Testing the Gallium neutrino anomaly… with CEvNS?

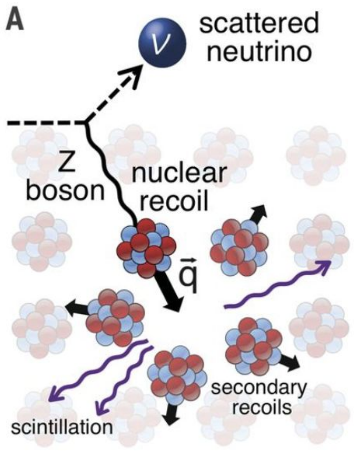
Giovanni Benato, A. Melchiorre, F. M. Pofi, A. Puiu, C. A. Ternes

TAUP 2025,
Xichang, China

GRAN SASSO SCIENCE INSTITUTE
INFN Istituto Nazionale di Fisica Nucleare

Towards precision measurements with CEvNS

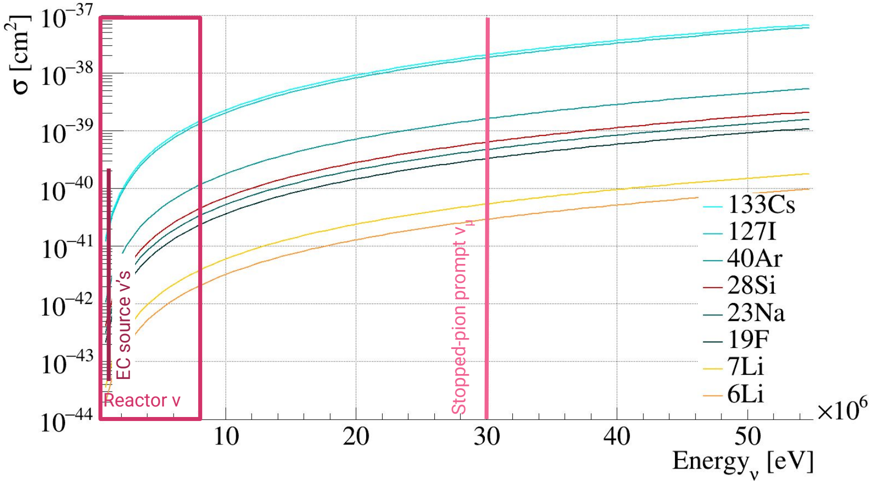
$$\frac{d\sigma_{\nu N}}{dT_N} = \frac{G_F^2 m_N}{\pi} \left(Q_V^{\rm SM}\right)^2 F_W^2(|\mathbf{q}|^2) \left(1 - \frac{m_N T_N}{2E_\nu^2}\right)$$



- Recoil spectrum depends on:
  - Incoming neutrino energy
    →Precise knowledge of neutrino spectrum is required
    →Mono-energetic neutrinos highly desirable
  - Weak charge $Q_V^{\rm SM} = g_V^p Z + g_V^n N$
    →Spectral deformation could allow measuring coupling constants
- Limitations of current approaches
  - Stopped-pion ν beams: non-monoenergetic delayed neutrinos; intrinsic neutron background?
  - Reactor neutrinos: spectrum poorly known; intrinsic neutron background?
- Possible alternative: EC source
  - Already considered in the past, but deemed as unfeasible…

Detecting CEvNS with EC neutrino sources

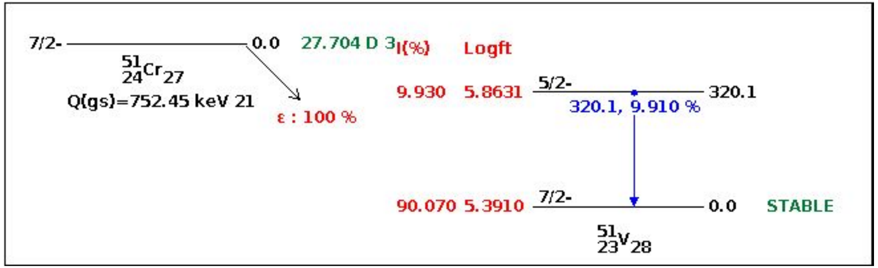
- ν energy ≲1 MeV
  - Required E_{thr} at few eV level
  - Practically, must use low temperature calorimeters
- Can measure source activity to percent level
- High ν fluxes achievable
  - Non-trivial source production and transportation
- Monoenergetic ν's with well-known energy
  - Can aim at precision study of recoil spectrum
- High Q-value ⇔ Short half-life
  - Allows source-on/source-off measurement
- Intrinsic source-on background possible
  - Most probably, low-E γ's spoiling nuclear recoil band
  - Can measure source contaminants with independent detection channel



Electron-capture ν sources

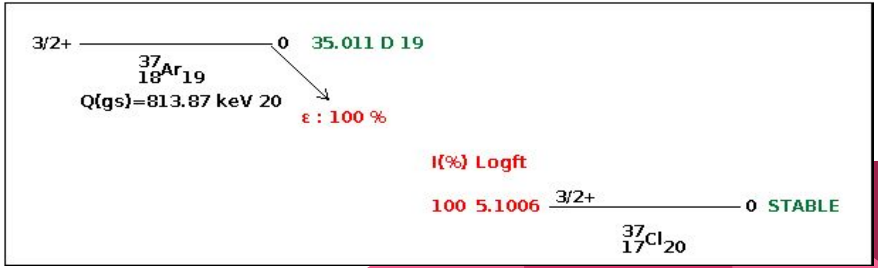
^{51}Cr

- Enrich chromium in ^{50}Cr, deplete in ^{53}Cr
- Activate ^{51}Cr with thermal neutrons
- Cr impurities could be activated
- A_{max} = 3.14 MCi (1.16 e17 Bq) from BEST
- Emitted particles:
  - ~750 keV neutrinos (90%)
  - ~430 keV neutrinos + 320 keV γ-rays (10%)



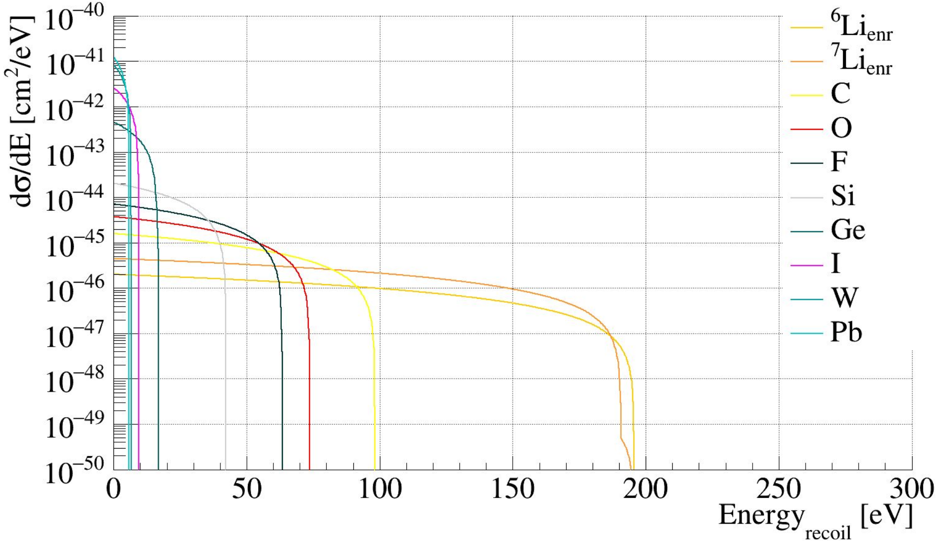
^{37}Ar

- Irradiate CaO with >2 MeV neutrons: ^{40}Ca(n,α)^{37}Ar
- Dissolve CaO in HNO_3 then collect ^{37}Ar → Compact and pure source!
- A_{max} = 409 kCi (1.5e16 Bq) from SAGE
- Emitted particles:
  - ~813 keV neutrinos (100%)



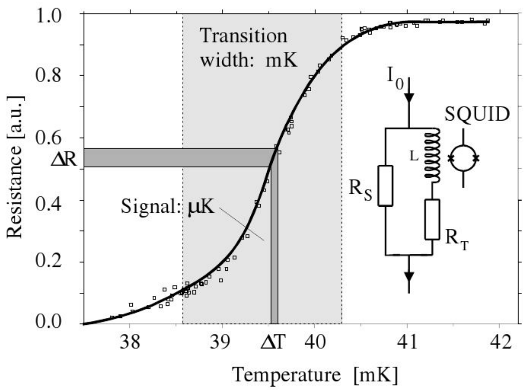
CEvNS on Lithium

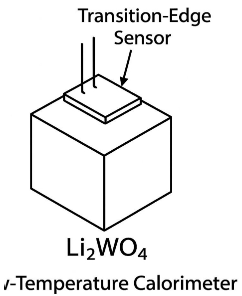
- Very low CEvNS cross section 😭
  - Need high-intensity ν flux
- Large nuclear recoil energy 😉
  - Relax E_{thr} requirement up to tens of eV
- No long-lived isotopes 😉
  - No intrinsic background
- Easily enriched to 99% in ^{6}Li or ^{7}Li 😉
  - Allows differential measurement of ν flux
  - Can be sensitive to axial-vector neutron coupling term
- Several Li-based commercial crystals available 😉
  - Several possibilities to operate as bolometers

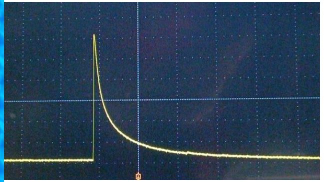


Experimental design

- Array of lithium-based crystals operated as bolometers
  - Possible crystals: LiF, Li_2WO_4, LiI, Li_2MoO_4
- Temperature readout: Transition Edge Sensors or Kinetic Inductance Detectors
  - Must find trade-off between threshold and crystal mass
  - Total mass up to O(10) kg can be conceived
- EC source surrounded by detectors to maximize geometric coverage
  - Requires custom cryostat vessel with borehole to allow source insertion without affecting detector operation
  - Also, the source would be literally too hot to be placed in the cryostat





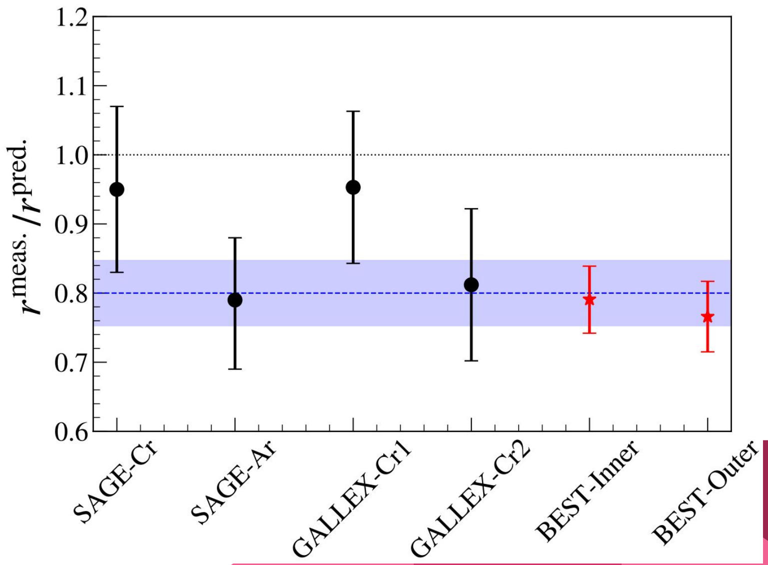


On the way to precision measurements

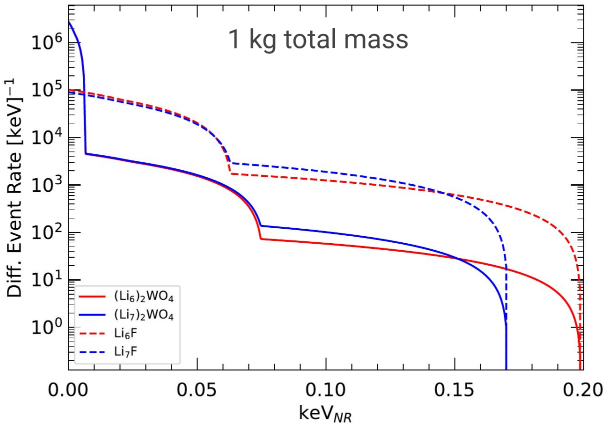
Why don’t we exploit CEvNS to test the Gallium anomaly?

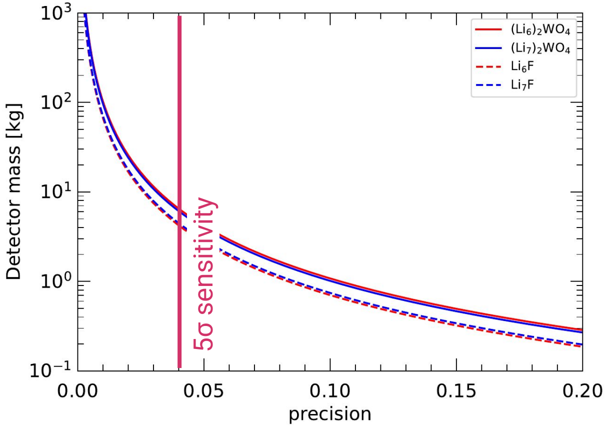
Gallium neutrino anomaly

- GALLEX/GNO and SAGE experiments build to cross-check Homestake anomalous result on solar neutrino flux
- Exploited signature:
  - Inverse electron capture on gallium: $^{71}Ga(\nu_e,e^-)^{71}Ge$ → No direct detection of IEC!
  - Collect Ge and measure X-rays from ^{71}Ge decay →Must keep total efficiency under control!
- Cross check of total efficiency: expose detector to neutrinos from EC source with well-known activity
  - Used both ^{51}Cr and ^{37}Ar sources
  - 20% deficit in ν activity w.r.t. calorimetric and γ/X-ray activity →This is the “Gallium neutrino anomaly”
- BEST (SAGE upgrade) confirmed the anomaly
- Overall significance ~5σ
- Sterile ν mostly excluded, but anomaly remains!



Testing the gallium neutrino anomaly with CEvNS on Li

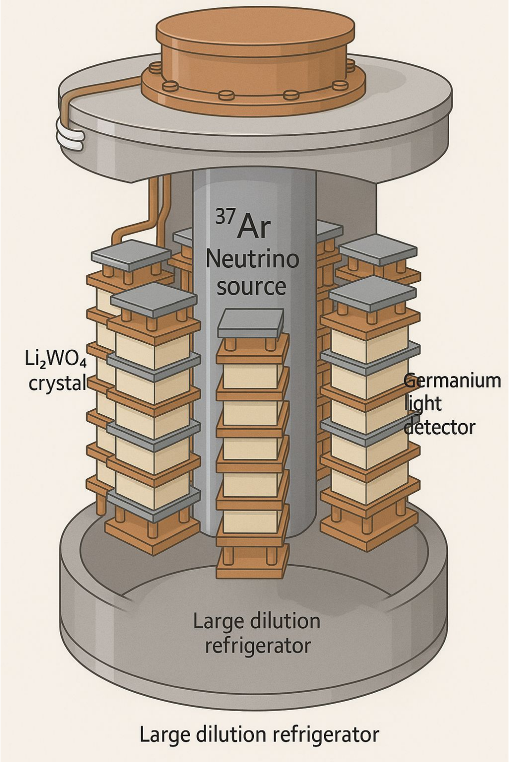




- Assumptions:
  - ^{51}Cr source with 61PBq (same as GALLEX)
  - Assume 20 eV threshold
  - 30 days of measurement
  - Zero background
  - LiF or Li_2WO_4 crystals 99% enriched in ^6Li or ^7Li
- Results:
  - 8 kg of total mass sufficient to provide 5σ sensitivity!
- Caveats:
  - Zero background assumption is very strong
  - Main expected background from “low-energy excess”

Experimental requirements

- Source production and transportation
  - Must reach O(MCi) activity
  - Painful bureaucracy and logistic
- Measurement of source activity with <1% precision
  - Calorimetric measurement (i.e. we measure the total heat produced by the source)
  - For ^{51}Cr, measure activity of 320 keV γ
  - For ^{37}Ar, measure X-ray activity
- Detector mass
  - Minimum requirement 8 kg, desirable 50kg
- Energy threshold
  - Minimum requirement, 90% trigger efficiency @50 eV, desirable @10eV
- Background
  - Minimum requirement <0.02 events/eV/kg/day, desirable <0.001 events/eV/kg/day
  - Low-energy excess must be addressed

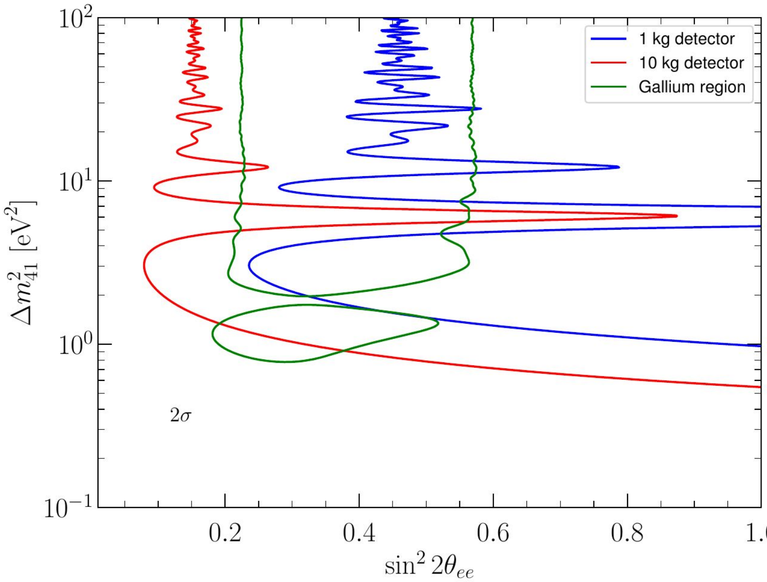


Testing sterile neutrino hypothesis of gallium anomaly

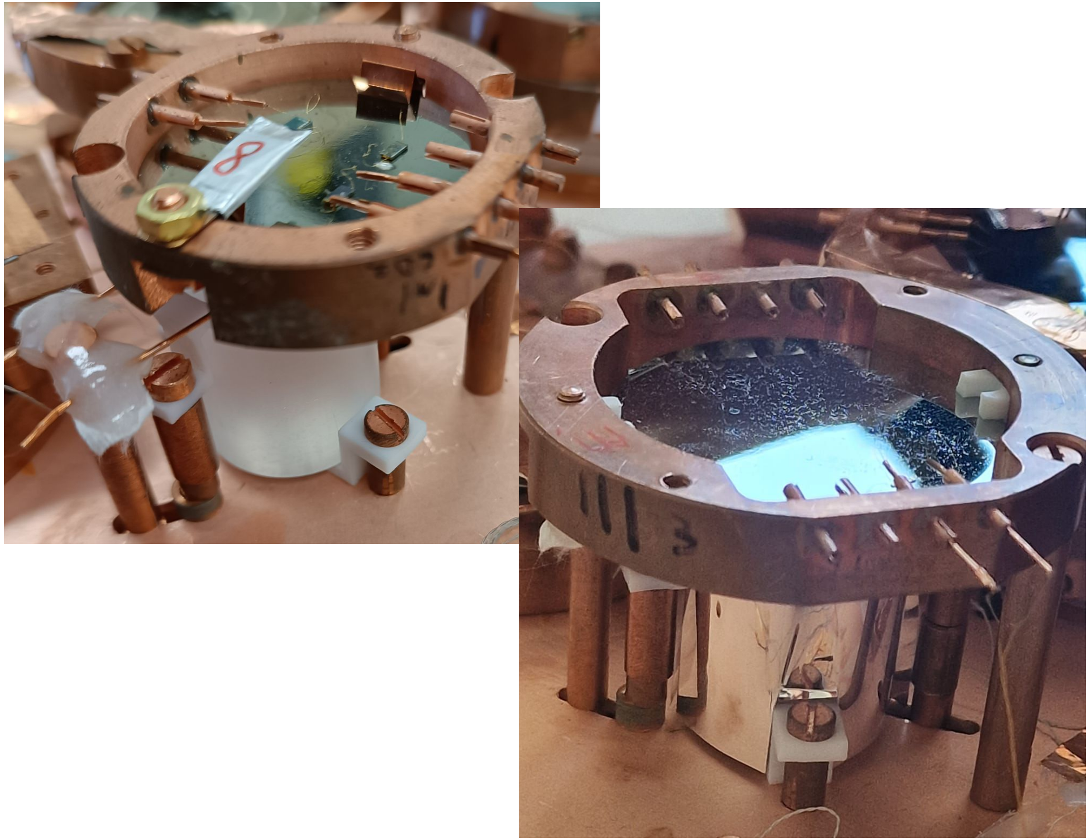
The Gallium anomaly can be explained by short baseline neutrino oscillations due to light sterile neutrinos

$$P_{ee} = 1 - \sin^2 2\theta_{ee} \sin^2\left(\frac{\Delta m_{41}^2 L}{4E}\right)$$

With a 10 kg detector and an exposure of 30 days our experiment can test nearly all of the parameter space required to explain the Gallium anomaly



First tests with Li_2WO_4 crystal

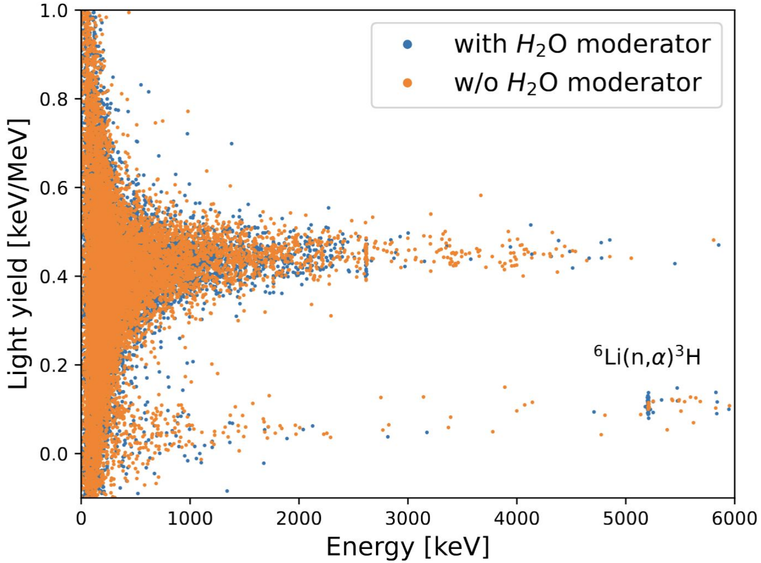


- Tested a 25 gram Li2WO4 crystal (produced in Novosibirsk and tested at LNGS)
- Calibrated with beta/gamma sources and neutron source
- Great crystal performance → feasiblity of array

(Previously measured also by https://doi.org/10.1016/j.nima.2019.162784)

First tests with Li_2WO_4 crystal

- 500 eV threshold: not immediately compliant with our purpouse, yet it came from an NTD based detector
- Feasibility of large mass (25 g) Li2WO4 dual readout



- The detector (LWO+NTD and LD) was calibrated with a Th source (gamma) and a Am:Be source
- Energy resolution: 900 eV @ 59 keV
- Next step: LWO+TES to push threshold below 50 eV

Conclusions

- Measuring CEvNS from EC source less crazy than we naively expected
- Li could allow for precision measurement, and to perform differential measurement of ν flux
- CEvNS on Li-based bolometer allows independent test of Gallium neutrino anomaly

Contributions:

- G. Benato, F. Pofi, C. Ternes: CEvNS and Ga calculations
- A. Melchiorre, A. Puiu: LiWO measurement

Backup: Low-energy excess

- CRESST bkg above 250 eV: ~0.01 counts/eV/kg/day
  →In line with our requirements of <0.02 counts/eV/kg/day
- CRESST bkg in low-E excess region: 1-10 counts/eV/kg/day
  →Must solve in order to enable any CEvNS measurement!