Searching for Gravitational Wave Events with HALO, and Other Projects

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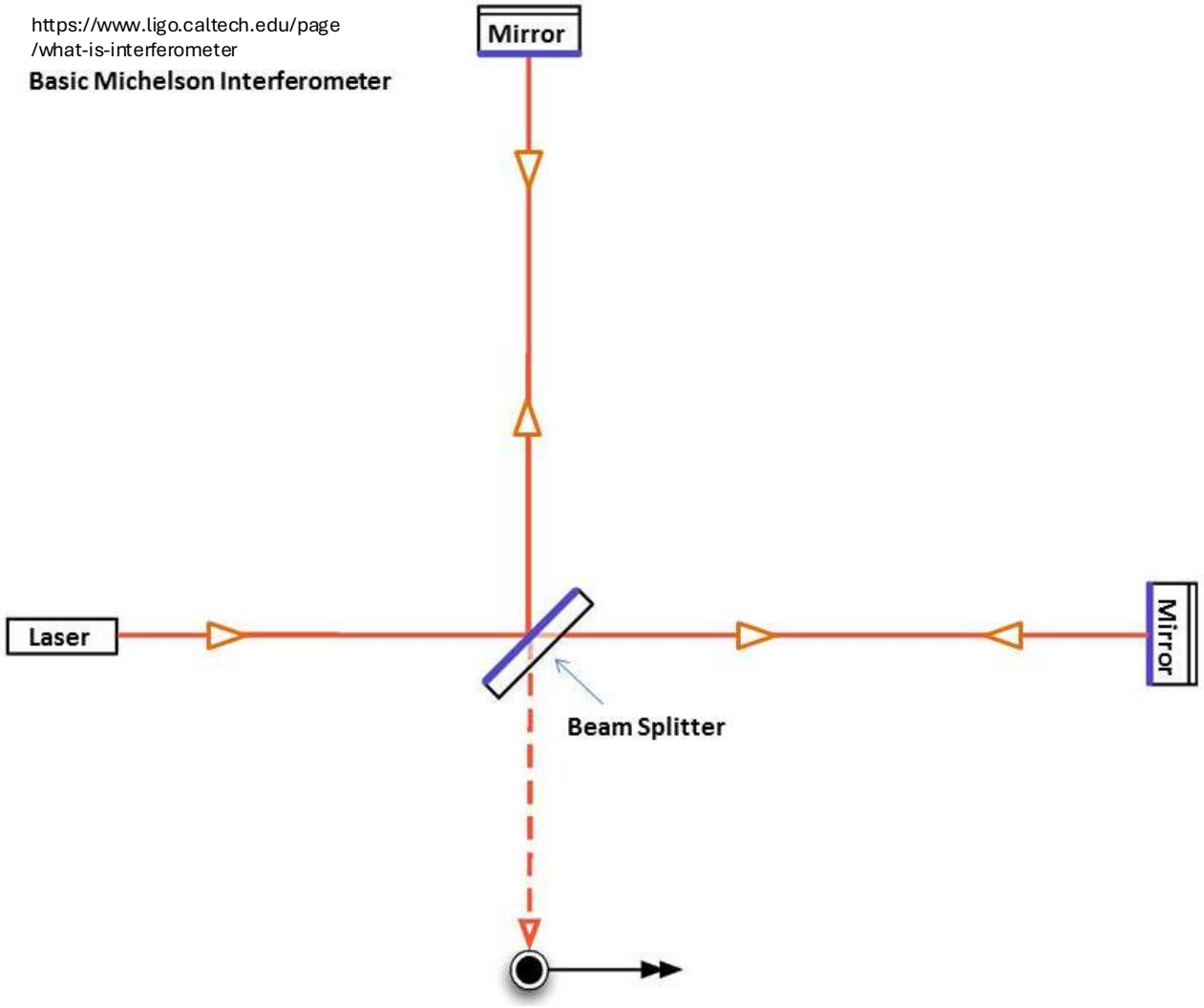
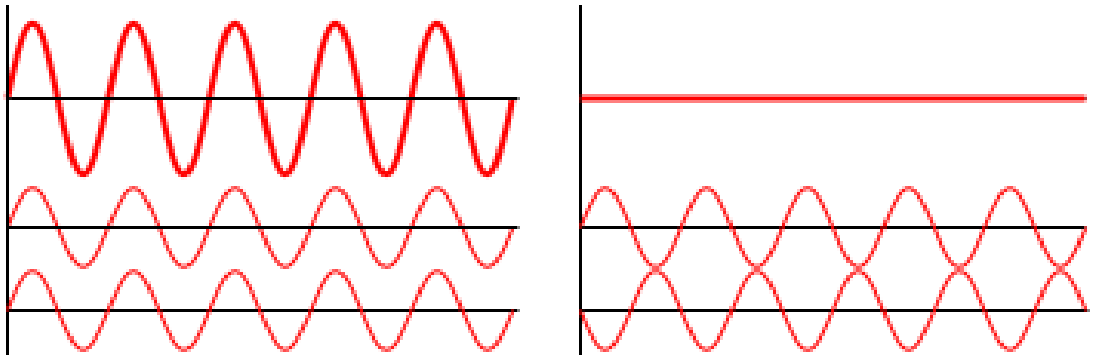
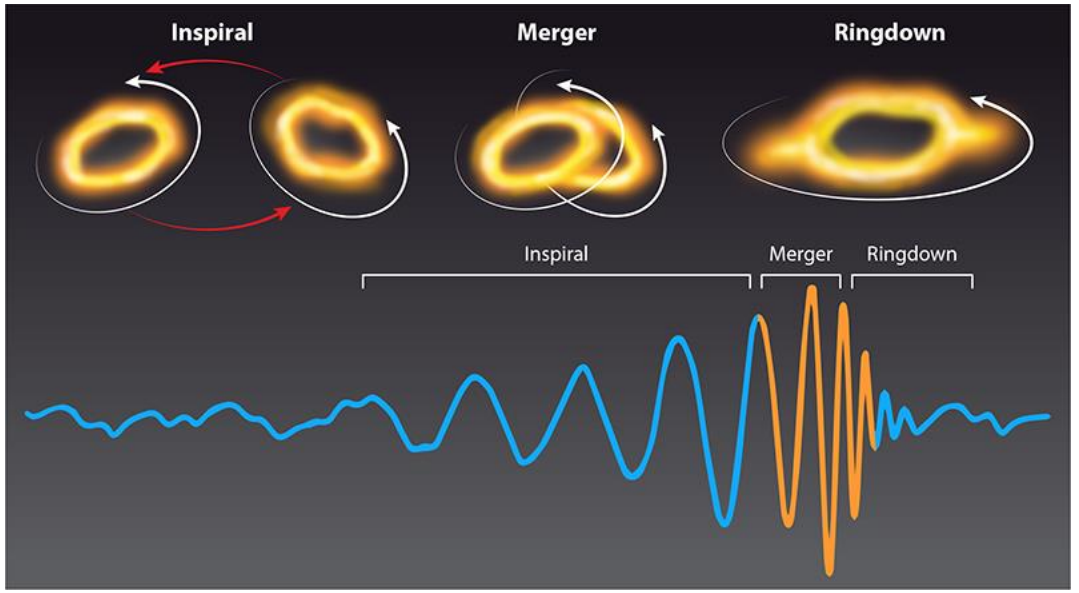
Gravitational Waves

https://www.ligo.caltech.edu/page/what-is-interferometer



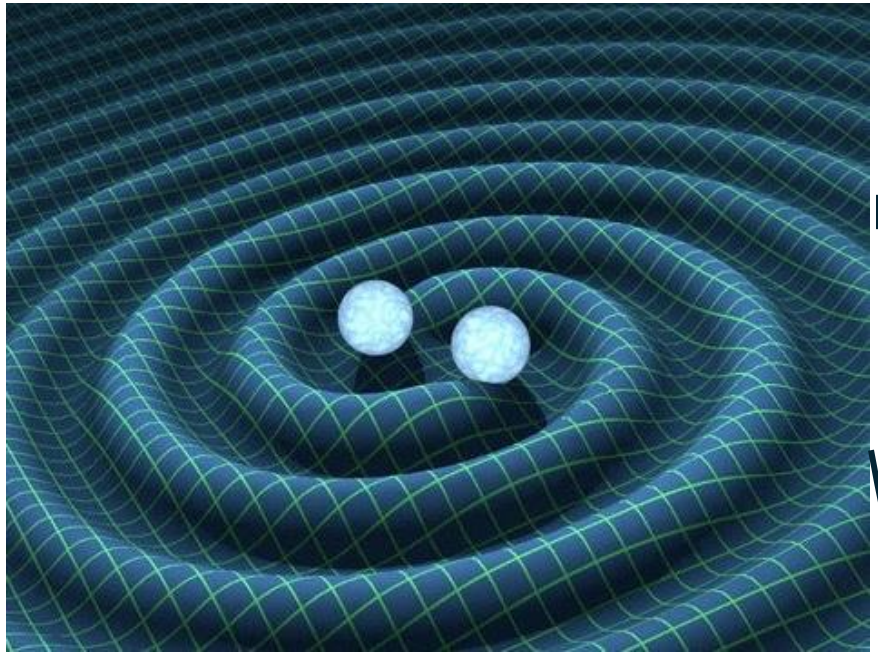


https://en.wikipedia.org/wiki/Wave_interference

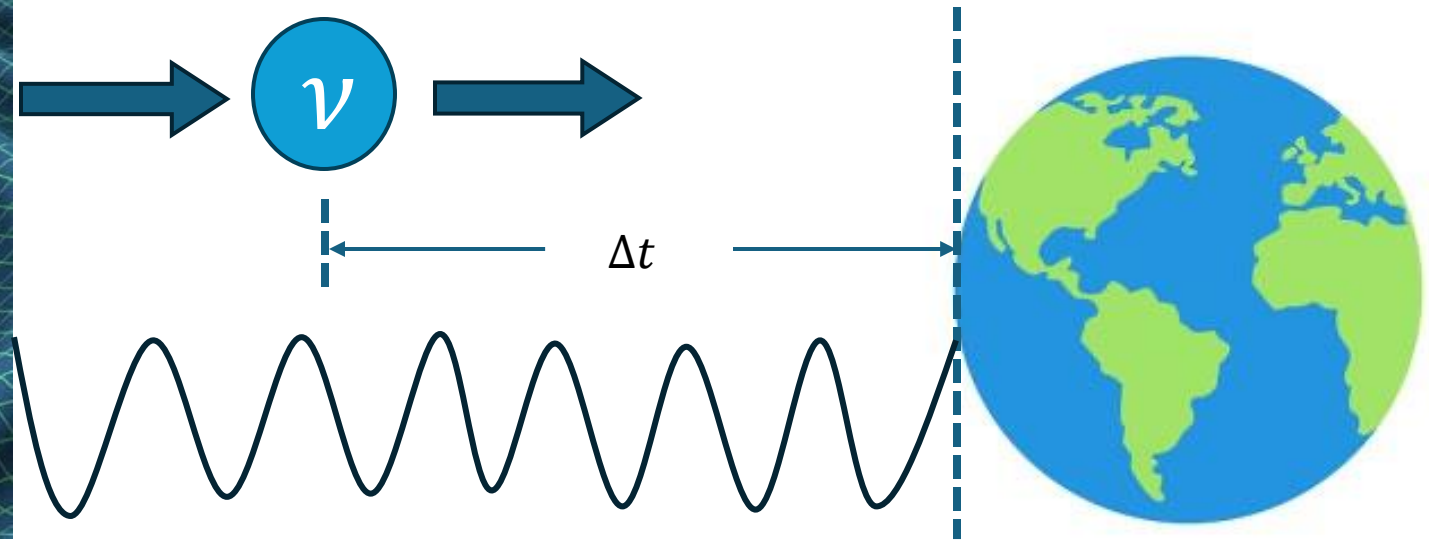


https://link.aps.org/doi/10.1103/Physics.16.29

Neutrino Signal Time Delay

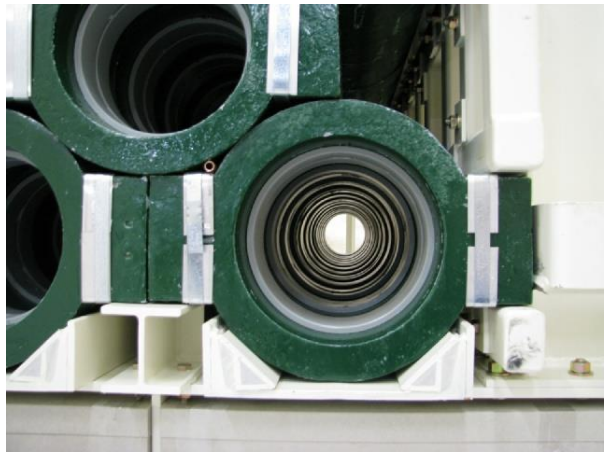


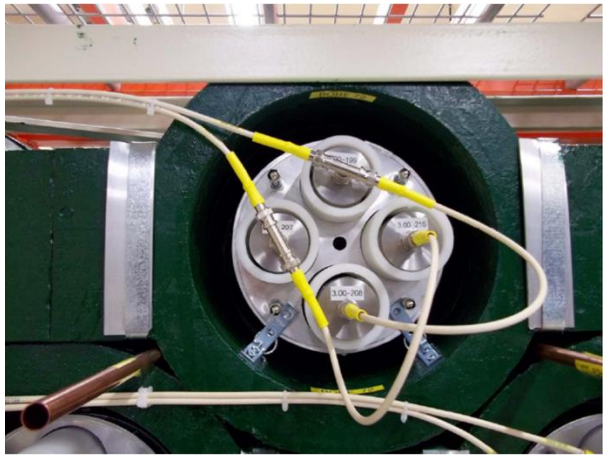
https://www.scientificamerican.com/article/gravitational-waves-discovered-from-colliding-black-holes1/



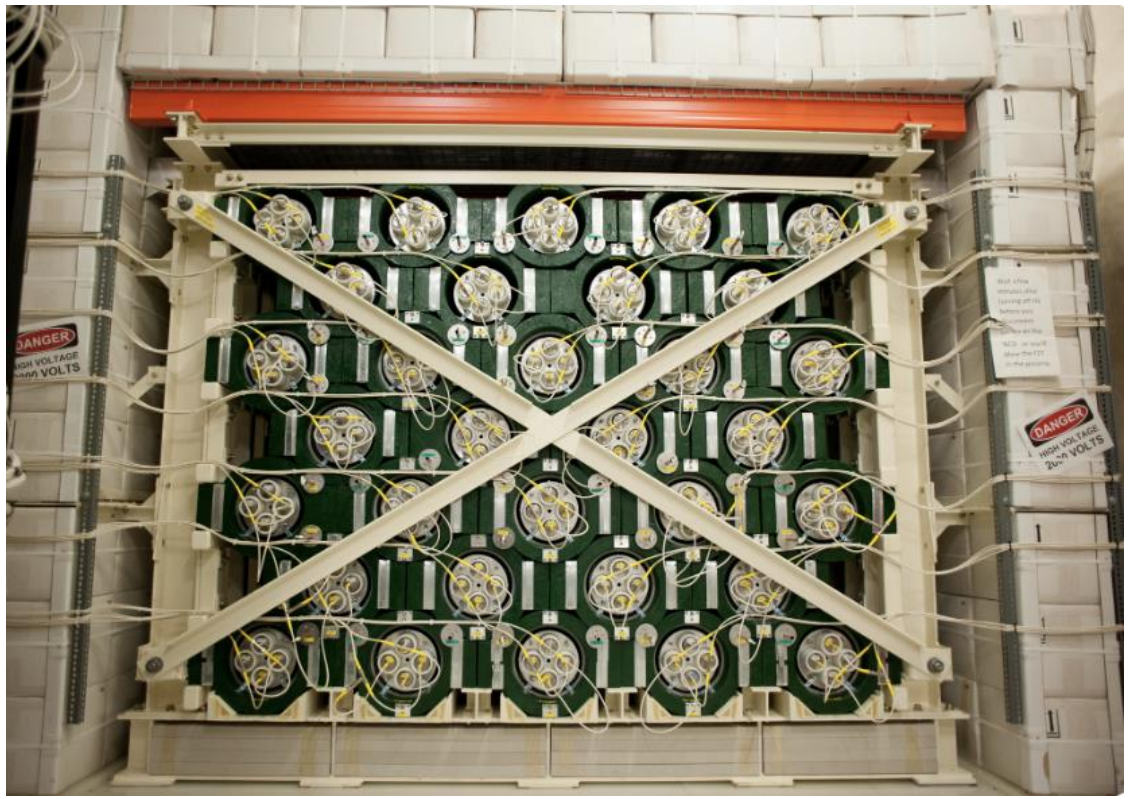
https://stock.adobe.com/search?k=cartoon+earth

HALO – Helium And Lead Observatory





https://www.snolab.ca/halo/gallery.html

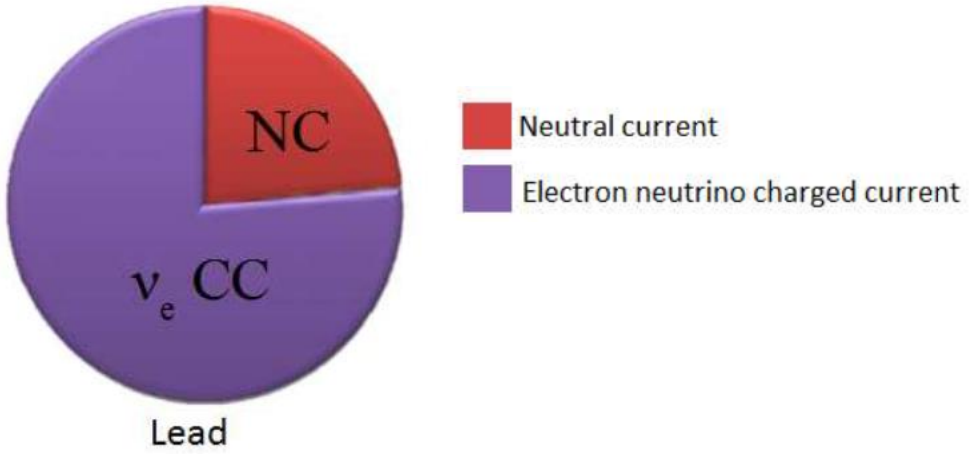


https://www.snolab.ca/experiment/halo/

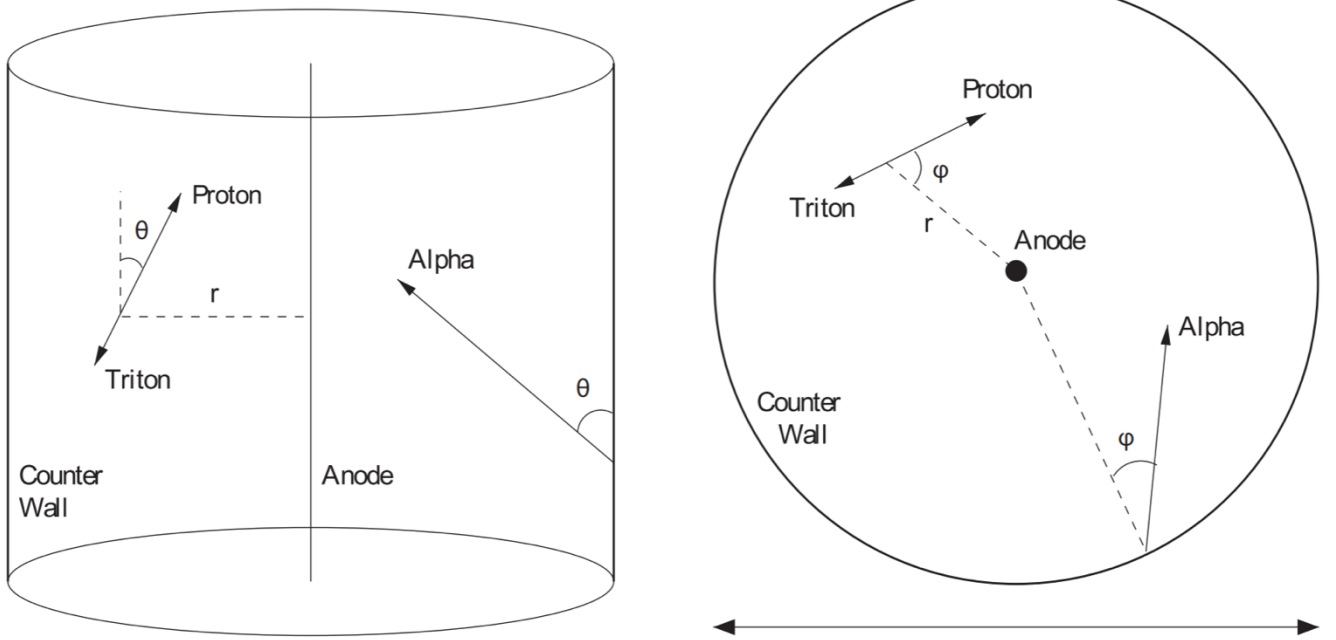
HALO Neutrino Detection

$$\nu_e + \mathrm{Pb} \rightarrow e^- + \mathrm{Bi}^*$$
$$\mathrm{Bi}^* \rightarrow \mathrm{Bi} + \gamma + \text{neutrons}$$

$$\nu_x + \mathrm{Pb} \rightarrow \nu_x + \mathrm{Pb}^*$$
$$\mathrm{Pb}^* \rightarrow \mathrm{Pb} + \gamma + \text{neutrons}$$



$$^3\mathrm{He} + \mathrm{n} \rightarrow \mathrm{p} + {}^3\mathrm{H} + 764\,\mathrm{keV}$$

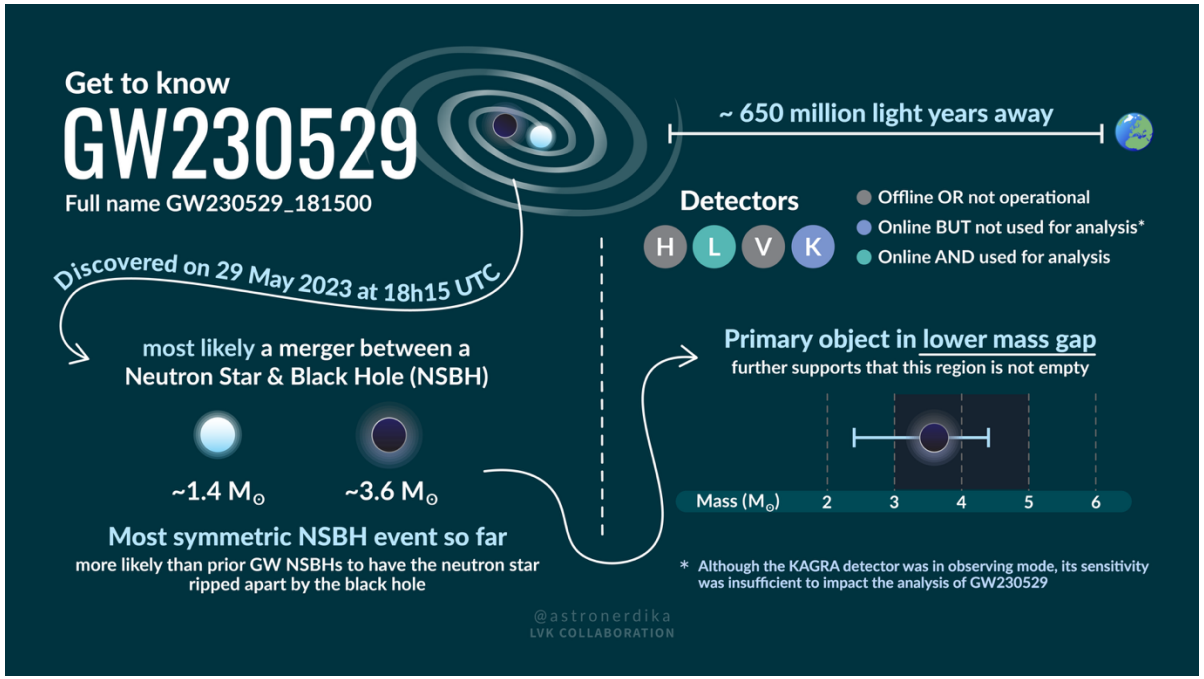


https://www.snolab.ca/experiment/halo/

Neutrino Signal Time Delay

Time window for neutrino signal: $[t_0, t_0 + \Delta t_{max}]$

$$d = 201 \pm 63 \text{ Mpc}$$



$$\Delta t_{max} = d_{max} * \left(\frac{1}{v} - \frac{1}{c}\right)$$

$$E^2 = (pc)^2 + (m_0 c^2)^2$$

$$p = mv = m_0 \gamma v$$

Parameters:

- $E = 10$ MeV
- *$m_0 \sim 0.45$ eV/c^2

$$d_{max} = 201 + 63 \text{ Mpc} \Rightarrow \Delta t_{max} = 24 \text{ s}$$

*KATRIN upper limit, April 2025
https://arxiv.org/pdf/2406.13516

Look for Neutron Burst Events in HALO

Time window for neutrino signal: $[t_0, t_0 + \Delta t_{max}]$

$t_0 = 2023\text{–}05\text{–}29\ 14{:}15{:}16\ \text{EDT}$ $\Delta t_{max} = 24\ \text{s}$

Coincidence	8644	Standard	3	2023-06-03 20:33:17 EDT
Spallation or SF	8641	Standard	3	2023-05-31 20:58:24 EDT
Spallation or SF	8641	Standard	3	2023-05-31 15:15:32 EDT
Spallation or SF	8640	Standard	3	2023-05-30 19:40:07 EDT
Spallation or SF	8639	Standard	3	2023-05-29 21:59:17 EDT
Other	8638	Standard	4	2023-05-29 10:49:50 EDT
Spallation or SF	8638	Standard	3	2023-05-28 21:52:35 EDT
Spallation or SF	8638	Standard	3	2023-05-28 18:10:46 EDT

Too late: $\Delta t_{max} > 7\ \text{hrs}$

Too early: $\Delta t_{max} \sim -3\ \text{hrs}$

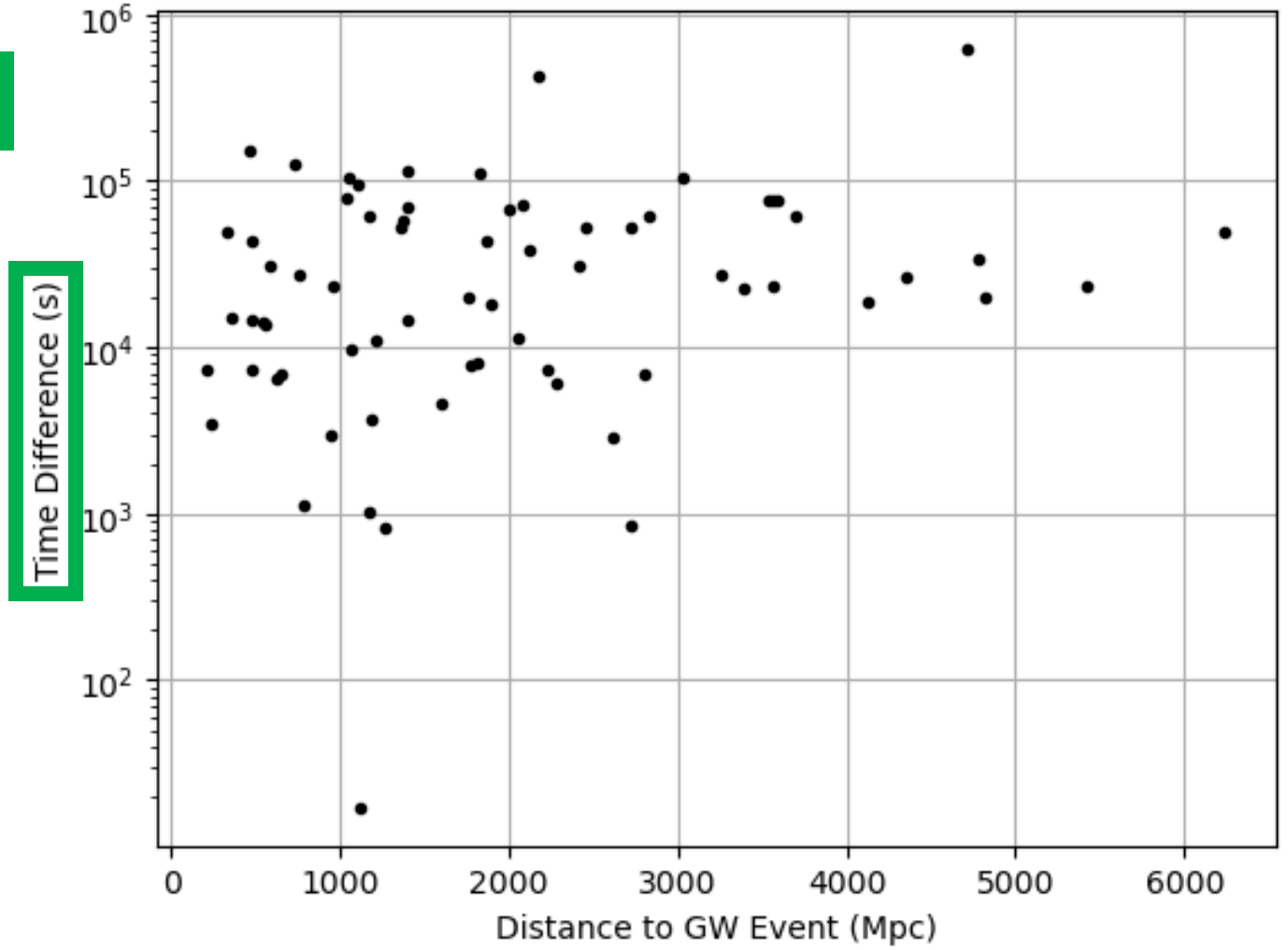
Neutron Bursts from Gravitational Wave Events

$$\text{Time Difference} = \Delta t_{real} - \Delta t_{estimate}$$

Δt_{real}: time delay between earliest detected burst in HALO

$\Delta t_{estimate} = d * \left(\frac{1}{v} - \frac{1}{c}\right)$: time delay estimate for neutrino from previous slide (E~10 MeV, m_0~0.45 eV/c^2)

No events from gravitational waves?



Do the Reverse: Estimate Neutrino Mass from Data

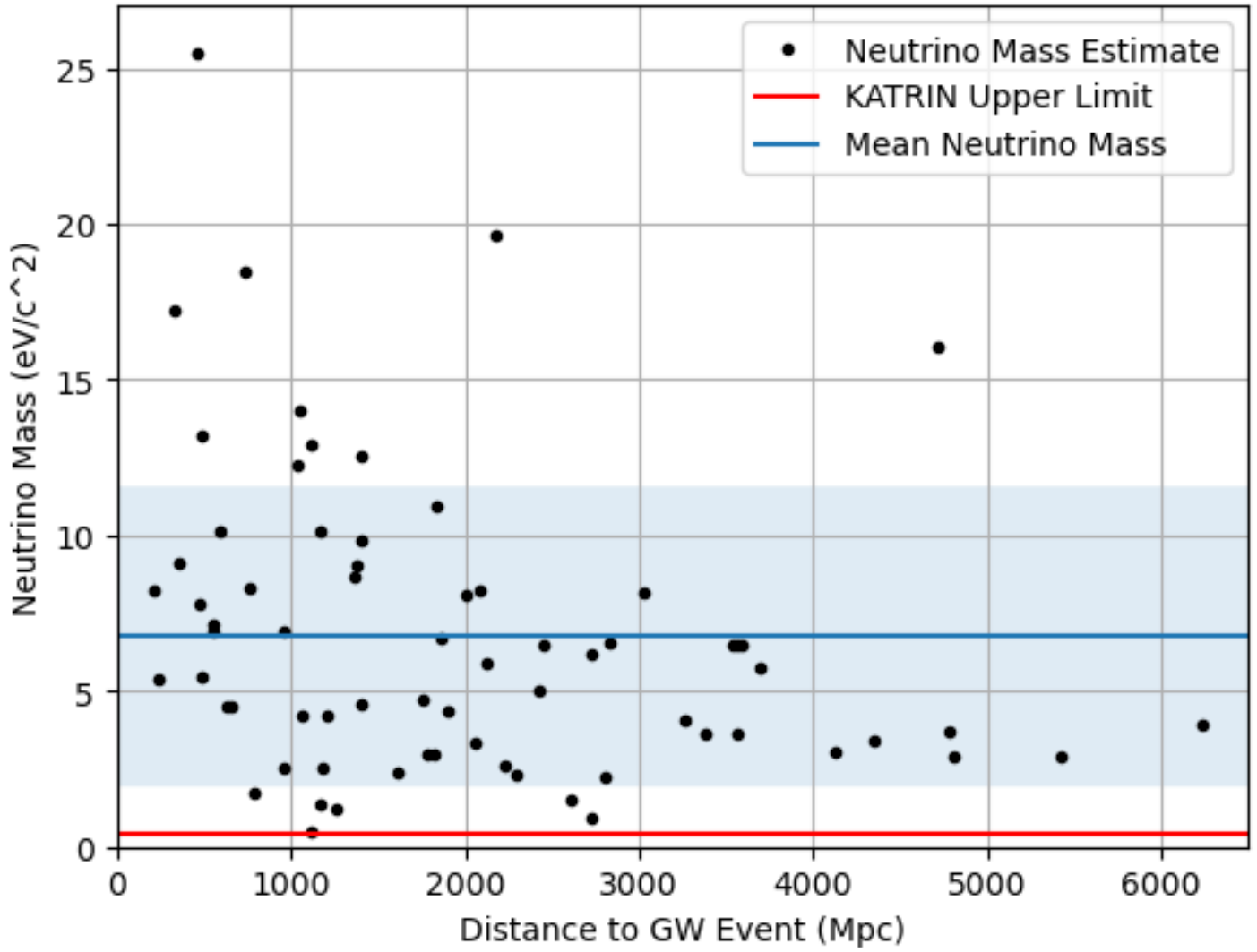
$\mathbf{\Delta t_{real}}$: time delay between earliest detected burst in HALO

$$\Delta t = d * \left(\frac{1}{v} - \frac{1}{c}\right)$$

$$\mathbf{E}^2 = (pc)^2 + (m_0 c^2)^2$$

$$p = mv = \mathbf{m_0}\gamma v$$

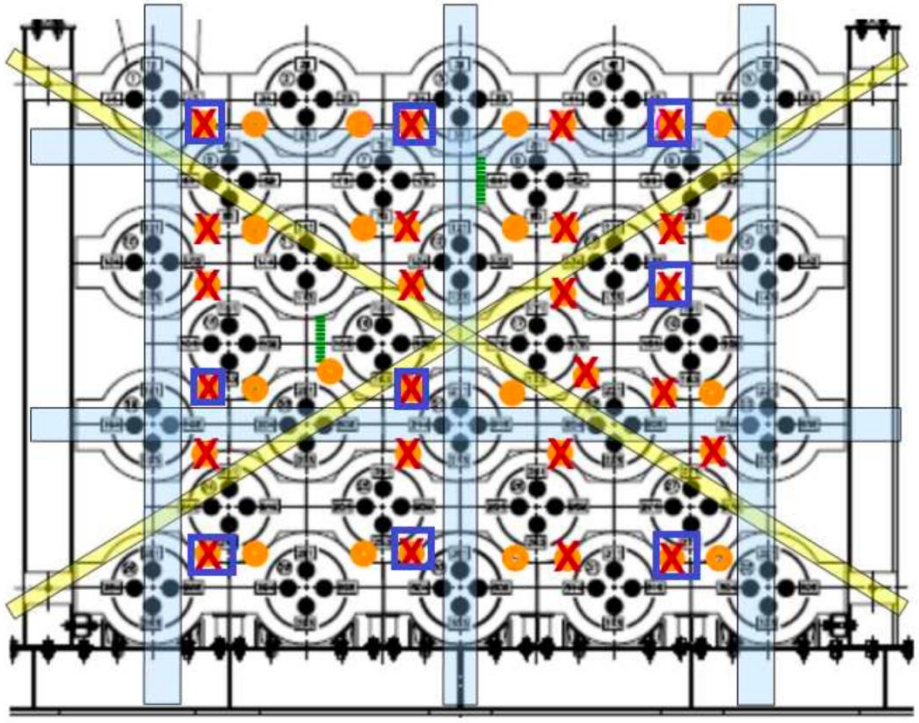
No gravitational wave events?

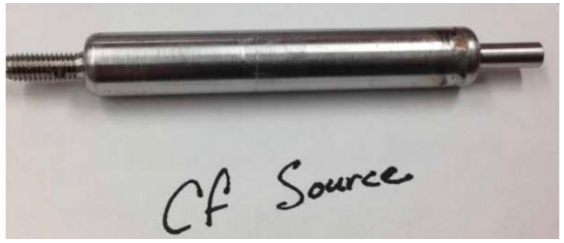


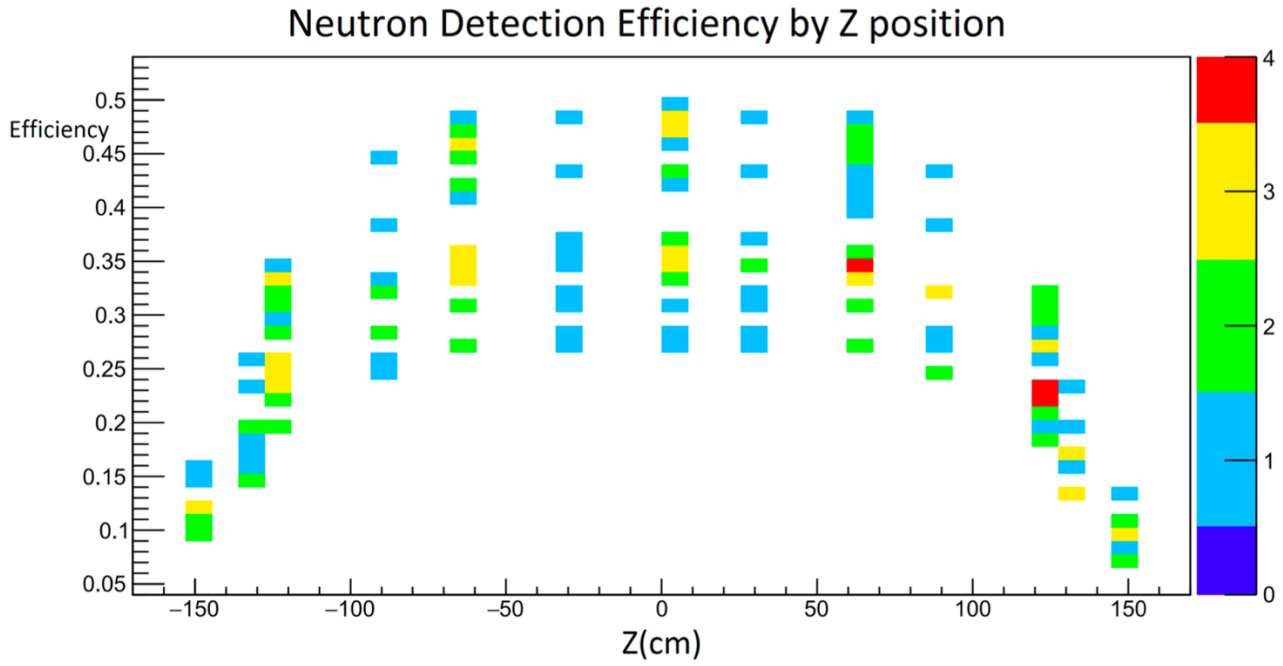
Credits: Colin Bruulsema

HALO Detection Efficiency

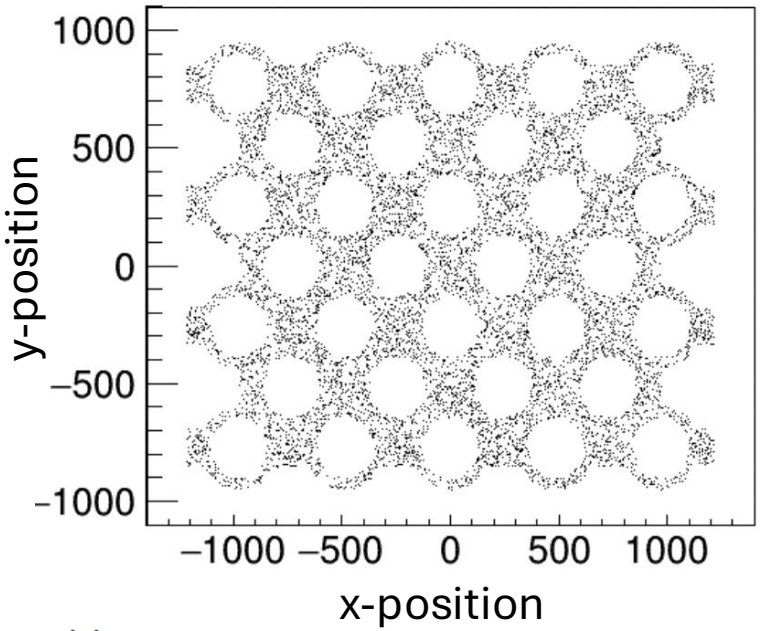
tubes that are not accessable through the shielding
tubes where 5 locations were sampled
tubes where 13 locations were sampled

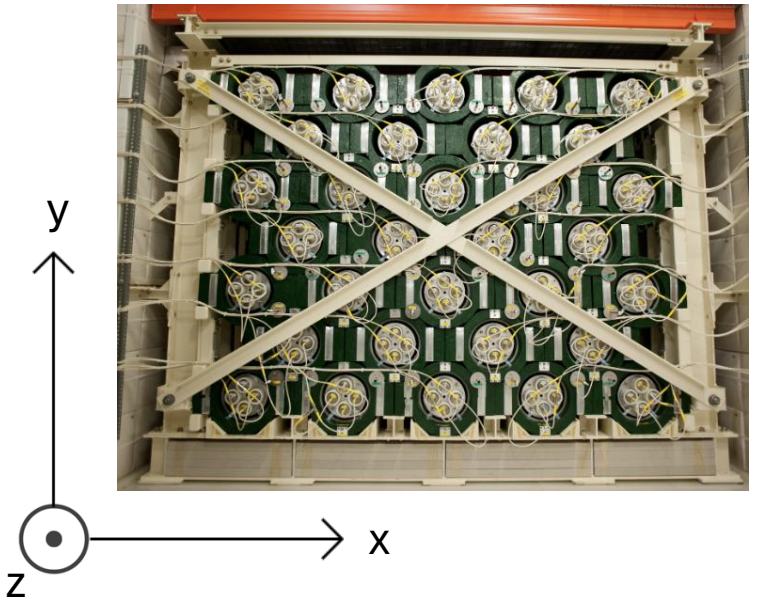


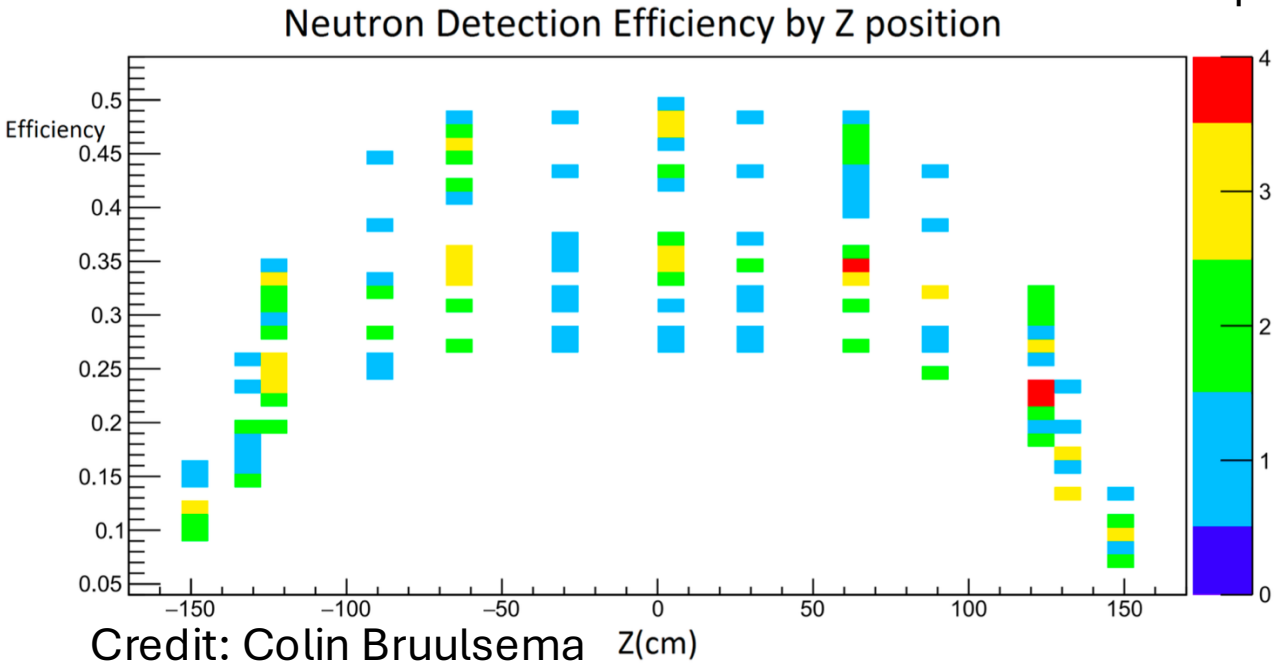




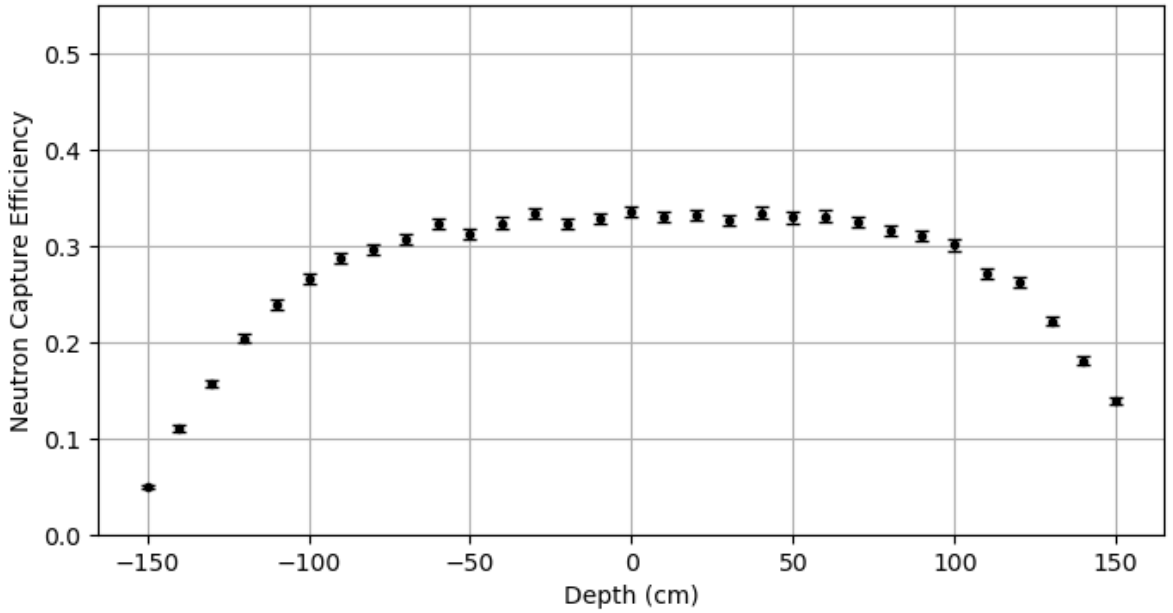
HALO Simulations: Efficiency vs. Detector Depth



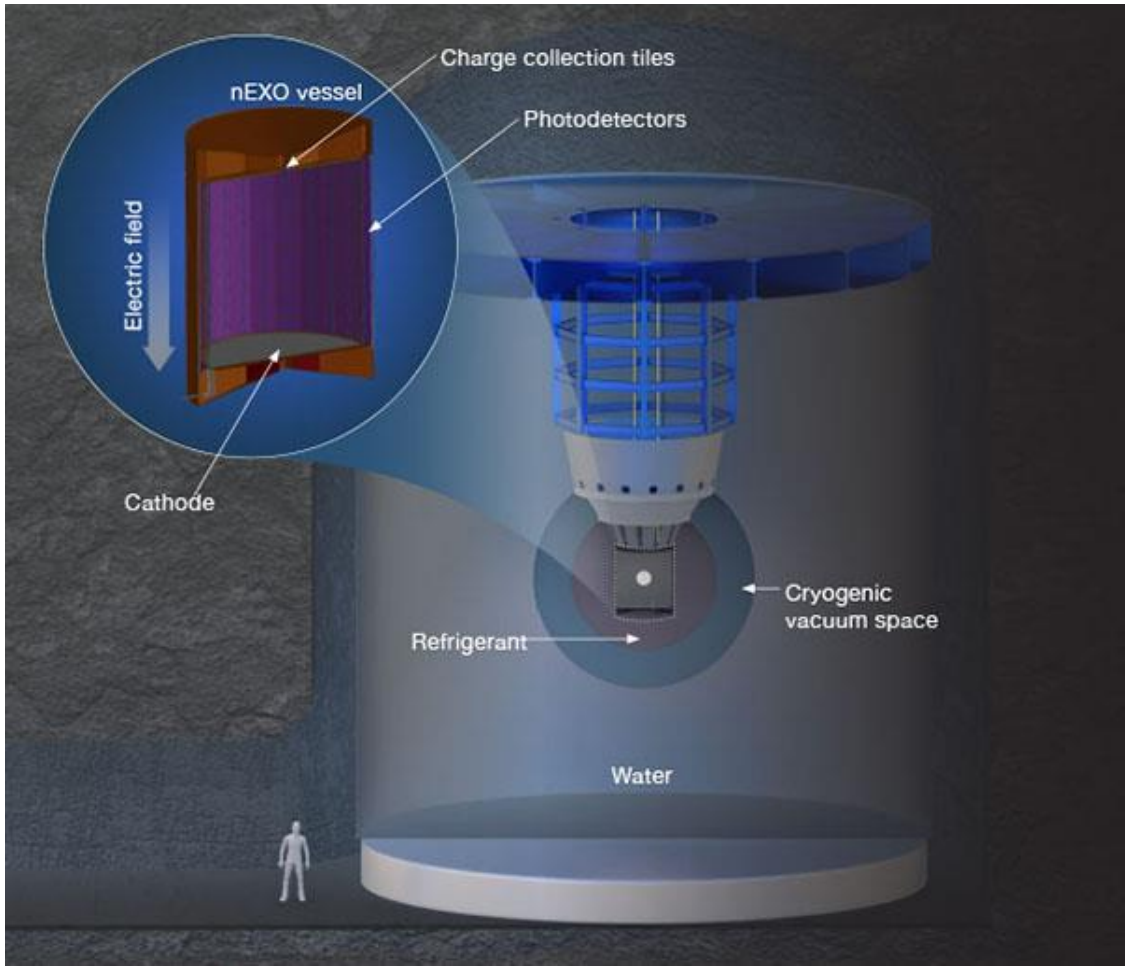




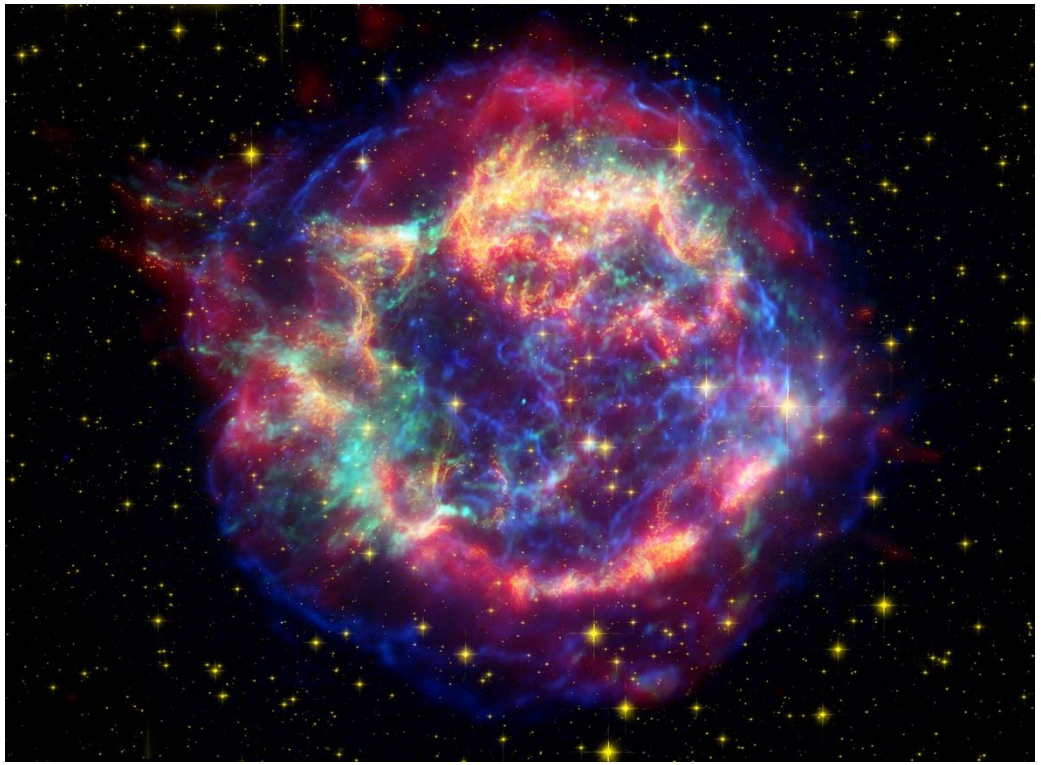
Credit: Colin Bruulsema



nEXO Simulations (Software Installation…)



https://nexo.llnl.gov/nexo-overview



https://www.scientificamerican.com/article/bizarre-supernova-defies-understanding/


Anyone across Canada can now install and run nEXO simulation software!
Hello,
The boot disk on the nearline cluster filled up with log files today. I have cleared some space, and will be doing further maintenance on Monday.
Thanks,
Tom

Thank you!

irina.nitu@mail.mcgill.ca

Appendix: Neutrino Velocity Estimate

$$E^2 = (\mathrm{pc})^2 + (\mathrm{m_0 c^2})^2$$

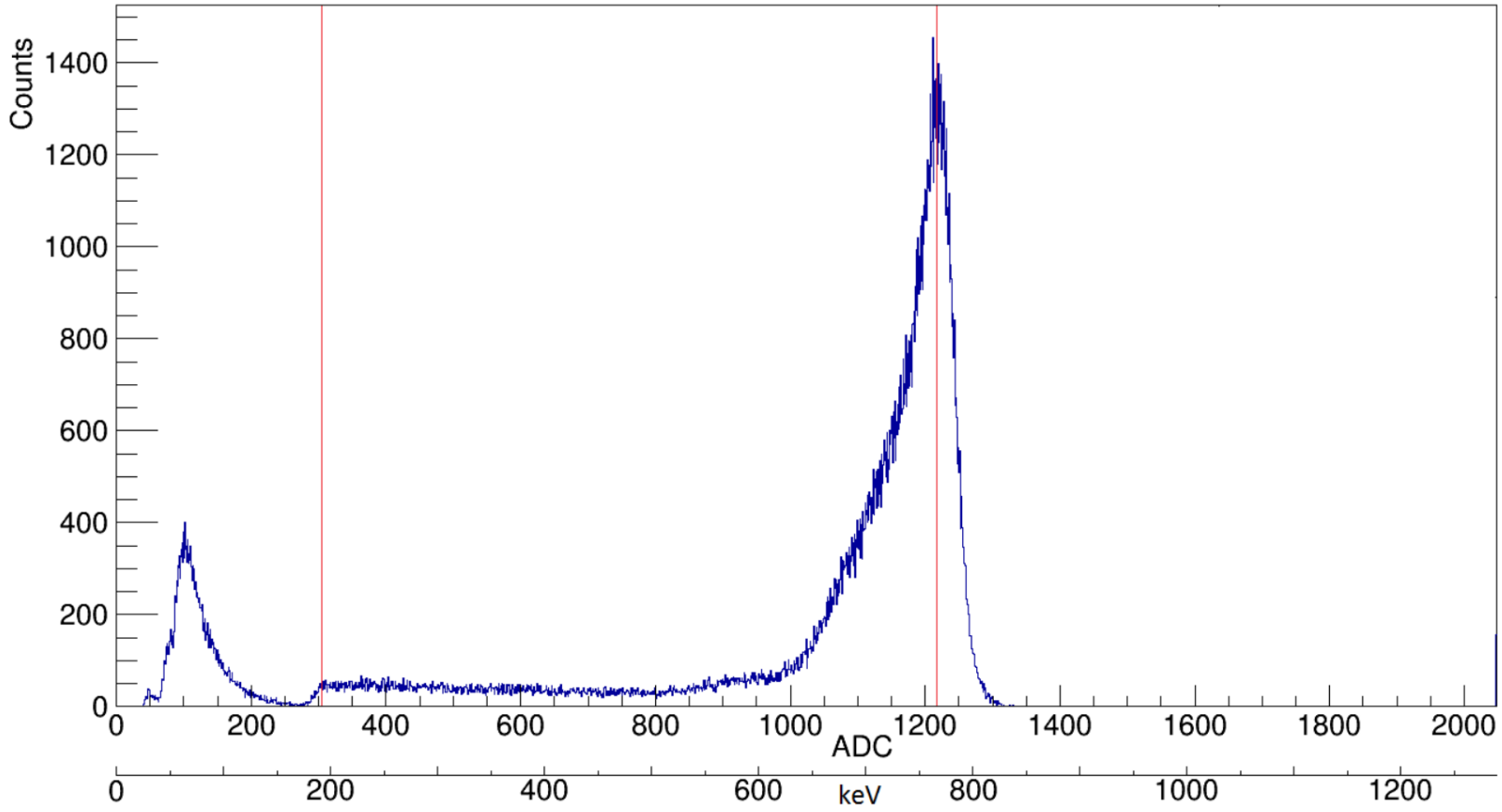
$$p = mv = m_0 \gamma v$$

$$E^2 = (m_0 \gamma v \mathrm{c})^2 + (\mathrm{m_0 c^2})^2$$

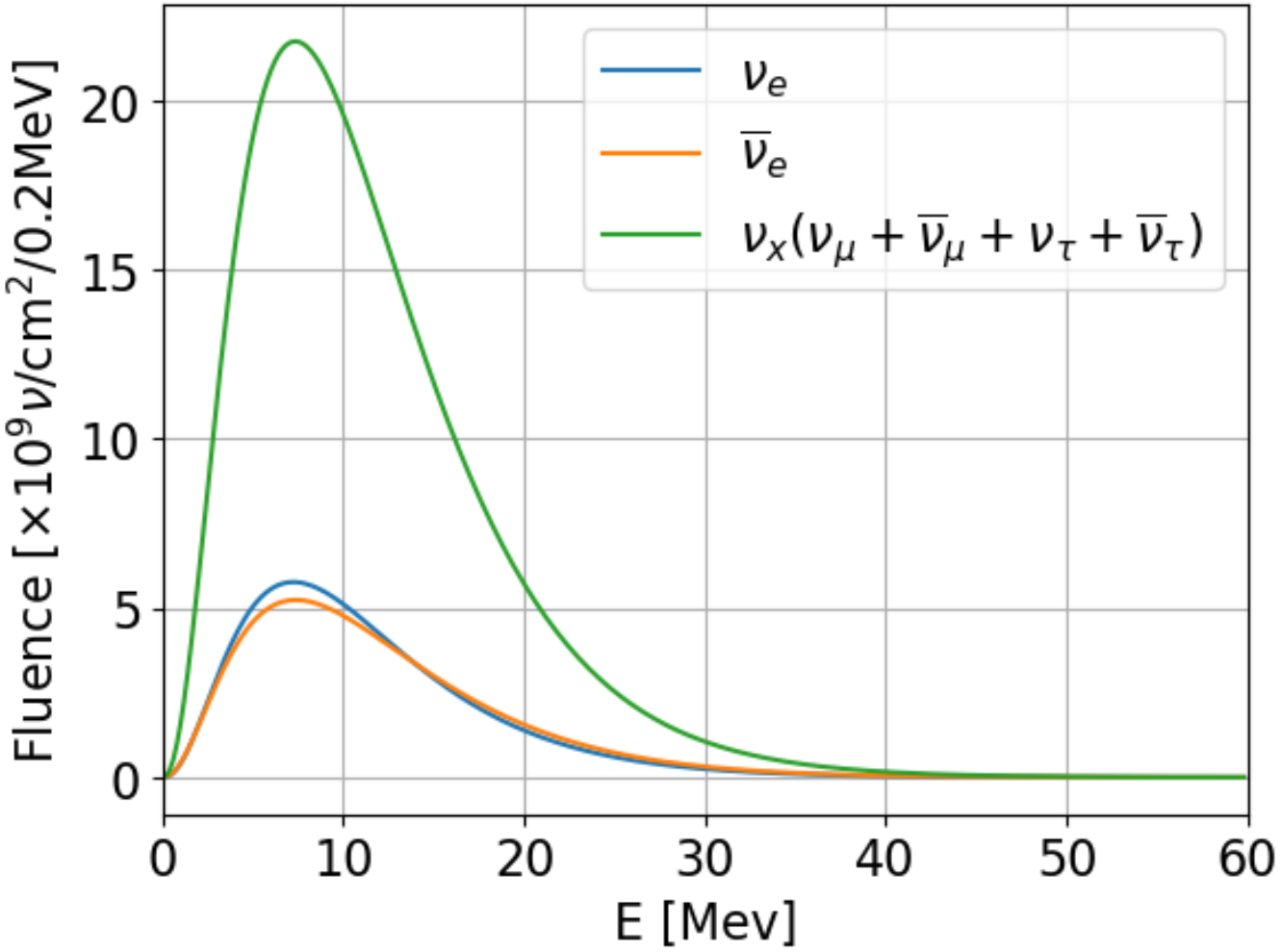
$$(v\gamma)^2 = \frac{E^2 - (m_0 c^2)^2}{(m_0 c)^2}$$

$$(v\gamma)^2 = \frac{v^2}{1 - v^2/c^2} = \frac{1}{\frac{1}{v^2} - \frac{1}{c^2}}$$

Appendix: Neutron Energy Deposition Spectrum



Appendix: Neutrino Spectrum



Appendix: HALO Simulations: Efficiency vs. Distance from Detector Center