The SAGE Collaboration

Measurement of the Solar Neutrino Capture Rate by the Russian-American Gallium Solar Neutrino Experiment During One Half of the 22-Year Cycle of Solar Activity

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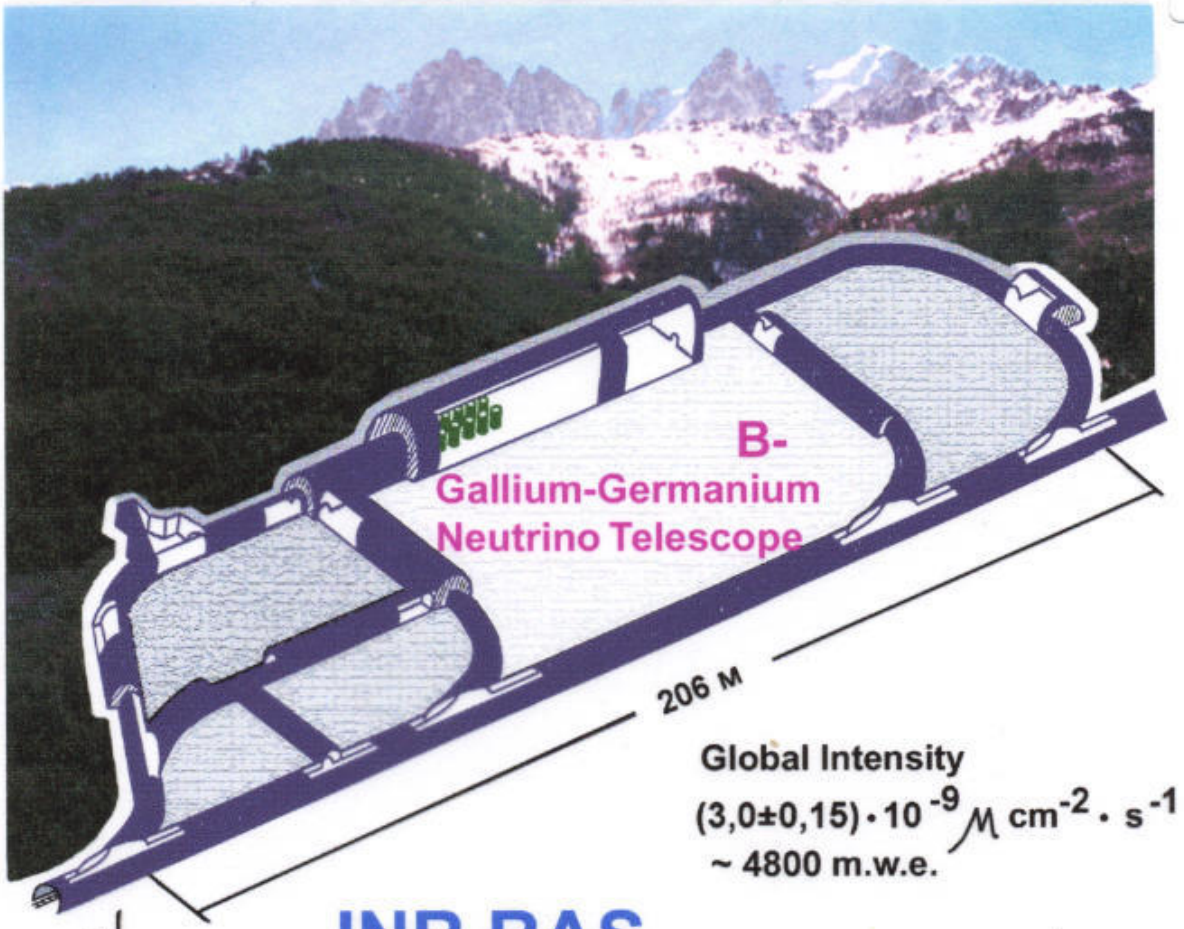
J.N.Abdurashitov et al (SAGE collaboration) "Measurement of the solar neutrino capture rate with gallium metal", Phys.Rev.C 60, 055801 (1999).

V.N.Gavrin, V.V.Gorbachev, and I.N.Mirmov "Effect of Radon on SAGE Results", Physics of Atomic Nuclei, V. 65, No. 5, 2002, p. 843.

B.T.Cleveland, V.N.Gavrin, V.V.Gorbachev, T.V.Ibragimova "The Germanium Isotopes Rate in Background Processes in Experiment SAGE", submited to Zh. "Yadernya Fizika" (2001).

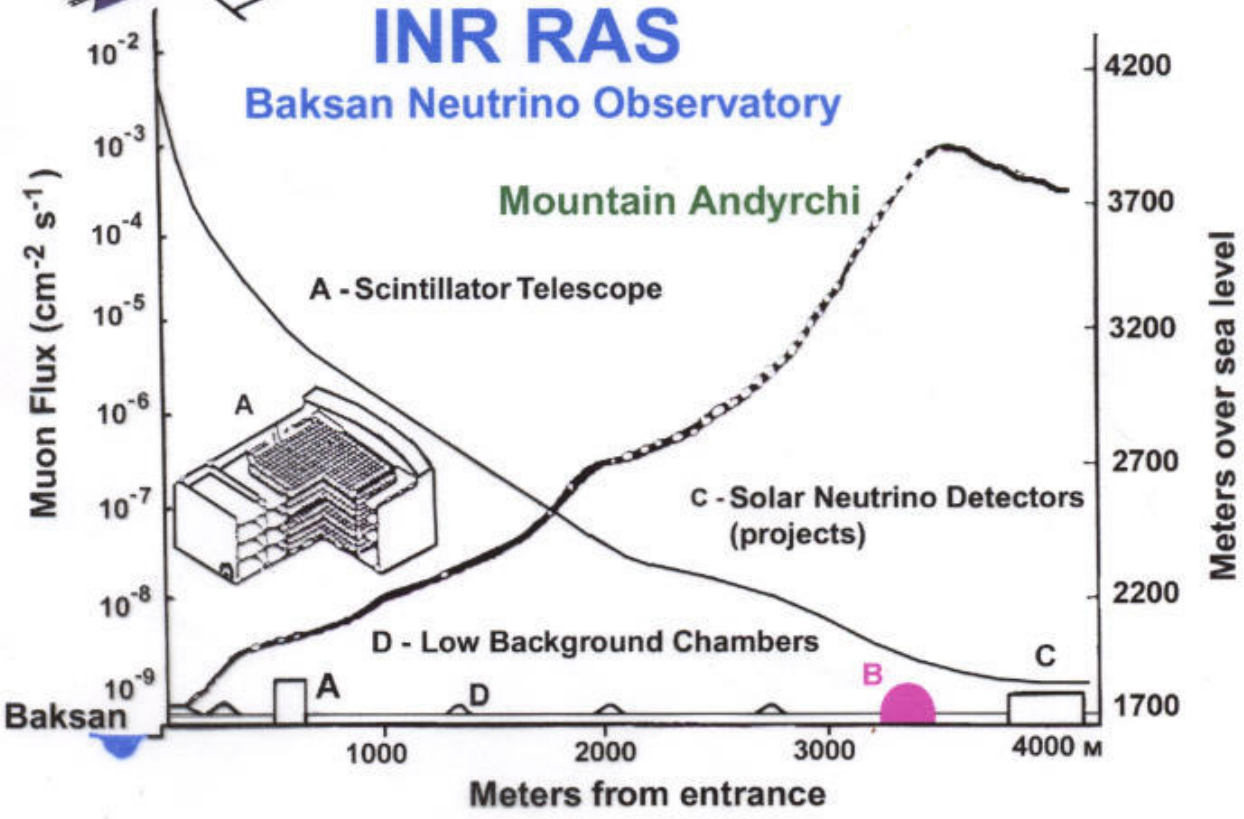
V.N.Gavrin and V.V.Gorbachev "Background of external gamma-irradiation in Proportional Counters in Experiment SAGE", submited to Zh. "Yadernya Fizika" (2001).



Global Intensity
$(3,0\pm0,15)\cdot10^{-9}$ м $cm^{-2}\cdot s^{-1}$
~ 4800 m.w.e.

INR RAS

Baksan Neutrino Observatory

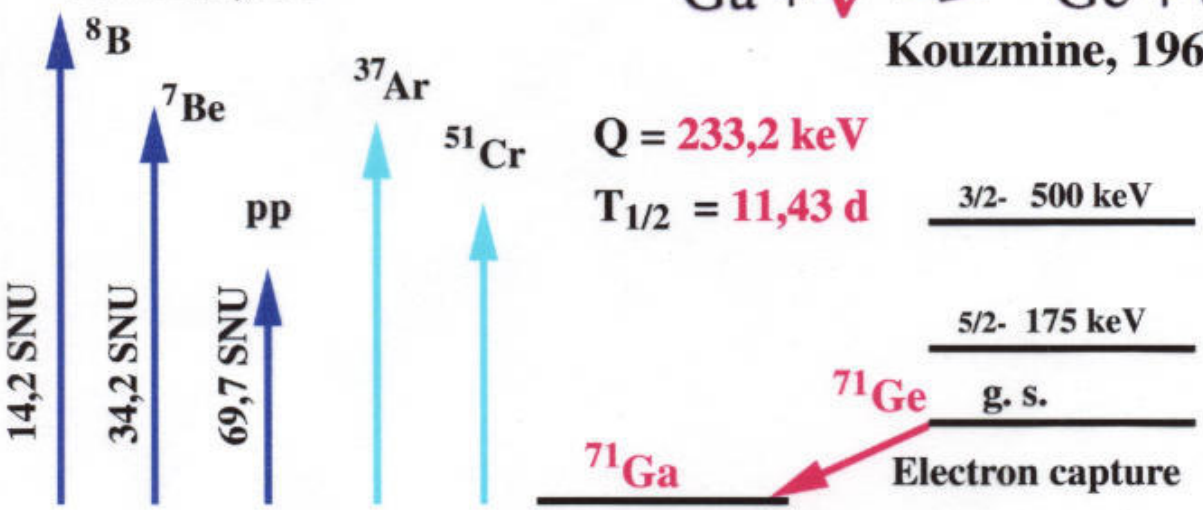


SAGE Experiment Overview

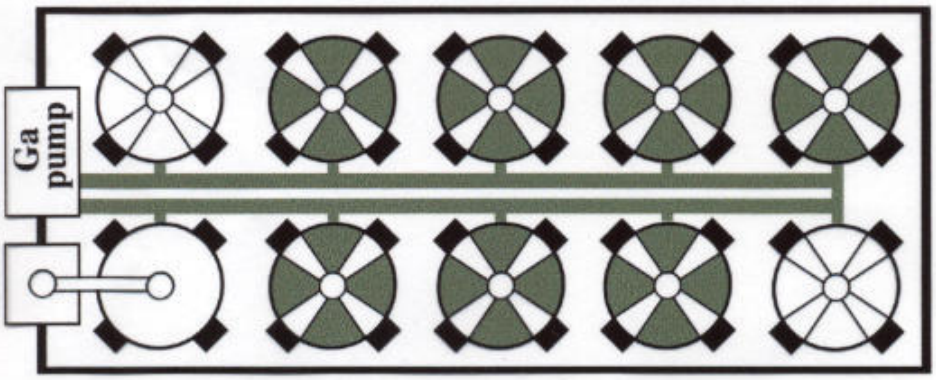
Bahcall, etc

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

Kouzmine, 1965



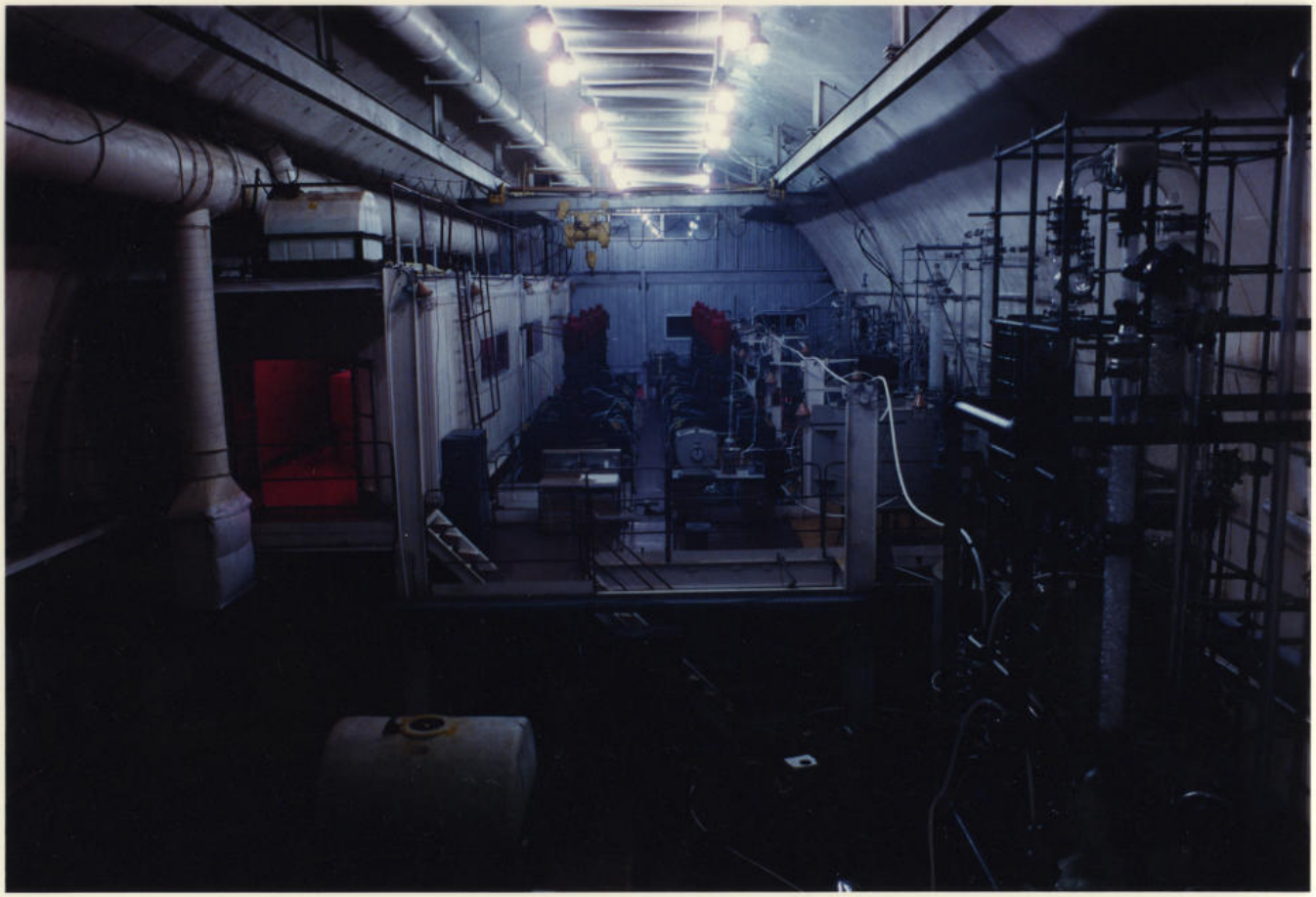
A plan view of the reactors layout in the laboratory



$t_{reac} \geq 30^{o}C$
$t_{melt} = 29.8^{o}C$

~7 tons metallic Ga in each

* 250 mkg Ge-76/72 carrier uniformly between reactors
* Exposure time ~ 27 d
* ^{71}Ge chemical extraction from metallic Ga to aqueous solution ~ 1.5 m^3
* Concentration of Ge to 50 ccm trithium free water
* Synthesis of germane - GeH_4
* Counting of Ge decays



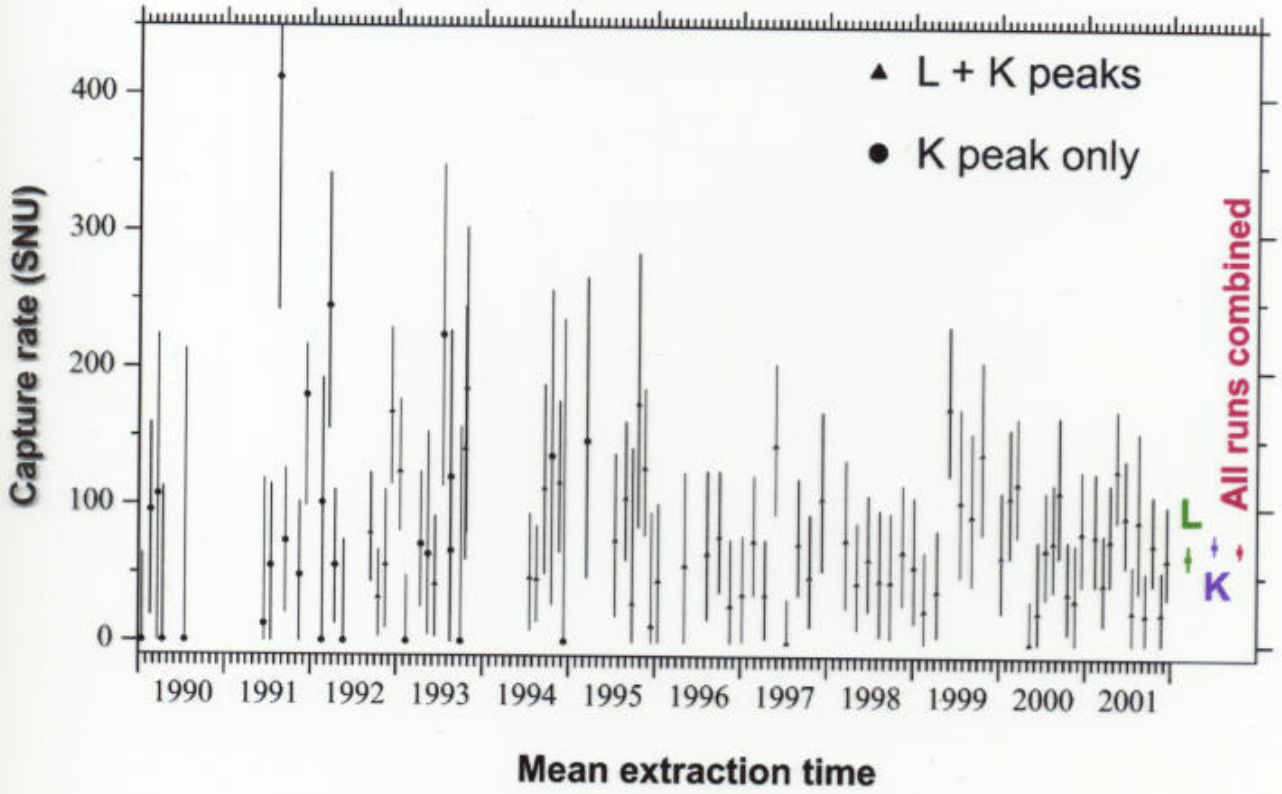
13A · 1K

Results of combined analysis of K-peak and L-peak events for all runs after 1997

Ext Name	N cts	N 71Ge	Best fit (SNU)	68%C.L. SNU	Nw^2	GOF %
Apr.98	39	5.4	75	26-134	0.052	72
May 98	23	3.4	44	10-88	0.051	68
Jul.98	22	4.8	61	24-108	0.065	52
Aug.98	33	3.6	46	5-97	0.039	84
Oct.98	40	3.8	45	4-95	0.028	95
Nov.98	32	5.9	67	28-116	0.101	30
Jan.99	21	4.5	56	15-107	0.036	84
Feb.99	16	1.6	24	0-67	0.114	28
Apr.99	10	1.8	38	5-83	0.105	36
Jun.99	14	12.9	172	123-232	0.048	80
Jul.99	17	5.5	103	49-172	0.118	20
Sep.99	20	7.1	93	43-154	0.099	28
Oct.99	16	10.0	138	80-206	0.066	56
Jan.00	24	5.4	63	23-111	0.060	59
Feb.00	21	9.1	107	63-157	0.058	55
Mar.00	19	10.1	117	78-165	0.046	79
May 00	15	0.0	0	0-32	0.143	40
Jun.00	17	1.4	23	0-75	0.179	17
Jul.00	29	6.4	69	33-111	0.088	34
Aug.00	14	5.2	74	39-117	0.086	33
Sep.00	30	9.2	111	64-166	0.093	24
Oct.00	14	3.0	37	8-75	0.020	99
Nov.00	25	2.9	32	0-73	0.208	9
Dec.00	27	7.6	81	43-127	0.062	68
Feb.01	21	6.3	79	43-125	0.088	34
Mar.01	18	3.8	44	14-80	0.120	24
Apr.01	17	6.7	76	43-117	0.074	45
May 01	21	11.9	127	90-171	0.088	31
Jun.01	20	9.4	93	57-135	0.025	96
Jul.01	9	2.0	24	0-58	0.033	92
Aug.01	21	5.4	90	38-155	0.065	57
Sep.01	10	2.1	22	0-53	0.139	18
Oct.01	12	8.1	79	51-115	0.071	50
Nov.01	15	4.2	37	13-69	0.115	20
Dec.01	9	3.8	44	17-79	0.087	44
Combined	727	192.3	67	60-74	0.076	40

SAGE

January 1990 - December 2001



Combined result:

L-peak - 64.8 +8.5/-8.2 SNU
K-peak - 74.4 +6.8/-6.6 SNU

Overall - 70.8 +5.3/-5.2 SNU

1 SNU = 1 interaction of ν_e /sec in 10^{36} atoms/day


SAGE
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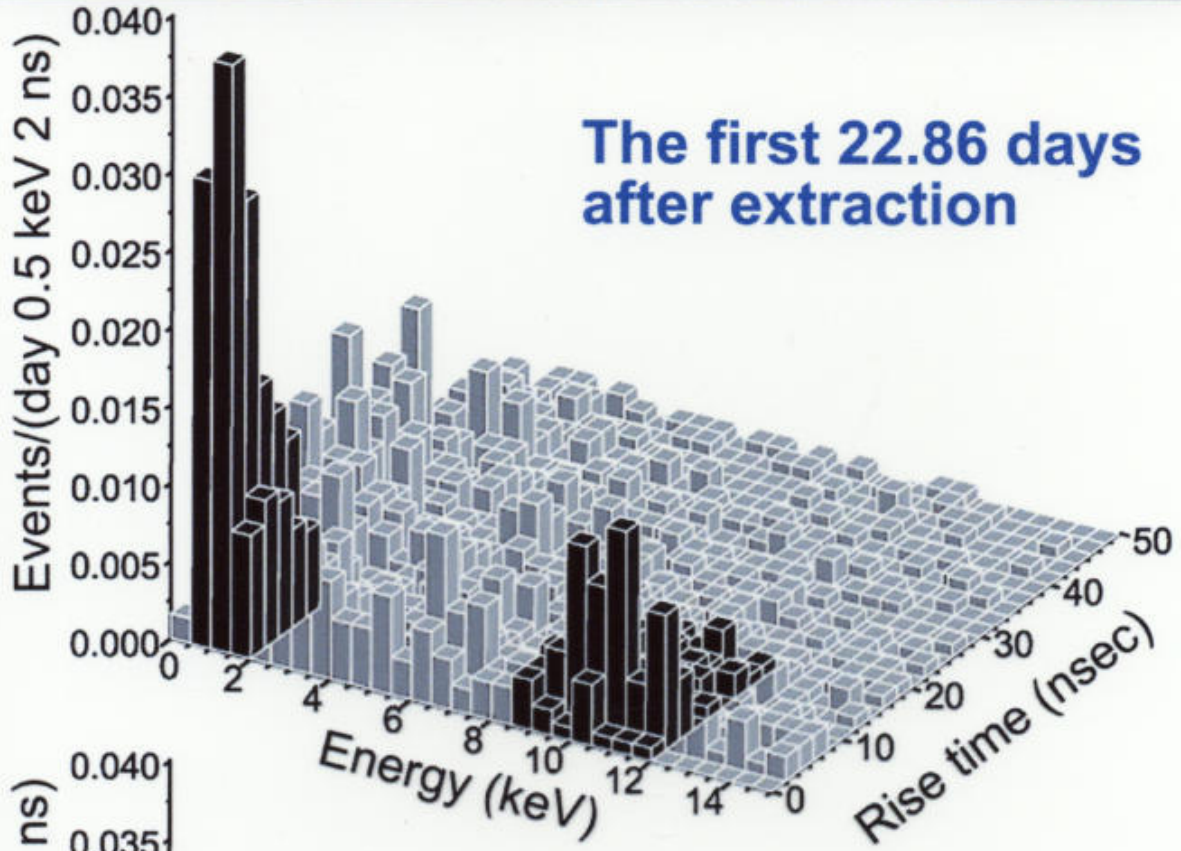
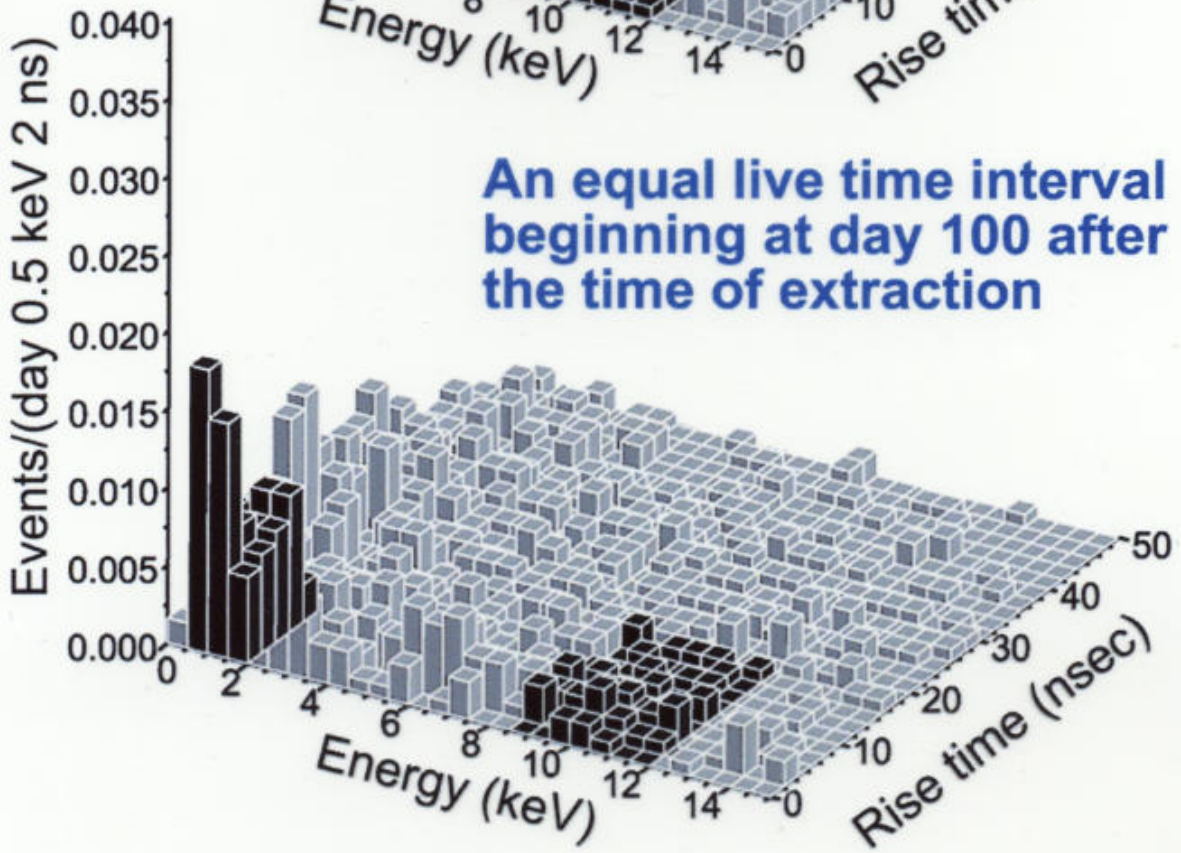

The first 22.86 days after extraction
Events/(day 0.5 keV 2 ns)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
2
4
6
8
10
12
14
Energy (keV)
0
10
20
30
40
50
Rise time (nsec)


An equal live time interval beginning at day 100 after the time of extraction
Events/(day 0.5 keV 2 ns)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
2
4
6
8
10
12
14
Energy (keV)
0
10
20
30
40
50
Rise time (nsec)

Summary of systematic effects and their uncertainties in SNU.

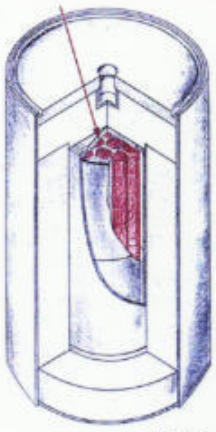
(The values for extraction and counting efficiencies are based on a rate of 70.8 SNU.)

Extraction efficiency	Ge carrier mass	±1.5
	Extracted Ge mass	±1.8
	Residual carrier Ge	±0.6
	Ga mass	±0.2
Counting efficiency	Counter effects	±1.3
	Gain shifts	+2.2
	Resolution	-0.4,+0.5
	Rise time limits	±0.7
	Lead and exposure times	±0.6
Backgrounds	Neutrons	<-0.02
	U and Th	<-0.7
	muons	<-0.7
	Internal radon	<-0.2
	External radon	0.0
	Other Ge isotopes	<-0.7
Total		**-3.2,+3.7**

^{51}Cr neutrino source experiment

Source strength
517 kCi

Chromium rods



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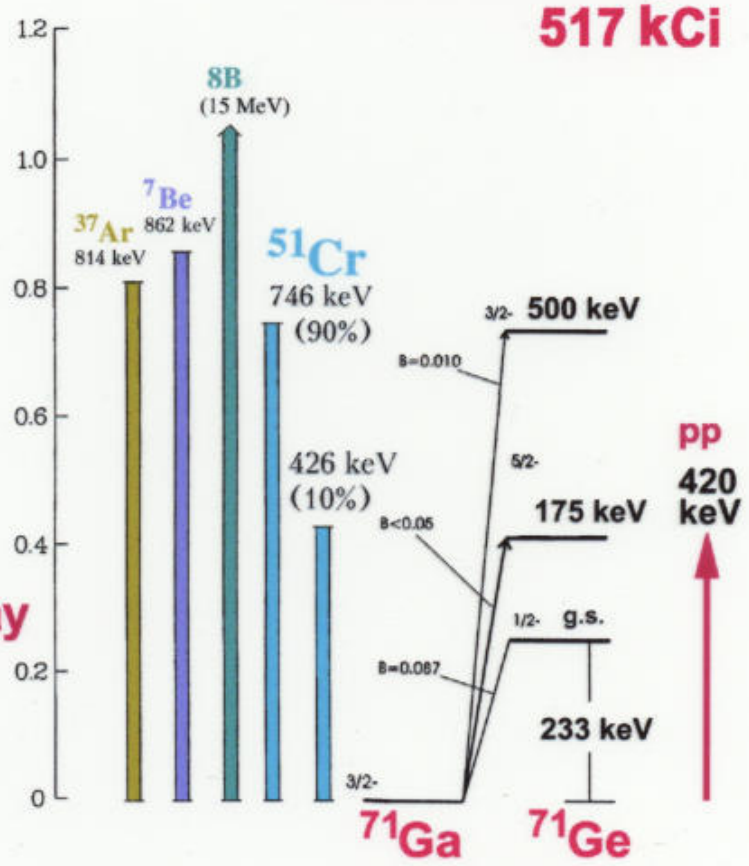

q_{exp} = 14.0 at/day

50 times higher,
than from the Sun

$$R = q_{exp.} / q_{pred.}$$

0.95 +/- 0.12 (exp.) +0.035/-0.027 (theor.)


SAGE
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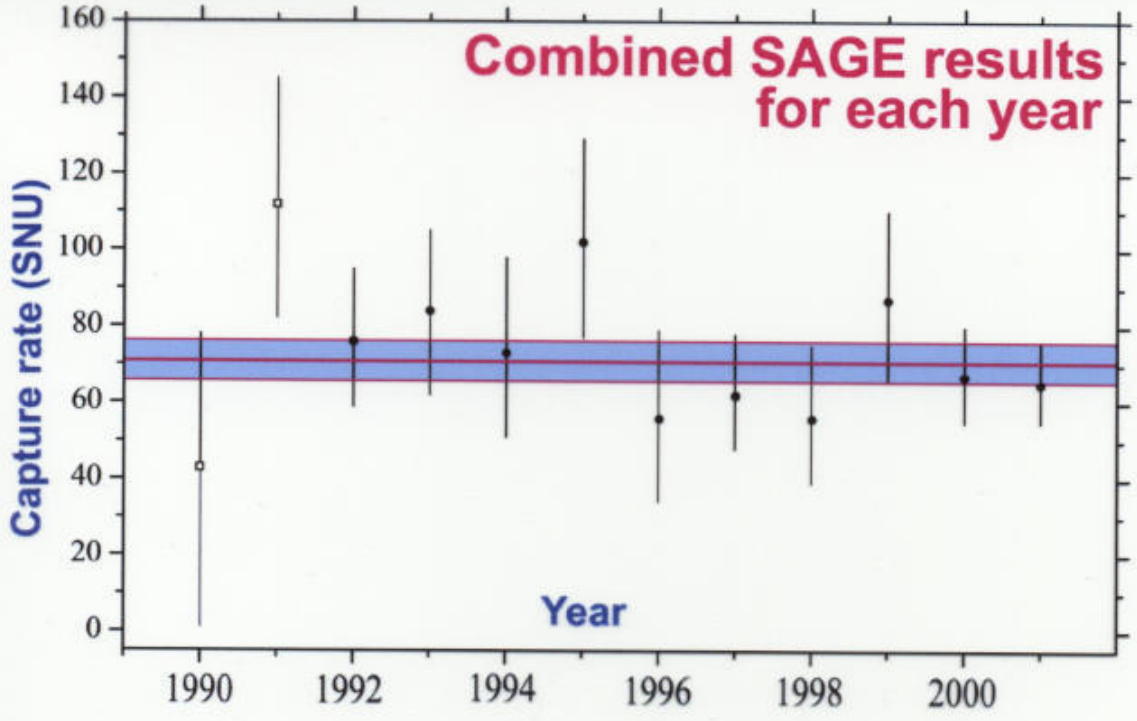
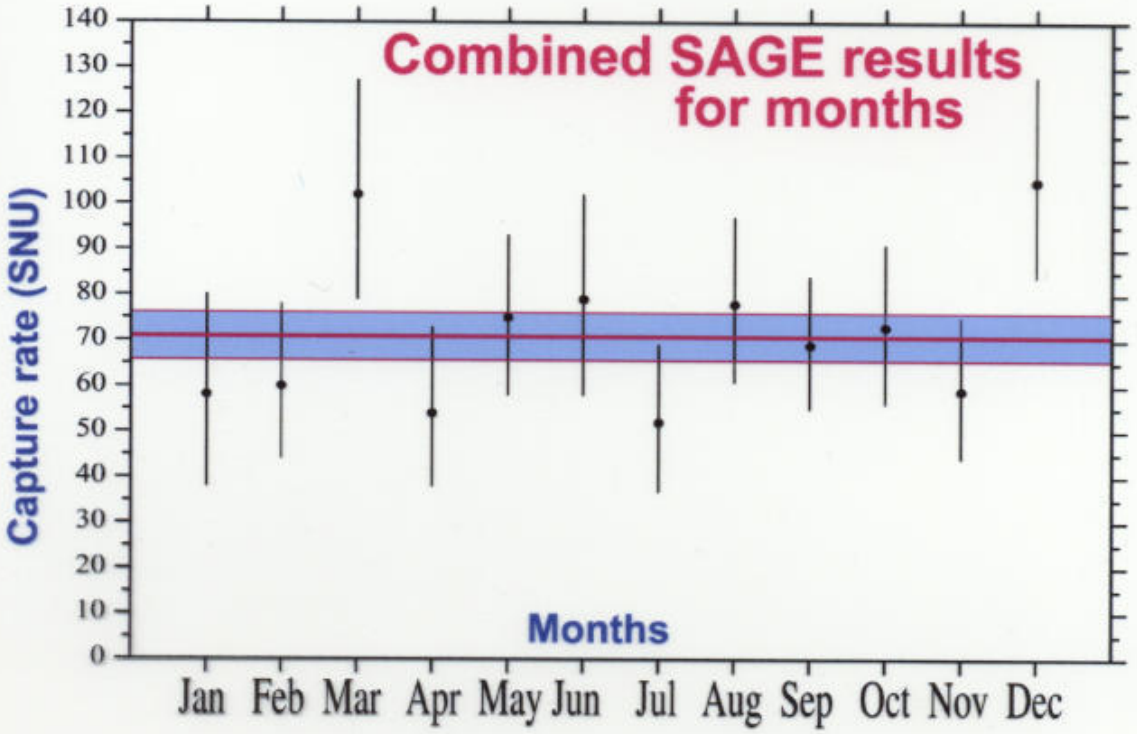
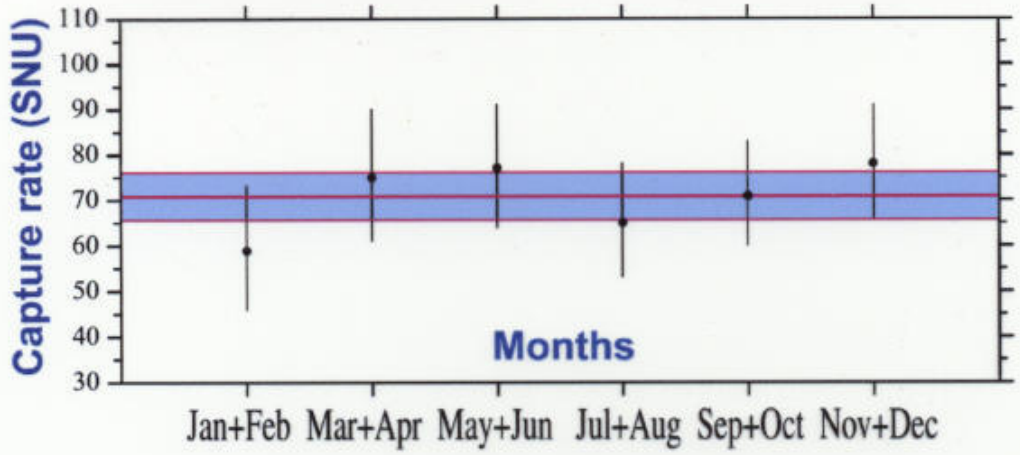
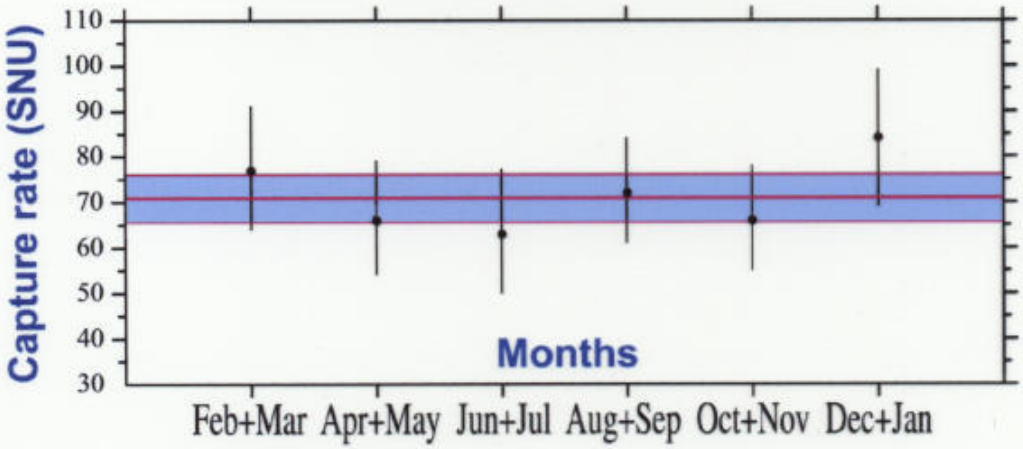
Neutrino' 2002
V.Gavrin

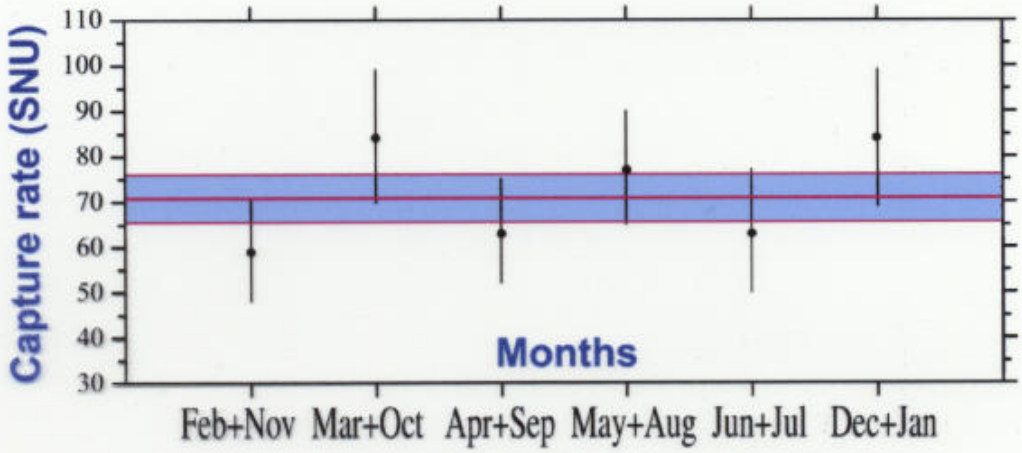

Combined SAGE results
for each year
Capture rate (SNU)
Year
160
140
120
100
80
60
40
20
0
1990
1992
1994
1996
1998
2000


Combined SAGE results
for months
Capture rate (SNU)
Months
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Two months combinations







SAGE Results

12-year period

January 1990 – December 2001

92 runs, 158 separate counting sets
Total counting live time – 29.5 years

In the L- and K- peaks – 1723 counts
with 406.4 assigned by time analysis to ^{71}Ge

L-peak – 64.8 +8.5/-8.2 SNU
K-peak – 74.4 +6.8/-6.6 SNU
Overall – 70.8 +5.3/-5.2 +3.7/-3.2 SNU
or

70.8 +6.5/-6.1 SNU

$Nw^2 = 0.053$
Probability = 72.0 ± 4 %

pre-SNO second presentation

submitted to ZhETP 02.15.2002
on the LANL archives
astro-ph/0204245 04.15.2002

PP NEUTRINO FLUX

simple analyses

- **SAGE, GALLEX + GNO**

  $[pp + {}^{7}Be + CNO + pep + {}^{8}B|Ga, exp] = 72 \pm 5$ SNU

- **Cl - Ar**

  $[{}^{7}Be + CNO + pep + {}^{8}B|Cl, exp] = 2.56 \pm 0.23$ SNU

- **SNO**

  Φ_{ve} , $E > 5.5$ MeV

  $[{}^{8}B|SNO, exp] = (1.75 \pm 0.15) \cdot 10^{6}$ ν_e/cm^2 sec

- **SSM**

  above 5 MeV shape of ^{8}B spectrum SNO ≈ SK ≈ SSM

  σ_{Ga}, σ_{Cl} is dominated by ν_e above 5 MeV

  σ_{Ga} (SSM) = $(2.4 \ {}^{+0.77}_{-0.36} \cdot 10^{-42})$ cm^2

  σ_{Cl} (SSM) = $(1.14 \ {}^{+0.04}_{-0.04} \cdot 10^{-42})$ cm^2

PP NEUTRINO FLUX

simple analyses

$[^8B|Ga, exp] = 4.2.\ +1.4/-0.7$ SNU

$[^8B|Cl, exp] = 2.00 \pm 0.18$ SNU

$[pp + {}^7Be + CNO + pep|Ga, exp] = 67.8\ +5.1/-5.2$ SNU

$[{}^7Be + CNO + pep|Cl, exp] = 0.56 \pm 0.29$ SNU

$[{}^7Be + CNO + pep|Cl, SSM] = 1.79 \pm 0.23$ SNU

Assuming neutrinos oscillate and their survival factor P_{ee} varies slowly with E_ν ,

$P_{ee} = (0.56 \pm 0.29)/(1.79 \pm 0.23) = 0.31 \pm 0.17$

${}^7Be \sim 64\%$; CNO + pep $\sim 36\%$;

$P_{ee} = 0.31 \pm 0.17 \pm (0.31 \cdot 0.36) = 0.31 \pm 0.28$

$E_m^{Cl} = 0.31 \pm 0.28$, $E_m^{Ga} = E_m^{Cl}$ (no oscillation models)

$$[pp|Ga, exp] = 53 \pm 14 \text{ SNU}$$

$$\sigma_{Ga}\ (0.23 - 0.42) = (11.7 \pm 0.3) \cdot 10^{-46}\ cm^2$$

$$\Phi_{pp}^{exp}(\oplus) = (4.6 \pm 1.2) \cdot 10^{10}/cm^2\ sec$$

PP NEUTRINO FLUX

simple analyses

The rate of pp neutrino emission in the solar fusion reaction with survival factor 0.6 (favored LMA solution):

$$\Phi_{pp}^{exp}(\odot) = (7.6 \pm 2.0) \cdot 10^{10} / \text{cm}^2 \text{ sec}$$

Comparison with SSM

$$f_{(SAGE)} = \frac{\Phi_{pp}^{exp}(\odot)}{\Phi_{pp}^{SSM}(\odot)} = 1.28\ (1 \pm 0.26)$$

post-SNO second presentation	J.N.Bahcall, M.C.Gonzalez-Garcia, C.Pena-Garay archiv: ph/0204194 v2 05.09.2002

$$f_{(Bahcall)\ (all\ experiments)} = \frac{\Phi_{pp}^{exp}(\odot)}{\Phi_{pp}^{SSM}(\odot)} = 1.05\ (1 \pm 0.18)$$

After results from KamLAND and BOREXINO:

$$f_{(Bahcall(Ga/SNO/KamLAND/BOREXINO)} = 1.05\ (1 \pm 0.14)$$

↓

Error is dominated by uncertainty in Ga result; therefore need continuation Ga measurements