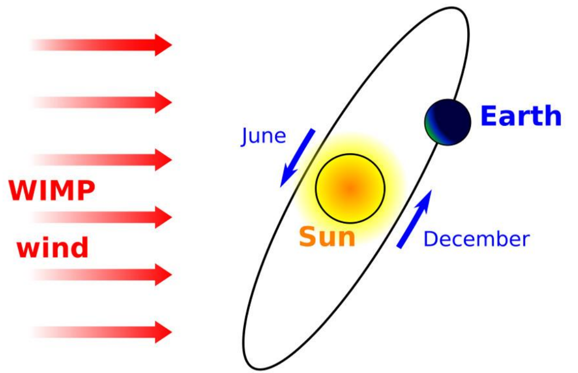
NaI Quenching factor measurement

Particle physics day 2023 - Jyväskylä

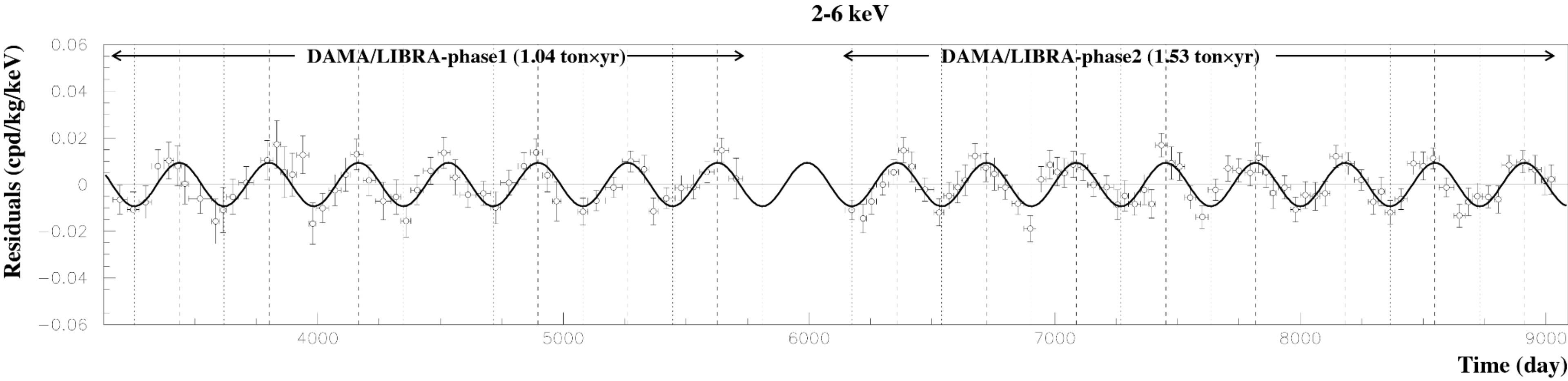
Outline

- Background: Direct detection & DAMA
- Setup
- Analysis
- Results

Background: Direct detection & DAMA



- Assume WIMPs have some interaction with ordinary matter
- Need (very) low background detectors
- Event rate above background is a dark matter signal
    - Modulation searches just takes all events and looks for a modulation
- DAMA: 13.7σ signal [1]

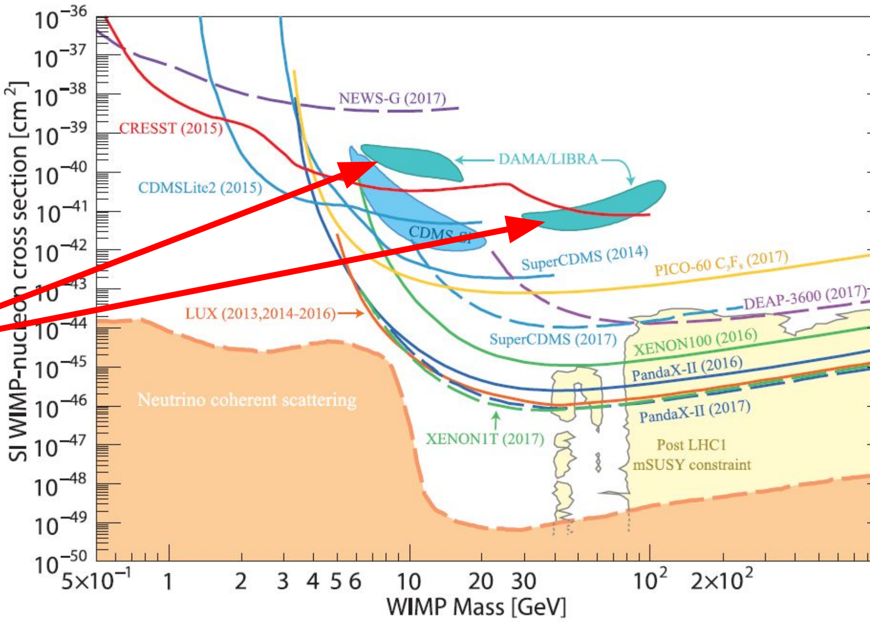


Background: Direct detection & DAMA

- DAMA is located in Gran Sasso, Italy
- Ultrapure NaI crystals w. Tl dopant
- See a significant statistical excess in nuclear recoils
- Only see scintillation light
- Through light yield and **Quenching factor**

we get the recoil energy

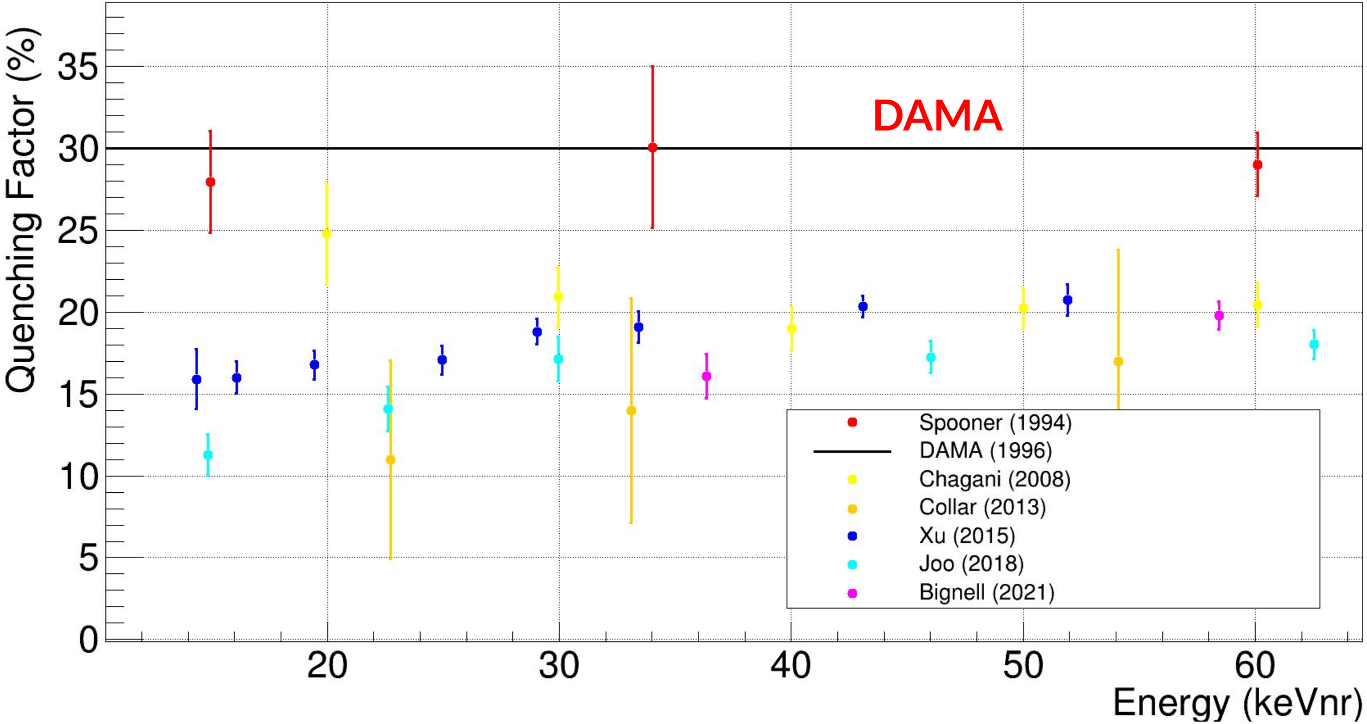
$$QF = \frac{E_{\text{nuclear recoils}}}{E_{\text{electron recoils}}}$$



Exclusion plot of WIMP type dark matter [3]

Background

- Different QF results [2]

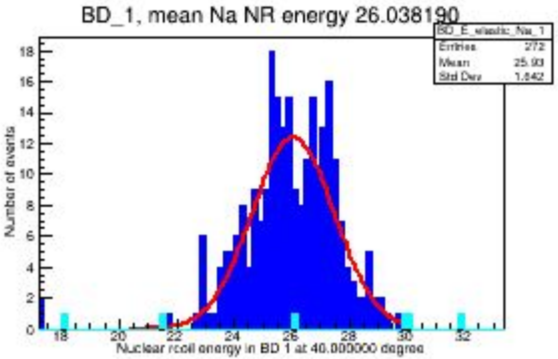


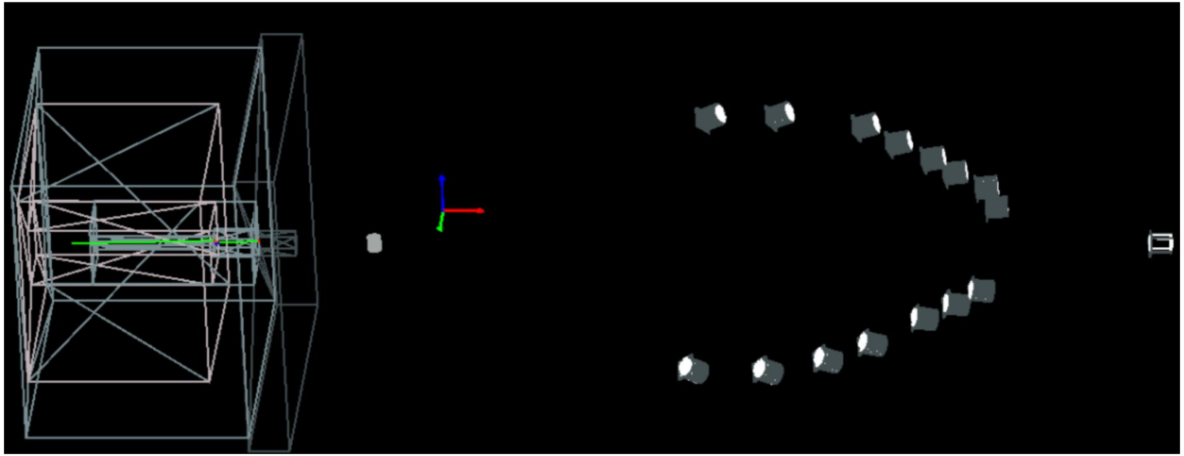
Setup - Facility

- Measurement done at Triangle Universities Nuclear Laboratory (TUNL)
- 5 NaI crystals with varying levels of Thallium dopant
- Proton accelerator -> neutrons via $^{7}Li(p,n)^{7}Be$ reaction
    - Mean E ≃ 1.28MeV
- NaI w. PMT placed in front of collimator
- 15+1 Backing detectors (Liquid scintillators coupled to PMTs)
    - Angles from 7 to 40 degrees (E_{Na} ≃ 0.8 - 26keV) and 0-degree detector
- Trigger scheme:
    - If BD triggers -> save cached NaI pulse

Setup - Simulations

- Simulate the recoil spectra in Geant4
- 100 Million events
- Obtain Recoil spectra for each scattering angle
- Beam profile from previous simulations
  - Working on improvements with data from 0-degree backing detectors

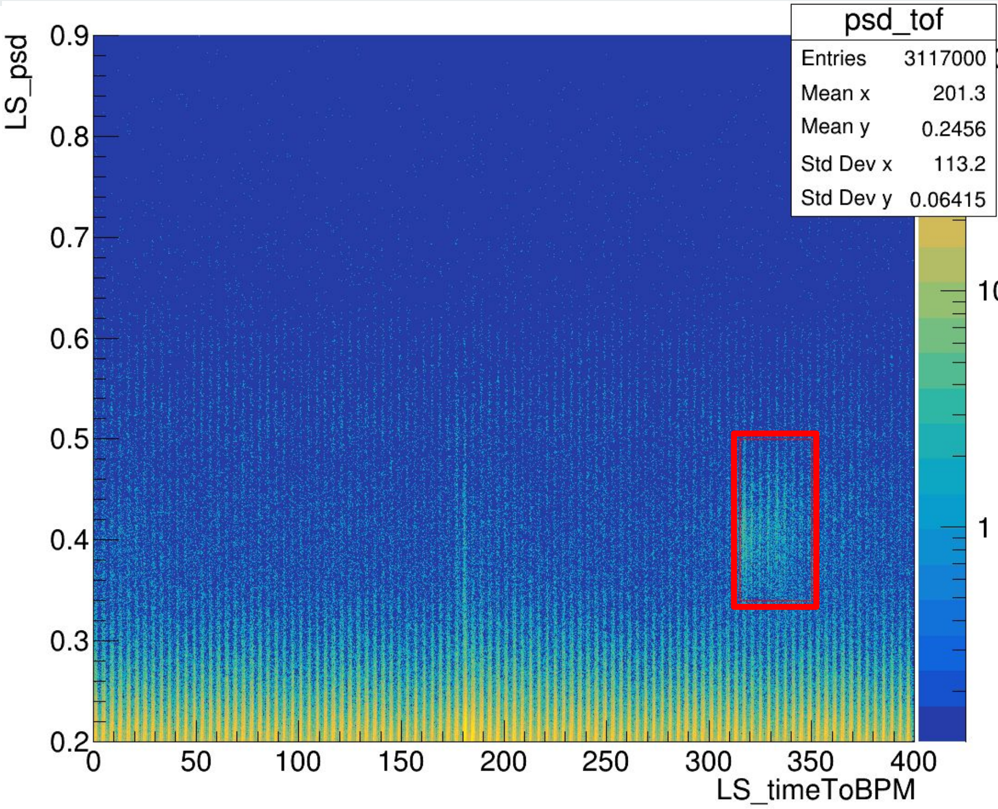




Analysis

Part 1:

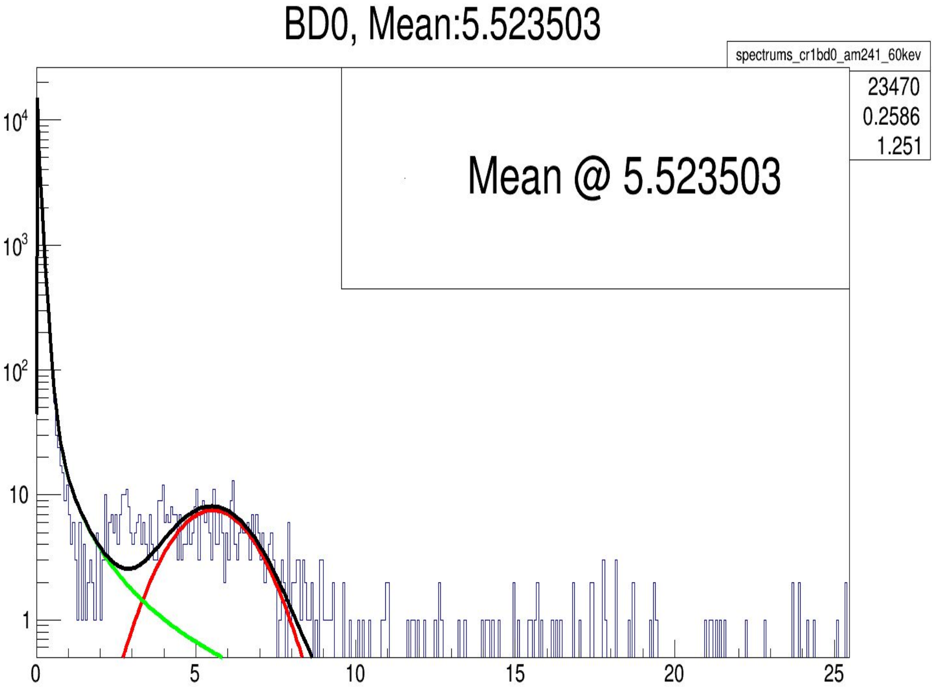
- Calibrate using different gamma sources
- Separate out neutron recoils from gamma events
- Output -> signal and background histograms



Analysis

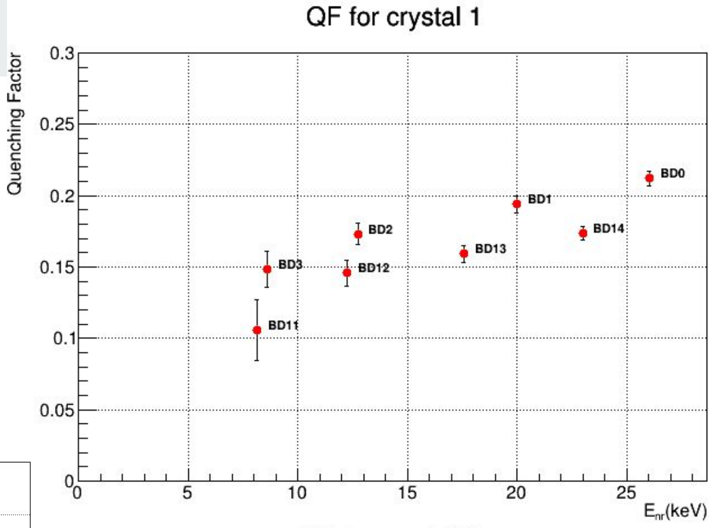
Part 2:

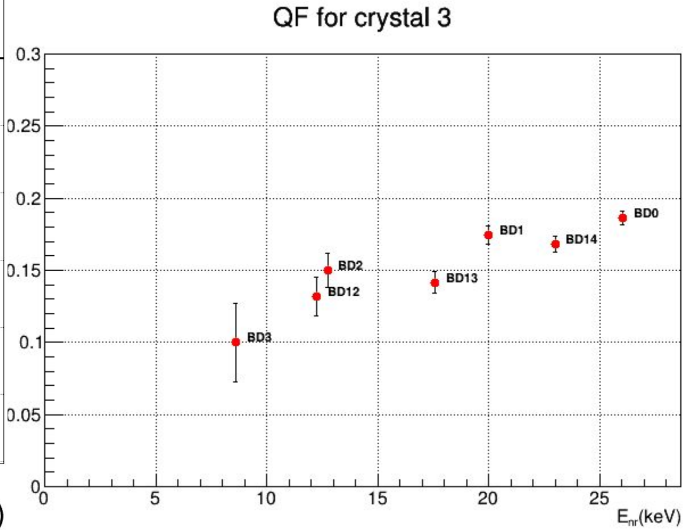
- Find the nuclear recoil peak
- Fit Gaussian + Background to signal histogram
    - Monte Carlo minimizing each potential point
    - Background is a function fit to histogram
    - Gaussian width is fixed from calibration resolution
- Compare to simulations

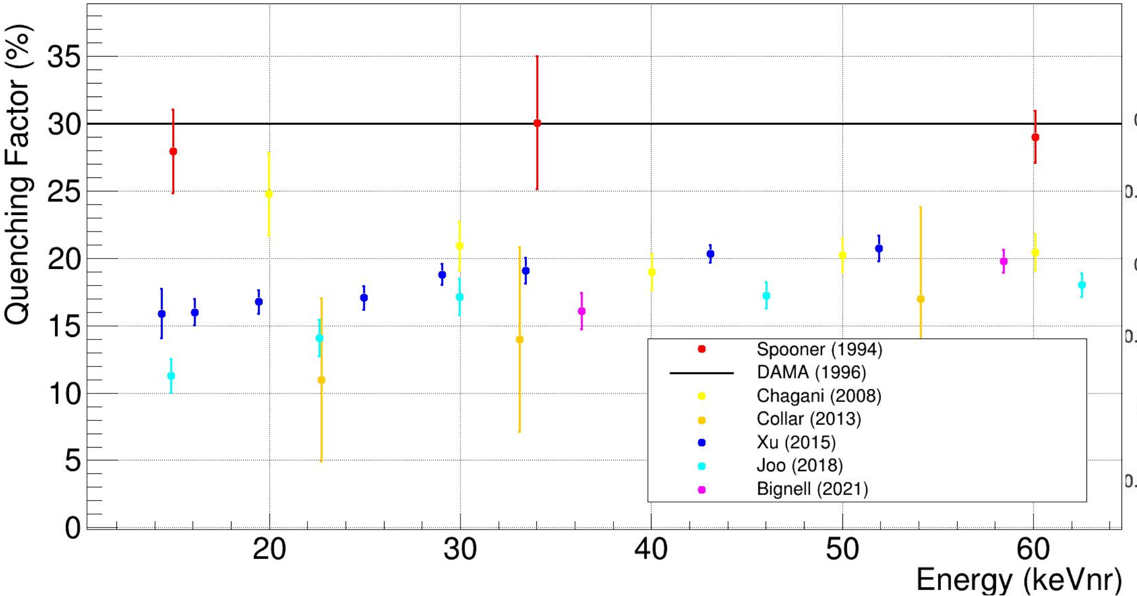


Results & Thank you

- Energy dependent QFs
    - In contrast to DAMA's constant
- Thallium dopant impact still in the works







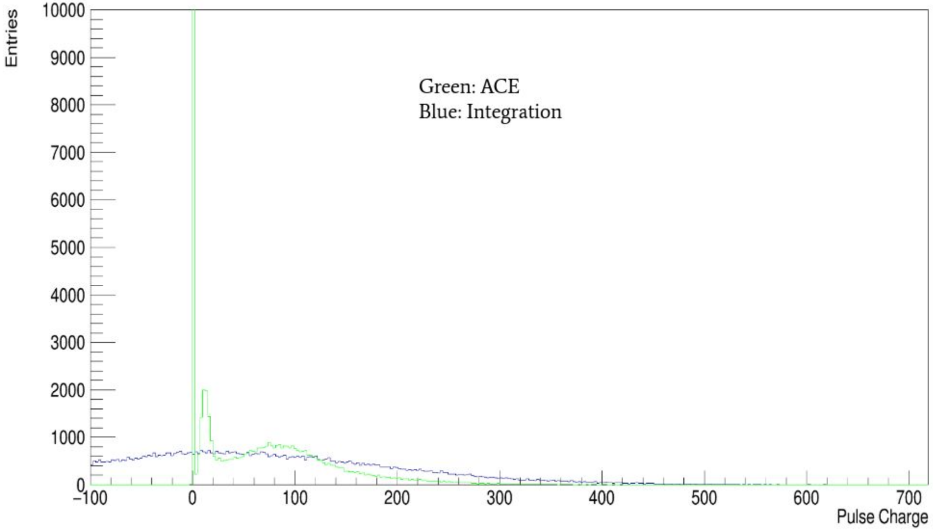
References

- [1] R Bernabei *et al* 2023 *J. Phys.: Conf. Ser.* 2586 012096
- [2] D. Cintas et al 2021 J. Phys.: Conf. Ser. 2156 012065
- [3] S. Hamdan, arXiv:2108.07752

Backup/Extra slides

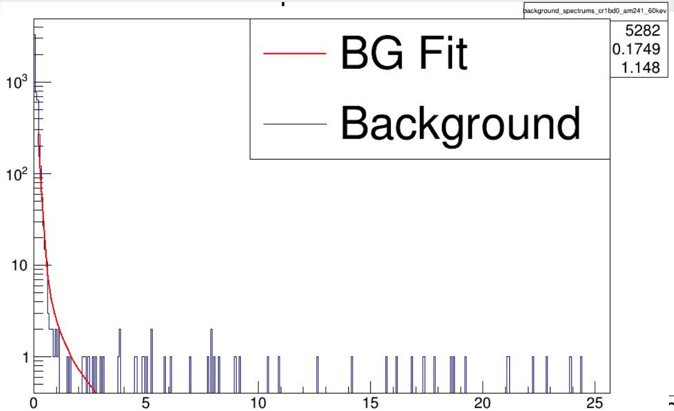
Energy integration

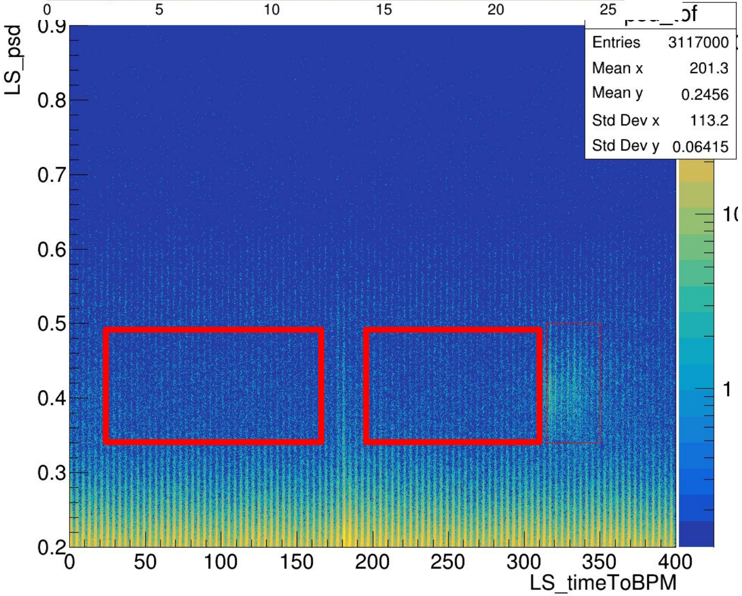
- Tried two methods:
  - Integration
  - Adopted Charge Estimate
- ACE = sum everything above threshold
- ACE has better low energy resolution



Background

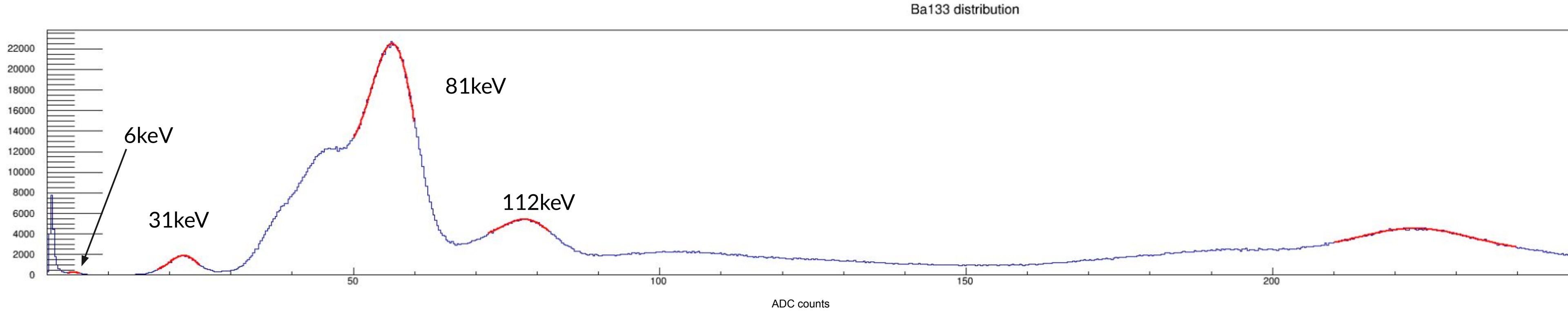
- "inverse" the cut criteria from neutron events
- Calibrate with same source and function as signal
- Save histogram
- Spectrum fitter fits function:
    - $A^*e^{-b^*x} + C^*x^d$
- Function is then used in peak finding





Calibration

- Sources (Am241, Ba133, Cs137) placed on top of crystal
- Record PMT with no trigger scheme
- Fit Peak with Gaussian + Linear function
  - Extract Gaussian mean and std. dev.



Resolution function

- Get the std. dev of the Ba133 calibration peaks
- Plot as a function of mean energy
- Add simulation "resolution" in quadrature