# Sub-Threshold Behavior for Low-Energy Germanium Detectors

- ULGe-PCGe: Phys & Requirements
- Event Selection & Efficiencies
- Status & Plans

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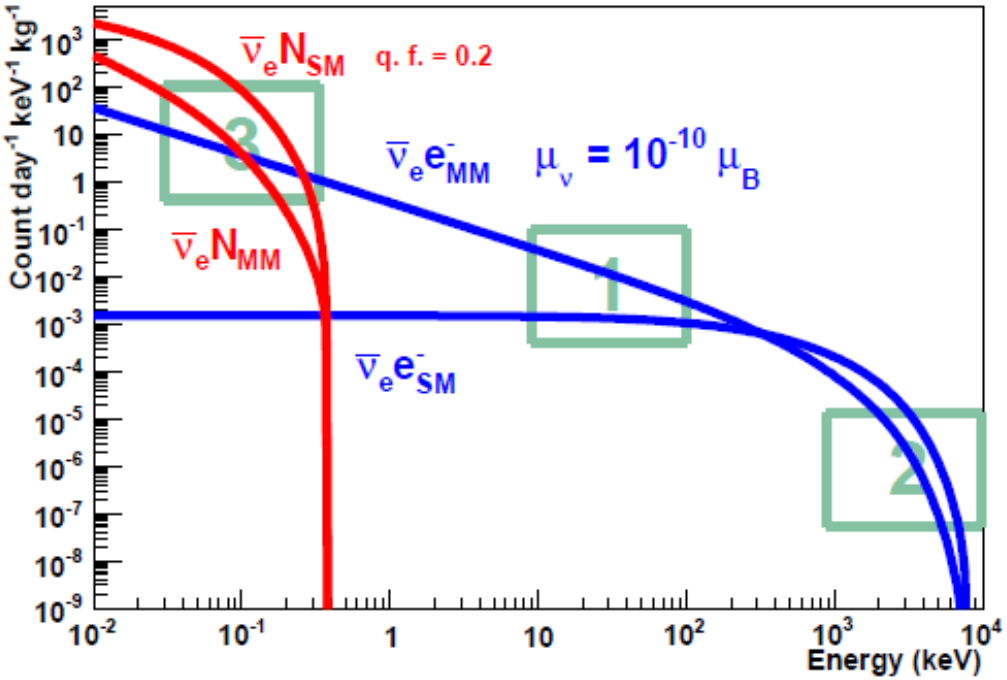
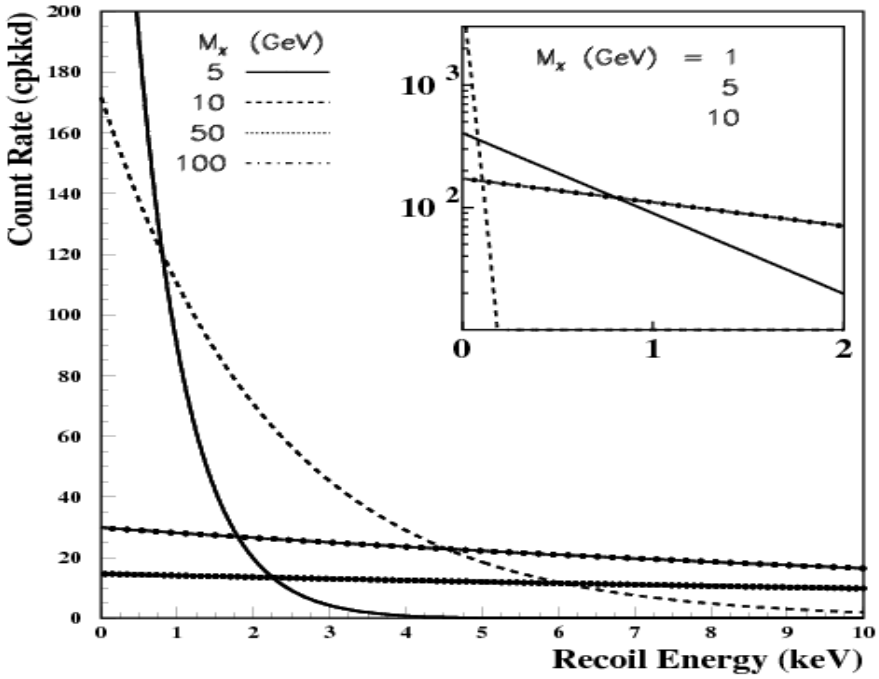
# Physics Programs at Reactor

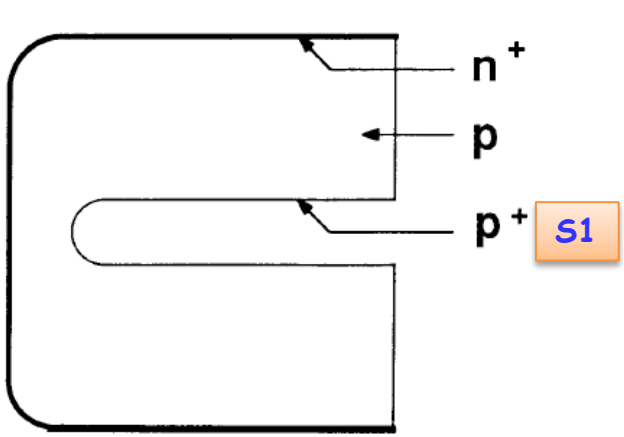


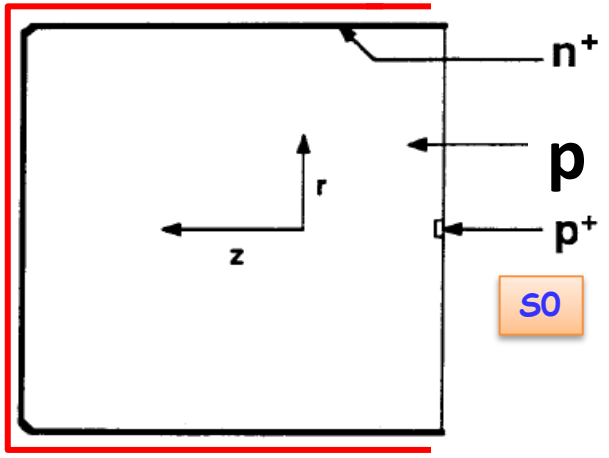




- [1] Magnetic Moment Search at ~ 10keV ⇨ [PRD 75 2007]
- [2] $\sin^2\theta_W$, Axion Search at MeV range ⇨ [PRD 81, 82 2010]
- [3] $\nu_e N$ Coherent Scattering
- [3] Low-mass WIMP Search ⇨ [PRD 79 2009]
- Critical Issues: Signal efficiencies for trigger, DAQ & Selection ⇨ *Main Topic of this talk*

# Detector Scale-up Plans: Point Contact Ge Detector



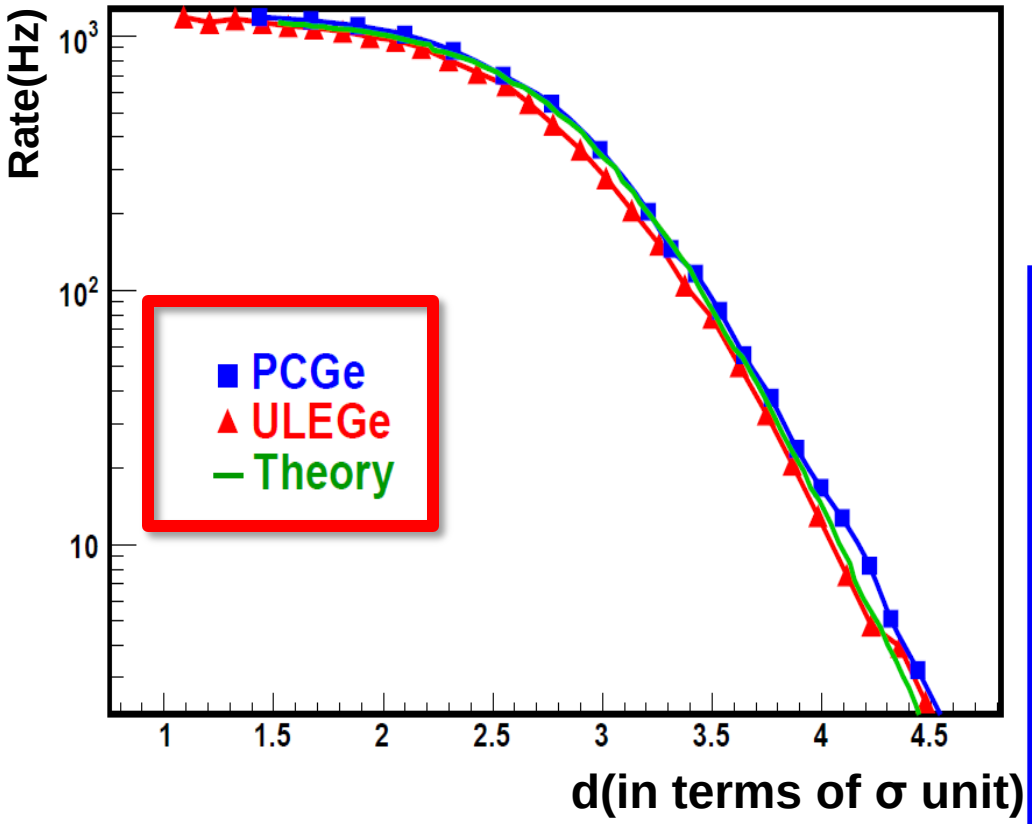




- Standard Coaxial Ge Detector ⇨ Large-capacitance, noise( ~keV); Short-charge drift times
- 4x5 g ULEGe ⇨ low threshold(~ few hundred eV) ⊕ small mass, large background
- 500 g, 900 g PCGe ⇨ low threshold ⊕ larger mass, lower background ⊕ Position-sensitive from drift ⊕ Add: Dual-electrode readout

# Noise Trigger Rate

$$R \sim \frac{1}{4\tau}\, exp\,[-\frac{d^2}{2\,\sigma^2}]$$

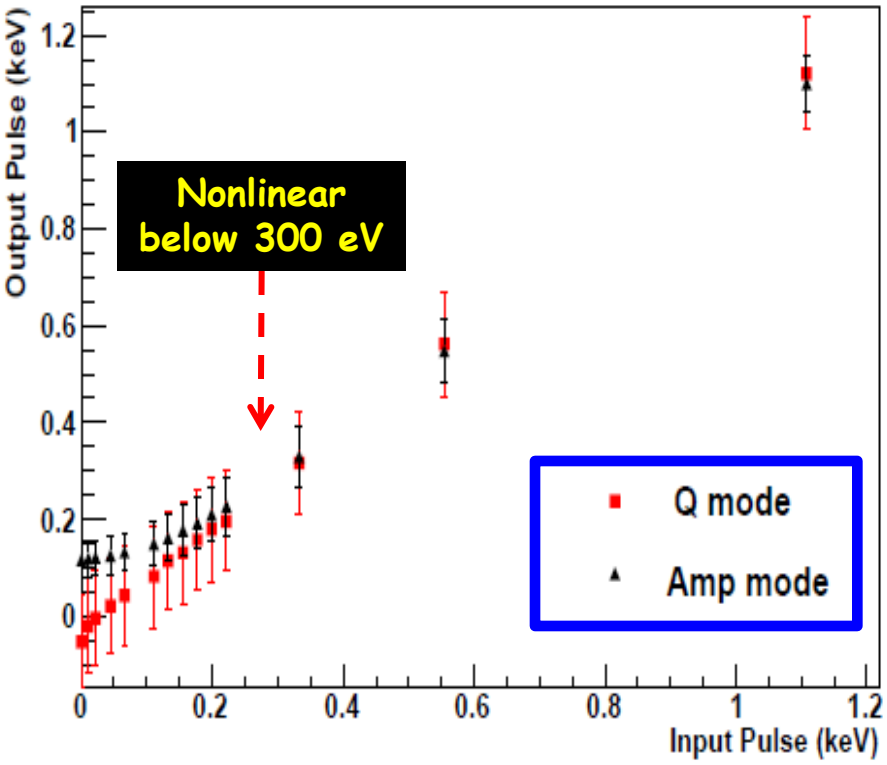
τ: shaping time
σ: RMS of the pedestal noise fluctuations
d: threshold level above the pedestal




- Detector Response:
  - ⇨ Match well with theoretical predcition
- Behaviour of the theoretical prediction
  - ⇨ Universal for all detectors
- DAQ threshold at ~ 4.3σ above mean of noise fluctuations
  - ⇨ minimal DAQ dead time (5Hz ⊕ 10% deadtime)

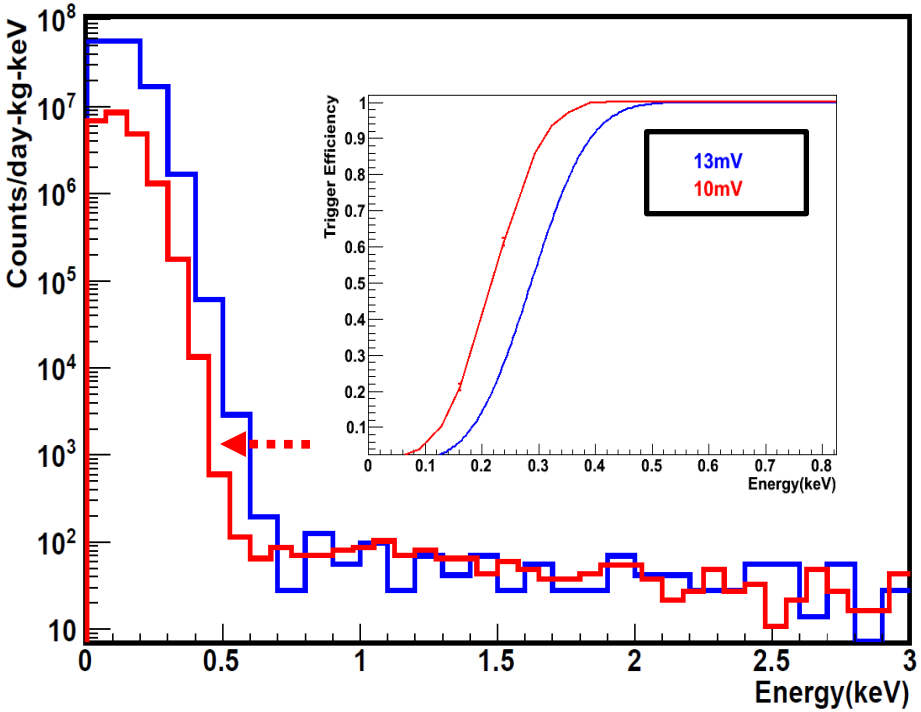
# Energy Measurement & Calibration

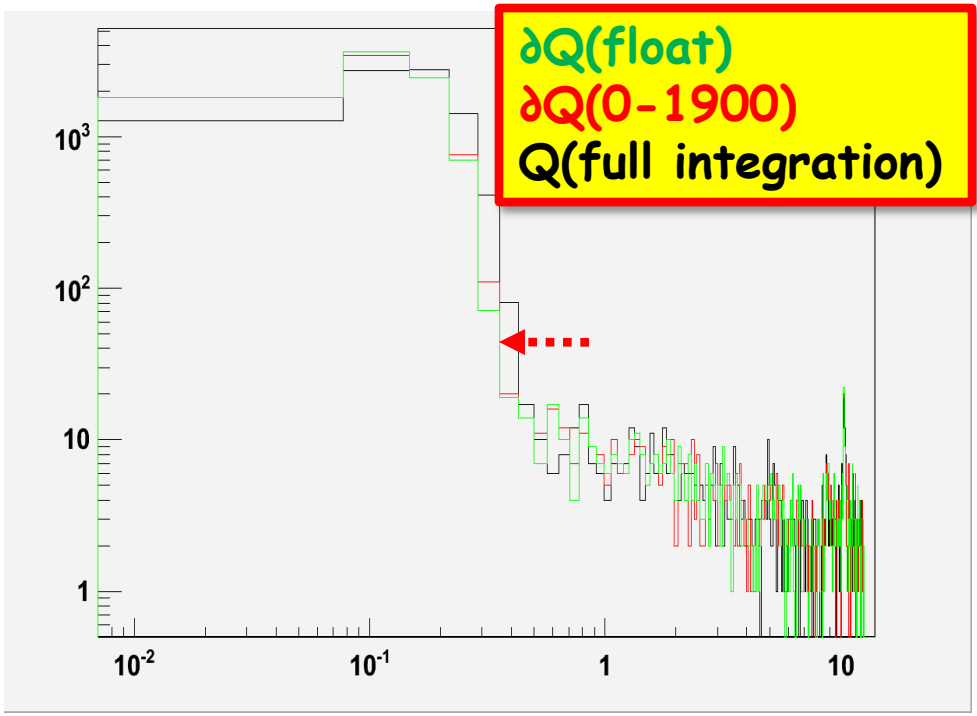
- Charge Integration (Q-Mode):
  - ⇨ linear for all region
- Maximum Amplitude (A-Mode):
  - ⇨ nonlinear below 300eV
- RMS of A/Q-Mode:
  - 10keV: σ(A)~120eV
  - σ(Q)~150eV
- Calibrations ⇨ by keV lines & "0" from random trigger in Q-Mode
- Pulser:
  - ♥ Excellent tool for low energy region




PCGe Response for two modes

# Elaborate Settings of Hardware & Software



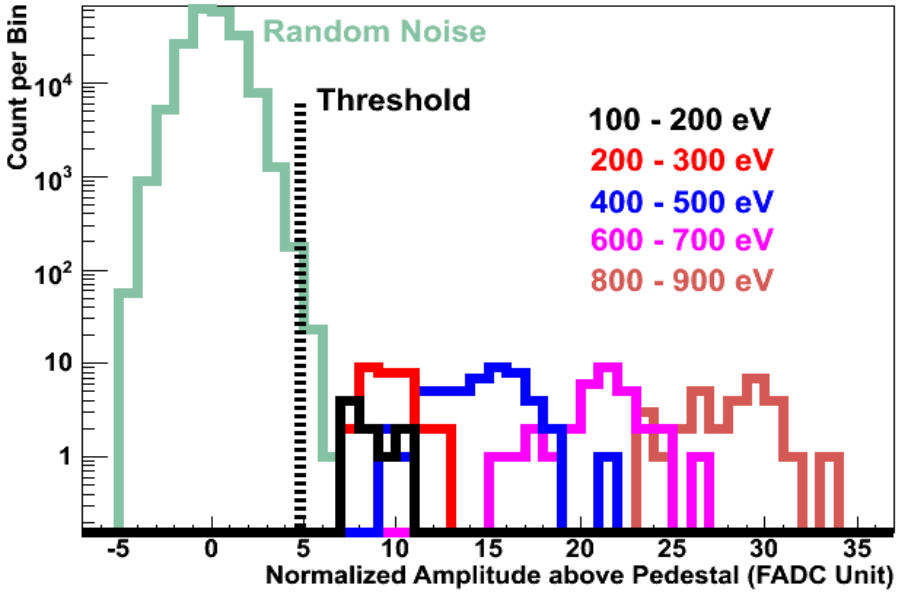

- Various setting for Hardware:
  - ⇨ further reducing threshold
- Fine tuning of Q-Mode spectrum:
  - ⇨ optimization of the resolution & threshold

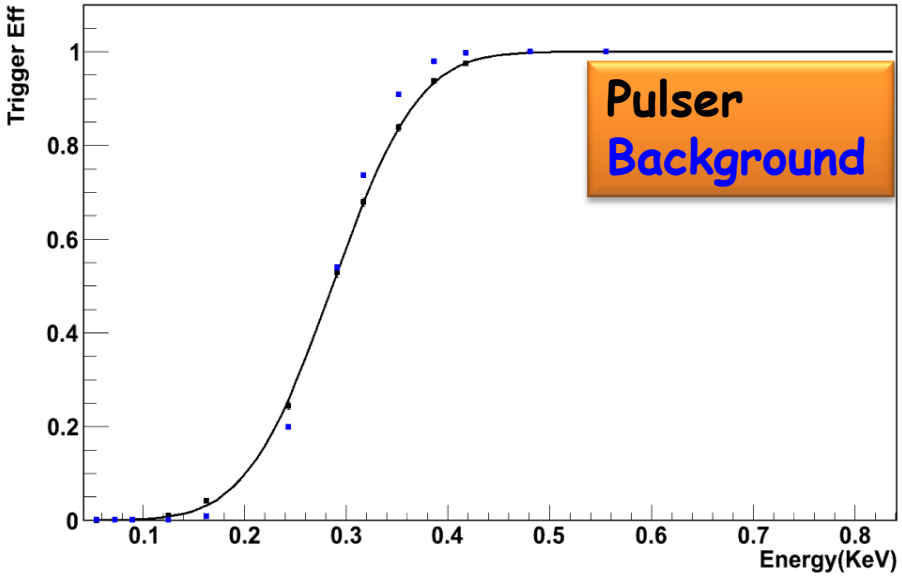
♥ Only good Hardware & software settings were preserved!

# Evaluation of Trigger Efficiency

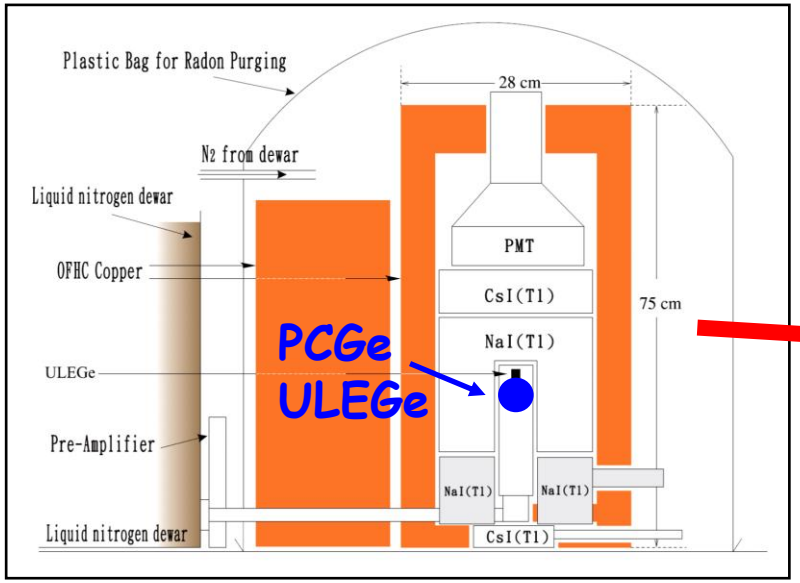
⇨ Reinforced by pulser method

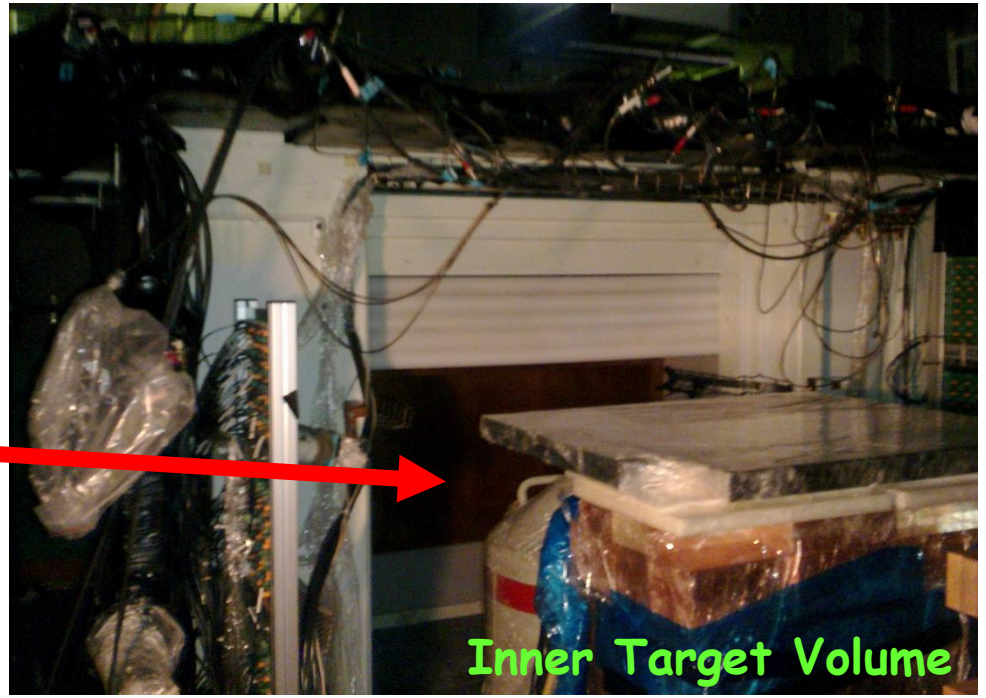
- Efficiency(background): from (*mean* , *RMS*) of Max. Amplitude distribution of physics events
- Trigger Efficency(pulser):
  - ⇨ Survival possibilities of pulser events
- Pulser Method:
  - ⇨ Consistent well with trig. efficiency from backgound
  - ⇨ Potentials for Simulating Physical (CRT+ACT) events



# Event Selection



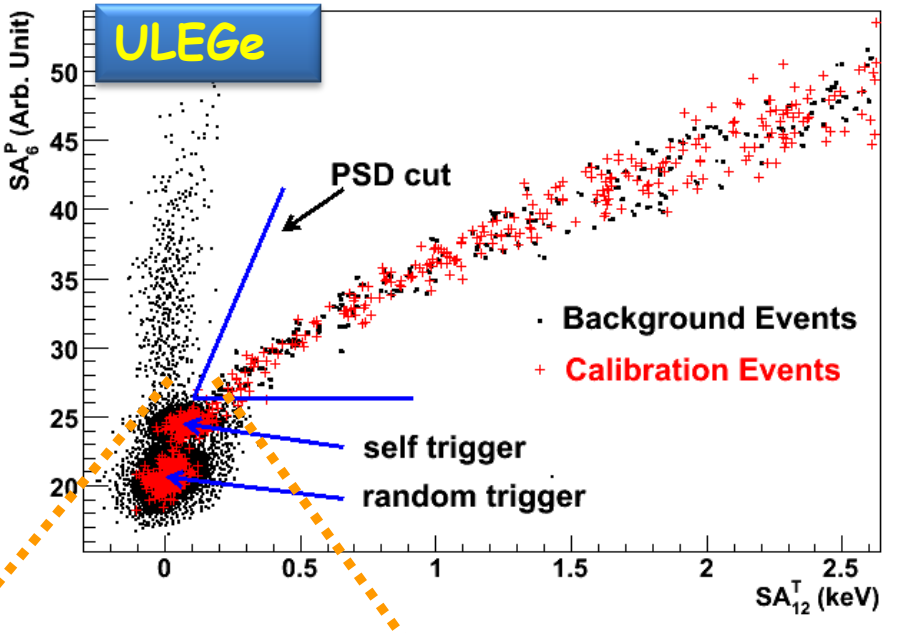




- Candidate Events:
  selected by ⇨
  Anti-Compton Vetos
  [ACV : γ] &
  Cosmic-Ray Vetos
  [CRV: μ] &
  Pulse-Shape Discrimination
  [PSD: electronic noise]

# PSD Selection to Suppress Electronic Noise

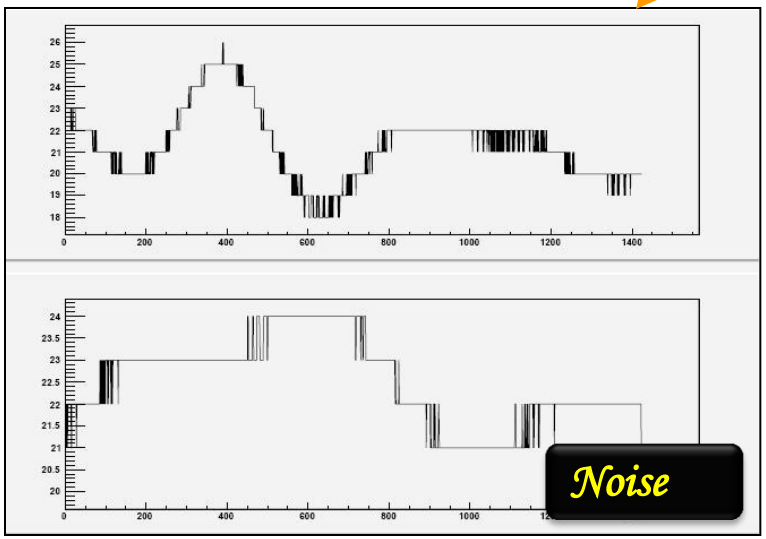
⇨ Correlations in two readout of different gains & shaping times

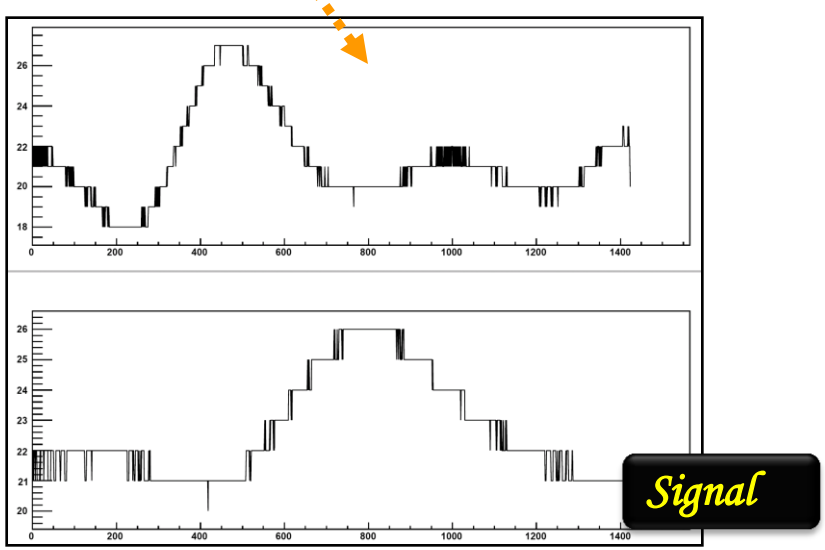
- look for specific pulse fluctuations at specific & known timing



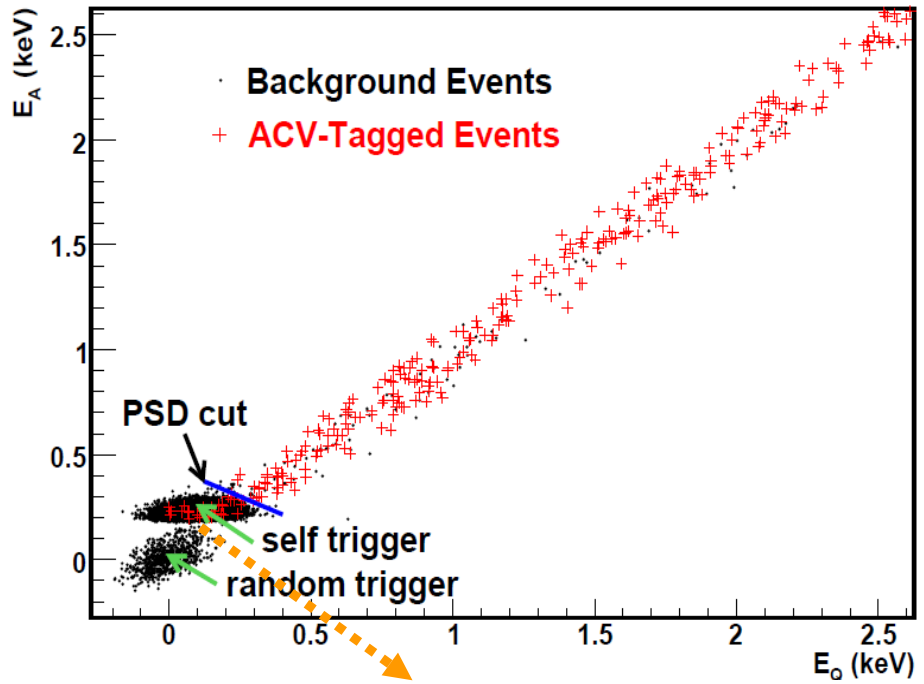

6 μs

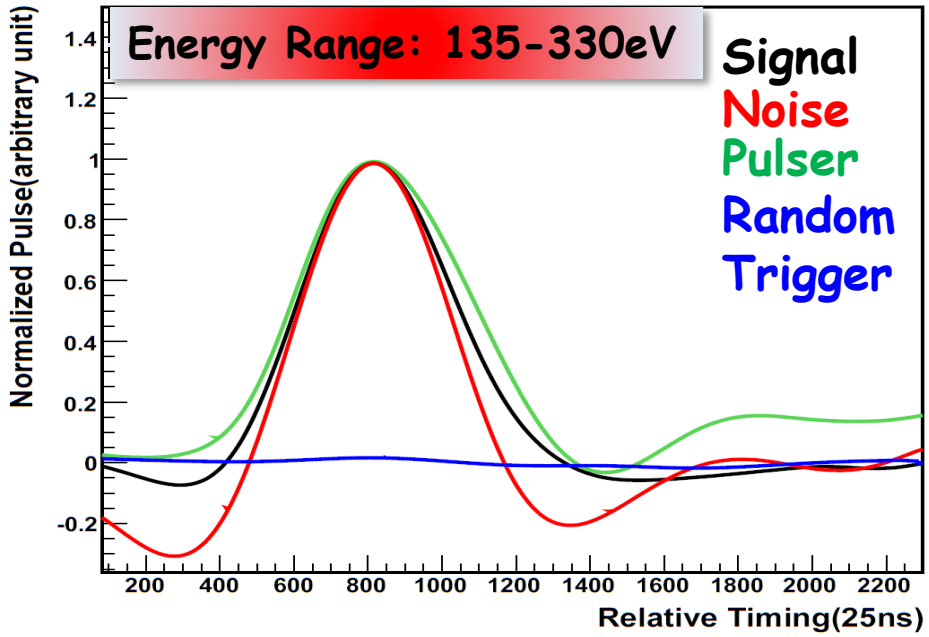
12 μs



# PCGe 500 g ⇨ PSD Cut

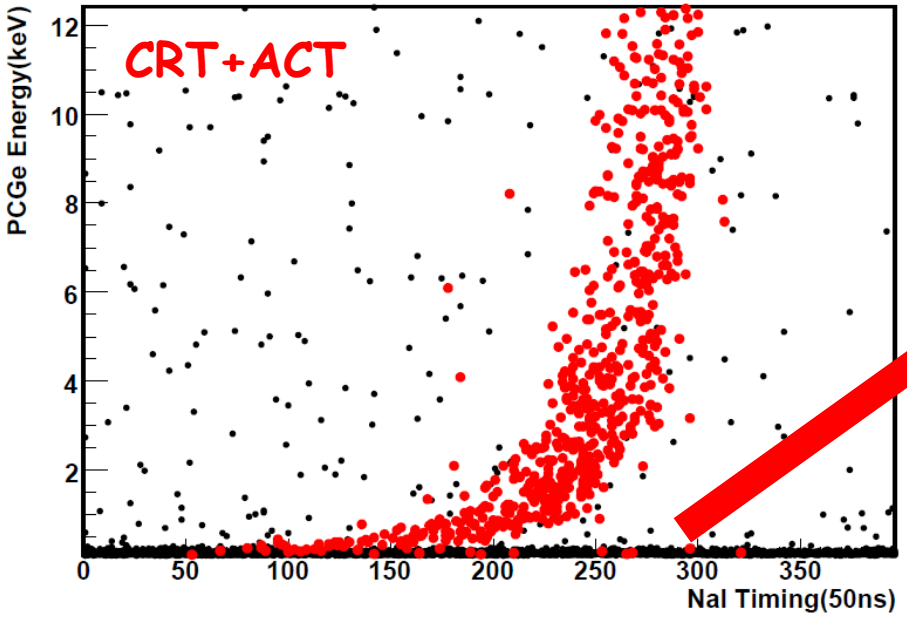


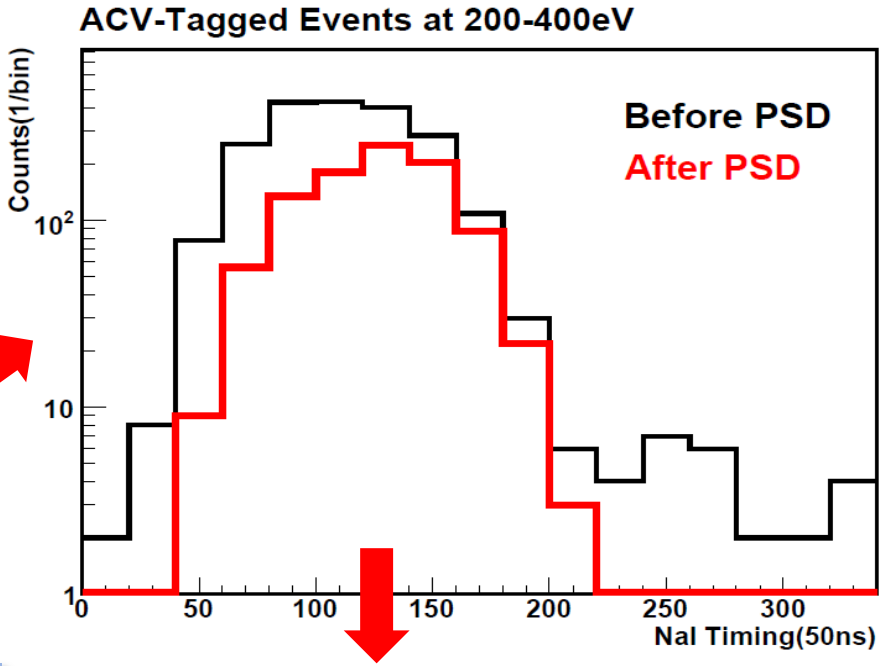




- Below Hardware Threshould:
  - ⇨ Statistical Pulse shape difference between Signal/Noise
- Rigorous PSD Cut Selection:
  - ⇨ good efficiency
  - ⊕ less background
  - ⊕ lower threshould

♥ Only "good" PSD Cut survives !

# PCGe 500 g ⇨ PSD Selection Efficiency



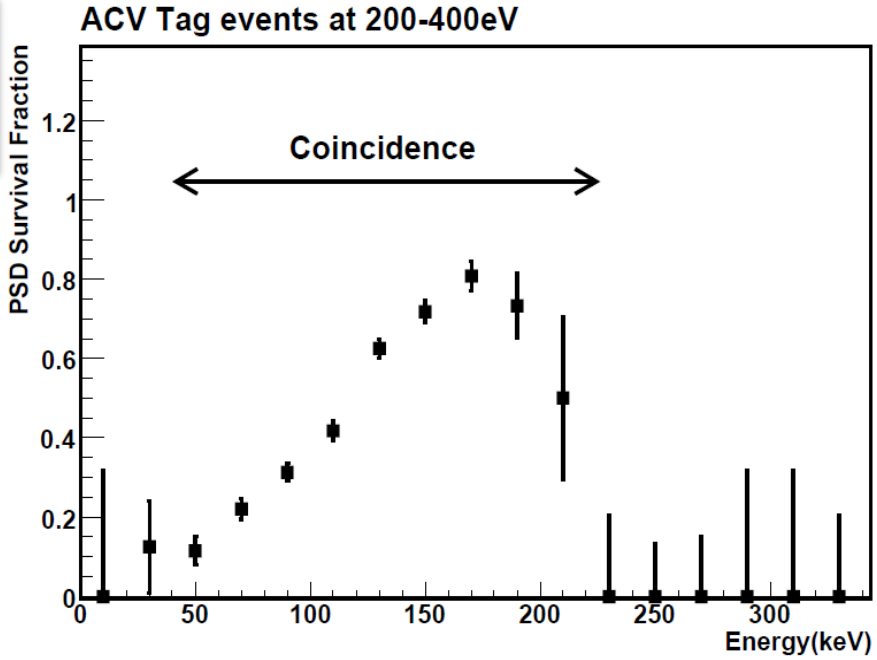




♥ Clean physics event samples selected by CRT+ACT

$$f = \frac{(\epsilon_{\mathrm{PSD}} * P + f_N * N)}{P + N}$$

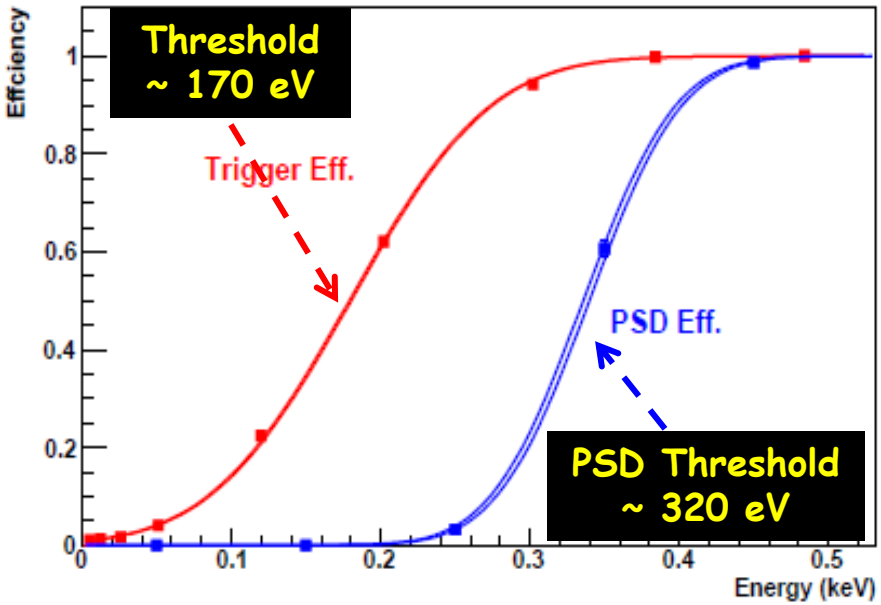
$f_N \sim 10^{-4}$

$$\epsilon_{\mathrm{PSD}} \geq f$$




⇨ Conservative choice :
$\varepsilon_{PSD}$ == survival probability after cut at correct timing

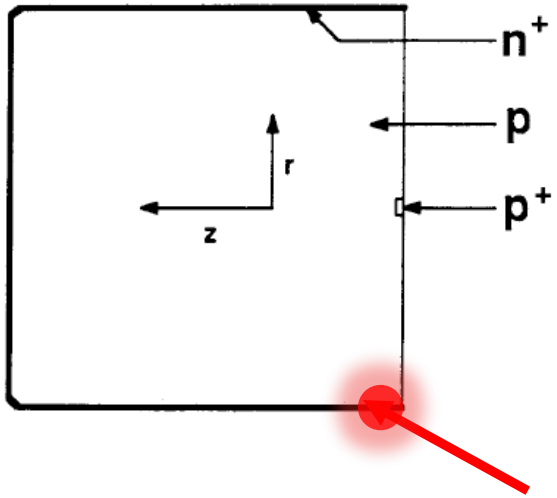
# PCGe 500 g ⇨ Threshold




- Trigger efficiency from background & Pulser
- Trigger threshould (50% eff.) ~ 170eV
- PSD Threshould (50% eff.) ~ 320eV

# PCGe 500 g ⇨ Surface & Bulk

- Origion of Surface Event ⇨
  n+ contact is not totally dead, deposit partial charge
- Surface Event ⇨
  Dominant in low energy
  - ♥ PCGe can reject surface events using "Rise Time cuts"
- Reference Sample for Bulk & Surface:
  selected by ⇨
  Cosmic without anti-Compton
  [CRT+ACV : n-rich, Bulk dominant]
  Cosmic-Veto with Compton
  [CRV+ACT: Ambient γ, Surface-rich]



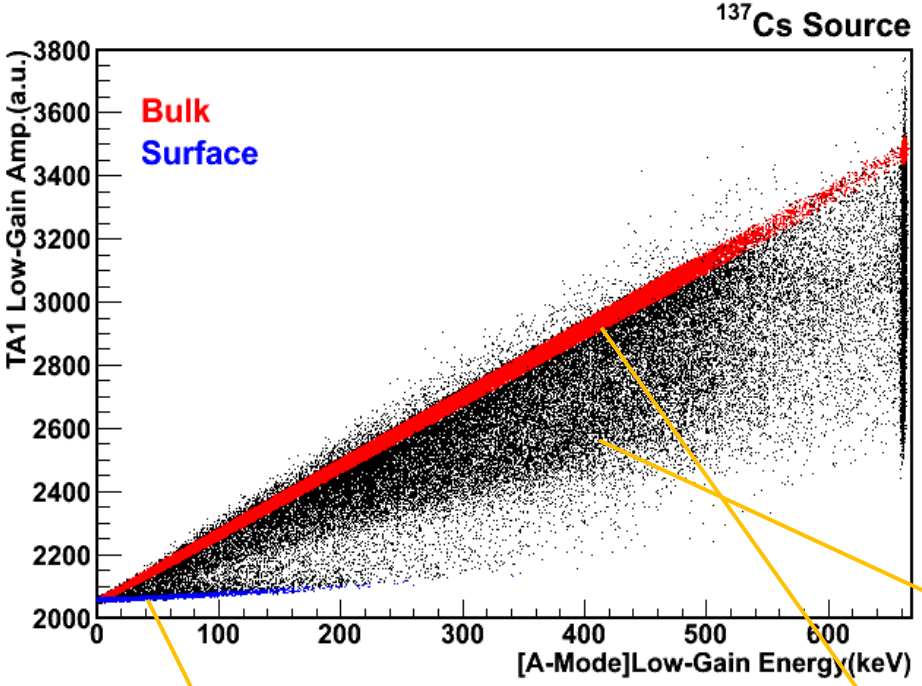


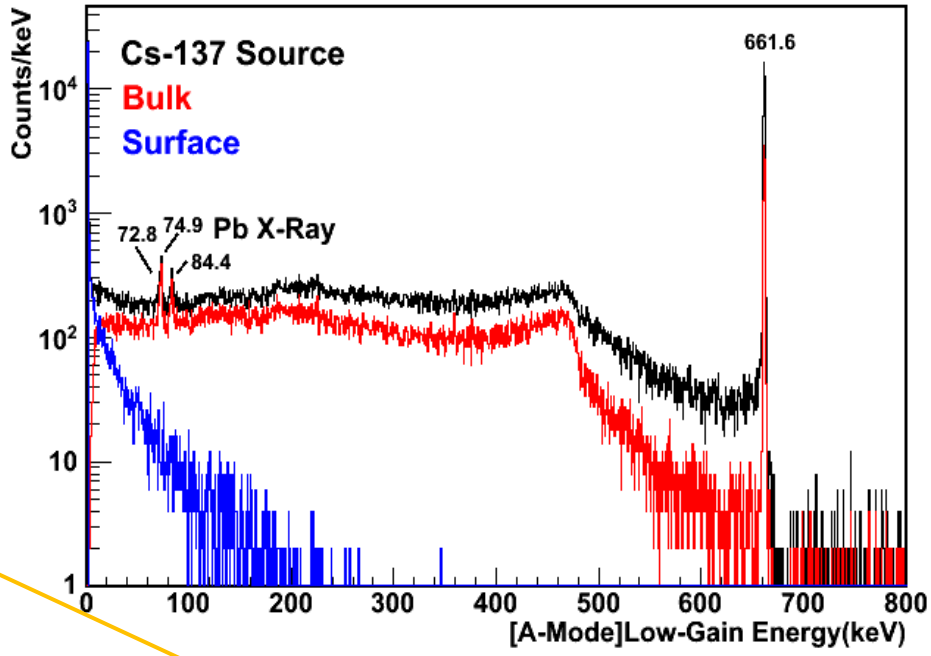
**Reference :**

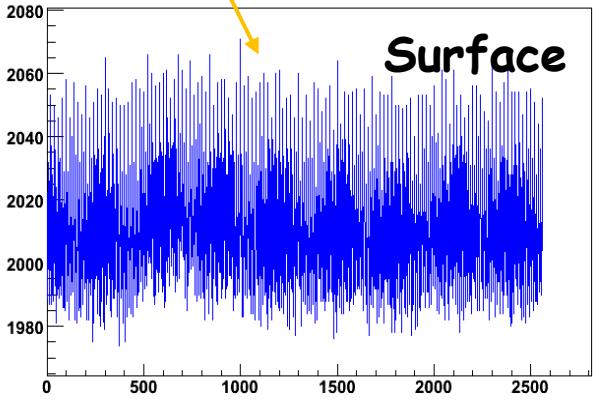
**Strauss and Larsen, NIM 56 (1967) p. 80**

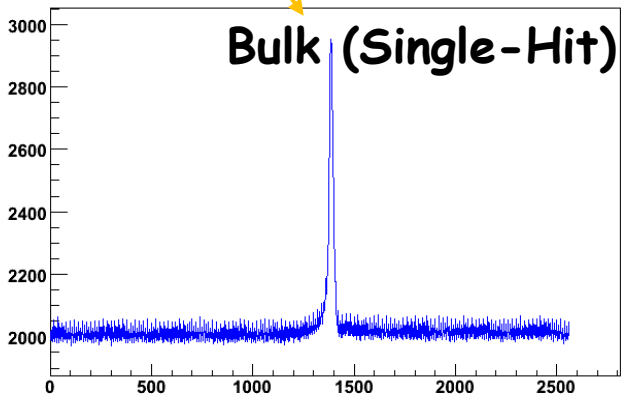
**Sakai, IEEE Trans. Nucl. Sci. 18 (1971) p. 208**

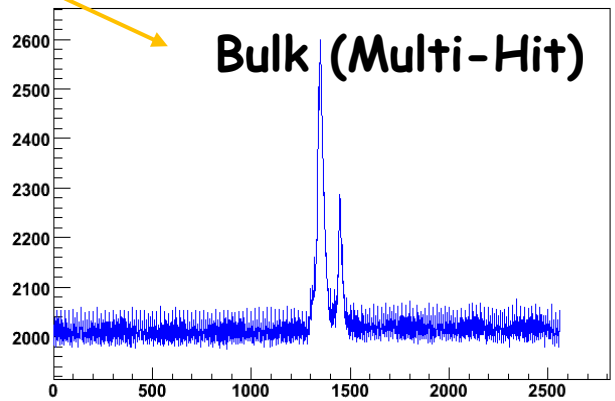
# PCGe 500 g ⇨ $^{137}$Cs Source



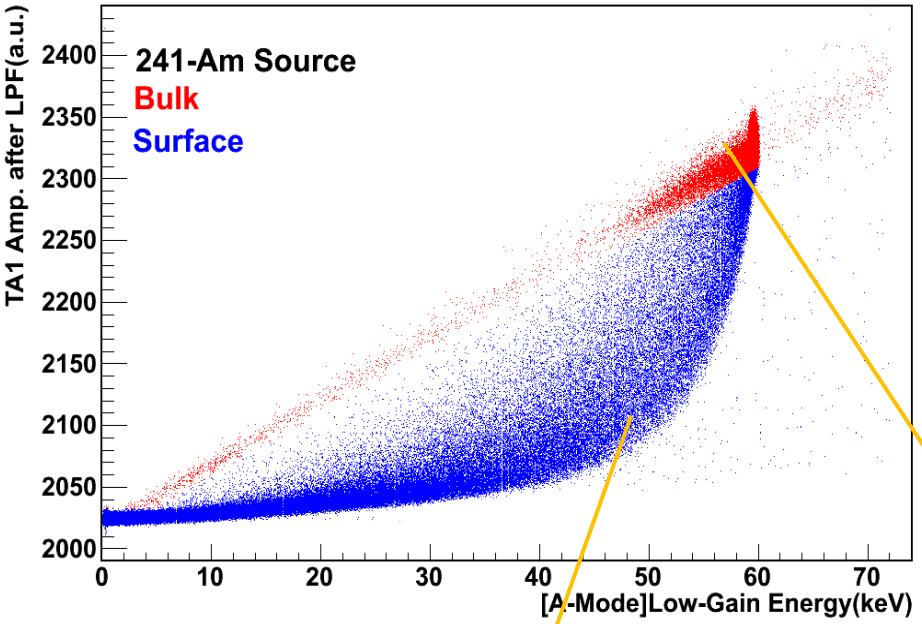



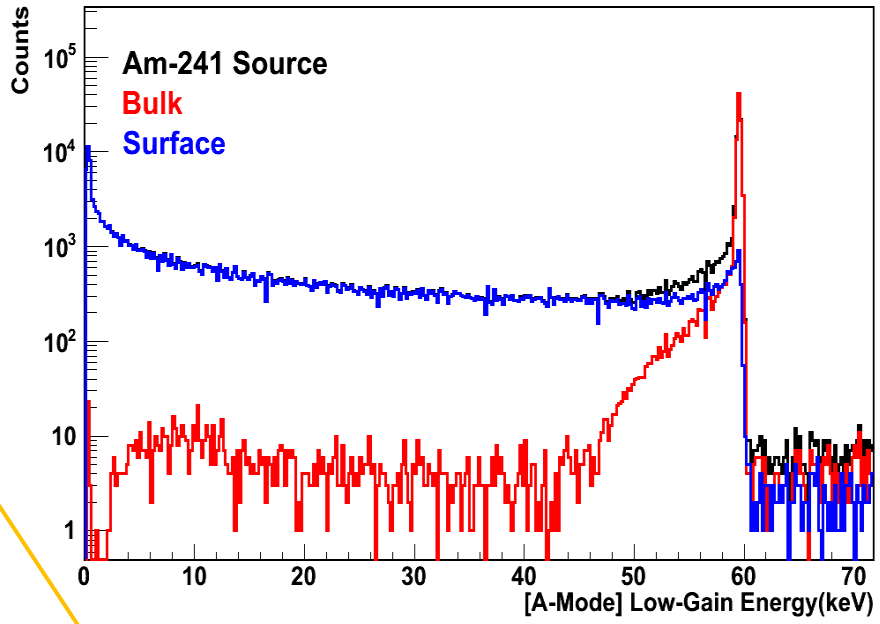



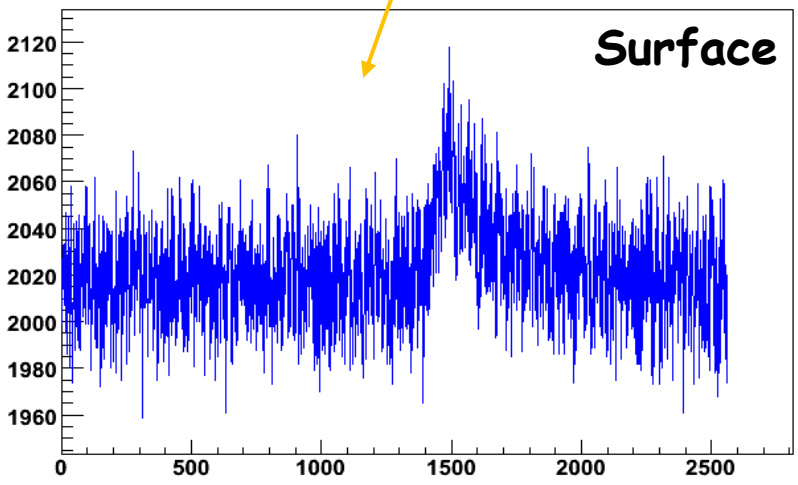



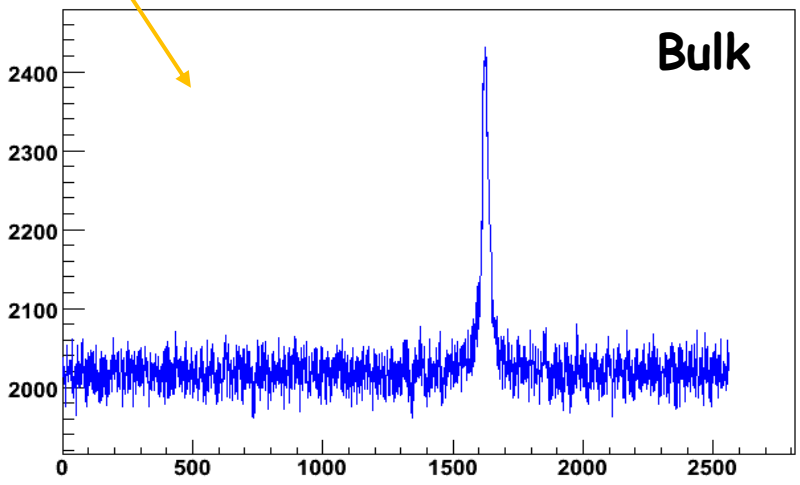



# PCGe 500 g ⇨ $^{241}$Am Source

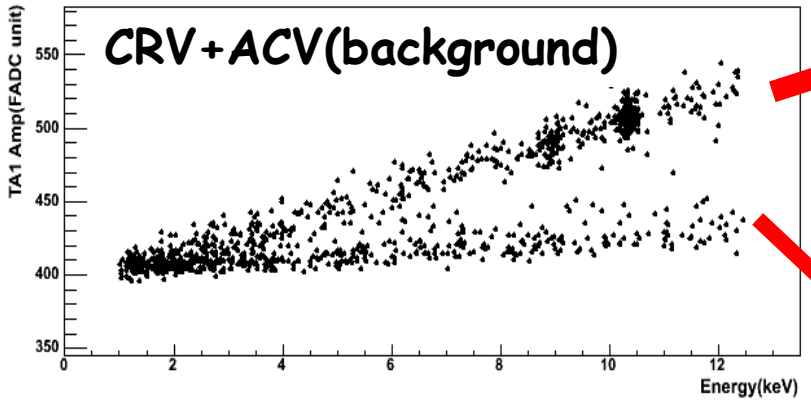


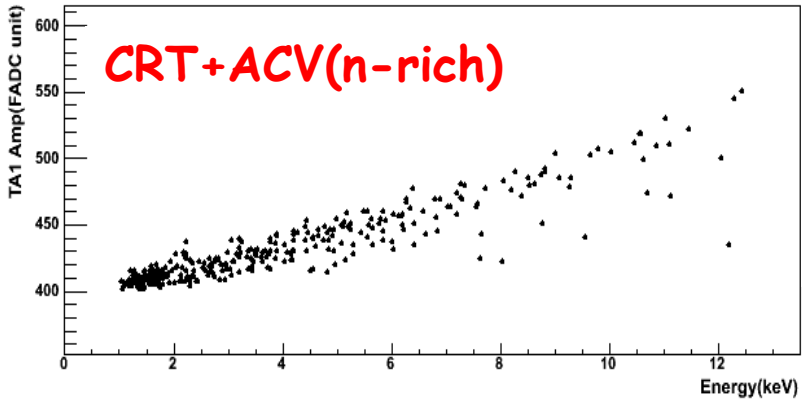



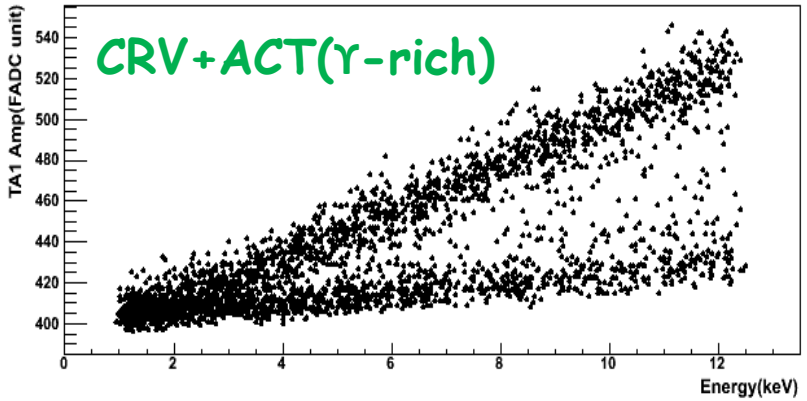



# PCGe 500 g ⇨ Surface & Bulk

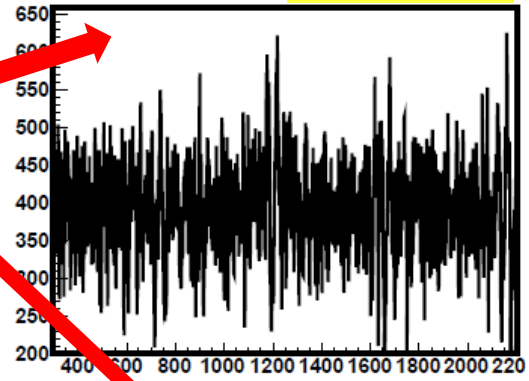


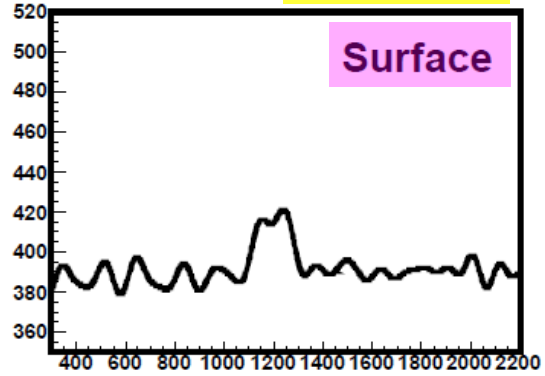



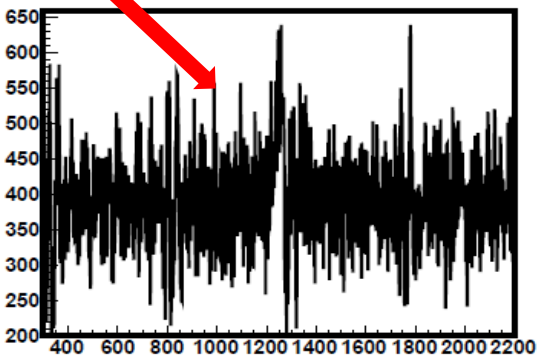



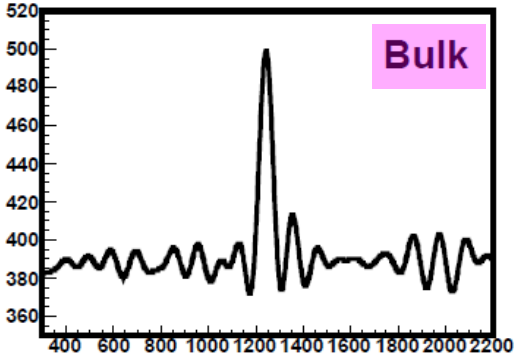

Raw pulse

After LPF



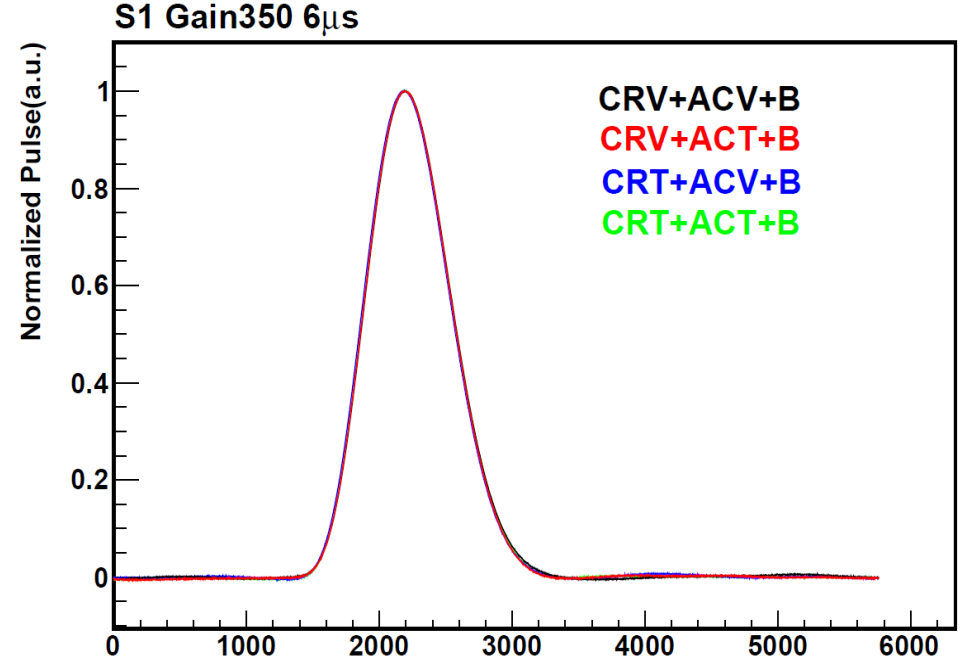


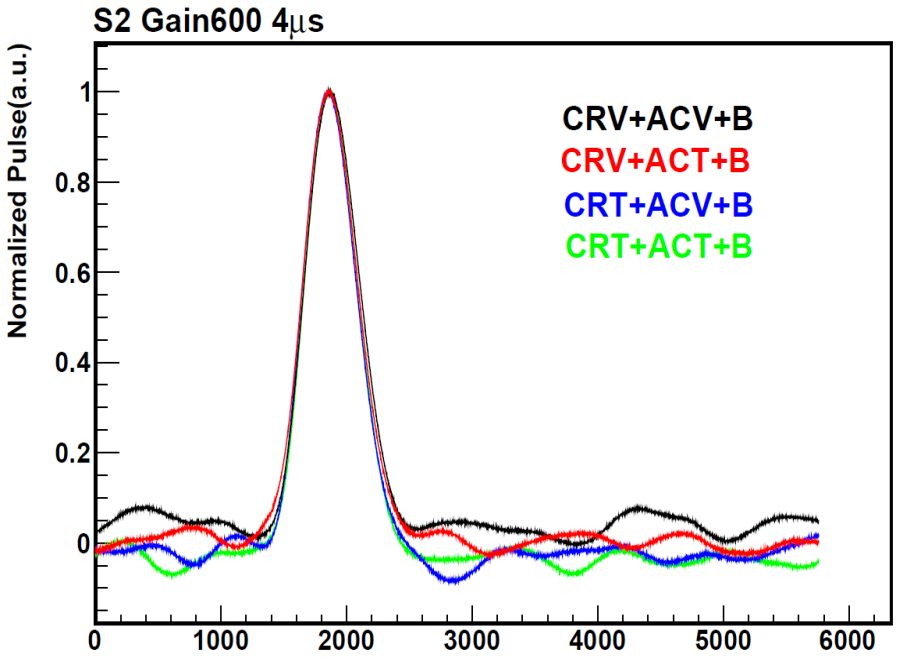



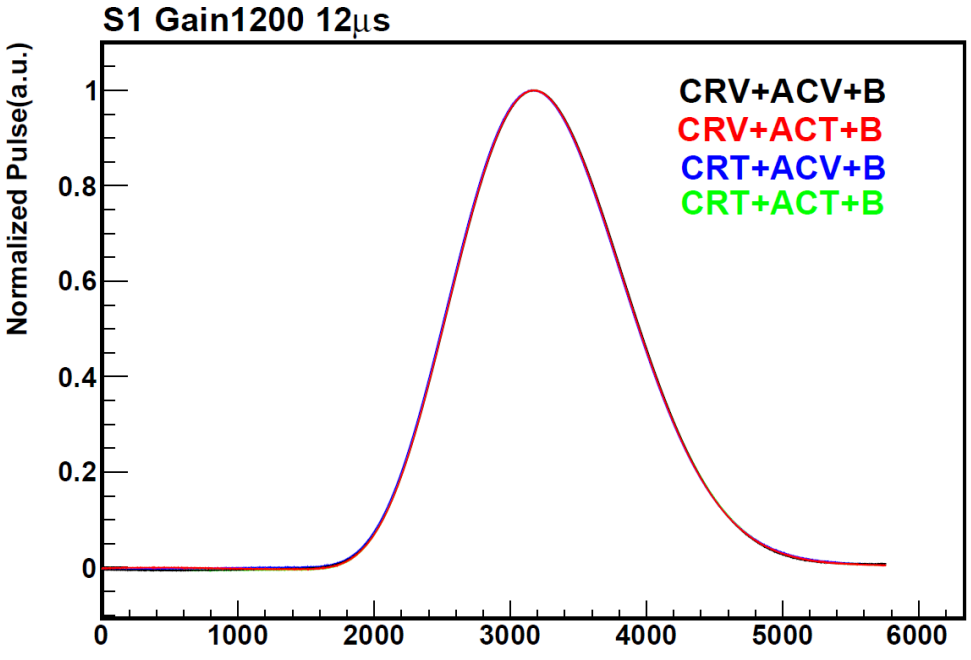


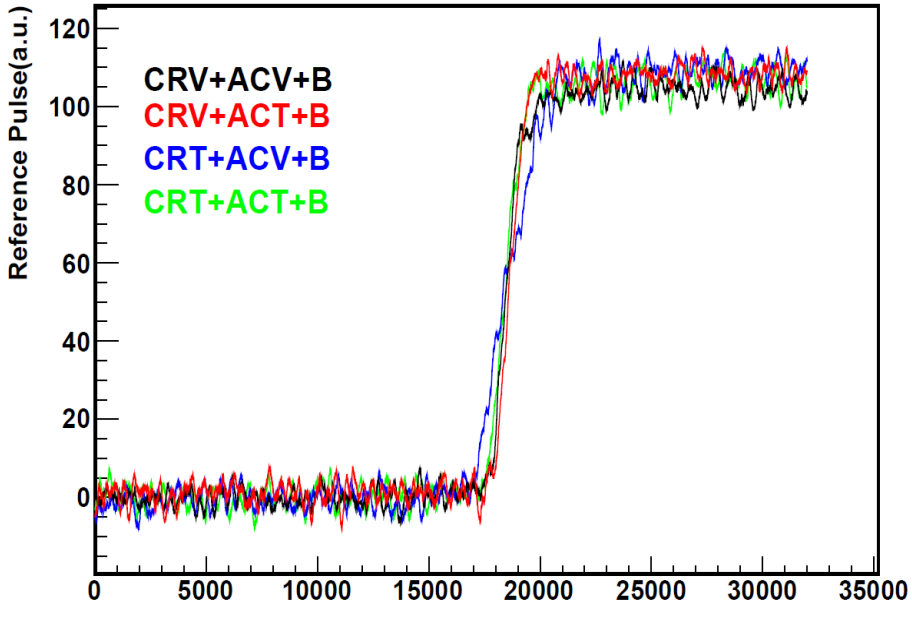

- Surface/Bulk well separate down to 2keV
- >2keV ⇨ ~50% Background Suppression ⊕ >90%efficiency
- <2keV ⇨ Will have good result soon !!

# PCGe 900 g ⇨ Neutron/Gamma Separation(on processing)



# Status and Plans

- Studies on sub-keV background understanding ⇨ reduce background
- Optimization of various *calibration scheme* at sub-keV range
- Develop *PSD techniques* to further suppress noise-edge ⇨ reduce threshold
- Ploishing software tools of S/B Cuts ⇨ further suppress surface events
- Data taking as KS with 900-g Point-Contact Ge Detector
- Goals : Probe low mass region, toward to ν-N Coherent Scattering,exclude un-excluded !!