The ALTO/nu-ball workshop
at the IPN of Orsay
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Lifetime determination using large fast-timing arrays

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Content:

The Generalized Centroid Difference Method

to analyze **γ–γ time-difference spectra** from a large **fast-timing array**

The **EXILL&FATIMA campaign 2013**

at the Institut Laue-Langevin

NEUTRONS FOR SCIENCE®

Results of **Germanium-gated γ–γ fast timing** of excited states in **fission fragments**

How to correct for background contributions to the time spectra?

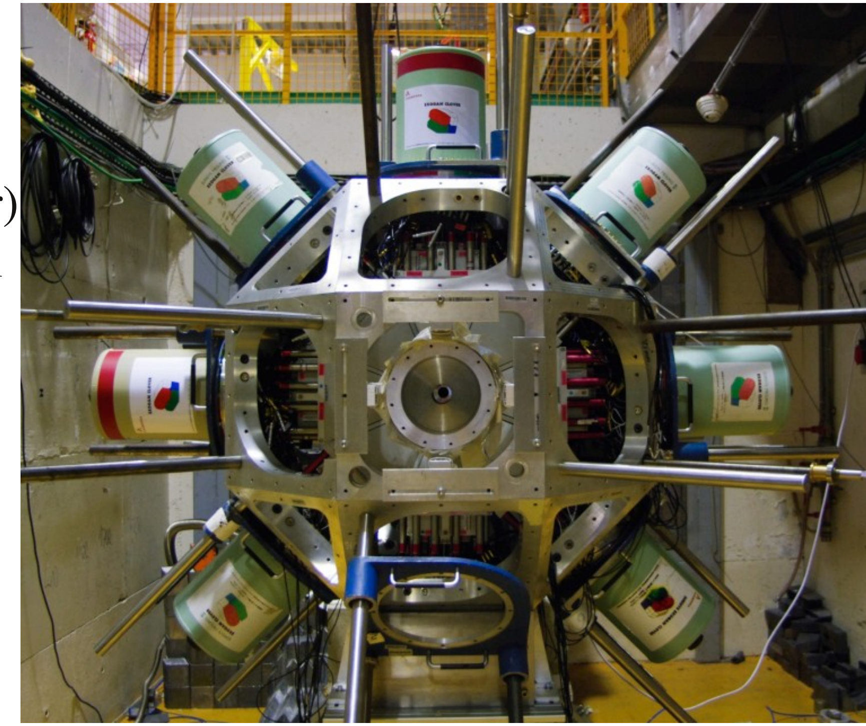
The EXILL and EXILL&FATIMA campaigns 2012 and 2013 at the

European research reactor of the

Institut Laue-Langevin

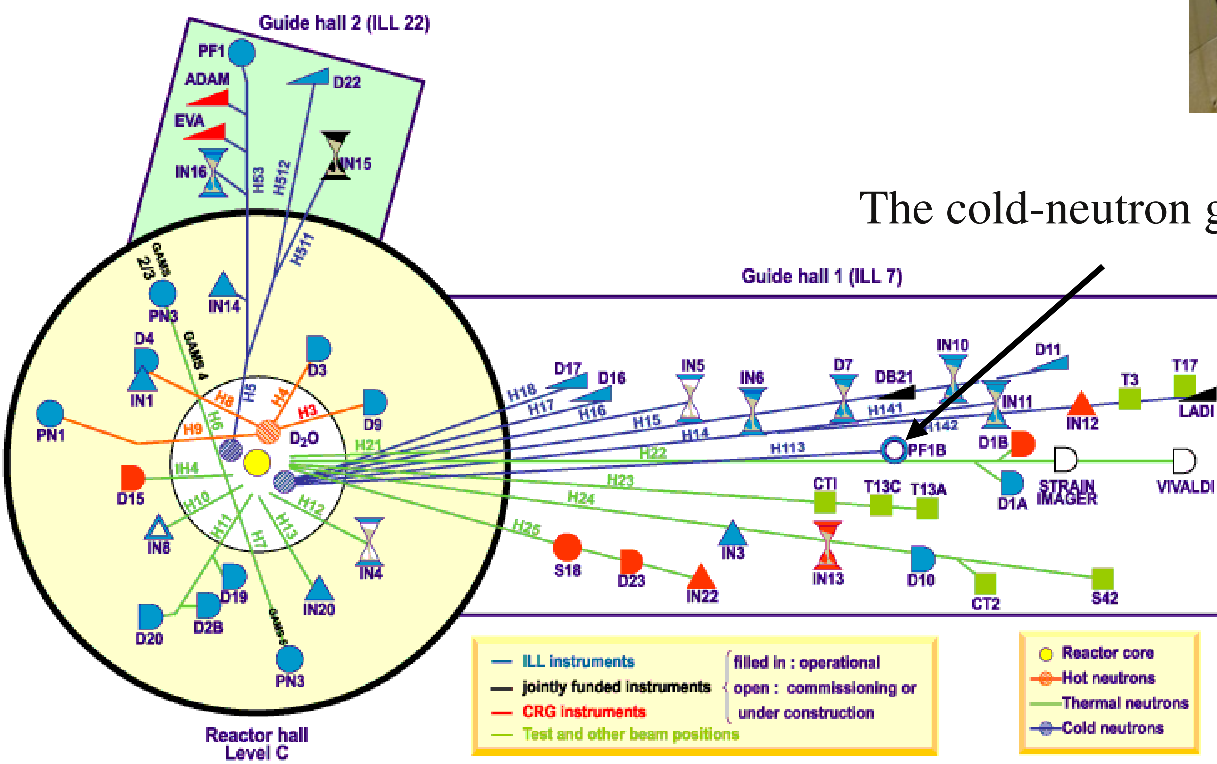
Grenoble, France

Part of the EXILL (EXOGAM@ILL) array



Collimated
(12 mm in diameter)
cold-neutron beam
with flux of about
10^8 n/(s cm²)

The cold-neutron guide PF1B



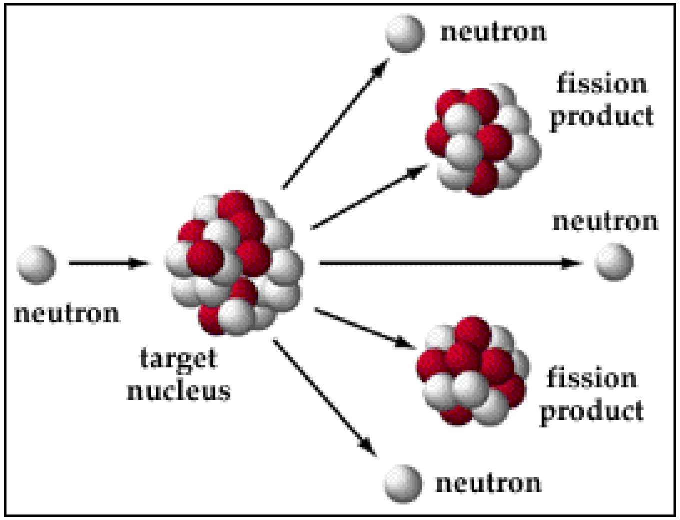
Aim: Prompt γ-ray spectroscopy for nuclear structure studies using

* neutron-capture (n,γ) experiments

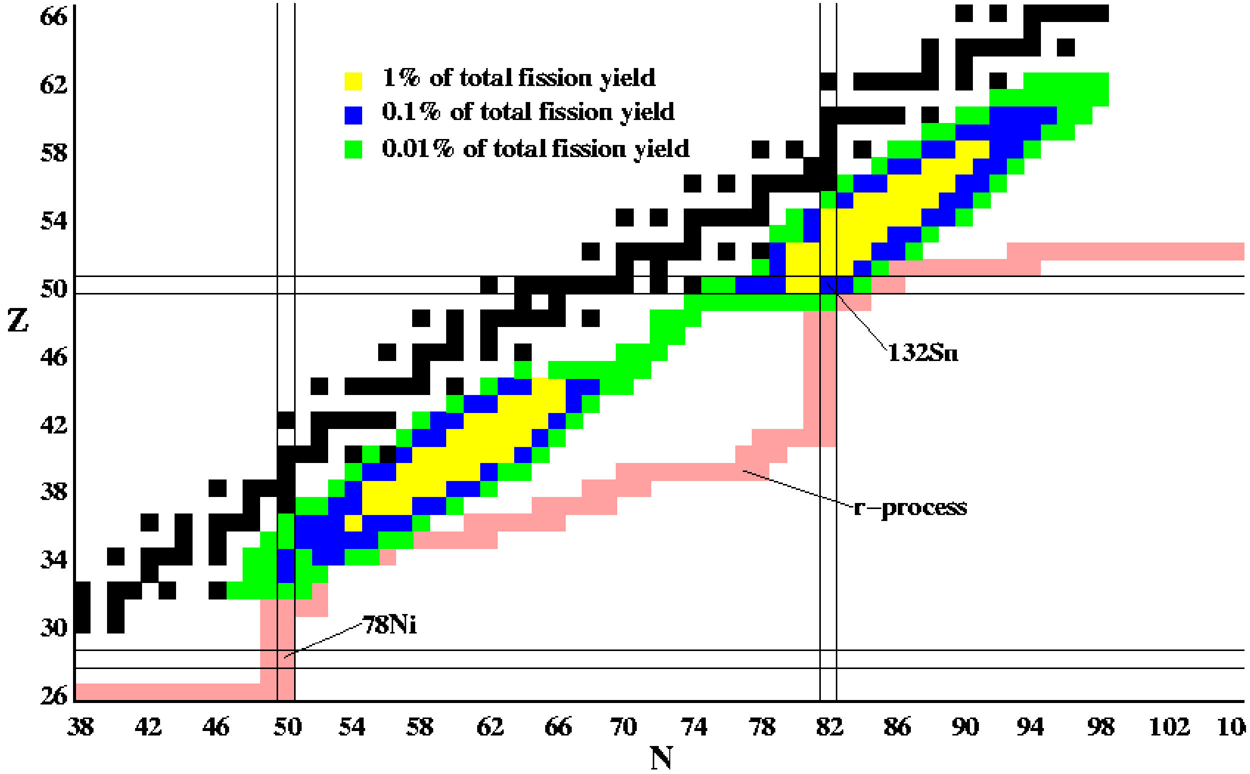
* neutron-induced fission experiments

EXILL campaigns 2012/2013:

Prompt γ-ray spectroscopy of neutron-rich fission products



Thermal-neutron induced fission of ^{235}U:



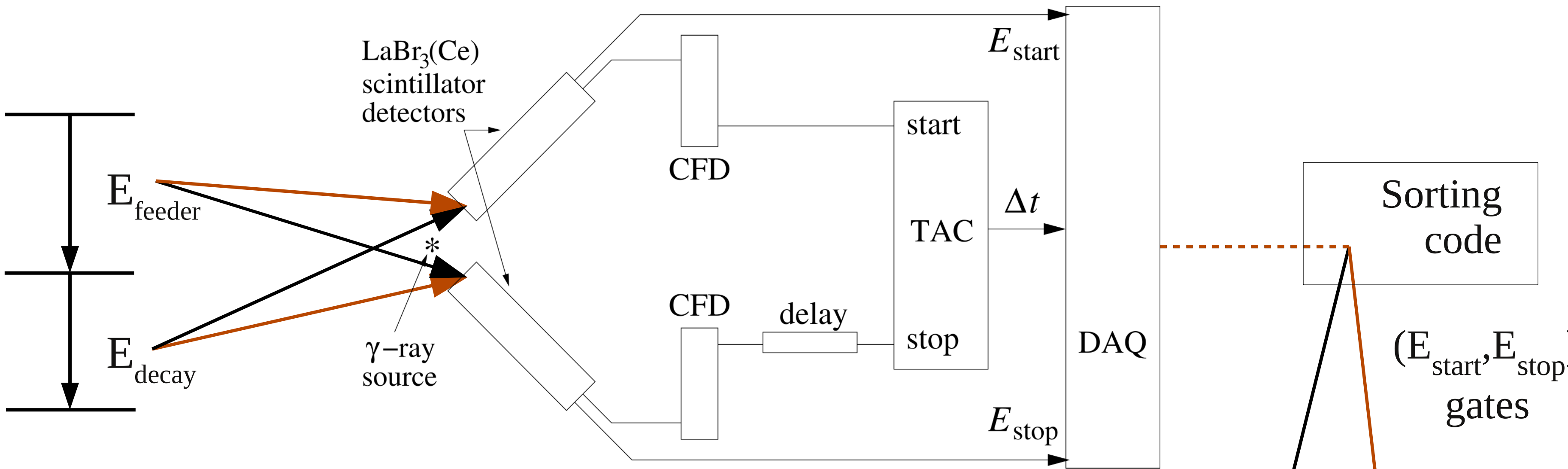
Physics cases:

The **A~100** mass region
Evolution of collective excitations
Shape transition or coexistence

Region close to the doubly magic
^{132}Sn
Investigation of nucleon-nucleon interactions

Nuclear astrophysics on r-process nuclei

The γ–γ fast-timing technique and the Generalized Centroid Difference method



Experimental centroid difference:

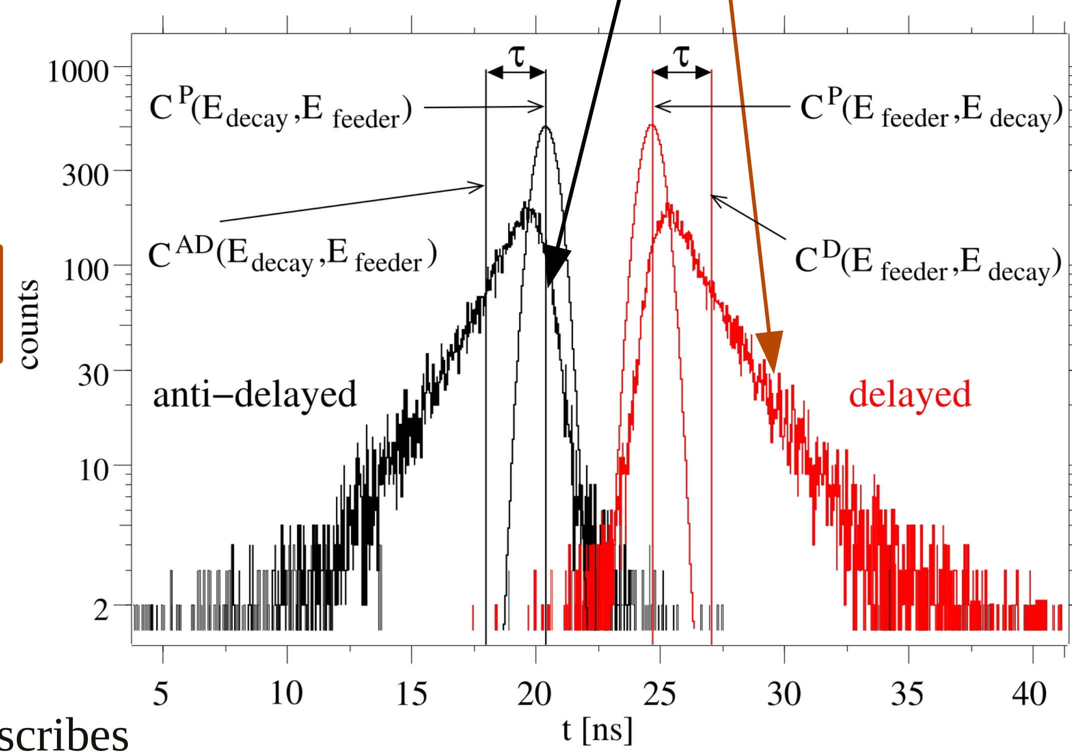
$$\Delta C(E_{feeder},E_{decay})=C^{Delayed} - C^{Anti\ Delayed}$$

Physics:

$$\Delta C(E_{feeder},E_{decay}) = PRD(E_{feeder},E_{decay}) + 2\tau$$

N Detectors, superposition of the data by distinguishing between the start and stop signals:

$$\overline{\overline{\Delta C}}_{FEP} = \overline{PRD} + 2\tau$$

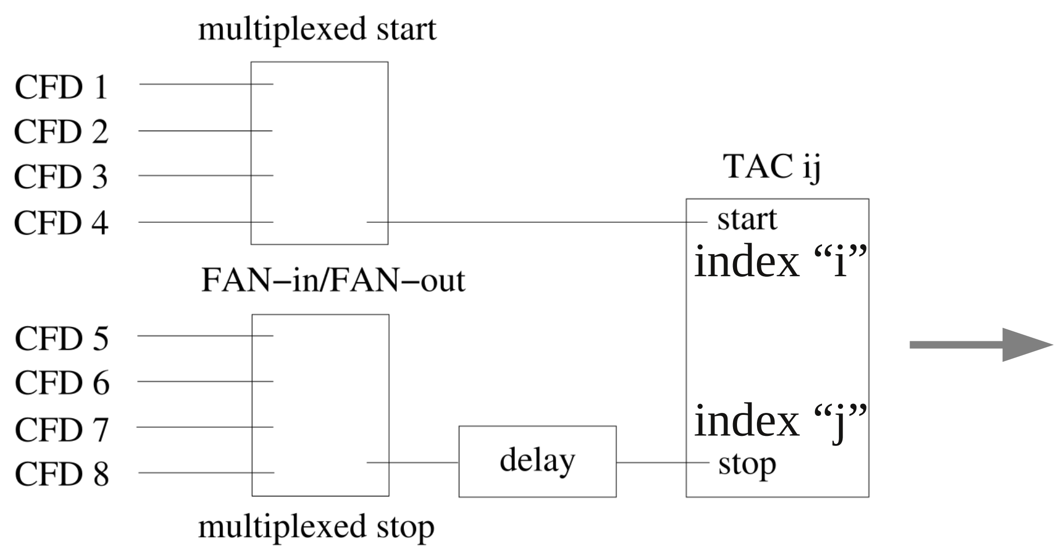


The **Prompt Response Difference** (PRD) describes the linearly combined **γ–γ zero-time** of the fast-timing array.

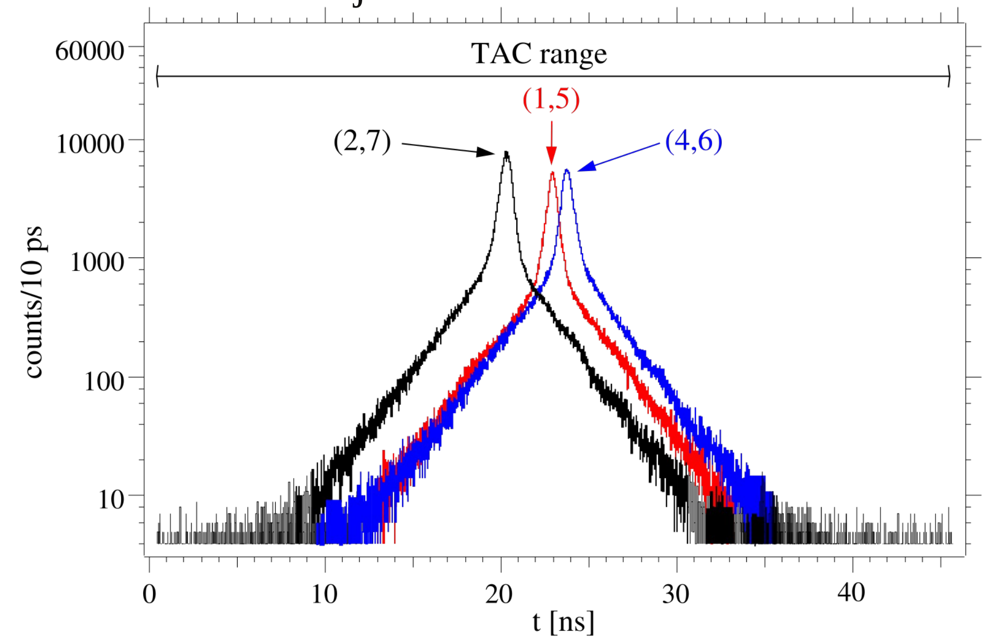
J.-M. Régis et al., NIM A **726** (2013)

The Generalized Centroid Difference (GCD) Method for γ–γ fast-timing arrays

An analog γ–γ fast-timing circuitry for an N detector fast-timing array:



The TAC$_{ij}$ projections:



{1,2,3,4} x {5,6,7,8} ∈ TAC A

{1,2,5,6} x {3,4,7,8} ∈ TAC B

{1,3,5,7} x {2,4,6,8} ∈ TAC C

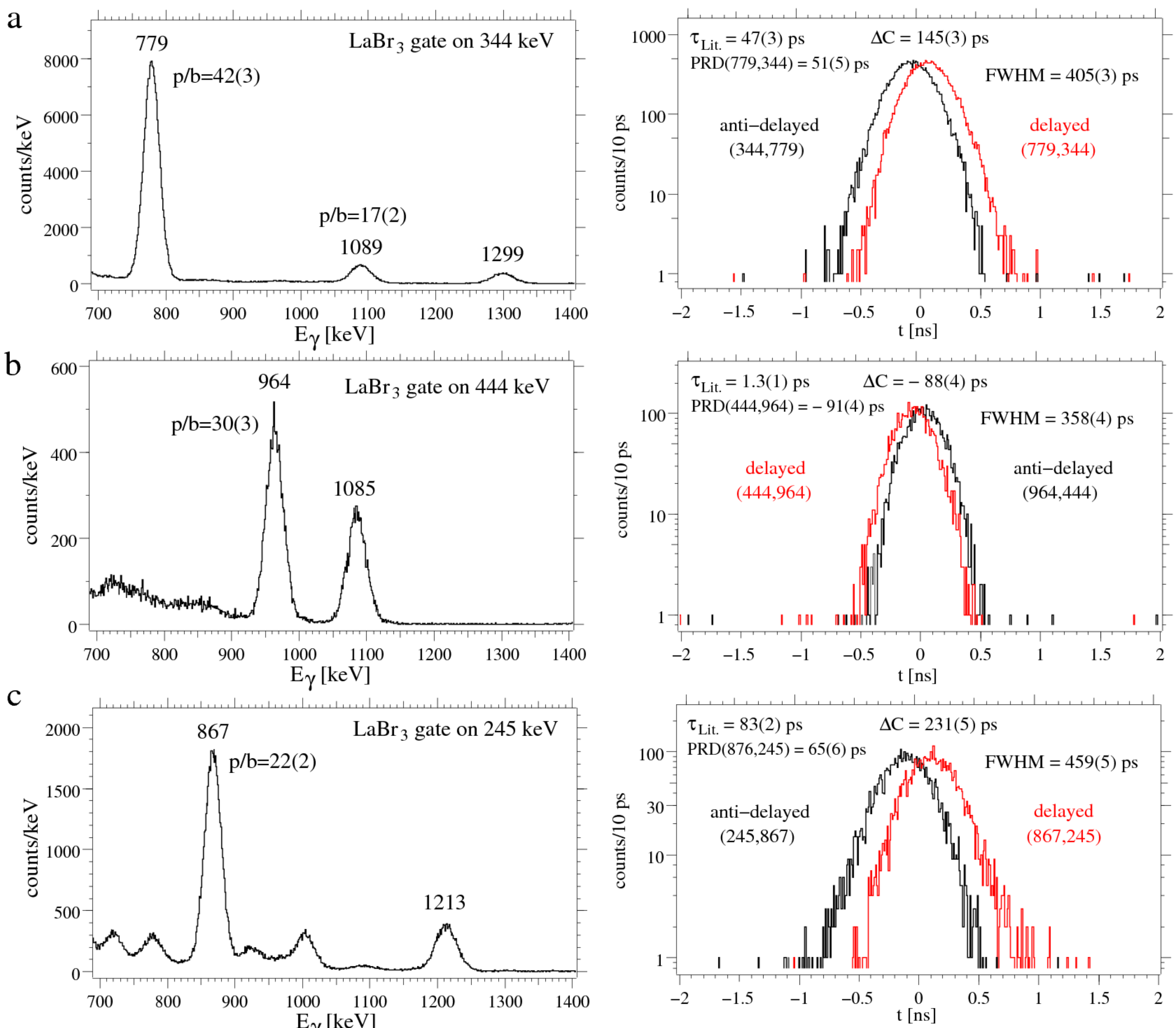
Offline alignment of the TAC$_{ij}$ projections using shift$_{ij}$ constants and superposition of the data to perform the GCD method.

Only combinations with i < j are accepted (simplified sorting algorithm).
Invalid or multiple combinations are excluded offline.
=> 3 TAC and 2 FAN modules for 8 detectors (28 combinations).

Main advantage: **almost no degradation of time resolution (<10 ps).**

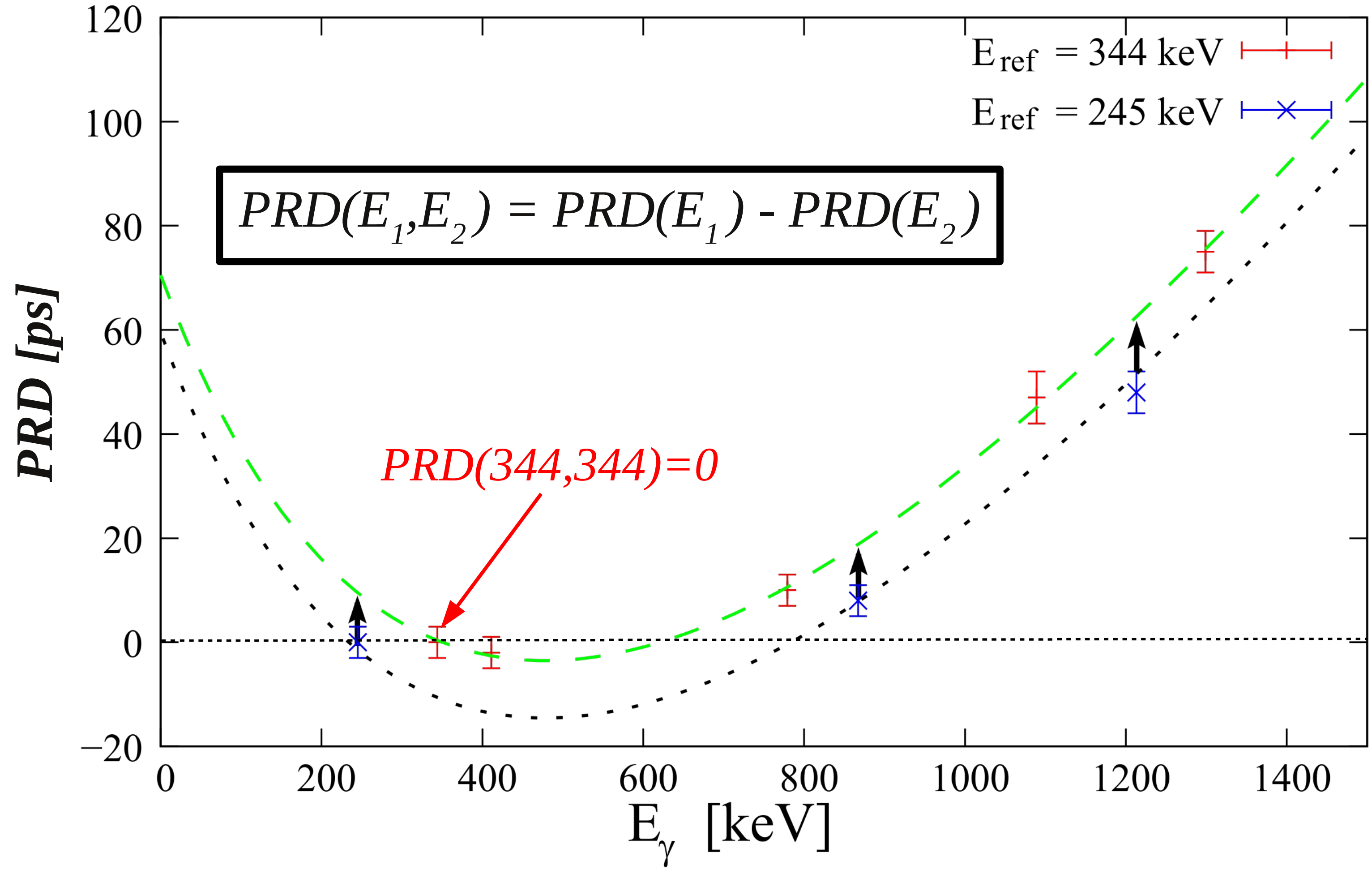
Also possible: digital time-difference measurements using multi-hit TDCs
(see talk of Matthias Rudigier)

Calibration of the PRD curve using the ^{152}Eu g-ray source:



Picosecond sensitive lifetime determination using the mirror-symmetric GCD method.

The PRD calibration procedure using ^{152}Eu:



Measured using
(Ge-) $LaBr_3$-$LaBr_3$ coincidences with
virtually no background contributions.

PRD uncertainty within 3σ: typically 5-10 ps

Advantage of the GCD method:
no correction and therefore,
no systematic error is introduced.

J.-M. Régis, N. Saed Samii et al., NIM A **823** (2016)

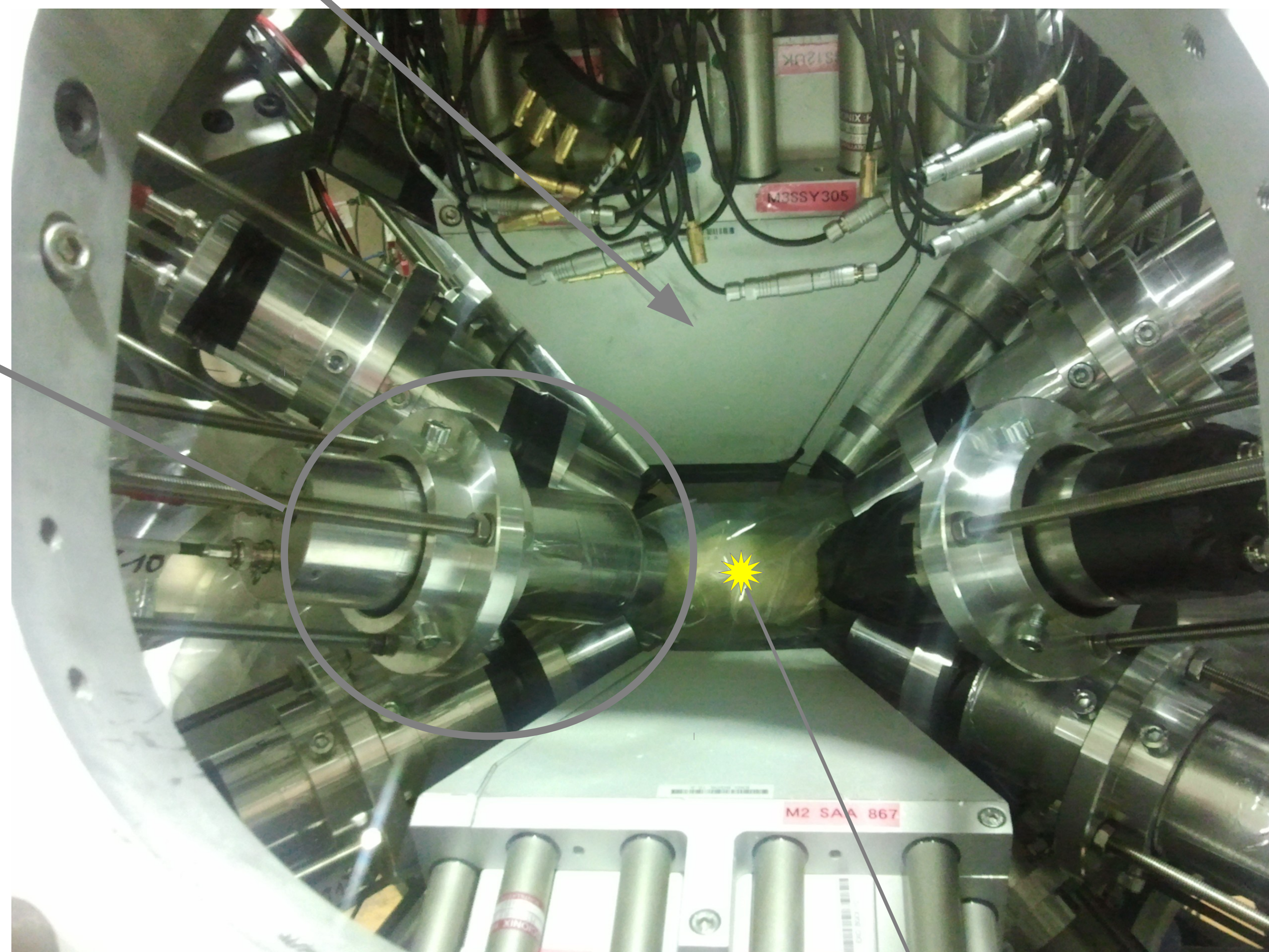
The fast-timing array FATIMA in combination with 8 EXOGAM clovers for Prompt γ-ray spectroscopy of neutron induced capture/fission experiments at ILL 2013

Ring of 8 BGO shielded EXOGAM clovers used to provide one or two selective γ-triggers.

16 almost equal
$LaBr_3(Ce)$ detectors
for γ–γ lifetime measurements.

Collimated
cold-neutron beam

Ø1.2 cm



Trigger-less digital
data acquisition of
71 ADC channels

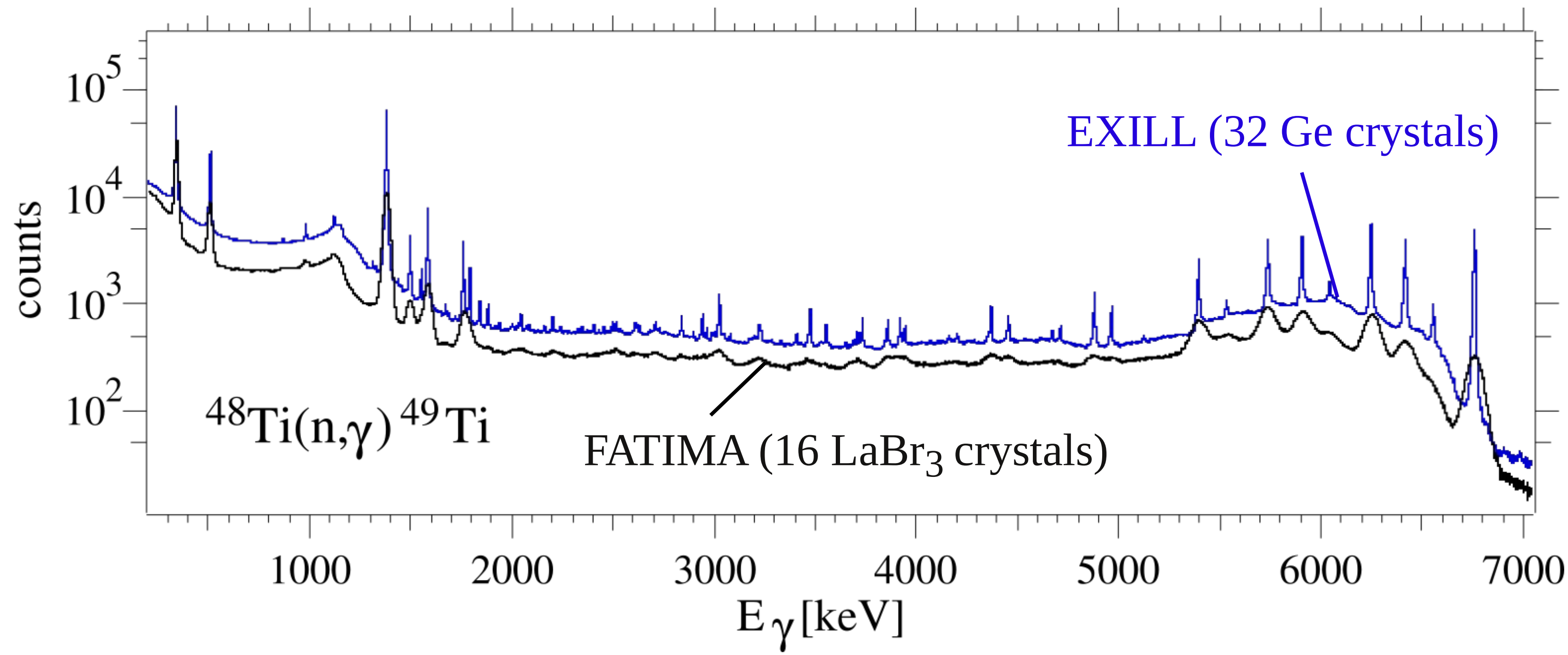
Detector rate: up to 25 kHz
Data rate: up to 6.5 MB/s
Acquired data: ~ 40 TB

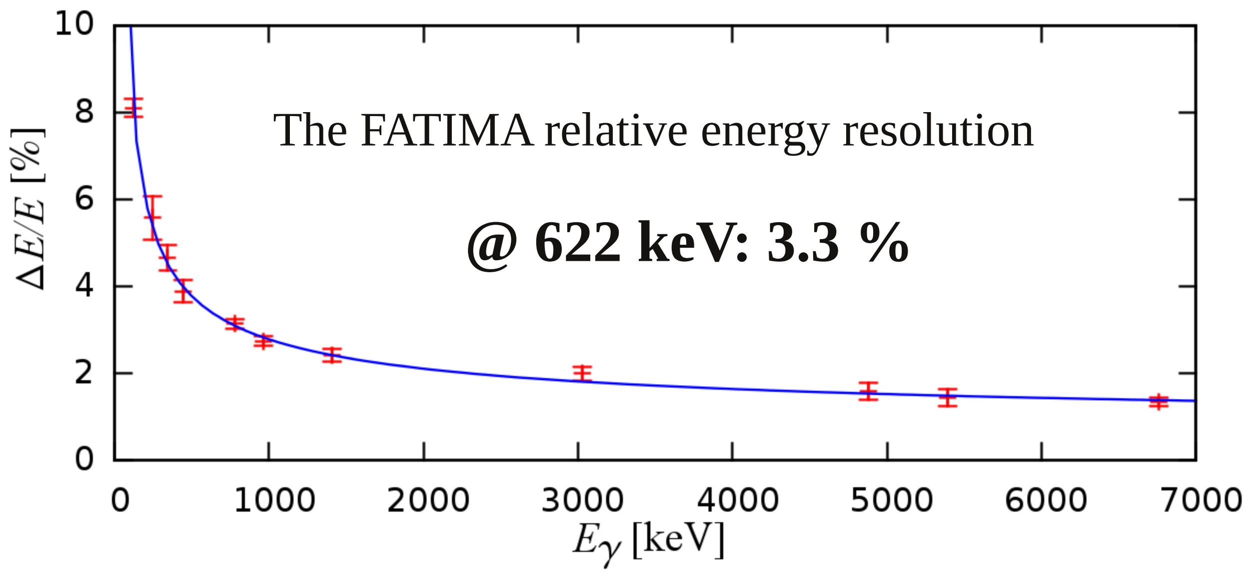
Target position

Energy performance of the EXILL & FATIMA spectrometer @ ILL 2013

Singles spectra

The $LaBr_3$ spectra are gain-matched to obtain the best energy resolution.





Absolute full-energy peak efficiencies:

	@ 662 keV	@ 1.3 MeV
EXILL	**4.9%**	**3.0%**
FATIMA	**3.7%**	**2.1%**

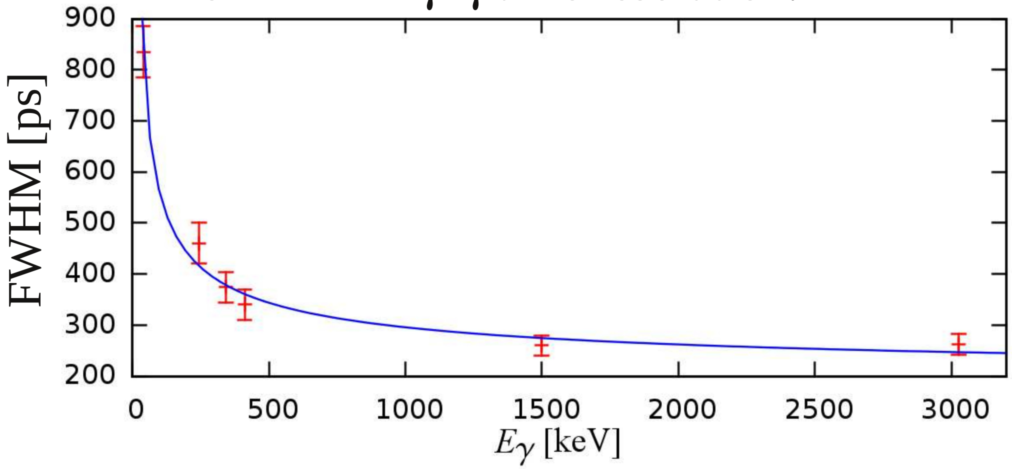
J.-M. Régis, G.S. Simpson et al., NIM A **763** (2014)

Timing performance of FATIMA @ ILL 2013

Consited of: 8 cylindrical Ø1.5”X1.5”

and 8 cylindrical Ø1.5”X 2” LaBr3(Ce) scintillators

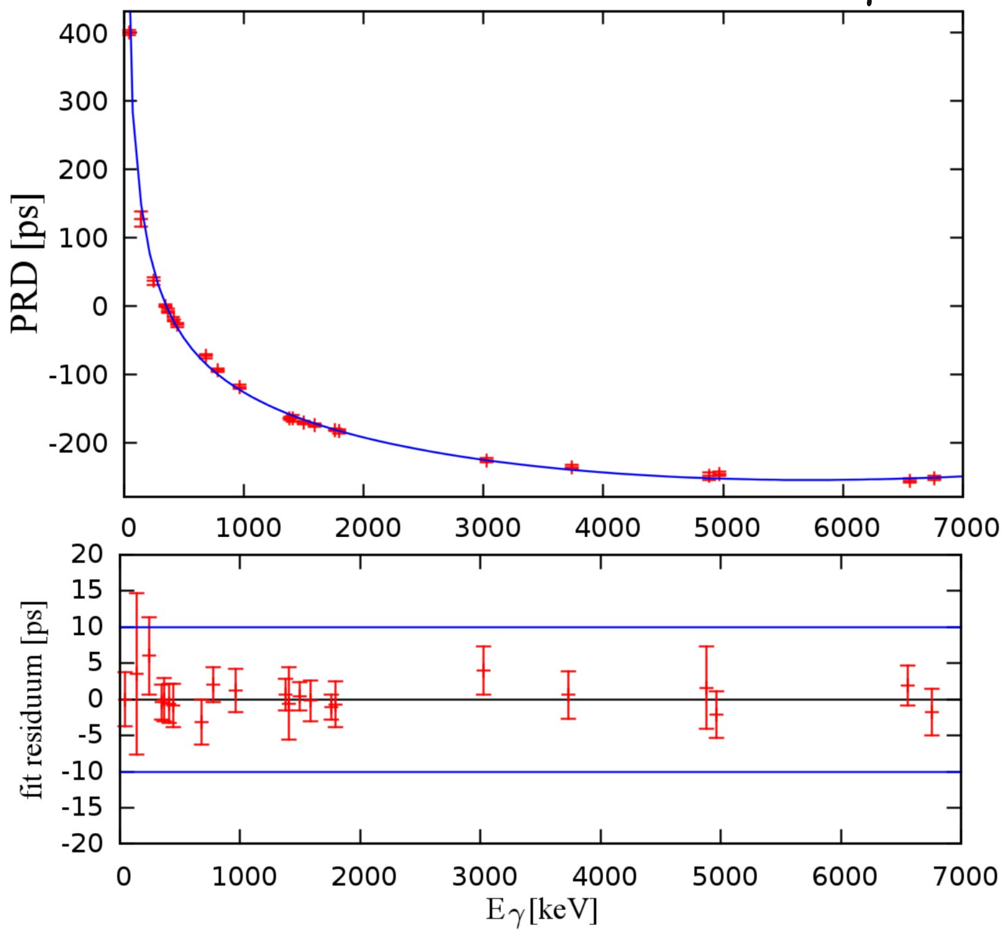
The FATIMA γ–γ time resolution:



The statistical centroid uncertainty: $\delta C = \dfrac{FWHM}{2.355\sqrt{n}}$

e.g. FWHM=500 ps and n=1000 counts: δC ~ 7 ps

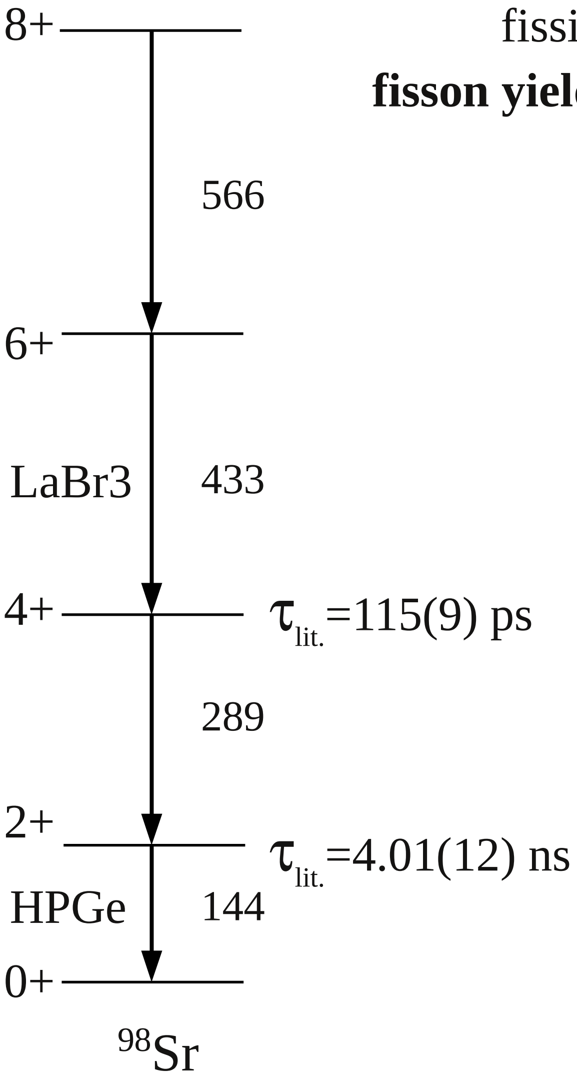
The FATIMA γ–γ time walk PRD(E_γ):



The systematic error of PRD determination:

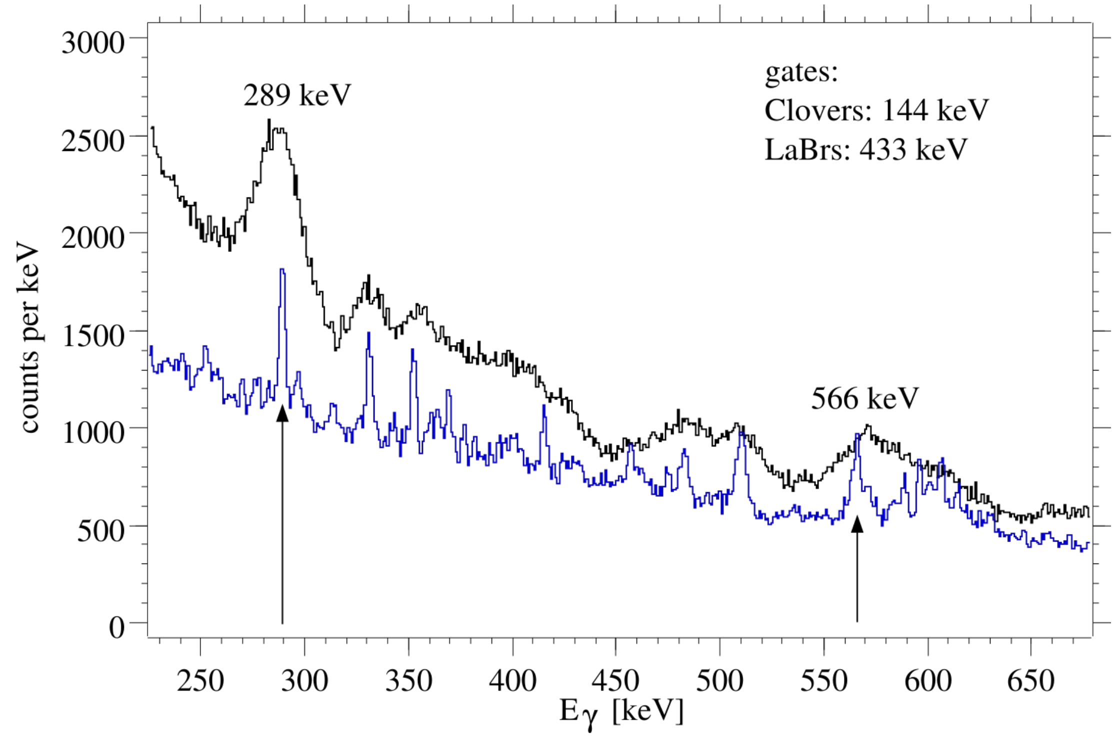
3 standard deviation: δPRD = 10 ps

Identification of fission fragments & investigation on background and contaminations

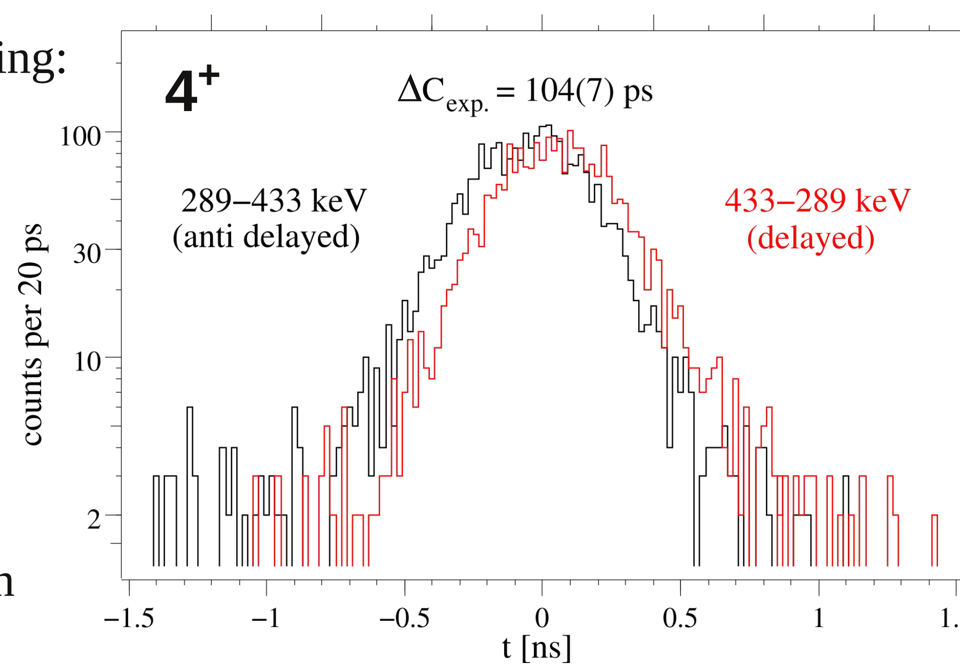


10 days neutron-induced fission of ^{235}U

fisson yield of ^{98}Sr: 0.81%



HPGe-gated γ–γ timing:

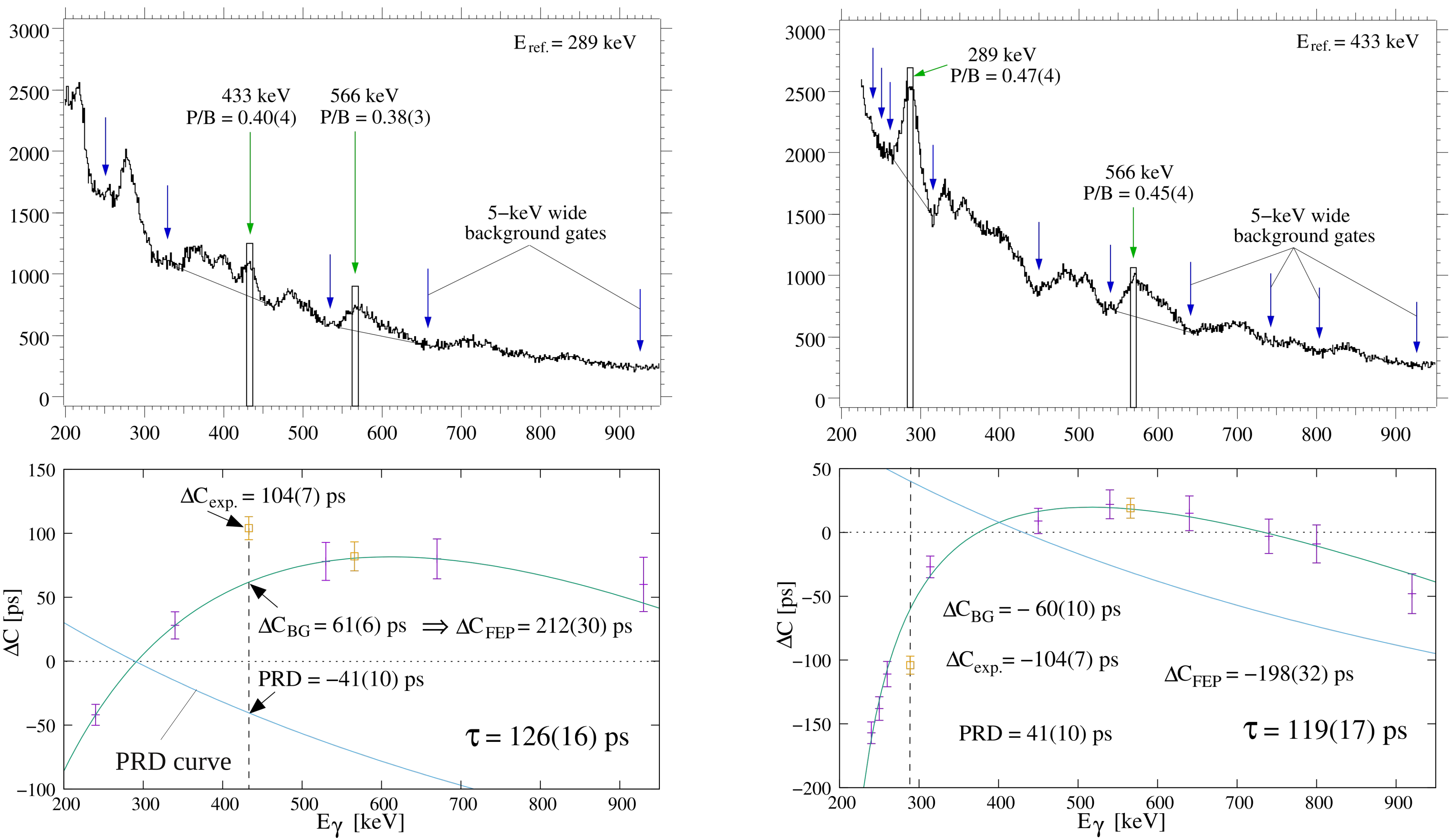


About 2600 counts per time distribution

The first 4+ state in 98Sr: $\tau_{lit.} = 115(9)$ ps (< FWHM)

The correction for background contributions: $\Delta C_{FEP} = \Delta C_{exp.} + \frac{\Delta C_{exp.} - \Delta C_{BG}}{P/B}$

Determination of the time response of the background ΔC_{BG} possible in two ways:

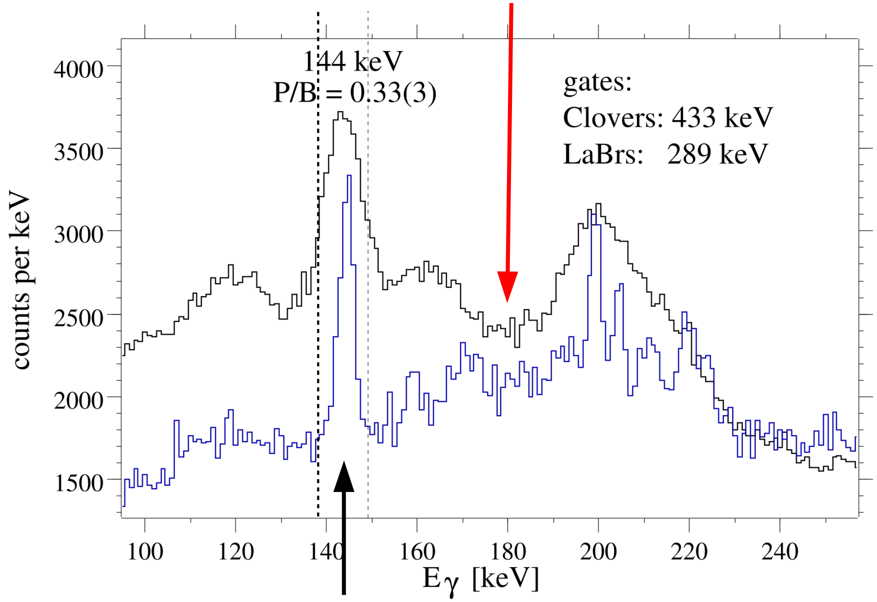


Considering long lifetimes τ >1 ns: Subtraction of the fast background component?

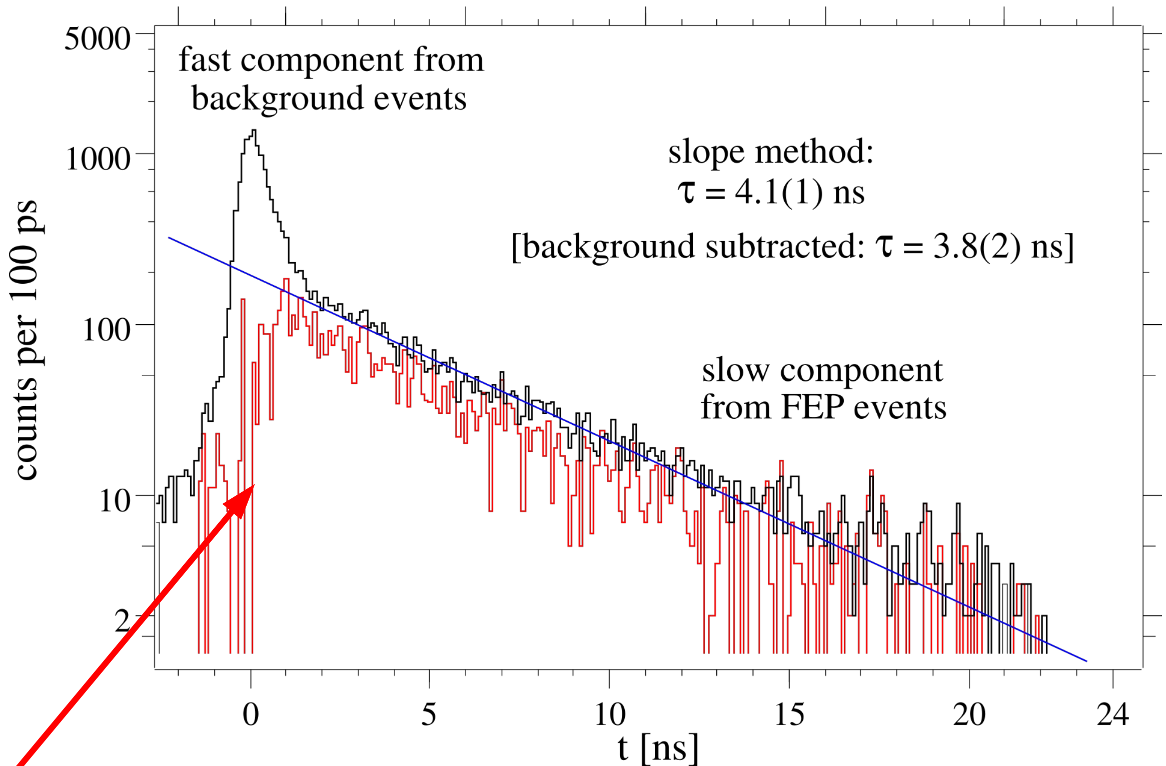
The first 2^+ state in ^{98}Sr

$\tau_{lit.} = 4.01(12)$ ns

Background gate



LaBr gate to generate the experimental time spectrum including FEP and background events



Statistics obtained for the slope method:

No subtraction: ~7500 counts

Background subtracted: ~6500 counts

After subtraction of the approximated and normalized background time spectrum

Conclusion:

The background underneath the **two** FEPs of the γ–γ cascade contribute to the γ–γ time distribution.

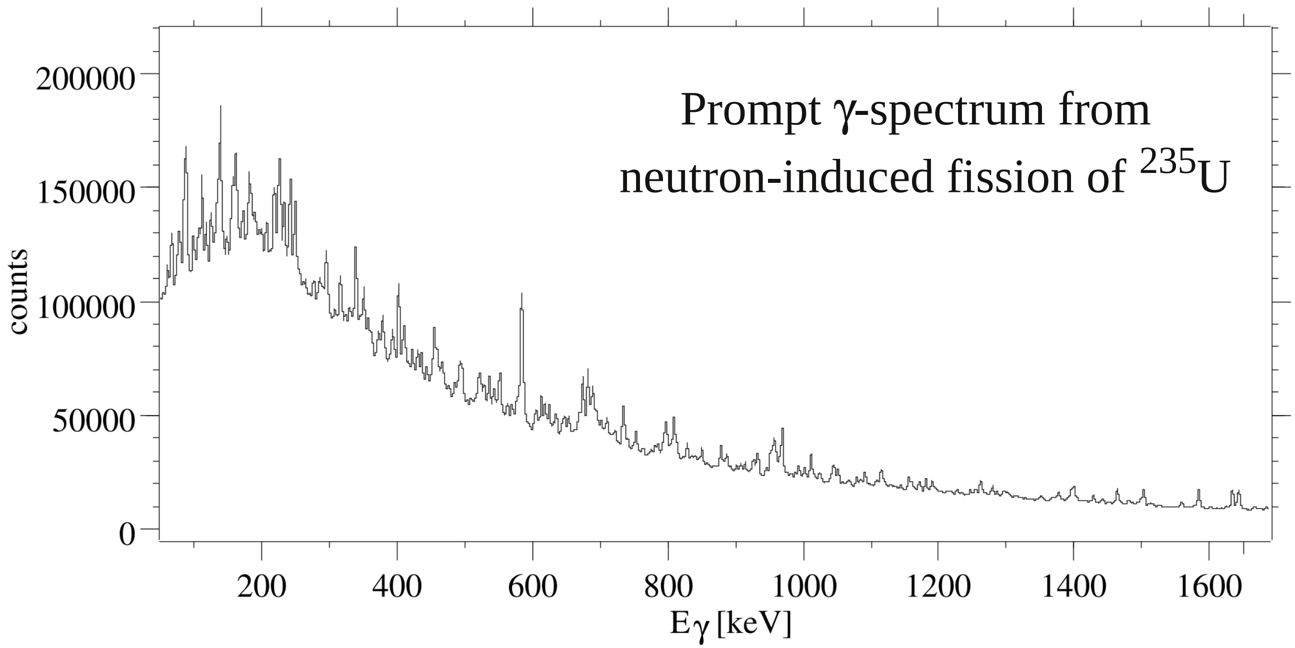
A reduction of the complexity of the γ-ray spectra is desired, e.g. using an additional trigger.

$\Rightarrow$ improved peak-to-backround ratio and reduced uncertainty of related time correction.

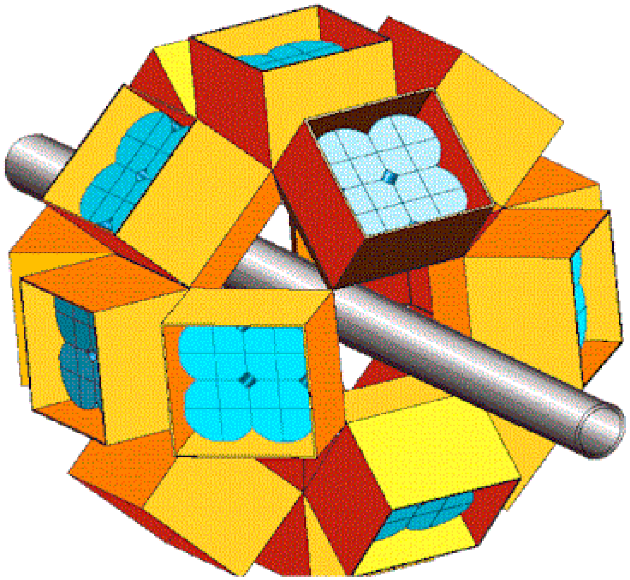
Thank you for your attention

EXILL campaigns 2012/2013:

Prompt γ-ray spectroscopy of neutron induced fission products



The EXOGAM array of SPIRAL at GANIL



Experiment:

More than **100 nuclei** are produced with intermediate **high mean spin and high γ-ray multiplicity**.

At least, **triple γ–γ–γ coincidences are needed** to resolve the level scheme of a fission product.

Highly segmented γ-ray detector array is needed.

Ge-gated γ–γ fast timing possible using $LaBr_3(Ce)$ scintillator detectors.