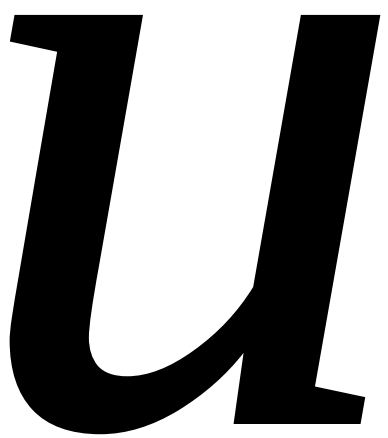
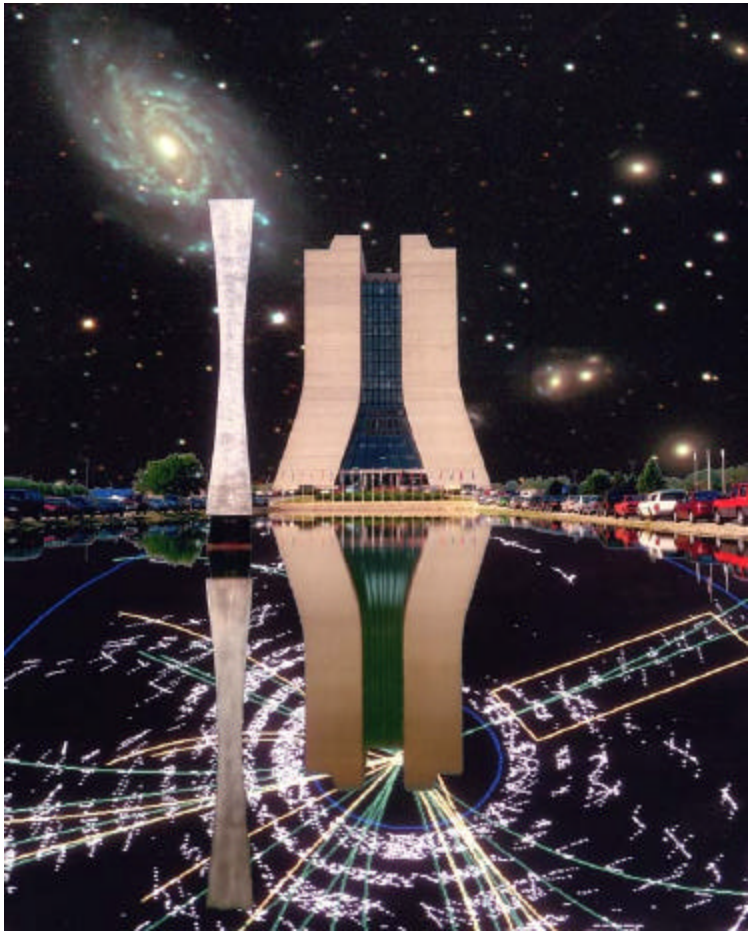


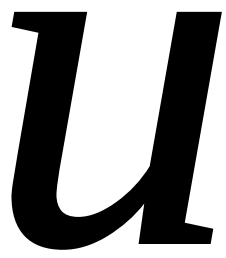
NEUTRINOS:



Ghosts of the Universe

Stephen Parke
Theoretical Physicist
Senior Scientist
Fermilab
March 21, 2004

Webster's Online Dictionary



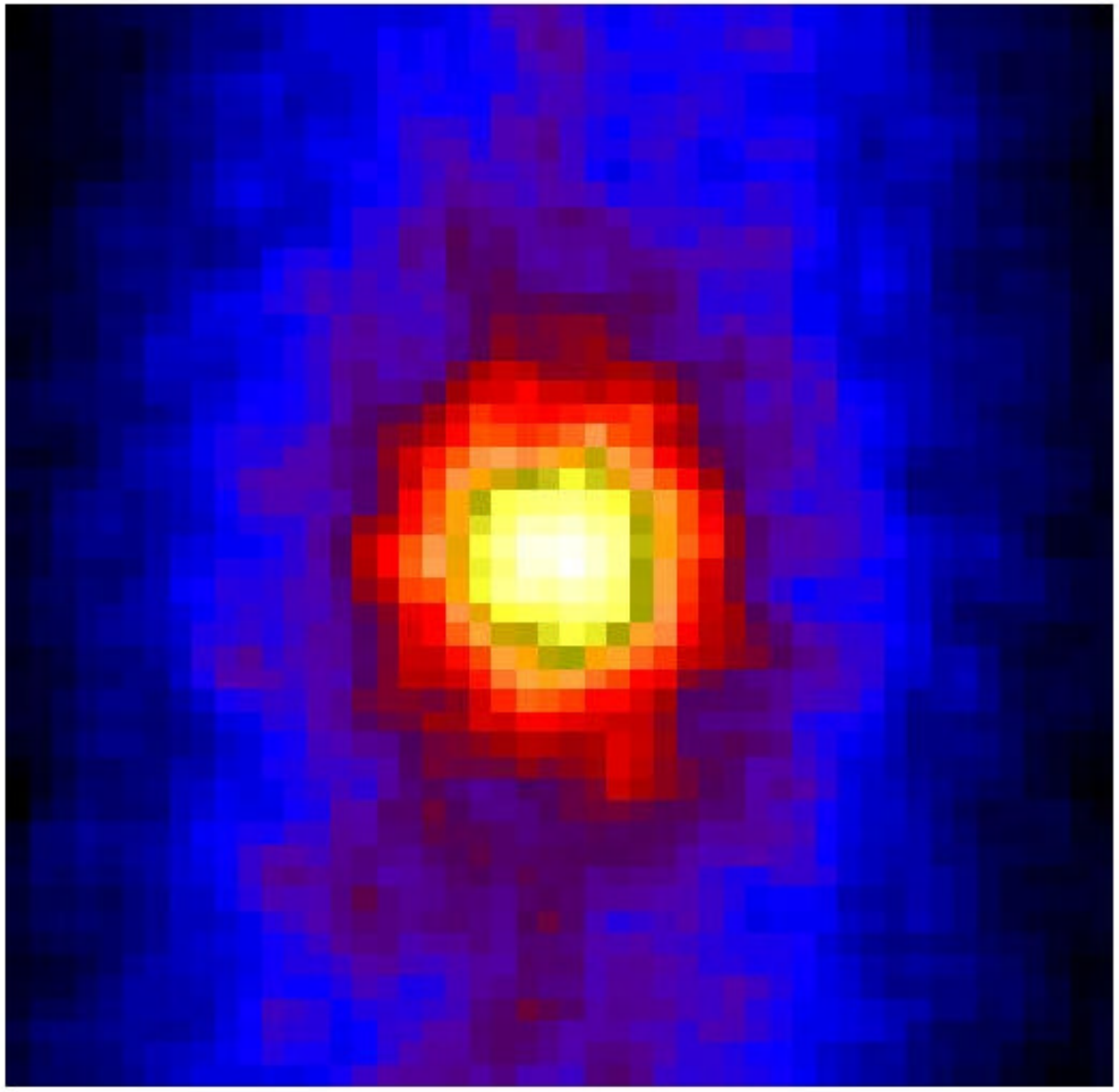
Main Entry: **neu·tri·no**
Pronunciation: nü-'trE-(")nO, nyü-
Etymology: Italian, from *neutro*

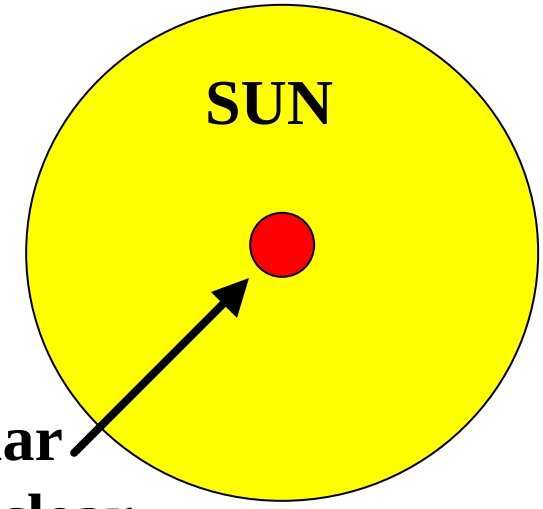
: an uncharged elementary particle that is believed to be massless or to have a very small mass,
that has any of three forms,
and that interacts only rarely with other particles

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 source

Neutrino Picture of the Sun





Solar
Nuclear
Reactor

4 protons + 2 electrons

Helium Nucleus (2p2n)

+

2 Neutrinos (2?)

+

Energy

at the earth

Using $E=mc^2$

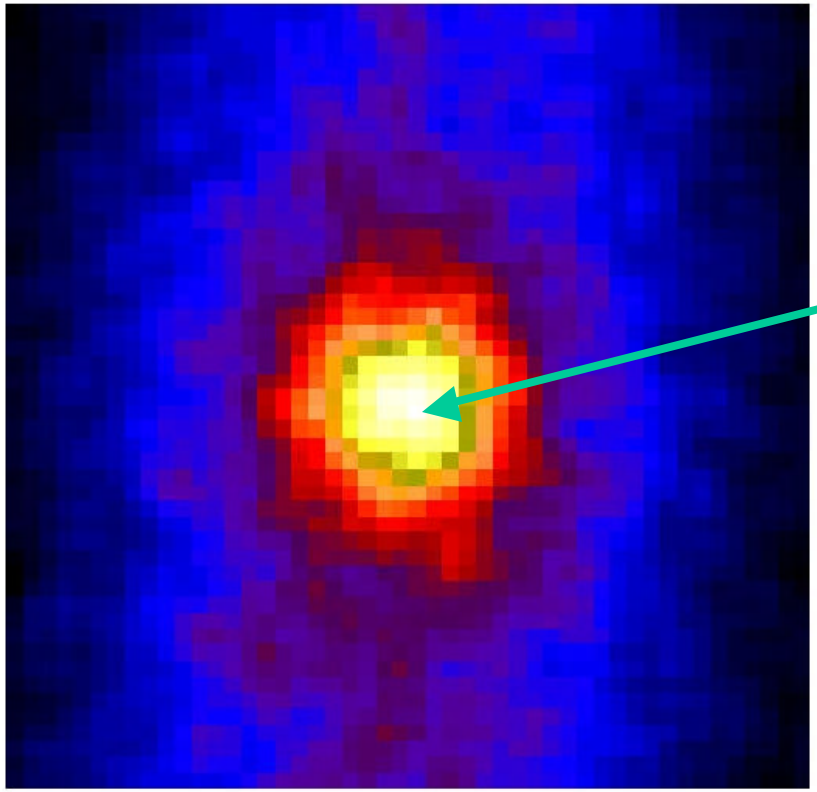
60,000,000,000 ?

per square cm 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”

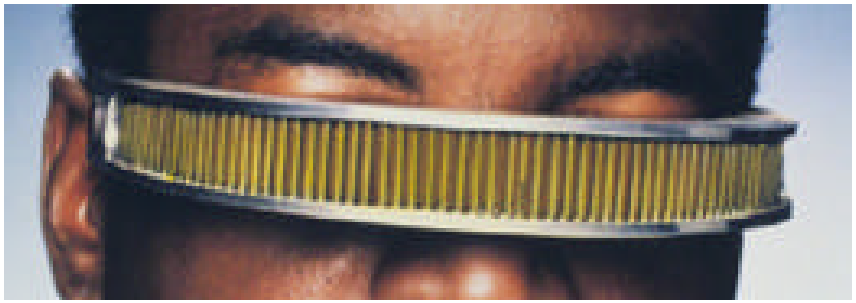
The Energy produced takes 1,000,000 yrs to get to the surface.

The Neutrinos take 2 seconds to get to the surface.

From the surface of the Sun to Earth takes 8 minutes.

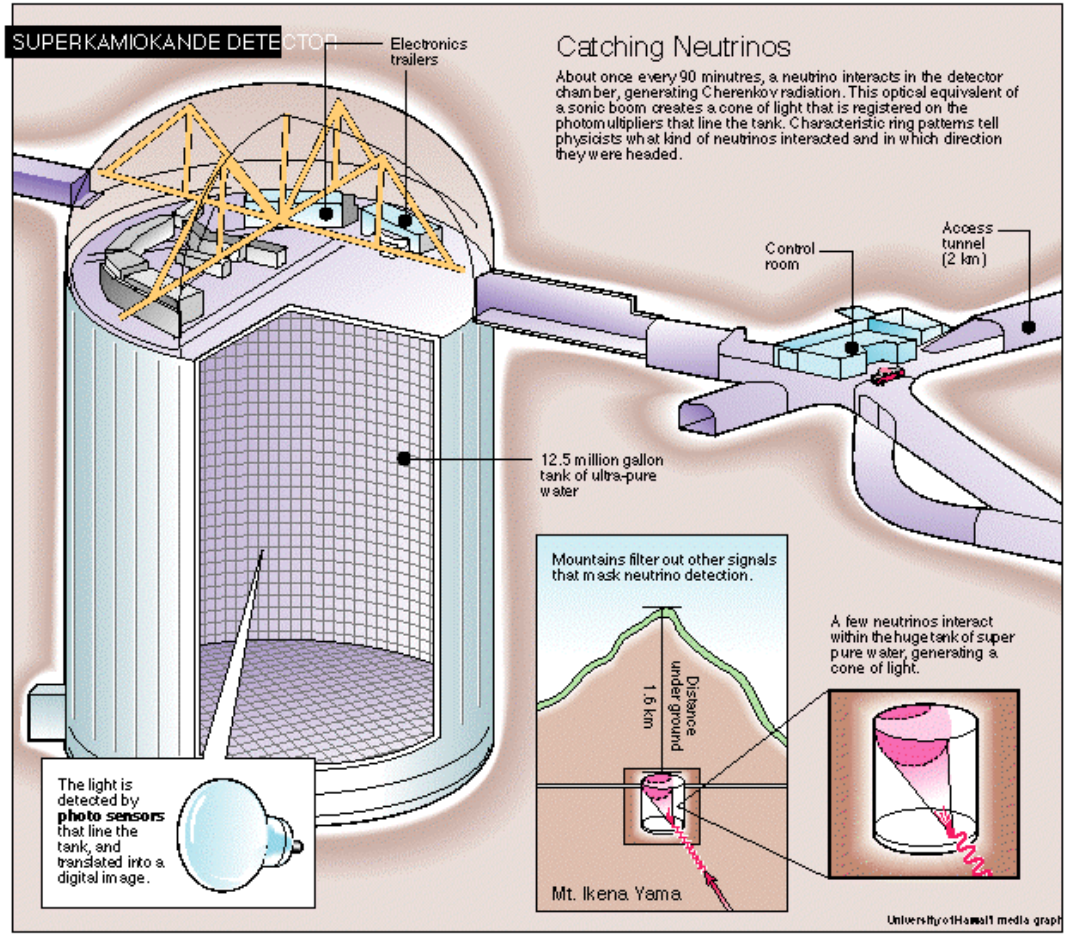
Star Trek: The Next Generation

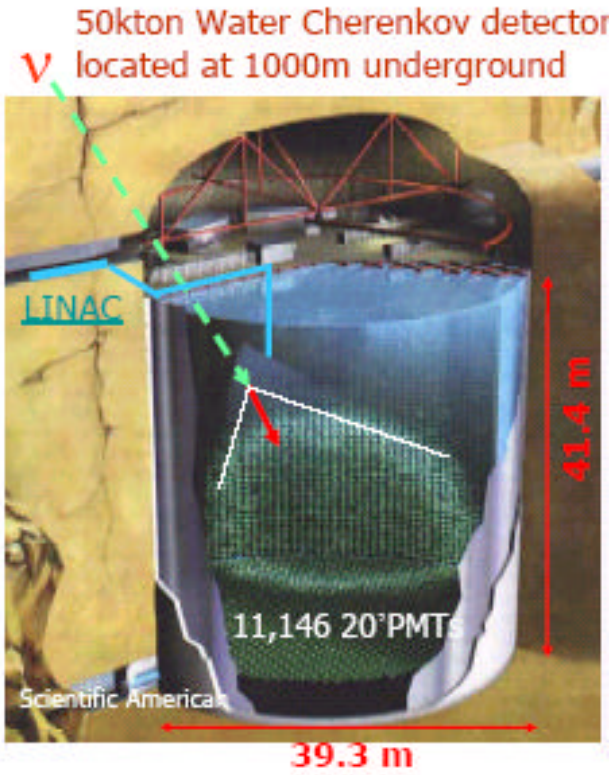
Geordi La Forge: in “The Enemy”



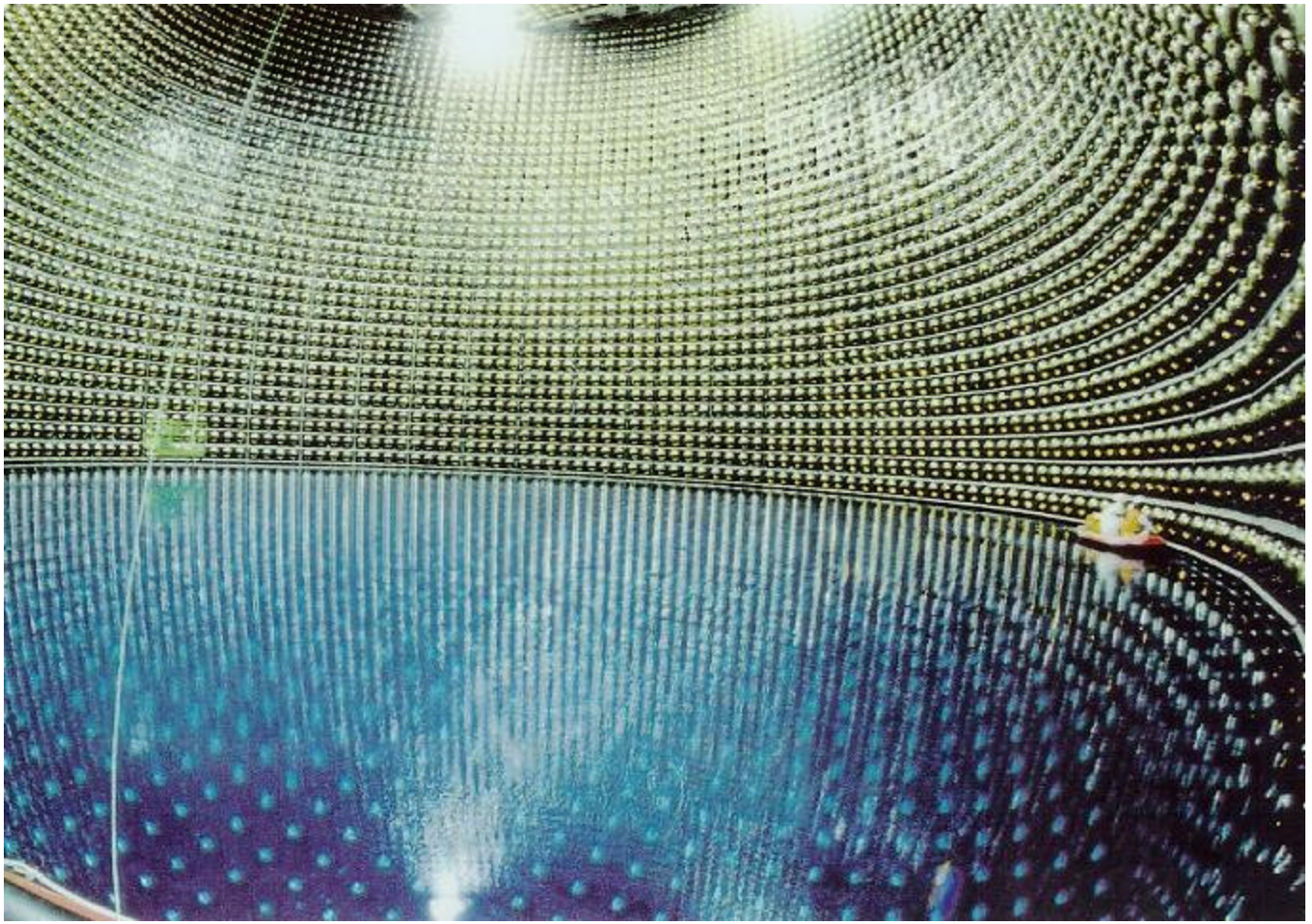
The visor “sees” Neutrinos!!!

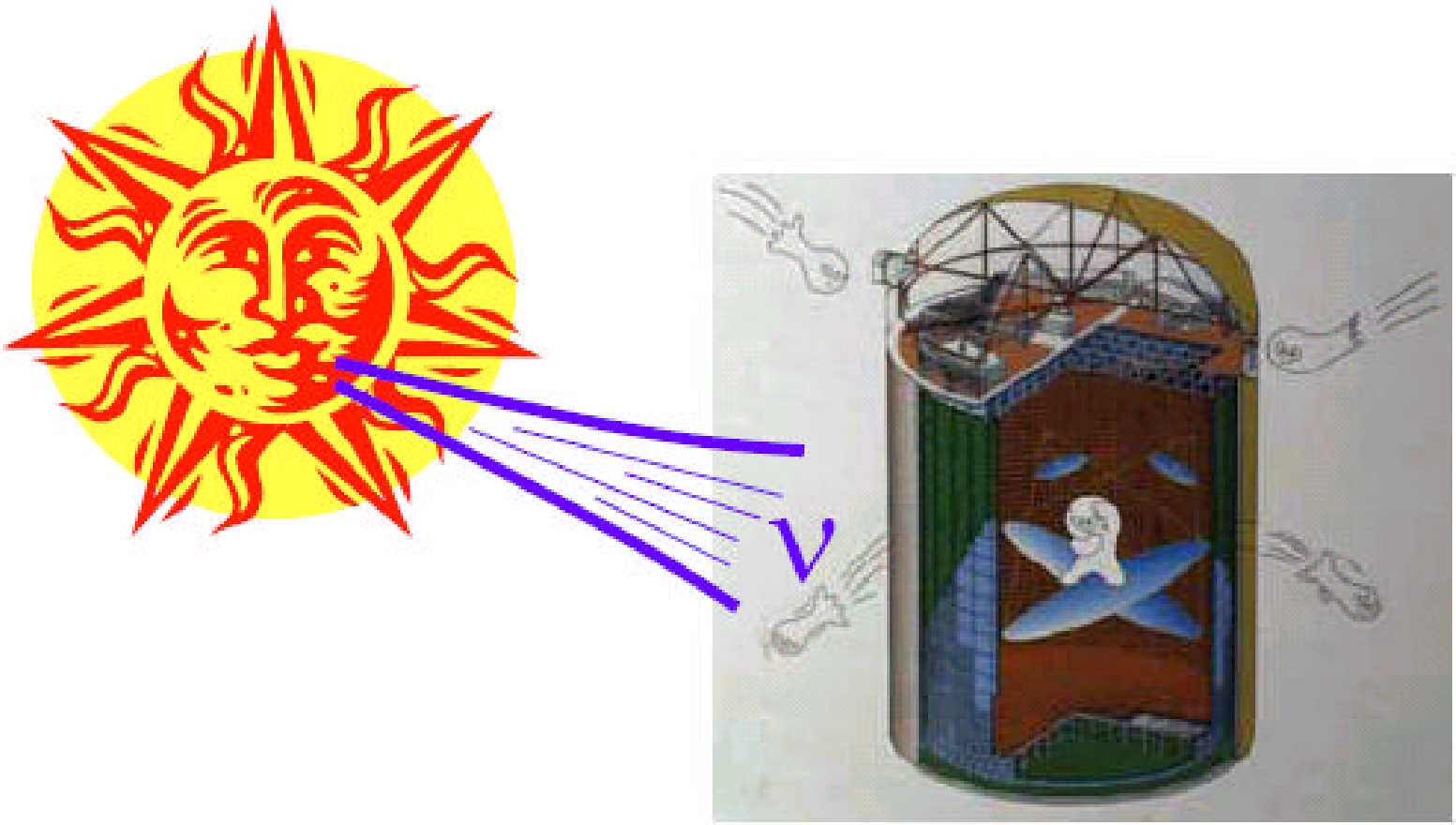
SuperKamiokande



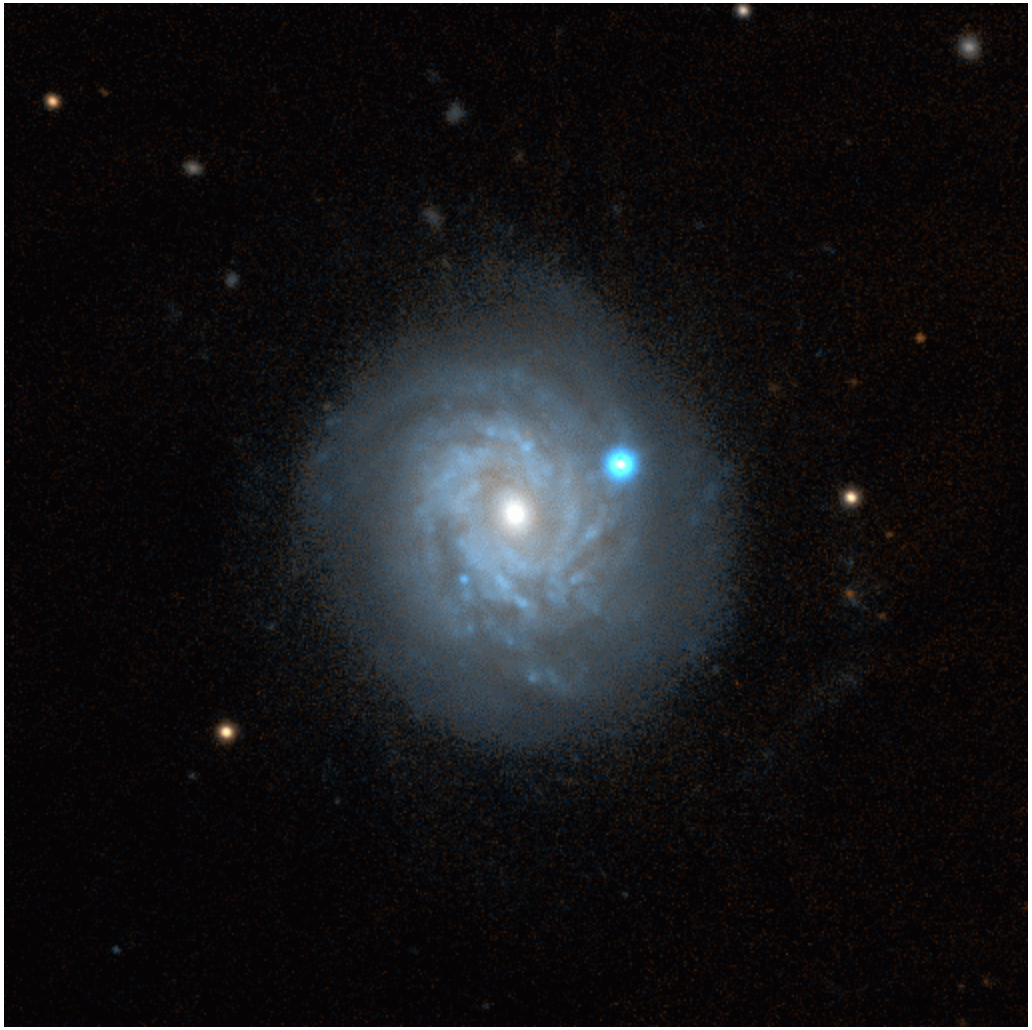


SuperKamiokande

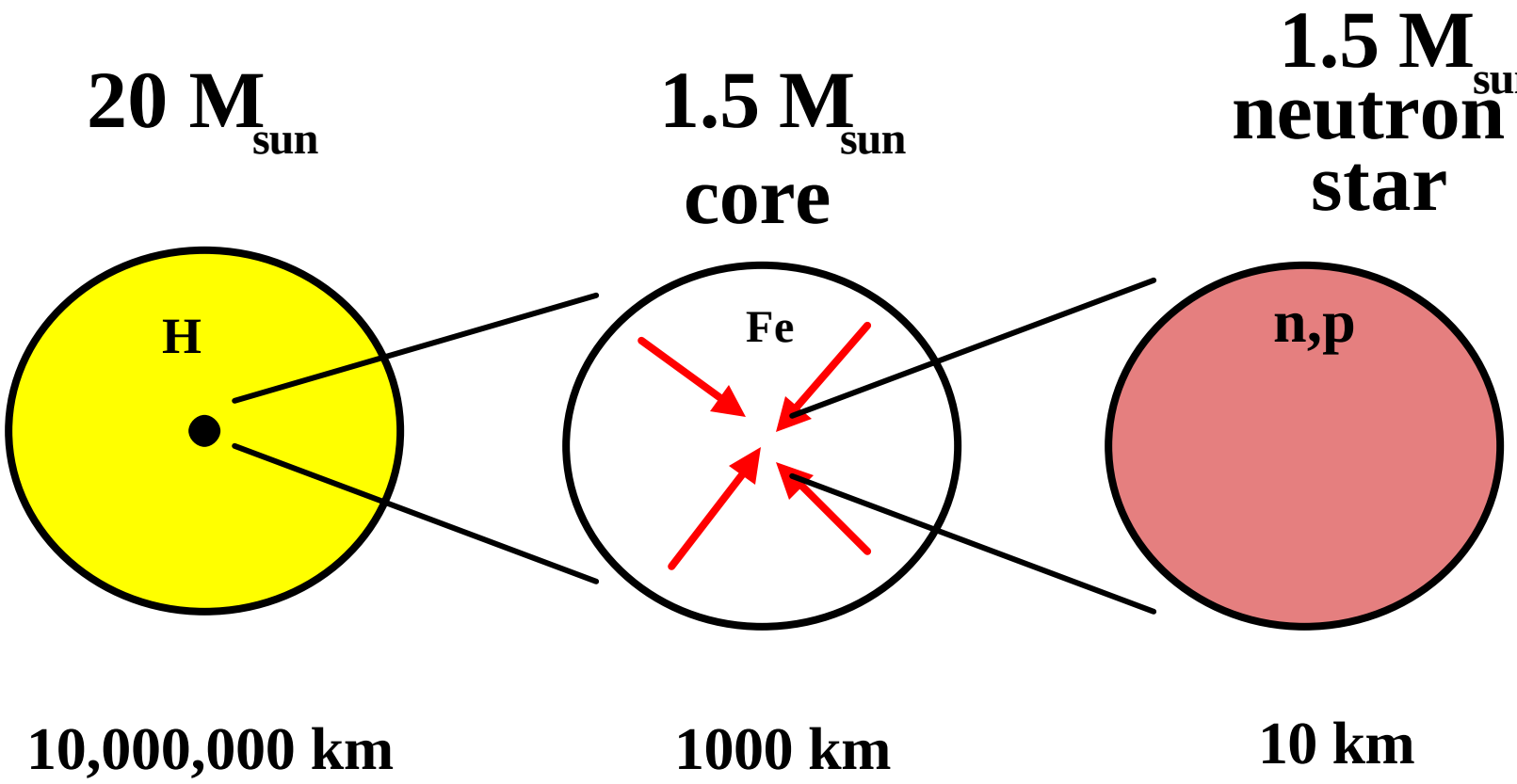



ν

Supernova



Mechanics of a Supernova



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

equivalent to 0.1 M_{sun}

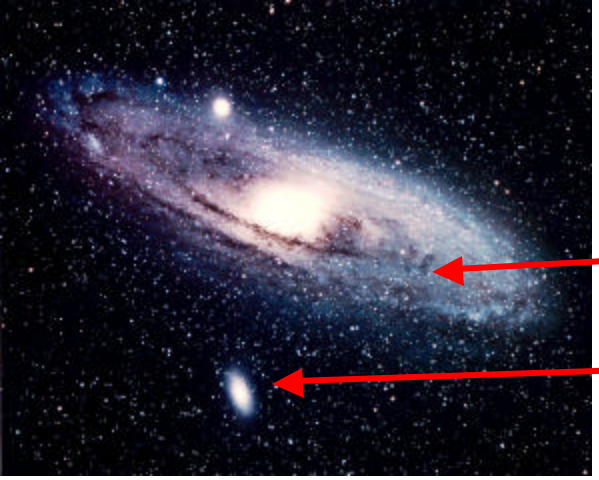
Supernova Energy Budget = $100

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

Light show lasts months

whereas

Neutrino tsunami lasts 10-20 seconds!!!



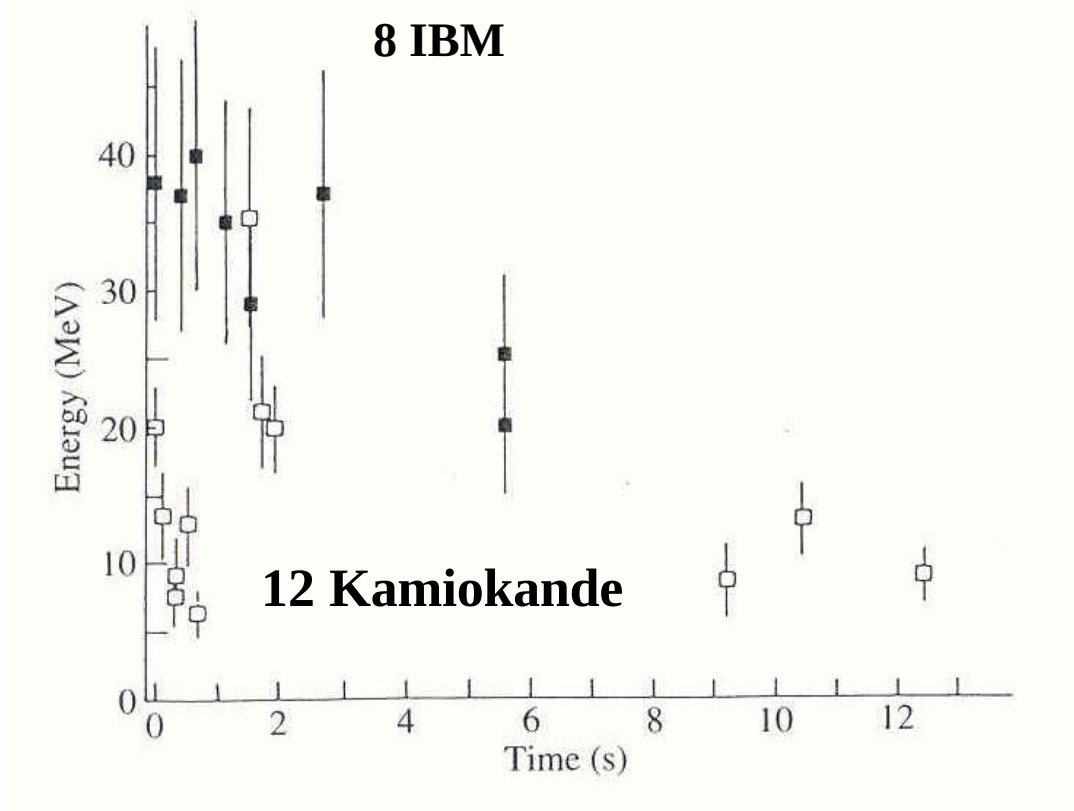
Supernova 1987a - Feb 24

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
from supernova in our galaxy are on their way !!!

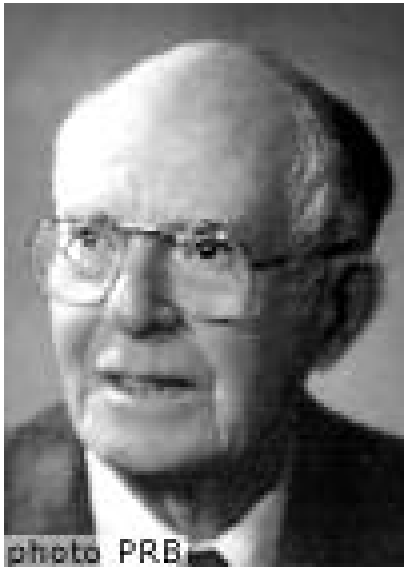
Bigger Detectors, More Detectors

Rate ? One every 10 to 30 years

Nobel Prize 2002

"….for the detection of cosmic neutrinos"

Davis, USA



solar

Koshiba, Japan

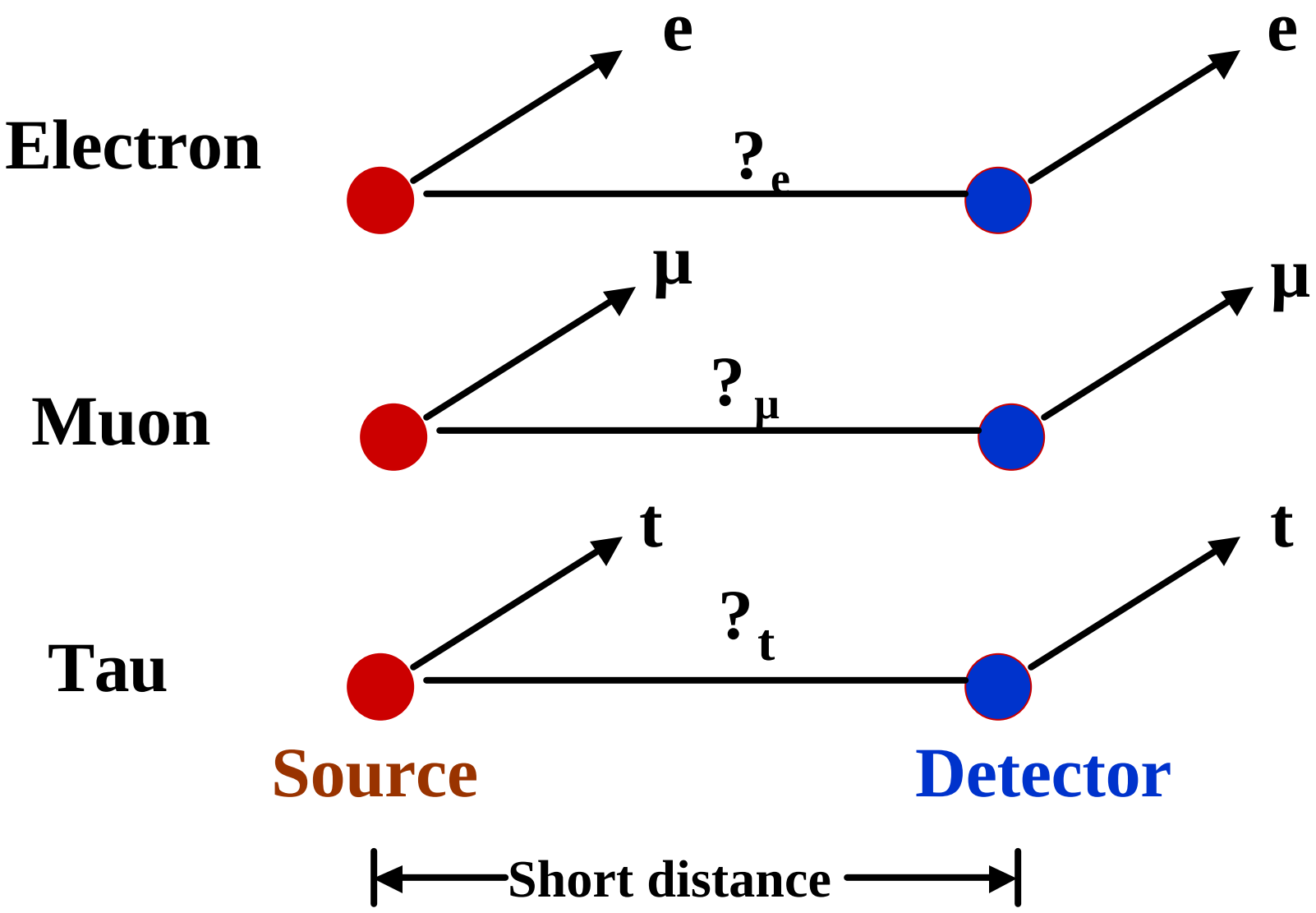
supernova

Neutrino Sources

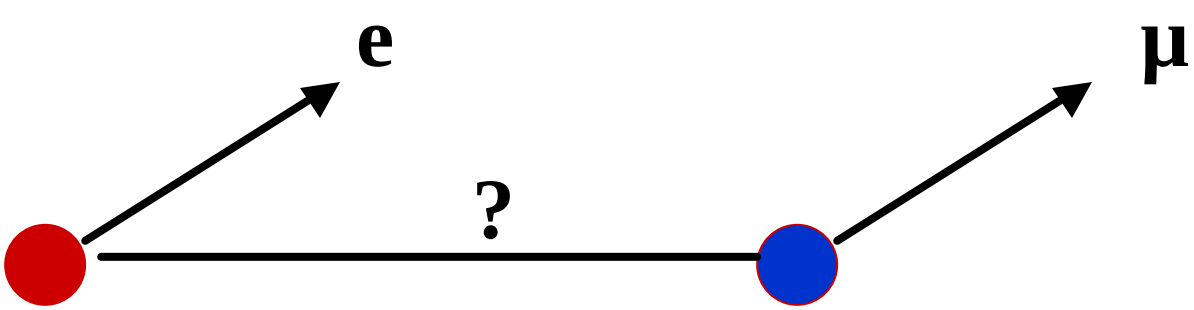
- **Reactors**
- **Sun**
- **Supernova**
- **Cosmic Rays on Atmosphere**
- **Accelerators**
- **Radioactive Sources**

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

Three Neutrino Flavors:

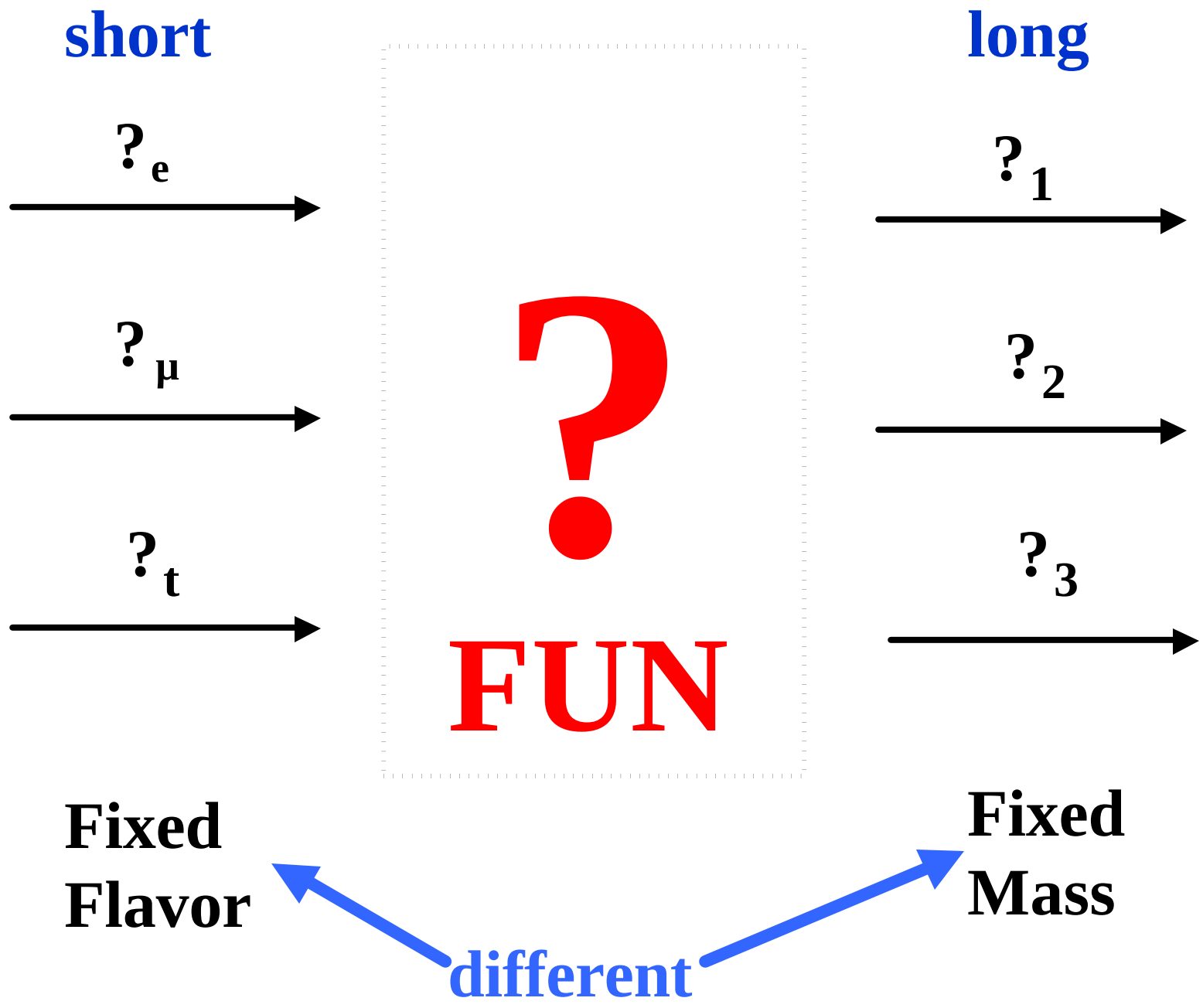


NEVER

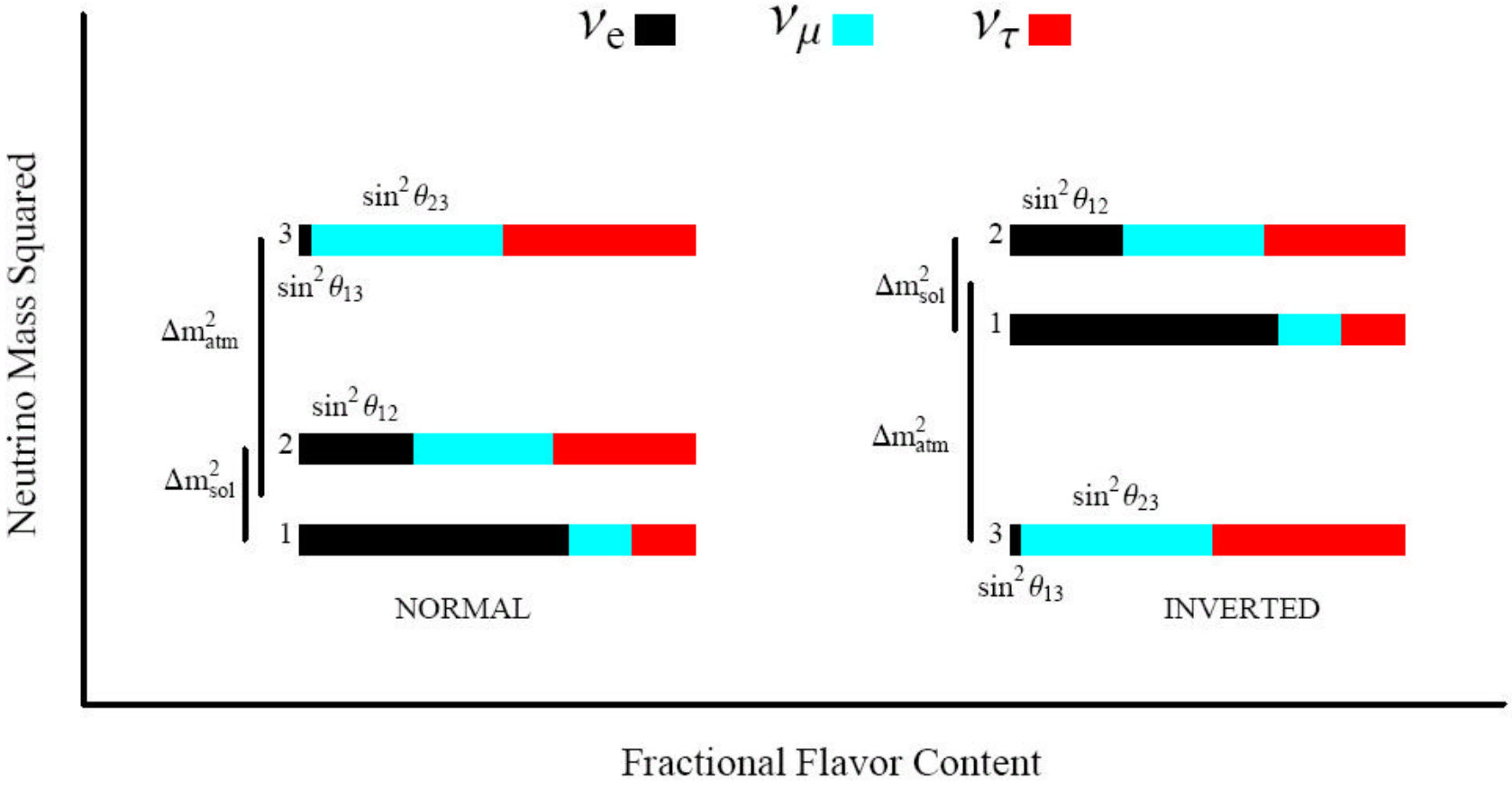


Until recently:

Long Distances needed!!!


short
long
?e
?μ
?t
?1
?2
?3
?
FUN
Fixed
Flavor
Fixed
Mass
different

Flavor content of Mass states:

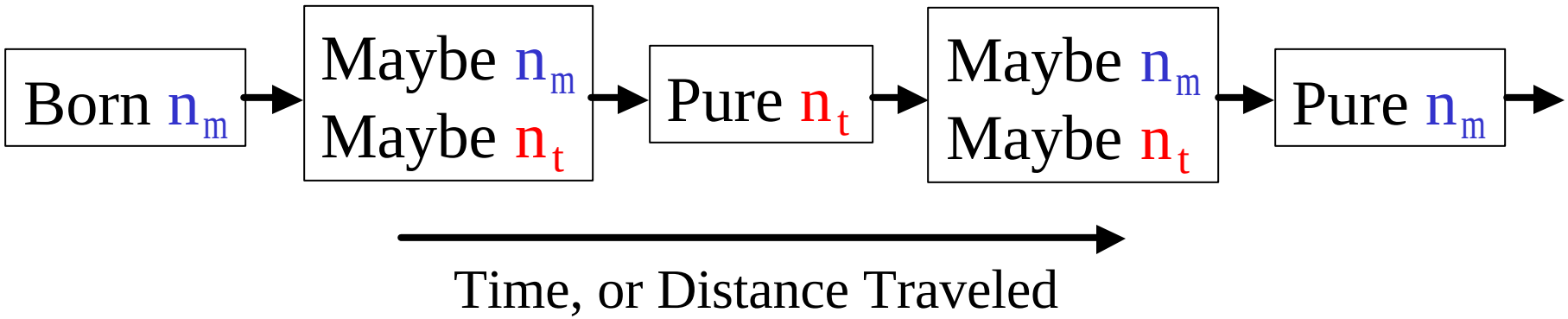


?

FUN

Here the world is truly Quantum Mechanical.

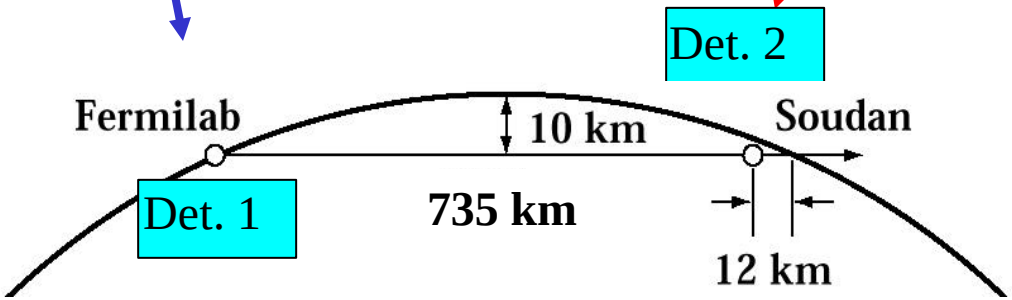
$?_{\mu}$ can oscillate into $?_{t}$ and back again

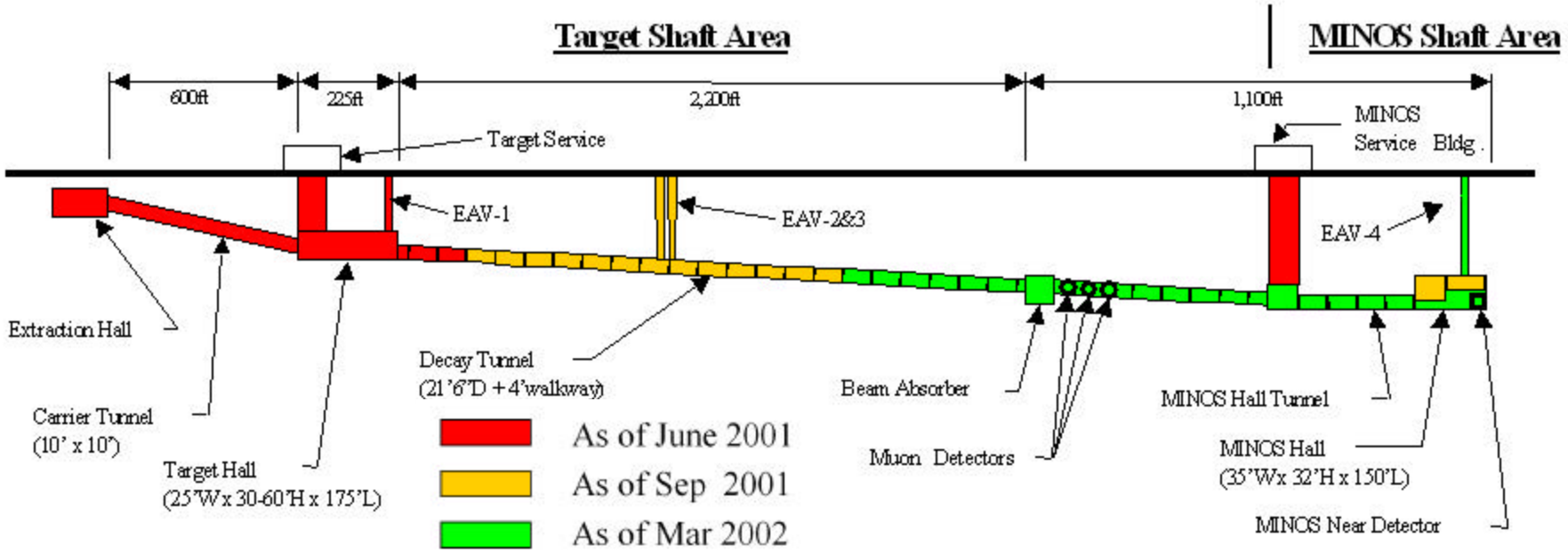


The MINOS Experiment

Near Detector: 980 tons

Far Detector: 5400 tons



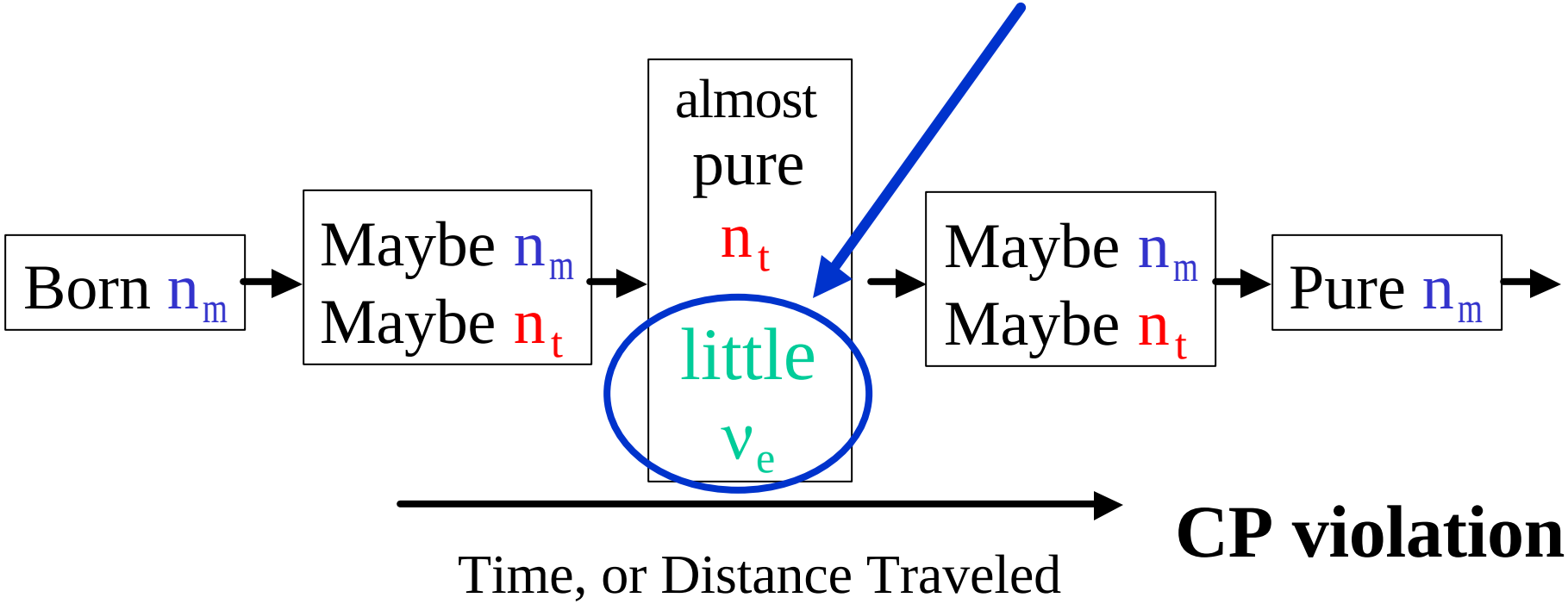


First piece of decay pipe

T

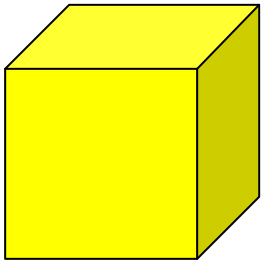
and

Neutrinos behave differently than Anti-Neutrinos



Neutrinos from the BIG BANG

1 cm^3



300 ? from Big Bang

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

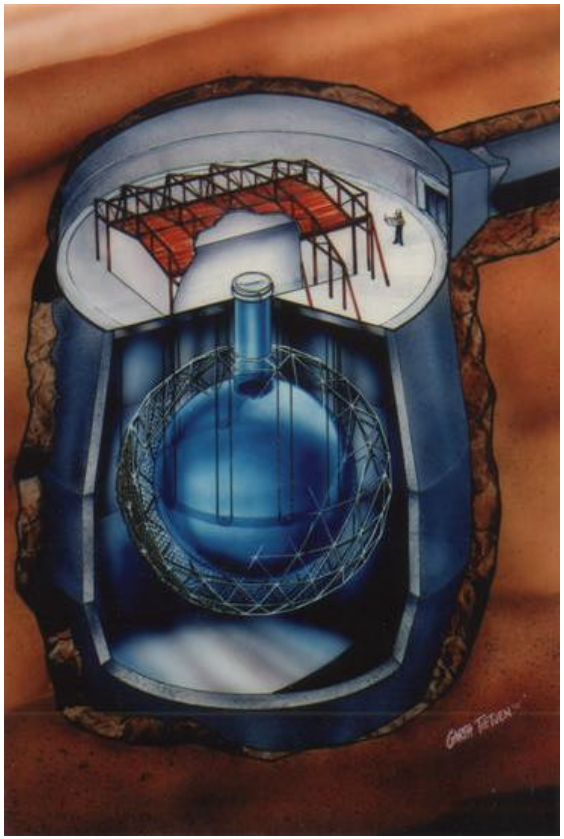
now dominated by matter

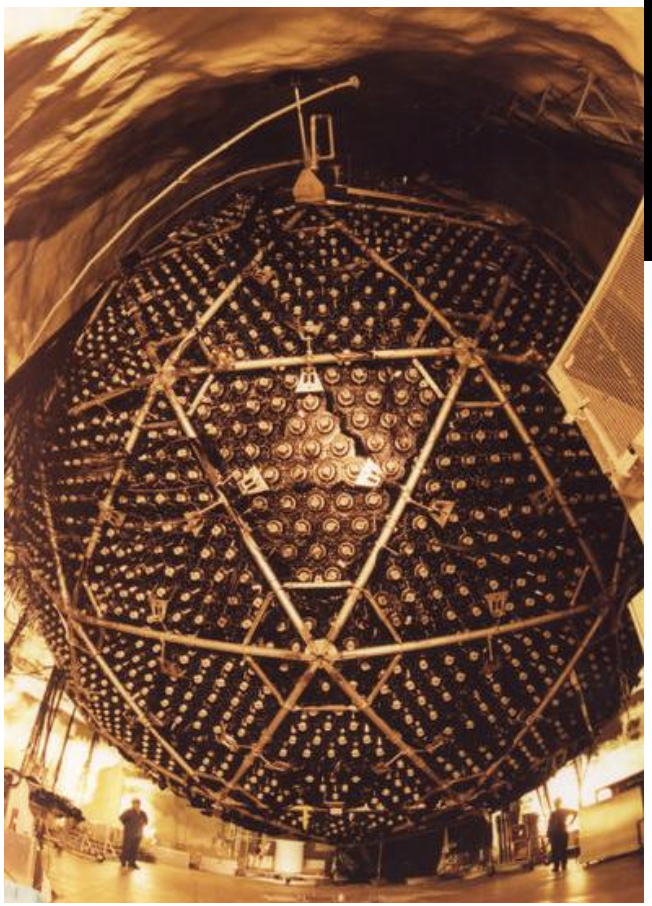
and

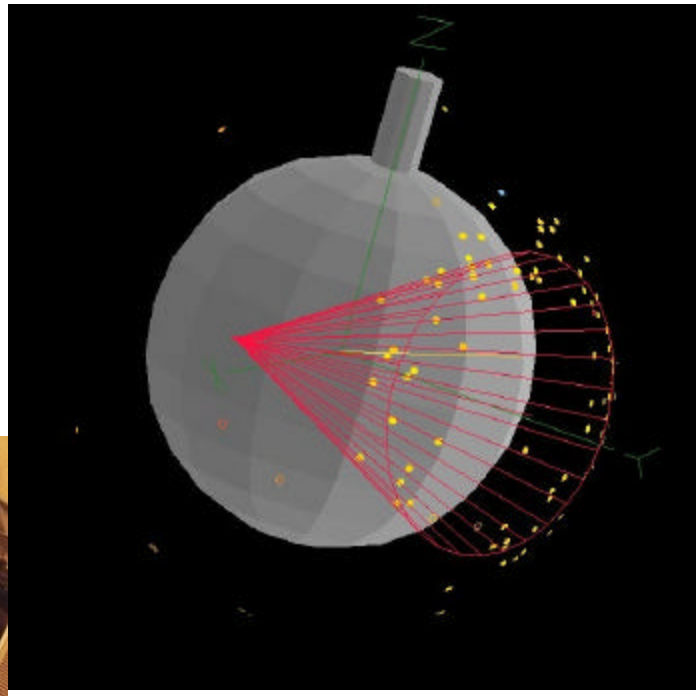
not a equal parts

matter and anti-matter

Sudbury Neutrino Observatory



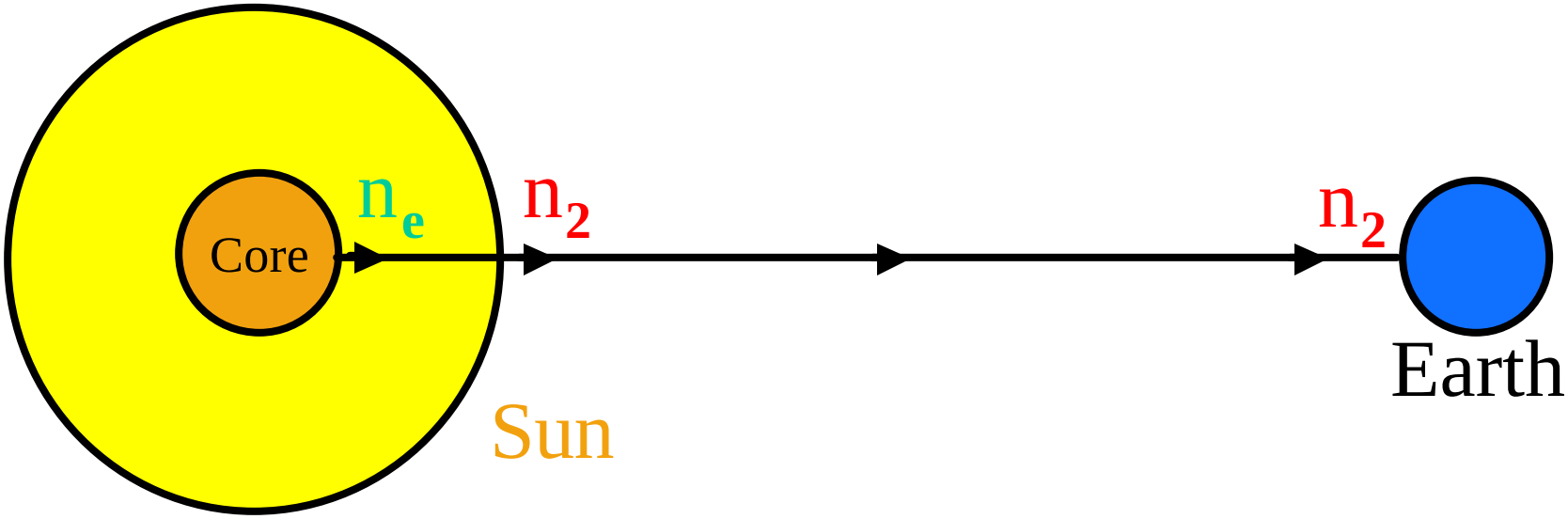




1000 tons Of D_2O

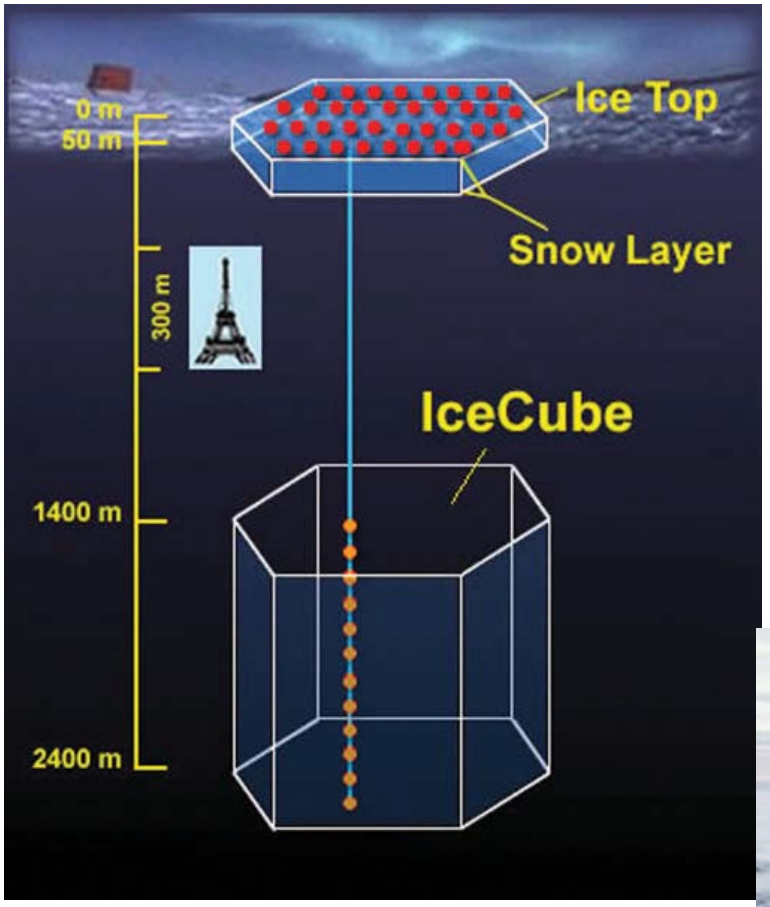
Solar Neutrinos

After 40 years of Solar Nu Exp.

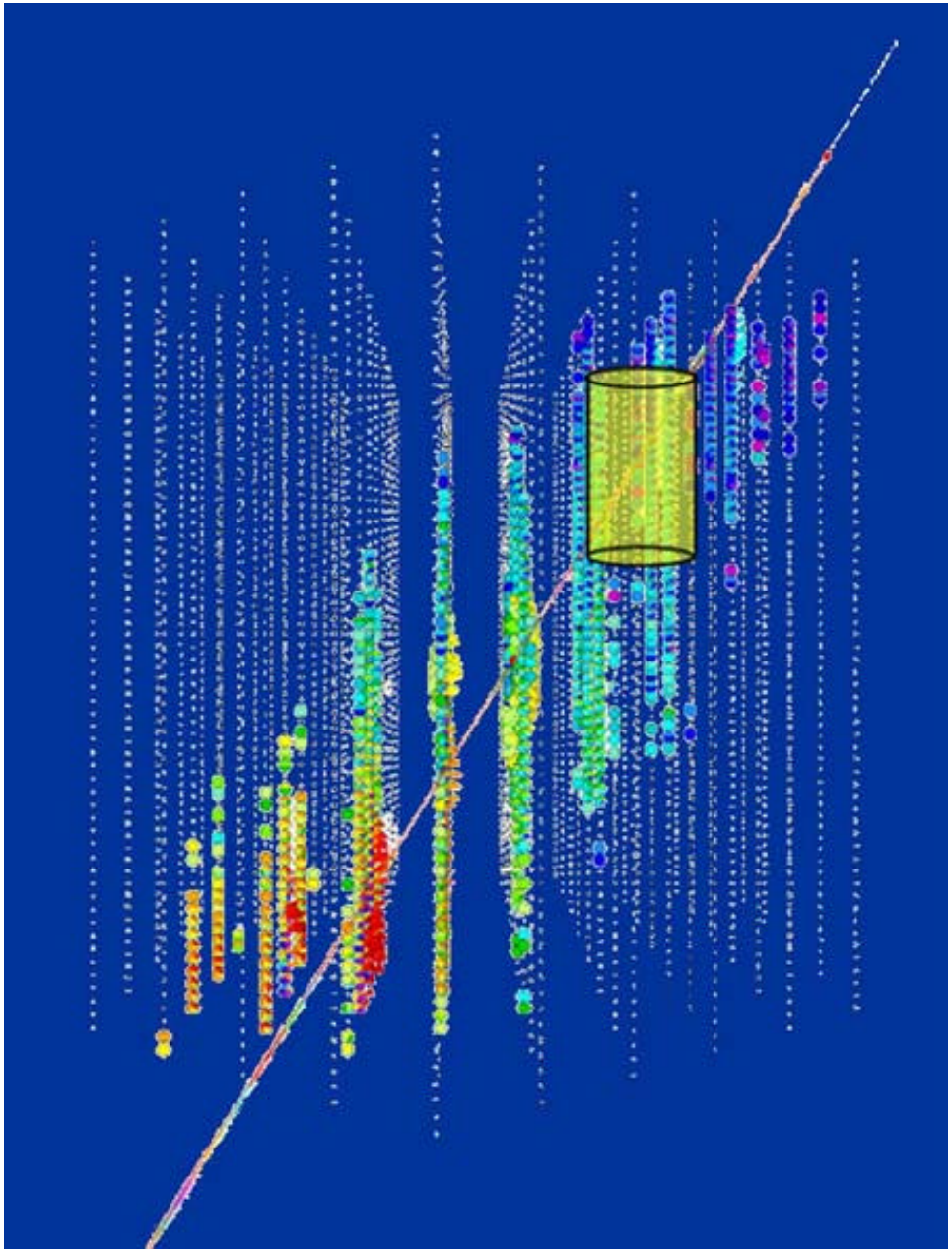


Born as n_e they exit the Sun and arrive at the earth as n_2 !!!

ie equal mixture of n_e n_μ and n_t



ICE CUBE
1 Km cubed



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.