Sub-keV electro-cooled PGGe development at ASIoP

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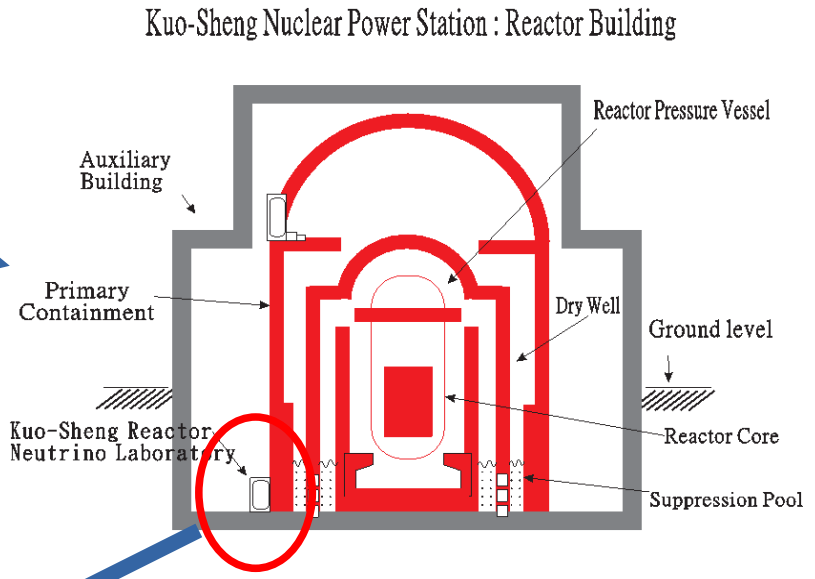
OUTLINE:

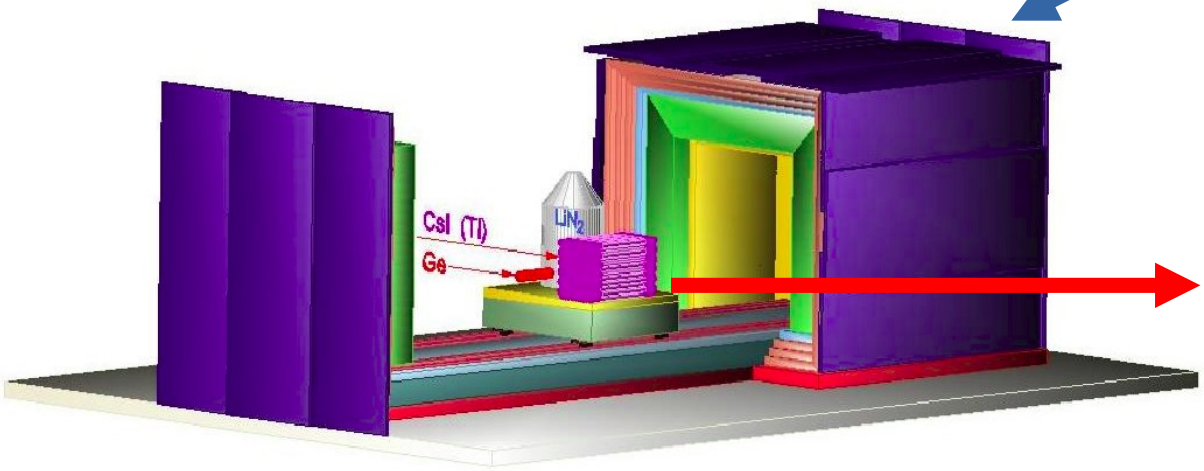
- electro-cooled PCGe detector
- low energy physics
- challenge and development

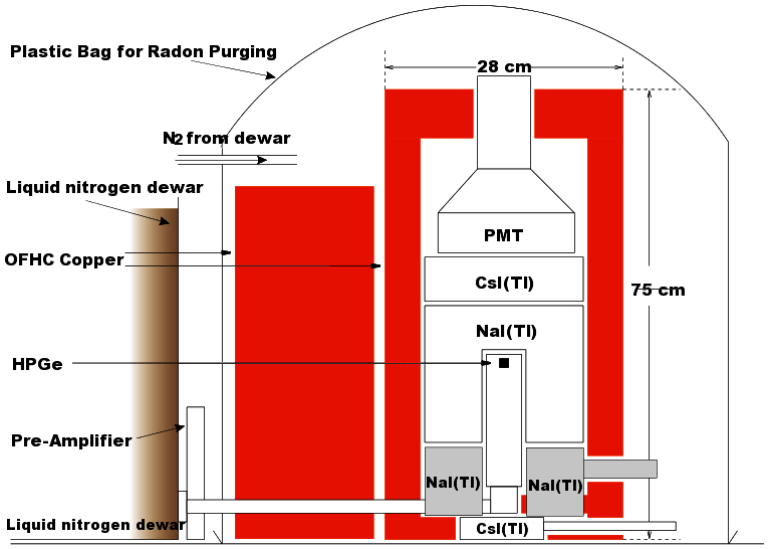
PIRE GEMADARC

2023 June 1

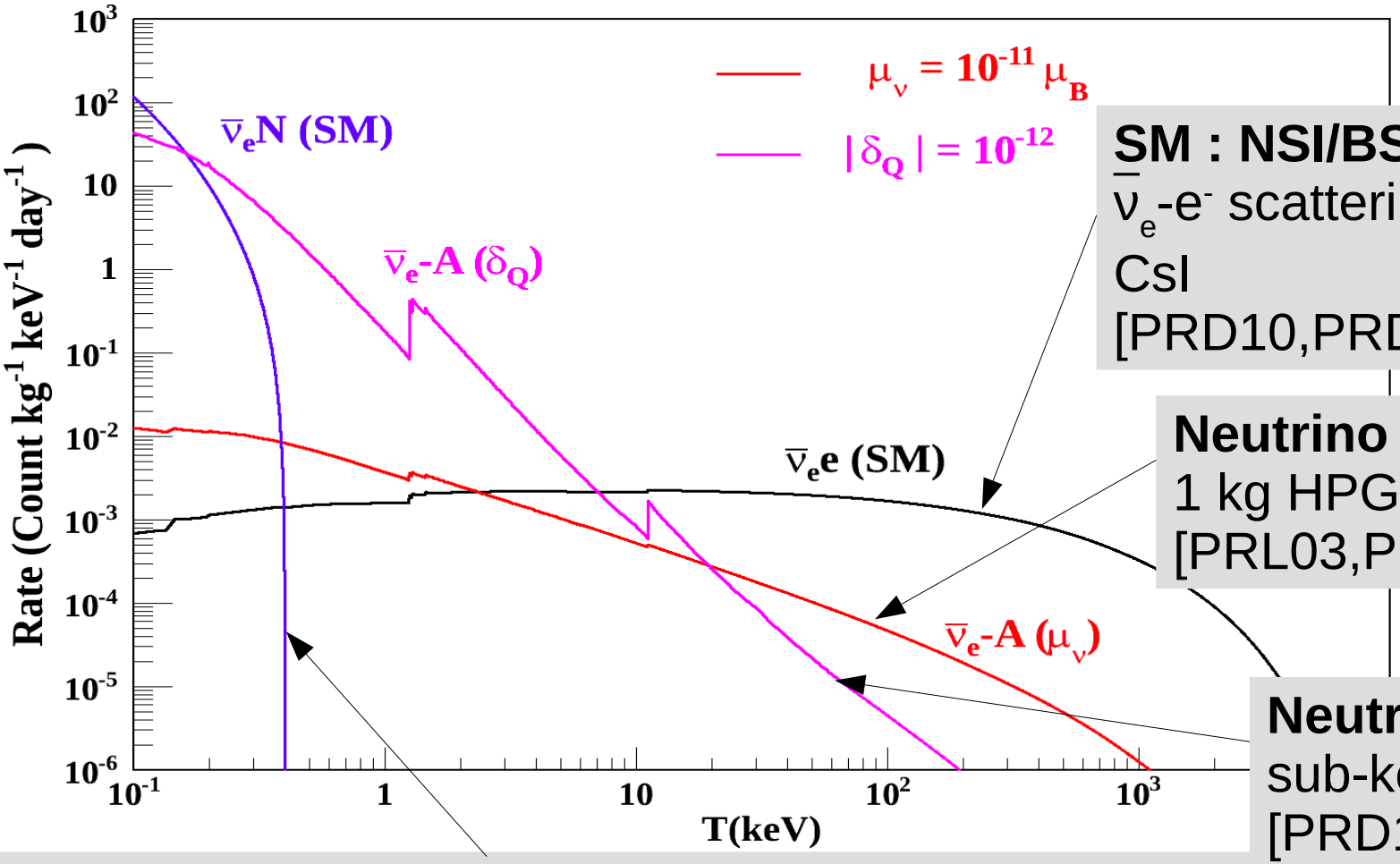
Kuo Sheng Reactor Neutrino Laboratory







sub-keV neutrino physics



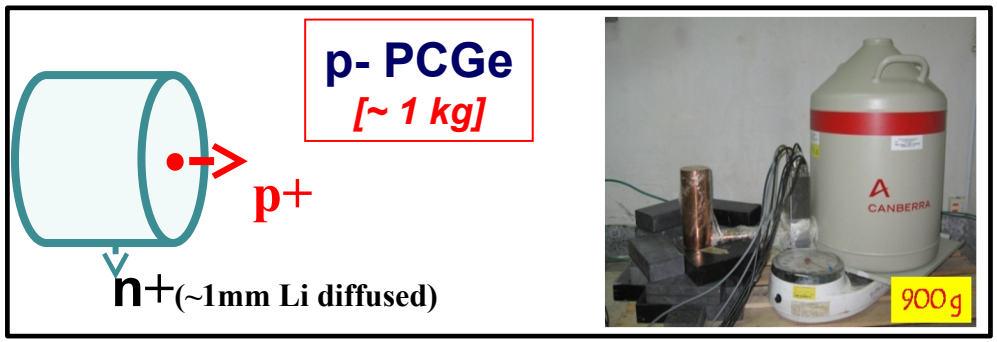
SM : NSI/BSM
$\bar{\nu}_e$-e$^-$ scattering with 200 kg CsI
[PRD10,PRD10,PRD12]

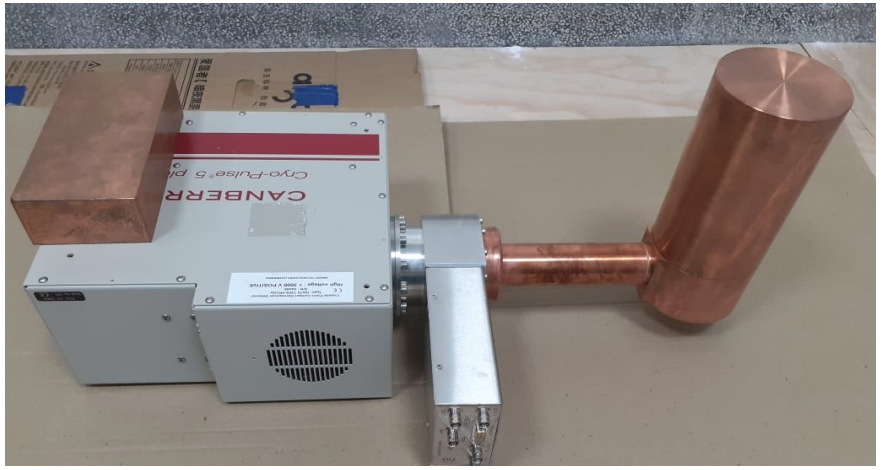
Neutrino Magnetic Moment
1 kg HPGe
[PRL03,PRD05,PRD07]

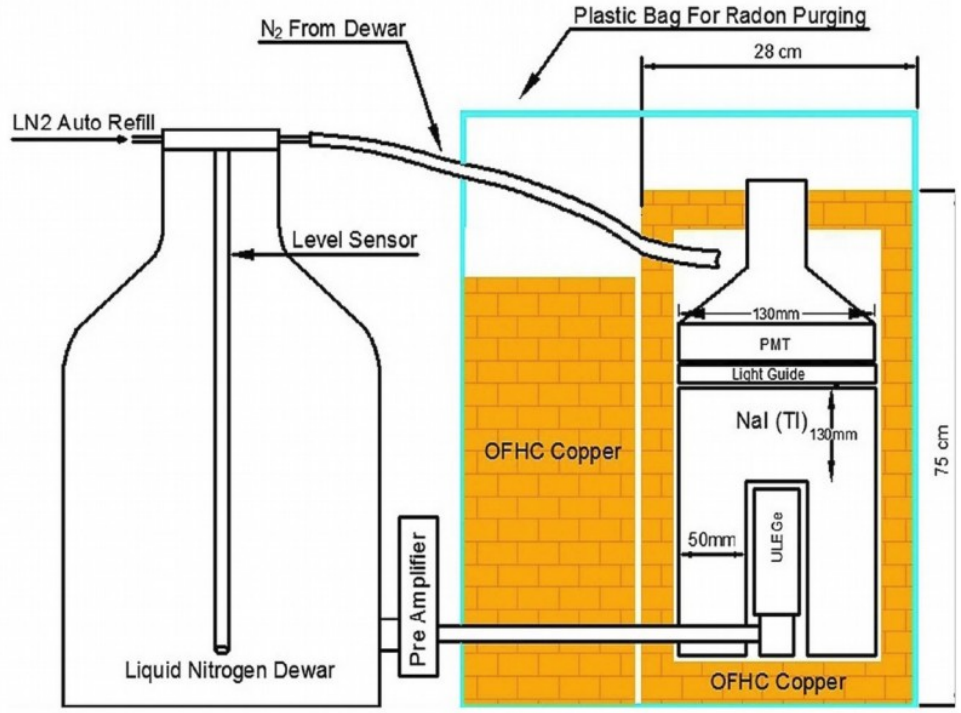
Neutrino milli-charge
sub-keV ULEGe, PCGe
[PRD14]

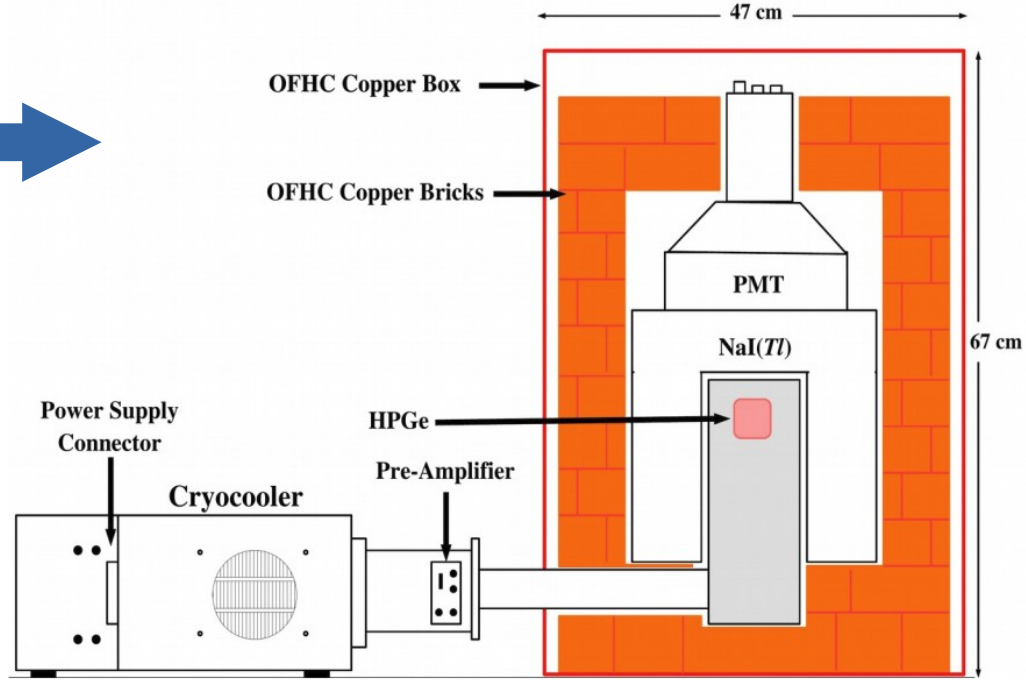
ν-Nuclei Coherent Scattering [goal]
sub-keV ULGe, PCGe
Dark Matter Searches at KSNL [PRD09,PRL13,AP14]

point contact Ge detector: from LN2 cooled to electro-cooled

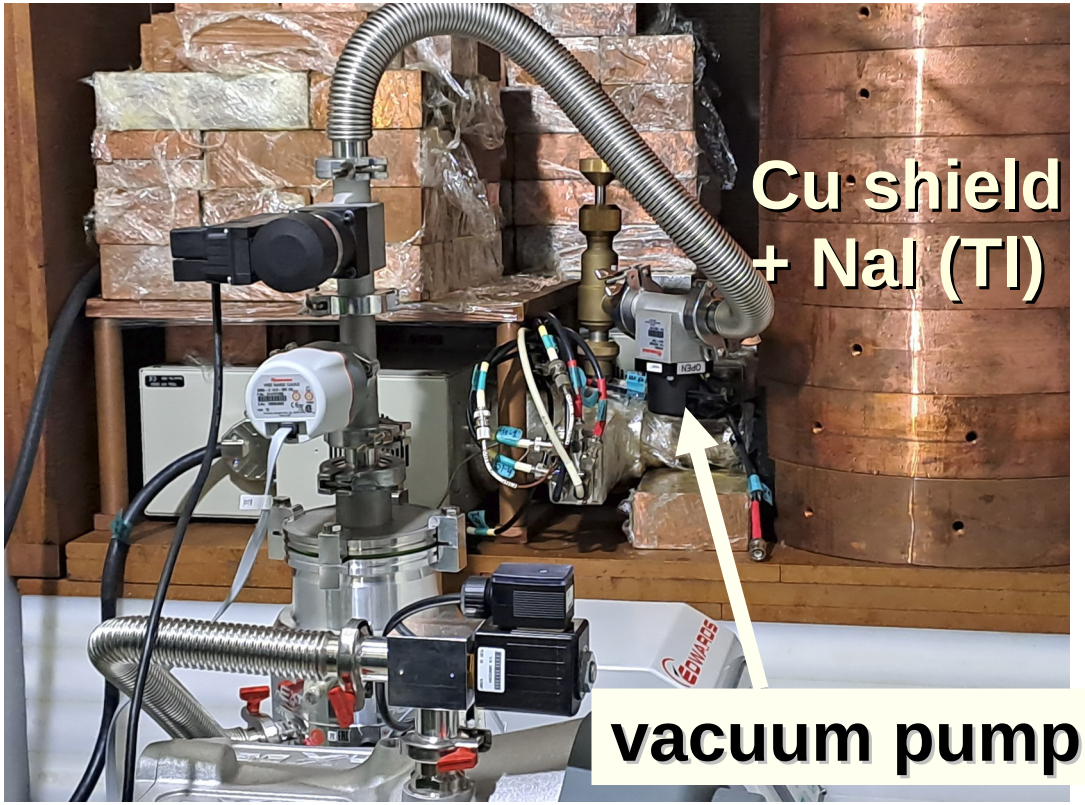


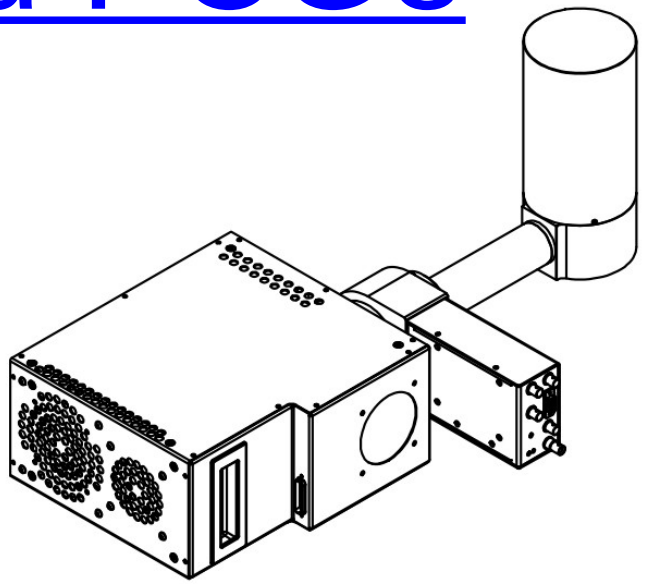


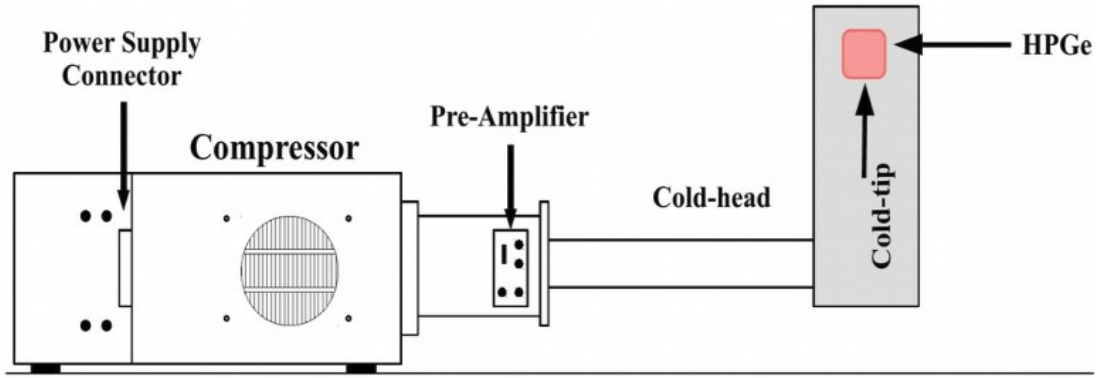




electro-cooled PCGe







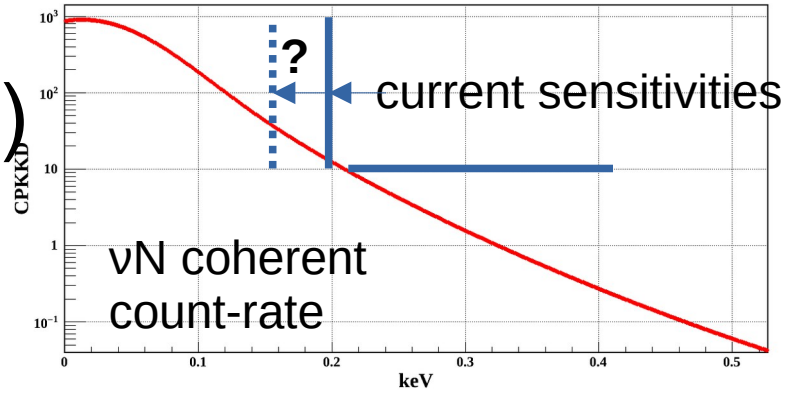
two detectors:
50mm × 50mm ~ 500g
70mm × 70mm ~ 1500g

electro-cooled PCGe

- vacuum pump on site
- low temperature, good resolution

  FWHM: 72.9 eV (-198℃) → 72.3 eV (-200℃)
- noise-edge ~ 200 eV
- analysis threshold ~ 160 eV (?)
- shielding re-design optimized

  for electro-cooled? → heat problem

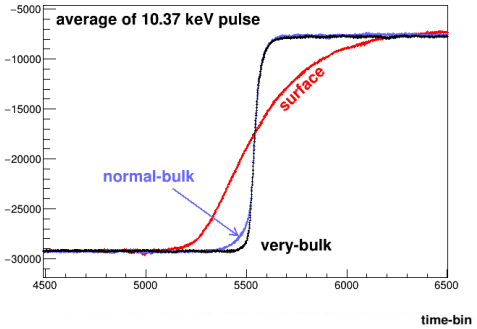


challenge at sub-keV

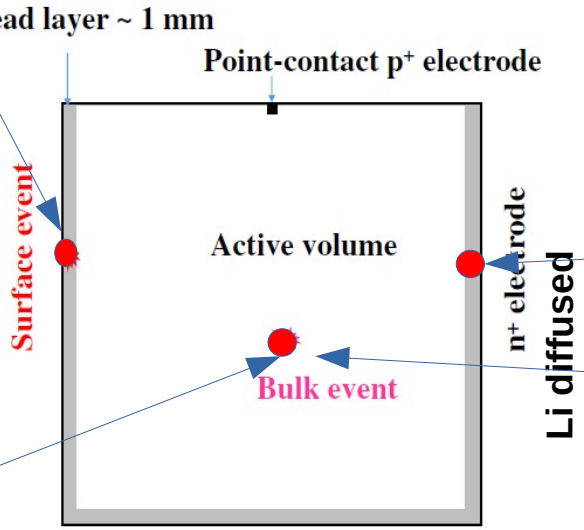
- Quenching Factors.
- Energy Definition & Calibration.
- Trigger Efficiencies near threshold.
- Physics vs. Noise Pulse-Shape Selection :
- algorithms & efficiencies.
- Bulk vs. Surface Events Selection :
- algorithms & efficiencies.
- Background understanding

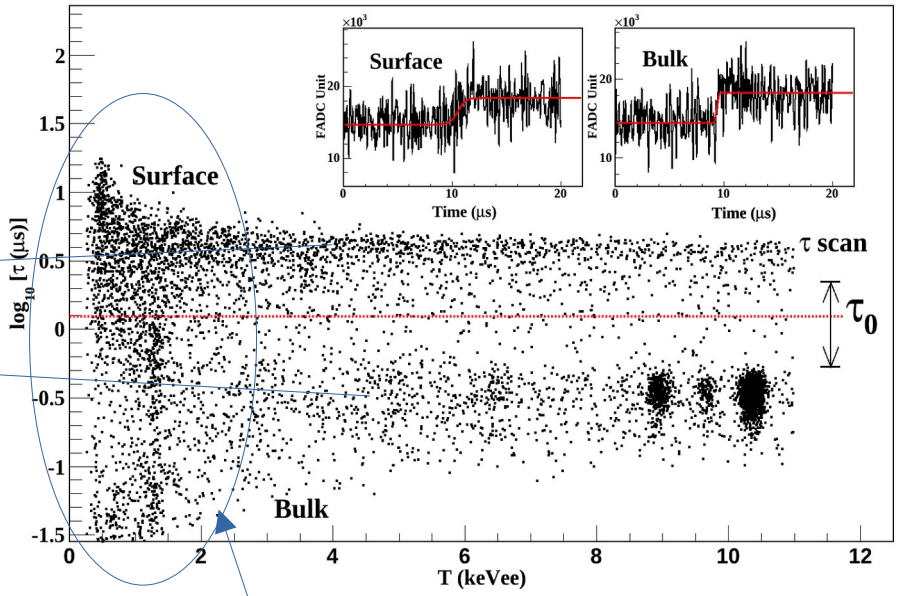
bulk/surface separation

surface
- partial energy deposit
- diffuse and drift → slow



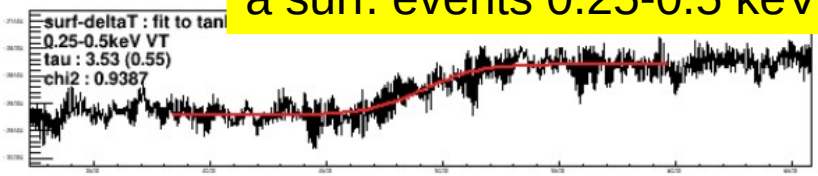
bulk
- full energy deposit
- drift → fast



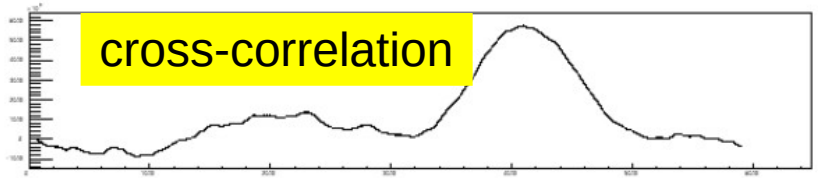


bulk and surface events are not well separated at < 1 keV

a surf. events 0.25-0.5 keV

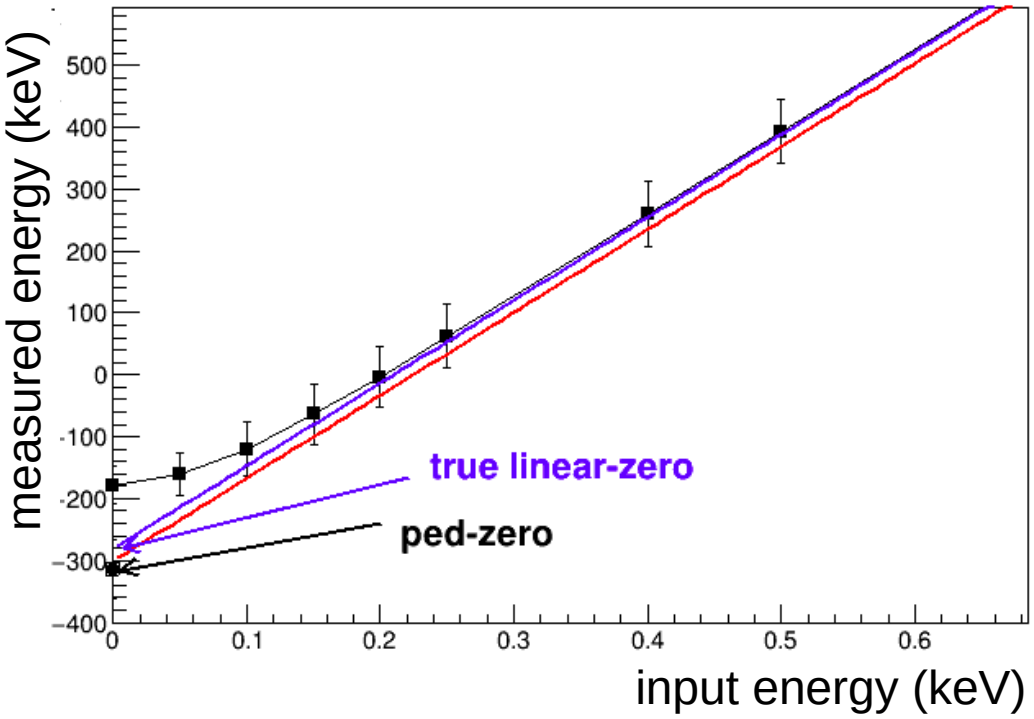


cross-correlation



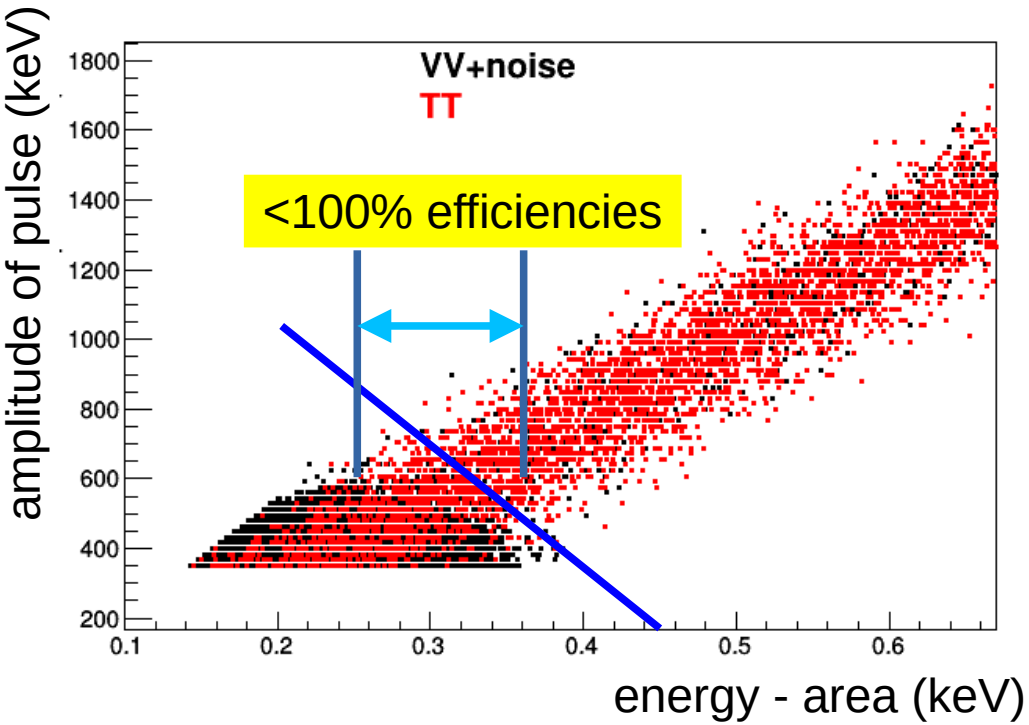
- cross-correlation between real pulse and "standard" pulses help to determine transition time → better bulk/surface
- cross-correlation with different "standard" pulses

energy defination at sub-keV



- high frequencies noise → shift energy relative to pedestal-zero.
- low frequencies noise → non-linear effect at < 100-200 eV.
- depend on energy definition : area of pulses, amplitude of pulses

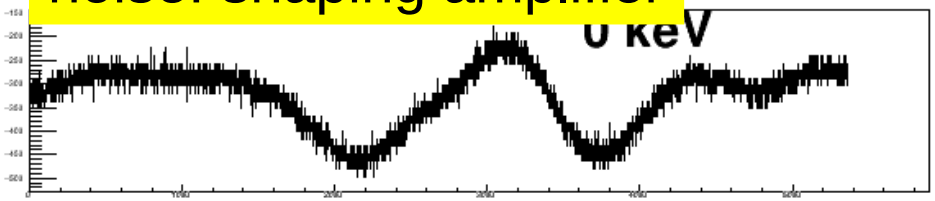
what are noise?



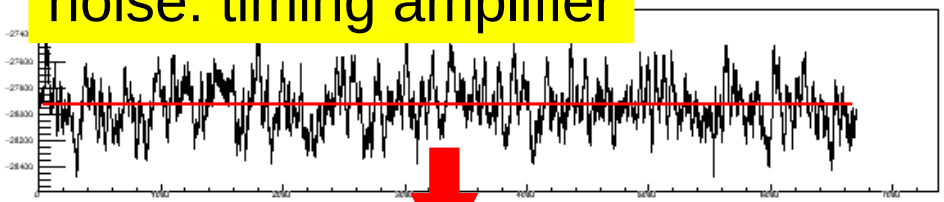
- **red** : events with Ge-triggered + Cosmic-triggered + NaI-triggered
- **black** : only Ge-triggered (DM, ν)
- basic tools to separate signal/noise.
- tricks : to get the efficiencies correct.

what are noise?

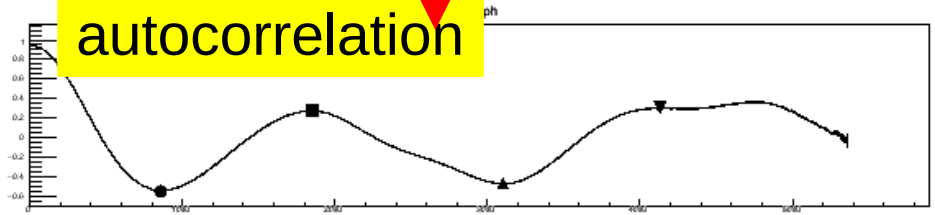
noise: shaping amplifier

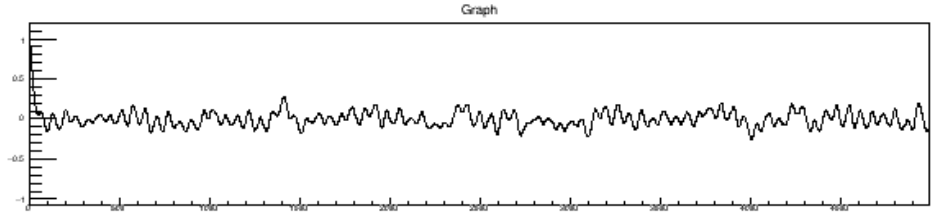


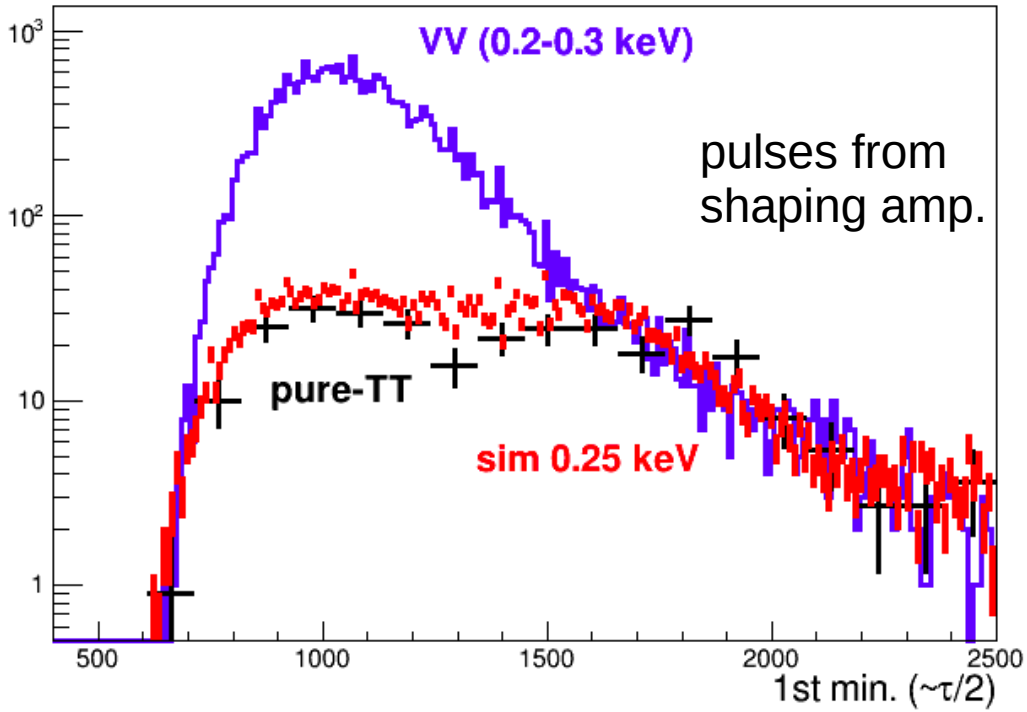
noise: timing amplifier



autocorrelation



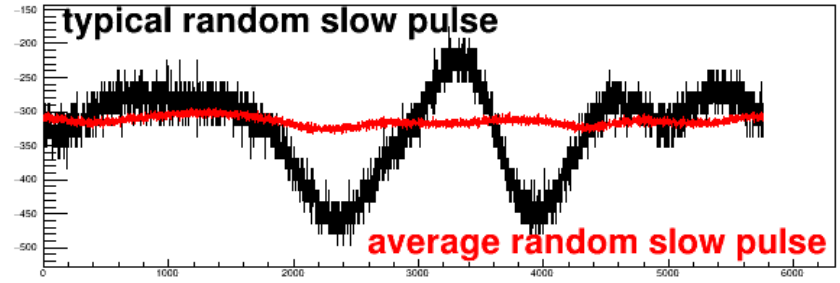




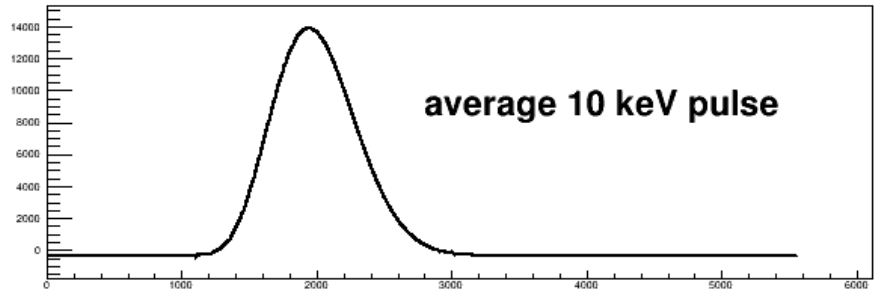
black: Cosmis+NaI+Ge-triggered
red: signal + noise simulation
blue: Ge-triggered

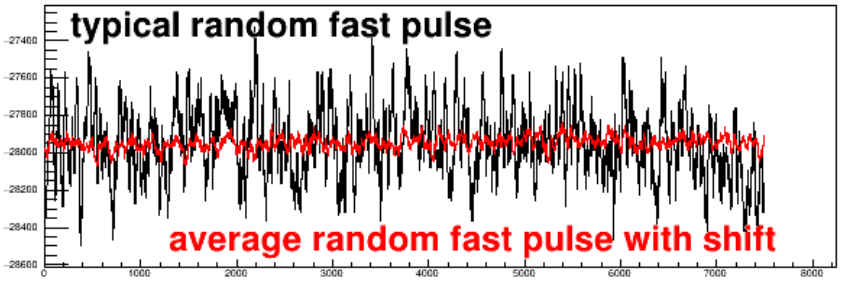
in this sample, noise from shaping amp. ~ period of 30 μs
true signal do not always auto-correlated at 30 μs.

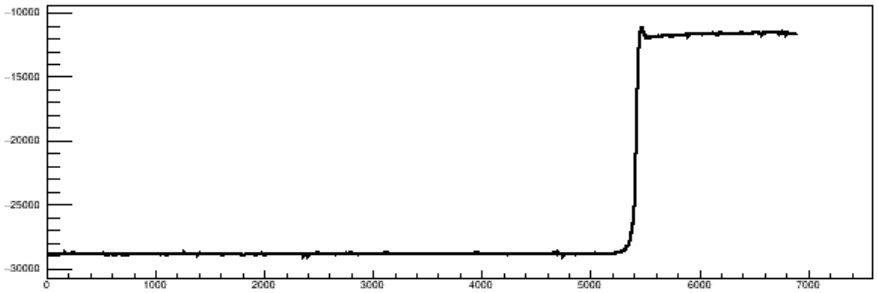
simulated signal+noise by software



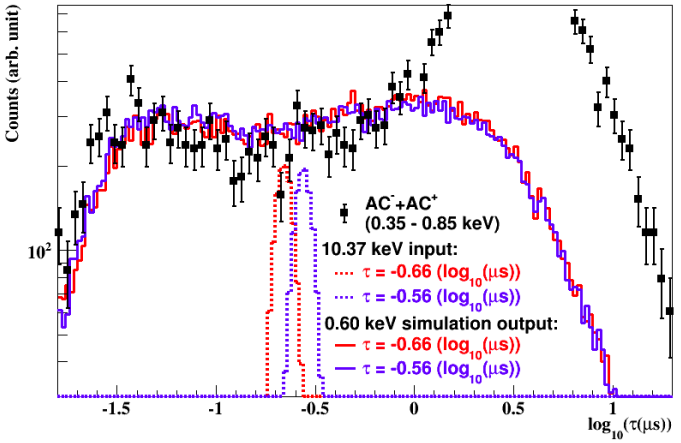
+





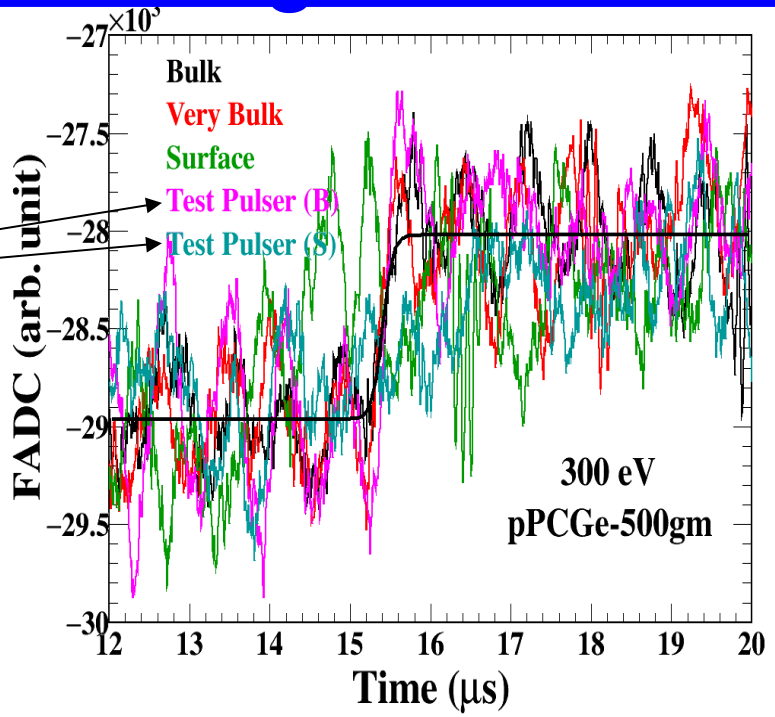


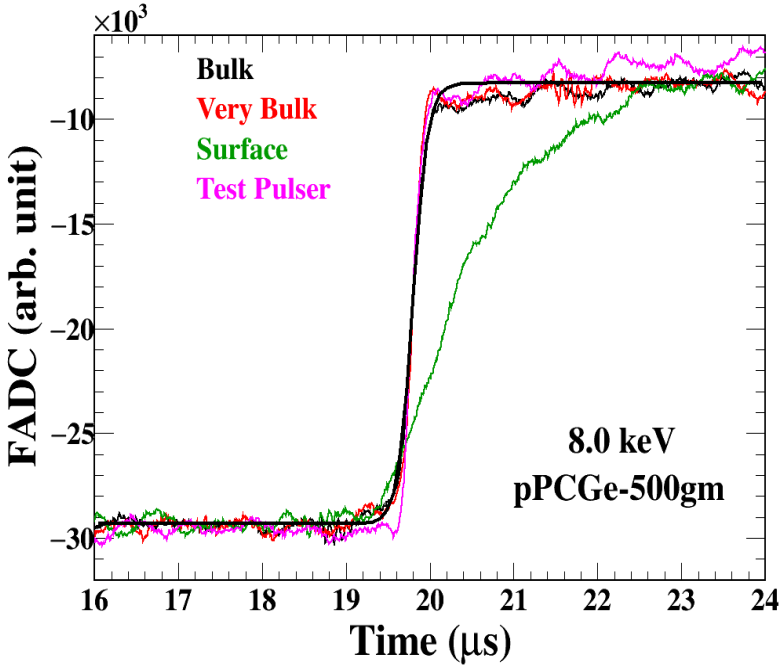
- data is taken with random-triggered (every ~ 10 sec.) → pure noise
- in-situ noise
- simulated pulses, except timing information
- "measured" energy
- produce matched rise-time distributions of bulk



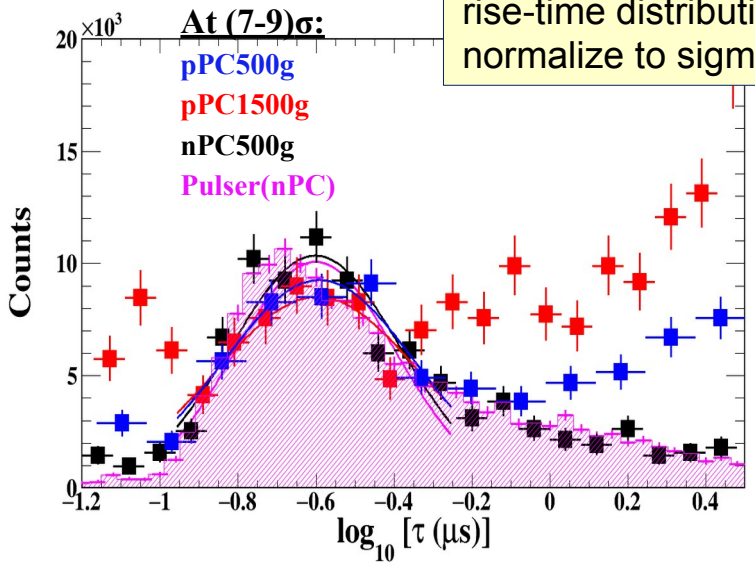
simulated signal+noise by hardware (pulser)

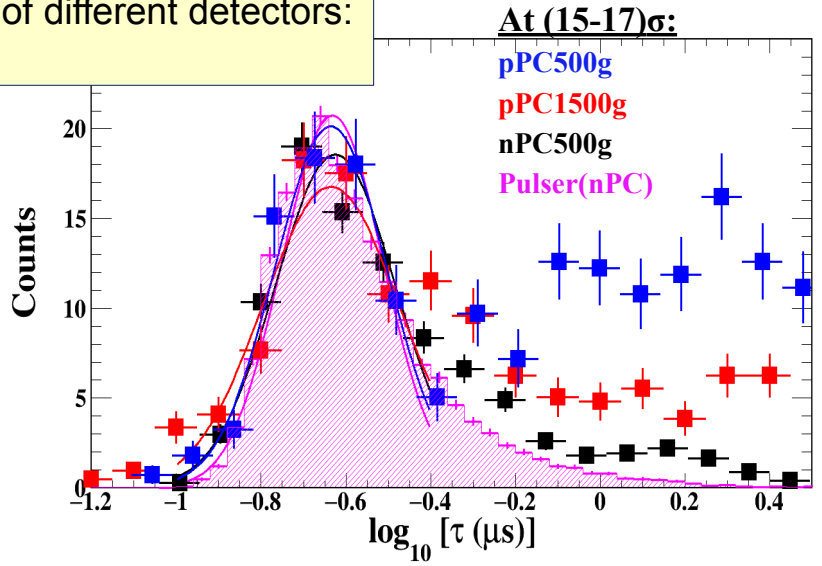
programmable pulse-shape





rise-time distributions of different detectors: normalize to sigma





simulated signal+noise

by hardware:

- not in-situ noise
- simulated pulses include timing information
- "input" energy (before smear-out by energy resolution)
- produce matched rise-time distributions of bulk
- critical to answer
  "probability to have a 180 eV events above 200 eV threshold"

both:

- all events selection, Bulk/Surf., non-linear correction and efficiencies at < 1 keV
  should be cross checked by both software and hardware signal+noise simulation
- enhanced statistic uncertainties.
- some efficiencies can only be calculated by noise simulation.

- more ideal for sub-keV signal/noise:

  neural network?

  established filters?

  others.

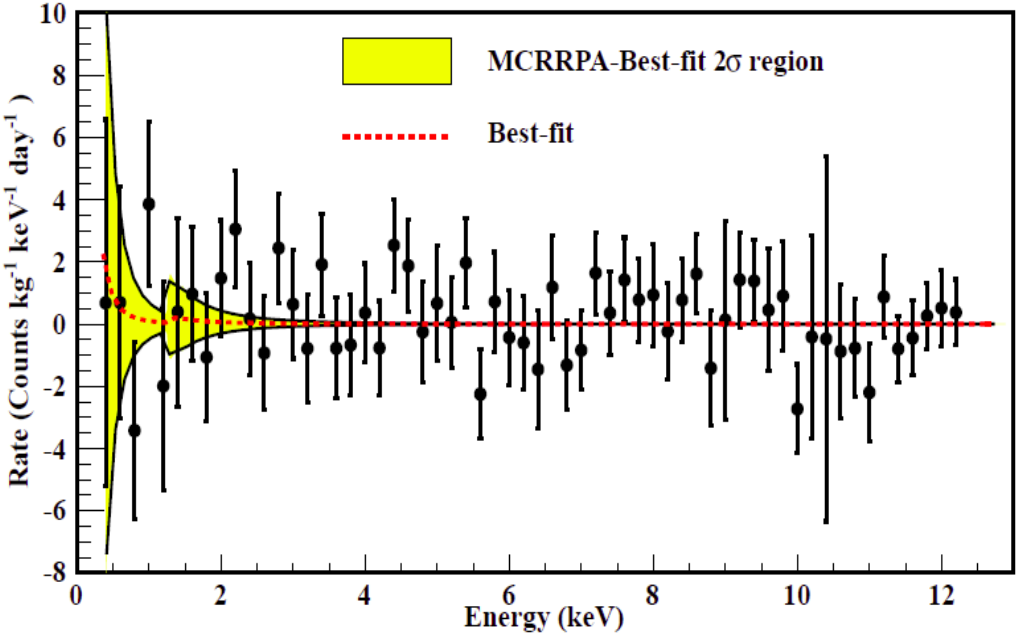
Thank you.

In KSNL					
High Voltage (V)	**Shape Filter**	**Shaping time (µs)**	**Temp. (°C)**	**PED (σ) (eV)**	**FWHM (eV)**
3000	Triangular	6	-200	31.2	73.5
3020	Triangular	6	-200	30.5	71.9
3020	Triangular	4	-200	31.3	73.6
3040	Triangular	6	-200	30.9	72.7
3040	Triangular	6	-198	31.0	72.9
3040	Triangular	6	-202	30.7	72.3

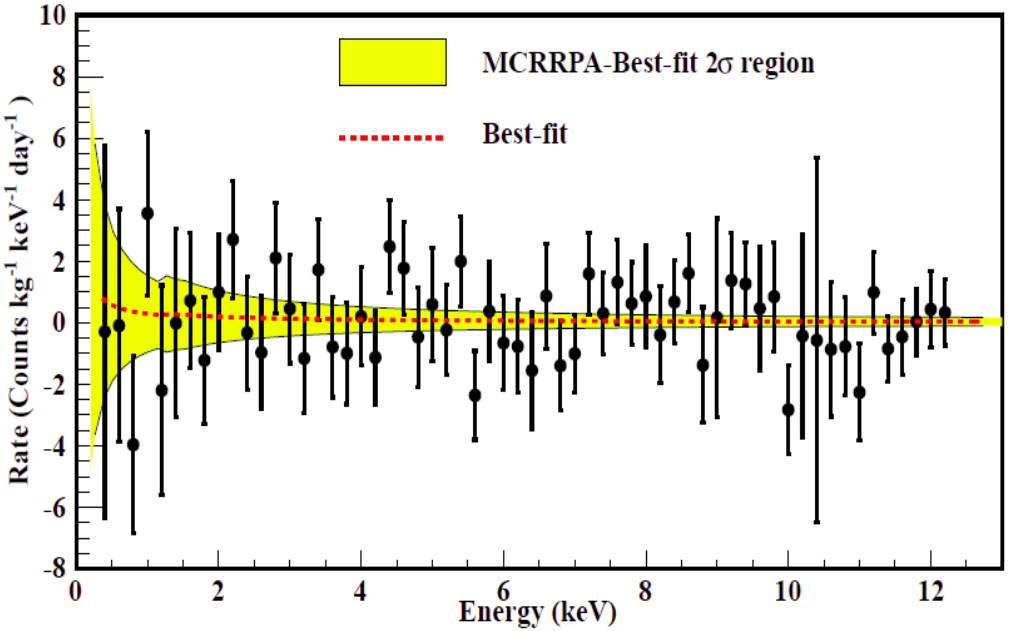
ECGe 70x70 – pPCGe

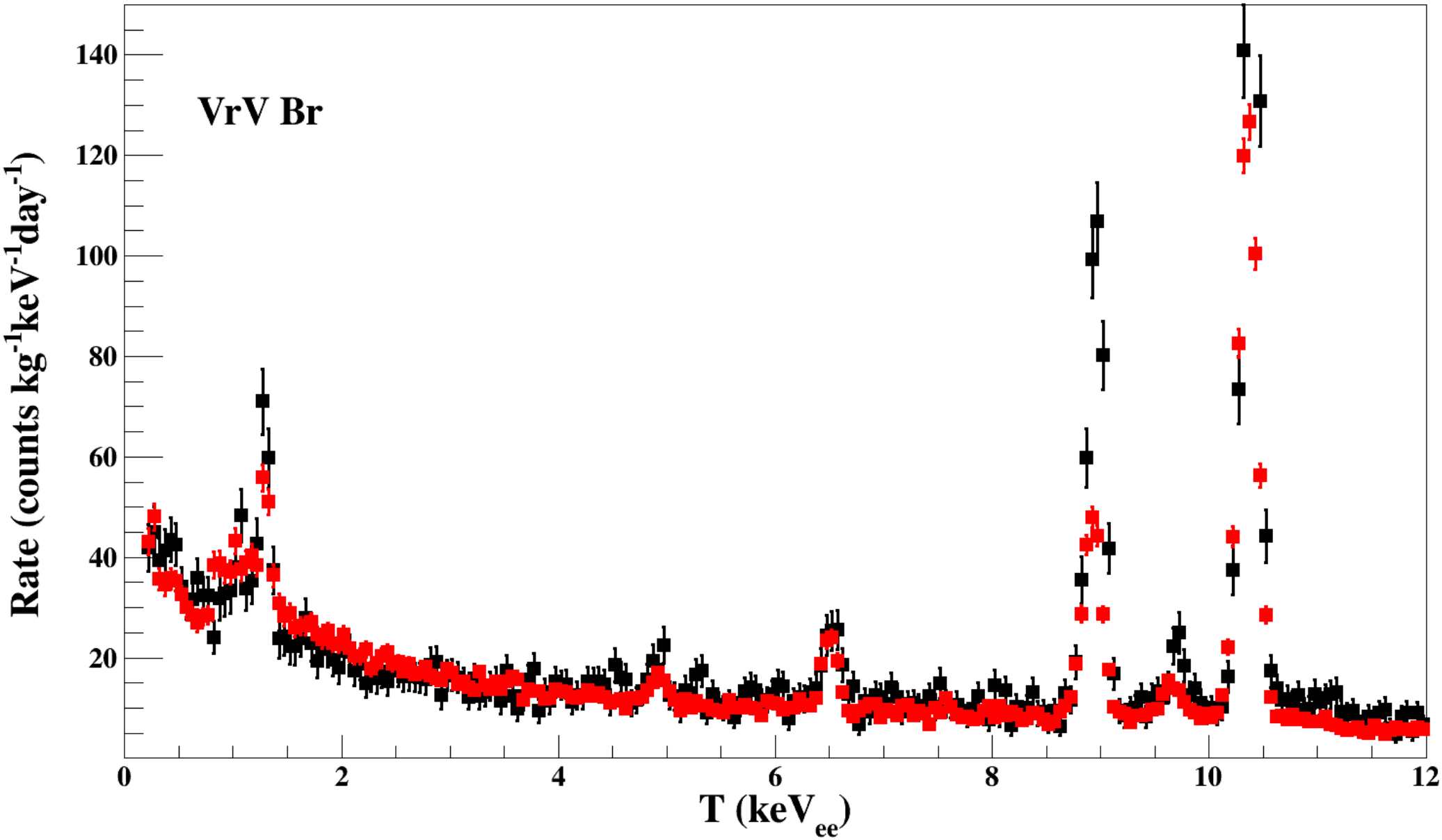
In L114					
High Voltage (V)	**Shape Filter**	**Shaping time (µs)**	**Temp. (°C)**	**PED (σ) (eV)**	**FWHM (eV)**
3000	Gaussian	6	-200	30.7	72.2
3000	Triangular	6	-202	28.1	66.1
3000	Triangular	6	-200	30.0	70.5
3000	Triangular	4	-200	28.5	67.1
3020	Triangular	6	-200	27.5	64.7
3020	Triangular	6	-202	29.5	69.4

ν milli-charge



ν magnetic moment




VrV Br
Rate (counts kg^{-1}keV^{-1}day^{-1})
T (keV$_{ee}$)
140
120
100
80
60
40
20
0
2
4
6
8
10
12