Double-coincidence gallium neutrino signals are a method used in neutrino detection that enhances the ability to discriminate against background noise, particularly from high-rate space backgrounds such as cosmic rays.

These interactions can be distinguished from random background rates of solar electromagnetic emissions, galactic charged cosmic-rays, and gamma rays by using a double pulsed signature.

Ga-71 detectors are highly sensitive to low-energy neutrinos, particularly those in the energy range of a few MeV (mega-electron volts), which are typical of solar neutrinos. This sensitivity is due to the specific nuclear properties of Ga-71

Comparison :

**Cherenkov Radiation**:

* + When a charged particle, such as an electron, travels through water at a speed greater than the speed of light in water, it emits Cherenkov radiation. This radiation appears as a cone of blue light, which can be detected by photomultiplier tubes (PMTs) surrounding the water volume.

Super Kamiokande (Super-K) and Borexino are both remarkable experiments in the field of neutrino physics, each contributing significantly to our understanding of the sun and solar neutrinos.

### Super Kamiokande (Super-K)

It is a large neutrino observatory located in the Kamioka Mine in Japan. One of its most notable achievements is producing an image of the sun using neutrinos. This groundbreaking work was possible because Super-K can detect the Cherenkov radiation produced by high-energy neutrinos interacting with electrons in its large water Cherenkov detector. The detector consists of a large tank filled with pure water, surrounded by photomultiplier tubes (PMTs) that detect the faint light produced by these interactions. The neutrino image of the sun provided by Super-K offers direct evidence of solar neutrinos and supports our understanding of the processes occurring in the sun's core.

### Borexino

Borexino is another prominent neutrino detector located in the Gran Sasso National Laboratory in Italy. Unlike Super-K, Borexino is designed to detect low-energy solar neutrinos, particularly those from the proton-proton chain reaction, which is the dominant source of energy production in the sun. Borexino has achieved remarkable sensitivity and precision in measuring solar neutrino fluxes, allowing it to test various solar models.

One of Borexino's significant contributions is the experimental verification of the high metallicity standard solar model (SSM) predictions of neutrino fluxes. The SSM predicts the production and flux of different types of neutrinos based on the composition and processes occurring in the sun. High metallicity models suggest a certain proportion of elements heavier than helium (metals) in the sun. Borexino's precise measurements of neutrino fluxes have provided evidence supporting these high metallicity models, helping refine our understanding of solar composition and dynamics.

Usually these neutrino detectors are large because:

1. Large Mass: Detectors like Super-K and Borexino are large to maximize neutrino capture rates.

2. Underground Location: Being underground reduces background noise from cosmic rays.

3. Increased Solar Neutrino Flux: Proximity to the sun enhances solar neutrino detection, beneficial for studying solar processes.

4. Space-Capable Detectors: Detectors in space can move away from the sun to decrease solar neutrino interference.

5. Galactic Neutrinos & Dark Matter: Space-based detectors could better search for galactic neutrinos and weakly interacting dark matter candidates.

We propose three distinct possibilities for science using the Neutrino Solar Observatory (νSOL):

1. Going closer to the Sun, see Table 1, the 1/r2 neutrino flux would provide 1,000x more neutrinos per second at a distance of seven solar radii (7R⊙ ≈ 5·106 km), approximately where the NASA Parker Solar Probe currently operates.

By flying in the region between the earth (215R⊙) and the sun, a space-based detector may be able to search for evidence that confirms the standard predictions of neutrino decoherence by the Sun’s surface, or it may be able to find that the neutrinos resistance to becoming radioactive in high-radiation environments. Beneath the iron shielding is a 1 cm thick polymer shell followed by several 0.2 cm thick alternating layers of aluminum and plastic to promote showering of any particles that penetrate the passive iron shield.

Layering:  I**ron Shielding**: Stops or significantly reduces the energy of incoming particles.

 **Polymer Shell**: Captures and reduces secondary radiation from the iron shielding.

 **Aluminum and Plastic Layers**: Encourage the development of particle showers, which helps in further reducing the energy of any penetrating particles. The alternating materials are chosen because they interact differently with incoming particles, maximizing the likelihood of particle interactions and energy dissipation.

Decoherence :

Decoherence is a concept from quantum mechanics that describes the process by which a quantum system loses its quantum coherence. Quantum coherence refers to the property of a system where all parts of the wavefunction or quantum state are in a specific, predictable relationship with each other. When decoherence occurs, this relationship is disrupted, causing the system to transition from a superposition of states to a mixture of states.

**Quantum Superposition**:

* In quantum mechanics, particles like electrons, photons, or neutrinos can be in multiple states at once. For example, a neutrino can be in a superposition of different types (or flavors) at the same time.

Interaction with environment: When a quantum system (like a neutrino) interacts with its surroundings (like particles in the Sun or in space), these interactions disturb the superposition.

Loss of coherence: Due to these interactions, the system's state becomes less well-defined in terms of its superposition. It starts to look more like a mixture of different states rather than one coherent superposition.

### Why is Decoherence Important?

* **Neutrino Studies**:
  + Neutrinos are tiny particles that rarely interact with matter, but when they travel through the Sun or other environments, they can experience decoherence.
  + Scientists want to study how neutrinos change (or decohere) to understand more about their properties and the environments they travel through.
* **Quantum to Classical Transition**:
  + Decoherence explains how the strange, counterintuitive behaviour of quantum particles (like being in multiple states at once) transitions to the more predictable behaviour of classical objects (like being in one place at a time).

### Inside the outer shield and showering layers is a 5 cm thick vetoing volume made of plastic scintillator:

### Vetoing Volume

A **vetoing volume** is a part of a detector system used to detect and ignore unwanted signals, known as background noise. This helps scientists focus on the signals that are important for their experiments.

### Plastic Scintillator

Plastic scintillators are materials that emit light (scintillate) when charged particles pass through them. The light produced is then detected by photodetectors, such as photomultiplier tubes (PMTs) or silicon photomultipliers (SiPMs). Plastic scintillators are popular in particle detection because they are:

* **Lightweight and easily shaped**: They can be molded into various geometries to fit different experimental setups.
* **Cost-effective**: They are less expensive compared to other scintillating materials like crystals.
* **Fast response**: They produce light quickly, which is important for precise timing measurements.

## "Vetoing volume made of plastic scintillator “:

*  **Particle Interaction**: When a particle enters the plastic scintillator, it causes the scintillator to emit light.
*  **Light Detection**: This light is detected by special devices called photodetectors (like PMTs or SiPMs), which convert the light into an electrical signal.
*  **Veto Decision**: If the detected signal is identified as unwanted noise (background), the system marks it as a vetoed event.
*  **Ignore Unwanted Signals**: The vetoed events are then ignored in the main data analysis, helping to reduce noise and improve the accuracy of the experiment.

**Solar Neutrino Experiments**

Ga-71 has been used in solar neutrino experiments such as:

* **SAGE (Soviet-American Gallium Experiment)**: This experiment is conducted in the Baksan Neutrino Observatory in Russia. It uses a large quantity of liquid gallium to detect neutrinos from the sun.
* **GALLEX (Gallium Experiment)**: This experiment took place in the Gran Sasso National Laboratory in Italy, also utilizing gallium to detect solar neutrinos.

(gallium is a metal used to detect the neutrinos)

### Process of Neutrino Detection

1. **Neutrino Interaction**:
   * A solar neutrino interacts with a Ga-71 nucleus within the detector. The interaction converts Ga-71 into germanium-71 (Ge-71).
   * Ga-71 + ν → Ge-71 + e⁻
2. **Collection and Extraction**:
   * The Ge-71 produced in the reaction is chemically extracted from the solution. This step is critical to isolate the product of the neutrino interaction.
3. **Counting and Analysis**:
   * The extracted Ge-71 undergoes further analysis to measure its decay back to Ga-71, providing evidence of the original neutrino interaction.

The proposed Neutrino Solar Observatory (νSOL) aims to address some of these limitations by taking advantage of the increased neutrino flux closer to the Sun and the reduced background noise further away from the solar system. Key advantages of such a space-based detector include:

1. **Higher Neutrino Flux Near the Sun**:
   * Operating closer to the Sun would provide a significantly higher neutrino flux, improving detection rates and enabling more precise measurements.
2. **Reduced Background Noise**:
   * A space-based detector, especially one located further from the Sun and the Earth, would experience lower background noise, making it easier to detect faint signals from neutrinos and other weakly interacting particles.
3. **Exploration of Exotic Neutrino Sources**:
   * By positioning the detector at various distances, including at the solar gravitational focus, νSOL could potentially detect neutrinos from the galactic core and investigate dark matter candidates more effectively than ground-based detectors.

References:

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Problems that should over come:

1.Decoherence