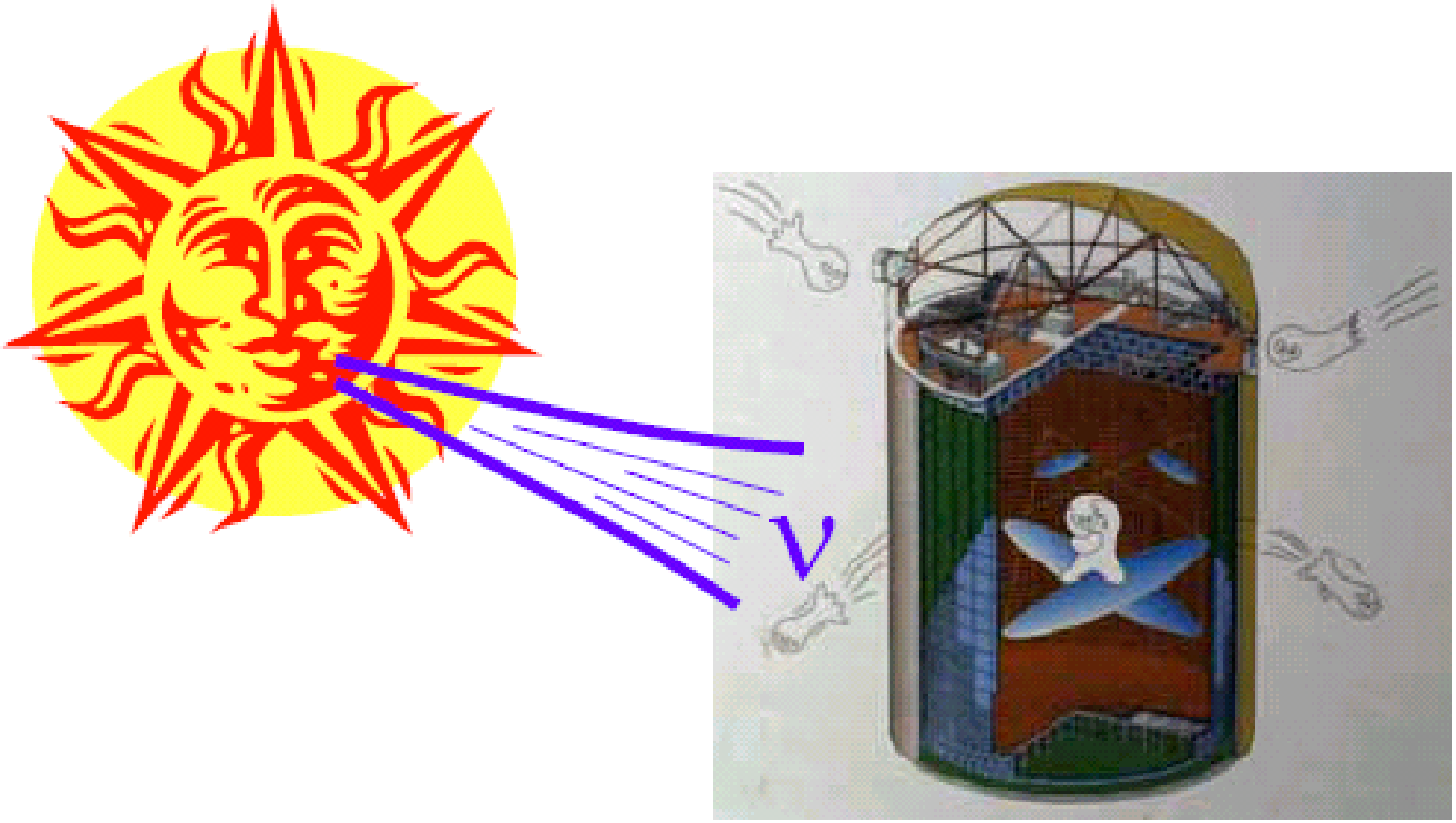
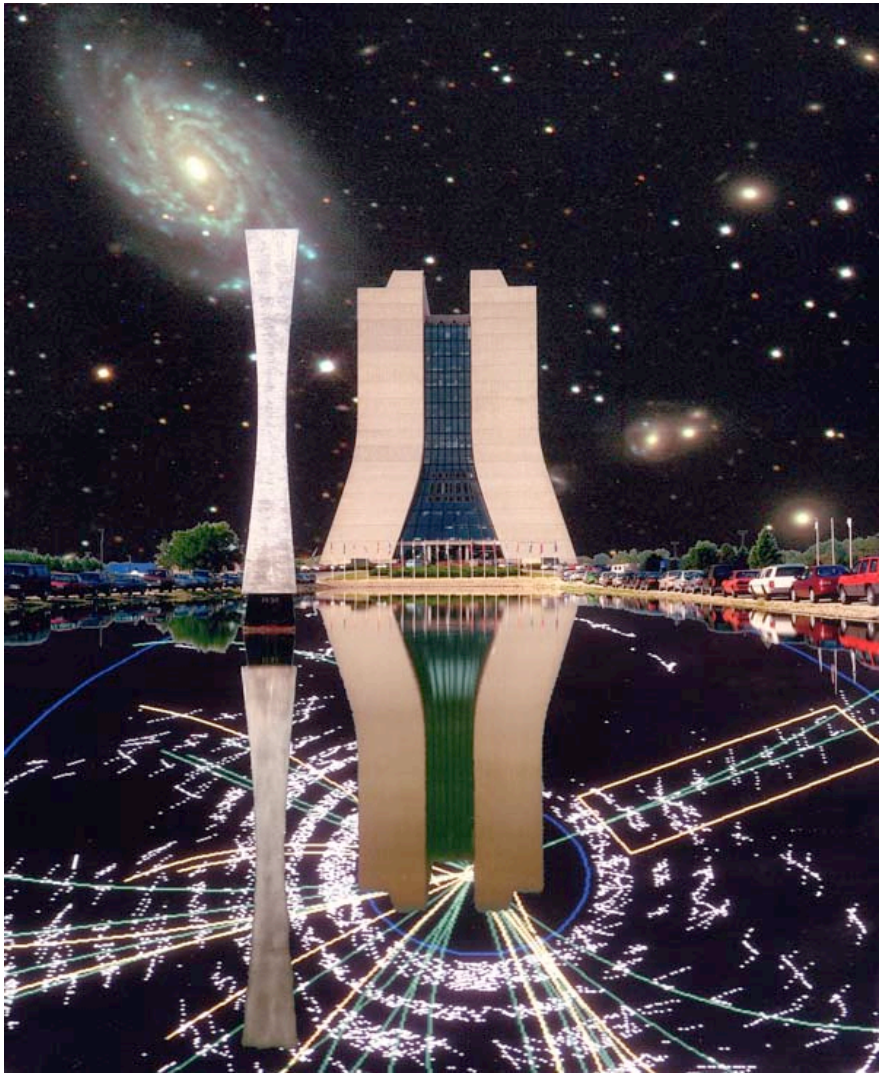


http://www.neutrino2008.co.nz

NEUTRINOS:



Ghosts of the Universe

Stephen Parke
Theoretical Physicist
Fermilab

Webster's Online Dictionary

ν

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

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Brief Early History of the Neutrino

- **1930 – postulated by Wolfgang Pauli**

  (to solve energy crisis in radioactive decay)

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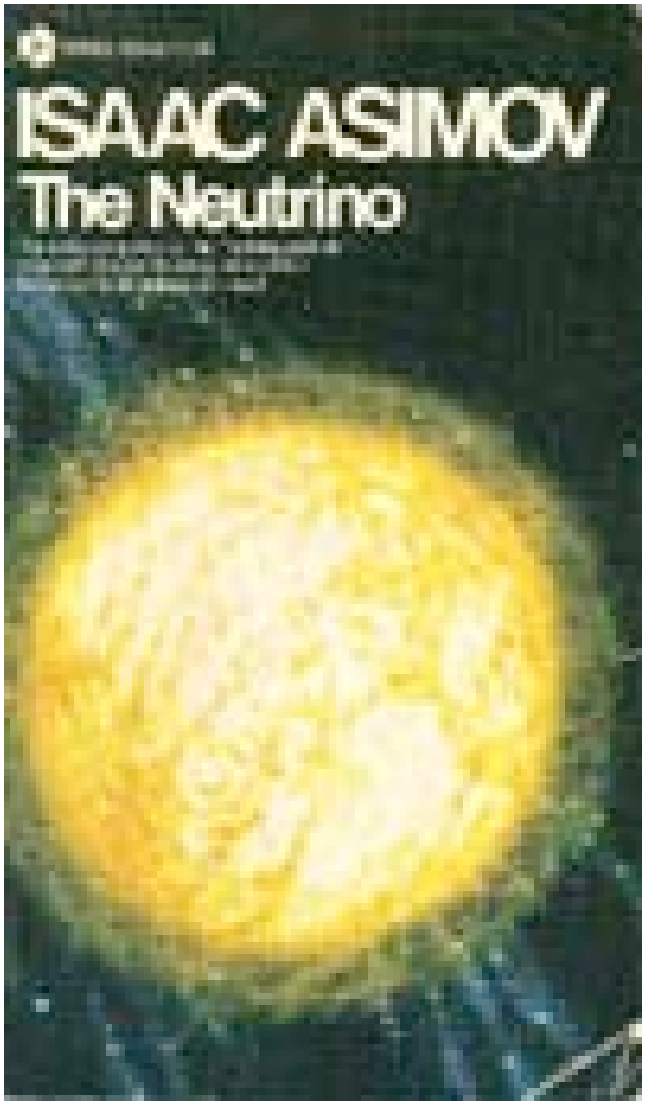
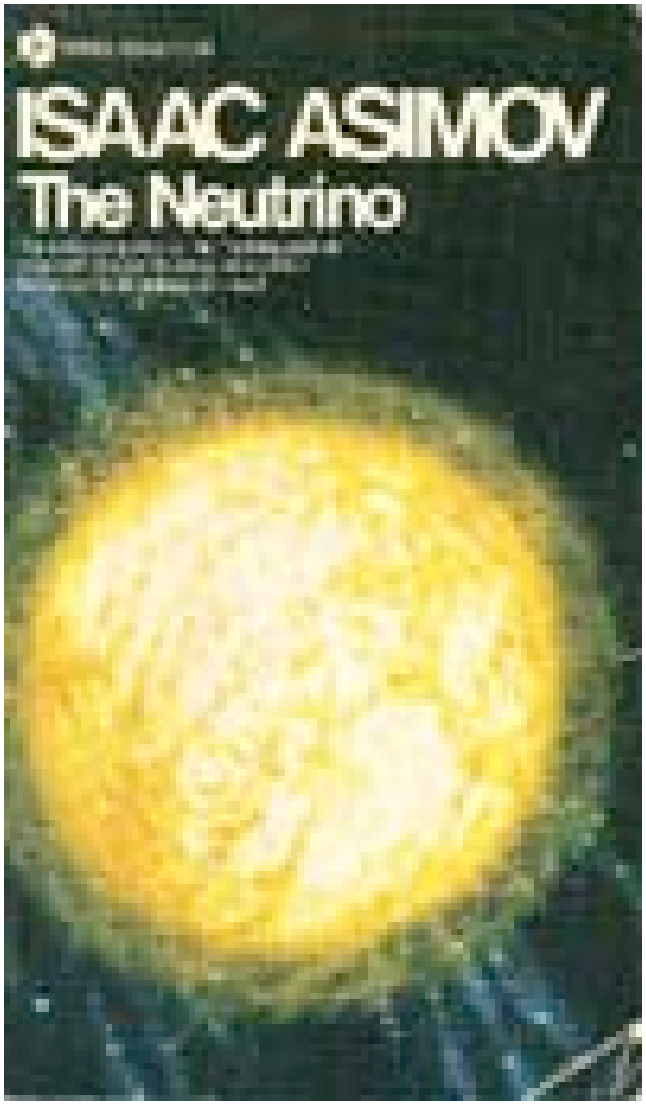
- 1957 – first observed by Cowan and Reines using nuclear reactor as the source.

1966



1966



And yet the nothing-particle is not a nothing at all

Neutron Decay:

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

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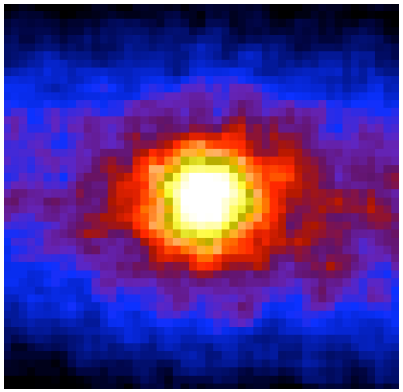
$$n \rightarrow p + e^- + \bar{\nu}_e$$

Solar Engine:

$$p + p \rightarrow d + e^+ + \nu_e$$



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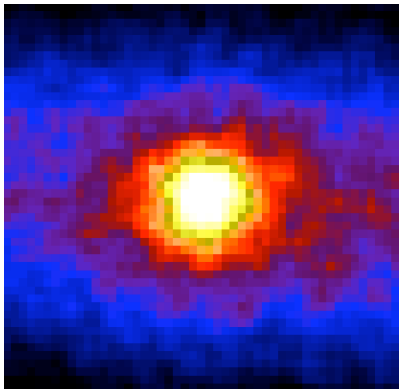


SuperNova Cooling:

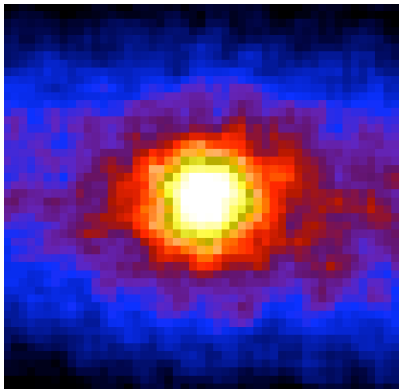
$$e^+ + e^- \rightarrow \nu + \bar{\nu}$$

Neutron Decay:

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

Solar Engine:

$$p + p \to d + e^+ + \nu_e$$



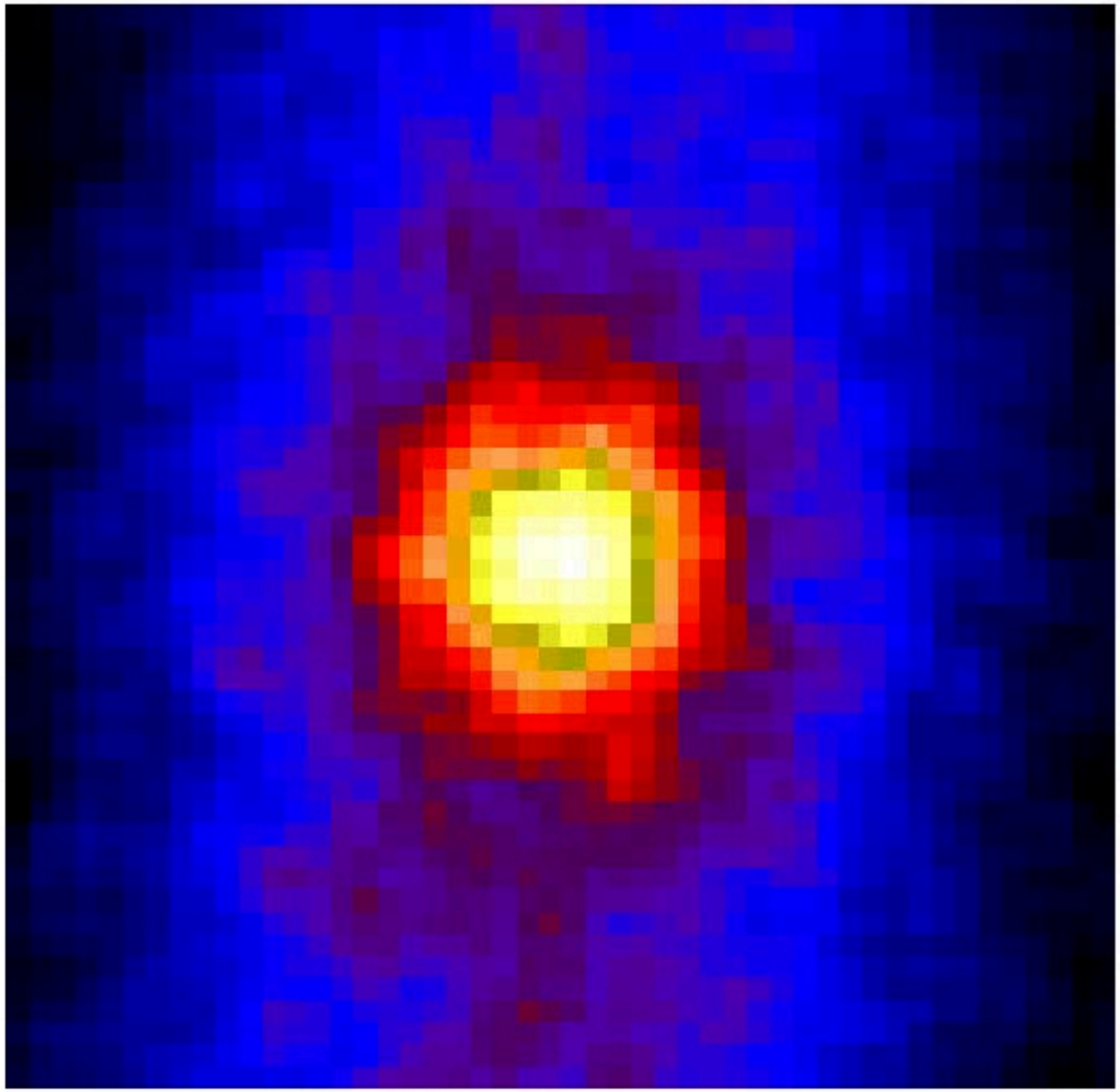
SuperNova Cooling:

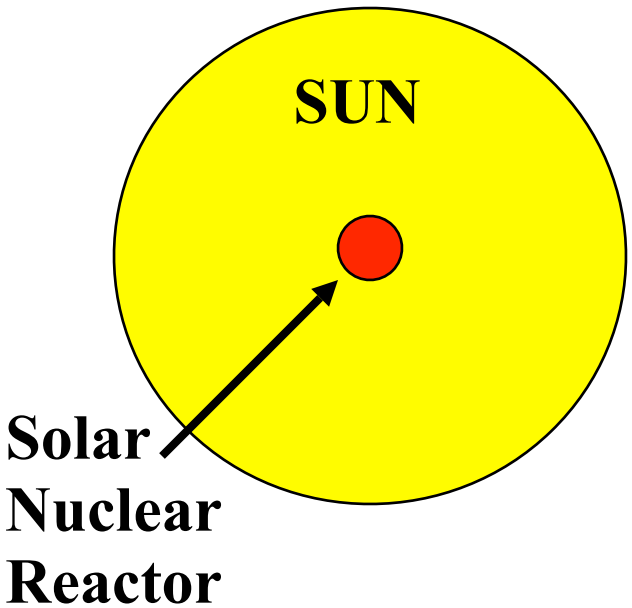
$$e^+ + e^- \to \nu + \bar{\nu}$$

Leptogenesis:

???

Neutrino Picture of the Sun





4 protons + 2 electrons

Helium Nucleus (2p2n)

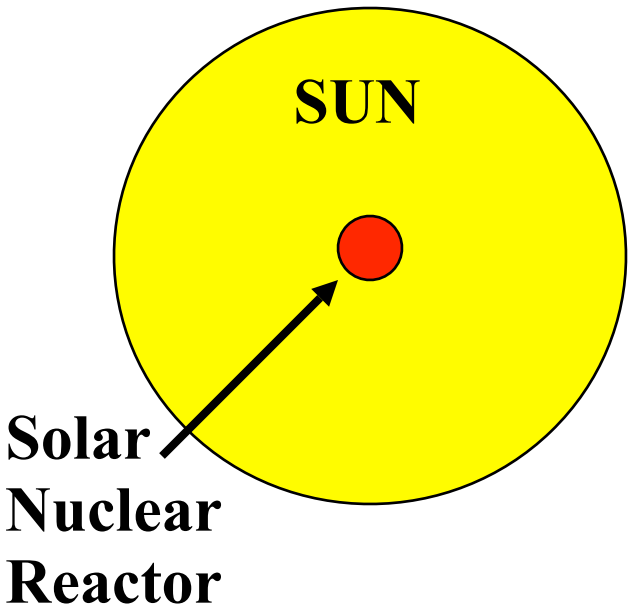
+

2 Neutrinos (2ν)

+

a little Energy

Using $E=mc^2$



4 protons + 2 electrons

Helium Nucleus (2p2n)

+

2 Neutrinos (2ν)

+

a little Energy

at the earth

Using $E=mc^2$

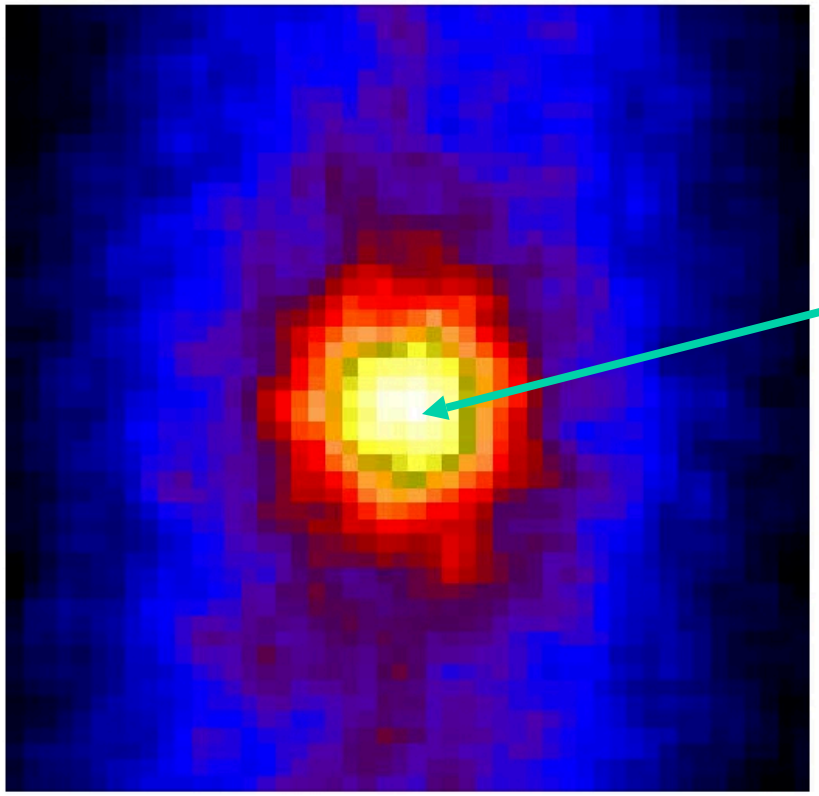
60,000,000,000 neutrinos

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.

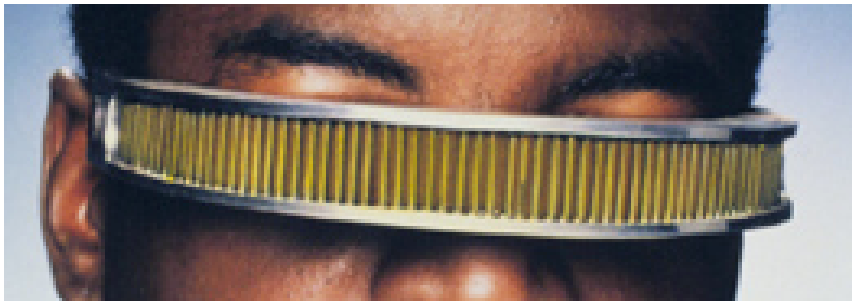
From the Sun to Earth takes 8 minutes.

Star Trek: The Next Generation

Geordi La Forge: in “The Enemy”

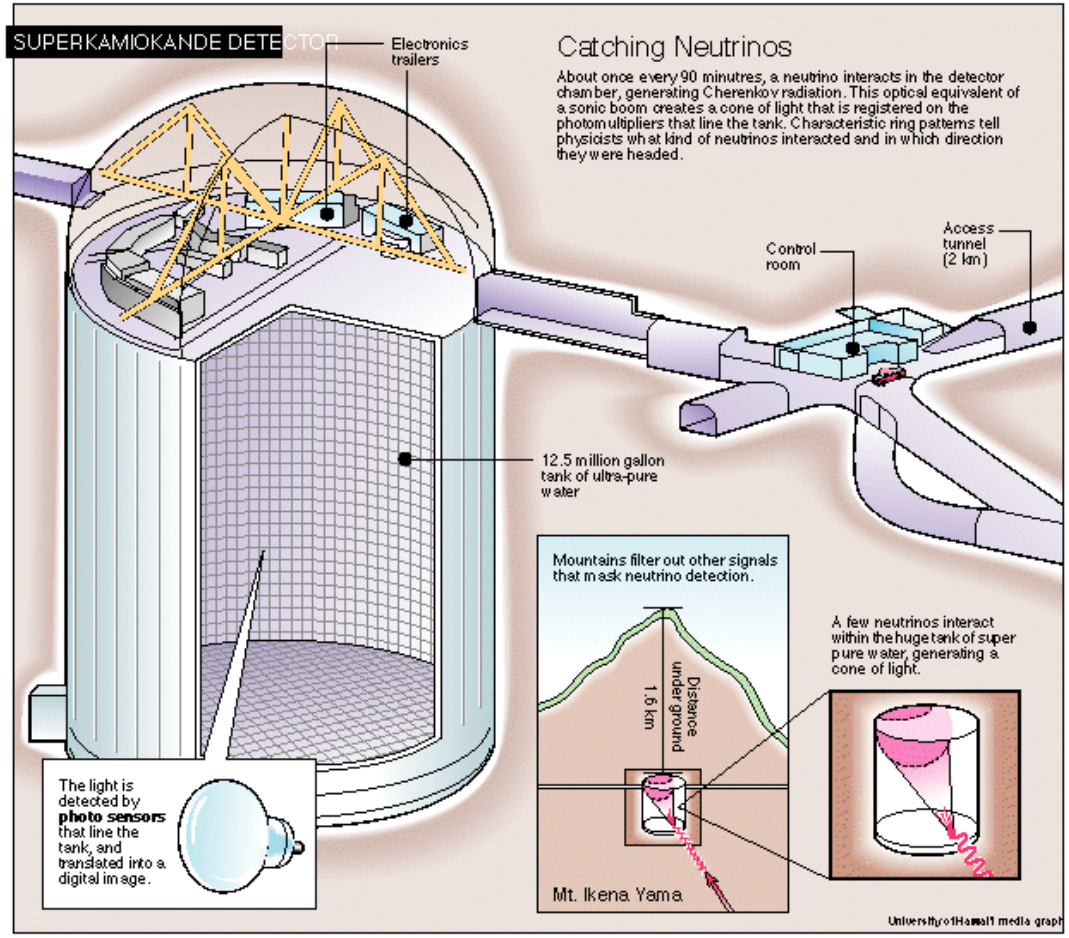
Star Trek: The Next Generation

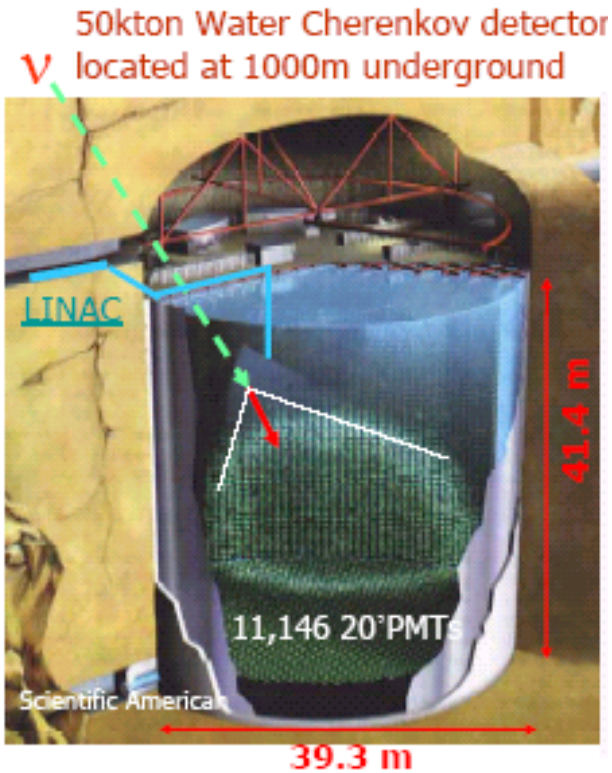
Geordi La Forge: in "The Enemy"



The visor "sees" Neutrinos!!!

SuperKamiokande





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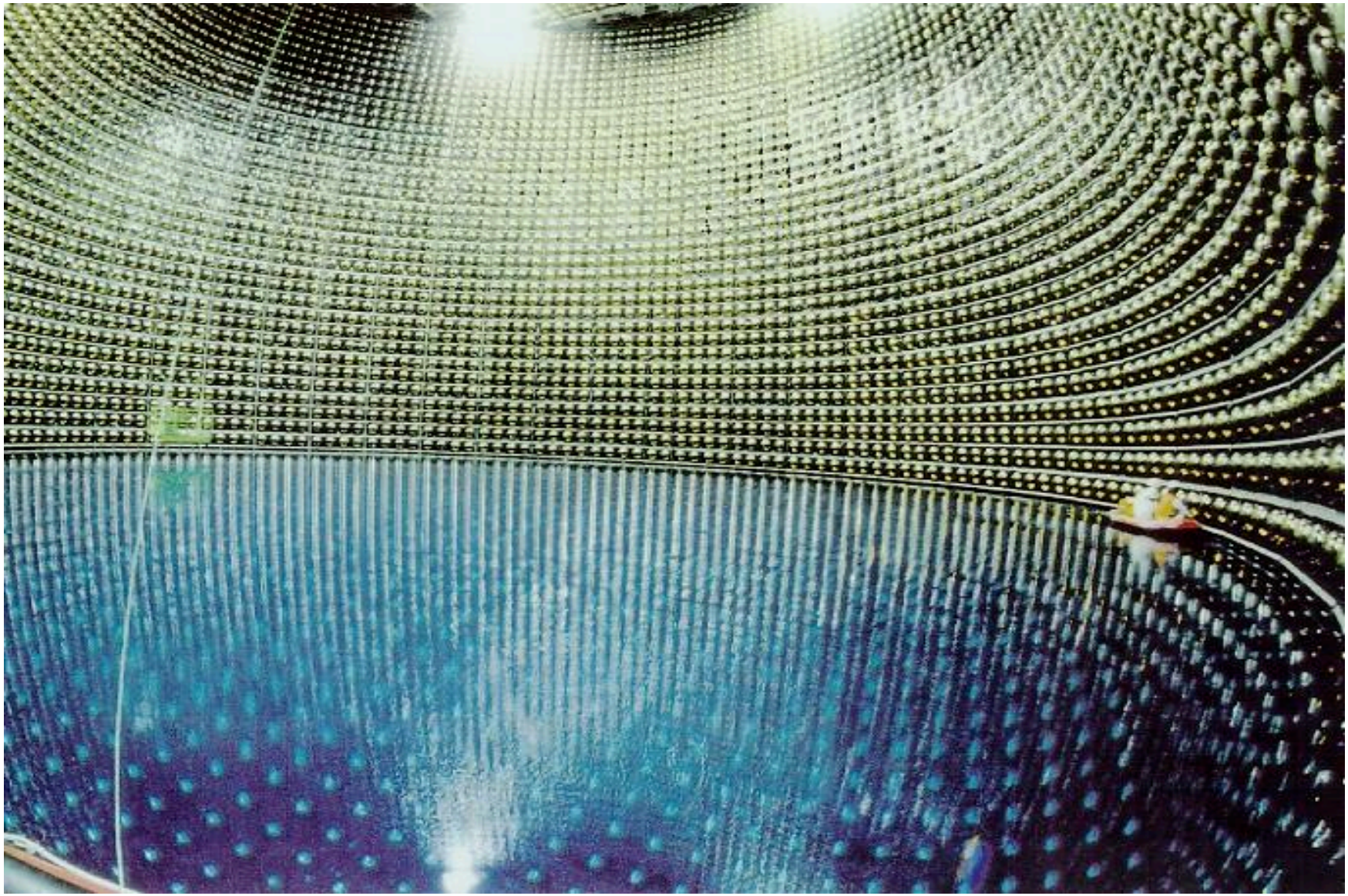
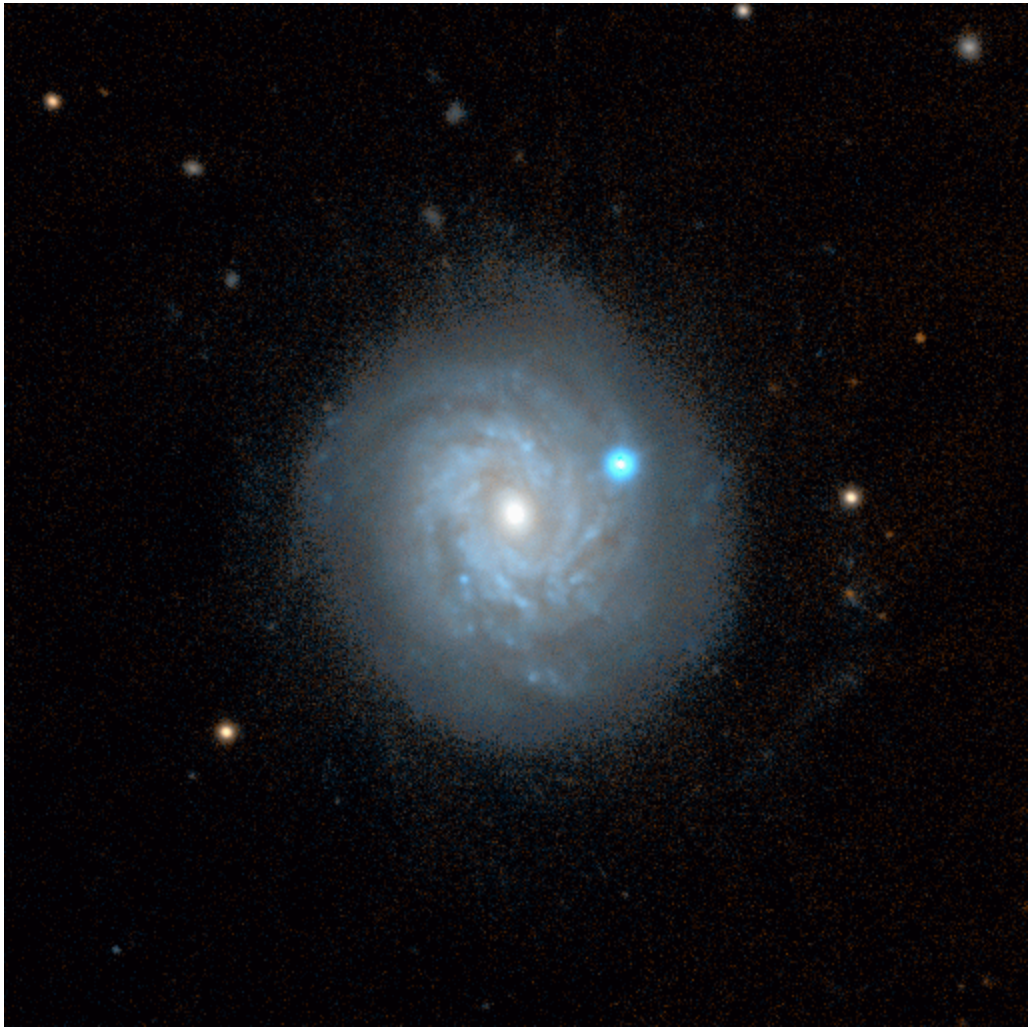
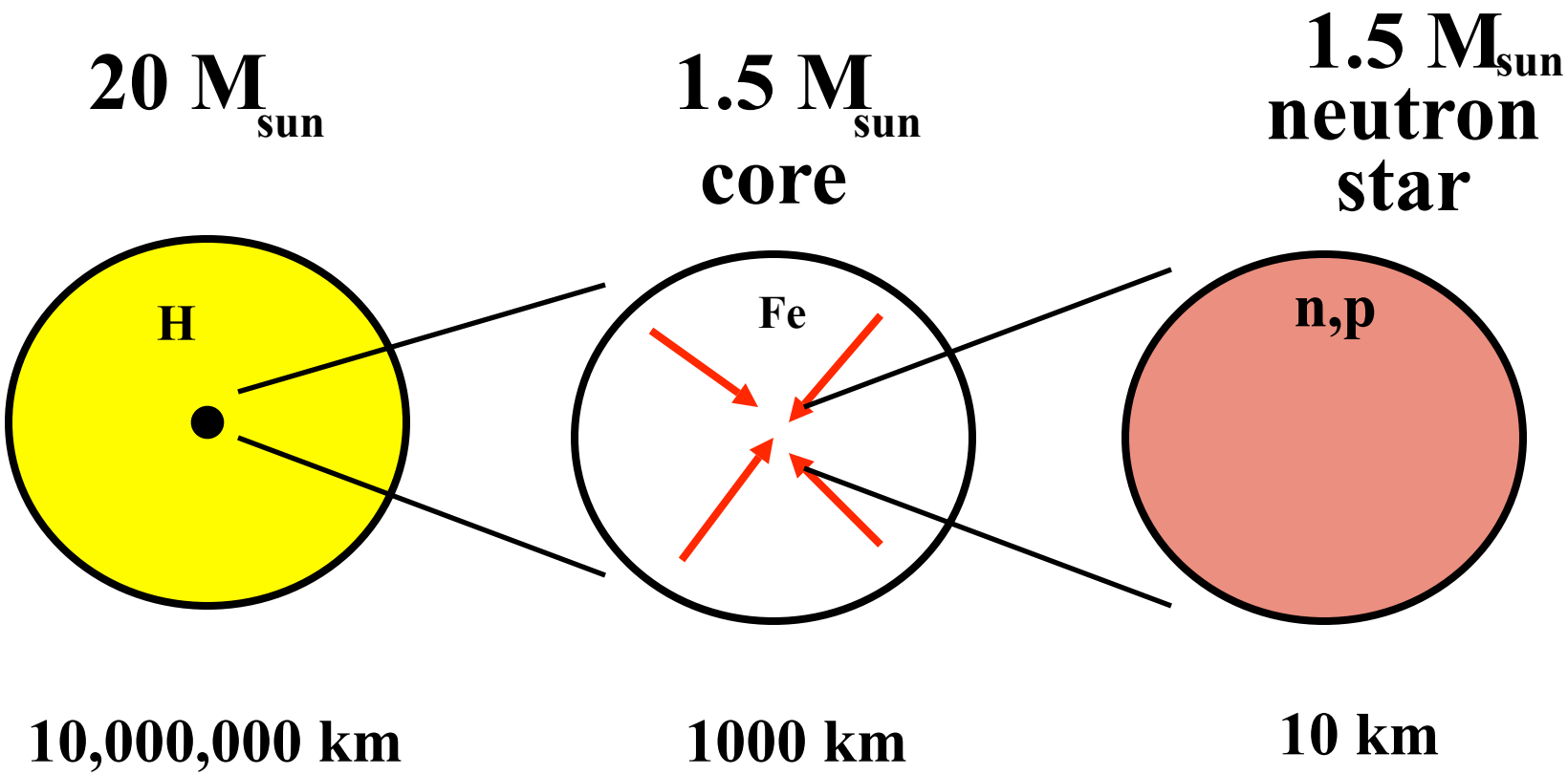


Supernova



Mechanics of a Supernova



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

equivalent to 0.1 M_{sun}

Supernova Energy Budget = $100

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- **Light show** **1c = 0.01%**

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- **Blowing Star Apart** **$1 = 1%**

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- **Neutrinos** — **$99 = 99%**

Supernova Energy Budget = $100

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

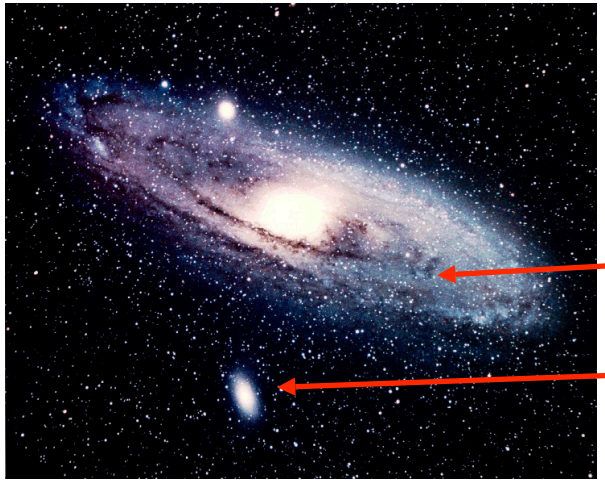
Light show lasts months

Supernova Energy Budget = $100

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

Light show lasts months

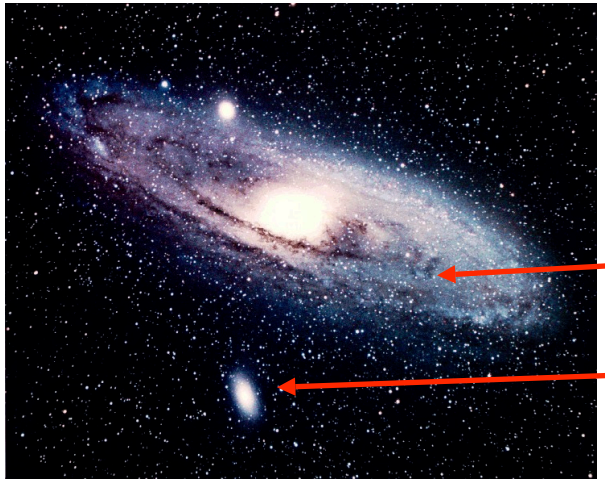
Neutrino tsunami lasts 10-20 seconds !!!



Supernova 1987a - Feb 24

We are here

Large Magelanic Cloud
170,000 light years away !



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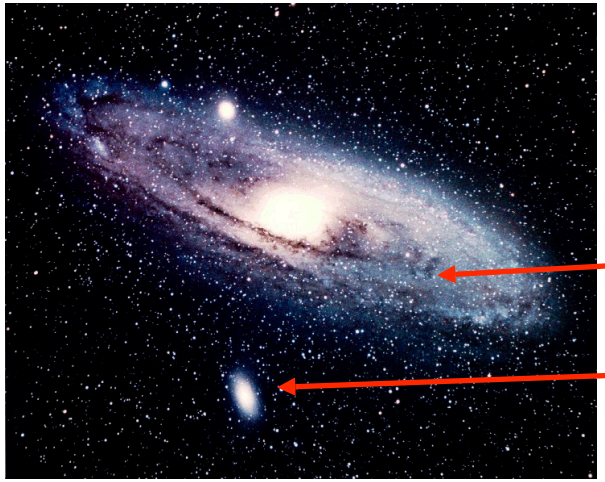


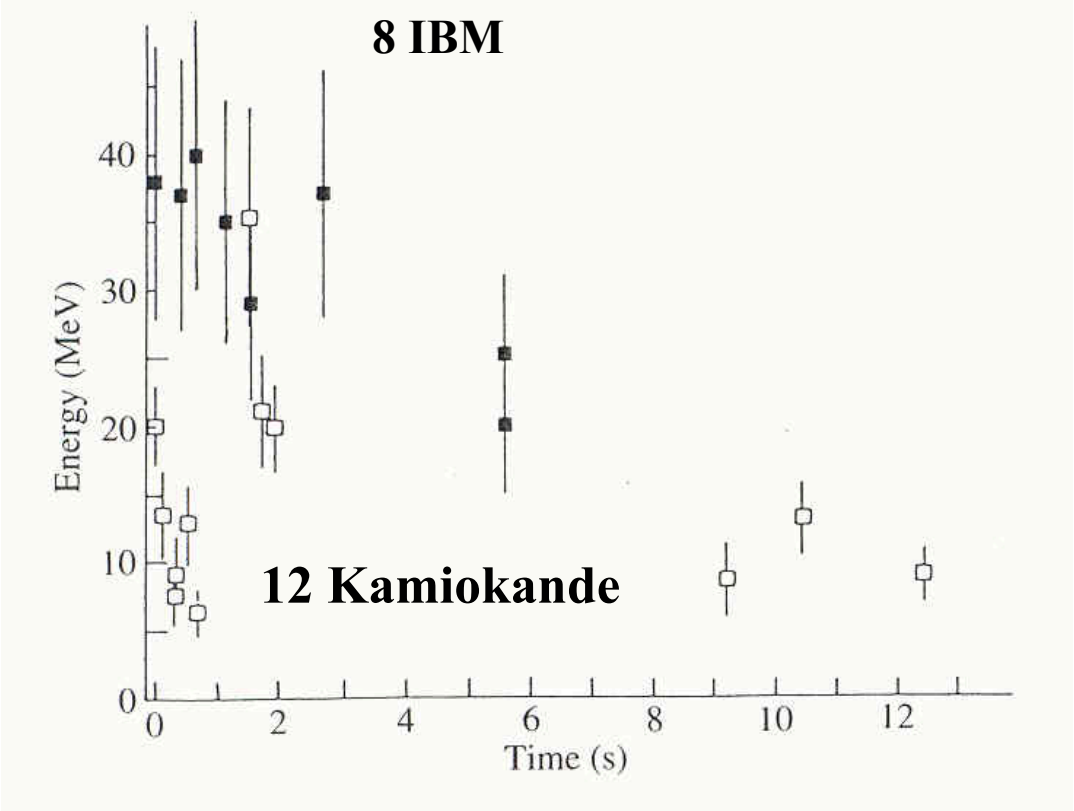
Supernova 1987a - Feb 24

We 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 ???

~ 500
Supernova Neutrino Tsunamis
are on their way
from supernova in our galaxy!!!

Bigger Detectors, More Detectors
Rate ???

2 +/- 1 per century !

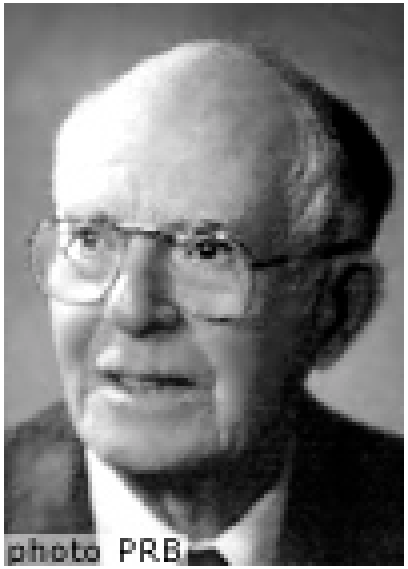
Nobel Prize 2002

“….for the detection of cosmic neutrinos"

Nobel Prize 2002

“….for the detection of cosmic neutrinos"

Davis, USA



solar

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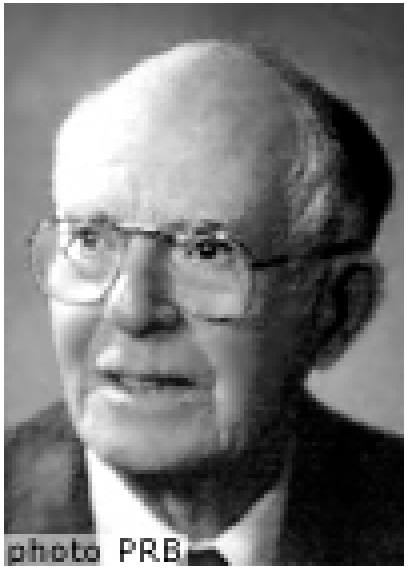


solar

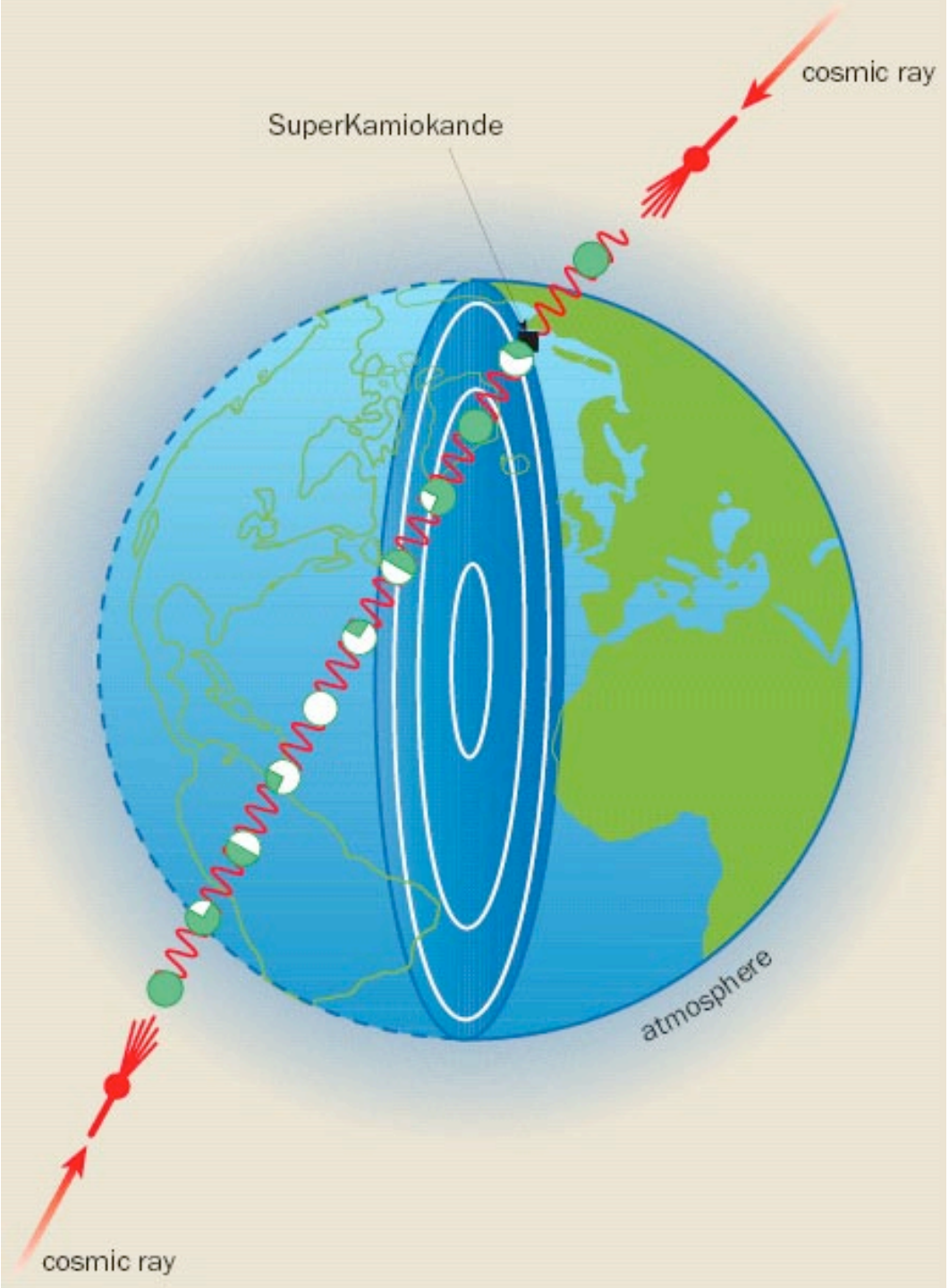
Koshiba, Japan

supernova

Neutrino Sources

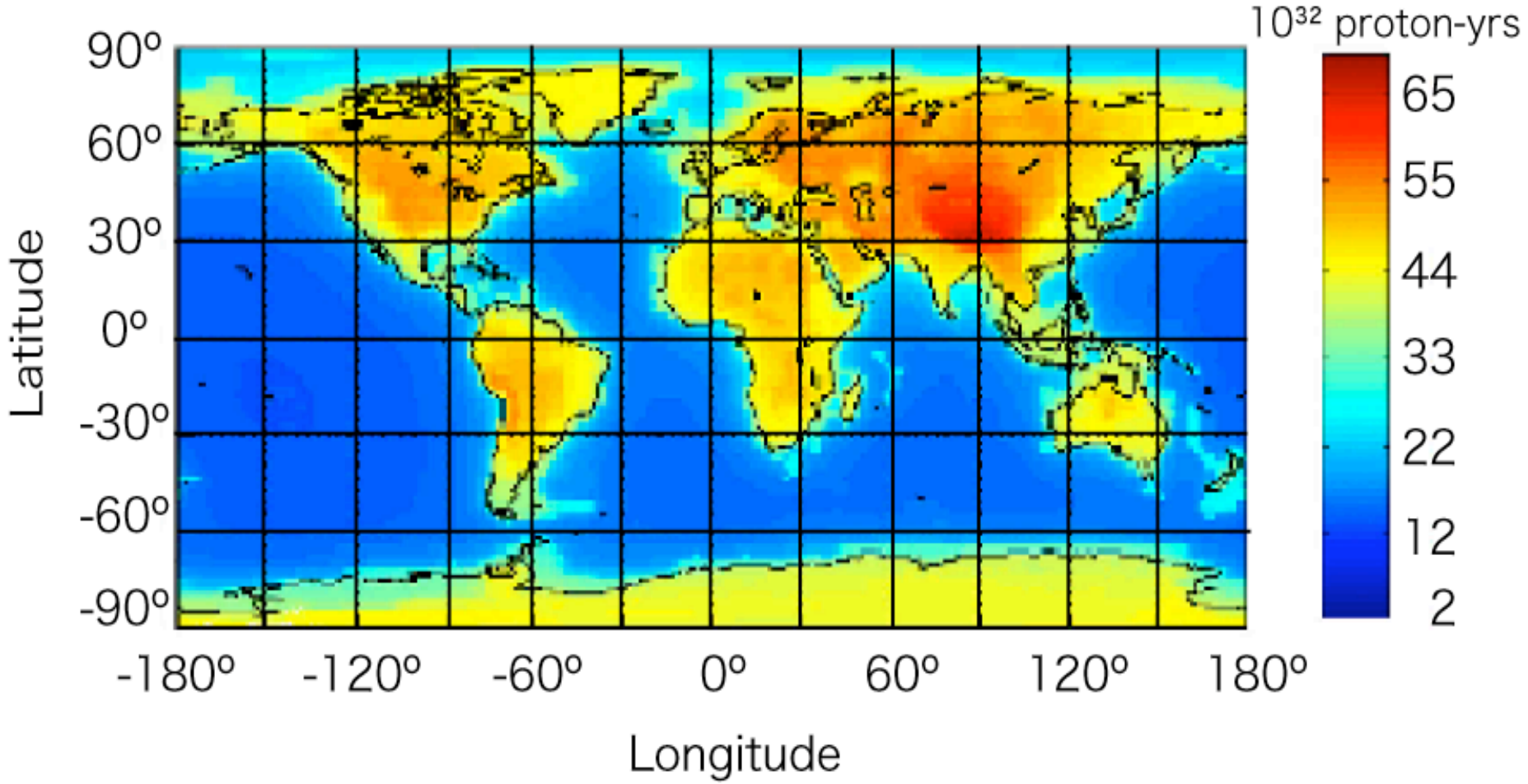
- Reactors
- Sun
- Supernova
- Cosmic Rays on Atmosphere
- Accelerators
- Radioactive Sources

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


cosmic ray
SuperKamiokande
atmosphere
cosmic ray

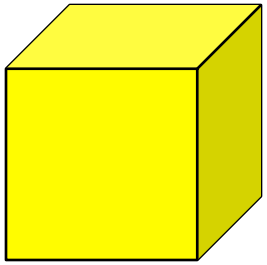
$$\#\nu's = 2 \times 10^{20} \ /\mathrm{sec/GW}$$

Predicted geo-neutrino signal



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

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Pronunciation: nü-'trE-(")nO, nyü-
Etymology: Italian, from *neutro*

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has a very small mass,

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$$\nu_e$$

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ν_e ν_μ

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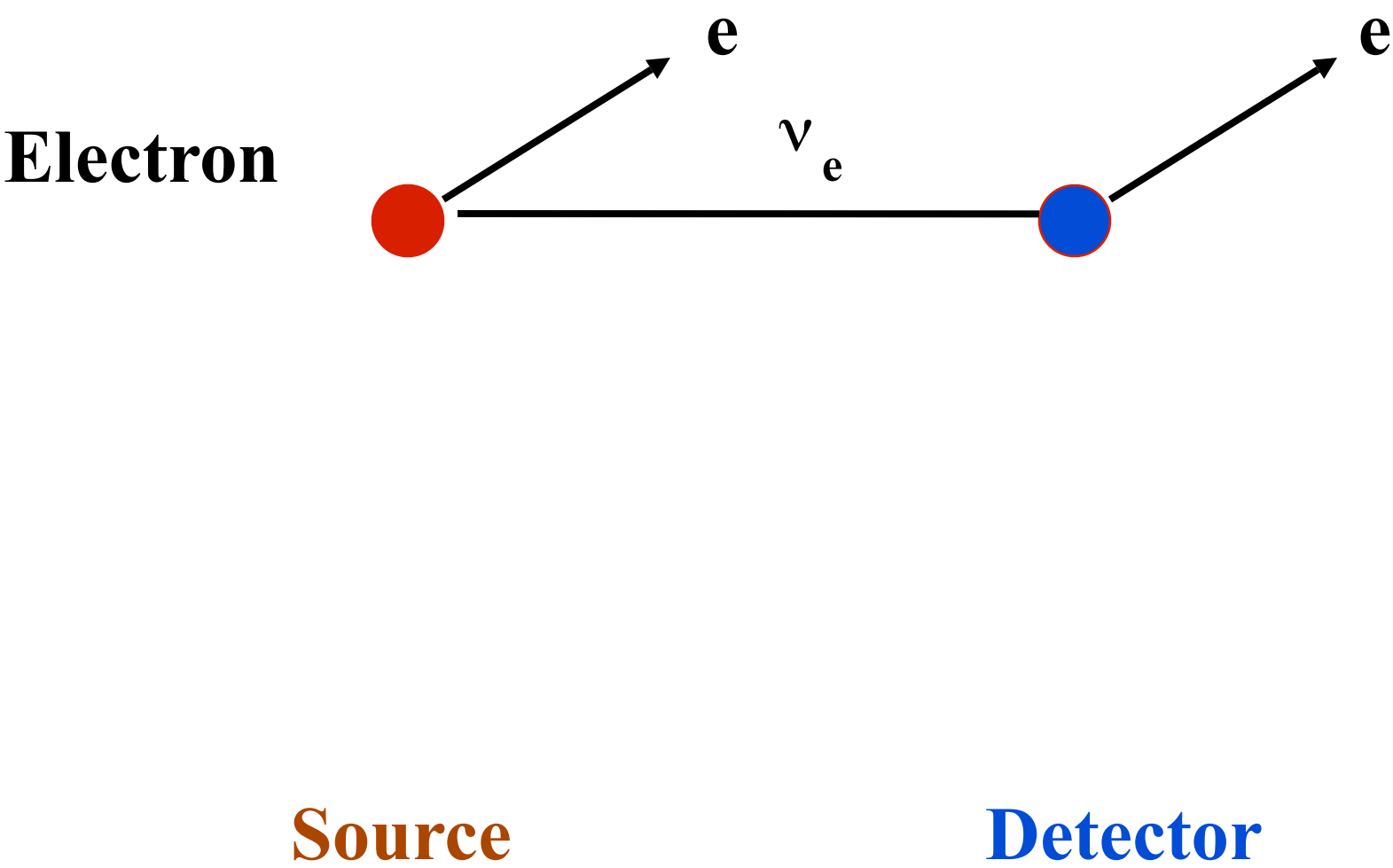
ν_e ν_μ ν_τ

Three Neutrino Flavors:



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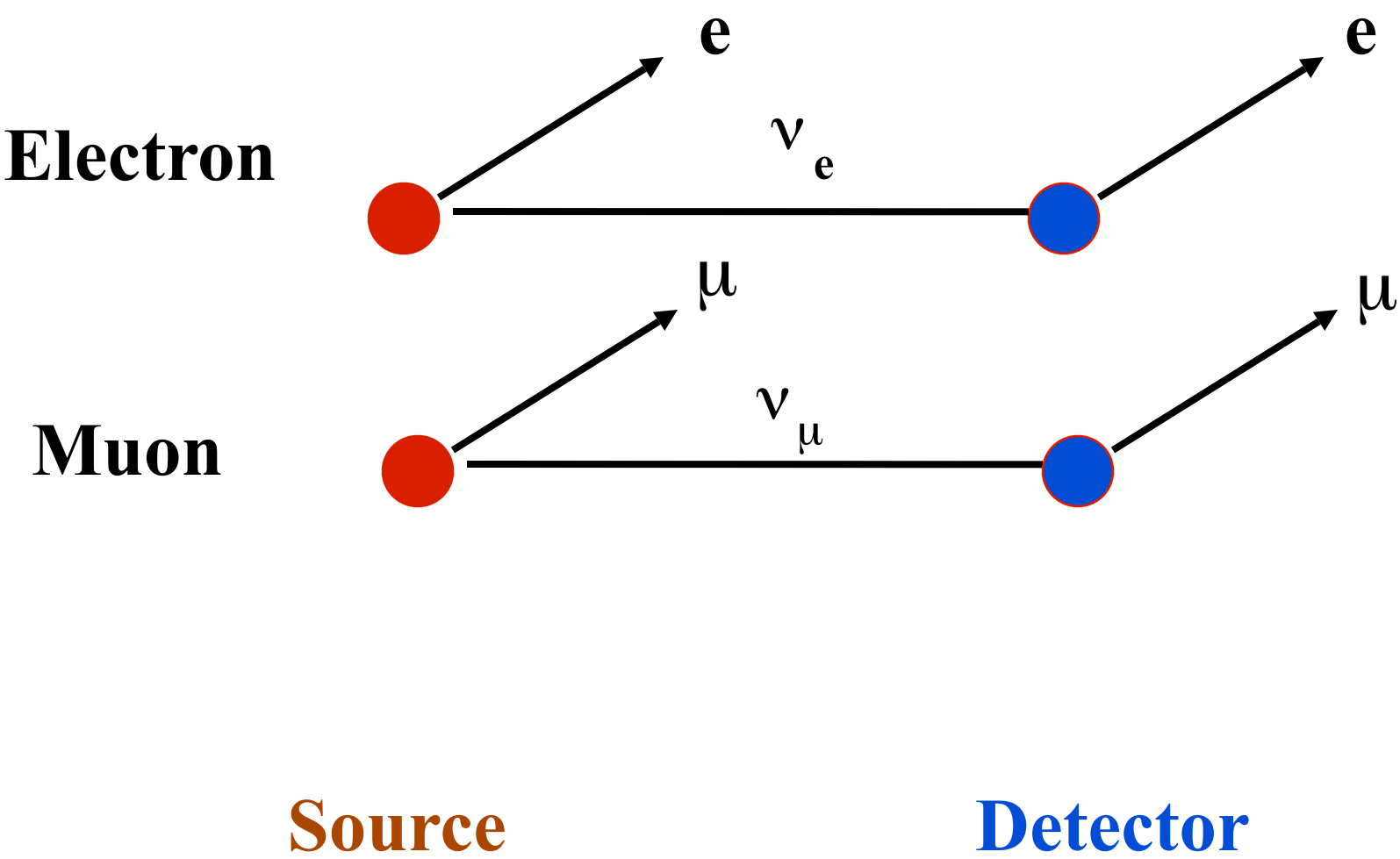

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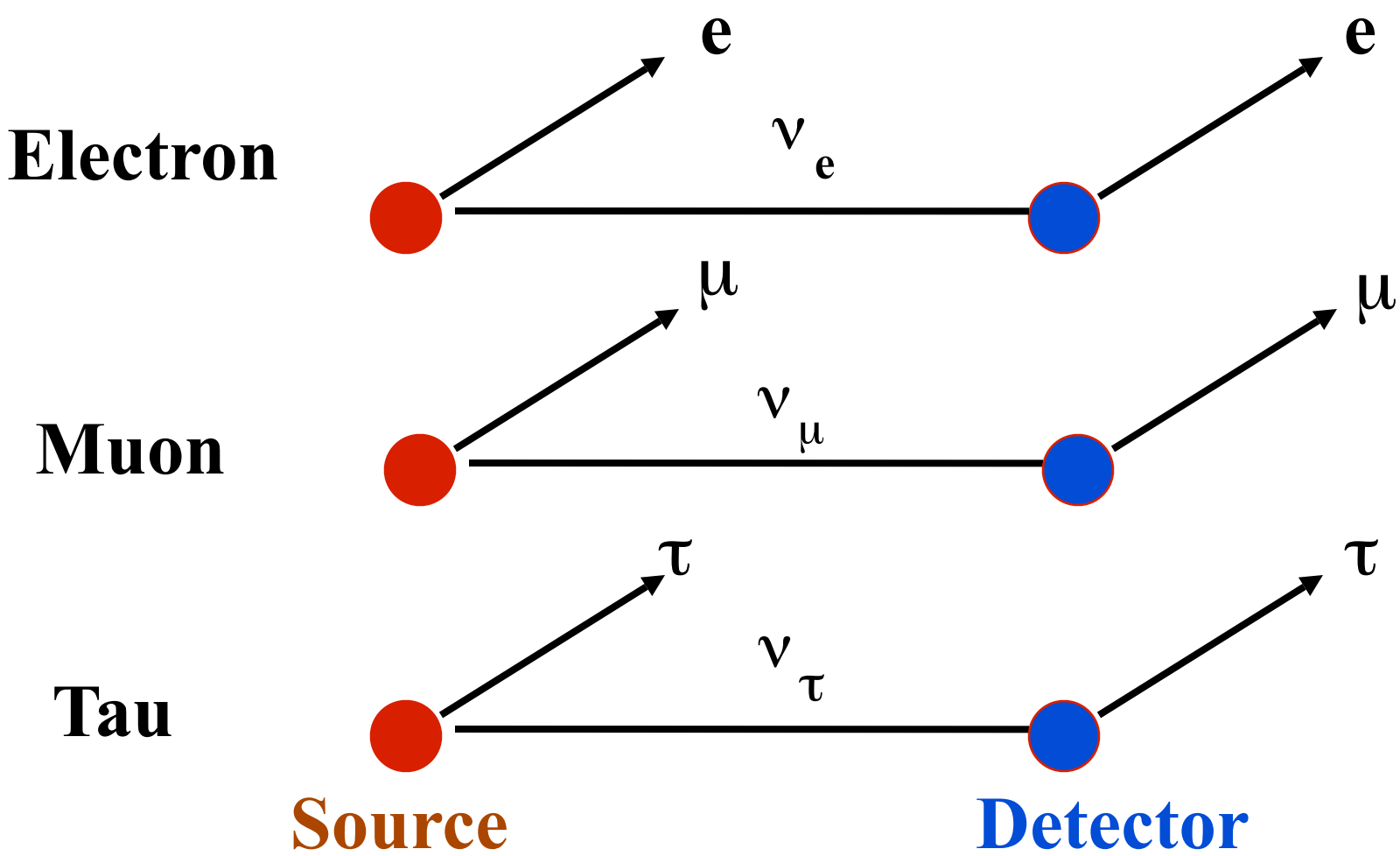

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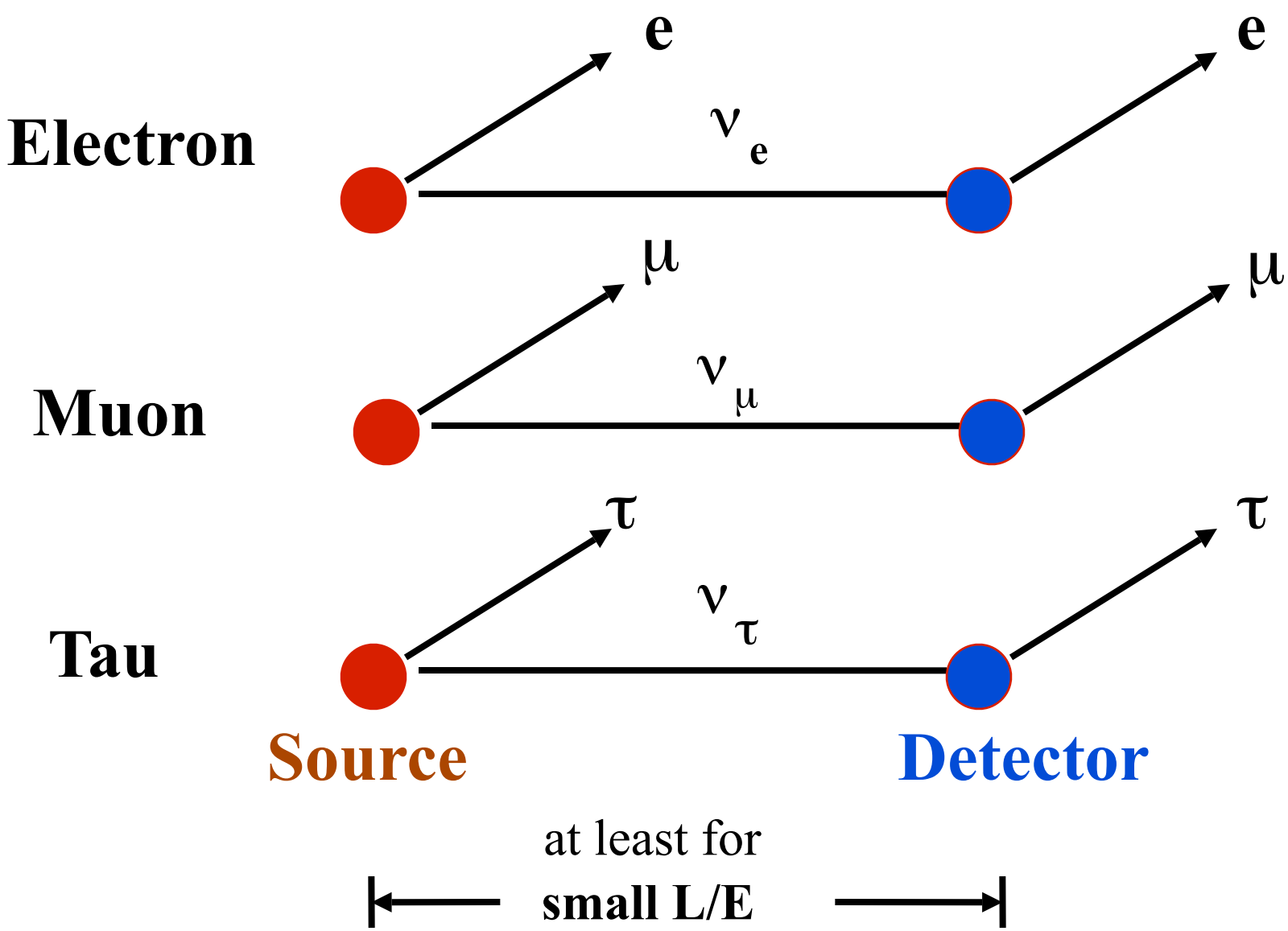
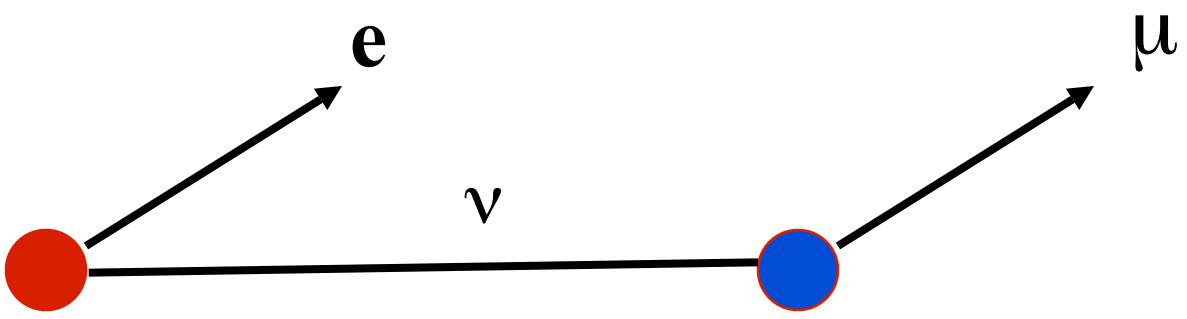


NEVER



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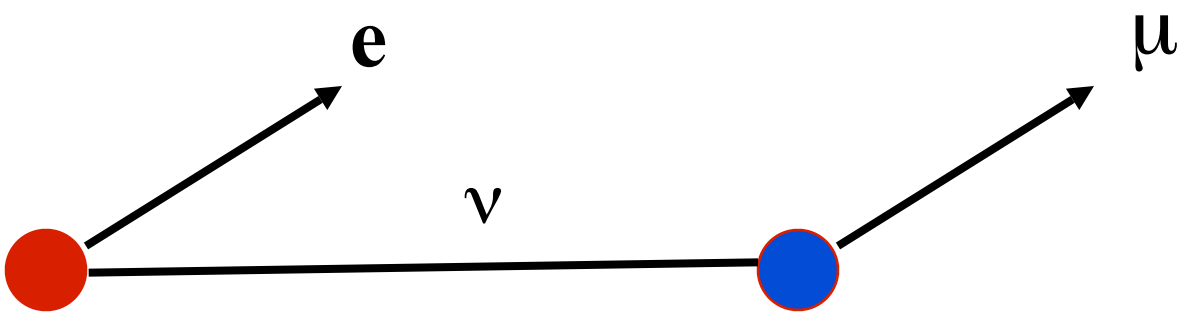
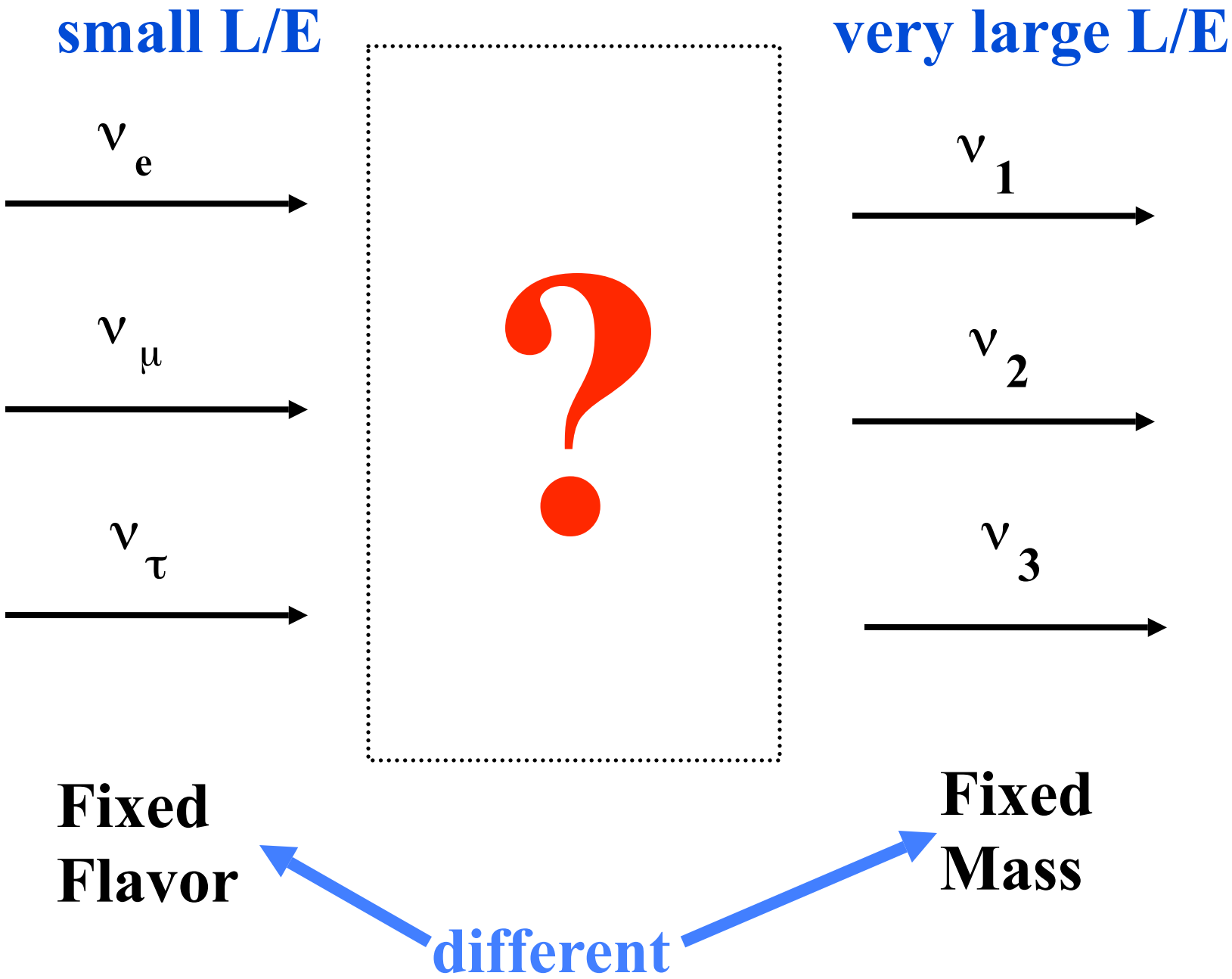
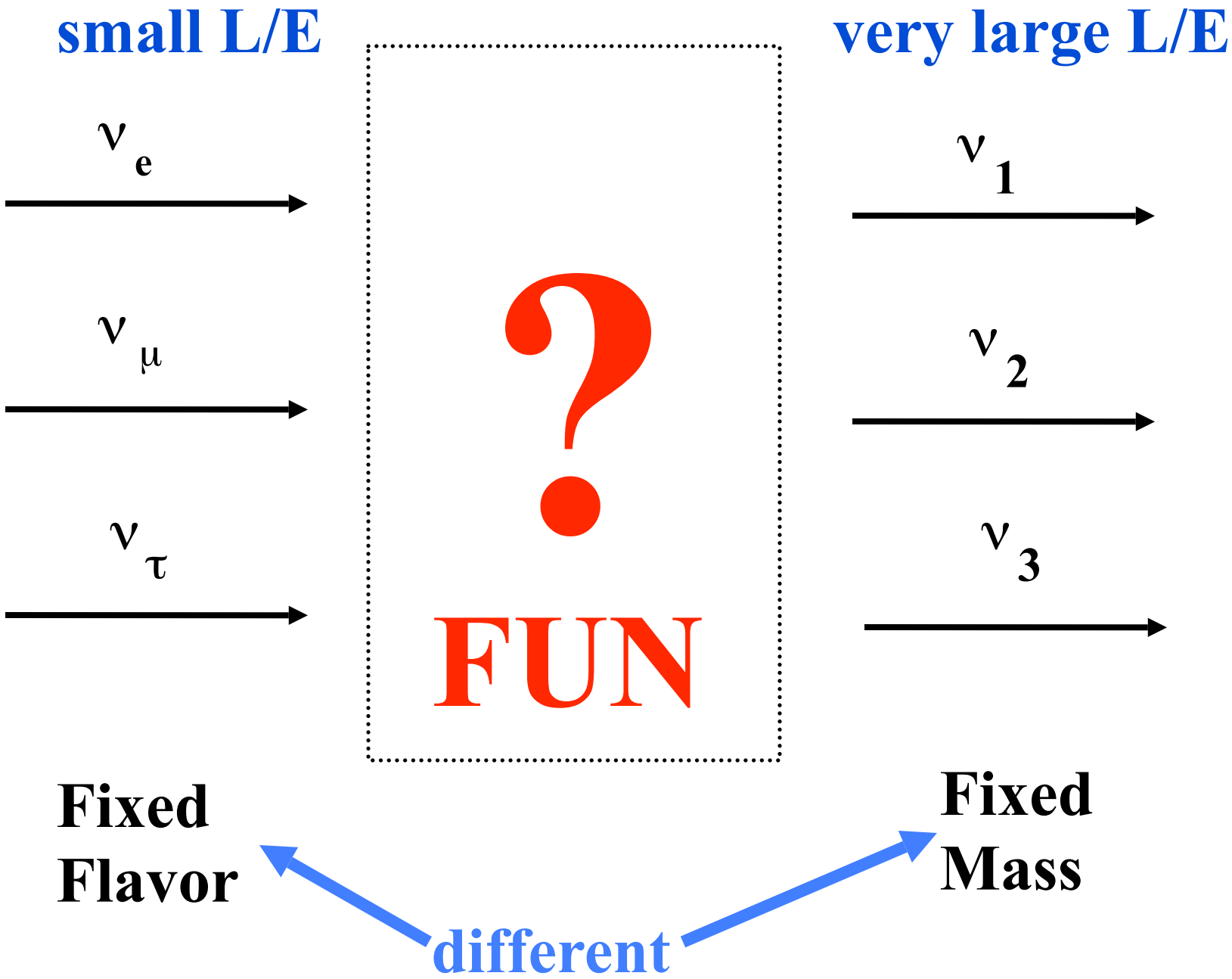


Until recently:

Long Distances needed!!!
(large L/E)


small L/E
very large L/E
ν_e
ν_μ
ν_τ
?
ν_1
ν_2
ν_3
Fixed Flavor
Fixed Mass
different

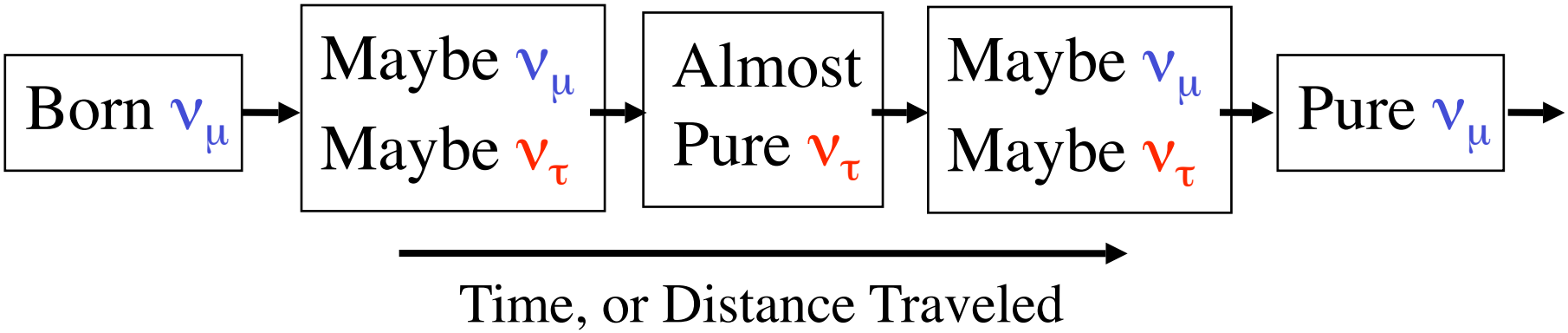

small L/E
very large L/E
ν_e
ν_μ
ν_τ
?
FUN
ν_1
ν_2
ν_3
Fixed Flavor
Fixed Mass
different

?

FUN

Here the world is truly Quantum Mechanical.

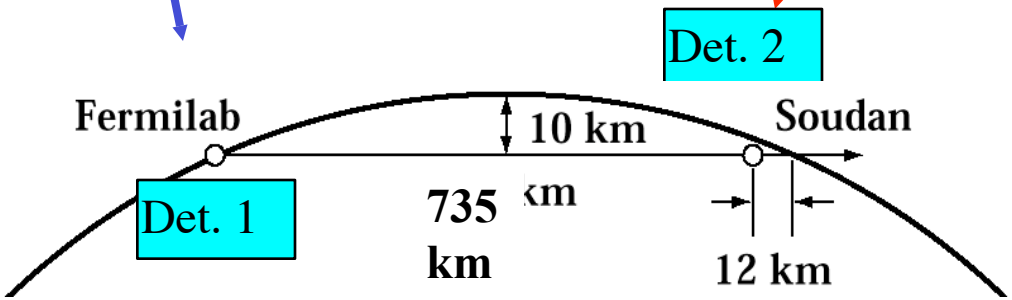
ν_μ **can oscillate into** ν_τ **and back again**

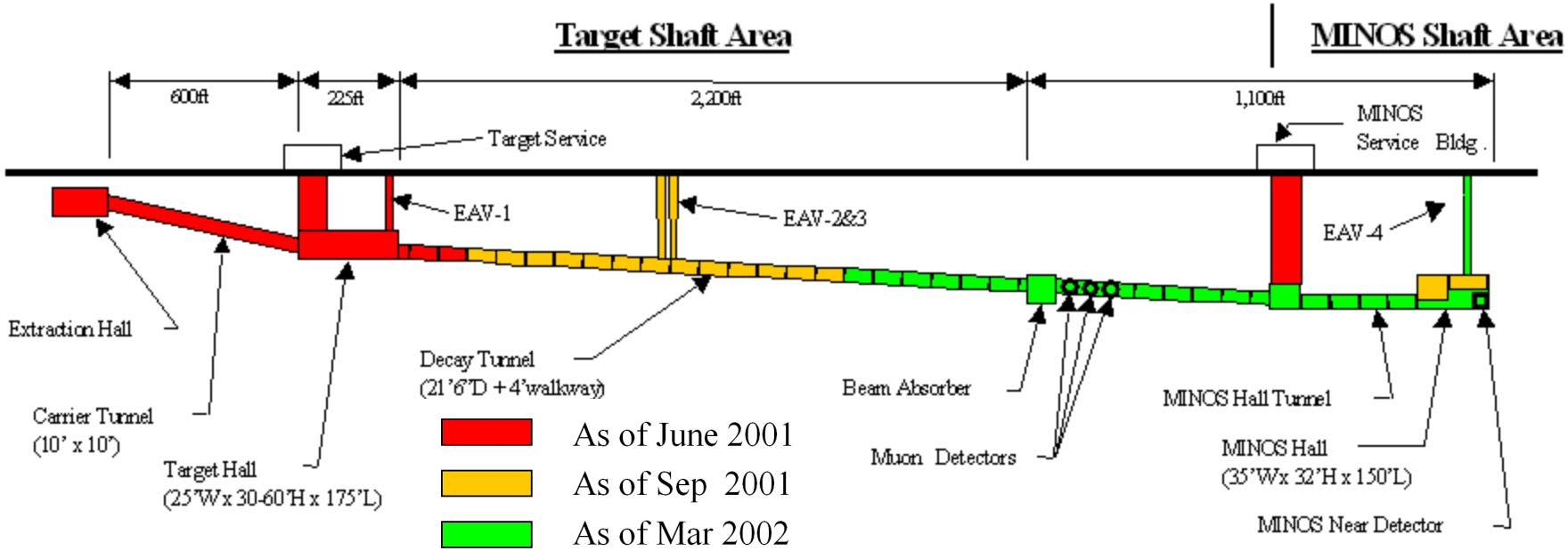


The MINOS Experiment

Near Detector: 980 tons

Far Detector: 5400 tons





T

First piece of decay pipe

Neutrino Flavor change $\Rightarrow$ Neutrino Masses

(Einstein)

m_e = electron mass = mass Hydrogen Atom / 2000

Neutrino Flavor change $\Rightarrow$ Neutrino Masses

(Einstein)

$$\sum m_\nu > m_e \;/\; 10^7$$

(0.05 eV)

m_e = electron mass = mass Hydrogen Atom / 2000

Neutrino Flavor change $\Rightarrow$ Neutrino Masses

(Einstein)

$$\sum m_\nu > m_e \ / \ 10^7$$

(0.05 eV)

and

$$\sum m_\nu < m_e \ / \ 10^6$$

(0.5 eV)

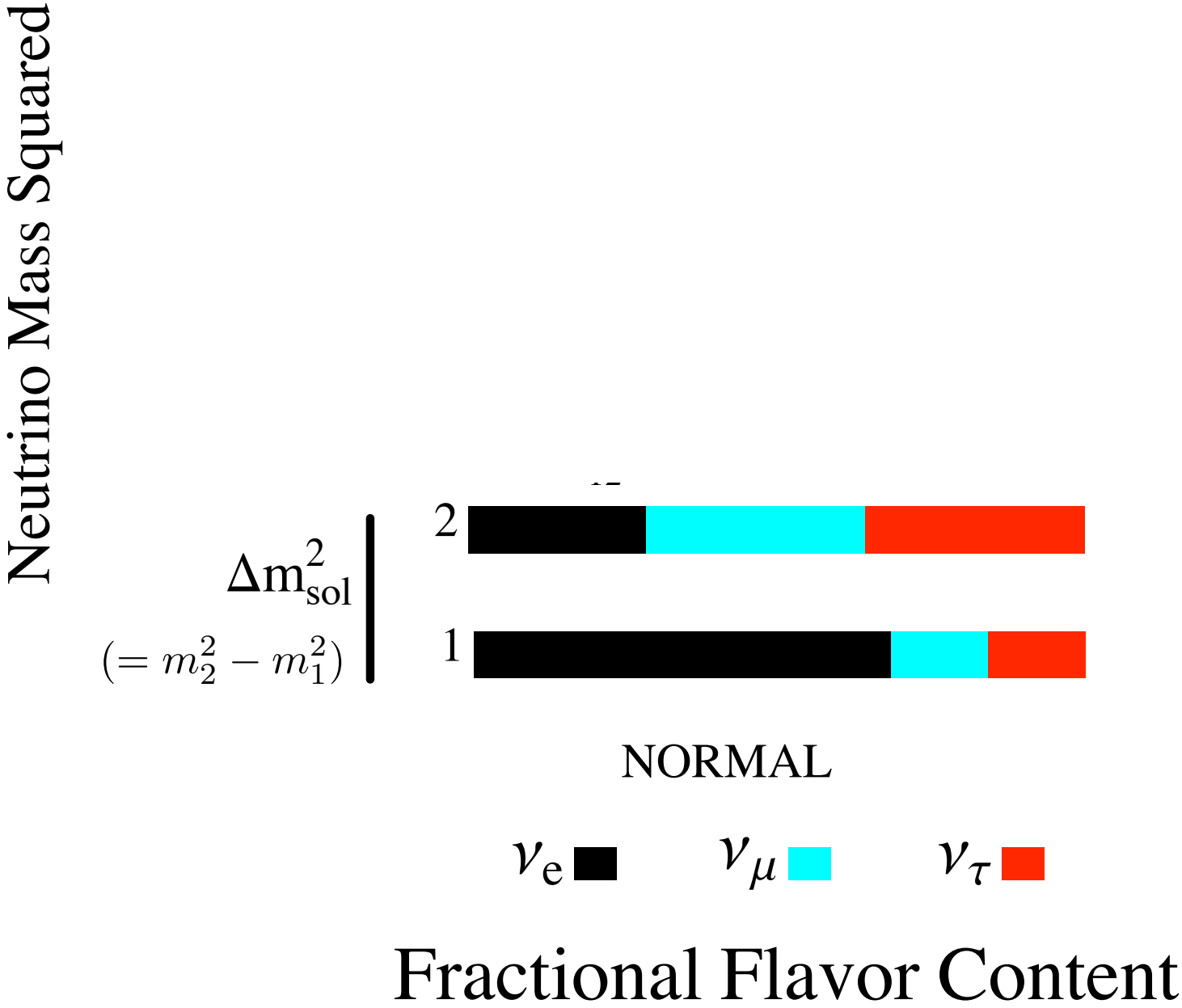
m_e = electron mass = mass Hydrogen Atom / 2000

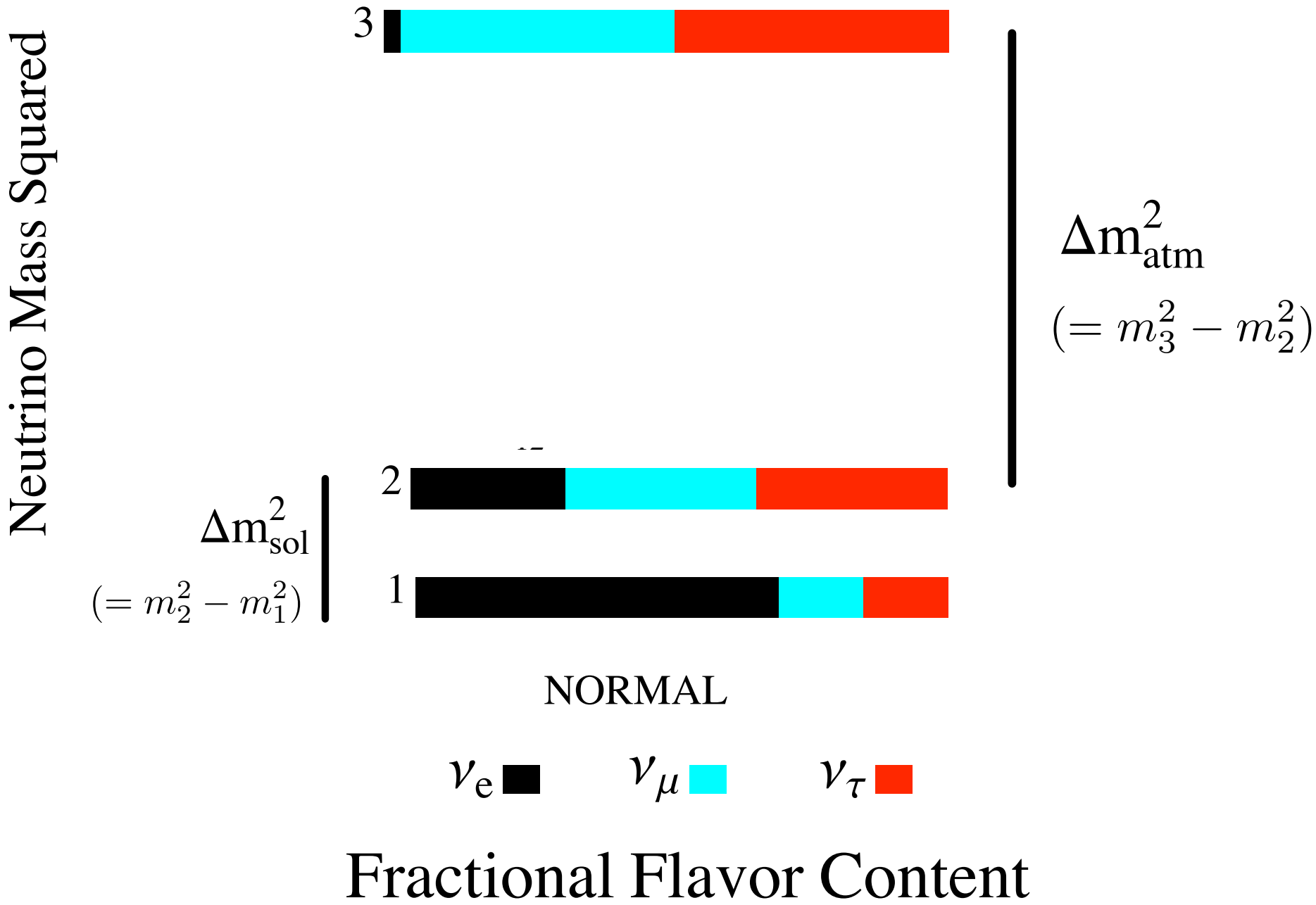
Neutrino Mass Squared

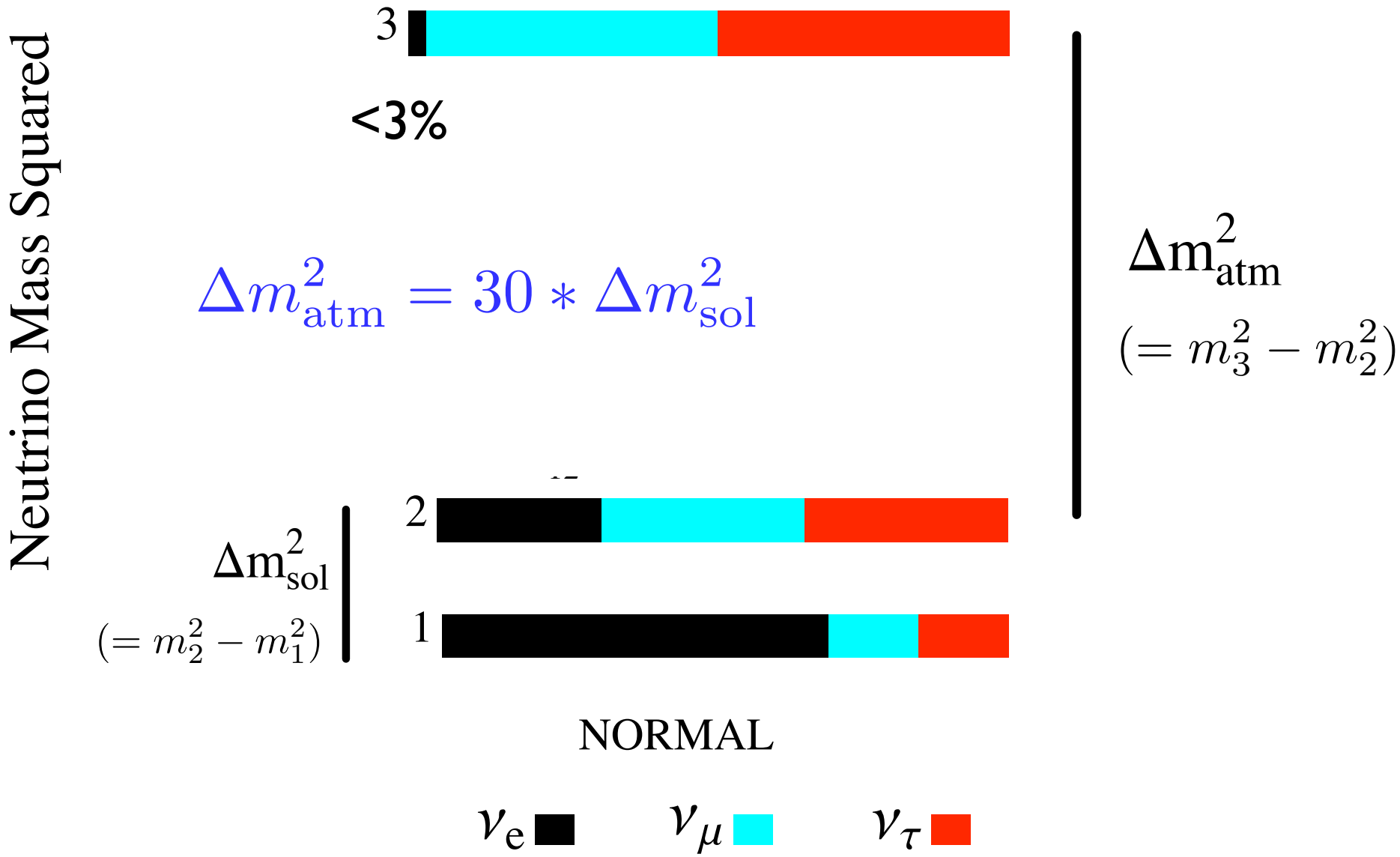
NORMAL

ν_e ν_μ ν_τ

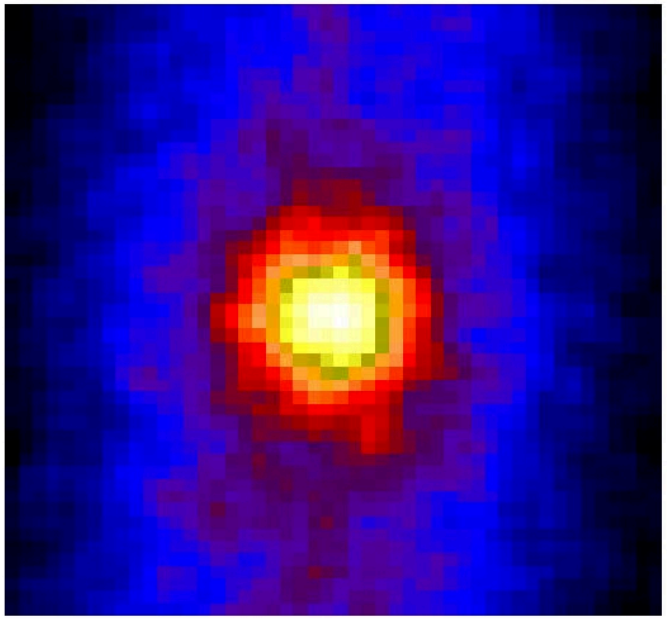
Fractional Flavor Content


Neutrino Mass Squared
Δm^2_{sol}
$(= m_2^2 - m_1^2)$
2
1
NORMAL
ν_e
ν_μ
ν_τ
Fractional Flavor Content


Neutrino Mass Squared
3
2
1
Δm^2_{atm}
$(= m_3^2 - m_2^2)$
Δm^2_{sol}
$(= m_2^2 - m_1^2)$
NORMAL
ν_e
ν_μ
ν_τ
Fractional Flavor Content

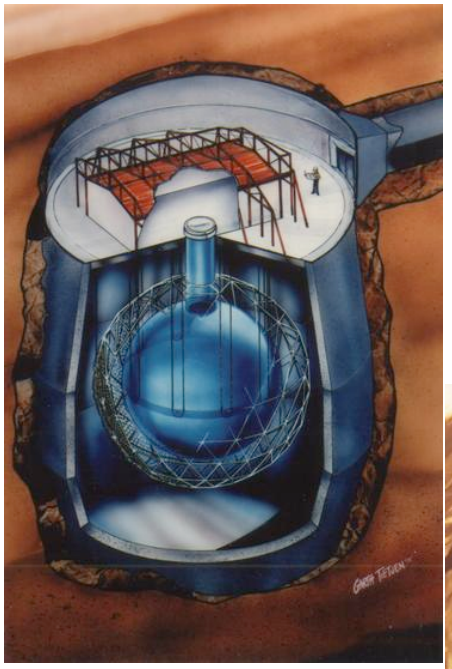

Neutrino Mass Squared
3
<3%
$\Delta m^2_{\rm atm} = 30 * \Delta m^2_{\rm sol}$
$\Delta m^2_{\rm atm}$
$(= m_3^2 - m_2^2)$
2
$\Delta m^2_{\rm sol}$
$(= m_2^2 - m_1^2)$
1
NORMAL
$\nu_{\rm e}$
ν_μ
ν_τ
Fractional Flavor Content

Solar Neutrinos:

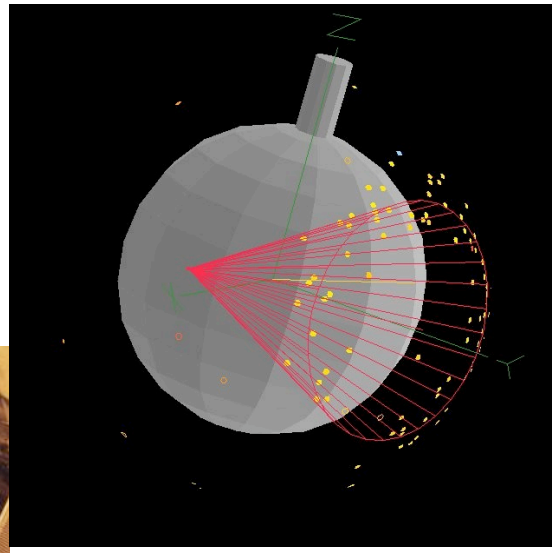


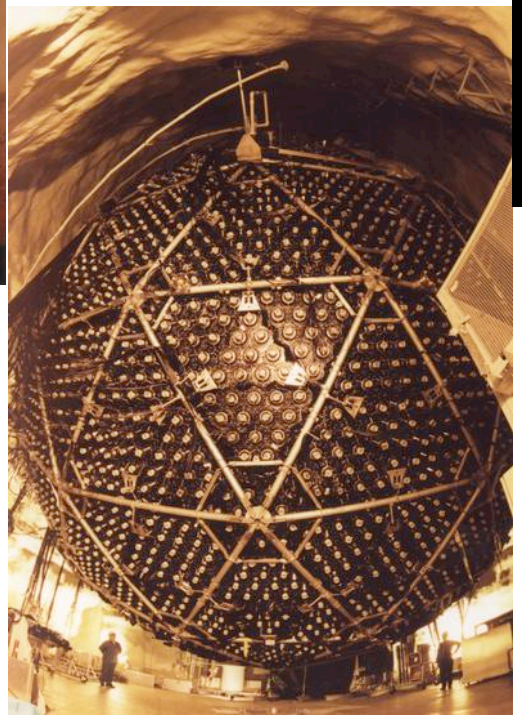
Ray Davis & John Bahcall

$$\frac{\text{Observed}}{\text{Expected}} \approx \frac{1}{3}$$



Sudbury Neutrino

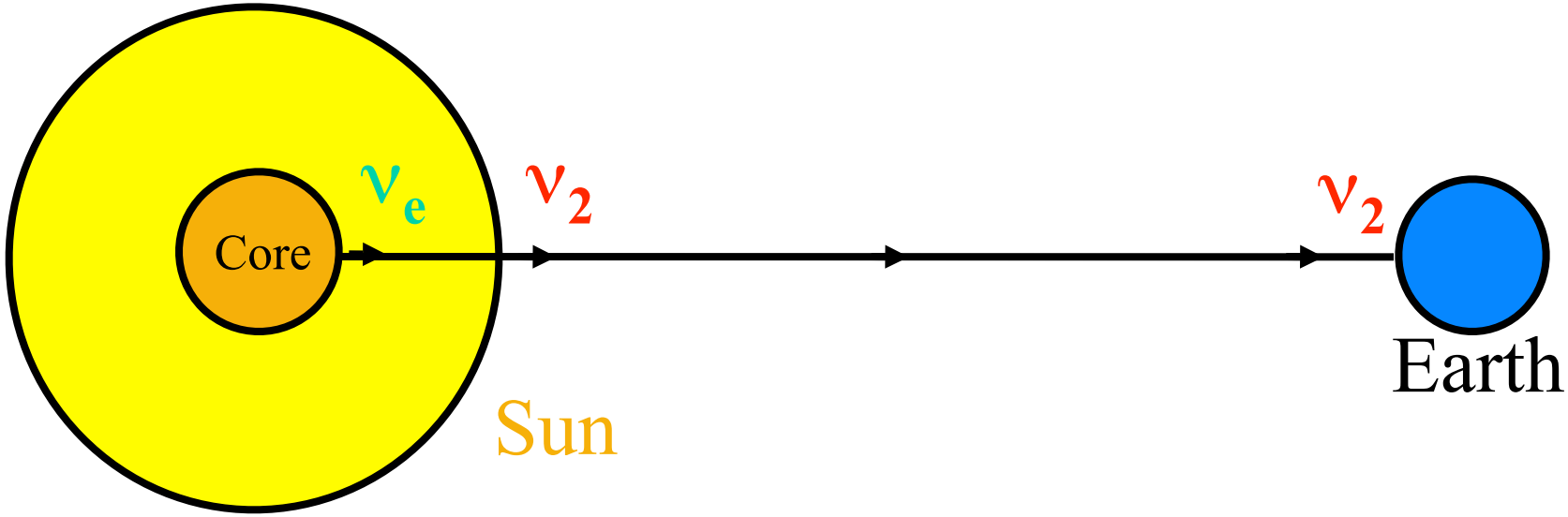




1000 tons

Solar

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 equal mixture of ν_e ν_μ and ν_τ

Davis

Neutrinos - Anti-Neutrinos

$$\nu_e \qquad \nu_\mu \qquad \nu_\tau$$

$$\bar{\nu}_e \qquad \bar{\nu}_\mu \qquad \bar{\nu}_\tau$$

Is $\bar{\nu}$ just a ν but with opposite spin ?

OR

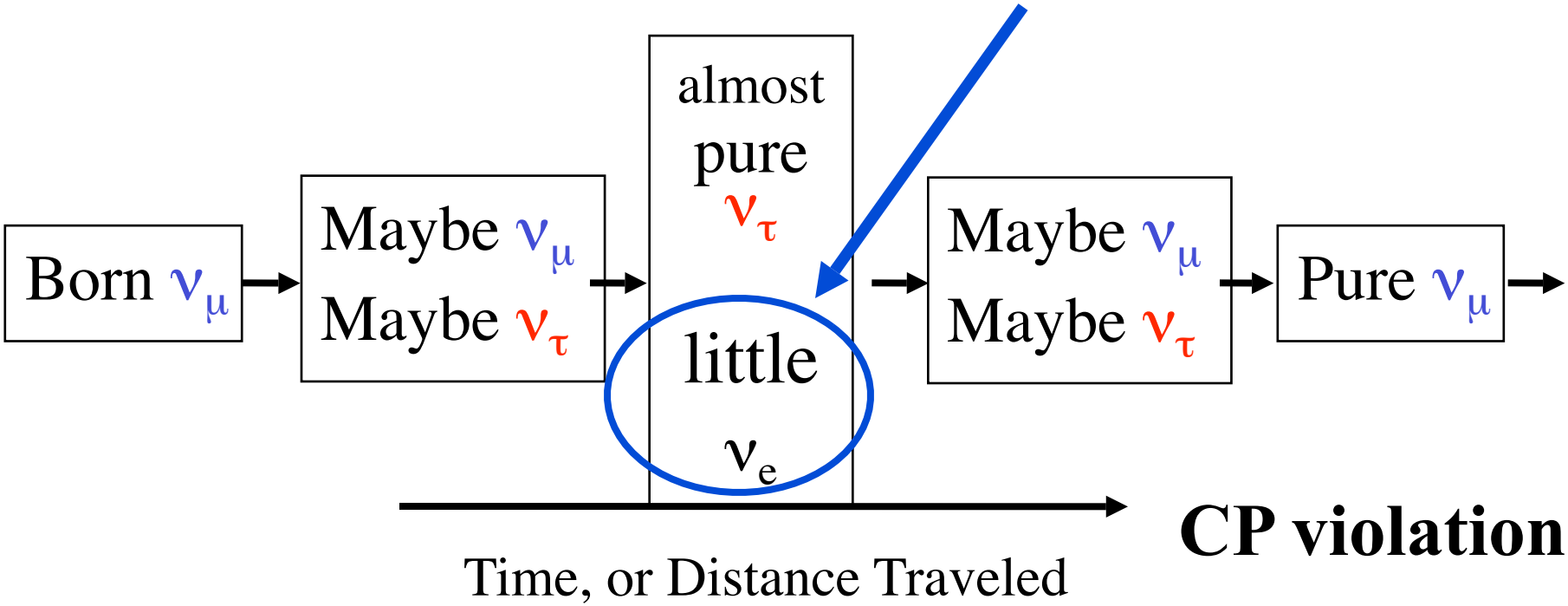
Is there a "leptonic charge" that is opposite?

Neutrinoless Double Beta Decay:

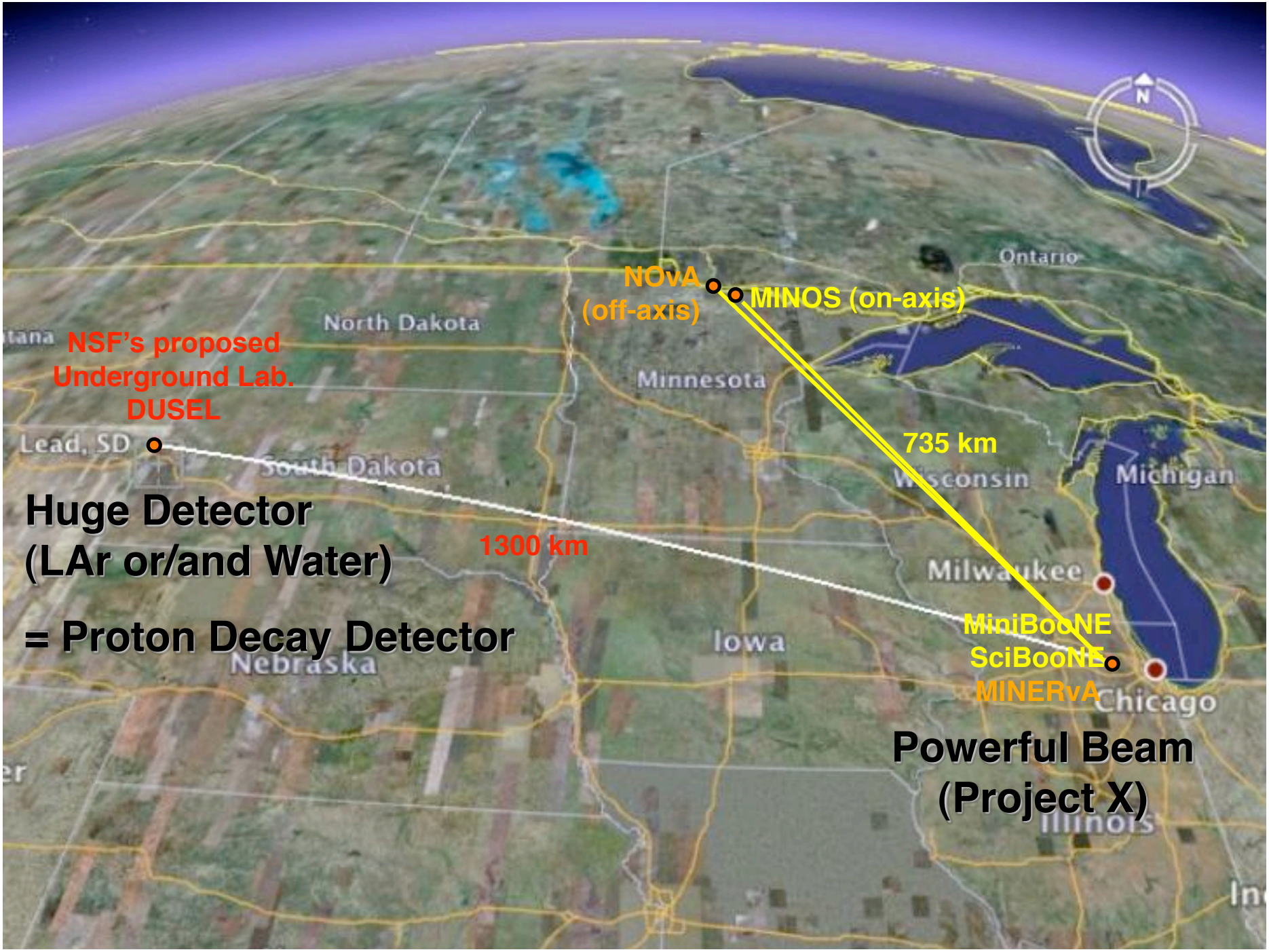
$$^{136}Xe \rightarrow ^{136}Ba + 2e^- \quad v \quad ^{136}Xe \rightarrow ^{136}Ba + 2e^- + 2\bar{\nu}_e \quad T_{1/2} \sim 10^{26}\ years$$

and

Neutrinos behave differently than Anti-Neutrinos



CP violation


NOvA
(off-axis)
MINOS (on-axis)
Ontario
North Dakota
NSF's proposed
Underground Lab.
DUSEL
Minnesota
Lead, SD
South Dakota
735 km
Wisconsin
Michigan
Huge Detector
(LAr or/and Water)
1300 km
Milwaukee
= Proton Decay Detector
MiniBooNE
SciBooNE
MINERvA
Iowa
Nebraska
Chicago
Powerful Beam
(Project X)
Illinois

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 !

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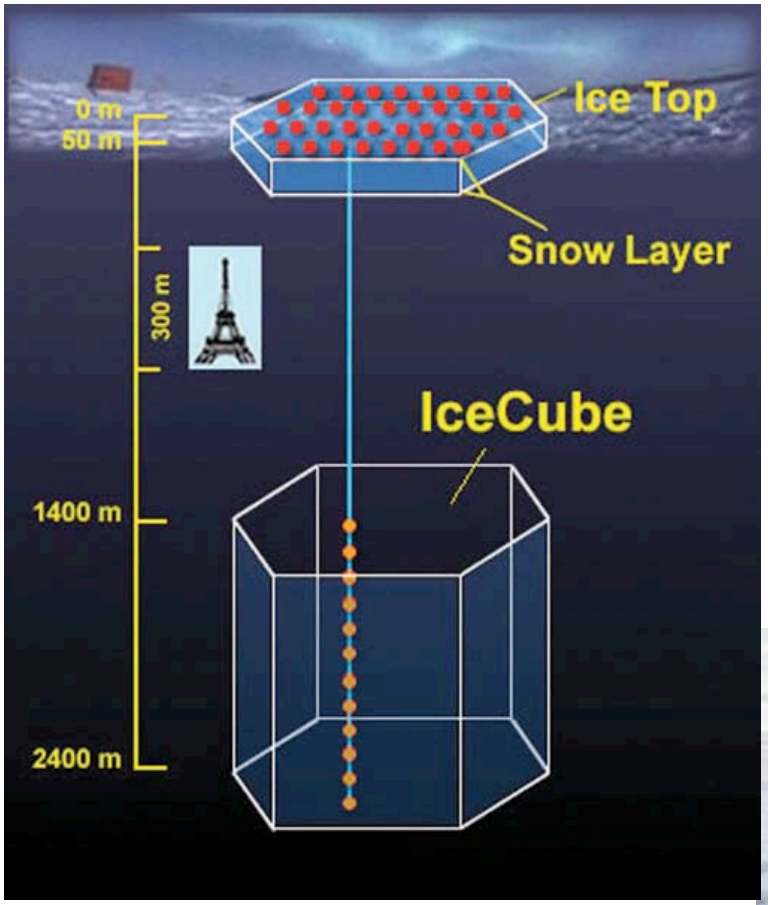
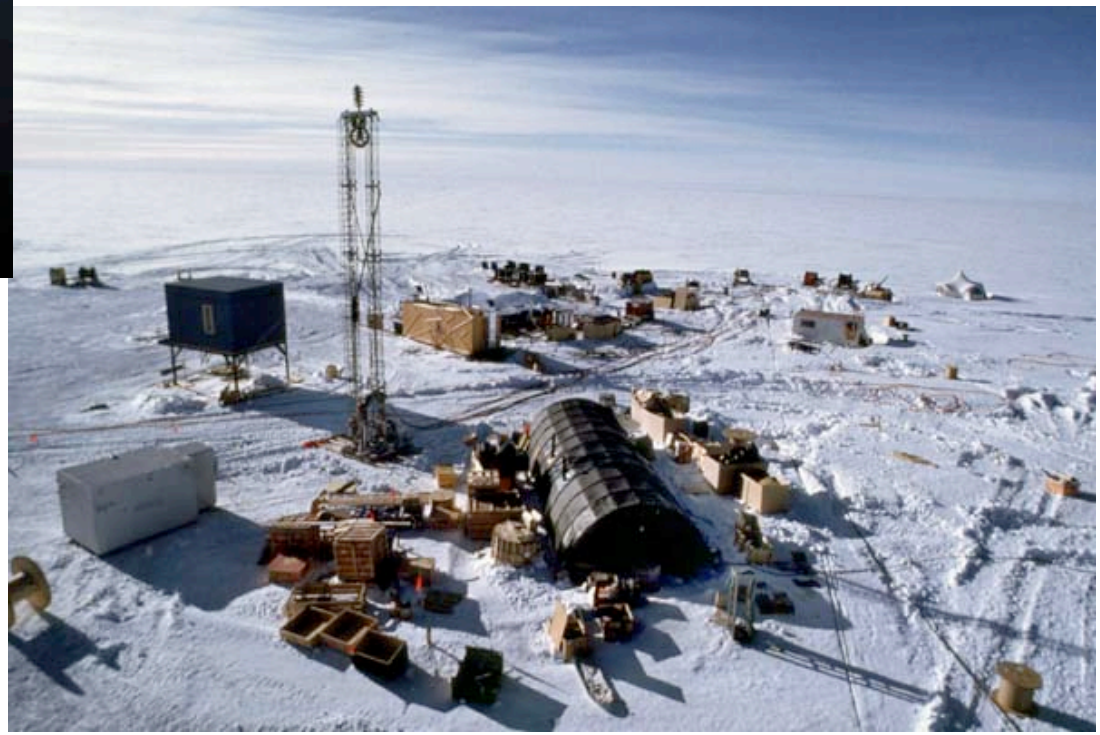
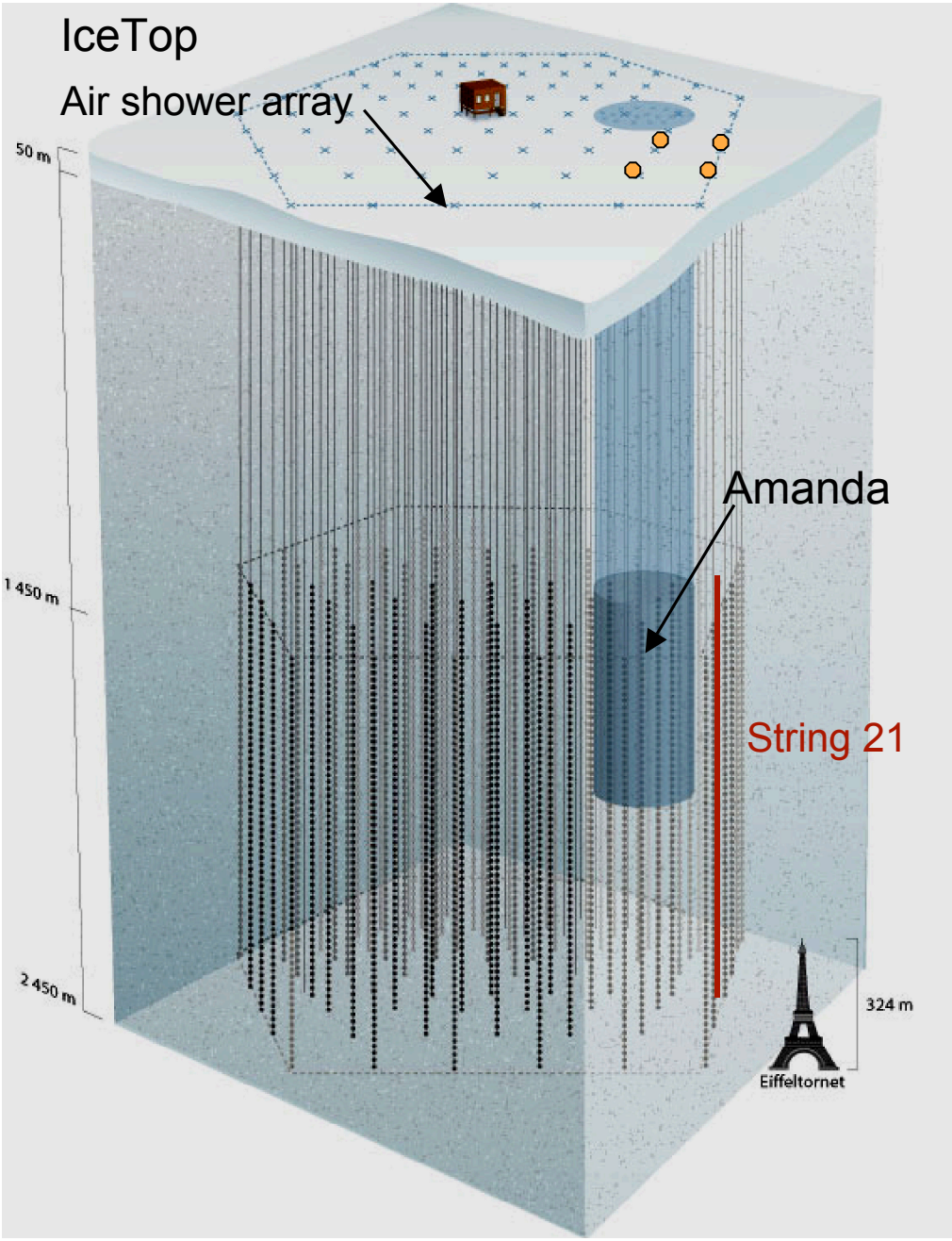
Leptogenesis

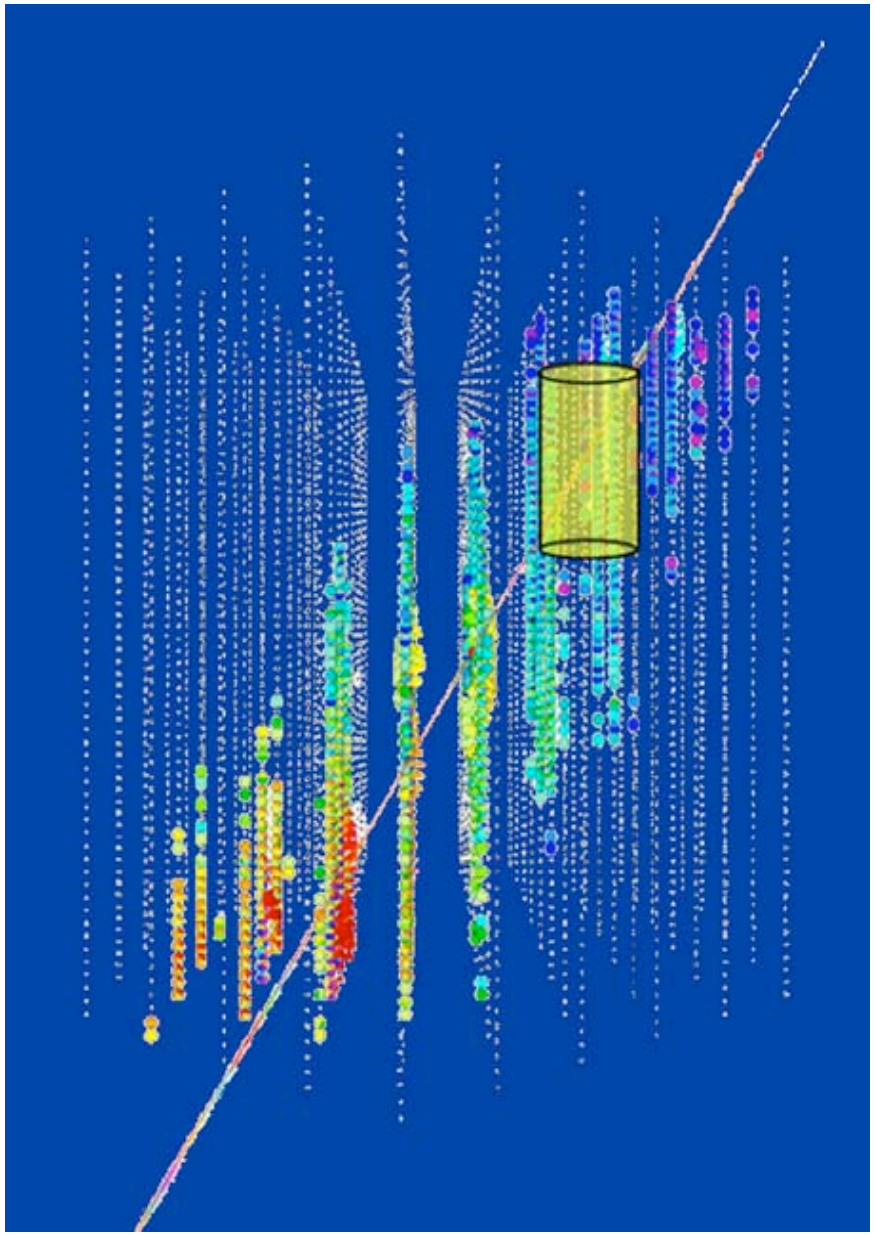


ICE CUBE
1 Km
cubed



Sears Tower
Neutrino
Proton
Cosmic
Accelerator
Crab nebula


IceTop
Air shower array
50 m
1 450 m
2 450 m
Amanda
String 21
324 m
Eiffeltornet



looking for rare high energy Neutrinos from point Sources.

Neutrino Telescope:

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.

Neutrinos are Everywhere, Abundant but Elusive

Neutrinos are Everywhere,
Abundant but Elusive

yet Fascinating
and
maybe Responsible for
our Existence in Universe.

Neutrinos are Everywhere, Abundant but Elusive

yet Fascinating
and
maybe Responsible for our Existence in Universe.

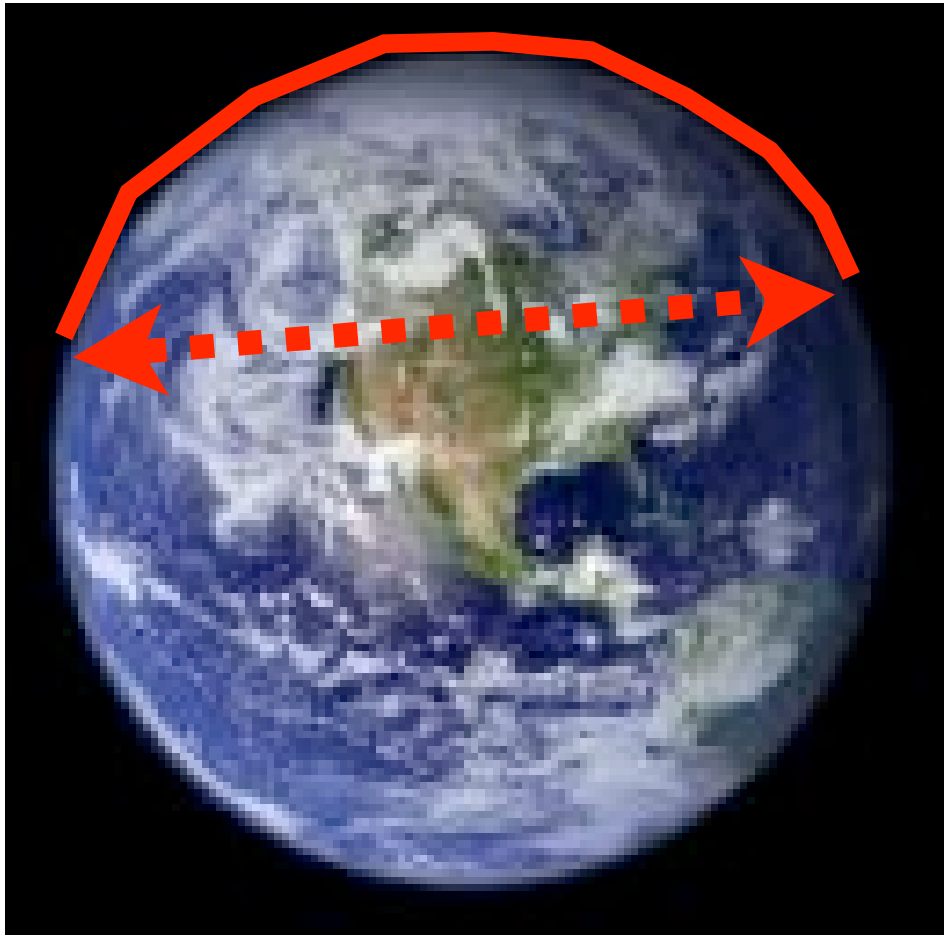
Asimov: The Neutrino
http://www.pbs.org/wgbh/nova/neutrino/

http://www.neutrino2008.co.nz

Extras:

Communications via Neutrinos:

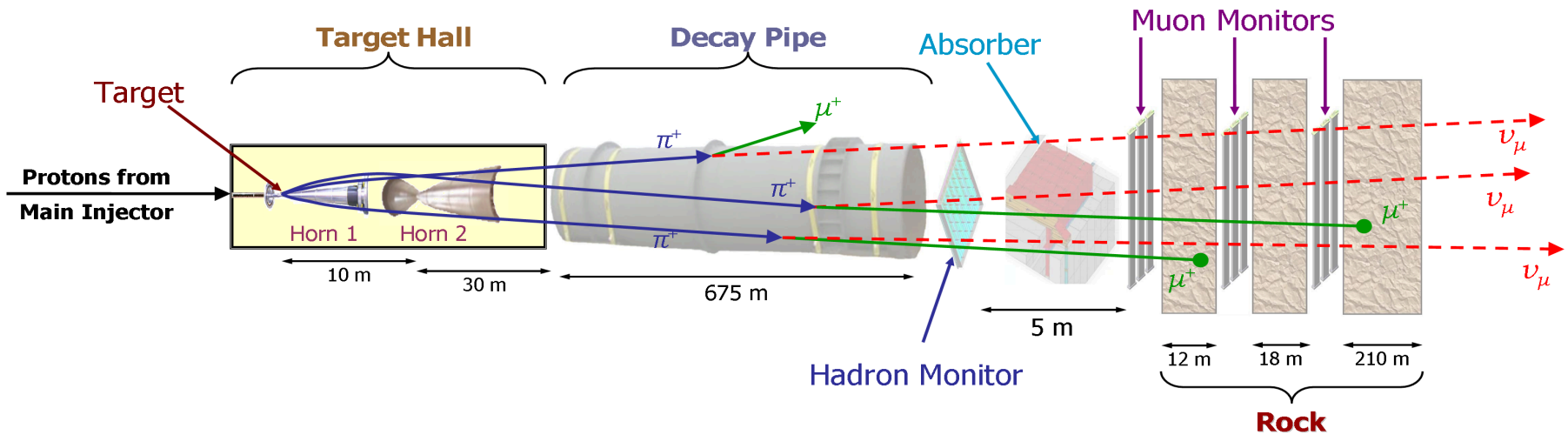
Shanghai

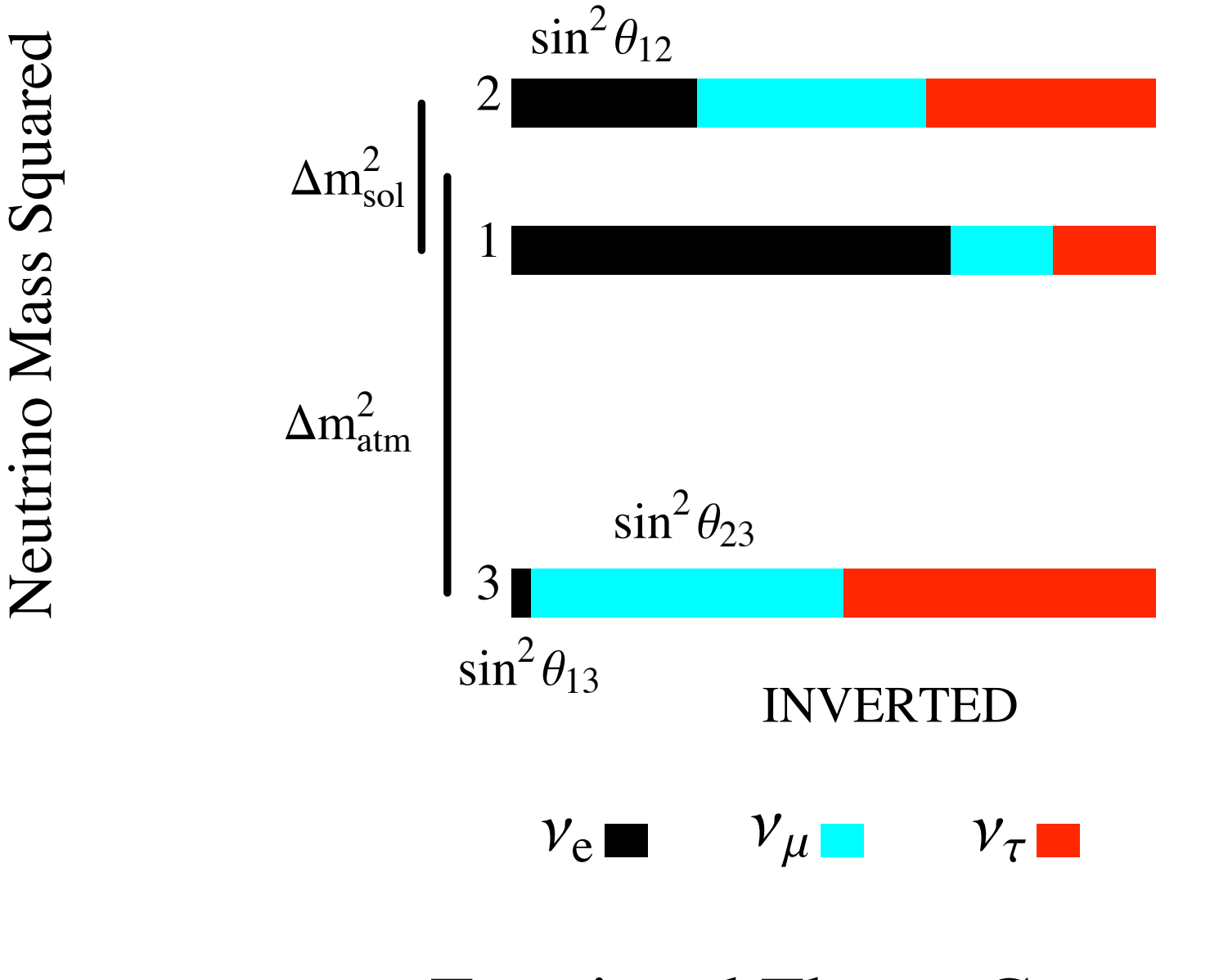


New York

Communications via Neutrinos:

$$\Delta Time = 20 - 30\ msec$$


Target Hall
Decay Pipe
Absorber
Muon Monitors
Target
Protons from
Main Injector
Horn 1
Horn 2
π^+
μ^+
ν_μ
10 m
30 m
675 m
5 m
12 m
18 m
210 m
Hadron Monitor
Rock


Neutrino Mass Squared
$\sin^2\theta_{12}$
2
Δm^2_{sol}
1
Δm^2_{atm}
$\sin^2\theta_{23}$
3
$\sin^2\theta_{13}$
INVERTED
ν_e
ν_μ
ν_τ
Fractional Flavor Content