The BEST Experiment

Steve Elliott

Los Alamos National Laboratory

Baksan Experiment on Sterile Transitions (BEST)

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arXiv:2201.07364, PRC

Spokesperson – Vladimir Gavrin

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V.V. Barinov,[1] B.T. Cleveland,[2] S.N. Danshin,[1] H. Ejiri,[3] S.R. Elliott,[4] D. Frekers,[5] V.N. Gavrin,[1,a] V.V. Gorbachev,[1] D.S. Gorbunov,[1] W.C. Haxton,[6,7] T.V. Ibragimova,[1] I. Kim,[4] Yu.P. Kozlova,[1] L.V. Kravchuk,[1] V.V. Kuzminov,[1] B.K. Lubsandorzhiev,[1] Yu.M. Malyshkin,[1] R. Massarczyk,[4] V.A. Matveev,[8] I.N. Mirmov,[1] J.S. Nico,[9] A.L. Petelin,[10] R.G.H. Robertson,[11] D. Sinclair,[12] A.A. Shikhin,[1] V.A. Tarasov,[10] G.V. Trubnikov,[8] E.P. Veretenkin,[1] J.F. Wilkerson,[13,14] and A.I. Zvir[10]

[1] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow 117312, Russia*
[2] *SNOLAB, Sudbury, ON P3Y 1N2, Canada*
[3] *Research Center for Nuclear Physics, Osaka University, Osaka, Japan*
[4] *Los Alamos National Laboratory, Los Alamos, NM, USA*
[5] *Institut für Kernphysik, Westfälische Wilhelms-Universität Munster, D-48149 Munster, Germany*
[6] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[7] *Department of Physics, University of California, Berkeley, CA 94720, USA*
[8] *Joint Institute for Nuclear Research (JINR) Joliot-Curie 6, 141980, Dubna, Moscow Region, Russia*
[9] *National Institute of Standards and Technology, 100 Bureau Dr, Gaithersburg, MD 20899, USA*
[10] *JSC 'State Scientific Center Research Institute of Atomic Reactors', Dimitrovgrad, 433510, Russia*
[11] *Center for Experimental Nuclear Physics and Astrophysics, and Department of Physics, University of Washington, Seattle, WA 98195, USA*
[12] *Carleton University 1125 Colonel By Drive Ottawa, K1S 5B6, Canada*
[13] *Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599, USA*
[14] *Triangle Universities Nuclear Laboratory, Durham, NC 27708, USA*

Overview of BEST

- Neutrinos produced at center of Ga by ^{51}Cr decay:

$$^{51}\text{Cr} + e^- \rightarrow {}^{51}\text{V} + \nu_e$$

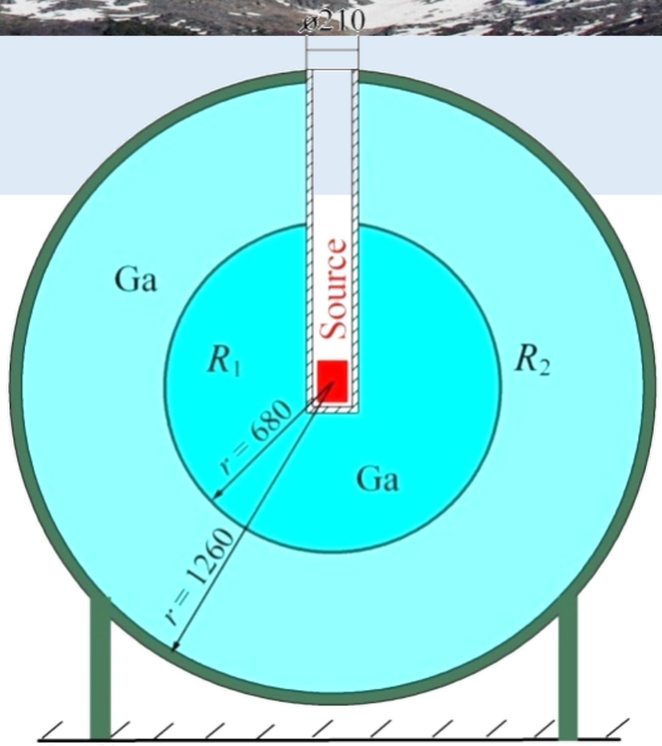
- This is a well-understood monochromatic spectrum of a compact source. The source intensity is well measured.
- These neutrinos are detected via a charged-current (CC) reaction on Ga surrounding the source:

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

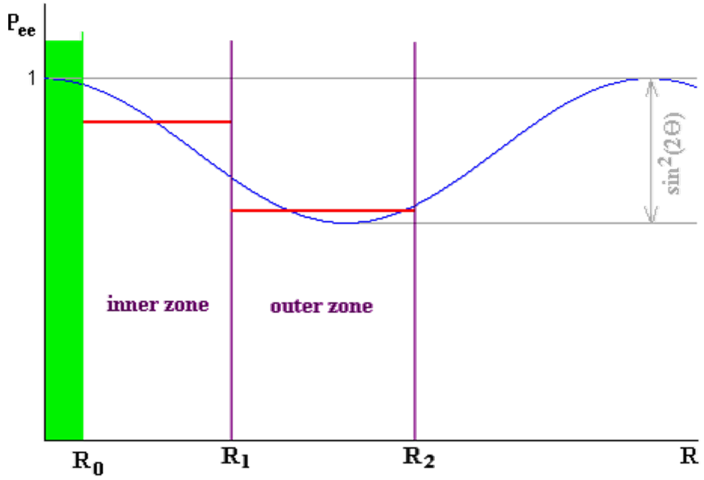
- Very Short Baseline. ~1m, two zone target to measure ν interaction rate at two distances.
- Almost zero background. Mainly from the Sun.

The source, 3.4 MCi, provides a capture rate in the Ga that exceeds the rate from the Sun by several factors of ten.

- Well established experimental procedures for extraction and counting of the ^{71}Ge developed in SAGE solar measurements.
- Simple interpretation of results. (Phys. Part. Nucl. 46 (2015) 131)

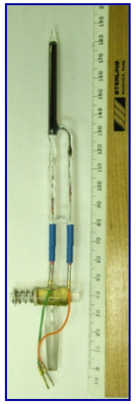


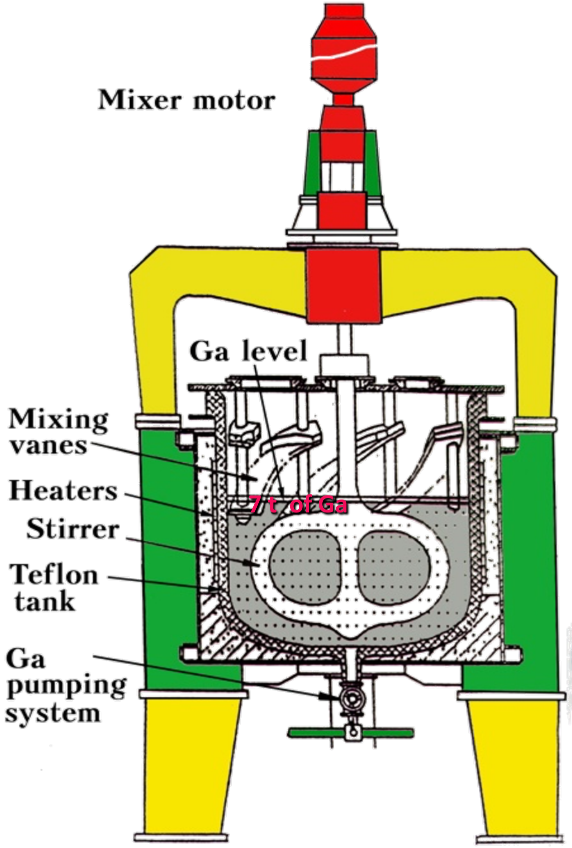
Schematic drawing of the BEST neutrino source experiment.



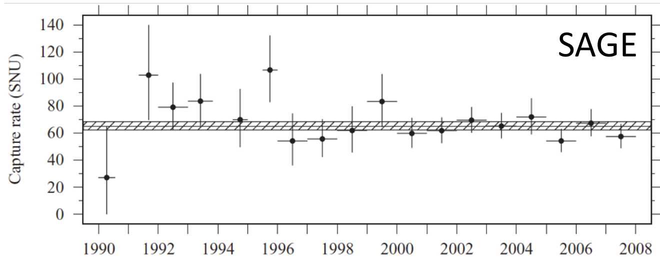
The Gallium Solar Neutrino Experiments (Kuzmin Eksp. Teor. Fiz. 49 (1965) 1532)

SAGE 50 t of Ga

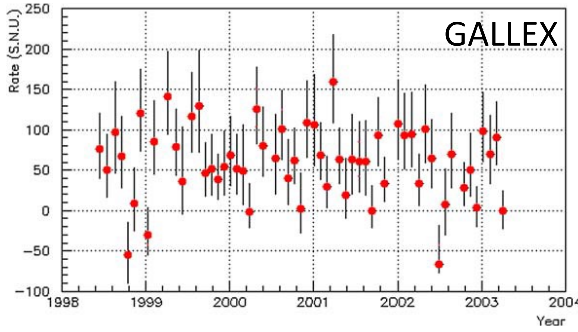




Both experiments were based on radio-chemical extraction technology of a few ^{71}Ge atoms from tons of a Ga target and on technology of counting of ^{71}Ge decays in small proportional counters (~0.5 cm^3).

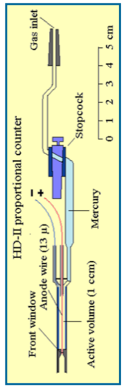


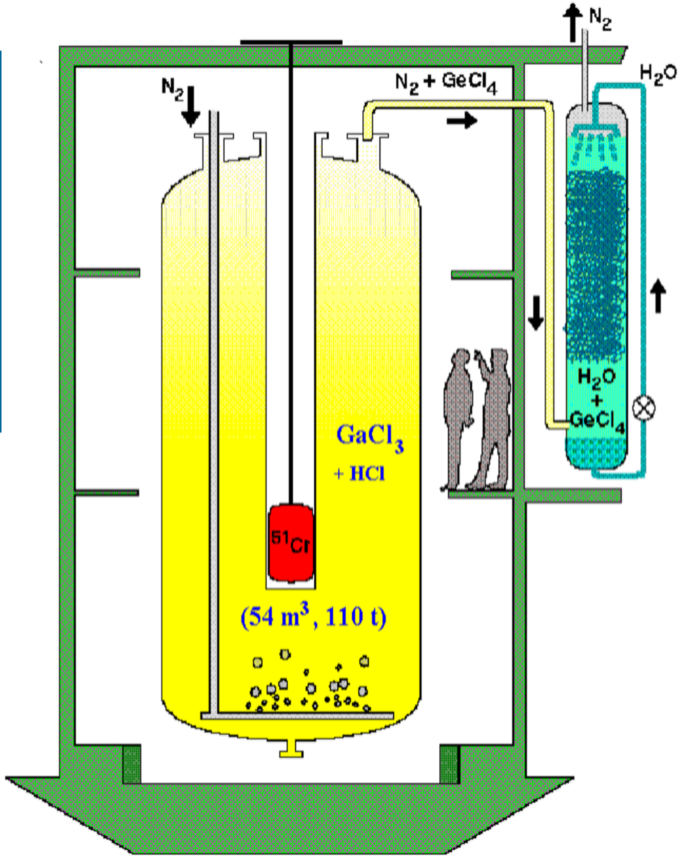
PRC 80 (2009) 015807



PLB 616 (2005) 174

GALLEX/GNO 30.3 t of Ga

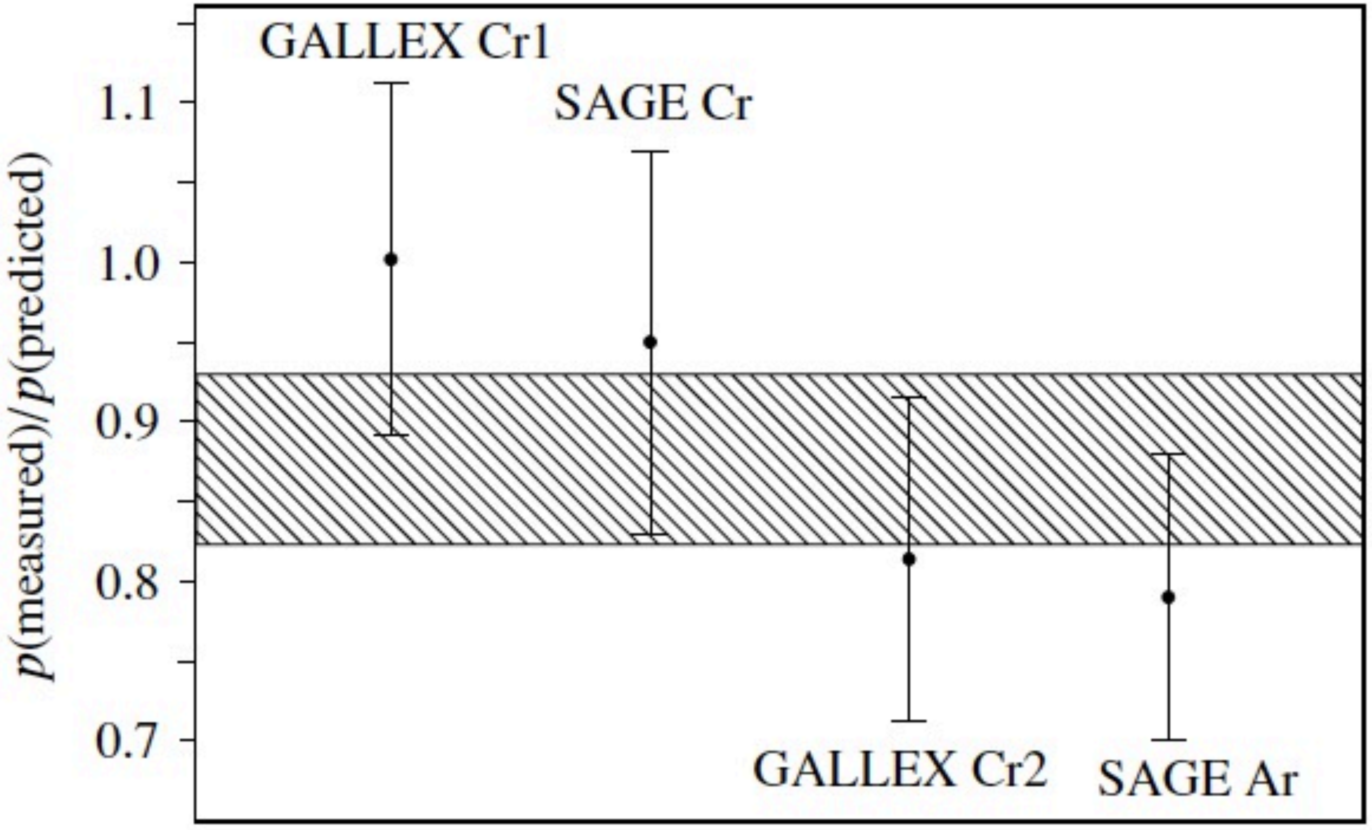




The Ga Anomaly

Previously measured rates of $^{71}Ga(\nu_e,e)^{71}Ge$ are lower than that predicted from the known cross section and ν_e flux. R=0.87±0.05

The ν_e sources in these experiments were the electron-capture isotopes, ^{51}Cr or ^{37}Ar.

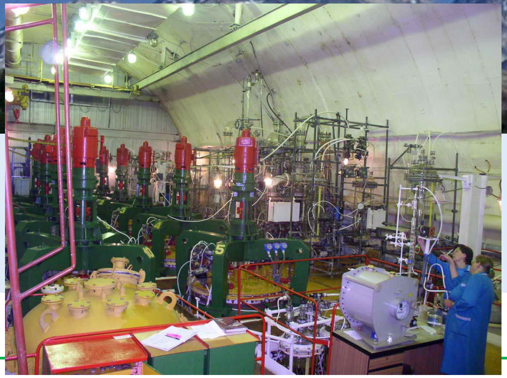


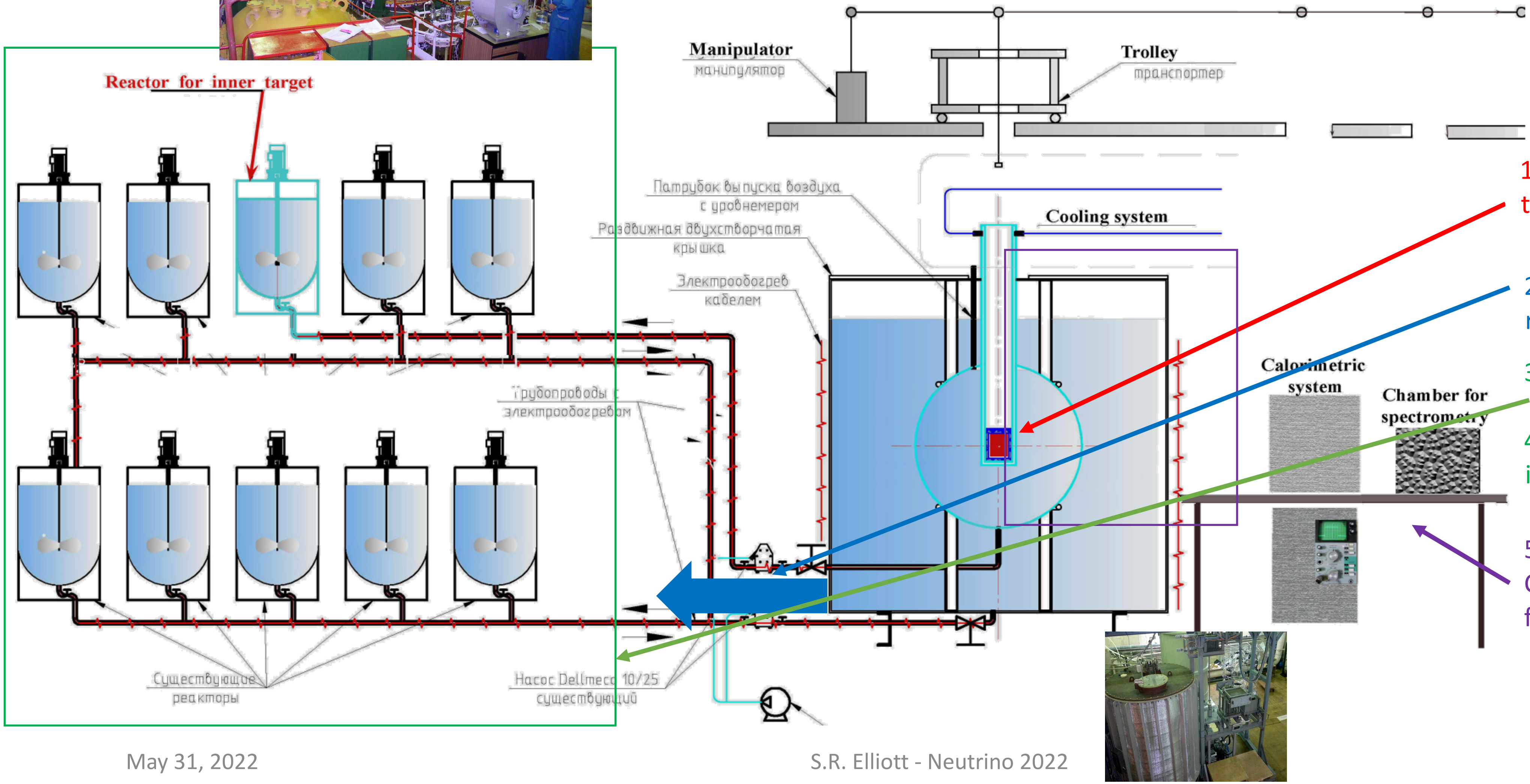
PRC 73 (2006) 045805, PRC 80 (2009) 015807

BEST Schedule

Construction began 2011
Source Arrived: July 5, 2019
Exposures: July 5 – Oct. 13, 2019
Counting: July 16, 2019 – Mar. 20, 2020
Counter Calibration: Mar. 2020 – Jan. 2021
PRL draft posted: Sept. 2021

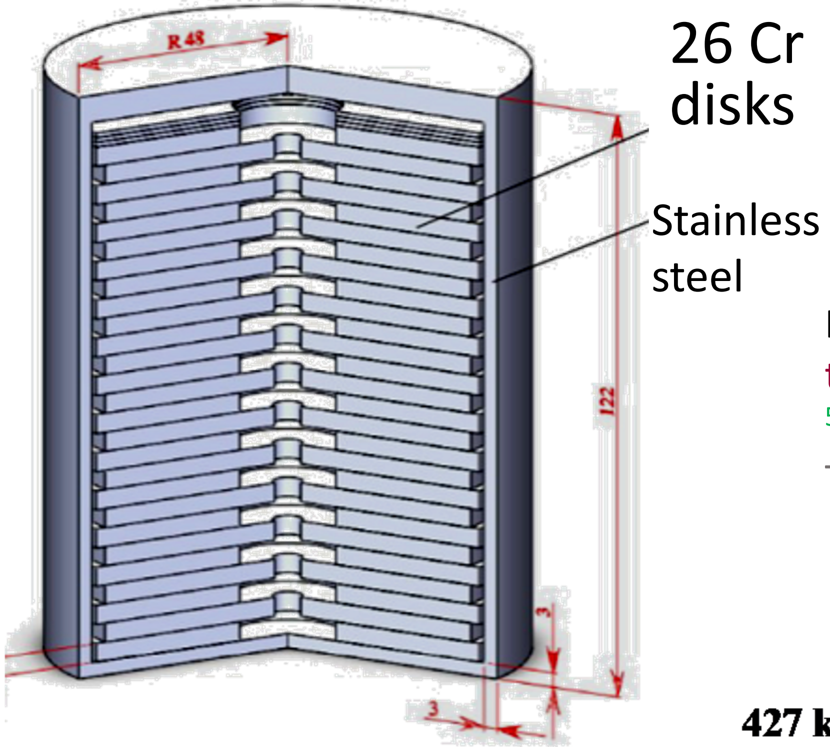
Installation and Operation

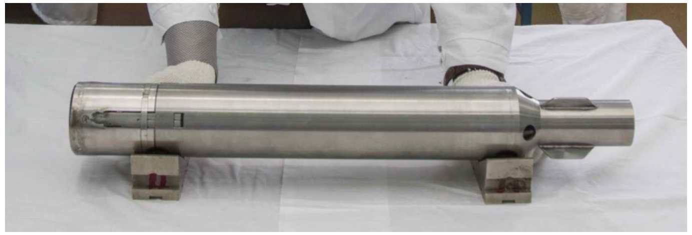




1. Expose gallium targets to the source
   $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$
2. Pump Ga to the chemical reactors
3. ^{71}Ge chemical extraction
4. ^{71}Ge decay measurement in proportional counters
5. Semiconductor & Calorimetric measurement for source activity

Neutrino Source A = 3.414 ± 0.008 MCi on July5, 2019 at 14:02



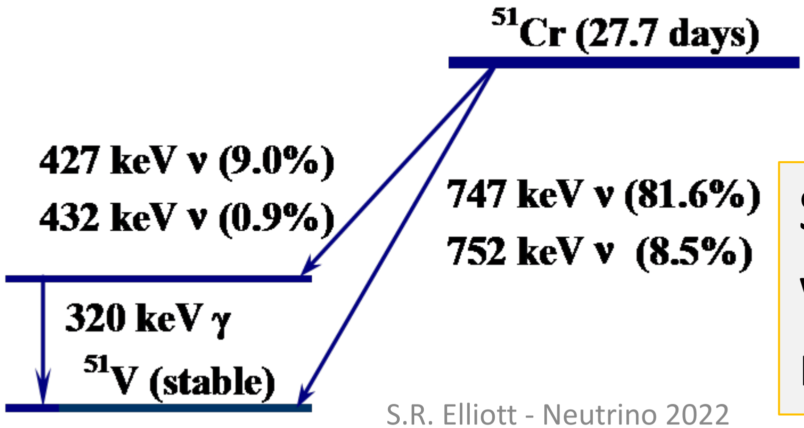


Installed at the center of the two concentric zones

Irradiated for ~100 days with thermal neutrons in the SM-3 reactor (RIAR, Dmitrovgrad) to produce ^{51}Cr neutrino source

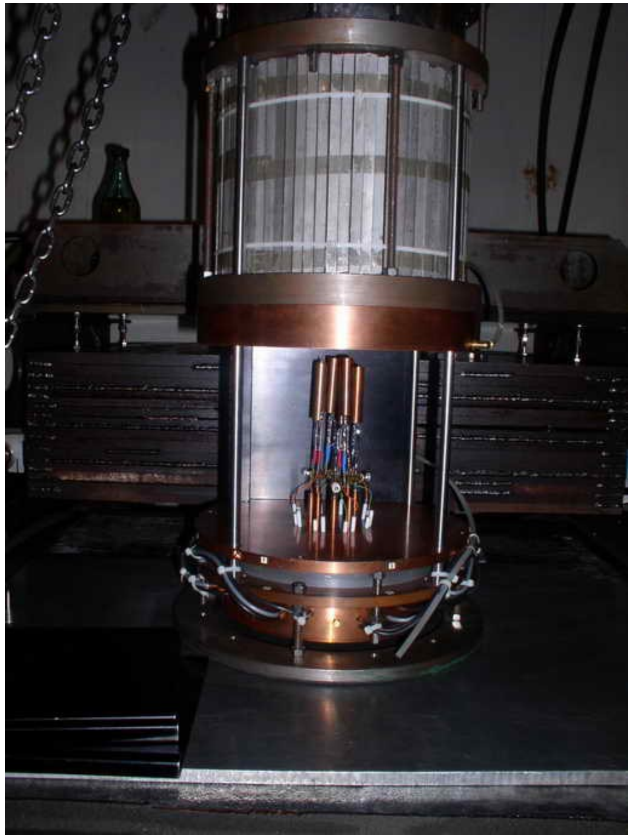
Thermal neutron flux density – 5×10^{15} n/(cm^2 s)

4 kg 97%-enriched ^{50}Cr,
26 chromium disks
h = 4 mm, ∅ 84 and 88 mm.



Simple and very well-understood neutrino spectrum

Data Acquisition



- Two 8-channel systems
- PC contained within NaI well
- PC pulses digitized at 1GHz, 100 MHz bandwidth, 8 bit
- Risetime = 3.5 ns
- 0.37<E<15 keV

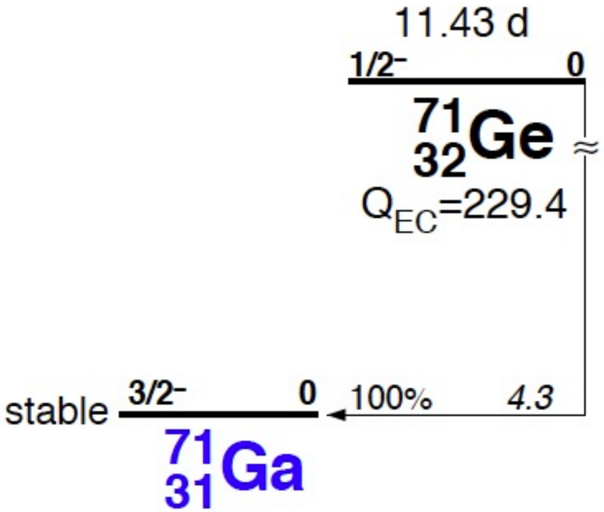
^{71}Ge Decay

Auger decays produce point-like ionization in gas. In contrast β's or Compton recoils might deposit a similar amount of energy, but over an extended path.

Leads to a pulse shape analysis technique to remove them. BEST fits the pulse waveform.

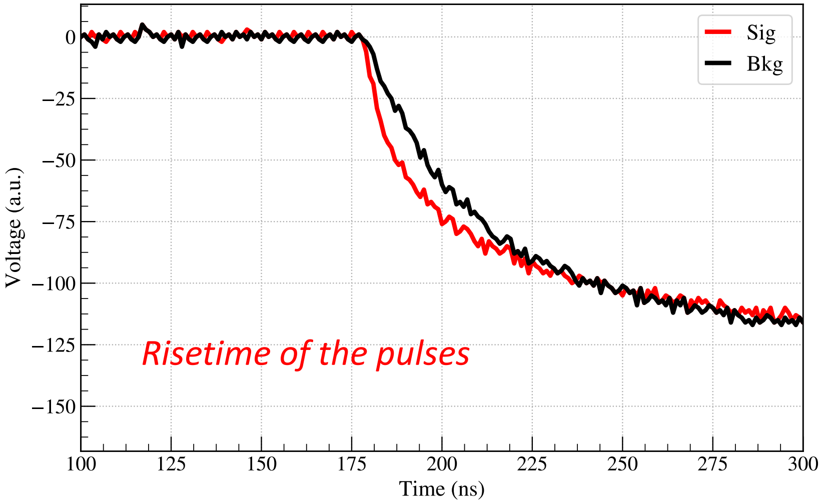
ADP (Cl expt.): Astrophys. J. 496 (1998) 505
Pulse fit: NIM A290 (1990) 158

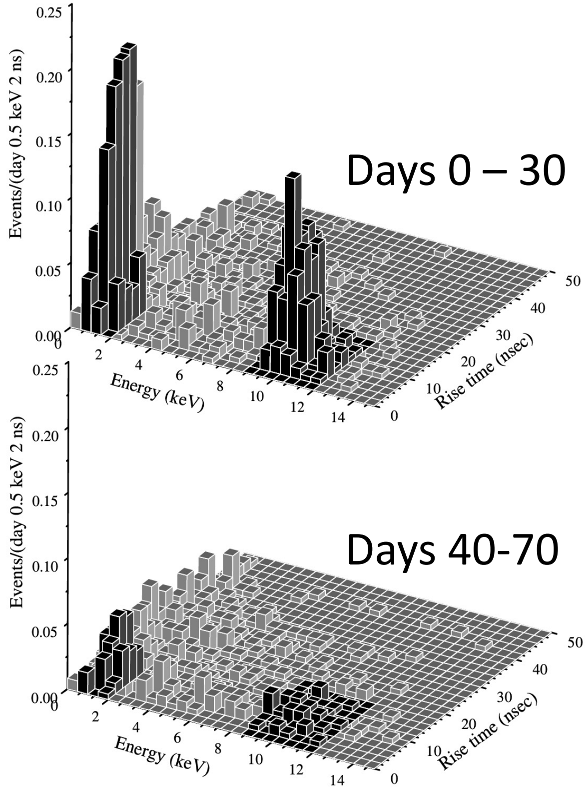
- Half-life of 11.43 d, ground state transition
- K Capture (88% of all decays)
  - 41.5% Auger e- 10.367 keV
  - 41.2% Auger e- 1.2 keV & x ray 9.2 keV
  - 5.3% Auger e- 0.12 keV & x ray 10.26 keV
- L and M capture give almost entirely Auger e-
  - L gives 1.2 keV Auger, M gives 0.12 keV Auger
- The proportional counter observes Auger e- with high efficiency
  - The X ray efficiency is much less
  - As a result, the number of K/L peak counts are about equal



^{71}Ge Candidate Event Selection

- Energy calibration
- Time tagging
  - Periods of expected high background
    - Reject 2.6-hour periods after shield opening, to eliminate Rn induced backgrounds (~1.2% of the total run time)
  - Anti-coincidence with NaI system (1/3 of events removed)
- Pulse shape analysis
  - ~1.5 evts /day: Alpha-induced events
  - ~1.5 evts /day: High-voltage breakdowns
  - Compton scattering
  - Beta-induced backgrounds





Predicted Production Rates

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

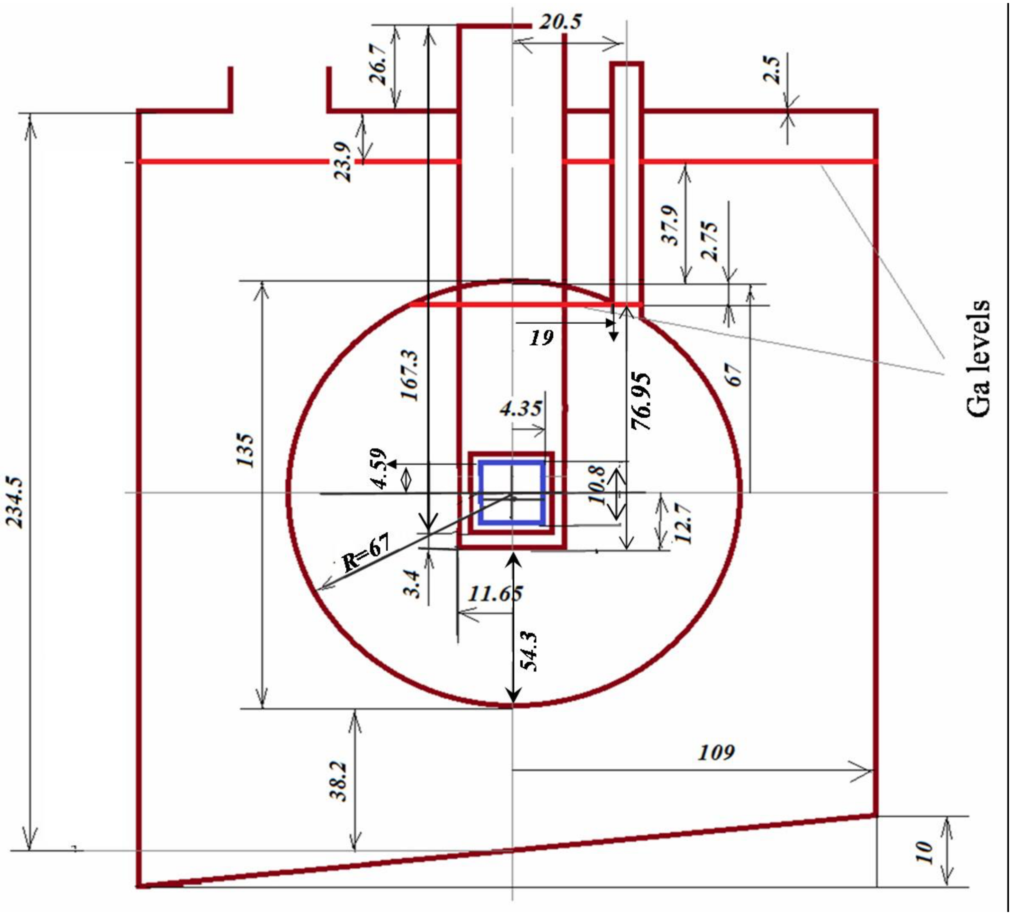
${}^{71}\mathrm{Ge} + e^- \rightarrow {}^{71}\mathrm{Ga} + \nu_e$

Production rates are predicted from cross section

$$P_{ee}(E_\nu, r) = 1 - \sin^2 2\theta \sin^2\left(1.27\frac{\Delta m^2[\mathrm{eV}^2] r[\mathrm{m}]}{E_\nu[\mathrm{MeV}]}\right)$$

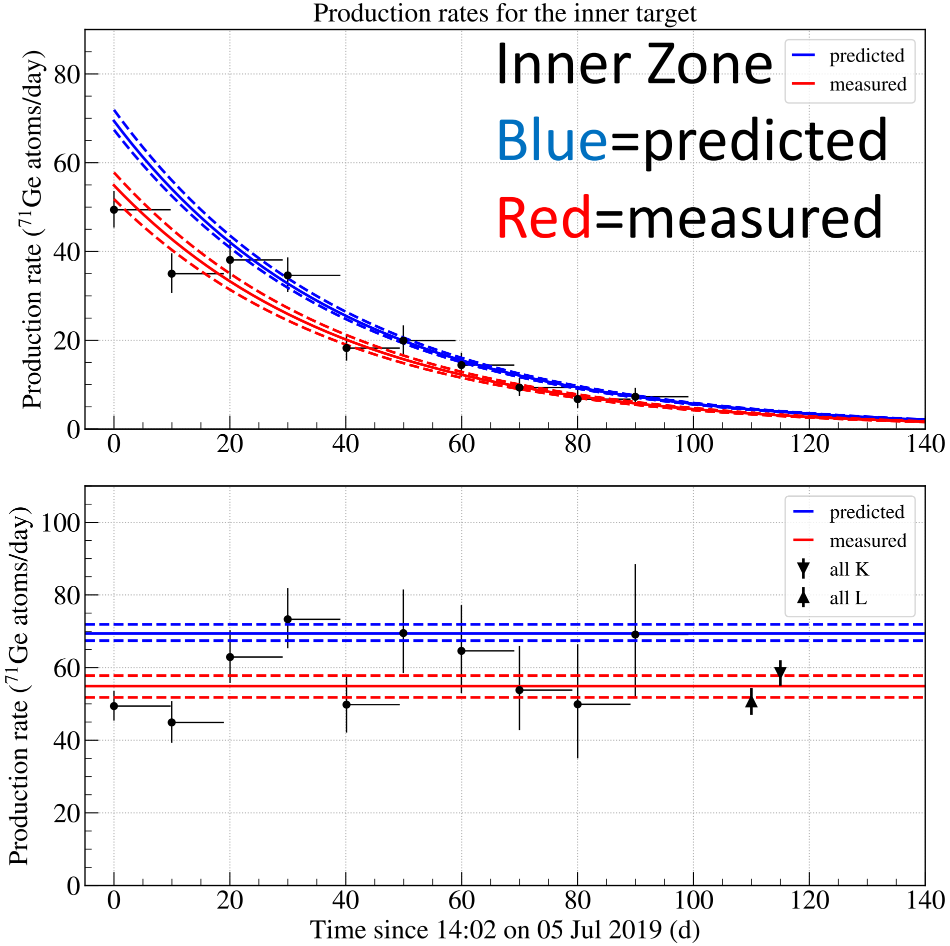
$$R_j = \frac{n\sigma A}{4\pi}\int_{V_j}\frac{P_{ee}(r)}{r^2}d\vec{x} \approx V_0\frac{1}{N}\sum_{i=1}^{N}\frac{P_{ee}(r)}{r^2}\Theta_j(\vec{x}_i)$$

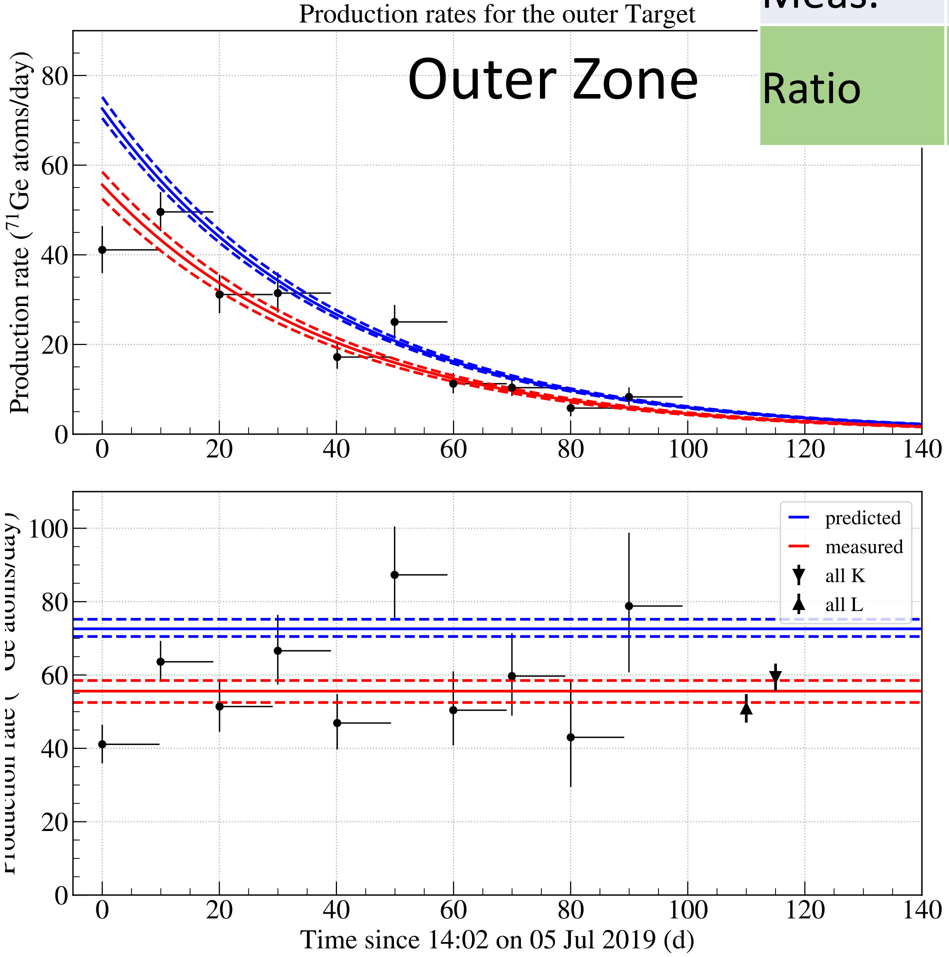
	Value	Uncertainty	
		Magnitude	%
Atomic density $D = \rho N_0 f_1 / M$			
Ga density ρ (g Ga/cm^3)	6.095	0.002	0.033
Avogadro's number N_0 (10^{23} atoms Ga/mol)	6.0221	0.0	0.0
Ga molecular weight M (g Ga/mol)	69.72307	0.00013	0.0002
Atomic density D (10^{22} atoms ^{71}Ga/cm^3)	2.1001	0.0008	0.037
Source activity at reference time A, MCi	3.414	0.008	0.23
Cross section σ (10^{45} cm^2/ (^{71}Ga atom ^{51}Cr decay)], Bahcall	5.81	+0.21,-0.16	+3.6,-2.8
Path length in Ga $< L_{in} >$ (cm)	52.03	0.18	0.3
Path length in Ga $< L_{out} >$ (cm)	54.41	0.18	0.3
Predicted production rate (^{71}Ge atoms/d), R_{In}	69.41	+2.5,-2.0	+3.6,-2.8
Predicted production rate (^{71}Ge atoms/d), R_{Out}	72.59	+2.6,-2.1	+3.6,-2.8



Counting Results

	IN	OUT
Pred.	$69.41^{+2.5}_{-2.0}$	$72.59^{+2.6}_{-2.1}$
Meas.	54.9 ± 2.9	55.6 ± 3.1
Ratio	0.79 ± 0.05	0.77 ± 0.05



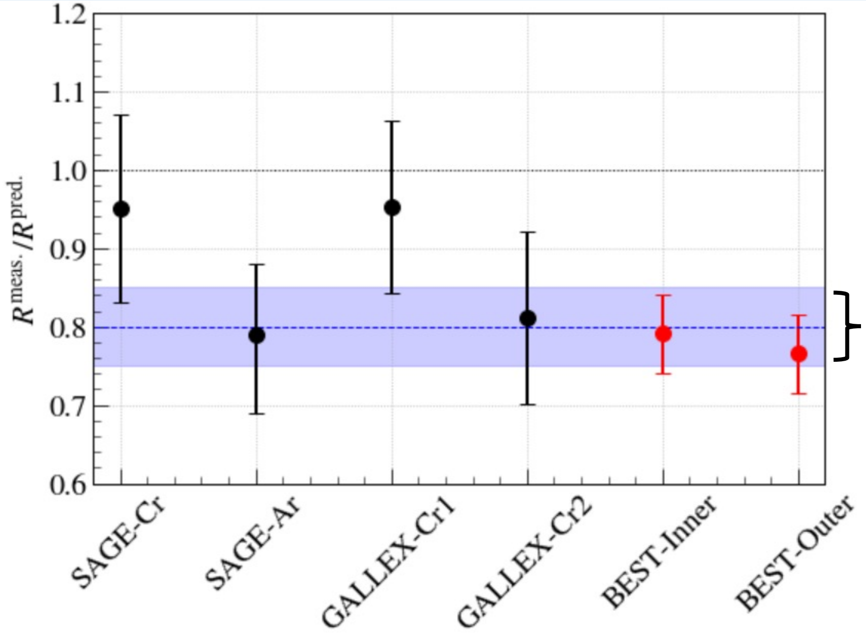


4.2σ and 4.8σ less than the unity

Note: $\frac{0.77 \pm 0.05}{0.79 \pm 0.05} = 0.97 \pm 0.07$

Similar deficits observed in both zones

Combined Analysis with Other Ga Source Experiments



Combined result:

$R_0 = 0.80 \pm 0.05$

Experiment	Measured/Predicted	Ref.
SAGE-Cr	0.95 ± 0.12	PRC **59**, 2246 (1999)
SAGE-Ar	$0.79^{+0.09}_{-0.10}$	PRC **73**, 045805 (2006)
GALLEX-Cr1	0.95 ± 0.11	PLB **420**, 114 (1998)
GALLEX-Cr1	0.81 ± 0.11	PLB **420**, 114 (1998)
BEST-Inner	0.791 ± 0.05	arXiv:2109.11482
BEST-Inner	0.766 ± 0.05	arXiv:2109.11482

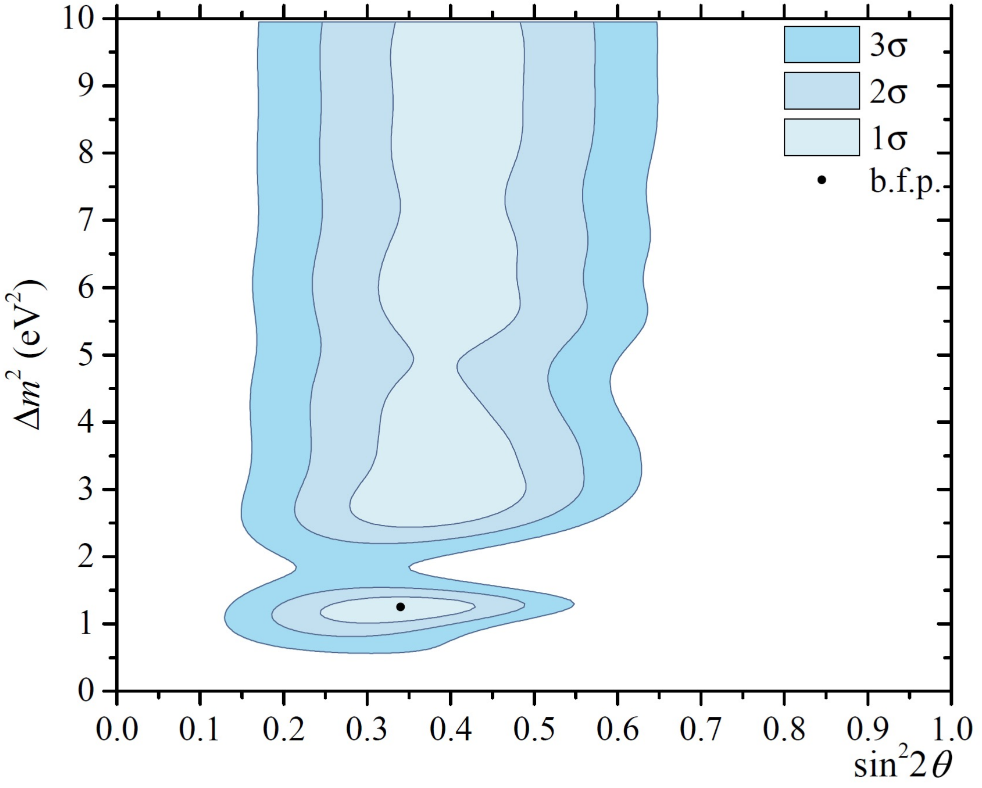


FIG. 8. Allowed regions for two GALLEX, two SAGE and two BEST results. The best-fit point is $\sin^2 2\theta = 0.33$, $\Delta m^2 = 1.25$ eV^2 and is indicated by a point.

Consistent with, but not Proof of, Oscillations

These results reaffirm the Ga anomaly, with higher statistical precision.

But no dependence on oscillation length was observed. So although the results are consistent with oscillations, there is no ‘smoking gun’ evidence that is not subject to caveats.

Because the rate in the two volumes is equally depressed, a number of potential explanations beyond oscillations have been considered. No clear alternative has been identified even though a great deal of research into each has been completed.

- Cross Section
- Source Strength
- Extraction Efficiencies
- Counting Efficiencies
- Average Path Length

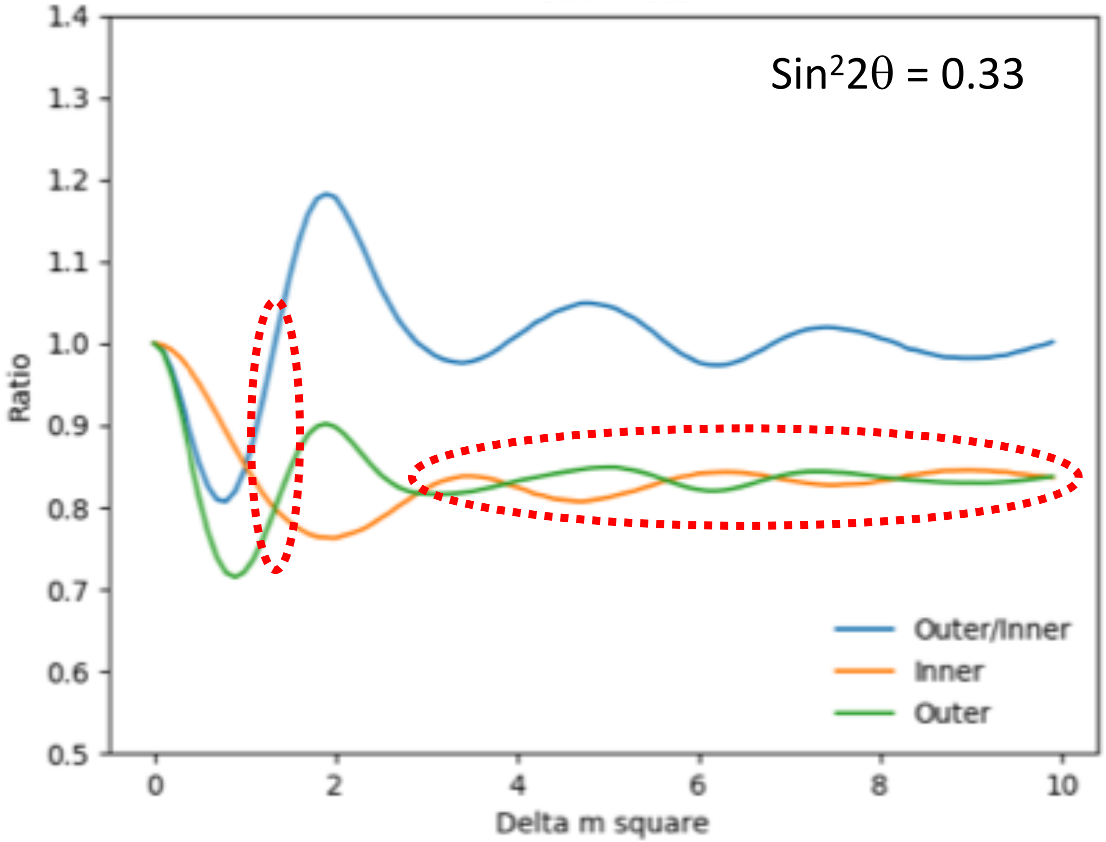
Possible Future Plans

If oscillations, the oscillation length is short (large Δm^2). BEST has poor Δm^2 resolution for values greater than ~2 eV^2.

- Smaller inner volume probably not feasible.
  - Half the radius, need 8x the source strength for same rate.

- ^{65}Zn Source (PRD 97 (2018) 073001)
  - Higher energy source (1.35 MeV vs. 0.75 MeV).
  - Almost twice the cross section.
    - But adds a couple additional excited states.
  - 13-14 kg of 95% enriched ^{64}Zn to produce 0.5 MCi.
  - About 9x longer half life (244 d), many more events even with lower activity.

Regions where inner/outer both about 0.8 of expectation



Summary: see arXiv:2109.11482

- BEST measured the ^{71}Ge production in Ga from neutrinos emitted by ^{51}Cr at two distances (inner zone: ~40 cm, outer zone: ~96 cm, but both have large spread.)
- The ratio of the measured-to-predicted rates in both the inner and outer zones are depressed by about 20% from unity. The ratio-of-ratios is ~1.
- The Ga Anomaly is reaffirmed.
- No dependence on oscillation length was observed.