ÖREBRO UNIVERSITY
DEPARTMENT OF SCIENCE

Measurement of prompt fission γ-rays with lanthanum halide scintillation detectors

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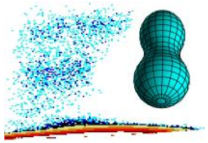
Outline

- Motivation
- Characterization of $LaCl_3$(Ce) detectors
  - intrinsic activity
  - energy resolution
  - intrinsic efficiency
  - timing resolution
- Experiment at IKI Budapest (cold neutrons)
- Results
- Summary and conclusions
- Outlook



Motivation

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

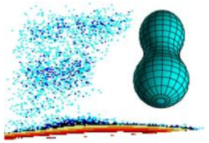
- about 10 % of total energy released in the core of a standard nuclear reactor by fission γ-rays
- about 40 % of those due to prompt γ-decay of fission products

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 (i.e. neutron-induced γ-rays)

-> requires good timing resolution

Back then:

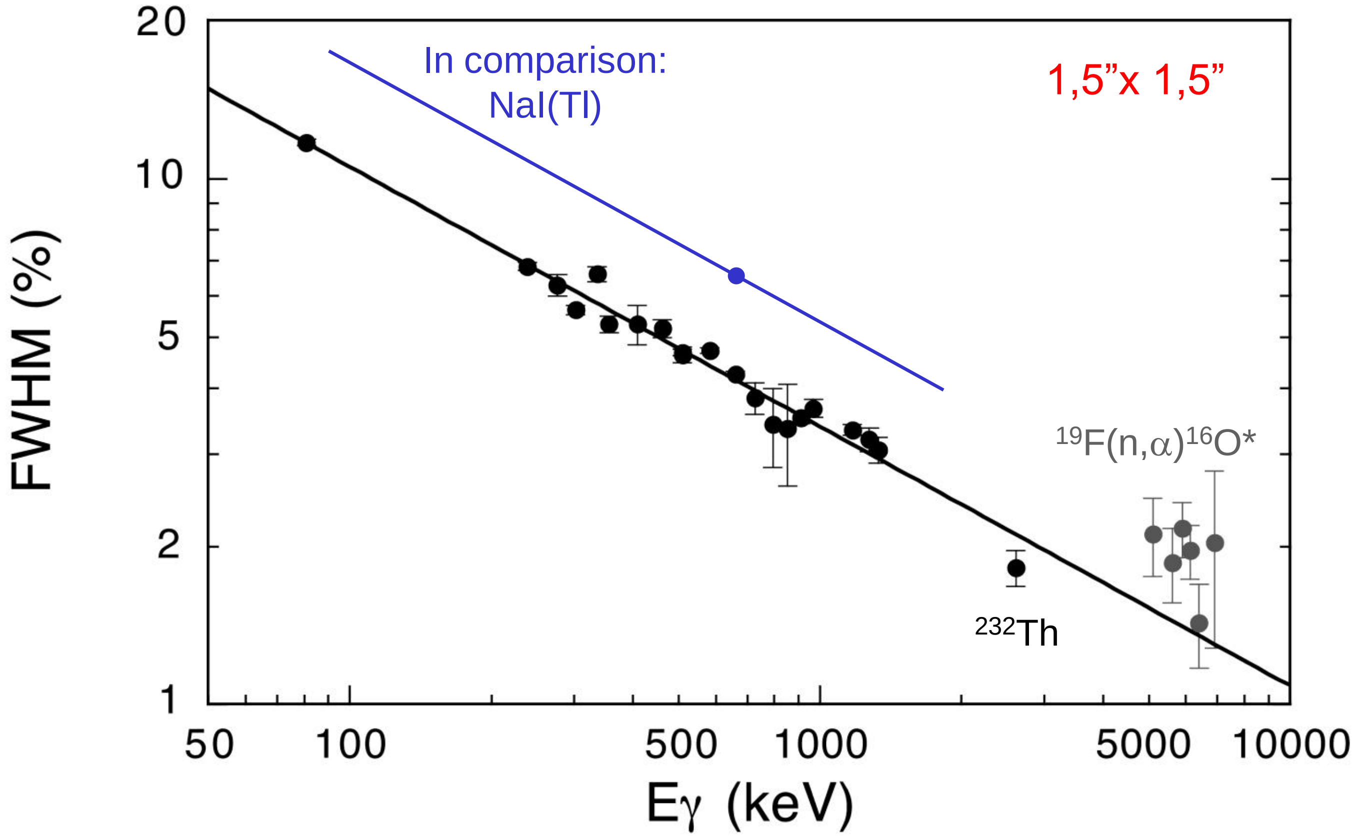
- NaI detectors and ionization chambers
- $\tau \approx 3 - 5$ ns and $\tau \geq 1$ ns

Today & tomorrow: new detectors offer new possibilities

- lanthanum halide crystals and pcCVD diamond detectors

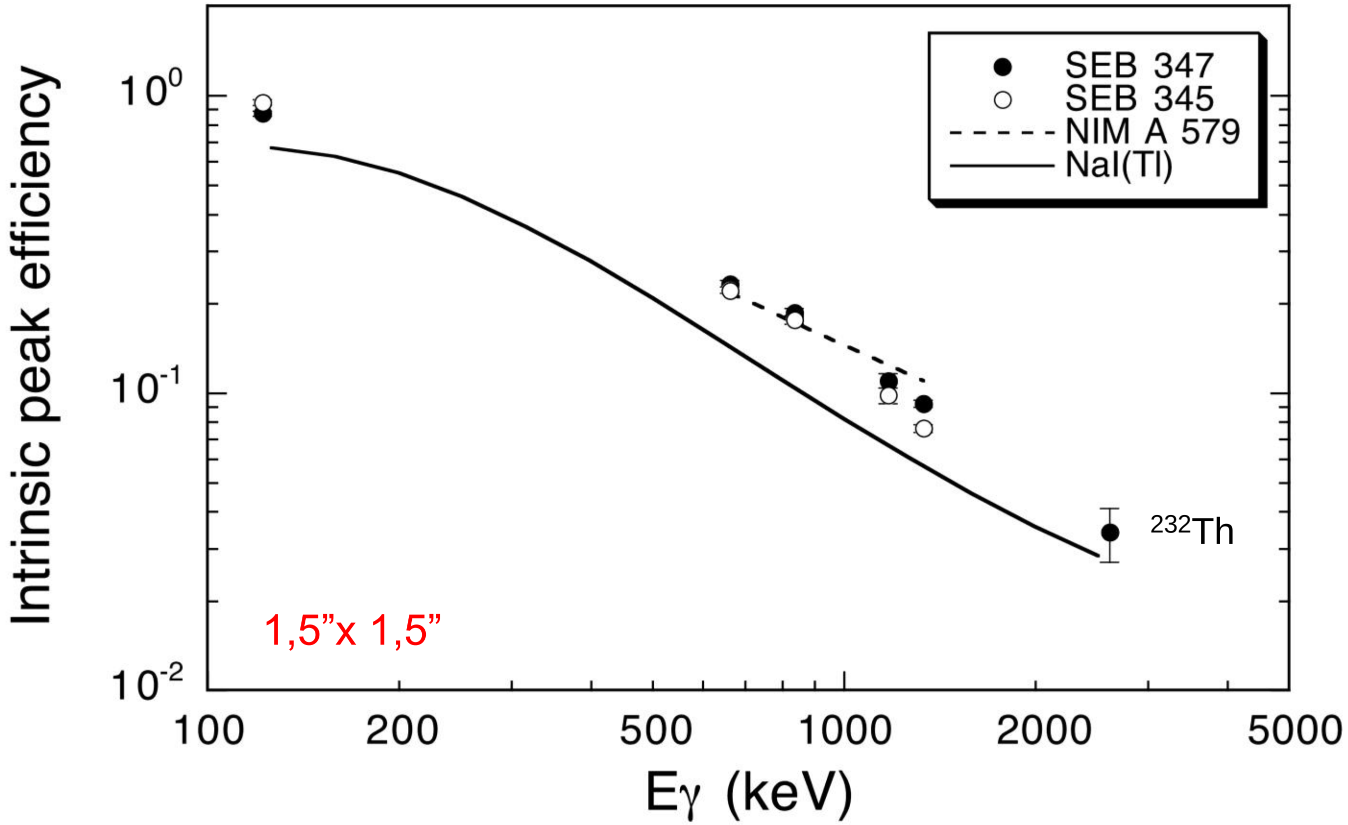
-> intended fission γ-ray measurements - a prerequisite to the assessment of γ-heating!

Energy resolution



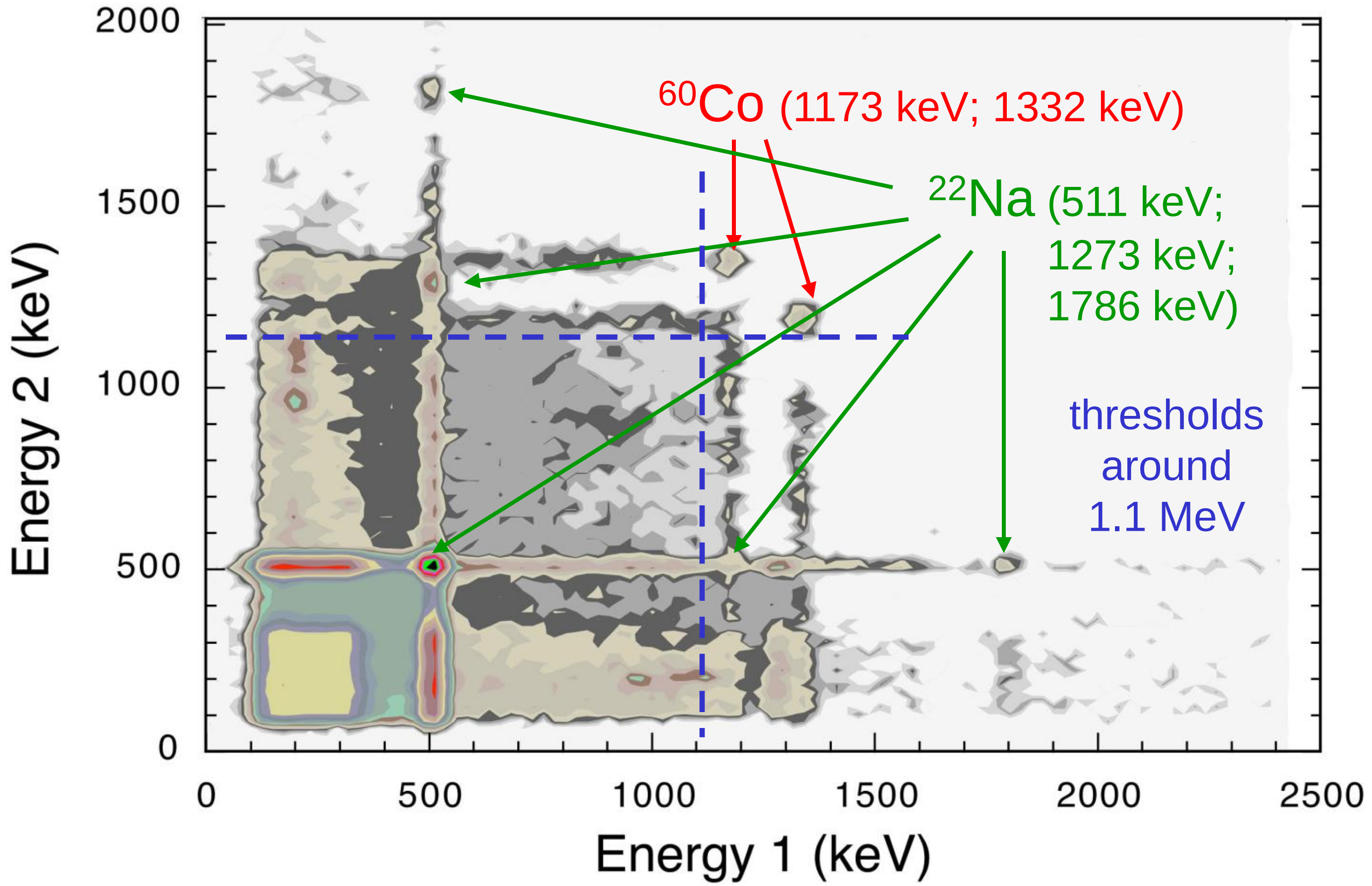
- expected $E^{-1/2}$ behaviour
- $\Delta E/E$ = 3.8 - 4.2 % (FWHM) at 662 keV (^{137}Cs)

Intrinsic efficiency



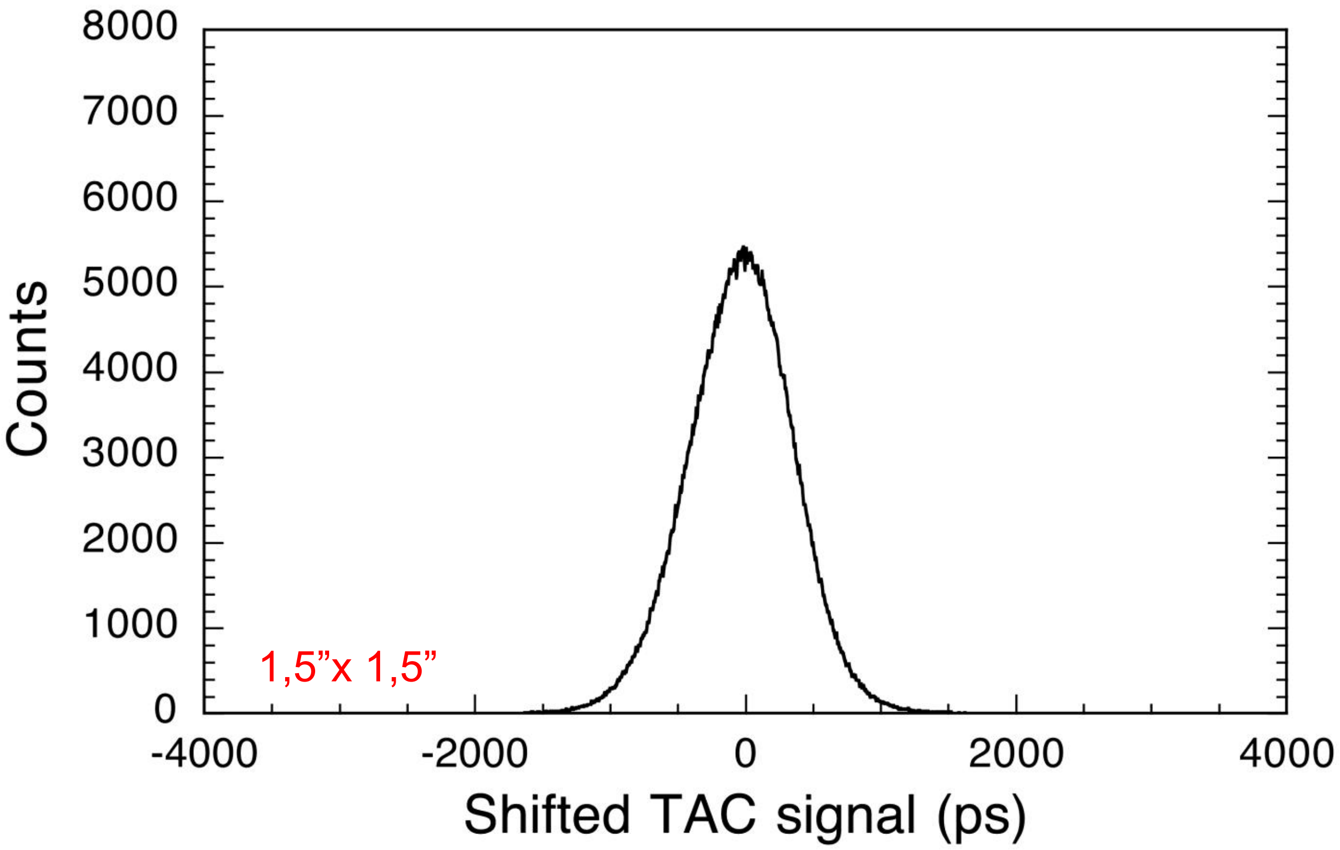
- in agreement with other $LaCl_3$ detectors (interpolated)
- 53 % better than NaI(Tl) detectors of same size

Timing - coincidence measurement

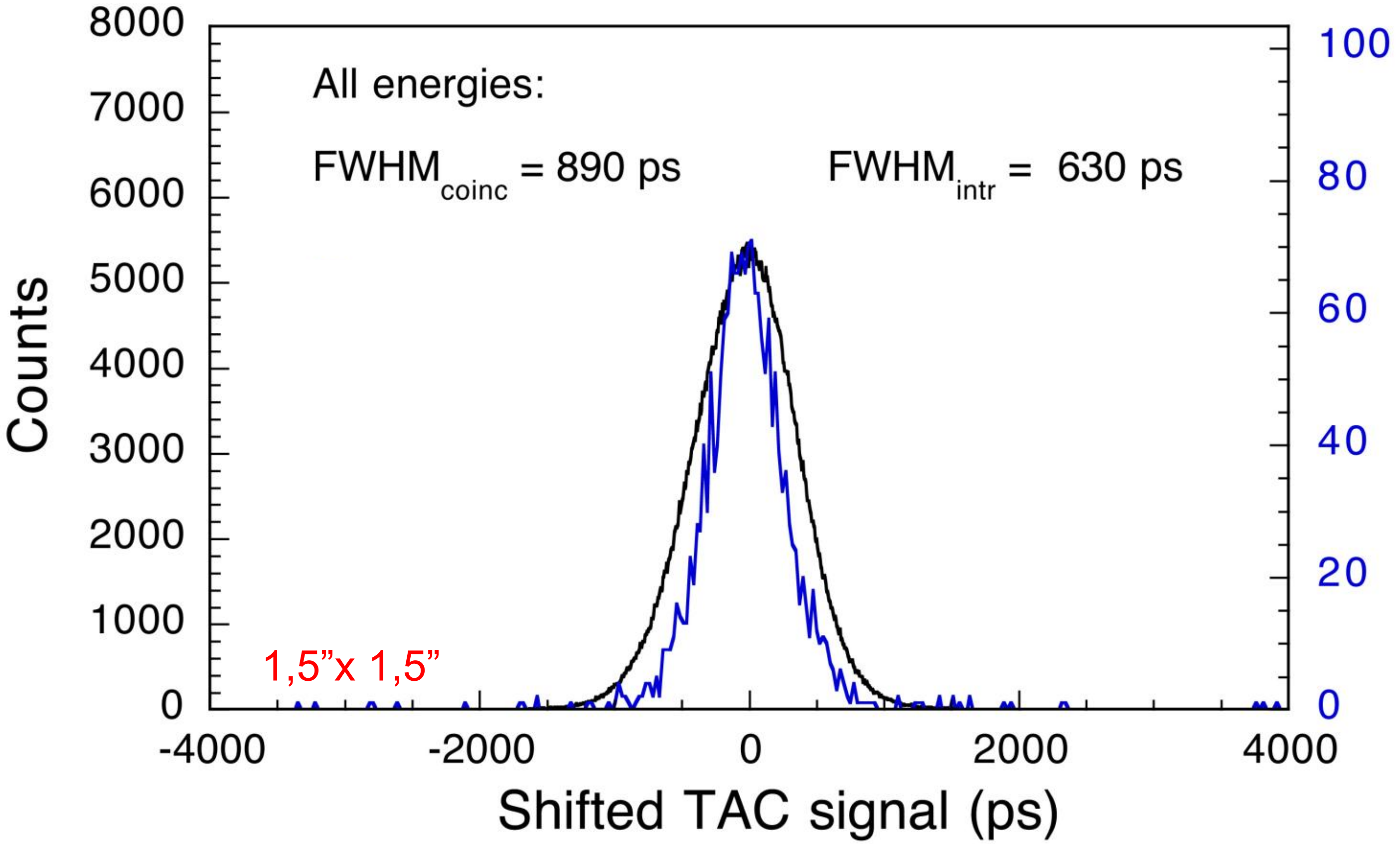


- two $LaCl_3$ detectors with multiple source (^{22}Na and ^{60}Co)

Timing - TAC spectrum



Timing - TAC spectrum



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 (-> talk S. Oberstedt)
  - pcCVD diamond detectors as fission trigger
- prompt fission γ-rays
  - two $LaCl_3(Ce)$ scintillation detectors (1,5"x 1,5", coaxial)
  - one $LaCl_3(Ce)$ scintillation detector (3"x 3", coaxial)
  - one $LaBr_3(Ce)$ scintillation detector (2"x 2", coaxial)
  - ^{6}Li shielding against thermal neutrons
  - coincidence with fission trigger (stop: fission - start: γ-ray)

Location:

- 10 MW research reactor at IKI Budapest

Experimental details

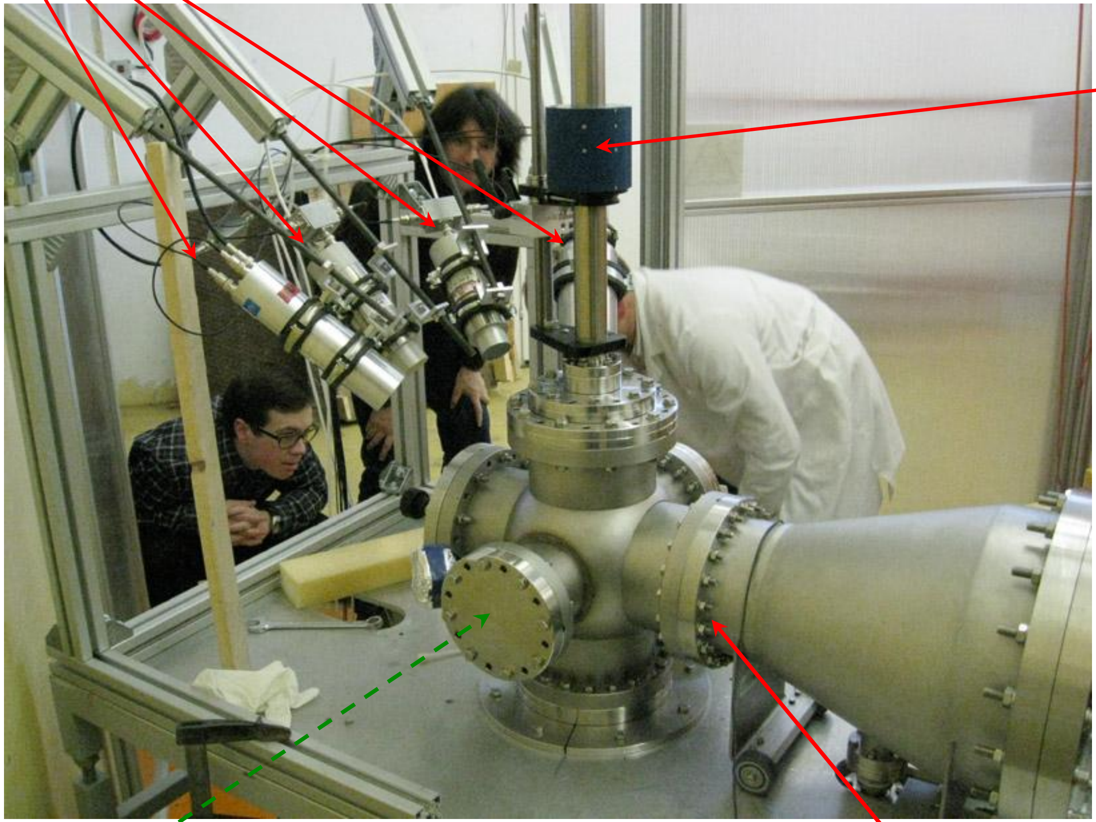
Sample:	^{235}U (113 μg)
Thermal neutron flux:	$7 \cdot 10^7$ cm^{-2} s^{-1}
Fission rate:	$1.18 \cdot 10^4$ s^{-1}
Fission fragment count rate:	12 s^{-1}
Fission γ count rate:	10 s^{-1}

Beam time:	2 weeks (10 days)
Expected number of counts	
– fission fragments:	$8.5 \cdot 10^6$
– γ-rays:	$\sim 3 \cdot 10^7$

Performed in February/March 2010

Experimental setup

γ-detectors: $LaBr_3$ (2"x 2"), 2 x $LaCl_3$ (1,5"x 1,5"), $LaCl_3$ (3"x 3")

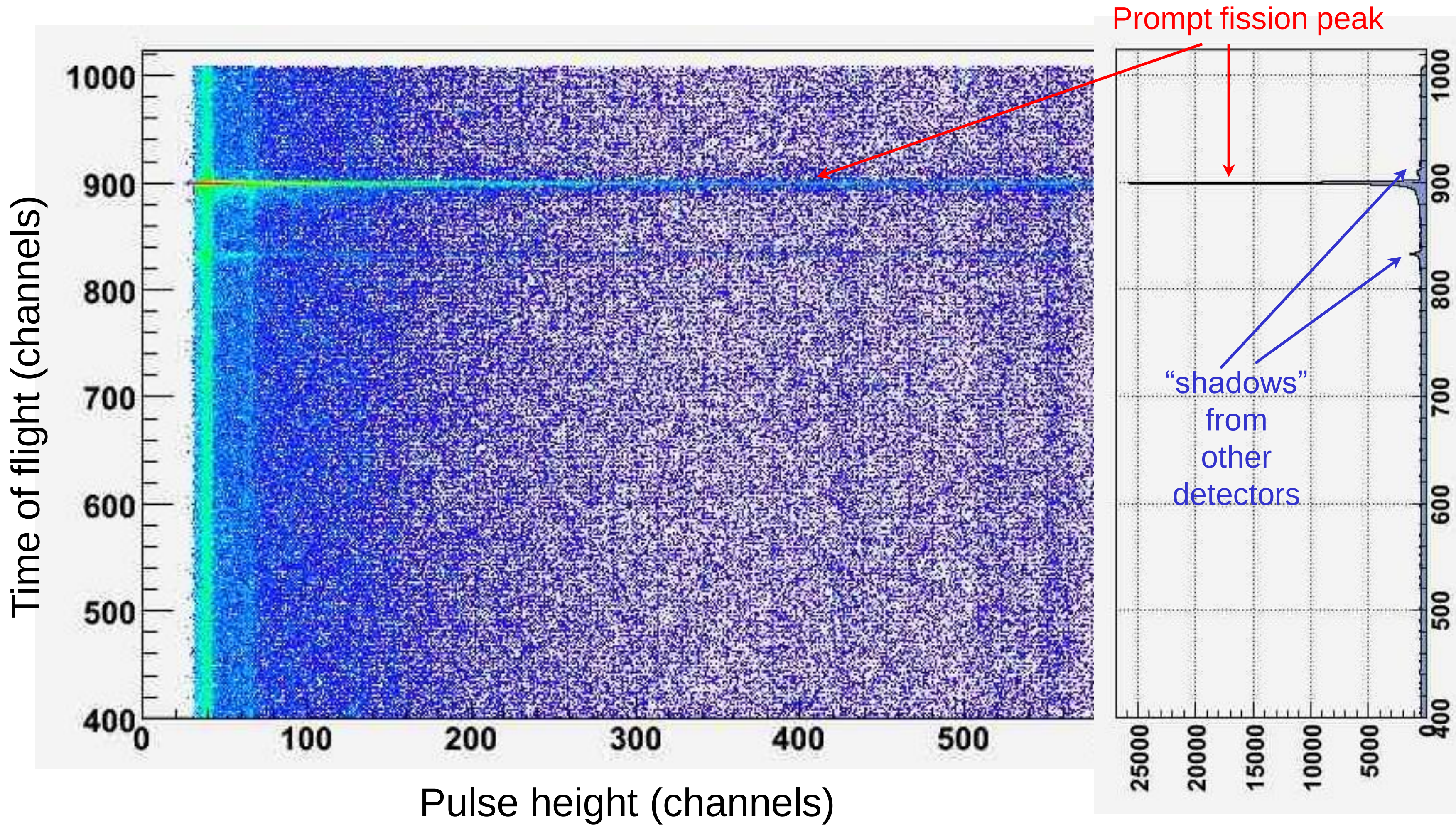


sample holder

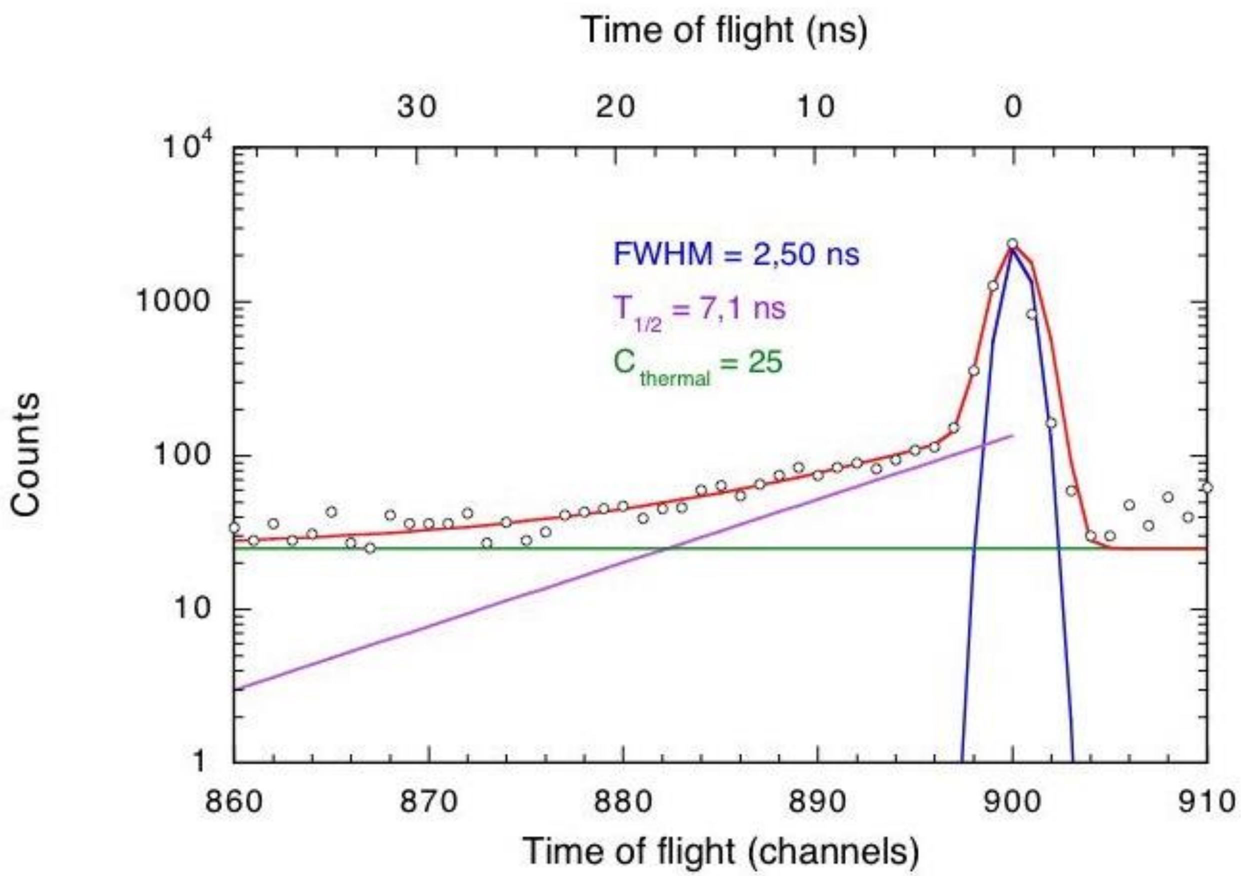
cold neutron beam

fission fragment spectrometer VERDI

TAC signal vs. PH signal

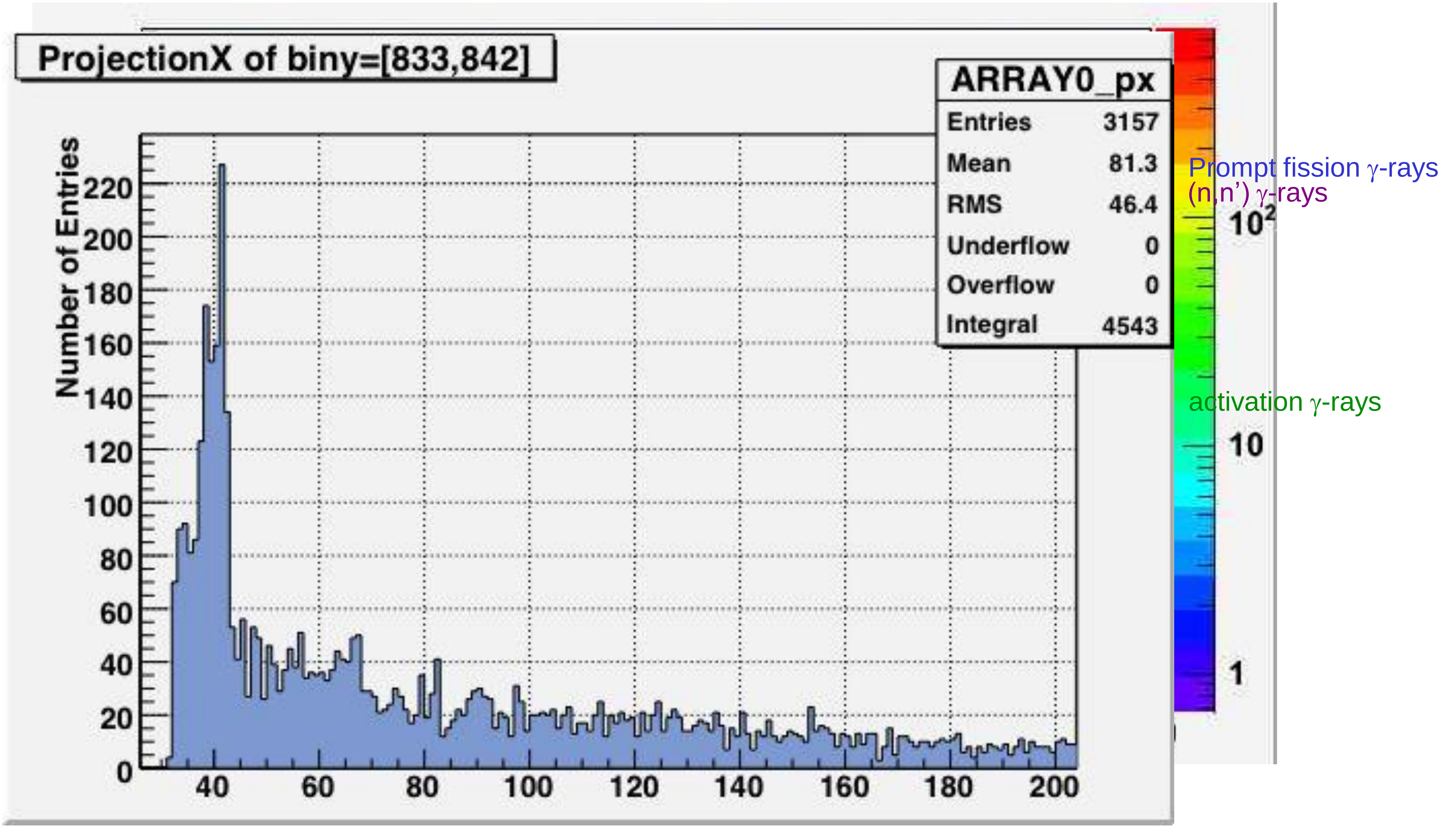


TAC spectrum (zoomed)

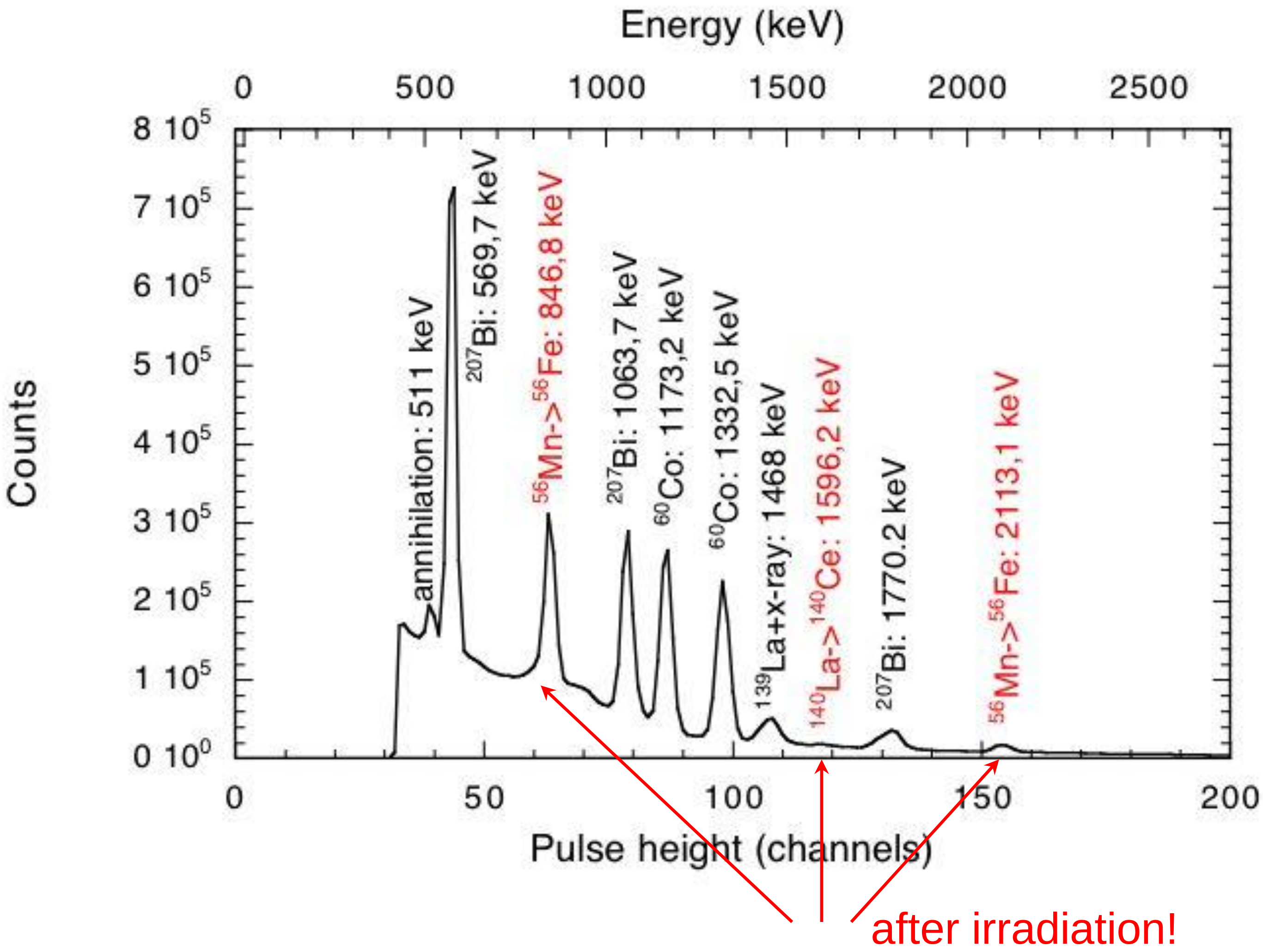


Prompt γ-peak + inelastic neutron scattering + neutron capture

Characteristic spectra vs. TAC signature

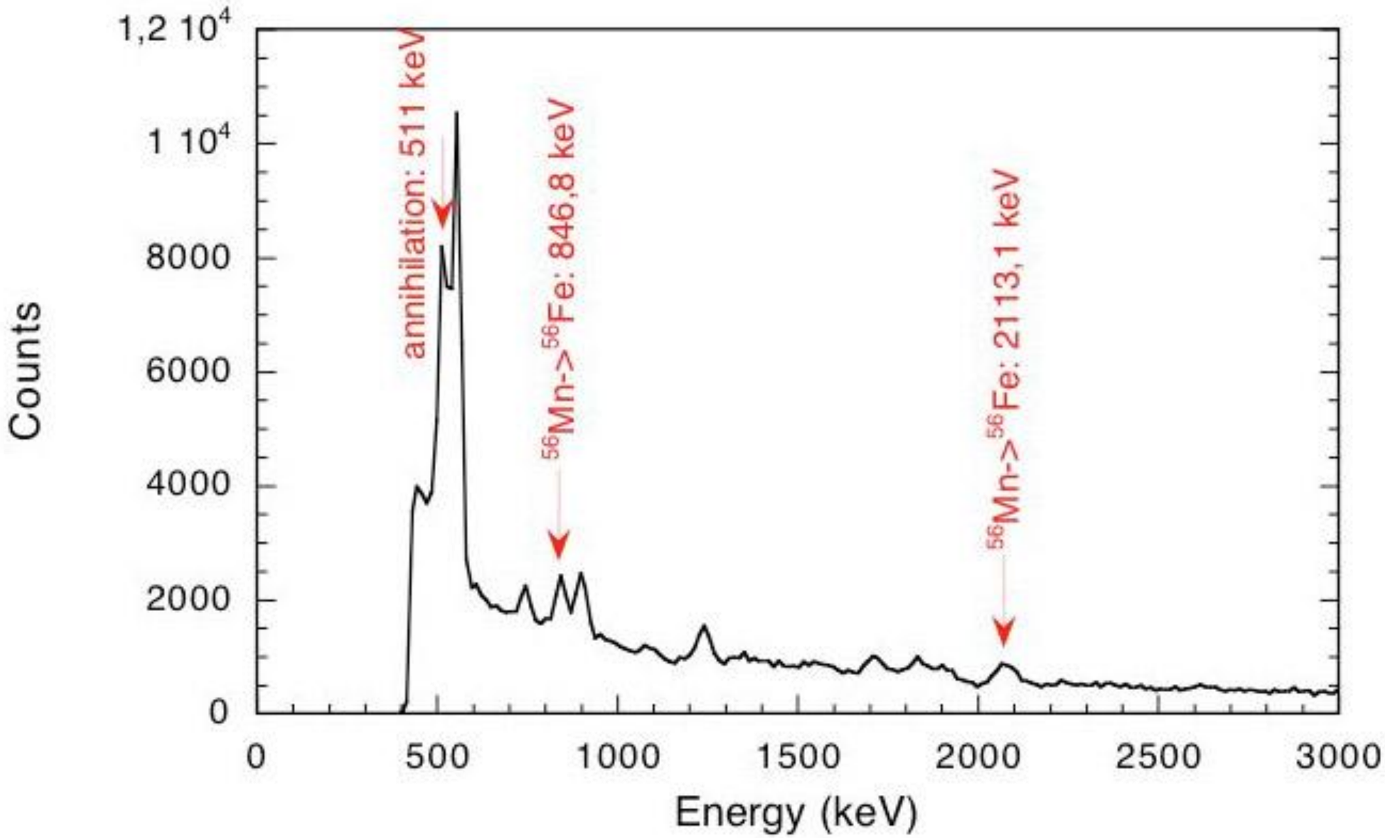


Energy calibration



Preliminary results I

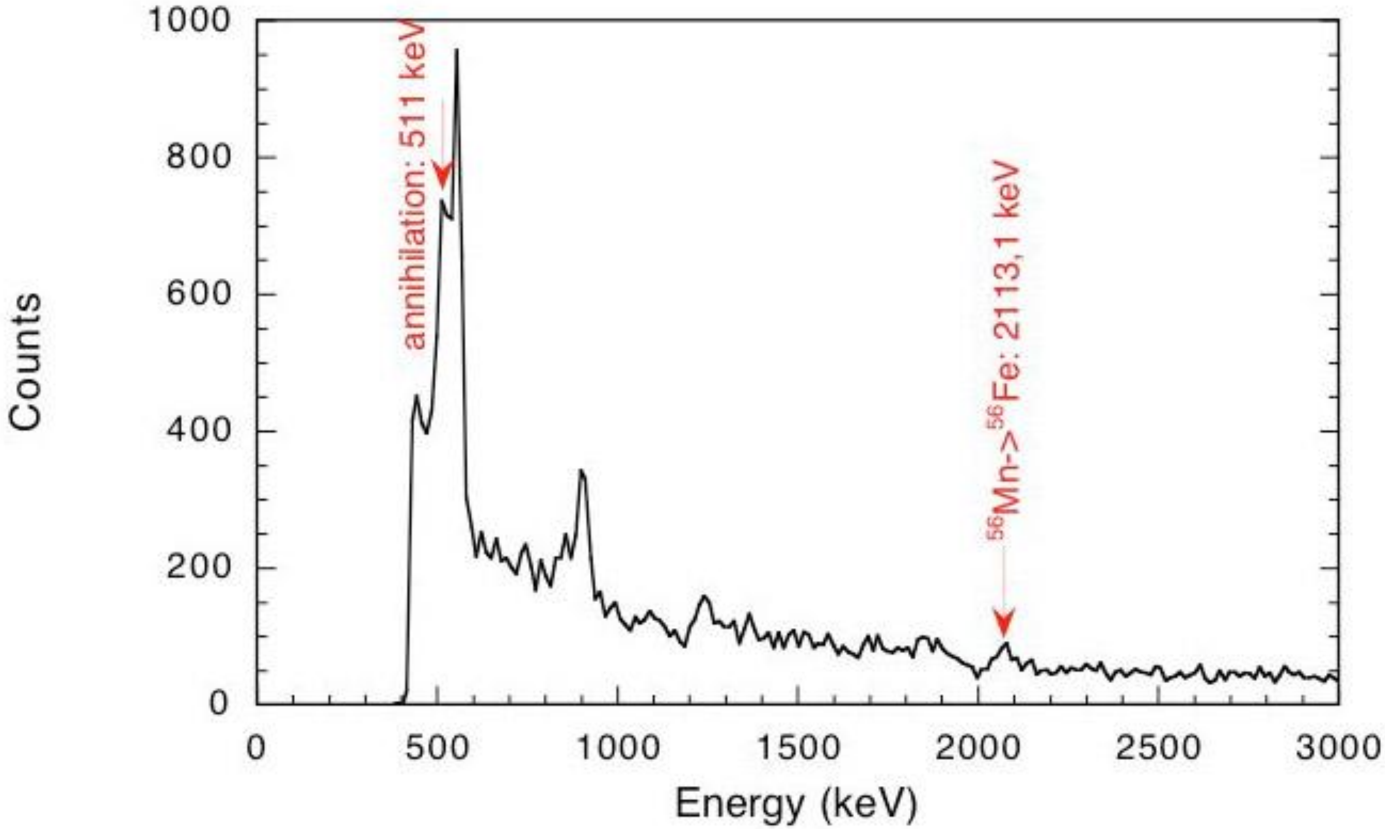
TAC regime of thermal neutron induced γ-rays: energy spectrum



Activation of iron (VERDI): $^{56}Fe(n, p) \rightarrow {}^{56}Mn$ ($T_{1/2}$ = 2.58 h)!

Preliminary results II

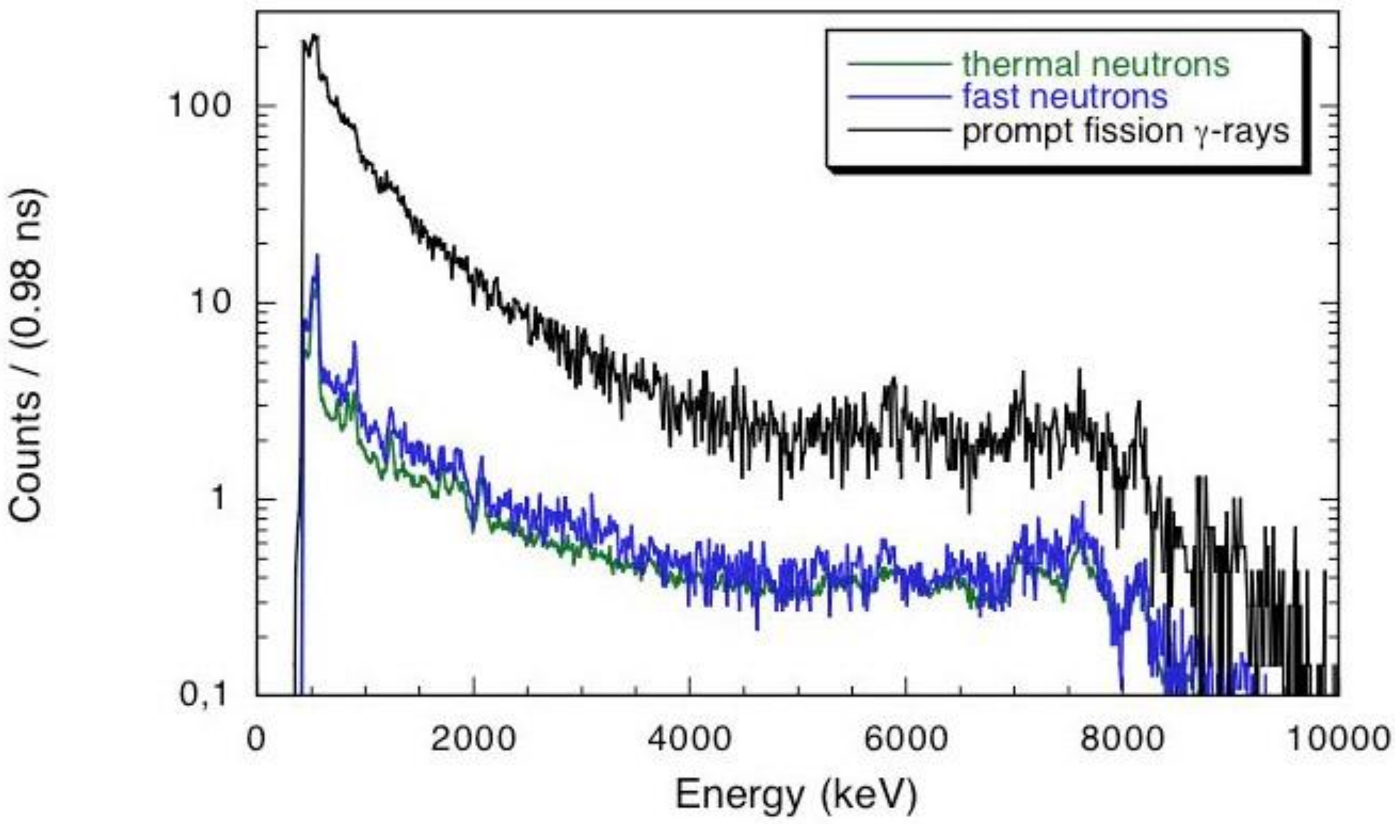
TAC regime of fast neutron induced γ-rays and isomers



Observe: more peaks have still to be identified!

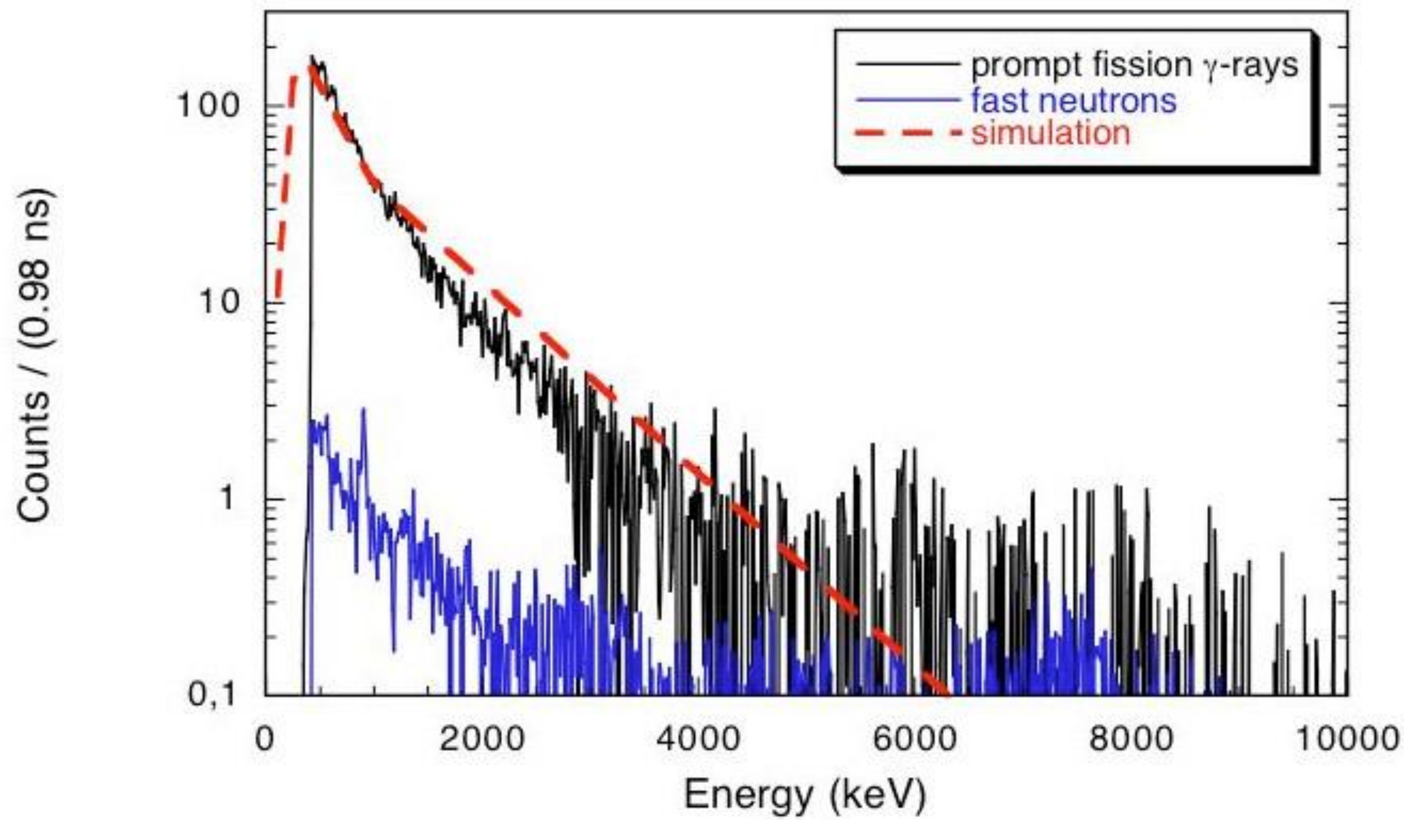
Preliminary results III

All TAC regimes: energy spectra - normalized & calibrated



Preliminary results IV

Prompt fission γ-spectrum - background subtracted



To guide the eye: simulation according to Verbeke et al., LLNL (2009)

Background on simulation

Prompt fission γ-energy distribution

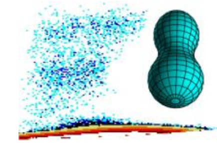
$$N(E) = \begin{cases} 38.13(E-0.085)e^{1.648E} & E < 0.3\ \mathrm{MeV} \\ 26.8e^{-2.30E} & 0.3 < E < 1.0\ \mathrm{MeV} \\ 8.0e^{-1.10E} & 1.0 < E < 8.0\ \mathrm{MeV} \end{cases}$$

Obtained from measurements by Maienschein et al.,
Neutron Phys. Ann. Prog. Rep., ORNL (1958)

Summary and conclusions I

Characterization of $LaCl_3$:Ce detectors (1,5"x 1,5"):

- 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 controlled by coincidence
- Good linearity (residuals < 0.3 % above 100 keV)
- Dynamical range up to ~ 17 MeV γ-rays



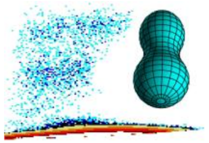
Summary and conclusions II

$LaCl_3$ 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

Prompt fission γ-rays from $^{235}U(n_{th}, f)$ measured:

- γ-rays distinguished with respect to their origin (fission, neutron-induced, β-delayed …)
- preliminary prompt fission γ-spectrum presented
- interactions between thermalized neutrons and detector material extremely rare, i.e. $\Phi(n_{th}) < 0{,}2\ s^{-1}\ cm^{-2}$



Outlook

To come:

- data analysis to be completed (3 more detectors)
- response functions have to be determined and applied
- $LaBr_3$:Ce (2”x 2”) detectors to be characterized
- new $LaCl_3$:Ce (1.5”x 2”) detectors to be characterized
- effect of BGO anti-Compton shield to be investigated
- new experiment contemplated: detection of fission γ-rays during measurement of ^{252}Cf(sf) at IRMM with VERDI
- …

Collaborators

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CIEMAT Madrid	D. Cano-Ott, T. Martinez-Perez

Thank you!