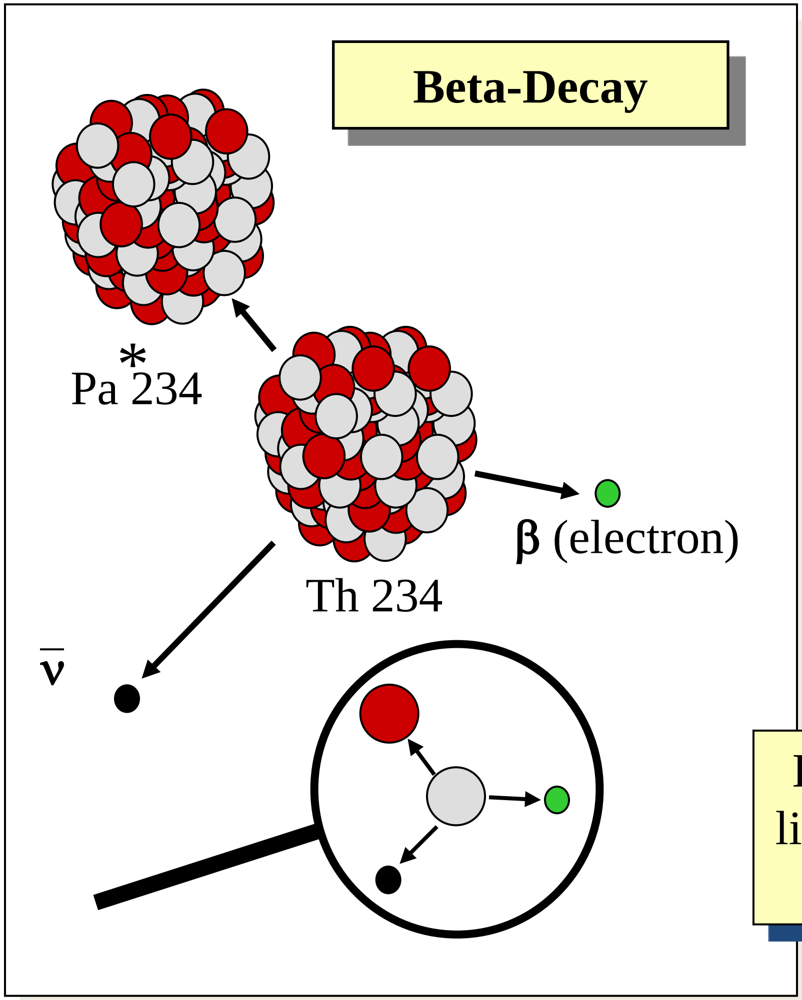
Pauli´s new particle

Wolfgang Pauli



Lepton	
charge –1	charge 0
Electron e	e-Neutrino ν_e
Myon μ	μ-Neutrino ν_μ
Tauon τ	τ-Neutrino ν_τ

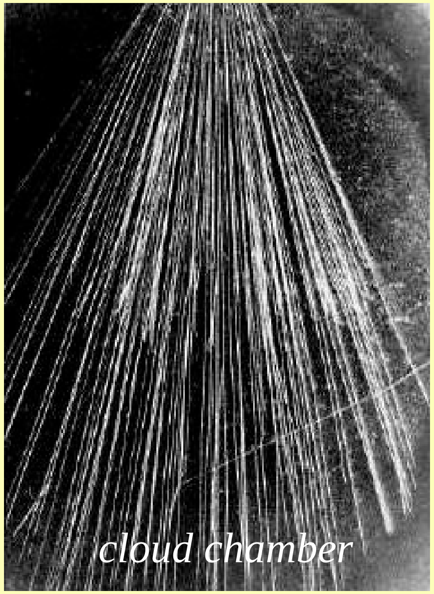
In addition to the electron a neutral, light particle is created, which carries away the „missing energy“!

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

Neutrino detection

• Detection of particles:

Interaction of particles with matter (detector)

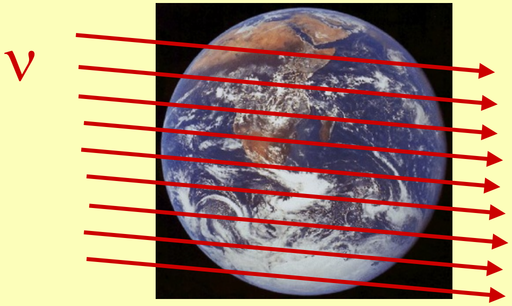


• Interaction with matter depends on the particle:

Charged particles: Ionization of the matter

Photons: Energy transfer to charged particles
Neutrons: Nuclear reactions create charged particles

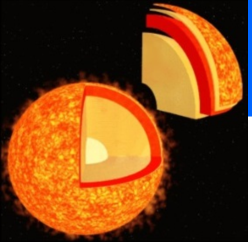
• Neutrinos interact only weakly:



Only one out of 100 billion neutrinos from a β-decay is discovered by the Earth.

Calculated 1934: „Hopeless“

Neutrinos from the Sun



$$4\,\text{Protons} \rightarrow \text{Helium} + 2e^{+} + 2\nu + 26MeV$$

- Known: total irradiated energy
- Known: Energy per fusion process

➢ Number of neutrinos produced [s^{-1}]!
On Earth: 66 billion ν per ($cm^2 \cdot s^1$)

proton-proton-cycle

pp-neutrino: $p+p \Rightarrow {}^2H+e^+ +\nu_e$ *(99%)*

pep-neutrino: $p+e^- +p \Rightarrow {}^2H+\nu_e$ *(1%)*

$2H+p \Rightarrow {}^3He+\gamma$

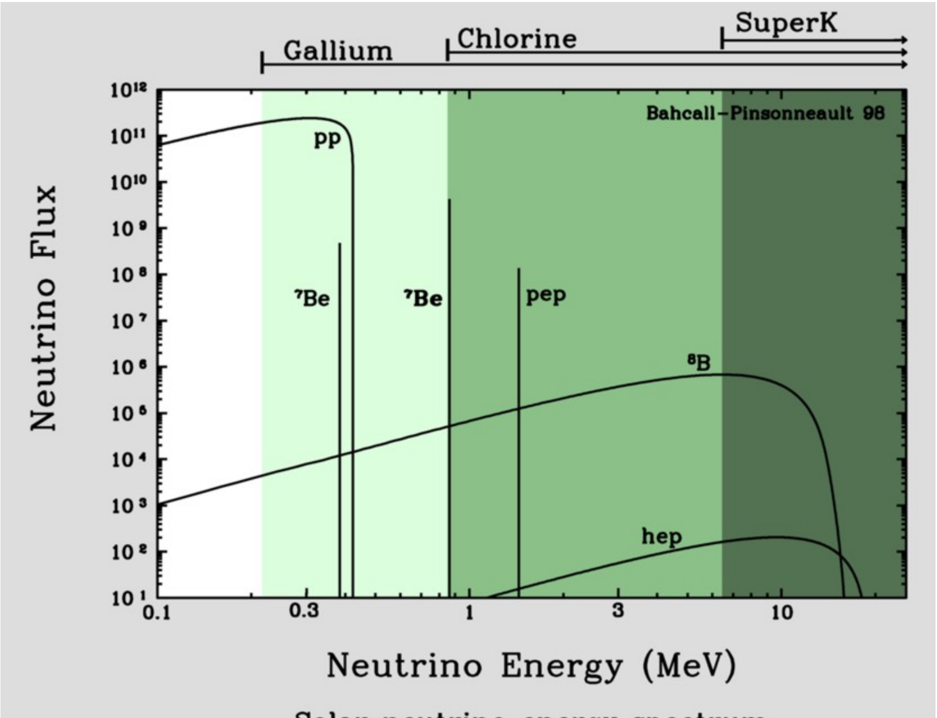
${}^3He+{}^3He \Rightarrow {}^4He+2p$ *(86%)*

hep-neutrino: ${}^3He+p \Rightarrow {}^4He+\nu_e+e^+$ *(<<1%)*

${}^3He+{}^4He \Rightarrow {}^7Be+\gamma$ *(14%)*

^{7}Be-neutrino:
${}^7Be + e^- \Rightarrow {}^7Li + \nu_e$
${}^7Li + p \Rightarrow 2\,{}^4He$ *(99%)*

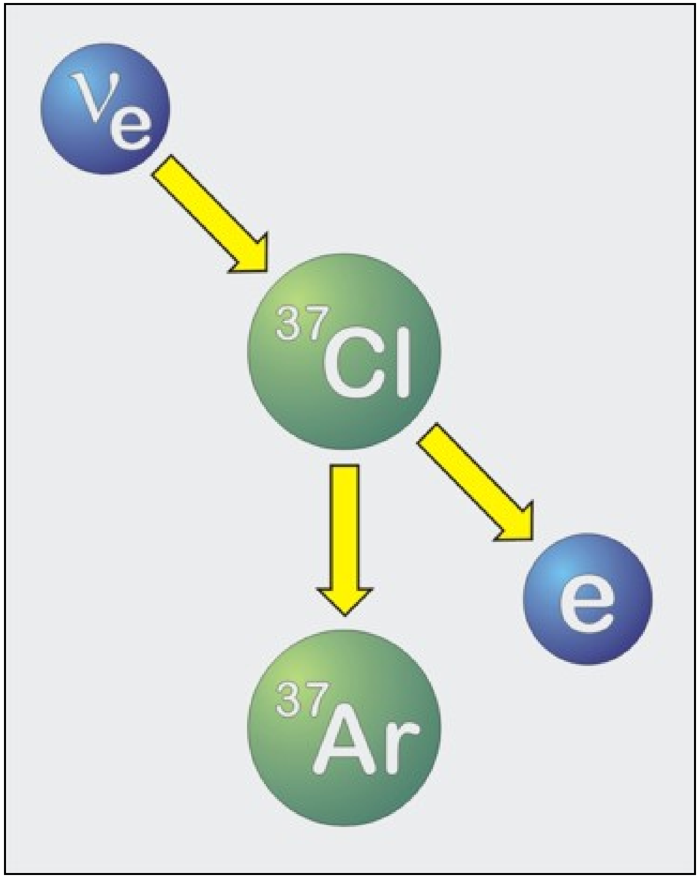
^{8}B-neutrino:
${}^7Be + p \Rightarrow {}^8B + \gamma$
${}^8B \Rightarrow {}^8Be + e^+ + \nu_e$
${}^8Be \Rightarrow 2\,{}^4He$ *(1%)*

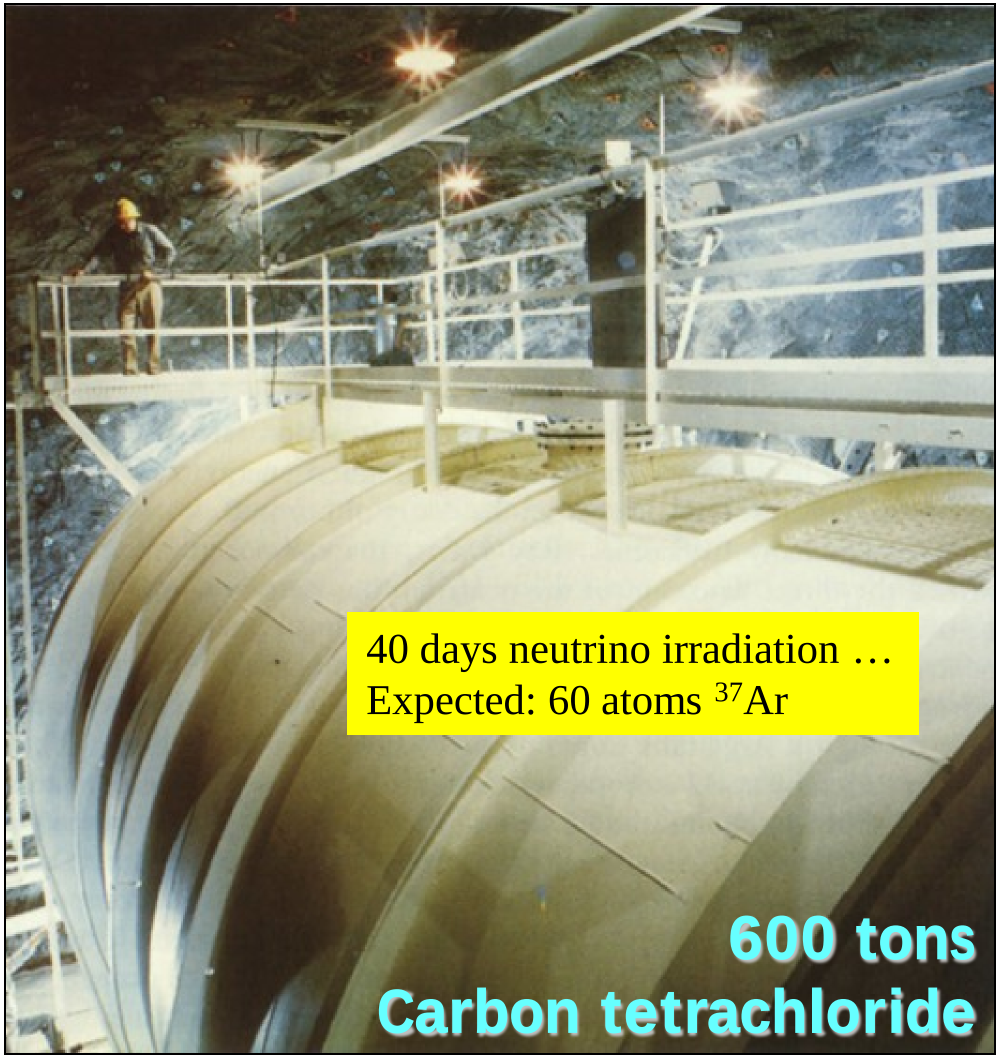


Solar neutrino energy spectrum

First measurement of the solar neutrinos

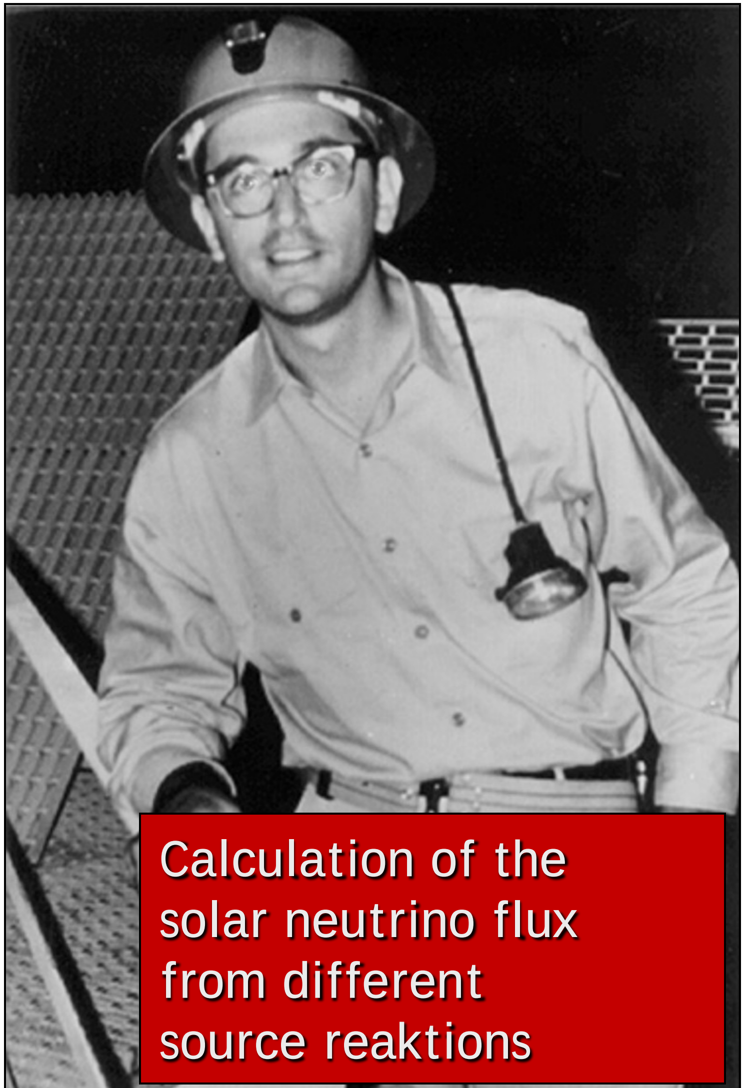
Inverse beta-decay („neutrino-capture")





Homestake Sun neutrino-Observatory (1967–2002)

The problem of the missing solar neutrinos

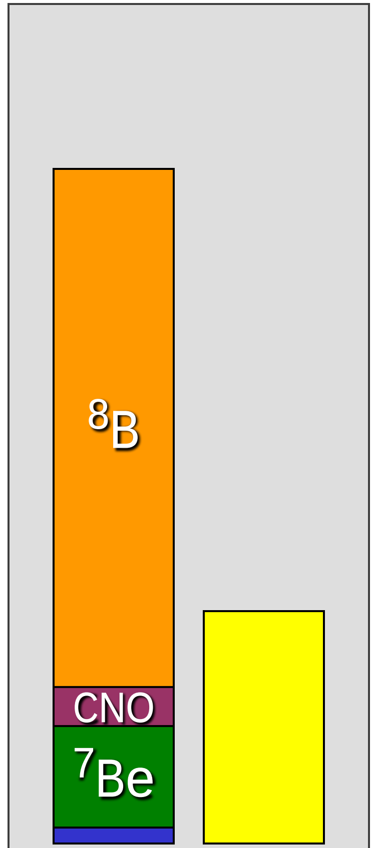


Calculation of the solar neutrino flux from different source reaktions

John Bahcall
1934 – 2005

Homestake

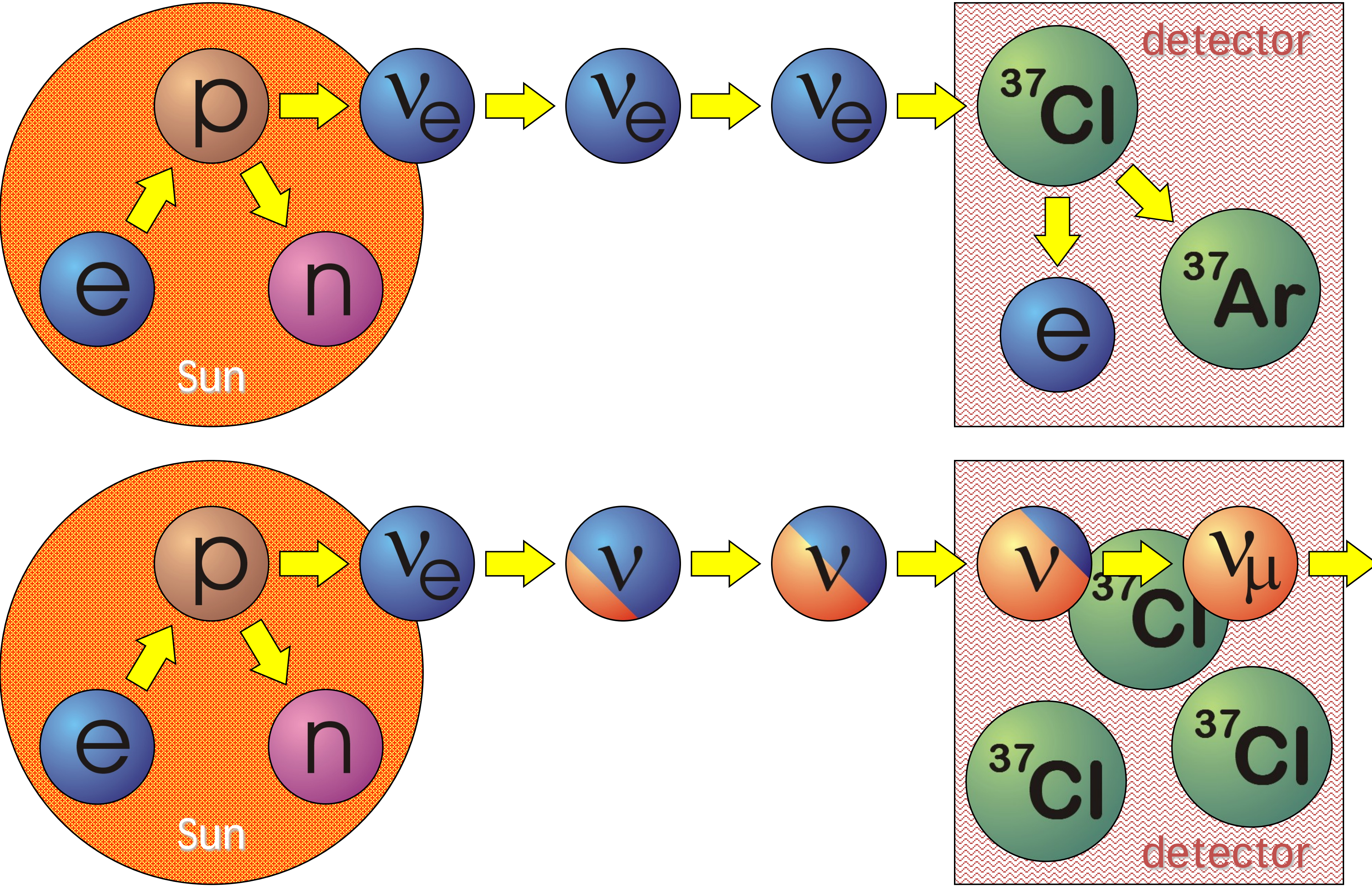
Chlorine



measurements (1970 – 1995)

Raymond Davis Jr.
1914 – 2006

“Neutrino transformation” the solution of the puzzle



Neutrino oscillations

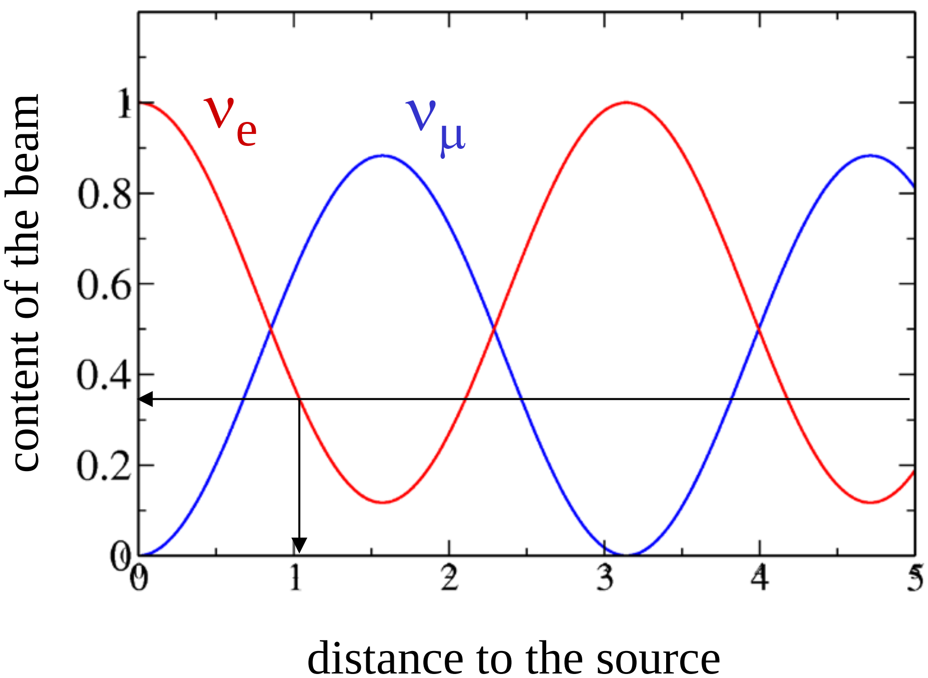
electron e	myon μ	tau τ
e-neutrino	μ-neutrino	τ-neutrino

Idea: If neutrinos have a mass, then they can convert themselves into one another!

Assumption: Mixture of

ν_e and ν_μ

Change of a neutrino-beam with the distance to the neutrino source:



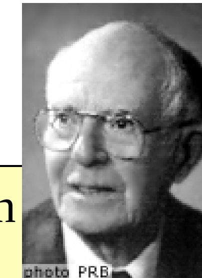
1998: Discovery of the oscillations between myon- and tau-neutrinos using Super-Kamiokande (myon-neutrinos from the atmosphere)

Solar neutrino problem

Sun
Since 4.5 billion years
fusion

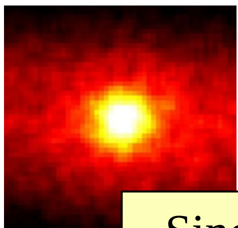
66 billion neutrinos/s/cm^2

Since 1964: Detection with
Homestake-experiment
Expected: 1,5 reactions/d
Observed: 0.5 reactions/d



R. Davis

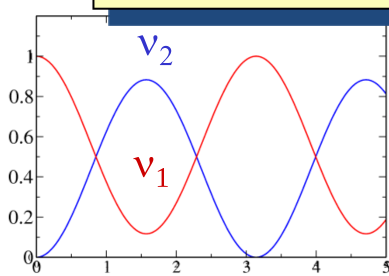
solar
neutrino
problem



Since 1986 Kamiokande:
confirmation of Homestake

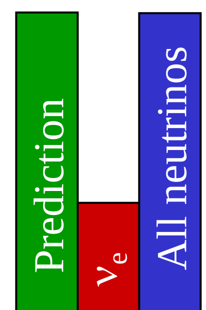
Masatoshi Koshiba

possible explanation:
neutrino-oscillation



2002 SNO-experiment:
checks neutrino-oscillation

solar
neutrino
problem
solved!



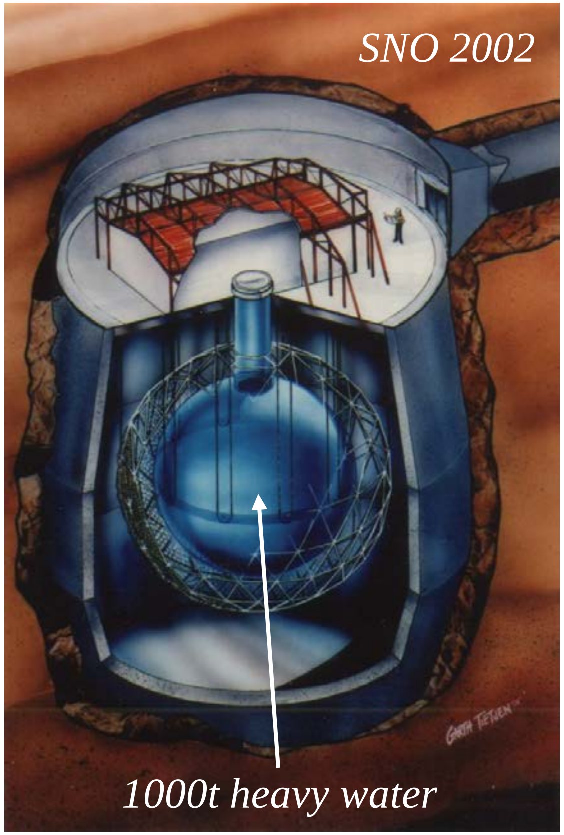
Examination of the oscillation-hypotheses for solar neutrinos

So far: Only electron-neutrinos detected

$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$	*Homestake*
$\nu_e + e^- \rightarrow \nu_e + e^-$	*Kamiokande*
$(\nu_\mu + e^- \rightarrow \nu_\mu + e^-$	*unlikely, undistinguishable*)

SNO: Detection of different neutrino-types using different reactions on D_2O

Sudbury Neutrino Observatory, Kanada



Only electron-neutrino:

detection

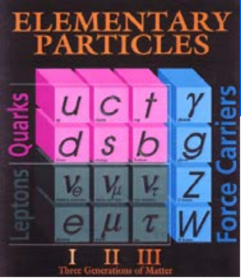
$$\nu_e + d \rightarrow p + p + e^-$$

p n p p

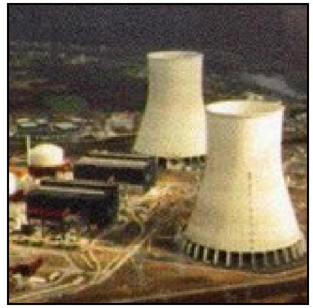
With equal probability for all neutrinos:

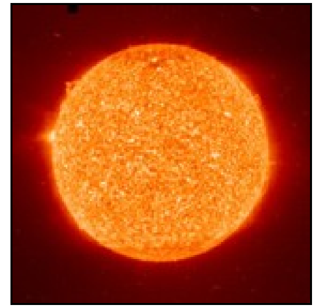
detection

$$\nu_x + d \rightarrow p + n + \nu_x$$



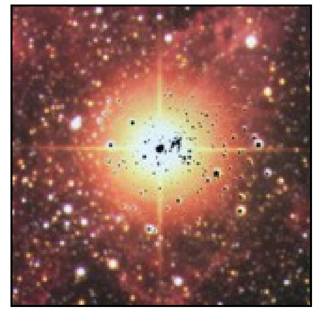
Neutrinos as astrophysical observer





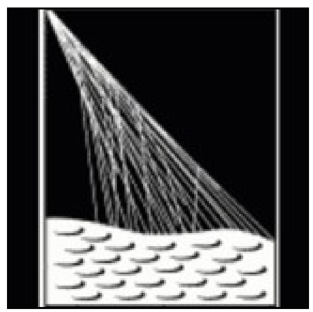
✓ nuclear reactors

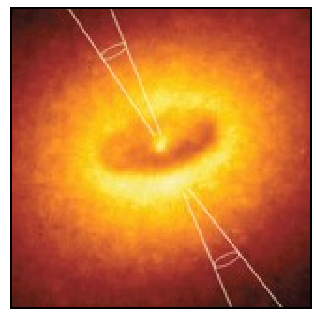
Sun ✓



✓ particle accelerator

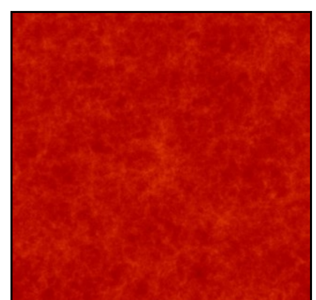
Supernovae (collapsing stars)
SN 1987A ✓





✓ Earth atmosphere (cosmic radiation)

astrophysical accelerator soon ?



✓ Earth crust (natural radioactivity)

Big bang of the universe (today 330 ν/cm^3)
indirect evidence