Searching for Cosmic Ray Induced Noise at LHO

Benjamin Mannix

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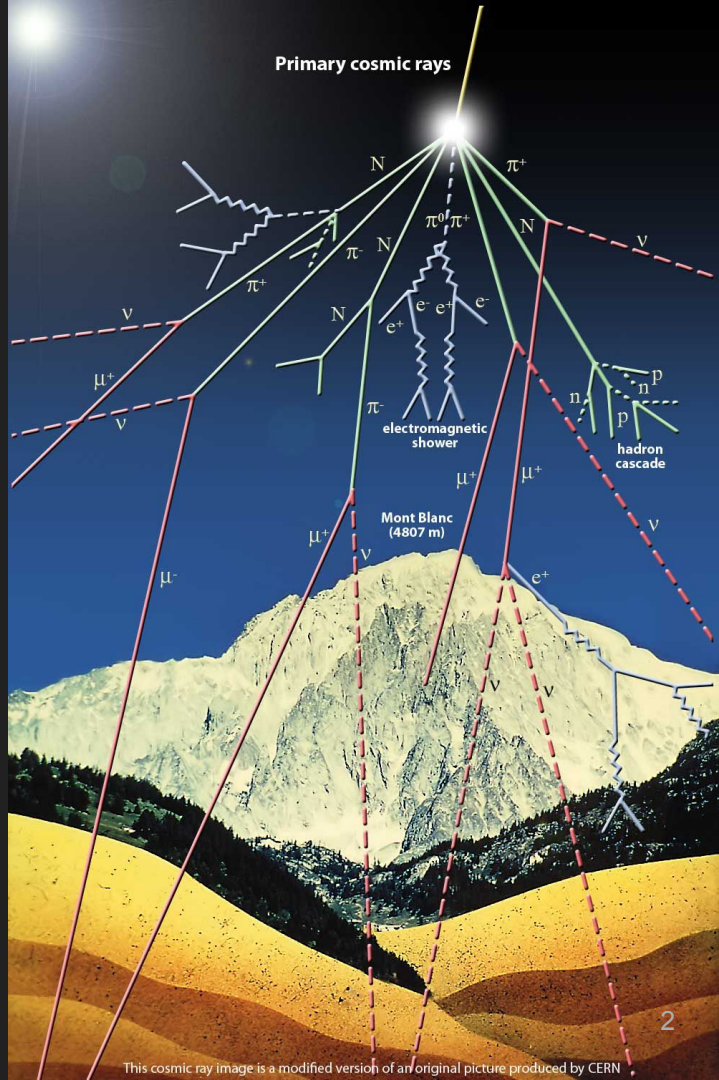
LIGO

UNIVERSITY OF OREGON

Cosmic Rays

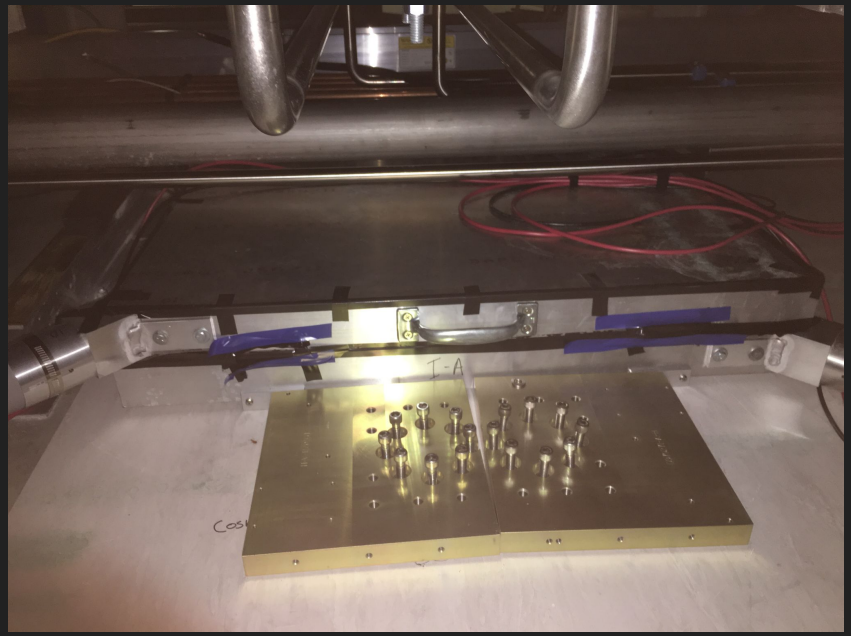
- Cosmic ray showers could potentially be a source of transient noise in LIGO detectors by:
  1. Transferring momentum to mirrors
  2. Heating the mirrors, creating vibrations
  3. Electromagnetic perturbation or depositing charge on the test mass

- We searched for effects of cosmic rays in LIGO Hanford data

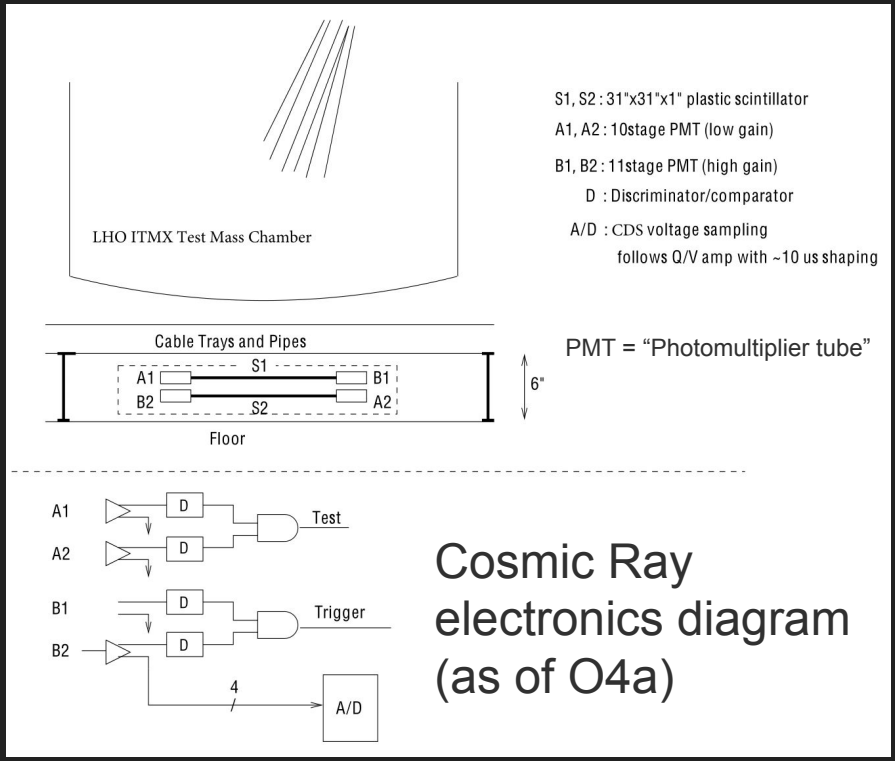


LHO Cosmic Ray Detector

Cosmic ray detector under LHO ITMX



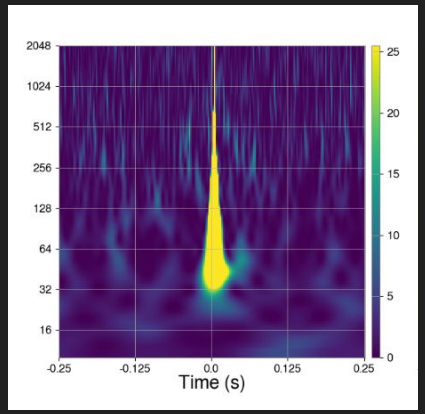
Detector Setup



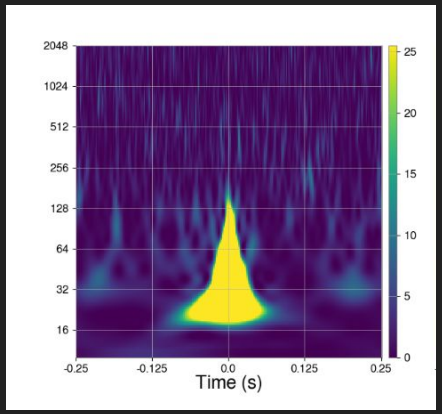
Glitches Considered

- Looking for something that could potentially be an effect of a cosmic ray shower impulse
- We consider glitches that are short in duration and of unknown origin (numbers correspond to amount reported from GravitySpy in Sept-Dec 2023):
  - Blips (661)
  - Low-Frequency Blips (330)
  - Repeating Blips (90)
  - Tomtes (1063)

Blip Glitch



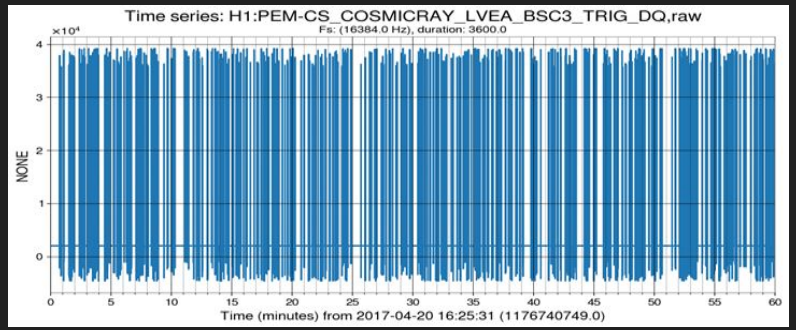
Tomte



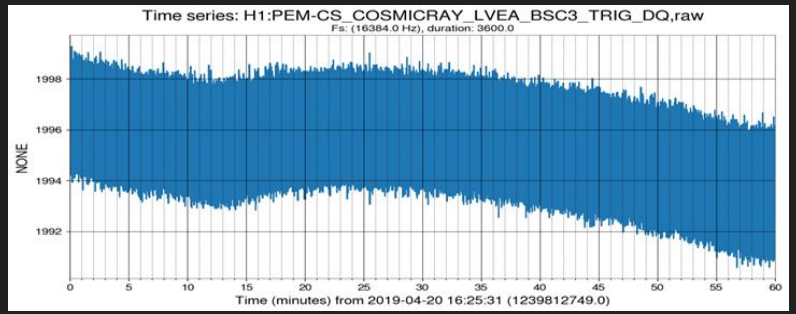
Previous Searches

- A search for correlations between blips and cosmic rays was done in O2 and O3. No connection was found.
- This search used data from the “cosmic ray trigger” channel but, cosmic ray rate dropped significantly from O2 to O3, likely due to an electronics issue

Cosmic Ray triggers in 1 hr of O2 data



No triggers in 1 hr of O3 data

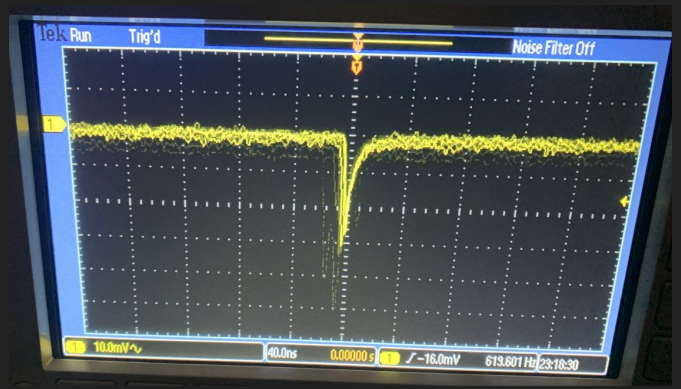


See DCC: LIGO-T2000261 or DOI 10.1088/1361-6382/abfd85

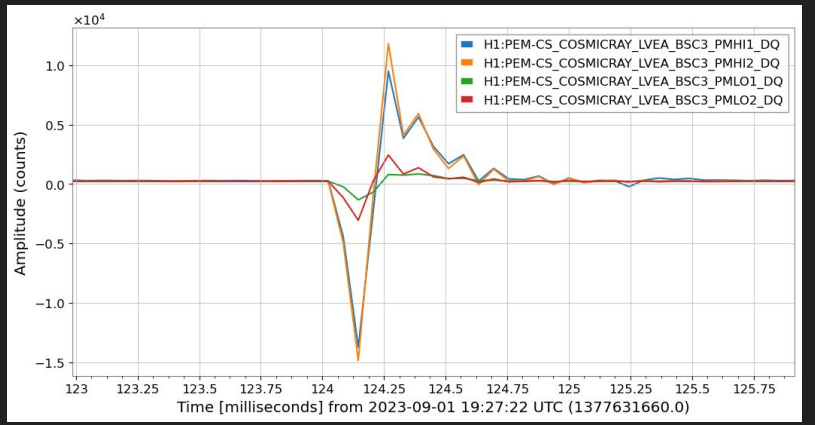
Electronics Upgrade

- The sampling needed to capture cosmic ray information is ~ MHz but LIGO data system is limited at ~16 kHz. Solved with voltage integrator scheme
- Now each photomultiplier tube has its own channel, giving both amplitude and timing information of cosmic ray events (alog)

PMT in oscilloscope on nanosecond timescale

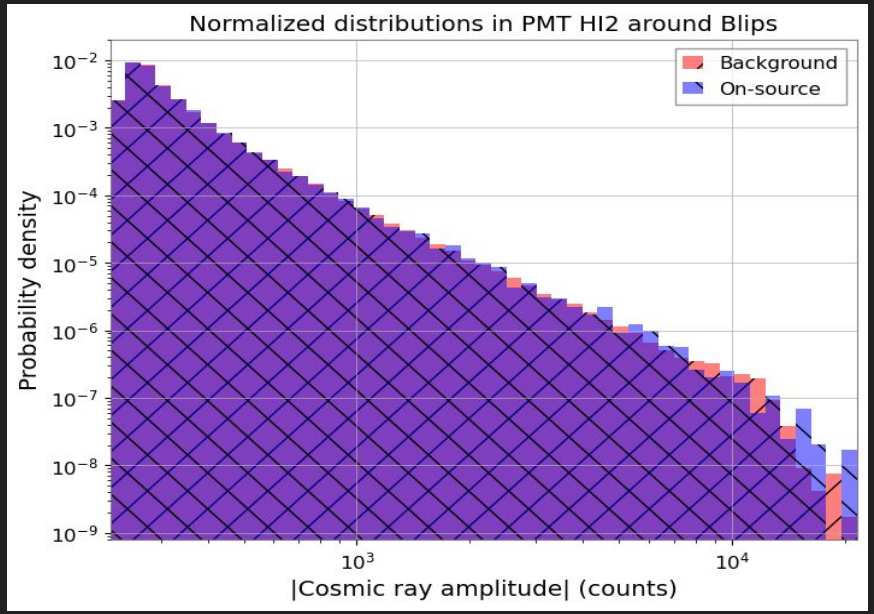


PMT channels on millisecond timescale



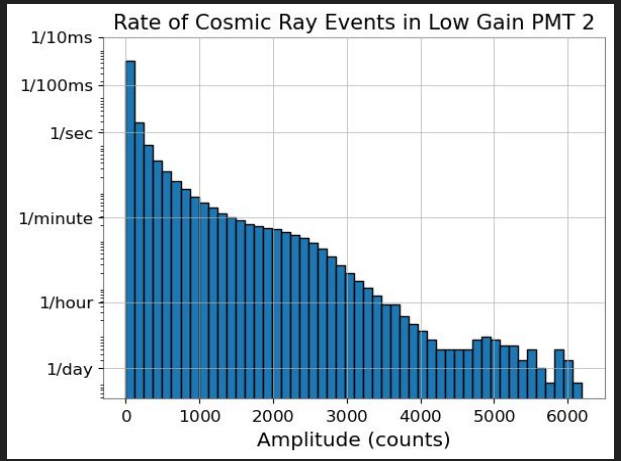
O4a results: Cosmic Ray Amplitude Near Glitches

- Look at amplitude of cosmic ray events within ±1 second of glitch (on-source)
- For every glitch, take 20 seconds of cosmic ray amplitudes far away from glitches (Background)
- If cosmic ray showers were the source, we might expect to see more higher amplitude events in on-source
- Overlaying these normalized distributions, we see no significant difference

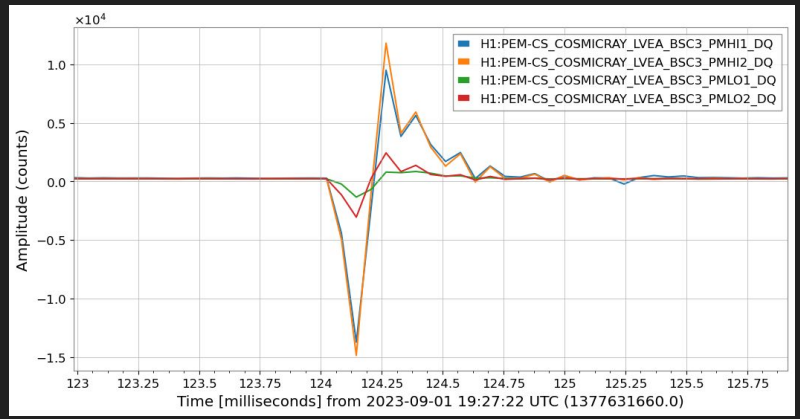


O4a results: temporal relation between cosmic rays and glitches

- We look at trends in cosmic ray data over a month to set some amplitude threshold (top 10% of of m-trend minimum events)
- We then require the event to be seen in multiple PMTs. This gives 1834 cosmic ray showers in the month
- This gives a set of the highest energy cosmic ray showers to compare to glitch times

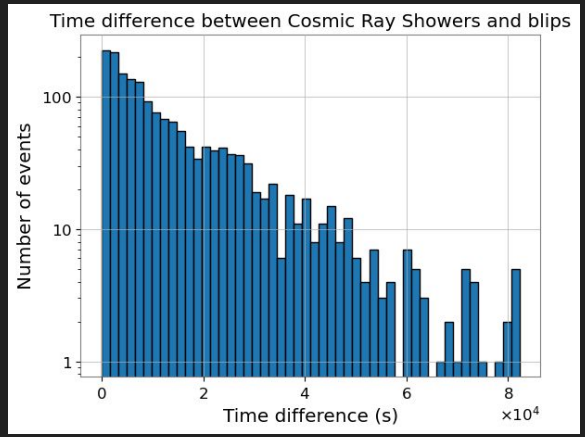


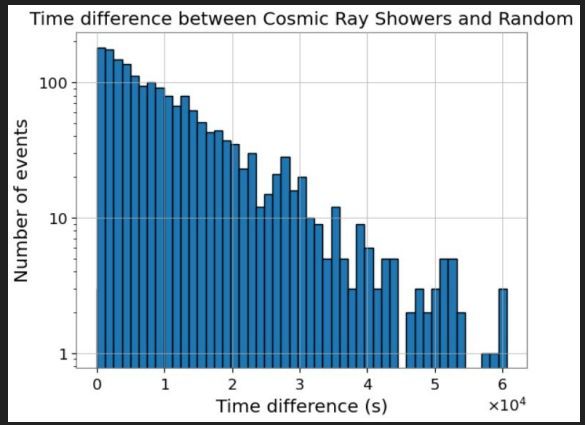
Coincident cosmic ray event in multiple PMTs



O4a results: Temporal Correlation Between Cosmic Rays and Glitches

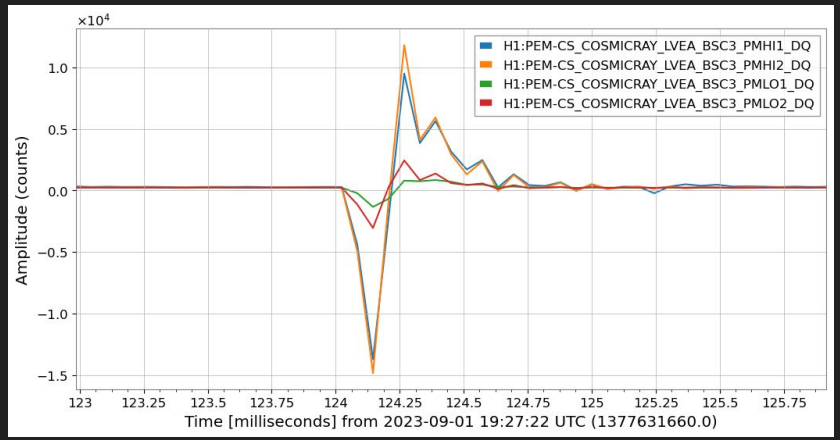
- In case there is some sort of delay between cosmic rays and reaction, we investigate a temporal correlation
- Take time difference between large cosmic ray events and next-nearest glitch in time
- Compare to the time difference between cosmic ray showers and random times
- No correlation was found here





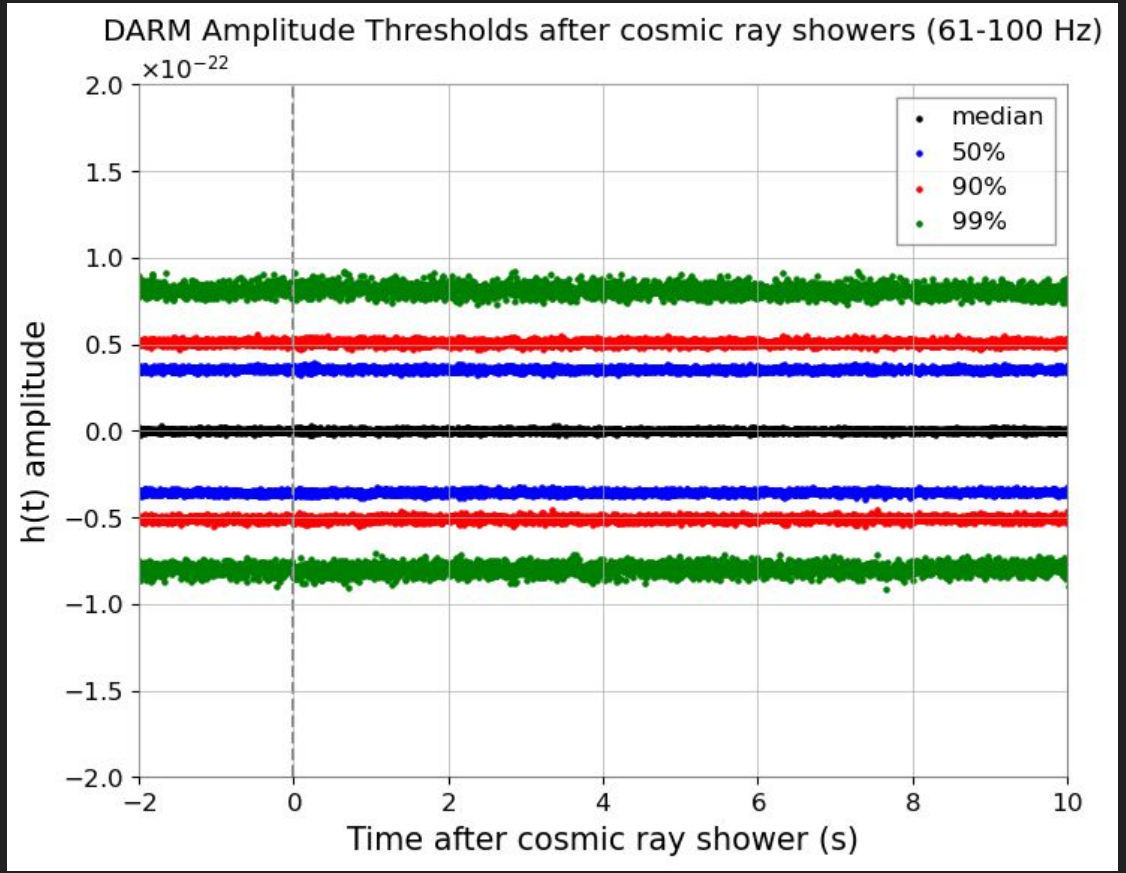
Looking at DARM

- Looking at large cosmic ray showers during observing time, can we see an impact in DARM (our gravitational wave channel)?
- Use cosmic rays as triggers to study the statistical behavior of DARM before and after a shower passes through



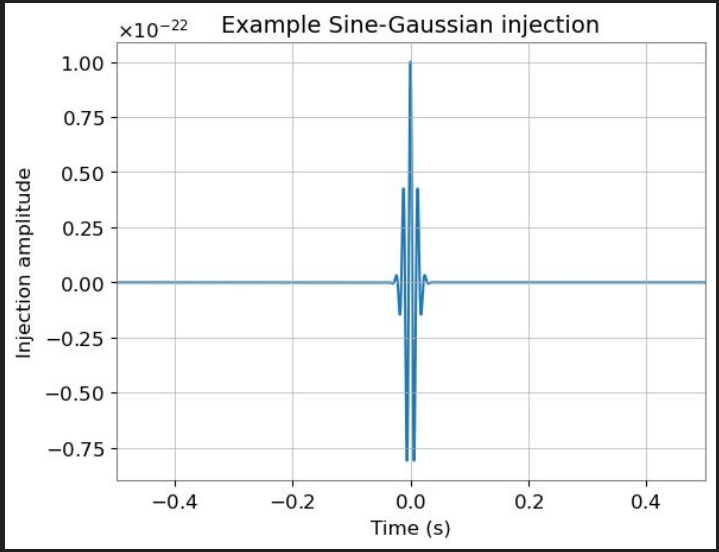
Looking at DARM

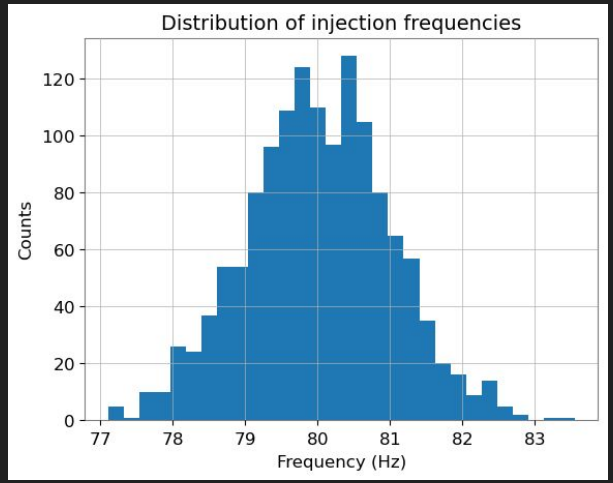
- Combine DARM time series from 1375 loudest cosmic ray showers
- DARM noise should follow Gaussian noise
- At every point in time measure what amplitude contains X% of values
- If an effect is consistently present, you might expect this curve to widen

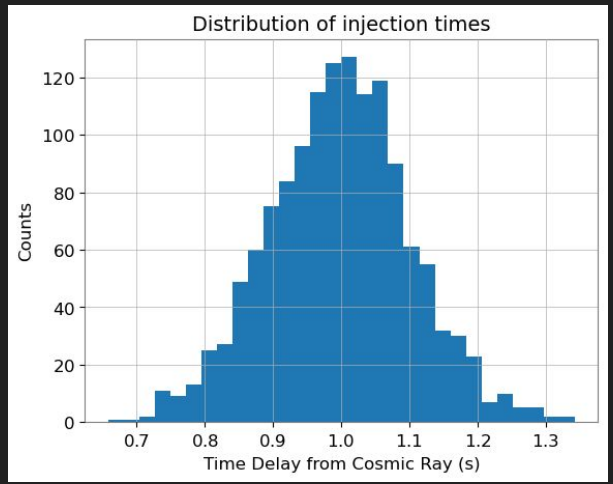


Injected Signal Test

- As a test of this method, inject a sine-gaussian pulse into each time series of varying frequencies and at varying times

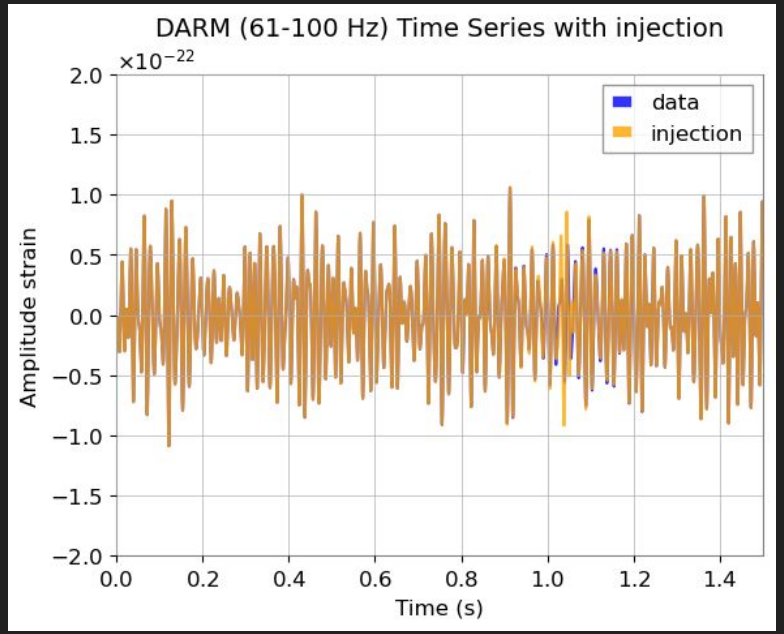


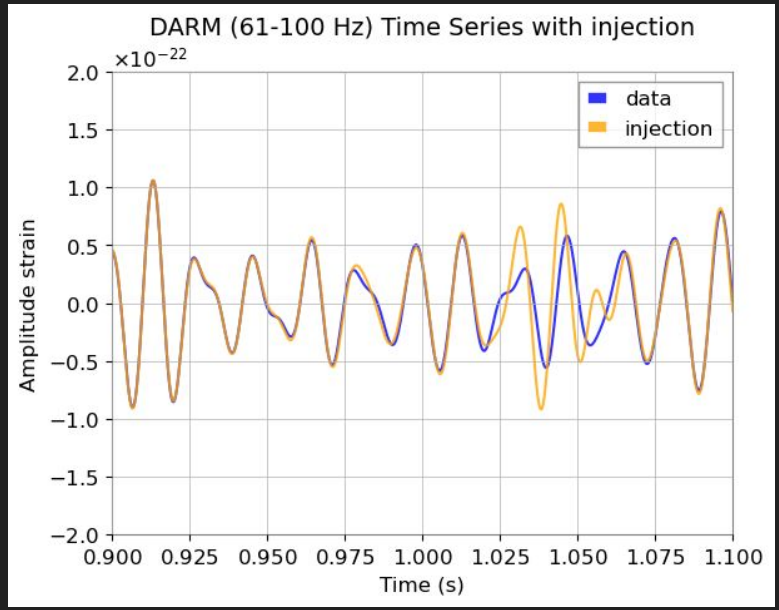




Injected Signal Test

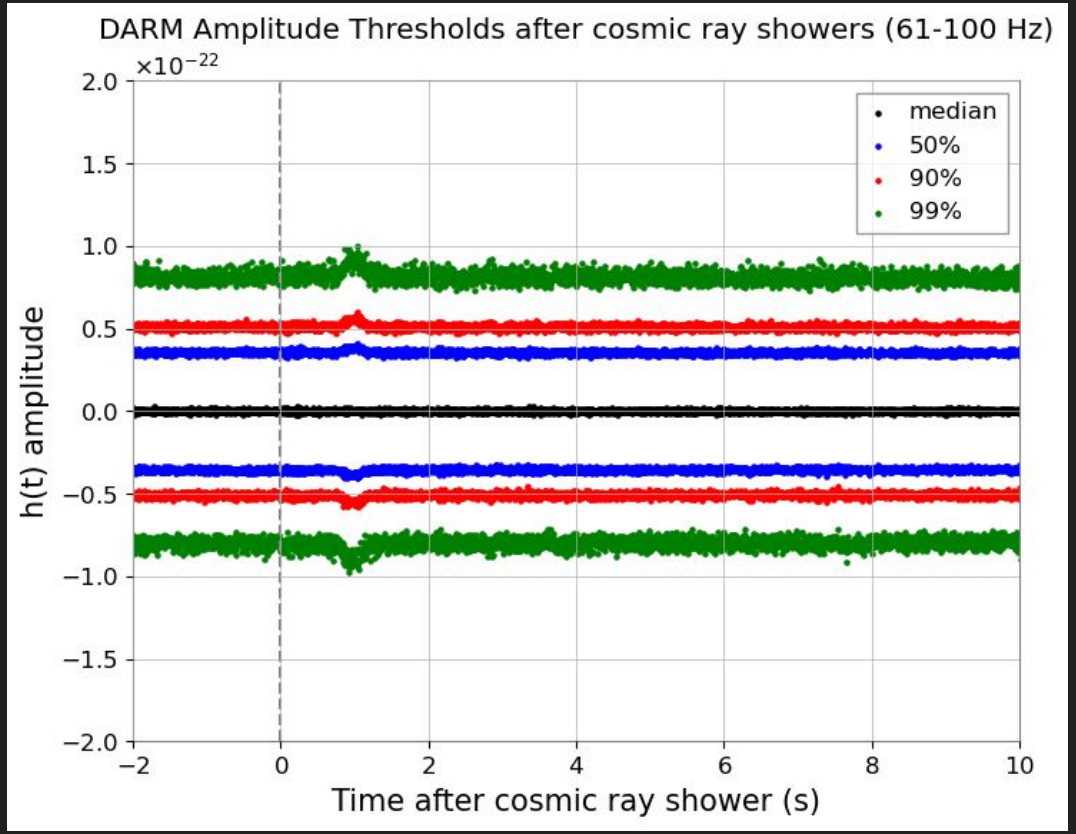
- Example Time Series with an injection (f = 78.6 Hz, t = 1.04 s)





Injected Signal Test

- Over a large number of time series with a signal present, we start to see an effect emerge around 1 second



Conclusions and Future Work

- Seeing no connection between cosmic ray showers and blips/tomtes
- Seeing no effect in DARM so far. (Analysis still underway)
- Given our current sensitivity, we would like to say whether or not this will be a problem for third generation detectors