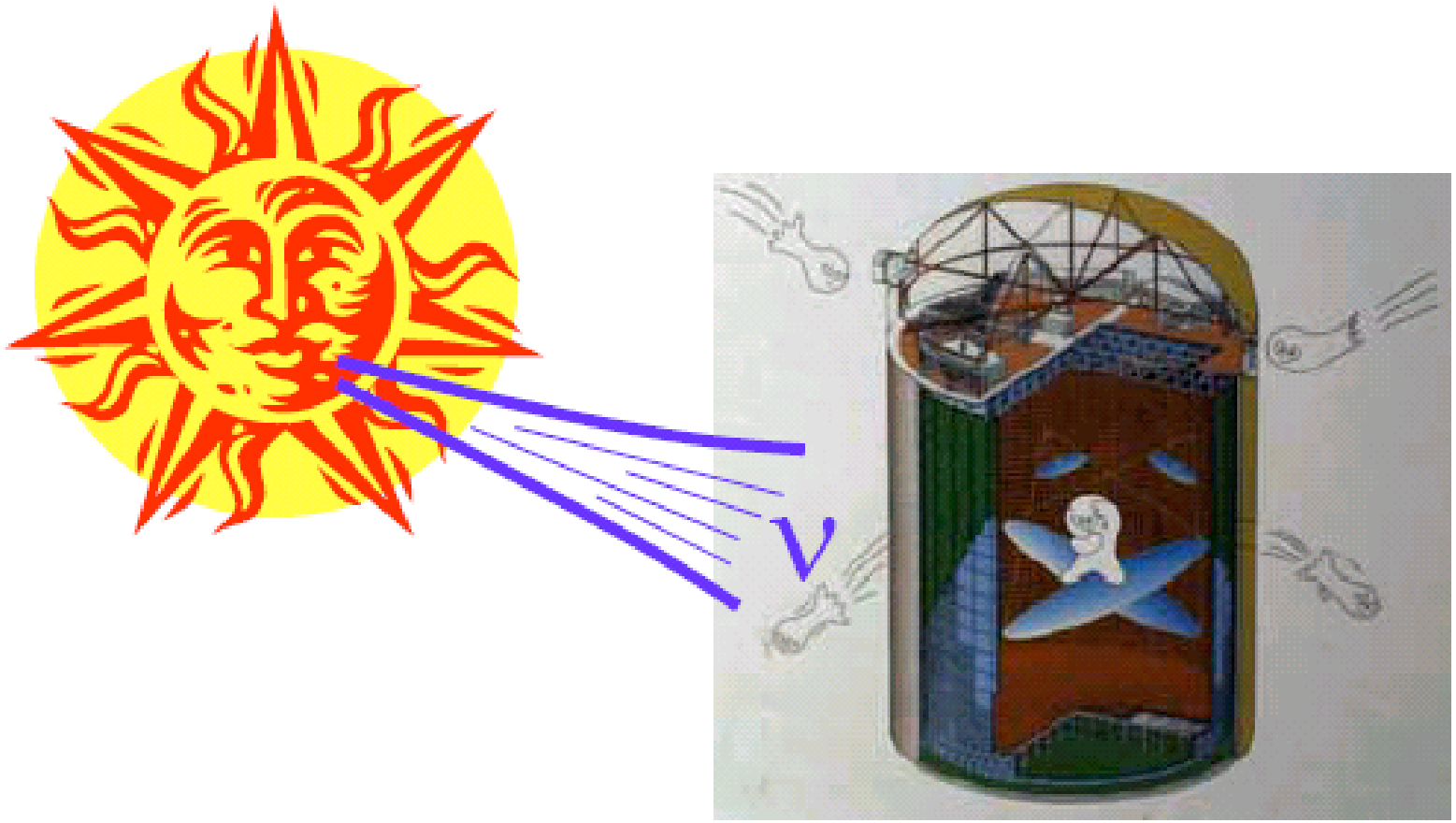
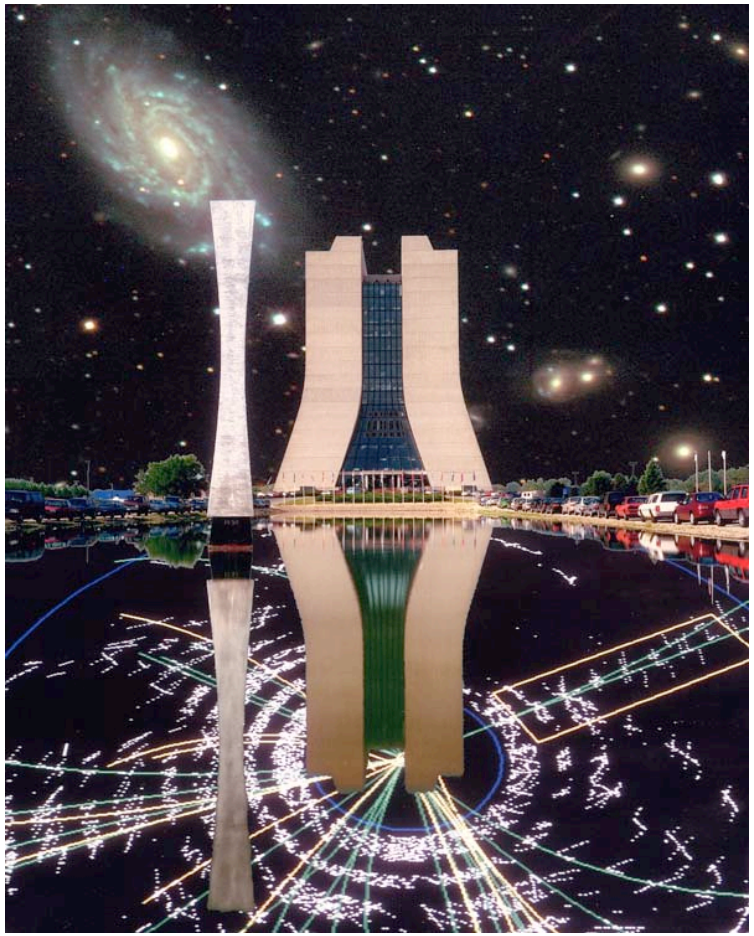

ν

NEUTRINOS:



Ghosts of the Universe

Stephen Parke
Theoretical Physics Dept
Fermilab
July 13, 2004

Webster's Online Dictionary

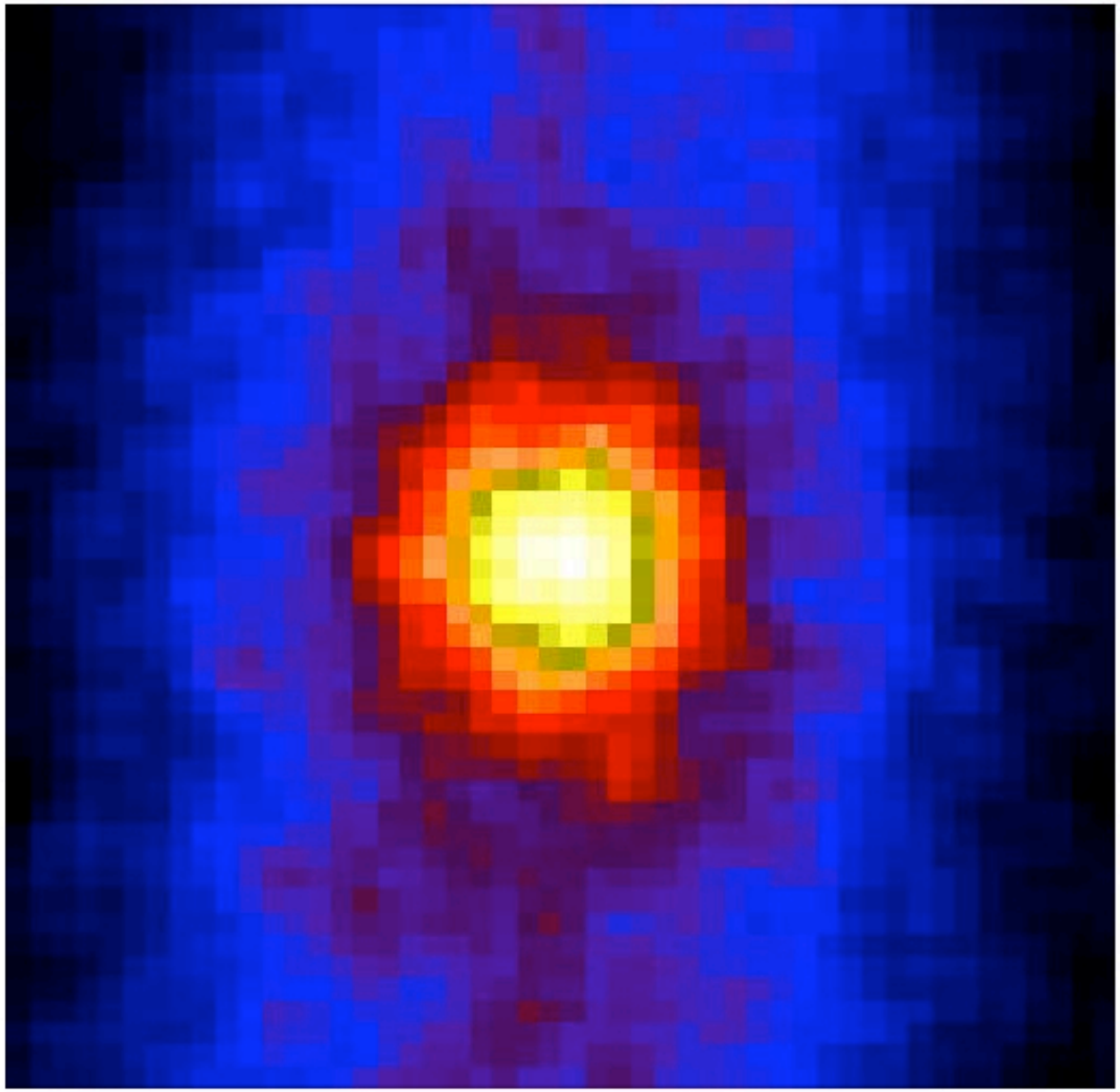
Main Entry: **neu·tri·no**
Pronunciation: nü-'trE-(")nO, nyü-
Etymology: Italian, from *neutro*

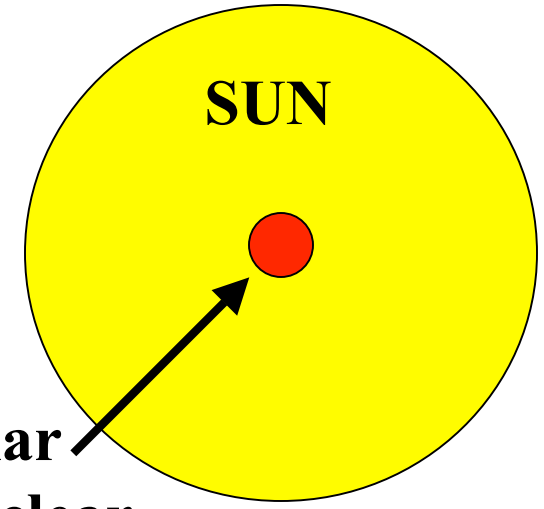
: an uncharged elementary particle that is believed to be massless or to have a very small mass,
that has any of three forms,
and that interacts only rarely with other particles

Brief Early History of the Neutrino

- 1930 – postulated by Wolfgang Pauli
- 1933 – incorporated into theory of radioactive decay by Enrico Fermi who named the ``neutrino = little neutral one''
- 1957 – first observed by Cowan and Reines using nuclear reactor as the source.

Neutrino Picture of the Sun





4 protons + 2 electrons

Helium Nucleus (2p2n)

+

2 Neutrinos (2ν)

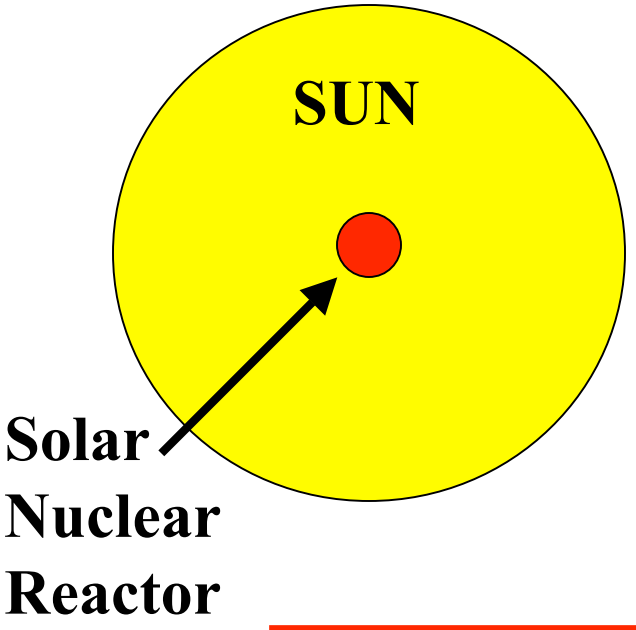
+

Energy

Using $E=mc^2$

$$E=\{ m_{He}-4m_p-2m_e \}\, c^2 = 26 \text{ MeV}$$

1 ν per 13 MeV



1 ν per 13 MeV
= 13 x 1.6x10^{-13} J

at the earth

Solar Luminosity= 1360 Watts/m^2

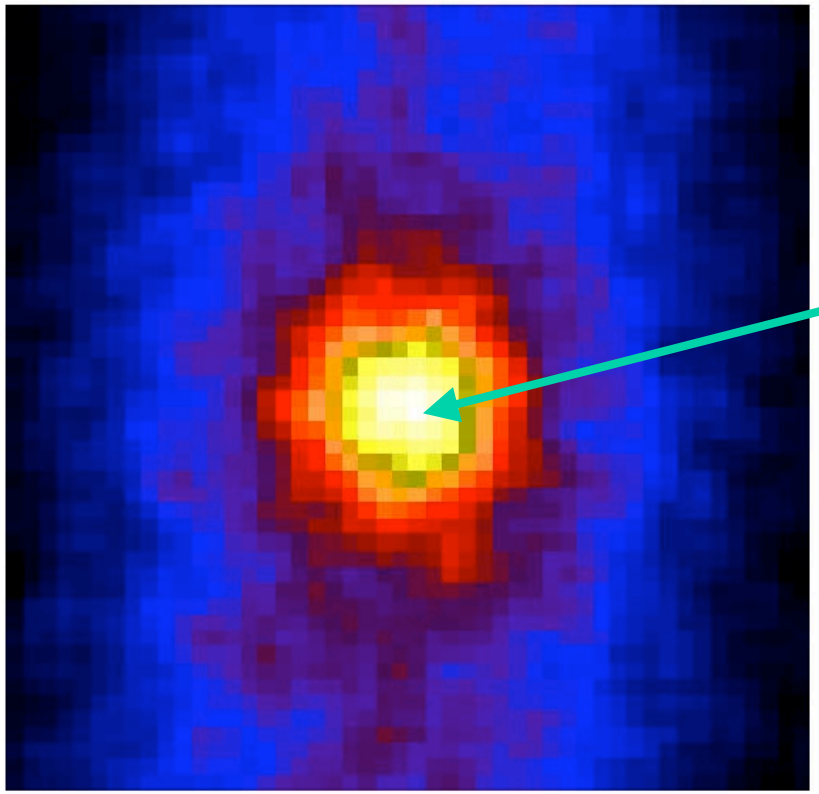
ν_e flux = 1360 / 13 x1.6x10^{-13} = 6.6 x 10^{14} /m^2.sec

66,000,000,000 ν per cm^2 per sec !!

Day and Night!

$$\frac{D - N}{D + N} \leq 1\%$$

Neutrino Picture of the Sun



Size of the Sun: about One pixel

4 yr exposure, big "camera"

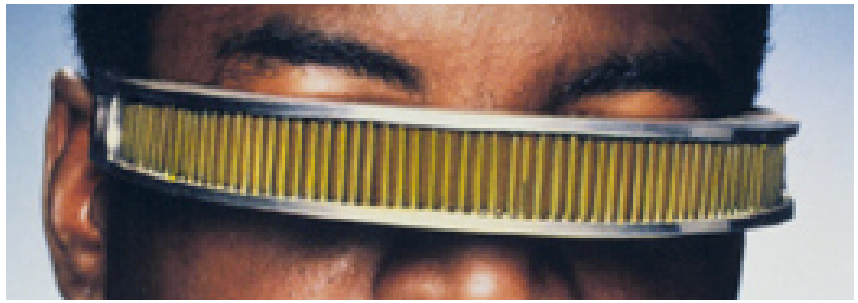
The Energy produced takes 1,000,000 yrs to get to the surface.

The Neutrinos take 2 seconds to get to the surface.

From the Sun to Earth takes 8 minutes.

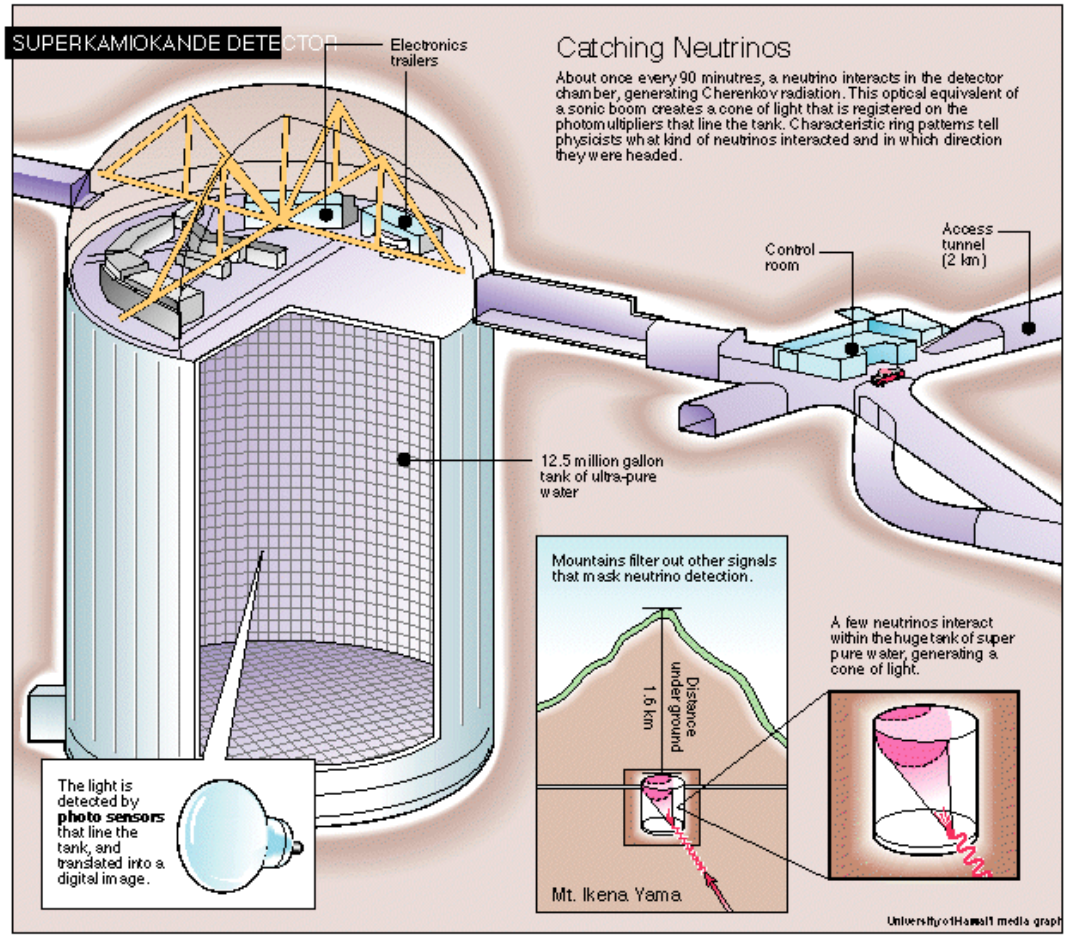
Star Trek: The Next Generation

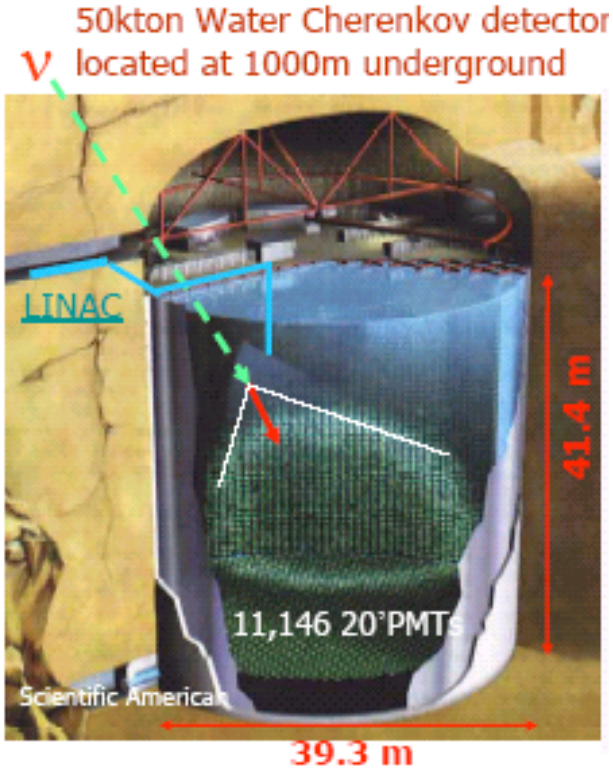
Geordi La Forge: in "The Enemy"



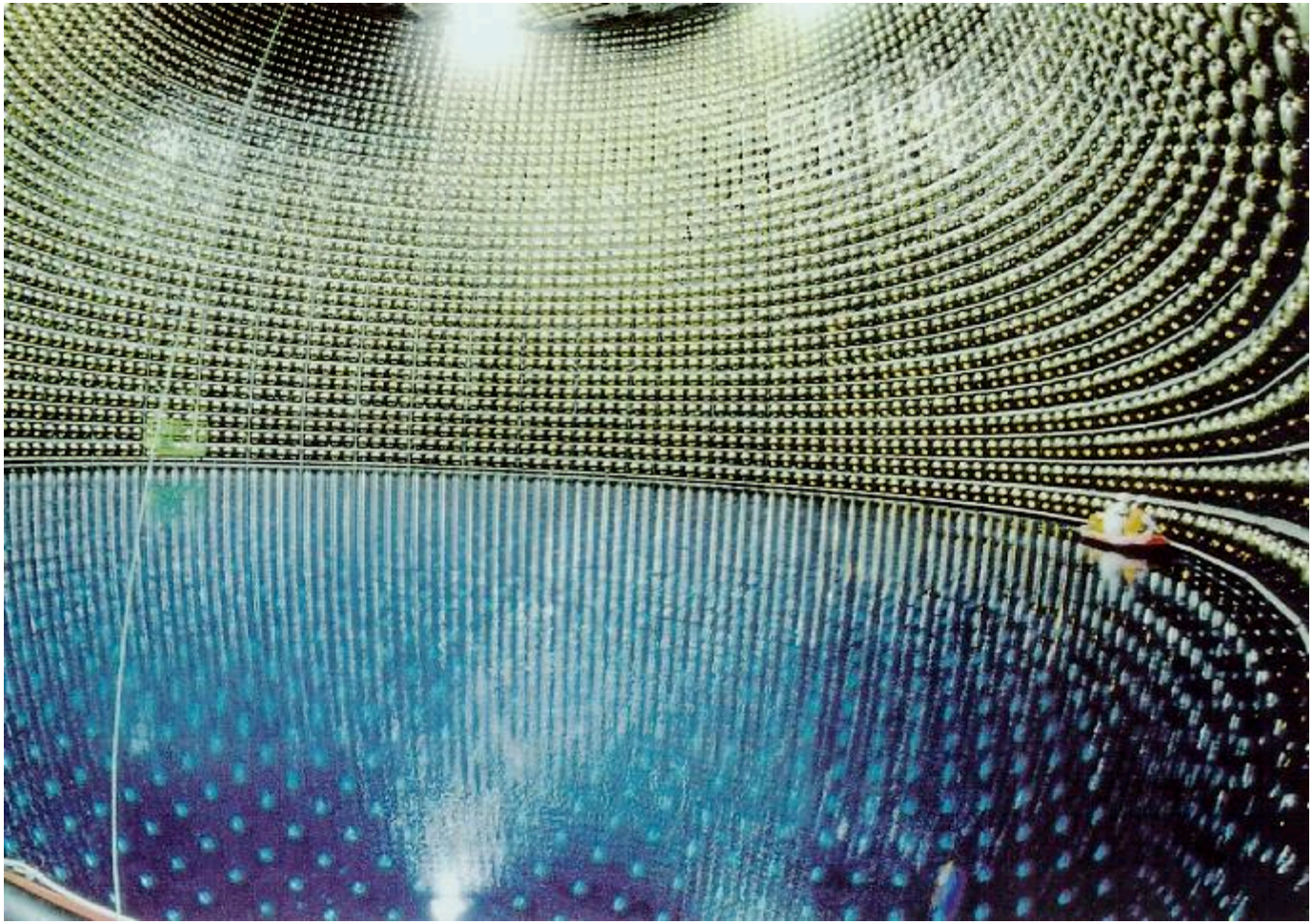
The visor "sees" Neutrinos!!!

SuperKamiokande

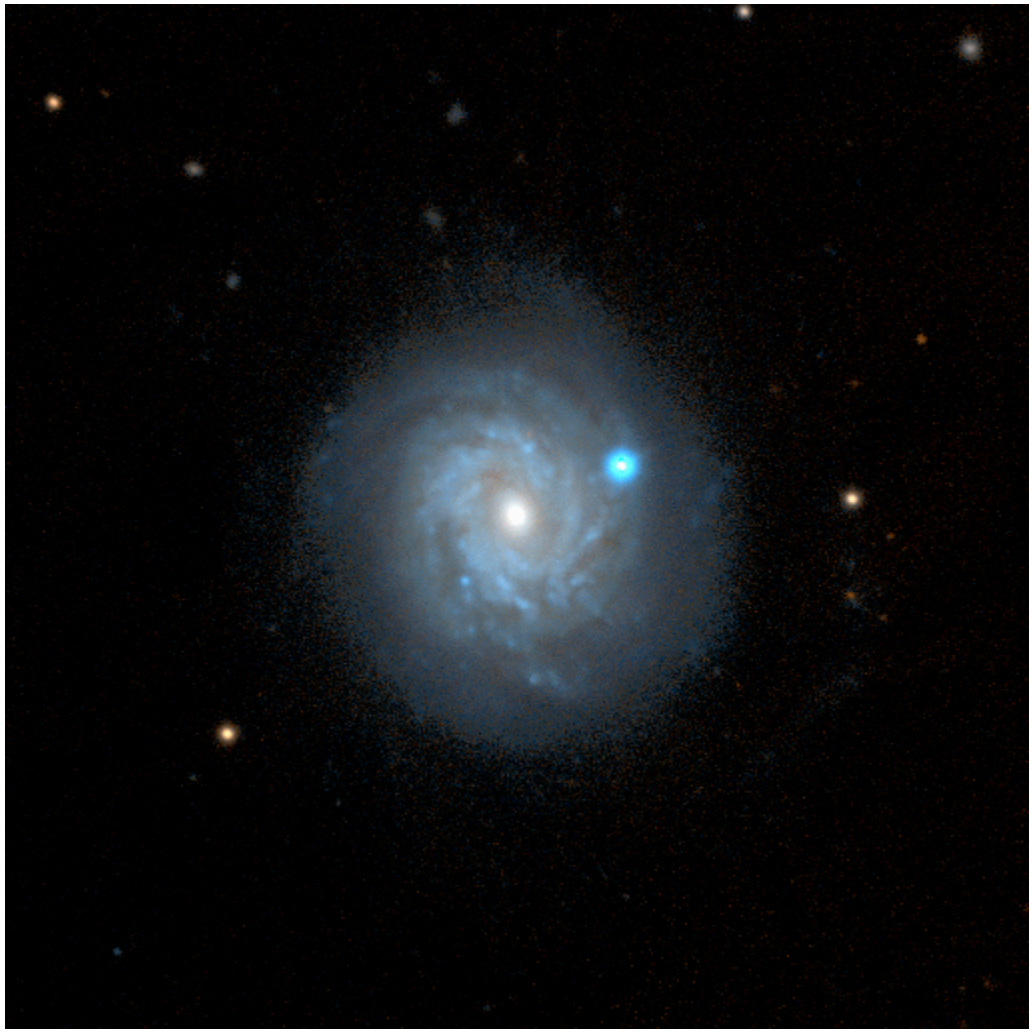




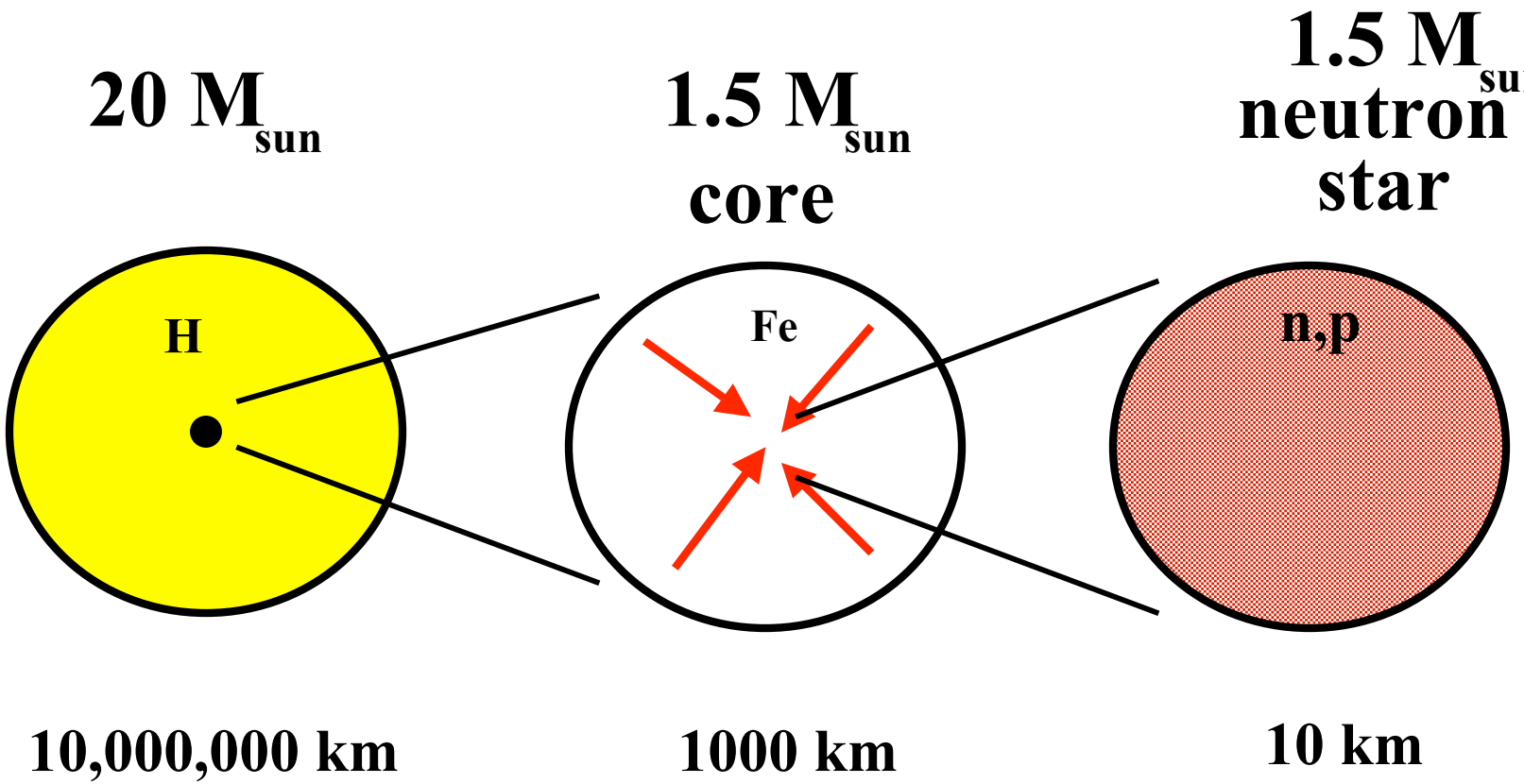
SuperKamiokande



Supernova



Mechanics of a Supernova



Energy Released 10^{40} kilowatt-hours!!!

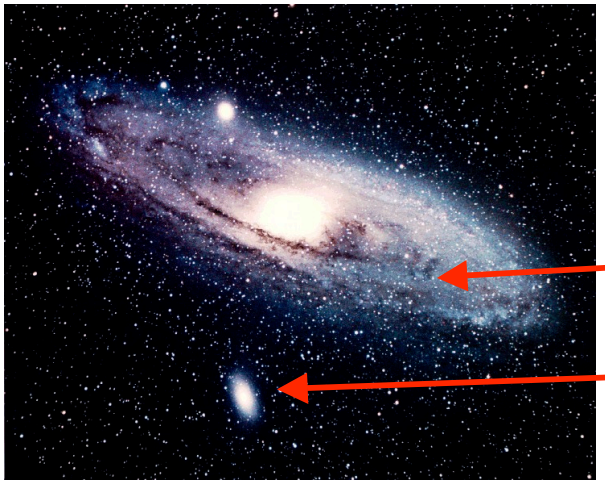
equivalent to 0.1 M_{sun}

Supernova Energy Budget = $100

- **Light show** — **1c = 0.01%**
- **Blowing Star Apart** — **$1 = 1%**
- **Neutrinos** — **$99 = 99%**

Light show lasts months

Neutrino tsunami lasts 10-20 seconds!!!



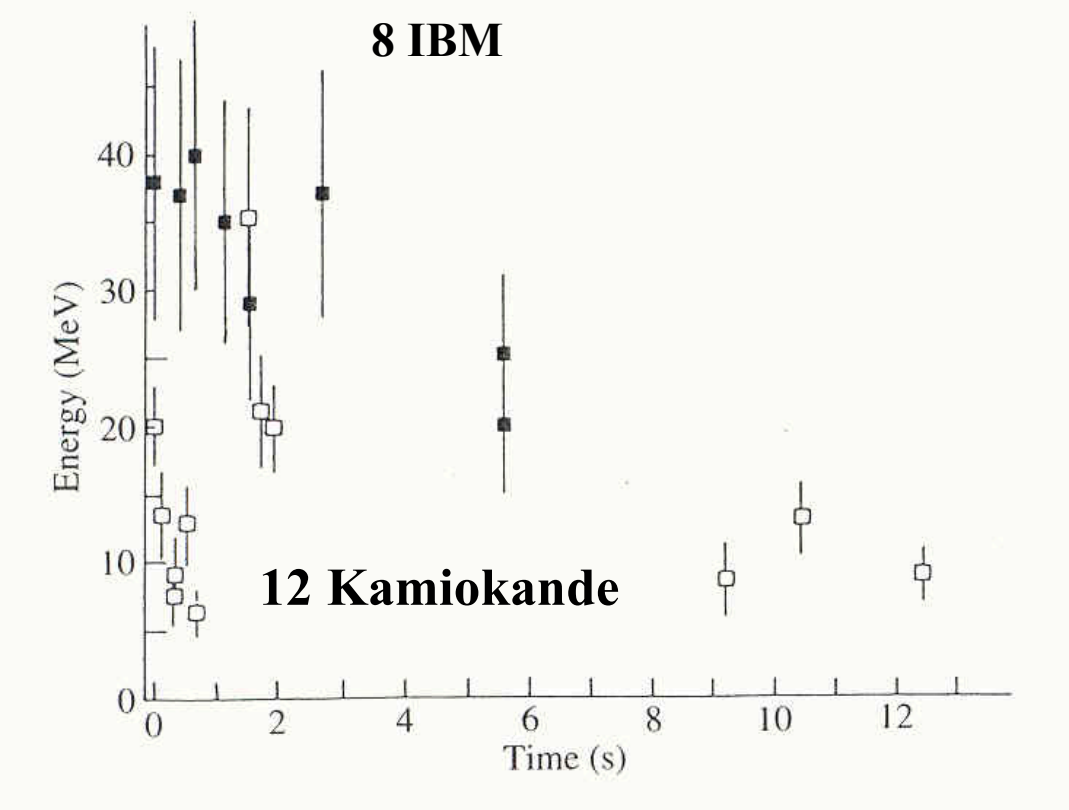
Supernova 1987a - Feb 24

you are here

Large Magelanic Cloud
170,000 light years away

First time in over 300 yrs SN visible to naked eye

Neutrinos from SN 1987a



100,000 times brighter than our Sun in Neutrinos arrived 3 hours before the light?

500

Supernova Neutrino Tsunamis

are on their way

from supernova in our galaxy!!!

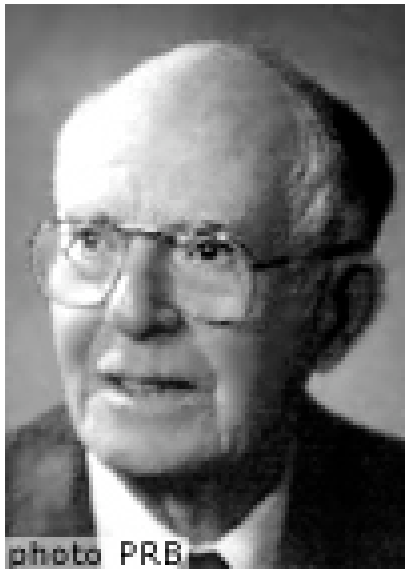
Bigger Detectors, More Detectors

Rate ? One every 10 to 30 years

Nobel Prize 2002

"….for the detection of cosmic neutrinos"

Davis, USA



solar

Koshiba, Japan

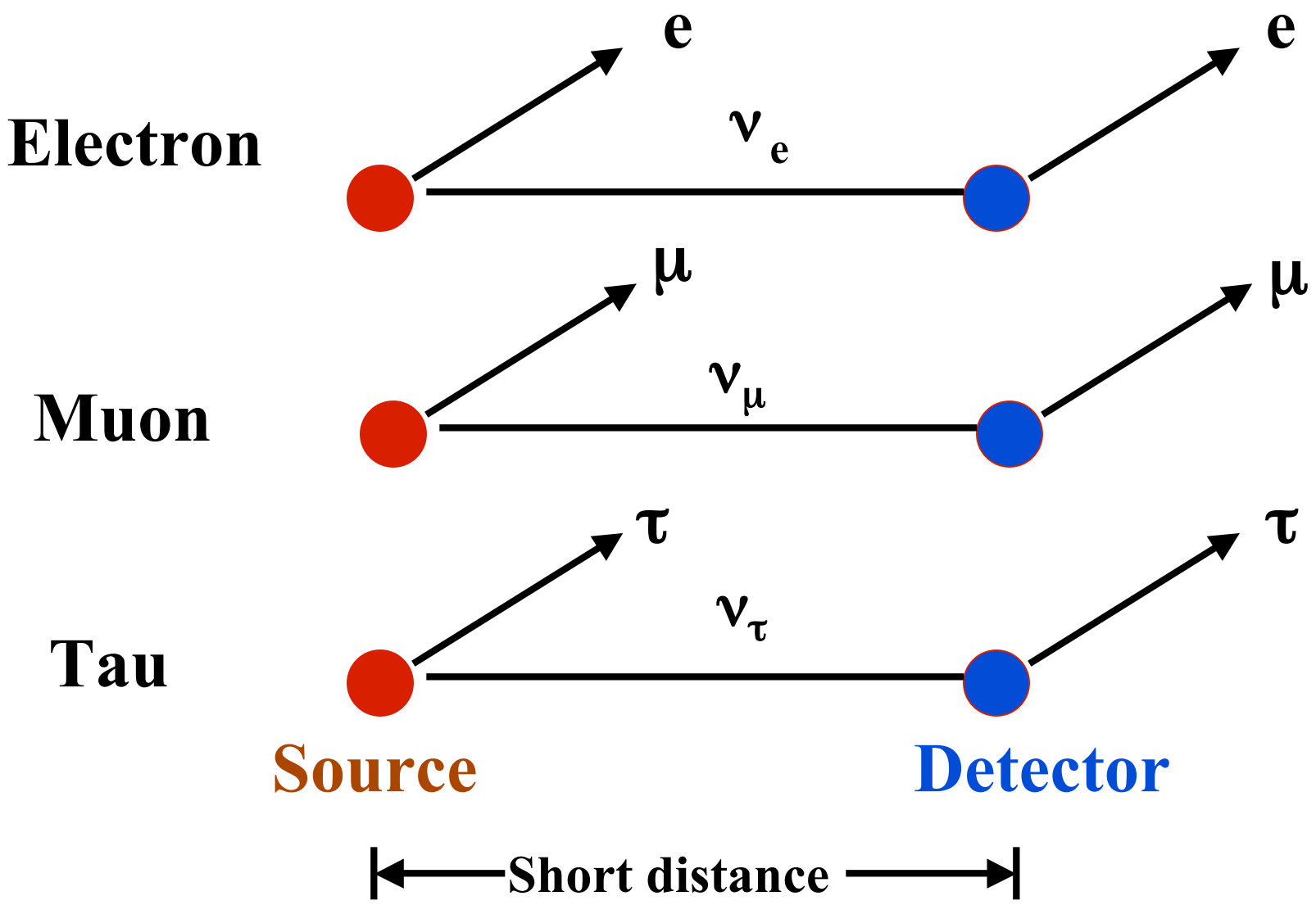
supernova

Neutrino Sources

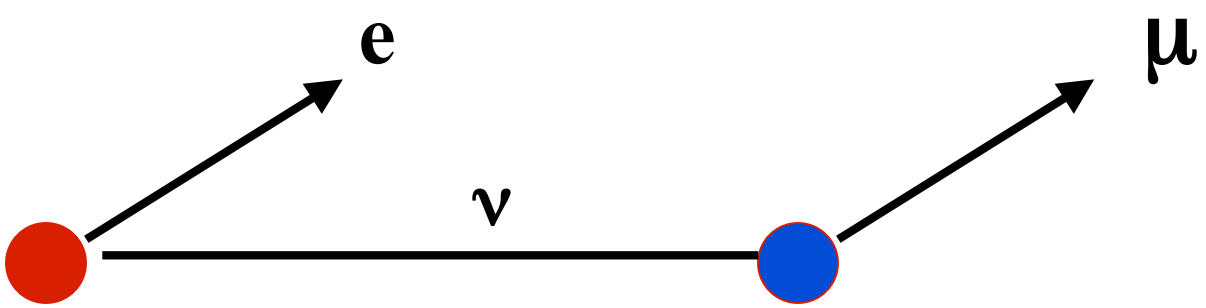
- Reactors
- Sun
- Supernova
- Cosmic Rays on Atmosphere
- Accelerators
- Radioactive Sources

- Earth
- Other Astrophysical point sources
- Sum of Past Supernova
- Cosmic Background

Three Neutrino Flavors:

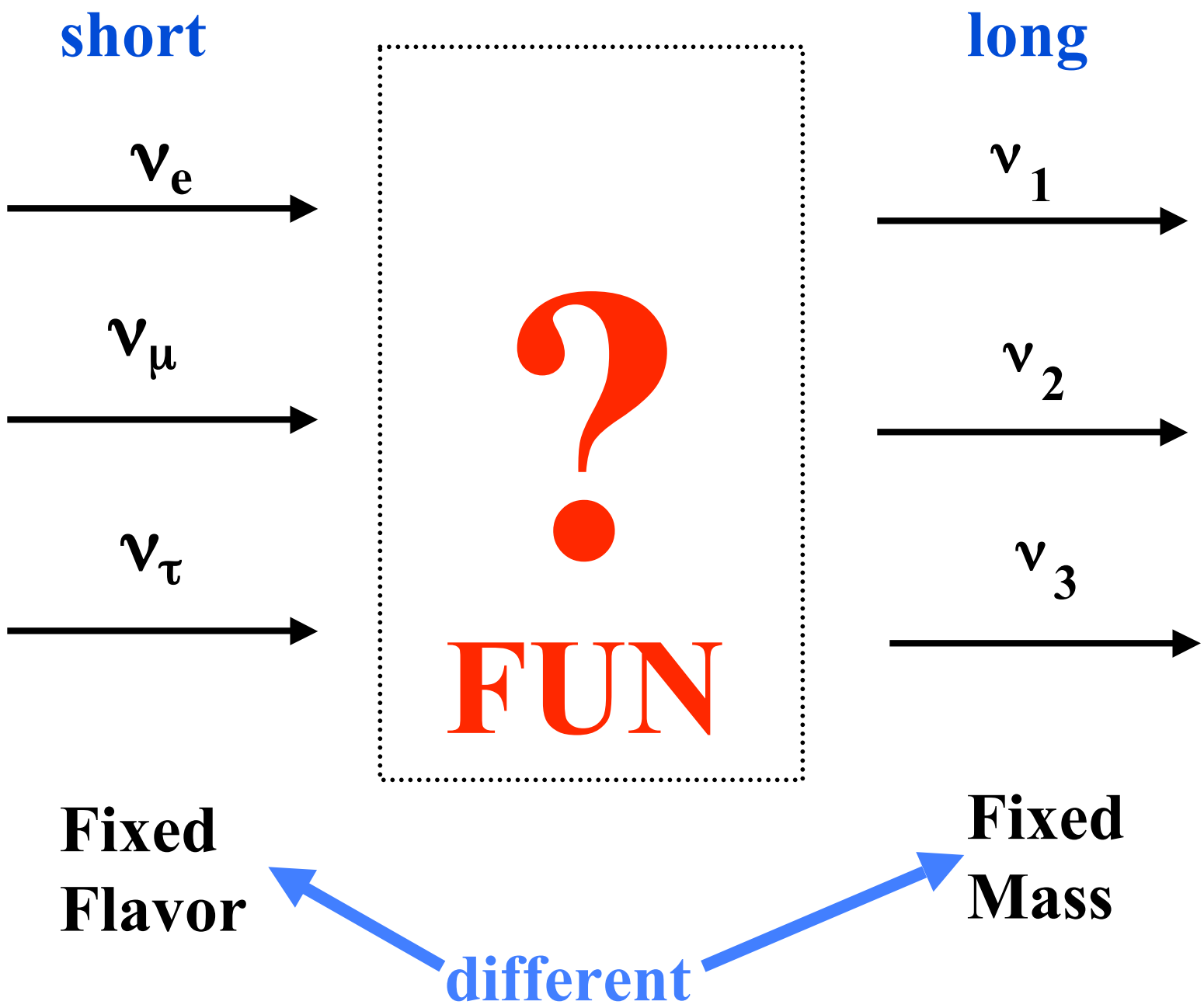


NEVER

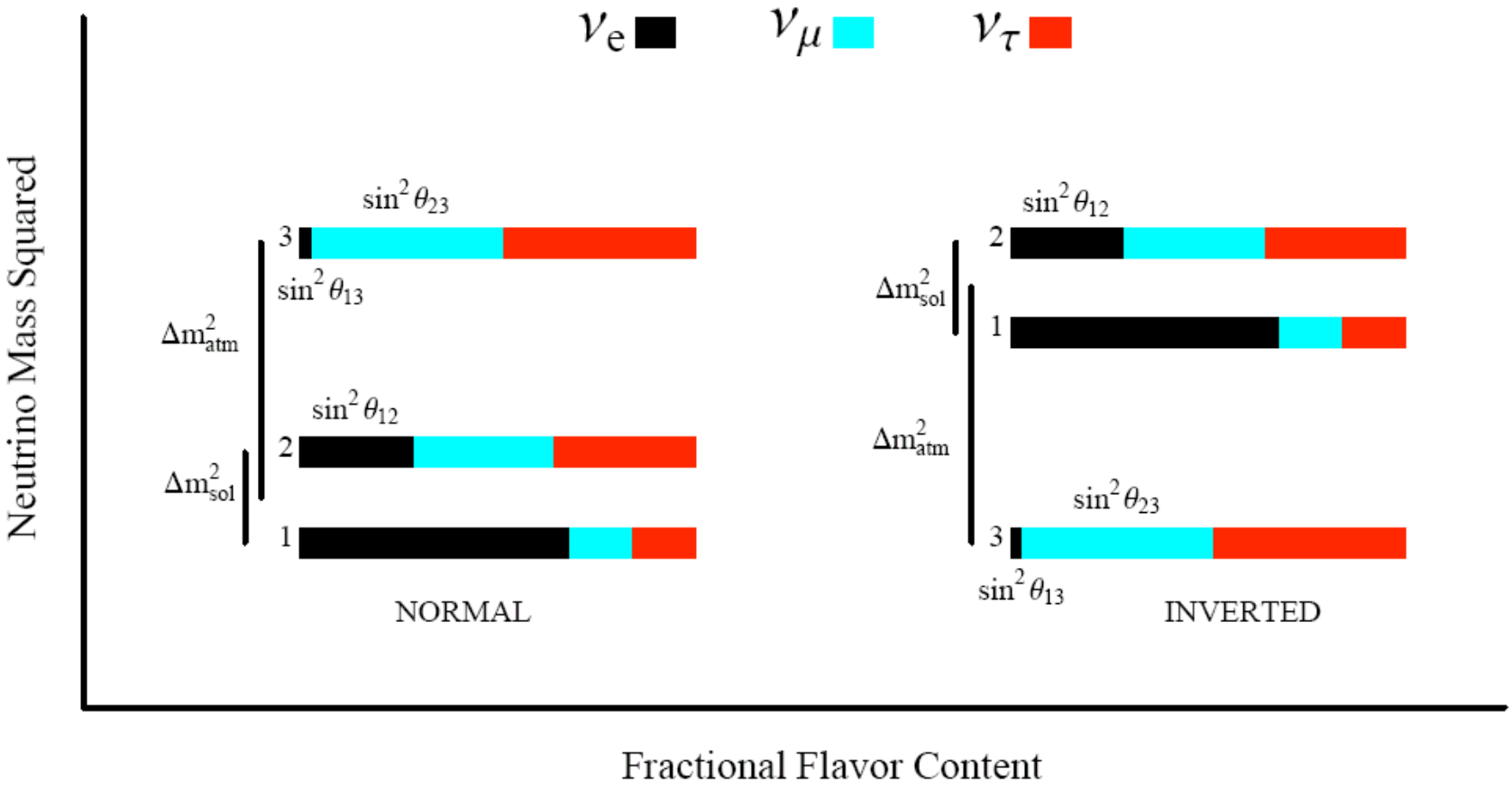


Until recently:

Long Distances needed!!!


short
long
ν_e
ν_μ
ν_τ
?
FUN
ν_1
ν_2
ν_3
Fixed
Flavor
different
Fixed
Mass

Flavor content of Mass states:

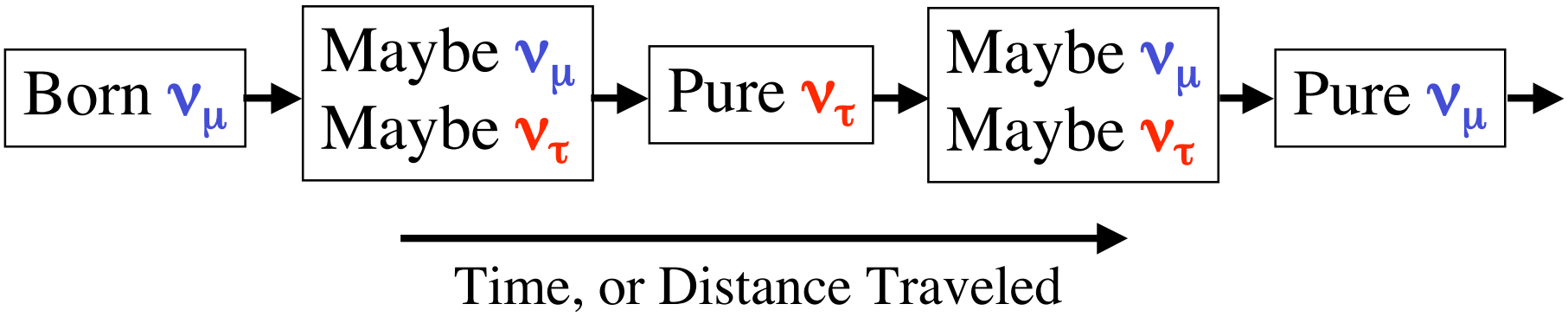


?

FUN

Here the world is truly Quantum Mechanical.

ν_μ **can oscillate into** ν_τ **and back again**



Neutrino Oscillations:

$$P(\nu_\mu \to \nu_\tau) = \sin^2 2\theta \quad \sin^2 \left\{ \frac{\delta m^2 L}{4\hbar c E_\nu} \right\}$$

Amplitude: $\sin^2 2\theta$

Oscillation length: $L_0 = \dfrac{4\pi\hbar c E_\nu}{\delta m^2}$

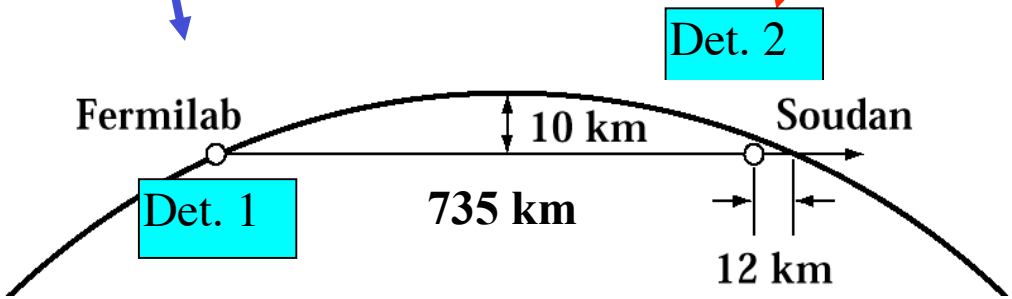
$$L_0 \to 0 \quad \text{when} \quad \hbar \to 0$$

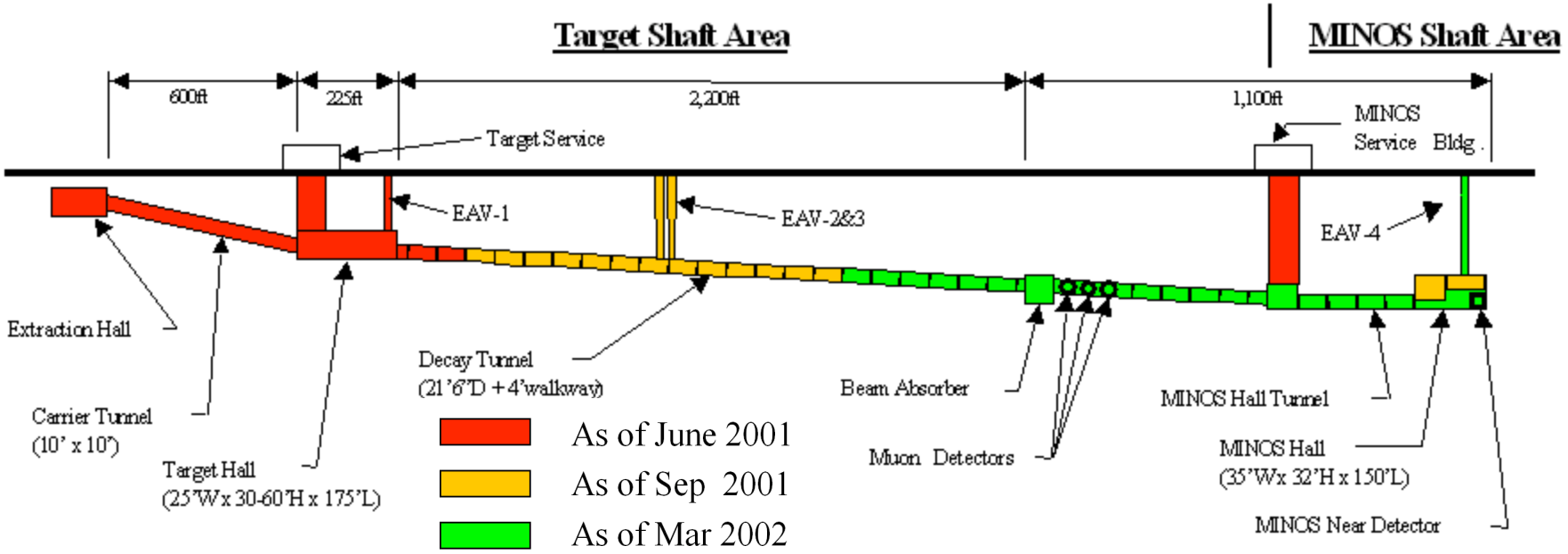
Macroscopic quantum phenomena

The MINOS Experiment

Near Detector: 980 tons

Far Detector: 5400 tons



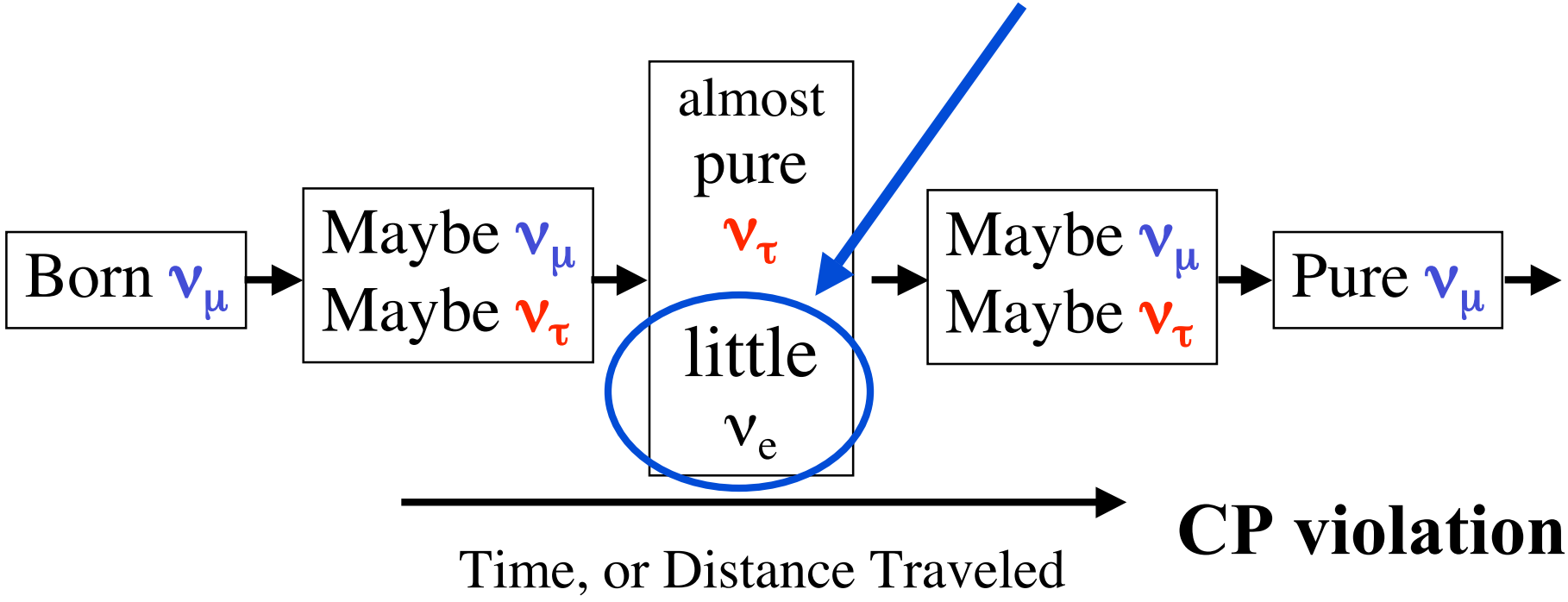


T

First piece of decay pipe

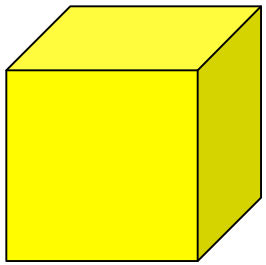
and

Neutrinos behave differently than Anti-Neutrinos



Neutrinos from the BIG BANG

1 cm^3



300 ν from Big Bang
(more than 100x solar)

30,000,000 inside YOU!!!

Neutrinos are Everywhere
Abundant but Elusive

The Asymmetry in the behavior of

Neutrinos verses Anti-Neutrinos

may explain why the universe is

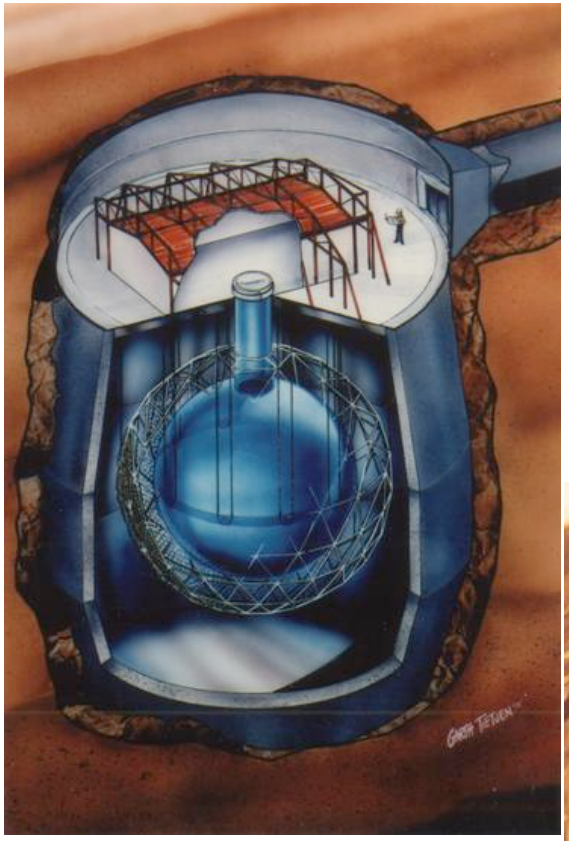
now dominated by matter

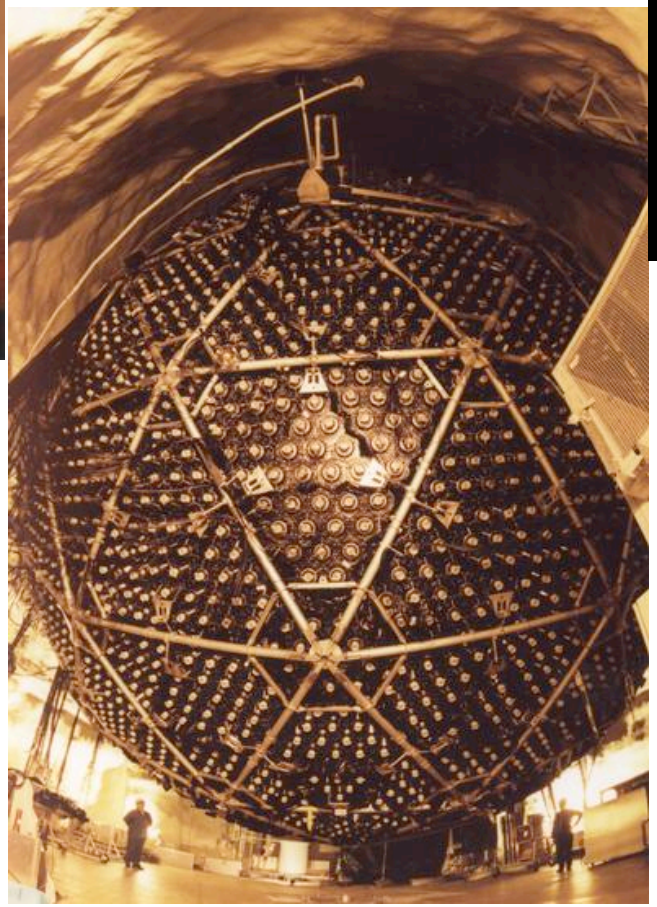
and

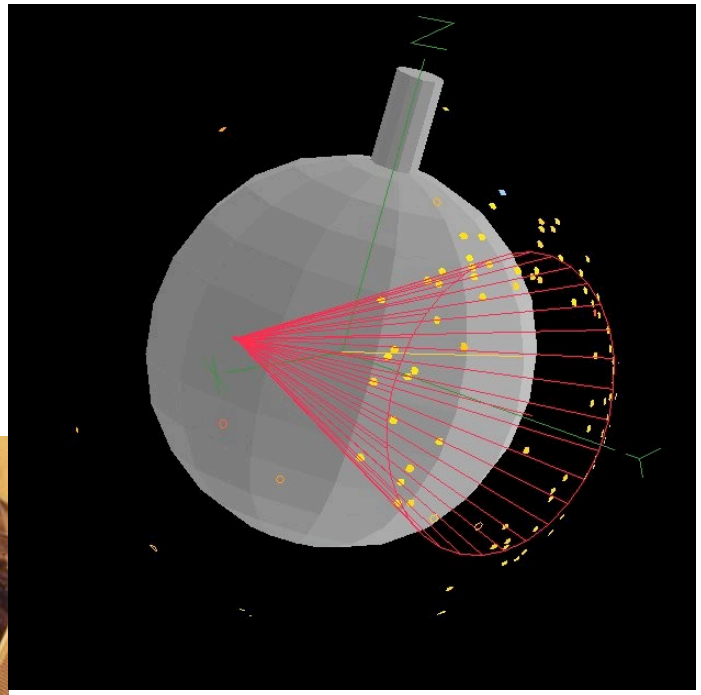
not equal parts

matter and anti-matter !

Sudbury Neutrino Observatory



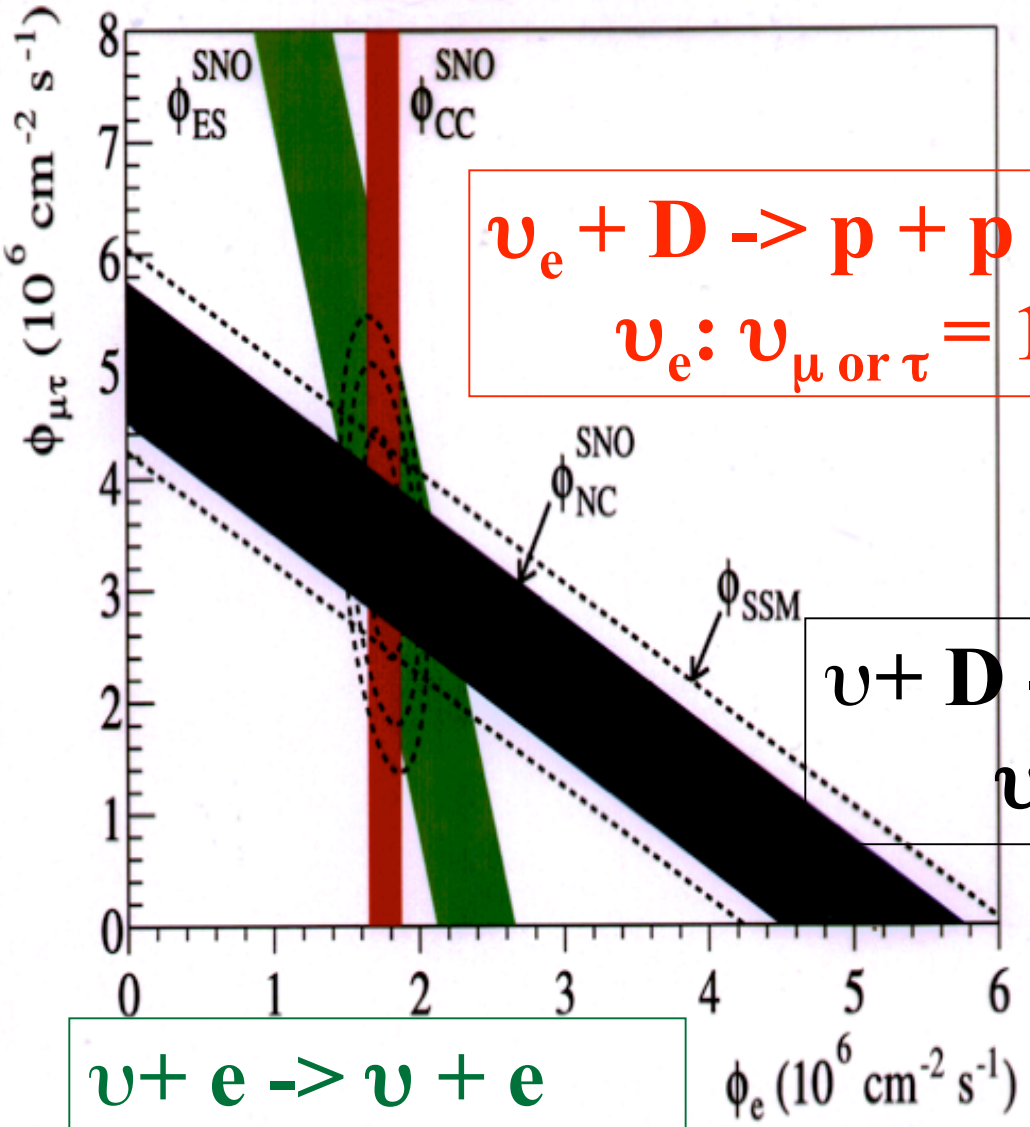




1000 tons Of D_2O

Solar Neutrinos

— SNO —



$\upsilon_e + D \rightarrow p + p + e$

$\upsilon_e : \upsilon_{\mu \text{ or } \tau} = 1:0$

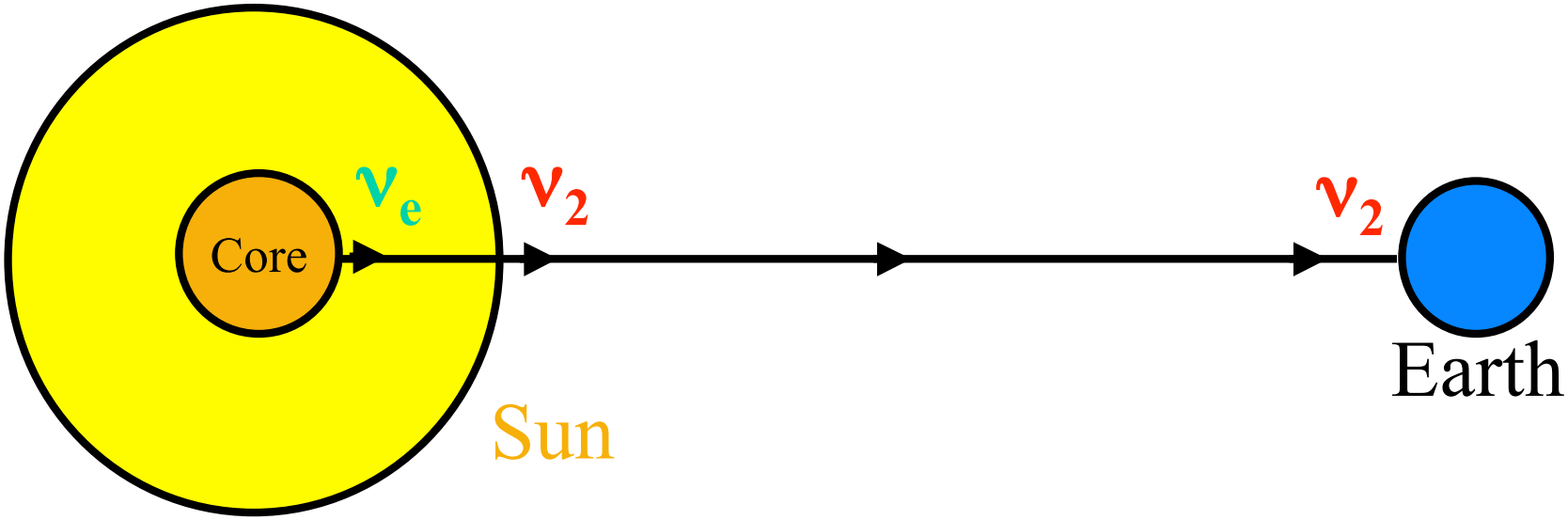
$\upsilon + D \rightarrow p + n + \upsilon$

$\upsilon_e : \upsilon_{\mu \text{ or } \tau} = 1:1$

$\upsilon + e \rightarrow \upsilon + e$

$\upsilon_e : \upsilon_{\mu \text{ or } \tau} = 1:1/6$

After 40 years of ^{8}B Solar Nu Exp.



Born as ν_e they exit the Sun and arrive at the earth as ν_2 !!!

ie approx equal mixture of ν_e , ν_μ and ν_τ

KamLAND

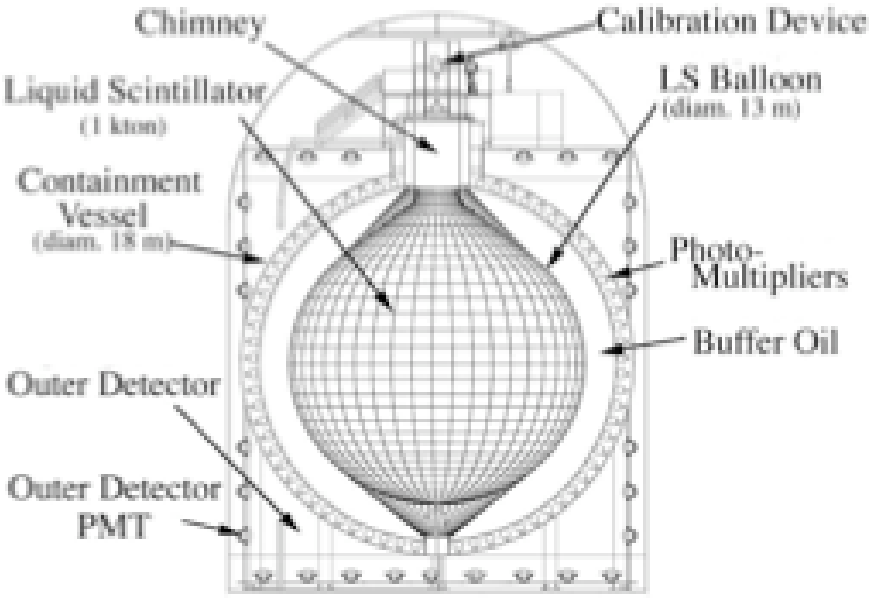
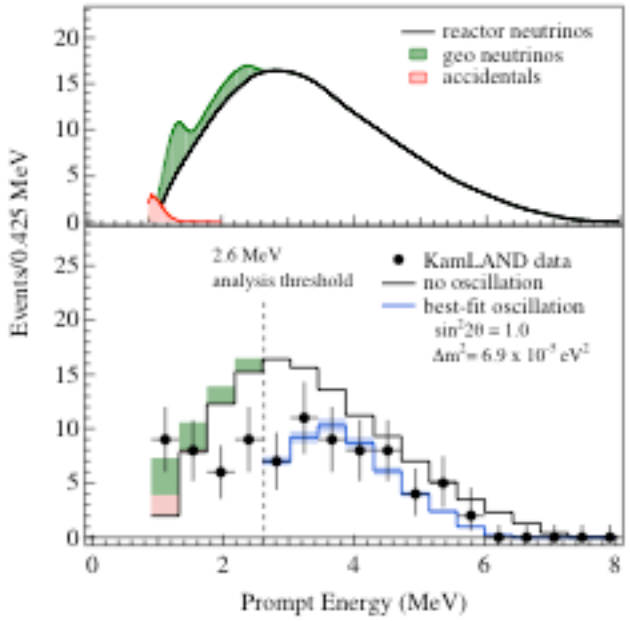
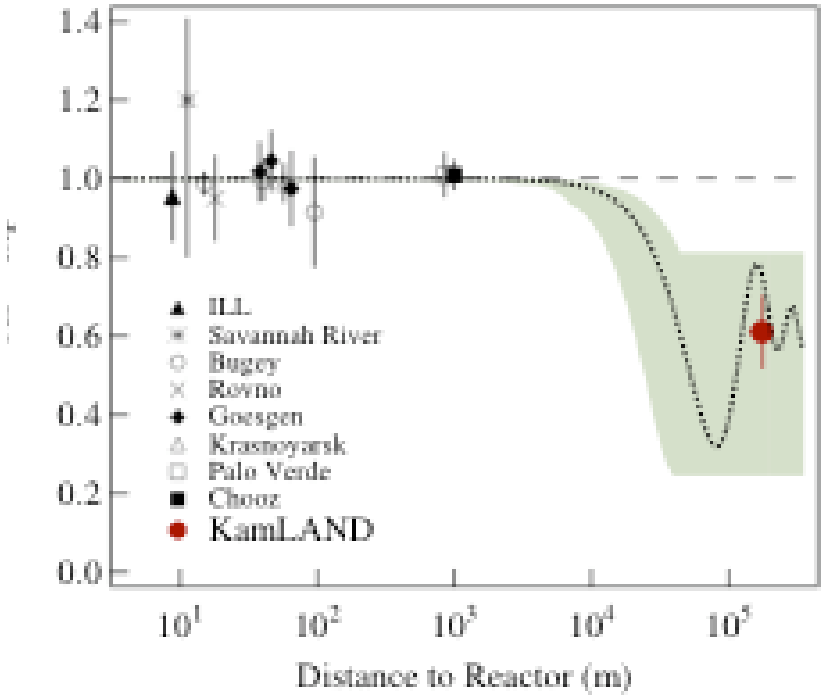
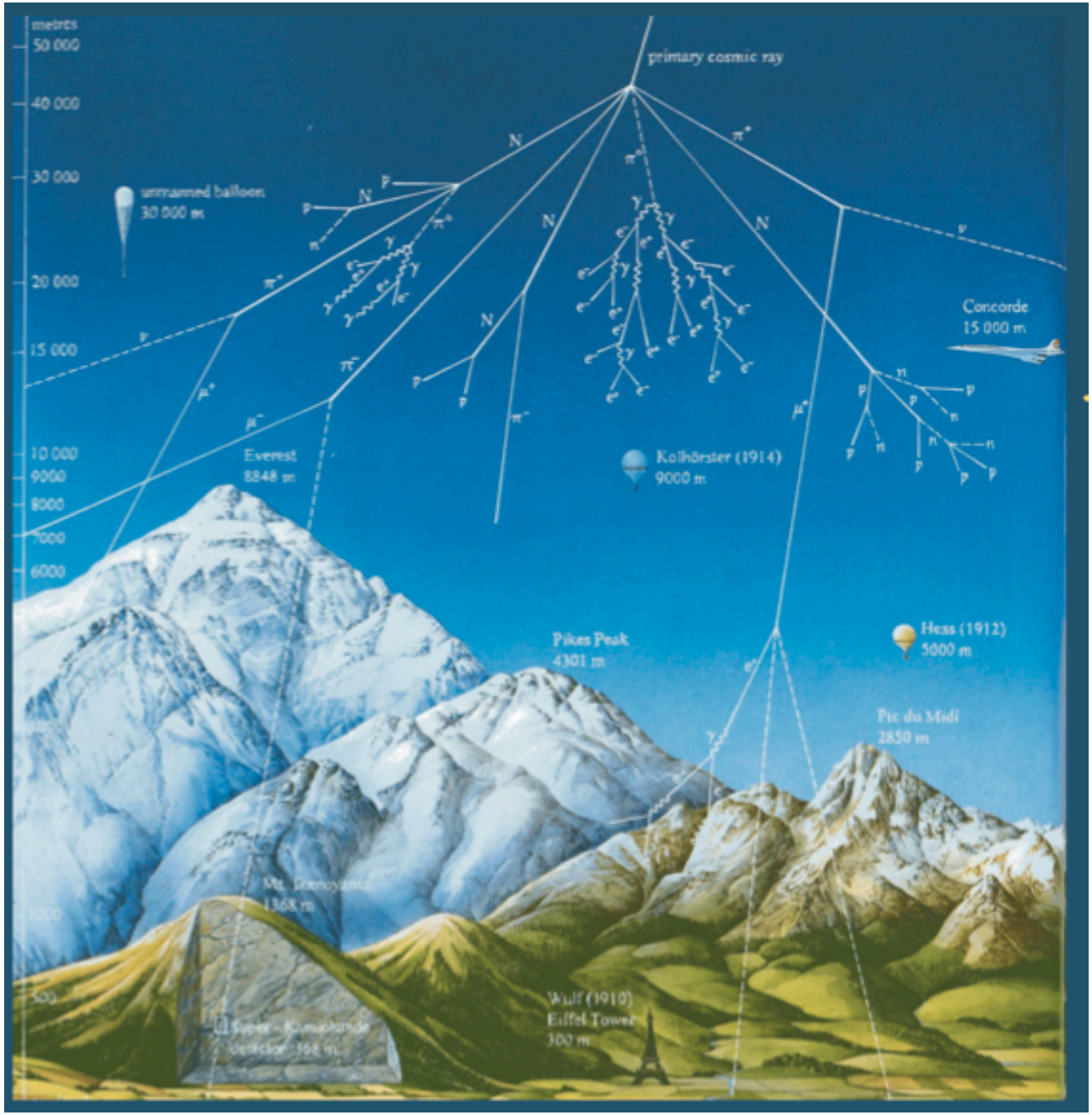


FIG. 1: Schematic diagram of the KamLAND detector.

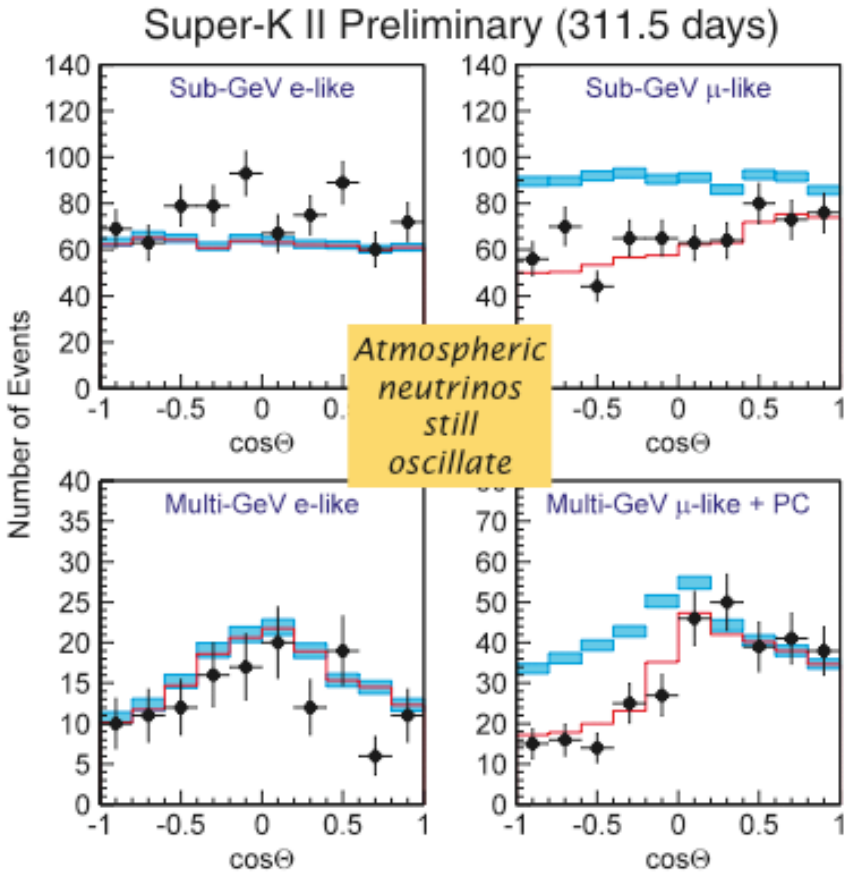




SuperK Atmospheric Neutrinos



Status of Super-K II Atmospheric Neutrinos

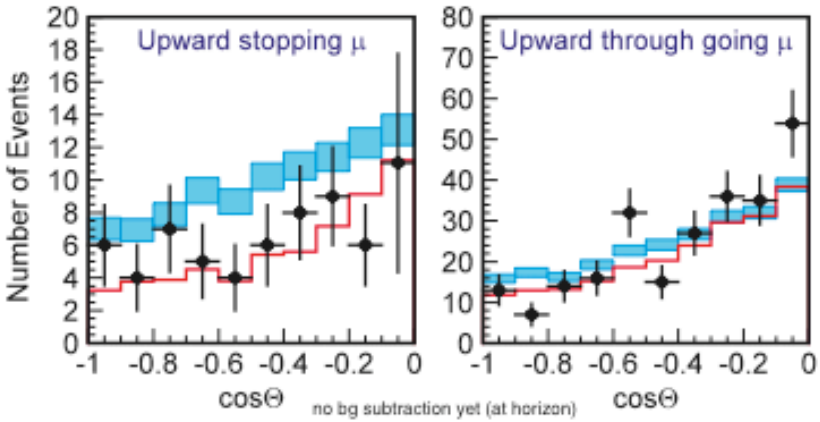


FC data reduction:
8.22 ± 0.16 ev/day (cf. 8.17 SK-I)

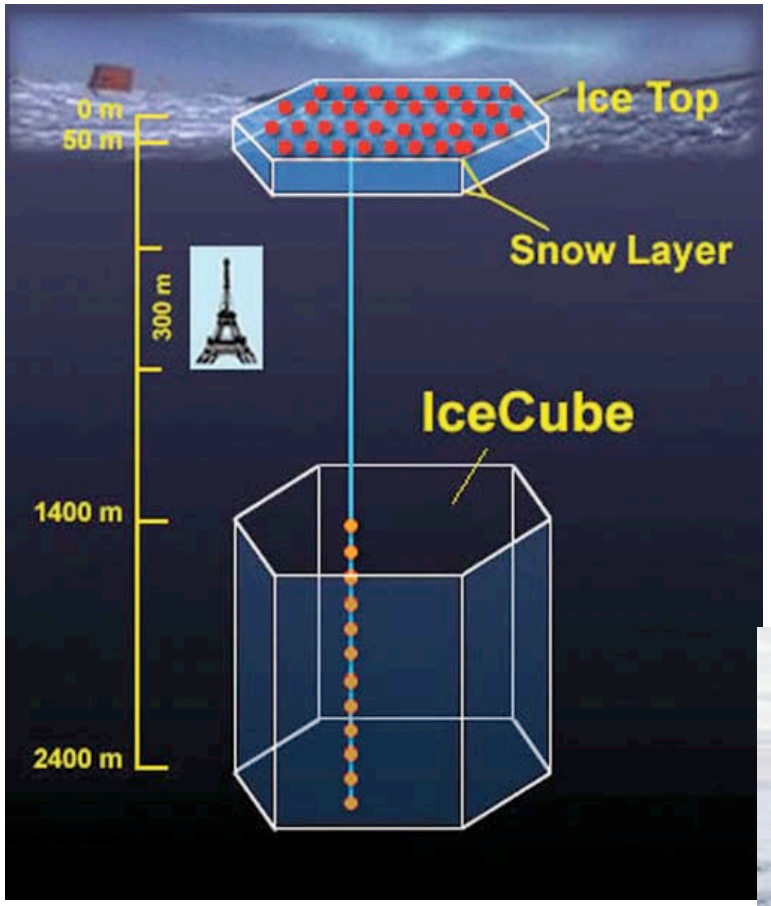
PC data reduction:
0.51 ± 0.04 ev/day (cf. 0.61 SK-I)

$R_{sub\text{-}GeV}$ = 0.61 ± 0.03 ± 0.05

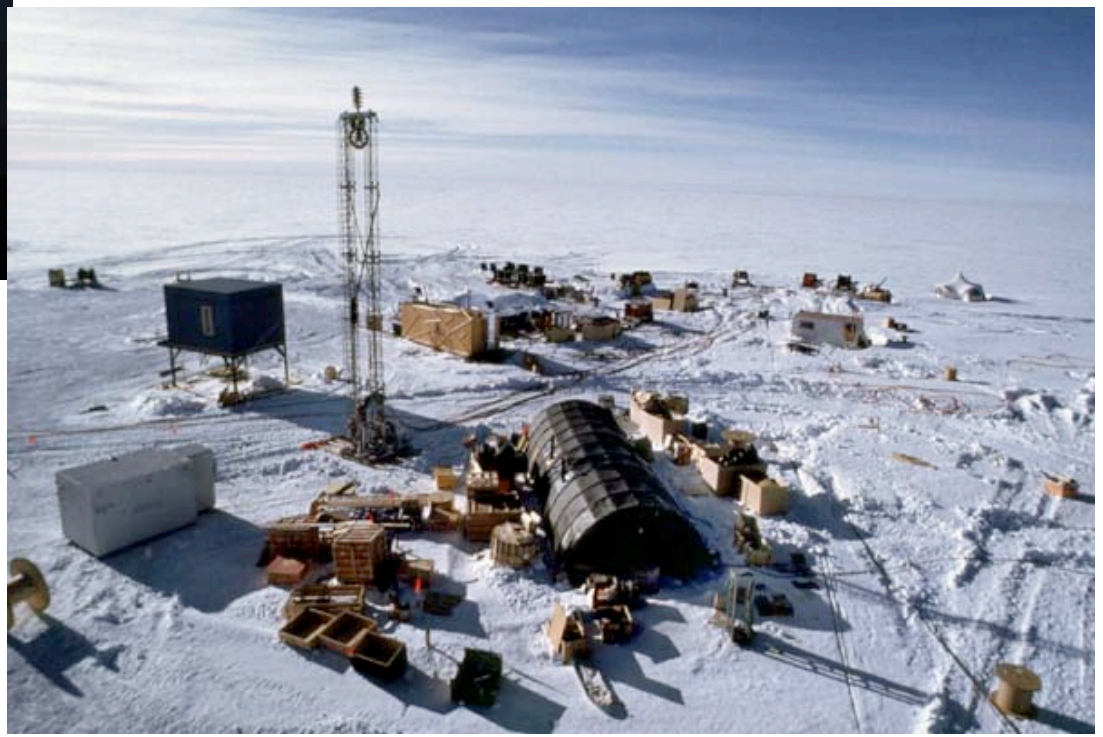
$R_{multi\text{-}GeV}$ = 0.89 ± 0.10 ± 0.16

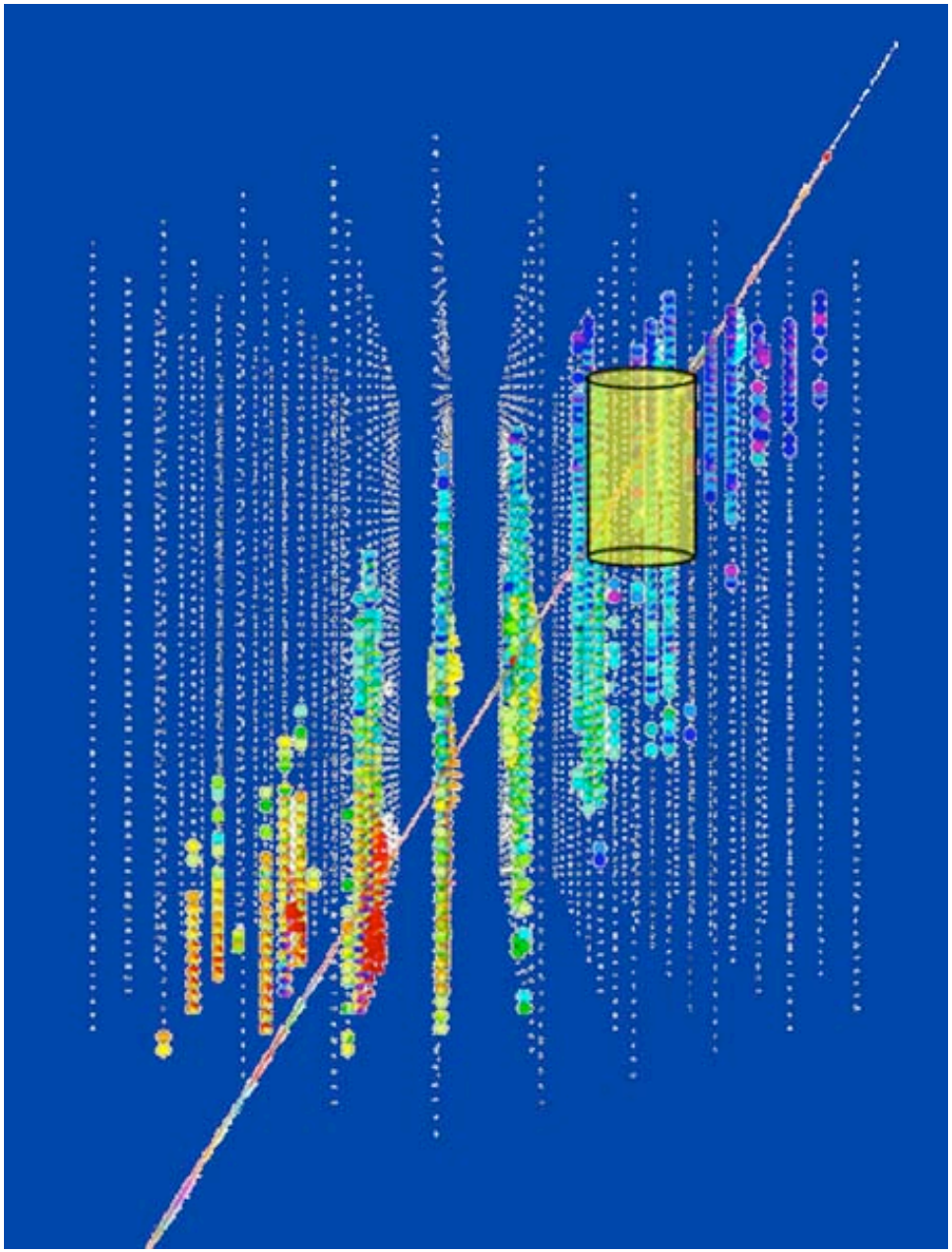


SK-II data is consistent with SK-I results. e/μ ID, energy scale look very good. Current studies emphasize ring counting, PC reduction, OD simulation.



ICE CUBE
1 Km cubed





Neutrino Telescope:

looking for rare high energy Neutrinos from point Sources.

Cosmic Gall

by **John Updike** NYer 1960

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids through a drafty hall
Or photons through a sheet of glass.
….

http://theory.fnal.gov/people/parke/TALKS/2004

Cosmic Gall

by **John Updike** NYer 1960

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids through a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold-shoulder steel and sounding brass,
Insult the stallion in his stall,
And scorning barriers of class,
Infiltrate you and me! Like tall
And painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed-you call
It wonderful; I call it crass.

http://theory.fnal.gov/people/parke/TALKS/2004