Lifetime measurements of neutron- rich Xe isotopes applying the fast-timing technique

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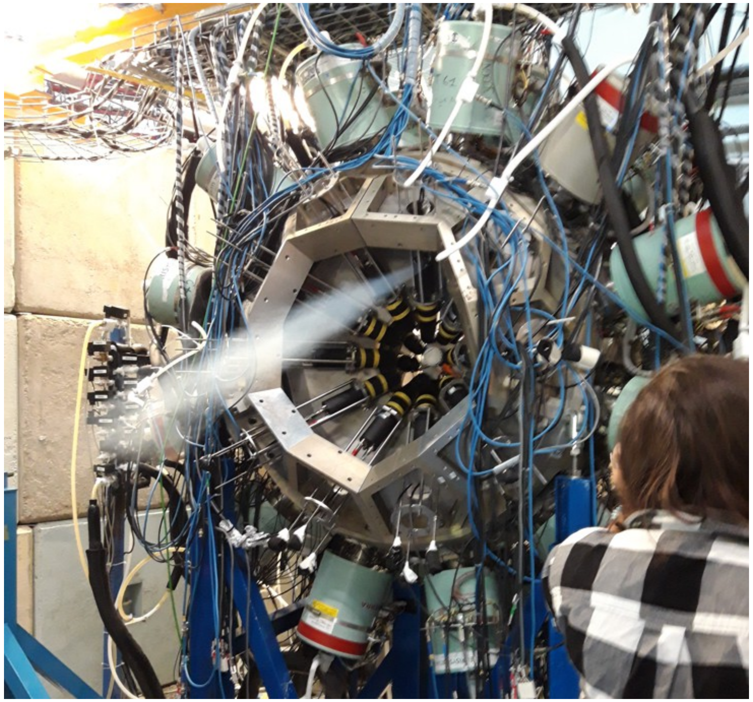

Topics:

- Motivation
- Theoretical background and experimental setup
- Data calibration
- Contaminations
- Lifetime analysis and reduced transition strengths

Motivation

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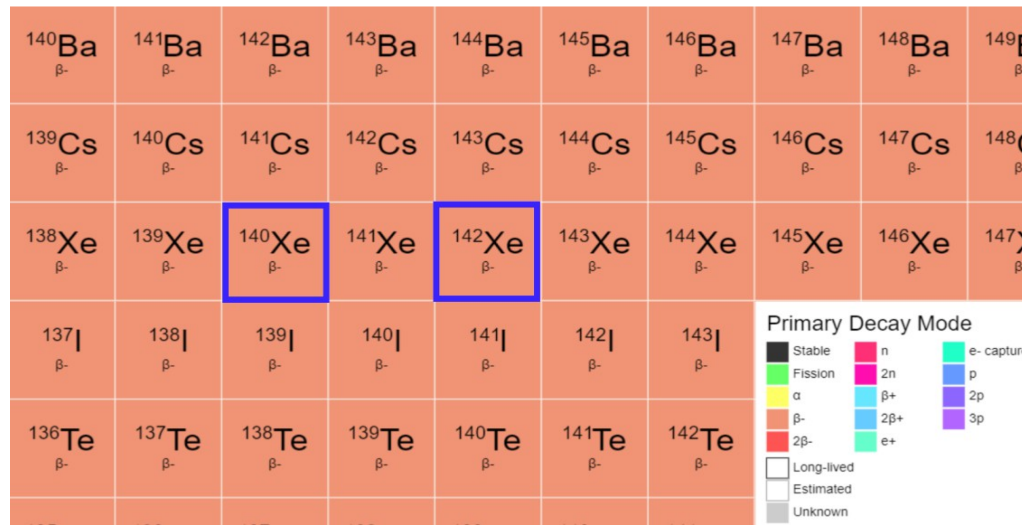
https://people.physics.anu.edu.au/~ecs103/chart/, online 02.03.2024



- Electromagnetic properties like B(E2) values → probing into the degree of collectivity of nuclear excitations.

- Disagreement between fast timing and Coulomb excitation in ^{142}Xe:
  - Coulex: **τ_{4+} = 37(9) ps** calculated from B(E2) value [1]
  - Fast-Timing: **τ_{4+} = 54(10) ps** [2]

- Confirm τ_{4+} in ^{142}Xe with different target in ^{238}U(n,f) than in Ref. [2] (with ^{235}U(n,f)) → different background

[1] C. Henrich et al. PhD thesis (2021), to be published
[2] S. Ilieva et al., PRC 94, 034302 (2016).

Experimental setup and theoretical basics

ν-Ball2 campaign 2022 @Alto (IJCLAB,Orsay)

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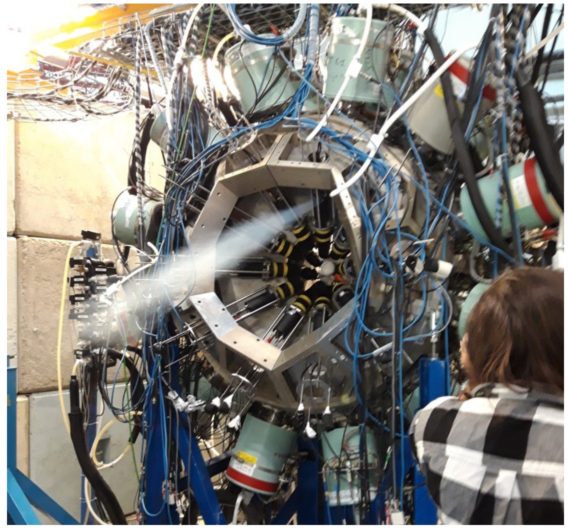

Goal of the campaign:

γ-ray spectroscopy of fission fragments produced by the ^{238}U(n,f) reaction

ν-Ball2 spectrometer:

4 rings
20 $LaBr_3$(Ce) FATIMA detectors
24 HPGe Clover detectors (24*4 HPGe detectors).

ν-Ball2 setup LICORNE

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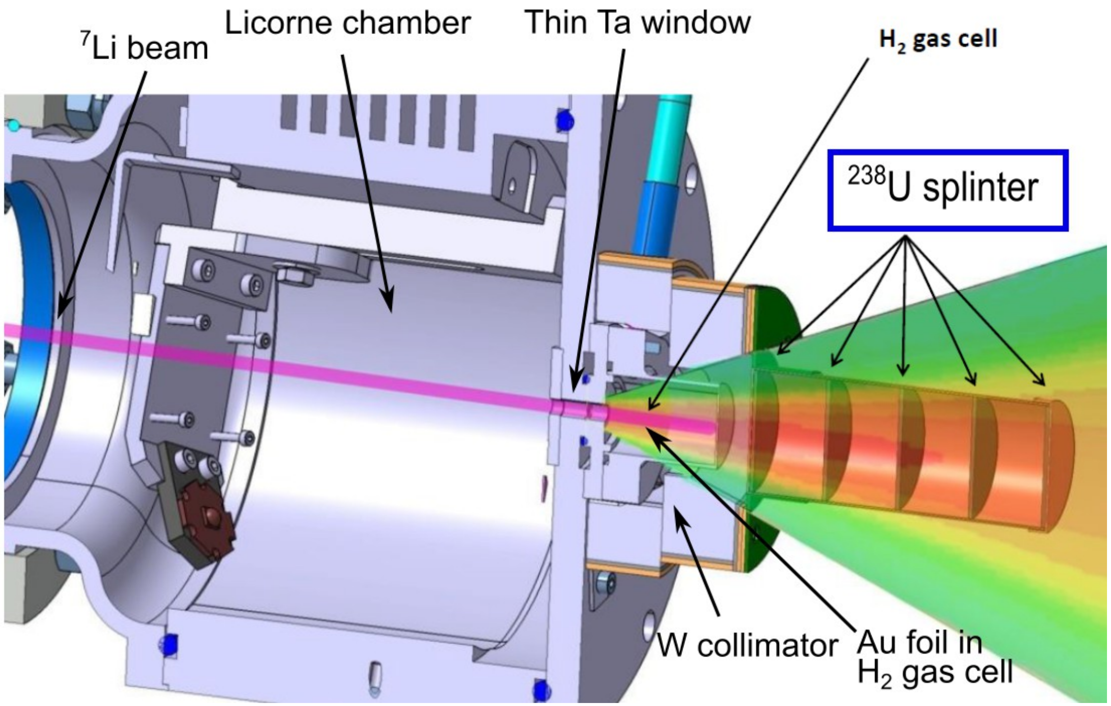
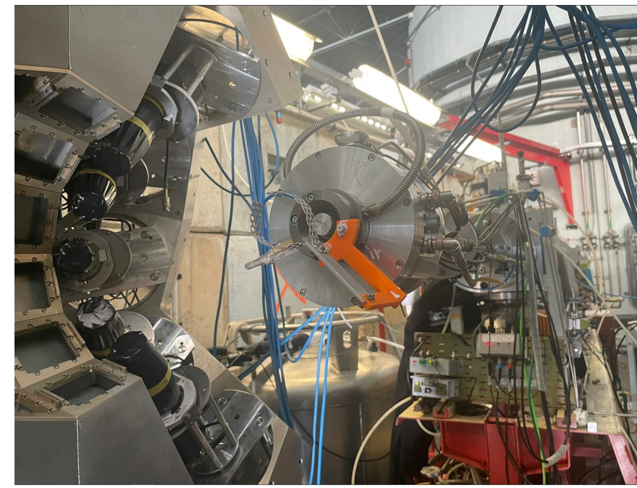
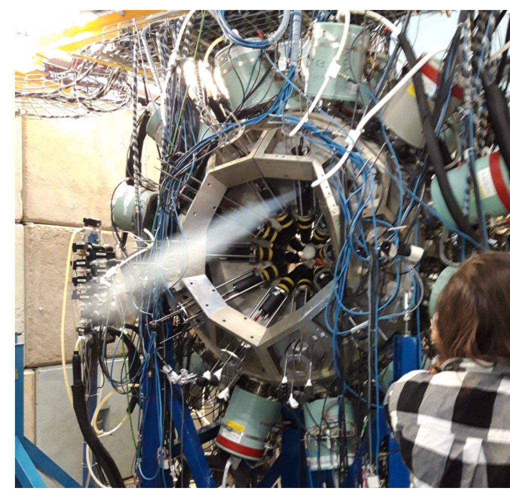


LICORNE1 scheme from J. Wilson in private conversation





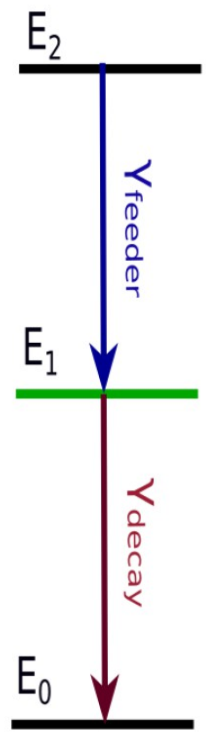
- ^{238}U splinter instead of disks
- Pulsed Li-beam → pulsed neutron beam from inverse kinematic ^{7}Li(p,n) reaction.
- Monoenergetic neutrons (~ 1.7MeV)

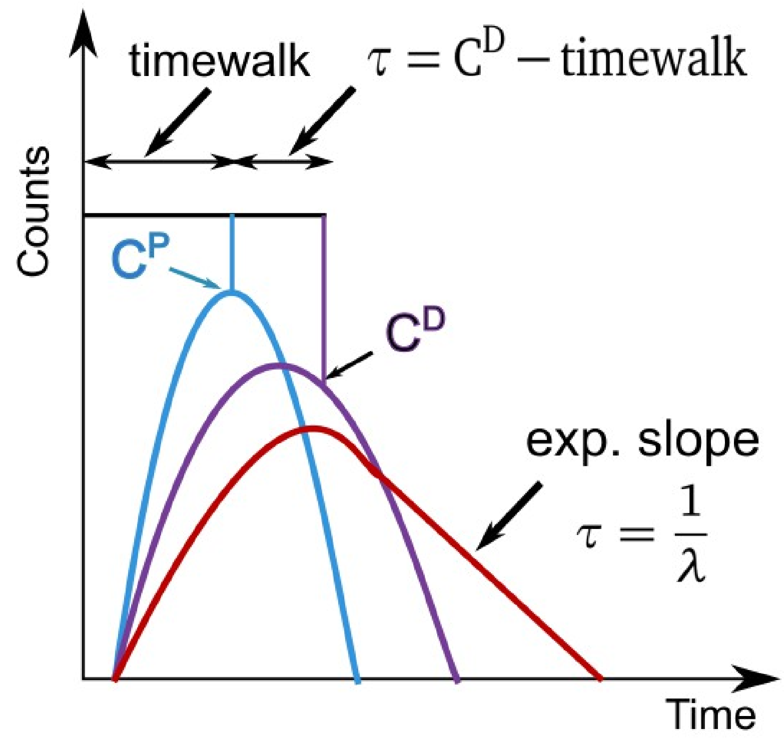
Fast timing technique

Time-difference distribution D(t) is a convolution between Prompt response P(t) and Decay rate N(t)

$D(t) = n\lambda \int_{-\infty}^{t} P(t' - t_0) e^{-\lambda(t-t')}$

with $\lambda = 1/\tau,\ C^D = < t > = \frac{\int tD(t)dt}{\int D(t)dt}$





$$\Rightarrow \quad C^D(E_{\text{feeder}}, E_{\text{decay}}) = C^P(E_{\text{feeder}}, E_{\text{decay}}) + \tau$$

Data calibration

Event building of data

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DAQ takes triggerless data (~ 41TB of raw data)

Trigger conditions for an event:

- **Neutron pulse**
  - **With $LaBr_3$(Ce)-$LaBr_3$(Ce)-HPGe**
  - **With HPGe-HPGe**

Done by C. Hiver

Eventbuilding of raw data in Orsay

Reconvert event built data (~ 1.1 TB)

Multiplicity	Label	Energy	Absolute timestamp	Pileup

Increase in performance and correction of data

- LaBr$_3$(Ce): Include gain shift calibration
- LaBr$_3$(Ce): Include time difference offsets TD (time alignment)
- HPGe: Include Compton suppression
- HPGe: Include Addback correction
- Branch: Add branch time relative to pulse
- Branch: Add branch detector type
- Throw out: Bad detector channels / pileup subevents

Mult	Label	Type	Energy	Time	Time rel. to pulse

Supression of Contamination

Contaminations

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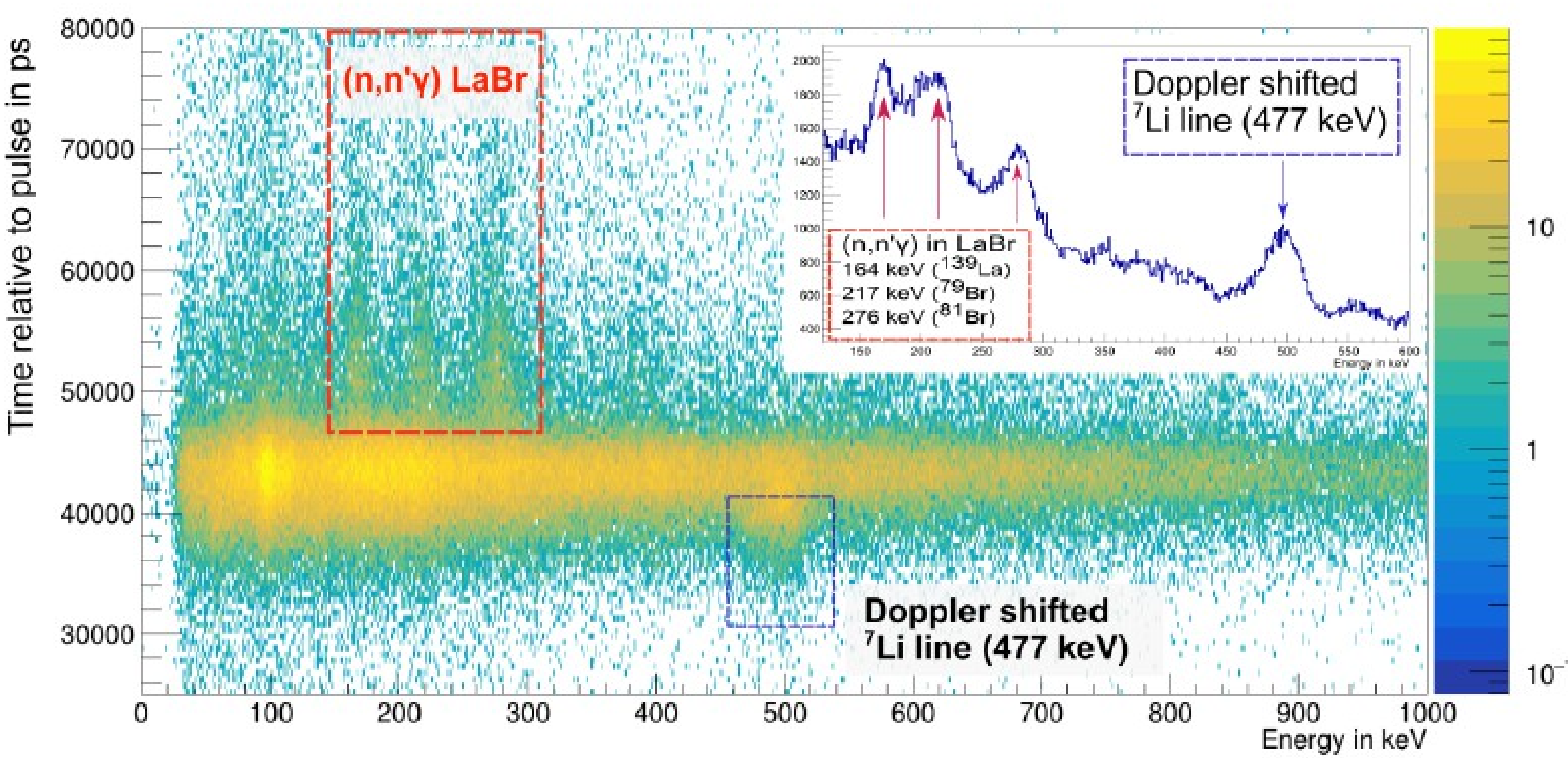
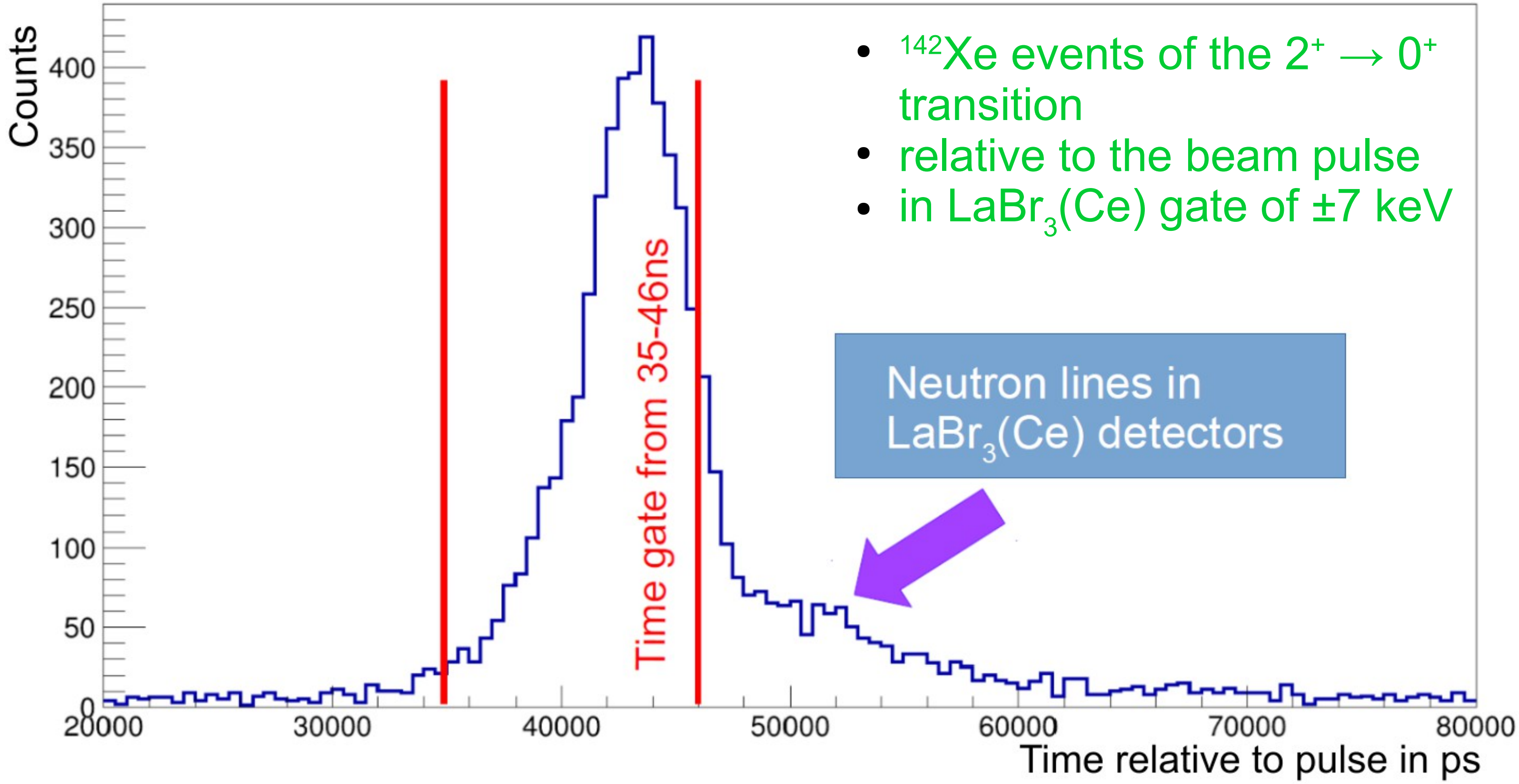


- LaBr$_3$(Ce) gate on $4^+ \rightarrow 2^+$ transition (404 keV) of ^{142}Xe
- HPGe gate on $6^+ \rightarrow 4^+$ (490 keV) or $8^+ \rightarrow 6^+$ (551 keV) transition of ^{142}Xe

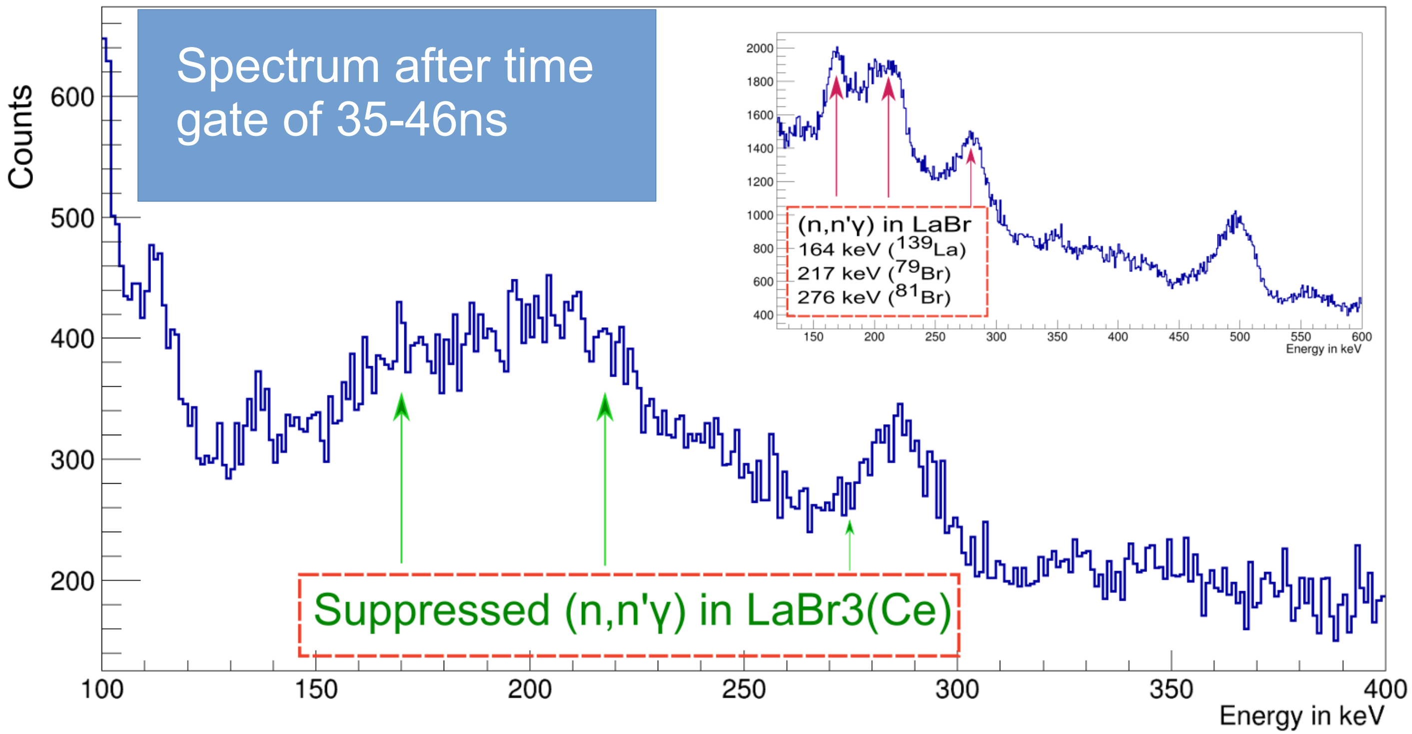
  → Energy time matrix of LaBr$_3$(Ce) events

Contamination inelastic neutron scattering in $LaBr_3(Ce)$



- HPGe gate on $4^+ \rightarrow 2^+$ transition (404 keV) of ^{142}Xe
- $LaBr_3(Ce)$ gate on $2^+ \rightarrow 0^+$ transition (287 keV) of ^{142}Xe → events rel. to pulsetime

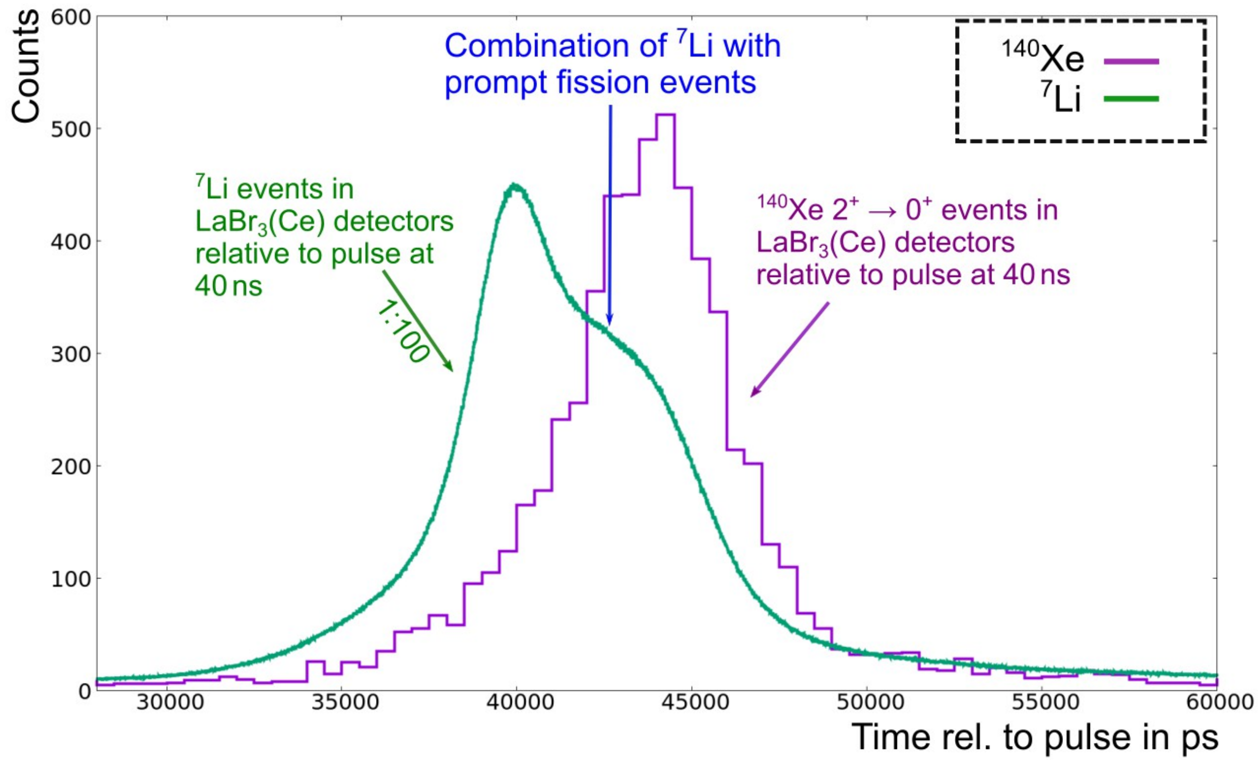
Contamination inelastic neutron scattering in $LaBr_3$(Ce)



- $LaBr_3$(Ce) gate on $4^+ \rightarrow 2^+$ transition (404 keV) of ^{142}Xe
- HPGe gate on $6^+ \rightarrow 4^+$ (490 keV) or $8^+ \rightarrow 6^+$ (551 keV) transition of ^{142}Xe
- Time gate of 35-46ns

→ $LaBr_3$(Ce) spectrum with suppressed neutron lines

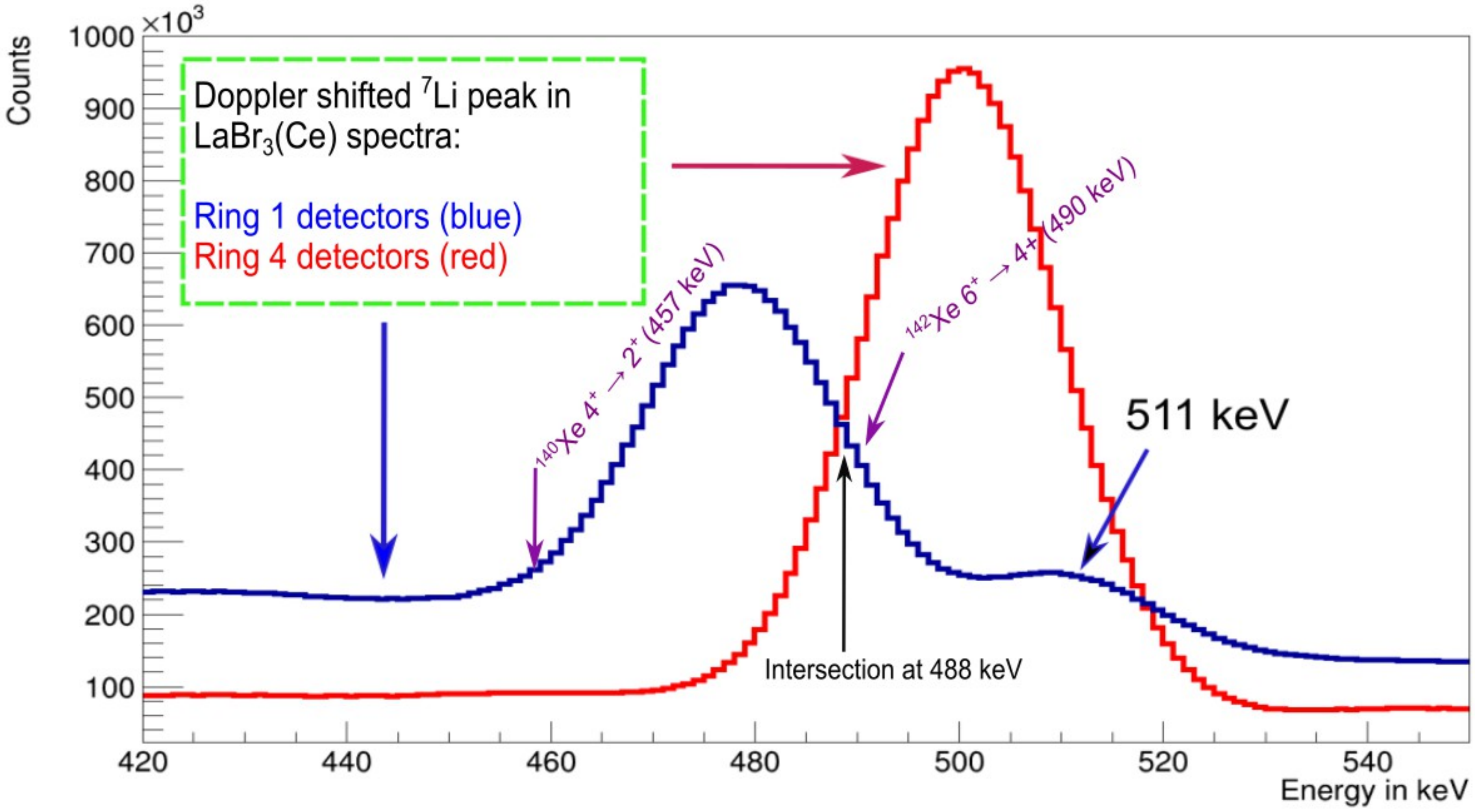
Lithium line contamination (time resolution)



- $LaBr_3$(Ce) gate (± 2keV) around ^{7}Li peak (477 keV) → Events rel. to pulsetime

- HPGe gate (± 2keV) on $6^+ \rightarrow 4^+$ transition (582 keV) of ^{140}Xe
- $LaBr_3$(Ce) gate (± 7keV) on $2^+ \rightarrow 0^+$ transition (376 keV) of ^{140}Xe → Events rel. to pulsetime

Lithium line contamination (detector gate)



→ $LaBr_3(Ce)$ spectra of ring 1 and ring 4 (timegate 25-37 ns, Singles)

Analysis of lifetimes and reduced transition strengths

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^{140}Xe determination of τ_{2+}

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LaBr$_3$(Ce) gates (± 7 keV) for feeder (457 keV) and decay (376 keV)

HPGe gates (± 2 keV) for $8^+ \rightarrow 6^+$ and $6^+ \rightarrow 4^+$ transitions of ^{140}Xe

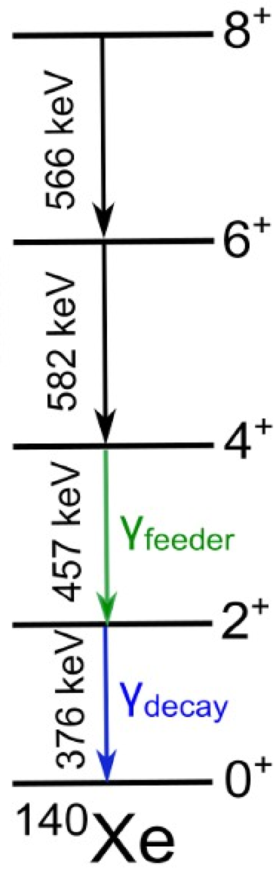
No HPGe gates on fission partners ^{94,95,96}Sr
(contamination $13/2^- \rightarrow 9/2^-$ of ^{141}Xe at 370 keV)

Time gate between 35-50 ns

^{7}Li contamination in feeder → only Ring 4 statistics for feeder

Multiplicity	3	4	5	6	7
P/B feeder peak	0.77	0.73	0.65	0.57	statistics to low
P/B decay peak	1.21	1.14	0.90	0.82	statistics to low

Best P/B ratio at multiplicity value of ≥ 3



^{140}Xe determination of τ_{2+} (background centroid of feeder peak)

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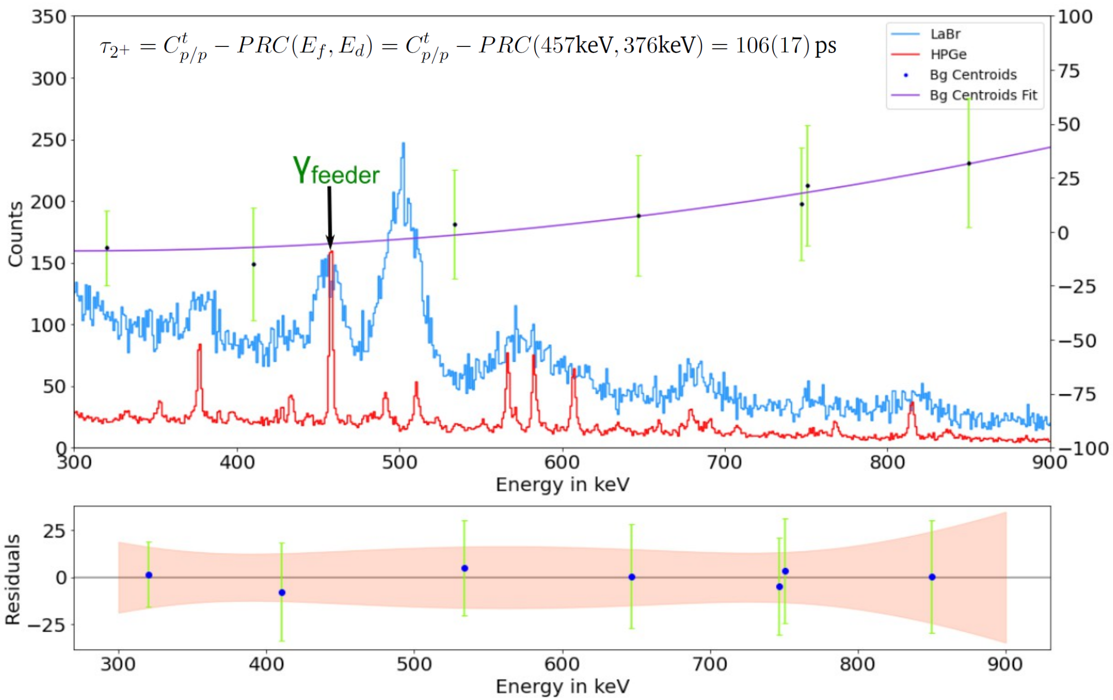
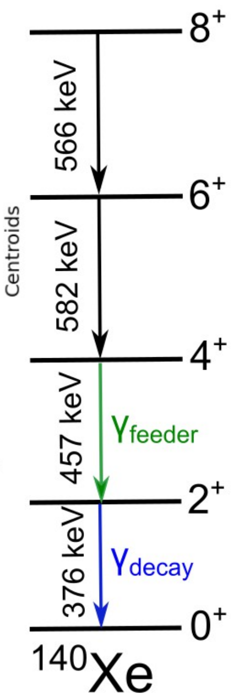
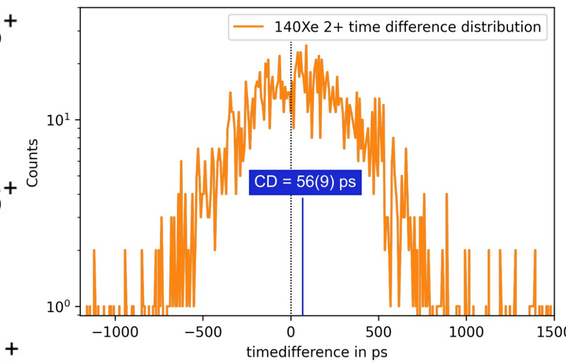






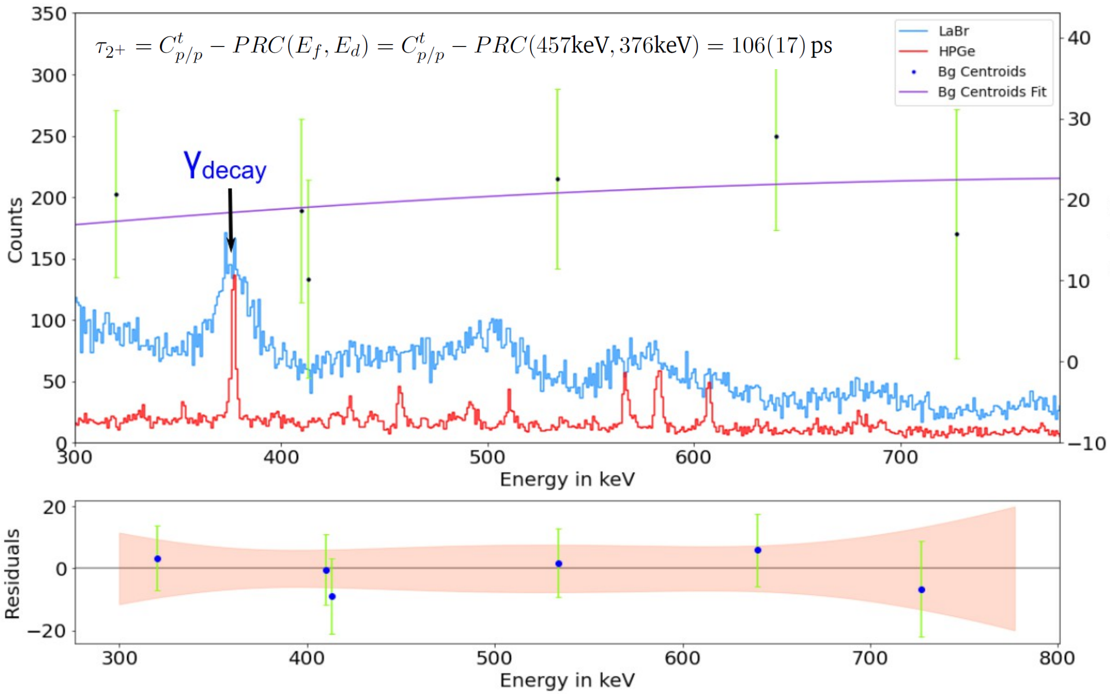
Time- difference distribution

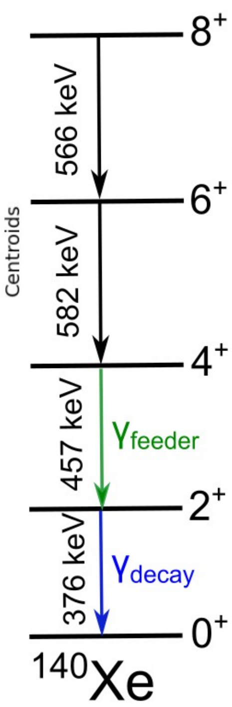
Applying BG-correction according to J.M. Regis [1]

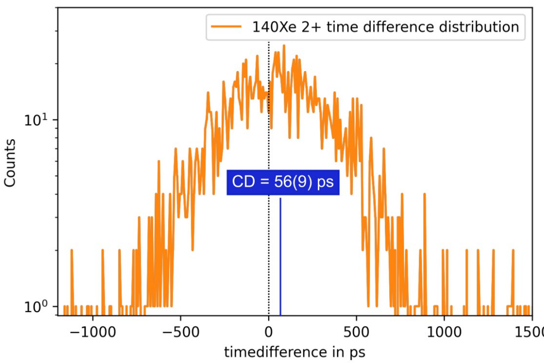
Transition	Centroid exp.	PRC value	Peak to background	Background Centroid	t_{cor}
Feeder	55.8 (89)	-13.6 (40)	0.77 (3)	-6.0 (157)	77.8 (221)
Decay		-4.6(40)	1.21(3)	17.9 (83)	32.3 (103)

[1] J.M. Régis et al. NIM Phys. Res. A, 897, p. 38 (2018)

^{140}Xe determination of τ_{2+} (background centroid of decay peak)







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^{140}Xe lifetimes

Lifetime ^{140}Xe	τ_{2^+} in ps	τ_{4^+} in ps	τ_{6^+} in ps
A. Lindroth et al. [1]	102(29)	20(33)	< 12
S. Ilieva et al. [2]	102(7)	17(5)	
This work	106(17)	24(16)	≤ 27

- Lifetime τ_{6+} of this work is 14(13) ps

[1] A. Lindroth et al. Phys. Rev. Lett. 82, 4783 (1991)
[2] S. Ilieva et al., PRC 94, 034302 (2016).

^{142}Xe lifetimes

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Lifetime ^{142}Xe	τ_{2^+} in ps	τ_{4^+} in ps	τ_{6^+} in ps
S. Ilieva et al. [1]	249(23)	54(10)	
C. Henrich et al. [2]		37(9)	11(3)
This work	247(28)	123(35)	≤ 46

^{7}Li contamination:

➔ Higher lifetime expected for τ_{4+} (contamination of feeder peak)

➔ Calculated value of τ_{6+} is 9(37)ps

[1] S. Ilieva et al., PRC 94, 034302 (2016).
[2] C. Henrich et al. PhD thesis (2021), to be published

^{142}Xe determination of τ_{4+}

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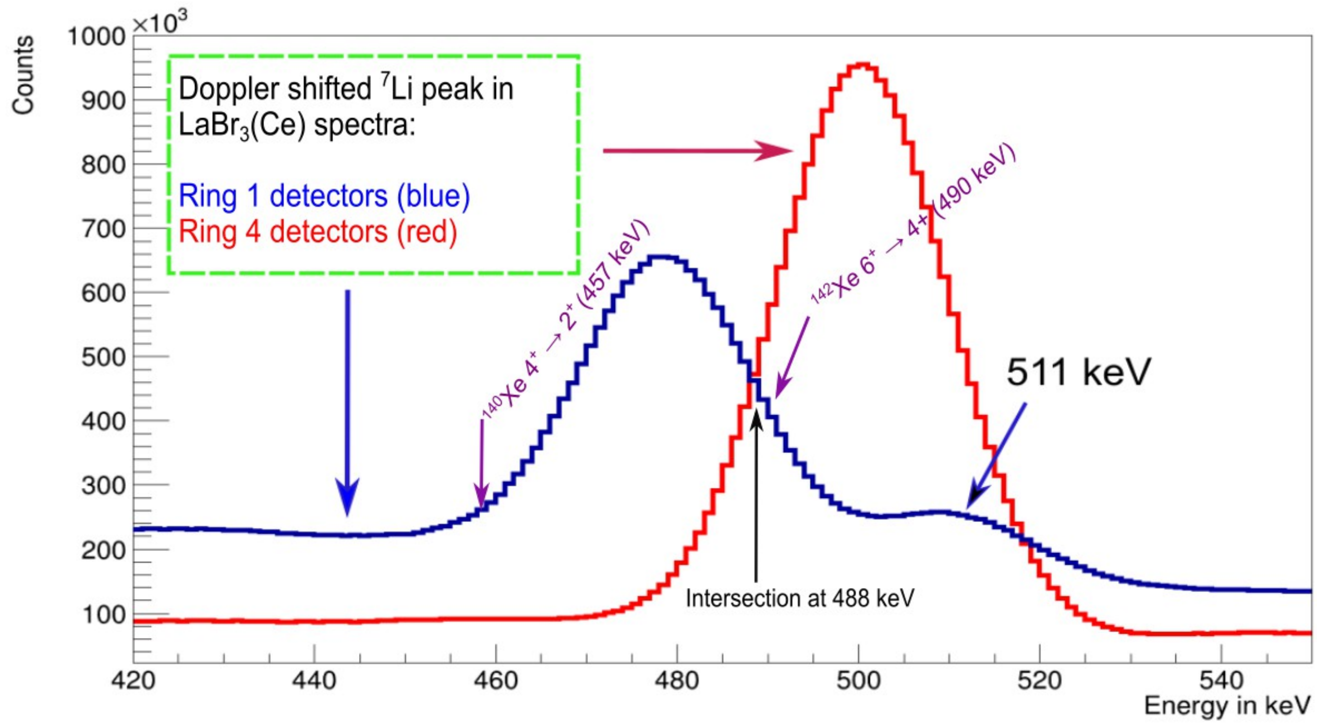

Getting around the Li contamination:

- ➔ Feeder (551 keV) $8^+ \rightarrow 6^+$ in ^{142}Xe
- ➔ Decay (404 keV) $4^+ \rightarrow 2^+$ in ^{142}Xe
- ➔ $\tau_4 = \tau_{4+6} - \tau_6$ (** τ_6 from C. Henrich)

C. Henrich et al. PhD thesis (2021), to be published

^{142}Xe determination of τ_{4+} (background centroid of feeder peak)

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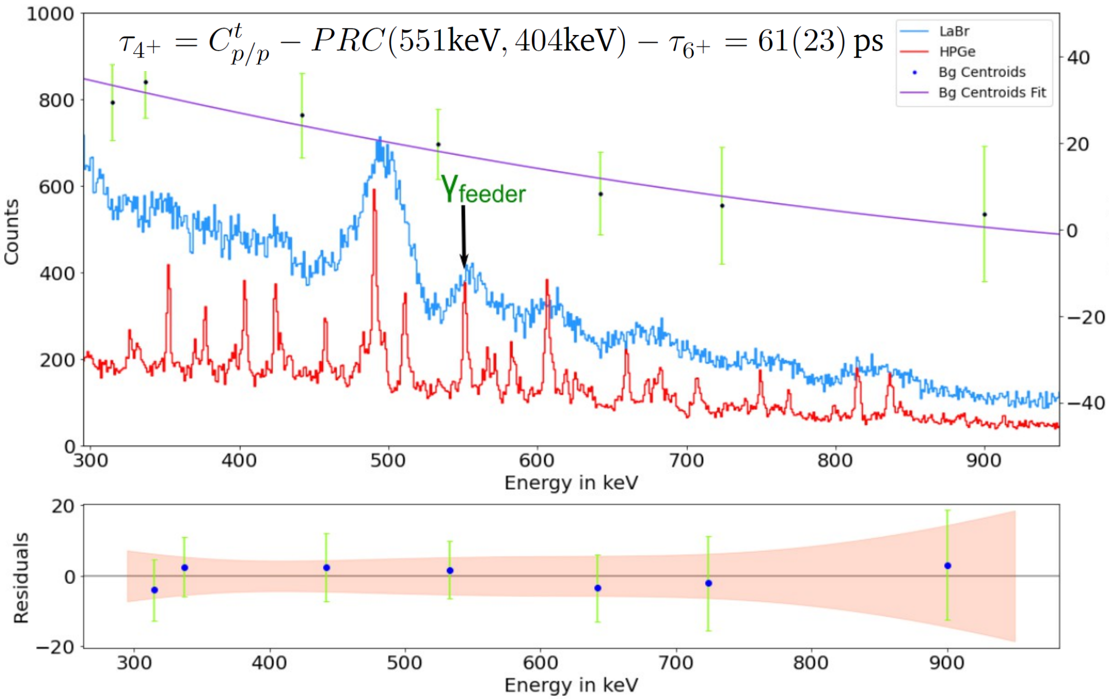
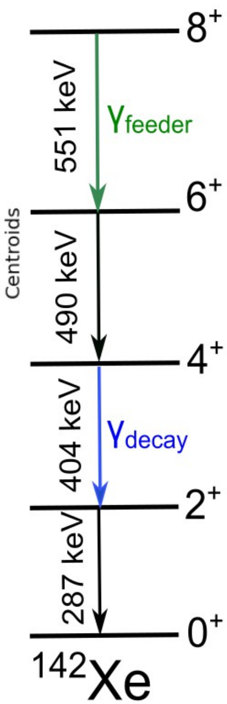
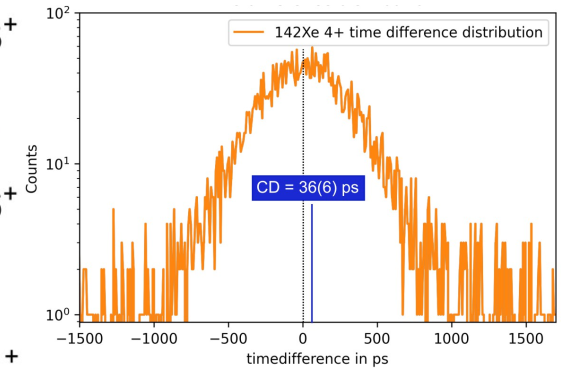






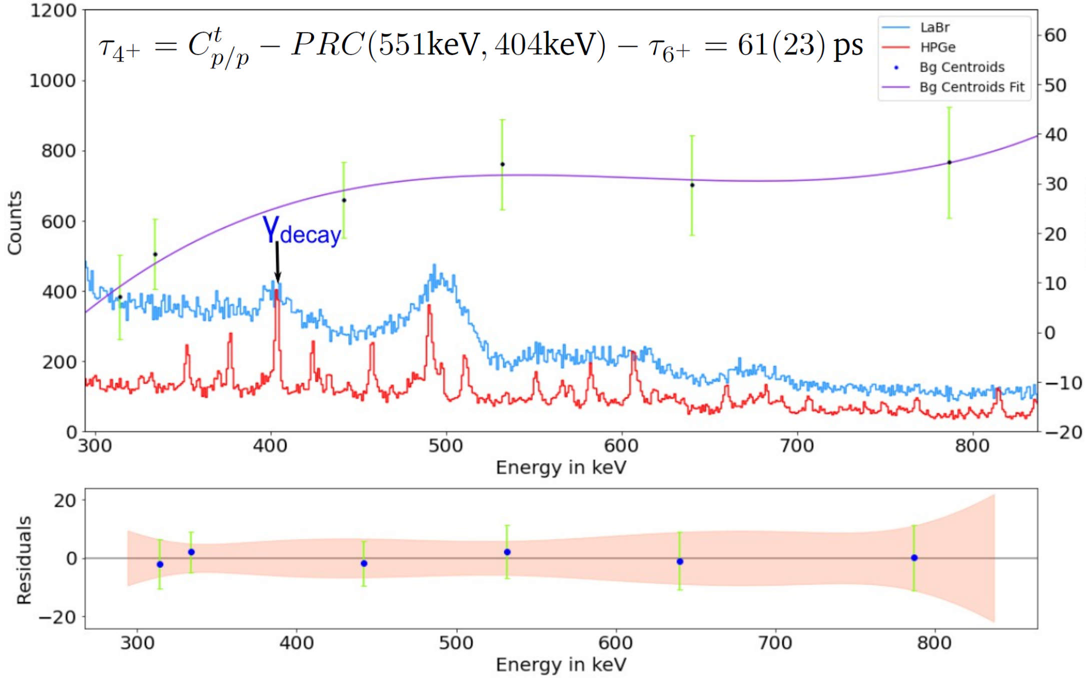
Time- difference distribution

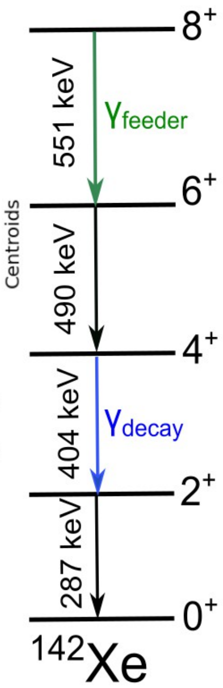
Applying BG-correction according to J.M. Regis [1]

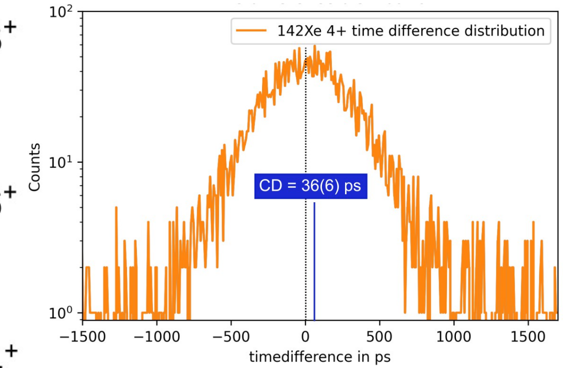
Transition	Centroid exp.	PRC value	Peak to background	Background Centroid	t_{cor}
Feeder	35.9 (61)	-21.8 (40)	0.32 (1)	16.3 (68)	61.5 (287)
Decay		-7.9 (40)	0.27 (1)	25.3 (61)	39.4 (323)

[1] J.M. Régis et al. NIM Phys. Res. A, 897, p. 38 (2018)

^{142}Xe determination of τ_{4+} (background centroid of decay peak)







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^{142}Xe determination of background corrected τ_{4+}

Lifetime ^{142}Xe	τ_{2+} in ps	τ_{4+} in ps	τ_{6+} in ps
S. Ilieva et al. [1]	249(23)	54(10)	
C. Henrich et al. [2]		37(9)	11(3)
This work	247(28)	123(35)	≤ 46
		61(23)	

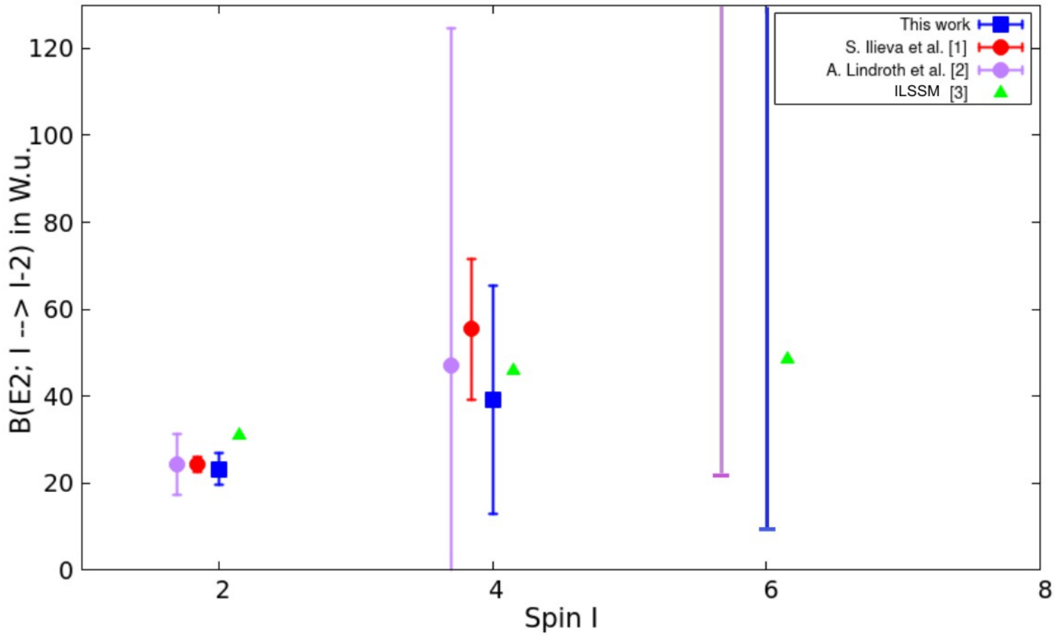
[1] S. Ilieva et al., PRC 94, 034302 (2016).
[2] C. Henrich et al. PhD thesis (2021), to be published

Reduced transition strengths of ^{140}Xe

Calculation of B(E2) values:

$$B(E2; I \rightarrow I-2) = \frac{1}{C(E2) \cdot E^5 \cdot \tau \cdot (1 + f_{ic})}$$

with $C(E2) = 1.23 \cdot 10^9 (s \cdot MeV^5 \cdot e^2 \cdot fm^4)^{-1}$



Isotop	J^π	E_γ in keV	τ in ps	f_{ic}	B(E2;↓) in W.u.
^{140}Xe	2_1^+	376	106 (17)	0.02066	23.3 (37)
	4_1^+	457	24 (16)	0.01158	39.2 (261)
	6_1^+	582	≤ 27	0.005945	≥ 10.5

- Experimental results agree with this work
- Trend predicted in ILSSM looks promising overestimate the B(E2) values for I = 2 by 17%

[1] S. Ilieva et al. Phys. Rev. *C* 94,034302 (2016)
[2] A. Lindroth et al. Phys. Rev. Lett. 82, 4783 (1991)
[3] D. Bianco et al. Phys. Rev. *C 88*,024303 (2013)

Reduced transition strengths of ^{142}Xe

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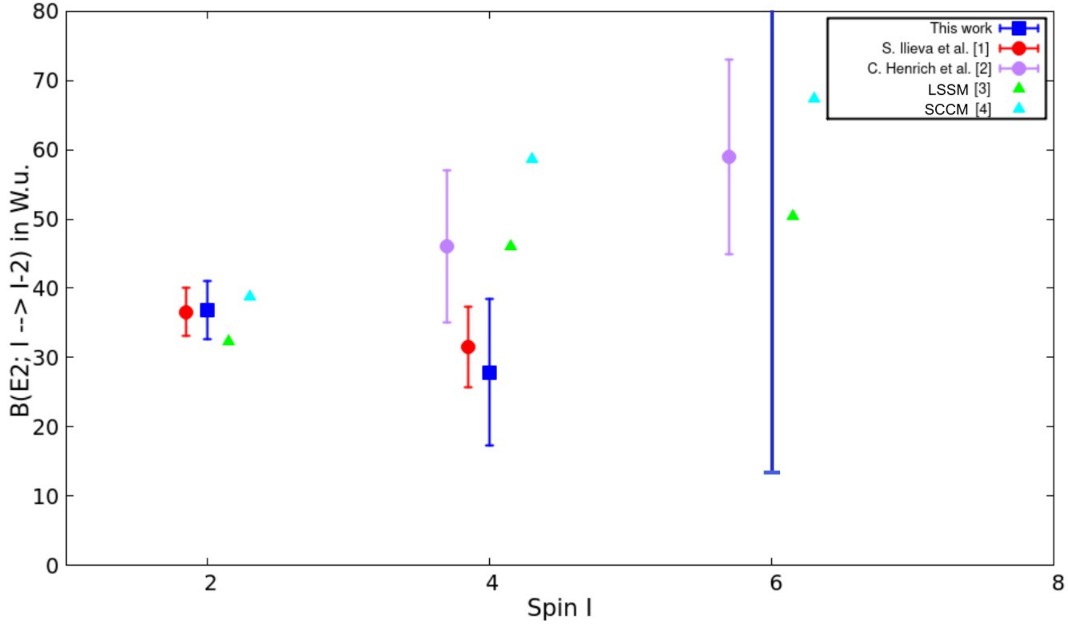
- Trend of B(E2) values predicted in SCCM looks promising.
- Same goes for pediction in LSSM which is slightly to low at I = 2^+
- Investigation of τ_{2+} confirms normalisation in Ref. [2]
- Theoretical models agree with Ref. [2] for I = 4^+.
- Disagreement between fast timing and Coulomb excitation. Uncertainty ranges overlap.



Isotop	J^π	E_γ in keV	τ in ps	f_{ic}	B(E2;↓) in W.u.
^{142}Xe	2_1^+	287	247 (35)	0.04825	36.9 (42)
	4_1^+	404	61 (23)	0.01661	27.9 (105)
	6_1^+	490	$\leq$ 46	0.009501	$\geq$ 14.2

[1] S. Ilieva et al. Phys. Rev. *C* 94,034302 (2016)
[2] C. Henrich et al. PhD thesis (2021), to be published
[3] H. Naidia in private comunication (2024)
[4] R. Rodriguez et al. J. Phys. G: Nucl. Part. Phys. 49,015101 (2022)

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