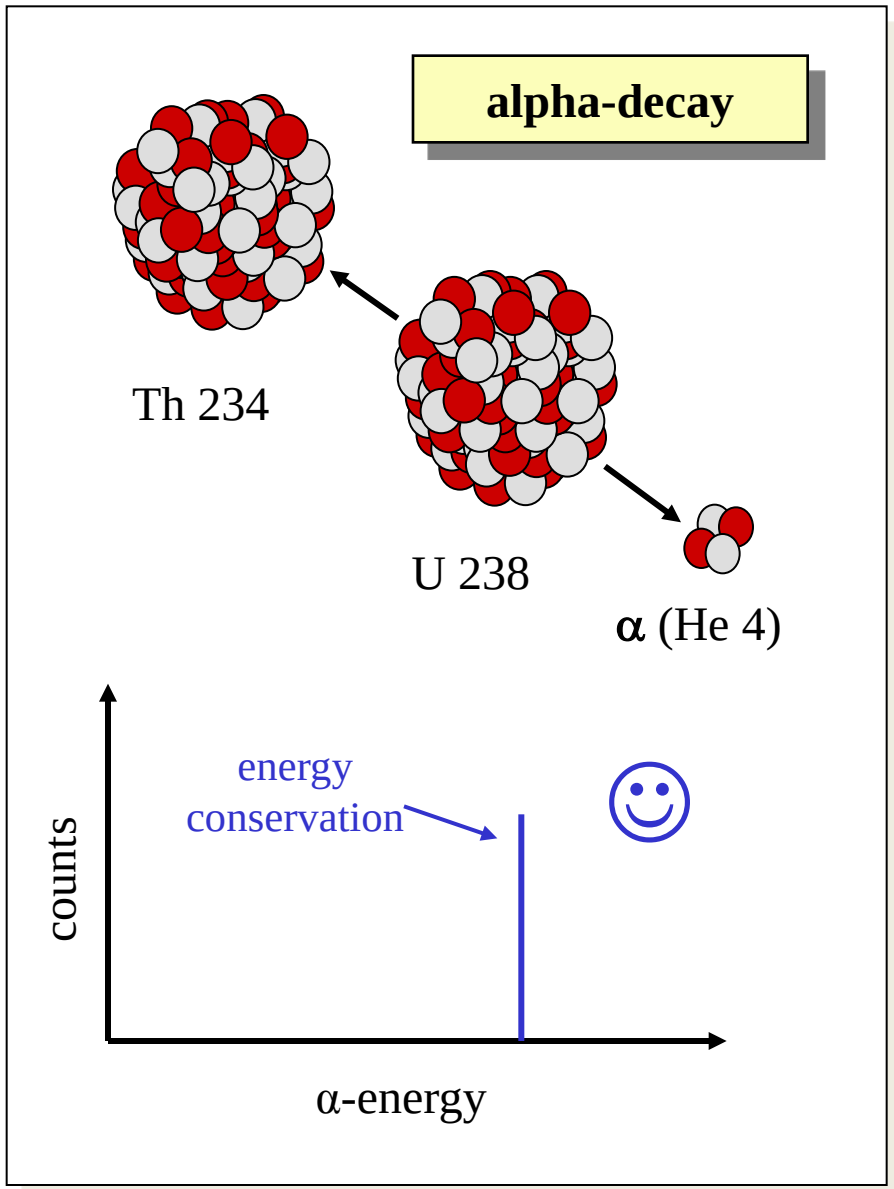
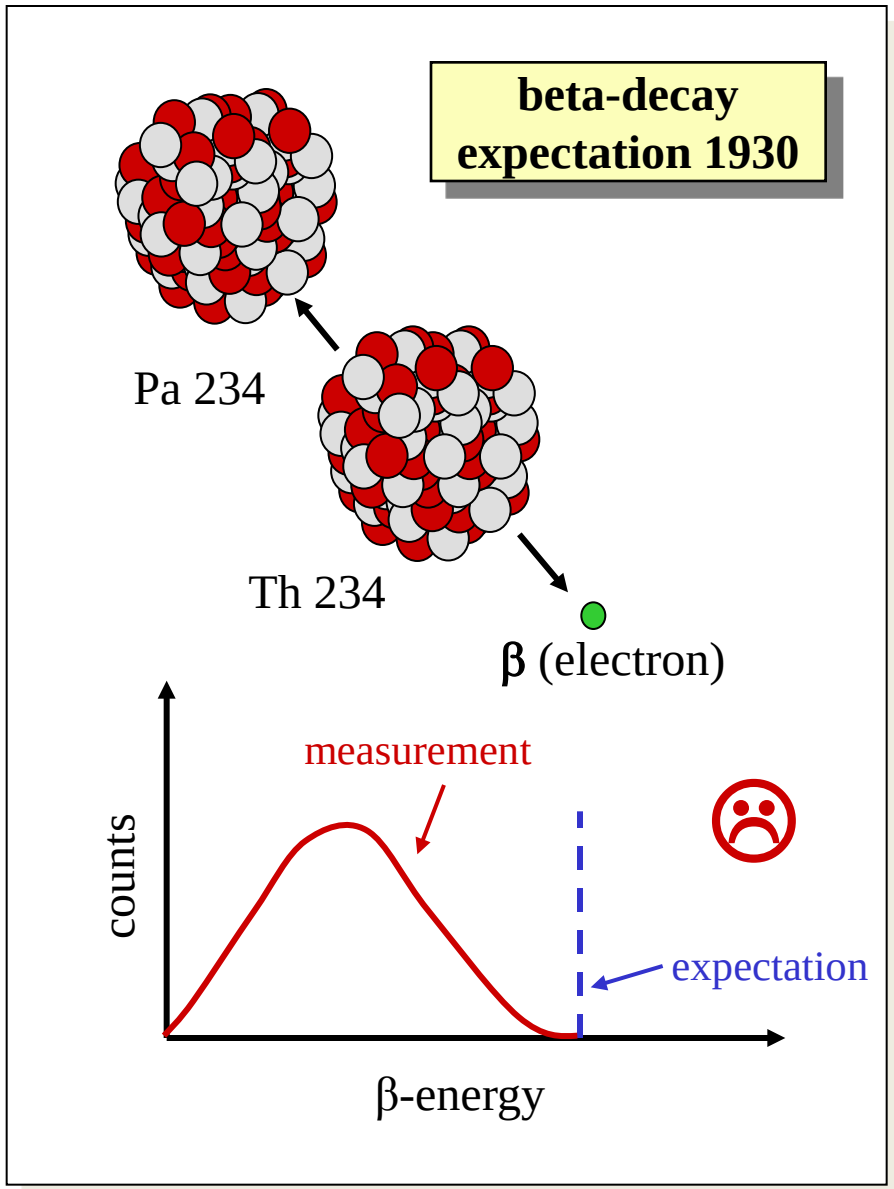
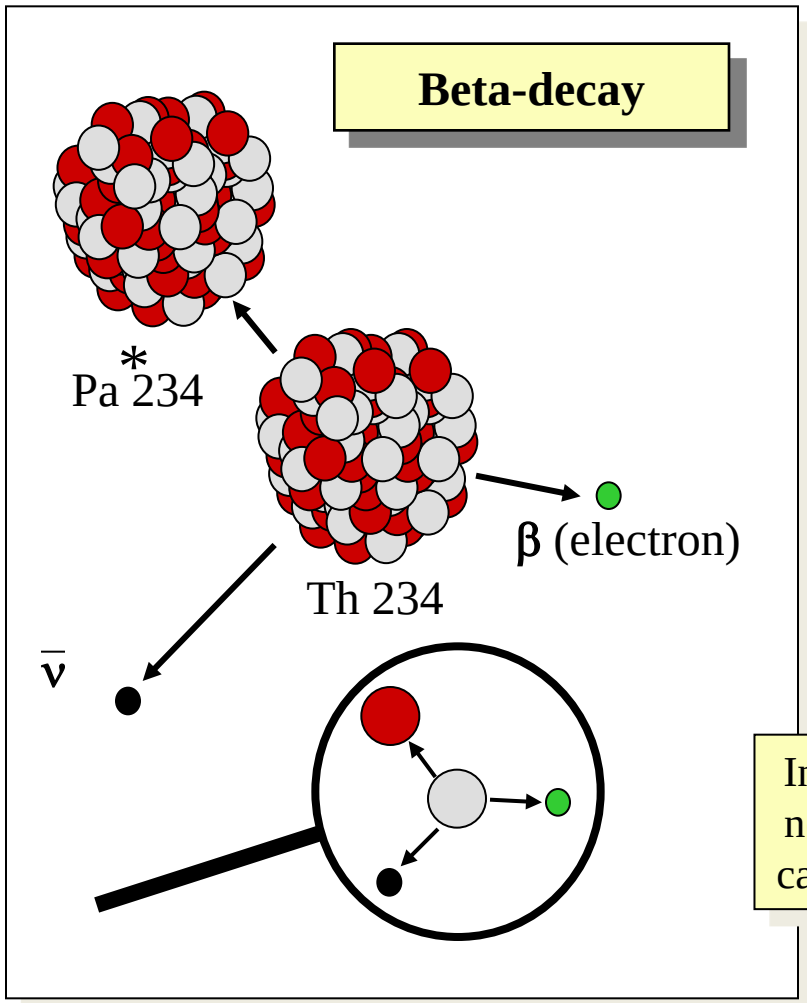
1930: Energy conservation violated in β-decay





The new particle proposed by Pauli

Wolfgang Pauli



Leptonen	
Charge –1	Charge 0
Electron e	e-Neutrino ν_e
Myon μ	μ-Neutrino ν_μ
Tauon τ	τ-Neutrino ν_τ

In addition to an electron a light neutral particle is created which carries away the missing energy!

„Today I have done something, what one should not do in theoretical physics. I have explained something, what is not understood, by something, which can not be observed!"

Neutrino detection

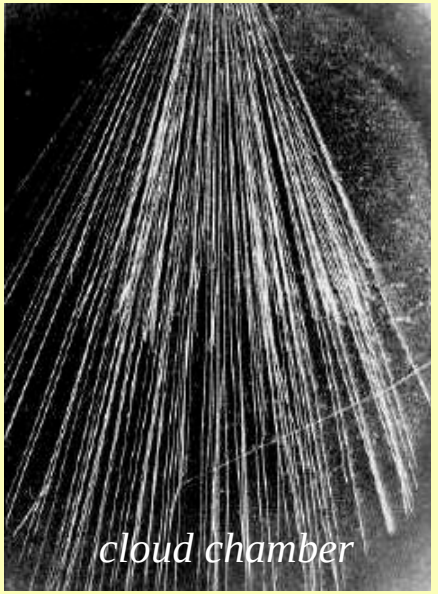
- Detection of particles:

  Interaction of particles with matter (detector)

- Interaction with matter depends strongly on the particle:

  Charge particles: Ionization of matter

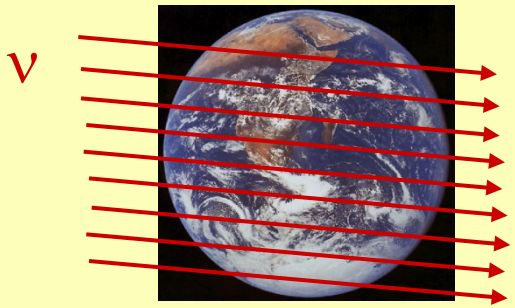
  Photons: Energy transfer to charged particles
  Neutrons: Nuclear reactions yield charge particles

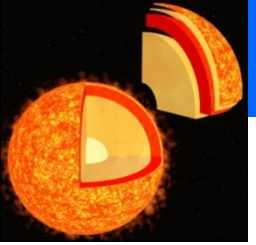


- Neutrinos interact very weakly:

  Only one out of 100 billions neutrinos from the β-decay will be recognized by the earth.

  Calculated 1934: „Hopeless“



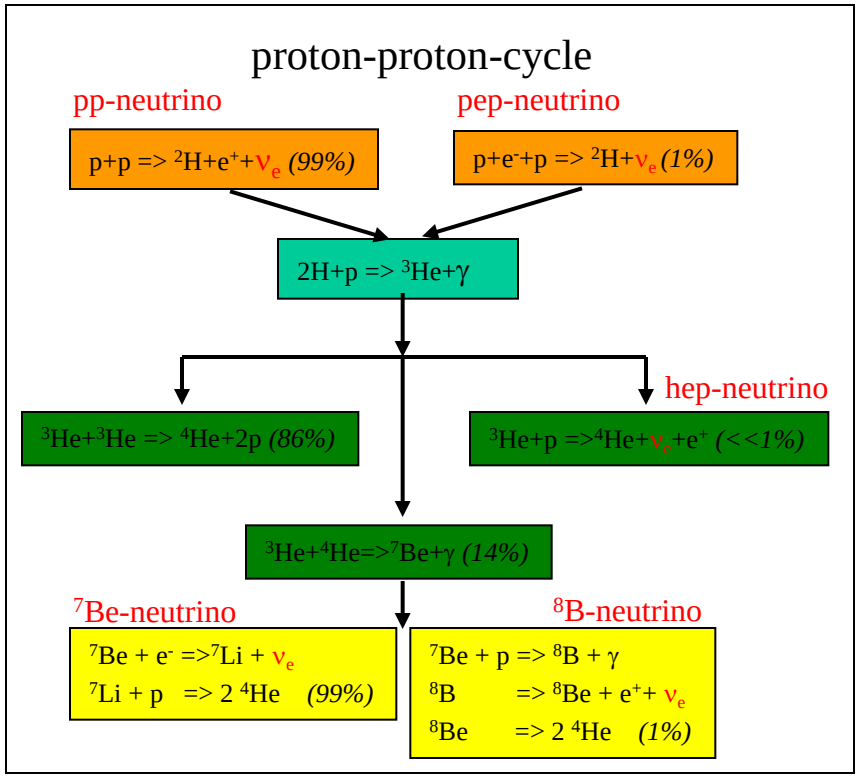


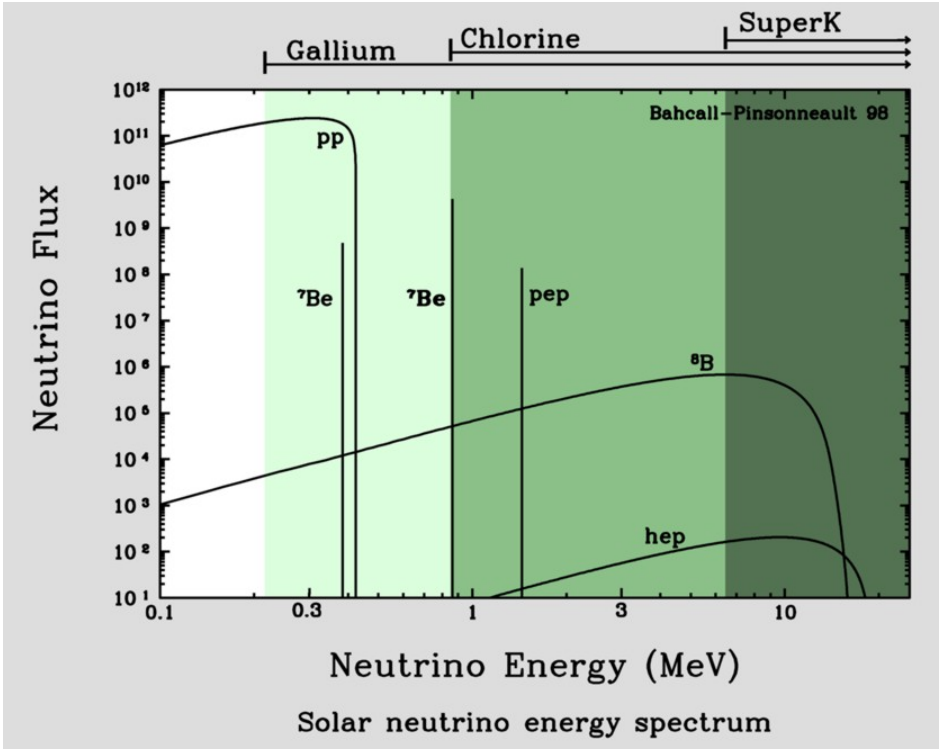
Neutrinos from the sun

$$4\,\text{protons} \rightarrow \text{He-nucleus} + 2e^{+} + 2\nu + 26MeV$$

- Known: total emitted energy
- Known: energy per fusion process

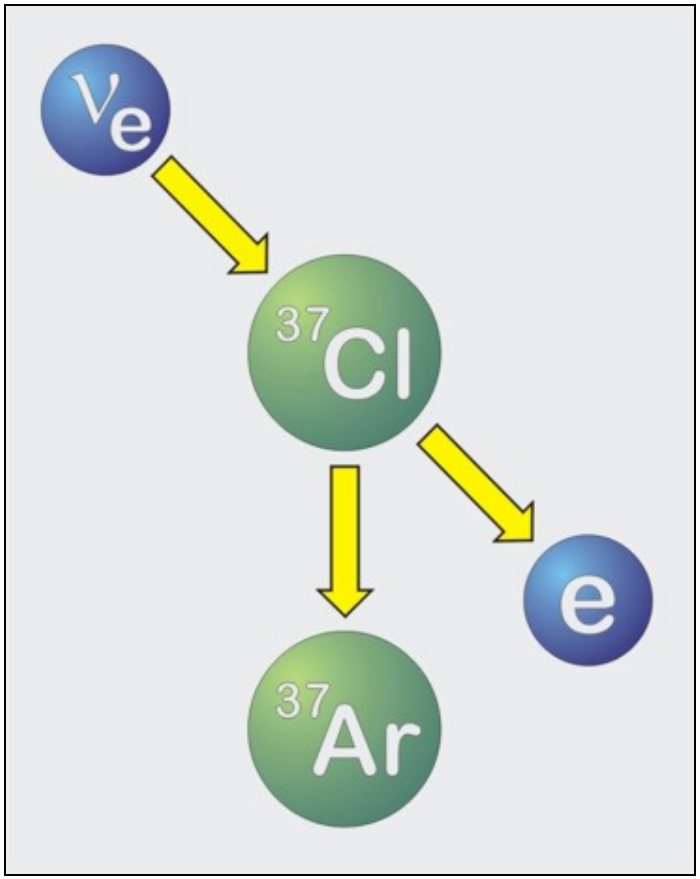
➢ number of created neutrinos per sec!
on earth: 66 billions ν per ($cm^2 \cdot s^1$)

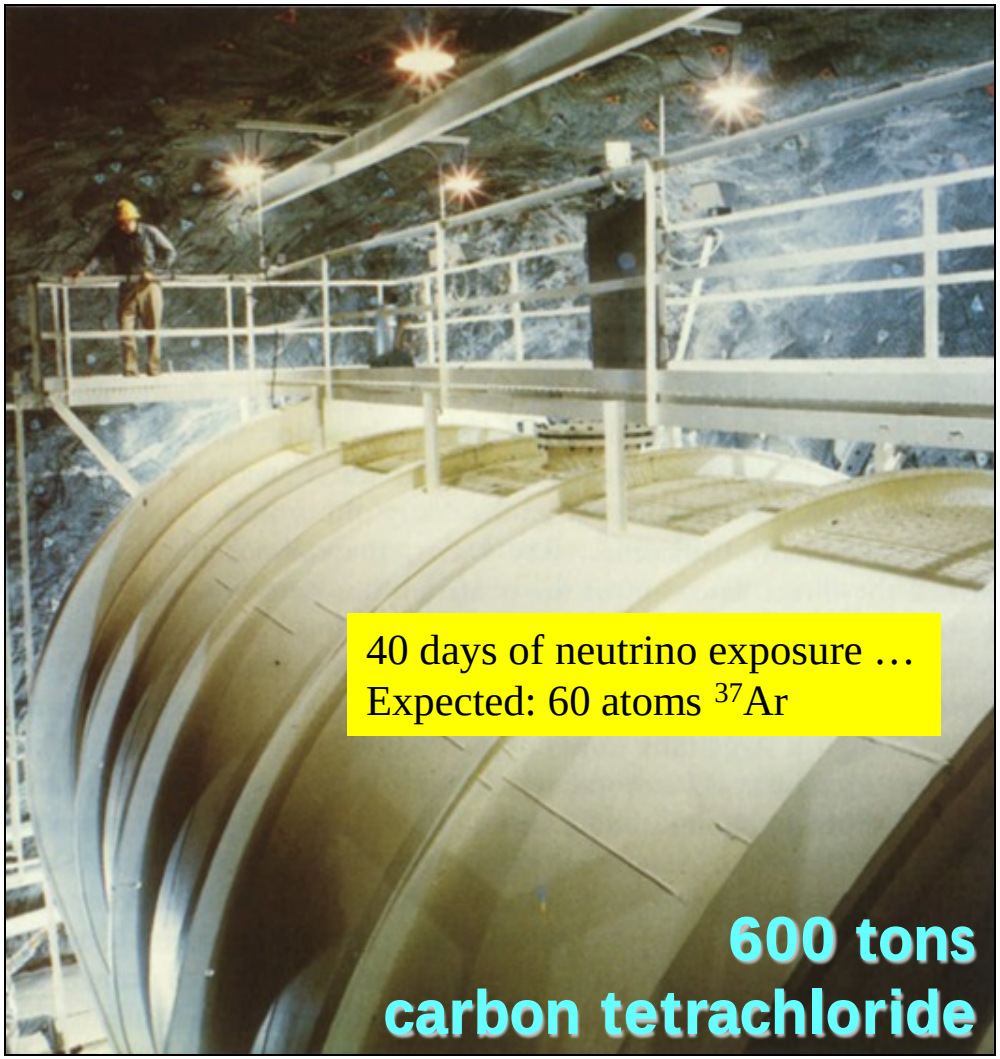




First measurements of the solar neutrinos

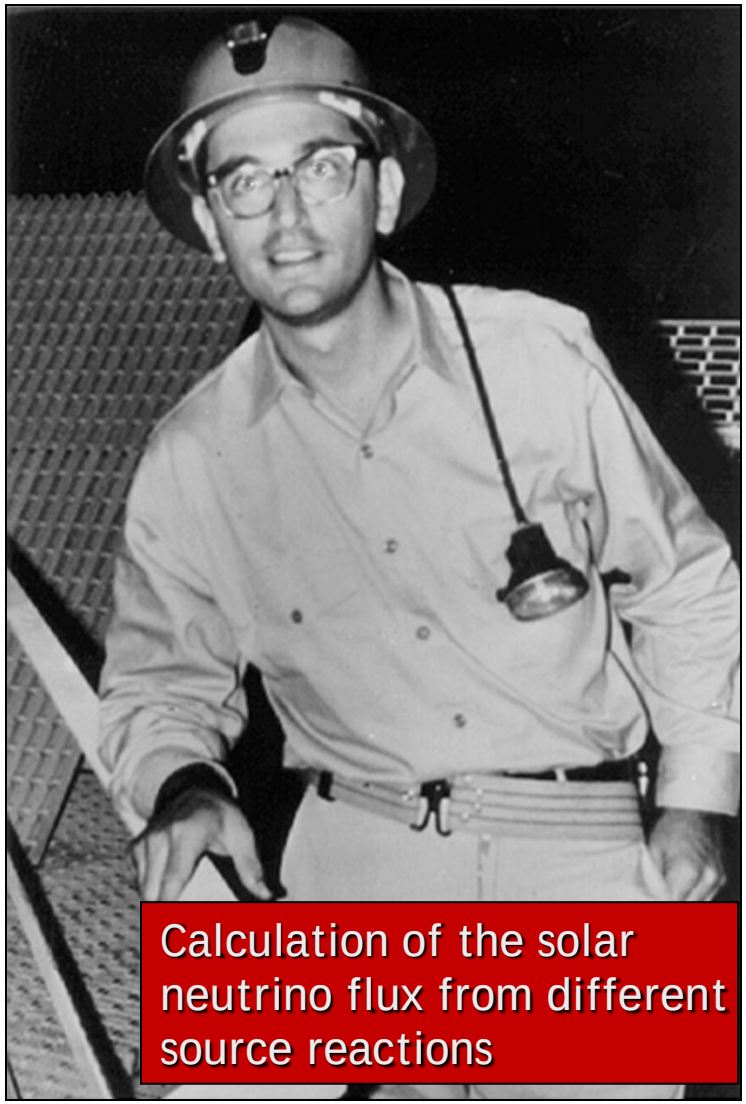
Inverse beta-decay („neutrino-capture")



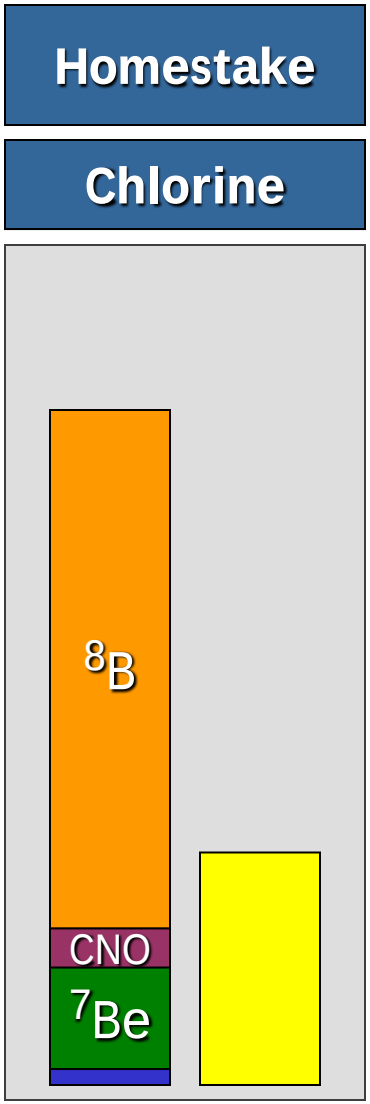


Homestake Solar Neutrino Observatory (1967–2002)

Problem of the “missing” solar neutrinos



Calculation of the solar neutrino flux from different source reactions

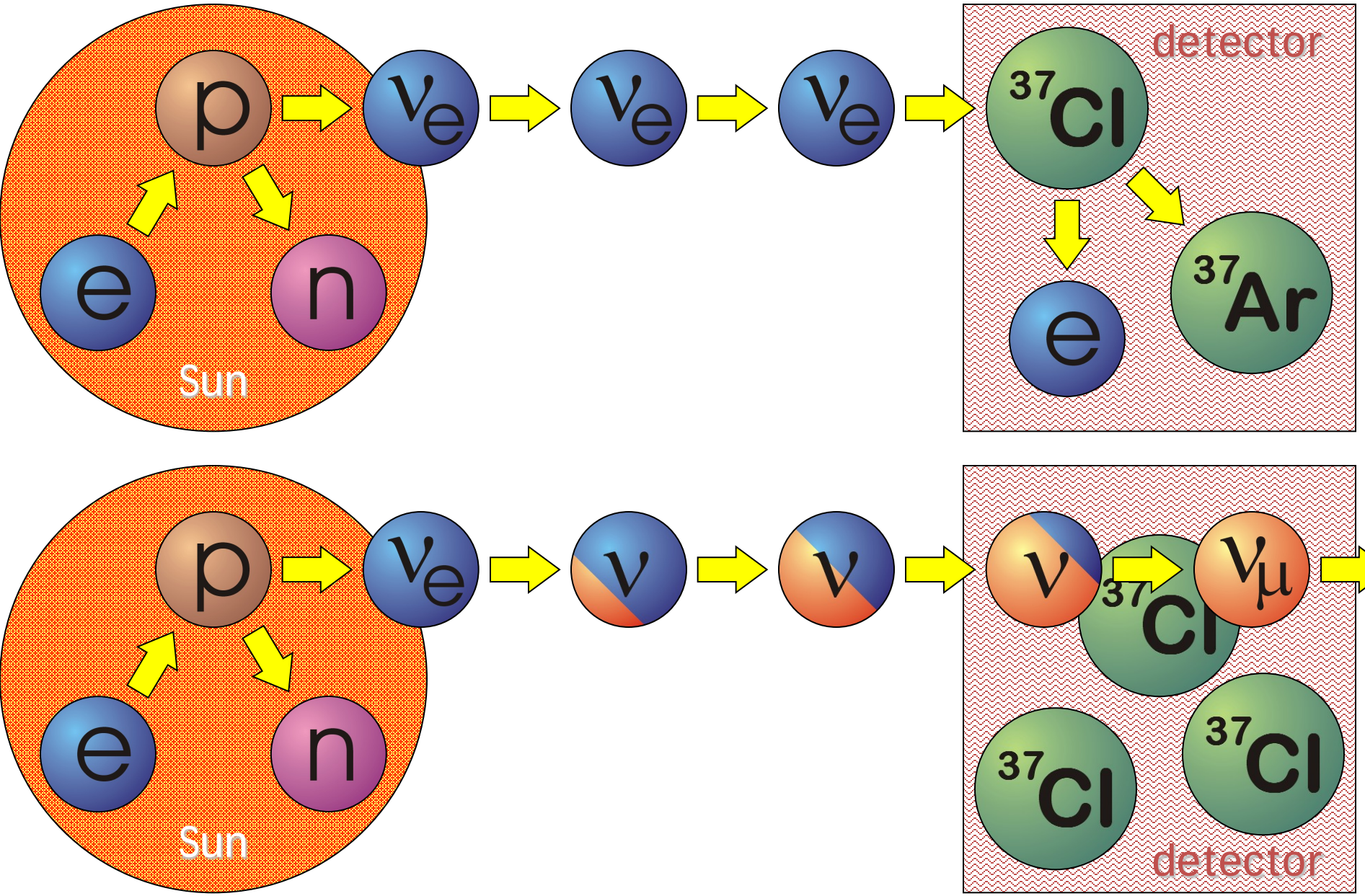


Measurements (1970 – 1995)

John Bahcall
1934 – 2005

Raymond Davis Jr.
1914 – 2006

Neutrino conversion is the solution of the problem



Neutrino oscillations

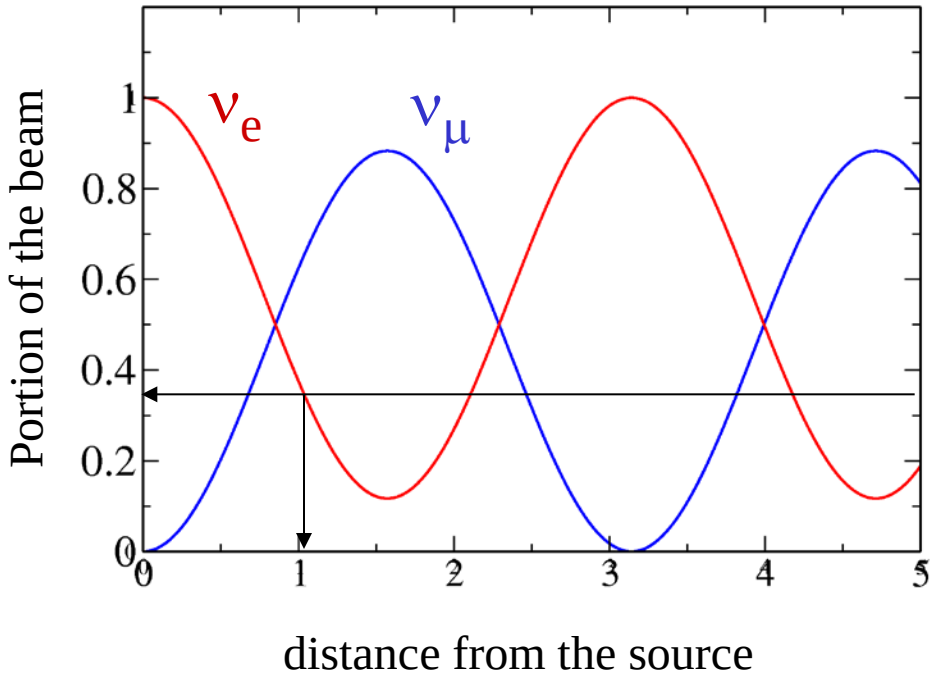
Electron e	Myon μ	Tau τ
e-Neutrino	μ-Neutrino	τ-Neutrino

Idea: when neutrinos have a mass, they may convert into each other!

Assumption: Mixture of

ν_e and ν_μ

Conversion of a neutrino beam with the distance from the neutrino source:

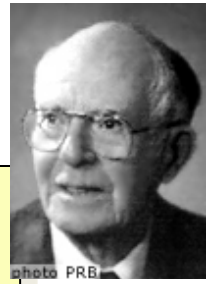


1998: Confirmation of the oscillations between Myon- and Tau-neutrinos with methods of Super-Kamiokande (Myon-neutrinos from the atmosphere)

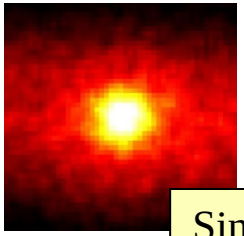
The solar neutrino problem

Sun
since 4.5 billion years
fusion

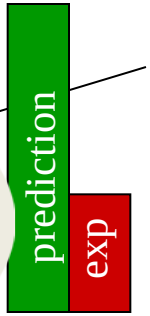
66 billion neutrinos/s/cm^2



since 1964: detection with
Homestake-experiment
expected: 1,5 reactions/d
measured: 0.5 reactions/d



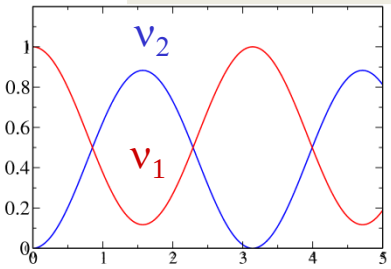
solar
neutrino
problem



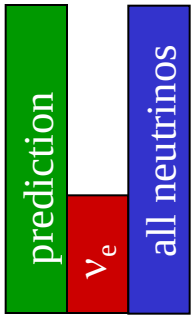
Since 1986 Kamiokande:
confirms Homestake

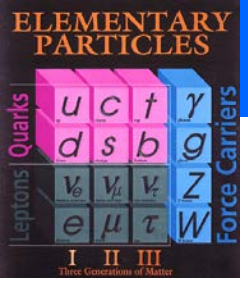
2002 SNO-experiment:
examines neutrino-oscillation

possible explanation:
neutrino-oscillation



solar
neutrino
problem
solved!

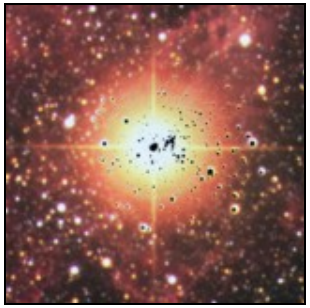




Neutrinos as astrophysical messenger

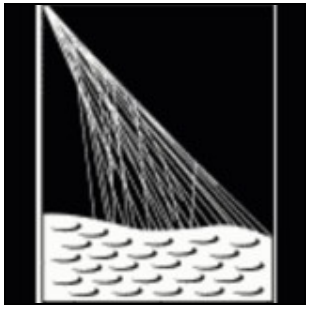
✓ nuclear reactors

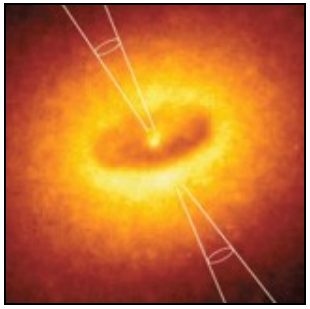
Sun ✓



✓ particle accelerator

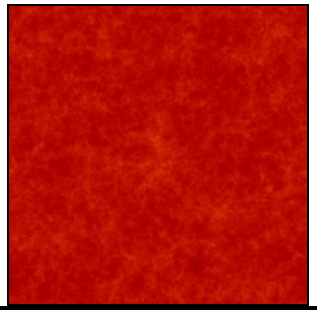
Supernovae
(collapsing stars)
SN 1987A ✓





✓ earth atmosphere
(cosmic radiation)

astrophysical
accelerators soon ?



✓ earth crust
(natural radioactivity)

Big Bang of the Universe
(today 330 ν/cm^3)
indirect evidence