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The Mirror Symmetric Centroid Difference Method

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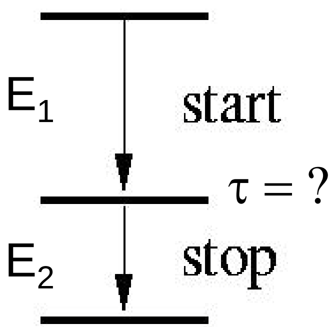
Contents

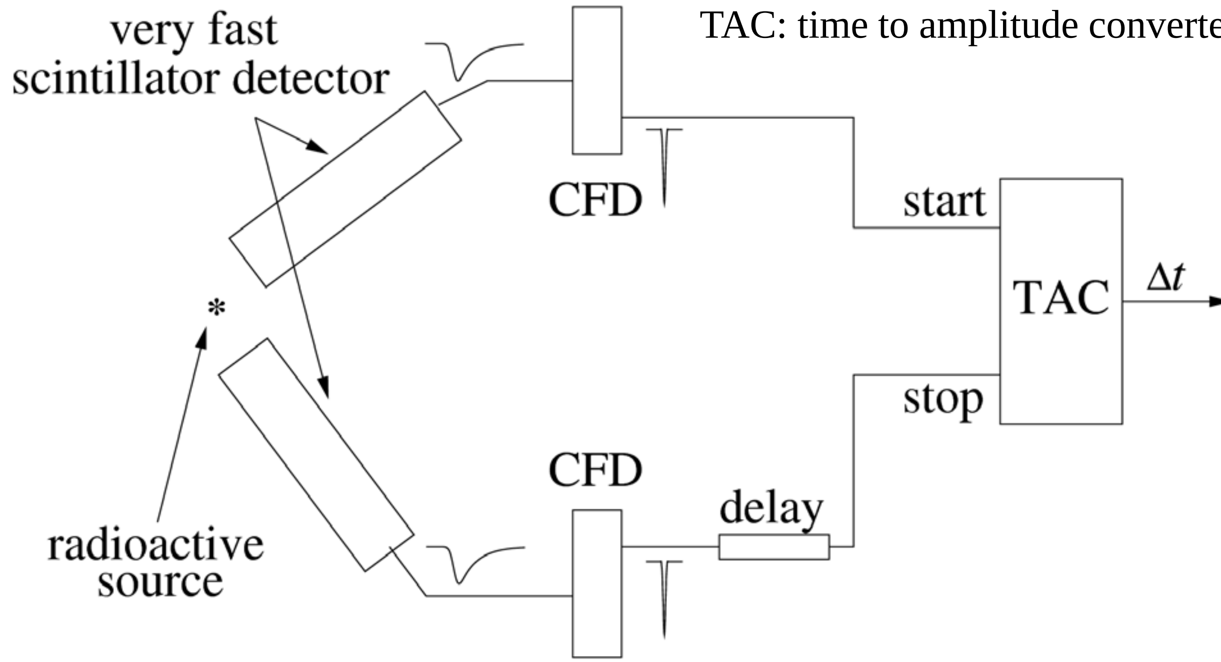
- The traditional electronic "**fast timing technique**"
- the ultra fast **$LaBr_3$(Ce) scintillator detectors** for γ-rays
- the centroid shift method &
  the new **mirror symmetric centroid difference** (MSCD) method

The traditional fast timing technique



The fast timing setup:
(the delayed coincidence circuitry)

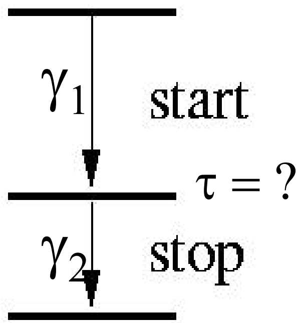
CFD: constant fraction discriminator
TAC: time to amplitude converter



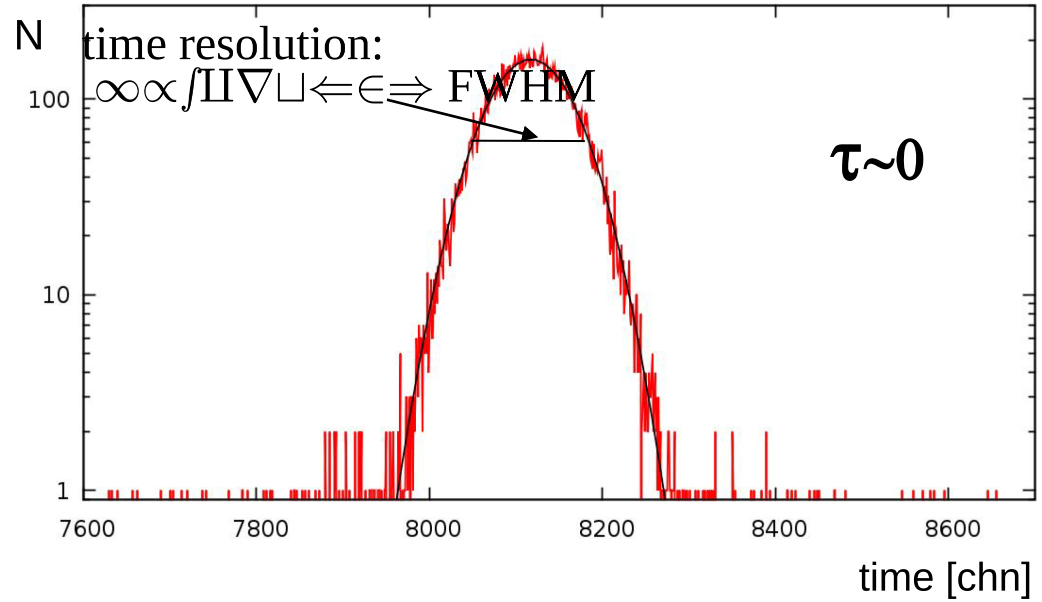
+ slow energy coincidence circuitry

$E_1, E_2, \Delta t$ listmode data

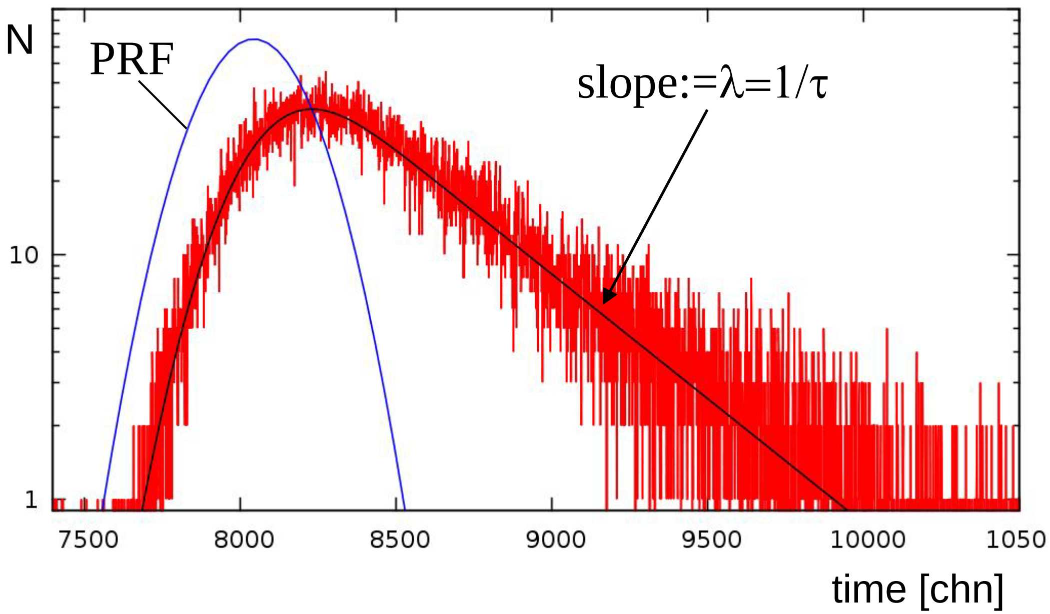
The time spectra of fast timing experiments



The **prompt response function** (PRF)
is a Gaussian distribution



τ > FWHM:



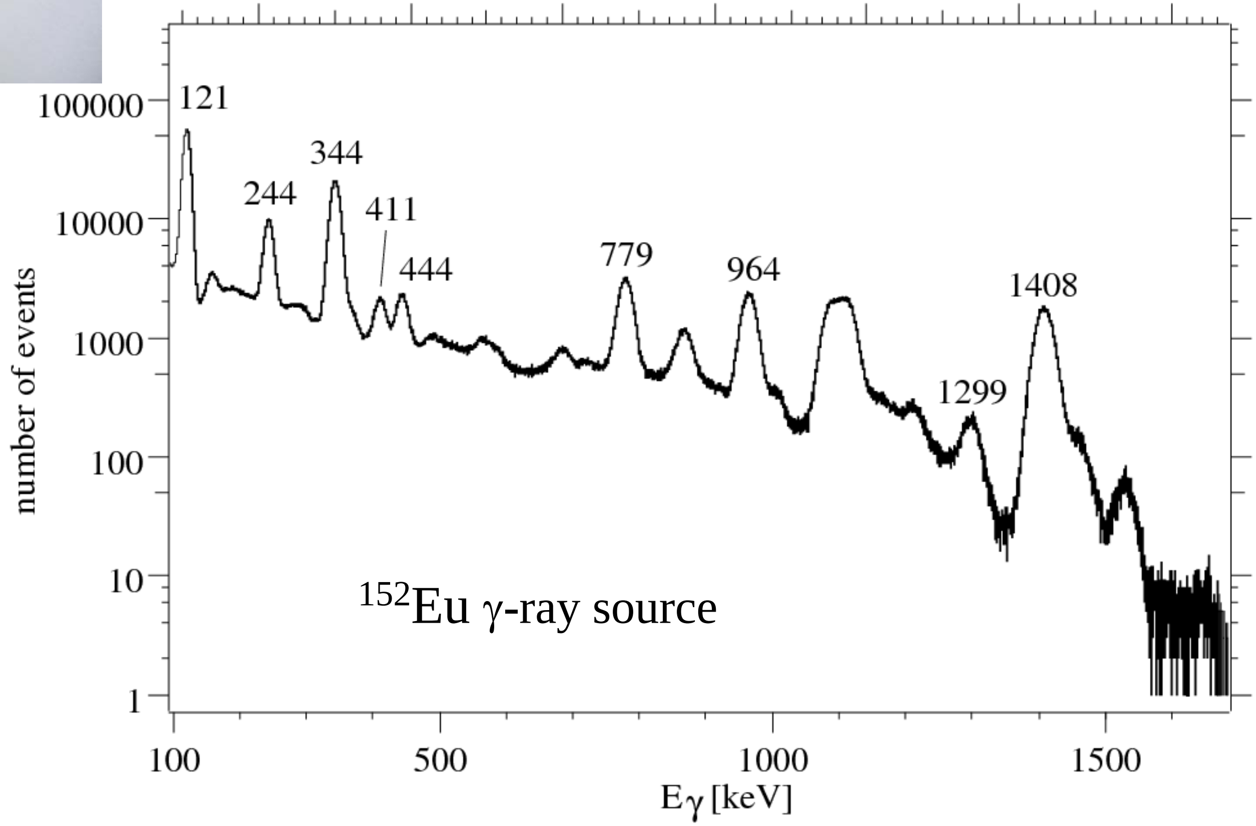
The **delayed time spectrum** *D(t)* is
a convolution of the
PRF *P(t)* with an exponential decay:

$$D(t) = \lambda N_0 \int_{-\infty}^{t} P(x) e^{-\lambda(t-x)} dx$$

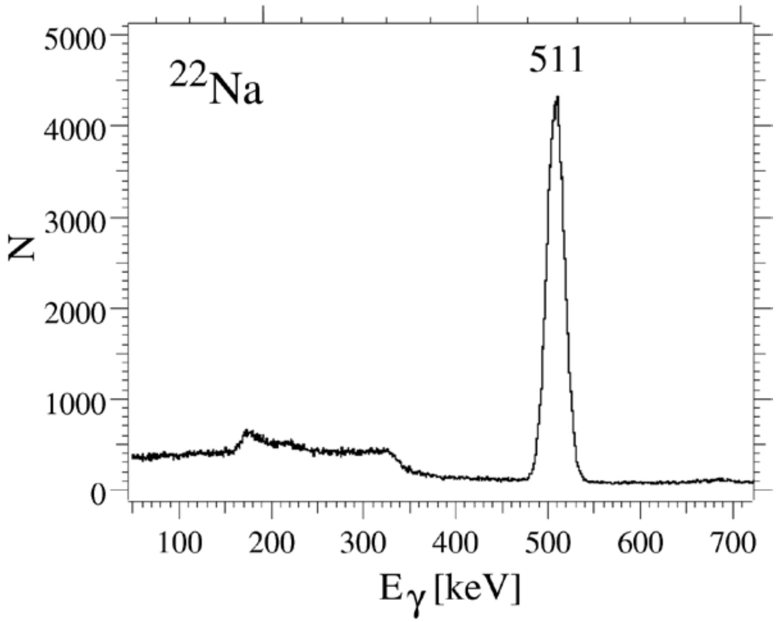
The $LaBr_3(Ce)$ scintillator detectors of the IKP

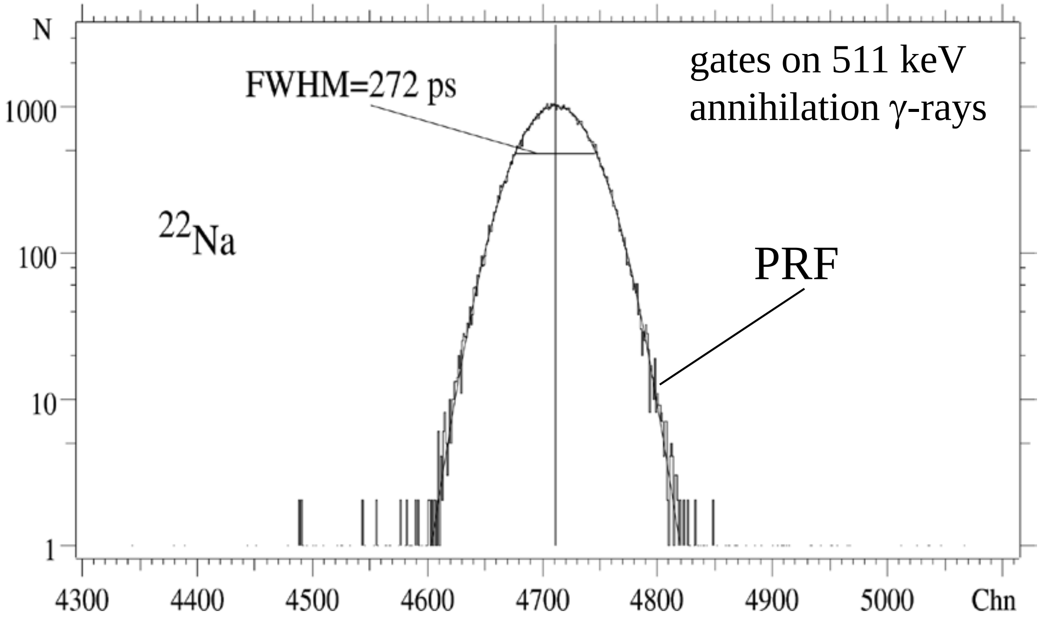
ø1.5" x 1.5" $LaBr_3(Ce)$ crystal coupled to the XP20D0 photomultiplier tube.

Excellent energy resolution of ~ 3% !



Time resolution of the IKP Cologne $LaBr_3(Ce)$ detectors





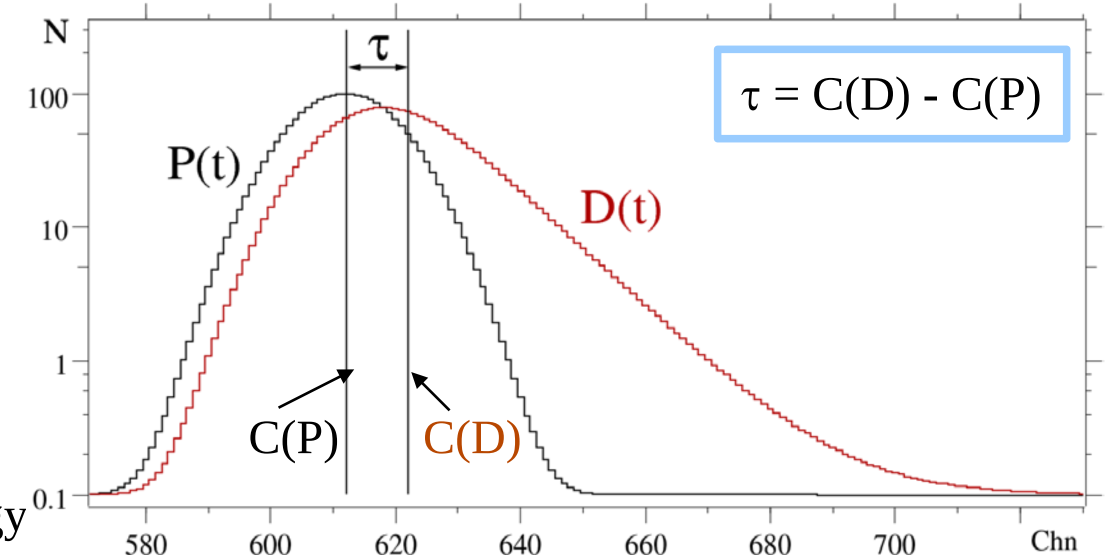
The timing property is comparable to the fastest scintillators available.

The centroid shift method:

Centroid of a time distribution D(t):

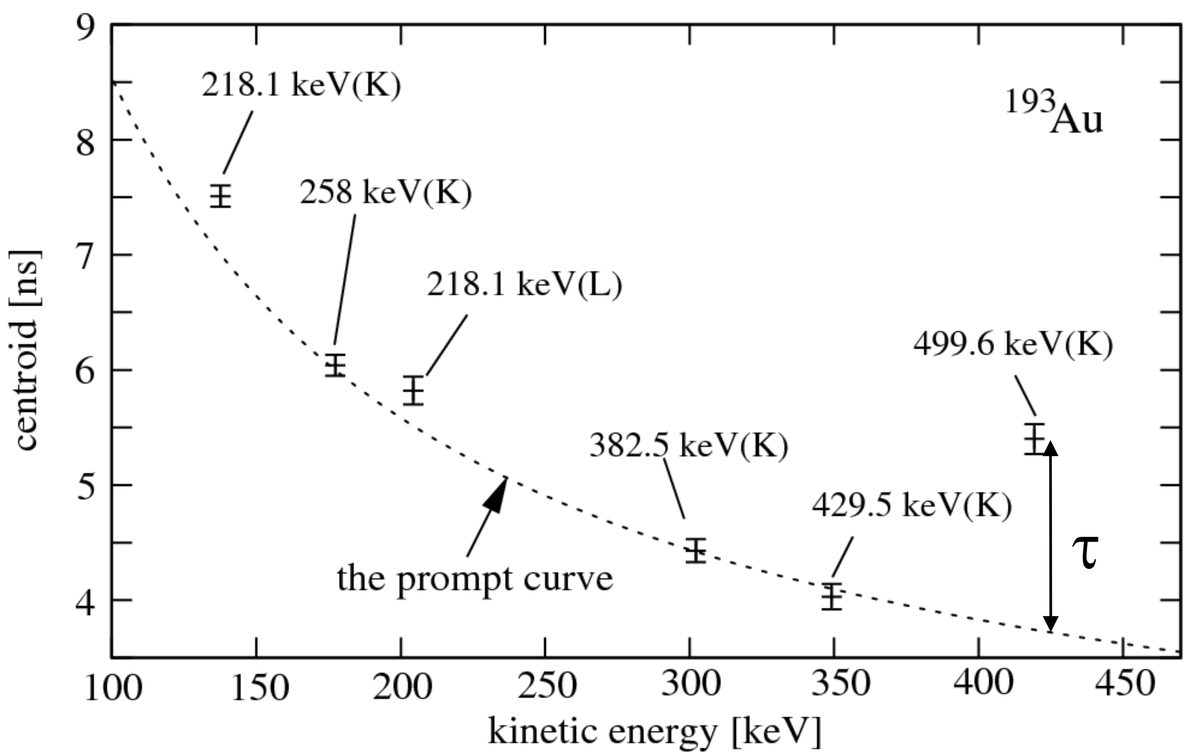
$$C(D) = \langle t \rangle = \frac{\int tD(t)dt}{\int D(t)dt}$$

The centroid C(P) of the PRF
P(t) is strongly dependent on the energy



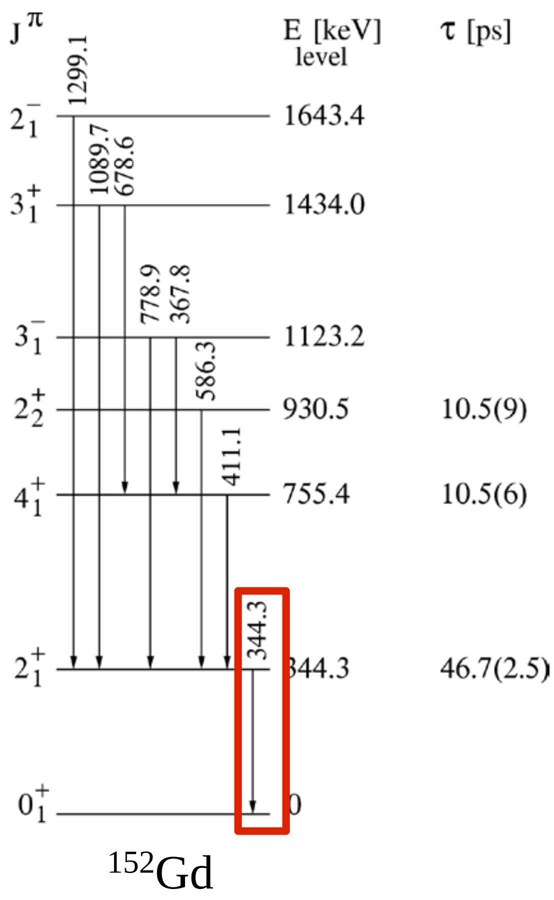
„The prompt curve“ indicating **τ = 0** is needed ! Example only one plastic scintillator.
(time-walk characteristics)

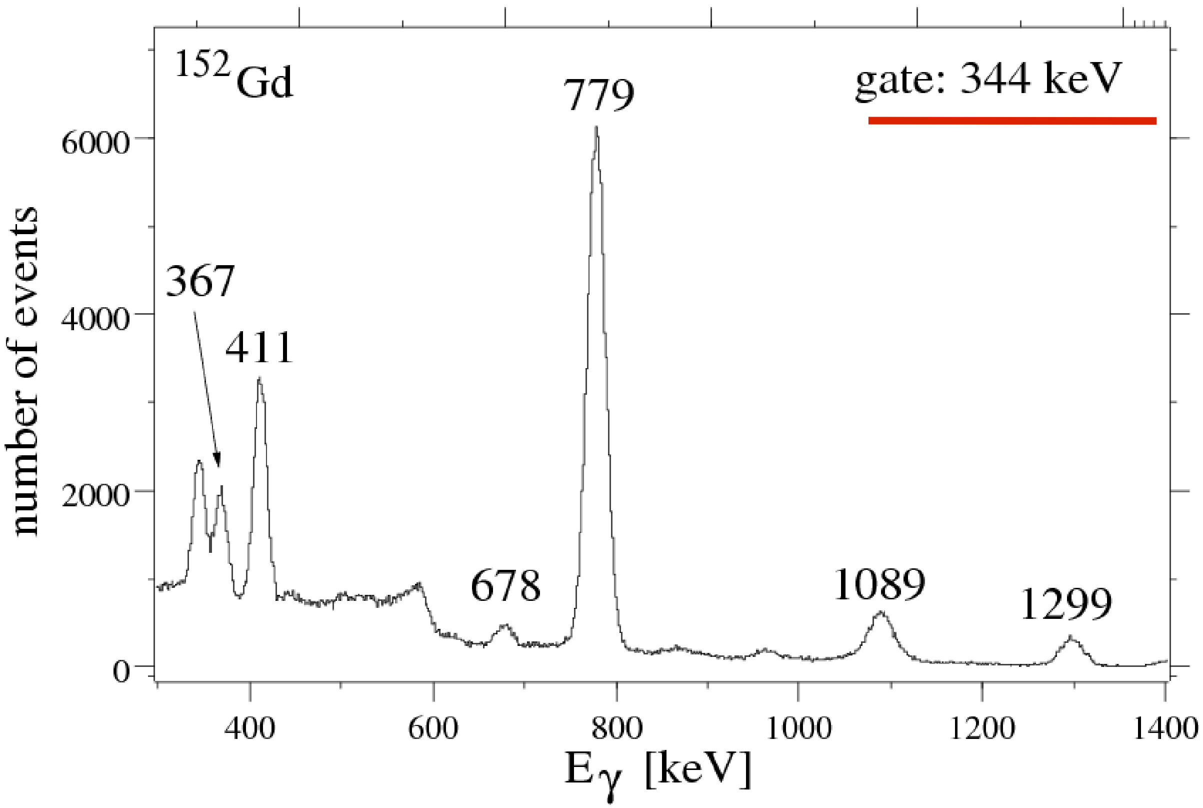
The centroid diagram
for a conversion electron (stop)
and a beam pulse (start):
for higher energies the stop
signal is faster produced.



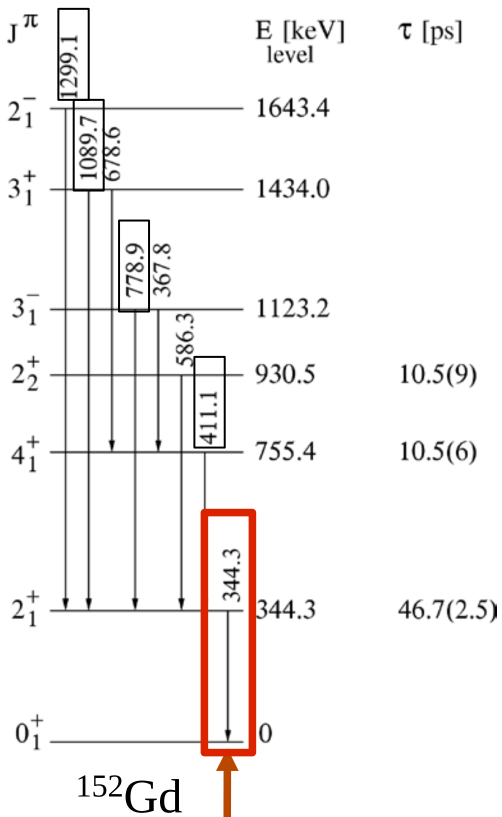
J.M. Régis et al. Rev. of Scientific Instruments 82 (2010) 113505.

γ–γ timing with $LaBr_3$(Ce) scintillator detectors; determination of the prompt curve using the ^{152}Eu γ-ray source

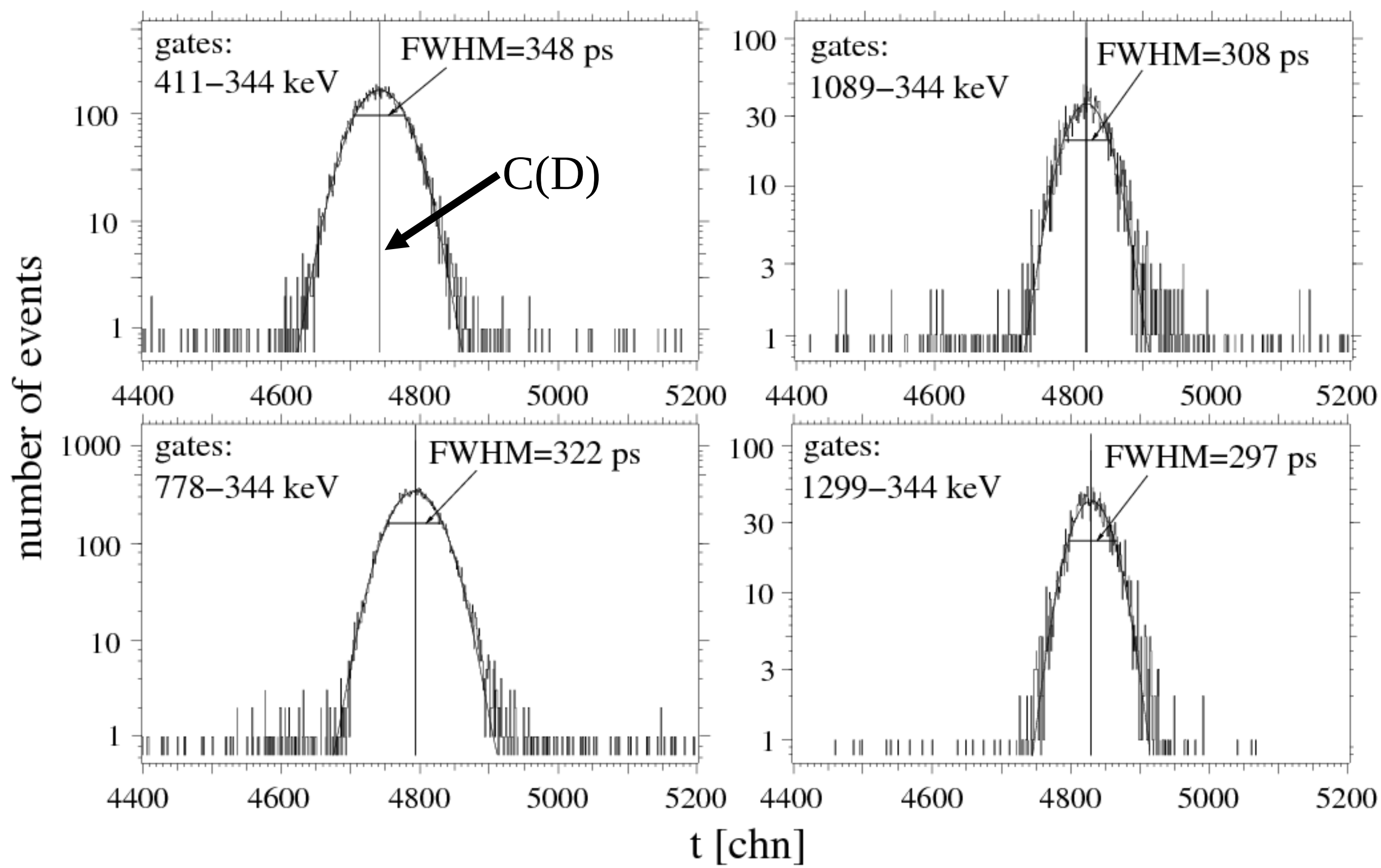




γ–γ timing with $LaBr_3(Ce)$ scintillator detectors; determination of the prompt curve using the ^{152}Eu γ-ray source

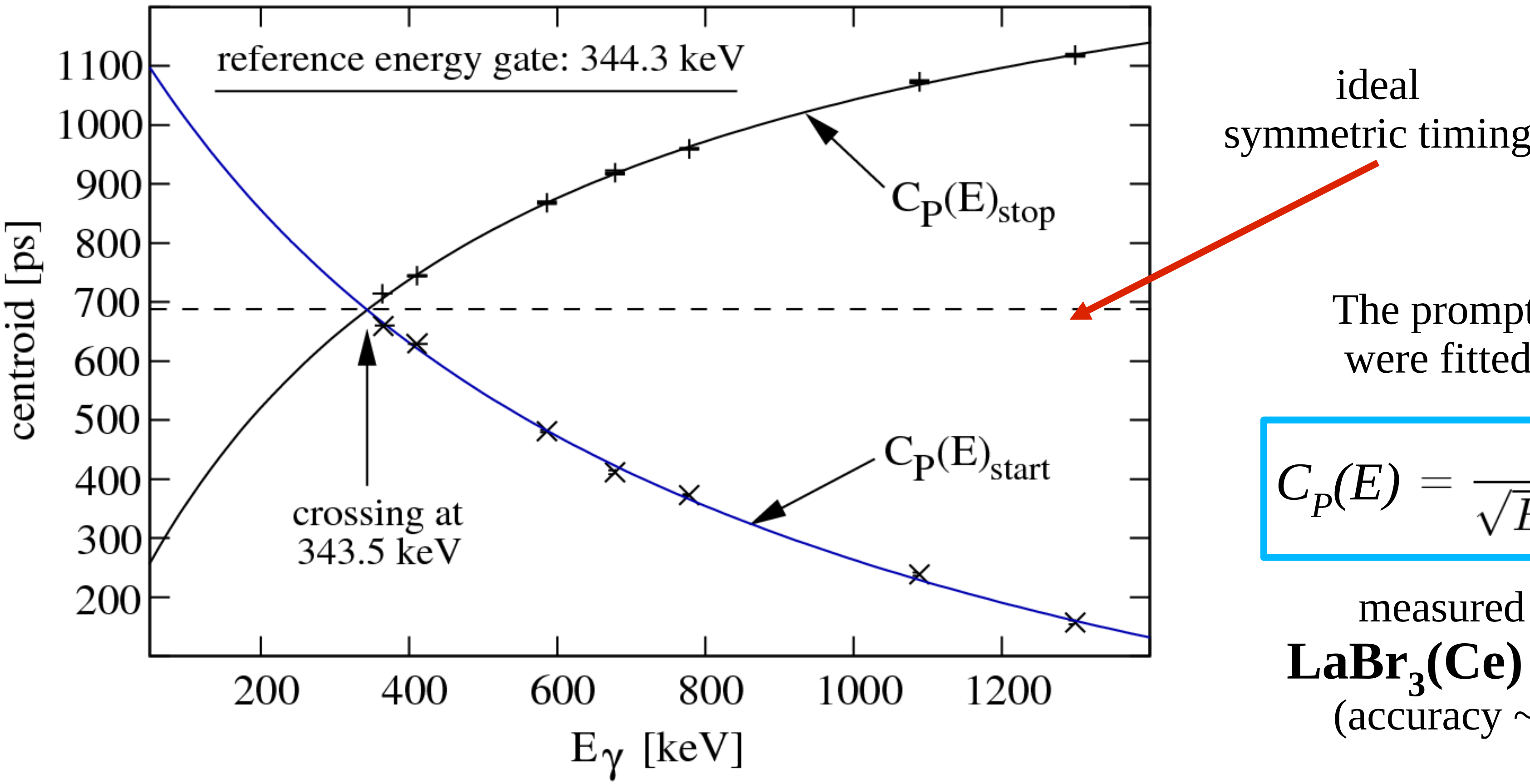


reference timing signal of the setup γ_2



$$C(P) = C(D) - \tau$$

In reality there are two prompt curves of a γ–γ fast timing setup using γ_2 both as start and stop gate.



The prompt curves were fitted using:

$$C_P(E) = \frac{a}{\sqrt{E+b}} + c$$

measured using **$LaBr_3$(Ce)** detectors. (accuracy ~ 10 ps)

- The centroid are corrected for the known lifetimes using C(P) = C(D)-τ
- the timing of the two detectors of a real γ–γ fast timing setup is asymmetric.
- electronic drift due to thermal fluctuations in electronics.
- prompt curve determination is sensitive to the experimental geometry.

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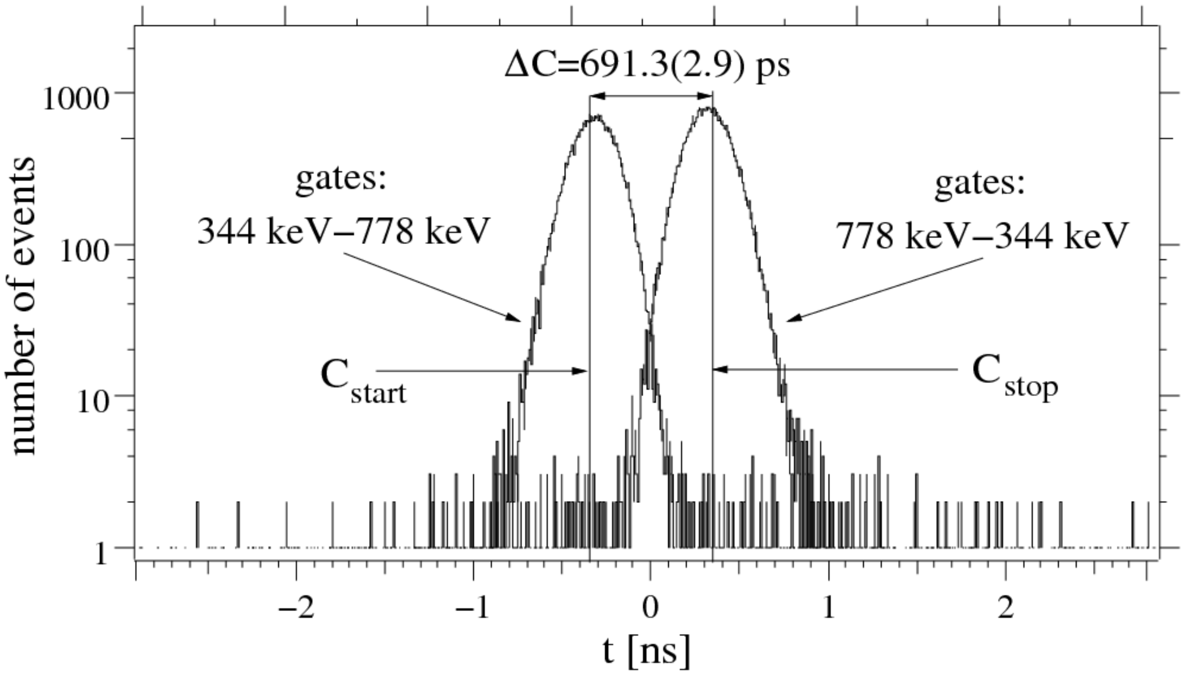
The Mirror Symmetric Centroid Difference (MSCD) method

The combined γ–γ time-walk characteristics is described by
the **prompt response difference (PRD)**:

$$PRD(E_\gamma)=C_P(E_\gamma)_{stop} - C_P(E_\gamma)_{start}$$

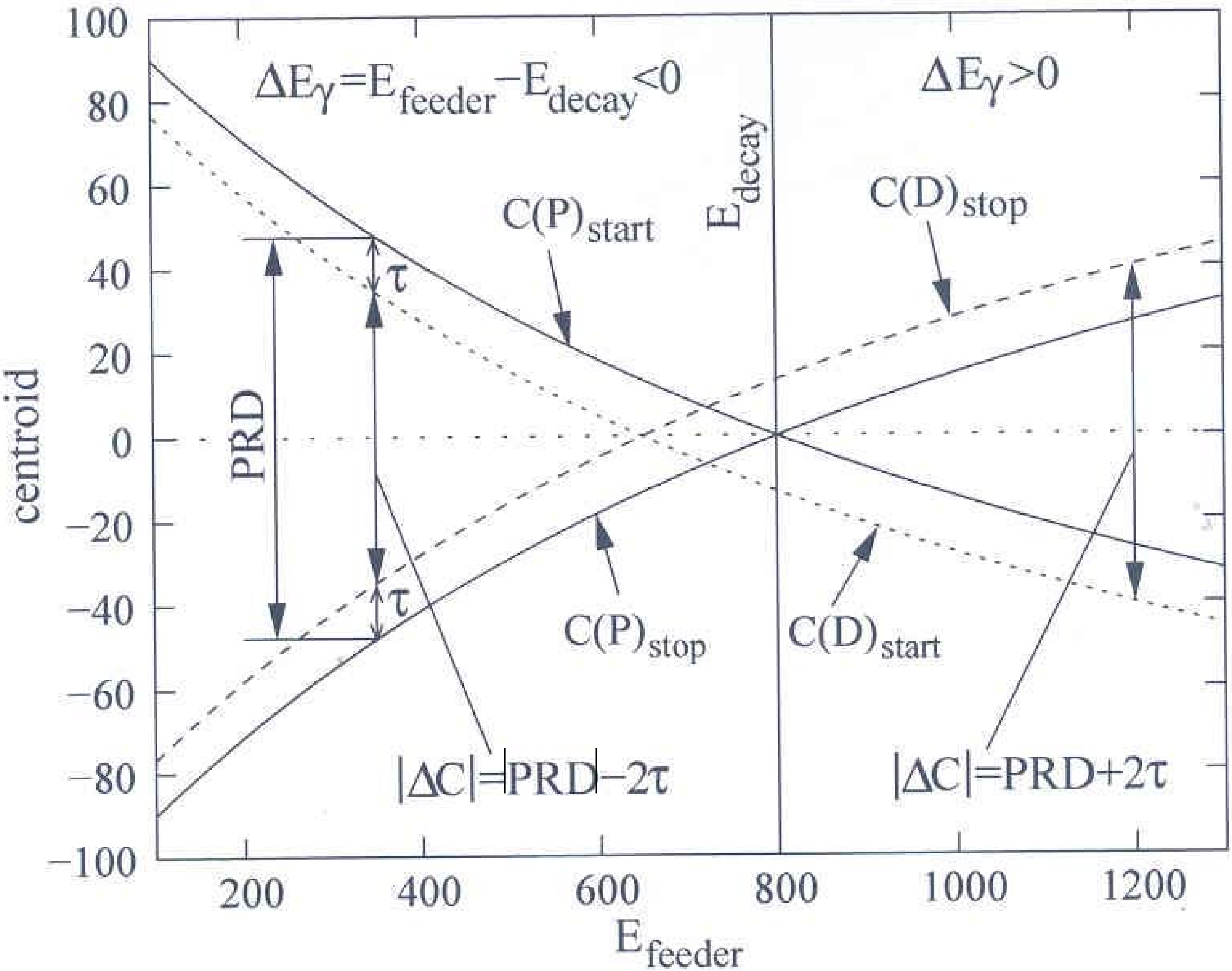


$$\Delta C(\Delta E)=C_{stop}-C_{start}=PRD(\Delta E)+2\tau$$

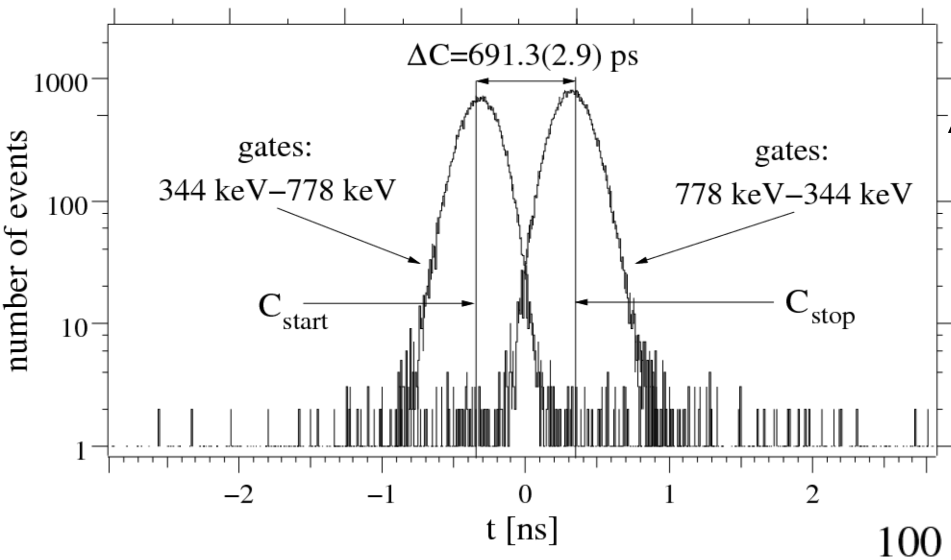
$$\Delta E=E_{feeder}-E_{decay}$$

$$\Delta C(\Delta E)=C(D)_{stop}-C(D)_{start}=C(P)_{stop}+\tau-(C(P)_{start}-\tau)=PRD(\Delta E)+2\tau$$

$$\Delta E=E_{feeder}-E_{decay}$$



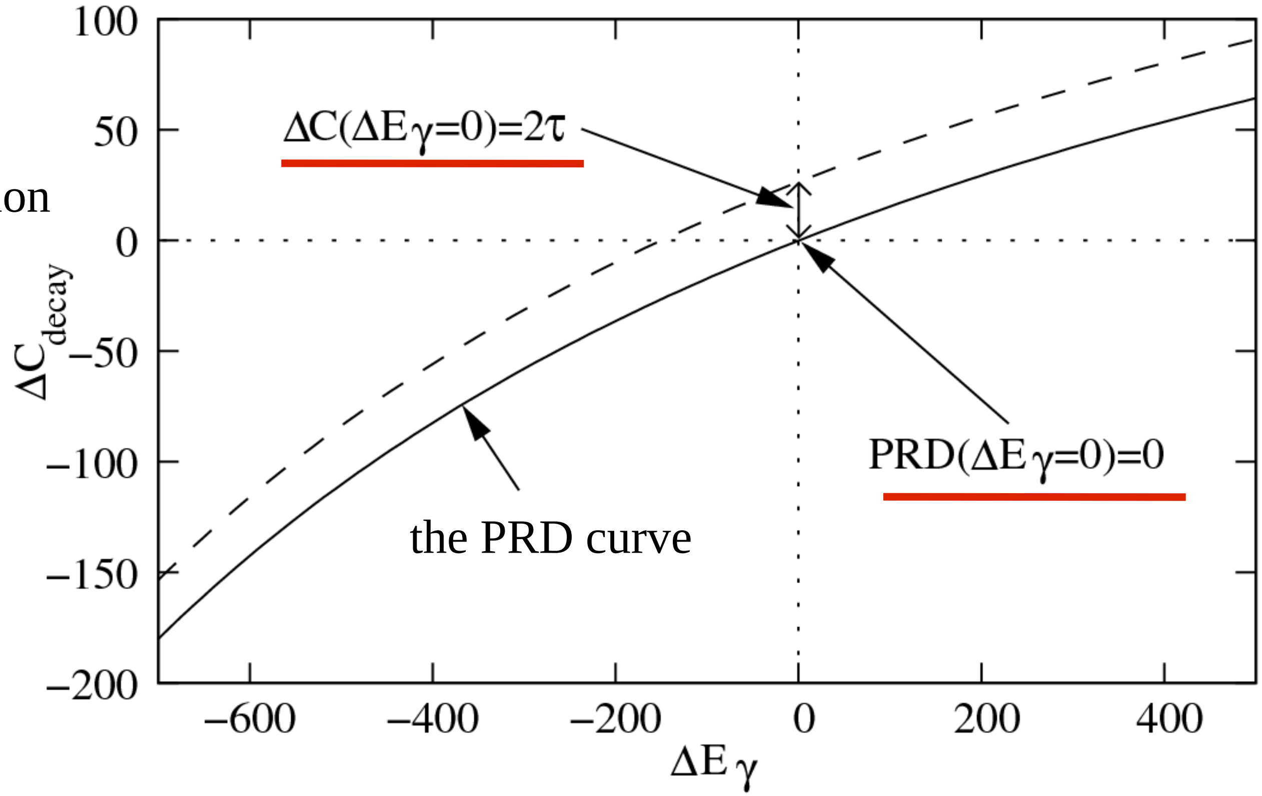
The Mirror Symmetric Centroid Difference (MSCD) method



$$\Delta C(\Delta E)_{decay} = C(D)_{stop} - C(D)_{start} = PRD(\Delta E)_{decay} + 2\tau$$

$$\Delta E = E_{feeder} - E_{decay}$$

The (ΔC, ΔE)-diagram:



Direct picosecond lifetime determination possible: $\Delta C(\Delta E=0)=2\tau$

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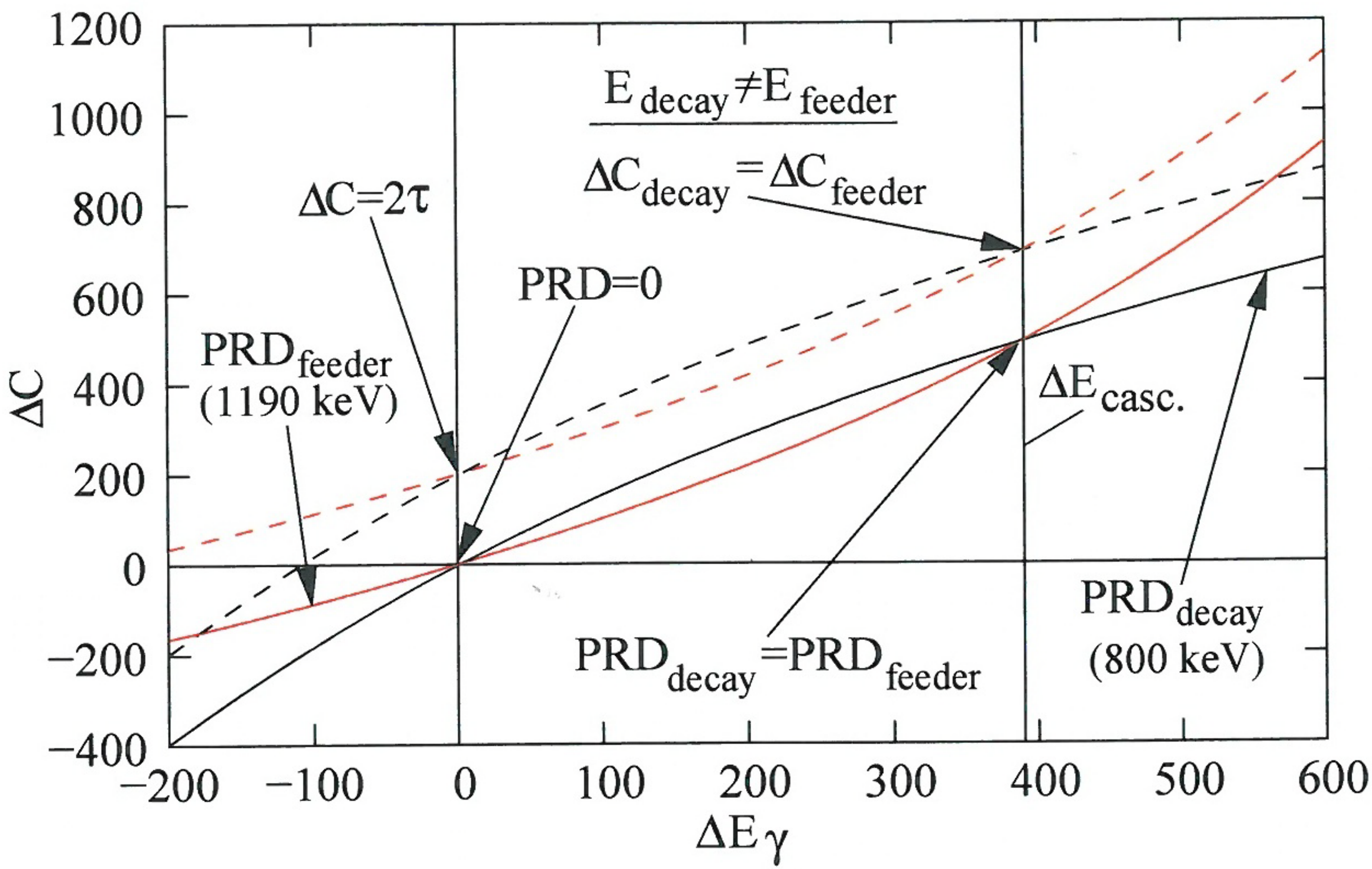
$$\Delta C(\Delta E)_{decay} = C(D)_{stop} - C(D)_{start} = PRD(\Delta E)_{decay} + 2\tau$$
$$\Delta E = E_{feeder} - E_{decay}$$

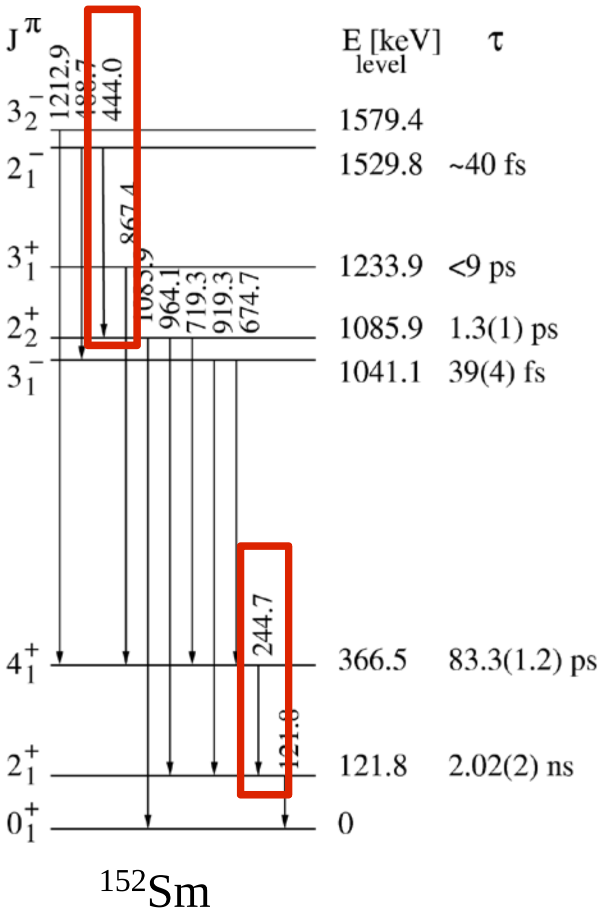
$$\Delta C(\Delta E)_{feeder} = C(D)_{start} - C(D)_{stop} = PRD(\Delta E)_{feeder} + 2\tau$$
$$\Delta E = E_{feeder} - E_{decay}$$

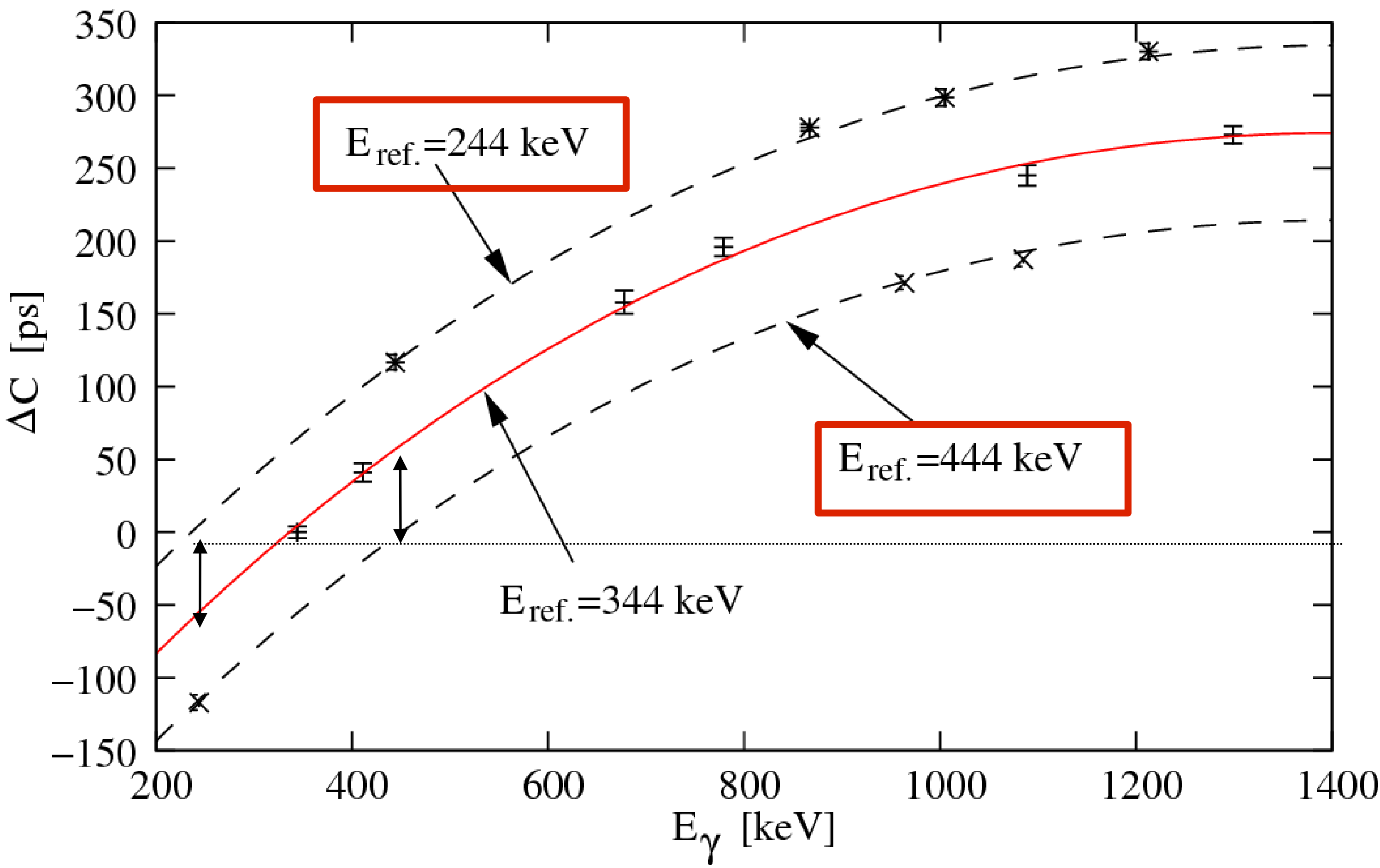
The PRD is mirror symmetric: $PRD(\Delta E)_{decay} = -PRD(-\Delta E)_{feeder}$ $\quad \Delta C(\Delta E)_{decay} = -\Delta C(-\Delta E)_{feeder}$



Advantage: one can construct one PRD curve both for feeders and decay transitions

The MSCD method; calibration of the PRD curve using the ^{152}Eu source





PRD=ΔC-2τ

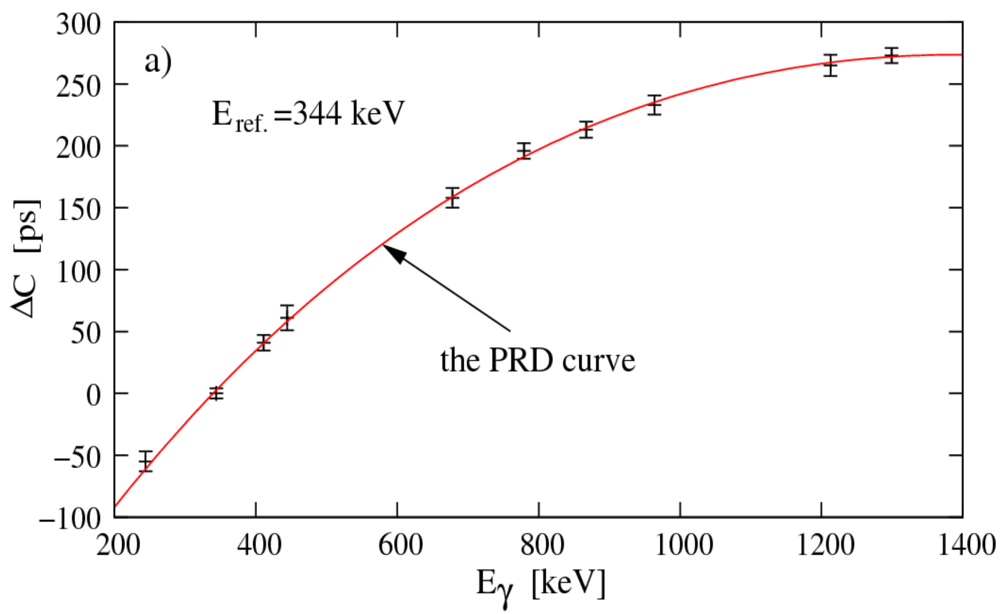
As the combined γ–γ time-walk characteristics,
the PRD curve is shifted in parallel
using different reference energies (reference timing signals).

These shifts are directly obtained from the PRD curve !

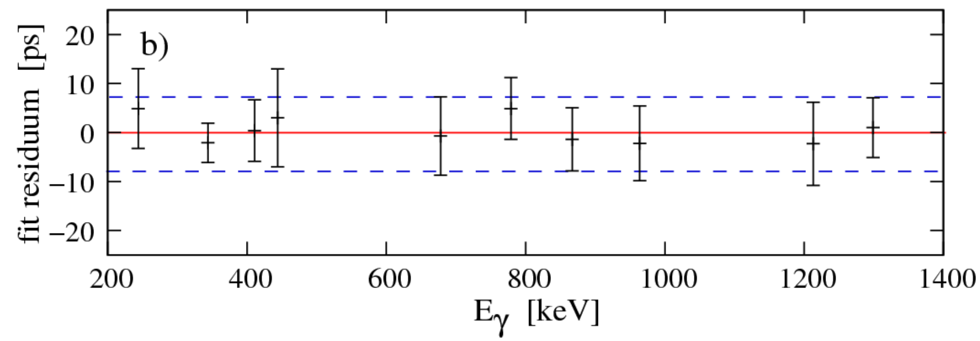
The final PRD curve obtained using the ^{152}Eu source

Calibration function:

$$\Delta C(E_\gamma) = \frac{a}{\sqrt{b + E_\gamma}} + cE_\gamma + d$$



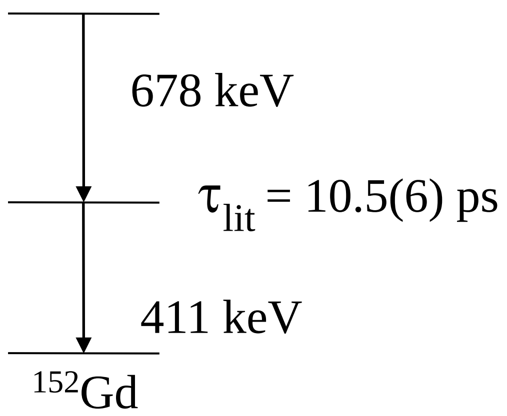
Accuracy of the PRD:
$2\sigma_{PRD} \sim 8$ ps

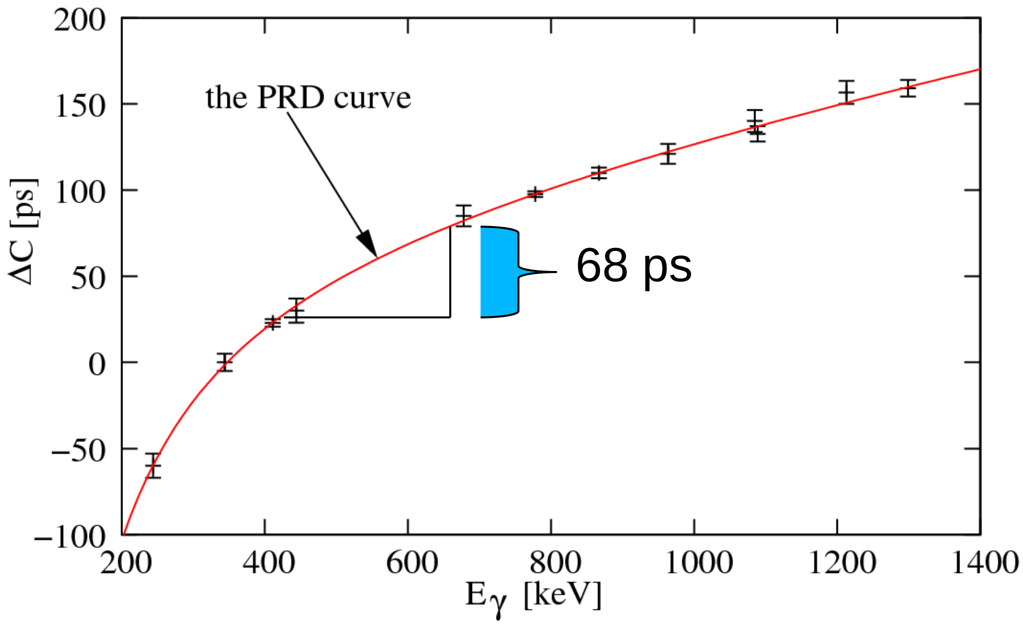


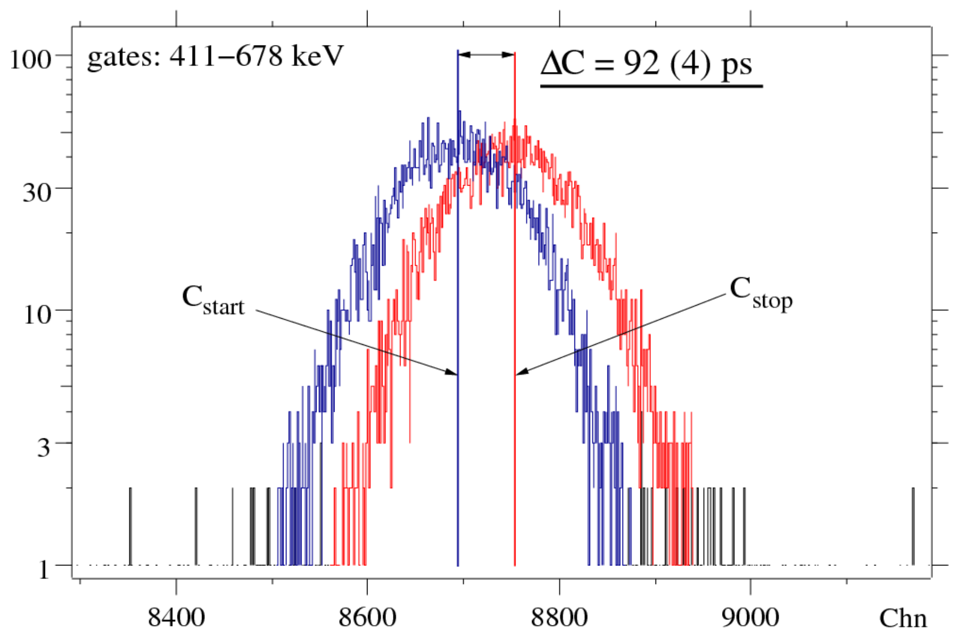
Limitation of the lifetime determination for 250 keV < E_γ < 1300 keV:

$\delta\tau \sim 4$ ps

Lifetime determination using the MSCD method



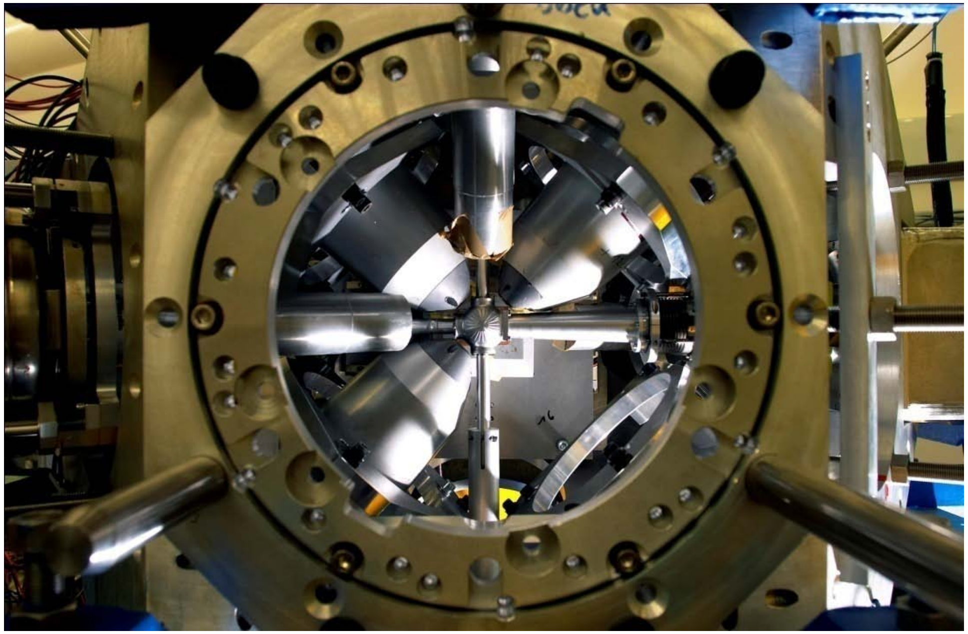




PRD(678-411)
:= PRD(678)-PRD(411) = 68 (8) ps

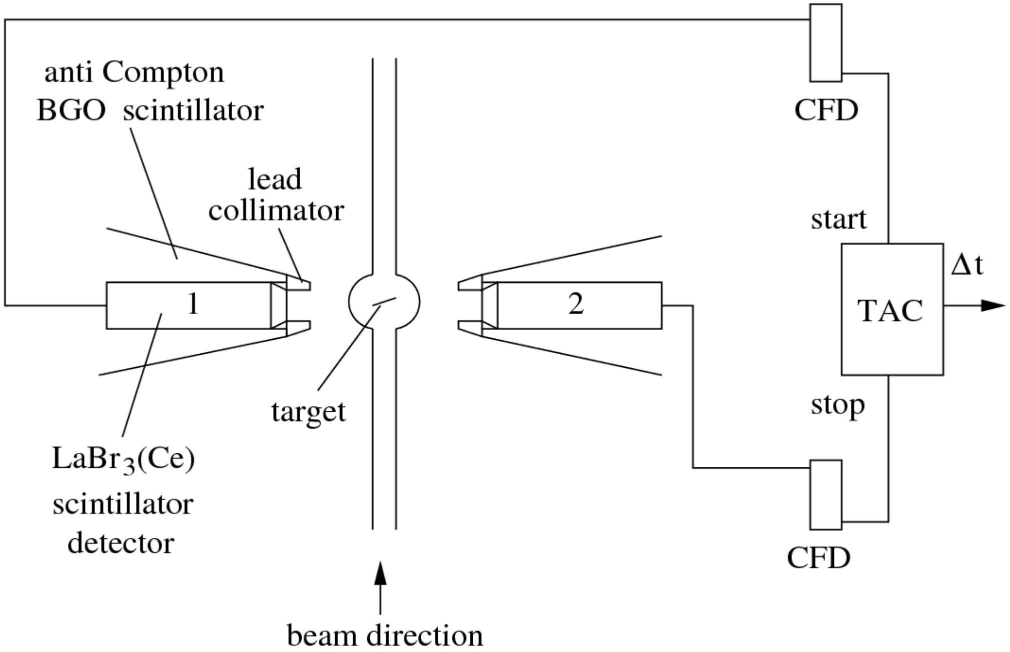
τ = (ΔC - PRD)/2 = 12 (5) ps

γ–γ fast timing @ the Cologne HORUS cube spectrometer

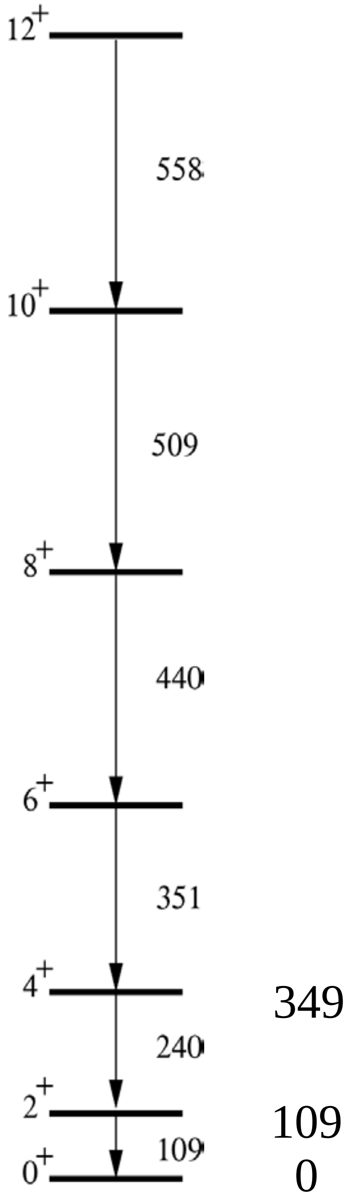


- 4π geometry
- 14 detector positions (4% efficiency)
- 6 large anti Compton BGOs

Setup for fast timing with $LaBr_3(Ce)$ scintillator detectors:



In-beam γ-ray spectroscopy with $LaBr_3(Ce)$ scintillator detectors



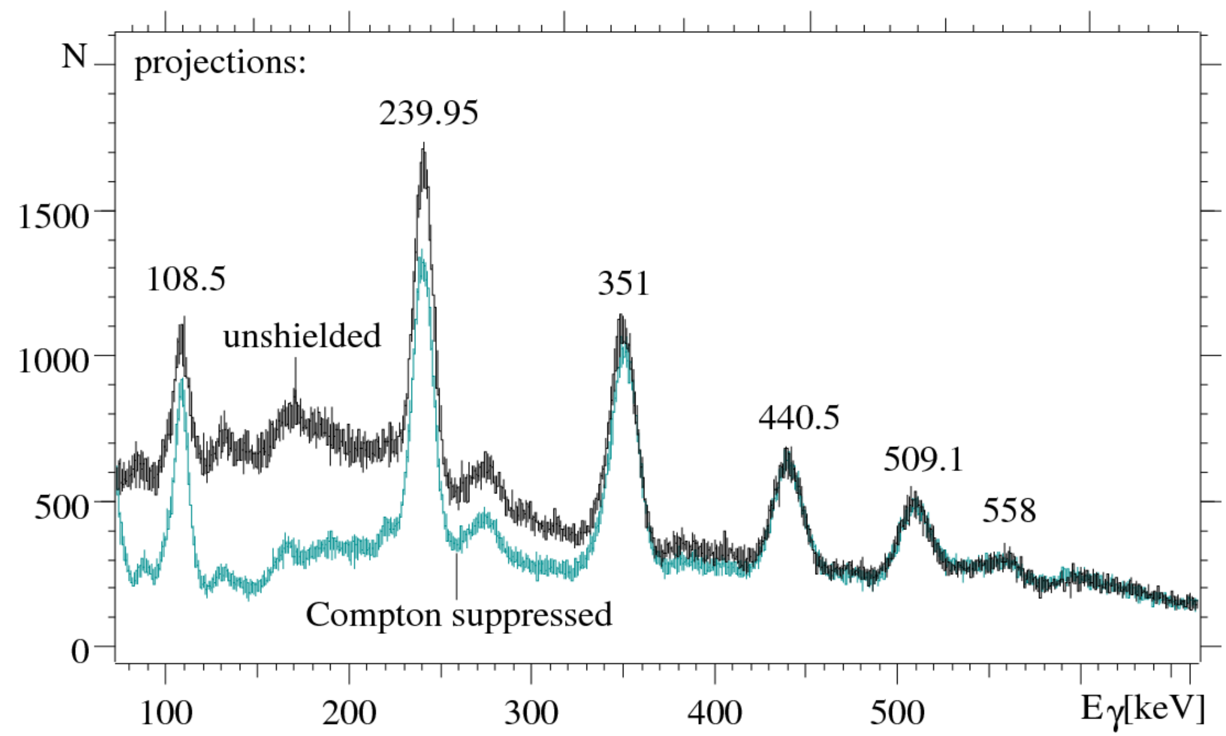
Yrast band in ^{176}W,

$R_{4/2}=E(4+)/E(2+)=3.21$

(rigid deformation: $R_{4/2}=3.33$)

$^{169}Tm(^{11}B,4n)^{176}W$ @ 55MeV

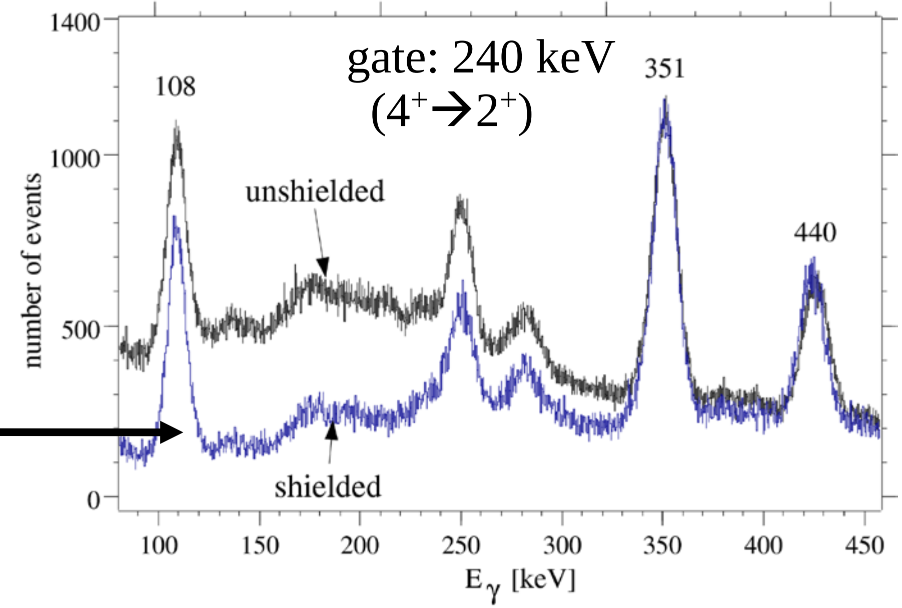
σ = 900 mb



Low energy background in γ–γ timing:

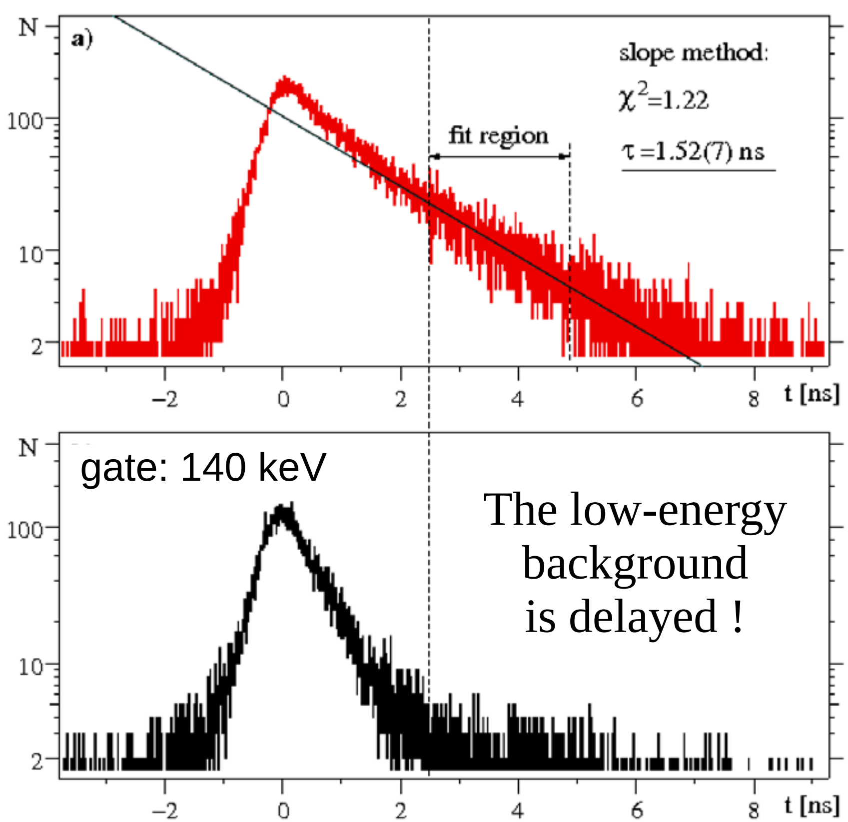
The first 2+ state at 108 keV in ^{176}W:

τ_{lit}=1.43(2) ns (e^--γ)

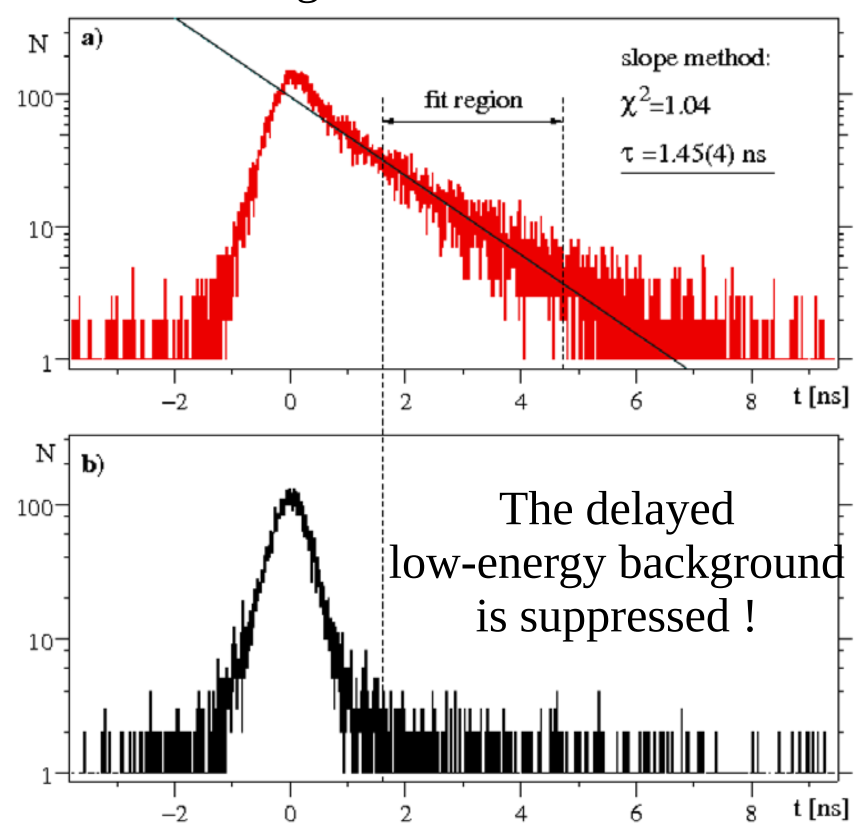


Using active BGO shielding,
the peak-to-background ratio @ 108 keV
is improved by factor **3** !

unshielded:

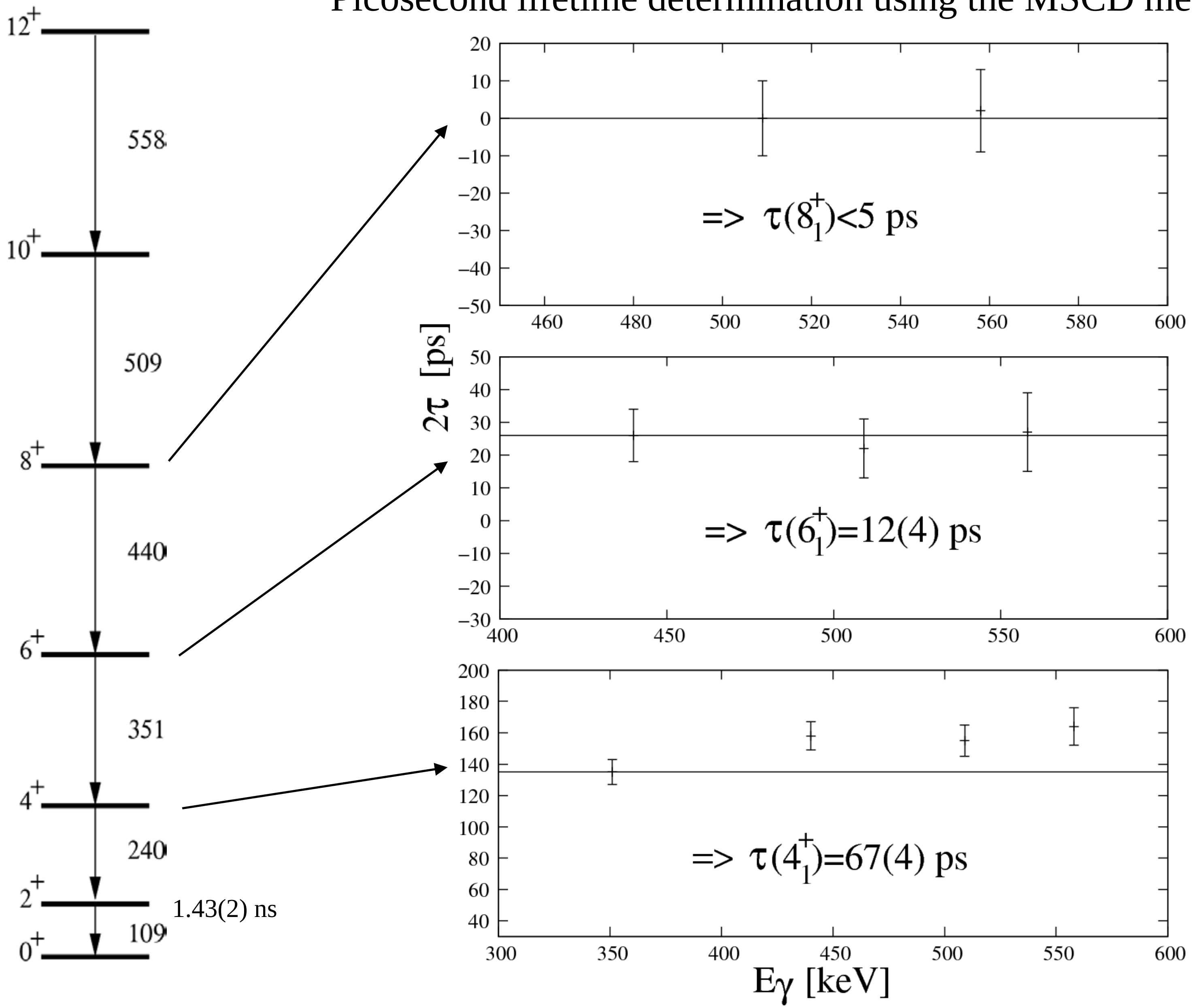


shielded using active BGO detectors:



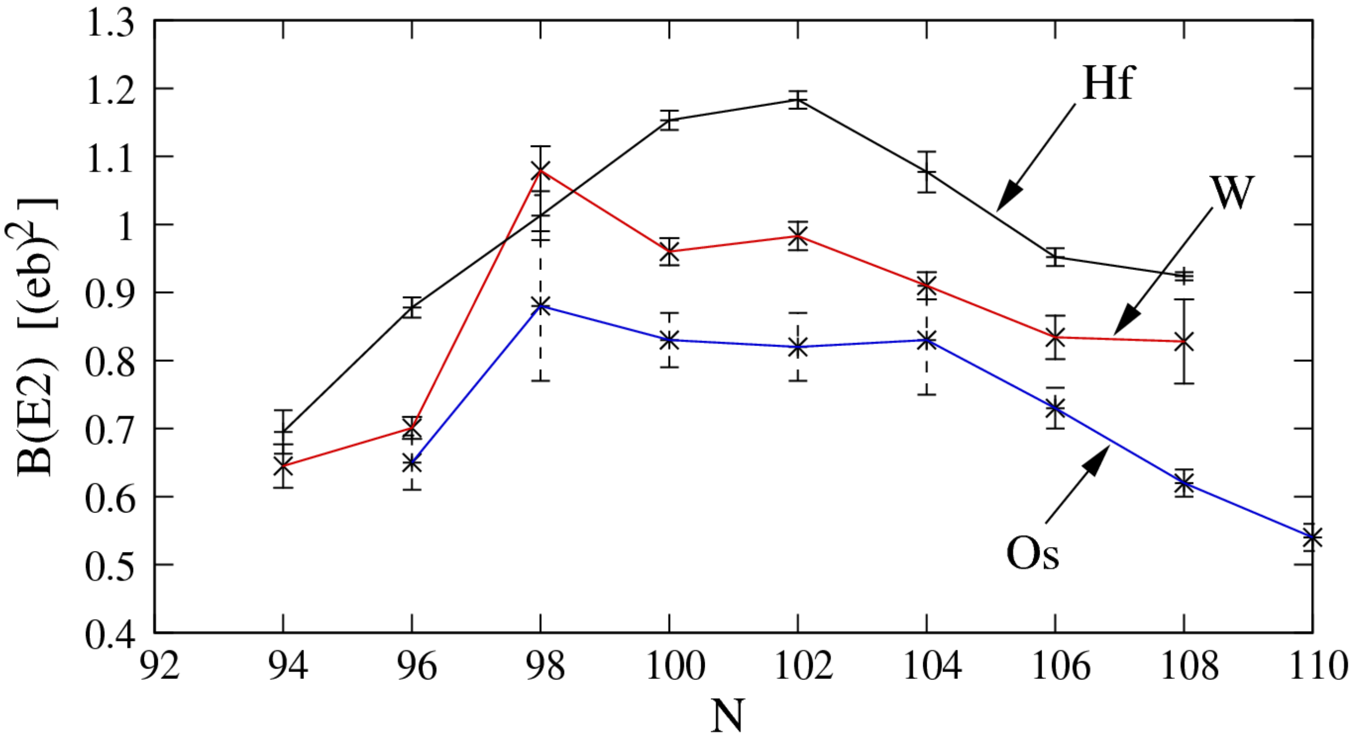
The lifetimes of the yrast states in ^{176}W

Picosecond lifetime determination using the MSCD method:



Evolution of B(E2) strength in even-even isotopic chains

Valence proton boson number: 3 (Os), 4 (W) and 5 (Hf)



Increase of B(E2) values with valence proton boson number: IBA ✓

Peaking near neutron mid-shell (N=104): ✓ IBA

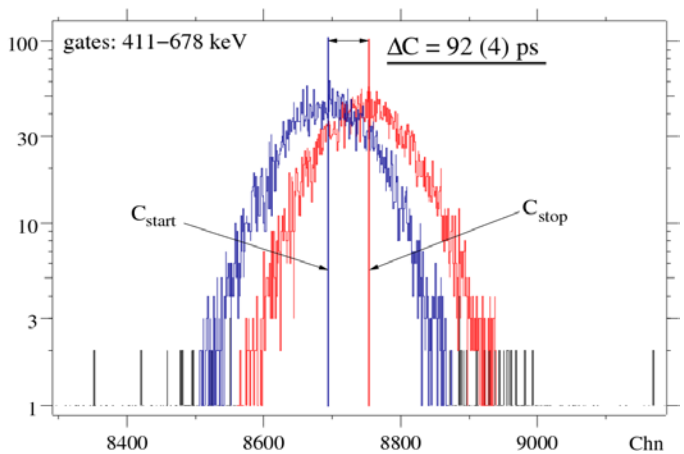
Maxima at N=98 and N=102: ⚡ IBA

^{176}Os (N=100): B. Melon, PhD thesis (2011)

Conclusions:

- The LaBr$_3$(Ce) scintillator detector:

Lifetime determination in the energy region **$50 < E_\gamma < 1500$ keV** with **absolute time resolving power of 3-5 ps** is feasible.

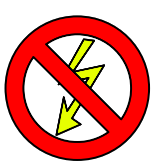


- Development of attractive MSCD method:

The method is **simple, highly sensitive** and the **most accurate method** for **picosecond lifetime measurements** (using the fast timing technique).

- Proposition of a calibration function for the time response of fast timing setups:

$$C(E_\gamma) = \frac{a}{\sqrt{b + E_\gamma}} + cE_\gamma + d$$



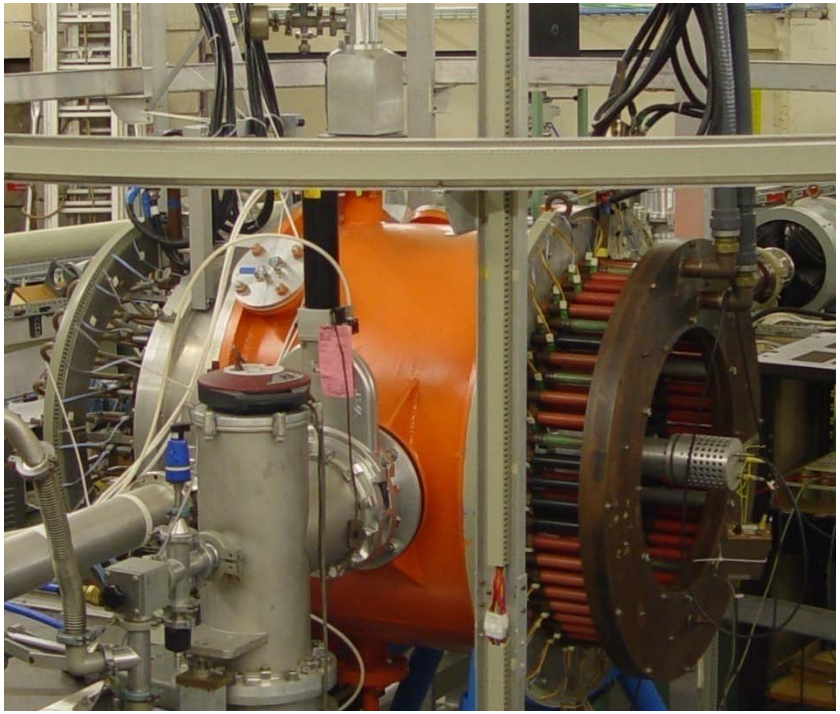
- Origin of background in γ-ray spectroscopy identified:

The „low-energy background“ **($E\gamma < 400$ keV)** originates from **scattered and back-scattered γ-rays** and includes **cross-talk events**.
An **effective suppression** is obtained using **active BGO** scintillator detectors.

Outlook:

The MSCD method is very useful for a two detector timing system, as for

e^{-}-e^{-} timing using the IKP Double Orange Spectrometer



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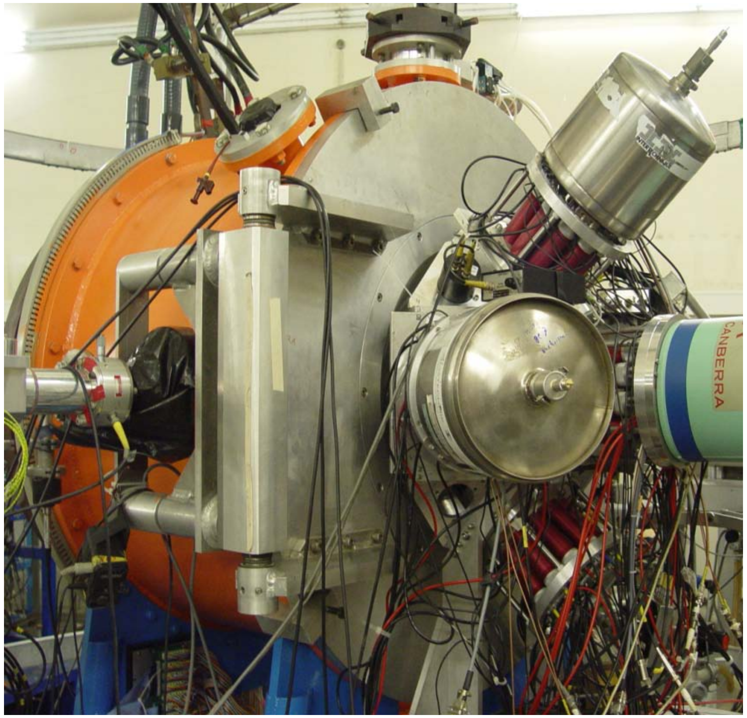
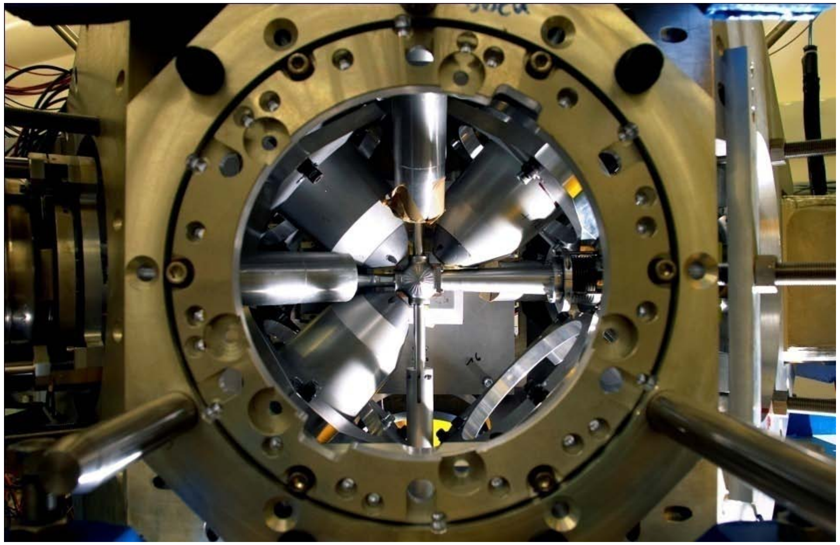
e^{-}-γ timing at the IKP



γ-γ timing at the IKP HORUS cube spectrometer



Thank You for Your Attention