ANALYZING A NOVEL CLASS OF INSTRUMENTAL BACKGROUND EVENTS IN THE SNO+ DETECTOR

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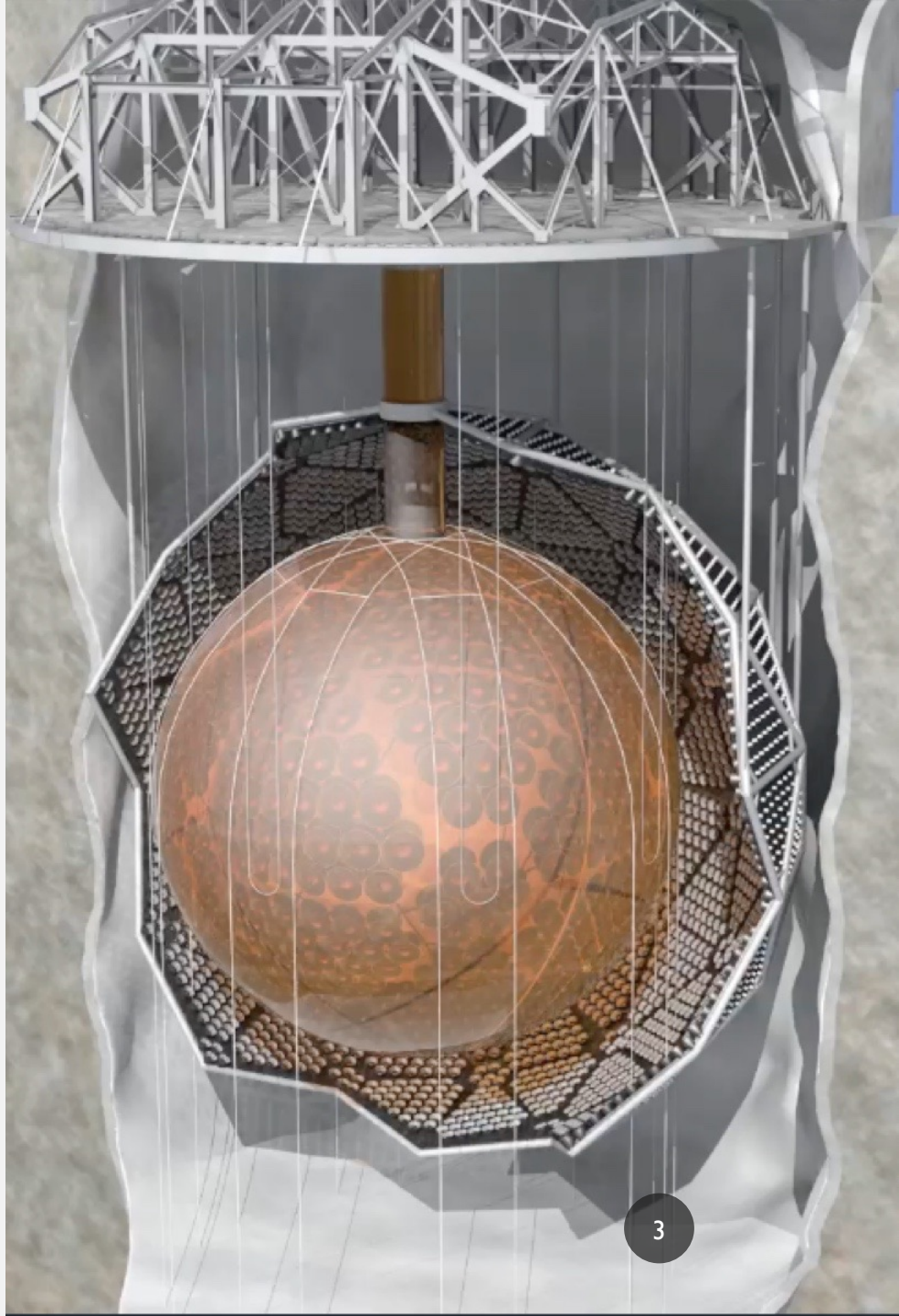
THE SNO+ EXPERIMENT

- Successor of the Nobel Prize winning SNO experiment
- Located 2km underground at SNOLAB
- Multipurpose detector, focuses on neutrino interactions
  - Primary goal of detecting $0\nu\beta\beta$ decay but also
    - Low energy solar neutrinos
    - Reactor neutrinos
    - Geo-neutrinos
    - Supernova neutrinos
    - Invisible nucleon decay

THE DETECTOR

- 12m diameter acrylic sphere
- Filled with 780 tonnes of liquid scintillator
  - Produces light when a charged particle passes through it
- Surrounded by array of nearly 10000 photomultiplier tubes (PMTs)
  - Detects the light from the scintillator
- Structure is suspended in 30m tall cavity filled with ultra-pure water

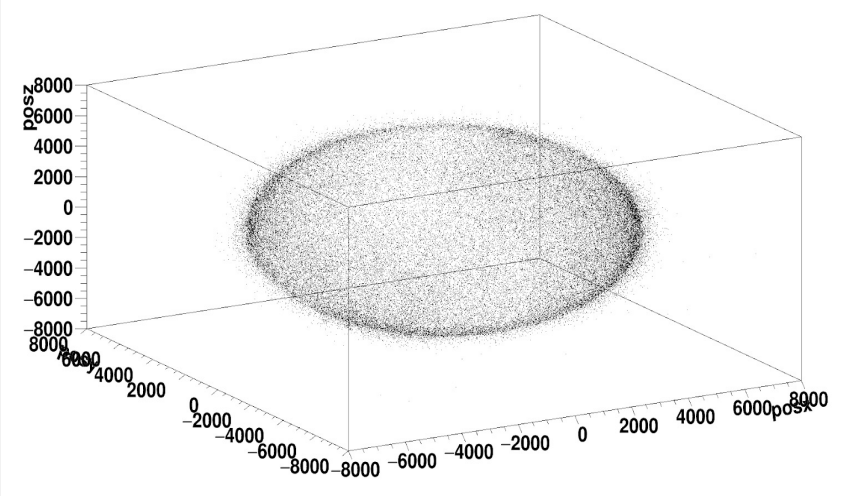


BACKGROUND ANALYSIS

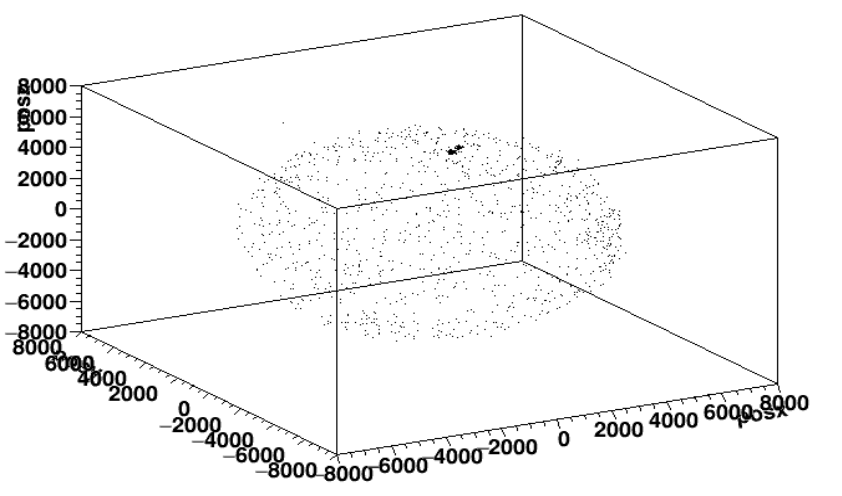
- To study neutrino interactions, it is crucial to achieve minimal, well understood detector backgrounds
  - A team constantly works to analyze the backgrounds
  - In May of 2022, a novel class of instrumental background events was observed
    - Events do not interfere with SNO+ data analysis but are interesting in their spatial and temporal distributions

SPATIAL DISTRIBUTION OF HIGH LIGHT YIELD EVENTS

May 7, scintFit==1



200<nhitsCleaned<300

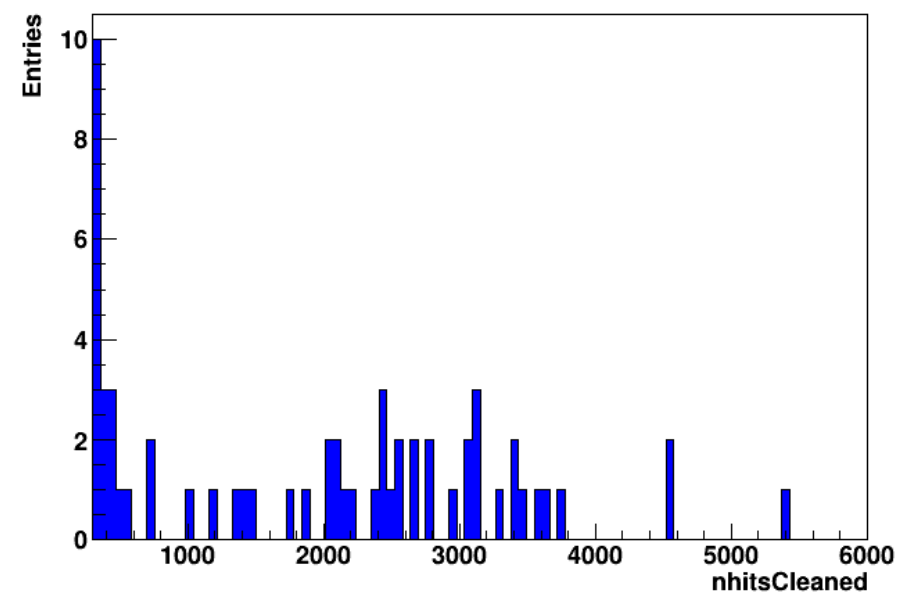


nhitsCleaned>300

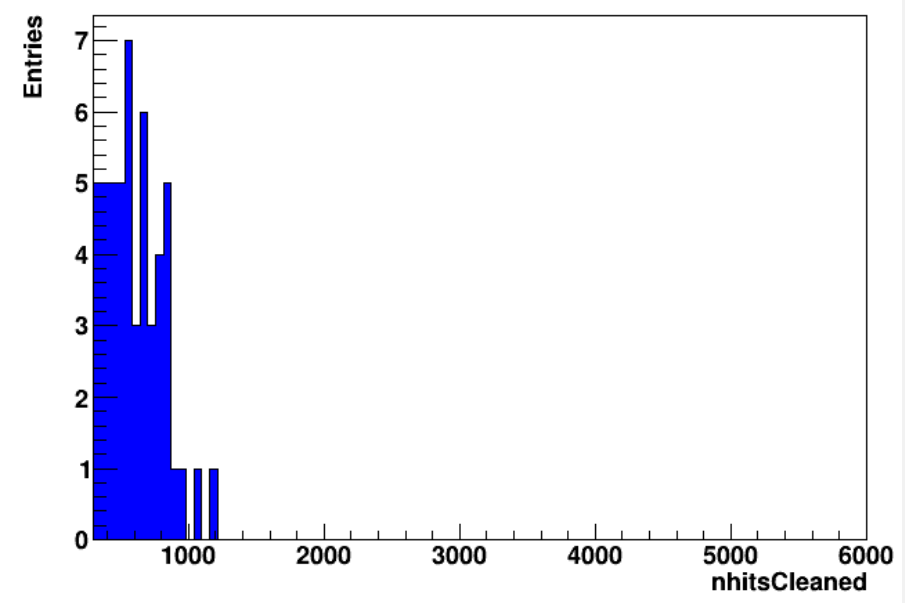
- nhitsCleaned is number of PMTs that detected light, after data cleaning cuts
- Homogeneous spatial distribution of events for 200<nhitsCleaned<300
- Two distinct dark spots at the top of the detector for nhitsCleaned>300

NHIT DISTRIBUTIONS

May 7, scintFit==1, nhitsCleaned>300, posz>5500



0<posx<500
-1300<posy<-900



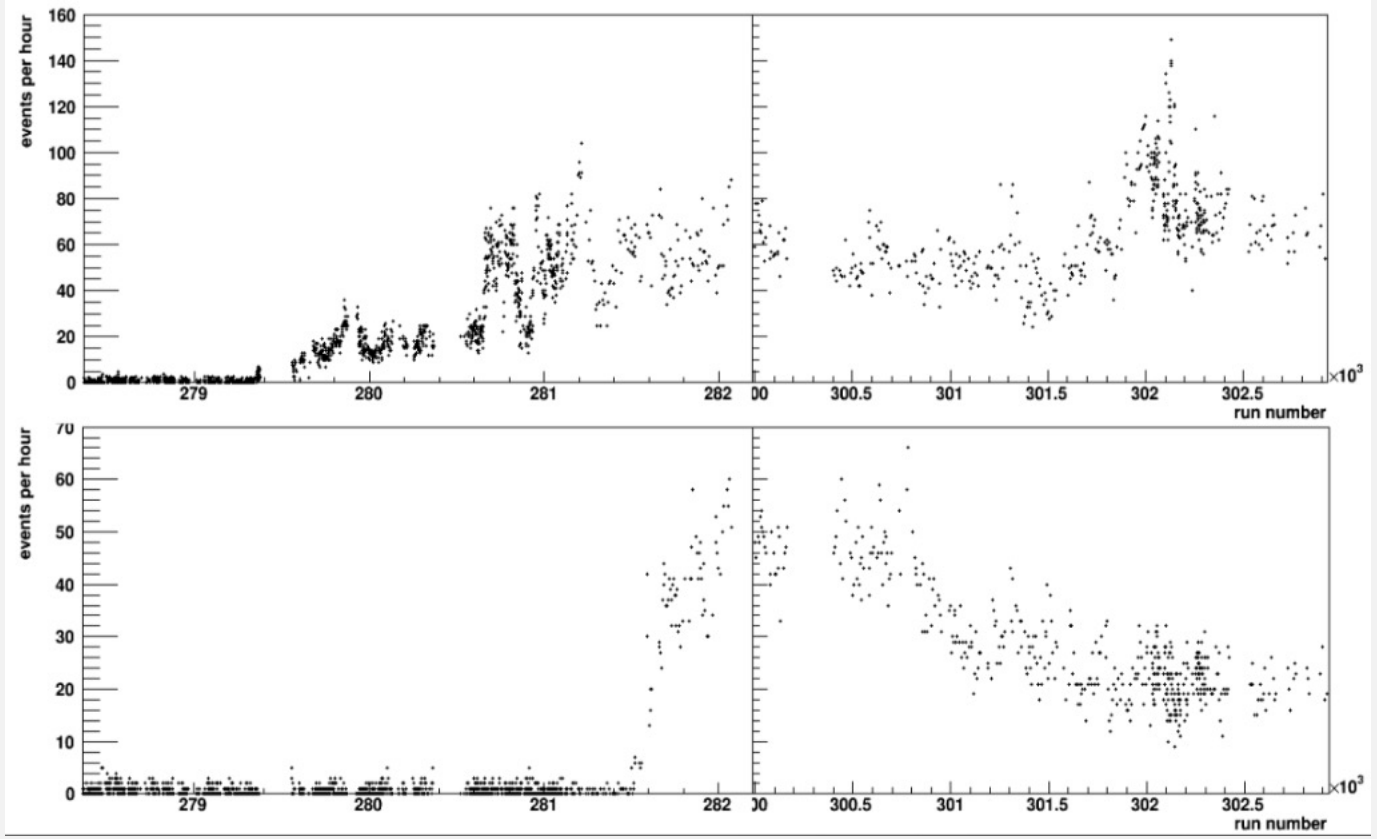
500<posx<1000
-1000<posy<-500

- nhitsCleaned is roughly proportional to amount of energy deposited in the scintillator
- ~350nhitsCleaned/MeV
- Higher energy than we'd expect from a radioactive background
- Significant difference between nhit distributions for both hotspots during the same run

EVENT FREQUENCY OVER TIME

January 1, 2022 – July 4, 2022, nhitsCleaned>300, fitValid==1, posz>5500

0<posx<500
-1300<posy<-900

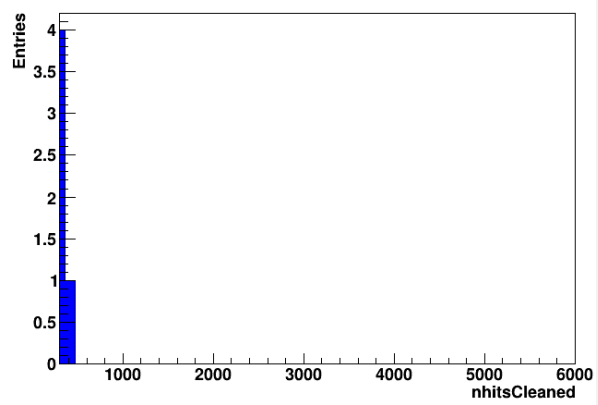


400<posx<800
-1000<posy<-500

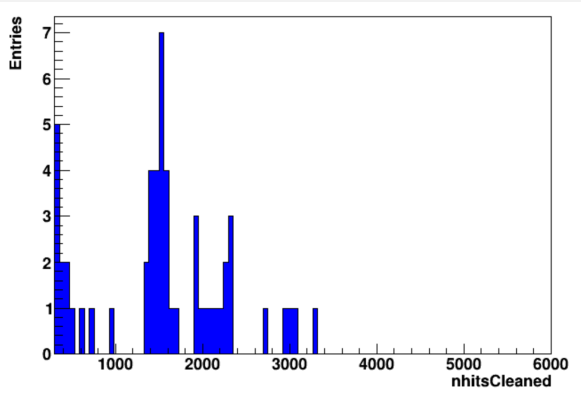
- Hotspots started at different times (one in early February, one in mid April)
- Hotspots started suddenly
- Changing frequency also makes radioactive source an unlikely candidate

HOTSPOT NHIT DISTRIBUTIONS OVER TIME

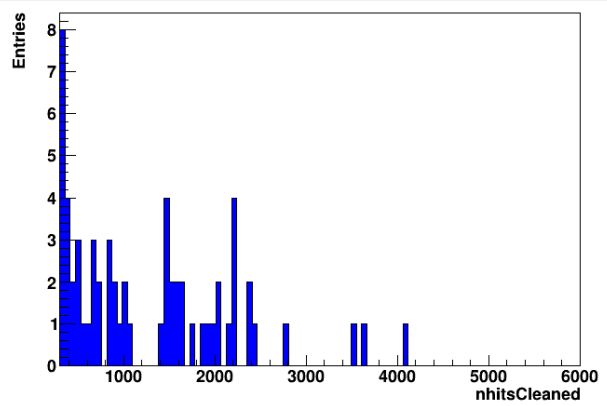
Feb 9, 2022



Mar 30, 2022

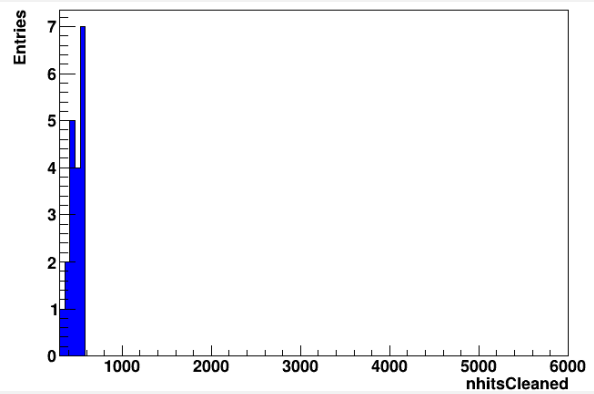


May 24, 2022

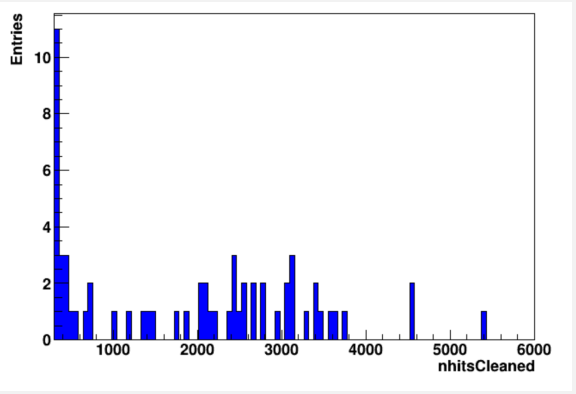


nhitsCleaned>300,
fitValid==1,
posz>5500,
0<posx<500,
-1300<posy<-900

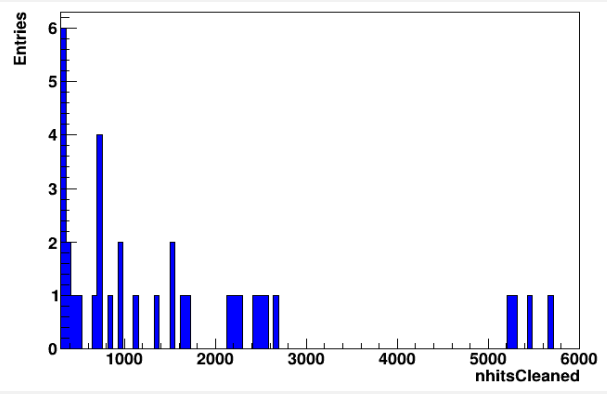
Feb 16, 2022



May 7, 2022

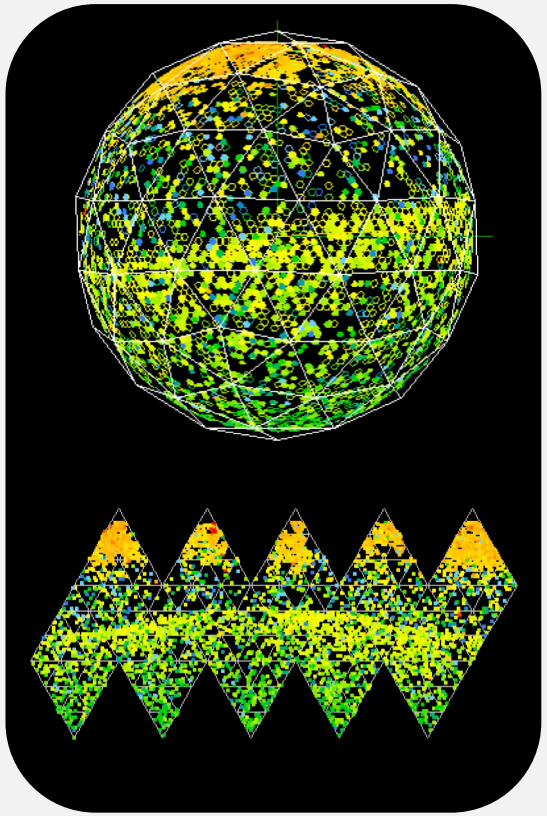


Jun 10, 2022

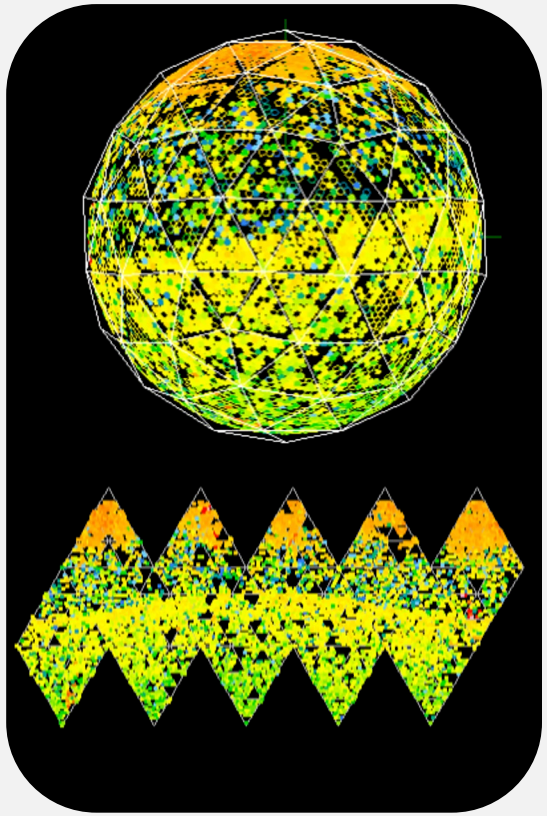


- Average event energy increased over time
- Despite this, hotspot positions remained unchanged

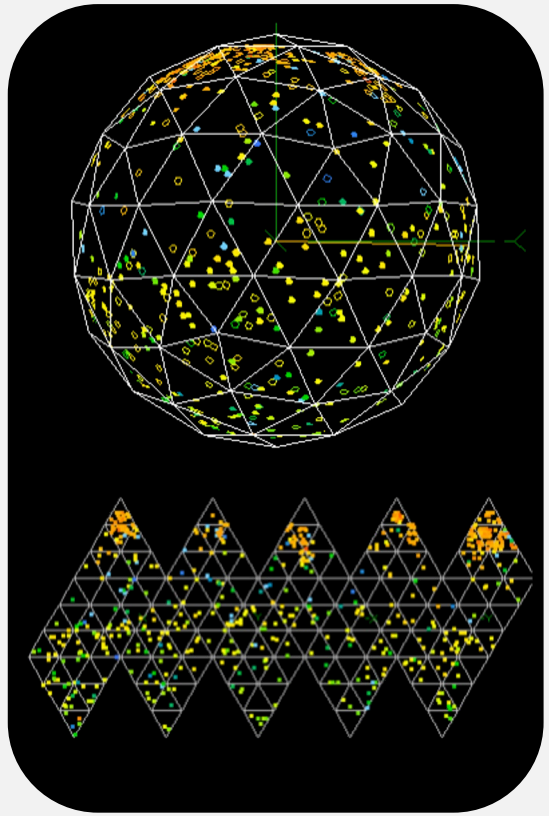
REAL TIME EVENTS IN XSNOED



(223,-1142,5826)
nhitsCleaned: 2676



(225,-1044,5825)
nhitsCleaned: 5825

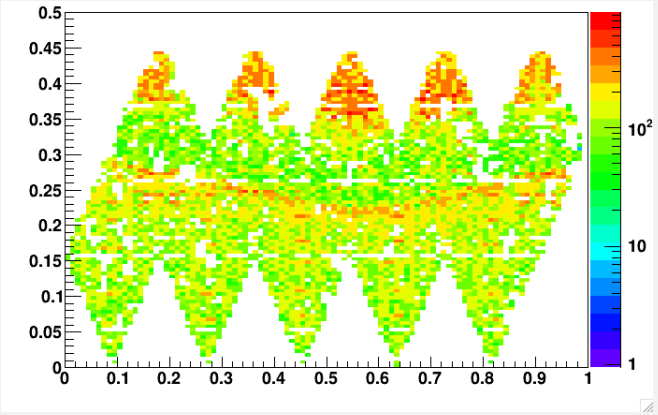


(90,-1105,5909)
nhitsCleaned: 533

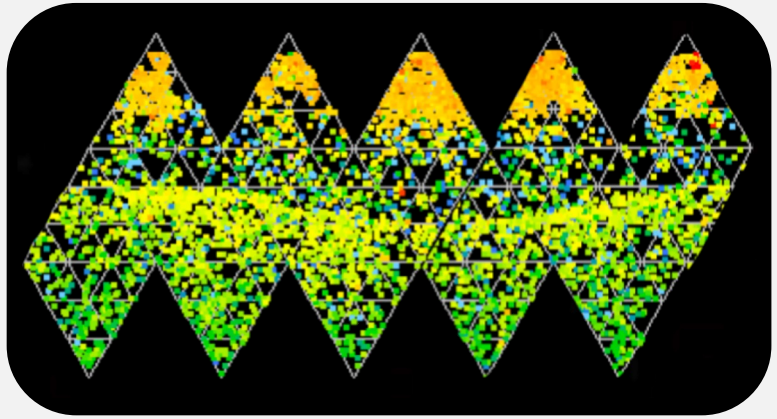
- XSNOED is display tool used to view SNO+ events in real time
- Bin colour represents relative PMT hit time
- Distinct structure with gap in PMT hit density partway down the detector

SIMULATION AGREEMENT TO DATA

- High-energy events were simulated in hotspot region using SNO+ simulation code
  - 200 20MeV electrons, shot in random direction from a specific point
- Monte Carlo flatmap and XSNOED flatmap agree very well with each other
  - Less likely the hotspots are due to external light
- Through similar simulations, we have also observed PMT hit structure is characteristic of any events close to the acrylic vessel (internal reflection)



MC simulation results (200,-1100,5800)



(223,-1142,5826), nhitsCleaned: 2676

Note bin colour on XSNOED flatmap represents PMT hit times while bin colour on MC flatmap represents pmt hit density (number of pmt hits per bin)

WHAT WE KNOW

- Two hotspots housing high frequencies of high light yield events appeared suddenly, didn't correlate with anything as far as we can tell
- Rate and energy of events increased over time, seem to have plateaued a bit now
- Positions have not moved, remain very close to the acrylic vessel at the top of the detector
- MC results agree with real data fitter
- Hotspots do not interfere with data analysis

POTENTIAL CAUSES

What it can't be

- Events from somewhere else getting mis-reconstructed
  - The results from the Monte Carlo simulations were a very strong match to the real data
- Components that we've tested
  - Light production from low velocity gas flow
  - Emission by specific electronics

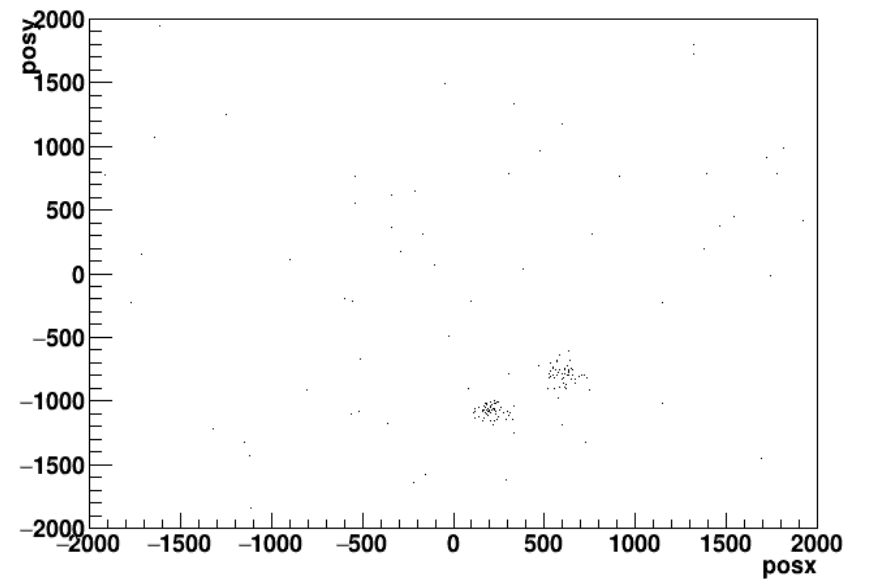
What it could be

- Light leak from an untested electronic source
- Bubble trapped against the acrylic vessel

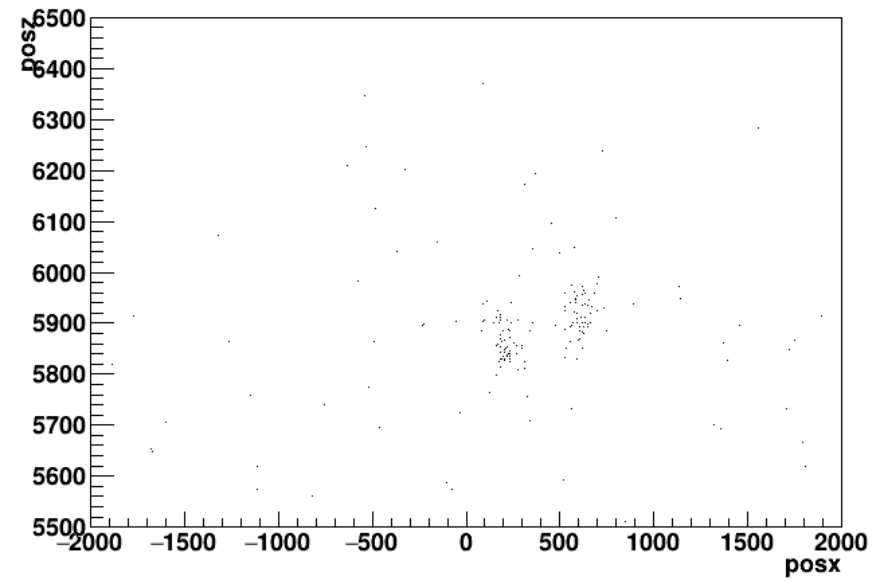
BACKUPS

HOTSPOT XY AND XZ POSITIONS

May 7, scintFit==1, nhits>300, posz>5500



xy positions

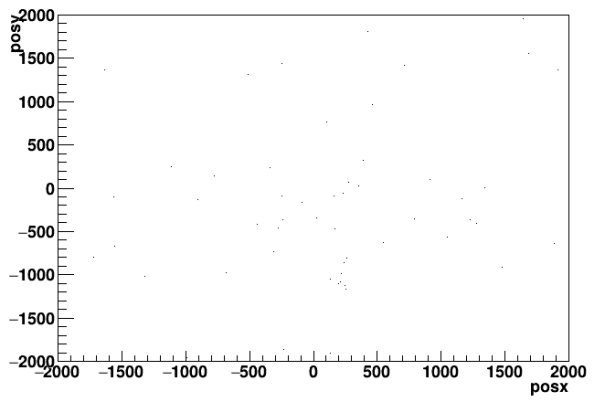


xz positions

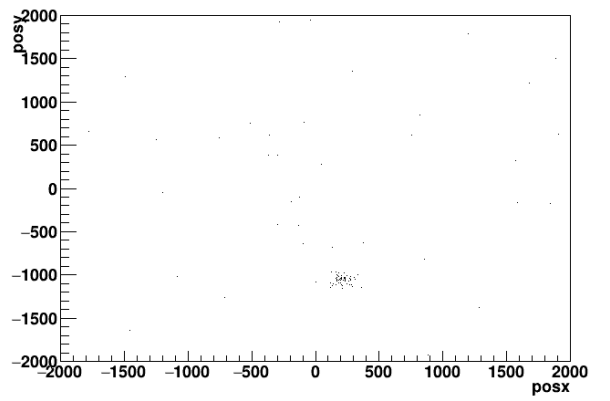
- Events are mostly confined to two ‘hotspots’
- xz plot indicates events are very close to the AV (at 6000mm)

HOTSPOT POSITIONS OVER TIME

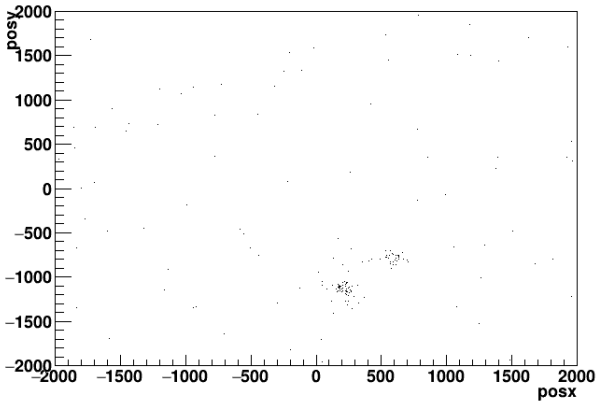
Feb 9, 2022



Mar 30, 2022

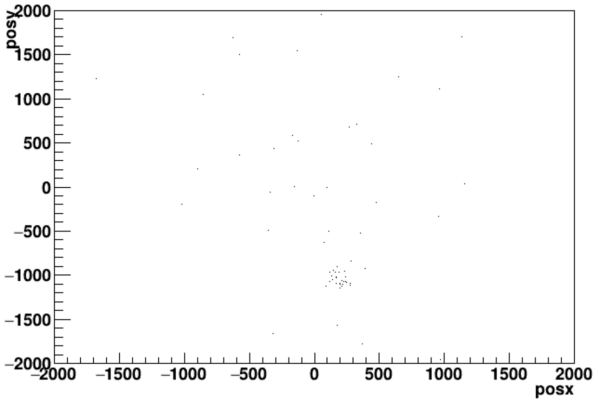


May 24, 2022

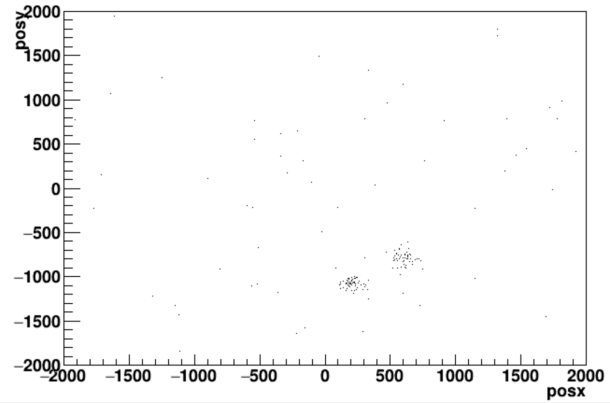


nhits>300, fitValid==1, posz>5500

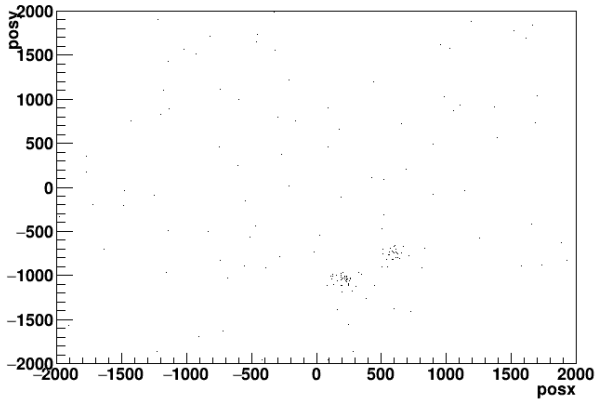
Feb 16, 2022



May 7, 2022

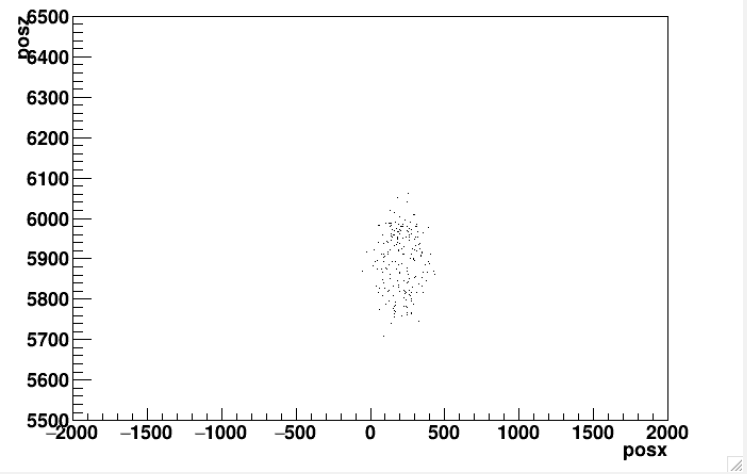


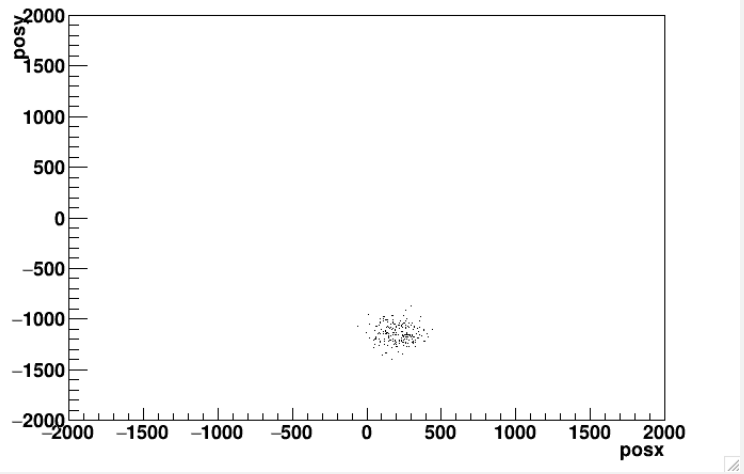
Jun 10, 2022

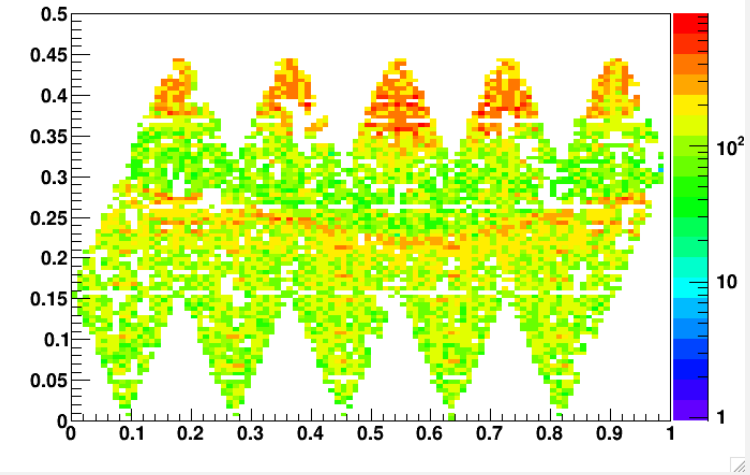


- xy positions have not changed over time
- Can see the appearance of second hotspot between March 30 and May 7

MC HOTSPOT SIMULATION RESULTS





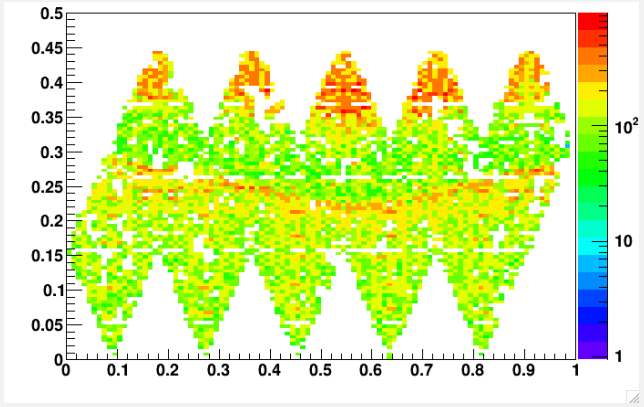


MC simulation results (200,-1100,5800)

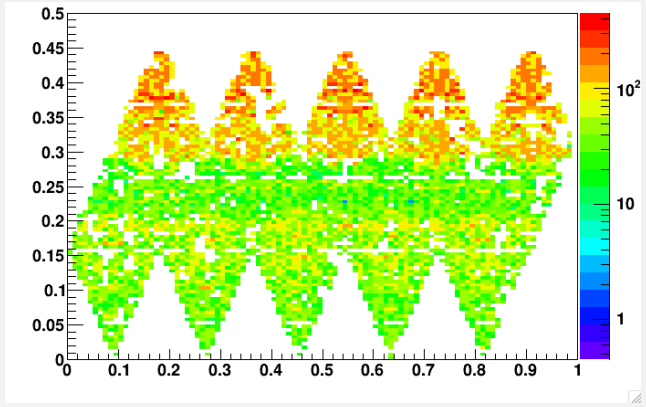
ELECTRON GUN SIMULATIONS

200 20MeV events from point electron gun point, shot in random direction

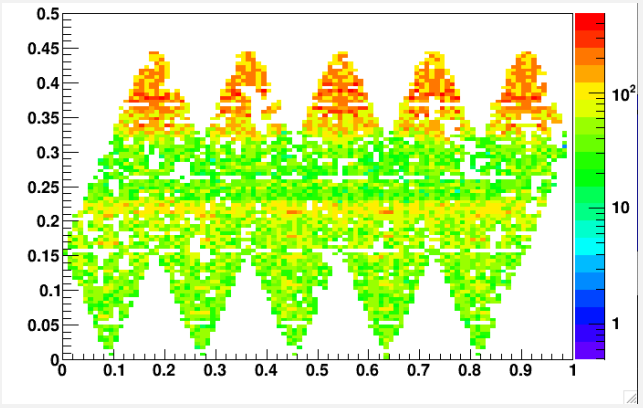
(200,-1100,5800)



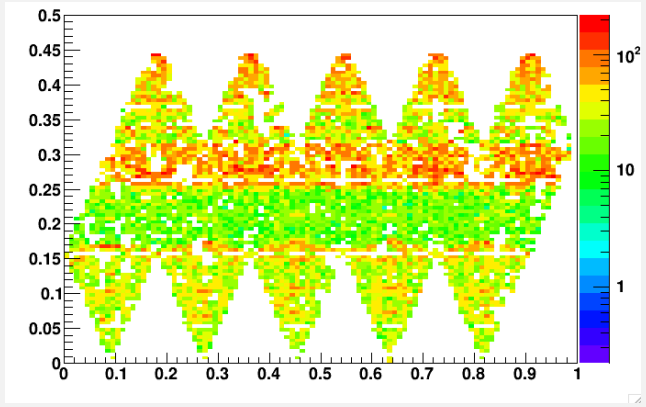
(0,0,7000)



(0,0,6500)

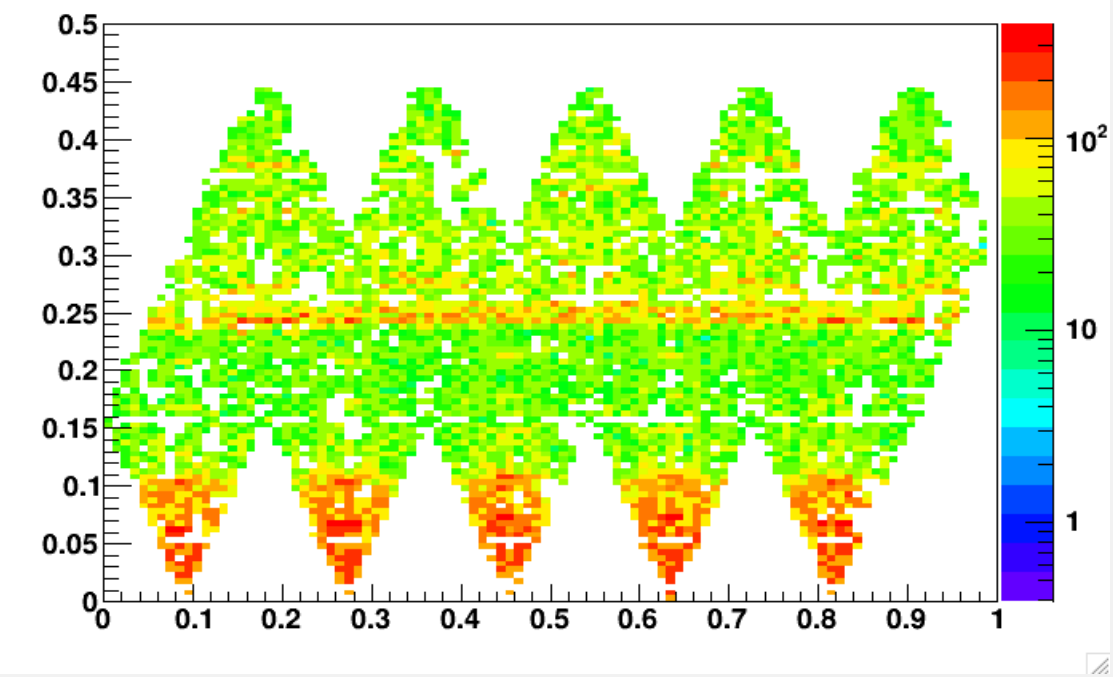


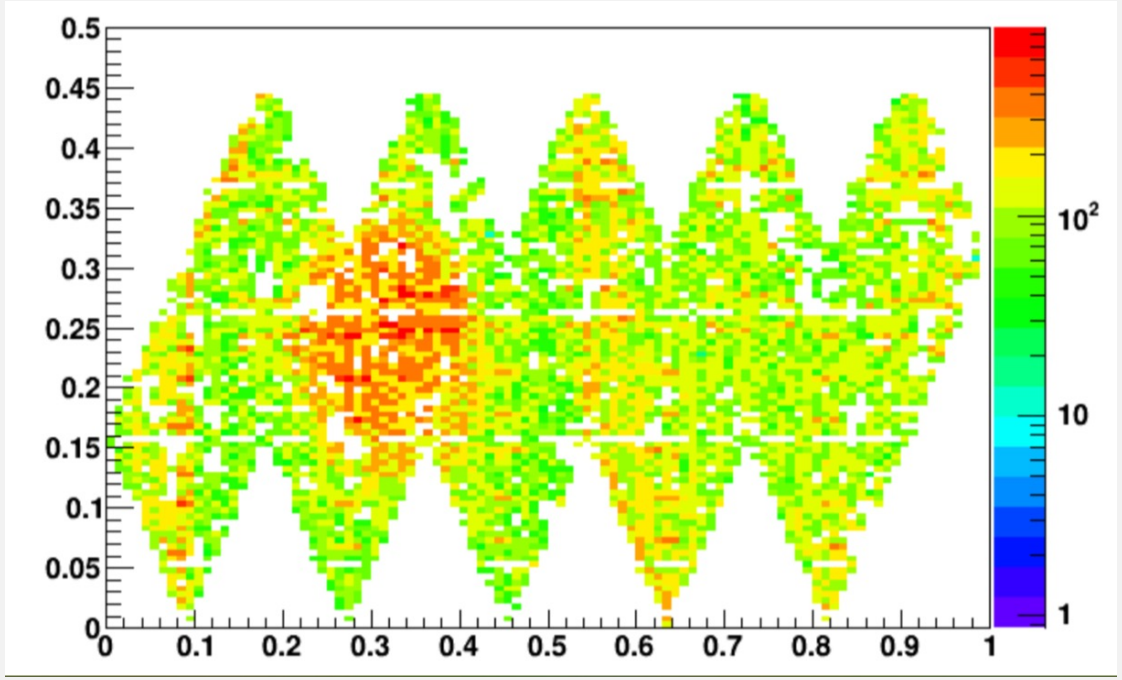
(0,0,8000)



- Similar pmt hit structure as what we saw in XSNOED (gap in hit density partway down the detector)

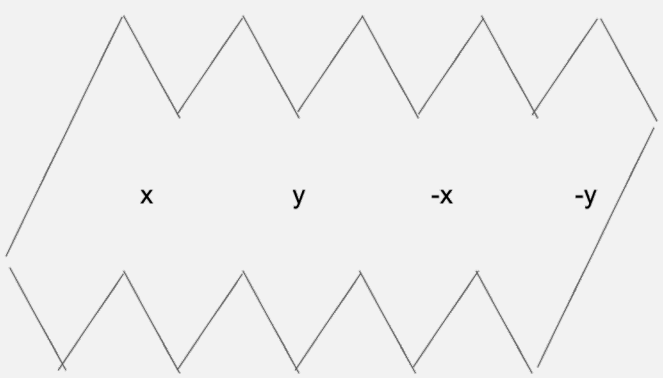
ELECTRON GUN FROM BOTTOM AND SIDE OF ACRYLIC VESSEL

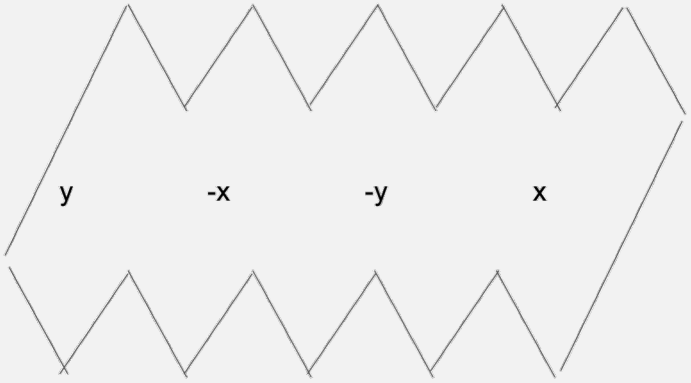




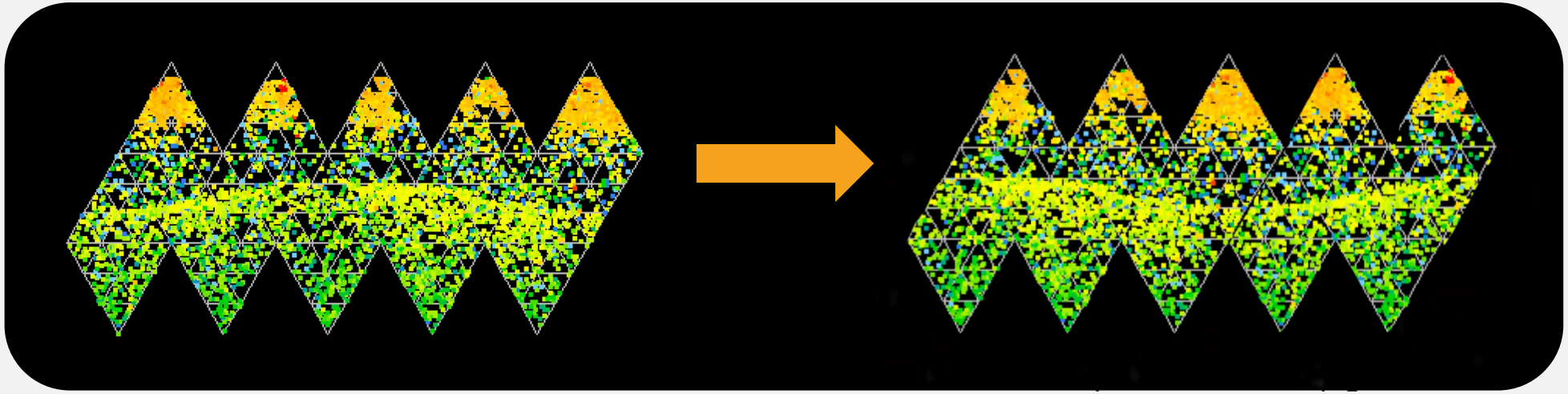
COORDINATE CONVERSION

Monte Carlo flatmap





XSNOED flatmap



NHIT DISTRIBUTION FOR MC SIMULATION