The Solar Neutrinos

1. A little bit history

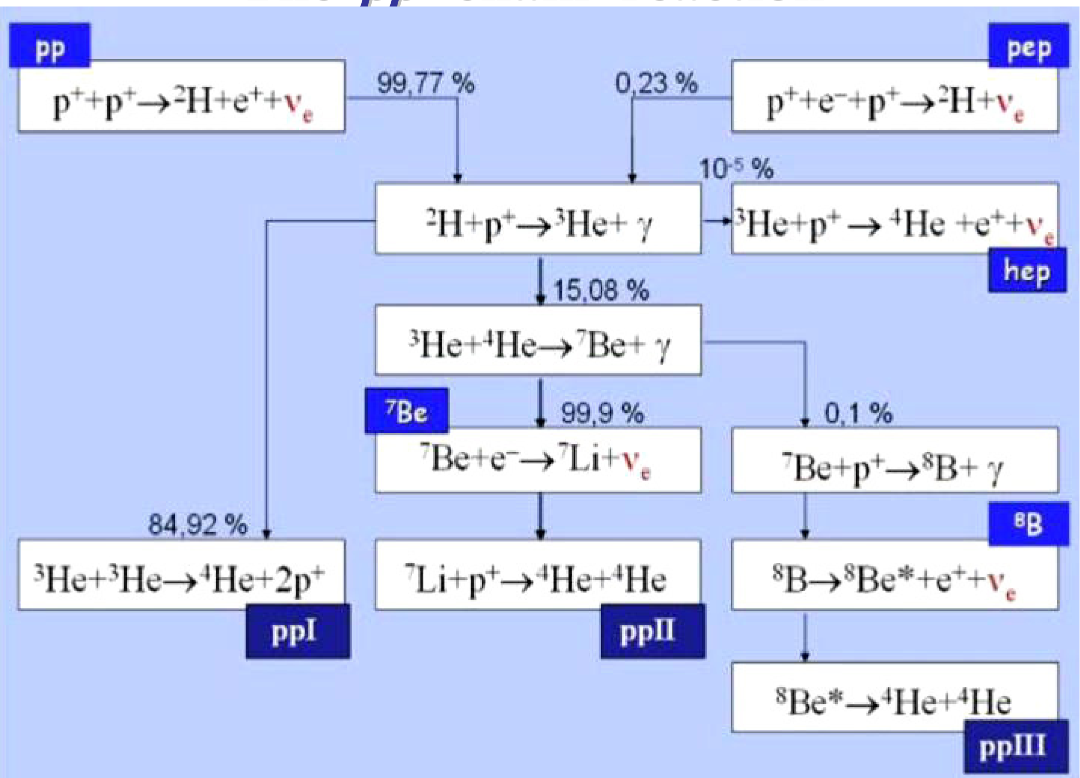
2. The past and current solar neutrino experiments: last results and future plans

3. Future projects

Neutrino production in the Sun

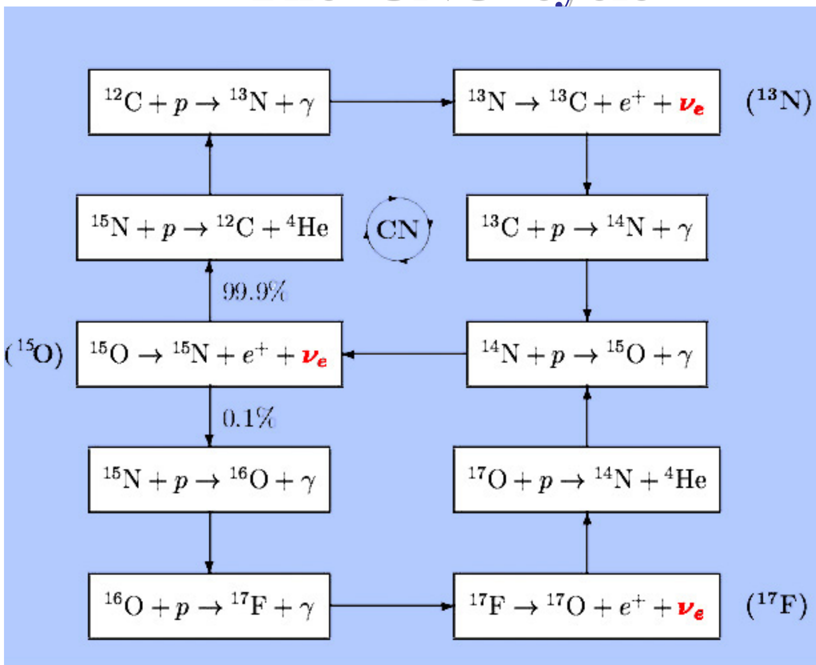
There are different steps in which energy (and neutrinos) are produced

The *pp* chain reaction



>99% of the energy is created in *pp* chain reaction

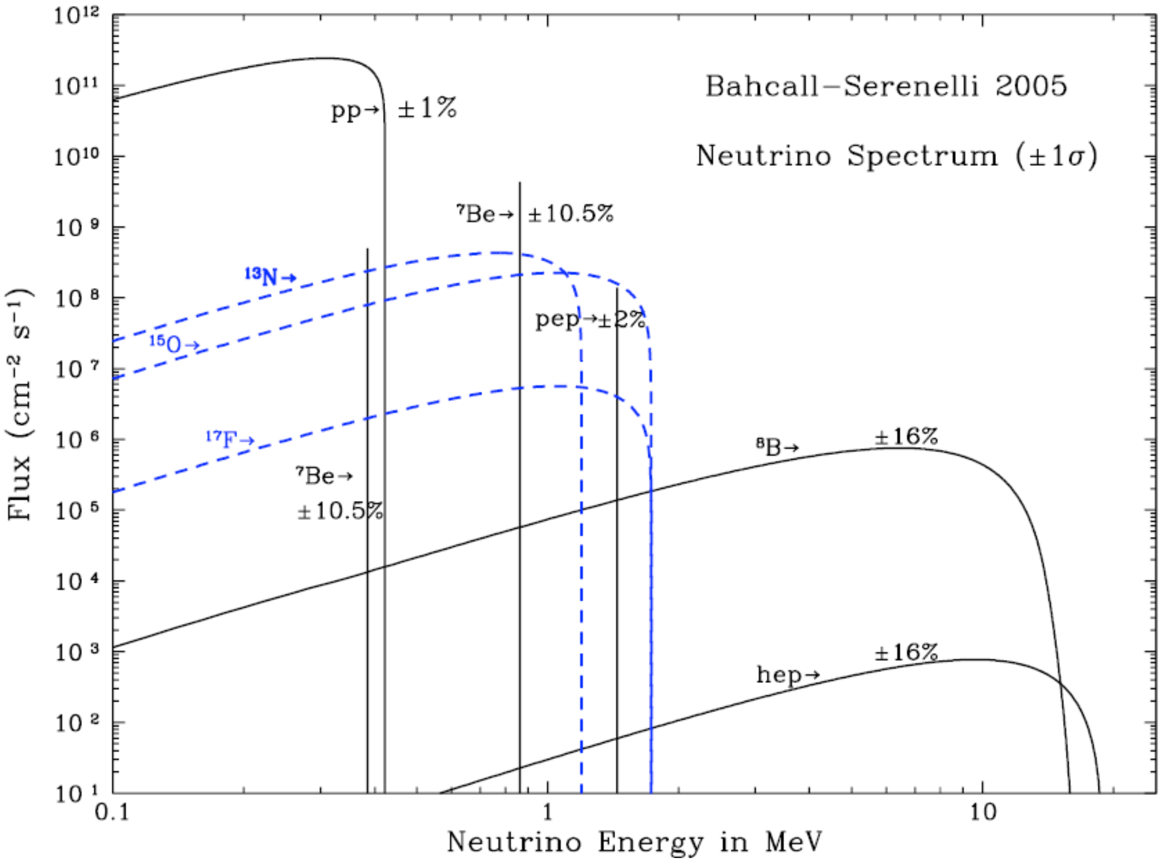
The CNO cycle



<1% in CNO cycle

Neutrino production in the Sun

Neutrino energy spectrum as predicted by the **Solar Standard Model (SSM)**



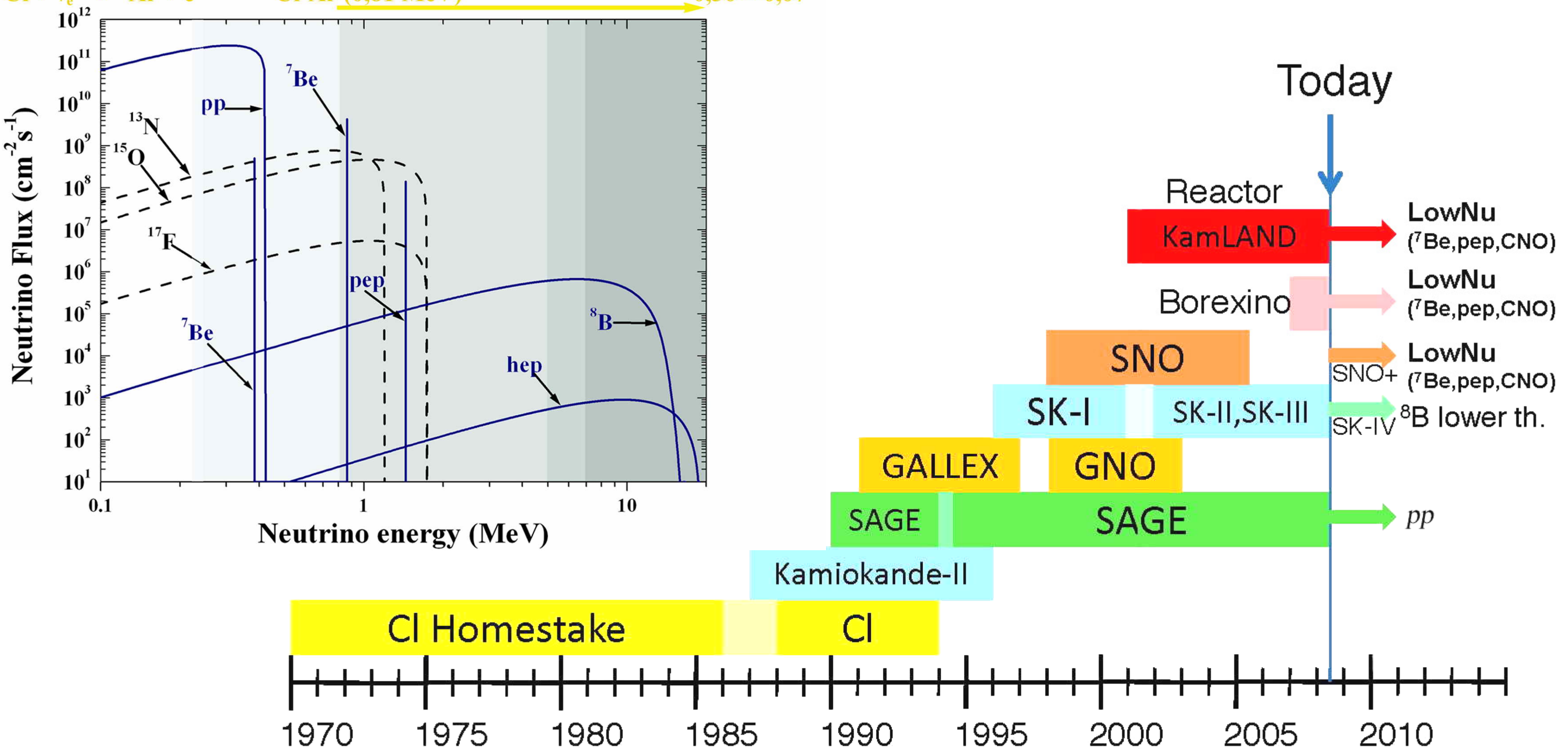
John Norris Bahcall
(Dec. 30,1934 – Aug. 17, 2005)

^{7}Be: 384 keV (10%)
862 keV (90%)
Pep: 1.44 MeV

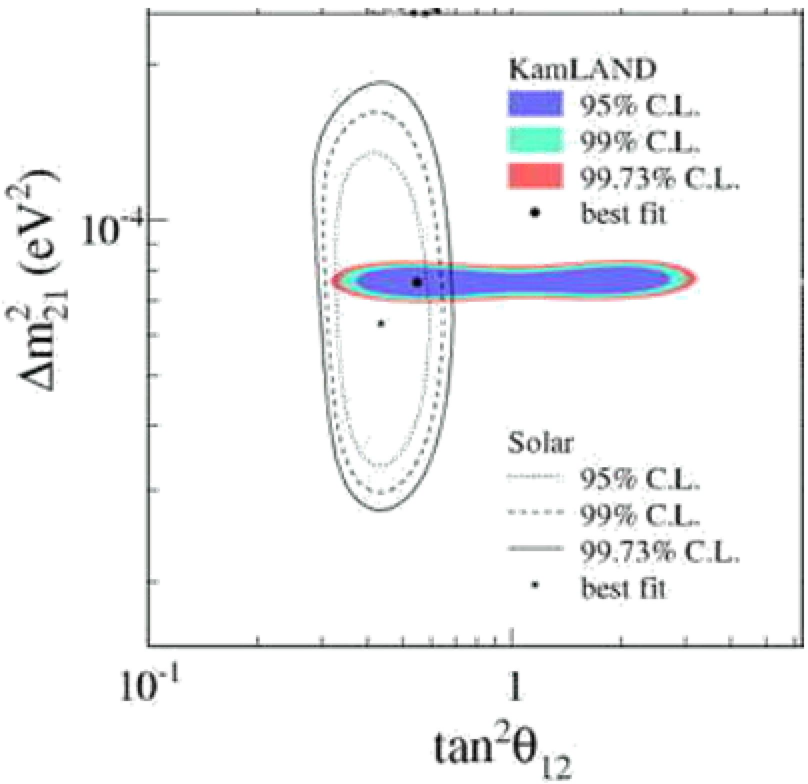
14-th Lomonosov conference
on elementary particle physics
Moscow, August 19-25,2009
INR V.N. Gavrin

40 years of solar neutrino mystery

ve	BOREXINO (0,25 MeV)	0,63 ± 0,19
ve, CC, NC	SNO (5,0 MeV)	0,90 ± 0,08
ve	SuperK (5,0 MeV)	0,406 ± 0,09
$^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$	Ga-Ge (0,23 MeV)	0,50 ± 0,05
ve	Kamiokande II (7,0 MeV)	0,48 ± 0,08
$^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$	Cl-Ar (0,81 MeV)	0,30 ± 0,07



Long standing discrepancy between measured and predicted fluxes: SNP
Culminated with a crystal clear proof that neutrino oscillates



SOLAR + KAMLAND (Reactor ν's)

$$\Delta m^2 = 7.59^{+0.19}_{-0.21} \times 10^{-5}$$

$$\theta_{12} = 34.4^{+1.3}_{-1.2}$$

Phys.Rev.Lett.101:111301,2008

MSW matter enhanced flavor conversion LMA solution

Solar + KamLAND fit results

$$\Delta m^2 = 7.59^{+0.19}_{-0.21} \times 10^{-5}\ \text{eV}^2$$

$$\phi_{8B} = 4.91 \times 10^6 cm^2 s^{-1} (\pm \sim 7\%)$$

$$\theta_{12} = 34.4^{+1.3}_{-1.2}\ \text{degrees}$$

$$\theta_{12} = 33.9^{+2.4}_{-2.2}\ \text{deg (previous)}$$

Neutrino flavour symmetry phenomenology:
(Smirnov summary at Neutrino 2008)
Tri-Bi-Maximal Mixing: 35.2 deg
Quark-Lepton Complementarity: 32.2 deg
($\theta_{12} + \theta_{Cabbibo} = 45$ deg)

The accuracy on θ_{12} and ϕ_{8B} will improve with new data analysis: SNO LETA

This work:

- SNO NCD results agree well with previous SNO phases. Minimal correlation with CC. Different systematics.
- New precision on θ

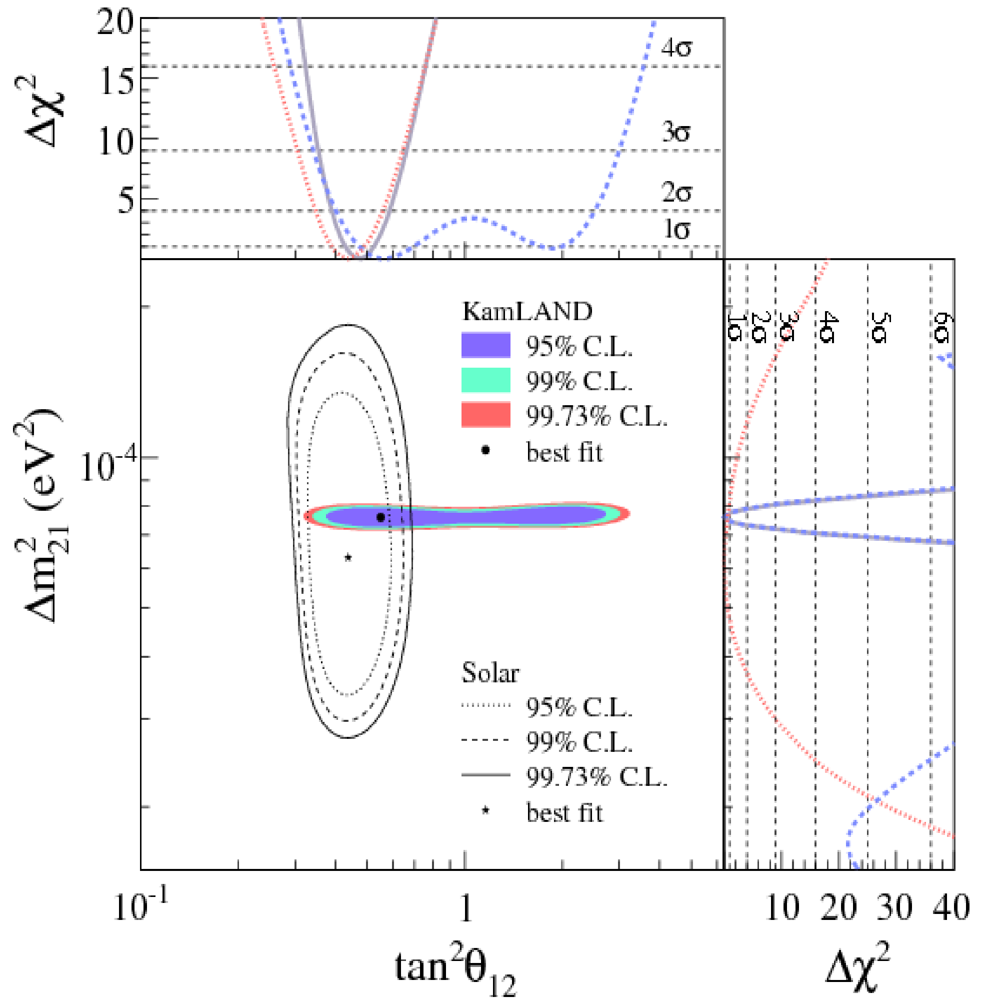
Future solar analysis:

- LETA (Low Energy Threshold Analysis)
- 3-neutrino analysis
- *hep* flux
- Day-night, other variations
- Muons, atmospheric ν

Slight disagreement between

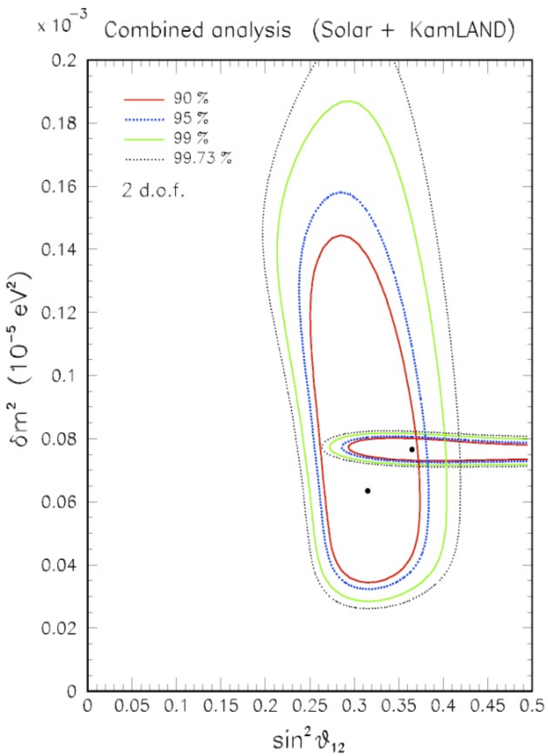
- Solar data (SNO dominated)
- KamLAND data (at $\theta_{13} = 0$)

when the two best-fits are compared in the usual plane (m^2_{12}, $\tan^2\theta_{12}$)

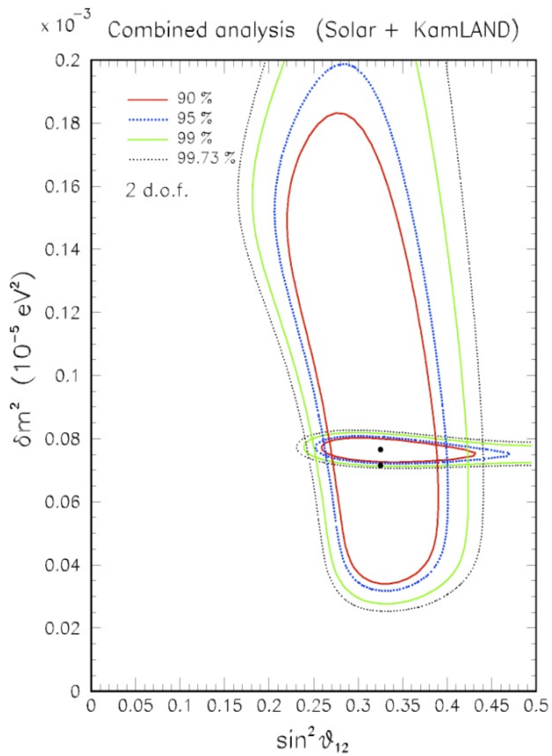


[figure taken from the official Kamland site (2008)]

Disagreement reduced for $\theta_{13} > 0$ …



$\sin^2\theta_{13}$ = 0



$\sin^2\theta_{13}$ = 0.03

(figures prepared by A.M. Rotunno for this talk)

… thanks to the different dependence in SNO and KamLAND from (θ_{13} , θ_{12}).

Summary

- Low Energy Threshold Analysis nearly complete
- Expect significant improvements in precision
- Many other SNO analyses also finishing up

The Sudbury Neutrino Observatory: SNO

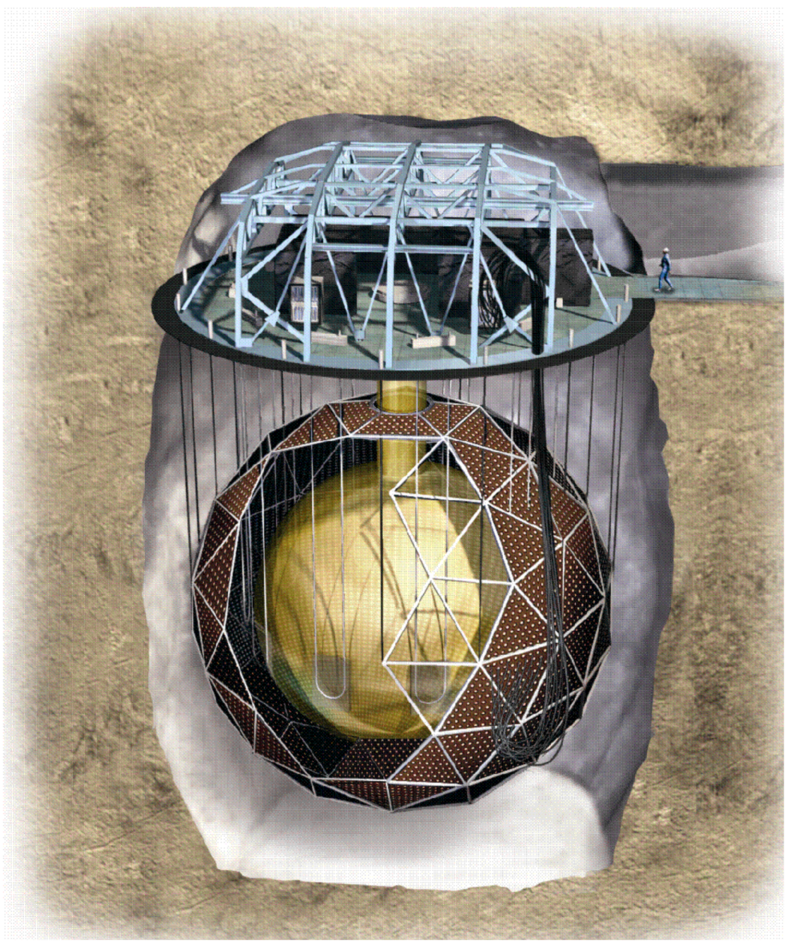
Acrylic vessel (AV)
12 m diameter

1000 tonnes D_2O
($300 million)

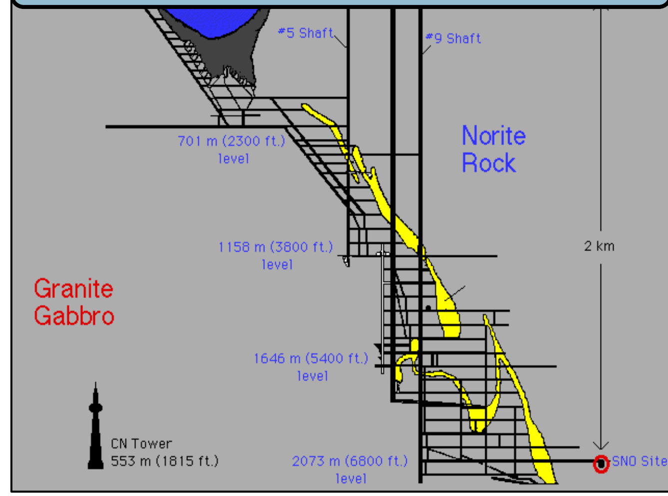
1700 tonnes H_2O
inner shielding

5300 tonnes H_2O
outer shielding

~9500 PMT's



6800 feet (~2km) underground



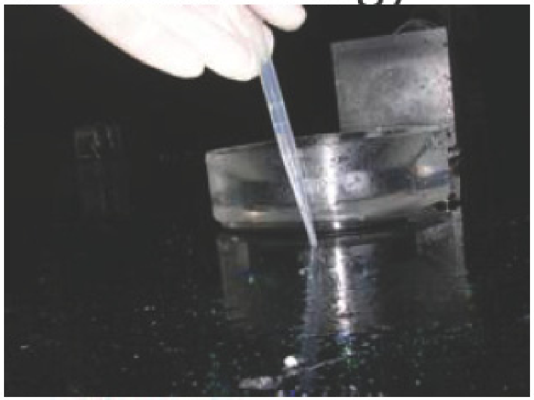
Creighton mine
Sudbury, CA

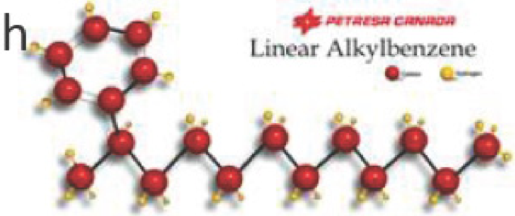
- Entire detector Built as a Class 2000 Clean room
- Low Radioactivity Detector materials

The heavy water has been returned and development work is in progress on SNO+ with liquid scintillator and ^{150}Nd additive.

SNO+

- $300M of heavy water removed and returned to Atomic Energy of Canada Limited (every last drop)
- SNO detector to be filled with liquid scintillator
  - 50-100 times more light than Čerenkov
- linear alkylbenzene (LAB)
  - compatible with acrylic, undiluted
  - high light yield, long attenuation length
  - safe: high flash point, low toxicity
  - cheaper than other scintillators
- physics goals: *pep* and *CNO* solar neutrinos, geo neutrinos, reactor neutrino oscillations, supernova neutrinos, double beta decay with Nd



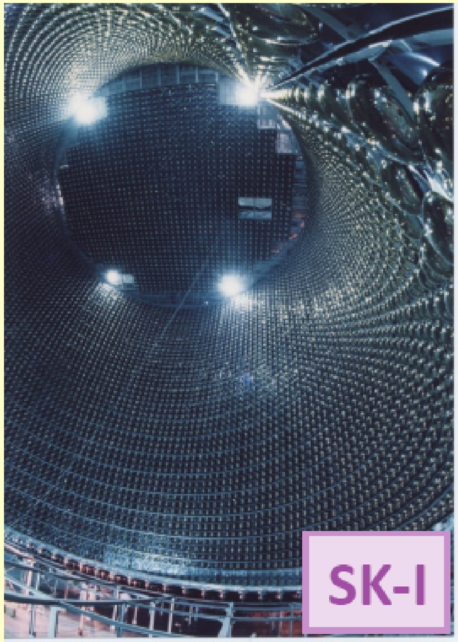


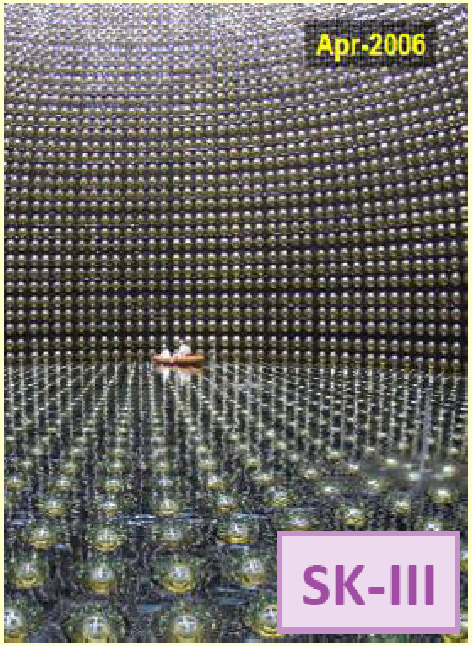
Super-Kamiokande History

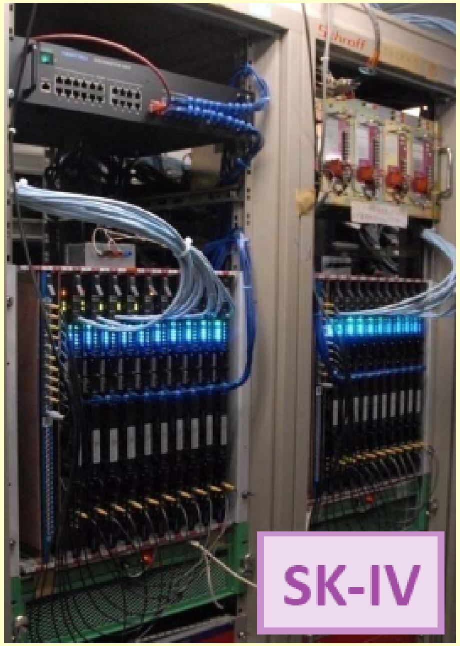
inner detector mass: 32kton fiducial mass: 22.5kton

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009

SK-I SK-II SK-III SK-IV



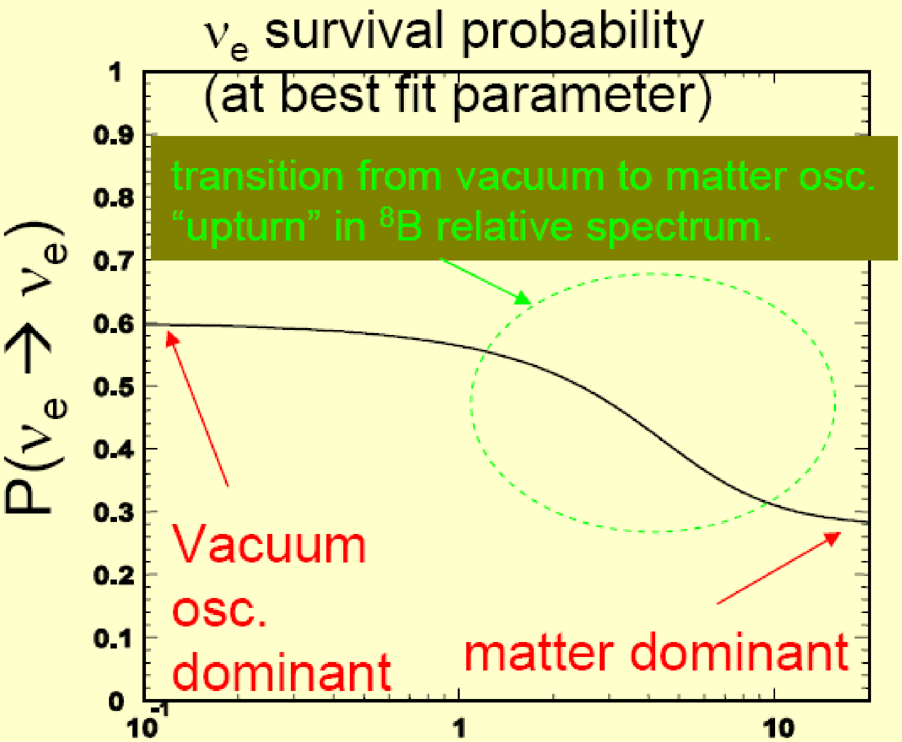


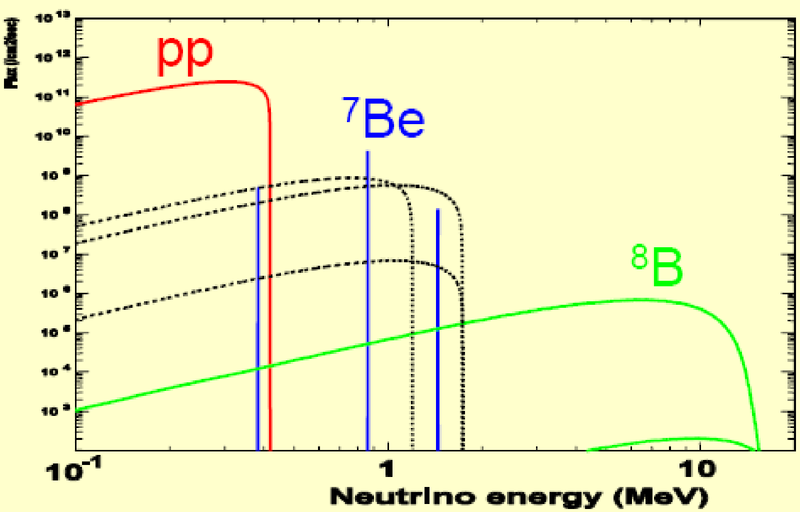


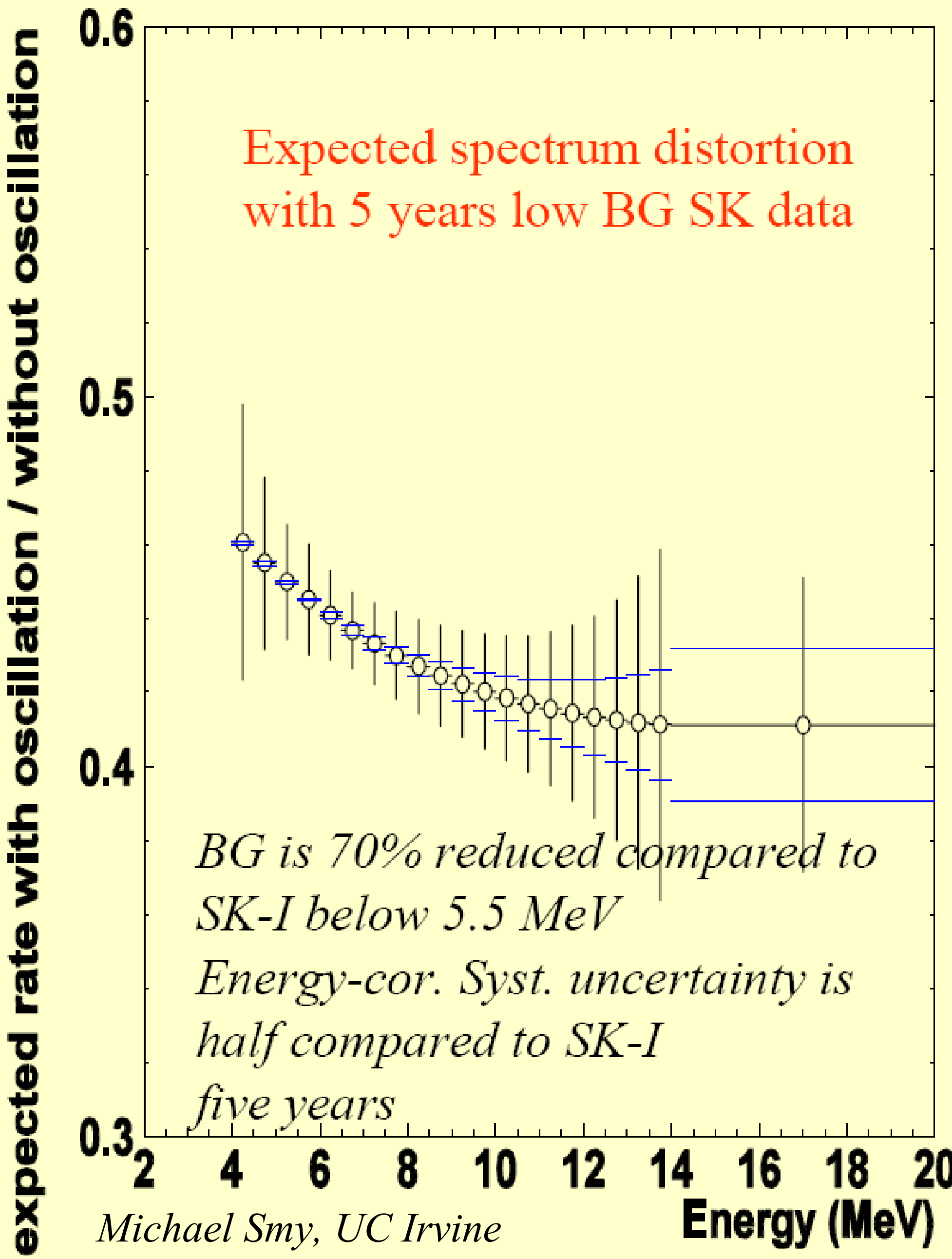
	SK-I	SK-II	SK-III	SK-IV
	11146 ID PMTs (40% coverage)	5182 ID PMTs (19% coverage)	11129 ID PMTs (40% coverage)	Electronics Upgrade
Energy Threshold (total electron energy)	5.0 MeV	7.0 MeV	4.5 MeV work in progress	< 4.0 MeV target

Michael Smy, UC Irvine

Solar Neutrino Future Prospects in SK







Michael Smy, UC Irvine

Borexino - 2008

- 8″ PMT – 2212
- Scintillator – 278.3 ton
- Energy region – (250 – 800) KeV
- SSM (osc.) – (49±4) counts/day 100ton

  without osc. – (75±4) counts/day 100ton

Exp. – (49 ± 3) cpd/100 tons

•Borexino is located under the Gran Sasso mountain which provides a shield against cosmic rays (4000 m water equivalent);

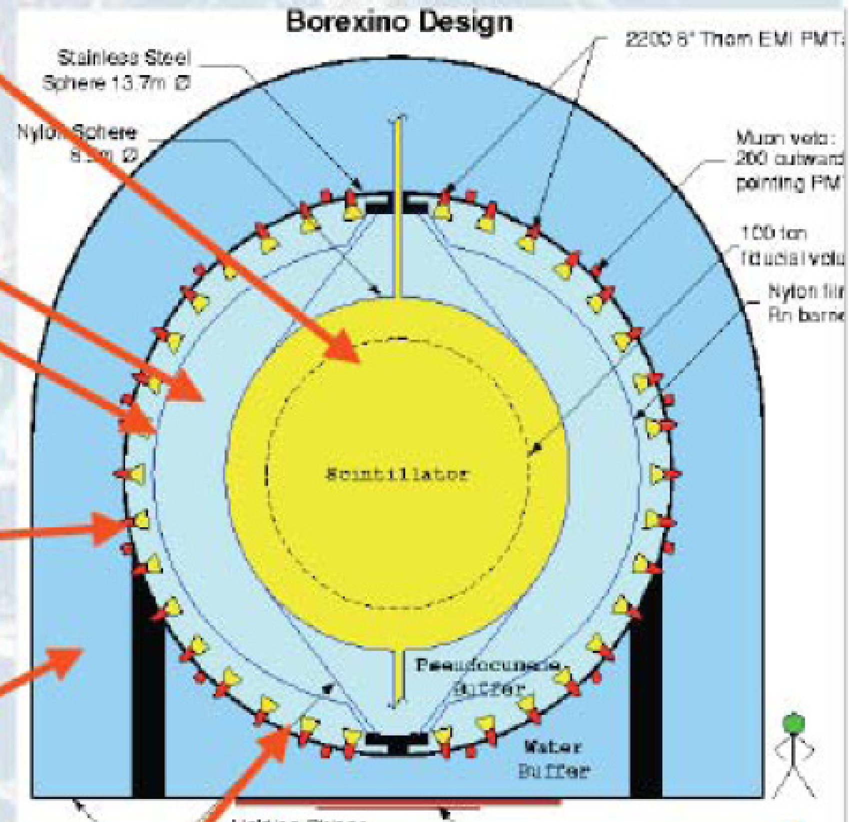
Core of the detector: 278 tons of liquid scintillator contained in a nylon vessel of 4.25 m radius (PC+PPO);

1st shield: 890 tons of ultra-pure buffer liquid (PC+quencher) contained in a stainless steel sphere of 6.75 m radius;

External nylon vessel; it is a barrier against Rn emitted by PMT and s.steel

2214 photomultipliers pointing towards the center to view the light emitted by the scintillator (1843 with opt. concentr.)

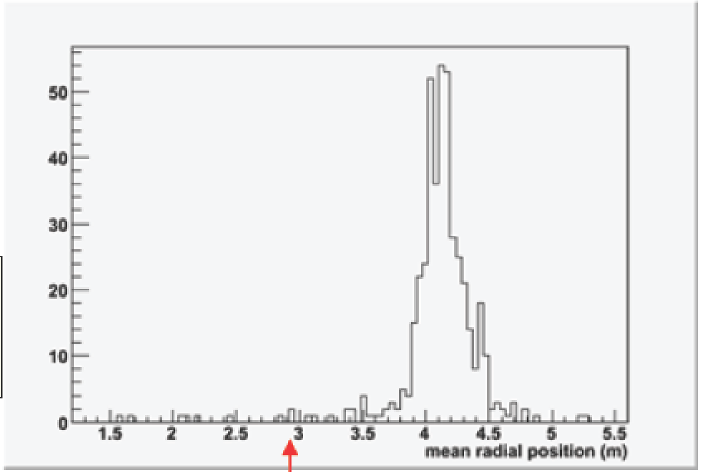
2nd shield: 2100 tons of ultra-pure water contained in a cylindrical dome;



200 PMTs mounted on the SSS pointing outwards to detect light emitted in the water by muons crossing the detector;

Unprecedented intrinsic ultra lowbackground levels

Th: (6.8±1.5) 10^{-18} g/g
from ^{212}Bi-^{212}Po



^{238}U: (1.6±0. 1) 10^{-17} g/g
from ^{214}Bi-^{214}Po

^{nat}K ≤3 10^{-14} g/g
From spectrum

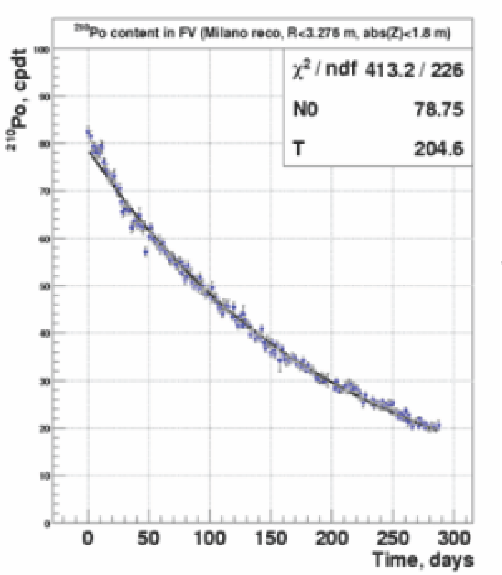
^{85}Kr β decay- 687 keV

8 events → 29±14 c/d

^{85}Kr —β→ ^{85m}Rb —γ→ ^{85}Rb

173 keV   514 keV

τ= 1.46 μs - BR: 0.43%



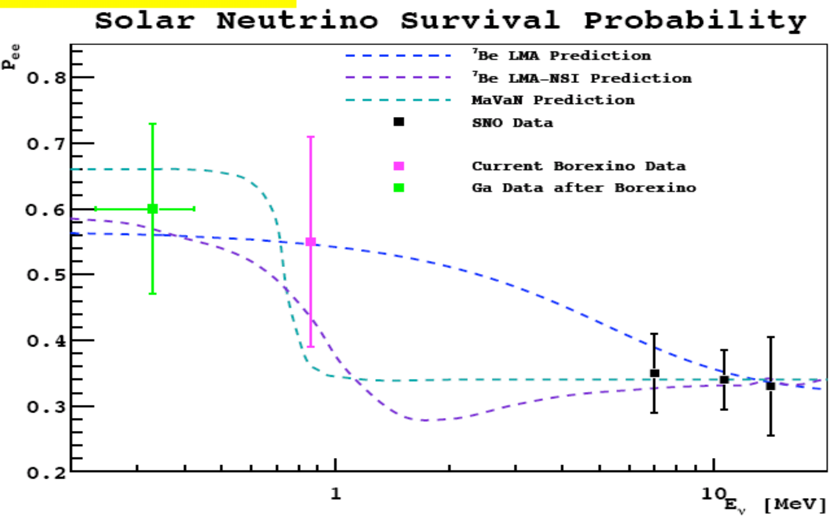
^{210}Po- α, Q=5.41 Mev quenched by ≈13-
no evidence of ^{210}Bi,initially 80 c/d/t

^{7}Be: 49 ± 3_{stat} ± 4_{sys} cpd/100 tons

Borexino results

	Expected rate (cpd/100 t)
No oscillation	75 ± 4
BPS07(GS98) HighZ	48 ± 4

After Borexino



Under the assuptions of High-Z SSM the measurement corresponds to

$$P_{ee} = 0.56 \pm 0.1\ (1s)\ \text{at}\ E=862\ \text{keV}$$

which is consistent with the number derived from the global fit to all solar and reactor experiments

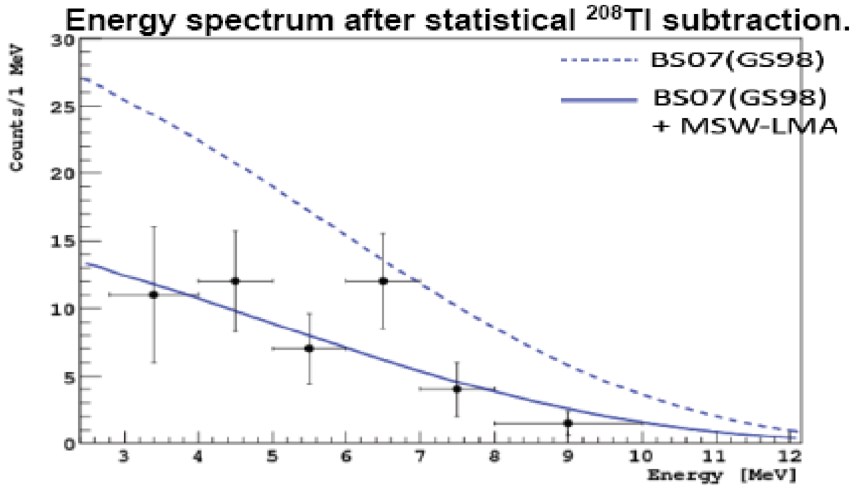
^{8}B solar neutrino flux

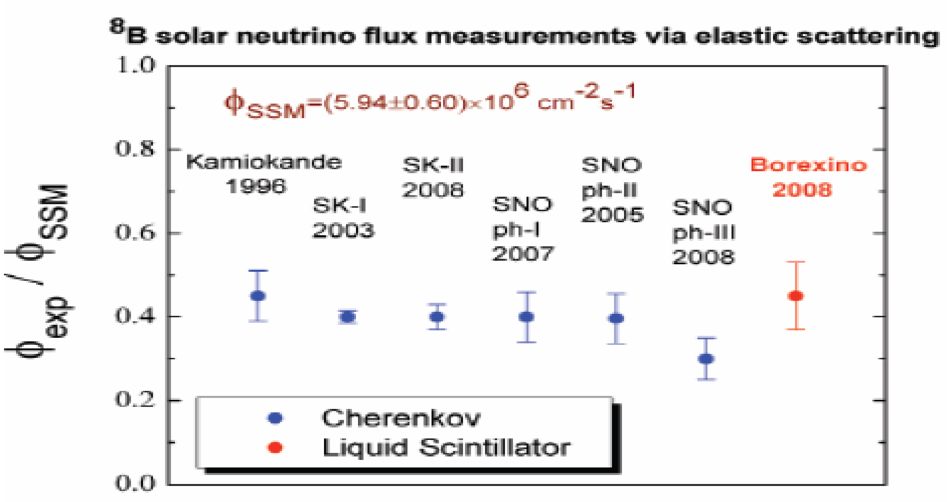
First real-time measurement down to 2.8 MeV:

$$Rate_{>2.8MeV} = (0.26 \pm 0.04_{stat} \pm 0.02_{sys})\ \text{counts/day/100 tons}$$

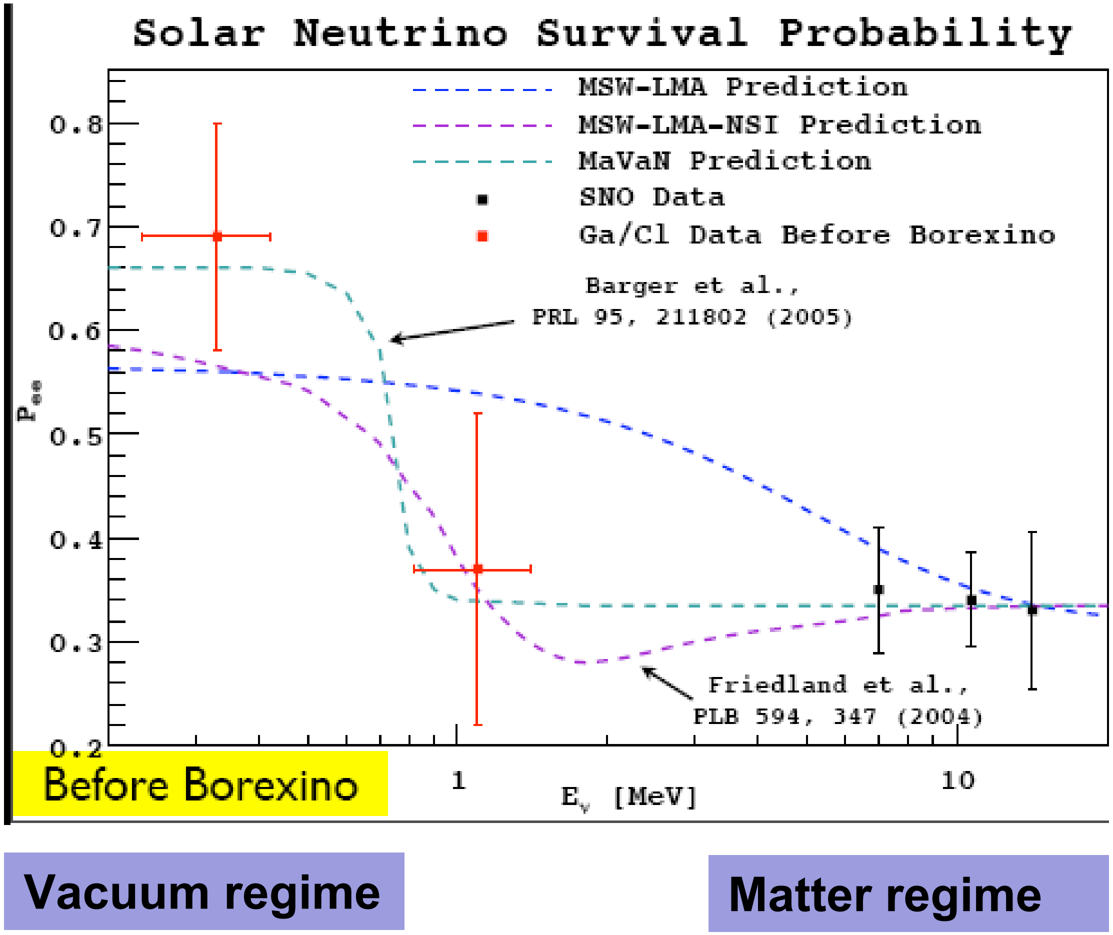
Above 5 MeV in agreement with SNO and SuperK:

$$Rate_{>5MeV} = (0.14 \pm 0.03_{stat} \pm 0.01_{sys})\ \text{counts/day/100 tons}$$





Solar neutrino survival probability
BEFORE BOREXINO



Low energy neutrinos:
flavor change dominated
by vacuum oscillations;

High energy neutrinos:
Resonant oscillations in matter
(MSW effect):
Effective electron neutrino mass
is increased due to the charge
current interactions
with electrons of the Sun

Transition region:
Decrease of the ν_e survival probability (P_{ee})

What next for solar neutrinos

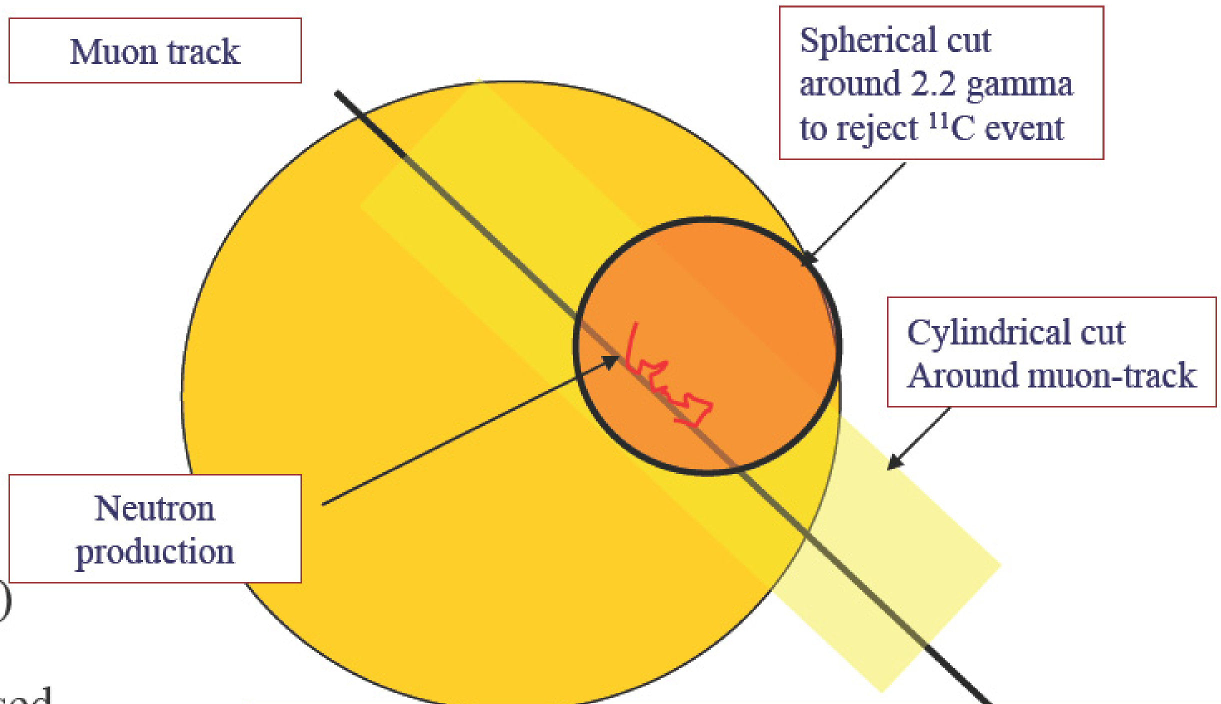
@ continue the efforts on ^{7}Be ν to shrink errors below 5 %
(more statistics, source calibration, etc)

@ pep and CNO ν investigation Main problem:cosmogenic ^{11}C

$\mu + ^{12}C \rightarrow ^{11}C + n + \mu$

$^{11}B + e^{+} + \nu_e$

n capture
γ (2.2 MeV)



≈ 14% of ν ev. are missed

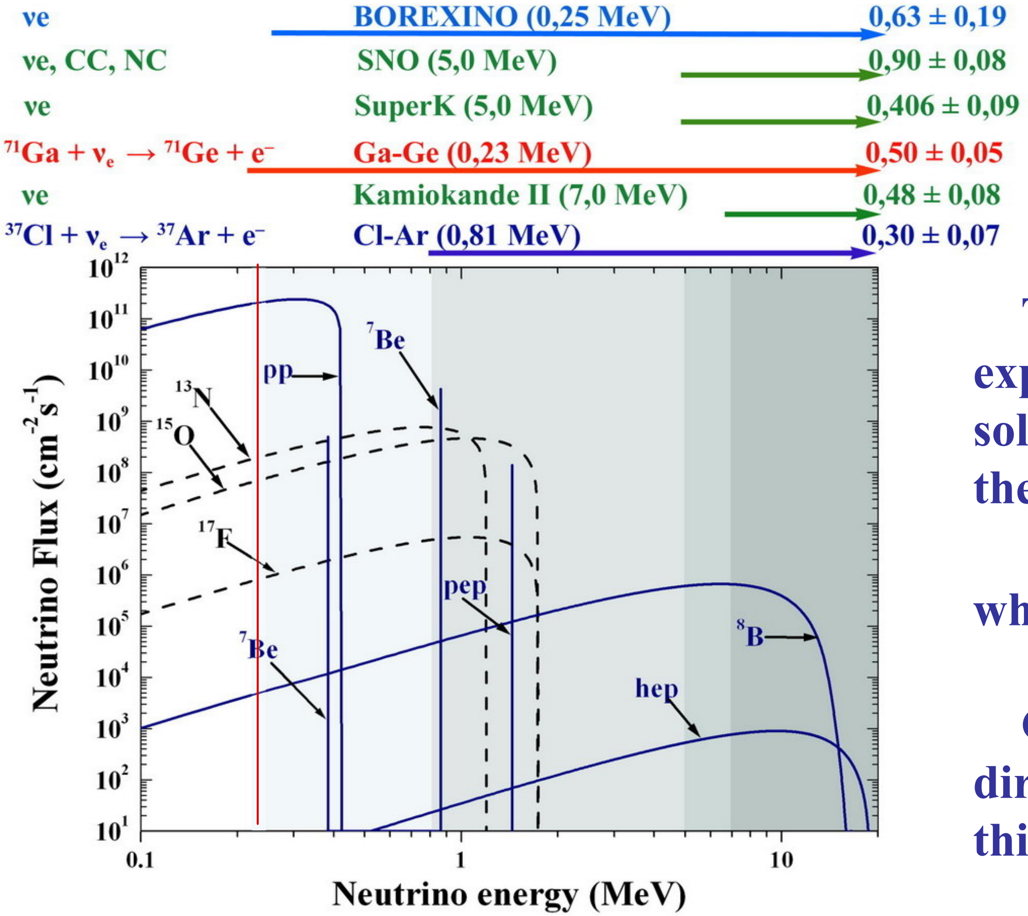
#Borex. Coll.Phys.Rev.C74,2006

Disentangling High Z vs Low Z SSM
Peña-Garay and Serenelli arxiv:810.0000
Currently the major SSM challenge

Neutrinos and Solar Metallicity

- A direct measurement of the CNO neutrinos rate could help solve the latest controversy surrounding the Standard Solar Model
- One fundamental input of the Standard Solar Model is the metallicity of the Sun - abundance of all elements above Helium
- The Standard Solar Model, based on the old metallicity derived by Grevesse and Sauval (Space Sci. Rev. **85**, 161 (1998)), is in agreement within 0.5% with the solar sound speed measured by helioseismology.
- Latest work by Asplund, Grevesse and Sauval (Nucl. Phys. A **777**, 1 (2006)) indicates a metallicity lower by a factor ~2. This result destroys the agreement with helioseismology
  - maybe it was fortuitous agreement before with high metallicity?
- use solar neutrino measurements to help resolve!
  - ^{7}Be (12% difference) and CNO (50-60% difference)

Gallium solar neutrino experiments
SAGE, GALLEX/GNO



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

The feature that distinguishes the Ga experiment from all other past or present solar neutrino detectors is its sensitivity to the pp fusion reaction,

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

which generates most of the Sun's energy.

Ga experiments have provided the only direct measurement of the current rate of this reaction.

Ga experiments:

$^{71}Ga(\nu_e, e^-)^{71}Ge$, $E_{th} = 233$ keV

Measurement of the solar neutrino capture rate

with gallium metal:

SAGE, 50 tons of metallic ^{71}Ga

168 runs for the 18-year period (Jan 1990 – Dec 2007) give the result: **$65.4^{+4.0}_{-4.1}$ SNU**

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

with gallium chloride $GaCl_3$ acidic solution:

GALLEX, 103 tons of $GaCl_3$ acidic solution containing 30 tons of natural gallium

65 runs for the 4.4-year period (May 1991 – Jan 1997) give the result: **$73.1^{+7.1}_{-7.3}$ SNU**

(Till Kirsten at TAUP2007, Sendai, September 11-15, 2007)

GNO, 103 tons of $GaCl_3$ acidic solution containing 30 tons of natural gallium

58 runs for the 4.7-year period (May 1998 – Apr 1993) give the result: **$62.9^{+5.5}_{-5.3}$ SNU**

The weighted average of the results of all Ga experiments is now

66.1±3.1 SNU

Comparison of gallium result to predictions standard of solar model

$$R = \Sigma_i \, \phi^{\odot}{}_i \langle P^{ee}{}_i \rangle \langle \sigma_i \rangle$$

i *- (pp, ^{7}Be, pep, ^{13}N, ^{15}O, ^{17}F, ^{8}B, and hep)*

Capture rates R_i for Ga experiment

$$R_i = \phi_i^{\odot} < P_i^{ee} >< \sigma_i >$$

	With GS98 composition (high metallicity)							With AGS05 composition (low metallicity)						
Spect.	Cap. rate	Percent uncertainty in rate due to					Total unc.	Cap. rate	Percent uncertainty in rate due to					Total unc.
comp.	(SNU)	ϕ	σ	Δm^2_{12}	θ_{12}	θ_{13}	in rate (%)	(SNU)	ϕ	σ	Δm^2_{12}	θ_{12}	θ_{13}	in rate (%)
pp	39.27	+ 0.8,- 0.8	+ 2.4,- 2.3	+ 0.0,- 0.0	+ 3.0,- 2.7	+ 0.0,- 3.7	+ 3.9,- 5.1	39.73	+ 0.8,- 0.8	+ 2.4,- 2.3	+ 0.0,- 0.0	+ 3.0,- 2.7	+ 0.0,- 3.7	+ 3.9,- 5.1
pep	1.43	+ 1.3,- 1.3	+17.0,- 2.4	+ 0.2,- 0.3	+ 2.4,- 2.0	+ 0.0,- 3.5	+17.2,- 4.9	1.48	+ 1.3,- 1.3	+17.0,- 2.4	+ 0.2,- 0.3	+ 2.4,- 2.0	+ 0.0,- 3.5	+17.2,- 4.9
^{7}Be	18.75	+ 5.0,- 5.0	+ 7.0,- 2.3	+ 0.1,- 0.1	+ 2.8,- 2.4	+ 0.0,- 3.6	+ 9.1,- 7.0	16.79	+ 5.0,- 5.0	+ 7.0,- 2.3	+ 0.1,- 0.1	+ 2.8,- 2.4	+ 0.0,- 3.6	+ 9.1,- 7.0
^{13}N	0.91	+20.0,-15.0	+ 9.8,- 2.3	+ 0.1,- 0.1	+ 2.8,- 2.4	+ 0.0,- 3.6	+22.4,-15.8	0.60	+20.0,-15.0	+ 9.8,- 2.3	+ 0.1,- 0.1	+ 2.8,- 2.4	+ 0.0,- 3.6	+22.4,-15.8
^{15}O	1.26	+23.0,-16.0	+12.9,- 2.3	+ 0.2,- 0.2	+ 2.6,- 2.2	+ 0.0,- 3.5	+26.5,-16.7	0.78	+23.0,-16.0	+12.9,- 2.3	+ 0.2,- 0.2	+ 2.6,- 2.2	+ 0.0,- 3.5	+26.5,-16.7
^{17}F	0.03	+25.0,-25.0	+12.9,- 2.3	+ 0.2,- 0.2	+ 2.6,- 2.2	+ 0.0,- 3.5	+28.3,-25.4	0.02	+25.0,-25.0	+12.9,- 2.3	+ 0.2,- 0.2	+ 2.6,- 2.2	+ 0.0,- 3.5	+28.3,-25.4
^{8}B	4.91	+10.1,-10.1	+31.8,-14.4	+ 0.4,- 0.4	+ 5.5,- 5.4	+ 0.0,- 3.4	+33.8,-18.7	3.90	+10.1,-10.1	+31.8,-14.4	+ 0.4,- 0.4	+ 5.5,- 5.4	+ 0.0,- 3.4	+33.8,-18.7
hep	0.02	+15.4,-15.4	+32.7,-15.4	+ 0.2,- 0.2	+ 6.3,- 6.1	+ 0.0,- 3.5	+36.7,-22.9	0.02	+15.4,-15.4	+32.7,-15.4	+ 0.2,- 0.2	+ 6.3,- 6.1	+ 0.0,- 3.5	+36.7,-22.9
Total	66.58	+ 1.7,- 1.7	+ 3.4,- 1.8	+ 0.1,- 0.1	+ 2.0,- 1.8	+ 0.0,- 2.4	+ 4.3,- 3.9	63.32	+ 1.6,- 1.6	+ 3.1,- 1.8	+ 0.0,- 0.0	+ 2.0,- 1.8	+ 0.0,- 2.5	+ 4.1,- 3.9

SAGE + GALLEX/GNO → **66.1 ± 3.1 SNU**

Excellent agreement

THE *pp* NEUTRINO FLUX

[*pp*|Ga] = 39.9 ± 5.2 SNU

the measured electron neutrino ***pp*** flux at Earth of :

$$(39.9 \pm 5.2) \ / \ \text{cross. sect.} \ = \ (3.40^{+0.44}_{-0.46}) \times 10^{10} \, \nu_e / (\text{cm}^2 \, \text{s})$$

- the ***pp*** flux produced in the Sun :

$$(3.40^{+0.44}_{-0.46}) \times 10^{10} / (\langle P^{ee}_i \rangle = 0.560(1^{+0.030}_{-0.045})) \ = \ (6.1 \pm 0.84) \times 10^{10} \, \nu_e / (\text{cm}^2 \, \text{s})$$

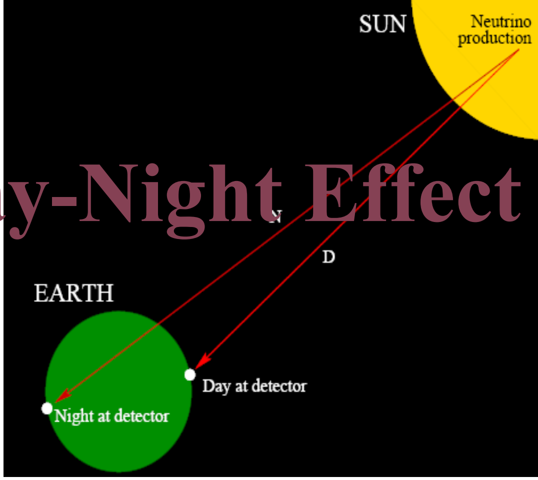
the predicted ***pp*** flux from the two recent SSM:

$(5.97 \pm 0.05) \times 10^{10} \, \nu_e/(\text{cm}^2 \, \text{s})$ (GS98) (high metallicity)

$(6.04 \pm 0.05) \times 10^{10} \, \nu_e/(\text{cm}^2 \, \text{s})$ (AGS05) (low metallicity)

There is good numerical agreement

Day-Night Effect



SNO The combined data set has a day live time of 128.5 days and a night live time of 177.9 days.:

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

No evidence for asymmetries from matter effects in the earth

S-K I low energy data set consisting of 1496 live days (May 31, 1996 through July 15th, 2001): The observed day-night asymmetry is

ADN = (Day − Night)/(0.5*(Day + Night)) = $-0.021 \pm 0.020^{+0.013}_{-0.012}$

No indication of spectral distortion is observed.

BOREXINO - 422.12 days total live time. Night 212.87 days. Day 209.25 days**:**
The Day Night asymmetry of the neutrino signal needs the result of the spectral fit and it is influenced by its statistical error

$$\sigma_{ADN^{\upsilon}} \approx \frac{1}{\sqrt{2}} \frac{\sigma_{\Phi_{7Be}}}{\Phi_{7Be}} \qquad ADN^{\upsilon} = 0.02 \pm 0.04_{stat}$$

Systematic errors under study

GNO + Gallex (123 SRs): Winter (66 SR): $66.5^{+5.6}_{-5.4}$ SNU ,Summer (57 SR): $74.1^{+6.4}_{-6.2}$ SNU

W-S: -7.6 ± 9 SNU **(expected from $1/d^2$: +2.5)**

No excess in W-S, as expected for LMA !!

SAGE (168 runs): the winter minus summer difference in SAGE capture rate is

$$\mathbf{R_W - R_S = 5.8^{+6.2}_{-6.1}\ SNU}$$

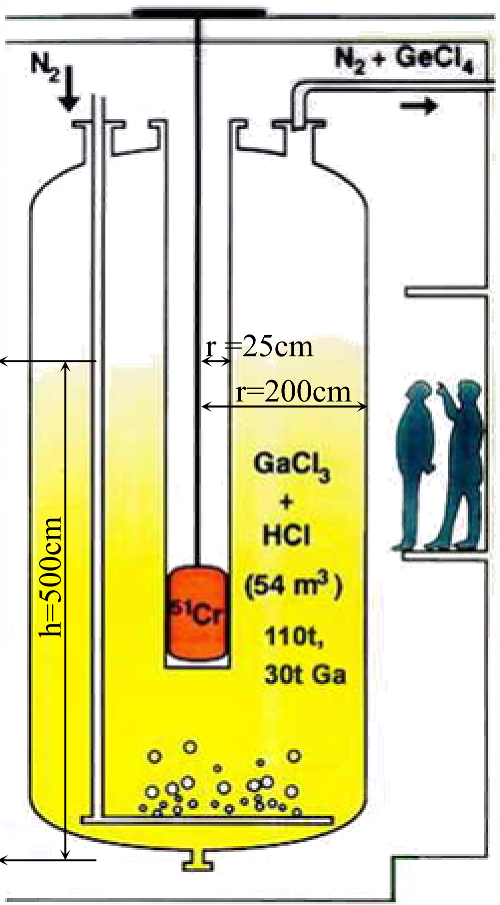
where the stated uncertainty is only statistical. For this calculation summer was defined as the ±¼-year interval centered on 21 June and winter as the rest of the year.

R_W-R_S, is consistent with zero, indicating that there is no appreciable difference between the day and night capture rates in Ga, as is expected for the currently determined values of the neutrino oscillation parameters

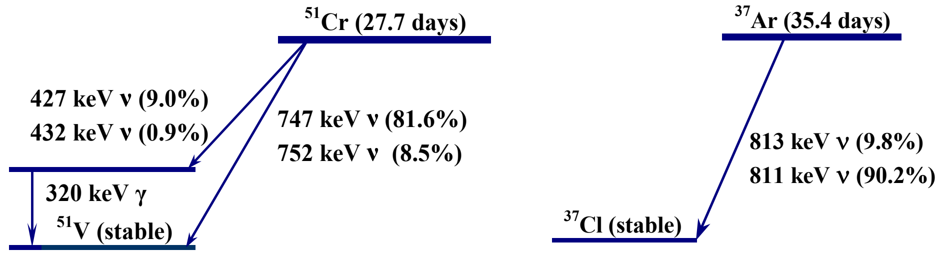
Gallium source experiments

The experimental procedures of the SAGE and Gallex experiments, including the chemical extraction, counting, and analysis techniques, have been checked by exposing the gallium target to reactor-produced neutrino sources.

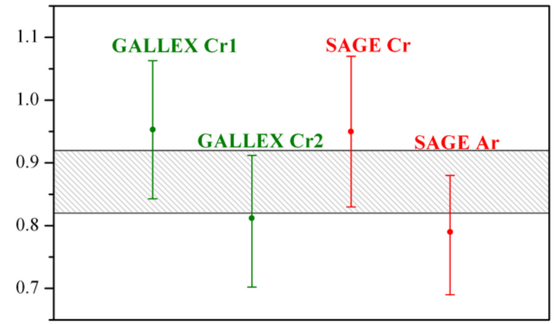
GALLEX



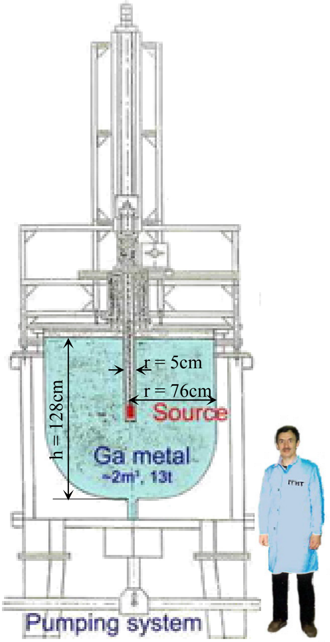
Gallex has twice used ^{51}Cr



	GALLEX m(Ga)=30 t		SAGE m(Ga)=13 t	
Source	^{51}Cr -1	^{51}Cr -2	^{51}Cr	^{37}Ar
Activity, MCi	1.714	1.868	0.517	0.409
$R = (p_{meas}/p_{pred})$	0.95±0.11	0.81±0.11	0.95±0.12	0.79±0.10
R_{comb}	0.88 ± 0.08		0.86 ± 0.08	



SAGE



SAGE has used ^{51}Cr and ^{37}Ar

R=0.87±0.05 χ^2/dof=1.9/3, GOF=59%

(2)

- **The cross sections for neutrino capture to the two lowest excited states in ^{71}Ge have been overestimated (W. Haxton).**

Maximum contribution of these excited states – 5%.

If the contribution of these states to the predicted rate were to be zero then R=0.92±0.06 and the fit to the expected value of 1.0 becomes quite reasonable (χ^2 /dof = 4.58/3, GOF = 21%).

The preparation of the measurements of (^{3}He, t) reaction on Ga is carried out in RCNP, Japan (H. Ejiri).

- **Electron neutrinos disappear due to a real physical effect of unknown origin.**

Some possibilities:

- transition to sterile neutrinos (VSBL, C.Guinti and M.Laveder, arXiv:0902.1992),
- quantum decoherence in neutrino oscillations (Y.Farzan, T.Schwetz, A.Yu.Smirnov, arXiv:0805.2098)

To check this hypothesis we consider a new measurement that will use 2MCi ^{51}Cr neutrino source in SAGE optimized target geometry.

From Hiro Ejiri:

RCNP EXPERIMENT E327

Proposal for experiment at RCNP Jan.22, 2009.
High resolution study of the 71,69 Ga (3He,t) reactions at 0.42 GeV and GT neutrino responses for 71,69 Ga

"…We hope that the beamtime will be scheduled in the period from the end of 2009 to the middle of 2010."

Two-zone Ga source experiment

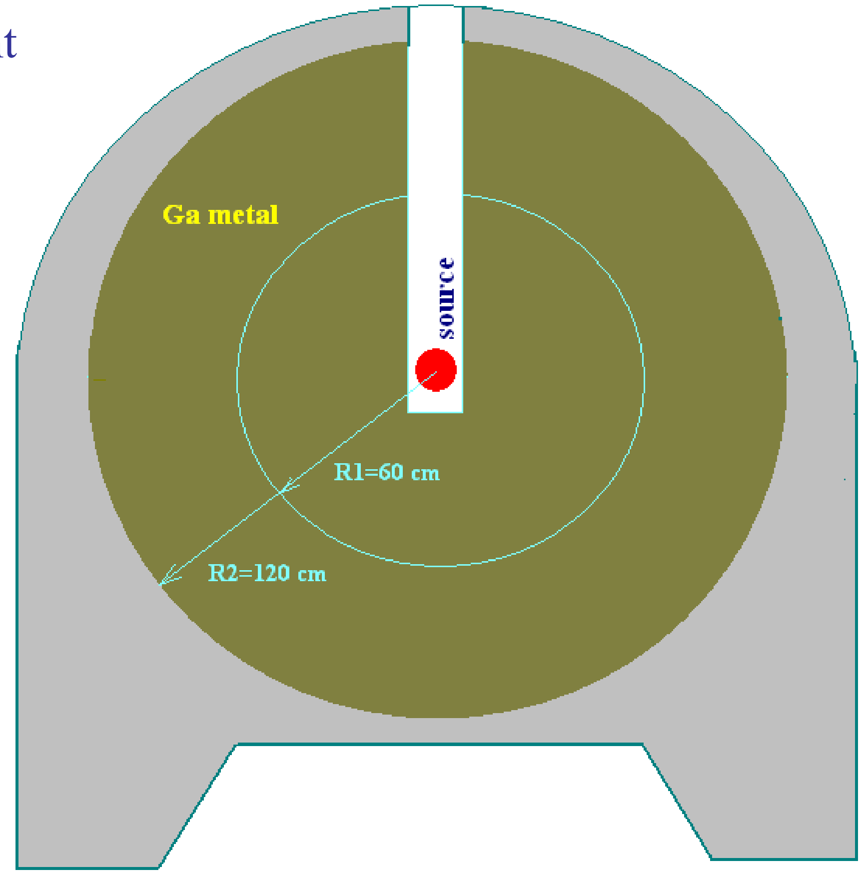
To get additional information in source experiment we separate the SAGE Ga target (50 tons) on two independent spherical zones.

It gives:

dependence on distance of source (test of ν_e disappearance)

additional possibilities for statistical analysis

For two zones of target with thickness 60 cm each, the total uncertainty for each zone will be 5-5.5%, and statistical error of combined result will be about 3%



Conclusion

New source experiment in SAGE will shed light on the problem of low result in the source experiments in gallium. For these it is necessary to make:

– ^{51}Cr neutrino source with activity 2 MCi or higher,

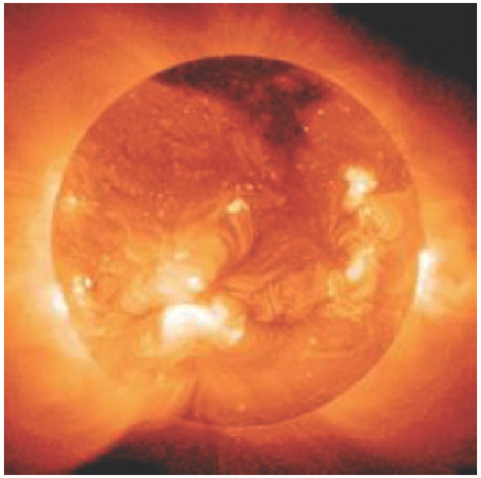
– the optimized two-zone spherical target,

– the measurement with accuracy 4 – 4.5%

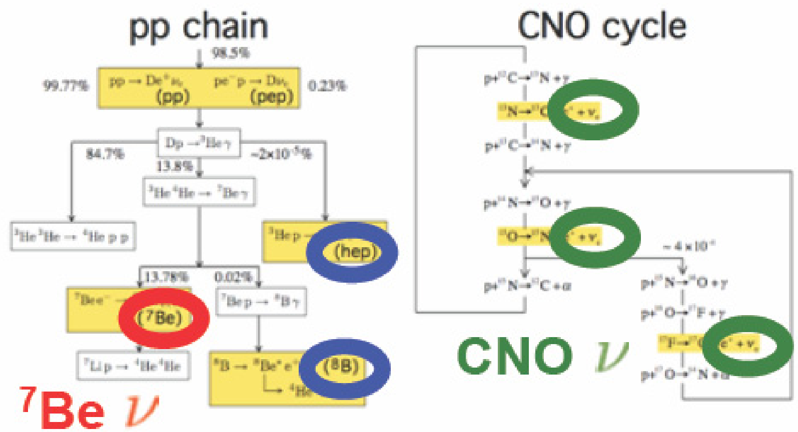
This is a part of future experimental program in SAGE.

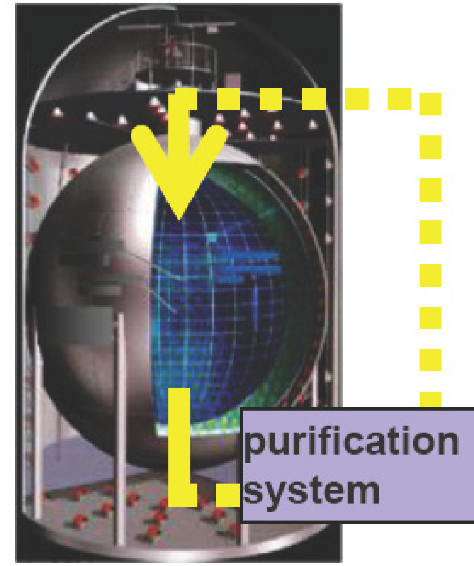
Experiment	Detection Reaction	Targeted Solar νs	Technology	Other Physics	Status
KamLAND	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	^{7}Be,CNO, pep	Liq. scintillator	Reactor νs, geo-νs	Purification underway
SNO+	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pep, CNO	Liq. scintillator	0νββ, geo-νs	Engineering, purification
LENS	$\nu_e + {}^{115}In \rightarrow e^- + 2\gamma + {}^{115}Sn$	pp, ^{7}Be, pep	In-doped liq. scintillator	----------	Prototype bkd studies
XMASS	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pp	Scintillation in cryogenic Xe	dark matter, 0νββ	800 kg stage in design
CLEAN	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pp	Scintillation in cryogenic Ne	dark matter (DEAP/CLEAN)	0.1 and 1 ton engineering
MOON	$\nu_e + {}^{100}Mo \rightarrow e^- + {}^{100}Tc$	pp, ^{7}Be, pep	Scintillator/ Fiber sandwich	0νββ	Prototype for 0νββ
MUNU/TPC	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pp, ^{7}Be, pep, CNO	CF4 TPC	μ_ν (reactor)	μ_ν results, recon studies
HERON	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pp	Scintillation in cryogenic He	----------	R&D complete Proposal ended
XAX	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	pp	Scintillation in cryo. Xe+Ar	dark matter, 0νββ	Design and simulation
Mega-H_2O	$\nu_{e(\mu\tau)} + e \rightarrow \nu_{e(\mu\tau)} + e$	^{8}B, hep	H_2O Cerenkov	P-dk, LBL νs	Design, sim.

Solar Neutrino in KamLAND



nuclear fusion reaction in the sun





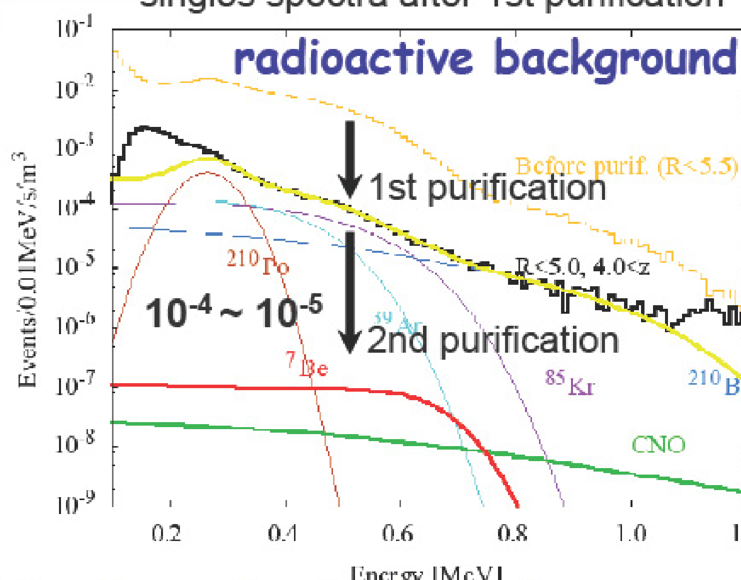
Standard Solar Model (SSM)

J.N. Bahcall and A.M. Serenelli, Astro. Phys. J. 621, 85 (2005)

Model	pp	pep	hep	^{7}Be	^{8}B	^{13}N	^{15}O	^{17}F
BP04(Yale)	5.94	1.40	7.88	4.86	5.79	5.71	5.03	5.91
BP04(Garching)	5.94	1.41	7.88	4.84	5.74	5.70	4.98	5.87
BS04	5.94	1.40	7.86	4.88	5.87	5.62	4.90	6.01
BS05(^{14}N)	5.99	1.42	7.91	4.89	5.83	3.11	2.38	5.97
BS05(OP) GS98	5.99	1.42	7.93	4.84	5.69	3.07	2.33	5.84
BS05(AGS,OP) AGS05	6.06	1.45	8.25	4.34	4.51	2.01	1.45	3.25
BS05(AGS,OPAL)	6.05	1.45	8.23	4.38	4.59	2.03	1.47	3.31

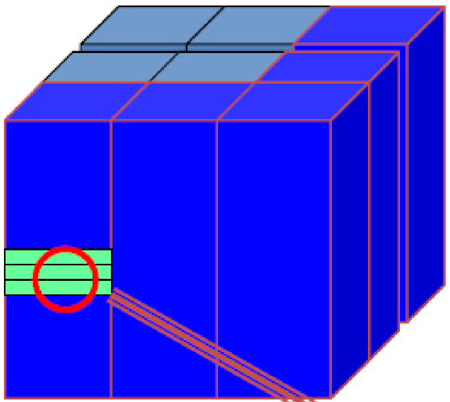
Test low abundance of heavy element (AGS05) -10% S_{34} : 2.5% -38% $S_{1,14}$: 8.4%

singles spectra after 1st purification



Radioactive BG reduction (^{85}Kr) : 10^{-4}~10^{-5} after the 2nd purification

MOON OSAKA CTU FNAL HU ICU JINR LANL UNC TU UW VNIIEF



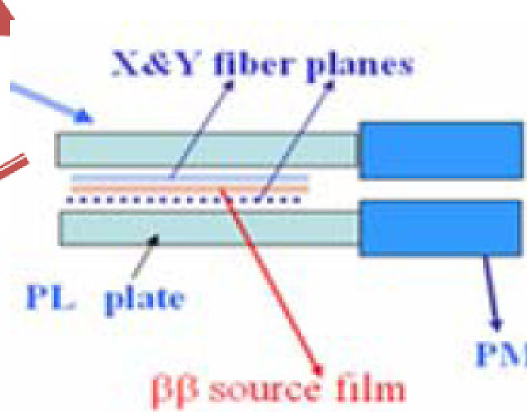
Multilayer PL plates and PL fiber planes with thin ^{100}Mo source film for pp-Be7 solar ν and ββ with 30 meV.

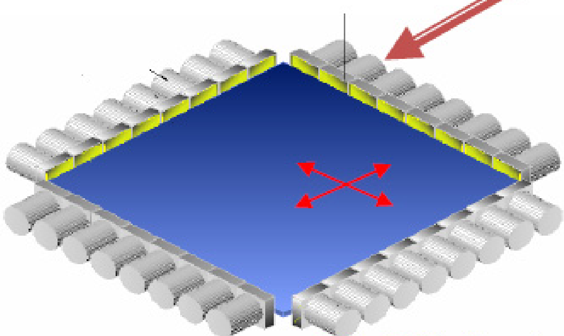
A. Low Q=0.17 MeV, large CC of 680 & 220 SNU for pp & ^{7}Be-ν.

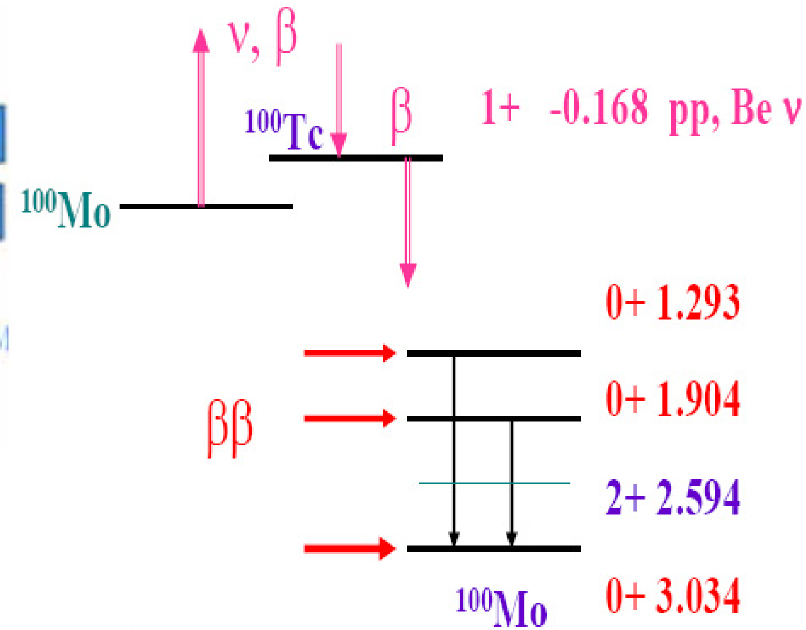
B. Real time studies of inverse β rays in delayed coincidence with the β decays from ^{100}Tc.

C. 9-units 0.27 ton 100m^{3} , 32 units, 1 ton 300 m^{3}

Detector ≠ββ source
Select ββ sources
Solar ν as well





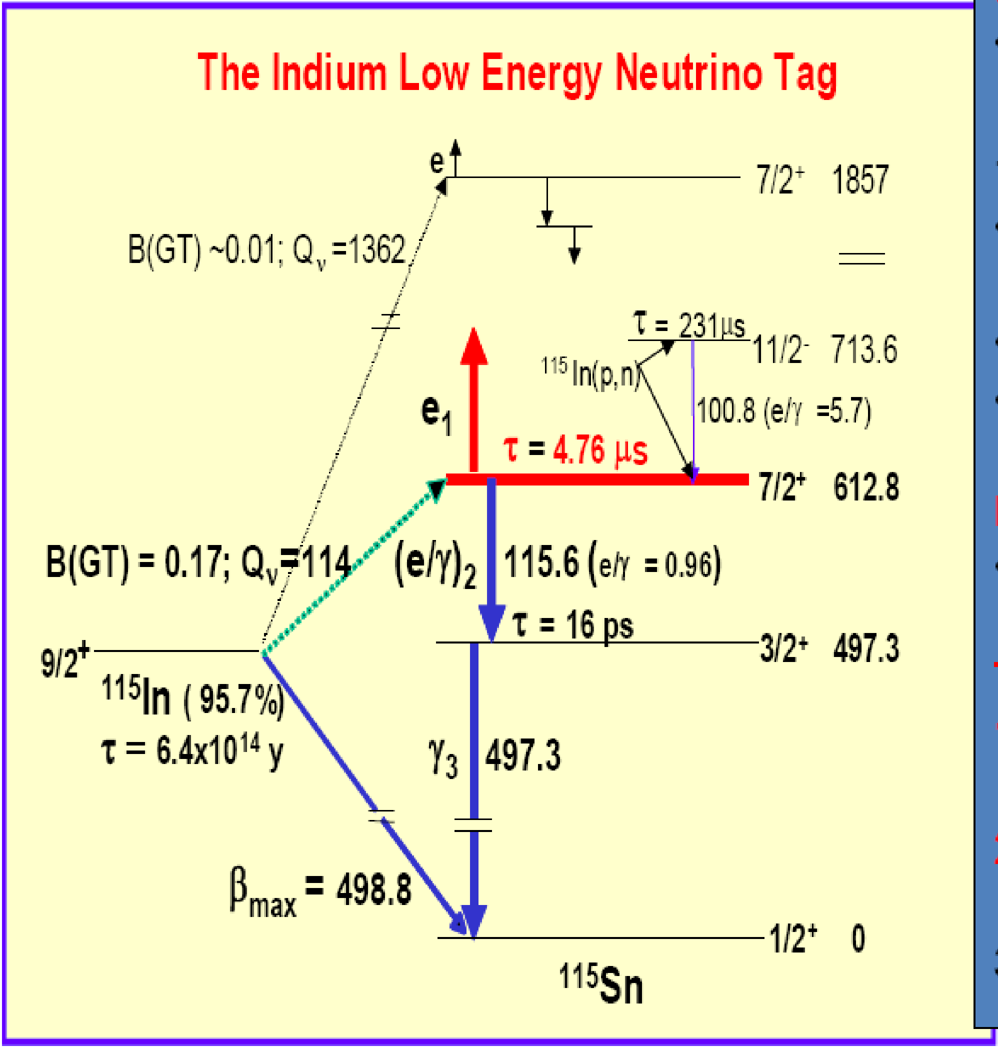


H. Ejiri, et al., PRL, 85, 2000.
H. Ejiri, J. Phys. Soc. Japan 74 2005.
H. Ejiri European Phys. J. 162 2008

LENS Detection Scheme

$$\nu_e + {}^{115}In \rightarrow e^- + (\tau = 4.76\,\mu s)2\gamma + {}^{115}Sn$$

Also IPNOS
Fukuda@parallel session



Unique:

- Specifies ν Energy
  $E_\nu = E_e + Q$

→ Complete LE nu spectrum

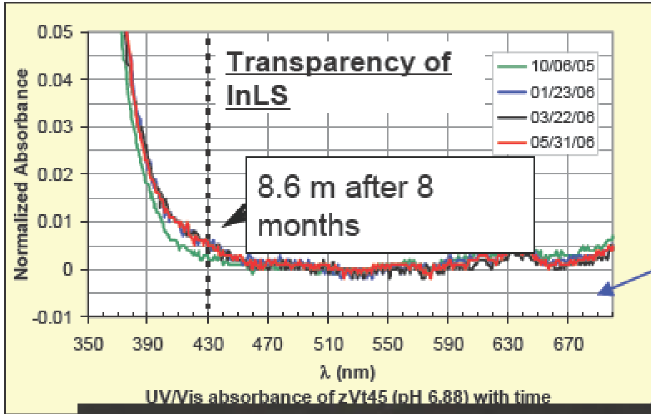
- Lowest Q known→ 114 keV
  →access to 95.5% pp nu's
- Target isotopic abundance ~96%
- Powerful delayed coinc. Tag
  Can suppress bgd $=10^{11}$ x signal

Downside:

- Bgd from ^{115}In radioactivity to
  (pp nu's only)→ rate= 10^{11} x signal

Tools:

1. Time & Space coinc.→ Granularity
   (10^7 suppression already)
2. Energy Resolution—important for
   In betas <500 keV; ∑Tag = 613 keV
3. Other analysis cuts

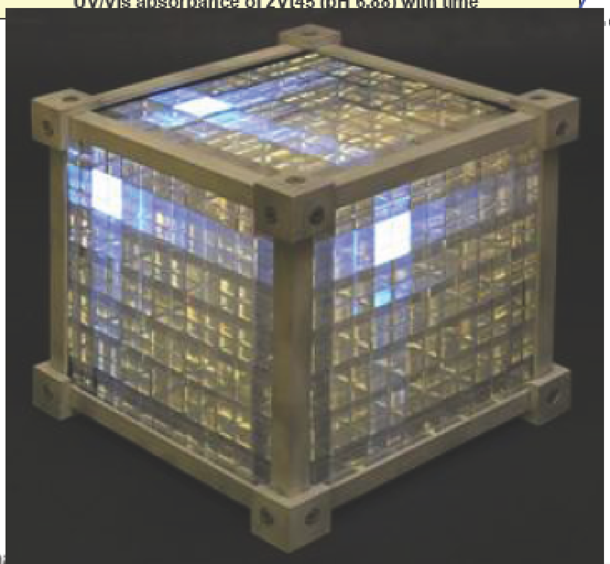


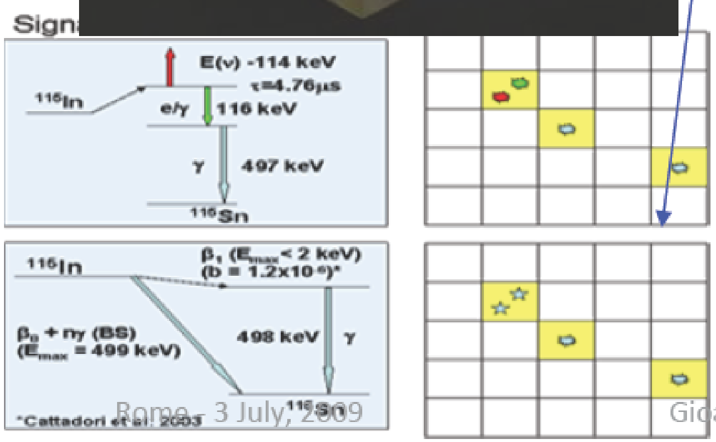
Technology and Bgd Control

< Towards **Hi Precision** fluxes >

- **Hi Quality InLS**
- **New Detector Design**
- **Background Analysis Insights**

→ In decay bgd suppressed →S/N ~3 for first time





	Status
Design of Detector	Cubic Lattice Chamber
InLS: In content Light attenuation L(1/e) Signal Eff Pe/MeV	>8% >8m 900
Indium Mass(1900 pp/5y)	10 ton
Total Mass	125 ton
PMT's	13,300
Neutrino detection eff.	64%

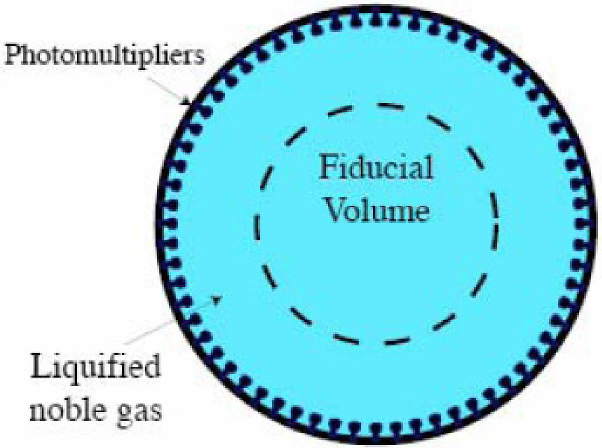
Raghavan@Physun workshop

The CLEAN Approach

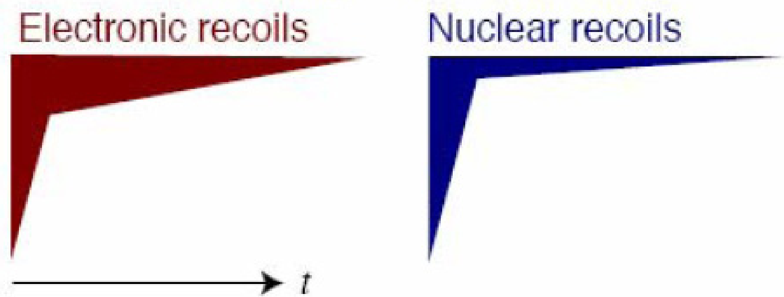
Scaleable technology based on detection of scintillation in liquified noble gases. No E field.
Ultraviolet scintillation light is converted to visible light with a wavelength-shifting film.

Liquid neon and liquid argon are bright scintillators (30,000 - 40,000 photons/MeV).
Do not absorb their own scintillation.
Are inexpensive (Ar: $2k/ton, Ne: $60k/ton).
Are easily purified underground.
Exhibit effective pulse shape discrimination.
Exchange of targets allows better characterization of radioactive backgrounds

Self-shielding



Pulse-shape discrimination



Fast component: < 10 ns
Slow component: 1.6 μs (LAr), 15 μs (LNe)
Discriminate based on fraction of light in first 100 ns (Fprompt)

D. N. McKinsey and J. M. Doyle, J. Low Temp. Phys. 118, 153 (2000).
D. N. McKinsey and K. J. Coakley, Astropart. Phys. 22, 355 (2005).
M. Boulay, J. Lidgard, and A. Hime, nucl-ex/0410025
M. Boulay and A. Hime, Astropart. Phys. 25, 179 (2006).

A little bit history of neutrino

- Since in 1930 Pauli has postulated (as “a desperate way out”) the existence of neutrino, it remains one of the most intriguing particles in nuclear physics.
- Conception about neutrino in the theory of beta decay, which was developed a year later by Fermi, turned out to be so fruitful that neutrino was included with confidence into the family of particles well in advance it was discovered.
- In 1956, when Cowen and Reines with colleagues succeeded to detect neutrino the main characteristics of this particle were obtained from indirect data of a large number of previous experiments with natural and artificial beta-decay and k-capture isotopes, as well as from accelerators in meson-neutrino reactions.
- In spite of questions about existence of neutrino mass and its nature (Dirak or Majorana) were open, conception about neutrino based on these previous investigations, was in good agreement with all experimental observations up to the 1970th, that is up to the start of solar neutrino experiments.
- First solar neutrino experiment had originally a goal to check the hypothesis of thermonuclear nature of the energy of the Sun and has led us to the first disagreement – to SNP.