KamLAND

Giorgio Gratta
Stanford University

The KamLAND Collaboration

S.Dazeley, K.Eguchi, S.Enomoto, K.Furuno, Y.Gando, J.Goldman, H.Hanada, H.Ikeda, K.Ikeda, K.Inoue, K.Ishihara, W.Ito, T.Iwamoto, H.Kinoshita, T.Kawashima, M.Koga, T.Maeda, T.Mitsui, M.Motoki, K.Nakajima, M.Nakajima, T.Nakajima, I.Nishiyama, H.Ogawa, K.Oki, T.Sakabe, I.Shimizu, J.Shirai, F.Suekane, A.Suzuki, O.Tajima, T.Takayama, K.Tamae, H.Watanabe
Tohoku University

T.Taniguchi
KEK

T.Chikamatsu
Miyagi Gakuin Women's School

H.Higuchi
Tohoku-Gakuin University

Y-F.Wang
IHEP, Beijing

J.Busenitz, Z.Djurcic, K.McKinny, D-M.Mei, A.Piepke
University of Alabama

B.Berger, R.N.Cahn, Y.D.Chan, X.Chen, S.J.Freedman, B.K.Fujikawa, K.T.Lesko, K.-B.Luk, H.Murayama, D.R.Nygren, C.E.Okada, A.W.Poon, H.M.Steiner
LBNL/UC Berkeley

L.Hannelius, G.A.Horton-Smith, R.D.McKeown, J.Ritter, B.Tipton, P.Vogel
California Institute of Technology

C.E.Lane
Drexel University

J.Learned, J.Maricic, S.Matsuno, S.Pakvasa
University of Hawaii

S.Hatakeyama, R.C.Svoboda
Louisiana State University

B.D.Dieterle, C.Gregory
University of New Mexico

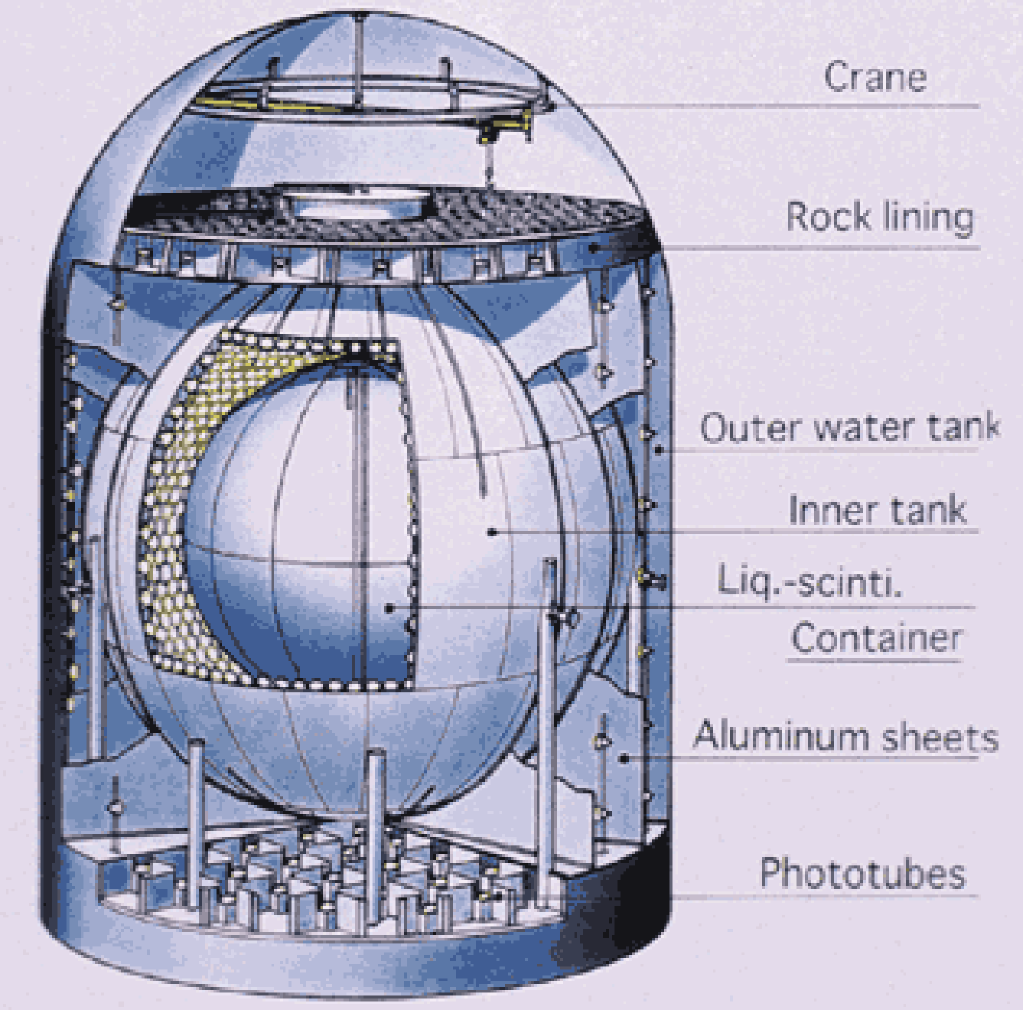
J.Detwiler, G.Gratta, H-L.Liew, D.Murphree, N.Tolich, Y. Uchida
Stanford University

Y.Kamyshkov, W.Bugg, Y.Efremenko, H.Cohn, A.Weidemann, S.Berridge, M.Schram, M.Batygov, Y.Nakamura
University of Tennessee

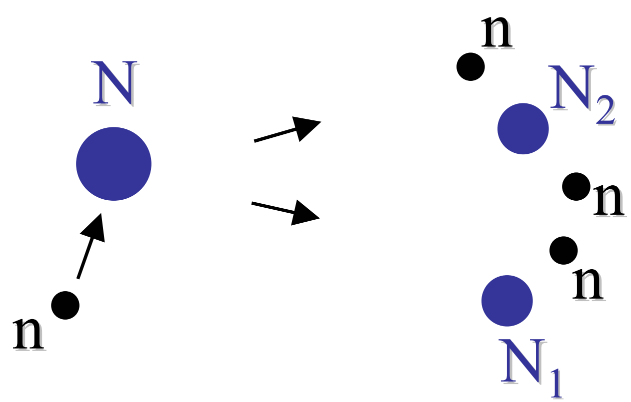
L.Braeckeleer, C.Gould, C.L.HoeM.Hornish, H.Karwowski, D.Markoff, J.Messimore, K.Nakamura, R.Rohm, N.Simmons, W.Tornow
TUNL

KamLAND: the ultimate reactor neutrino oscillation experiment

- 1 kton liq. Scint. Detector
  in the Kamioka cavern
- ~1300 17" fast PMTs
- ~700 20" large area PMTs
- 30% photocathode coverage
- H_2O Cerenkov veto counter
- Multi-hit deadtime-less
  electronics
- Δm^2 sensitivity $7*10^{-6}$ eV^2
  LMA-MSW solution
  within reach on the earth !



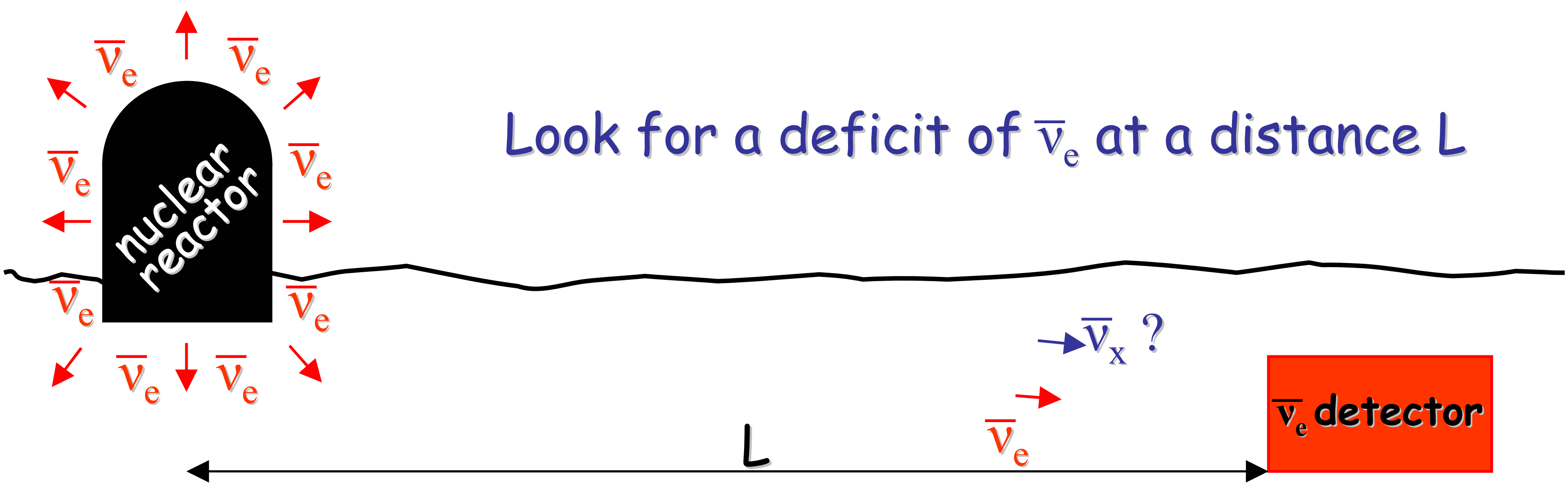
Nuclear reactors are very intense sources of ν_e deriving from beta-decay of the neutron-rich fission fragments



N_1 and N_2 still have too many neutrons and decay

$$N_2 \rightarrow N_3 + e^- + \nu_e$$

Look for a deficit of $\bar{\nu}_e$ at a distance L

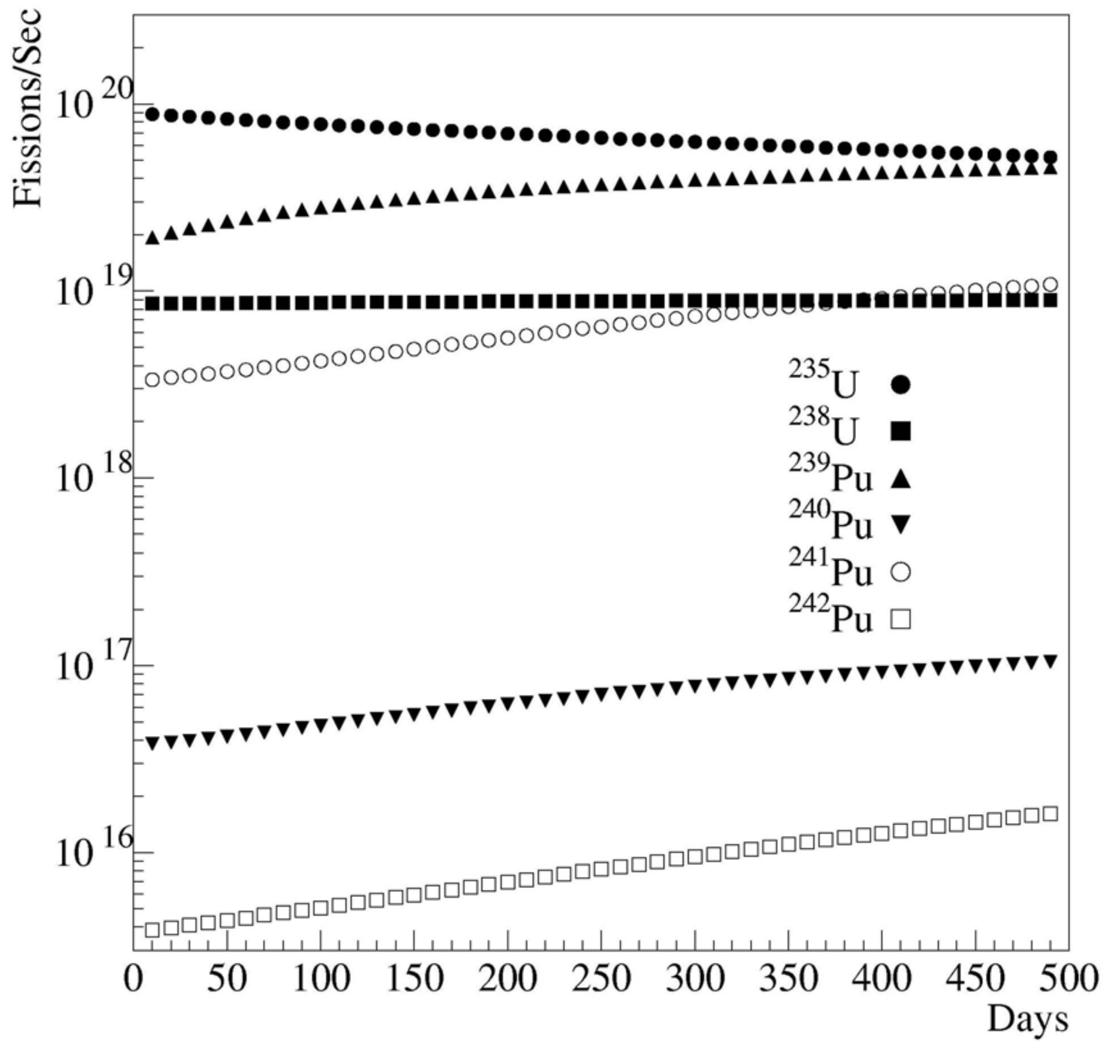


>99.9% of ν are produced by fissions in ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu

$$200 MeV / fission$$

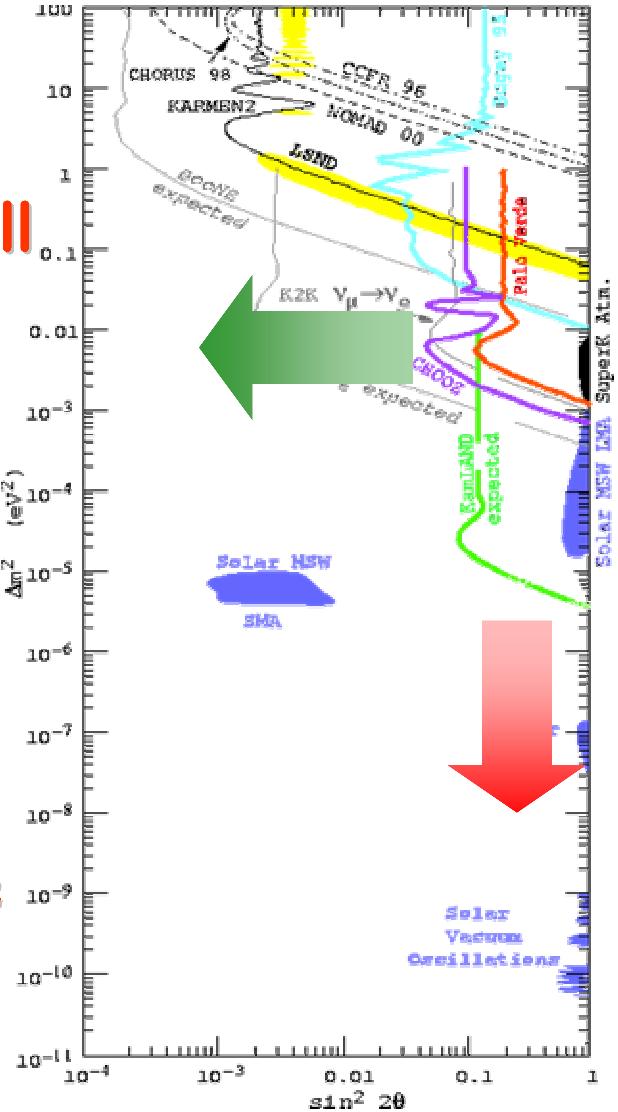
$$6\overline{\nu}_e / fission$$

A typical large power reactor produces 3 $GW_{thermal}$ and $6 \cdot 10^{20}$ antineutrinos/s



Complementary properties of Reactors and Accelerators

Reactors	Accelerators
E_ν~few MeV	E_ν~few GeV



- Can probe very small Δm^2
- Disappearance only $\rightarrow$ fair $\sin^2 2\theta$ sensitivity
- 4π source $\rightarrow$ detector mass grows with L^2

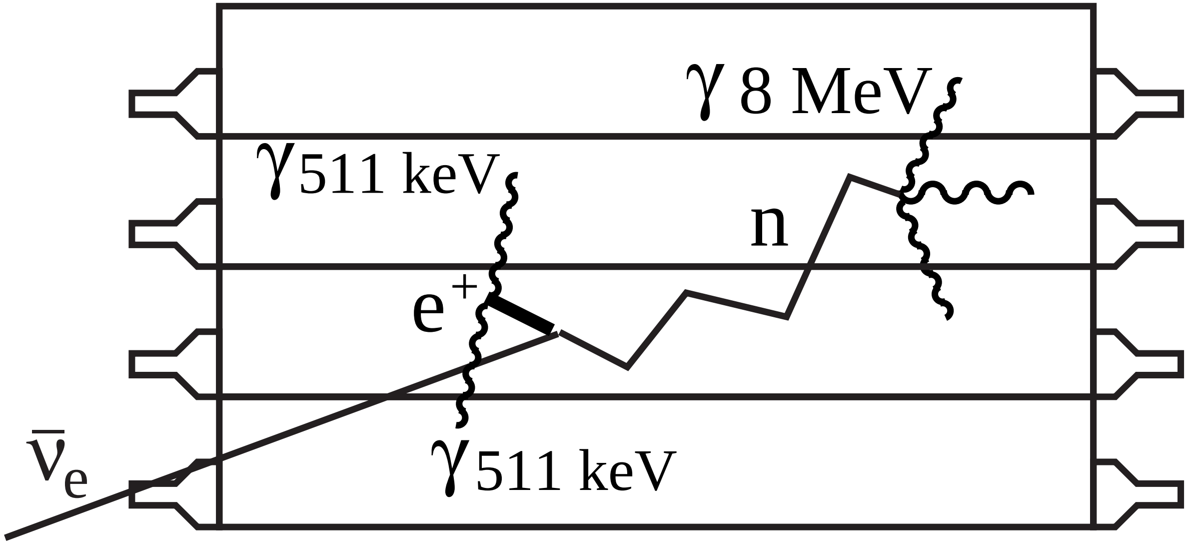
- Good mass sensitivity requires very large L
- Appearance possible (produce μ and τ)
- (More) collimated beam

Particle detection at low energy rather delicate: beware of backgrounds !

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

- Large(r) cross-section
- Specific signature

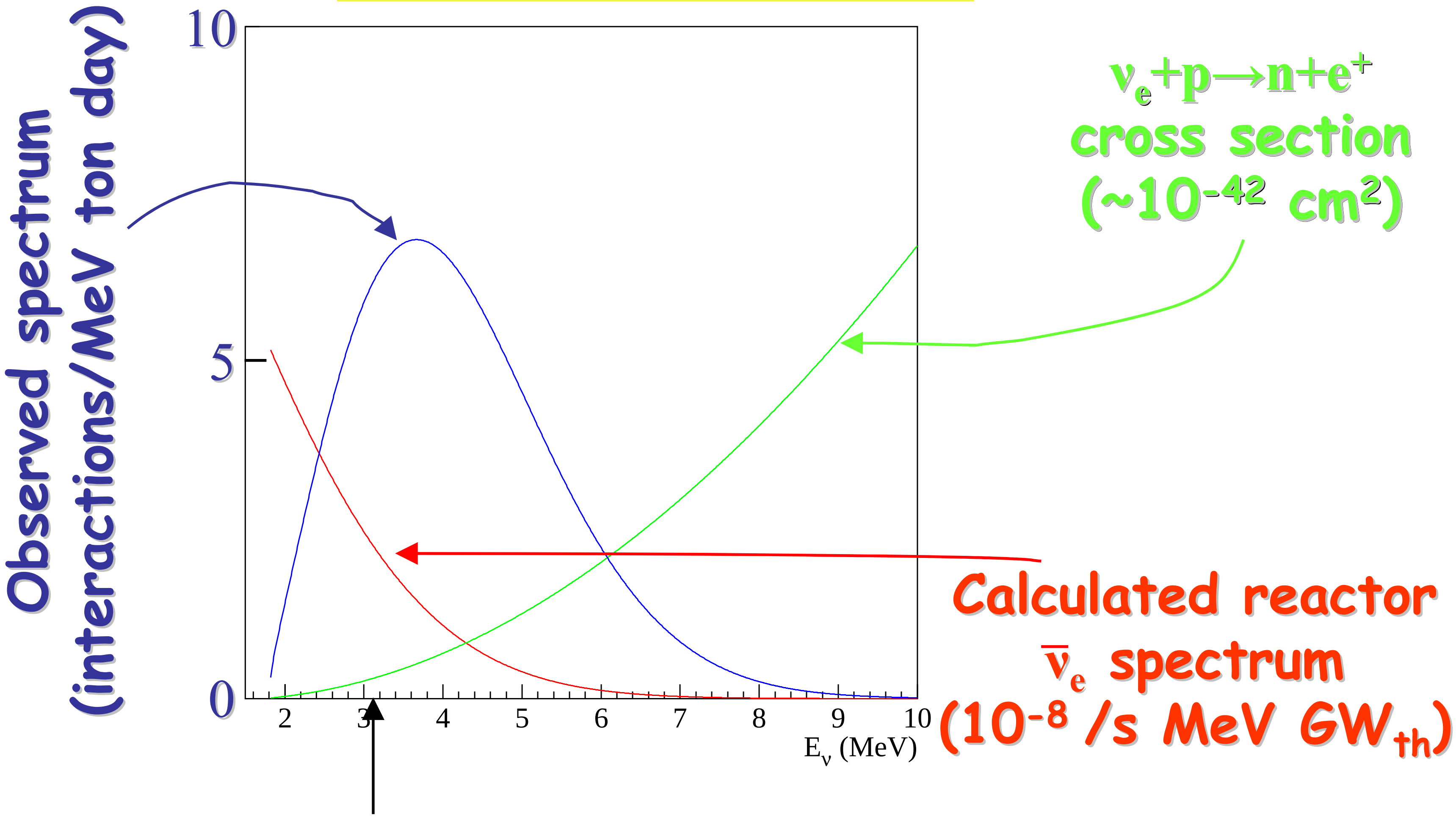
- e^+ kinetic energy (<8 MeV)
- 2 annihilation γs (0.5 MeV)
- neutron capture (2 to 8 MeV)



Neutrino energy measured from positron energy

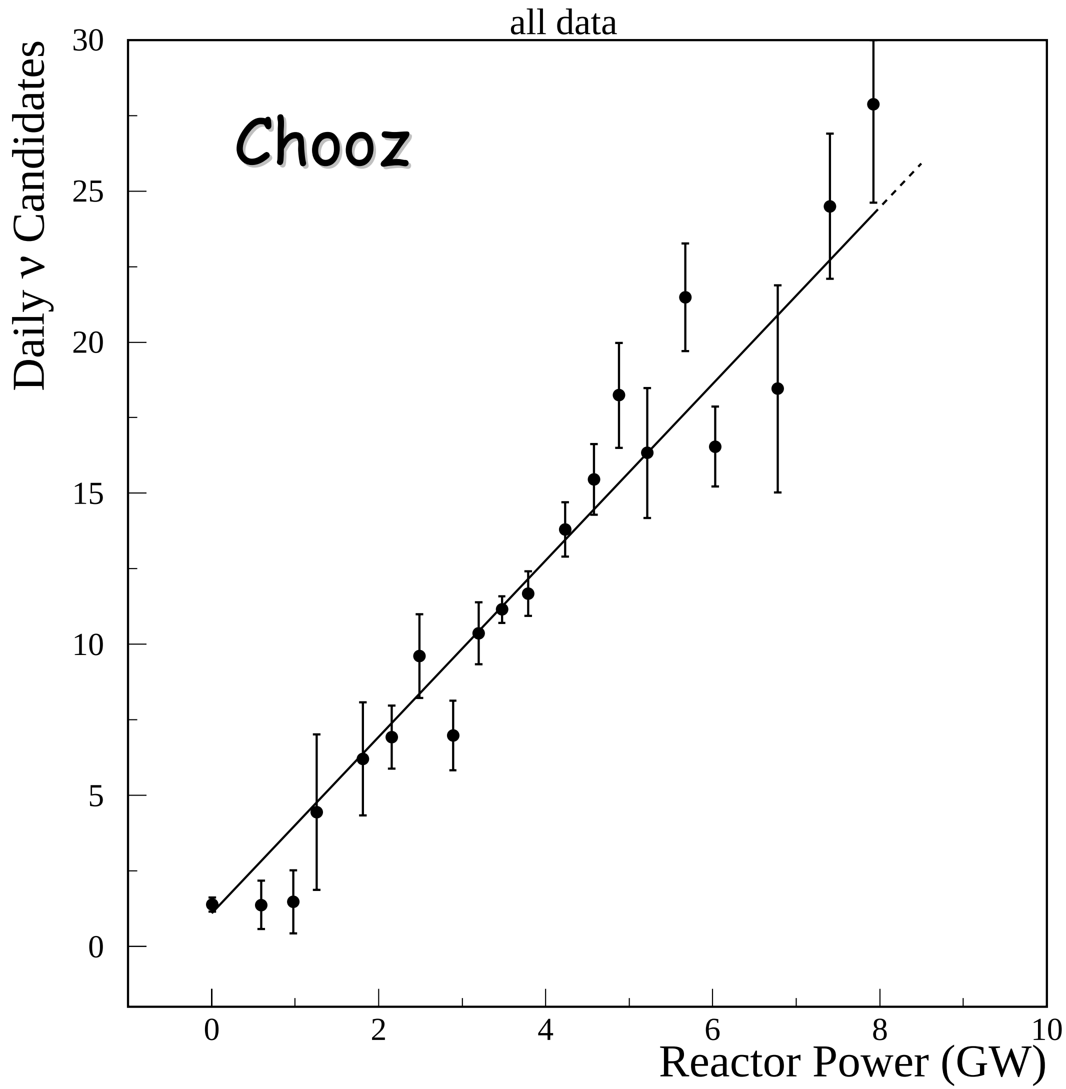
$$E_{\bar{\nu}} \cong E_{e^+} + (M_n + M_p) + m_{e^+}$$

The $\bar{\nu}_e$ energy spectrum



Neutrinos with E<1.8 MeV are not detected

The detected neutrino rate is proportional to the reactor's thermal power



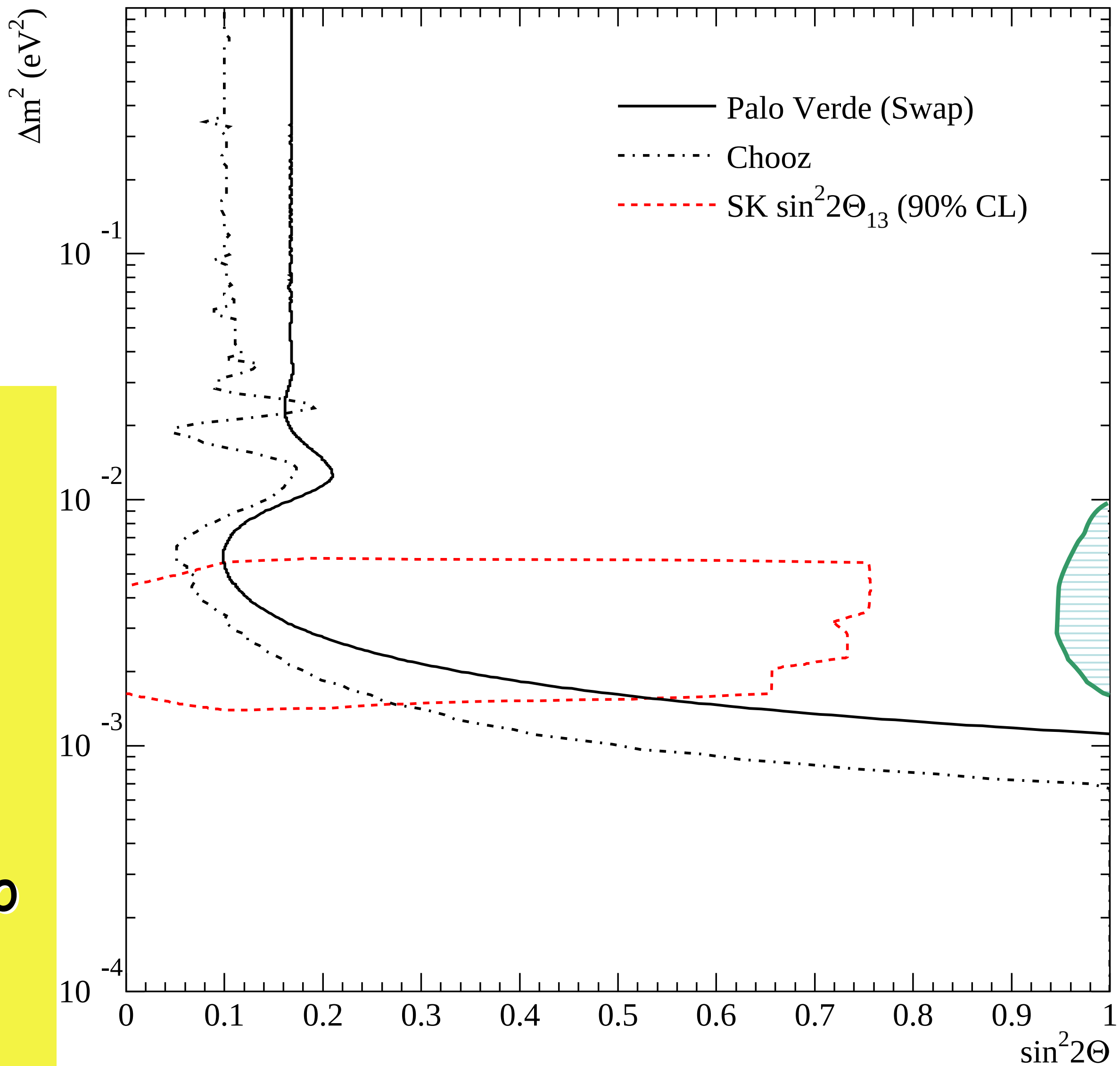
The neutrino oscillation experiment at the Palo Verde Nuclear Generating Station (AZ)

$$\frac{\text{neutrinos detected}}{\text{neutrinos expected}}$$

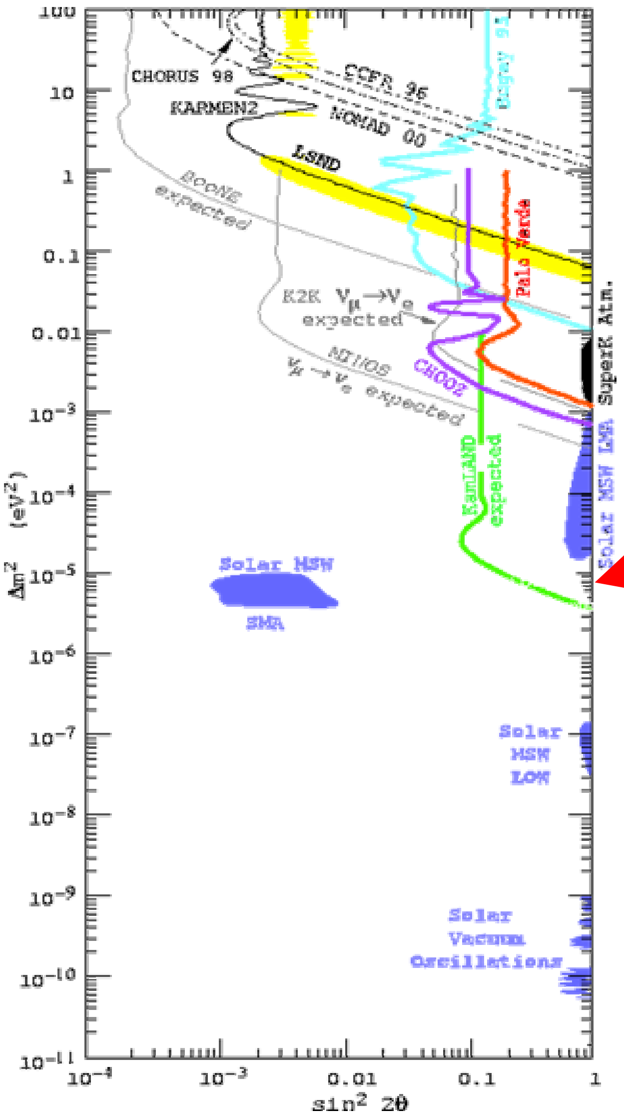
1.01±0.04 Chooz
1.04±0.08 Palo Verde

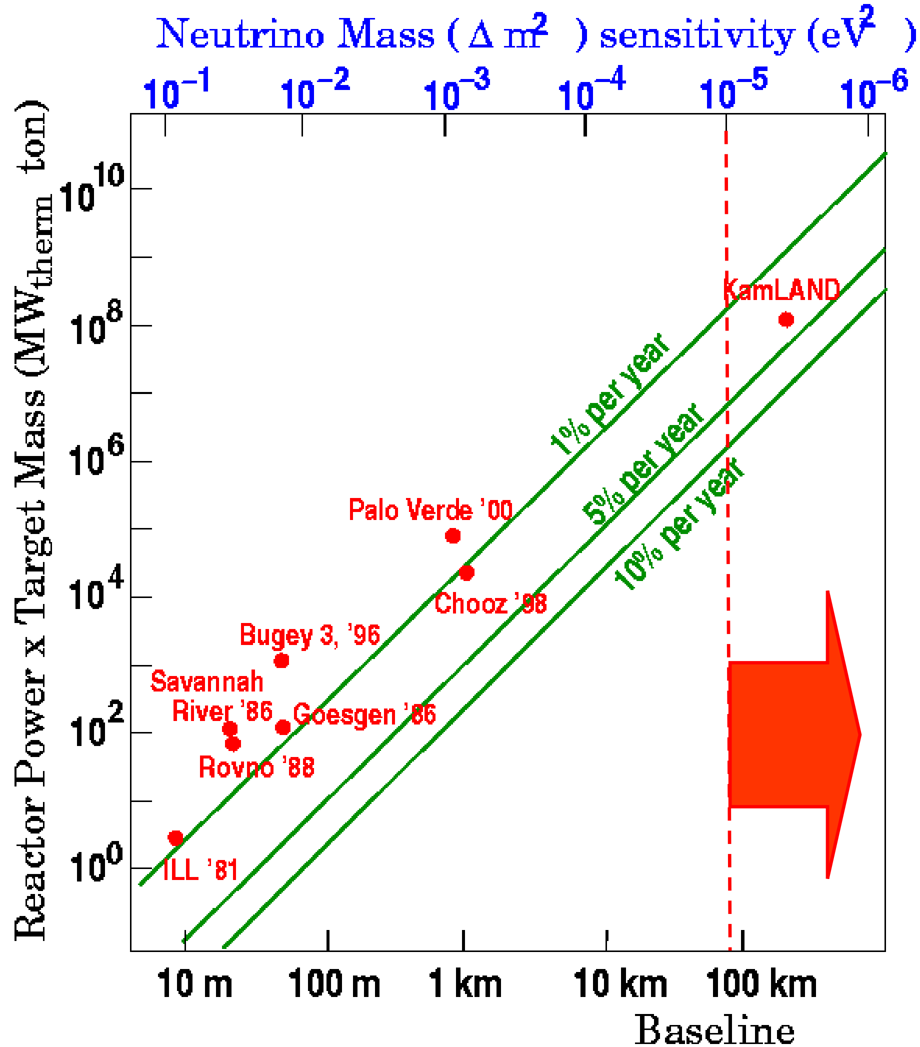
Conclusion:

Chooz and Palo Verde saw no evidence for neutrino oscillations involving ν_e down to 10^{-3} eV^2
→ Atmospheric neutrino oscillations are mainly ν_μ-ν_τ

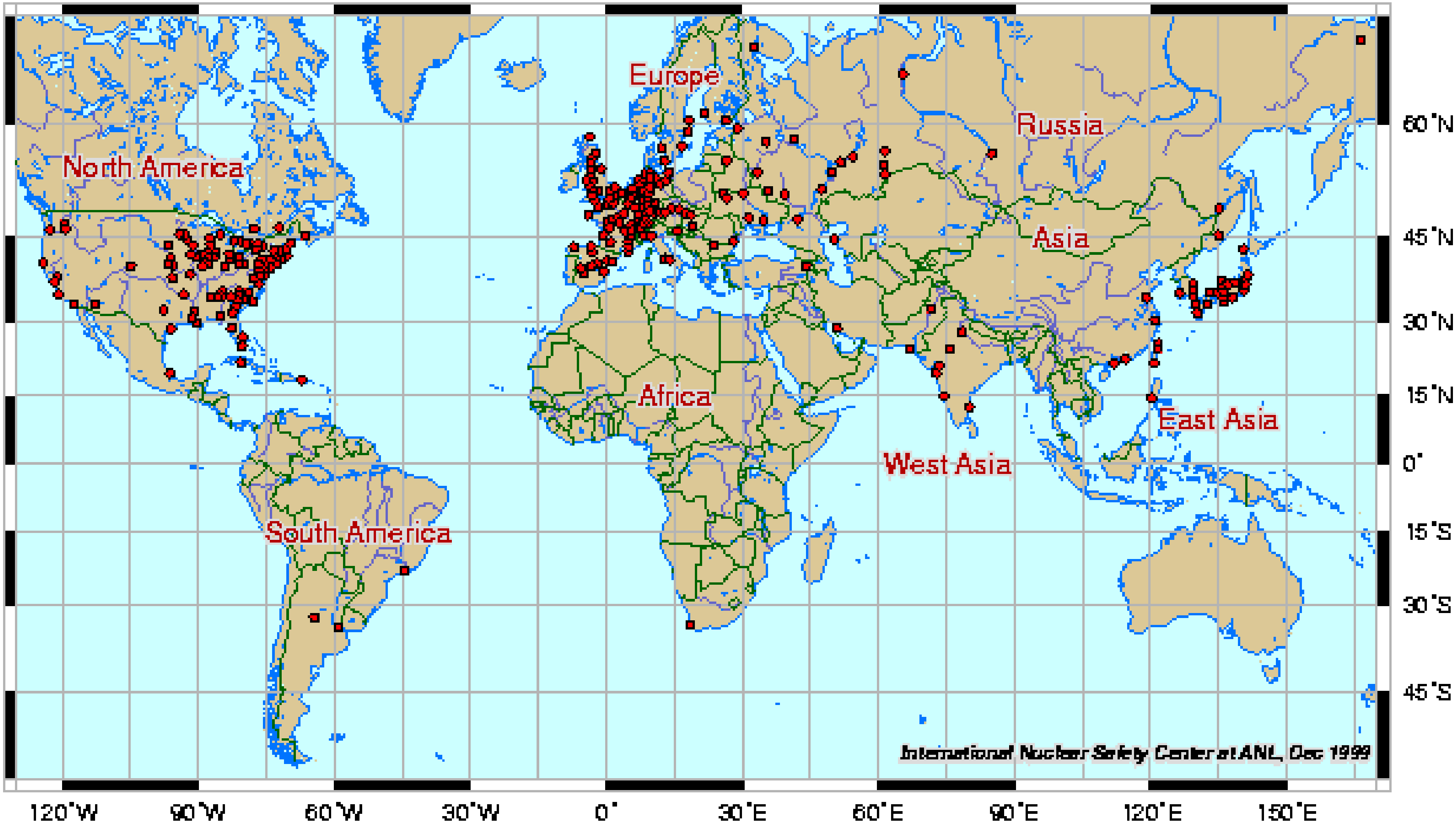


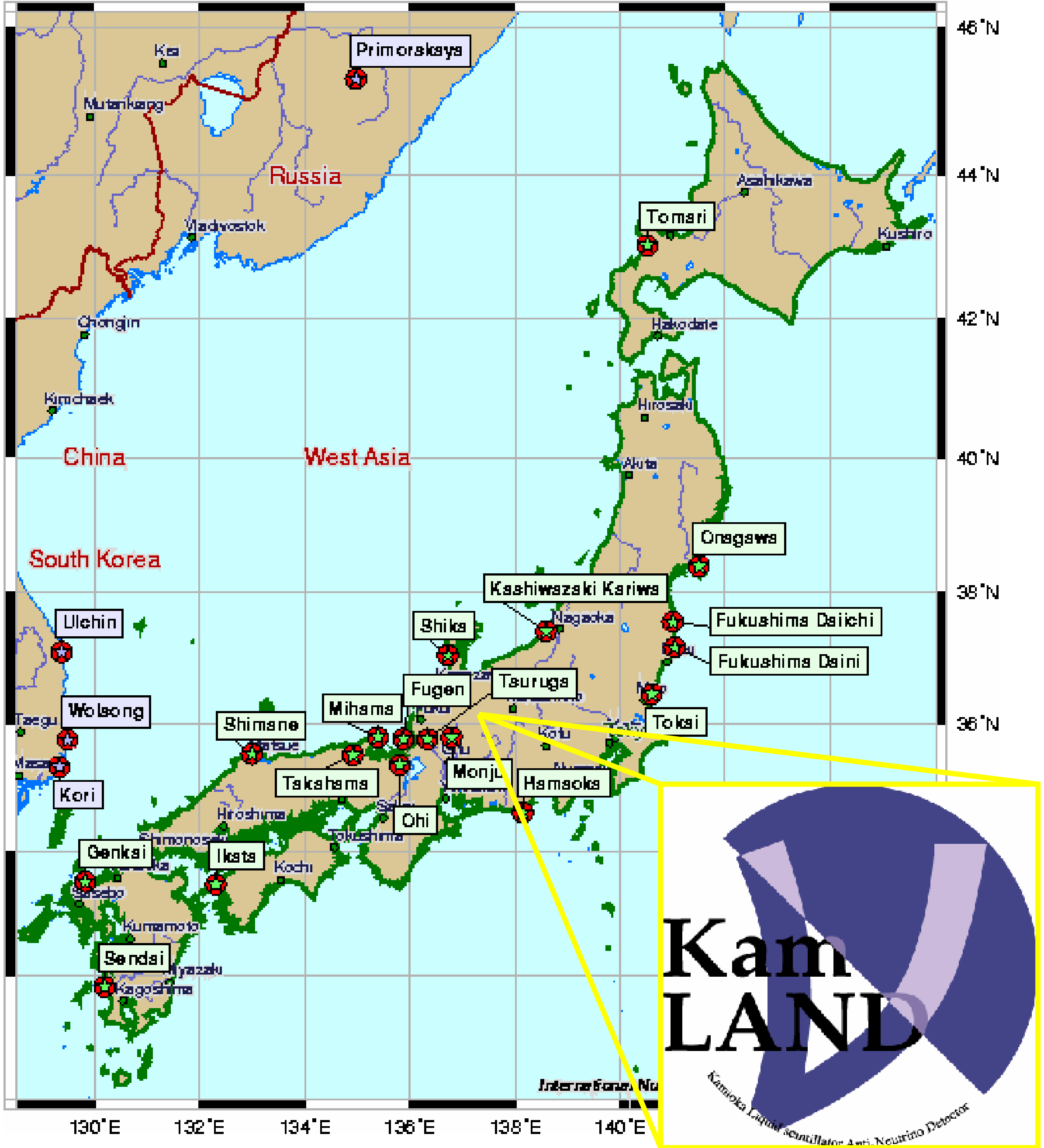
To access the region interesting for solar neutrino $\Delta m^2 < 10^{-5}$ eV^2 need >100 km baseline





Need to think regionally: large concentration of nuclear power plants exist in Europe, eastern US and Japan




Primorskaya
Russia
Tomari
Asahikawa
Kushiro
Vladivostok
Chongjin
Hakodate
Hirosaki
Akita
China
West Asia
South Korea
Onagawa
Kashiwazaki Kariwa
Nagaoka
Fukushima Daiichi
Fukushima Daini
Shika
Ulchin
Tsuruga
Fugen
Tokai
Mihama
Wolsong
Taegu
Shimane
Kori
Takahama
Monju
Hamaoka
Ohi
Hiroshima
Genkai
Ikata
Kochi
Kumamoto
Sendai
Kagoshima
Kam
LAND
Kamioka Liquid scintillator Anti-Neutrino Detector
46°N
44°N
42°N
40°N
38°N
36°N
130°E
132°E
134°E
136°E
138°E
140°E

Site	Distance	# of	P(ther.)	flux	Signal
Japan	(km)	cores	(GW)	($\bar{\nu}$ cm^{-2}s^{-1})	($\bar{\nu}$/yr)
Kashiwazaki	160.0	7	24.6	4.25×10^{5}	348.1
Ohi	179.5	4	13.7	$1.88\text{X}10^{5}$	154.0
Takahama	190.6	4	10.2	1.24×10^{5}	101.8
Hamaoka	214.0	4	10.6	1.03×10^{5}	84.1
Tsuruga	138.6	2	4.5	1.03×10^{5}	84.7
Shiga	80.6	1	1.6	1.08×10^{5}	88.8
Mihama	145.4	3	4.9	1.03×10^{5}	84.5
Fukushima–1	344.0	6	14.2	5.3×10^{4}	43.5
Fukushima–2	344.0	4	13.2	4.9×10^{4}	40.3
Tokai–II	294.6	1	3.3	1.7×10^{4}	13.7
Shimane	414.0	2	3.8	9.9×10^{3}	8.1
Onagawa	430.2	2	4.8	9.8×10^{3}	8.1
Ikata	561.2	3	6.0	8.4×10^{3}	6.9
Genkai	755.4	4	6.7	5.3×10^{3}	4.3
Sendai	824.1	2	3.3	3.5×10^{3}	2.8
Tomari	783.5	2	5.3	2.4×10^{3}	2.0
Korea					
Ulchin	~750	4	11.2	8.8×10^{3}	7.2
Wolsong	~690	4	8.1	7.5×10^{3}	5.2
Yonggwang	~940	6	16.8	8.4×10^{3}	6.9
Kori	~700	4	8.9	8.0×10^{3}	6.6
Total		69	175.7	1.34×10^{6}	1102

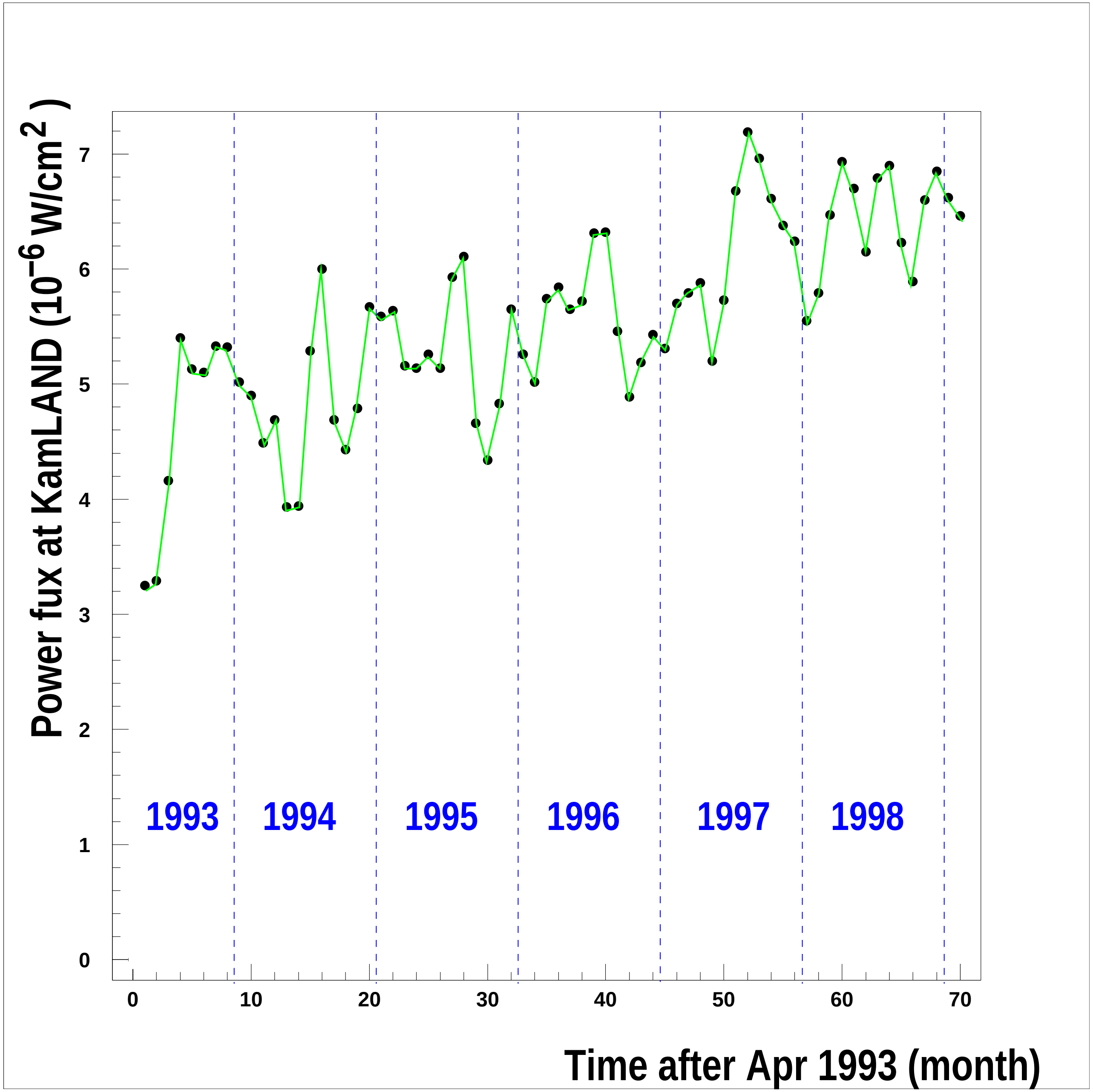
Total expected signal from reactors: ≈2 ev/day

S/N ratio ≈ 20 @ 10^{-14} U, Th, ^{40}K contamination in the scintillator

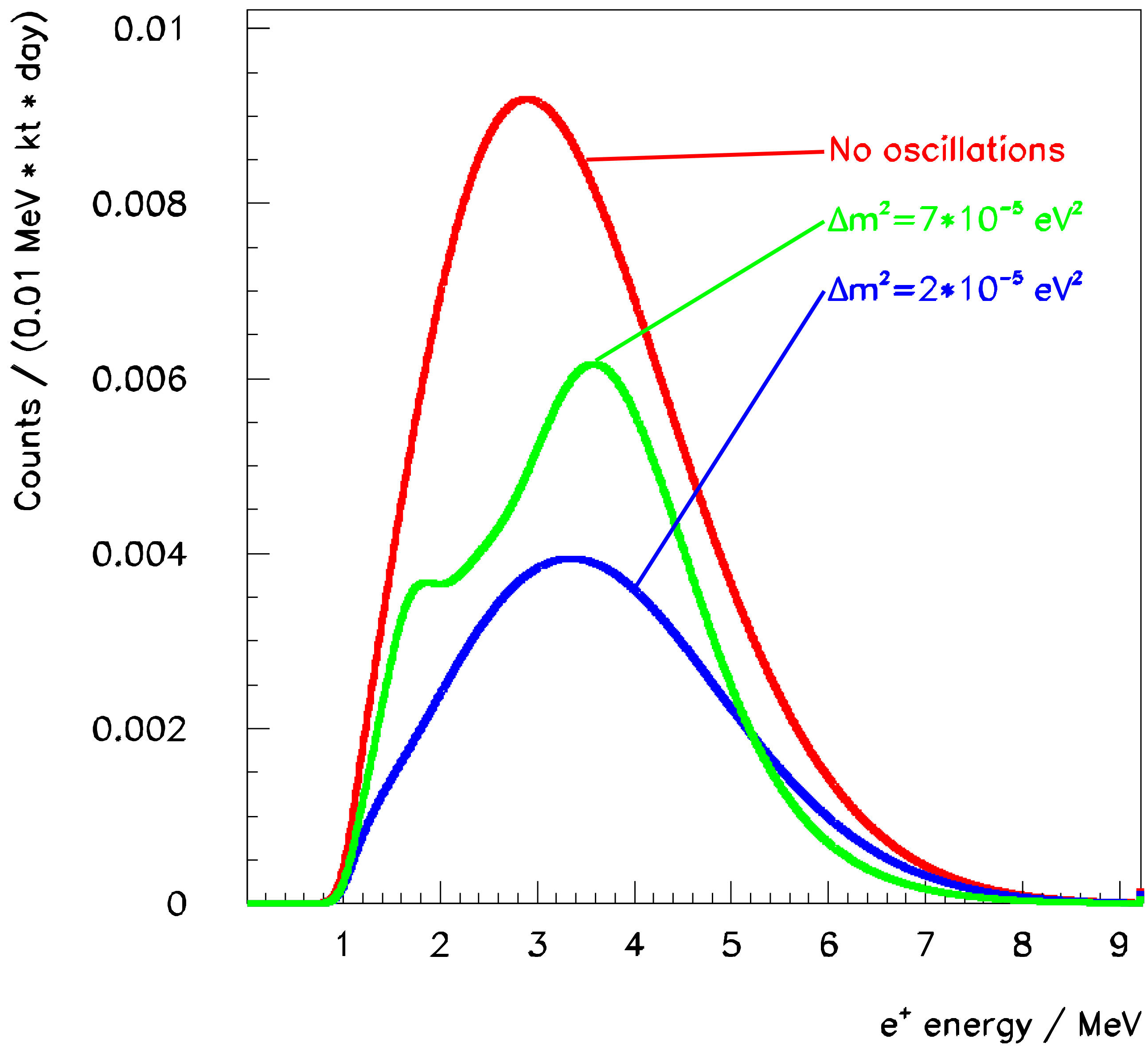
Baseline is limited: 85.3% of signal has 140 km < L < 344 km

The total electric power produced "as a by-product" of the νs is:

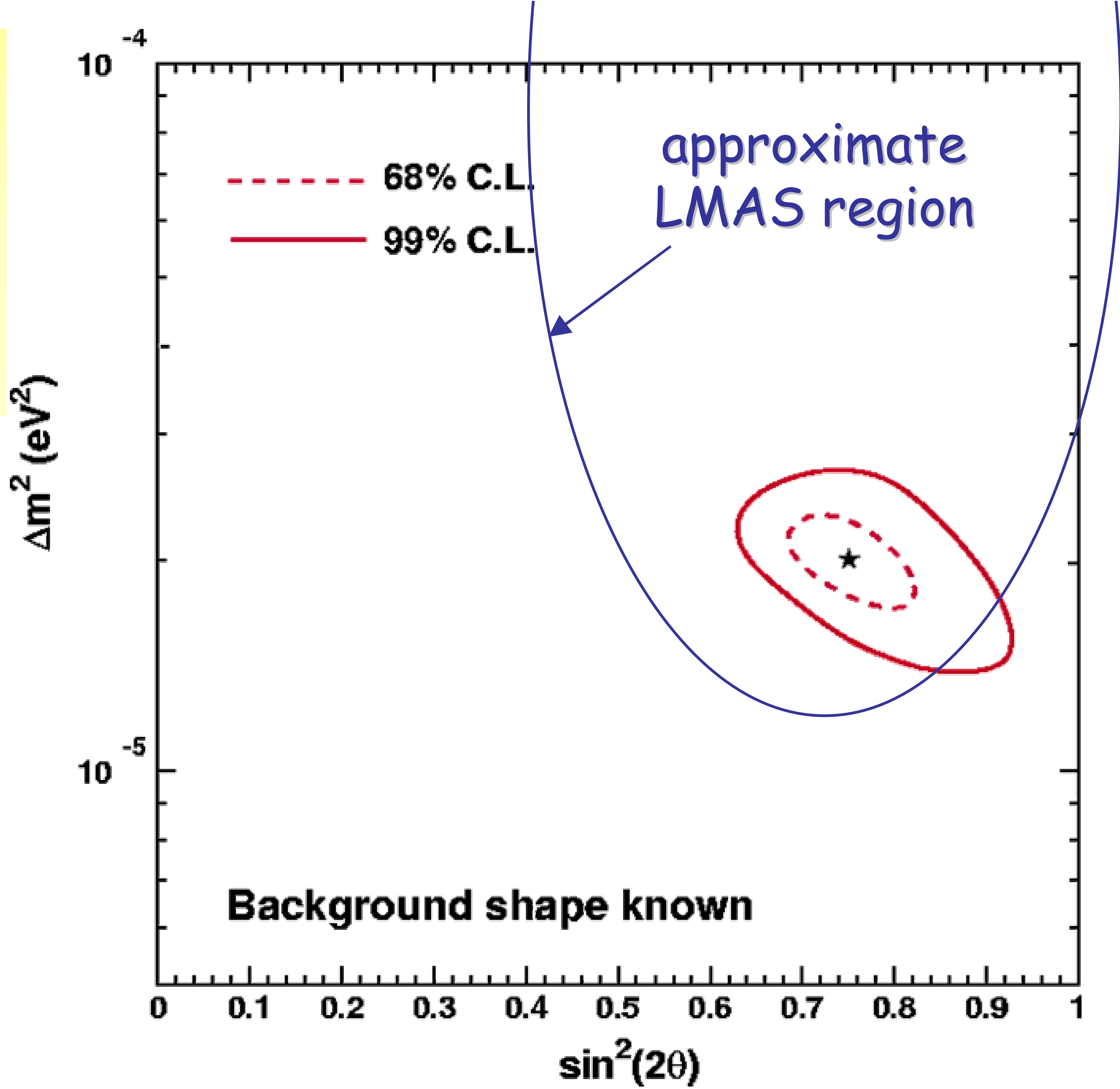
- ~60 GW or...
- ~4% of the world's manmade power or…
- ~20% of the world's nuclear power


Power fux at KamLAND (10^{-6} W/cm^2)
Time after Apr 1993 (month)
1993
1994
1995
1996
1997
1998
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
70

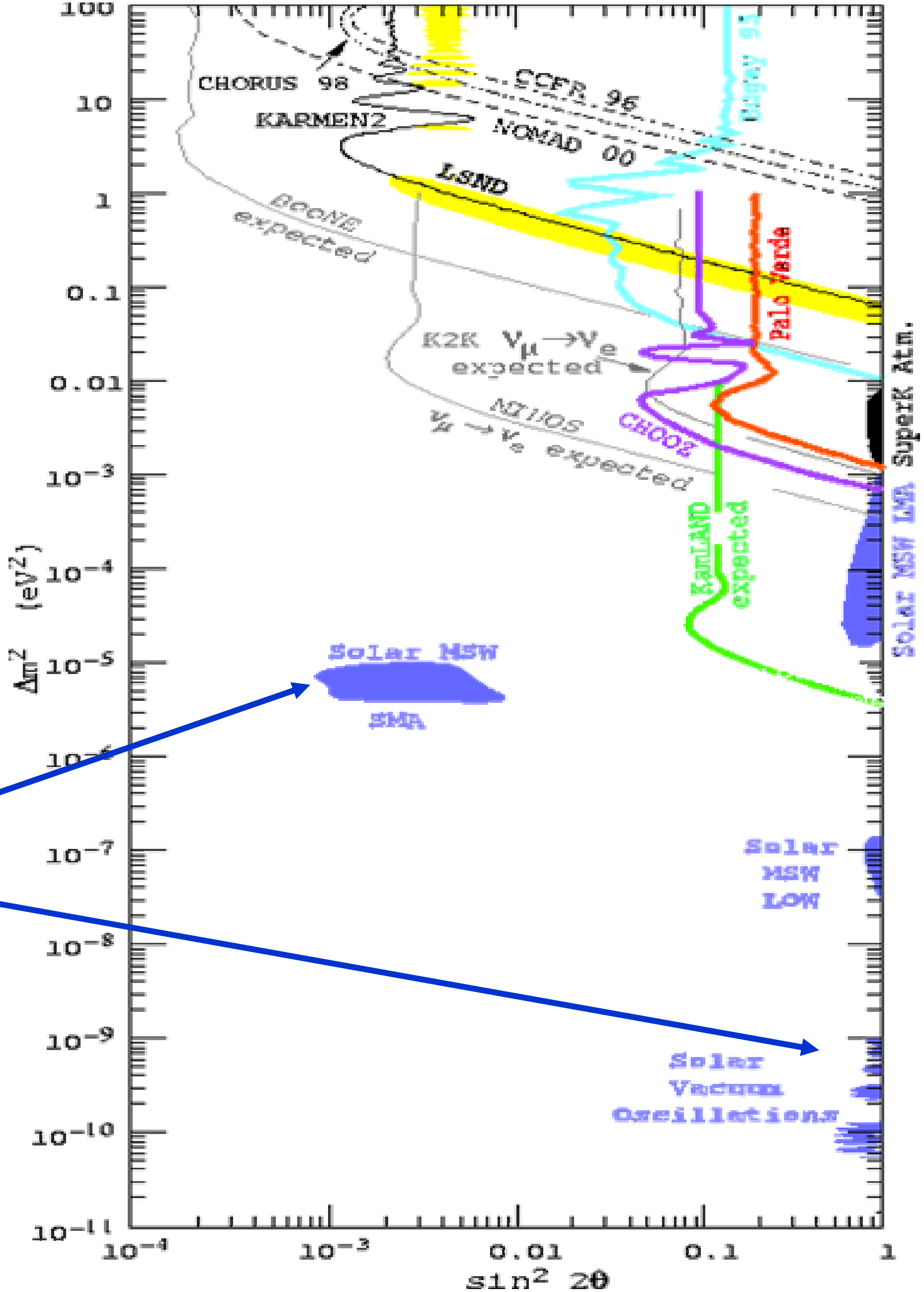
Neutrino oscillations in KamLAND could result in distortion of the energy spectrum along with a deficit of detected events



...if oscillations are detected very accurate measurement possible !



KamLAND has a real chance of observing oscillations in the LMA-MSW regime !!



Mostly ruled out By most recent SNO result

Since reactors produce $\bar{\nu}_e$ while the sun produces ν_e the equivalence of solar neutrino oscillations with what can be observed with the KamLAND reactor experiment rests on the validity of CPT (see B. Kayser's talk)

An unexpected oscillation pattern in KamLAND could be an indication of CPT violation

Other physics topics include:

- Terrestrial neutrinos
- Supernovae
- Solar anti-neutrinos
- Exotic nucleon decay modes

In addition KamLAND is a *scalable* detector

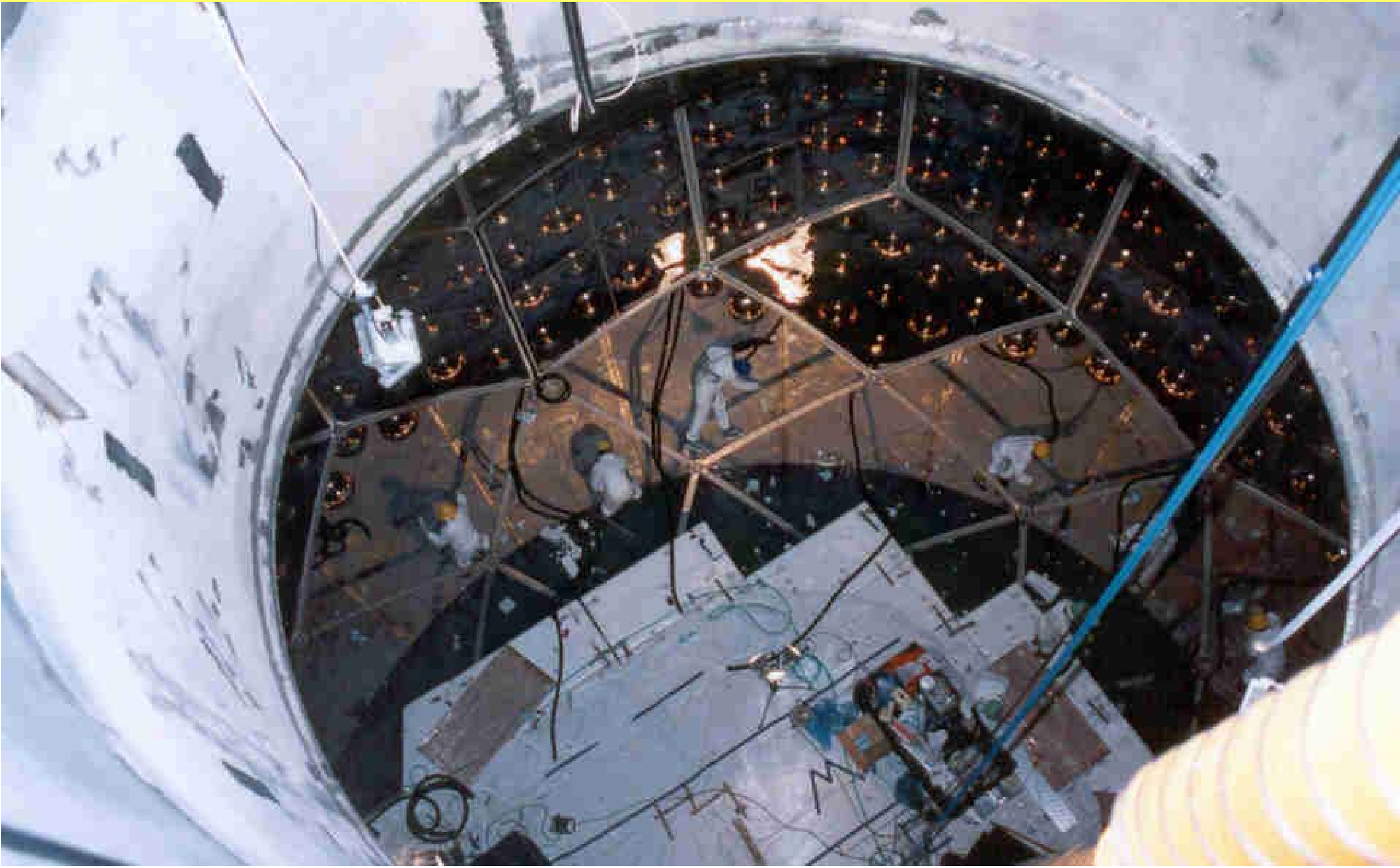
A possible future physics topic is the detection of Be^7 neutrinos from the sun… if backgrounds will allow this

Every effort has been made to preserve this possibility and during reactor neutrino running we will learn how large backgrounds for singles are

KamLAND construction timeline

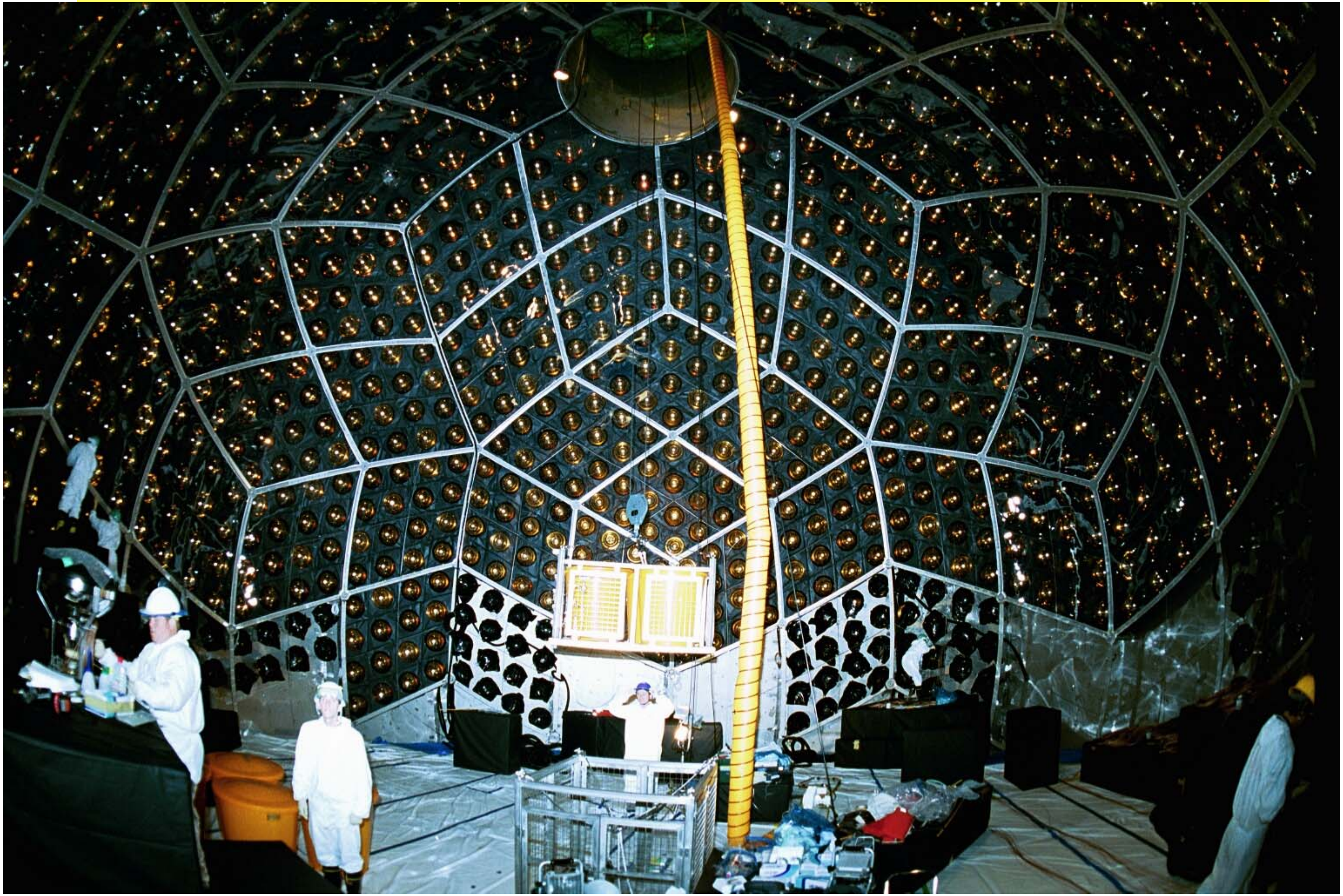
•Summer 2000	PMT installation
•Winter 2000-01	Veto counter installation
•Feb 2001	Balloon insertion
•Mar-Apr 2001	Balloon inflation and test
•Apr-May 2001	Plumbing for fill
•Jun-Sept 2001	Fill MO and LS
•Aug-Sept 2001	Eng. runs with Macro Elec.
•Sept 2001	FEE/DAQ/Trigger int. (LBL)
•end Sept 2001	First data taking with FEE
•Jan 22, 2002	Begin Data Taking

Cleaning the KamLAND sphere (Summer 2000)

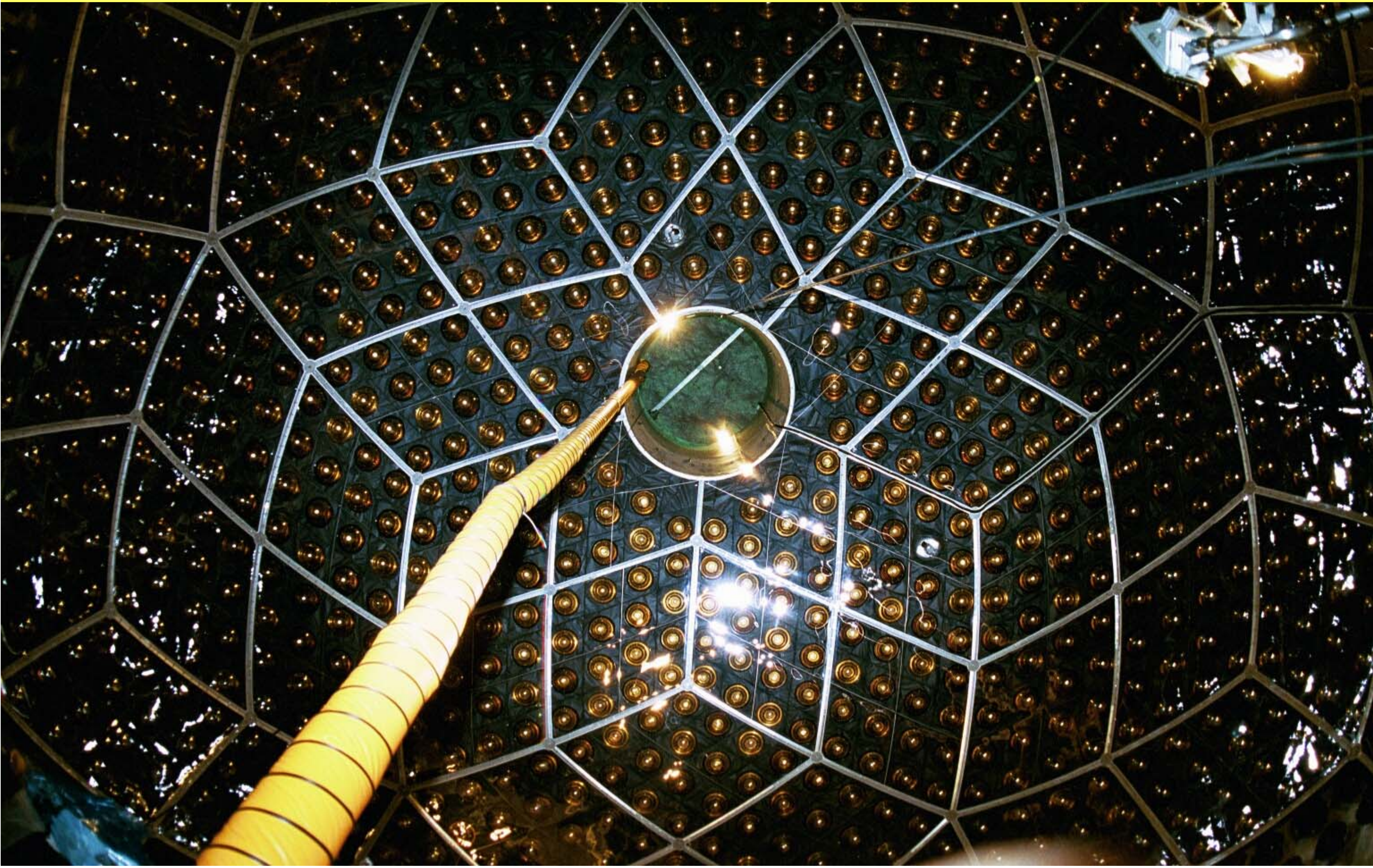


Installing 17" and 20" PMTs in KamLAND (Summer 2000)

KamLANDers hard at work (Summer 2000)

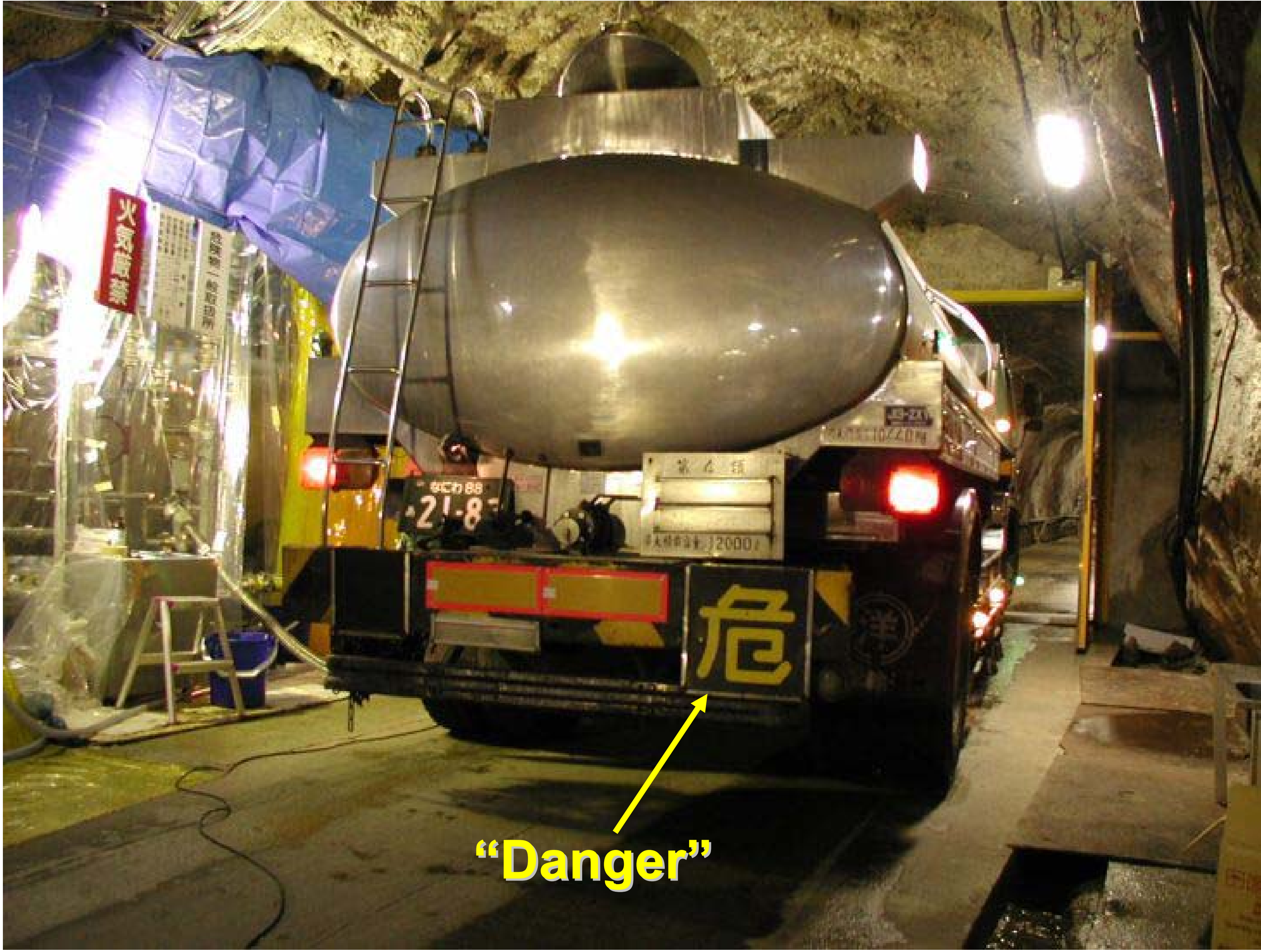


The completed detector, looking up



Balloon installed (Apr 2001)

Receiving a paraffine load in the mine

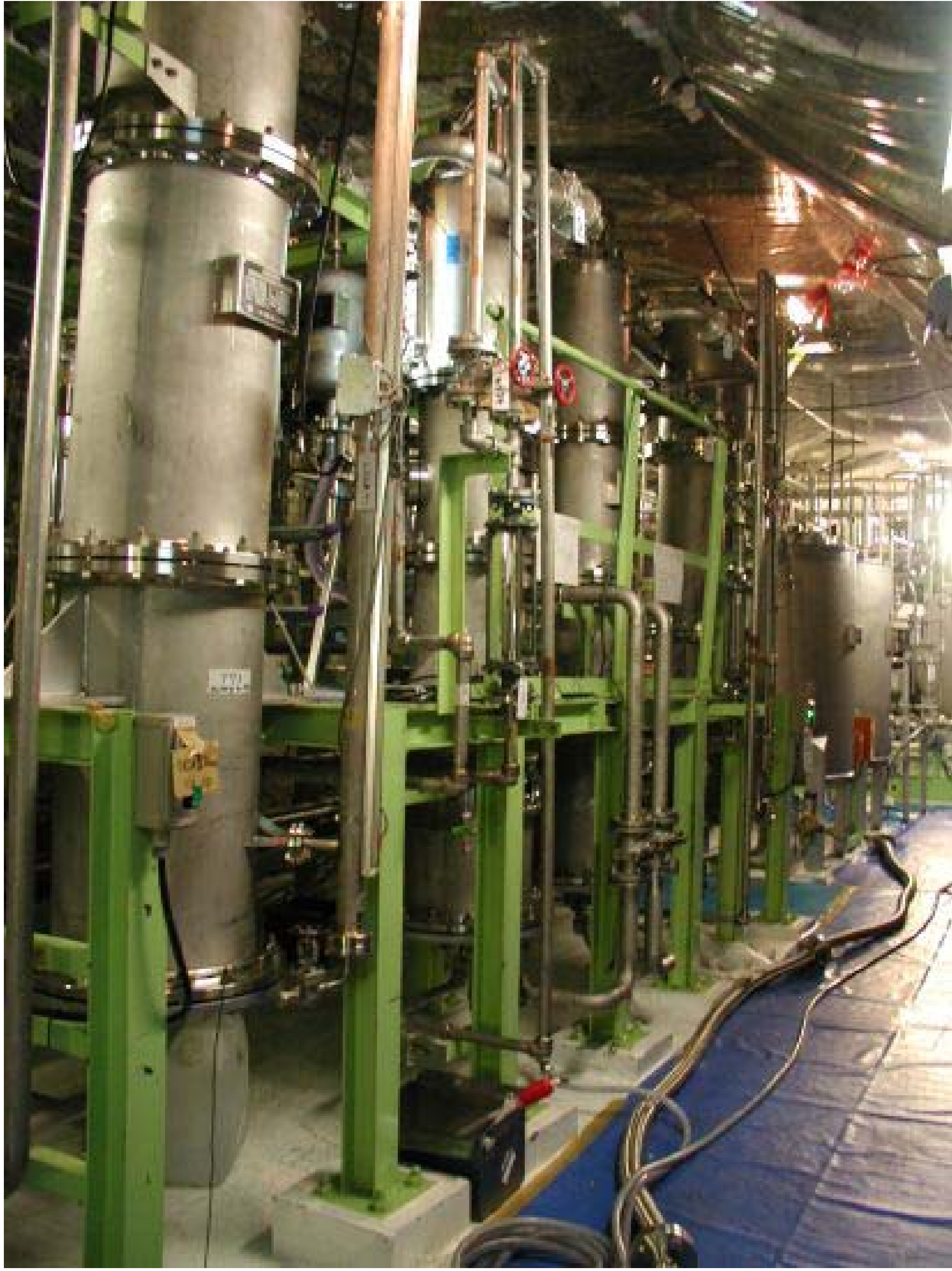


Scintillator is a blend of 20% pseudocumene and 80% paraffine oil.

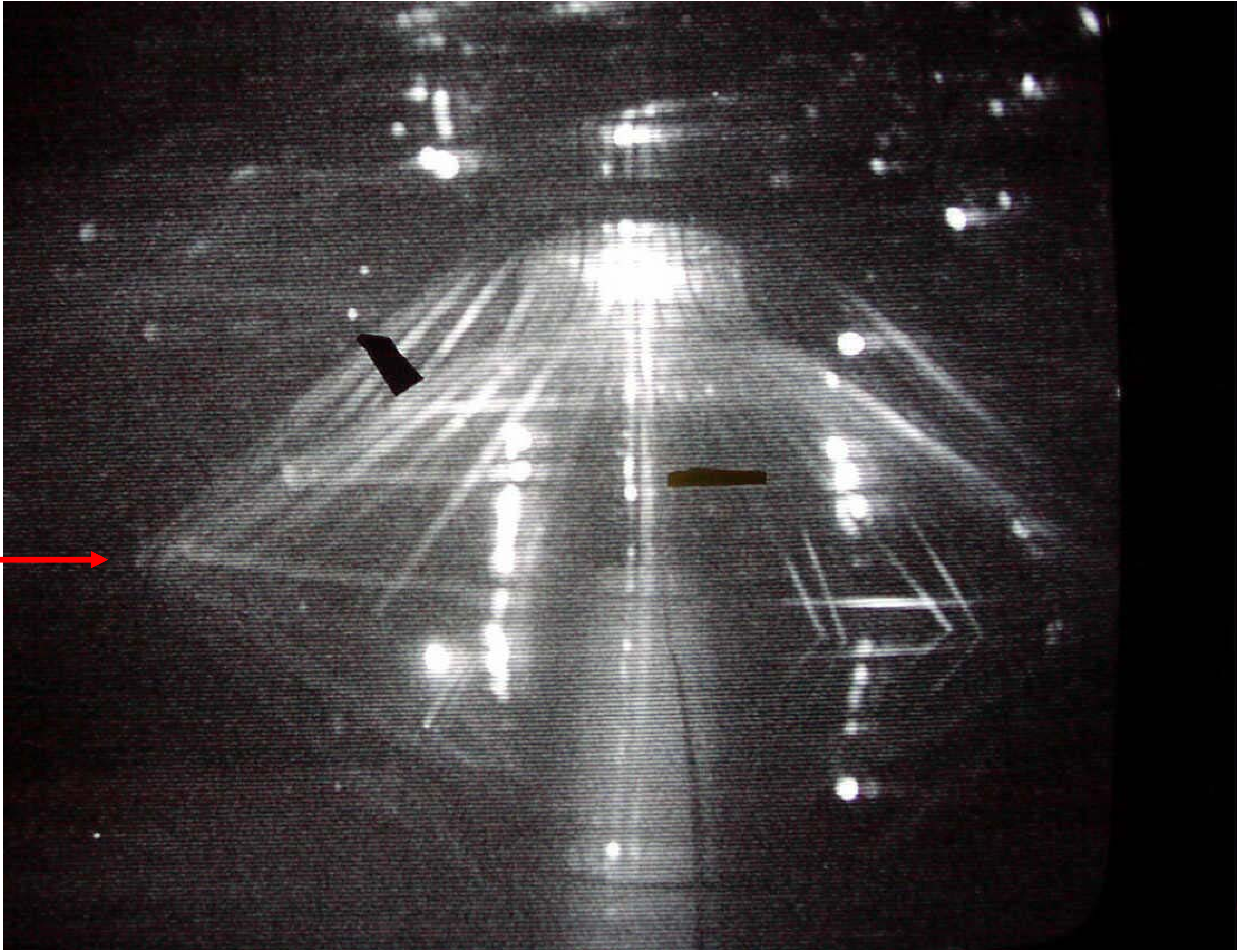
Different density paraffines are used to obtain the same density inside and out of the balloon.

PPO concentration is 1.5 g/l of the final blend.

During blending the liquids are pre-purified.

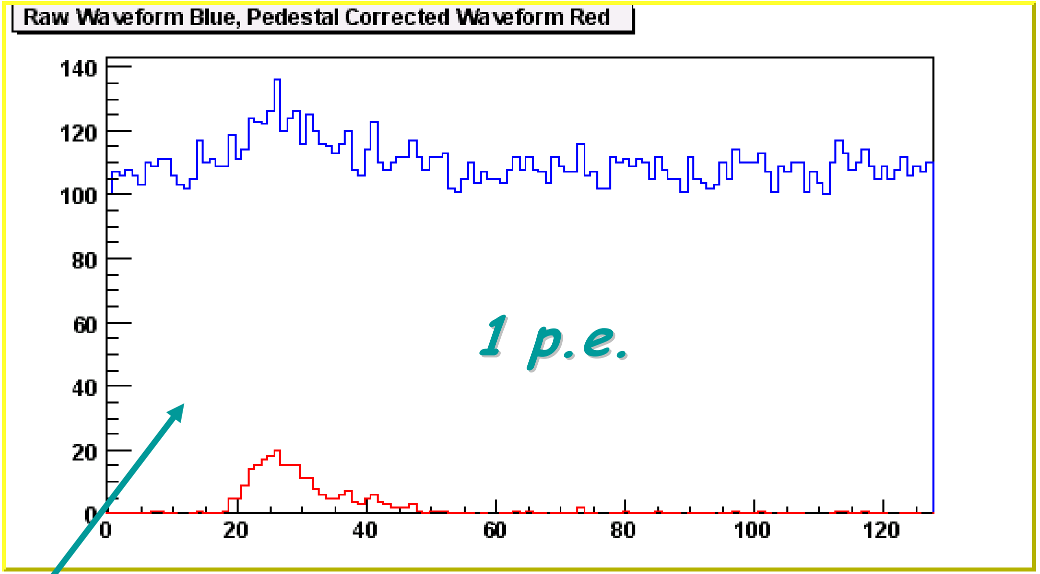


Liquid level in KamLAND on Sept 11, 01

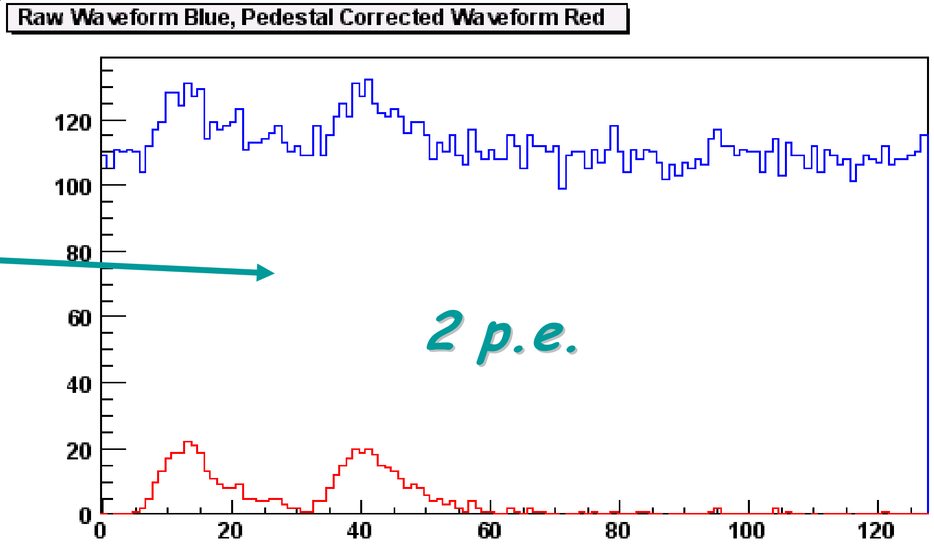


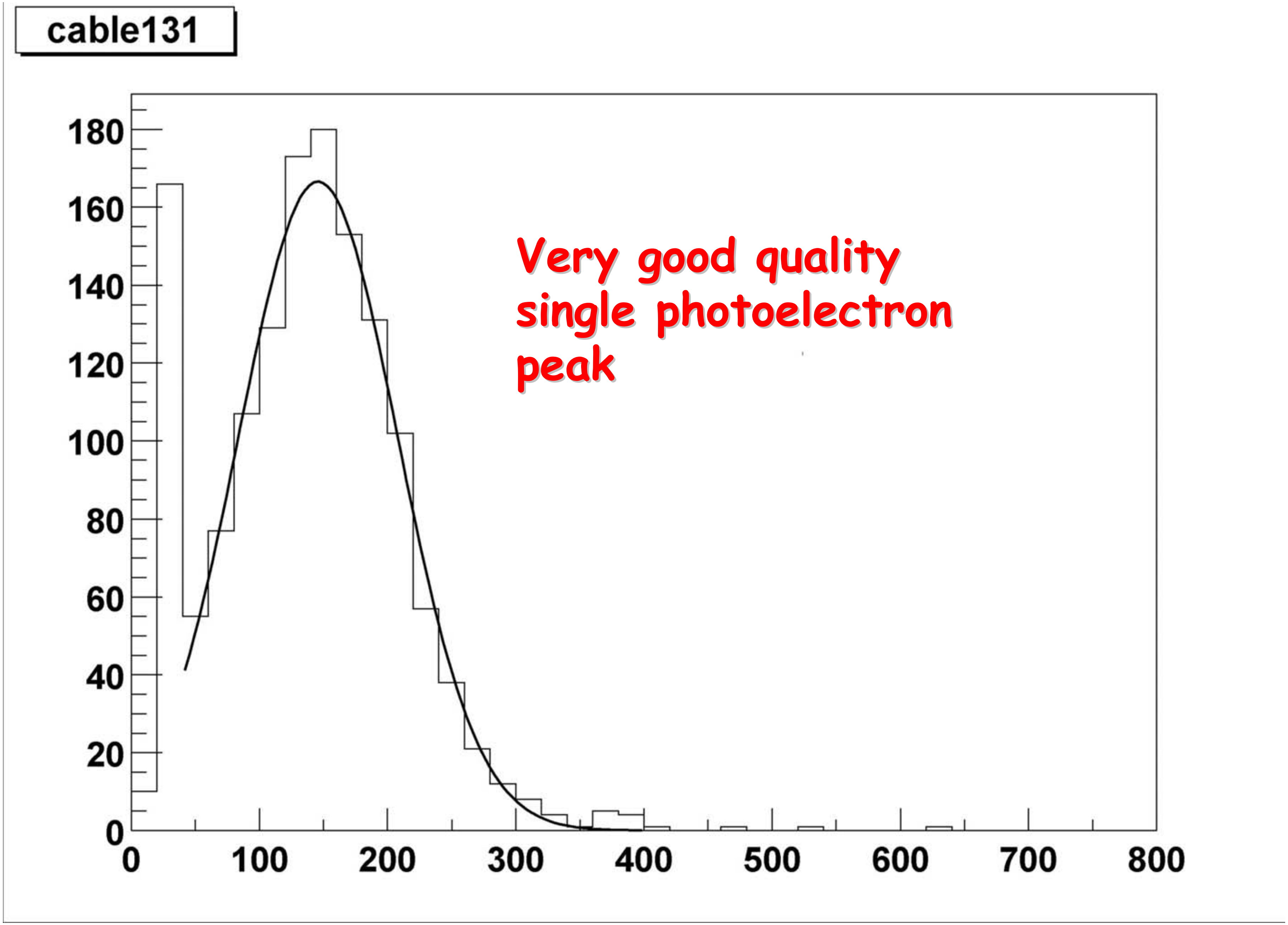
Have full waveform digitizers on every central and veto channel

Very important for exploring new physics and reject complex background signatures



Signals from blue LED flashers in the detector



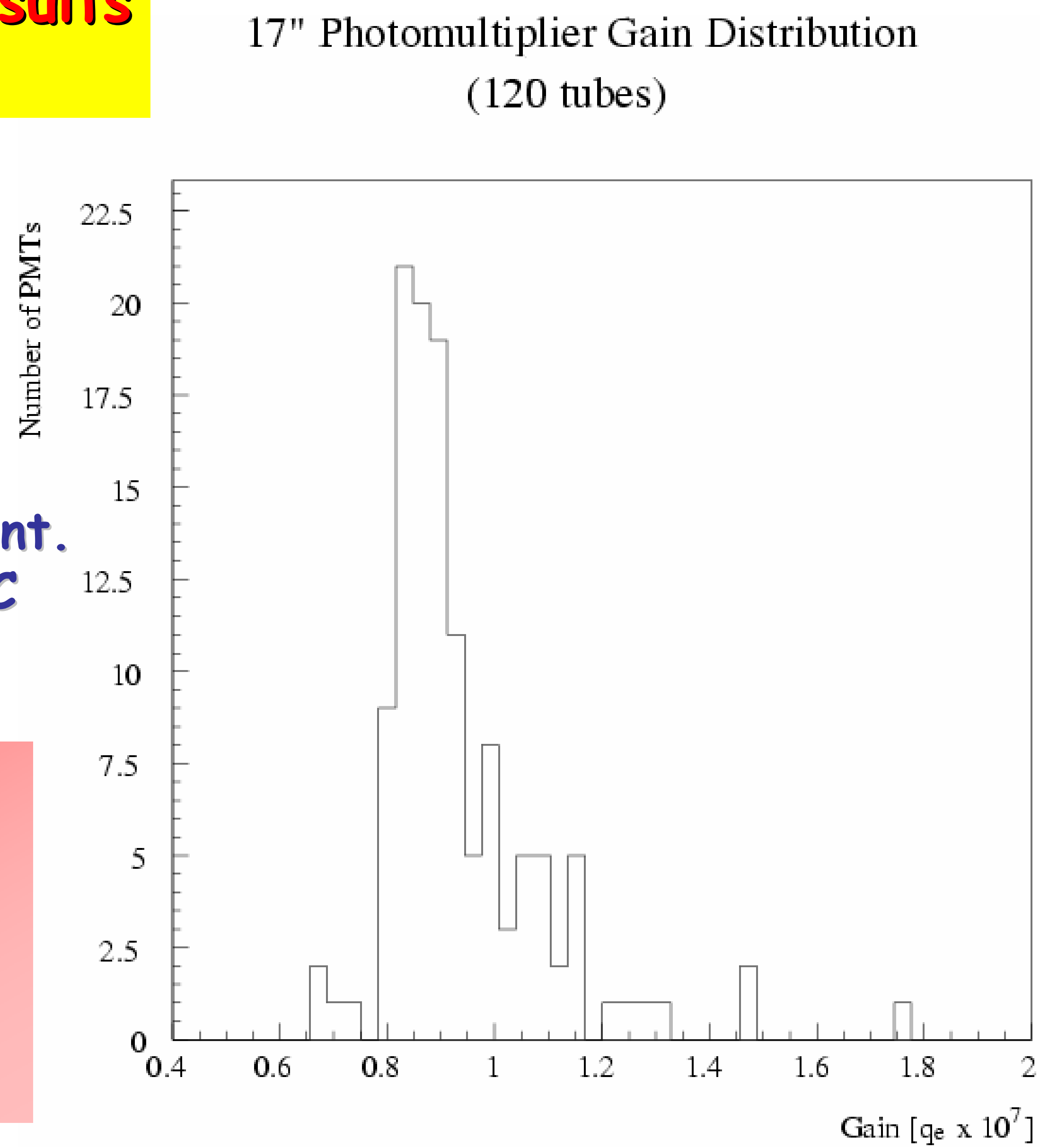

cable131
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Very good quality
single photoelectron
peak

Initial 17" PMTs gain results using s.p.e.

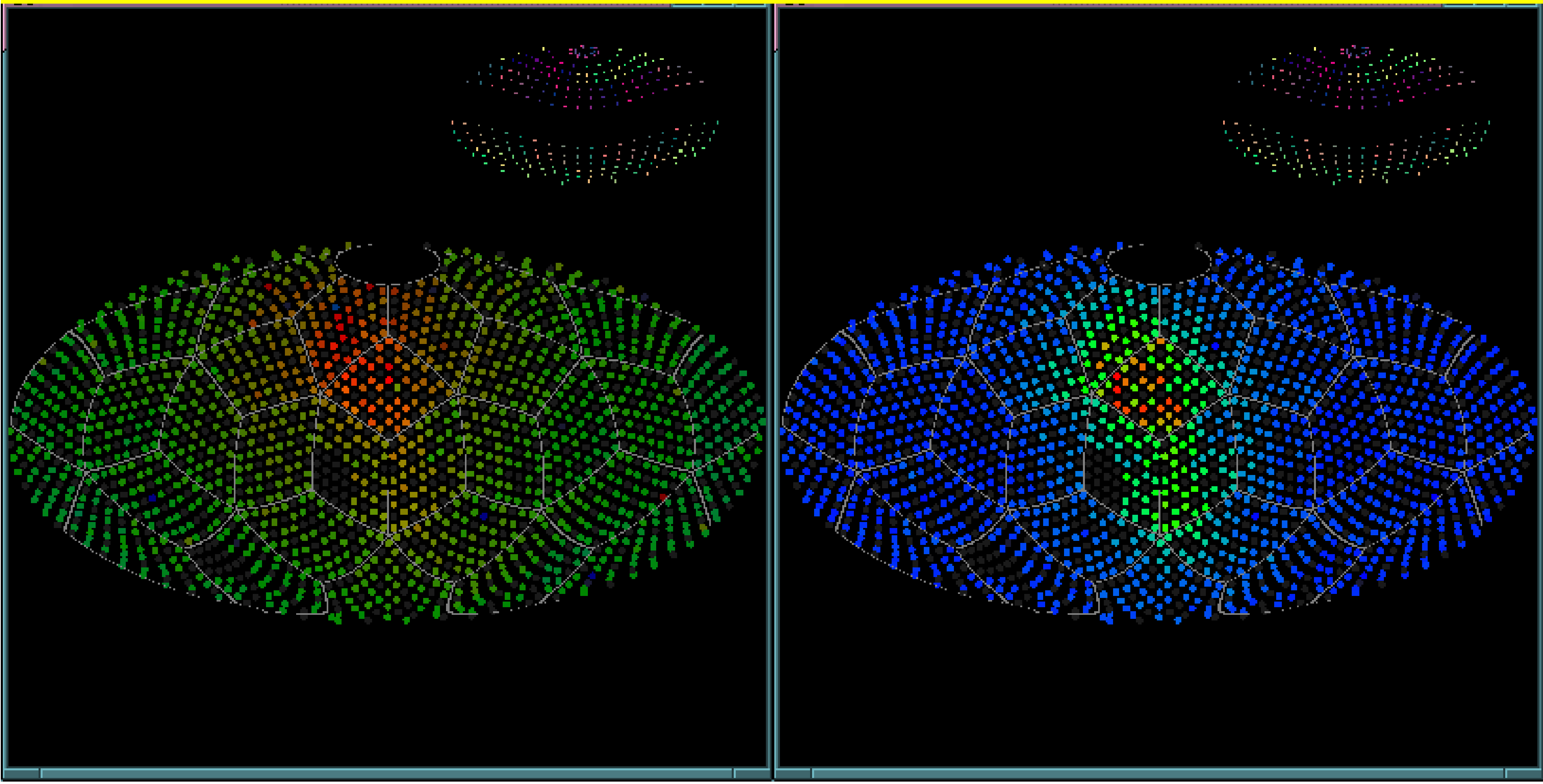
Gain peaks ~$0.9*10^7$

10% low respect to the calibration done in Sendai
⇒ reasonable:
temp = 20C Sendai
10C in the scint.
CuBe dy tempco ~ -0.001/C
for 11 dy 9.99^{11} = 0.89

First run using the magfield comp. coils: good comp. (earth magfield effect up to 50%)



So… what does an event look like ?

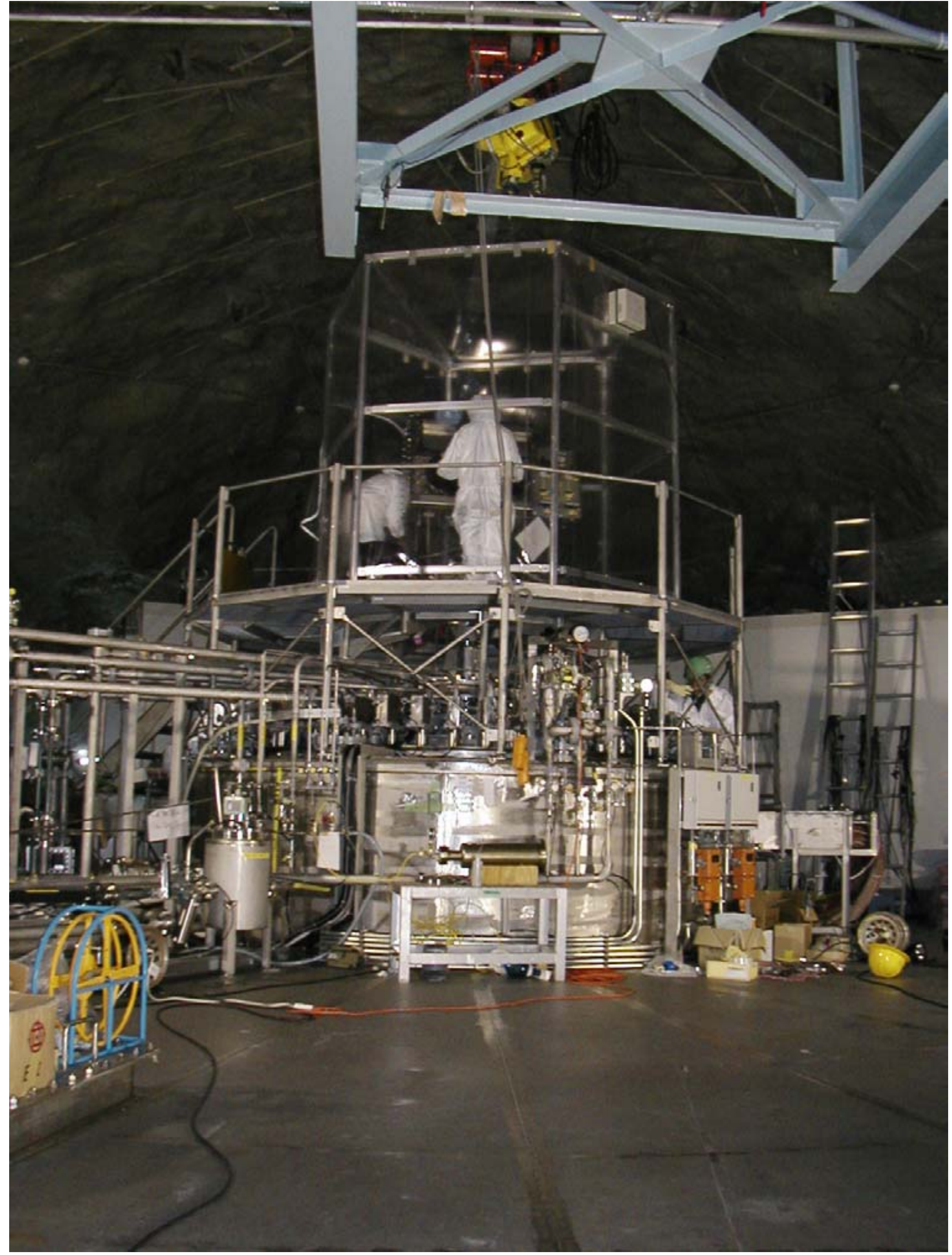


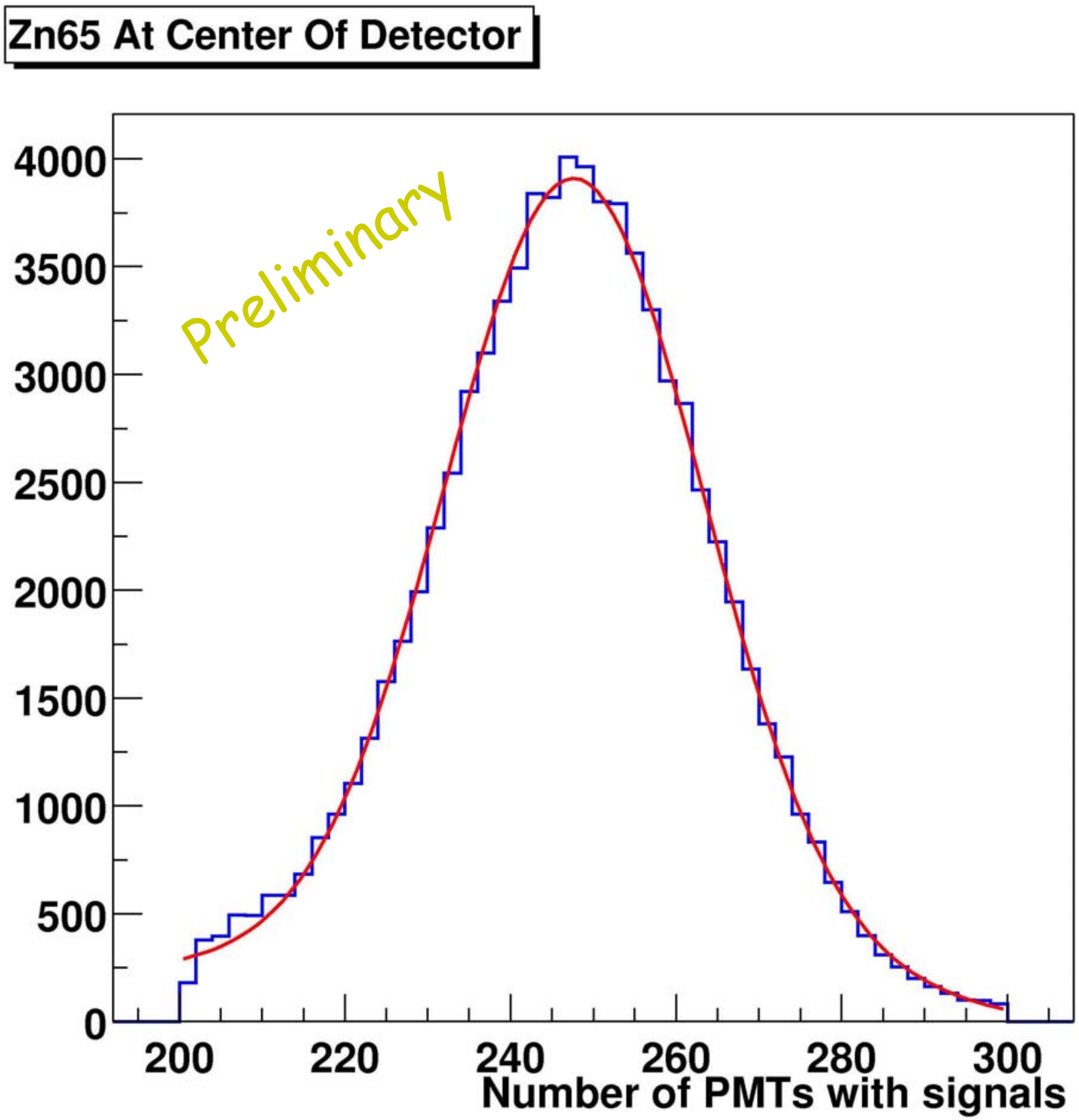
Time: Red soon, Blue late

Charge: Red alot, Blue little

Radioactive and other sources can be inserted in the central detector using a special access port in the chimney normally closed by a set of gate valves

A glove box inside a clean room is used to perform this operation

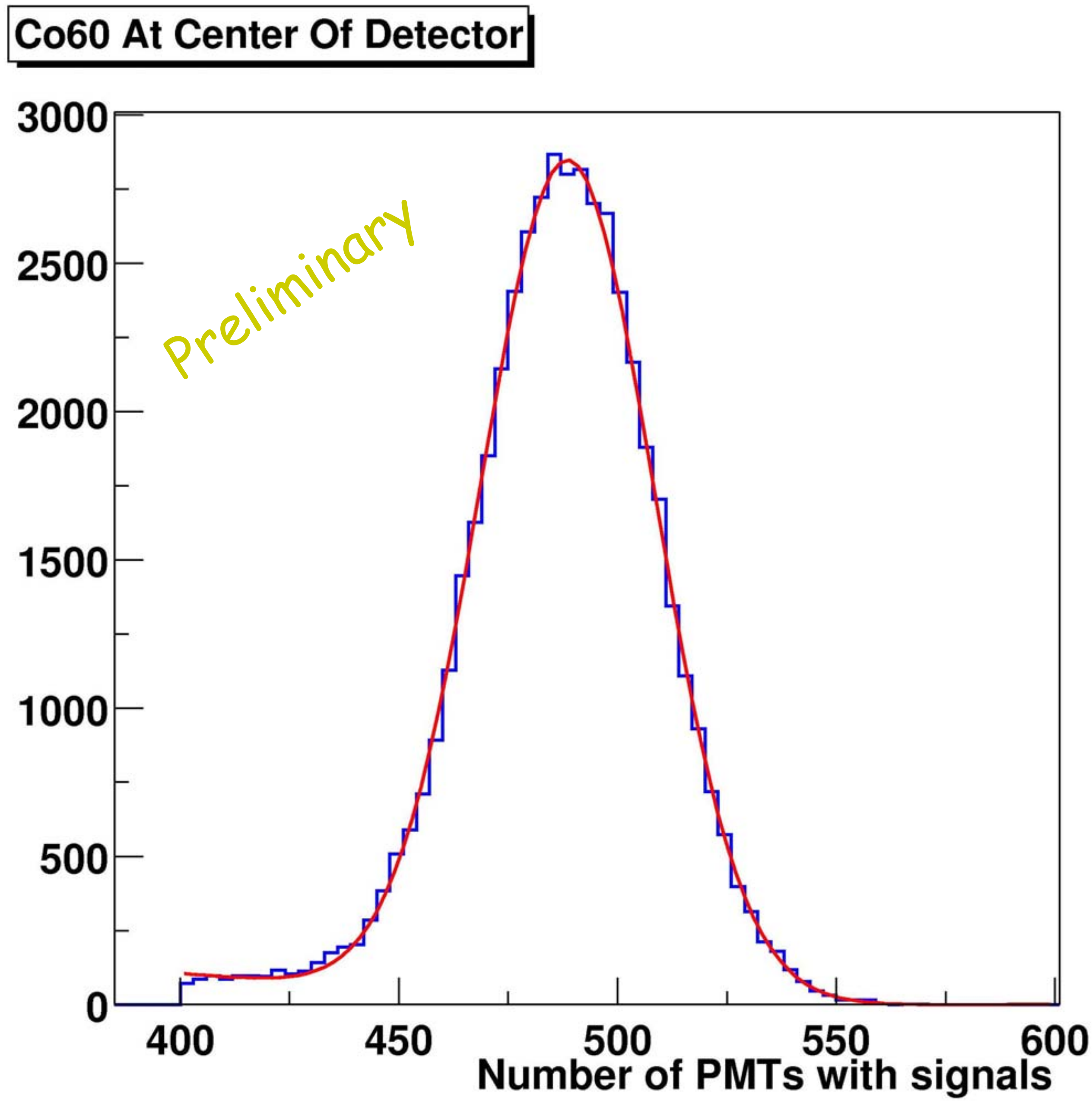




^{65}Zn :
a 1.115 MeV in the detector

σ/E = 6.5 %

Light Yield 241 p.e./MeV

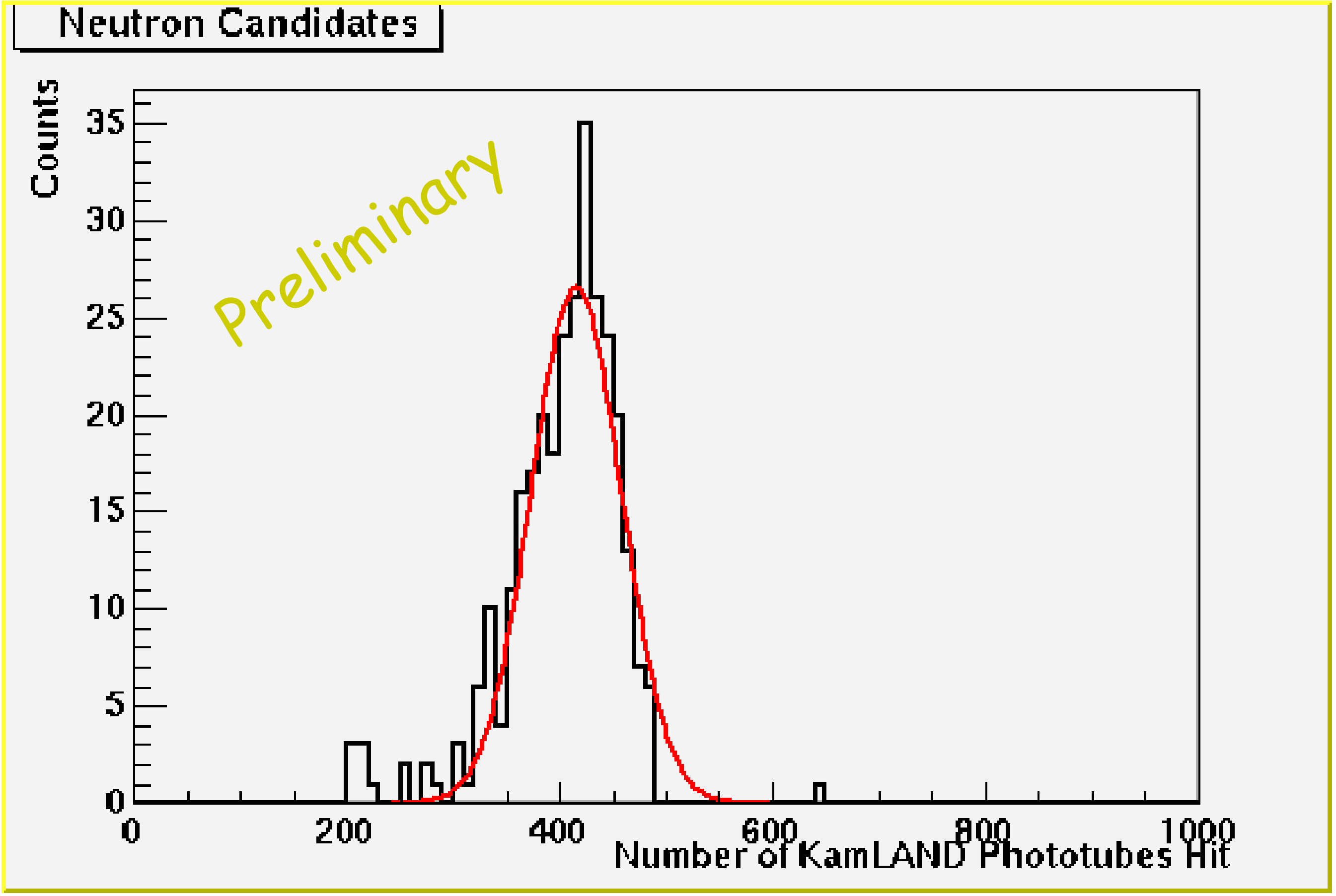


^{60}Co :
a 2.824 MeV in the detector

σ/E = 4.2%

Light Yield 239 p.e./MeV

Now find cosmic ray muons traversing the detector and look for energy deposits following them

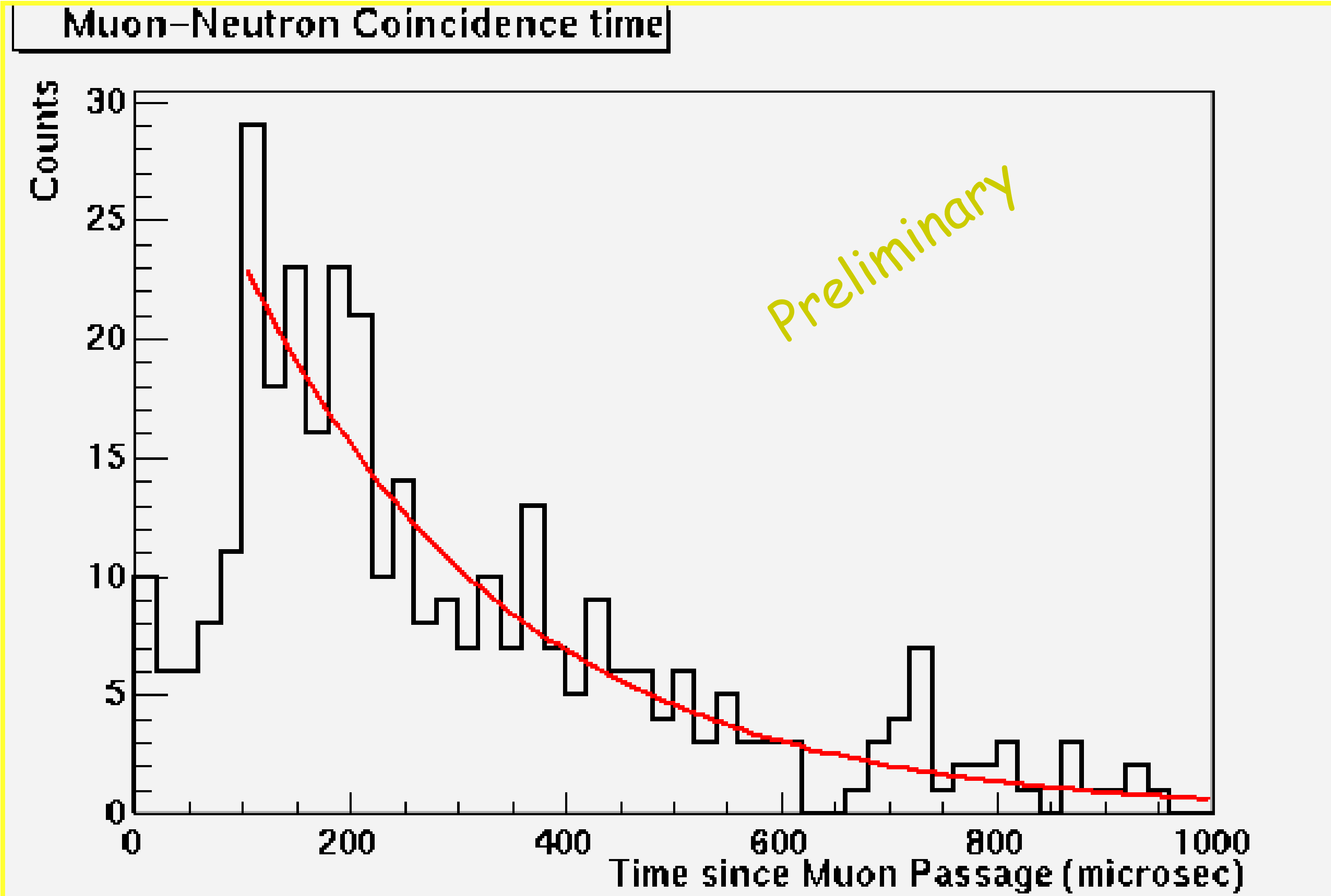


Using E cal. from previous slide the peak is here at ≈ 2.3 MeV

n-capture in hydrogen gives 2.2 MeV

Prompt – delayed correlation time distributed as an exponential with 189±19 μs

MC expectation for neutron capture is 180 μs



Data is now coming in smoothly…

stay tuned for results…