Energy calibration of SNO+ with scintillator

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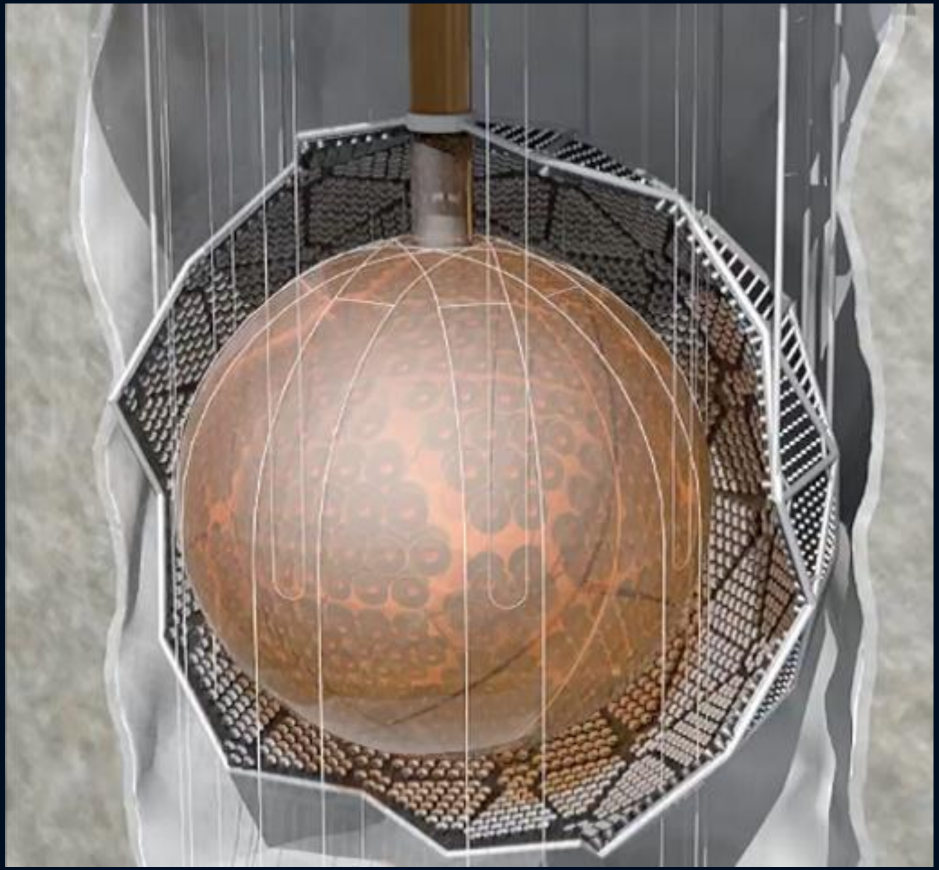
SNO+ Experiment

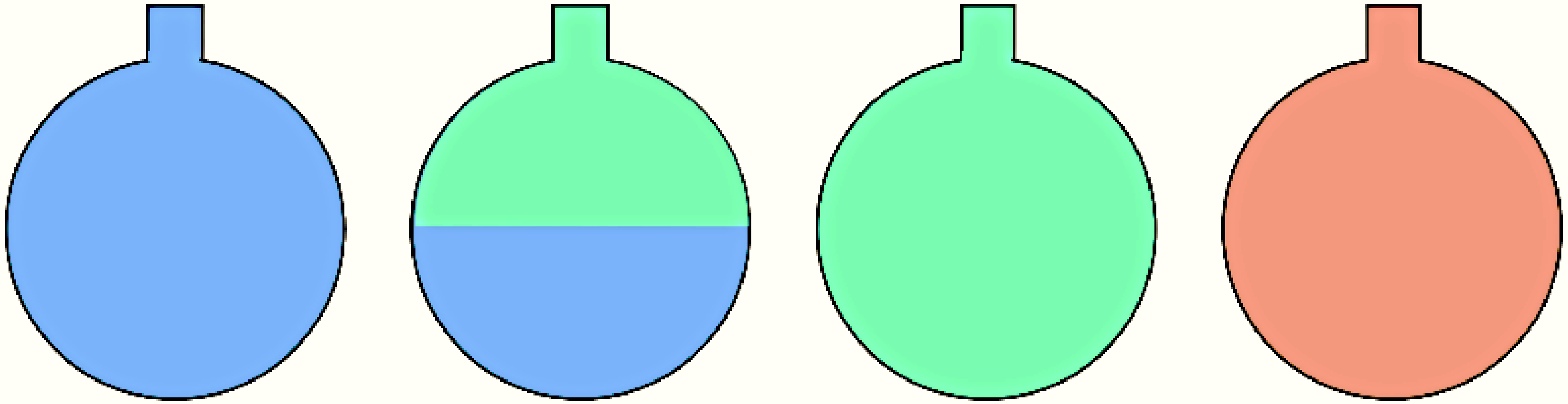
- SNO successor
- Multi-purpose neutrino detetor
- “Subdury neutrino observatory” in SNOLAB
- Subdury, Ontario, Canada



Structure:

- ~9400 PMT´s structure with 9m radius
- Acrylic vessel (AV) with 6m radius and 5cm thickness
- Various active mediums inside the AV
- 7000 tonnes of ultra-pure water for shielding

SNO+ Detector phases



Water Phase

905t of ultrapure light water

Cherenkov detector; Neutron capture efficiency and calibrations

Partial Fill Period

365t scintillator: LAB + 0.6g/L PPO

First Scintillator characterization; Background response

Pure Scintillator Phase

780t Scintillator: LAB + 2.2g/L PPO

Solar and Supernova neutrinos; geo and reactor anti-neutrinos

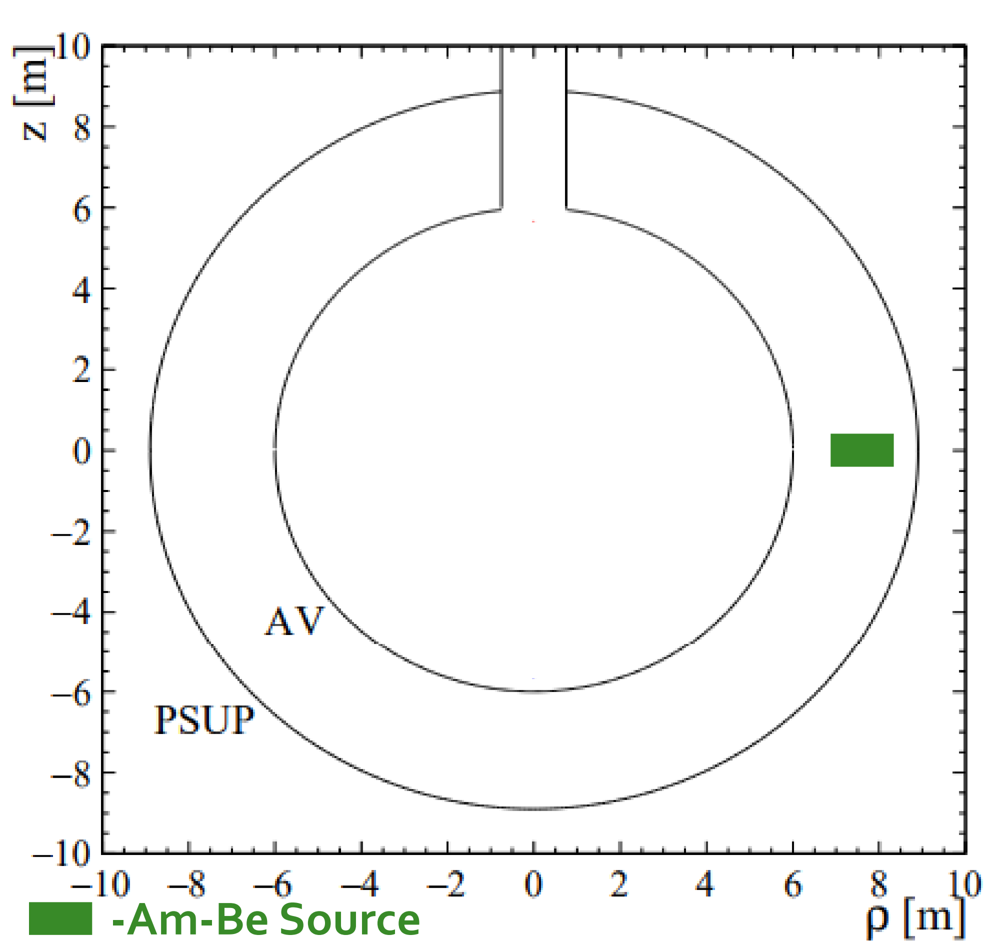
Te-loaded Scintillator Phase

780t Scintillator: LAB + 2.2g/L PPO + 15mg/L bisMSB + DDA + 0.5% ^{nat}Te loading

Search for neutrinoless double beta decay in Tellurium-130

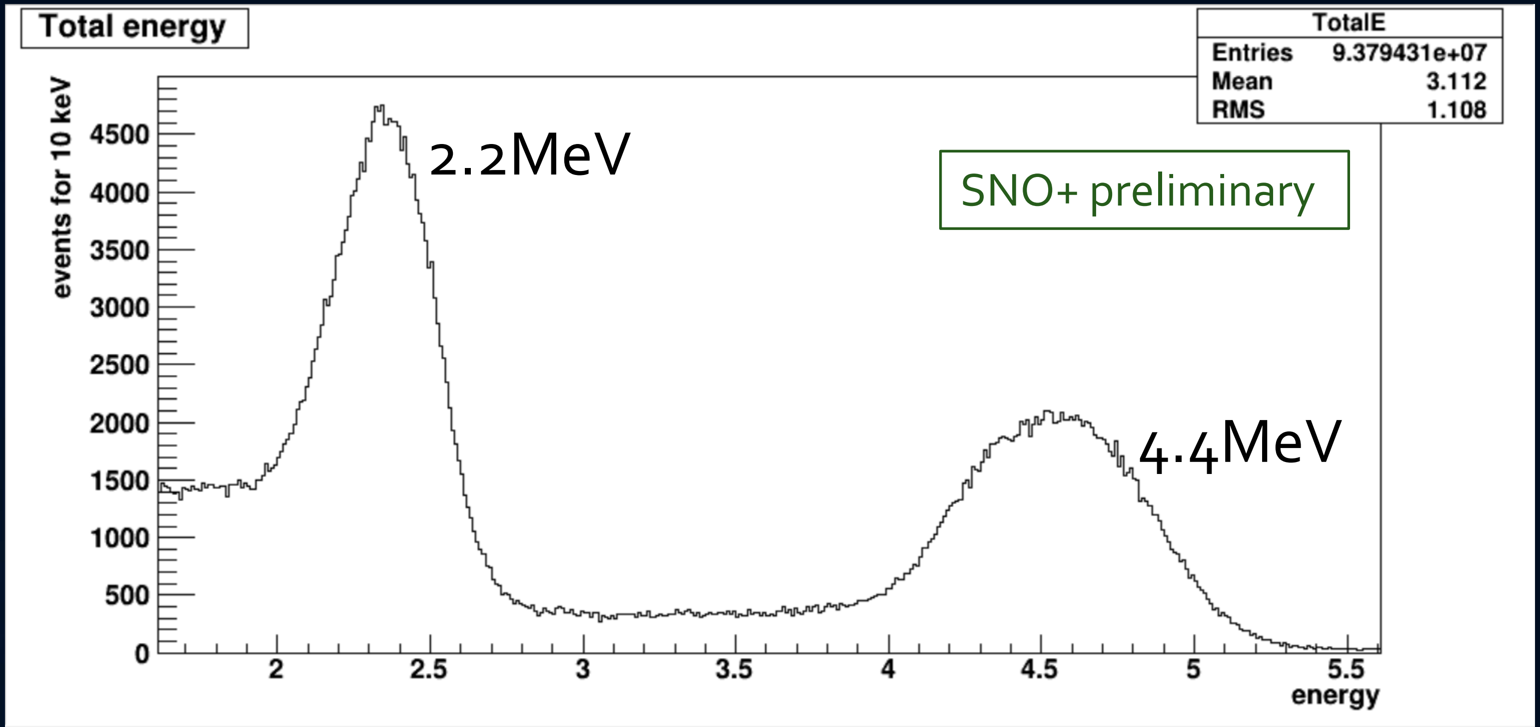
My Work:

- Using an Am-Be source to calibrate the data from the “Scintillator phase”.
- May and August 2022 data analysis;
- Energy calibration;
- Events position;
- Time distributions & decay time;



Energy calibration with Am-Be

Main reactions:

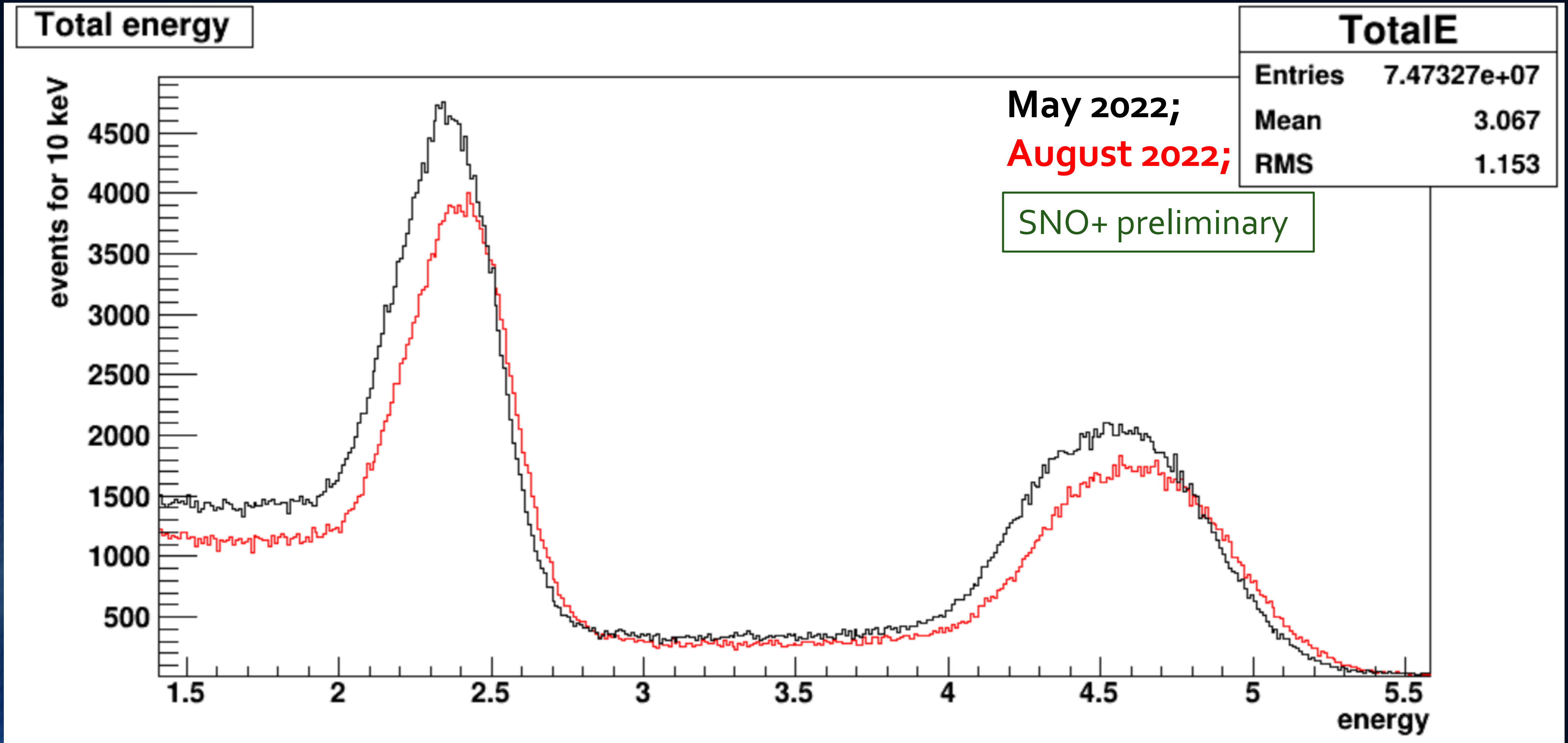


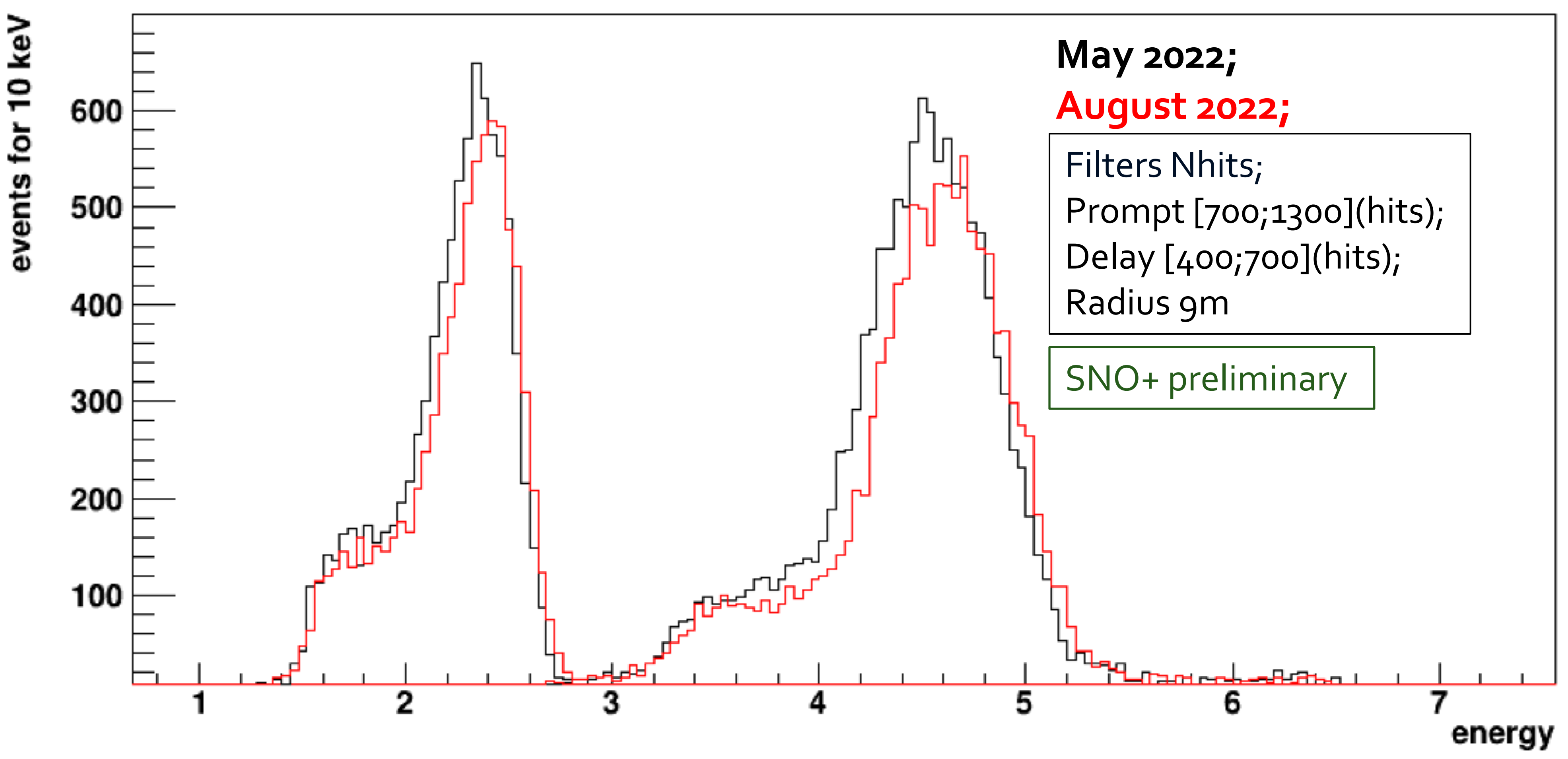
- 241Am -> 237Np + α
- 9Be + α -> 13C*
- 13C* -> 12C* + n + 1.27MeV

- 12C* -> 12C + 4.43MeV (prompt)
- 1H + n -> 2H + 2.2MeV (delay)
- (coincidence in 200 microseconds)

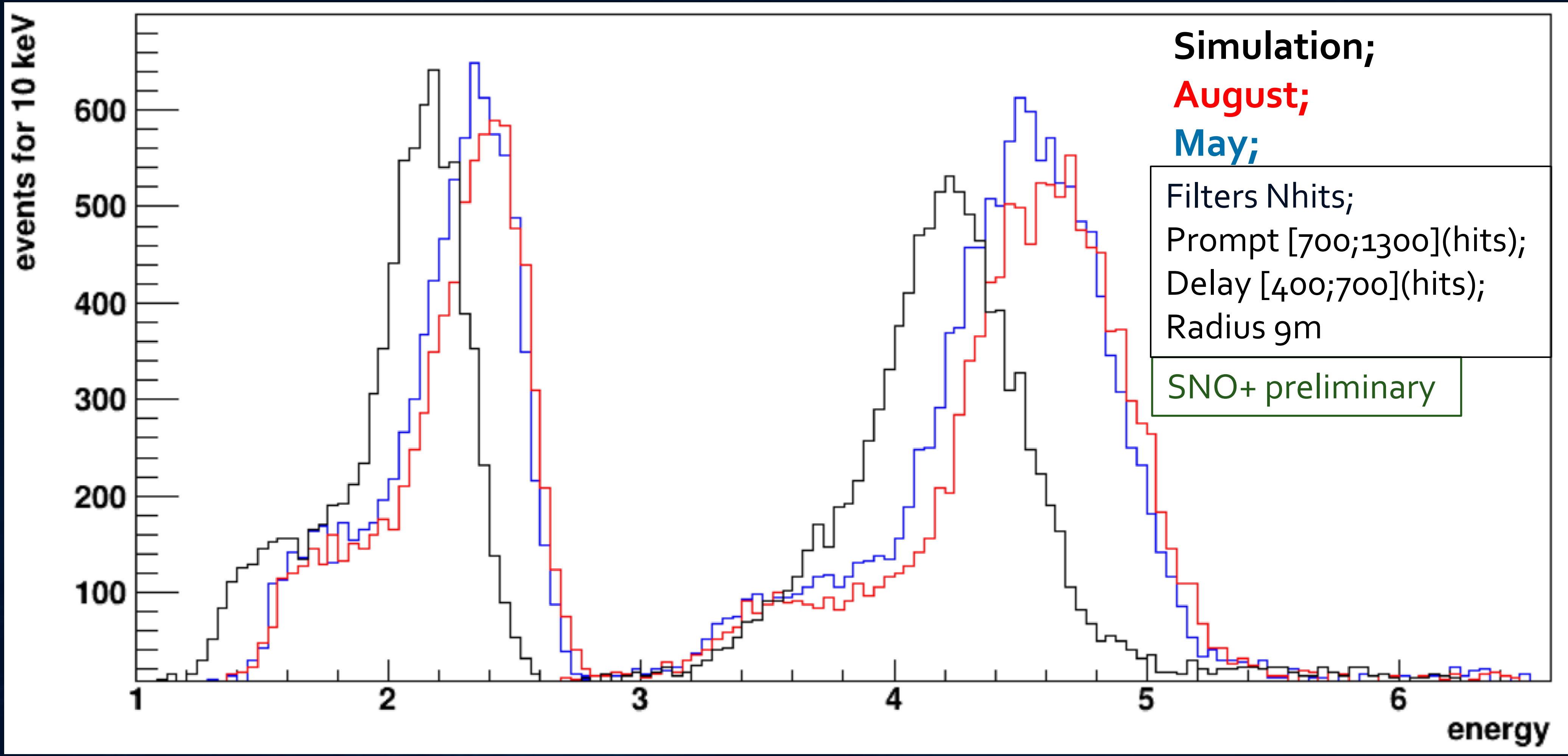
May & August comparations

Events reconstructed inside the vessel





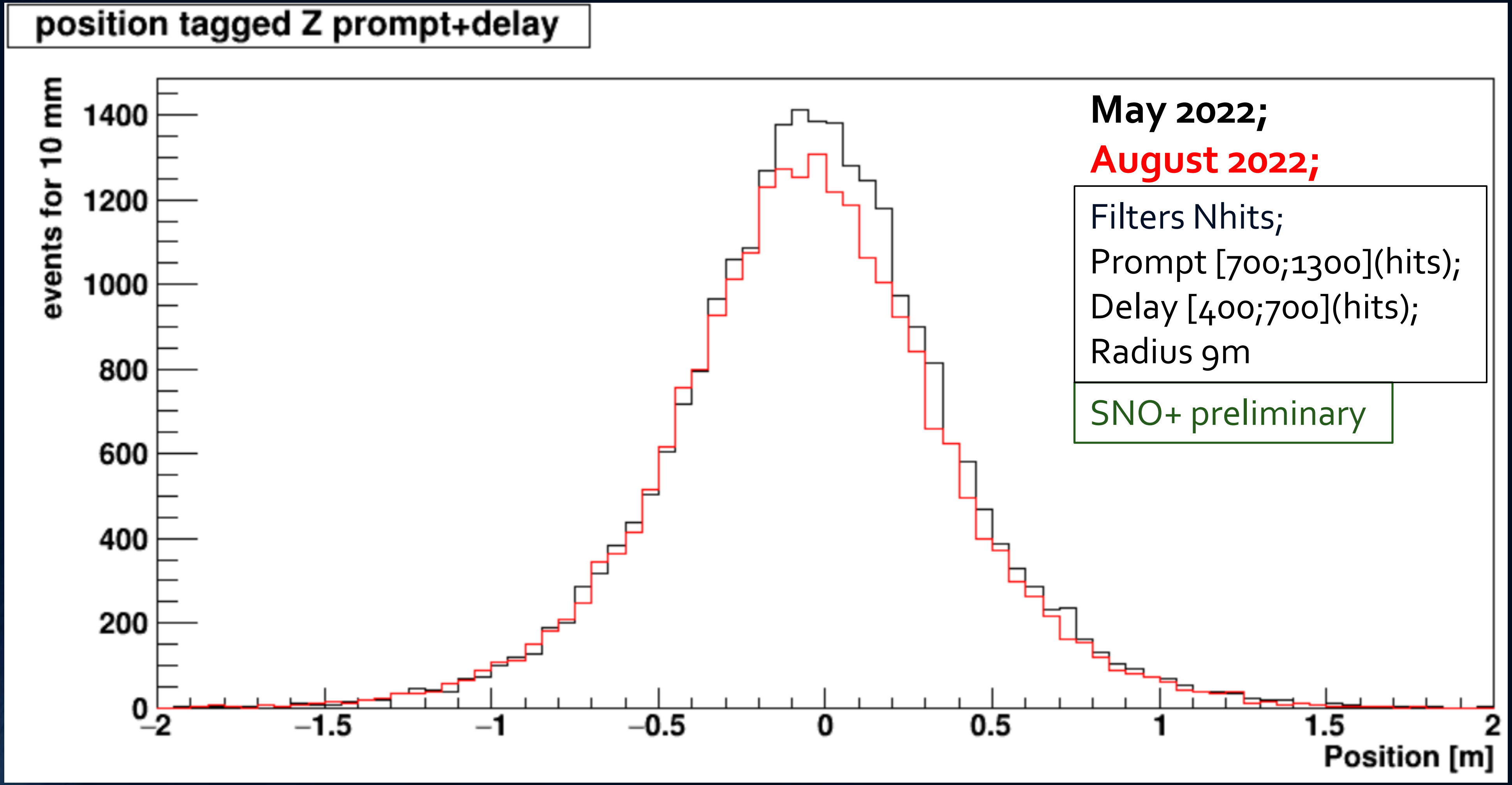
Both prompt and delay energy's distribution, when compared between august and may, show a shift on the average value, 1.15% both in delay prompt events.



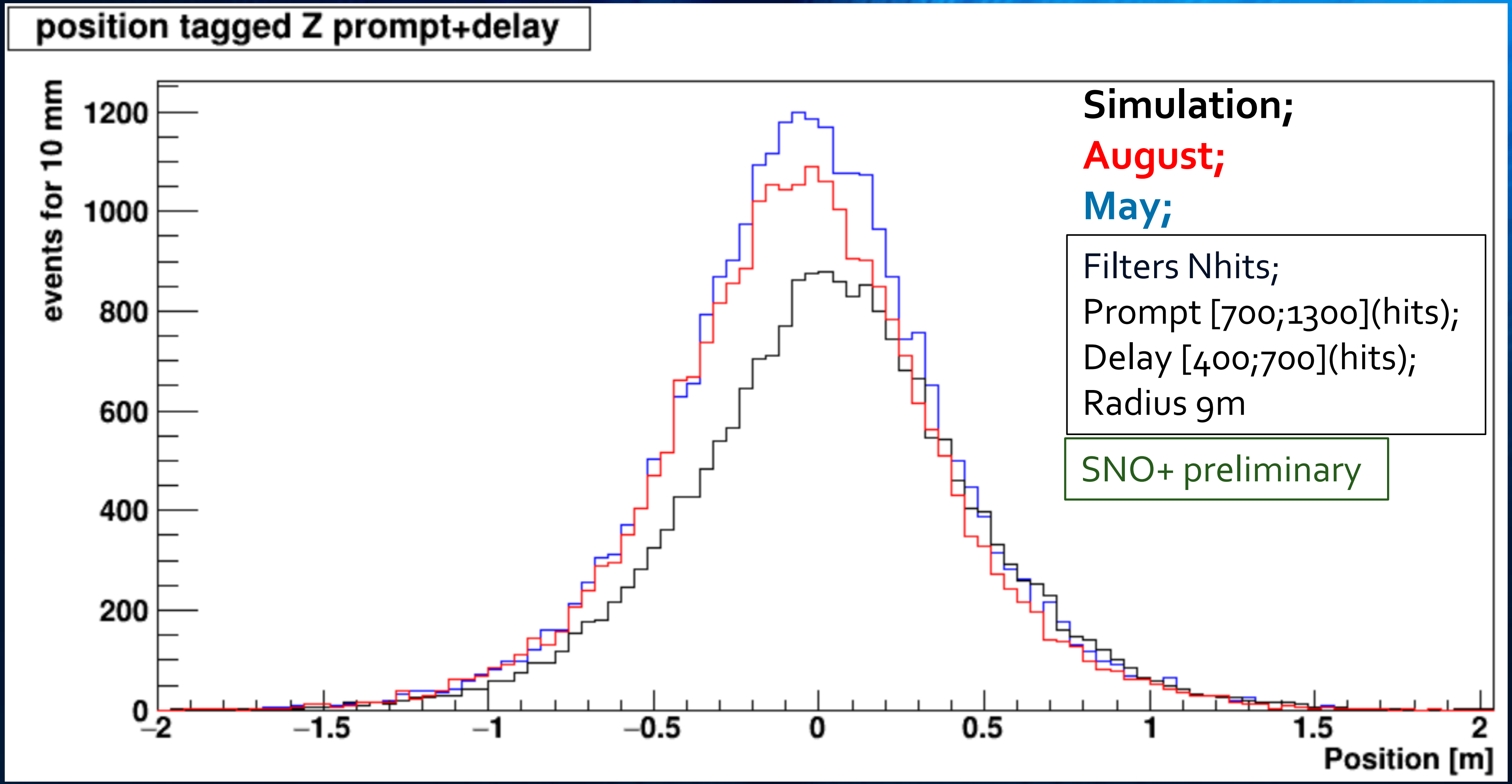
Energy values and Nhits values are completely off in the simulation when compared with the data analyzed in the same conditions. This discrepancy appears to grow with the energy, while in relative terms the energy is always overstated by around 10%.(in the simulation the energy is 10% lower than in data)

Real Value	May	August	Simulation	Ratio May	Ratio August	Simulation ratio
4.43	4.541	4.607	4.202	1.025	1.040	0.948
2.223	2.348	2.375	2.146	1.056	1.068	0.965

Looking at this values shows that every single one is far from perfect when compared to the “real” values accepted by the literature, the energies from SNO+ have been overestimated while the MC simulations have been underestimated.



Despite having a clear shift in energy between May and August when comparing the positions of the events is very hardly noticeable the difference, with that said the average Z position for delay event is shifted -1.7cm and the average Z position for prompt event is shifted -0.95cm.



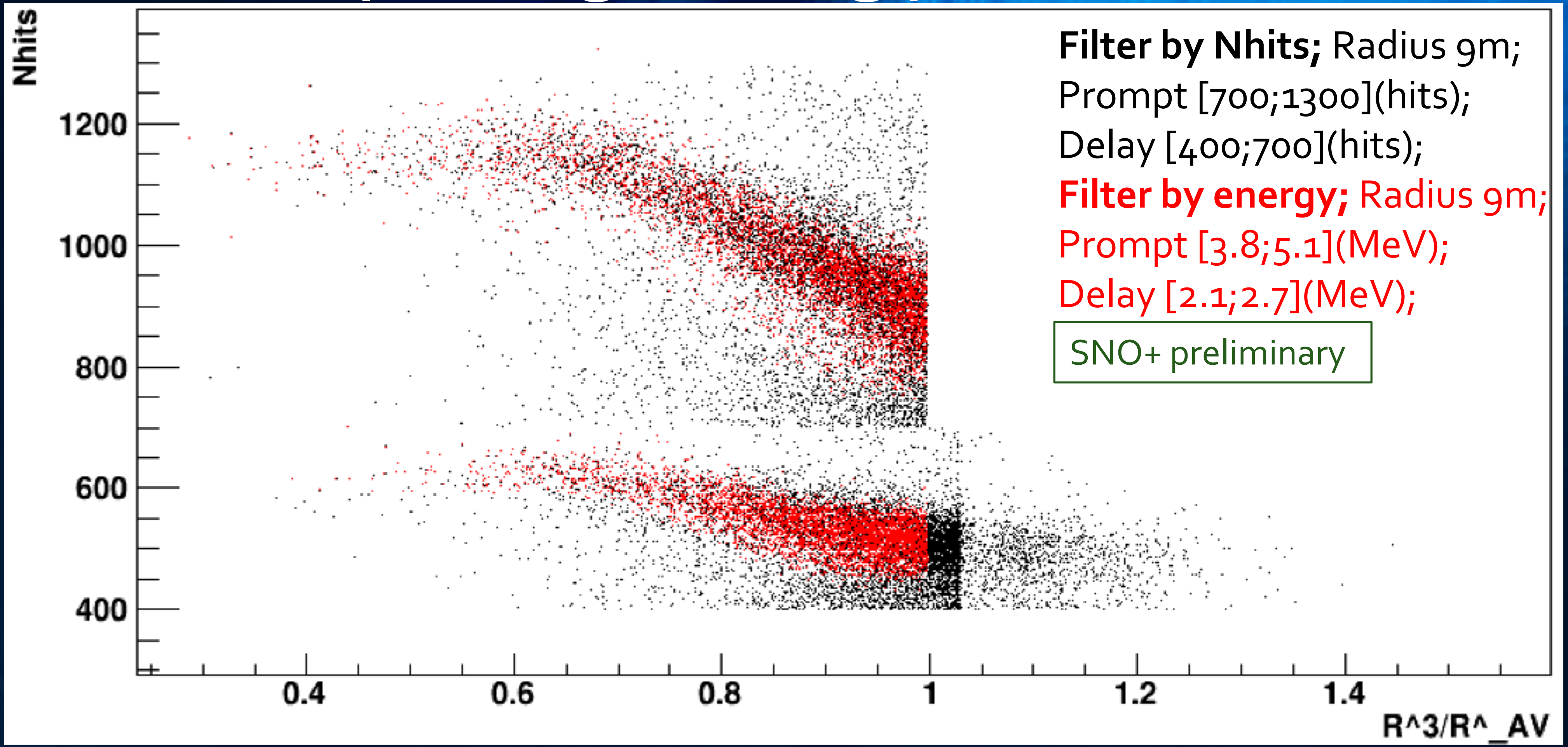
- As showed by the graphs the position of the events have similar variance and mean value while the simulation has a higher variance and a shift in the mean value of about 8cm, most likely, the last, has to do with how the source was "placed" in the simulation .

Conclusions:

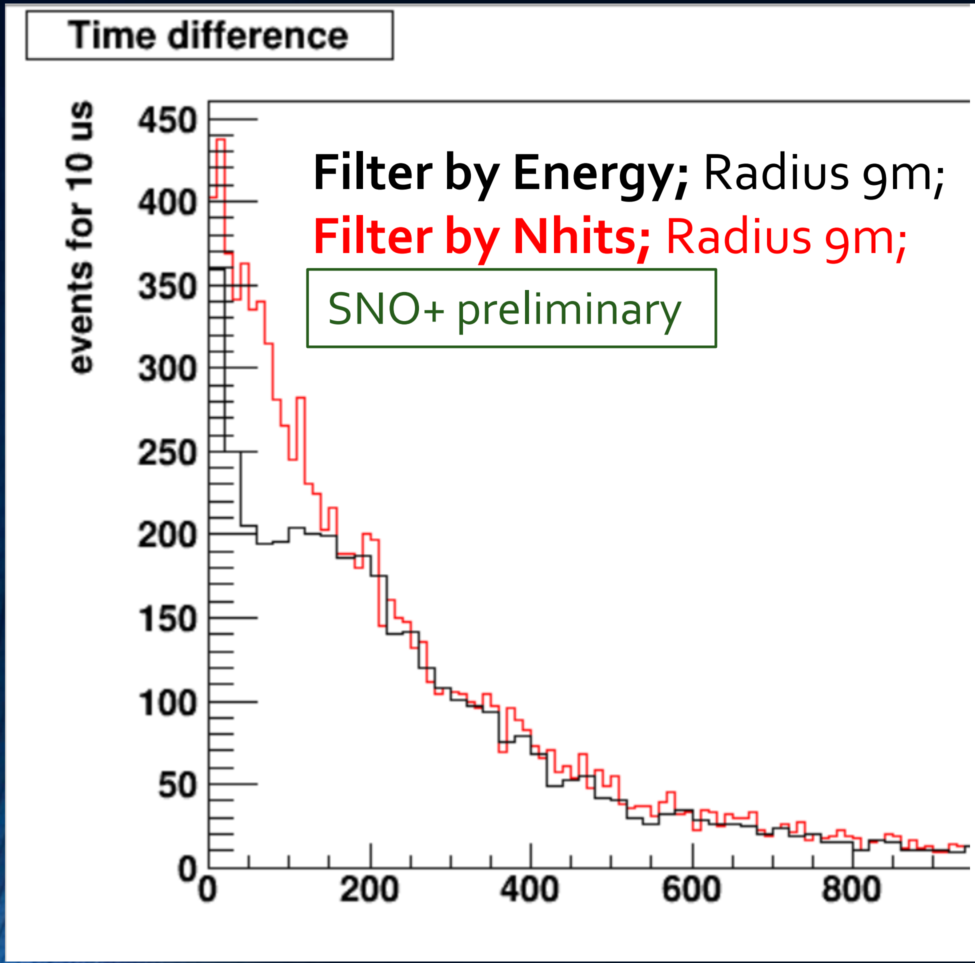
- Since May and August data are very similar, when searching for major differences in other cuts and/or with other filters, I will sometimes only show the data from one of the two months.
- Am-Be source translation or rotation merged with the randomness of the events can explain the small shift in event's position from May to August. The shift in energy is larger and more important to explain: one of the possibilities is the non-homogeneity of the Scintillator and the Wavelength-shifting solution in May.
- Correcting the energy response of the detector in the simulation at larger radii will make it better match the data.

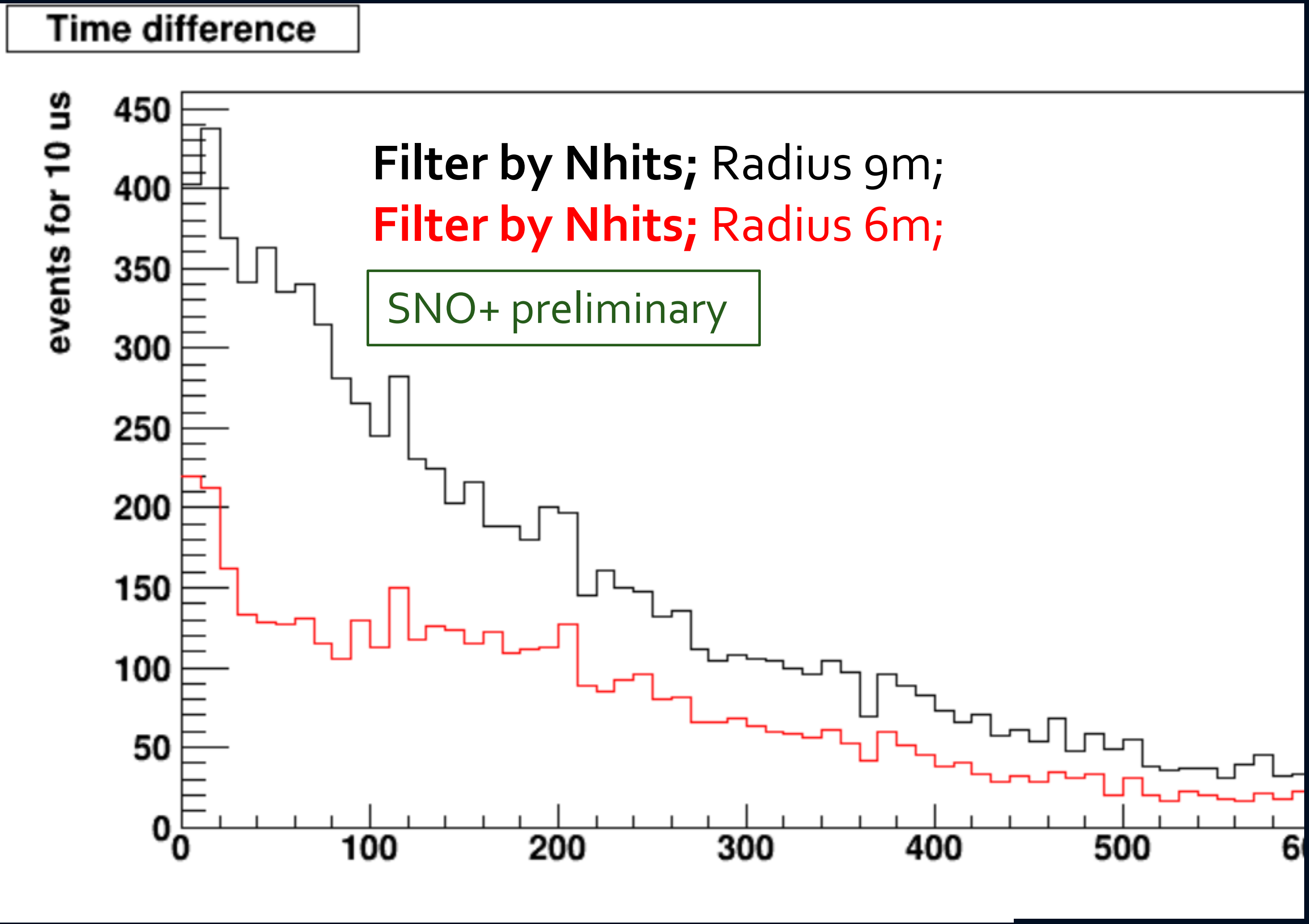
Feature of Time difference between prompt and delay events

Data comparing energy and Nhits filter



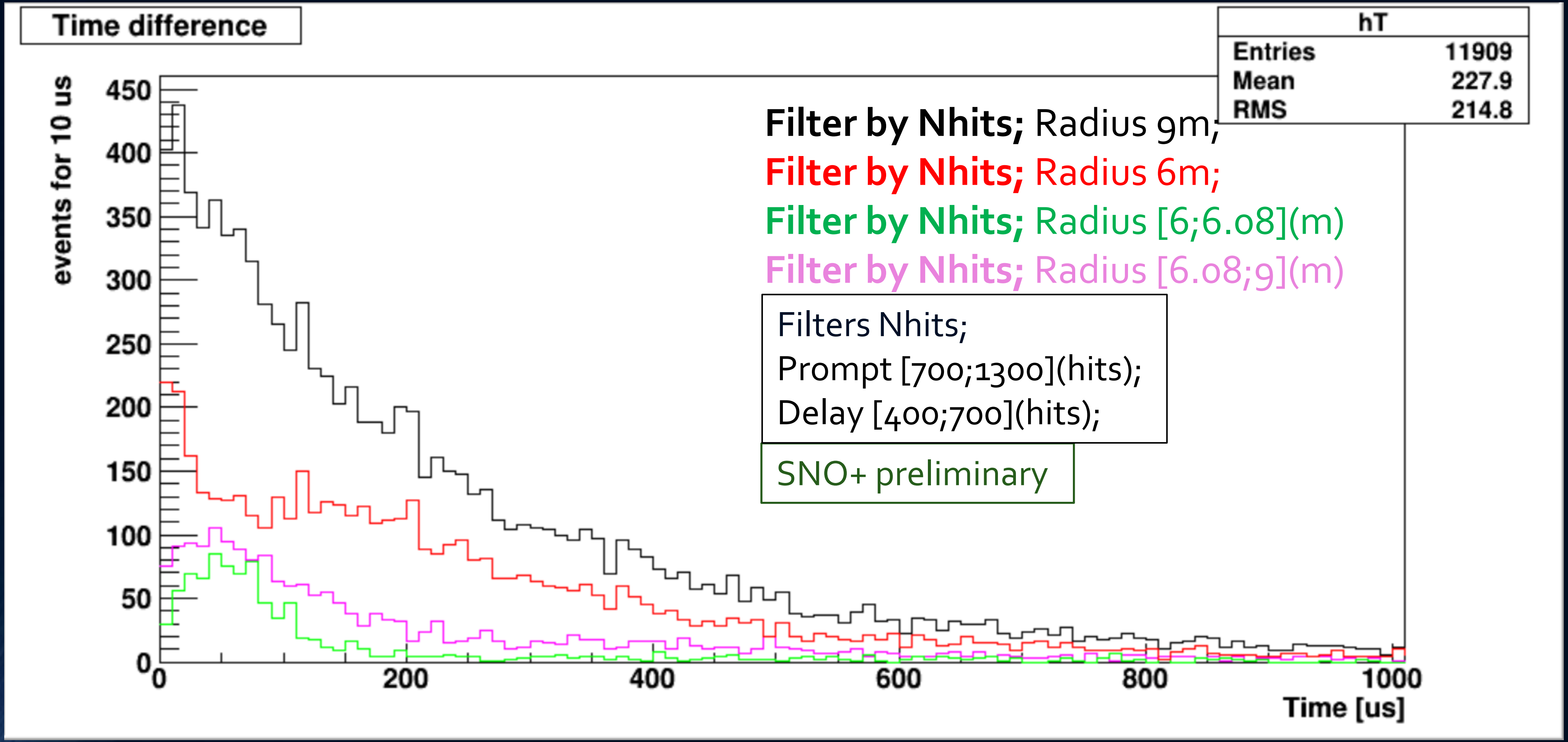
When changing the filter from energy to Nhits we easily see a vast amount of "deleted" delay events outside of the 6m radius, delimited by the vessel.



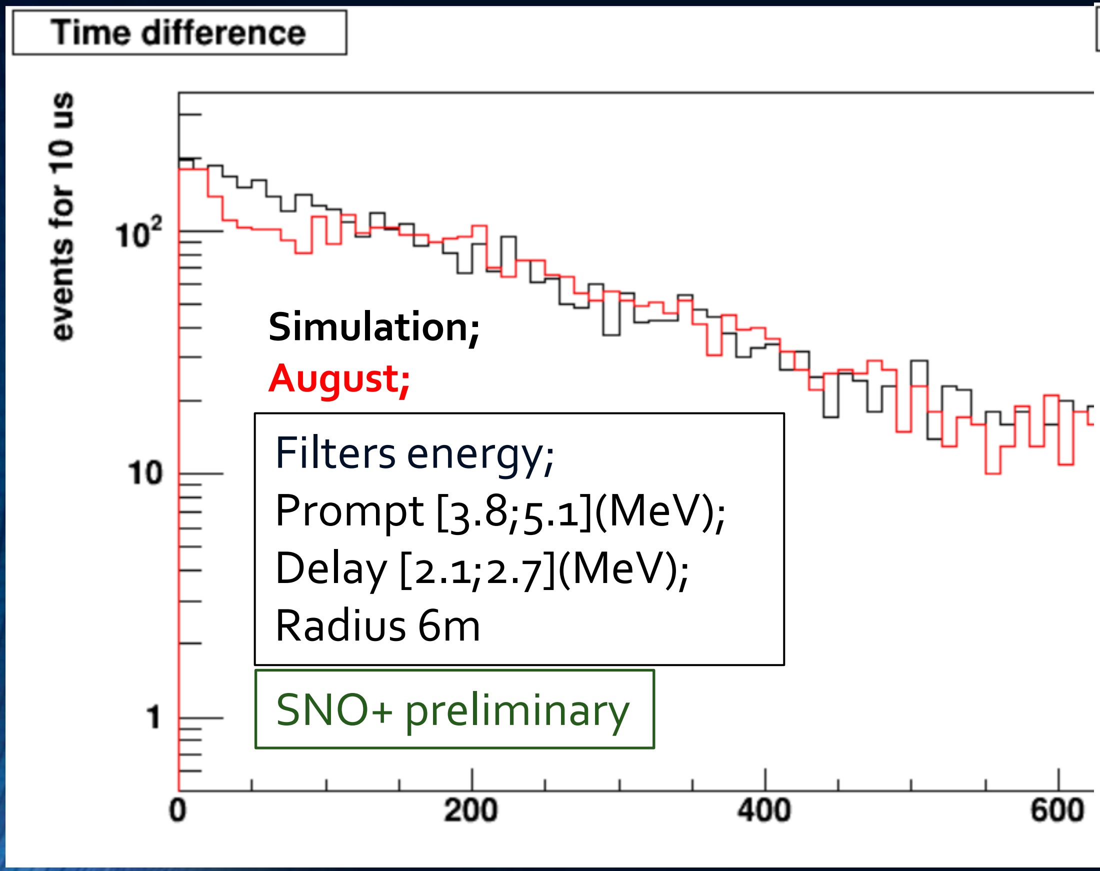


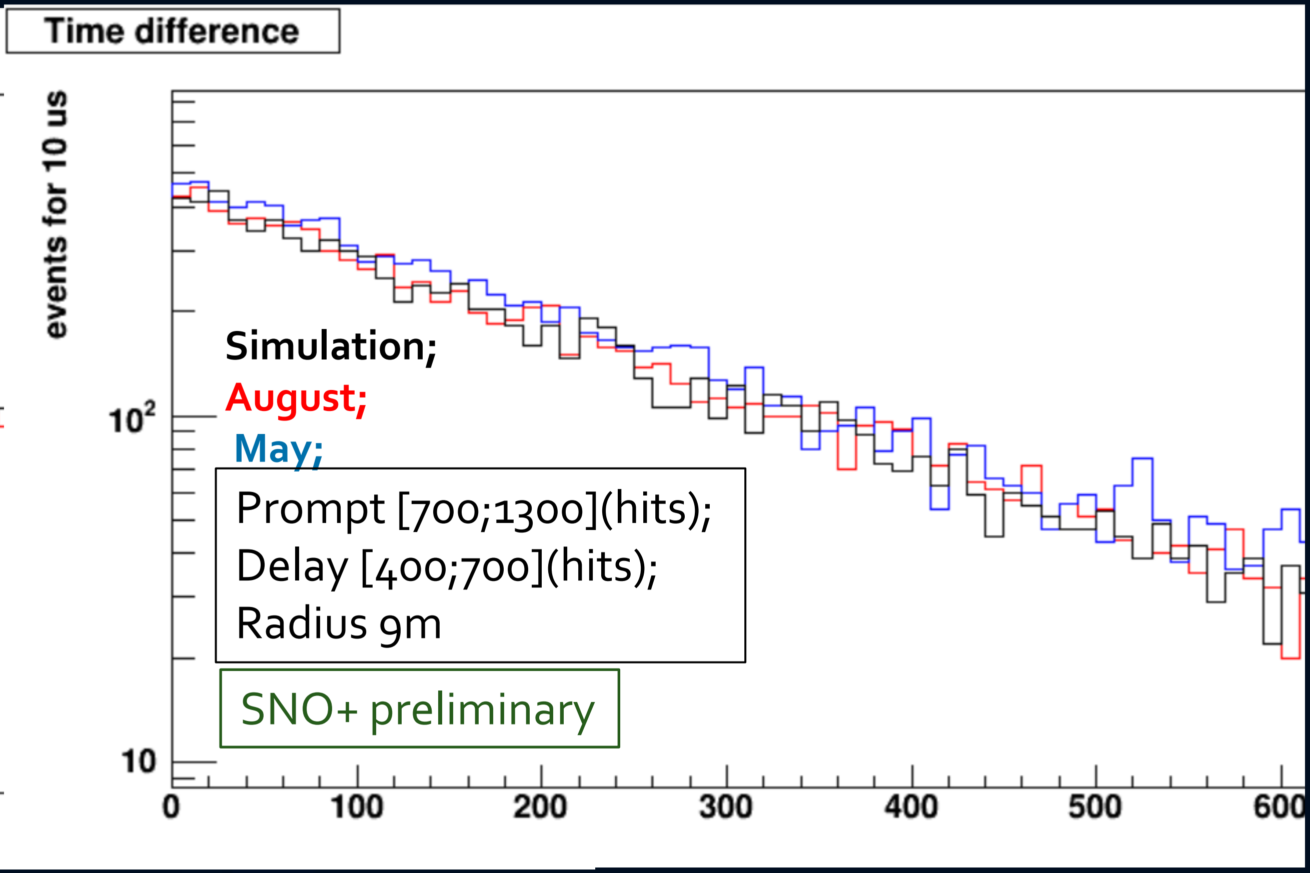
The events filtered by energy show a good chunk of data "missing" between the 10 to 200 microseconds range compared to those filtered by Nhits.

If we then filter the Nhits results by a radius of 6m we find a similar result.

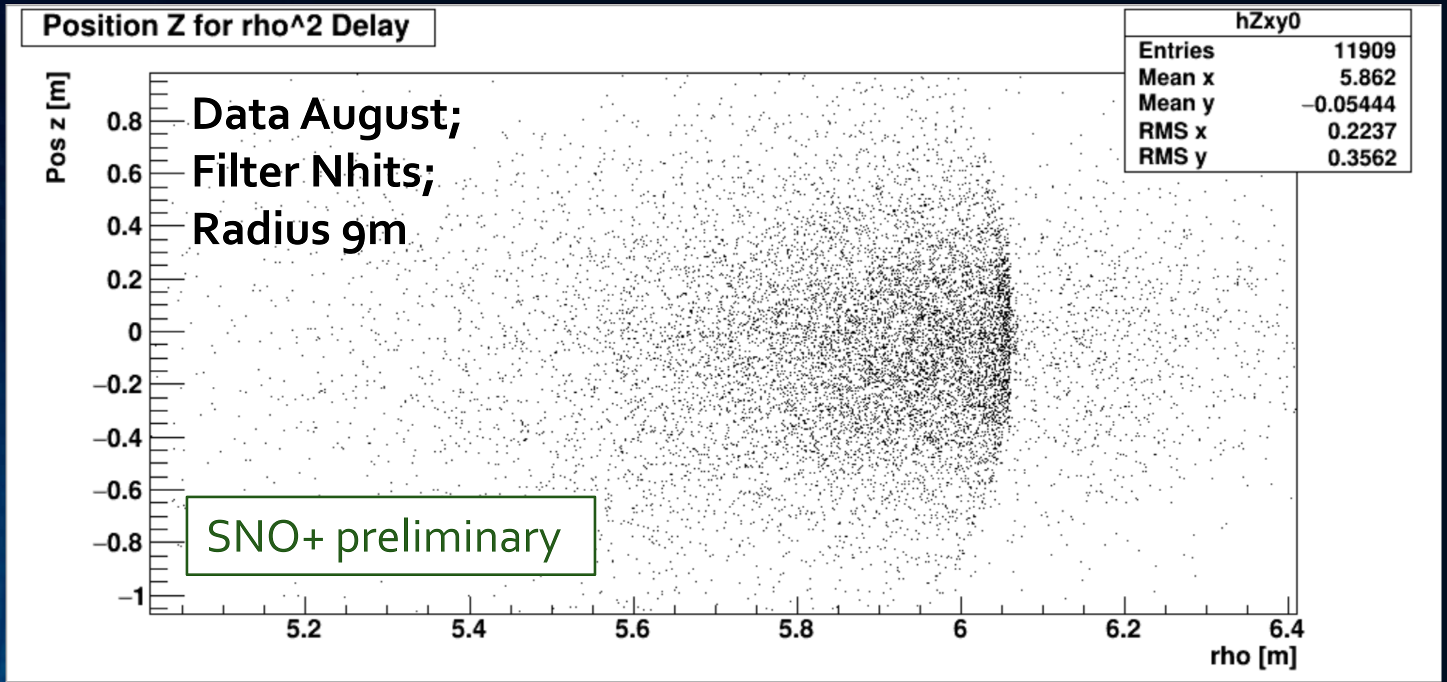


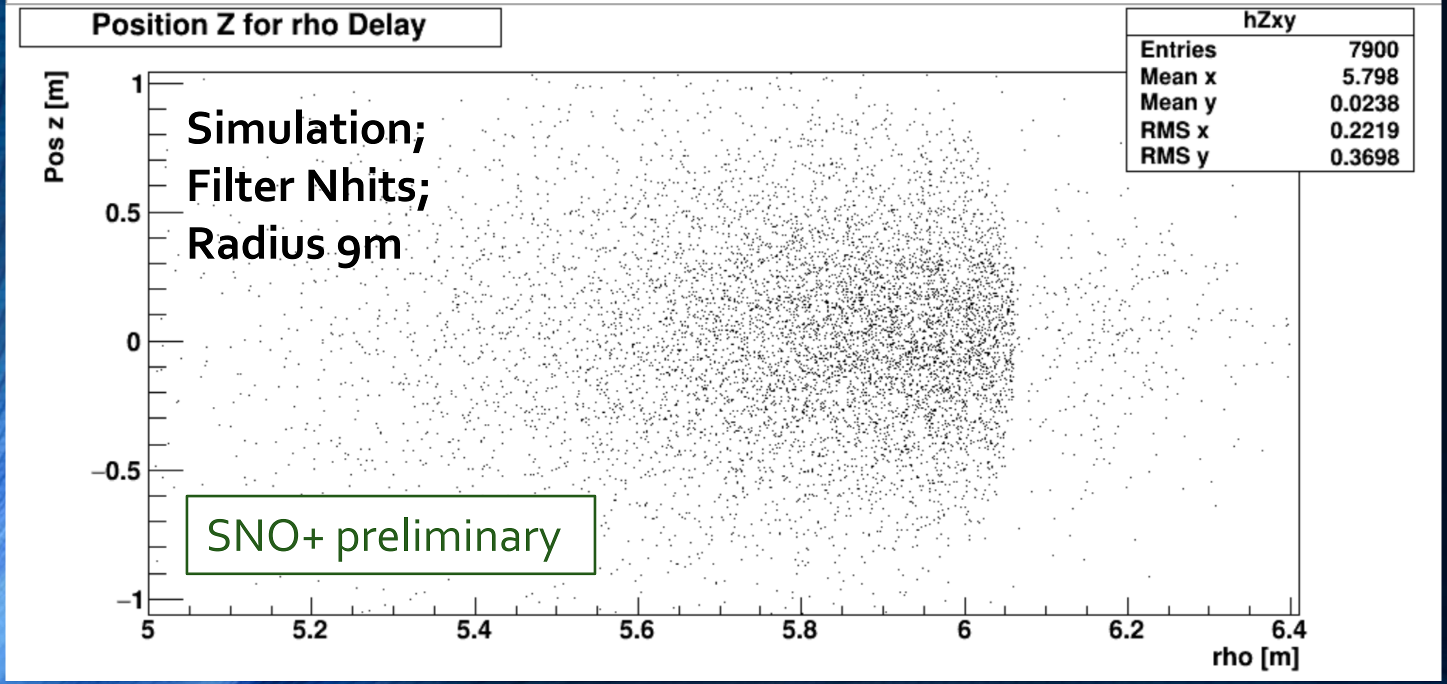
This shows that making any type of filter using only the calculated energy will be using “incomplete” data, especially in the 10 to 200 microseconds range where the events inside the acrylic vessel and the events outside the vessel are the most probable, the sum of all ranges give’s a much better exponential decay .



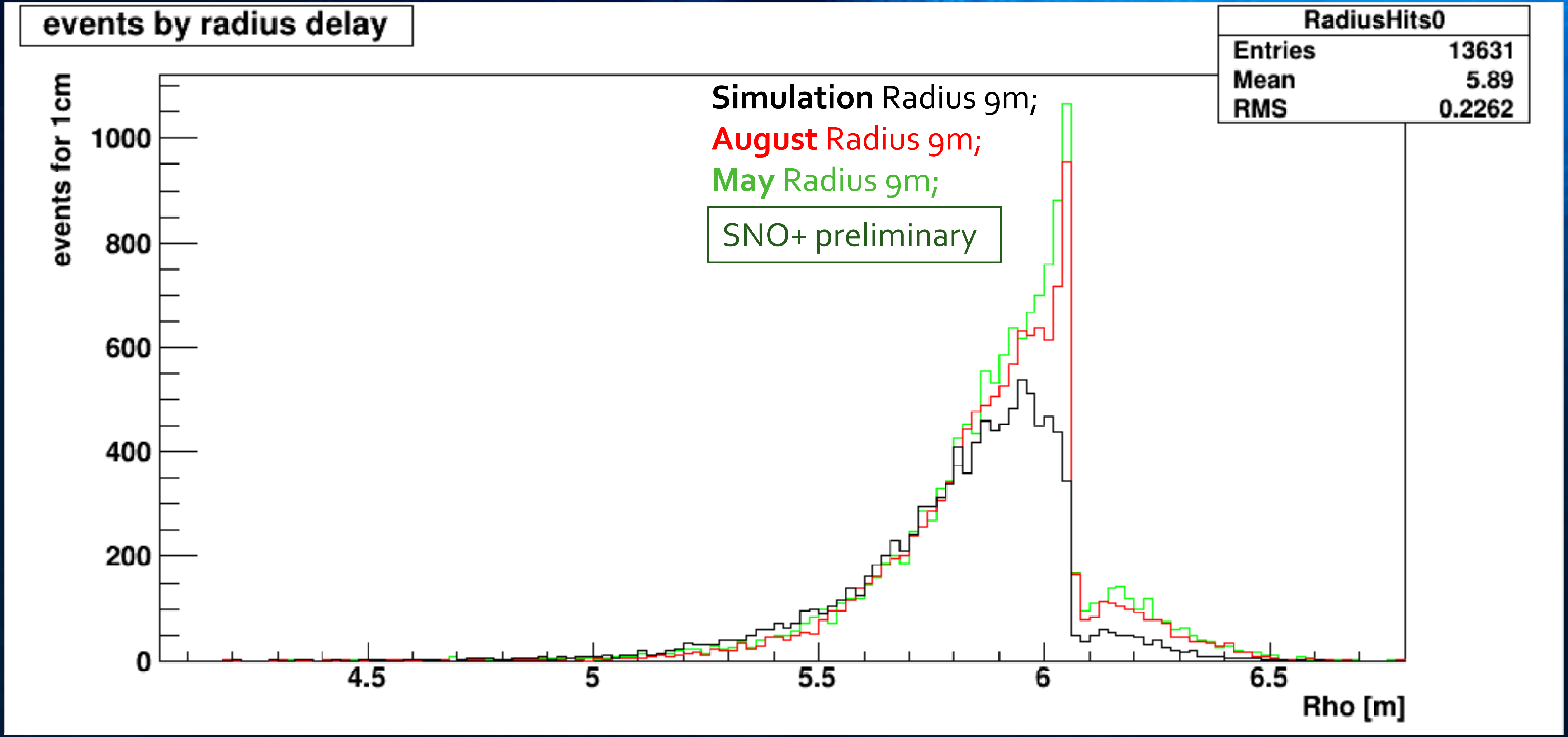


Starting by the "Time difference", which is the interval of time between the 2 events, where we see a very good simulated value, having the exponential constant between May and August constants and not leaving the statistical error brackets.

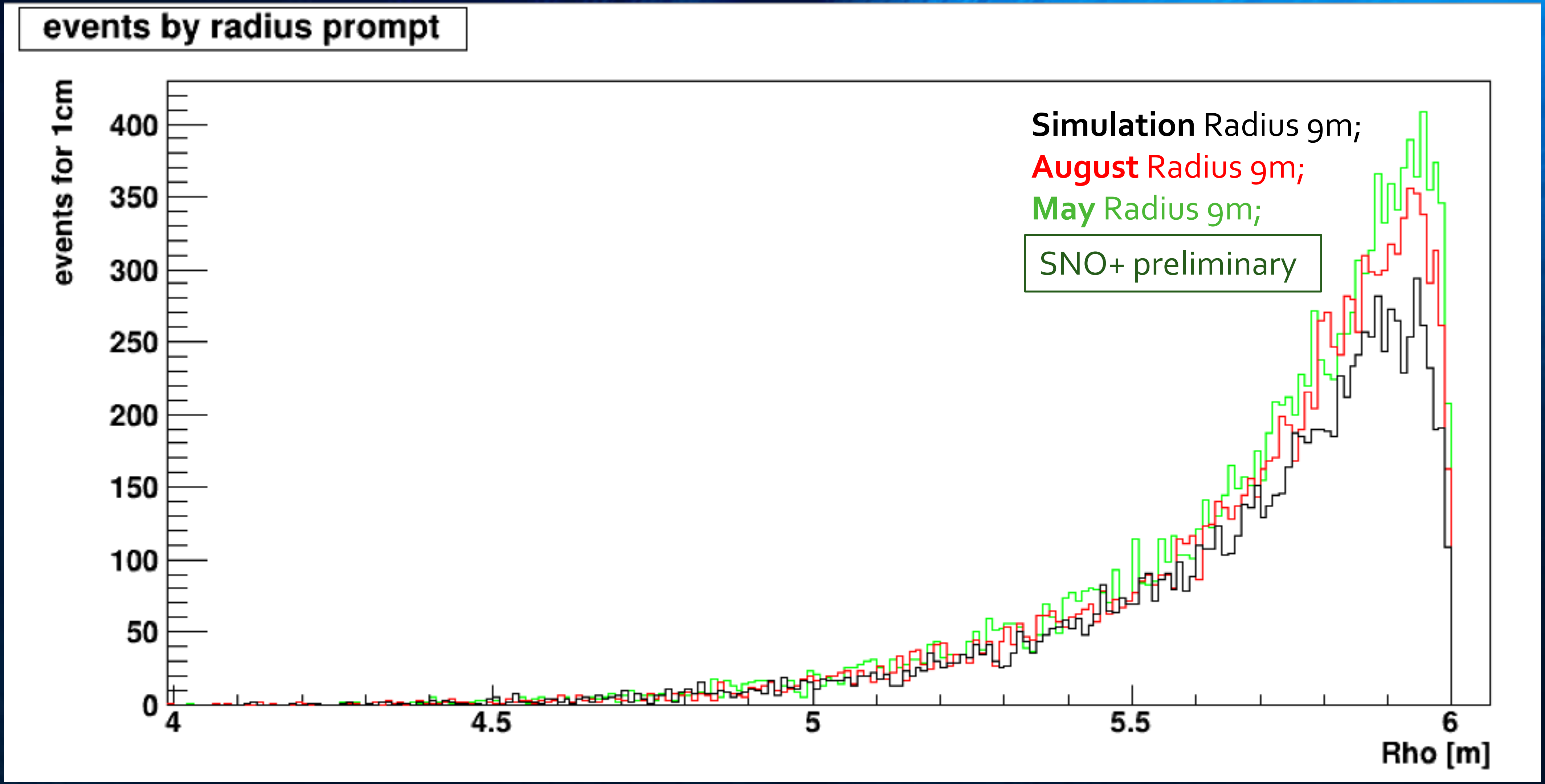




These graphs show that the higher concentration of delay events in the data happens in the outer layer of the acrylic.
When we look to the simulation there isn't any signal of the outer layer concentration that we see in the data.



The potential explanation of the different behavior between simulation and data at the acrylic border is a mismodeling of the optical properties of the acrylic itself therefor creating a difference in the efficiency of detection.



Even if the delay events distribution are badly represented in the simulation the prompt events are close to the data:

August Data exponential constant: K=3.503±0.037

May Data exponential constant: K=3.485±0.038

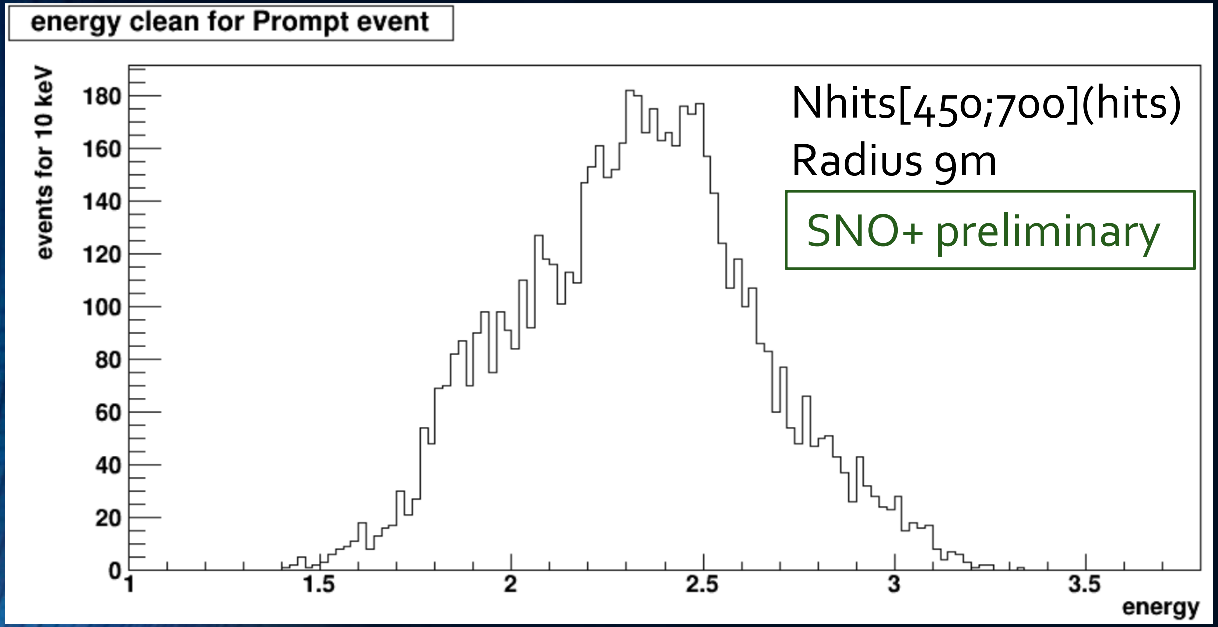
Simulation exponential constant: K=3.411±0.039

Thoughts and future work:

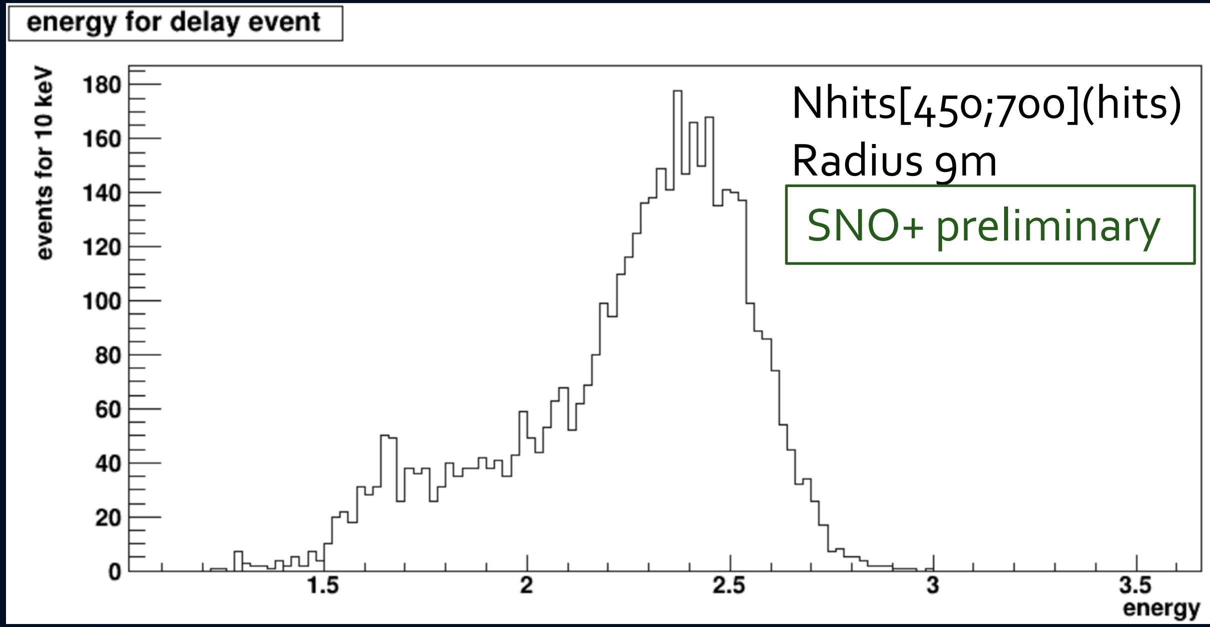
- Analyze other month data (November);
- Better understand the optical effects happening around the acrylic and see if they fit the data;
- Correct the energy response of the detector at larger radii to better match the data;

Additional coincidences

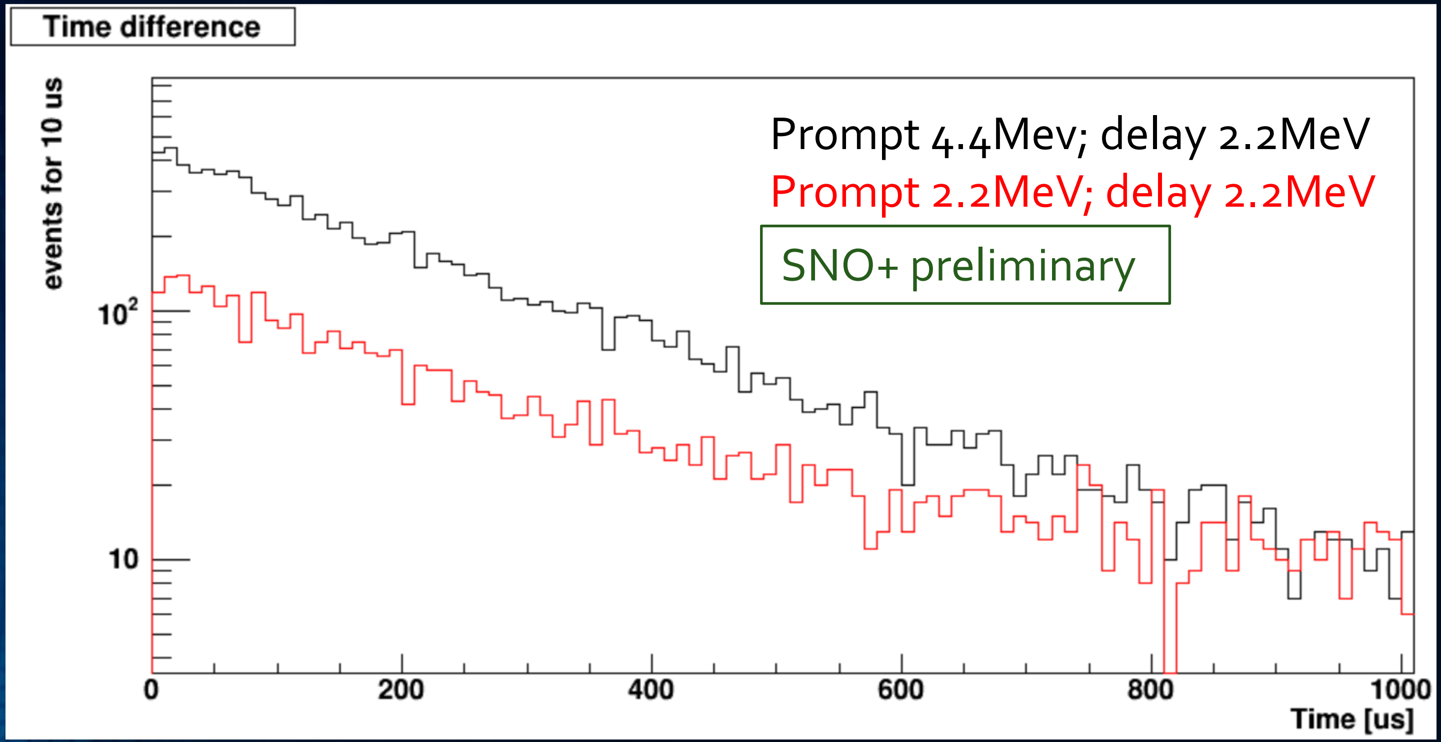
Prompt 2.2MeV



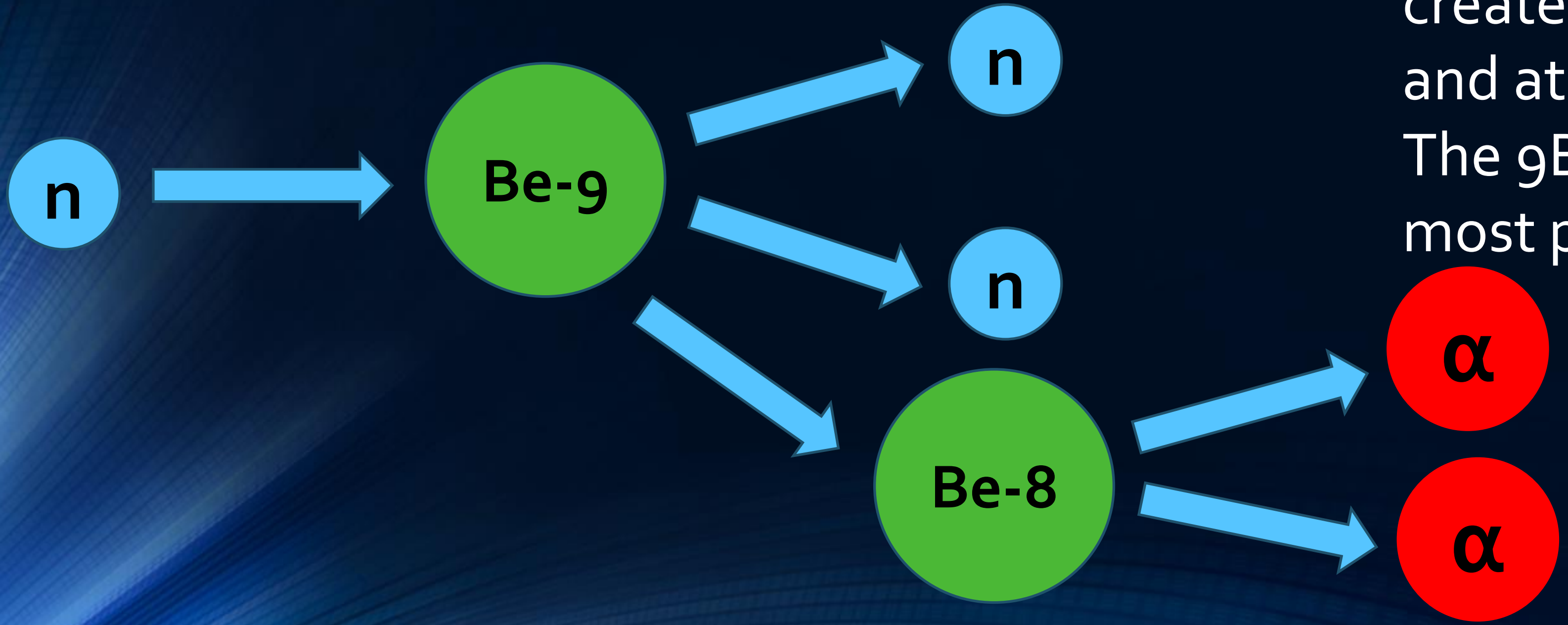
Delay 2.2MeV



Throughout the data analysis was found 2 2.2MeV gammas in coincidences in larger quantities than would be expected by chance, this meant that there was a reaction or chain of reactions emitting 2 or more neutrons close enough in time that they have been captured in coincidence.



When comparing the "Time difference" between a 4.4Mev prompt and a 2.2MeV prompt with the same delay target, a 2.2MeV gamma, we see that both have the same exponential constant, this means the (2.2MeV;2.2MeV) coincidence neutrons are created by the same reaction and at the same time.
The 9Be(n,2n) reaction is the most probable reason.



Thanks to Dra. S.Andriga for the tip