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NANPino-2000

OSCILLATIONS OF REACTOR ANTINEUTRINOS

L. MIKAELYAN

KURCHATOV INSTITUTE, MOSCOW

LMIKAEL@POLYN.KIAE.SU

ABSTRACT

WE CONSIDER OSCILLATION EXPERIMENTS AT REACTORS AS A TOOL TO INVESTIGATE MIXING AND MASS STRUCTURE OF THE ELECTRON NEUTRINO

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OSCILLATION EXPERIMENTS AT REACTORS

PREVIOUS	MODERN	FUTURE
ILL	CHOOZ	KAMKLAND
	1999 y	START: 2002 y
GOESGEN		
ROVNO-1	PALO-VERDE	BOREXINO
	2000 y	START: ?
KRASNOYARSK		
ROVNO-2		Kr-2-DET
		R&D
SAVANNAH RIVER		
RUGEY		

BUGEY

SEE Dr. T. Hagner (Münich), THIS morning report.

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OSCILLATIONS

THE SURVIVAL PROBABILITY

$$P_{\nu_e \to \nu_e} = 1 - \sin^2 2\theta \cdot \sin^2 \phi$$

$$\phi = \frac{1.27\ \delta m^2 \cdot R}{E_\nu},$$

E_ν - MeV, R - meter, δm^2 - eV^2

FOR REACTOR $\tilde{\nu}_e$ THE DISAPPEARENCE IS MAXIMAL FOR

$$\delta m^2 \cdot R = 5\ eV^2 \cdot m$$

DETECTION:

$$\tilde{\nu}_e + p \longrightarrow e^+ + n$$

$$E_e \simeq E_\nu - 1.8 + (1)\ MeV$$

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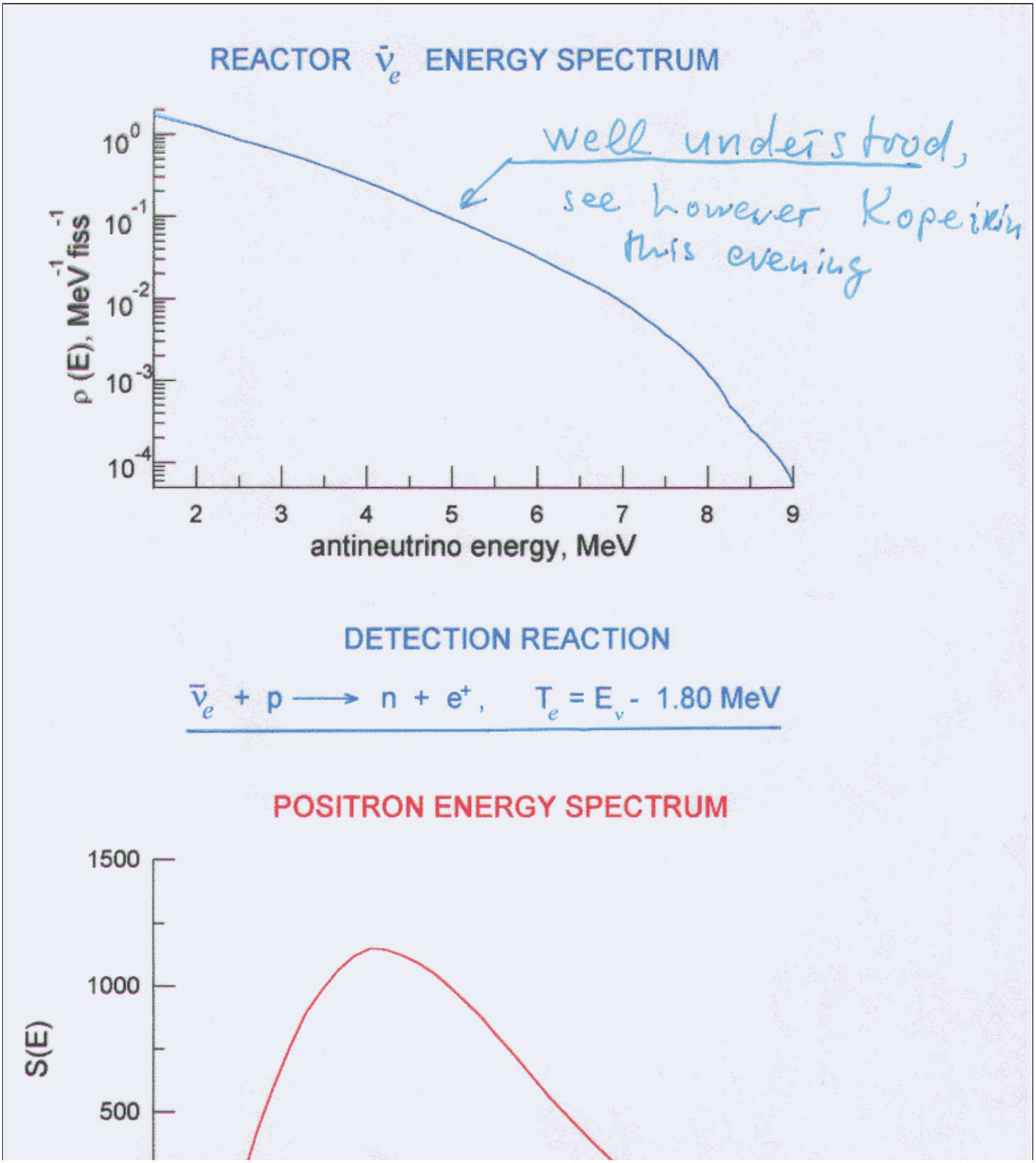

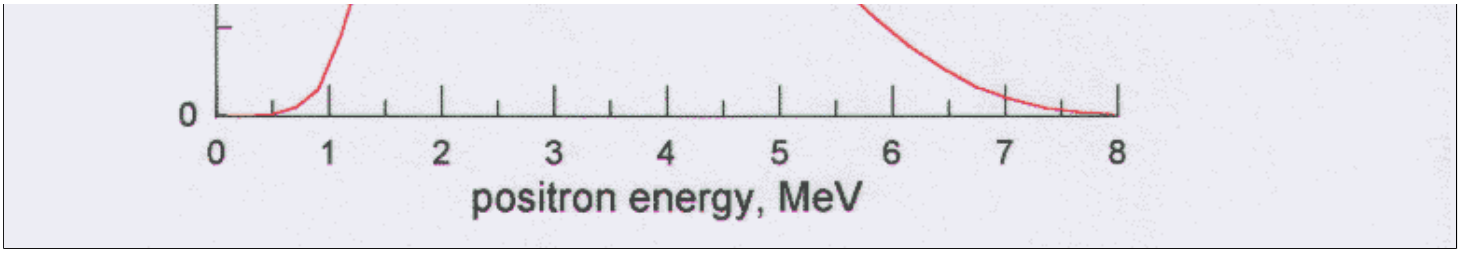
0
0
1
2
3
4
5
6
7
8
positron energy, MeV

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HOW FAR FROM THE SOURCE THE REACTOR ν_e OSCILLATIONS SHOULD BE SEAECHED FOR?

WHAT ARE THE VALUES OF THE MASS PARAMETER Δm^2 ?

INDICATION GIVE STUDIES OF THE ATMOSPHERIC AND SOLAR NEUTRINOS

ATMOSPHERIC NEUTRINOS:

FROM SK:

$\Delta m^2_{atm} \approx 3\times10^{-3} eV^2$, $\sin^2 2\theta_{atm} \sim 1$ (for $\nu_\mu \rightarrow \nu_\tau$)

~ 1 *km* baseline reactor experiments CHOOZ, P-VERDE (and, hopefully, KR2DET)

SOLAR NEUTRINOS:

$\Delta m^2_{sol} \approx 3 \times 10^{-5} eV^2$ $\sin^2 2\theta_{sol} \sim 0.7$...(the LMA-solution)

- Very long (more than 100 *km*) baseline reactor experiments
- KAMLAND and BOREXINO

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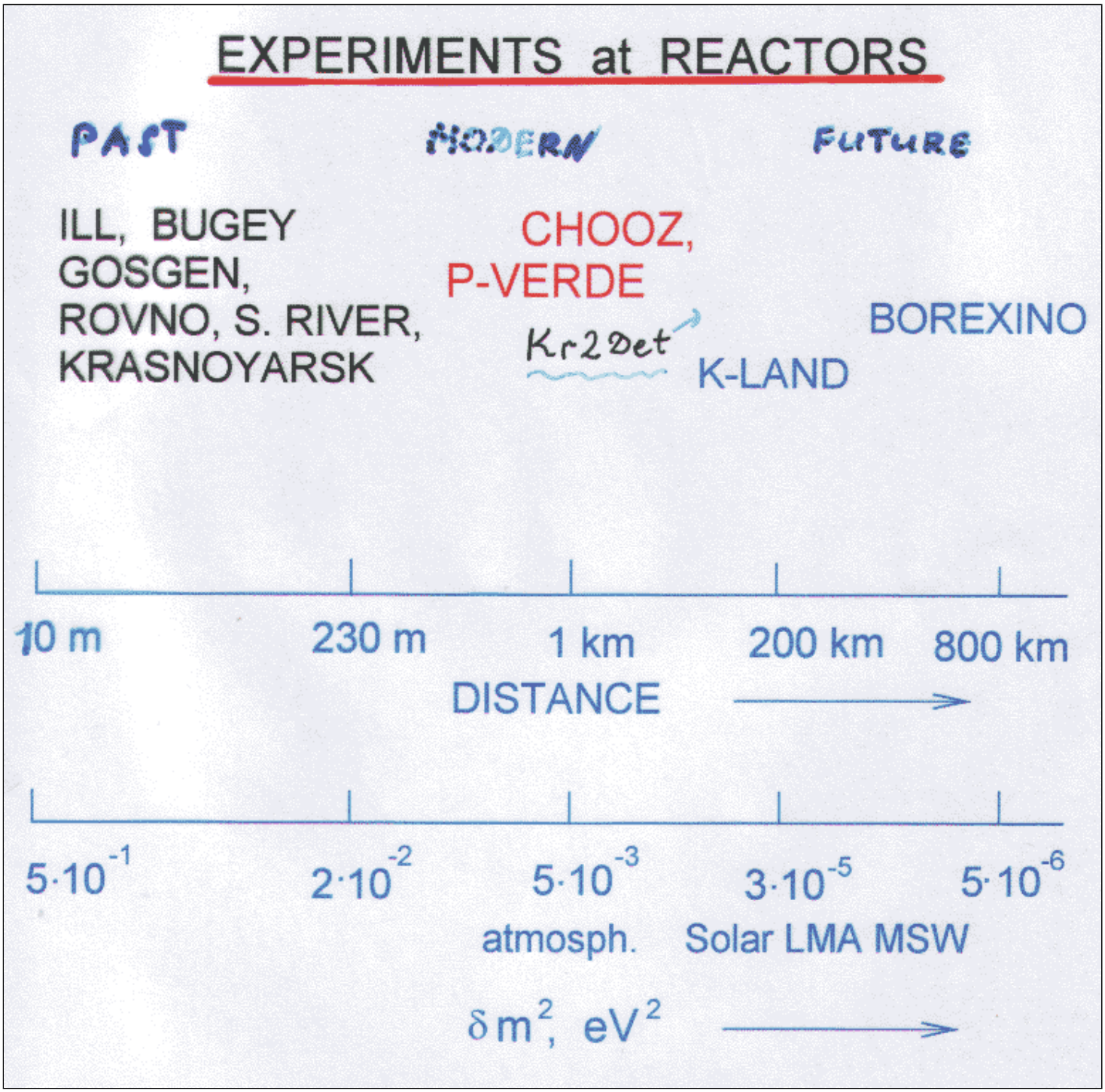

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WHAT INFORMATION ABOUT ν_e MIXING GIVE 1 *km* AND VERY LONG B-L REACTOR EXPERIMENTS?

IN THE 3- ACTIVE NEUTRINO OSCILLATION THEORY:

$$\sin^2 2\theta_{1km} = 4U_{e3}^2(1 - U_{e3}^2) \qquad \text{(i)}$$

$$\sin^2 2\theta_{\geq 100\ km} = 4U_{e1}^2 \times U_{e2}^2, \qquad \text{(ii)}$$

Where

U_{ei} are contributions of mass states ν_i to the electron neutrino flavor state ν_e :

$$\nu_e = U_{e1}\nu_1 + U_{e2}\nu_2 + U_{e3}\nu_3$$

HOPEFULLY:

THE 1*km* and VERY LBL EXPERIMENTS at REACTORS WILL GIVE A COMPLETE INFORMATION on the ν_e MASSES and MIXING.

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hep-ex/9907037 12

CHOOZ FINAL RESULTS

France-Italy-Russia-US Collaboration

College de France — LAPP, Annecy
INFN & Univ. of Pisa — INFN & Univ. of Trieste
Kurchatov Institute, Moscow
Univ. of Irvine — Drexel Univ.
Univ. of New Mexico

Two reactors of summed rated power W=8.5 GW (thermal)

Detector located at a depth of 300 mwe,
at ~1000 m from the reactors.

NEUTRINO EVENTS SELECTION

Summary of data acquisition (April 1997-July 1998)

Reactor 1	Reactor 2	Time (d)	W(GW)
+	0	86	4
0	+	50	3.5
+	+	64	5.7
0	0	142	-

Neutrino detection efficiency: 70%
Total # of detected neutrinos: ~2700
Neutrino detected rate at full power: 25 d^{-1}
Background: ~1.2 d^{-1}
Neutrino/BKG, typically ~10:1

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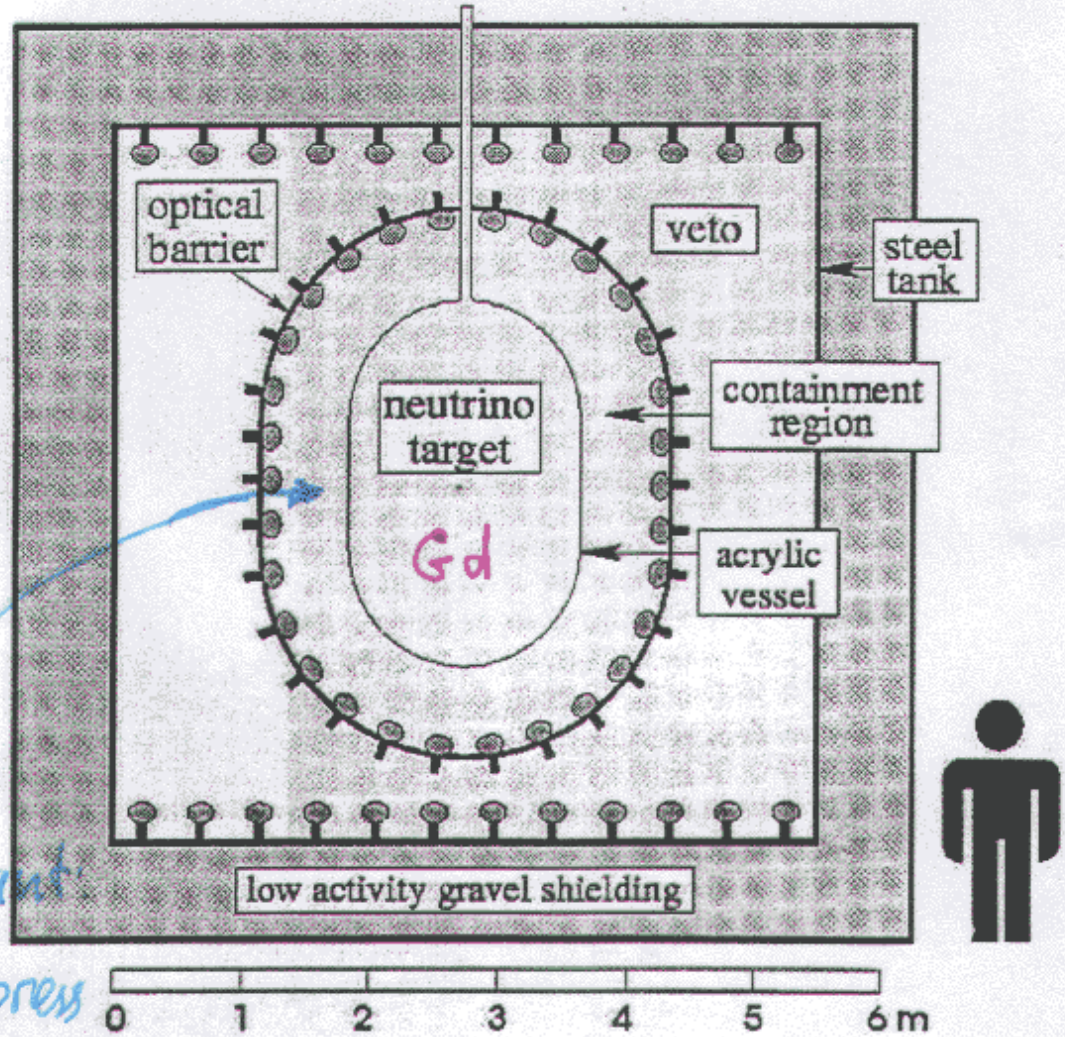
300 MWE

7

Chooz detector.

The detector is contained in 5.5 m diameter cylindrical steel tank shielded by low radioactivity sand (75 cm) and cast iron (14cm).



VERY Important! to suppress γ's

Inside the tank there are 3 concentric region:

- a central 5-ton target in a transparent plexiglas container filled with a 0.09% Gd-loaded scintillator,
- an intermediate 17-ton volume filled with unloaded scintillator,
- an outer 90-ton optically separated veto counter filled with unloaded scintillator.

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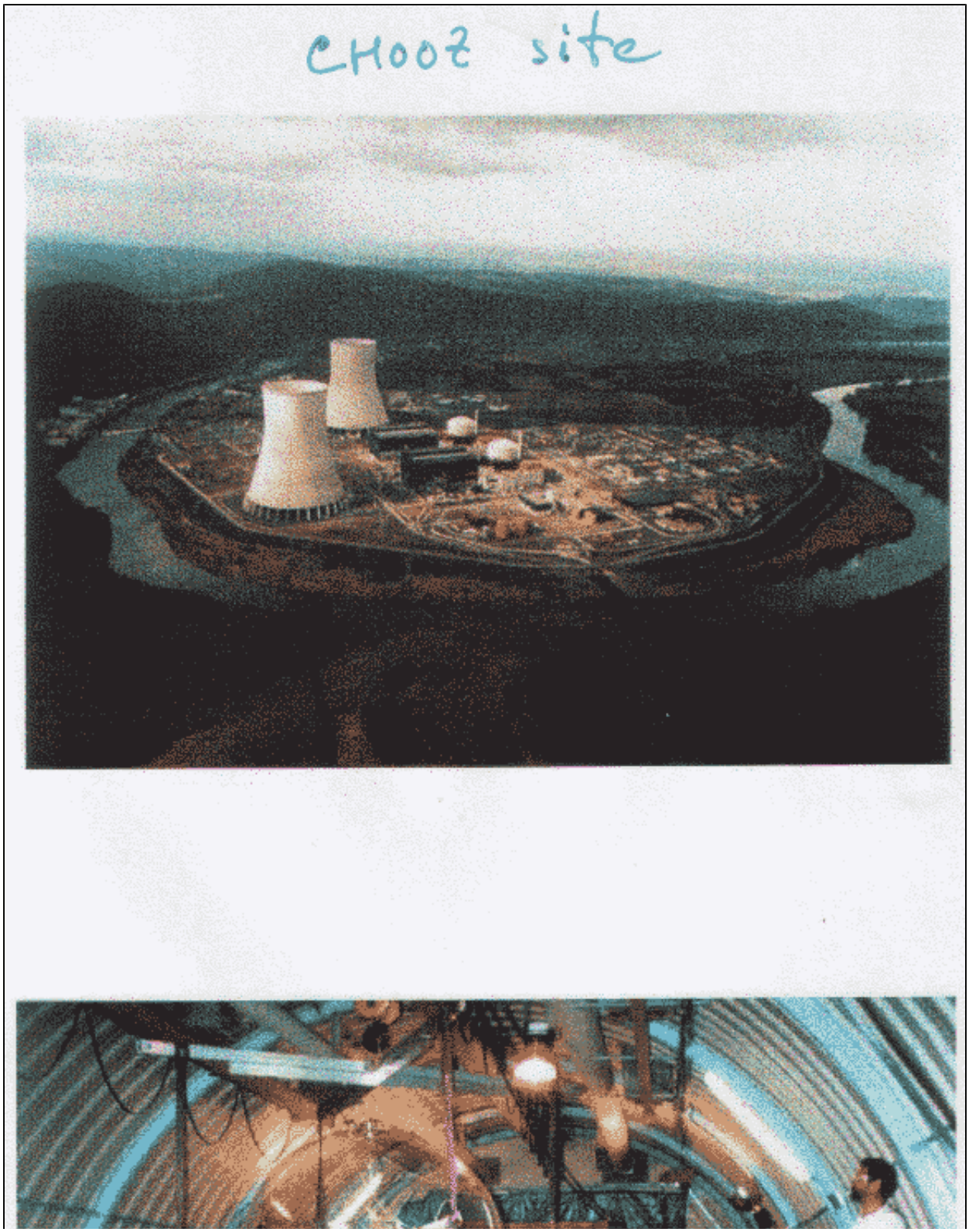

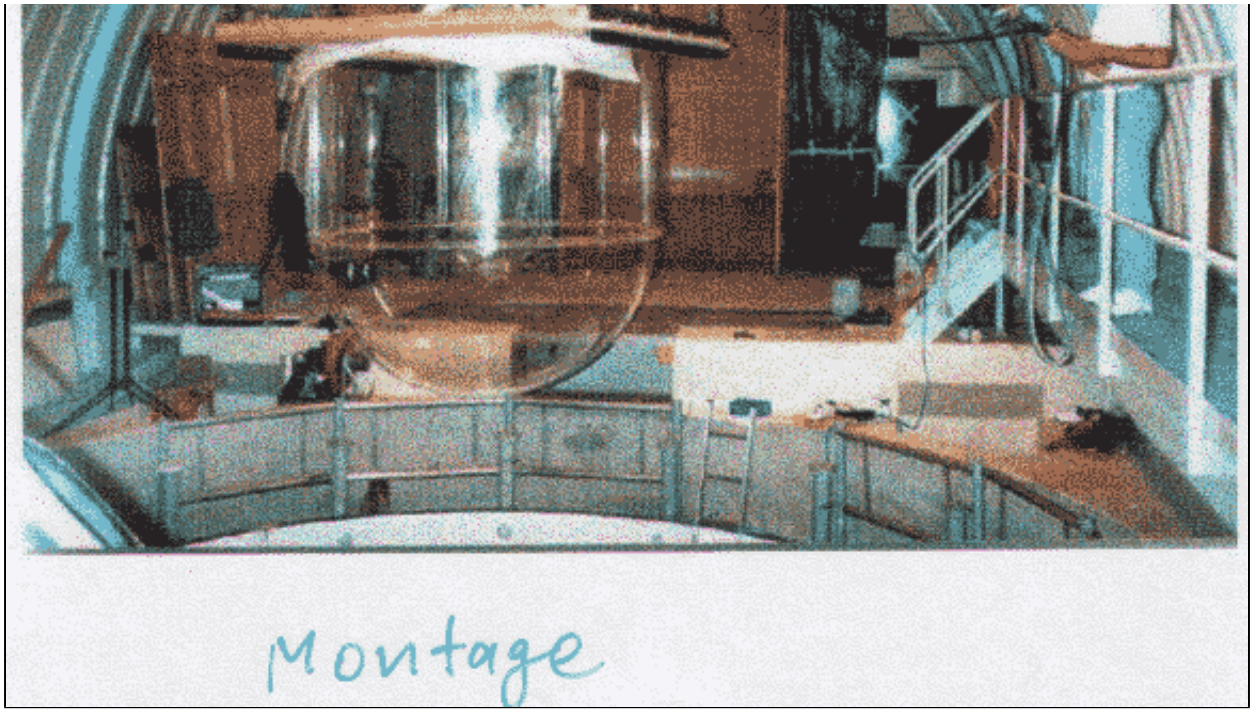
Montage

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CHOOZ COMBINED DATA ANALYSIS

Neutrino detection rates X_{rate} = measured/expected

Positron spectrum shape: measured vs expected

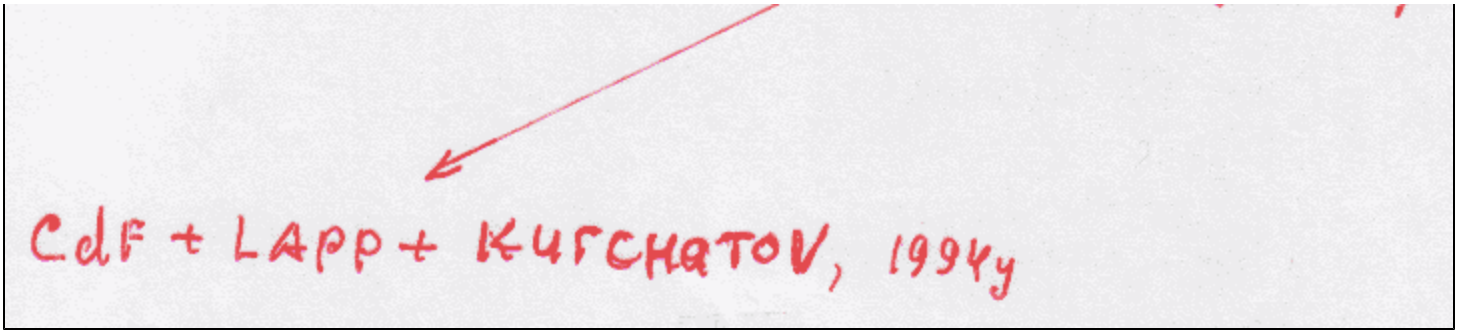
Number neutrino separately measured from two reactors

CHOOZ'97 $X_{rate} = 0.98 \pm 4\%(\text{ stat}) \pm 4\%\ (\text{syst})$

CHOOZ'99 $X_{rate} = 1.01 \pm 2.8\%(\text{ stat}) \pm 2.7\%\ (\text{syst})$

CHOOZ'97 USES σ(0) calculated (2.5%)

CHOOZ'99 USES σ(0) measured (1.4%)


CdF + LAPP + KURCHATOV, 1994y

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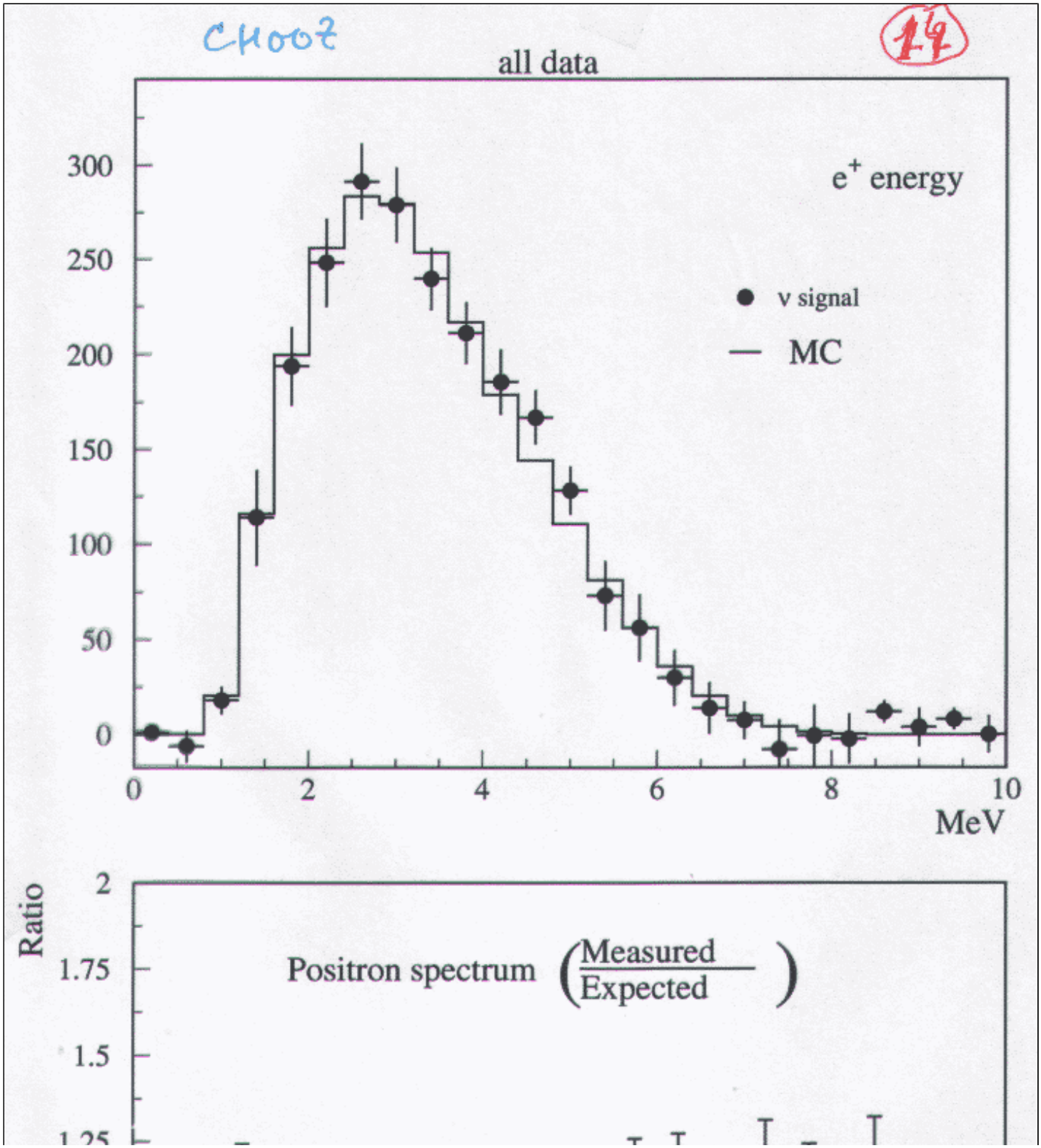

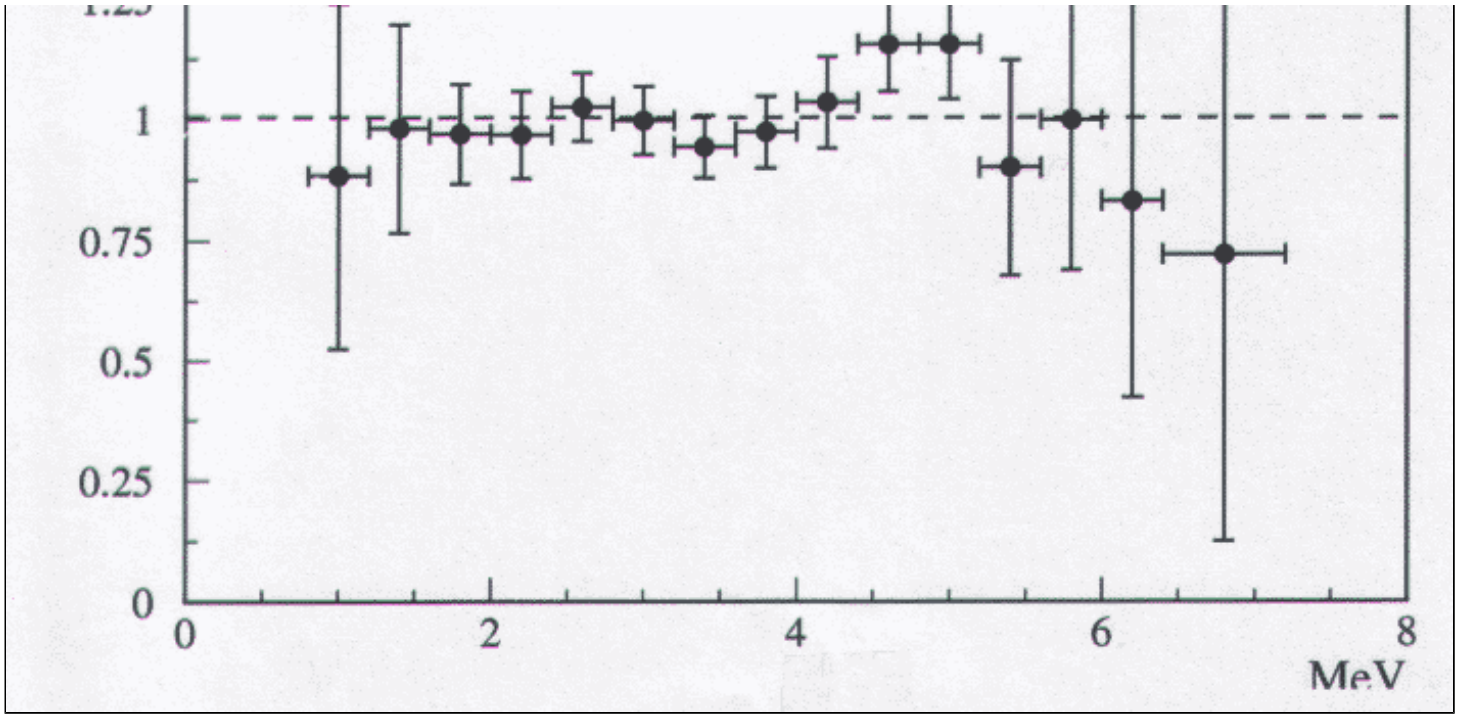
1
0.75
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0.25
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MeV

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REVOLUTION IN $\tilde{\nu}_e$ DETECTION

	BEFORE CHOOZ		CHOOZ	FUTURE	
	ROVNO	BUGEY		K-LAND	BOREXINO
$\tilde{\nu}_e$/t·day	1700	370	2.2	$2\ 10^{-3}$	$3\ 10^{-4}$
BKG/t·day	220	160	0.24	$<10^{-3}$	$<10^{-4}$

CHOOZ DEMONSTRATED 500-1000 TIMES LOWER BACKGROUND LEVEL PER TARGET TON THAN IN PAST $\tilde{\nu}_e$ EXPERIMENTS

THE SECRET IS WELL UNDERSTOOD:

- M.W.E. — TO SUPRESS COSMIC MUONS
- BOREXINO GEOMETRY — TO SUPRESS THE NATURAL RADIOACTIVITY (PM's)

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THE PALO VERDE EXPERIMENT

Caltech, Stanford Univ., Univ. of Alabama,
Arizona State Univ.

3 reactors at 890 m, 890 m and 750 m,
of summed power W=11 GW

Detector: 66 MACRO sells, 12 tons of liquid scintillator (Gd)

Fast triple coincidence $e^+\gamma\gamma$ + delayed n, γ signal

Neutrino detection efficiency: 8.2%

RESULTS FROM THE FIRST 72 DAYS
(November and December 1998):

3 Reactors ON - 2 Reactors ON = (6.4 ± 1.4) per day

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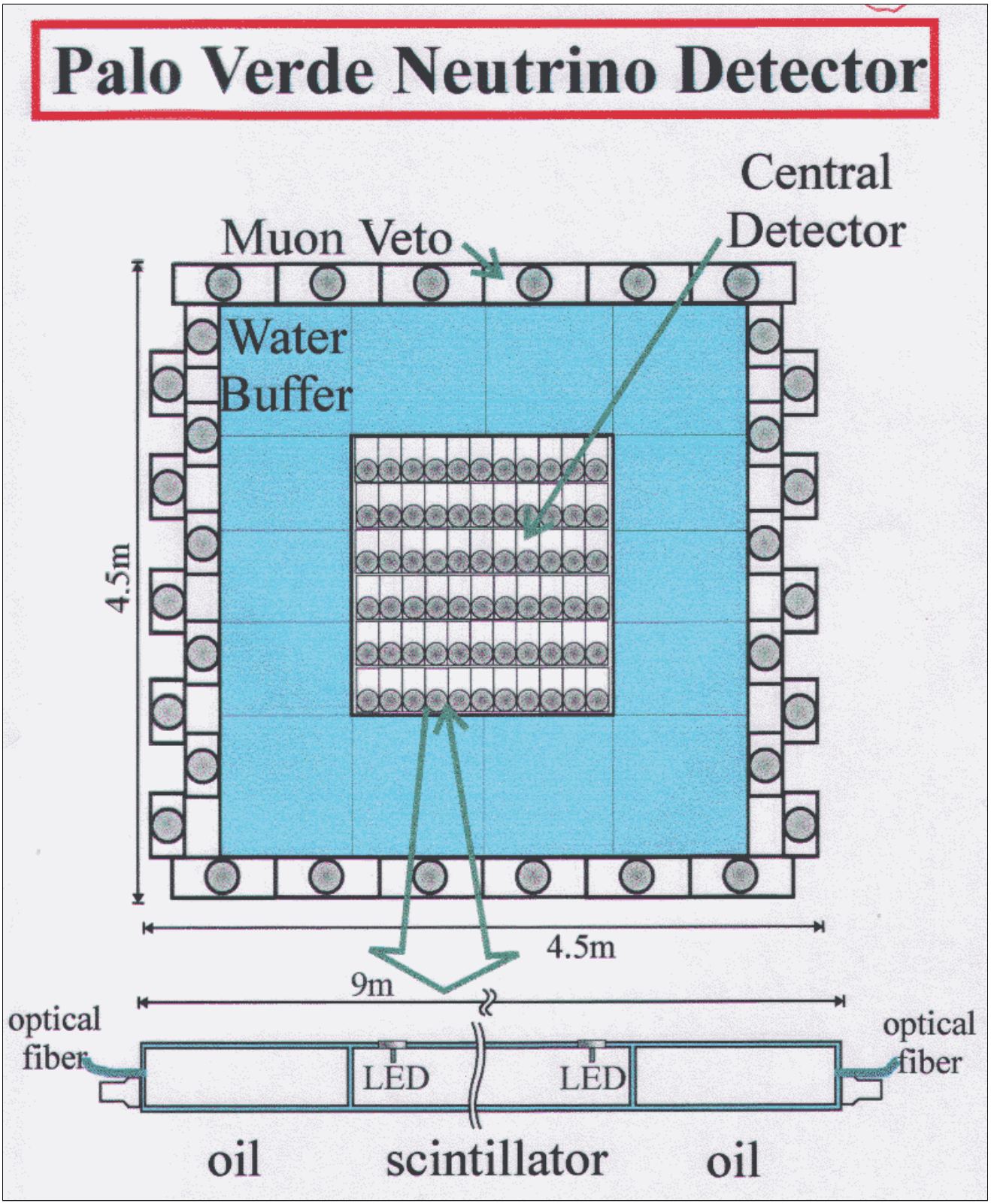

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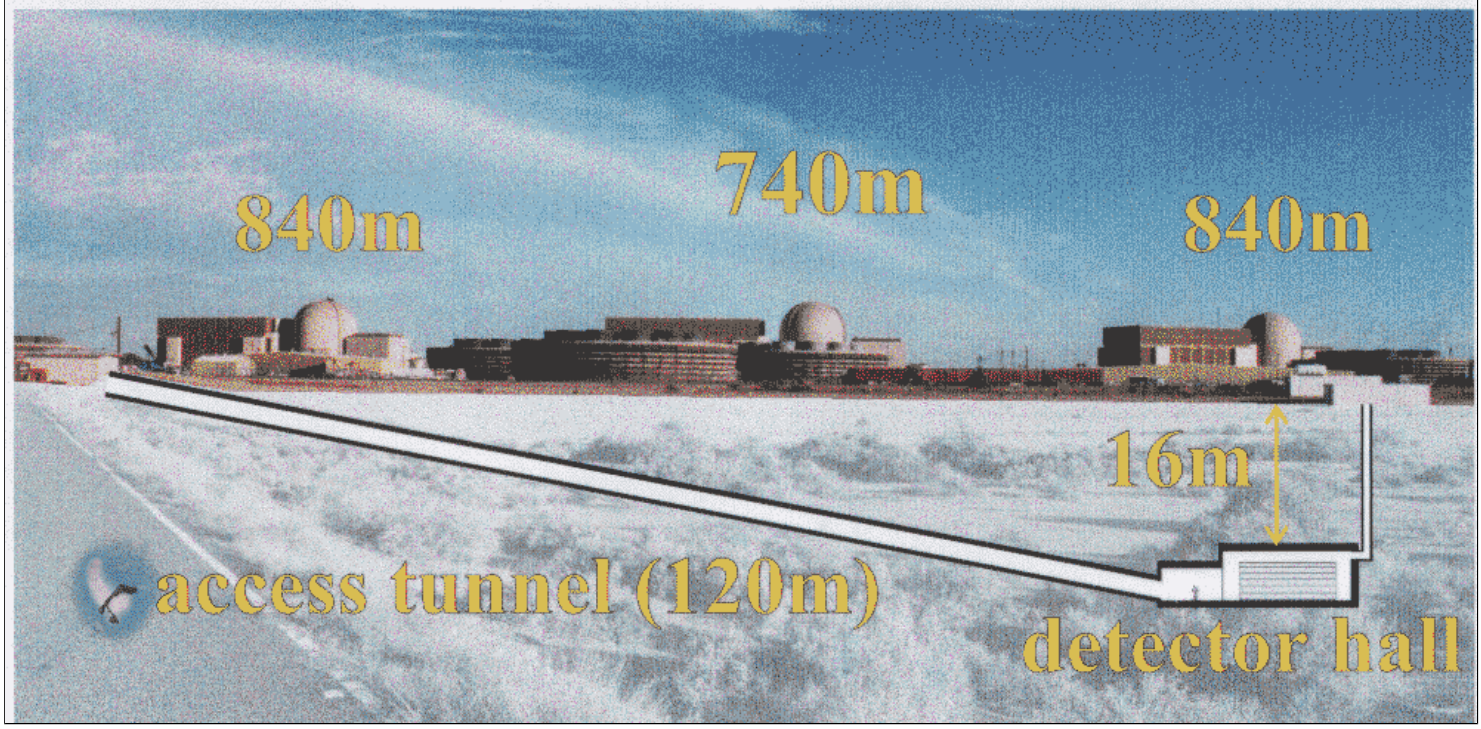
Palo Verde Neutrino Experiment

- three reactors with thermal power of 10.9 GW
- two distances to the experiment: 740 m and 840 m
- $\bar{\nu}_e$ flux ($E_\nu > 2$ MeV): $7.4 \cdot 10^9$ $\bar{\nu}_e$/s cm^2
- two refueling cycles per year, each 40 days long



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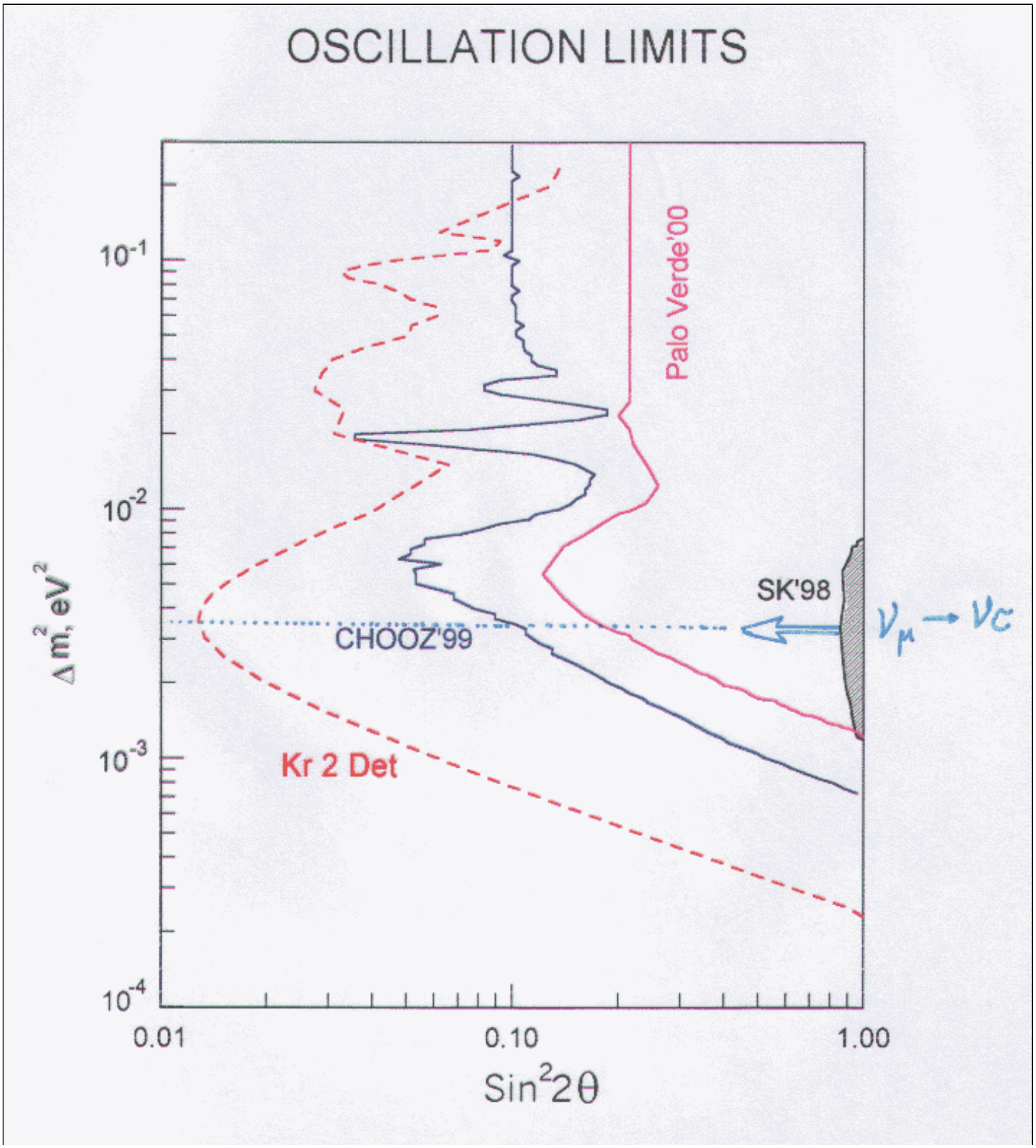

For reactor $\tilde{\nu}_e$ at 1 km:

$$\mathrm{Sin}^2 2\theta = 4U_{e3}^2(1 - U_{e3}^2) \approx 4U_{e3}^2$$

$$\nu_e = U_{e1}\,\nu_1 + U_{e2}\,\nu_2 + U_{e3}\,\nu_3 \qquad U_{e3} \equiv \sin\theta_{13}$$

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INSTEAD OF DISCUSSION

Do we
Are needed more sensitive searches for neutrino oscillations at a distance of ~1 km from the reactor $\tilde{\nu}_e$ source?

Answer # 1: **No**, not important. From SK and CHOOZ data we already know that electron neutrinos do not contribute much (if at all) to the atmospheric neutrino anomaly. Why go into insignificant details?

Answer # 2: **Yes.** The goal of primary importance is to explore the intrinsic properties of the neutrino, such as its mass contents and mixing.

Theorists tell us:

One km reactor experiments are sensitive to U_{e3}, the contribution of the mass-3 state to the $\tilde{\nu}_e$ flavor state.

The CHOOZ'99 limits are not so terribly strong:

CHOOZ'99 : $U_{e3} \leq 0.15$

(in 3-neutrino model, with $\Delta m^2_{atm} >> \Delta m^2_{sol}$)

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NEUTRINO2000

FUTURE REACTOR NEUTRINO OSCILLATION EXPERIMENTS AT KRASNOYARSK

TOWARDS VERY SMALL MIXING ANGLES IN THE ATMOSPHERIC NEUTRINO MASS REGION

L. Mikaelyan, Kurchatov Institute, Moscow; lmikael@polyn.kiae.su

THE MAIN GOAL OF THE PROJECT IS:

TO FIND THE CONTRIBUTION OF *M*-3 STATE TO THE ELECTRON NEUTRINO FLAVOR STATE.

- CHOOZ, PALO-VERDE vs SuperKAMIOKANDE
- TWO DETECTOR EXPERIMENT Kr2 Det

The Site, Detectors, Lay out, Statistics, Systematics

- EXPECTED SENSITIVITY
- OTHER APPLICATIONS: Sterile Neutrinos?
- CONCLUSIONS

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3

Mika

Kr2Det:

1. STATISTICS: CHOOZ × 20

2. RETAINE ν/BKG: > 300 MWE

3 SYSTEMATICS: CHOOZ/(5÷10)

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PROPOSED EXPERIMENT AT KRASNOYARSK

— TWO IDENTICAL DETECTORS at 1100 m and 200-300 m from the $\tilde{\nu}_e$ source.

— TARGETS: Liquid scintillator, 50 tons.

— GEOMETRY : «BOREXINO»

$\tilde{\nu}_e$ detection rate at 1100 m position $15 \cdot 10^3$/year

Estimated effect to BKG ratio: ~ 10:1

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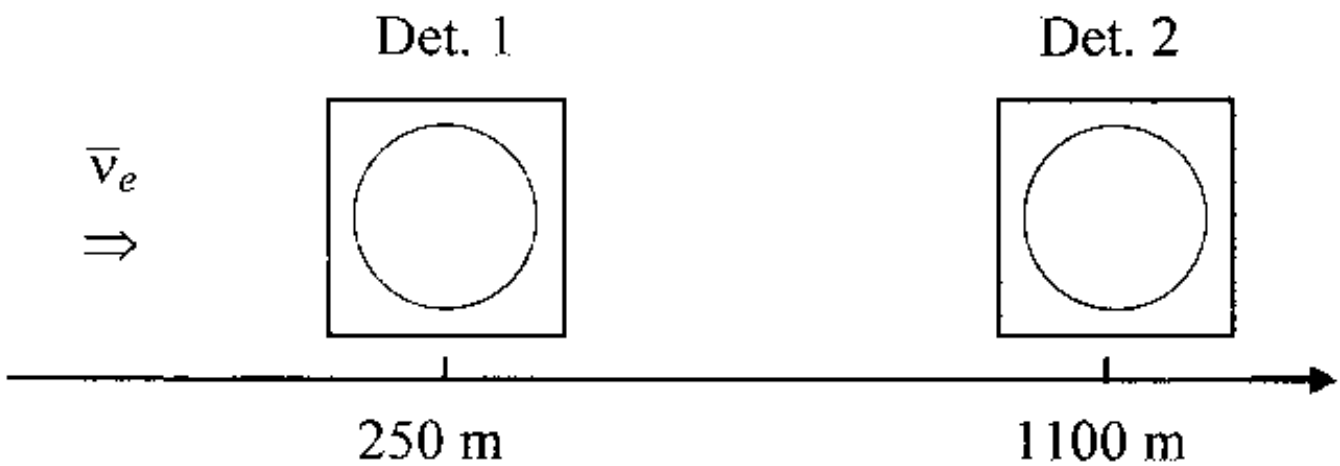
Krasnoyarsk 2 Det. IDEA

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



TARGET:	50 m^3 OIL + PPO	50 m^3
RATE:	250×10^3 y^{-1}	1.5×10^3 y^{-1}
$\bar{\nu}_e$/BKG:	>> 1	~10:1

IN NO-OSCILLATION CASE

THE RATIO OF POSITRON SPECTRA

THE RATIO OF POSITRON SPECTRA

IS CONSTANT

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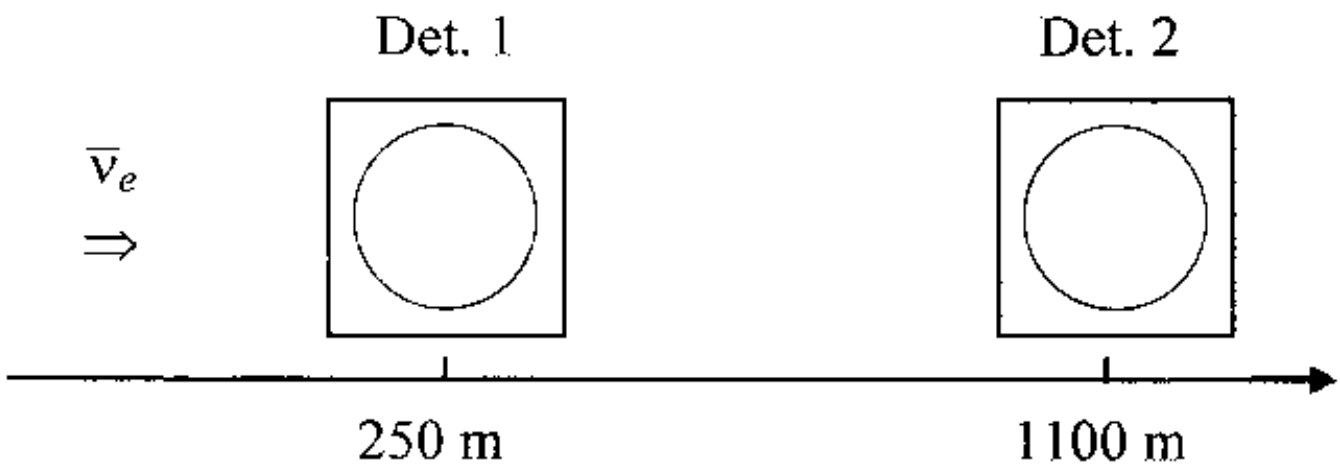
Krasnoyarsk 2 Det. IDEA

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



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ANALYSIS

I. Ratio of $\tilde{\nu}_e$ rates:

$$\frac{N_\nu(R_1)}{N_\nu(R_2)} = \frac{R_2^2}{R_1^2} \cdot \frac{V_{sc1}}{V_{sc2}} \cdot \frac{\varepsilon_1}{\varepsilon_2} \cdot f(\delta m^2, \sin^2 2\theta)$$

V_i are the scinillator volumes

ε_i are (e^+,n) detection efficiencies

II. Ratio of positron spectra

$$\frac{S_1(T)}{S_2(T)} = \text{const} \cdot \frac{1 - \sin^2 2\theta \sin^2 \phi_1}{1 - \sin^2 2\theta \sin^2 \phi_2}$$

$$\phi_{1,2} = \frac{1.27 \cdot R_{1,2}\, m^2}{\ }$$

E_ν

In no-oscillation case $\frac{S_1(T)}{S_2(T)}$ should be constant

CALIBRATIONS

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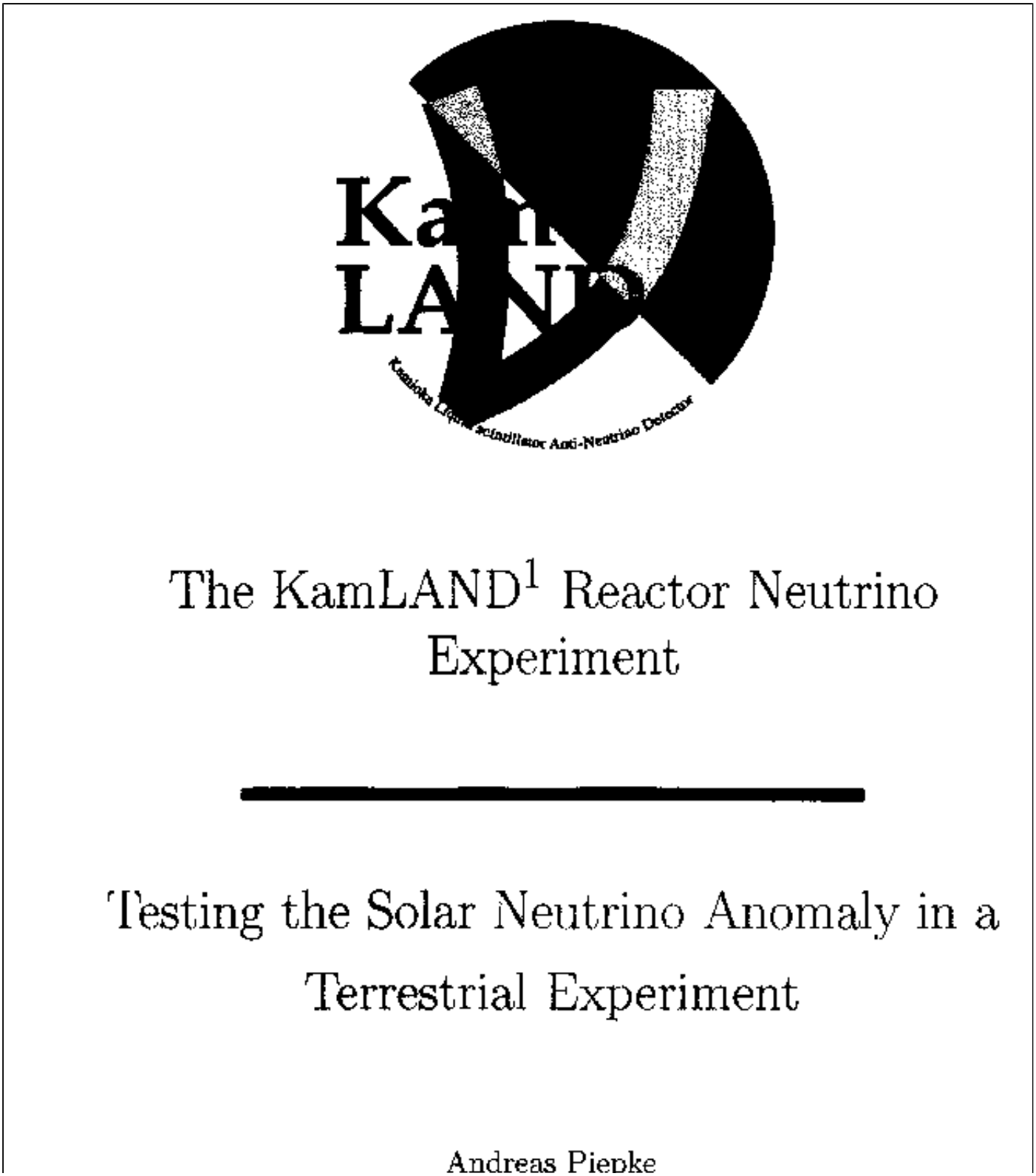

University of Alabama

for the KamLAND Collaboration

Neutrino 2000, Sudbury

[1]Supported by the Japanese Minstry of Science and Education and US Department of Energy

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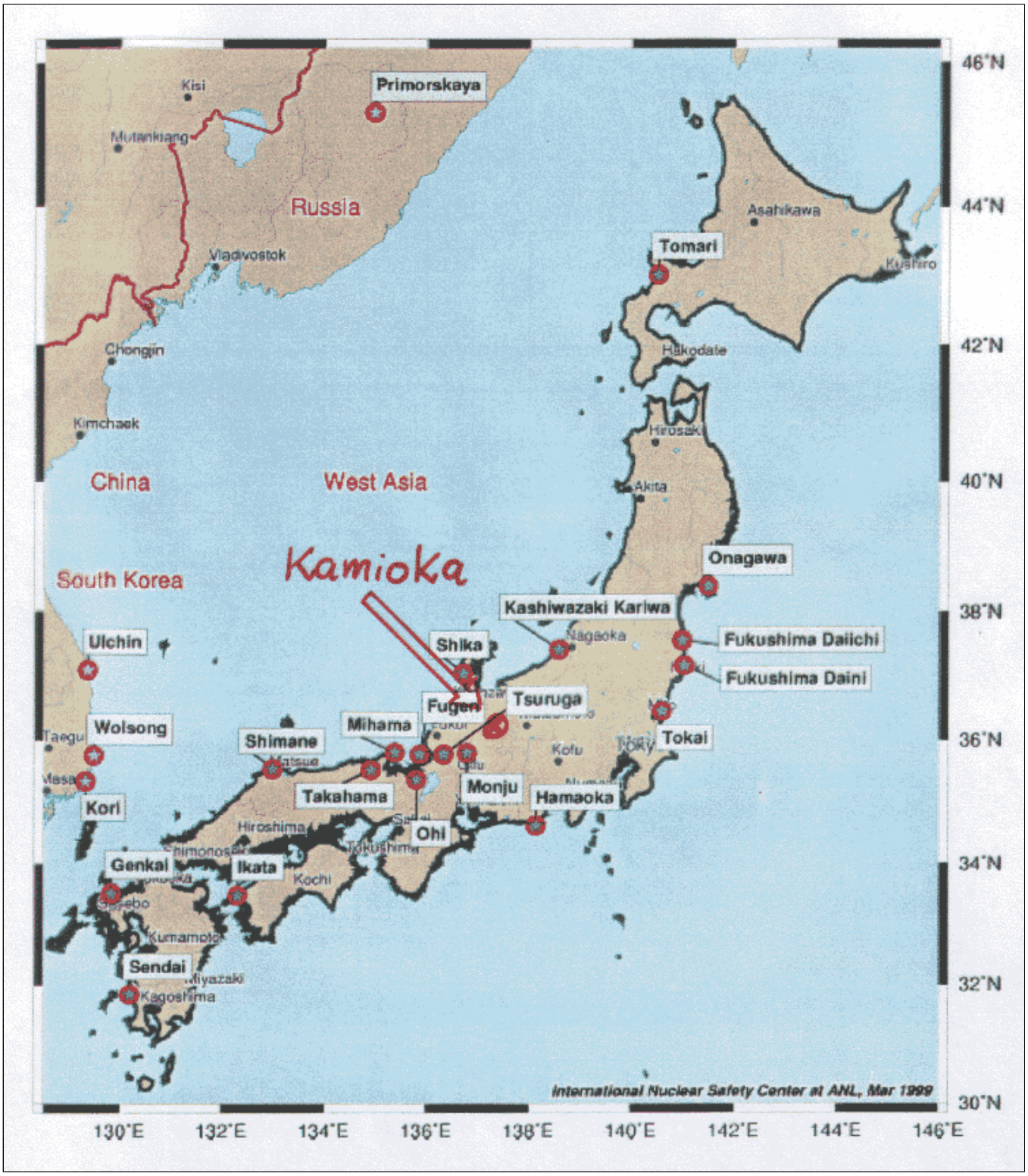

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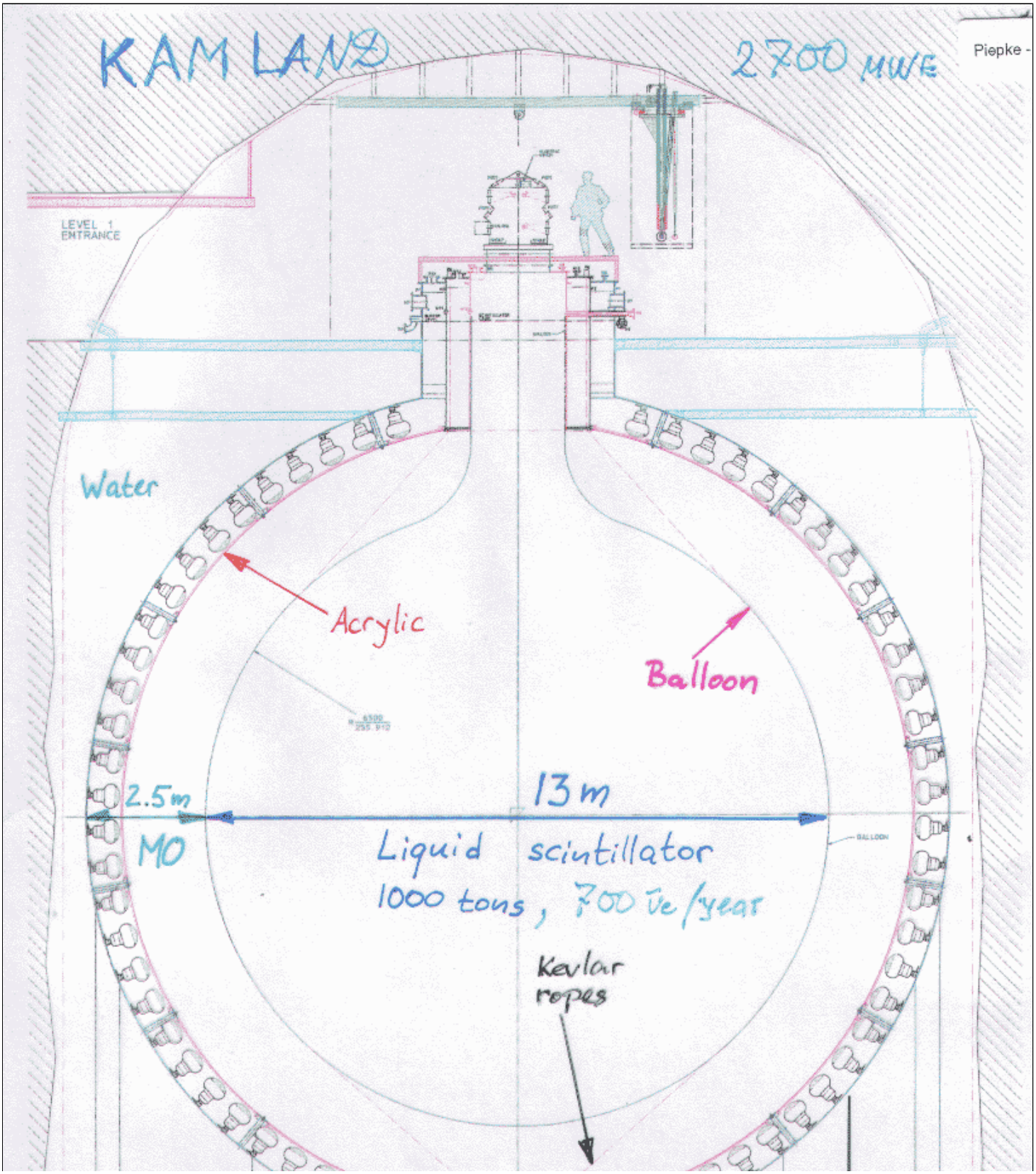

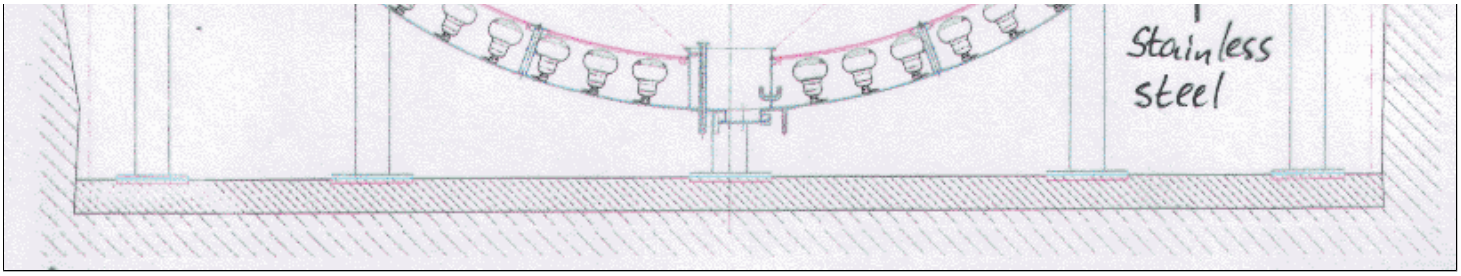
Stainless
steel

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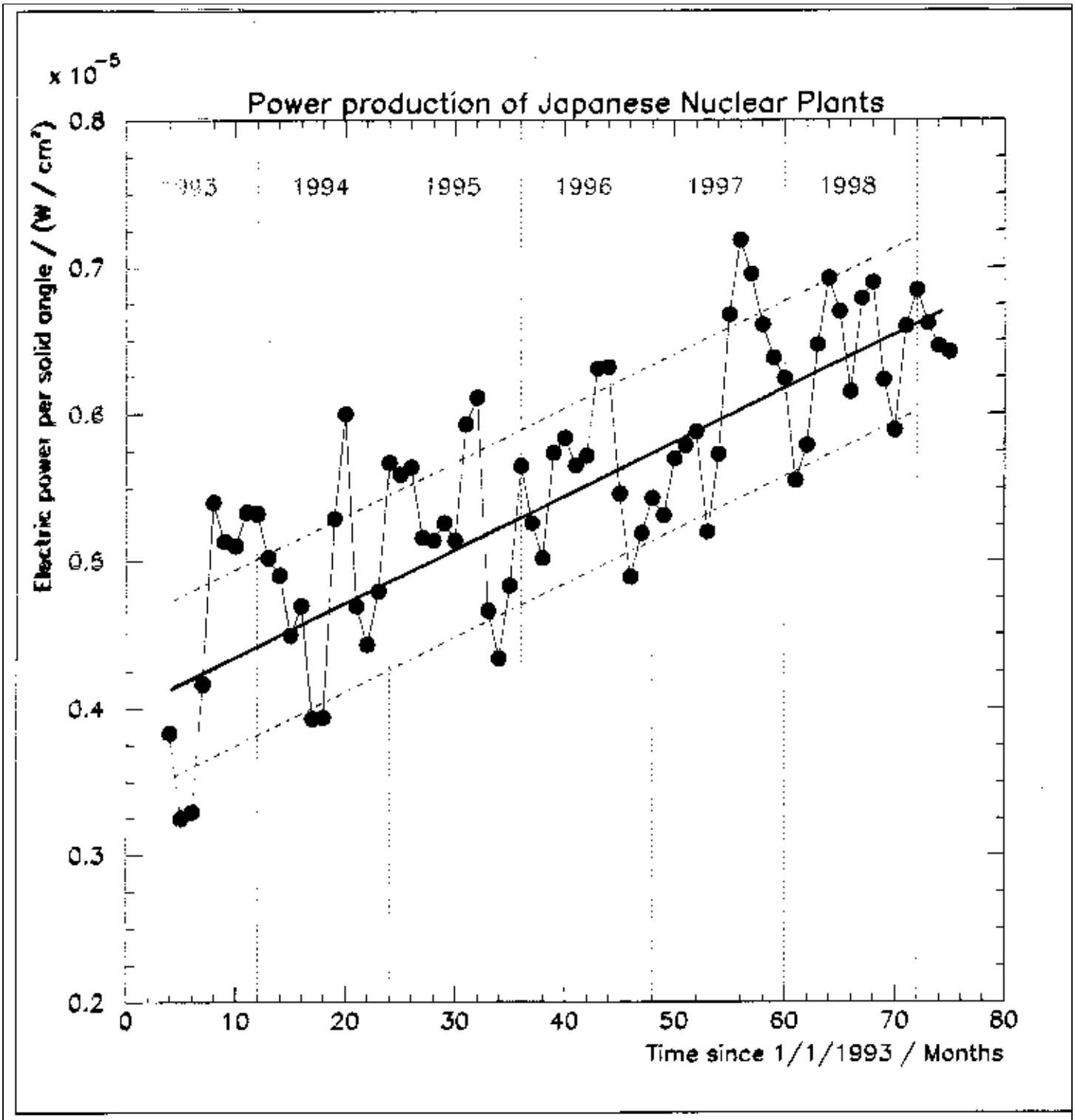

EXPECTED ν_e rate: ~ 100/y.

BKG ??

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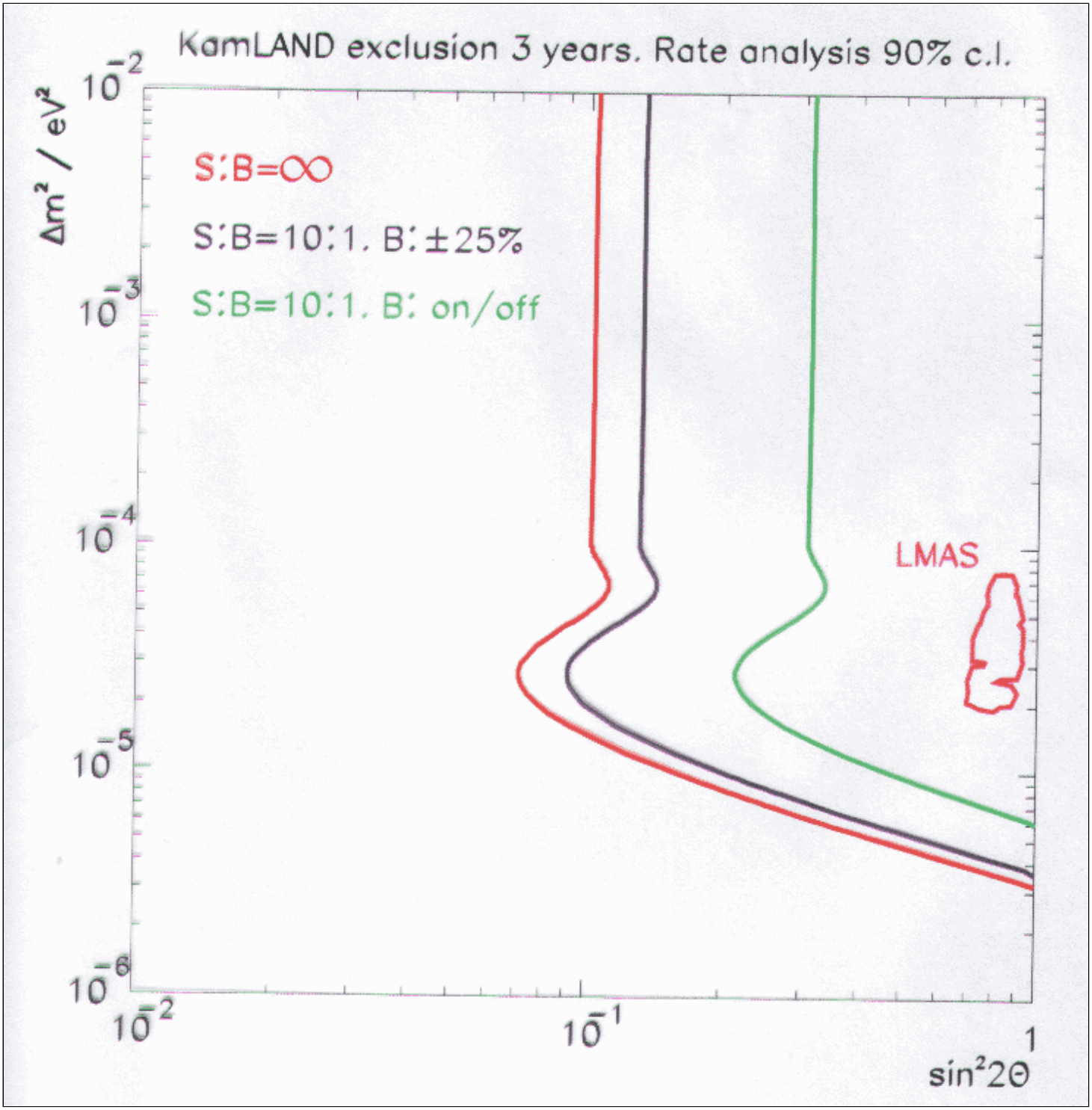

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CONCLUSIONS

PRESENT AND FUTURE EXPERIMENTS AT REACTORS CAN EXPLORE THE ELECTRON NEUTRINO MASS STRUCTURE:

$$\nu_e = U_{e1}\,\nu_1 + U_{e2}\,\nu_2 + U_{e3}\,\nu_3$$

THE CHOOZ 1 *km* EXPERIMENT HAS ALREADY RESTRICTED THE CONTRIBUTION OF MASS-3:

$$U_{e3}^2 \leq 2.5\ 10^{-2}$$

FURTHER PROGRESS IN U_{e3} IS POSSIBLE WITH TWO DETECTOR EXPERIMENT Kr2Det :

$$U_{e3}^2 < 5\times 10^{-3}$$

THE VERY LONG BASELINE EXPERIMENTS *KAMLAND* and *BOREXINO* WILL hopefully SUCSEED IN FINDING MASS -1 and MASS - 2 CONTRIBUTIONS

MASS -1 and MASS – 2 CONTRIBUTIONS.

LIFE HOWEVER CAN BE MORE COMPLICATED AND INTERESTING THAN 3- NEUTRINO MIXING SCENARIO.