Lifetime measurement of ^{93}Ru and ^{94}Ru: Seniority symmetry breaking

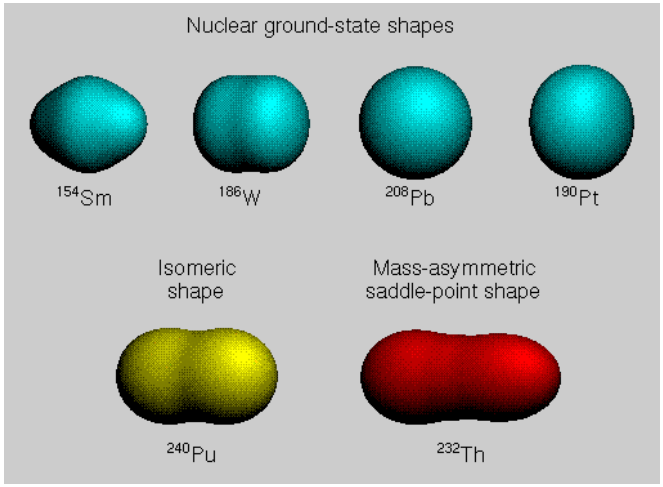
NP2112-RIBF212 : IDATEN Commissioning

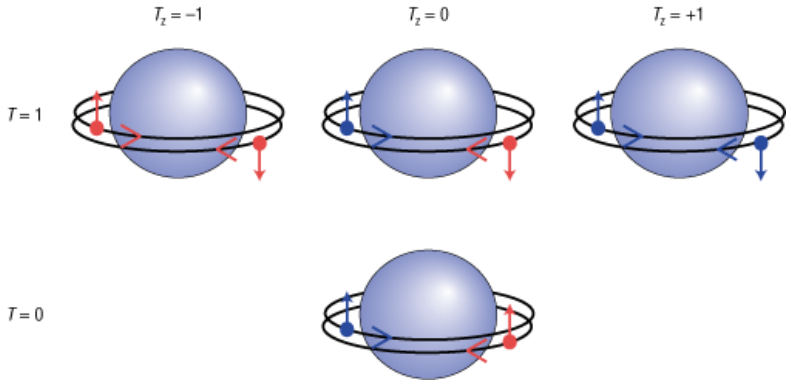
CENuM Workshop 2025

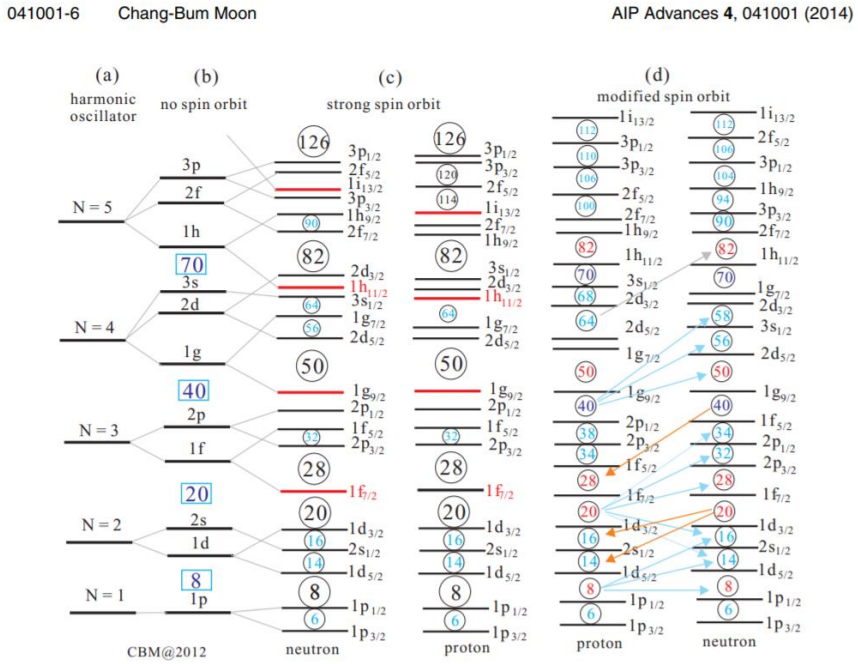
Jaehwan Lee

Lifetime Measurement for Nuclear Structure Study

- Level lifetime is an important probe for
  - nuclear deformation and shell evolution to exotic nuclei
  - seniority scheme and pairing property
    - n-n, p-p, p-n interactions and pairing behavior near shell closer







Chang-Bum Moon, AIP Advances 4, 041001 (2014)

Transition probability describes overlapping and mixing of orbitals

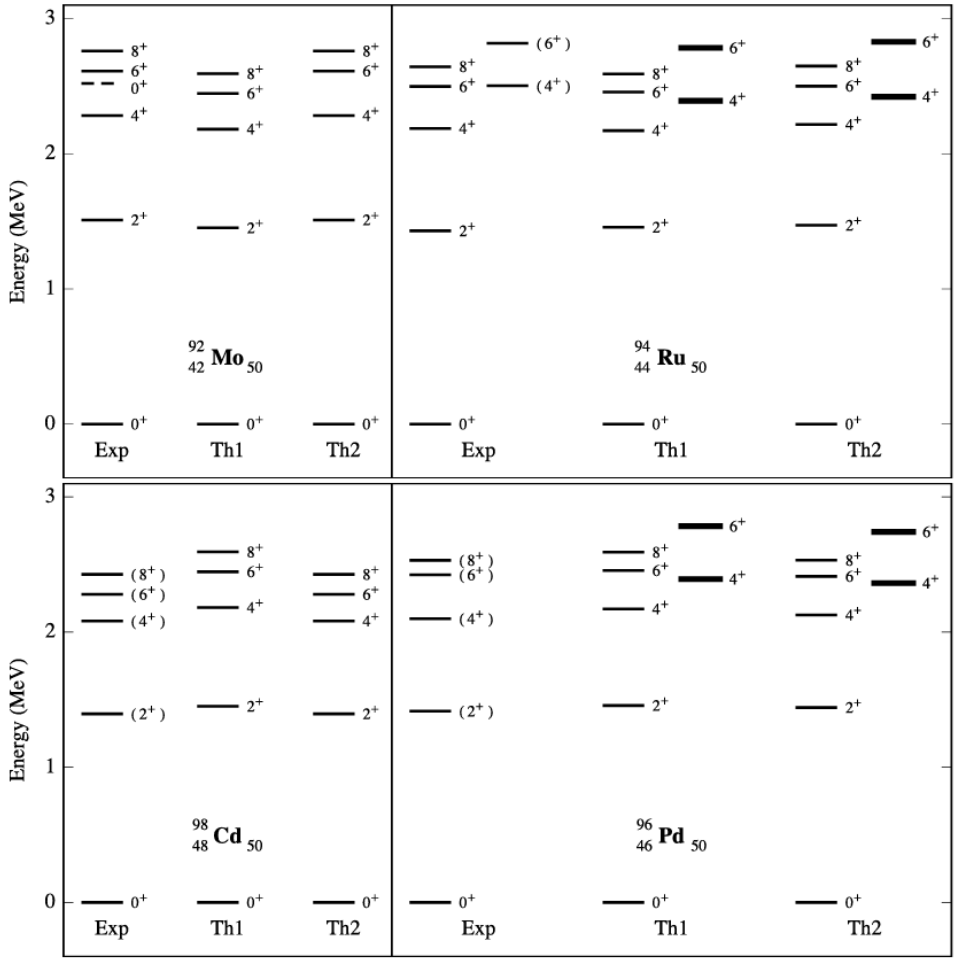
Seniority in N=50 semi-magic nuclei

- Seniority quantum number ν:
  number of nucleon not coupled to J=0
  (1 pair break$\rightarrow \nu = \nu + 2$)

- 10 proton slots for $\pi\, g_{9/2}$ shell

- ^{92}Mo, ^{98}Cd:
  2 valence protons (holes),
  2^+ state form by pair breaking

- ^{94}Ru, ^{96}Pd
  4 valence protons (or holes)
  making $4^+_{\nu=4}$, $6^+_{\nu=4}$ also.

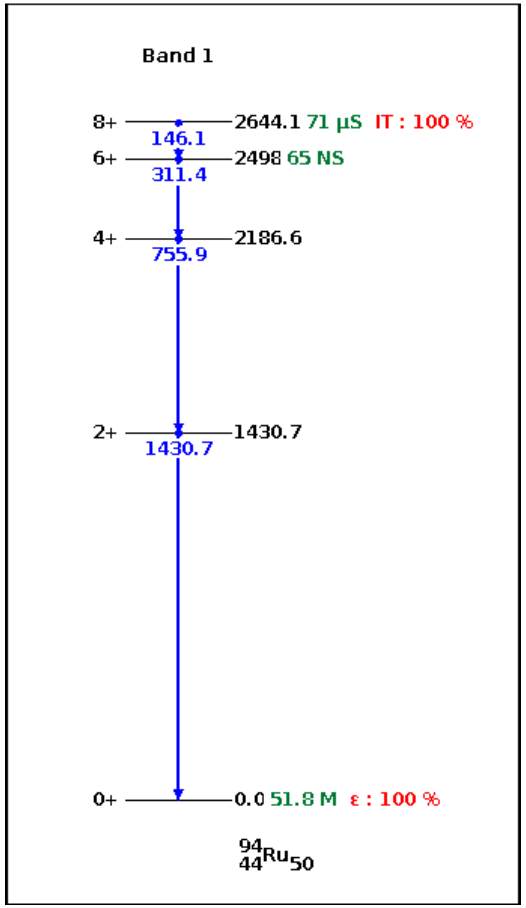


P. Van Isacker, S. Heinze / Annals of Physics 349 (2014) 73–9

^{94}Ru anomaly

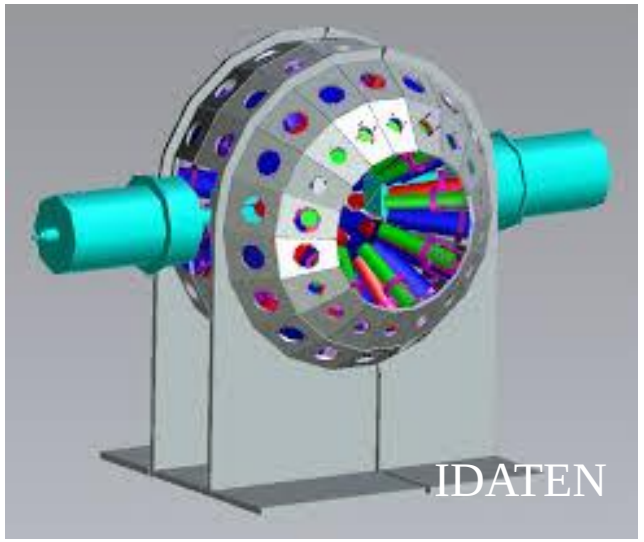
- Enhanced E2 transition probability from 4+ to 2+ was reported.
- Attributed to wave function mixing of $\nu = 2$ and $\nu = 4$ for 4+, 6+, ..
- Still need new precise value.

	population		τ [ps]	B(E2: 4+→2+) $[e^2\mathrm{fm}^4]$	reference
FATIMA @GSI	95Pd εp	$\gamma-\gamma$ coincidence	32 (11)	103 (24)	B. Das *et al.*, Phys. Rev. C **105**, L031304 (2022).
VAMOS++, AGATA @GANIL	92Mo-92Mo MNT	plunger	83 (8)	38 (3)	R. M. Pérez-Vidal *et al.*, Phys. Rev. Lett. **129**, 112501 (2022).
@Köln	92Mo $(\alpha, 2n)$ 94Ru fusion-evaporation	$\gamma-\gamma$ coincidence	66 (2)	50 (2)	M. Ley et al., Phys. Rev. C 110, 034320 (2024).
SM	SMLB		-	6.8	
	SDGN		-	85.2	
	SR88MHJM		-	7.4	
IDATEN @RIBF	94Ru IT	$\gamma-\gamma$ coincidence	[ ]		



IDATEN

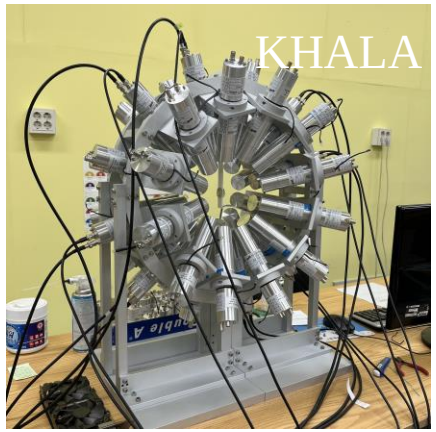
- **I**nternational **D**etector **A**ssembly for fast-**T**iming measurements of **E**xotic **N**uclei



World's largest fast-timing array
84 LaBr3(Ce)

=

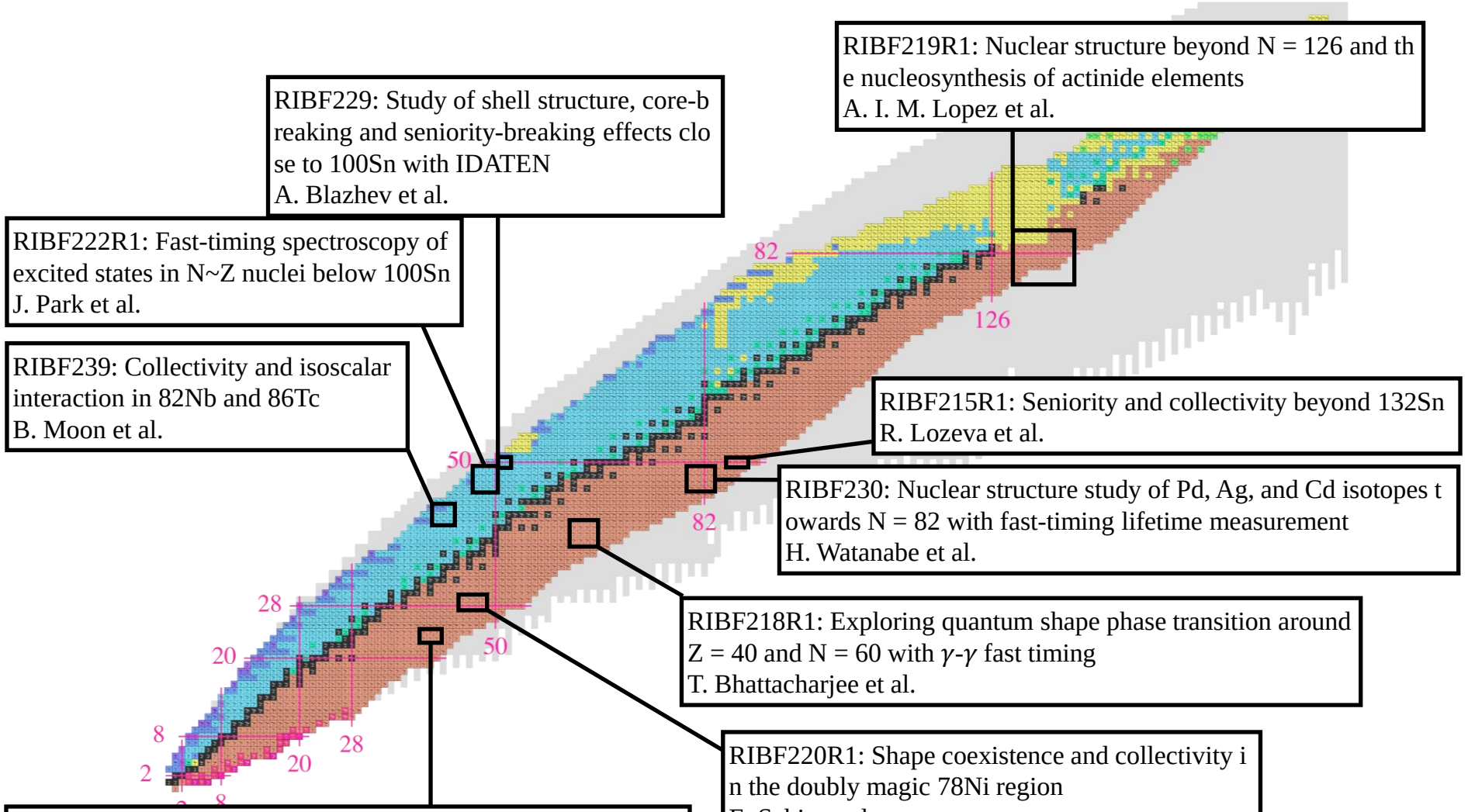
+



36 LaBr3(Ce) (U. Surrey, U. Brighton)
ϕ1.5″ x 2″
3.4% @779 keV
334 ps @1332-1173 keV
Optional Pb shield
M. Rudigier et al., NIMA 969, 163967 (2020).

36+12 LaBr3(Ce) (Korea Univ, SNU)
ϕ1.5″ x 1.5″
3.3% @779 keV
335 ps @511-511 keV
no Pb shield
B. Moon et al., NIMB 541, 253 (2023).

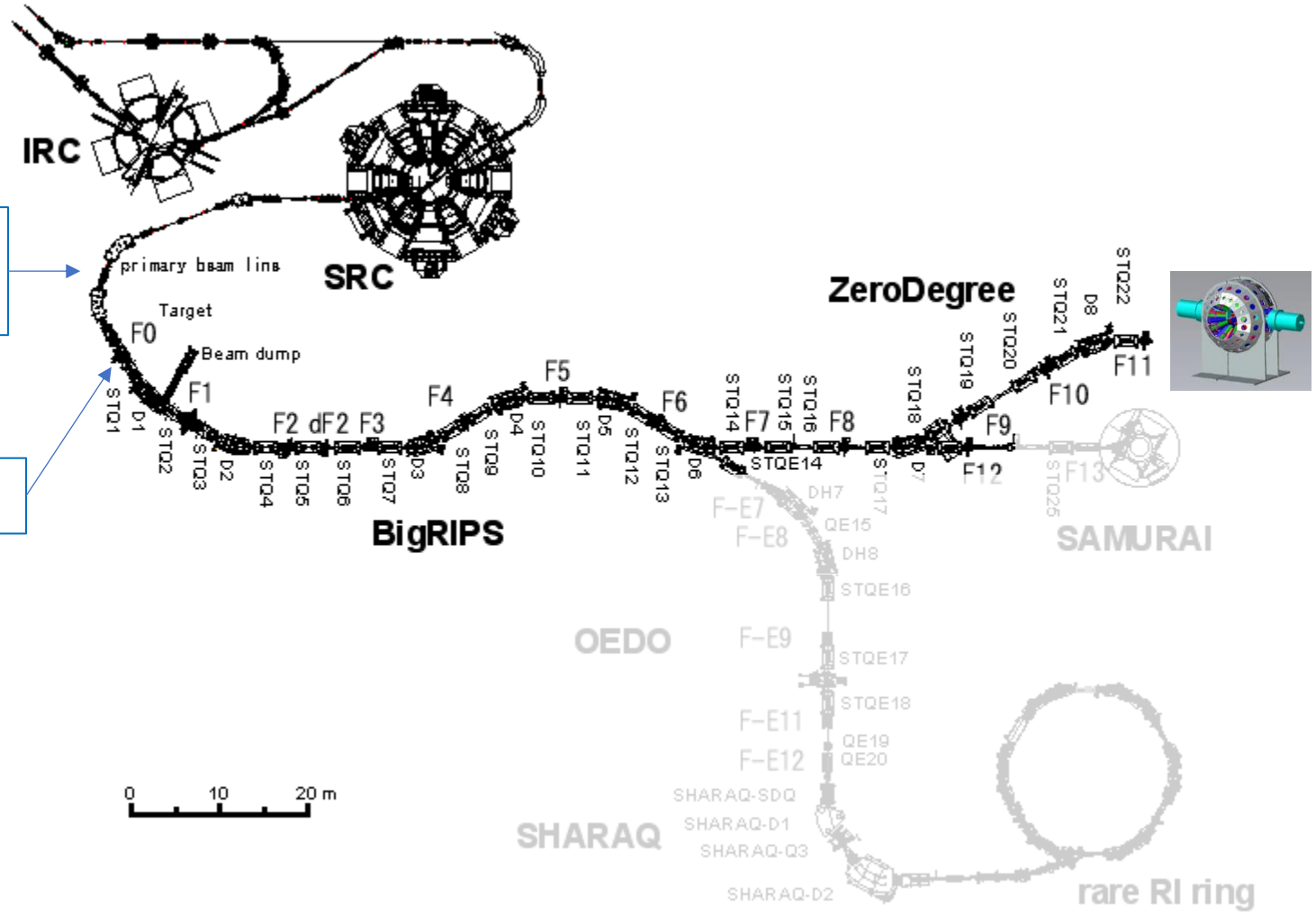
Approved Proposals



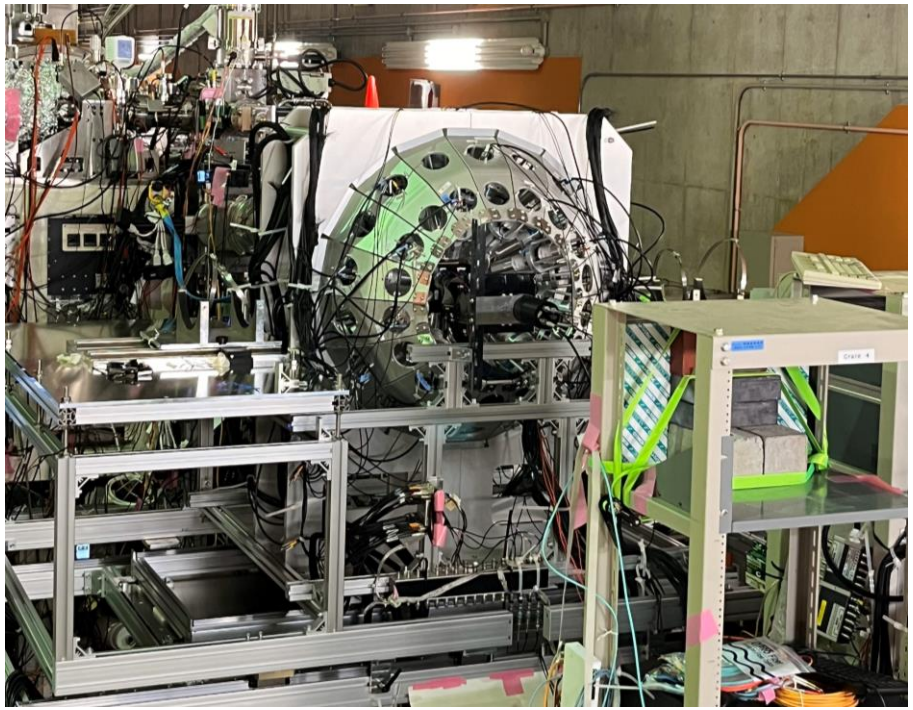
RIBF @RIKEN

^{124}Xe beam
345 MeV/u

^{9}Be target

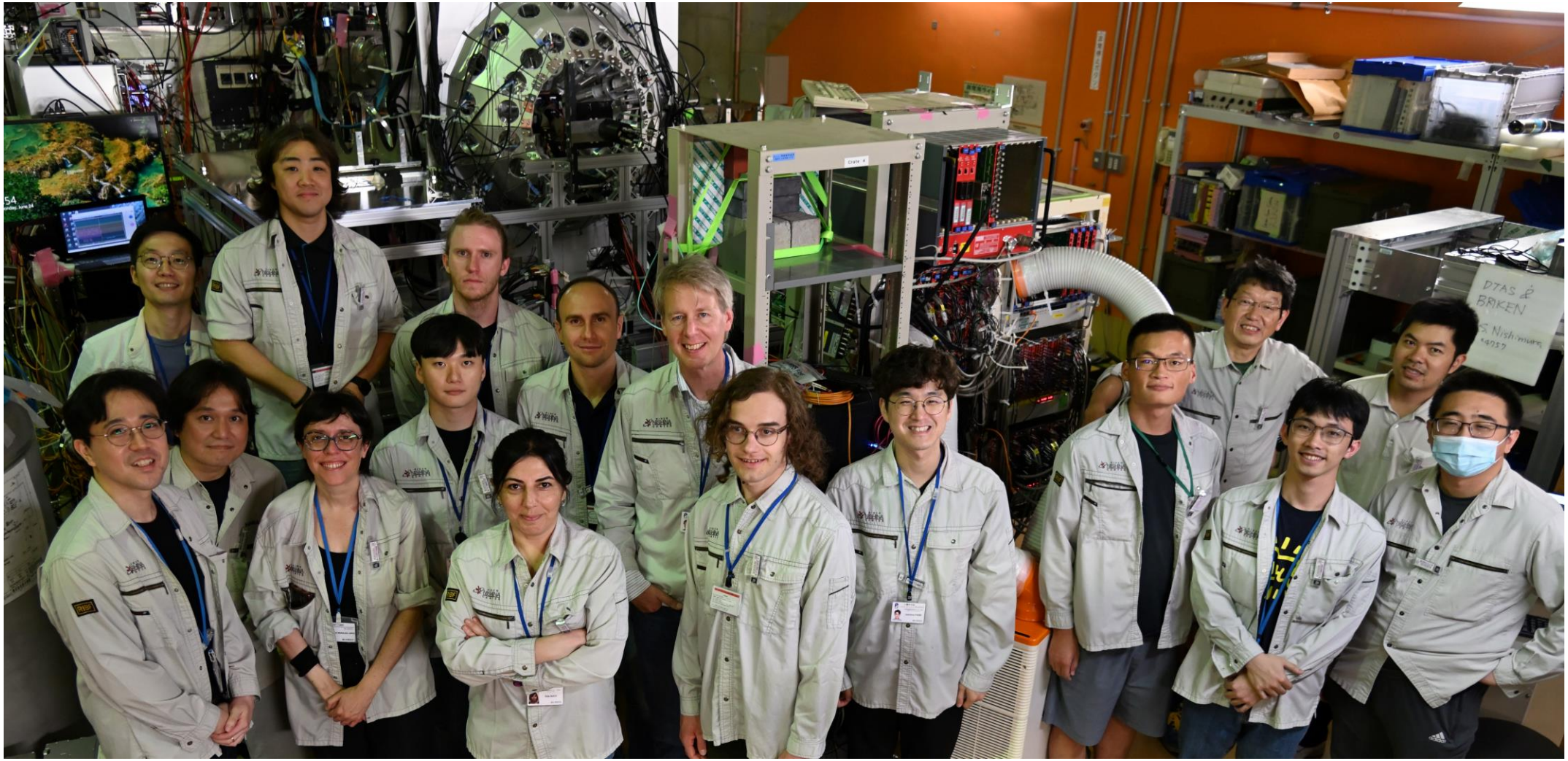


Installation @F11

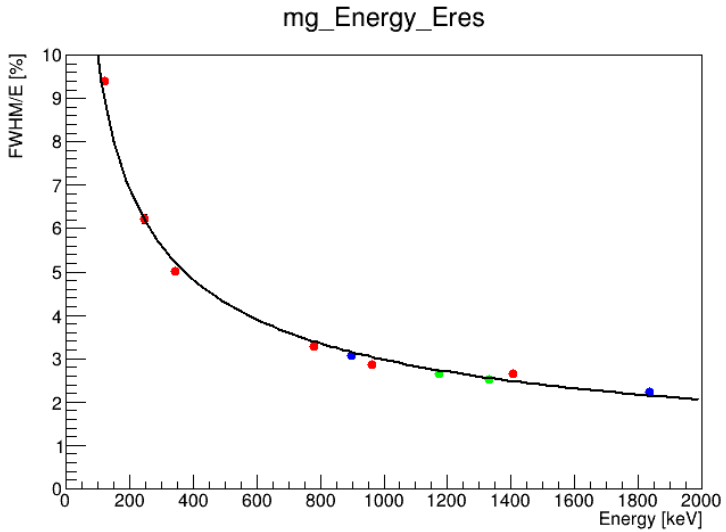


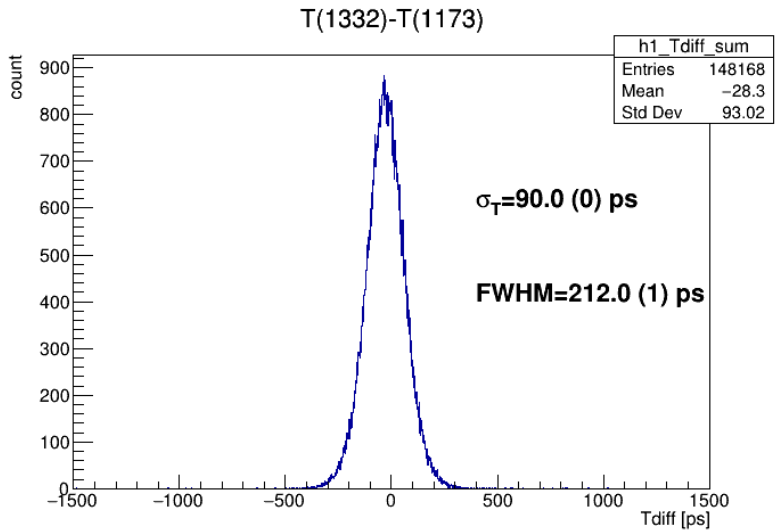
No Fatima, no HPGe this time :(

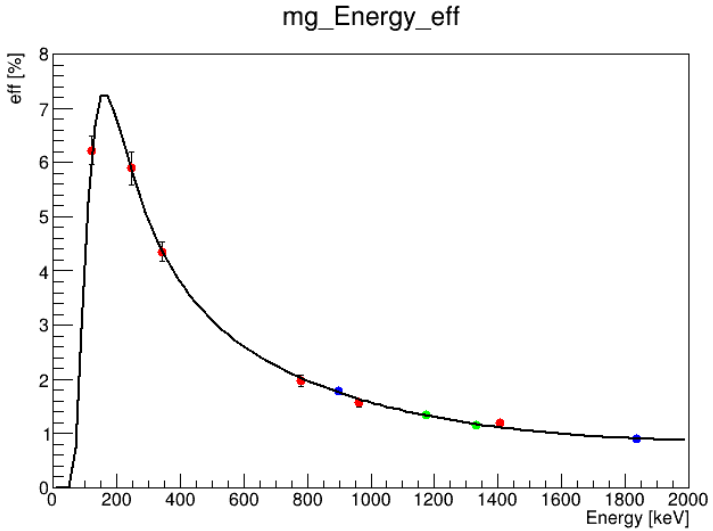
On-site participants

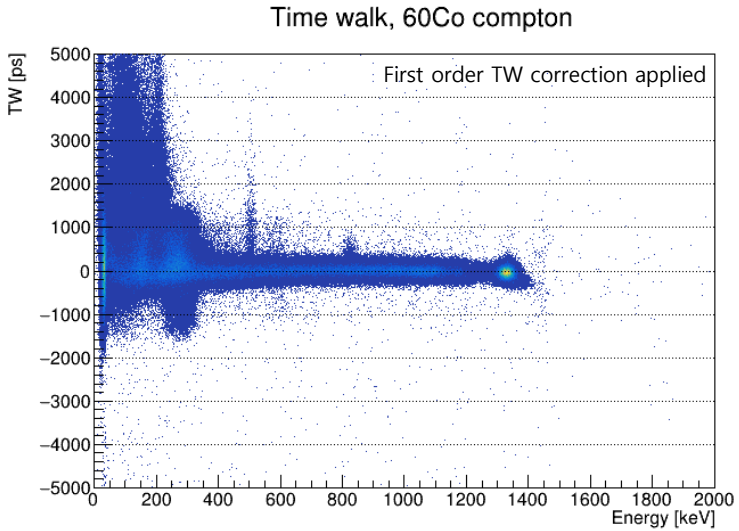


Performances (check source)



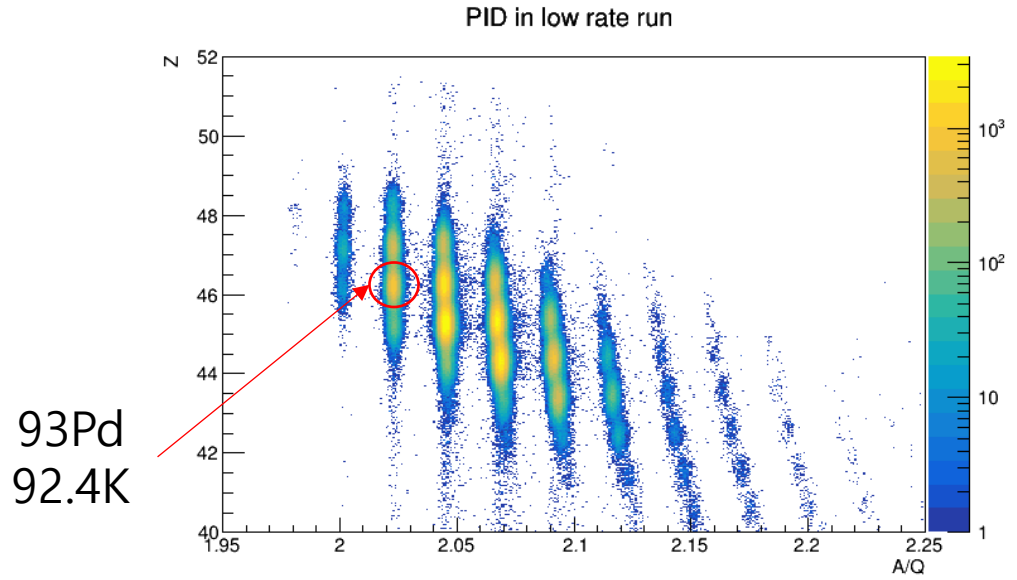


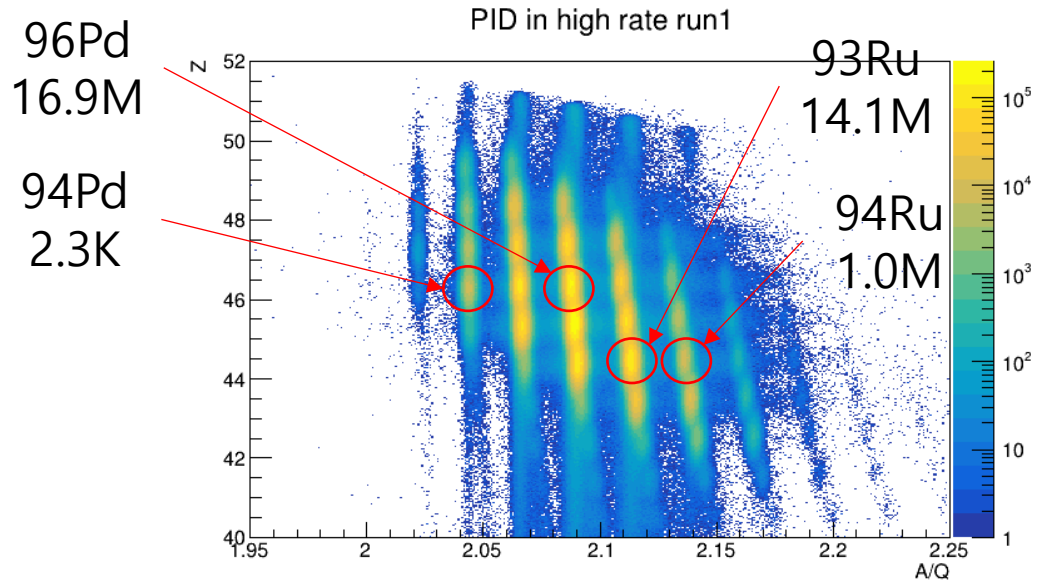




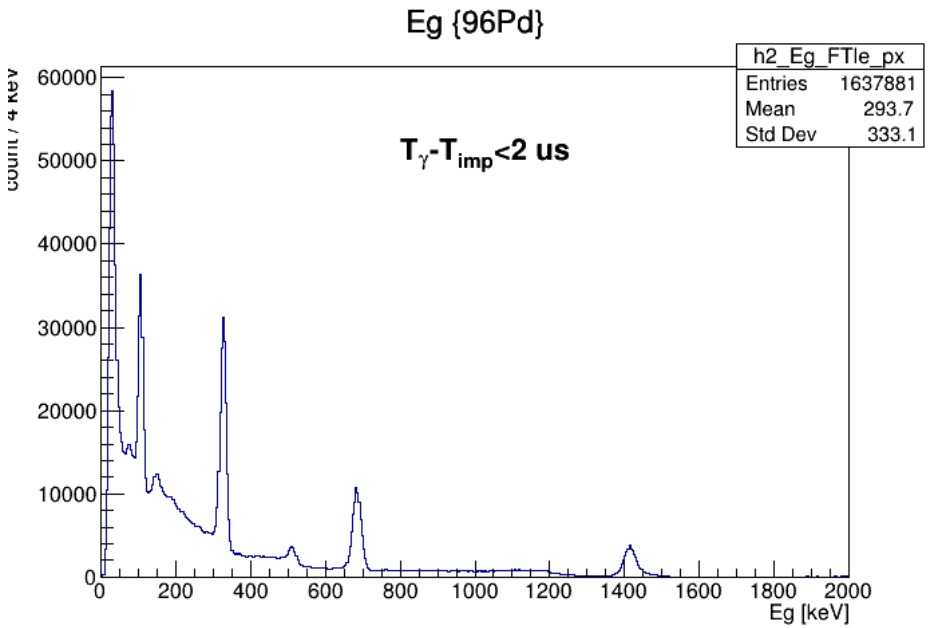
Run Summary

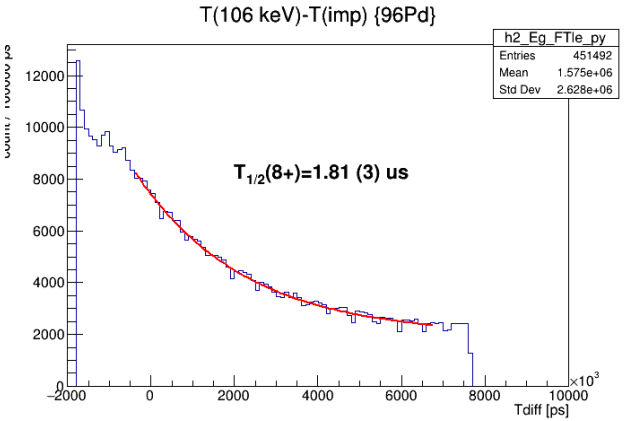
- Low rate
  - 4.5 hours
  - 140 pps on F7
  - For beta-gamma measurement
- High rate I
  - 7.6 hours
  - 8K pps on F7
  - MBS trigger on BRS-accepted trigger
- High rate II
  - 13 hours
  - 8K pps on F7
  - MBS trigger on F11pl
  - PID from FADC(ZDS)

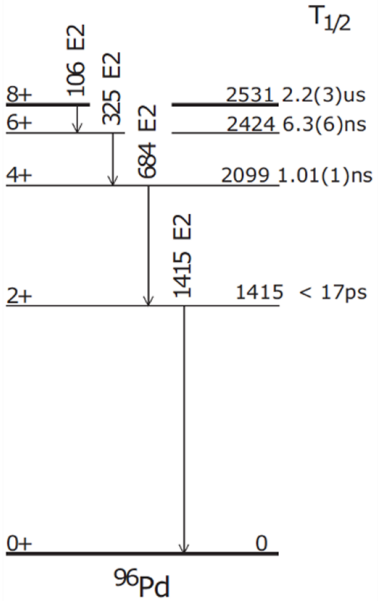


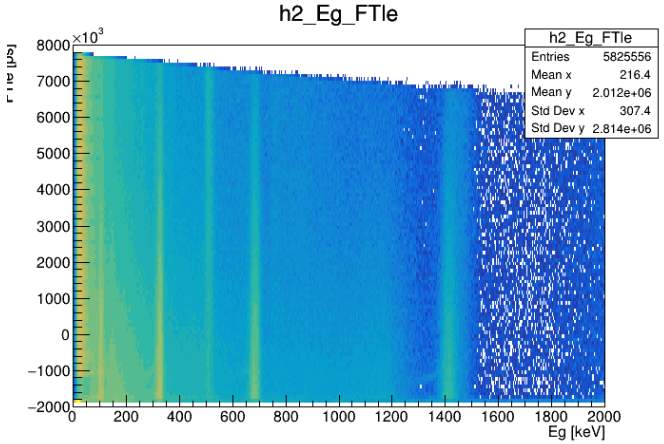


Preliminary ^{96}Pd



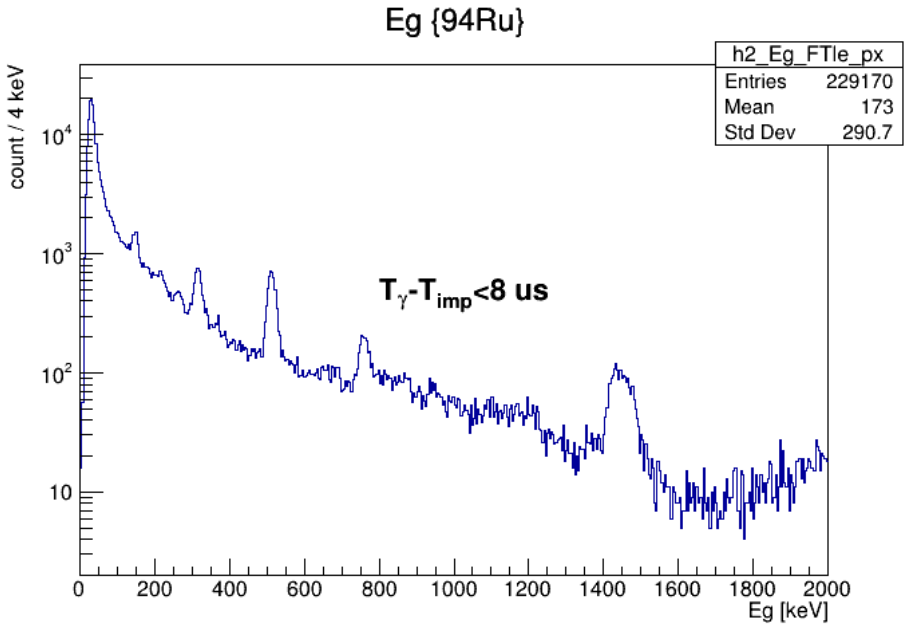


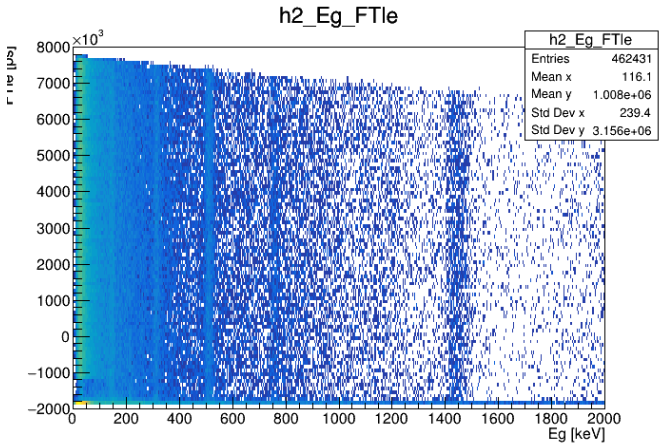




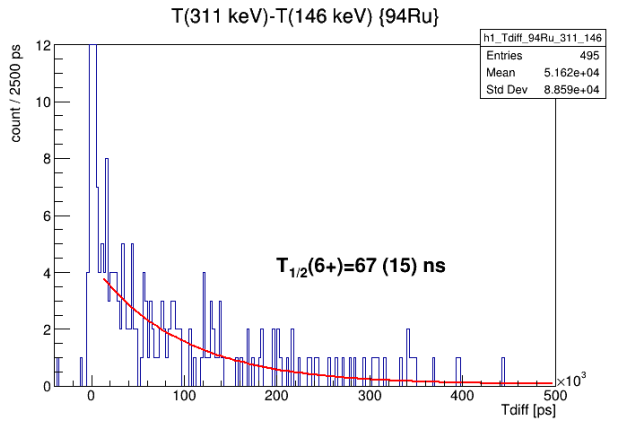
30% of data used

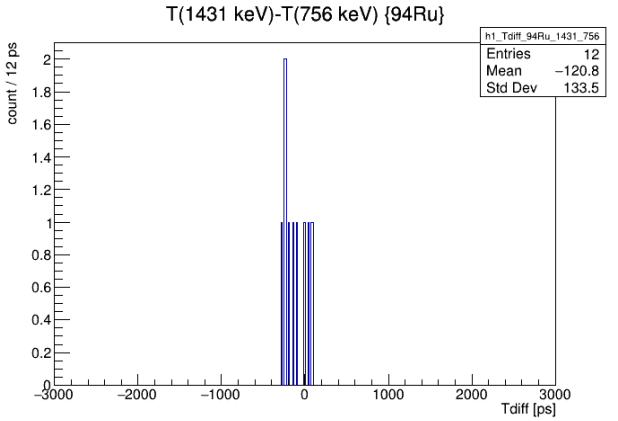
Preliminary ^{94}Ru

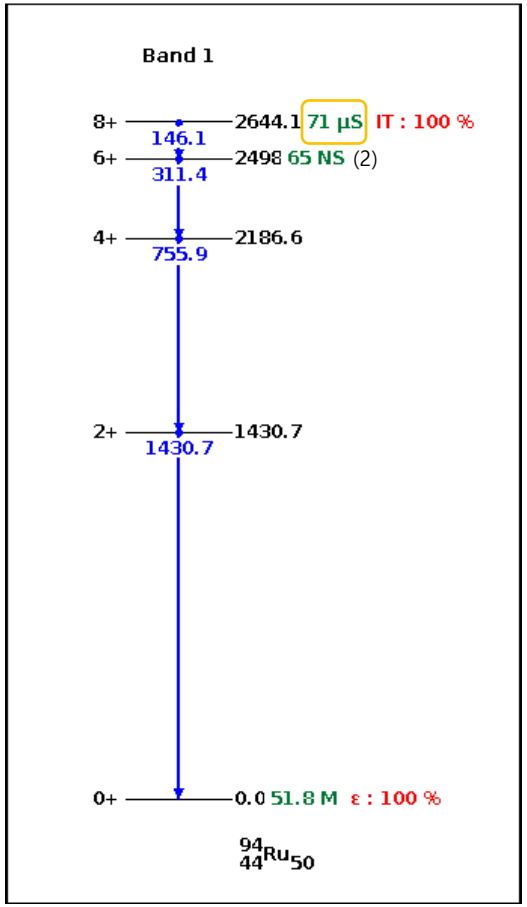




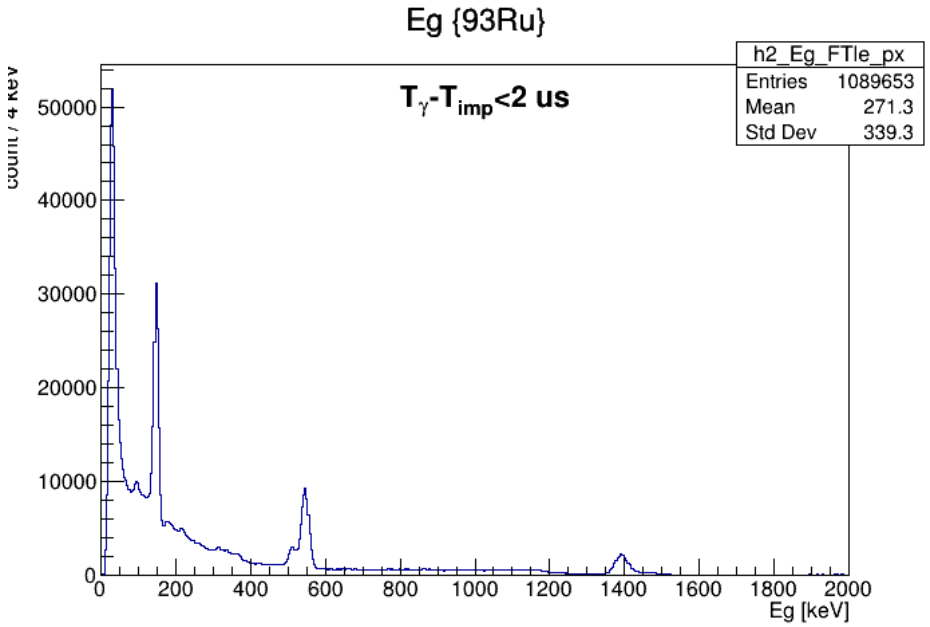
30% of data used

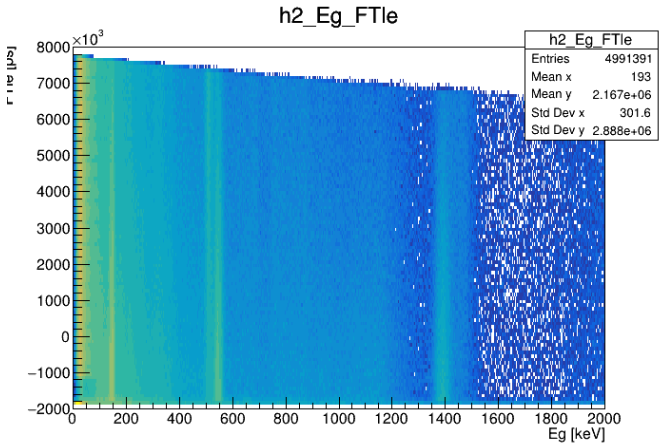




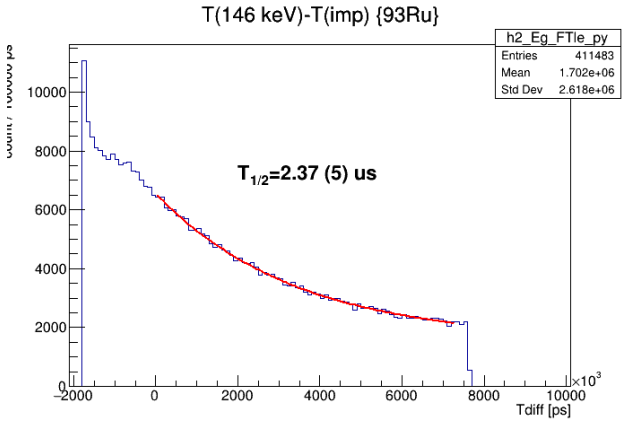


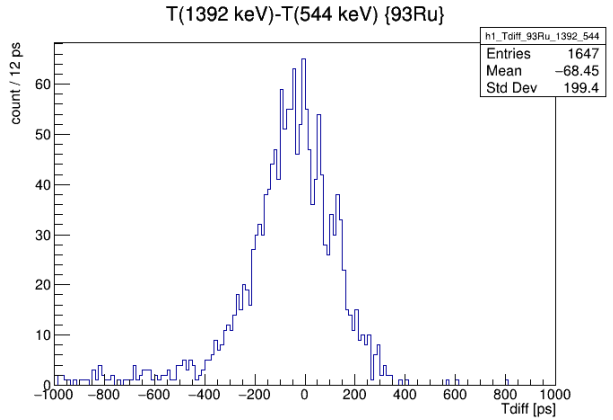
Preliminary ^{93}Ru

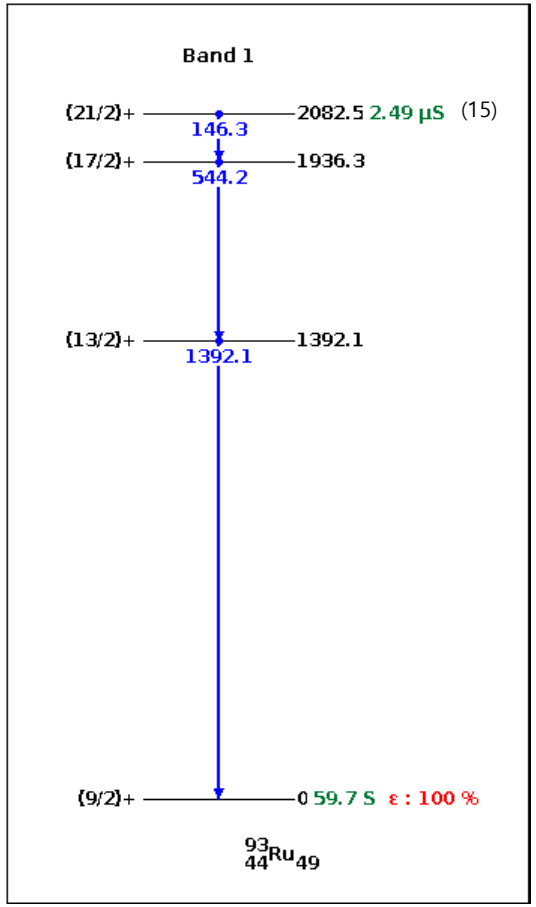




30% of data used

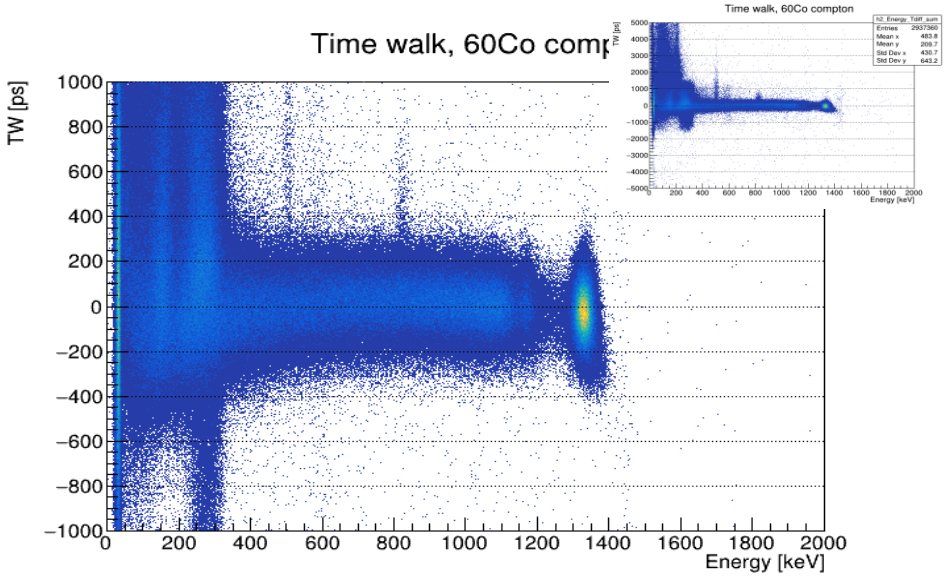




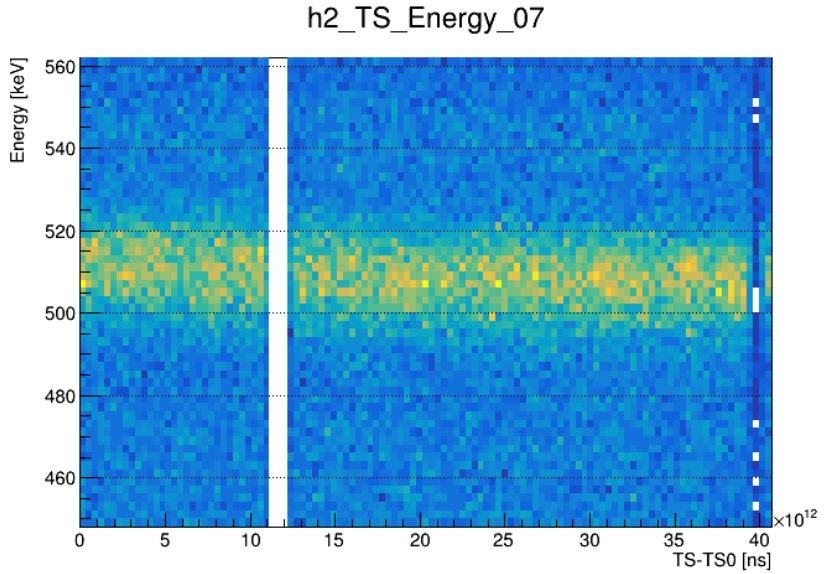


Further Corrections to be applied

- Fine time walk correction



- Gain drift



- Prompt response delay
  - time walk for full-energy-peaks
  - for centroid shift method

- Fine-tune background subtraction

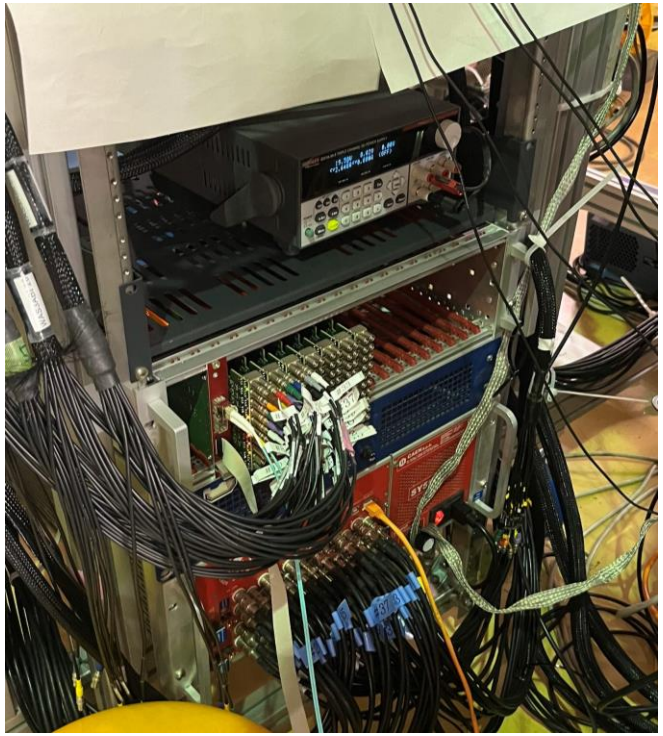
Summary

- Commissioning experiment of IDATEN was conducted successfully.
- Lifetimes of 96Pd isomer and following states were reproduced narrowing uncertainties.
- Lifetime of 93Ru 17/2+ state is newly measured to be 2.6 (1) ns.
- Lifetimes of 93Ru 13/2+, 94Ru 4+, 96Pd 2+ will be newly determined, using centroid difference method after fine time corrections.
- Seniority symmetry breaking will be studied from measured lifetimes.

backup following

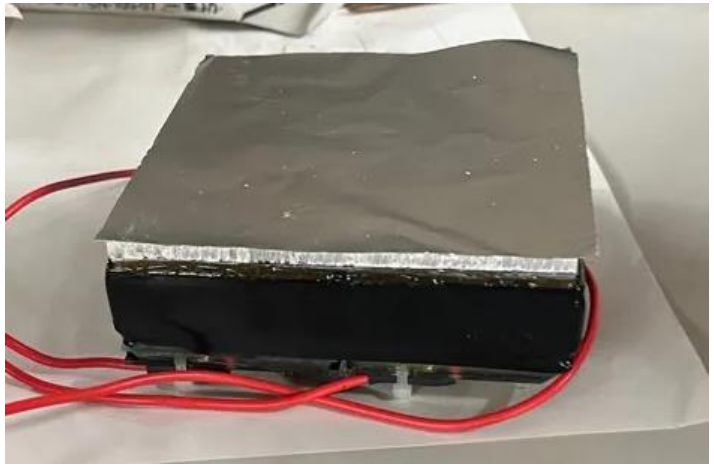
Main DAQ for LaBr3(Ce)

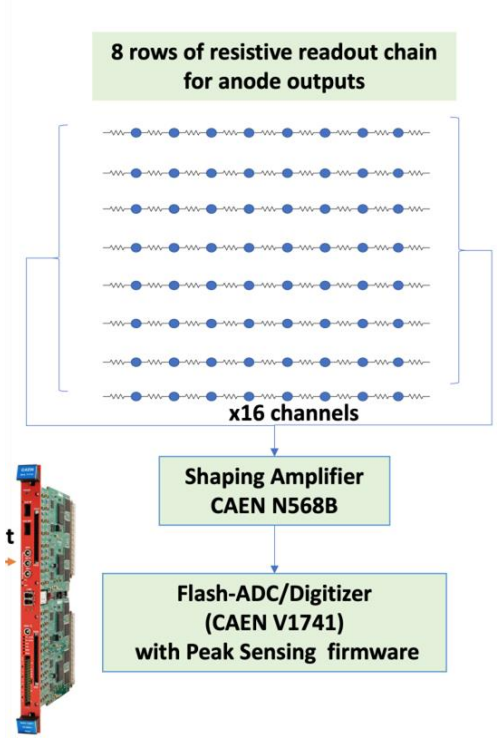
- Twinpeaks FEE
  - fast branch: fast-amp / Time measurement
  - slow branch: charge-to-time converter / Energy measurement
- TAMEX4
  - TDC module based on MBS(GSI)
  - gate width ~ 10 us
- 16 x 7=112 channels in compact size



GARi: active stopper & beta counter

- segmented plastic scintillator (very fast!)
  - 10 cm x 10 cm x 6 mm
- MS PMT
  - 5 cm x 5 cm
  - 8 x 8 anode, 1 common dynode
  - resistor chain for every 8 anodes, 16 output
- Low gain branch
  - raw, or attenuated signal
  - RI implantation position
- High gain branch
  - amplified signal
  - β decay / proton emission position
- Typical $\tau_\beta > \frac{1}{beam\ rate}$
  - set constraint on position to identify decay events.





Time stamp alignment btw DAQs

- MBS for LaBr3
  - EXPLODER <-time stamp- WRS
- BigRIPS DAQ for beam line PID
  - trigger, EoB shared for all rack. Event built for each trigger.
  - LUPO @ F11 <-10 MHz clock- WRS
- CAEN FADC for GARi, HPGe
  - self-trigger system (a.k.a. triggerless system)
  - FADC <-62.5 MHz- LUPO <-10 MHz clock- WRS

ADOPTED LEVELS, GAMMAS for ^{93}Ru

Author: Coral M. Baglin | Citation: Nucl. Data Sheets 112, 1163 (2011) | Cutoff date

Full ENSDF file | Adopted Levels (PDF version)

Q(β-)=-8205 keV 4 S(n)= 10987 keV 4 S(p)= 5580 keV 4 Q(α)= -4627 keV

Reference: 2012WA38

References:

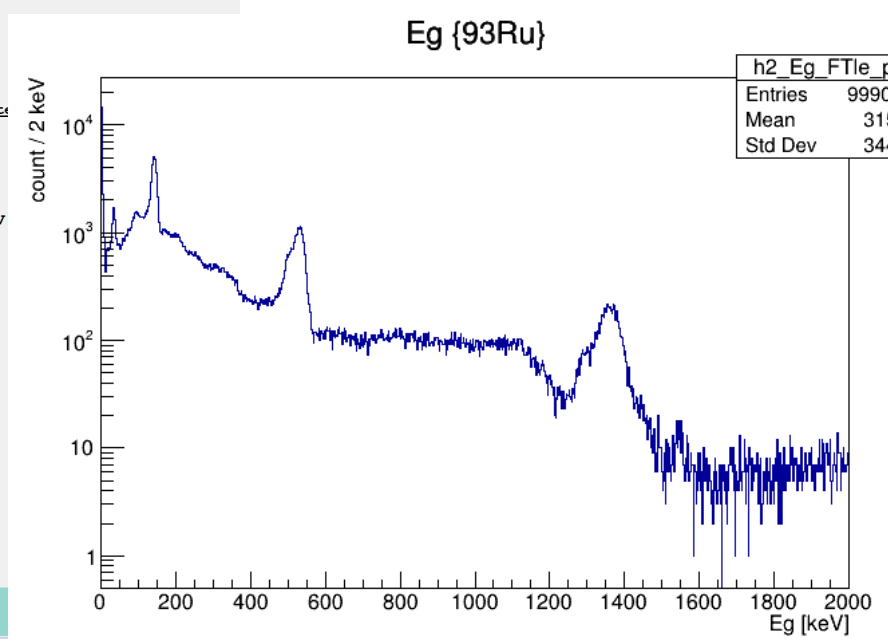
A ^{92}Mo(α,3nγ), B ^{93}Ru IT decay

C ^{58}Ni(^{40}Ca,4PNG), D ^{93}Rh ε decay

E ^{9}Be(^{107}Ag,xγ)

General Comments:

E(level) (keV)	XREF	Jπ(level)	T1/2(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
0	ABCDE	(9/2)+	59.7 s 6 % ε = 100					
734.40 10	B	(1/2)-	10.8 s 3 % IT = 22.0 23 % εp = 0.027 5 % ε = 78.0 23	734.4 1	100	[M4]	0	(9/2)+
1359.42 10	D			1359.4 1	100		0	(9/2)+
1392.11 20	A CDE	(13/2)+		1392.1 2	100	E2	0	(9/2)+
1629.92 10	D			1629.9 1	100		0	(9/2)+
1842.1 3	D			482.6 3 1842.4 6	65 23 100 42		1359.42 0	(9/2)+
1936.3 3	A C E	(17/2)+		544.2 2	100	E2	1392.11	(13/2)+
2082.5 9	A C E	(21/2)+	2.49 μs 15	146.3 10	100	E2	1936.3	(17/2)+
2112.8 7	A C	(15/2+)		176.6 10 720.7 10	100 4 60 6	D D	1936.3 1392.11	(17/2)+ (13/2)+
2129.4 7	C	(17/2+)		193.3 10 737.3 10	54 11 100 16	 Q	1936.3 1392.11	(17/2)+ (13/2)+
2273.53 14	D			643.6 1 2273.8 9	88 17 100 27		1629.92 0	(9/2)+
2280.5 7	A C	(17/2-)	35 ns 4	151.3 10 167.8 10 343.8 10	23.6 16 100 4 10.2 26	[E1] (E1) [E1]	2129.4 2112.8 1936.3	(17/2+) (15/2+) (17/2)+
2713.3 10	C	(19/2-)		432.6 10	100	D	2280.5	(17/2-)
2733.7 11	C	(23/2+)		651.2 10	100	D	2082.5	(21/2)+
3121.1 11	C	(25/2+)		387.2 10 1038.4 10	100 3 2.6 9	D	2733.7 2082.5	(23/2+) (21/2)+
3240.5 10	C	(21/2-)		527.1 10 960.1 10	100 5 68 5	D	2713.3 2280.5	(19/2-) (17/2-)
3375.5 12	C	(25/2+)		1293.1 10	100	Q	2082.5	(21/2)+
3722.7 11	C	(25/2-)		482.1 10 601.5 10 989.1 10	52.4 22 100 3 25.2 20	Q D	3240.5 3121.1 2733.7	(21/2-) (25/2+) (23/2+)
E(level) (keV)	XREF	Jπ(level)	T1/2(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
4022.0 12	C	(27/2+)		646.6 10	100 7	D	3375.5	(25/2+)



ADOPTED LEVELS, GAMMAS for ^{94}Ru

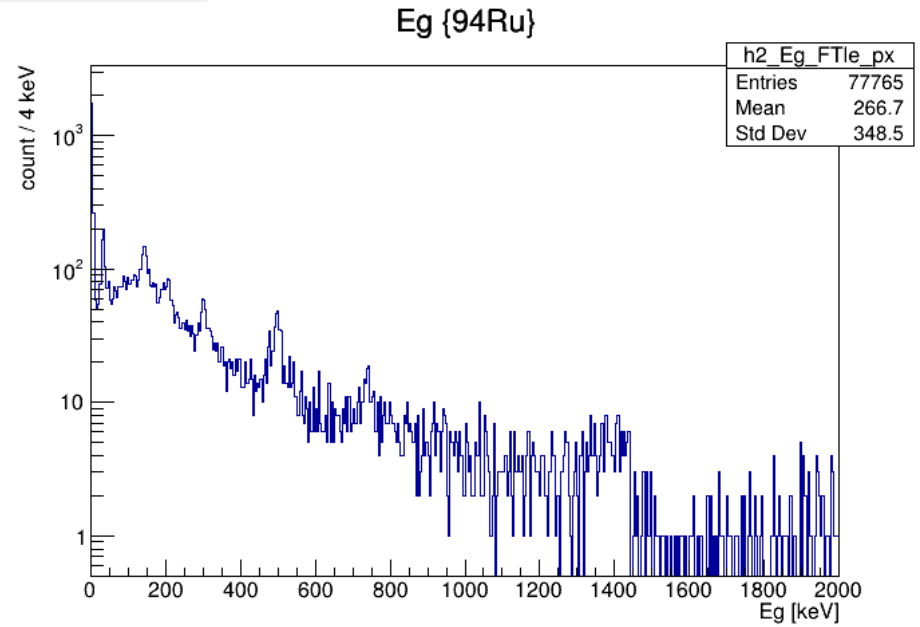
Authors: D. Abriola, A.A. Sonzogni | Citation: Nucl. Data Sheets 107, 2423 (2006) | Cutoff

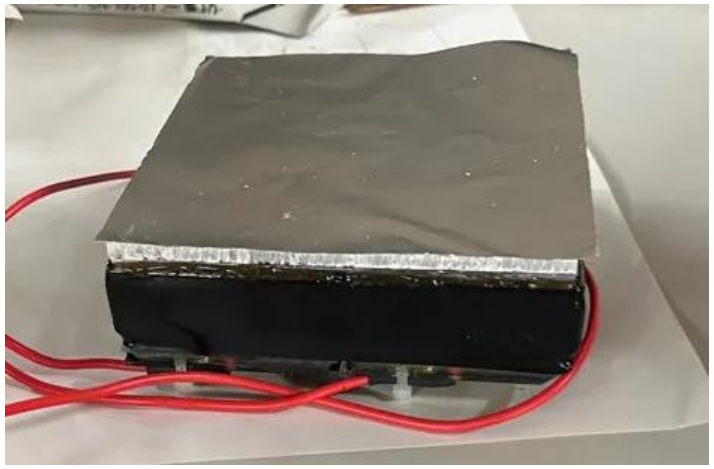
Full ENSDF file | Adopted Levels (PDF version)

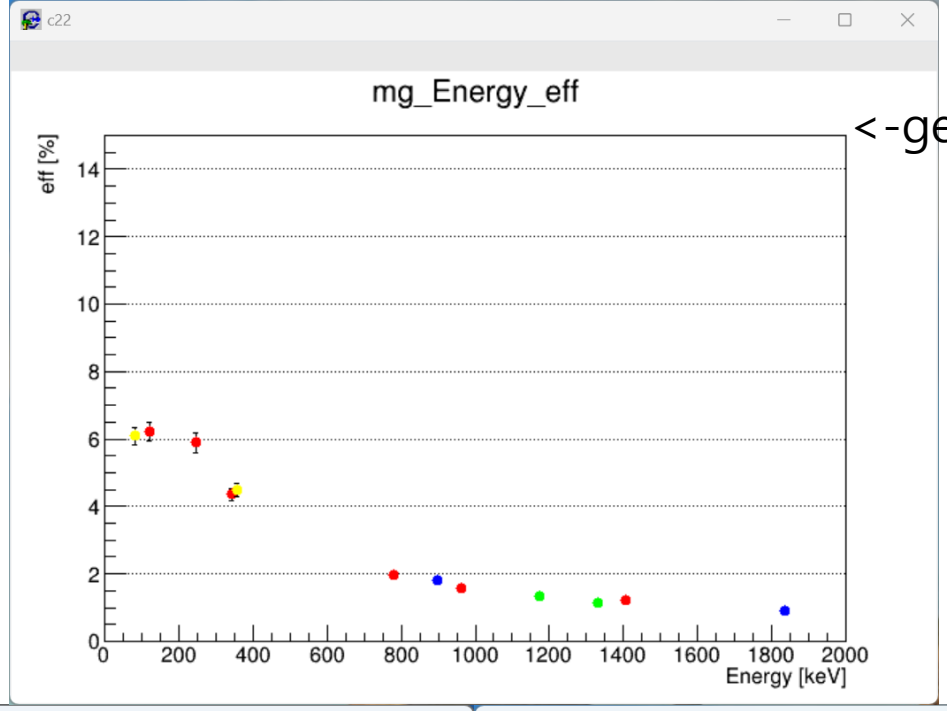
Q(β-)=-9676 keV 5 S(n)= 13438 keV 4 S(p)= 6267 keV 4 Q(α)= -4836 keV 5
Reference: 2012WA38

References:
A ^{95}Pd β$^+$p decay (13.3 S) B ^{94}Rh ε decay (70.6 S)
C ^{94}Rh ε decay (25.8 S) D ^{92}Mo(^{3}He,n)
E ^{96}Ru(p,t) F (HI,xnγ)

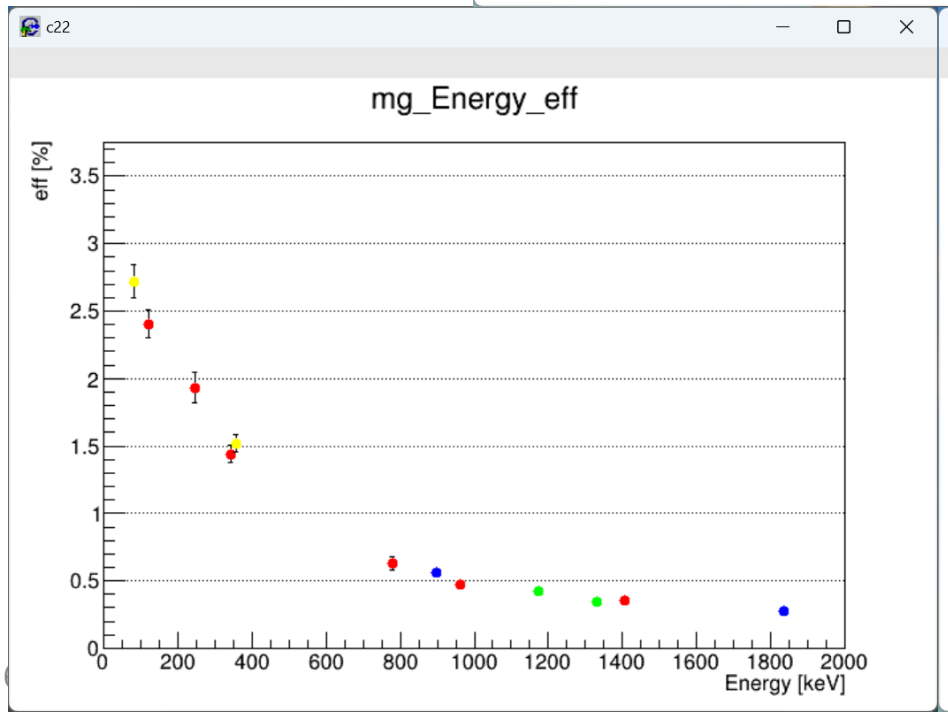
E(level) (keV)	XREF	Jπ(level)	T1/2(level)	E(γ) (keV)	I(γ)	M(γ)	Fin	
0.0	ABCDEF	0+	51.8 m 6 % ε = 100					
1430.71 20	ABCDEF	2+		1430.7 2	100	(E2)	0	
2186.6 3	ABC EF	4+		755.9 2	100	(E2)	1430	
2498.0 3	ABC EF	6+	65 ns 2	311.4 2	100	E2	2186	
2503.2 3	B E	(3,4,5)		1072.5 2	100		1430.71	2+
2624.4 3	BC EF	5-	0.51 ns 5	126.5 2 437.7 2	46.0 18 100 3	E1 E1	2498.0 2186.6	6+ 4+
2644.1 4	A C F	8+	71 μs 4 % IT = 100	146.1 2	100	E2	2498.0	6+
2965 6	E	(3-)						
2995 6	E	0+						
3117.0 4	B	(3,4,5)		492.6 3	100		2624.4	5-
3177.3 4	B	(3,4,5)		552.9 3	100		2624.4	5-
3254.7 4	B	(3,4,5)		1068.1 3	100		2186.6	4+
3520 7	E							
3615 7	E	0+						
3657.6 4	C F	(7-)		1033.3 2	100	(E2)	2624.4	5-
3770 8	E	0+						
3820 8	E							
3930.1 4	F	(8+)		1432.1 2	100		2498.0	6+
3991.2 4	F	(10)+	< 3.47 ps	1347.1 2	100	E2	2644.1	8+
4000 8	E							
4197.3 4	F	(9)-		267.2 2 539.6 2 1553.2 2	13.4 6 100.0 17 16.8 11		3930.1 3657.6 2644.1	(8+) (7-) 8+
4338.5 4	F	(9)-		680.9 2	100		3657.6	(7-)
4489.1 4	F	(11)-	0.760 ns 35	150.7 2 291.7 2 498.0 2	1.65 24 46.8 5 100.0 9	E2 E2 E1	4338.5 4197.3 3991.2	(9)- (9)- (10)+
E(level) (keV)	XREF	Jπ(level)	T1/2(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
4716.6 4	F	(12)+	23.8 ps 11	227.4 2 725.3 2	1.54 19 ≤100	E2	4489.1 3991.2	(11)- (10)+
5567.8 4	F	(13)-	2.01 ps 22	1078.8 2	100	E2	4489.1	(11)-
6275.1 4	F	(12+)		2283.8 2	100		3991.2	(10)+
6357.6 4	F	(12+)		1641.0 2	33 6		4716.6	(12)+

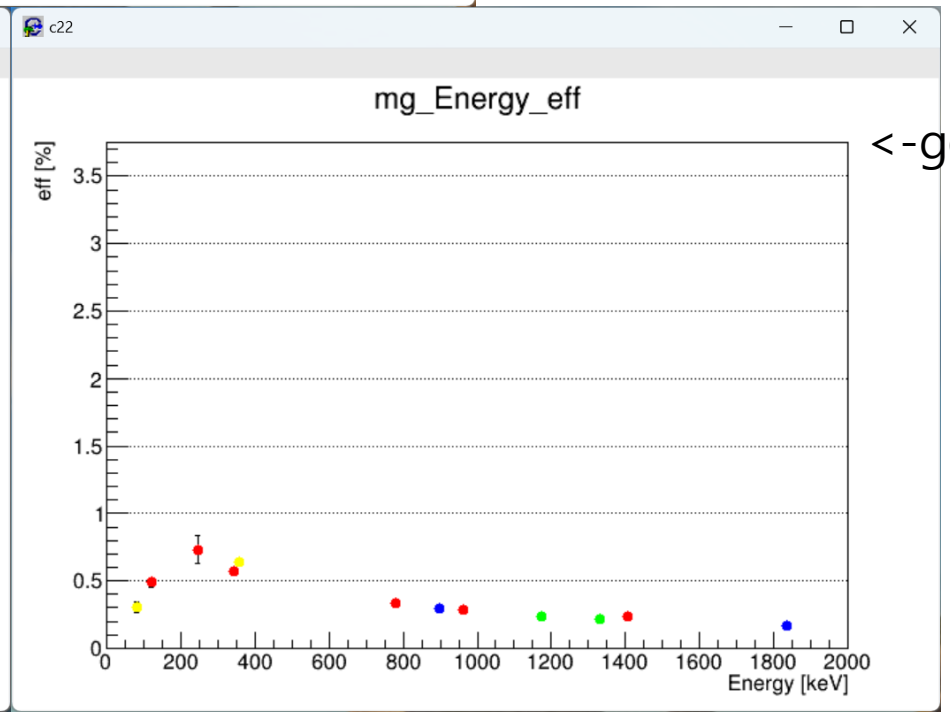




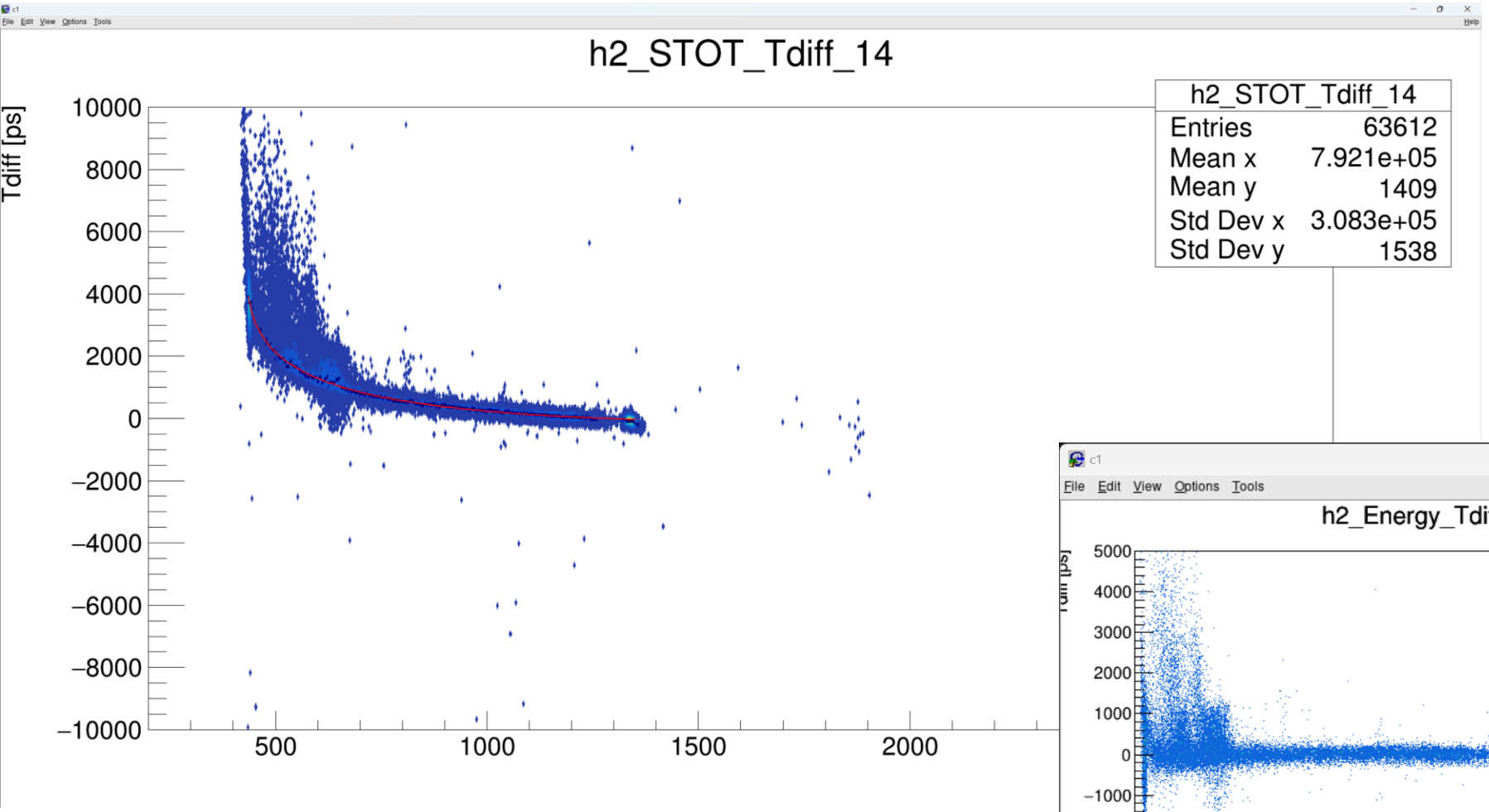


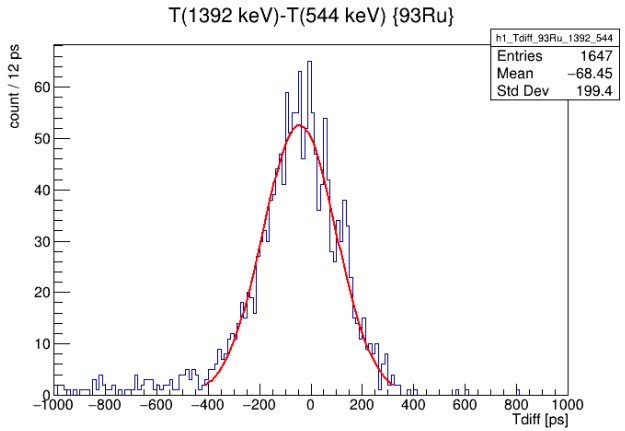
<-geometrical coverage, full sphere

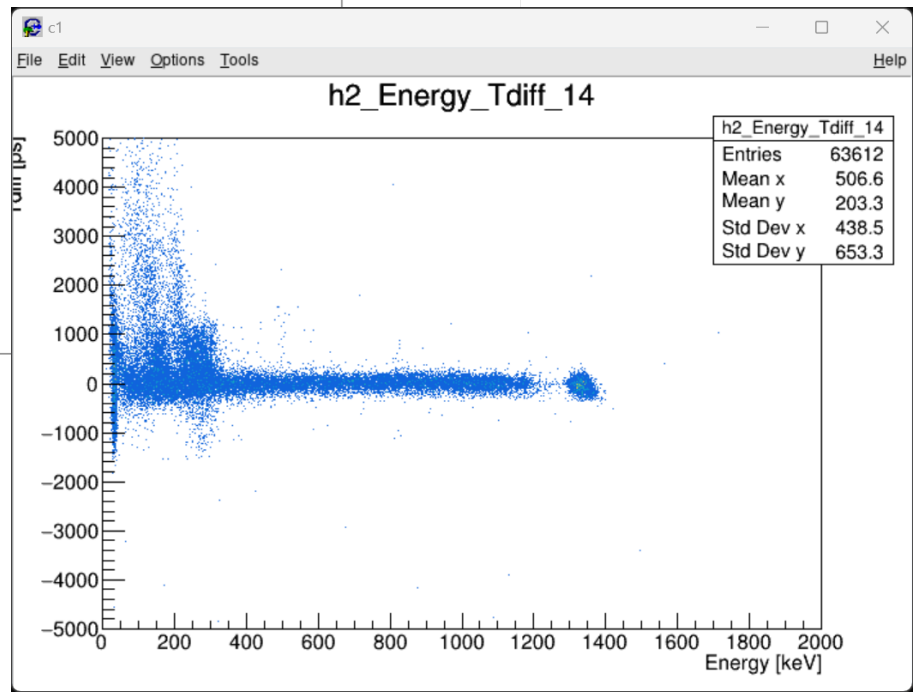




<-geometrical coverage (quarter-sphere)

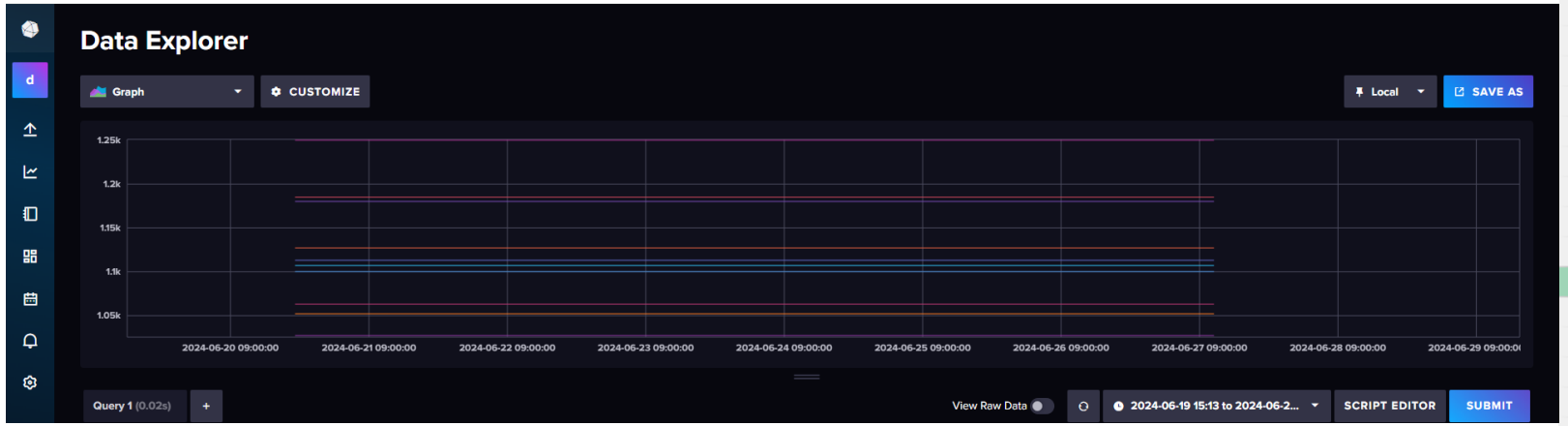

c1
File Edit View Options Tools
Help
h2_STOT_Tdiff_14
Tdiff [ps]
10000
8000
6000
4000
2000
0
−2000
−4000
−6000
−8000
−10000
500
1000
1500
2000
h2_STOT_Tdiff_14
Entries 63612
Mean x 7.921e+05
Mean y 1409
Std Dev x 3.083e+05
Std Dev y 1538

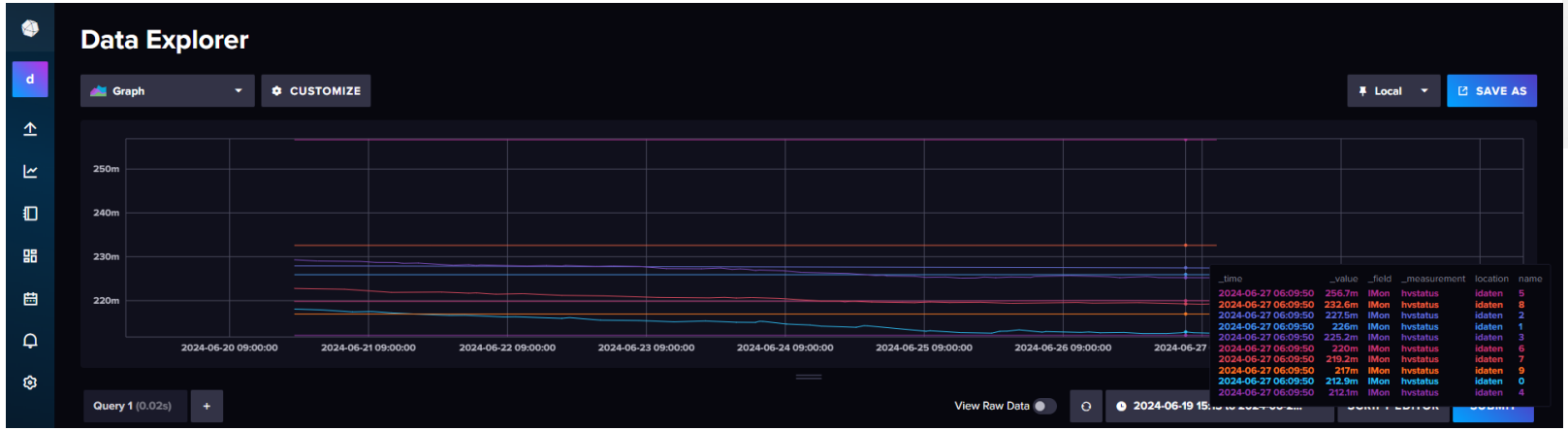

T(1392 keV)-T(544 keV) {93Ru}
h1_Tdiff_93Ru_1392_544
Entries 1647
Mean −68.45
Std Dev 199.4
count / 12 ps
Tdiff [ps]


c1
File Edit View Options Tools
Help
h2_Energy_Tdiff_14
h2_Energy_Tdiff_14
Entries 63612
Mean x 506.6
Mean y 203.3
Std Dev x 438.5
Std Dev y 653.3
Energy [keV]

Large Gain Drift in ch00, ch03, ch07

- voltages are constant, but currents keep falling



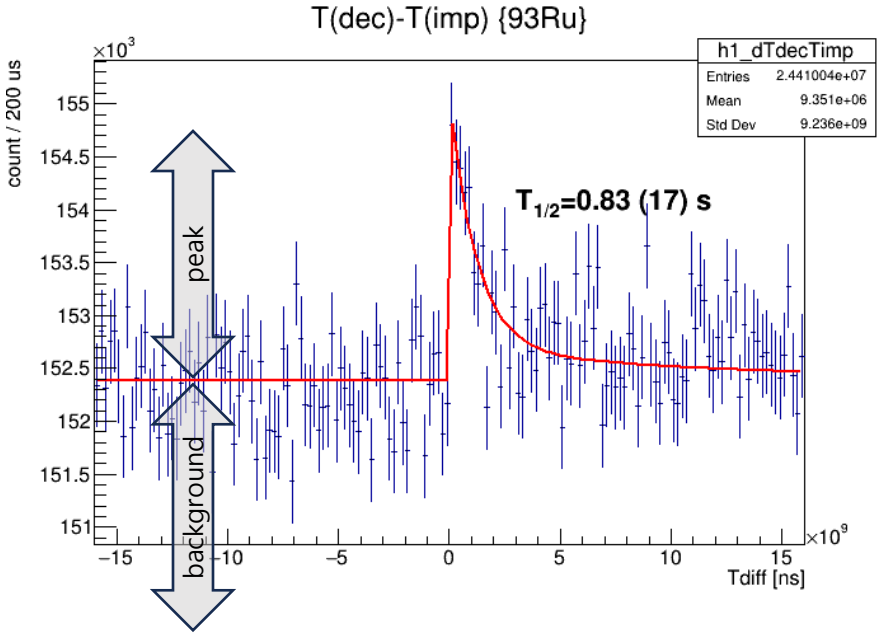


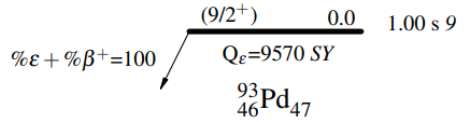
	A	B	N	O	W	X	Y	Z
1	id	name	VMon	IMon		Vmon/Imon		* PMT base
2	0	00	1100.18	205.695		5.348599		resistance:
3	1	01	1107.18	229.055		4.833686		4.95 Mohm
4	2	02	1113.19	226.915		4.905758		
5	3	03	1180.13	222.89		5.294675		
6	4	04	1027.38	212.055		4.844875		
7	5	05	1250.1	256.69		4.870077		
8	6	06	1063.2	219.865		4.835695		
9	7	07	1185.05	217.145		5.457413		
10	8	08	1127.16	232.6		4.845916		
11	9	09	1052.21	216.94		4.850235		
12	10	10	1092.18	225.47		4.844015		
13	11	11	1178.07	241.955		4.868963		
14	12	12	1116.23	230.515		4.842331		
15	13	13	1144.18	235.205		4.864607		
16	14	14	1150.12	236.305		4.8671		
17	15	15	1127.14	231.75		4.863603		
18	16	16	1247.05	256.06		4.870148		
19	17	17	1142.17	234.39		4.872947		
20	18	18	1183.01	242.555		4.877286		
21	19	19	1169.08	240.155		4.868023		

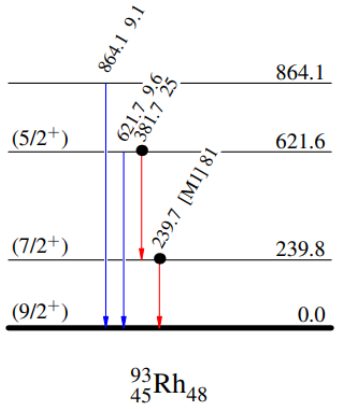
- HV channel swap
  -> higher resistance in ch00 (less current)
- Internal resistance in HV board?
- Monitor R(=V/I) next time.

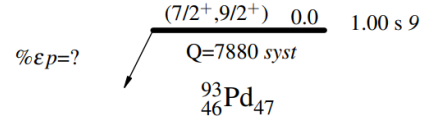
gari

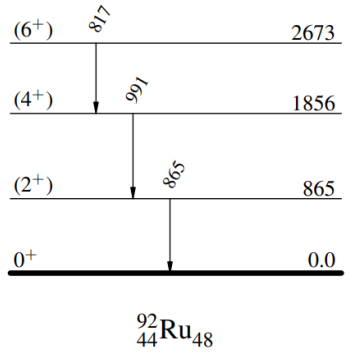
- poor p/b ratio (0.01)





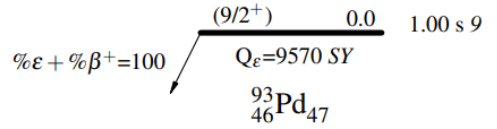


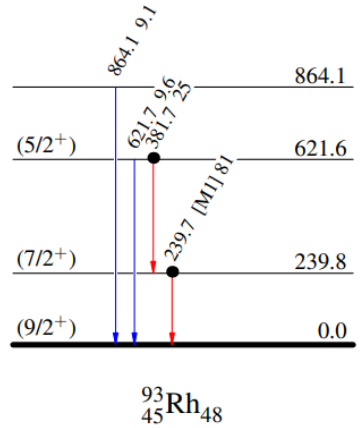




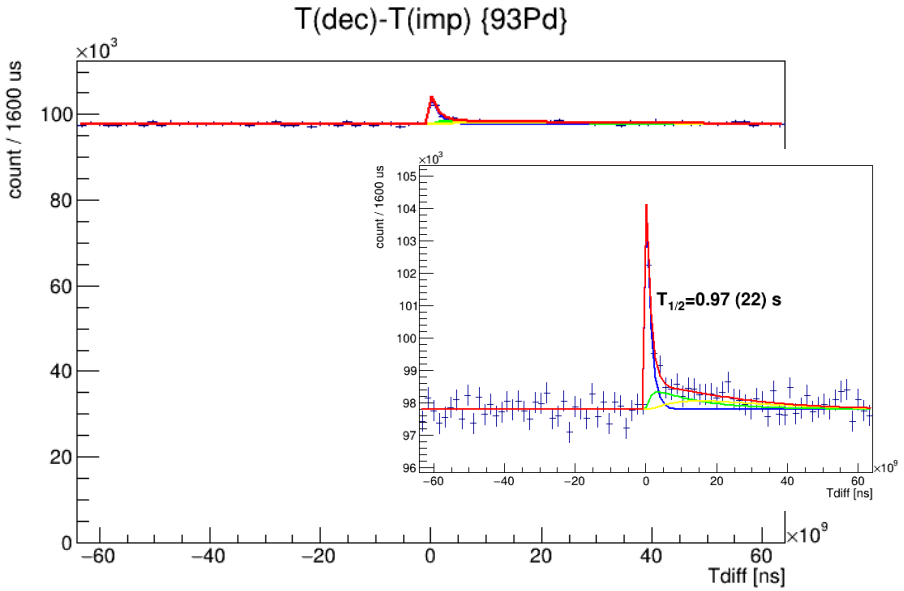
GARi

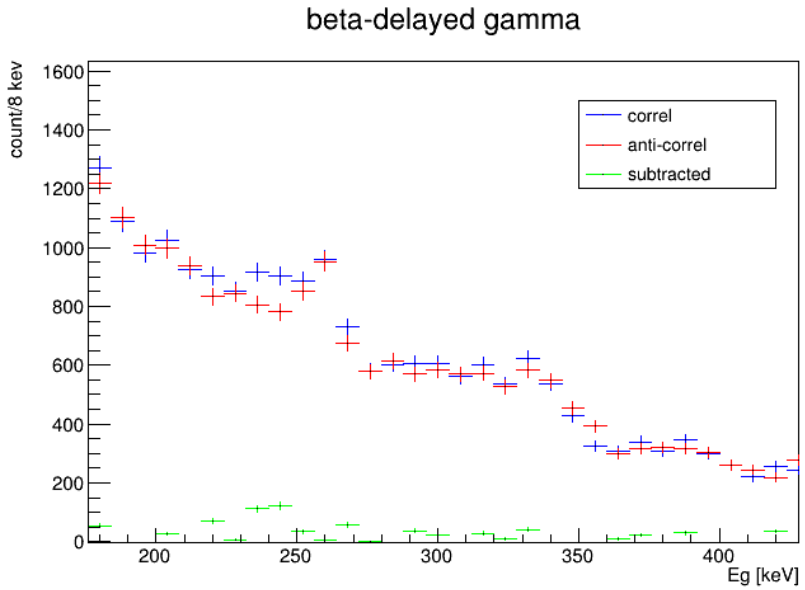
- correlating ion implantation - β decay
- position constraint in FWHM
  - $\Delta X \sim 2.2$ mm, $\Delta Y \sim 3.5$ mm
- poor p/b ratio (0.01), efficiency (12%)





$^{93}_{45}Rh_{48}$





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  - KHALA+~~FATIMA, HPG~~e …, setup, … …
  - Electronics: MBS based TPTMX -> Here arise technical issues: TS alignment, clock sync, event building
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  - LUPO/mpv : clock counter
  - WRS->VETAR/pexaria: TS recorder
- calibration (5 min)
  - resolution, efficiency, LED timewalk
- Run summary (5 min)
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  - PID in vme, fadc
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  - gain shift
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    - 6+ tailed 65 ns
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    - 17/2-, 13/2+ unknown. sub-ns
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