# New methods of neutrino and anti-neutrino detection from 0.1 to 105 MeV

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## Solar Neutrino Detection

Neutrino detectors are normally large and deep underground. They are large because they need as much mass as possible to capture more neutrinos, and they are underground to reduce backgrounds.

If a neutrino detector could operate in space [1], what advantages would it have to perform unique science? Clearly to just take a neutrino detector into space does not bring any new science unless the possibility for dramatically enhancing the neutrino flux was associated with this endeavor, but it could also be of interest if it can dramatically reduce solar neutrino backgrounds to see other processes such as Dark Matter or Galactic neutrinos currently hidden by a large Solar neutrino presence at the Earth.

We propose three distinct possibilities for science [2]:

1) Going closer to the Sun, see Table 1, the $1/r^2$ neutrino flux would provide 1000x more neutrino rates at seven solar radii distance where the current NASA Parker Solar probe operates, and 10,000x more neutrino rate at three solar radii where some NASA scientists think it is possible to go. Here, new science would be a larger statistical observation of solar neutrino emission, the study of the size of the fusion emission region, and particle physics looking for the transition from coherent to de-coherent neutrino oscillations.
2) Because the neutrino has a non-zero mass, which we know from the existence of neutrino oscillations, the Sun bends space to create a gravitational focus. For neutrinos, this gravitational focus would be very close to us at only 20 to 40 AU. The galactic core is 25,000 light years away from us and is about two times larger than the moon when viewed from Earth and is the 2nd largest neutrino source in the sky after the Sun. The galactic core not only has many neutrino-producing stars, but also ~10,000 neutron stars and black holes in the central cubic parsec of the core. Matter falling into these objects is crushed, producing neutrons and isotopically emitted neutrinos of higher energy than solar fusion neutrinos. A detector at the solar neutrino focus would permit imaging of the galactic core using its $10^{13}$ "light" collecting power and just finding the neutrino gravitational focus of the Sun would be a new way to measure the neutrino mass.
3) Any neutrino-detecting space probe could take advantage of a flight towards the Sun to observe the shape of the solar neutrino changes due solely to the distance from a nonpoint source of solar neutrinos inside the Sun, while when traveling away from the Sun, deviations from the expected $1/r^2$ curve are an indication of the direct observation of Dark Matter or galactic neutrinos.

*Table 1: Intensity of solar neutrinos at various distances from the Sun.*

| Distance from Sun | Solar Neutrino intensity relative to Earth |
|---|---|
| 696342 km | 46400 |
| 1500000 km (~3 Sun R) | 10000 |
| 4700000 km (~7 Sun R) | 1000 |
| 15000000 km | 100 |
| 47434000 km | 10 |
| Mercury | 6.7 |
| Venus | 1.9 |
| Earth | 1 |
| Mars | 0.4 |
| Astroid belt | 0.1 |
| Jupiter | 0.037 |
| Saturn | 0.011 |
| Uranus | 0.0027 |
| Neptune | 0.00111 |
| Pluto | 0.00064 |
| KBP | 0.0002 |
| Voyager 1 probe 2015 | 0.00006 |

We have devised a technique to observe solar neutrinos in space using a double delayed coincidence pulse within a 500 ns time window [2, 3]. The double pulse adds a clean identification method while losing only a fraction of the solar neutrino interactions [4].

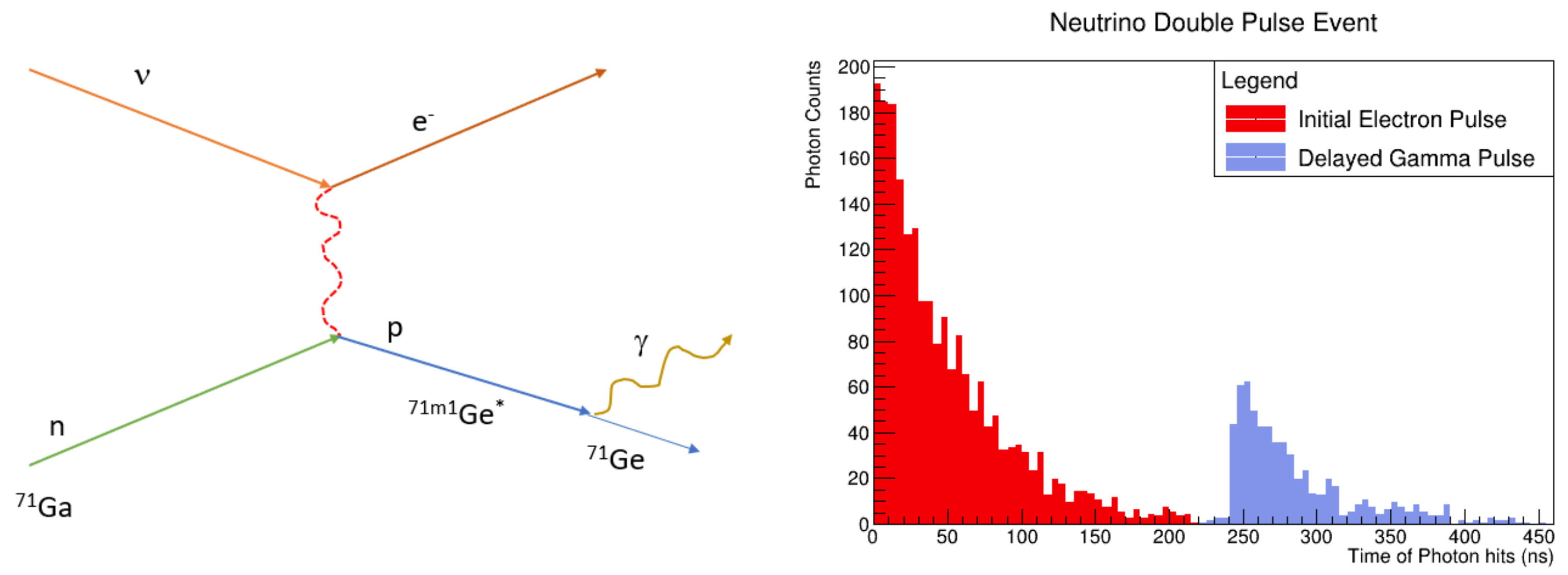
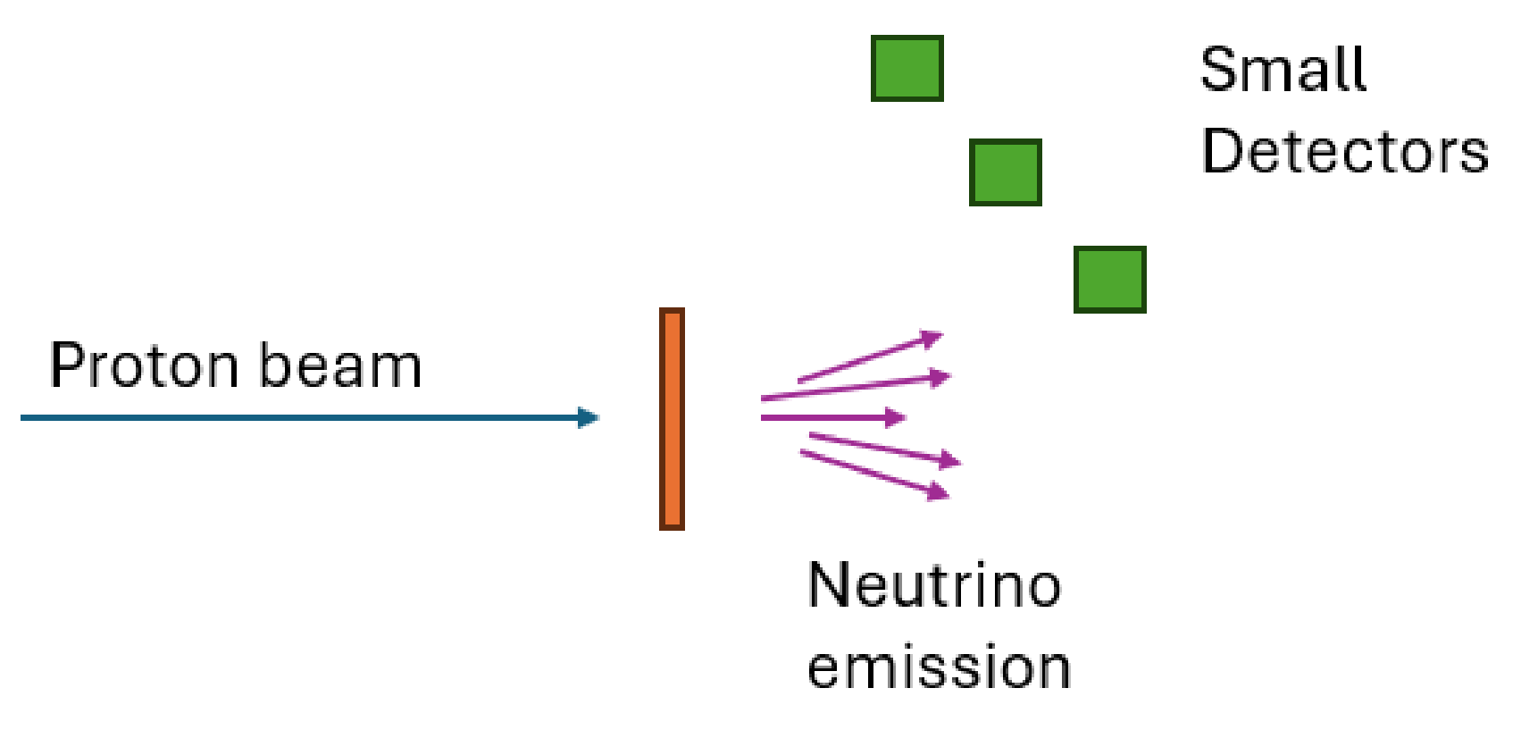


*Figure 1: On the left is the Solar neutrinos from Hydrogen fusion in the sun's core captured on $^{71}$Ga Isotope producing a delayed secondary pulse with a 79 ns half-life and on the left the simulation of an observed double delayed coincidence pulse. The parameters of these interactions can be seen in Table 2, but this technique can be used with Indium-115 which has a much lower solar neutrino threshold.*

## Accelerator Beamline Neutrino production studies

If the momentum transfer from the neutrino interaction to the excited state nuclei is below the threshold for disintegrating the nuclei, then this technique could be used to study neutrino and anti-neutrino production from a target up to the muon production threshold of 105 MeV/c.

Beamline Neutrino Production Study:



Small Detectors

Proton beam

Neutrino emission

Abstract: We have developed a neutrino detector with threshold energies from ~0.1 to 100 MeV in a clean detection mode almost completely void of accidental backgrounds. It was initially developed for the NASA νSOL project to put a solar neutrino detector very close to the Sun with 1000 to 10,000 times higher solar neutrino flux than on Earth. Similar interactions have been found for anti-neutrinos, which were initially intended for Beta decay neutrinos from reactors, geological sources, or for nuclear security applications. These techniques work at the 1 to 100 MeV region for neutrinos from the ORNL Spallation Neutron Source or low energy accelerator neutrino and anti-neutrino production targets less than ~100 MeV. The identification process is clean, with a double pulse detection signature within a time window between the first interaction producing the conversion electron or positron and the secondary gamma emission 100 ns to ~1 µs, which removes most accidental backgrounds. These new modes for neutrino and anti-neutrino detection of low energy neutrinos and anti-neutrinos could allow improvements to neutrino interaction measurements from an accelerator beam on a target.

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NASA Innovative Advanced Concepts

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| Reaction | Excited State delayed emission by | Threshold | Decay half-life | Secondary emission energy |
|---|---|---|---|---|
| $^{69}$Ga + ν → e⁻ $^{69}$Ge* | $^{69}$Ge$_{m1}$ X-ray | 2.314 MeV | 5.1 µs | 87 keV |
| $^{69}$Ga + ν → e⁻ $^{69}$Ge* | $^{69}$Ge$_{m2}$ gamma | 2.625 MeV | 2.8 µs | 398 keV |
| $^{71}$Ga + ν → e⁻ $^{71}$Ge* | $^{71}$Ge$_{m1}$ gamma | 0.408 MeV | 81 ns | 175 keV |
| $^{115}$In + ν → e⁻ $^{115}$Sn* | $^{115}$Sn$_{m1}$ gamma | 0.115 MeV | 3.3 µs | 613 keV |
| $^{183}$W + $\bar{\nu}$ → e⁺ $^{183}$Ta* | $^{183}$Ta$_{m1}$ X-ray | 2.167 MeV | 106 ns | 73 keV |
| $^{107}$Ag + $\bar{\nu}$ → e⁺ $^{107}$Pd* | $^{107}$Pd$_{m1}$ gamma | 1.172 MeV | 850 ns | 116 keV |
| $^{180}$Ta$_{m1}$ + $\bar{\nu}$ → e⁺ $^{180}$Hf*$_{e1}$ | $^{180}$Hf$_{e1}$ gamma | 0.192 MeV | 2.5 ns | 93 keV |
| $^{180}$Ta$_{m1}$ + $\bar{\nu}$ → e⁺ $^{180}$Hf*$_{m2}$ | $^{180}$Hf$_{m2}$ gamma | 1.463 MeV | 570 ns | 1374 keV |
| $^{1}$H + $\bar{\nu}$ → e⁺ n$^{0}$ | Neutron Capture γ | 1.806 MeV | ~180 µs | 5 to 8 MeV |

*Table 2: Properties of all the double pulse with fast decay isotopes for neutrino and anti-neutrino interactions such as threshold, secondary decay half-life, and secondary decay gamma ray emission energy. Although the Ga-71 mode has been seen, its cross section has not been measured and the neutrino interaction on In-115 and anti-neutrino interaction on W-183, Ag-107 and Ta-180 have not been seen but are certain to exist.*

Citations:
1) N. Solomey, Studying the Sun's Nuclear Furnace with a Neutrino Detector Spacecraft in Close Solar Orbit, Poster at AAS/Solar Physics Division meeting Boulder Colorado, Abstract#47 47, 209.03, 2016.
2) N. Solomey, Development of a neutrino detector capable of operating in Space, NIM-A, v1047, p167840, 2023.
3) N. Solomey et al., Concept for a space-based near-solar neutrino detector, NIM-A, v1049, p168064, 2023.
4) J. Folkerts et al., Method to Reduce Noise for Measurement of Be-7 and B-8 Solar neutrinos on Ga-71, submitted to NIM-A in December 2023, see arXiv/2312.10157.
5) J. Novak et al., New lower background and higher rate technique for anti-neutrino detection using Tungsten W-183 Isotope, JINST v19, #6, P06037, 2024.

## Reactor Anti-Neutrino Detection

Our group has developed a nuclear reactor anti-neutrino detector, using a similar anti-neutrino reaction process in our Solar Neutrino studies. We initially focused on W-183 [5] with a double delayed coincidence pulse as seen in figure 2. We have since discovered other fast processes on Cu-56, Ag-107 and Ta-180 which have thresholds from 0.19 MeV to 2 MeV. An interesting application of this anti-neutrino detector is that, with a large enough detector, it could feasibly detect submersed and highly movable fission reactors. Furthermore, we propose to build a test detector prototype oriented towards W-183 or Ag-107 anti-neutrino interactions which would be a proof-of-concept demonstrator by using it at the either the HFIR 85 MW ORNL reactor or the 10 MW Missouri University Research Reactor in which a well-known anti-neutrino flux would not only allow us to perform a proof of principle detector but would also measure the absolute anti-neutrino cross section on these elements.

The goal of a small prototype anti-neutrino and solar neutrino detector is threefold:

1) To observe the delayed coincidence pulses of solar neutrino type interactions on Ga transmuting to a nuclear excited state of Ge and measure its cross-section. Both the <µs process and the ~100 ns process could potentially be used to detect and measure solar neutrinos when a detector is close to the Sun with minimal shielding with the GAGG detector surrounded by an active veto array.
2) A corollary of this project has been the interest in developing an improved anti-neutrino detector. Fission reactors such as those on submarines are a continuous source of anti-neutrinos, even if the reactor is off. Using simulations, we have studied the nuclear isotope materials for such a detector using the standard double pulse Inverse Beta Decay (IBD) technique first used by Cowan and Reines in the 1950s. This traditional anti-neutrino produces a conversion positron and a neutron where the neutron can then be absorbed by an isotope with a large neutron capture cross section and its subsequent gamma emissions, see figure 2-left. We have also developed a double pulse technique like the Ga to Ge* process being used in our NASA project, but for anti-neutrinos by using the isotope $^{183}$W transition to $^{183}$Ta* where the nuclear excited state of 107 ns half-life emits a delayed 73 keV gamma to reduce background and with a minimally amount of shielding and an active charged particle veto.
3) The red giant star Betelgeuse may go supernova within decades. Recent peer reviewed articles have shown that Helium burning in this star is complete, and the star is burning carbon and sulfur. A supernova can produce a tremendous number of neutrinos over a six-second period, as was seen with the 1987 supernova. That supernova was 170,000 light years away, and an equivalent supernova of Betelgeuse or another nearby star would result in two million events in the same size detector over six seconds. Because a nearby supernova would provide a higher neutrino flux at earth, even a small detector can find a nearby supernova. Measuring the neutrino and anti-neutrino supernova flux with a small detector would be a notable scientific achievement. Because our detection technique can distinguish lower energies it would be able to see the neutrino time evolution of the supernova pulse. This prototype test detector for ORNL could eventually become, in a Salt Mine of Kansas 650 ft below ground, a nice monitoring station once neutrino and anti-neutrino detection is calibrated at the ORNL HFIR and SNS test areas.

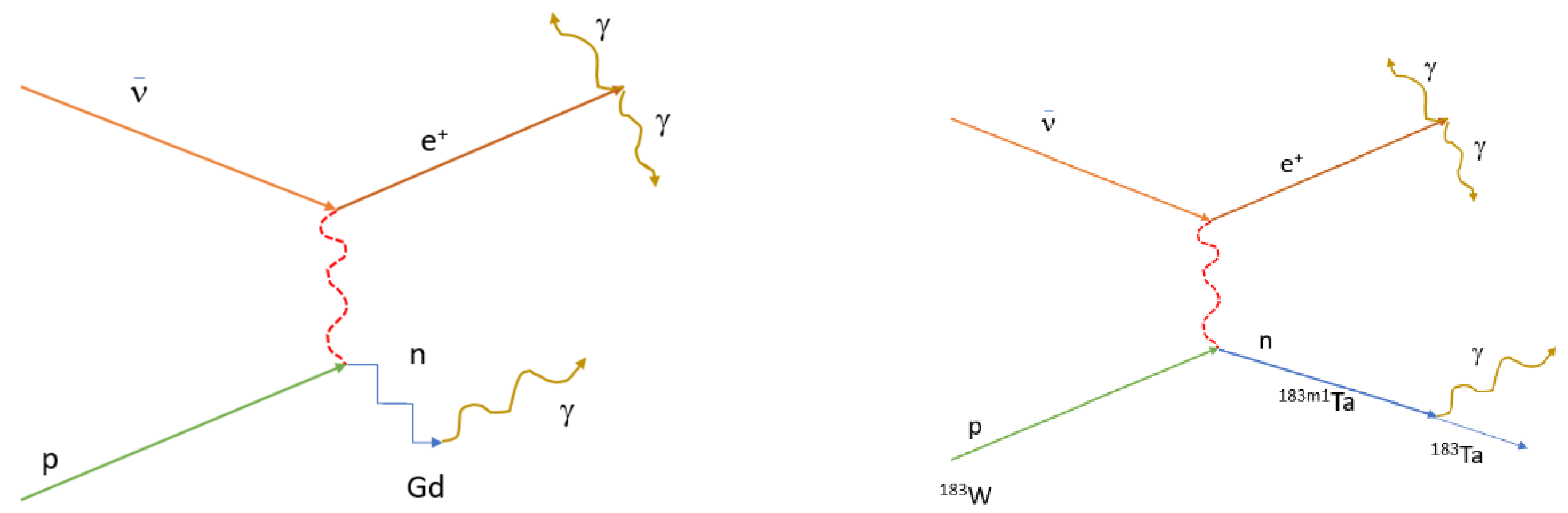

*Figure 2: On the left is the traditional anti-neutrino IBD reaction use for more than 75 years, and its secondary emission is 200 µs delayed and on the right is an ultra-clean method of detection with minimal shielding and using an active veto array employing either $^{183}$W or $^{107}$Ag, see parameters in Table 2, both are fast secondary emissions which helps clean up the process and the $^{107}$Ag has the advantage of a much lower anti-neutrino threshold.*

## Conclusion

In collaboration with ORNL it is hoped that the DOE would fund our study for a small prototype demonstrator detector for neutrinos at the ORNL Spallation Neutron Source and the anti-neutrino methods at either HFIR or MURR reactor. Once demonstrated the small detector could be put downstream of a target being hit by protons at various angles to look at neutrino and anti-neutrino production in the MeV regime.