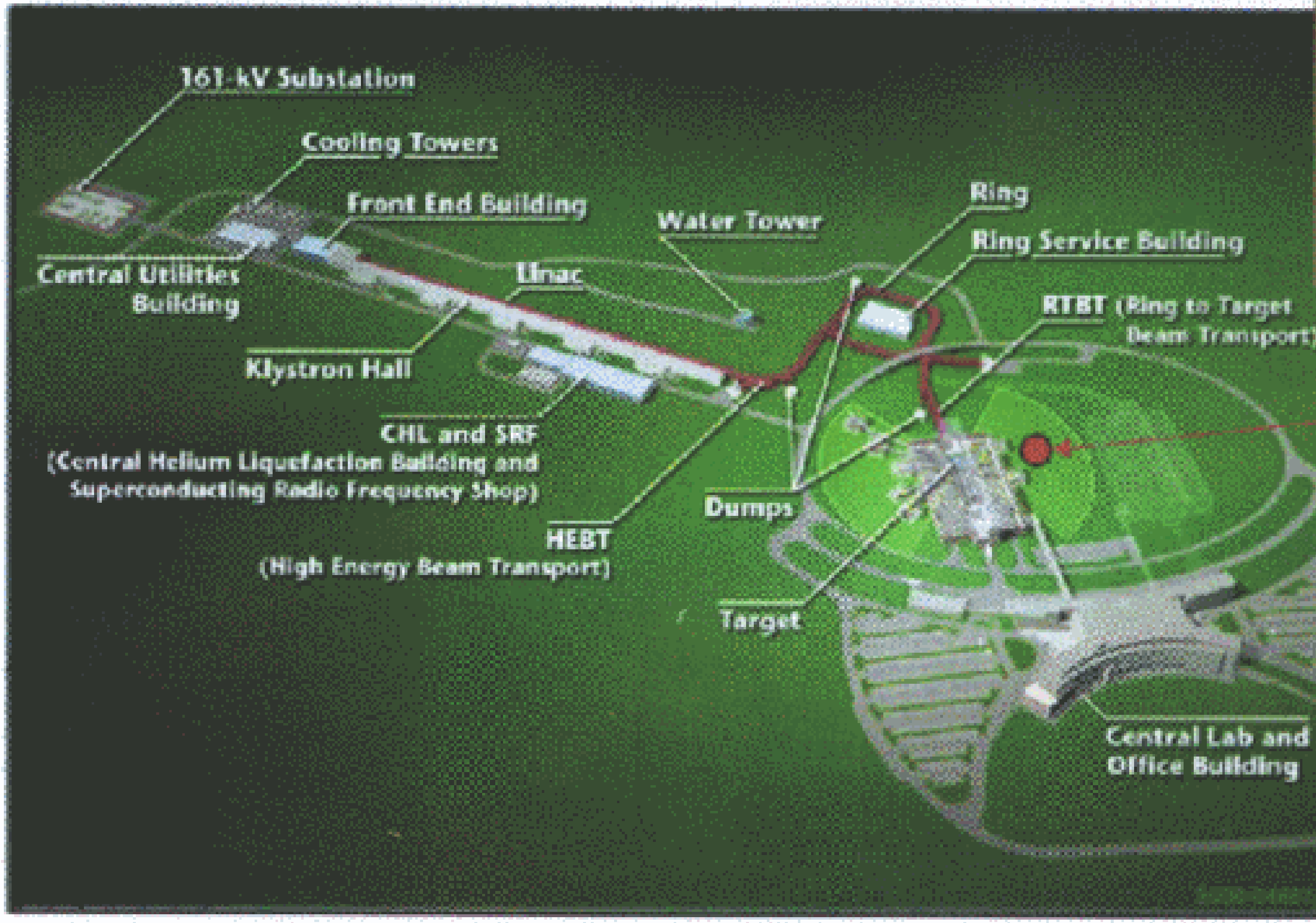
University of South Carolina
and
Oak Ridge National Laboratory

1.4 B$

ORLaND and the SNS

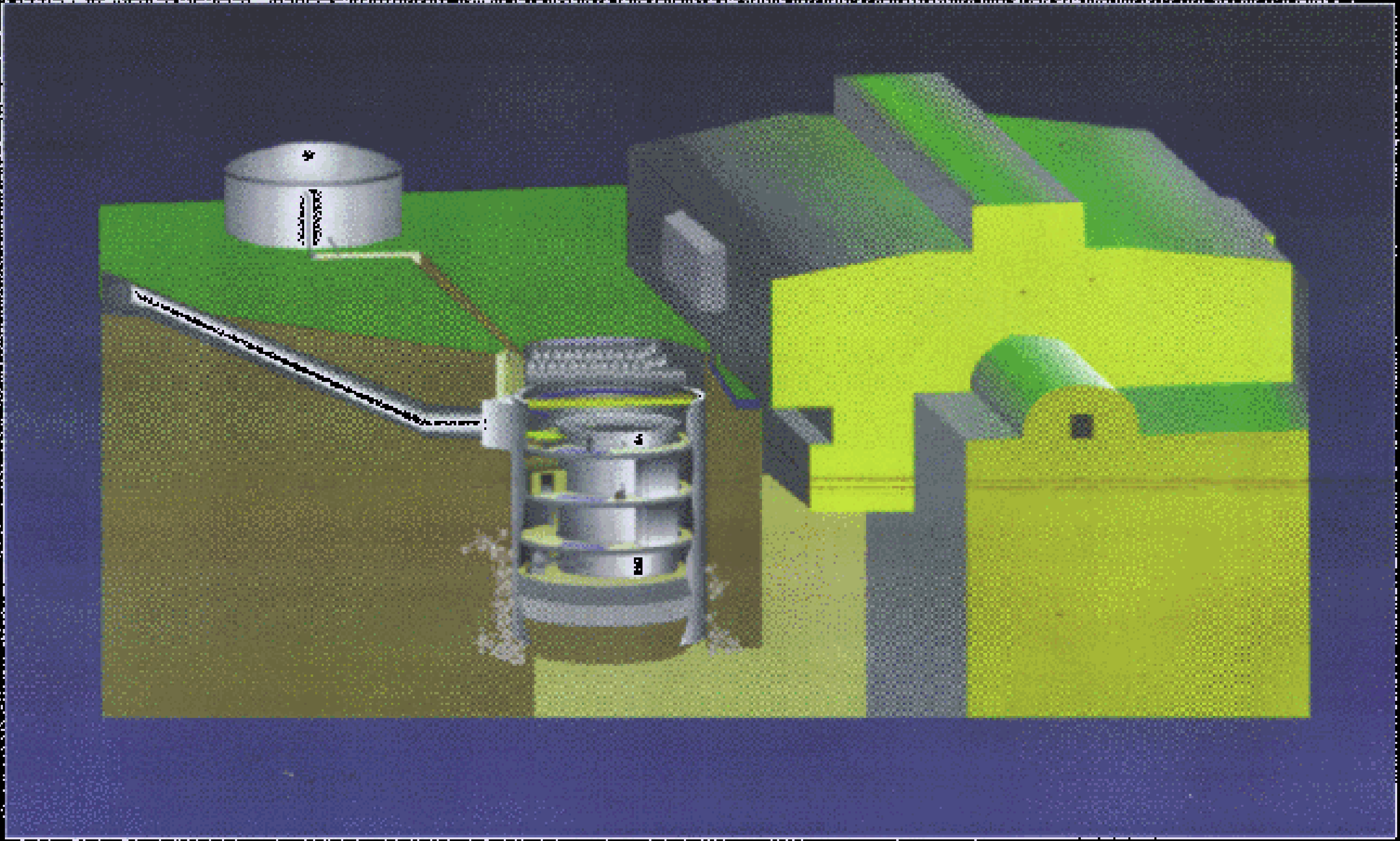




Projected ORLaND bunker site

2.1%

ORLaND: an undergound laboratory for stopped-pion ν physics at the SNS



ORLaND Member Institutions

- Carleton University
- Drexel University
- Duke University
- Embry Riddle Aeronautical University
- Institute for Theoretical and Experimental Physics
- Jefferson Laboratory
- Kent State University
- Los Alamos National Laboratory
- Louisiana State University
- North Carolina State University
- Oak Ridge Associated Universities
- Oak Ridge National Laboratory
- Ohio State University
- SNS/ORNL
- Southern University, Baton Rouge
- Southern University, New Orleans
- Tel Aviv University
- TUNL Laboratory
- University of Alabama
- University of California, Los Angeles
- University of California, Riverside
- University of Mississippi
- University of Pennsylvania
- University of South Carolina
- University of Tennessee, Knoxville
- Valparaiso University
- Virginia Tech

What is ORLaND

Oak Ridge Laboratory for Neutrino Detectors

- A high-intensity stopped-pion neutrino facility using the SNS parasitically
- A detector hall and instrument suite to support
  - a broad long-term program of neutrino science
  - multiple experimental collaborations
- A user facility
  - A Joint Institute for Neutrino Science to be formed
    - ORAU, ORNL, Universities
  - Experiments to be selected by a broad-based PAC
- Independent Detector Collaborations
- Excellent example of Lab/University collaboration

Neutrino Production at the SNS

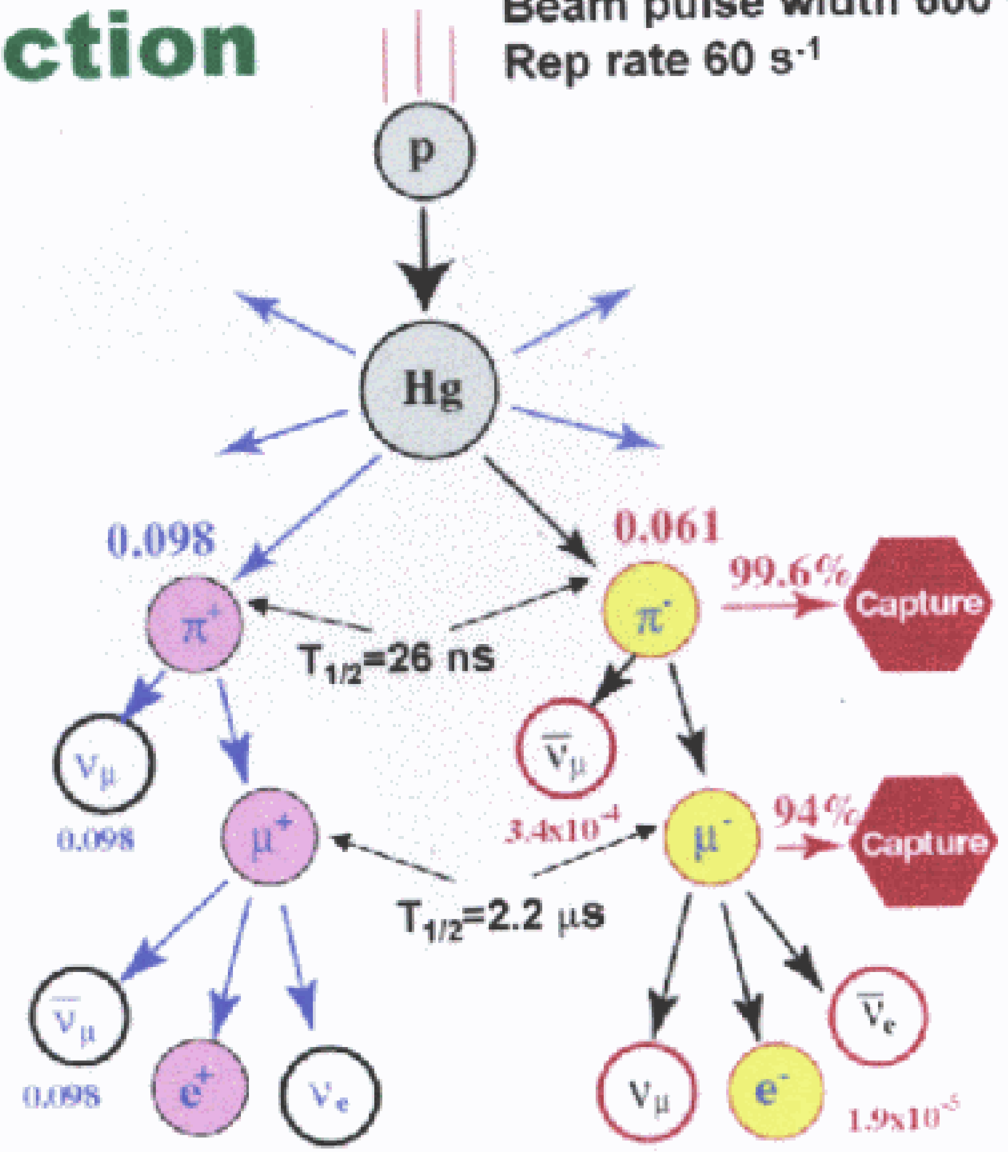
Neutrinos result from decay of pions and muons produced in p+Hg collisions in the SNS target.

ν_e production is strongly suppressed by capture of negative π, μ before decay.

SNS will produce ~10^{15} neutrinos per second. $3\text{x}10^6$ at 50 meters.

Time structure of neutrino beam suppresses cosmic background and separates neutrino types.

Beam pulse width 600 ns
Rep rate 60 s^{-1}

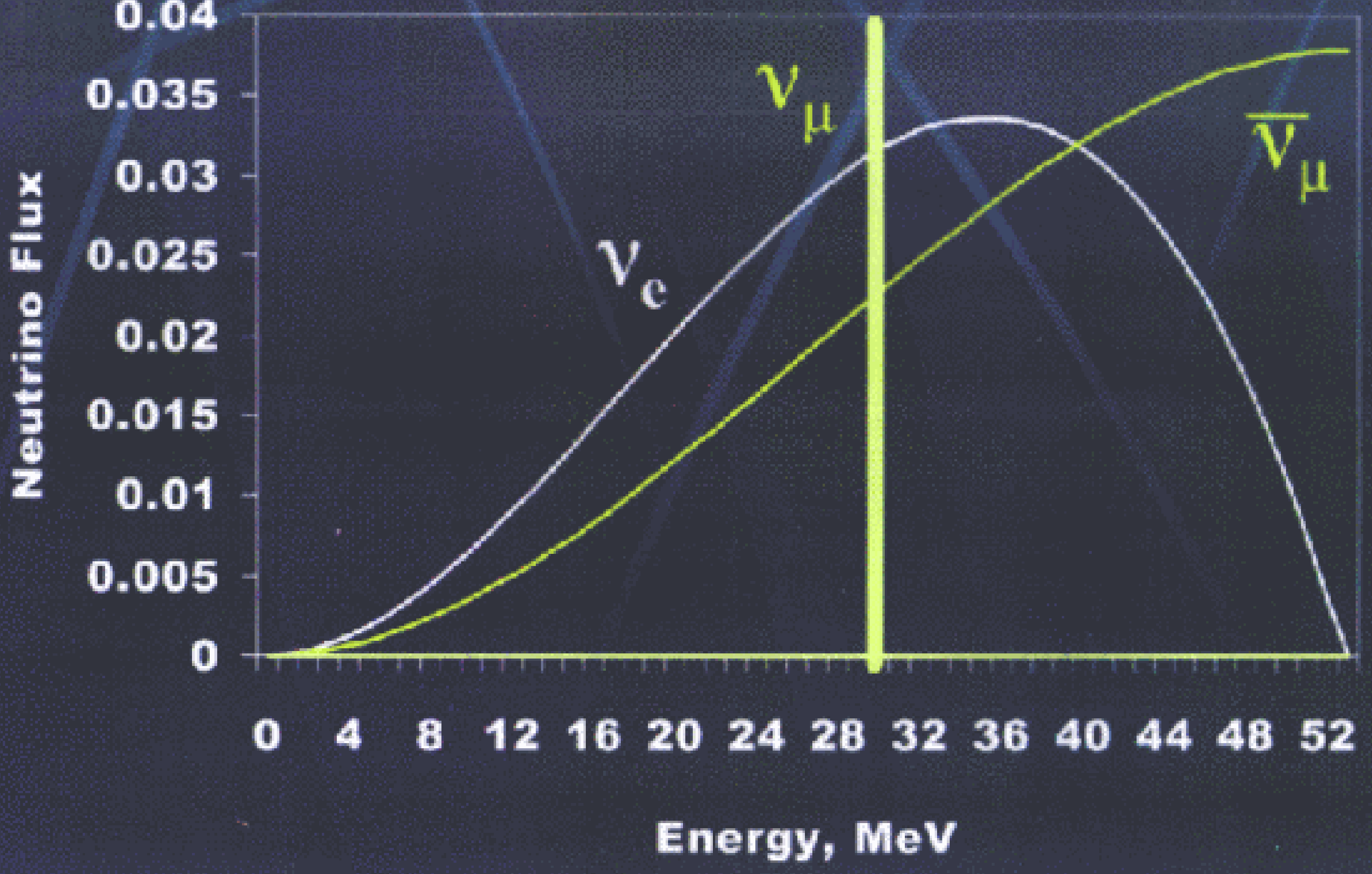


$\bar{\nu}_e << \nu_e , \nu_\mu , \bar{\nu}_\mu$

UT-BATTELLE

OAK RIDGE NATIONAL LABORATORY
U.S. DEPARTMENT OF ENERGY

Neutrinos From SNS



NEUTRINO FLUX AND ENERGY SPECTRA

Normalized spectra

$N(\nu_e) = (12 / W^4) E^2_\nu (W - E_\nu)$

$N(\overline{\nu}_\mu) = (6 / W^4) E^2_\nu (W - 2 / 3 E_\nu)$

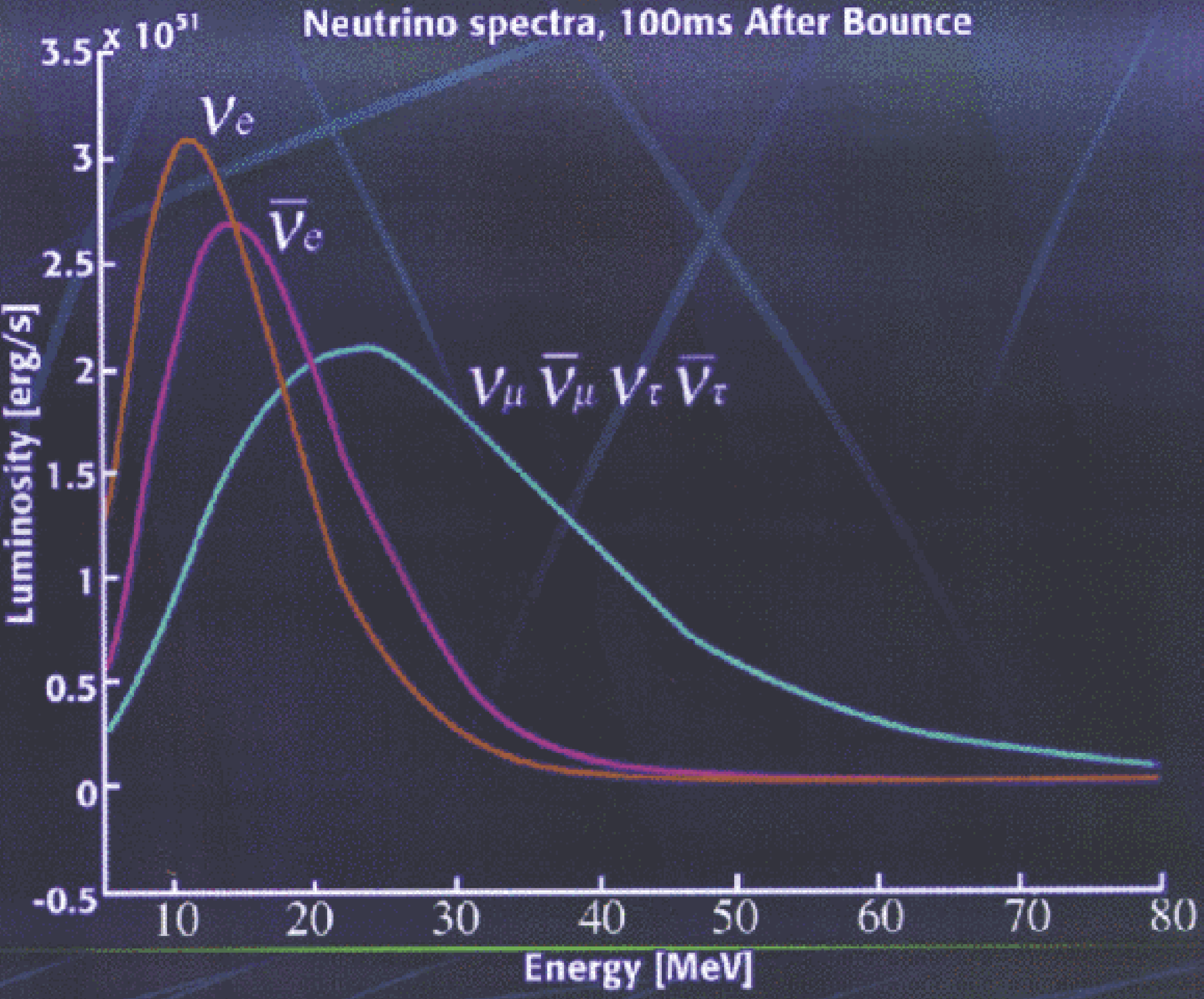
W=52.83 MeV

ν_μ is monoenergetic at ~ 30 MeV

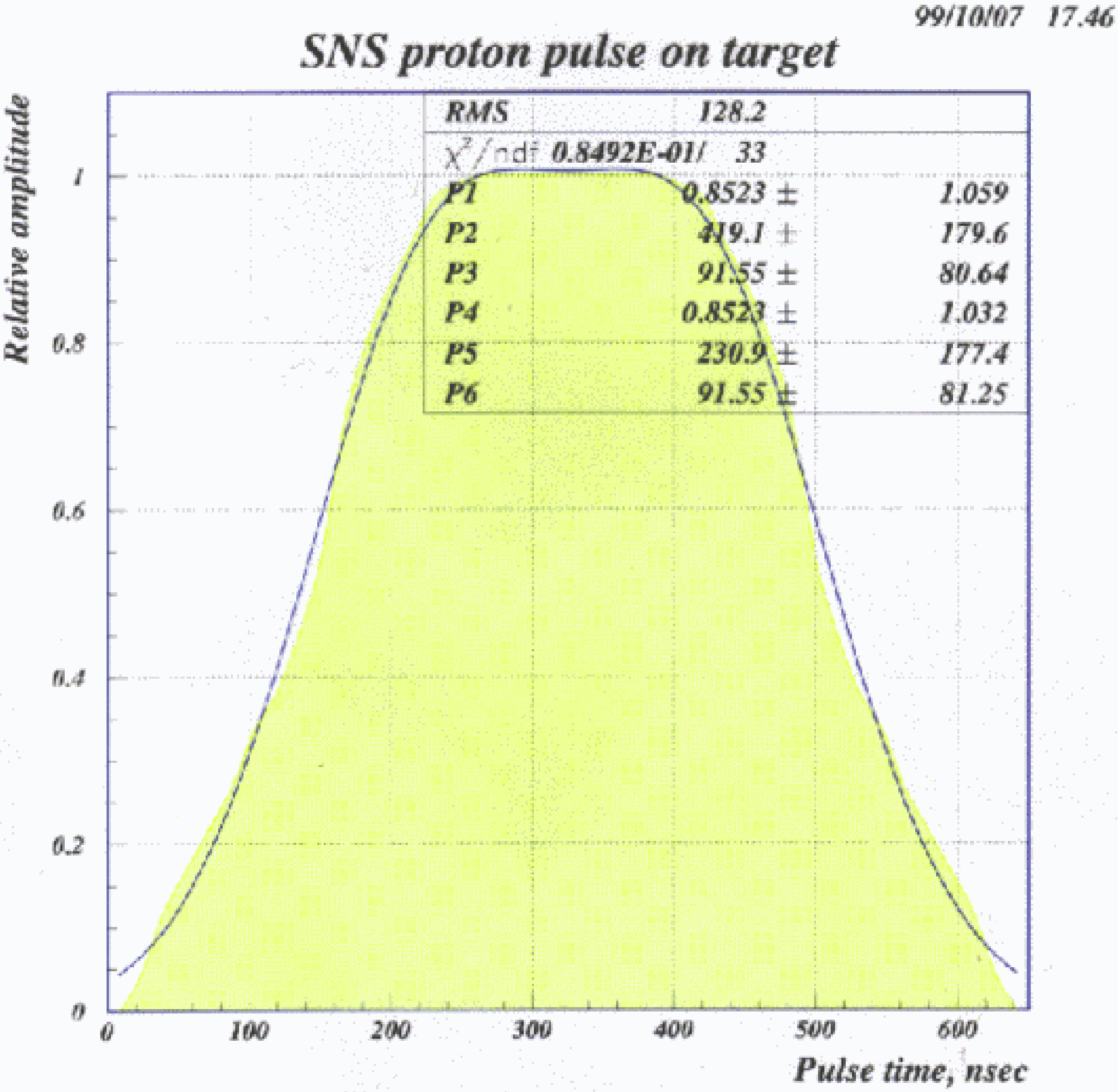
$R_\nu = 3.5 \cdot 10^{15}$ ν/sec

E_p=1.3 GeV Rep. rate 60 Hz

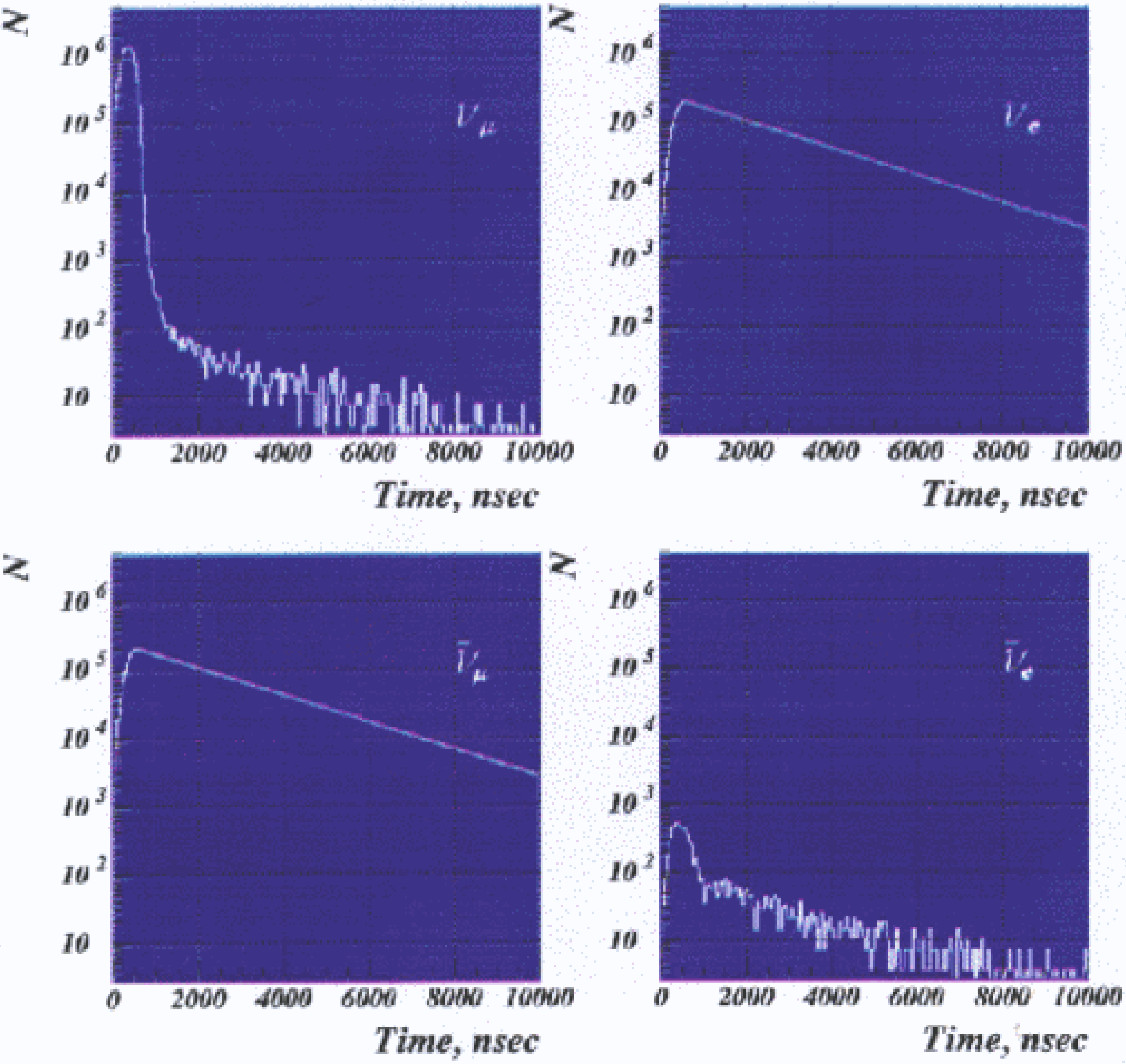
P=2 MW RMS ~ 340 nsec FWHM 600 nsec



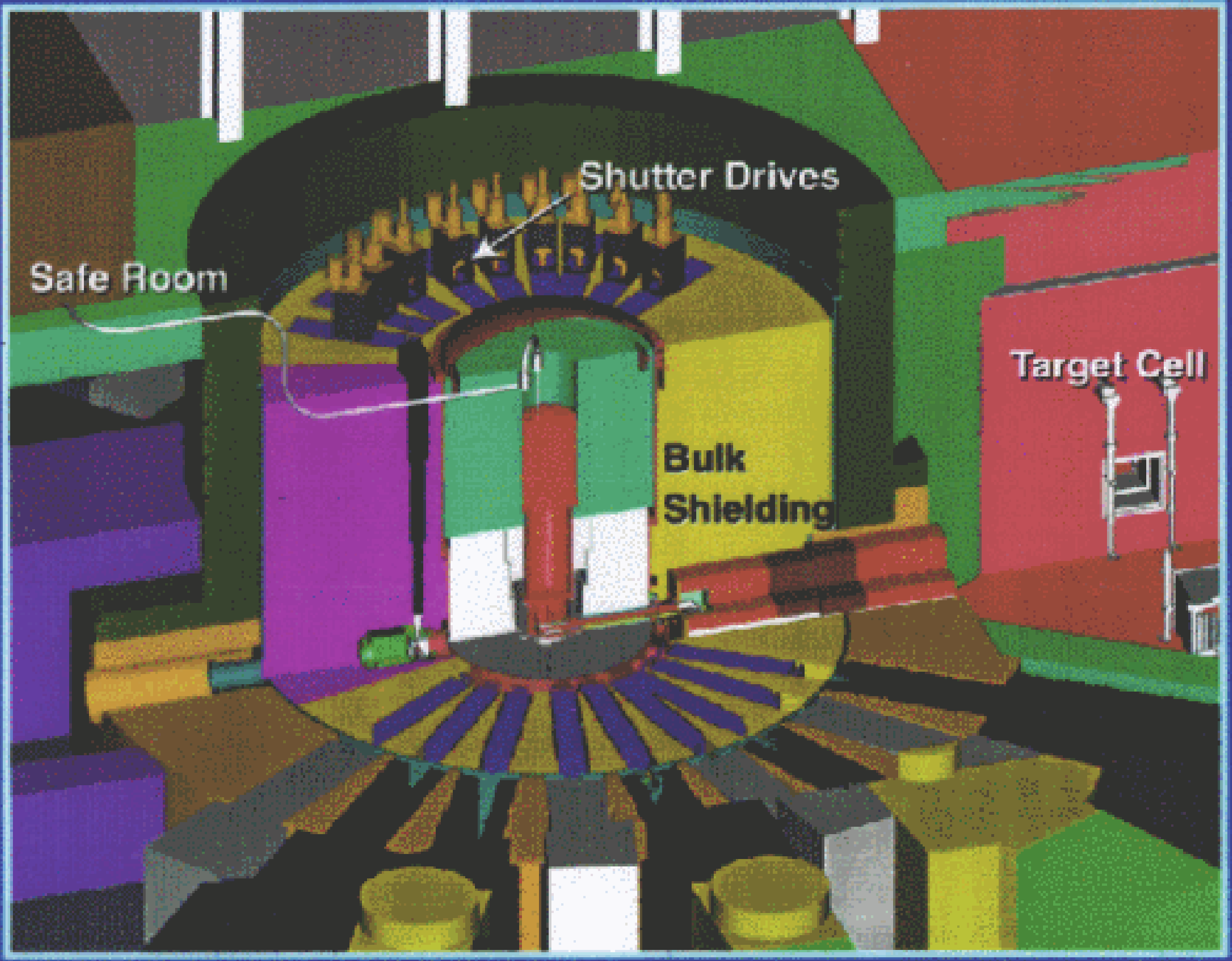
Neutrino spectra, 100ms After Bounce

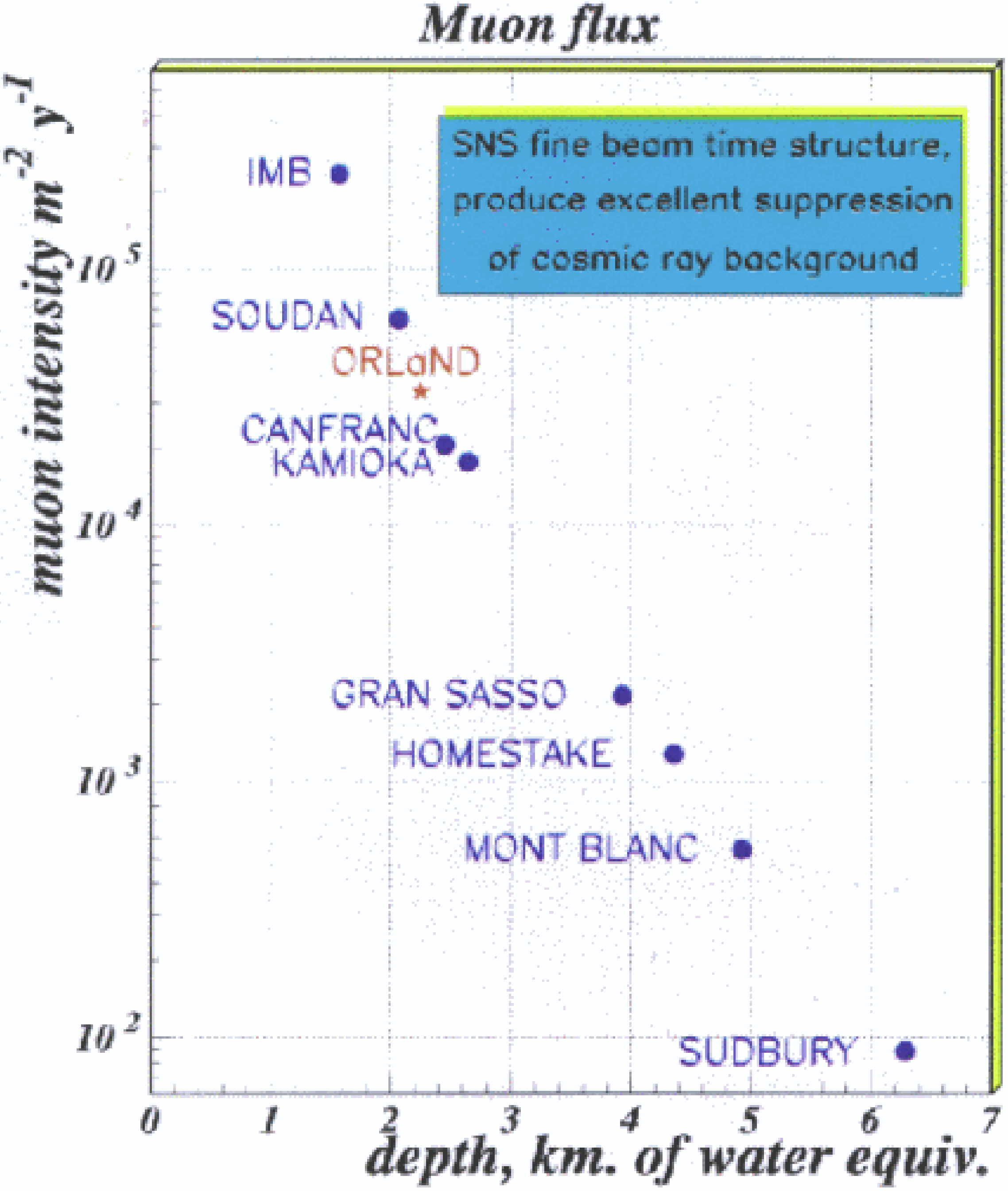

99/10/07 17.46
SNS proton pulse on target
RMS 128.2
χ²/ndf 0.8492E-01/ 33
P1 0.8523 ± 1.059
P2 419.1 ± 179.6
P3 91.55 ± 80.64
P4 0.8523 ± 1.032
P5 230.9 ± 177.4
P6 91.55 ± 81.25
Relative amplitude
0
0.2
0.4
0.6
0.8
1
0
100
200
300
400
500
600
Pulse time, nsec

Neutrino Time Spectra at SNS



Target Systems: Target Station Cutaway



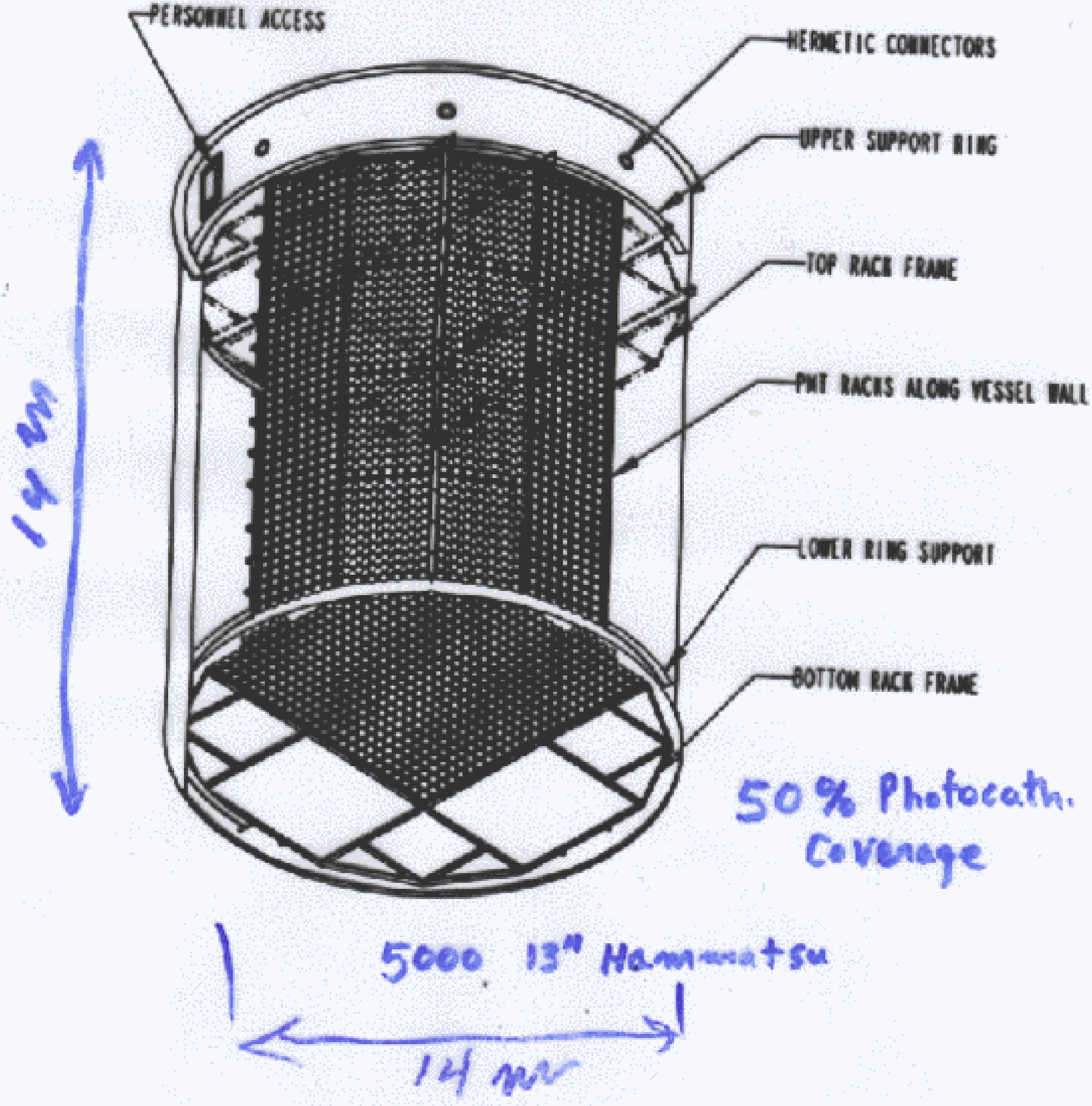


SNS fine beam time structure, produce excellent suppression of cosmic ray background

H_2O
min oil
min. oil
Dilute Scint

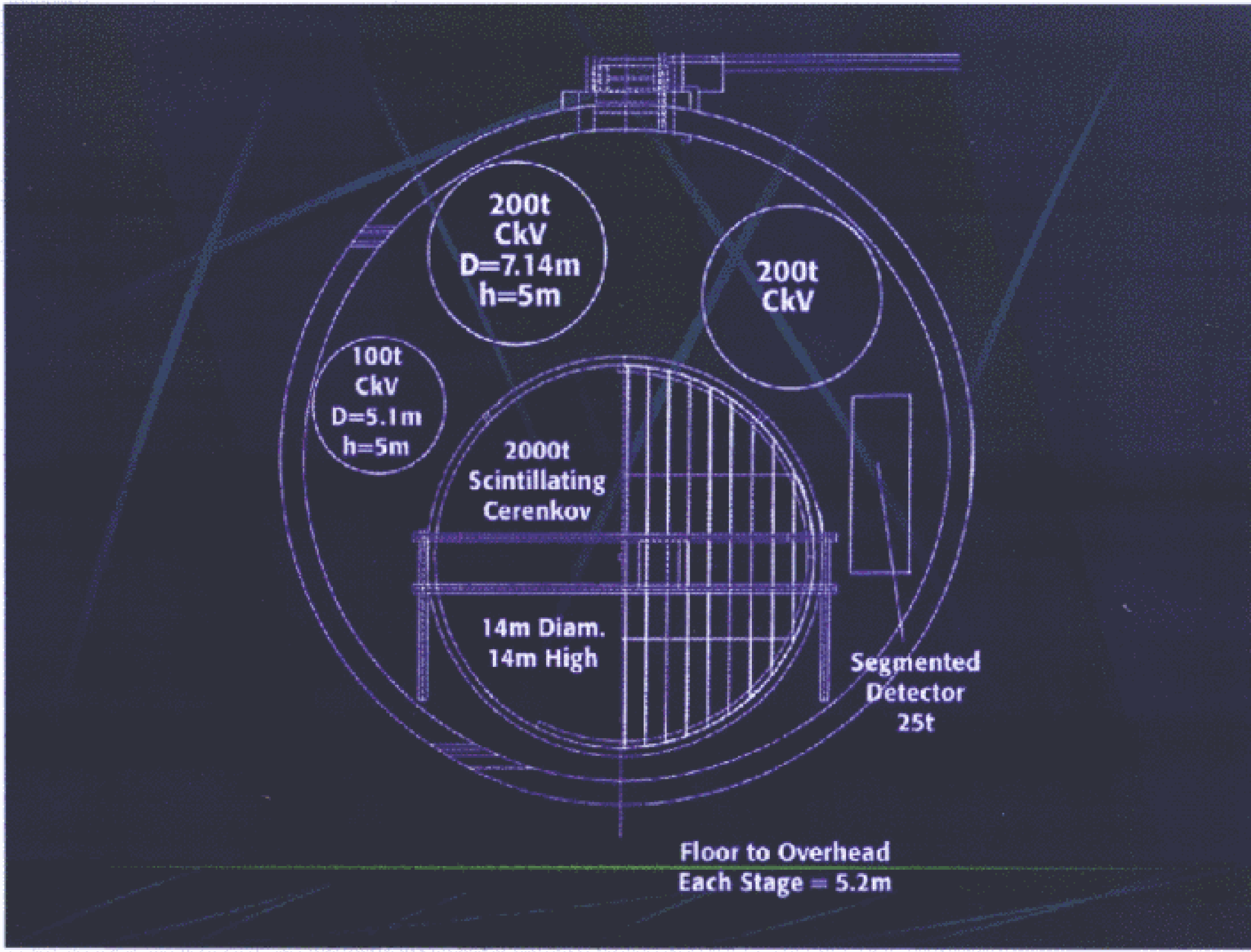
2000 t TOTAL

~1500 t Fiducial ~18 LSND



50 % Photocath. Coverage

5000 13" Hamamatsu


200t
CkV
D=7.14m
h=5m
200t
CkV
100t
CkV
D=5.1m
h=5m
2000t
Scintillating
Cerenkov
14m Diam.
14m High
Segmented
Detector
25t
Floor to Overhead
Each Stage = 5.2m

ORLaND Large Detector

Experiments for Liquid Cherenkov Detector

$D(\nu_e,e^-)pp$	Precision Measurement
$^{16}O(\nu_e,e^-)^{16}F$	$d\sigma/d\Omega\ dE$
$^{16}O(\nu_x, \nu_x`n)^{15}O$	

Neutrino Oscillations in five different channels

Precision Measurement of ν,e^- scattering:

- Precise measurement of ν fluxes
- Precise Measurement of Charge-Current Neutral Current interference
- Accurate measurement at $Sin^2\vartheta_W$ at very low Q, ~ 0.005 GeV
- Improve bounds on magnetic moment of ν_μ by a factor of 10

$^{12}C(\nu_e,e^-)^{12}N_{gs}$	Precision Measurement
$^{12}C(\nu_e,e^-)^{12}N^*$	Precision Measurement
$^{12}C(\nu_x,\nu_x`\gamma)^{12}C$	Precision Measurement

Two detector options:

Homogenous detectors (transparent targets)

- Carbon (Mineral Oil)
- Oxygen (Water)
- Deuterium (Heavy Water)
- Silicon (Silicon Oil)
- Lead (Lead Glass)
- Various Crystals.

Segmented detectors (nontransparent targets)

Combination targets and sensitive media

- Segmented detector made out of scintillator bars with WLS fibers readout from the top and the side.
- Detector, made out of cylindrical gas drift tubes, with pipe targets around.

CHERENKOV DETECTOR

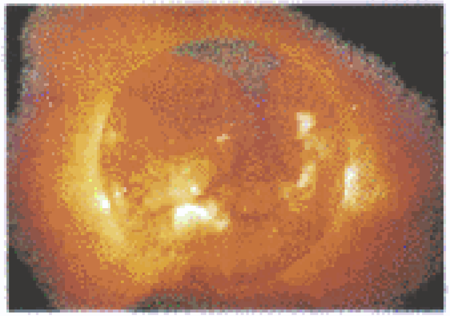
LIQUID TARGETS

$D(\nu_e,e^-)pp$	(heavy water)
$^{16}O(\nu_e,e^-)^{16}F$	(water)
$^{16}O(\nu_x,\nu_x{}' n)^{15}O$	(water+Gd)
$^{127}I(\nu_e,e^-)^{127}Xe$	(NaI aqueous solution)
$^{208}Pb(\nu_e,e^- n)^{207}Bi$	($Pb(ClO_4)_2$)
$^{28}Si(\nu_e,e^-)^{28}P$	(silicone-200 oil)

Is it possible to dissolve some rare earth and other elements in solutions appropriate for Cerenkov detectors?

Stability? Index of refraction?

light transmission vs. λ safety (health, fire, etc.)



Calibrating the Sun

"99.75% of the solar energy is generated
by the pp chain"

$p + p \longrightarrow d + e^{+} + \nu_e$

- SNO :
  - Provide a determination of the ^{8}Be neutrino flux & energy spectrum from measuring the reaction $\nu_e + d \longrightarrow p + p + e^{-}$
  - Will also measure the neutral current reaction $\nu + d \longrightarrow \nu + p + n$
  - The absolute rates of these reactions are not known - solar models However, can be cleanly understood from effective field theory with one unknown parameter - L1A

- ORLaND :

  Can measure the cross section $\nu_e + d \longrightarrow p + p + e^{-}$ thus determining L1A with a known neutrino and thereby a laboratory measurement of:

The p + p rate initiating solar fusion

Calibration of $\nu + d$ at SNO


SNOINO
d_2O

$D(\nu_e,e^-)pp$

SNOINO

30 ton Cerenkov Detector(D_2O is expensive, 30 ton can be borrowed, but 2000 ton - I don't know)

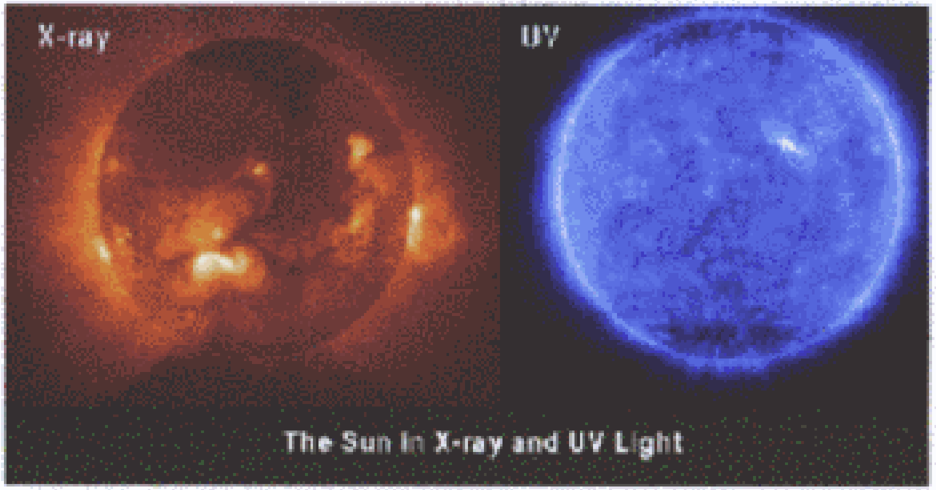
30 tons of D_2O is contained in an acrylic cylinder inside a large water cerenkov detector

Event rate

R(detected) ~ 2800 y^{-1} 30 ton^{-1}

Kubodera and Myhrer in "Proceedings of the Accelerator Production of Tritium Symposium", May 14,15, 1996, Columbia S.C. eds. F.T.Avignone and T.A.Gabriel, World scientific p.148

$<\sigma>=5.4\cdot10^{-41}$ cm^2 DAR spectrum



ORLaND - Can measure ~ 1% the cross section with a known neutrino flux , and thus determine $L_{1,A}$

$$\nu_e + d \longrightarrow p + p + e^-$$

Calibrating the Sun

$p + p \rightarrow \; d + e^+ + \nu_e$ (99.75% solar energy)

Can be deduced from:
$\nu_e + d \rightarrow \; p + p + e^-$

Theory: Kubodera + Nozawa

$$\sigma = 52 \times 10^{-42}\ \text{cm}^2$$

Experiment: Lampf E31

$$\sigma = (53 \pm 18) \times 10^{-42}\ \text{cm}^2\ (34\%)$$

A Measurement to a few % needed

νe^- Scattering and $\mathrm{Sin}^2\,\theta_w$

$$\frac{d\sigma(\nu_i)}{dT} = \frac{2G_F^2 m_e}{\pi}\left[g_{iL}^2 + g_R^2\,(1 - \frac{T}{E_\nu})^2 - g_{iL}\,g_R\,\frac{m_e T}{E_\nu^2}\right]$$

and

$$\frac{d\sigma(\overline{\nu}_i)}{dT} = \frac{2G_F^2 m_e}{\pi}\left[g_R^2 + g_{iL}^2\,(1 - \frac{T}{E_\nu})^2 - g_{iL}\,g_R\,\frac{m_e T}{E_\nu^2}\right]$$

$$g_R = \mathrm{Sin}^2\,\theta_w$$

$$g_{eL} = \tfrac{1}{2} + \mathrm{Sin}^2\,\theta_w$$

$$g_{\mu L} = -\tfrac{1}{2} + \mathrm{Sin}^2\,\theta_w$$

$$R = \frac{\sigma(\nu_\mu e)}{\sigma(\nu_e e) + \sigma(\overline{\nu}_\mu e)}$$

Integrate over T:

$$R = \frac{3/4 - 3\sin^2\theta_w + 4\,(\sin^2\theta_w)^2}{1 + 2\sin^2\theta_w + 8\,(\sin^2\theta_w)^2}\ .$$

ν_e CC+NC interference

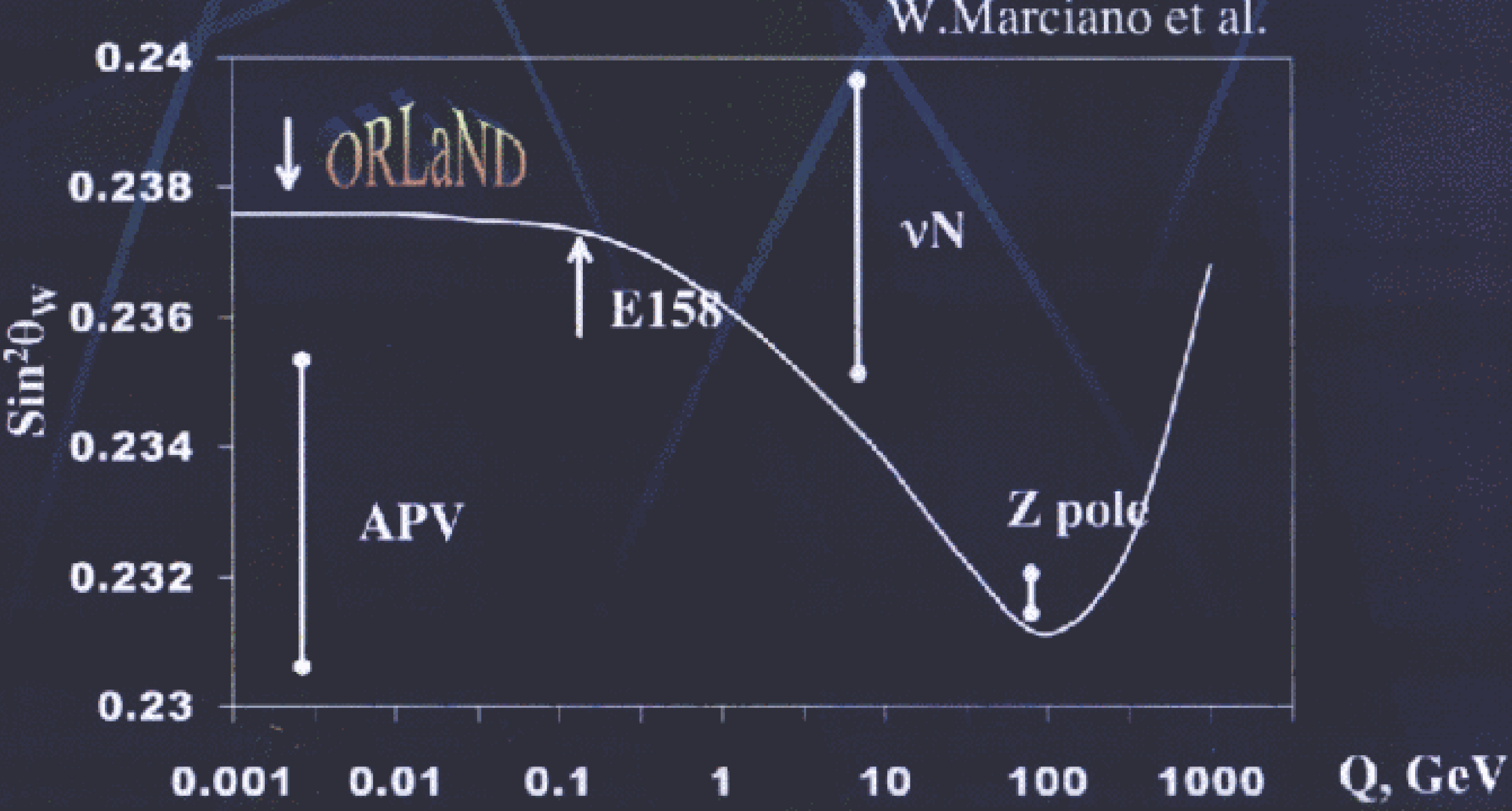
$$\mathcal{M} = \mathcal{M}_{NC} + \mathcal{M}_{CC}$$

$$\frac{N(\nu_\mu)\ 26\ \text{nsec}}{N(\nu_e) + N(\overline{\nu}_\mu)\ \ 2.2\ \mu\text{sec}}$$

Flux cancels

The first accurate measurement of this interference, and another stringent test of the Standard Model

$\sin^2\theta_W(Q^2)$



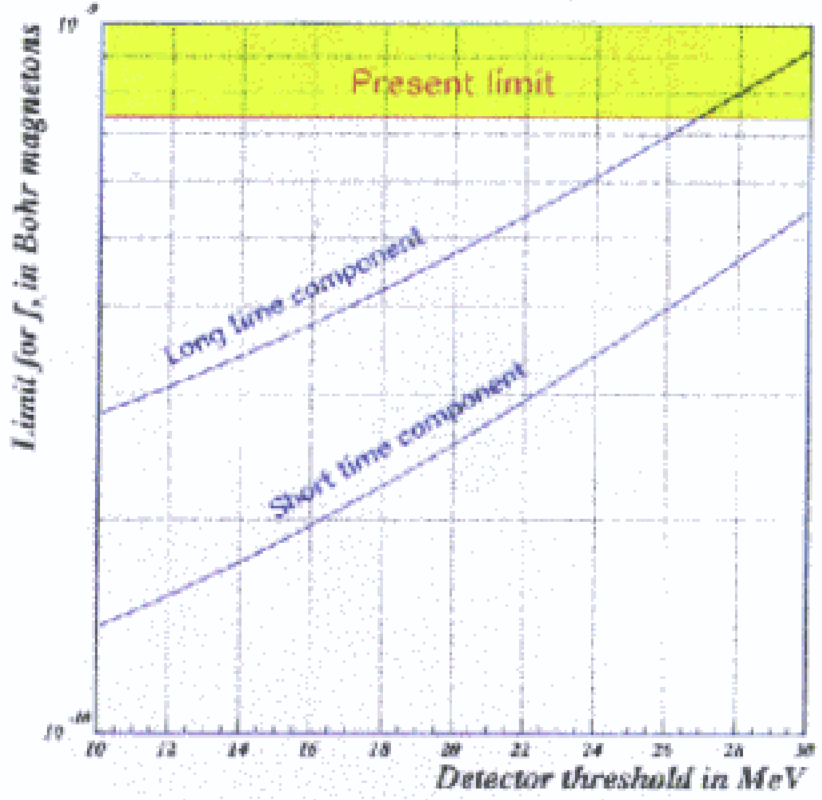
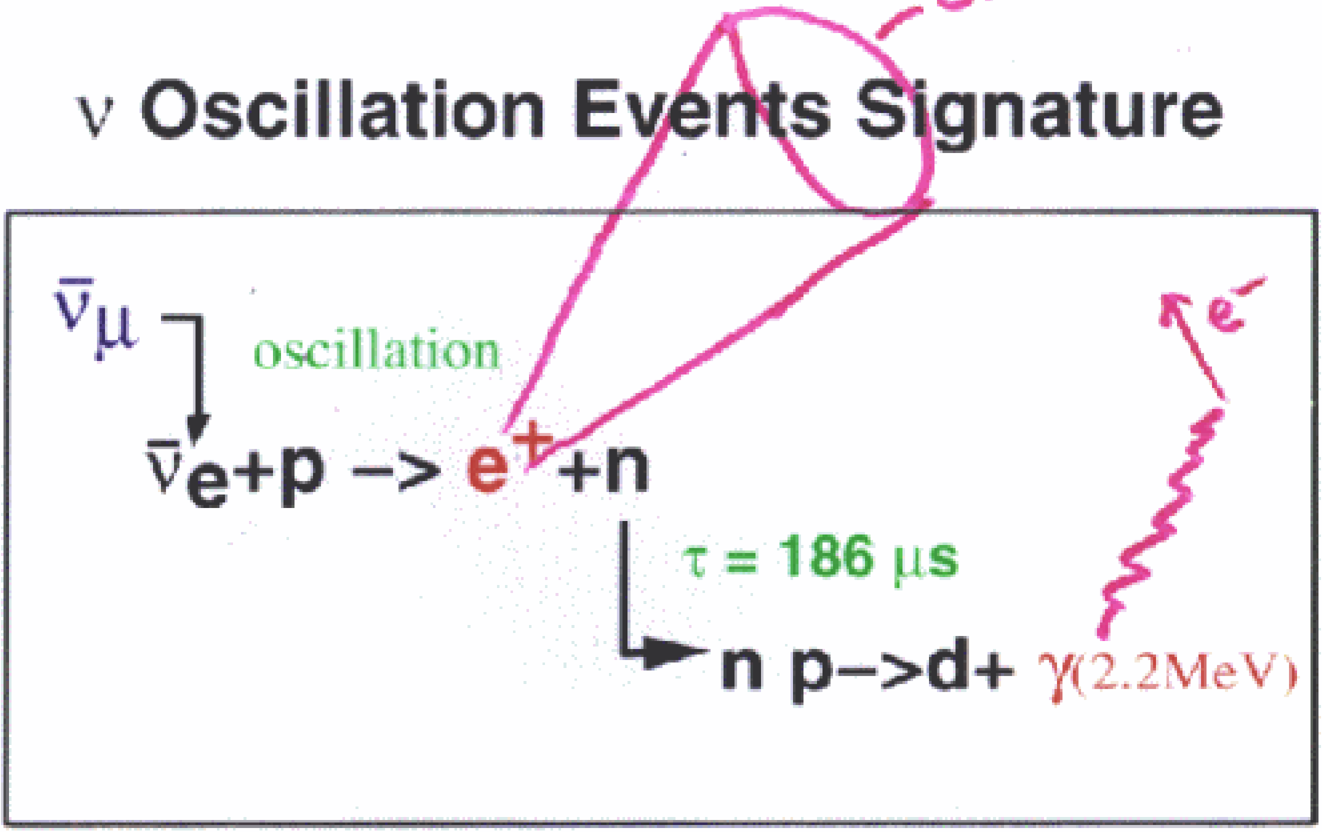


Figure 38: Comparison of possible constraints on the magnetic moment of ν_μ for th absolute measurement of neutrino electron scattering cross sections as a function detector threshold. The two lines are for the short and for the long time spectru components. The existing experimental limit is shown by the horizontal line.

CERENKOV

ν Oscillation Events Signature



$\bar{\nu}_\mu$ oscillation

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

$\tau = 186\ \mu s$

$n\, p \to d + \gamma$ (2.2MeV)

e^-

– e^+ selection

- ✓ Particle ID : cut cosmic neutrons
- ✓ $d_{PMT} > 35$cm: fiducial volume
- ✓ $\Delta t_{previous} > 20\mu s$: cut cosmics
- ✓ $\Delta t_{next} > 8\mu s$: cut muons
- ✓ $n_\gamma < 2$: cut cosmic neutrons
- ✓ < 4 veto hits: cut cosmics
- ✓ $S > 0.5$: cut cosmics

Efficiency : 0.37

– γ selection : Likelihod ratio, R method

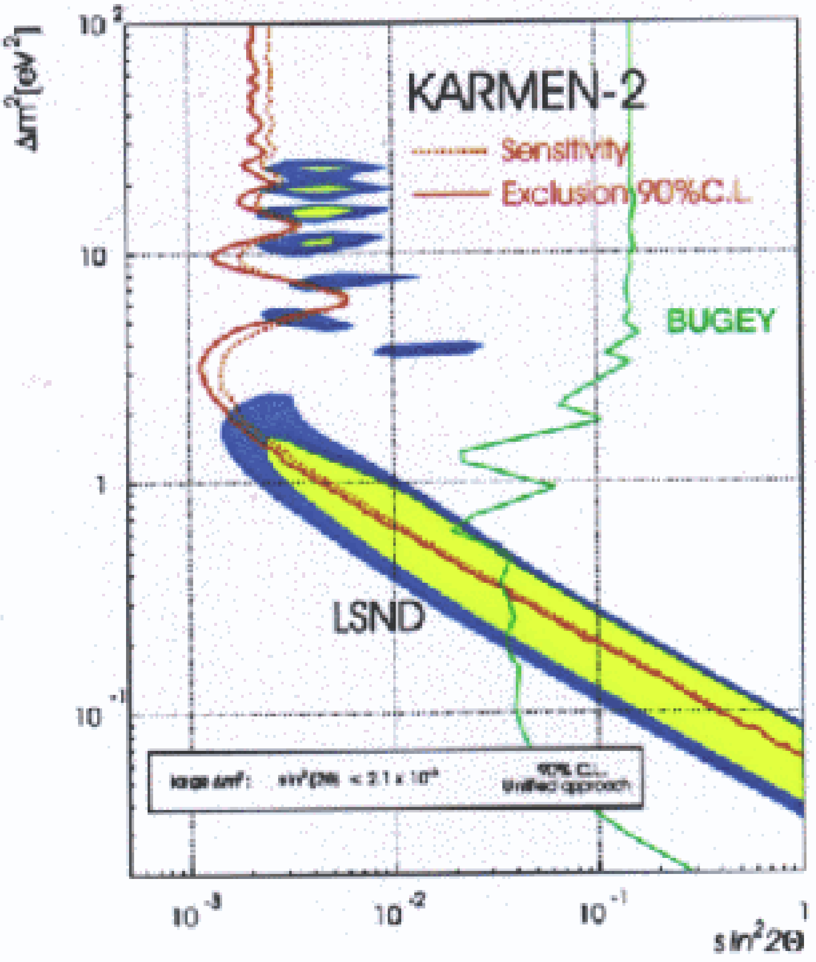
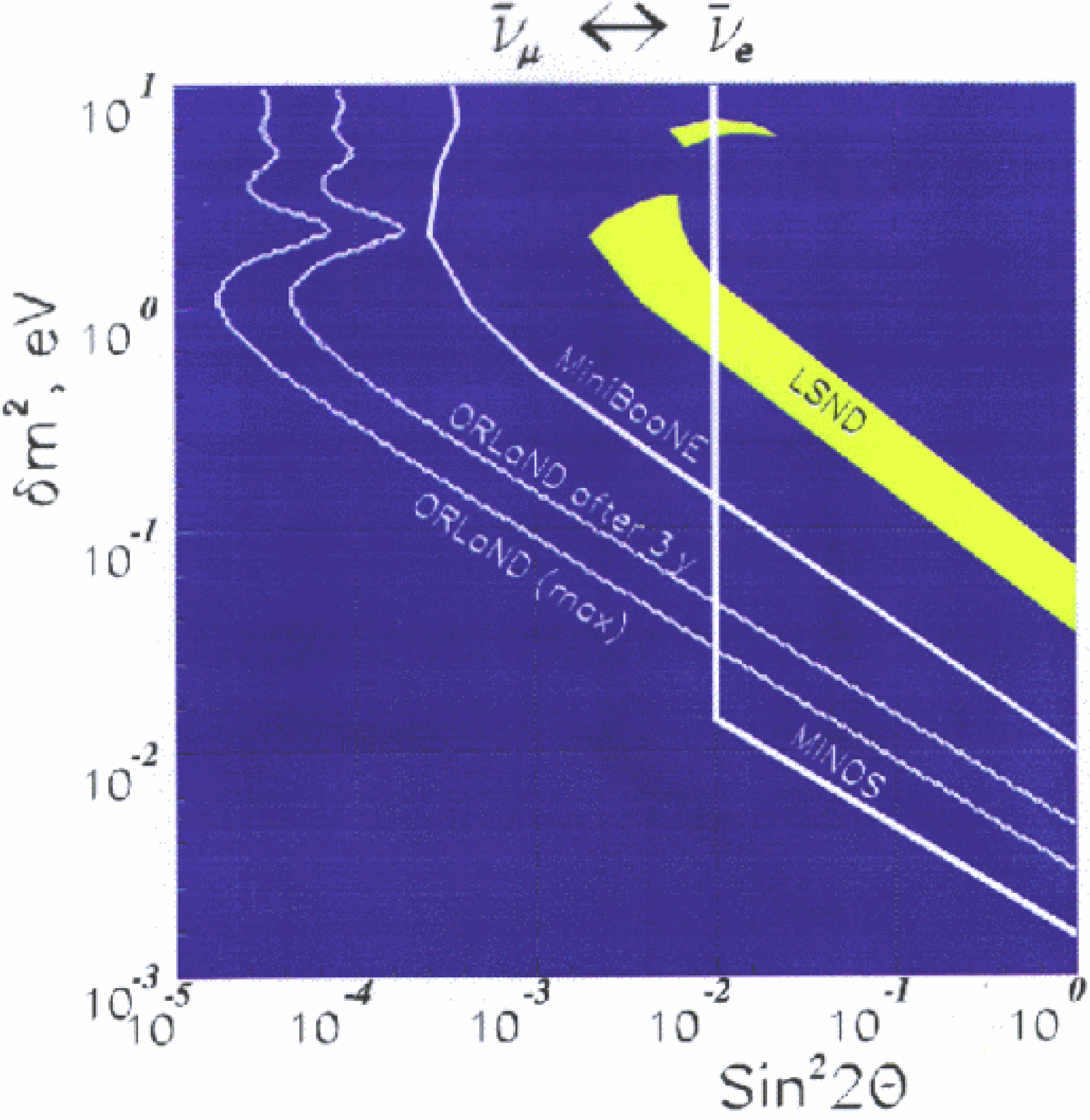
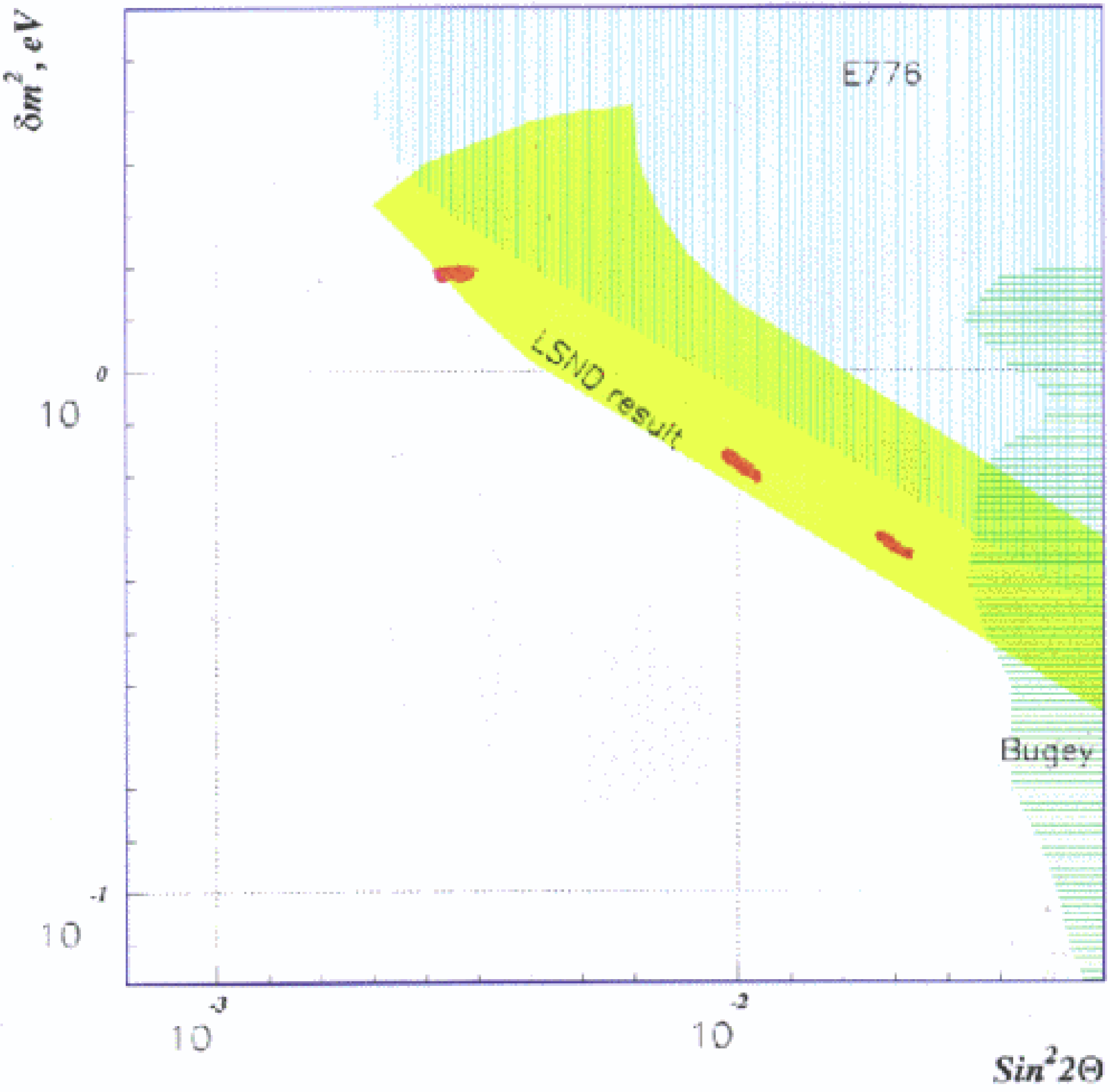


Figure 12: *Preliminary* LSND DAR allowed regions in the ($\sin^2 2\theta$, Δm^2) space from the 1993-1997 data. In addition to the previous limits from Bugey, the latest limit from KARMEN-2 (with its corresponding sensitivity) has been included as well.



$$P(\bar{\nu}_\mu \to \bar{\nu}_e) = \sin^2 2\theta \, \sin^2\left[\frac{1.27\,(m_1^2 - m_2^2)\,L}{E}\right]$$

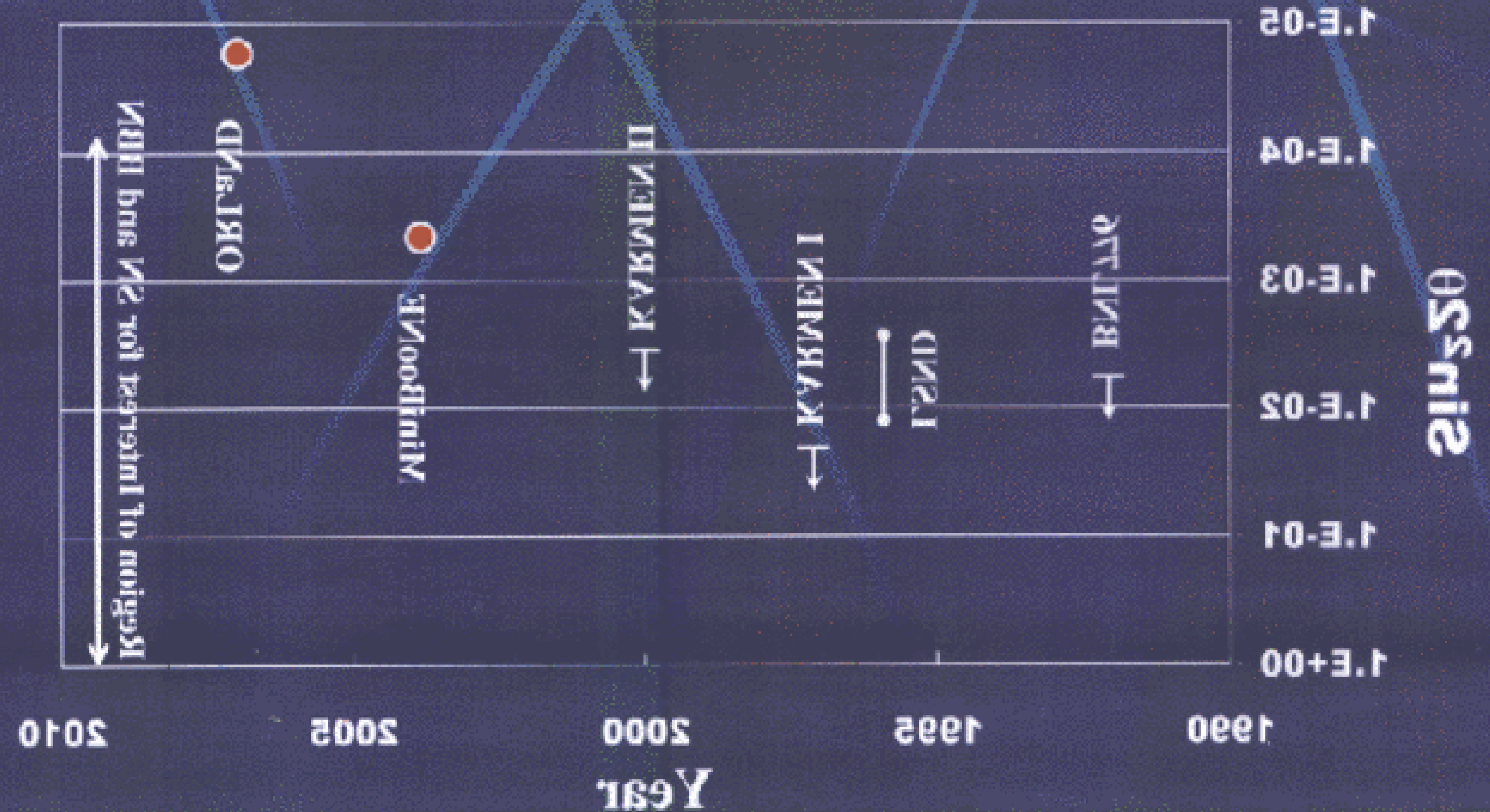
O R L a N D, Single Target - 3 MWY.

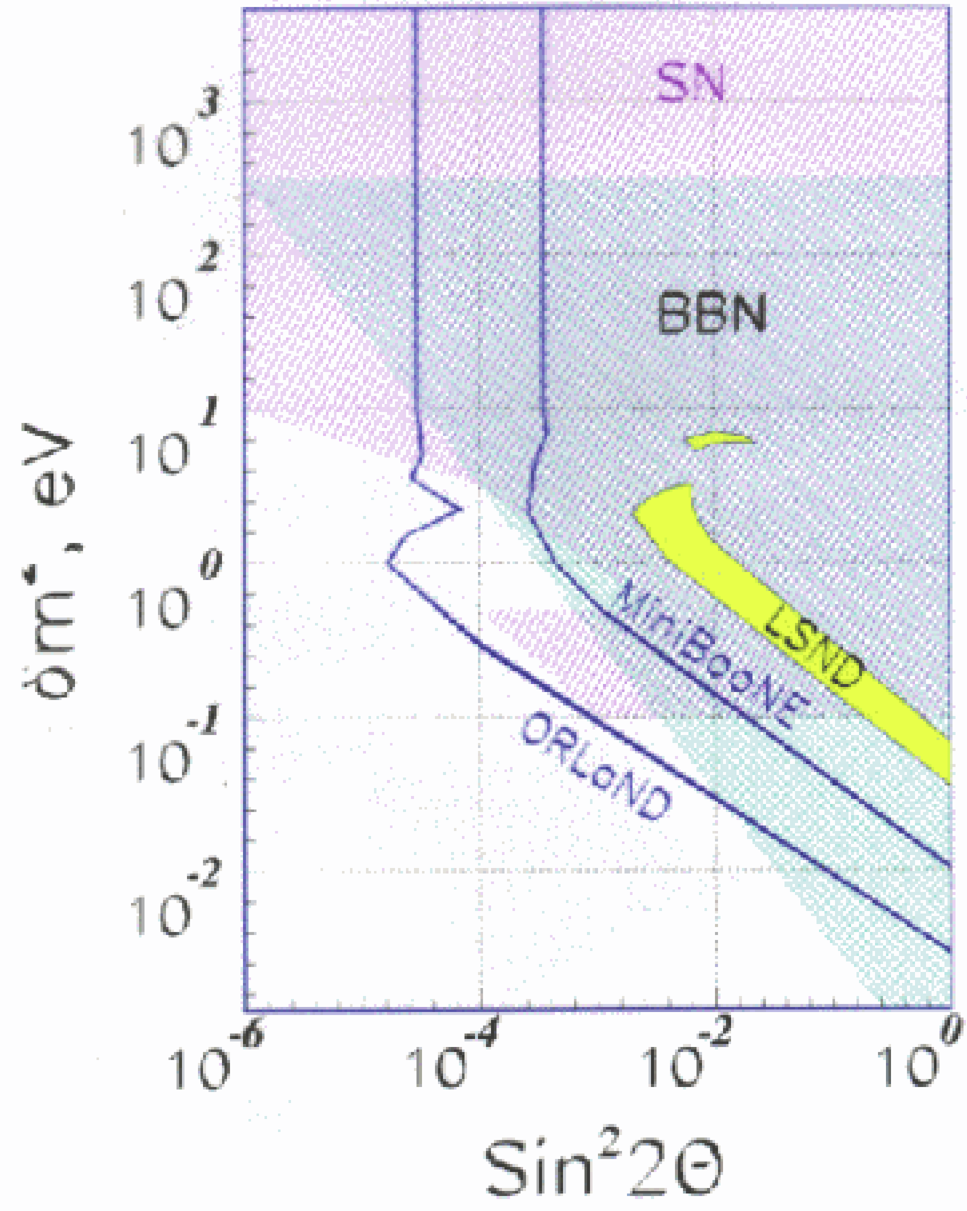


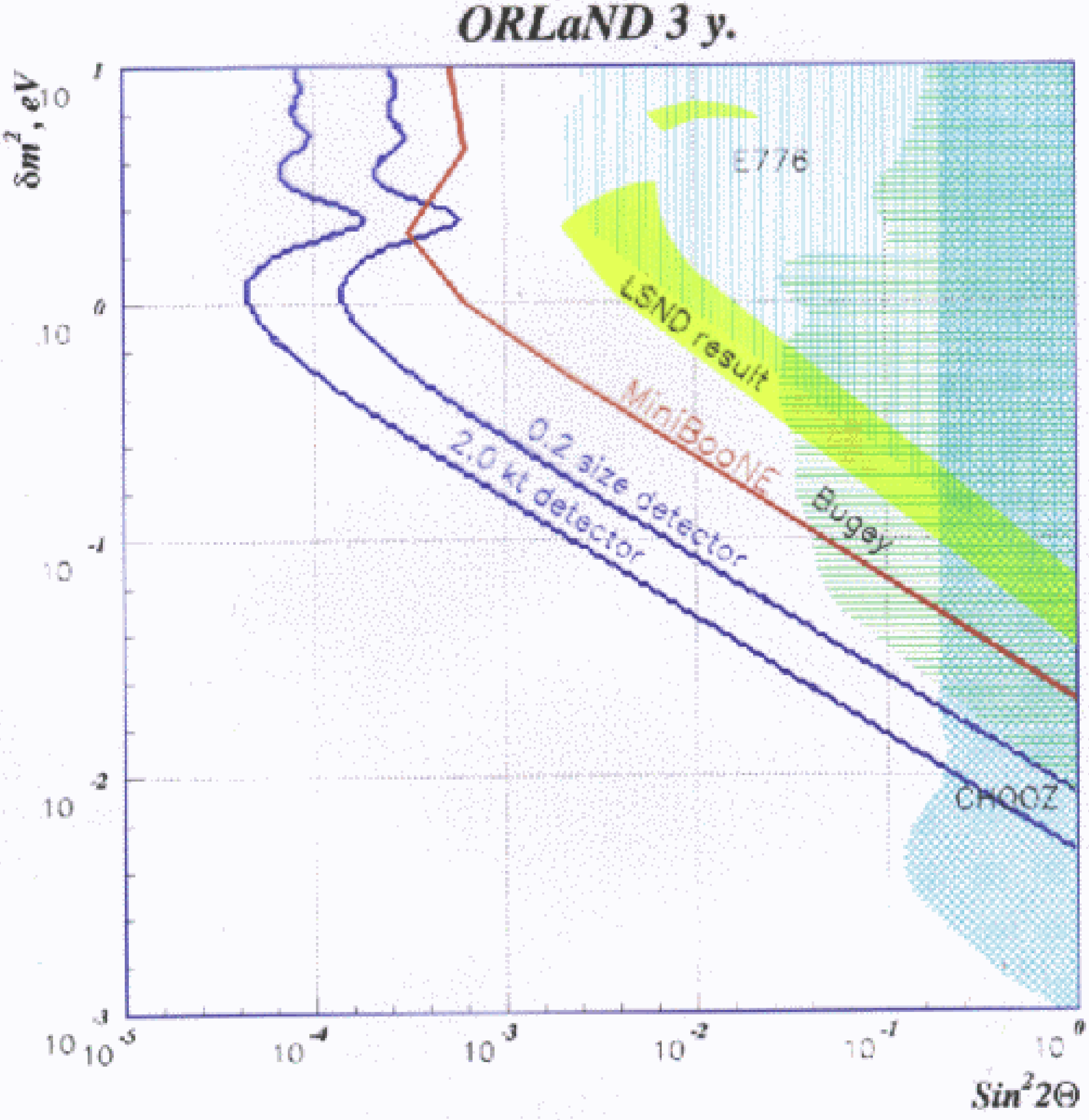
$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2 2\Theta \sin^2\left[\frac{1.27(m_1^2 - m_2^2)L}{E}\right]$$

$\bar{\nu}_\mu \leftrightarrow \bar{\nu}_e$ Oscillations

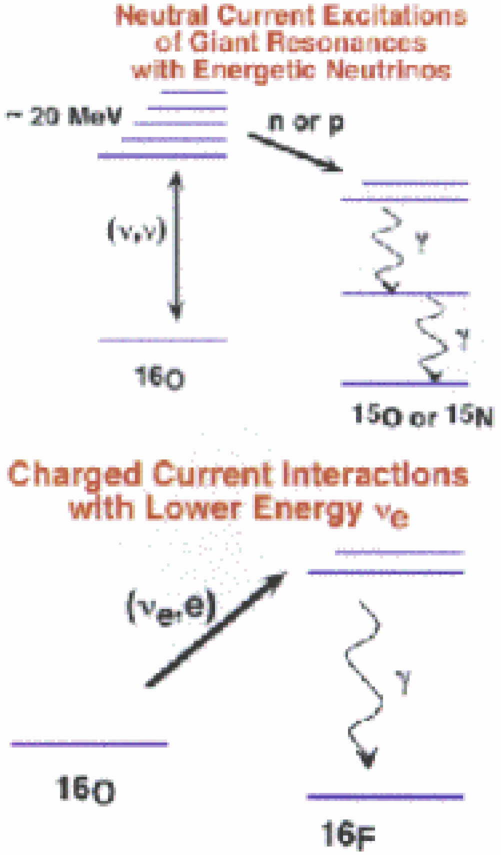
Sensitivity to $\sin^2 2\theta$ for $\delta m^2 \sim 1$ eV




SN
BBN
LSND
MiniBooNE
ORLoND
δm^2, eV
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-6}
10^{-4}
10^{-2}
10^0
$\sin^2 2\Theta$

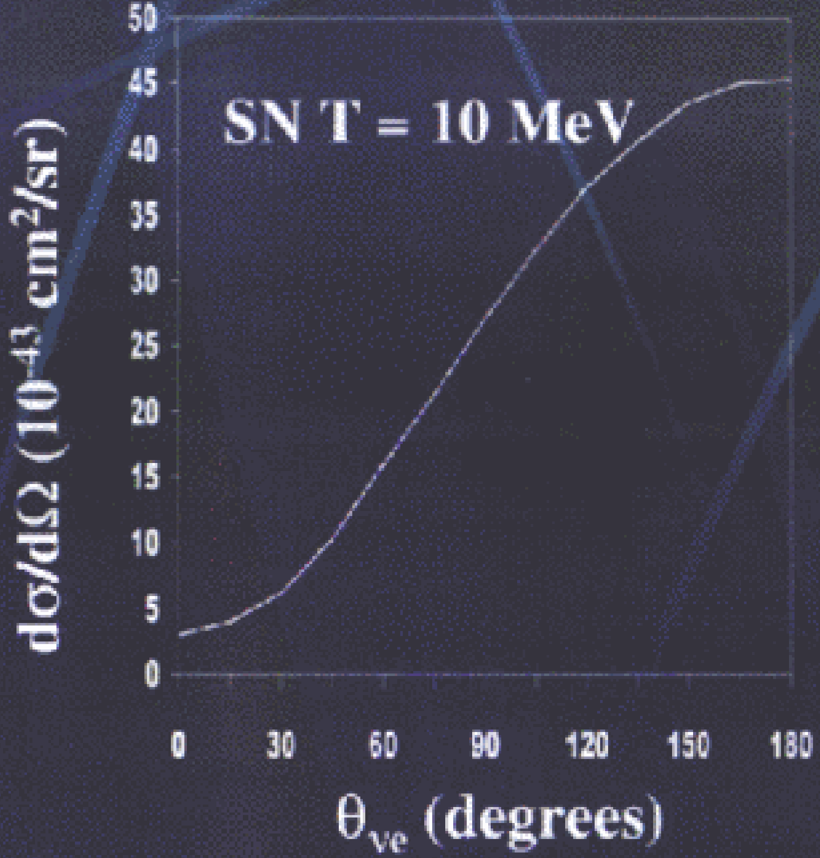

ORLaND 3 y.
δm^2, eV
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
$Sin^2 2\Theta$
E776
LSND result
MiniBooNE
Bugey
0.2 size detector
2.0 kt detector
CHOOZ

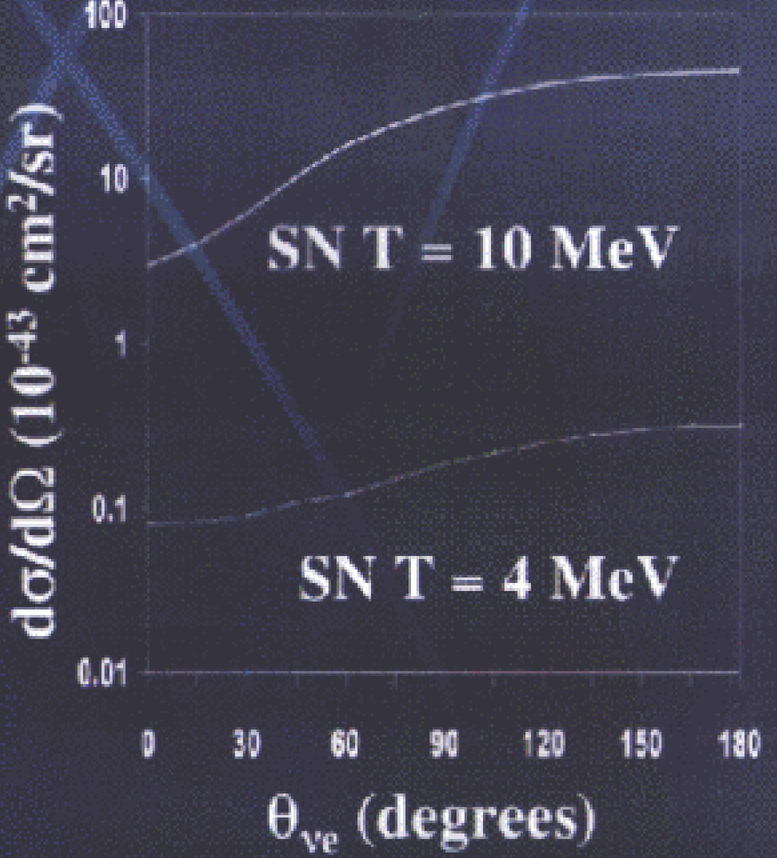
Supernovae Thermometry



- Different energy neutrinos of the same flavor have different signatures of their interaction with matter energy and angular distributions are sharply correlated
- Supernova models predict that ν_μ & ν_τ de-couple from core material at higher temperatures than ν_e about 8 & 3.5 MeV respectively
- ORLaND can measure doubly-differential cross sections $d^2\sigma/d\Omega dE$ of neutrinos with ^{16}O to determine effective de-coupling temperatures in supernovae
- Future supernova signals could be analyzed for temperatures, and possible ν_μ & ν_τ to ν_e oscillation events

$d\sigma/d\Omega(^{16}O(\nu_e,e^-)^{16}F)$





W.C.HAXTON Phys.Rev.D 36, 2283 (1987)

$^{16}O(\nu_e,e^-)^{16}F$

LARGE CERENKOV DETECTOR

Fiducial vol. 1472 m^3 of water N ~ $4.9 \cdot 10^{31} \cdot {}^{16}O$

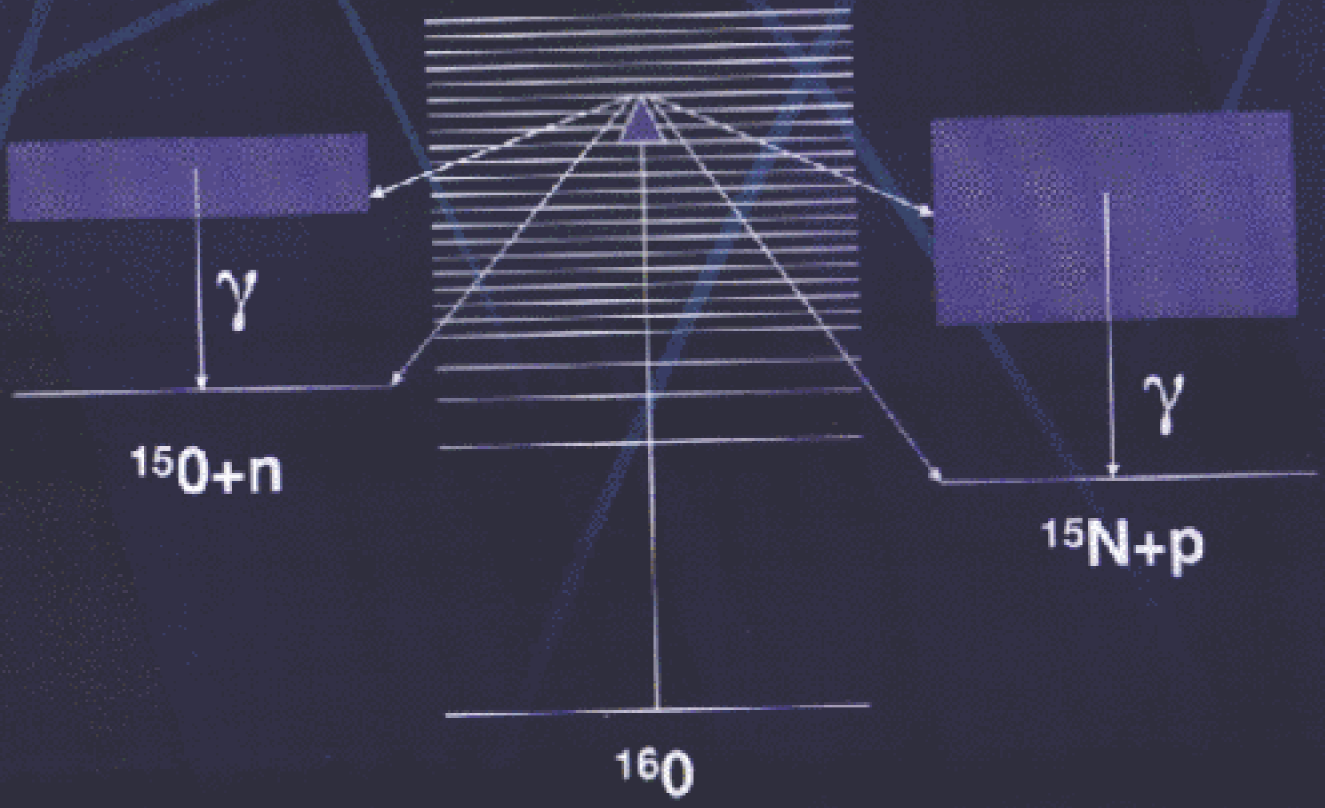
Event rates

For 30% efficiency ~ 12300 events per year

Haxton, PRD 36, 2283 (1987)

$<\sigma>=8.84 \cdot 10^{-42}$ cm^2 DAR spectrum

K. Langanke, P. Vogel and E. Kolbe*



Unique Signal for Supernova ν_μ and ν_τ in Water Cerenkov Detectors

Phys. Rev. Lett. 76, 2629 (1996)

$^{16}O(\nu_x,\nu_x`n\gamma)^{15}O$

Use Large Size Cerenkov Detector

$N \sim 4.9 \cdot 10^{31}$ of ^{16}O

Event rates:

For $^{16}O(\nu_x,\nu_x`n\gamma)^{15}O$ $R \sim 4200\ y^{-1}$

For $^{16}O(\nu_x,\nu_x`(n \text{ or } p)\gamma)^{15}X$ $R \sim 21500\ y^{-1}$

Can some compound of Gd be added to boost neutron detection?

Langanke, Vogel, and Kolbe, Phys.Rev.Lett. 76, 2629 (1996) (SN spectrum)

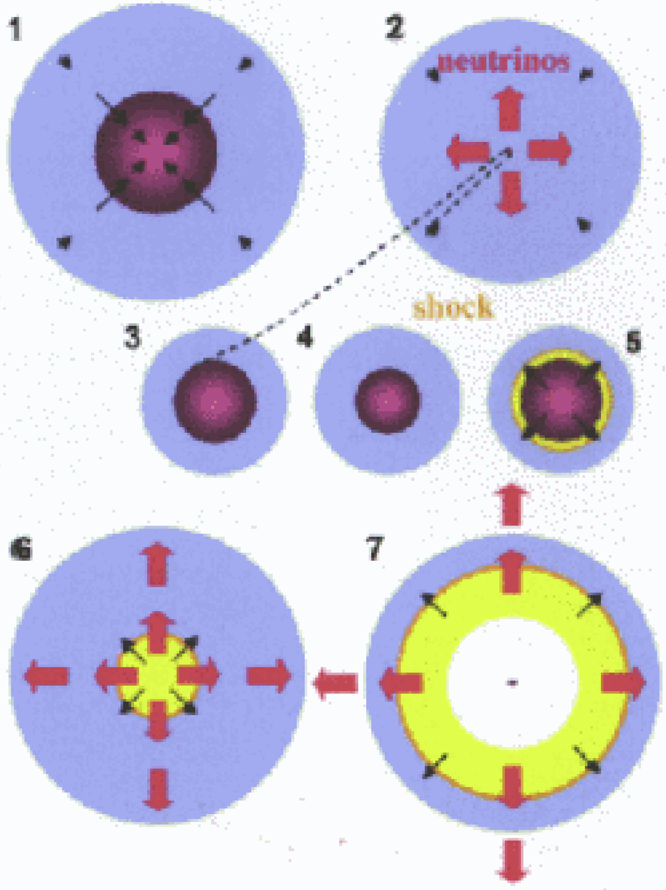
Kolbe, Langanke, Thielemann, Eur.Phys.J. A3, 389 (1996) DAR spectrum.

$<\sigma>=9 \cdot 10^{-43}\ cm^2$ DAR spectrum

Supernova Studies at Beam Stop Facilities

Supernova Explosions - Delayed Shock Mechanism

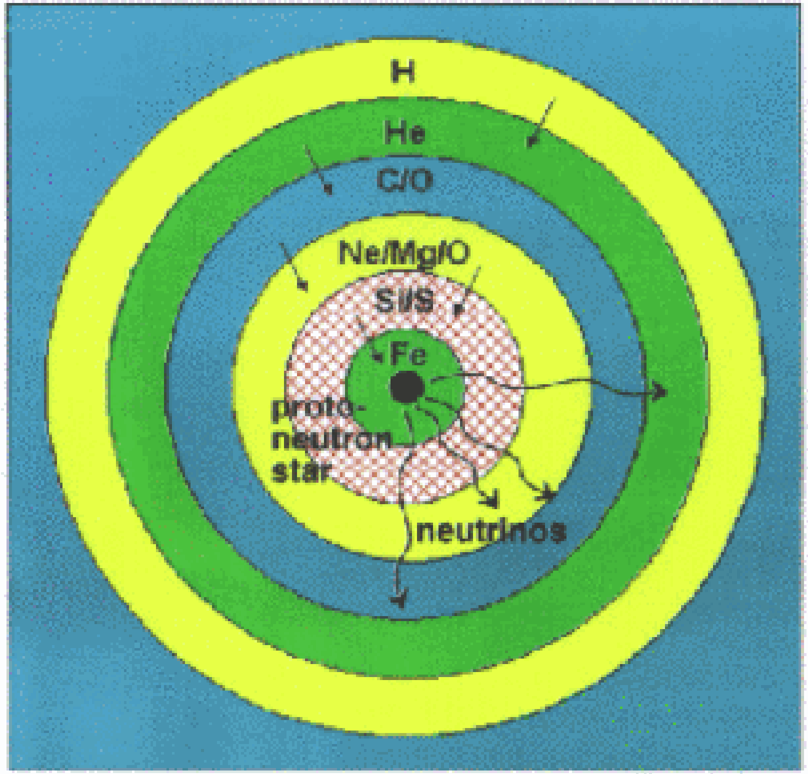
Core Collapse and Explosion



- Collapse and re-bound(1-4) creates ashock wave(5) propagating outward from center of core(6) , meeting infalling outer core material
- Shock stalls due to neutrino escape & nuclear dissociation
- Neutrino interactions behind the shock reheat the shock and drive it outwards(7)
- Measuring ^{56}Fe(ν_e,e$^-$) ^{56}Co provides valuable data to guide shock formation models; other cross sections, ^{28}Si, should also play an important role.

ν-Process Nucleosynthesis in Supernovae

Structure of Massive Star Undergoing Core Collapse



- "ν process nucleosynthesis" could be an important new dramatically altering the r-process.
- "ν process nucleosynthesis" can produce rare isotopes - ^{180}Ta, ^{138}La, ^{19}F, ^{10,11}B
- These isotopes cannot be produced at other sites and thus form "fingerprints"

$^{181}\mathrm{Ta}(\nu, \nu' \, n)\, ^{180}\mathrm{Ta}$

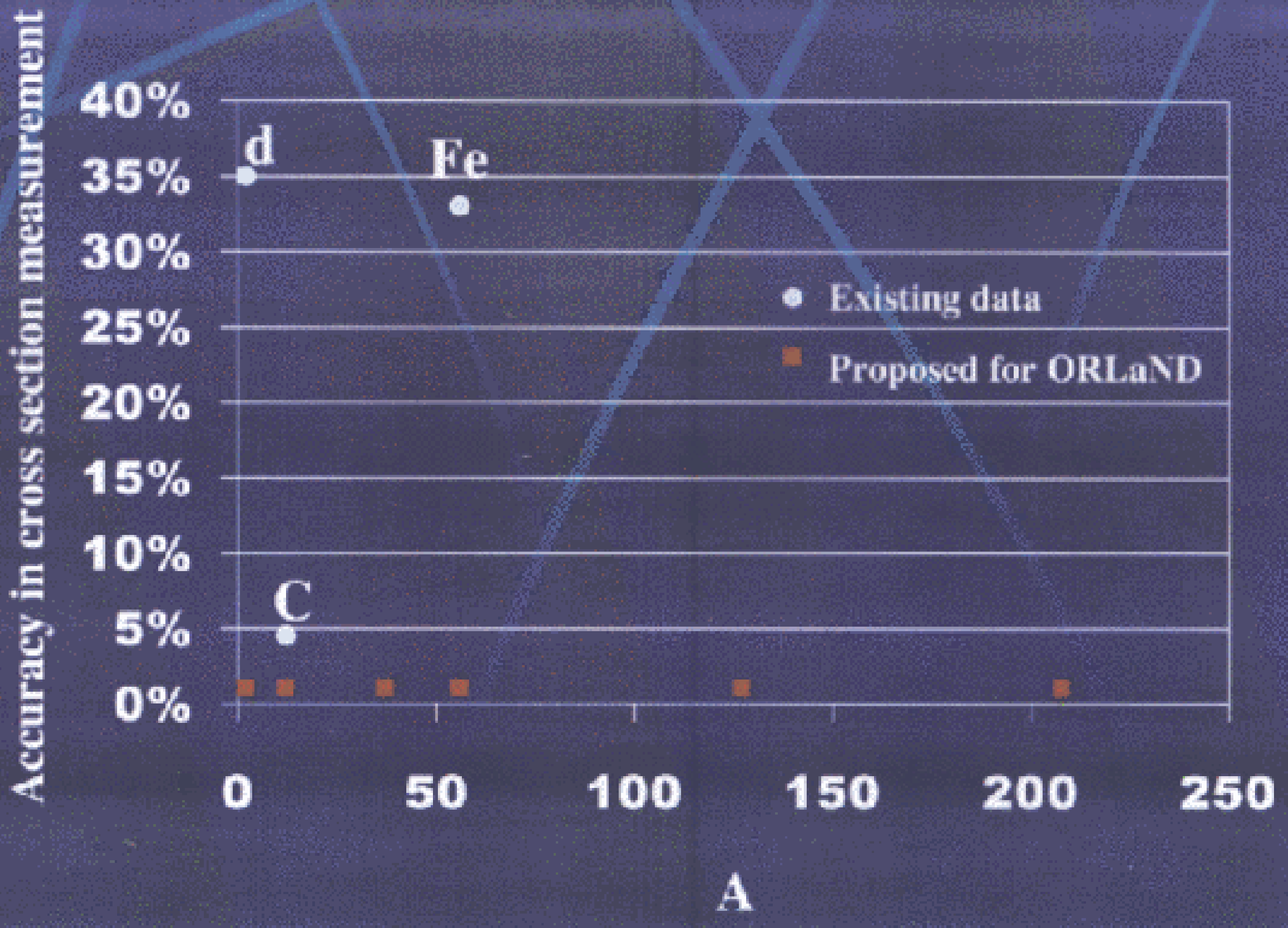
$^{138}\mathrm{Ba}(\nu_e, e^-)\, ^{138}\mathrm{La}$

$^{20}\mathrm{Ne}(\nu, \nu' \, n)\, ^{19}\mathrm{Ne} \rightarrow {}^{19}\mathrm{F}$

$^{12}\mathrm{C}(\nu, \nu' \, p)^{11}\mathrm{B}$, $^{12}\mathrm{C}(\nu, \nu' \, pn)^{10}\mathrm{B}$

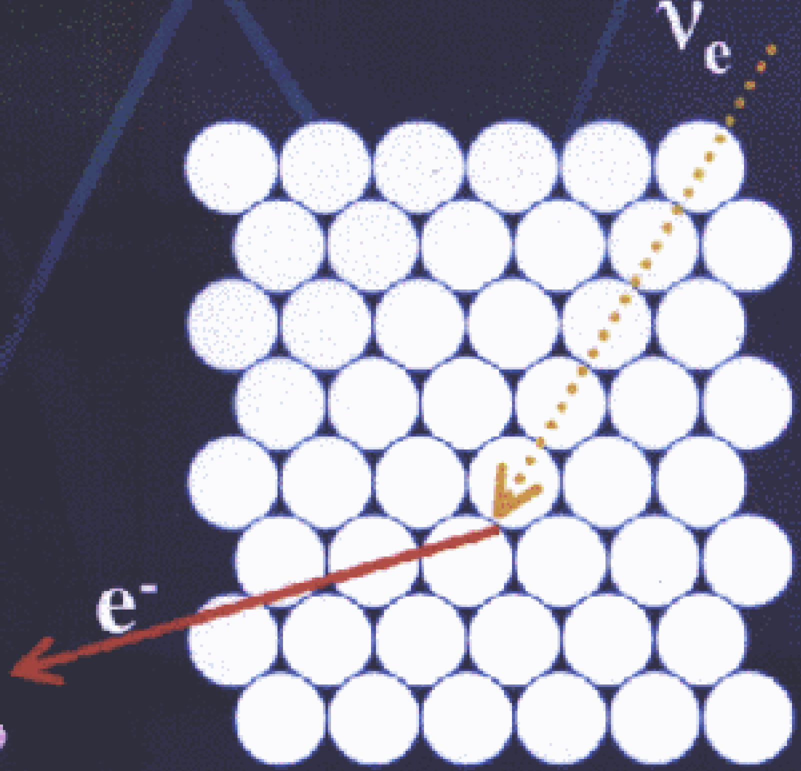
ORLaND measurements would give the first experimental basis for this process

Neutrino nucleus cross sections.



DC

OTHER AVAILABLE TARGETS



Metal or other solid
(SOUDANINO)

^{51}V, ^{27}Al, ^{9}Be, ^{11}B, ^{52}Cr,
^{56}Fe, ^{59}Co, ^{209}Bi, ^{181}Ta

ANALYSIS ON $^{56}Fe(\nu_e, e^-)^{56}Co$
COMPLETE

$^{56}F(\nu_e,e^-)^{56}Co$

SOUDANINO

0.5 mm thick walls tubes 10 mm OD ~ 3400 tubes/ton

Event rates

Efficiency ~ 30 % R(detected)=75 y^{-1} ton^{-1}

For 1000 events per year - 13.5 tons fiducial.

Detector size - 3.5m·3.5m·3.5m or 10^5 tubes

Kolbe, Langanke, and Martinez-Pinedo,arXiv:nucl-th/9905001

$<\sigma>=2.73\cdot10^{-40}$ cm^2 DAR spectrum

AVAILABLE TARGETS

^{7}Li(92%) ^{9}Be(100%) ^{11}B(80%) ^{12}C(98.9%)

^{14}N(99.6%) ^{16}O(99.8%) ^{19}F(100%) ^{23}Na(100%)

^{27}Al(100%) ^{28}Si(92%) ^{31}P(100%) ^{32}S(95%)

^{39}K(93%) ^{40}Ca(97%) ^{45}Sc(100%) ^{51}V(99.8%)

^{52}Cr(84%) ^{55}Mn(100%) ^{56}Fe(92%) ^{59}Co(100%)

^{89}Y(100%) ^{93}Nb(100%) ^{115}In(96%) ^{127}I(100%)

^{133}Cs(100%) ^{139}La(100%) ^{159}Tb(100%) ^{169}Tm(100%)

^{209}Bi(100%) ^{181}Ta(100%) ^{206,207,208}Pb

LARGE DETECTOR COLLABORATION AT ORLaND

- 18 US Universities
- U.Tel Aviv, Israel
- U.Carleton, Canada
- ORNL/ORAU
- LANL
- J.LAB
- ITEP
- TUNL

LARGE DETECTOR COLLABORATION

TASKS AND TASK UNIT COORDINATORS

Calibration:	Richard Imlay, LSU
Data Acquisition:	Glen Young, ORNL
Deuterium System:	Alfredo Galindo-Uribarri, ORNL
Electronics:	Carl Rosenfeld, USC
Liquid Systems:	Jerry Busenitz, U.Alabama
Photomultipliers:	William Bugg, UT
Simulations:	Ion Stancu, U.Alabama
Slow Controls:	Luke Mo, VA Tech.
Tank Design:	Christopher Gould, NC State
Veto:	Werner Tornow, TUNL/Duke

Task Unit Technical Coordinator:	Yuri Efremenko UT/ORNL
ORAU Technical Coordinator:	Ken Carter
Spokesman:	Frank Avignone, USC/ORNL

ORLaND Science

Intersection of Nuclear, Particle, Astrophysics

- Solar Physics
  - The solar neutrino problem - too few
  - Measure fundamental processes "Calibrating the Sun"
- Why Stars Explode
  - The supernova problem
  - Neutrino driven
  - Measure neutrino cross sections for stellar processes
  - Ideal neutron energy spectrum
  - Calibrate supernova neutrino detectors
- Neutrino Nucleosynthesis
  - Neutrino reactions - only mechanism to produce some elements
  - Measure cross sections for these processes
- Nucleon and Nuclear Structure
  - Nuclear strangeness
  - Strange quark pairs
  - Neutrino scattering best method of study
- Intrinsic Neutrino Properties
  - Do neutrinos change type - oscillations
  - Neutrino magnetic moment
  - Neutrino mass

EXPERIMENTS CONSIDERED INITIALLY

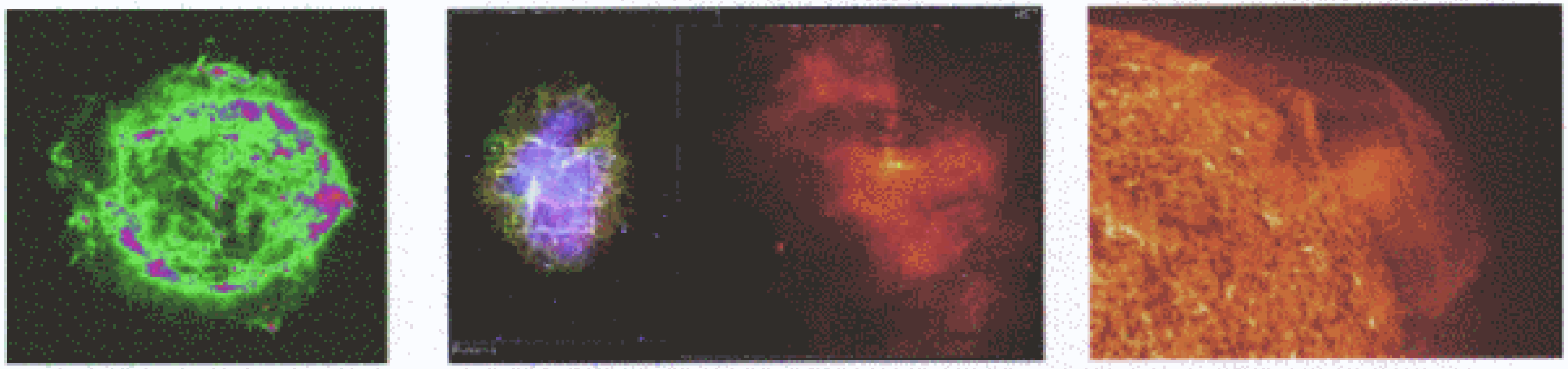
CERENKOV DETECTOR
(2000 t)
$D(\nu_e,e^-)pp$
$^{16}O(\nu_e,e^-)^{16}F$
$^{16}O(\nu_x, \nu_x' n)^{15}O$
$^{16}O(\nu_x, \nu_x' p)^{15}N$
(νe) scattering: $\sin^2\theta_W$
$\nu_\mu \Leftrightarrow \nu_e$ Oscillations

CERENKOV DETECTOR
(50-200 t)
$^{28}Si(\nu_e,e^-)^{28}P$
$^{37}Cl(\nu_e,e^-)^{37}Ar$
$^{127}I(\nu_e,e^-)^{127}Xe$
$^{71}Ga(\nu_e,e^-)^{71}Ge$

SEGMENTED DETECTORS
$^{56}Fe(\nu_e,e^-)^{56}Co$
$^{59}Co(\nu_e,e^-)^{59}Ni$
$^{52}Cr(\nu_e,e^-)^{52}Mn$
$^{nat}Pb(\nu_x, \nu_x' n)Pb$
$^{209}Bi(\nu_e,e^-)^{209}Po$
$^{181}Ta(\nu_e,e^-)^{181}W$
$^{51}V(\nu_e,e^-)^{51}Cr$

Any technique
Other under investigation for feasibility

Summary



- Measure, for the first time, the reaction that initiates nuclear fusion at the core of our Sun
- Help determine the strange quark content of the nucleon
- Establish, for the first time, a firm experimental basis for important ν-induced reactions occurring in supernovae
- Study and confirm important intrinsic properties of the Neutrino

Where Do We Stand?

- Engineering feasibility study complete
- Science workshop held, white paper completed
- FY 2001 ORNL program development funds $1000k
  - FY2000 ORNL PD funds $400k
  - Prior years- ORAU/universities ~$200k
- Coordination with SNS established
  - Site selected
  - Basic schedule requirements established
- Advisory committee established
  - Louis(chair), Balantiken, Drexlin, Freedman, Garvey, Geesaman, Haxton, Robertson
- Letters to solicit formation of experimental collaborations
- LDC formed - 10 universities, NSF MRE
- PRE-CDR engineering continues
- Long Range Plan for Nuclear Science

ORLaND Cost Breakdown

($M)

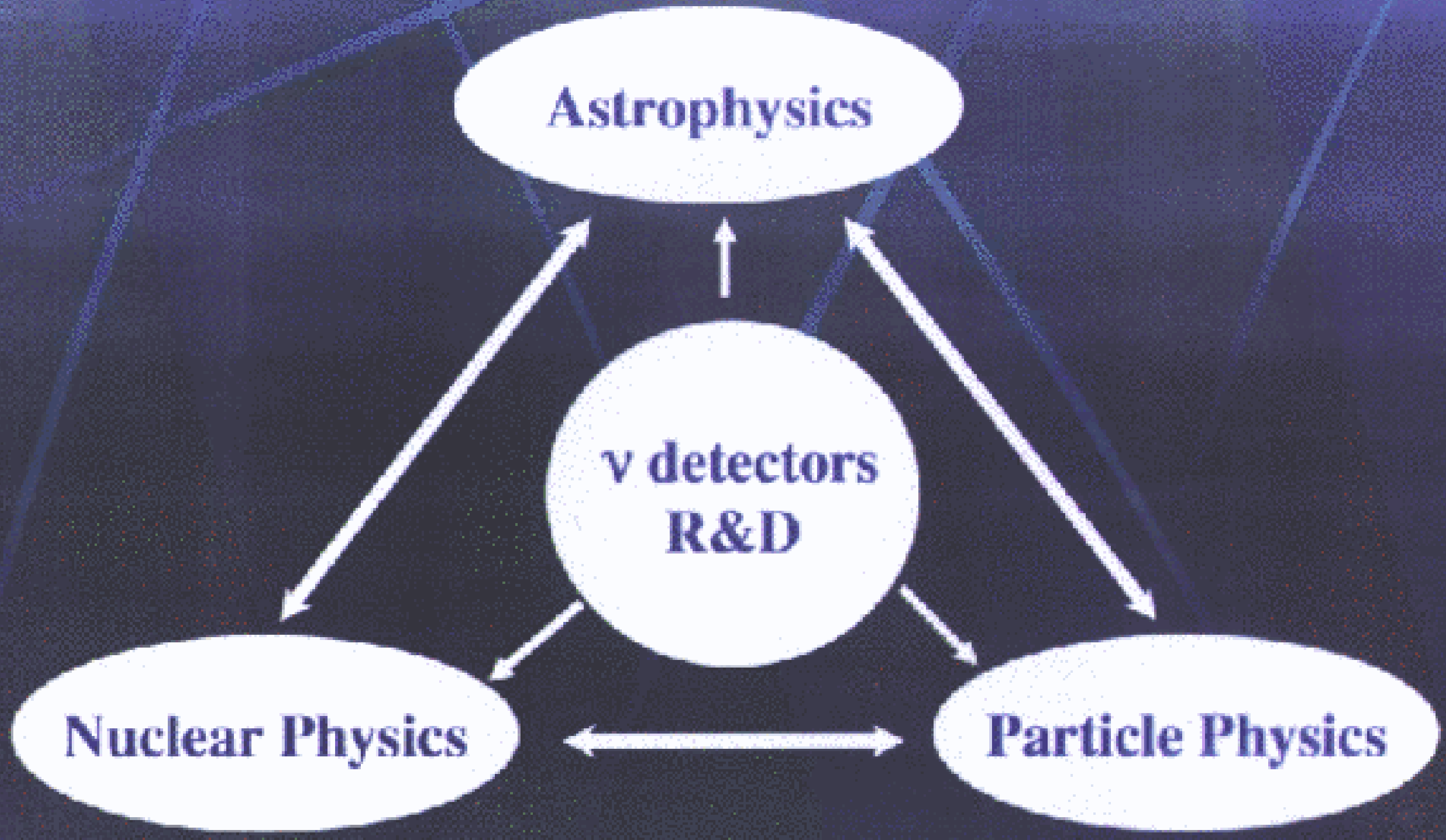
	Facility Construction*	Experiments (3)	Total
Engineering, design & mgt.	5.7	4.7	10.4
Construction	8.8	0.5	9.3
Special facilities & equip	4.2	11.0	15.2
ES&H	0.5	0.0	0.5
Other costs	0.2	0.1	0.3
Contract burdens	1.3	1.1	2.4
Total direct cost	20.7	17.4	38.1
Contingency	4.3	5.5	9.8
Total direct cost	25.0	22.9	47.9
CDR,Planning,R&D	1.1	1.0	2.1
Commisioning & Preops	1.5	7.3	8.8
Escalation	2.4	2.6	5.0
Total Project	30.0	33.8	63.8

*Construction cost includes fabrication and installation of 2 kton tank for LDC

SNS is a Unique Neutrino Source

- Most Powerful Pulsed neutrino Source
- Fine Beam Time Structure
- Two Target Stations
- Chance To Optimize Facility To Best Utilize SNS neutrinos
- Large suppression of $\bar{\nu}_e$ production relative to others neutrino flavors

ORLaND



Astrophysics

ν detectors
R&D

Nuclear Physics

Particle Physics


IL LAVORO MI PERSEGUITA, MA IO SONO PIU' VELOCE!