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Ka
LAN

Anti-Neutrino

KamLAND

The current status of KamLAND

Tohoku university

Kenji Ishihara

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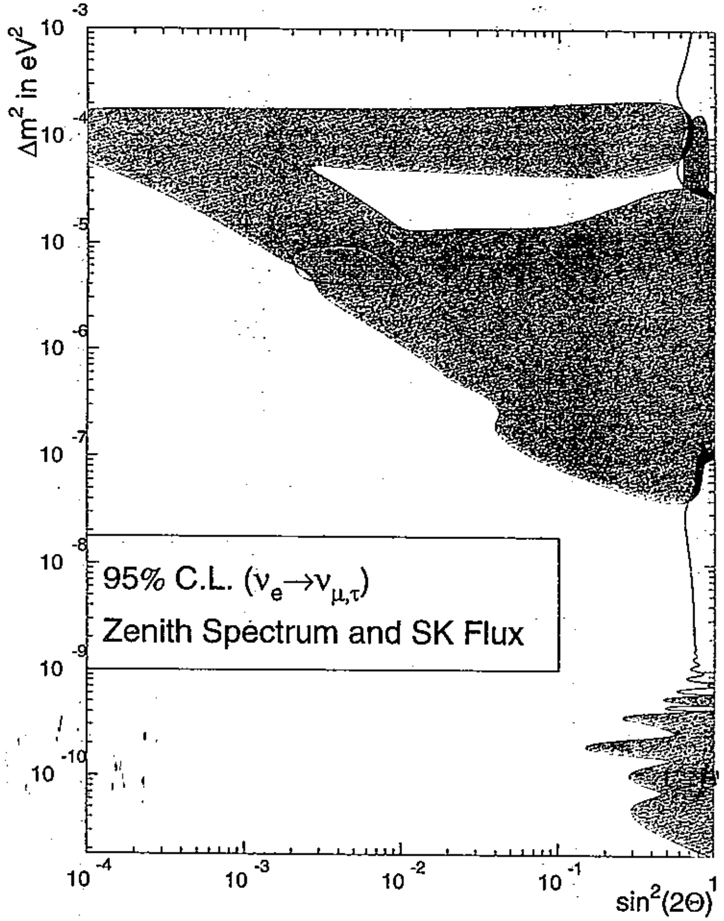
- Solar neutrino probrem
- What is KamLAND ?
- $\bar{\nu}_e$ from Reactor

Latest status of Solar neutrino probrem



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From Super-Kamiokande

hep-ex/0103033

- ○ deficit of ν_e
- × distorion of energy spectrum
- × day-night effect

LMA (Δm^2 $10^{-5} \sim 10^{-4} eV^2$)

seems to be promising solution

But, no positive evidence !

Is defisit of ^8B due to SSM ?

Need Artitifical Neutrino Source !

Can Experiment using Reactor $\bar{\nu}_e$ survey all LMA ?

$\bar{\nu}_e \sim 5.6 \times 10^{20} / \ 3\ GWth \leftarrow$ generating power of typical reactor
$E_\nu \sim 4MeV$

Existing Reactor $\bar{\nu}$ Experiment

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	mass (ton)	path Length (km)	Event (/day)	Sensitive eV^2	lower limit eV^2
CHOOZ	5	1	24	6×10^{-3}	8×10^{-4}
Palo Verde	12	0.8	220	8×10^{-3}	2×10^{-3}

Detector with 10 times greater sensitivity is required !

Requirements to investigate into LMA($\sim 5 \times 10^{-5} eV^2$) are

- Long base line experiment
  $L_\nu \sim 160$ km
- large mass detector
  ~ 100 $events/year \Rightarrow$
  Target mass $\sim 100t$!
- High power reactor
  generating power
  $50 \sim 100 GWth$
  (CHOOZ 8.5 GWth)
- low background enviroment

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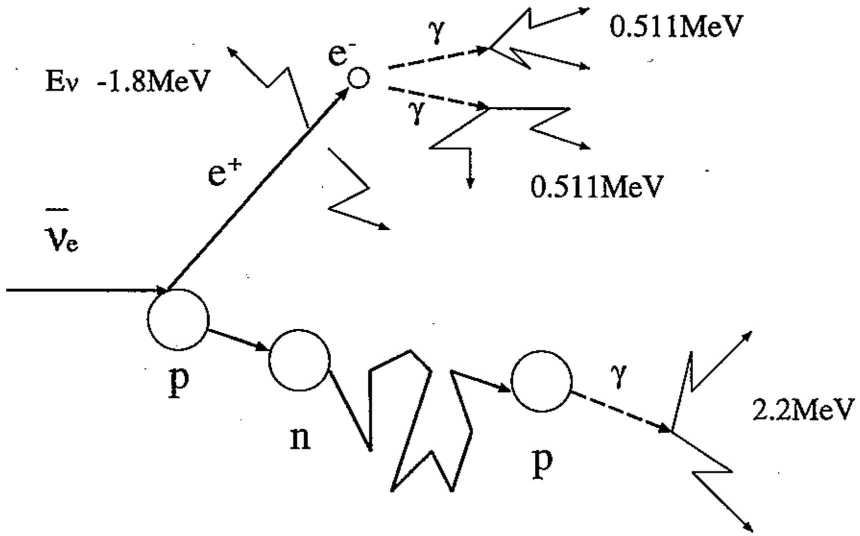
KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector



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

$\Downarrow$ 175 μs delay

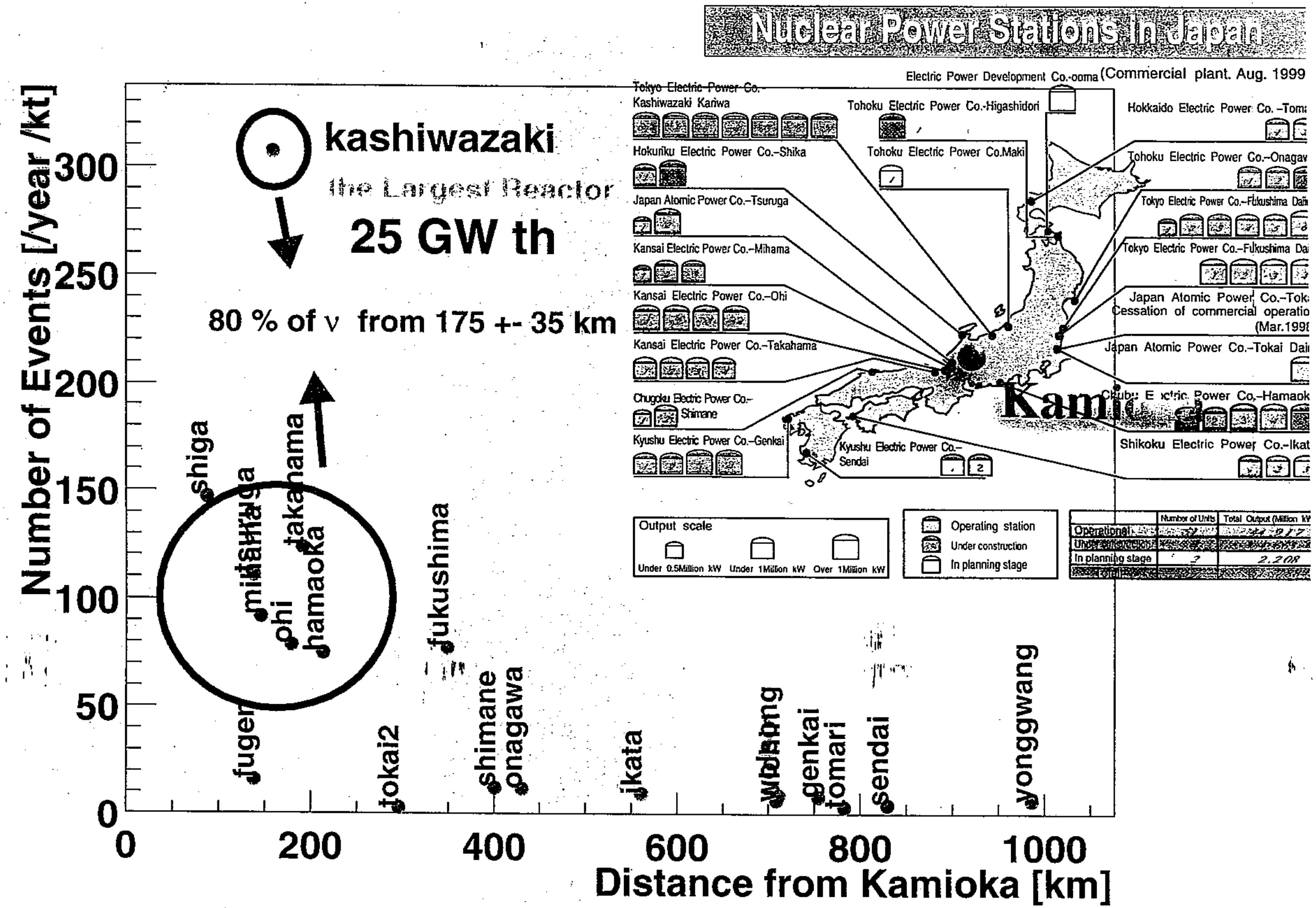
$$n + \ p \ \rightarrow d + \gamma \ (\mathrm{E} = 2.2 \ \mathrm{MeV})$$

special feature

- can measure $E_{\bar{\nu}_e} (= E_{vis} + 0.8 \ \mathrm{MeV})$
- can be distinglish $CC \ \bar{\nu}_e$ than the other neuttrino events
- low background enviroment

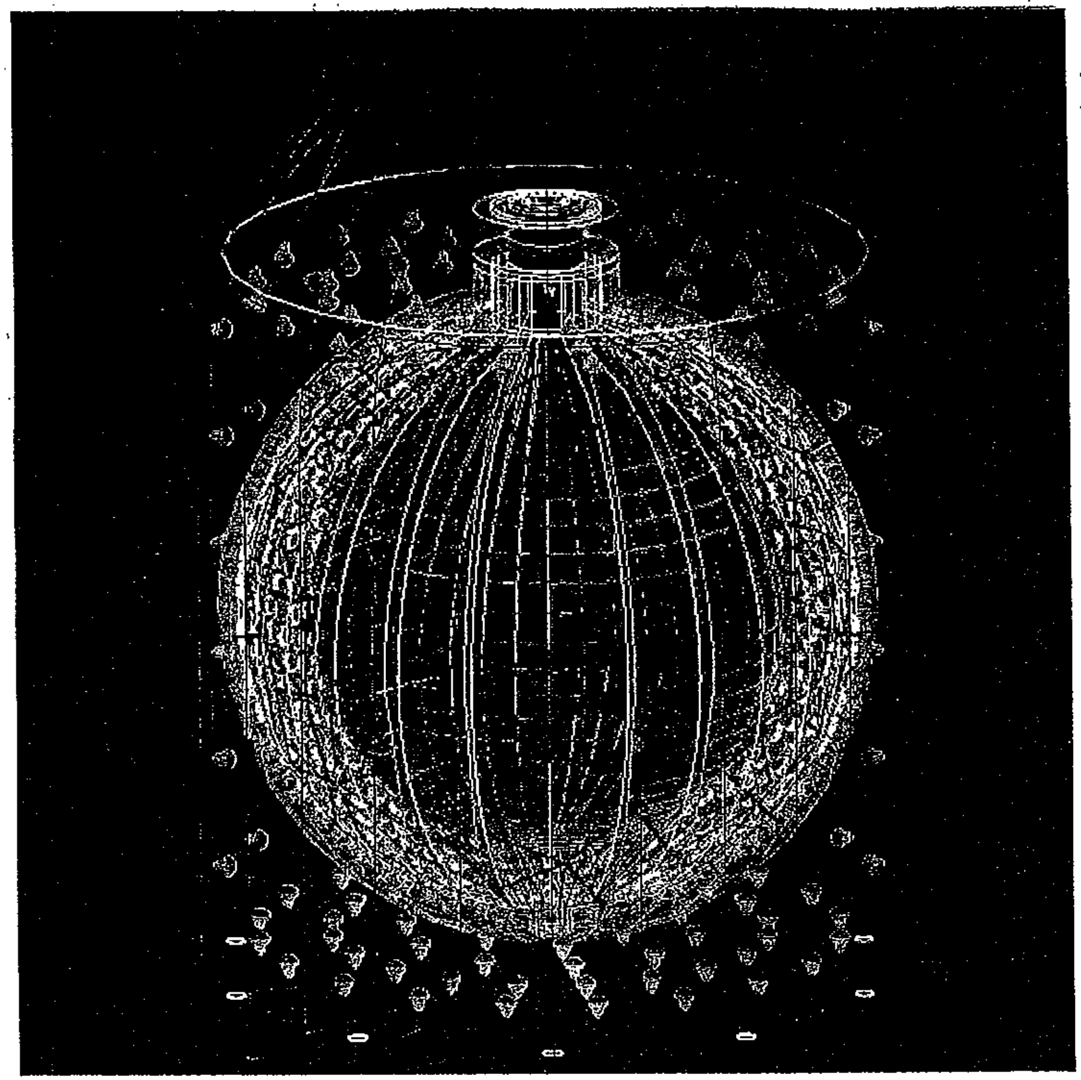
K :	$1.4 \times 10^{-10} g/g$
Th :	$1.5 \times 10^{-14} g/g$
U :	$4.2 \times 10^{-15} g/g$

- background free



Nuclear Power Stations in Japan
(Commercial plant. Aug. 1999
kashiwazaki
the Largest Reactor
25 GW th
80 % of ν from 175 +- 35 km
Number of Events [/year /kt]
Distance from Kamioka [km]
shiga
mitsuhama
tsuruga
ohi
takahama
hamaoka
fugen
tokai2
fukushima
shimane
onagawa
ikata
woo...
genkai
tomari
sendai
yonggwang
Electric Power Development Co.-ooma
Tokyo Electric Power Co.-Kashiwazaki Kariwa
Tohoku Electric Power Co.-Higashidori
Hokuriku Electric Power Co.-Shika
Tohoku Electric Power Co.Maki
Japan Atomic Power Co.-Tsuruga
Kansai Electric Power Co.-Mihama
Kansai Electric Power Co.-Ohi
Kansai Electric Power Co.-Takahama
Chugoku Electric Power Co.-Shimane
Kyushu Electric Power Co.-Genkai
Kyushu Electric Power Co.-Sendai
Shikoku Electric Power Co.-Ikat
Output scale
Under 0.5Million kW
Under 1Million kW
Over 1Million kW
Operating station
Under construction
In planning stage
Number of Units
In planning stage

KamLAND Detector



Inner Detector

- 18m ϕ stainless tank
- 13m ϕ balloon
- L.S. volume $1,200m^3$ (1 k ton)
  transparency 10 m at 400 nr
- buffer oil volume $1,800m^3$
- # of PMTs (17 inch) 1325
  (20 inch) 554
- photo cavarage 36 %

Outer Detector

- water $3,200m^3$
- PMT (20 inch) 225

Detector performance

light emission	390 p.e./MeV at center (direct 190 + re-emission 200) based on CDF
$\frac{\sigma_E}{E}$	$5/\sqrt{E_{(MeV)}}$ %
σ_t of PMT	1.7 ns (17 inch) 5.0 ns (20 inch)
ΔPos	$\sim$ 10 cm (at 1 MeV)
Waveform (ATWD module)	128 sampling $\times$ 2ns
PSD (n/γ)	86 % (at 2 MeV) 93 % (at 3 MeV)
(α/γ)	$>$ 99 % (at 0.5 MeV)

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Neutrino oscillation using Reactor $\bar{\nu}_e$

- Reactor $\bar{\nu}_e$ as neutrino source
  How acurate in Neutrino Intensity ?

- Background estimation
  Radio activity
  Neutron produced by Cosmic ν

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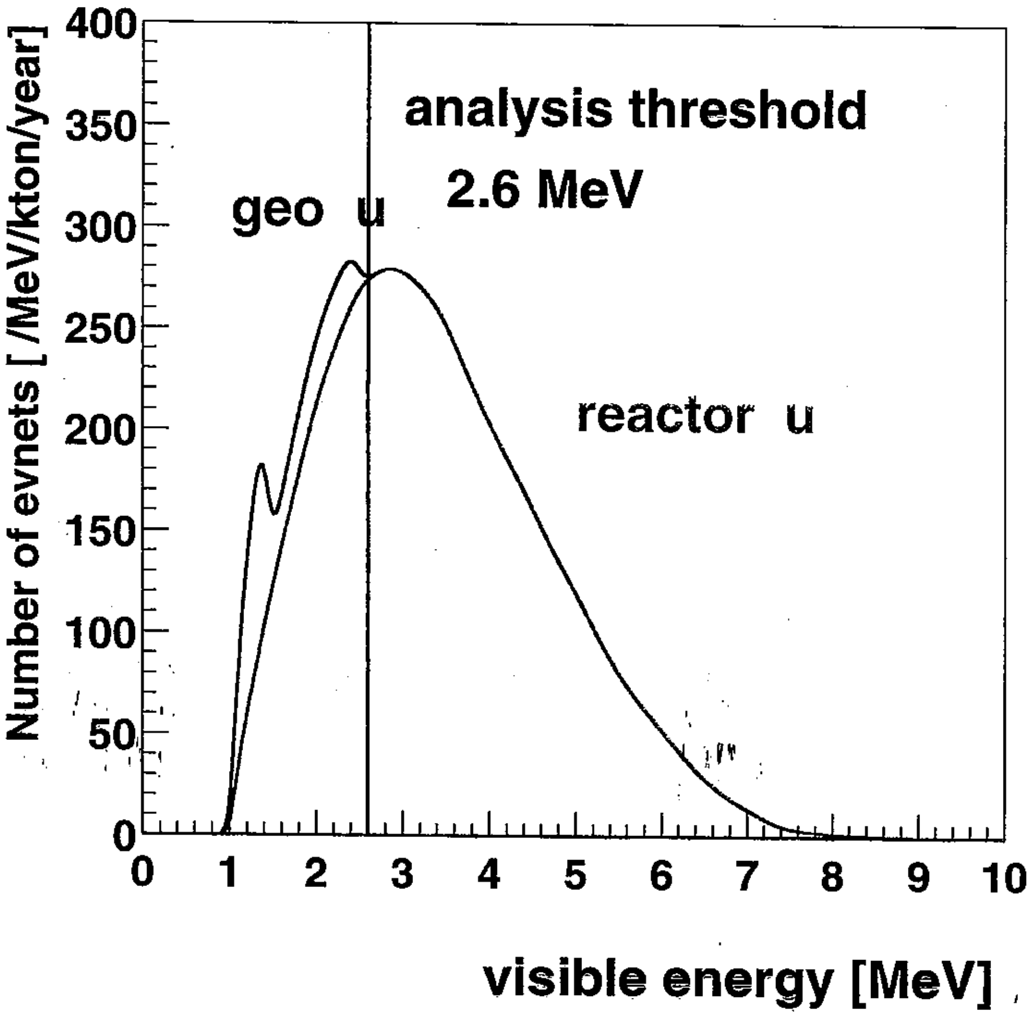
- systematic error

- Phycal Potential
  sensitive reagion
  expected allowed reagion

$\bar{\nu}_e$ energy spectrum at KamLAND



$\Delta E/E = 5\%/\sqrt{E}$

We can also observe geo $\bar{\nu}_e$.
First obvervation !

However, it is background to reactor $\bar{\nu}_e$ analysis.

$\Downarrow$

$E_{th} = 2.6$ MeV
Reactor $\bar{\nu}_e = 320$ /year
(fiducial 0.5 kt)

Unsertainty in Reactor $\bar{\nu}_e$ flux

We estimate based on both theoretical expection and observation.

Unsertainty

Theoretical expection

A.A.Hahn *etal.* Phys.Lett.B218. 365

- fission rate
  ~ 0.7 %
- $^{235}U/\ ^{239}Pu$ ratio in fuel rod
  < 0.3 %
- $\bar{\nu}_e$ yield / fission
  3 %

observation

G.Zacek *etal.* Phys.Rev. D34. 2621

B.Achkar *etal.* Phys.Lett. B374. 243

Bugey measured $\bar{\nu}_e$ flux by

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

absolute 1%

shape ± 1.5%

inclusing unsertainty from cross section

Comparing two independent data

Unsertainty in $\bar{\nu}_e$ flux is esitimated to be $\sim 3\%$.

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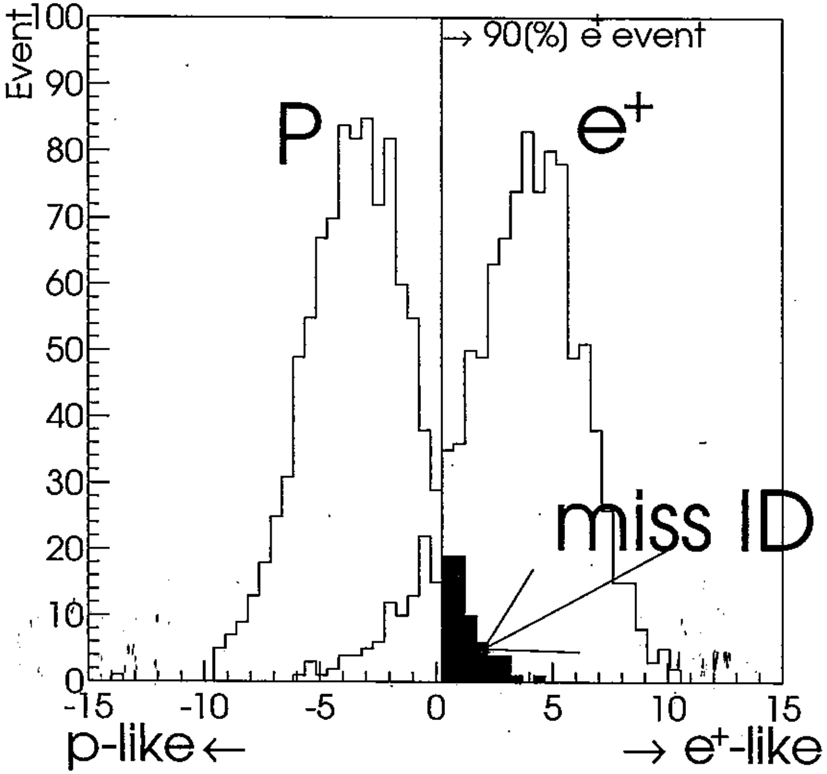
Background from Neutron induced cosmic μ

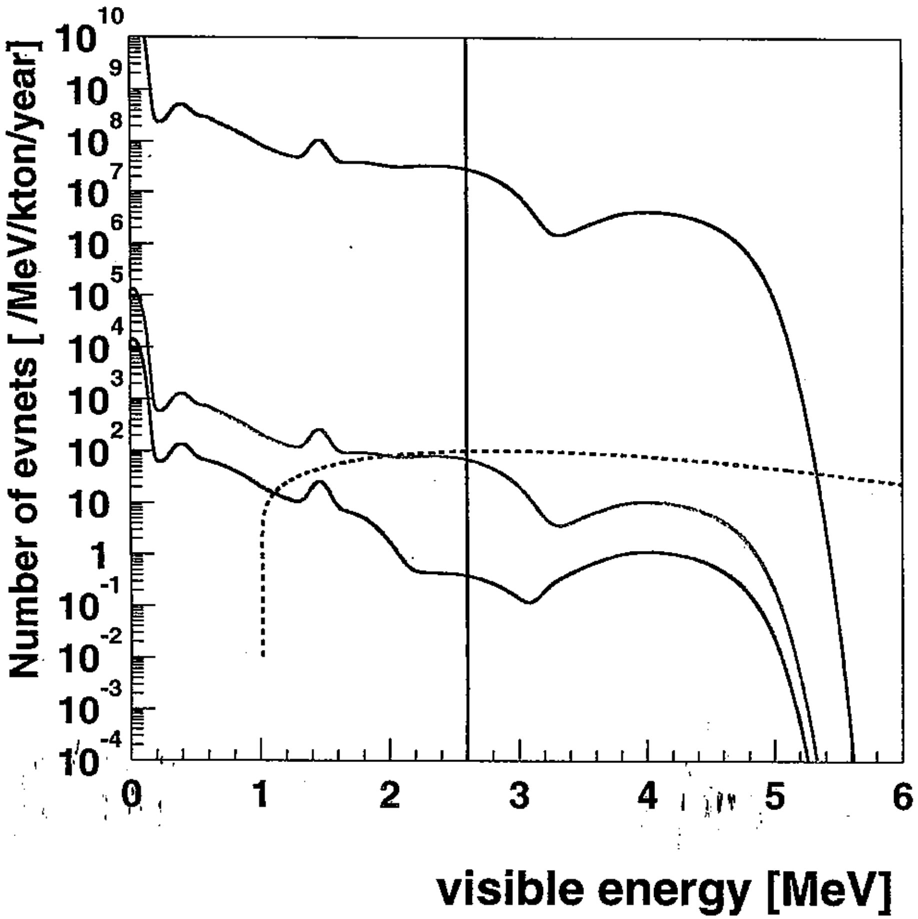


Neutron events can be rejected by PSD
PSD eff. is 93 % at $E = 3MeV$

Expected neutron
$\lesssim$ 10 event / year
$\Downarrow$ PSD
$\lesssim$ 1 event / year

Neutron events can be rejected !

Background from Radioactivities



Reduction

1. Delayed Coincidence
   $\Delta t < 1msec$, $\Delta L < 1m$,
   $1.9 < E_\gamma < 2.5MeV$
2. Tag $^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$
   $^{212}Bi \rightarrow {}^{212}Po \rightarrow {}^{208}Pb$
   Tagging eff. for Po 95 %
   α/γ separation eff. 90 %

Assuming	$\Delta E/E$	$5/\sqrt{E}\%$
	^{238}U	10^{-13} g/g
	^{232}Th	10^{-13} g/g
	^{40}K	10^{-10} g/g

background is ~ 0.7 / year !

Background from Radioactivity can be rejected !

Systematic error for reactor neutrino analysis

Source	Assumption	%
absolute $\bar{\nu}_e$ flux	from Bugey	1.4
	(include $\sigma_{c.s.}$)	
	caluclation	3
cross section		~ 2
fiducial volume	vertex shift $= 1$ cm	< 1
	vertex shift $= 3$ cm	~ 2
absolute E_{ν_e}	$\sigma_E = 3\%$	~ 3.0
	$\sigma_E = 1\%$	~ 1.0
Background		$< 1\%$
Total		$4 \sim 8$

Oscillation Analysis

1/3 year $\sim$ 100 events

this result will be shown at international conference at Sendai in Feb. 2002

(at latetest Neutrino 2002)

$$N_{th} = (1+\alpha)N_{mc}$$

$$\chi 2 = \frac{(N_{obs}-N_{th})^2}{N_{obs}} + \frac{\alpha^2}{\sigma_\alpha^2}$$

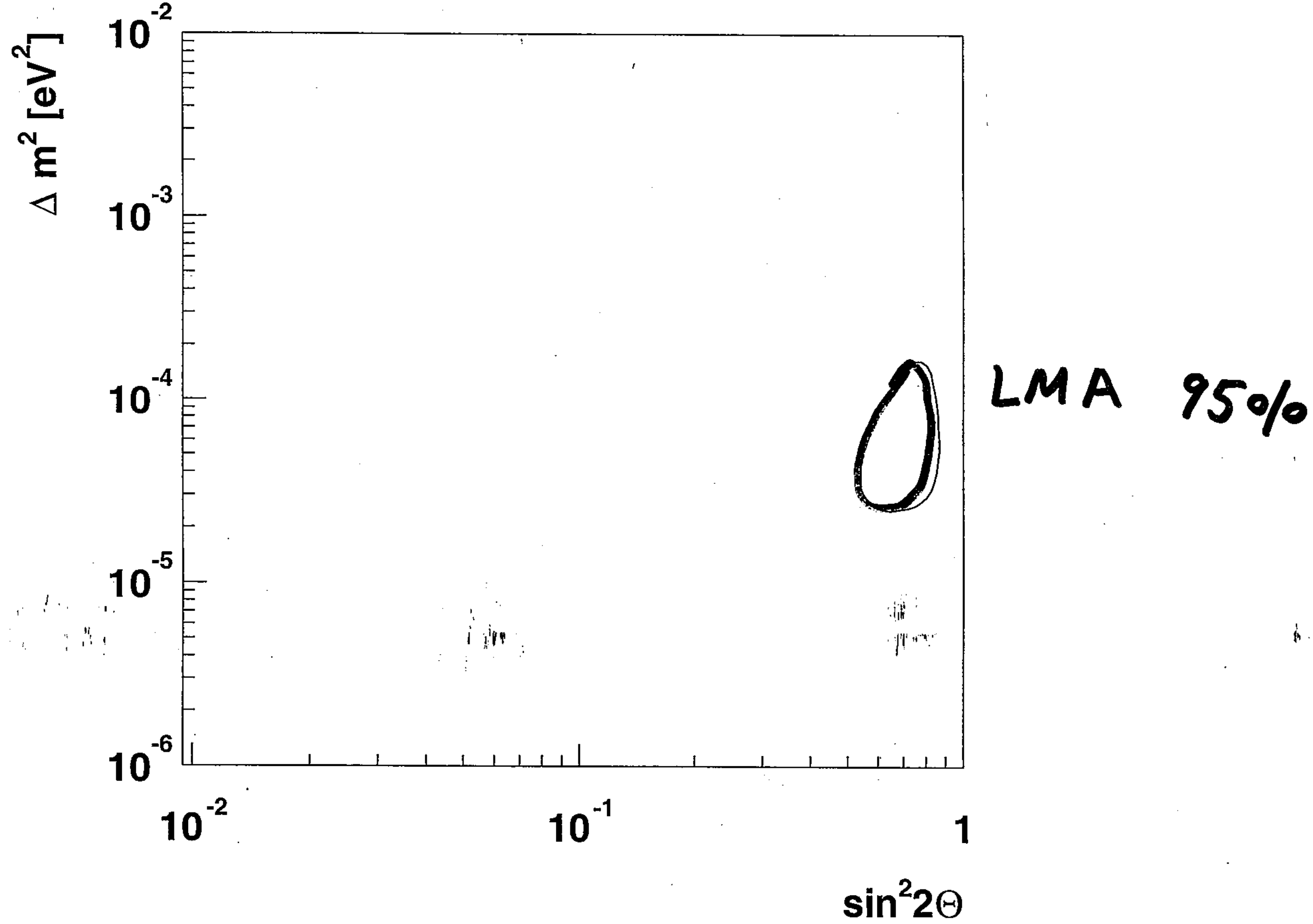
$\alpha = 10$ %

3 years $\sim$ 1000 evensts

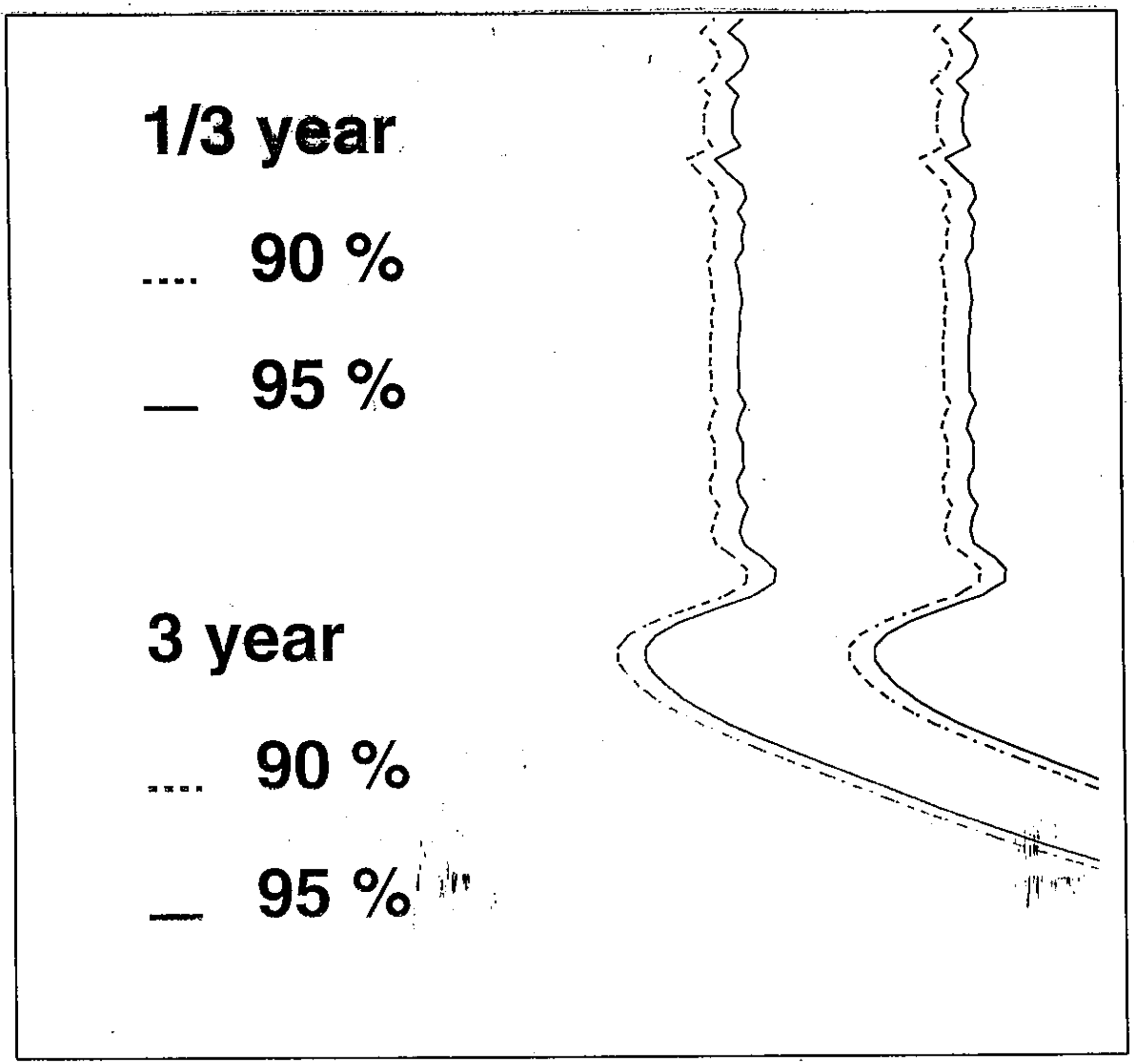
energy shape analysis is O.K.

$$\chi 2 = \sum 2(N^i_{th} - N^i_{obs}(1 - \log(N^i_{obs}/N^i_{th}))) + \frac{\alpha^2}{\sigma_\alpha^2}$$

$\alpha = 4$ %

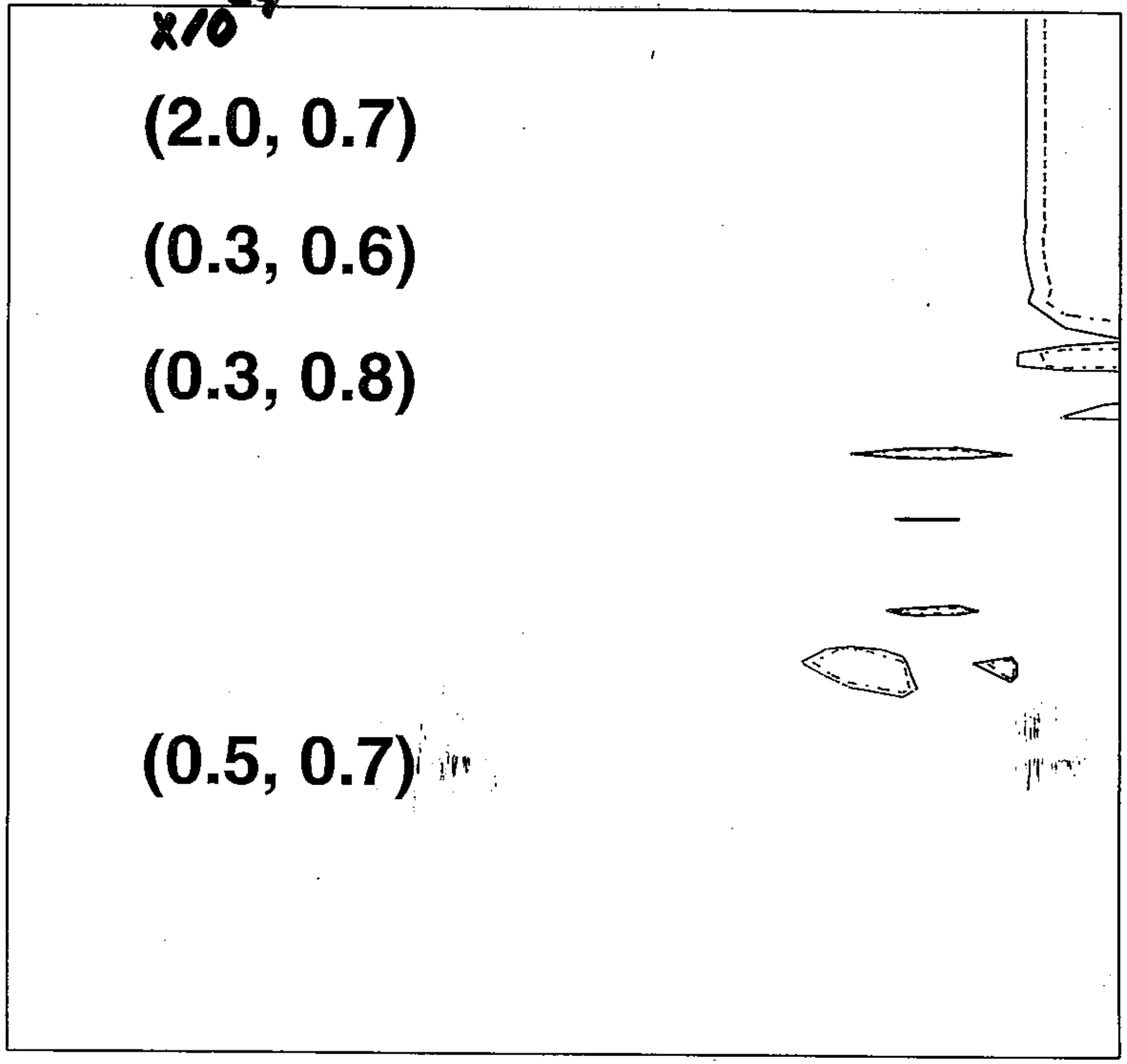


Δ m² [eV²]
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻²
10⁻¹
1
sin²2Θ
LMA 95%

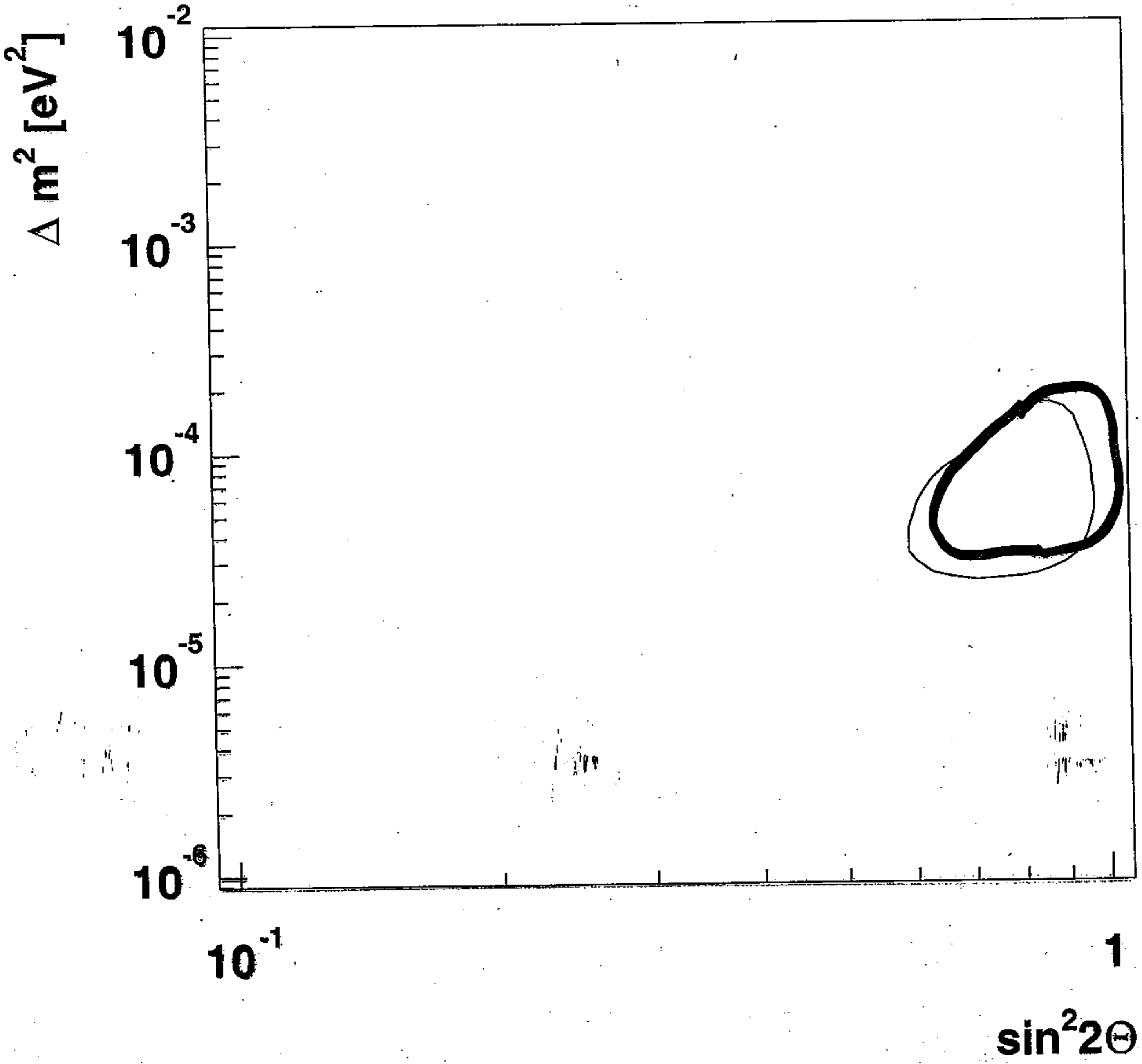

1/3 year
.... 90 %
_ 95 %
3 year
.... 90 %
_ 95 %

(Δm^2, $\sin^2\theta$)

$\times 10^{-4}$



3 years



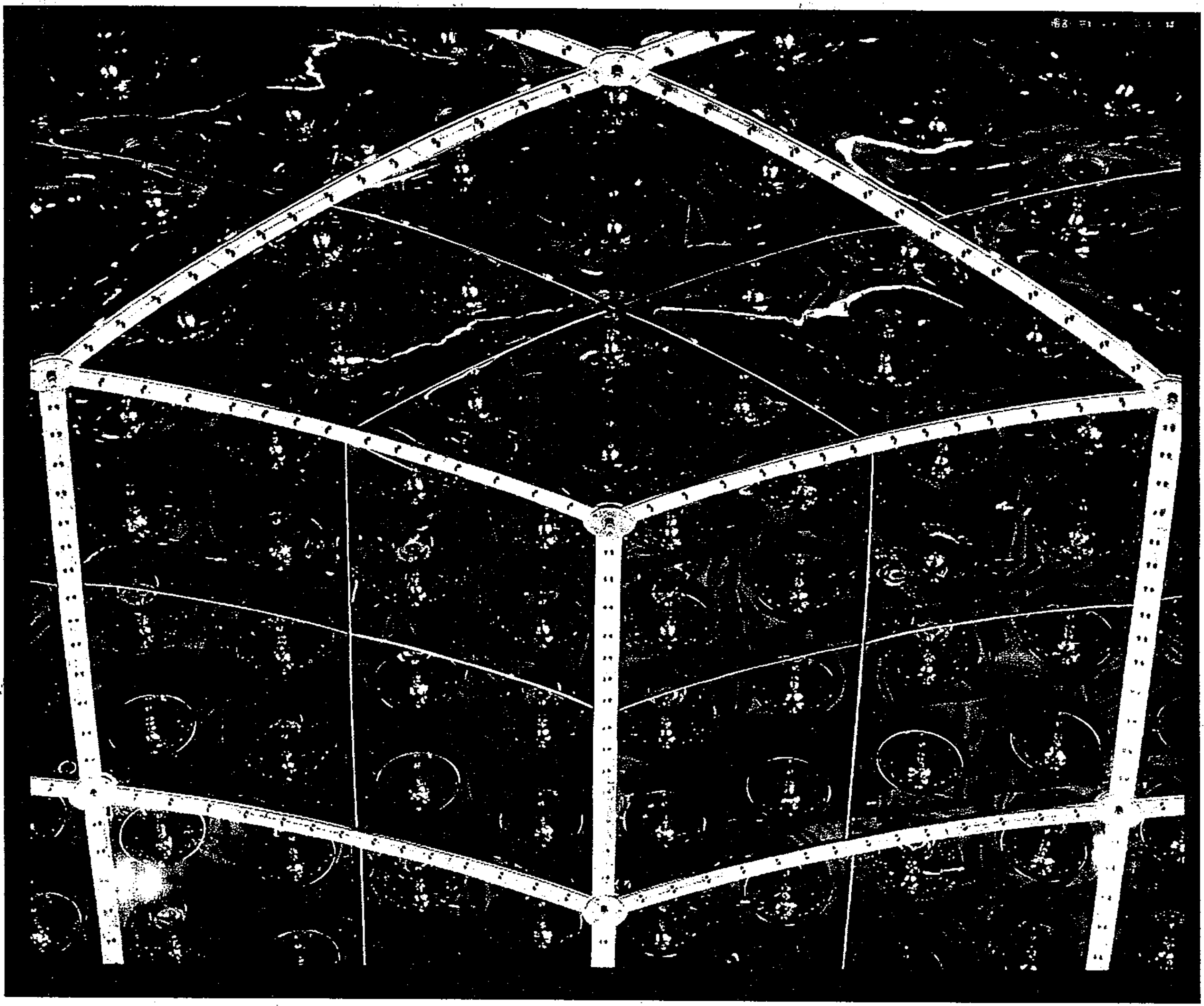
Δm^2 [eV^2]
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-1}
1
$\sin^2 2\Theta$

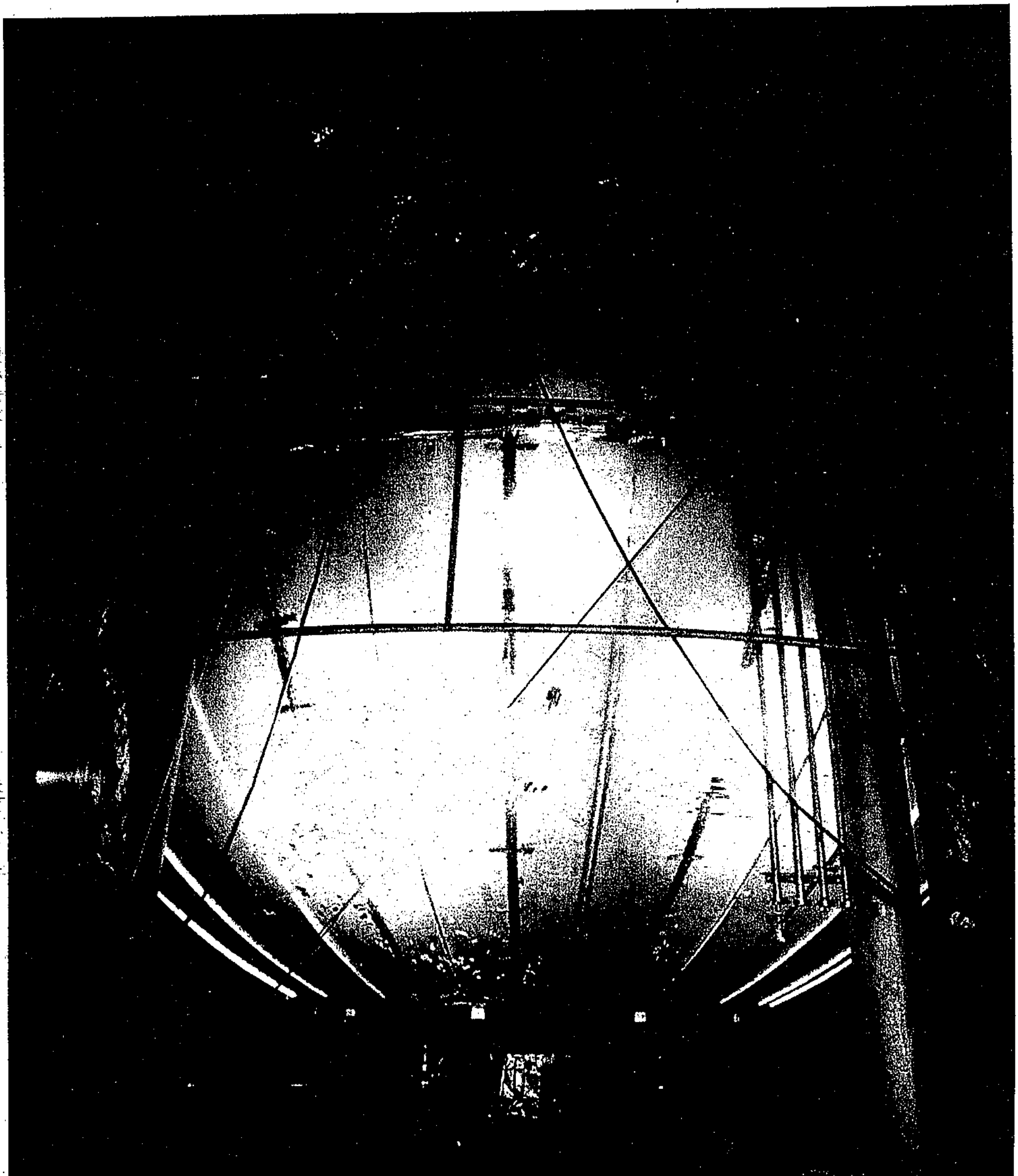
Time Table

- Inner PMT installation has completed in Sep. 2000.
- Balloon installation has completed in Feb. 2000.
- Final cleaning of th purification system has completed in Apr. 2001.
- Outer PMT installation has completed in Apr. 2001.
- Oil filling started from May. 2001 and will finish by Sep. 2001.
- Front end electronics will be installed by Aug. 2001.
- Physics run will start from Oct. 2001.
- Hopefully, striking results will show up in early 2002.

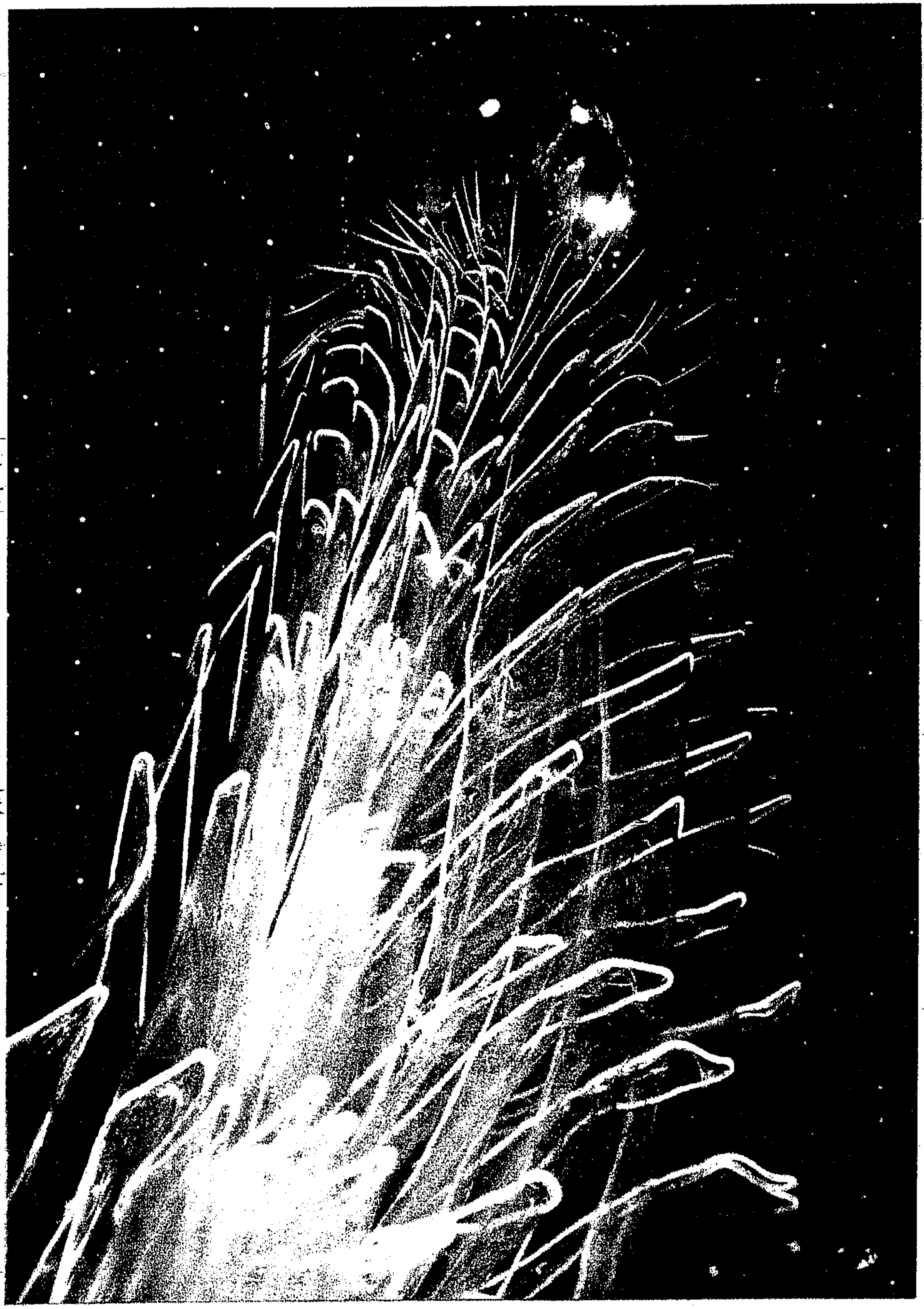
Summay

- KamLAND is the largest liquit syntirator detector with 10 times greater sensitivity than exiting reactor experiments.
- KamLAND has a capability to survey all region in LMA.
- We find out any striking results using reactor $\bar{\nu}_e$ by next spring, and determine parameter region very well within 3 years, if LMA is an answer.

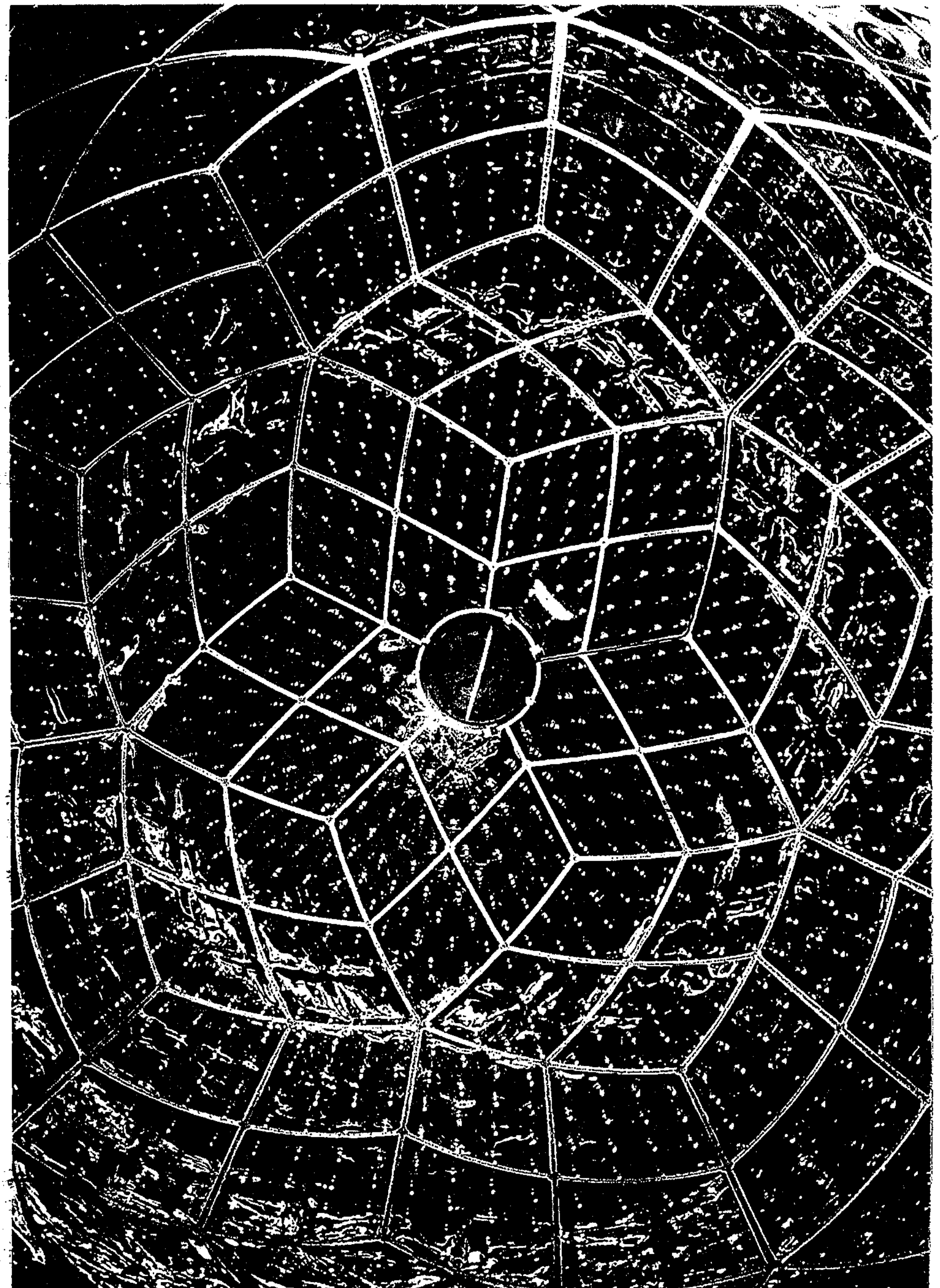


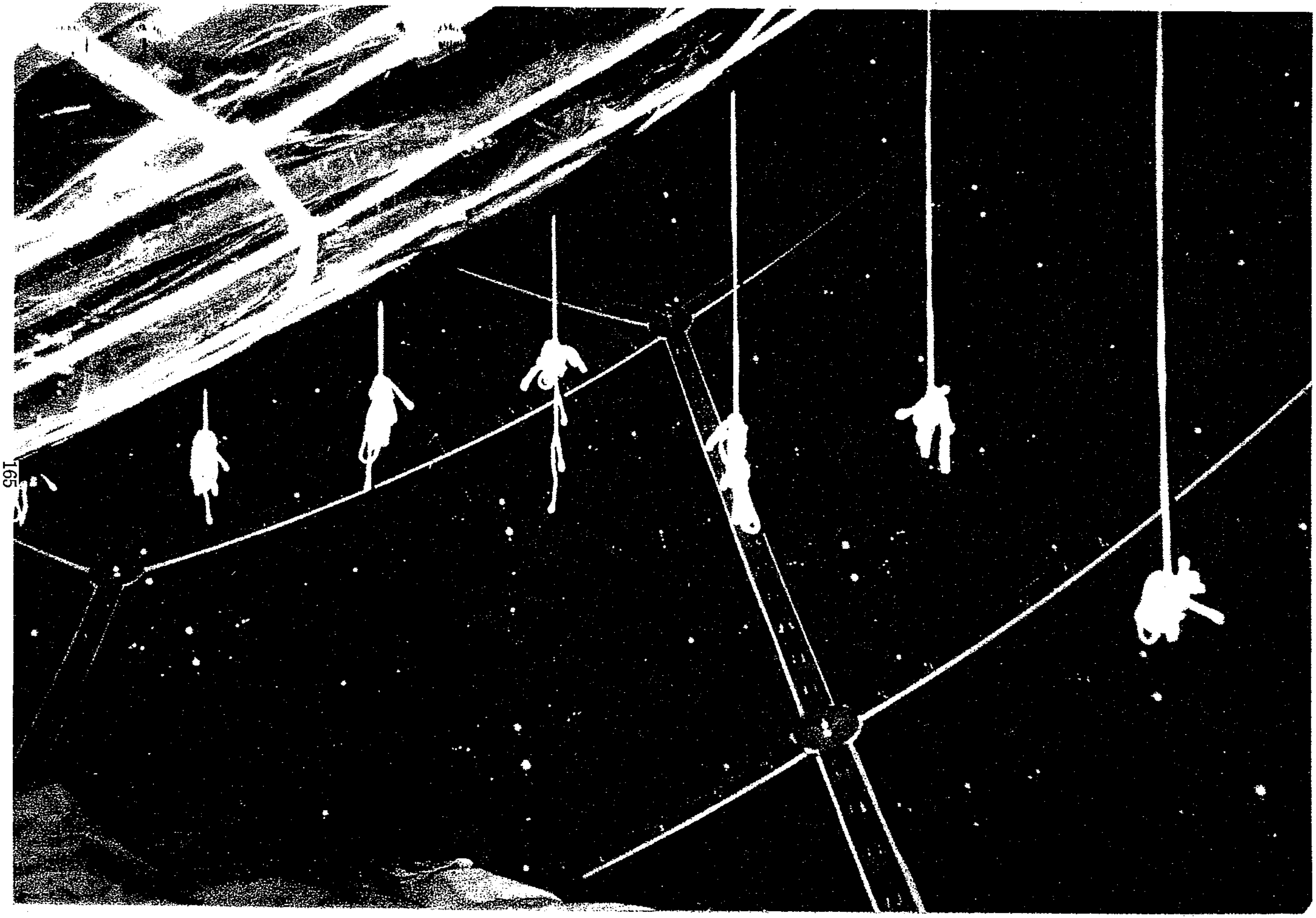


撮影 浜松ホトニクス（株）



163 Deployment of the real balloon, Feb. 2001





The real balloon being inflated, Feb. 2001

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