Recent Updates (Gamma-X, SLAC work, MDC, etc.)

Jonathan Nikoleyczik

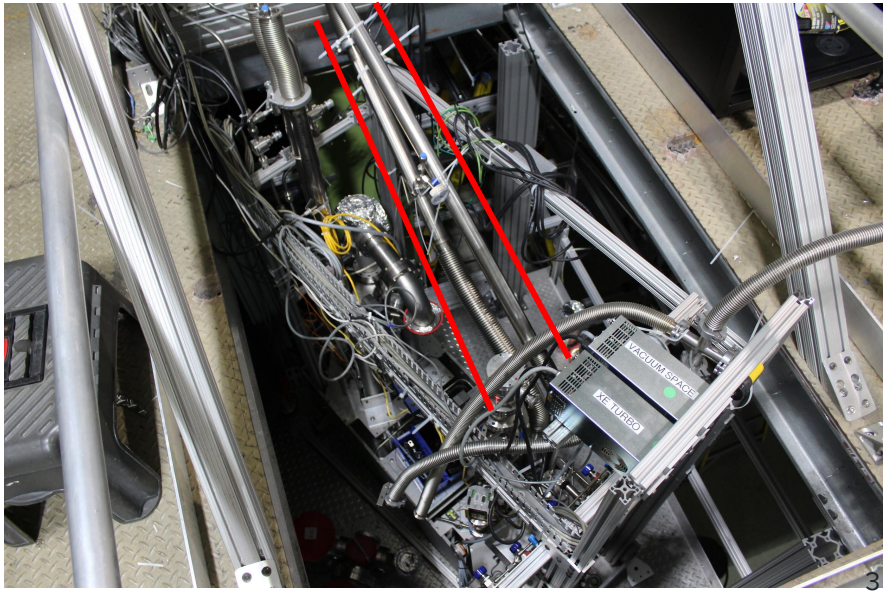
Today's update starts on slide 61

Summer in review

- “Finished” Gamma-X studies
  - More on this next
- Built Gas test and Phase 2 clean rooms
  - Gas test clean hood is currently in use
  - Phase 2 clean room is assembled but not cleaned
- Participated in MDC1
  - Calculated the electron lifetime for 30 days of simulated data which will hopefully look similar to real LZ data

Thermosyphon lines

Replaced thermosyphon lines (marked in red) to make room for new Phase 1 breakout



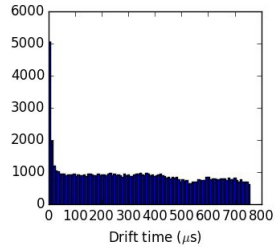
Clean rooms

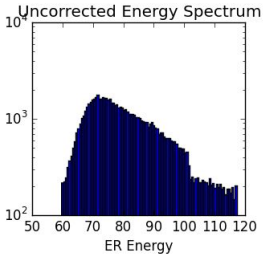
Gas test hood

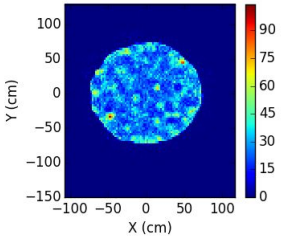
Phase 2 cleanroom

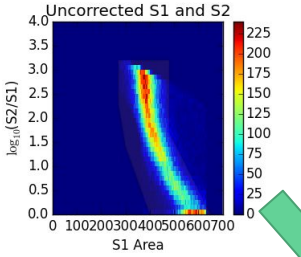
MDC 1

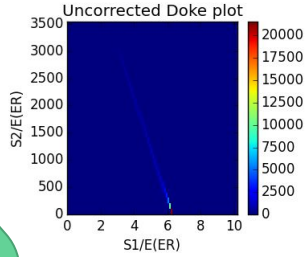
Day 1

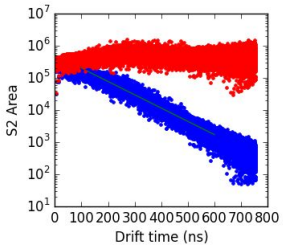


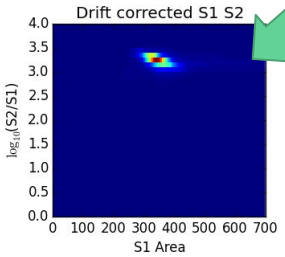


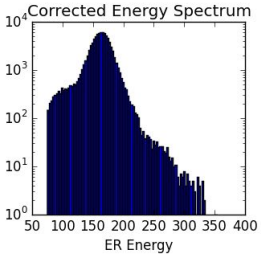




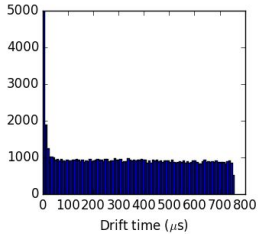


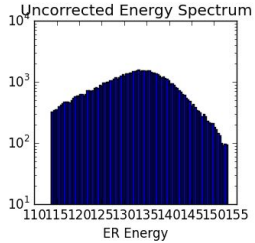


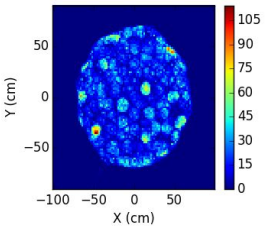


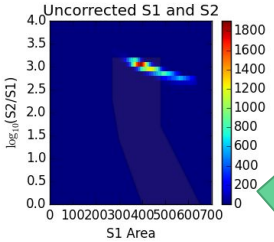


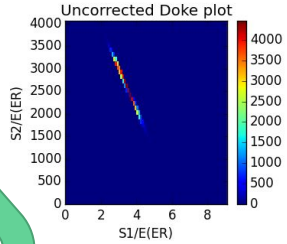
Day 30

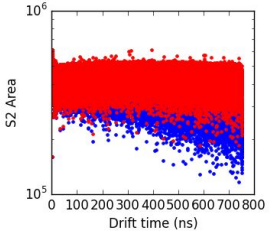


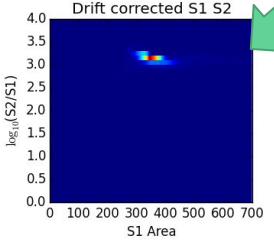


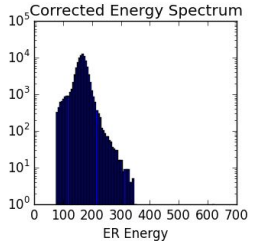




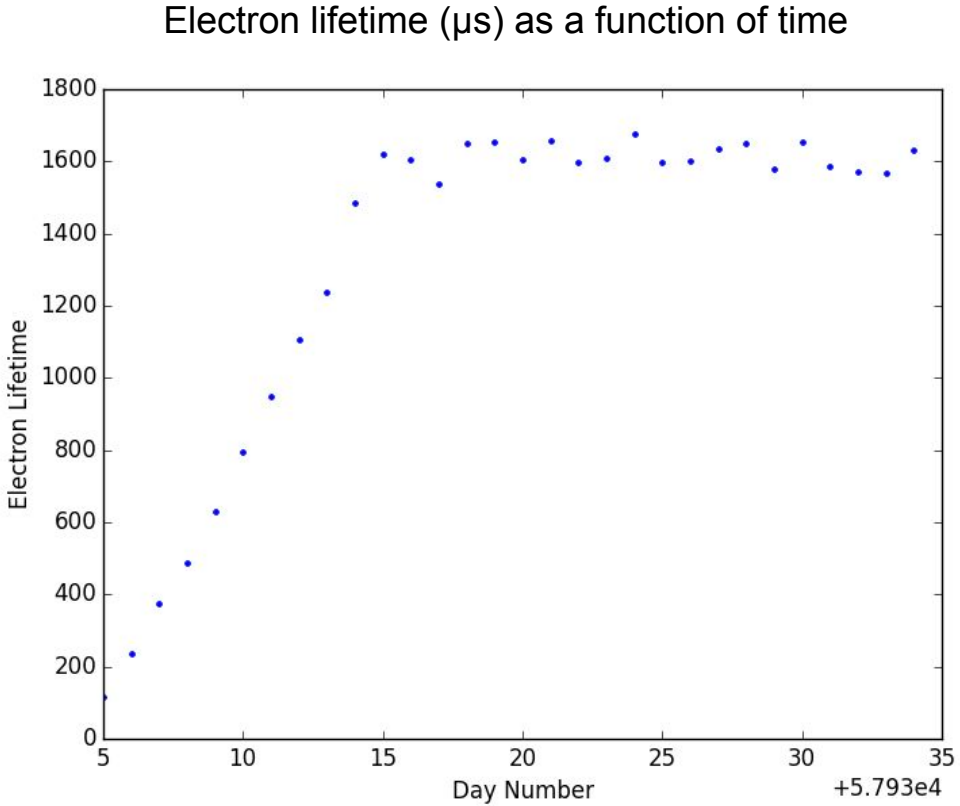








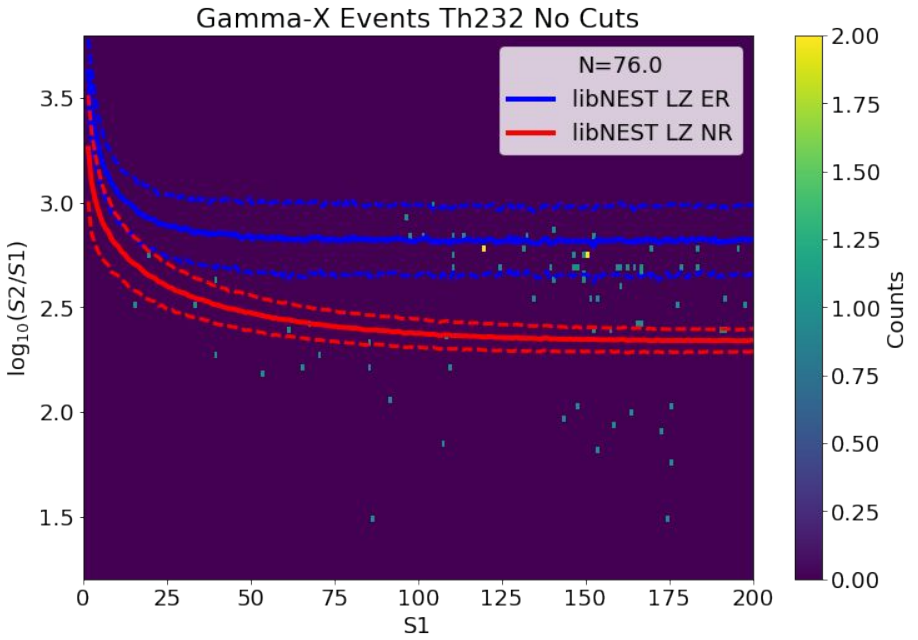
MDC 1 Electron Lifetime



Gamma-X

Wrote code to calculate the expected rate of Gamma-X events from the PMT windows.

Produced plots like the one on the right which show a large number of events in the WIMP search region (the left side of the red region)



Previous Gamma-X Results

Higher than all combined LZ backgrounds

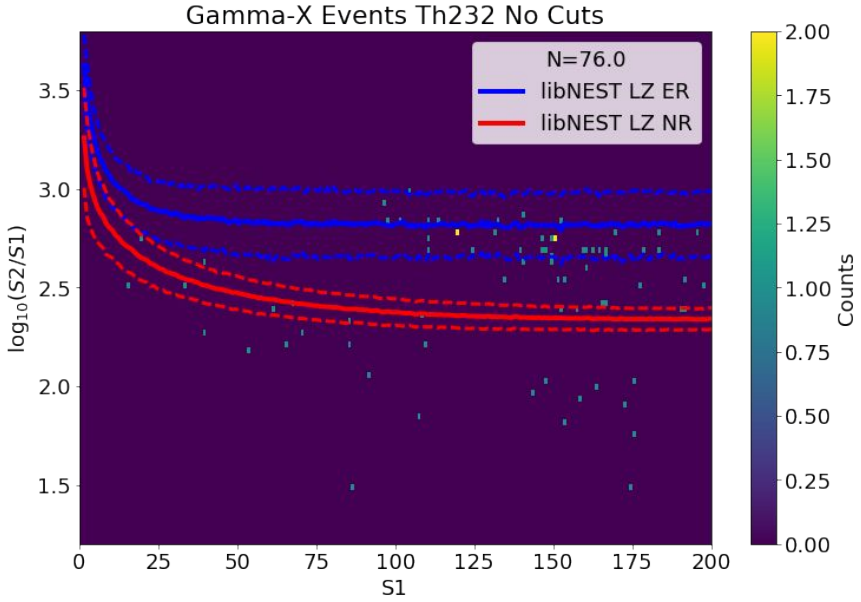
Source	Decays Simulated	Fraction which produce Gamma-X (all)	Fraction in WIMP search region (Depending on S1 S2 cut)	Approximate rate (assuming production from PMT windows and **no cuts**)
Th-232	14,900,000	0.012887 192507 Events	~ 4.0×10^{-7}	0.24 events per year
U-238	4,150,000	0.013739 57094 Events	~1.2×10^{-6}	3.83 events per year
Co-60	9,800,000	0.080683 790704 Events	~4.0×10^{-7}	0 (No Co60 in PMT windows)
K-40	9,400,000	0.004208 39559 Events	< 1.0×10^{-7}	< 0.13 events per year

Comparing Apples to Apples

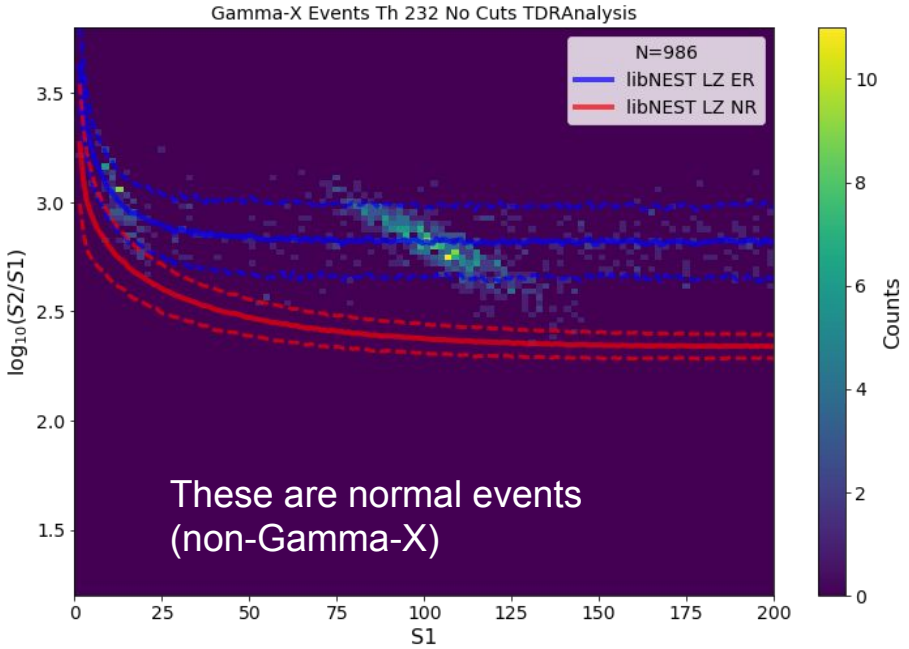
All of the LZ backgrounds are summarized in the backgrounds control table which follows a very specific procedure to generate background rates.
I was doing something similar but not exactly the same.
To see how well my rates compare with the total rates I modified the control table to work with gamma-x events.

Source	Mass (g/unit)	Mass (g)	Activity (mBq/kg)	Livetime equivalent	# beamOn	# beamOn E-scaled	# Surv. All	R-factor	Surviving 1000 days	Events Per year
U early (γ)	38.0	9158	13.21	1.39E+01	1.00E+07	1.45E+08	17.00	1.68E-08	1.75E-01	6.41E-02
U late (γ)	38.0	9158	0.75	2.43E+02	1.00E+07	1.45E+08	17.00	1.17E-07	6.98E-02	2.55E-02
Th (γ)	38.0	9158	1.01	1.85E+02	1.02E+07	1.48E+08	36.00	2.43E-07	1.94E-01	7.09E-02

Gamma-X Plots With New TDRAnalysis Method

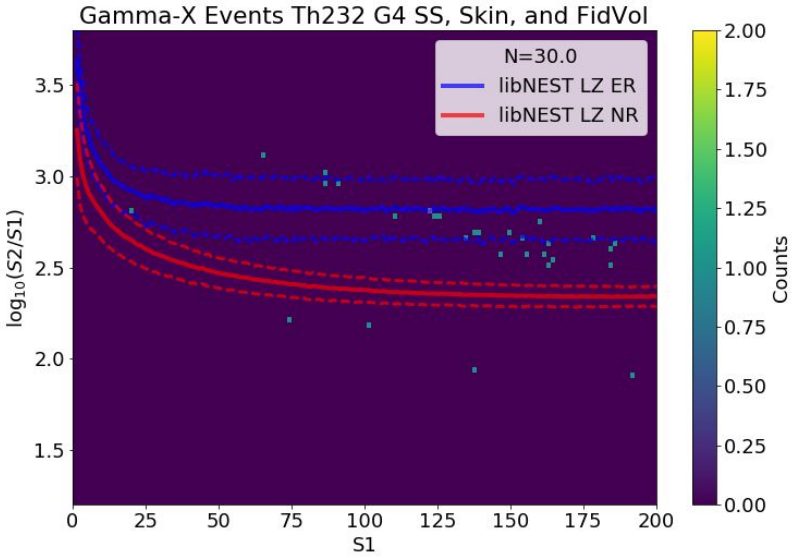


Old Method

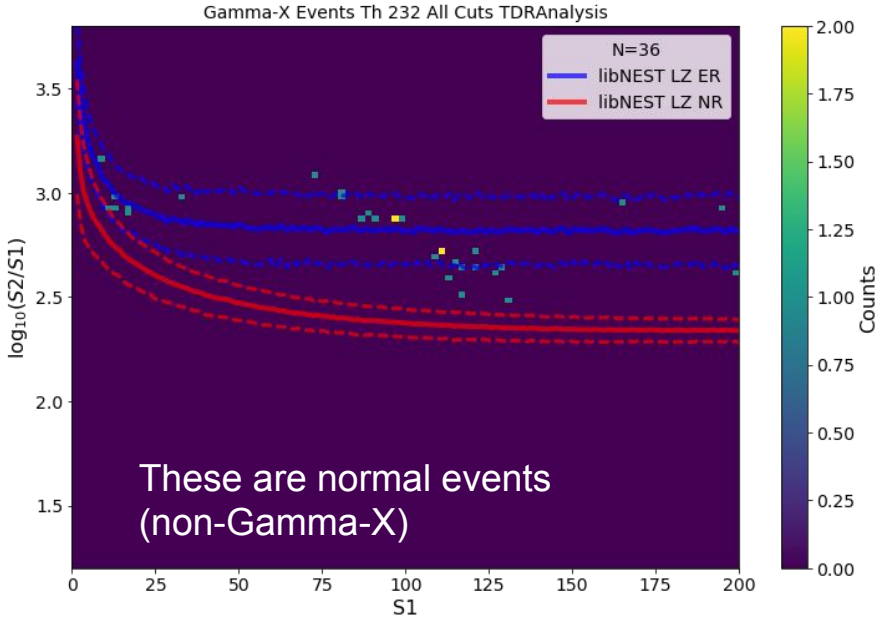


New Method

Gamma-X Plots With New TDRAnalysis Method W/ Cuts



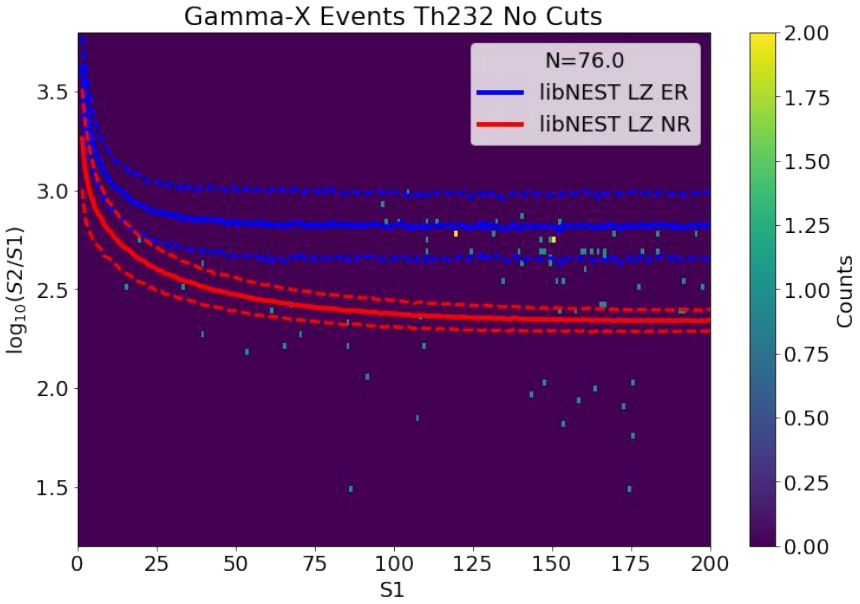
Old Method



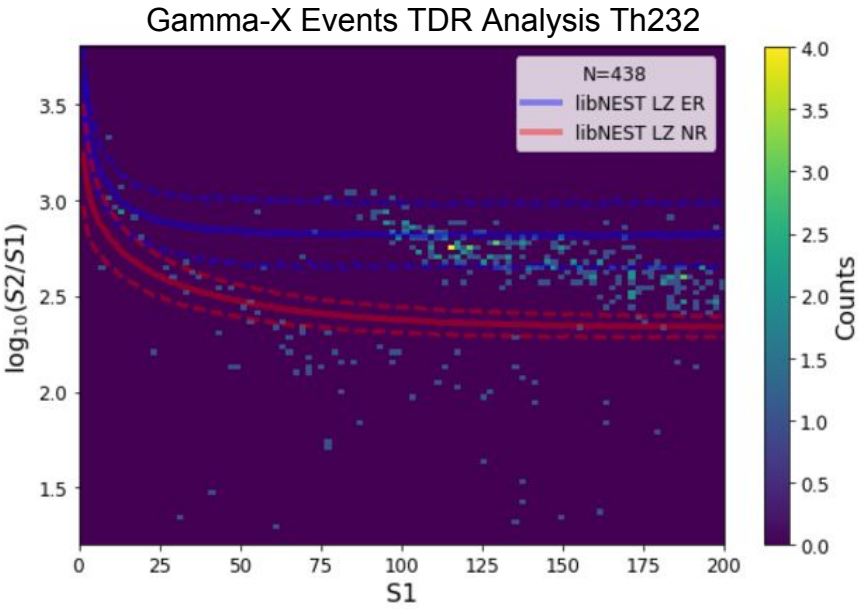
New Method

Latest Gamma-X Update

- Plots shown last week were only “normal” events



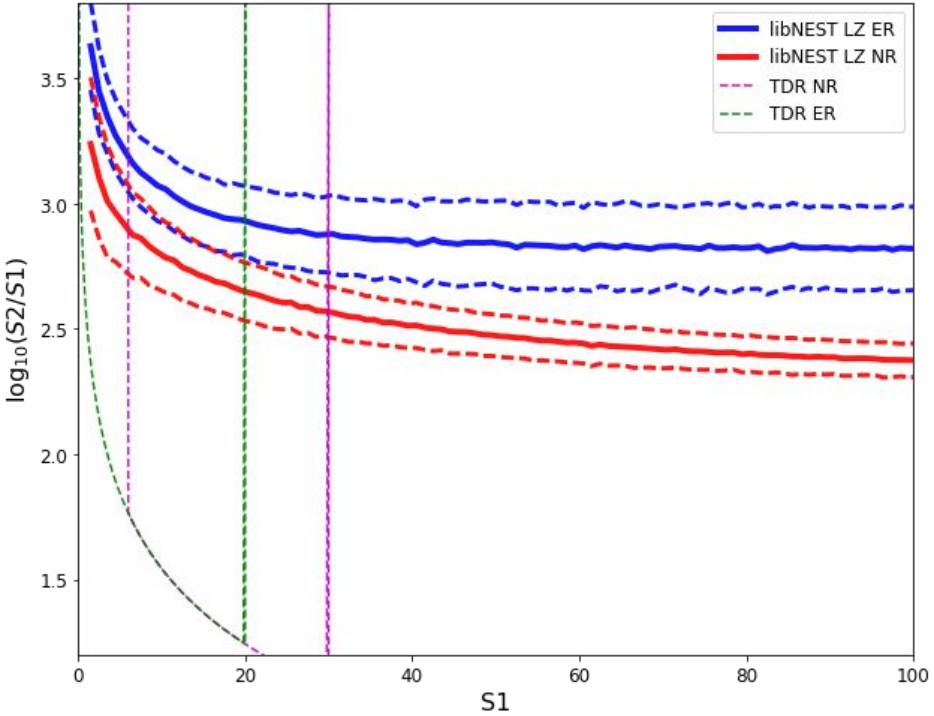
Old Method



New Method

TDR vs. My Cuts

- The TDR Analysis assumes that when ER events are produced that only ER events are seen. With that assumption it can make a more rough cut on S1 and S2. This only works for normal events, but not Gamma-X events.
- I will use all 4 cuts to be able to compare my rate to the TDR as well as provide a more accurate estimate of the rate



Fall 2017 Plan

- Gamma-X
  - Continue to improve and compare the Gamma-X result with those of others
  - Look for Gamma-X events in the MDC 1 data then see if there is some way to discriminate against them.
- Cable making
  - Will soon begin clearing out the server room
- Phase 1 Data Analysis
  - Assist with the Phase 1 analysis in run 7
- Cameras
  - Possibly work on cameras that would be able to run in cold gas or liquid xenon. These would likely need to be different than those used in Phase 2.

Gamma-X rates

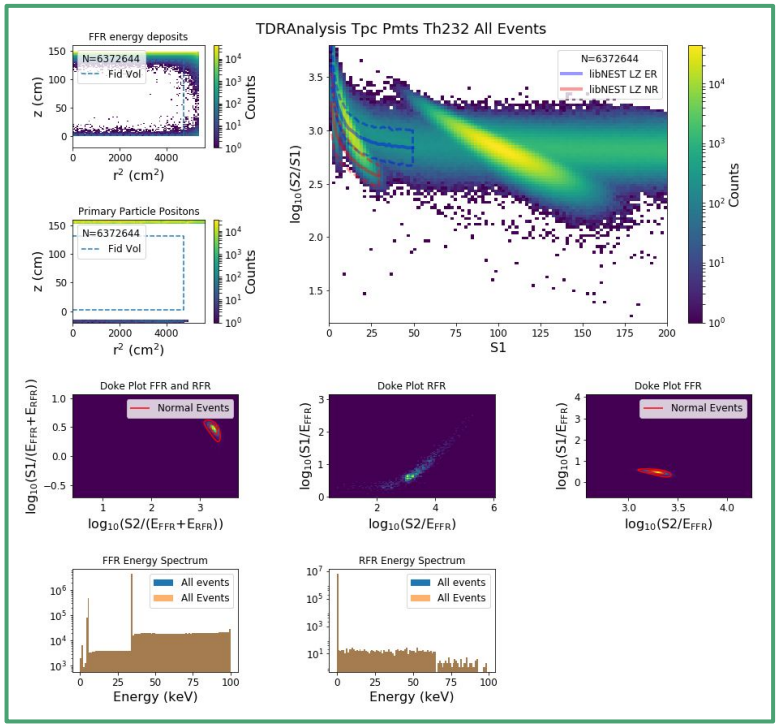
I ran the TDR Analysis which outputs whether or not an event is a Gamma-X

I did the same thing for a few sources (Full PMTs, Bottom Grid, Anode Grid, Cathode Grid, Field Rings, and Vessels)

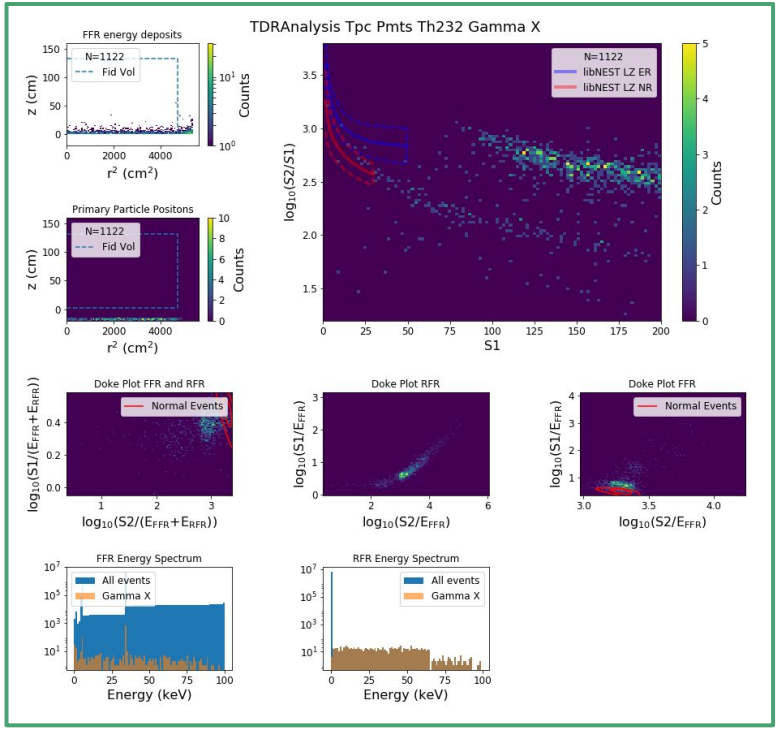
Compare the rates expected after making the three different energy cuts (the TDR ER cut, libNEST ER band cut, libNEST NR band cut)

Gamma X Update

Full PMTs with no cuts

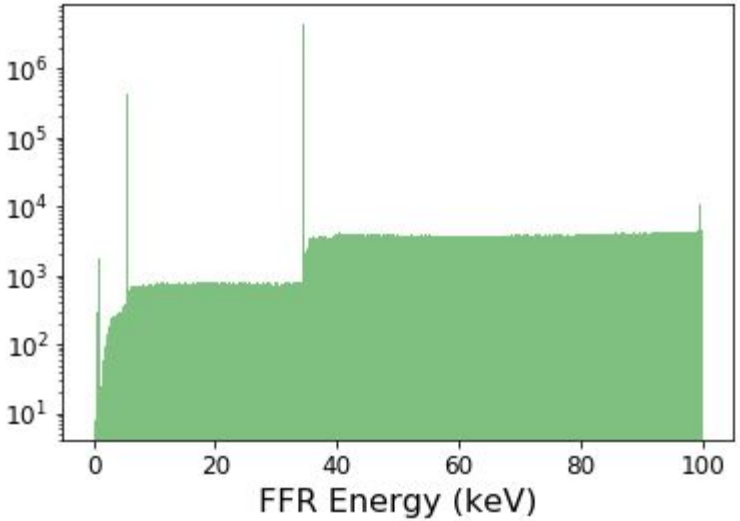


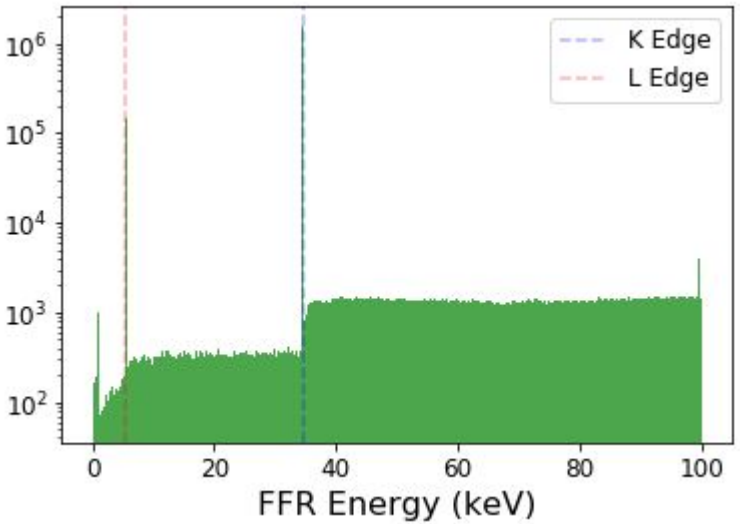
All events (Gamma-X and Normal)



Gamma-X events only

Lines in Energy





Lines in energy deposition correspond to Xenon energy levels. Not sure why this is happening. I would not have expected the energy depositions to be so discrete.

Gamma-X rates All PMTs (including all cuts)

Type of Events	Energy Cut	Events per 1000 days	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	16.80	0.14%	1.46	1055%
	My ER ROI	15.36	0.00%		954%
	My NR ROI	2.14	9.87%		63%
Gamma-X Events	TDR ROI	0.02			
	My ER ROI	0.00			
	My NR ROI	0.23			

Gamma-X rates Anode Grid (including all cuts)

Type of Events	Energy Cut	Events per 1000 days	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	0.50	0.00%	Not Calculated	Not Calculated
	My ER ROI	0.46	0.00%		Not Calculated
	My NR ROI	0.06	0.00%		Not Calculated
Gamma-X Events	TDR ROI	0.00			
	My ER ROI	0.00			
	My NR ROI	0.00			

Gamma-X rates Bottom Grid (including all cuts)

Type of Events	Energy Cut	Events per 1000 days	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	0.132	4.84%	Not Calculated	Not Calculated
	My ER ROI	0.105	4.39%		Not Calculated
	My NR ROI	0.015	42.62%		Not Calculated
Gamma-X Events	TDR ROI	0.007			
	My ER ROI	0.005			
	My NR ROI	0.011			

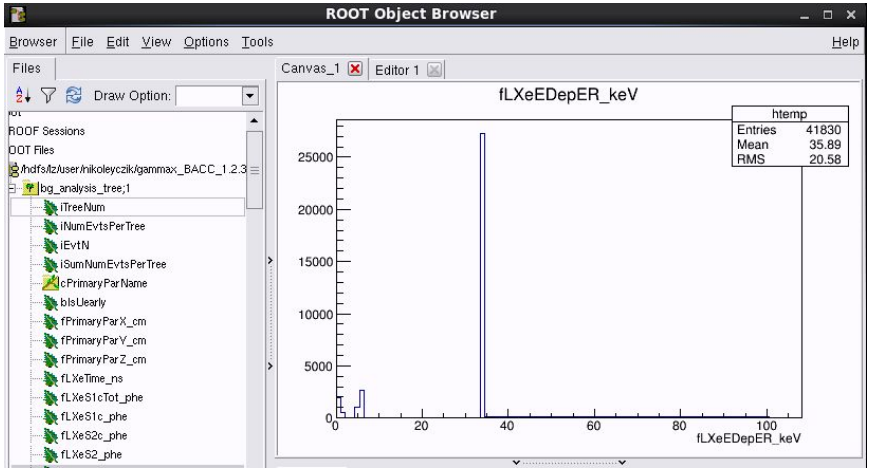
The problem with BACCARAT

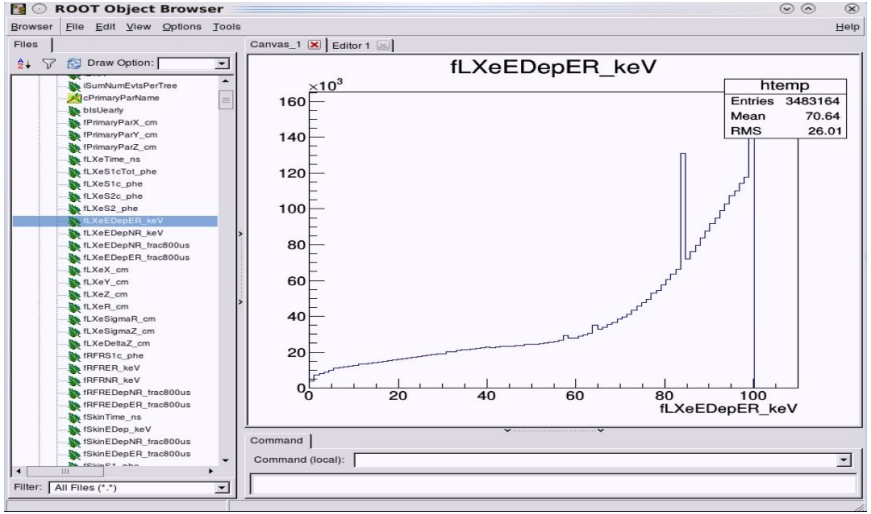
I had been using an outdated version of BACCARAT (1.2.3) and the most recent version (2.4.0) appears to have changed some properties at low energies.

Instead of rerunning the sims local I used the latest results for the backgrounds review which were run using BACCARAT 2.4.0 and reduced using TDRAnalysis 5.3.0
Note that these sims only include:

- Conduit Feedthrough
- HV conduit
- **PMTs (Focused on these so far)**
- PTFE Walls
- Vessels

The Difference Between 1.2.3 and 2.4.0 Energy Dep

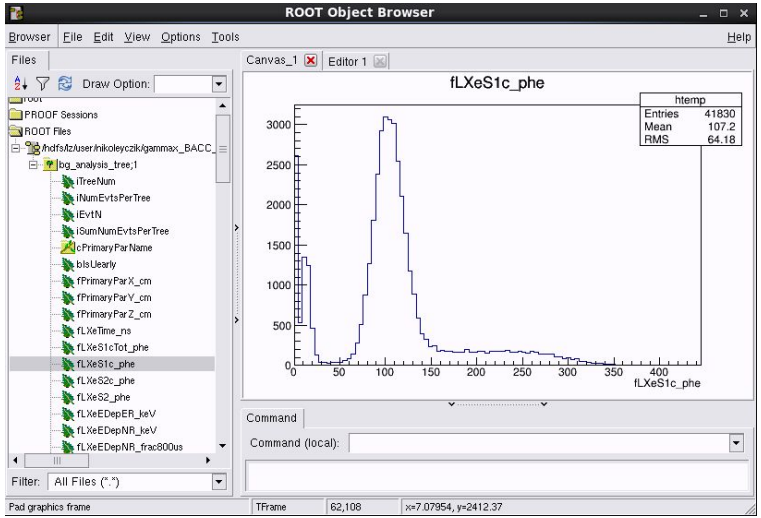


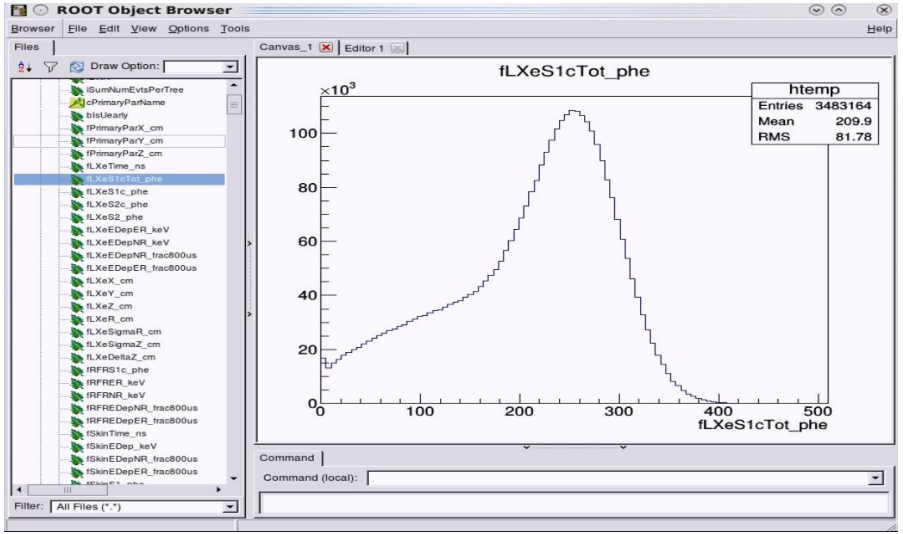


My output: BACC 1.2.3 and TDR ~5.2.1 (slightly modified), libNEST 3.0.2 Get same results using TDR 5.3.0, libNEST 4.2.0

PDSF output: BACC 2.4.0 and TDR 5.3.0, libNEST 4.2.0

The Difference Between 1.2.3 and 2.4.0 S1





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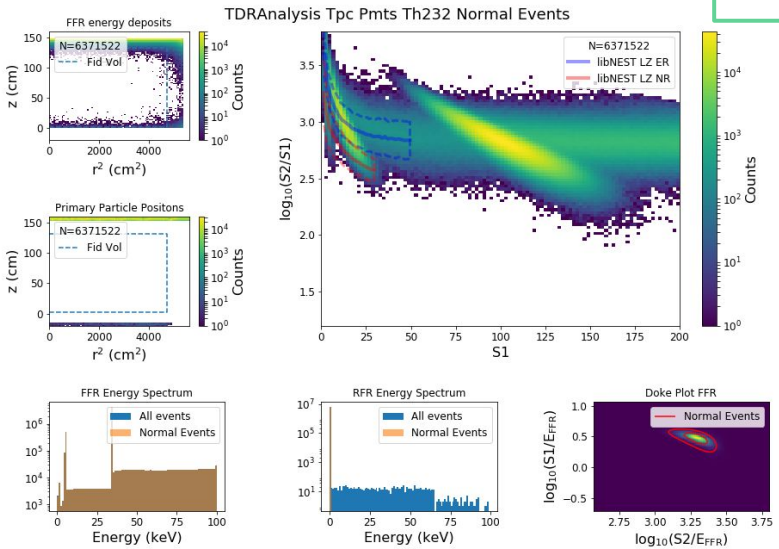
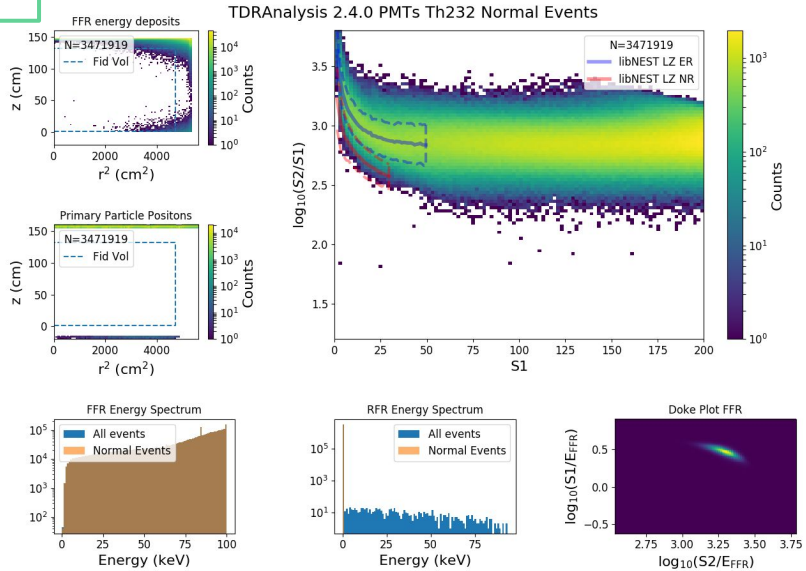
PDSF output: BACC 2.4.0 and TDR 5.3.0, libNEST 4.2.0

The Difference Between 1.2.3 and 2.4.0 Normal Events

NO CUTS





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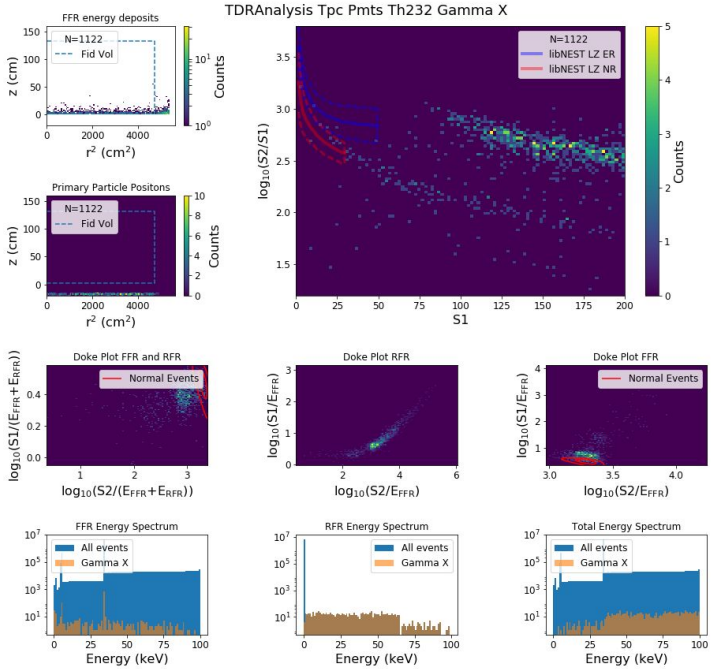
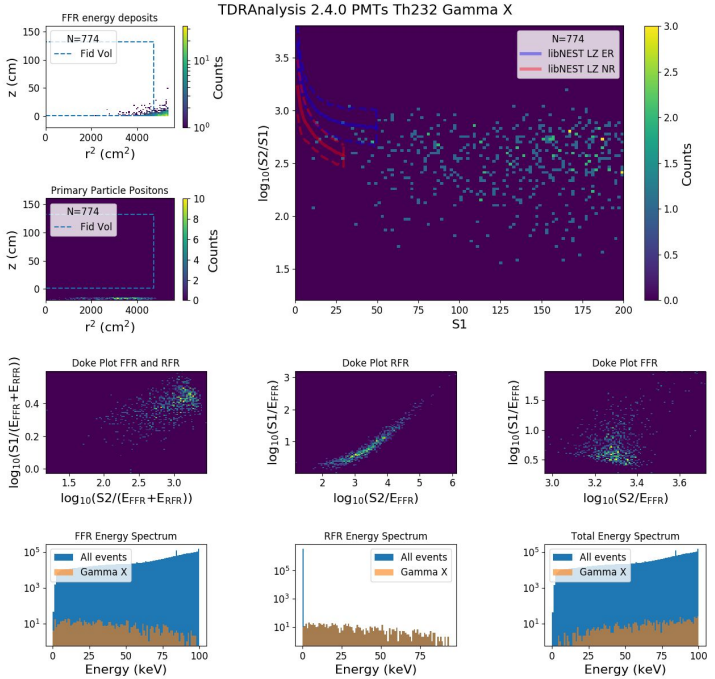
PDSF output: BACC 2.4.0 and TDR 5.3.0, libNEST 4.2.0

The Difference Between 1.2.3 and 2.4.0 Gamma-X Events



NO CUTS



My output: BACC 1.2.3 and TDR ~5.2.1 (slightly modified), libNEST 3.0.2 Get same results using TDR 5.3.0, libNEST 4.2.0

PDSF output: BACC 2.4.0 and TDR 5.3.0, libNEST 4.2.0

Gamma-X rates 2.4.0 PMTs (including all cuts)

Type of Events	Energy Cut	Events per 1000 days	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	0.06	0.00%	1.46	-96%
	My ER ROI	0.14	0.00%		-90%
	My NR ROI	0.02	0.00%		-99%
Gamma-X Events	TDR ROI	0.00			
	My ER ROI	0.00			
	My NR ROI	0.00			

Gamma-X rates 2.4.0 PMTs (including all cuts)

Type of Events	Energy Cut	Events per 1000 days	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
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	My NR ROI	0.02	0.00%		-99%
Gamma-X Events	TDR ROI	0.00			
	My ER ROI	0.00			
	My NR ROI	0.00			

There was one K40 event that got classified by my NR band (within the 90% bands for libNEST NR energy deposits)

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Normal Events	TDR ROI	0.06	0.00%	1.46	-96%
	My ER ROI	0.14	0.00%		-90%
	My NR ROI	0.02	0.00%		-99%
Gamma-X Events	TDR ROI	0.00			
	My ER ROI	0.00			
	My NR ROI	0.00			

No Gamma-X events pass all cuts in ~4e8 events
But Gamma-X events are ~1e-4 of all events

Gamma-X rates 2.4.0 PMTs (including all cuts)

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Normal Events	TDR ROI	0.06	0.00%	1.46	-96%
	My ER ROI	0.14	0.00%		-90%
	My NR ROI	0.02	0.00%		-99%
Gamma-X Events	TDR ROI	0.00			
	My ER ROI	0.00			
	My NR ROI	0.00			

My numbers are ~10% lower than the backgrounds control table but many sims saw 0 events pass all cuts. If we use upper limits instead my numbers are only ~50% lower

Backup (Raw Data)

Simulation name	N files	N beamOn	ROI	+SS	+Skin	+OD	+Skin+OD	+5.6t FV	U_early	U_late	R-factor
2.4.0_tpc_pmts_Th232_NormalTDRROI	3.94E+02	3.94E+08	49395	49162	41455	36039	30694	7			1.22E-09
2.4.0_tpc_pmts_Th232_NormalMyERROI	3.94E+02	3.94E+08	133593	132756	114674	98664	86065	15			2.62E-09
2.4.0_tpc_pmts_Th232_NormalMyNRROI	3.94E+02	3.94E+08	7563	7557	6300	5507	4628	0			0.00E+00
2.4.0_tpc_pmts_Th232_GammaXTDRROI	3.94E+02	3.94E+08	6	6	1	6	1	0			0.00E+00
2.4.0_tpc_pmts_Th232_GammaXMyERROI	3.94E+02	3.94E+08	10	10	1	10	1	0			0.00E+00
2.4.0_tpc_pmts_Th232_GammaXMyNRROI	3.94E+02	3.94E+08	8	8	0	6	0	0			0.00E+00
2.4.0_tpc_pmts_U238_NormalTDRROI	3.78E+02	3.78E+08	40593	40399	34040	30650	26220	3	0	3	5.46E-10
2.4.0_tpc_pmts_U238_NormalMyERROI	3.78E+02	3.78E+08	108202	107428	92691	82066	71792	10	0	10	1.82E-09
2.4.0_tpc_pmts_U238_NormalMyNRROI	3.78E+02	3.78E+08	6323	6322	5308	4845	4129	0	0	0	0.00E+00
2.4.0_tpc_pmts_U238_GammaXTDRROI	3.78E+02	3.78E+08	0	0	0	0	0	0	0	0	0.00E+00
2.4.0_tpc_pmts_U238_GammaXMyERROI	3.78E+02	3.78E+08	3	3	0	3	0	0	0	0	0.00E+00
2.4.0_tpc_pmts_U238_GammaXMyNRROI	3.78E+02	3.78E+08	1	1	0	1	0	0	0	0	0.00E+00
2.4.0_tpc_pmts_K40_NormalTDRROI	4.00E+02	4.00E+08	2378	2376	1893	1868	1462	0			0.00E+00
2.4.0_tpc_pmts_K40_NormalMyERROI	4.00E+02	4.00E+08	6338	6314	5035	5056	3987	0			0.00E+00
2.4.0_tpc_pmts_K40_NormalMyNRROI	4.00E+02	4.00E+08	386	386	322	310	254	1			1.72E-10
2.4.0_tpc_pmts_K40_GammaXTDRROI	4.00E+02	4.00E+08	1	1	0	1	0	0			0.00E+00
2.4.0_tpc_pmts_K40_GammaXMyERROI	4.00E+02	4.00E+08	0	0	0	0	0	0			0.00E+00
2.4.0_tpc_pmts_K40_GammaXMyNRROI	4.00E+02	4.00E+08	2	2	0	2	0	0			0.00E+00
2.4.0_tpc_pmts_Co60_NormalTDRROI	3.97E+02	3.97E+08	25186	25077	17688	9526	6243	3			5.20E-10
2.4.0_tpc_pmts_Co60_NormalMyERROI	3.97E+02	3.97E+08	65342	64941	47499	24706	16947	8			1.39E-09
2.4.0_tpc_pmts_Co60_NormalMyNRROI	3.97E+02	3.97E+08	4066	4066	2838	1588	1031	0			0.00E+00
2.4.0_tpc_pmts_Co60_GammaXTDRROI	3.97E+02	3.97E+08	6	6	0	4	0	0			0.00E+00
2.4.0_tpc_pmts_Co60_GammaXMyERROI	3.97E+02	3.97E+08	10	10	0	9	0	0			0.00E+00
2.4.0_tpc_pmts_Co60_GammaXMyNRROI	3.97E+02	3.97E+08	7	7	0	7	0	0			0.00E+00

Gamma-X Update

I was misusing the factor 14. For the backgrounds control table they assume that the ER spectrum is flat from 0 to 100 S1. Even though the WIMP search region is defined up to 20 in S1 they use the full 0 to 100 and scale the number of counts by 14. This gives increased stats.

I was applying the same scaling but it does not apply to Gamma-X events. The factor for Gamma-X should be about 37. Instead of applying the scaling I will live with reduced stats.

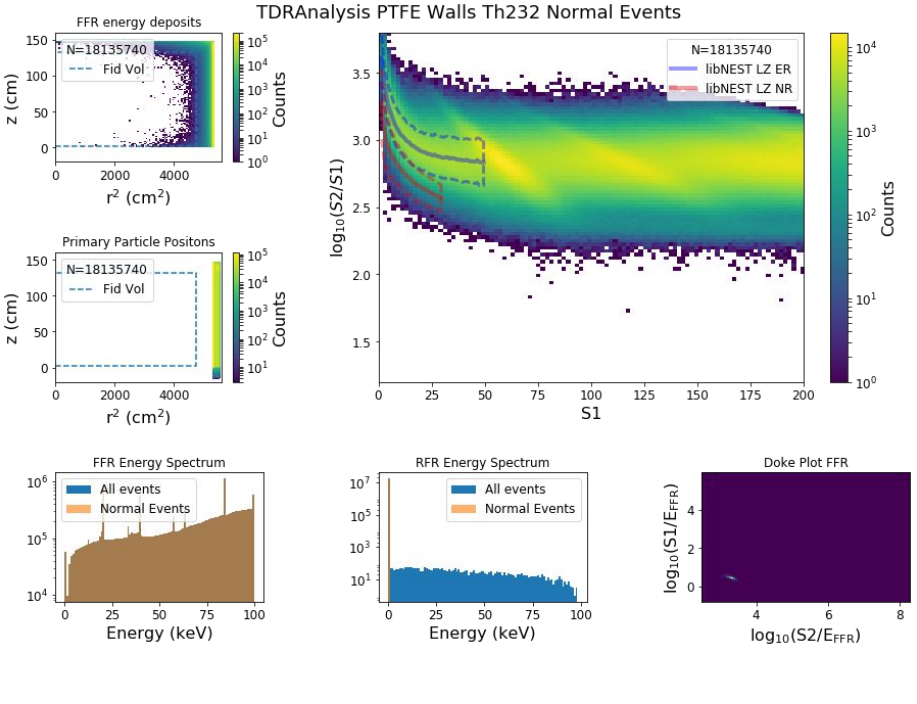
PMT Results (Now without factor of 14)

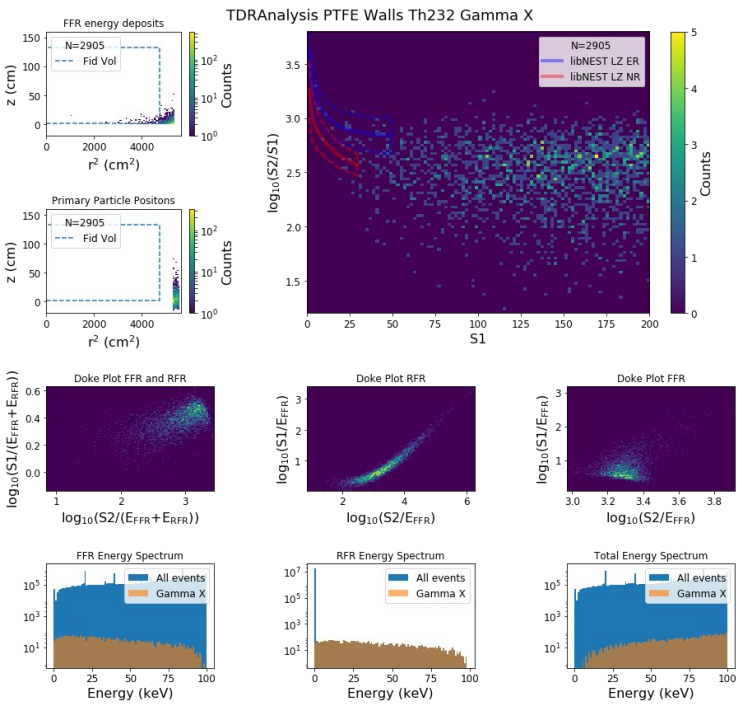
Type of Events	Energy Cut	Events per 1000 days	Approx. Error	Number of events after cuts	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	0.8	±0.4	13	0.00%	1.46	55%
	My ER ROI	2.0	±0.6	33	0.00%		140%
	My NR ROI	0.3	±0.3	1	0.00%		21%
Gamma-X Events	TDR ROI	0.0		0			
	My ER ROI	0.0		0			
	My NR ROI	0.0		0			

PTFE Walls Results

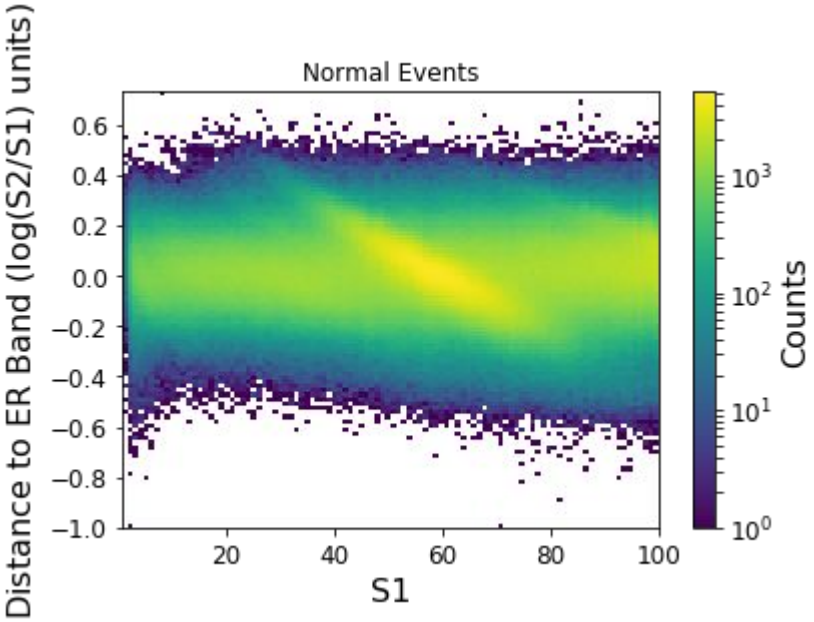
Type of Events	Energy Cut	Events per 1000 days	Approx. Error	Number of events after cuts	Fraction of all events that are Gamma-X	BG Table Rate (per 1000 days)	Difference between my results and BG table
Normal Events	TDR ROI	0.030	±0.007	31	0.00%	0.0558	54%
	My ER ROI	0.074	±0.010	56	0.00%		133%
	My NR ROI	0.004	±0.003	4	83.61%		43%
Gamma-X Events	TDR ROI	0.000		0			
	My ER ROI	0.000		0			
	My NR ROI	0.020	±0.008	22			

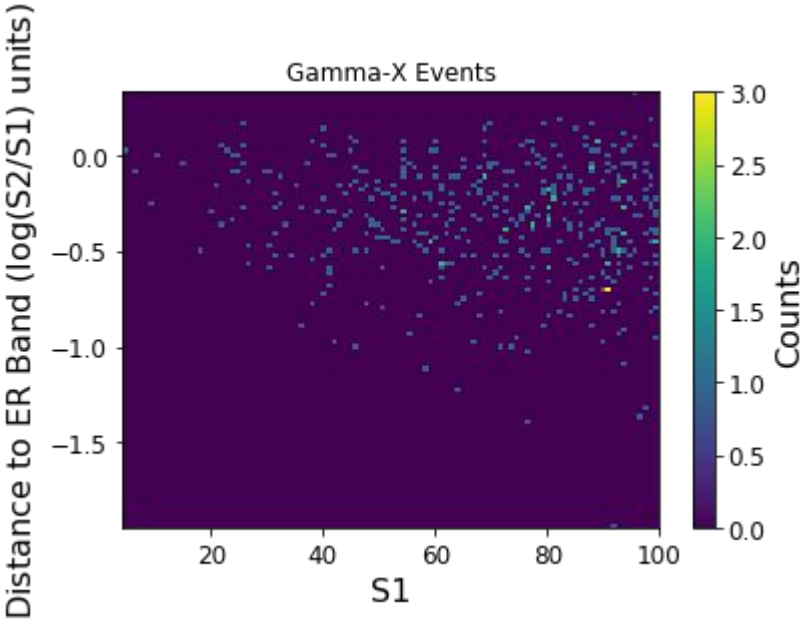
PTFE Plots (before cuts)





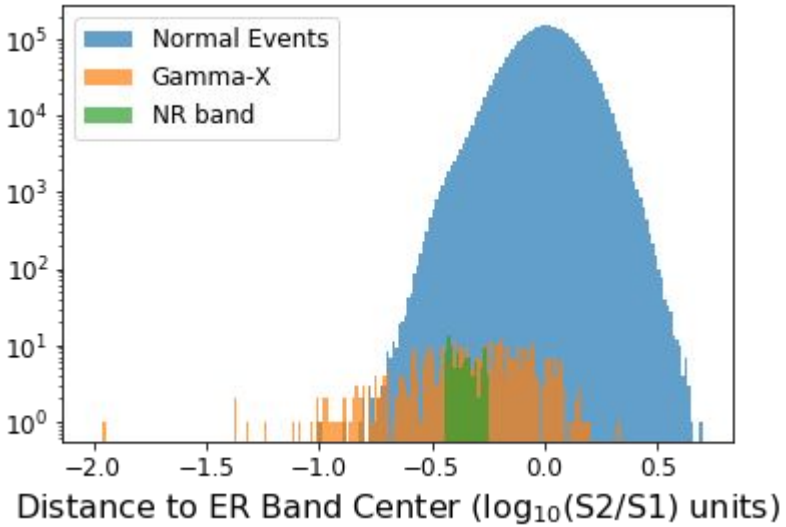
An attempt to quantify distance from ER Band





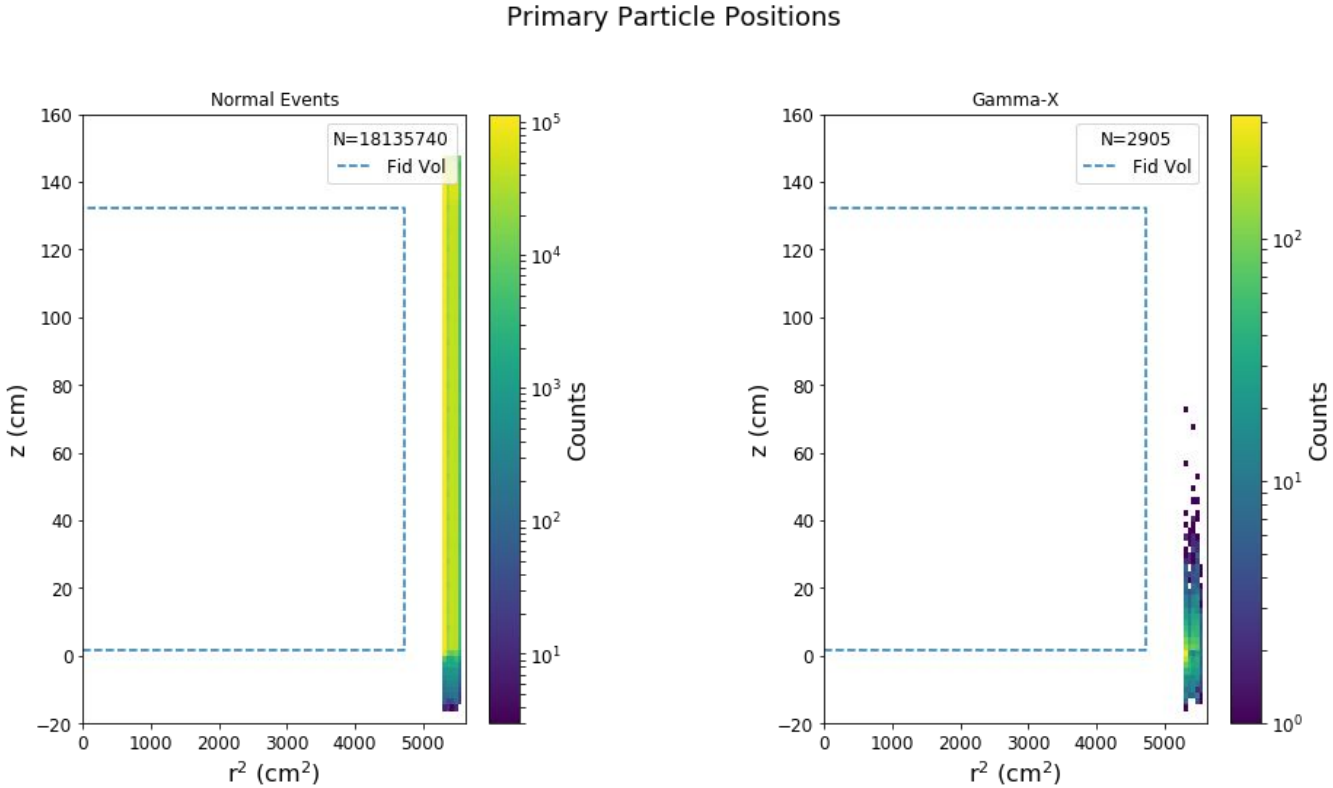
Same data collapsed onto one axis

- Normal Events are gaussian around ER band mean (as expected)
- Gamma-X Events are all below the ER band mean
- The distance from the ER band increases with S1
- Looks like an exponential decrease from the ER band

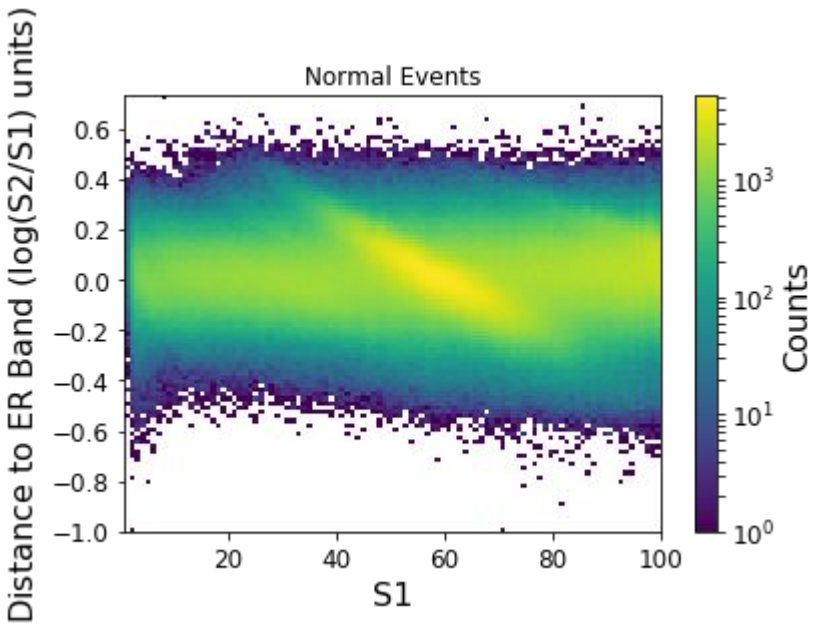


Where Gamma-X events come from (PTFE Walls)

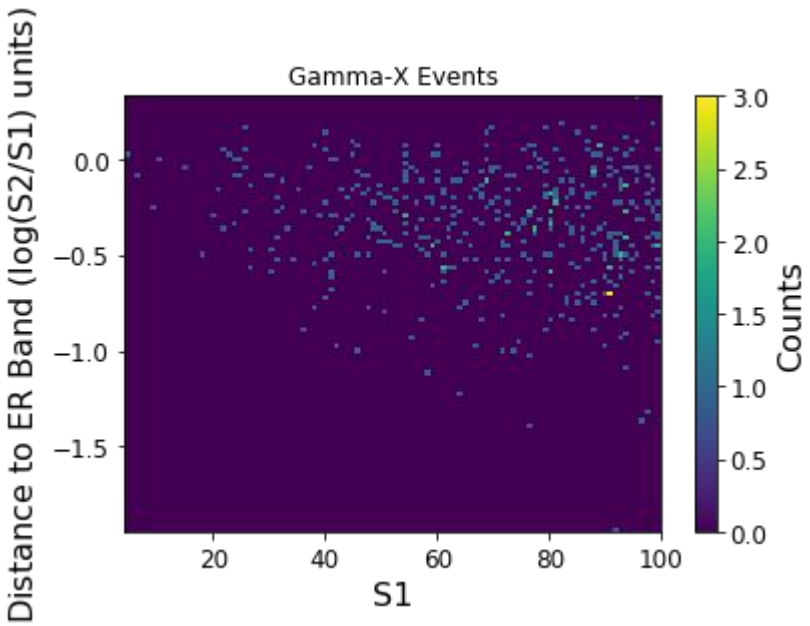
- Events must start out close to the cathode
- Fall off exponentially both above and below



(From last time) An attempt to quantify distance from ER Band

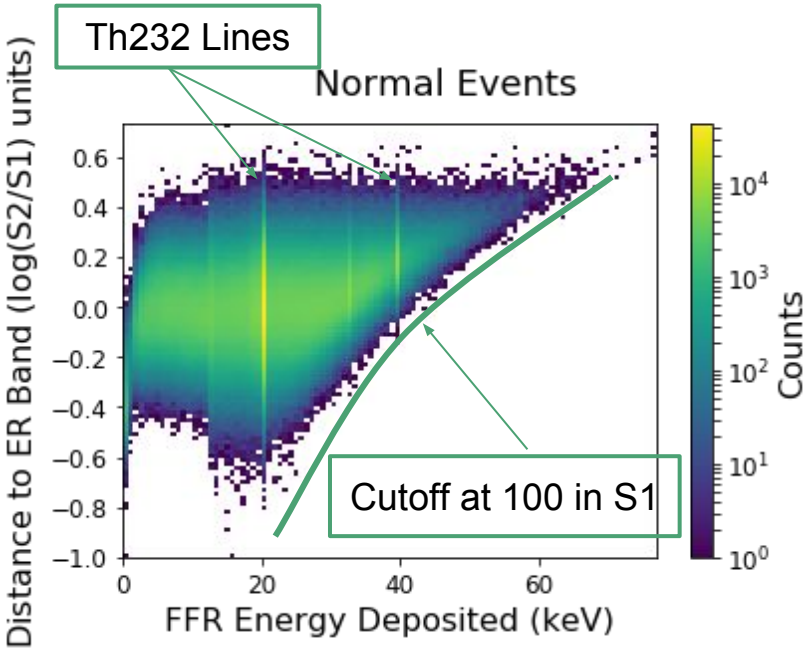


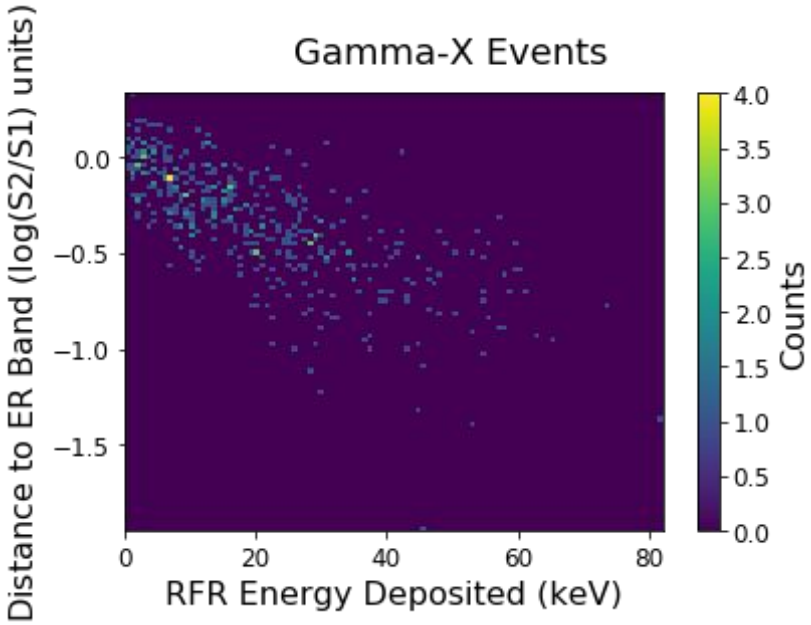
Normal events are gaussian centered around the ER band (as expected)



Gamma-X becomes more of a problem at higher S1 (higher energy)

A new correlation

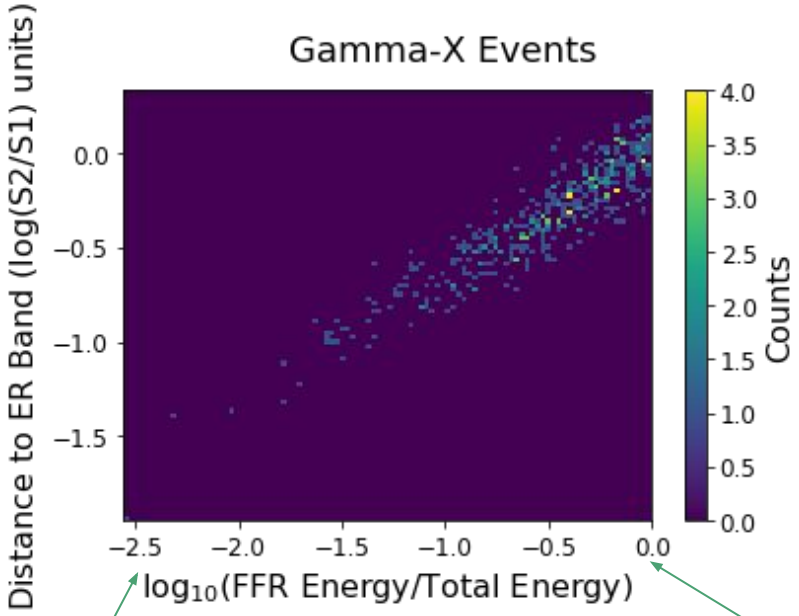




Gamma-X becomes more of a problem if there is more energy deposited in the RFR

A tighter correlation by going a step further

Here S1<100
(WIMP search region)
And no other cuts applied

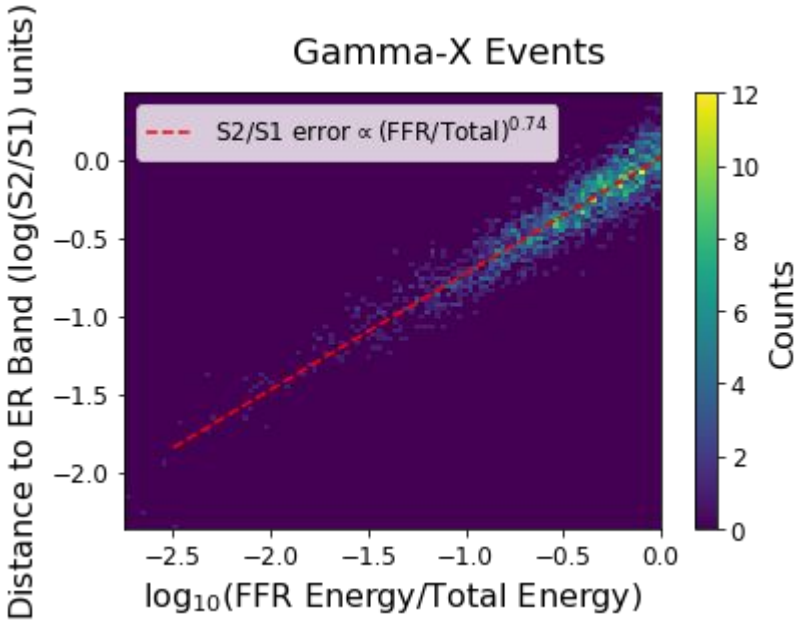


“Gamma-X Event”-like
(Most energy is in RFR)

“Normal Event”-like
(Most energy is in FFR)

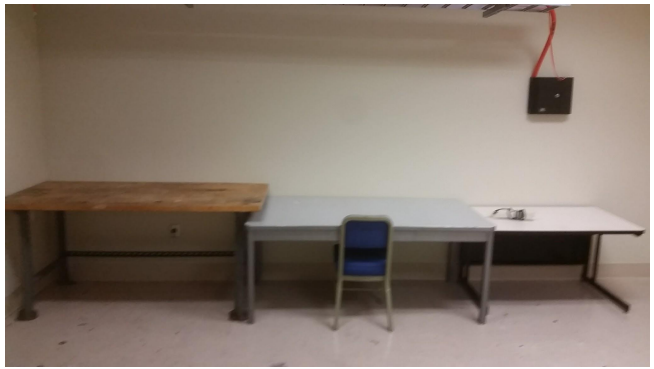
This correlation holds even at higher S1

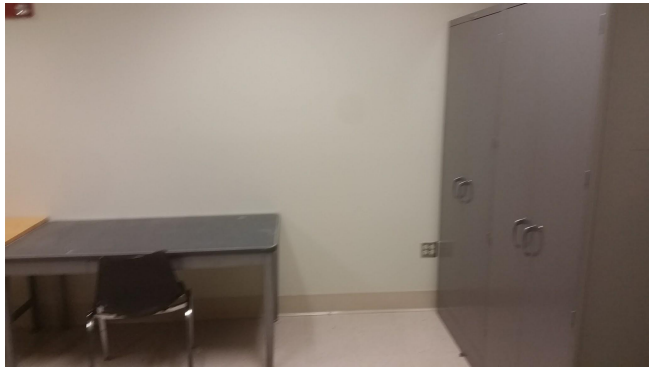
Here S1<200 just to see the behavior with more stats



Gamma-X events are really only significant when more than a third of the total energy is deposited in the RFR

New room ready to make cables





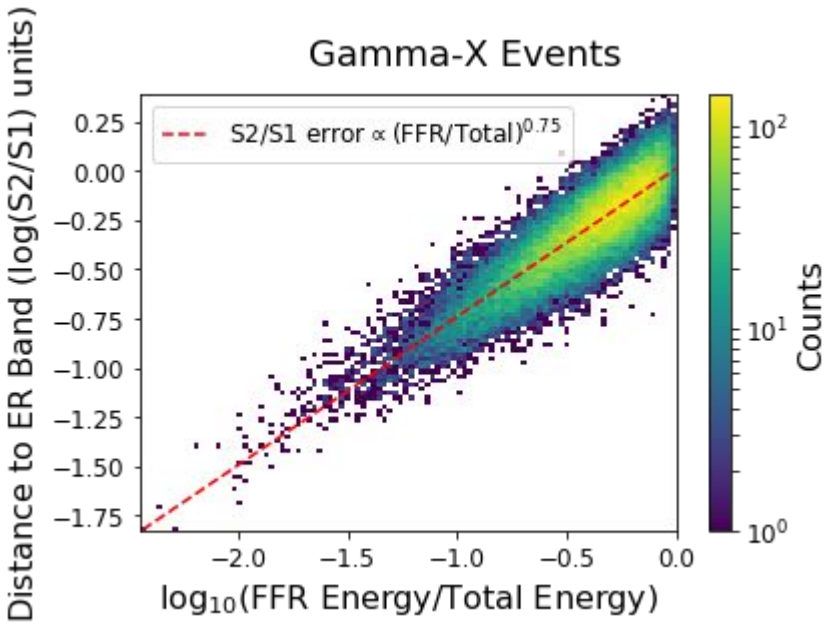
ER band error as a function of energy

This relationship implies that:

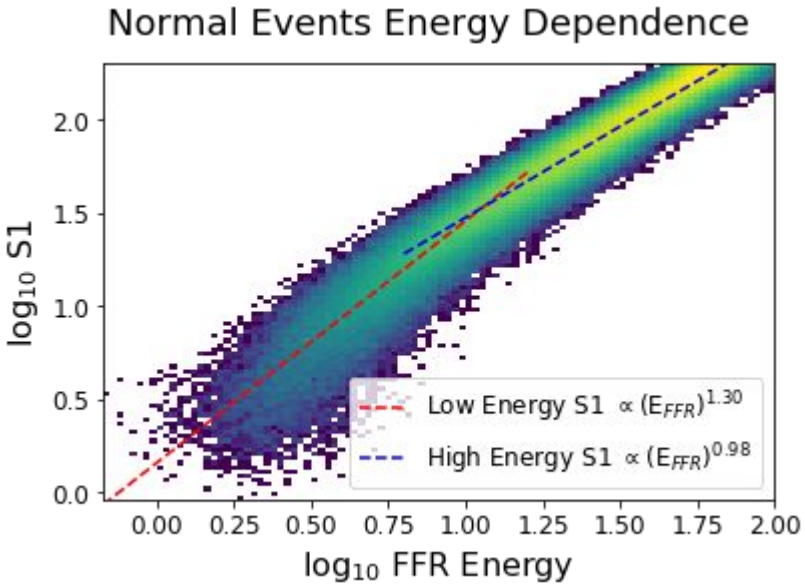
(S2obs/S1obs)/(S2exp/S1exp)∝(FFR Energy/Total Energy)^0.75

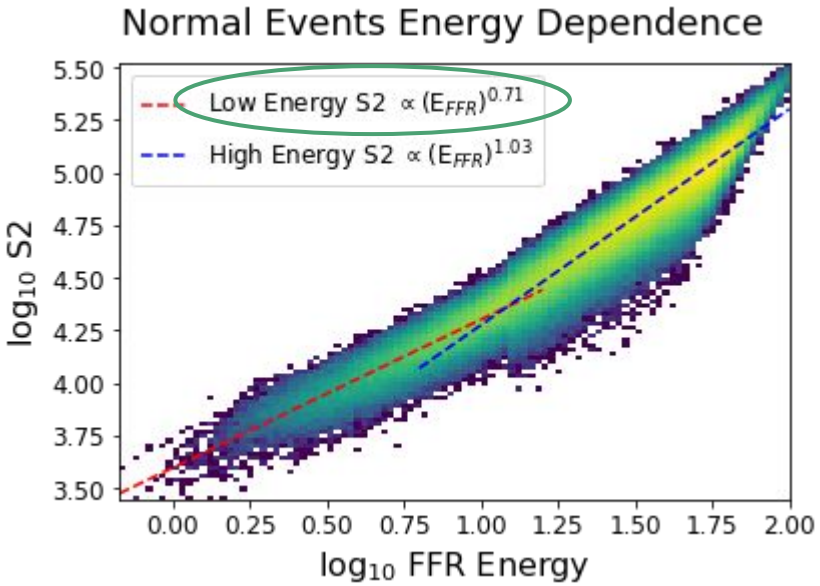
Assume S1obs≃S1exp

S2obs/S2exp∝(FFR Energy/Total Energy)^0.75



Normal Events Energy Dependence



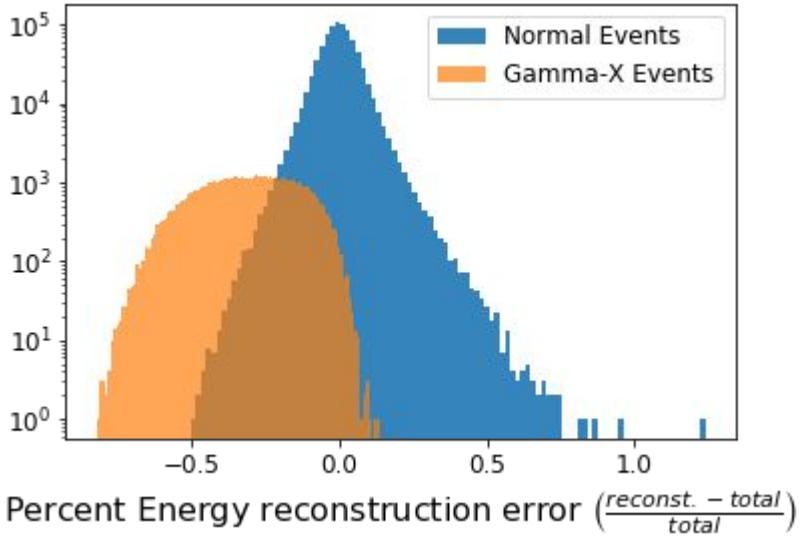


So what we are seeing in the plot on the previous slide is just the low energy dependence of S2 vs energy

Energy reconstruction

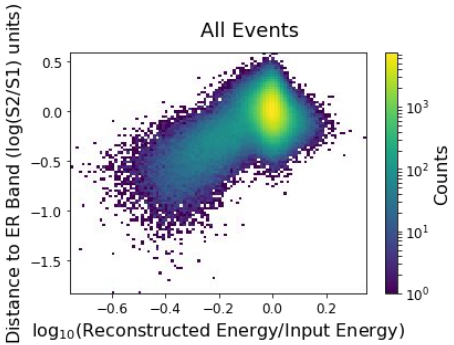
For Reconstructed Energy=13.7(S1/g1+S2/g2)
Where g1 and g2 are found from the normal events
g1=71.2 photons/eV
g2=62800 photons/eV

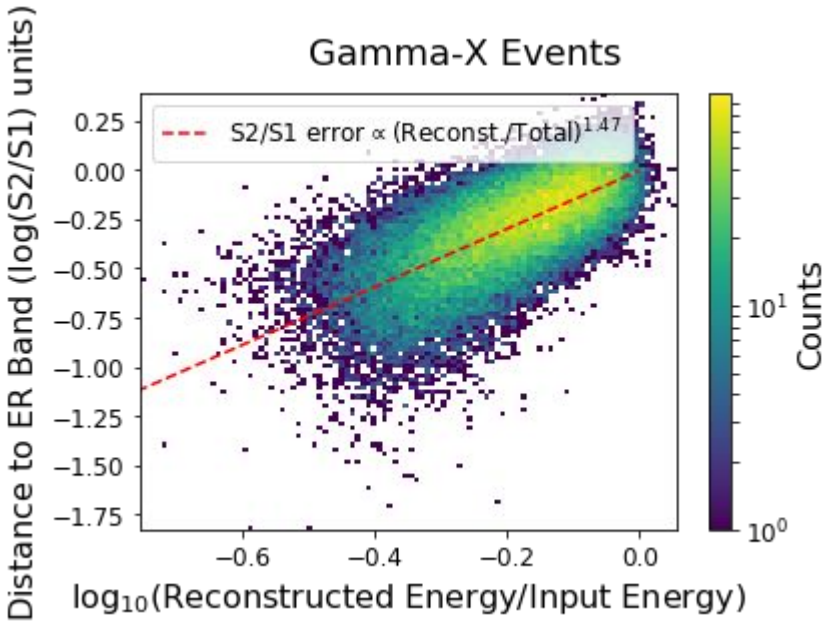
Energy reconstruction underestimates gamma-x energies by 30%



Correlation still holds if reconstructed energy is used

There is some spreading but this is still distinct from the primary normal events peak:





More Sims coming

Waiting on UKDC to finish sims of the cathode and bottom grid wires.

These should have significantly more stats than I have shown here (which are run on our cluster).

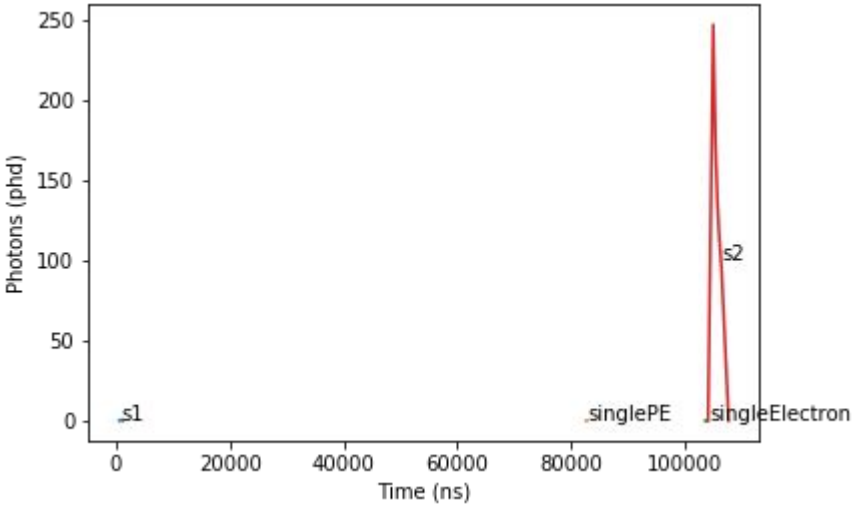
DER LZAP and more

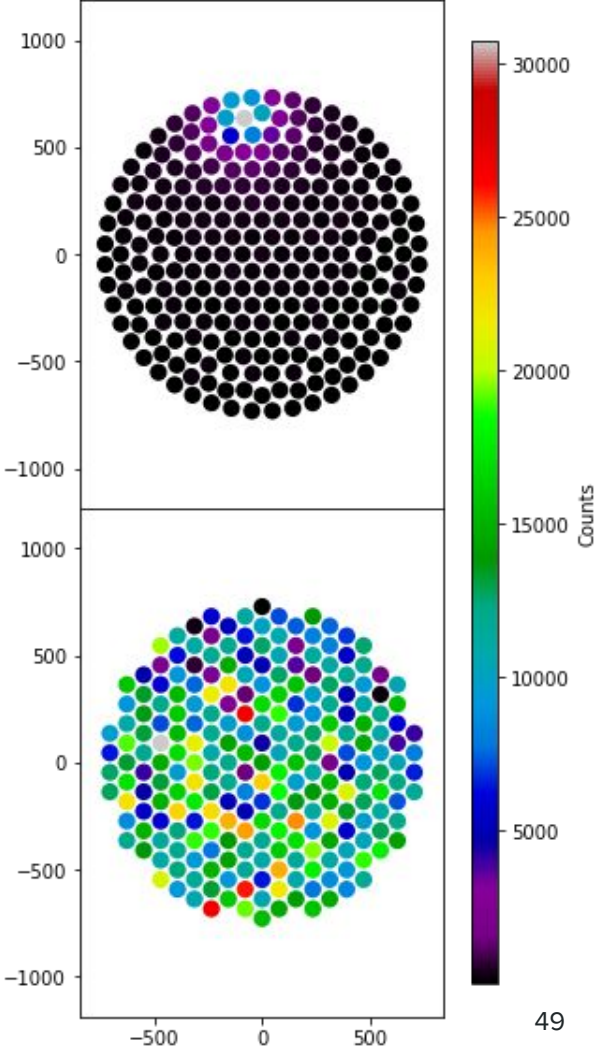
- Installed DER and LZAP
- Started running optical sims of Gamma-X events as a test
  - BACCARAT is extremely slow or might not be working optimally
- DER does not work on the BACCARAT output
  - Says 0 of 494 PMTs are found
- Can’t test LZAP without a DER output

LZAP analysis

Revisiting MDC1 data to test LZAP analysis.

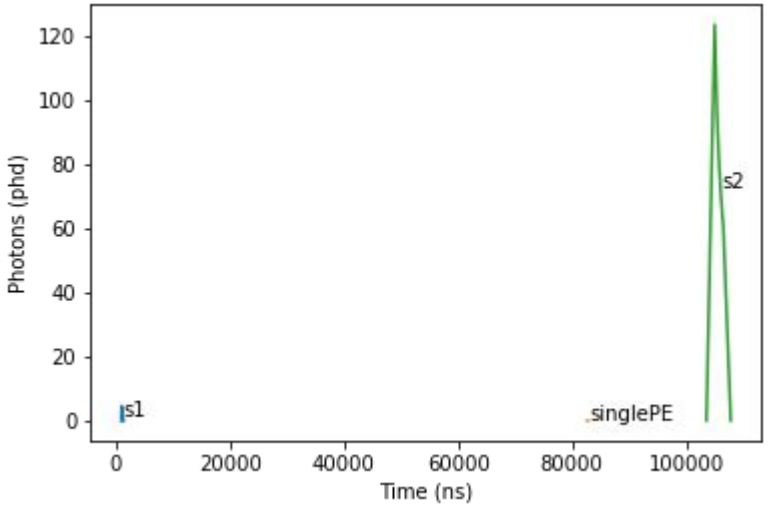
Want to come up with a quick way to do analysis, like LUX event viewer

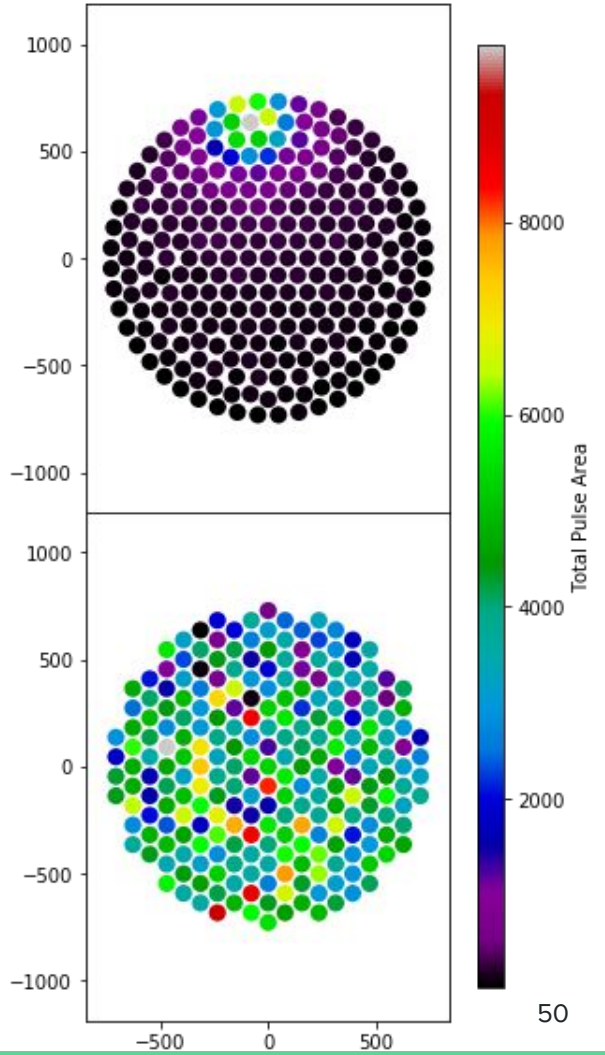




LZAP analysis

Works for all detectors (High gain, Low gain, Outer, and Skin)



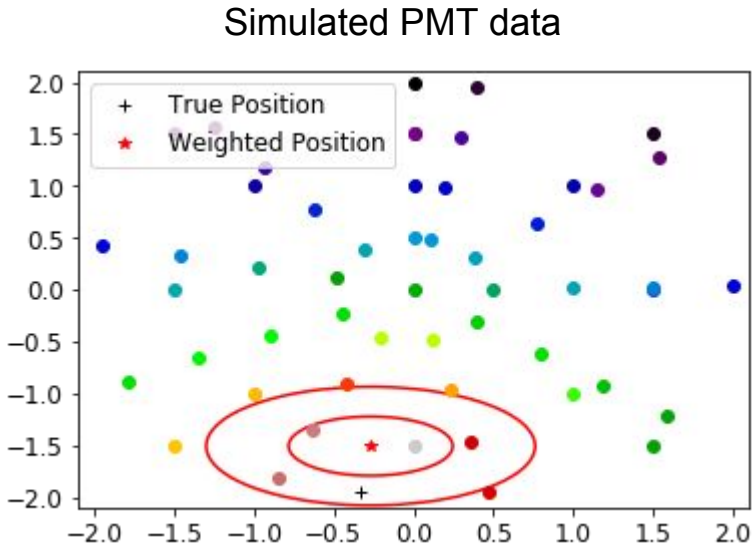


Position Reconstruction

Position reconstruction using weighted averages fails when the source is located outside the ring of PMTs

Used semi random dispersed PMTs and a diffuse point source ($1/r^2$)

We might need a better method for Phase 2



Ready to make cables

- Have most of the necessary tools to begin making cables
- Still need an ultrasonic cleaner
- Need to decide which metcal tips we want to use
  - We have a large selection to choose from but can’t keep them all
  - Assuming we want 600 series (675^0)

The reason BACCARAT is so slow

Previously wasn’t using the commands /Bacc/detector/useMapOptical true and

/Bacc/physicsList/setQeGains true

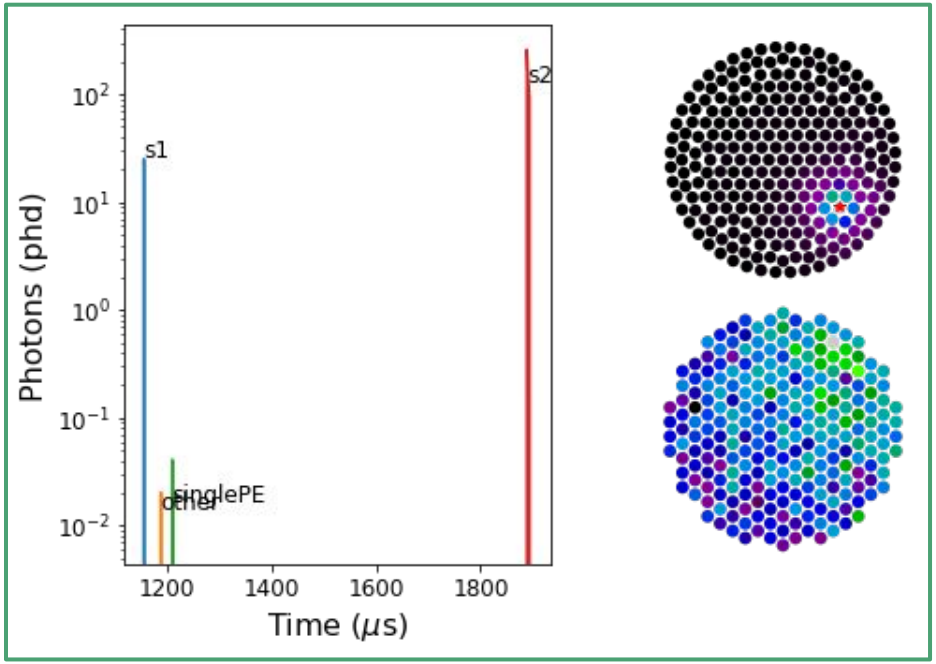
These essentially skip the production of S2 light by creating a map between extraction region position and the signal seen in every PMT.

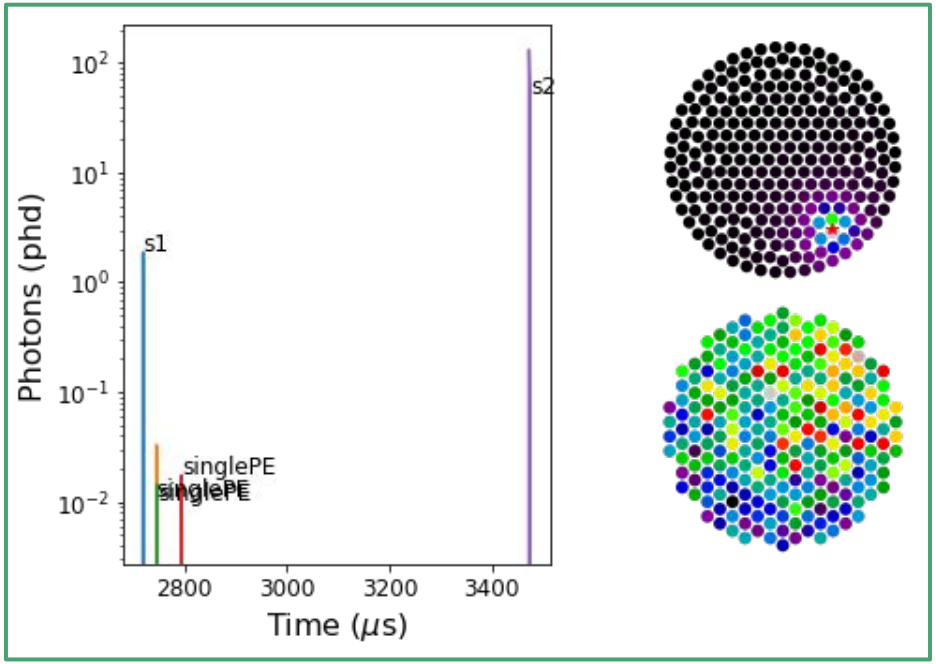
Now generating events at a rate of ~1 per 10 minutes

Running DER and LZAP

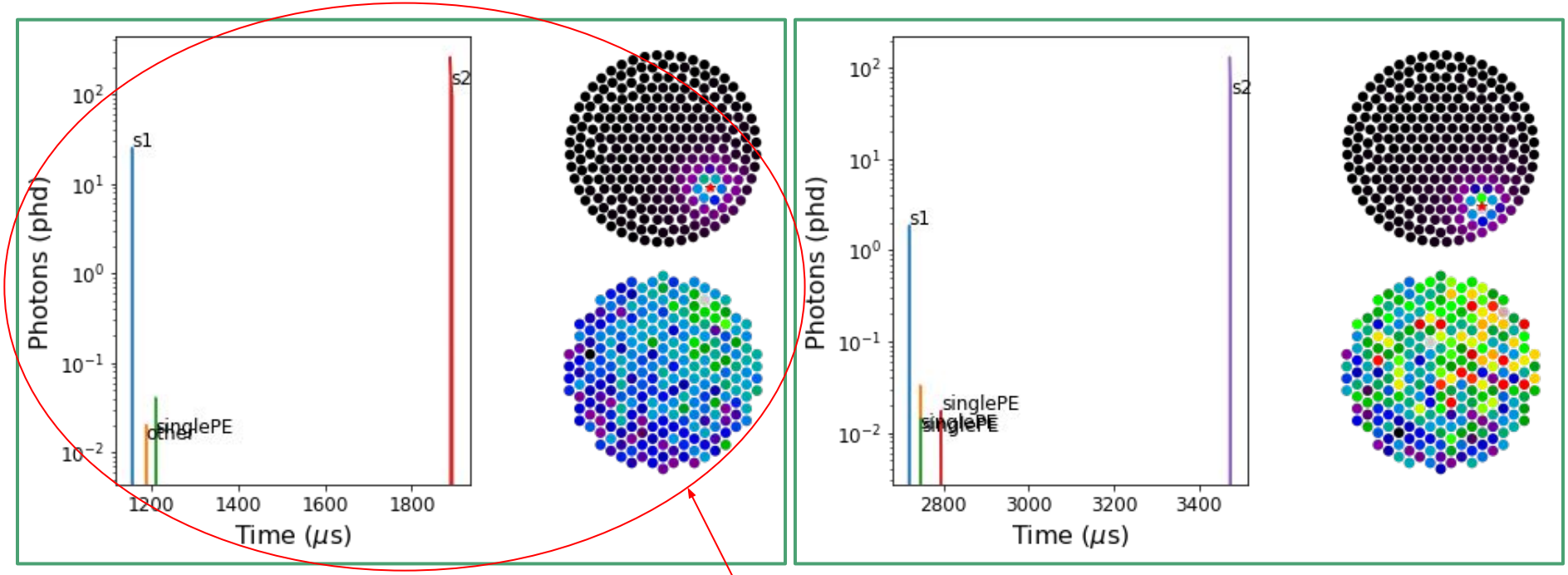
- I was able to produce DER and LZAP output from events on the cathode grid wires
  - These gave the highest ratio of gamma-x to normal events
- Passed through electronics response (DER) then post-processing (LZAP)
- Starting to divide up into normal and Gamma-X populations

Which one is the Gamma-X event?



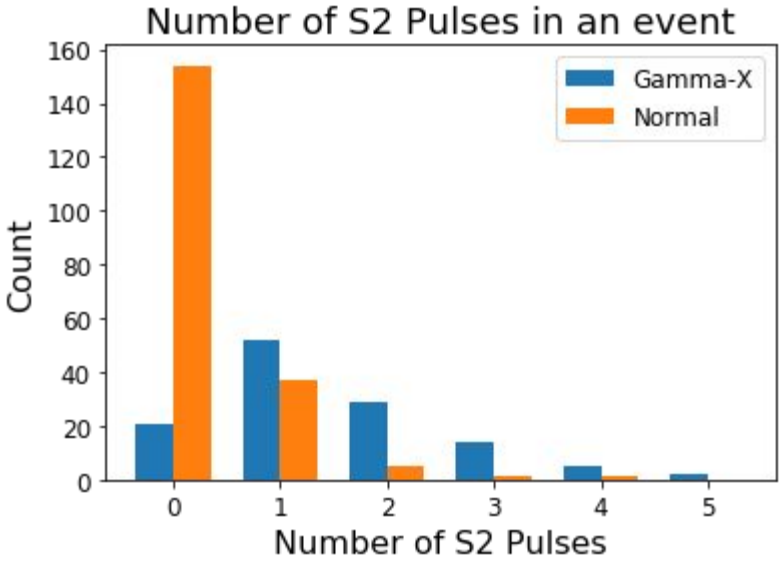


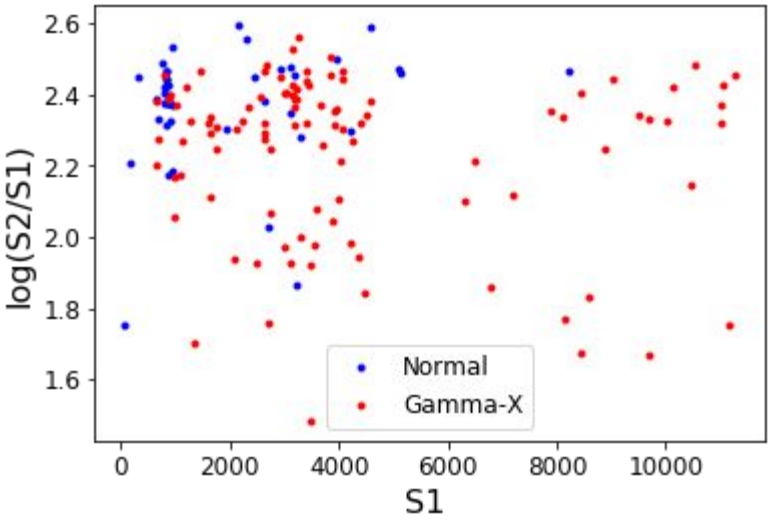
Which one is the Gamma-X event?



Its this one

Differences between Gamma-X and normal populations





There are a lot of multiple scatters in both populations but they are more extreme in the Gamma-X events

Hard to differentiate the two populations in S1 S2 space. Need more stats at low energies and to use corrected S1 and S2

Gamma-X Update

- The electron lifetime in MDC1 was set by a BACCARAT command
  - /Bacc/physicsList/driftElecAttenuation 0.20 m
  - Default BACCARAT calculates this
  - New Gamma-x sims have this set to 10 m
- Also added reflectivities and NEST for optical processes
- File sizes increased significantly
  - Previous script 25 events / GB
  - New script ~5 events / GB

Cable Making

- Received cable and connectors from Shaun
- Started cutting cable
- Cleanliness?
  - Iso to clean surfaces and cables? Gloves while handling?
- How many spare cables should we make? Should I use all the cable we have?
- Only equipment I think we still need is chemicals
  - Was told the Plasma group handles the chemicals but not sure who to talk to
- Following Pinout found here (Phase 2 cables)
  - Lists Ceramtec HV feedthru

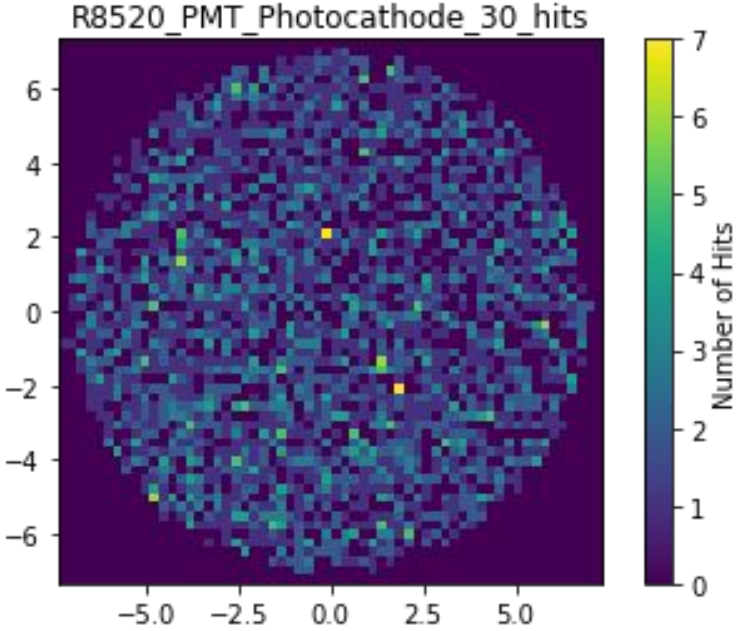
What I learned this semester

- Gamma-X
  - There may be some way to differentiate gamma-x events from normal events
  - Would need high statistics
  - The expected gamma-x rate is less than one event per 1000 live days
  - Started looking to see if there is a way to see gamma-x in fully simulated data
- Cable making
  - Setting up a lab is much more work than I thought it would be
  - I learned everything that can go wrong when making cables
  -

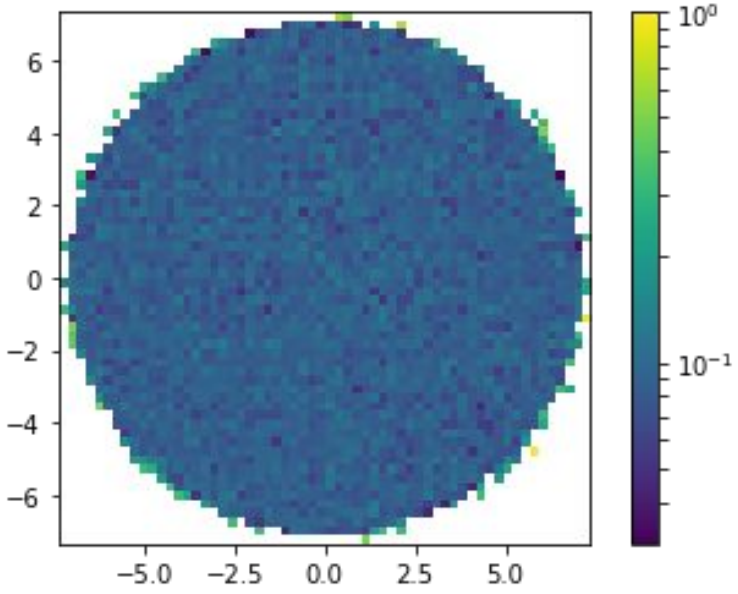
Phase 1 S1 and S2 photon maps

- Used the scripts from Amy to make maps of ~10 million photons distributed in the liquid xenon for S1s and in the gas for S2s
- Working on implementing this into BACCARAT
- Believe I have done this correctly in a way that won't break LZ sims
- Currently stuck running a test macro
  - Bad_alloc error
  - This is a common error for BACCARAT but gives no description of the cause. Possibly root version conflicts?

Phase 1 photon maps (S1)

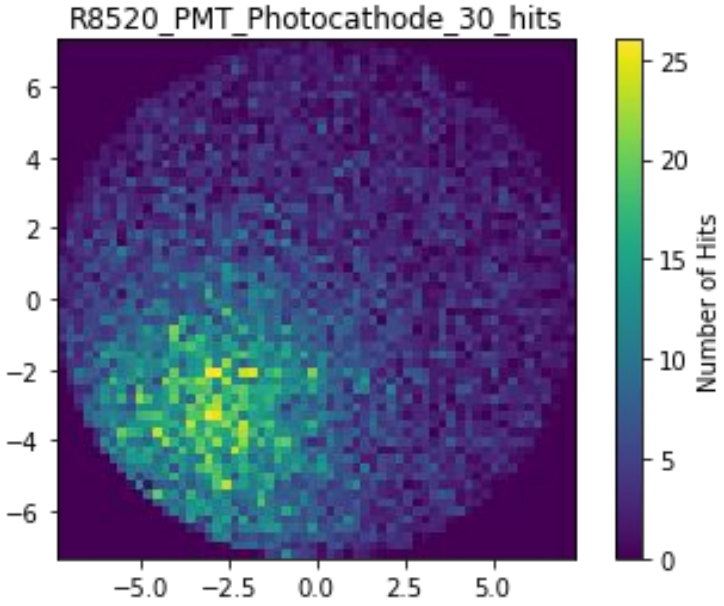


Example of a single PMT

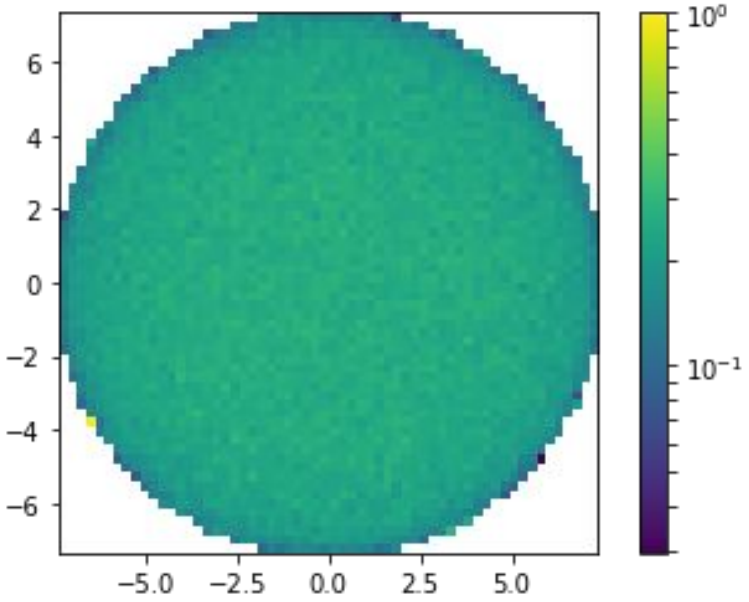


Combined light collection efficiency
Avg: 9% With QE: ~2.6%

Phase 1 photon maps (S2)



Example of a single PMT



Combined light collection efficiency
Avg: 23% With QE: ~7%