Data Reconstruction in Mid-to-high Energy Range in PandaX-4T

Lingyin Luo (PKU)

On behalf of PandaX Collaboration

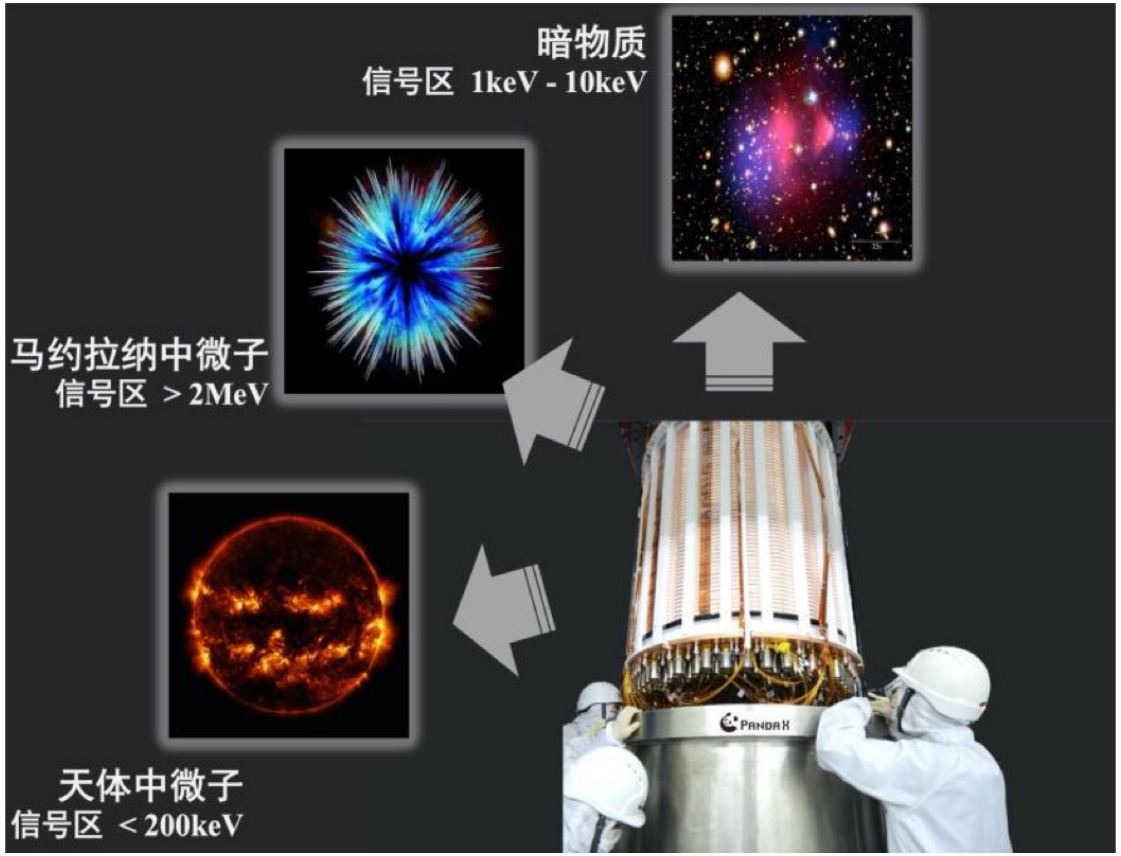
2022-08-11

CHEP, 2022/08/08 – 2022/08/11

PandaX-4T as a multi-physics detector

- neutrino physics
  - ^{136}Xe(Neutrinoless) Double Beta Decay (to excited state)
  - ^{134}Xe Double Beta Decay
  - ^{124}Xe (NL) Double electron capture (DEC)
  - Solar *pp* neutrino electron scatter
- Mid-to-high energy range rough from 100keV to 3MeV

- PMT waveform saturation
- Single/Multiple-site events



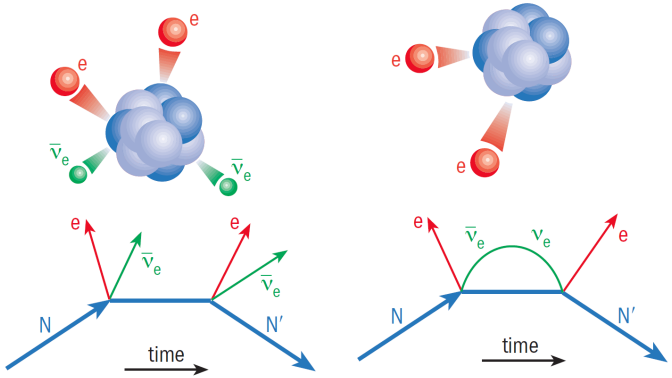
Xe136 DBD:arXiv:2205.12809

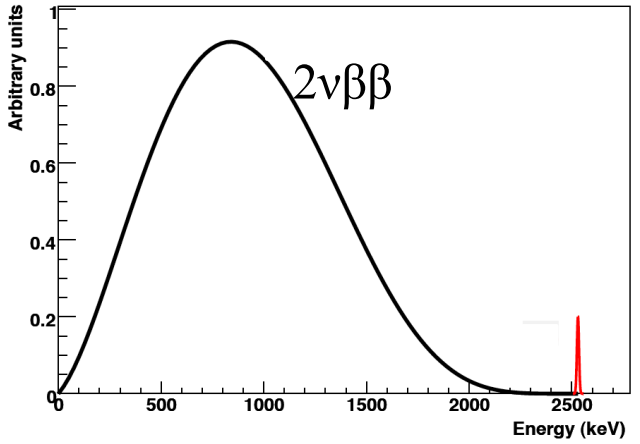
Example of Physical analysis

- ^{136}Xe(Neutrinoless) Double Beta Decay
  - 2 electrons energy measurement
- ^{136}Xe DBD through excited state
  - 2 γ and 2 electrons

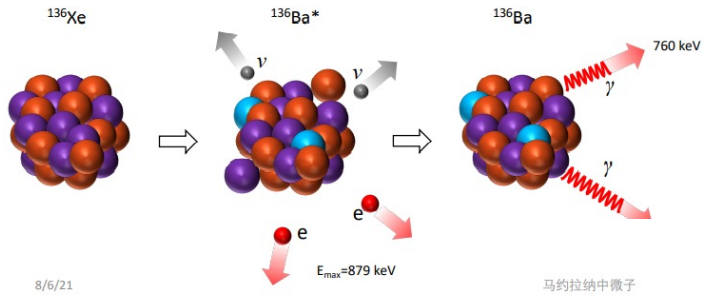
- Energy reconstruction of MeV range
  - Energy resolution and linearity
- Single-Scattering /multiple-Scattering
  - Signal identify from background

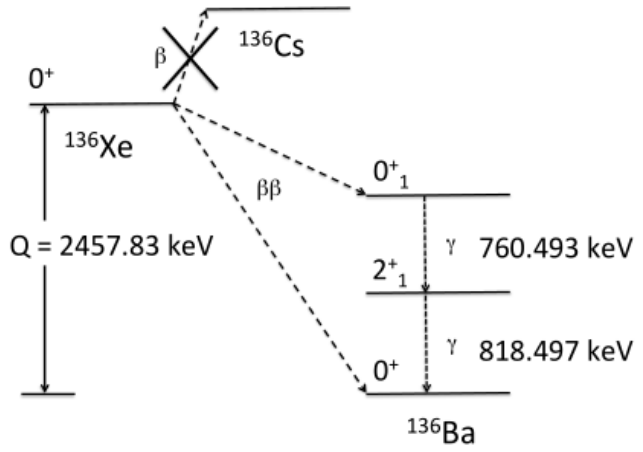
- ^{136}Xe(Neutrinoless) Double Beta Decay





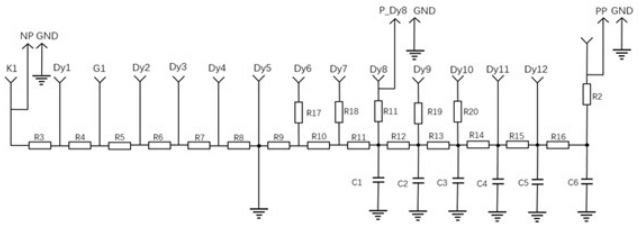
- ^{136}Xe(Neutrinoless) Double Beta Decay through excited state

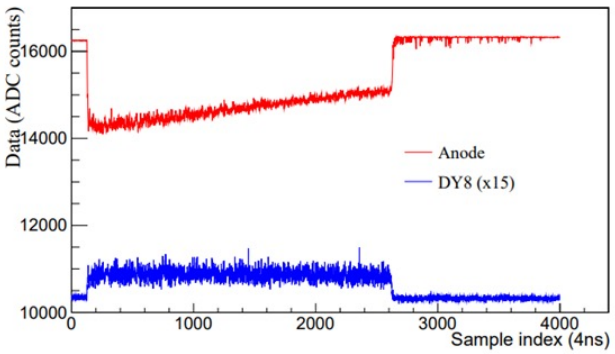


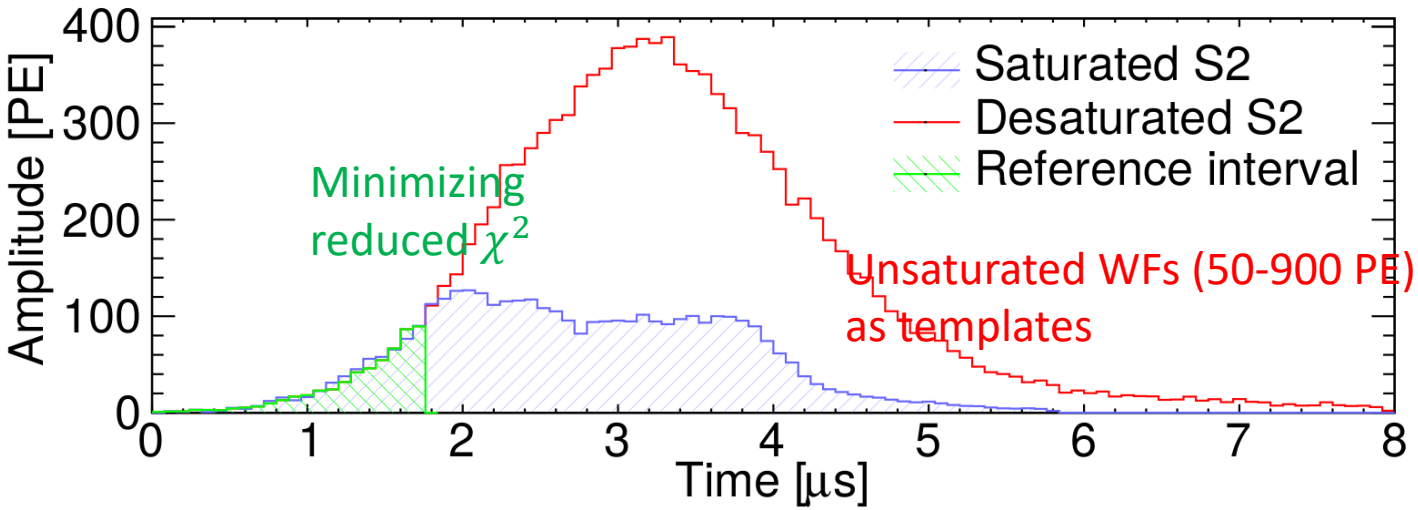


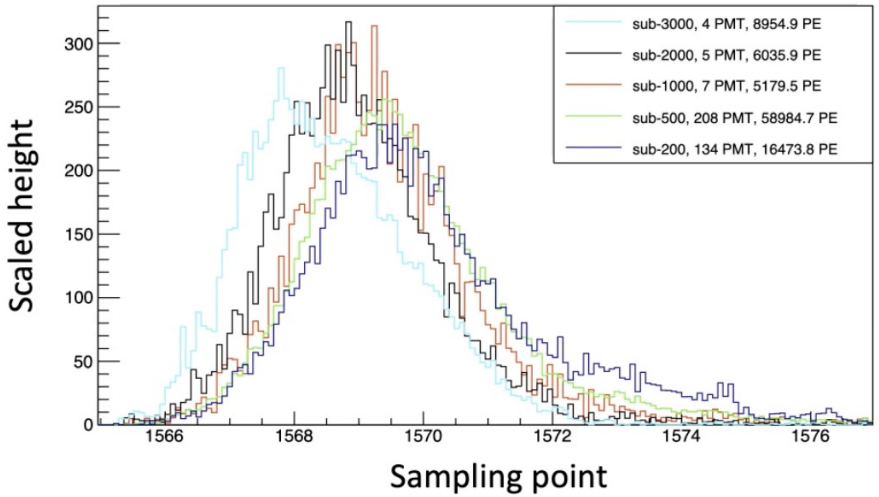
PMT pulse saturation and desaturation

- PMT bases suffer serious saturation for MeV range events.
- Match the rising slope of the saturated to the non-saturated templates in the same events→ True charge collected
- For events in the energy range of 1 to 3 MeV, the average correction factor is ~3.0 for the top PMT array







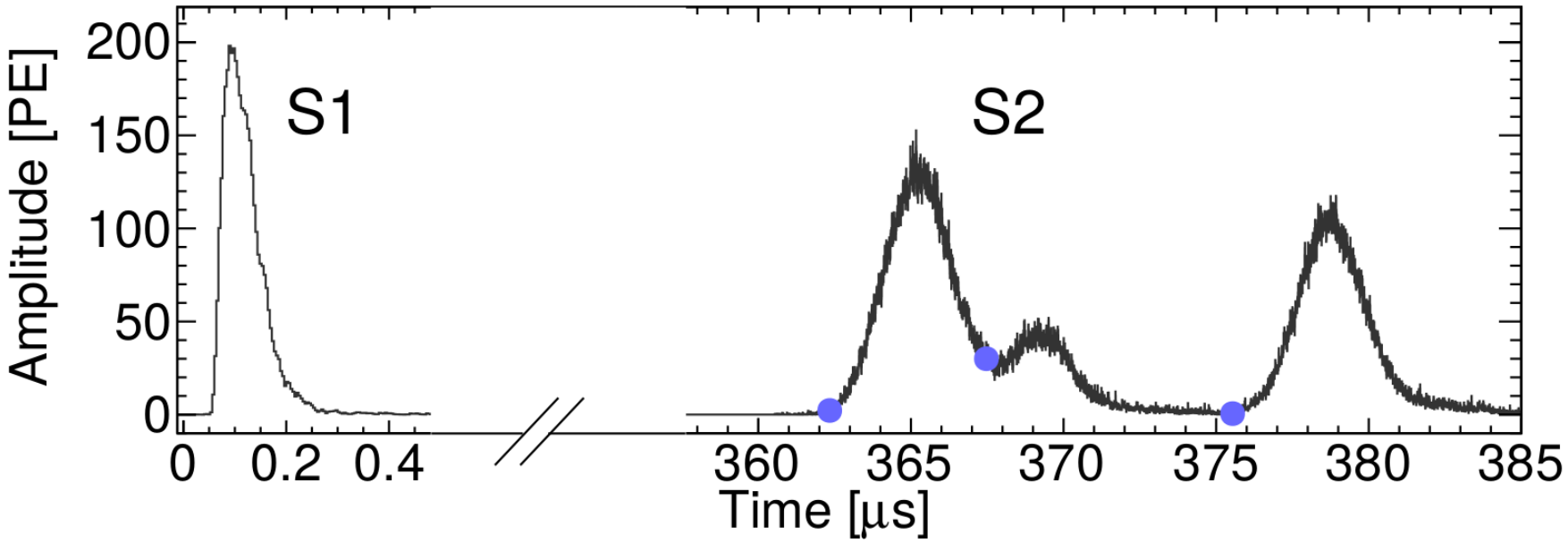


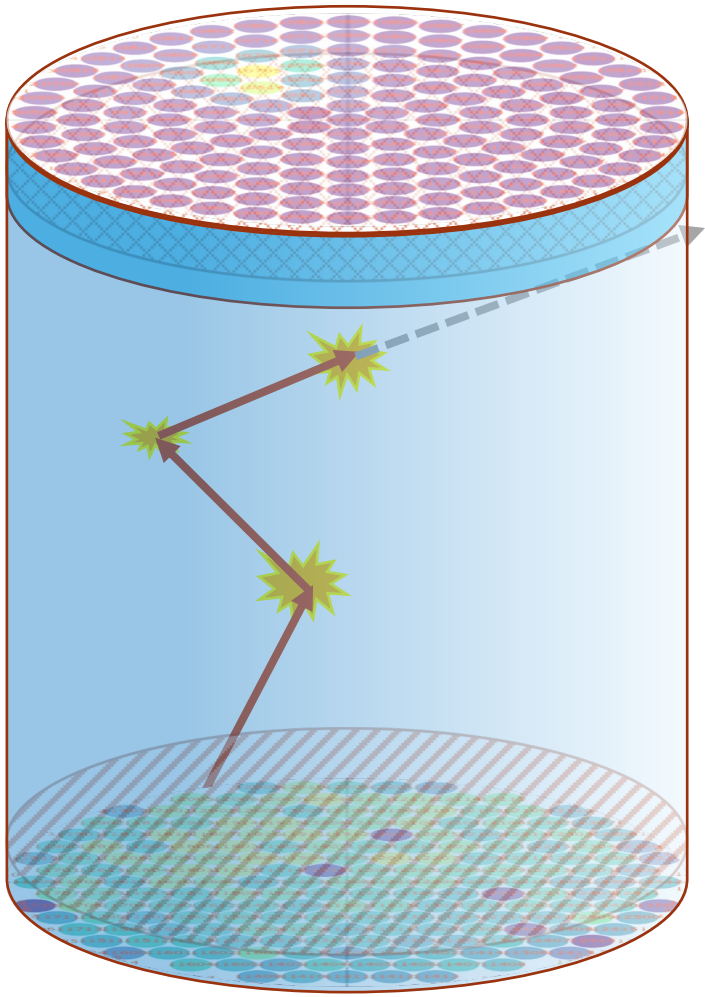
Identify Single/Multi-Site events

- MeV gamma events are mostly multiple-scattering events;

  while signals (DBD) are mostly single site (SS)

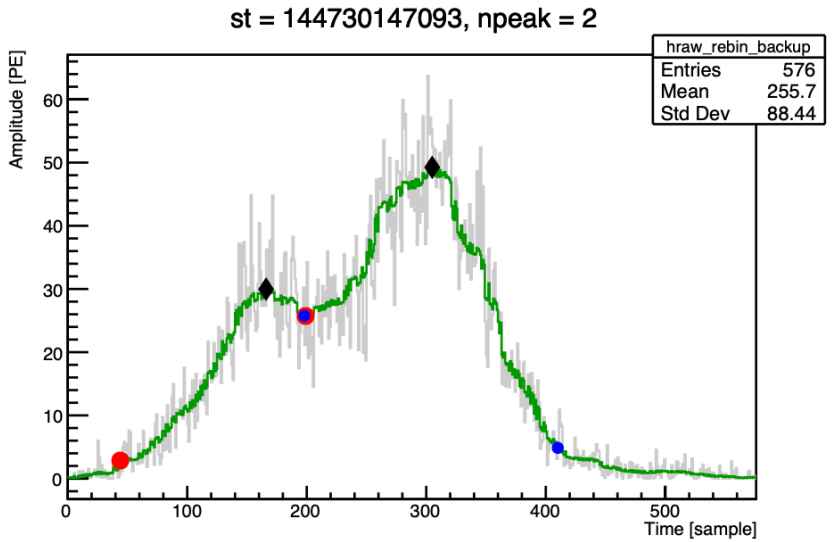
- Identifying Multi-Site (MS) events with PMT waveforms
  - Divide S2

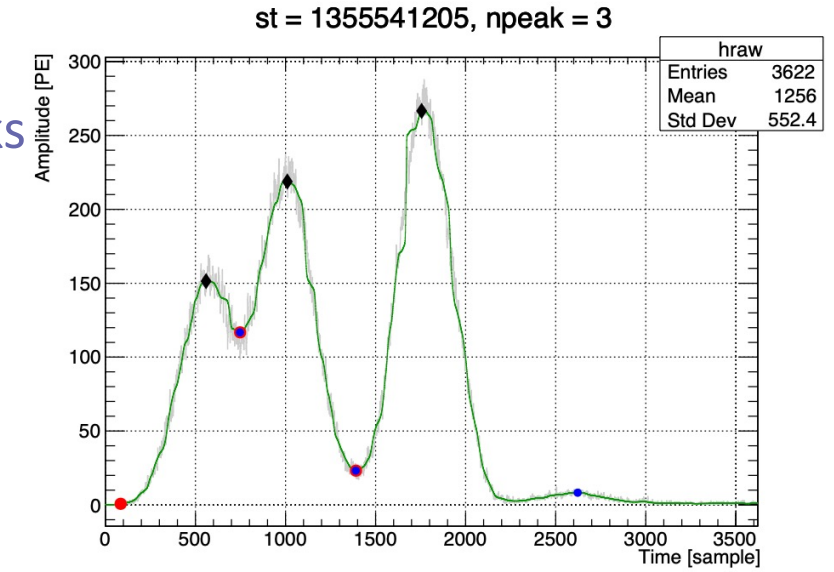




Waveform smoothing and division

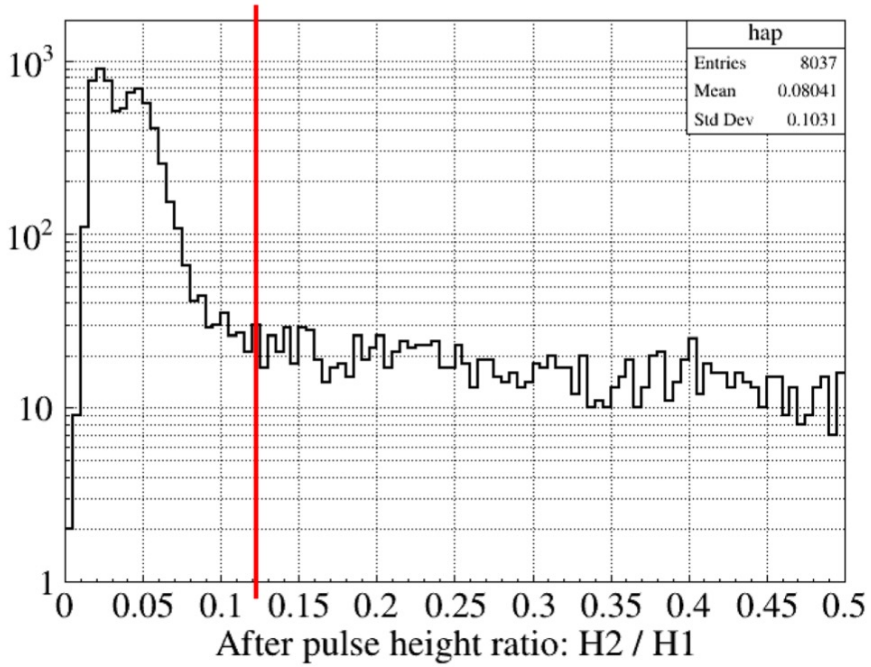
- Locally Weighted Regression and Smoothing Scatterplots (Lowess)
- Peak Searching：
  - Maximum sample in 1.5us window
  - Thres_height > 1pe
- Start time : thres_start > 0.75pe or minimum between two peaks
- End time : 5% of peak height or thres_end 1pe or minimum between two peaks

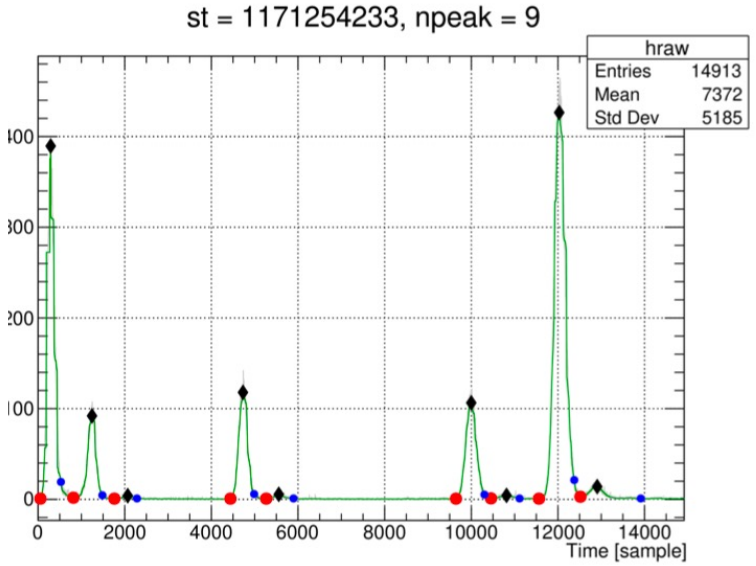




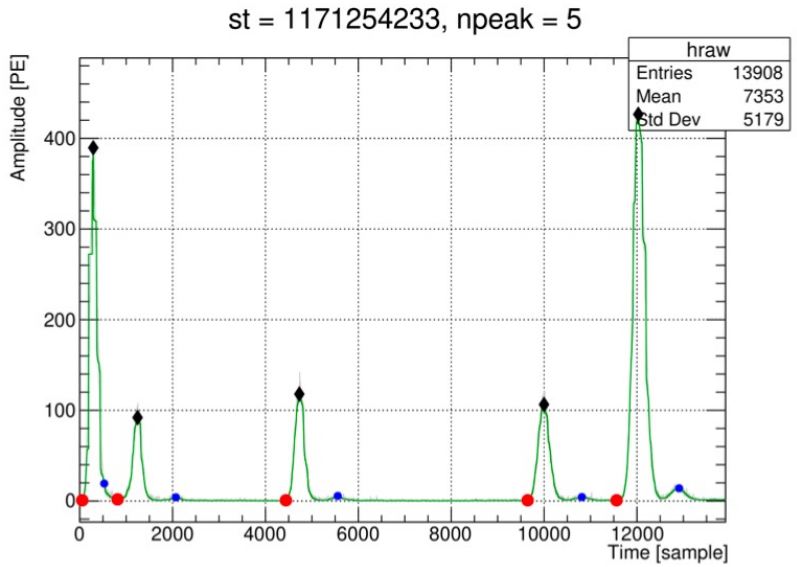
After-pulse from gate ionization

- AP 900 samples(.i.e3.6us) after a large S2, with charge ratio of ~5%
- Time to previous S2 peak is less than 5 μs ;
- Height ratio is less than 12%





(a)



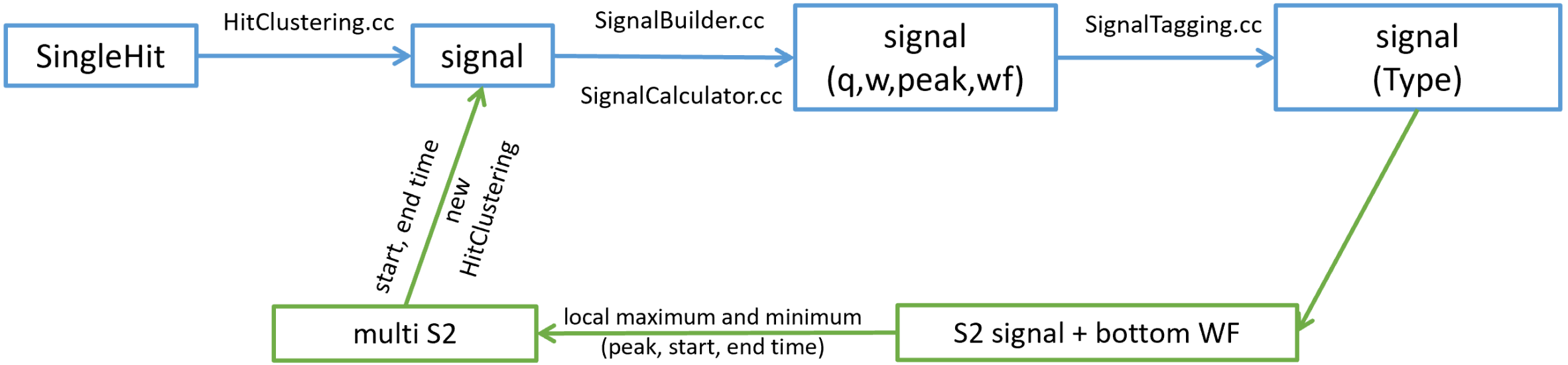
(b)

Process flow in p4-Chain

- Redefine S2 signals
  - S2b waveform
  - Peak, start, end
  - New HitClustering

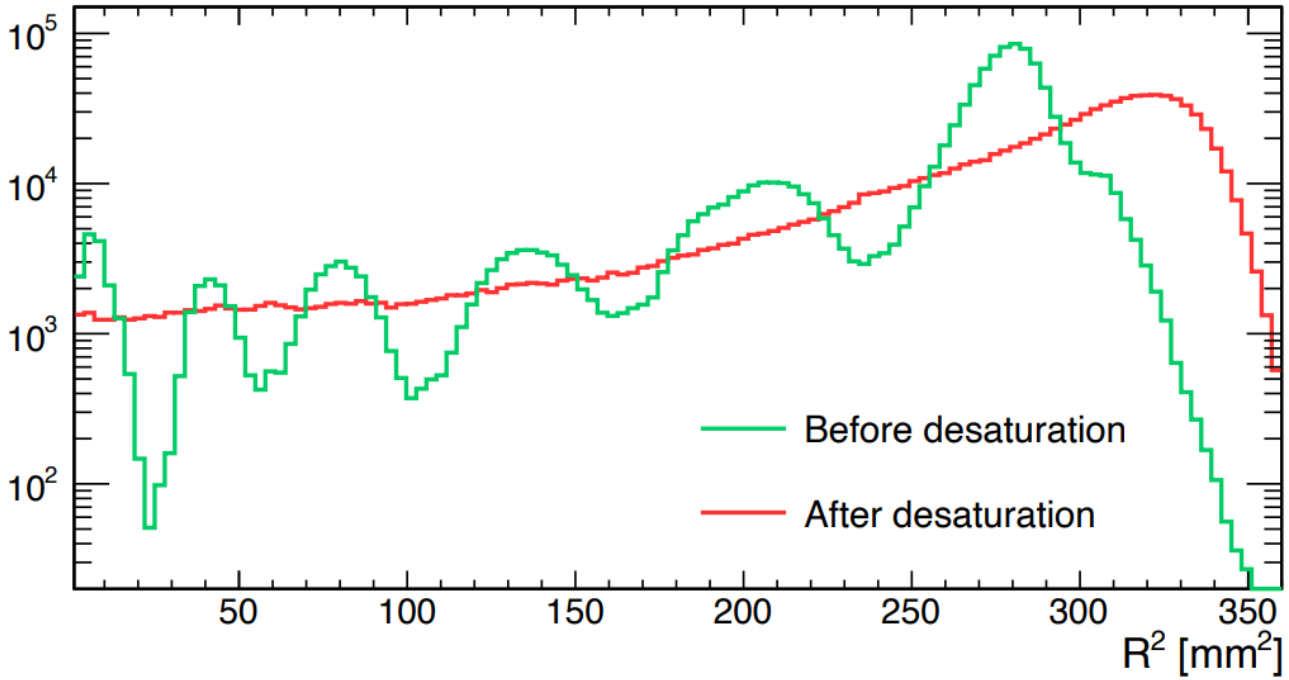
SingleHit: PMT waveforms

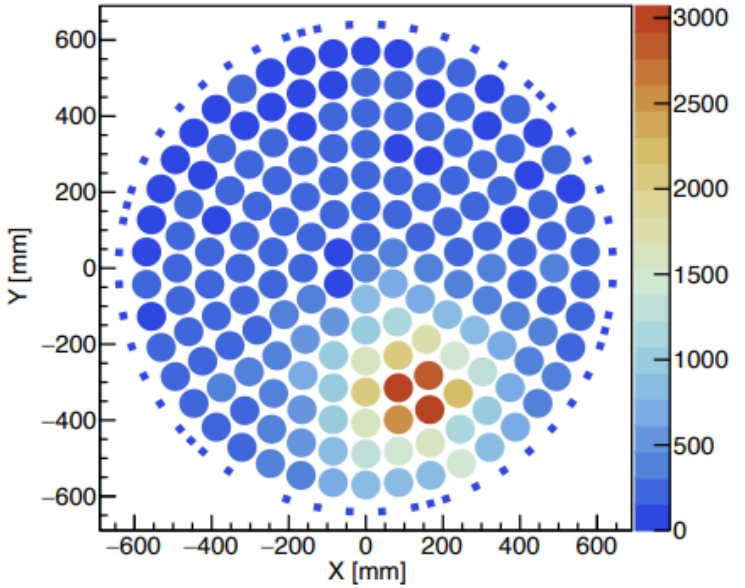
Signal(type): S1 and S2/S2b signal from a event



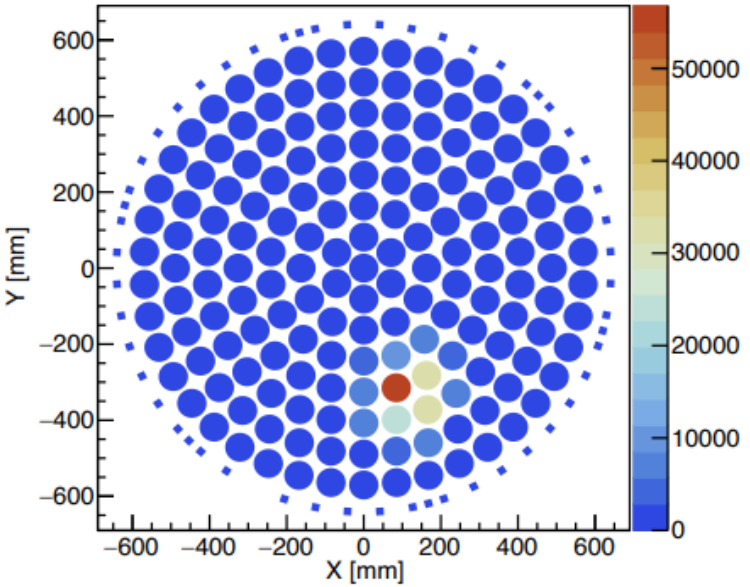
Position reconstruction improvement with desaturation

- Position reconstruction based on PAF (photon acceptance function) methods devloped in DM analysis
- Reconstruction at HE is significantly improved with desaturation
- Removed the band structure in R^2 distribution





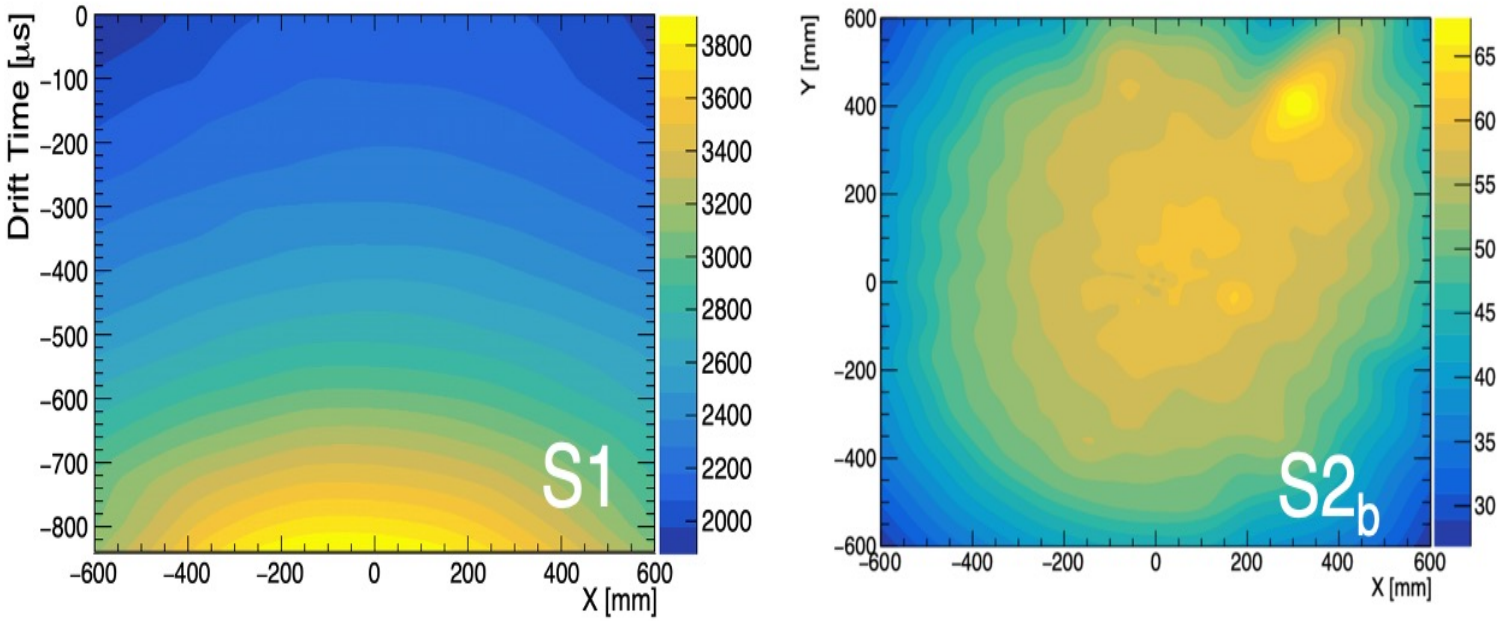
Before



After

Data-driven detector response and correction

- Gaseous ^{83m}Kr feed into the TPC → uniformly distributed 41.5 keV events → 3D detector response
- S1 (3D) and S2 (2D) signals are corrected respectively; E-lifetime correction done for S2 before this
- Also validated with higher energy peaks (164 keV and even 2615 keV)



Energy reconstruction

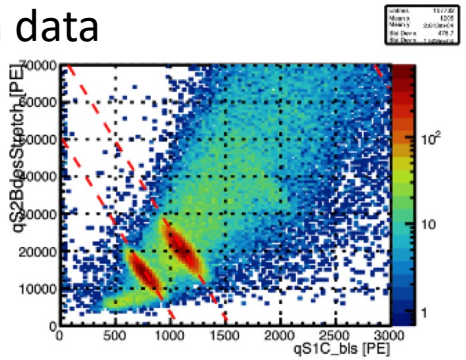
- Energy reconstruction: $E = 13.7\ eV \times (S1/PDE + S2_b/(EEE \times SEG_b))$
- High energy peak positions off by ~10% with inputs from DM analysis
- Further tune S1 and $S2_b$ vs. energy and position → deviations of peak positions to the percent level.

PDE: photon detection efficiency for S1

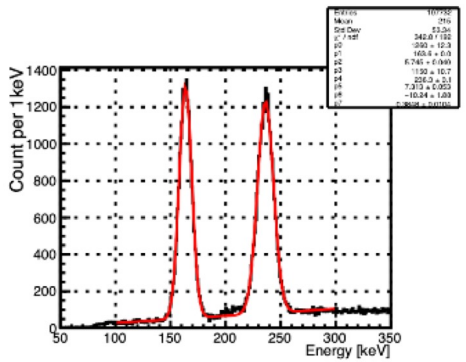
EEE: electron extraction efficiency

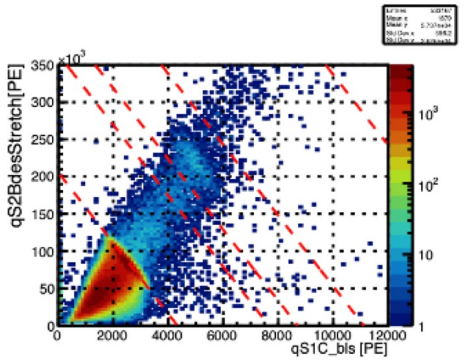
SEG_b: single-electron gain for $S2_b$

Calibration data

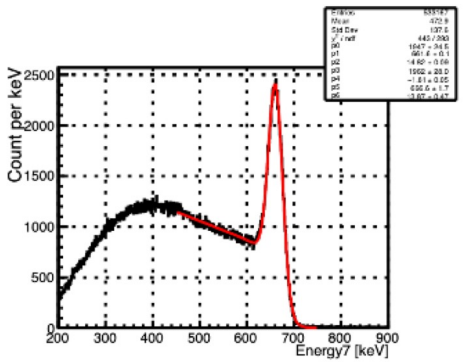


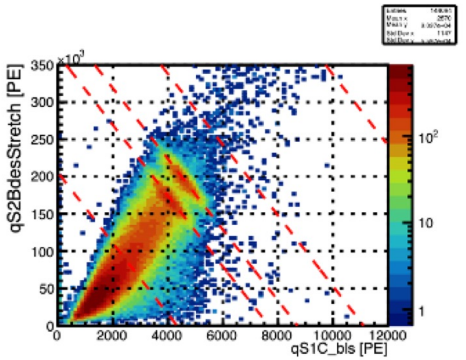
^{131m}Xe (164 keV), ^{129m}Xe (236 keV)



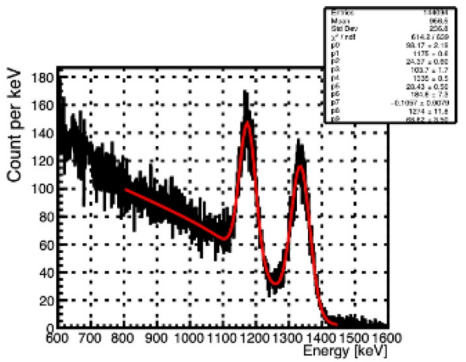


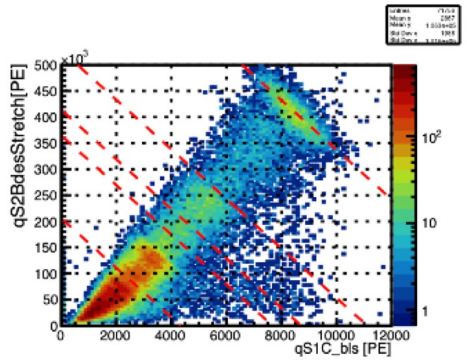
^{137}Cs



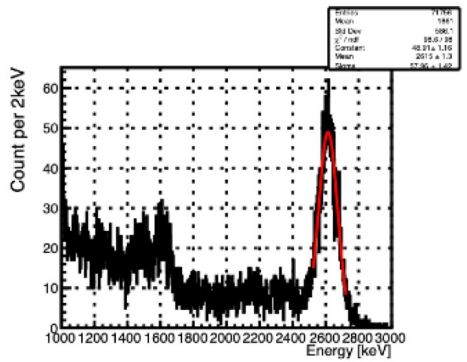


^{60}Co



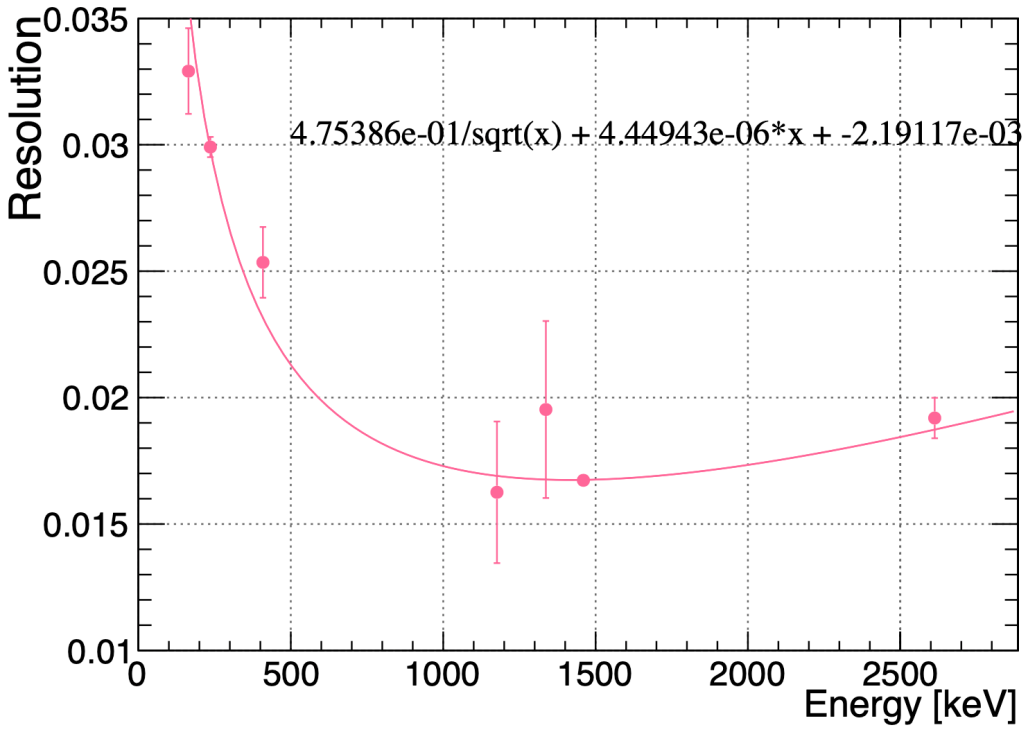


^{208}Tl

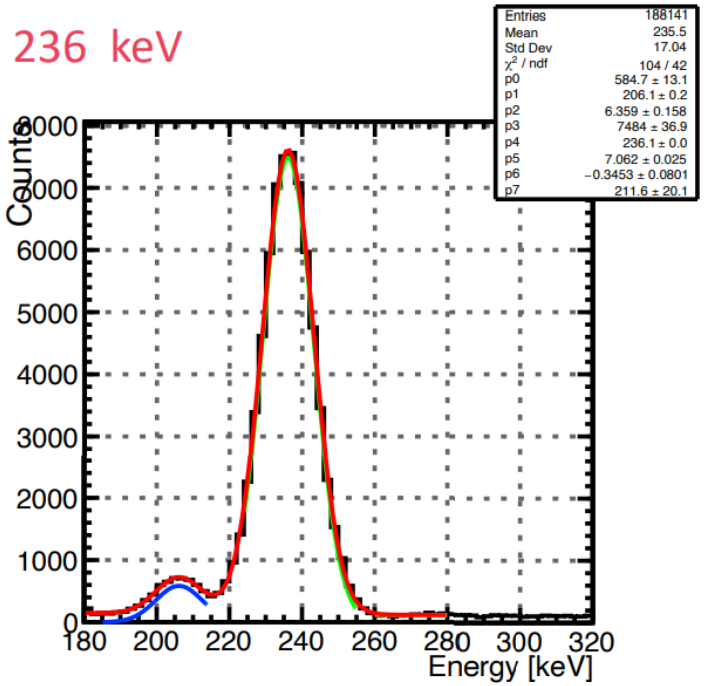


Background peaks

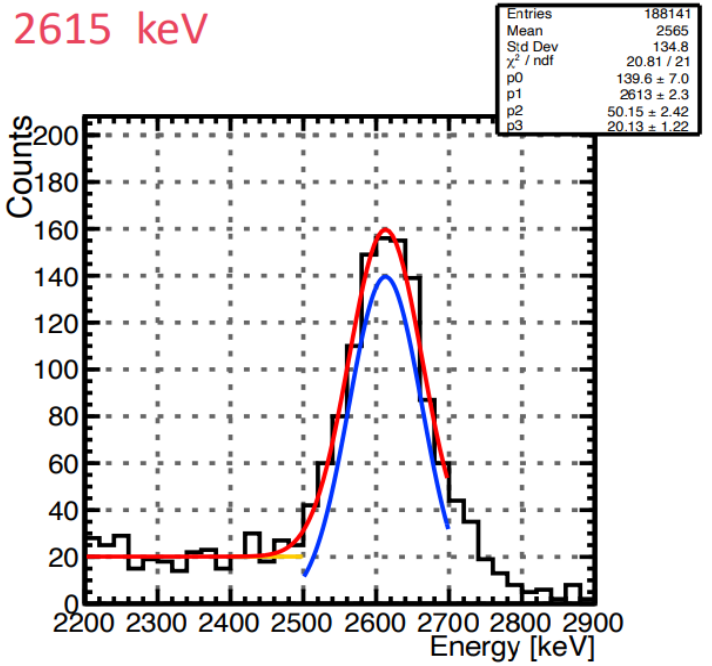
- Resolution of background data: 1.9% at 2615 keV; 3.0% at 236 keV
- Resolutions from different peaks as input for simulated spectrum



236 keV



2615 keV



Summary and outlook

- We developed a set of data analysis process suitable for signals in the MeV energy range.
- The new algorithms include identification of single- and multiple-scattering events, de-saturation of MeV waveforms, and improved position reconstruction etc.
- The new analysis procedure was successfully applied to double beta decay analysis and other neutrino physics topics in MeV range.

- Multi-site events reconstruction
- Engagement with dark matter range

Thanks!


PANDAX
PARTICLE AND ASTROPHYSICAL XENON TPC

Validation with bench tests and improvement of PMT bases

- Desaturation algorithm validated with a bench measurement
  - PMTs illuminated by high intensity photons with S2 timing profiles
- Newly designed PMT bases can improvement the linear dynamic range by >30