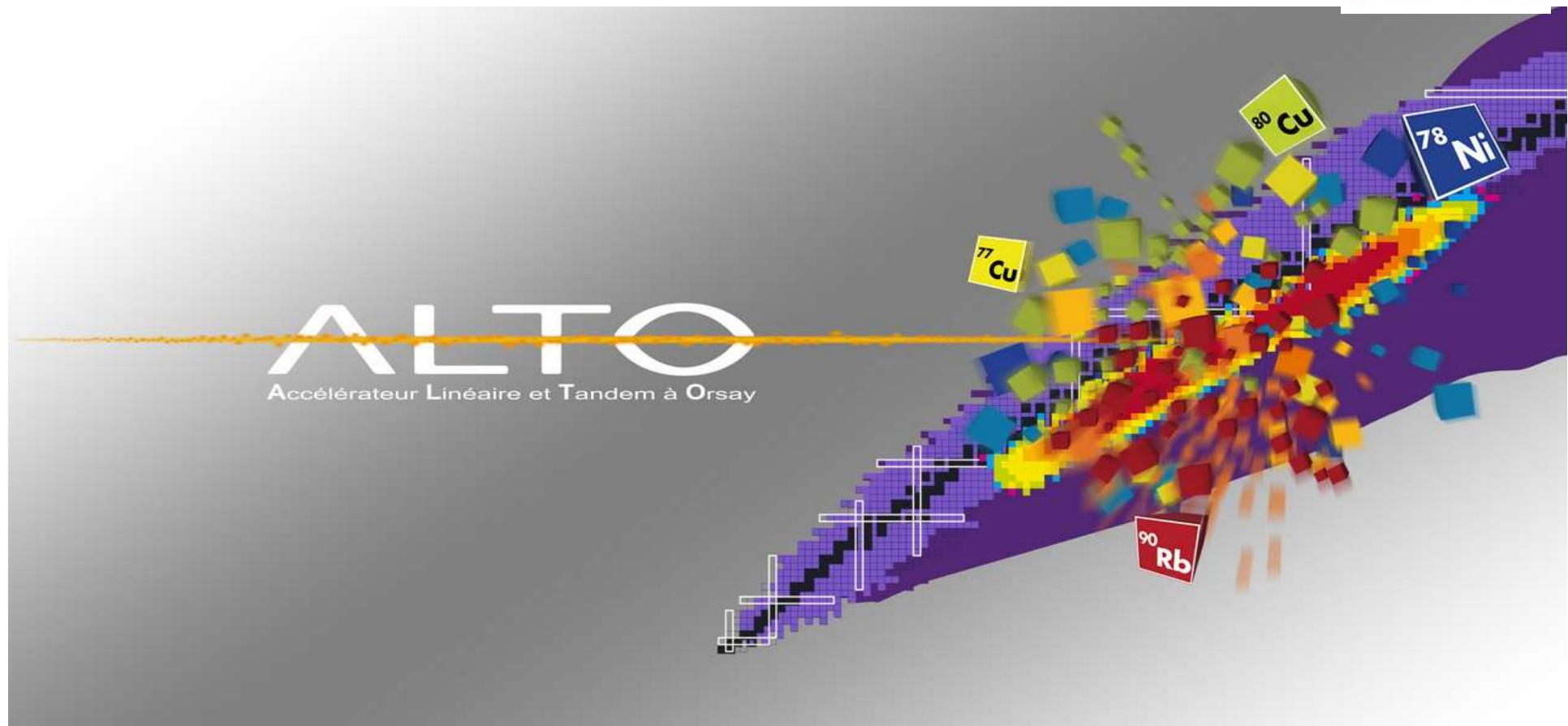


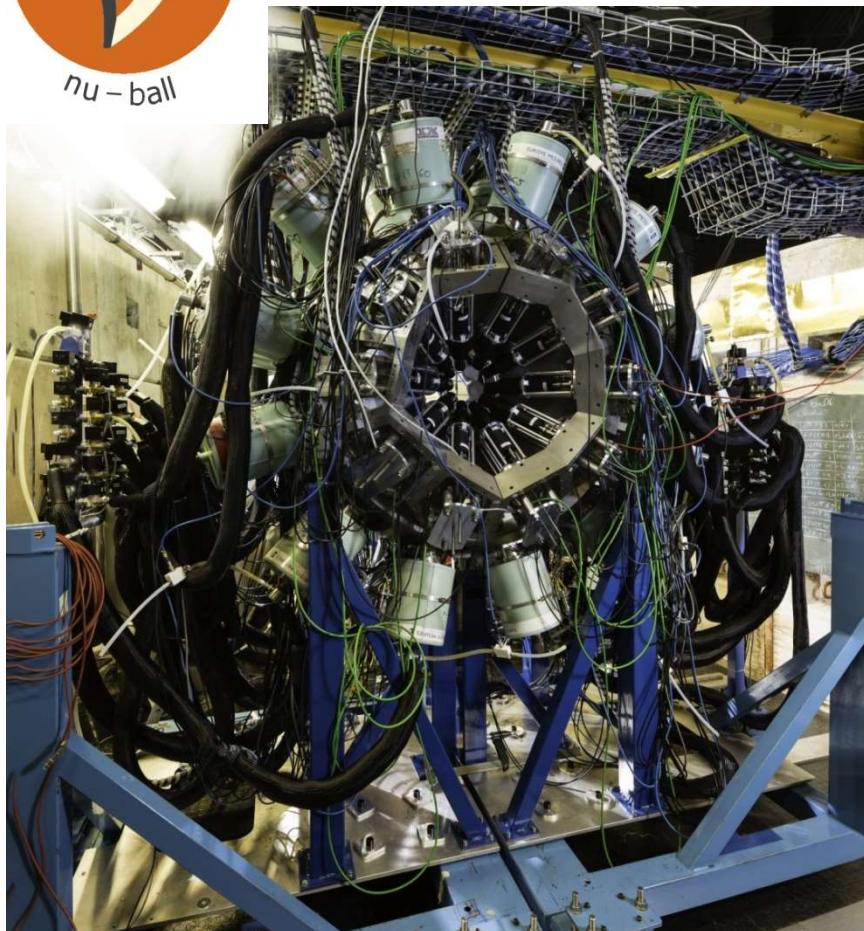
# Potential coupling of PARIS/nu-ball2

Jonathan Wilson, Matthieu Lebois,  
Nikola Jovancevic, Damien Thisse  
**IPN Orsay**





# The $\nu$ -ball spectrometer @ ALTO



## v-ball international collaboration

153 researchers from 16 countries and 37 institutes, including 80 Ph.D students

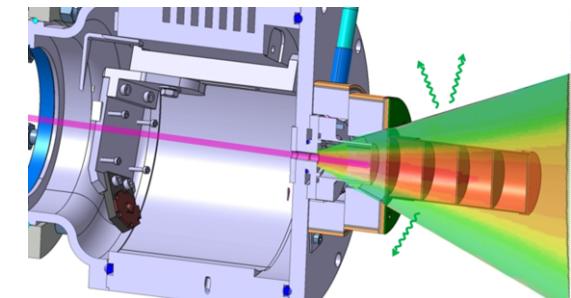
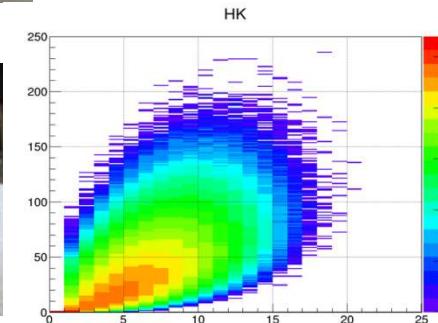
## v-ball experimental campaign

Nov. 2017-June 2018. 10 experiments  
3200 hours of beam time

## Innovations

- ✓ Hybrid Spectrometer (Ge/BGO/LaBr<sub>3</sub>)  
high resolution, high efficiency
- ✓ Coupling with the LICORNE directional neutron source
- ✓ Calorimetry for reaction studies/selection
- ✓ Fully digital, 200 channels, including BGO
- ✓ Modes Triggered or Triggerless

24 Clover Ge + BGO  
10 Coaxial Ge + BGO  
20 LaBr<sub>3</sub>  
or 36 PARIS phoswich



# The v-ball2 International Collaboration

153 researchers from 16 different countries, 37 institutions, including ~80 thesis students

**France(44)** 

IPN Orsay (16)

CSNSM Orsay (6)

CEA DAM/CEA Saclay (5)

Subatech, Nantes (3)

CENBG Bordeaux (6)

IPHC Strasbourg (3)

GANIL (2)

LPC Caen (2)

ILL (1)

**Italy(8)** 

University of Milano(6)

University of Padova(1)

Legnaro(1)

**Bulgaria(8)** 

University of Sofia (8)

**Canada(4)** 

University of Guelph (4)

**UK(29)** 

University of Surrey (13)

National Physical Laboratory (5)

University of Brighton (2)

University of West Scotland (4)

University of Manchester (3)

University of York (2)

**Finland(2)** 

Jyvaskyla(2)

**Germany(16)** 

TU Darmstadt (7)

IFK- Koln (9)

**Poland(14)** 

IFJ-PAN Krakow (8)

University of Warsaw (6)

**Spain(6)** 

Madrid (4)

IFIC Valencia (2)

**Belgium(4)** 

JRC-Geel (3)

Leuven (1)

**India(1)** 

Tata Institute (1)

**Romania(7)** 

IFIN-HH, Bucharest (1)

ELI-NP, Bucharest (6)

**Norway(6)** 

University of Oslo (6)

**South Africa(1)** 

iThemba (1)

**Japan(1)** 

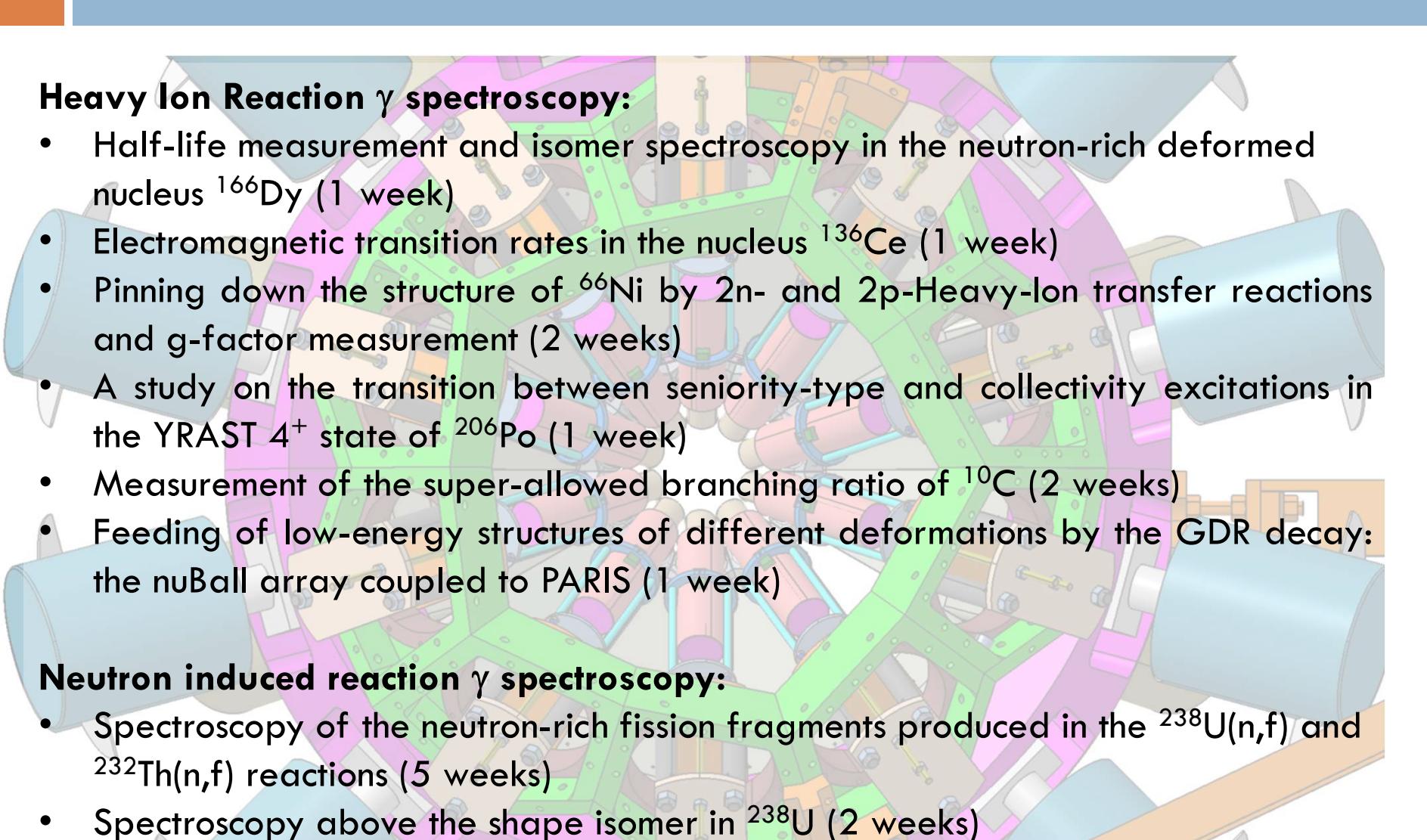
Riken(1)

**Serbia(2)** 

University of Novi Sad (1)

University of Belgrade (1)

v-ball experimental campaign (Nov. 2017-June 2018)  
3200 hours of beam time delivered. 200Tb of data acquired



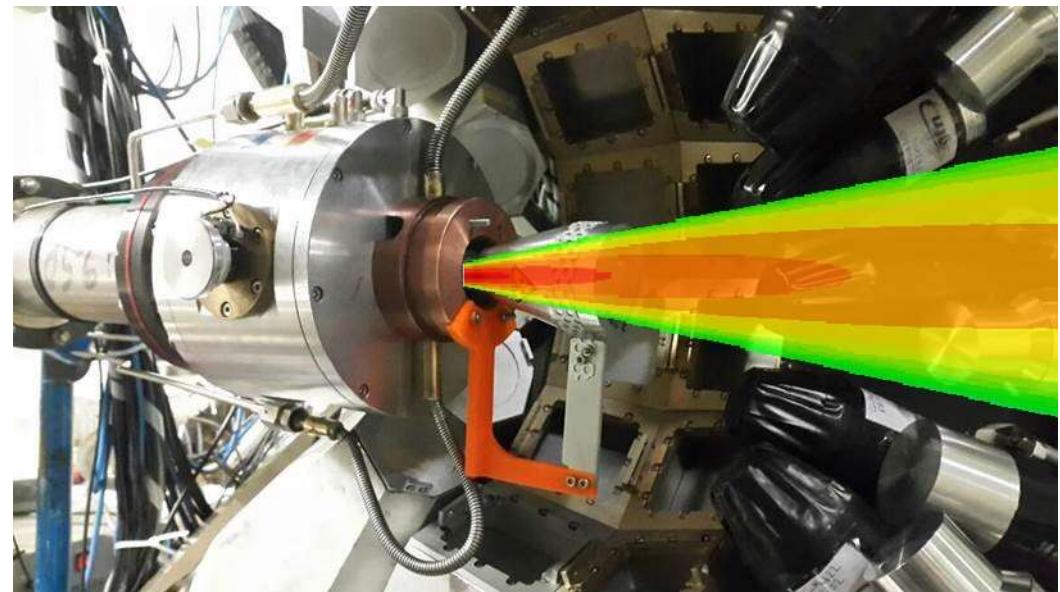
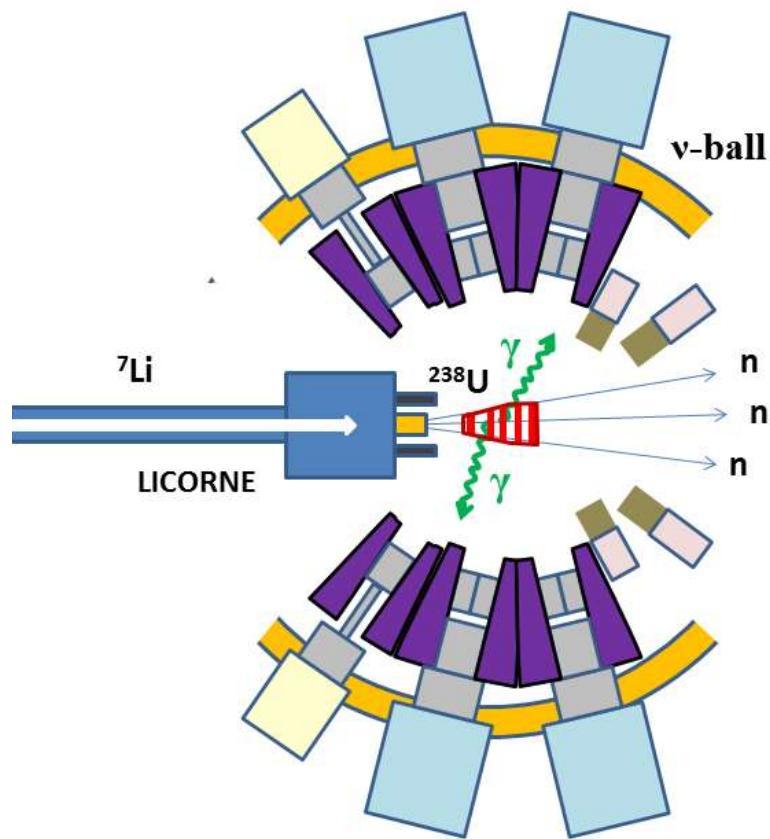
### Heavy Ion Reaction $\gamma$ spectroscopy:

- Half-life measurement and isomer spectroscopy in the neutron-rich deformed nucleus  $^{166}\text{Dy}$  (1 week)
- Electromagnetic transition rates in the nucleus  $^{136}\text{Ce}$  (1 week)
- Pinning down the structure of  $^{66}\text{Ni}$  by 2n- and 2p-Heavy-Ion transfer reactions and g-factor measurement (2 weeks)
- A study on the transition between seniority-type and collectivity excitations in the YRAST  $4^+$  state of  $^{206}\text{Po}$  (1 week)
- Measurement of the super-allowed branching ratio of  $^{10}\text{C}$  (2 weeks)
- Feeding of low-energy structures of different deformations by the GDR decay: the nuBall array coupled to PARIS (1 week)

### Neutron induced reaction $\gamma$ spectroscopy:

- Spectroscopy of the neutron-rich fission fragments produced in the  $^{238}\text{U}(n,f)$  and  $^{232}\text{Th}(n,f)$  reactions (5 weeks)
- Spectroscopy above the shape isomer in  $^{238}\text{U}$  (2 weeks)

# LICORNE/ $\nu$ -ball coupling principle



**Primary beam**  
 $2 \times 10^{11} / \text{s}$

${}^7\text{Li}$  (16 MeV)

**Target**

$\text{H}_2$

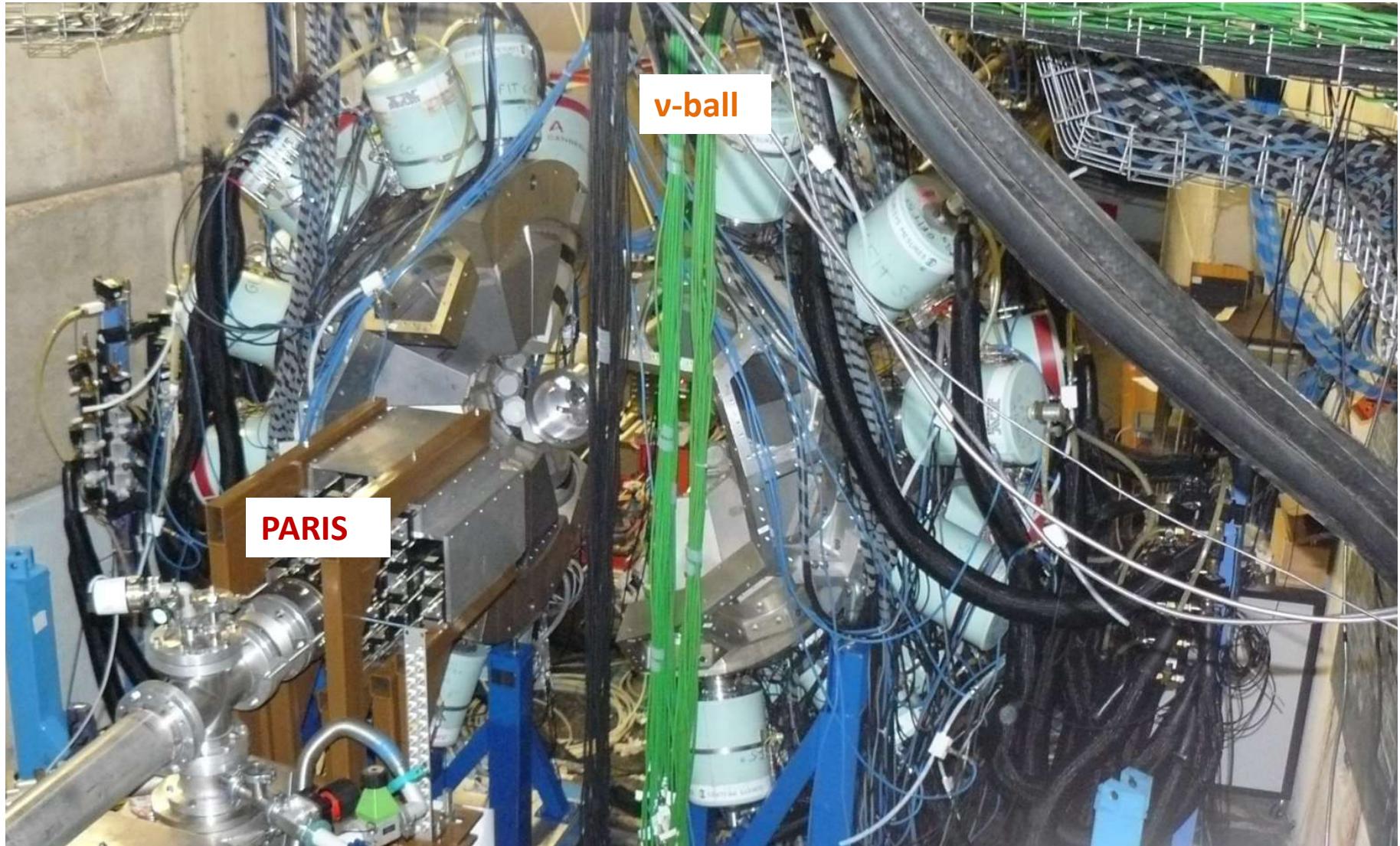
$3 \times 10^{20} \text{ atoms/cm}^2$

**Secondary beam**  
 $2 \times 10^7 / \text{s}$

1.5 MeV neutrons

**Sample**  
 $10^5 \text{ fissions/s}$   
 ${}^{238}\text{U}$    
 ${}^{232}\text{Th}$  ~100 g

# PARIS/v-ball coupling



# Recent workshops and preparation for ν-ball2

<https://indico.in2p3.fr/event/17761/overview>



**Nu-ball2-workshop, November 2018, JRC-Geel, European Commission, Belgium**



**Nu-ball workshop and fission data analysis meeting, March 2019, University of Köln, Germany**

# Recent workshops and preparation for ν-ball2



**Nu-ball collaboration meeting and data analysis workshop,  
September 2019, University of Warsaw, Poland**

# Publications in progress

Last 5 years  
11 journal articles  
9 proceedings

**M. Rudigier et al. "Multi-quasiparticle subnanosecond isomers in  $^{178}\text{W}$ "**  
**Phys. Lett. B (comments for referees incorporated and resubmitted)**

**M. Lebois et al., "The nuball spectrometer" , Nucl. Instrum. and Meth. A (undergoing minor corrections from the referee)**

**R. Canavan et al., "Half-life measurements in  $^{164,166}\text{Dy}$  using  $\gamma - \gamma$  fast-timing spectroscopy with the v-Ball spectrometer" , Phys. Rev. C (recently submitted)**

**R-B. Gerst et al., "Spectroscopy of neutron-rich  $^{94}\text{Kr}$  and structure of a new high-spin isomer"**  
**Phys. Rev. C (first draft before submission)**

**D. Rutte, et al. Boutique neutrons advance  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronology**  
**Science Advances 11, Vol. 5, no. 9 (2019)**

**J.N. Wilson and M. Lebois, "Precision Gamma-Ray Spectroscopy of Fast-Neutron-Induced Fission with the Nu-Ball Spectrometer", Nuclear Physics News, Volume 28 - 4 (2018)**

Just the start of production. Many more results in the pipeline.  
Analys is ongoing.



# The v-ball2 proposal for gpool resources

*The nu-ball2 collaboration – (2019)*

J.N. Wilson<sup>1</sup>, M. Lebois<sup>1</sup>, D. Thisse<sup>1</sup>, N. Jovancevic<sup>1</sup>, R. Canavan<sup>2,9</sup>, R-B. Gerst<sup>8</sup>, A. Maj<sup>11</sup>, M. Ciemala<sup>11</sup>, M. Kmiecik<sup>11</sup>, P.H. Regan<sup>2,9</sup>, S. Leoni<sup>7</sup>, B. Fornal<sup>11</sup>, T. Kröll<sup>18</sup>, S. Oberstedt<sup>20</sup>, A. Oberstedt<sup>32</sup>, A. Dragic<sup>27</sup>, I. Matea<sup>1</sup>, O. Dorvaux<sup>17</sup>, G. Georgiev<sup>10</sup>, J. Ljungvall<sup>10</sup>, R. Lozeva<sup>10</sup>, M. Moukaddam<sup>17</sup>, S. Courtin<sup>17</sup>, D. Jenkins<sup>30</sup>, P.J. Napiorkowski<sup>36</sup>, K. Hadyńska-Klęć<sup>36</sup>, E. Adamska<sup>4</sup>, P. Adsley<sup>1</sup>, A. Algora<sup>5</sup>, L. Atanasova<sup>33</sup>, M. Babo<sup>1</sup>, K. Belvedere<sup>2</sup>, J. Benito<sup>6</sup>, G. Benzoni<sup>7</sup>, A. Blazhev<sup>8</sup>, A. Boso<sup>9</sup>, S. Bottoni<sup>7</sup>, M. Bunce<sup>9</sup>, R. Chakma<sup>10</sup>, N. Cieplicka-Orynczak<sup>11</sup>, L. Cortes<sup>12,16</sup>, P.J. Davies<sup>13</sup>, C. Delafosse<sup>34</sup>, M. Djongolov<sup>28</sup>, D. Etasse<sup>3</sup>, M. Fallot<sup>14</sup>, A. Fijalkowska<sup>4</sup>, L. Fraile<sup>6</sup>, L. Gaudefroy<sup>35</sup>, D. Gjestvang<sup>15</sup>, K. Gladnishki<sup>28</sup>, A. Gottardo<sup>16</sup>, V. Guadilla<sup>14</sup>, G. Häfner<sup>8,10</sup>, M. Heine<sup>17</sup>, C. Henrich<sup>18</sup>, I. Homm<sup>18</sup>, F. Ibrahim<sup>1</sup>, L. Iskra<sup>7,11</sup>, P. Ivanov<sup>9</sup>, S. Jazwari<sup>2,9</sup>, D. Knezevic<sup>27</sup>, M. Komorowska<sup>36</sup>, A. Korgul<sup>4</sup>, P. Koseoglou<sup>18,26</sup>, T. Kurtukian-Nieto<sup>19</sup>, L. Le-meur<sup>14</sup>, A. Lopez-Martens<sup>10</sup>, I. Matea<sup>1</sup>, K. Miernik<sup>4</sup>, J. Nemer<sup>1</sup>, W. Paulsen<sup>15</sup>, M. Piersa<sup>4</sup>, Y. Popovitch<sup>1</sup>, C. Porzio<sup>7,7b,29</sup>, L. Qi<sup>1</sup>, G. Rainovski<sup>28</sup>, D. Ralet<sup>21</sup>, D. Reygadas-Tello<sup>22,31</sup>, K. Rezynkina<sup>23</sup>, M. Rudigier<sup>2</sup>, V. Sanchez-Tembleque<sup>6</sup>, C. Schmitt<sup>17</sup>, P-A. Söderström<sup>18</sup>, K. Stoychev<sup>28</sup>, C. Sürder<sup>18</sup>, G. Tocabens<sup>1</sup>, V. Vedia<sup>6</sup>, D. Verney<sup>1</sup>, N. Warr<sup>8</sup>, B. Wasilewska<sup>11</sup>, J. Wiederhold<sup>18</sup>, M. Yavachova<sup>25</sup>, F. Zeiser<sup>15</sup>, S. Zilliani<sup>7,7b</sup>

**94 authors, 36 different institutions in 12 different countries**



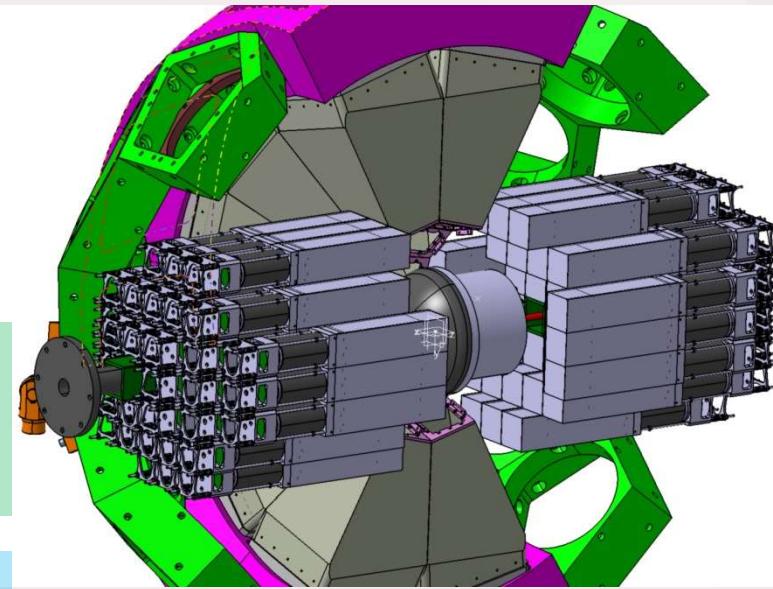
# $\nu$ -ball2 campaign foreseen 2021 - 2022

(Precise timing to be negotiated with Jyvaskyla)

## New Configurations

### $\nu$ -ball/PARIS

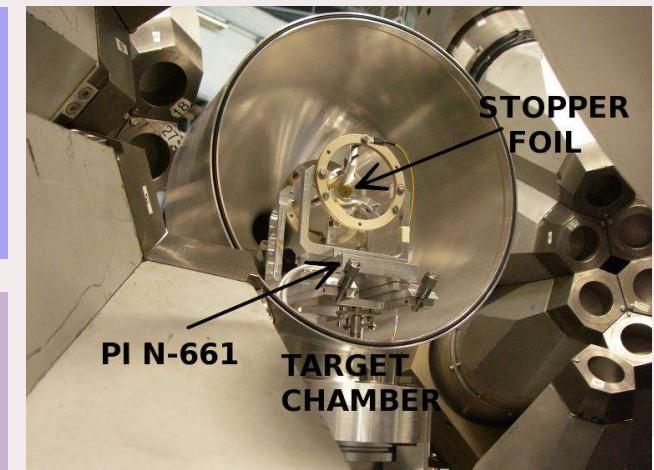
GDR studies. High energy gamma detection for light nuclei (ALTO high intensity  $^{6,7}\text{Li}$ ,  $^{14}\text{C}$  beams)



### $\nu$ -ball/OUPS plunger and/or charged particle detector RDM lifetimes

### $\nu$ -ball/Fast Timing

24 clovers coupled with 40 FATIMA for best hybrid array performance. Lifetime measurements 10-ps 10ns range for weakly populated states



### $\nu$ -ball/LICORNE

Improve fission technique: Reduce gamma backgrounds from the source and intrinsic target activity. More primary beam. Low density targets for DPM lifetime measurements.  $^{252}\text{Cf}$  IC

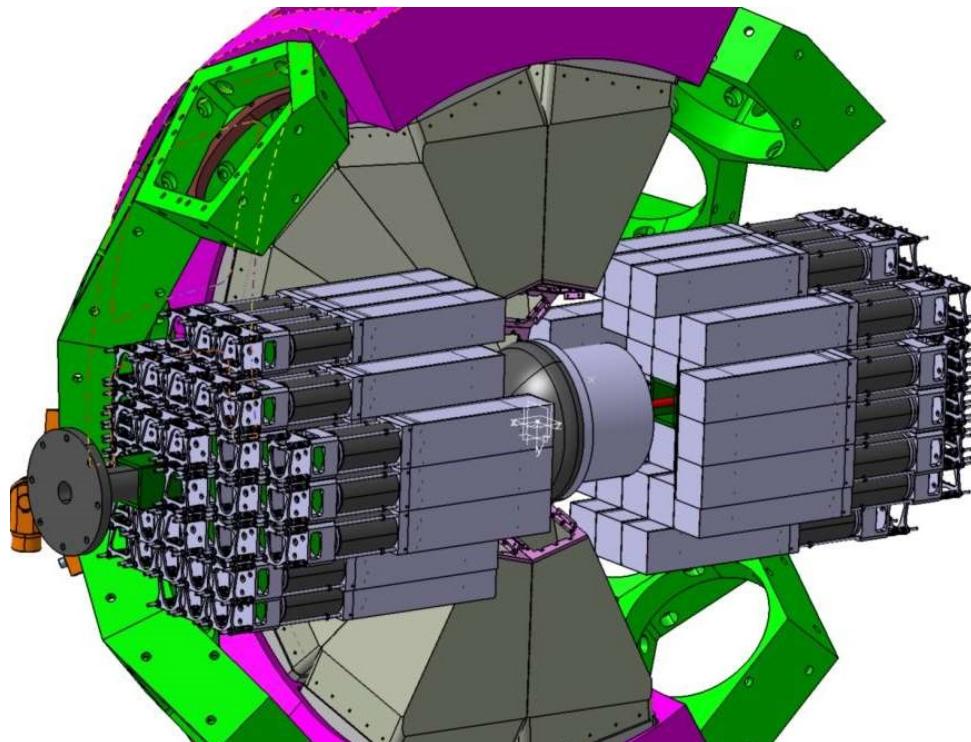
# v-ball2 - Physics Cases

1. GDR studies with v-ball2/PARIS – A. Maj, M. Ciemala, M. Kmiecik
2. Gamma decay from narrow unbound states in n-rich B, C, O and N isotopes: a testing ground for cluster and ab-initio theoretical approaches – S. Leoni, B. Fornal
3. Direct measurement of carbon-clustering in  $^{24}\text{Mg}^*$  - M. Moukaddam, S. Courtin, D. Jenkins
4. Fusion-fission and quasi-fission studies and ternary fission studies with CORSET - I.Matea, O. Dorveaux
5. Further studies of the fission fragments produced in the  $^{238}\text{U}(n,f)$  reaction – J.N. Wilson, M. Lebois
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7. v-ball2/FATIMA fast timing configuration – new opportunities - P.H. Regan, Z. Podolyak
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9. Two photon decay in  $^{72}\text{Ge}$  – A. Dragic
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12. Nuclear moments of short-lived excited states by TDRIV measurements – G. Georgiev, A. Stutchberry
13. Coulomb excitation of the super-deformed band in  $^{40}\text{Ca}$  - P.J. Napiorkowski, K. Hadyńska-Klęk

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# $\nu$ -ball2/PARIS coupling

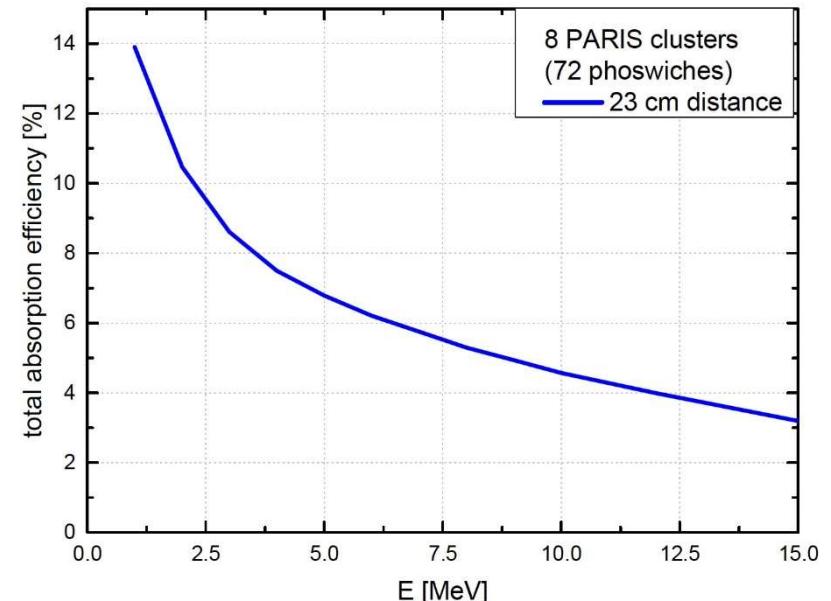


216 FASTER channels total

96 MOSAHR 14-bit 125 MHz

120 CARAS 12-bit 500 MHz

(Need an extra 42 CARAS = 29 k euro)



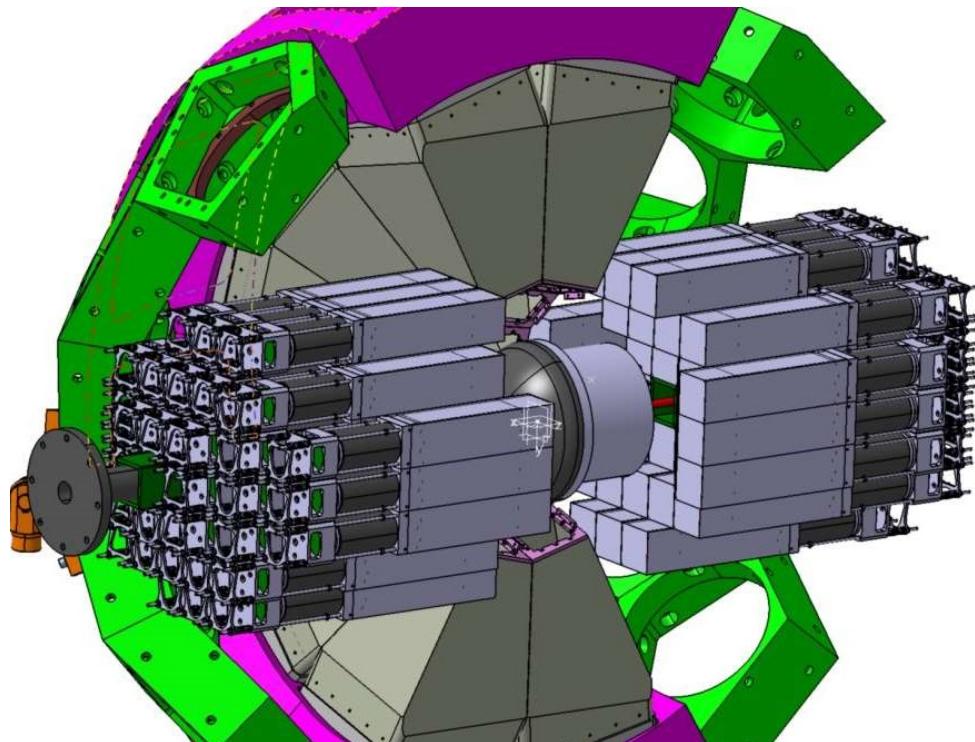
## Perfect for:

- GDR, PDR studies
- Studies of light nuclei
- $4\pi$  calorimetry (Reaction mechanism studies)

## Extra capabilities:

- Neutron/gamma discrimination via TOF
- Some fast timing capabilities (>70 ps lifetimes)

# $\nu$ -ball2/PARIS coupling

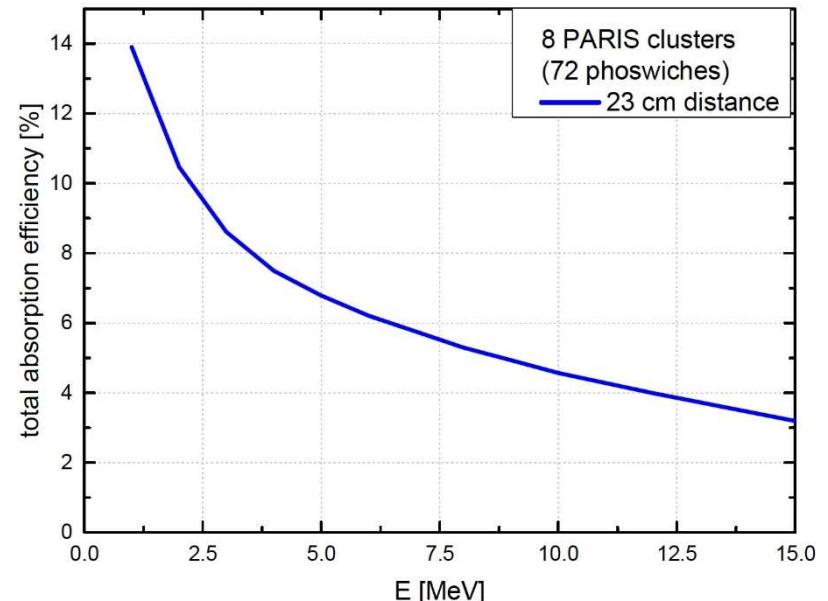


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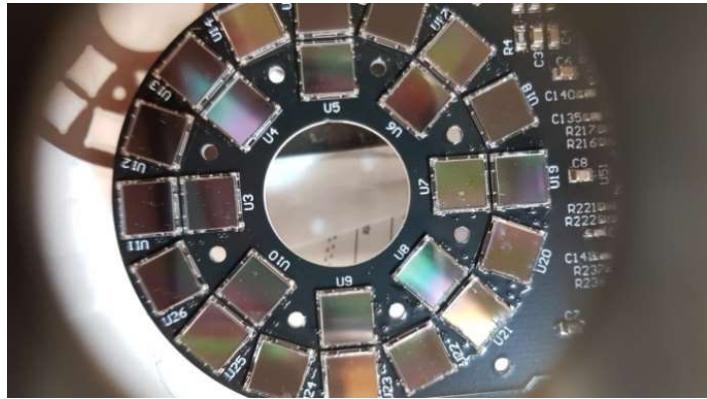
## Perfect for:

- GDR, PDR studies
- Studies of light nuclei
- $4\pi$  calorimetry (Reaction mechanism studies)
- High spin studies?

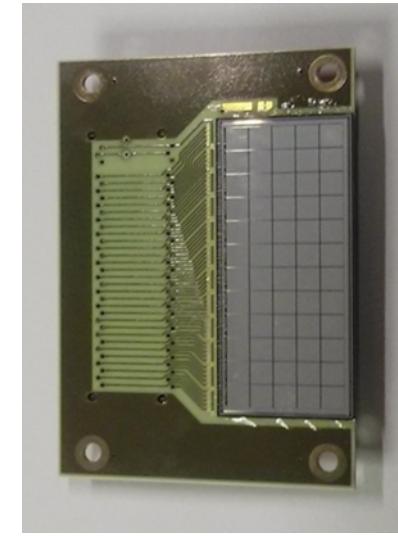
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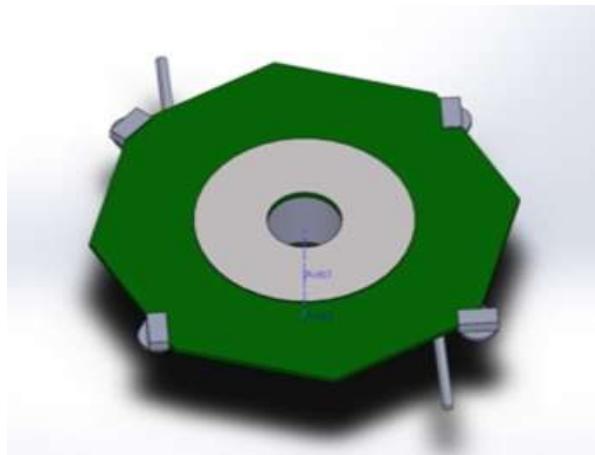
# Charged particle detection systems



ANU LYSO detector



Milano TRACE detectors



Warsaw DSSD detector

- Requires 1 or 2 newly developed FASTER multichannel digitizer cards
- FULLY supported by David Etasse and his team (LPC Caen)

# Calorimetry

## New Fission Observables and Correlations

Calorimeter (BGO + Ge + LaBr3)	Correlated with detected fragment A,Z (and partners)  + Isomeric Ratios
Gamma multiplicity distribution	
Gamma sum energy distribution	
Average gamma multiplicity, $\langle M_\gamma \rangle$	
Average total gamma energy, $\langle E_{\text{tot}} \rangle$	
High energy gamma spectra	
Average neutron multiplicity	

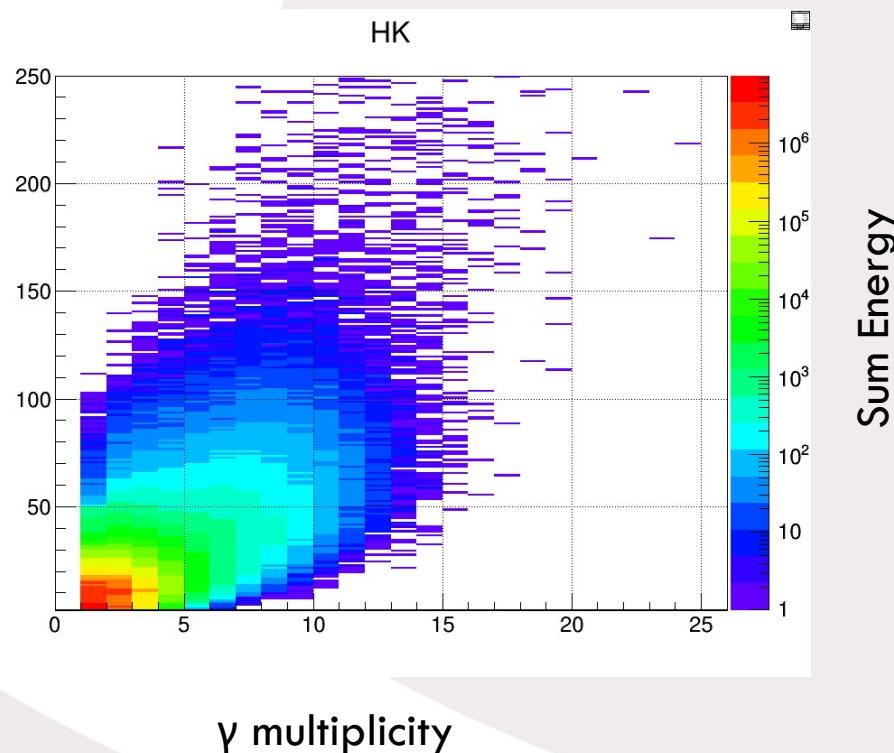
**$^{252}\text{Cf}$  (SF)**

**$^{238}\text{U}(n,f)$**  @ 1.7 and 3.5 MeV

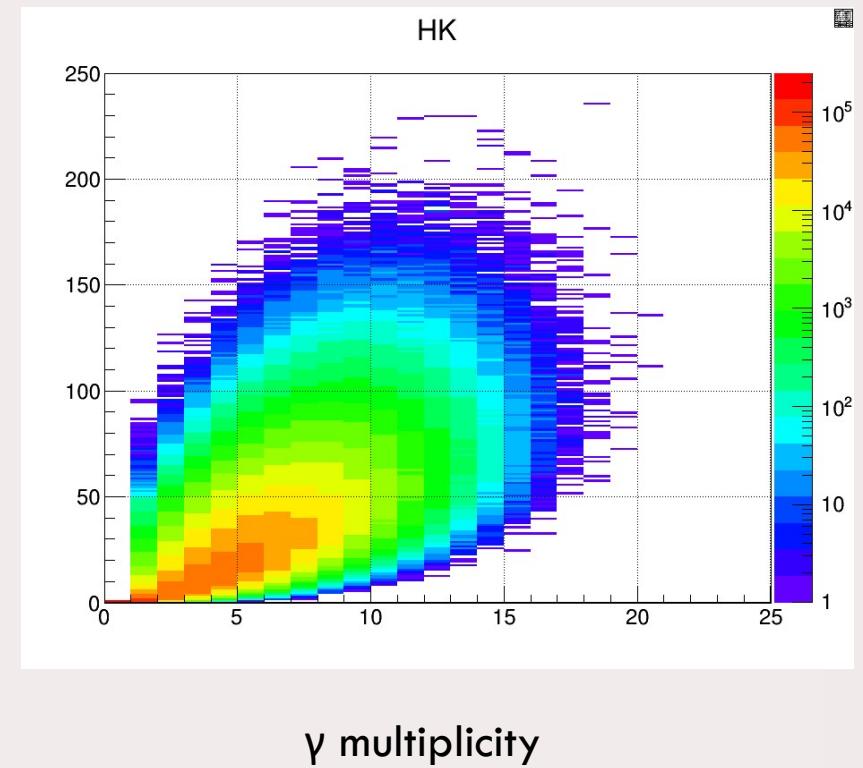
**$^{232}\text{Th}(n,f)$**  @ 1.7 MeV

# $\nu$ -ball calorimetry (sources)

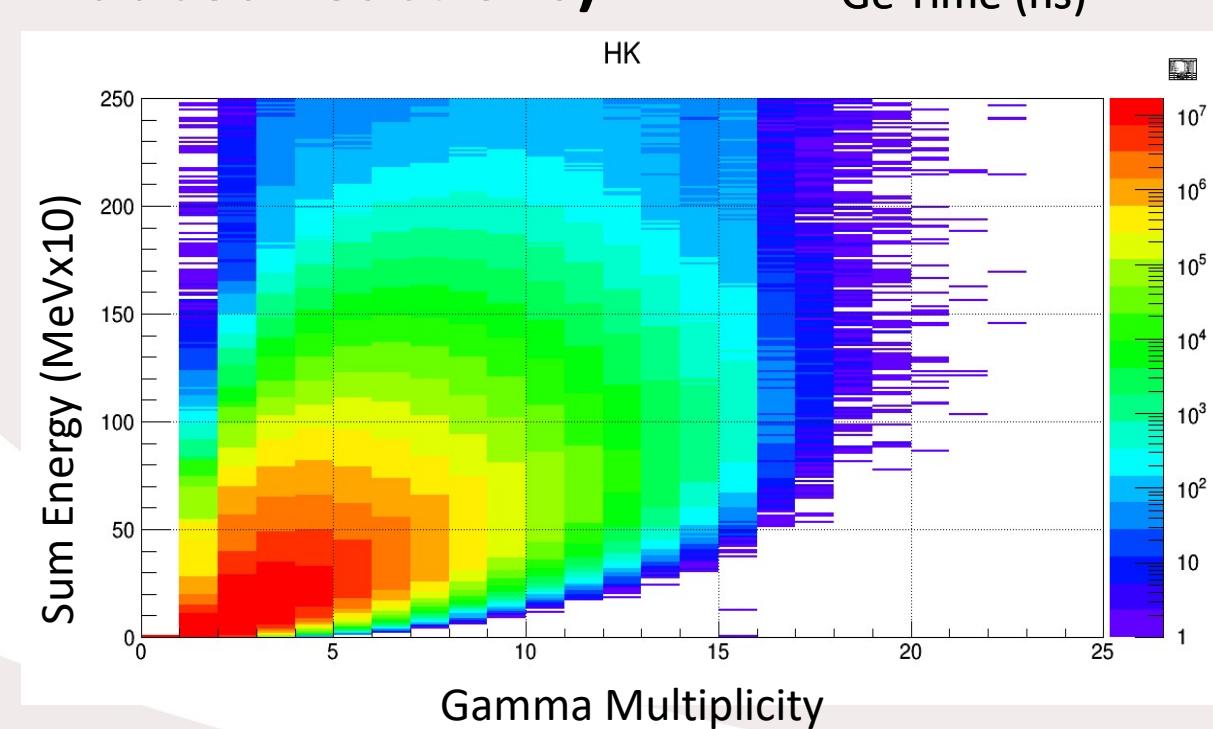
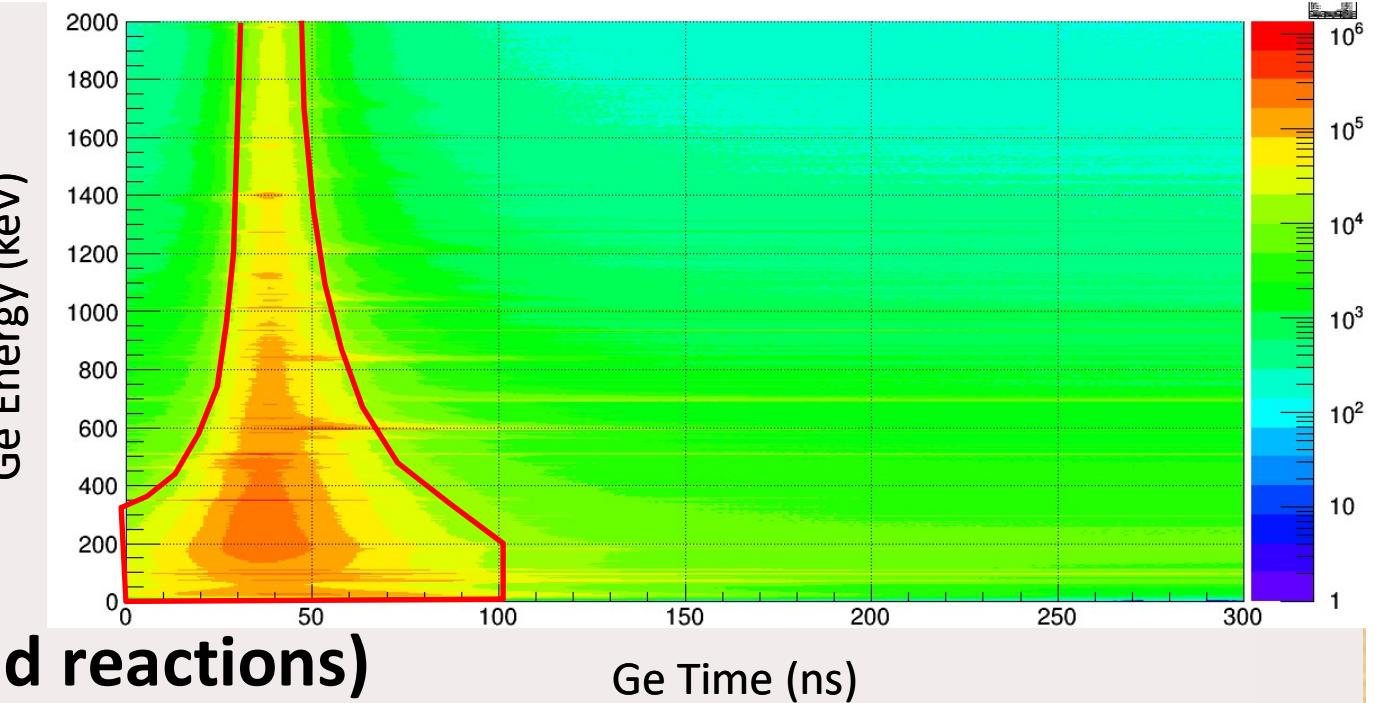
**$^{152}\text{Eu}$  beta decay events**



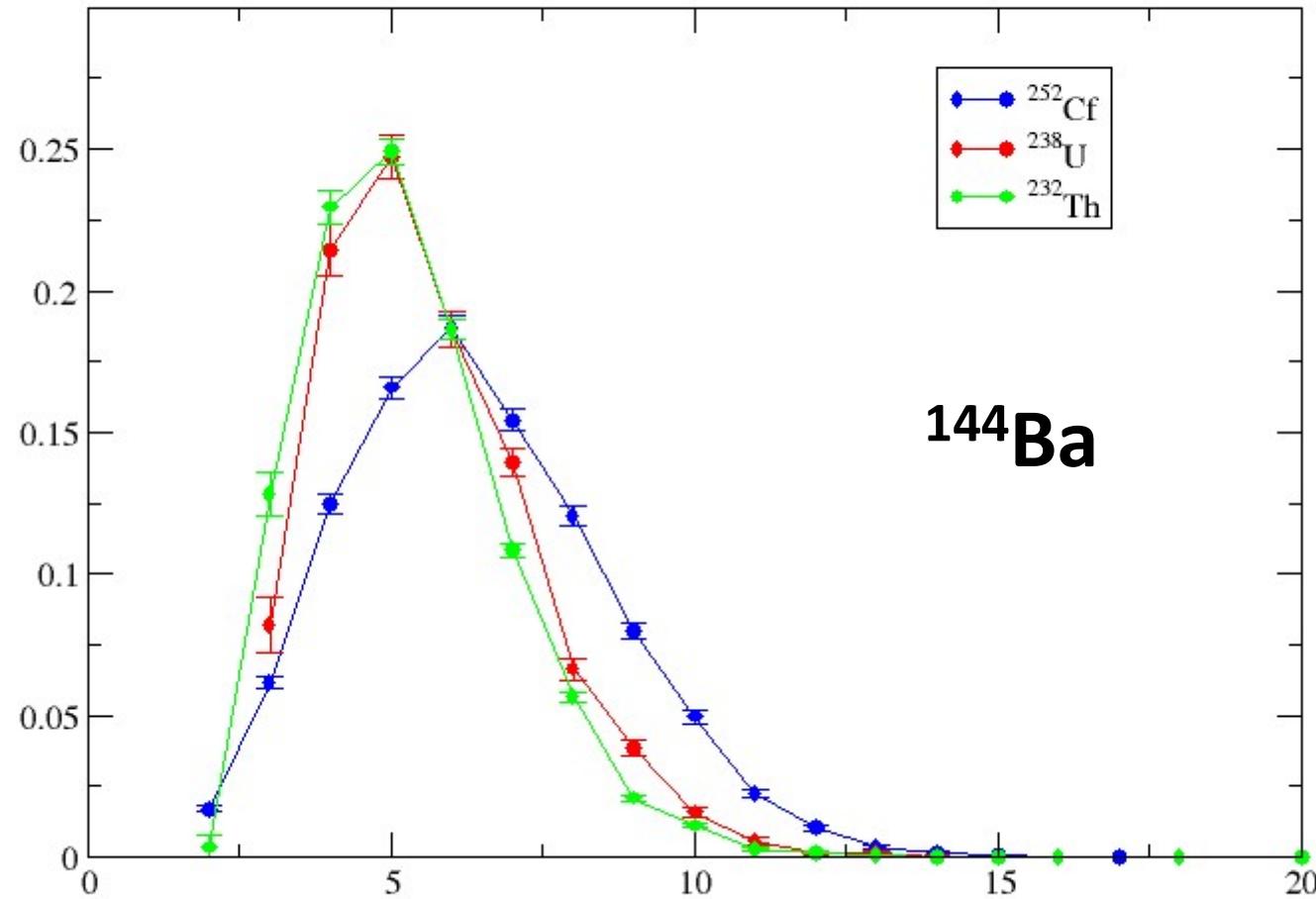
**$^{252}\text{Cf}$  fission events**



## v-ball timing and calorimetry (neutron-induced reactions)

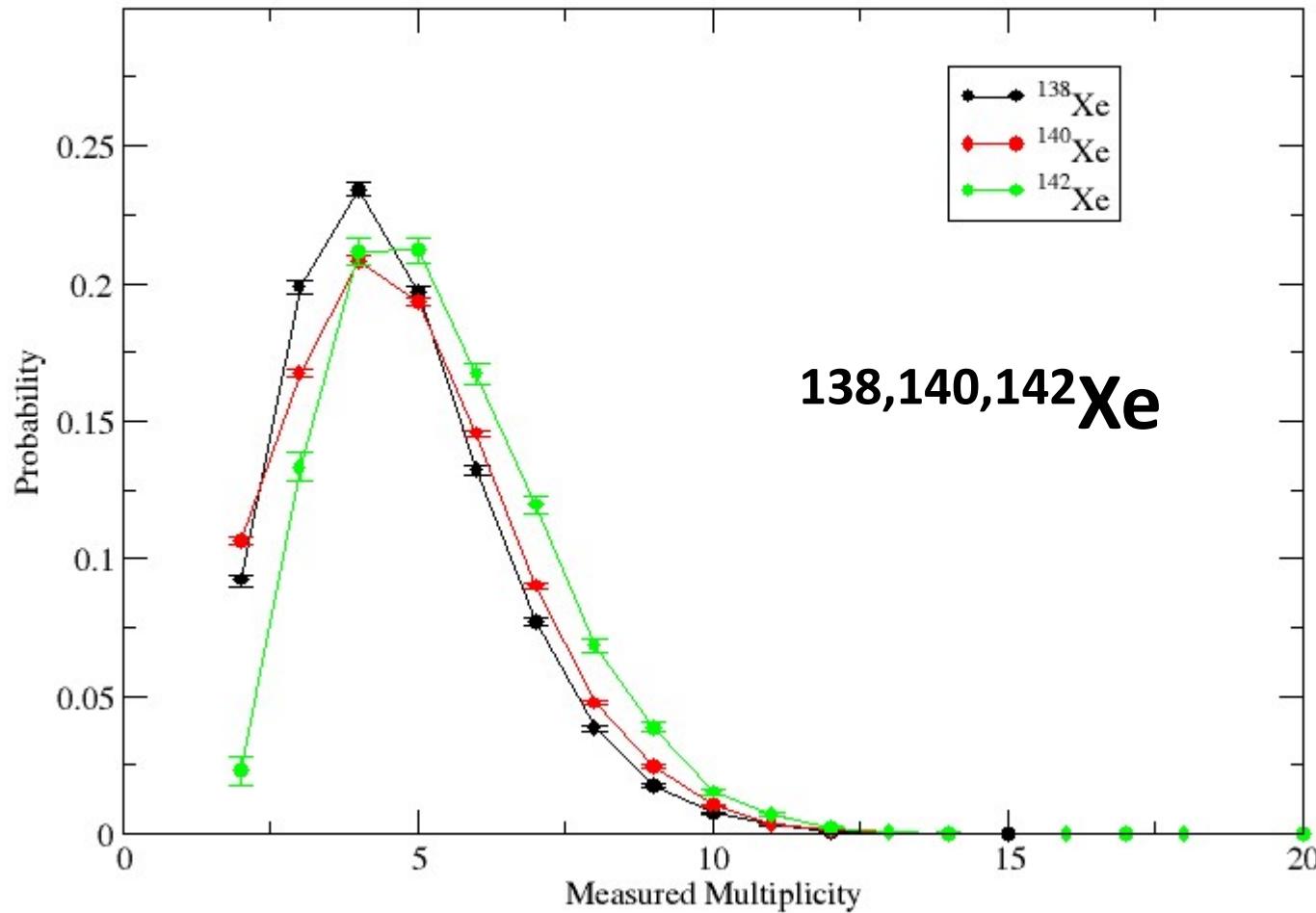


# Gamma multiplicity distributions



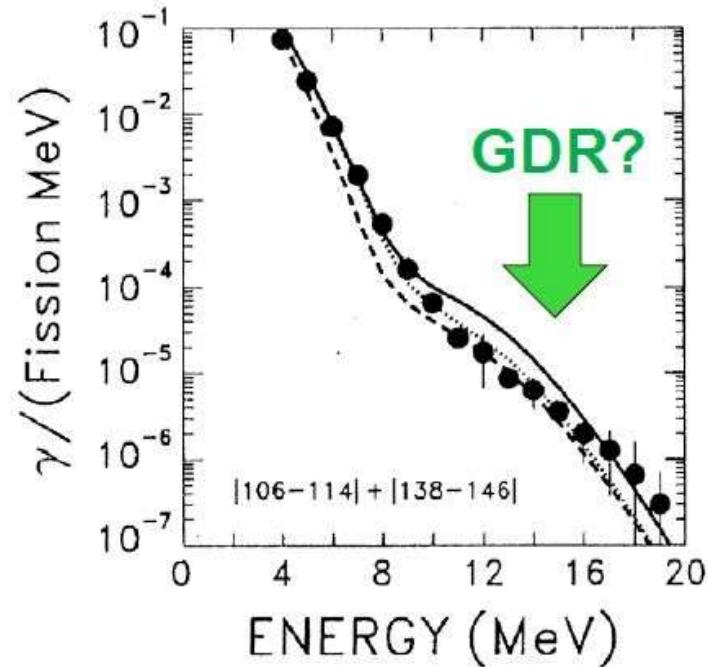
$^{144}\text{Ba}$

## $^{238}\text{U}(\text{n},\text{f})$ Gamma Multiplicity Distributions - Xe isotopes

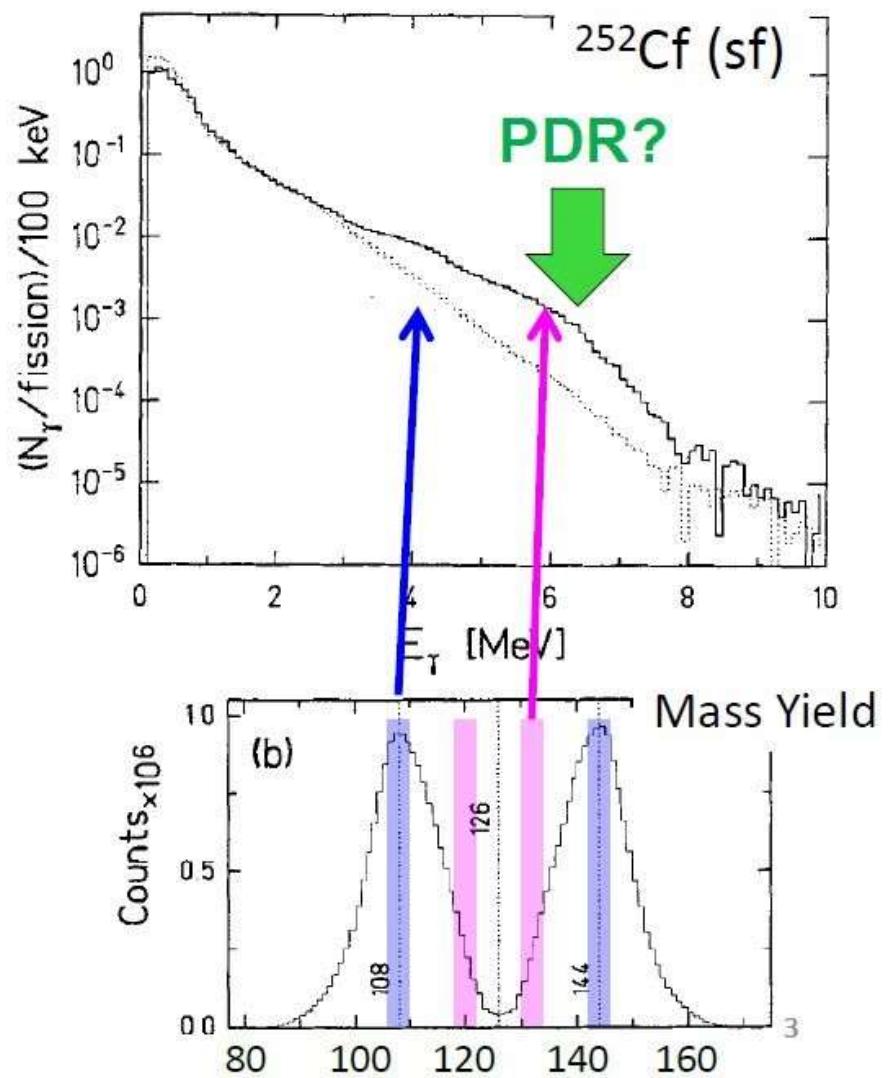


# High Energy gamma-rays produced in fission

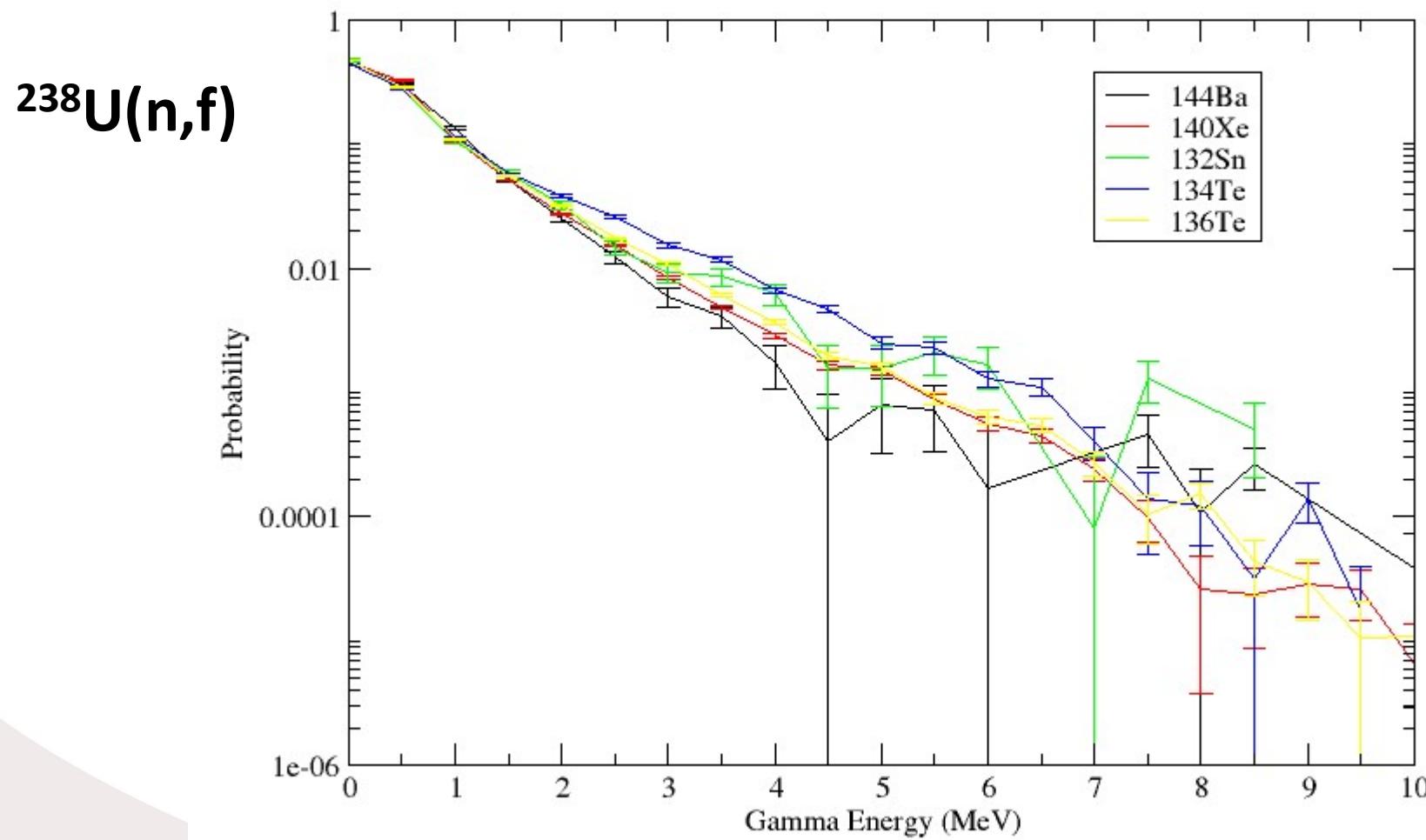
H. van der Ploeg *et al.*,  
Phys. Rev. C, **52**, 1915 (1995).



A. Hotzel *et al.*, Z. Phys. A336 (1996) 299.

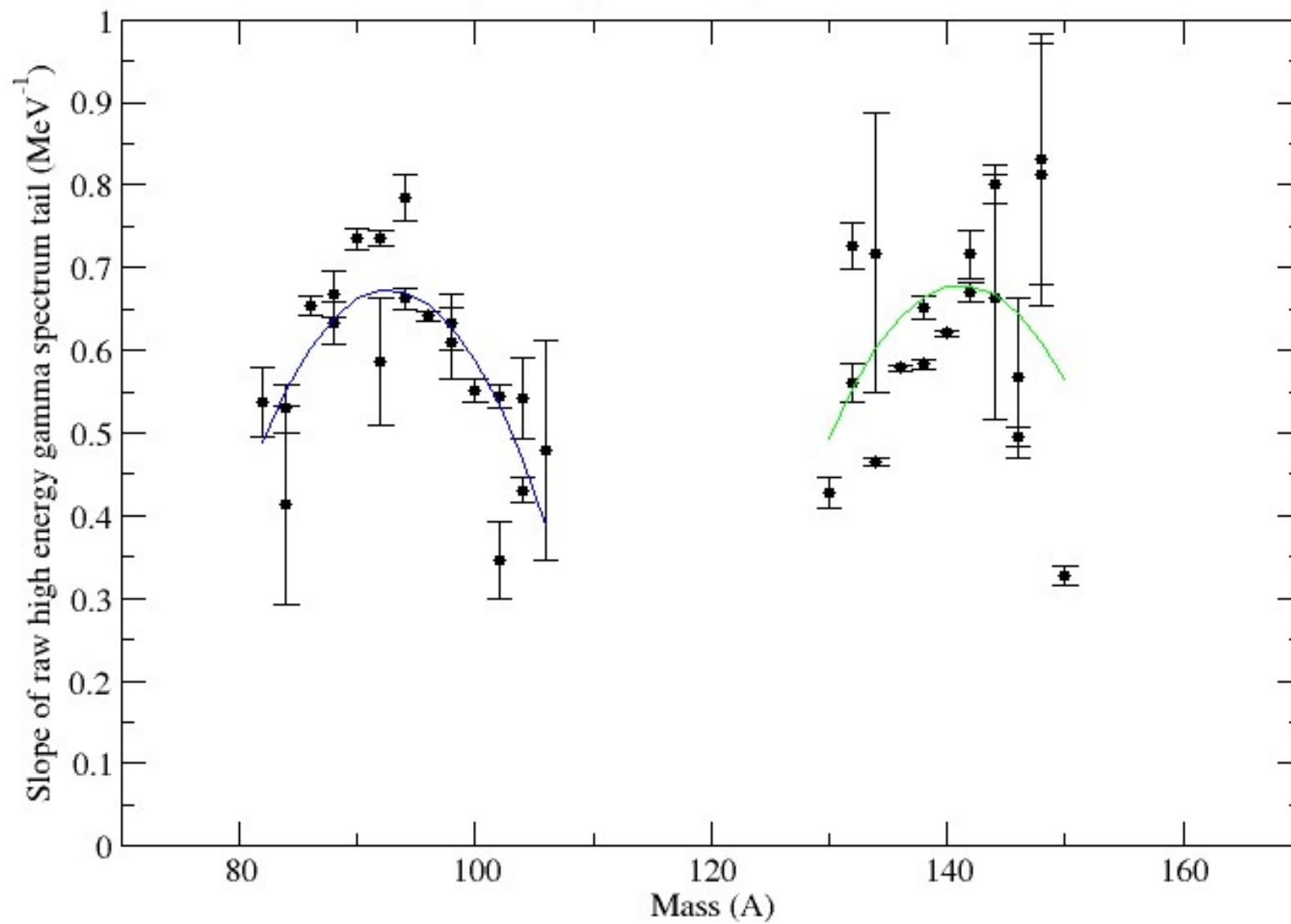


# High Energy Gamma Spectra (BGO) correlated with A/Z (and partners)

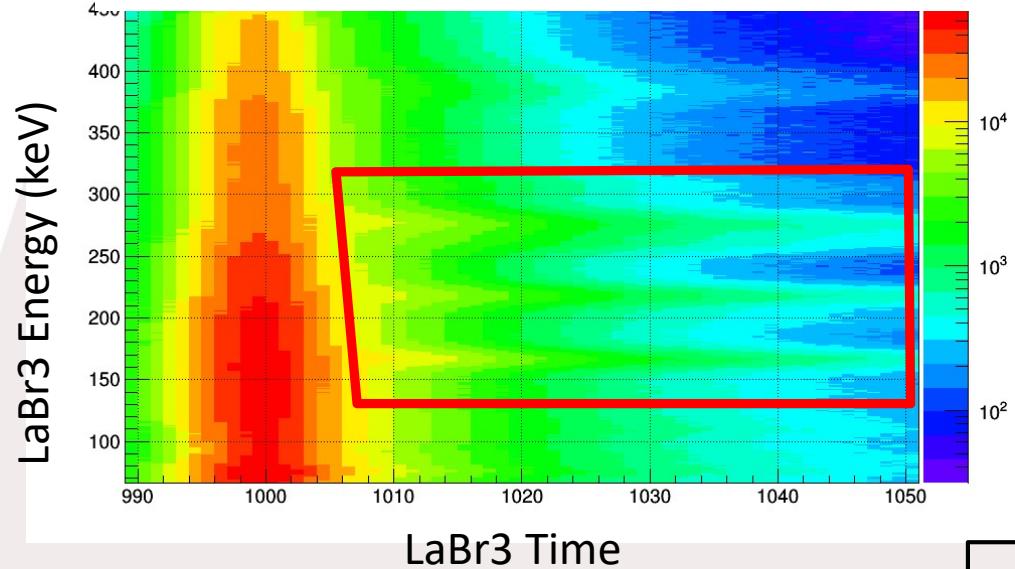


# $^{238}\text{U}(\text{n},\text{f})$

High Energy Gamma Spectrum Hardness

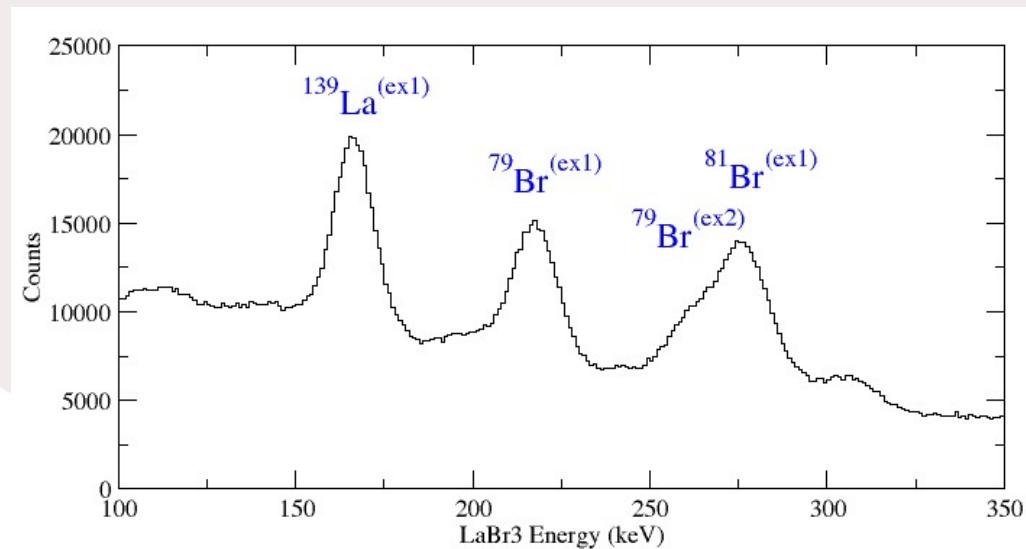


# $\nu$ -ball LaBr<sub>3</sub>s as prompt neutron detectors

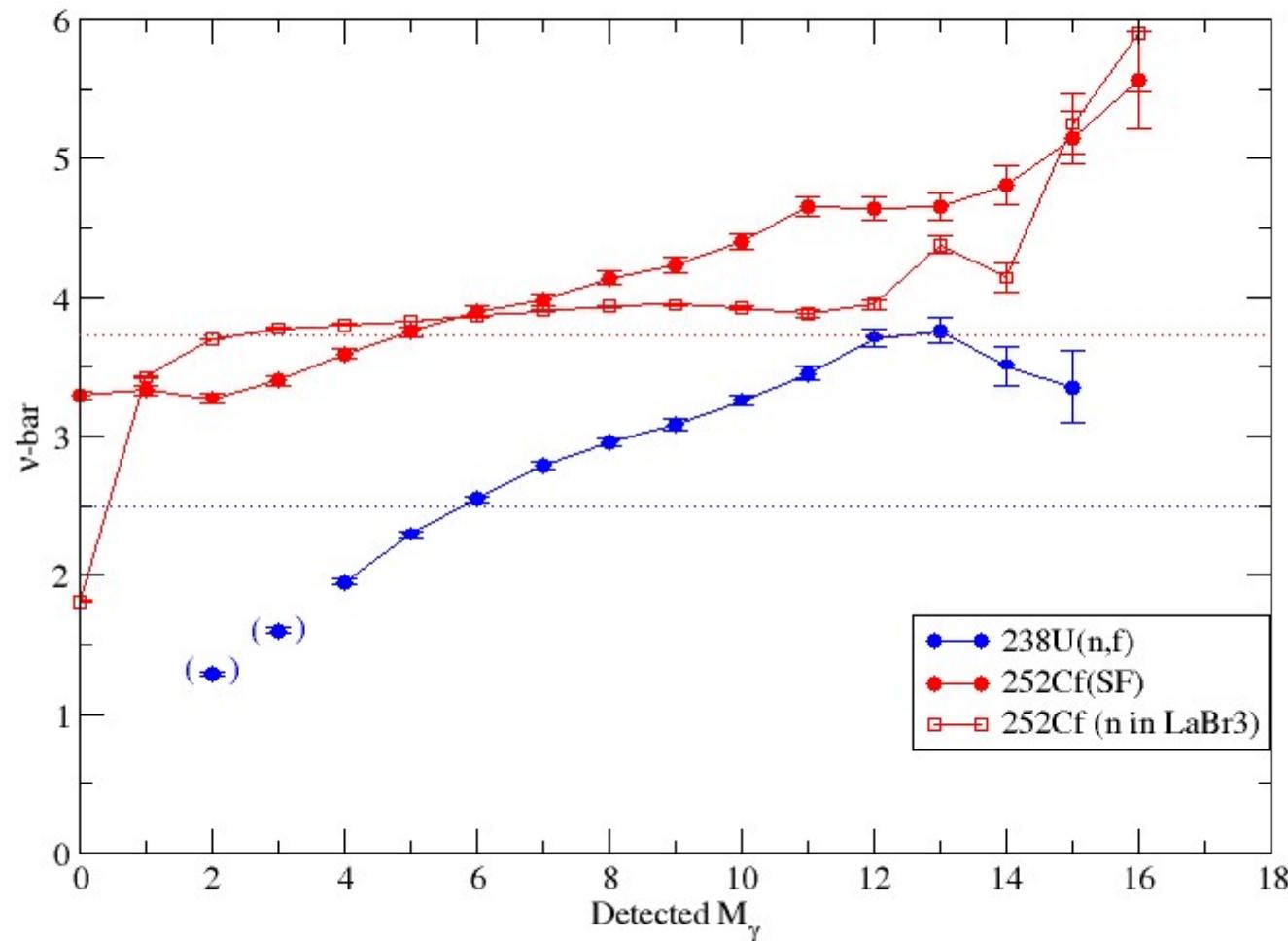


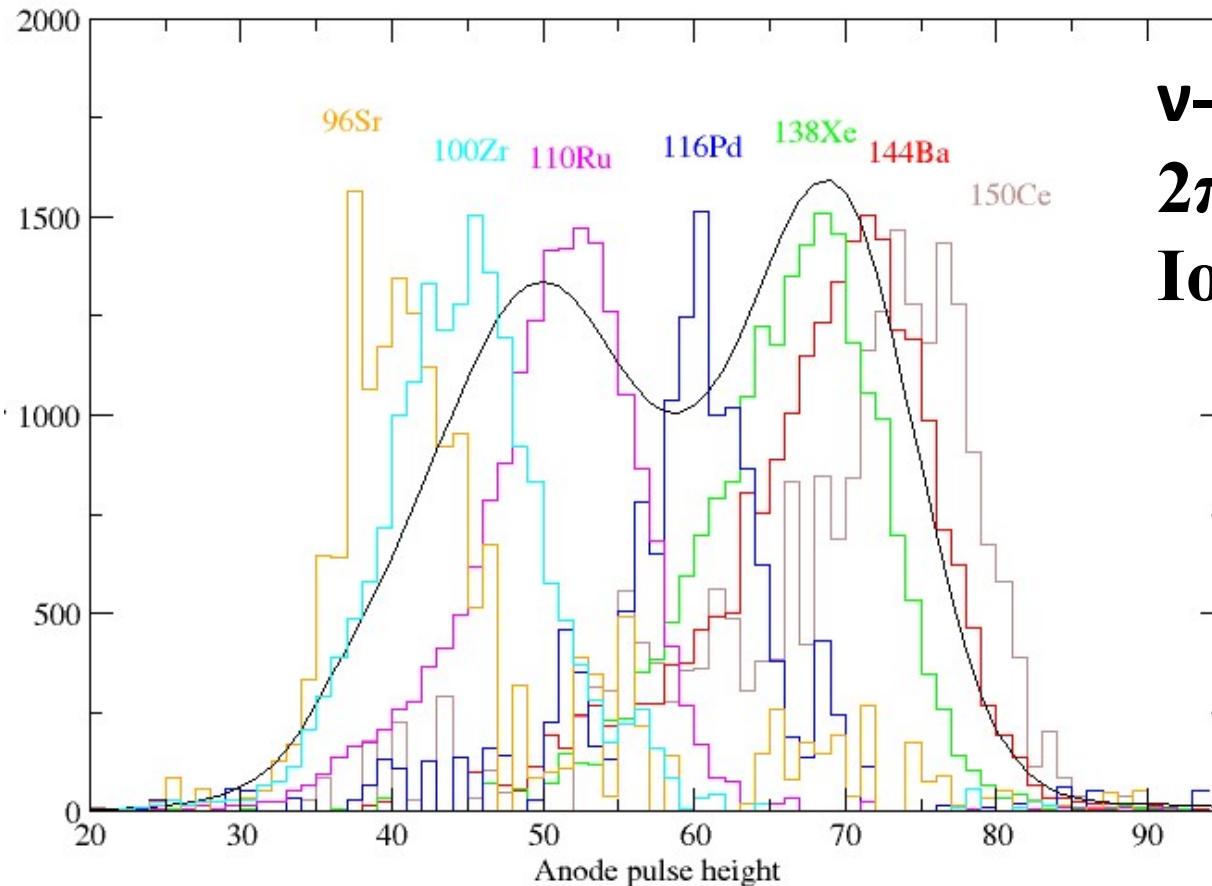
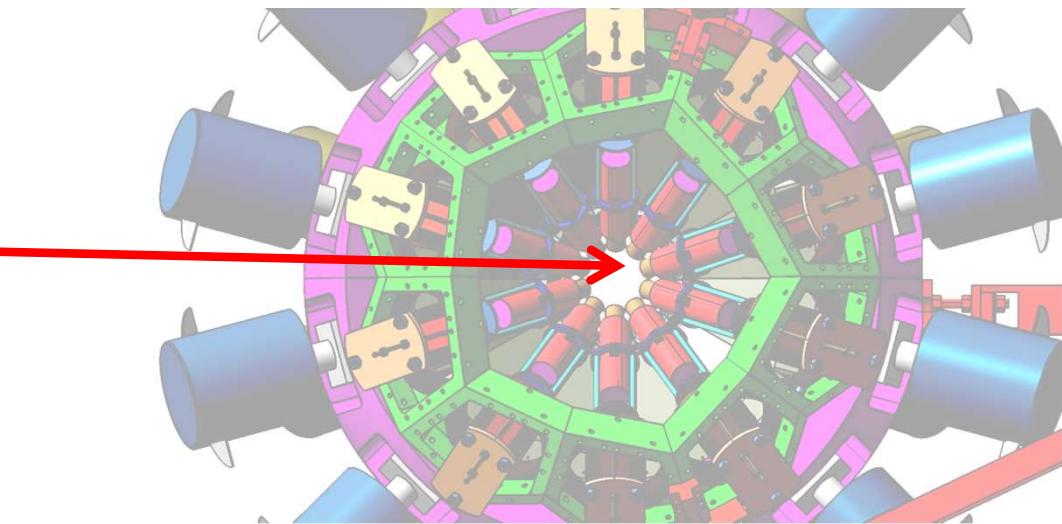
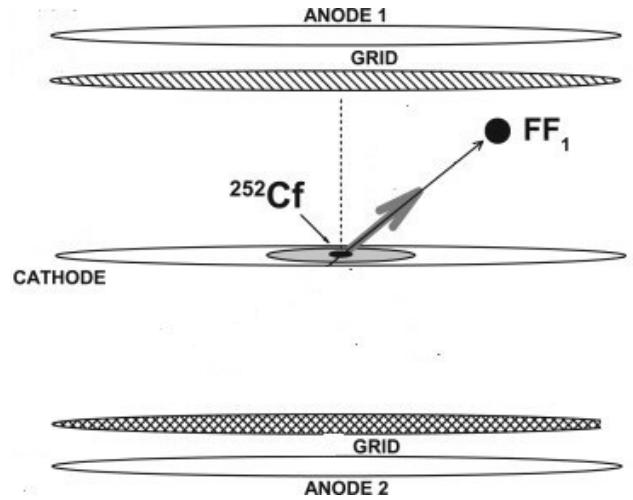
Prompt neutrons: (n,n'γ) events

$$\epsilon_{\text{neutron}} = 0.15\%$$



## $\bar{\nu}$ -bar positivly correlated with $M_\gamma$





**ν-ball +  
2π 252Cf source +  
Ionisation chamber**

# $\nu$ -ball2 + $4\pi$ $^{252}\text{Cf}$ source + Segmented Ionisation chamber

