New evidence for alpha clustering structure in the ground state band of ^{212}Po

Martin von Tresckow

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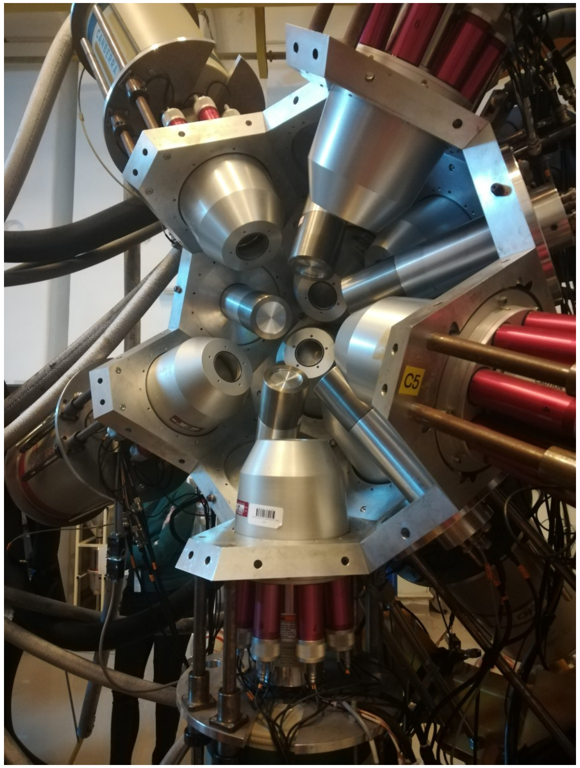
CGS17



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Motivation

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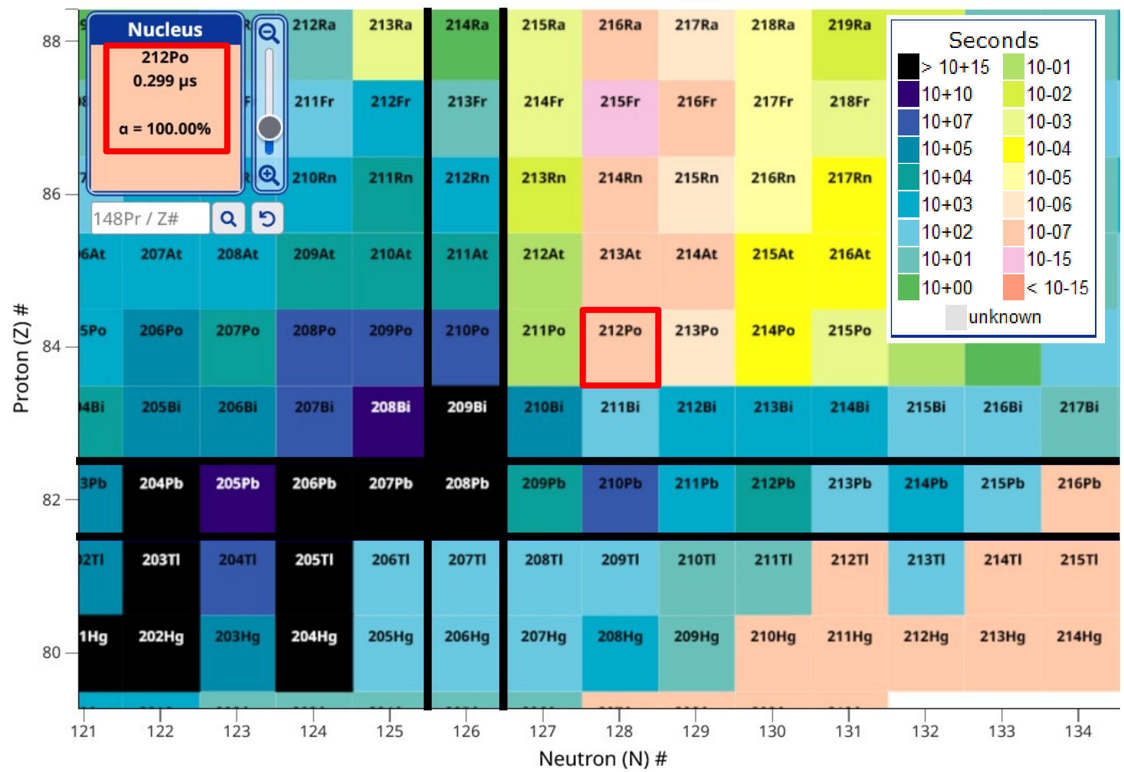
- ^{212}Po has 2 protons and neutrons more than the doubly magic nucleus ^{208}Pb
- Nuclei in the vicinity of ^{208}Pb should be well described by shell model
- Excitation energy of the low-lying yrast states of ^{212}Po are well described by the shell model [1]
- Large α-decay width of the ground state cannot be described inside of the shell model



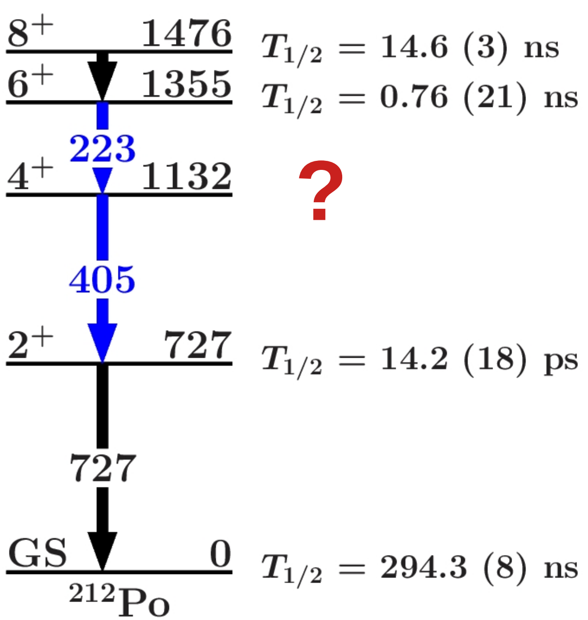
Source: NNDC

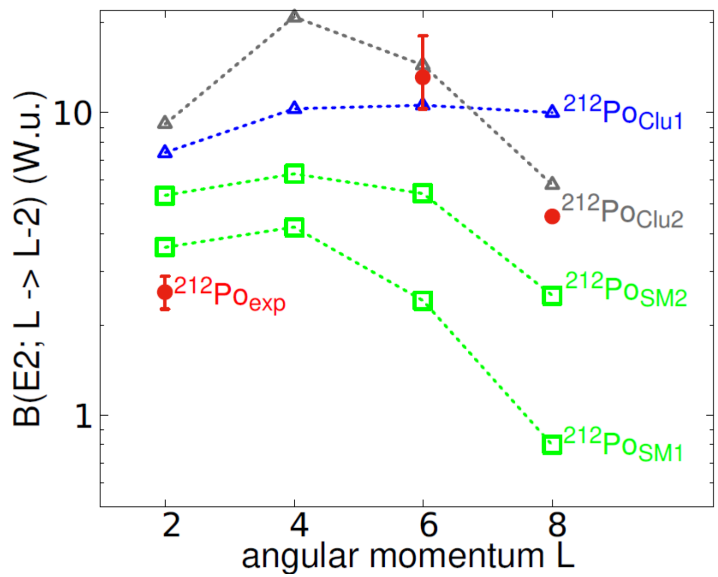
Motivates the preformation of an α-particle by the valence nucleons

[1] H. Naïdja Phys. Rev. C 103:054303, 2021

Motivation

- Strongly mixing shell-model and α-cluster configurations can reproduce the α-decay width of the ground state
- Reduced transition strengths of the transitions from the low-lying yrast states are not well described by the shell model





[Clu1] F. Hoyler et al., Rev. C, 50:2631–2634, Nov 1994
[Clu2] D. S. Delion et. al. Phys. Rev. C 85:064306, Jun 2012
[SM1] D. Kocheva et al. Phys. Rev. C, 96:044305, Oct 2017
[SM2] H. Naïdja Phys. Rev. C 103:054303, 2021
[Exp] NNDC

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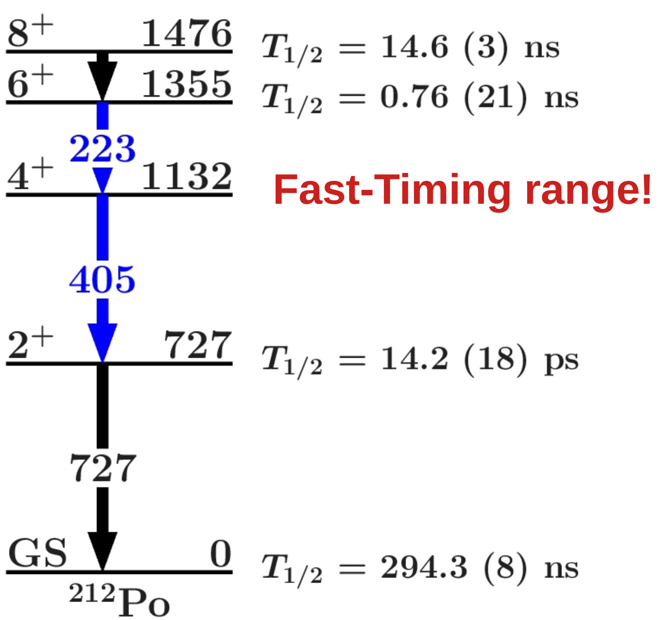

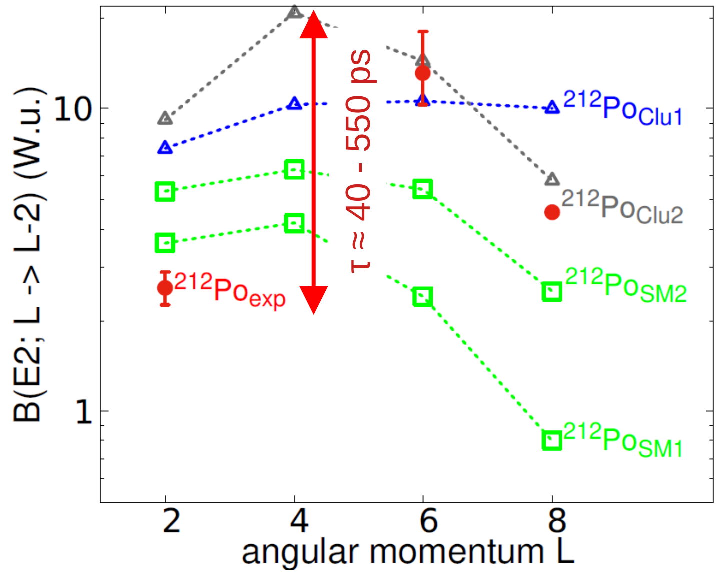

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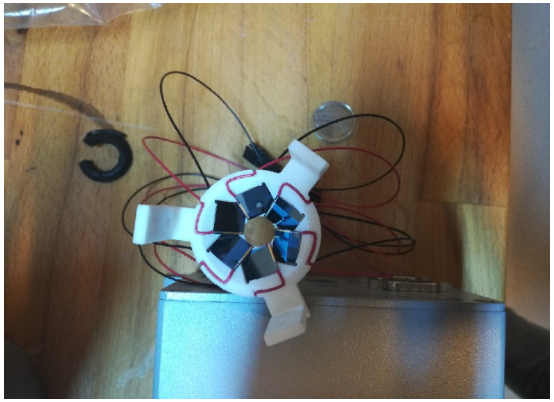
[Exp] NNDC

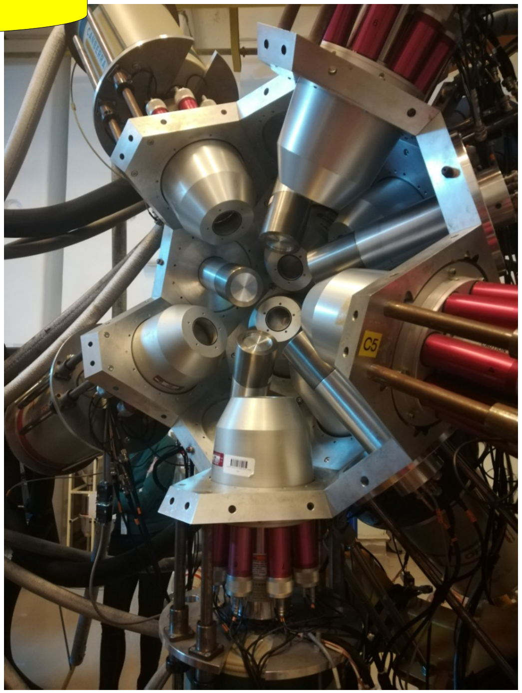
Experimental setup

- ROSPHERE array [2] @IFIN-HH in Magurele/Bucharest (Romania) (15 HPGe + 10 $LaBr_3$(Ce) detectors with PMTs)

(+): Good time res. (~300 ps @1336 keV-1173 keV)
(-): Worse energy res. (~3.6% @779 keV)

- SORCERER [3] (6 Si photodiodes/solar cells)
  - Covers the angles between 121.7 ° and 163.5 ° with respect to the ion beam direction

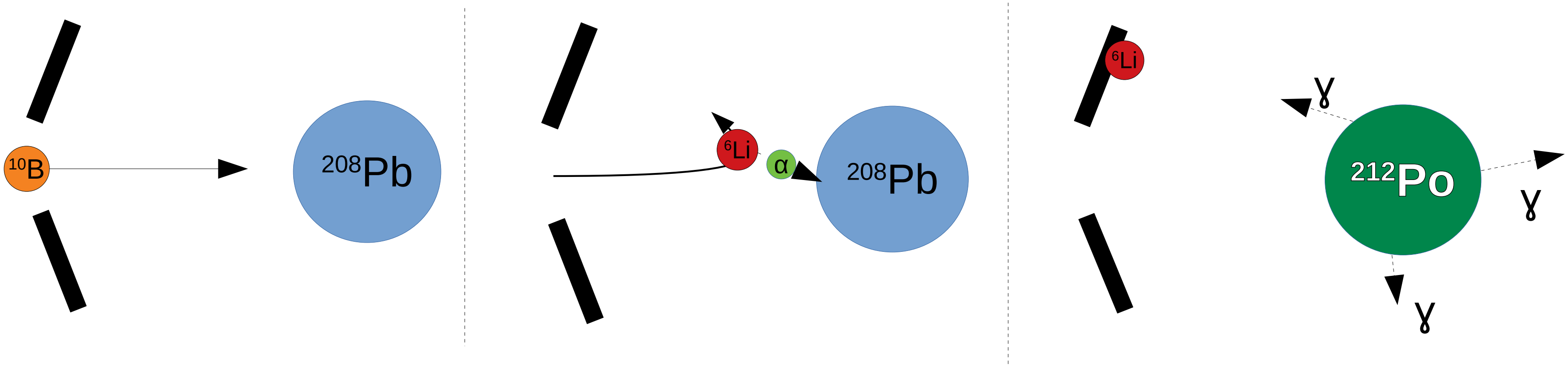




[2] D. Bucurescu, et al. NIM A837, Pages 1-10, 2016
[3] T. Beck et. al. NIM A951, 163090, 2020

Experimental idea

- Impinging a ^{10}B beam on ^{208}Pb target (9.65 mg/cm^2, 99.14 %)
  - Beam energy: 51 MeV
  - Coulomb barrier: ~ 51 MeV [4]
- Gate on the particle spectrum to clean up the γ-spectrum



[4] LISE QT Utilities

Coincidence spectrum with a $LaBr_3(Ce)$ gate on 405 keV

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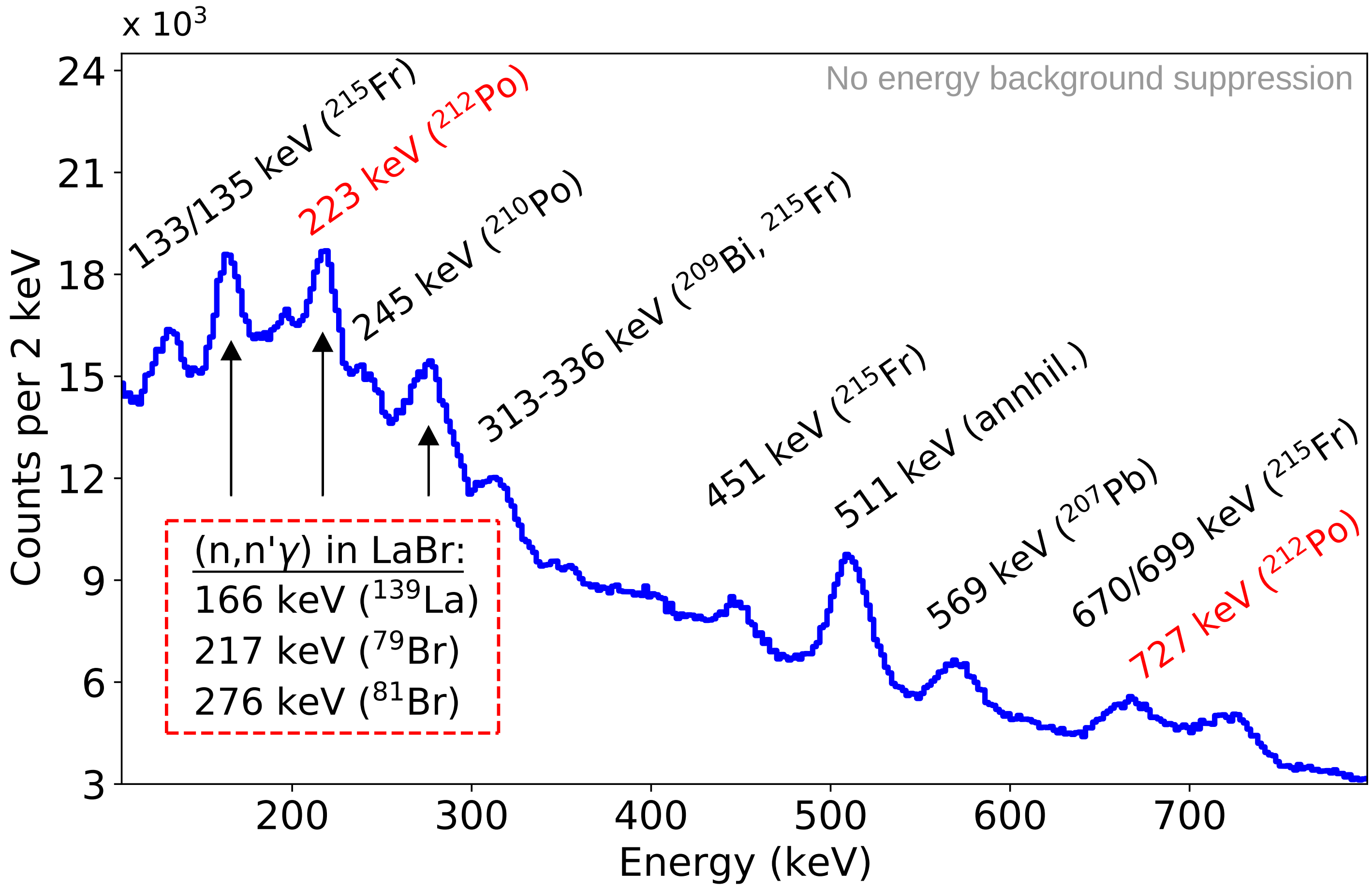
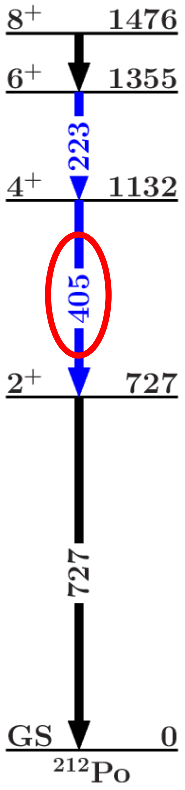
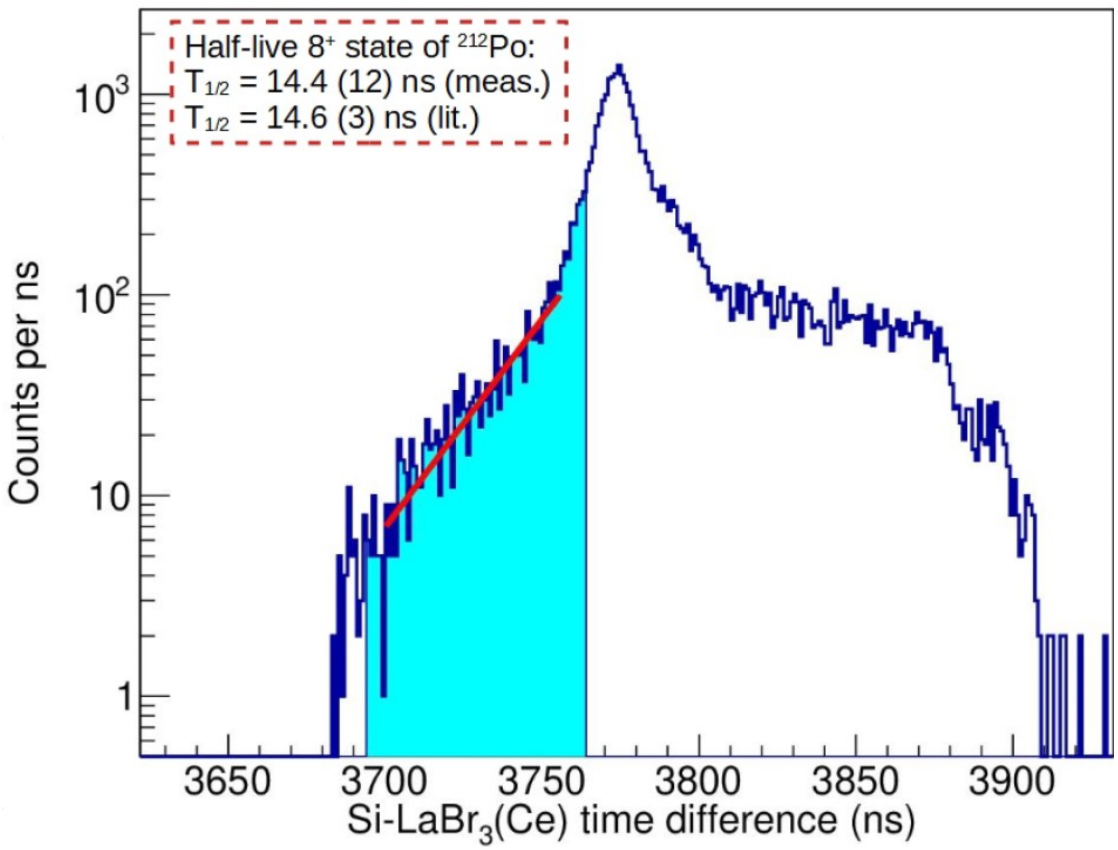
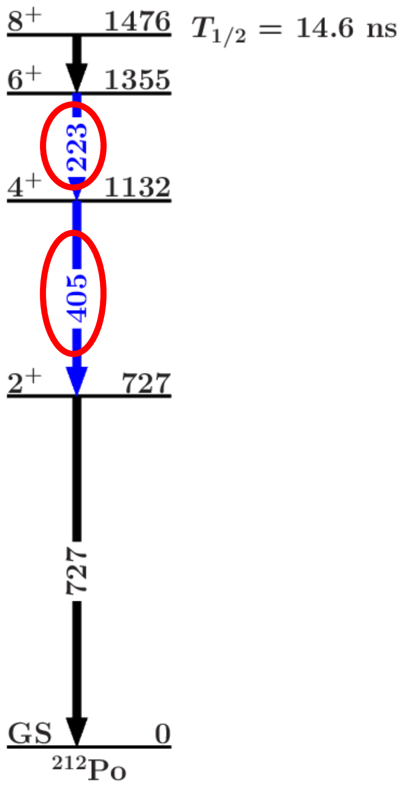




Si-LaBr time difference (SLTD) spectrum

- $LaBr_3$(Ce) - $LaBr_3$(Ce) coincidence gate on the 223 keV-405 keV transitions





Lifetime determination of 4_1^+ state of ^{212}Po

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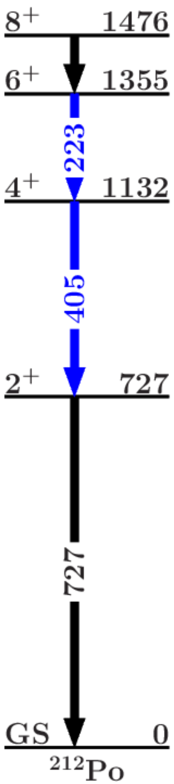
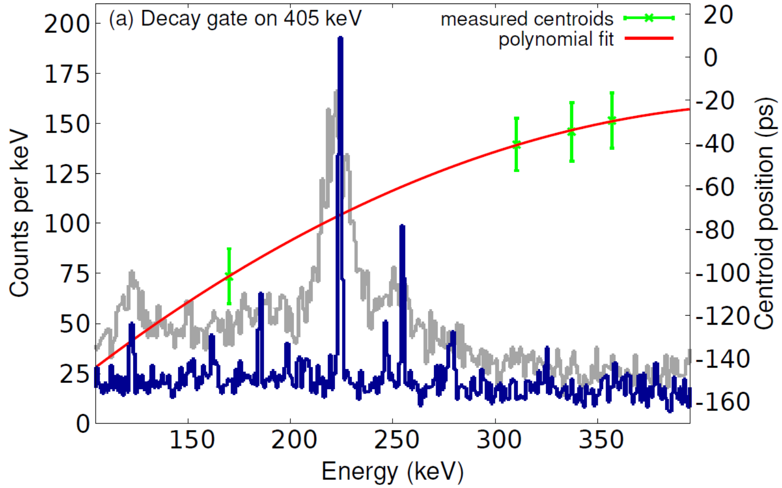
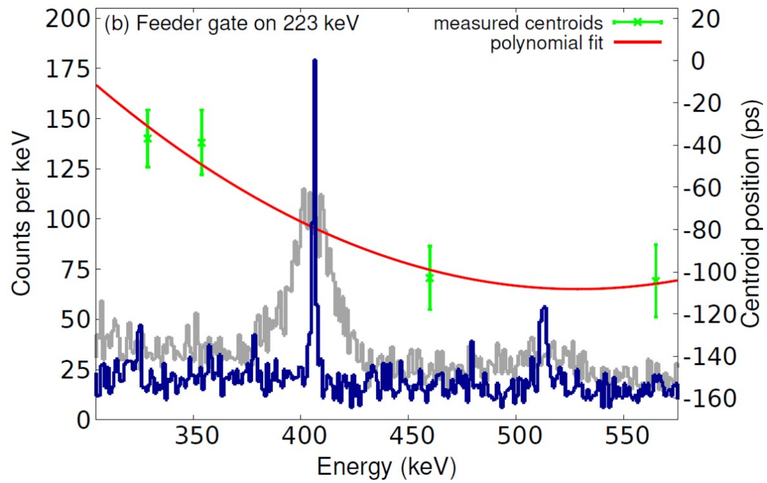
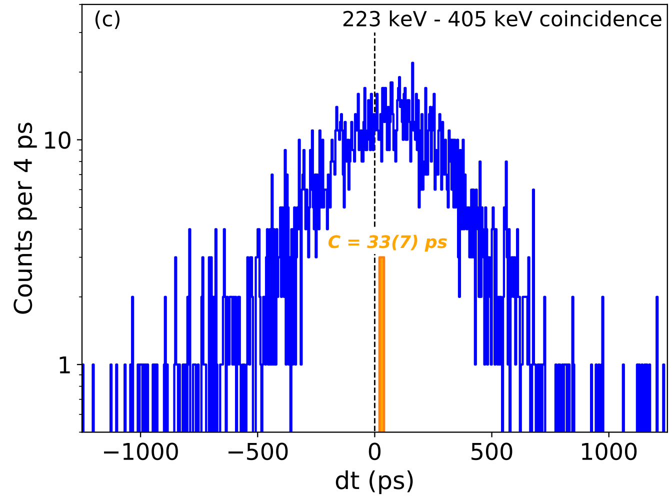








$$\tau_{4_1^+} = C^D_{cor}(223\,\mathrm{keV}, 405\,\mathrm{keV}) - PRC(223\,\mathrm{keV}, 405\,\mathrm{keV})$$

- With Compton timing background correction according to Ref. [5]

$$PRC(223\,\mathrm{keV}, 405\,\mathrm{keV}) = -7(7)ps$$

$$C^D_{cor}(223\,\mathrm{keV}, 405\,\mathrm{keV}) = 93(10)ps$$

$$\tau_{4_1^+} = 100(14)ps$$

[5] J.-M. Régis et al. NIM A955 163258, 2019

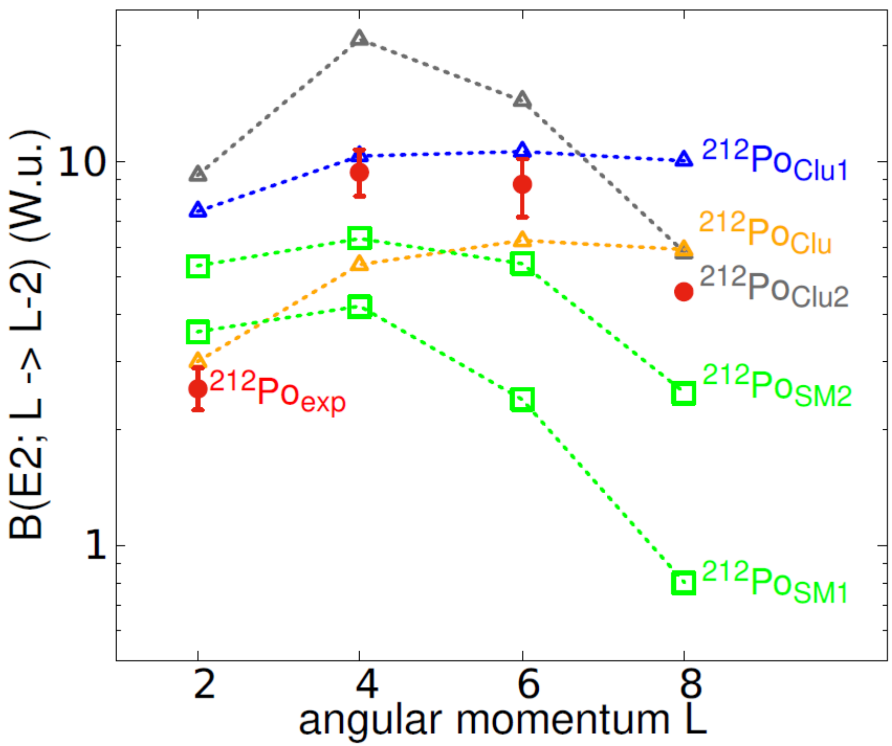
Discussion

- Lifetime of the low-lying yrast states could be determined

State I	mean lifetime τ this work	lit.	B(E2; I → I-2)
2_1^+	16(13) ps	20.5(26) ps	2.6(3) W.u.
4_1^+	100(14) ps	-	9.4(13) W.u.
6_1^+	1.66(28) ns	1.1(3) ns	8.7(15) W.u.
8_1^+	20.8(17) ns	21.1(4) ns	4.6(1) W.u.

- α-cluster components play an important role in the structure of these states

State I	ω_I	$\Gamma_\alpha(I)/\hbar$ in s^{-1}
0_1^+	0.116	$2.36\ 10^6$
2_1^+	0.170	$1.02\ 10^8$
4_1^+	0.199	$2.32\ 10^8$
6_1^+	0.190	$7.49\ 10^7$
8_1^+	0.158	$4.99\ 10^6$



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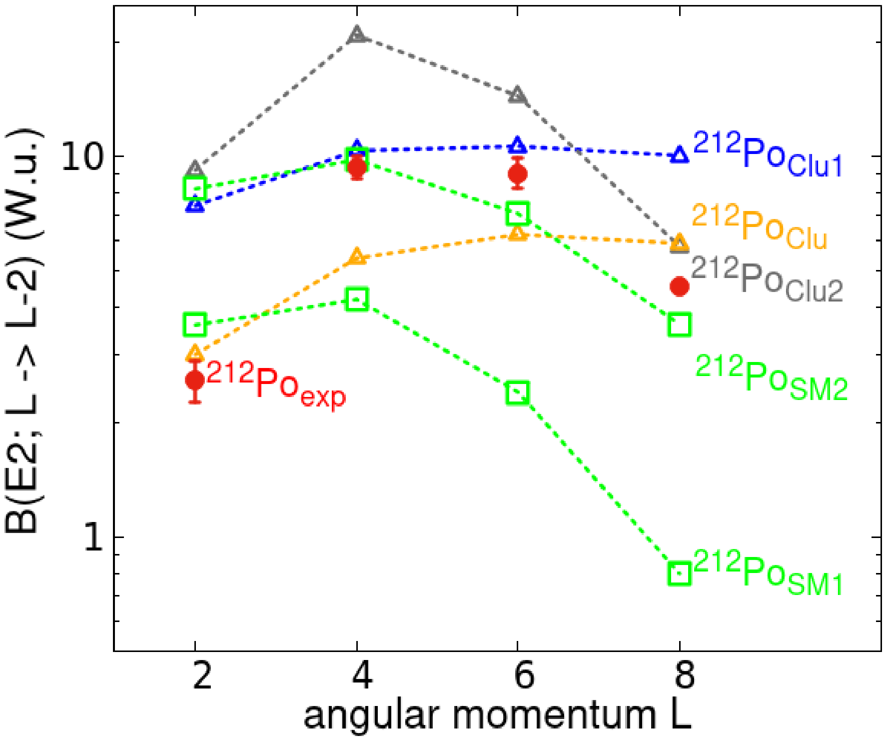
Lifetimes confirmed by RDDS [6]:
4^+: 101(7) ps
6^+: 1.65(15) ns

- **For theorists and experimentalists, there is still work to be done**
  - **State dependent effective charge?**



[6] V. Karayonchev et al., Phys. Rev. C 106:064305, 2022

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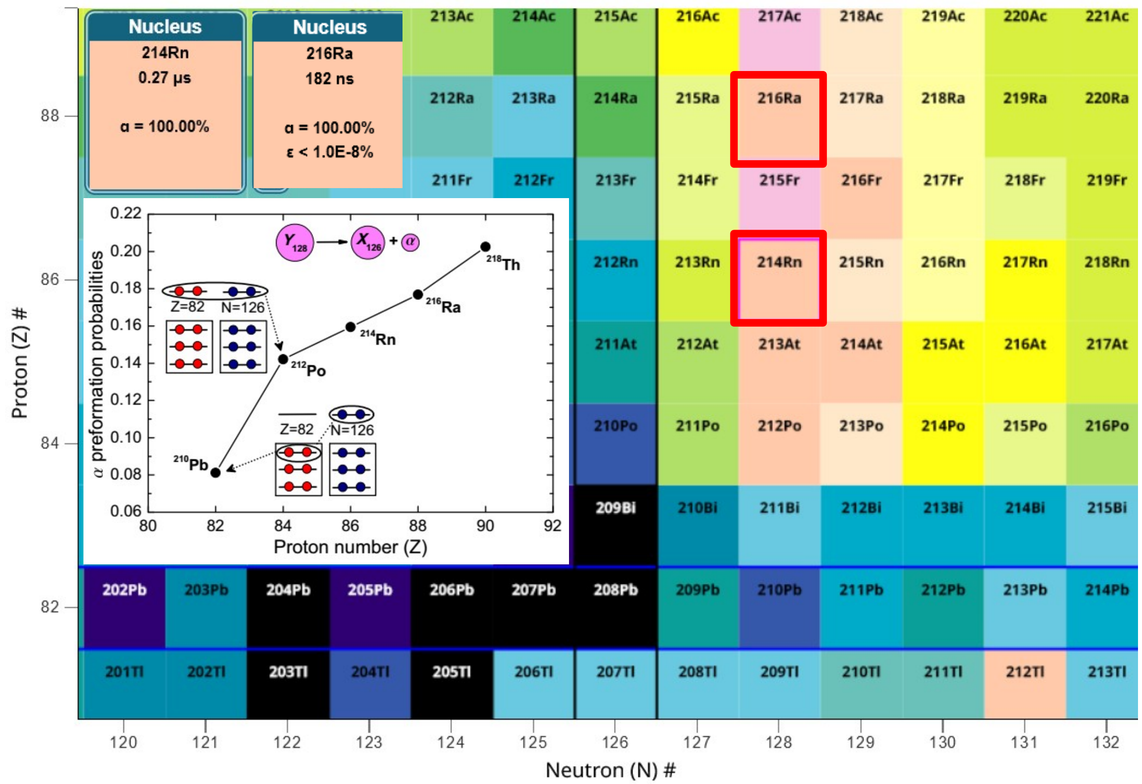
[SM2] V. Karayonchev et al., Phys. Rev. C 106:064305, 2022
[Exp] NNDC and V. Karayonchev et al., Phys. Rev. C 106:064305, 2022

Outlook

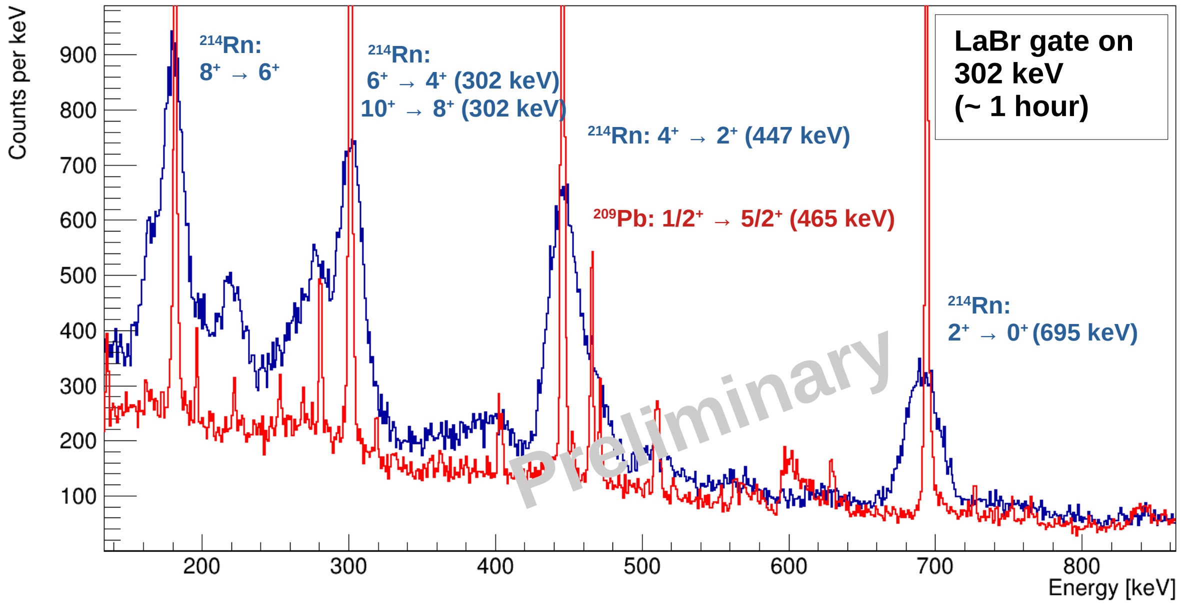
- Measuring unknown lifetimes of the low-lying yrast states from ^{214}Rn and ^{216}Ra
  - Strong α-preformation



Figures are taken from NNDC and
Chang Xu et al., Phys. Rev. C 95, 061306(R) (2017)

Outlook

- Measuring unknown lifetimes of the low-lying yrast states from ^{214}Rn and ^{216}Ra
  - Strong α-preformation
- Successful ^{214}Rn experiment last month with the same setup at IFIN-HH ^{208}Pb(^{9}Be,3n)^{214}Rn



Special thank the collaboration:

Ma. von Tresckow[a,*], M. Rudigier[a], T. M. Shneidman[b], Th. Kröll[a], M. Boromiza[c], C. Clisu[c], C. Costache[c], D. Filipescu[c], N. M. Florea[c], I. Gheorghe[c], K. Gladnishki[d], A. Ionescu[c], D. Kocheva[d], R. Lică[c], N. Mărginean[c], R. Mărginean[c], K. R. Mashtakov[e,g], C. Mihai[c], R. E. Mihai[c], A. Negret[c], C. R. Nita[c], A. Olacel[c], A. Oprea[c], S. Pascu[c], G. Rainovski[d], T. Sava[c], M. Scheck[e], P. Spagnoletti[e,f], C. Sotty[c], L. Stan[c], I. Stiru[c], S. Toma[c], A. Turturică[c], S. Ujeniuc[c]

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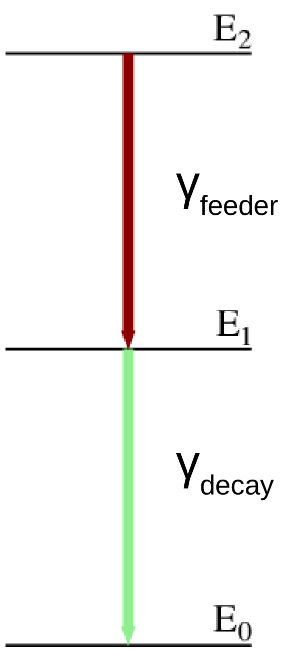
Thank you for your attention!

For more informations: Ma. von Tresckow et al., PLB 821, 136624 (2021)

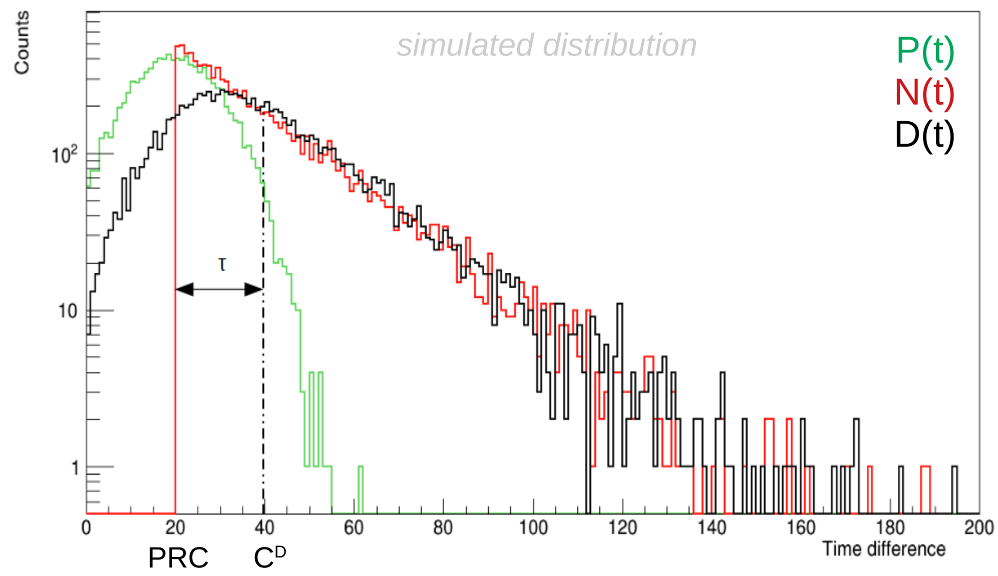
Backup slides

Lifetime determination applying Centroid shift method

- Time difference spectrum D(t) between Feeder and Decay
  => convolution of decay rate N(t) and prompt response P(t)



$$D(t) = N(t) * P(t)$$



$$C^D(E_{feeder},\ E_{decay}) = \tau + PRC(E_{feeder},\ E_{decay})$$

Lifetime determination applying Centroid shift method

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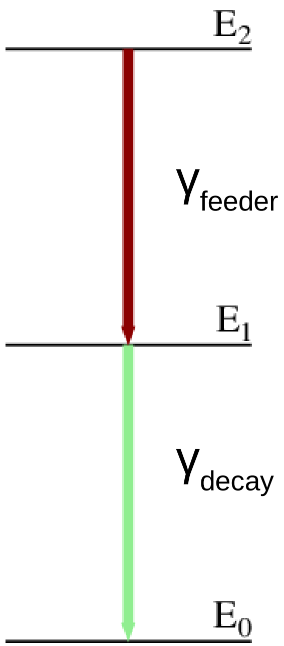

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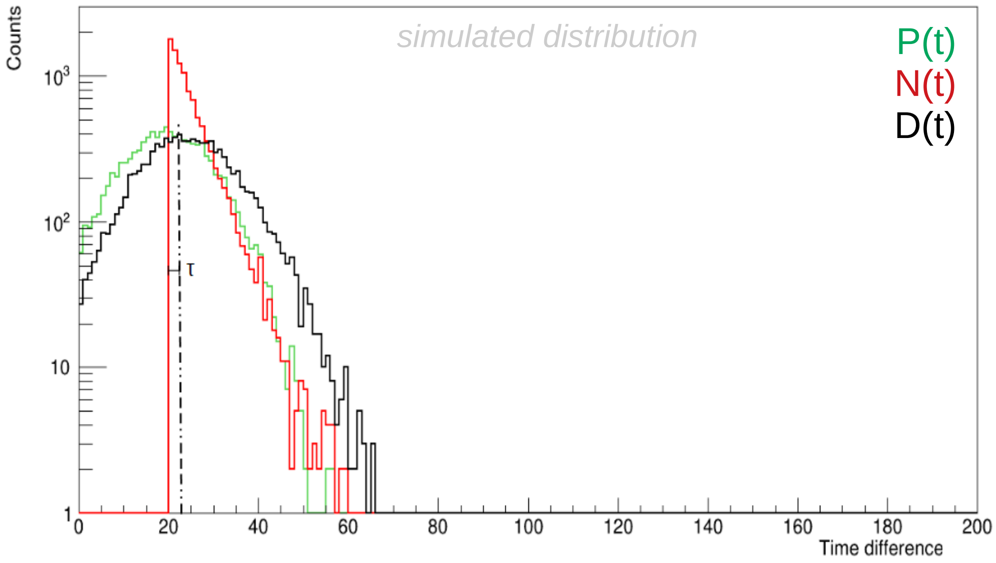

$$C^D(E_{feeder},\ E_{decay}) = \tau + PRC(E_{feeder},\ E_{decay})$$

Prompt response centroid (PRC) curve

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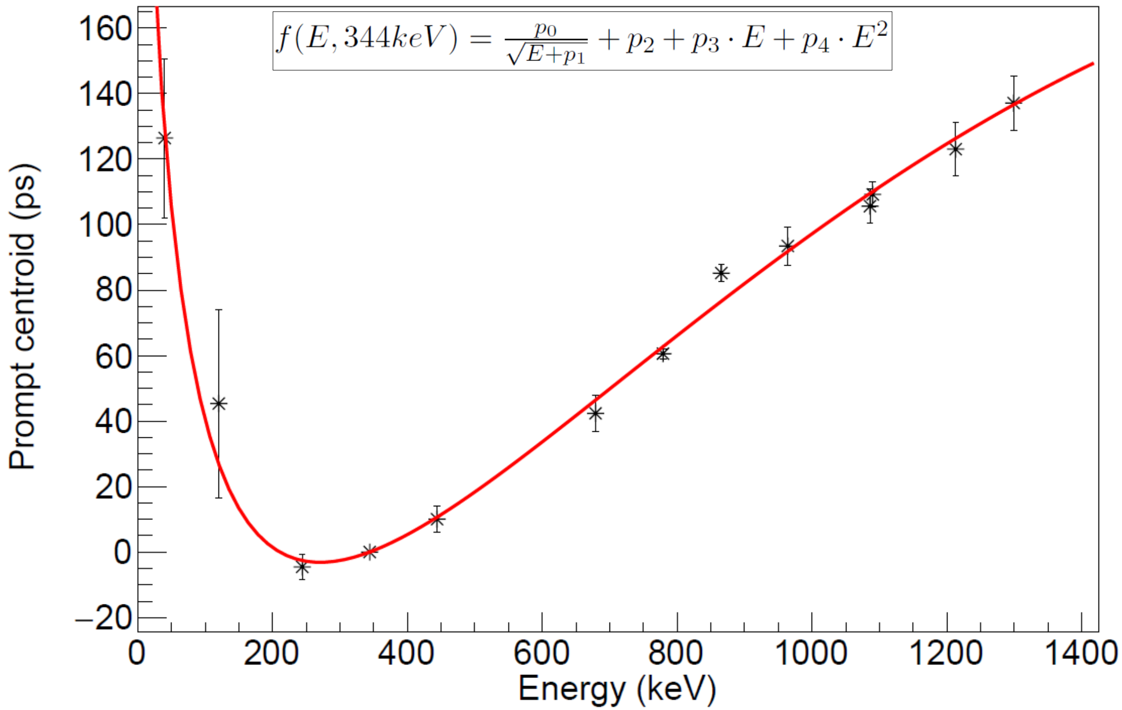
- Calibrated using ^{152}Eu source

measured

known

$$PRC(E_{feeder}, E_{decay}) = C^D(E_{feeder}, E_{decay}) - \tau$$

- PRC to reference energy 344 keV as decay: PRC(E, 344 keV)



Lifetime determination of 6_1^+ state of ^{212}Po

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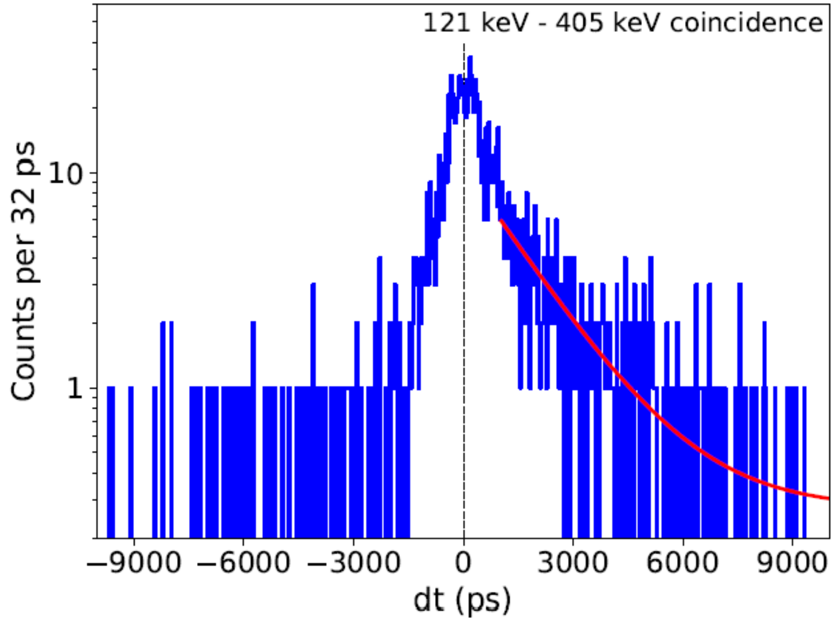
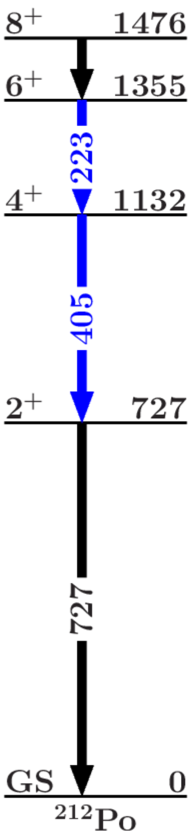
- Only once measured so far [1]: τ_{lit} = 1.1(3) ns
  [1] A. Poletti et al. Nucl. Phys. A473, 1987

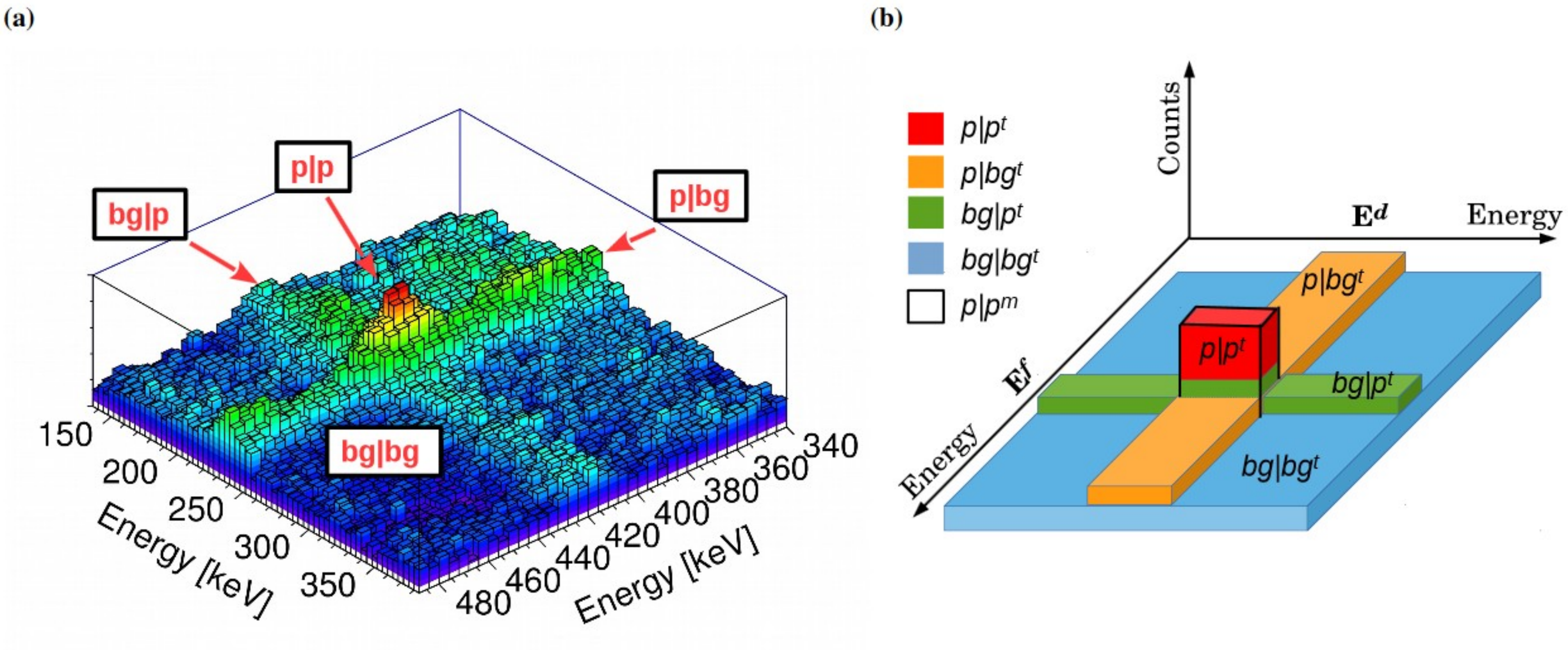




- Slope method: τ = 1.75(26) ns
  Centroid shift method: τ = 1.56(30) ns
- Average: τ = 1.66(28) ns

Compton background correction

Compton background



E.R. Gamba et al., Nuclear Physics Research Section A 928:93 – 103, 2019

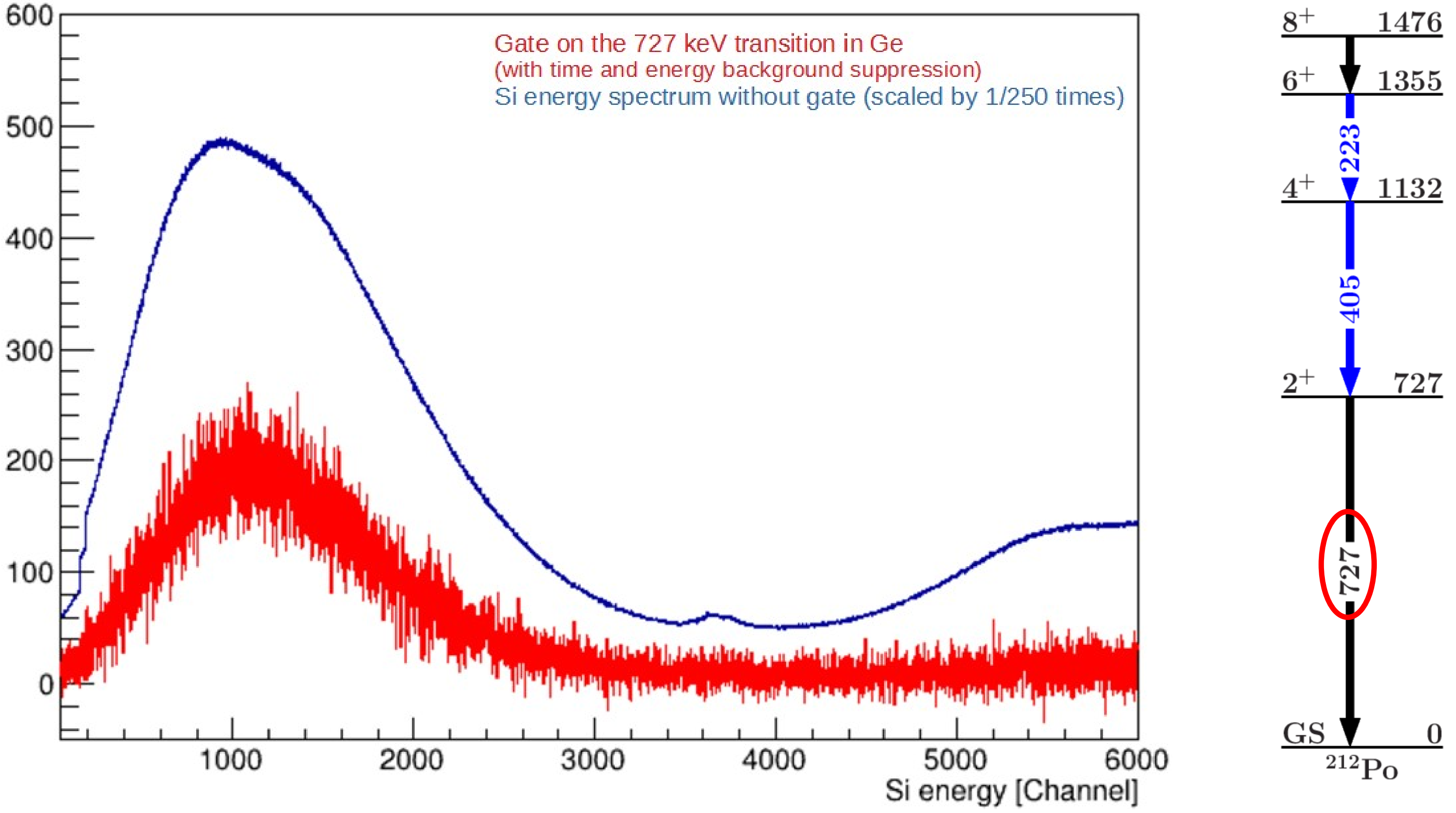
“Analytical time-correction” (ATC)

$$C^{t}_{p/p} = C^{m}_{p/p} + \widetilde{t}_{cor}$$

$$\widetilde{t}_{cor} = \frac{P/B(E_f)\cdot t_{cor}(E_d) + P/B(E_d)\cdot t_{cor}(E_f)}{P/B(E_f) + P/B(E_d)},$$

$$t_{cor}(E_f) = \frac{C^{m}_{p/p} - C^{m}_{bg/p}}{P/B(E_f)} \qquad t_{cor}(E_d) = \frac{C^{m}_{p/p} - C^{m}_{p/bg}}{P/B(E_d)}.$$

Si energy gate



Experimental runs

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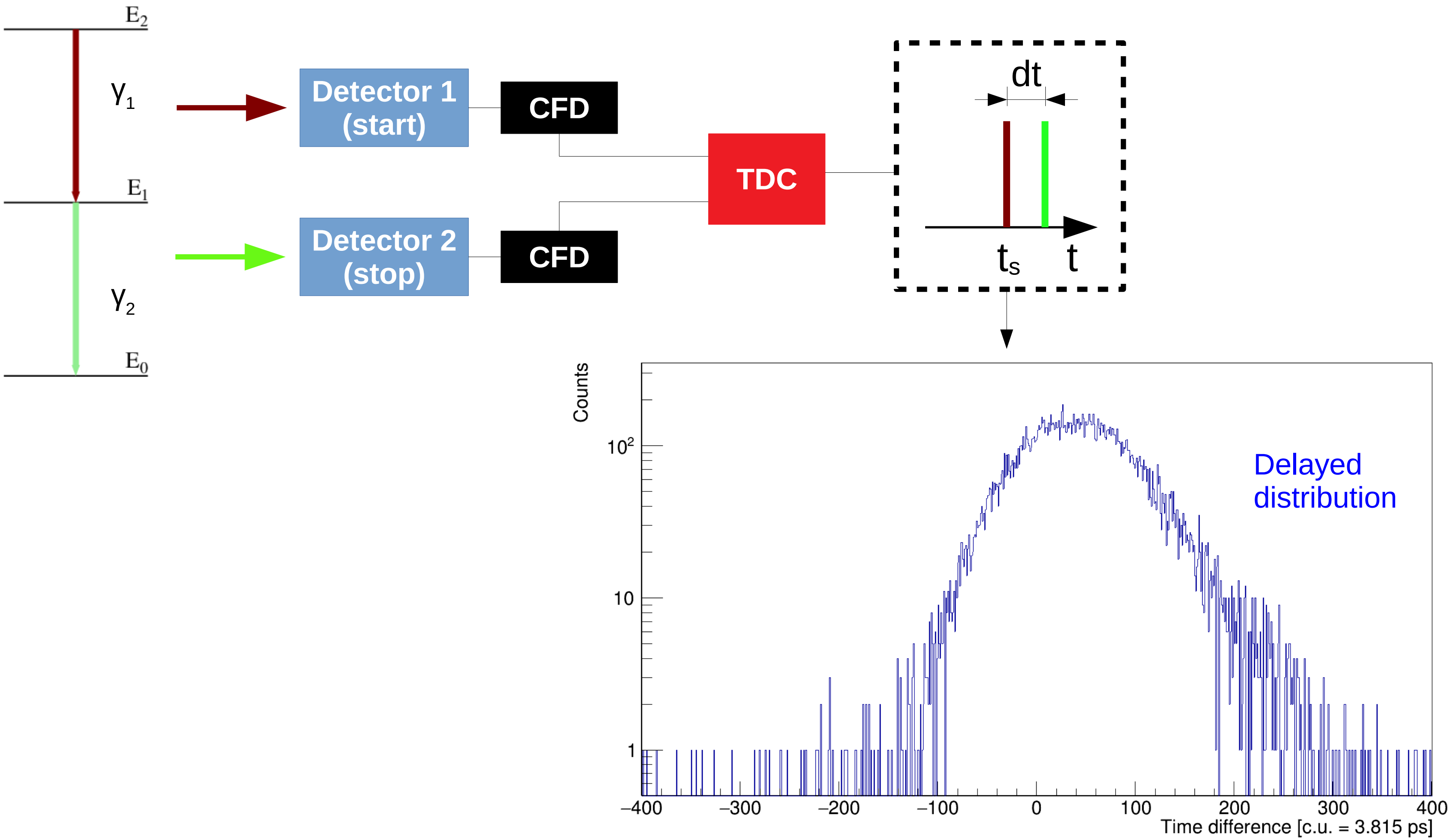
Name of the run	Source	Length [days]	Trigger
Eu-before	^{152}Eu	2	LaBr + LaBr
LaBr-centre	^{138}La	3	LaBr-centre + LaBr-ring
Run/NRun	^{10}B beam @ ^{208}Pb target	1	Ge + Ge (LaBr +) LaBr + Ge
1LRun	^{10}B beam @ ^{208}Pb target	2	Ge + Ge LaBr + Ge
SRun	^{10}B beam @ ^{208}Pb target	10	LaBr + Si Ge + Ge

Delayed time difference distribution



Anti-delayed time difference distribution

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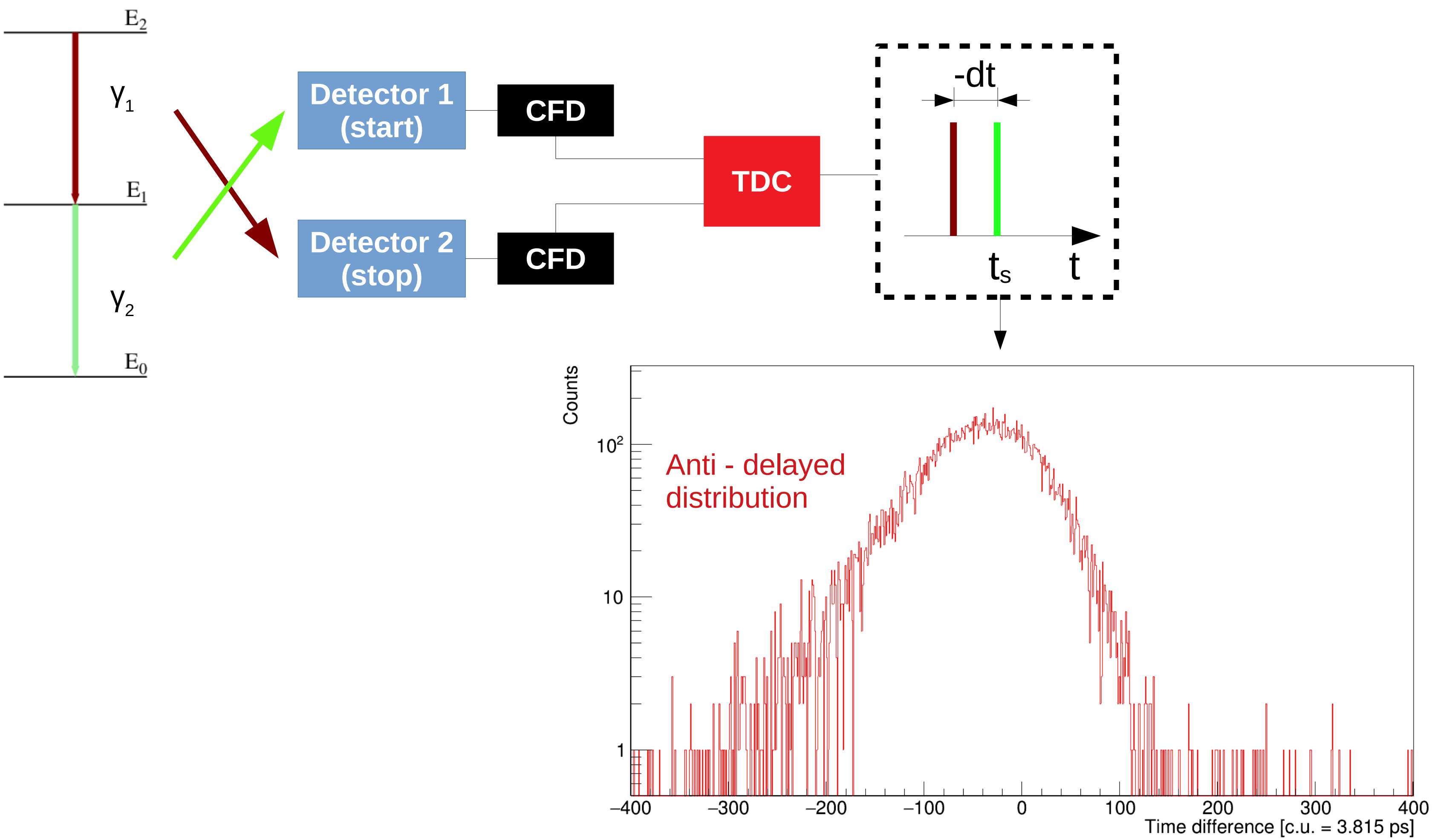

PRC values from ^{152}Eu source

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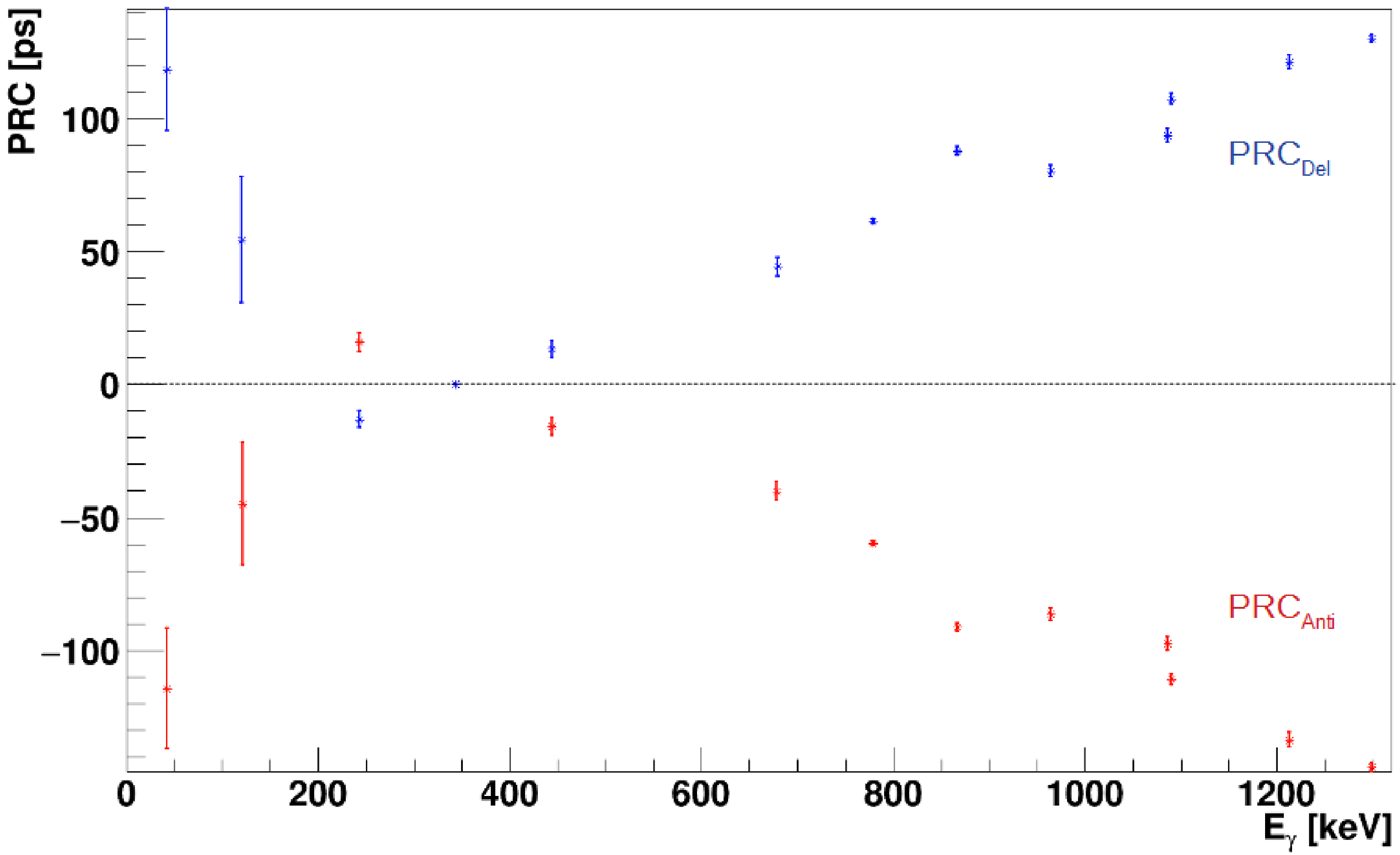
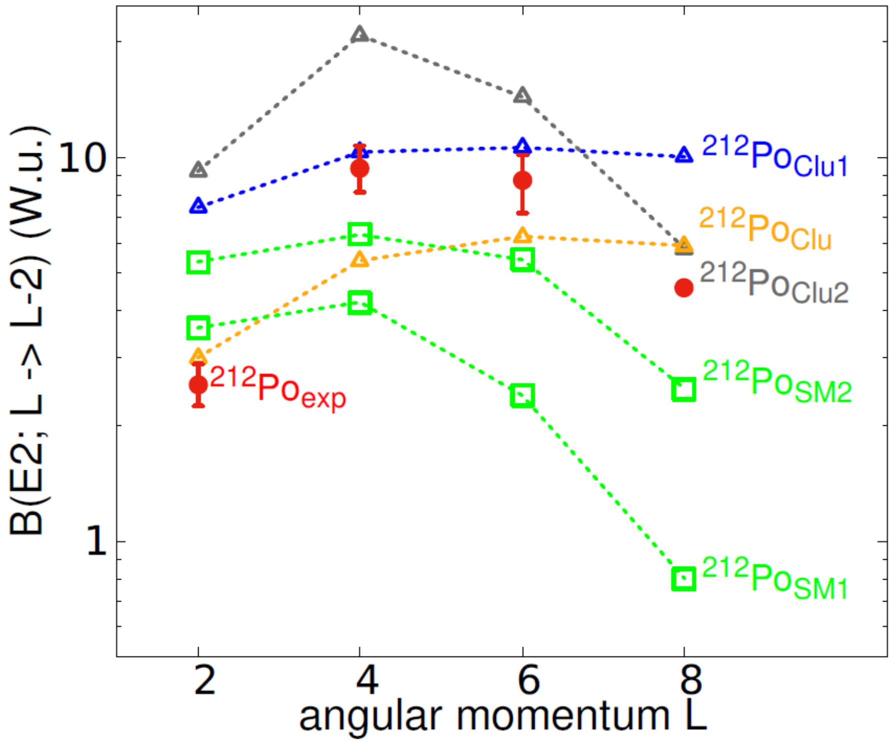


Clustering models

- Clu:
  - Dinuclear system model
  - Cluster-type shapes are produced by the collective motionof the nuclear system in asymmetry coordinates
  - Wave function of the nucleus is treated as a superposition of a mononucleus and cluster configurations
  - Excitation energy of the low-yrast states are not determined in this work, the theoretical energy are fitted to the experimental results



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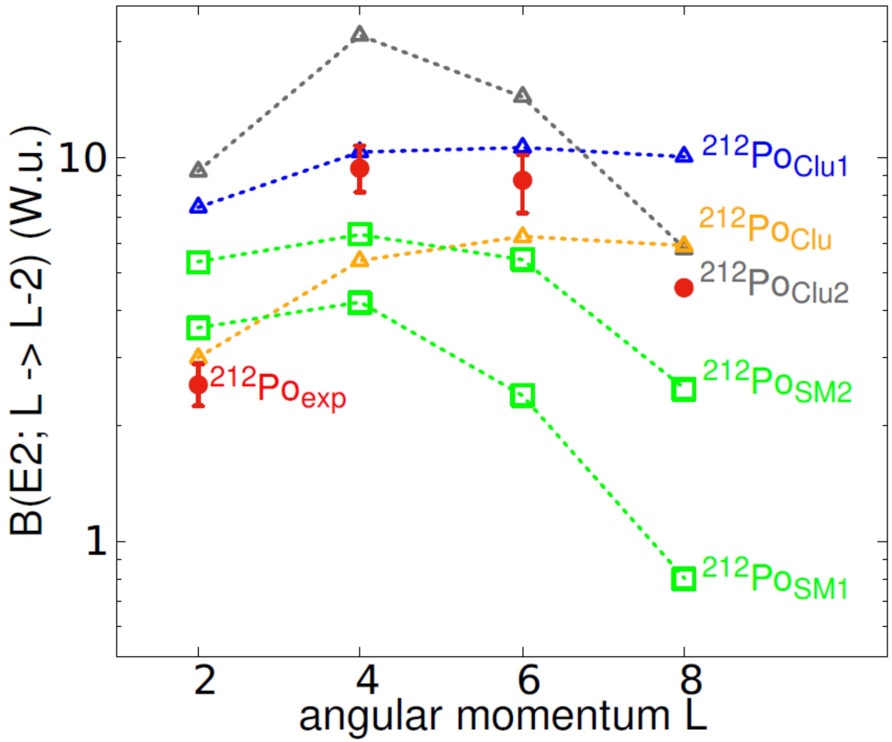
[SM2] H. Naïdja Phys. Rev. C 103:054303, 2021
[Exp] NNDC and this work

Clustering models

- Clu1:
  - Optical potential deduced from experimentally known charge distributions

    U(r) = V(r) + i W(r)
  - Wave functions are determined applying the DWBA
  - Small alpha branchings are predicted



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Clustering models

- Clu2:
  - Add to each single particle shell model radial wave function a cluster component

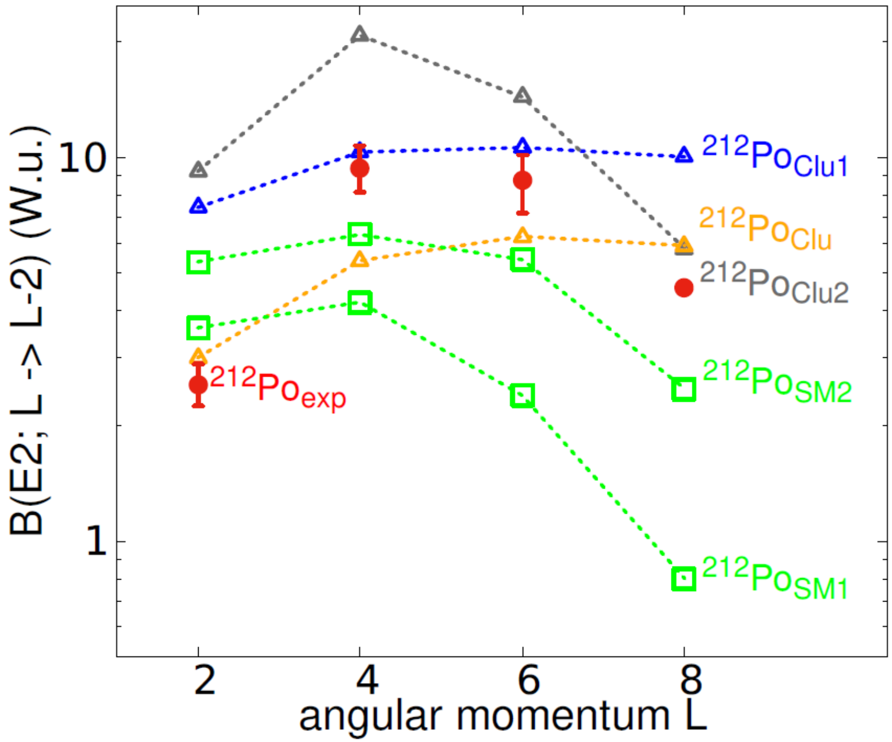
$$\psi_l(r) = \psi_l^{(\mathrm{SM})}(r) + \psi_l^{(\mathrm{clus})}(r),$$

$$\psi_l^{(\mathrm{SM})}(r) = \sum_{N \leqslant N_0} b_{nl}(-)^n \mathcal{R}_{nl}^{(\beta_0)}(r).$$

$$\psi_l^{(\mathrm{clus})}(r) = \sum_{N} c_{nl}(-)^n \mathcal{R}_{nl}^{(\beta)}(r),$$

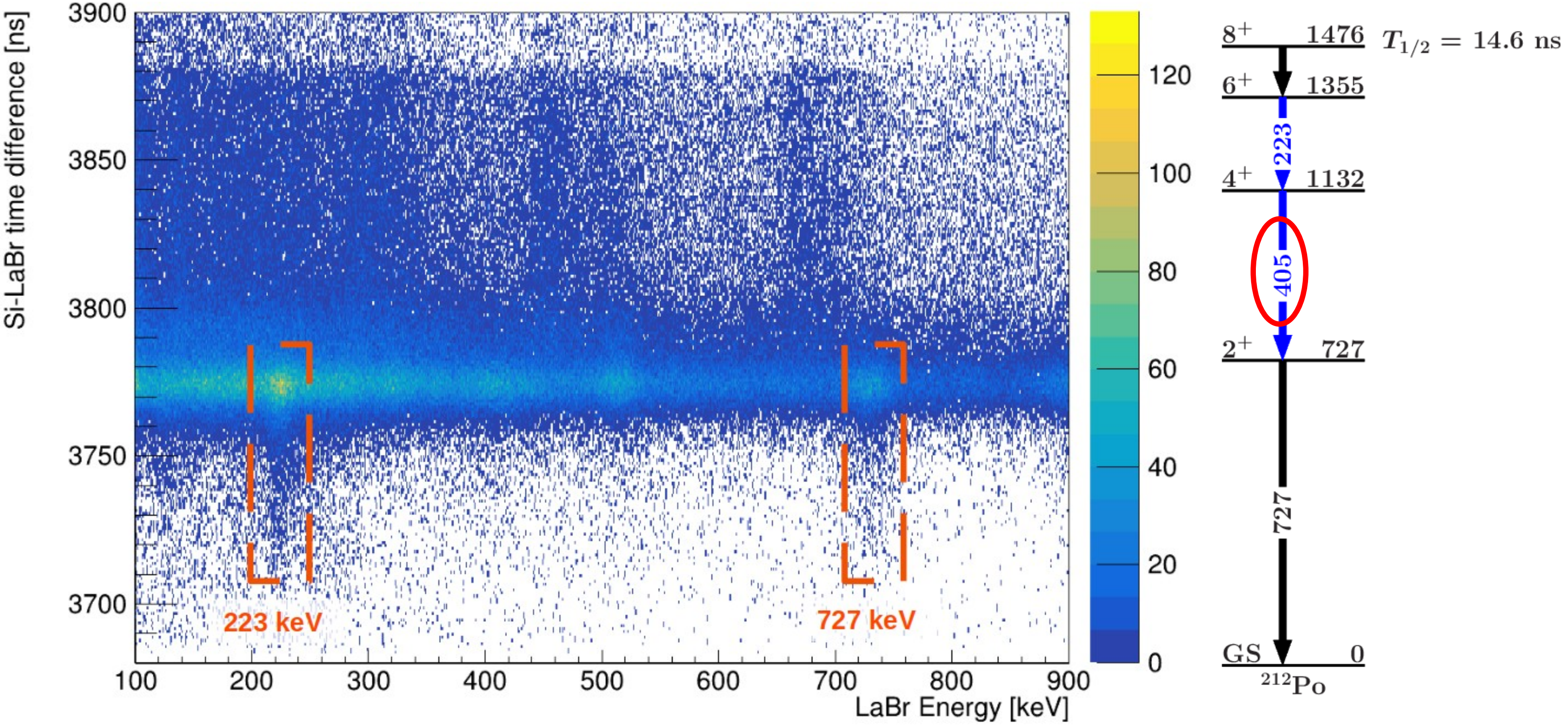
$N > N_0$ (= 5,6)

  - b_{nl} and c_{nl} can determined by diagonalizing the potential mean field
  - Or diagonalizing the residual two-body interaction
  - Basis contains single partical Gaussian-like wave functions: $\psi_l^{(\mathrm{clus})}(r) = \mathcal{N}_l^{(\mathrm{clus})} e^{-\beta_c (r-r_0)^2/2},$



[Clu] T.M. Shneidman from the collaboration
[Clu1] F. Hoyler et al., Rev. C, 50:2631–2634, Nov 1994.
[Clu2] D. S. Delion et. al. Phys. Rev. C 85:064306, Jun 2012

SLTD – LaBr energy matrix



- LaBr energy gate on the 405 keV transition

Germanium spectrum low energy region