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Preparatory experiments for cold-neutron induced fission studies at IKI

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Outline

- Motivation
- Planned experiments at IKI Budapest
- Characterization of $LaCl_3$(Ce) detectors
    - intrinsic activity
    - energy resolution
    - intrinsic efficiency
    - timing resolution
- $LaCl_3$(Ce) detectors in strong neutron fields
- Summary
- Conclusions and outlook

Motivation

Assessment of γ-heating for design of Gen-IV reactors

- about 10 % of total energy released in the core of a standard nuclear reactor by fission γ-rays
- about 40 % of those due to prompt γ-decay of fission products

Modelling requires uncertainty not larger than 7.5 % (1σ)

- but: present γ-ray emission data determined in early 1970's, underestimating γ-heating with 10 - 28 % for ^{235}U and ^{239}Pu

→ NEA Nuclear Data High Priority List:

- measurement of prompt γ-ray emission from $^{235}U(n,f)$ and $^{239}Pu(n,f)$!

Experimental task

Time-of-flight method to distinguish between γ-rays and neutrons
$\rightarrow$ requires good timing resolution

Back then:

- NaI detectors and ionization chambers
- $\tau \approx 3$ - 5 ns and $\tau \geq 1$ ns

Today & tomorrow: new detectors offer new possibilities

- lanthanum halide crystals and pcCVD diamond detectors

$\rightarrow$ intended fission γ-ray measurements - a prerequisite to the assessment of γ-heating!

Fission-fragment and γ-spectrometry

Simultaneous measurement of:

- post-neutron fission fragment distributions of $^{235}U + n_{th}$
  - time-of-flight and kinetic energy
  - fission-fragment spectrometer VERDI (→ S. Oberstedt *et al*.)
  - pcCVD diamond detectors as fission trigger
- prompt fission γ-rays
  - three $LaCl_3(Ce)$ scintillation detectors
  - ^6Li shielding against thermal neutrons
  - coincidence with fission trigger

Location:

- 10 MW research reactor at IKI Budapest

Experimental details

Sample: ^{235}U (113 μg)

Thermal neutron flux: $7 \cdot 10^{7}$ cm^{-2} s^{-1}

Fission rate: $1.18 \cdot 10^{4}$ s^{-1}

Fission fragment count rate: 12 s^{-1}

Fission γ count rate: 10 s^{-1}

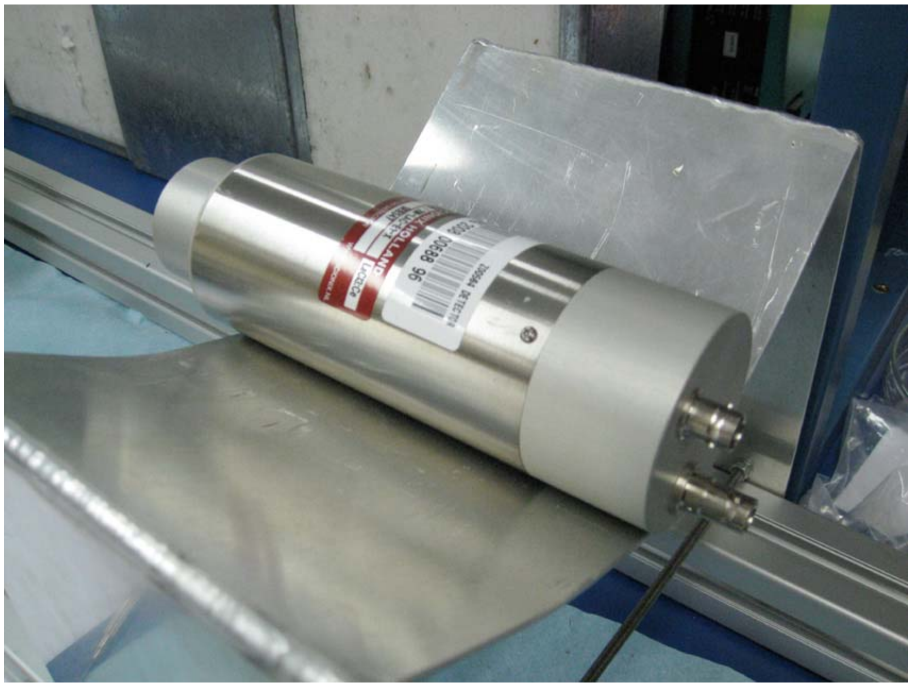
Beam time: 2 weeks (10 days)

Expected number of counts

- fission fragments: $8.5 \cdot 10^{6}$
- γ-rays: $\sim 3 \cdot 10^{7}$

Envisaged for February 2010 !

The detectors



Crystal:
- $LaCl_3(Ce)$

Cerium concentration:
- 5 %

Dimensions:
- 1.5” × 1.5” (coaxial)
- 43 cm^3

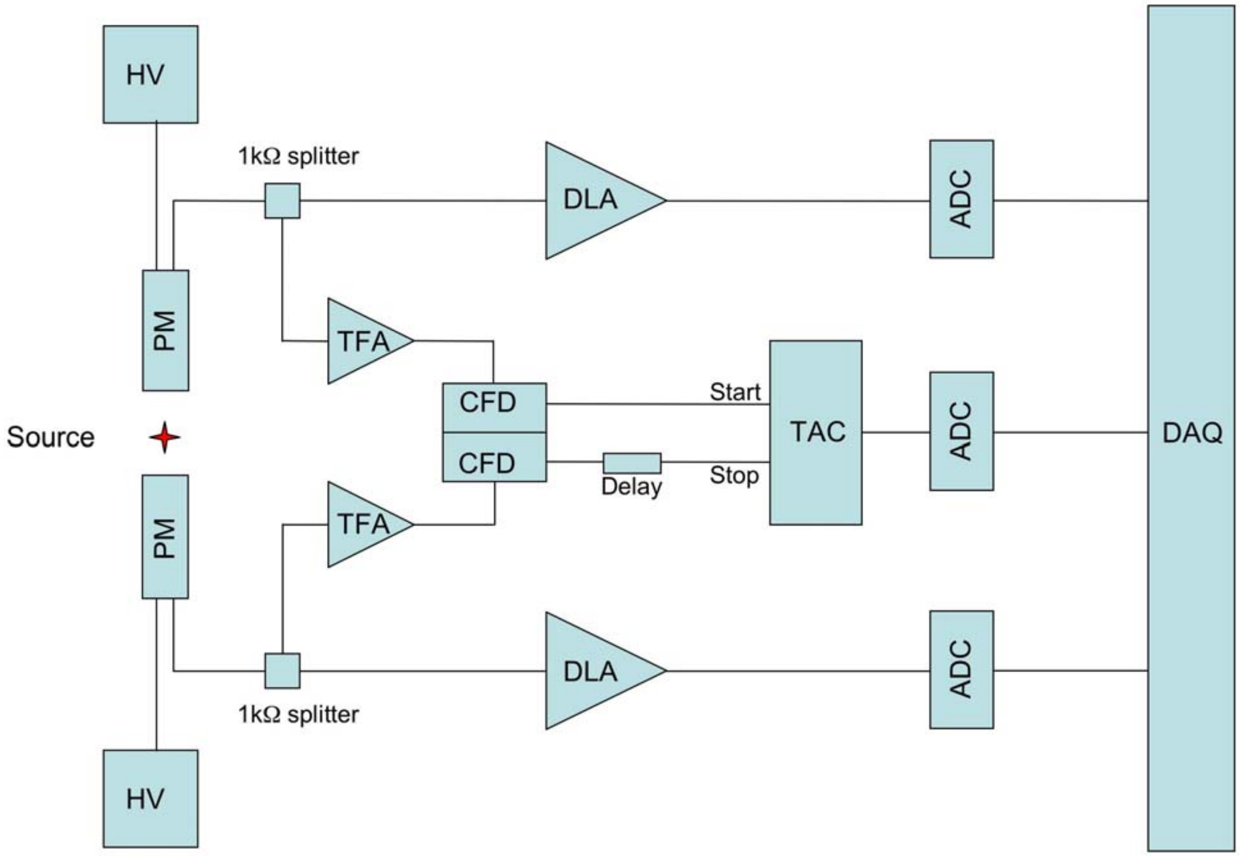
Photomultiplier:
- Photonis XP2500/FB

Manufacturer:
- SCIONIX Holland BV

Observe: only 2 connectors - power supply and 1 signal output!

Experimental set-up

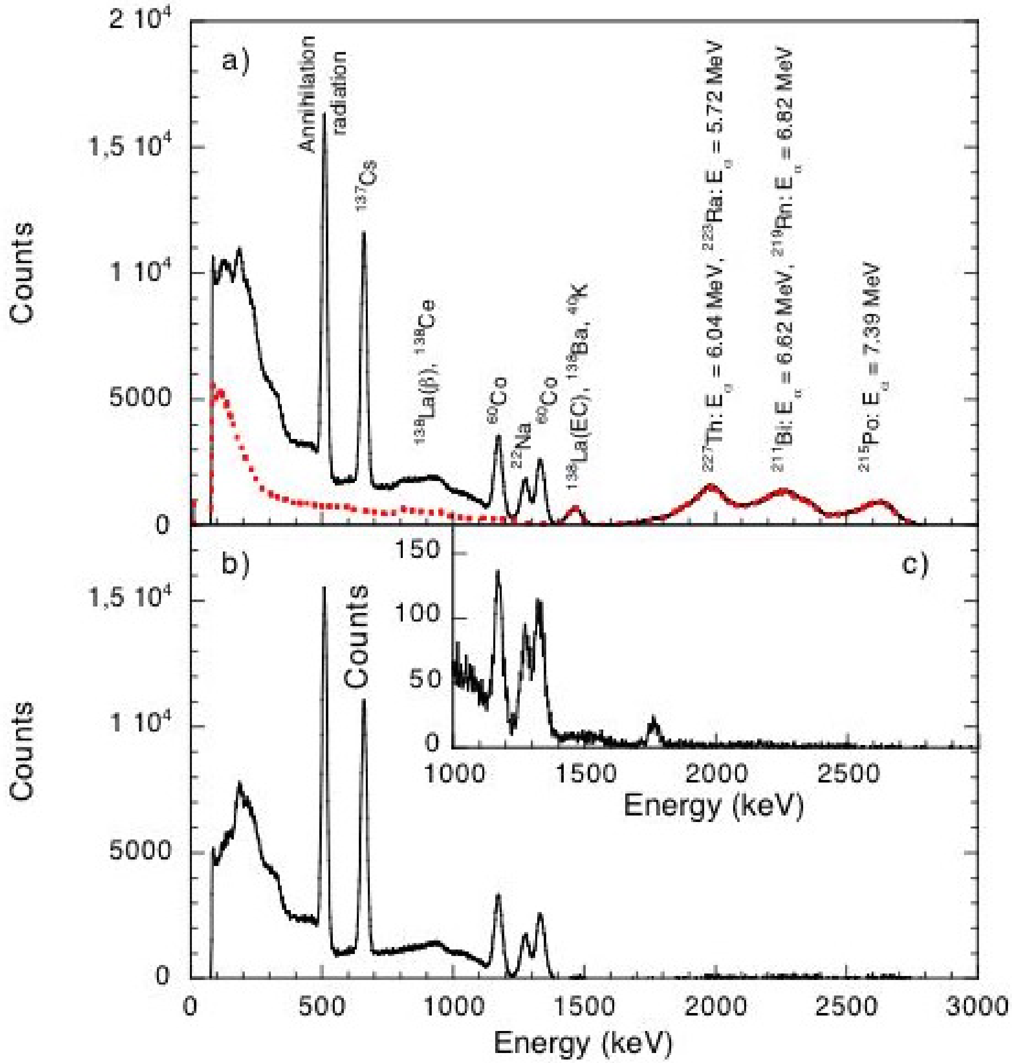
Example: coincidence measurements



γ-sources:

Energy (keV)	Nuclide
81.00	^{133}Ba
122.06	^{57}Co
136.47	^{57}Co
276.40	^{133}Ba
302.85	^{133}Ba
356.01	^{133}Ba
511.00	^{22}Na
661.66	^{137}Cs
834.84	^{54}Mn
1173.23	^{60}Co
1274.54	^{22}Na
1332.49	^{60}Co

Spectra



a) typical spectrum with properly normalized background *)

b) background subtracted spectrum (^{22}Na, ^{60}Co and ^{137}Cs photo-peaks and Compton-edges)

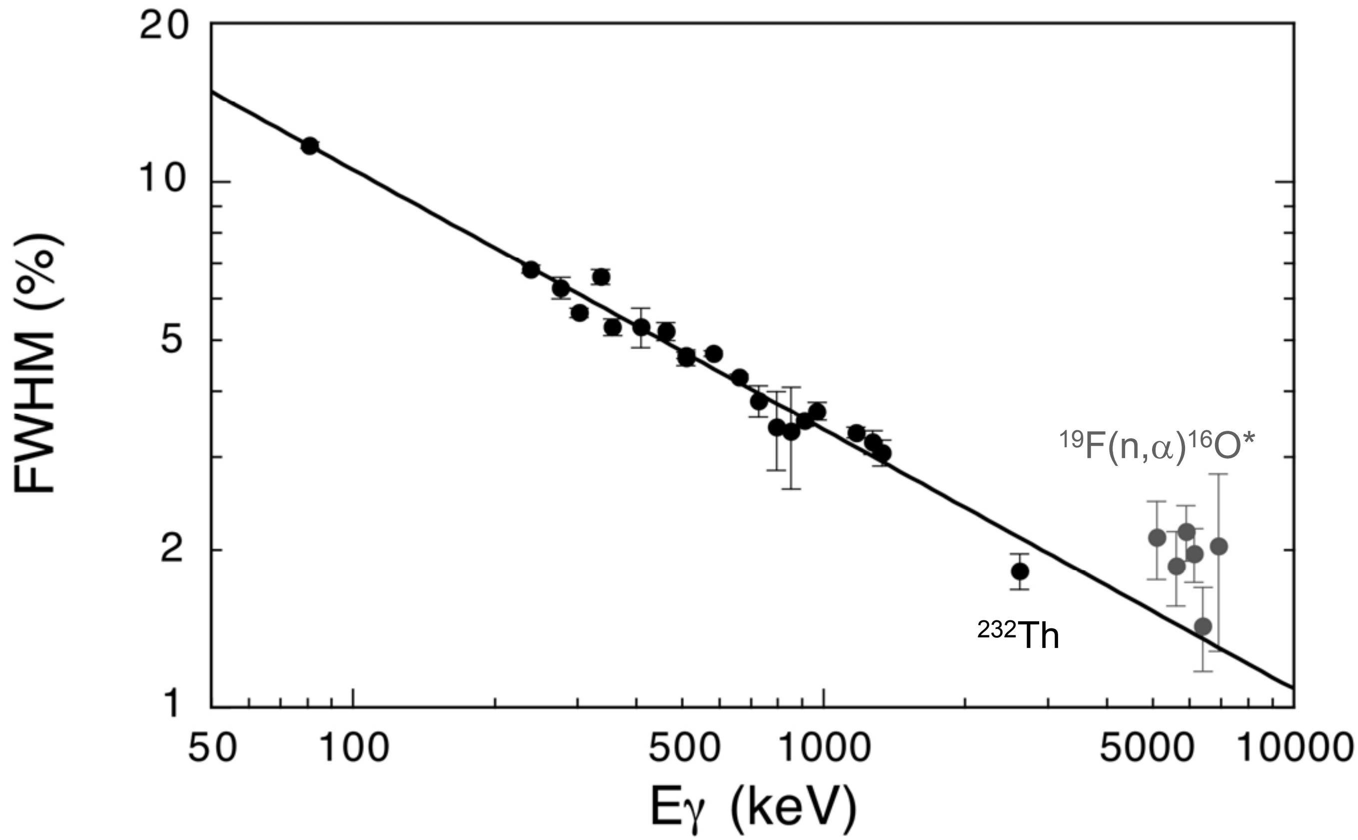
c) coincidence spectrum of two detectors (peak at 1786 keV from ^{22}Na)

*) intrinsic activity:

1.2 Bq cm^{-3} (α-particles)

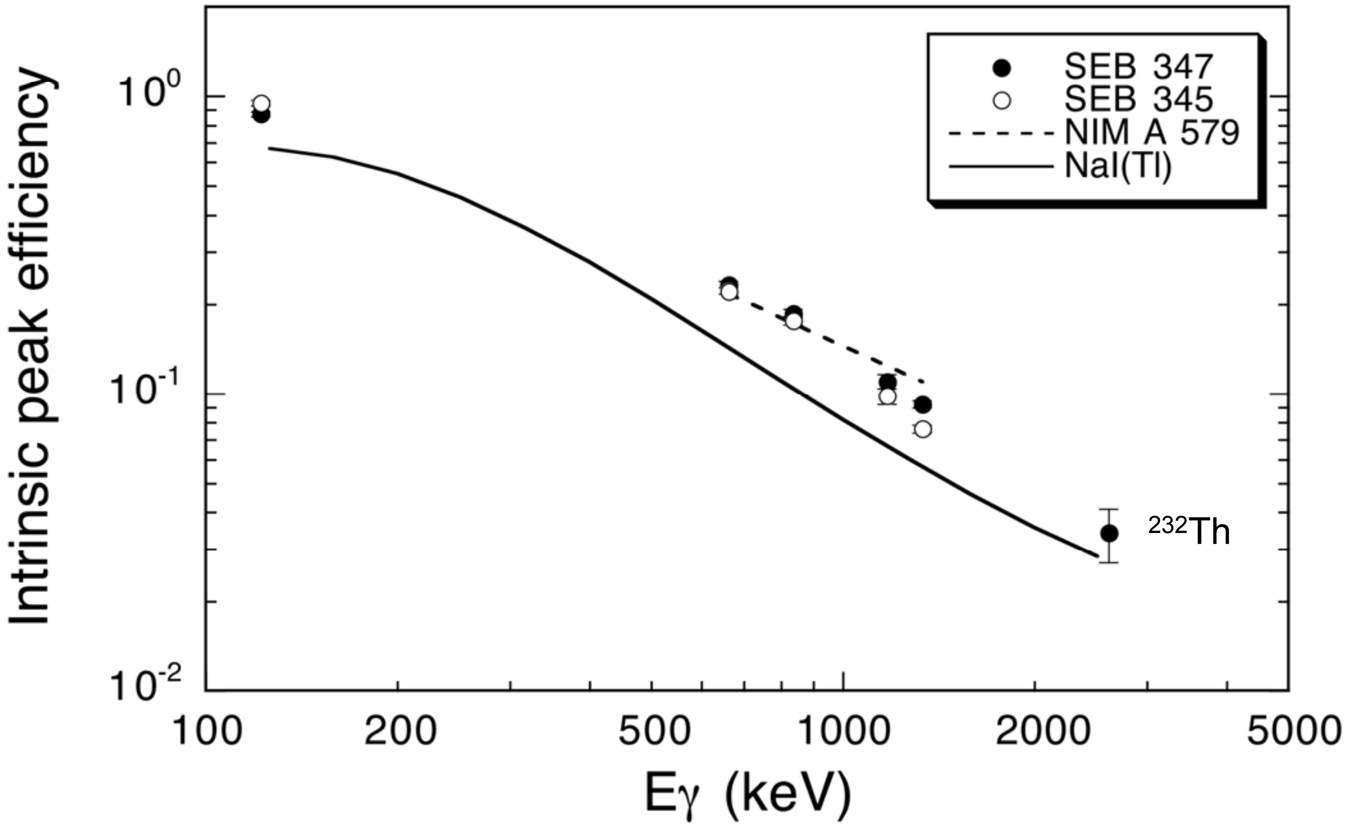
0.06 Bq cm^{-3} (^{138}La, ^{40}K)

Energy resolution



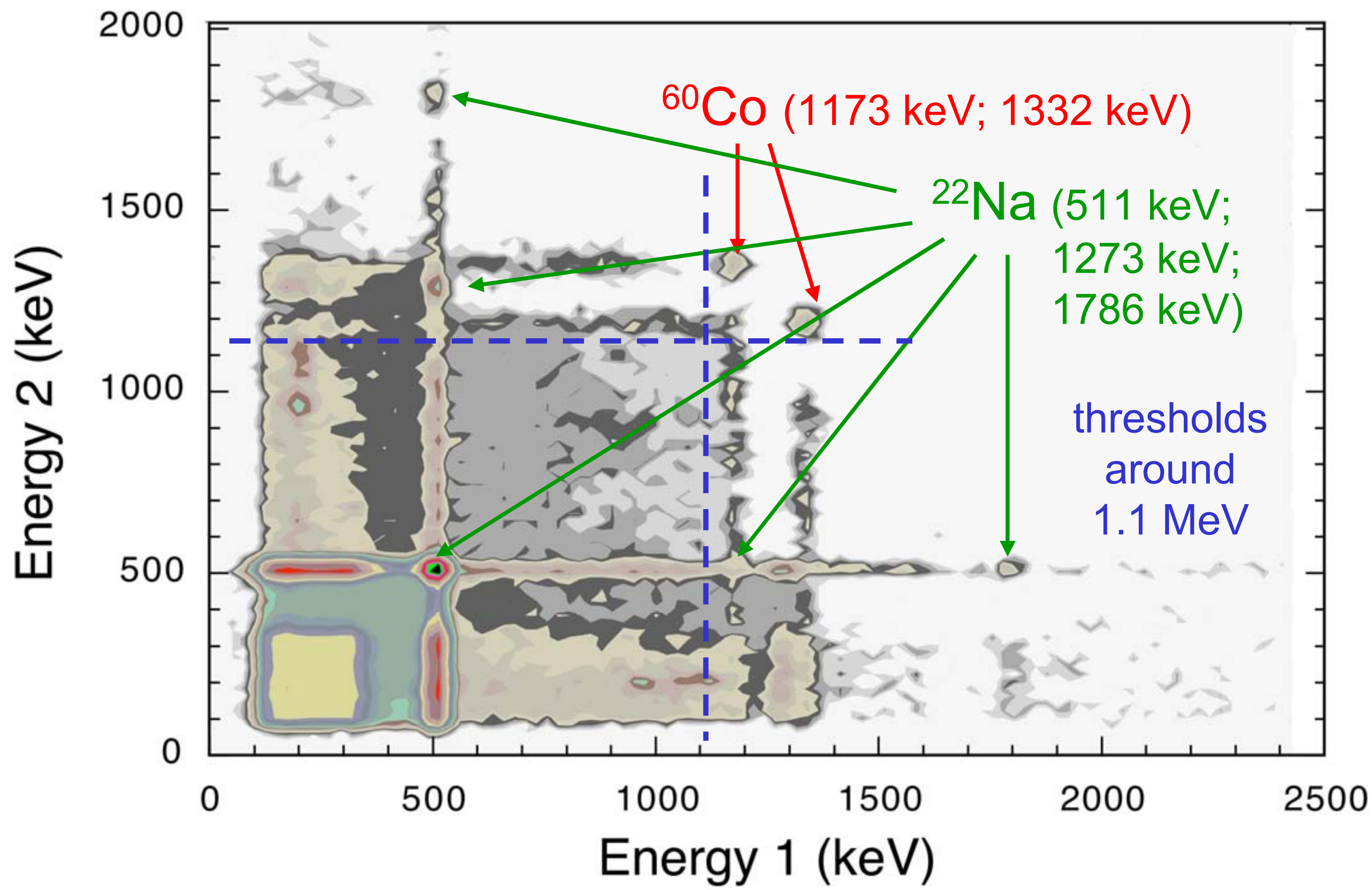
- expected $E^{-1/2}$ behaviour
- $\Delta E/E$ = 3.8 - 4.2 % (FWHM) at 662 keV (^{137}Cs)

Intrinsic efficiency



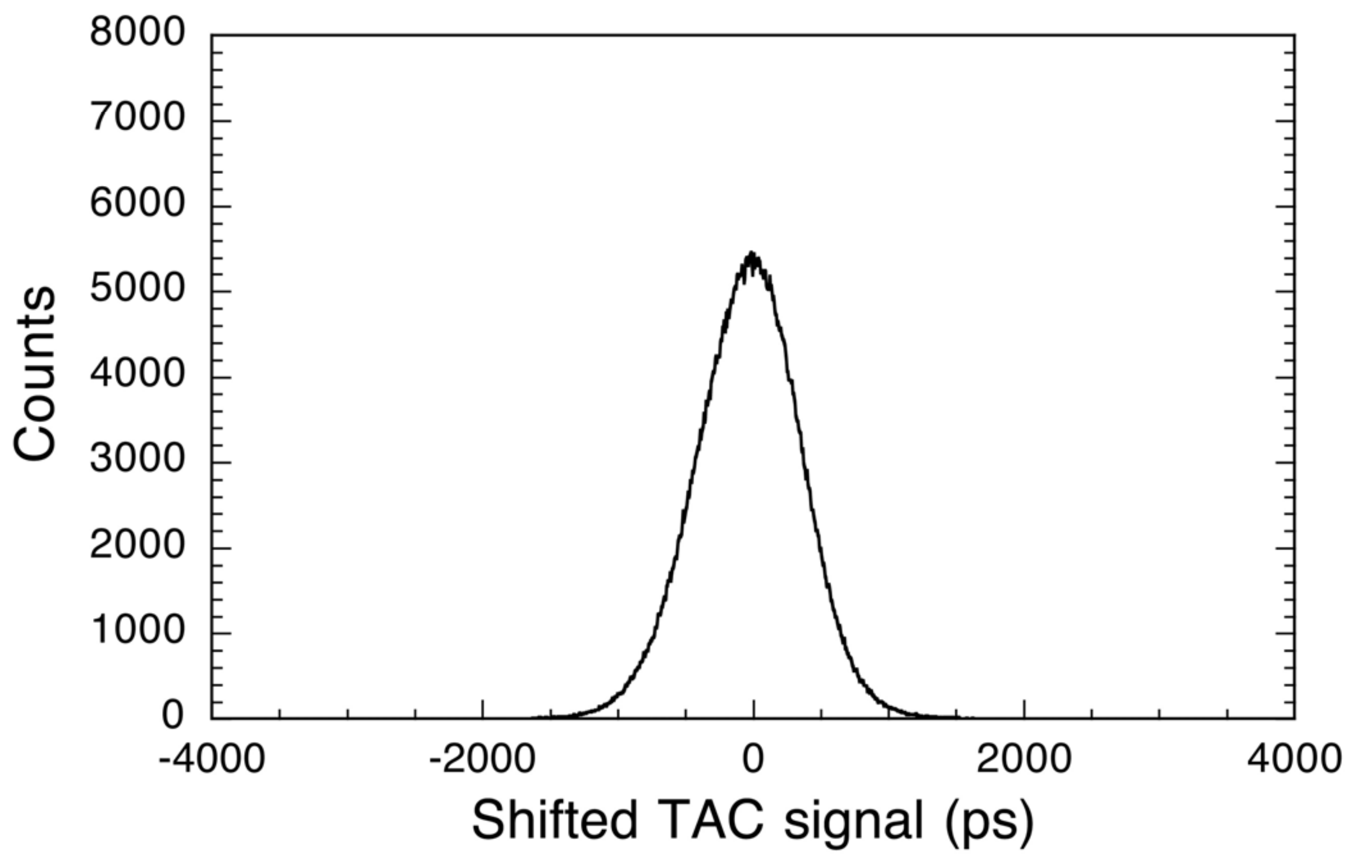
- in agreement with other $LaCl_3$ detectors (interpolated)
- 53 % better than NaI(Tl) detectors of same size

Timing - coincidence measurement

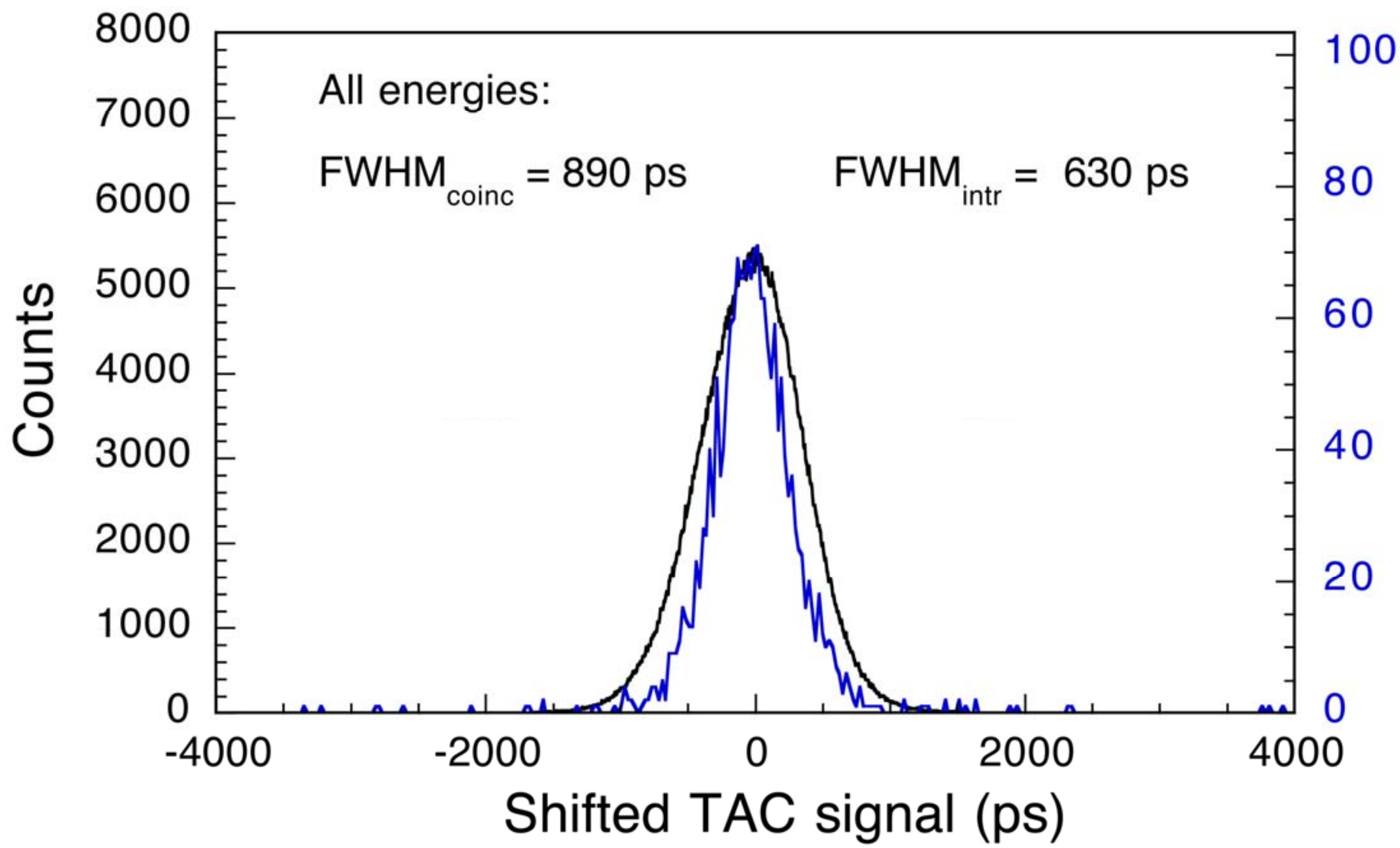


- two $LaCl_3$ detectors with multiple source (^{22}Na and ^{60}Co)

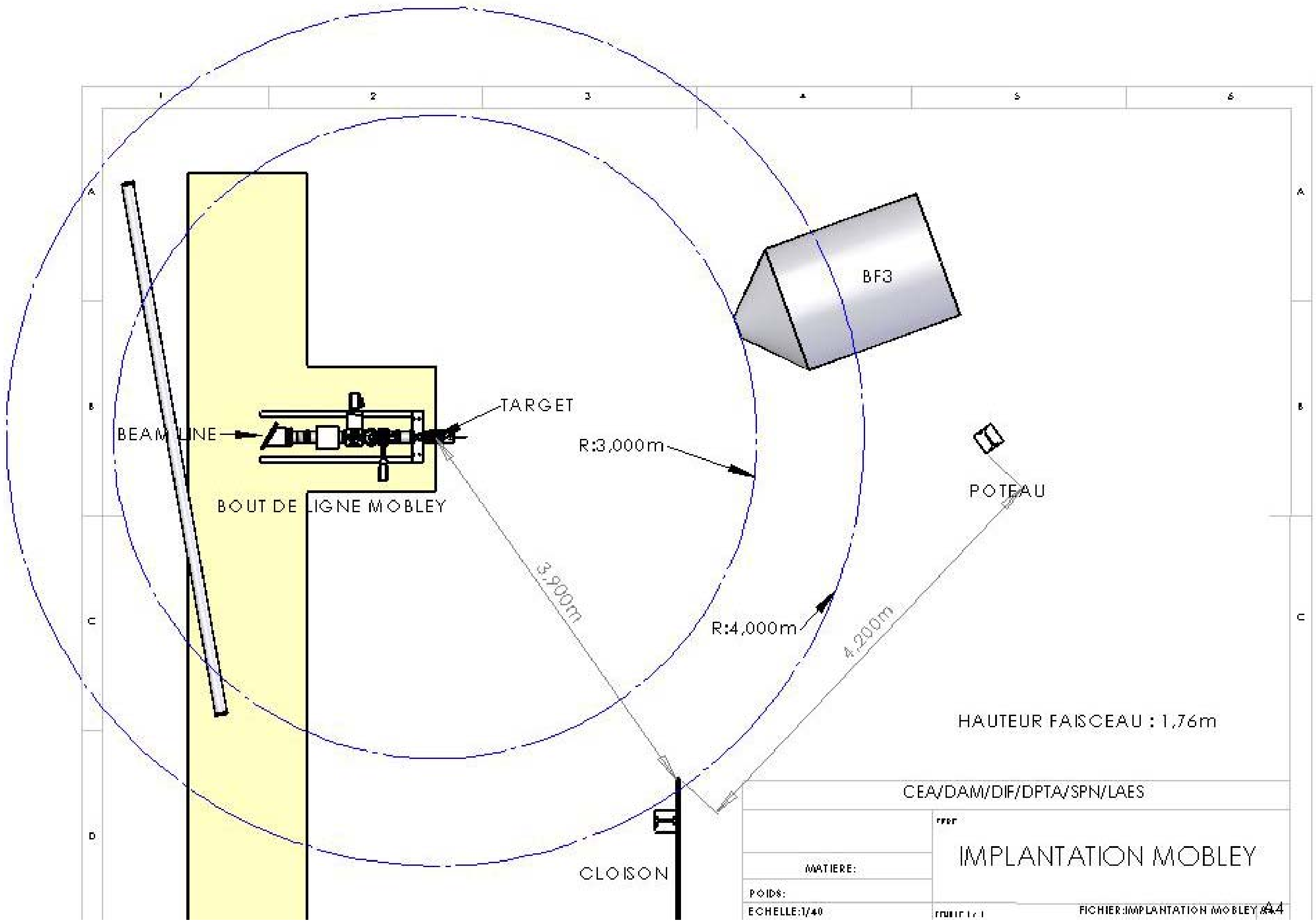
Timing - TAC spectrum



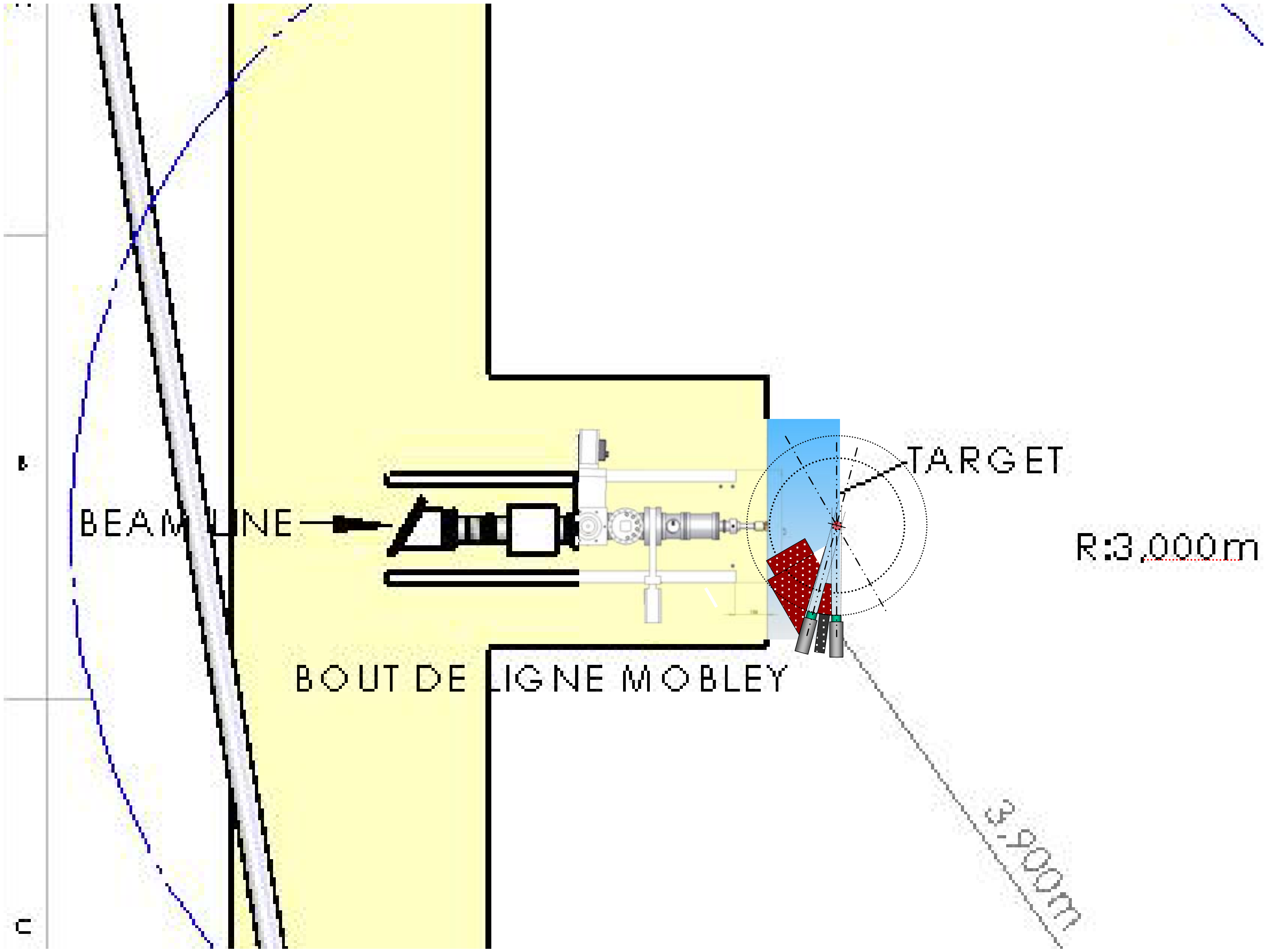
Timing - TAC spectrum



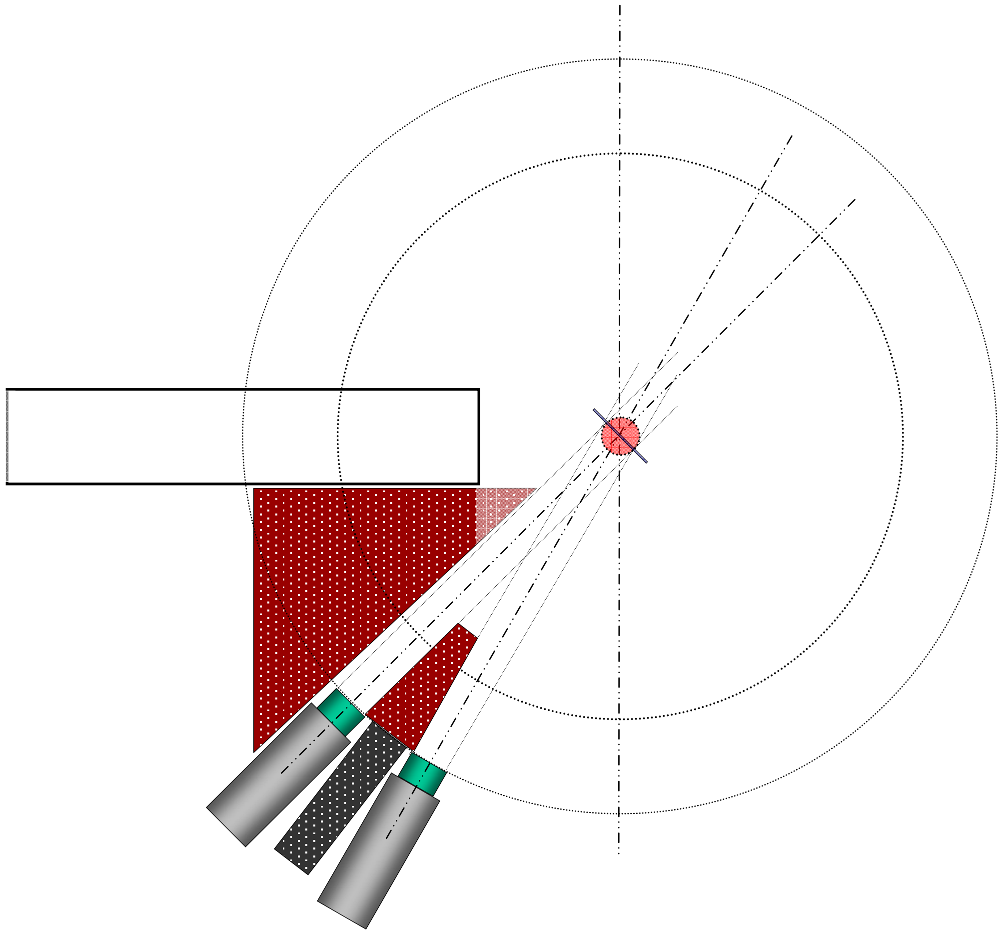
Geometry


BF3
TARGET
BEAM LINE
R:3,000m
POTEAU
BOUT DE LIGNE MOBLEY
3,900m
R:4,000m
4,200m
HAUTEUR FAISCEAU : 1,76m
CEA/DAM/DIF/DPTA/SPN/LAES
IMPLANTATION MOBLEY
MATIERE:
POIDS:
ECHELLE:1/40
CLOISON
A4

Geometry



Geometry



- different detector positions
- w/o different shielding materials
  - Cu
  - Pb

Experimental setup

two $LaCl_3(Ce)$ scintillation detectors

Beam:

E_n = 5 MeV from the reaction $D(d,n)^3He$ (1 mg/cm^2 TiD) with E_d = 1.86 MeV
$I_d \approx 1.8\ \mu A$

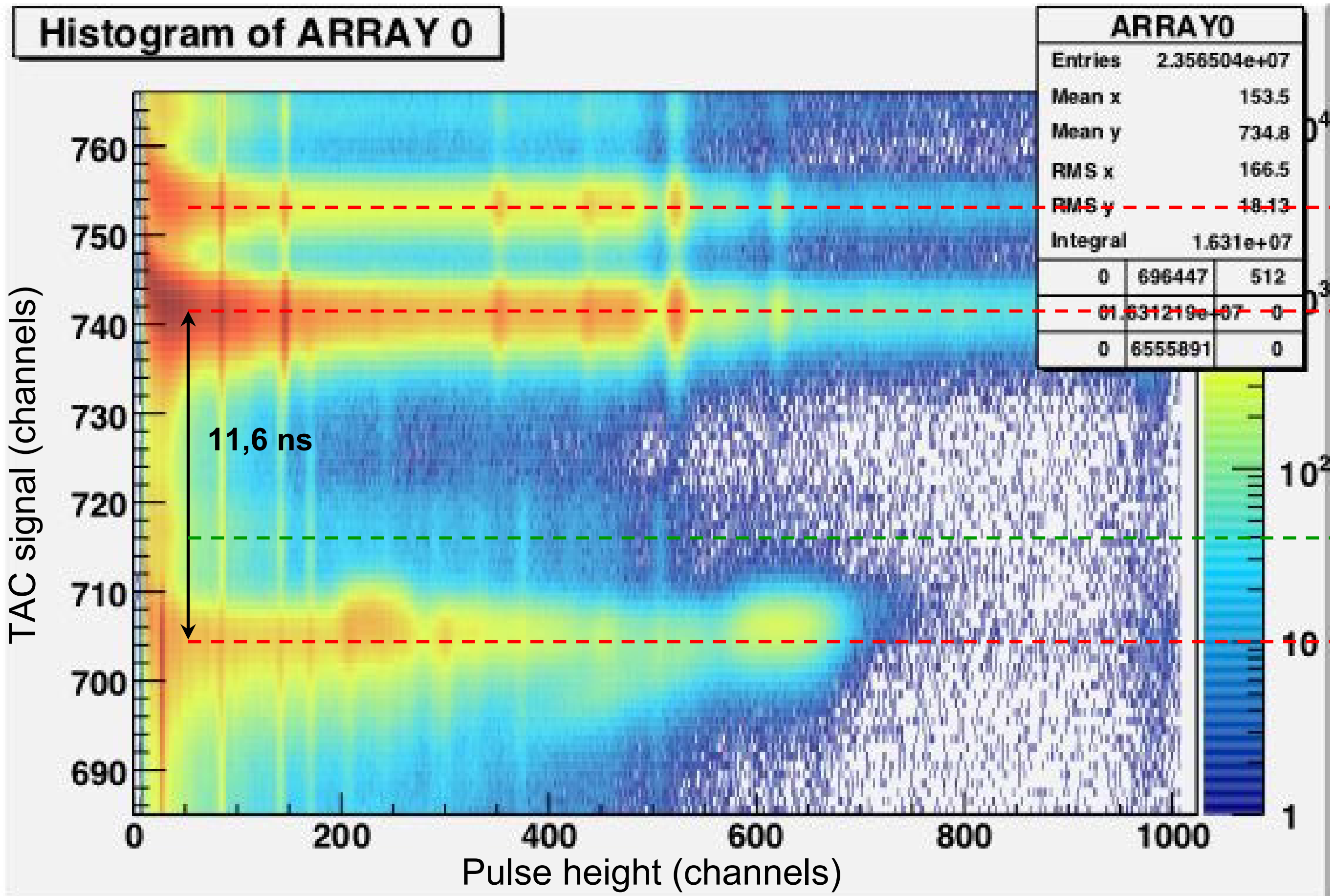
Pulse:

3 ns width
400 ns distance

Targets:

30 g ^{238}U
90 g ^{197}Au
240 g ^{209}Bi

Raw data (analysis pending)



Target: ^{209}Bi

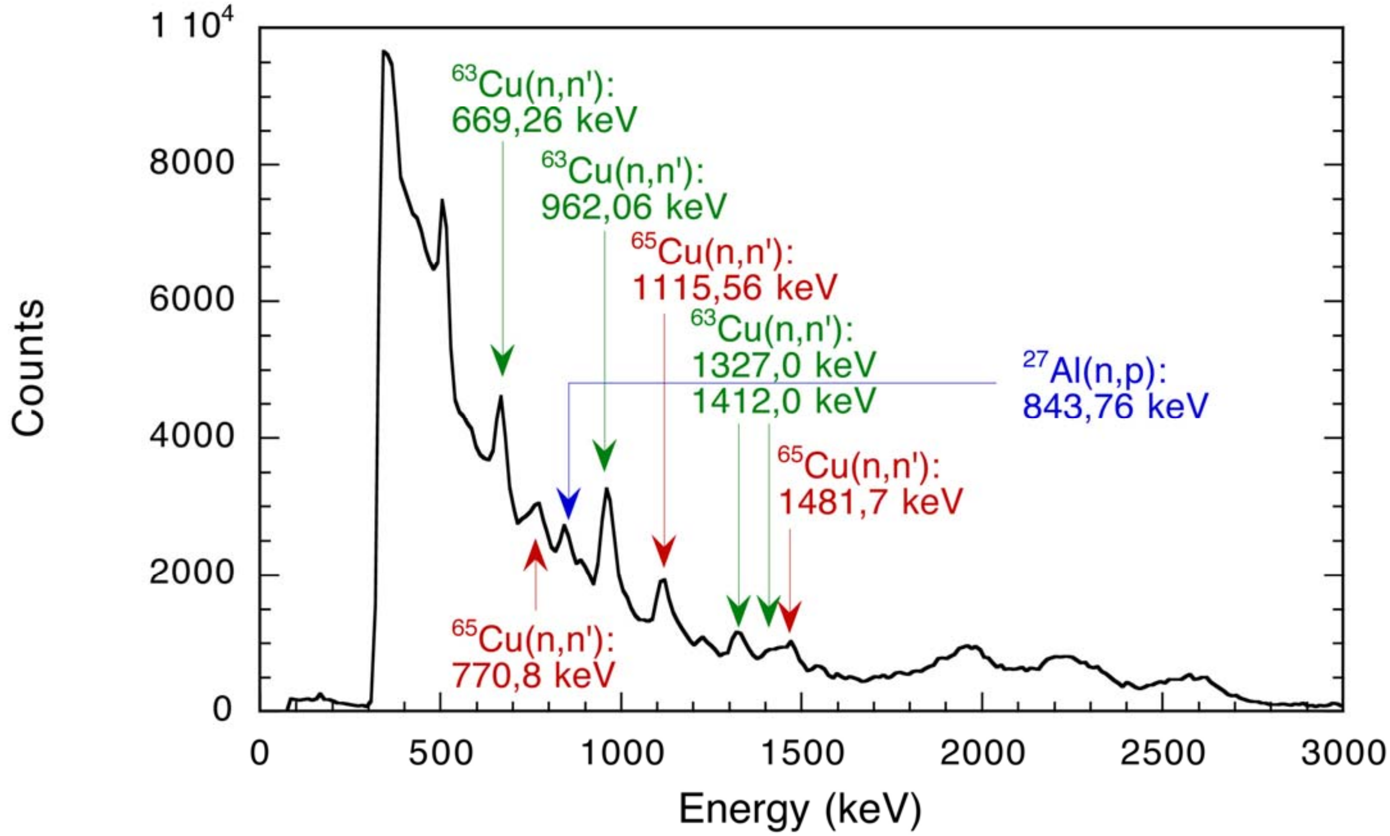
γ's from scattering off beam line

prompt γ-flash from n-production

γ's from target

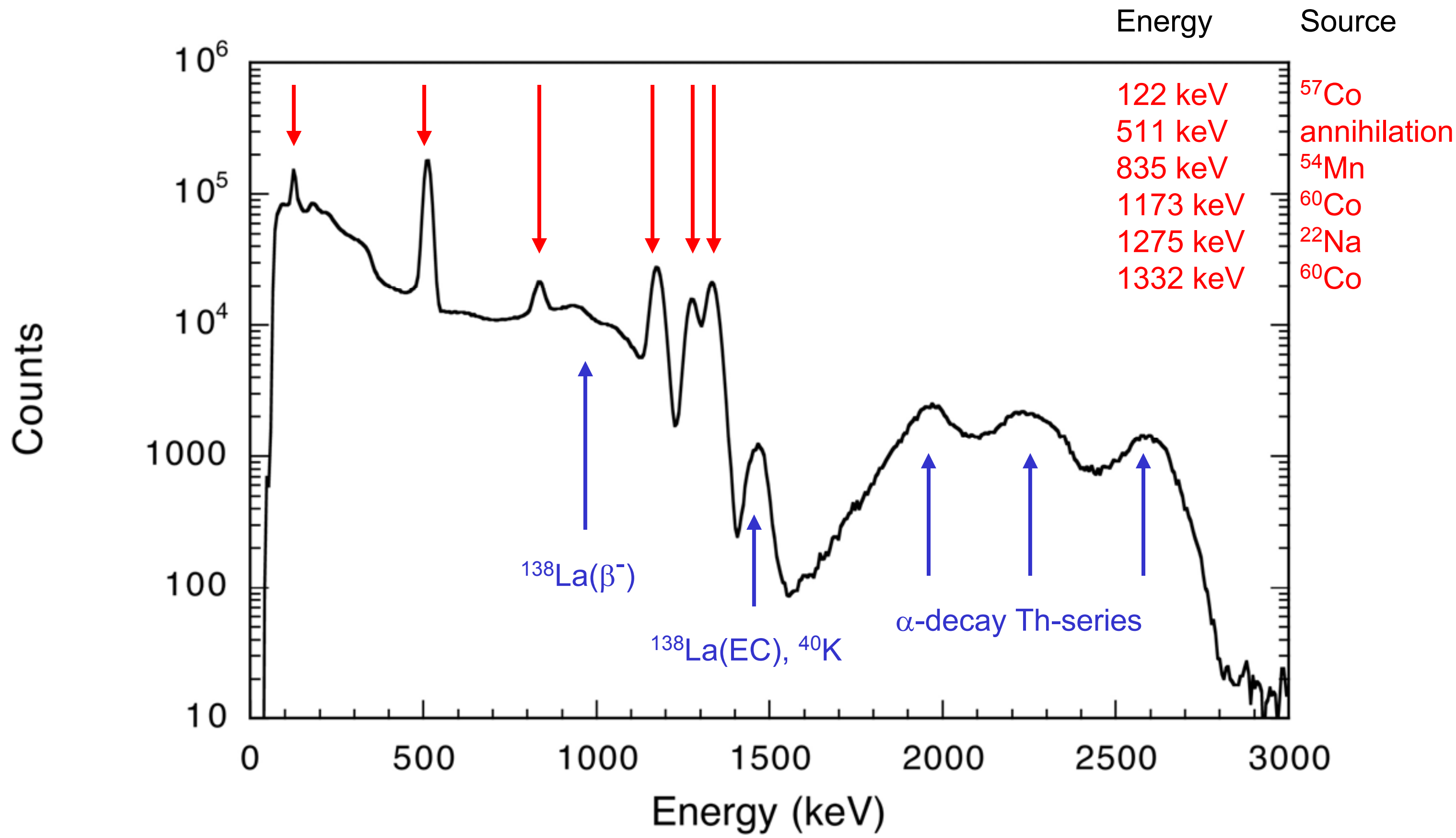
5 MeV neutrons on detector and γ's from (n,n'), (n,α), (n, γ)

Spectra



- prompt γ-rays from shielding material ($^{63,65}Cu$)
- … and detector caps (^{27}Al)

Spectra



- calibration spectrum after irradiation, no beam
- no further γ-lines, i. e. no activation

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Summary

- Energy resolution $\Delta E/E \leq 4$ % at 662 keV
  - 40 % better than NaI (Tl) up to $E\gamma \approx 7$ MeV
- Intrinsic peak efficiency determined
  - 50 % better than NaI (Tl) of same size up to $E\gamma \approx 2.6$ MeV
- Timing resolution $\tau_{intr} \approx 630$ ps (FWHM) for entire energy range (441 ps for ^{60}Co)
  - $\tau_{intr} \approx 3$ - 5 ns for NaI(Tl)
  - previously published $\tau_{intr} \approx 300$ ps, but smaller detectors and higher Ce-concentration
- Considerable intrinsic activity, but can be controlled
- Good linearity (residuals < 0.3 % above 100 keV)
- Dynamical range up to ~ 17 MeV γ-rays

Conclusions and outlook

$LaCl_3$ scintillation detectors do indeed fulfill requirements for the measurement of prompt fission γ-rays, in particular in conjunction with pcCVD diamond detectors ($\tau \approx 300$ ps)

- excellent timing resolution
- improved n/γ-discrimination (time-of-flight method)
- neutron sensitive, but no activation of $LaCl_3$ by fast neutrons

To come:

- $LaBr_3$ detectors purchased (even better energy resolution)
- Experiment: $^{235}U(n_{th},f)$ at IKI Budapest with VERDI in February 2010 (EFNUDAT, approved)

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Thank you

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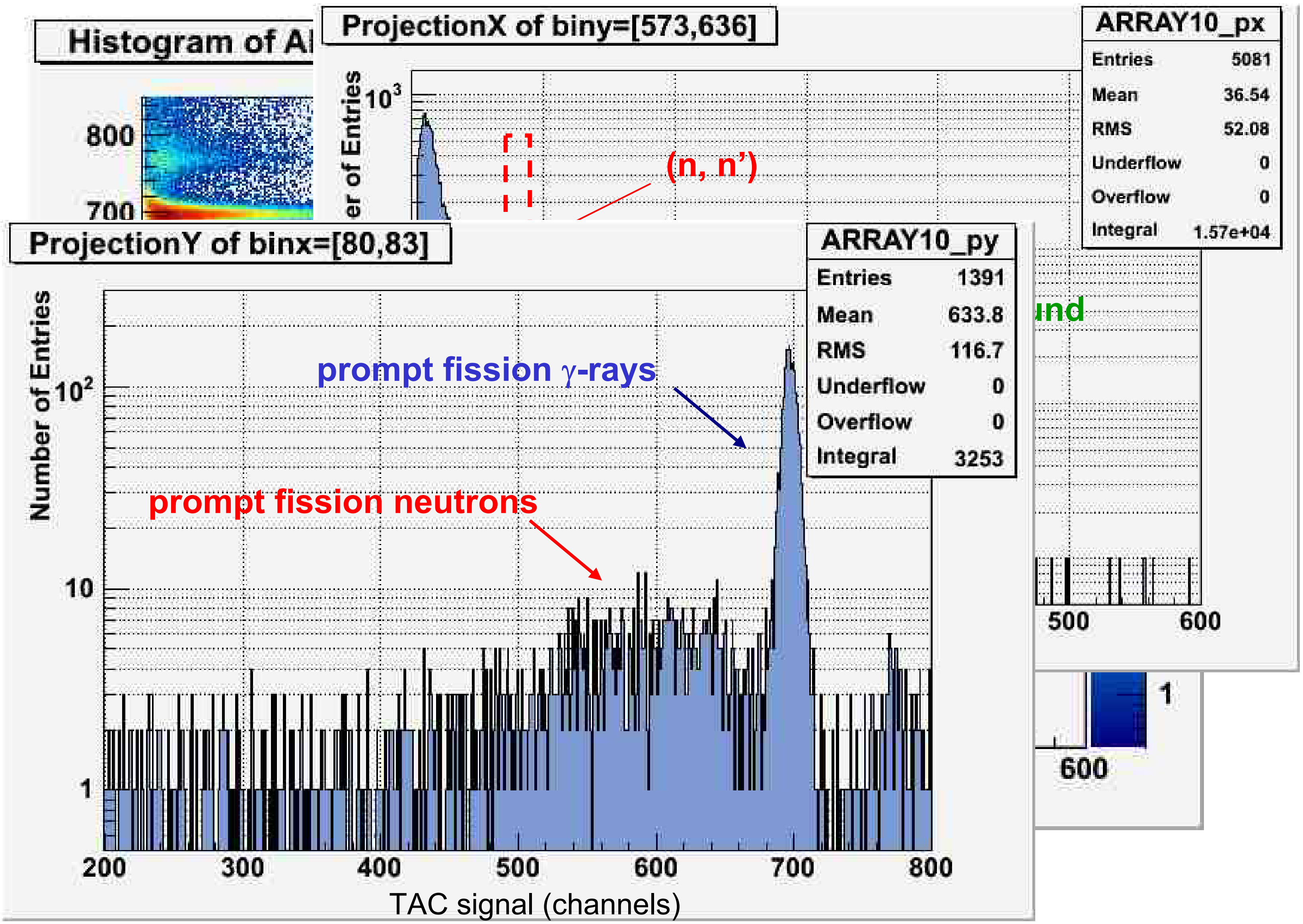
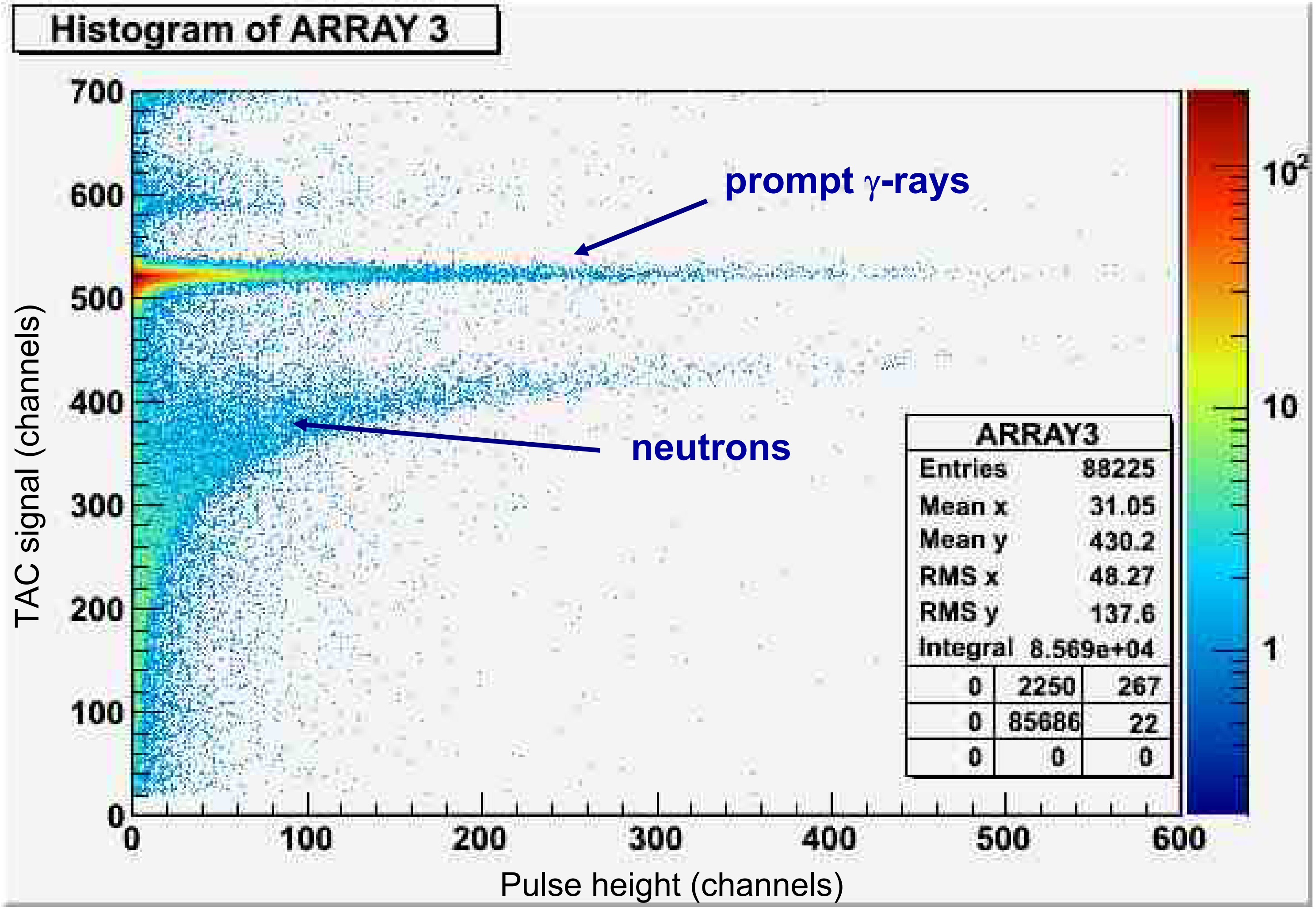
$^{252}Cf(SF)$ – $LaCl_3$ & pcCVDDD



^{252}Cf(SF) – pilotU & pcCVDDD



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$^{252}Cf(SF)$ – $LaCl_3$ & pcCVDDD