Solar KK axion search

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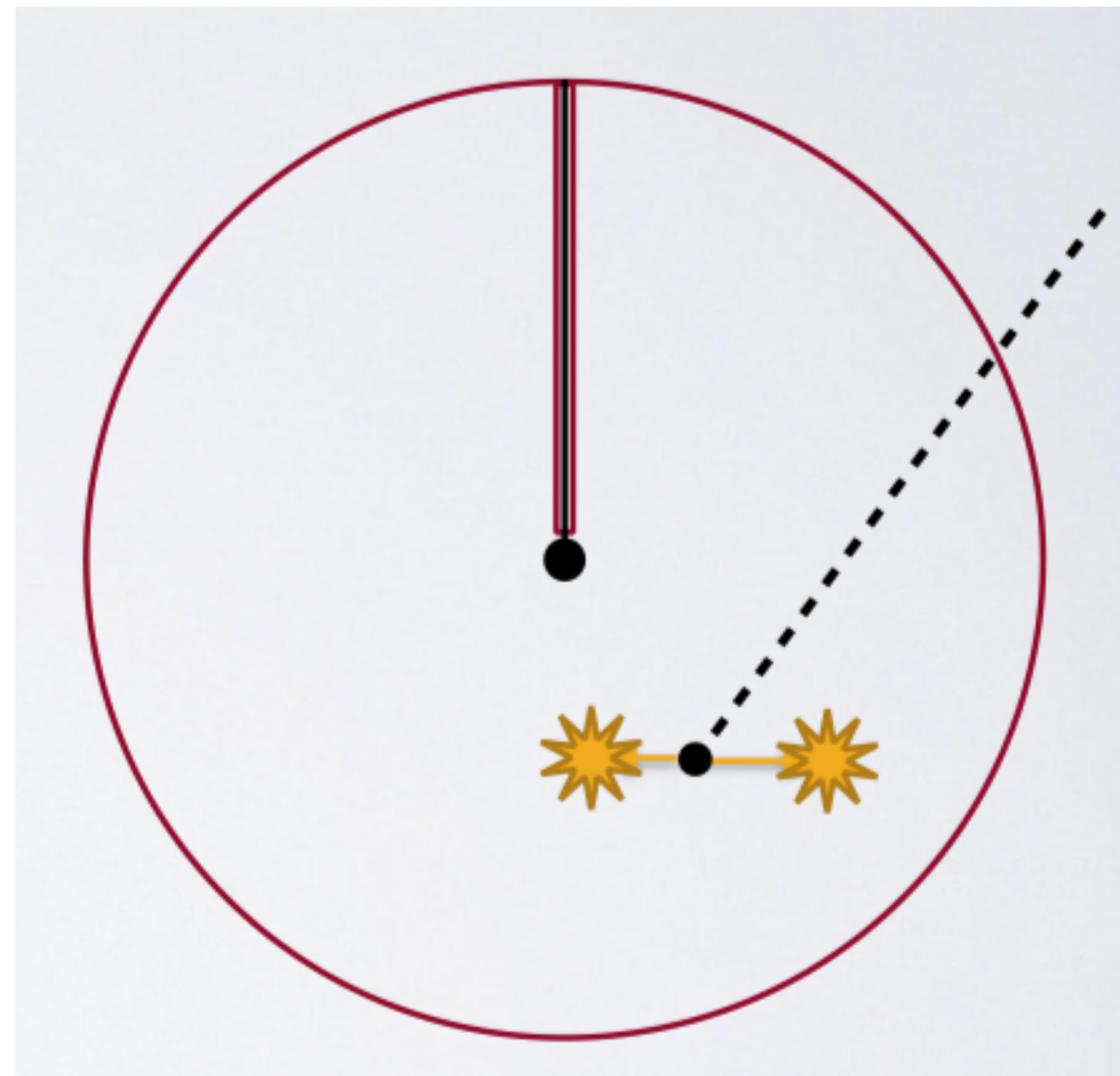
Summary

- Introduction
- Axion-like background: simulations and RoI
- Systematics
- Simulations and calibrations: problems

Introduction

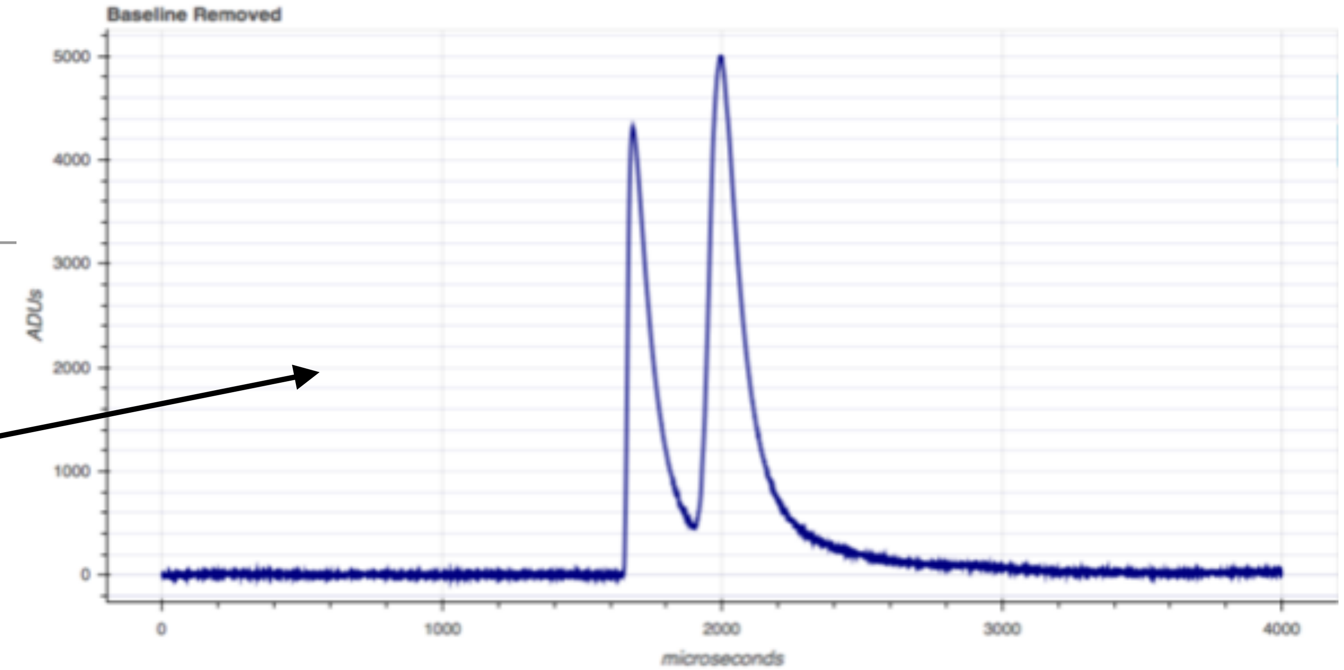
Intro to KK axion

- In theories with extra compact dimensions, QCD axion gains heavy-mass excitations.
- The heavy axions produced in the Sun can **decay** into two photons (event rate depends on volume instead of target mass). We can see these two photons interact in different positions with NEWS-G detectors.



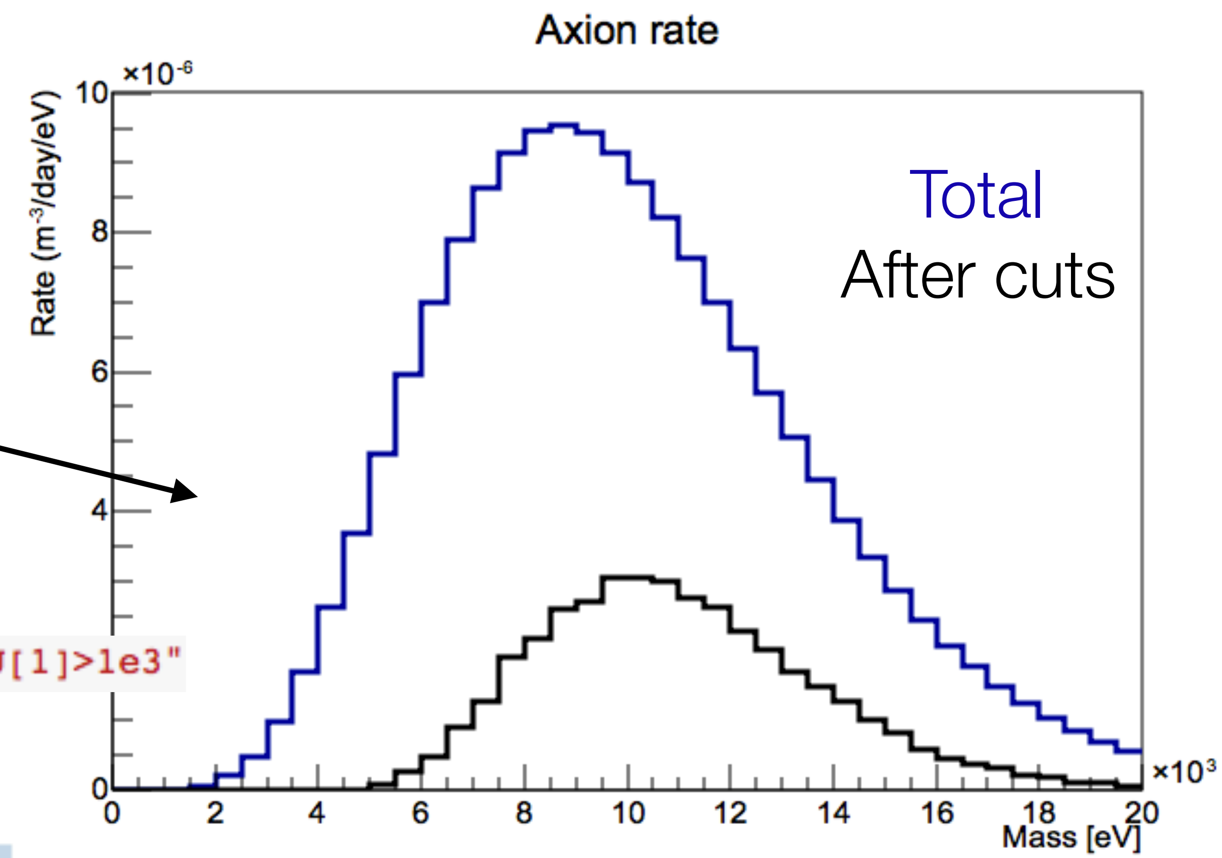
KK axion search

- Look for axion-like events in data (see cuts)



-> ~70 events in 42-day run

- Use simulations to get sensitivity of detector to axion events

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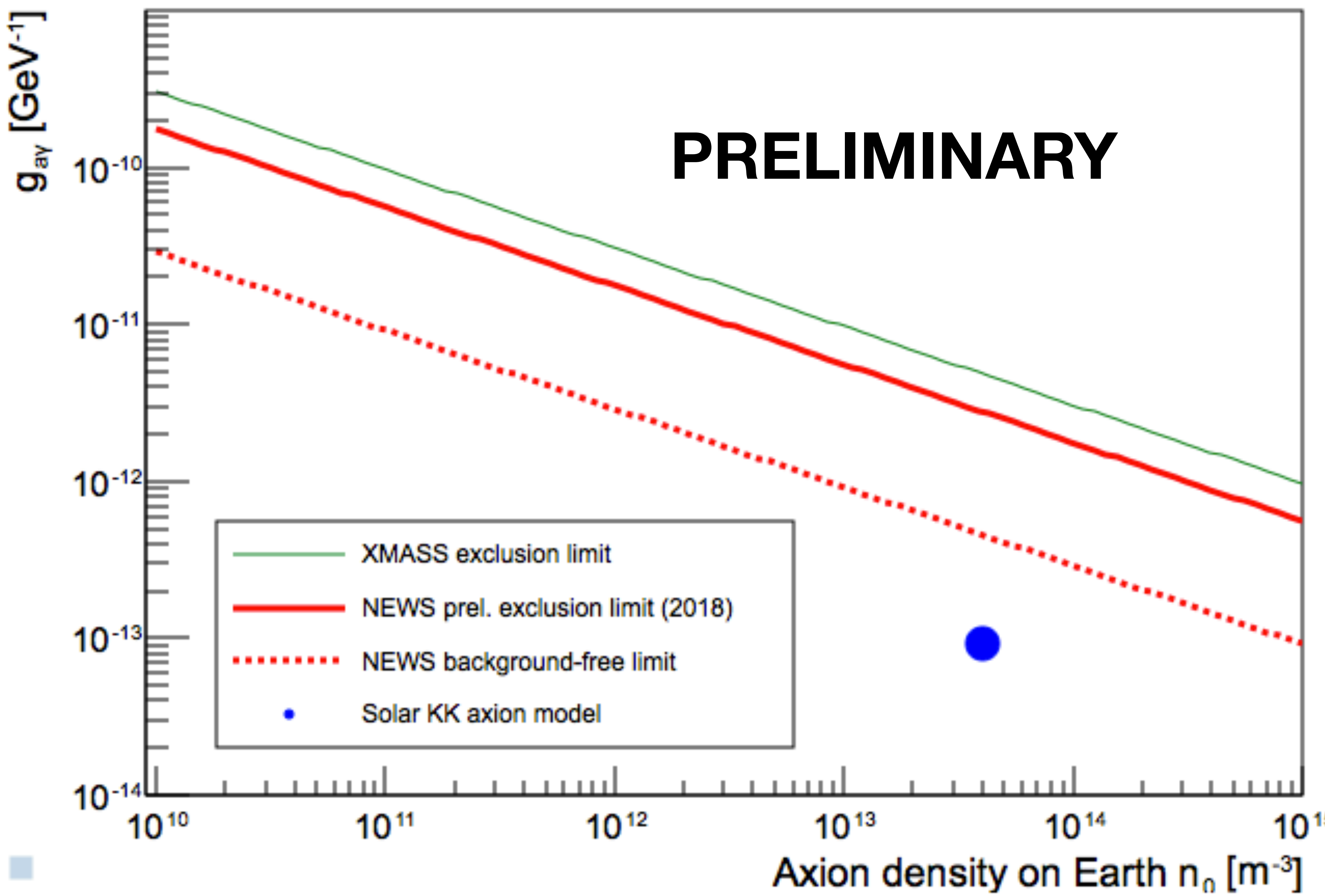
"DD_RawAmpl> 500 && DD_RawRise>10 && DD_RawAmpl<55000"
"&& DD_NPulses>1 && DD_VectorAmplADU[0]>1e3 && DD_VectorAmplADU[1]>1e3"
"&& DD_VectorAmplADU[0]+DD_VectorAmplADU[1]>5000"
"&& DD_VectorAmplADU[0]+DD_VectorAmplADU[1]<50000"
"&& DD_VectorAmplADU[0]<DD_VectorAmplADU[1]*2+10000"
"&& DD_VectorRise[0]<70 && DD_VectorRise[1]<70"
"&& DD_VectorRise[(DD_PulseNumber[1]<DD_PulseNumber[0])] < DD_VectorRise[!(DD_PulseNumber[1]<DD_PulseNumber[0])]"
"&& (DD_VectorStopBin[0]-DD_VectorStartBin[0])/2<300 && (DD_VectorStopBin[1]-DD_VectorStartBin[1])/2<300"
"&& (DD_VectorStartBin[0]+DD_VectorStopBin[0])/2-(DD_VectorStartBin[1]+DD_VectorStopBin[1])/2<1000"
"&& (DD_VectorStartBin[0]+DD_VectorStopBin[0])/2-(DD_VectorStartBin[1]+DD_VectorStopBin[1])/2>-1000"
```

Axion simulations

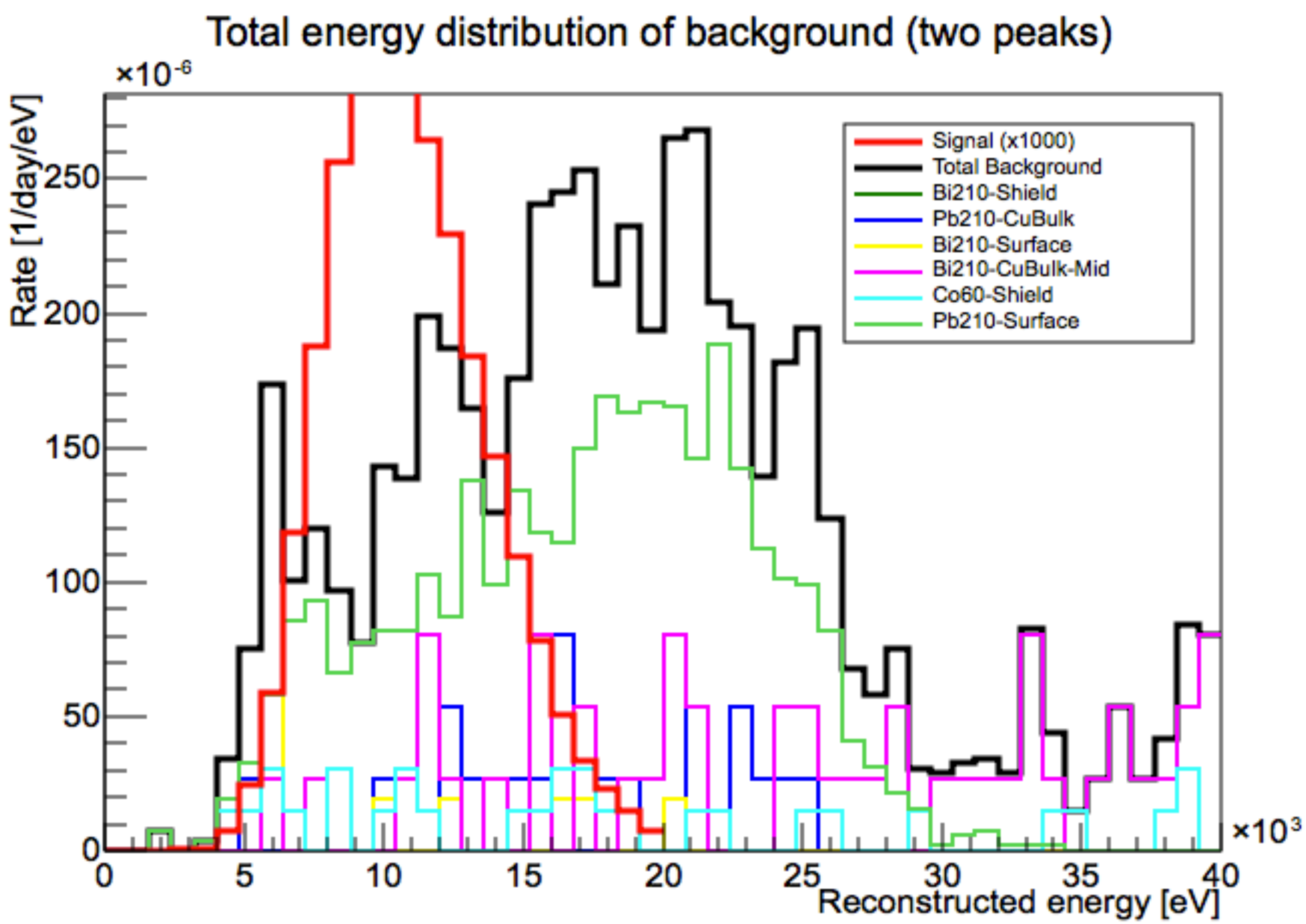
- Select mass of axion from expected decay rate.
- Select random position in detector.
- Select random opposite directions for decay photons, half energy each.
- Find photon travel distance from NIST data.
- Generate primary electrons from Poisson distribution and W (mean ionization energy) for both.
- Drift electrons from COMSOL simulated field and Magboltz electron drift/diffusion data.
- Generate avalanche for each electron (based on calibrations).
- Build pulse with ion induced current, preamplifier decay time.
- Add noise (empty) pulse from data.

Exclusion limits (90% CL)



Axing-like background and RoI

Background simulations



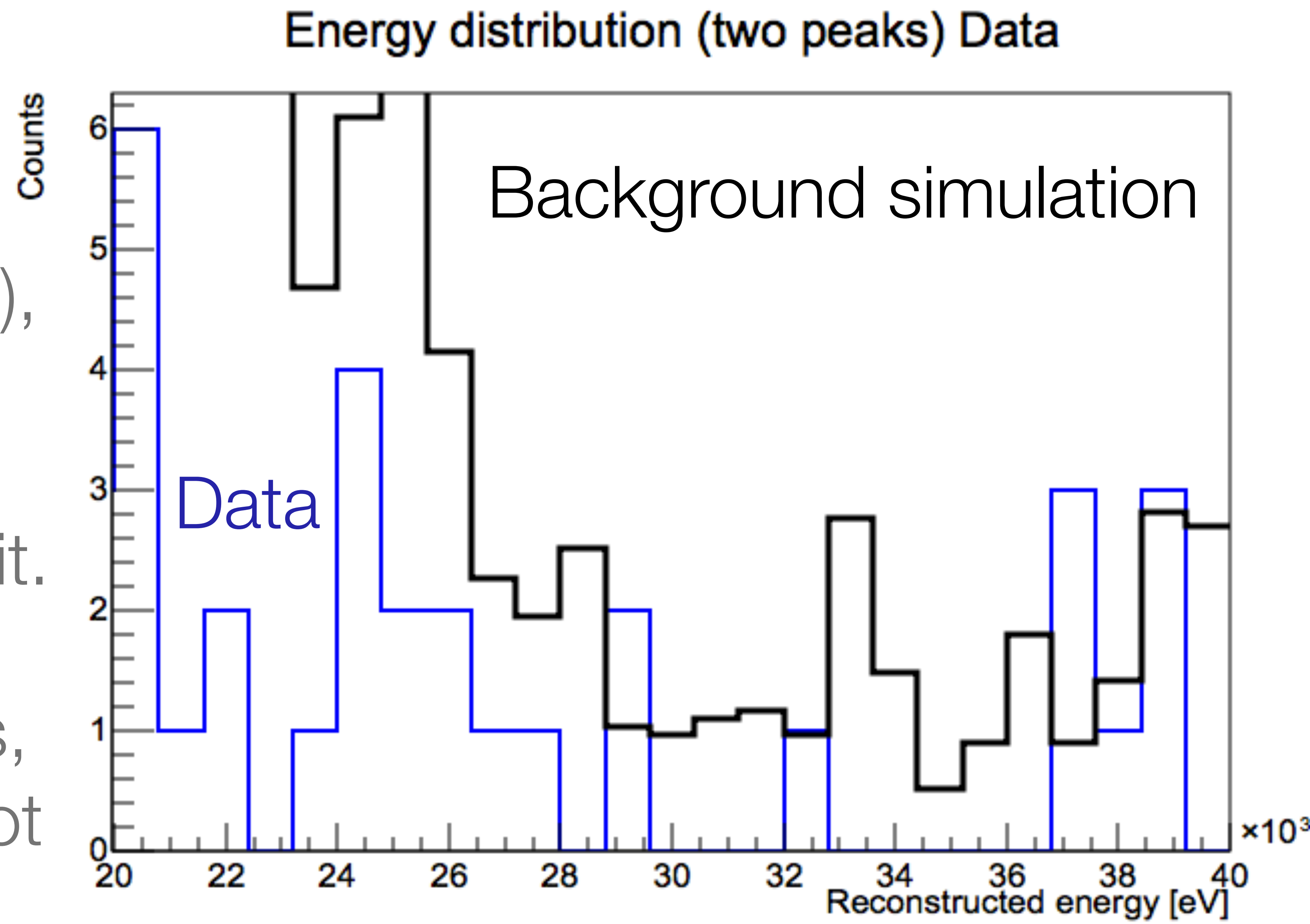
Based on contamination estimations by Alexis, can estimate axion-like background in the sphere for the 42-day run.

Pb210 on the inner surface of the sphere is the principal background under 20 keV.

Background subtraction?

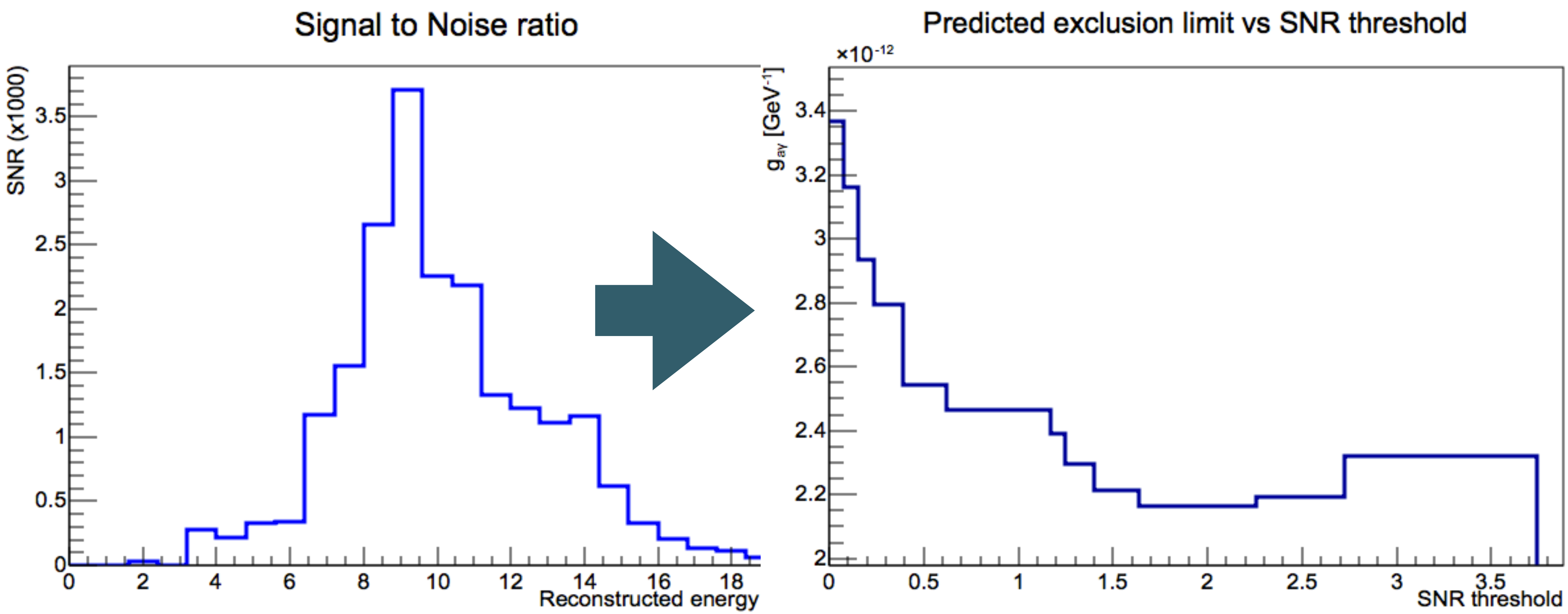
Can't calibrate background over RoI (or would bias analysis), but can compare background and simulations outside of it.

However, low statistics, and bad match. Cannot do background subtraction.



Energy range outside RoI

Choosing RoI

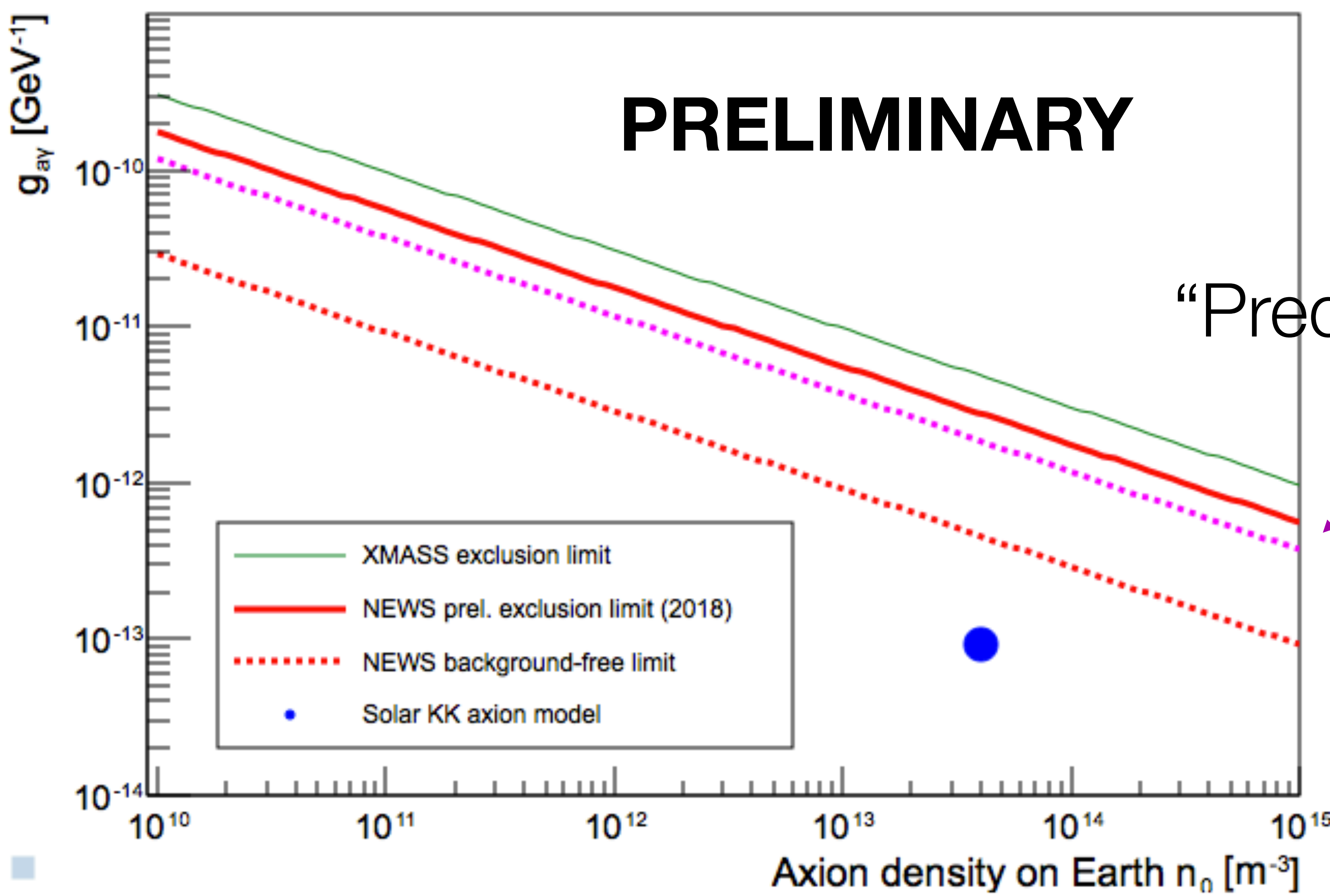


- Can use Signal to Noise Ratio from previous simulations to select region of interest for optimal “predicted” exclusion limit.
- Since choice of RoI is independent of data, this is conservative, even if simulations are wrong.

Choosing RoI

By choosing "optimal" RoI of ~ 8 keV to 11.2 keV , we reduce efficiency by ~50%, but improve expected limit by factor ~1.5

For comparison: in an ideal world, background subtraction would improve limit by factor ~3



"Predicted" limit

Systematics

Systematics (control)

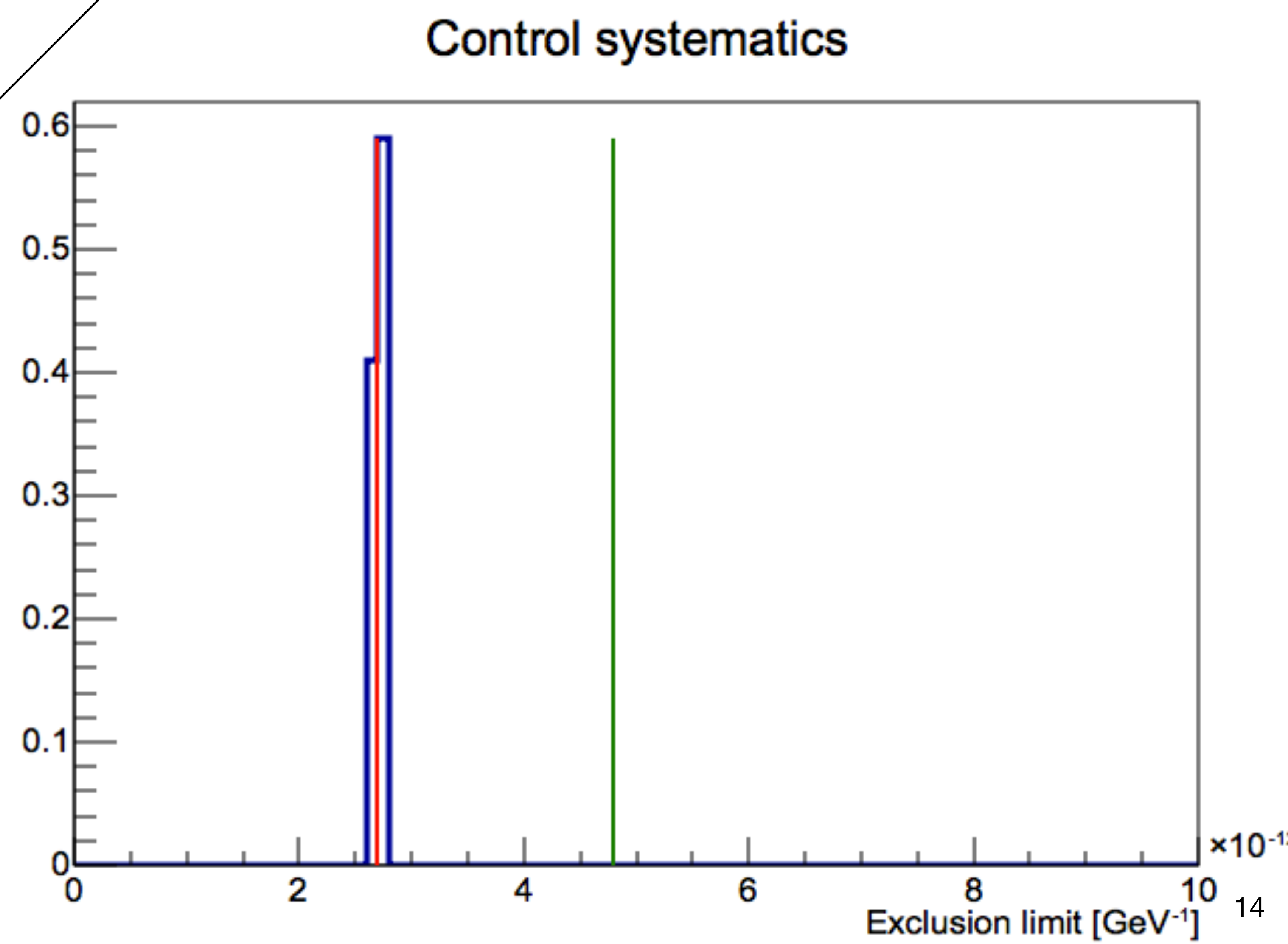
100 simulations, 10^4 events per simulation

Leave all parameters fixed to estimate precision of this simulation. Get 1% relative uncertainty on limit.

Considered uncertainties:

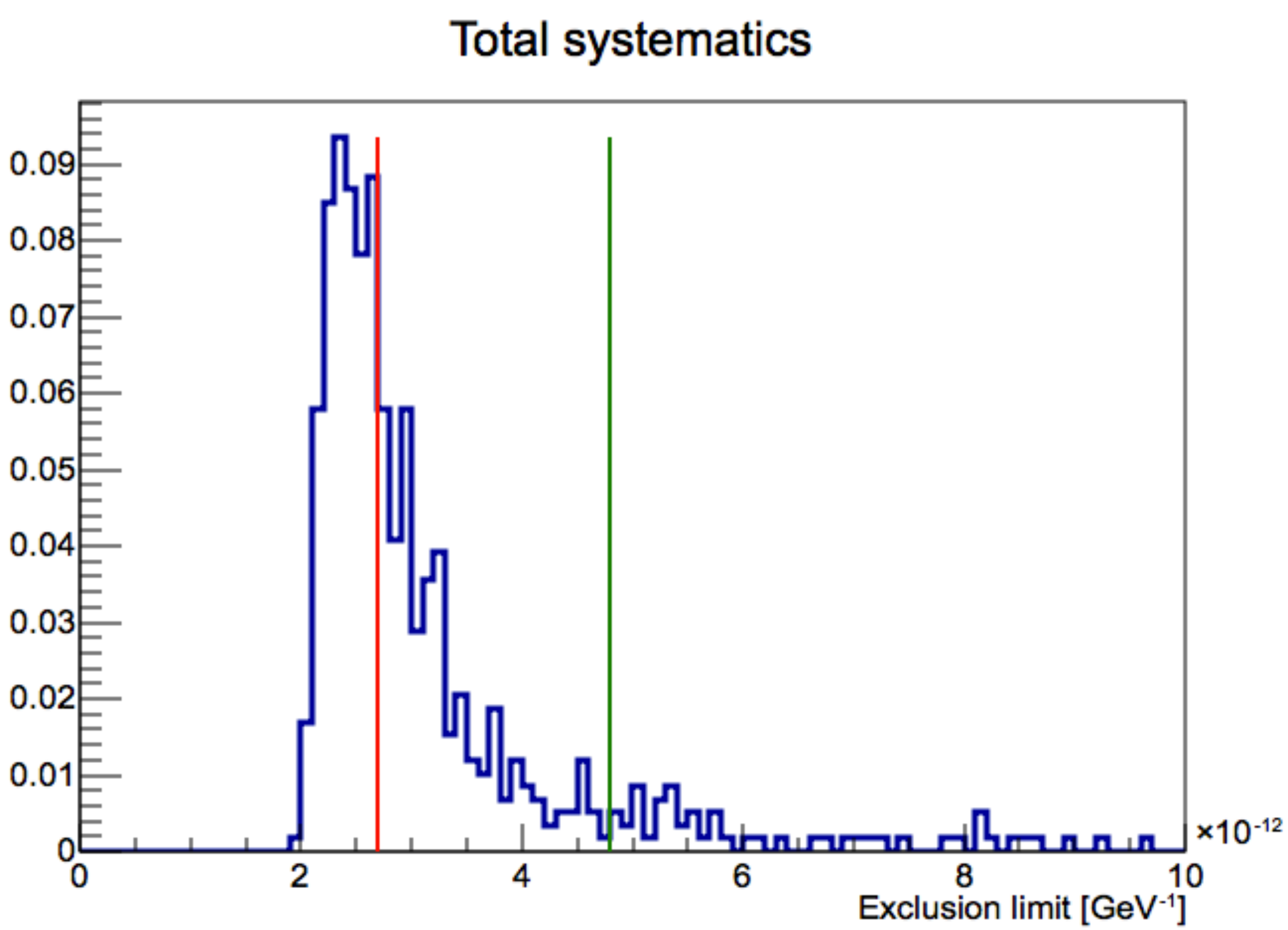
- Gain (not done yet)
- Drift time
- Diffusion time
- NIST x-ray data
- Attachment rate
- Mean ionization energy

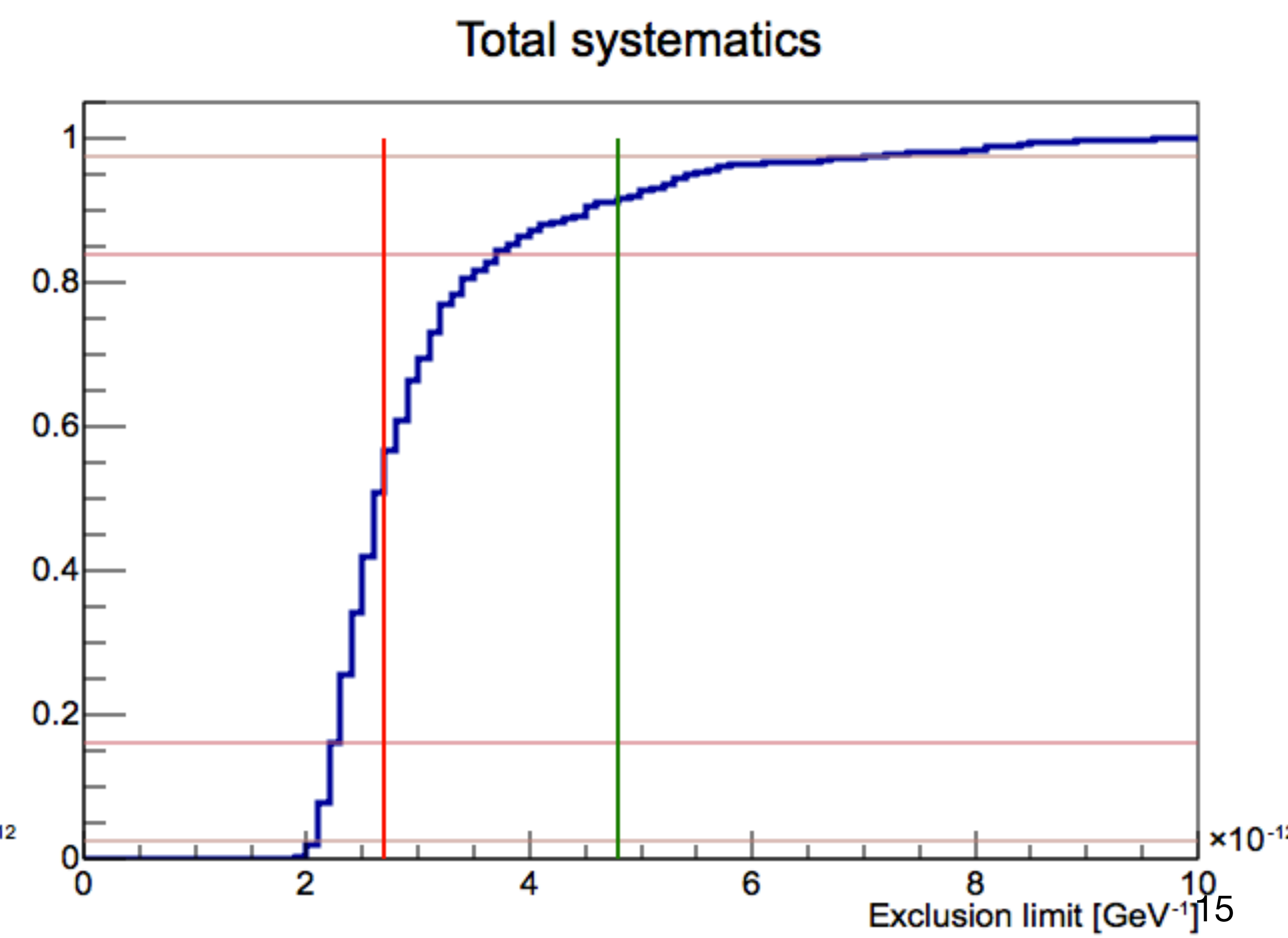
10^4 events per simulation is enough for this study



Systematics (Total)

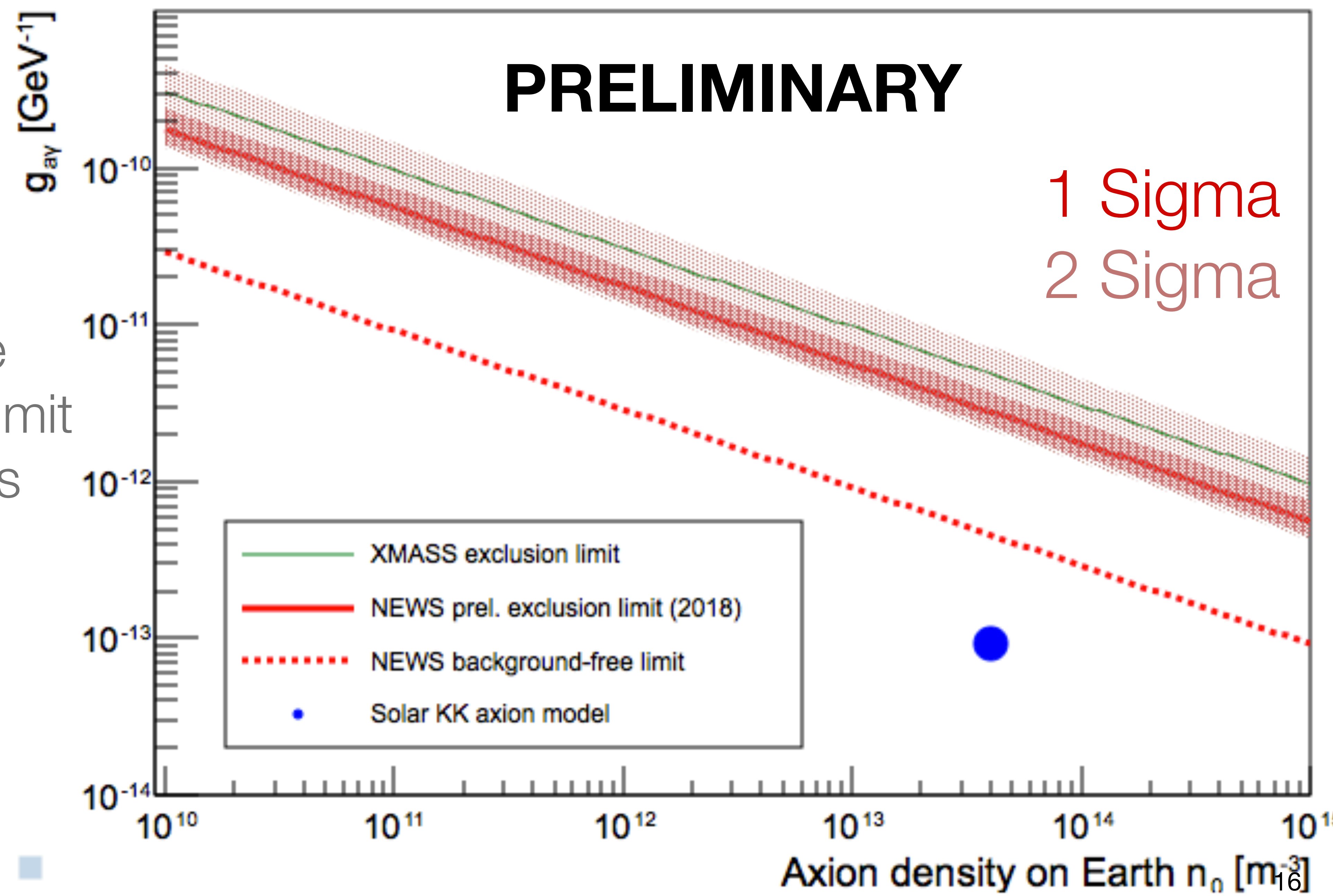
- 598 simulations, 10^4 events each. Parameters chosen randomly via Gaussian distribution (with lower bound of 10% of expected value for NIST, drift, and diffusion)
- Note: I kept W and gain fixed





Systematics (Total)

With 2 sigma, we are worse than XMASS limit (before improvements from optimal RoI or updated simulations)



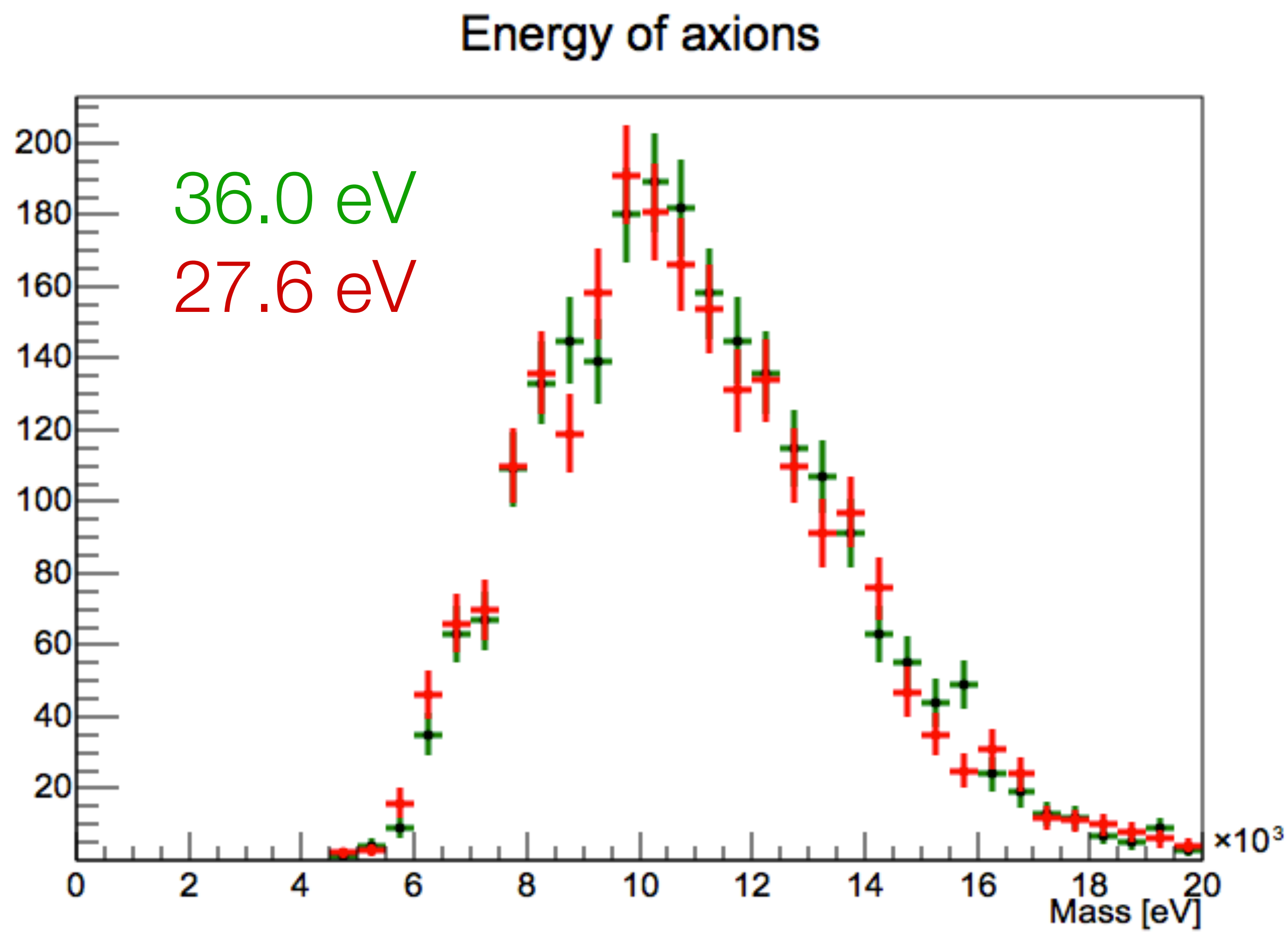
Systematics (mean ionization energy)

- Pure Neon: 36 eV

- Neon +2% CH4: 27.6 eV

Simulate both, with compensating amplification gain to match energy calibration

Results: no noticeable difference

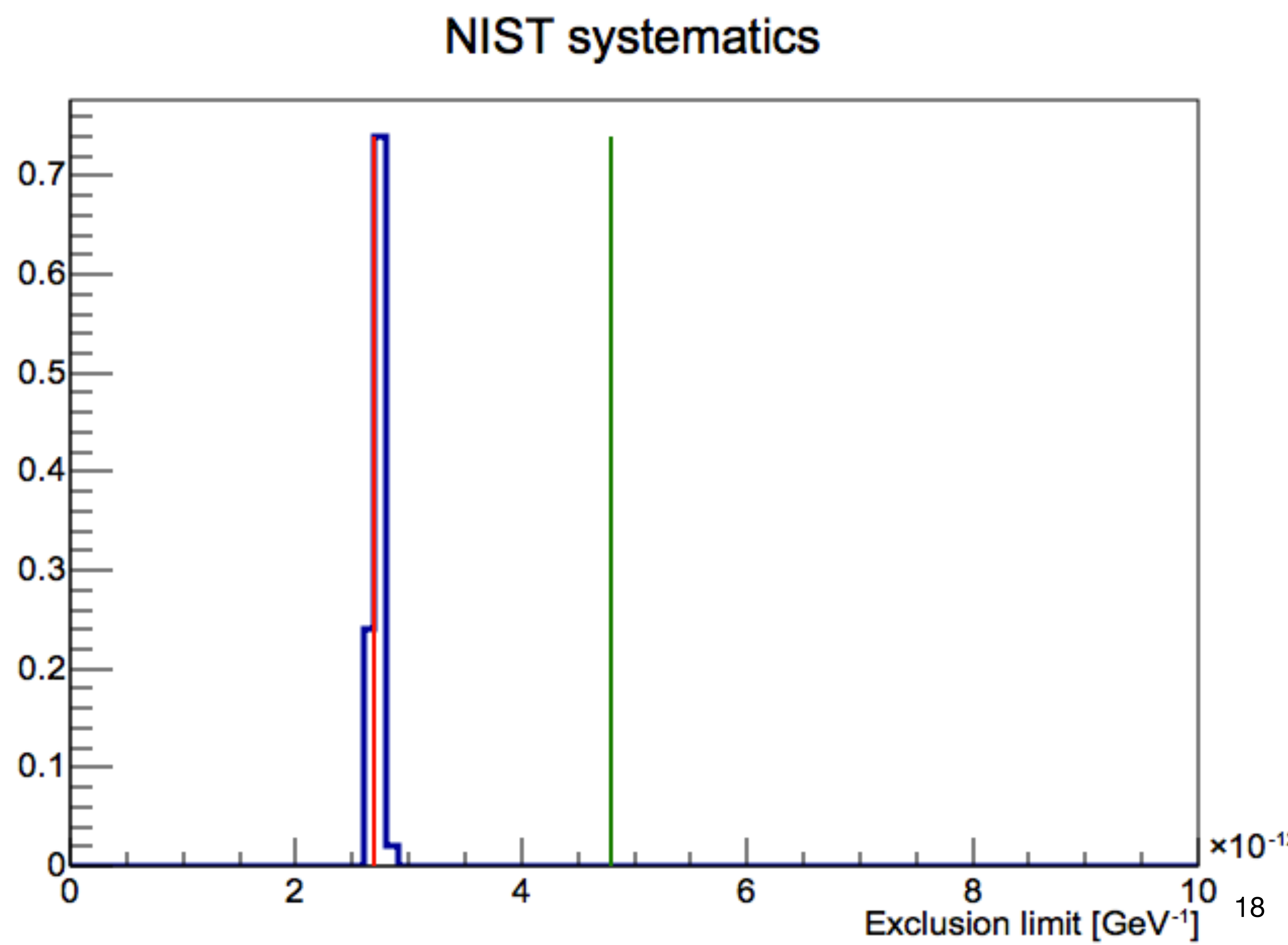


Systematics (NIST)

100 simulations (evenly spaced in normal distribution), 10^4 events per simulation

NIST relative uncertainty assumed to be 10%, (VERY conservative)

Results: Barely makes a difference on exclusion limit (1.5% relative uncertainty)



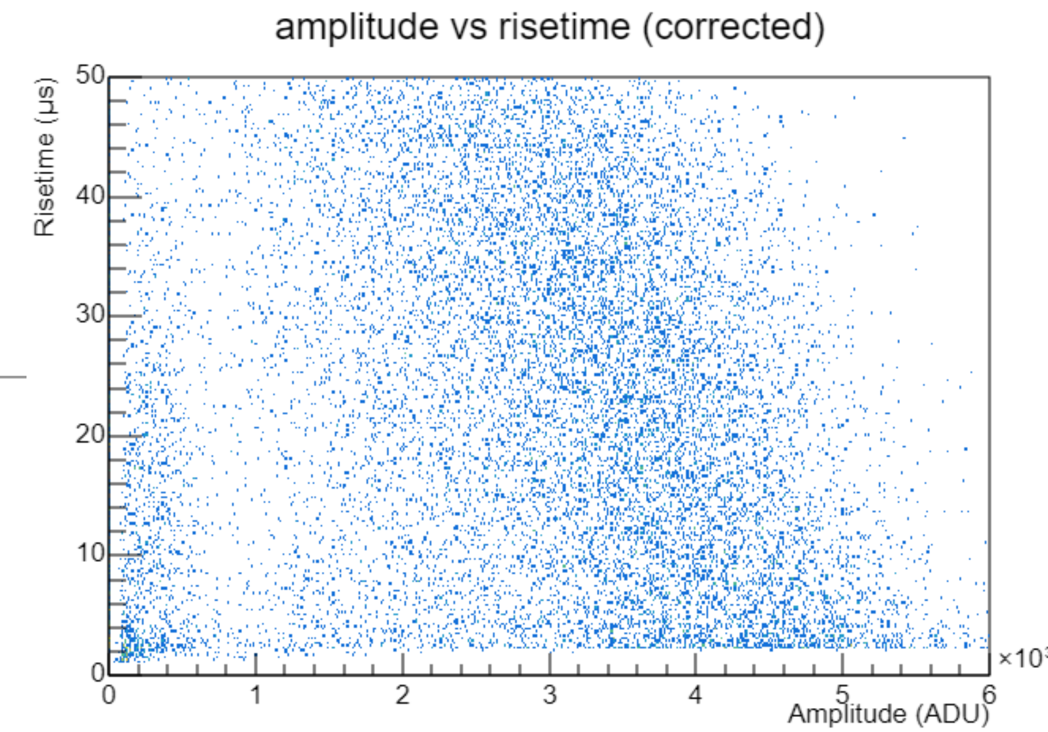
Systematics (Attachment)

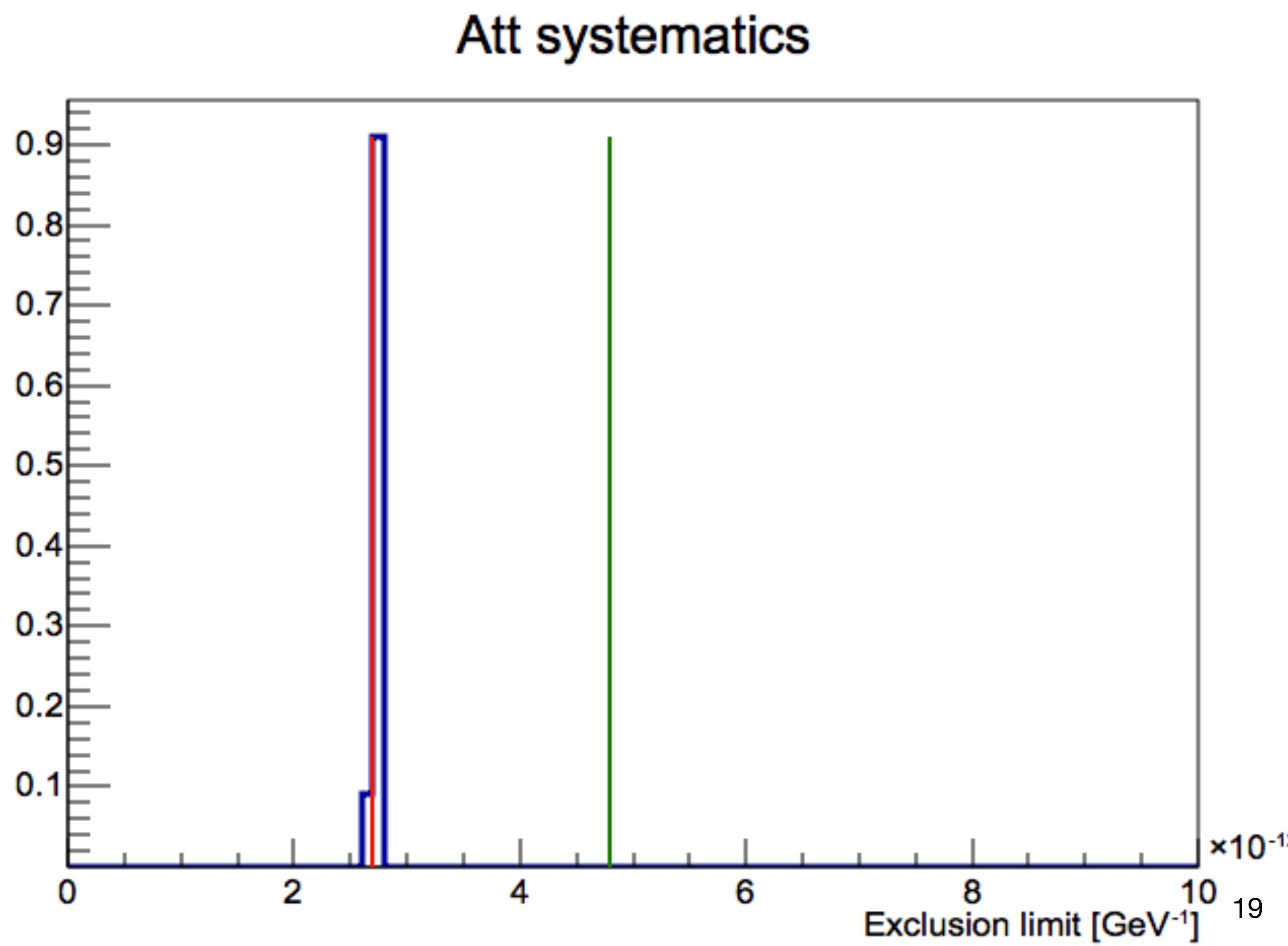
100 simulations (evenly spaced in uniform distribution), 10^4 events per simulation

Attachment varied between 0. and 2. the "measured" attachment (0.0160ppm O_2 contamination)

Results: Makes no difference on exclusion limit (1.0% relative uncertainty)

pg07b001
Ar37 calibration



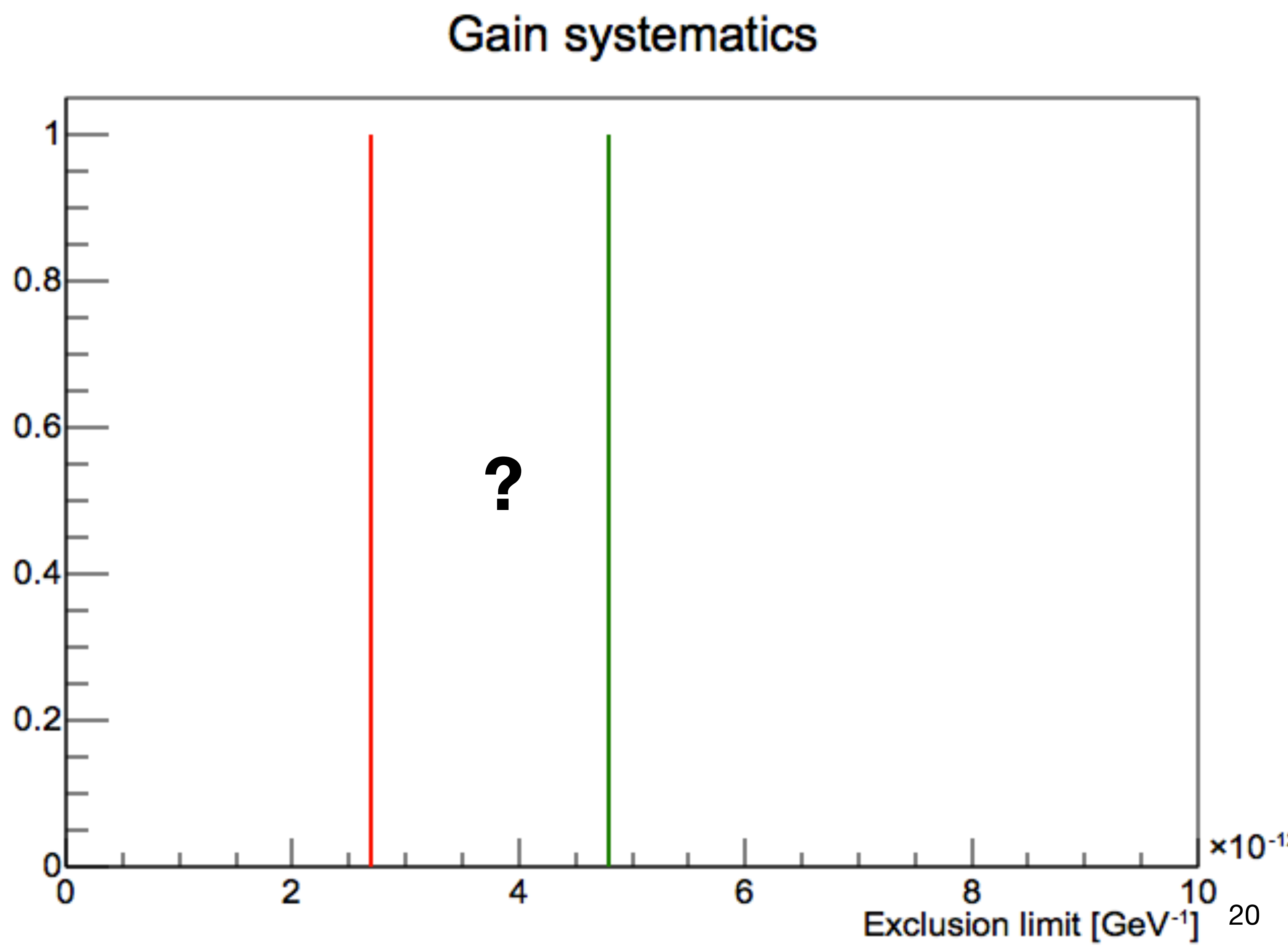


Systematics (Gain)

Not done yet, but not expected to have a large effect.

Gain relative uncertainty was measured to be around 5% (see WIMP paper)

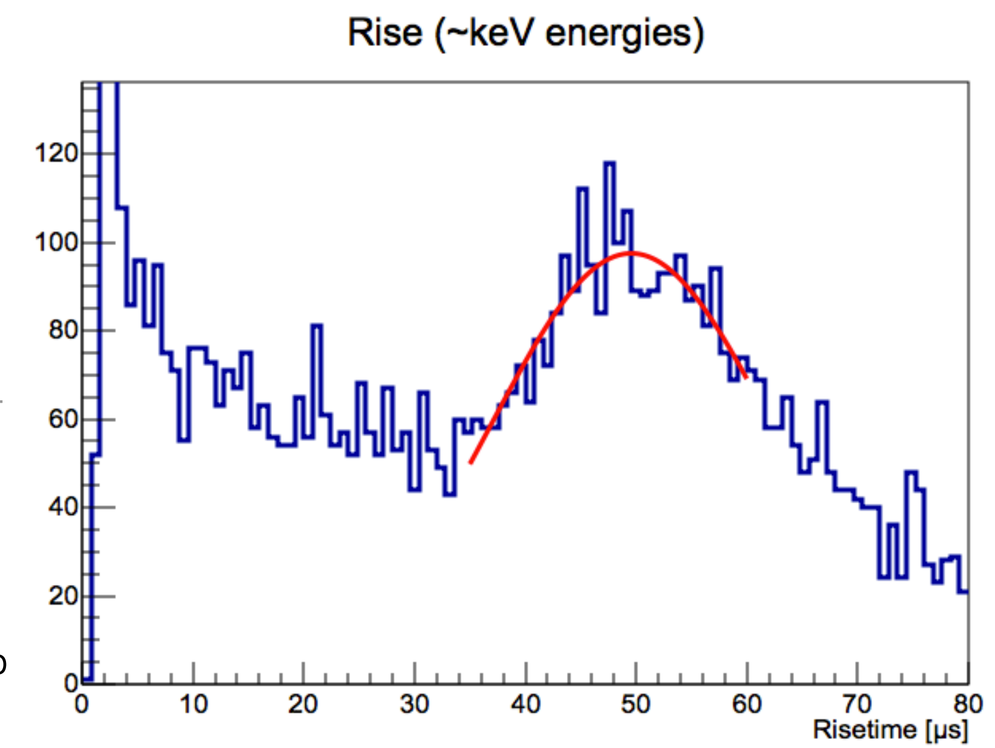
Effect on limit expected to be smaller than that in optimal RoI, and negligible in default RoI.



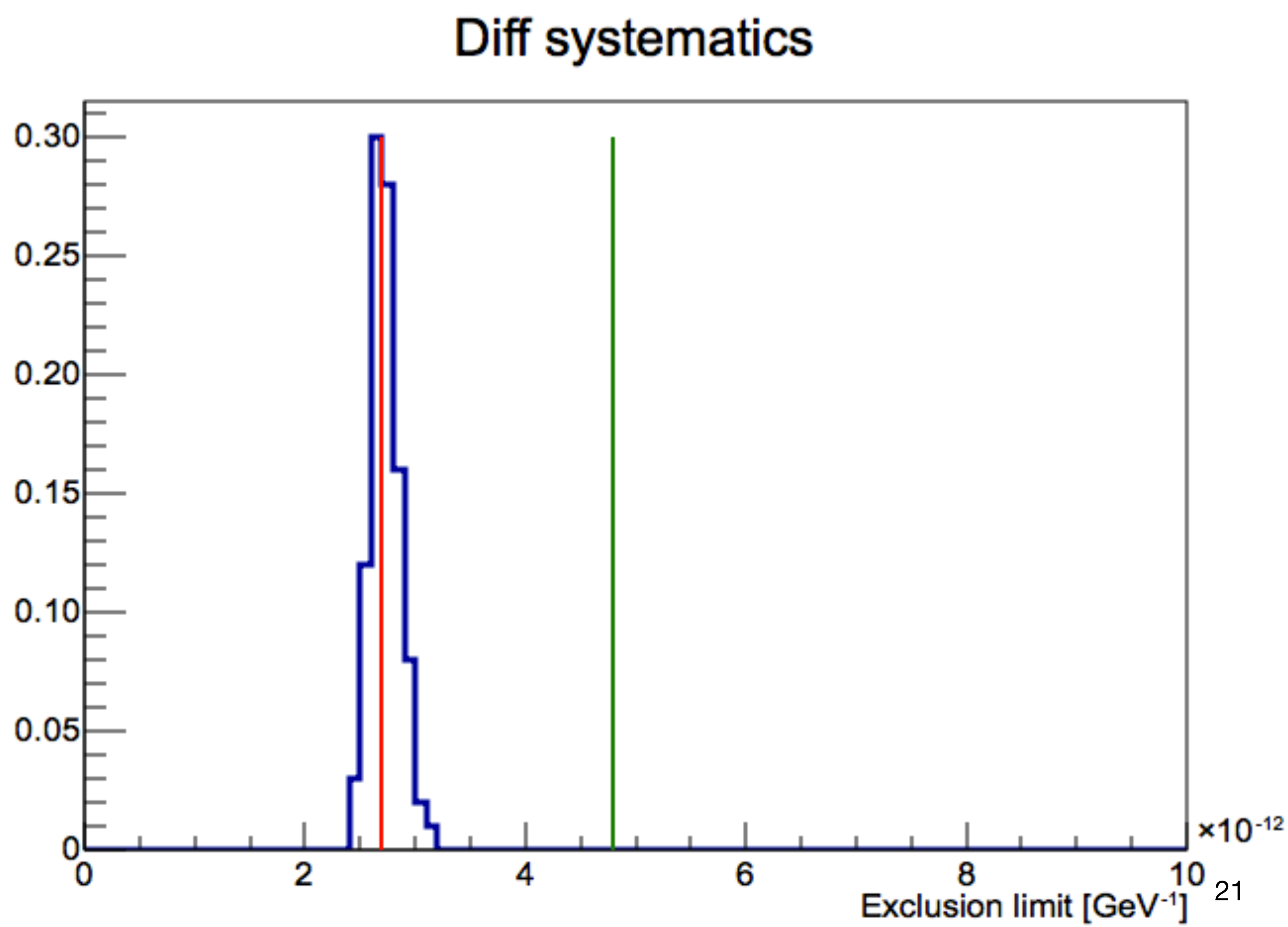
Systematics (Diffusion)

100 simulations (evenly spaced in normal distribution), 10^4 events per simulation

Surface events in pd02b000.
Fit precision ~1%, but simulations disagreed ~10%



Diffusion time calibrated on surface events, relative uncertainty assumed to be 10%



Results: Mild effect on exclusion limit (5.0% relative uncertainty)

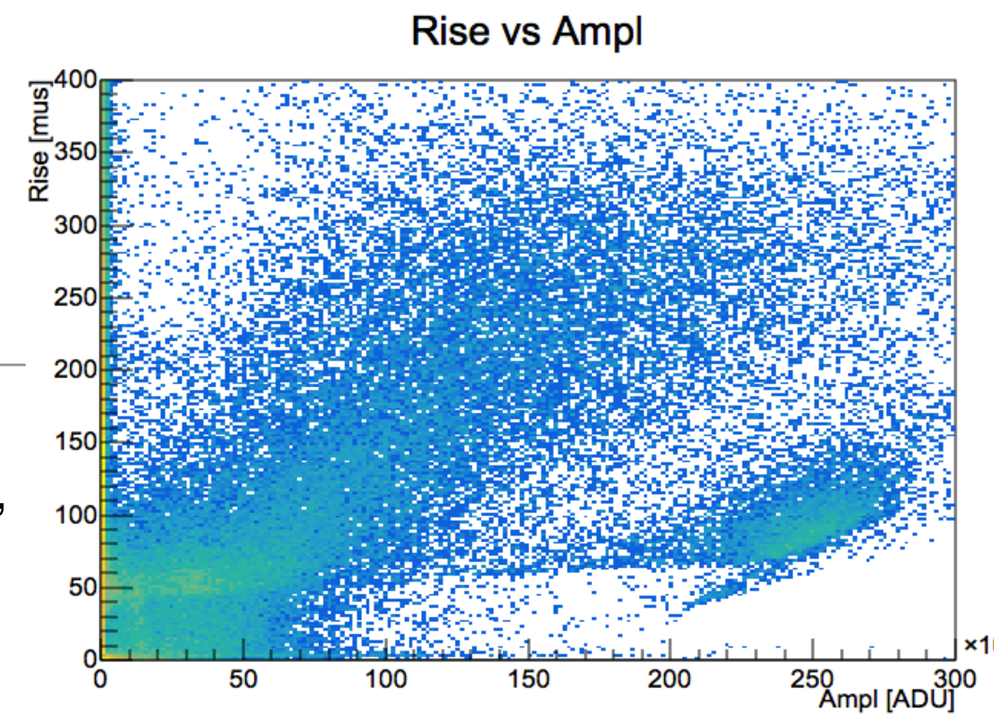
Systematics (Drift)

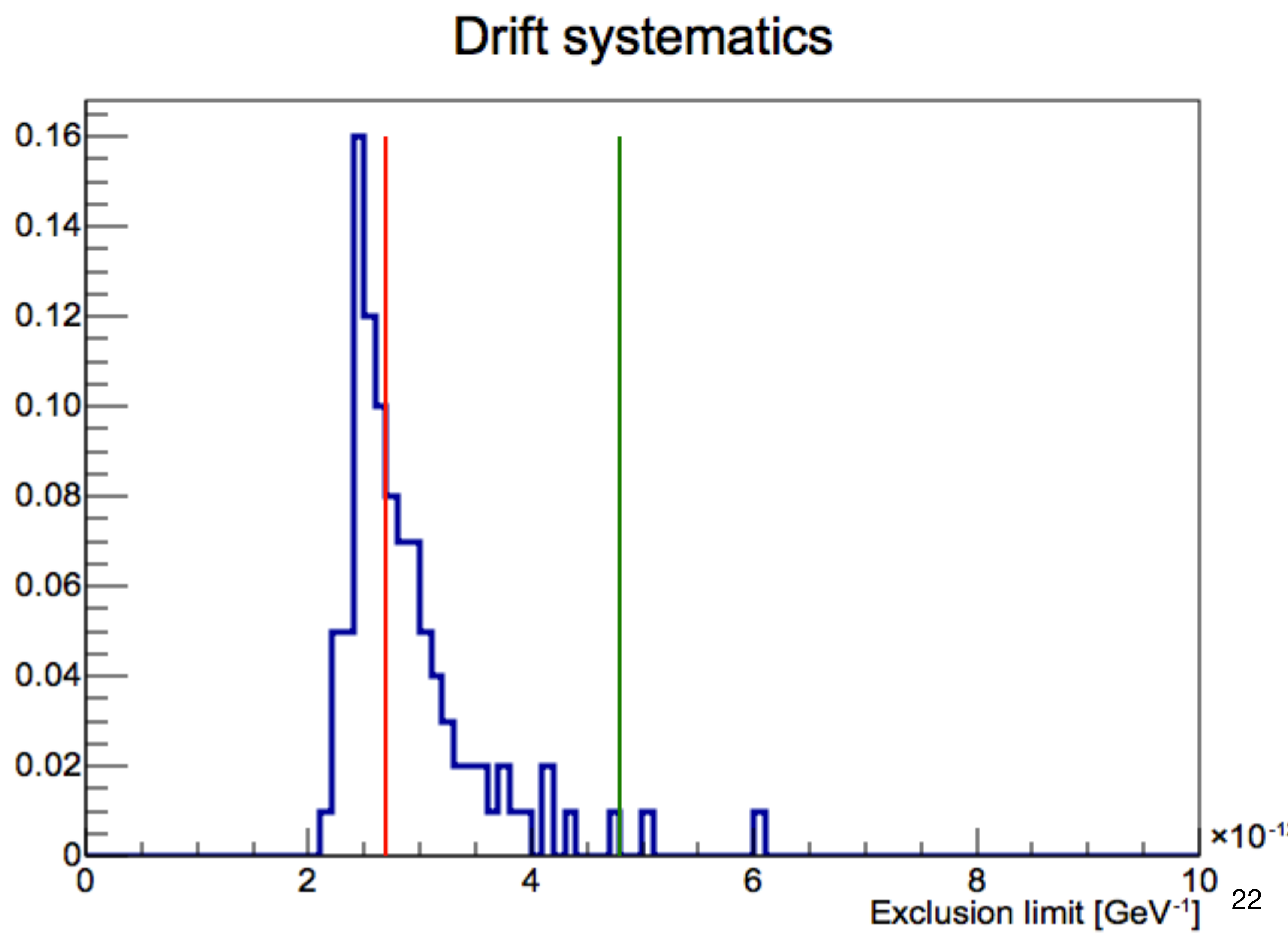
100 simulations (evenly spaced in normal distribution), 10^4 events per simulation

No good calibration for drift time… Used higher range of lengths of track events as bound on drift time. Assumed relative uncertainty of 25%

Results: Large, non-gaussian effect on exclusion limit!

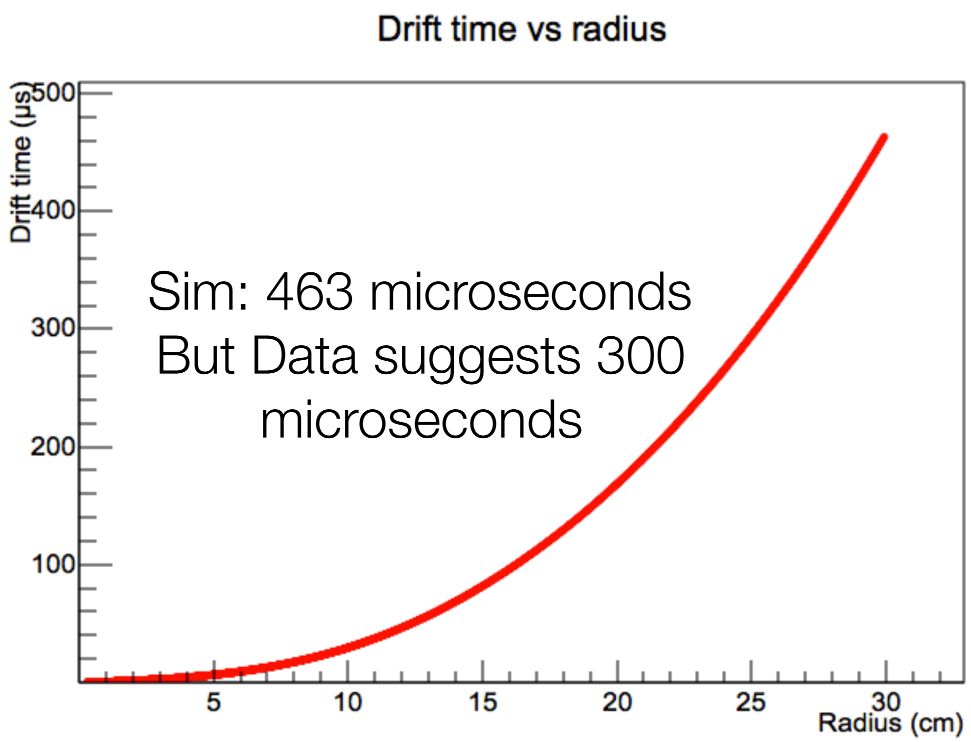
“Track” events in pd02b000. Diff / Drift at maximum ~15%, but simulations disagreed ~25%

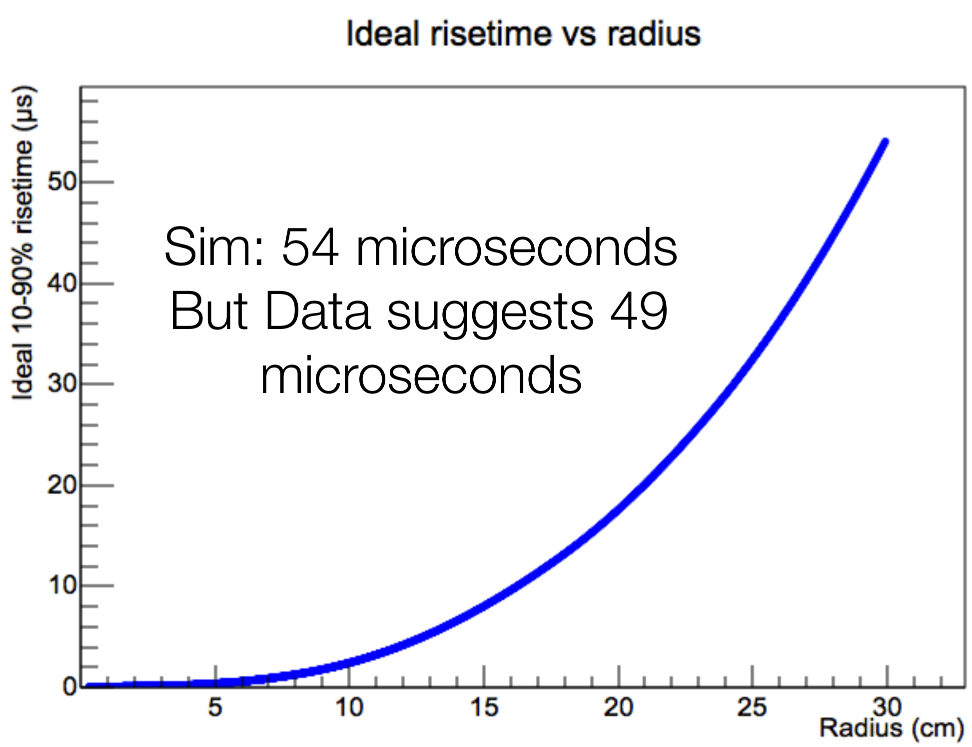




Simulations and calibrations: problems

Limits of drift / diffusion simulations

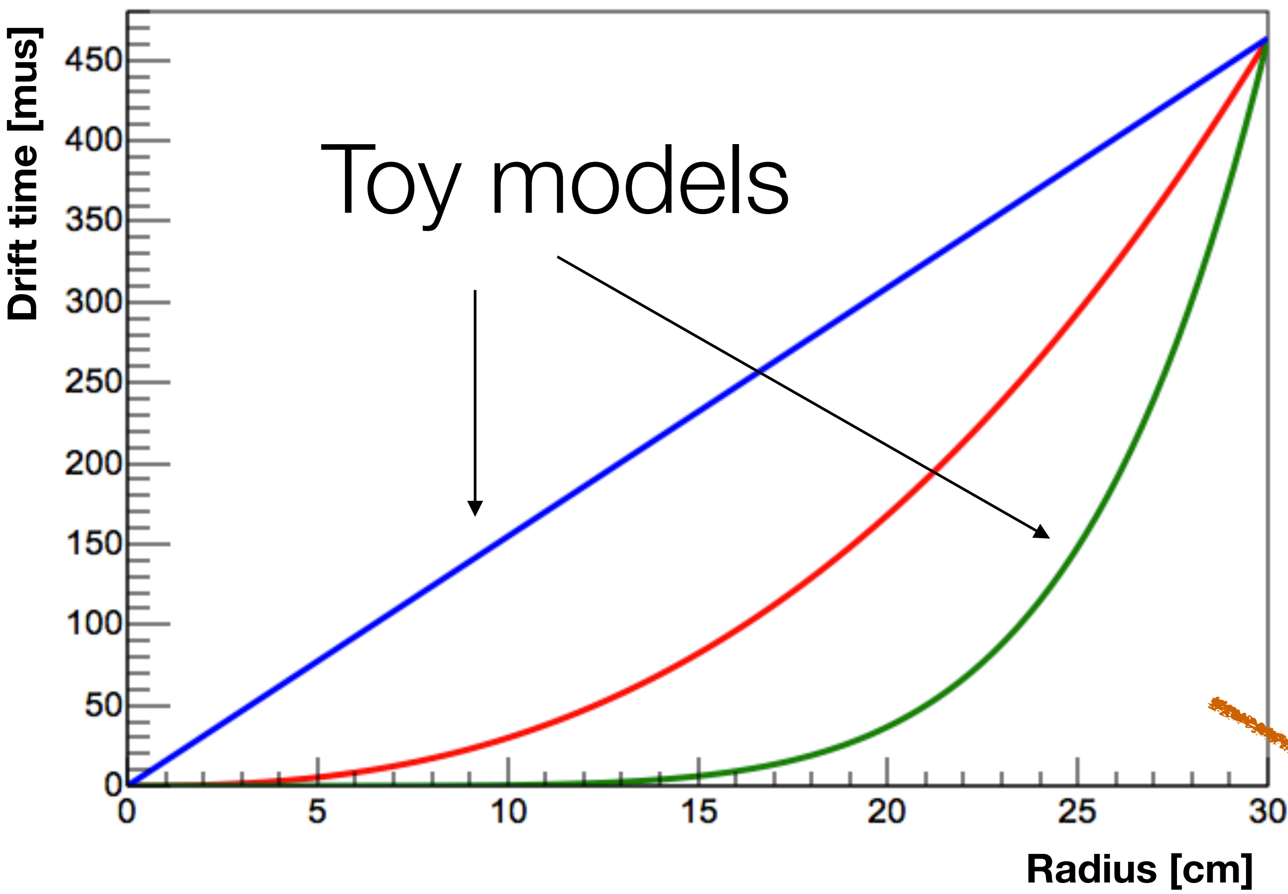




- Default values of electron speed / diffusion from Magboltz (or of COMSOL field) don't lead to same values as calibration

- Diffusion time is close (~10%), but drift time isn't (>25%)

Limits of drift / diffusion simulations

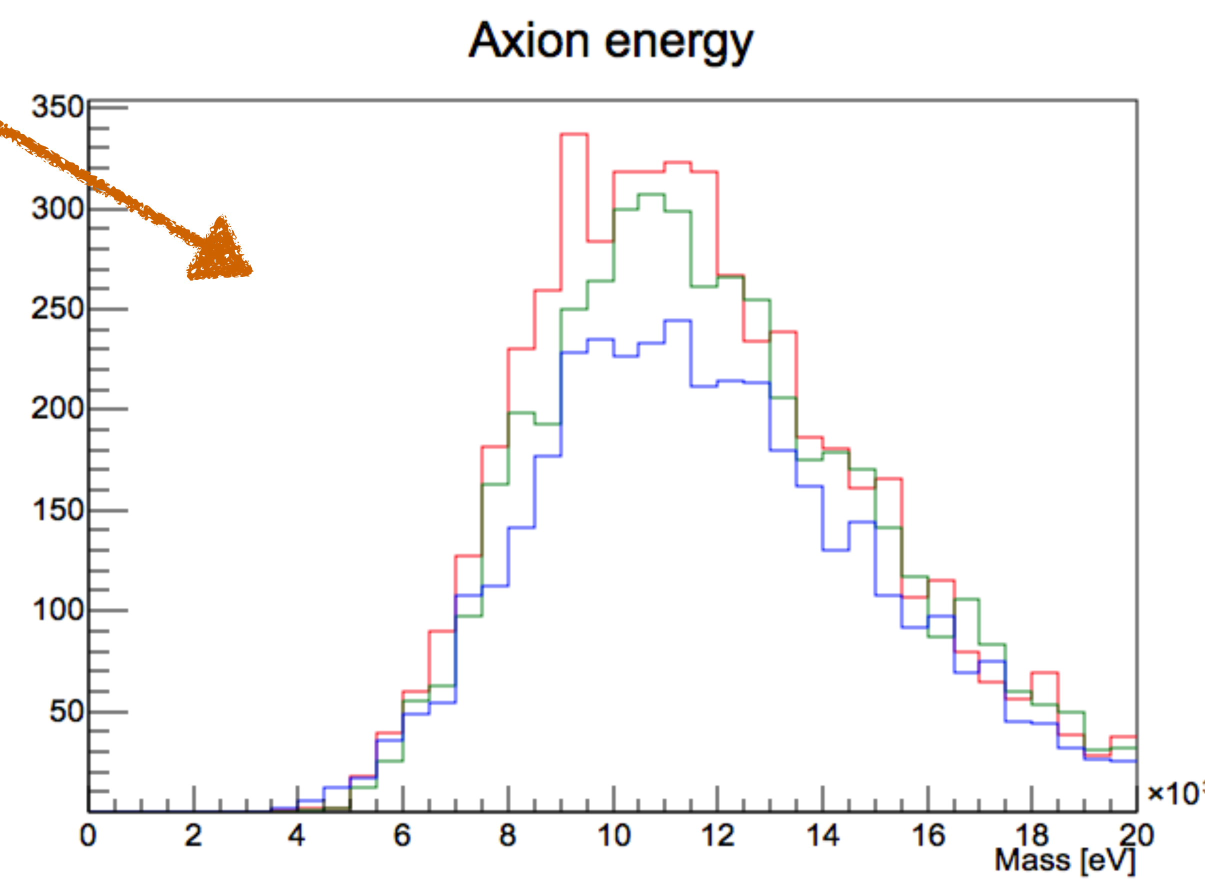


We also only have ONE calibration point… Efficiency depends on drift (and diffusion time) everywhere, not just the surface

If dependency of drift time from radius is wrong, we get different detector efficiency:

-10% efficiency

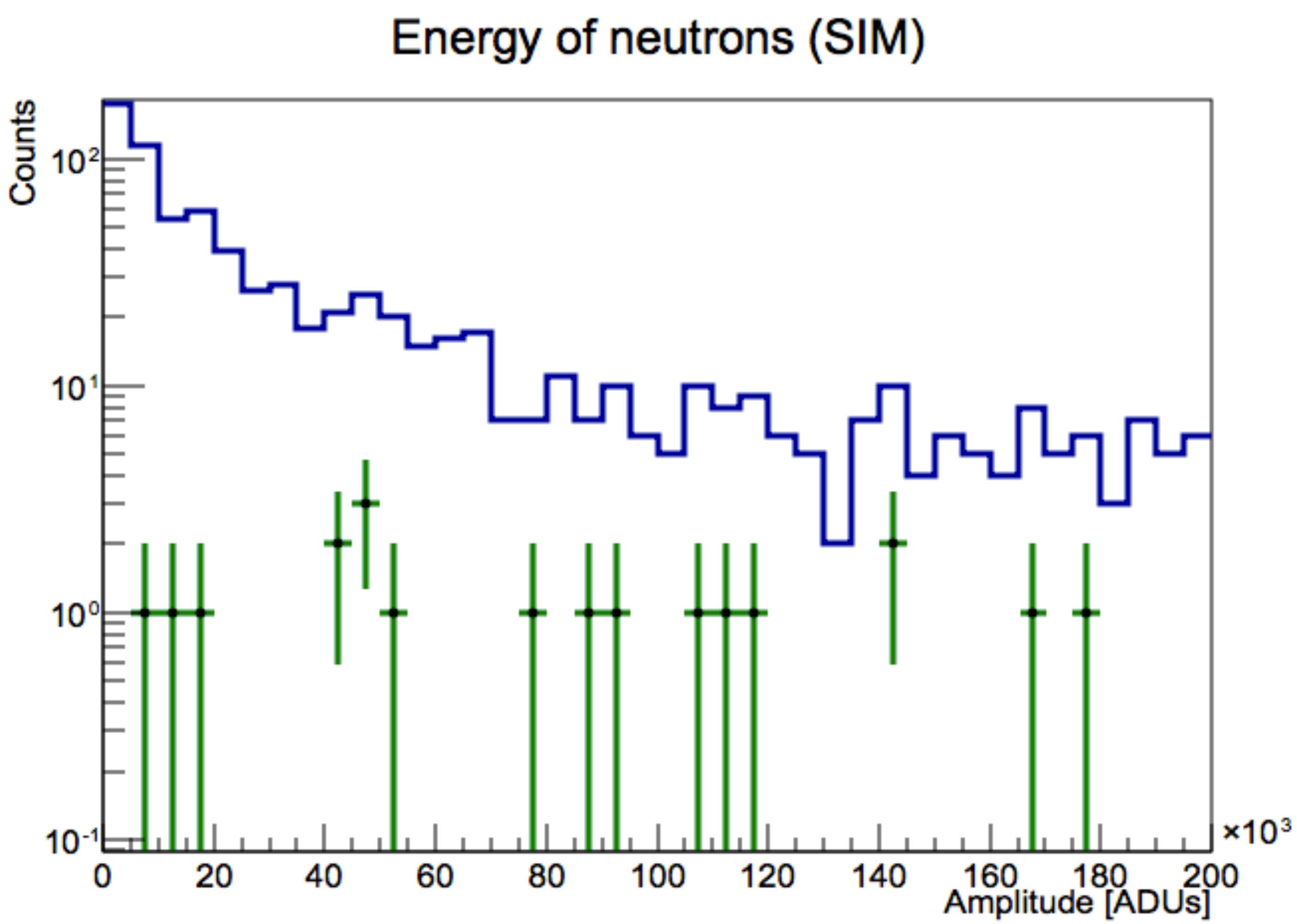
-25% efficiency

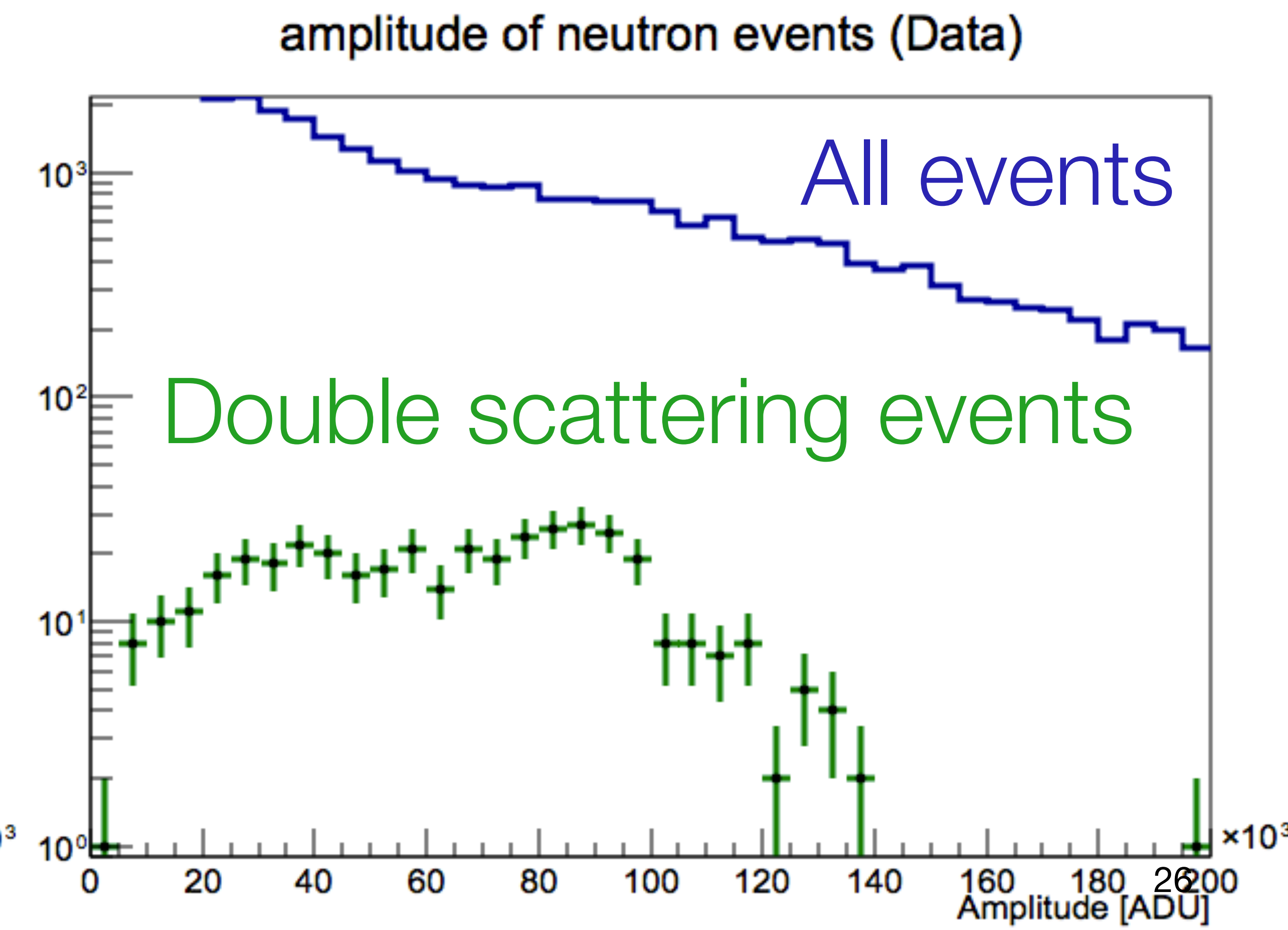


Neutron "calibration"

Use AmBe neutrons to calibrate MPA method efficiency?

Geant4 does not have neutron-Neon scattering data, uses Sodium data instead: these "calibrations" are qualitative at best. But suggest more "double" events in simulation than in data?





Conclusion

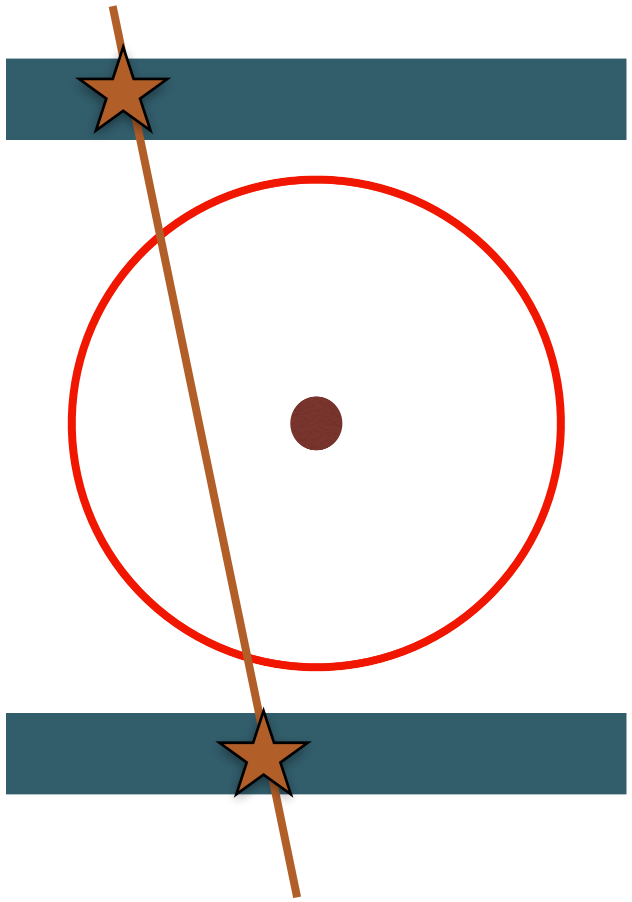
- 90% CL exclusion limits are better than XMASS limits, but preliminary 2-sigma limit from systematics appears to be worse.
- Systematics are dominated by uncertainty on drift time.
- No good drift time calibration. Still, electron drift simulation doesn't match available data.
- Background simulations have been performed. Background subtraction cannot be done, but choice of RoI can be optimized based on it, improving limit by ~1.5.

Looking forward to the future

- ABSOLUTELY need better calibrations, especially for drift time!

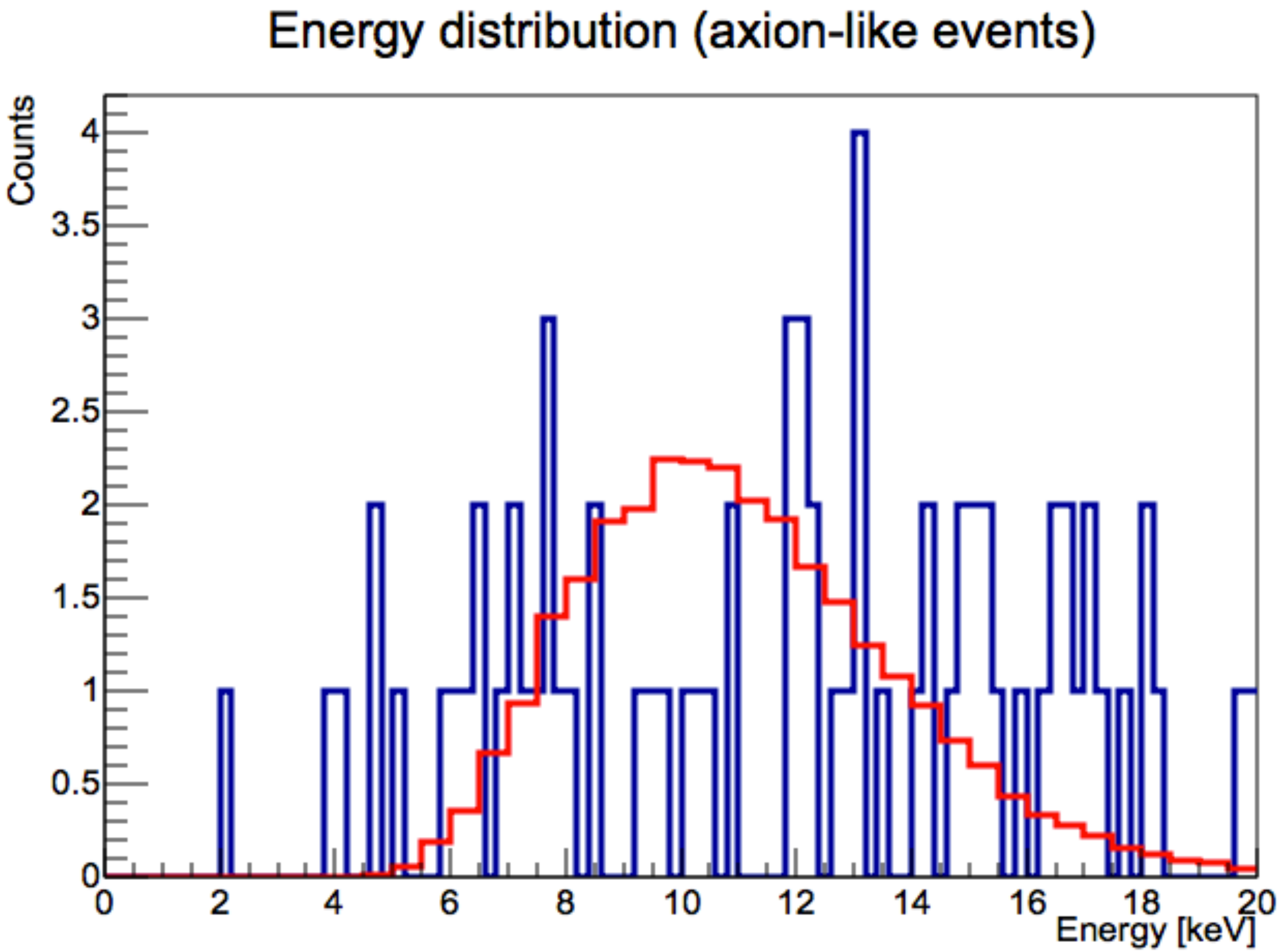
- Laser calibrations are a good start, but need multiple calibration points for drift and diffusion, not just surface events.

- Muon veto would be great for this: give t_0 of event, and location of closest approach based on location of crossing of both vetos. Can calibrate diffusion and drift time at all positions!



Thank you for your attention!

Extra slides


Energy distribution (axion-like events)
Counts
0
0.5
1
1.5
2
2.5
3
3.5
4
0
2
4
6
8
10
12
14
16
18
20
Energy [keV]

Separability