GALLEX @ LNGS

- 1 Solar Neutrinos
- 2 The `Solar Neutrino Problem´ (SNP)
- 3 The early years of the Gallium-Project
- 4 GALLEX at Gran Sasso (LNGS)
- 5 Result of GALLEX I
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Till Kirsten, Max-Planck-Institut für Kernphysik, Heidelberg (MPIK)

Roma, Accademia dei Lincei, Sept. 2023

1. Solar Neutrinos

The solar core, the strongest accessible low energy neutrino source

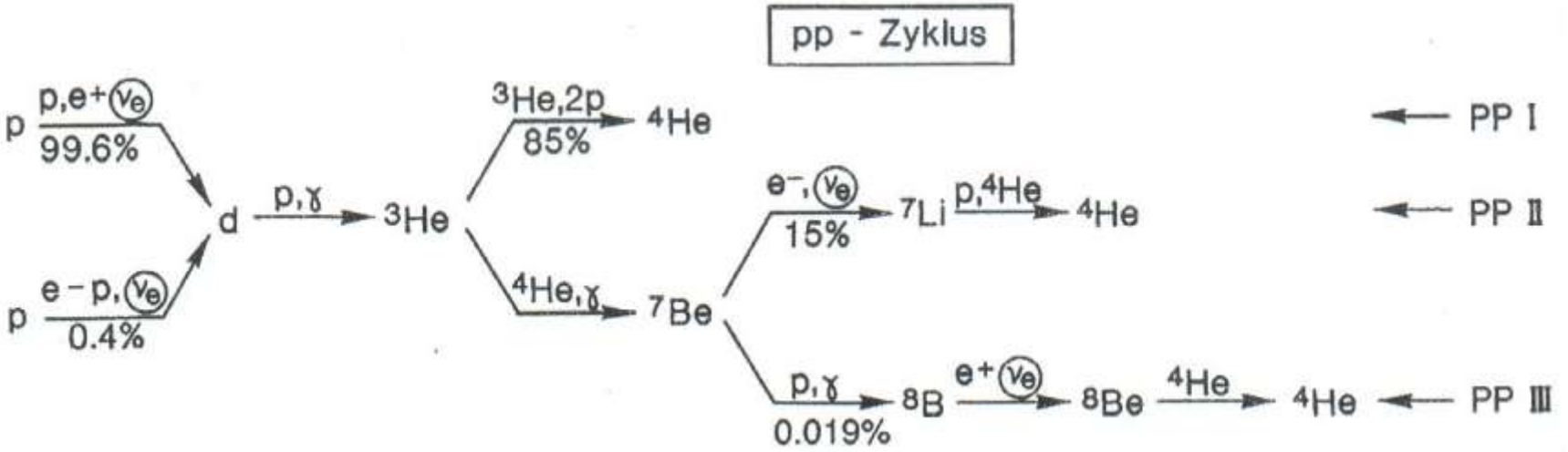
$$N_\nu(E)dE = f[T(r);\rho(r),composition]$$

Test of stellar structure and evolution

Real time look into the stellar interior!

For the SUN, the pp-cycle dominates

$$4\,H^+ + 2e^- \rightarrow {}^4He^{++} + 2\,\nu_e + 26.73\ MeV$$
$$< E(2\nu_e) > = 0.59\ MeV$$

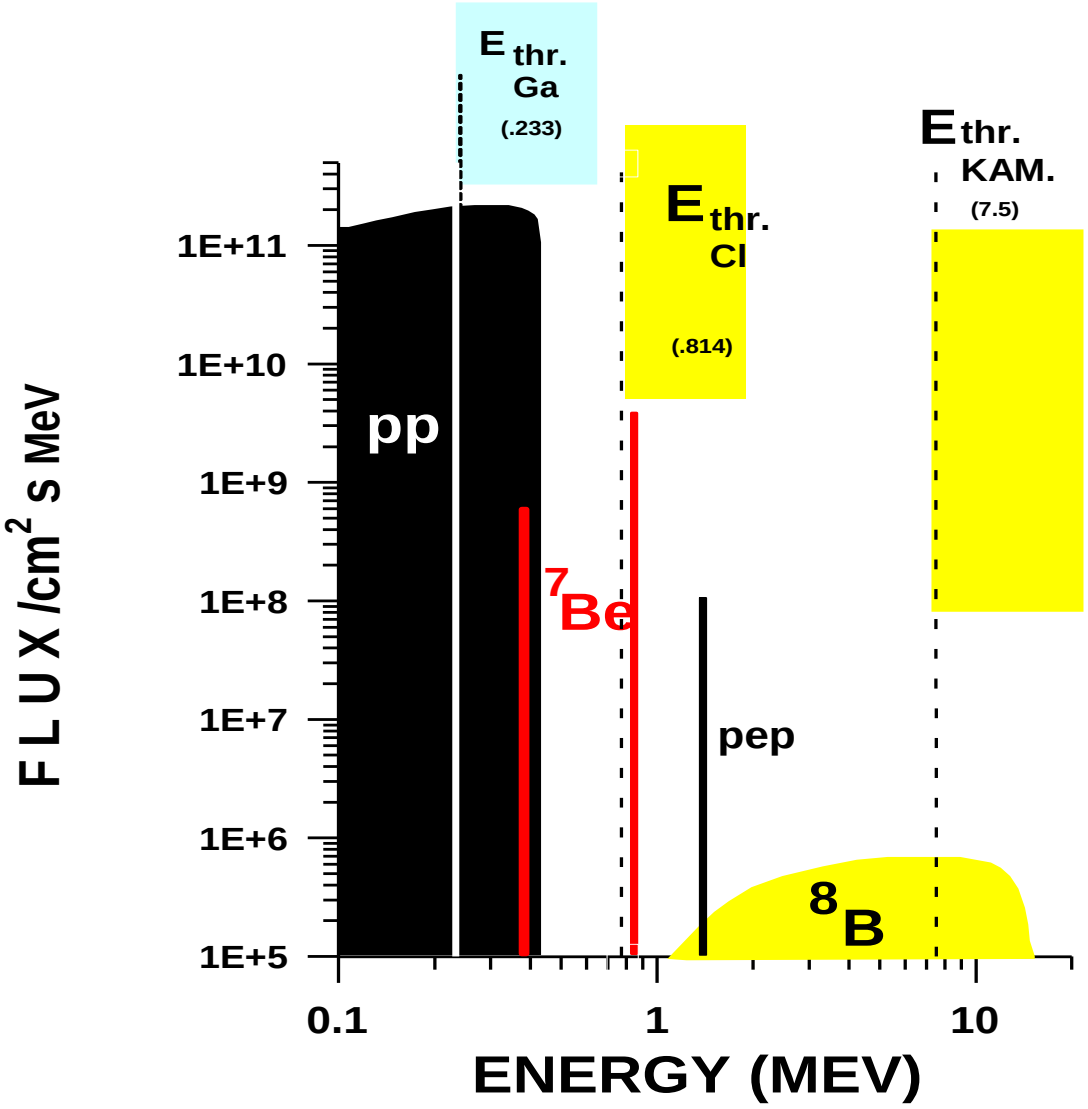


EXPECTED NEUTRINO FLUXES

predicted by the Standard Solar Model to arrive at the Earth:

pp - ν :		60 billions /cm^2,s	~ T_c^{-1}
^{7}Be - ν :	~	5 billions /cm^2,s	~ T_c^{8}
^{8}B - ν :	~	5 millions /cm^2,s	~ T_c^{18}

SOLAR NEUTRINO SPECTRUM



Bruno Pontecorvo

The first considerations for actually *detecting* solar neutrinos go back to Bruno Pontecorvo, as early as 1946.

He proposed solar neutrino detection through inverse Beta-decay on ^{37}Cl, leading to radioactive ^{37}Ar:

$$^{37}\mathrm{Cl}\ (\nu_e,\ e^-)\ ^{37}\mathrm{Ar}$$

(EC, half-live 35 d)

Raymond Davis jr.

1964:

First practical feasibility study for a Chlorine Experiment at Brookhaven National Laboratory (BNL)

1967:

Start of data taking at the Homestake gold mine in South Dakota.

2. The Solar Neutrino Problem

The signal in the pioneering Homestake Experiment turned out to be about 1/3 of what was expected from the Standard Solar Model (mainly for B^8-neutrinos). This established the `Solar Neutrino Problem' (SNP). The deficit could have been caused

either: **by deviations due to an incomplete or false description of the solar interior in the Standard Solar Model (SSM) and/or by inaccurate input parameters:**

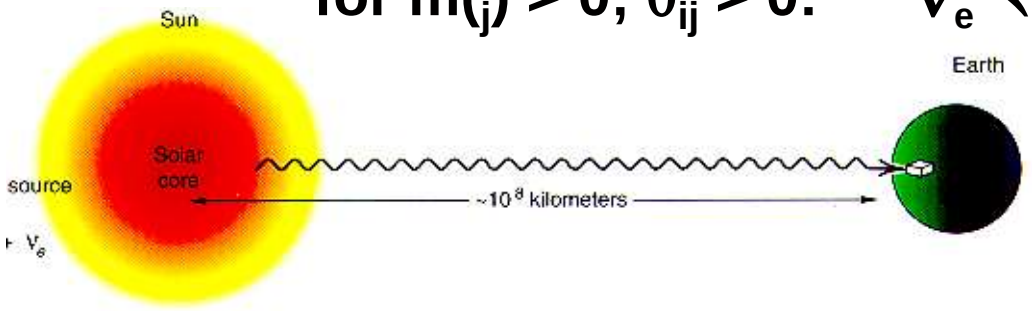
- **ASTROPHYSICAL SOLUTION of the SNP**

or: **by non-standard neutrino properties, such as e.g., non-zero neutrino mass at the root of neutrino flavour oscillations:**

- **PARTICLE PHYSICS SOLUTION of the SNP**

Neutrino Flavour Oscillations

for $m(_j) > 0$; $\theta_{ij} > 0$: $\nu_e \leftrightarrow \nu_{\mu(\tau}$



In vacuo:

$$\nu_e = \nu_1 \cos\theta_\nu + \nu_2 \sin\theta_\nu$$
$$\nu_\mu = -\nu_1 \sin\theta_\nu + \nu_2 \cos\theta_\nu$$

$$\Delta m^2_{12} = \left| m^2_{\nu_1} - m^2_{\nu_2} \right|$$

$$\textit{Oscillation length } L \propto E / \Delta m^2$$

for the distance Sun-Earth, this is sensitive to masses as small as $\Delta m^2 \approx 10^{-11}$ $(eV/c^2)^2$

3. The early years of the Gallium Project

Radiochemical Method

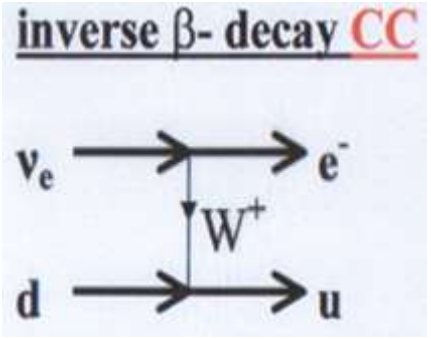
(product accumulation)

$$\nu_e + Ga^{71} \rightarrow Ge^{71} + e^-$$

$T_{1/2} = 11.4$ d

Low threshold! (0.233 MeV)

Implies a serious challenge concerning backgrounds



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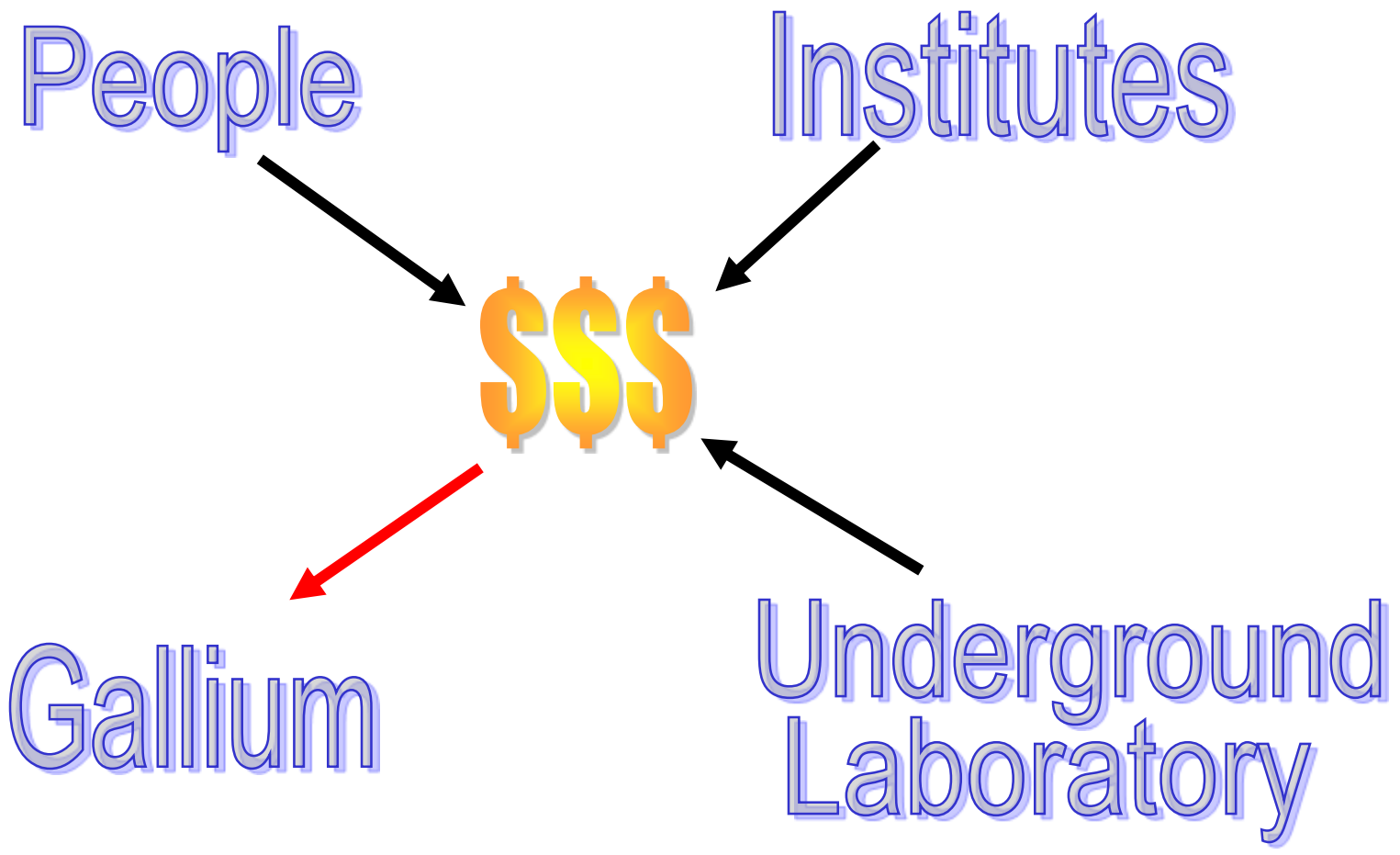
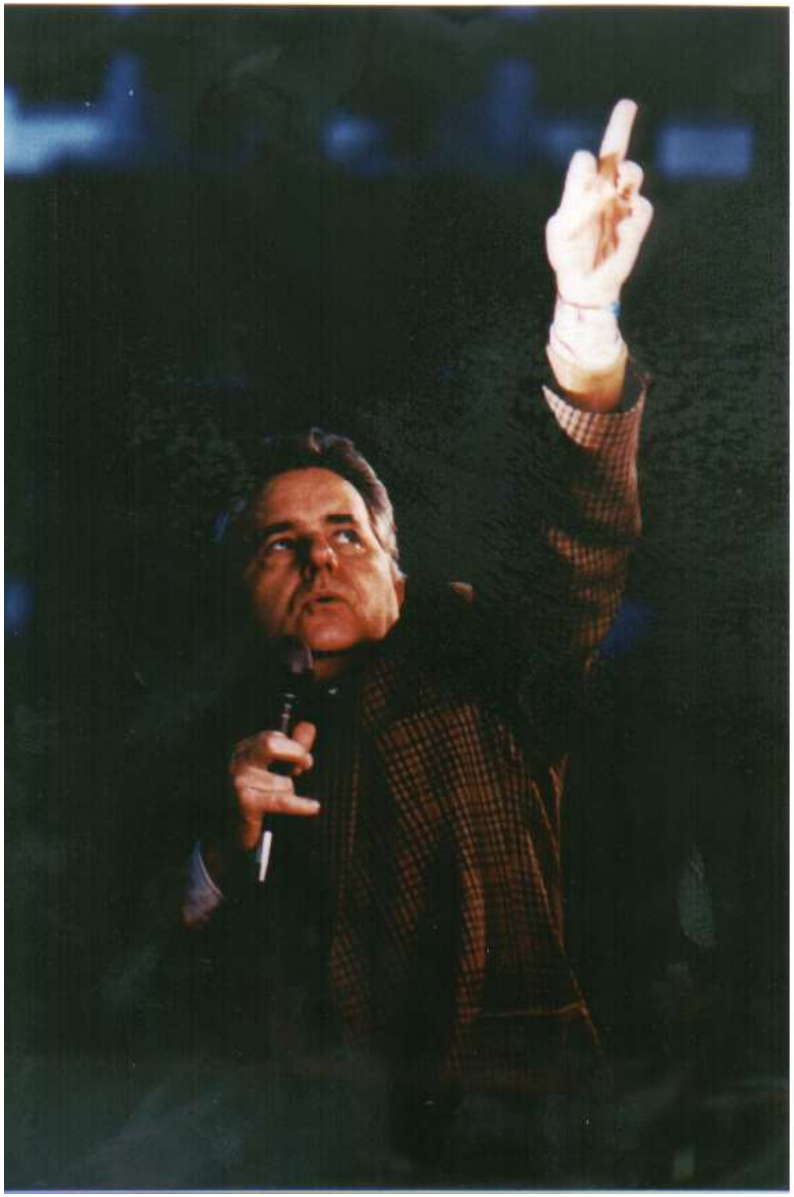
4. GALLEX@GRAN SASSO (LNGS)



- Could industry achieve the required **amount** and **radiopurity** of **Gallium ?**
- Would it be possible to develop a functioning **Ge-Ga separation** technique with a separation factor of $>10^{30}$ **?**
- Could one develop a **Low-Level-Counting procedure** for ^{71}Ge counting **?**
- Could one establish a committing international **network of top scientists** with the respective expertise and **support by their agencies?**
- Is there a suitable **underground laboratory?**
- Before all these questions are answered, can one dare to ask for **funding of order 100 Mio$?**

Enrico Bellotti

Nicola Cabibbo

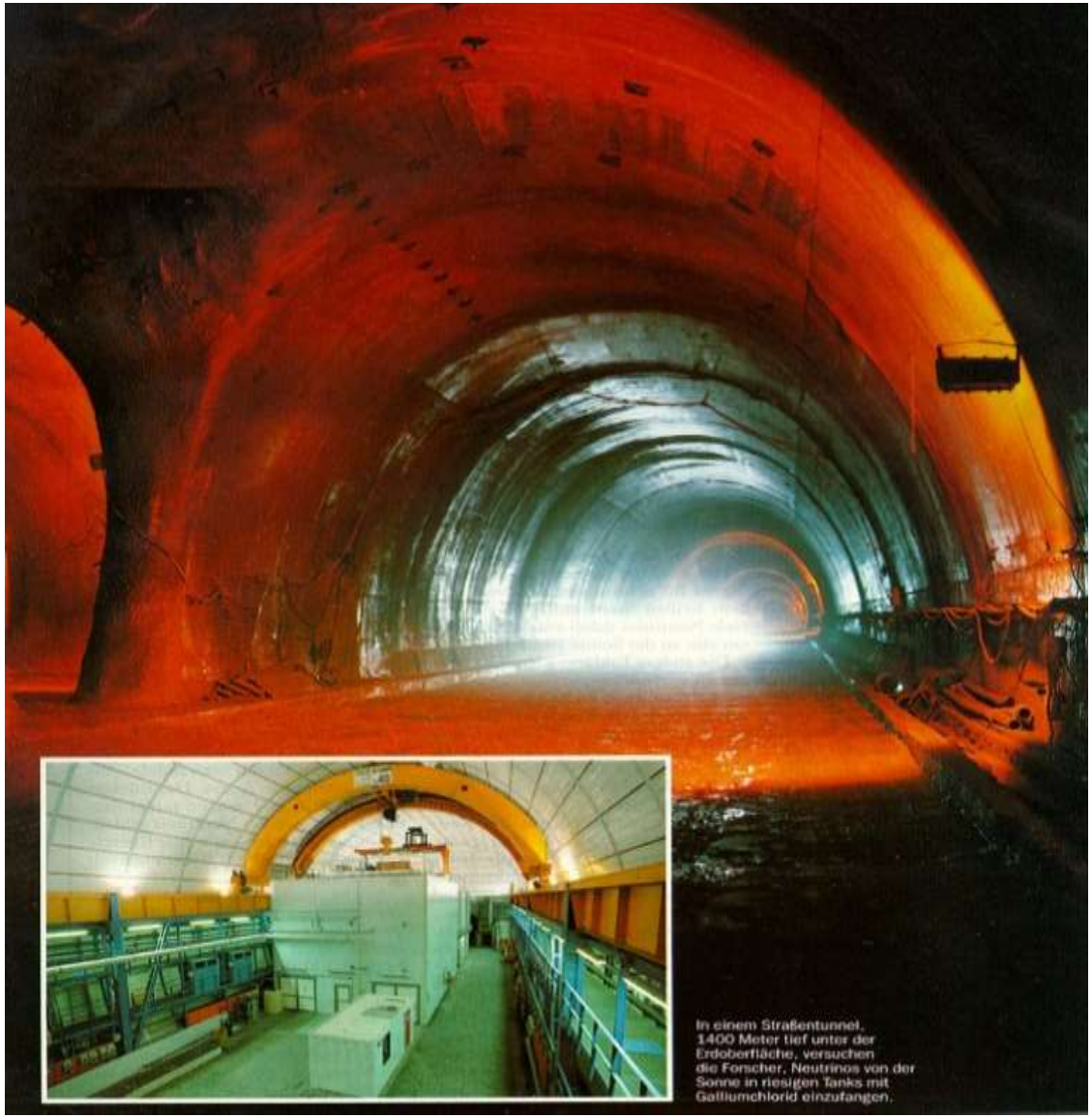


THE COURSE OF EVENTS

- **1979 Underground laboratory proposed by Antonio Zichichi, President of INFN**
- **1982 Start of excavations**
- **1984 First meeting of TK with Nicola Cabibbo**
- **1984 N. Cabibbo strongly supports solar neutrino research as a major topic at LNGS**
- **1983-1985 Formation of the GALLEX-Collaboration**
- **30.7.1985 Assurance of GALLEX allocation at LNGS**
  1986-1991 Construction and Preparation
- **14.5.1991 Start of Solar Neutrino Recordings**
- **8.6.1992 First Data Release (GALLEX I):**

GALLEX Collaboration

At Hall A excavation site, 1987


In einem Straßentunnel, 1400 Meter tief unter der Erdoberfläche, versuchen die Forscher, Neutrinos von der Sonne in riesigen Tanks mit Galliumchlorid einzufangen.

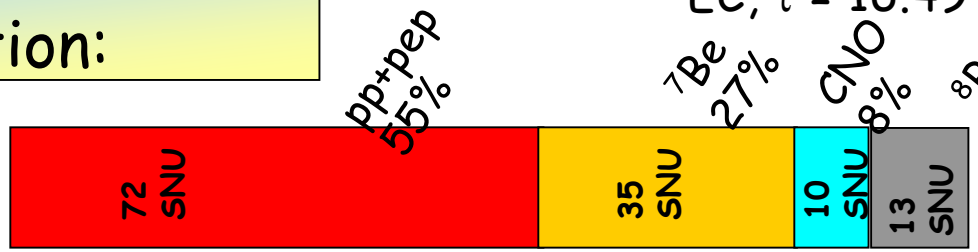
Conception of GALLEX / GNO

Purpose: detection of low energy solar neutrinos

Basic interaction: $^{71}Ga(\nu_e,e)^{71}Ge$ (E_{thr} = 233 keV), Ga^{71}=39.6%

EC, τ = 16.49 days

ν signal composition:



Tot: 128^{+9}_{-7} SNU

Technique: Radiochemical 1 SNU =1 event /10^{36} target atoms, sec

Target: 103 tons of $GaCl_3$ acidic solution containing 30 t of natural gallium

Chemical extraction of ^{71}Ge every 3-4 weeks (nitrogen purging of $GeCl_4$)

Detection of ^{71}Ge decay with gas proportional counters

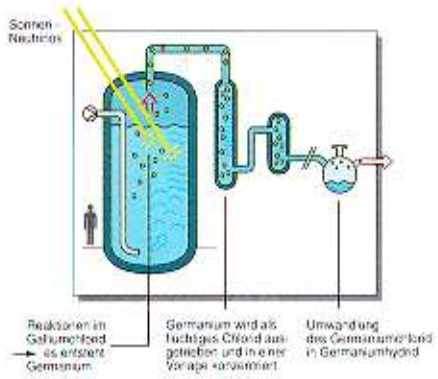
Expected signal (SSM): $\approx$ 9 ^{71}Ge counts detected per extraction

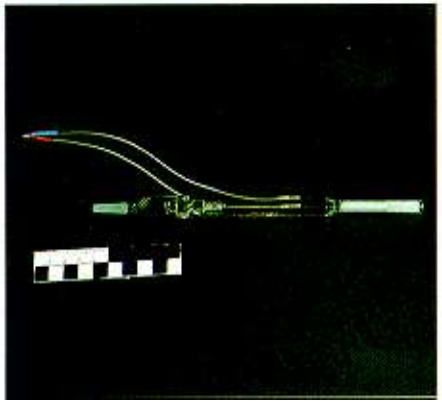
GALLEX COMPONENTS

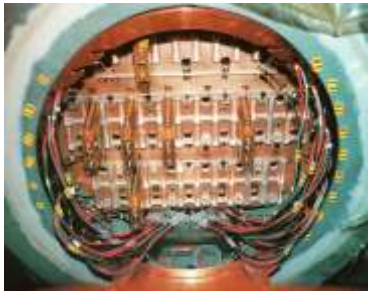
Gallium Experiment at Gran Sasso

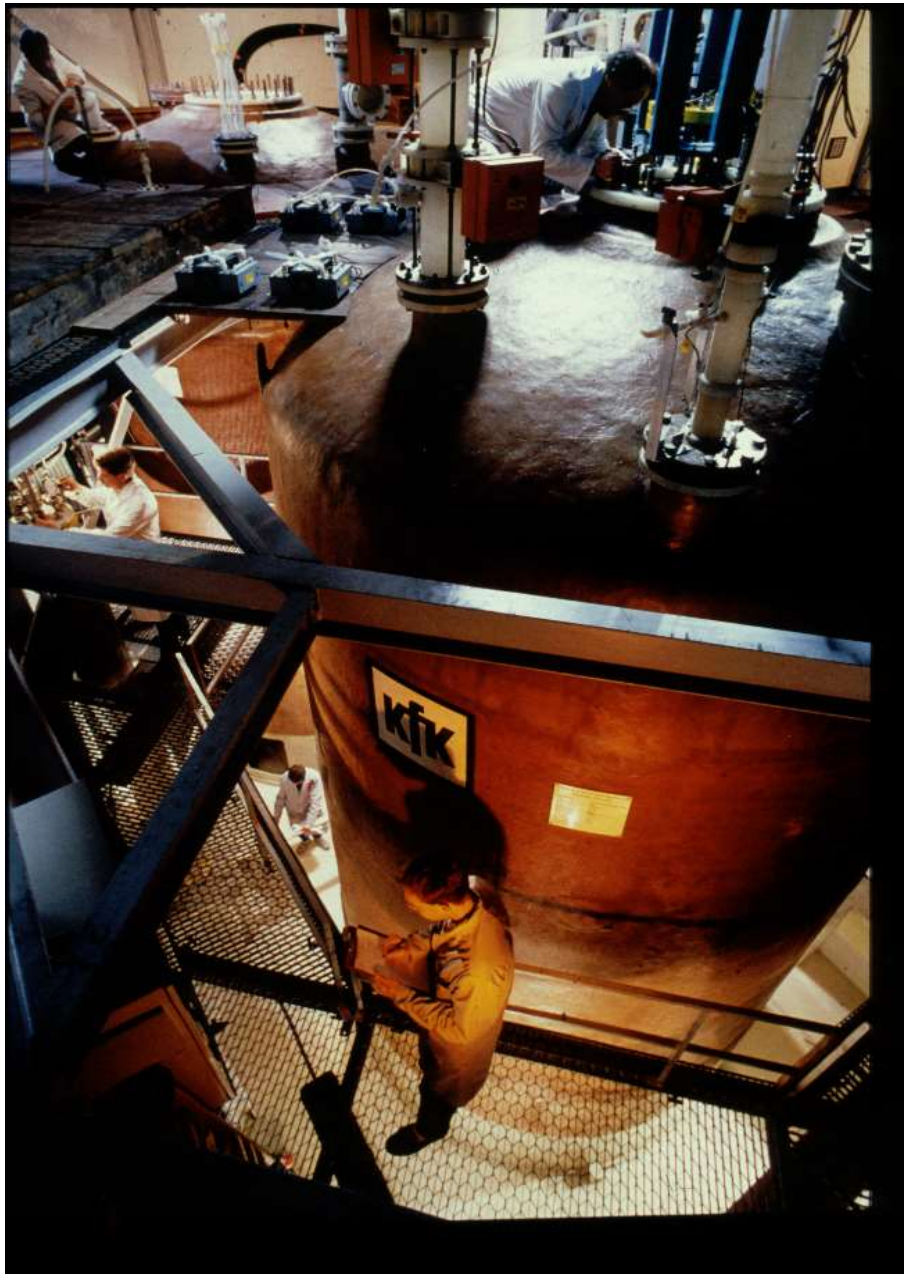
GALLEX

INTERNATIONAL
SOLAR NEUTRINO RESEARCH
COLLABORATION



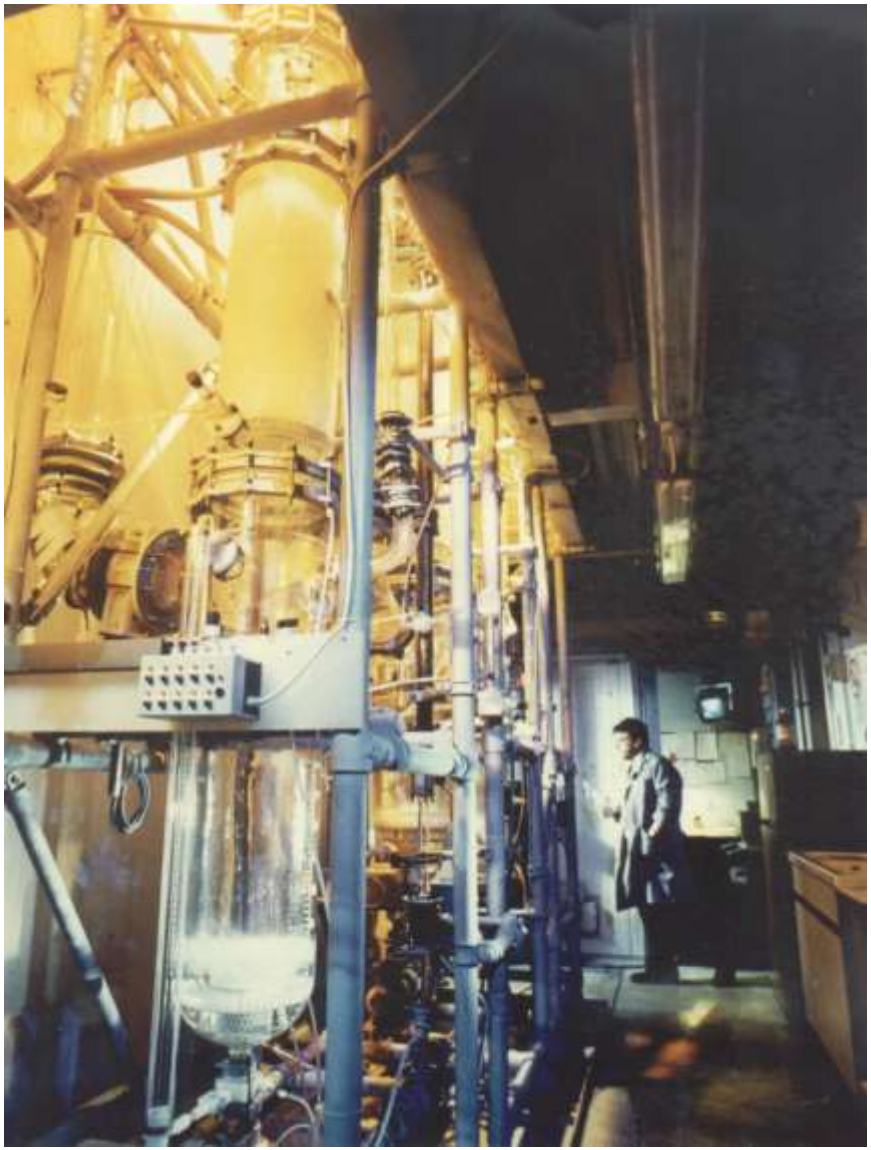






Tanks installed, September 1989

2 of them for redundancy and safety

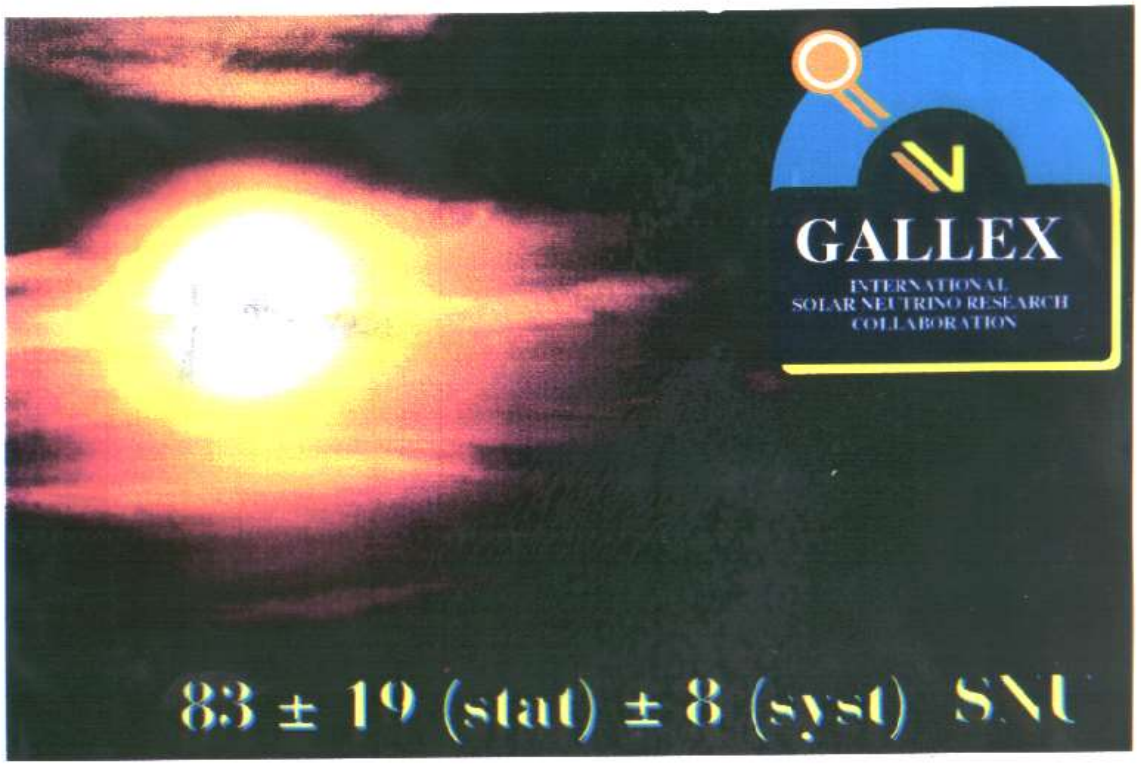


Germanium-Extraction System

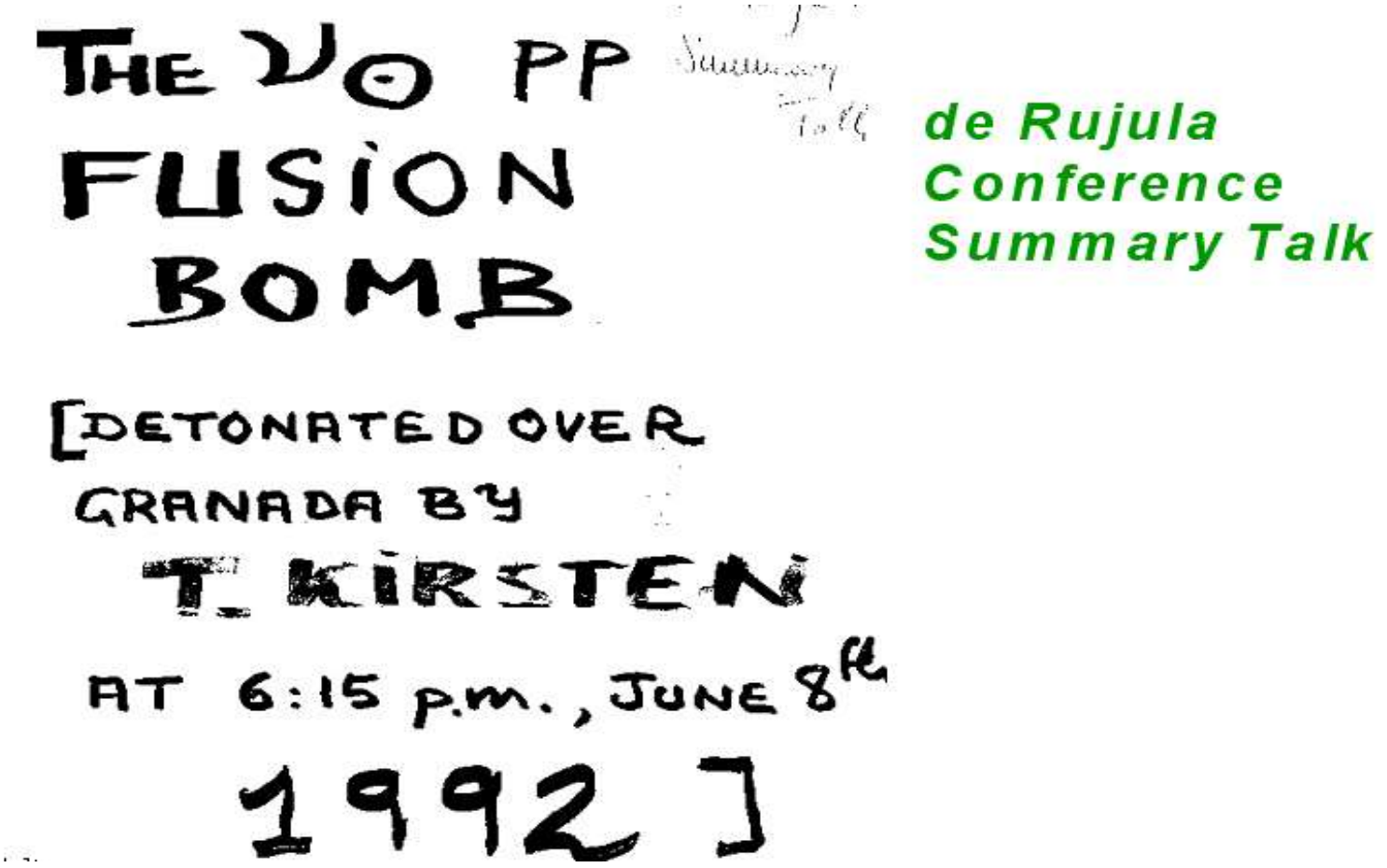
5. RESULTS of GALLEX 1

Granada, June 8th, 1992

GALLEX announces first observation of solar pp-neutrinos at „Neutrino 92“



NEUTRINO 92, Granada 7-12 June 1992



de Rujula
Conference
Summary Talk

Fred Reines at Granada

GALLEX RESULT IMPLICATIONS (1992)

Physics Letters B285 (1992) 376 *Citation index 31.5.92:* **# 5 + # 11**
Physics Letters B285 (1992) 390

≈ 105 % of the pp- expectation
⇒ Hydrogen fusion in the solar interior experimentally observed

≈ 60 % of the total SSM- expectation
⇒ Definite deficit of pp- and/or ^{7}Be- neutrinos observed

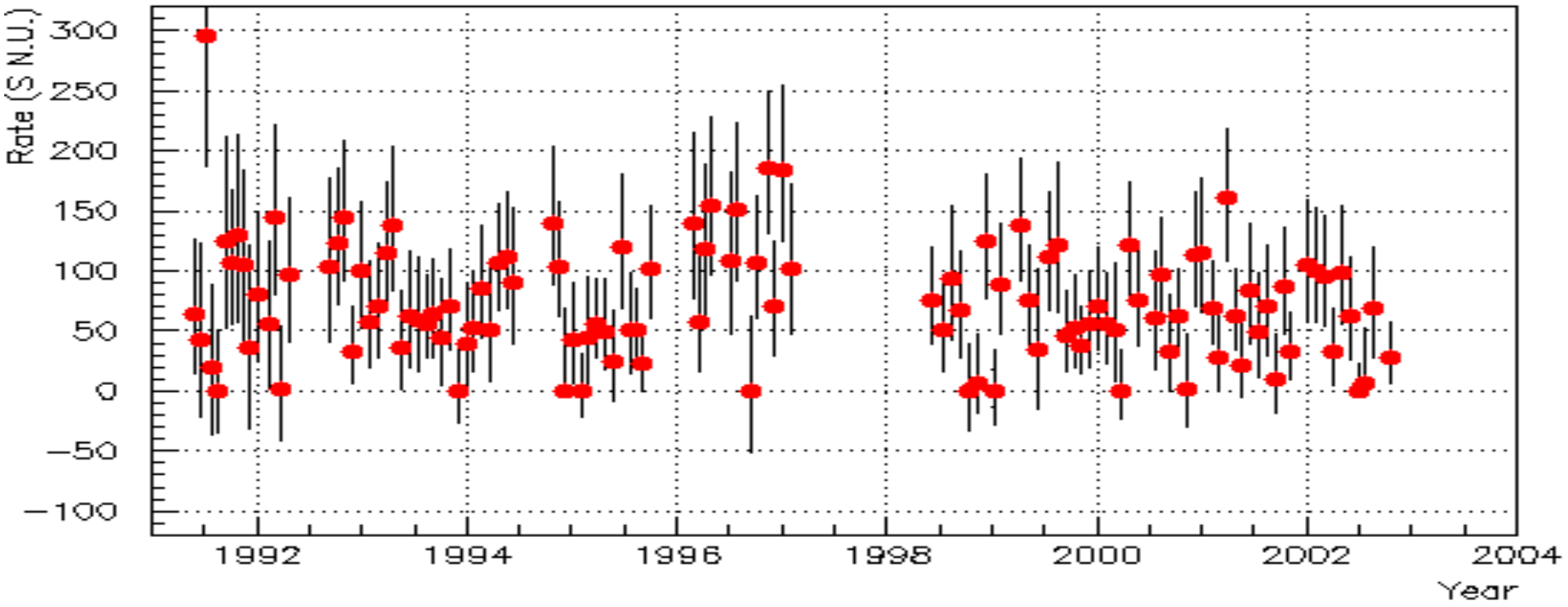
6. PROOF and VERIFICATION

Recordings after Gallex I

- **GALLEX II Recordings: 8/1992 - 6/1994**
- **1st ^{51}Cr Source Experiment 6/1994 - 10/1994**
- **GALLEX III Recordings: 10/1994 - 9/1995**
- **2nd ^{51}Cr Source Experiment 10/1995 - 2/1996**
- **GALLEX IV Recordings: 2/1996 – 23.1.1997**
- **^{71}As-Test of the Detector: 2/1997 - 4/1997**
- **GNO Data Taking: 5/1998 – 9.4.2003**

GALLEX + GNO ("Davis plot")

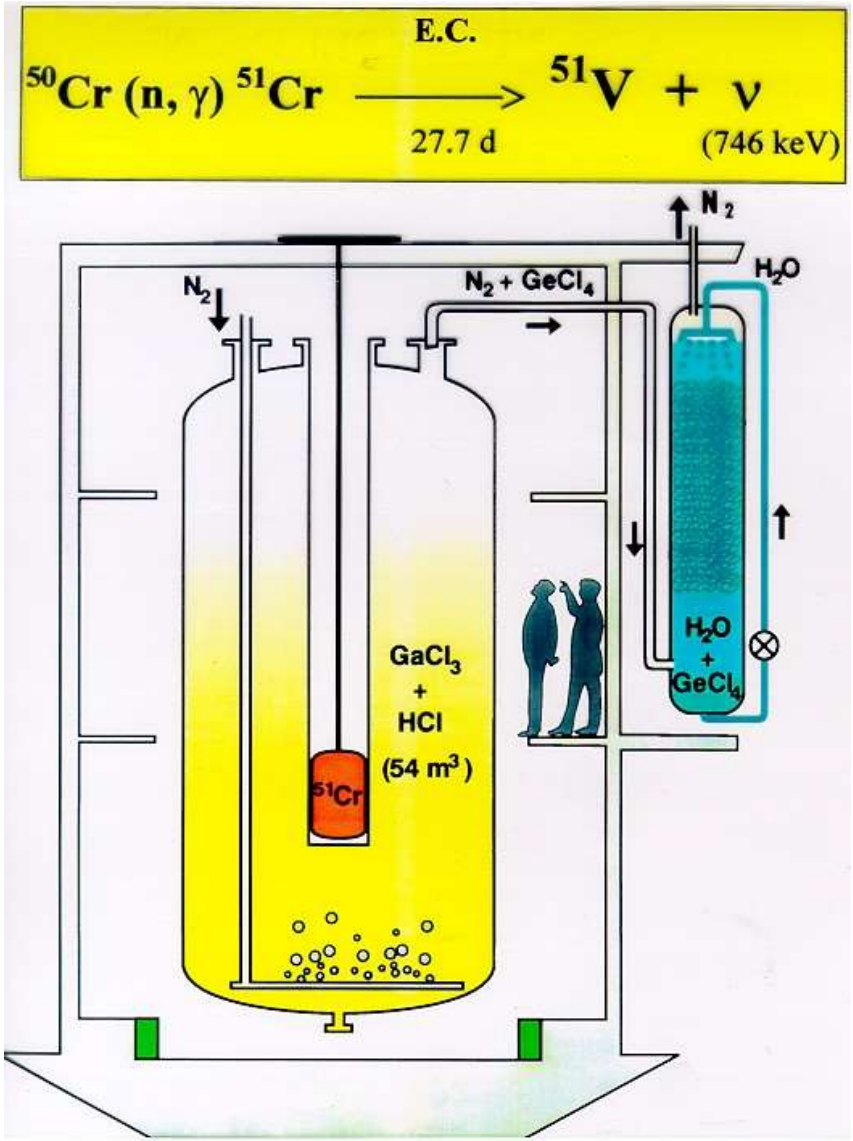
Nucl.Phys.Proc.118,33 (2003)



GALLEX
65 solar runs

GNO
52 solar runs

Cr-Neutrino Source Experiment



Arsenic 71 spiking Tests

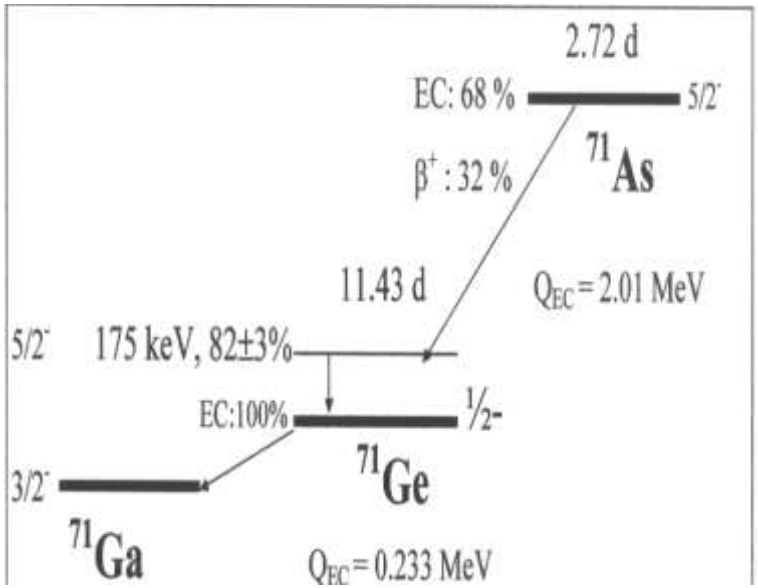
Repeated tests under variable and purposely unfavorable conditions respective to the

- **standing time**
- **mixing- and extraction conditions**
- **method and magnitude of carrier addition**

to exclude witholdings (classical or 'hot-atom'-effects)

Method:

Triple-batch comparison,
≈ 30 000 ^{71}As atoms added to:
Tank sample
External sample
Calibration sample (γ-spectrom.)

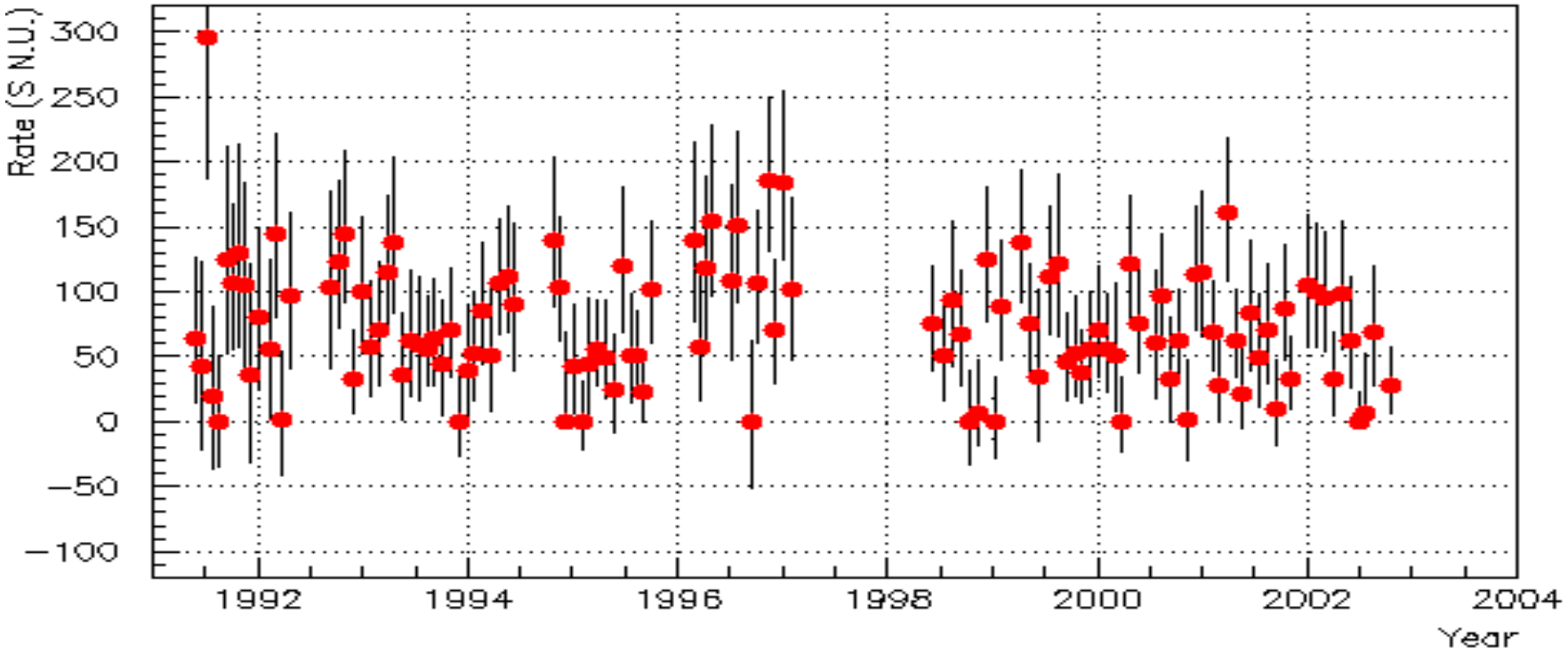


Result:

Recovery **99+ %**

GALLEX + GNO ("Davis plot")

Nucl.Phys.Proc.118,33 (2003)



GALLEX
65 solar runs

GNO
52 solar runs

7. Credits and Mementos

- **INFN** *Nicola Cabibbo, Luciano Maiani,…*
- **LNGS** **still unique facility worldwide**
  Enrico Bellotti,…
- **MPG**
- **KRUPP Foundation**
- **CNRS**
- **Smoothly functioning international collaboration with wonderful colleagues**

Credit to those who helped to make GALLEX/GNO a success story

In memoriam

- Luciano Paoluzi
  2002
- Burkhard Freudiger
  05.09.2005
- Dario Motta
  2005
- Michael Altmann
  31.07.2006
- Nicola Ferrari
  31.07.2006
- Keith Rowley
  29.10.2006
- Evry Schatzman
  25.04.2010
- Israel Dostrovsky
  28.09.2010
- Rudolf Mößbauer
  14.11.2011
- Silio d´Angelo
  02.02.2015
- Clemens Schlosser
  02.08.2021
- Enrico Bellotti
  11.09.2021
- Ettore Fiorini
  09.04.2023

Emiko Kirsten

+16.12.2016

SPARES


Mme.Labberique, Emiko K., Bruno

Dear Emiko, thank you very Dubna 3-2-91
much for your 18 December 1990 letter of congratulations for the New Year. I am replying terribly late, but there is some justification in my delay. As a matter of fact, in May 1990 at Dubna I fell from a bycicle (I am 77 years old and I have the Parkinson disease!), I broke my left hip, flew to a Rome clinic, was operated, and ... did not dye. I remained in Italy 7 months. Now I am able to walk, though not very well.

I too was very pleased with the journey to Erice and its environments. Thank you very much for the nice photos. I am sending also the photos for Mme Laberrigue. Maybe we shall meet again at some neutrino meeting. I am going to Italy in May-June Time 1991. Wishing all the best to

Осенний пейзаж
Фото В. Катаева

© «Планета», 1989. 7/8в-8836. 2849. 950 000 экз. 3 к.

ОТПРАВЛЯТЬ ПО ПОЧТЕ ТОЛЬКО В КОНВЕРТЕ

How to distinguish?

If a significant deficit would be observed for pp-neutrinos, one could rule out the astrophysical solution since their flux at origin is directly fixed to the well-known solar luminosity.

pp-neutrinos are by far the most abundant solar neutrinos, yet their energy is very low (<420 keV). This demands a detection reaction with very low threshold. The only practical option is

$$Ga^{71}(\nu_e, e^-)Ge^{71}.$$

The GALLEX experiment, a big technological challenge, was the solution. Here I will recall in the historical context the GALLEX/GNO discovery of solar pp-neutrinos in 1992 and the later assurance of non-zero neutrino mass - related to neutrino flavour oscillations.

Published data 1990-1998