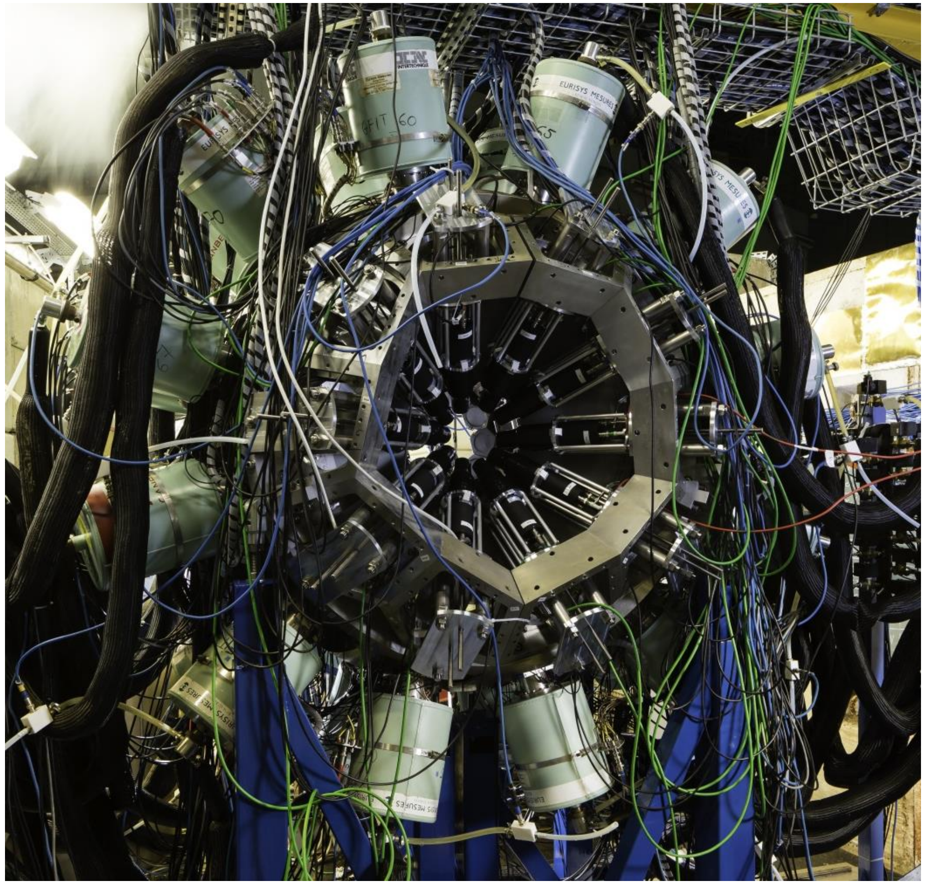
Verification and first Results of the Fast-Timing Analysis within the ν-Ball2 Fission Campaign

Julia Fischer

Motivation of the ν–Ball2 Fission Campaign

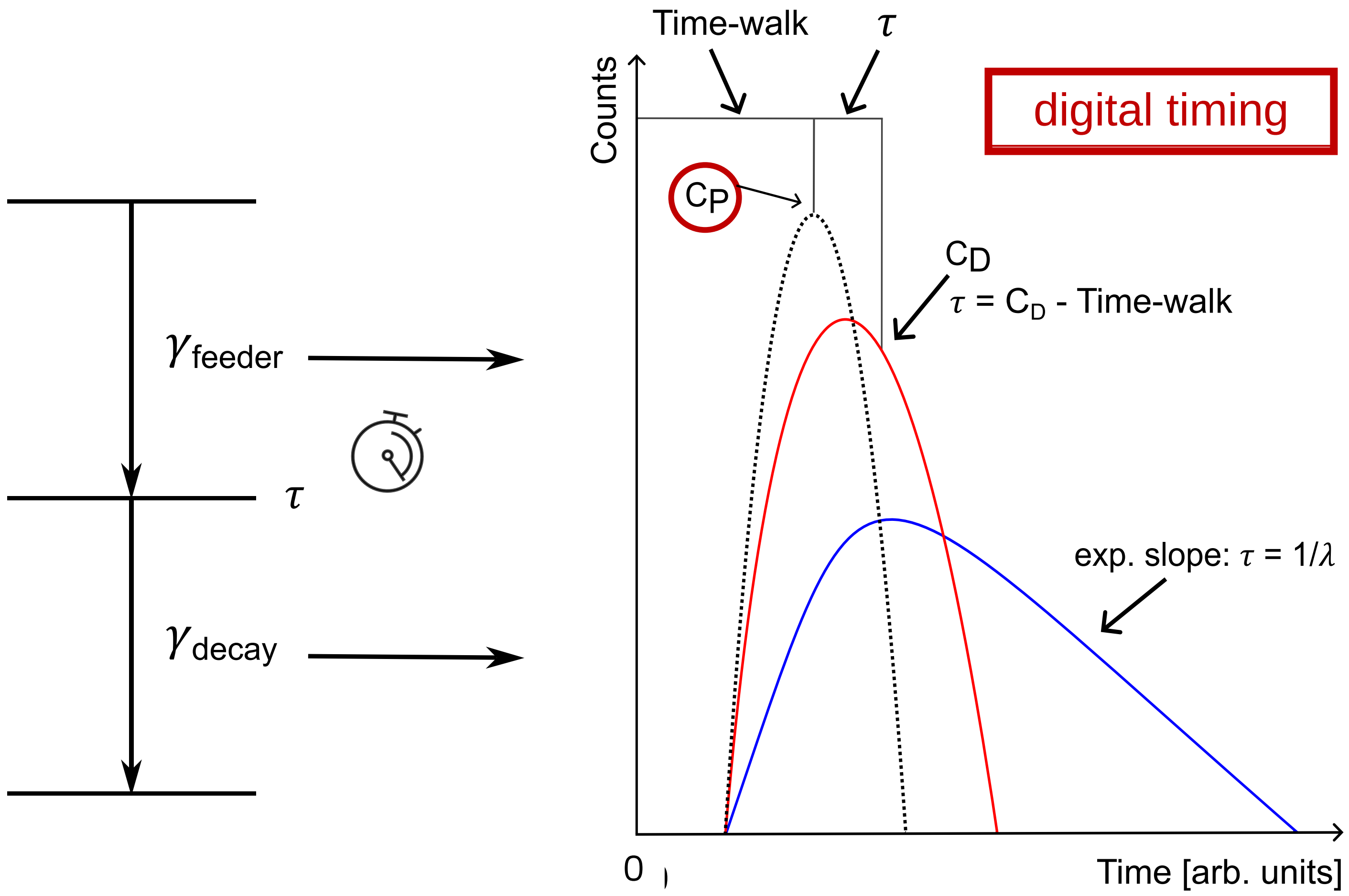
- ν–Ball1 (2018): Problems with LaBr detectors and data
  - Insufficient time–walk calibration
  - Limited fast–timing technique: slope/convolution method

- ν–Ball2 (2022): follow–up campaign successfully accomplished
  - Successful time–walk calibration and time alignment using ^{152}Eu source data
  - Verification of the fast–timing technique using strongly–produced ^{134,136}Te as test cases



https://alto.ijclab.in2p3.fr

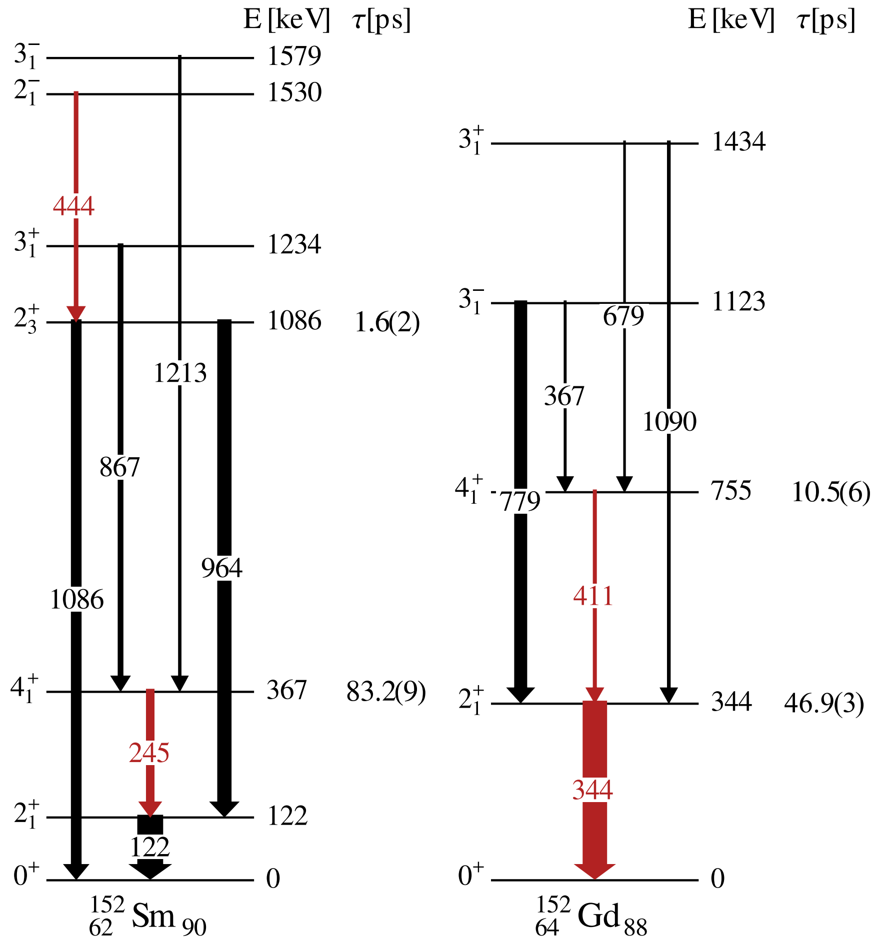
The Fast-Timing Technique: The Centroid Shift Method



$$\Rightarrow \ \tau = C_D\left(E_{feeder}, E_{decay}\right) - \underline{TW\left(E_{feeder}, E_{decay}\right)}$$

A. Harter et al. Nucl. Instrum. Methods A, 1053:168356 (2024)

The Fast-Timing Technique: Time-Walk Calibration



L. Knafla et al., Nucl. Instrum. Methods A, 1052:168279 (2023)

Calibration source ^{152}Eu

- Transitions within broad energy range
- Excited states with precisely-known lifetimes

Total measurement time: ~48h

→ Determination of the TW for different reference energies (marked in red)

The Fast-Timing Technique: Time-Walk Calibration

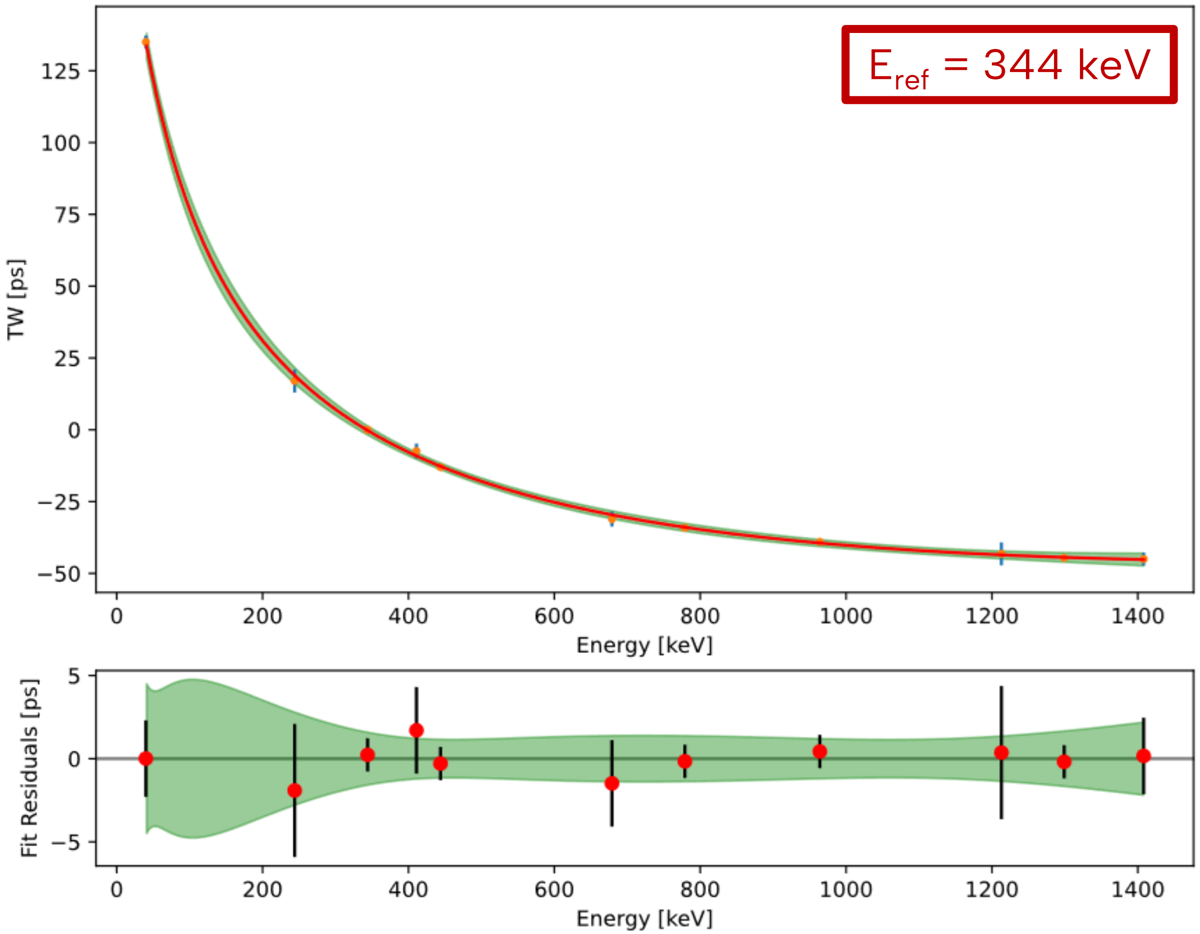
- datapoints for different reference energies shifted parallel to one another:

$$shift(E_1, E_2) = TW_{E_1} - TW_{E_2}$$

- Fitting data points according to:

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

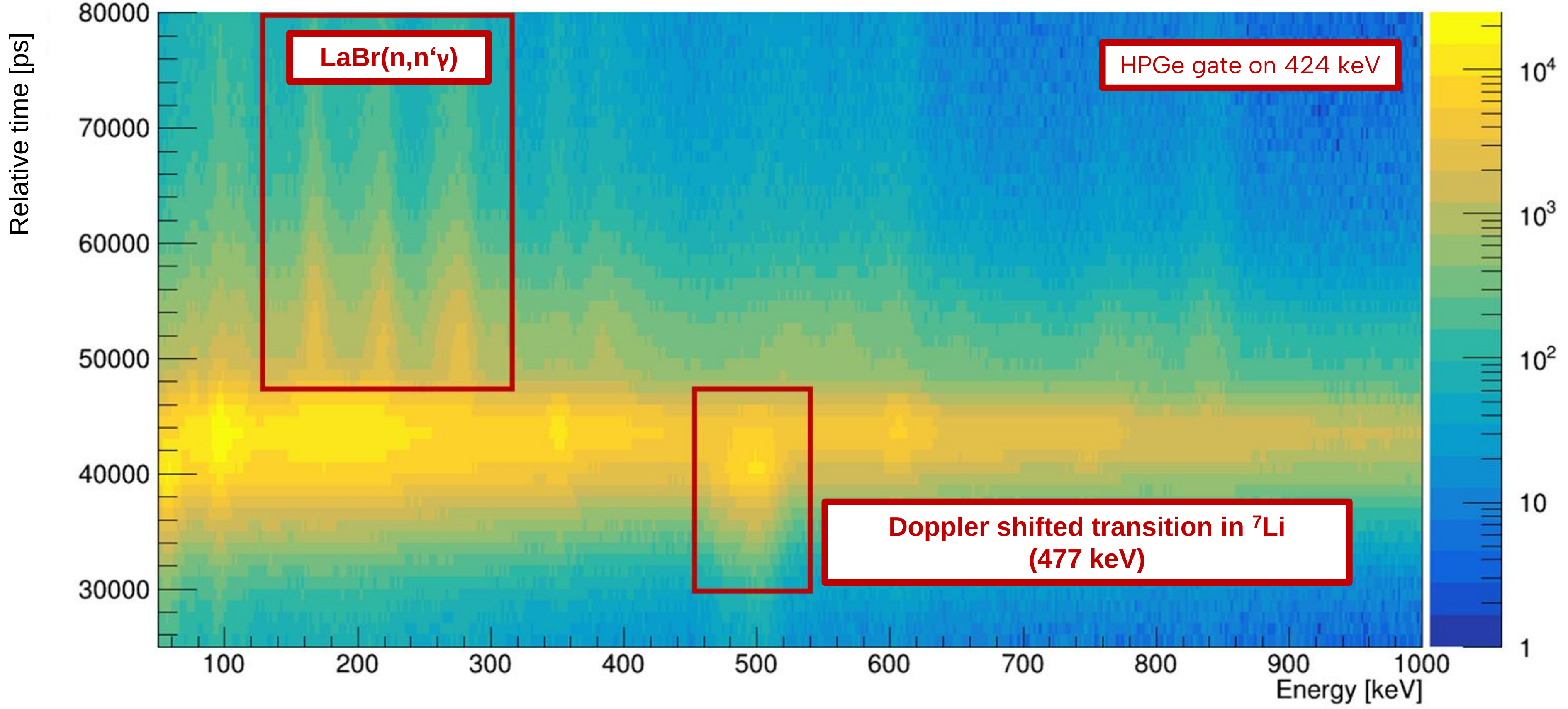
$$TW(200{,}1300) \approx 70(4)\ \text{ps}$$



J.-M. Régis et al, Nucl. Insrum. Methods A, 684:36-45 (2012)

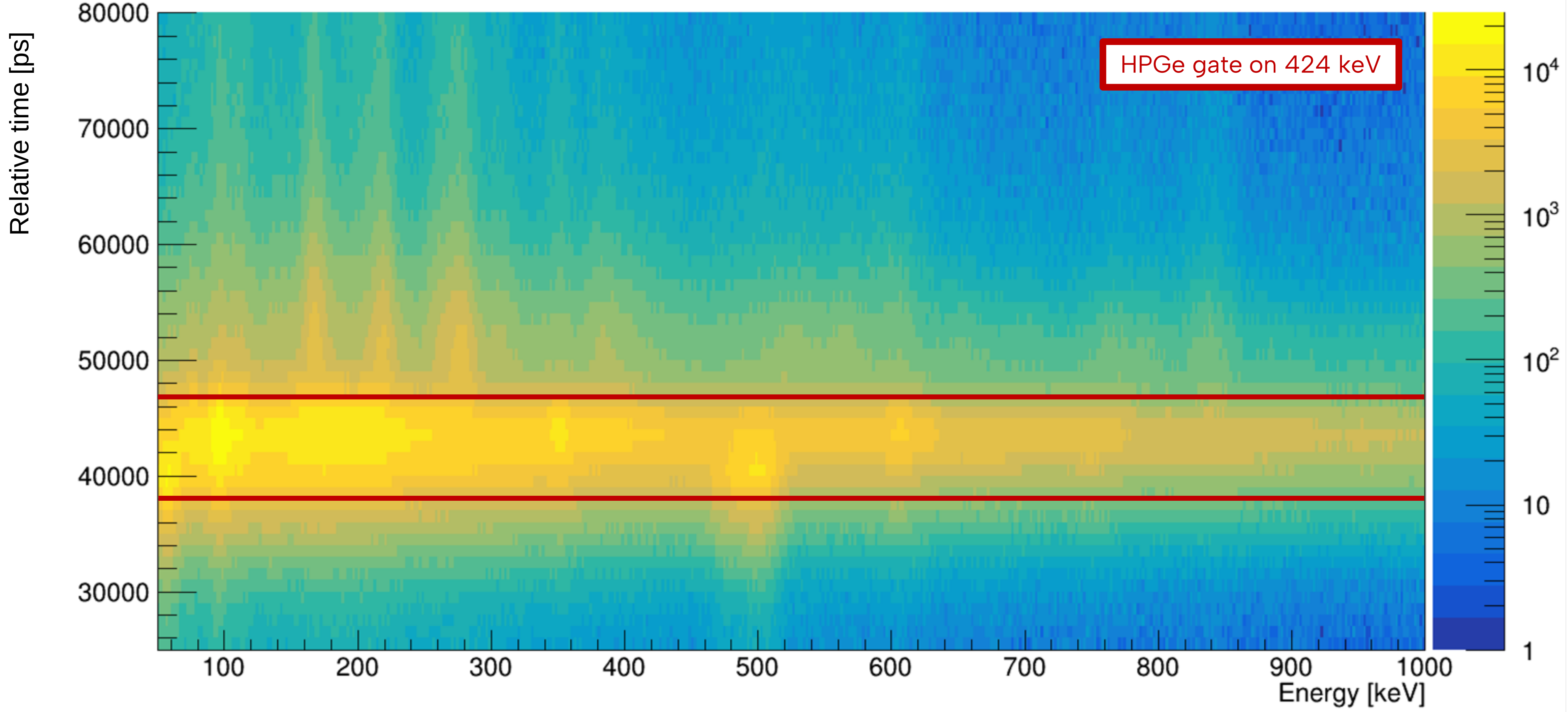
Selection of Prompt and Delayed Events
LaBr Detectors

Event time window:
400 ns



Selection of Prompt and Delayed Events LaBr Detectors

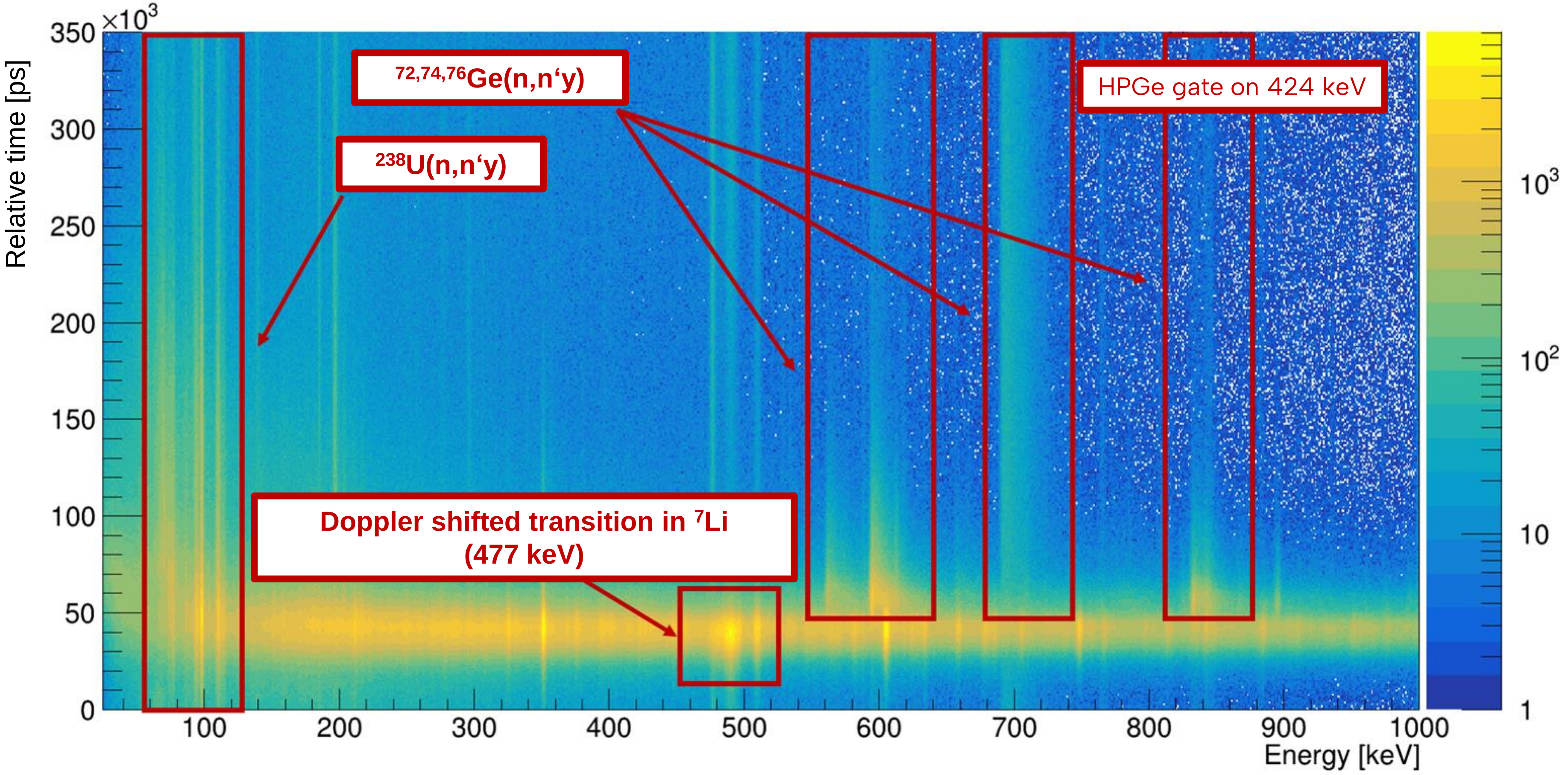
Event time window: 400 ns



Prompt time window: 38–47 ns

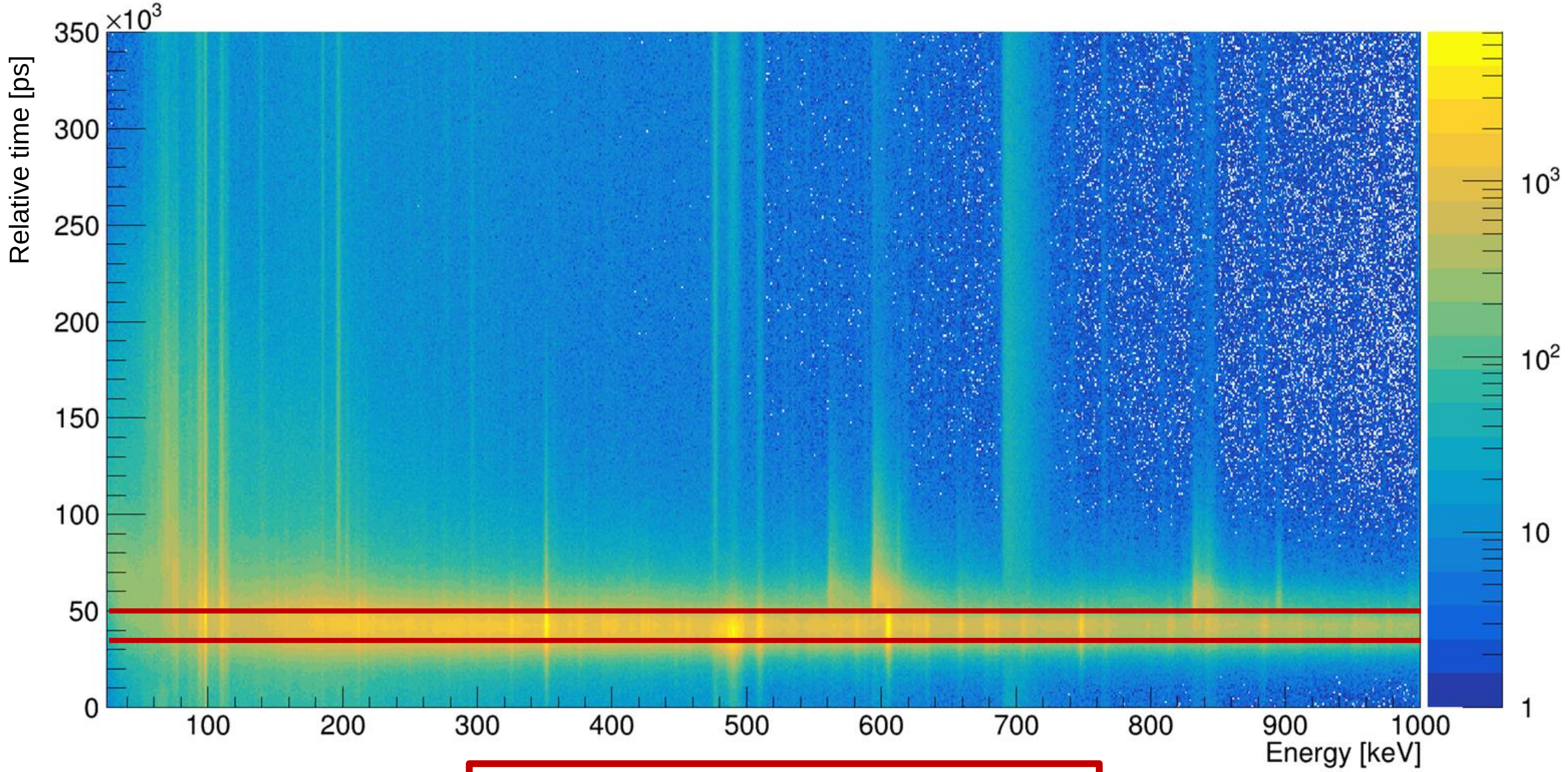
Selection of Prompt and Delayed Events HPGe Detectors

Event time window: 400 ns



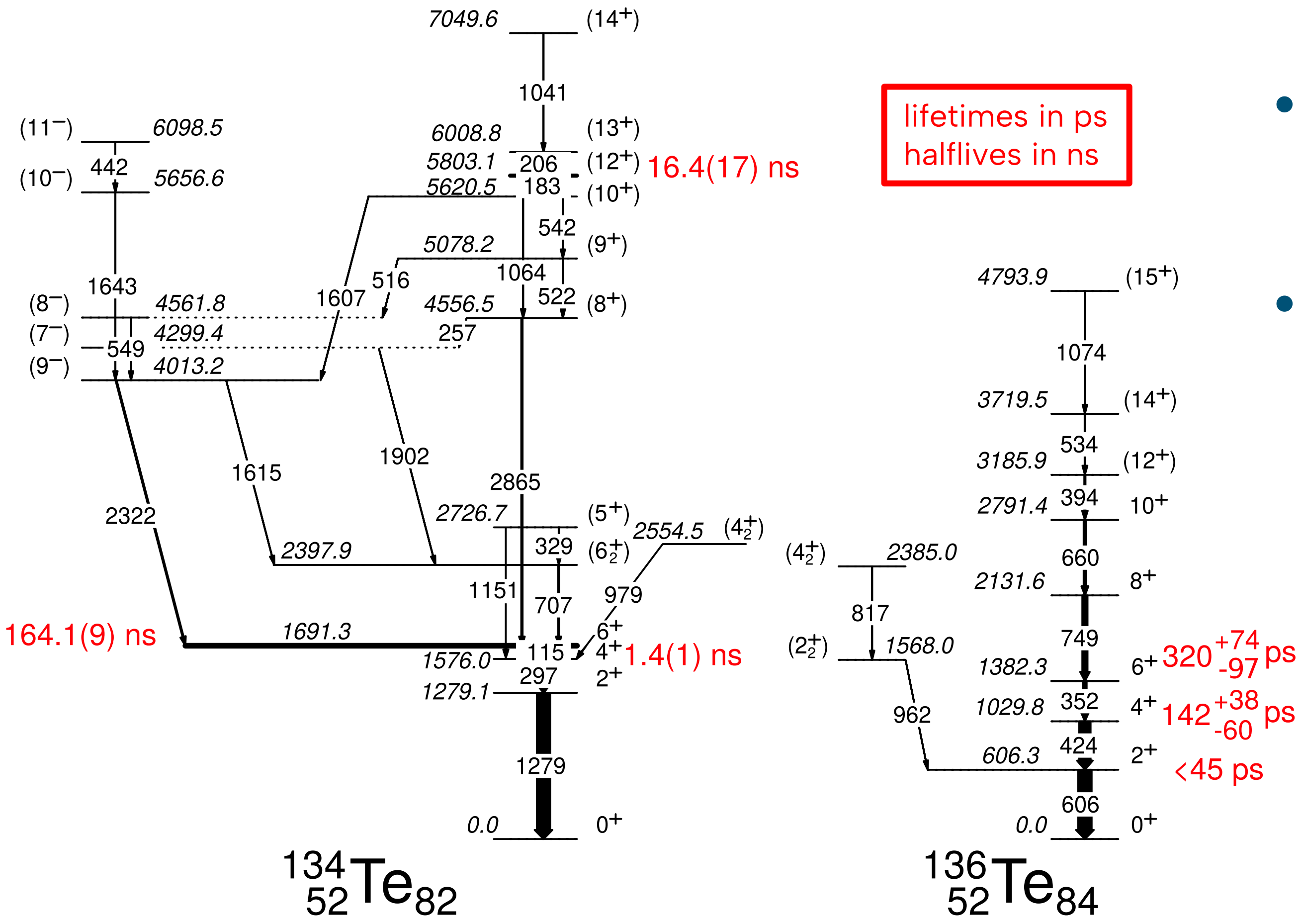
Selection of Prompt and Delayed Events
HPGe Detectors

Event time window: 400 ns



Prompt time window: 35–50 ns

Verification of the Fast-Timing Technique @ν-Ball2 using $^{134,136}Te$



- Production of various neutron-rich isotopes at different yields ranging from 0.1% – 4%

- $^{134-136}Te$:

  ✓ Strongly produced (~4%)

  ✓ Studied extensively in recent years [1,2]*

  ✓ Lifetimes in the range of ps to a few ns

  ✓ Studied in nu-Ball1 [3]

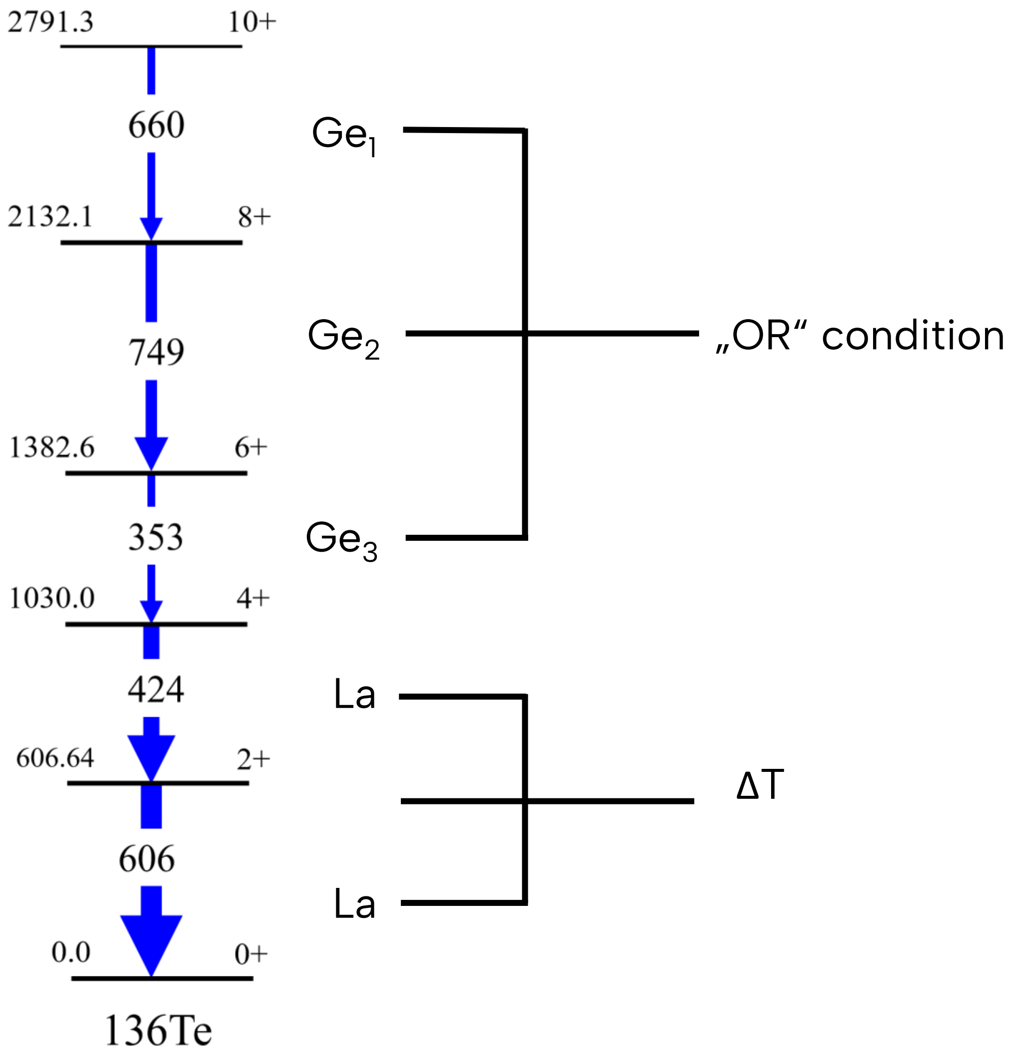
Ideal test cases for the fast-timing measurement using the centroid shift method with ν-Ball2

[3] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)

[1] J. M. Allmond et al., Phys. Rev. Lett., 118 (2017), [2] C. J. Barton et al., PLB, 551:269-276 (2003)

*more studies are presented on slide 23

Lifetime Measurements in ^{136}Te



Data Analysis

- Ge–La–La (triple) events

  → HPGe gate for cleaner spectra

  → Determination of time difference using LaBr

- Ge–La–Ge (triple) events

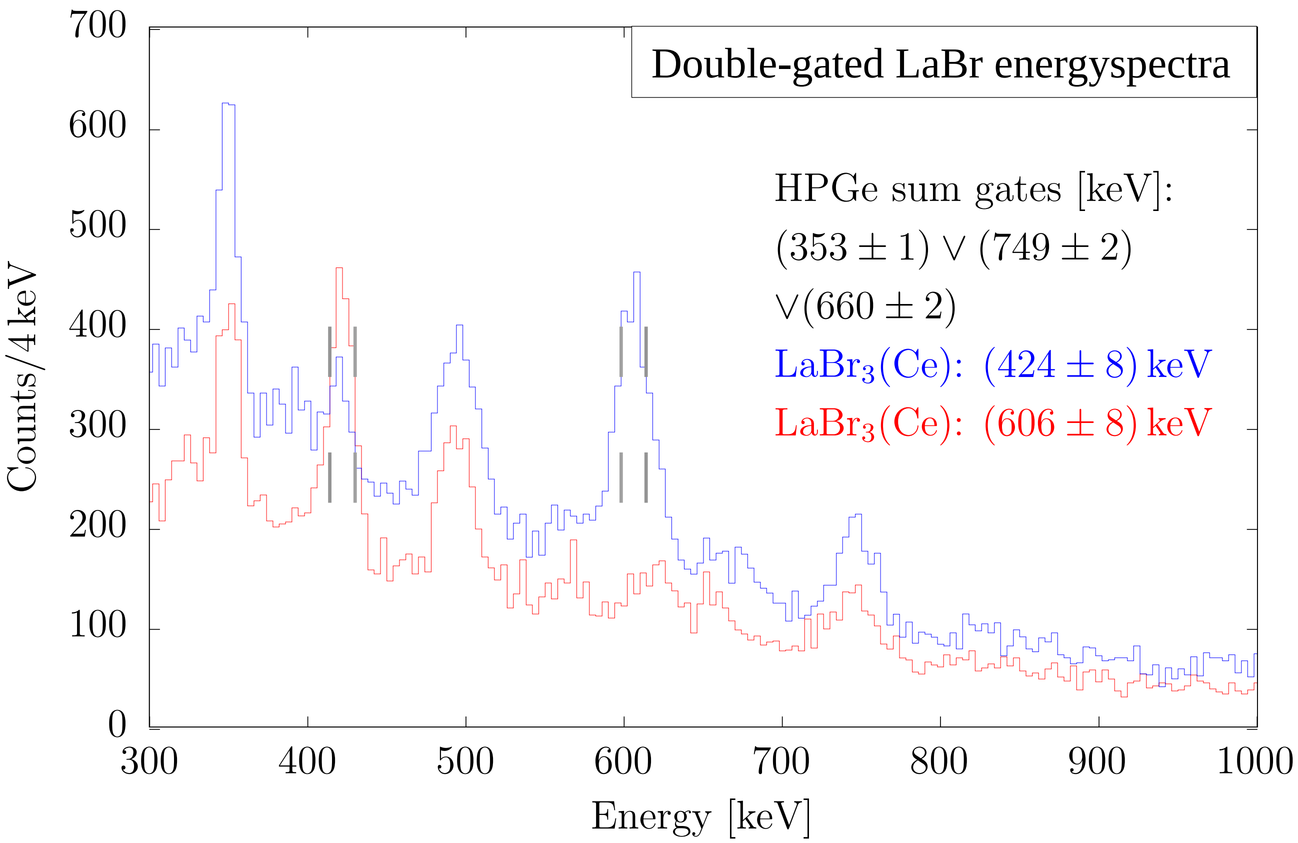
  → Energy projections in HPGe detectors to validate quality of the HPGe gate and cleanliness of LaBr coincidence spectra

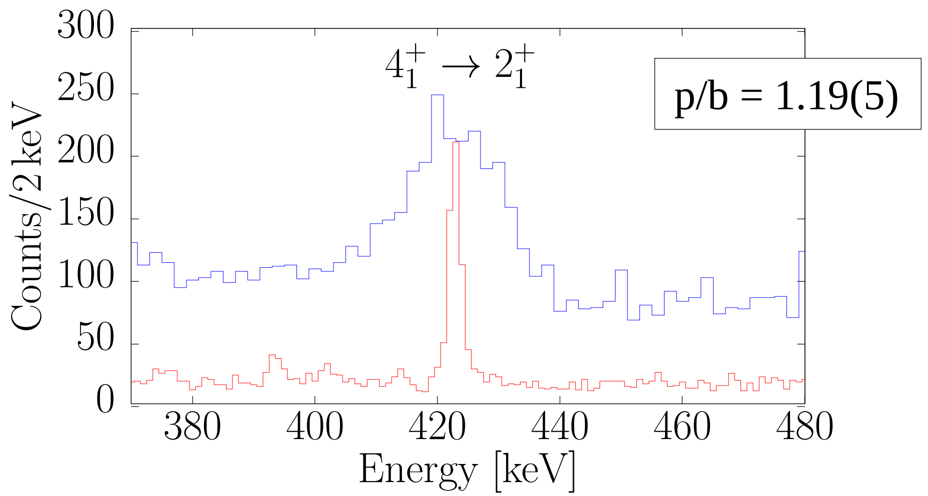
- HPGe sum gates: coincidence spectra and time spectra summed up for different HPGe gates:

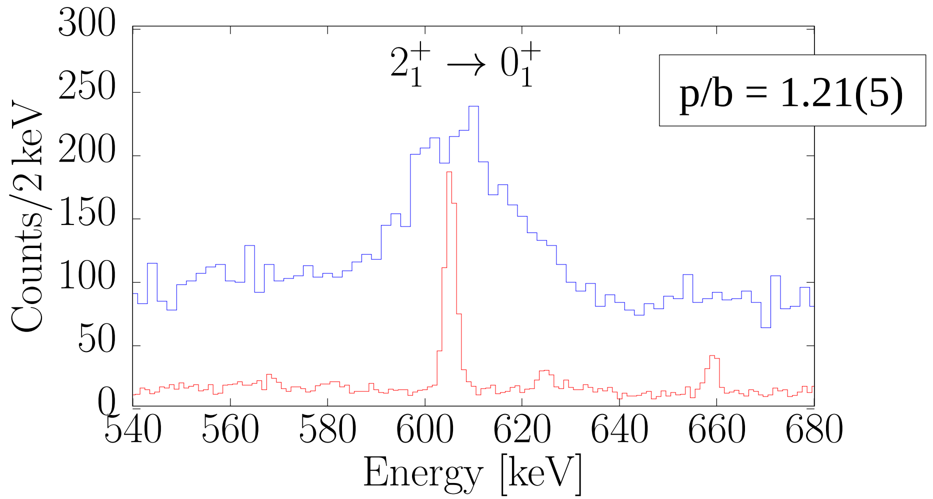
  $[Ge_1–La–La] + [Ge_2–La–La] + [Ge_3–La–La]$

  → Increased statistics

Lifetime Measurements in ^{136}Te: 2^+_1 state







- HPGe sum gates [keV] (^{136}Te): 353, 749, 660
- Prompt time window for all HPGe/LaBr gates

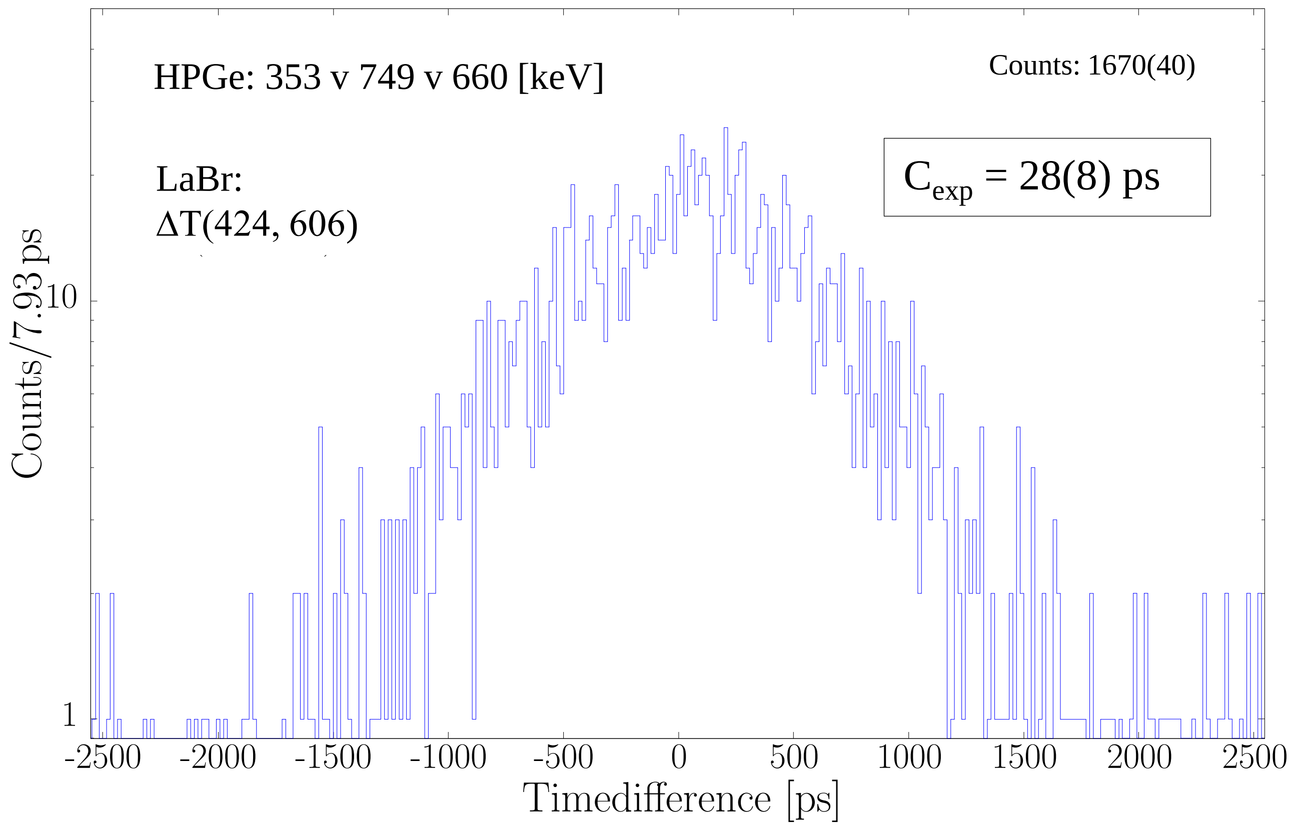
Lifetime Measurements in ^{136}Te: 2^+_1 state

Background Correction:

- Measurement of centroids at different energies around the FEP
- Interpolation of the Background C_{BG} below the FEP
- Correction is applied for both feeder (f) and decay (d) transition

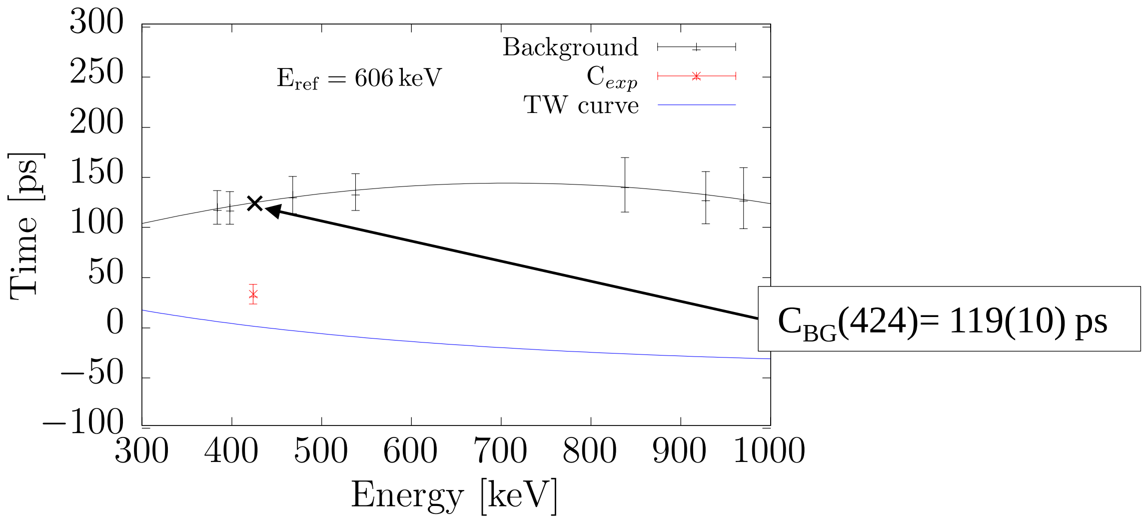
$$C_{FEP} = C_{exp} + \frac{p/b(E_d)\, t_{cor}(E_f) + p/b(E_f)\, t_{cor}(E_d)}{p/b(E_f) + p/b(E_d)}$$

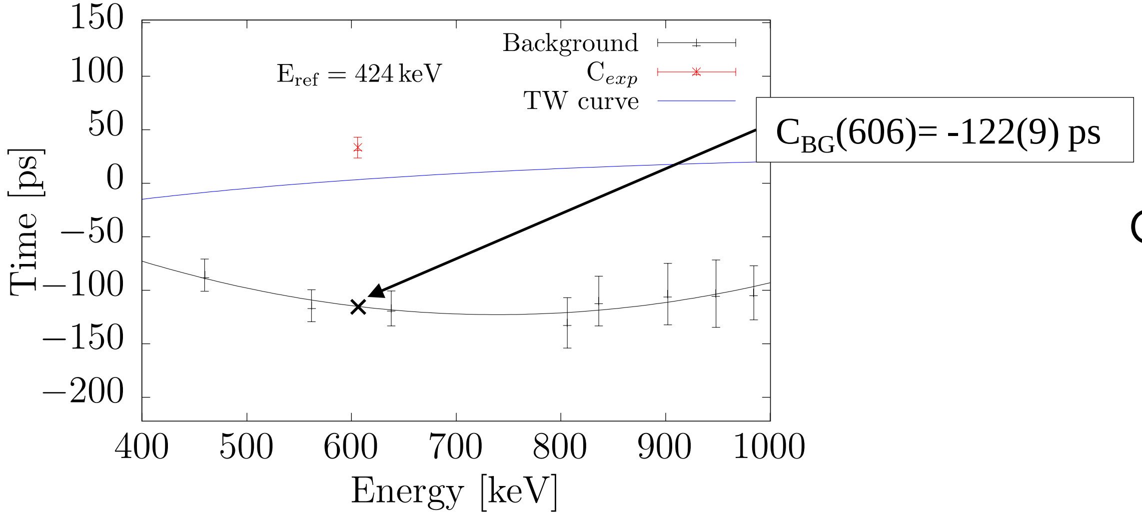
$$t_{cor}(E) = \frac{C_{exp} + C_{BG}(E)}{p/b(E)}$$

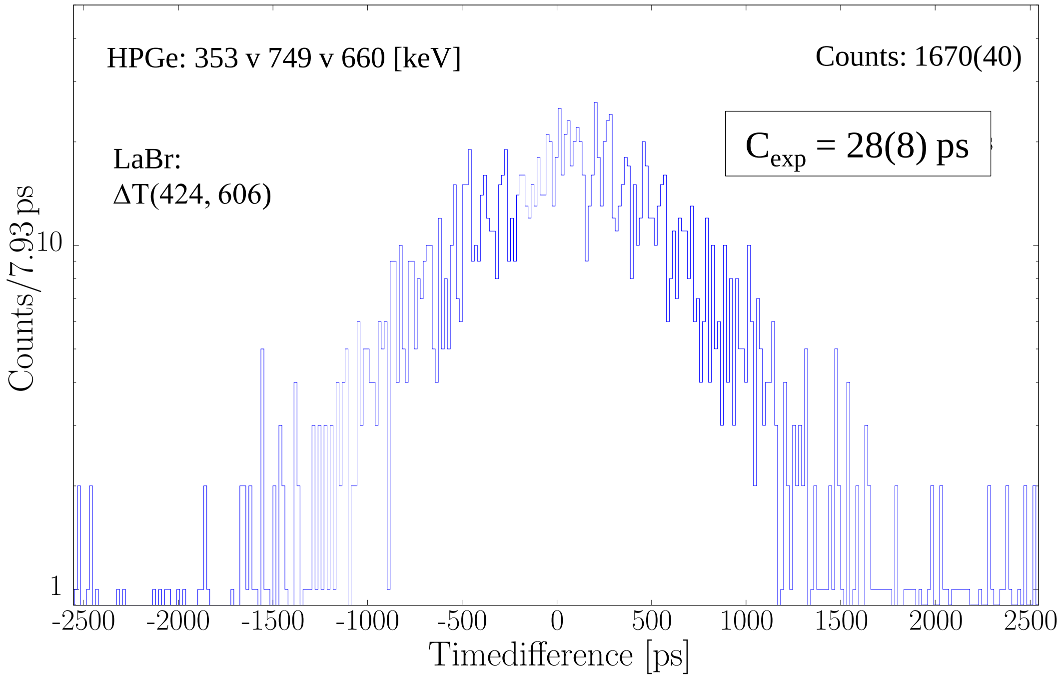


J.M. Régis, et.al, Nucl. Instrum. Methods Phys. Res. A, 955 (2020)

Lifetime Measurements in ^{136}Te: 2^+_1 state preliminary







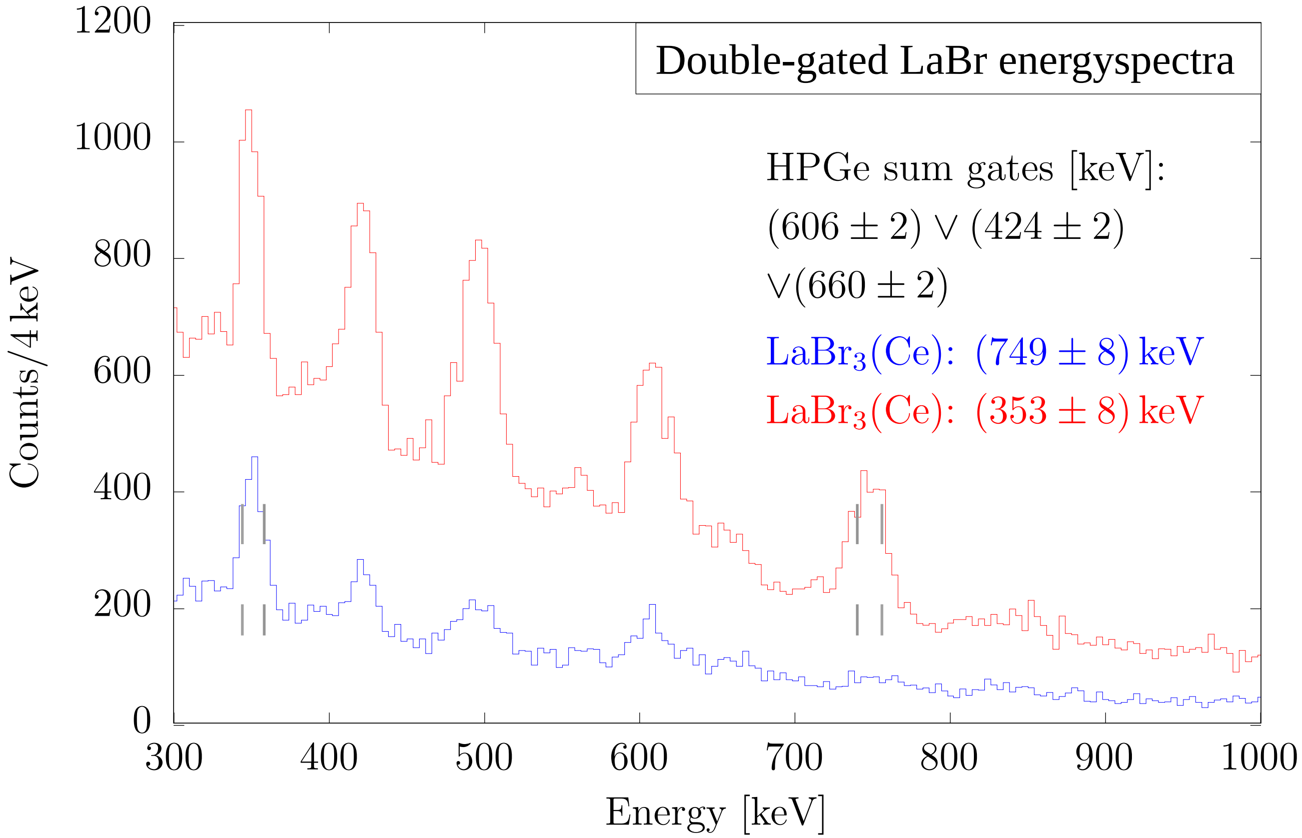
C_{FEP} = 49(12) ps
TW=15(2) ps

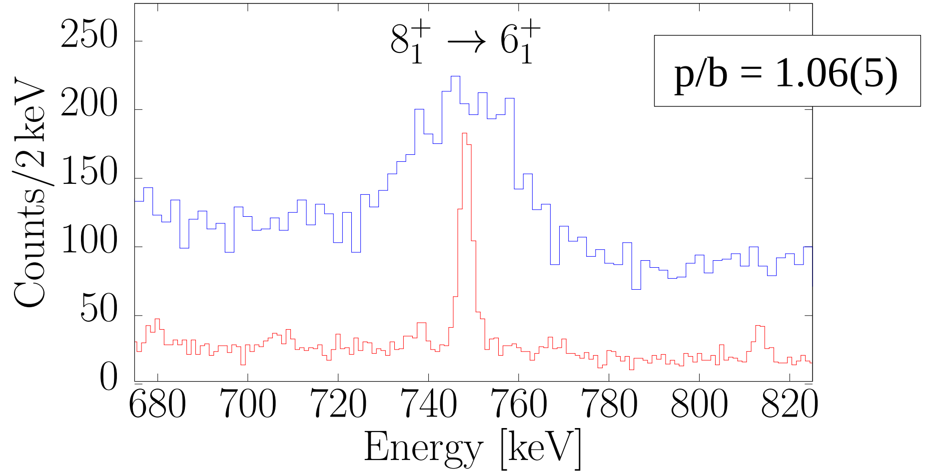
$\Rightarrow$ τ = 34(12) ps

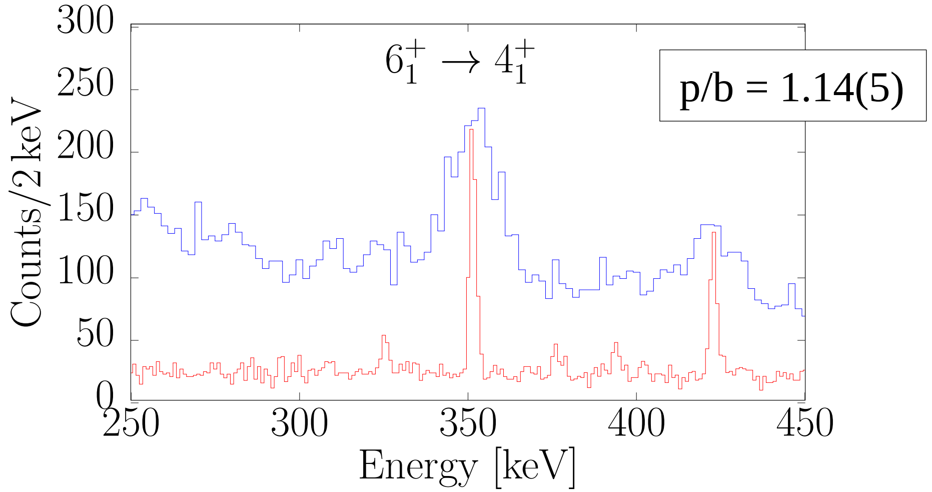
τ < 45 ps (nuBall1) [1]
τ_{lit} = 31(6) ps [2]

[1] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)
[2] E.A. Mccutchan, Nucl. Data Sheets, 152:331–667 (2018)

Lifetime Measurements in ^{136}Te: 6^+_1 state



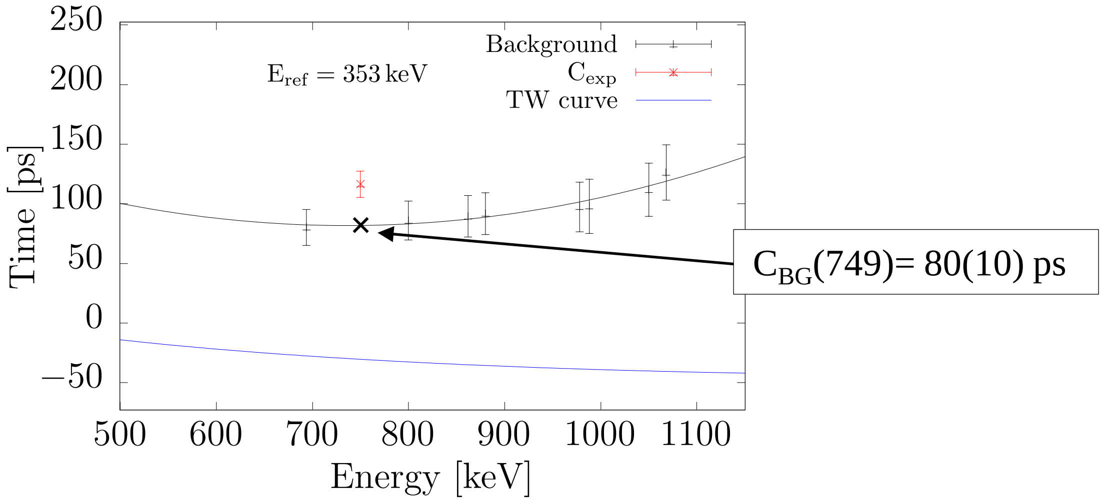


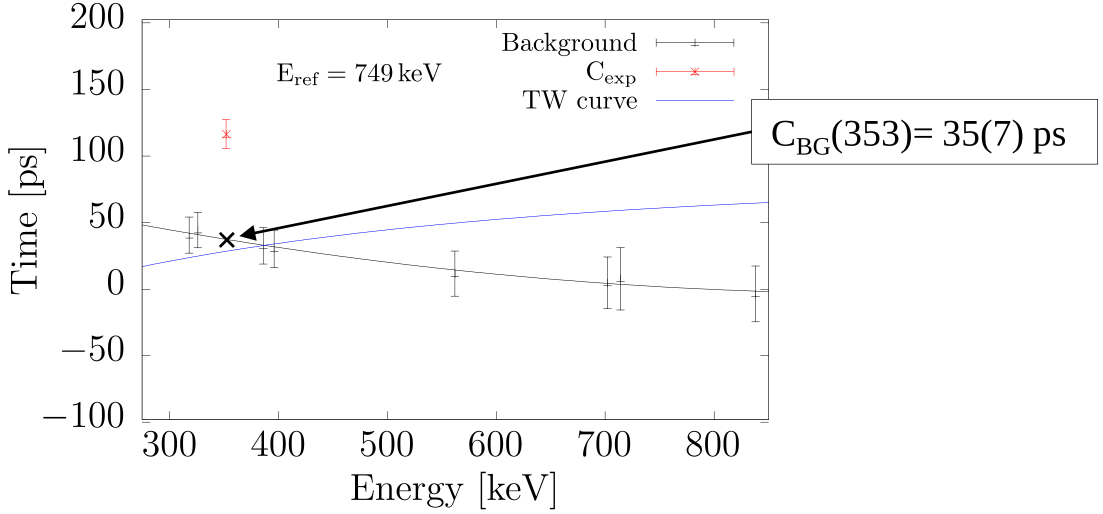


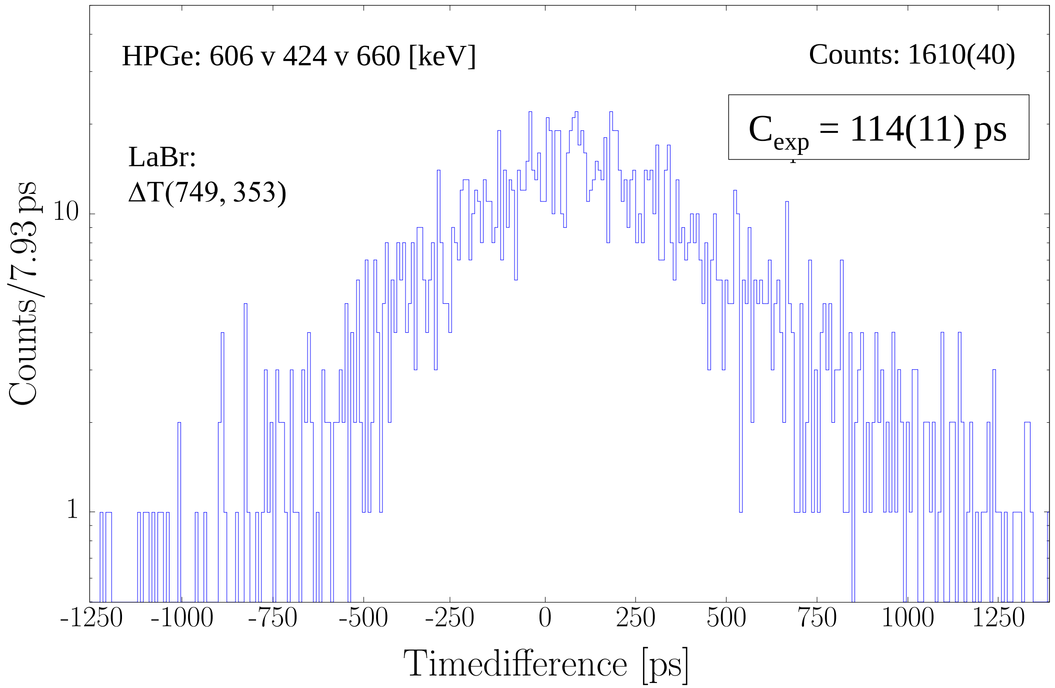
- HPGe sum gates [keV] (^{136}Te): 606, 424, 660
- Prompt time window for all HPGe/LaBr gates

Lifetime Measurements in ^{136}Te: 6^+_1 state

preliminary







C_{FEP} = 164(14) ps
TW=-31(2) ps

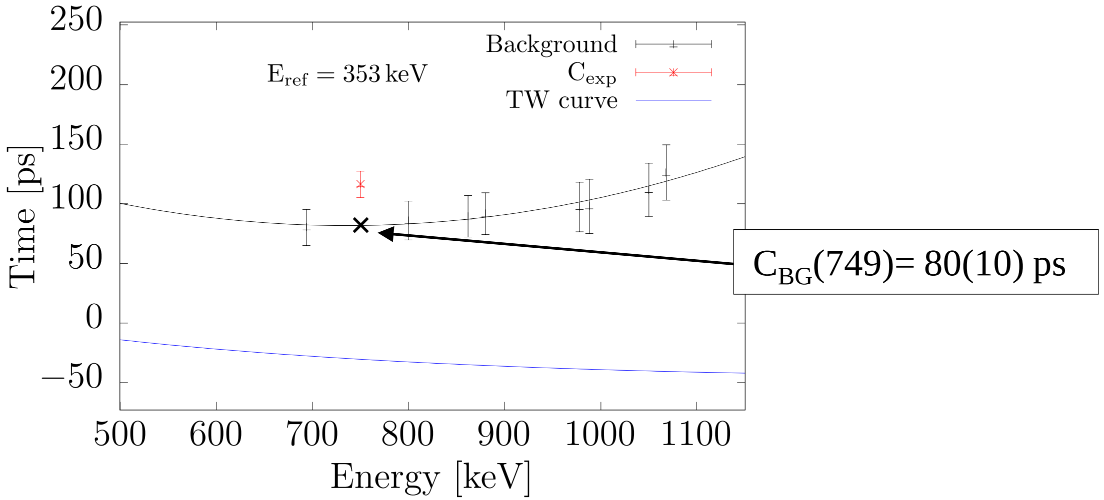
$\Rightarrow$ τ =195(15) ps

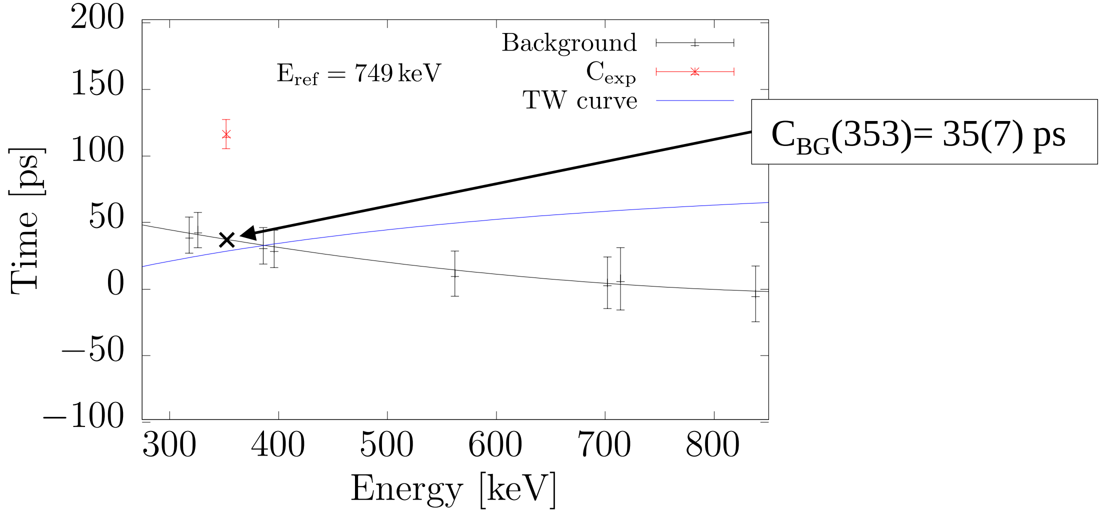
$\tau = 320^{+74}_{-97}$ ps [1]
(nuBall1)

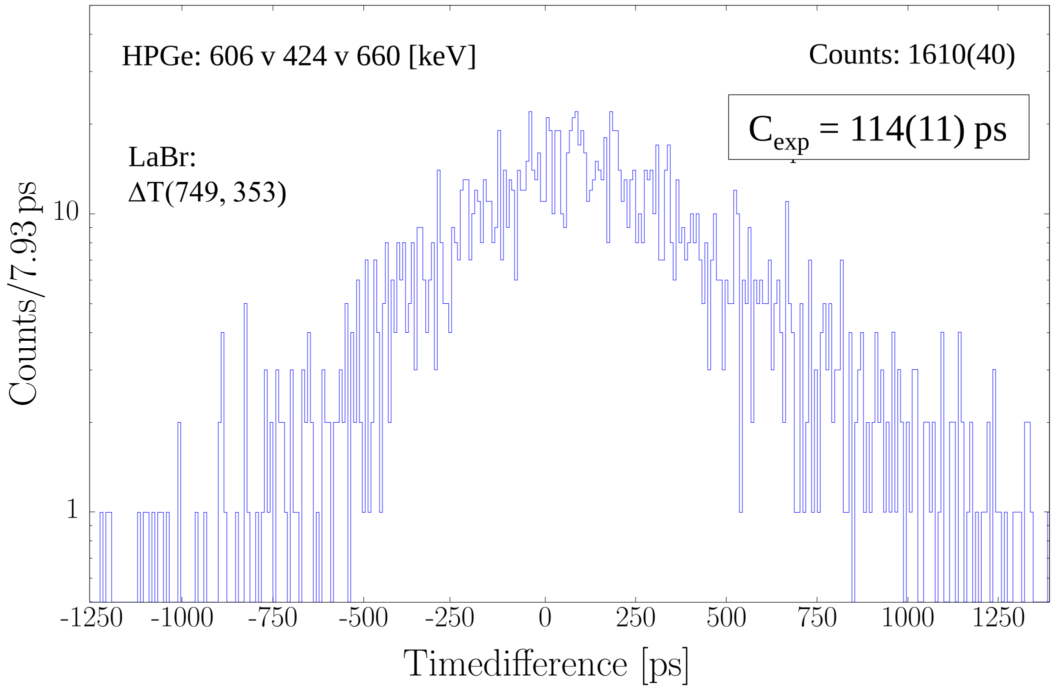
[1] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)

Lifetime Measurements in ^{136}Te: 6^+_1 state

preliminary







C_{FEP} = 164(14) ps
TW=-31(2) ps

$\Rightarrow$

$*\tau$ =195(15) ps

$\tau = 320^{+74}_{-97}$ ps [1]
(nuBall1)

[1] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)
*possible contamination by fission partners γ-rays

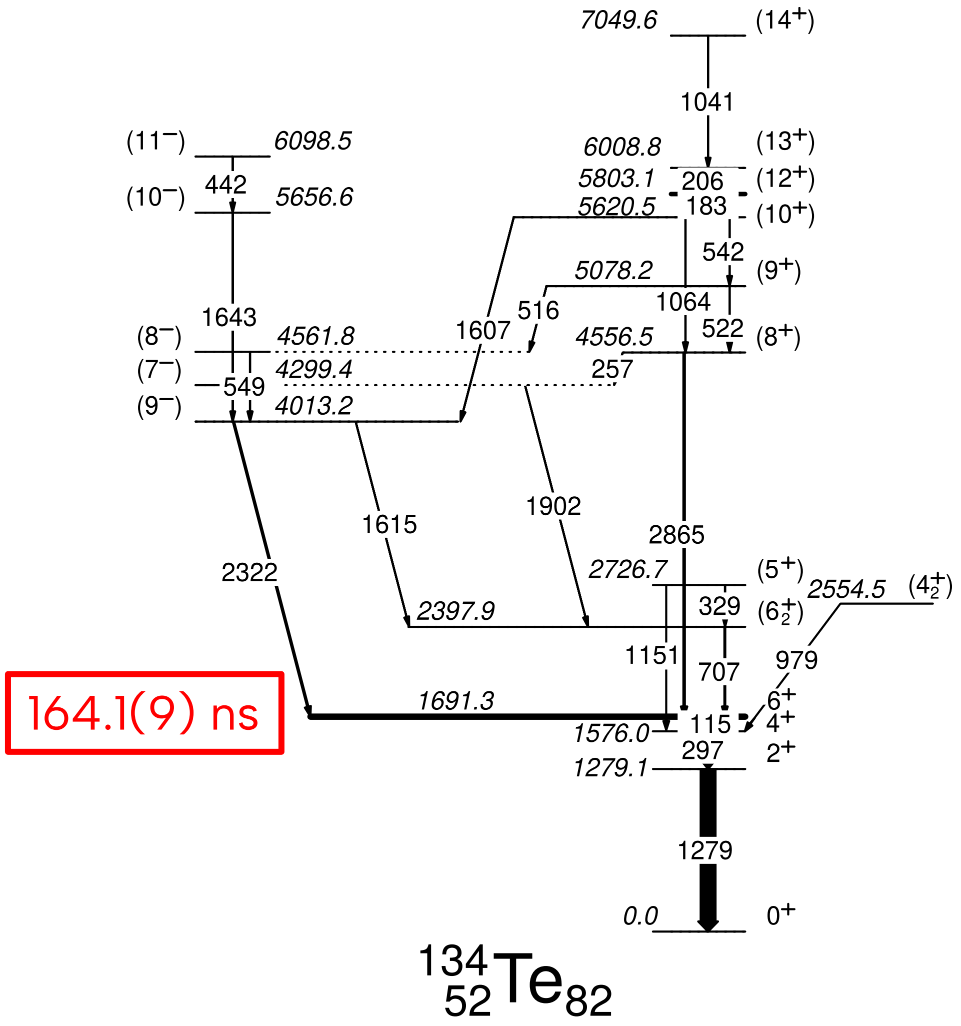
Lifetime Measurements in ^{134}Te: 2^+_1 state

- HPGe sum gates [keV]
  - 115, 706, 2322, 2865 (^{134}Te)
  - 152, 326 (^{102}Zr, strongest fission partner)

- Isomeric 6^+ state in ^{134}Te with $T_{1/2}$ = 164.1(9) ns:

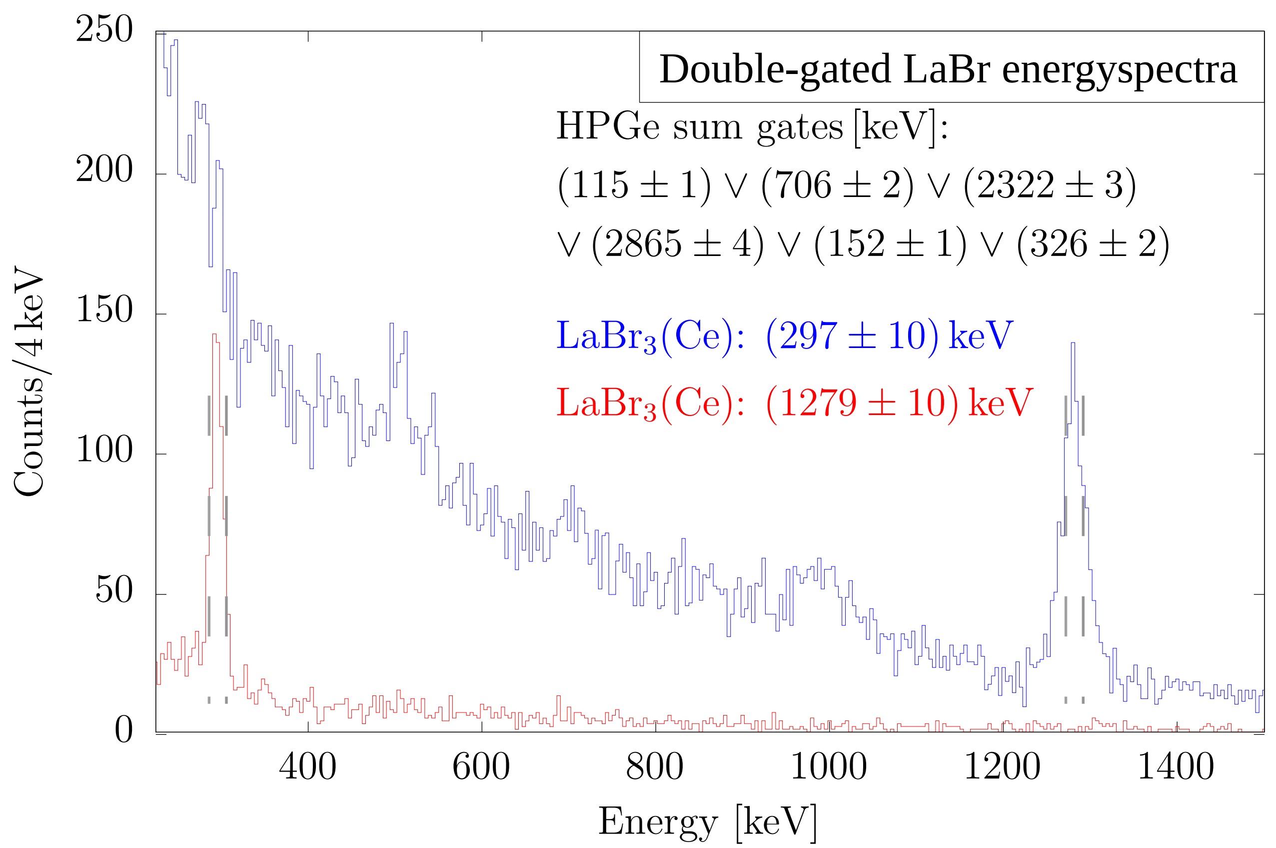
  → Gates on transitions below the isomer are asigned to a delayed time window of 100-350 ns

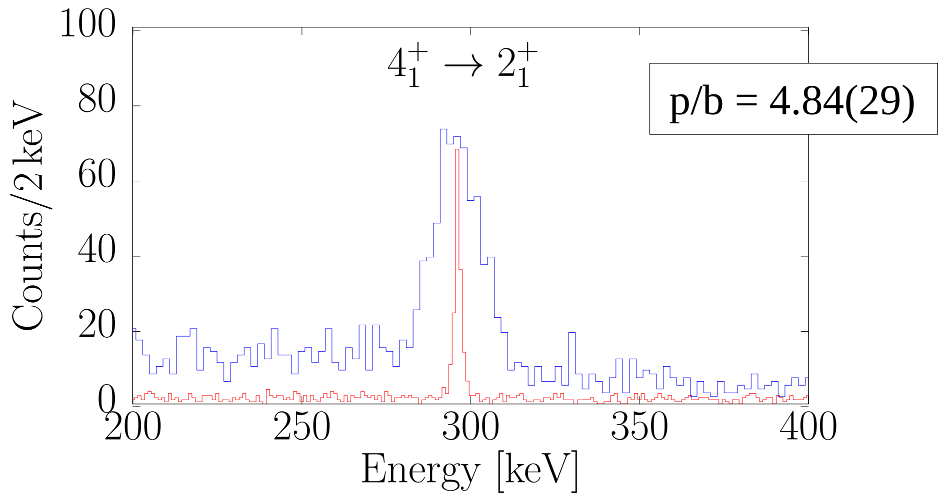
- Prompt time window for gates on transitions above the isomeric state in ^{136}Te and on transitions in ^{102}Zr

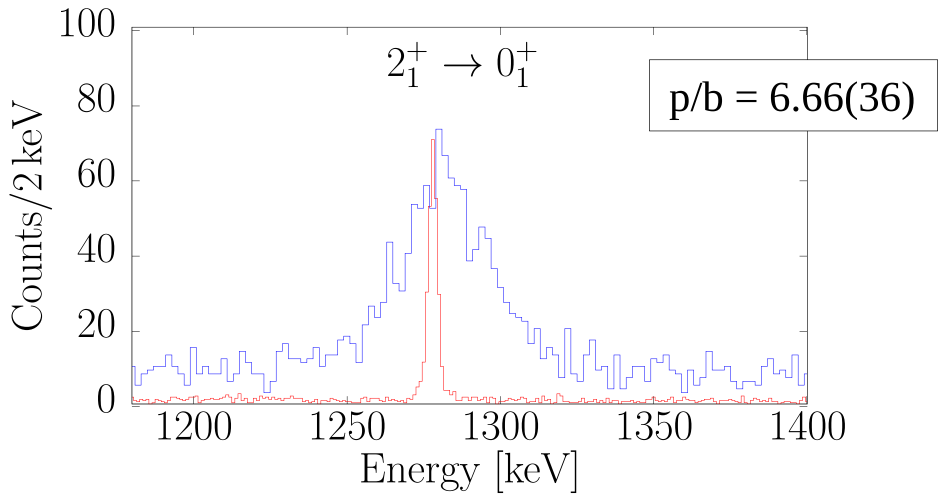


G. Häfner et al., Phys. Rev. C, 103:034317 (2021)

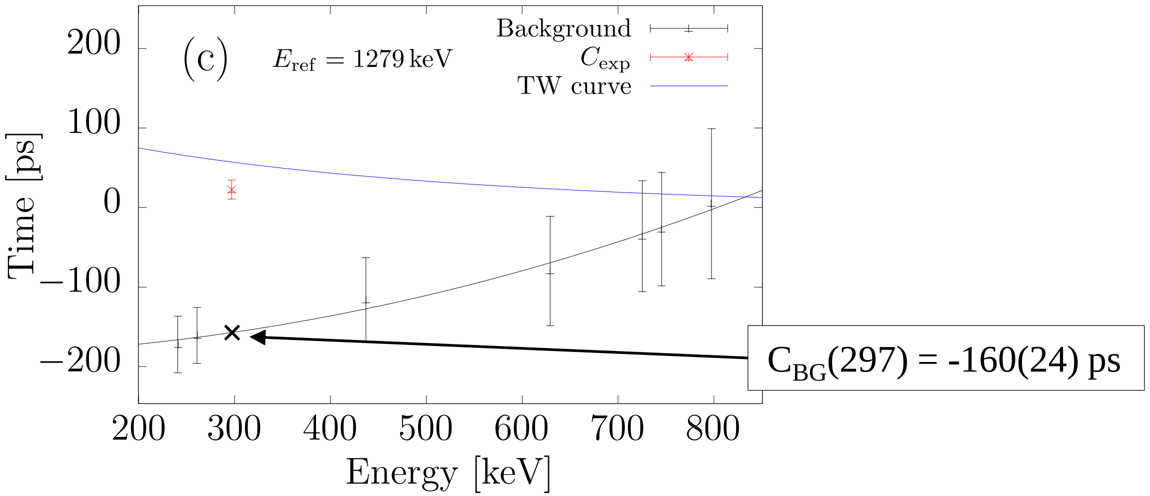
Lifetime Measurements in ^{134}Te: 2^+_1 state

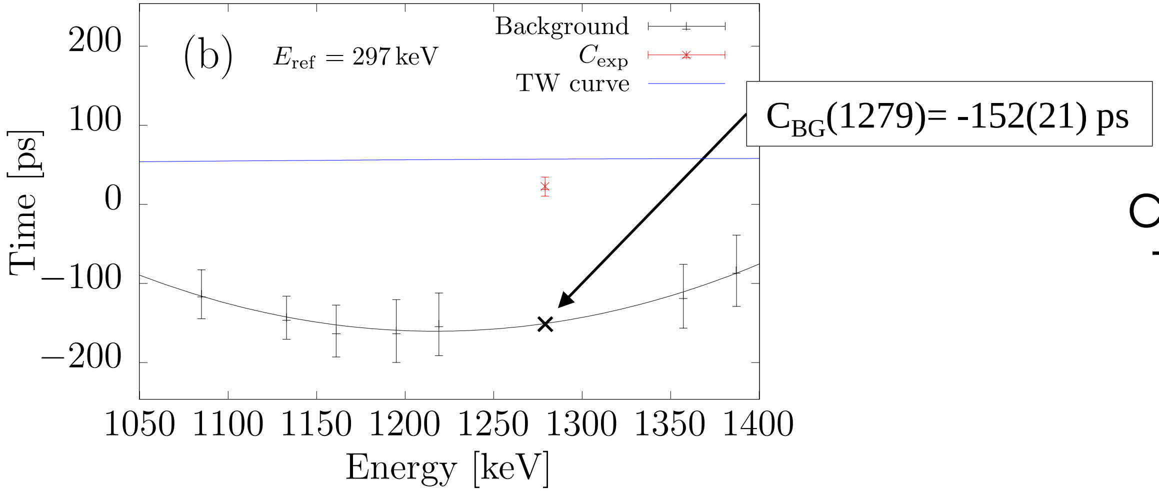


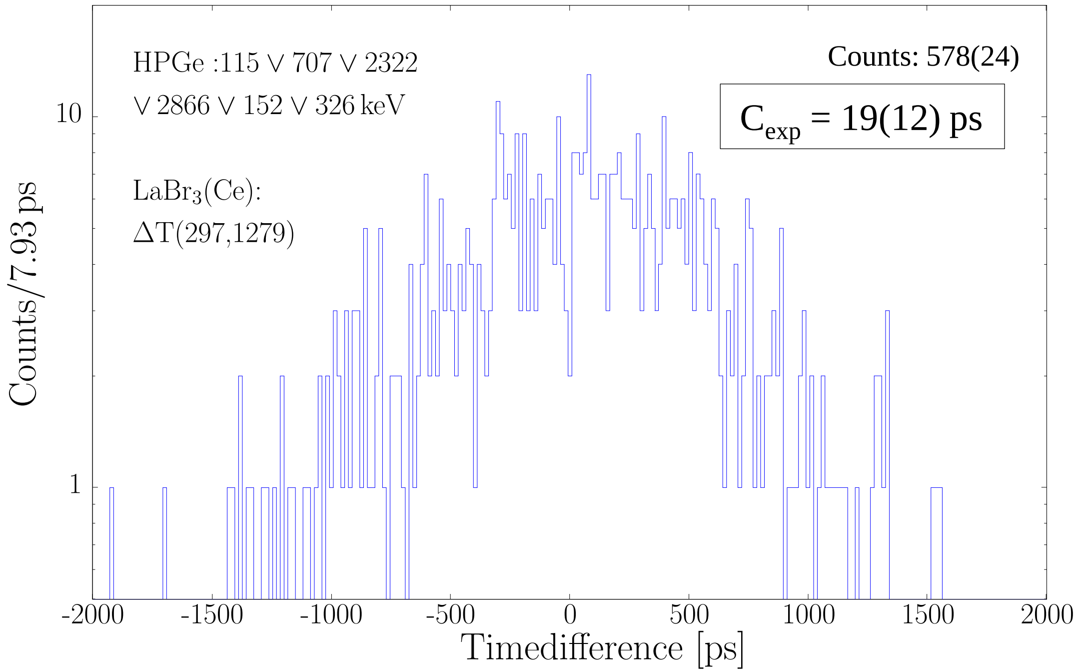




Lifetime Measurements in ^{134}Te: 2^+_1 state preliminary







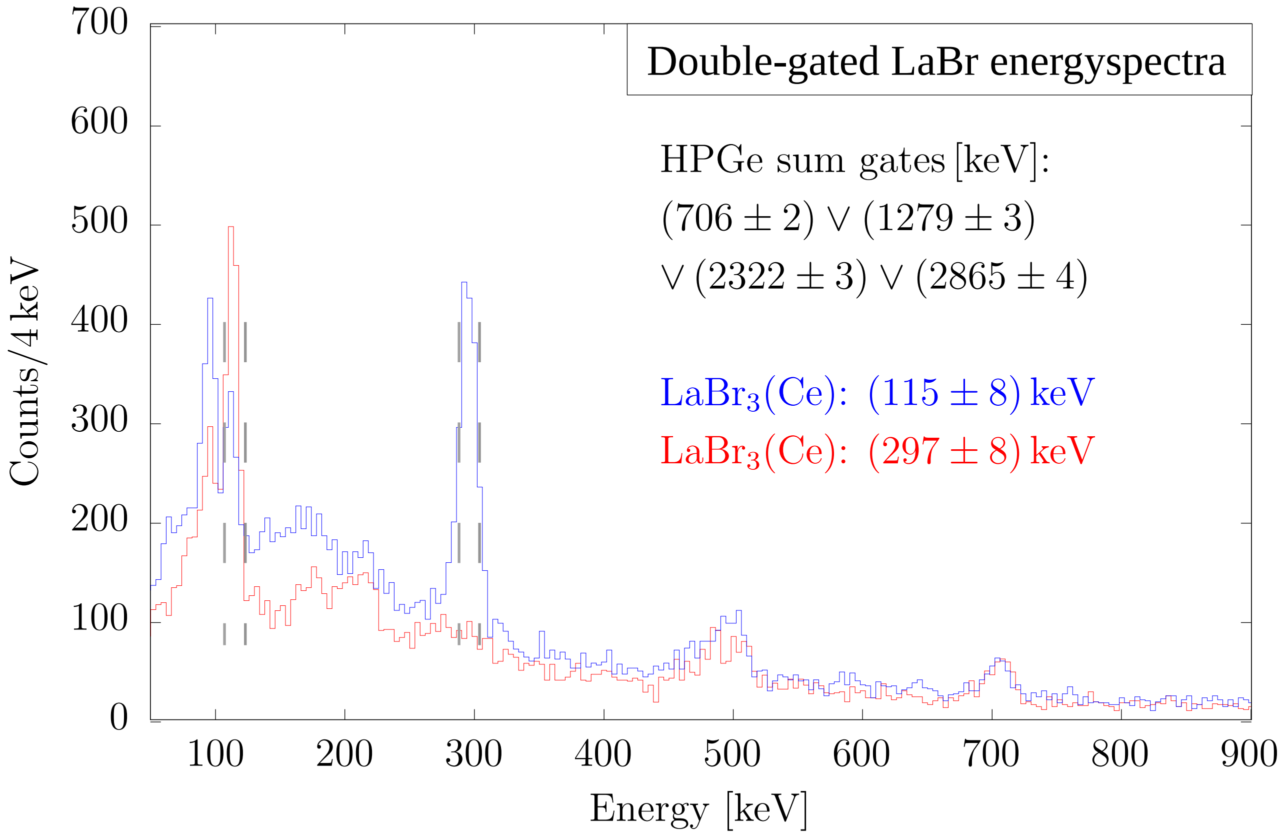
C_{FEP} = 51(13) ps
TW=52(3) ps

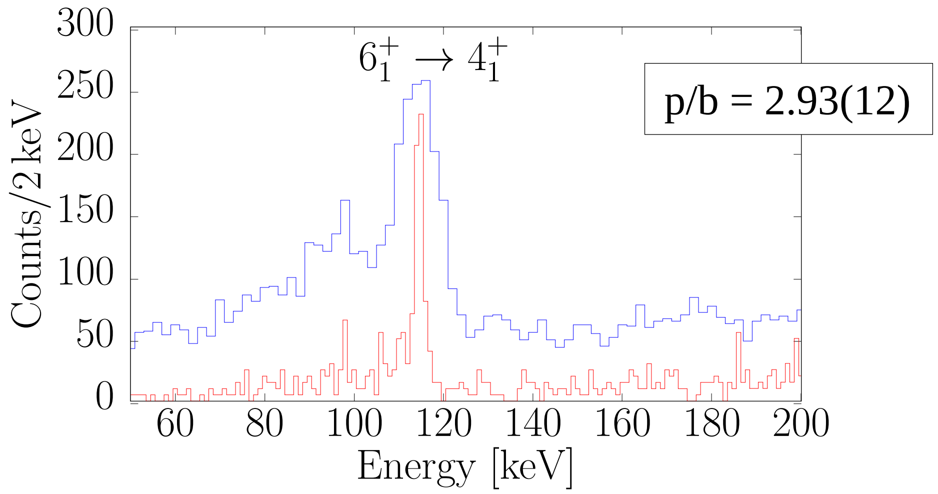
⇒ τ <13 ps

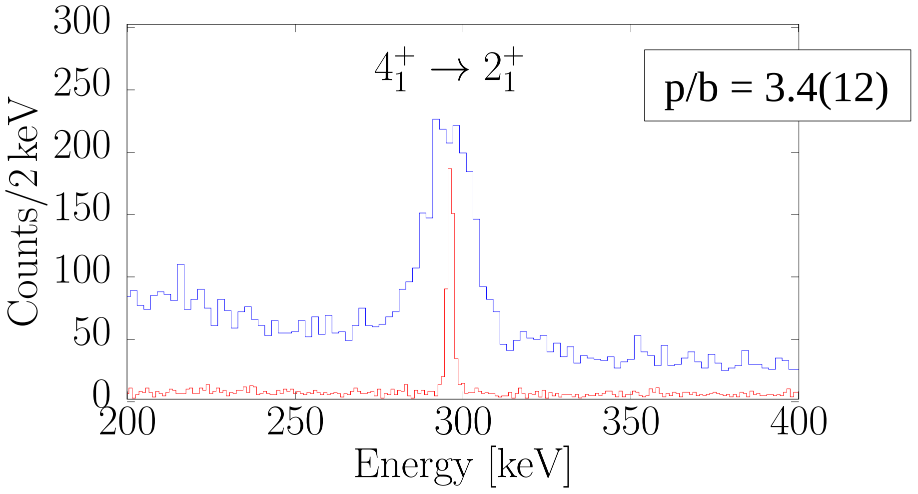
τ_{lit} = 0.9(1) ps [1]

[1] C. J. Barton et al., Phys. Lett. B, 551:269–276 (2003)

Lifetime Measurements in ^{134}Te: 4^+_1 state

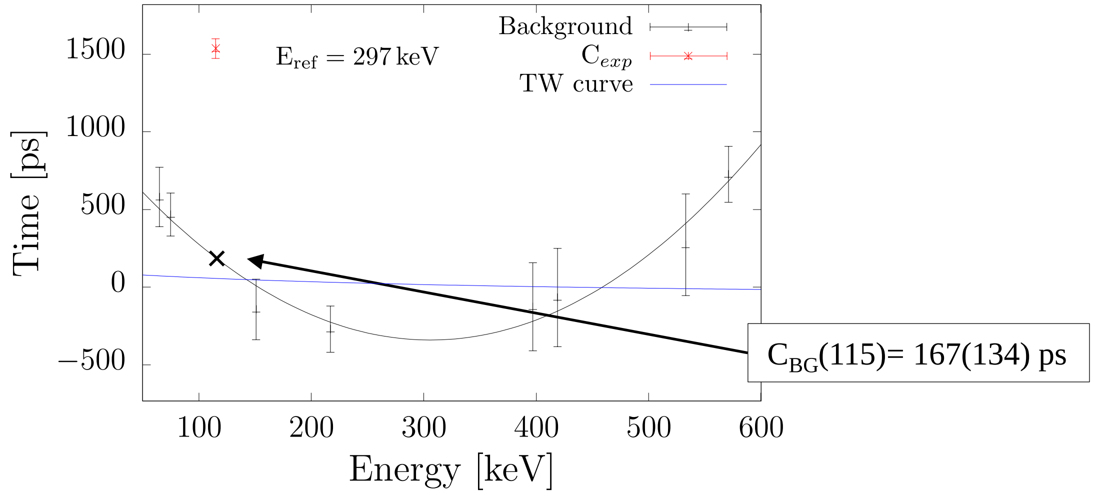


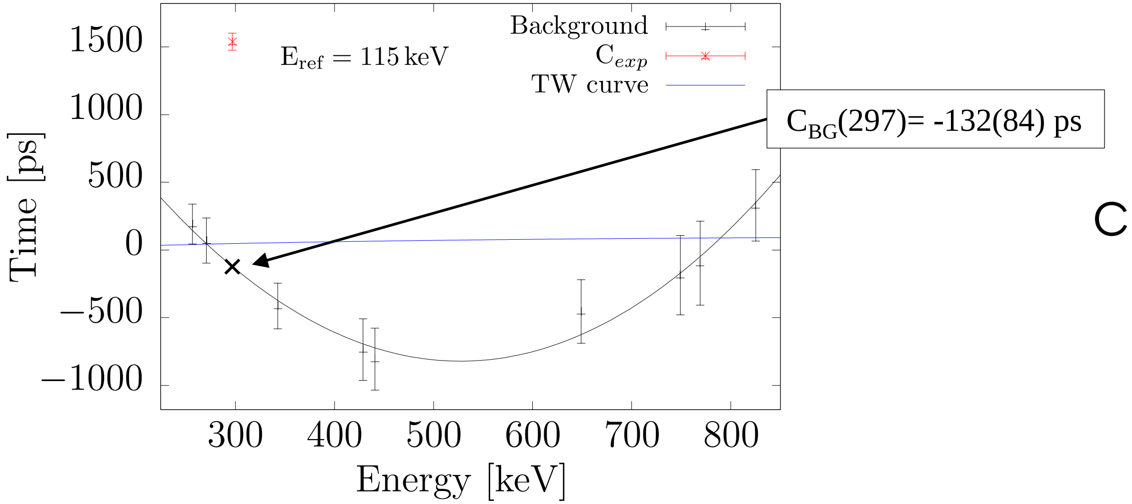


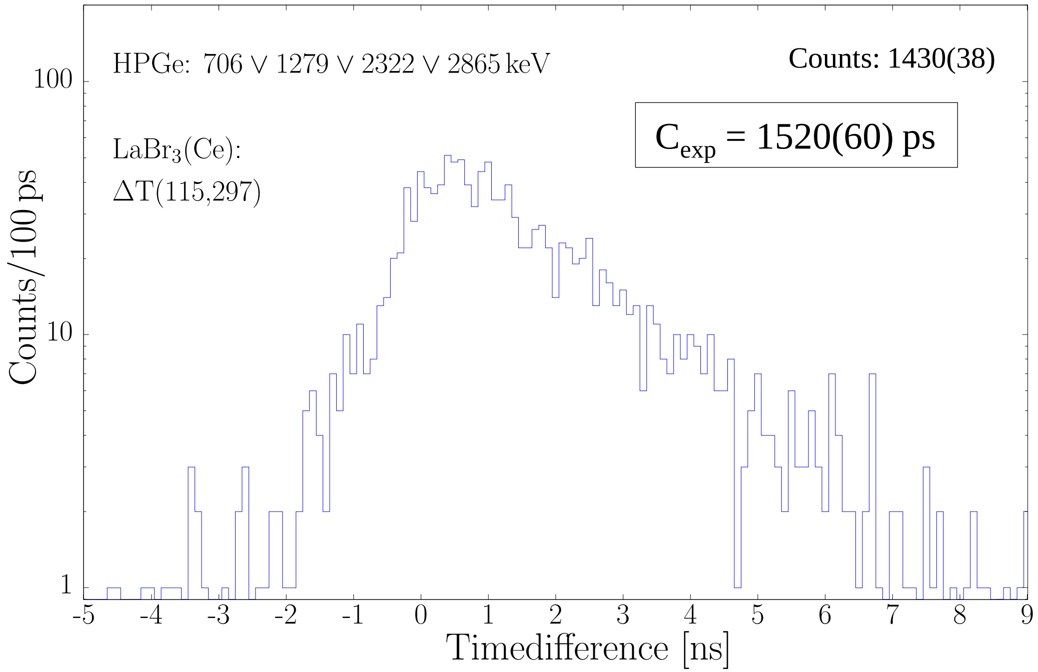


Lifetime Measurements in ^{134}Te: 4^+_1 state

Centroid Shift Method preliminary







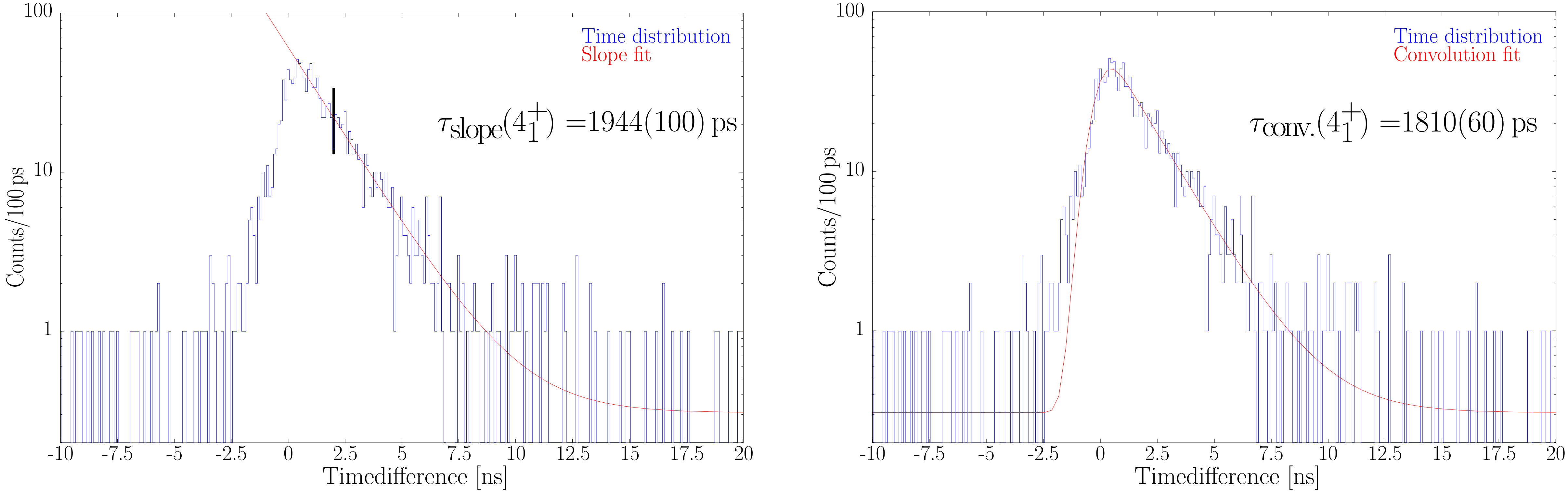
C_{FEP} = 1994(68) ps
TW=60(5) ps

⇒ **τ = 1934(69) ns**

τ = 1960(160) ps [1]
τ = 2020(140) ps [2]
(nuBall1)

[1] A.A. Sonzogni, Nucl. Data Sheets A=134, 103:1–182 (2004)
[2] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)

Lifetime Measurements in ^{134}Te: 4^+_1 state slope and convolution method preliminary



Summary of first Results from the Fast-Timing Analysis within the ν-Ball2 Fission Campaign preliminary

Isotope	J_i^π	lifetime [ps]: this work (ν-Ball2)	lifetime [ps]: ν-Ball1	lifetime [ps]: Literature	Reference
^{134}Te	2_1^+	< 13		0.9(1)	C. J. Barton et al., Phys. Lett. B, 551:269–276 (2003)
	4_1^+	1934(69)	$2020^{‡}(140)$[1]	1960(160)	A. A. Sonzogni, Nucl. Data Sheets, 103:1–182 (2004)
		$1944^{†}(100)$		2160(190)	J. P. Omtvedt et al., Phys. Rev. Lett., 75:3090 (1995)
				1850(140)	A. Kawade et al., Z. Phys. A, 298:187 (1980)
^{136}Te	2_1^+	34(12)	$< 45^{‡}$[1]	31(6)	E. A. Mccutchan, Nucl. Data Sheets, 152:331 (2018)
				42(8)	H. Mach et al., World Scientific, Singapore (2008)
				41(6)	M. Danchev et al., Phys. Rev. C, 84 (2011)
				27(2)	J. M. Allmond et al., Phys. Rev. Lett., 118:092503 (2017)
				33(15)	V. Vaquero et al., Phys. Rev. C., 99:034306 (2019)
				26(4)	V. Vaquero et al., Phys. Rev. C., 99:034306 (2019)
	4_1^+	112(12)	$142^{‡}{}^{+38}_{-60}$[1]	100(14)	J. M. Allmond et al., Phys. Rev. Lett., 118:092503 (2017)
				98(50)	V. Vaquero et al., Phys. Rev. C., 99:034306 (2019)
	6_1^+	195(15)	$320^{‡}{}^{+74}_{-97}$[1]	–	

† slope fit
‡ convolution fit

[1] G. Häfner et al., Phys. Rev. C, 103:034317 (2021)

Summary and Outlook

- Successful ν–Ball2 fission campaign with very good statistics (Oct. 2022)
  - ✓ Time–walk calibration curve
  - ✓ Successfull verification of ν-Ball2 fast-timing analysis with known lifetimes $^{134,136}Te$ using the centroid-shift method
  - ✓ Good agreement of experimental results with theoretical predictions

- Next steps:
  - ▶ Complete sorting of the ^{238}U data set (June 2022)
  - ▶ Using events for fast-timing with higher orders of multiplicity (M >= 3) ?
  - ▶ New analysis of the 6^+ in ^{136}Te using different approaches ?
  - ▶ Finalising of the new fast-timing results for $^{134,136}Te$
  - ▶ Determination of lifetimes in neutron–rich $^{94-96}Kr$

Thanks to the ν-Ball2 N-SI-120 Collaboration

J.N. Wilson[1], A. Algora[2], D. Bittner[3], A. Blazhev[3], J.A. Briz Monago[4], A. Bruce[5], L. Canete[6], C. Chatel[7], G. de Angelis[8], P. Dessagne[7], F. Didierjean[7], G. Duchêne[7], A. Esmaylzadeh[3], E. Gamba[9], J. Fischer[3], L.M. Fraile[4], F. Recchia[10], N. Fritz[11], G. Georgiev[1], K. Gladnishki[12], G. Kosir[13], A. Harter[3], K. Hauschild[1], J. Heery[6], G. Henning[7], C. Hiver[1], L. Iskra[14], J. Benito[10], J. Ljungvall[1], J. Jolie[3], N. Jovancevic[15], D. Kalaydjieva[16], M. Kerveno[7], L. Knafla[3], D. Knezevic[17], D. Kocheva[12], D. Korgul[18], T. Kröll[19], K. Miernik[18], M. Lebois[1], M. Ley[3], M. Llanos[4], A. Lopez- Martens[1], R. Lozeva[1], M. Markova[11], A. Messingschlager[19], T. Milanovic[20], M. Moukaddam[7], P. Aguilera[10], S. Pascu[6], G. Pasqualato[1], W. Paulsen[11], Z. Podolyak[6], W. Poklepa[18], P. Regan[6], K. Rezynkina[10], M. Rudigier[19], E. Seme[13], S. Jazrawi[6], S. Bottoni[9], K. Solak[18], K.Stoychev[1], M. Stryjczyk[21], G. Torvund[11], J. Vesic[13], M. von Tresckow[19], N. Warr[3] und G. Zhang[10]

1CNRS/IN2P3 IJCLab Orsay, France — 2IFIC, CSIC-University of Valencia, Spain—3IKP, University of Cologne, Germany — 4Grupo de Fisica Nuclear & IPARCOS, Complutense University of Madrid, Spain — 5University of Brighton, United Kingdom — 6University of Surrey, United Kingdom — 7IPHC, Strasbourg, France — 8INFN Legnaro National Laboratory, Italy — 9INFN Milan, Italy — 10INFN Padova, Italy —11University of Oslo, Norway — 12INRNE, Bulgarian Academy of Sciences, Sofia, Bulgaria — 13IJS, Ljubljana, Slovenia — 14IFJ, Polish Academy of Sciences, Krakow, Poland — 15University of Novi Sad, Serbia — 16IRFU, CEA, Universite Paris-Saclay, France — 17IPB Belgrade, Serbia — 18University of Warsaw, Poland — 19IKP, TU Darmstadt, Germany — 20Vinča Institute of Nuclear Science, University of Belgrade, Serbia — 21JYFL, University of Jyväskylä, Finland