GALLIUM-EXPERIMENTS
GALLEX / GNO

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

i = 39.6 % ; $T_{1/2}$ = 11.43 days
threshold energy: 233 keV

SSM-Expectation:

$130 \pm {}^{9}_{7}$ SNU (1σ) [B.G.P.01]new ^{8}B

[1 SNU = solar neutrino unit = 10^{-36} captures per target nucleus per second]

55.8 % from pp - ν (incl.pep) **(72.5 SNU)**

26.3 % from ^{7}Be **(34.2 SNU)**

7% from CNO - ν (9 SNU); 11 % from ^{8}B (14 SNU)

100 tons of aqueous Gallium chloride solution (= 30.3 t Gallium);

correspond to a SSM-production rate of
1.18 atoms of ^{71}Ge per day or
≈14 atoms at the end of a 3-week exposure

Extraction every 3 - 4 weeks , ε ≅ 99 %

Why sub-MeV - Neutrinos ?

★ **98 % of all solar neutrinos are sub-MeV (Φ_7 ~ 7 % , Φ_{pp} ~ 91 %)**

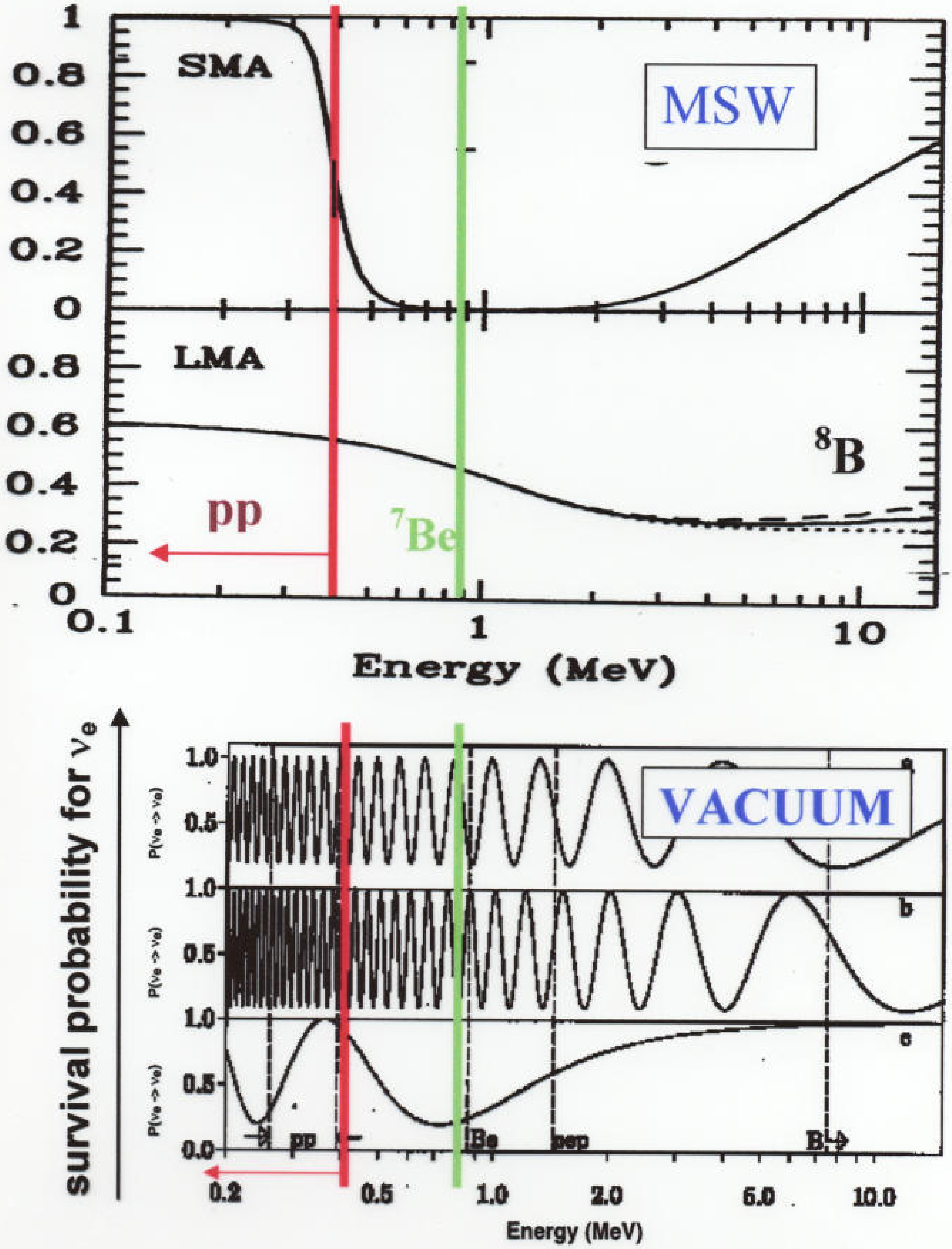
→ The flux is constraint by the solar luminosity. There is no need to chose a specifically constrained solar model.

→ To the contrary, the measured fluxes can lead to more stringent limitations of departures from the standard solar model, especially if the flux of **converted** neutrinos could be deduced with Borexino precision measurements (combination of Bx + Ga +Cl experiments).

→ The sub-MeV range is particularly discriminating among the various neutrino oscillation parameters that are still allowed by the presently available experimental data. So far this dominant part of the solar neutrino spectrum is explored only with Gallium, soon to be followed by Borexino for the ^{7}Be part

→ There is a high exploratory potential for time variations (day/night: espec. Borexino, seasonal: GNO).

→ All this will take time, but no practical competition to explore the sub-MeV region is seen in the next 5 years, with the possible exception of "High purity-Kamland", which would not differ in the principal approach.


SMA
MSW
LMA
8B
pp
7Be
Energy (MeV)
survival probability for νe
VACUUM
P(νe -> νe)
a
b
c
pp
Be
pep
B
Energy (MeV)

Determination of the pp- neutrino flux from GNO and Borexino

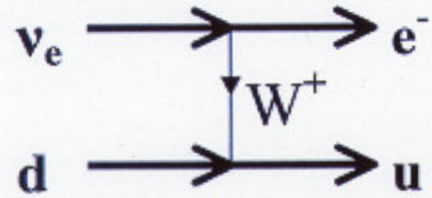
Experiment	Threshold [keV]	pp-ν (0-420 keV)	^{7}Be-ν (862 keV, 90%)
GNO	233	ν_e c.c. $\nu_{\mu,\tau}$ -	ν_e c.c. $\nu_{\mu,\tau}$ -
Borexino	500 (E_ν)	ν_e - $\nu_{\mu,\tau}$ -	ν_e c.c.,n.c.* $\nu_{\mu,\tau}$ n.c.*

* n.c.- sensitivity ≈ 1/6.

radiochemical

GNO

inverse β- decay CC



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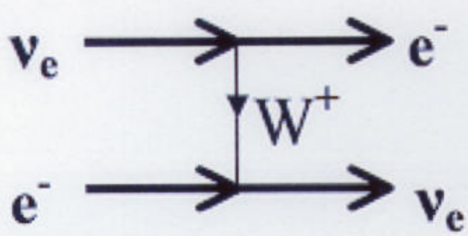
real time

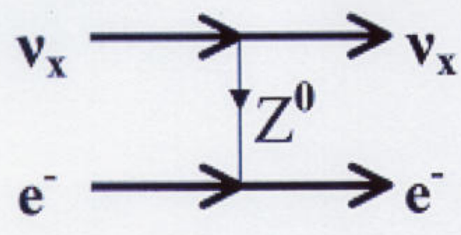
BOREXINO

ν - e scatt. CC



$\sigma \approx 5.3 \cdot 10^{-45} cm^2$

ν - e scatt. NC



$x = e, \mu, \tau$

$\sigma \approx 1 \cdot 10^{-45} cm^2$

Reduction factor for pp-ν alone:

GNO RESULT [SNU] (after subtraction of small known ^{8}B-contribution)

Cr Source RESULT

Borexino RESULT

$$F_{pp} = \frac{{}^{\text{♁}}\Phi_{e,pp}}{{}^{\text{☼}}\Phi_{pp}} = \frac{P_{GNO}}{{}^{\text{☼}}\Phi_{pp}\ {}^{i.\beta}\sigma_{pp}} - \frac{{}^{i.\beta}\sigma_{7\ g+e}}{{}^{\text{☼}}\Phi_{pp}\ {}^{i.\beta}\sigma_{pp}} \left[\frac{6 \cdot P_{7,Bx}}{5 \cdot {}^{e.s.}\sigma_{7}} - \frac{{}^{\text{☼}}\Phi_{7}}{5} \right]$$

from solar luminosity

fundamental

P = production rate, [Φ·σ] ;   ♁ : Earth   ☼ : Sun

i.β = inverse β-decay; e.s.= electron-scattering; g+e = ground st.+ exc. st.

GALLEX - RESULT

78 ± 8 SNU (1σ)

= (59 ± 6) % of the SSM-EXPECTATION;
= 105 % of pp - EXPECTATION

SIGNAL

HYDROGEN - FUSION IN THE SOLAR INTERIOR OBSERVED

DEFICIT

DEFINITE DEFICIT OF ^{7}Be- (or pp-) NEUTRINOS OBSERVED:
Not explainable by Solar Physics

Data status and recent progress in GNO

GNO is the modernized and improved continuation of the GALLEX experiment at Gran Sasso

→ newly structured collaboration

→ new analog electronics

→ new digital electronics; one Transient Digitizer for each line; led to much improved pulse shape recording

→ In-shield counter calibration with X-ray tube

→ Improved internal radon correction

→ Internal calibration of individual counter efficiencies*

→ Neural network pulse shape analysis*

* in progress

Principal goals

1. separation of pp and ^{7}Be fluxes
2. significant exploration of presence or absence of time variations (D/N; seasonal; solar parameters,..)
3. CC/NC ratio for bulk solar flux

What must be done ?

1. Error reduction - statistical
2. Error reduction - systematic
3. Error reduction - cross section

GNO

(a) Statistical errors:

Continue measurements for full solar cycle *[ongoing]*

increase target mass ($ € or joining existing Ga experiments) *[pursued]*

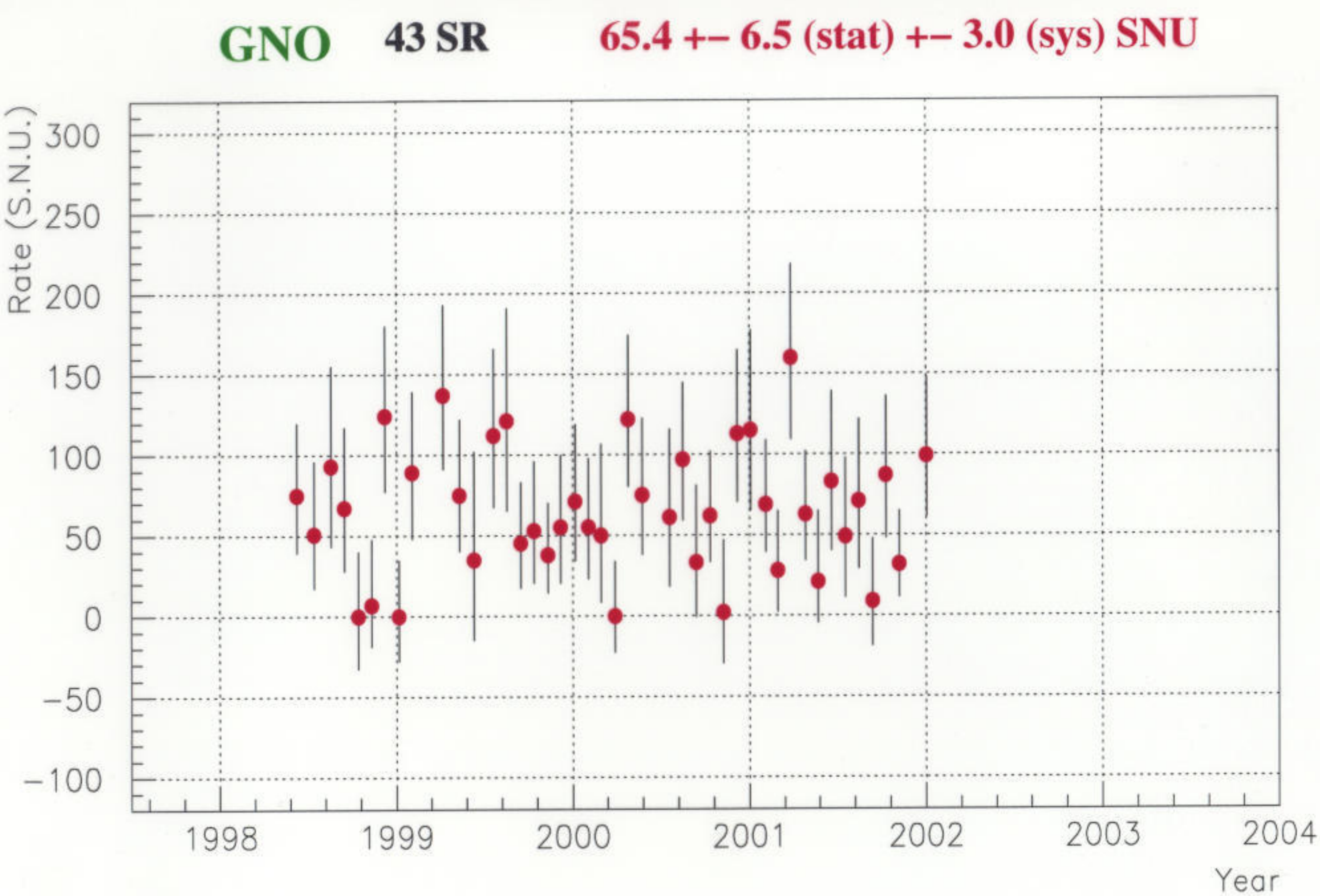
(b) Systematical errors:

Reduce counter efficiency errors by new ('more daring') procedures *[ongoing]* **and/or by new counting concepts** *[R&D ongoing].*

note: little gain is expected from further counter background improvement because the latter can not get negative

(c) Production cross section errors:

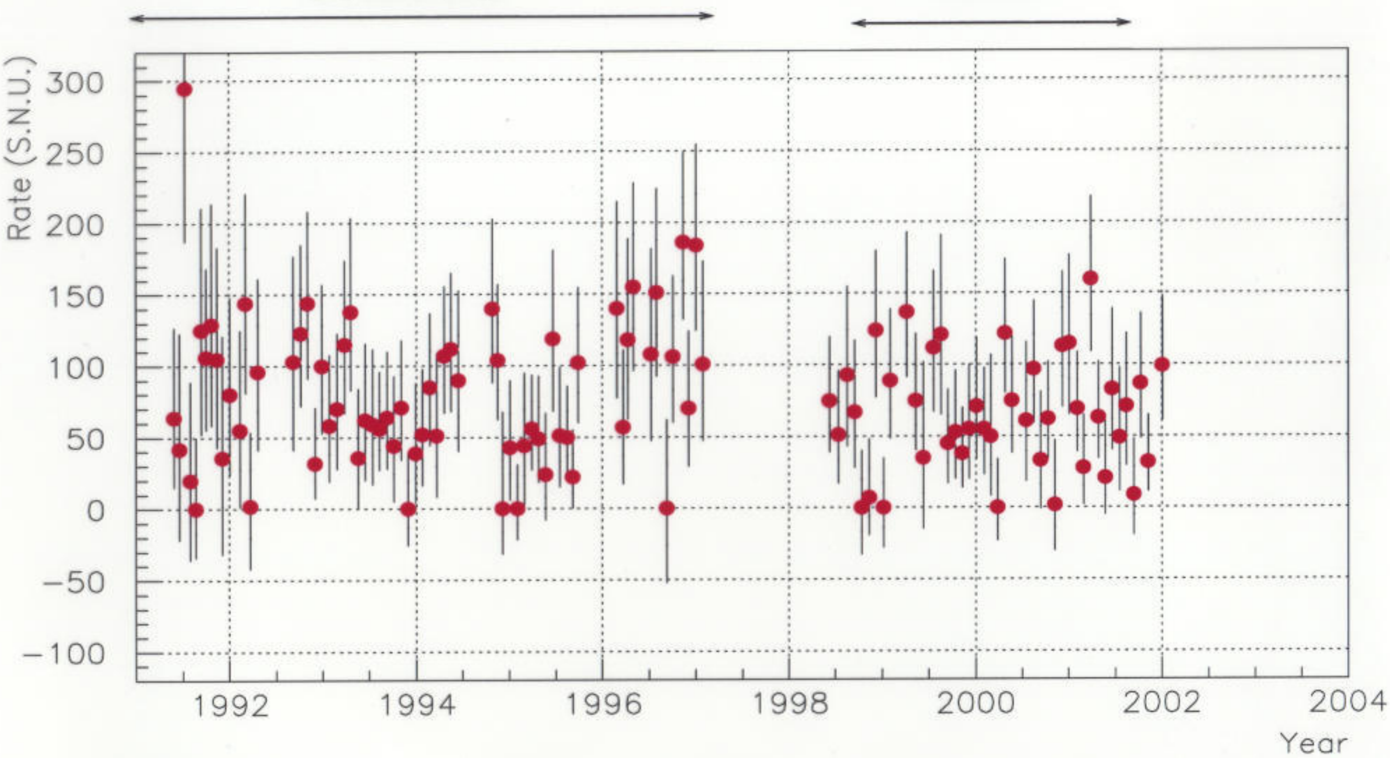
Advanced MCi neutrino source exposure for more precise determination of excited state contributions *[ongoing]*


GNO
43 SR
65.4 +- 6.5 (stat) +- 3.0 (sys) SNU
Rate (S.N.U.)
300
250
200
150
100
50
0
−50
−100
1998
1999
2000
2001
2002
2003
2004
Year

Neutrino 2002

Energy–RT analysis
GALLEX

Energy–PS/NN analysis
GNO

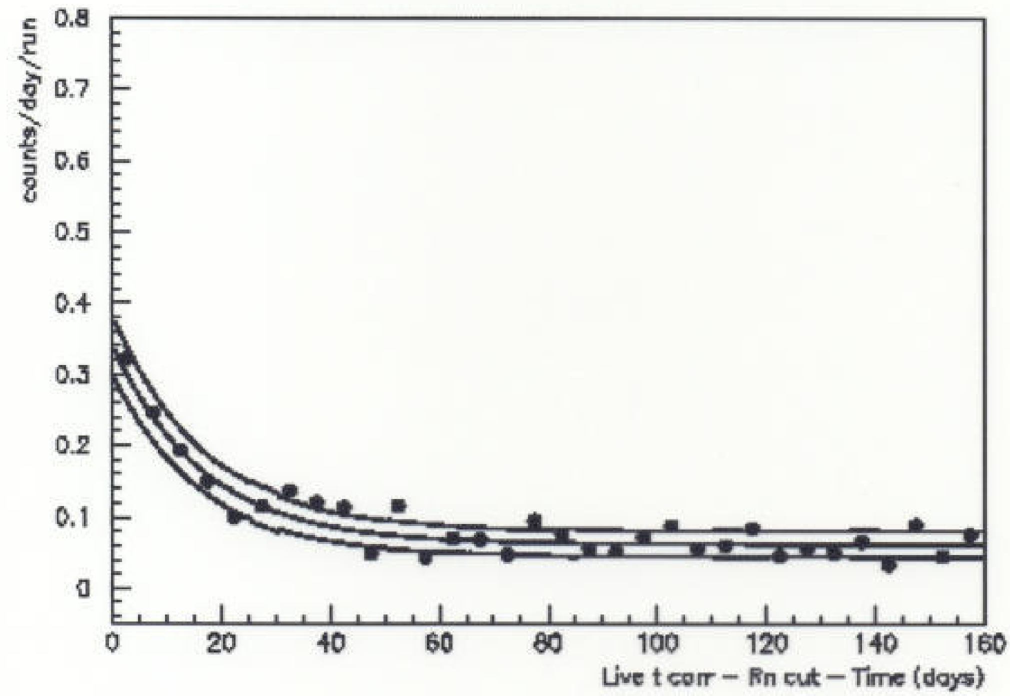


GALLEX	**65 SR**	**77.5 +– 6.2 (stat) +– 4.5 (sys) SNU**
GNO	**43 SR**	**65.2 +– 6.4 (stat) +– 3.0 (sys) SNU**
GNO+GALLEX	**108 SR**	**70.8 +– 4.5 (stat) +– 3.8 (sys) SNU**

43 GNO Runs

$^{71}\tau = 16.7 \pm 3$ d

($^{71}\tau_{true} = 16.49$ d)

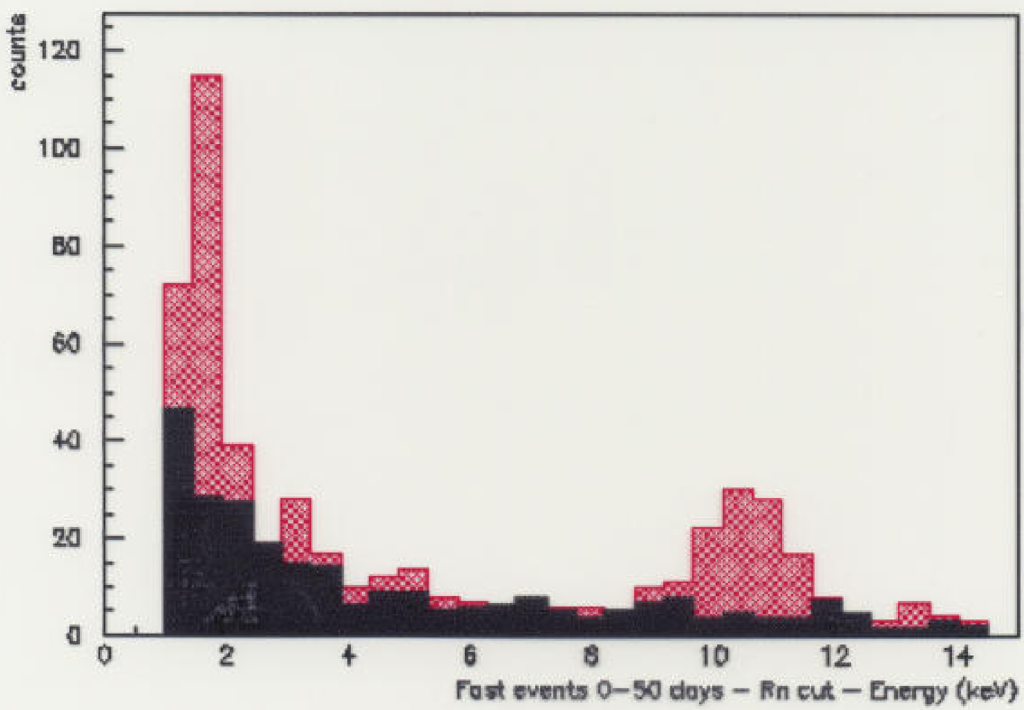


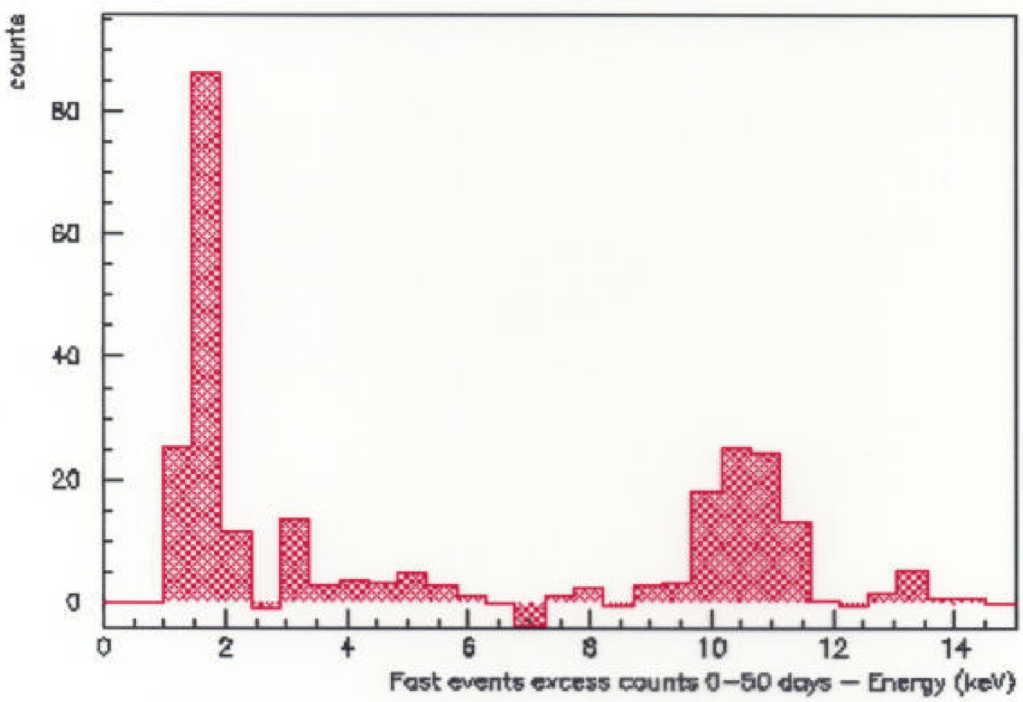
GNO

fast events occuring at t < 50 days

fast events occuring at t > 50 days

(50 d ≈ 3 τ)





L_{only} : 69.6 ± 10.3 SNU

K_{only} : 62.2 ± 8.2 SNU

L+K : 65.2 ± 7.1 SNU (N.N.)

L+K : 69.4 ± 7.1 SNU (R.T.)

GNO II Blank Runs

Why Blank Runs?
To check each 3 month the proper functionality of the whole setup (no tailig effect,background from isotopes other than ^{71}Ge, ecc)

Run lable	Start exp. End exp.	Exp Time [d]	Chem Yield [%]	Counting [d]	*Excs Cnts*	*Bckg Cnts 160 d*
A023	12-01/13-01-00	27	91.2	165	1.4	8.6
A027	5-04 / 6-04-00	28	94.8	166	0.0	15.0
A031	28-06 / 29-06-00	28	97.7	164	0.0	11.0
A035	20-09 / 21-09-00	27	94.7	166	1.7	5.3
A039	12-12/13-12-00	28	93.0	165	1.3	8.7
A043	7-03/8-03-01	28	98.1	166	0.7	9.3
					3.7	59.3
				Average per run	0.85 ± 0.73	9.65 ± 3.2

NN pulse shape

Summary of systematic errors in GNO (SR1 – SR43)

Neutrino 2002

ITEM	GNO	GLX	GNO+ GLX
Target size	0.8 %	0.8 %	
Chemical yield	2.0 %	2.0 %	
Energy cuts	2.9 %	4.0 %	
Pulse shape cuts	1.3 %(NN)	2.0 %	
ev. sel. (others)	0.6 %	0.3 %	
Subtotal	4.0 %	5.0 %	4.6 %
Side react.	1.2 snu	1.2 snu	
Rn cut ineff.	0.8 snu	1.2 snu	
68Ge	–	+0.7 snu +2.0 snu	
Subtotal	1.4 snu	+1.8 snu −2.6 snu	1.9 snu

	GNO	GLX	GNO+GLX
Rate (SNU)	**65.2**	**77.5**	**70.8**
stat. err. (SNU)	**6.4**	**6.2**	**4.5**
sys err. (SNU)	**3.0**	**4.5**	**3.8**
Tot err. (SNU)	**7.1**	**7.6**	**5.9**
Tot err. (%)	**10.9**	**9.8**	**8.2**
# of solar runs	43	65	108

GNO main results

→ High performance duty cycle now for 3.7 years

→ Substantial reduction of systematic error to 4.6%

→ 14 GNO Blank runs, zero-compatible

→ Result from 43 runs (from 5/98 through 1/02) is

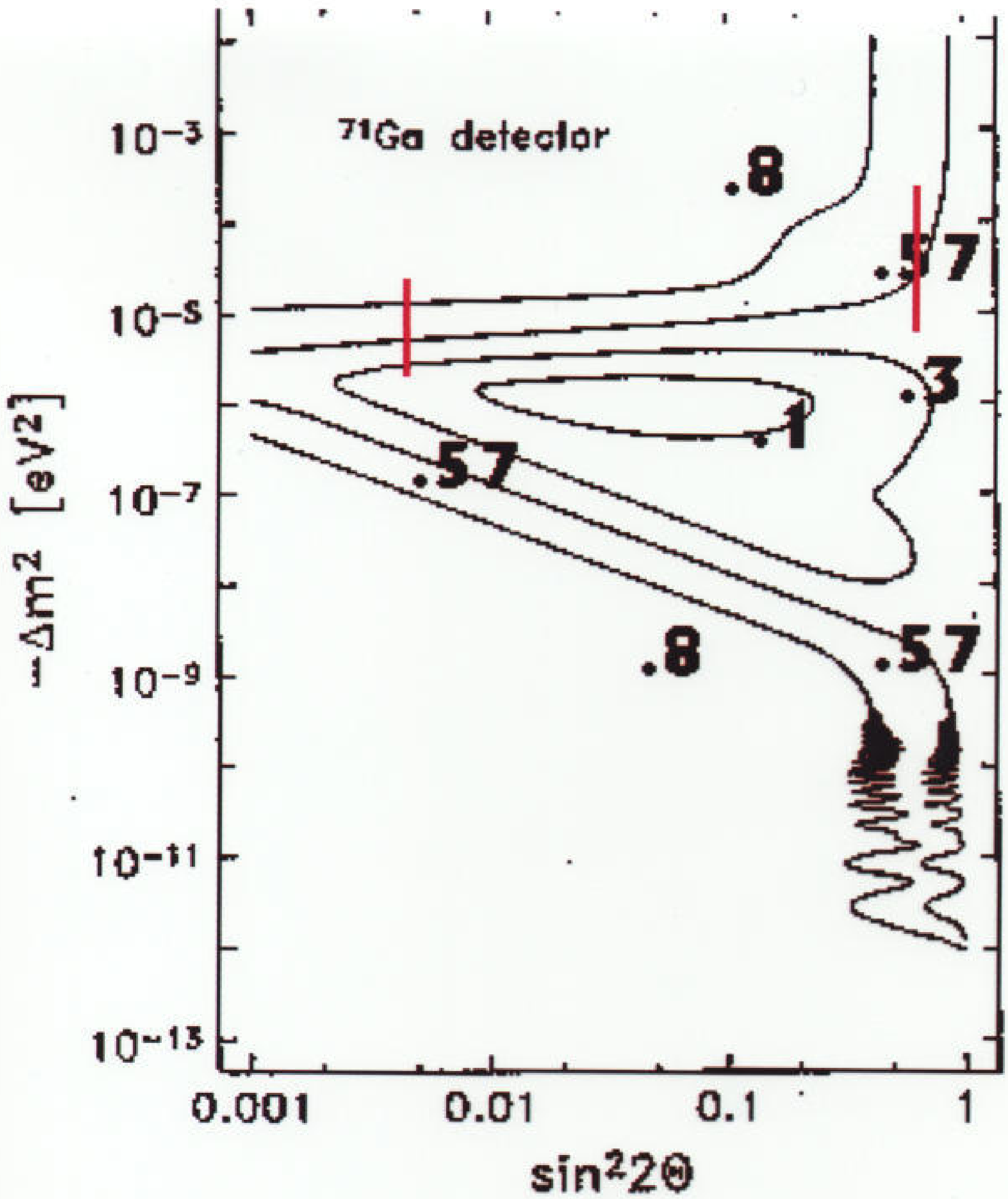
$65.4 \pm 6.5_{st} \pm 3.0_{syst}$ or 65 ± 7 SNU

GALLEX + GNO combined (108 runs)

$70.8 \pm 4.5_{st} \pm 3.8_{syst}$ or **71 ± 6 SNU**

→ No seasonal variation:

Winter - Summer = -11 ± 9 SNU



depression factor = .57

Future Plans in GNO

→ Further reduction of systematic error to 3% within 2 years (completion of internal counter calibrations and implementation of neural network analysis). Later: new cryogenic ^{71}Ge detection (efficiency gain up to 35%).

→ continued exploration of joining Gallium from Sage and GNO in one experiment: potential for 100 t Ga experiment, for a statistical error of $\pm$ 4 SNU

→ New 3 MCi ^{51}Cr source experiment for cross section determination to $\pm$ 5% rem: Gallex result: (89 $\pm$ 7)% .
(this is a true cross section due to the results from the Gallex ^{71}As experiment (chemical recovery 100 $\pm$ 1 %)

Allows also a model independent proof of non-standard neutrinos from Gallium alone (exclusion of 'minimal' model, $\approx$ 90 SNU [2σ])

New GNO Calibration 2002/2003

^{51}Cr Source Production at RIAR,
2.5 – 3 MCi
from 11 kg Cr (38% ^{50}Cr)

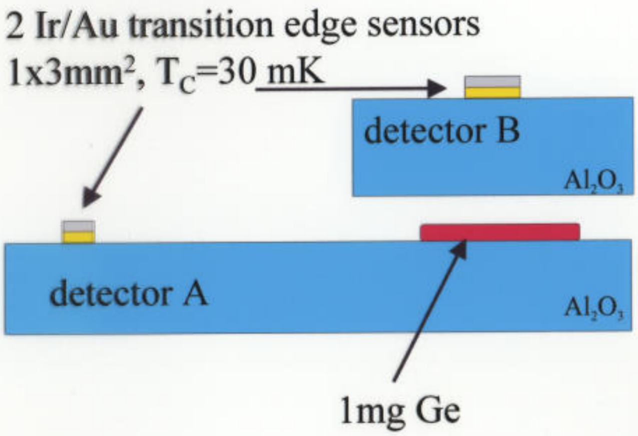
Determination of absolute cross section with error ≤ 5 %
Important for splitting of GNO signal in pp – and ^{7}Be - contributions

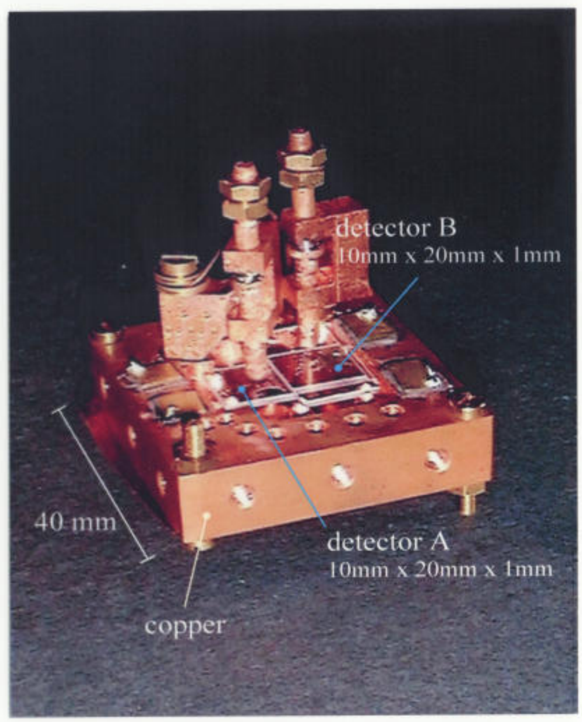
→ **A 'real' calibration**

→ a stepping stone for a full LNGS neutrino source program

→ also a check of 'ageing' of the target after 7 years of operation

Cryogenic detectors for GNO





- 4π-efficient setup with 2 absorbers
- counting efficiency 98%
- deposition by CVD: $GeH_4 \rightarrow Ge + 2H_2$
- deposition efficiency ~ 95% in 3h

Status of cryo-GNO

- detector geometry for 4π absorption ✓
- Ge deposition (compatibility with the existing chemistry) ✓
- determination of the deposition efficiency on a 1% level ✓
- detailed understanding of spectra ✓
- decoupling of fabrication and Ge deposition ✓ ✓

- long-term stability of cryostat
- background investigations, detector shielding, material selection
- long-term operation of detector system

ongoing activity