R&D in the framework of the GERDA Experiment:

Background diagnosis using liquid argon scintillation

Untersuchungen zur Untergrunddiagnose mittels Flüssig Argon Szintillation im Rahmen des GERDA Experiments

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Outline

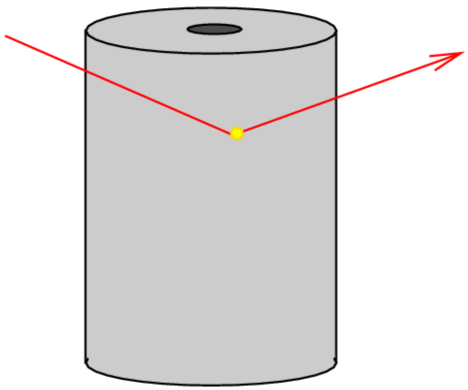
- Motivation
- R&D on liquid argon as active shielding
  - LArGe @ MPI-K results
  - Gerda/LArGe @ GS
- Pulse shape analysis on LAr scintillation light
- Background diagnosis examples
- Summary

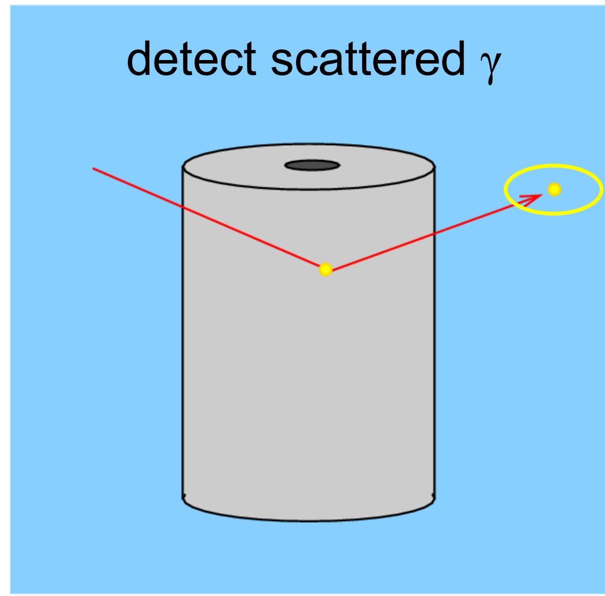
Motivation

- Phase I: anti-coincidence + PSA, 10^{-2} cts/(kg·keV·y)
- Phase II: segmented detectors, 10^{-3} cts/(kg·keV·y)
- additional active background reduction methods required to go beyond 10^{-3} cts/(kg·keV·y)
- LAr scintillates (λ=128 nm)
- R&D project: detect scintillation light and use it as anti-coincidence signal for background suppression
  - Investigate LAr scintillation properties
  - Pulse shape analysis on LAr scintillation

LAr veto principle

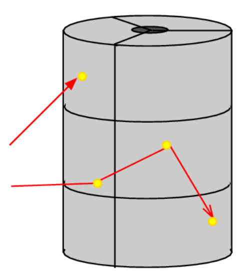
example of
γ-background event





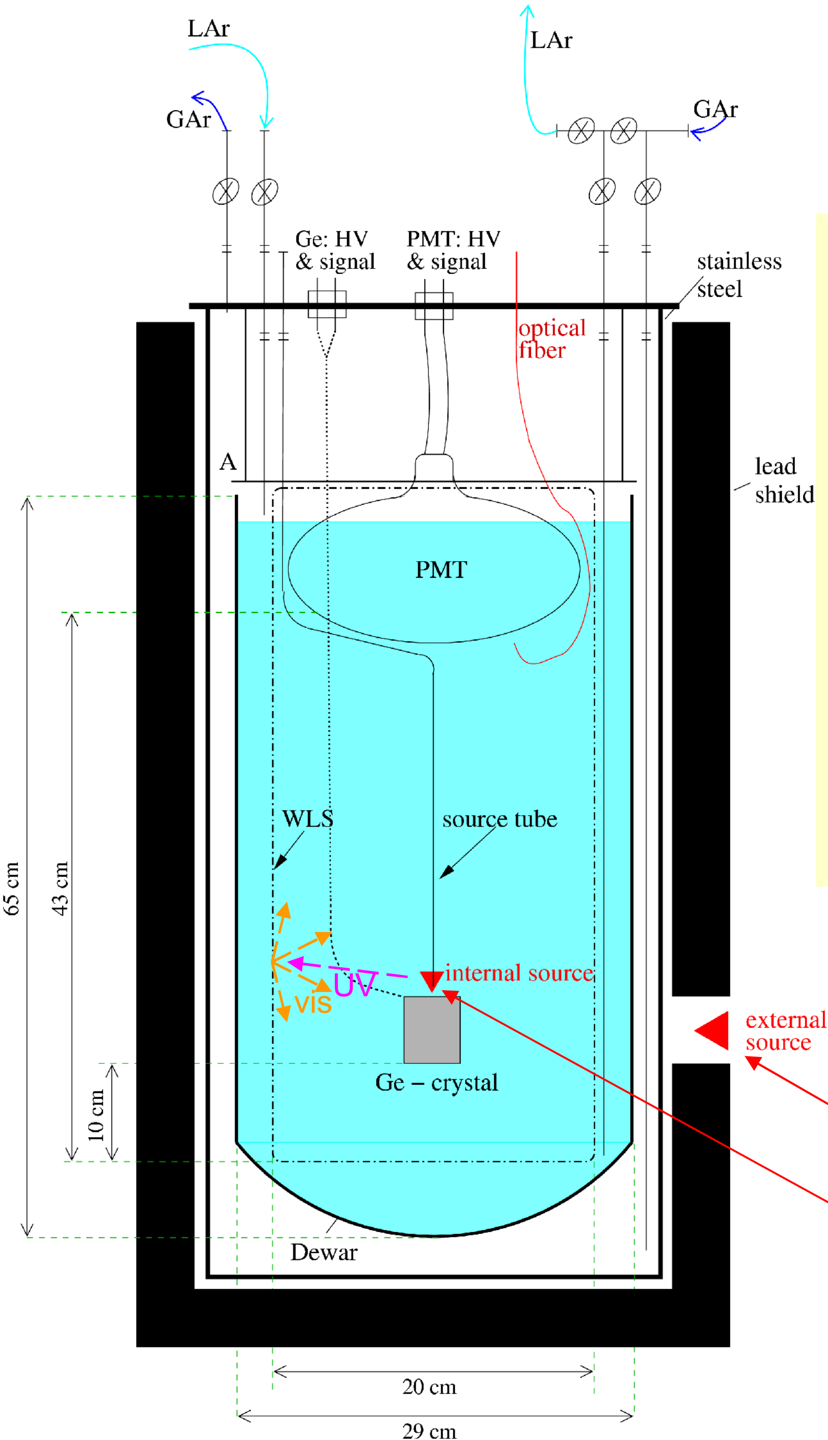
LAr scintillation

→ discard event



LAr veto is complementary to segmentation and pulse shape discrimination on the Ge-diode signal

LArGe@MPI-K:
Schematic system description



- Dewar ∅29 cm, h=65 cm (43 L – total volume)
- Light detection: WLS (VM2000 + PST/TPB) + PMT(8“, ETL 9357-KFLB)
- Active volume ∅20 cm, h=43 cm ≈ 19 kg **LAr** (13,5 L)
- Shielding: 5 cm lead +15 mwe underground

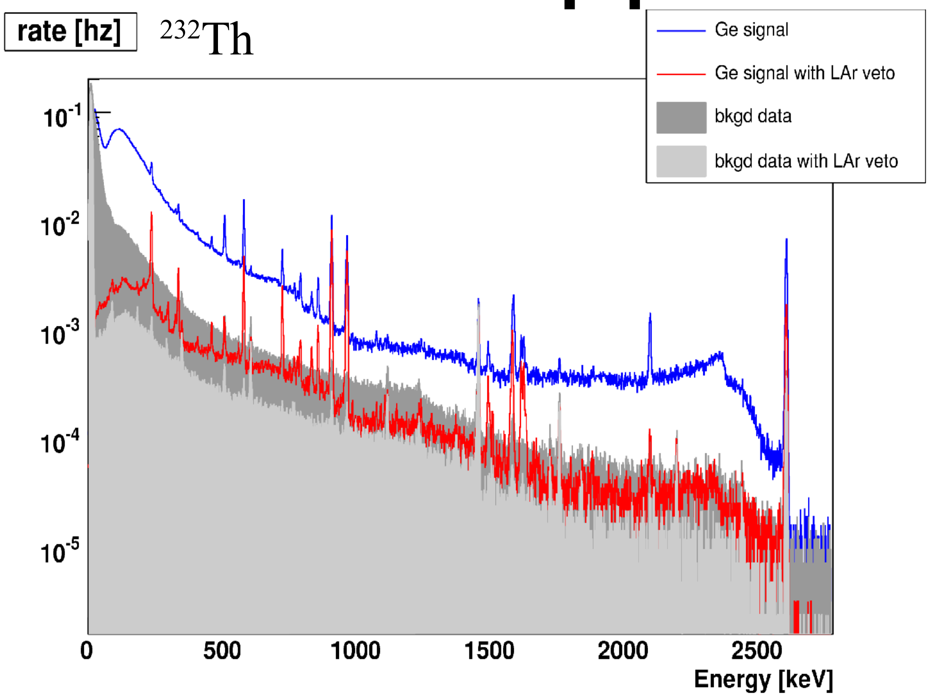
Diode: 390 g Canberra HP-Ge p-type diode

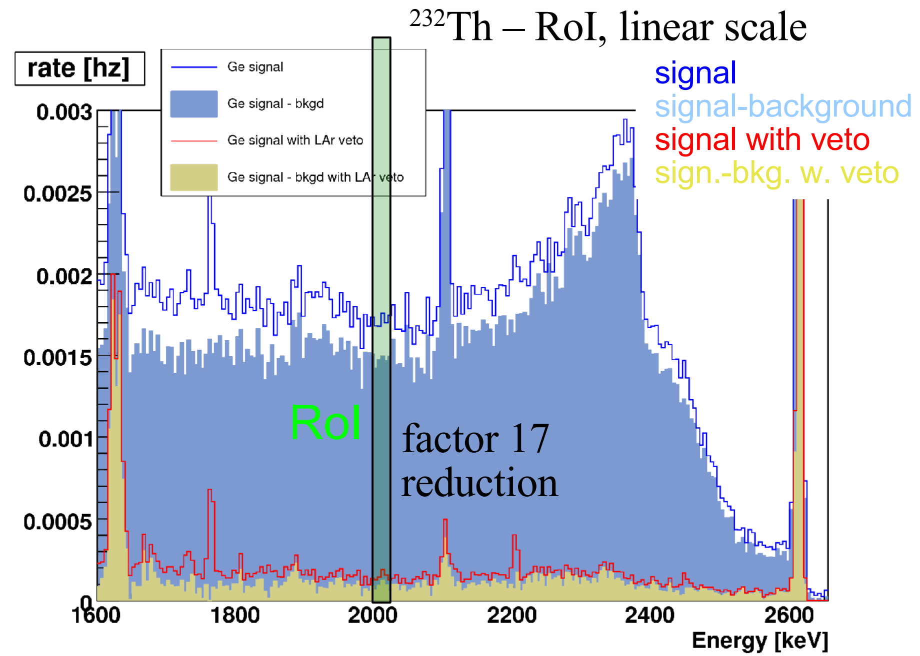
Measurements:

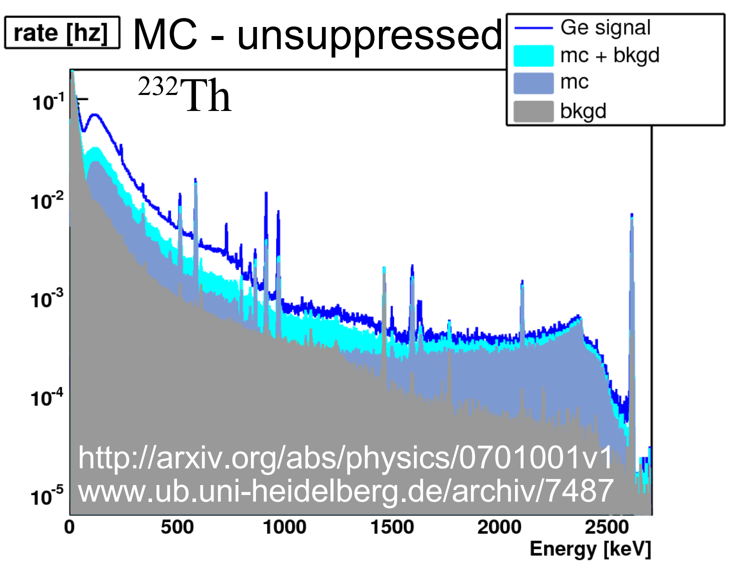
External source

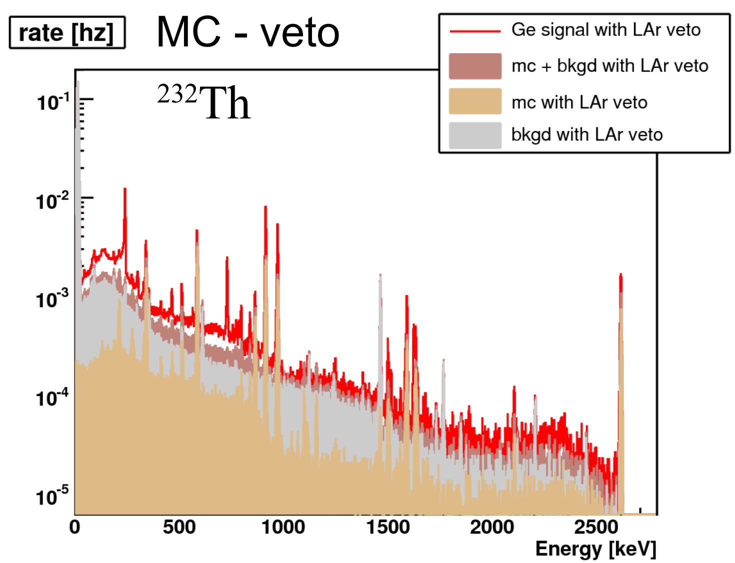
Internal source

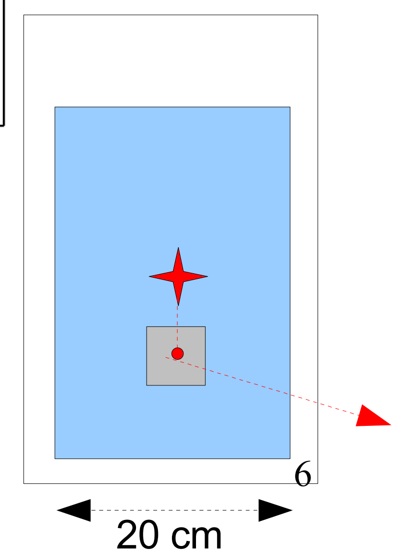
Suppression spectra

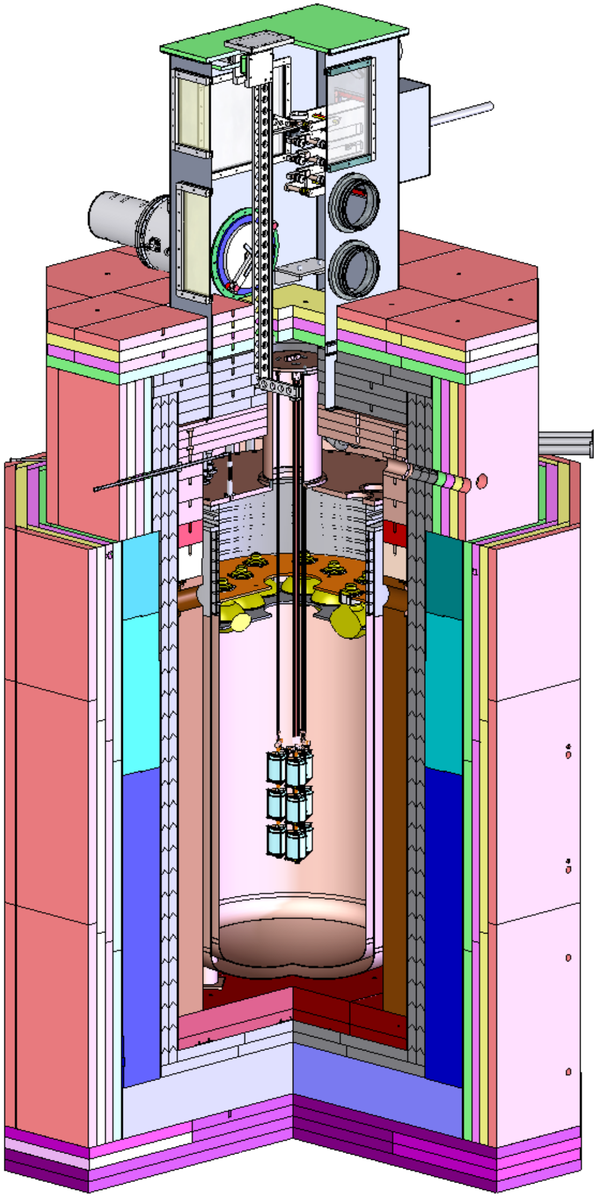






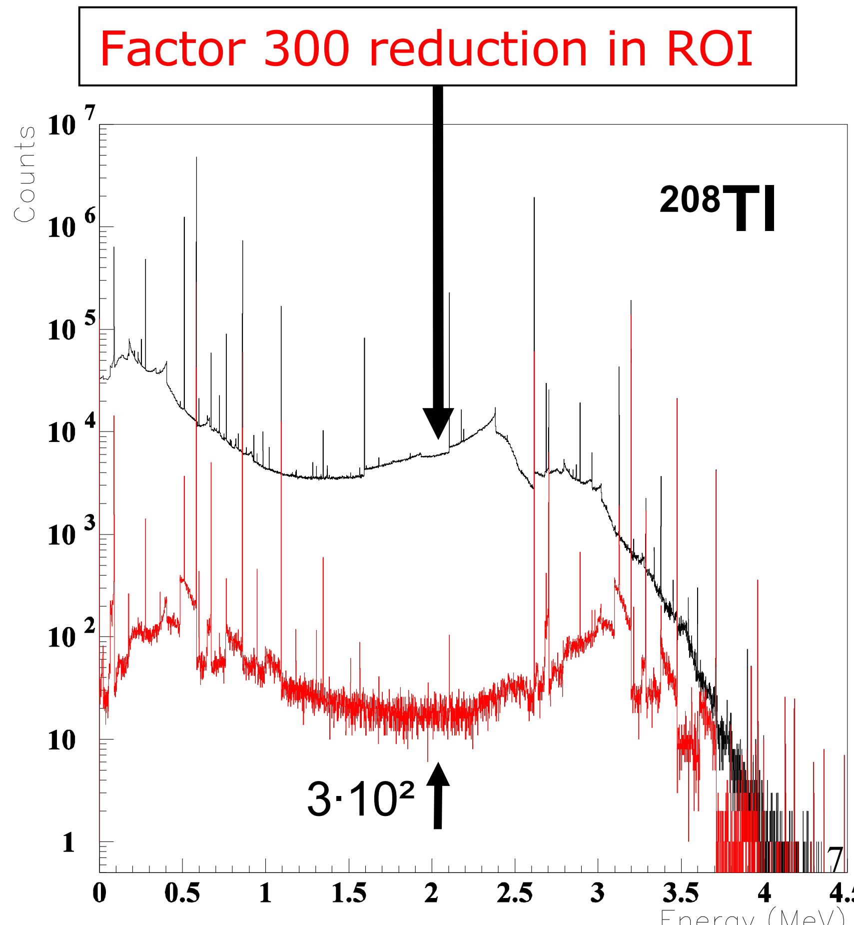






LArGe @ Gran Sasso in GDL

MC example: Background suppression for contaminations located in detector support

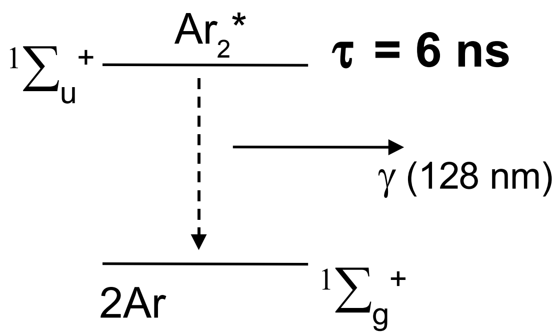


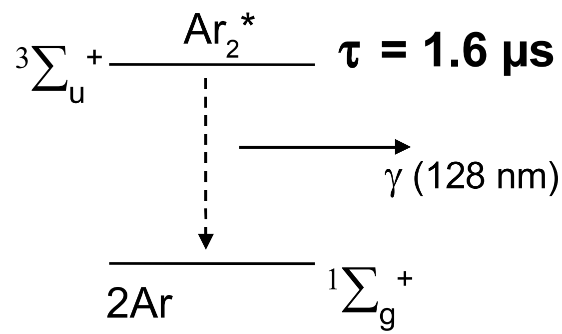
LAr scintillation pulse shape discrimination principle

Excimer creation:

$$Ar^{*}+Ar \rightarrow Ar_2^{*} \quad \text{or} \quad Ar^{+}+Ar \rightarrow Ar_2^{+} \quad \text{and} \quad Ar_2^{+}+e \rightarrow Ar_2^{*}$$

De-excitation:





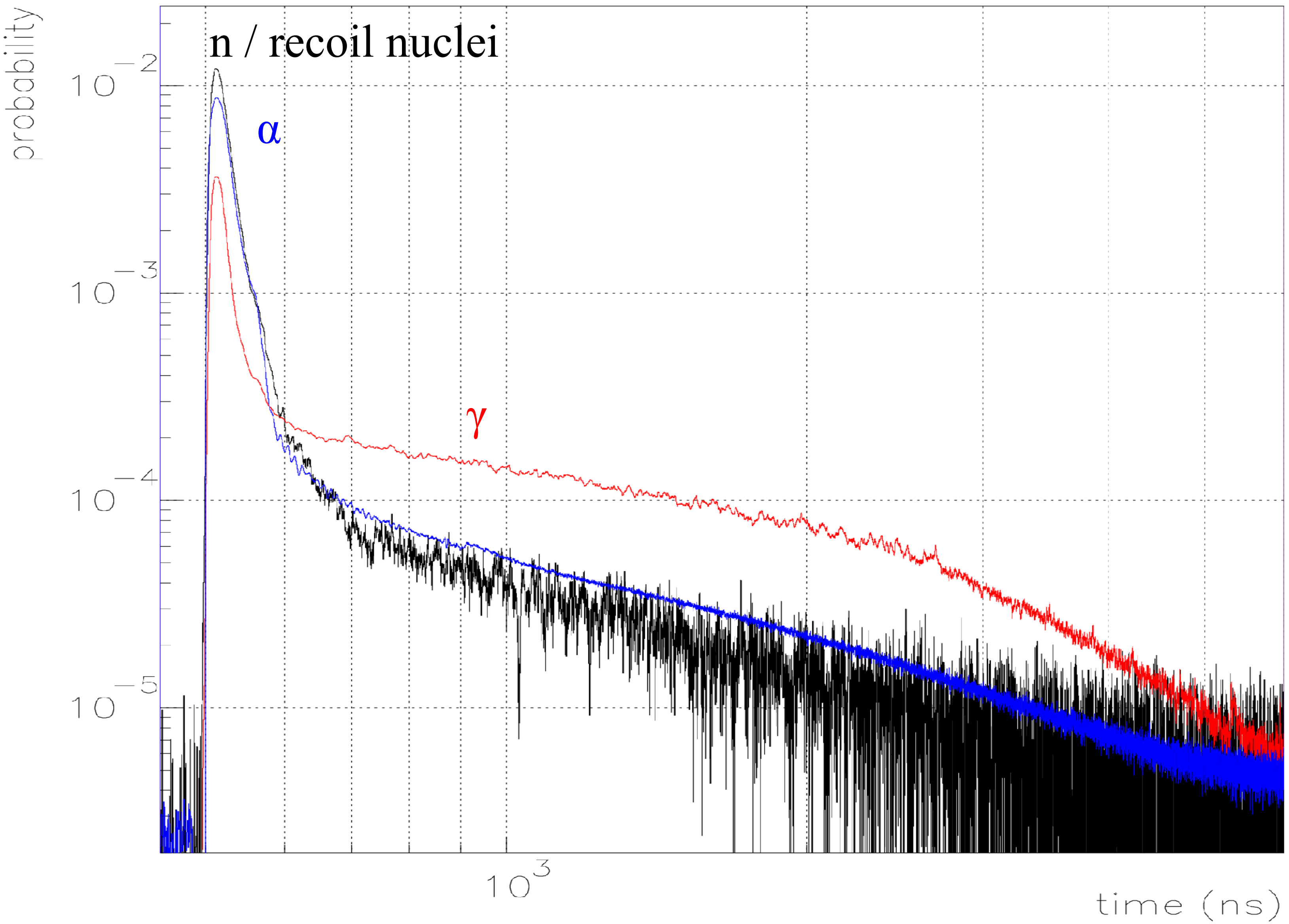
Population depends on ionisation density

Ratio singlet/triplet emission (I1/I2)*:

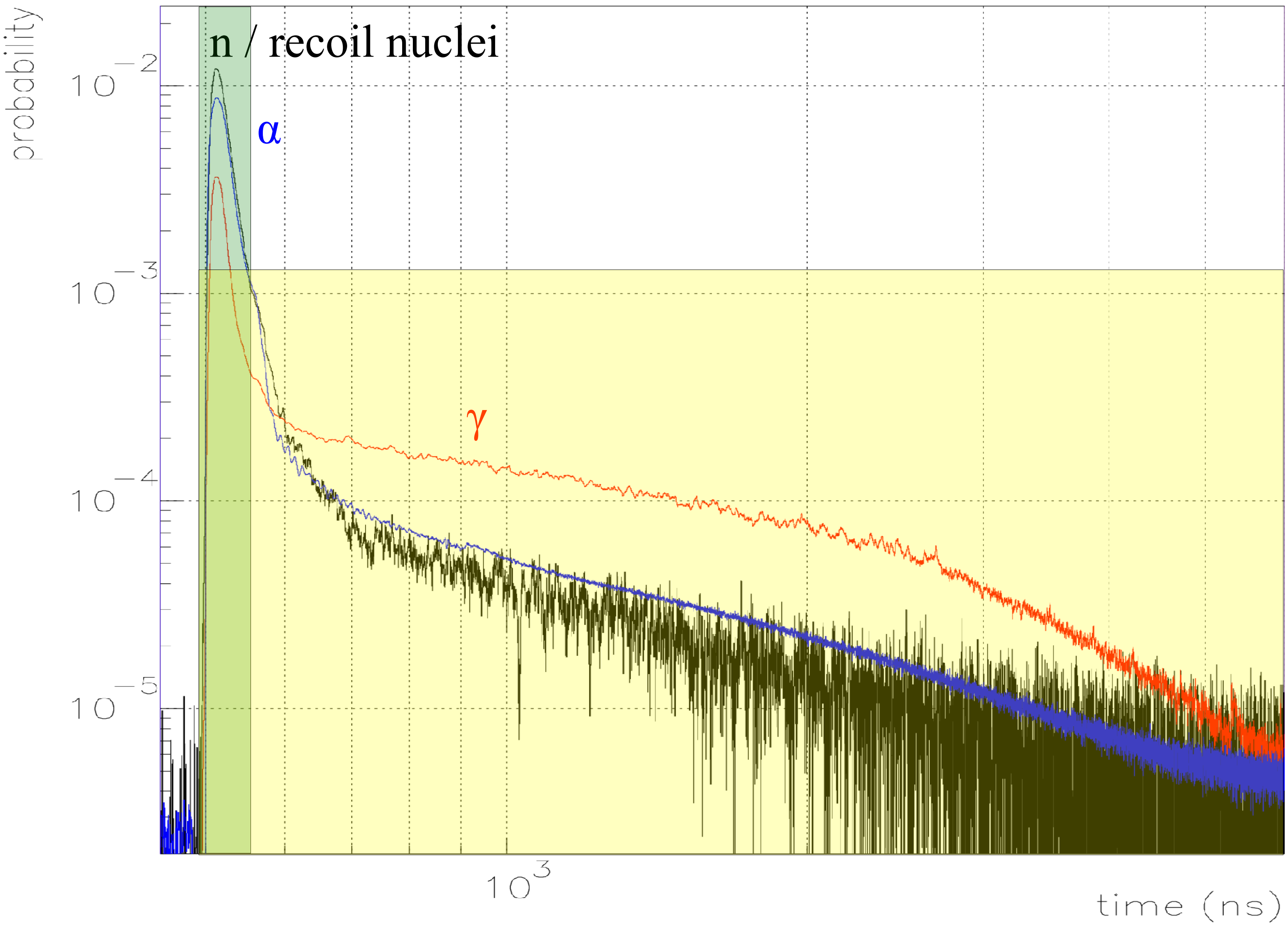
electrons / γ's : **0.3**   α's : **1,3**   fission fragments/nuclei : **3**

* Hitachi et al. Phys.Rev.B 27(9):5279, 1983

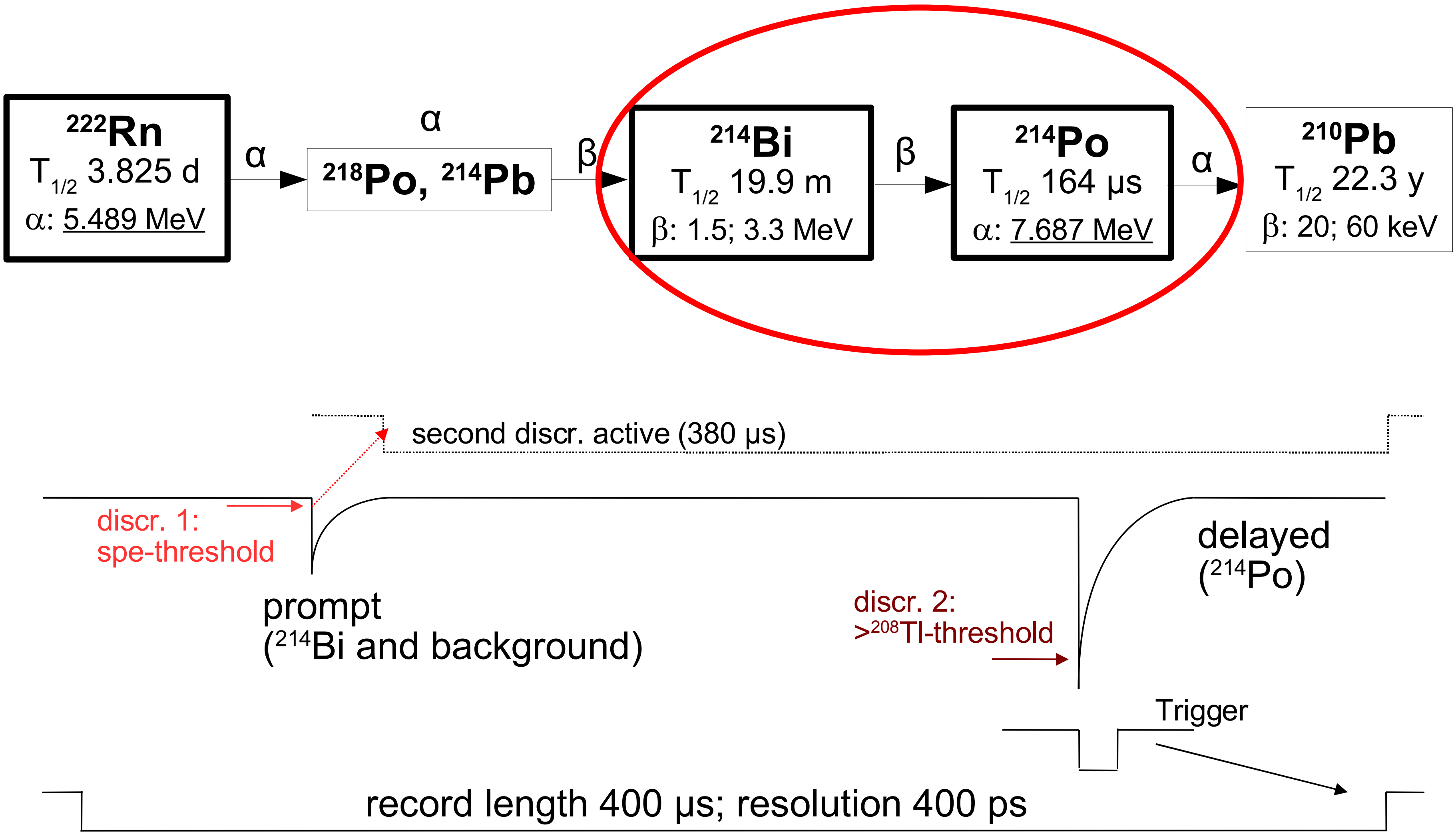
Measured probability density functions of the scintillation light intensity



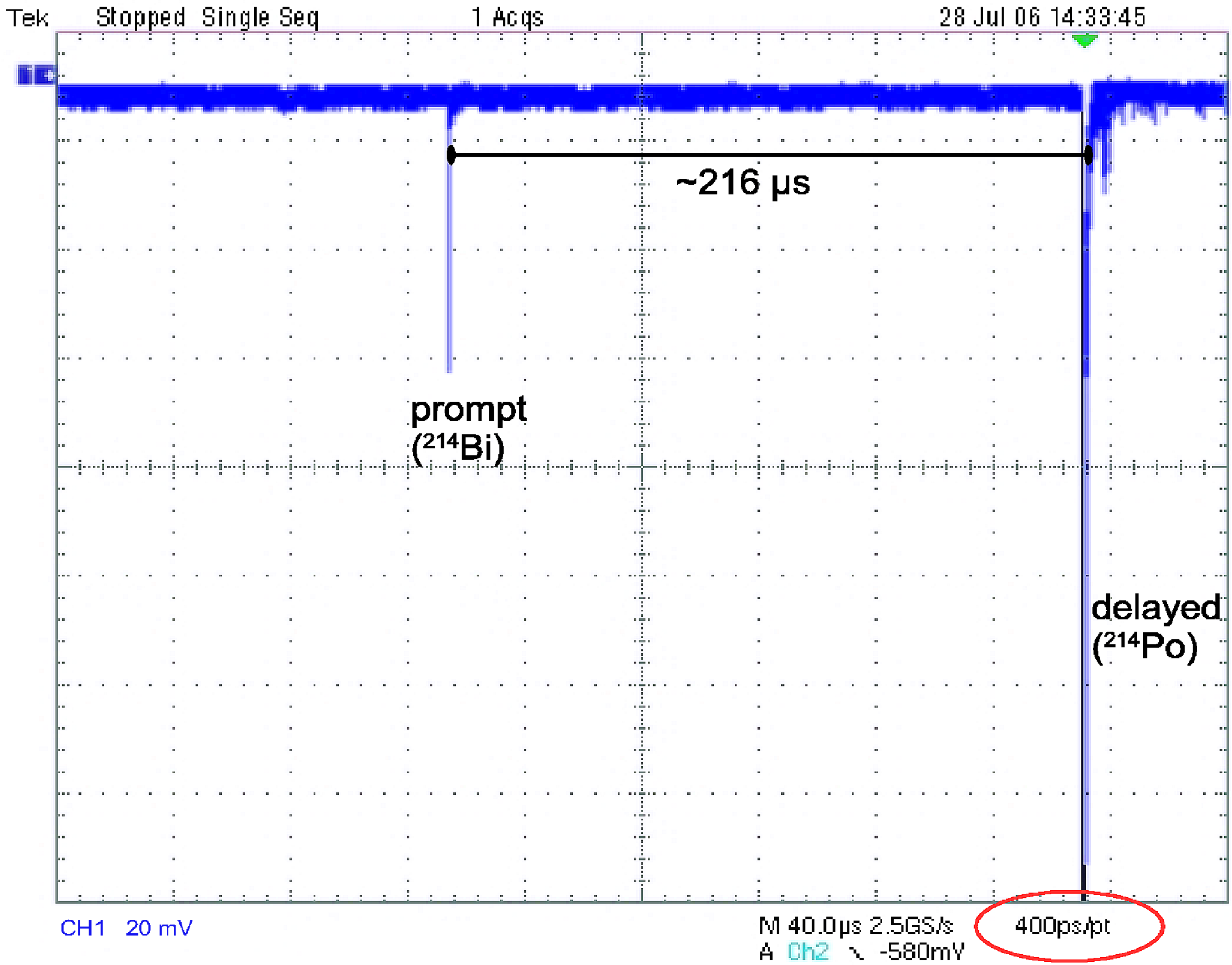
Pulse-shape discrimination



^{222}Rn detection: tagging the coincident ^{214}Bi-^{214}Po - decay

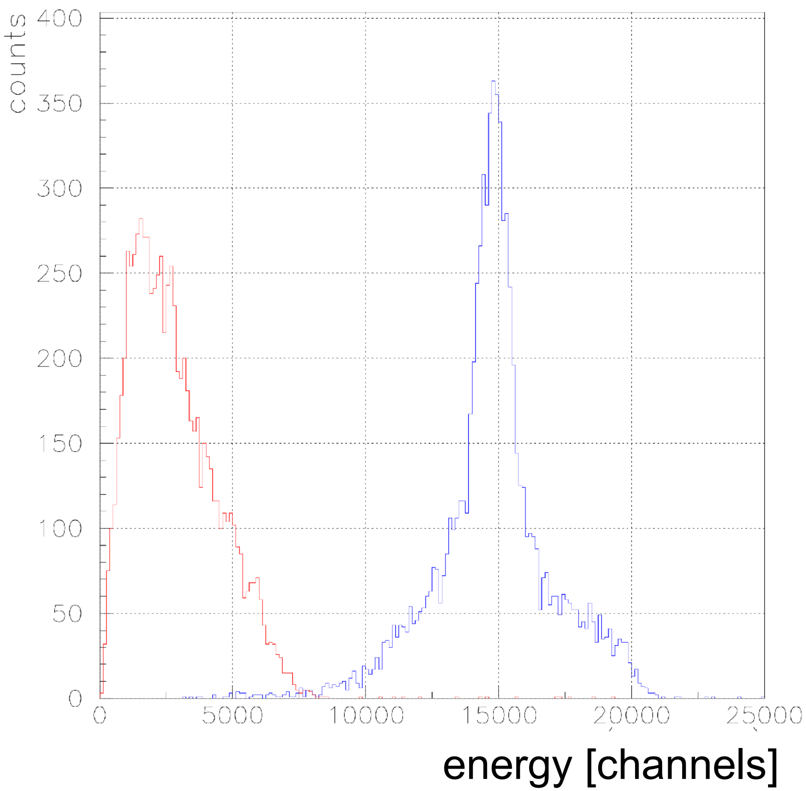


Sample ^{214}Bi-^{214}Po coincident pulses

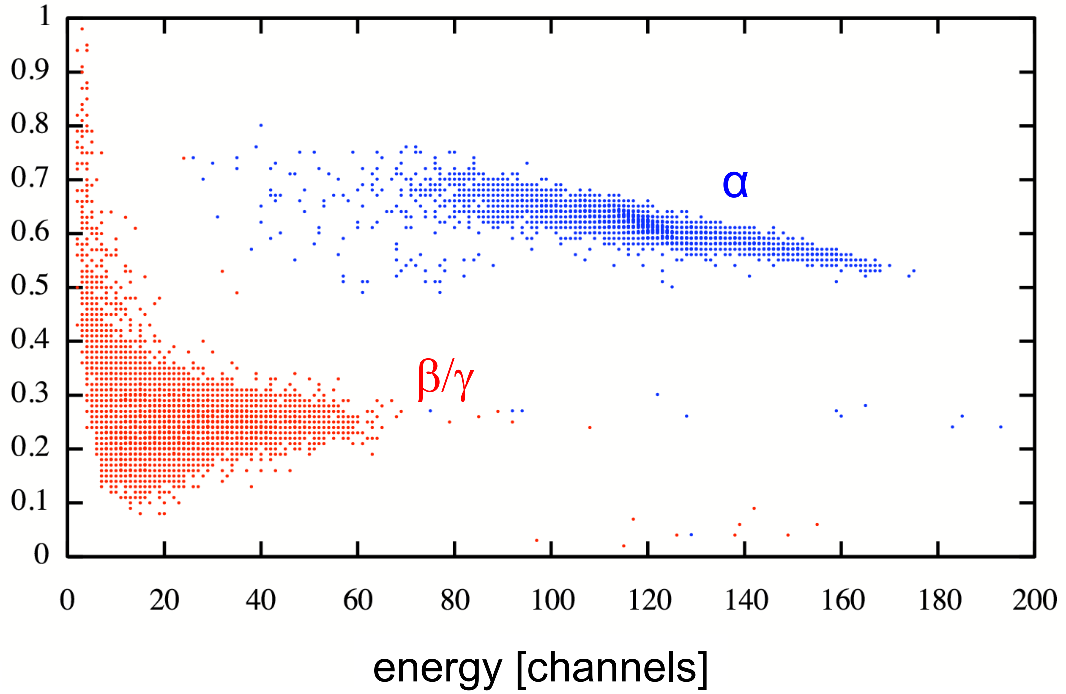


^{214}Po – spectrum and ratio fast/total intensity

spectrum: ^{214}Bi + ^{214}Po + random

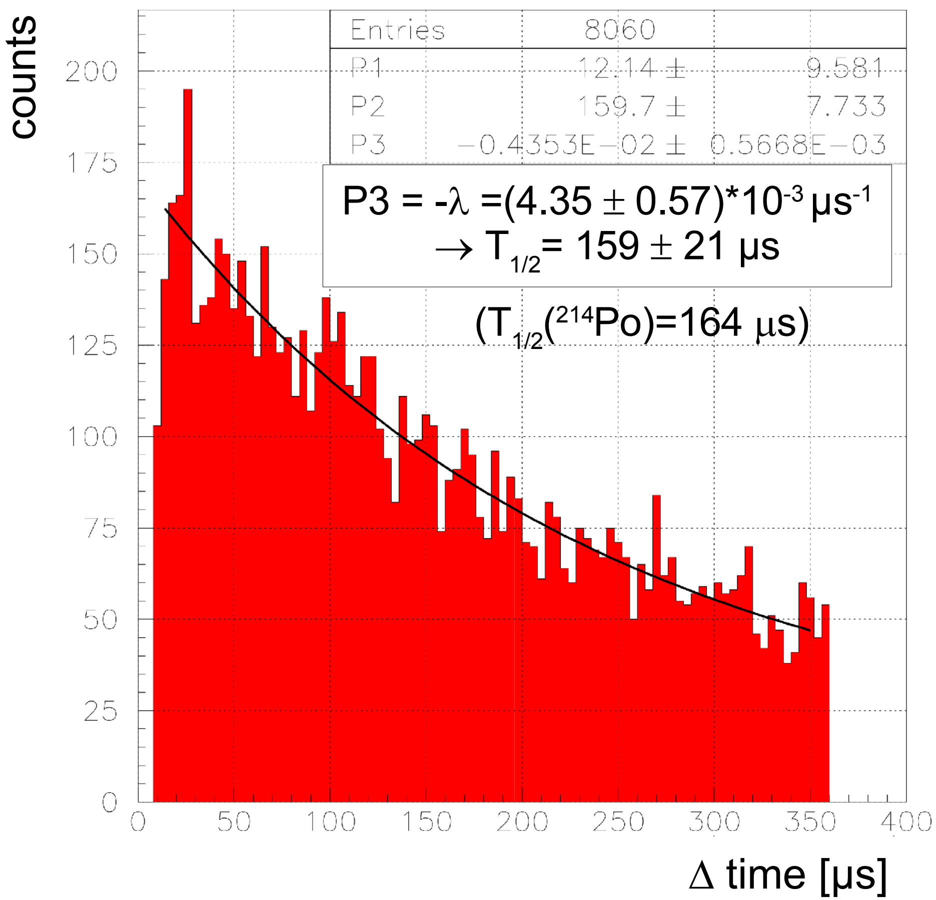


ratio fast/total

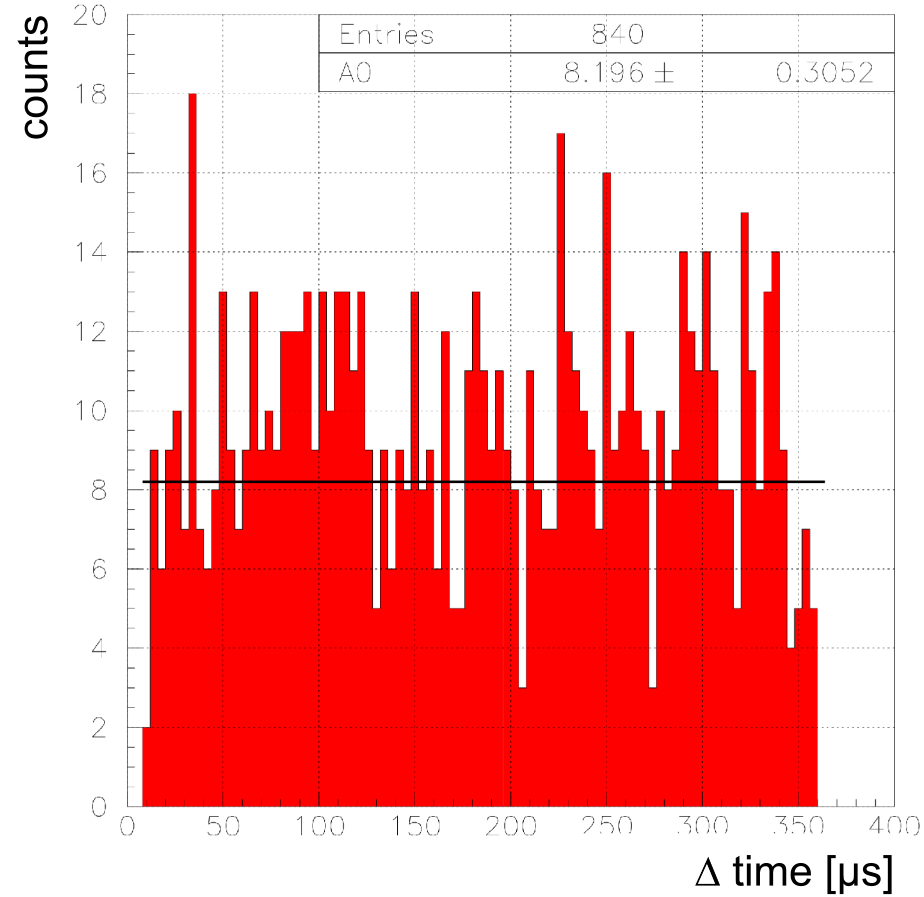


Signal timing

prompt signal in β/γ ratio band
+ fit: $f = P1 + P2 * \exp(P3 * t)$



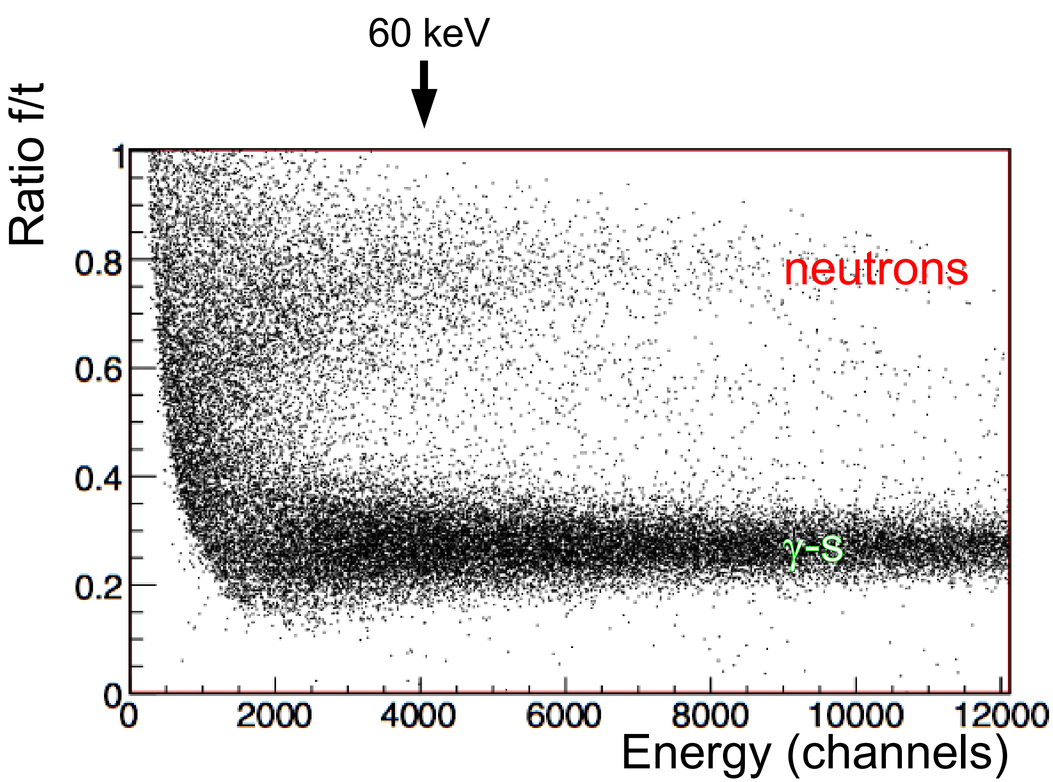
prompt signal in α ratio band
→ random coincidences

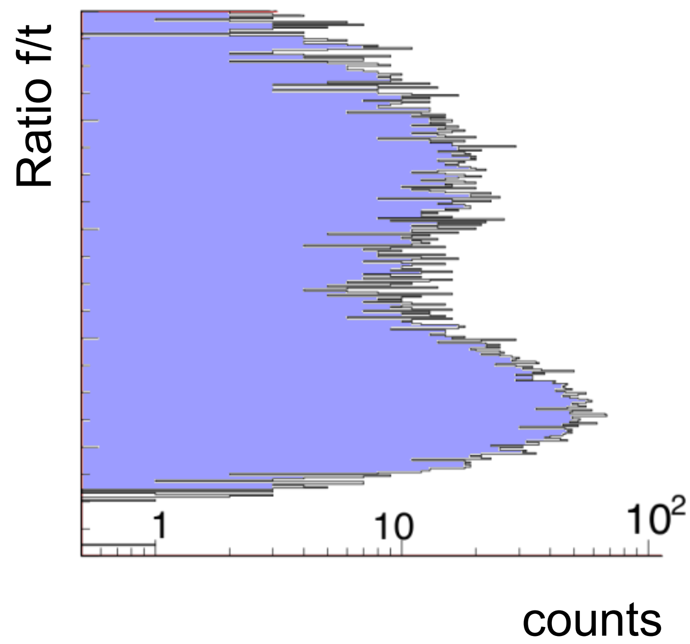


^{222}Rn-sensitivity reached in prototype: 10 µBq/kg LAr = 17 µBq/m³ Ar(STP)

Neutron tagging:

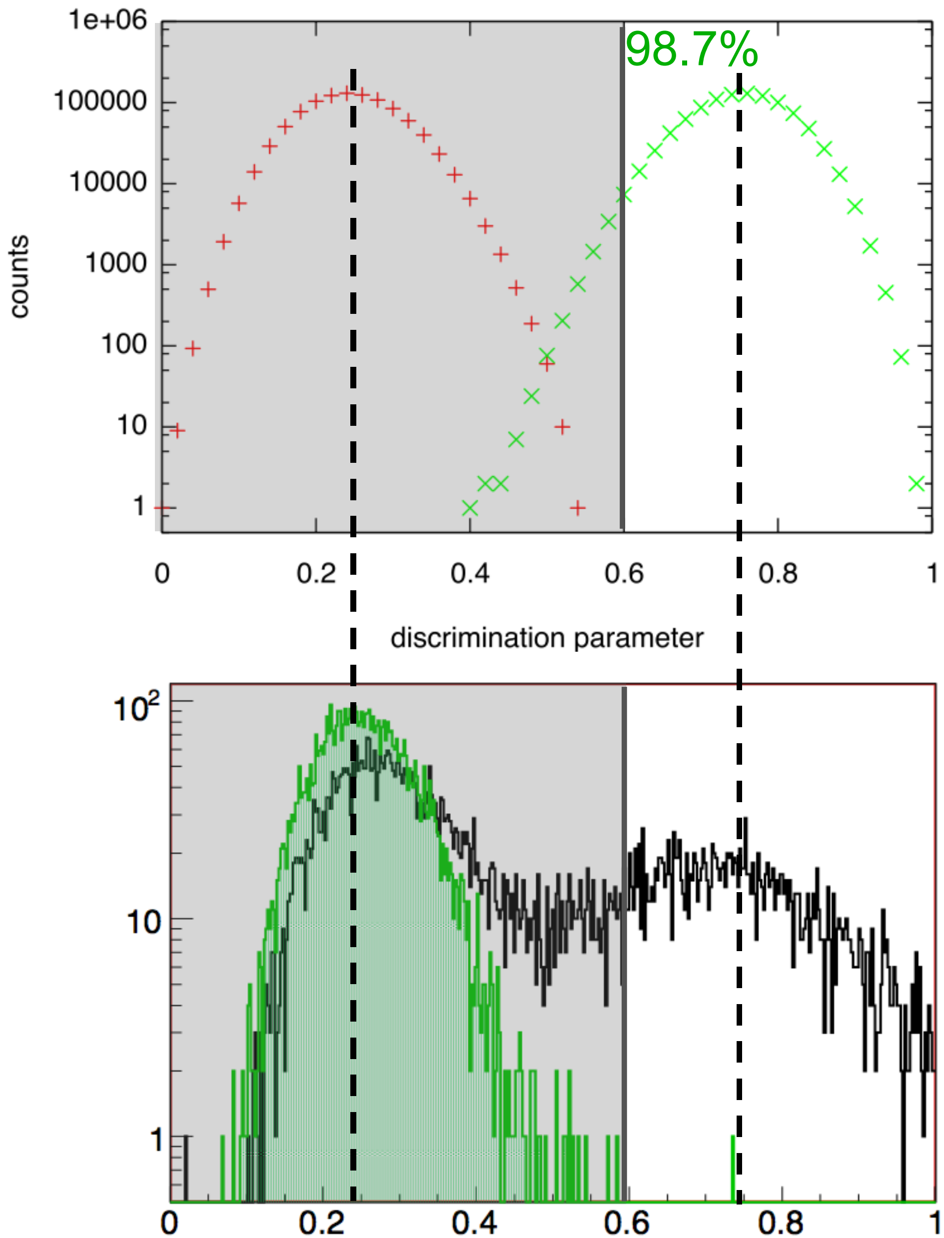
AmBe neutrons an γ-s ratio fast/total vs. energy





goal: fight neutron induced background

Discrimination efficiency



Simulation

E ≈ 45 keV

D > 10^6

Experiment

E = 40 – 80 keV

D > $3.7 \cdot 10^3$

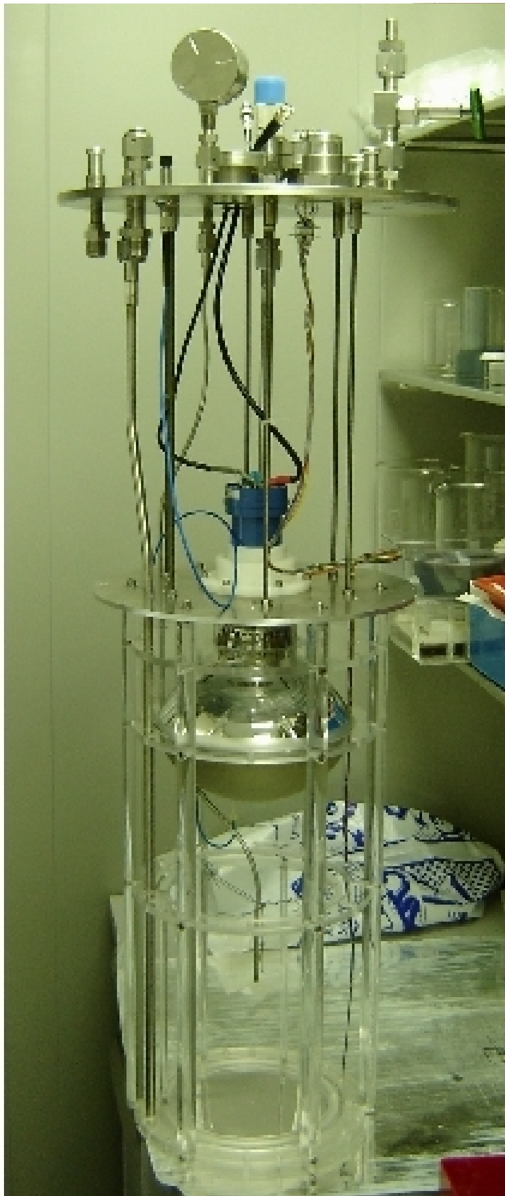
limited by background, low statistics and degraded α-s

Summary – LAr scintillation

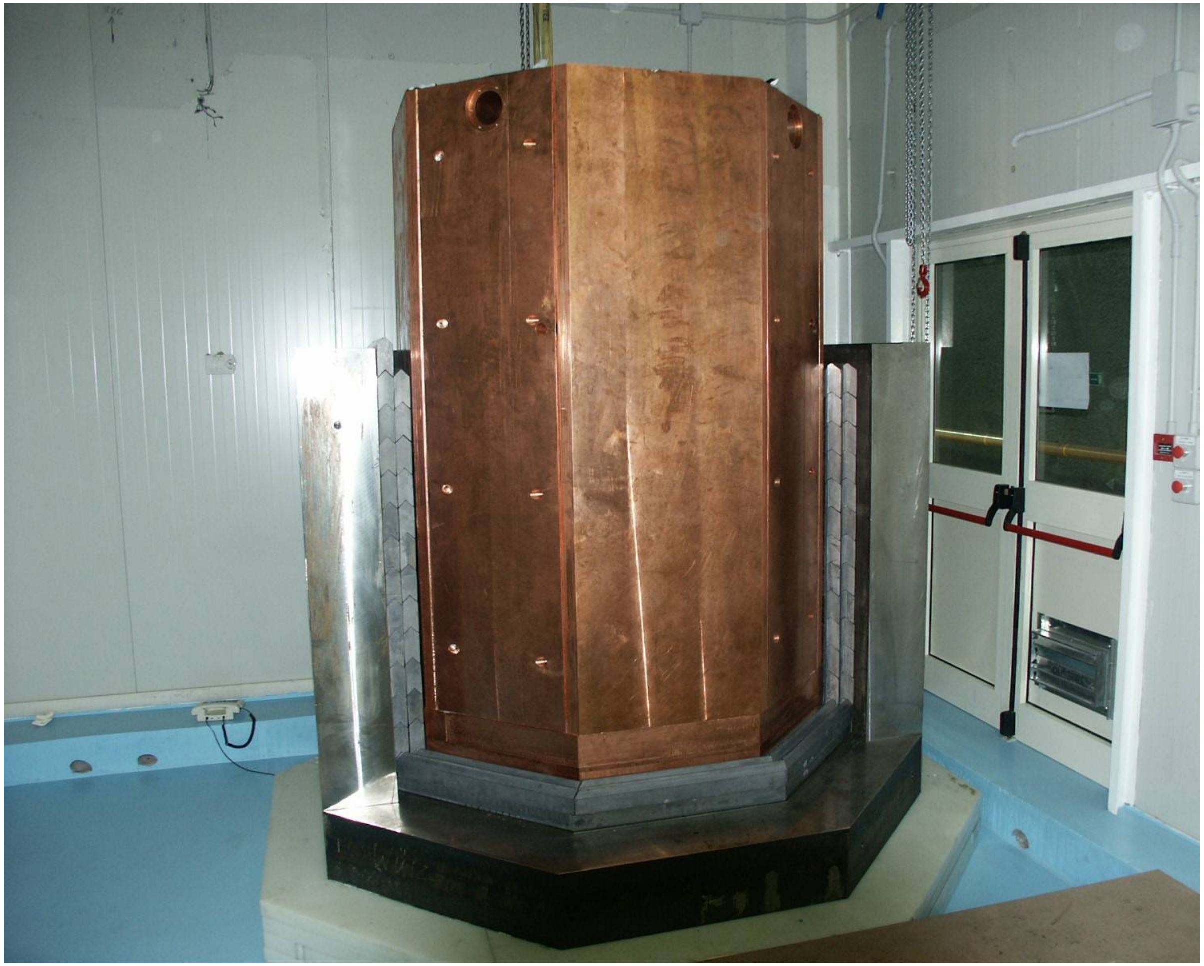
- Efficient veto technique with ~100% acceptance of $0\nu\beta\beta$-signal
- Stable light yield of 1240 $\pm$ 27 pe/MeV since 2 years
- Strong $(\gamma/\beta)-\alpha-$n discrimination
- Good γ and α spectrometer
- Rn sensitivity achieved in our setup:
  ~10 µBq/kg = 17 µBq/m³ STP
- α-quenching factor q_{α}(7.7 MeV)$=$ 0.72 $\pm$ 0.03
- Xe – doping increases light yield, shortens pulse length and decreases discrimination

Backup slides

LArGe@MPI-K setup



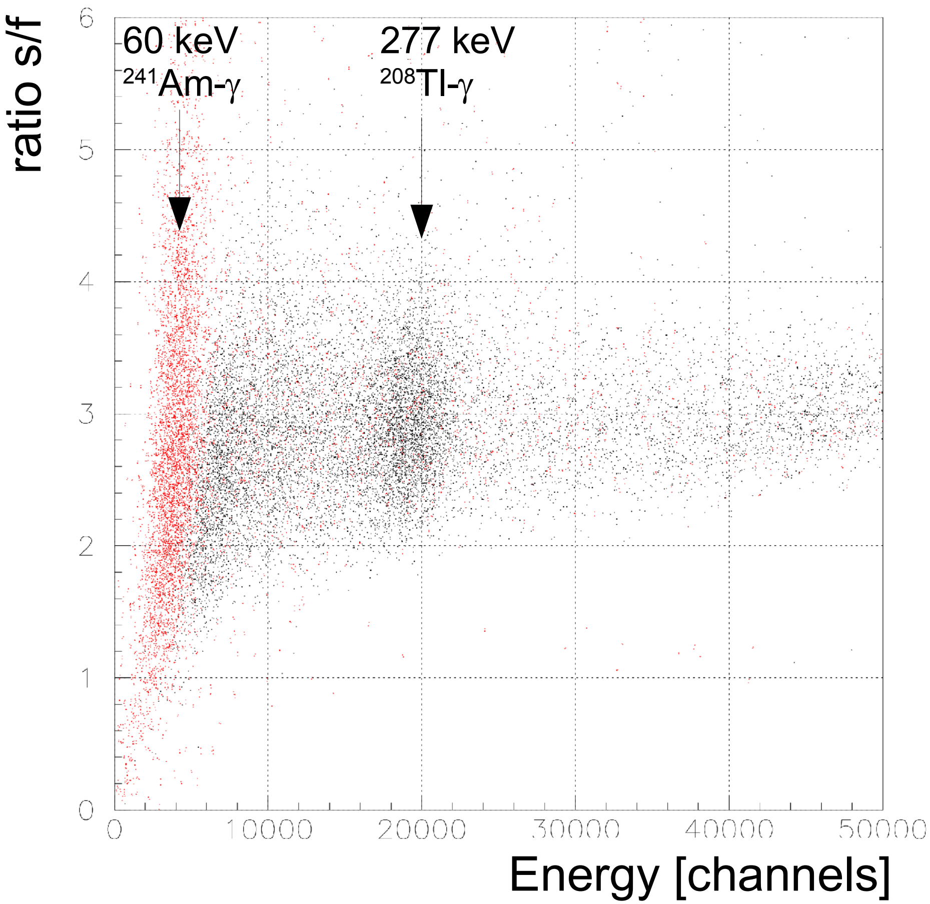
LArGe @ Gran Sasso
under construction



$^{222}Rn + ^{228}Th$
ratio slow/fast component

Low energy:

^{241}Am-γ and ^{228}Th-γ – ratio s/f vs. energy



High energy:

^{228}Th + ^{222}Rn – ratio s/f vs. energy

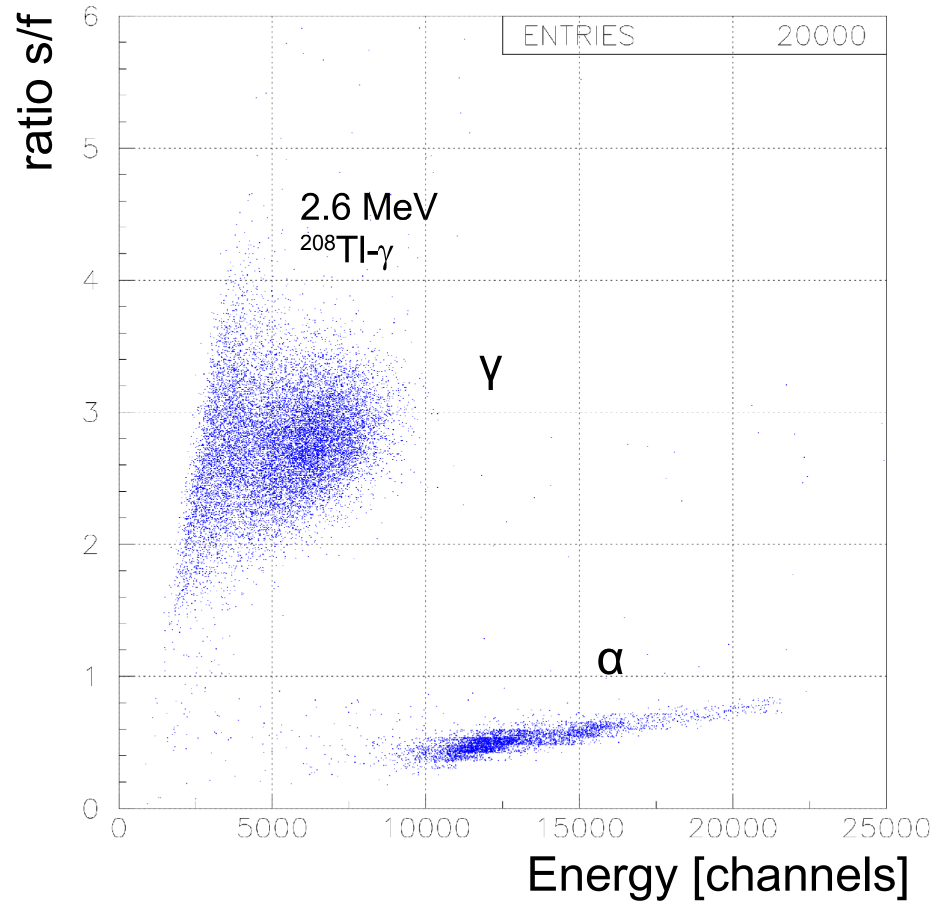
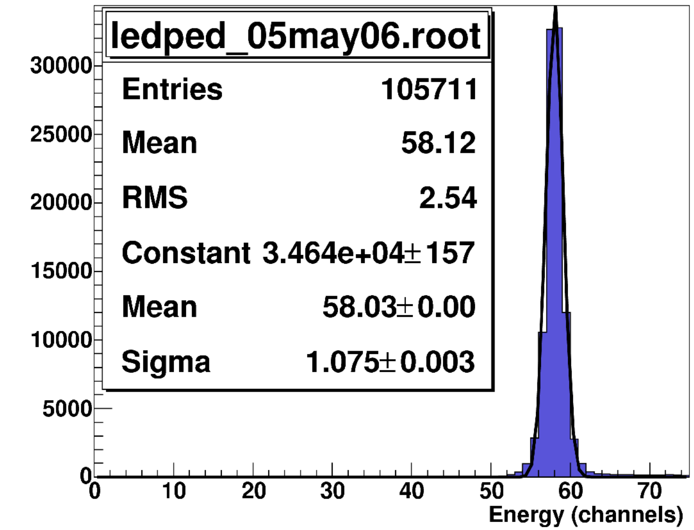
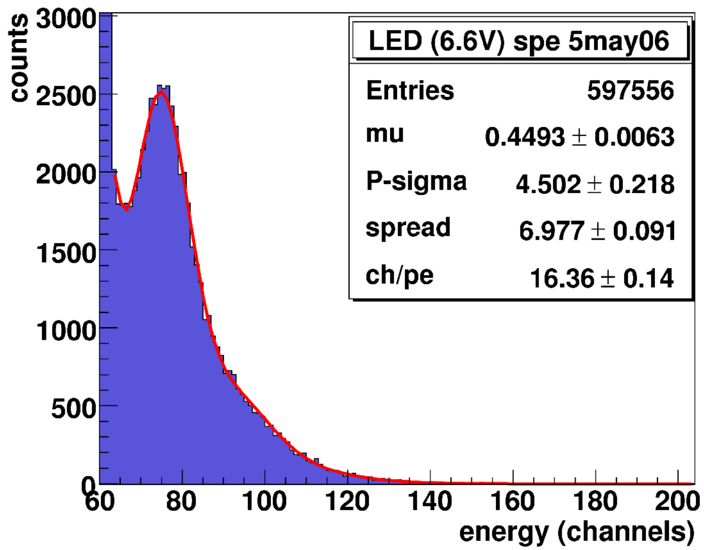
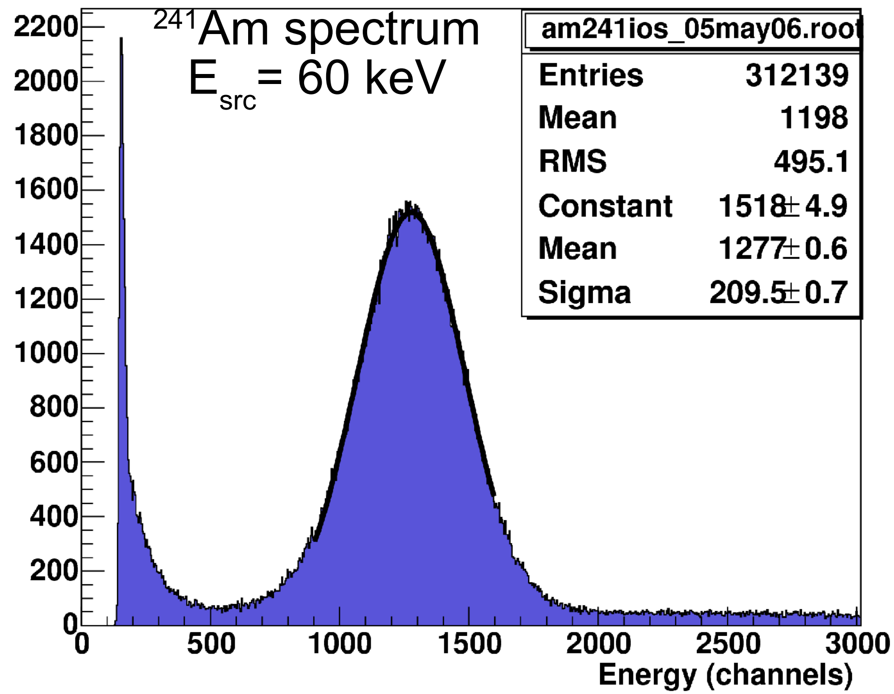


Photo electron yield



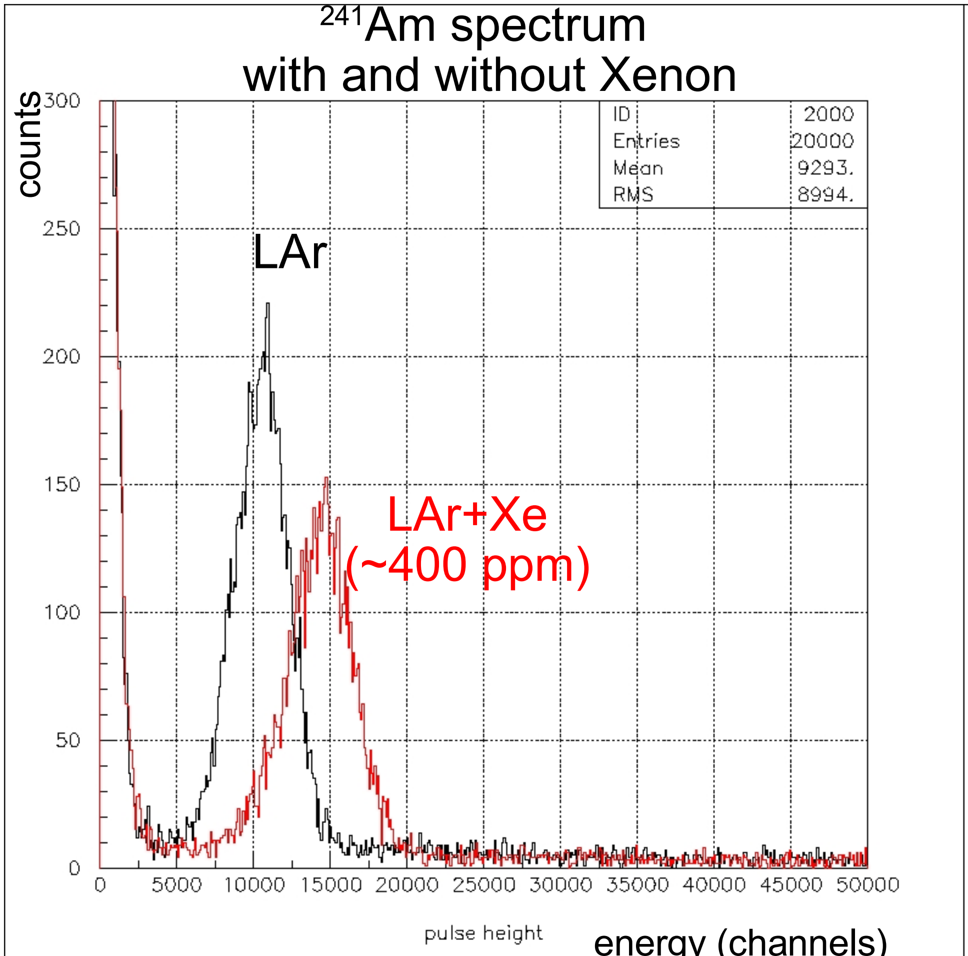


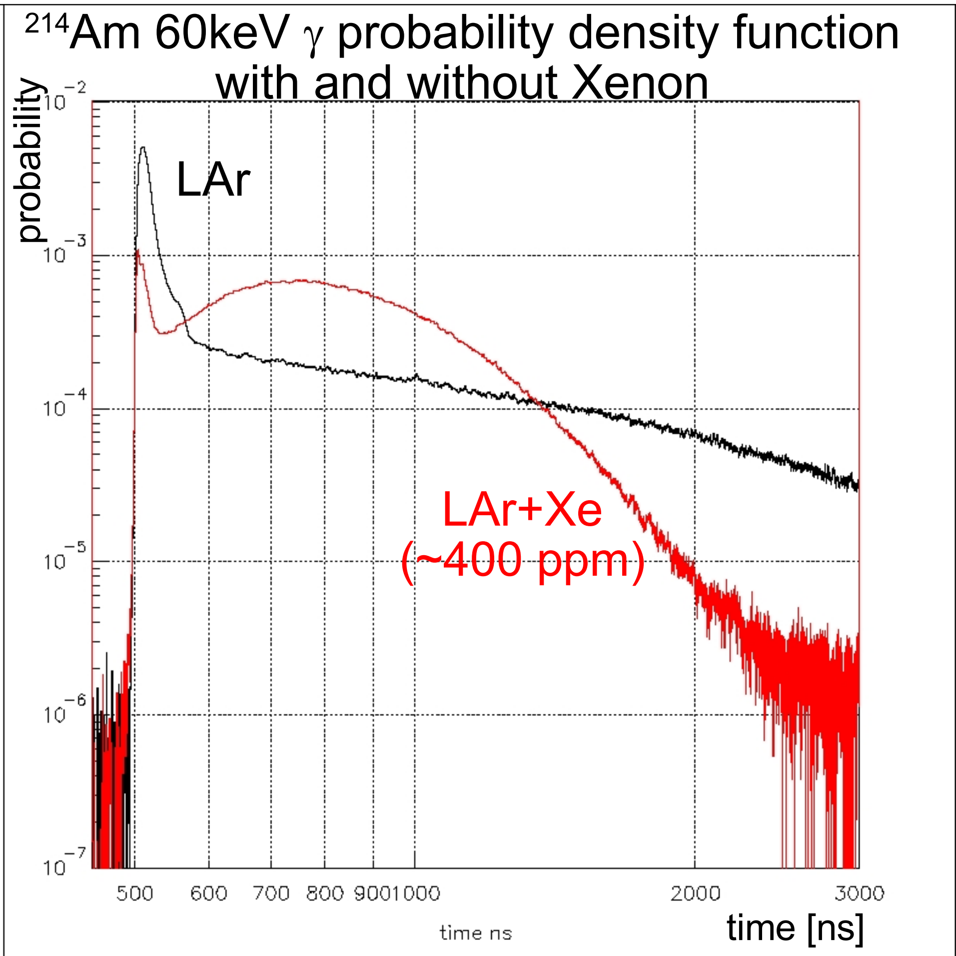


Pedestal P = channel 58
Source position C_{src} = channel 1277±0.6
channels/pe G_{pe} = 16.36 ± 0.14
Photo electron yield: $Y = (C_{src} - P)/(G_{pe} * E_{src})$

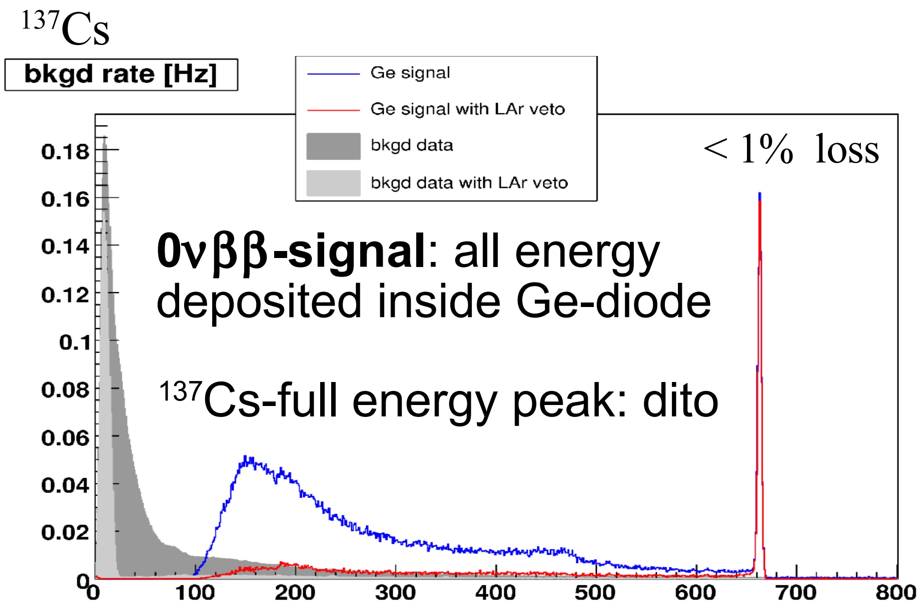
Y = (**1242** ± 27(sys) ± 10(stat)) pe/MeV

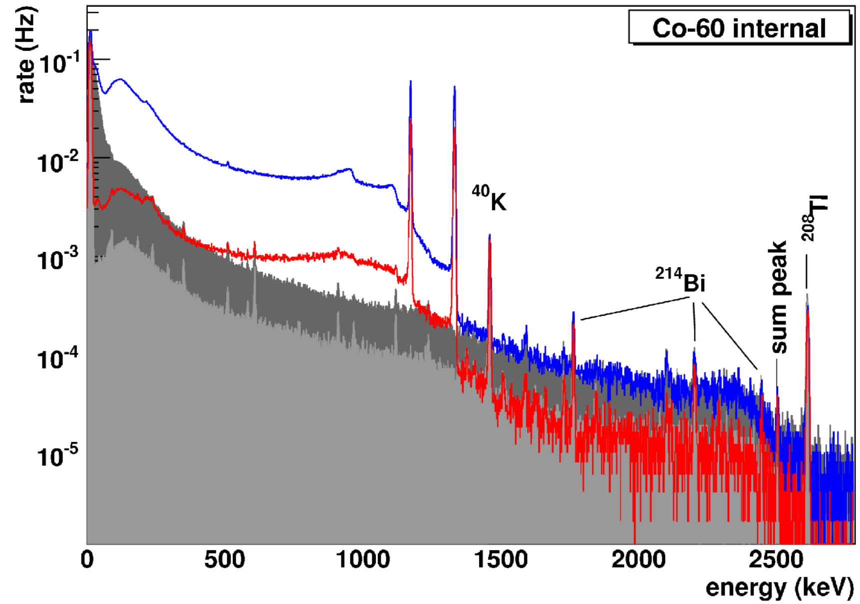
Adding Xenon

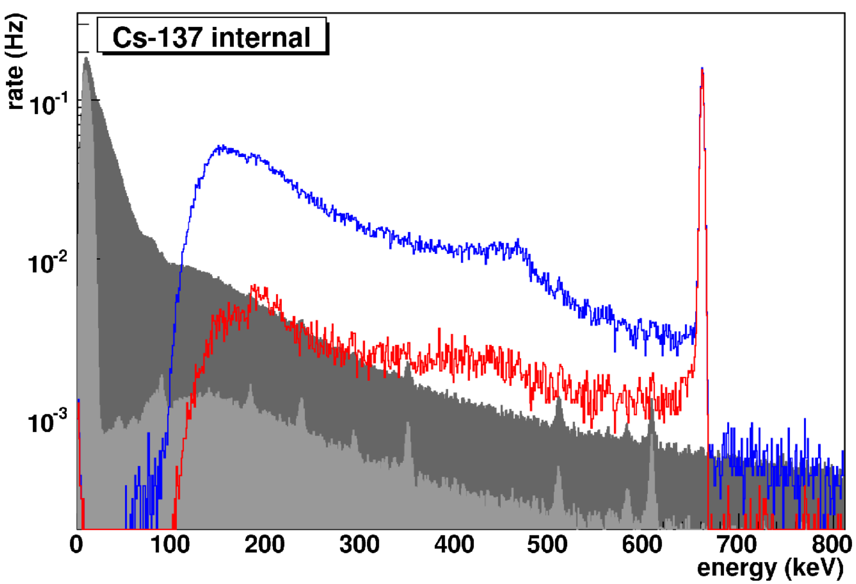


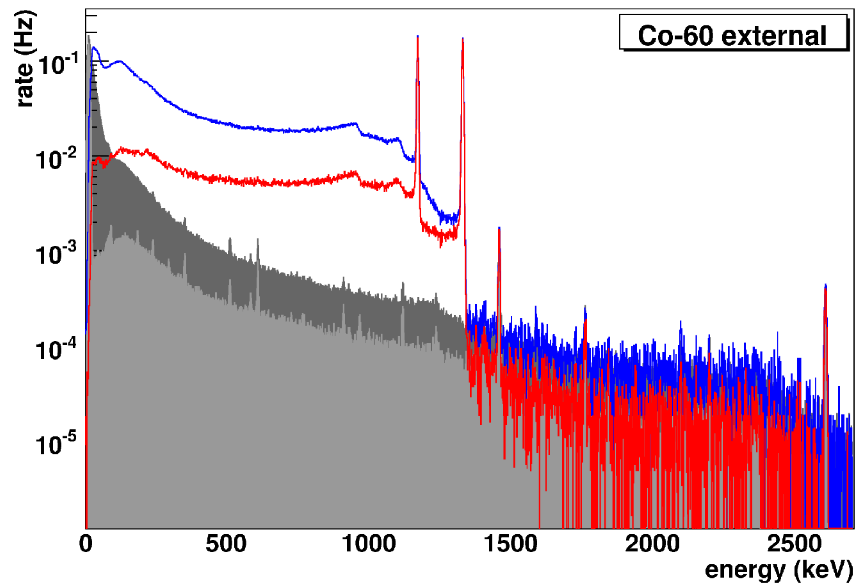


Suppression spectra









Improving the photo-electron yield

- *Previous:* (407±10) pe/MeV VM2000 w/o fluor
- *Past experience:* pure TPB coating improves light-yield, but deteriorates over time + reduces reflectivity
  → polymer matrix doped with fluor

- *Matrix material tested:* **PST (polystyrene)** + PVT
- PST emission max.: λ=335 nm, absorption max.: λ=260 nm
- Thickness of PST layer on VM2000: ~2.5 μm

- *Fluors tested:* **TPB** (tetra-phenyl-buthadiene), PMP, TFPB…
  Best performance: TPB in PST
  TPB absorption max. at λ = 345 nm → good overlap
  Emission maximum at λ = 450 nm

- *Result:* Photo-electron yield: **1240 ± 10 ± 17 pe/MeV**
  Stable since May `06

LAr veto electronic layout