Neutron Backgrounds

Shaun Alsum

Strategy

- Simulate neutron energy depositions
- Cluster depositions
- Use libNEST to get S1c, S2c
- Find and implement necessary cuts
- Determine dimensionality of PDF needed and create it
- Find rates of things that can be compared to neutron background rate (i.e. NR double-scatters) and compare to data

Disclaimer about plots

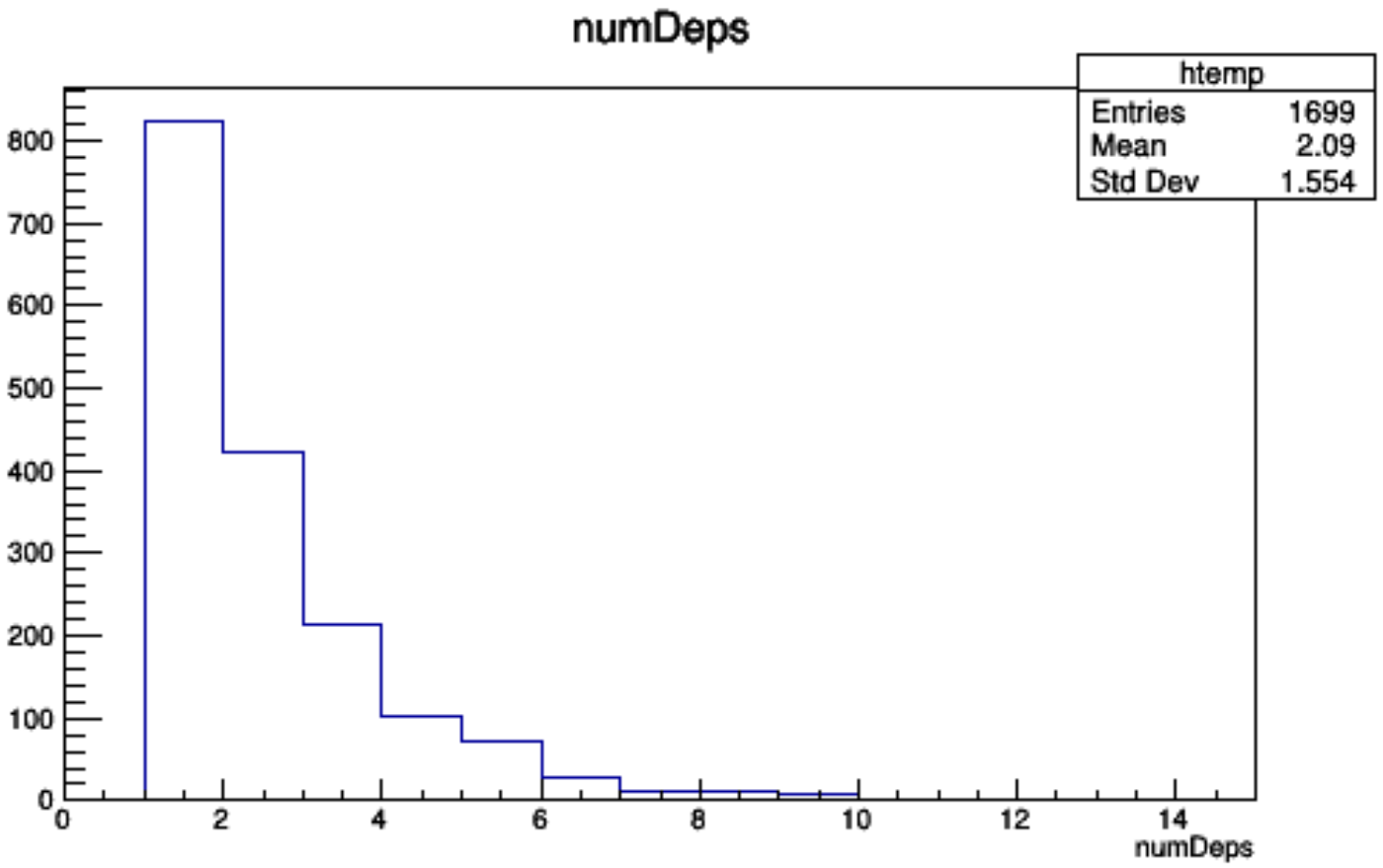
- All plots here are made using simulated data from one run of the neutrons originating in the PMTs as discussed previously. This run had 7681 events recorded, 1692 of which seem to have recorded a primary, but no actual energy deposits in the Lxe.

Multiple scatter distribution with cuts

Previously

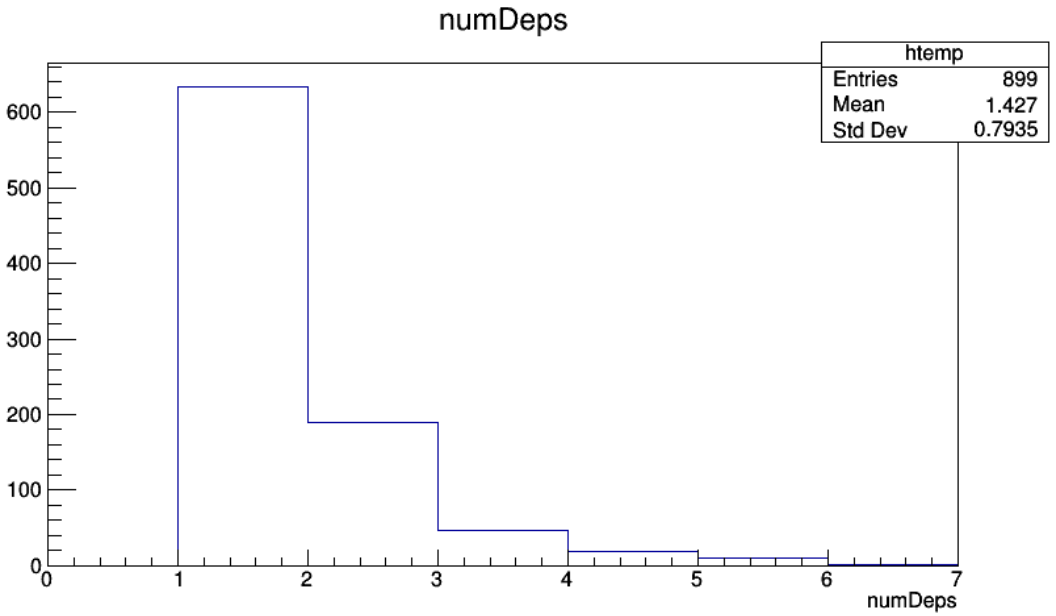
Includes all previously mentioned cuts *per deposition*. Probably not fully ideal way to do it, but first, naïve, thing to do.

Turns out this is probably really important

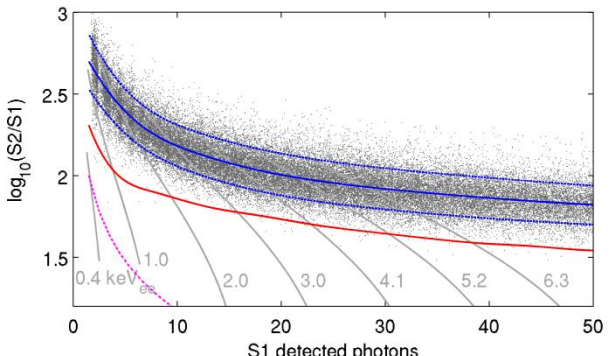


What happens if I add S2/S1 discrimination cut?

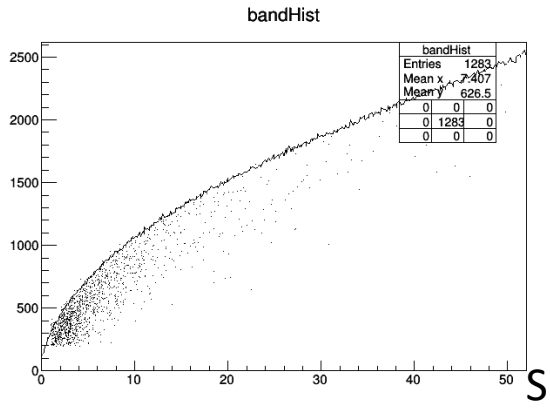
- Silly cut, just cut to include only events below NR band mean



Should have at most 50% acceptance. You can see that we go from ~8% to 6%. What's going on?

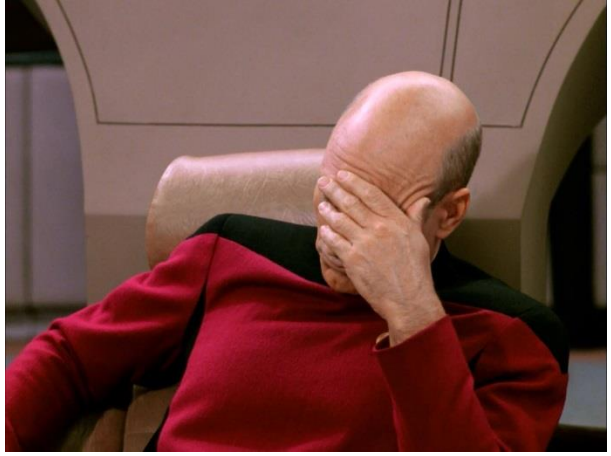


S2

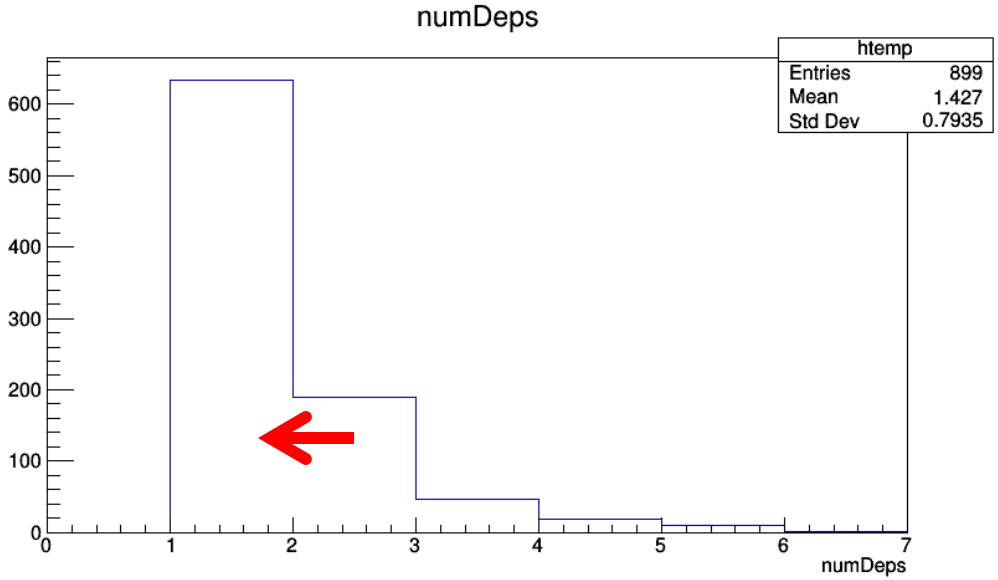


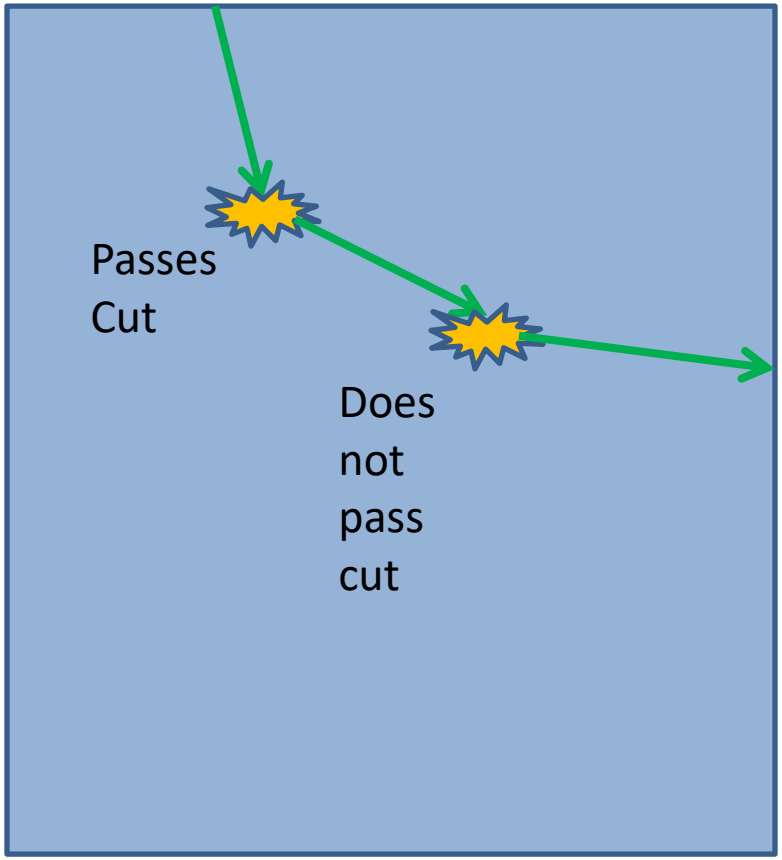
S1

Shaun's Folley



I haven't cut events like we would when we see data, I've only shifted them from one bin to another!





Instead:

- Cut only depositions that our detector won't even see.
- Cut entire *events* based on single/double scatter, *then* do other cuts on single only scatters.
- Still record double scatters so I can obtain ratio

Problem:

- Still need to tell if a multi-scatter is a neutron or is ER (gamma).
- S1s probably merged

Proposed Solution:

- Determine expected S1 from individual S2s
- Compare total measured S1 to the sum obtained from above

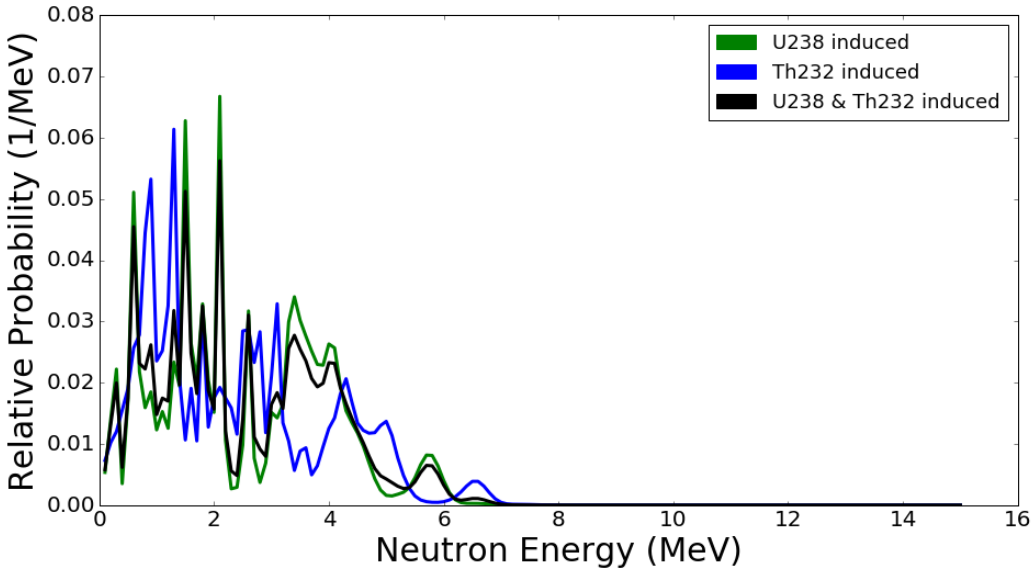
Pitfall: doesn’t account for gamma-x

From Previous Updates…

Considered Backgrounds

- PMTs
  - Neutrons from (alpha, n) from U238 chain alphas
  - Neutrons from (alpha, n) from Th232 chain alphas
  - Neutrons from U235 fission
- PTFE
  - Neutrons from (alpha, n) from Po210 (U238 late) chain alphas

Background Energy Spectra - PMTs

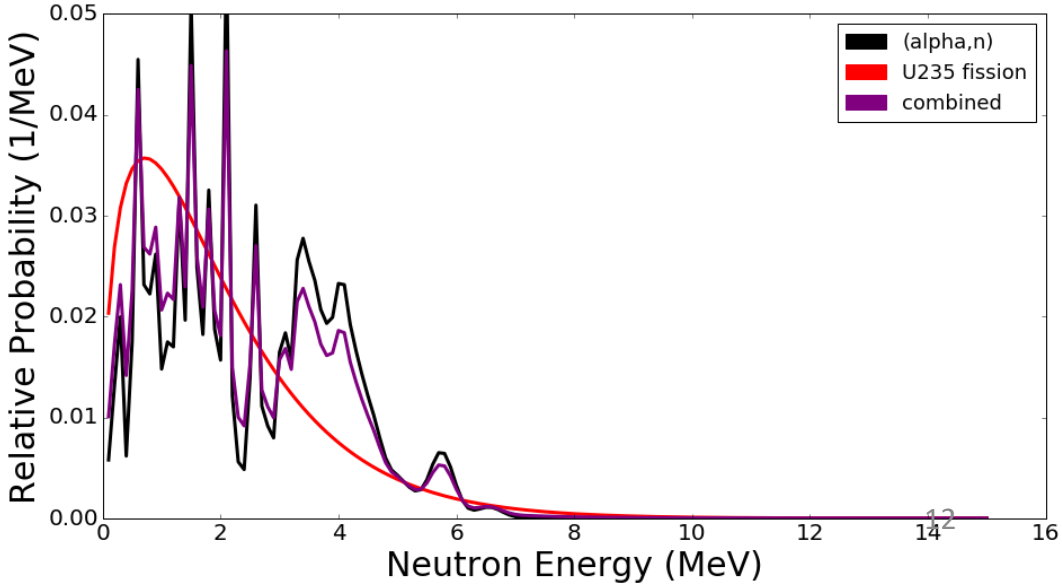


(alpha, n) from neutronyield.usd.edu

With the following concentrations

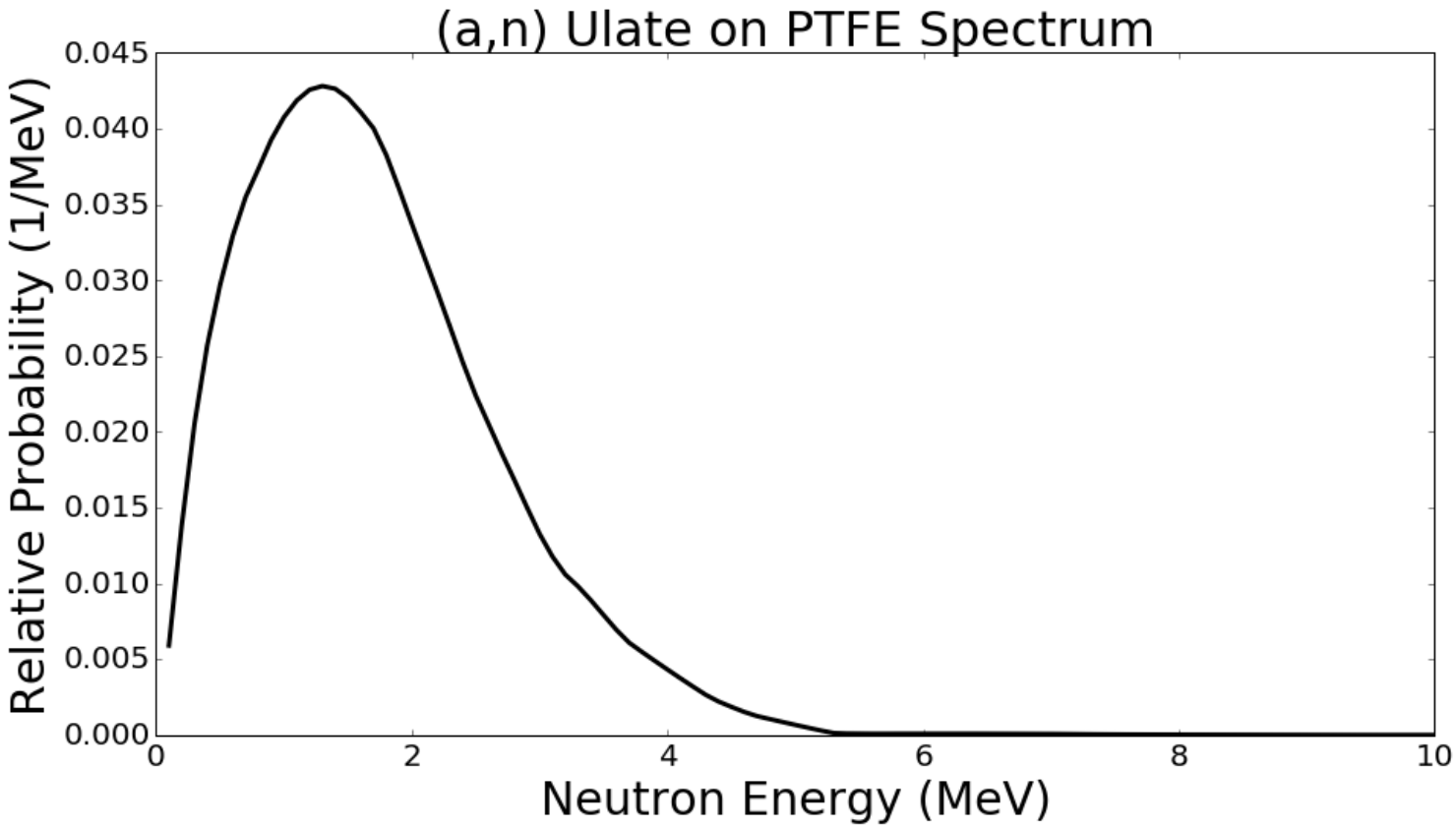
Compound	Mass [g]	(α,n) Yield [n/mBq/yr] ^{238}U	(α,n) Yield [n/mBq/yr] ^{232}Th	(α,n) Neutron Rate [n/PMT/yr] ^{238}U	(α,n) Neutron Rate [n/PMT/yr] ^{232}Th	(α,n) Neutron Rate [n/PMT/yr] Total
B2O3	4	1.17	0.950	2.67E-01	6.13E-02	3.28E-01
Al2O3	15	0.219	0.271	1.86E-01	6.55E-02	2.52E-01
Fe	63	0.0134	0.0426	4.78E-02	4.33E-02	9.11E-02
SiO2	26	0.0272	0.0303	4.02E-02	1.27E-02	5.29E-02
Na2O	1.3	0.329	0.322	2.43E-02	6.76E-03	3.10E-02
Co	13.6	0.0148	0.0524	1.14E-02	1.15E-02	2.29E-02
Li2O	0.22	0.764	0.554	9.54E-03	1.97E-03	1.15E-02
Cr	1.8	0.0502	0.187	5.13E-03	5.42E-03	1.06E-02
Al	0.26	0.402	0.502	5.93E-03	2.11E-03	8.04E-03
Mn	0.4	0.0378	0.100	8.59E-04	6.48E-04	1.51E-03
Ni	41	2.01×10^{-4}	1.45×10^{-3}	4.68E-04	9.62E-04	1.43E-03
Si	0.21	0.0449	0.0522	5.35E-04	1.77E-04	7.12E-04
BaO	0.44	1.22×10^{-3}	1.17×10^{-3}	3.06E-05	8.28E-06	3.88E-05
C	0.008	0.0306	0.0278	1.39E-05	3.59E-06	1.75E-05
S	0.0051	5.01×10^{-3}	7.63×10^{-3}	1.45E-06	6.28E-07	2.08E-06
Zr	0.042	5.34×10^{-6}	9.10×10^{-5}	1.27E-08	6.17E-08	7.44E-08
P	0.0068	5.16×10^{-8}	5.26×10^{-7}	1.99E-11	5.78E-11	7.77E-11
			Sum ((α,n) only)	**0.60**	**0.21**	**0.81**
			Sum ((α,n) + fission)	**0.93**	**0.21**	**1.15**

U238 fission from a parameterization I found in a lecture online…
https://indico.cern.ch/event/145296/contributions/1381141/attachments/136909/194258/lecture24.pdf



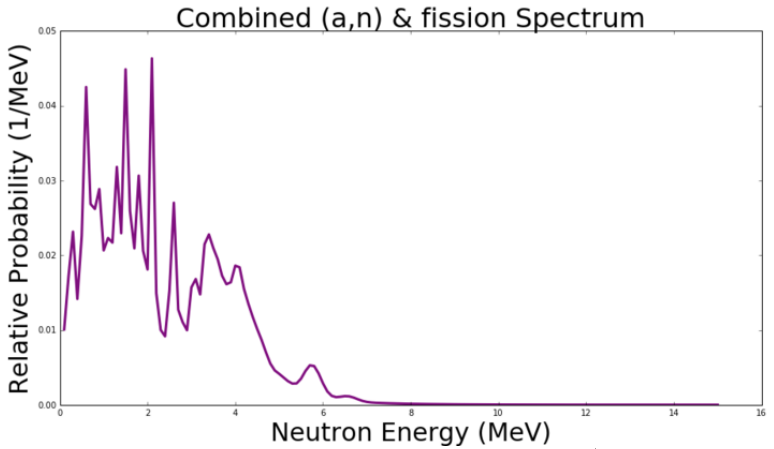
Background Energy Spectra - PTFE

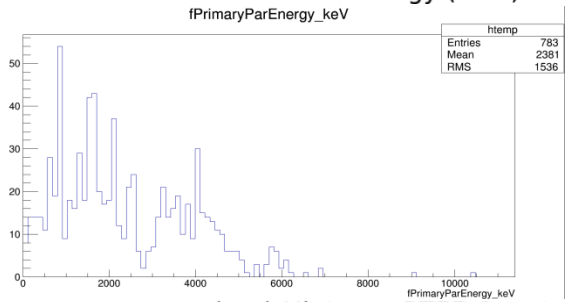
From Paolo…

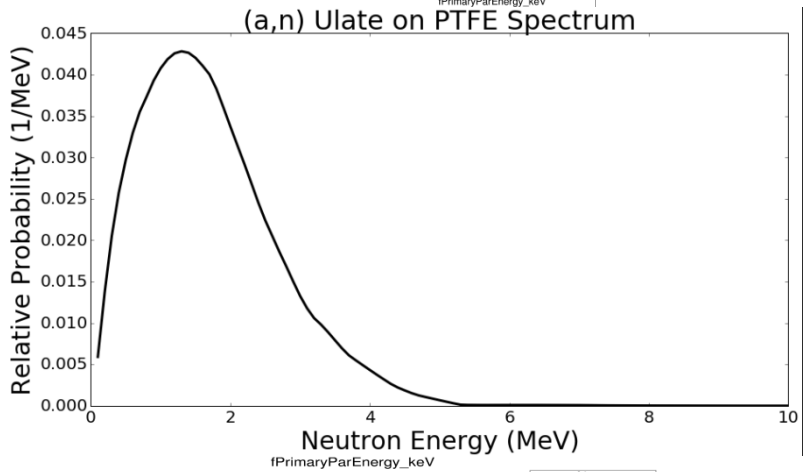


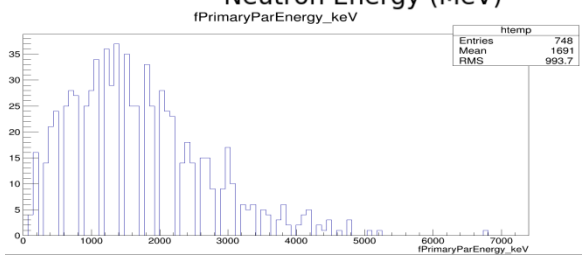
What was actually simulated?

- All components of PMTs, but all neutrons originating in the PMT window.
- All PTFE is the source (specifically, anything with PTFE in the name in LUXSim…)
- Discrete energies normalized to approximate the correct spectrum.









Current status

- 490,000 Energy deposition only sims of PMT backgrounds run (batches of 10,000, one must have failed)
- PTFE ready to run (I think), but haven't actually been run (error in first submission).

Future work

- Clustering
- Further determine what the detector would see for each event (an average of 29 interactions occur in LXe for each neutron, most of which deposit some energy, maybe mostly taken care of with clustering, maybe not)
- libNEST -> S1c, S2c PDFs for each spacetime bin (time bin and z-slice)

The Macros

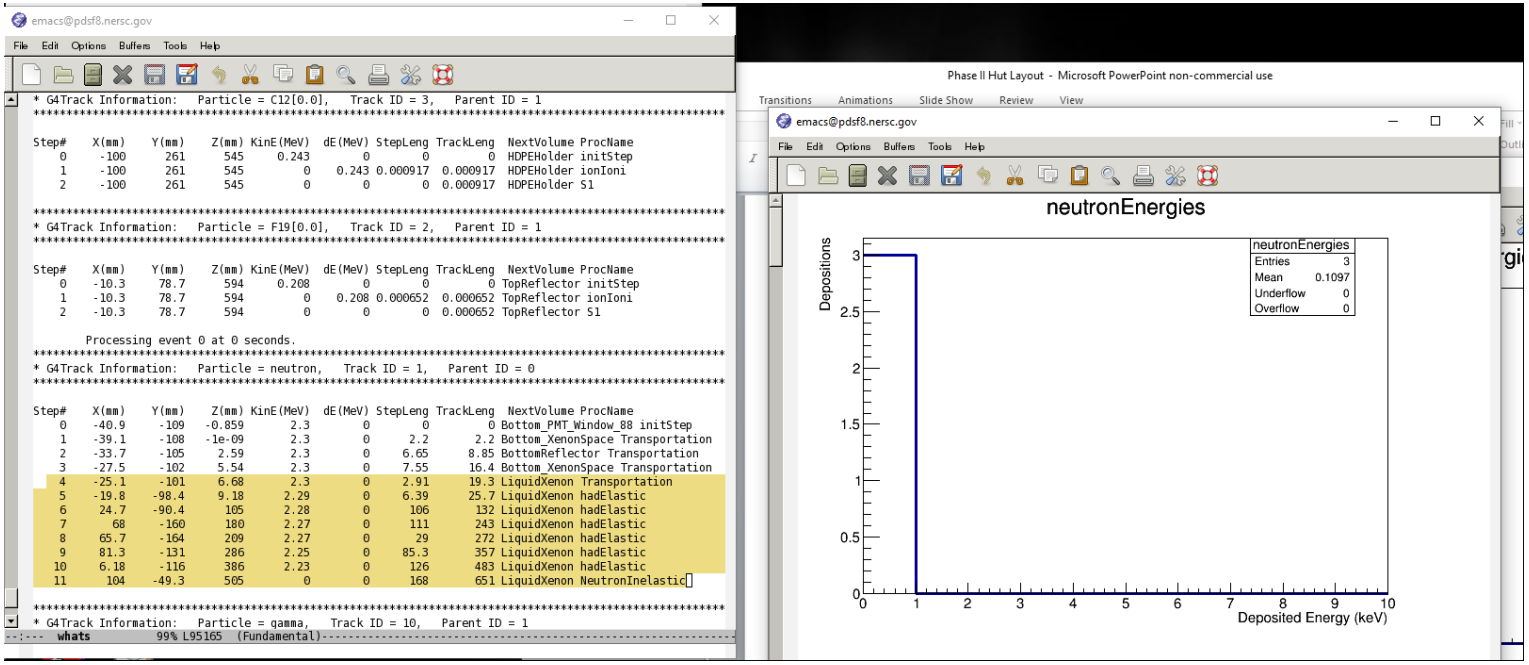
PMT Macro

```
# I need to do this
/run/initialize
# set how frequently the sims will update it's progress, i.e. every n events
/LUXSim/io/updateFrequency 100
# choose a directory to which to save the output
/LUXSim/io/outputDir .
# choose name of output files
/LUXSim/io/outputName PMT_an_
# geometry?
/LUXSim/detector/select 1_0Detector
# no grids (faster and not doing optics or activity from them)
/LUXSim/detector/gridWires off
# no cryostand
/LUXSim/detector/cryoStand off
# I need to do this as well
/LUXSim/detector/update
# record energy deposits in the volume "LiquidXenon" (i.e., in the active xenon)
/LUXSim/detector/recordLevel LiquidXenon 2

# place source
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0100862457815 Bq/kg 0.1 MeV
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0172169043921 Bq/kg 0.2 MeV
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0231564684468 Bq/kg 0.3 MeV
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0141594862236 Bq/kg 0.4 MeV
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0225755162408 Bq/kg 0.5 MeV
/LUXSim/source/set PMT_Window SingleParticle_neutron 0.0425102014676 Bq/kg 0.6 MeV

(more of the same, a LOT more)


# optics off
/LUXSim/physicsList/useOpticalProcesses false
# set number of particles to simulate
/LUXSim/beamOn 10000

# later!
exit
```

PTFE is the exact same, but with PTFE in place of PMT_Window and different numbers.

Where have all the Neutrons gone?

- First thing to notice…
  - Can’t just look at neutron depositions.

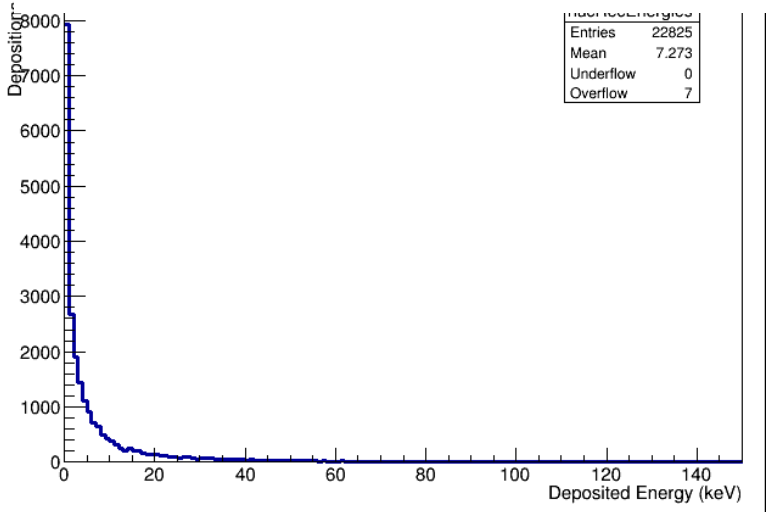


Neutron depositions above a certain energy are not counted, but instead have their energy imbued into heavy particles which instantly deposit their energy.

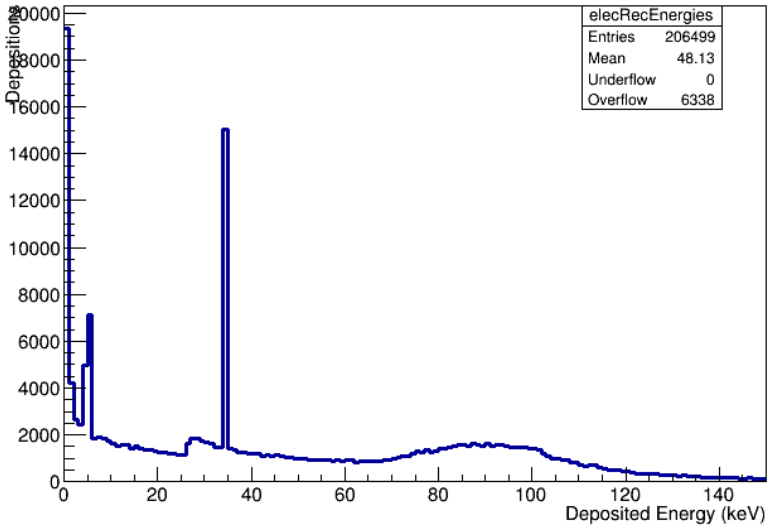
What are we going to do about it?

- Include both heavy particle (atom sized) as well as neutron depositions as NR.
  - This INCLUDES kinetic energy gained by heavy particles which gain their energy via decay after neutron capture.
- Call interactions from gammas, electrons, and positrons ER.
- Doing this, get the following spectra

Spectrum of all nuclear recoils



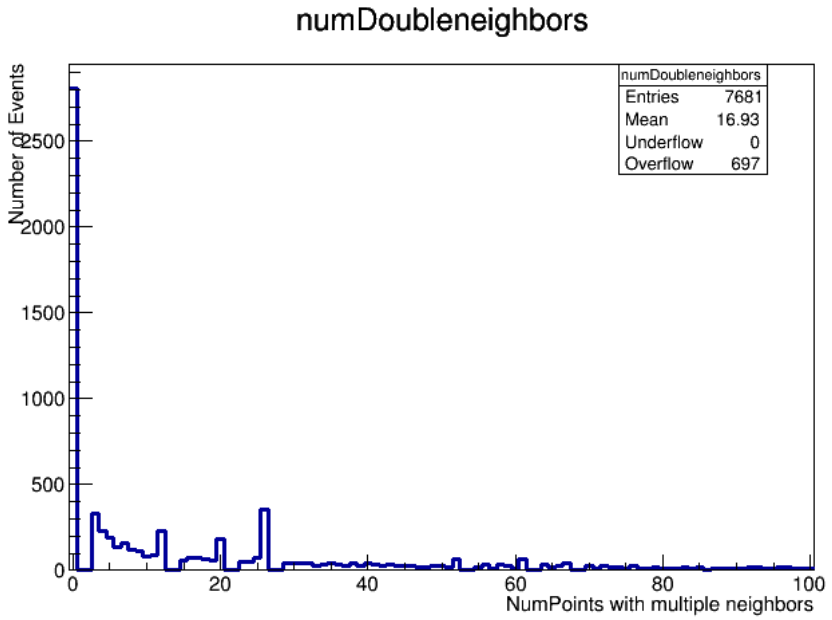
Spectrum of all electron recoils



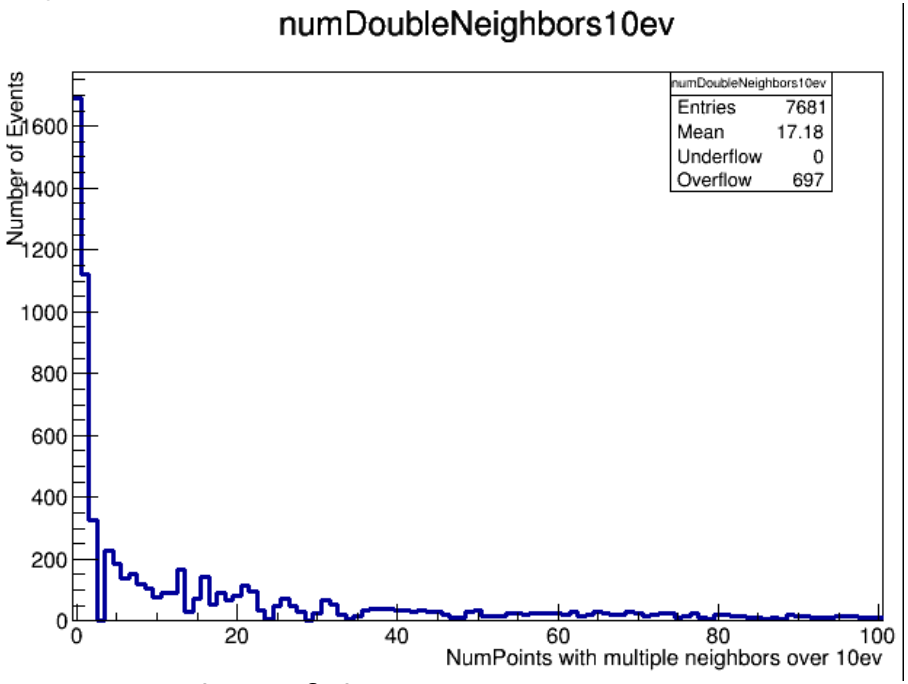
Do I need to practically worry about the case where a cluster would have more than 2 depositions?

- Yes

Maybe many of them are tiny and negligible? Nope.



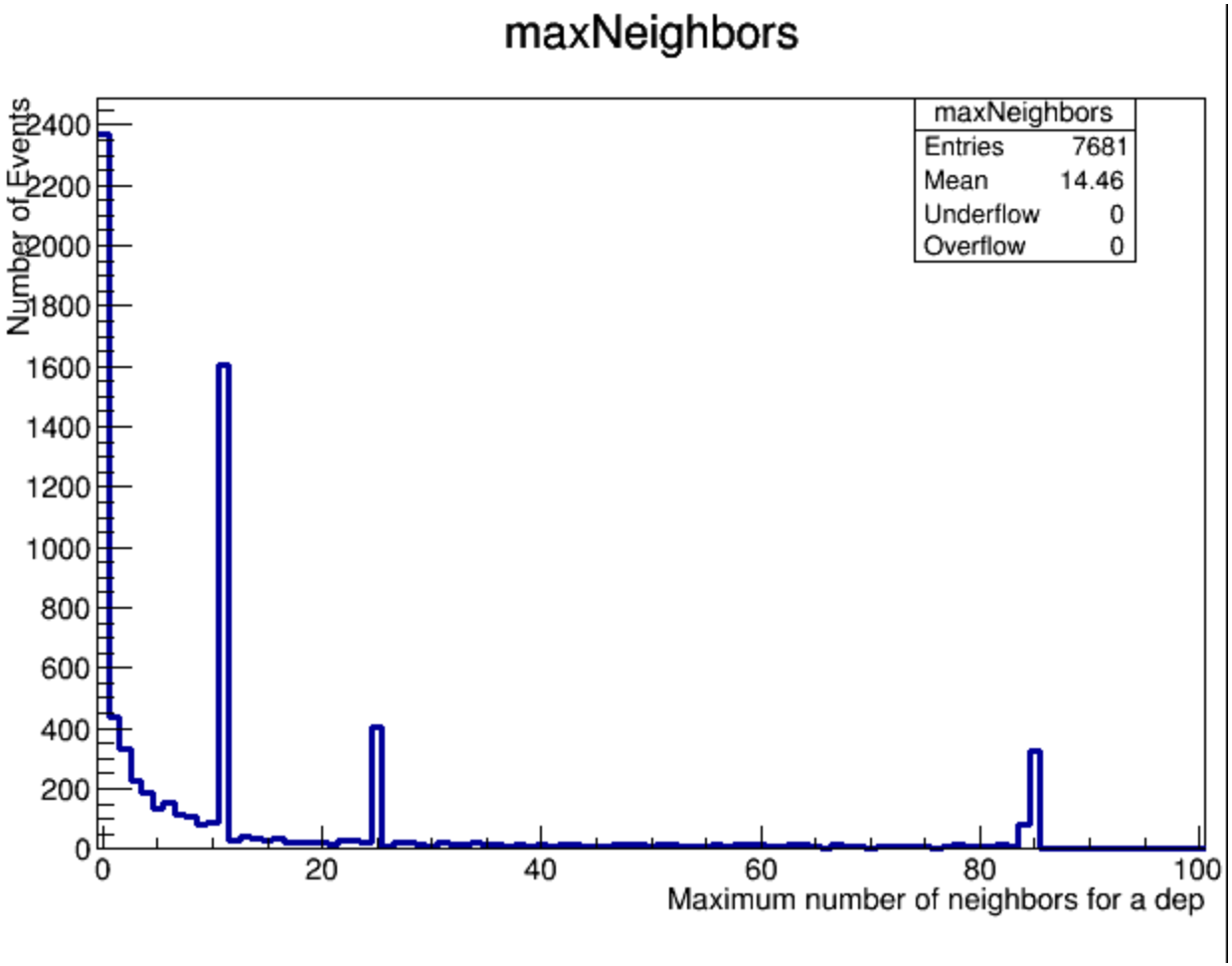
Number of depositions in a given event with two or more neighboring depositions within .5 cm



Number of depositions in a given event with two or more neighboring depositions within .5 cm *that deposit 10 eV or more.*

Do I somehow have to account for many, or can I cut it off at a few?

Must account for many.

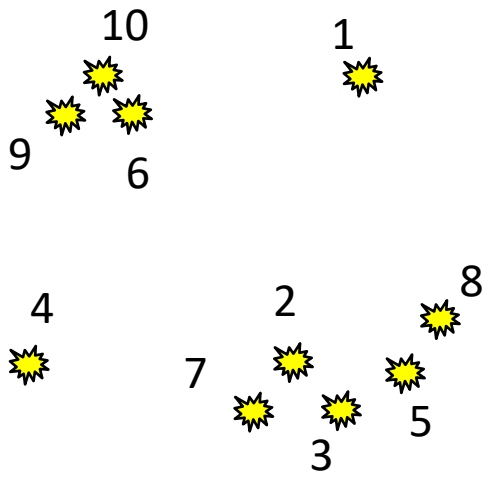


Number of depositions within 0.5 cm of the deposition with the most in any given event.

The Clustering algorithm

- Cluster into cylinders (right now $\Delta xy < 0.5$ cm, $\Delta z < 1$ cm)
- Pick a deposition,
  - add it to a cluster,
  - check around it for any others.
    - If found, add that one.
    - check around *that one* for any others
      - and add them continue on in this fashion.
      - Once no more are found, step back up to the last and keep searching.
- Once all in a cluster are found, start with another point (not in the cluster)
- Illustration on next slide.

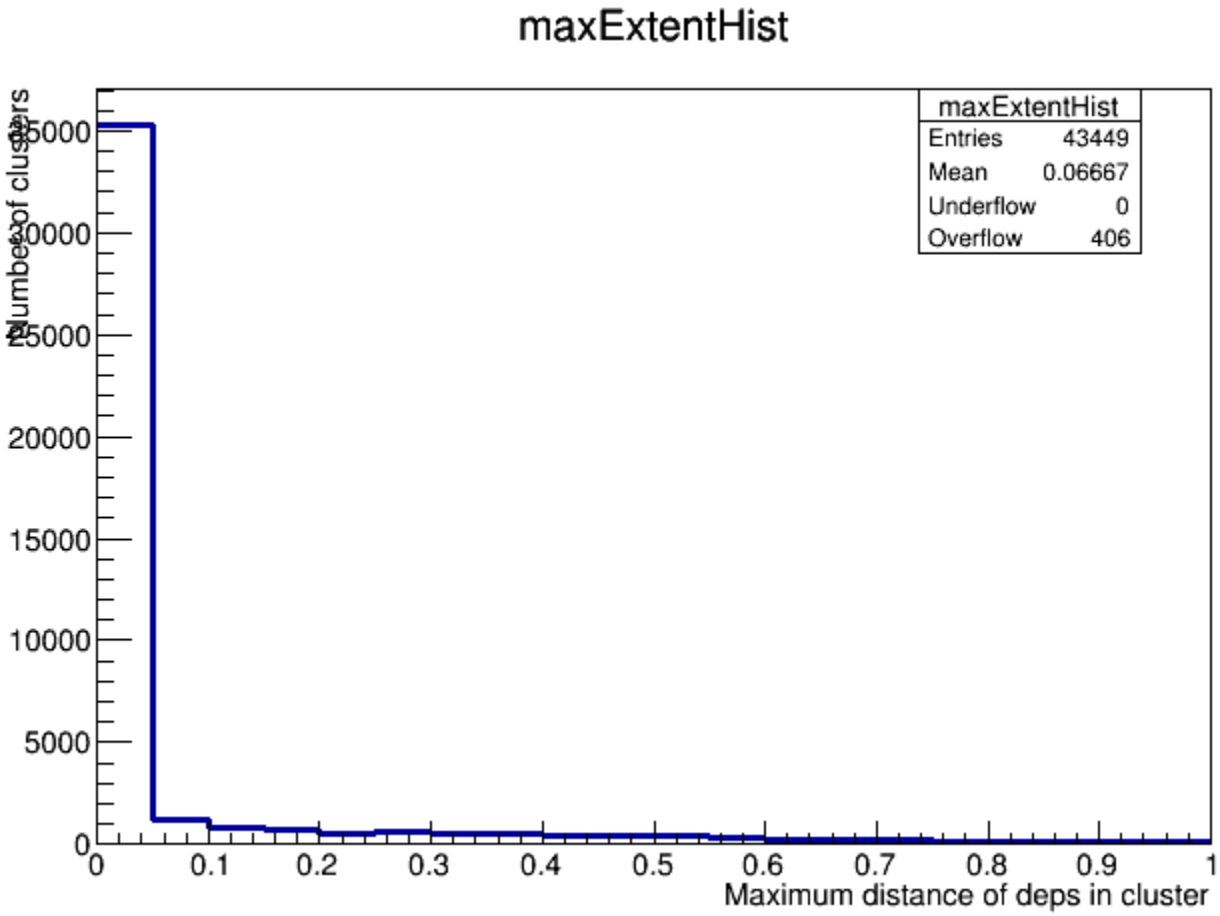
Clustering Algorithm illustration



1. Creates new cluster containing dep 1 (cluster 1)
2. No more neighbors. Marks dep 1 as clustered and moves on to a new point.
3. Creates new cluster containing dep 2 (cluster 2)
4. Looks around dep 2 for neighbors, finds dep 3, adds dep 3 to cluster 2
5. Looks around dep 3 for neighbors, finds dep 5, adds dep 5 to cluster 2
6. Looks around dep 5 for neighbors, finds dep 8, adds dep 8 to cluster 2
7. No more neighbors, resumes search around dep 5.
8. No more neighbors, resumes search around dep 3, finds dep 7, adds dep 7 to cluster 2.
9. No more neighbors. Marks deps 2, 3, 5, 8, and 7 as clustered and moves on.
10. Creates new cluster containing dep 4 (cluster 3)
11. No more Neighbors. Marks dep 4 as clustered and moves on.
12. Creates new cluster containing dep 6 (cluster 4)…

This can create a cluster out of chains, is this a problem?

- Fortunately, it doesn't seem like it.

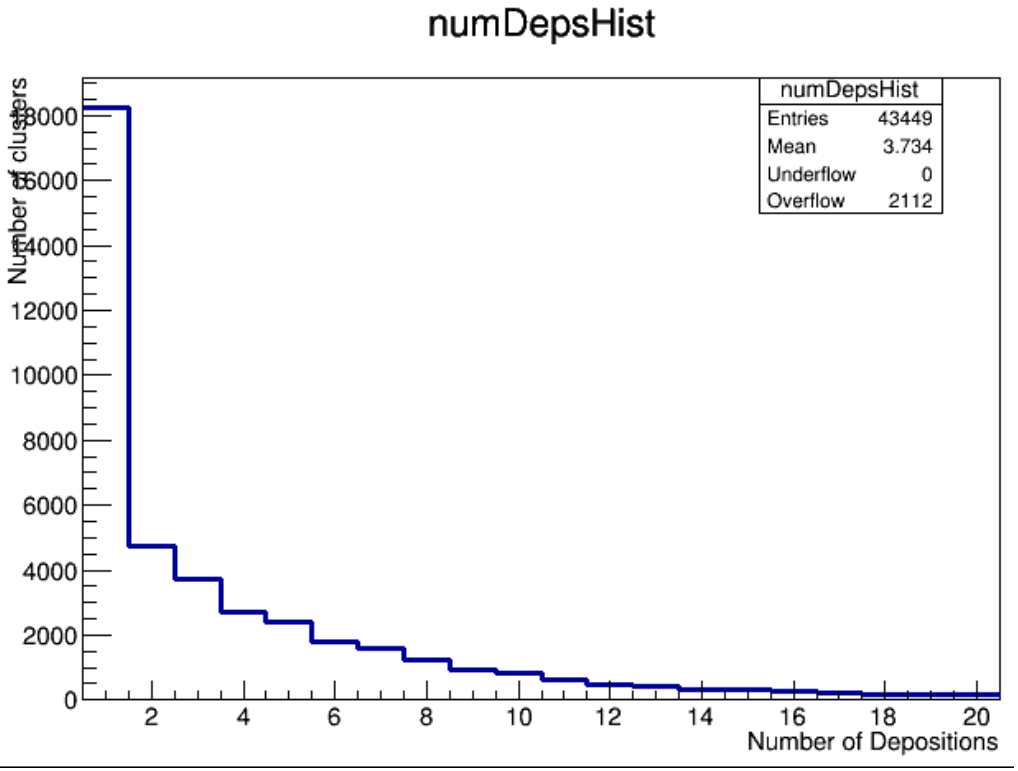


Distance (in cm) between the two most distant depositions in each cluster.

The vast majority are still very compact.

Then was this level of clustering sophistication really necessary?

- Maybe not… But the ability to include arbitrarily many depositions in a cluster *is* and is easy to accomplish with recursion.

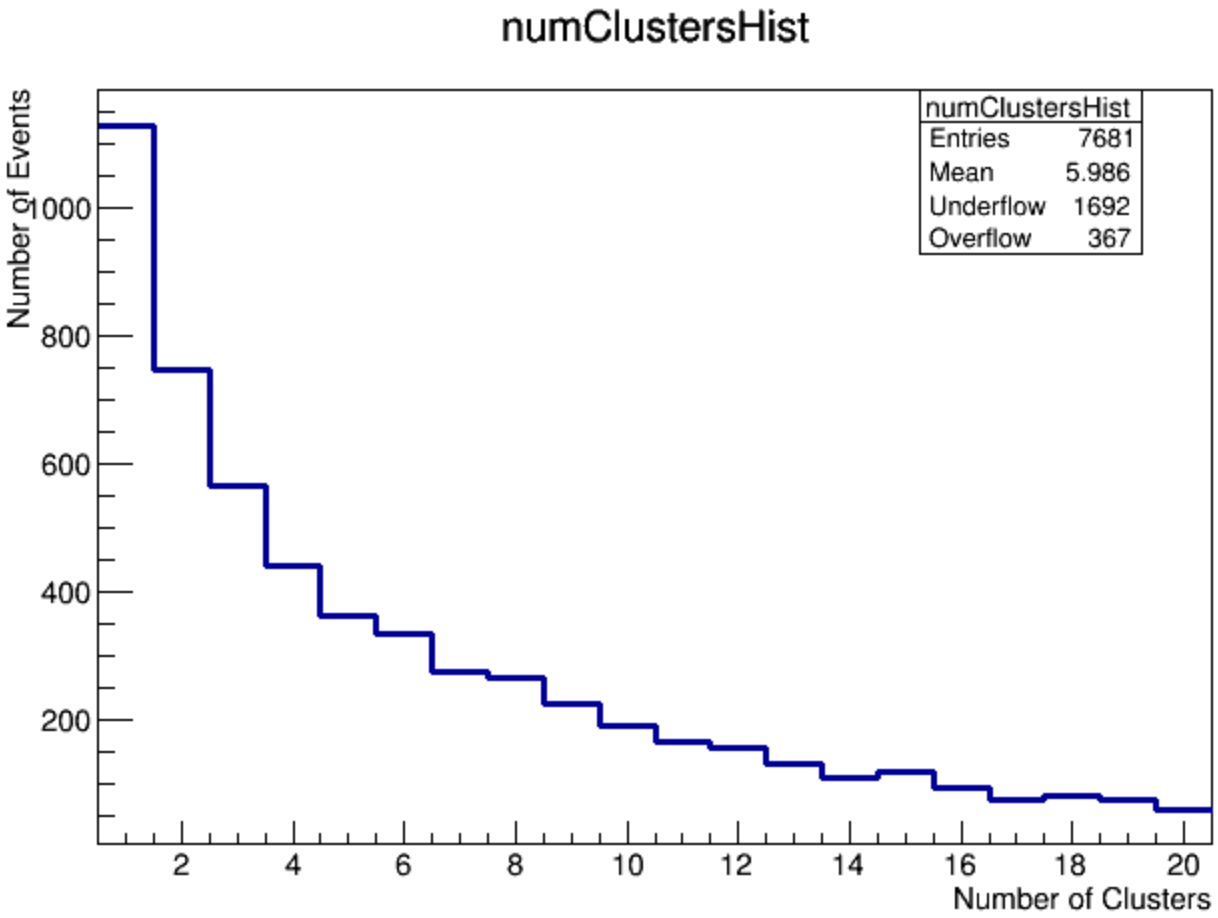


Number of depositions that make up each cluster.

Left-most bin is 1, and has the most, but comprises less than ¼ of all the depositions.

Numbers >2 are occur frequently

How many clusters are in each event, then?

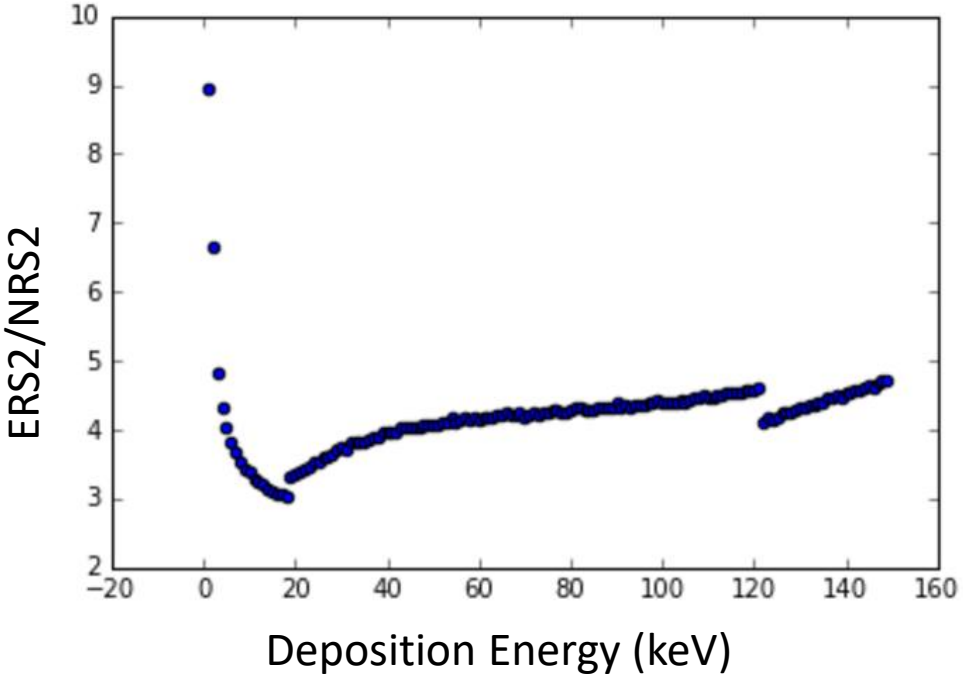


The number of clusters in each event.

The number that have enough energy to be detected has not yet been determined…

The unmentioned part of the clustering algorithm.

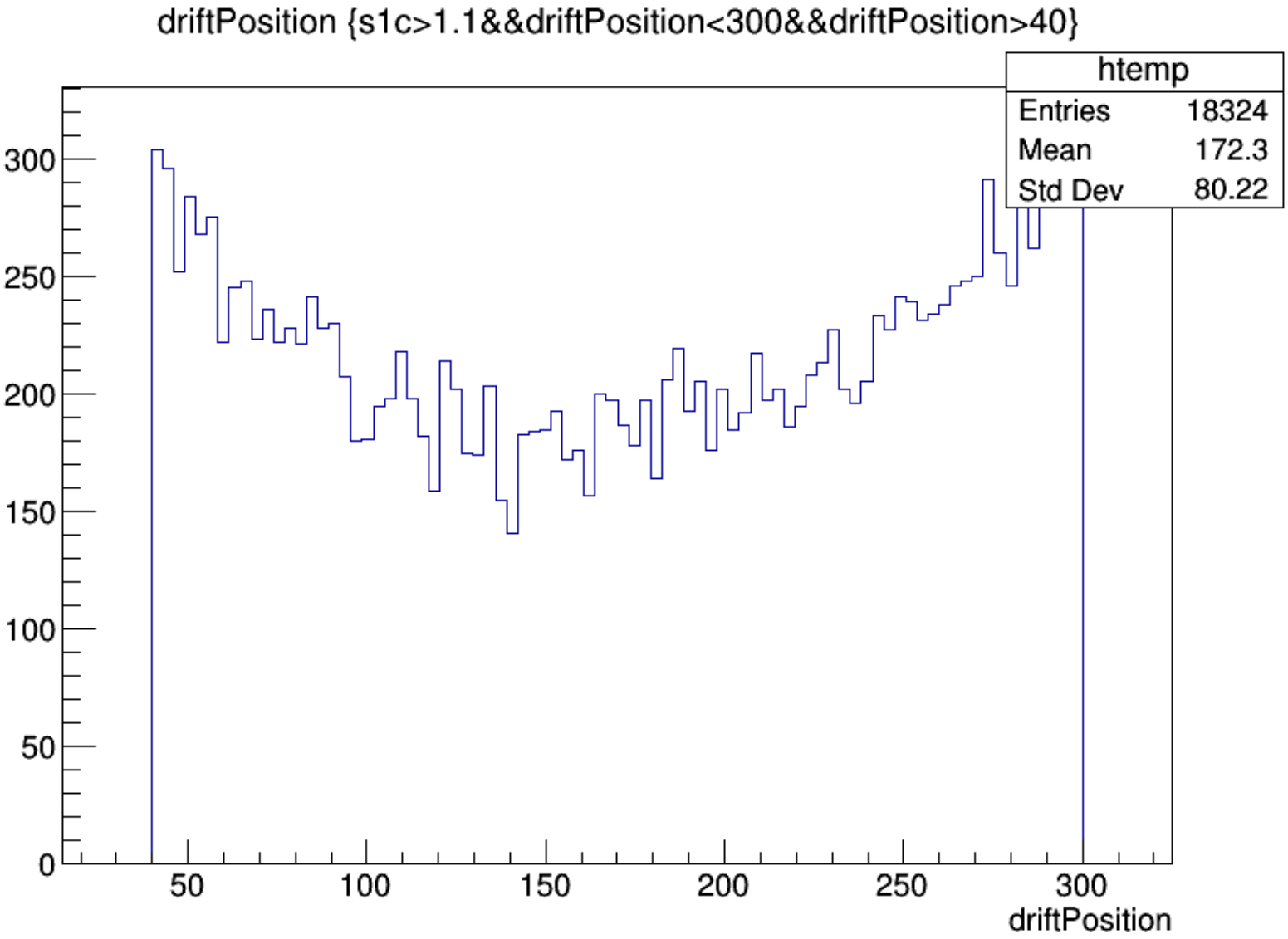
- Where should the cluster be?
  - The xy cluster position is determined by an expected-S2 weighted average in x and y
  - The z cluster position is determined to be at the location of the uppermost deposition in the cluster



- What is the cluster's energy?
  - Energy from NR are summed into an NR total energy.
  - Energy from ER are summed into an ER total energy.

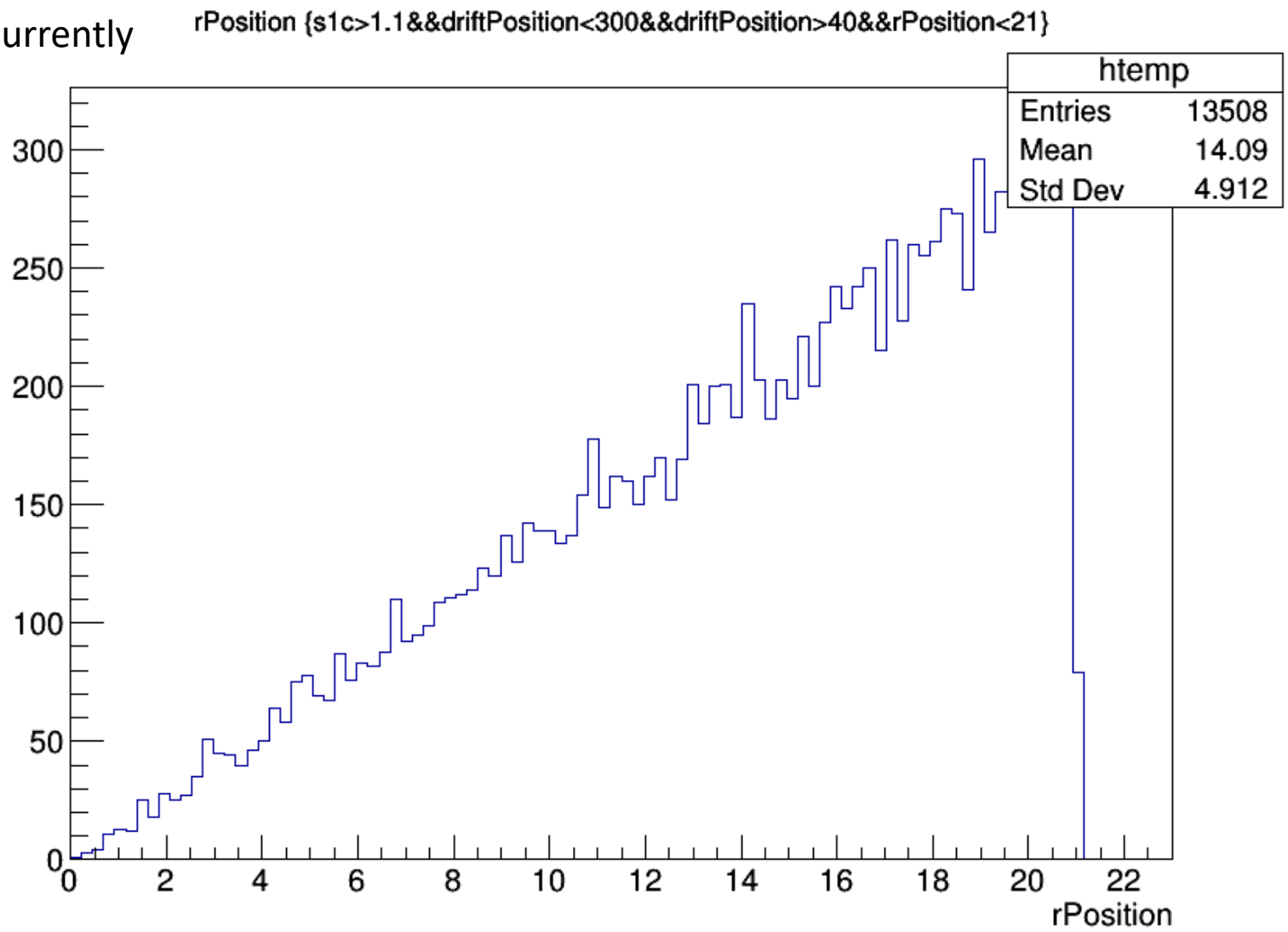
    This is because in the end what we want to simulate is the total S1 and S2 from the cluster, so the energy deposited via different methods needs to be distinguished.

Drift


driftPosition {s1c>1.1&&driftPosition<300&&driftPosition>40}
htemp
Entries 18324
Mean 172.3
Std Dev 80.22
300
250
200
150
100
50
0
50
100
150
200
250
300
driftPosition

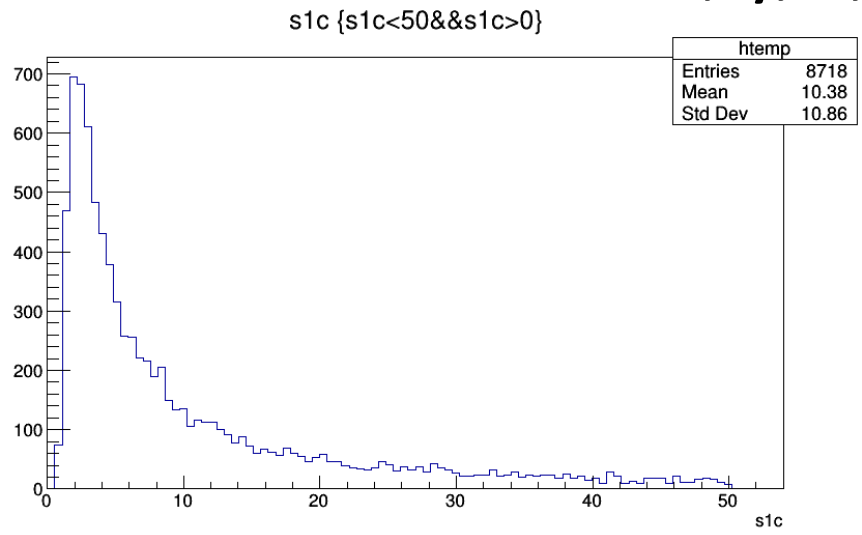
R

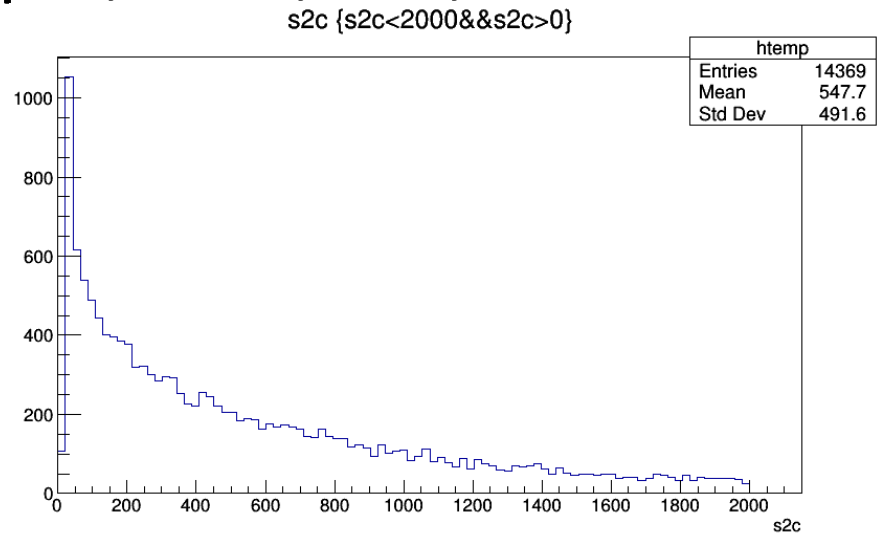
Recall only neutrons from PMTs currently



libNEST

- Run libNEST twice for each cluster.
  - Once with the NR energy in NR mode
  - Once with ER energy in ER mode
- Sum the S1c and S2c from the two runs
- Save file with x, y, z, r, phi, drift, s1c, s2c



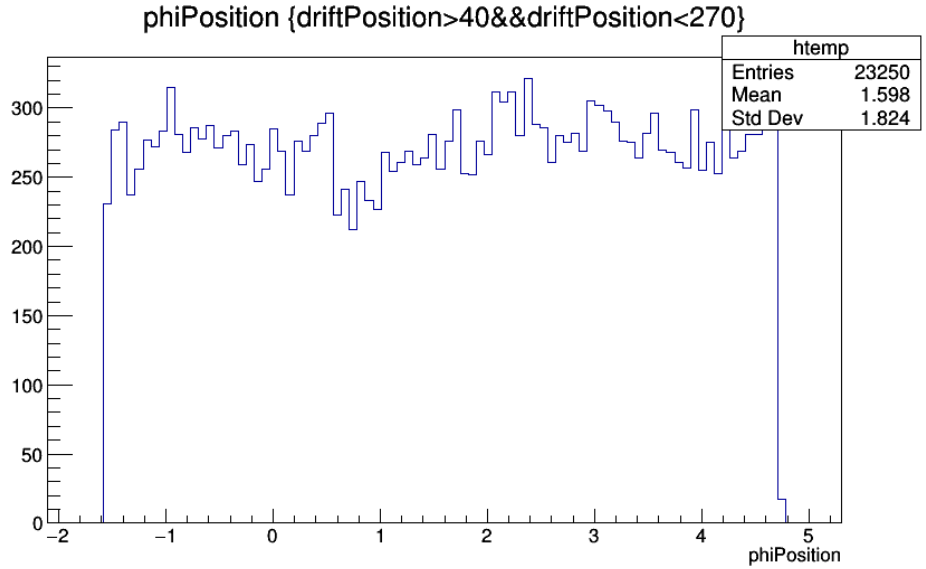


PDF creation

- 5-d PDF may well kill the PLR (drastic increase in integration time)
- Luckily, PDF is made in r, phi, drift_time, S1c, log(S2c). Phi seems uniform to within bin-scale inside fiducial volume.
- Should be able to

Make a 4x1-d PDF

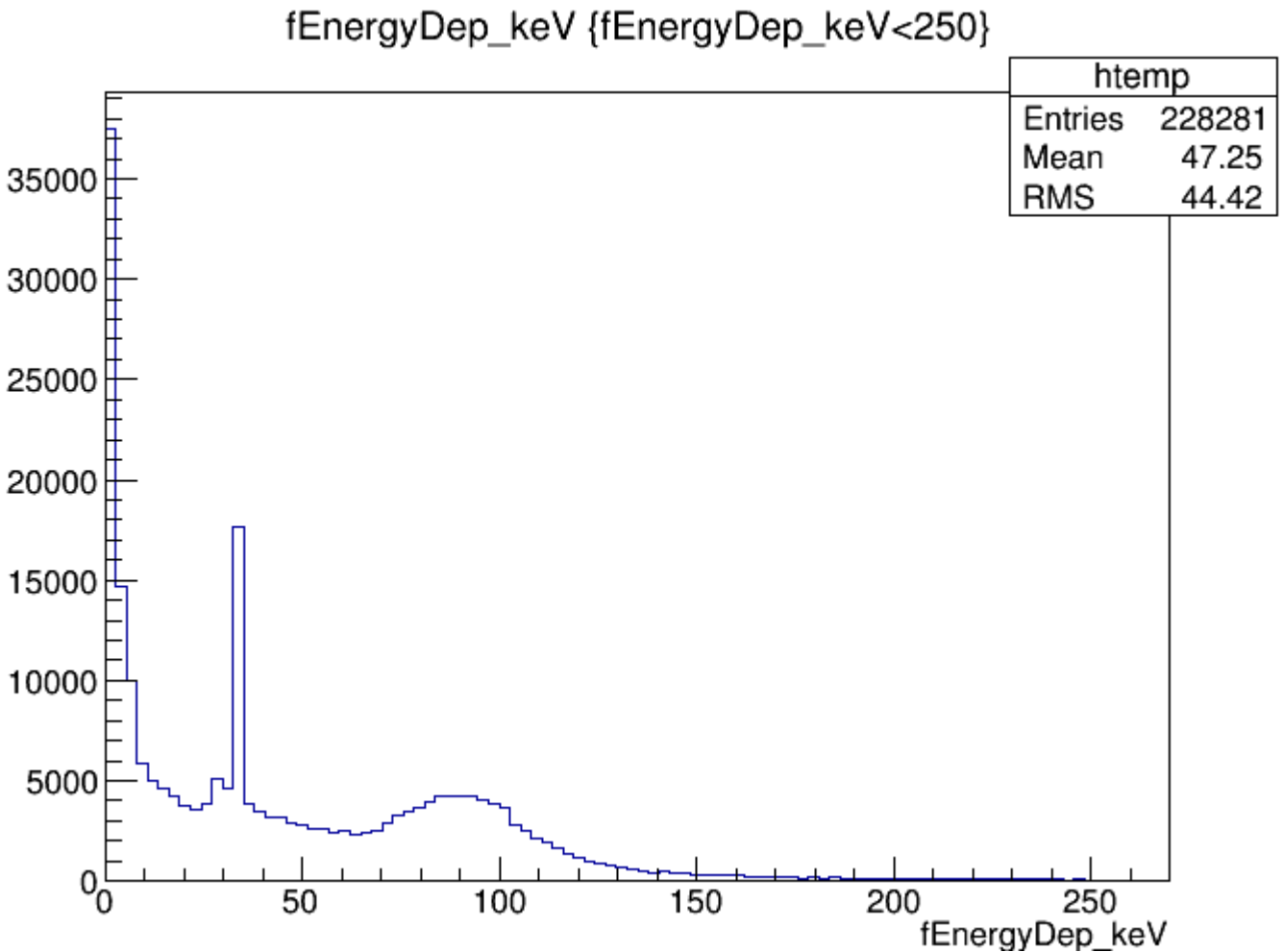
With uniform phi



Time cut studies

Peaks in the energy deposition spectrum

- Imagine they come from decay after neutron capture.



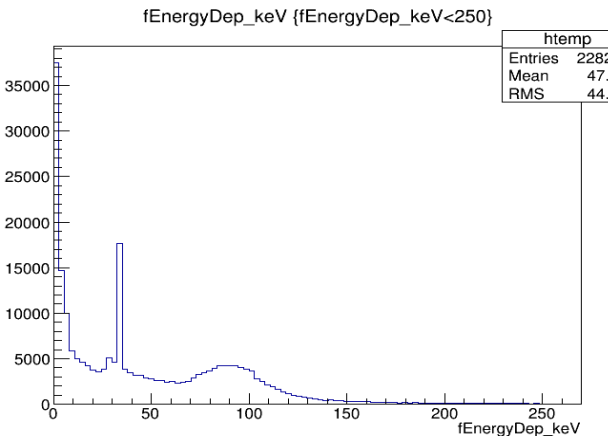
Time-cut

- If the process takes too long, it won't be seen as part of the initial event.
- Create a time-cut in Geant4 that kills a track if it takes longer than a certain amount of time.

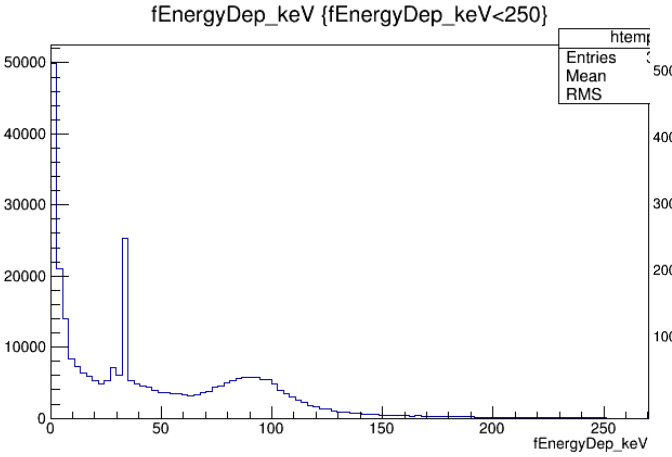
```
void LUXSimSteppingAction::UserSteppingAction( const G4Step* theStep )
{
        //      Initialize step specifics
        theTrack = theStep->GetTrack();

    if( luxManager->Get100keVHack() &&
           luxManager->GetLiquidXenonEnergy() > luxManager->Get100keVHack() )
        theTrack->SetTrackStatus( fStopAndKill );

    else if( luxManager->GetKillTime() > -1 && luxManager->GetKillTime() < theTr
ack->GetLocalTime()){  // used to be Global time but that had weird behavior
      theTrack->SetTrackStatus(fStopAndKill);
    }
```

See what happens…

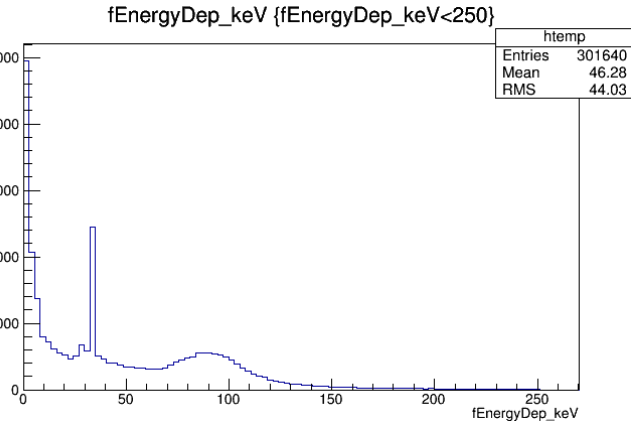
No Time-cut



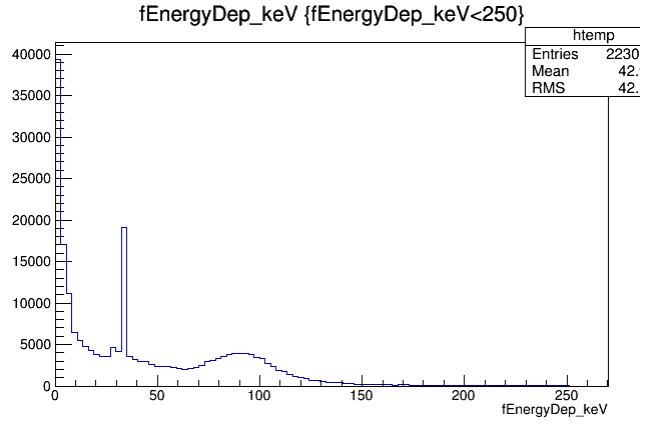
1 ms



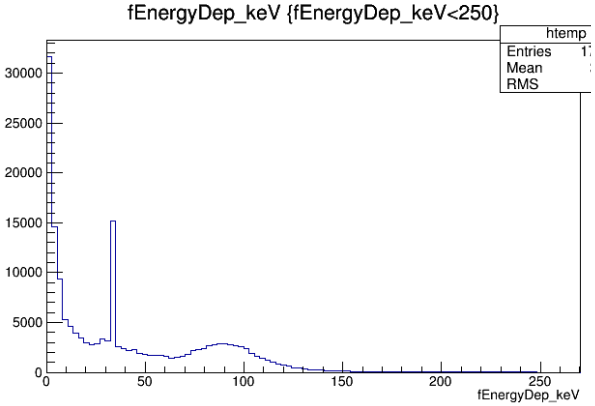
0.1 ms



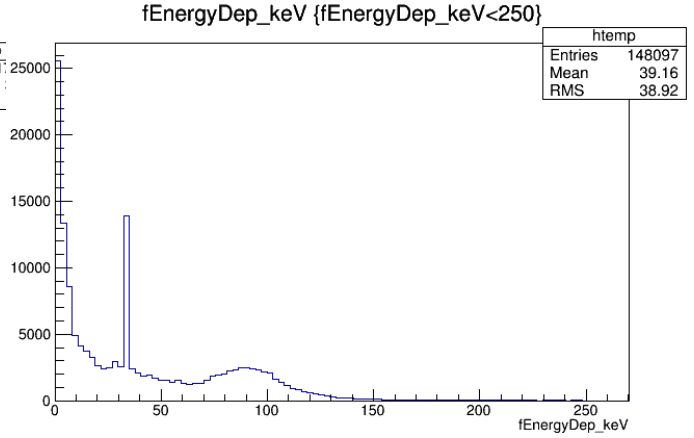
0.01 ms



0.001 ms



0.0001 ms

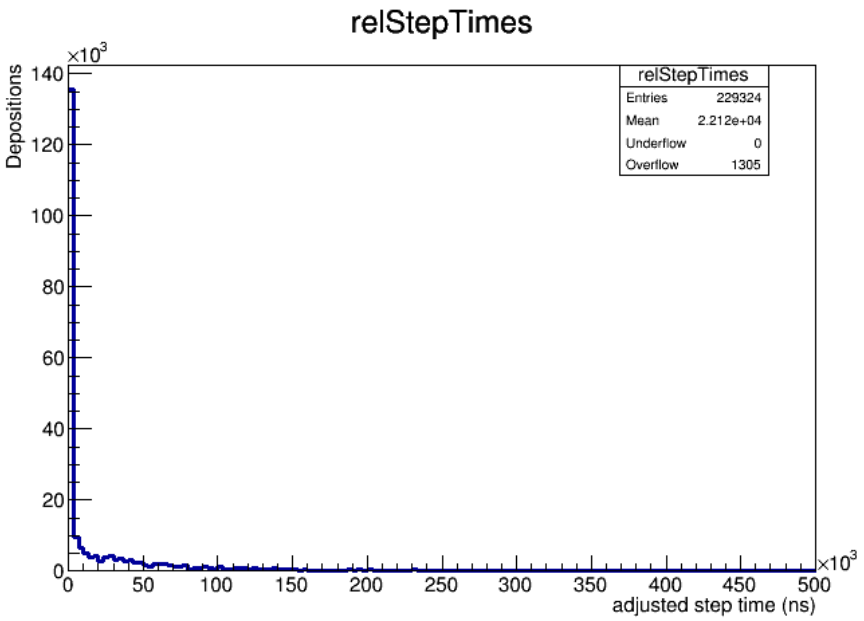


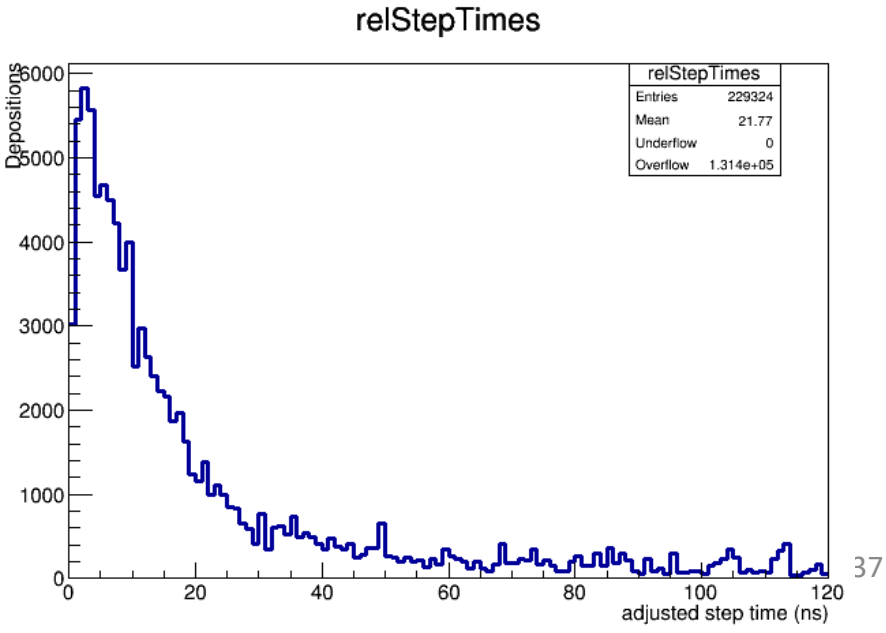
Pushing ahead anyway

- Got list of cuts for the data and beginning to implement those that apply…
  - http://teacher.pas.rochester.edu:8080/wiki/bin/view/Lux/Run4_frozen_page

When to depositions actually occur?

- Ran full simulations and found the timestamp of each deposition in post-analysis
- A cut of 500us accepts 99.994% of depositions



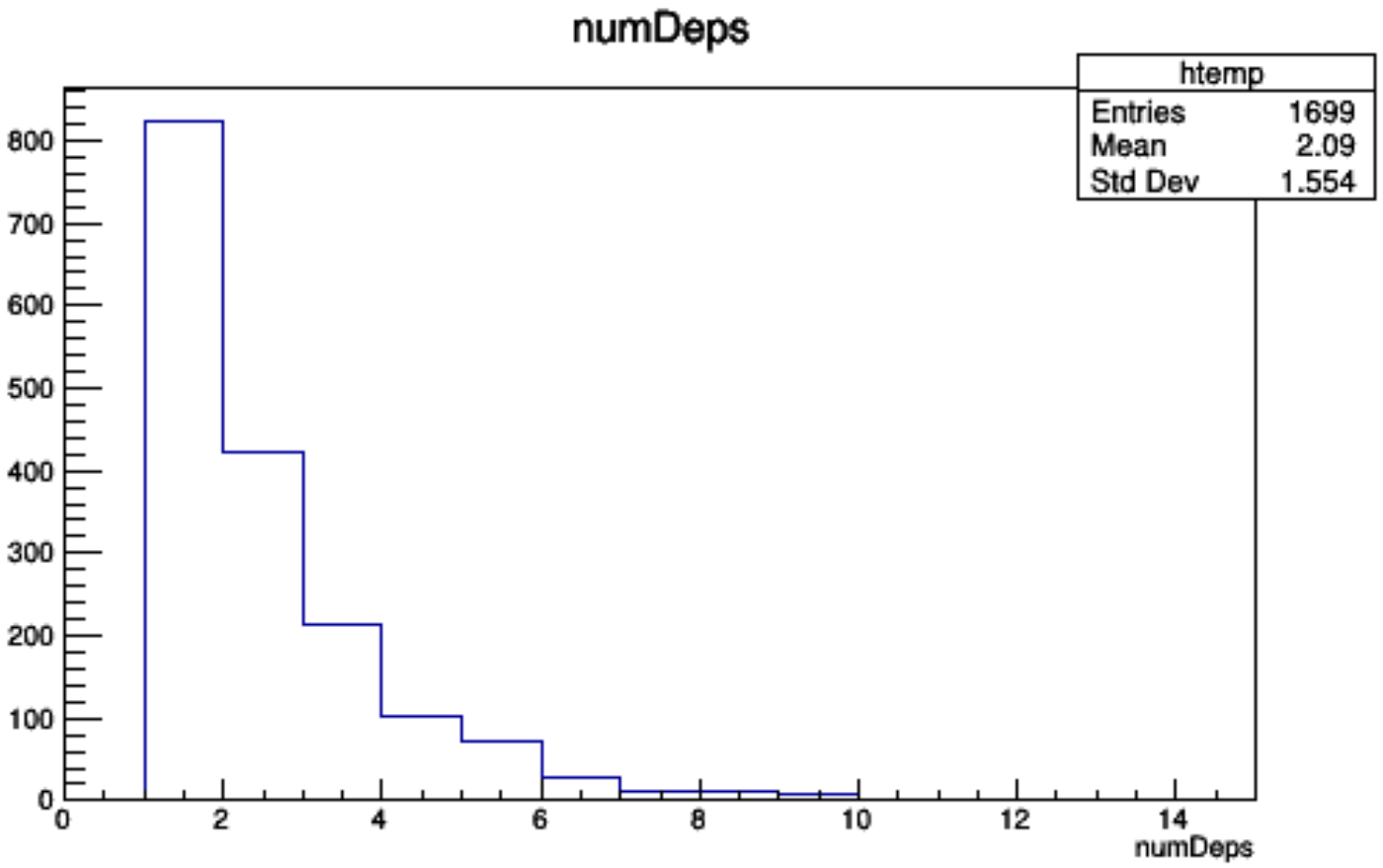


Implementing a time-cut

- Since so few of the simulated events took place at an irrelevent time anyway, abandoned efforts (which may have been successful, it turns out) to implement cut in MC itself
- Cut added during clustering algorithm of 400us after primary

Implementing other cuts

- Created a new file to cut depositions that don't meet the LUX run04 golden-event cuts
- Cuts detailed here (for those with LUX twiki access)
  http://teacher.pas.rochester.edu:8080/wiki/bin/view/Lux/Run4_frozen_page
  - Fiducial cut
  - S1 cut
  - S2 cut
  - ER_mean + 3 sigma
  - NR_mean – 7 sigma

Multiple scatter distribution with cuts

Includes all previously mentioned cuts *per deposition*. Probably not fully ideal way to do it, but first, naïve, thing to do.