Multiple Interaction Event Rejection in the LZ Dark Matter Detector

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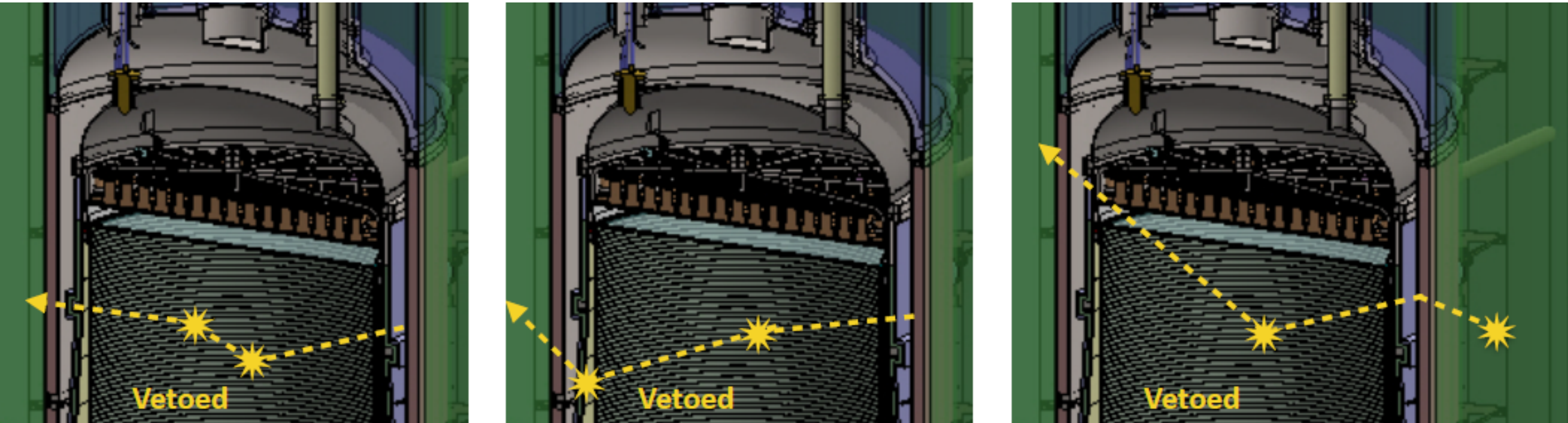
In This Talk

- Motivation.
- LZSim Overview.
- Multiple interaction algorithms.
- Identifying optimal algorithm.
- Results.
- Conclusions.
    - Multiple interaction rejection very important.
    - A framework for algorithm optimisation has been developed.
    - Need to improve signal identification.

Motivation

- LZ – future successor of LUX WIMP detector.
  - 7 tonne active Liquid Xenon (LXe) volume.
  - Predicted sensitivity: 2×10^{-48} cm^2 at 50GeV/ c^2.

- Effective background rejection and modelling necessary to achieve this sensitivity.
- Simulations must include multiple interaction identification.



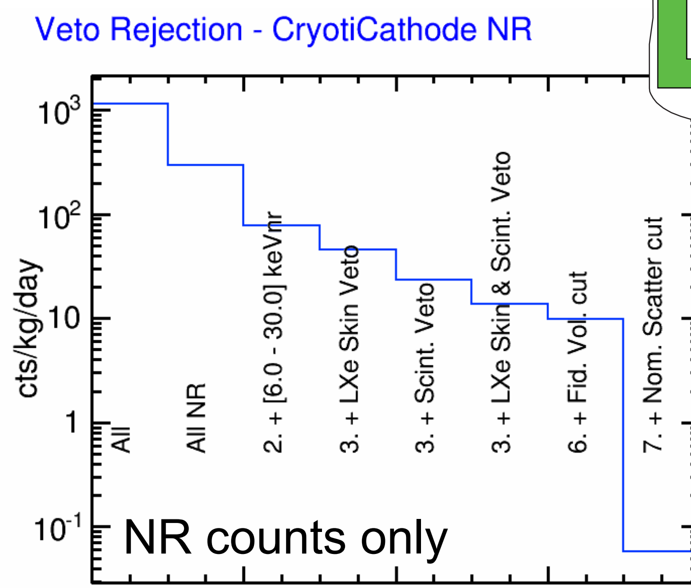
The Background Vetoing Systems

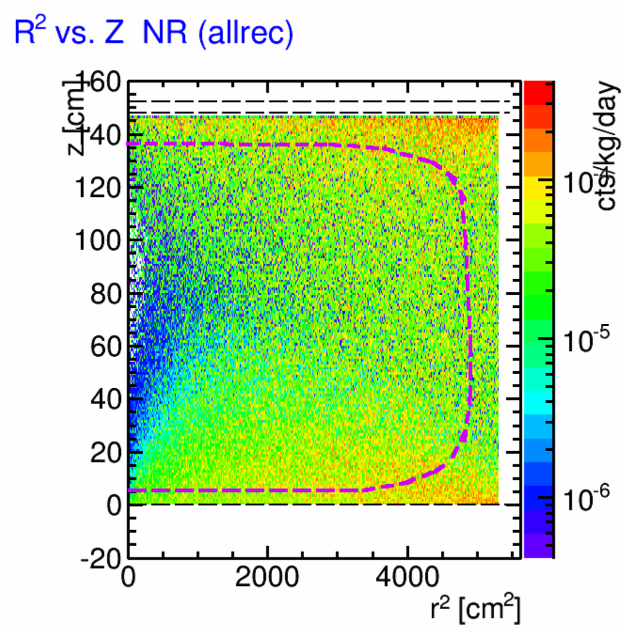
- Energy cut (6-30keVnr and 1.5-6.5keVee).
- Time co-incidence cuts with LXe skin and Gd-LS vetoing systems.

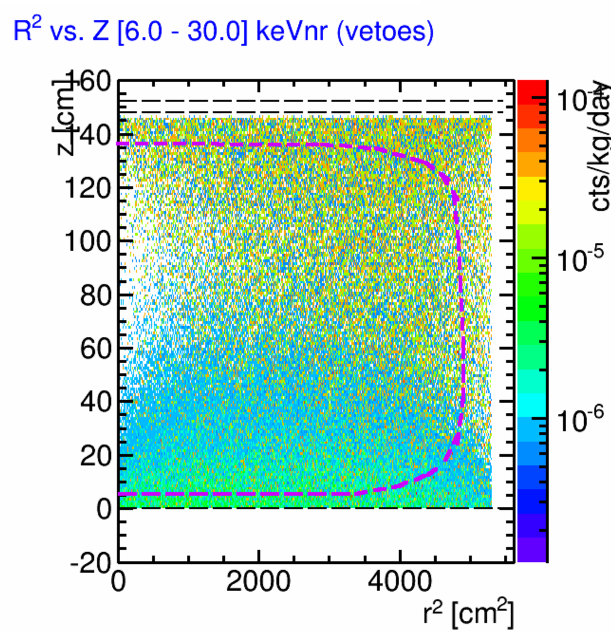
- Fiducial volume cut.
  - reduces target size but increases sensitivity.

- **Multiple interaction rejection.**

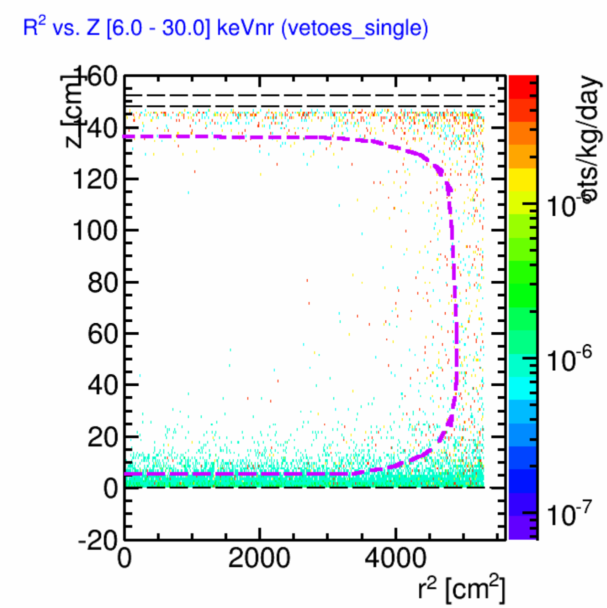
- ER/NR discrimination gives final counts/exposure:
  - **NR: 0.0724. ER: 7.58.**







veto selection



LZSim Overview

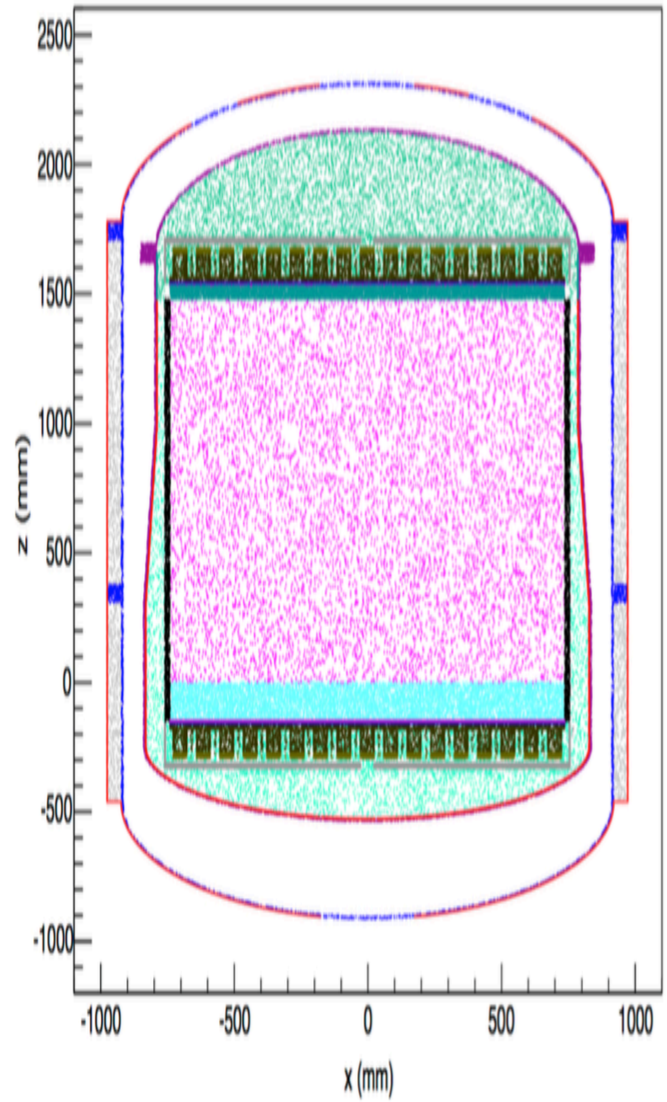
- LZSim GEANT4 Monte Carlo particle simulations model our background.

- This background modelling needs:

  – full LZ detector **geometry** and **materials** coded.

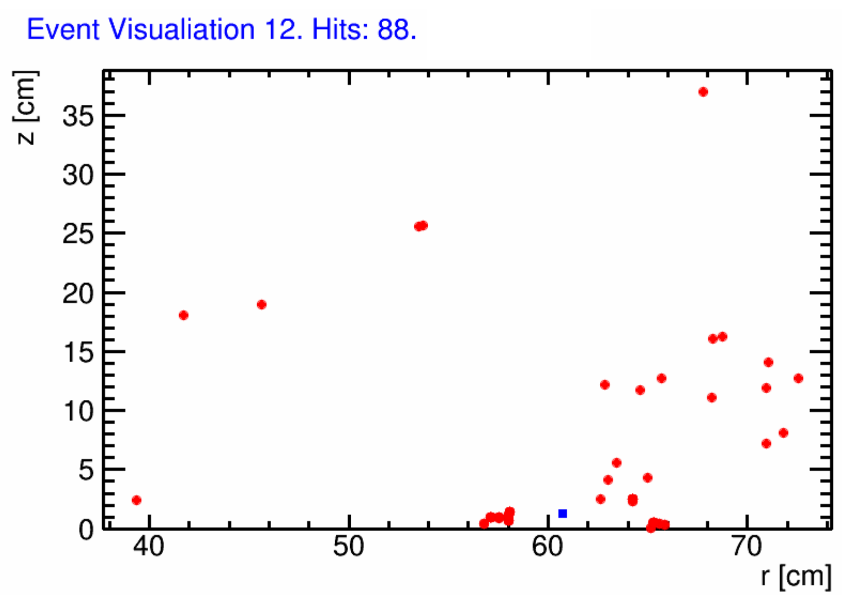
  – **event generators** for radioactive isotopes.

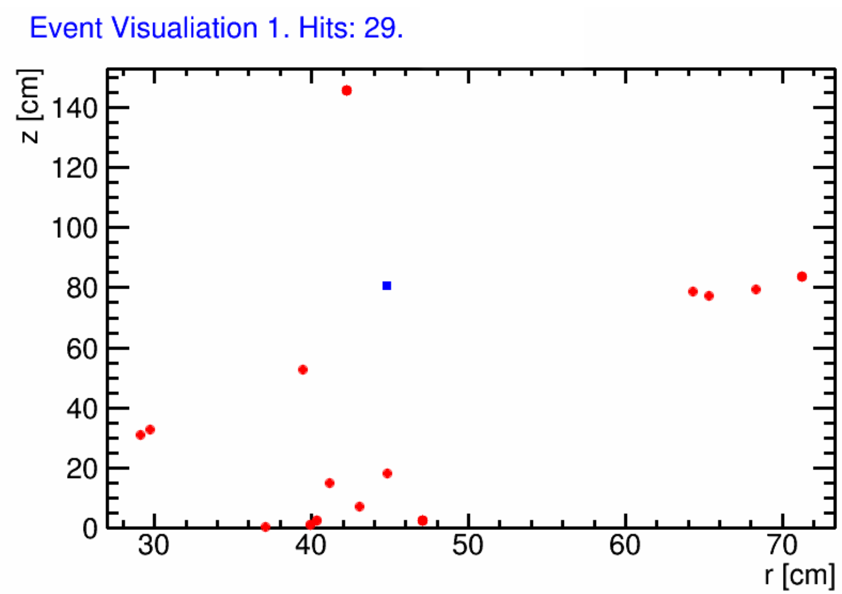
  – **real measurements** of radiogenic isotopes for all materials in detector.



LZSim Event Visualisations

- LZSim output:
  - magnitudes, positions and timing of particles' **energy deposits** into LXe.
  - Also Truth info, e.g. particle type/ physics process.





- Red dots = all hits
- Blue dots = energy weighted position Ω

$$\Omega_x = \frac{\sum E_i x_i}{\sum E_j}$$

Multiple Interaction Algorithm - Story so Far

- Ideally simulate S1/S2 signals (e.g. from NEST DRM).
  - Current algorithms use **energy deposits** approx.

- Ideally test algorithm robustness against real data.
  - LZ detector does not yet exist.
  - Compare against simulations **truth info**.

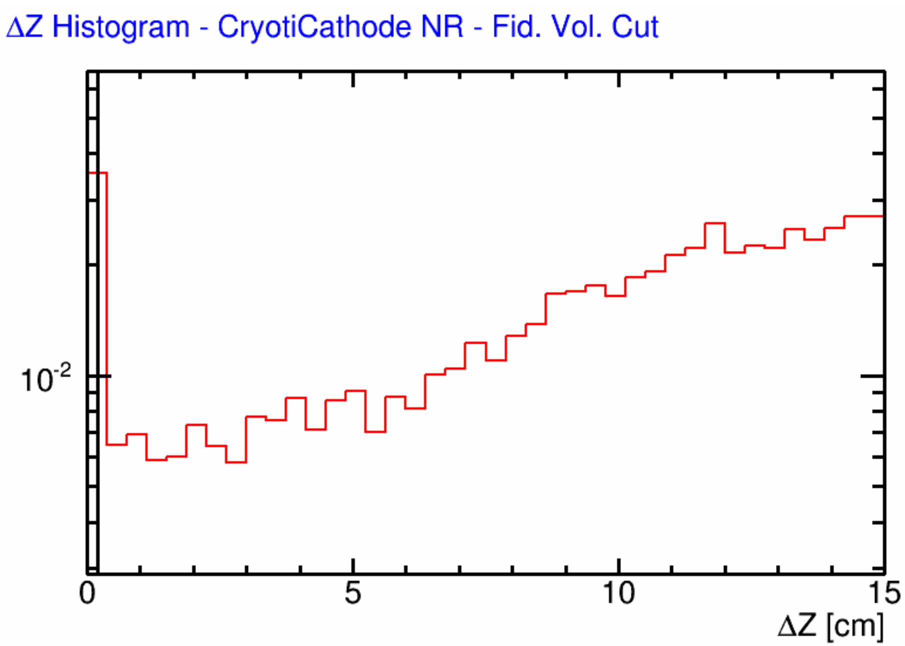
- No problems identified in current algorithm.
  - Simulations evolved since original algorithm implementation.
  - Further optimisation may be needed.

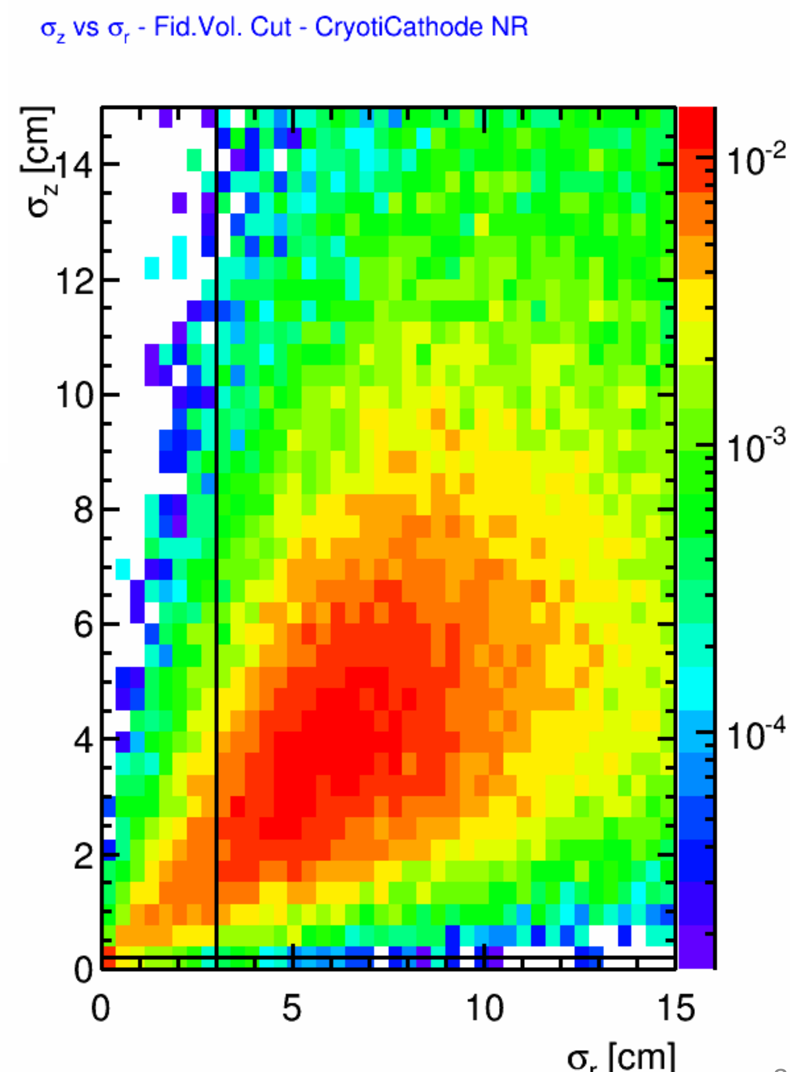
Multiple Interaction Identification Algorithms

- **Energy Weighted Standard Deviation** (in r and z)
  - box cut **(current)**
  - circular cut

- **Range** (in z).

- Nominal cuts
  - z_{cut}= 0.2cm.
  - r_{cut} = 3cm.





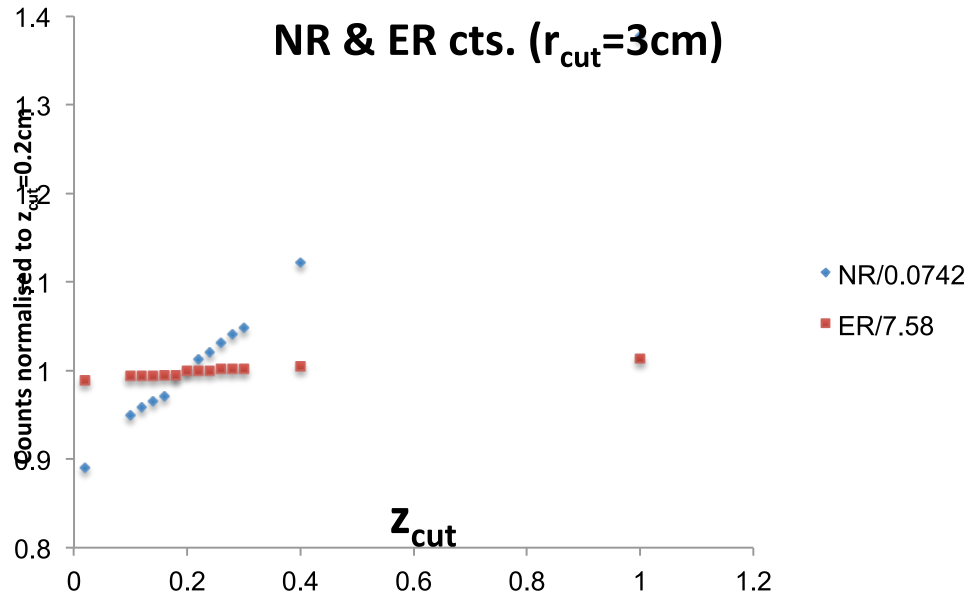
Optimising Algorithm

- Choose algorithm with maximum Figure of Merit.
  - FoM = counts*signal/background, after **all cuts**.

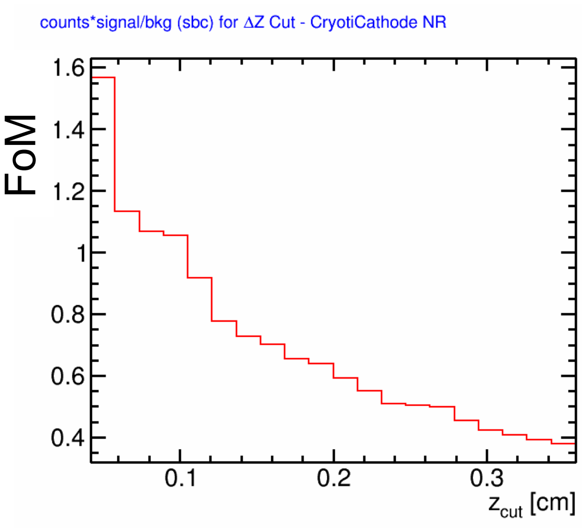
- Signal = single NR.
  - Count number of nuclei interacted with.

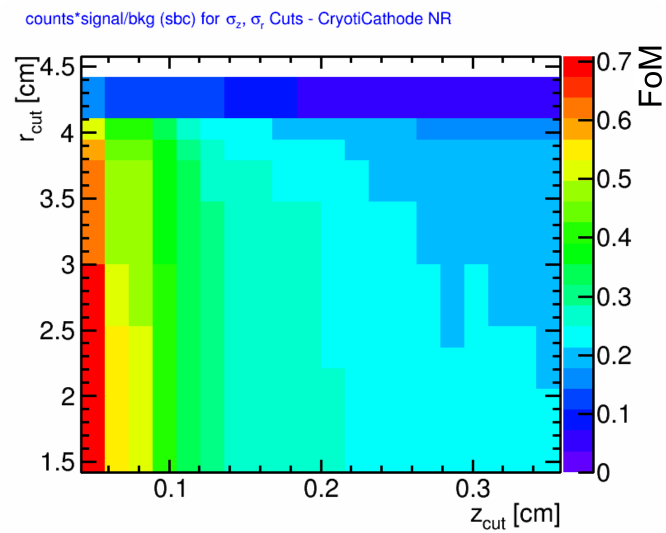
- (α,n) neutrons from **titanium cryostat** and **steel cathode**, due to **uranium** & **thorium** decay chains.
  - Single neutron scatter representative of a WIMP scatter.
  - Cryostat - main source of background.
  - Cathode - *in* the LXe.

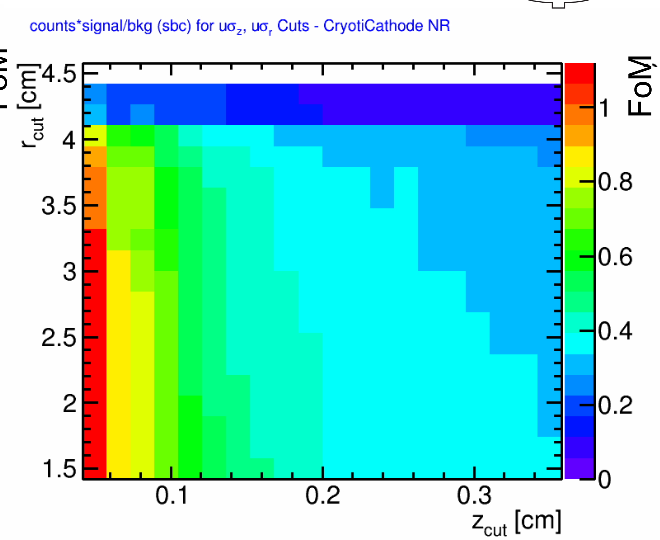
- Why no ER data?
  - Extremely low ER stats after all cuts.
  - 99.5% rejected after S1/S2 discrimination.
  - ER counts and not sensitive to variation multiple interaction cut.



Results so Far





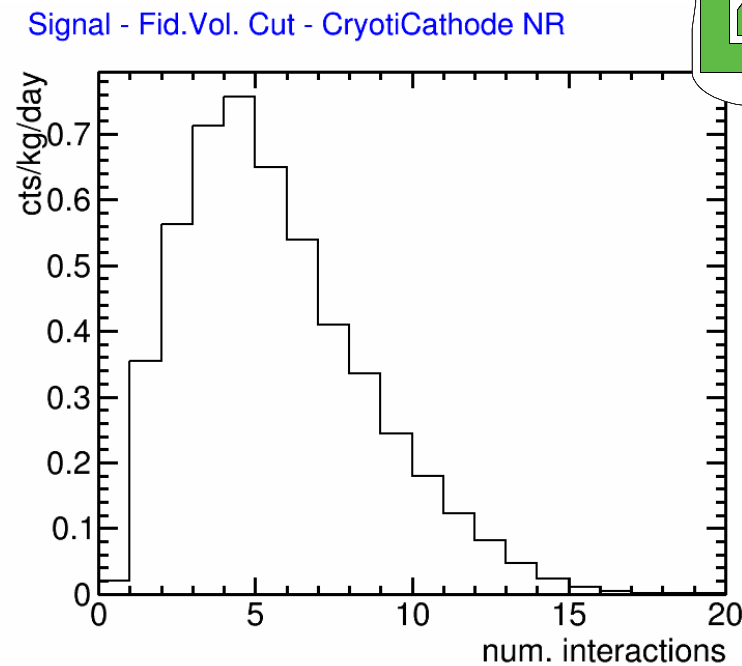


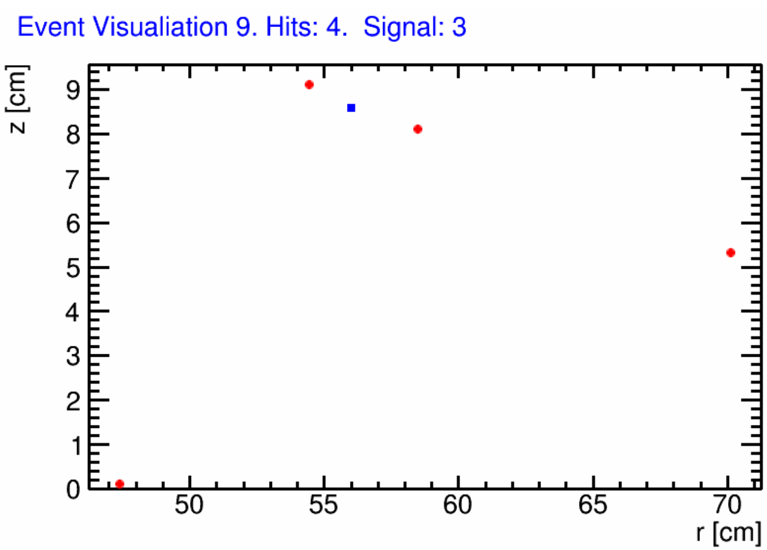
- Suggests cutting everything is best, obviously this is wrong because this would certainly cut WIMPs.

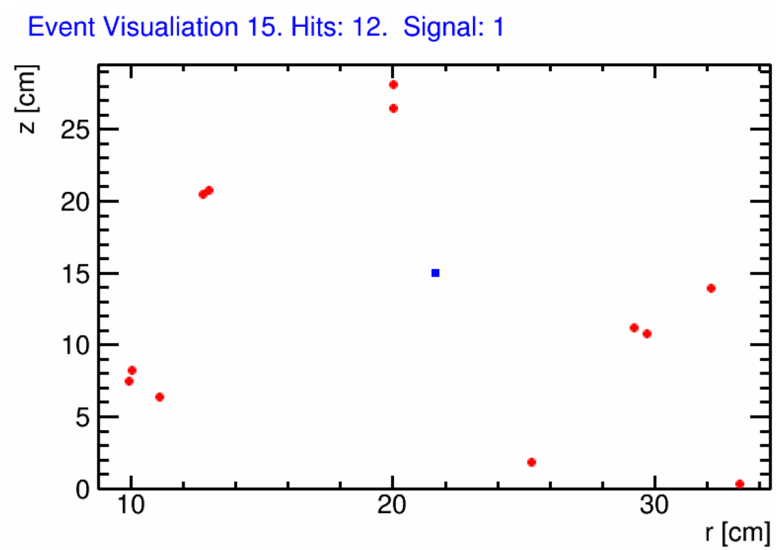
- LZ predicted to resolve 0.22-0.44cm in Z.
  - separation between S2 signals

What could the problem be?

- Signal from counting unique nuclei.
- The physics processes behind these nuclei:
  - Neutron capture.
  - Inelastic scattering.
  - Elastic scattering.
- Inelastic causes ER too.
- WIMPs interact elastically.







Future Developments

- Improve signal identification.
  - to include only elastic scatters.

- Can variation of algorithms in energy and position be used for further optimisation?
  - preliminary plots in extra slides.

- Start exploring ER data.

Conclusions

1. Multiple interactions vetoing is very important for achieving LZ's sensitivity.

2. A frame work for optimising multiple interaction algorithm has been developed.

3. Need to improve signal identification within this algorithm.

Thank you for listening.

Equations behind the algorithms.

$$\sigma_z^2 = \left(\frac{\sum E_i}{\left(\sum E_i\right)^2 - \sum\left(E_i^2\right)}\right)\left(\sum E_i\left(z_i - \Omega_z\right)^2\right)$$

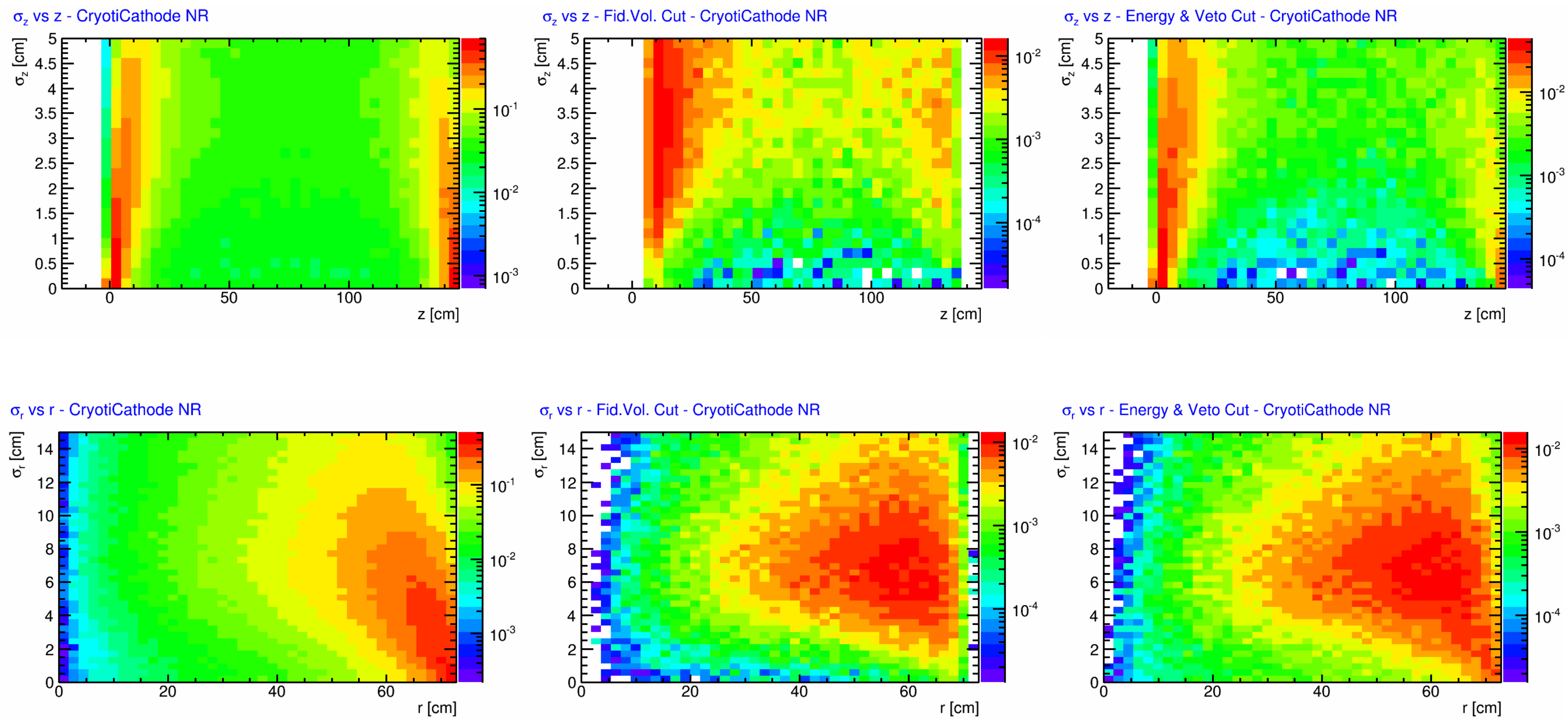
$$\sigma_r^2 = \left(\frac{\sum E_i}{\left(\sum E_i\right)^2 - \sum\left(E_i^2\right)}\right)\left(\sum E_i\left(\left(x_i - \Omega_x\right)^2 + \left(y_i - \Omega_y\right)^2\right)\right)$$

$$\sigma_u^2 = \left(\frac{\sigma_r}{r_{cut}}\right)^2 + \left(\frac{\sigma_z}{z_{cut}}\right)^2$$

$$\Delta Z = \left(z_{max} - z_{min}\right)\Big|_{\text{electrons excluded}}$$

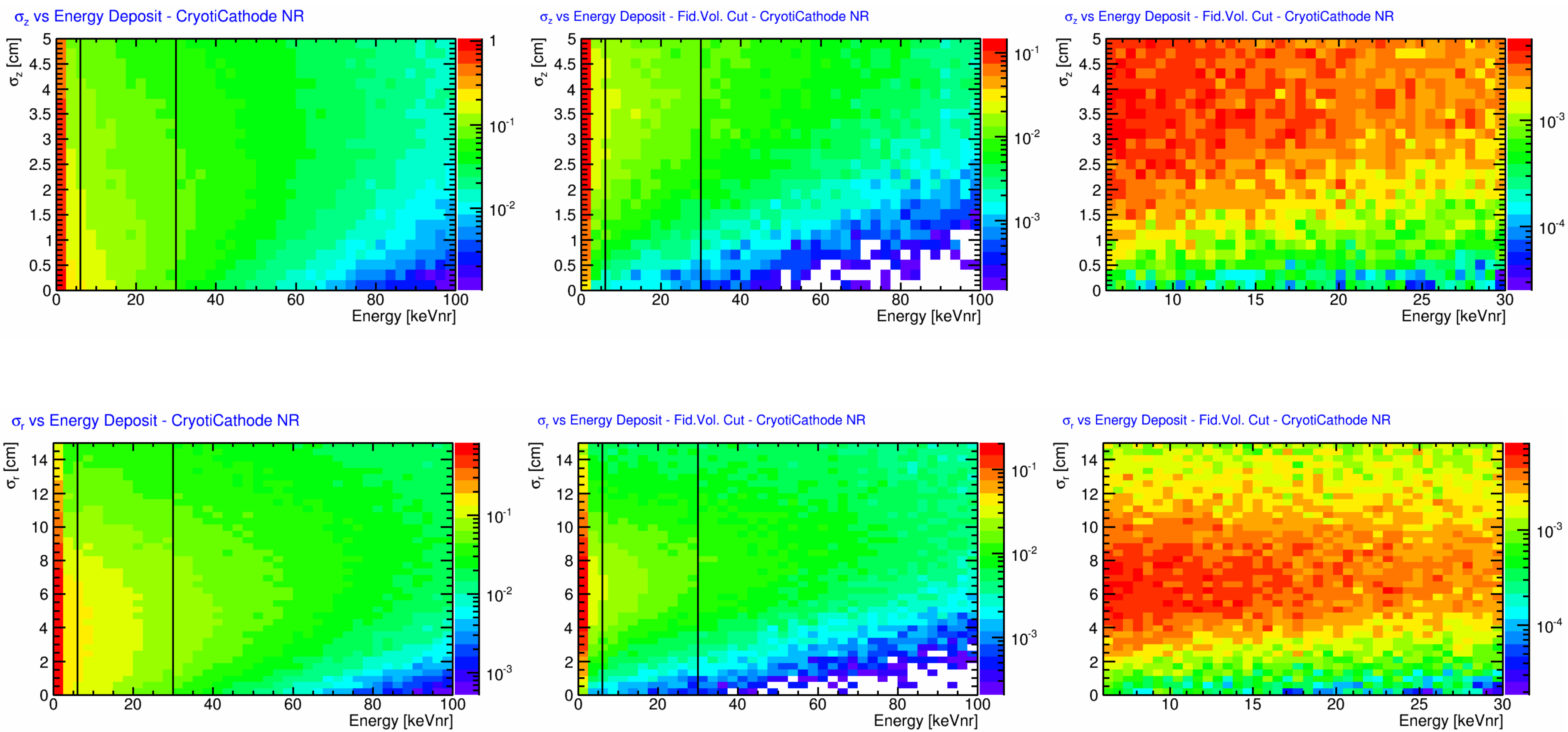
$$\Omega_x = \frac{\sum E_i x_i}{\sum E_j}$$

Variation with Position



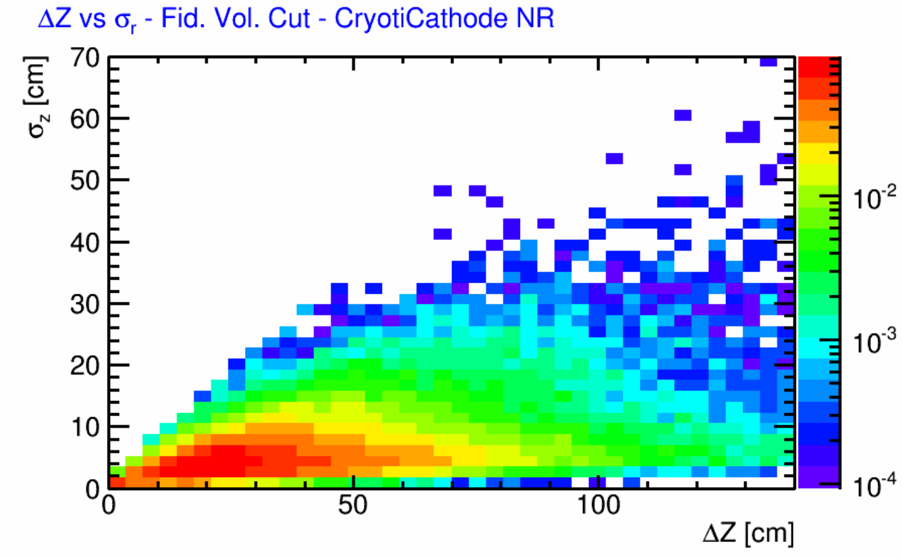
Left: Before all cuts. Middle: After all cuts (except fid. vol.). Right: with fid. vol. cut.

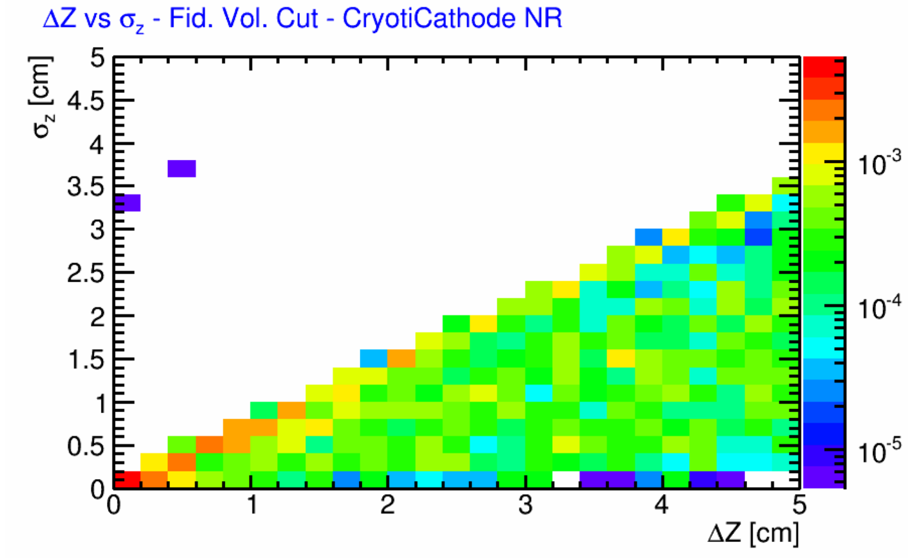
Variation with Energy

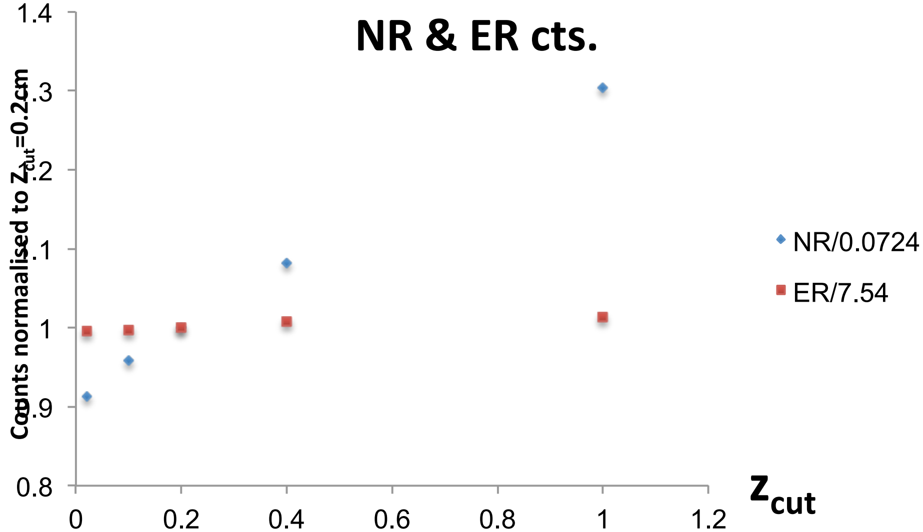


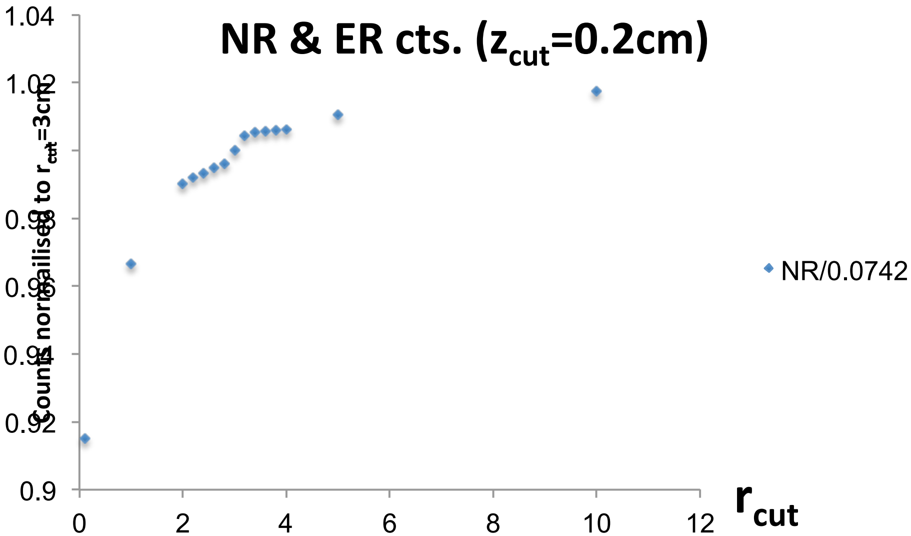
Left: Before all cuts. Middle: After all cuts (except energy). Right: with energy cut.
Black vertical lines show NR search region.

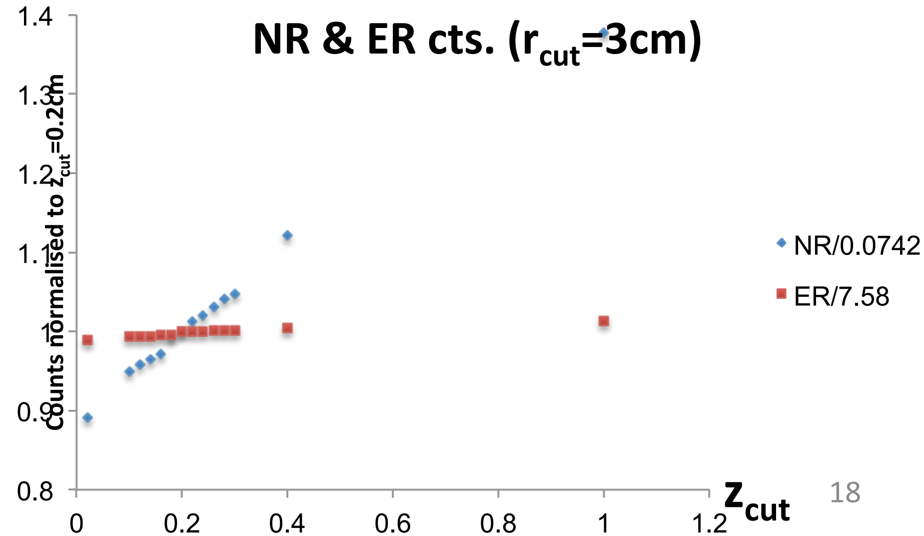
Standard Deviation and Range Correlation






NR & ER cts.
Counts normaalised to Z_{cut}=0.2cm
Z_{cut}
NR/0.0724
ER/7.54
1.4
1.3
1.2
1.1
1
0.9
0.8
0
0.2
0.4
0.6
0.8
1
1.2


NR & ER cts. (z_{cut}=0.2cm)
Counts normaalised to r_{cut}=3cm
r_{cut}
NR/0.0742
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
2
4
6
8
10
12


NR & ER cts. (r_{cut}=3cm)
Counts normalised to Z_{cut}=0.2cm
Z_{cut}
NR/0.0742
ER/7.58
1.4
1.3
1.2
1.1
1
0.9
0.8
0
0.2
0.4
0.6
0.8
1
1.2