Current status of Ga-Cr neutrino project

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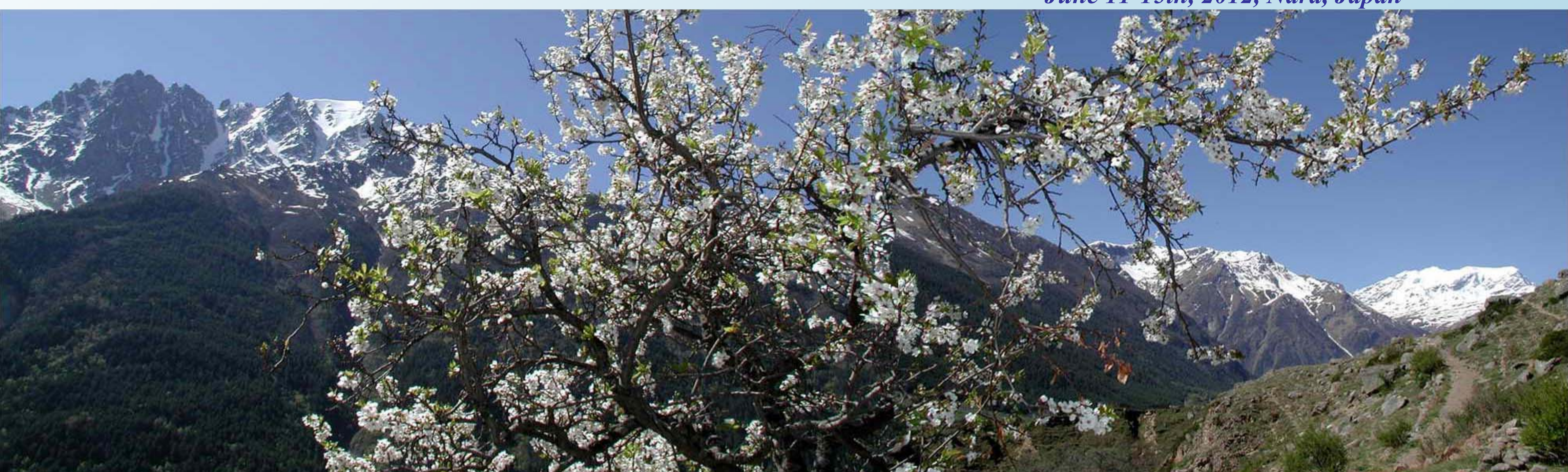
Institute for Nuclear Research
of the Russian Academy of Sciences, Moscow

The 4th International Symposium on
Neutrinos and Dark Matter in Nuclear Physics
(NDM12)
June 11-15th, 2012, Nara, Japan



Outline

- Introduction
- Ga solar neutrino measurements
- Ga neutrino source measurements
- What is the origin of "Ga anomaly"
- Do there exist sterile neutrino?
- New Ga experiment with a ^{51}Cr source as a way to investigate active-sterile transitions

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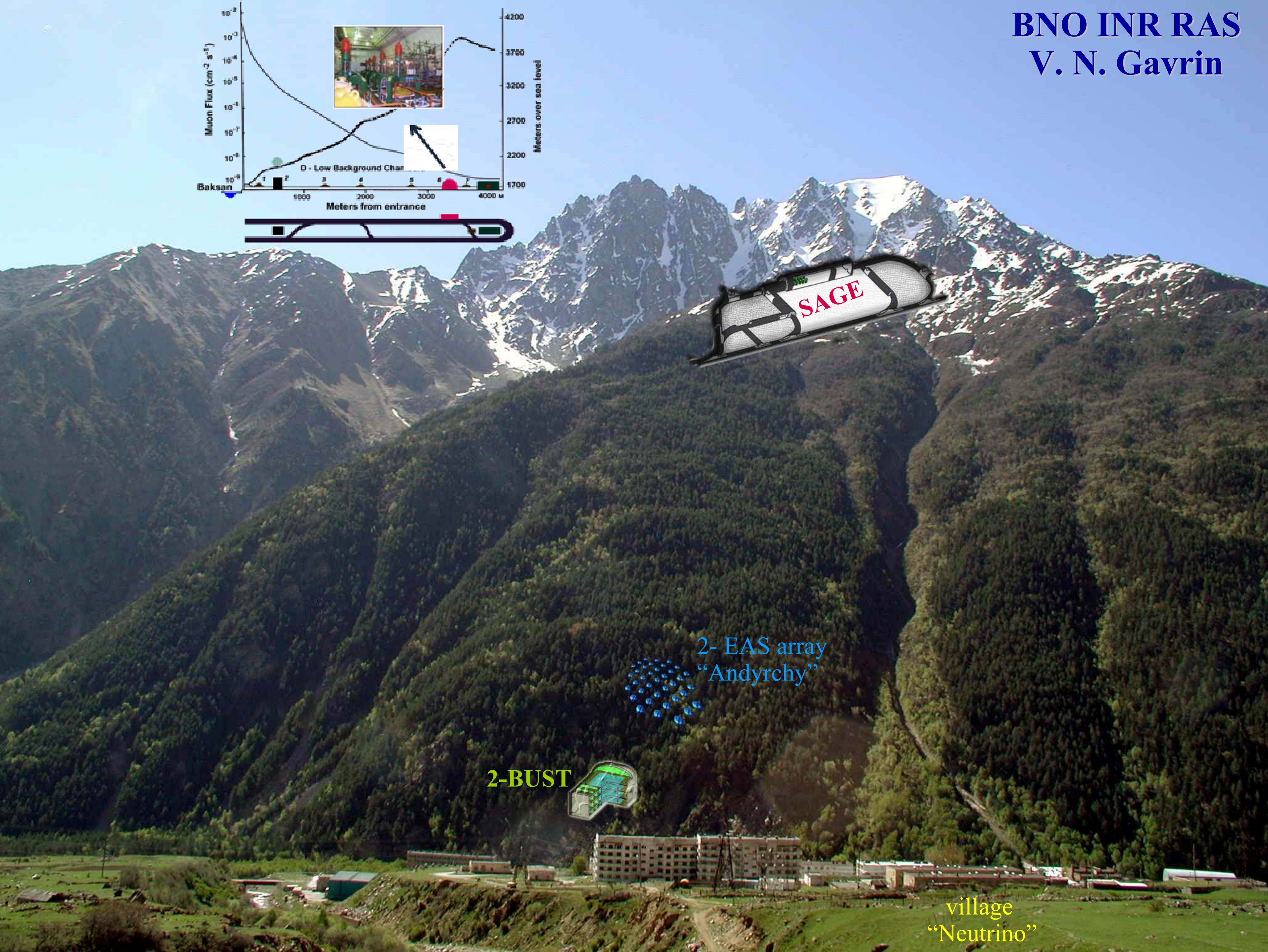


SAGE
Ga_{met} ~ 50 tons
Global intensity of muon
$(3.03 \pm 0.19) \times 10^{-9}$ $(cm^2s)^{-1}$
Fast neutron flux (>3MeV)
$(6.28 \pm 2.20) \times 10^{-8}$ $(cm^2s)^{-1}$

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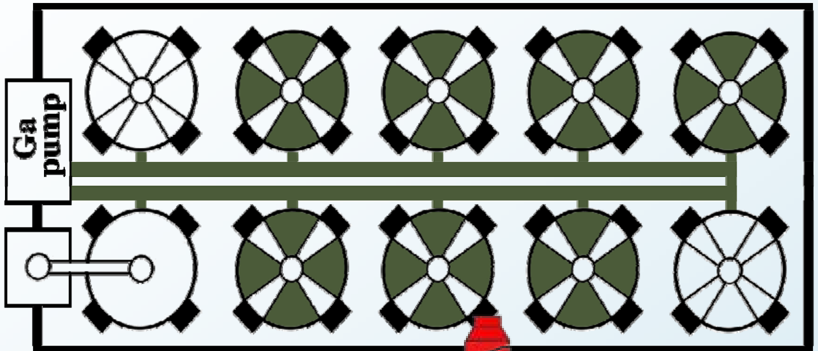
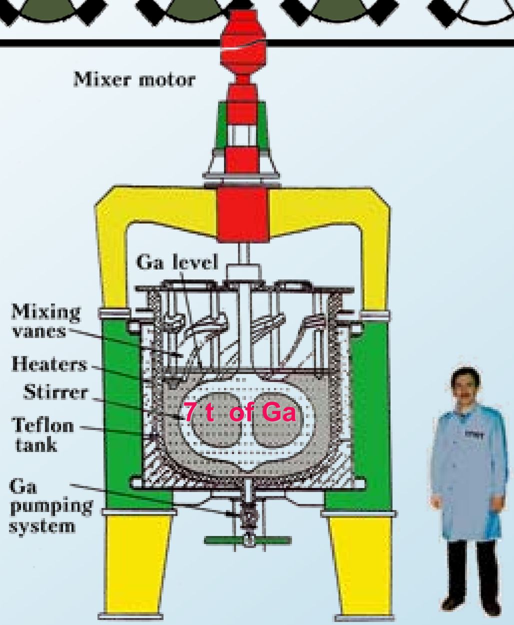
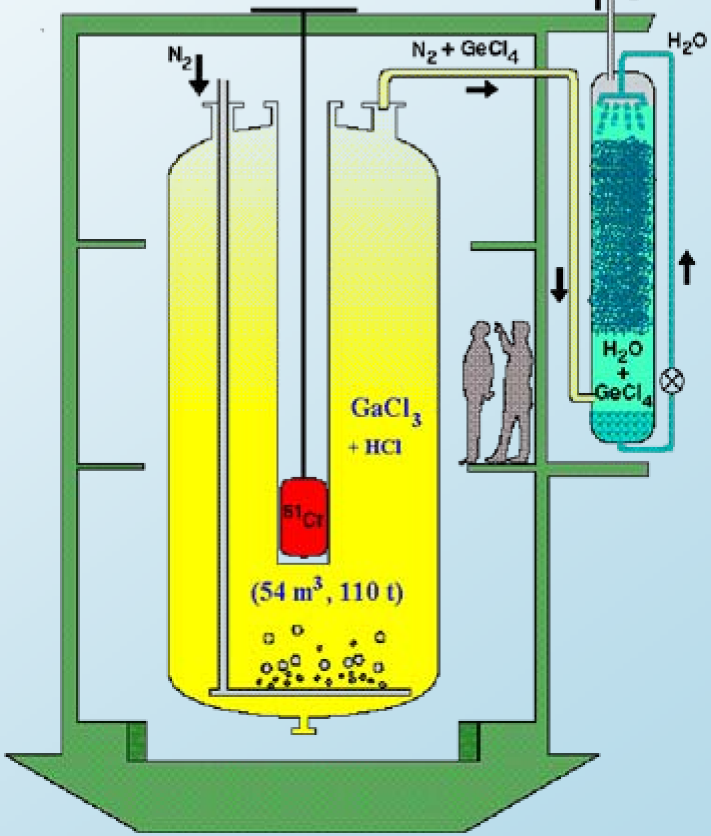
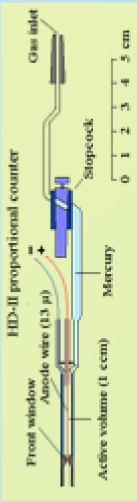
SAGE 50 t of Ga **$^{71}Ga(\nu,e^-)^{71}Ge$** **GALLEX/GNO 30,3 t of Ga**









Both experiments are based on chemical technology of extraction a few ^{71}Ge atoms from large amount (tens ton) of Ga target and on technology of counting of ^{71}Ge decay in small proportional counters (less than 1 cm^3)

SAGE

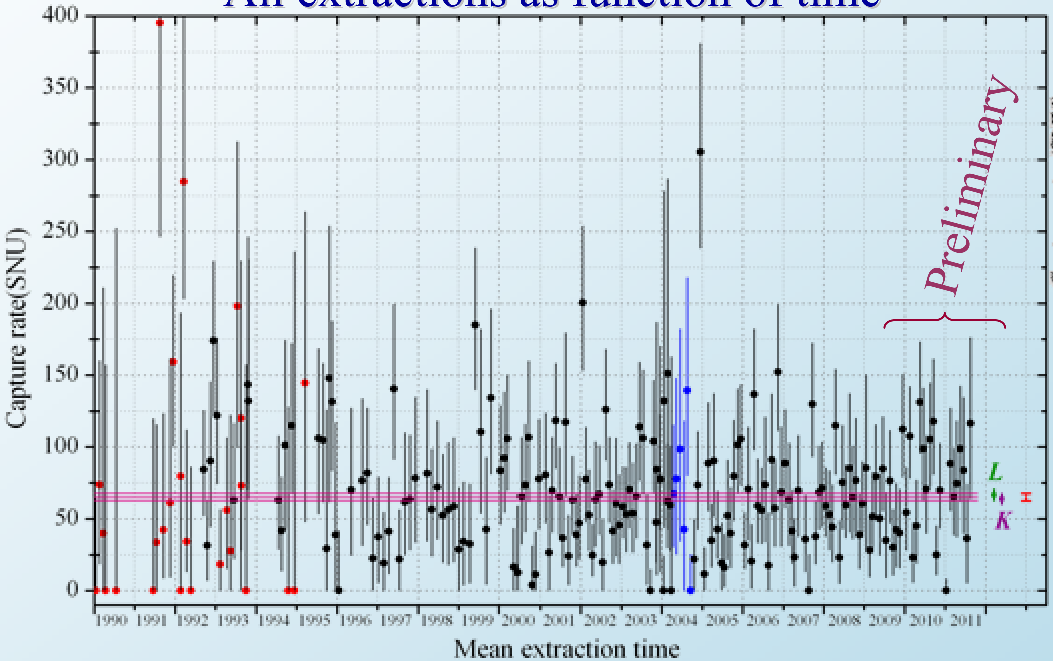
Presently SAGE is the only experiment sensitive to the *pp* neutrinos

It has the longest almost uninterrupted time of measurements among operating solar neutrino experiments

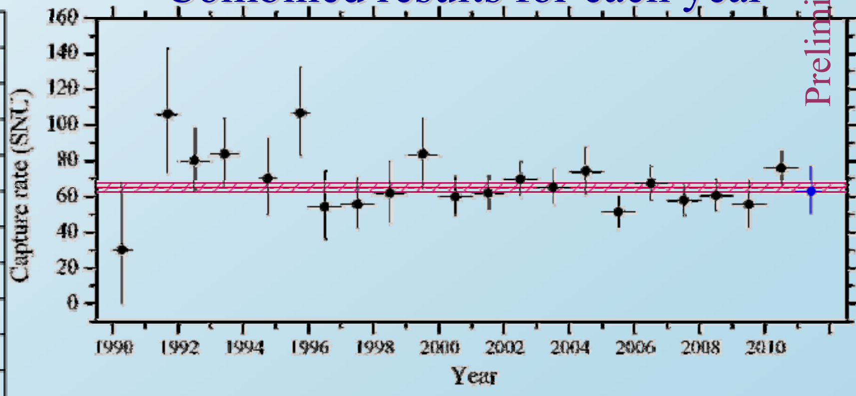
20.6 year period (1990 – 11.2011): 214 runs, 396 separate counting sets

Result: $64.5^{+2.7}_{-2.7}\,\text{(stat)}\,^{+2.6}_{-2.8}\,\text{(syst)}$ SNU or $64.5^{+3.7}_{-3.9}$ SNU

All extractions as function of time



Combined results for each year

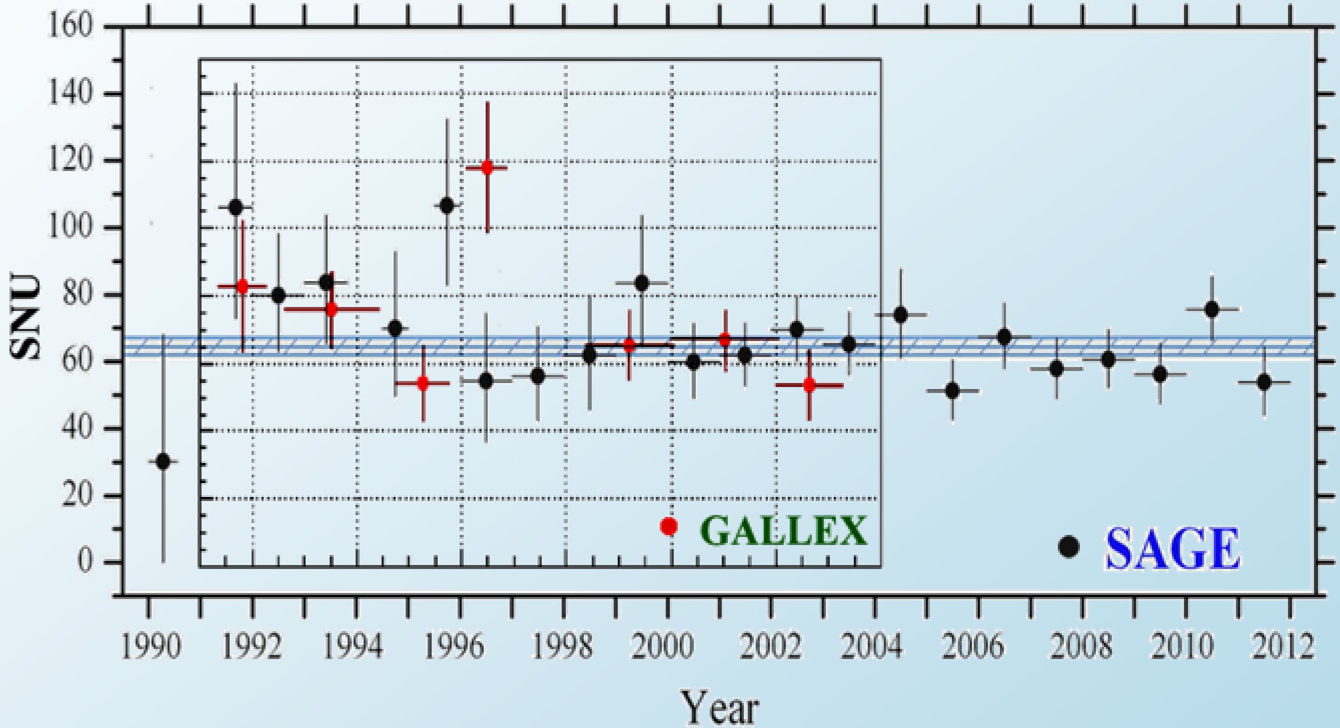


(1 SNU = 1 interaction/s in a target that contains 10^{36} atoms of the neutrino absorbing isotope).

SAGE continues to perform regular solar neutrino extractions every four weeks with ~50 t of Ga

*"**Ga** experiments have given a great impact upon a view of neutrino oscillation"*

John Bahcall, April 2004



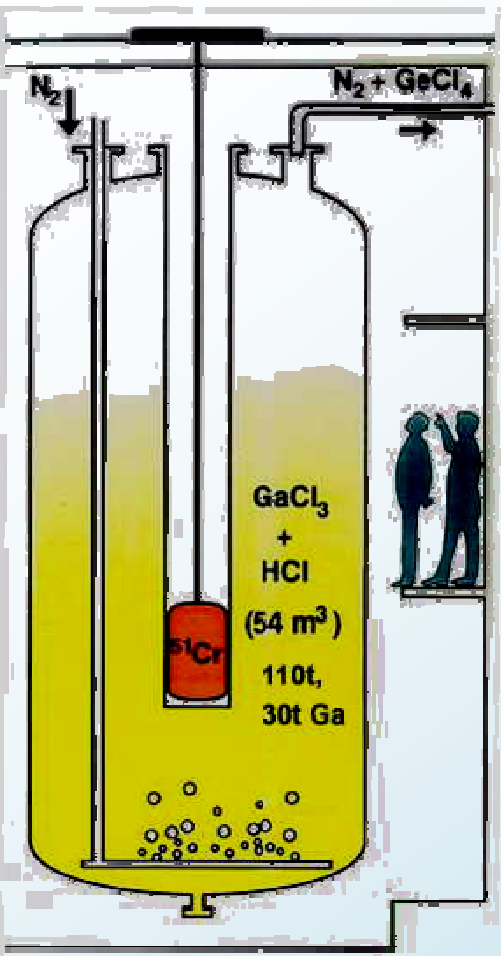
SAGE/GALLEX have shown deficit of solar neutrino in the entire energy range :

[*pp*+7Be+CNO+*pep*+8B|**Ga**] = 66.1 ± 3.1 SNU

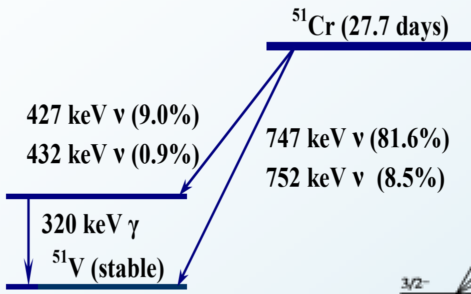
	BPS08(GS)	BPS08(AGS)
SSM:(Ga)	$127.9^{+8.1}_{-8.2}$	$120.5^{+6.9}_{-7.1}$

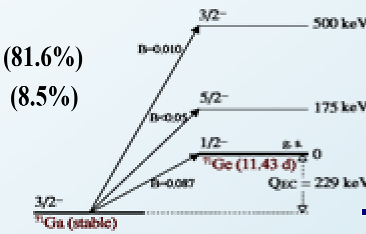
Gallium source experiments

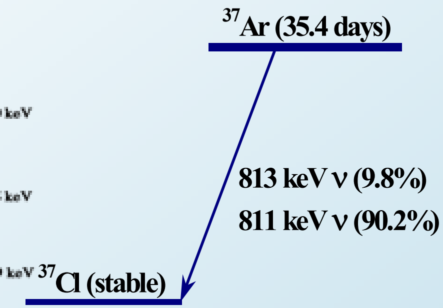
GALLEX



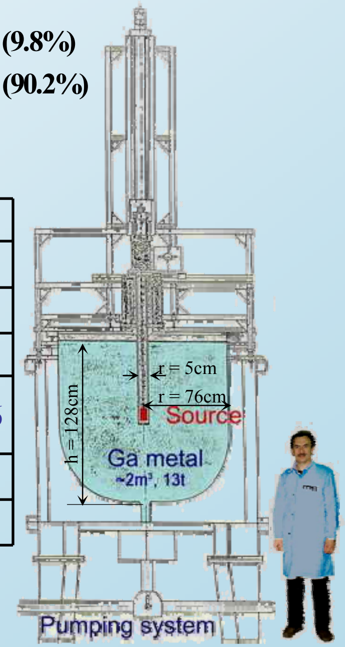
Gallex has twice used ^{51}Cr







SAGE



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

	GALLEX		SAGE	
	m(Ga)=30 t		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
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_{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	

$$R = p_{\text{measured}}/p_{\text{predict}} = 0.87 \pm 0.05$$

The reason of low result in the source experiments can be :

(1) the capture rate, predicted by Bahcall, can be overestimated (W.Haxton),
(2) statistical fluctuation (probability~5%),
(3) electron neutrinos disappear due to a real physical effect. For example, neutrino oscillations with a transition from active to sterile neutrinos with $\Delta m^2 \sim 1\text{eV}^2$.

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РОССИЙСКАЯ АКАДЕМИЯ НАУК

ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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Professor Tadafumi Kishimoto
Director
Research Center for Nuclear Physics
10-1 Mihogaoka, Ibaraki, Osaka
567-0047 JAPAN

July 23, 2008

Dear Professor Kishimoto,

We write to you in an attempt to spark your interest to solve the problem of the discrepancy between experiments and predictions found in neutrino source experiments with Ga.

In the attached file you can find some details about this problem. We would very much appreciate it if you could let us know your opinion regarding this problem and whether or not you believe there may be researchers at your institution who could be interested in experimental work aimed at its resolution.

Sincerely,

Victor Matveev

Academician, Director
Institute for Nuclear Research RAS
Moscow 117312 Russia

for SAGE Collaboration:

Vladimir Gavrin

Professor, Head of Gallium Laboratory
Institute for Nuclear Research RAS
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Bruce Cleveland

Professor
University of Washington
Seattle, WA 98195 USA

江尻宏泰

Research Proposal to the

Research Center for Nuclear Physics,
Osaka University (B-PAC Jan. 2009)
High resolution study of the $^{71\ 69}$Ga(^{3}He,t) reactions at 0.42 GeV
and GT neutrino responses for $^{71\ 69}$Ga

SPOKESPERSONS:

Hidetoshi Akimune (Asociate Professor)
Dept. Physics, Konan University

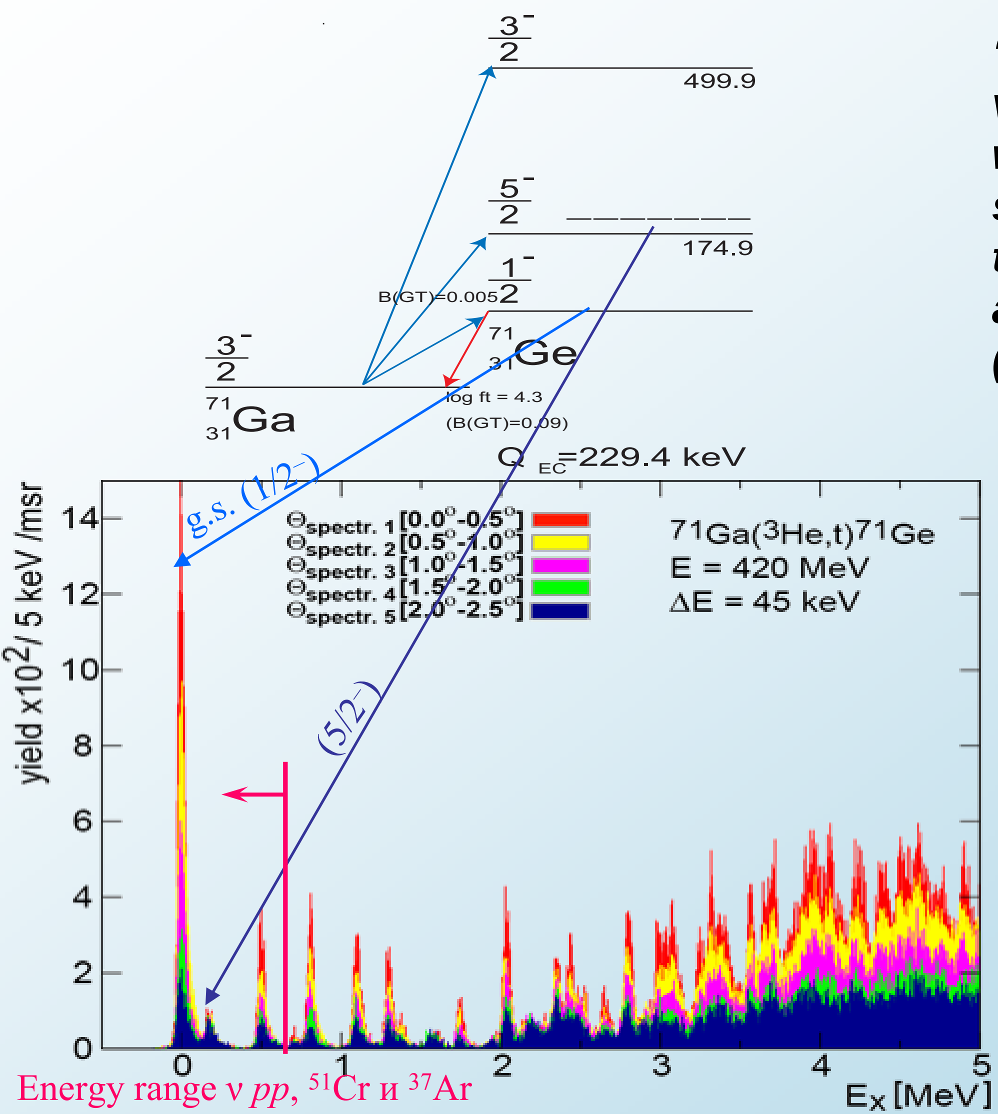
Hiroyasu Ejiri (Professor EM Visiting Professor)
Research Center for Nuclear Physics, Osaka Univ.
Ibaraki, Osaka 567-0047
Czech Technical University, Praque

Dieter Frekers (Professor)
IKP Univ. Munster Germany

Remco Zegers (Assistant Professor)
National Superconducting Cyclotron Laboratory,
Michigan State University,
East Lansing, MI 48823, USA.

1. Maximum contribution of these excited states – 5.1%.
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 ($\chi 2$ /dof = 4.58/3, GOF =21%).

Spokespersons : D. Frekers, J. Dilling, H. Ejiri



"At RCNP the GT transition strengths to various states in ^{71}Ge were re-measured with the main objective to extract the GT strength values to the g.s., the 175 keV and the 500 keV states with highest resolution and highest possible accuracy using the (3He,t) reaction at 420 MeV."

"A rather precise value of 7.2 ± 2.0% for this contribution has been evaluated, which exceeds the 5.1% value previously used by Bahcall. Thus, the discrepancy observed in the SAGE and GALLEX calibration data is further confirmed and possibly even slightly amplified."
Physics Letters B 706, 134 (2011)

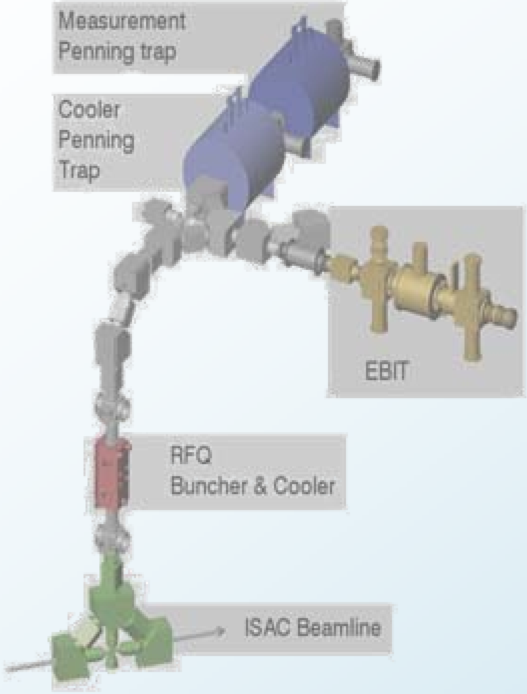
"… it may be worthwhile to review past measurements of the ^{71}Ge EC Q-value and lifetime, which together define the final ft-value."
[TRIUMF Research Proposal]

TRIUMF Research Proposal

Q-value measurement for the ^{71}Ge electron capture process using TITAN

(TRIUMF's Ion Trap for Atomic and Nuclear science)

Spokespersons : D. Frekers, J. Dilling, H. Ejiri



The TITAN beamline

"A renewed mass measurement using the ion trap technique will help to clarify the origin of a rather long-standing and still unresolved discrepancy of the calibration measurements performed by both neutrino experiments, SAGE and GALLEX."

$$\sigma(^{51}Cr) = \sigma_0(^{51}Cr)\left[1 + 0.67\frac{B_1(GT)}{B_0(GT)} + 0.22\frac{B_2(GT)}{B_0(GT)}\right]$$

$$\downarrow$$

$$\sigma_0(^{51}Cr) = F(atom)\frac{1}{ft}$$

$$\downarrow$$

$$ft \propto Q^2_{EC} \cdot t$$

"… The Q-value was about 233.0 keV, but this value is still preliminary and might change by one or at most 2 keV (some systematics still need to be analysed)".

[From D. Frekers letter.]

Consequences of ^{71}Ga(^{3}He, t) ^{71}Ge and Q_{EC} -value measurements:

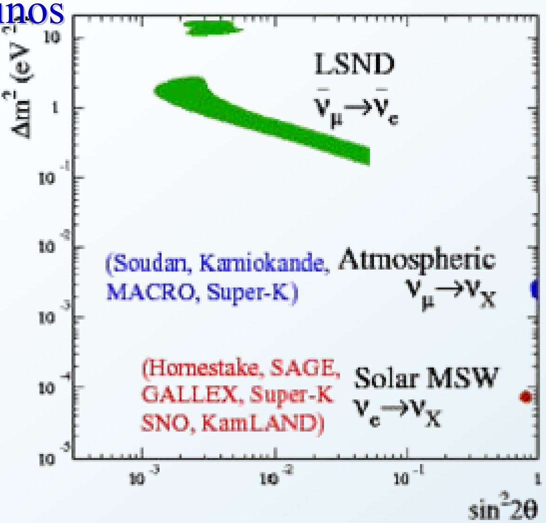
1. contribution from excited states: 7.2 % ± 2.0 % (5.1 % by Bahcall)
2. Q_{EC} is close to the value employed by Bahcall
3. the observed discrepancy is **NOT** due to any unknowns in Nuclear Physics.

⇓

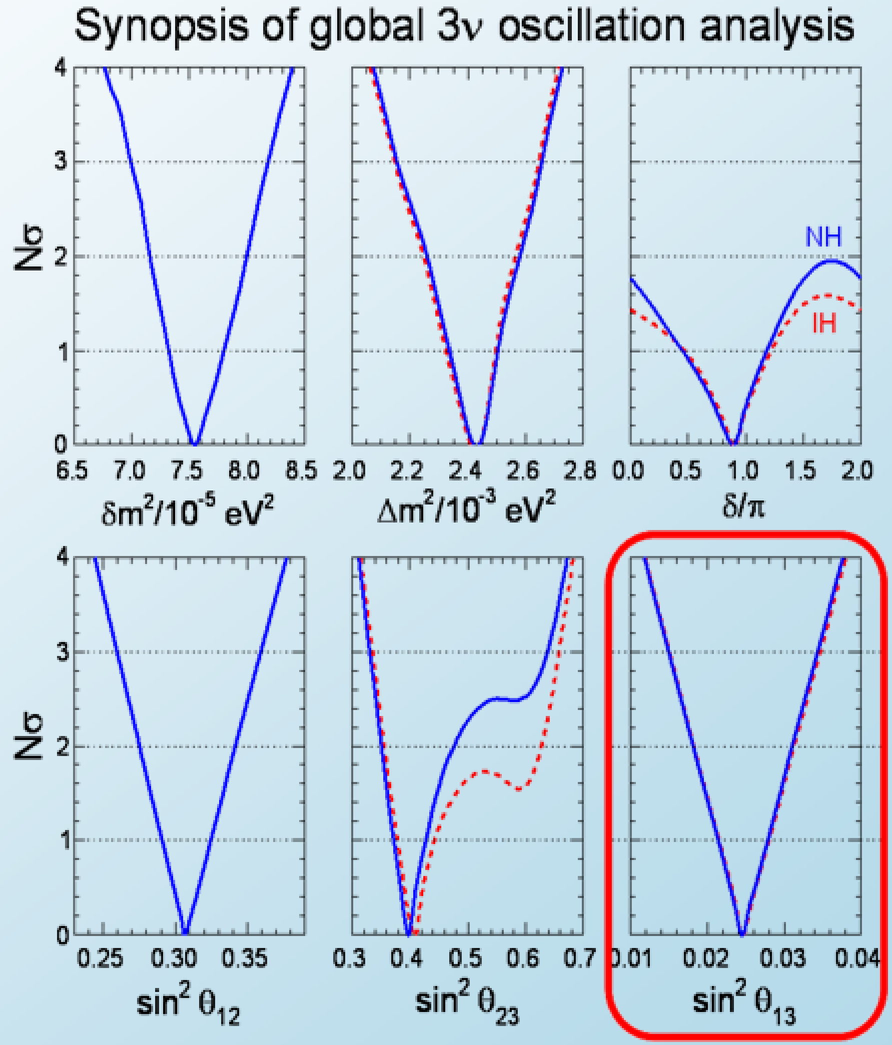
The deficit of neutrinos in the Ga source experiments can be a real physical effect of unknown origin, such as a transition to sterile neutrinos

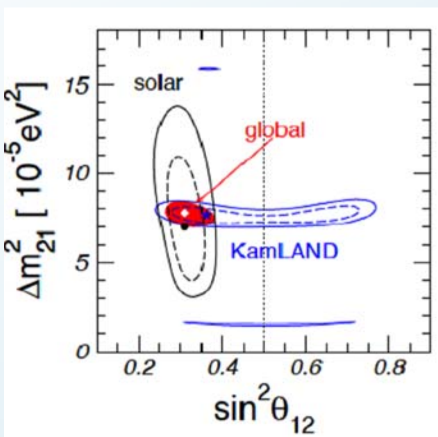
Do there exist sterile neutrino?

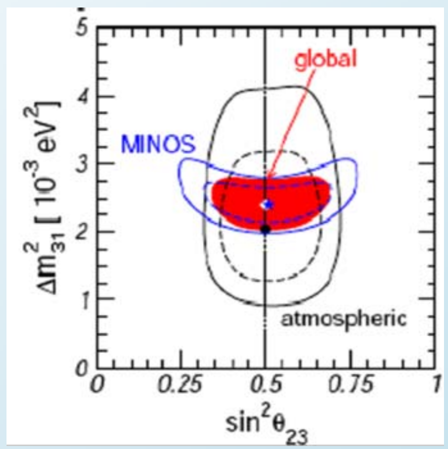
For many years, all direct experimental data well fit into the scheme with three active neutrinos



Summary of 2012 analysis







$\nu_e \to \nu_\mu, \nu_\tau$ with $\Delta m^2_{\rm SOL} \cong 7.6\times10^{-5}$ eV^2 [SOL,KamLAND]

$\nu_\mu \to \nu_\tau$ with $\Delta m^2_{\rm ATM} \cong 2.4\times10^{-3}$ eV^2 [ATM,K2K,MINOS]

$\sin^2\theta_{12} \cong 0.3$ $\sin^2\theta_{23} \cong 0.5$ $\sin^2\theta_{13} \cong 0.024$ [DayaBay]

… with new (2012) SBL reactor data:

Double Chooz (far detector): $\sin^2\theta_{13} = 0.022 \pm 0.013$

Daya Bay (near + far detectors): $\sin^2\theta_{13} = 0.024 \pm 0.004$

RENO (near + far detectors): $\sin^2\theta_{13} = 0.029 \pm 0.006$

(G. Fogli, 9 May, νTURN'2012)

Hints for High $\Delta m^2 \sim 1\ eV^2$ Oscillation
$\Rightarrow$ Sterile Neutrinos? or Something Else?

- **Positive indications:**
  - LSND/MiniBooNE $\bar{\nu}_\mu \to \bar{\nu}_e$ appearance signal
  - MiniBooNE low-energy excess ($\nu_\mu \to \nu_e$?)
  - Reactor disappearance anomaly ($\bar{\nu}_e \to \bar{\nu}_e$)
  - Gallex-Sage reduced calibration source rate (ν_e disappearance?)
- **Negative indications:**
  - CDHS and MiniBooNE restrictions on ν_μ disappearance
  - MiniBooNE restrictions on $\bar{\nu}_\mu$ disappearance
  - Karmen restrictions on $\bar{\nu}_\mu \to \bar{\nu}_e$
  - Other negative results

Experiments with $\Delta m^2 \sim 1 eV^2$ sensitivity

Positive indications				Negative indications			
		Channel	L/E (m/MeV)			Channel	L/E (m/MeV)
LSND (DAR) $\bar{\nu}_\mu$	Appear.	$\bar{\nu}_\mu \to \bar{\nu}_e$	30 / [20-55]	Karmen2 (DAR) $\bar{\nu}_\mu$	Appear.	$\bar{\nu}_\mu \to \bar{\nu}_e$	17 / [20-55]
LSND (DIF) ν_μ	Appear.	$\nu_\mu \to \nu_e$	30 / [20-55]	MiniBooNE ν_μ	Appear.	$\nu_\mu \to \nu_e$	541 / [475-1500]
MiniBooNE ν_μ (low En.)	Appear.	$\nu_\mu \to \nu_e$	541 / [200-475]	MiniBooNE -NuMI ν_μ	Appear.	$\nu_\mu \to \nu_e$	745 / ~800
MiniBooNE $\nu_\mu \bar{\nu}_\mu$	Appear.	$\bar{\nu}_\mu \to \bar{\nu}_e$	541 / [200-3000]	Karmen ν_e	Disappear.	$\nu_e \to \nu_x$	17 / [20-55]
Gallium	Disappear.	$\nu_e \to \nu_x$	1 / 0.75	MiniBooNE ν_μ $\bar{\nu}_\mu$	Disappear.	$\nu_\mu \to \nu_x$	541 / [200-3000]
Reactor (new)	Disappear.	$\bar{\nu}_e \to \bar{\nu}_x$	[9-100] / 4	CDHS	Disappear.	$\nu_\mu \to \nu_x$	[130-885] / 1000
				Bugey	Disappear.	$\bar{\nu}_e \to \bar{\nu}_x$	[15-95] / 4
				Chooz	Disappear.	$\bar{\nu}_e \to \bar{\nu}_x$	1050 / 4

- If sterile neutrino hints are accepted , then neutrino oscillations should be quantified in all channels:

– ν_e and $\bar{\nu}_e$ appearance

– ν_μ and $\bar{\nu}_\mu$ disappearance

– ν_e and $\bar{\nu}_e$ disappearance

- SAGE and Borexino experiments with artificial neutrino source provide a unique opportunities to searches for very short baseline oscillations associated with:

– ν_e disappearance

Region of allowed mixing parameters inferred from 4 gallium source experiments assuming oscillations to a sterile neutrino

$$P_{ee} = 1 - \sin^2 2\theta \cdot \sin^2\left(1.27\frac{\Delta m^2(eV^2)\cdot L(m)}{E_\nu(MeV)}\right)$$

In Ga experiments: $E_\nu \sim 1$ MeV

$L \sim 1$ m

Oscillations affect the capture rate with $\Delta m^2 \sim 1\ eV^2$

Limits for oscillation parameters obtained in the four artificial neutrino source experiments:

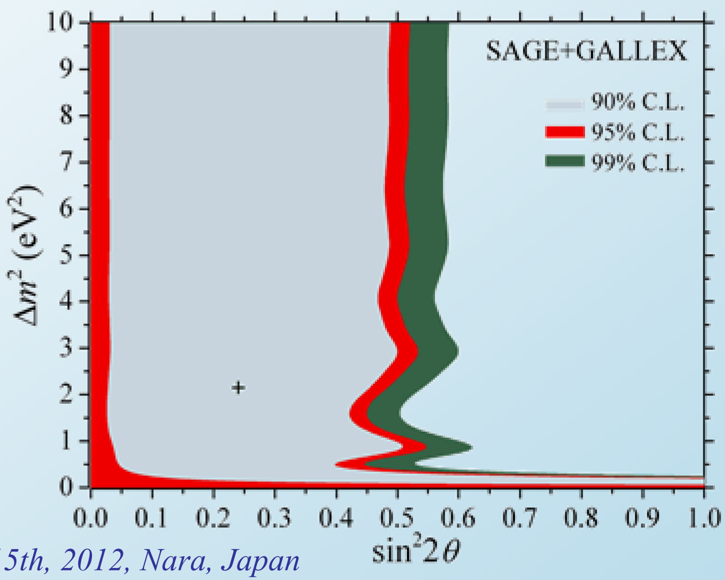
the best-fit point (plus) at

$\Delta m^2 = 2.15$ эВ^2

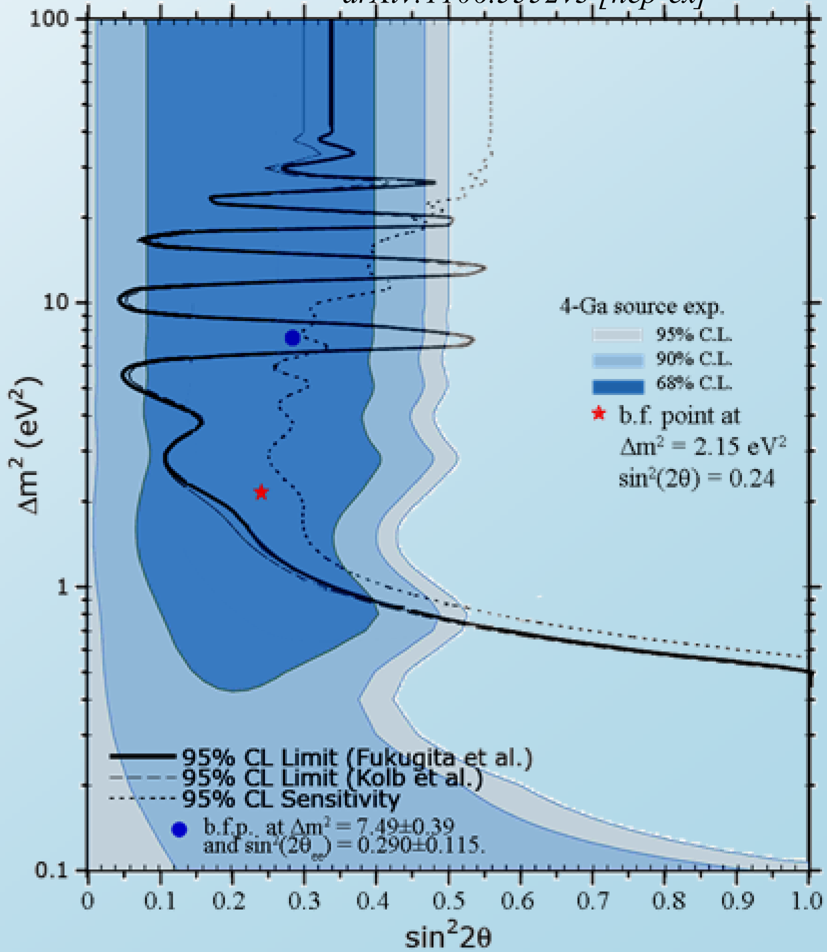
$\sin^2(2\theta) = 0.24$

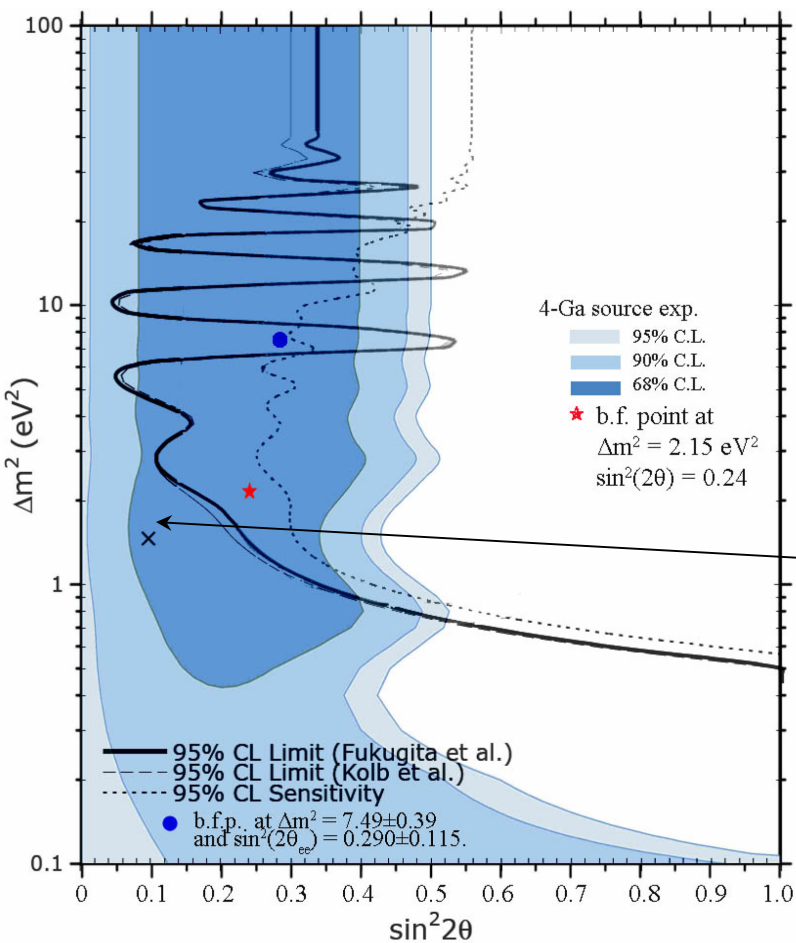
$\chi 2/dOf = 1.77/2$,

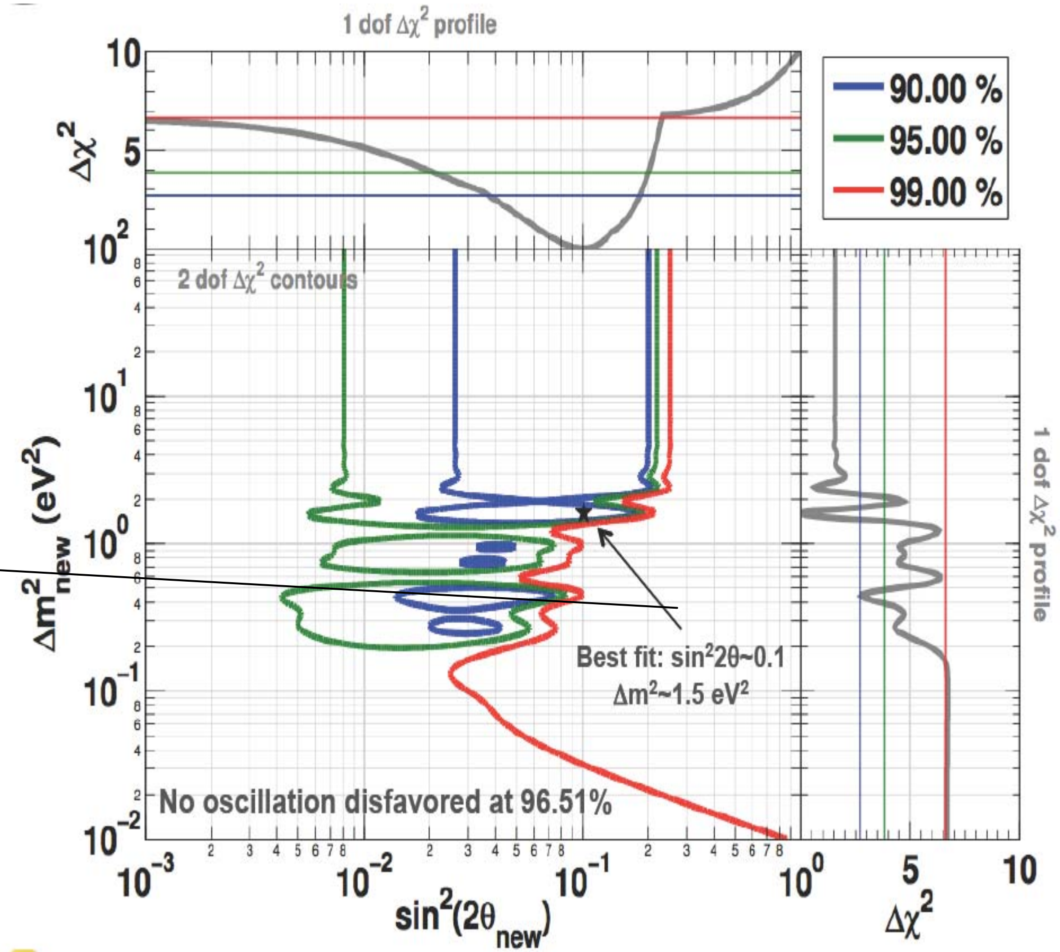
GOF=41%



J.M. Conrad and M.H. Shaevitz
arXiv:1106.5552v3 [hep-ex]





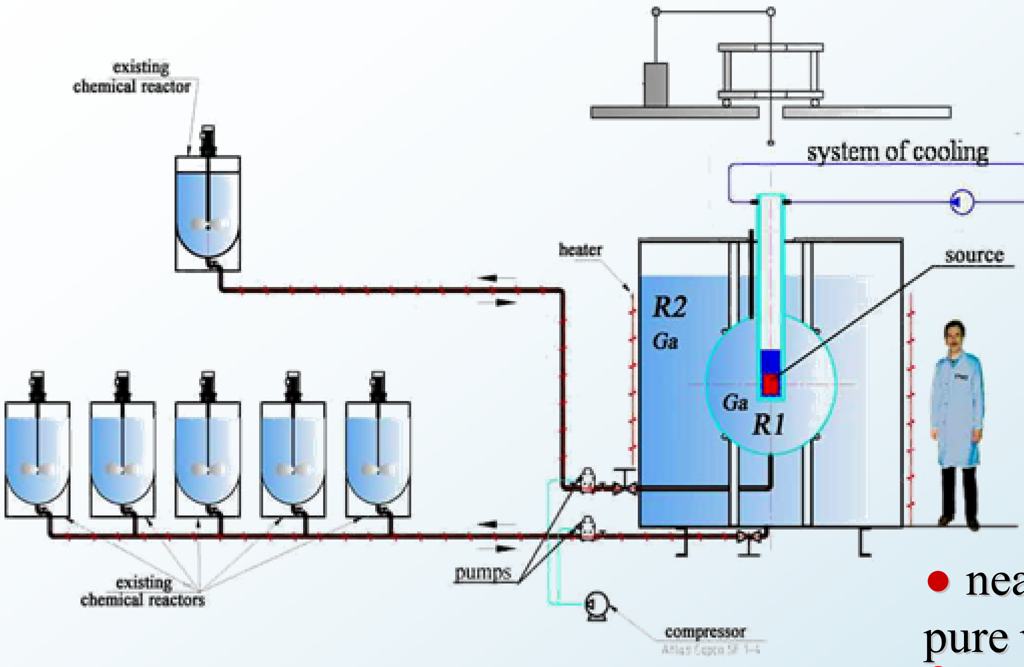


Contours from the 4 Gallium source experiments

Combined Reactor Rate+Shape contours

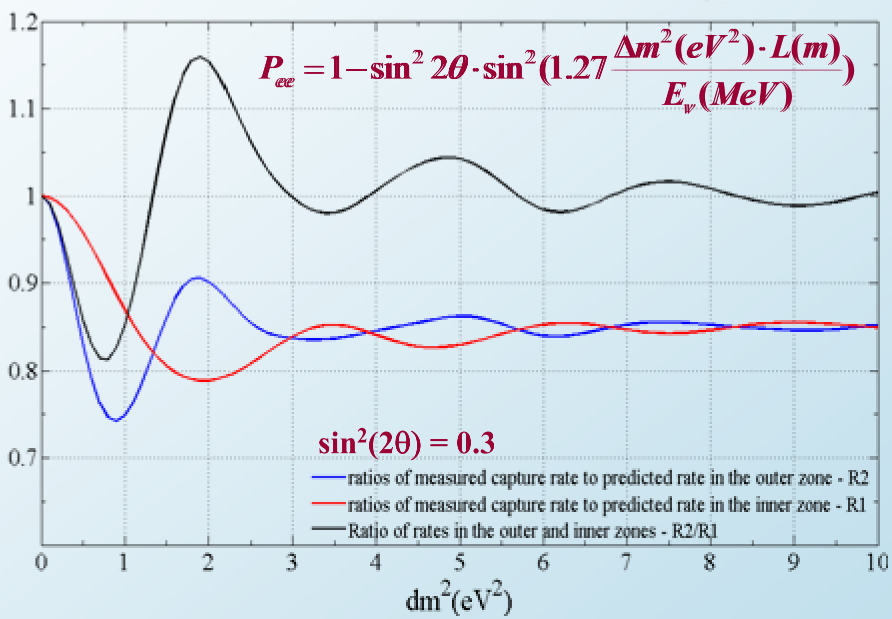
Th. Lasserre, NuTel'11

Sketch of two zone Ga experiment with ^{51}Cr (3MCi) source



Target: 50 т Ga metall
Masses of the zones: 8 t and 42 t
Path length in each zone: <L> = 55 cm
σ – cross sect. {5.8×10^{-45} cm^2 *[Bahcall]*}

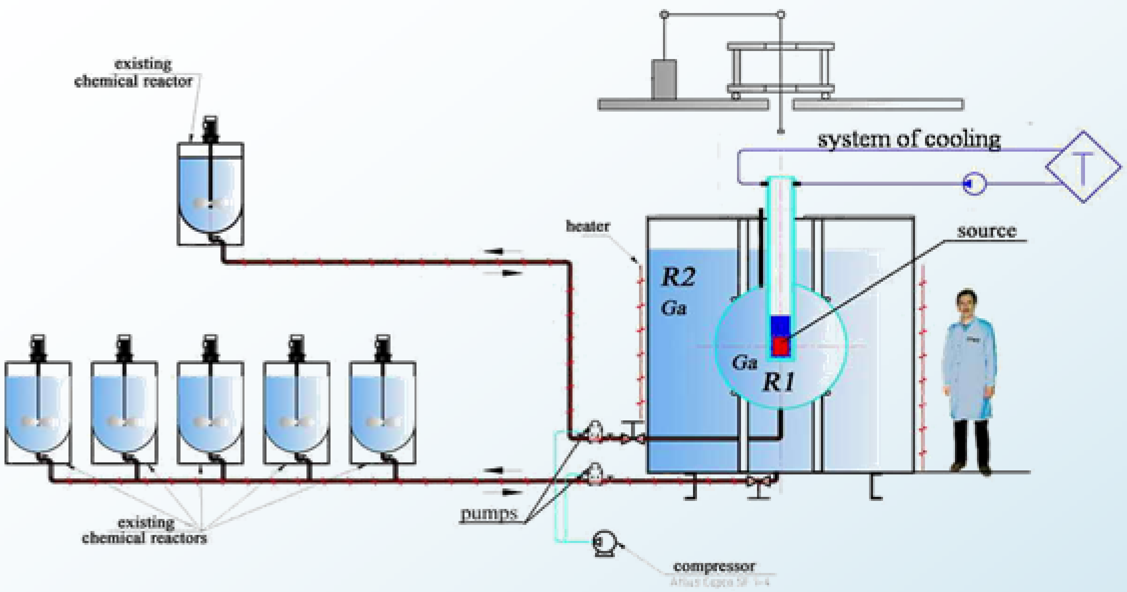
The rate at SOE: 64.5 ± 0.1 atoms/day



The advantages:

- nearly-monochromatic very compact source of pure ν_e flux with well known activity
- independent measurements on two different baselines
- the dense target of Ga metal provides a high interaction rate and good statistical accuracy
- all procedures are well understood and were used in the prior solar and source experiments
- the absence of background and uncertainties connected with inaccurate knowledge of neutrino spectrum will provide the simplicity of results interpretation

Sketch of two zone Ga experiment



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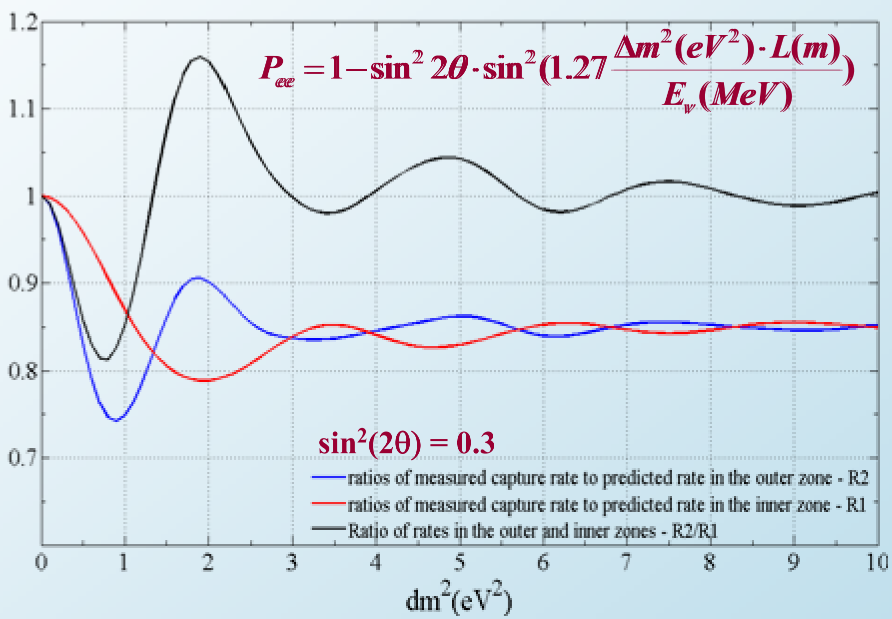


The evidence of nonstandard neutrino properties:

- there is a significant difference between the capture rates in the two zones
- the average rate in both zones is considerably below the expected rate

Statistics of the experiment

Expected capture rates of neutrinos from 3 MCi source in each zone of the target in the absence of transitions to sterile neutrinos

Source ^{51}Cr with activity 3 MCi
10 measurements of 9 days each

Capture rate ~65 d^{-1} in a zone at the start of the first exposure (is obtained from M-C simulatons)

Capture rate ~7 d^{-1} at the start of the last exposure.

Production rate from solar neutrinos is constant at 0.0197 atoms ^{71}Ge/(day – 1 tonne Ga). After 10 days (9 days of source exposure and an additional interval of about 1 day when the source is placed in the calorimeter)
1.18 ^{71}Ge at. in 8 tonne of Ga and
6.20 ^{71}Ge at. in 42 tonne of Ga

№ extraction	at.^{71}Ge/day at the start of irradiation	number of at.^{71}Ge at the end of exposure	at.^{71}Ge in the counter	at.^{71}Ge from Source/at.^{71}Ge from Sun, 1	at.^{71}Ge from Source/at.^{71}Ge from Sun, 2
1	64.6	397.2	210.5	336.6	64.1
2	50.3	309.3	164	262.1	49.9
3	39.1	240.9	127.6	204.1	38.8
4	30.5	187.5	99.4	158.8	30.3
5	23.7	146.0	77.4	124	23.5
6	18.5	113.6	60.2	96.3	18.4
7	14.5	88.5	46.9	75	14.3
8	11.2	68.9	36.5	58.4	11.1
9	8.7	53.6	28.5	45.4	8.7
10	6.8	41.8	22.1	35.4	6.8
Σ		1647.3	873.1	139.6	26.6

Total number of the captures ~ 1650 in 1 zone
Total number of ^{71}Ge pulses ~ 873

Statistical uncertainty: 3.7 % in 1 zone
2.6 % in the entire target

Systematic uncertainties in percent for a two-zone experiment with a 3MCi source

- Chemical extraction efficiency: ±2.3
  - Ge carrier mass
  - Mass of extracted Ge
  - Residual Ge carrier
  - Ga mass
- Counting of the ^{71}Ge decays in the prop. counters: ±0.9
  - Volume eff
  - Peak efficiency
  - Resolution
  - Rise time cut
- Nonsolar ν production of ^{71}Ge: <-0.07
  - Fast neutrons
  - ^{232}Th
  - ^{226}Ra
  - Cosmic-ray muons
- Backgrounds: ±0.16
  - Internal ^{222}Rn
  - Internal ^{69}Ge
  - Solar neutrino background
  - ^{71}Ge carryover
- Energy weighting in analysis : ±0.15
- Source activity: ±0.5

Total systematic uncertainty : ±2.6%

The uncertainty of the theoretical prediction of the cross section for absorption of ^{51}Cr ν by ^{71}Ga is +3.6 /-2.8 % – 1σ

[Bahcall PRC.56, 1997]

For a two-zone experiment with a 3MCi source the statistical and systematic uncertainties combined in quadrature :

4.5% in 1 zone

3.7% in the entire target

With the cross section uncertainty:

5.5 % and 4.8 %

Sensitivity to oscillations with large values Δm^2 (90% CL)

$\sin^2 2\theta > 0.12$

(stat.+ syst.+ uncert. cross section)

Systematic uncertainties

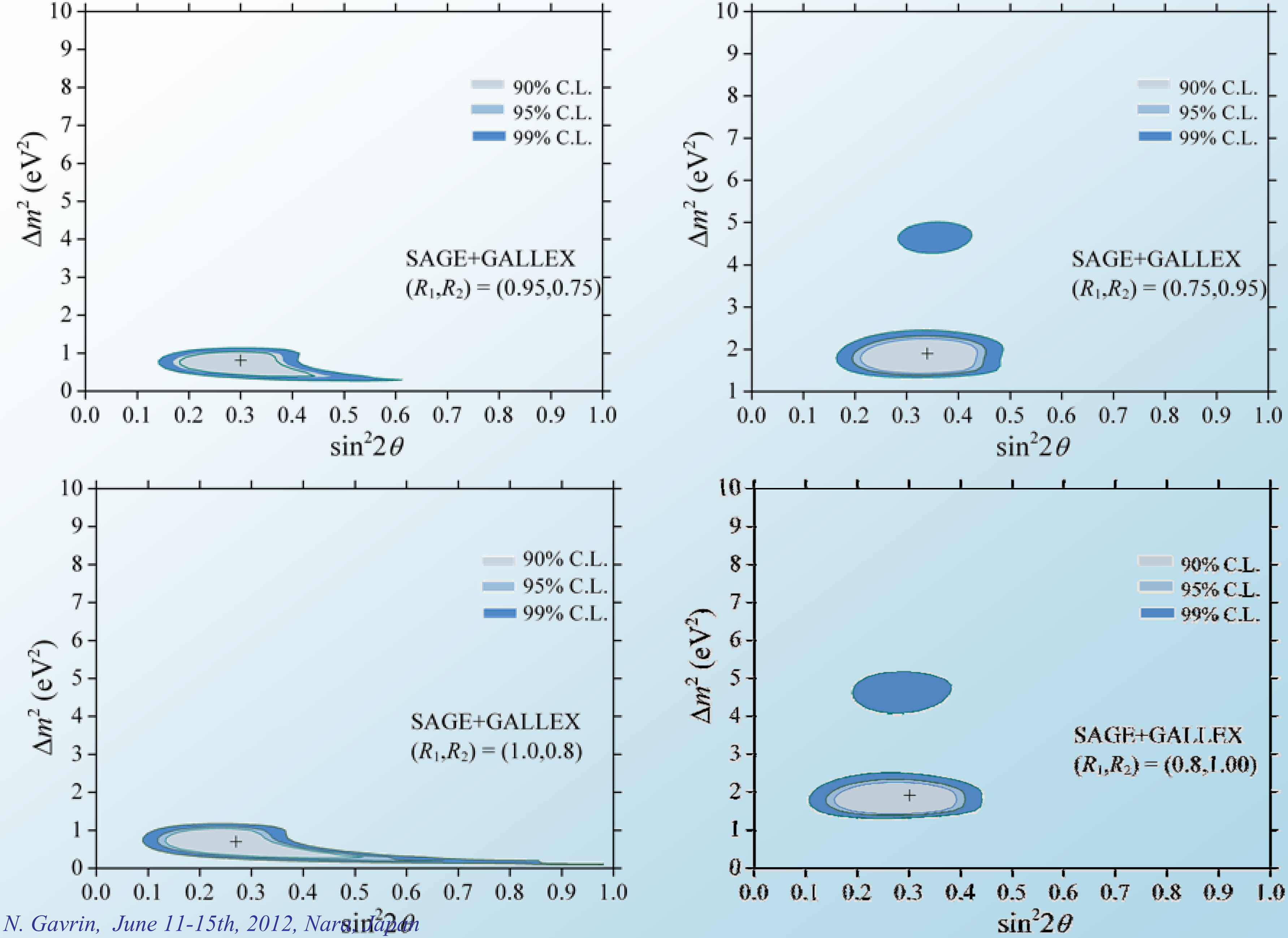
	Uncorrelated errors (%)	Correlated errors (%)
Chemical extraction efficiency: • Ge carrier mass • Mass of extracted Ge • Residual Ge carrier • Ga mass	 ±0.8 ±0.3 ±0.5	 ±2.1
Counting efficiency • Volume eff • Peak efficiency • Resolution • Rise time cut	 ±0.4 ±0.4 ±0.3 ±0.6	
Non-neutrino production of ^{71}Ge (Fast neutrons, ^{232}Th, ^{226}Ra, Cosmic-ray muons)	<-0.07	
Bg mimic ^{71}Ge • Internal ^{222}Rn • External ^{222}Rn • Internal ^{69}Ge	 <-0.01 0 <-0.03	
Solar neutrino bg	±0.16	
Energy weighting in analysis	±0.15	
Source activity		±0.5
(ν, Ga) Cross section (Bahcall'97)		+3.6 / -2.8
Total	±1.34	

Total uncertainty (stat.. + syst..(uncorr+corr.)):

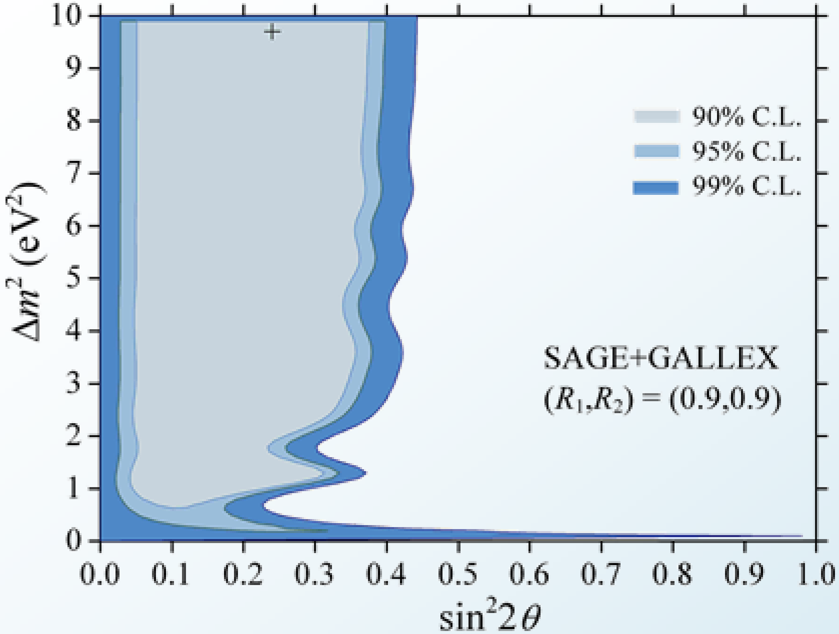
5.5 % for each zone

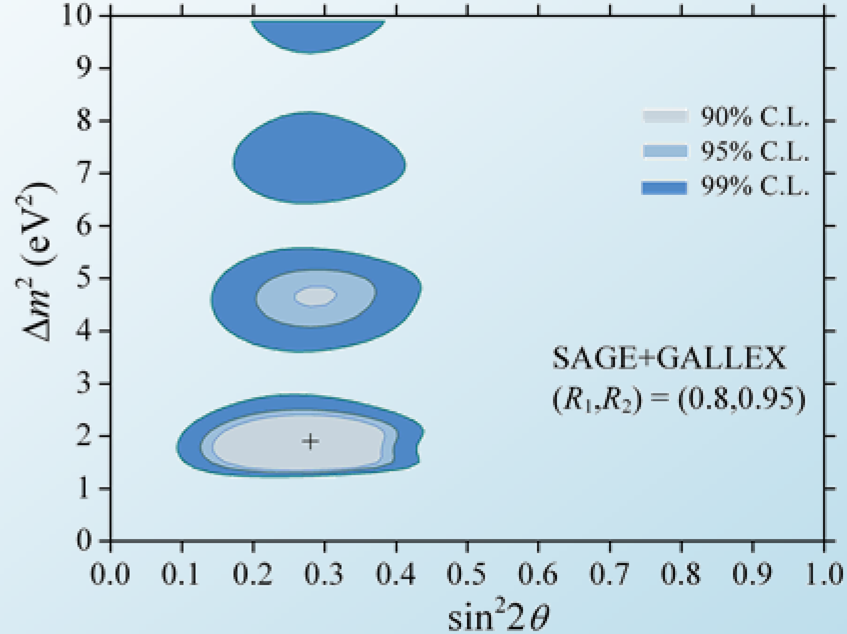
4.8 % for total target

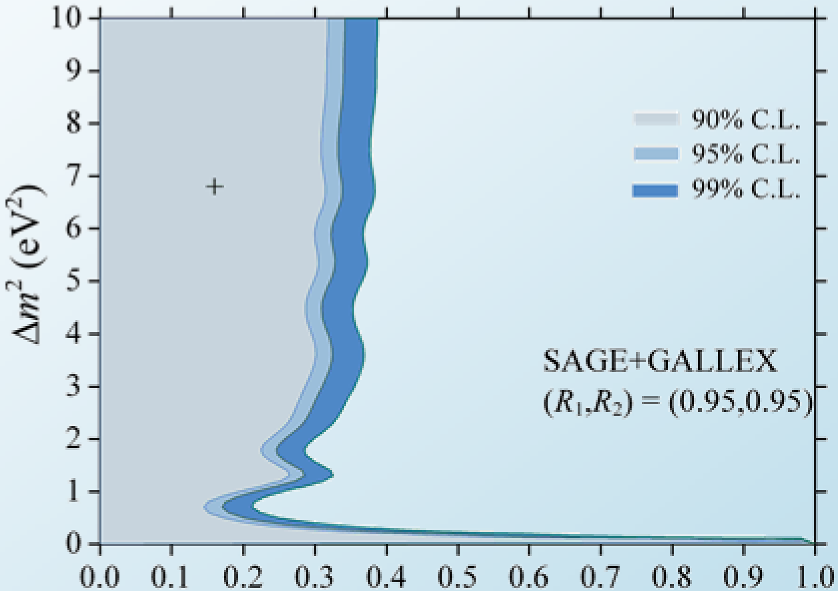
Region of allowed mixing parameters inferred from 4 gallium + 2-zone source experiments 1 - the ratio of rates R in the two zones are statistically incompatible

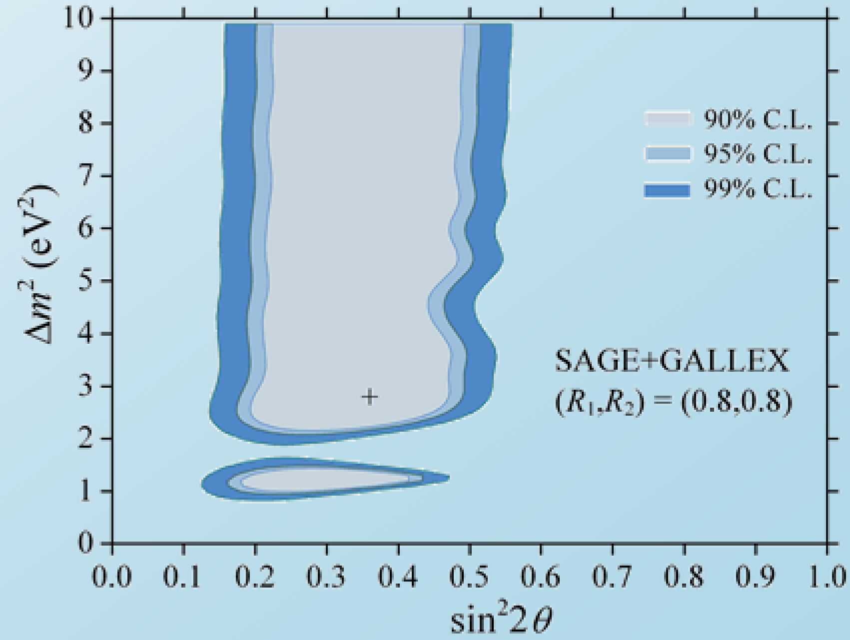


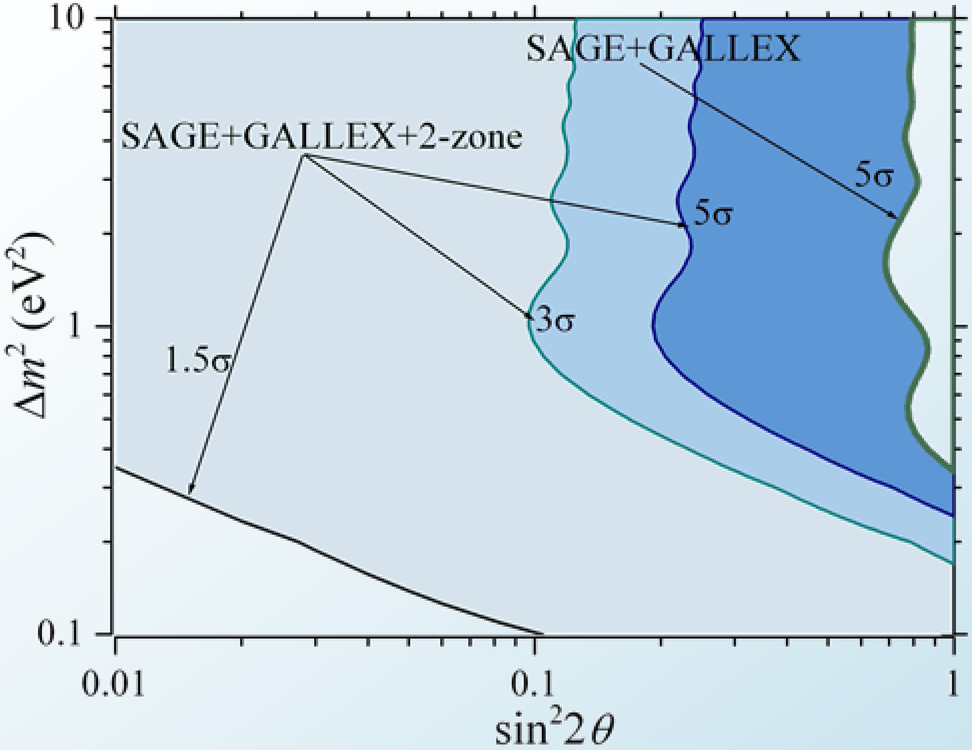
Region of allowed mixing parameters inferred from 4 gallium + 2-zone source experiments 2 - the ratio of rates R in both zones are statistically compatible











The region in Δm^2 - $\sin^2(2\theta)$ space to which the new 3 MCi ^{51}Cr experiment will be sensitive

Light Sterile Neutrinos: A White PaperarXiv, 1204.5379v1 [hep-ph] 18 Apr 2012

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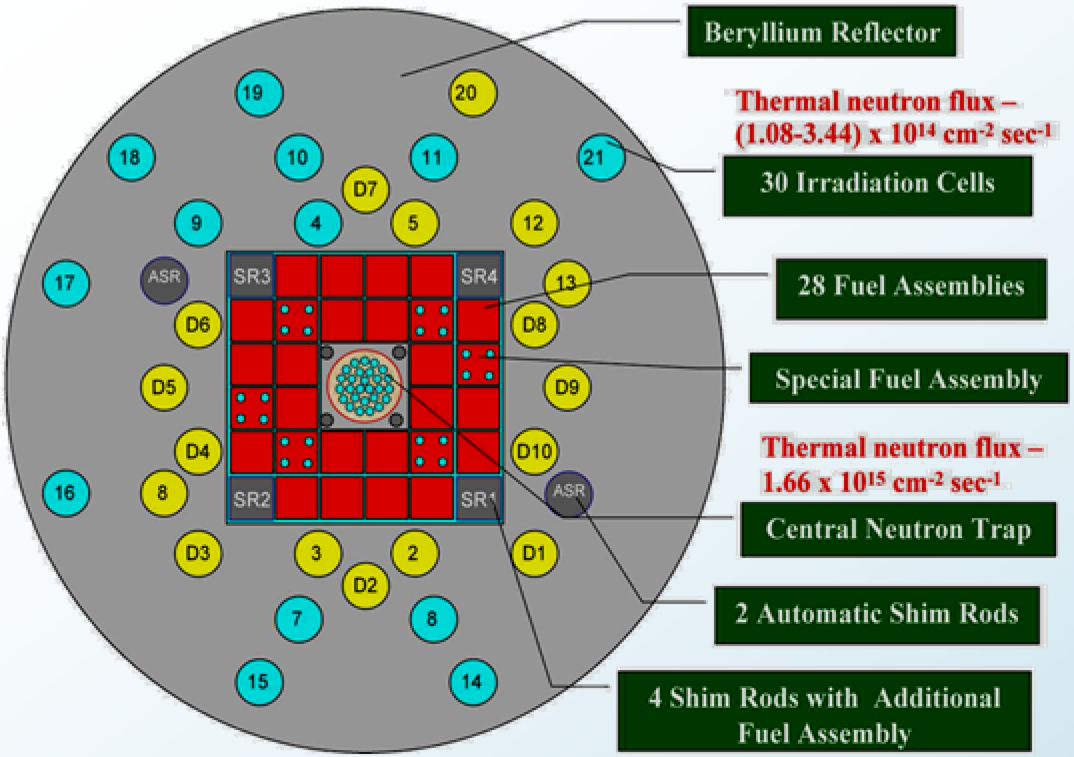
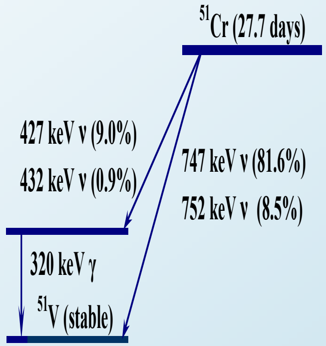
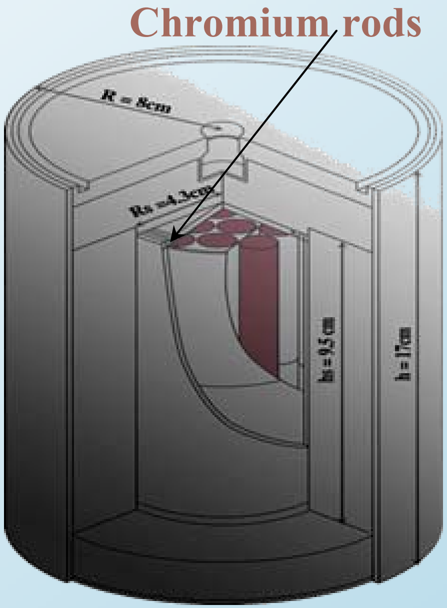
Reactor SM Cross-section



Sketch of source





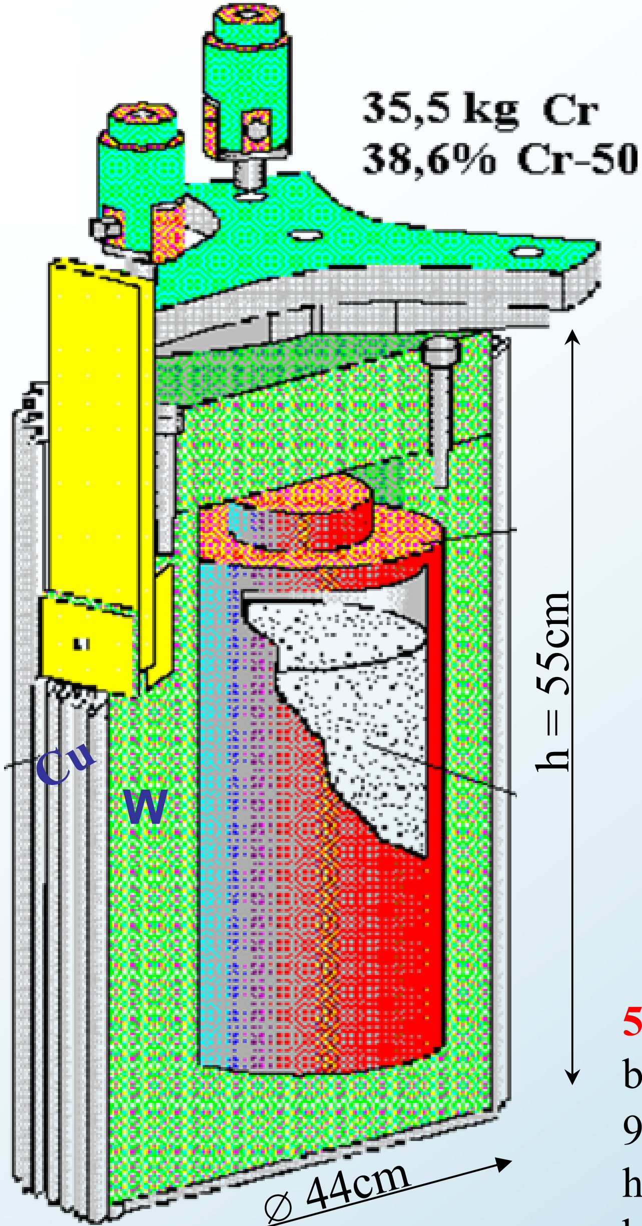
$^{50}Cr(n,\gamma)^{51}Cr$

^{50}Cr isotope in natural Cr is 4.35%

-3.5 kg of Cr with 97% enrichment by ^{50}Cr in the form of Cr_2O_3 of ultrahigh purity will be produced

-81 chromium rods with Ø8.5×95 мм and total mass – 3015g will be prepared and placed in cells of the central neutron trap of the reactor SM

-irradiation will continue within 58.9 eff. days (69 calendar days)
the expected average specific activity - 1016 Ci/g, and total activity -3.20 MCi



(1) 1.17 MCi 1994 –1995

(2) 1.87 MCi 1995 –1996

SAGE – GALLEX

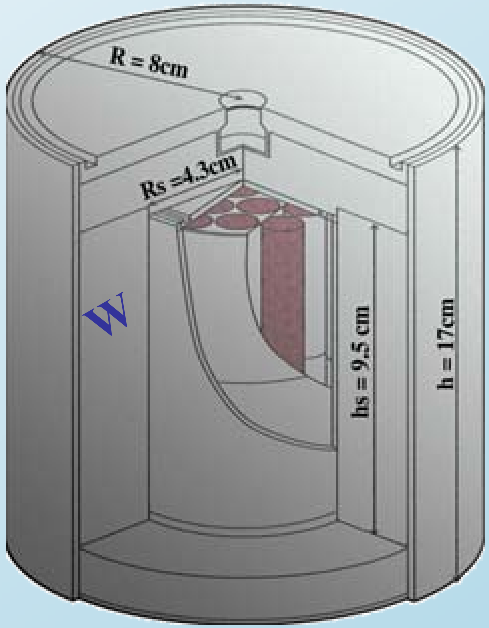
517 **kCi ^{51}Cr** produced by irradiatin 512.7 g of 92.4%-enriched ^{50}Cr in high-flux fast neutron breeder reactor BN-350

1994 –1995

409 **kCi ^{37}Ar** produced by irradiatin 330 kg of CaO in the fast neutron breeder reactor BN-600

2004

SAGE–…?

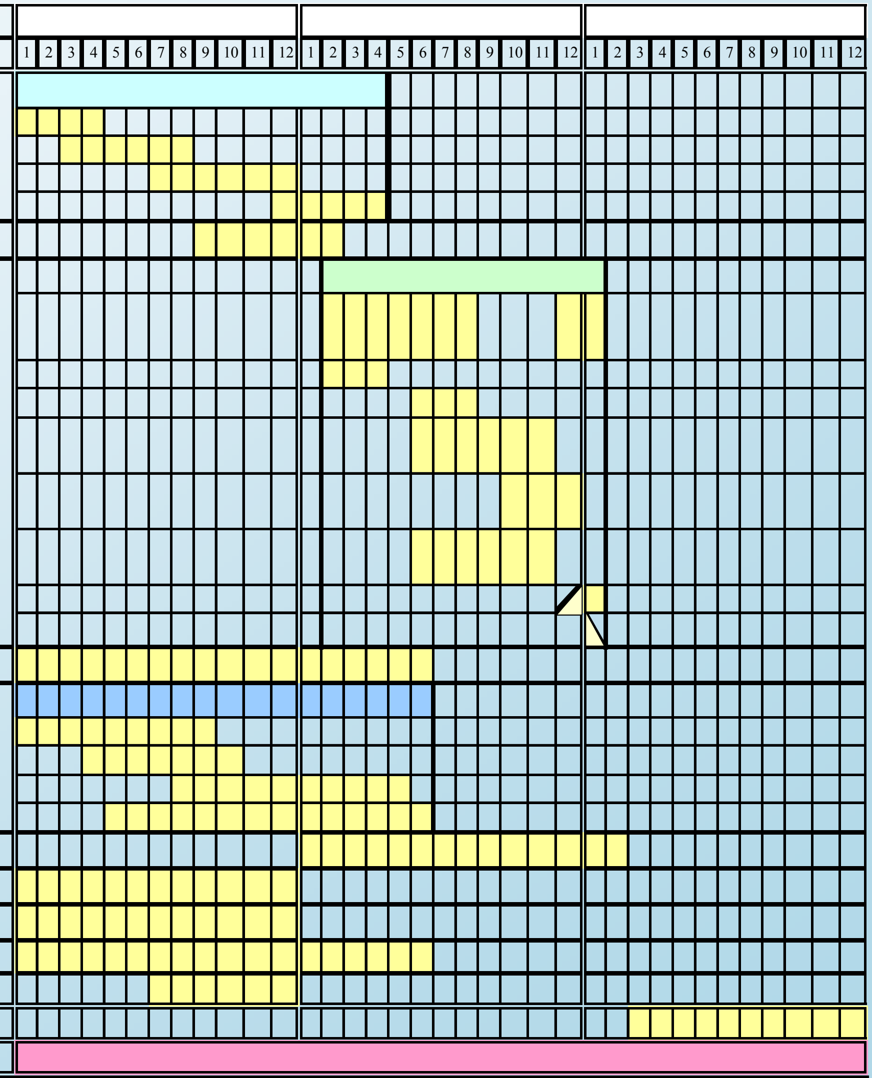


3 **MCi ^{51}Cr**

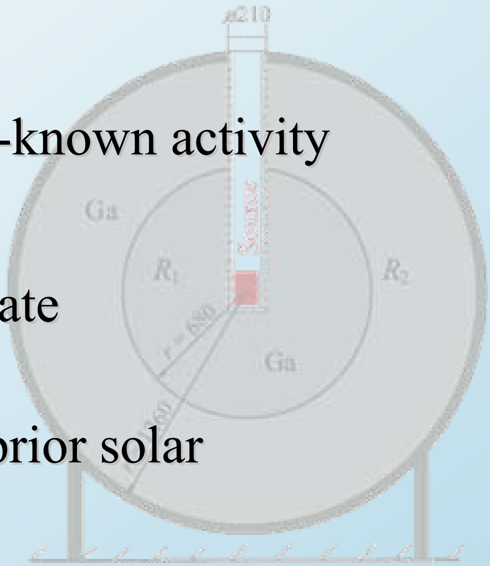
201?

Time schedule and costs

№	Items	Duration	Cost K $
1	**Generation of 3.5 kg of ^{50}Cr with 97% enrichment:** 1) calculation of the separation mode, 2) optimization on parameters 3) preliminary enrichment; 4) obtaining 97% of enriched chromium.	16 mon.	1170
2	Preparation of a target from the enriched ^{50}Cr	6 mon.	40
3	**Irradiation of the target in reactor SM-3:** 1) Neutron-physical calculations and calculations of trans-mutation of the nuclei, release of tech. documentation. 2) Design and manufacture of the irradiation unit and reactor targets. 3) Optimization of design and size of biological shielding of the source. 4) Development and production of components and devices intrachamber needed for the assembling. 5) Full-scale irradiation of enriched chromium in the central channel of the reactor SM 6) Development and production of components and devices intrachamber needed for the assembling. 7) The assembly and pre-certification of the neutrino source. 8) Transportation of the neutrino source to the Customer	12 mon.	2500
4	Modernization of the GGNT extraction system	18 mon.	235
5	**Design, manufacture and installation of:** - two-zone detector; - calorimeter to measure the activity of ^{51}Cr; - manipulator for the source; - manufacture of protective container	18 mon.	370
6	Monthly solar extractions on a 2-zone target	14 mon.	
7	Preparation and certification of counters	12 mon.	17
8	Development and preparation of an additional counting system	12 mon.	83
9	Regeneration of Ga to bring the target mass to 50 tons	18 mon.	250
10	Licensing, authorization-based documents, dosimetry	6 mon.	10
11	Data acquisition		
	TOTAL(including ~6% escalation/ year)		4955.5



The proposed Ga-Cr experiment :



- independent measurements on two different baselines
- nearly-monochromatic neutrino and the source with well-known activity
- very compact source of pure ν_e flux
- the dense target of Ga metal provides a high interaction rate and good statistical accuracy
- all procedures are well understood and were used in the prior solar and source experiments
- the absence of background and uncertainties connected with inaccurate knowledge of neutrino spectrum will provide the simplicity of results interpretation

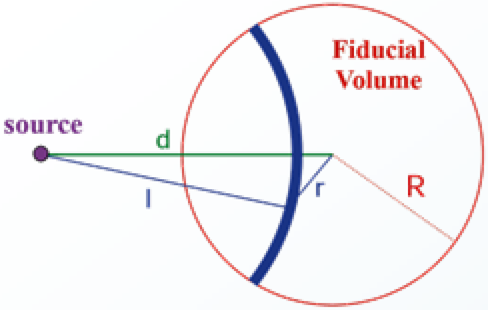
The proposed experiment has the potential to test neutrino oscillation transitions with $\Delta m^2 > 0.5$ eV^2

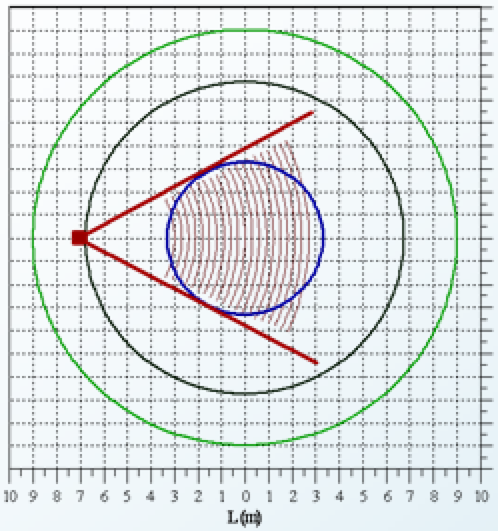
The sensitivity to disappearance of electron neutrinos is expected to be a few percent

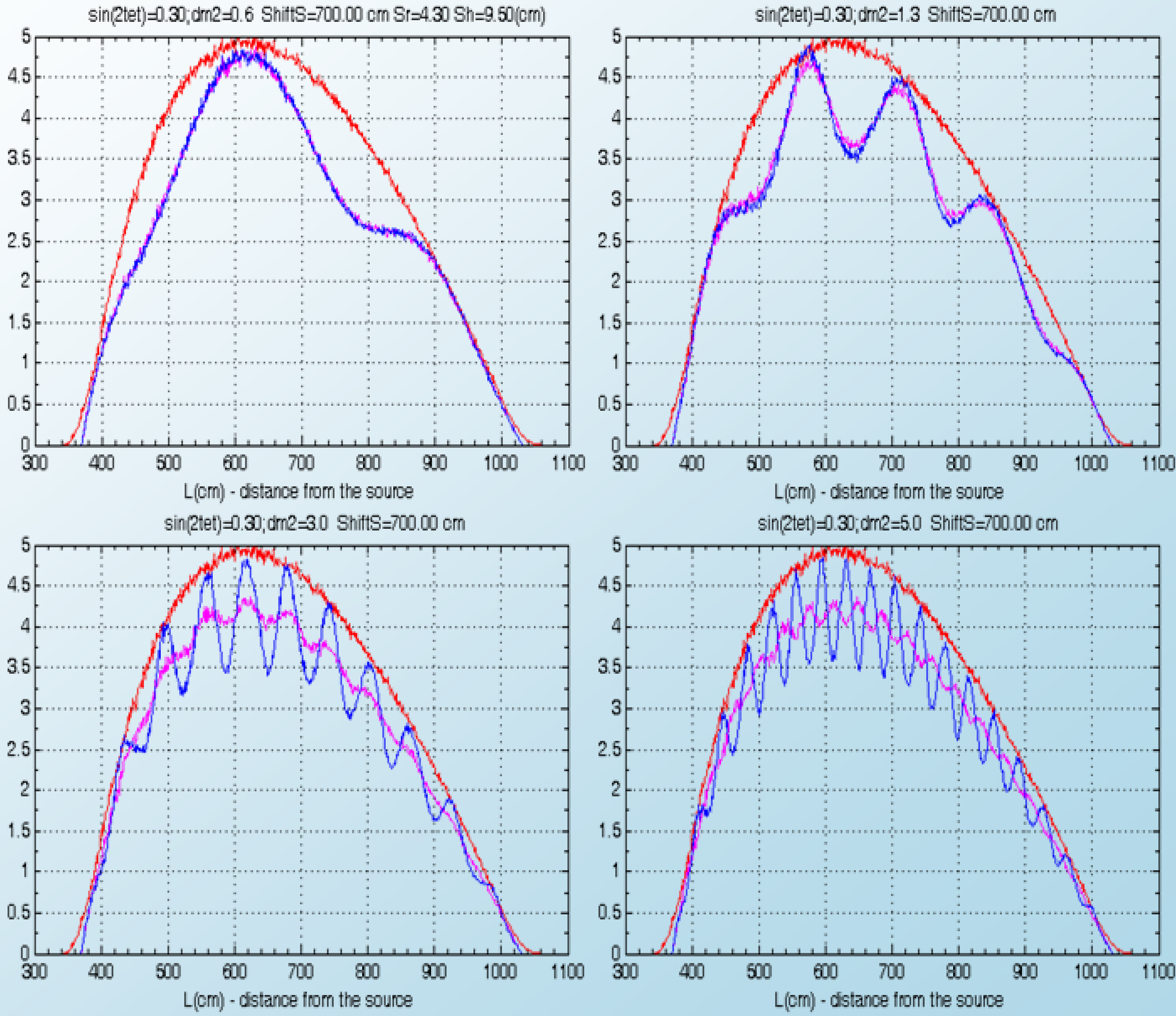
Back up

Waves with ^{51}Cr source in WT(7m) BOREXINO

From M-C 5000000 simulations, 3.3m FV,







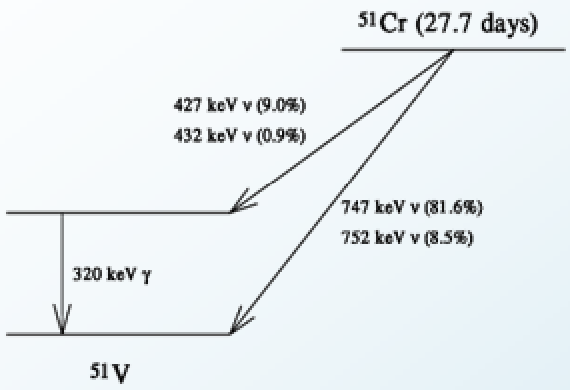
NO oscillation.

for source size
(∅ 44 cm, h = 55cm)

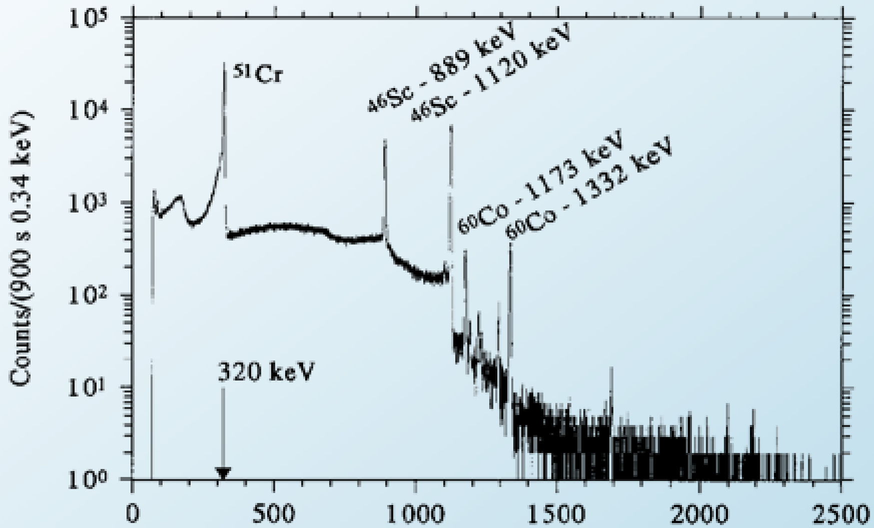
for SAGE source size
(∅ 8.6 cm, h = 9.5cm)

^{51}Cr source activity determination - 1994

^{51}Cr source



Decay scheme of ^{51}Cr to ^{51}V through electron capture



Unshielded Ge detector spectrum of the gamma rays emitted by the source, taken shortly after the start of the first Ga irradiation. The total activity of all contaminants was estimated to be less than 2 Ci at this time.

1. The heat produced by the ^{51}Cr source was measured with a calorimeter between extractions for a total of seven measurements. The conversion constant 36.671 ± 20keV/ decay was used in estimating the power for the Cr.

2. The activity of each rod was measured at three points along its length to determine the average value of the total activity of the source.

The final value of 516.6 ± 6.0 kCi at the reference time.

3. Based on test results from the experimental reactor at Obninsk and irradiation of a small mass of ^{50}Cr in the reactor at Aktau, the calculated activity was 554±55 kCi at our ref. time, in agreement with the calorimeter measurement.