13-th Lomonosov conference
on elementary particle physics
Moscow, August 23-29,2007

BNO INR V.N. Gavrin

The Solar Neutrino Experiments

Solar Neutrinos Chronology

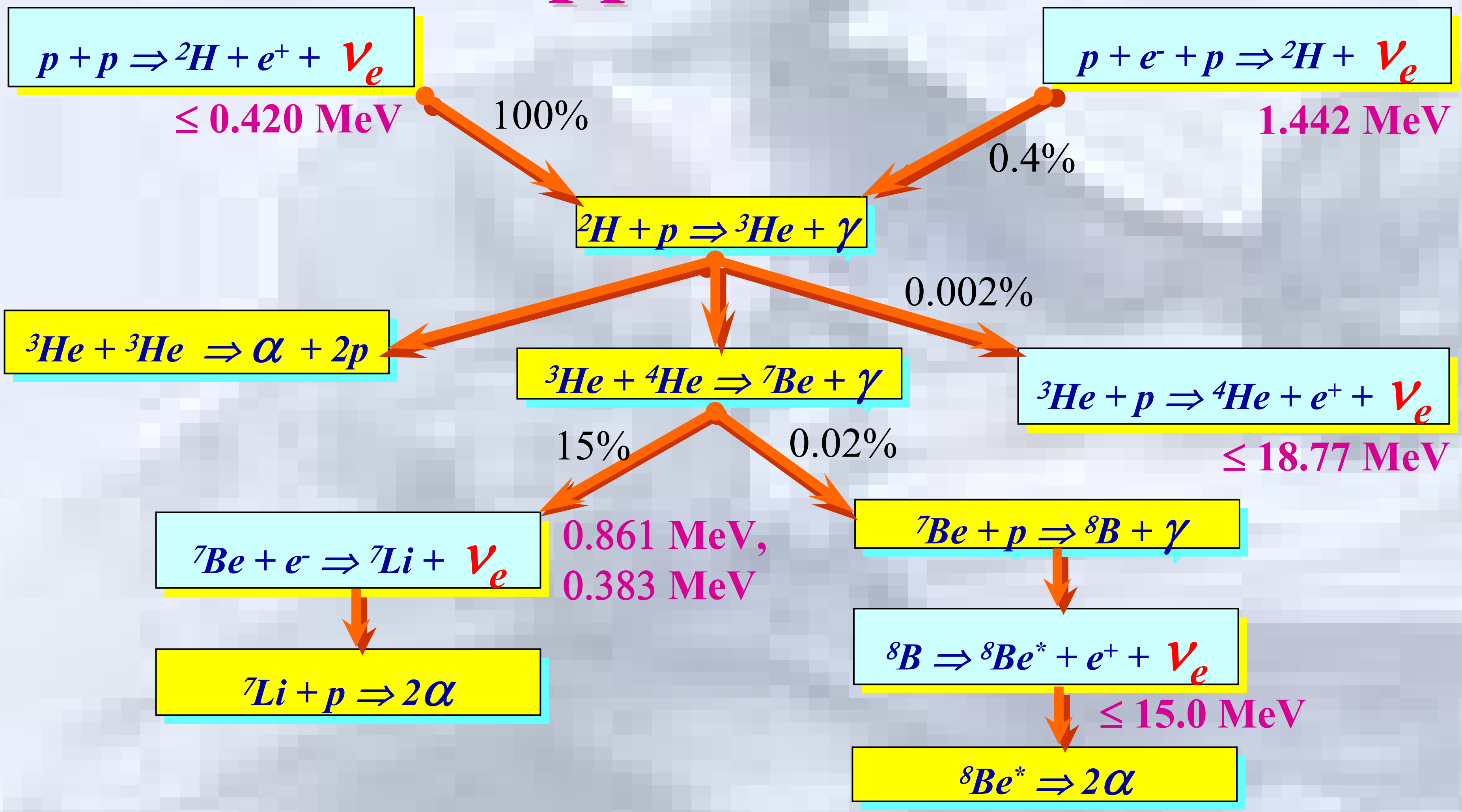
2008	SNO+
2007	Borexino
2006	KamLAND II for ^{7}Be ν
2005	Super-Kamiokande III (running)
2002	Super-Kamiokande II (2005)
2001	KamLAND I for $\bar{\nu}$ from nuclear reactors
1998	SNO (2006)
1997	GNO (2003)
1996	Super-Kamiokande I (2001)
1991	GALLEX (1997)
1990	SAGE (running)
1986	Kamiokande II (1995)
1985	*Mikheyev* and *Smirnov* develop theory or resonant oscillations
1970	*R. Davis* Cl-Ar experiment (1994)
1965	*V. Kuzmin* ^{71}Ga(ν,e^{-})^{71}Ge for ν from the Sun
1956	*F. Reines* and *C. Cowen* detect $\bar{\nu}$ from Savannah River reactor p($\bar{\nu}$,e^{+})n
1949	*L. Alvarez* considered Cl-Ar method of detecting ν and proposed an extended experiment of detecting the theoretically expected cross section for ν of 2×10^{-45} cm^2/atom
1946	*B. Pontecorvo* ^{37}Cl((ν,e^{-})^{37}Ar for ν discovery
1939	*H. Bethe* had postulated that the source of the sun's energy was fusion reactions in its core
1934	*E. Fermi* renamed Pauli's particle as the "neutrino" and had incorporated the particle into a theory of β-decay
1930	*W. Pauli* proposed the existence of a neutral particle of low mass

Solar Neutrinos

$4p \Rightarrow \alpha + 2e^{+} + 2\nu_e$

(Q = 26.731 MeV)

pp – chain



Solar Neutrinos

$$4p \Rightarrow \alpha + 2e^{+} + 2\nu_e$$

(Q = 26.731 MeV)

CNO cycle

$$p + {}^{12}C \Rightarrow {}^{13}N + \gamma$$

$${}^{13}N \Rightarrow {}^{13}C + e^{+} + \nu_e$$ 0.720 MeV

$$p + {}^{13}C \Rightarrow {}^{14}N + \gamma$$

$$p + {}^{14}N \Rightarrow {}^{15}O + \gamma$$

$${}^{15}O \Rightarrow {}^{15}N + e^{+} + \nu_e$$ $\leq$ 0.980 MeV

$$p + {}^{15}N \Rightarrow \alpha + {}^{12}C$$

The results of the seven solar neutrino experiments and comparison with predictions of the standard solar models

Facilities	$^{37}Cl \to ^{37}Ar$ (SNU)	$^{71}Ga \to ^{71}Ge$ (SNU)	^{8}B ν flux (10^6 $cm^{-2} \cdot s^{-1}$)
Homestake (CLEVELAND 98)	2.56±0.16±0.16	–	–
Kamiokande (FUKUDA 96)	–	–	2.80 ± 0.19 ± 0.33 †
SAGE (ABDURASHITOV02)	–	67.2+3.7/-3.6 +3.5/-3.2	–
GALLEX (HAMPEL 99)	–	77.5±6.2+4.3/-4.7	–
GNO (ALTMANN 00)	–	65.8+10.2/-9.6+3.4/-3.6	–
Super-Kamiokande (FUKUDA 02)	–	–	2.35 ± 0.03+0.07/-0.06 †
SNO (NaCl в D2O), 391days, PRC 72, 055502 (2005)	–	–	1.68 ± 0.086 ± 0.08 ‡ 2.35 ± 0.22 ± 0.15 † 4.94 ± 0.21 ± 0.36 *
(Bahcall 01)	7.60+1.3/-1.1	128 +9/-7	5.05(1.00+0.20/-0.16)
(Turck-Chieze 01)	7.44 ± 0.96	128 ± 8.6	4.95 ± 0.72

* - ϕ_{NC}, measurement of the flux via the NC.
†- ϕ_{ES}, measurement of the flux via the ES.
‡- ϕ_{CC}, measurement of the flux via the CC

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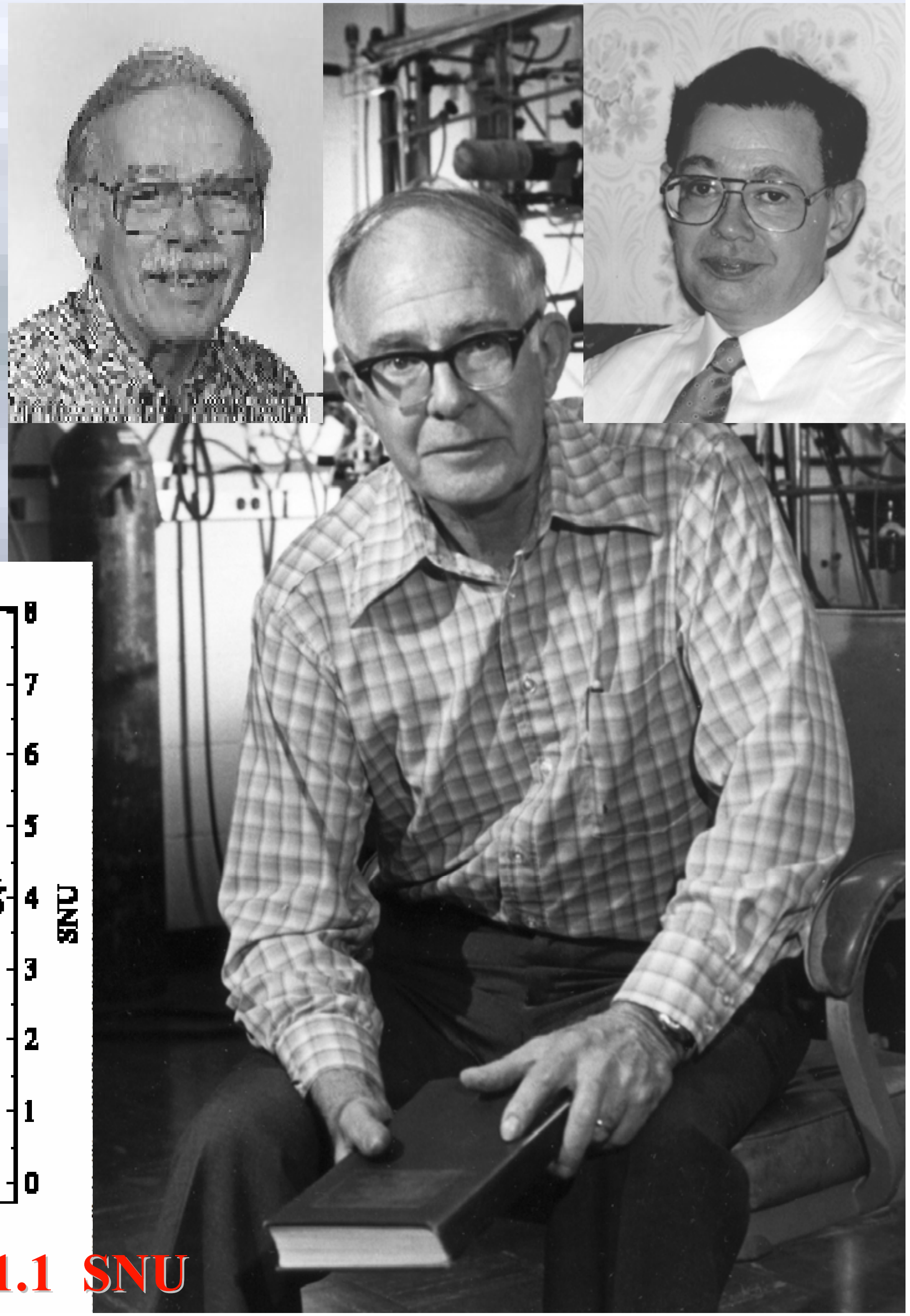
‡- ϕ_{CC}, measurement of the flux via the CC

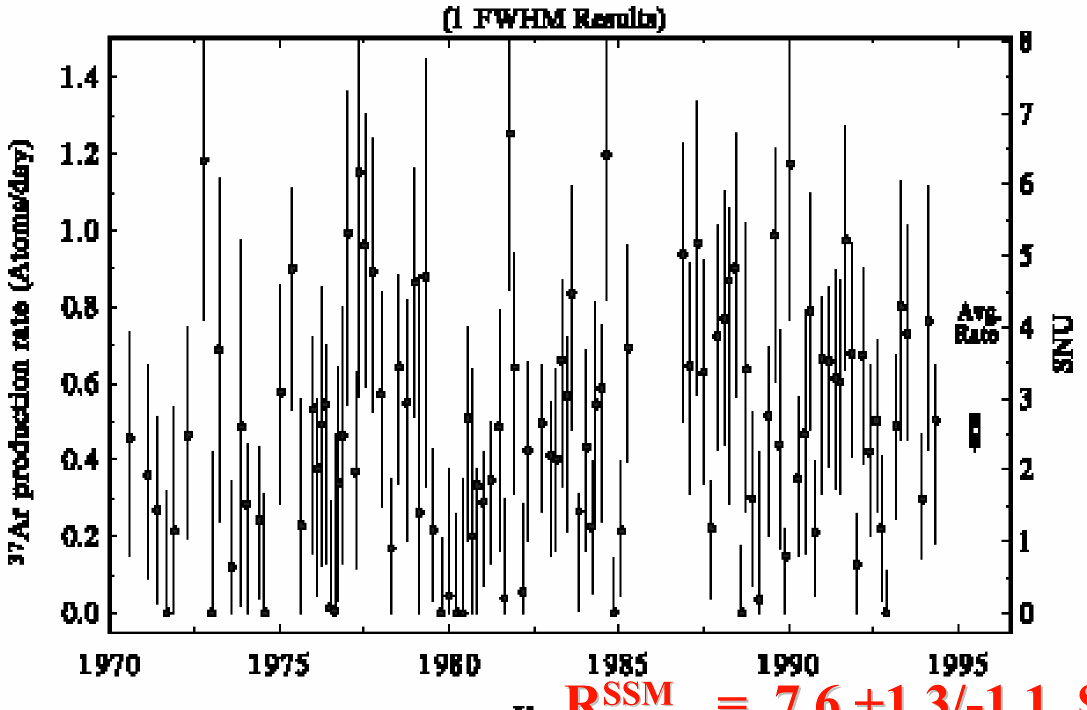
Homestake Radiochemical experiment

$\nu_e + {}^{37}Cl$ ->

Homestake ... akota, USA)
1478 m deep ... $^{-2}$ day^{-1}
steel tank, 6. ... g (6x10^5 liters)
615 tons of t...
(C_2Cl_4), 2.16 ... tons)
energy thres...
E^{Cl}_{th} = 0.814 ...
data taking: ... s



R^{exp}_{Cl} = 2.56 ± 0.16 ± 0.16 SNU = 2.56 ± 0.23 SNU



R^{SSM}_{Cl} = 7.6 +1.3/-1.1 SNU

New radiochemical solar neutrino detectors considered in 1972

(Evans J C 1972 *Proc Solar Neutrino Conf.*
(25-26 February, Irvine: unpublished) p. B-6E)

Target	Product	Relative response (%)					Mass
		pp	*pep*	^{7}Be	^{8}B	CNO	(tons)
^{87}Rb	^{87m}Sr	74	2	21	1	3	32
^{55}Mn [1]	^{55}Fe	67	3	25	1	3	420
^{71}Ga [2]	^{71}Ge	69	2	26	0	3	19
^{7}Li [3]	^{7}Be	0	18	15	51	16	17

[1] Domogatsky G V 1977, Soviet J. of Nucl. Phys. 25, 133

[2] Kuzmin V A 1965 *Zh Eksp Teor Fiz* **49** 1532 [1966 *Sov Phys JETP* **22** 1051]

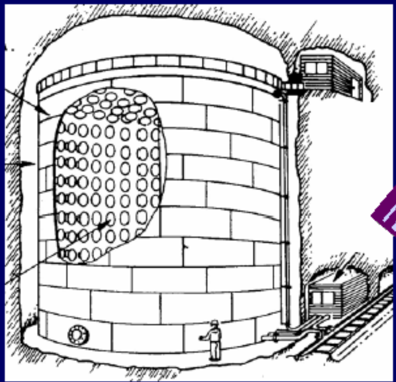
[3] Bahcall J N 1969 *Phys Rev Lett* **23** 251

From p decay to solar neutrino

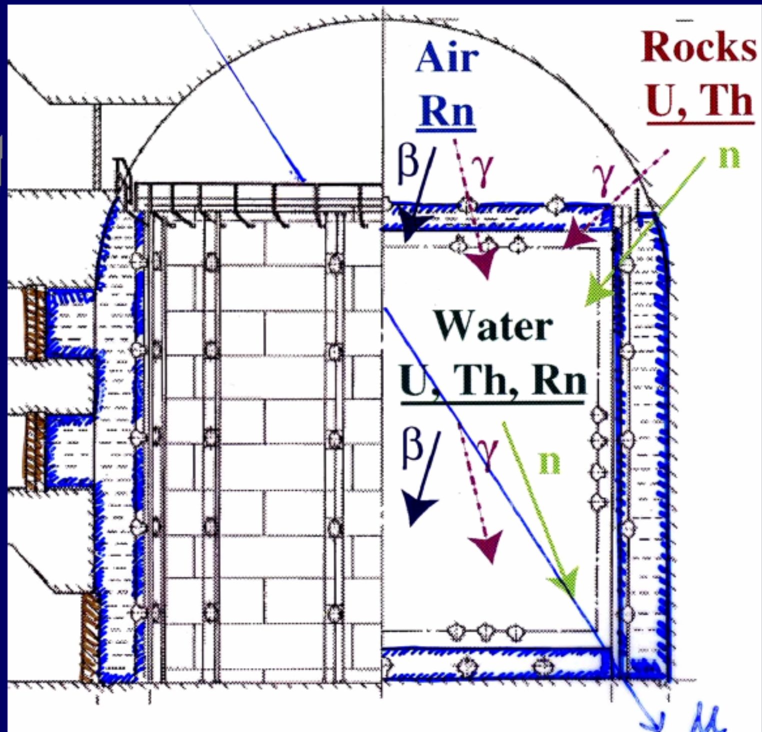
1986-1995

$\nu + e^- \rightarrow \nu + e^-$

Kamiokande-I



Kamiokande-II Detector



upgrade :

- hermetic, live anticounter
- water purification system
- multi-hit time and charge measurements

The Kamiokande II detector: **3,000 tons of water**, viewed by **948 PMTs**.

The final data sample in the fiducial volume of 680 tons with energy above 7 MeV (7.5 MeV) and less than 20 MeV consists of 6368 events.

Direction to the Sun.

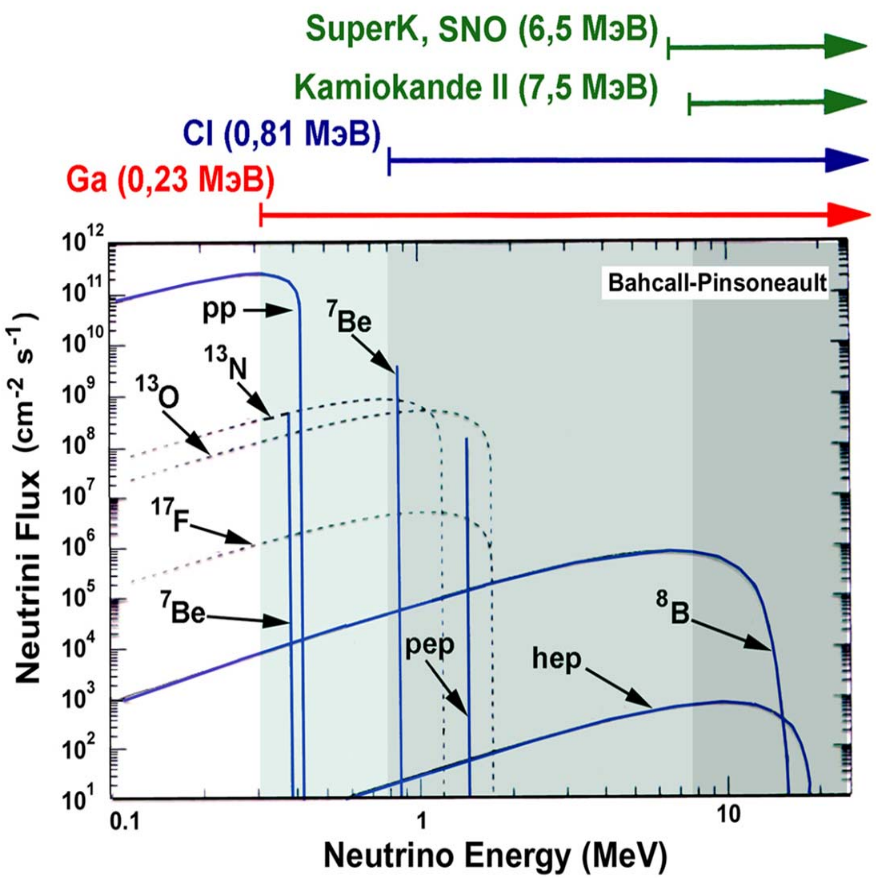
The number of solar neutrino events is **390^{+35}_{-33}**, whereas expected is **785** for the SSM

$$R_{K_{II}} = \frac{\Phi_{measured}}{\Phi_{predicted}} = 0.48 \pm 0.08$$

Paradox:

$$R_{Cl}(^8B + {}^7Be) - R_{KII}(^8B) \sim 0$$

(~15%)



- **1 SNU** = 1 interaction/sec in a target that contains 10^{36} atoms of the neutrino absorbing isotope.

1986-1995 $\nu + e^- \rightarrow \nu + e^-$

Kamiokande II

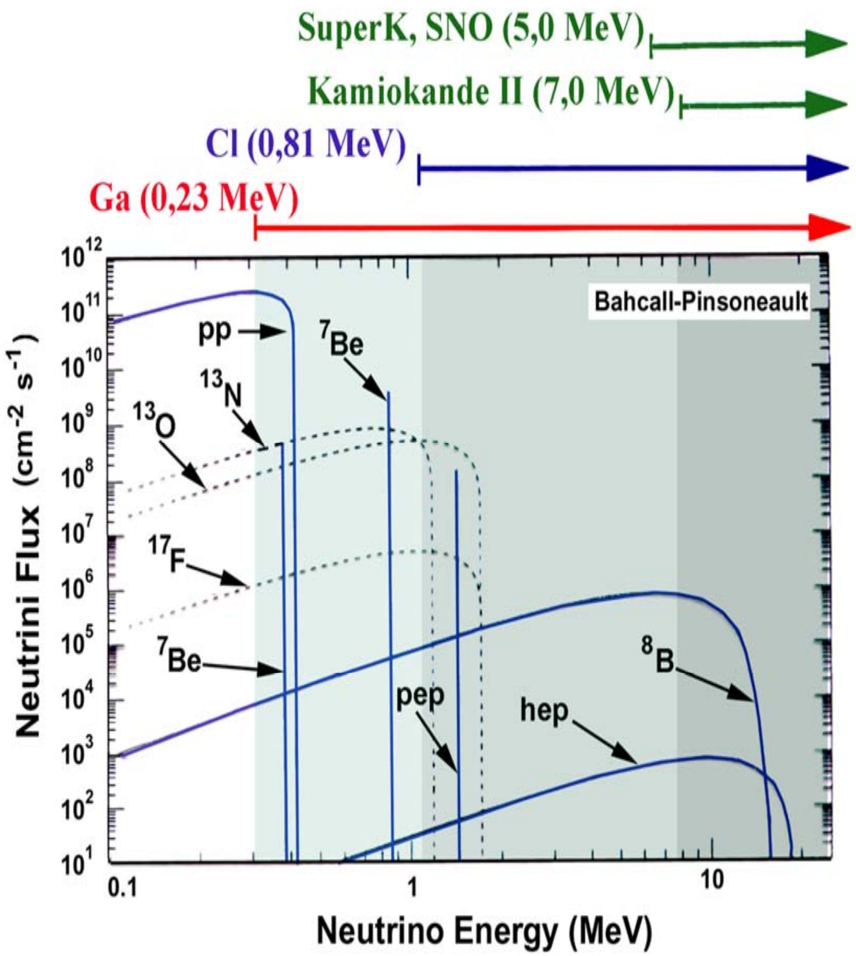
$$R_{KII} = \frac{\Phi \text{ measured}}{\Phi \text{ predicted}} = 0.54 \pm 0.08 /^{+0.10}_{-0.07}$$

$$^{7}Be + p \rightarrow {}^{8}B + \gamma$$

$$\quad \hookrightarrow {}^{8}Be^{*} + e^{+} + \nu_e$$

$$\quad\quad \downarrow 2\alpha$$

GALLIUM SOLAR NEUTRINO EXPERIMENT



• 1 SNU = 1 interaction/sec in a target that contains 10^{36} atoms of the neutrino absorbing isotope.

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

Kouzmine, 1965

Q = 233,2 keV

$T_{1/2}$ = 11,43 d

LOW THRESHOLD:

233 keV

SENSITIVE TO

DOMINANT p-p NEUTRINOS

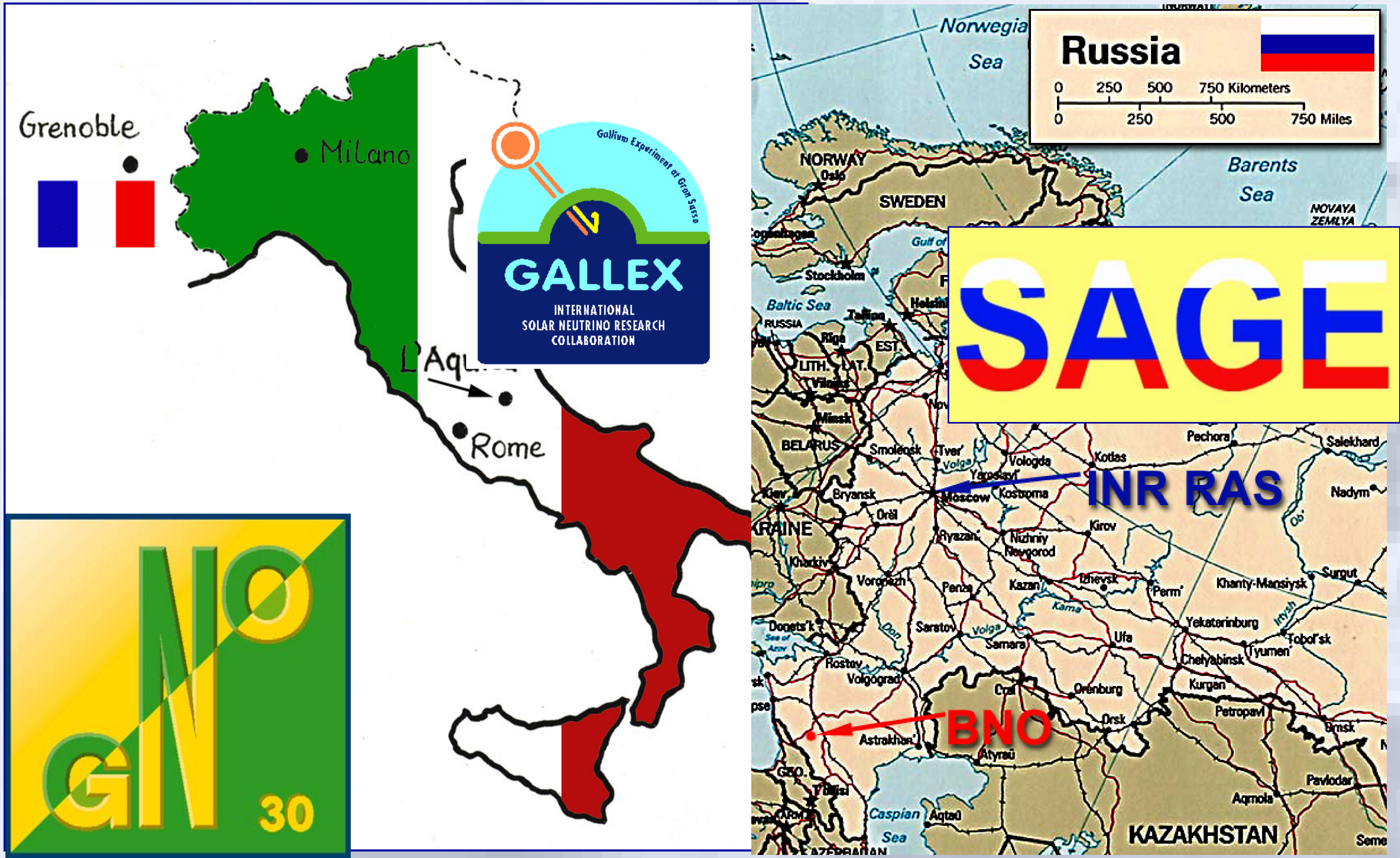
SSM PREDICTIONS:

BAHCALL-PINSONNEAULT:

128 +9 / -7 SNU (lσ)

p-p NEUTRINOS CONTRIBUTE 70 SNU (54%) OF THE RATE

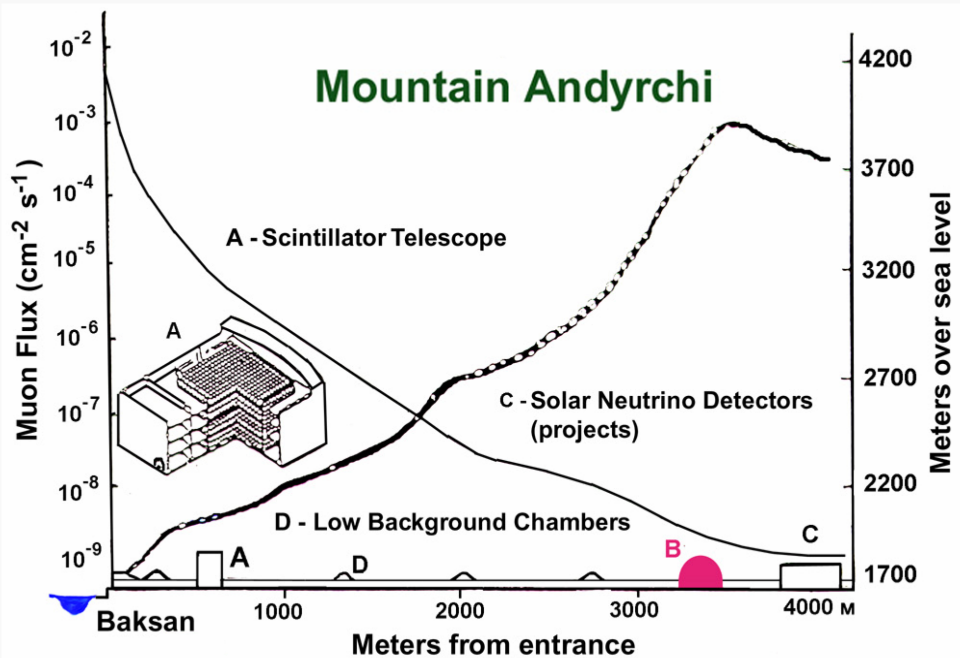
IF ONE ASSUMES ONLY THAT THE SUN IS INTHERMAL EQUILIBRIUM, THEN THE MINIMUM RATE IN A GALLIUM EXPERIMENT IS 79 SNU.

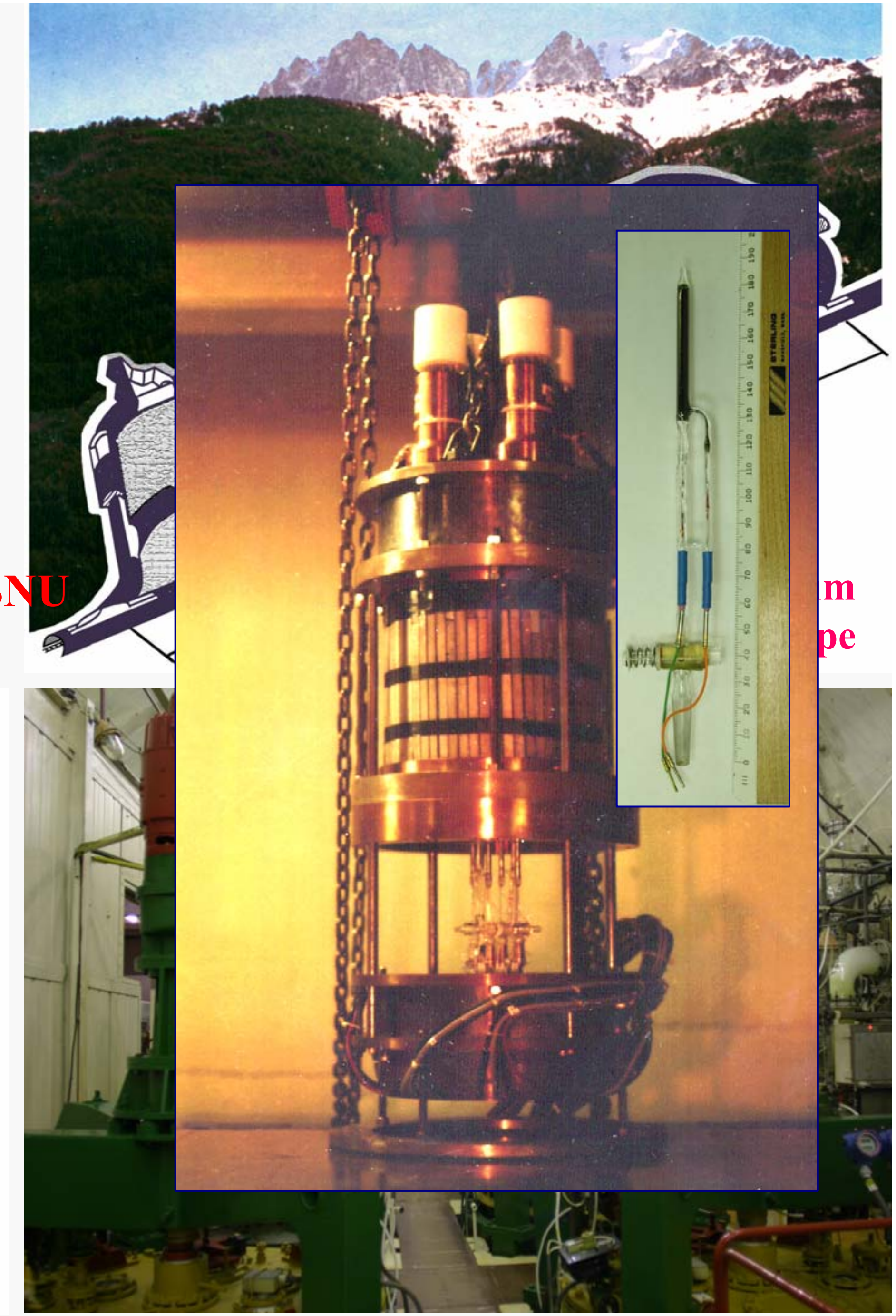

Grenoble
Milano
Rome
GALLEX
INTERNATIONAL
SOLAR NEUTRINO RESEARCH
COLLABORATION
GNO
30
Russia
0 250 500 750 Kilometers
0 250 500 750 Miles
SAGE
INR RAS
BNO
Barents Sea
NORWAY
SWEDEN
Baltic Sea
BELARUS
Moscow
Caspian Sea
KAZAKHSTAN

SAGE

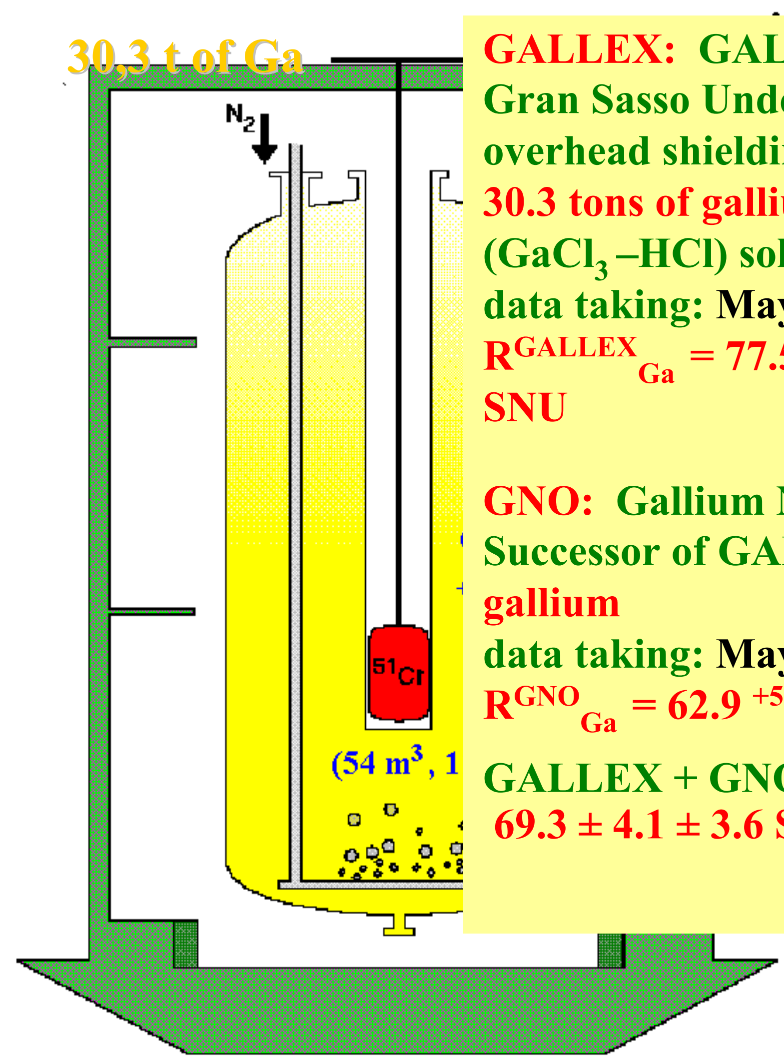
Baksan Neutrino Observatory, northern Caucasus,
3.5 km from entrance of horizontal adit,
50 tons of metallic ^{71}Ga, 2000 m deep,
4700 m.w.e. => $\Phi\mu \sim 2.6\ m^{-2}\ day^{-1}$.
Data taking: Jan 1990-Dec 2005, 145 runs, running.
Atoms of ^{71}Ge chemical are extracted and
its decay is counted.
Sensitivity: One ^{71}Ge atom from $5\cdot10^{29}$ atoms Ga
with efficiency ~90%

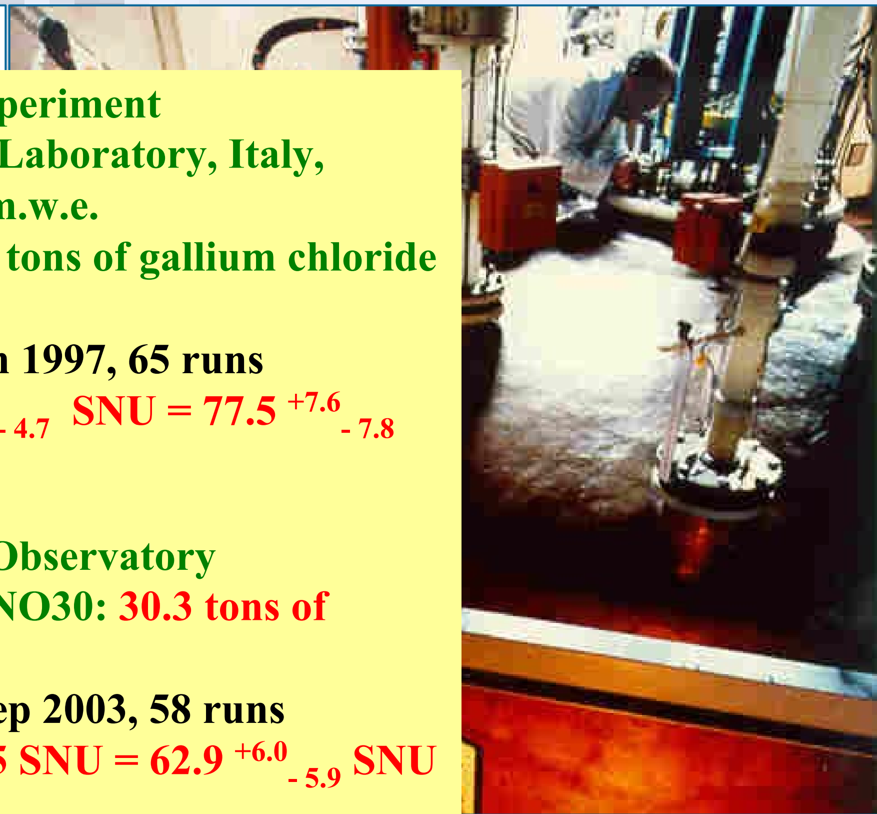
$$R^{SAGE}_{Ga} = 66.5^{+3.5}_{-3.4}\ {}^{+3.5}_{-3.2}\ SNU = 66.5^{+4.9}_{-4.7}\ SNU$$





GALLEX/GNO

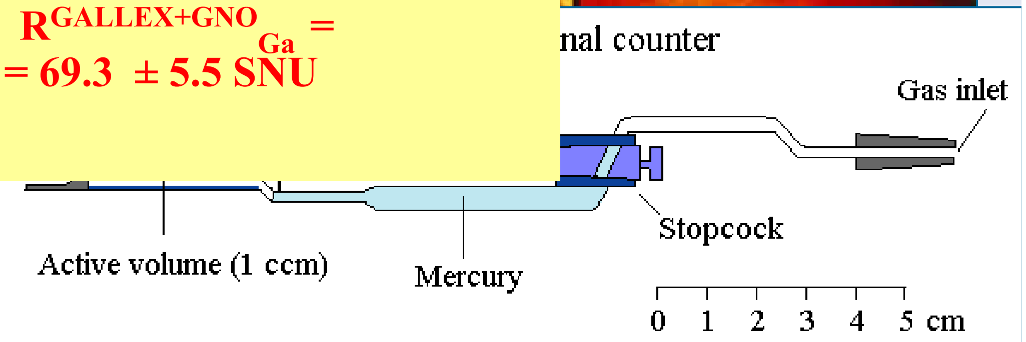




GALLEX: GALLium EXperiment
Gran Sasso Underground Laboratory, Italy,
overhead shielding: 3300 m.w.e.
30.3 tons of gallium in 101 tons of gallium chloride ($GaCl_3$–HCl) solution
data taking: May 1991-Jan 1997, 65 runs
$R^{GALLEX}_{Ga} = 77.5 \pm 6.2\ ^{+4.3}_{-4.7}$ SNU $= 77.5\ ^{+7.6}_{-7.8}$ SNU

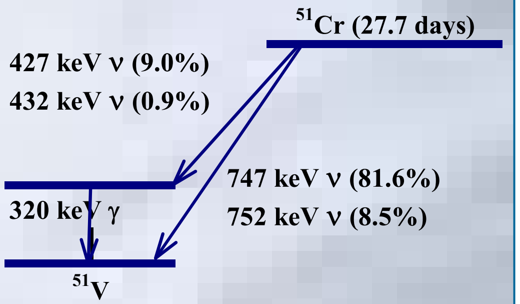
GNO: Gallium Neutrino Observatory
Successor of GALLEX, GNO30: 30.3 tons of gallium
data taking: May 1998 - Sep 2003, 58 runs
$R^{GNO}_{Ga} = 62.9\ ^{+5.5}/_{-5.3} \pm 2.5$ SNU $= 62.9\ ^{+6.0}_{-5.9}$ SNU

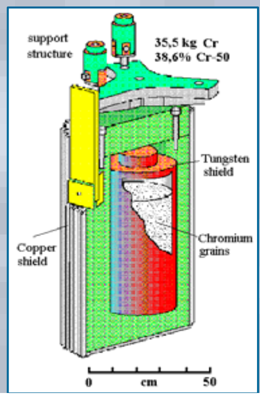
GALLEX + GNO => $R^{GALLEX+GNO}_{Ga}$ =
$69.3 \pm 4.1 \pm 3.6$ SNU $= 69.3 \pm 5.5$ SNU

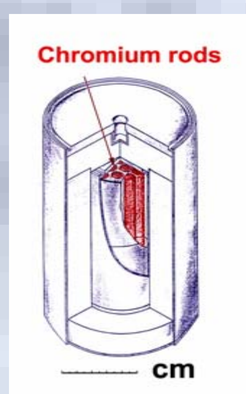


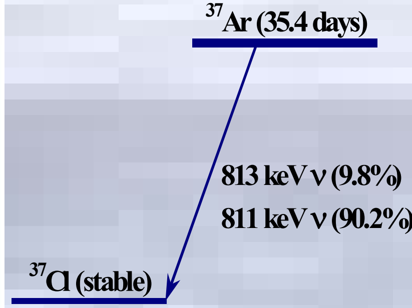
^{51}Cr ^{37}Ar

	Gallium chloride solution (GALLEX) (1)	(2)	*Gallium metal*	*(SAGE)*
m_{Ga} (tons)	30.4	30.4	13.1	13.1
$m_{of\ target}$ (kg)	35,5	35,5	0,513	330
enrichment (% ^{50}Cr)	38,6	38,6	92,4	96,94% ^{40}Ca (natural Ca)
source specific activity (KCi/g)	0,048	0,052	1,01	92,7
source activity (MCi)	1,71	1,87	0,52	0,41
expected rate	11,7	12,7	14,0	13,9

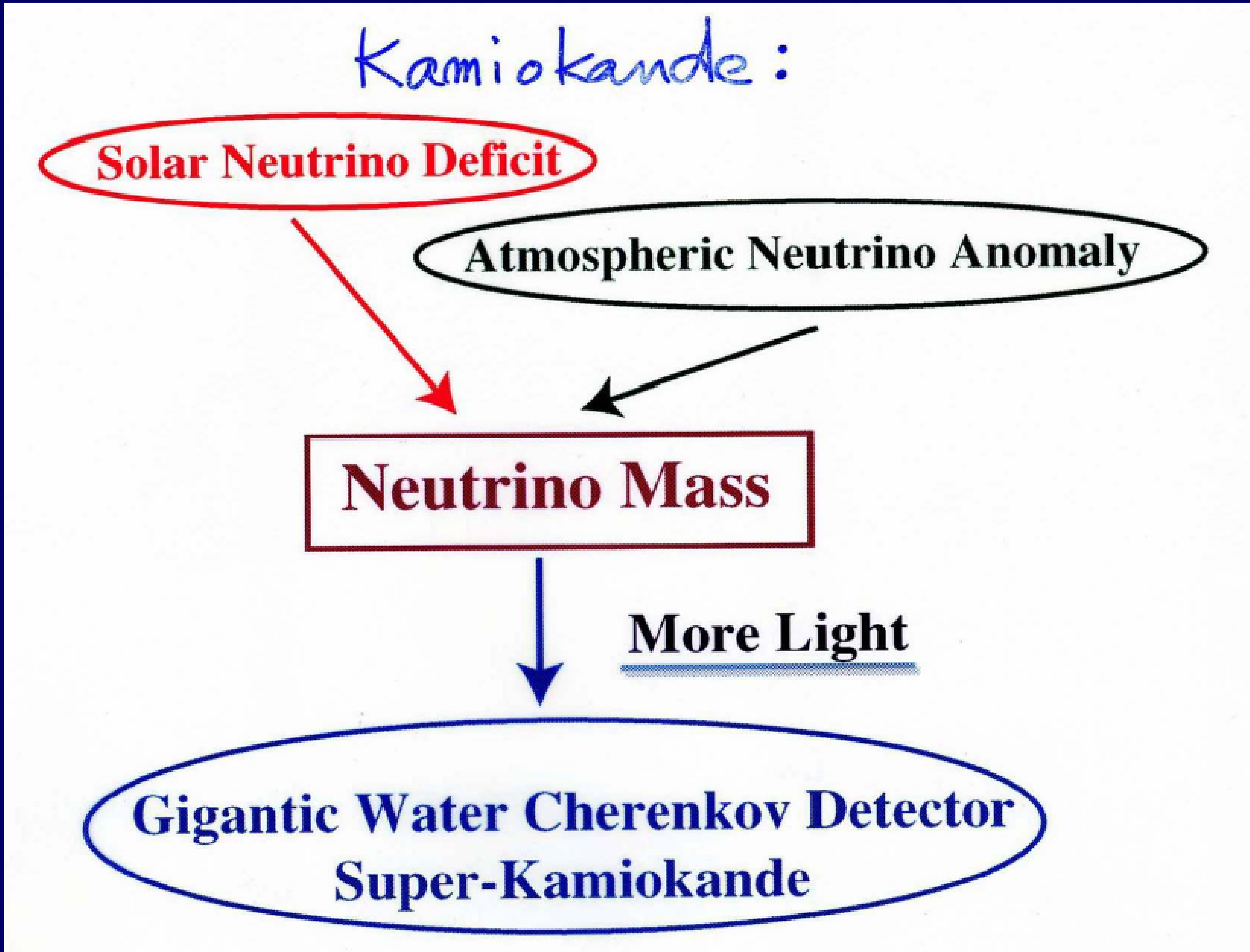




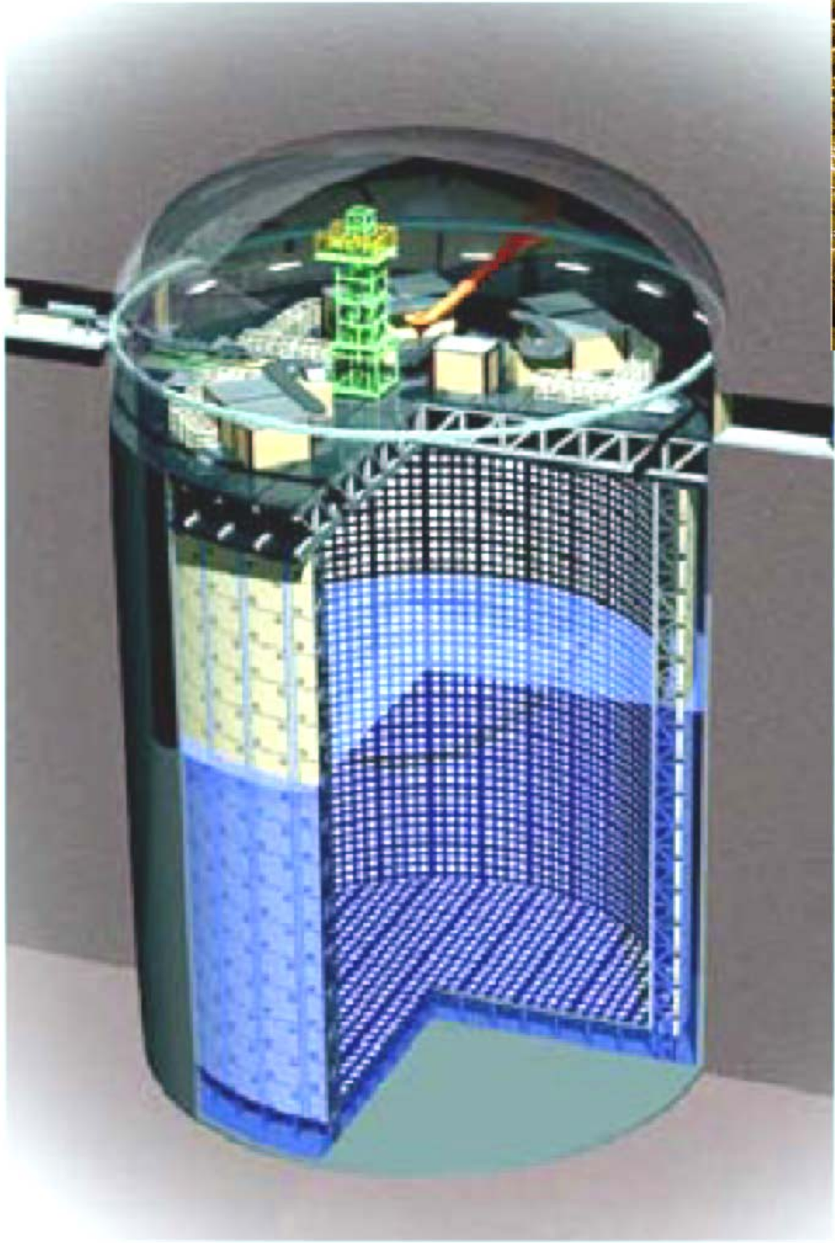


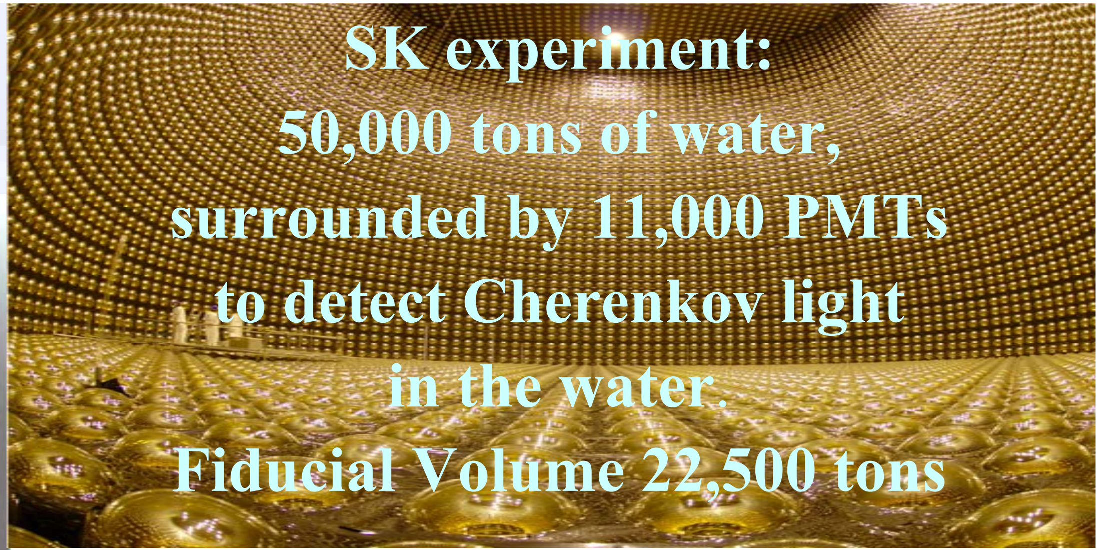


Kamiokande to Next Generation Experiments



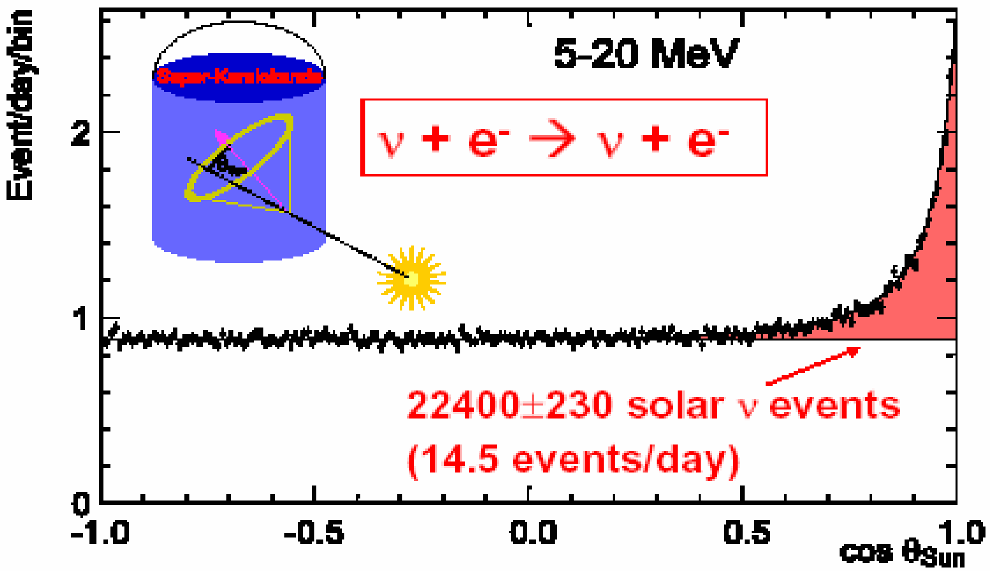
Super-Kamiokande (1996)





Super-Kamiokande-I solar neutrino data

May 31, 1996 – July 13, 2001 (1496 days)

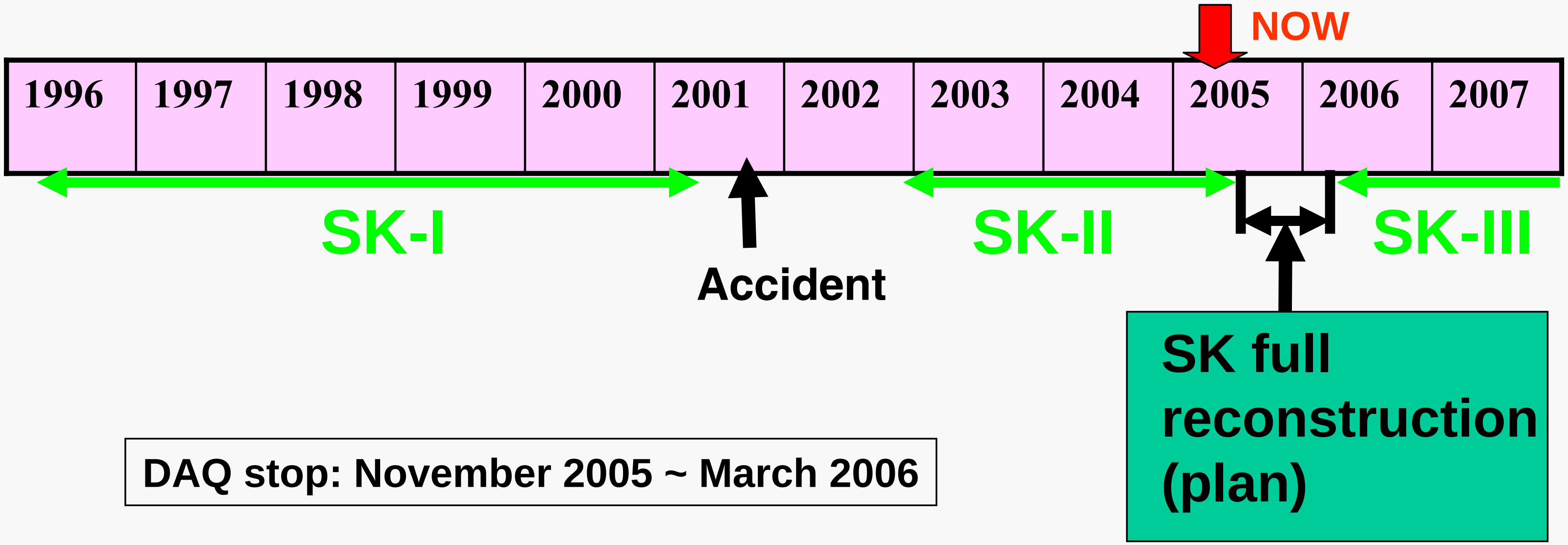


^{8}B flux : 2.35 ± 0.02 ± 0.08 [x 10^6 /cm^2/sec]

$$\frac{\text{Data}}{\text{SSM(BP2004)}} = 0.406 \pm 0.004 \ ^{+0.014}_{-0.013}$$

(Data/SSM(BP2000) = 0.465 ±0.005 +0.016/-0.015)

Schedule for Future

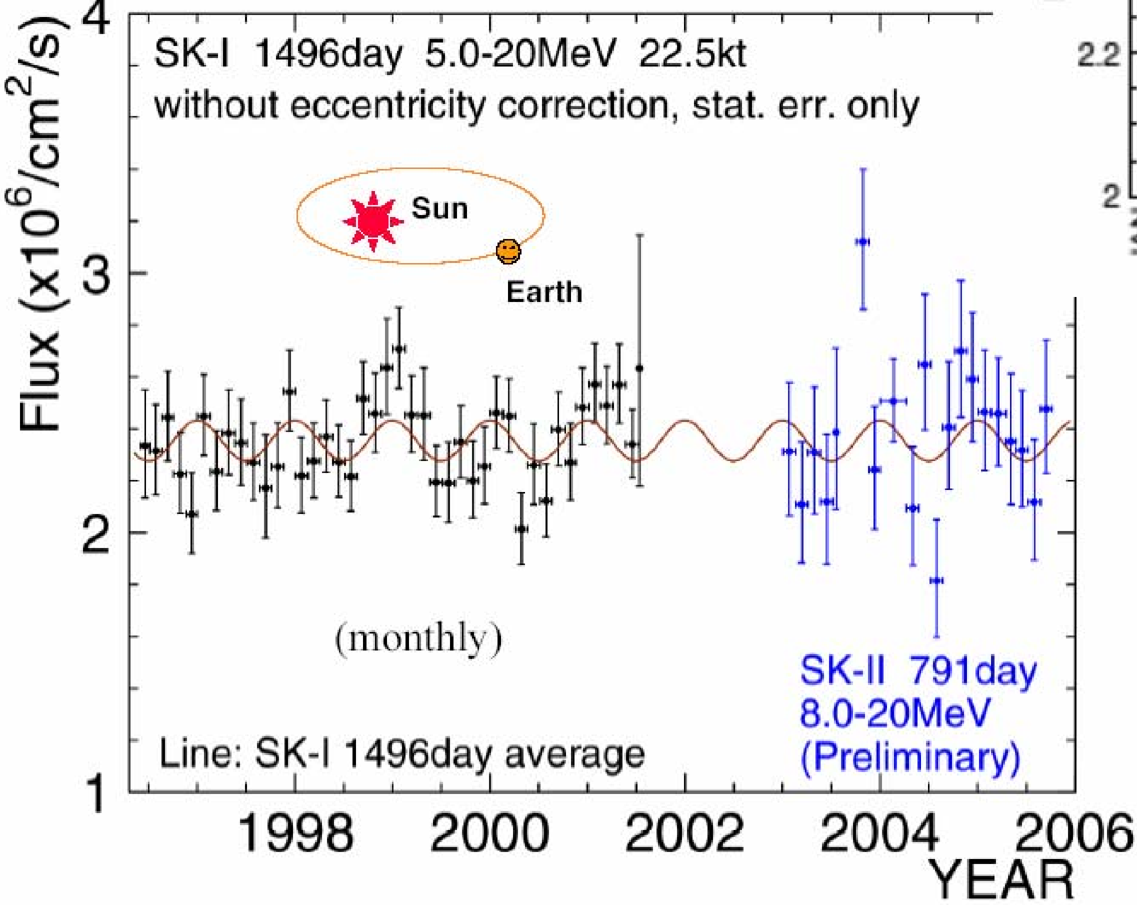


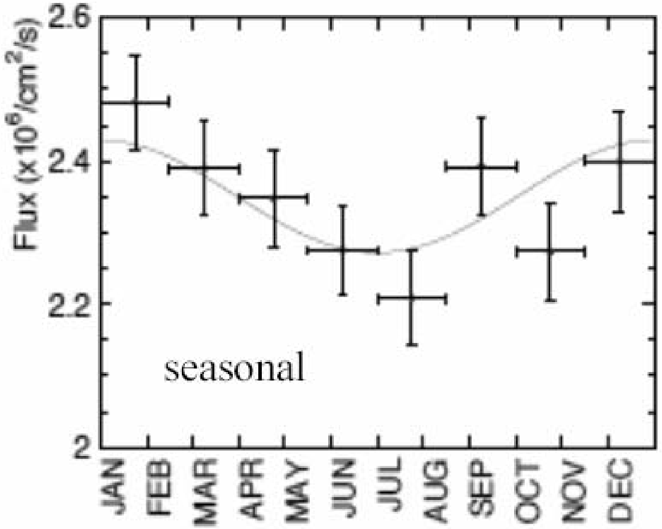
DAQ stop: November 2005 ~ March 2006

ID PMT: SK-II = ~5200 ⇨ SK-III = 11146 (same as SK-I)
Original energy & vertex resolutions for low-energy events

⇨ **Solar neutrinos below 5.0MeV with improved analysis tools and lower Rn backgrounds**

⇨ **Precise study on spectrum distortion in SK-III**





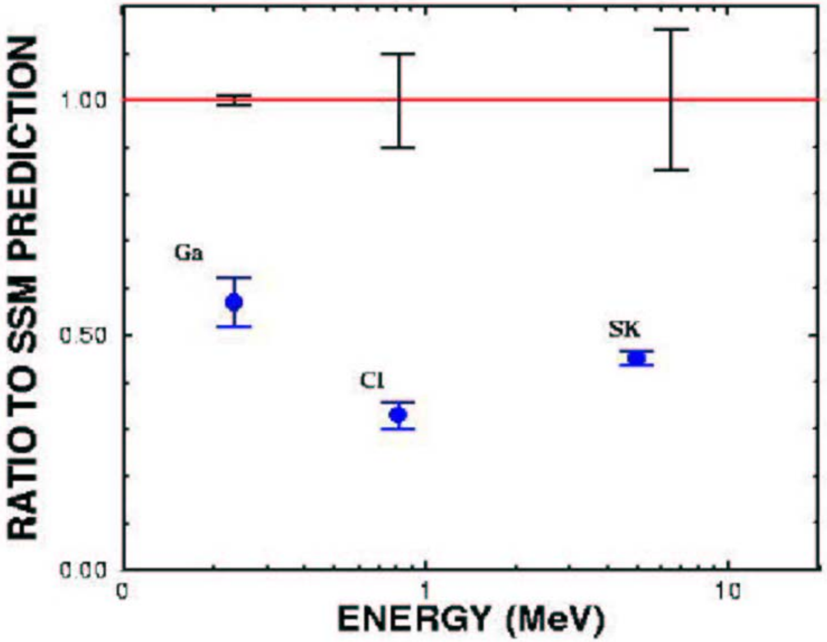
SK-I

↓

Eccentricity = (2.1 ± 0.3) %

After Six Solar ν Experiments

- 3 Gallium (Radiochemical)
- 1 Chlorine (Radiochemical)
- Kamiokande +Super-Kamiokande (Water Cherenkov)



What's Going On??

- Or Solar Theory?
- Or the neutrino?

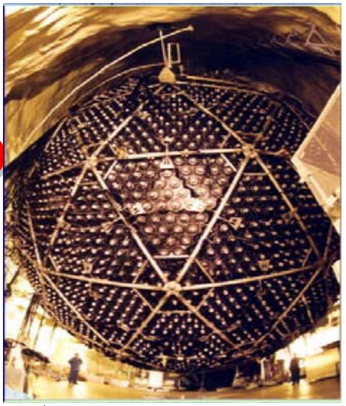
Where have Solar Neutrinos gone?

Solar Neutrino Observations (~ 1995)

experiment	solar neutrinos	data / theory
Homestake (Cl)	$^7Be + {}^8B + \cdots$	0.29 ± 0.03
Kamiokande (H_2O)	^8B	0.48 ± 0.08
GALLEX (Ga)	$pp + {}^7Be + {}^8B + \cdots$	0.60 ± 0.09
SAGE (Ga)	$pp + {}^7Be + {}^8B + \cdots$	0.52 ± 0.09

Where have Solar Neutrinos gone ?

Sudbury Neutrino Observatory



Key physics signatures

CC $\nu_e + d \Rightarrow p + p + e^-$

- Gives ν_e energy spectrum well
- Weak direction sensitivity $\propto$ 1-1/3cos(θ)
- ν_e only.

NC $\nu_x + d \Rightarrow p + n + \nu_x$

- Measure total ^8B ν flux from the sun.
- Equal cross section for all ν types

ES $\nu_x + e^- \Rightarrow \nu_x + e^-$

- Low Statistics
- Mainly sensitive to ν_e, some
  -sensitivity to ν_μ and ν_τ
- Strong direction sensitivity

$$\frac{\Phi_{cc}}{\Phi_{nc}} = \frac{\nu_e}{\nu_e + \nu_\mu + \nu_\tau}$$

$$\frac{\Phi_{cc}}{\Phi_{es}} = \frac{\nu_e}{\nu_e + 0.154(\nu_\mu + \nu_\tau)}$$

$$\Phi_{day} \quad \text{vs} \quad \Phi_{night}$$

Background to SNO

- **1984** Herb Chen proposes a heavy water solar neutrino detector with Neutral Current detection capability
- **1985** Mikheyev and Smirnov develop theory or resonant oscillations
- Suddenly the ‘World’ believes in neutrino oscillations
- Single set of parameters solves SNP with small vacuum mixing, dark matter and supernova!!!
- **1990** SAGE shows greatly suppressed Ga rate
- **1990** Start of construction of SNO

SNO - 3 neutron detection methods

Phase I (D_2O)
Nov. 99 - May 01

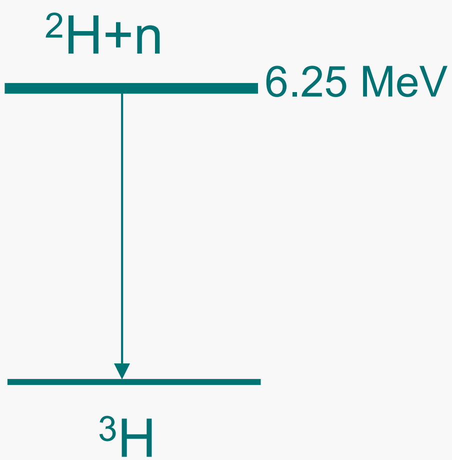
n captures on
$^2H(n, \gamma)^3H$
σ = 0.0005 b
Observe 6.25 MeV γ
PMT array readout
Good CC

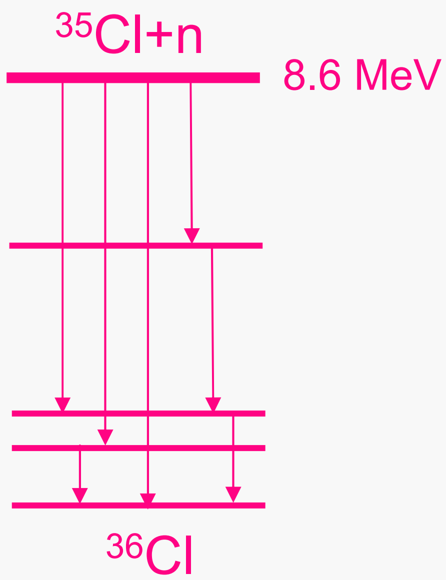
Phase II (salt)
July 01 - Sep. 03

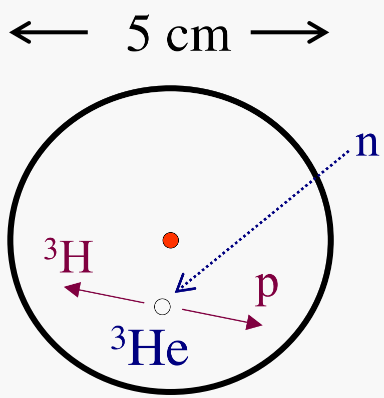
2 t NaCl. n captures on
$^{35}Cl(n, \gamma)^{36}Cl$
σ = 44 b
Observe multiple γ's
PMT array readout
Enhanced NC

Phase III (^3He)
Summer 04 - Dec. 06

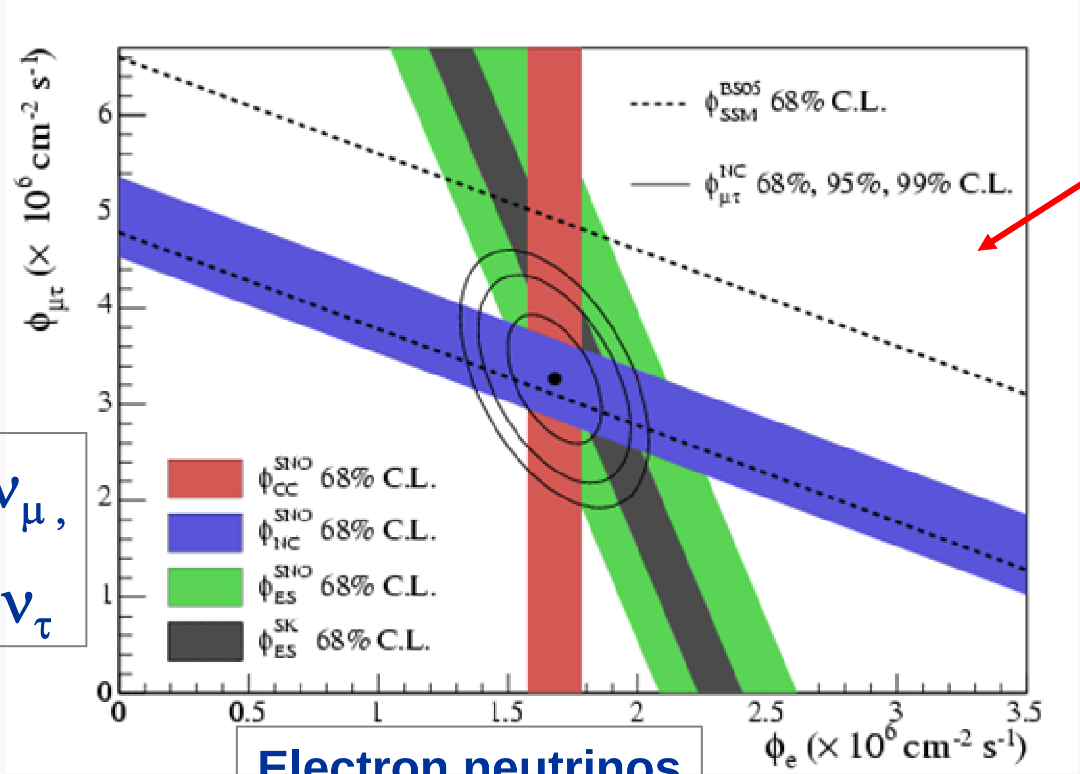
40 proportional counters
$^3He(n, p)^3H$
σ = 5330 b
Observe p and ^3H
PC independent readout
Event by Event Det.







$n + {}^3He \rightarrow p + {}^3H$



Flavor change determined by > 7 σ.

CC, NC FLUXES MEASURED INDEPENDENTLY

The Total Flux of Active Neutrinos is measured independently (NC) and agrees well with solar model Calculations:

5.82 +- 1.3 (Bahcall et al),

5.31 +- 0.6 (Turck-Chieze et al)

$$\phi_{CC} = 1.68\ ^{+0.06}_{-0.06}(\text{stat.})^{+0.08}_{-0.09}(\text{syst.})$$

$$\phi_{NC} = 4.94\ ^{+0.21}_{-0.21}(\text{stat.})^{+0.38}_{-0.34}(\text{syst.})$$

$$\phi_{ES} = 2.35\ ^{+0.22}_{-0.22}(\text{stat.})^{+0.15}_{-0.15}(\text{syst.})$$

(In units of $10^6\,\text{cm}^{-2}\text{s}^{-1}$)

$$\frac{\phi_{CC}}{\phi_{NC}} = 0.34 \pm 0.023(\text{stat.})^{+0.029}_{-0.031} = \cos^4\theta_{13}\sin^2\theta_{12}$$

Improved accuracy for θ_{12}.

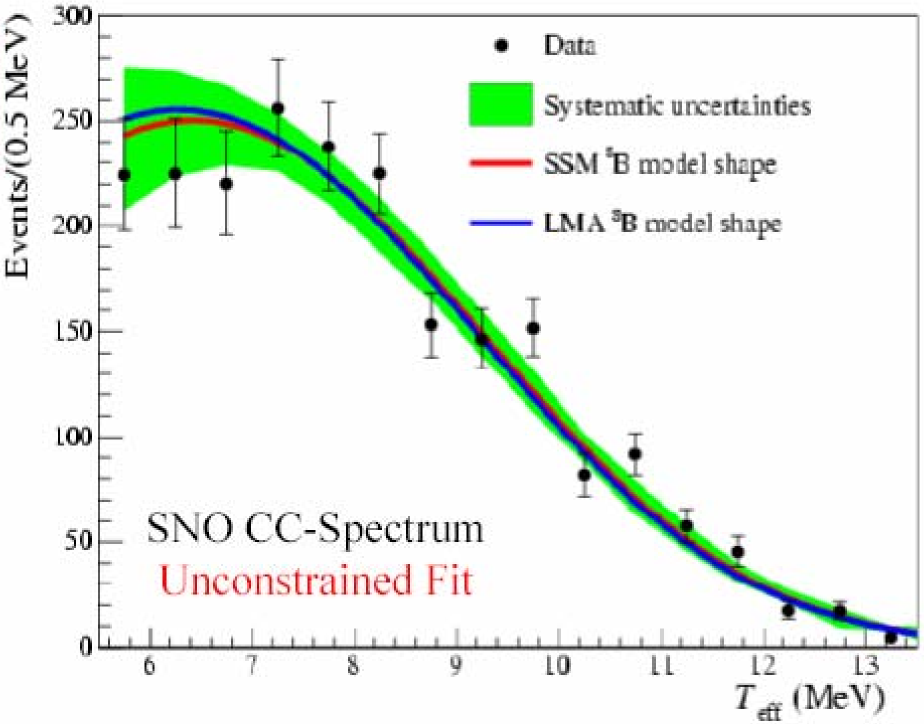
SNO Collaboration, PRC **72**, 055502 (2005)
391 Days of Dissolved Salt Data

$$\phi_{CC} = 1.68 \;{}^{+0.06}_{-0.06}(\text{stat.})^{+0.08}_{-0.09}(\text{syst.})$$

$$\phi_{NC} = 4.94 \;{}^{+0.21}_{-0.21}(\text{stat.})^{+0.38}_{-0.34}(\text{syst.})$$

$$\phi_{ES} = 2.35 \;{}^{+0.22}_{-0.22}(\text{stat.})^{+0.15}_{-0.15}(\text{syst.})$$

$\times\, 10^6 \text{ cm}^{-2}\,\text{s}^{-1}$



$$A_{DN} = \frac{\text{(Night-Day)}}{\text{(Day+Night)/2}}$$

$$A_{salt\,+\,D_2O} = \mathbf{0.037 \pm 0.040}$$

(assuming $A_{NC} = 0$)

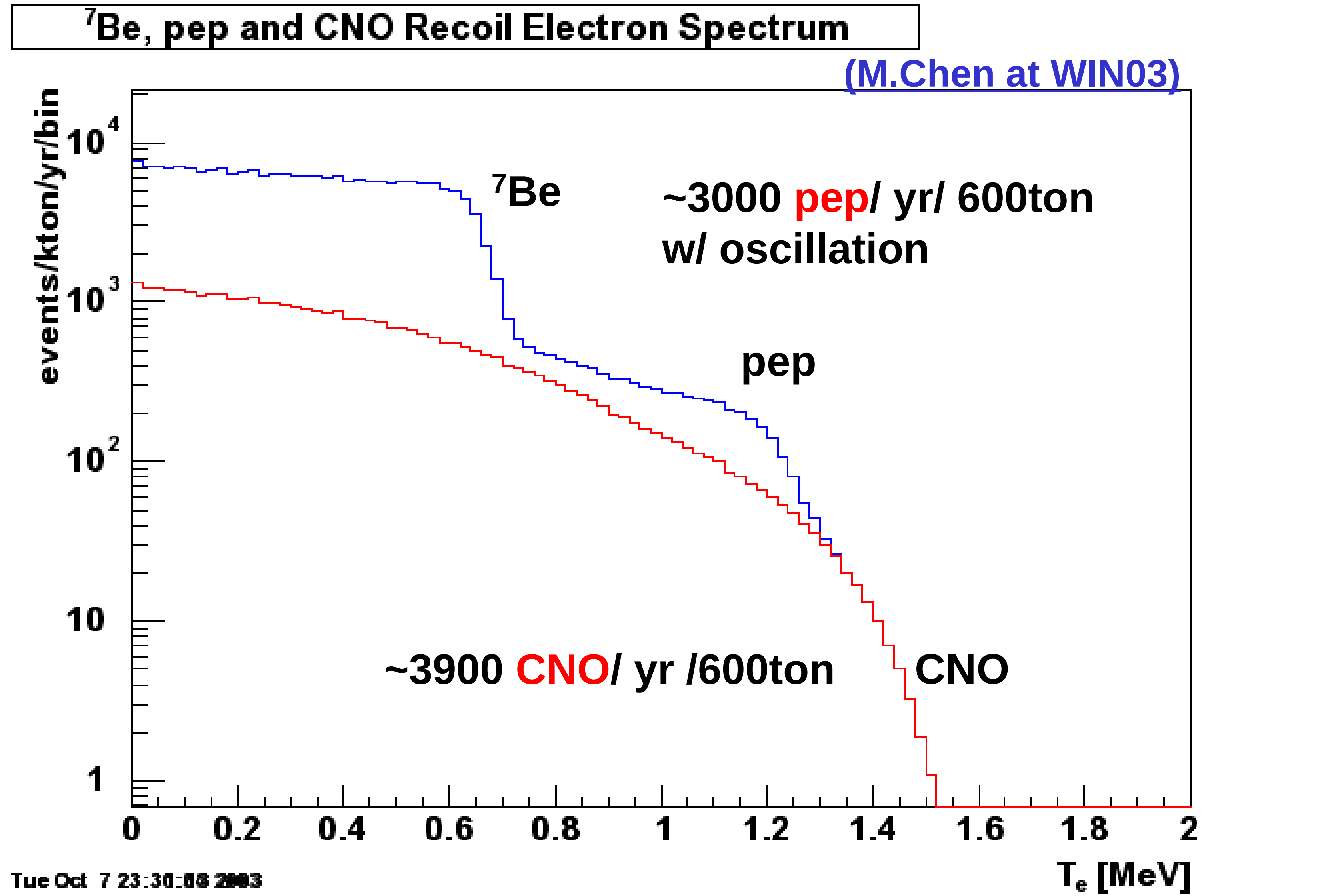
Statistical Limitation for Observing "Small" Day-Night Asymmetry

➔ Combined "Low-Energy Threshold" Analysis of D2O & Salt-Phase Data Sets

➔ Break CC-NC Correlation with Neutral-Current-Detectors (NCDs)

➔ Ultimately Combine Data from all Phases

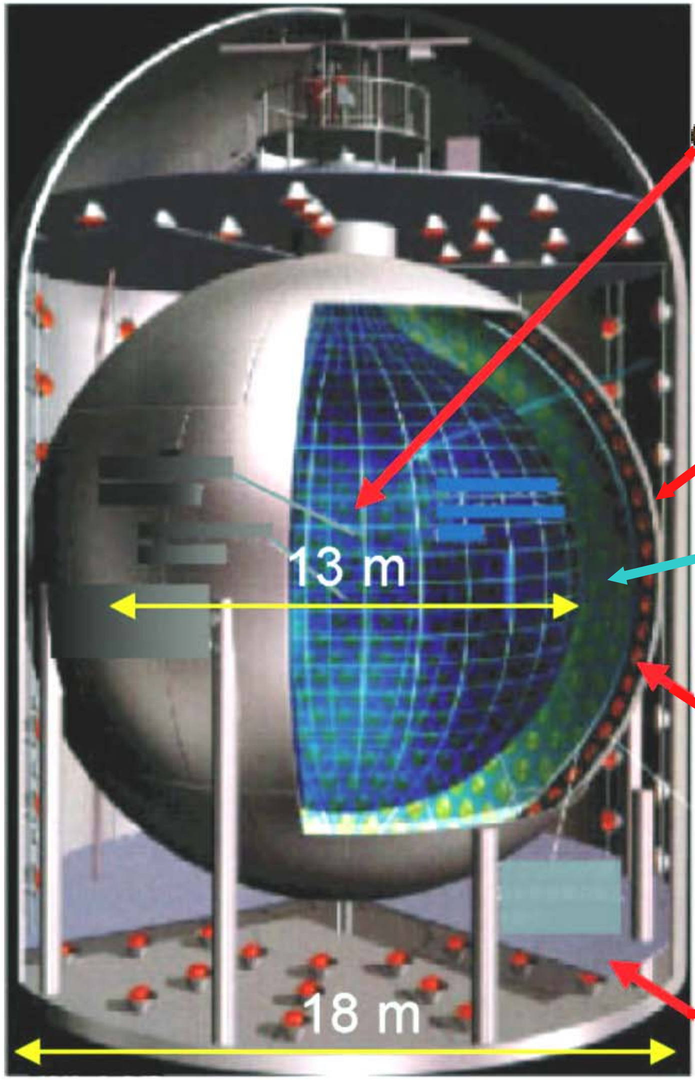
SNO with liquid scinitillator for *pep and CNO*



KamLAND detector

detector location: old Kamiokande site

: 2700 m.w.e.



1000 ton liquid scintillator

: 80% (dodecane) + 20% (pseudocumene)
+ 1.52 *g/l* PPO

: housed in spherical plastic balloon

3000 m^3 stainless steel vessel

: filled with a mixture of paraffin oil
and dodecane ($\Delta\rho$ = 0.04%)

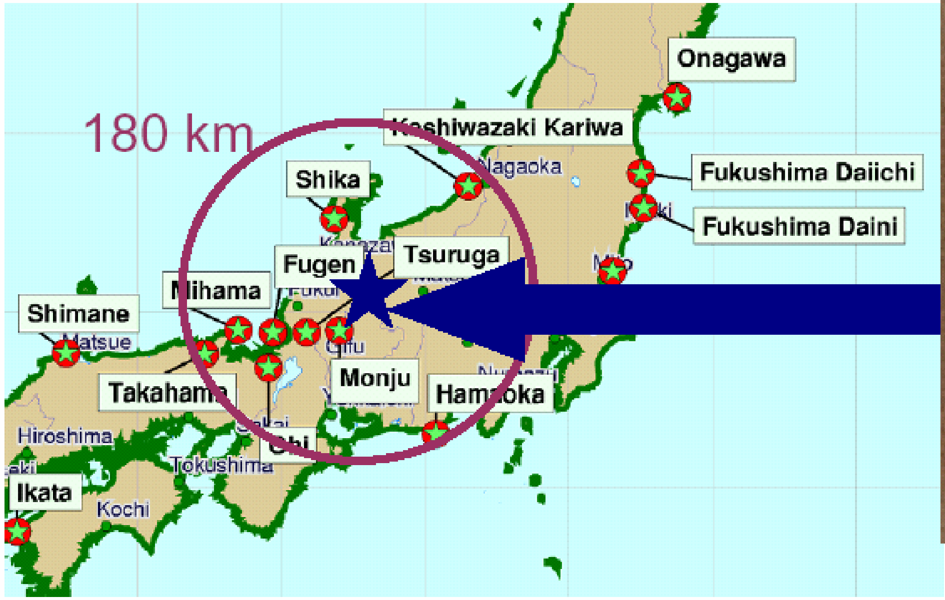
1325 17-inch + 554 20-inch PMT's

commissioned in February, 2003

photocathode coverage : 22% → 34%
energy resolution at 1 MeV : 7.3% → 6.3%

water Cerenkov outer detector

Reactor Experiment in KamLAND



Liquid Scintillator
1000 ton

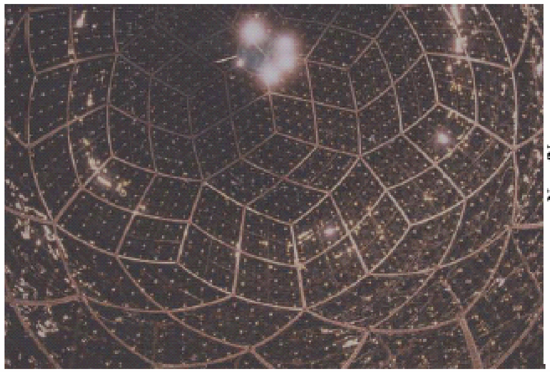
reactor anti-neutrino is detected by inverse beta-decay process.

$\bar{\nu}_e + p \rightarrow e^+ + n$

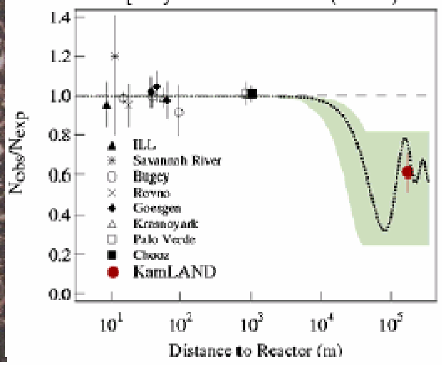
2000 — Construction

2002 — Disappearance

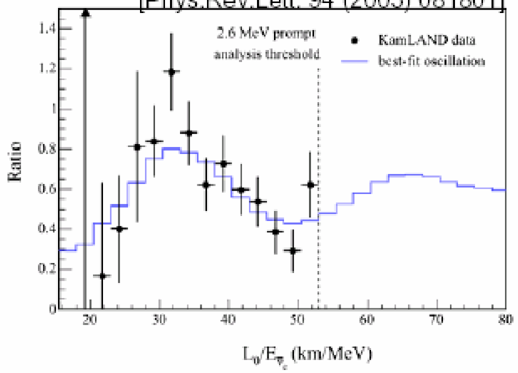
2005 — Spectral Distortion



[Phys.Rev.Lett. 92 (2003) 021802]



[Phys.Rev.Lett. 94 (2005) 081801]



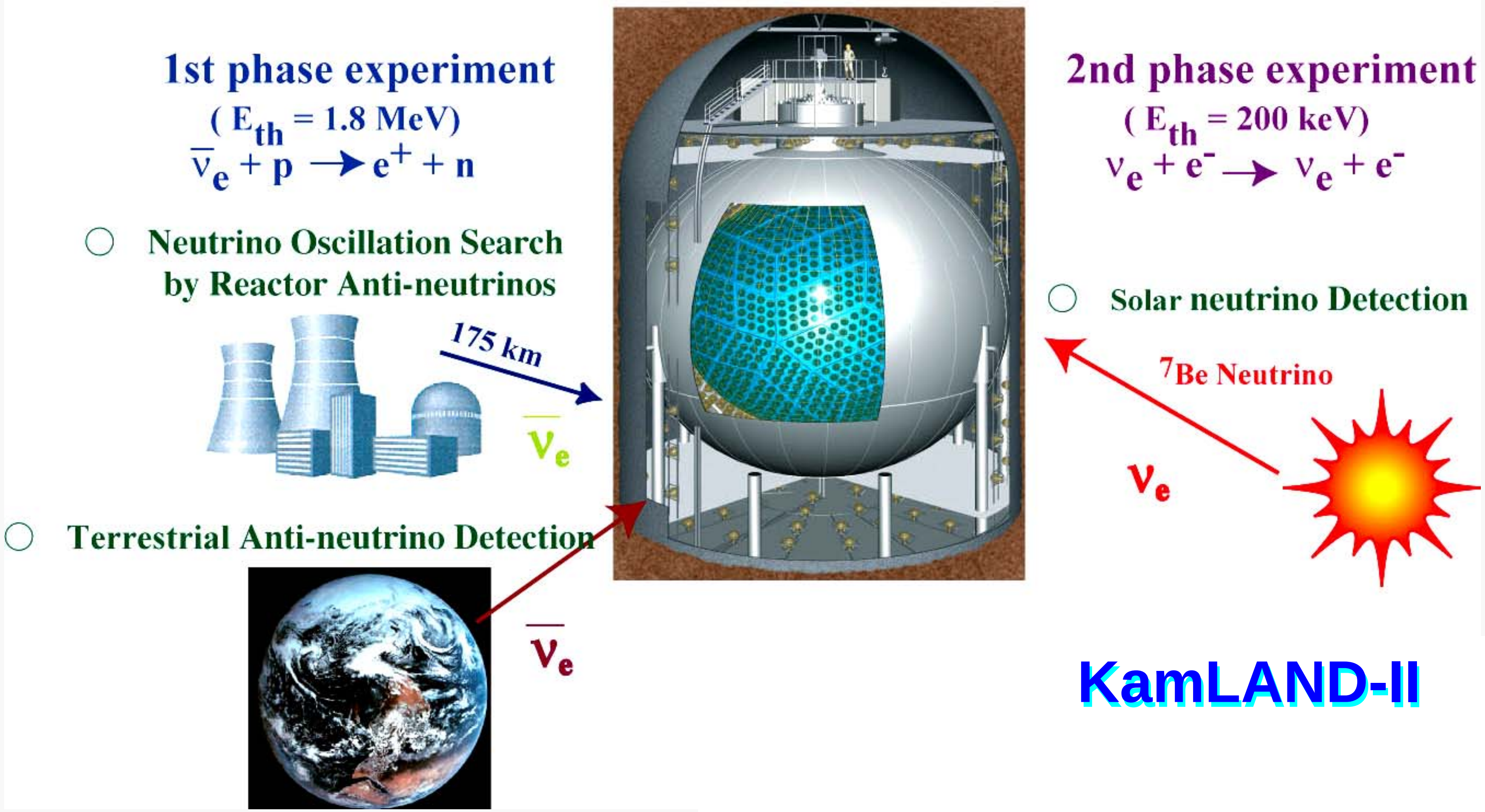
1. KamLAND-II (summer in 2006)

^{7}Be solar neutrino detection:

Precise measurements of reactor-, geo- and solar neutrinos:

JSPS 5-year project from 2004

MEXT 5-year project from 2005

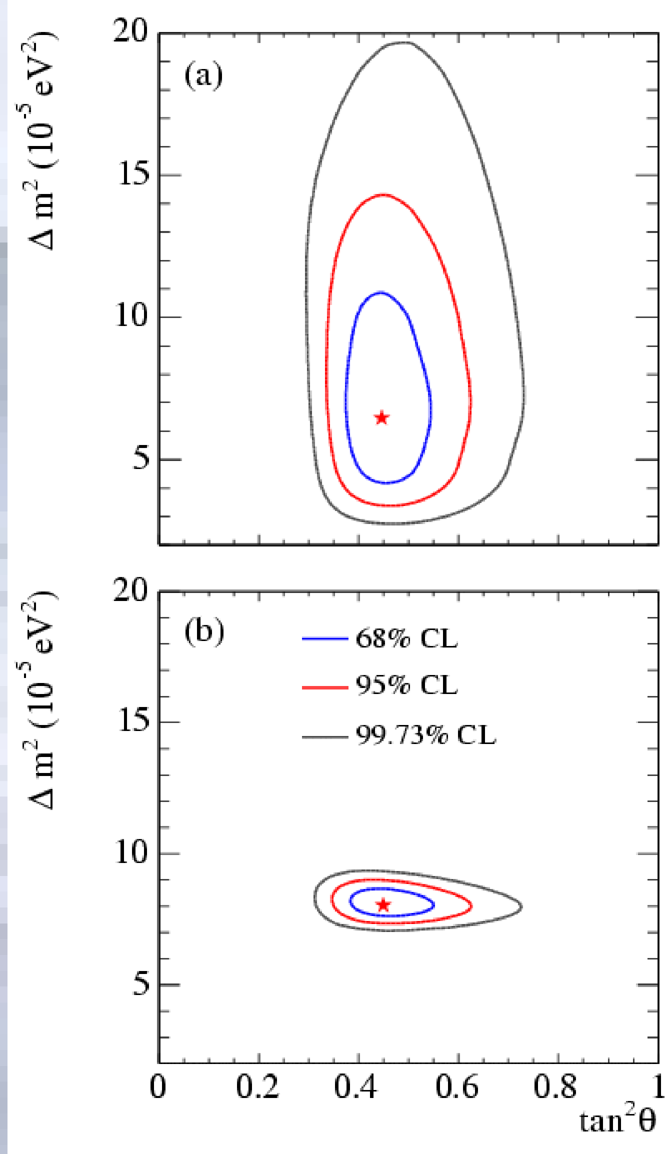


KamLAND-II

Combined Solar/KamLAND Fit

Analysis	Δm^2 $(10^{-5}\ eV^2)$	$\tan^2\theta$
SNO only	$5.0^{+6.2}_{-1.8}$	$0.45^{+0.11}_{-0.10}$
Global solar	$6.5^{+4.4}_{-2.3}$	$0.45^{+0.09}_{-0.08}$
KamLAND	$7.9^{+0.6}_{-0.5}$	$0.46^{+0.09}_{-0.08}$
Combined	$8.0^{+0.6}_{-0.4}$	$0.45^{+0.09}_{-0.07}$

Stan Wojcicki, NuFact'06, Irvine, CA August 24, 2006



Gallium Experiments: SAGE, GALLEX, GNO

Radiochemical experiments

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

threshold E^{Ga}_{th} = 0.233 MeV => all ν fluxes (*pp*, ^{7}Be, ^{8}B, *pep, hep*, ^{13}N, ^{15}O, ^{17}F)

SAGE + GALLEX + GNO => R^{exp}_{Ga} = 67.7 ± 3.6 SNU

Standard Solar Model => R^{SSM}_{Ga} = 128^{+9}_{-7} SNU

The measured electron neutrino *pp* flux at Earth of $(3.23^{+0.76}_{-0.78}) \times 10^{10}/(cm^2\text{-}s)$
$(5.94 \pm 0.06) \times 10^{10}/(cm^2\text{-}s)$ (SSM) $\times(\langle P_i^{ee} \rangle = 0.555)$ = $(3.30 \pm 0.07) \times 10^{10}/(cm^2\text{-}s)$

Excellent agreement

1 SNU = 1 interaction/sec in a target that contains 10^{36} atoms of the neutrino absorbing isotope.

Present status of solar neutrino facilities

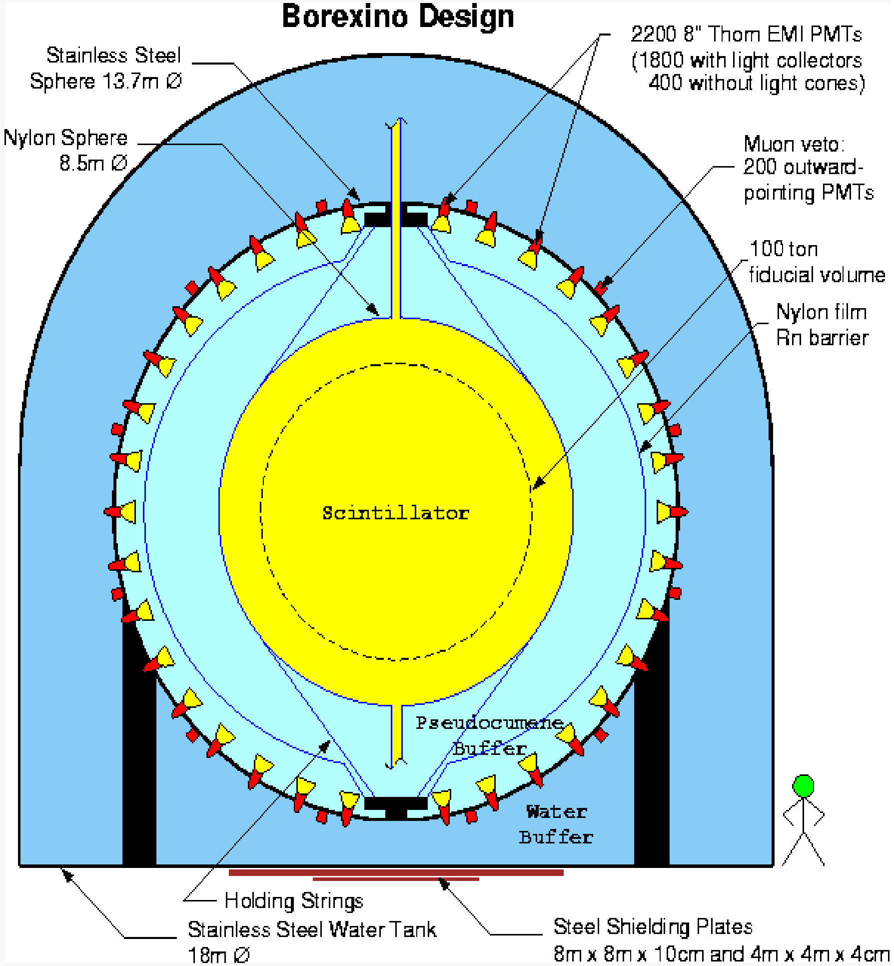
1

SAGE	Radiochemical	50 ton of Ga	Russia	pp,pep,CNO, ^{7}Be,^{8}B	Running and will run at least 3-4 years
SNO	Scintillator	1000 ton	Canada	pep,CNO, ^{7}Be,^{8}B	Under reconstruction
Super-K	Water Cherenkov	50000 ton of H_2O	Japan	^{8}B	Running as SK III will run long time
KamLAND II	Scintillator	1000 ton	Japan	pep,CNO, ^{7}Be,^{8}B	Plan to start in 2007!
Borexino	Scintillator	300 ton	Italy	pep,CNO, ^{7}Be,^{8}B	Hope to start in 2007?

BOREXino Experiment

Borexino is an unsegmented liquid detector: 300 tonnes of well shielded ultrapure scintillator (Pseudocumene), viewed by 2200 photomultipliers.

The detector core is a transparent spherical vessel (Nylon Sphere, 100 micron thick), 8.5 m of diameter, surrounded by 1000 tonnes of a high-purity buffer liquid.



The detection of the ^{7}Be neutrino signal in the 100 tonnes of the Borexino Fiducial Volume requires the intrinsic radiopurity of the scintillator to bebelow 5×10^{-15} g/g of U,Th equivalent.

The Borexino physics:

- First measurement of solar neutrinos below 1 Mev in real-time!

(arXiv:0708.2251v1 [astro-ph] 16 Aug 2007,

First real time detection of ^{7}Be solar neutrinos by Borexino)

5. Conclusions

We have measured the 0.862 MeV ^{7}Be component of solar neutrino spectrum in the Borexino detector. The best value for the rate is <u>47 ± 7stat ± 12sys counts/(day · 100 ton)</u>. The expected rate based on solar models and neutrino oscillations is 49±4 counts/(day · 100 ton) while the rate expected without oscillations is 75±4 counts/(day · 100 ton).

- Gran Sasso is favorite over Kamland, being deeper (less ^{11}C background): expected (<u>signal/noise~0.4</u>);
- possibility to apply three-fold coincidence cut to further reduce ^{11}C background (<u>signal/noise>2</u>); *[Phys.Rev.C 71,055805 (2005)]*

(from http://borex.lngs.infn.it/)

May 15, 2007 11:25 CEST: Borexino filling completed!!

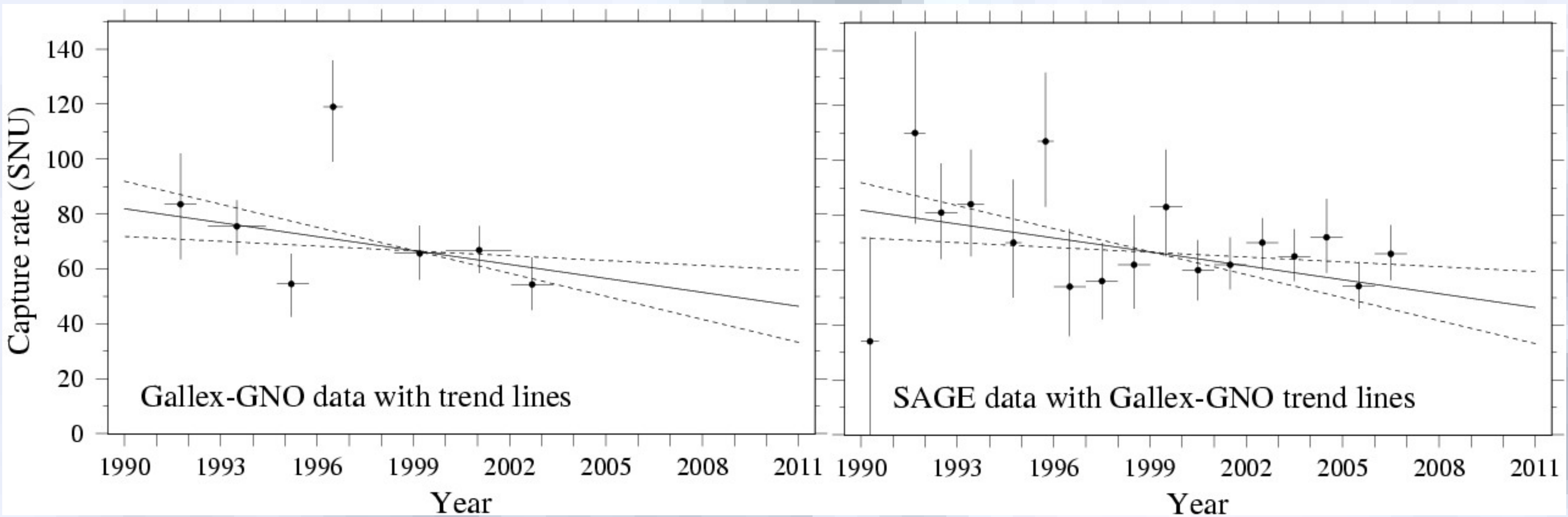
May 16, 2007 01:25 CEST: first run with full detector started

- we are taking data! -

Time period	05/91-01/97	05/98-04/03	05/91-04/03	04/03-12/06	Full data set 01/90-12/06
Number of runs	65	58	123		
GALLEX/GNO	$77.5 \pm 6.2^{+4.3}_{-4.7}$	$62.9^{+5.5}_{-5.3} \pm 2.5$	$69.3 \pm 4.1 \pm 3.6$	–	–
	$77.5^{+7.6}_{-7.8}$	$62.9^{+6.0}_{-5.9}$	69.3 ± 5.5		
Number of runs	45	49	94	50	157
SAGE	$79.4^{+8.8}_{-8.4} \pm 3.9$	$65.0^{+5.1}_{-4.9} \pm 3.4$	$68.9^{+4.5}_{-4.3} \pm 3.4$	$64.0^{+5.3}_{-5.1} \pm 3.4$	$66.3^{+3.3}_{-3.2}{}^{+3.5}_{-3.2}$
	$79.4^{+9.6}_{-9.3}$	$65.0^{+6.1}_{-6.0}$	$68.9^{+5.6}_{-5.5}$	$64.0^{+6.3}_{-6.1}$	$66.3^{+4.8}_{-4.5}$
Number of runs	(110)	(107)	(217)		(288)
SAGE+GALLEX/GNO	78.3 ± 5.9	63.9 ± 4.2	69.1 ± 3.9		67.6 ± 3.6

$\Delta \sim 2\sigma$

If one assumes the rate in Gallex-GNO varies linearly in time then the best fit gives
[Capture rate = 82 ± 10 - (1.7 ± 1.1) × [t(year) - 1990] Altmann M *et al.* 2005 *Phys Lett* B **616]**



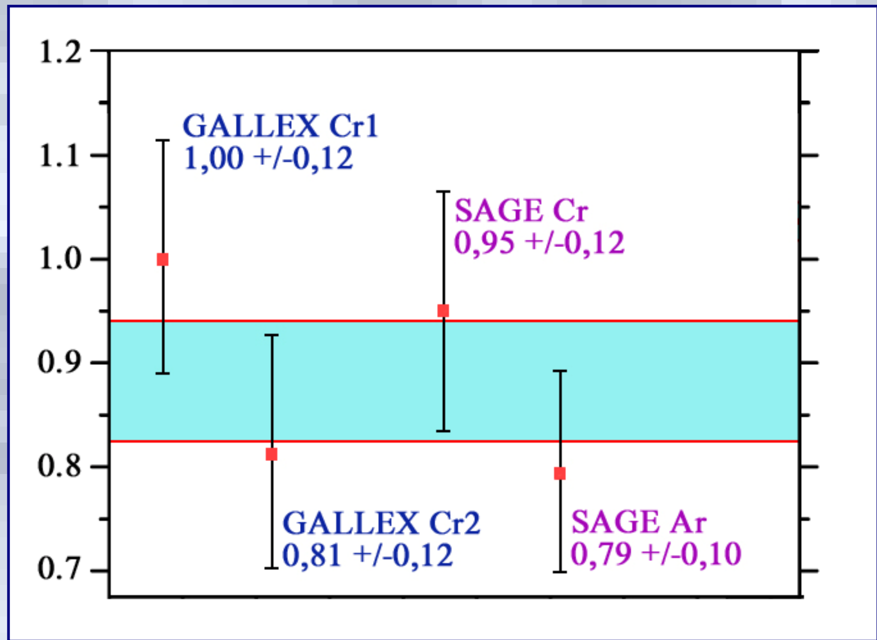
time variation	χ^2/dof	prob	χ^2/dof	prob
with	10.8/5	5.6%	11.7/16	76%
without	13.2/6	4.0%	11.4/17	83%

At the present time we cannot differentiate between these two hypotheses, but it should become possible to do so with additional data.

Comparison of source experiments with Ga

Item	GALLEX Cr1[2, 3]	GALLEX Cr2 [2,3]	SAGE ^{51}Cr [1]	SAGE ^{37}Ar
Source production				
Mass of reactor target (kg)	35.5	35.6	0.512	330
Target isotopic purity	38.6% ^{50}Cr	38.6% ^{50}Cr	92.4% ^{50}Cr	96.94% ^{40}Ca
Source activity (kCi)	1714 +30/-43	1868 +89/-57	516.6 ± 6.0	409 ± 2
Specific activity (kCi/g)	0.048	0.052	1.01	92.7
Gallium exposure				
Gallium mass (tones)	30.4 ($GaCl_3$:HCl)	30.4 ($GaCl_3$:HCl)	13.1 (Ga metal)	13.1 (Ga metal)
Gallium density (10^{21} ^{71}Ga/cm^3)	1.946	1.946	21.001	21.001
Measured production rate ρ (^{71}Ge/d)	11.9 ±1.1 ±0.7	10.7 ±1.2 ±0.7	14.0 ±1.5 ±0.8	11.0 +1.0/-0.9 ±0.6
R=P(measured)/P(predicted)	1.00 +0.11/-0.10	0.81 ±0.10	0.95 ±0.12	0.79 +0.09/-0.10

The weighted average value of *R*, the ratio of measured to predicted ^{71}Ge production rates, is 0.88 ± 0.05, more than two standard deviations less than unity.



2 Stage of R&D

CC exp. (ν_e only)

νe scattering exp. ($\nu_e + \alpha(\nu_\mu + \nu_\tau)$)

proposed

experiment	reaction	detector
LENS	$\nu_e\ {}^{115}In \rightarrow {}^{115}Sn, e, \gamma$	60 tons In-loaded scintillater ($pp, {}^7Be$)
MOON	$\nu_e\ {}^{100}Mo \rightarrow e^{-}\ {}^{100}Tc(\beta)$	3,3 ton 100Mo foil +plastic scintillator ($pp, {}^7Be$)
Lithium	$\nu_e\ {}^7Li \rightarrow e^{-}\ {}^7Be$	Radiochemical, 10 ton lithium
CLEAN	$\nu e \rightarrow \nu e^{-}$	10 ton Liquid Ne ($pp, {}^7Be$)
XMASS	$\nu e \rightarrow \nu e^{-}$	10 ton Liquid Xe ($pp, {}^7Be$)
HERON	$\nu e \rightarrow \nu e^{-}$	10 ton super-fluid He ($pp, {}^7Be$)
TPC type	$\nu e \rightarrow \nu e^{-}$	Tracking electron in gas target ($pp, {}^7Be$)
SNO	$\nu e \rightarrow \nu e^{-}$	1000 ton Liquid scintillater ($pep, {}^7Be, CNO$)
LENA	$\nu e \rightarrow \nu e^{-}$	50,000 ton Liquid scintillater Ne ($pp, {}^7Be, CNO, {}^8B$)

SNOLAB Underground facilities

Construction Status

- **Phase I (Cube Hall, Ladder Labs)**
  - Blasting is complete, concrete floors and wall covering almost complete and will be finished in June.
  - Outfitting contractor mobilizes in June. Outfitting of the new personnel facilities and laboratory spaces will be completed in early 2008. Construction activities for experiment installation in the new halls can begin in early 2008.
- **Phase II (Cryopit)**
  - Funding almost finalized. The intent is to begin excavation next month.
  - Excavation would be in parallel with outfitting of Phase I and would be ready for occupancy early 2009.

Underground Facilities

- All space will be clean (Class ~1000)
- All space at 2 km depth
- Services such as cooling, power, UPW etc
- Materials handling including cleaning

SNOLAB Science Programme

- Dark Matter Search
  - Picasso — Superheated droplets
  - DEAP — Liquid Argon scintillation
  - LUX, Zeplin — Liquid Xe scintillation/ionization
  - Super CDMS — Ge thermal + ionization
- All look for scattering of WIMPs from regular matter and employ some mechanism for rejecting gamma backgrounds

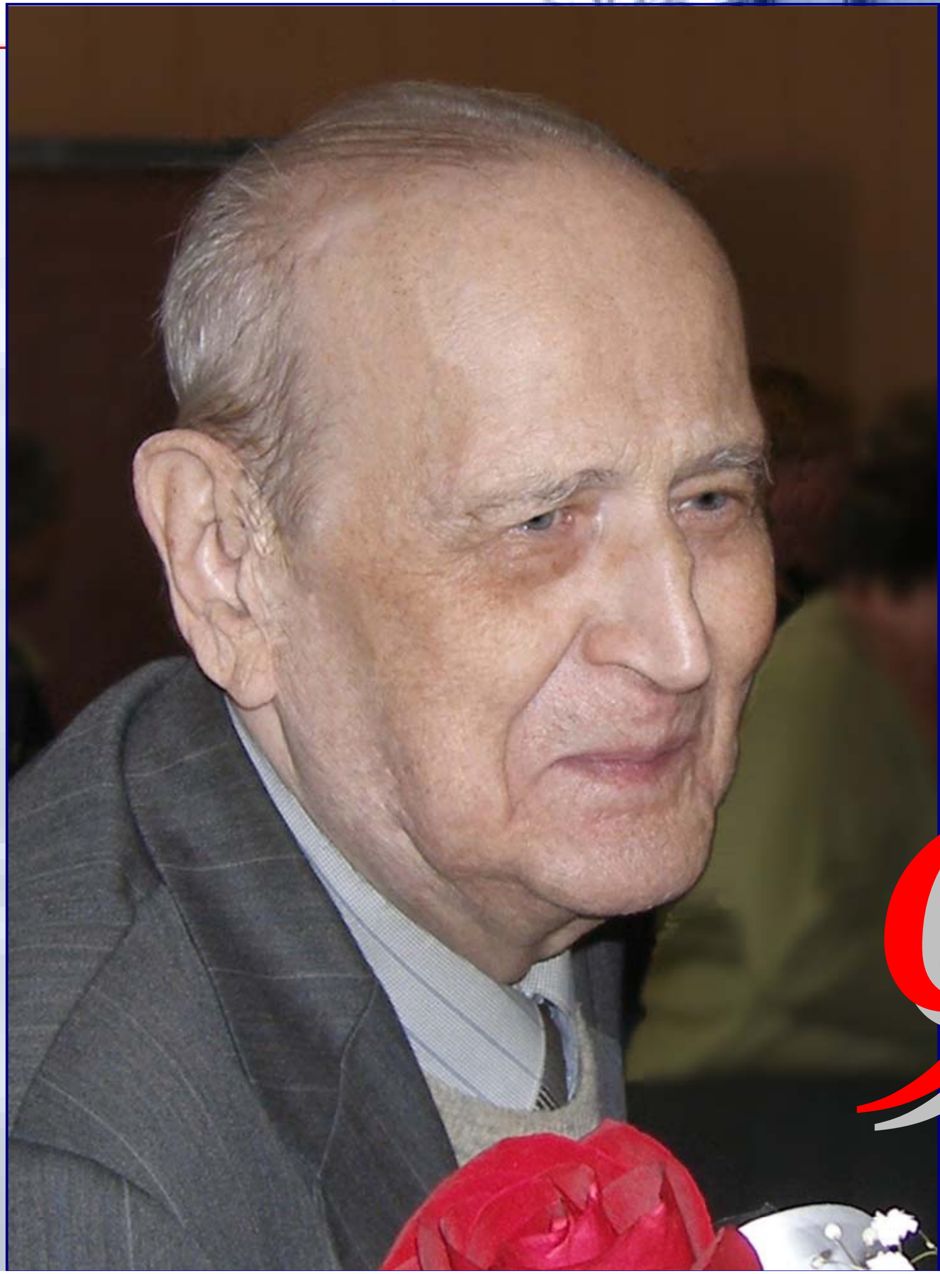
Low Energy Solar Neutrinos

- **SNO has measured the ^{8}B spectrum with precision comparable with theory**
- **SNO+ is a proposal to replace the heavy water in SNO with liquid scintillator**
  - Could provide a precision measure of ^{7}Be and pep – pep would be unique capability and would test the most precise predictions of solar models
  - Some sensitivity to CNO rates
- **CLEAN is a proposal for a liquid Ne scintillation detector**
  - offers a direct counting measure of pp neutrinos

The Future

- SNOLAB is almost complete
- The future for discoveries in Dark Matter, double beta decay, solar physics and geo-neutrinos looks very exciting
- We continue down the route established by the vision of Zatsepin

Академик Г.Т.Зацепин, 28.05.2007



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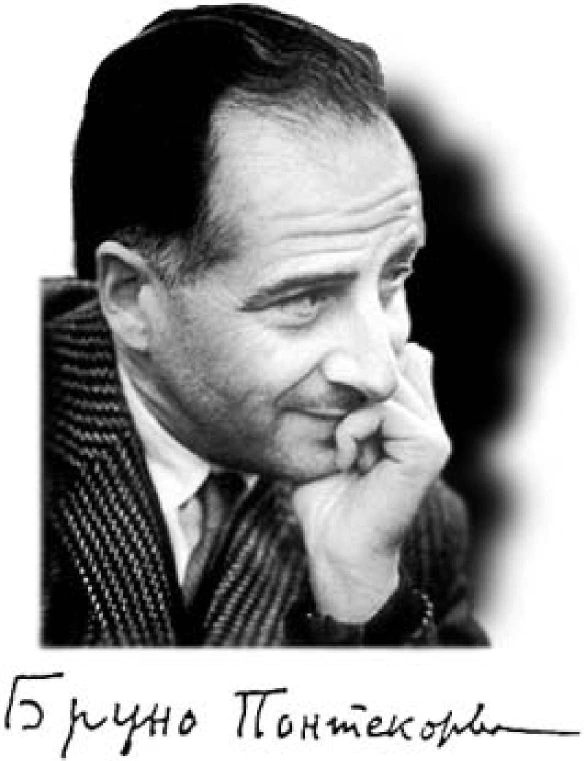


available, so that the requirement is of importance in a neutrino experiment.

5. The background, (i.e., the production of element Z ± 1 by other causes than the inverse β process), must be as small as possible.

An Example

" The object of this note is to show that the experimental observation of an inverse process produced by neutrinos is not out of the question with the modern experimental facilities, and to suggest a method which might make an experimental observation feasible. "

" The neutrino flux from the sun is of the order of $10^{10} cm^{-2} sec^{-1}$. The neutrinos emitted by the sun, however, are not very energetic. The use of high intensity piles permits two possible strong neutrino sources."

B. PO

CHALK R

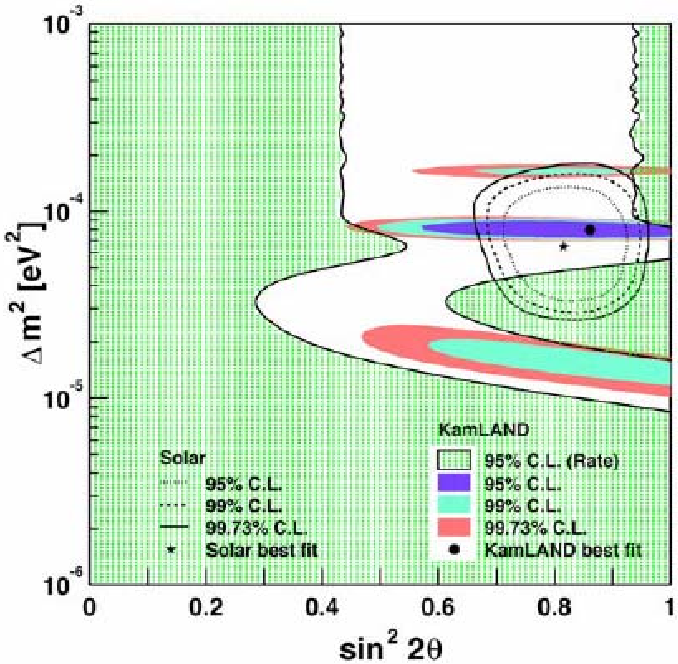
20 NOV

background, is fulfilled.

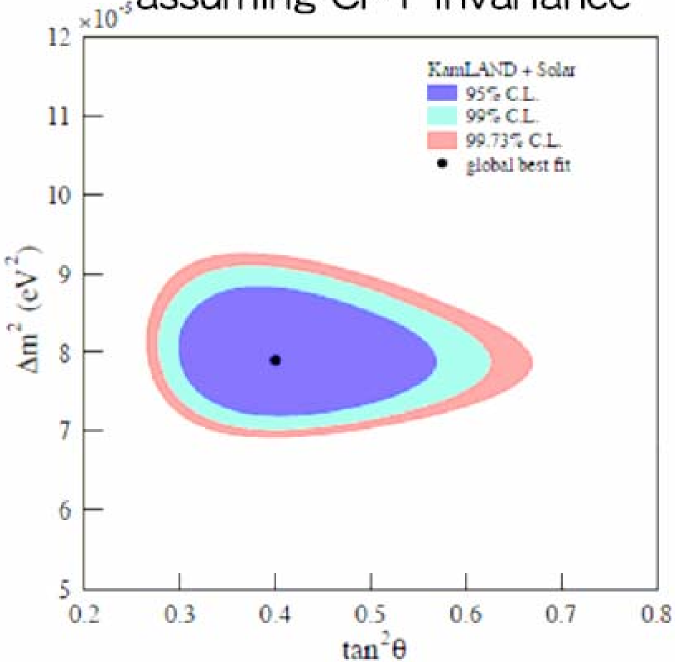
Causes other than inverse β processes capable of producing the radio element looked for are:-

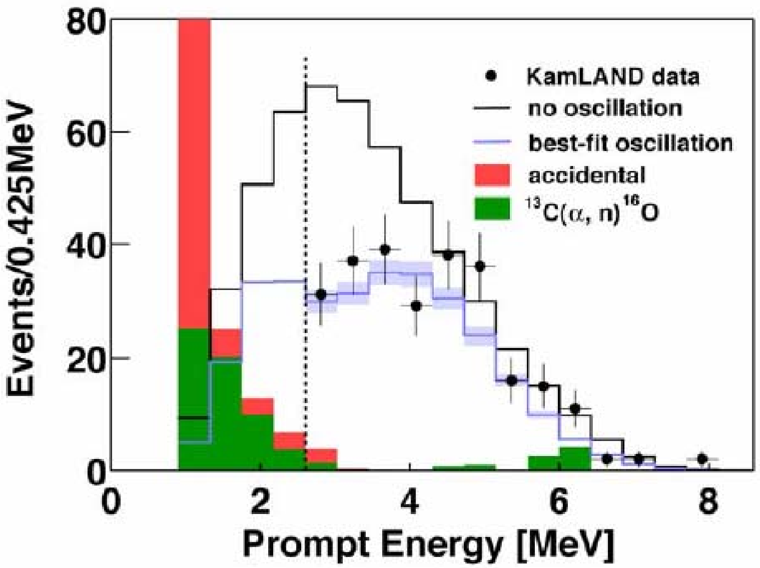
(a) (np) processes and Nuclear Explosions. The production of background by (np) process against the nucleus bombarded is zero, if the particular inverse β process selected involves the

Oscillation Analysis



KamLAND + Solar
assuming CPT invariance





KamLAND best-fit (rate + shape)

$$\Delta m^2 = 7.9 \times 10^{-5}\ \mathrm{eV}^2, \quad \tan^2\theta = 0.46$$

KamLAND + Solar

$$\Delta m^2 = 7.9^{+0.6}_{-0.5} \times 10^{-5}\ \mathrm{eV}^2, \quad \tan^2\theta = 0.40^{+0.10}_{-0.07}$$