THE PROBLEMATIC KID (II)

J.J. GÓMEZ CADENAS

IFIC-CSIC-U.VALENCIA
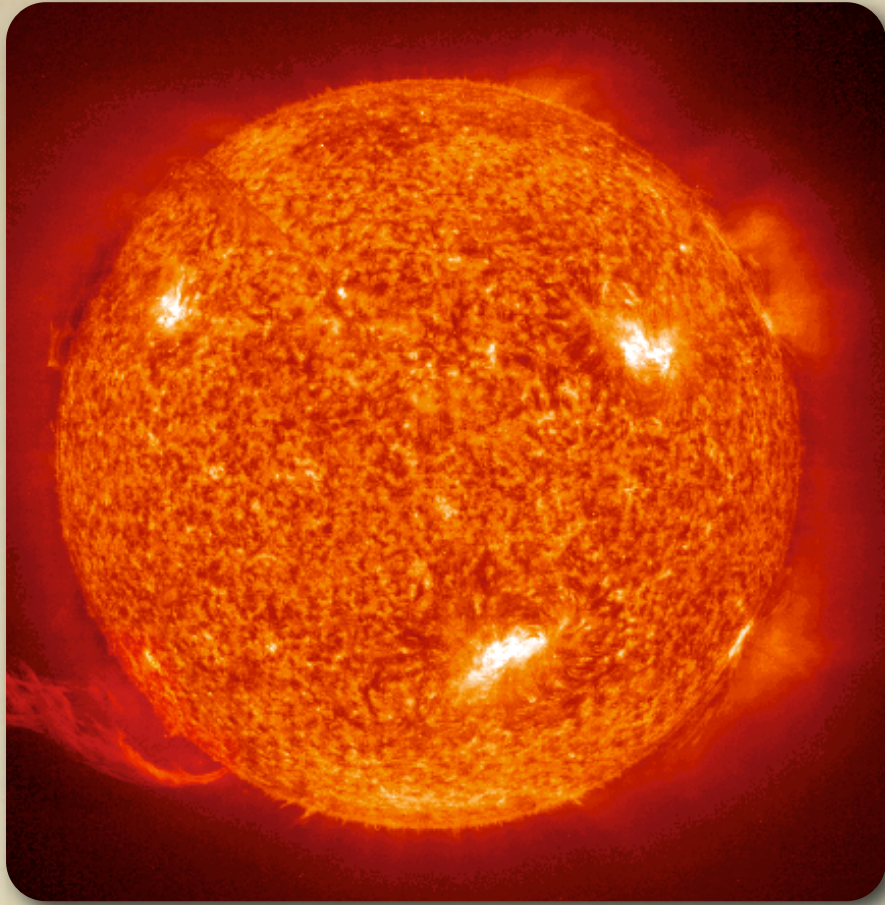
CERN SUMMER STUDENT LECTURES

2008

How many neutrinos cross your finger nail every second?
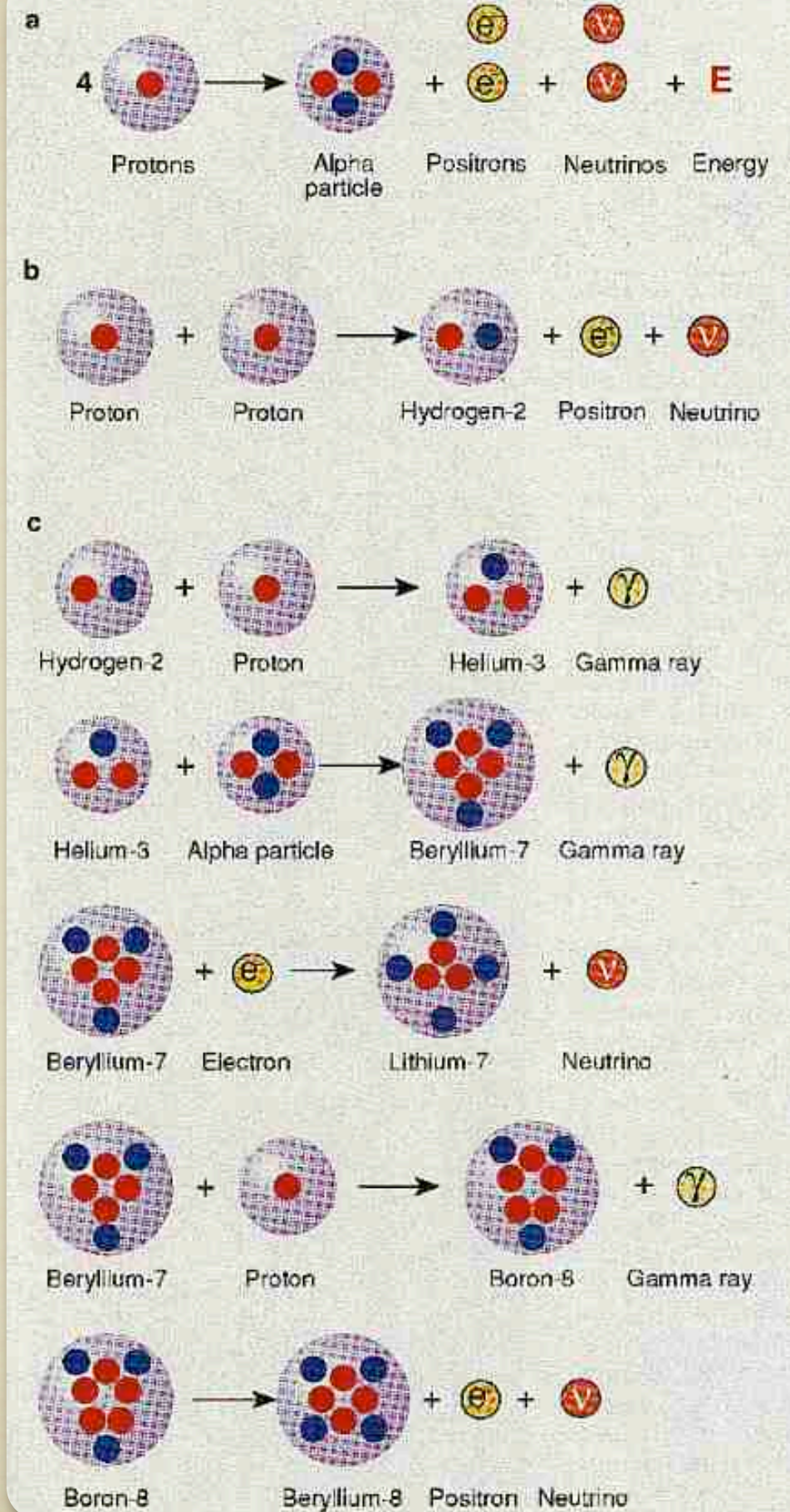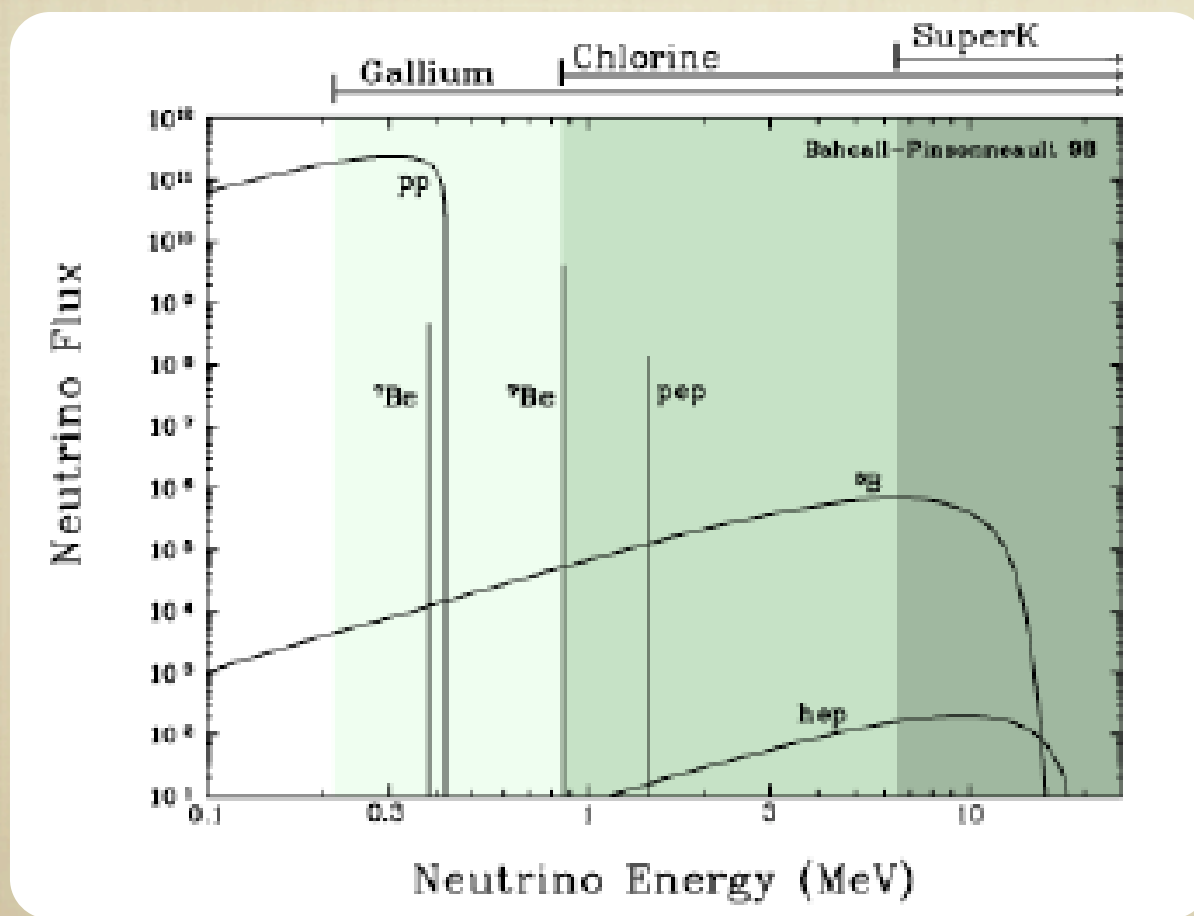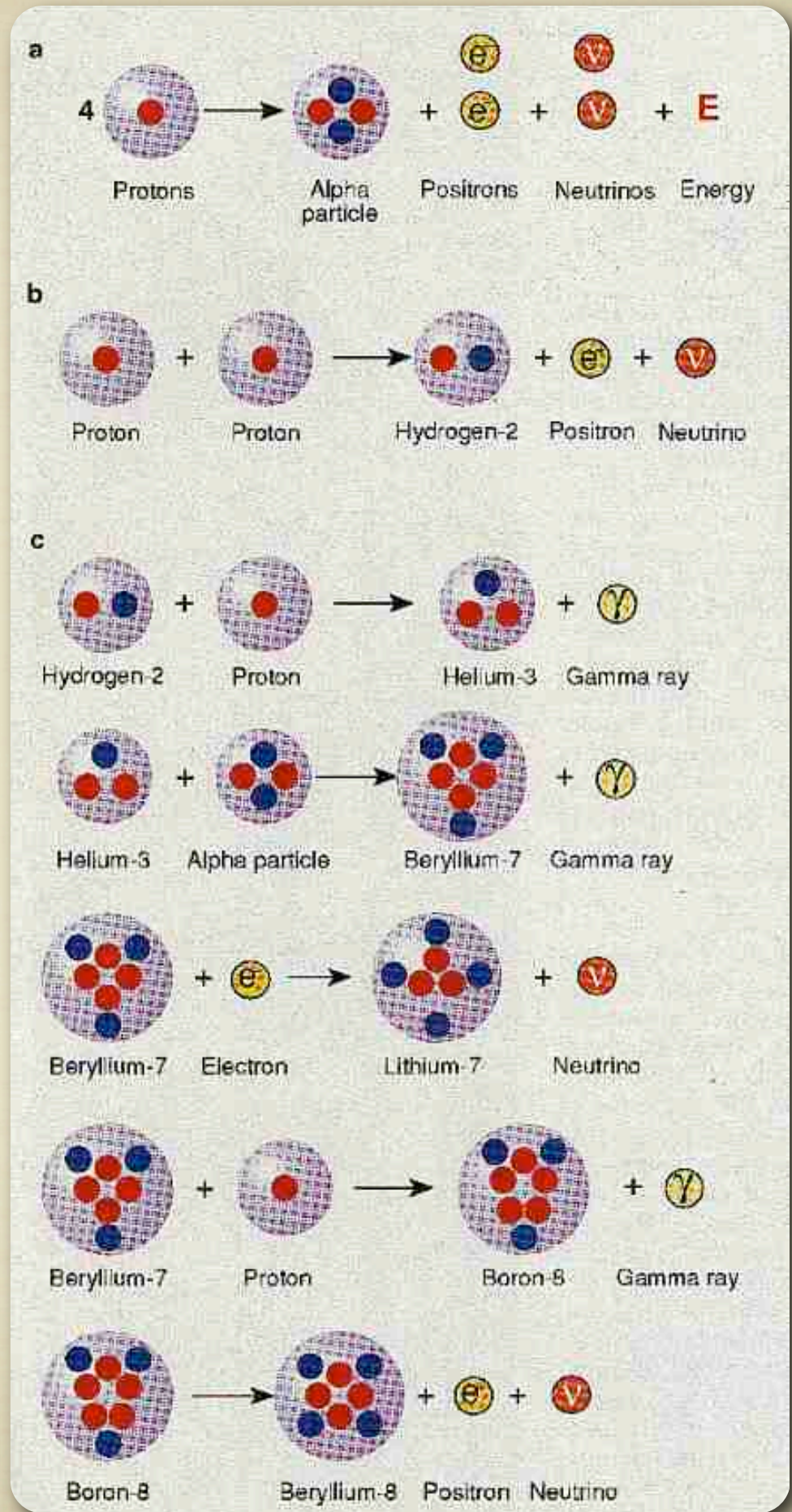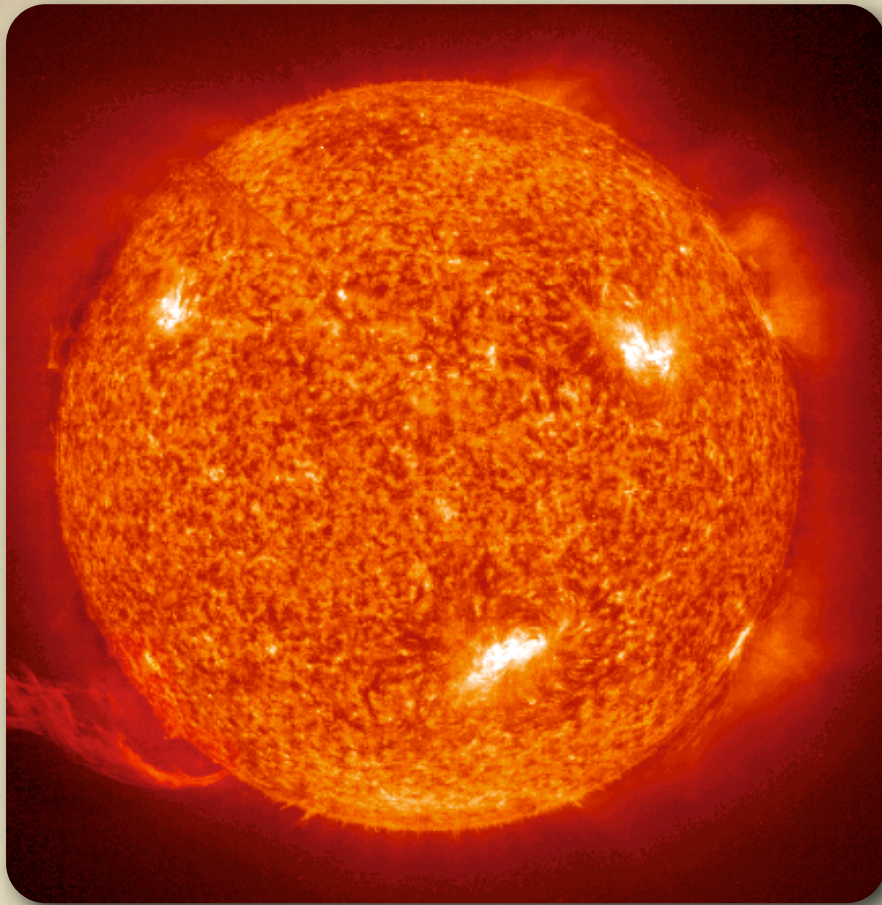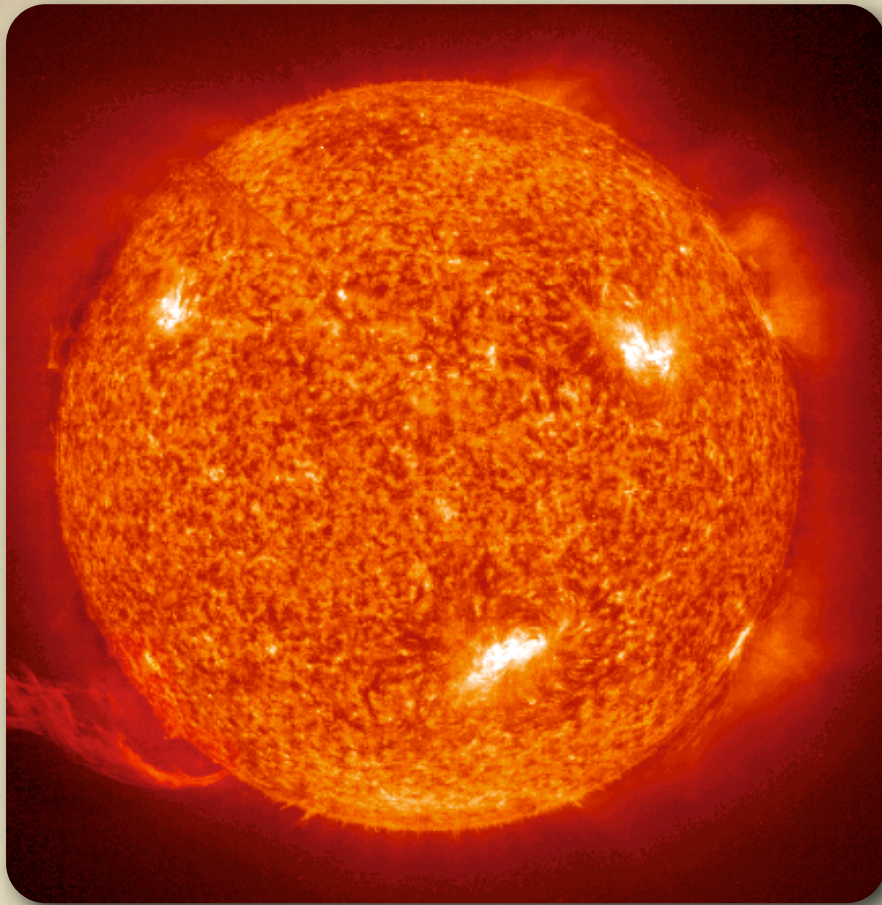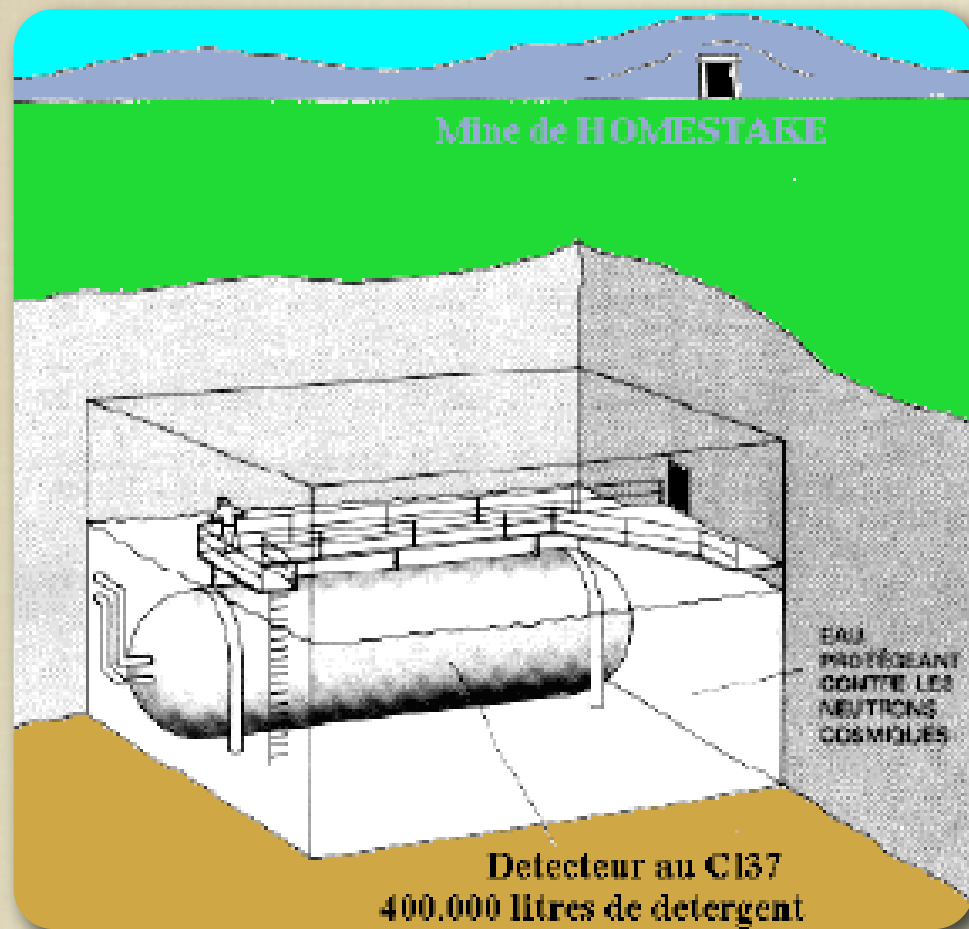
THE SUN

The Sun

The Sun

The hero in the mine (Davis, 1966)

Mine de **HOMESTAKE**

EAU PROTÉGEANT CONTRE LES NEUTRONS COSMIQUES

Detecteur au Cl37
400.000 litres de detergent

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Détecteur au Cl37
400.000 litres de détergent

Neutrino — Electron

Cl³⁷ → Ar³⁷

Stage 1
Neutrino absorption

35 days

Electron — Ar³⁷

Stage 2a
Argon-37 decay by electron capture

Electron — Cl³⁷

Auger electron

Stage 2b
Auger electron emission

The chlorine experiment
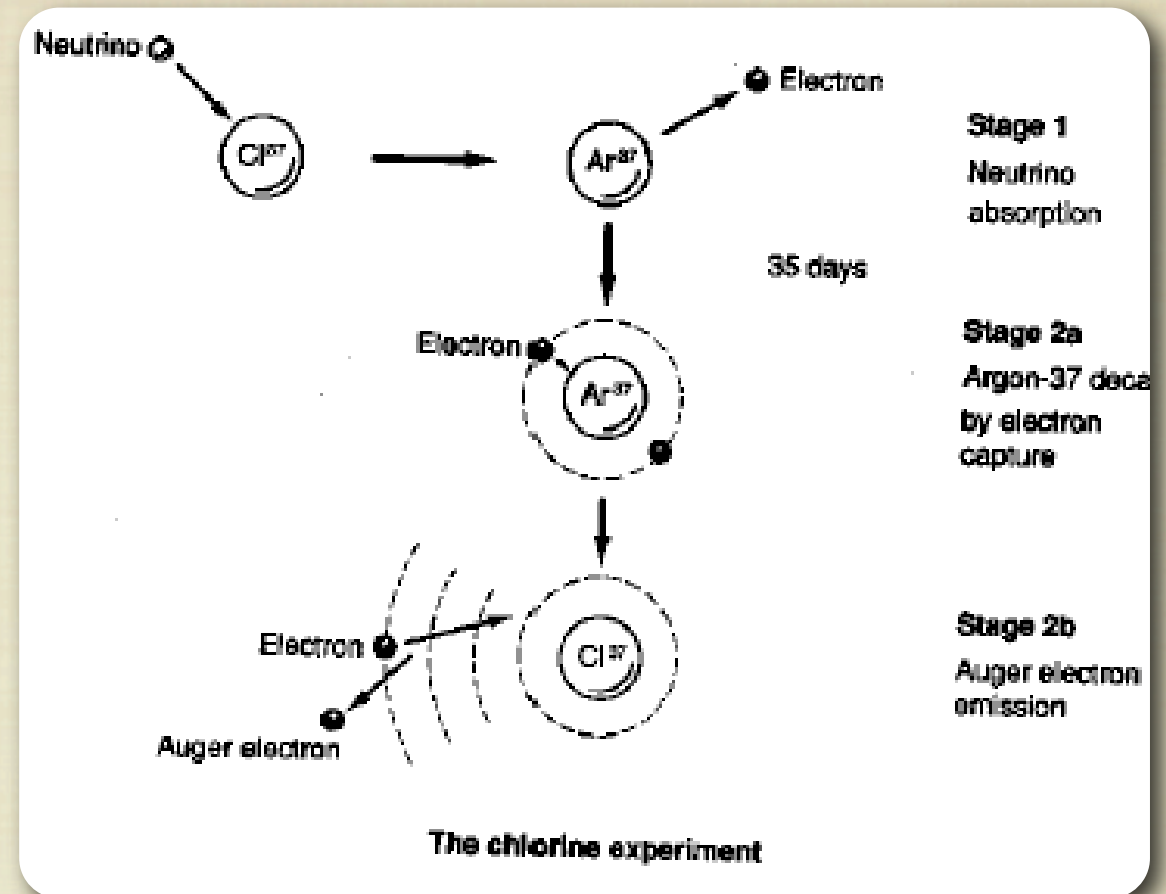
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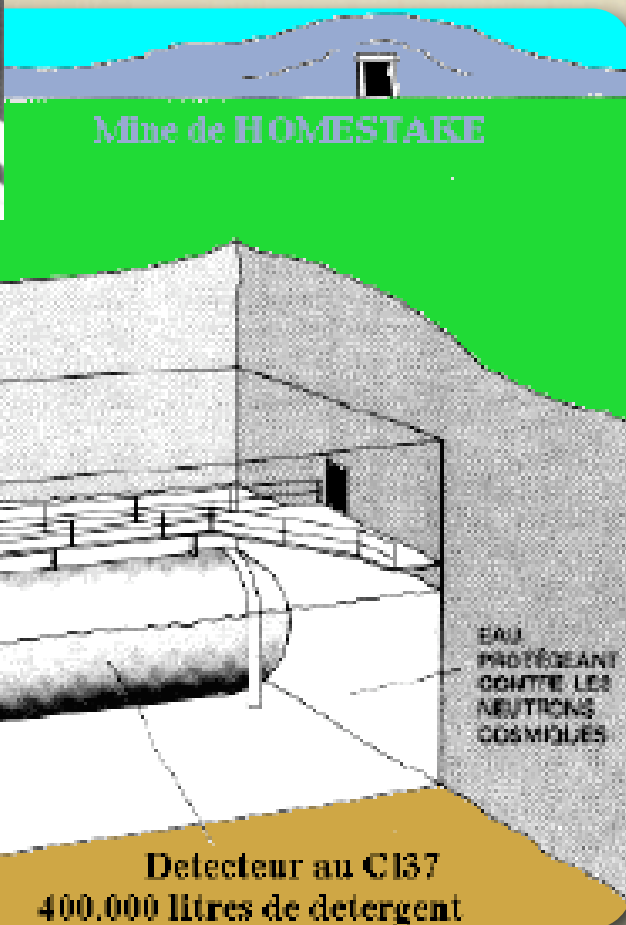
The idea: Count the number of ^{37}Ar atoms produced in the experiment!
Separate a few argon atoms from 1/2 million liters of chlorine by radiochemical methods
more than twenty years taking data
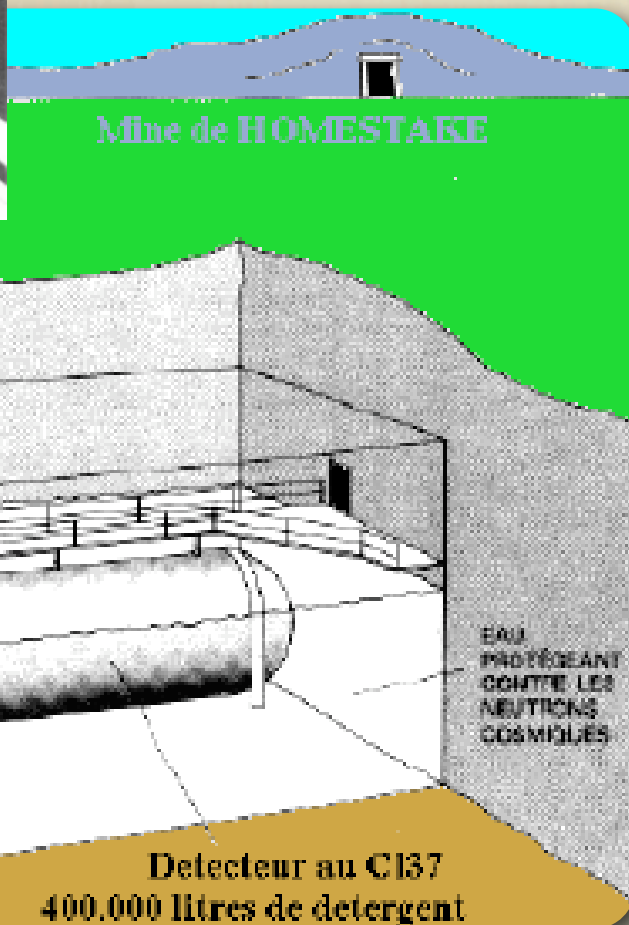
Mine de HOMESTAKE

EAU PROTÉGEANT CONTRE LES NEUTRONS COSMIQUES

Détecteur au Cl37
400.000 litres de détergent

380 000 liters of C_2Cl_4 (a cleaning fluid) deep inside Homestake mine to shield from natural radiation (a Olympic swimming pool)

Mine de HOMESTAKE

EAU PROTÉGEANT CONTRE LES NEUTRONS COSMIQUES

Détecteur au Cl37
400.000 litres de détergent

Let Argon-37 accumulate from 1 to 3 months. Flush with He gas to remove Ar from fluid. Let the Ar condensate in a 77 K charcoal trap. Collect and purify Ar. Count the number of Auger electrons from Ar^{37}

380 000 liters of C_2Cl_4 (a cleaning fluid) deep inside Homestake mine to shield from natural radiation (a Olympic swimming pool)

The neutrino deficit in Davis experiment
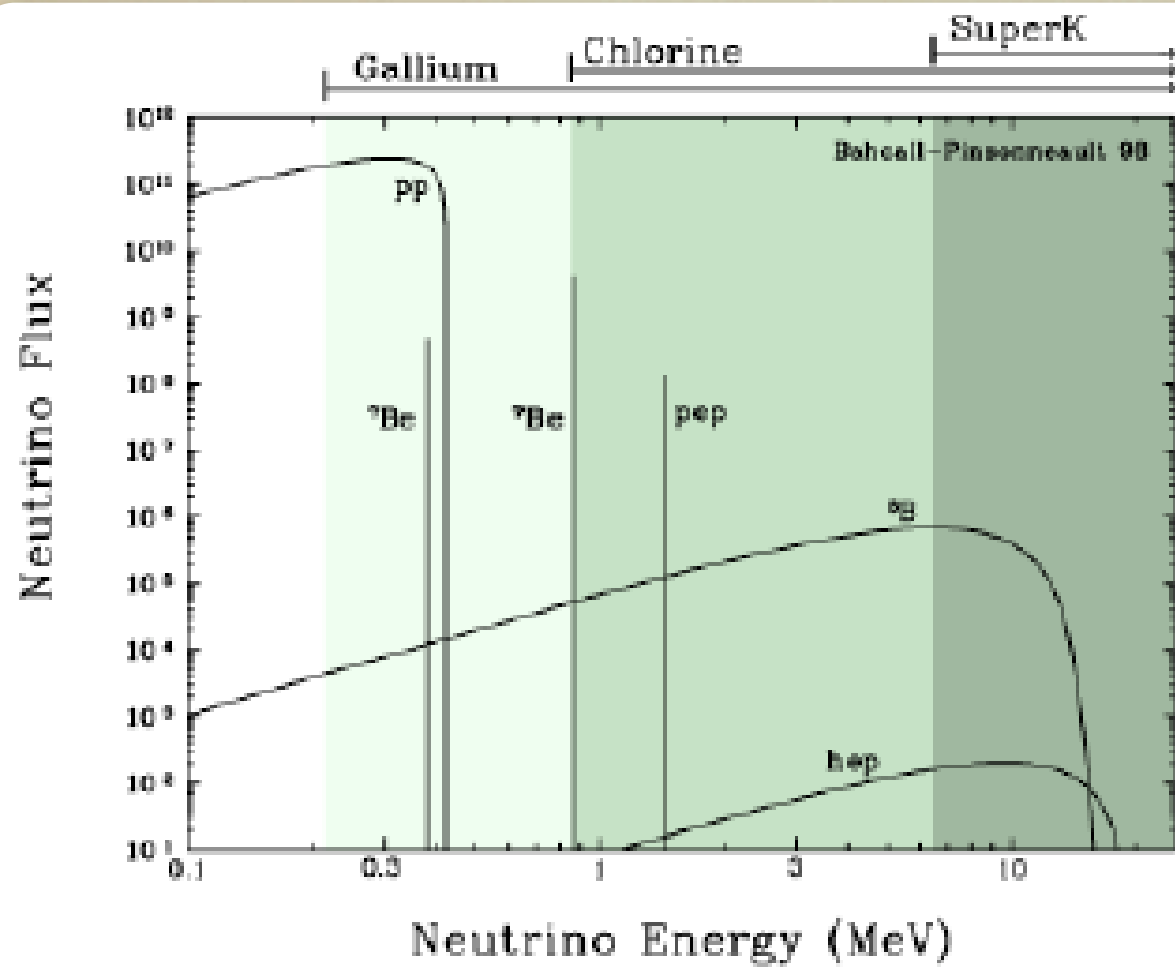
The neutrino deficit in Davis experiment
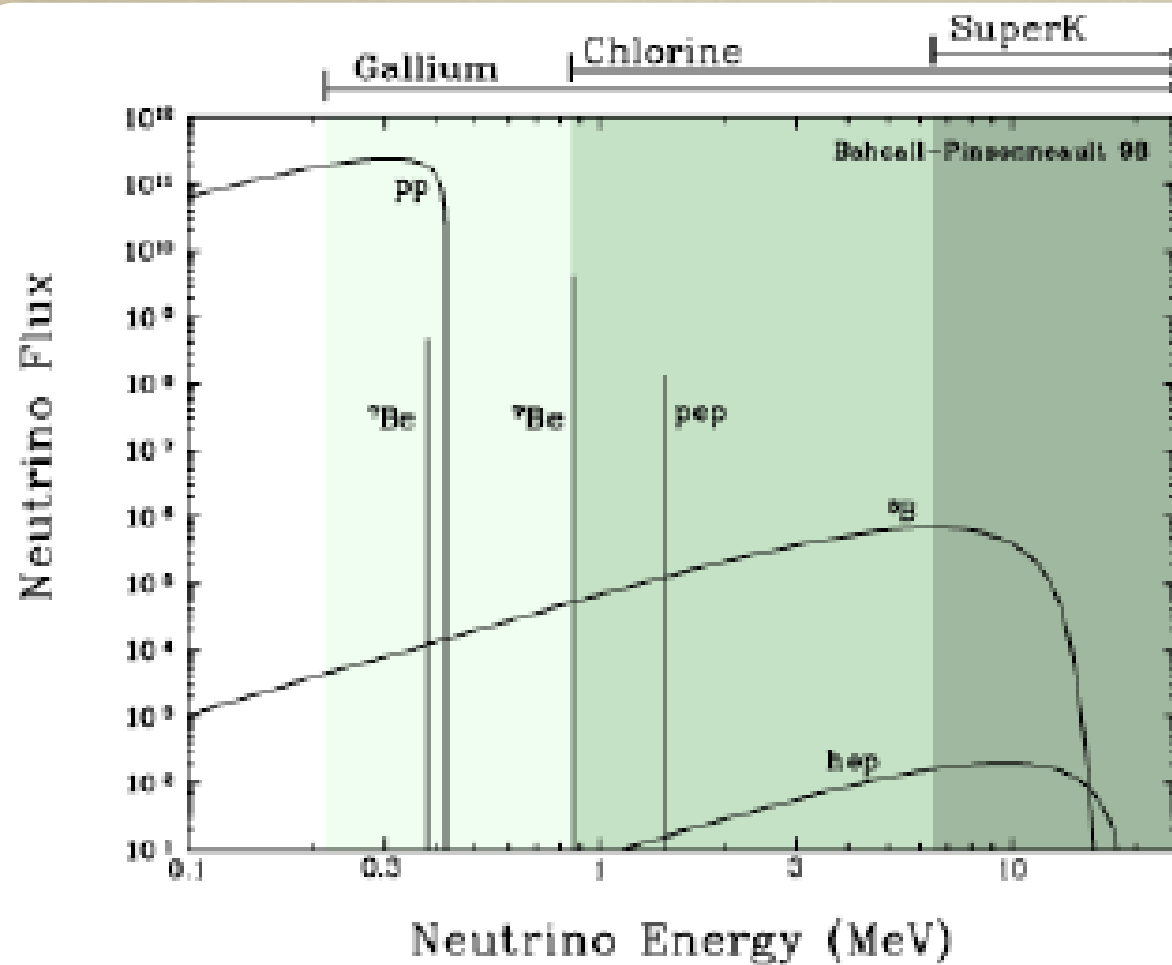
Expects

8.2 SNU ±1.8

Observs

2.56 SNU ±0.23

The neutrino deficit in Davis experiment
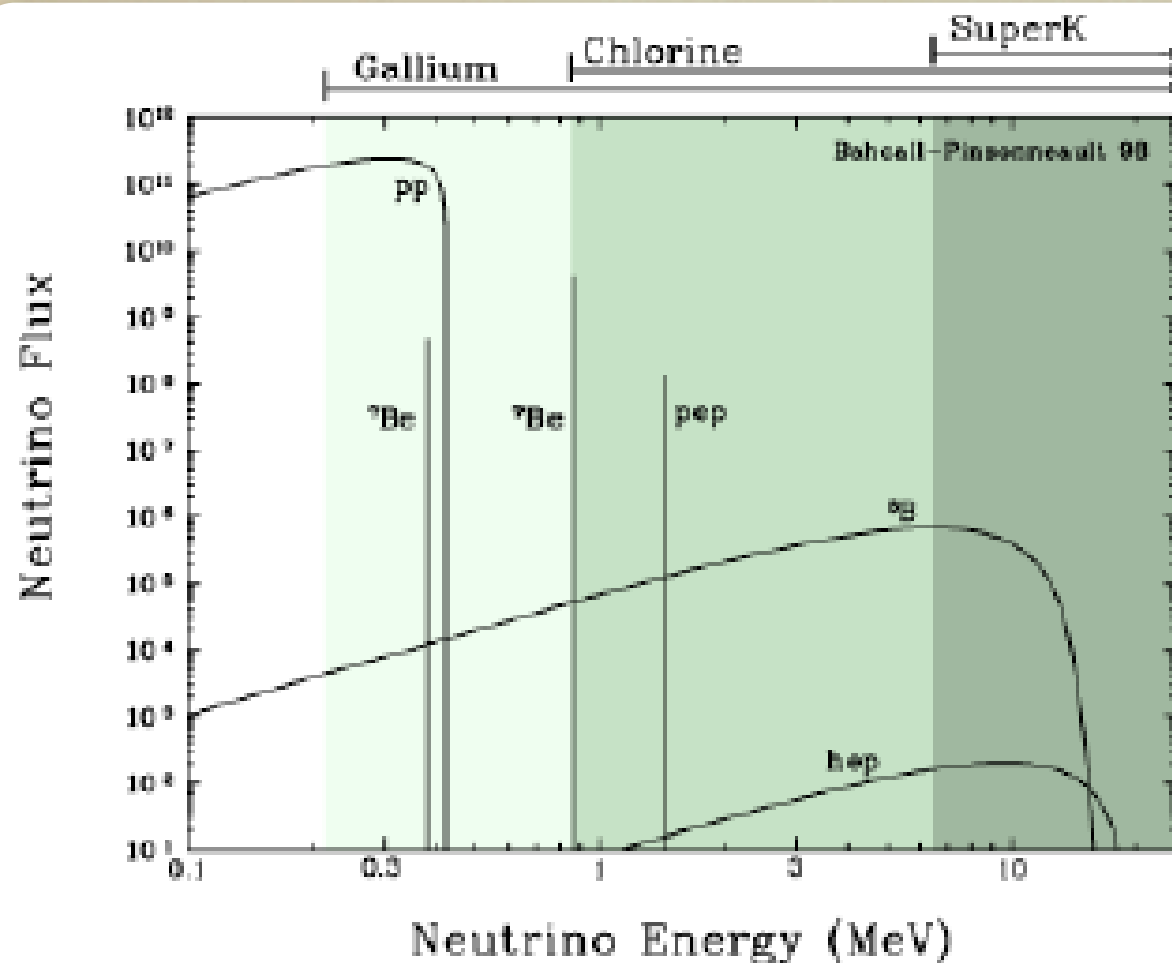
Expects

8.2 SNU ±1.8

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2.56 SNU ±0.23

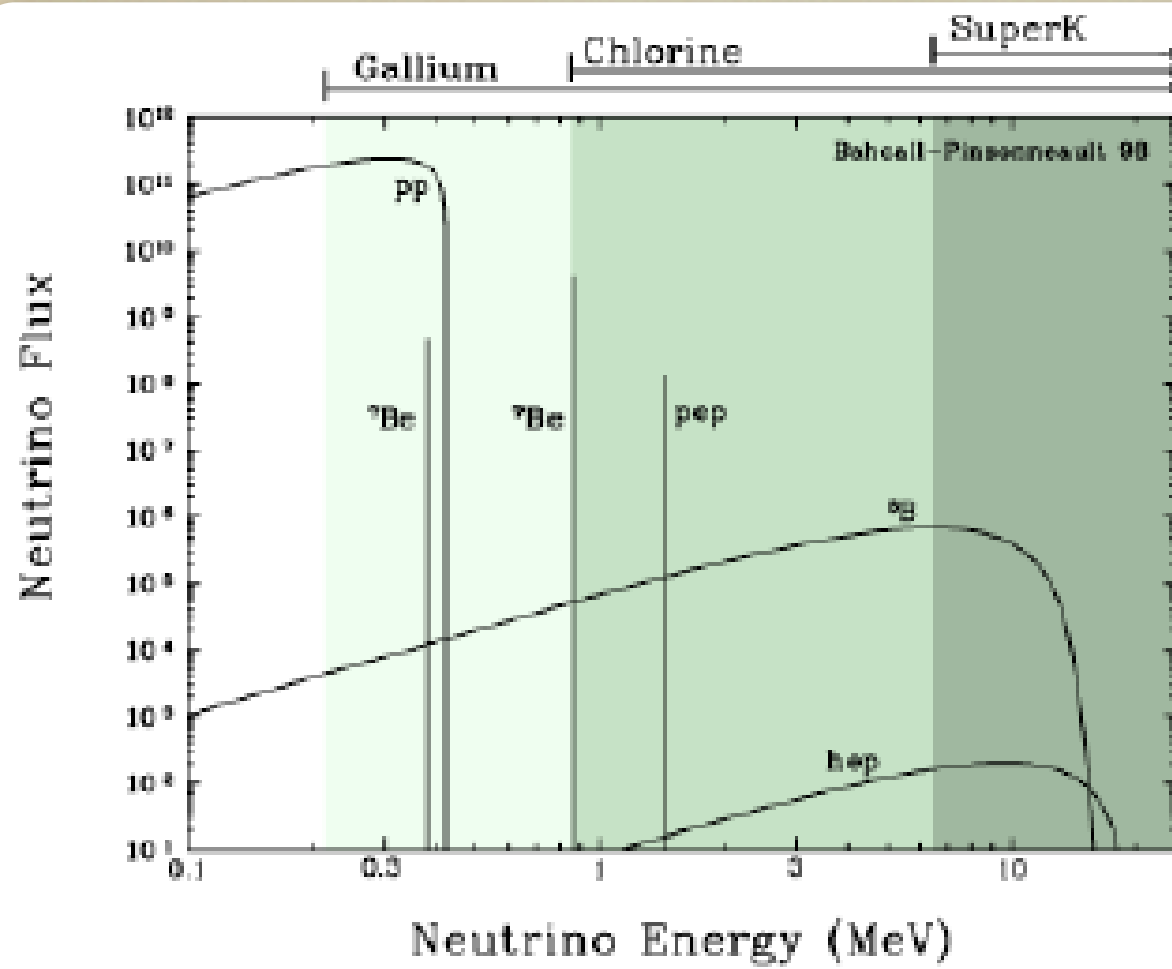Also called "paradox", "dilemma", "puzzle" and other nice words that showed that every body (secretly) believed that:
Davis (Chlorine experiment) was wrong
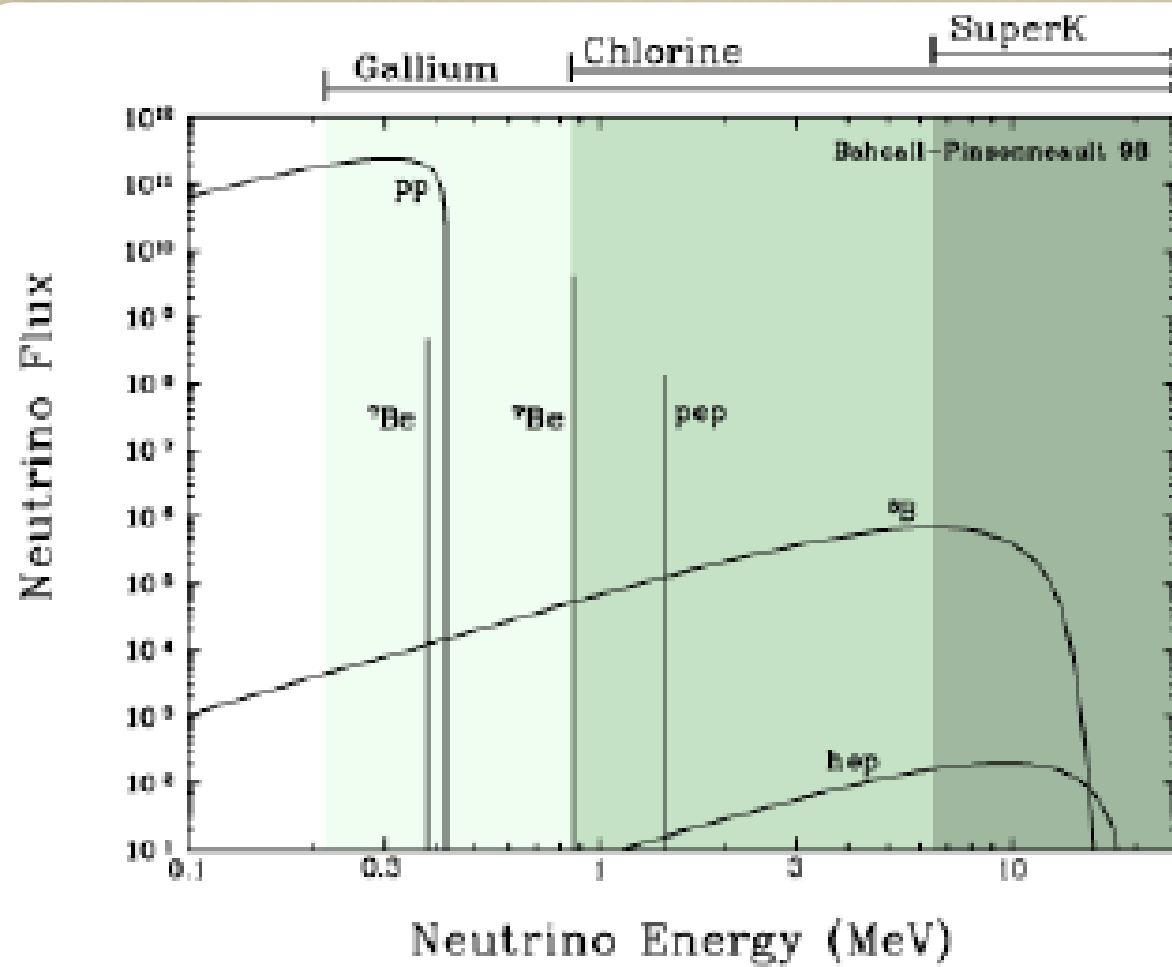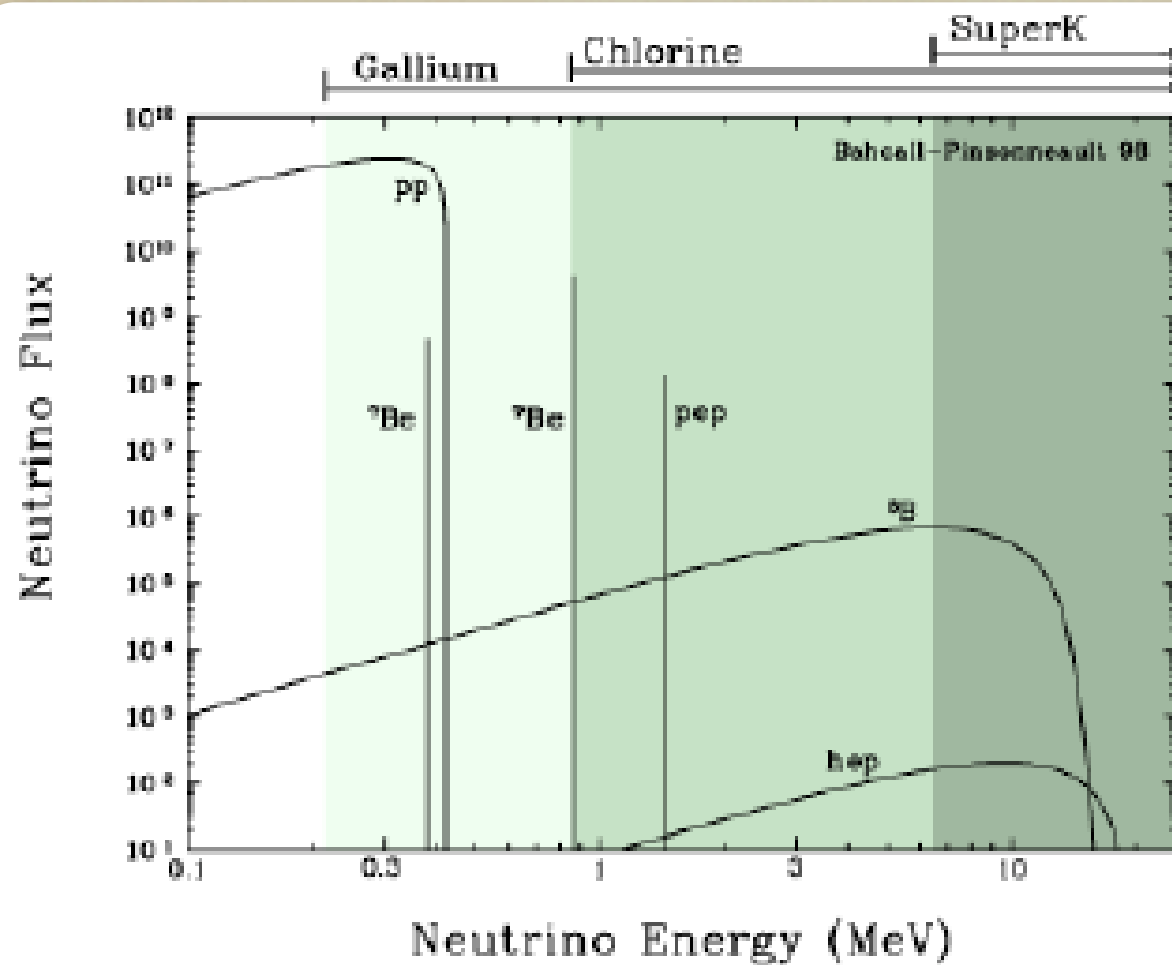Bahcall (The solar model) was wrong
Or BOTH were wrong

Gallium experiment

Gallium experiment

Expects

127 SNU ±12

Observs

68.1 SNU ±3.75

Gallium experiment

Expects

127 SNU ±12

Observs

68.1 SNU ±3.75

Problem with radiochemical methods:
Neutrino is not observed directly

What does a neutrino in water?

ν_e

nucleon

e

Usually nothing !

But sometimes it will strike a nucleon and "knock out" an e (or μ) moving in the same direction as the ν was

The e (or μ) will travel a short distance giving off Cherenkov light in the shape of a cone

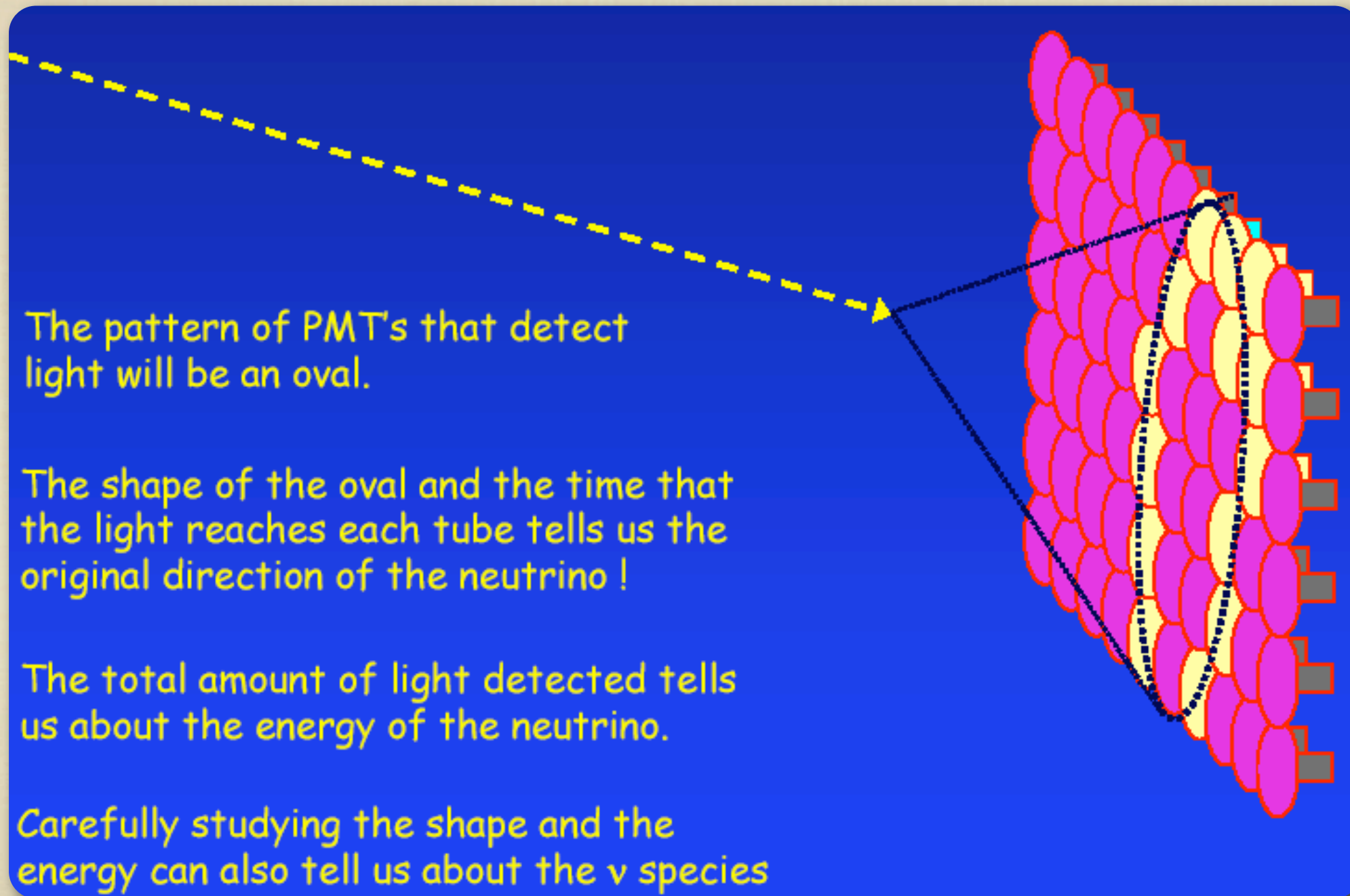# What does a neutrino in water?

Usually nothing !

But sometimes it will strike a nucleon and "knock out" an e (or μ) moving in the same direction as the ν was

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Array of PMT's

Tank full of water

Water detectors: Concept

The pattern of PMT's that detect light will be an oval.

The shape of the oval and the time that the light reaches each tube tells us the original direction of the neutrino !

The total amount of light detected tells us about the energy of the neutrino.

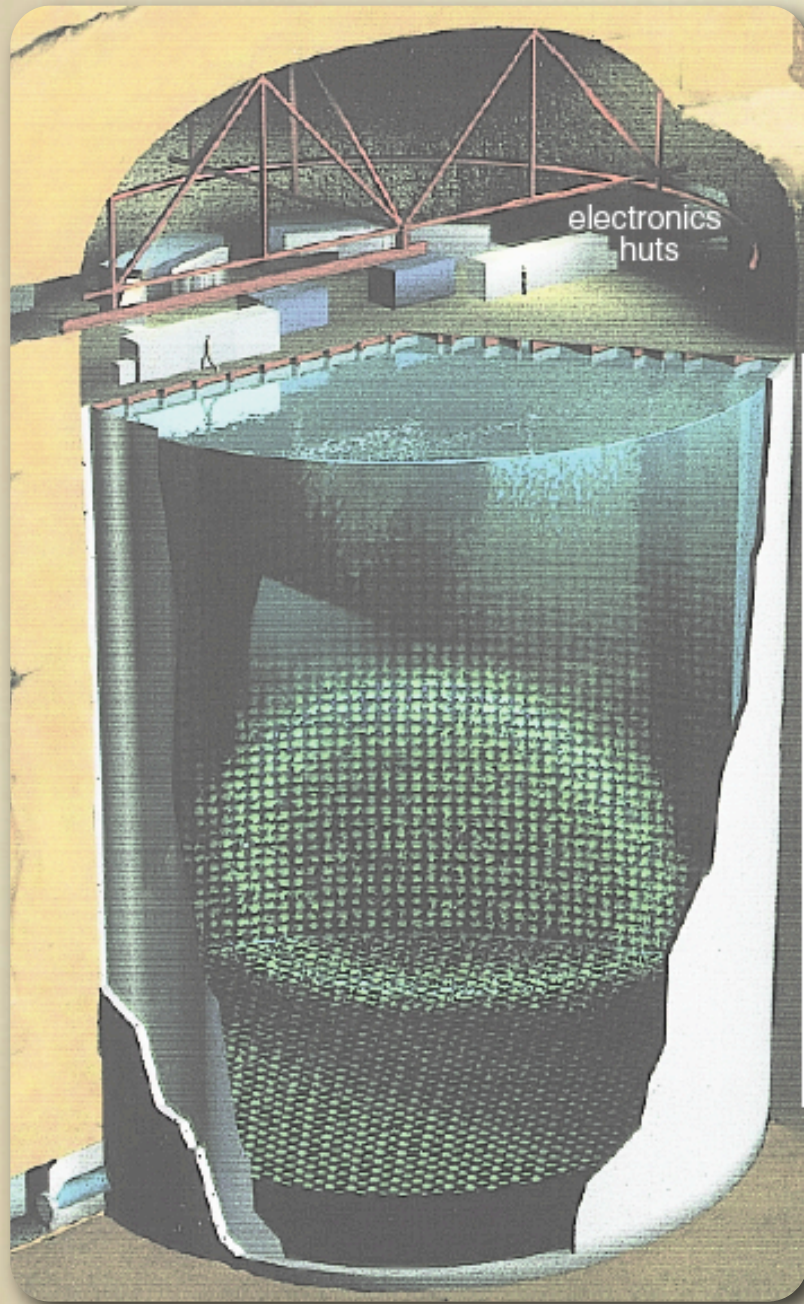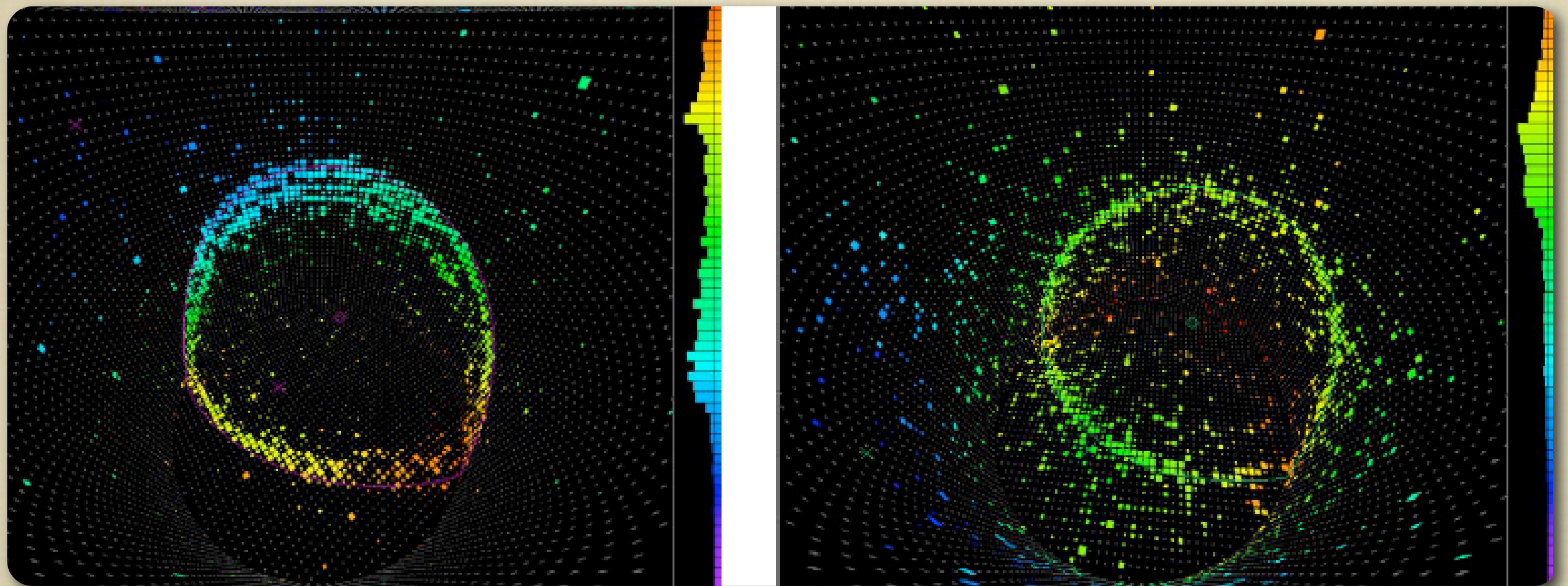Carefully studying the shape and the energy can also tell us about the ν species

Super Kamiokande: The cathedral of light
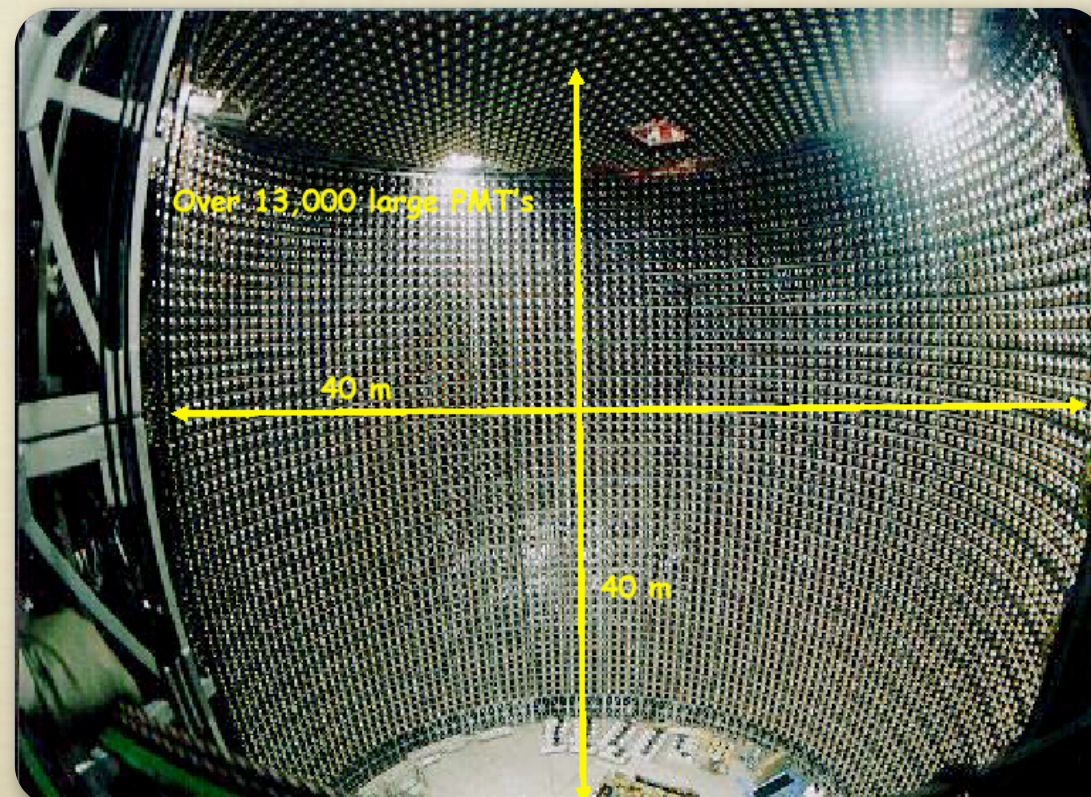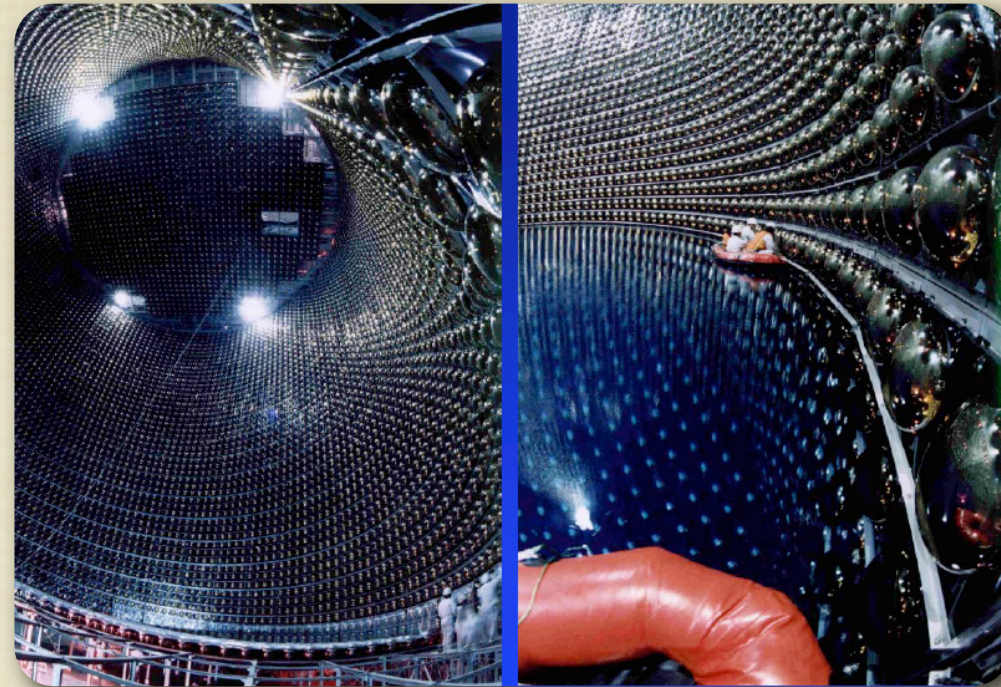
The Eyes of Super-Kamiokande
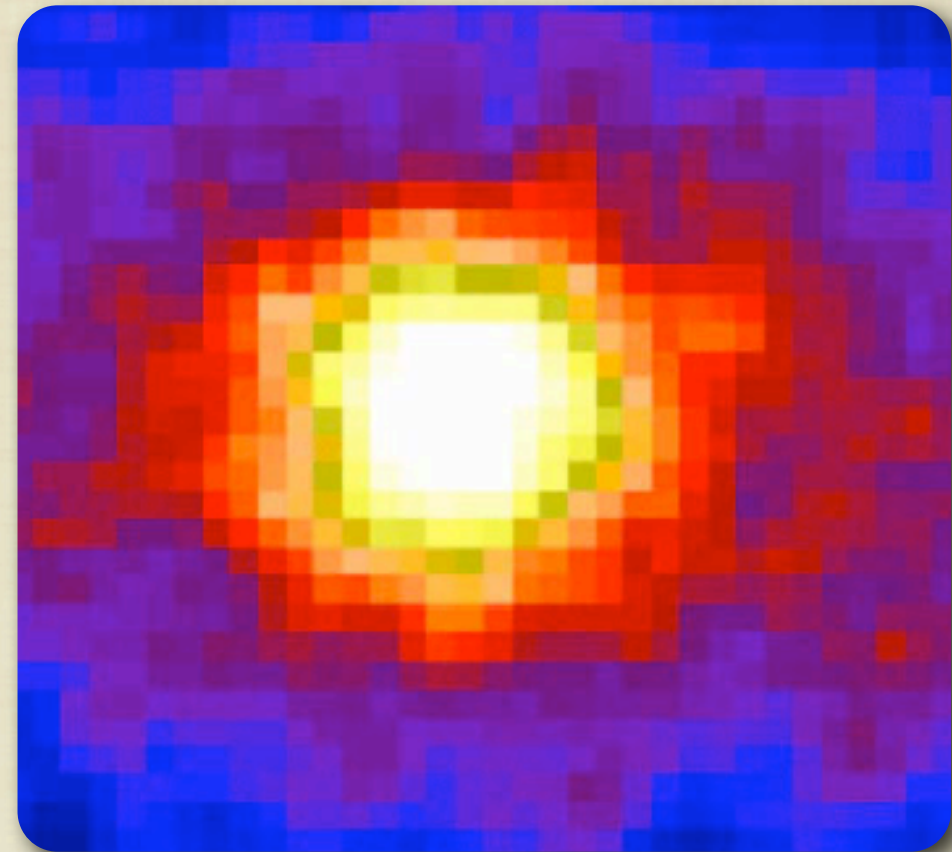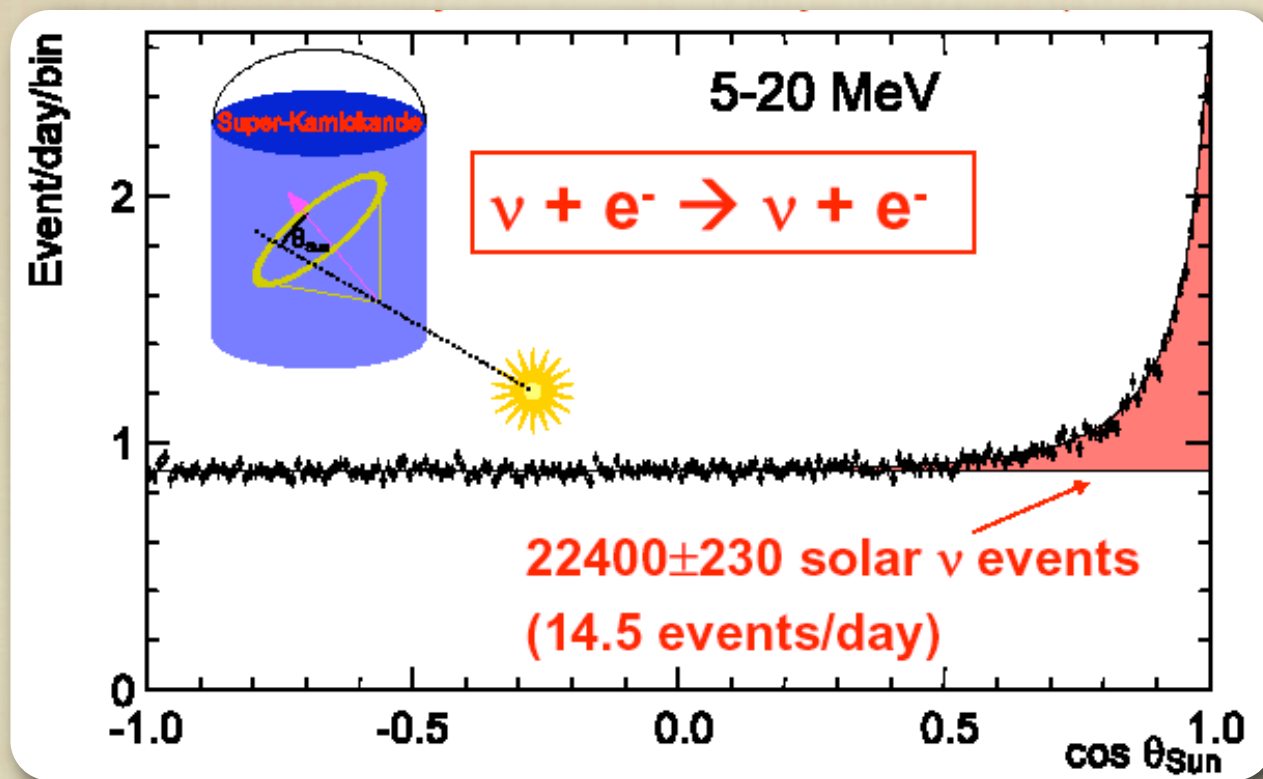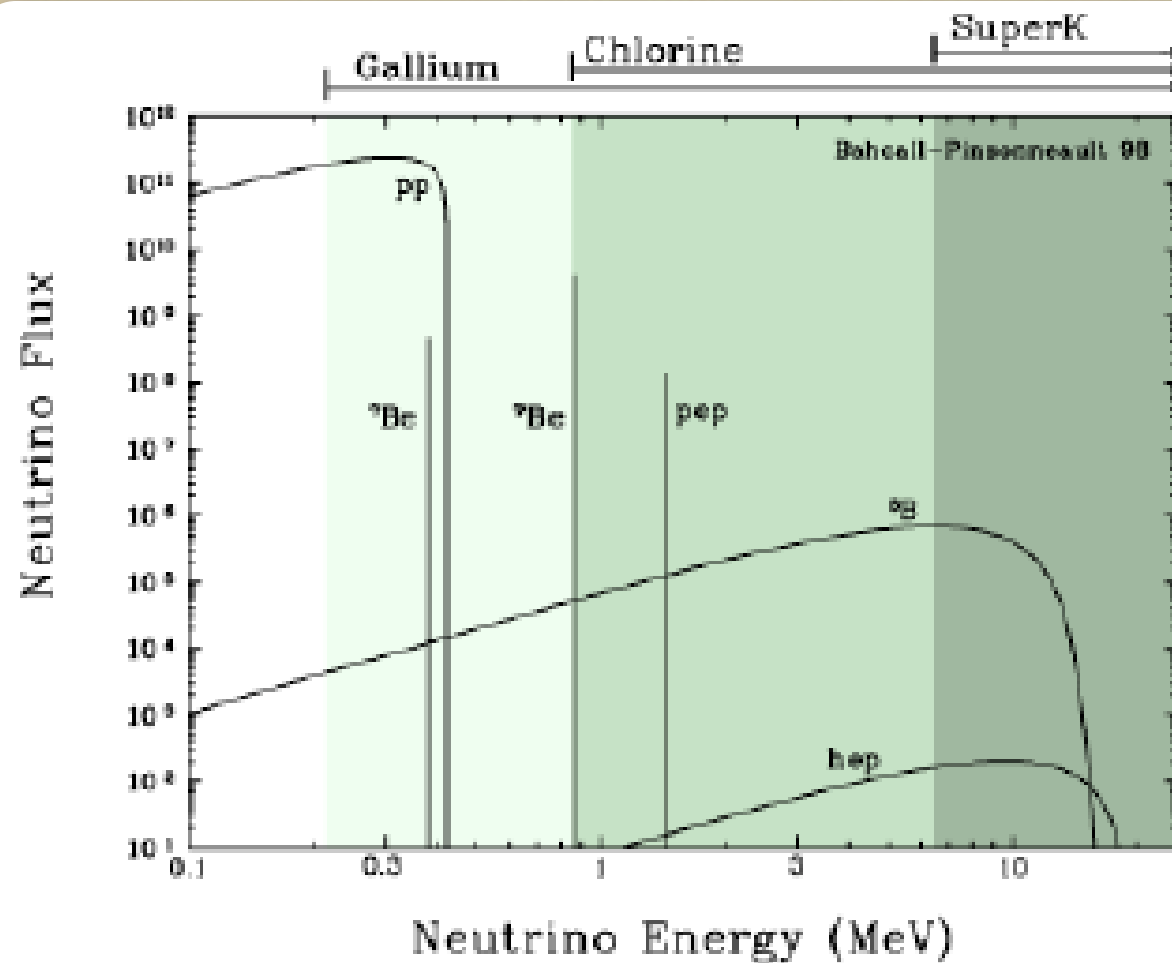
The Sun according to Super-Kamiokande
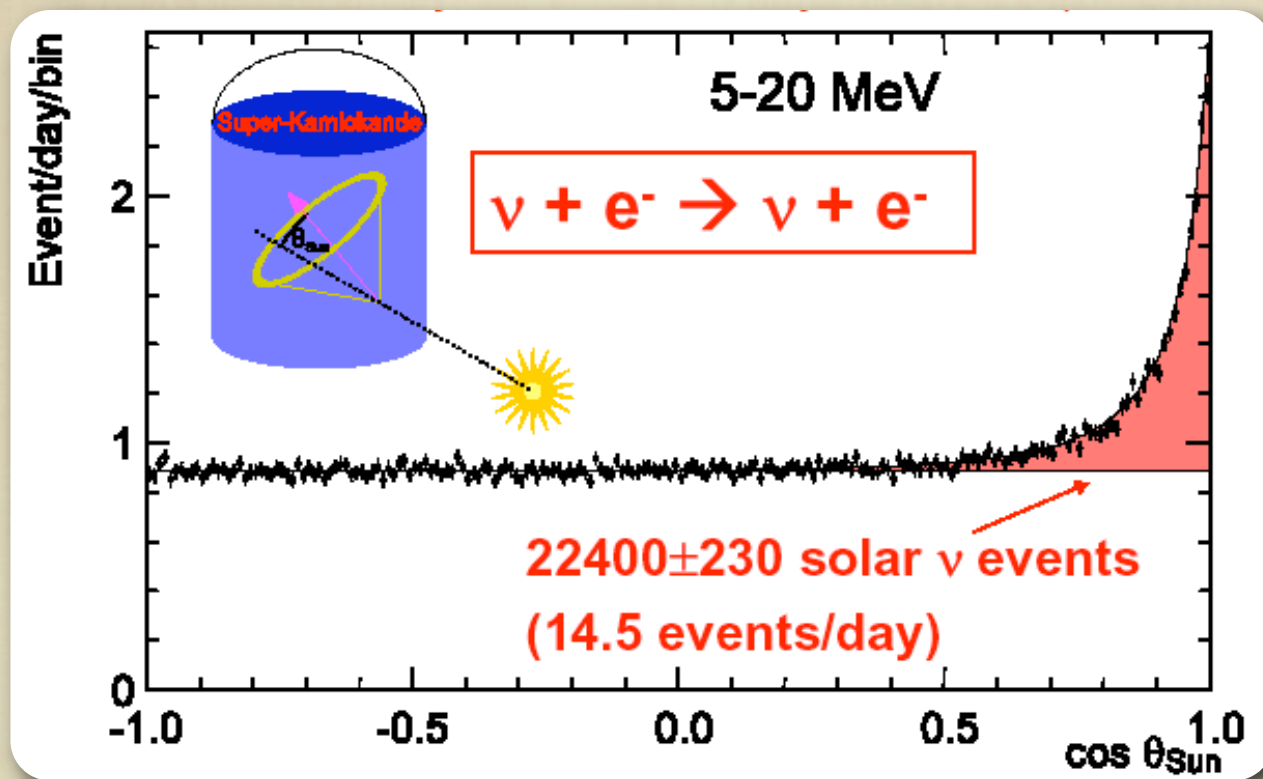
The Sun according to Super-Kamiokande

Expects

8.2 SNU ±1.8

Observs

2.56 SNU ±0.23

^8B flux : $2.35 \pm 0.02 \pm 0.08$ [x 10^6 /cm²/sec]

$$\frac{Data}{SSM(BP2004)} = 0.406 \pm 0.004 \, ^{+0.014}_{-0.013}$$

(Data/SSM(BP2000) = 0.465 ±0.005 +0.016/-0.015)

Expects
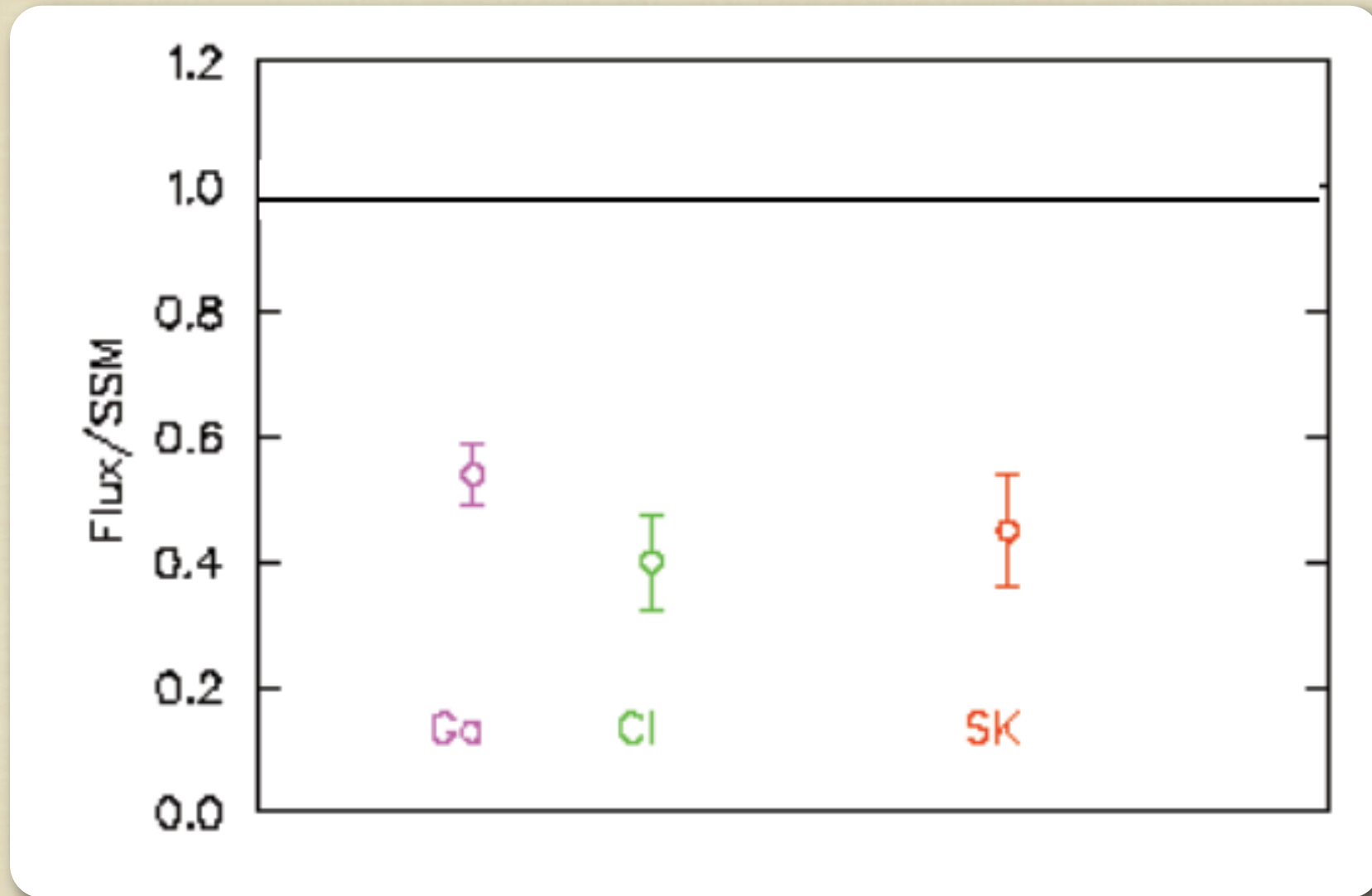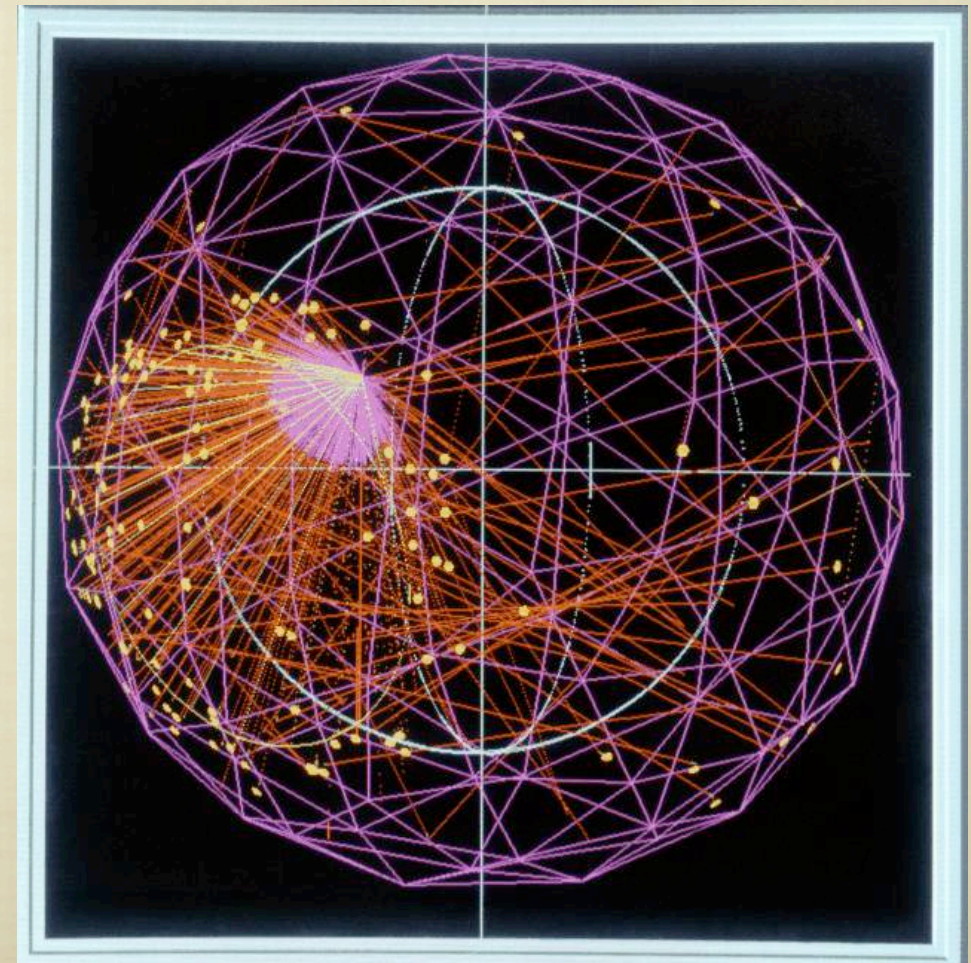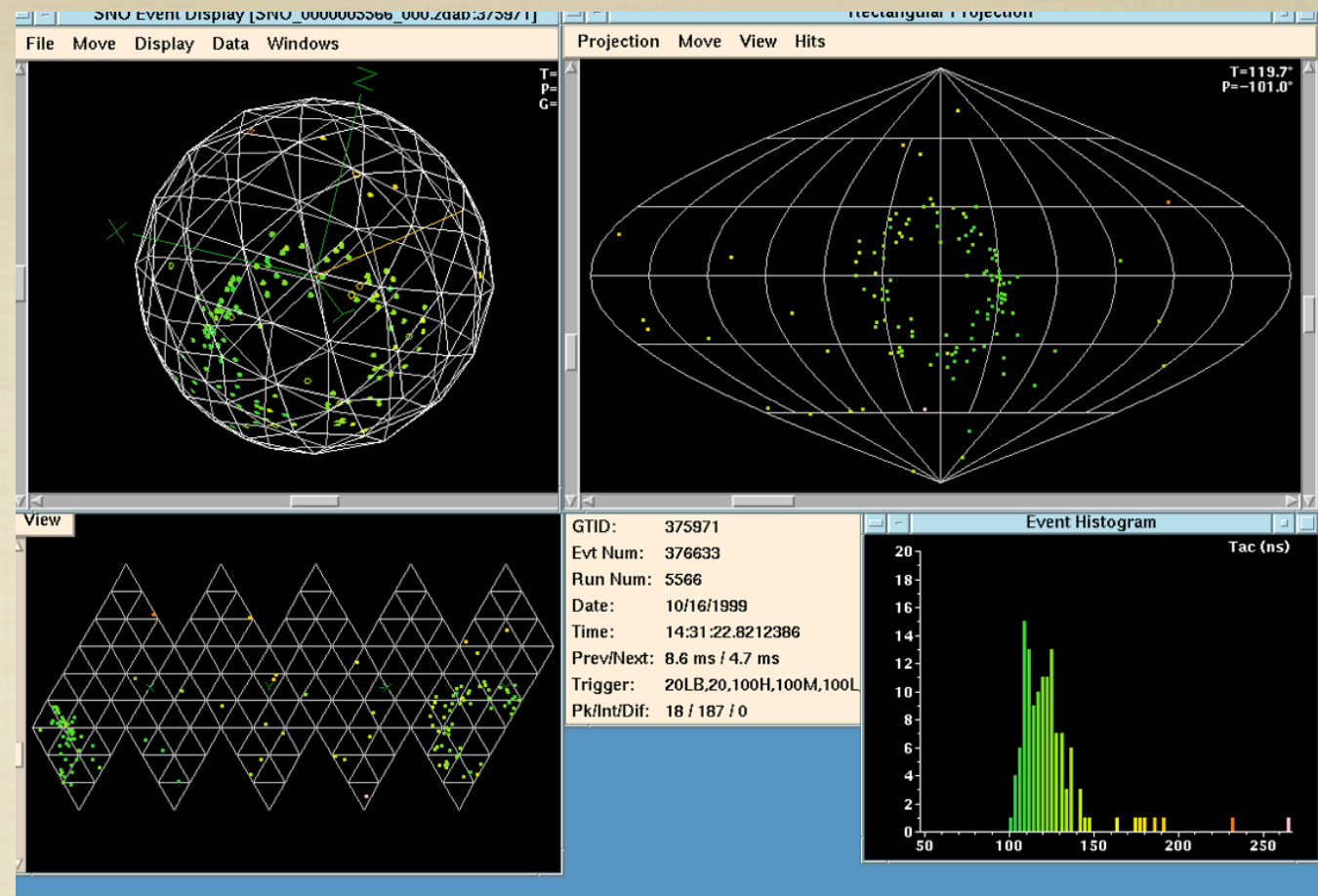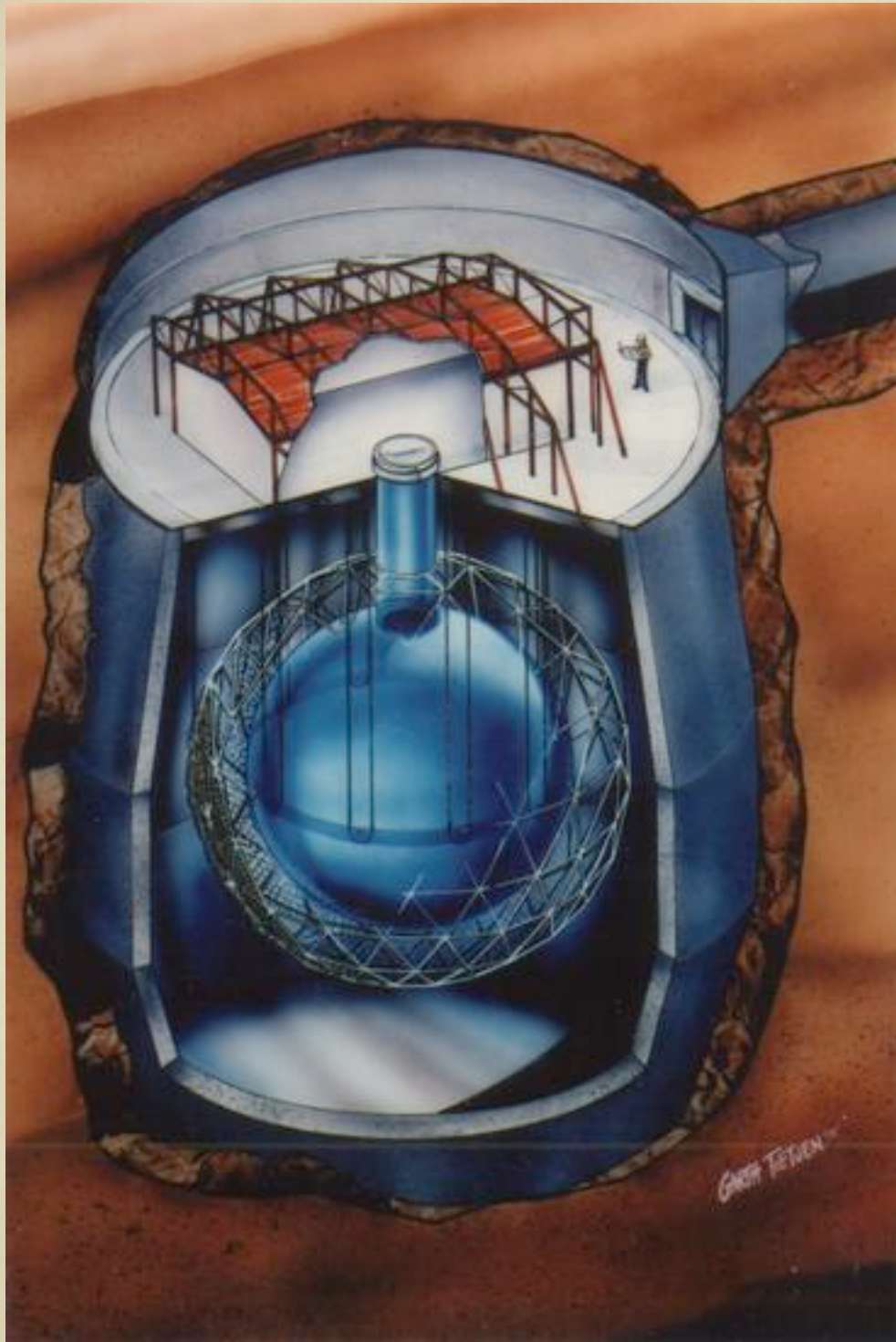
127 SNU ±12

Observs

68.1 SNU ±3.75
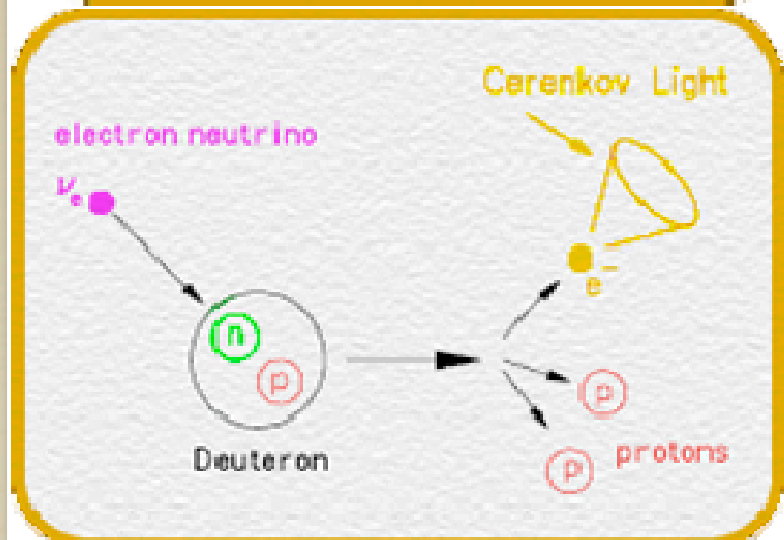
The solar neutrino problem after Super Kamiokande

SNO

Signals in SNO

$$\nu_x + e^- \Rightarrow \nu_x + e^-$$

CC $\quad \nu_e + d \Rightarrow p + p + e^-$
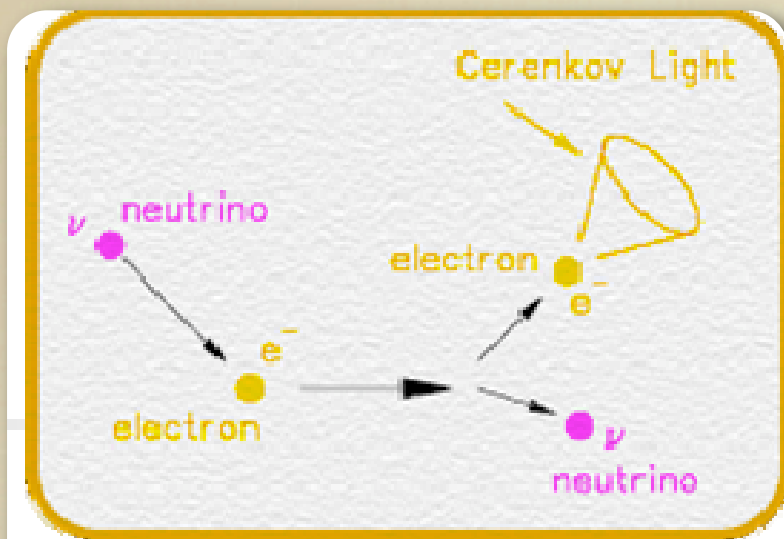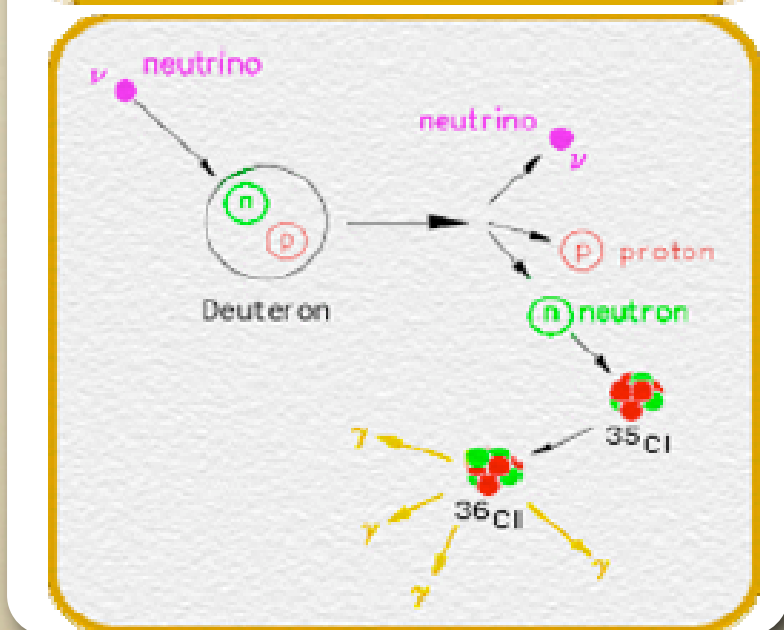
- Good measurement of ν_e energy spectrum
- Weak directional sensitivity $\propto 1 - 1/3\cos(\theta)$

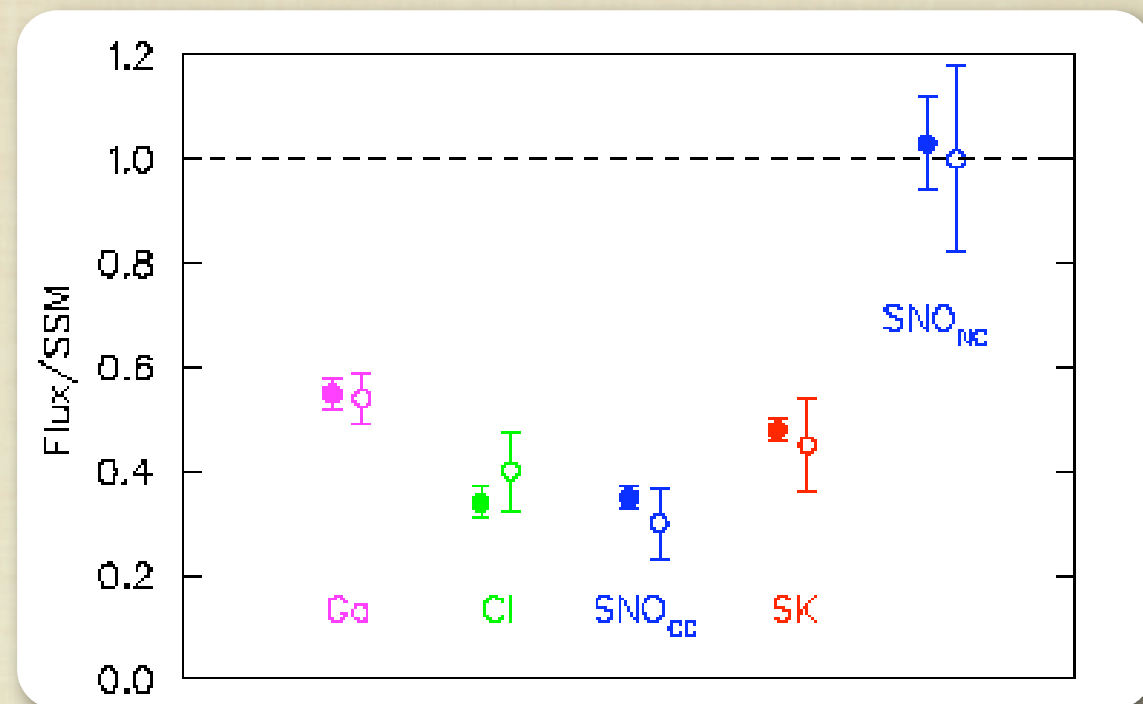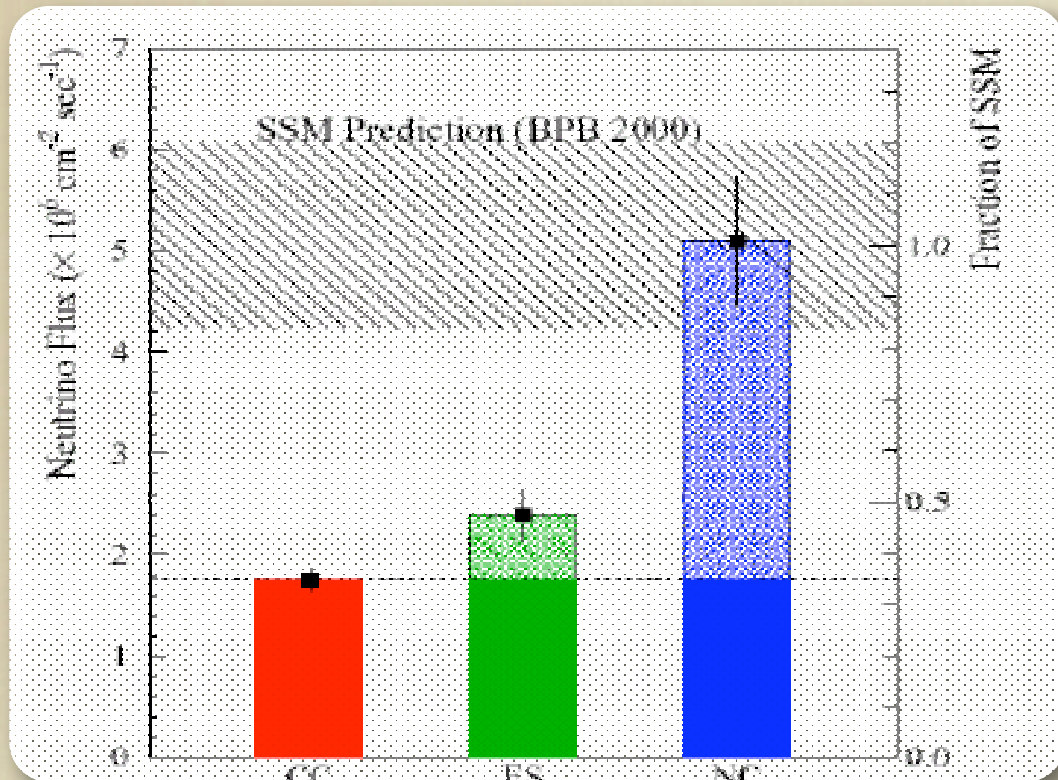   - ν_e ONLY

NC $\quad \nu_x + d \Rightarrow p + n + \nu_x$

- Measure total ^{8}B ν flux from the sun.
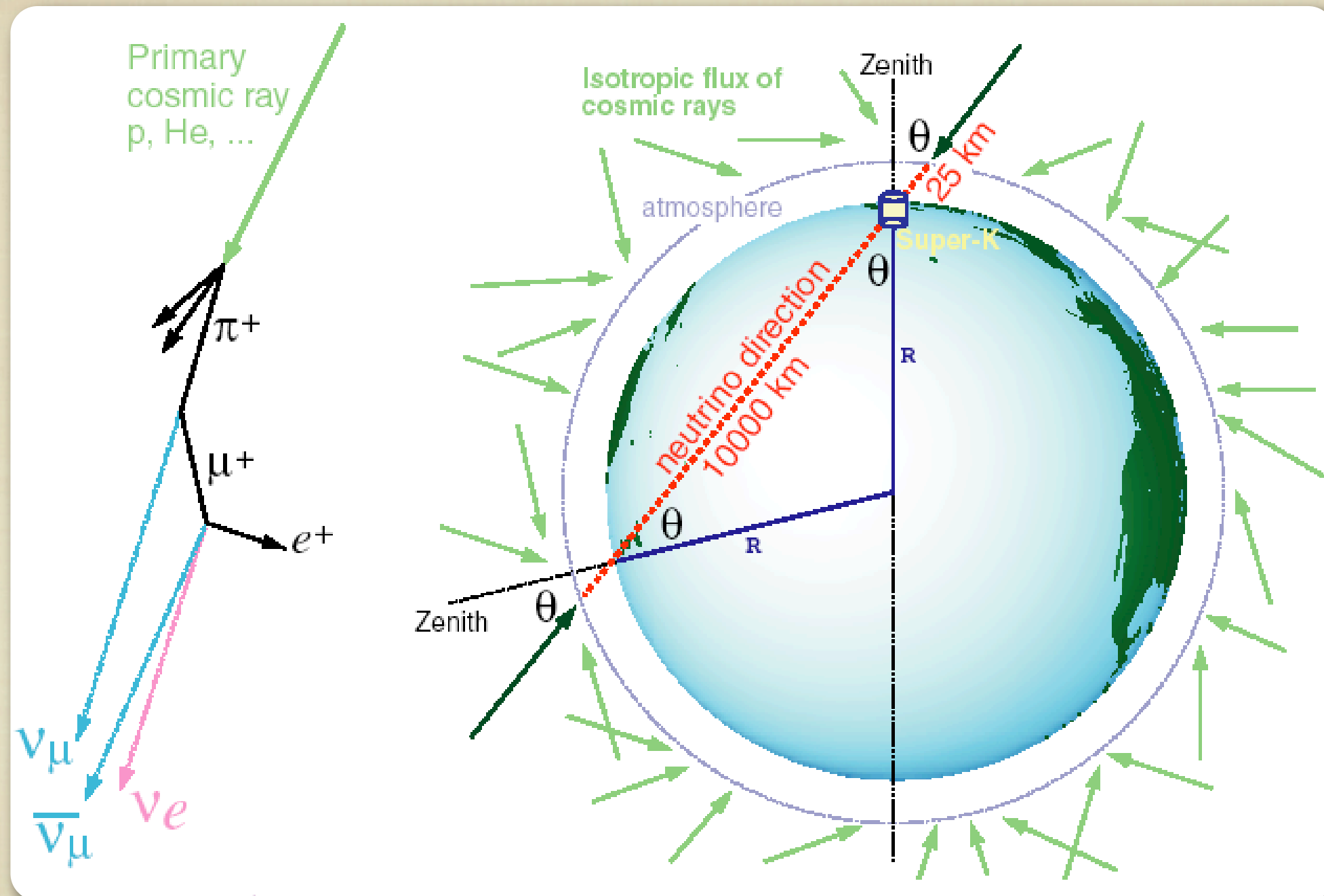
    - Equal cross section for all ν types
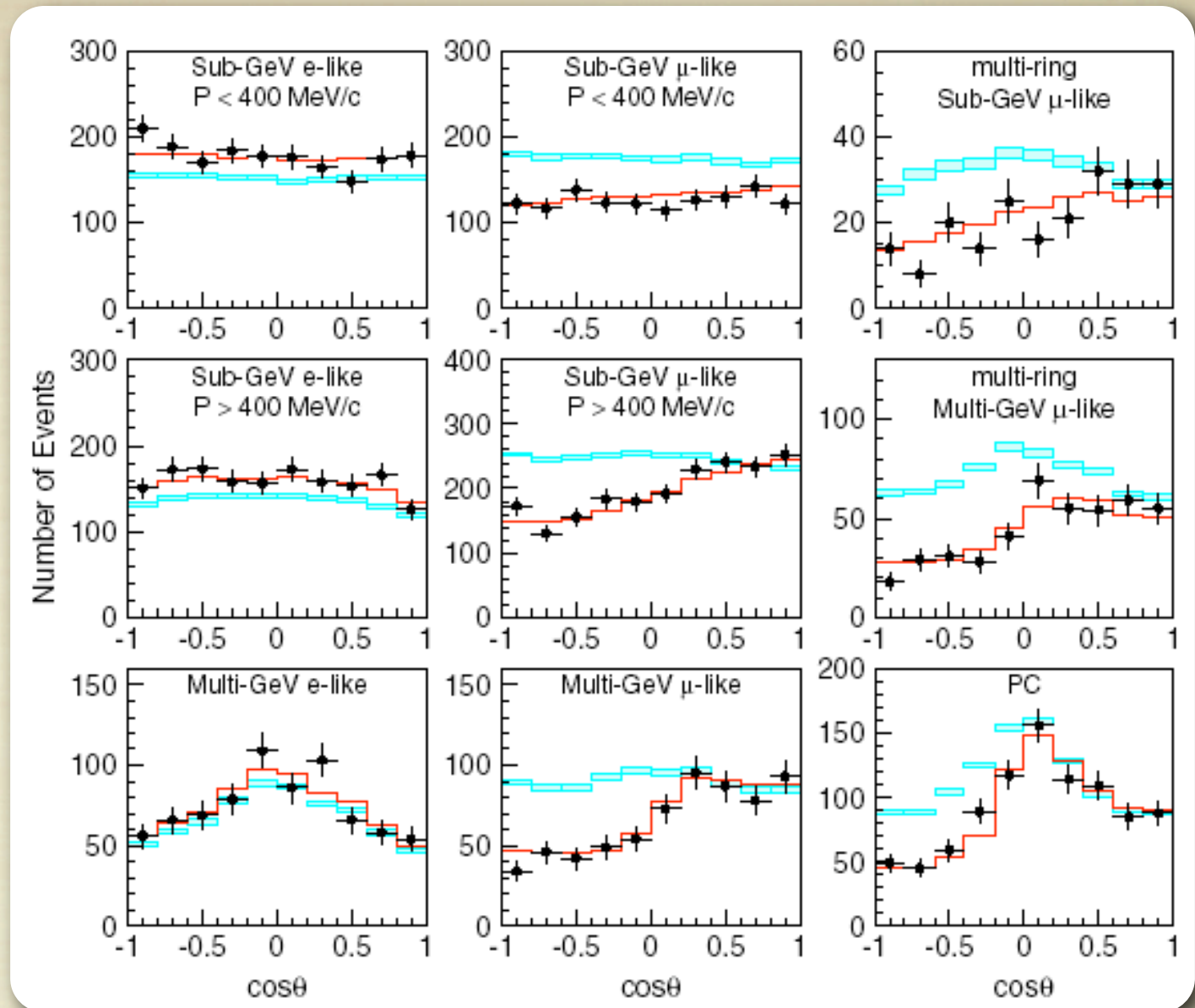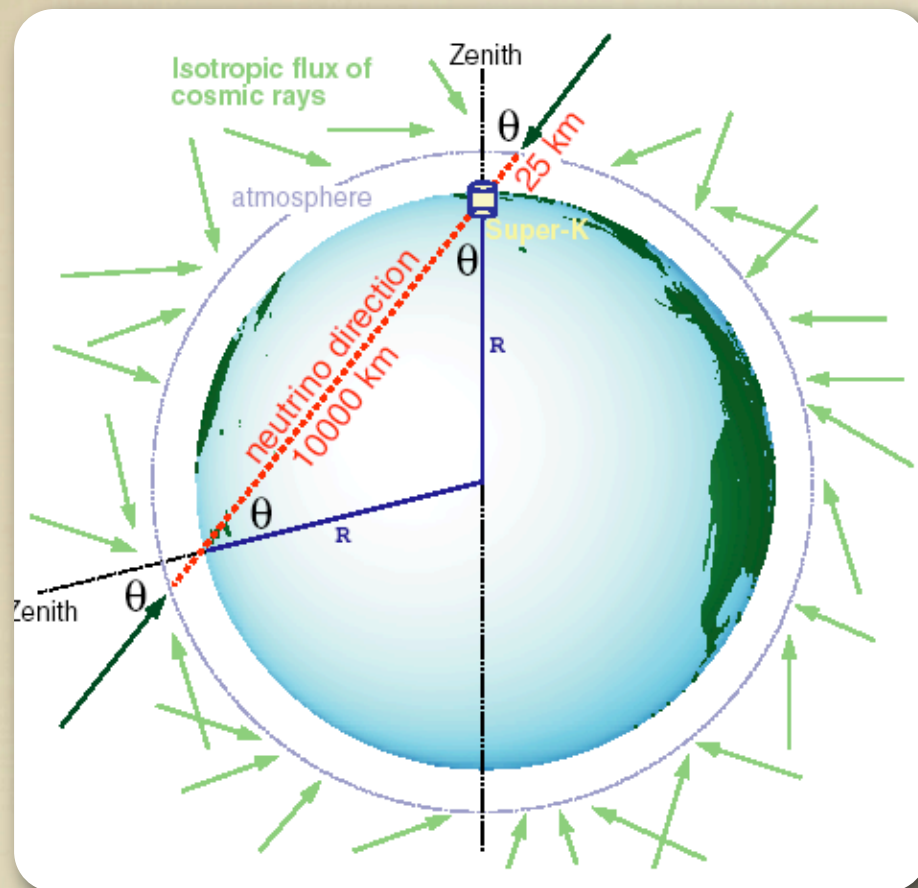
The solar neutrino problem revisited

So the sun is shining the expected number of neutrinos but many of them are ν_μ and/or ν_τ! Not only Davis, but also Bahcall was right!

Atmospheric neutrinos

Zenith angle measures the neutrino fly path
Atmospheric neutrinos travel all the way from 10 to 10,000 km
The "problem" is a function of L (or to be specific of E/L)