Avignone - 01

ORAU

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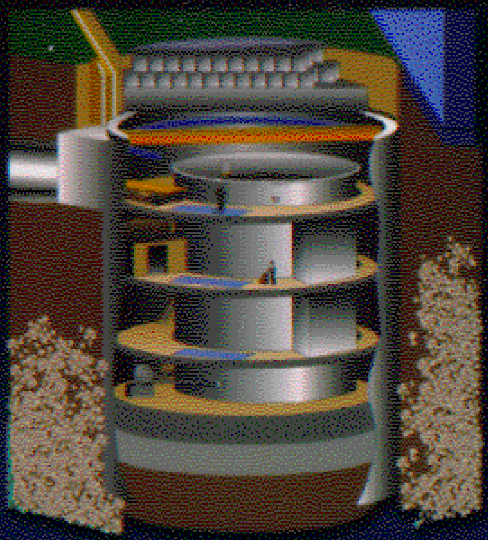

ORLaND

Oak Ridge Laboratory for Neutrino Detectors

May 24, 2000

Avignone - 02

ORAU

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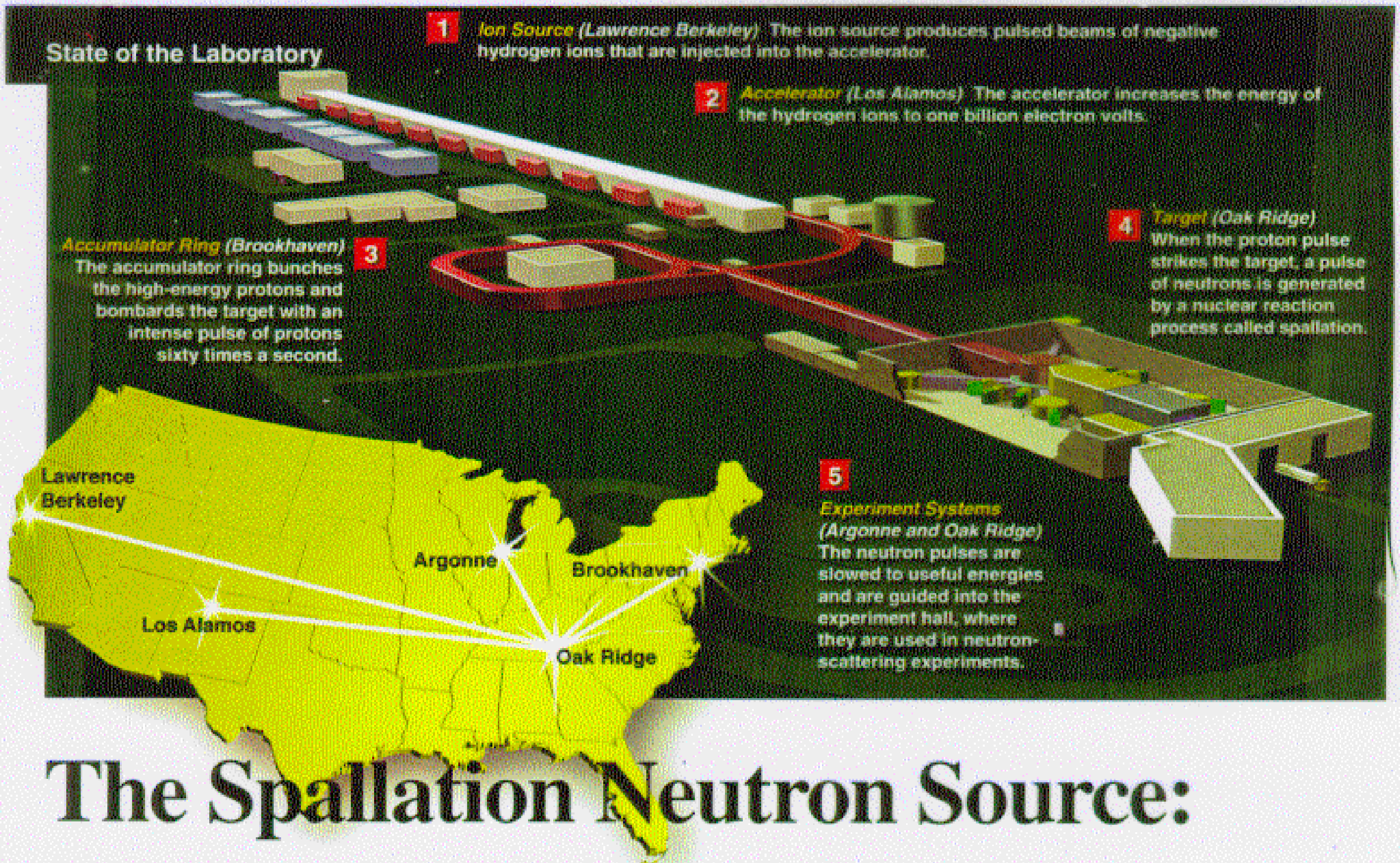
ORLaND
Oak Ridge Laboratory for Neutrino Detectors

A proposed national facility to support a number of different neutrino detector collaborations simultaneously.

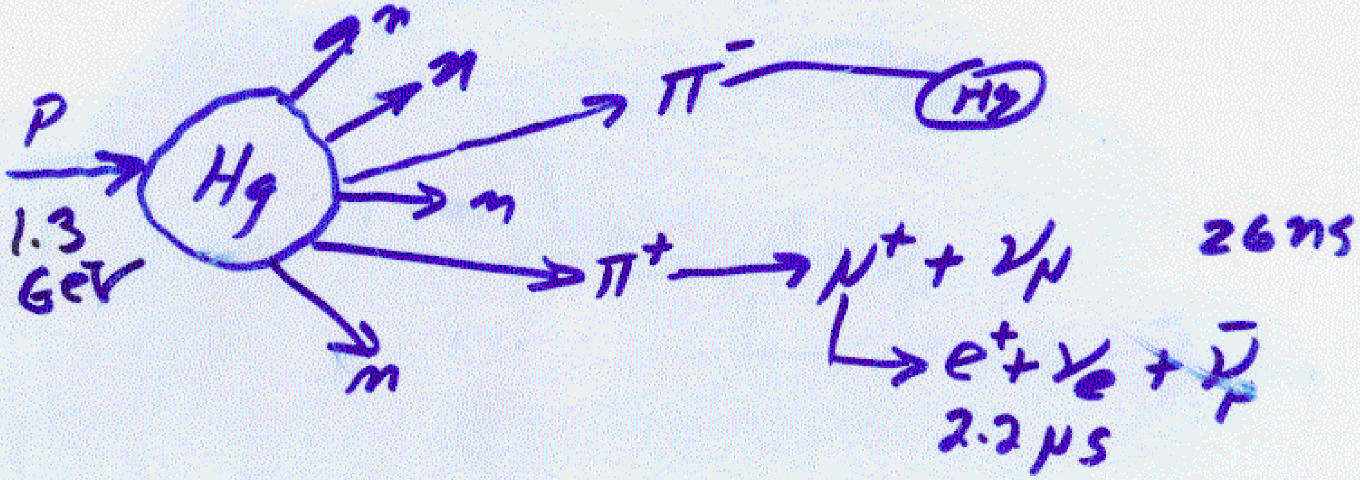
ORLaND: A facility to support a long-term neutrino research program in an underground laboratory at the SNS

1.4 Beg. $

APPROVED and under construction

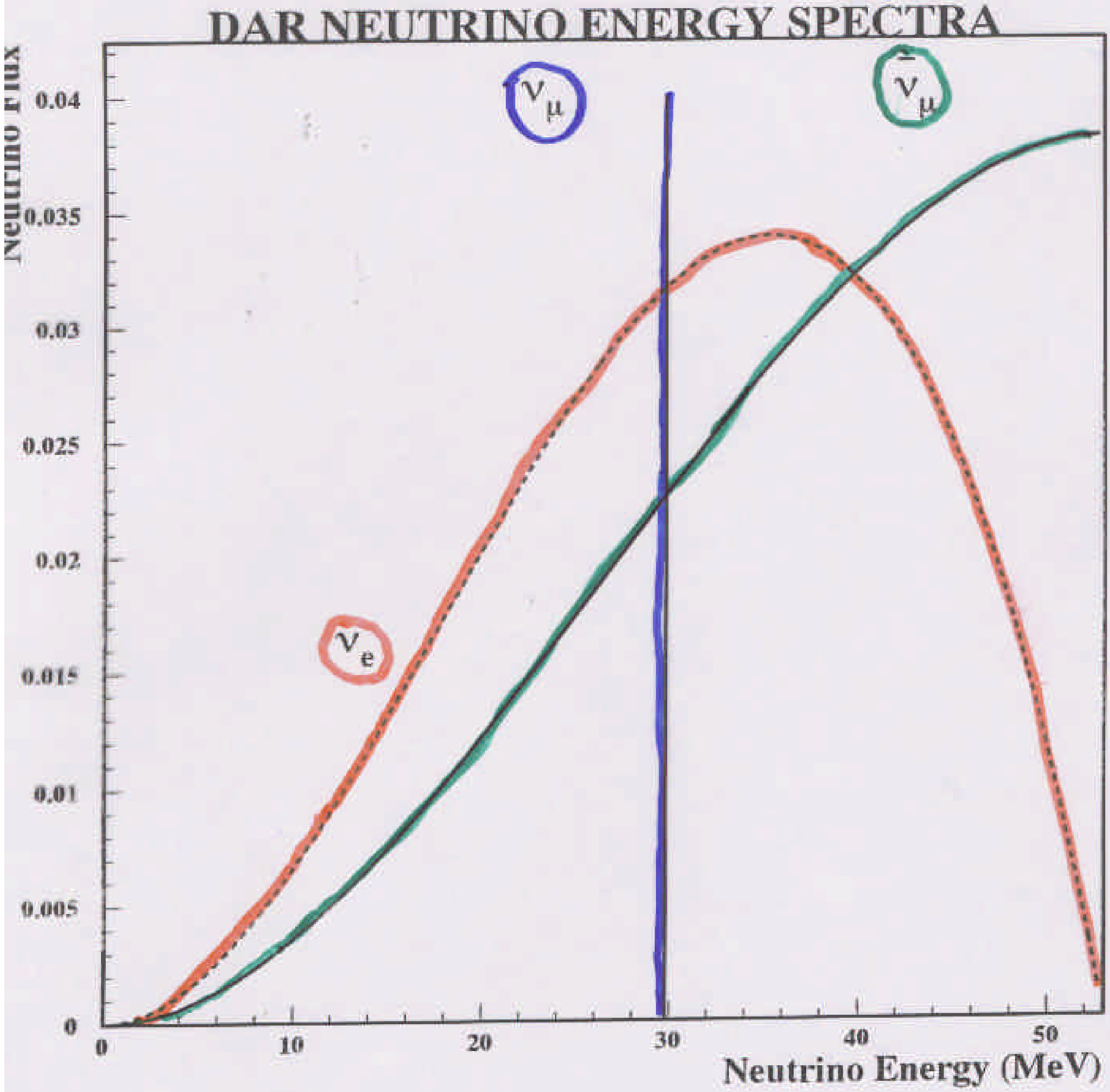


The Spallation Neutron Source: The Nation's Next-Generation Neutron-Scattering Facility



$\pi^+ \to \mu^+ + \nu_\mu$
$\quad \hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$

$\pi^- \to \mu^- + \bar{\nu}_\mu$
$\quad \hookrightarrow e^- + \bar{\nu}_e + \nu_\mu$



$\langle \Phi_{\nu_e} \rangle = 3 \times 10^6 \; \nu_e / \text{cm}^2 \cdot \text{sec}$

AT 50 meters

Fig. 2

NEUTRINO FLUX AND ENERGY SPECTRA

at 50 m: $<\Phi \nu_e> = 3 \cdot 10^6\ \nu_e\ /cm^2/sec$

Normalized spectra

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

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

W=52.83 MeV

ν_μ is monoenergetic at ~ 30 MeV

$R_\nu = 9.4 \cdot 10^{14}\ \nu_e$/sec at 1 GeV/2MW

E_p=1.3 GeV   Rep. rate 60 Hz

P=2 MW   RMS ~ 340 nsec   FWHM 600 nsec

BUGEY, CHOOZ, DONUT, HOMESTAKE, KAMLAND,

ORAU is Leading Joint ORISE-ORNL Proposal for ORLaND

ORAU

Universities:
- Drexel
- Duke University
- Triangle University National Laboratory
- Embry Riddle Aeronautical University
- Kent State
- Louisiana State University
- North Carolina State University
- Southern University, Baton Rouge
- Southern University, New Orleans
- University of Alabama
- University of California, Riverside
- University of Mississippi
- University of South Carolina
- University of Tennessee
- Valparaiso University
- Virginia Tech

We are Bringing National Labs and Universities Together to Leverage the SNS

International Labs and Universities:
- Institute for Theoretical and Experimental Physics, Moscow
[redacted]
- Tel Aviv University

DOE Facilities:
- Jefferson Laboratory
- Los Alamos National Laboratory
- Oak Ridge National Laboratory
- Oak Ridge Institute for Science and Education

Fundamental Research to Advance Basic Science

Neutrino-Nucleus Cross Sections:
- Nuclear Structure
- Supernova Mechanism
- Supernova Nucleosynthesis

Neutrino Oscillations:
- Physics Beyond the Standard Model
- Solar Neutrino Problem
- Dark Matter in the Universe

Oak Ridge Institute for Science and Education

MINOS, NOMAD, PALOVERDE

KARMEN, LSND, MINIBooNE

Avignone - 06

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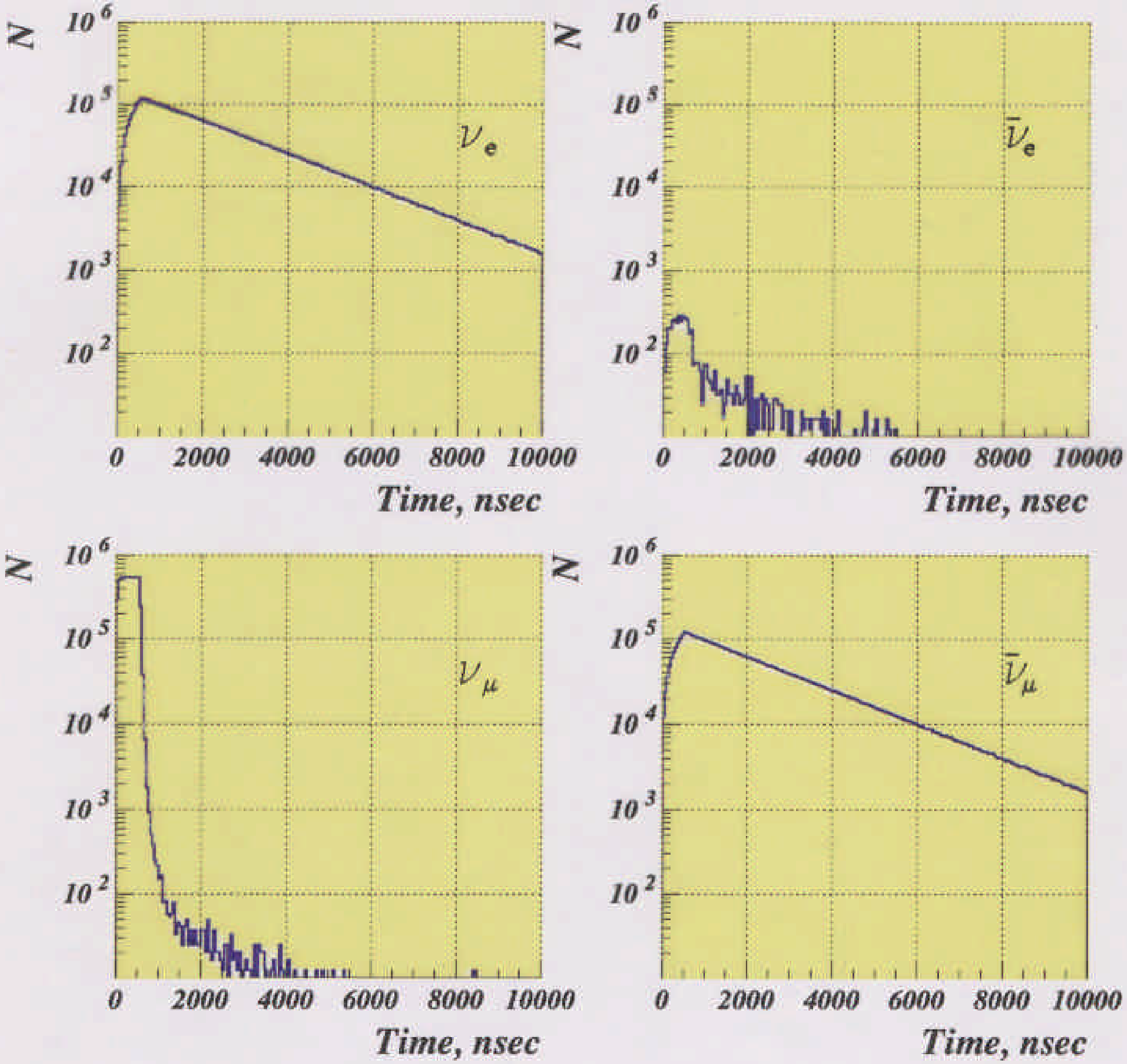
ORLaND

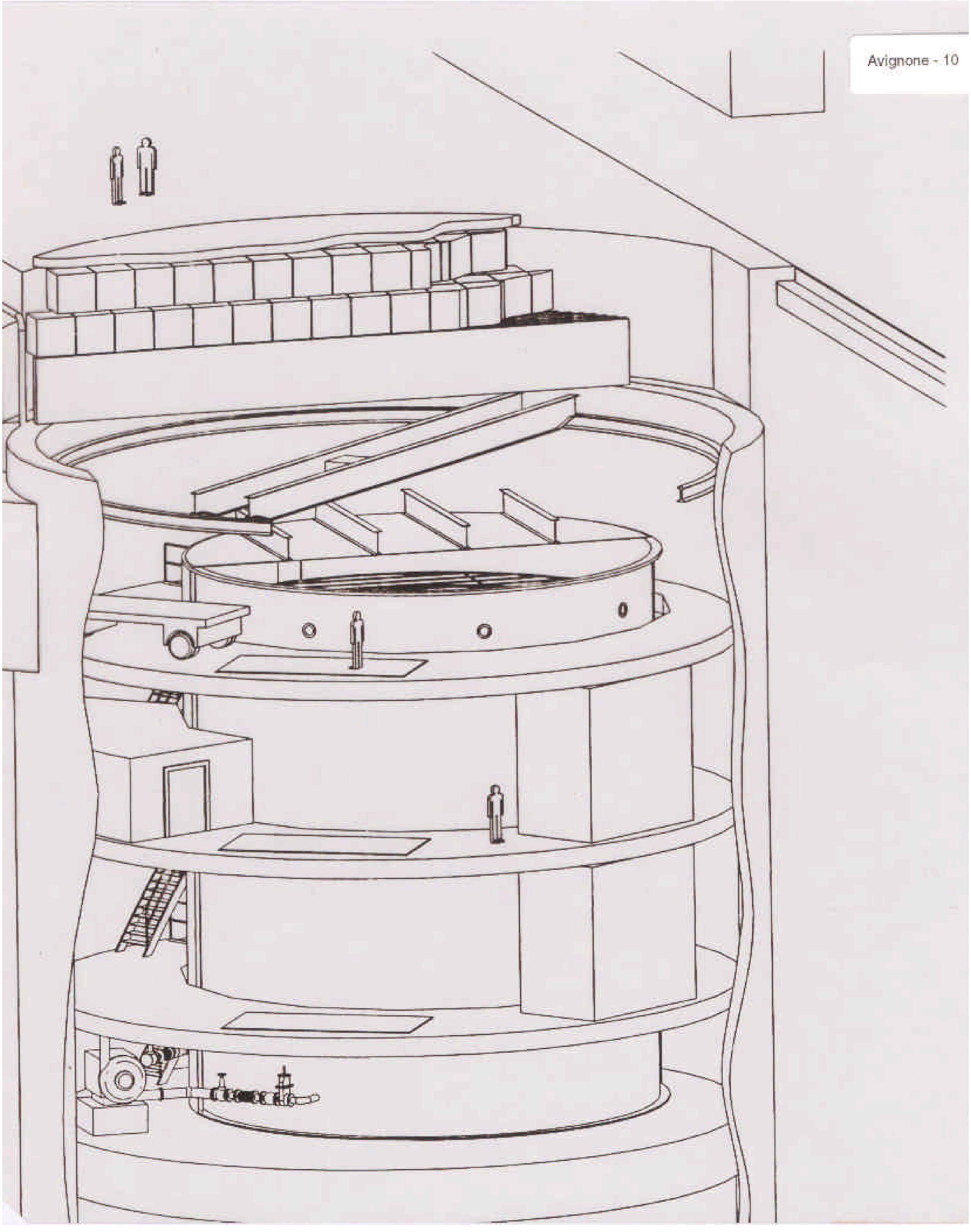
- The SNS will produce 9.4×10^{14} neutrinos in 60Hz pulses with FWHM less than 400 ns and total width ~ 600 ns!
- That will make it the most intense, pulsed, intermediate energy neutrino source in the world!
- The pulsed source would drastically reduce backgrounds from cosmic rays
- It would also allow separation of ν_μ from $\overline{\nu}_\mu$ and ν_e
- Spectra of ν_μ, $\overline{\nu}_\mu$ and ν_e well known
- Intensity of $\overline{\nu}_e$ severely suppressed: $\overline{\nu}_e / \overline{\nu}_\mu \approx 3 \times 10^{-4}$

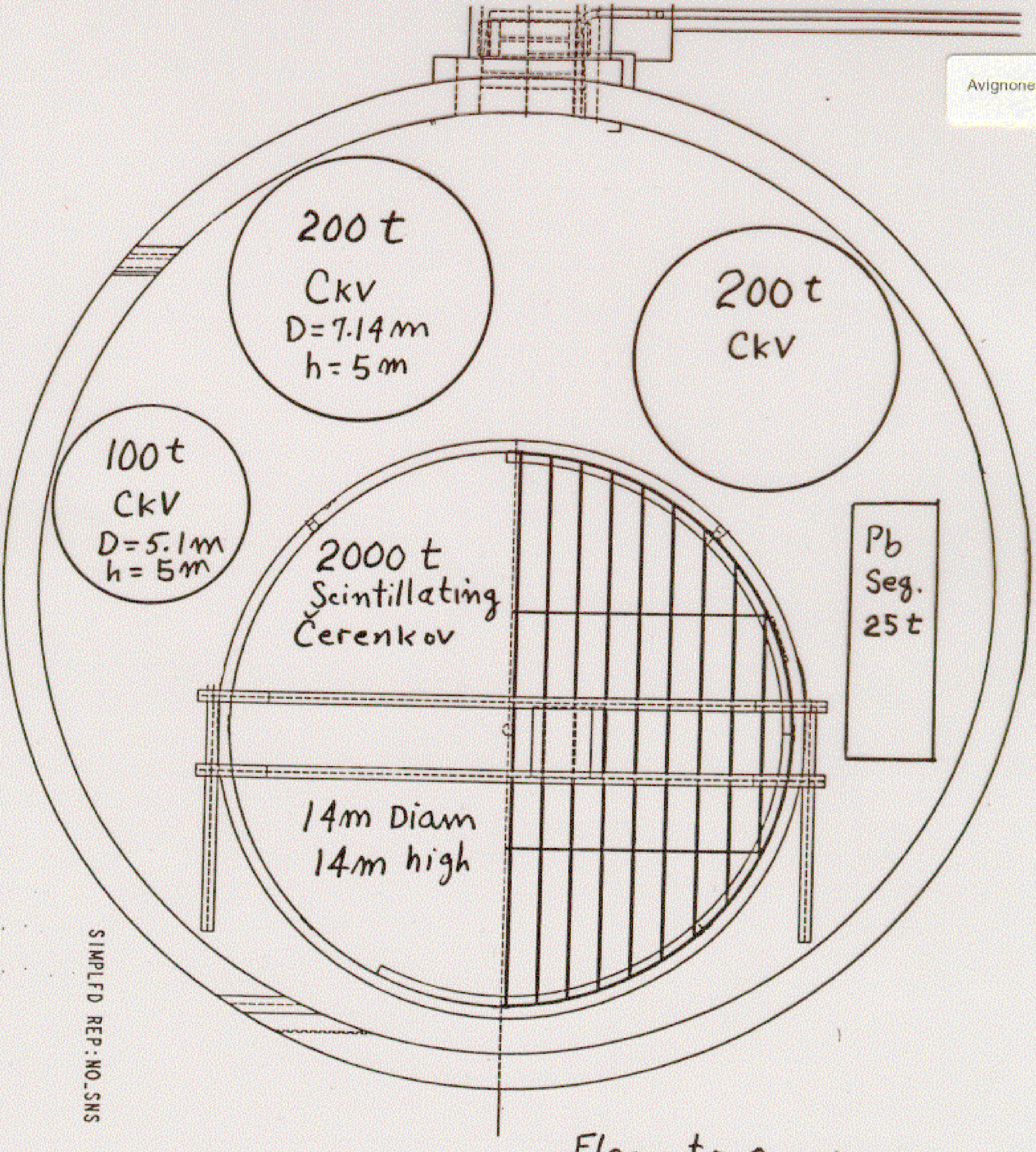
ORLaND


N
10^6
10^5
10^4
10^3
10^2
0
2000
4000
6000
8000
10000
Time, nsec
ν_e
ν̄_e
ν_μ
ν̄_μ

SNS as a Neutrino Source

- Most powerful pulsed neutrino source in the world
- Well known neutrino spectra
- Different neutrino flavors separated in time
- Excellent background conditions
- Two target stations





Floor to Overhead
Each stage = 5.2 m

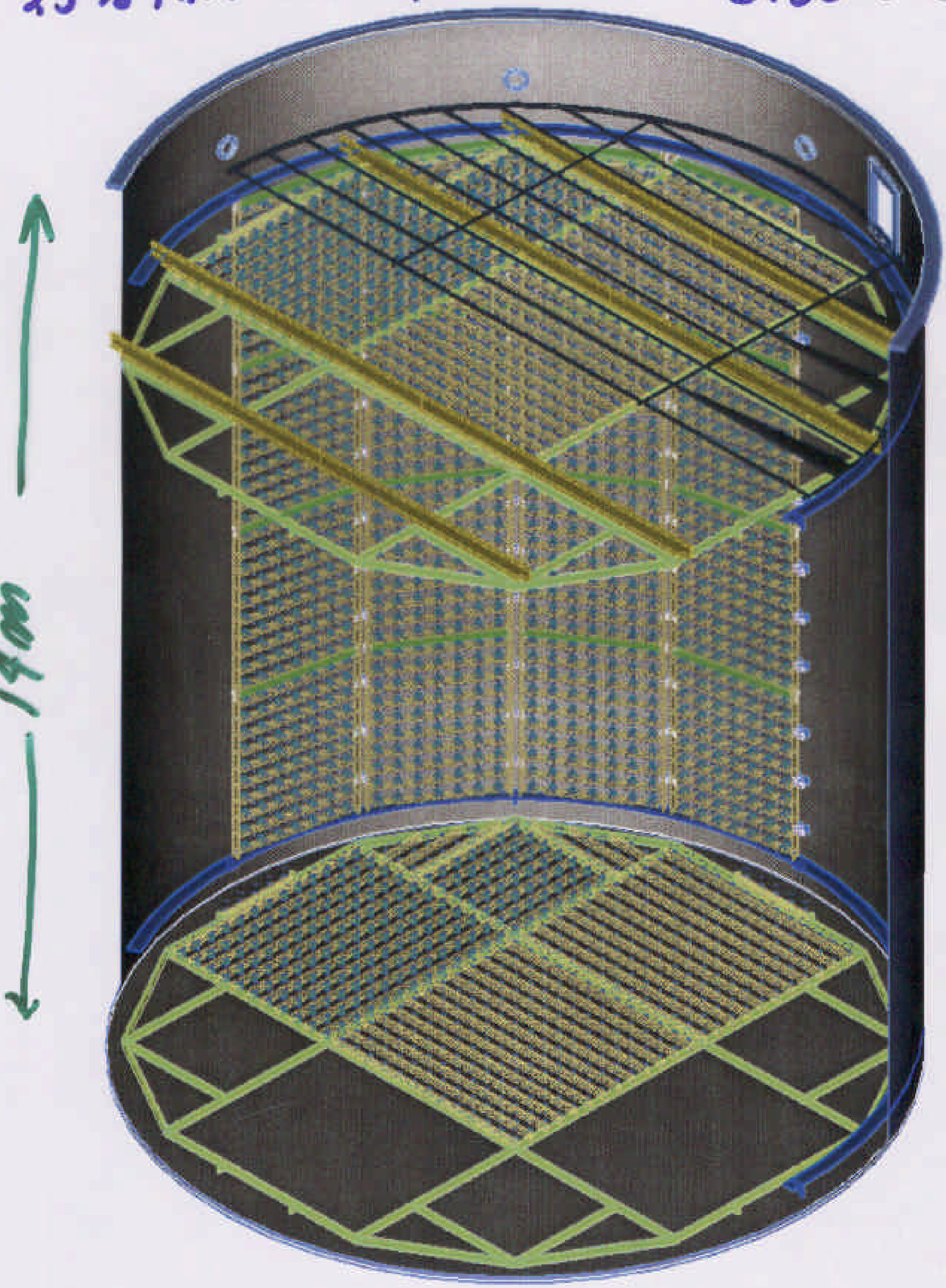
2kt → 1540 fiducial

12 m

25% Photo coverage

6730 tubes

14m




Supernova Studies at
Beam Stop Facilities

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

Haxton, PRD 36, 2283 (1987)

$\langle\sigma\rangle = 8.84\cdot10^{-42}$ cm^2 DAR spectrum

LARGE CHERENKOV DETECTOR

FIDUCIAL VOL. 1472 m^3 of water

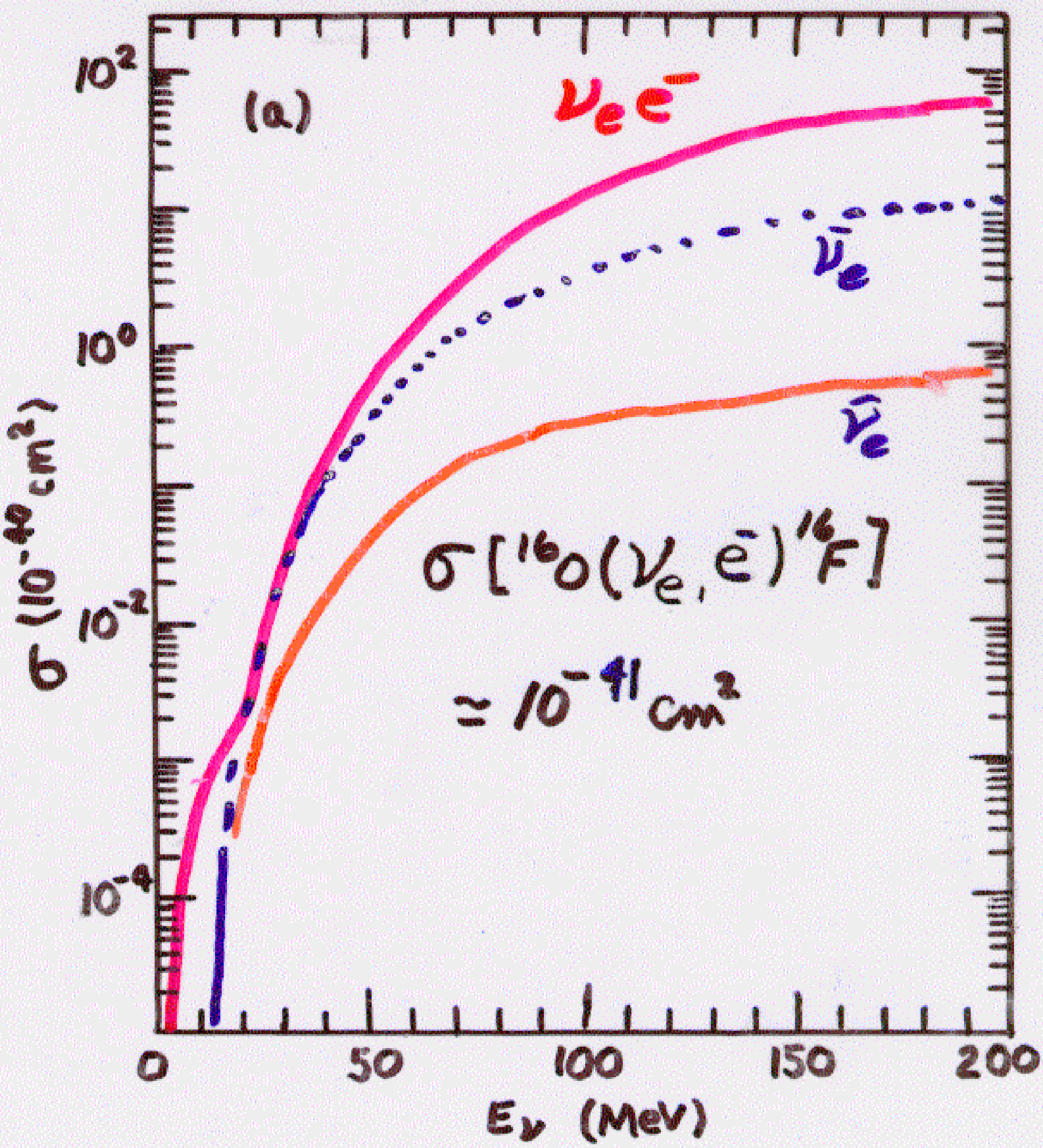
$N \sim 4.9\cdot10^{31}\cdot{}^{16}O$

Event rates

$R(y^{-1}) = (8.84\cdot10^{-42}\ cm^2)\ (3.0\cdot10^6\ cm^{-2}\ sec^{-1})\ (4.9\cdot10^{31})\ (3.2\cdot10^7 sec)$

$R \sim 41000\ y^{-1}$

For 30% efficiency ~ 12300 events per year



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

$R(\theta) \equiv \frac{\text{BACK ANGLE}}{\text{FWD ANGLE}}$

T = 4 MeV R = 3.7
T = 8 MeV R = 11.7

$\sigma(165°, 8\,MeV) \div \sigma(165°, 4\,MeV) \simeq 30$

VOLUME 76, NUMBER 15 PHYSICAL REVIEW LETTERS 8 APRIL 1996

Signal for Supernova ν_μ and ν_τ Neutrinos in Water Čerenkov Detectors

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[1]*W. K. Kellogg Radiation Laboratory, 106-38, California Institute of Technology, Pasadena, California 9112:*
[2]*Physics Department, California Institute of Technology, Pasadena, California 91125*
[3]*Institut für Physik, Universität Basel, Basel, Switzerland*
(Received 27 November 1995)

We suggest that photons with energies between 5 and 10 MeV, generated by the $(\nu, \nu' p \gamma)$ and $(\nu, \nu' n \gamma)$ reactions on ^{16}O, constitute a signal which allows a unique identification of supernova ν_μ and ν_τ neutrinos in water Čerenkov detectors. We calculate the yield of such γ events and estimate that a few hundred of them would be detected in Superkamiokande for a supernova at 10 kpc distance.

PACS numbers: 95.55.Vj, 25.30.Pt, 97.60.Bw

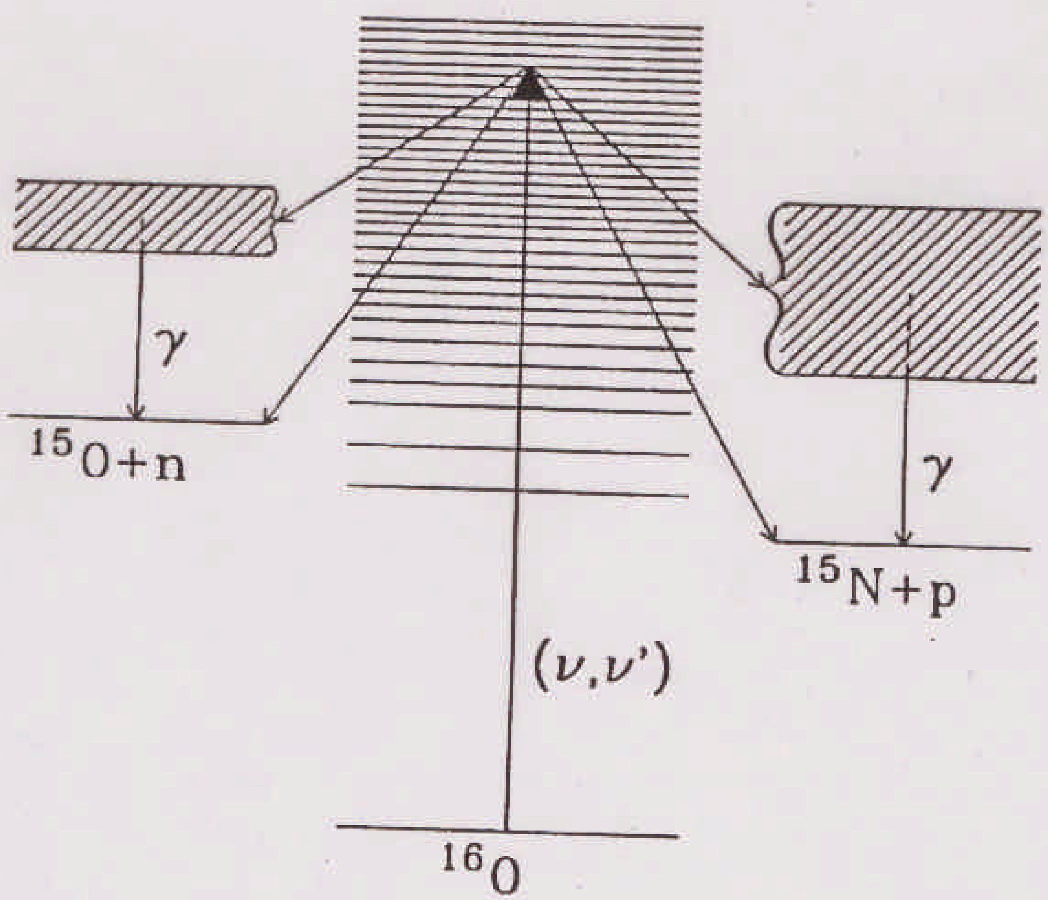


FIG. 1. Schematic illustration of the detection scheme foı supernova ν_μ and ν_τ neutrinos in water Čerenkov detectors.

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

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

USE AGAIN LARGE SIZE CERENKOV DETECTOR
$N \sim 4.9\cdot 10^{31}\cdot {}^{16}O$

Event rates:

For $^{16}O(\nu_x,\nu_x` n\gamma)^{15}O$
$R(y^{-1})=(9.\cdot 10^{-43}\ cm^2)\ (3.0\cdot 10^6\ cm^{-2}\ sec^{-1})\ (4.9\cdot 10^{31})\ (3.2\cdot 10^7 sec)$
$R \sim 4200\ y^{-1}$

For $^{16}O(\nu_x,\nu_x`(n\ or\ p)\gamma)^{15}X$
$R(y^{-1})=(4.6\cdot 10^{-42}\ cm^2)\ (3.0\cdot 10^6\ cm^{-2}\ sec^{-1})\ (4.9\cdot 10^{31})\ (3.2\cdot 10^7 sec)$
$R \sim 21500\ y^{-1}$

But can some compound of Gd be added to in 0.1% concentration, and not kill transmission of Cherenkov light?

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

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

$<\sigma>=5.4 \cdot 10^{-41}$ cm^2 DAR spectrum

SNOINO

30 ton Cherenkov 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 cylinder filled with H_2O.

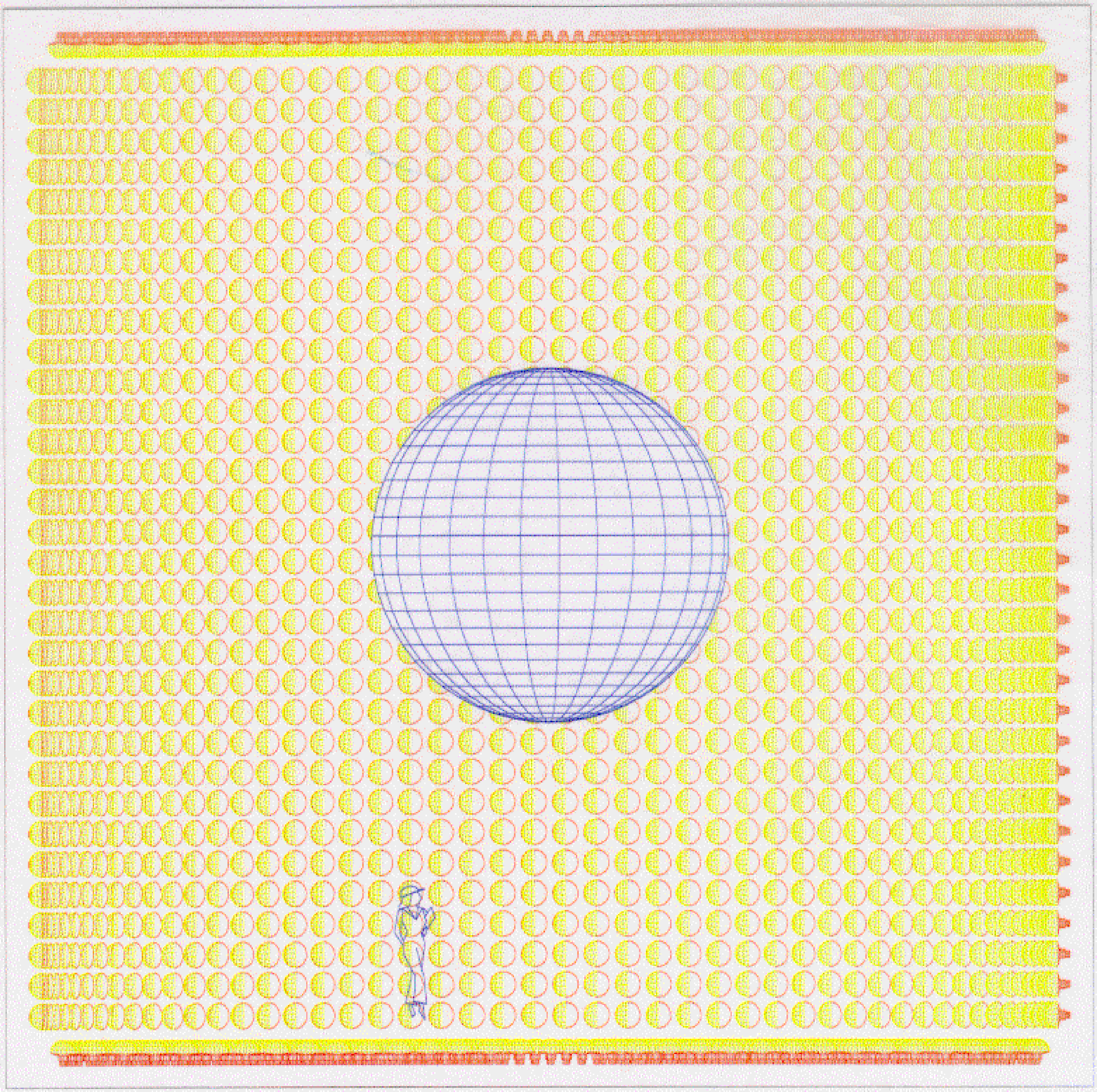
Event rate

$R(\text{ton}^{-1})=(5.4 \cdot 10^{-41}\ \text{cm}^2)\ (3.0 \cdot 10^6\ \text{cm}^{-2}\ \text{sec}^{-1})\ (6. \cdot 10^{28}\ \text{ton}^{-1})$

$R=0.842\ \text{day}^{-1}\ \text{ton}^{-1}$ Efficiency ~ 30 %

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

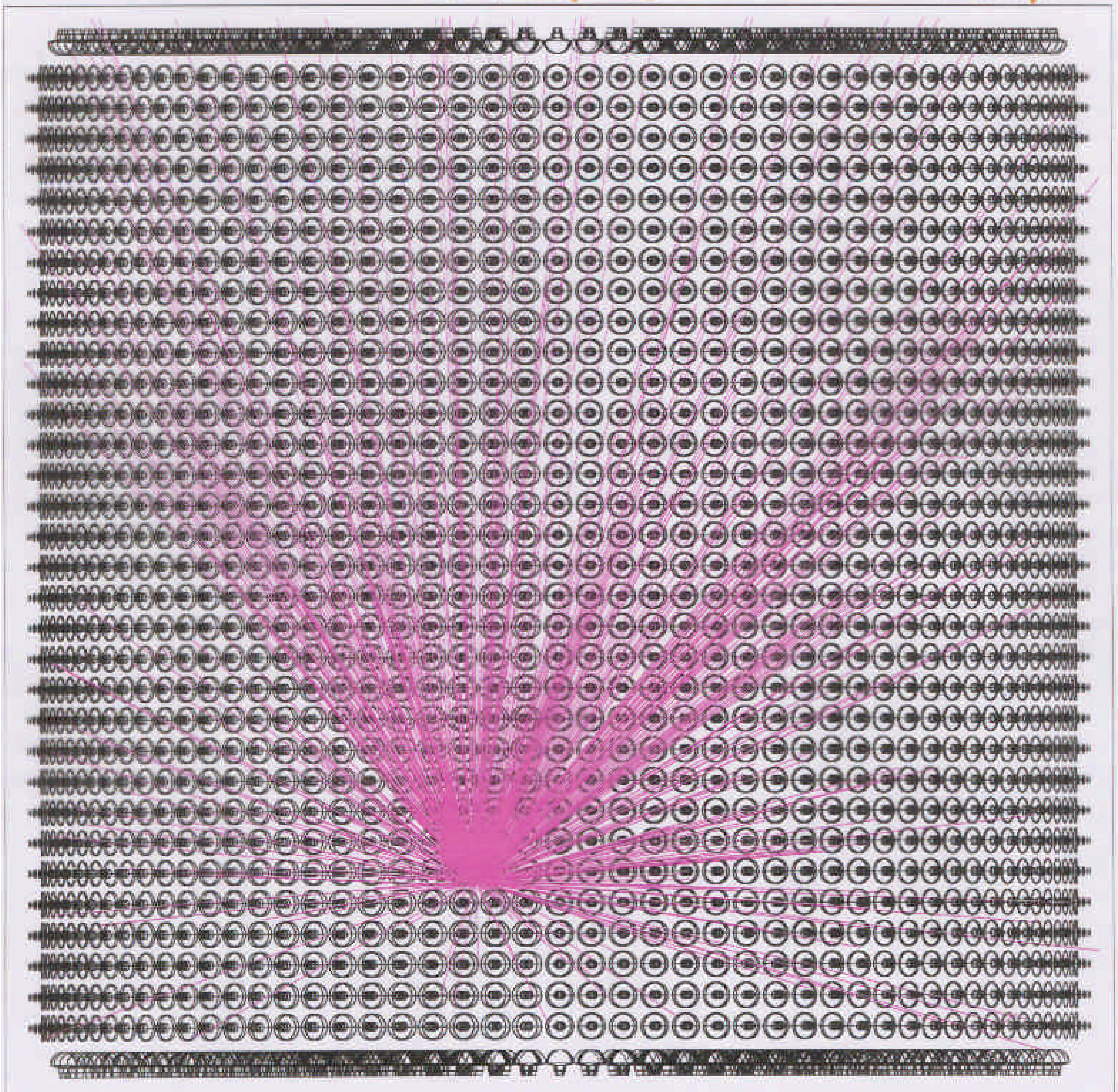
Detector is 5.4 m in diameter, and 5.4 m in high.
1456, 8"PM tubes for 40% coverage



H_2O

30 MeV e^-

5000 13" PMT
7-8 phe/MeV



Nuclear Physics for Core Collapse Supernovae

Infall Epoch

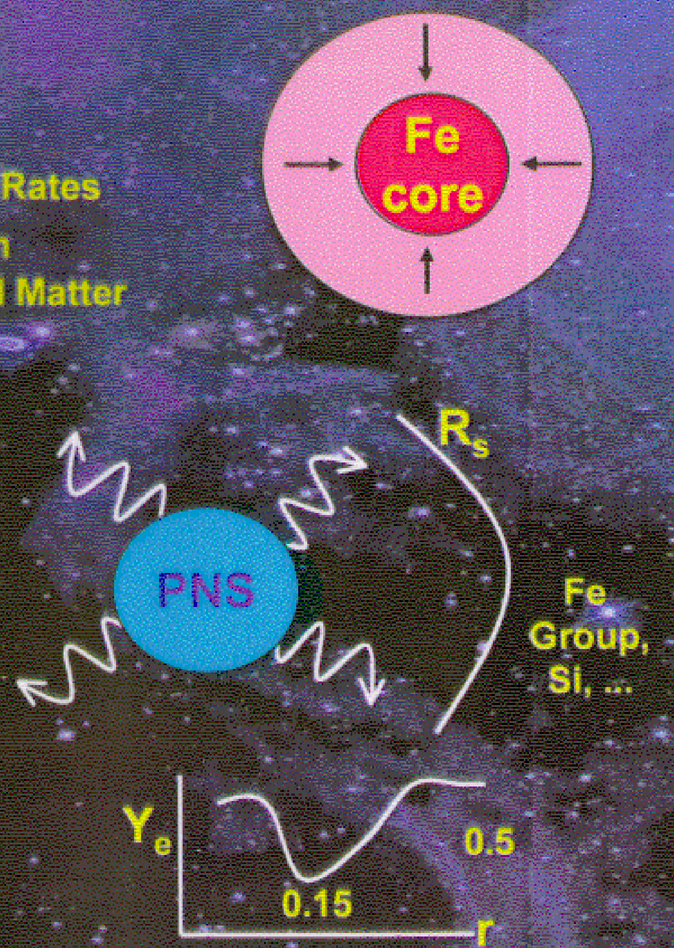
- Core Deleptonization via e-p,A
  - Need Accurate e-A, ν-A Weak Rates
  - Single Nucleus Approximation vs. Ensembles of Nuclei and Matter

Key Nuclei

- NSE Nuclei (<0.3 MeV)
  - ^{56,58,62,66,68,78}Ni, ^{54,56,58,60}Fe
  - ^{52,54}Cr, ^{80,82}Ge
  - ^{80}Zn, ^{79}Cu, ^{48}Ca, ^{84}Se, ^{50}Ti

Postbounce Epoch

- Fueling the Shock
  - Neutrino Opacities in Correlated Nuclear Matter



Astrophysics Program at ORLaND

Energy spectrum of neutrinos from SNS is similar to the typical supernova neutrino spectrum.

- Neutrino nuclear interaction cross sections are critical for understanding dynamics of supernova explosion
- Neutrino nuclear interaction strongly affects production of heavy elements during supernova explosion
- At SNS we can measure νN cross sections by building highly segmented detector where we can install targets of different materials

At 40 m from the SNS target, ν flux is $\approx 1.0 \cdot 10^{14}\ \nu\ cm^{-2}\ y^{-1}$. With 30% efficiency, to achieve 3% accuracy in one year we need $N = 3.2 \cdot 10^{30}$ nucleons or 5 ton target.

First targets on the shopping list are ^{7}Li, ^{12}C, ^{16}O, ^{24}Mg, ^{40}Ca, ^{56}Fe, ^{127}I, ^{181}Ta, ^{209}Bi

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)

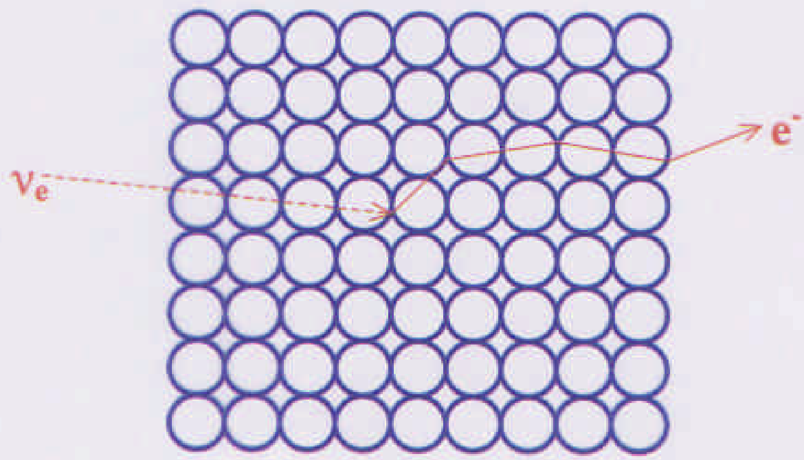
Is it possible to dissolve some rare earth and other elements in solutions appropriate for Cherenkov detectors?

- stability
- index of refraction
- light transmission vs. λ
- safety (health, fire, etc.)

OTHER AVAILABLE TARGETS

Metal or other solid (SOUDANINO)

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



- **ANALYSIS ON $^{56}Fe(\nu_e,e^-)^{56}Co$ COMPLETE**
- **WRITE-UP IN PROGRESS**

EXPERIMENTS CONSIDERED ALREADY

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

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

$^{28}Si(\nu_e,e^-)^{28}P$

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

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

} ORNL UT USC ORLAND

$^{208}Pb(\nu_x,xn)^{208-x}Pb$ OMNIS OSU UCLA, UK

$^{208}Pb(\nu_e,e^-)^{208}Bi^* \Rightarrow ^{208}Bi+n+\gamma_s$

$^{208}Pb(\nu_x, \nu_x')^{208}Pb^* \Rightarrow ^{207}Pb+n+\gamma_s$

} U. Wash.

$^{127}I(\nu_e,e^-)^{127}Xe$ -- U. Penn

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

Kolbe, Langanke, and Martinez-Pinedo
arXiv:nucl-th/9905001
$\langle\sigma\rangle=2.73\cdot10^{-40}$ cm^2 DAR spectrum

SOUDANINO

0.5 mm thick walls tubes
10 mm OD - 9 mm ID = 14.9 mm^2
for 2.5 meter tube - 0.075 cm$^2\cdot$250 cm = 37.25 cm^3/tube
ρ=7.87 ρV=0.294 kg/tube
~ 3400 tubes/ton

Event rates

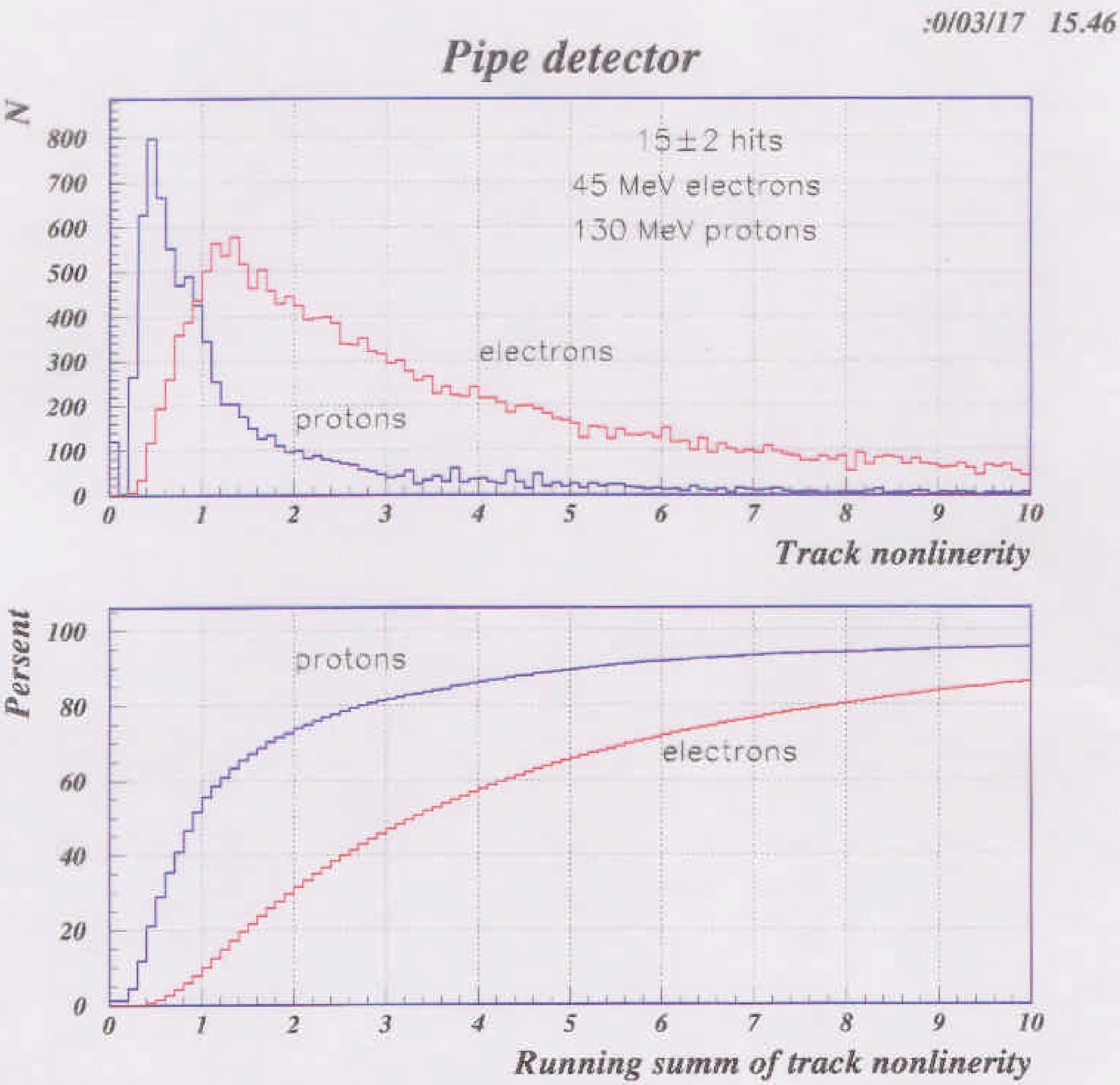
$R(ton^{-1})=(2.73\cdot10^{-40}\ cm^2)\ (3.0\cdot10^6\ cm^{-2}\ sec^{-1})\ (9.89\cdot10^{27}\ ton^{-1})$
R=0.677 day^{-1} ton^{-1} Efficiency ~ 30 %
R(detected)=75 y^{-1} ton^{-1}

To reconstruct the spectrum, we need 1000 events
For 1000 events per year - 13.5 tons fiducial.
In addition 50 cm on each face to contain events

Detector size - 3.5m·3.5m·3.5m
or 98596 tubes

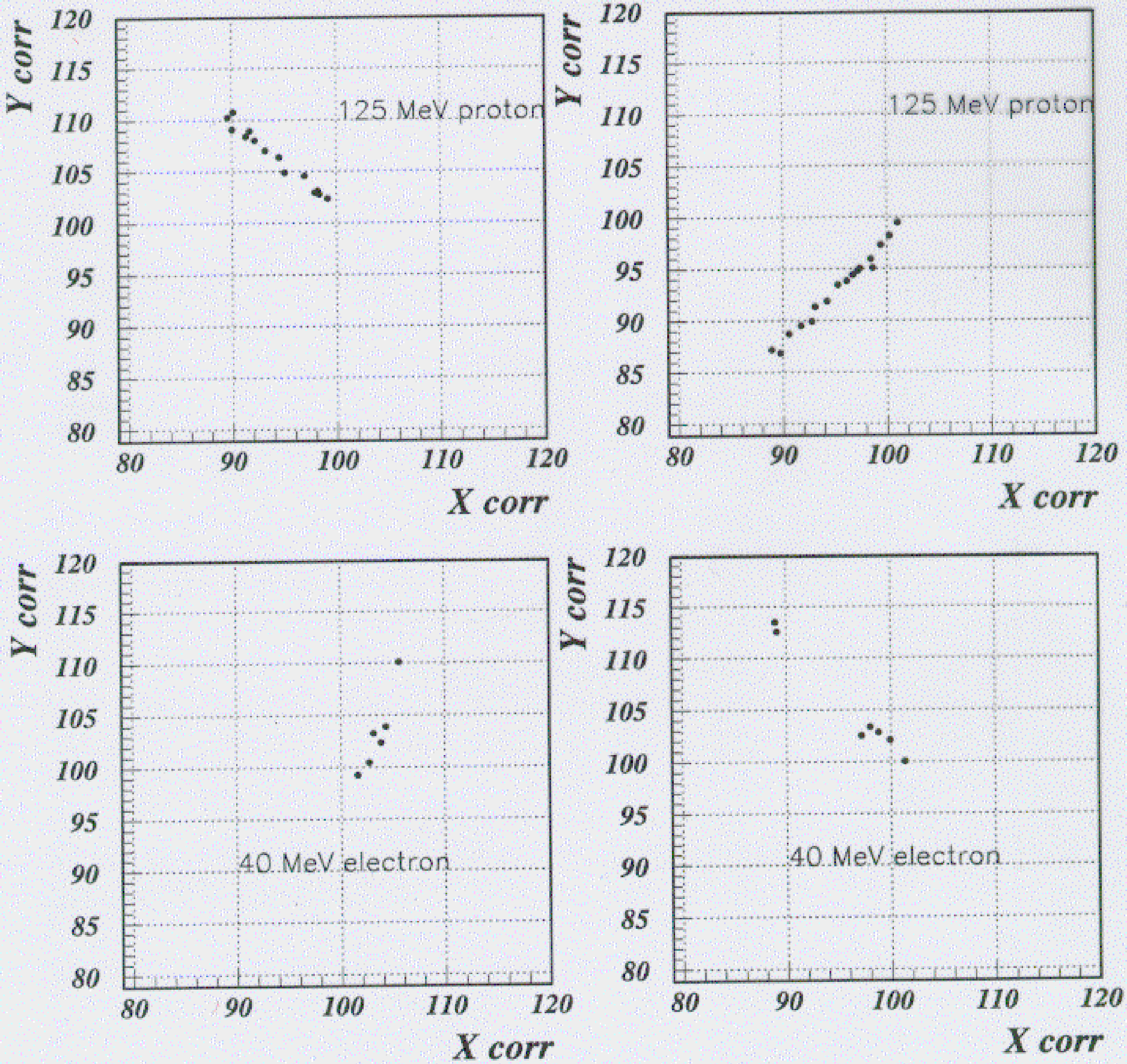
AVAILABLE TARGETS

^{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%)
	$^{206,207,208}Pb$	


:0/03/17 15.46
Pipe detector
N
15±2 hits
45 MeV electrons
130 MeV protons
electrons
protons
Track nonlinerity
Persent
protons
electrons
Running summ of track nonlinerity

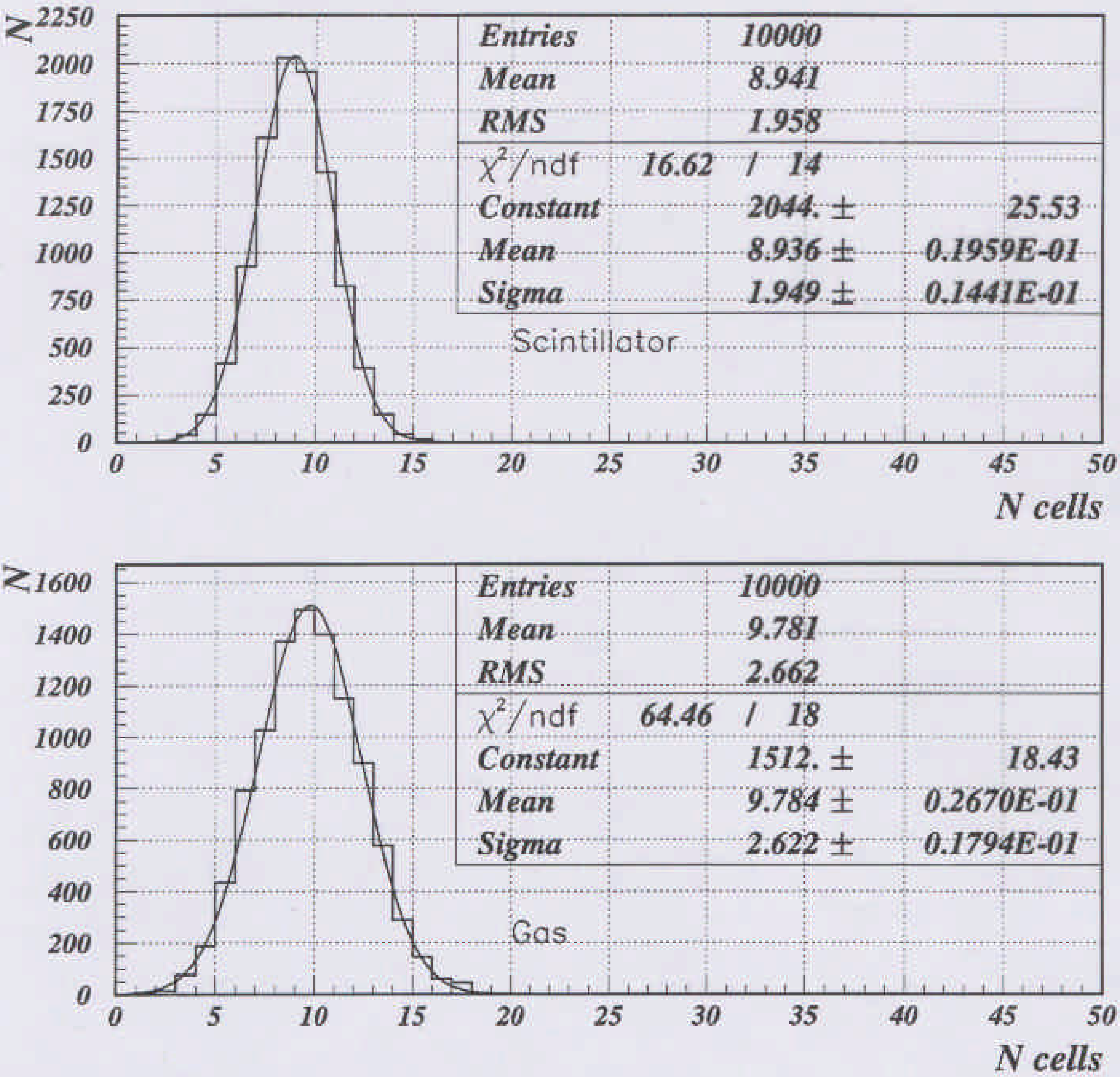
:0/03/17 14.15

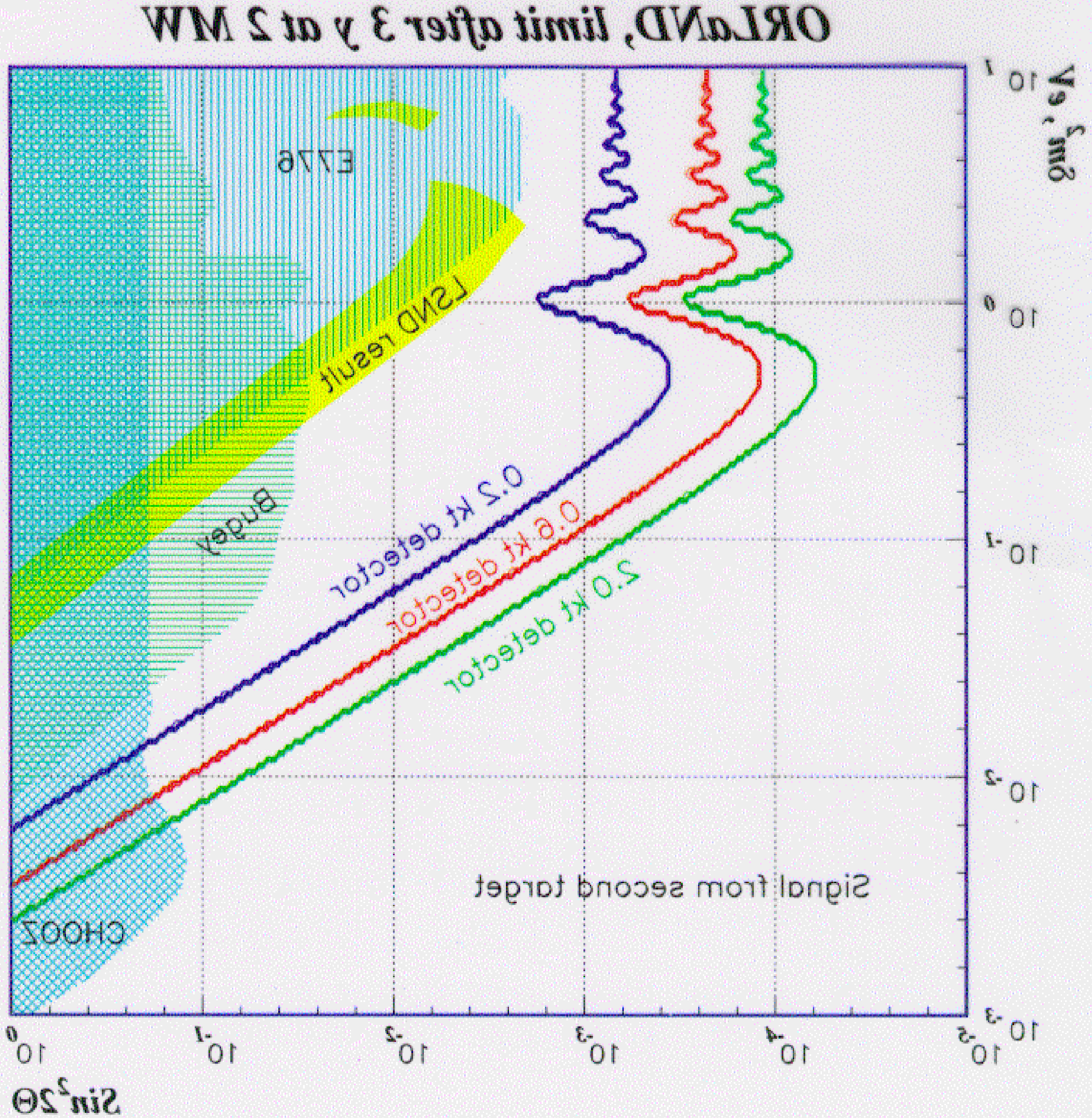
Pipe detector



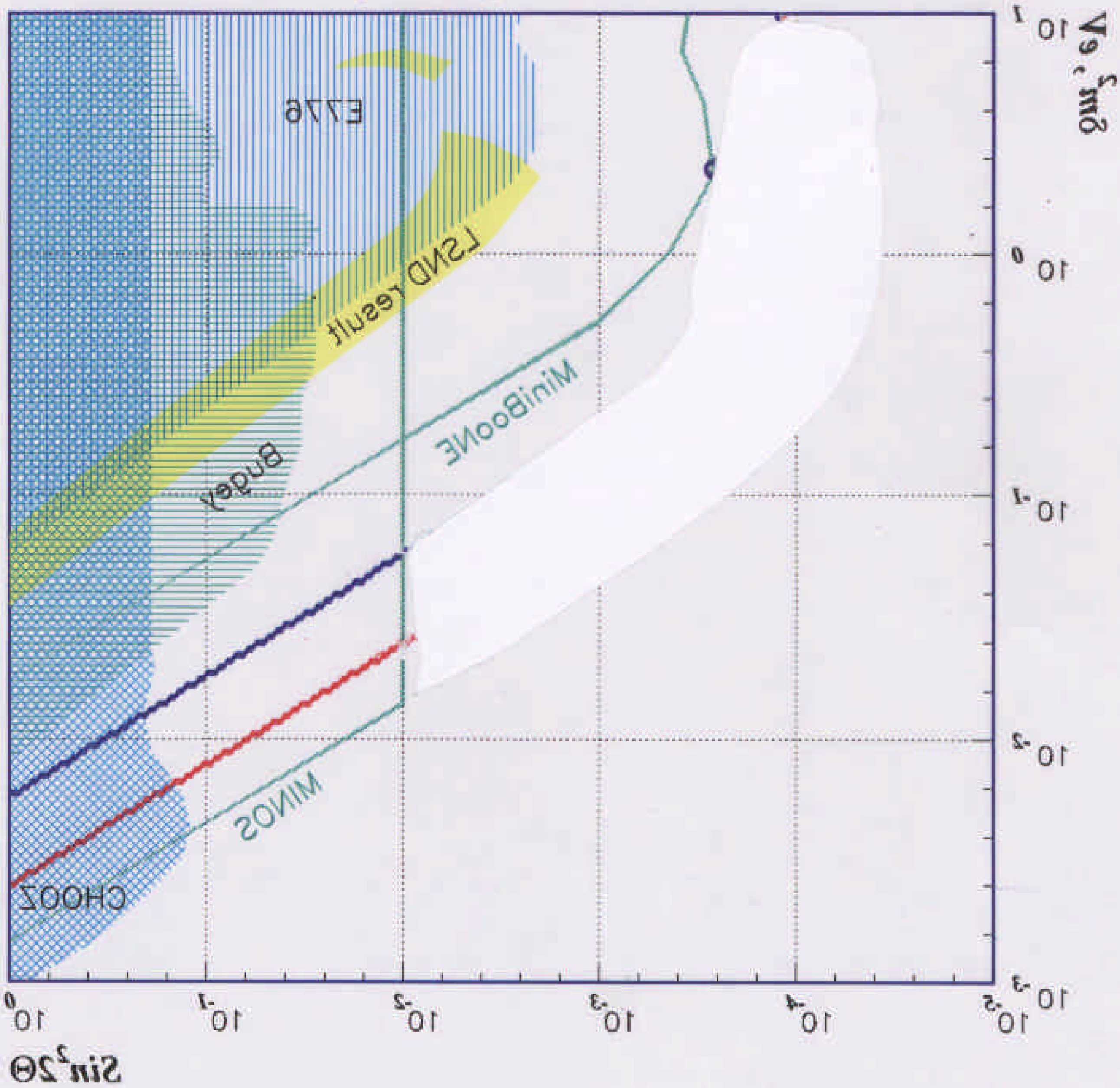
:0/02/29 12.24

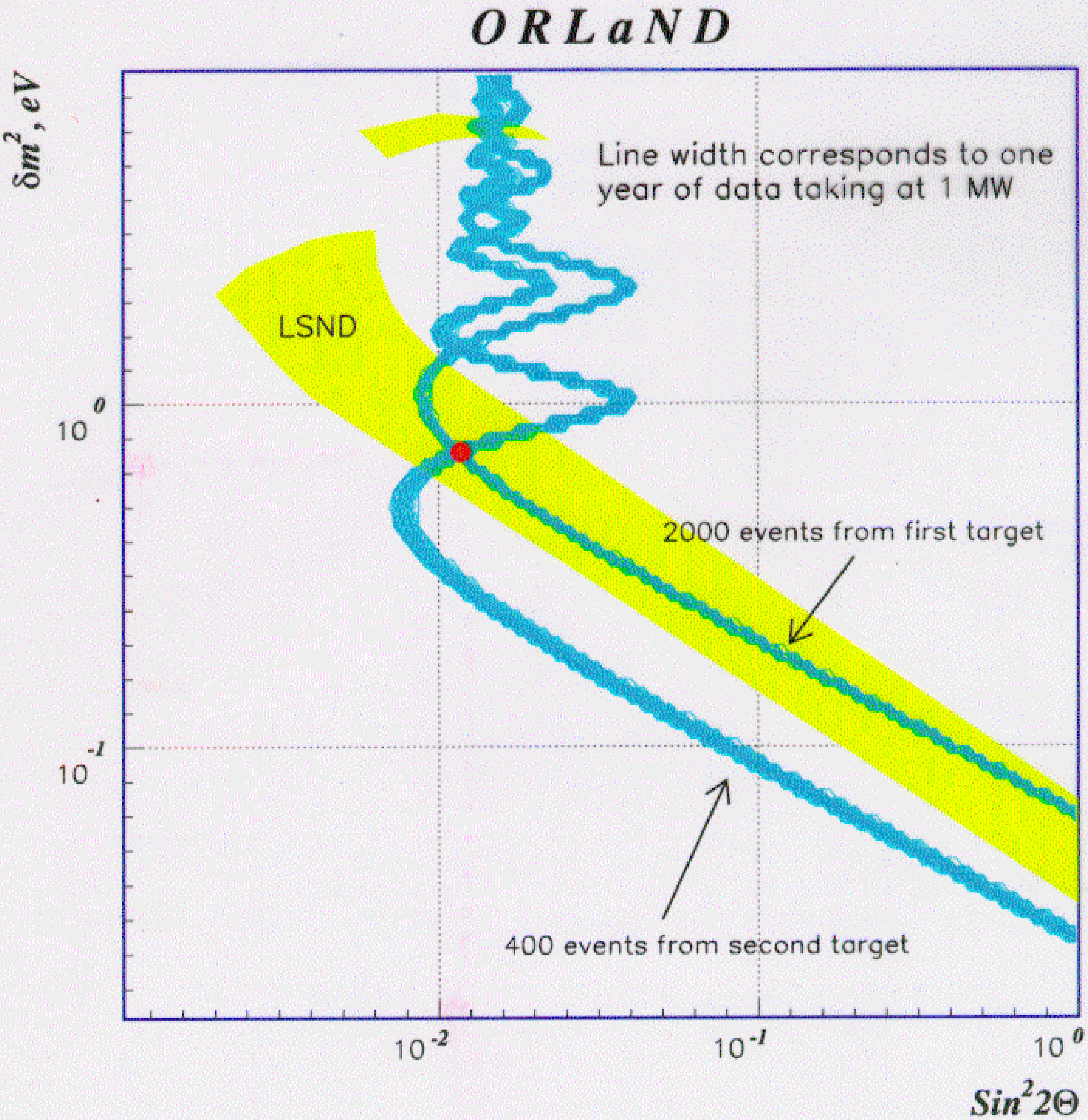
Scintillator vs. Gas tubes




ORLaND, limit after 3 y at 2 MW
E776
LSND result
Bugey
CHOOZ
0.2 kt detector
0.6 kt detector
2.0 kt detector
Signal from second target
Sin²2Θ
δm², eV²
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10¹
10⁰
10⁻¹
10⁻²
10⁻³

ORLaND, limit after 3 y at 2 MW




ORLaND
δm², eV
Line width corresponds to one year of data taking at 1 MW
LSND
2000 events from first target
400 events from second target
10^0
10^-1
10^-2
10^-1
10^0
Sin²2Θ

Size of Detector at ORLaND

(number of events is for ~ 2MWY)

Task	Target	20t ~1 k event	200t ~10 k event	2000t ~100 k event
Deuterium	D_2O	Cross section		
Strangeness		?	?	?
Oxygen	H_2O	Cross section		Double diff. Cross section
Iron	Fe	Cross section		
Silicon	SiO_2	Cross section		
Lead	$PbSiO_2$	Cross section		
Tantalum	Ta	Cross section		
Neutrino Oscillations	Mineral oil, H_2O?		Test of LSND signal	Search in new regions of parameters, precise measurement in the LSND region
$Sin^2\theta_w$	Mineral oil, H_2O?			Measurement with 1%, accuracy
Neutrino magnetic moment	Mineral oil, H_2O?			10 times better sensitivity for ν_μ than present limit
"KARMEN" time anomaly	Any?		Test	Study

Size of Detector at ORLaND
(number of events is for ~ 2MWY)

TASK	20t ~1 k event	200t ~10 k event	2000t ~100 k event
Deuterium	Cross section		
Oxygen			Double diff. Cross section
Strangeness	?	?	?
Iron	Cross section		
Silicon	Cross section		
Lead	Cross section		
Tantalum	Cross section		
Oscillations		Test of LSND signal	Search in new regions of parameters
$\mathrm{Sin}^2\theta_w$			Measurement with 1%
"KARMEN" time anomaly		Can be done	