# Developing a Neutrino-Detector for Space Flight

## Pisa Conference for Advanced Detectors

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In cooperation with colleagues from:

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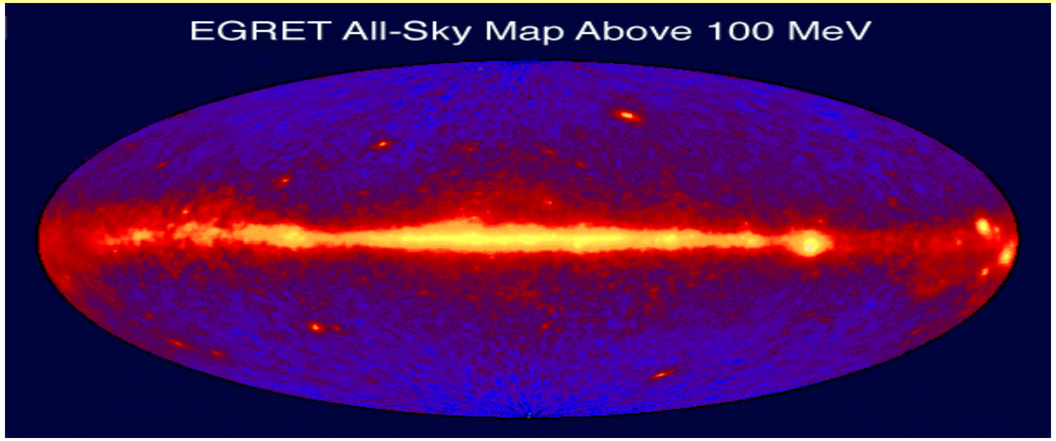
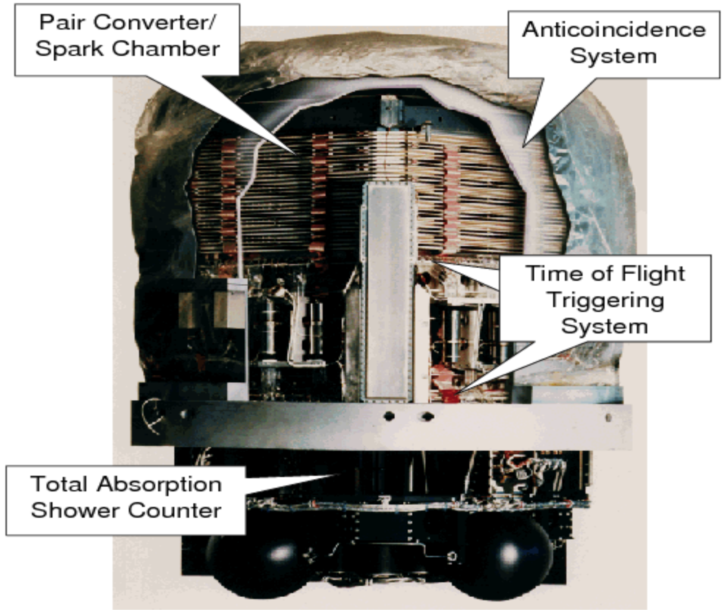
# Background:

- Experimental Particle Physicists are starting since 1990s to get involved with NASA Astrophysics experiment developments.
- Take something simple, put it into someplace where NASA or ESA can bring it to do new unique science that cannot be done on Earth.
- Past Example: High Energy Gamma Rays

Using a small spark-chamber particle detector in 1992 NASA launched the EGRET spacecraft, which opened our eyes to high-energy Gamma-ray Astronomy. Now a large amount of gamma ray astronomy like this is done with the Fermi Satellite.



# Question:

- If we can operate a neutrino detector in Space What new Science can be done?
  - On Earth a few hundred solar neutrinos have been detector from the Sun's core. By going closer to the Sun the $1/r^2$ dependence would let us get a solar neutrino flux up to 45,000x.
  - A detector with 25 kg active target is equal to 25 T on Earth at 7 Solar Radii.
  - A detector with 25 kg active target is equal to 1/4 kT on Earth at 3 Solar Radii.
  - Close to the Sun a collection of neutrino events would permit the internal radius structure of neutrino emitting core to be studied 900x better, so each event is equal to 900 events on earth, for internal structure.

*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 |

- Dark Matter searches would be 10x less solar neutrino backgrounds in an asteroid, 100x less at Saturn and 1000x less at Neptune.

# Neutrino Detection Technique for Spacecraft

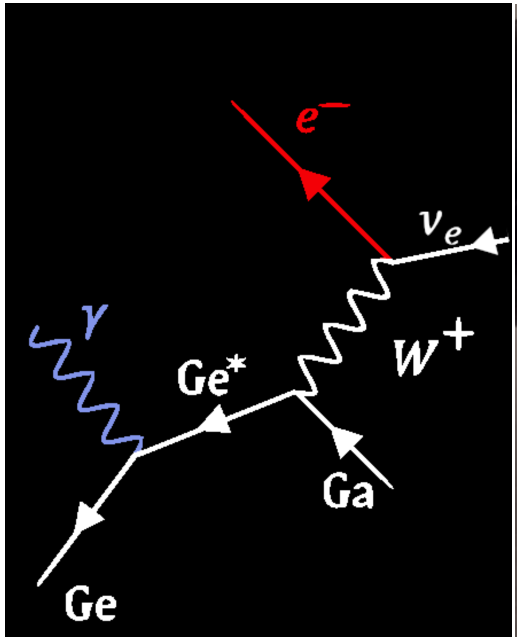
**Ray Davis Homestakes Solar neutrino observatory technique**

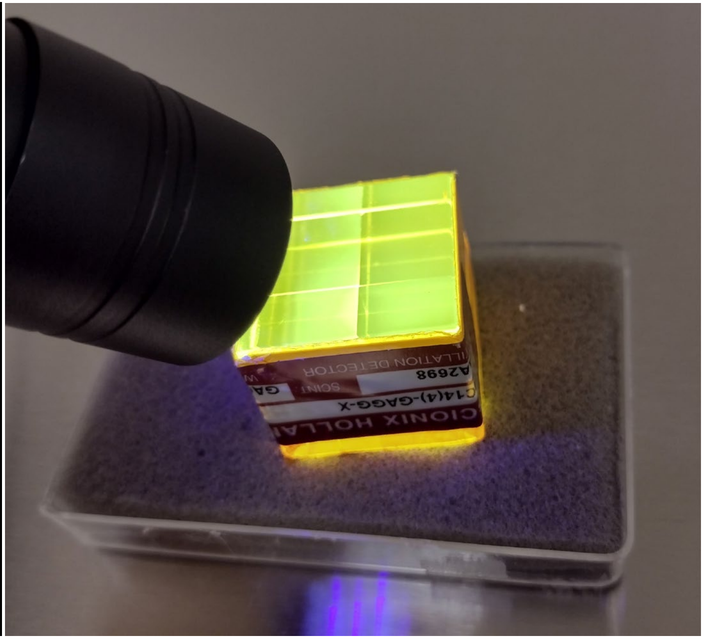
$$\nu_e + {}^{37}Cl \mapsto {}^{37}Ar + e^-$$

**Our Technique: Double timing pulse**

| | | | |
|---|---|---|---|
| $^{69}$Ga + ν into e- $^{69}$Ge m1 or m2 | $^{69}$Ge m1 decays X-ray<br>$^{69}$Ge m2 decay gamma | 5 us<br>2.8 us | 86 keV<br>397 keV |
| $^{71}$Ga + ν into e- $^{71}$Ge m1 | $^{71}$Ge m1 decay gama | 20 ms | 175 keV |

GAGG Crystal with 20% Ga, large and fast light yield:



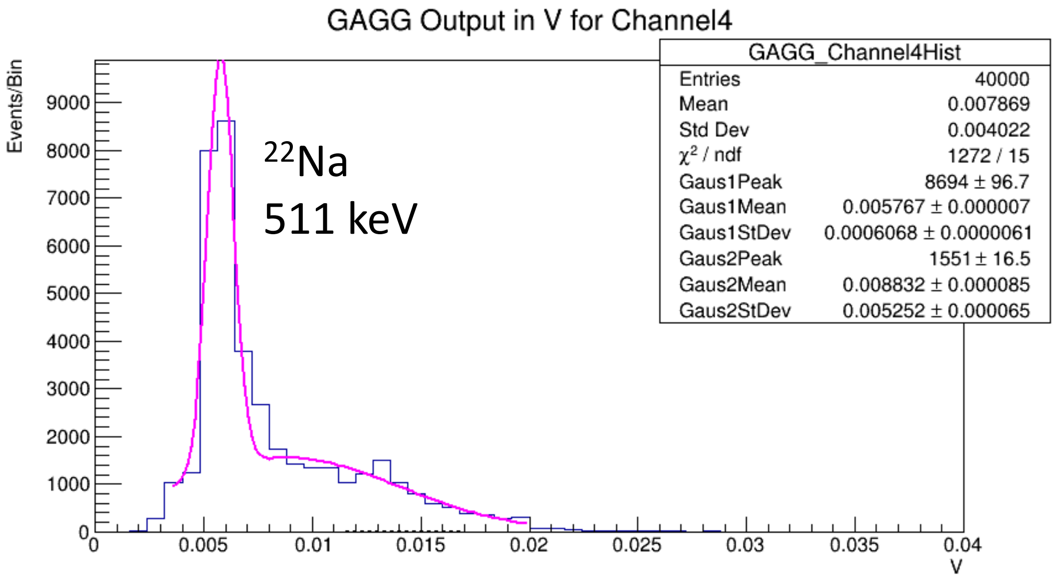
# Lab Testing of GAGG detector at Wichita State U.

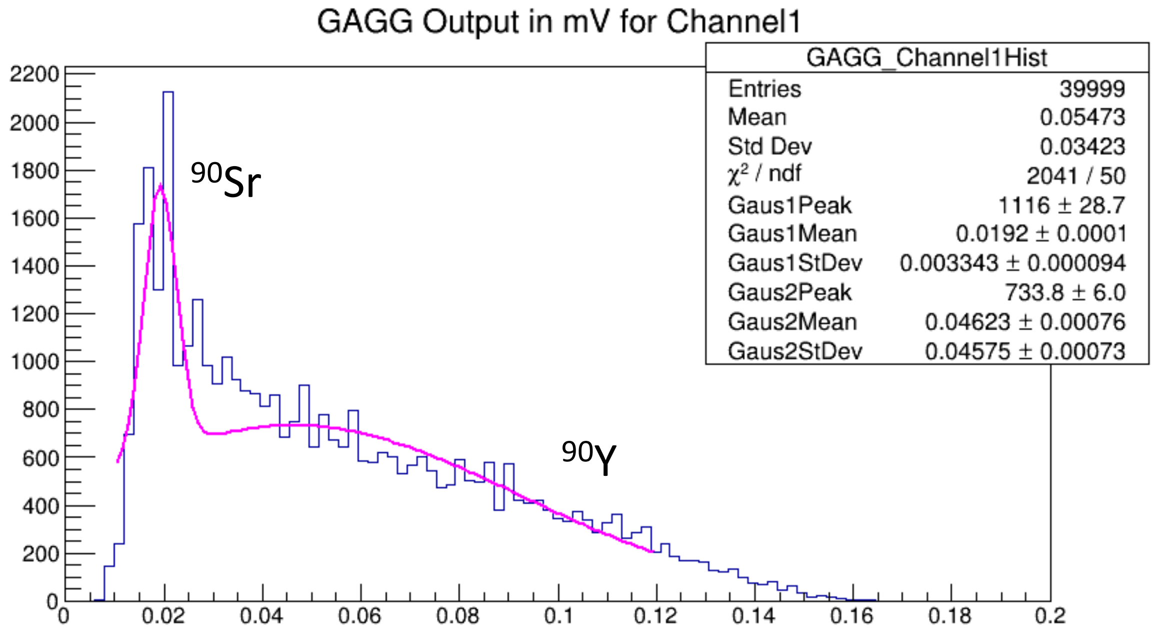
**Gamma sources**

- Energy Resolution
- Linearity
- Signal shape

**Beta Decay electrons**

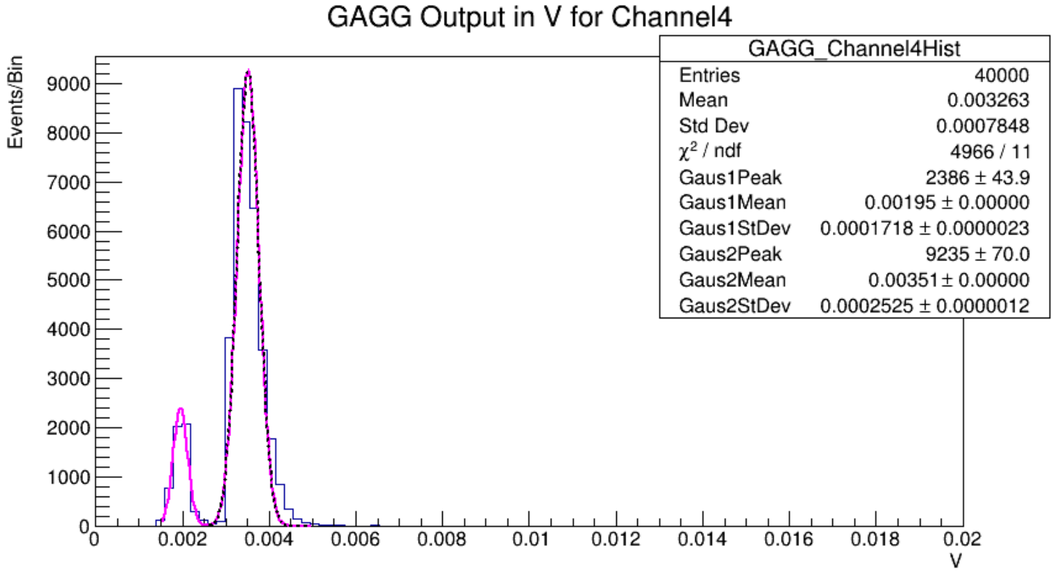
- Energy tagging
- Length of tail for timing restrictions



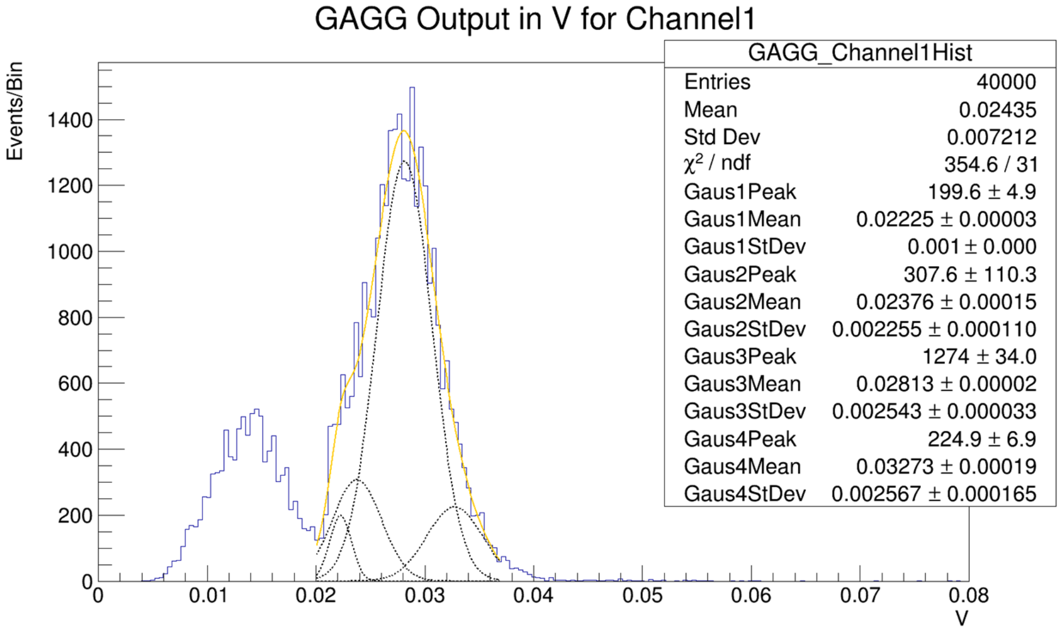



# Gamma sources closer to energy of double delayed coincidence expected is 100-200 keV

**$^{57}$Co source of 122 keV on right is escape peak of 46 keV with good energy resolution to resolve both at 17% FWHM**

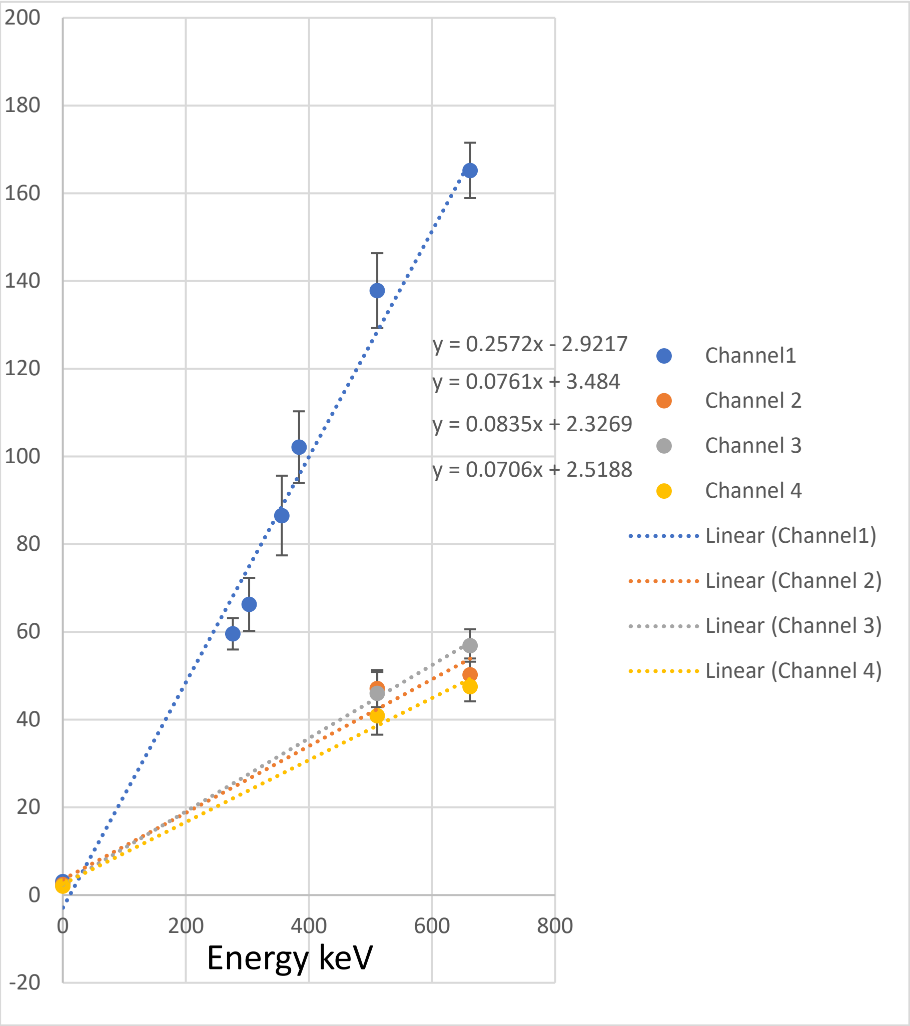



**$^{133}$Ba source with 4 gamma very close together cannot visually be separated but can resolve in spectrum 276, 302, 356 and 386 keV, at 18% FWHM**

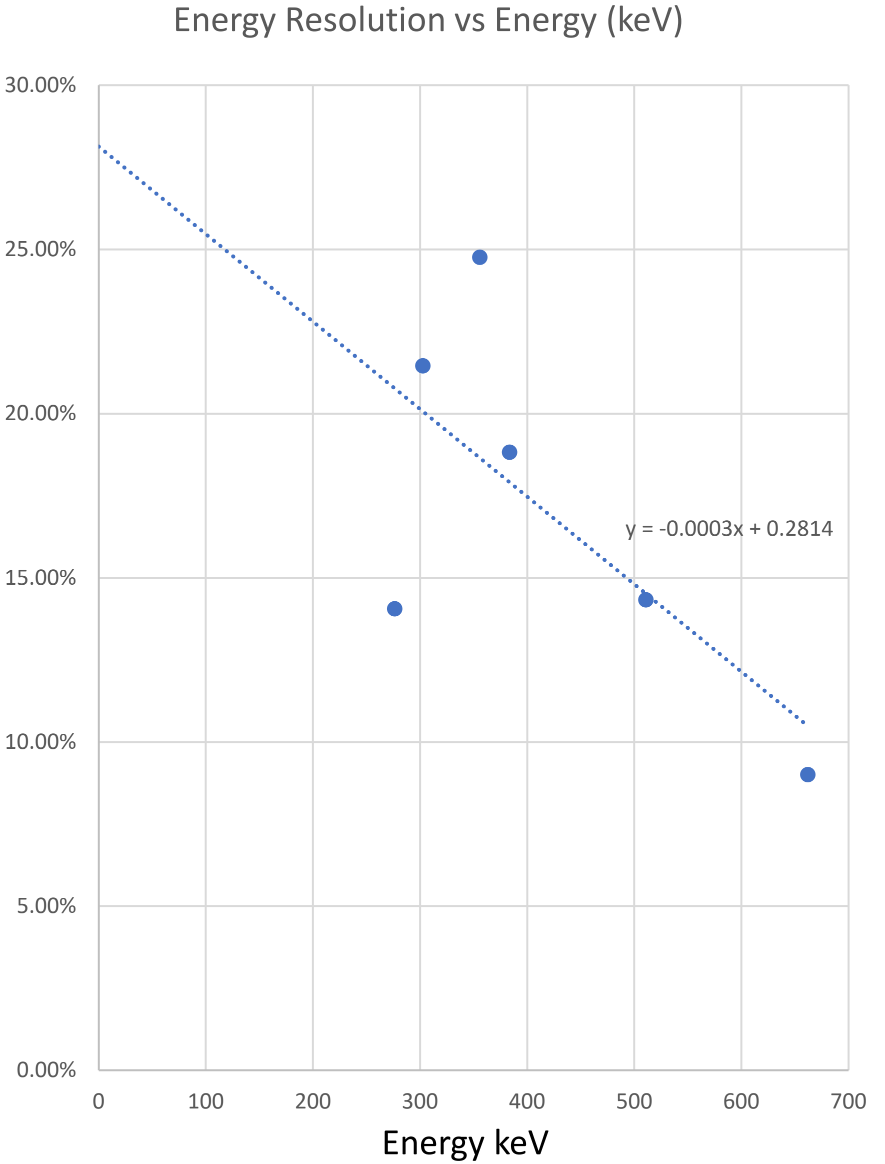


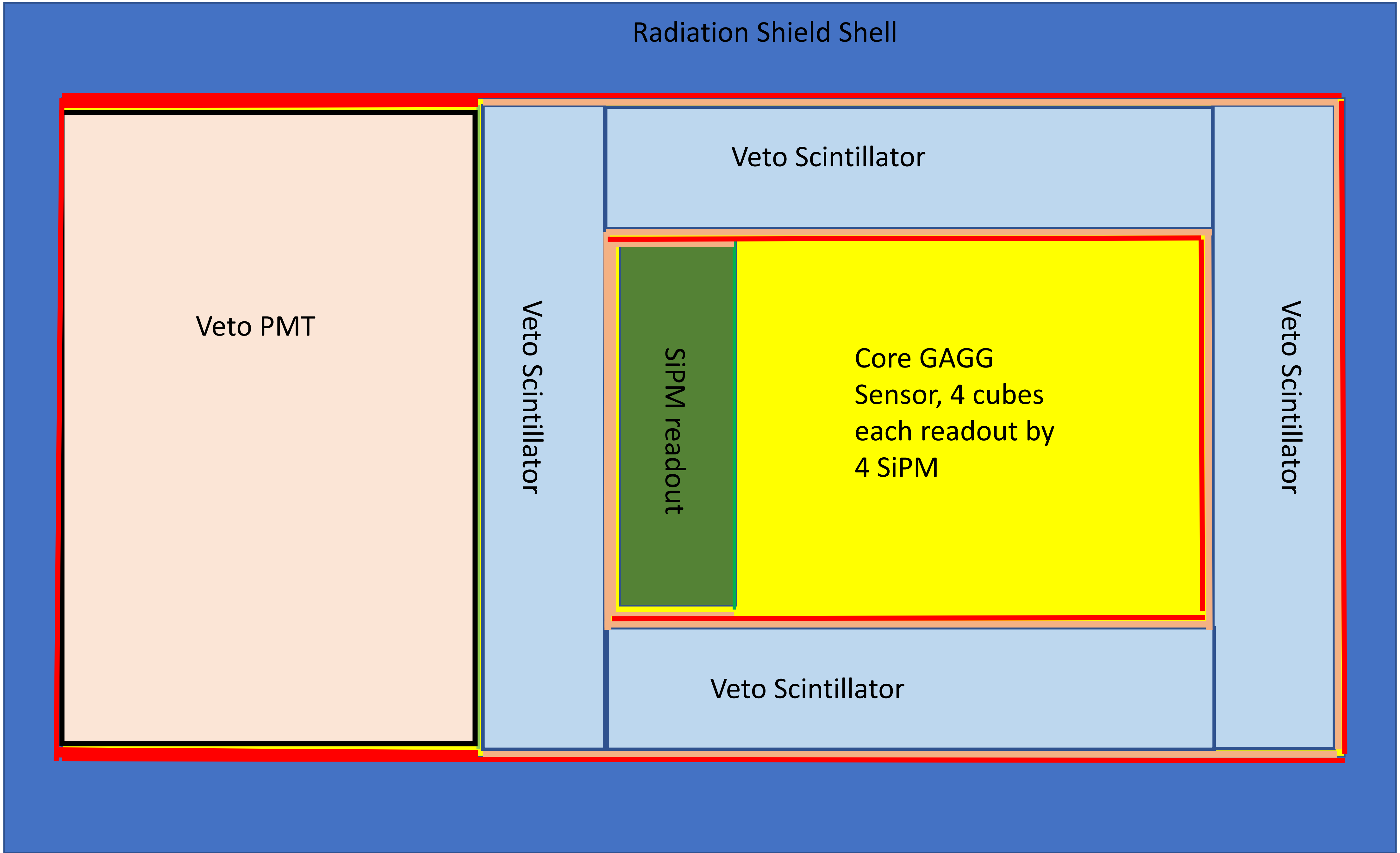
# Gamma Ray Lab studies Performance Summary

## Detector Linearity



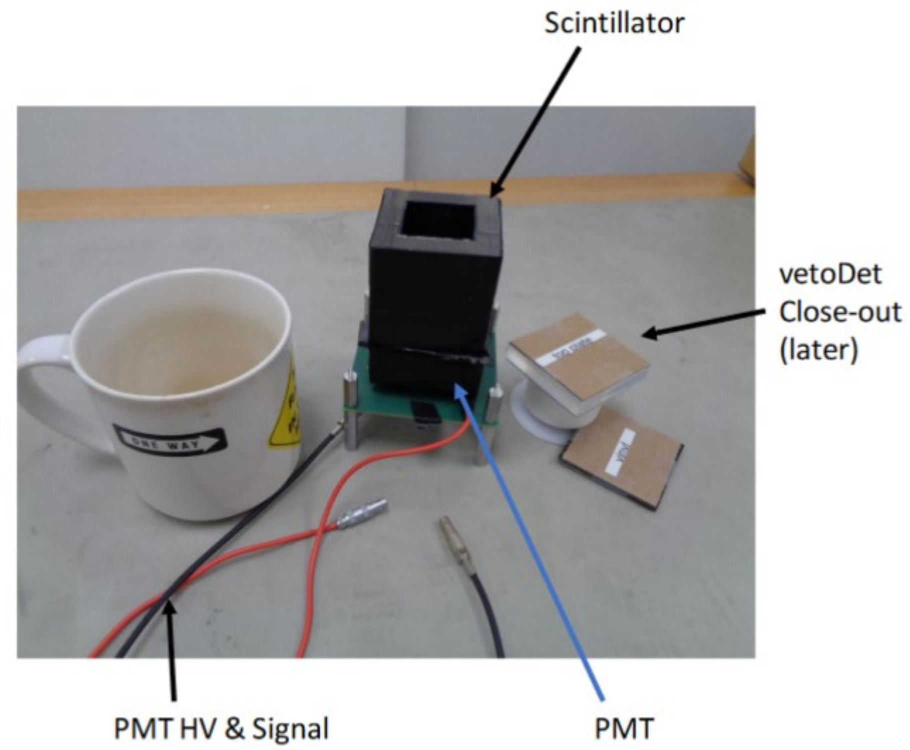

## Energy Resolution



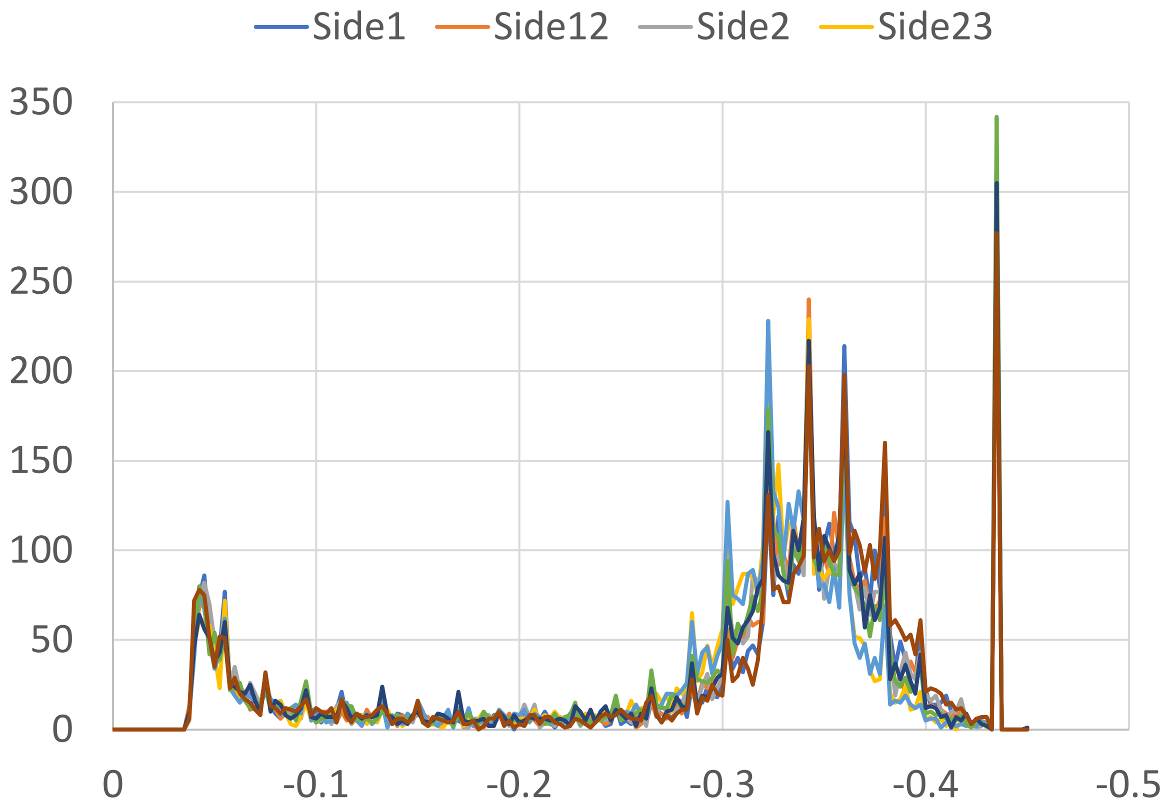

Radiation Shield Shell
Veto PMT
Veto Scintillator
Veto Scintillator
SiPM readout
Core GAGG Sensor, 4 cubes each readout by 4 SiPM
Veto Scintillator
Veto Scintillator

# Scintillator Veto around Detector is by NASA MSFC

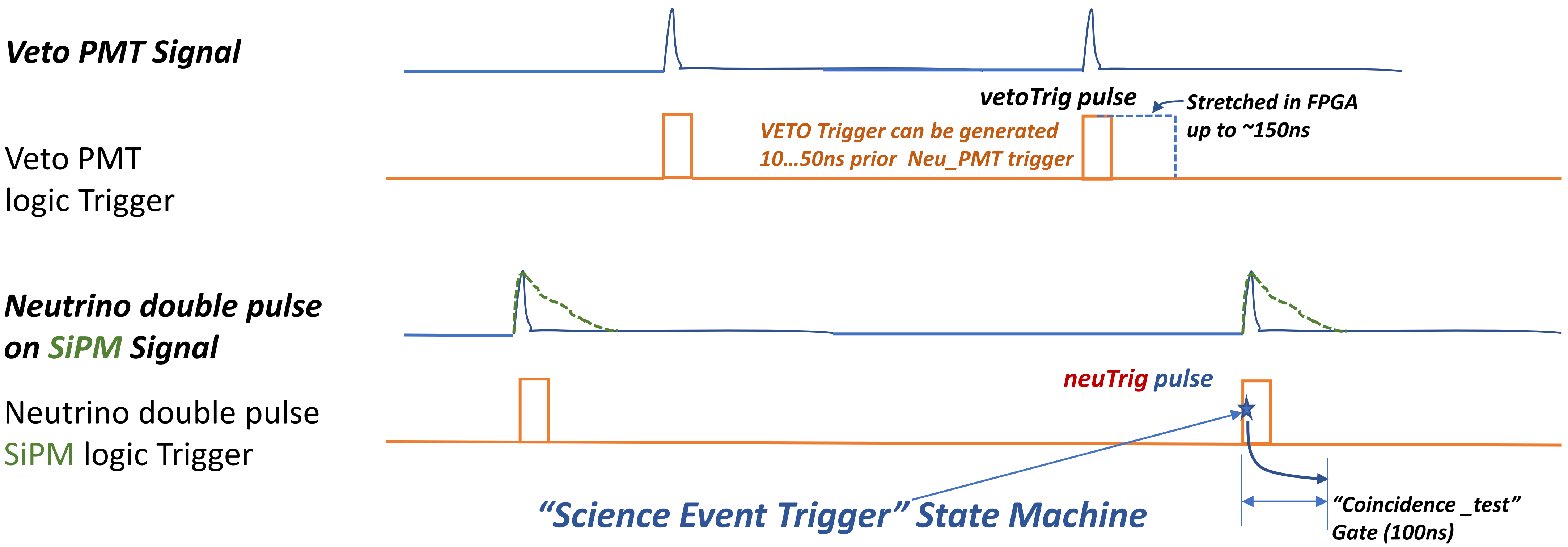
**Detector hardware compared to coffee mug**



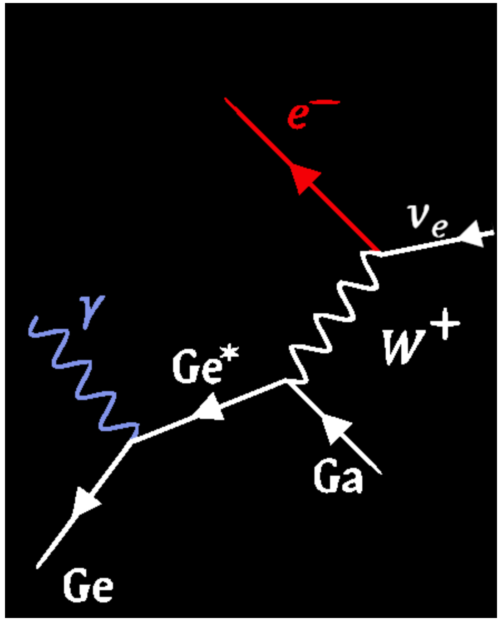

**Study of $^{241}$Am source on many different sides, where all light is collected on only one end**



# Signal Channels



# Study of Double Delayed Coincidence

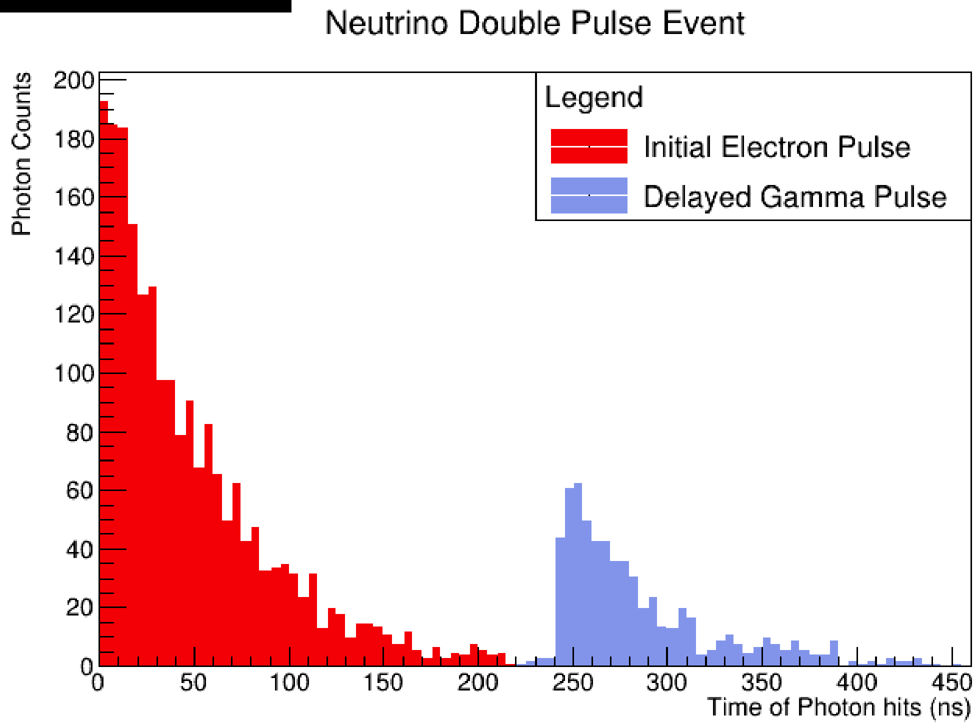



**Interaction**

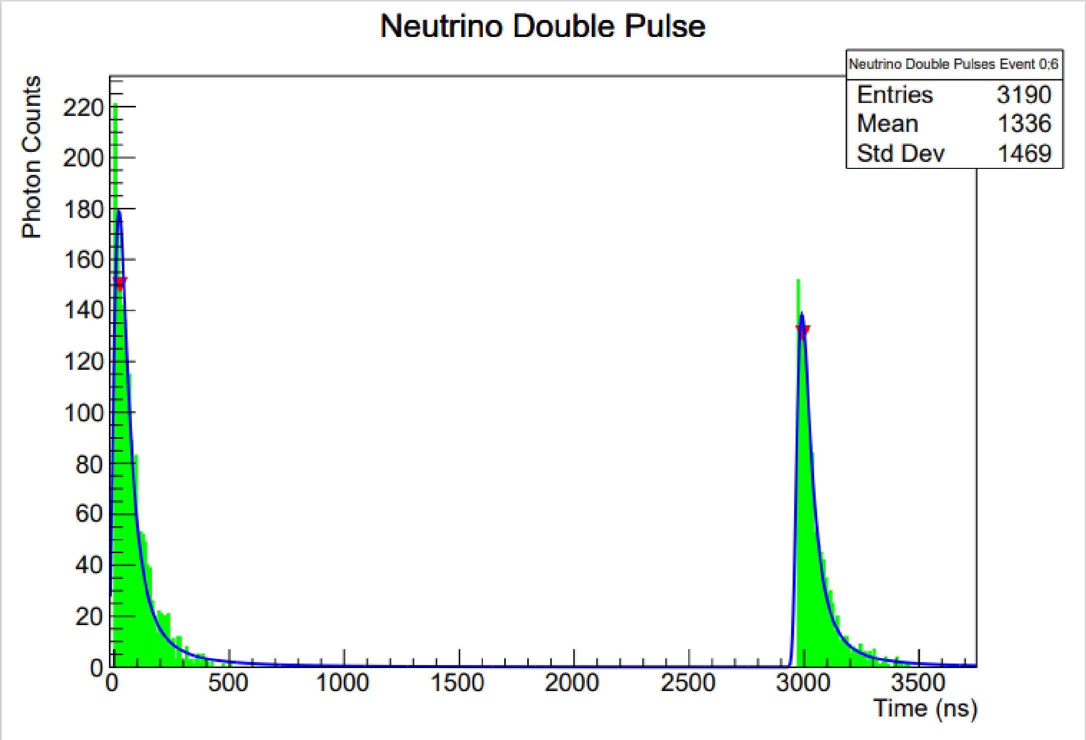
Neutrino interactions with Gallium will produce 66% of the time a double event

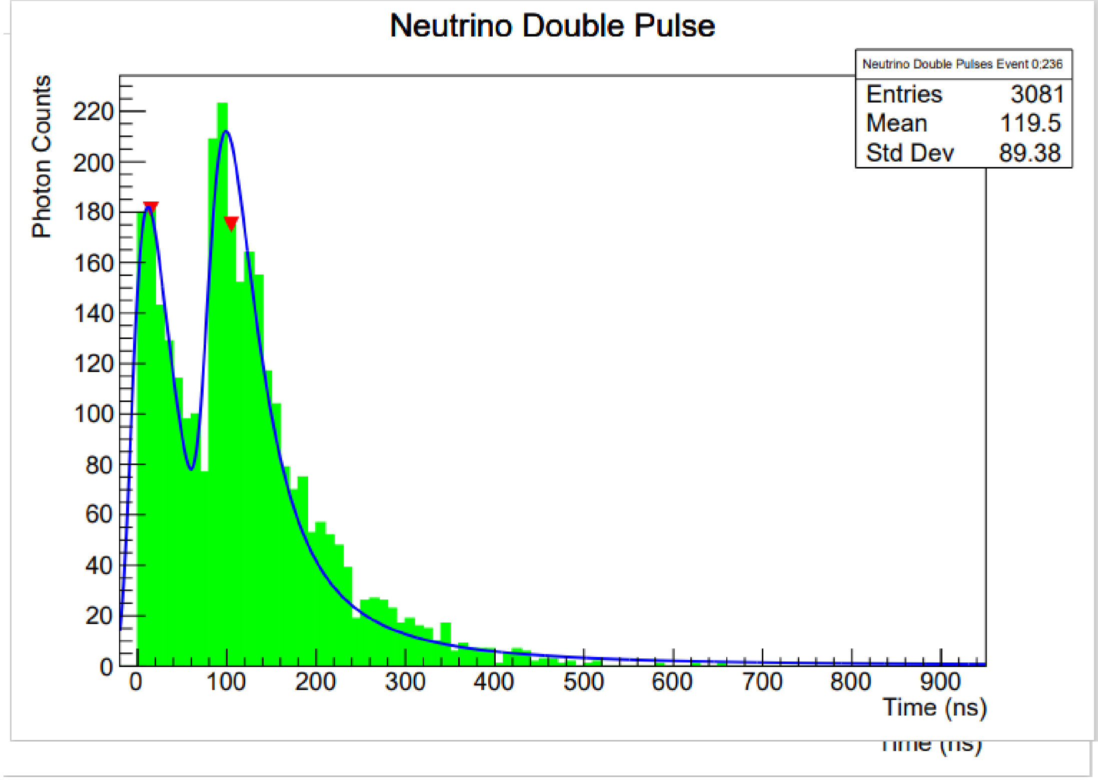
Primary conversion electron creates first signal like our beta decay lab signal

Look for secondary pulse having the characteristic gamma peak that appears some time after, out to maybe 10 half-lives



# Double pulse Fits

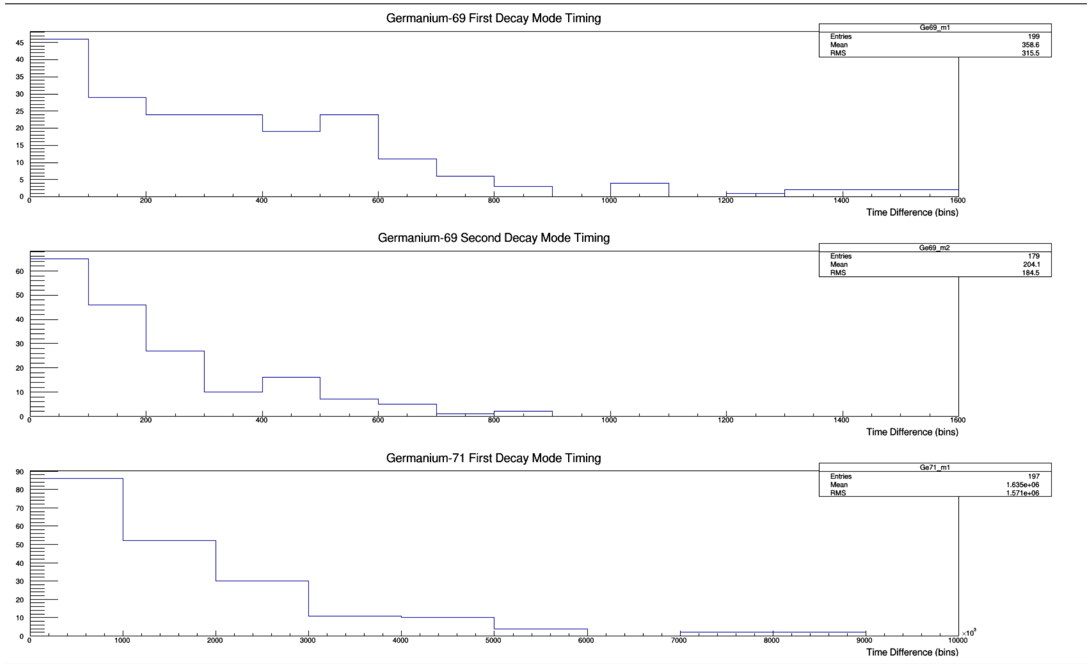


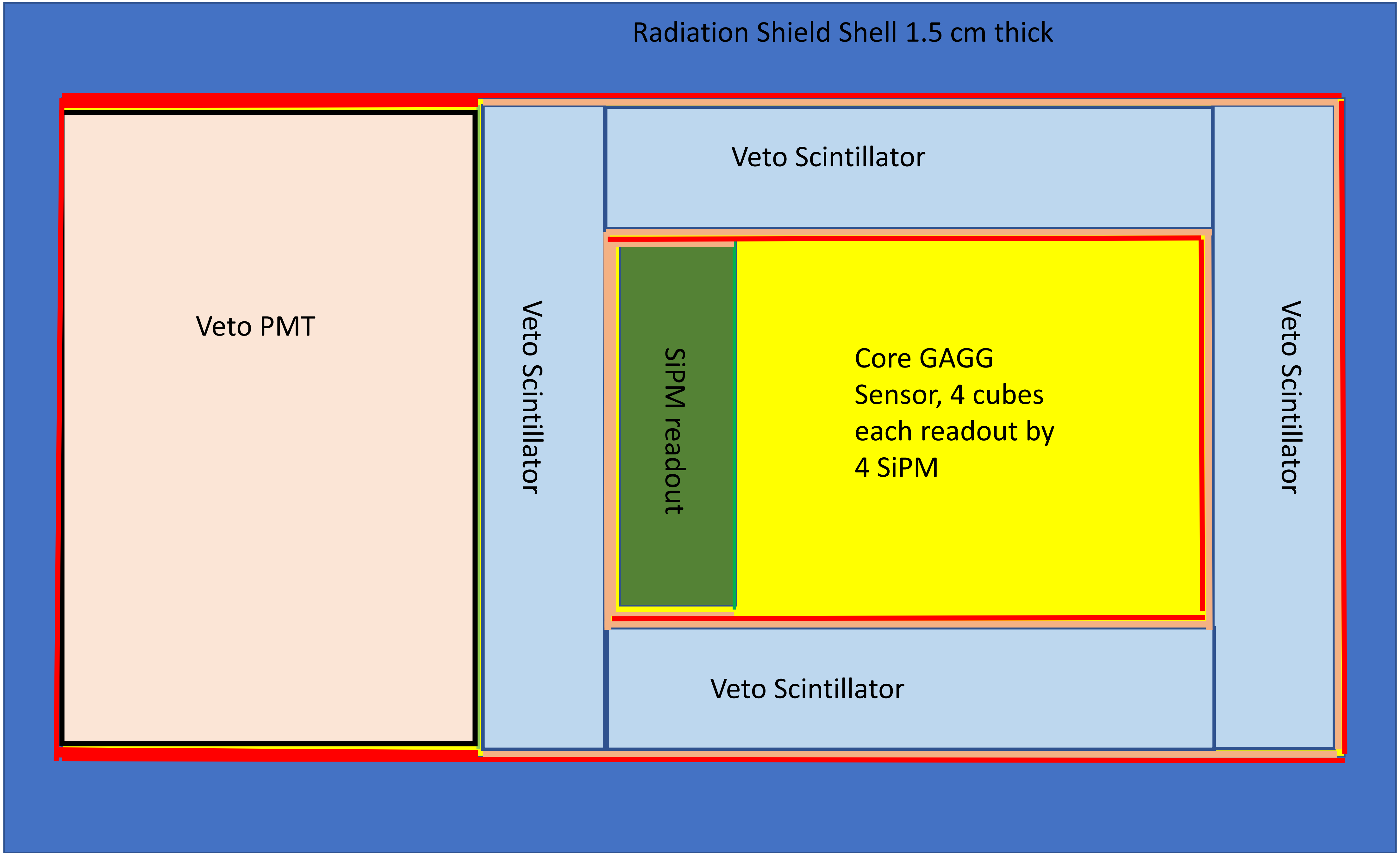




Both figures demonstrate double pulse events, left well separated and right is a situations where the pulses are very close in overlap, but the function can still correctly identify the respective pulses.
But this is for perfect resolution, whereas actual detector measurements would spread the signal so we would not be able to identify the pulses easily.

# Simulations Reconstructing double timing neutrino events with expected backgrounds

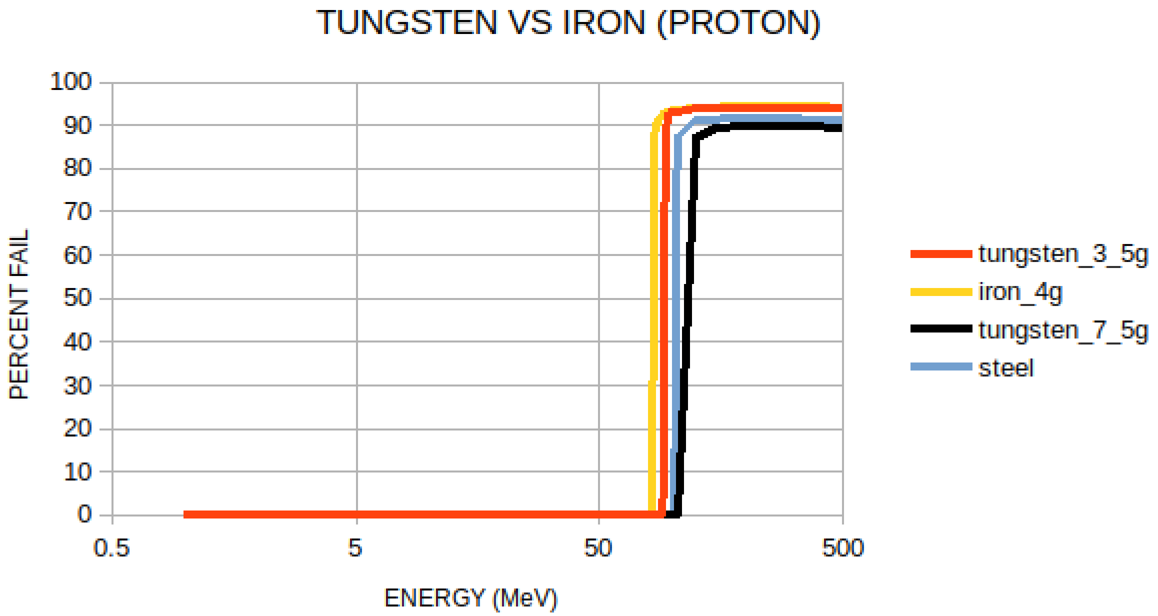
- Using correct rates for:
  - Galactic Cosmic Rays (Solar Modulation at 7 Sun Radii)
  - Galactic Gamma Rays
  - Neutrino rates close to Sun (7 Solar Radii)
- The three double timing modes events were reconstructed, these have the worst case of 15% fake double pulses from backgrounds and 85% real neutrino double pulses.

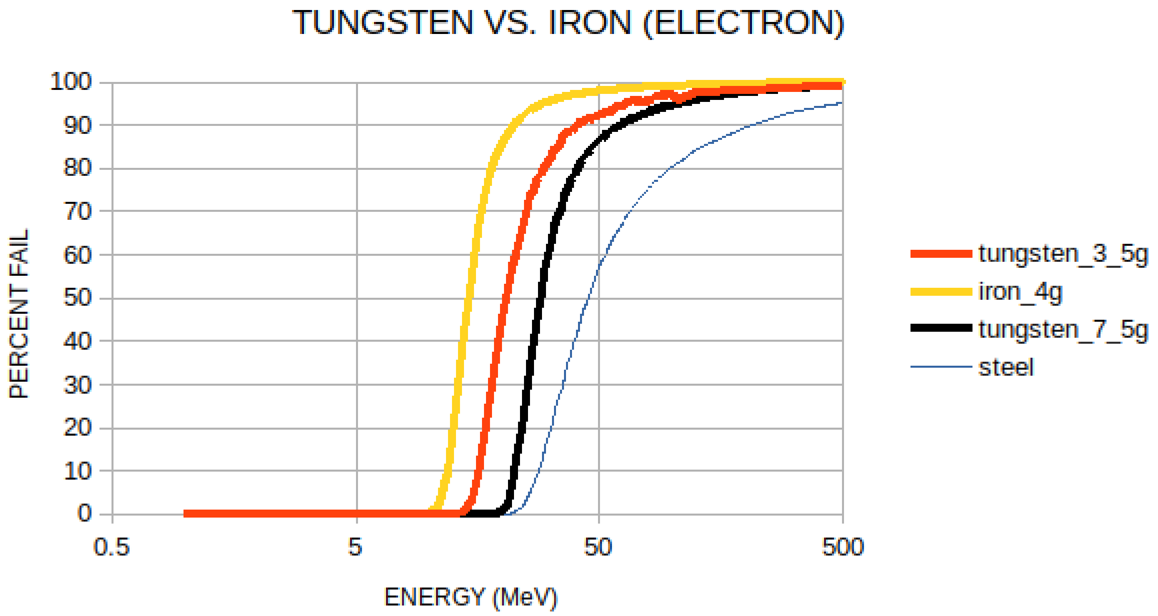



Radiation Shield Shell 1.5 cm thick
Veto PMT
Veto Scintillator
Veto Scintillator
SiPM readout
Core GAGG Sensor, 4 cubes each readout by 4 SiPM
Veto Scintillator
Veto Scintillator

# Epoxy-based Shielding loaded with metal dust

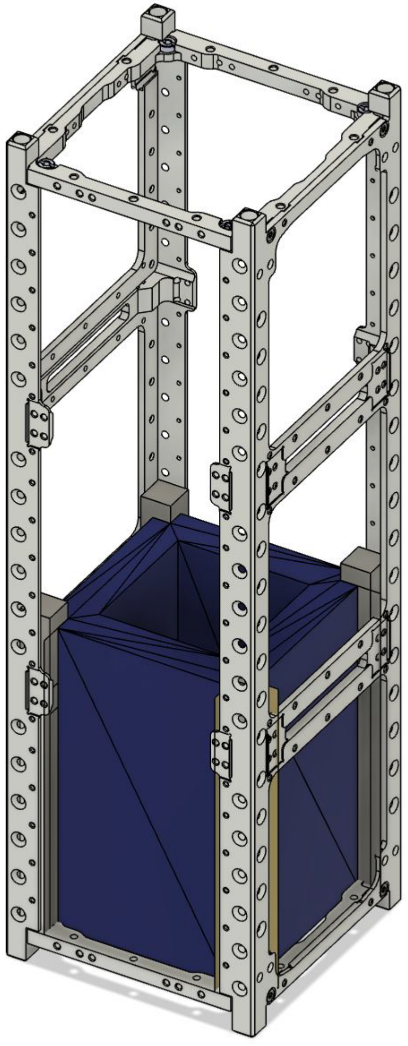
- Proton
  - Shielding driven by charge density
  - Shielding driven by number and mass of heavy nuclei
  - Particles of up to ~100 MeV completely stopped by tungsten-doped epoxy
  - Slightly outperforms steel of similar density in all energy regimes
- Electron, positron or gamma
  - Shielding driven by electron density
  - Particles of up to ~20 MeV completely stopped by tungsten-doped epoxy
  - Slightly underperforms steel of similar density at low energy
  - Slightly outperforms steel at high energy



# Test Detector occupies a 3rd of the 3U CubeSat

- Detector unit will be placed on one end of the CubeSat, while custom supporting cards made by NASA's NSSTC at MSFC will be just above it.
- Will be fixed in place with slide key mechanism and additional restraints
- NanoAvionics is providing for $239,000 the 3U CubeSat with flight computer, avionic controller, solar panels, power card and transceiver with S-band communications to NASA Near Space Network

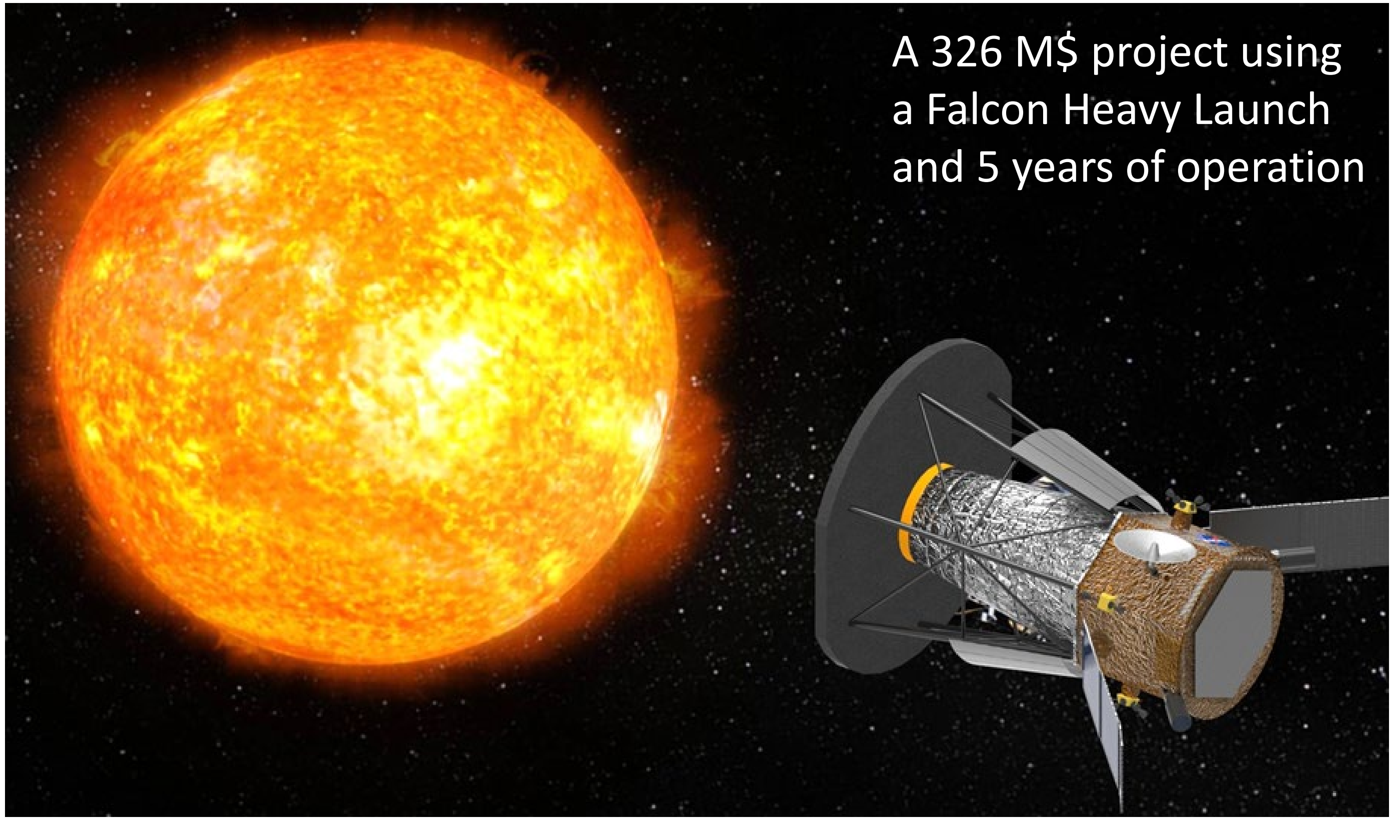


# CubeSat Launch into Space

- A rideshare launch on either a SpaceX or RocketLab vehicle
- For our 8 kg, 3U CubeSat into Polar Low Earth Orbit
- 4.5 g maximum acceleration so a smooth ride into space
- $180,000 for the launch
- $425,000 for two years of communications
- Aiming for launch in late Summer of Fall of 2024

# Conclusion:

- Detector R&D on Space Based Neutrino Detector:
  - NASA funding started in 2016
  - Current NASA funding 2 M$/year
  - Building 3U CubeSat detector to be tested in space and custom logic cards, high voltage and readout
  - Launch, Operations, Communications and Data Analysis Fall of 2024 through Summer of 2026
- A future mission, called neutrino Solar Orbiting Lab ($\nu$SOL), close to Sun is in development and budgeting; this is also supposed to do proton, neutron and electron studies from the Sun's surface




[1] N. Solomey, Studying the Sun's Nuclear Furnace with a Neutrino Detector Spacecraft in Close Solar Orbit, AAS/ Solar Physics Division, Abstracts# 47 Presentation and poster P7-26, Boulder Colorado June 2016.

[2] N. Solomey (PI), NASA Innovation and Advanced Concept Phase-1 2018 Grant "Astrophysics and Technical Study of a Solar Neutrino Spacecraft", May 15, 2018 ot Feb. 14 2019 80NSSC18K0868, and NASA Innovation and Advanced Concept Phase-2 2019-2021 Grant, Astrophysics and Technical Lab Studies of a Solar Neutrino Spacecraft Detector, 80NSSC19M0971.

[3] N. Solomey (PI), CubeSat test of a space neutrino detector, NIAC Phase-3 grant, Oct. 1, 2021 through Sept. 30, 2023, 80NSSC21K1900.