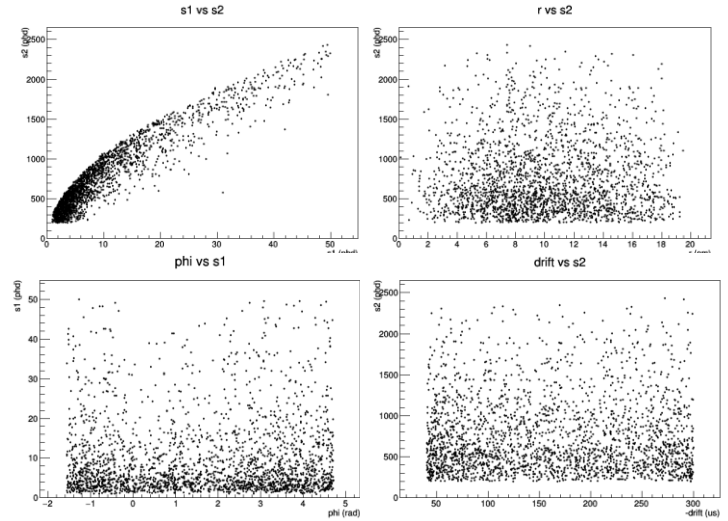# Neutron Backgrounds
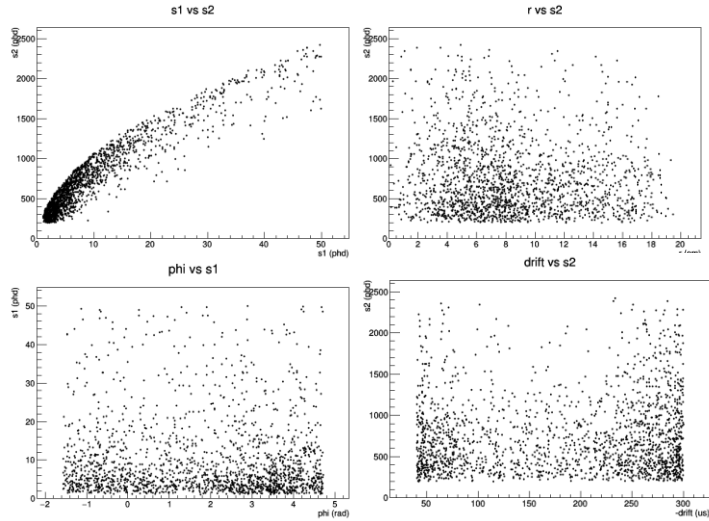
Shaun Alsum

Plots to determine PDF dimensionality
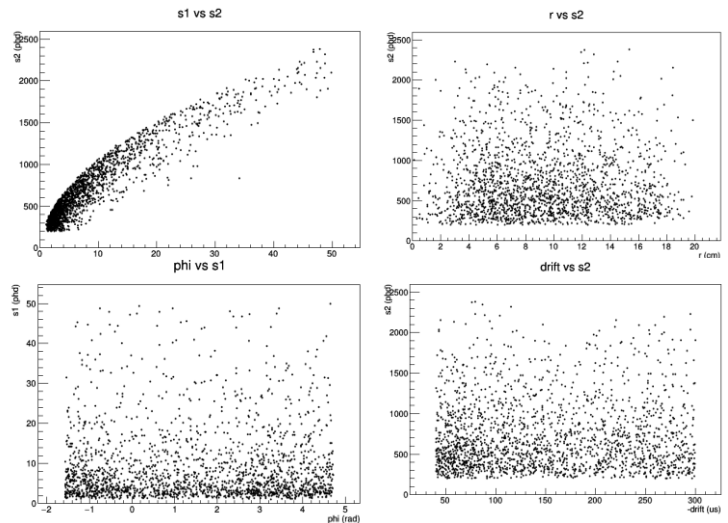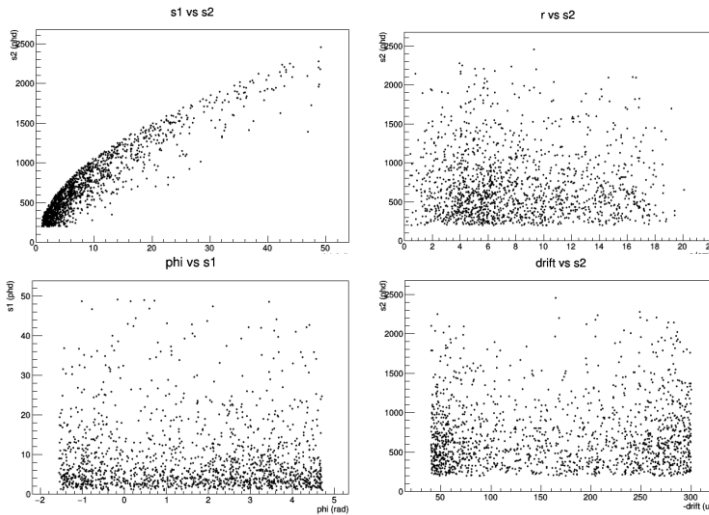
PMT

PTFE

tb1

tb4

Correlation Matrices

Order is (s2R, s2Phi, drift, s1c, s2c)

PMT

tb1

1	0.038348	-0.71189	-0.09228	-0.07449
0.038348	1	0.024852	-0.03186	-0.03008
-0.71189	0.024852	1	0.087557	0.073527
-0.09228	-0.03186	0.087557	1	0.936193
-0.07449	-0.03008	0.073527	0.936193	1

tb2

1	-0.01782	-0.73014	-0.05713	-0.0524
-0.01782	1	0.087523	-0.01438	-0.01623
-0.73014	0.087523	1	0.051623	0.04339
-0.05713	-0.01438	0.051623	1	0.926534
-0.0524	-0.01623	0.04339	0.926534	1

tb3

1	0.015255	-0.76422	-0.07692	-0.0592
0.015255	1	0.048662	-0.03268	-0.02901
-0.76422	0.048662	1	0.066563	0.04441
-0.07692	-0.03268	0.066563	1	0.934456
-0.0592	-0.02901	0.04441	0.934455	1

tb4

1	-0.04515	-0.76227	-0.02367	-0.02062
-0.04515	1	0.073236	-0.05028	-0.06333
-0.76227	0.073236	1	0.058368	0.044627
-0.02367	-0.05028	0.058368	1	0.928679
-0.02062	-0.06333	0.044627	0.928679	1

PTFE

tb1

1	-0.01823	-0.71251	0.00669	0.01652
-0.01823	1	0.062657	0.034068	0.035132
-0.71251	0.062657	1	0.024891	0.012057
0.00669	0.034068	0.024891	1	0.938586
0.01652	0.035132	0.012057	0.938586	1

tb2

1	-0.04057	-0.72231	0.000252	0.013491
-0.04057	1	0.086113	0.045914	0.038045
-0.72231	0.086113	1	0.069078	0.049003
0.000252	0.045914	0.069078	1	0.931879
0.013491	0.038045	0.049003	0.931879	1

tb3

1	-0.09264	-0.73922	0.01368	0.020828
-0.09264	1	0.059898	0.010869	-0.0008
-0.73922	0.059898	1	-0.00754	-0.01837
0.01368	0.010869	-0.00754	1	0.936692
0.020828	-0.0008	-0.01837	0.936692	1

tb4

1	-0.03953	-0.76952	-0.01774	-0.00056
-0.03953	1	0.028558	0.010215	0.007231
-0.76952	0.028558	1	0.041957	0.017651
-0.01774	0.010215	0.041957	1	0.93395
-0.00056	0.007231	0.017651	0.93395	1

Consequences

- Each (I think) have the structure below if 0.1 is chosen as a threshold

- Could likely faithfully construct PDF as

  (s2R, drift) $\otimes$ (s2Phi) $\otimes$ (s1c, s2c)

TRUE	FALSE	TRUE	FALSE	FALSE
FALSE	TRUE	FALSE	FALSE	FALSE
TRUE	FALSE	TRUE	FALSE	FALSE
FALSE	FALSE	FALSE	TRUE	TRUE
FALSE	FALSE	FALSE	TRUE	TRUE

Previous Work

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.

Simulating the Neutrons

Considered Backgrounds

Following Dave Malling's Thesis

- 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

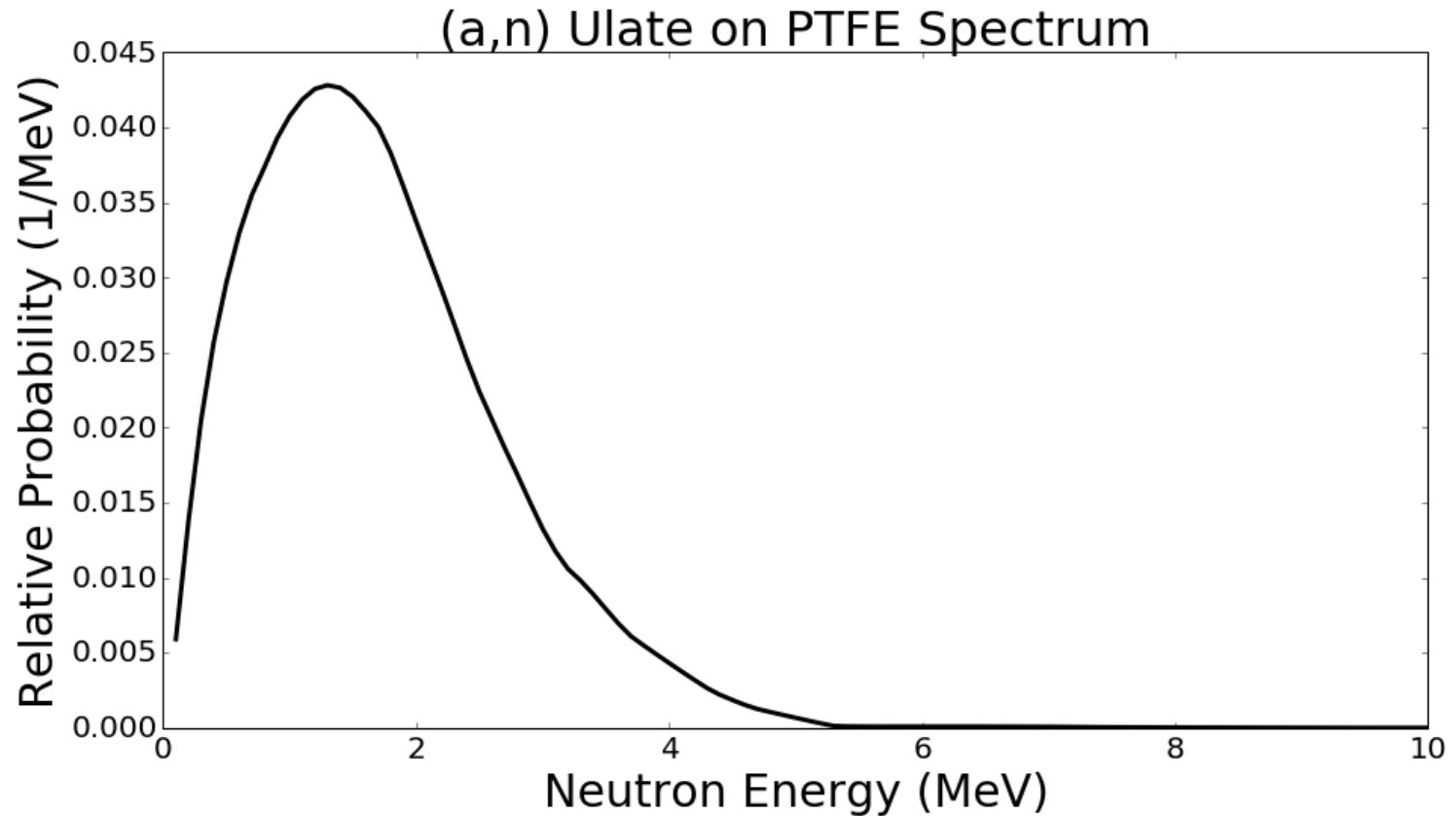| Compound	Mass [g]	(α,n) Yield [n/mBq/yr]		(α,n) Neutron Rate [n/PMT/yr]		
		^{238}U	^{232}Th	^{238}U	^{232}Th	Total
B2O3	4	1.17	0.950	2.67E-01	6.13E-02	3.28E-01
Al2O3	15	0.219	0.271	1.86E-01	6.55E-02	2.52E-01
Fe	63	0.0134	0.0426	4.78E-02	4.33E-02	9.11E-02
SiO2	26	0.0272	0.0303	4.02E-02	1.27E-02	5.29E-02
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
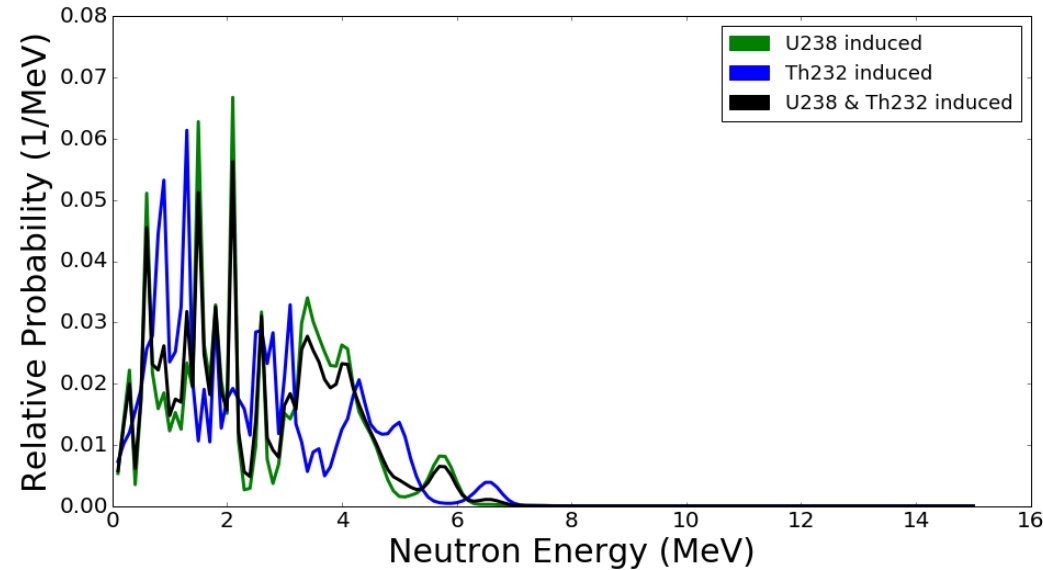
U238 fission from a parameterization I found in a lecture online...
https://indico.cern.ch/event/145296/contributions/1381141/attachments/136909/194258/lecture24.pdf
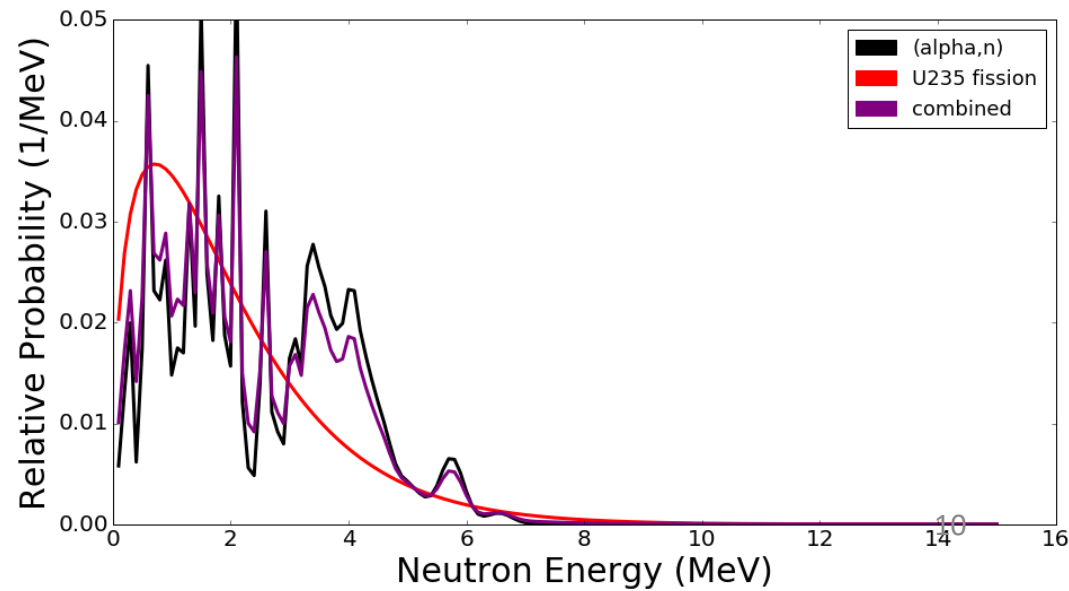
Background Energy Spectra - PTFE

From Paolo…

(a,n) Ulate on PTFE Spectrum

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.
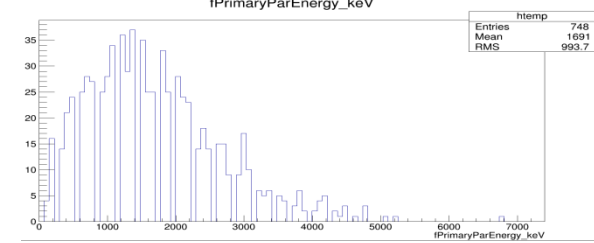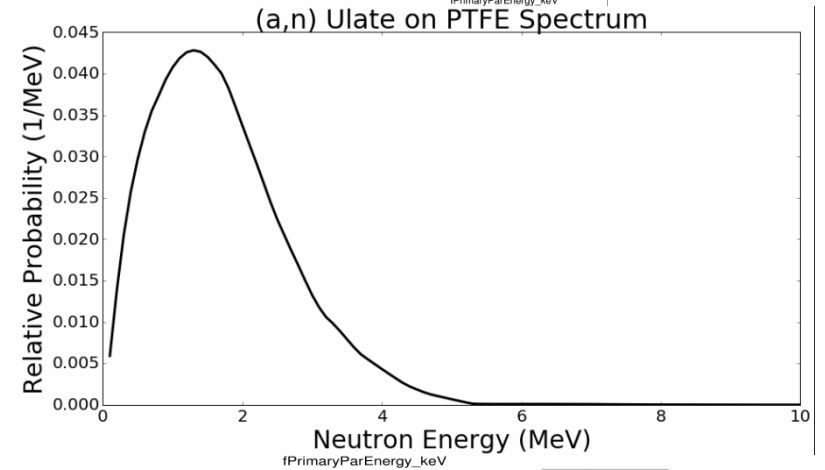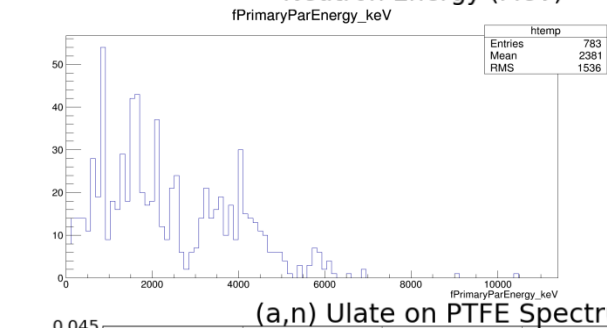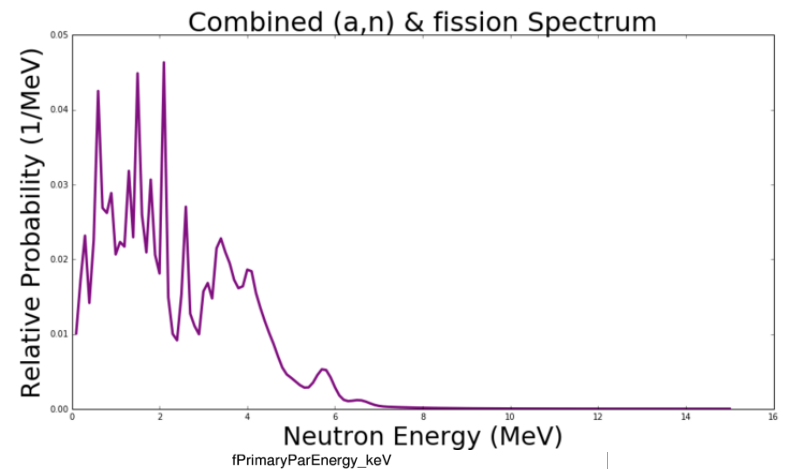
Clustering the Output

Splitting up ER and NR

- 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
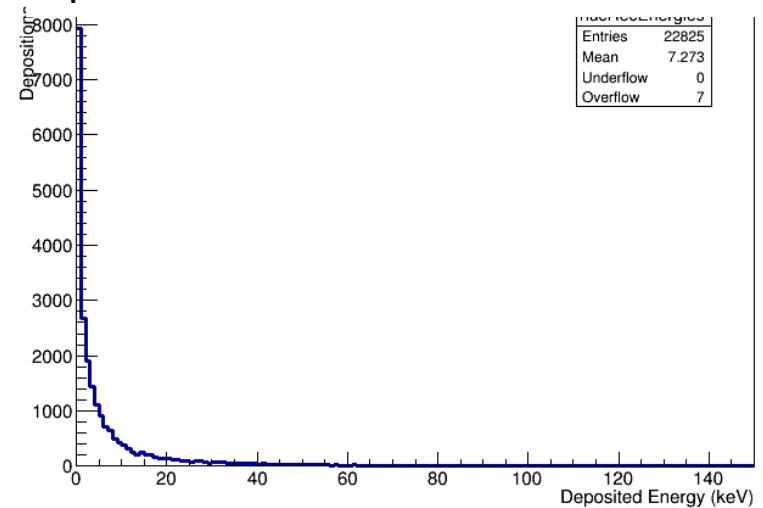
Spectrum of all electron recoils
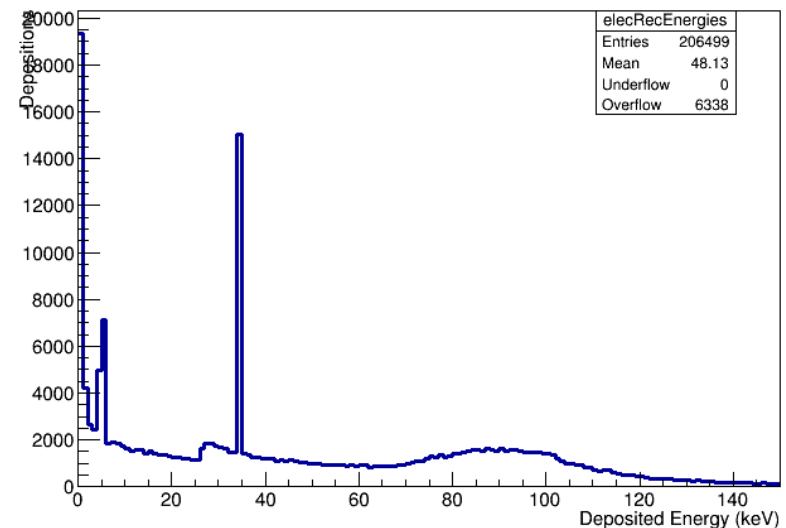
Do I somehow have to account for many, or can I cut it off at a few?

Must account for many.

maxNeighbors

maxNeighbors	
Entries	7681
Mean	14.46
Underflow	0
Overflow	0
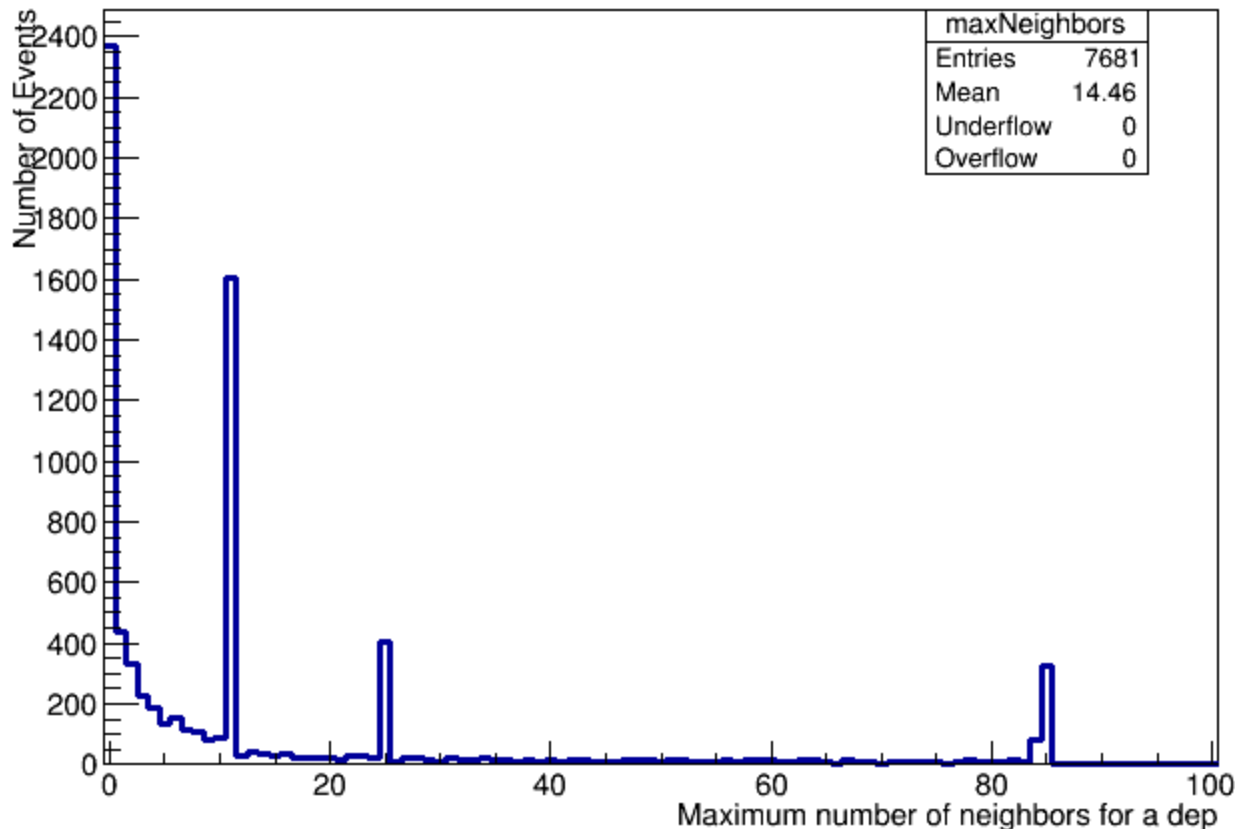
Number of depositions within 0.5 cm of the deposition with the most in any given event.

Number of Events (y-axis), Maximum number of neighbors for a dep (x-axis)

The Clustering algorithm

- Cluster into cylinders (right now Δxy < 0.5 cm, Δz < 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
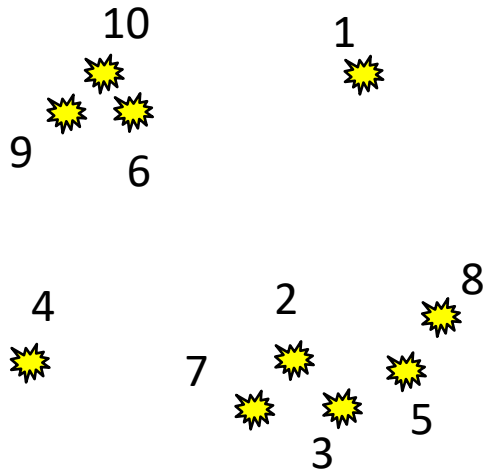
1. Creates new cluster containing dep 1 (cluster 1)
2. No more neighbors. Marks dep 1 as clustered and moves on to a new point.
3. Creates new cluster containing dep 2 (cluster 2)
4. Looks around dep 2 for neighbors, finds dep 3, adds dep 3 to cluster 2
5. Looks around dep 3 for neighbors, finds dep 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.
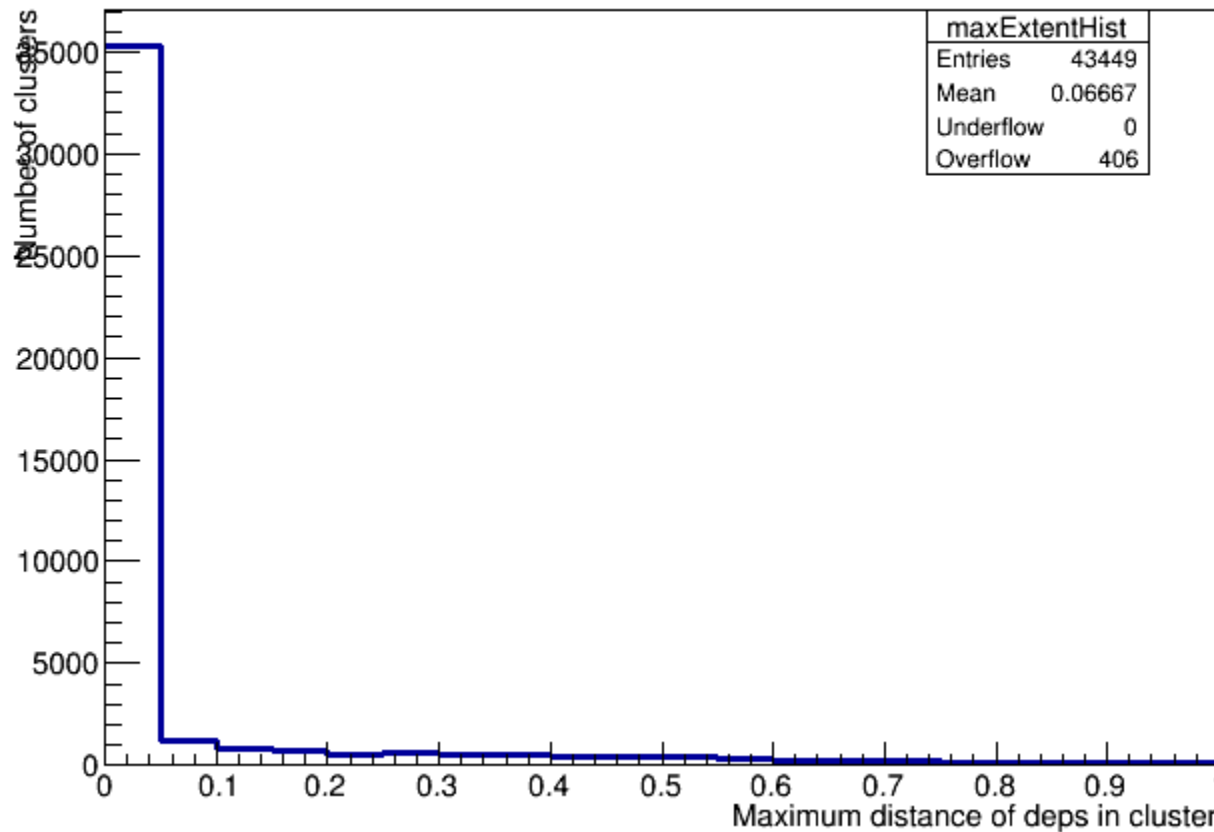
Distance (in cm) between the two most distant depositions in each cluster.

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.
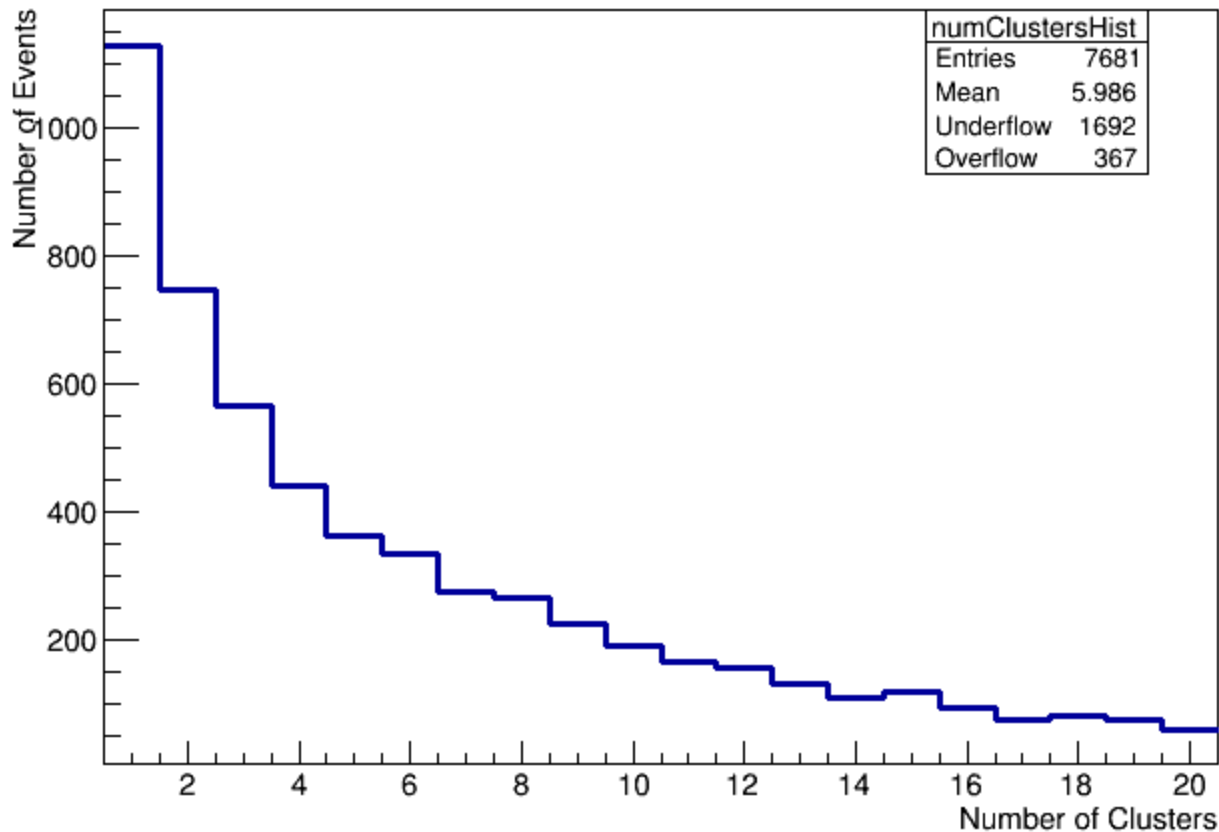
numDepsHist

numDepsHist	
Entries	43449
Mean	3.734
Underflow	0
Overflow	2112
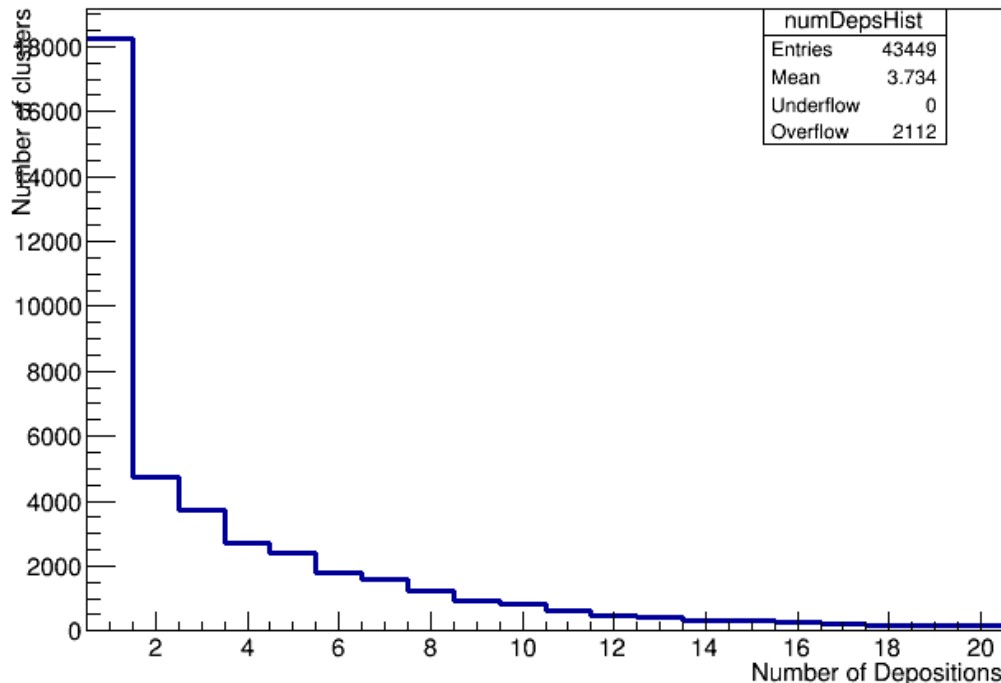
Number of depositions that make up each cluster.

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…

What about the cluster's position and energy?

- 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

Deposition Energy (keV)
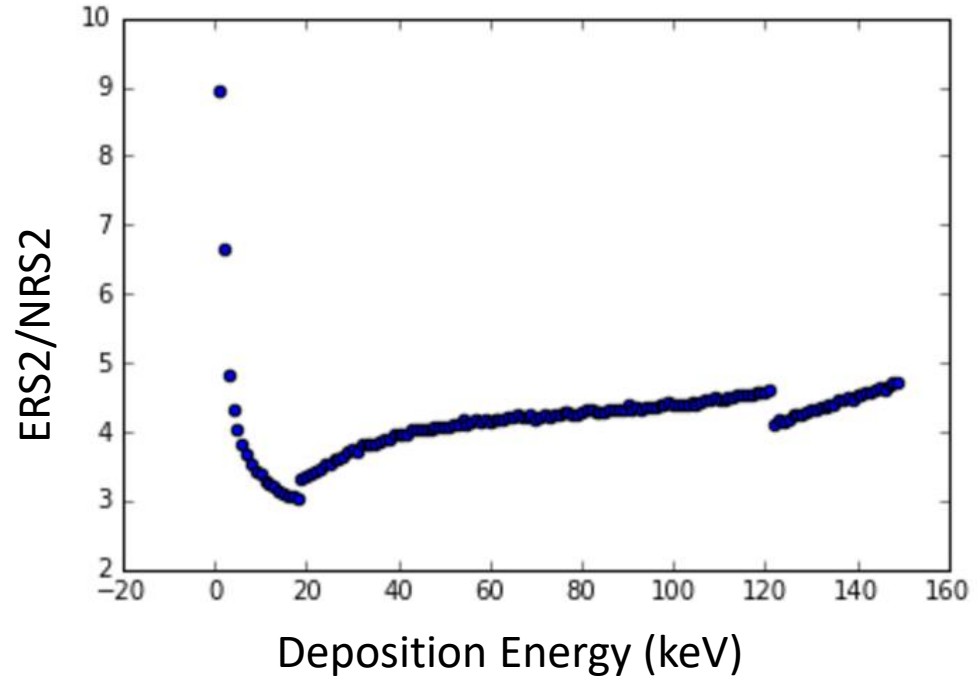
- What is the cluster's energy?
  - Energy from NR are summed into an NR total energy.
  - Energy from ER are summed into an ER total energy.
    This is because in the end what we want to simulate is the total S1 and S2 from the cluster, so the energy deposited via different methods needs to be distinguished.

# Get the S1 and S2 from libNEST

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
- Currently just using run04 tb4 g1 and g2 etc, but run03 fields (Lucie's maps not yet implemented)
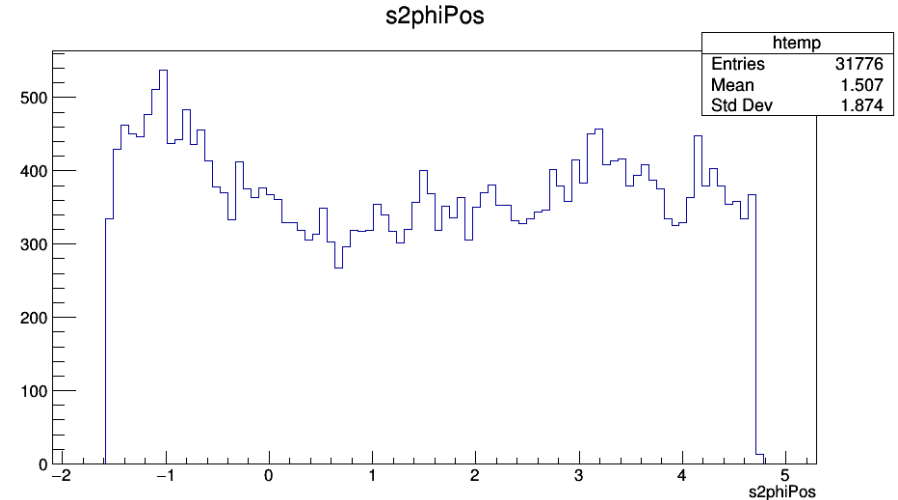 - Both for Qy/Ly and for translation from z to drift

The S1 and S2 plots
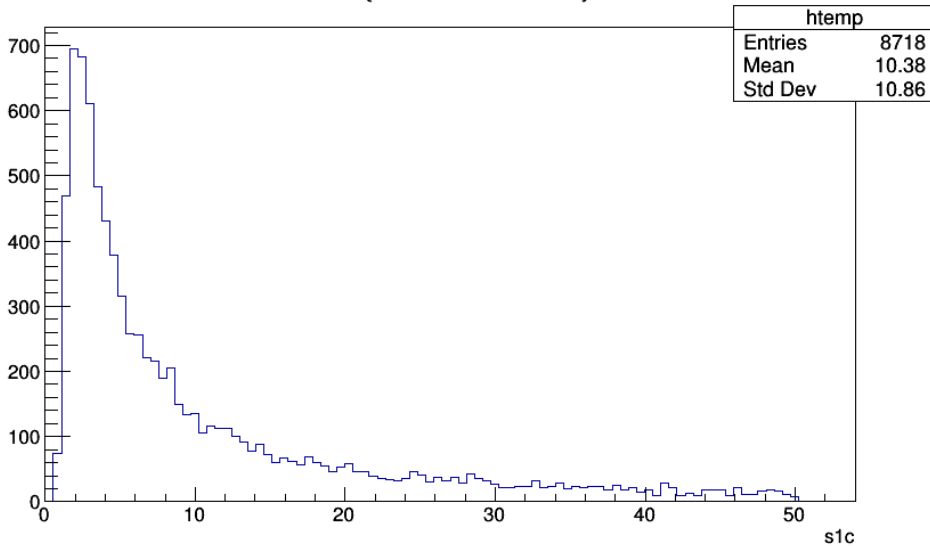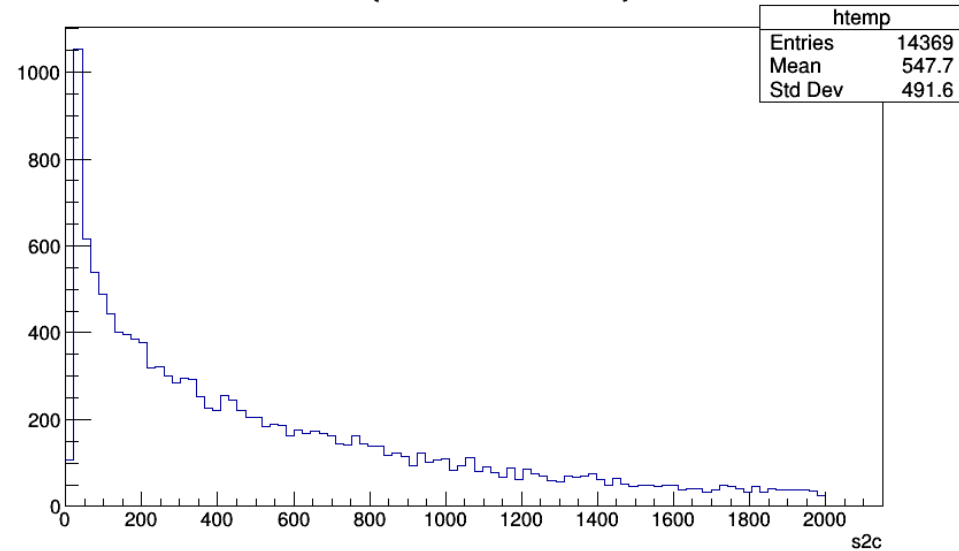
Positions mapped to S2-space
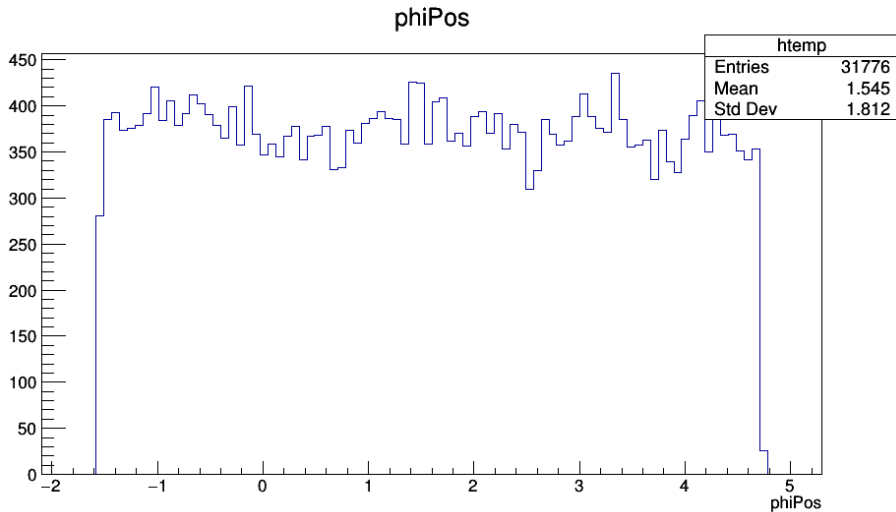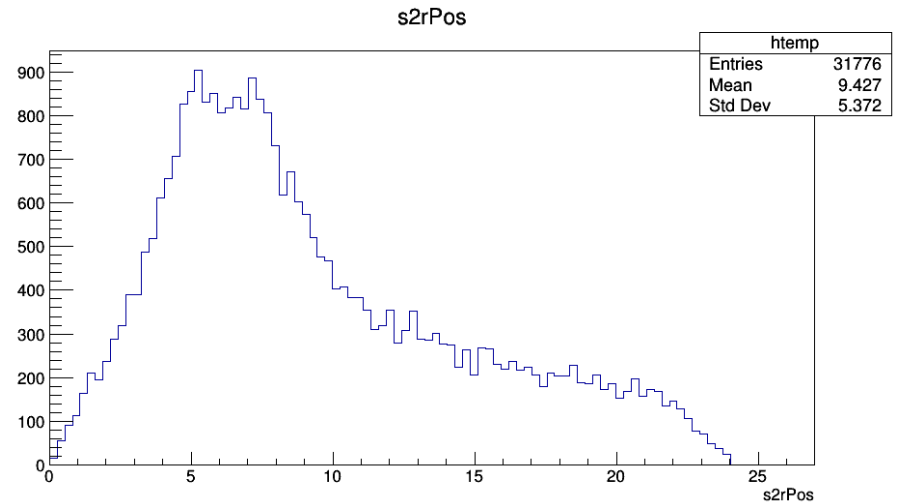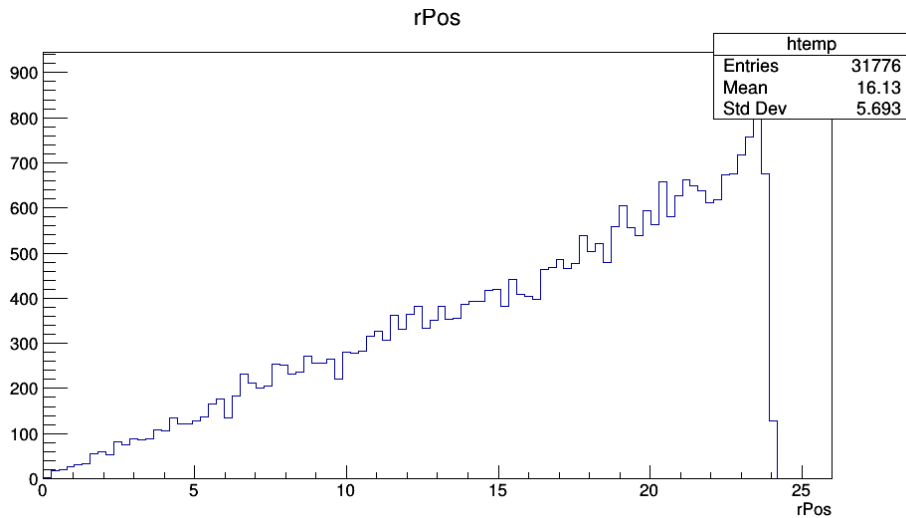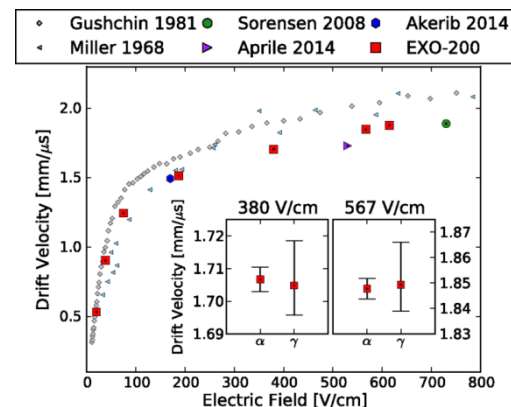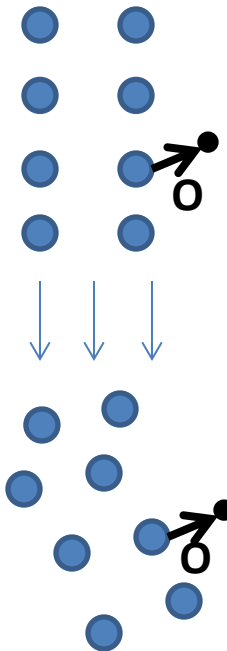
(x,y,z) -> (s2x, s2y, drift)

- ## Real-Space
- ## S2-Space

Implementation

- Find offset of nearest point, maintain offset from mapped point
- Need to know drift speed vs. electric field to translate z-offset to drift offset.
  - Very nice Exo data (inc LUX)
  - Fit to the form of b*log(c*x)+d/x works nearly perfectly.

Now Make the Cuts

Time Cut

- Make sure I'm not contaminating my data with depositions that occur long after the initial deposits.
  - i.e. if a neutron takes a long time to capture or the capture product decays after a long time
- A cut of 500us accepts 99.994% of depositions
- Currently using a cut of 400us
- Implemented *before* clustering
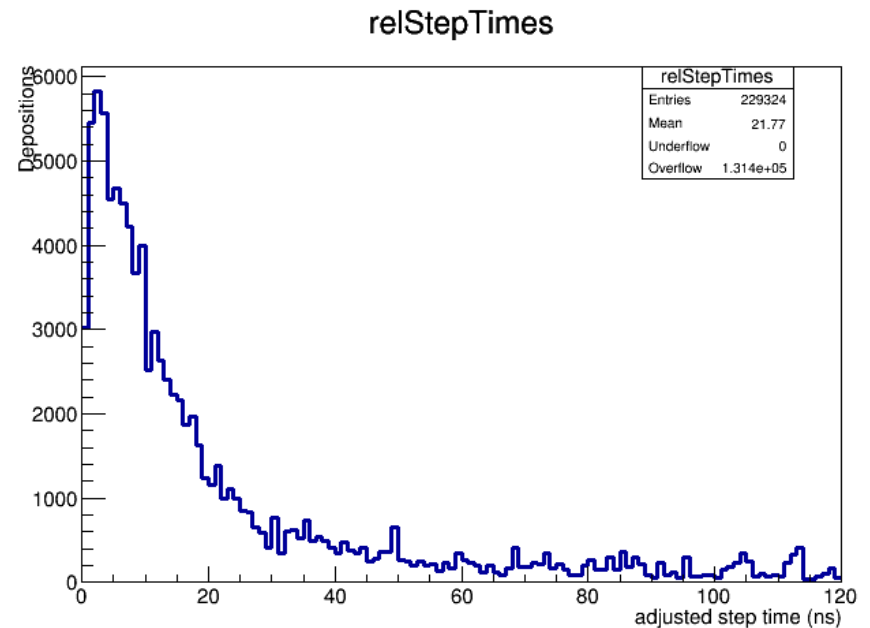
Deposition Cuts

- Cut depositions that will not be seen by the detector
  - Outside the TPC (i.e., in the skin)
- Cut depositions whose S2 would not be classified correctly by the detector
  - S2 < 60
  - *Keep* the S1 and add it to a total tally for the event

Event Cuts

- Treat Multiple Scatters and Single Scatters differently.

- Multiple scatter defined as an event which contains 2 or more depositions *after* the previous deposition cuts.

  - Does *NOT* need to pass any fiducial cuts

Multiple Scatter Cuts

- Determine whether the MS is ER or NR.
- Problem: can't do a traditional S2/S1 cut in the traditional style
  - S1s possibly merged, or the pairing of s1 to s2 is unknown.
- Solution: predict S1 for each event based on S2 *as if it were a NR* using the NR band mean. Sum all S1s and compare to the sum of expected S1s. Cut if measured S1 is lower.
  - Equivalent to cutting above NR band mean
  - Possibly not equivalent in ER p-value due to differences in combined standard deviations
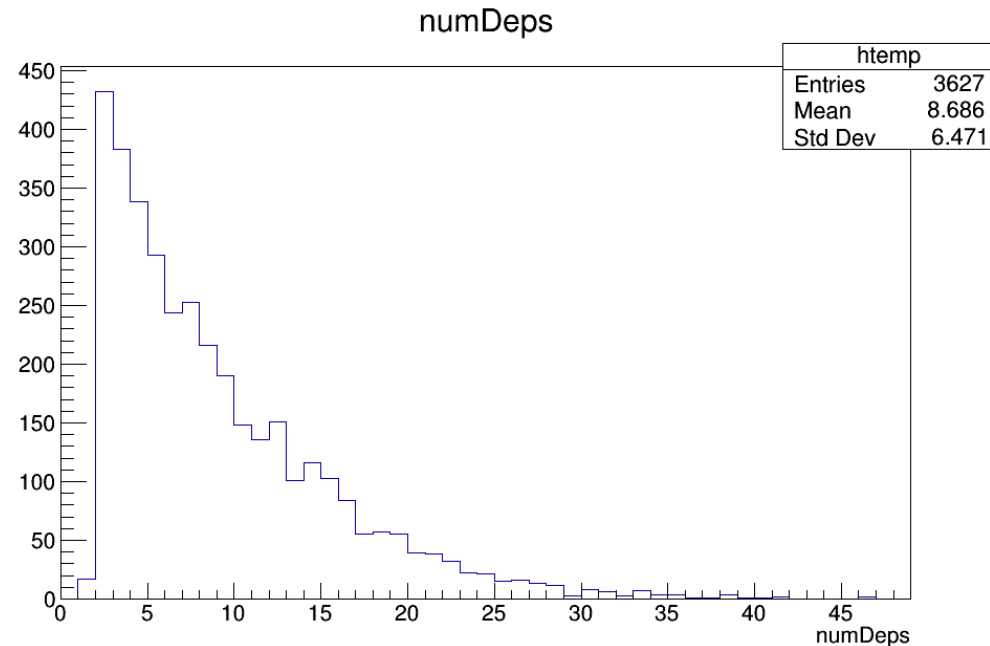
Single Scatters

- Use the standard Run04 cuts detailed on the frozen page 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
- Also cut events above NR band mean (it occurs to me that this is only necessary for finding the overall normalization, if that)

Correct Fiducial cut Implemented

- $r(event) < r_{wall}(\phi_{event}, drift_{event})$
- Impact of this change still pending
- This, of course, depends on time bin so have to run sims dedicated to each. In progress.

Result of Cuts: PMTs

- Main result is ratio of total MS to cut SS
  - 430/17 Double Scatter/SS)
- Ratio of total simulated to WIMP-like events: 0.0017
  - Taking the guess of 138 n/yr from PMTs this amounts to 0.23 WIMP-foolers/yr. Or 0.21 in our 332 live-day run strictly from PMTs.

htemp	
Entries	3627
Mean	8.686
Std Dev	6.471

Recall: SS and MS were treated differently in cuts.

34

Results of Cuts: PTFE

- Ratio of total simulated to WIMP-like events: .0019

- From Dave Malling's thesis "9.5 n/yr from PTFE" which means in 332 live days ~.016 WIMP-like.

numDeps

htemp	
Entries	4603
Mean	8.531
Std Dev	6.106
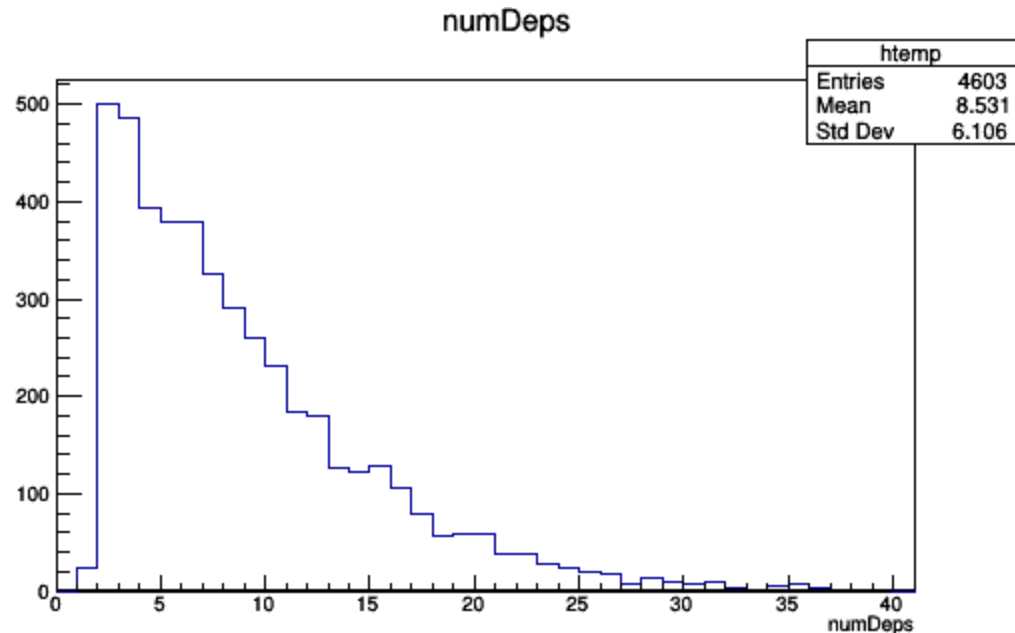
# Lots of Data, Single Scatter Only Info Added

- 1 million events for each (PMTs, PTFE, 4 time bins)
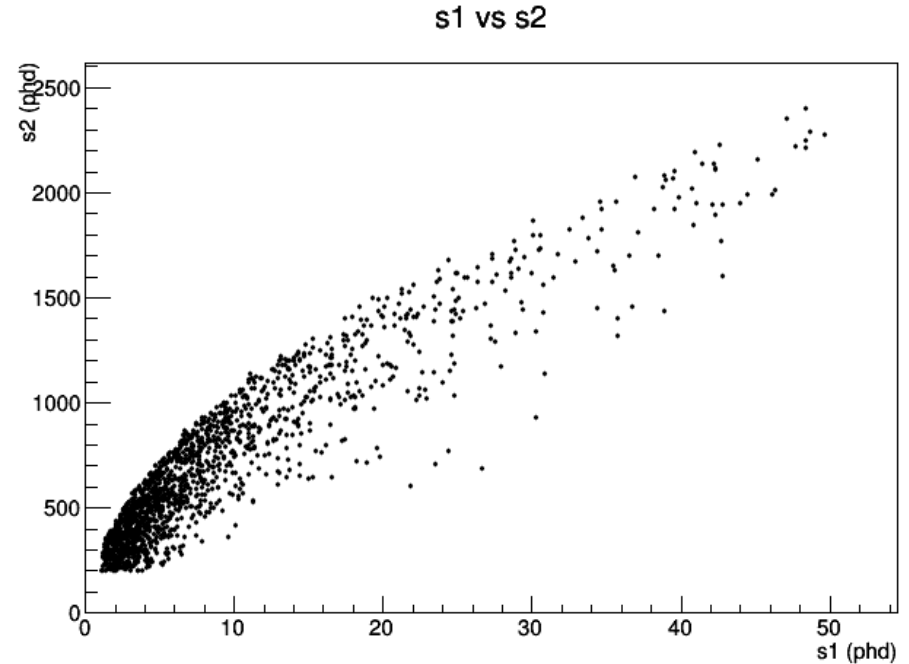- Both multiple scatter and single scatter information recorded
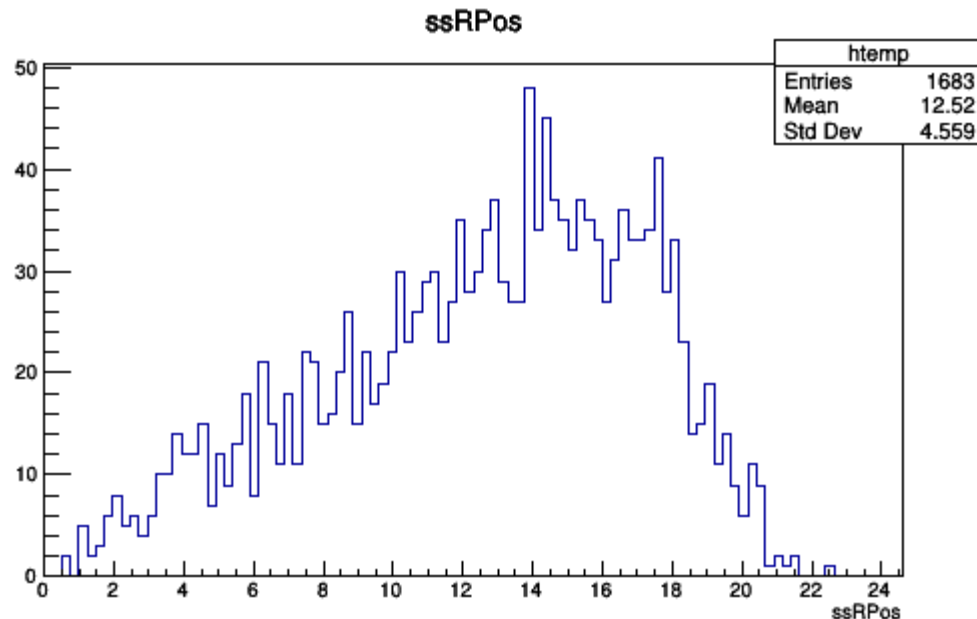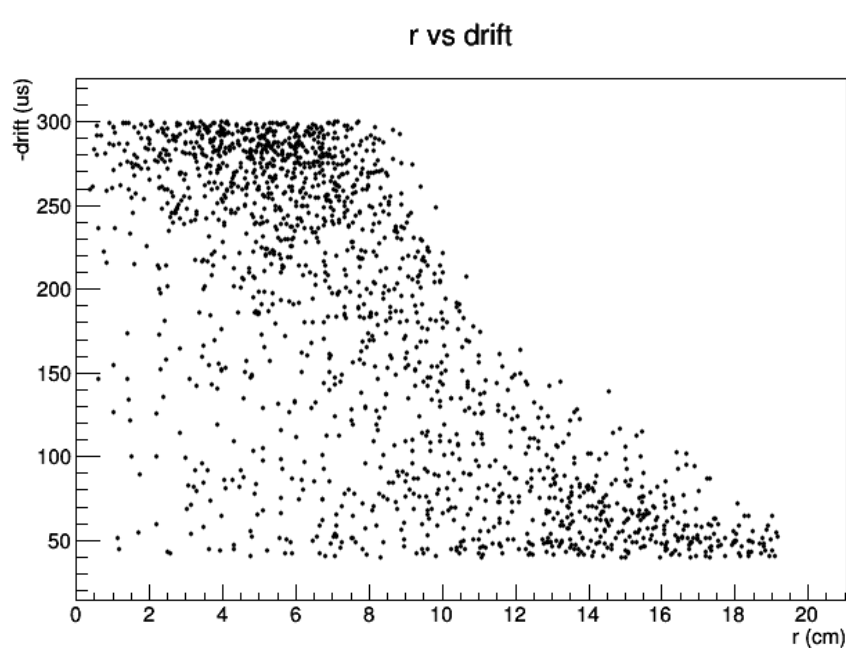
PDF Creation

Dimensionality

- Now that I actually have effective cuts, I need to look at more data to actually determine this, but based on all depositions (not just n SS) it appears the distribution is uniform in phi to within PDF bin size
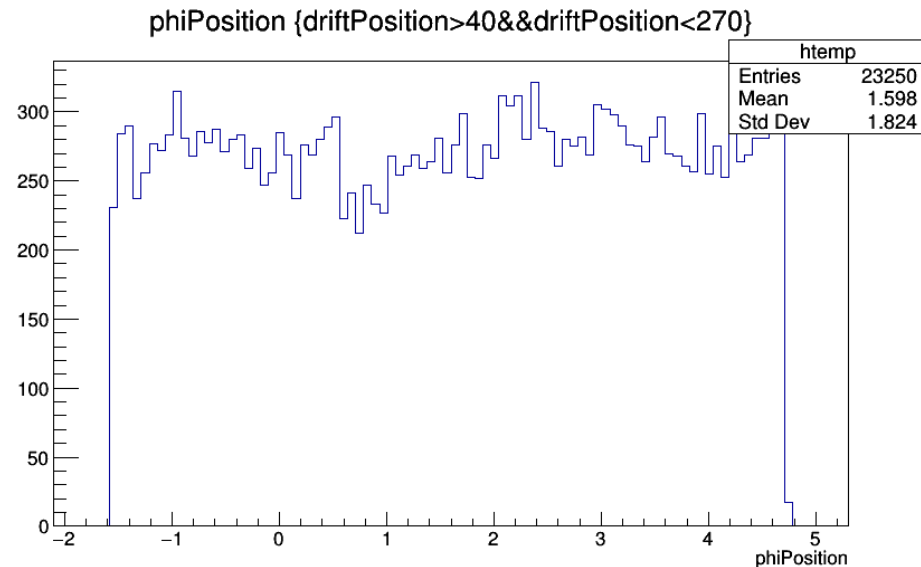
Script to plot SS quantities of interest

r vs drift

s1 vs s2

Discovered some anomalies that indicated a mistake in the field mapping while doing this. They have been corrected.

Lingering Questions…

- To what extent do we want the overall normalization to be data driven? I.E. do we want to look at actual double-scatters, etc?

- How crude do we want this to be?
  - Implementation of Lucie's field maps in libNEST
  - Study clustering parameters
  - Study and implement better S2/S1 cuts when looking for normalization.

Backup

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.