The Gallium Anomalies

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The Ga Neutrino Detector Calibrations

The SAGE and GALLEX/GNO solar neutrino experiments were designed to measure the Sun's low energy pp neutrinos by detecting ^{71}Ge produced by

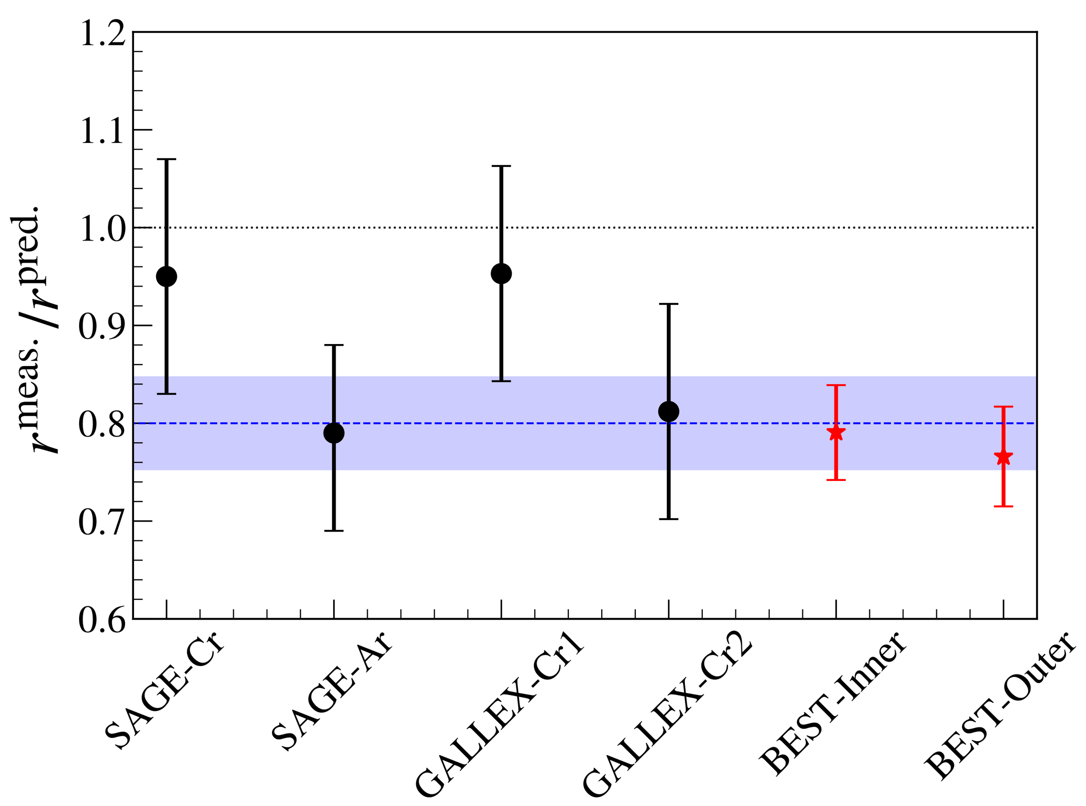
$$^{71}\mathrm{Ga}(\nu_e, e^-)^{71}\mathrm{Ge}$$

Although the efficiency of extracting and counting Ge was checked by multiple methods in these radiochemical experiments, direct calibrations were also done using intense (~ MCi) EC neutrino sources

$$^{51}\mathrm{Cr}(e^-, \nu_e)^{51}\mathrm{V} \quad \tau_{1/2} = 27.7\mathrm{d}$$

$$^{37}\mathrm{Ar}(e^-, \nu_e)^{37}\mathrm{Cl} \quad \tau_{1/2} = 35.0\mathrm{d}$$

producing line sources of neutrinos with energies 747 and 811 keV, respectively. These sources were produce by irradiating targets of ^{50}Cr and ^{40}Ca in the intense neutron flux of a reactor.



Four calibration experiments were done by the two collaborations. In the SAGE experiments, a neutrino source was inserted directly into a chemical reactor containing 13 tons of metallic Ga.

The source intensities can be determined very accurately. The resulting ratio R of the observed to expected event rates was significantly (2.5 σ) below expectations.

$$R = 0.87 \pm 0.05$$

This combined result became known as the "gallium anomaly," and has often been invoked as evidence for short-baseline oscillations into a sterile neutrino.

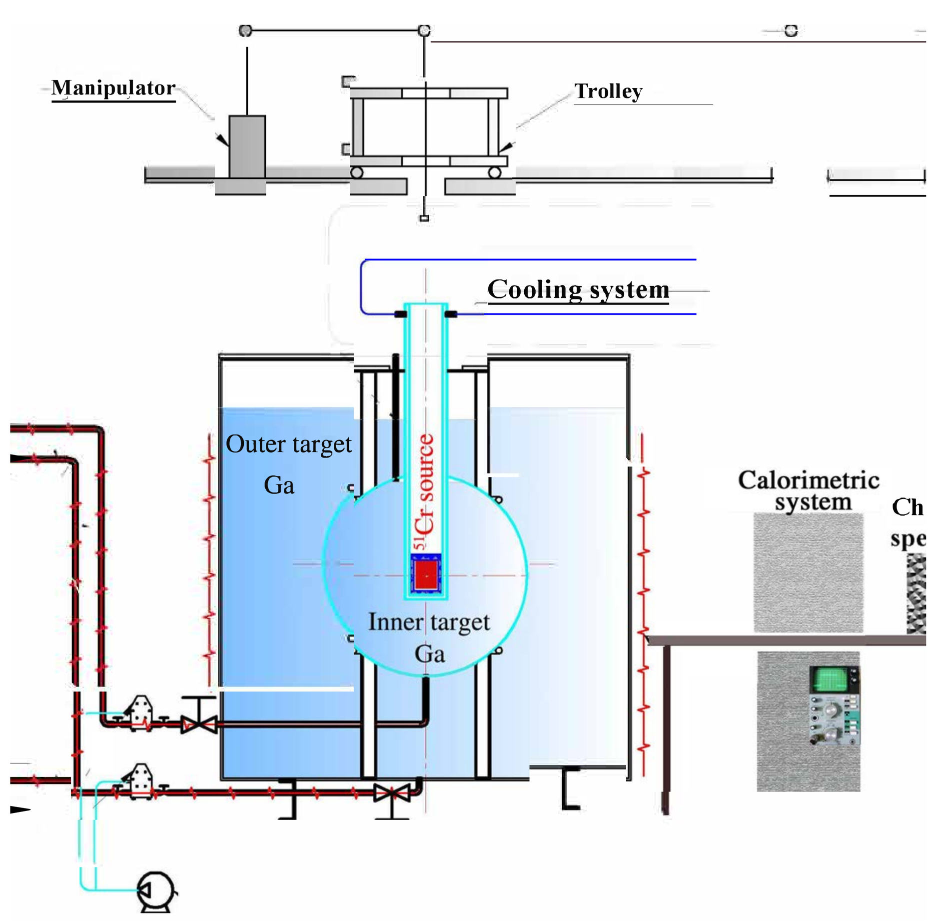
The BEST Experiment

The BEST experiment [1] was designed to check the Ga anomaly, including the possibility of oscillations into a sterile neutrino. Attributes included:

- A very high intense ^{51}Cr EC source of activity 3.14 MCi
- Use of a chemical reactor divided into inner and outer volumes, to provide sensitivity to oscillations characterized by $\delta m^2_{12} \sim 1\ \mathrm{eV}^2$

The two-volume geometry of the chemical reactor is shown below.

The intense EC source was lowered into the detector from above.



A total of ten extractions was done, each involving an exposure of about 10 days, as the source intensity gradually declined. Results from BEST were announced in 2023 [2,3].

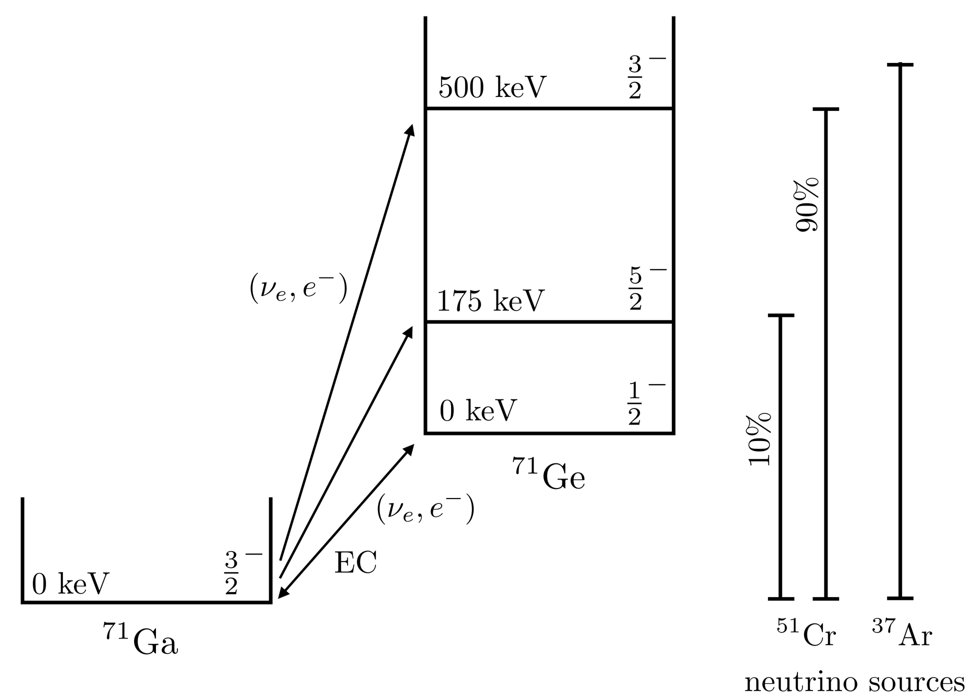
Results and Analysis

The results of the BEST experiment are shown as the red data in the figure to the left. Again a significant deficit, reflected in the value for R, was observed. A very conservative analysis that took into account possible correlated uncertainties — for example, the neutrino absorption cross section is a common systematic in all experiments — found that

$$R = 0.81 \pm 0.05$$

This is the combined result from the SAGE, GALLEX/GNO, and BEST calibration experiments.

The neutrino absorption cross section is dominated by the transition to the ground state of ^{71}Ge



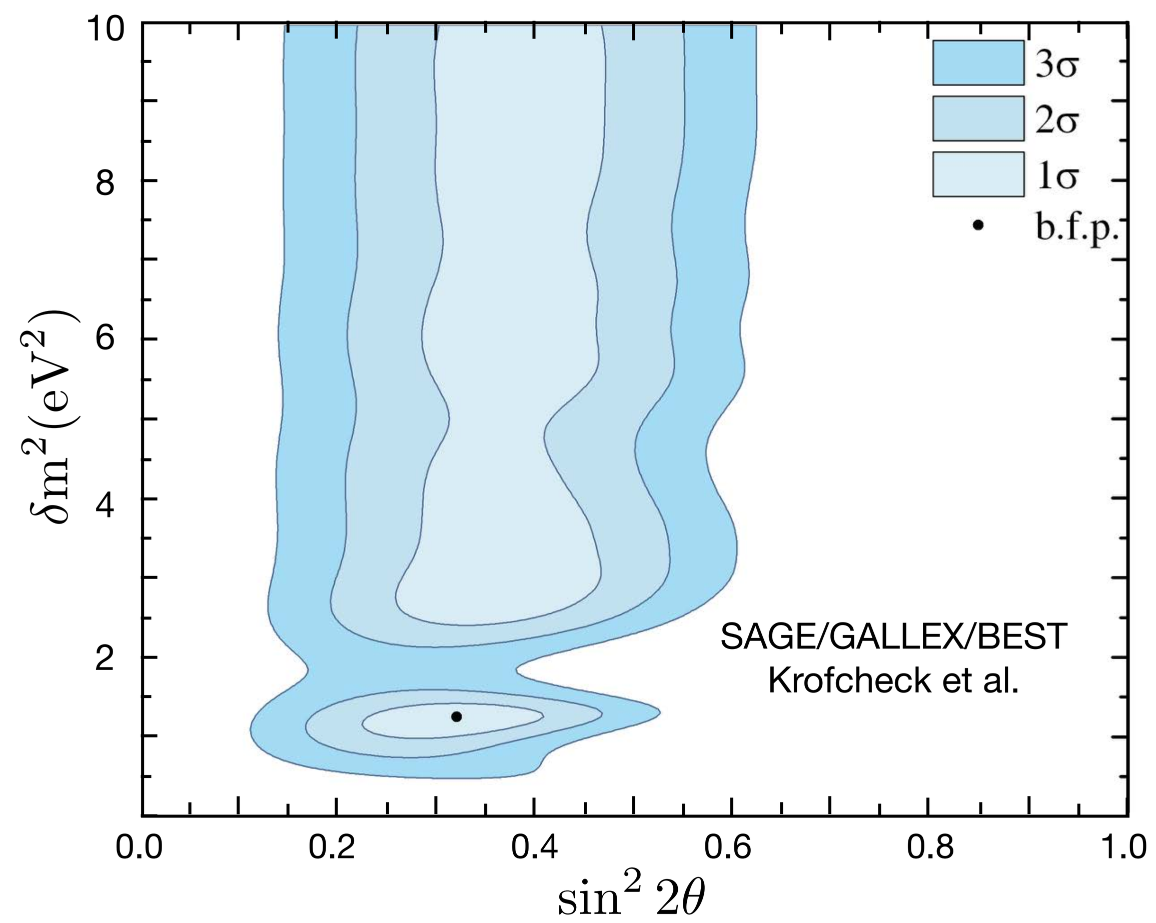
whose strength is determined by the known EC capture lifetime of ^{71}Ge. A recent reanalysis [4] that took into account various sub-1% effects such as radiative and weak magnetism corrections showed that this cross section is known to 1%. In addition, small corrections come from transitions to two excited states. These can be calibrated by (p,n) reactions — provided that important corrections associated with tensor amplitudes are made [4].

The strength of the ground state transition rules out any nuclear physics explanation of the gallium anomaly. Even if the excited-state contribution is neglected, a 2.6 σ discrepancy remains,

$$R = 0.87 \pm 0.05$$

Implications

The most exotic explanation of the Ga anomaly is an oscillation into a sterile state. But in the simplest 3+1 scenario this requires a very large mixing angle. When calculations are done taking into account how source and detector geometry affect the sensitivity to oscillations, one finds



The point indicates the best fit, but there is a large area in the $\delta m^2 - \sin^2 2\theta$ plane producing nearly equivalent results. The 3+1 sterile neutrino hypothesis requires a large mixing angle and a δm^2 of an eV^2 or larger.

While the reactor neutrino anomaly and Neutrino-4 have suggested similar parameters, the combination of all available experiments (including DANSS, Prospect, Stereo, RENO, NEOS, and KATRIN) rule out all but the smallest mixing angle BEST solutions.

Consequently the most likely explanation of the gallium anomalies may be a systematic error that has remained undetected despite two decades of experimental effort.

References

1. S. R. Elliott, V.Gavrin, and W. C. Haxton. Prog. Part. Nucl. Phys. 104082 (2023)
2. V. V.Barinov et al. (BEST Collaboration), Phys. Rev. Lett. 130 (2023) 131901
3. V. V. Barinov et al. (BEST Collaboration), Phys. Rev. C 105 (2022) 065502
4. S. R. Elliott, V. N. Gavrin, W. C. Haxton, T. V. Ibragimova, and E. J. Rule, Phys. Rev. C 108 (2023) 035502