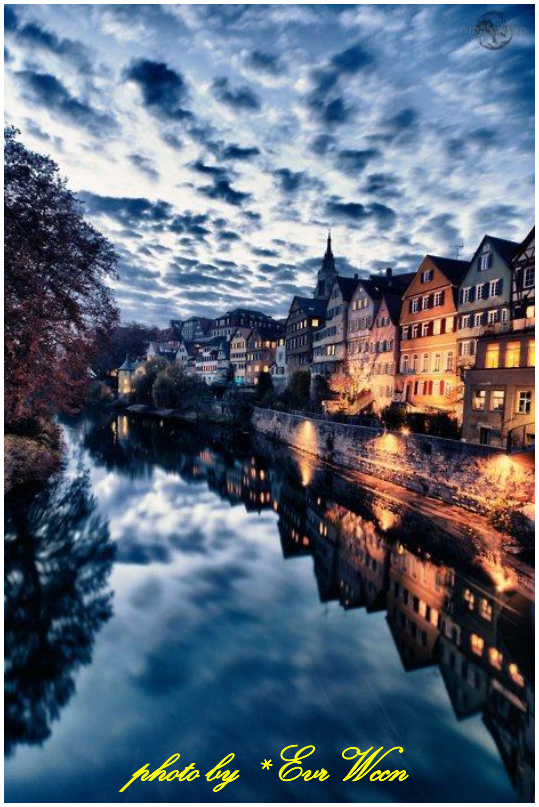
Pulse Shape Analysis A/E for GERDA experiment



Outline:

- Motivation
- Pulse Shape Discrimination for GERDA BEGes
- Systematic uncertainty on PSA
- Outlook & Summary

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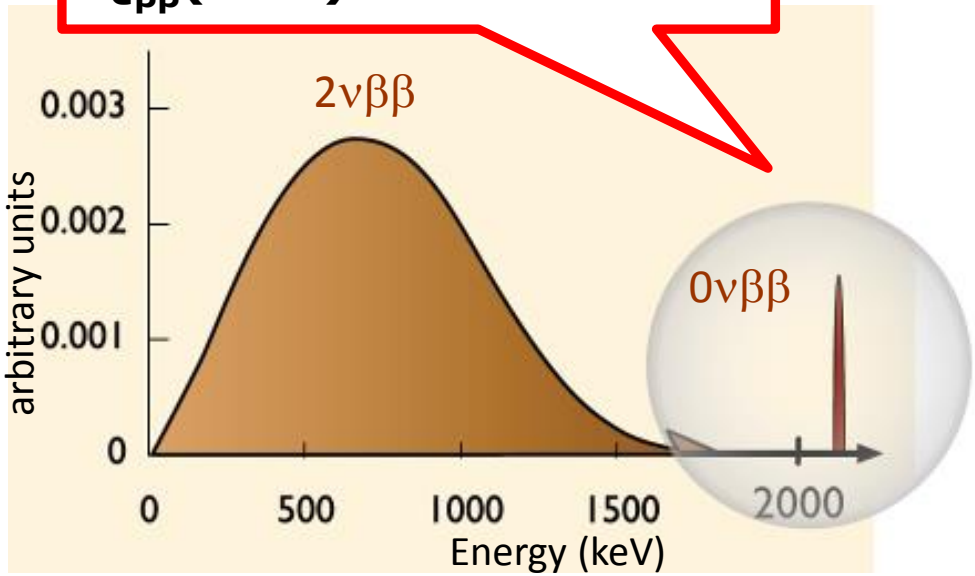
Symposium of the Sino-German GDT cooperation @ Tübingen, Deutschland, 10/04/2013

Neutrinoless Double Beta Decay

- **$2\nu\beta\beta$ decay: $\Delta L=0$**
  $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}$
  SM allowed & observed
- **$0\nu\beta\beta$ decay: $\Delta L=2$**
  $(A,Z) \rightarrow (A,Z+2) + 2e^-$
  if ν is Majorana particle

$\Rightarrow$ **Use Detector made of ββ emitting material:**
HP ^{76}Ge detector

Experimental Signature:
Sharp peak @
$Q_{\beta\beta}(^{76}Ge)$ = 2039 keV



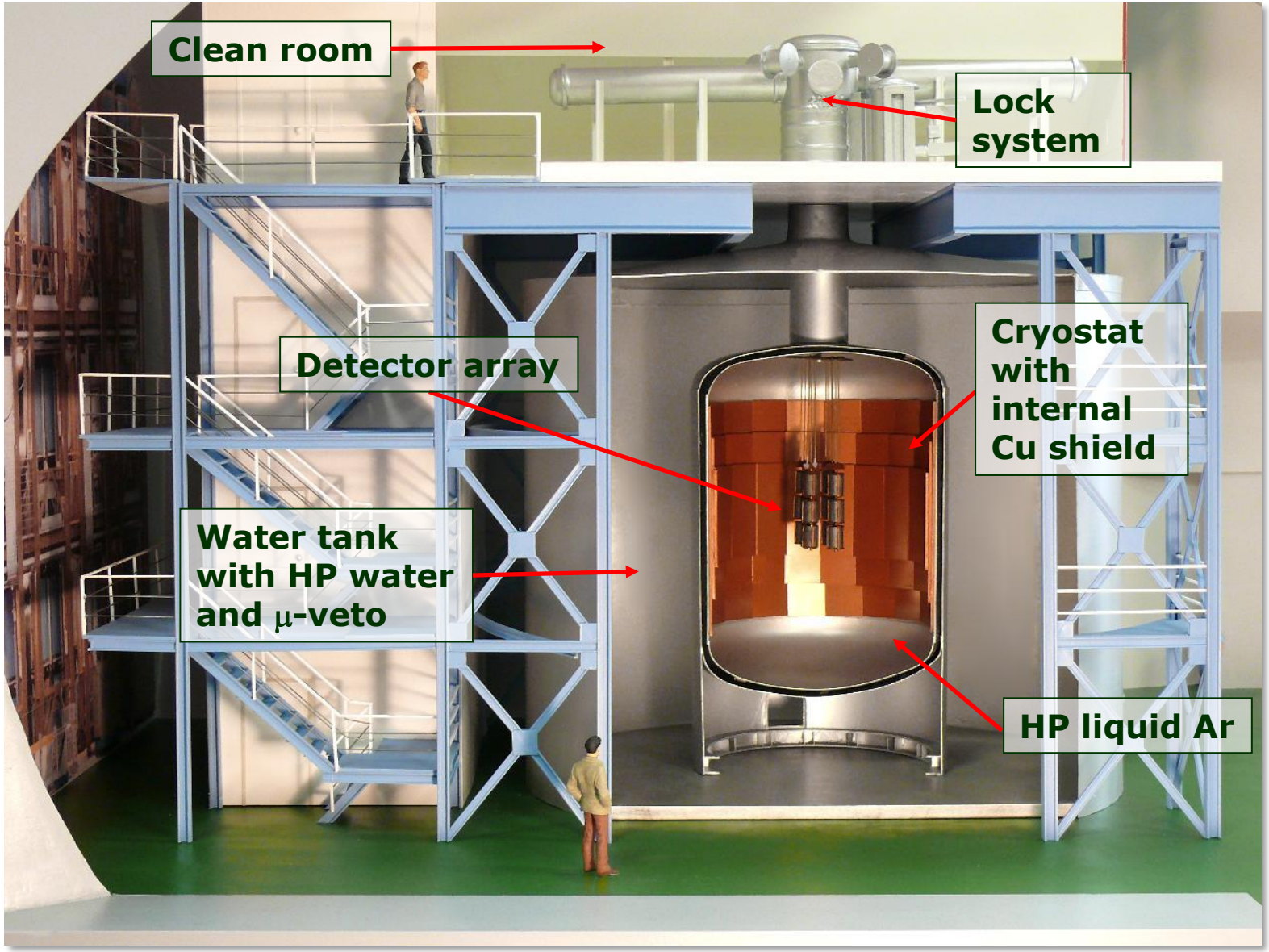
$0\nu\beta\beta$ decay can help us learn more on:

- **Nature of the neutrino (Majorana or Dirac?)**
- **Set the limits of absolute mass scale**
  -> Mass hierarchy of neutrinos
- **Information on CP violating phases**

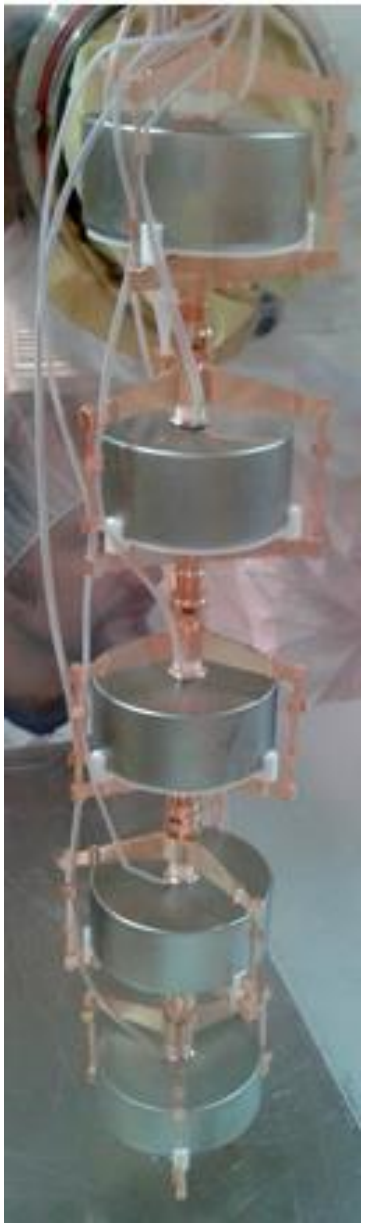
Motivation

- GERDA: Searching for 0νββ decay
- Background recognition utilizing PSD method
- Define PSD parameters for SSE/MSE discrimination using ^{228}Th calibration source
- Event topology & event location distribution :
  - 0νββ ≅ 2νββ except E dependence
  - Calibration ?= 2νββ
- Investigate systematic uncertainty due to event topology & event location on PSD
- The method:
  Comparison of PSD for 2νββ/calibration data

GERDA - Germanium Detector Array

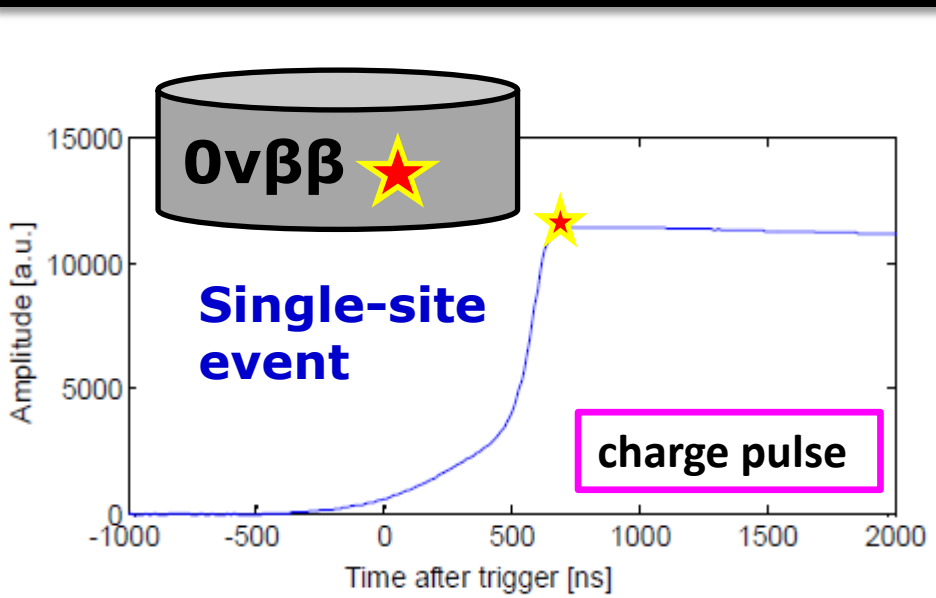


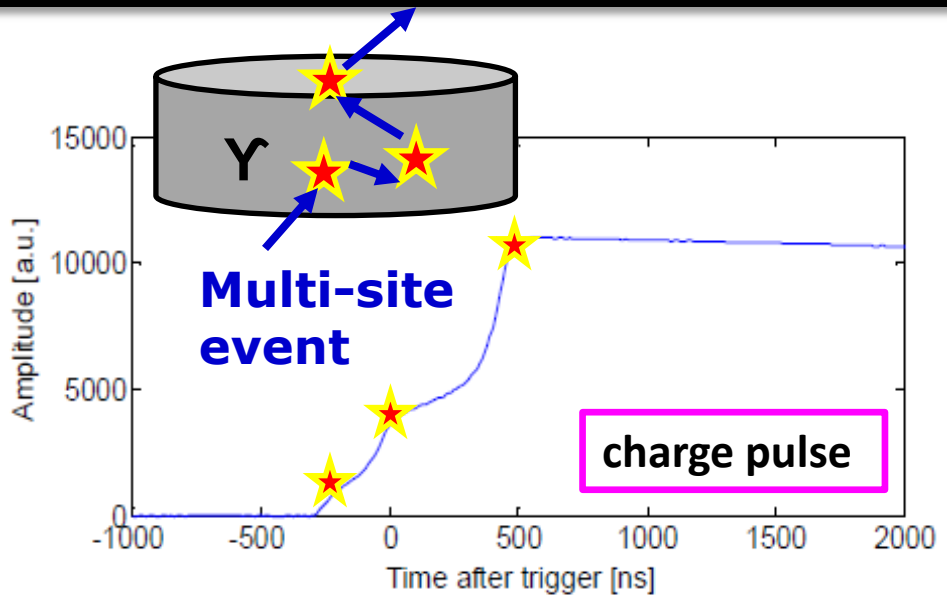
Pre-test mode for GERDA Phase-II

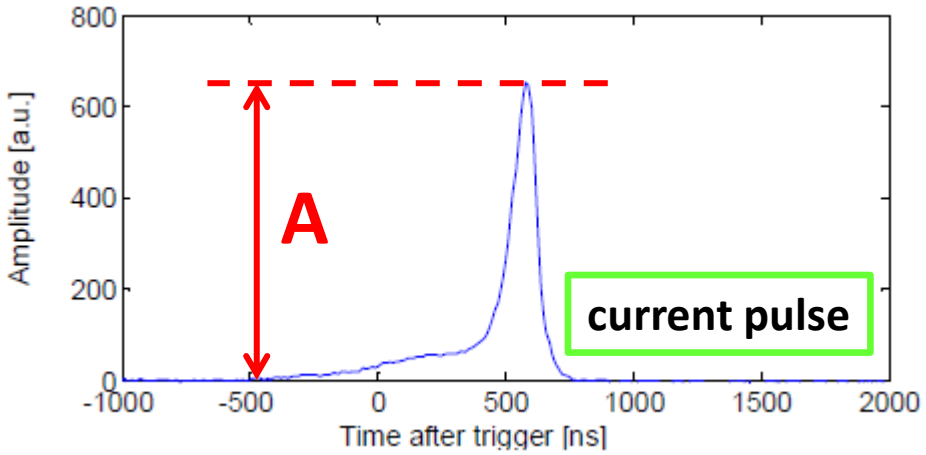


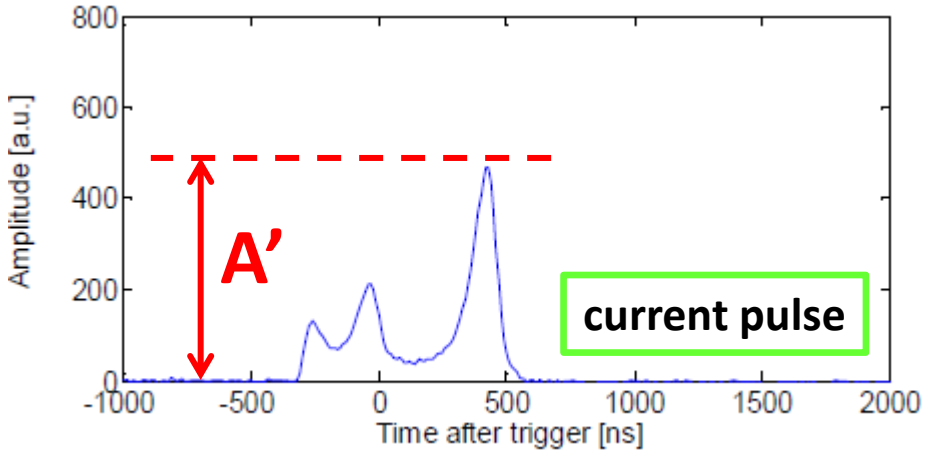
- GERDA Phase-I using 6 coaxial ^{enr}Ge detectors
- Pre-test mode for Phase-II: Additional 5 ^{enr}BEGe detectors
- Advantages of BEGe detectors:
  - ΔE < 3.0keV @ 2.6 MeV
  - Powerful PSD: A/E parameter
- Total mass of ^{enr}BEGe detectors:
  - 3.6 kg
- Data taking: Since July, 2012
- Exposure:
  - 2νββ: 0.59 kg·yr

A/E : Pulse Shape Discrimination Method





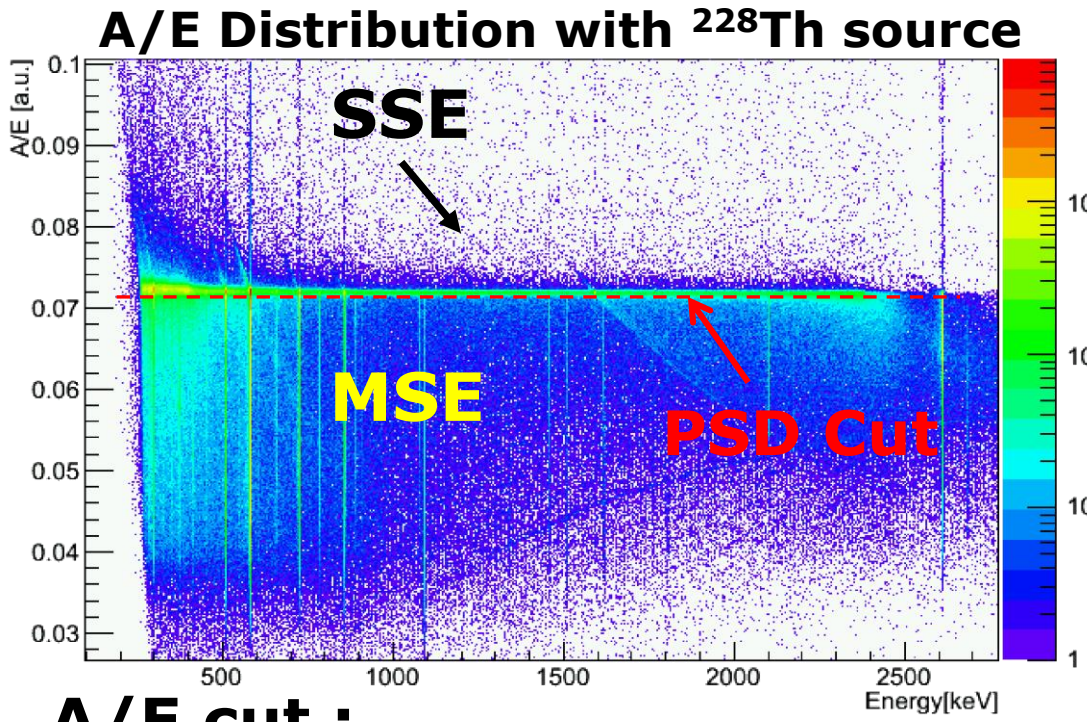


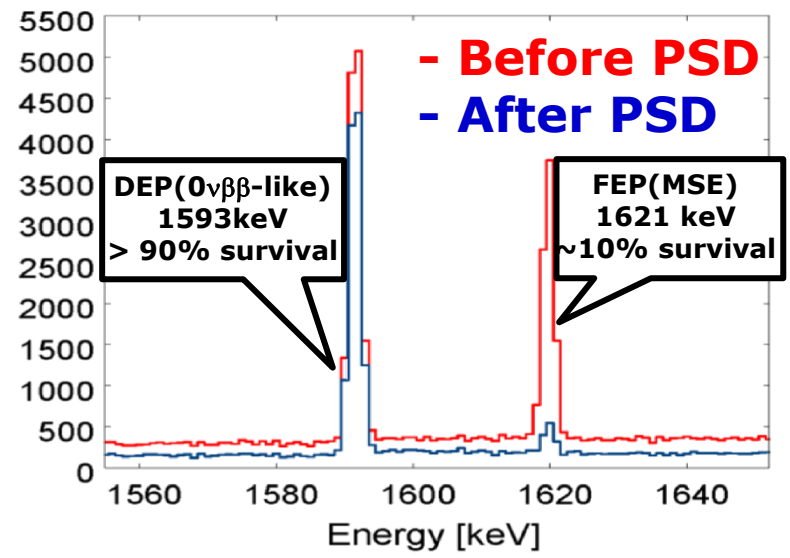


Dušan Budjaš et al, JINST 4 P10007, 2009

- **A/E PSD method:**
  Use "Ratio of Maximum Amplitude to Energy"
  for discriminating SSE/MSE

Determination of PSD cut





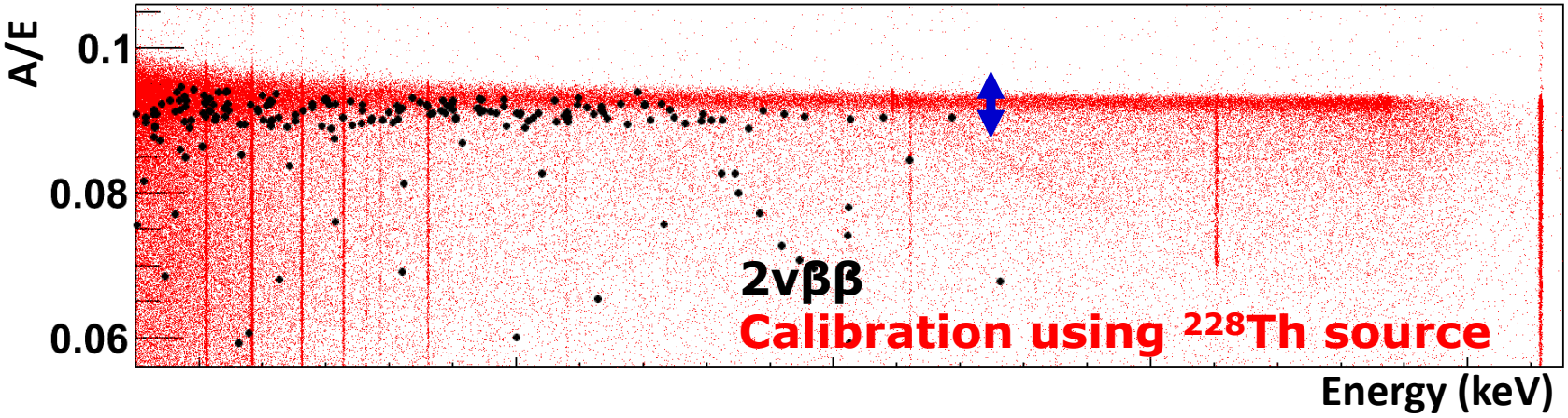
Dušan Budjaš et al, JINST 4 P10007, 2009

A/E cut :

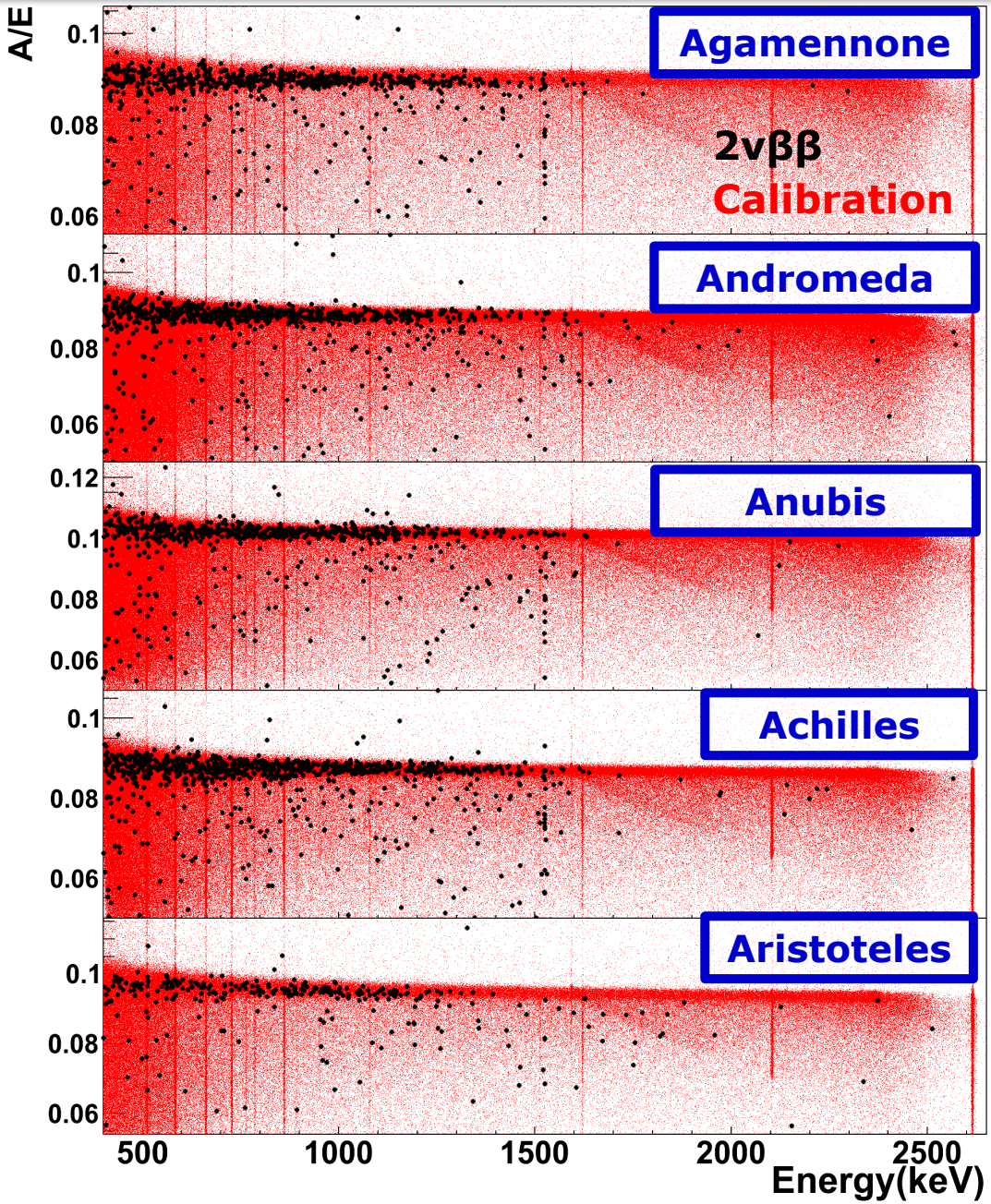
- Cut value is determined by using ^{228}Th source
- SSE/MSE are located in/below a horizontal band
- Double escape peak (DEP) from the ^{208}Tl-line @ 2614.5 keV are mostly SSE
- Full energy peaks (FEP) contain large fraction of MSE
- Acceptance in DEP usually set to 90%

Determination of cut values is happy ☺
however ….
Don’t forget the systematic uncertainty on your PSD method!!

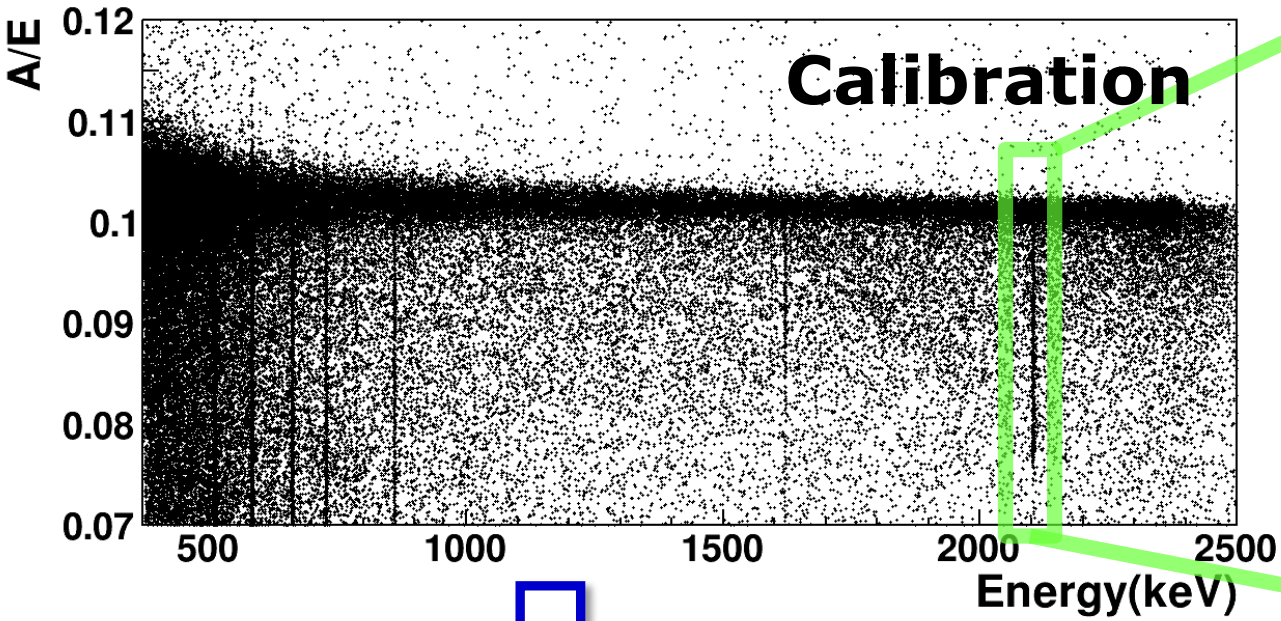
An example of systematic effect on PSD:

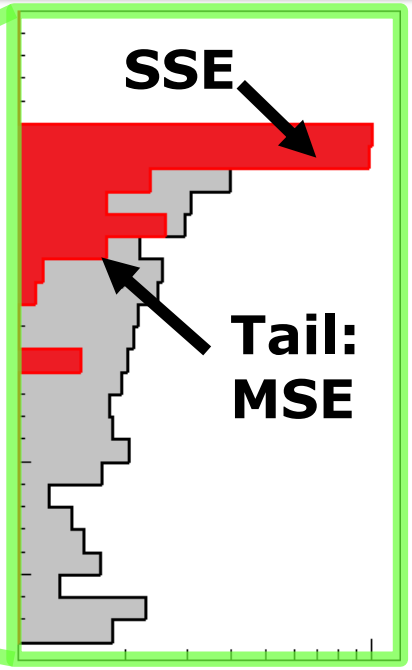


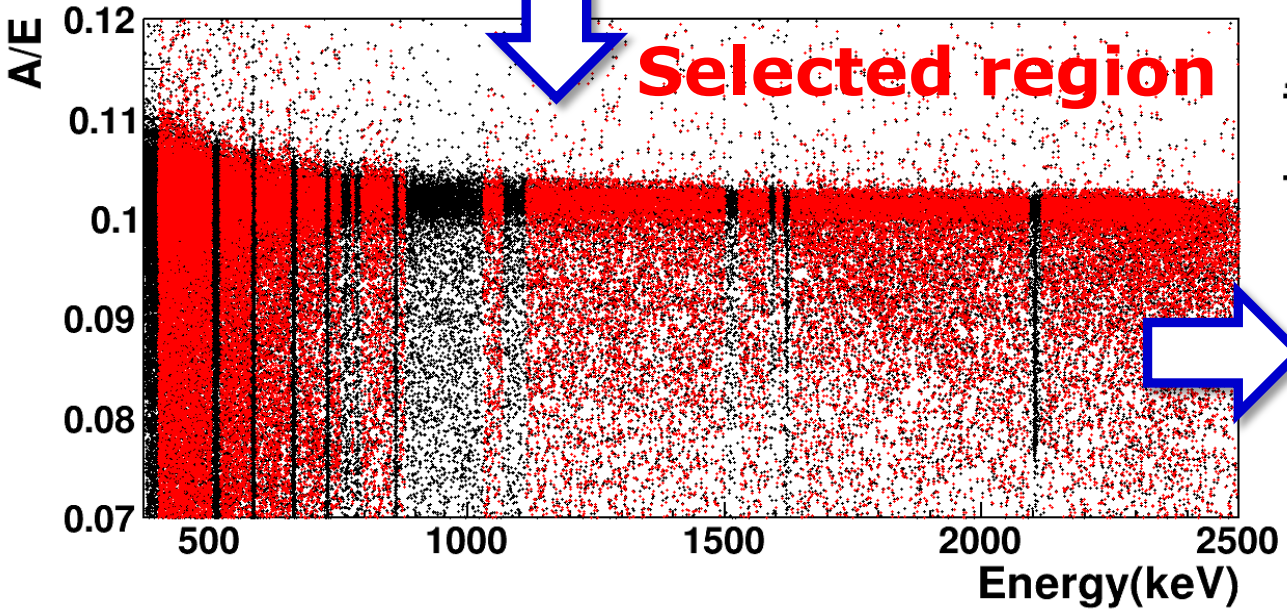
A/E-versus-E for 2vββ/calibration data

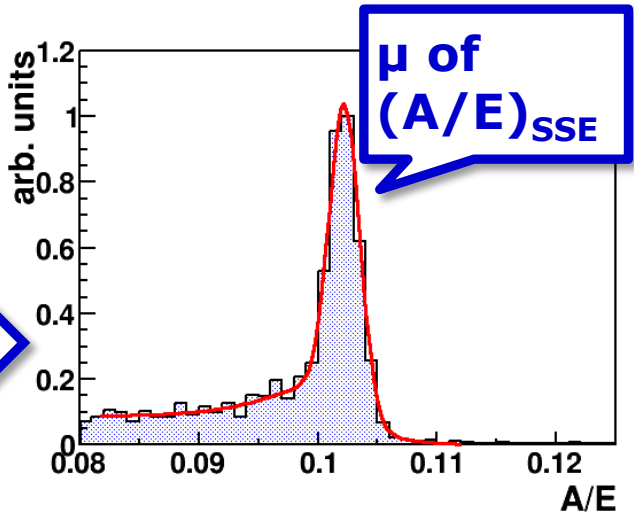


SSE for calibration data

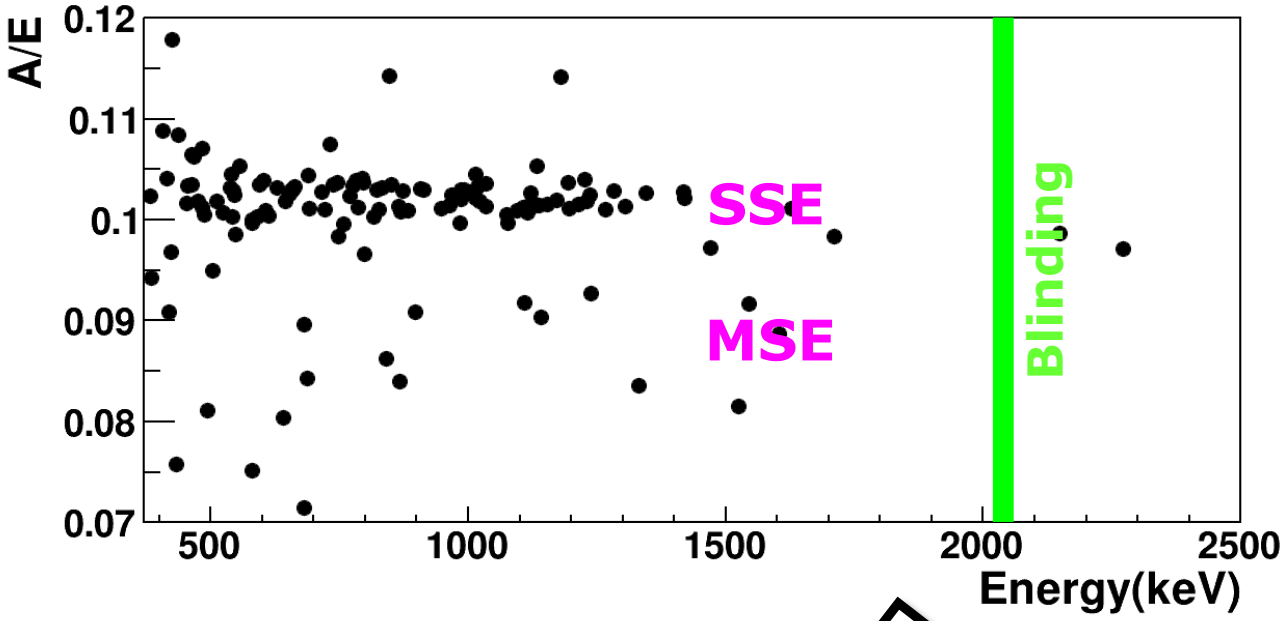






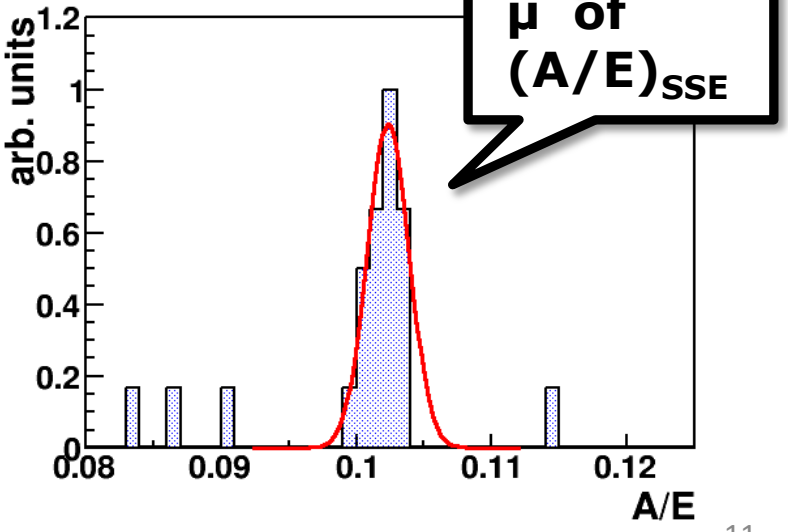


SSE for 2νββ data



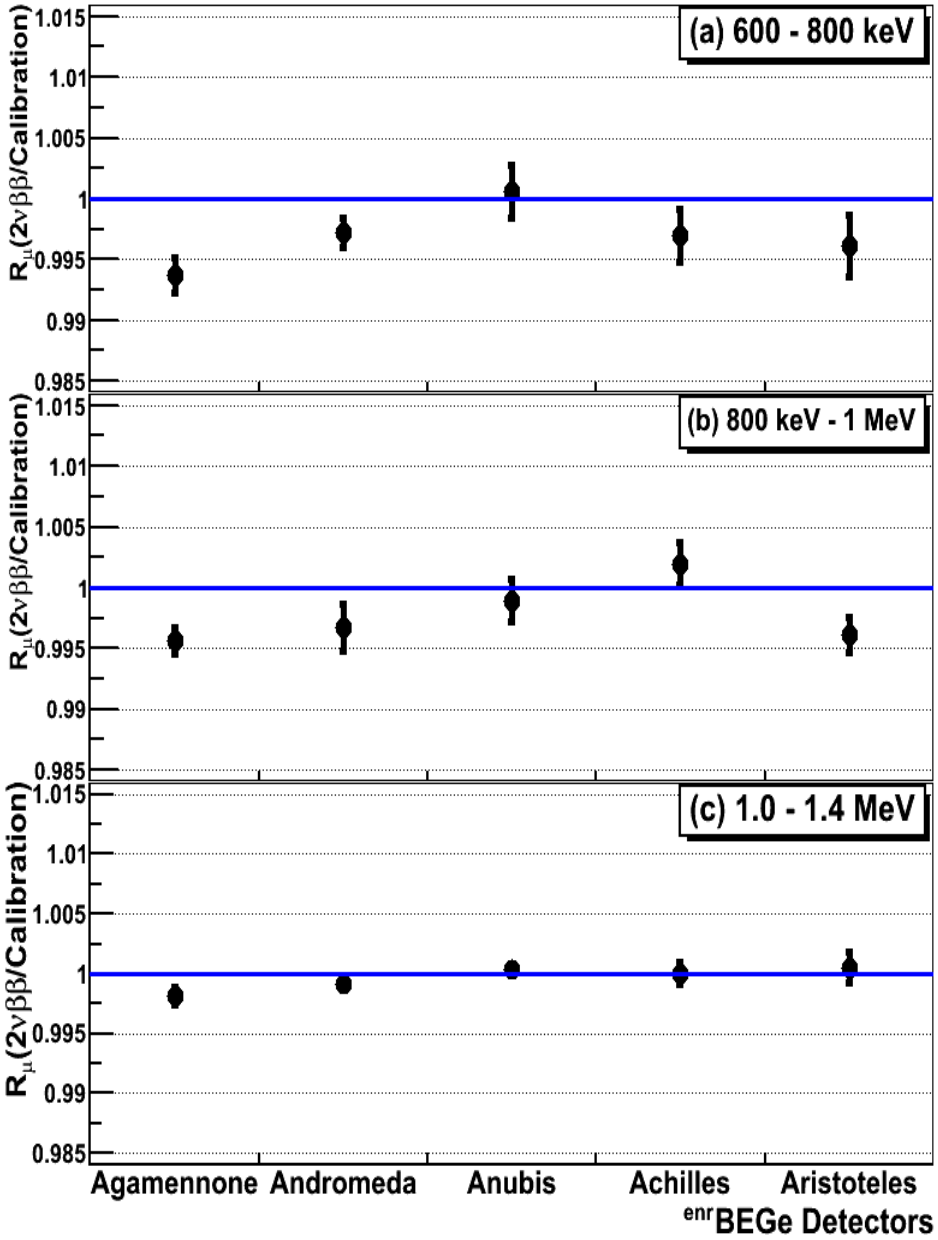
μ: mean value

μ of $(A/E)_{SSE}$



- **Energy region for consistency check : 600 keV - 1.4 MeV, ΔE = 200 keV**

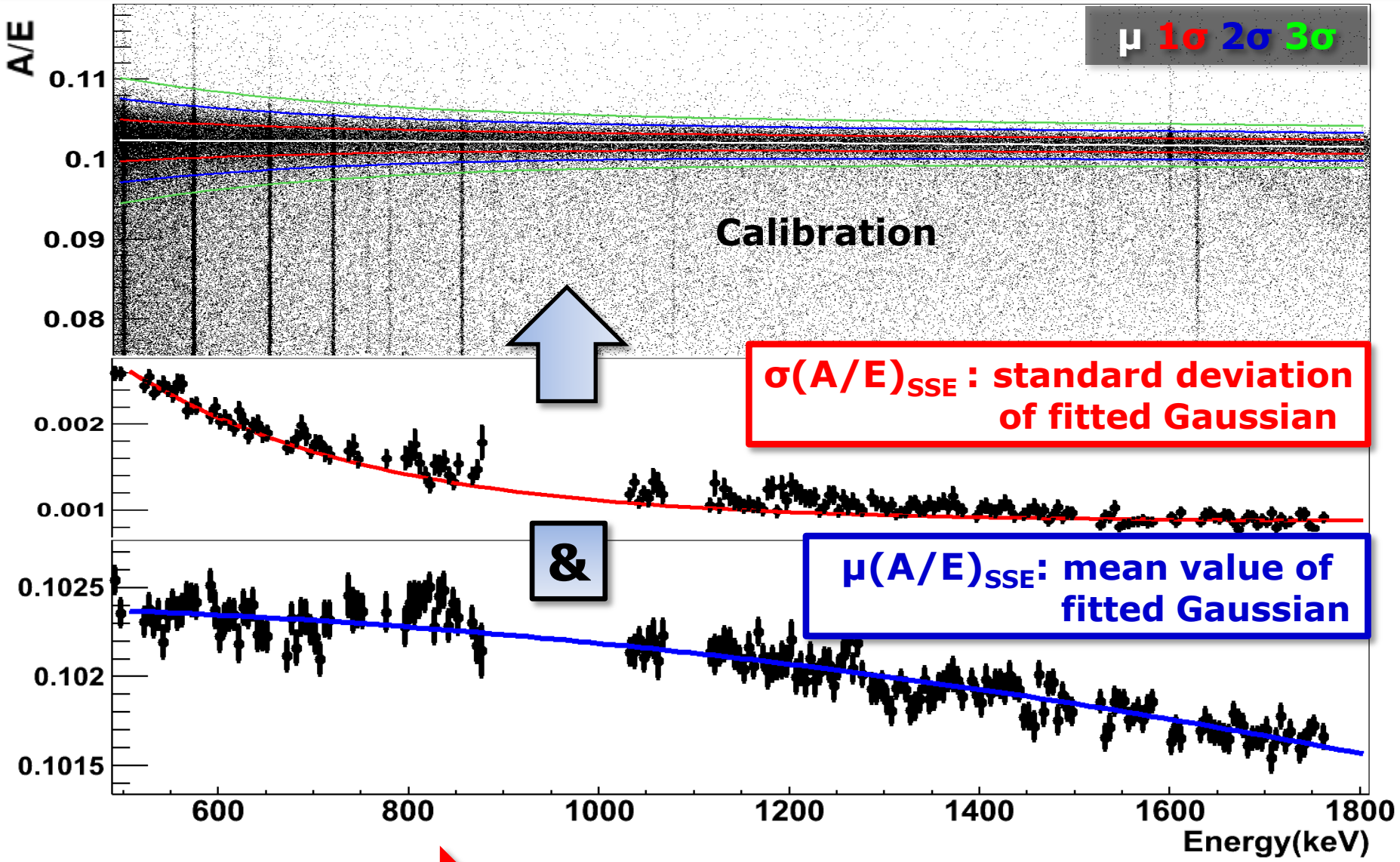
Consistency check for two methods



- **Preliminary systematic uncertainty on PSD ~ 0.1%**
- **Understanding & reducing deviations between 2vββ & calibration**

  =>Working in progress

A/E Resolution as function of Energy



➢ A/E (E) ➡ Improvement in recognition efficiency of SSE/MSE

Outlook & Summary

- **PSD can reduce background & improve sensitivity for 0νββ experiments**
- **A/E for BEGes provides powerful SSE/MSE pulse shape recognition efficiency**
- **Systematic uncertainty is crucial for determining the cut value of PSD**
- **Deviations between methods dominated by statistical uncertainties**
- **Possible improvement in recognition eff. of SSE/MSE by A/E(E)**

Backup Slides

Neutrinoless Double Beta Decay

- **Nature of the neutrino (Majorana or Dirac?)**
- **Set the limits of absolute mass scale**
  -> Mass hierarchy of neutrinos
- **Information on CP violating phases**
- **The observable: *half life***

$$\frac{1}{T^{0\nu\beta\beta}_{1/2}} = G(Q,Z)\,|M_{nucl}|^2\,\langle m_{ee}\rangle^2$$

0νββ Decay rate

Phase space factor

~ Q^5

Matrix element

Effective Majorana Neutrino mass

$$\langle m_{ee}\rangle = |\sum_i U_{ei}^2\, m_i|$$

➡ **One measurement, many answers (or questions)...**

Experimental Challenge

~ 30 isotopes are available, but …

Detection efficiency

Active target mass

Measuring time

Sensitivity of $T_{1/2}^{0\nu\beta\beta} \propto \epsilon\, a \sqrt{\frac{M\,T}{B\,\Delta E}}$

Isotopic Abundance

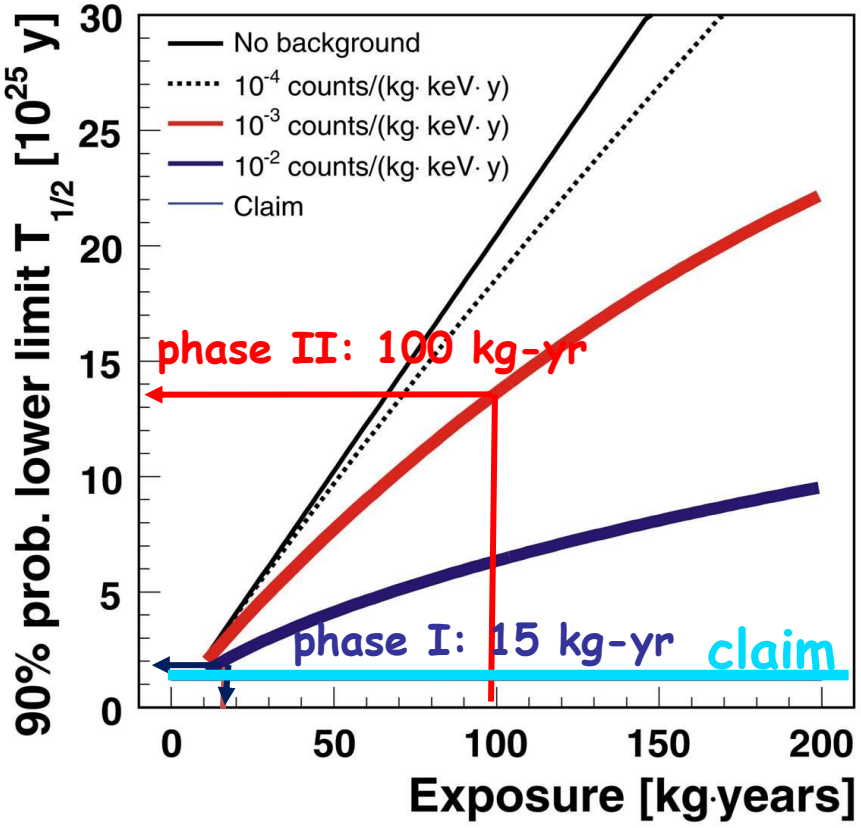
Energy Resolution

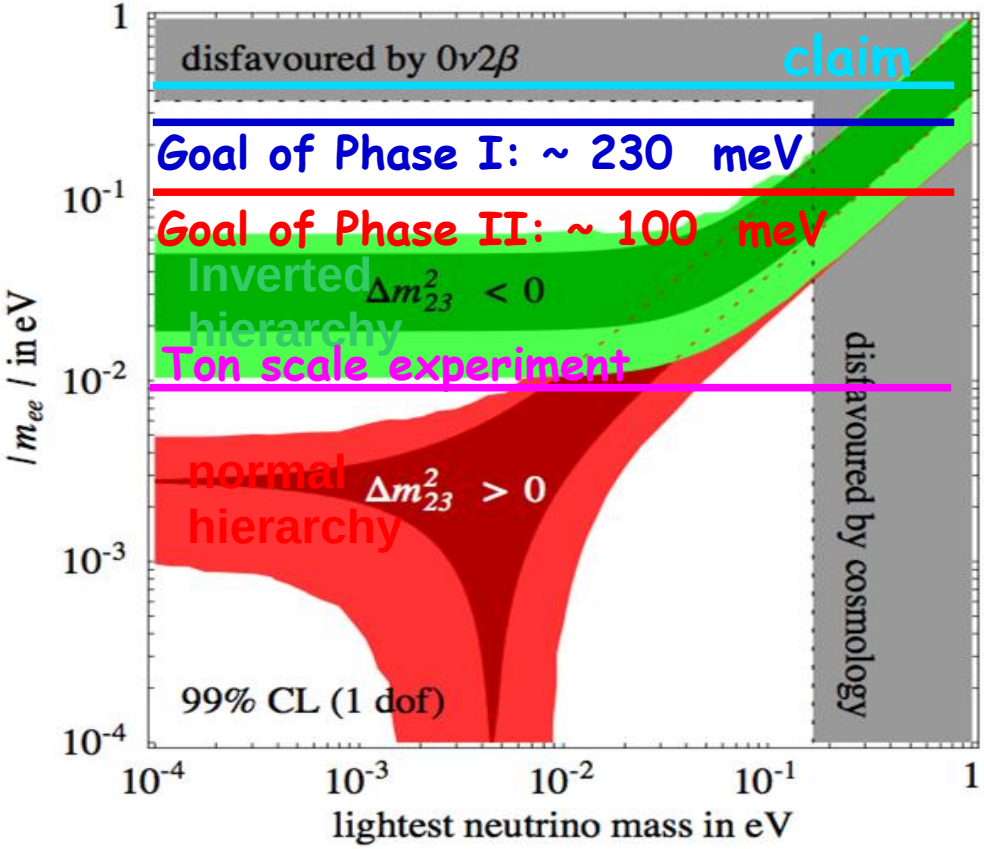
Background index

Why HP ^{76}Ge detector ?

- **High detection efficiency (source=detector)**
- **Very good energy resolution (0.2% in ROI)**
- **Very low intrinsic background**

GERDA: Phases & Goals





- **Phase I – Test claim, 15 kg-yr**
- **Phase II – Improve limits on $T_{1/2}$, 100 kg-yr, additional 30 enriched BEGe detectors(20kg)**