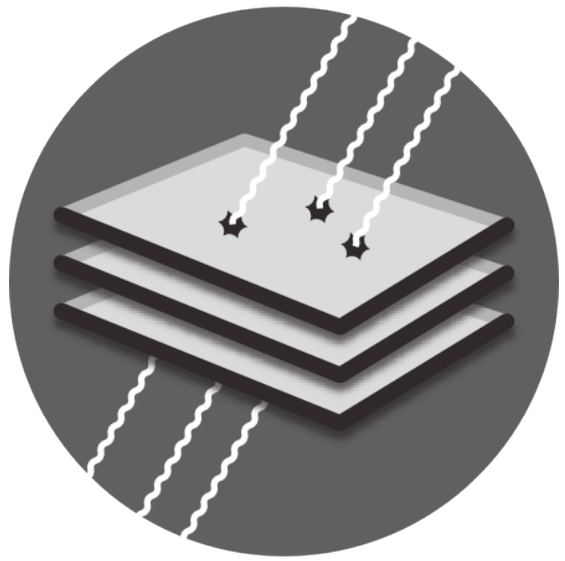


CCD response to a ^{124}Sb-^{9}Be source

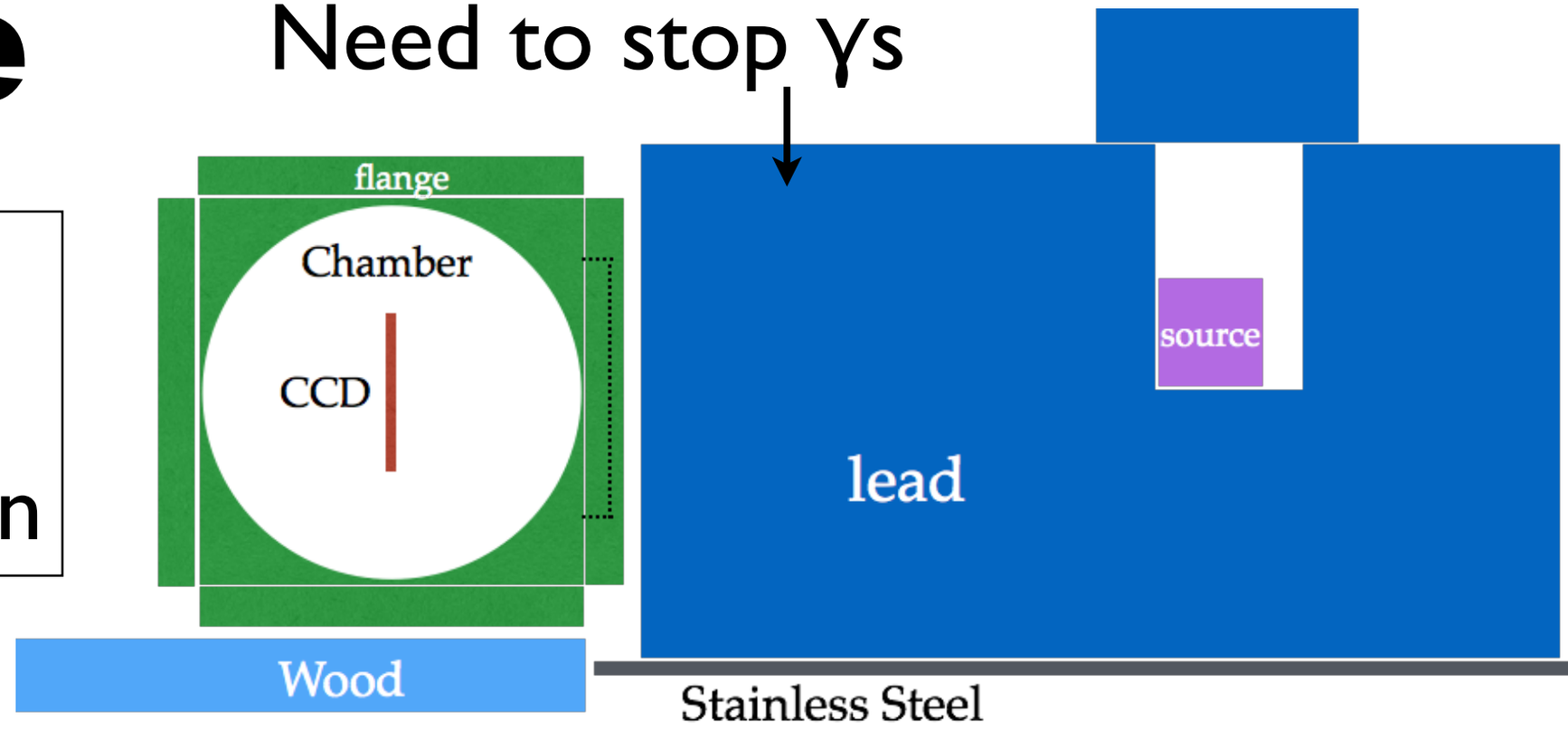
Alvaro E Chavarria
Kavli Institute for Cosmological Physics

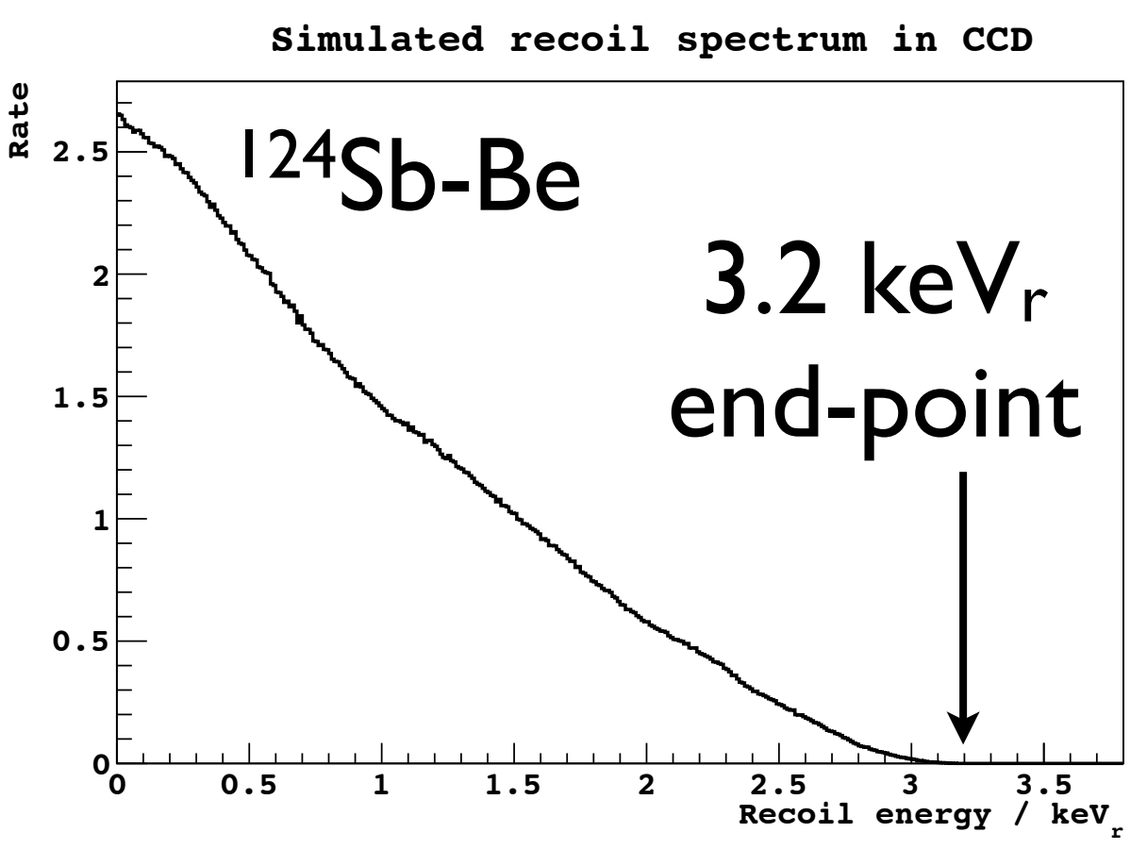
Outline

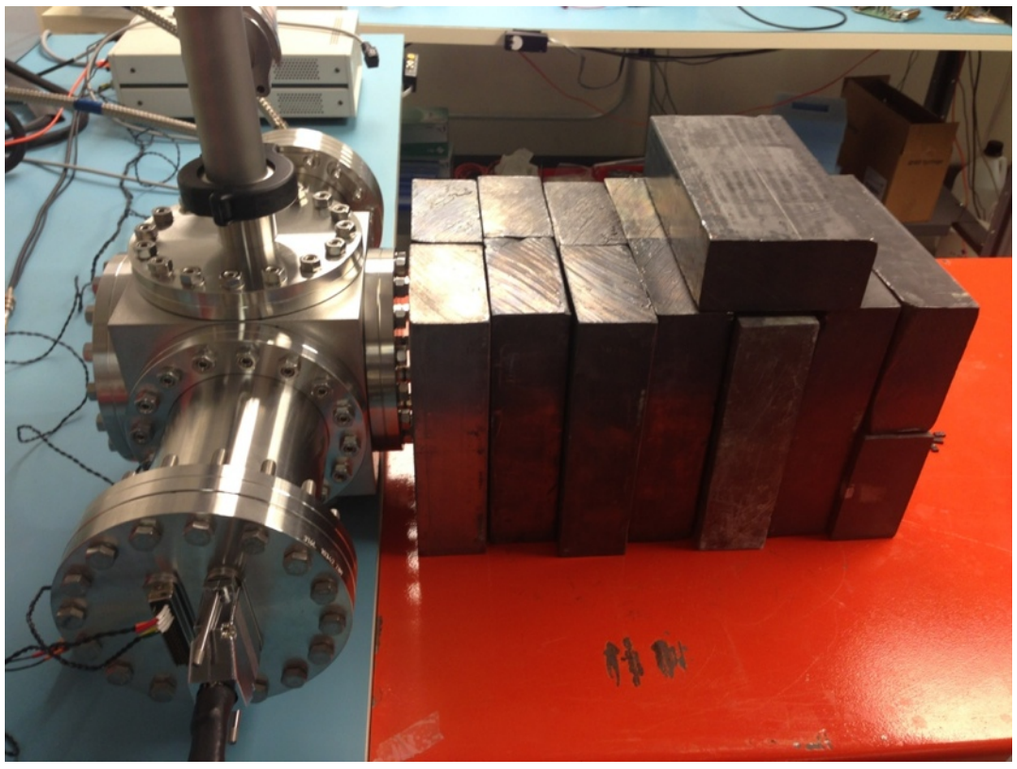
- Photo-neutron calibration principle.
- Nuclear recoil spectrum from data.
- Expected recoil spectrum from simulation.
- Extraction of ionization efficiency.
- Systematics.
- Results.

Source

24 keV
neutrons from
^{9}Be(γ,n) reaction







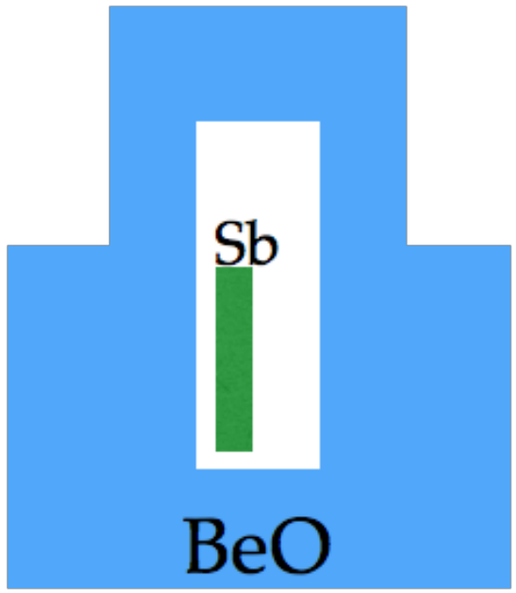
^{124}Sb Source

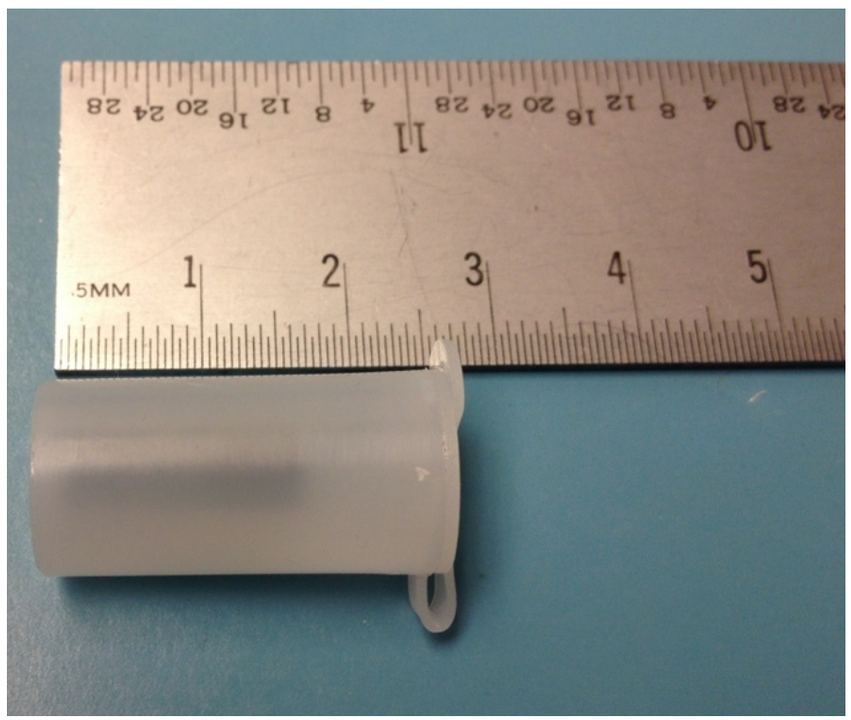
- Irradiated at NC State.
- Activity measured with HPGe on September 1st:

0.290 ± 0.010 mCi

~5 mCi when data taking started.

1000s n s^{-1} ⟶

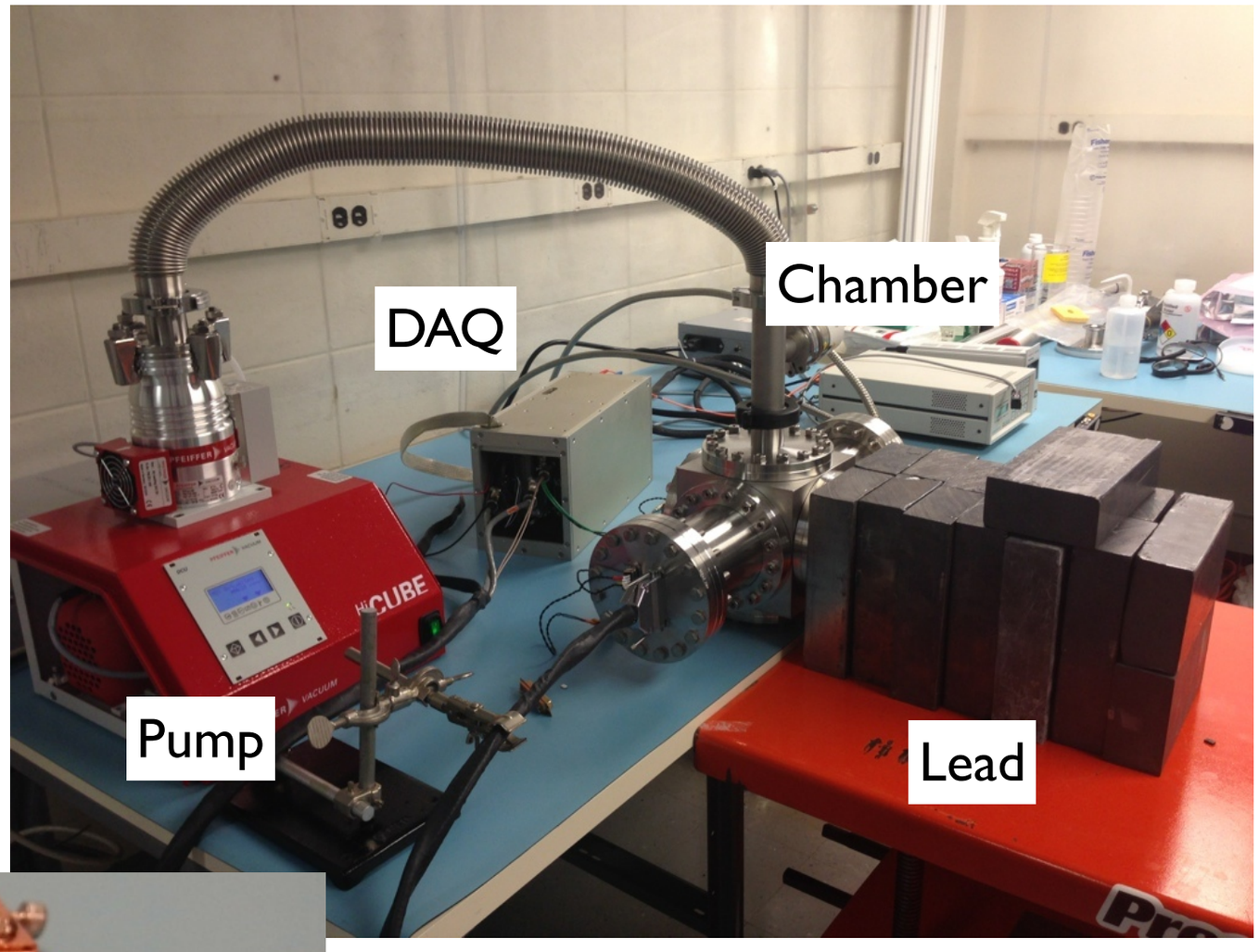




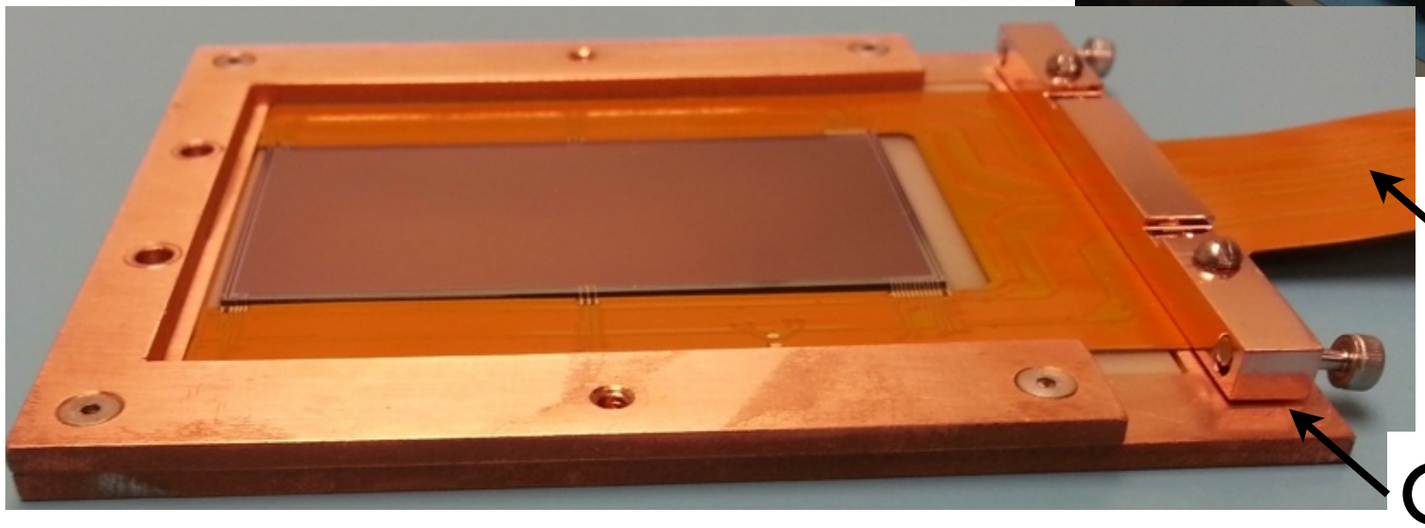
Replacing BeO parts with Al allows to measure γ background.

CCD setup

500 µm CCD.
8 Mpixel.
15 µm x 15 µm pixels.
Set temperature 130 K.
Substrate bias 130 V.

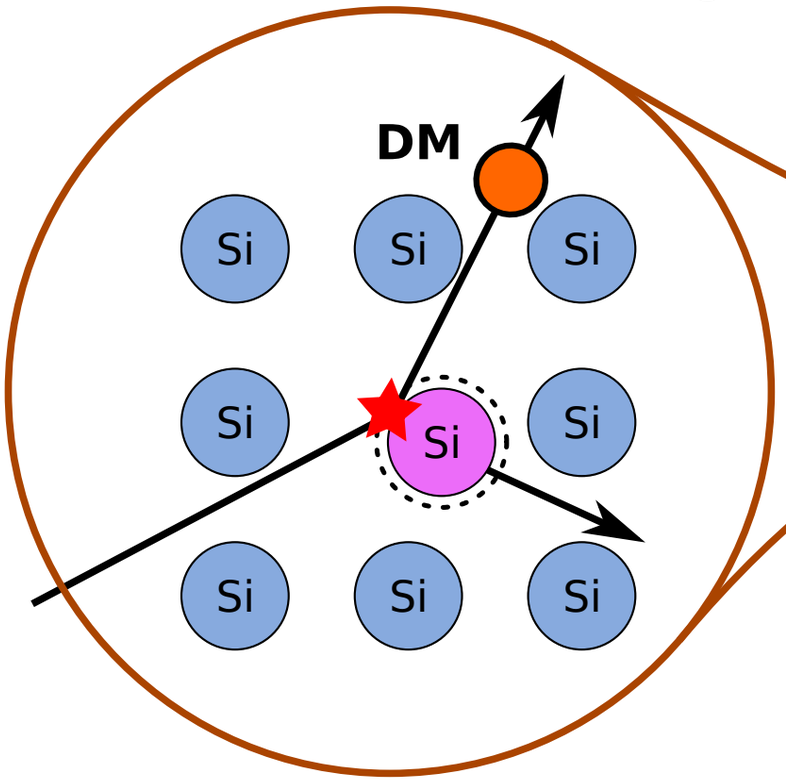


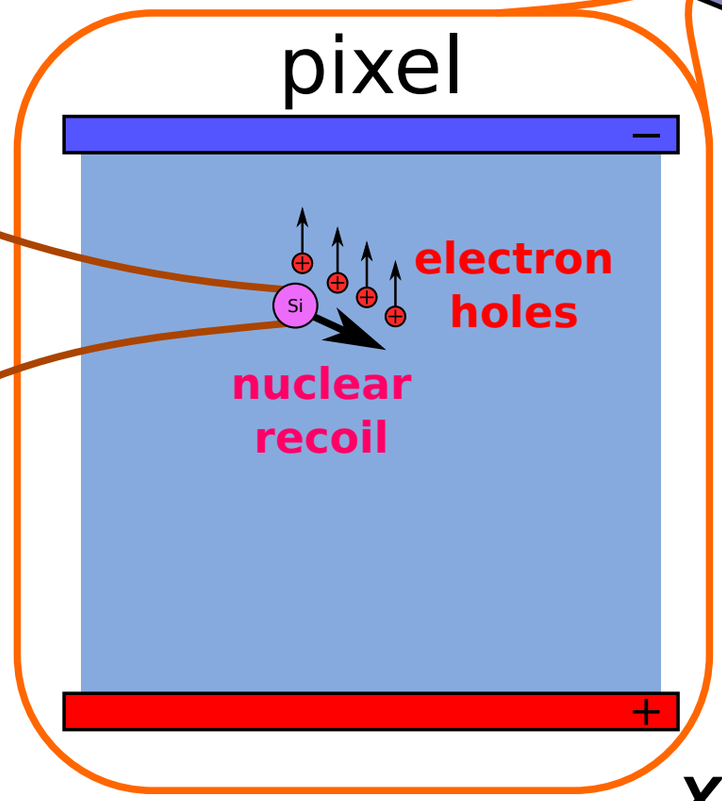
UChicago

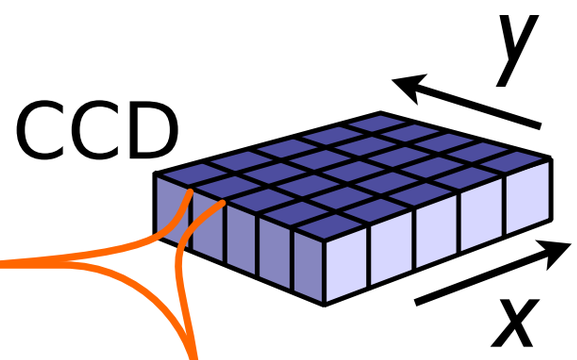


Detector

coherent elastic scattering



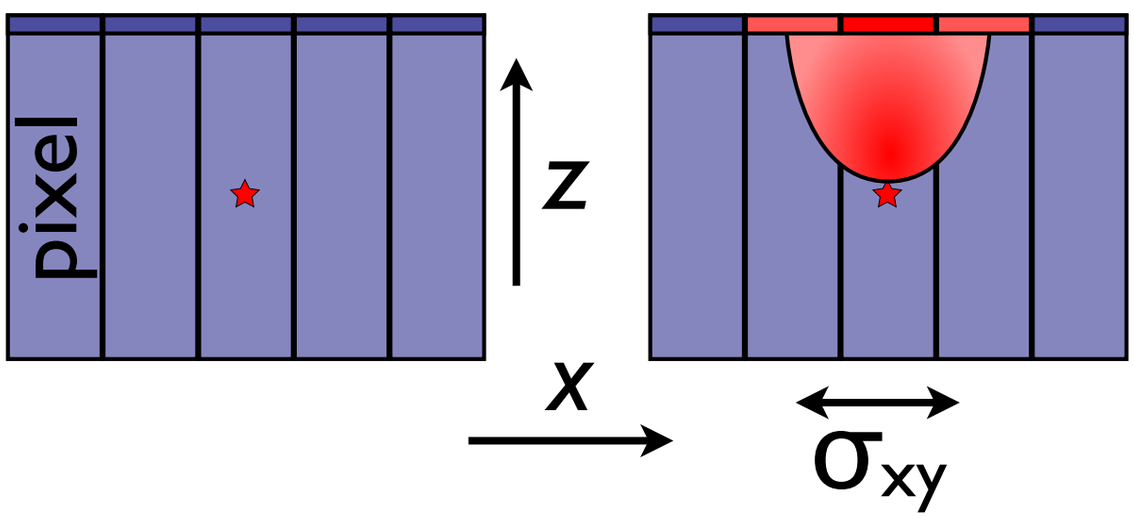


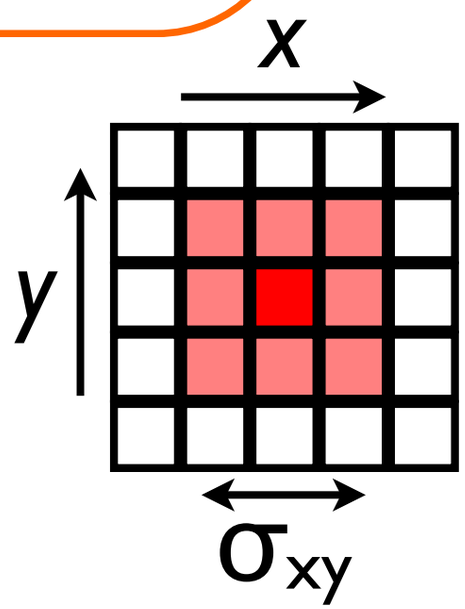


Charged particles produce ionization in CCD bulk.

3.62 eV for e-h pair.

Charge drifted up and held at gates.





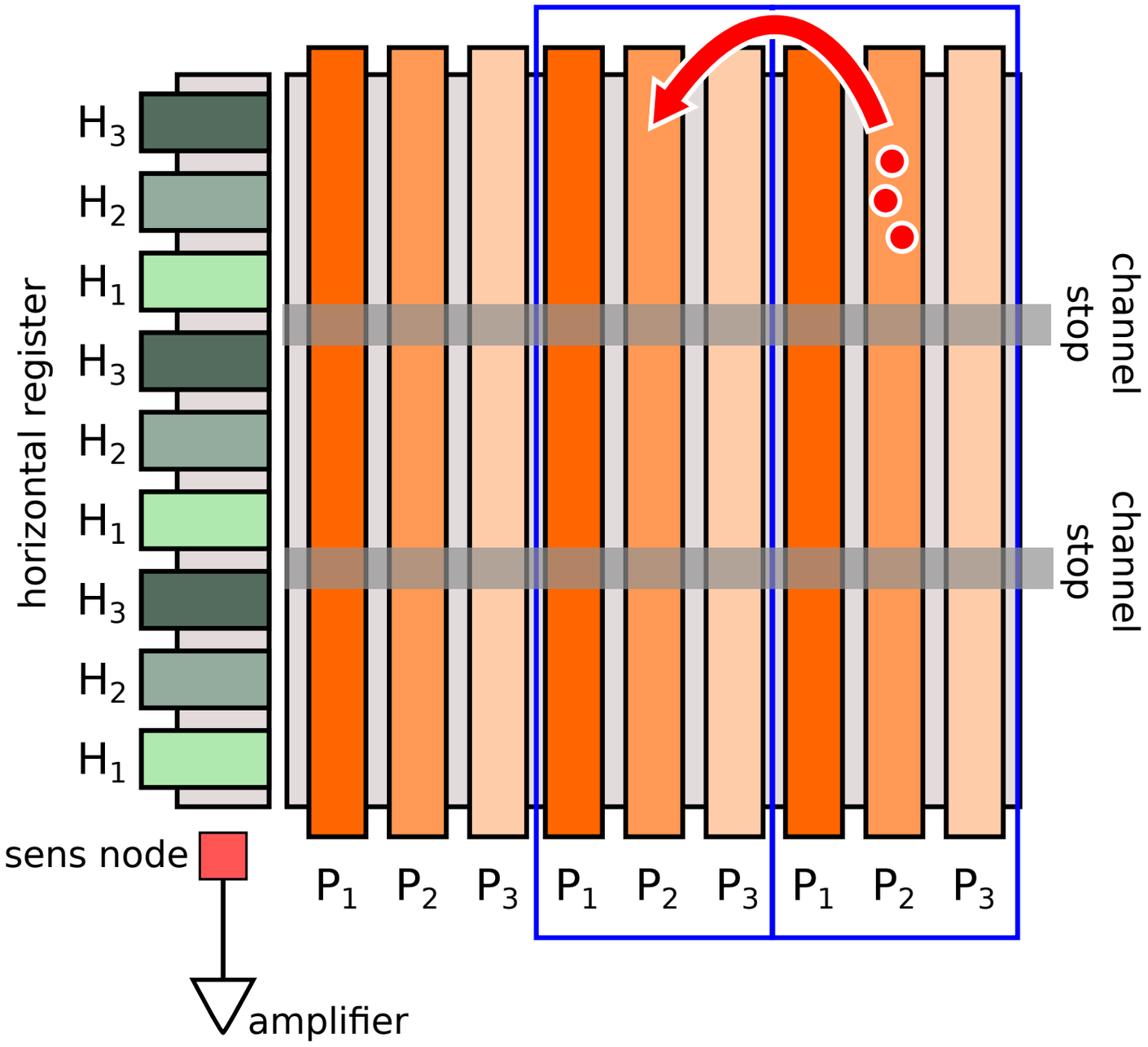
Charge collected by each pixel on CCD plane is read out.

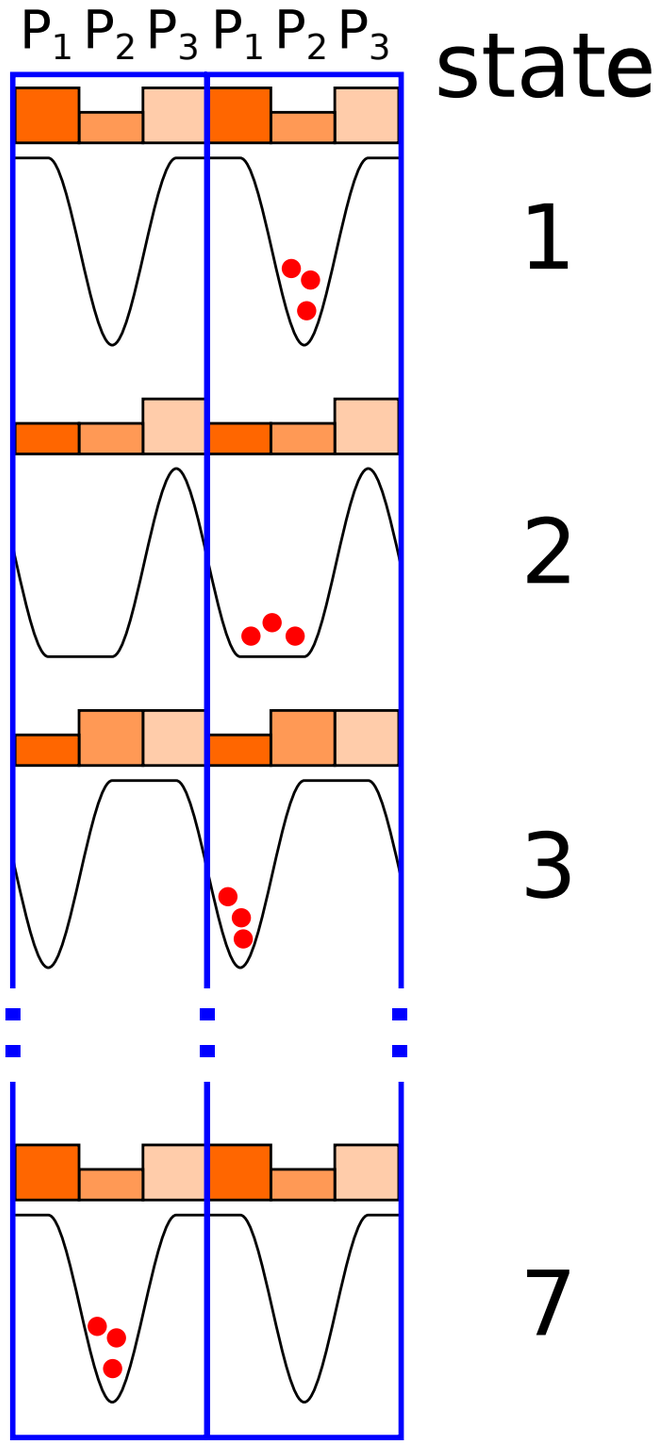
~2 e^- RMS read-out noise.

CCD readout

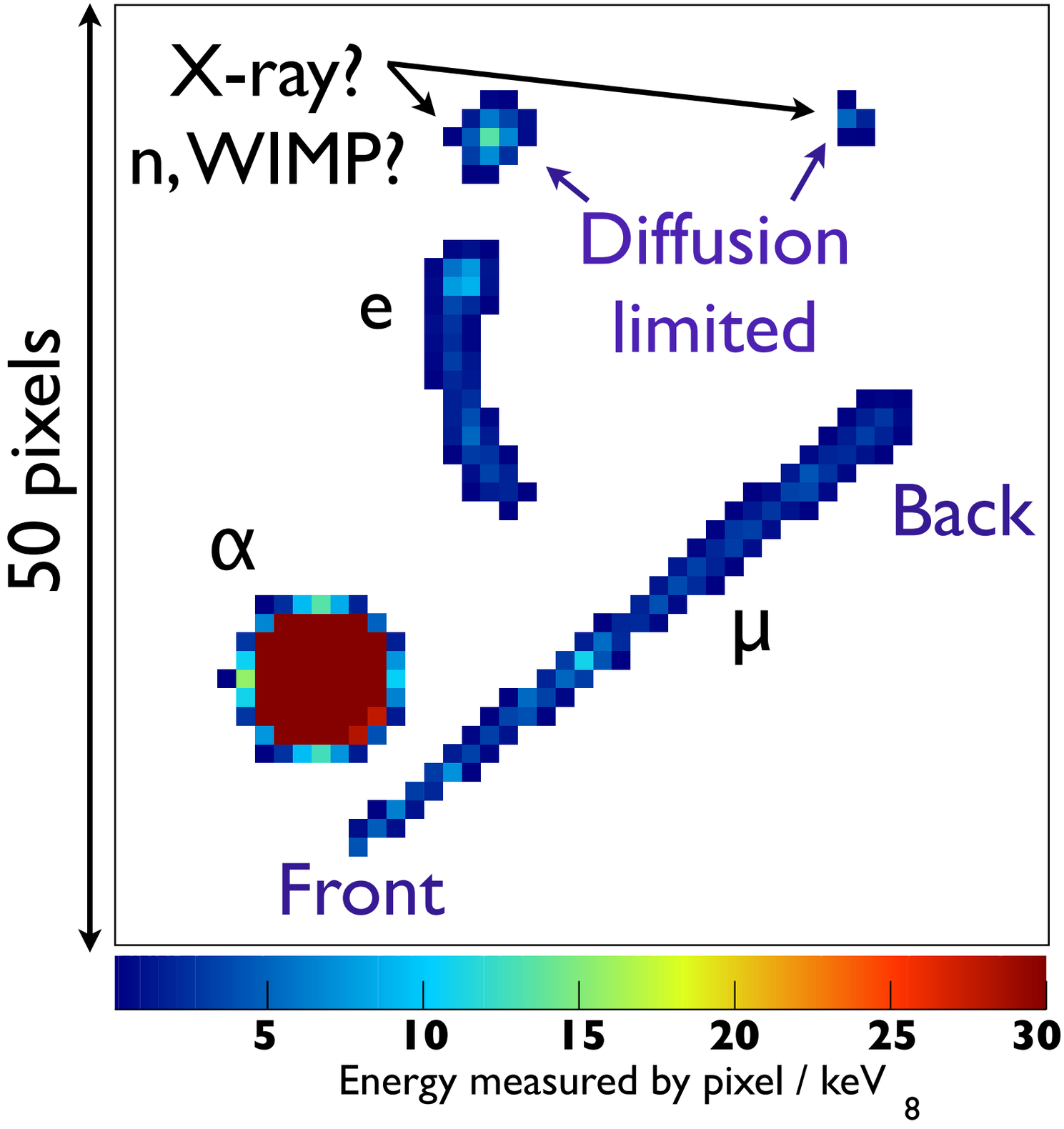
Not triggered

3x3 pixels CCD

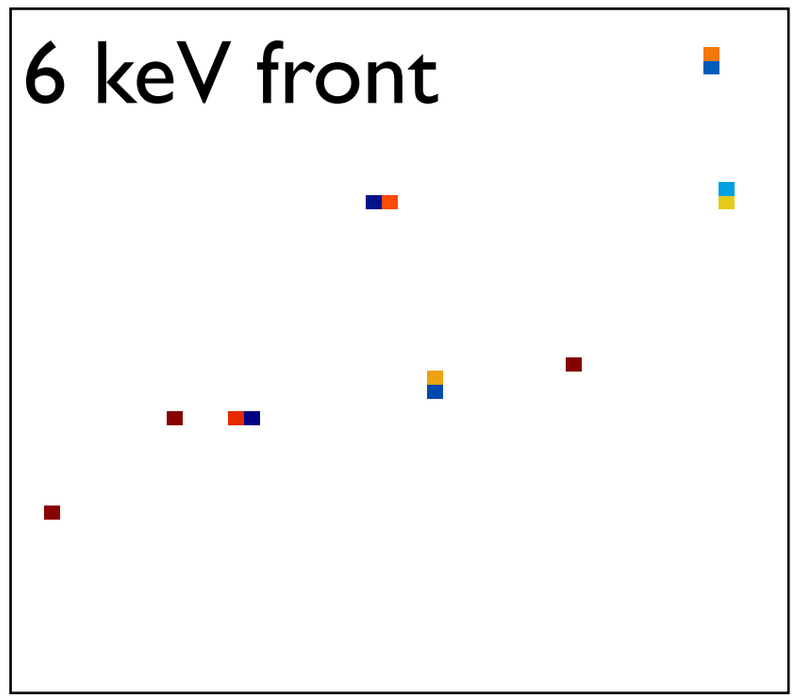


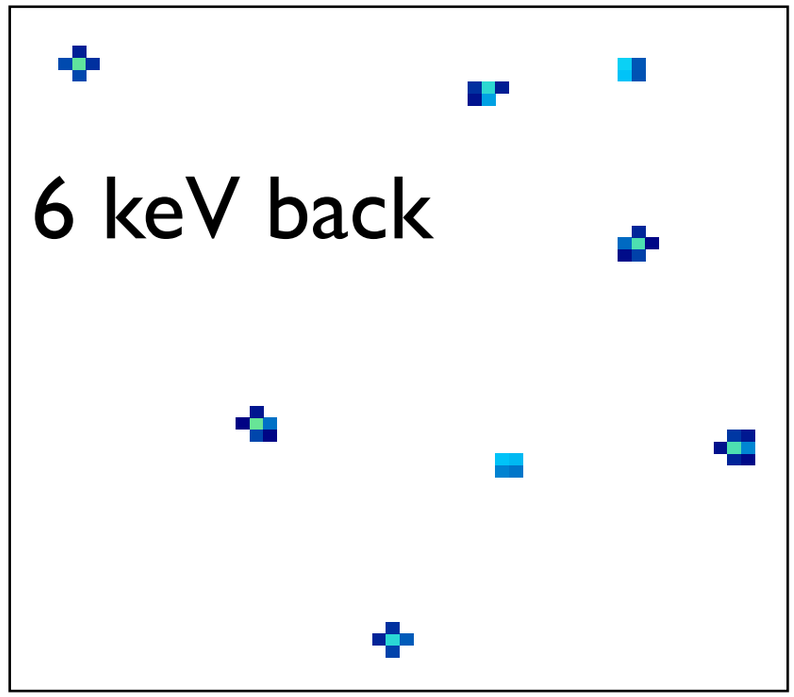


Particle tracks



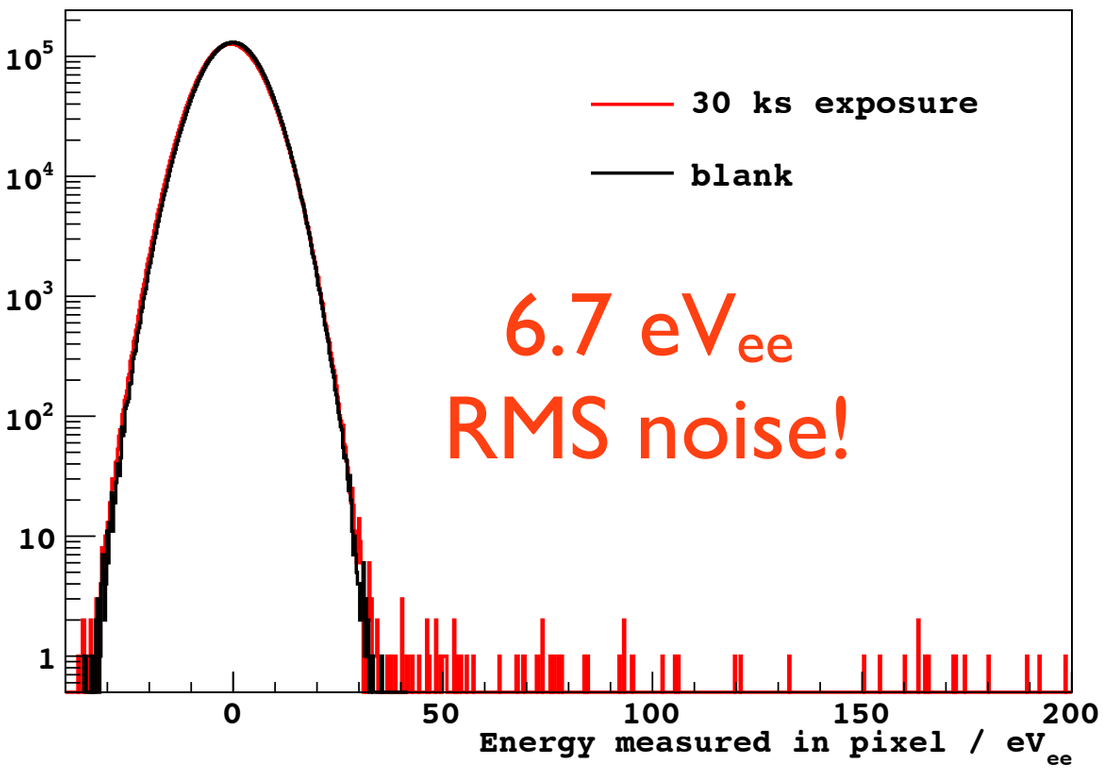
Diffusion limited

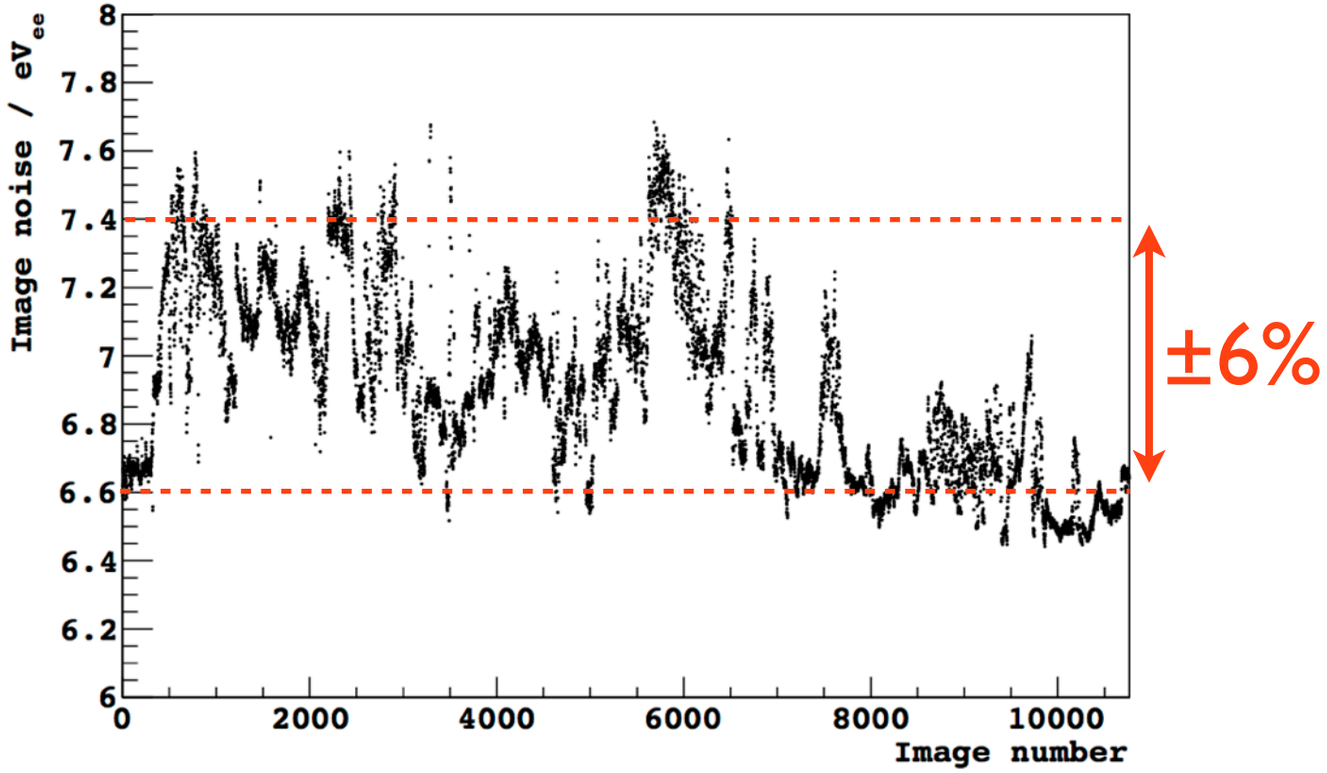




CCD Performance

SNOLAB

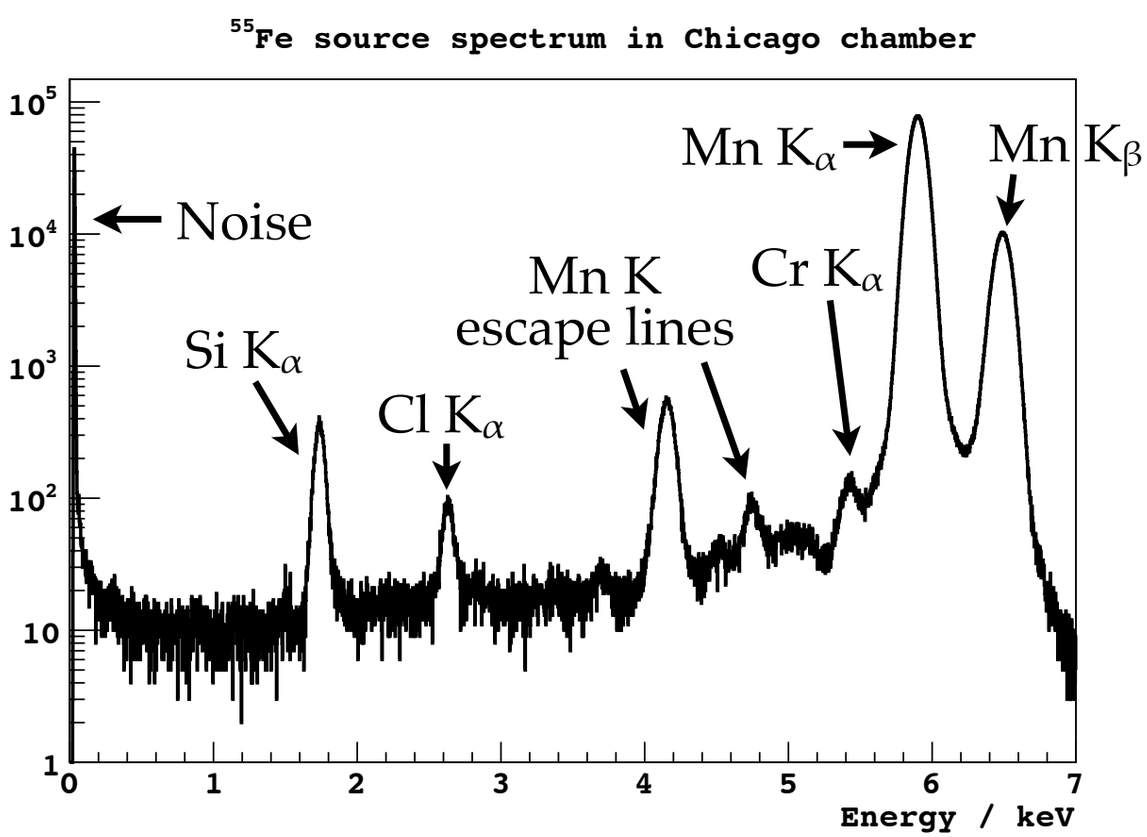




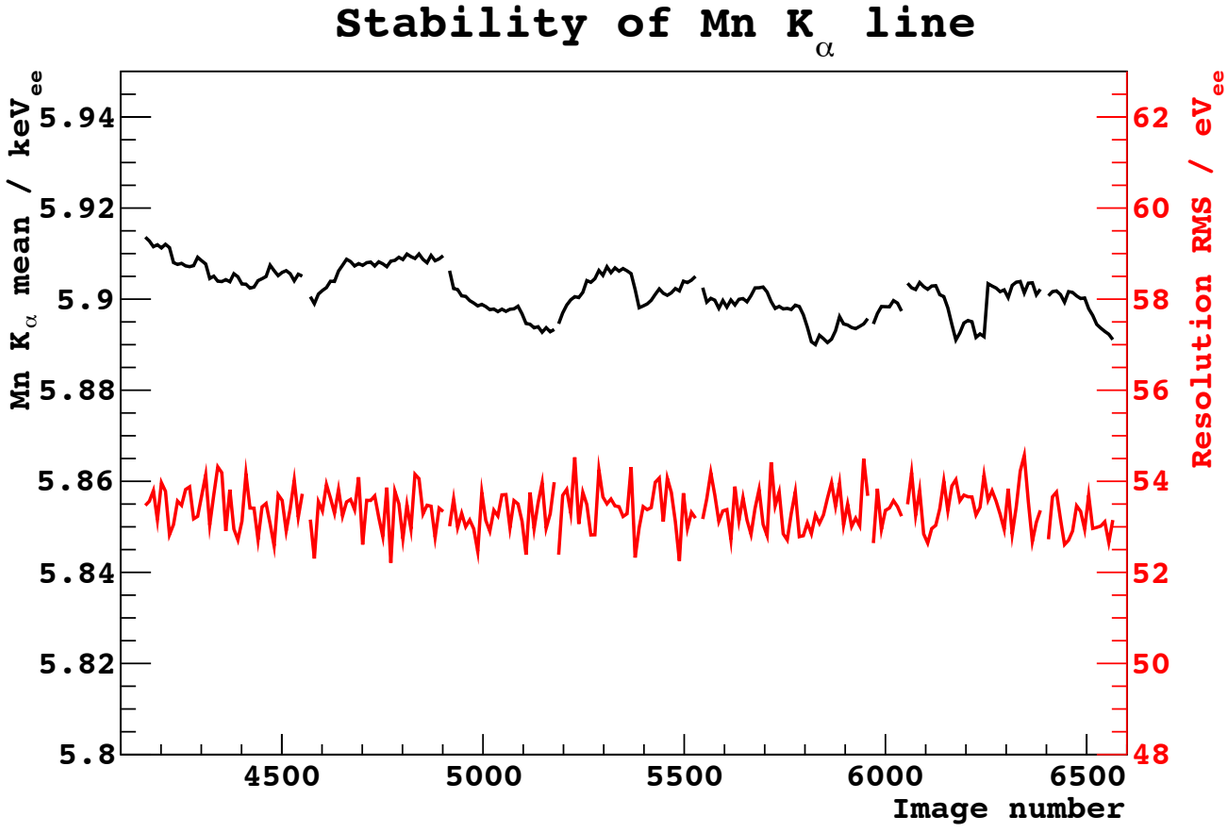
>95% of the image good quality.

10794 images acquired over 126 days. All good.

^{55}Fe data



53 eV at 5.9 keV from front

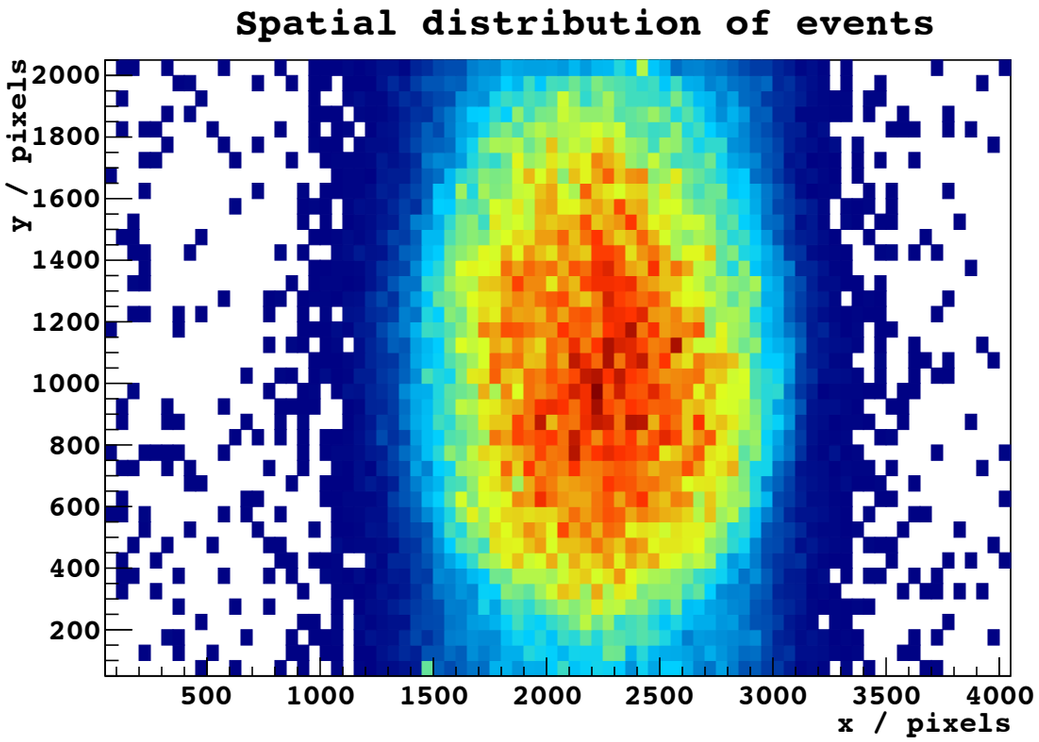


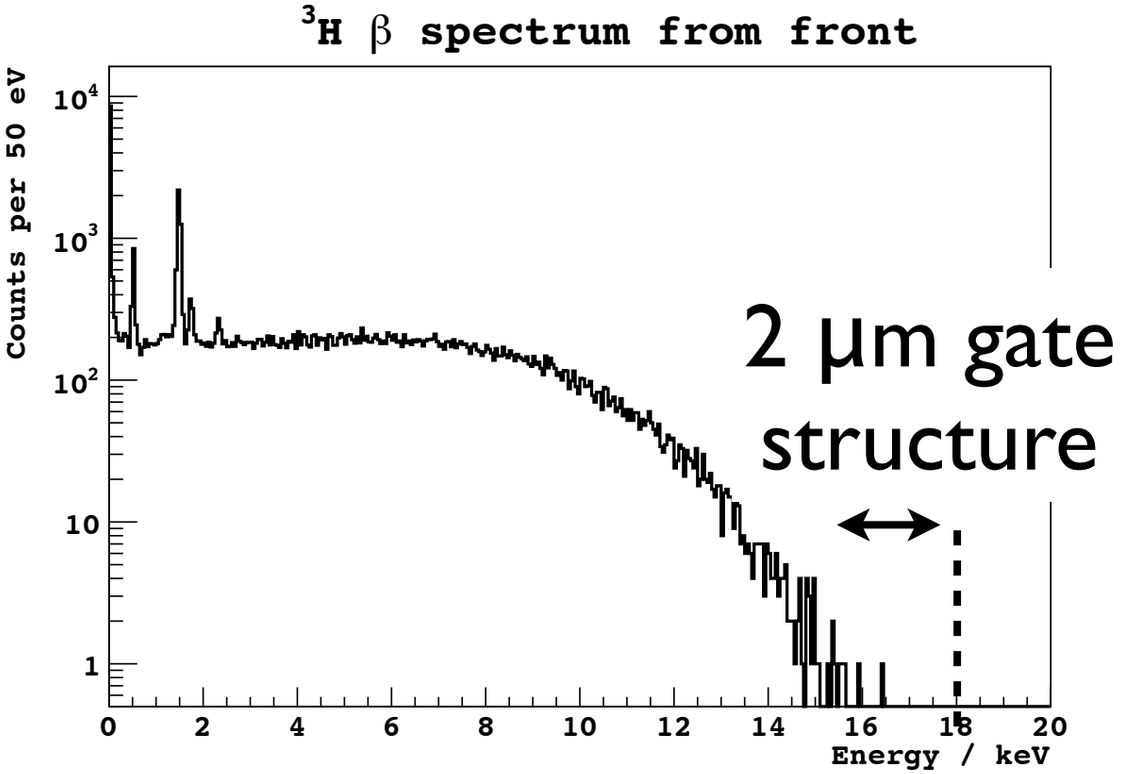
27 days of ^{55}Fe data

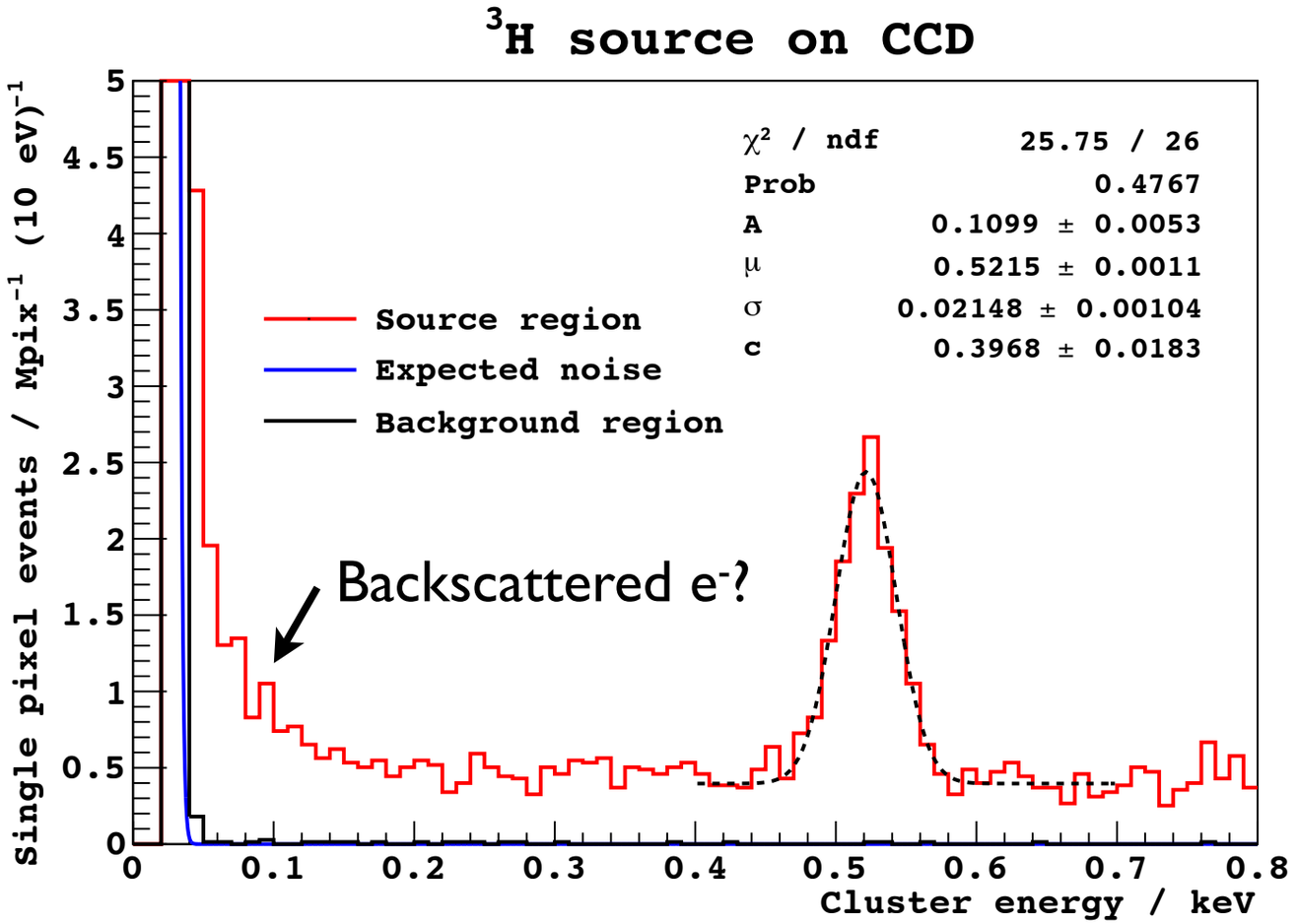
0.1% fluctuations in energy scale

1% fluctuations in resolution

Tritium source







21 eV_{ee} resolution at 525 eV_{ee}

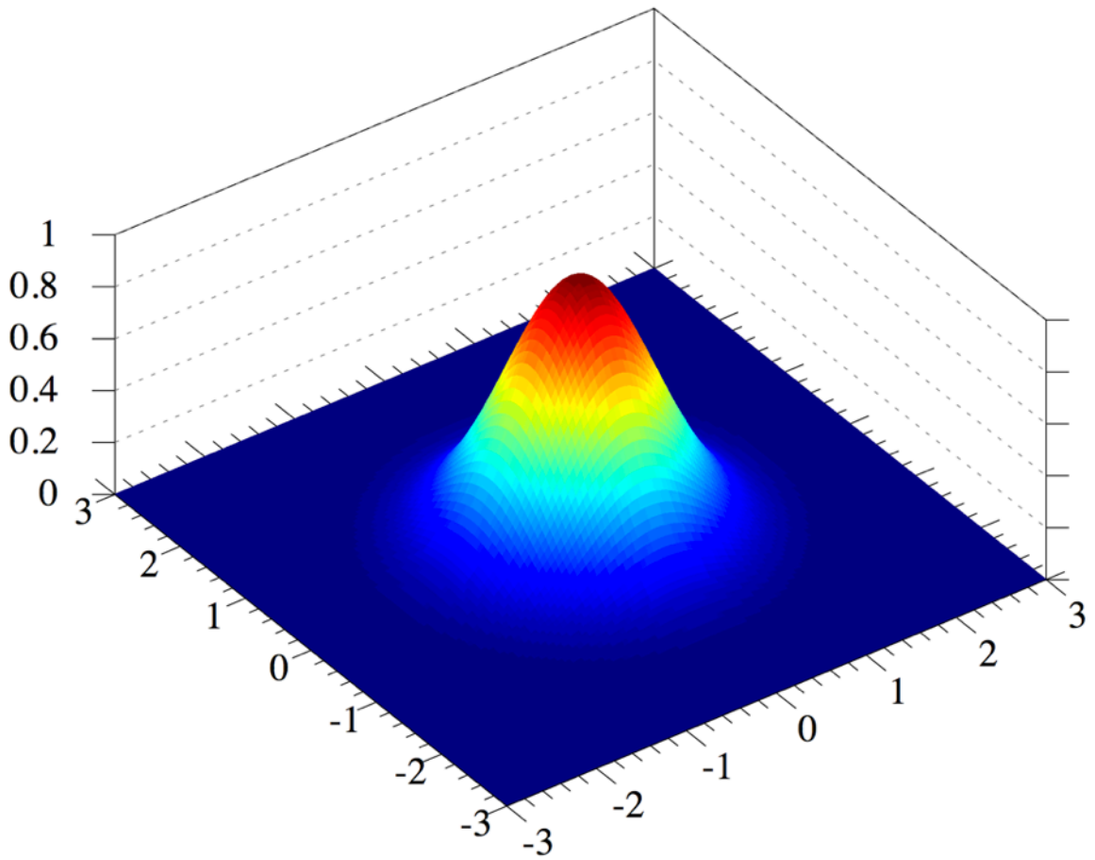
Likelihood clustering

$$N_e(E) \times \texttt{Gaus}(x, y, \mu_x, \mu_y, \sigma(z))$$

Number of ionized electrons

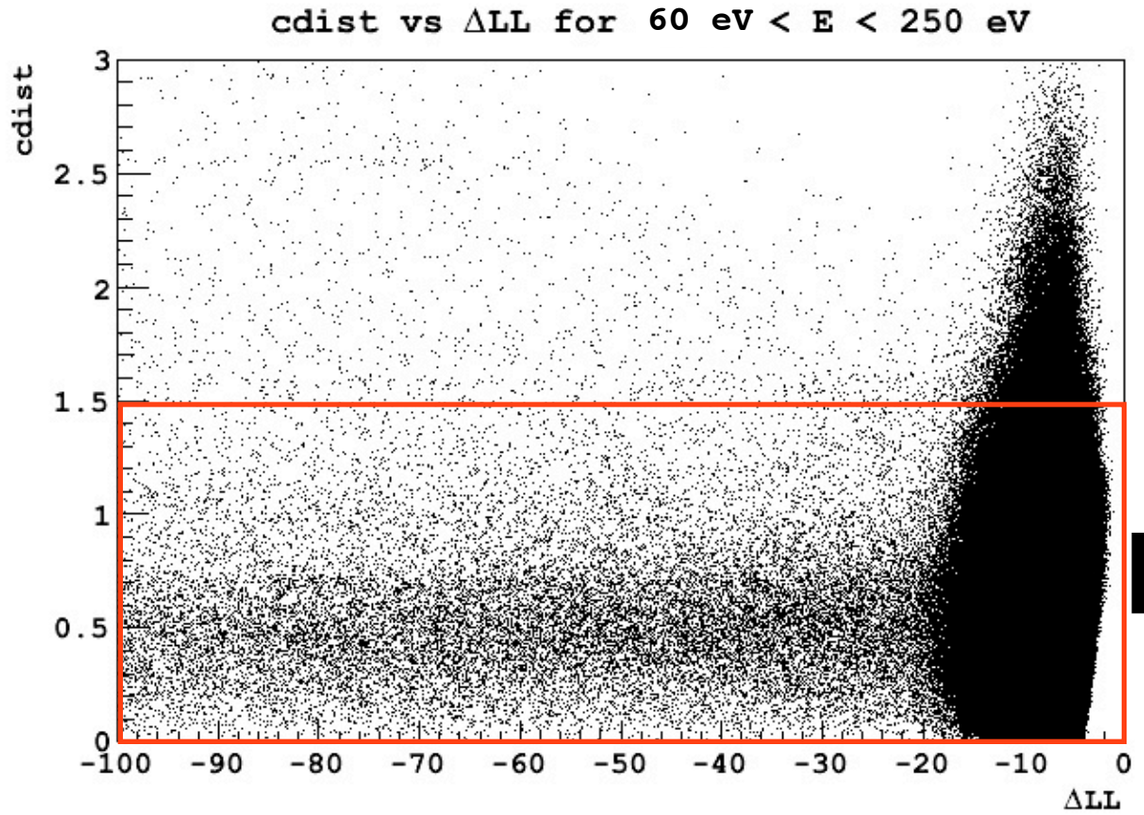
Best estimate for mean of energy deposition

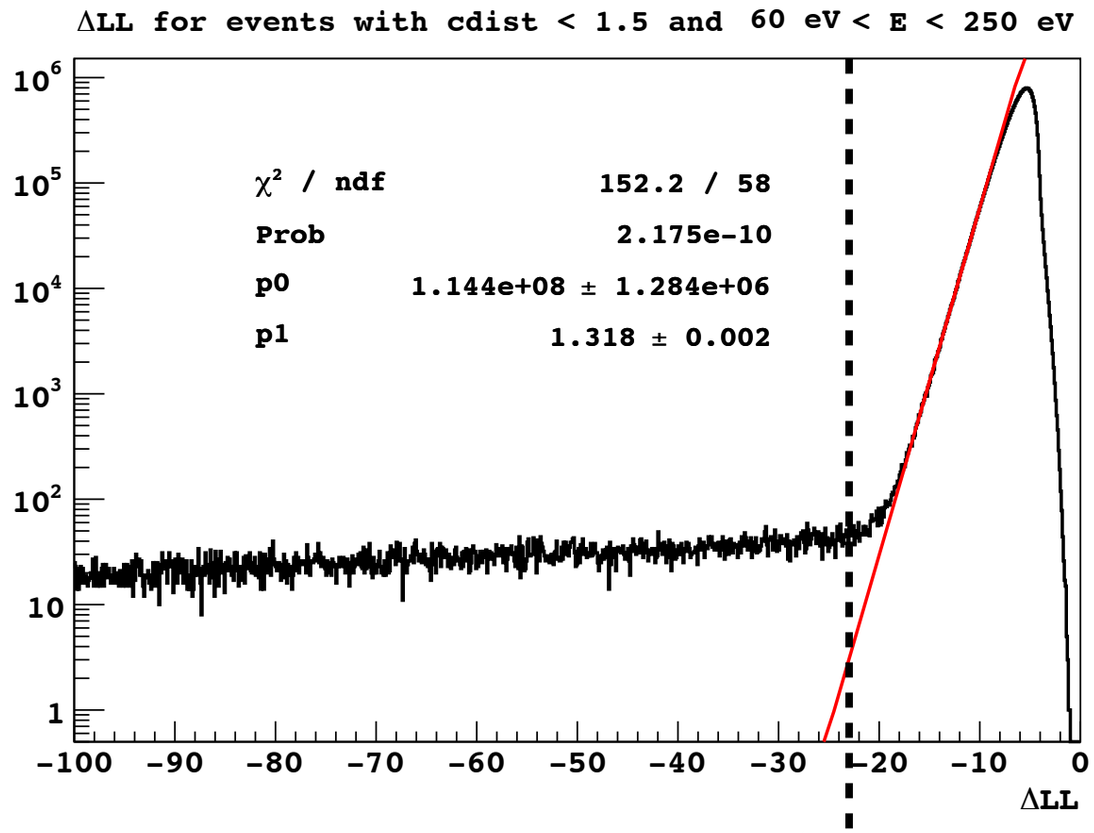
Lateral spread

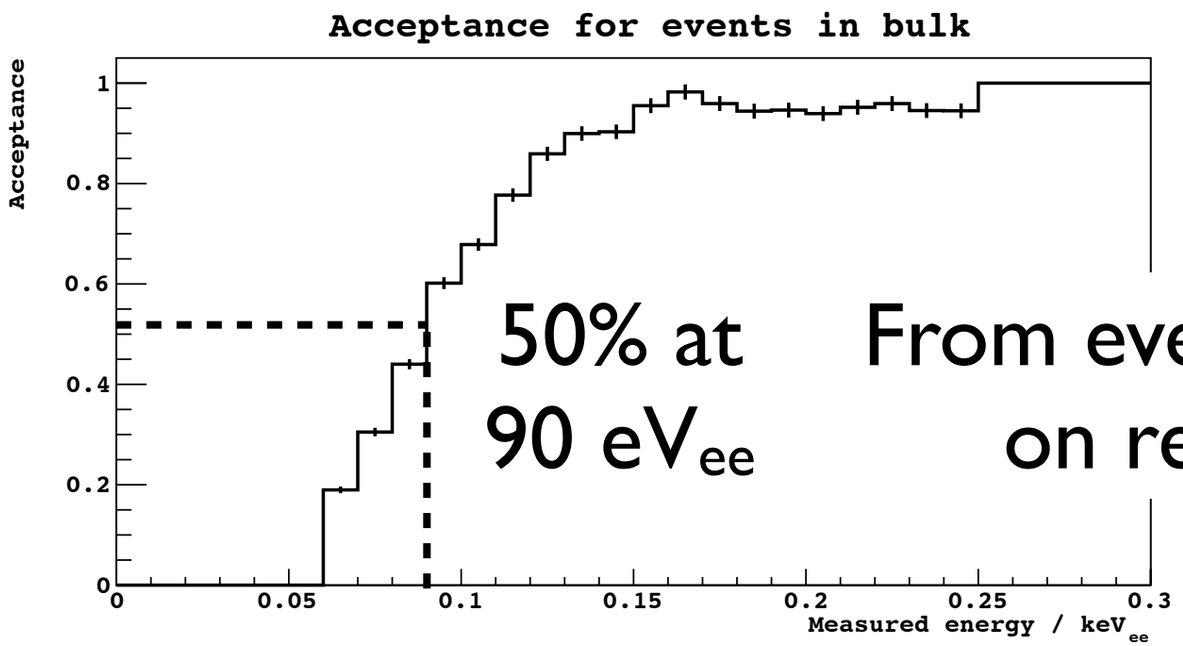


Use moving window and fit to a 2D Gaussian distribution. Register LL of best-fit. Compared to LL of constant pixel values. Difference between the two LL (ΔLL) allows us to select for physical events.

Selection cuts







50% at 90 eV_{ee}

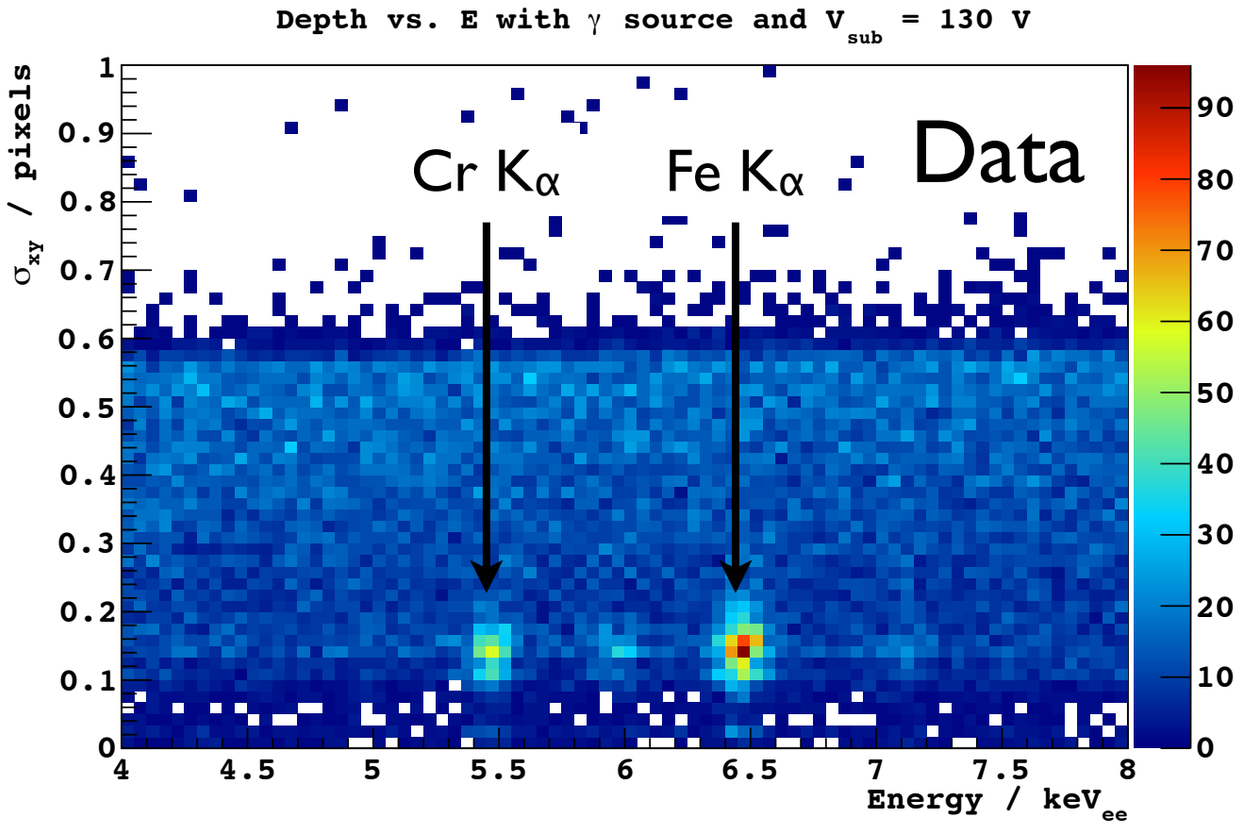
From events simulated on real images.

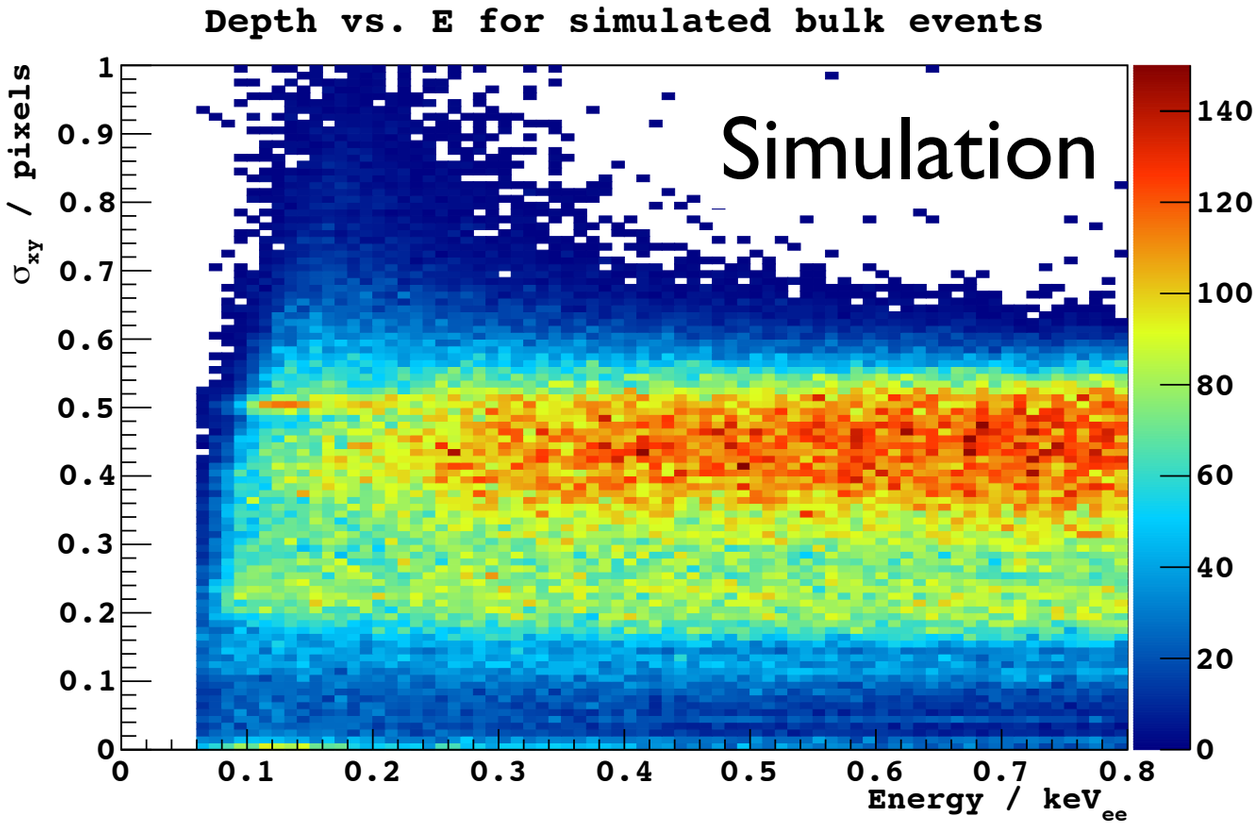
0.01 events per image from noise

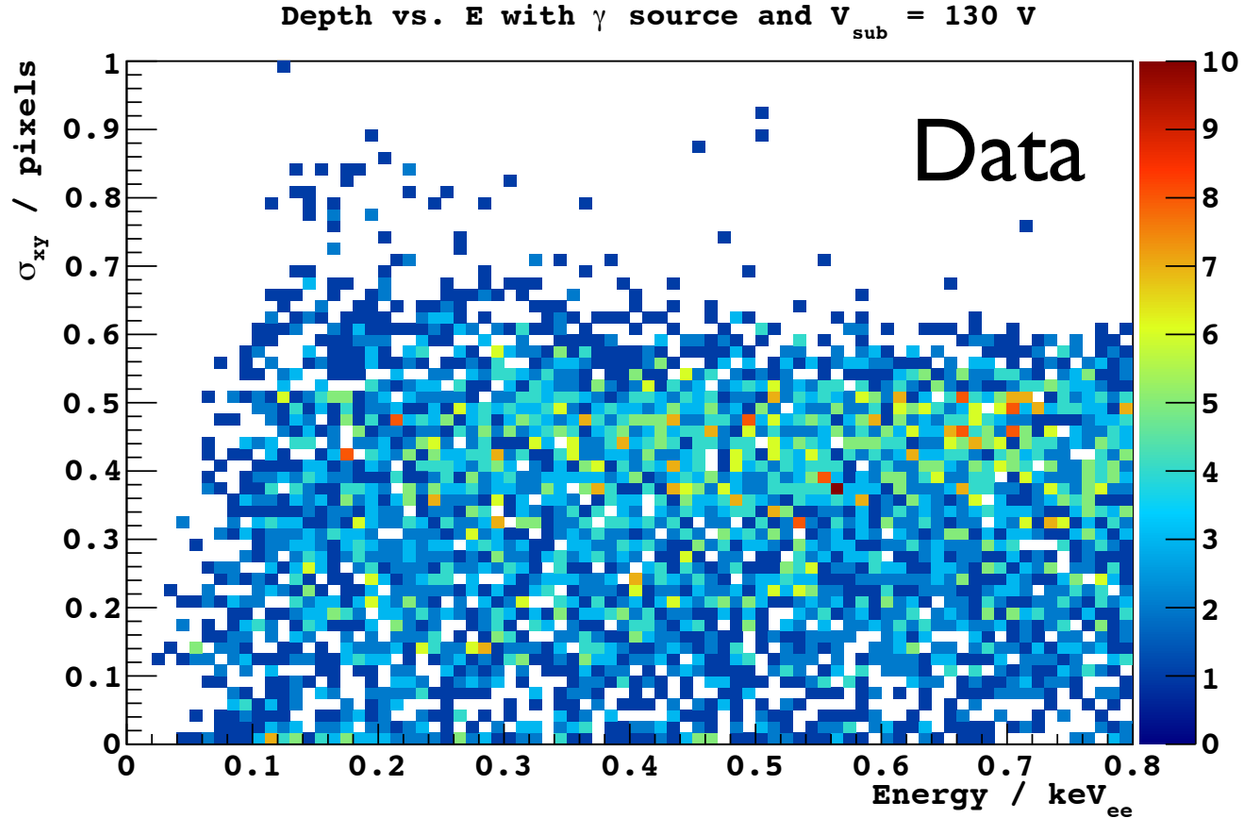
Simulation

Simulated events with diffusion model with parameters set to data.

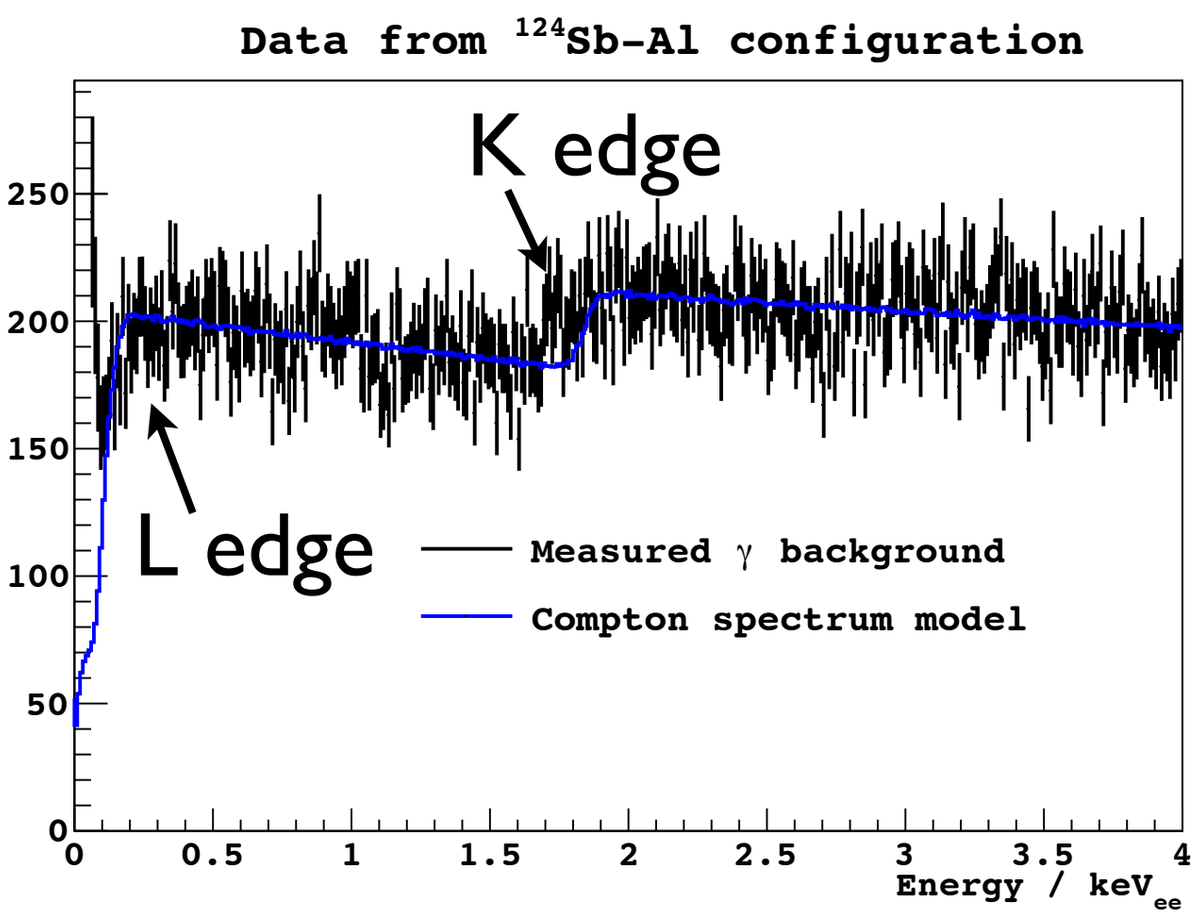
Events pasted on a subsample of 1000 acquired images.

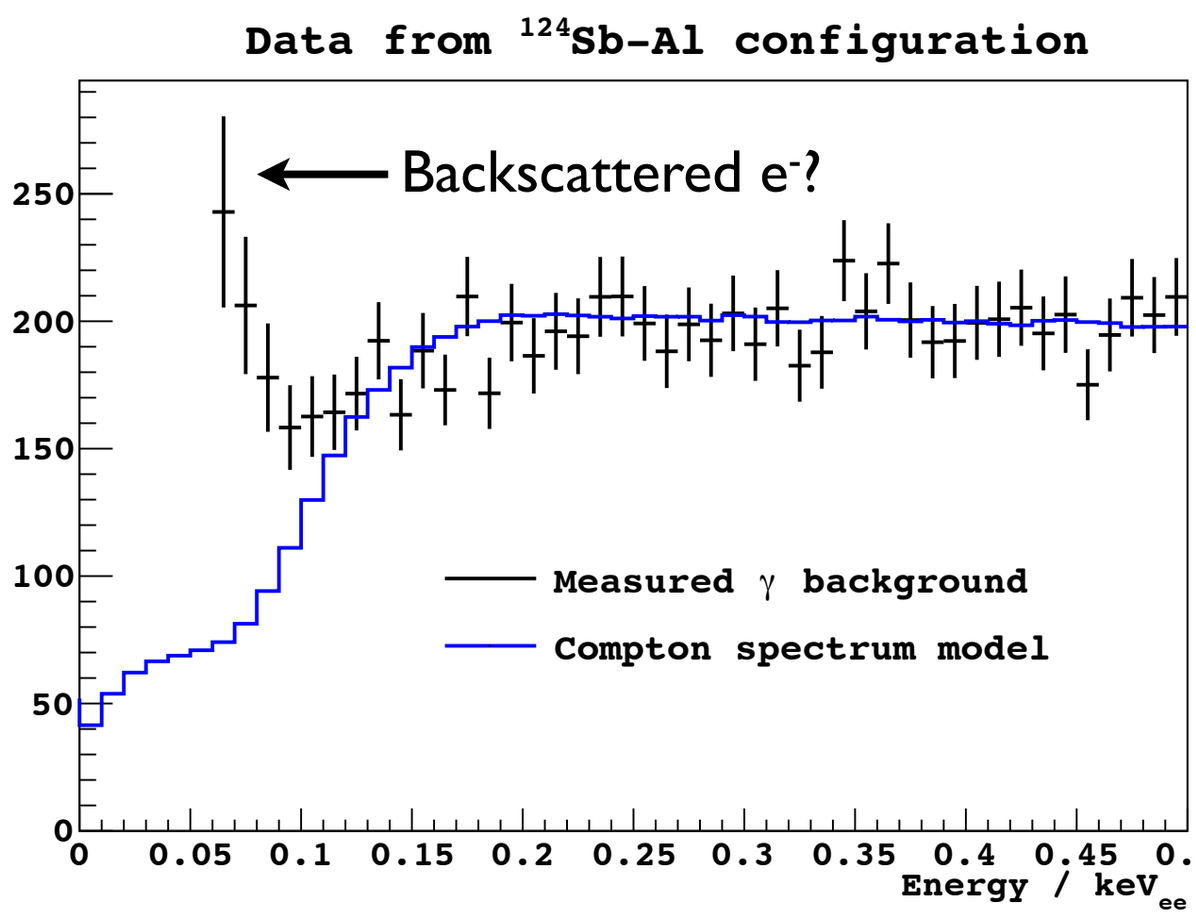






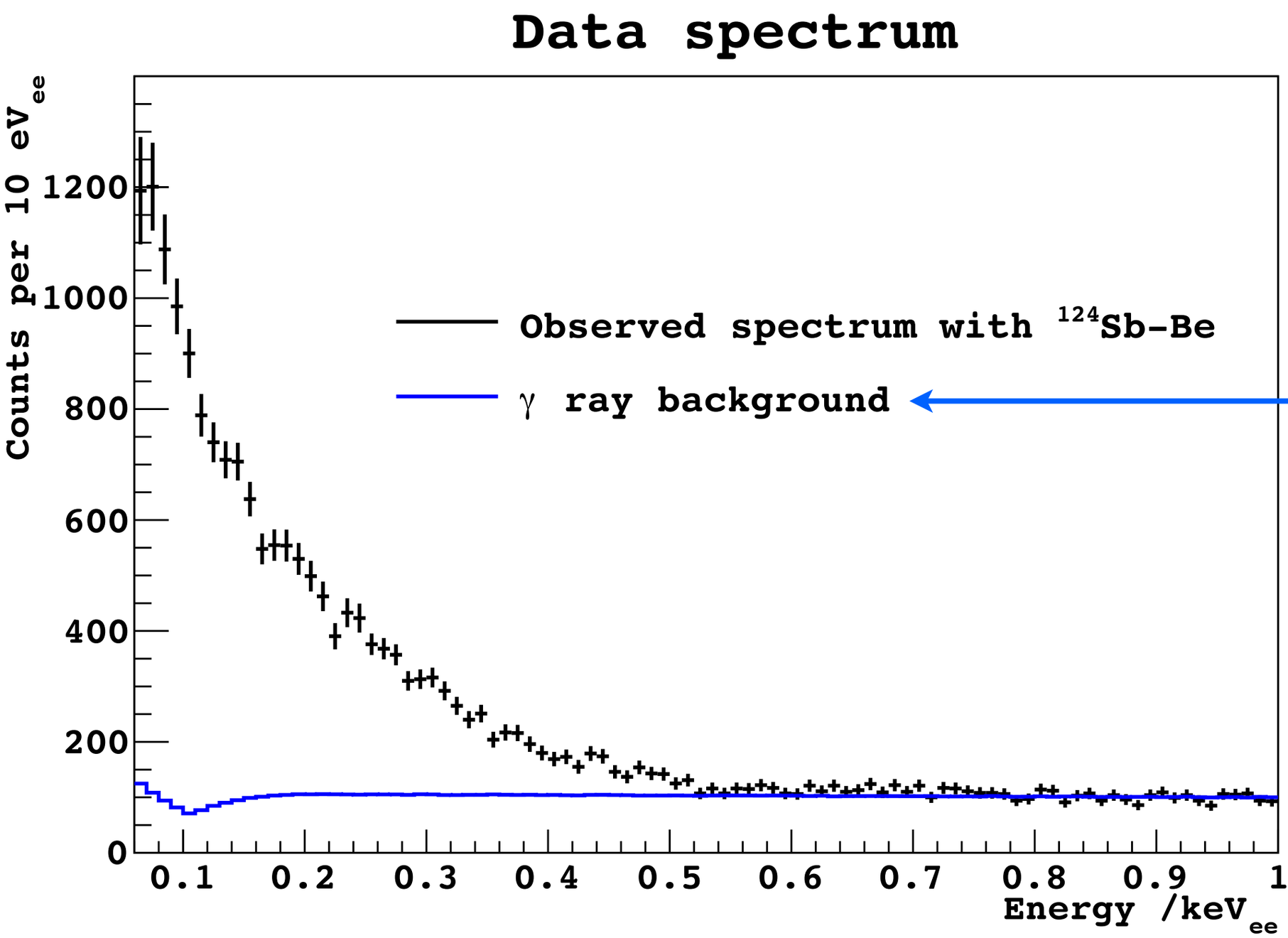
Background spectrum (neutrons off)





Increase at low energies correlated with source intensity.
Not CCD noise.

Observed spectrum

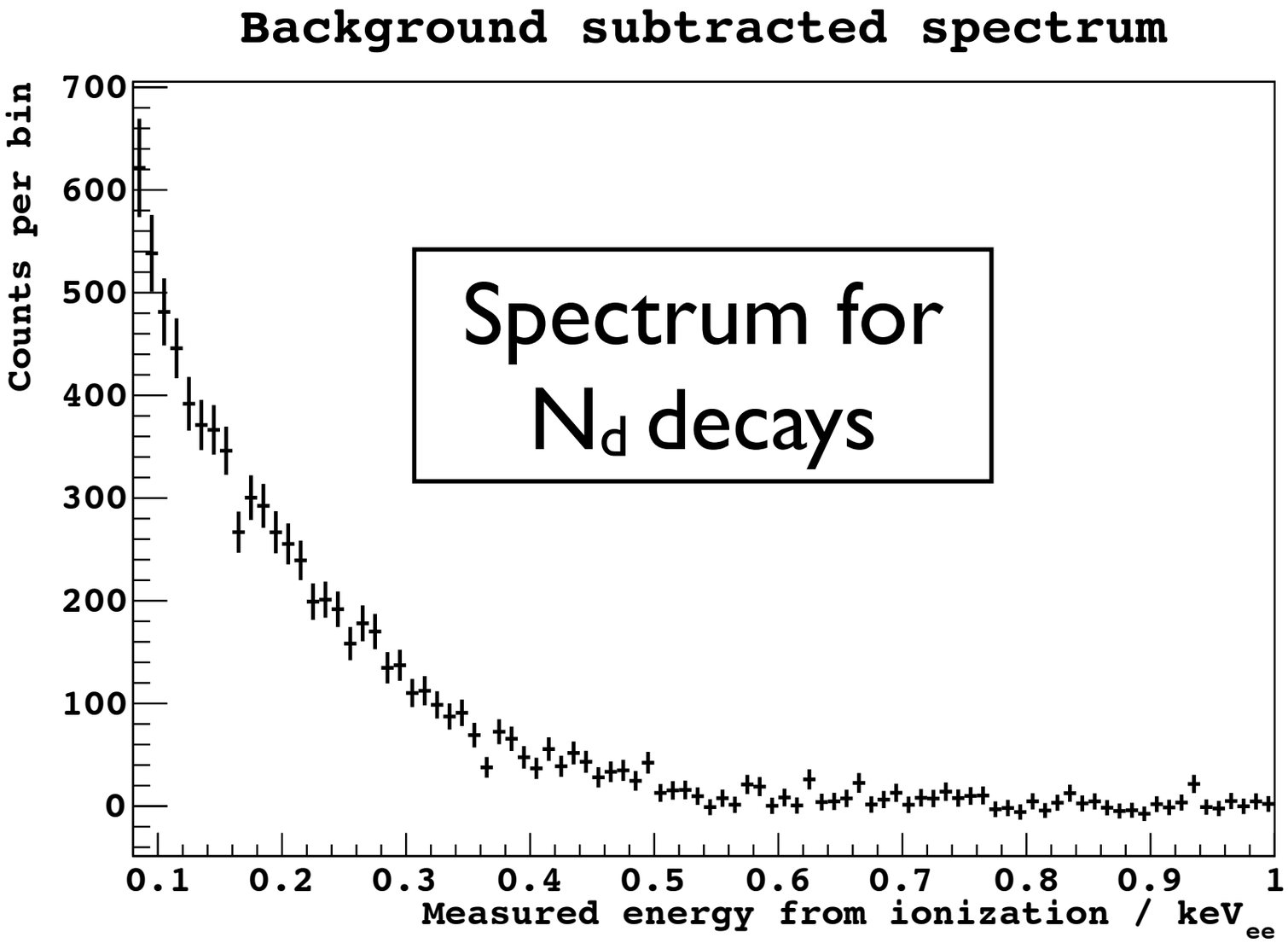


Normalized to count rate 2-5 keV_{ee}.

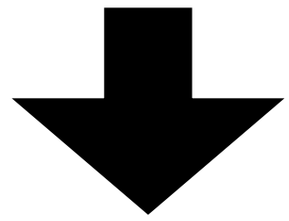
Uncertainty propagated in analysis.

Signal spectrum

For a particular run integrate number of ^{124}Sb decays during exposure.



CCDs is fully active and has very high spatial resolution



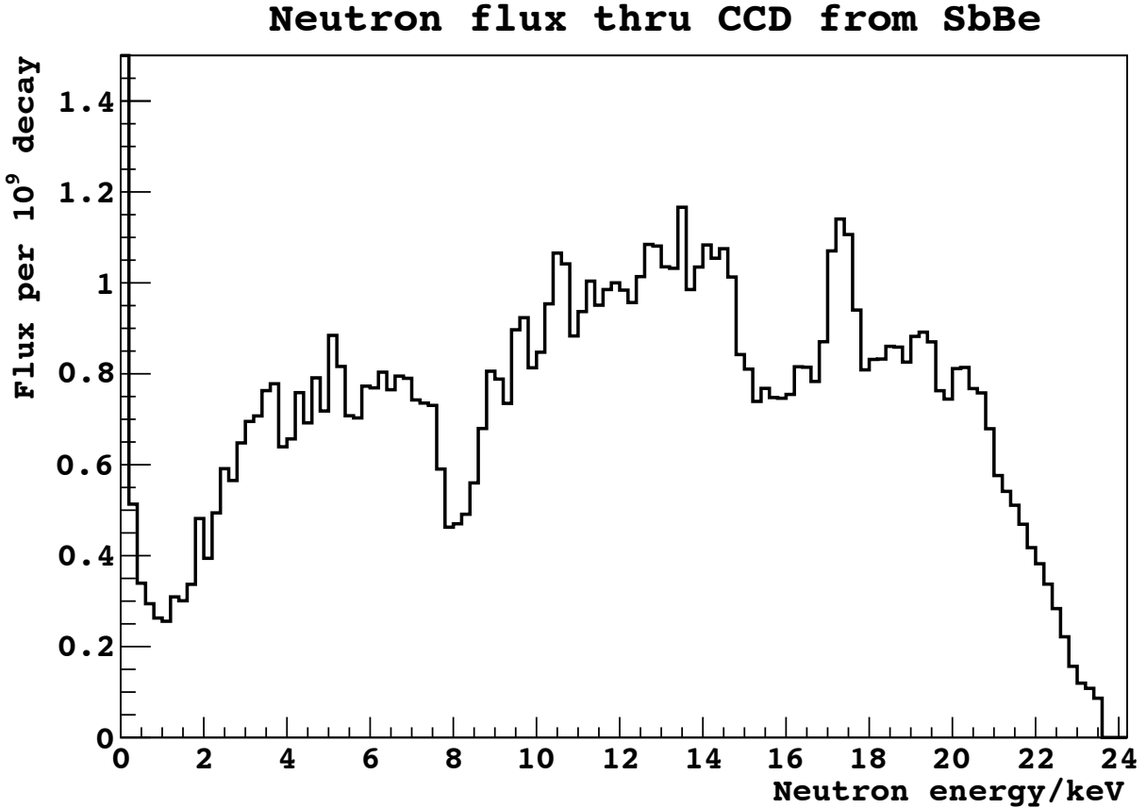
This is the *single recoil* spectrum

MCNP gives neutron flux

Full detector geometry modeled in MCNPX 5.

^{9}Be(γ,n) using latest value from Arnold et al[1].

Pb elastic scattering cross-sections from A. Robinson[2].



Spectrum moderated.

Resonances of nearby materials (mostly Cu) evident.

[1]PRC85 044605
[2]PRC89 032801

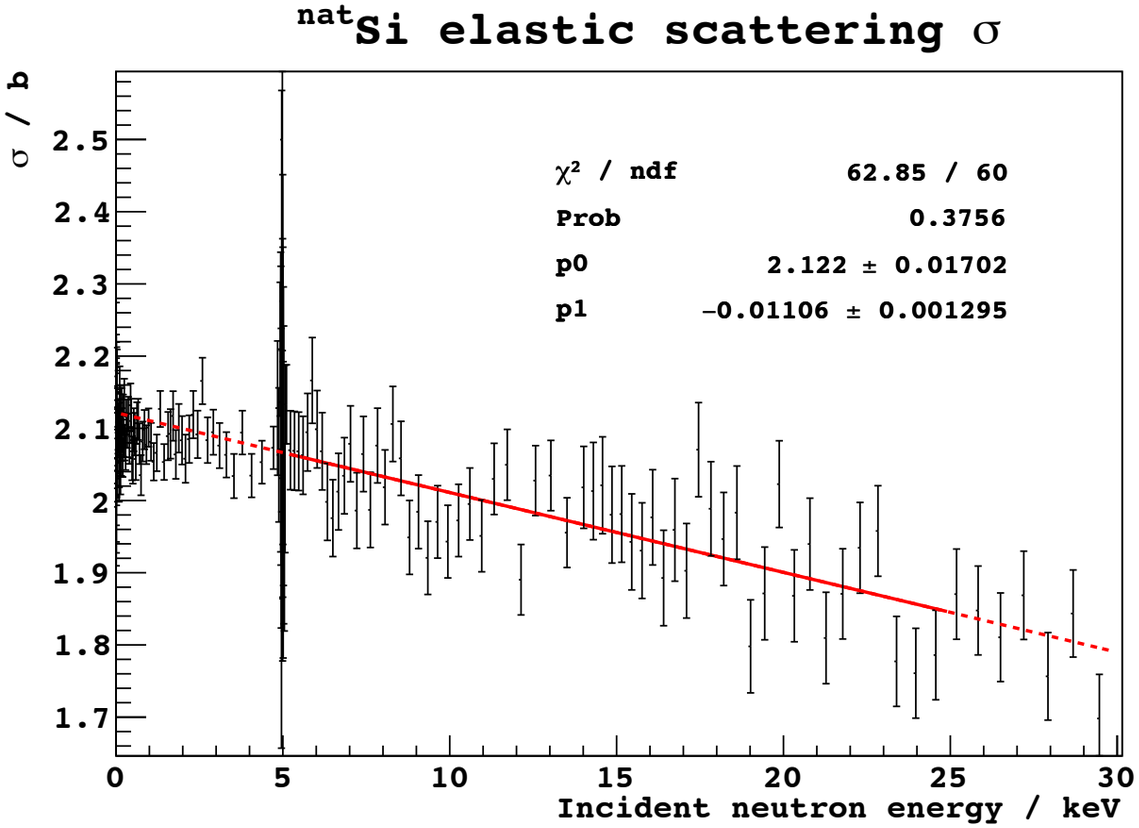
Recoil spectrum from flux

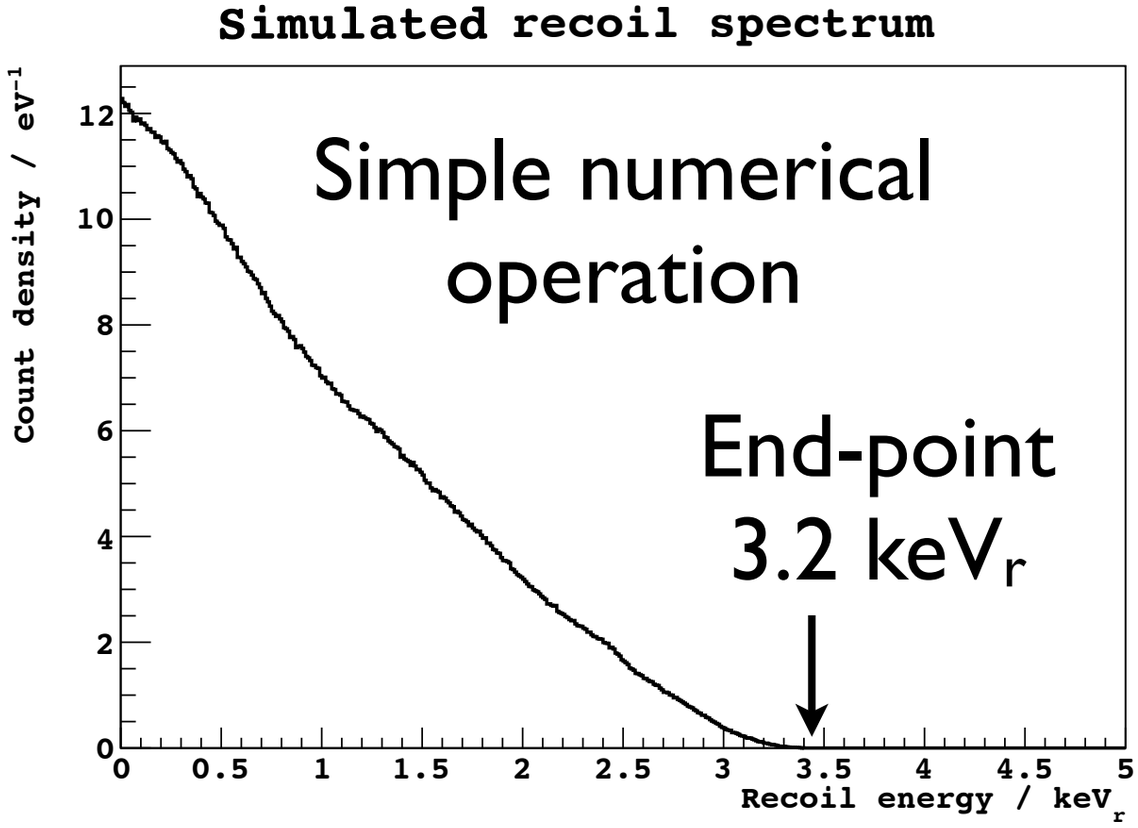
ENDF-VI

9.1 ELASTIC ANGULAR DISTRIBUTIONS

There is a large amount of neutron elastic scattering data from 40 keV to 15 MeV. Below 40 keV, the angular distribution is assumed to be isotropic, which was observed by Lane et al. (LA61, LA62).

Larson data (±3% systematic)

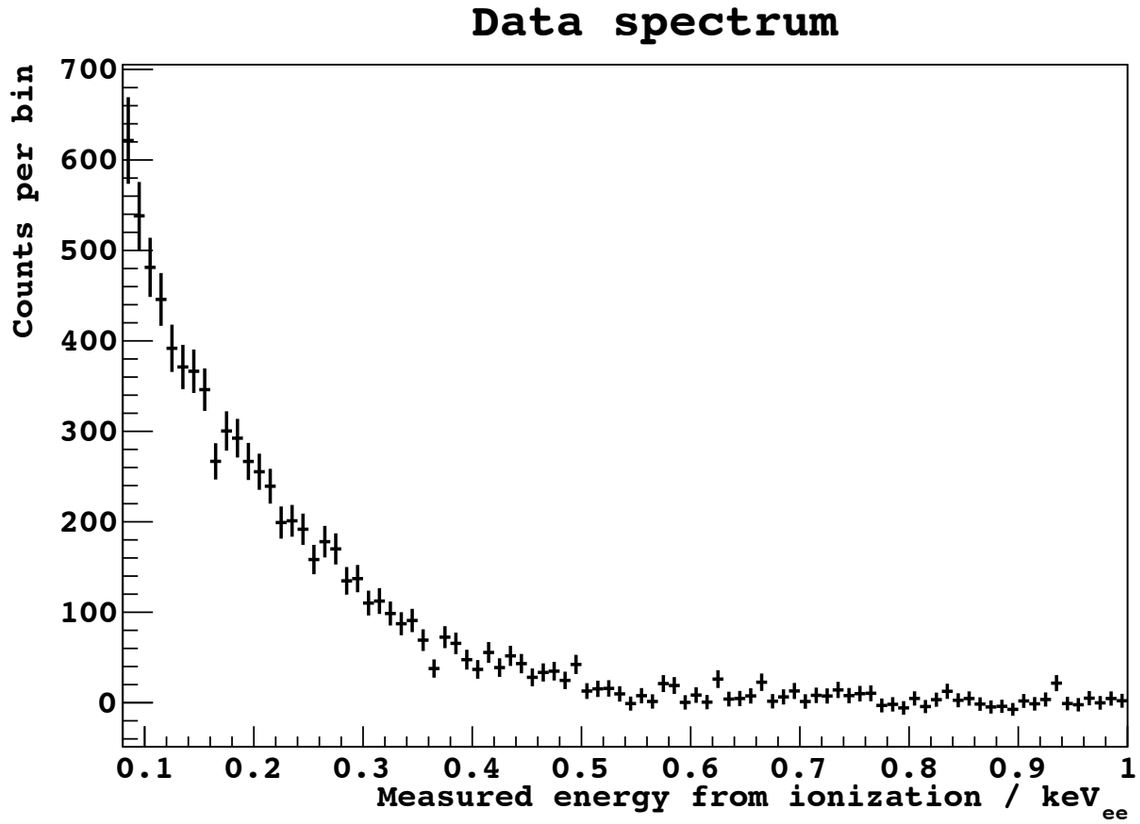


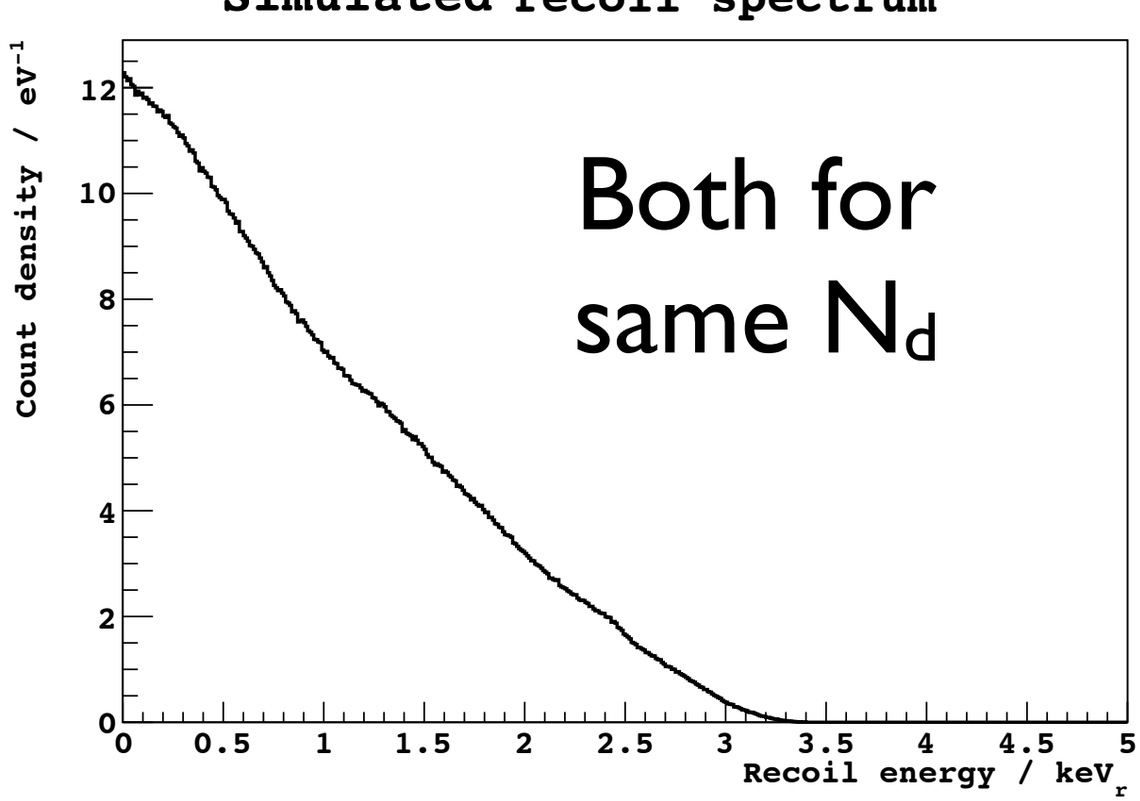


Principle

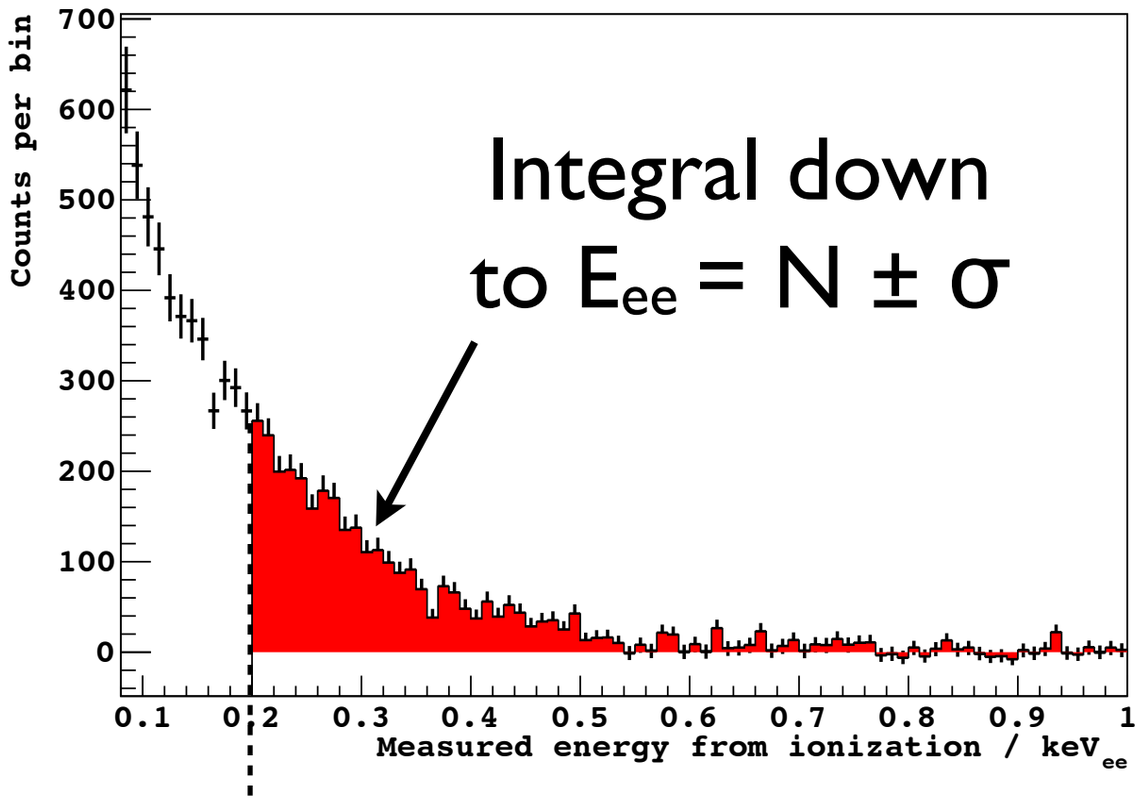
Given an expected recoil spectrum for our setup, we need to find mapping from E_{ee} to E_r that best matches our measured spectrum.

Expected spectrum is obtained from Monte Carlo.

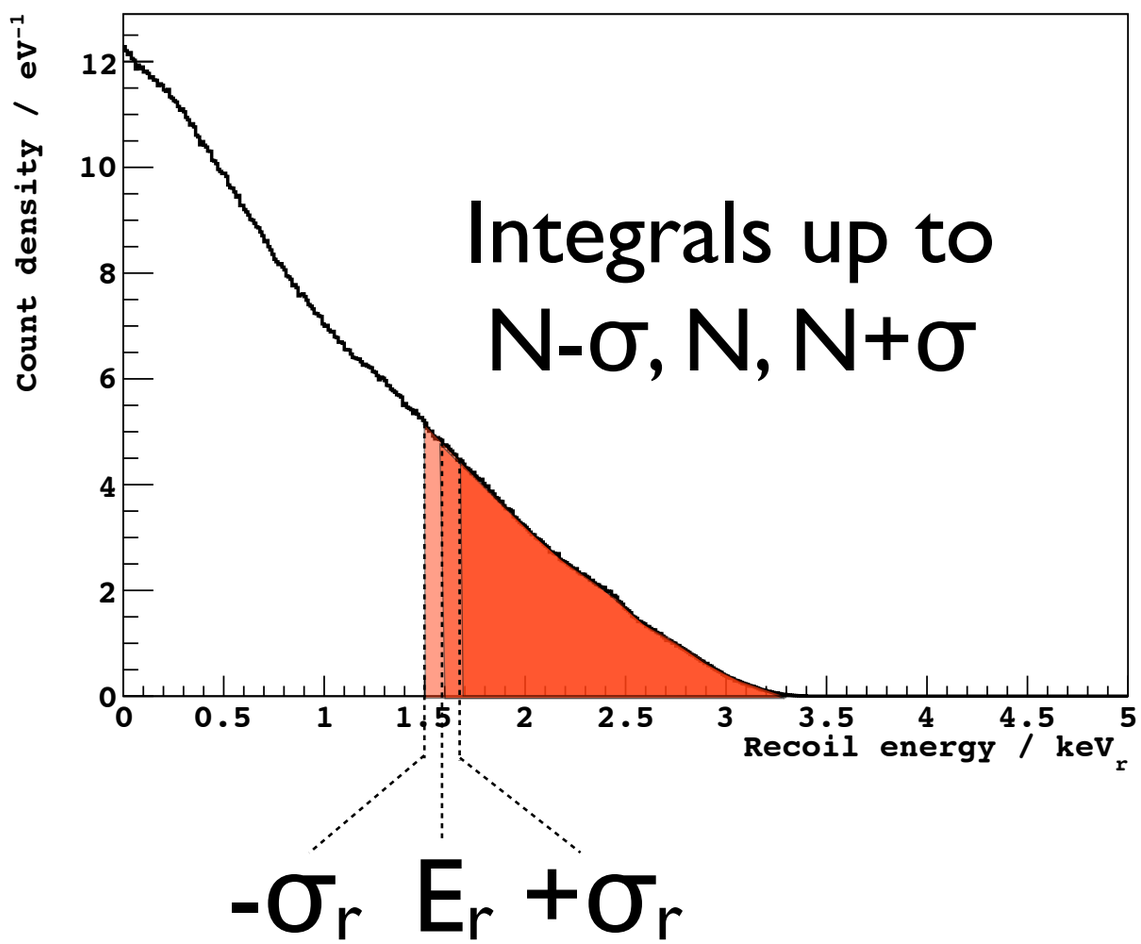




Integral solution

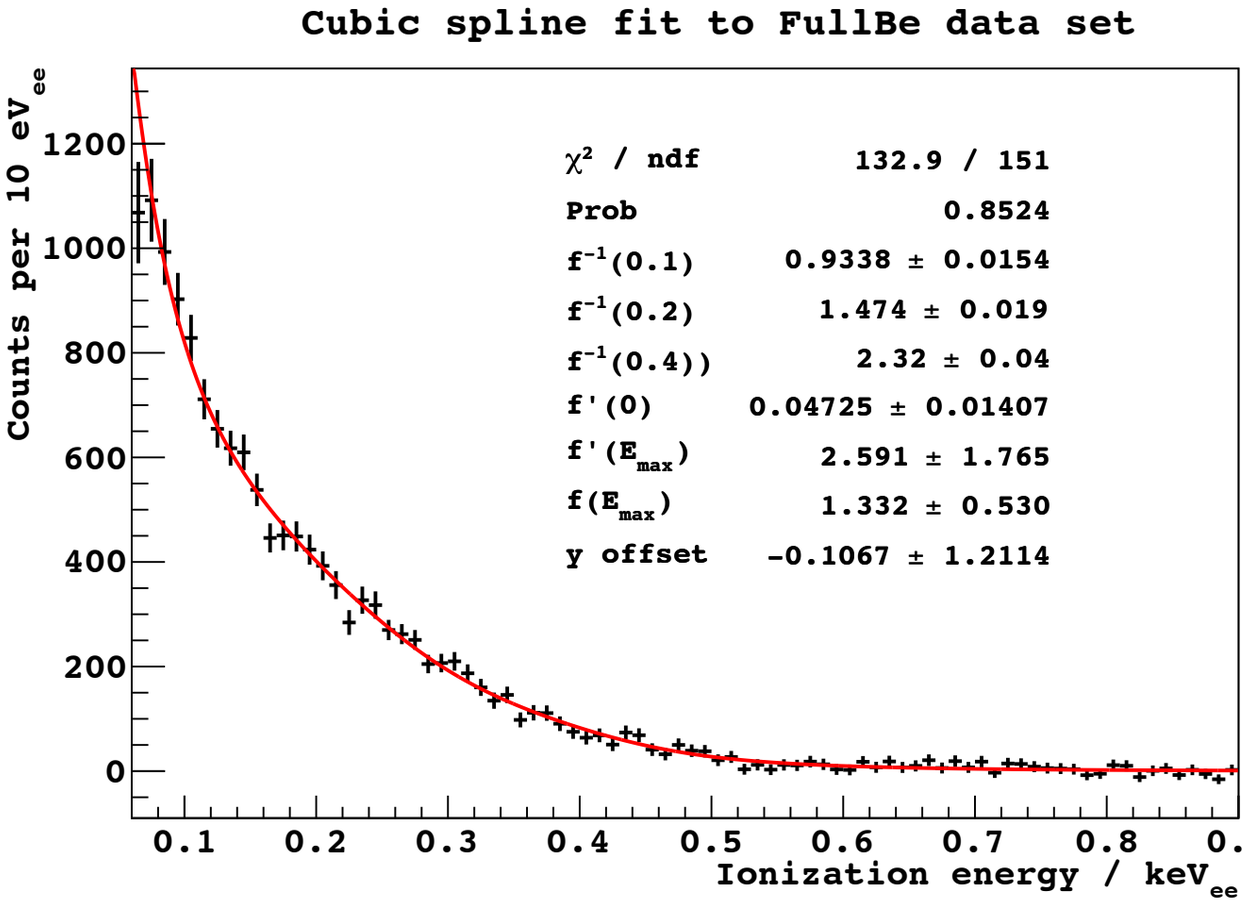


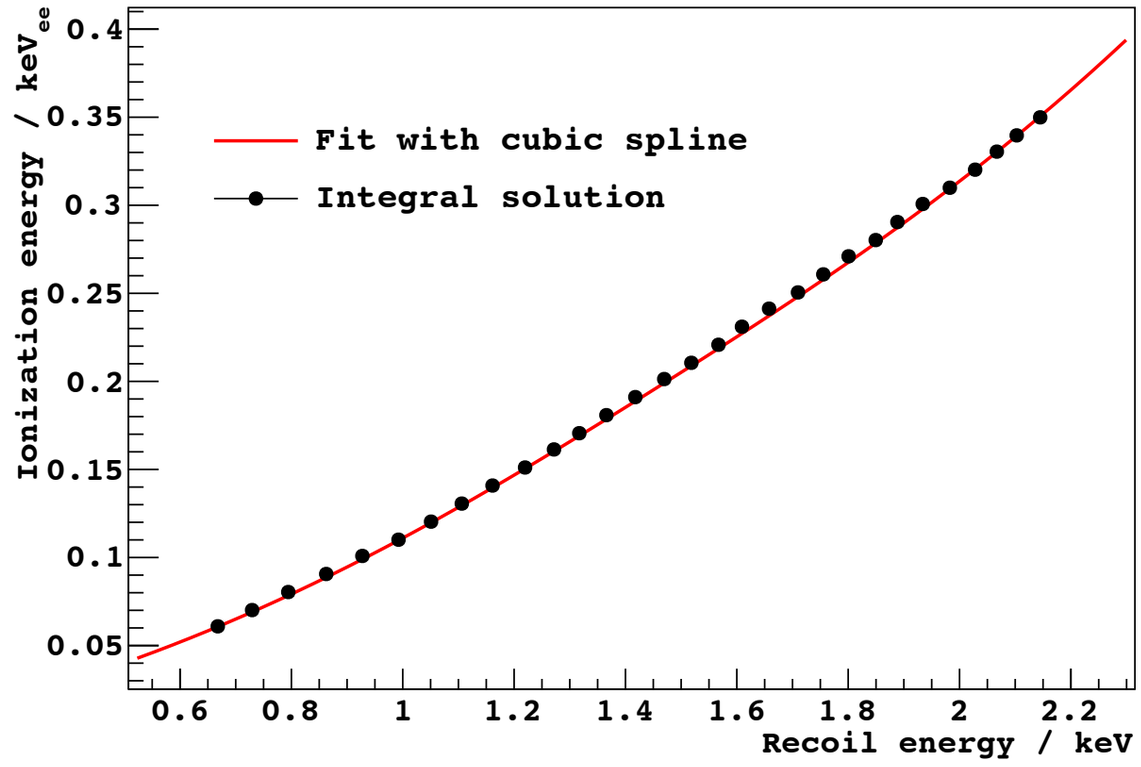
σ obtained by adding bin uncertainties in quadrature.



$\pm\sigma_r$ generally asymmetric.

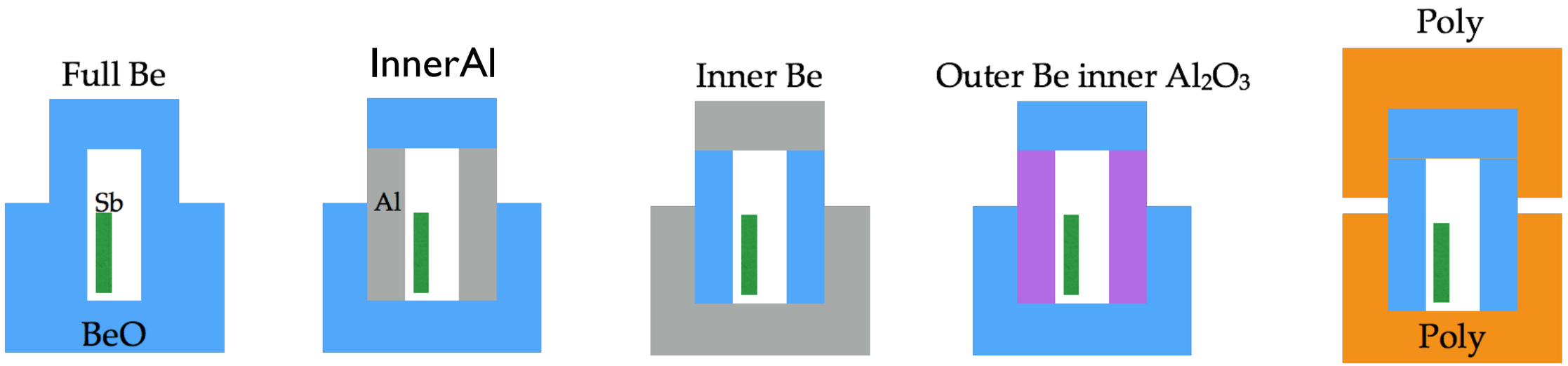
Cross-check



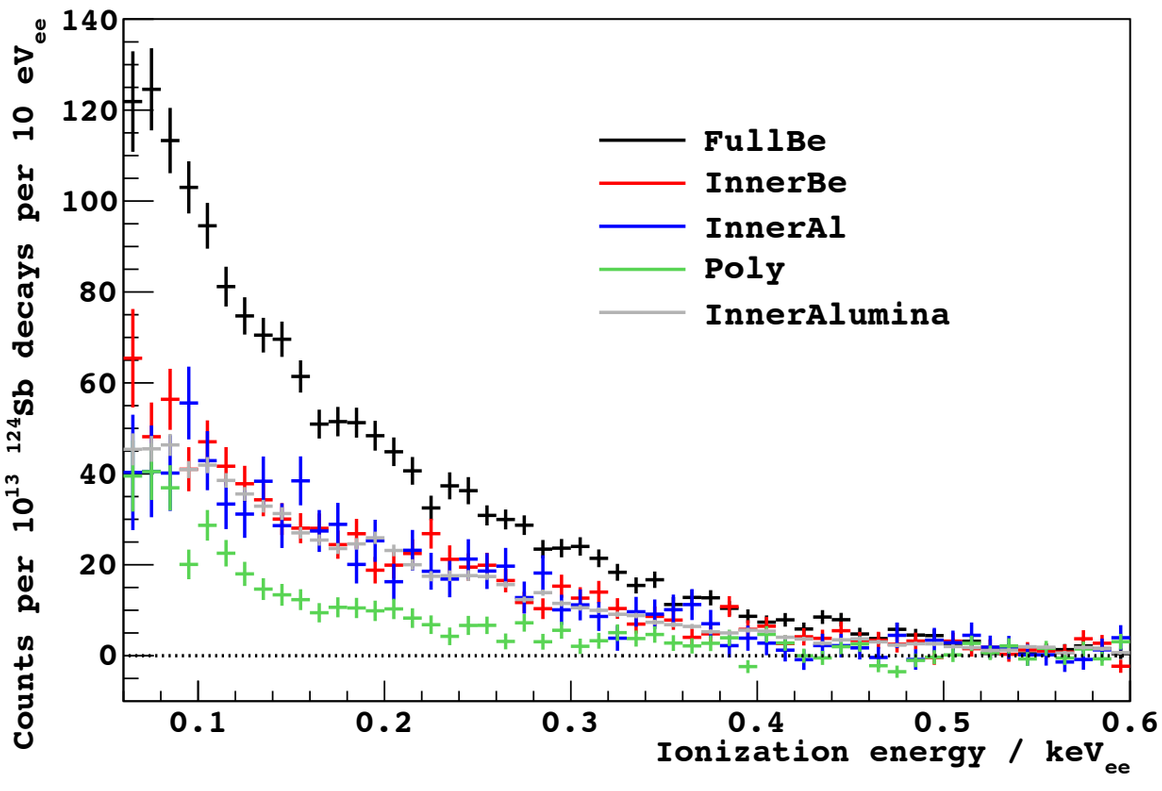


For every data set we also do a cubic spline spectral fit.
Fit result used to correct for detector resolution.
Fitting and integral solution give same result when they should.

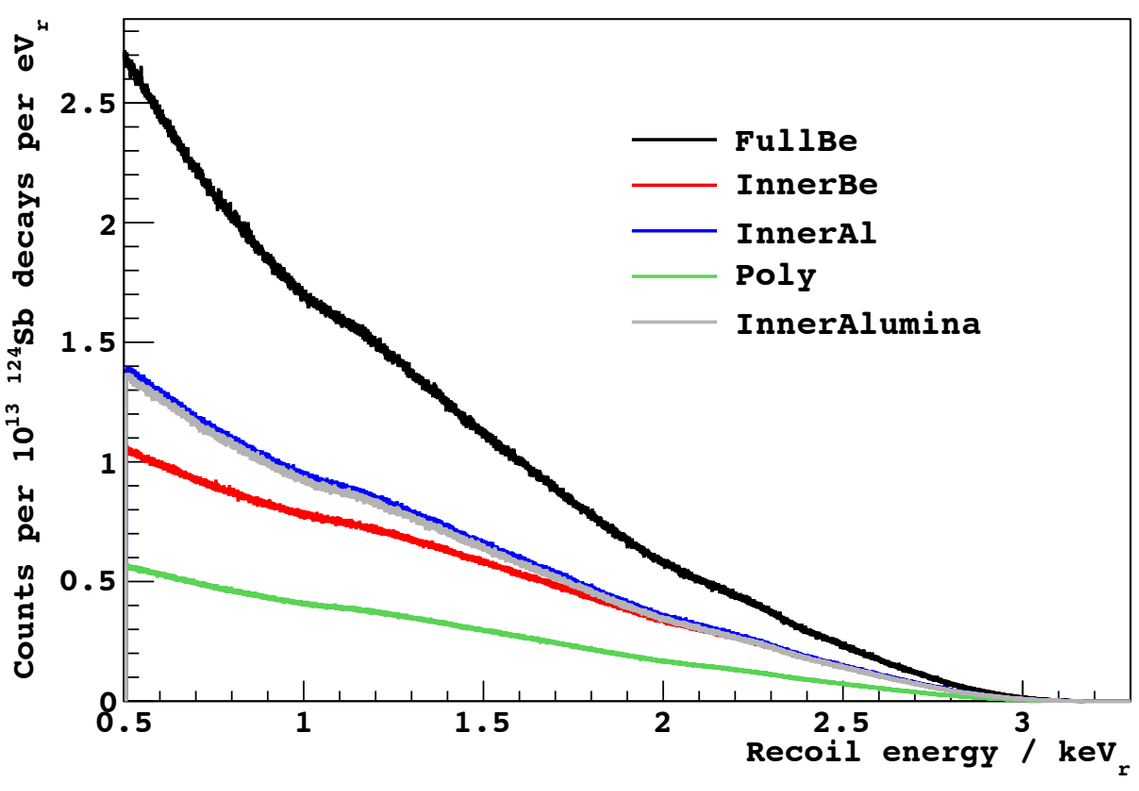
Source configuration



CCD data spectra

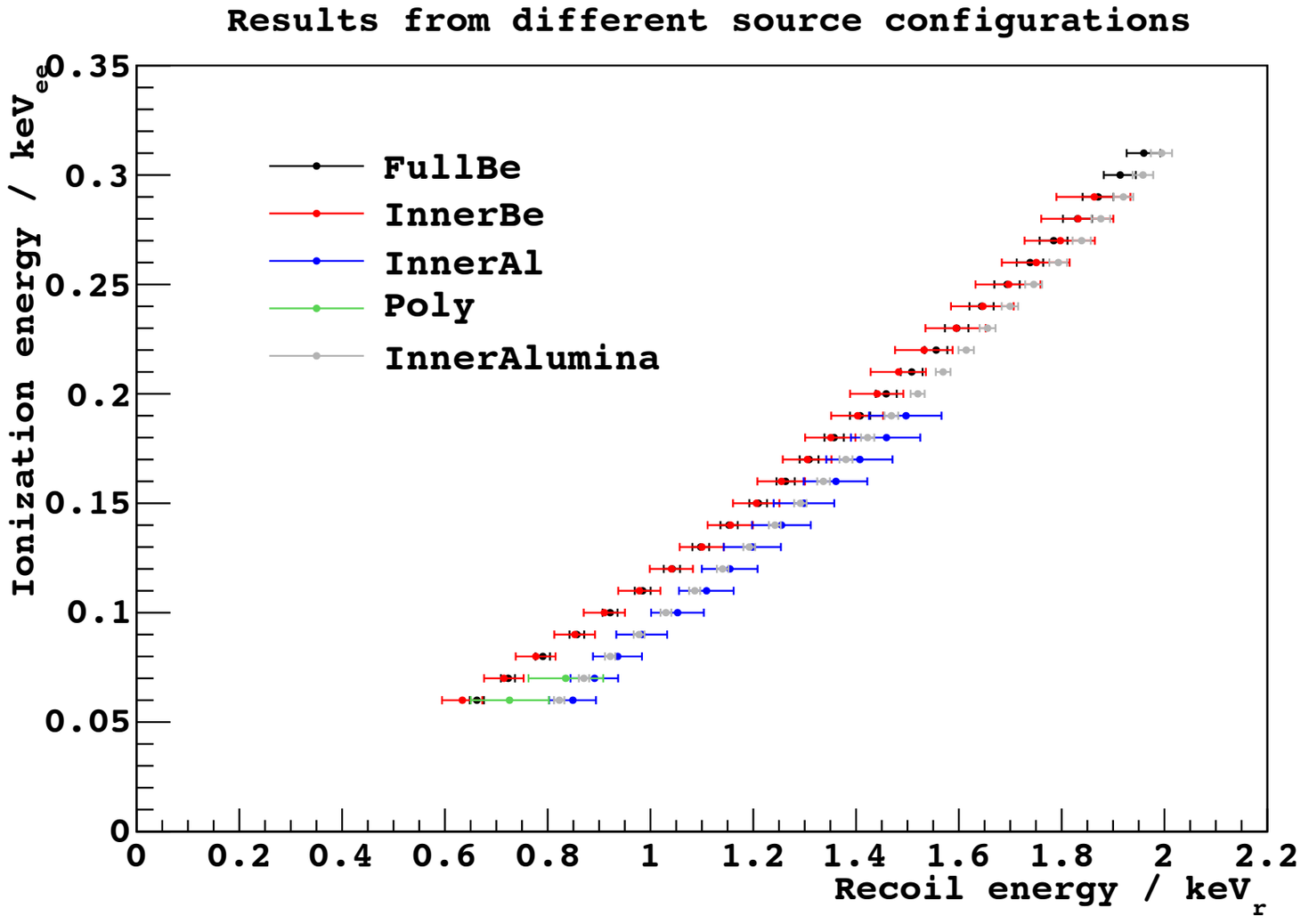


MCNP simulated spectra



Source configuration

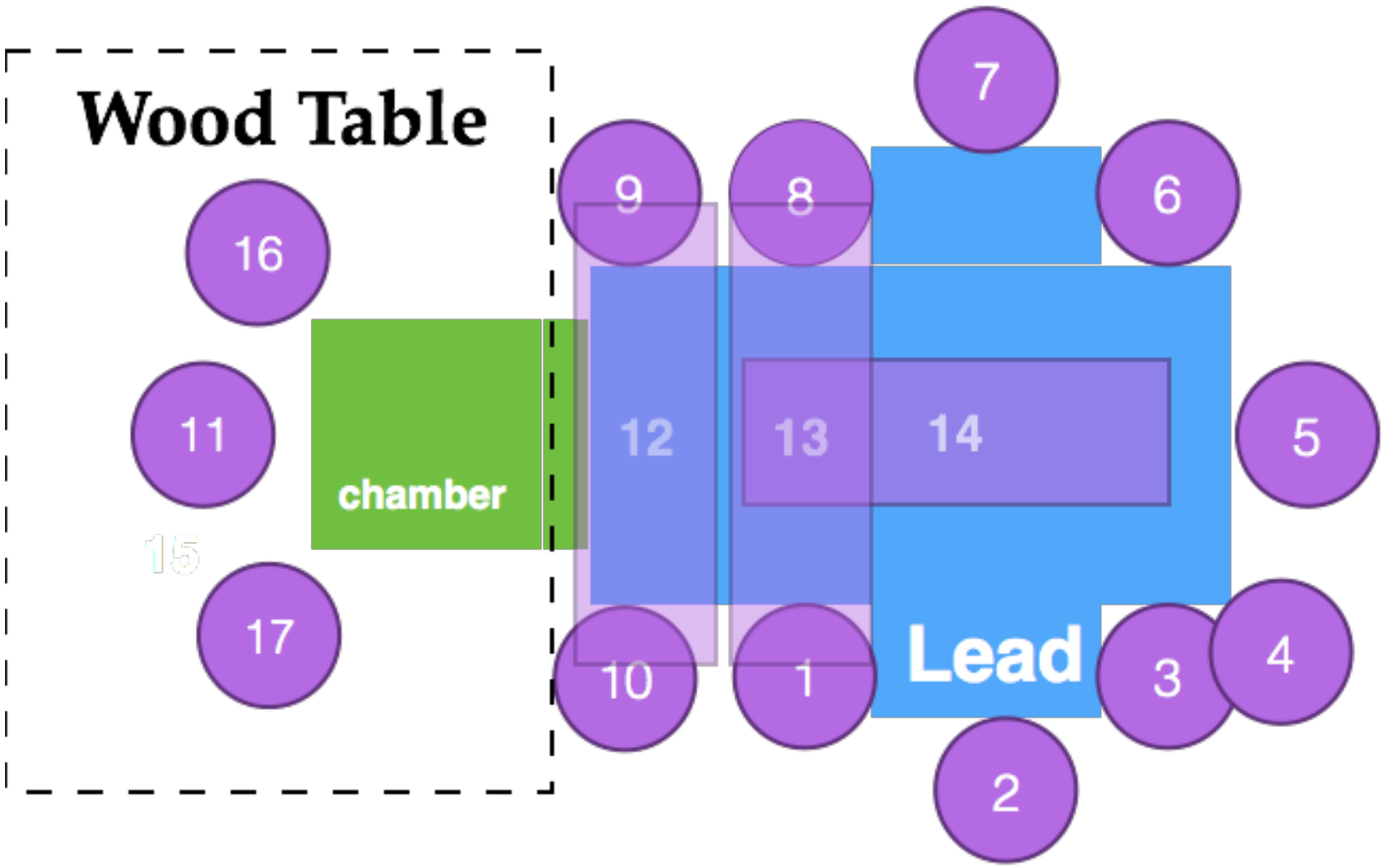
Use to study systematic on MCNP source modeling.
Test neutron propagation with modified neutron spectrum.



Tension between FullBe/InnerBe and InnerAl/InnerAlumina.

For today take difference as systematic.

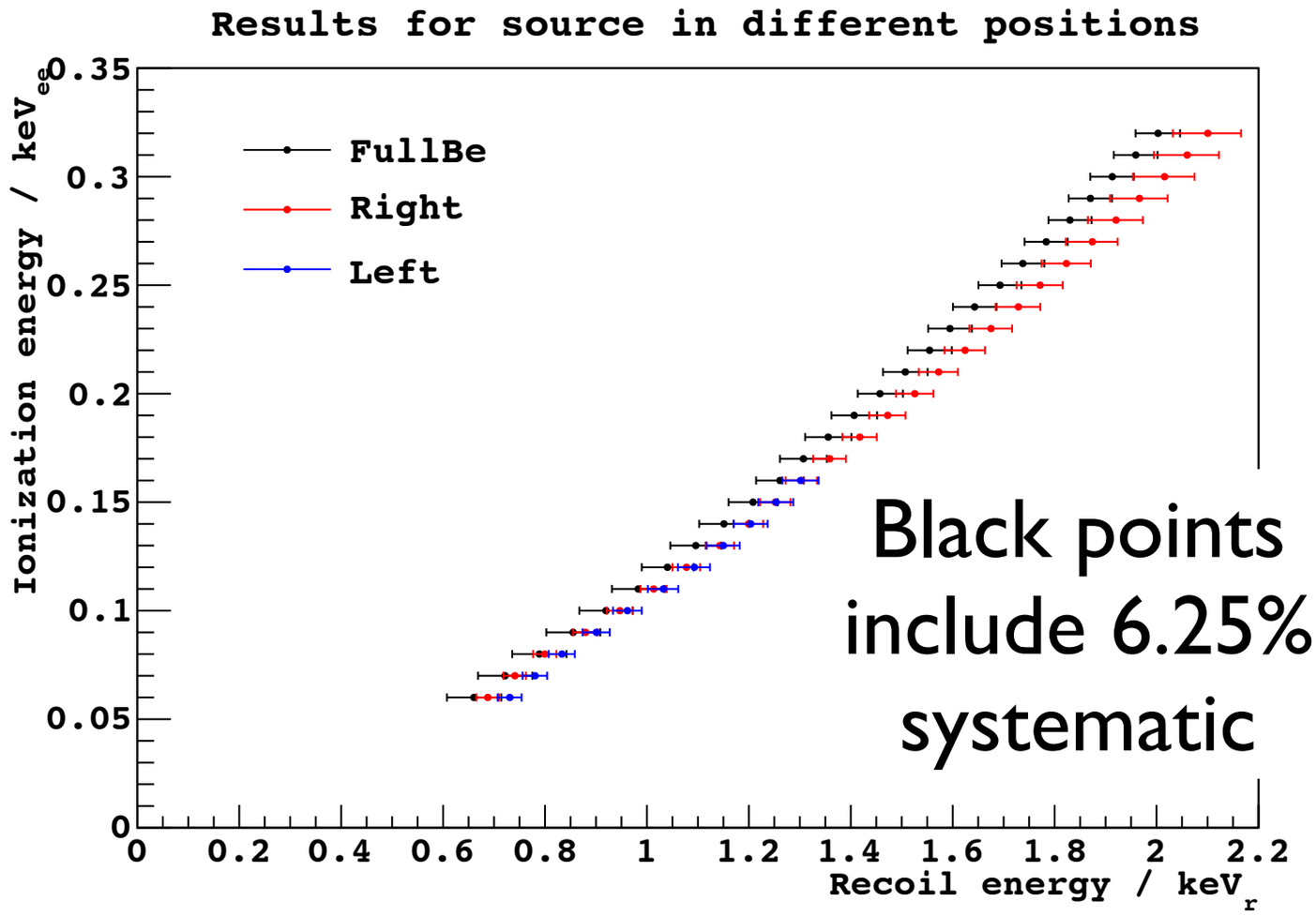
^{3}He counter test



Cadmium layer around ^{3}He counter to stop thermals.
Thickness of poly chosen as to be most sensitive to
15 - 25 keV neutrons.

^{3}He counter test

Position	Measured rate / s^{-1}	Predicted rate / s^{-1}
8	14.81	14.90 ± 0.83
9	4.00	4.09 ± 0.23
10	4.01	4.11 ± 0.23
11	0.45	0.46 ± 0.03
12	3.95	4.14 ± 0.23
16	0.70	0.63 ± 0.04
17	0.65	0.58 ± 0.03



Black points include 6.25% systematic

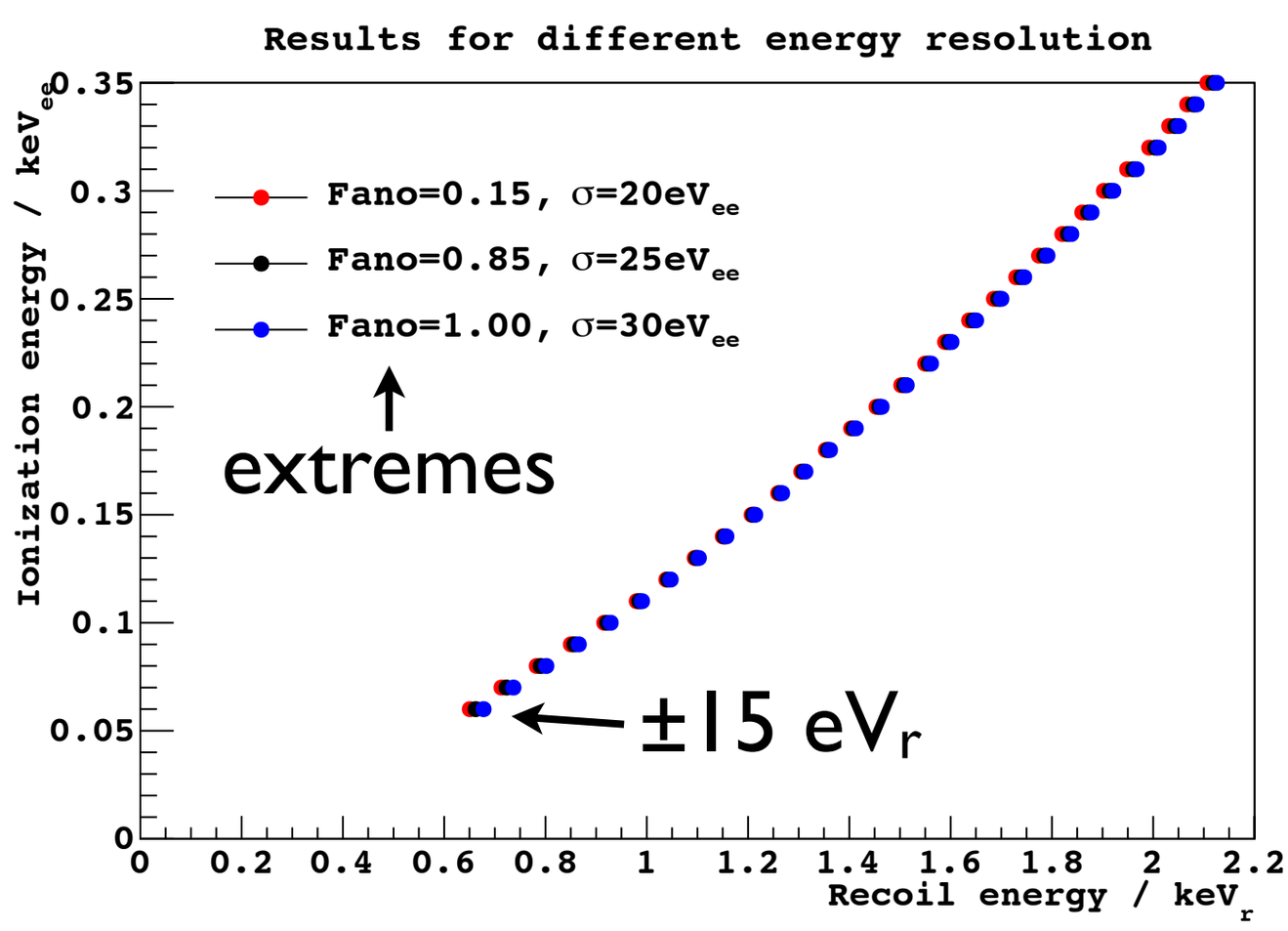
Result from moving the neutron source ±3.4 cm consistent with ^{3}He.

6.25% RMS ratio between measurement and simulation. Take as systematic.

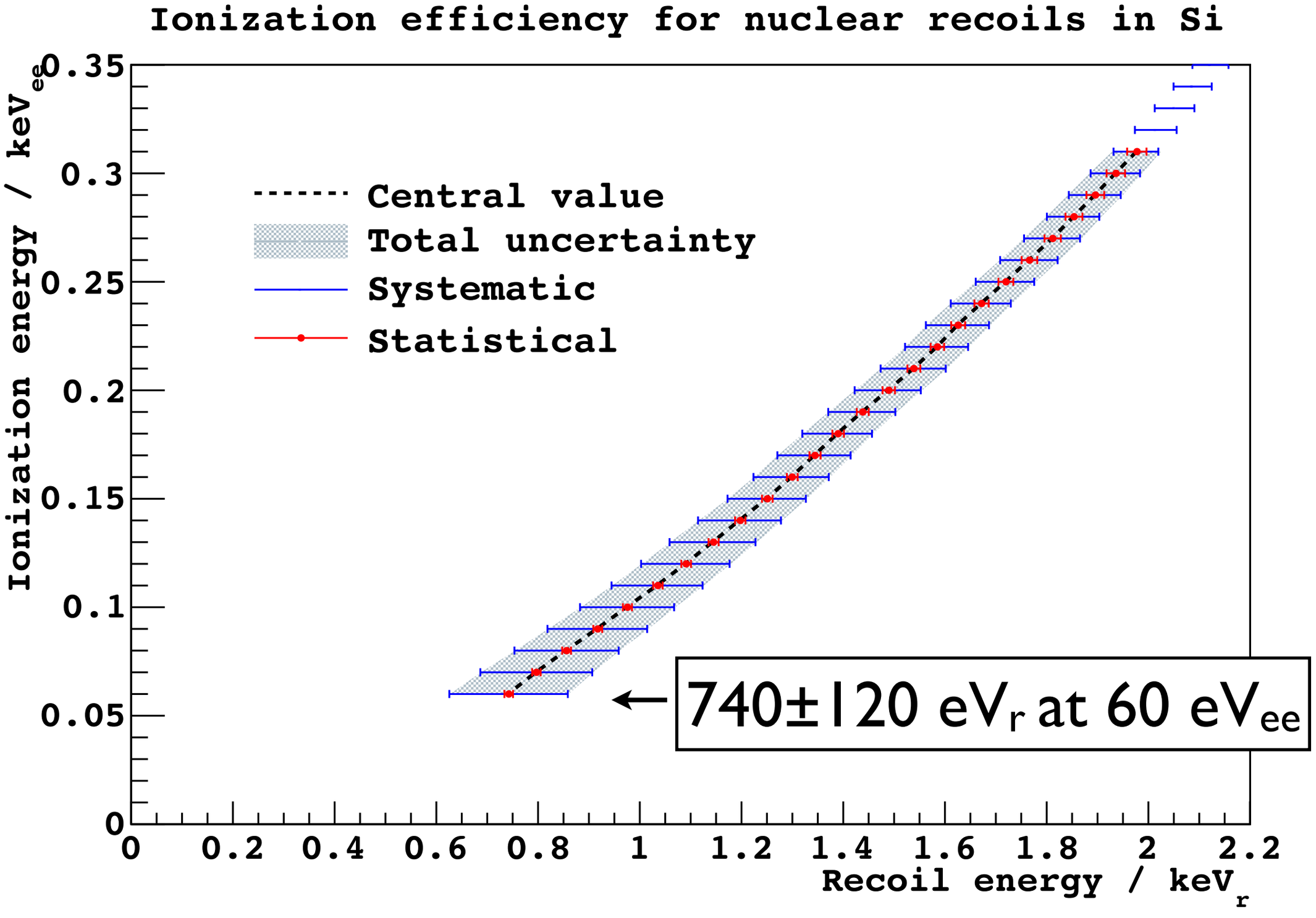
Systematics summary

- Difference between FullBe and Alumina setup.
- 5.6% from source intensity.
- 6.3% in amplitude from geometry.
- 3% total rate from elastic scattering σ.

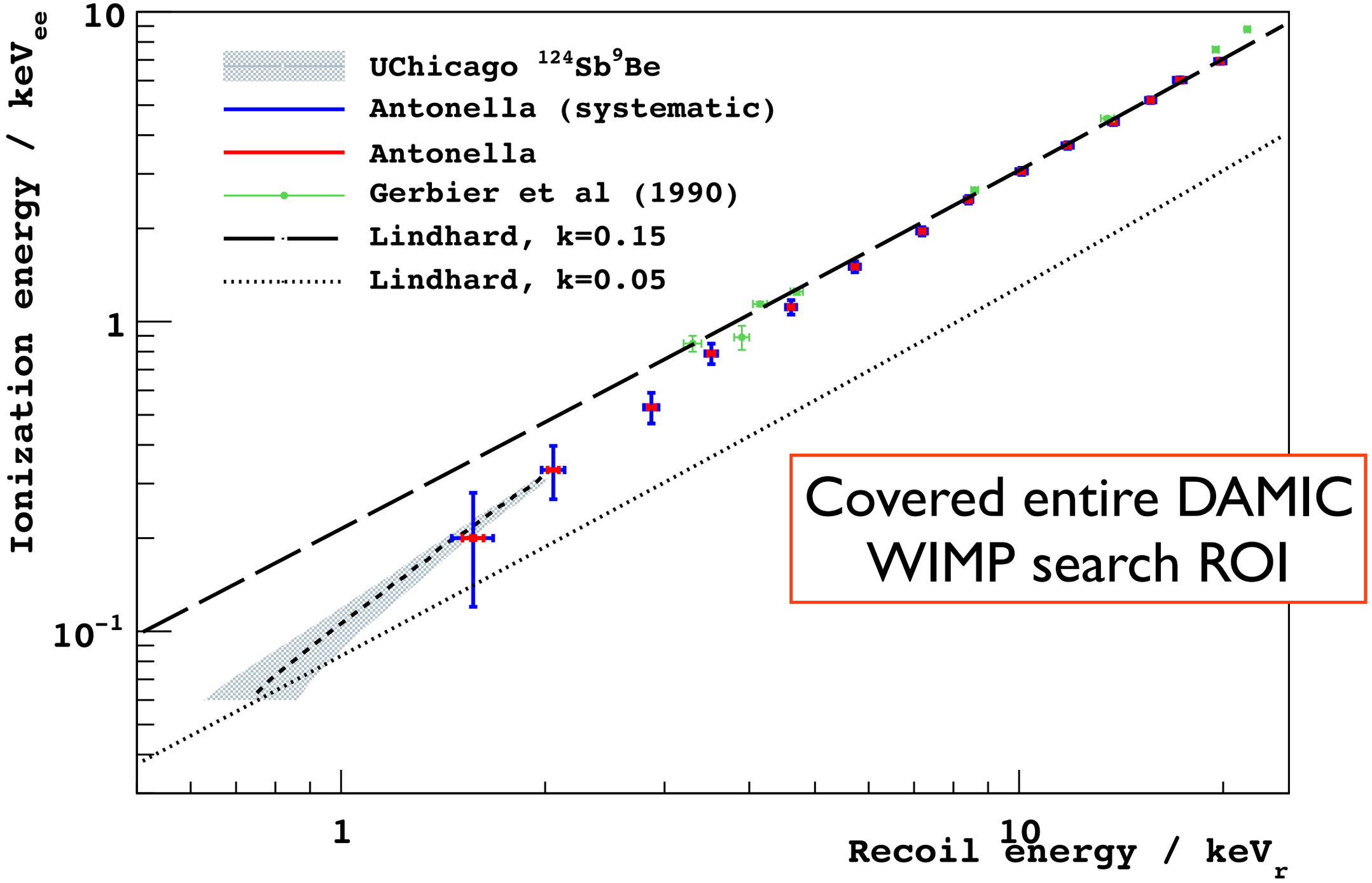
Other effects found negligible, e.g. resolution →



Results


Ionization efficiency for nuclear recoils in Si
Ionization energy / keV$_{ee}$
Recoil energy / keV$_r$
Central value
Total uncertainty
Systematic
Statistical
740±120 eV$_r$ at 60 eV$_{ee}$
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

In context


Ionization efficiency in silicon
Ionization energy / keV$_{ee}$
Recoil energy / keV$_r$
UChicago ^{124}Sb^{9}Be
Antonella (systematic)
Antonella
Gerber et al (1990)
Lindhard, k=0.15
Lindhard, k=0.05
10
1
10^{-1}
1
10
Covered entire DAMIC WIMP search ROI

Conclusions

- Photo-neutron sources offer promising alternative to calibrate detectors at the lowest energies.
- Complementary results by DAMIC collaboration down to DAMIC100 threshold (60 eV_{ee}).
- Discrepancy with Lindhard model below 5 keV_r in silicon.