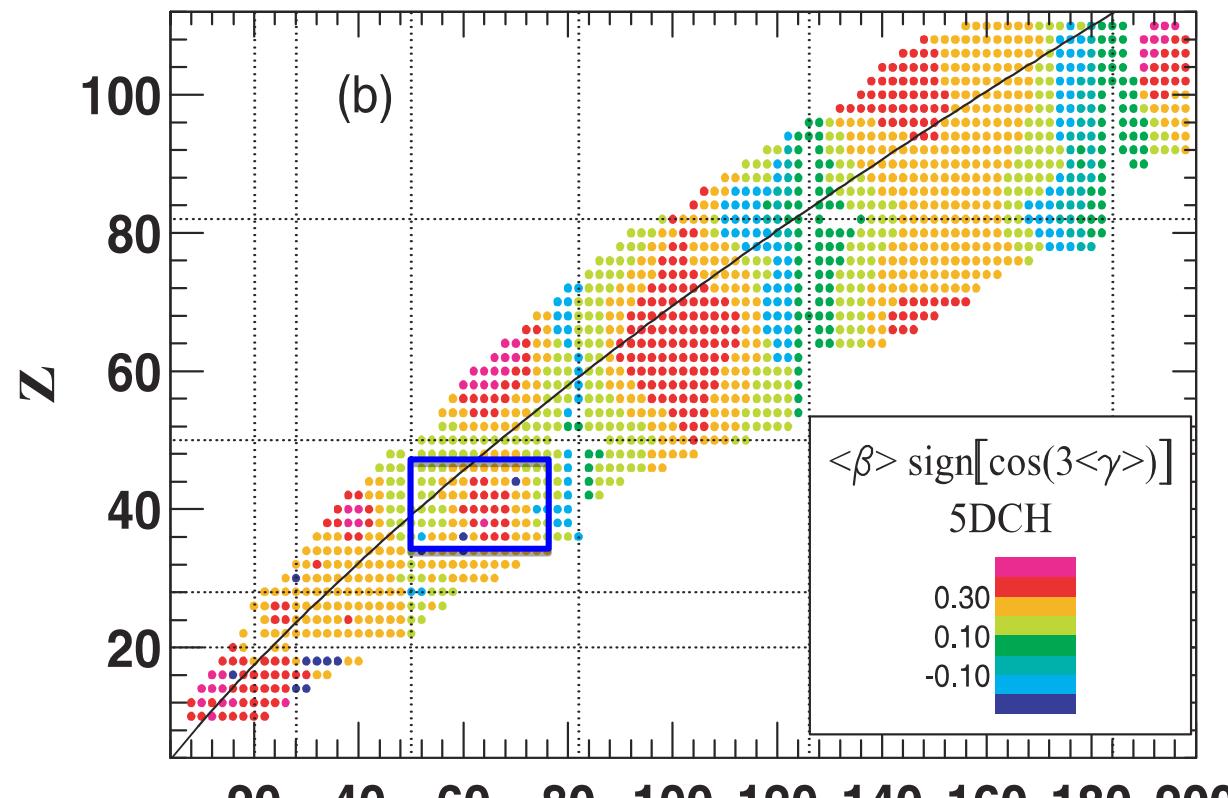


# Study of shape evolution around A~100



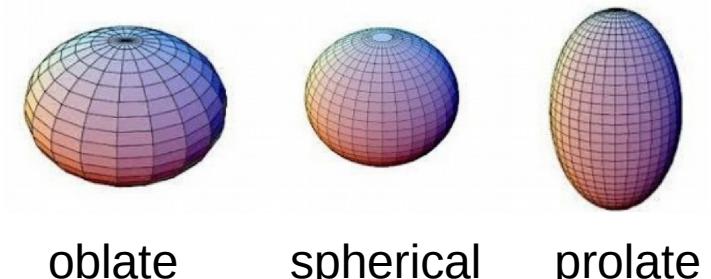
## Ground state deformation from HFB calculations



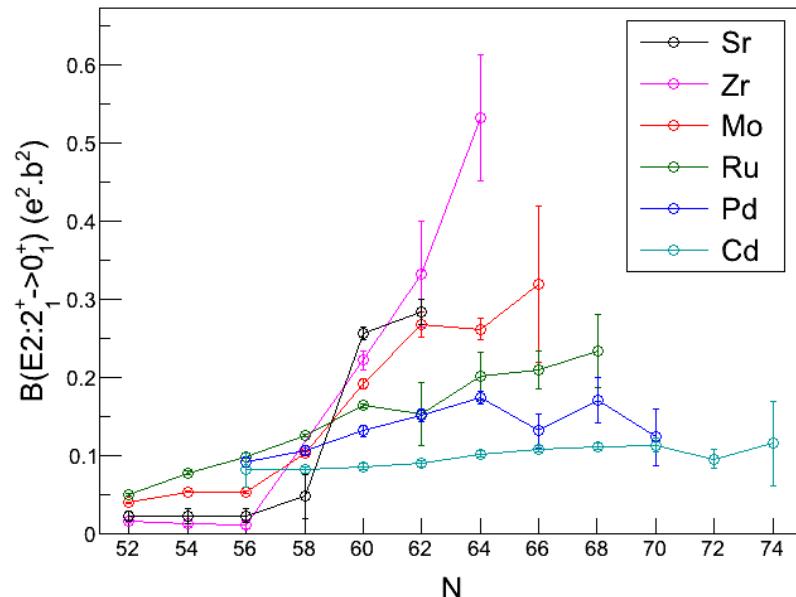
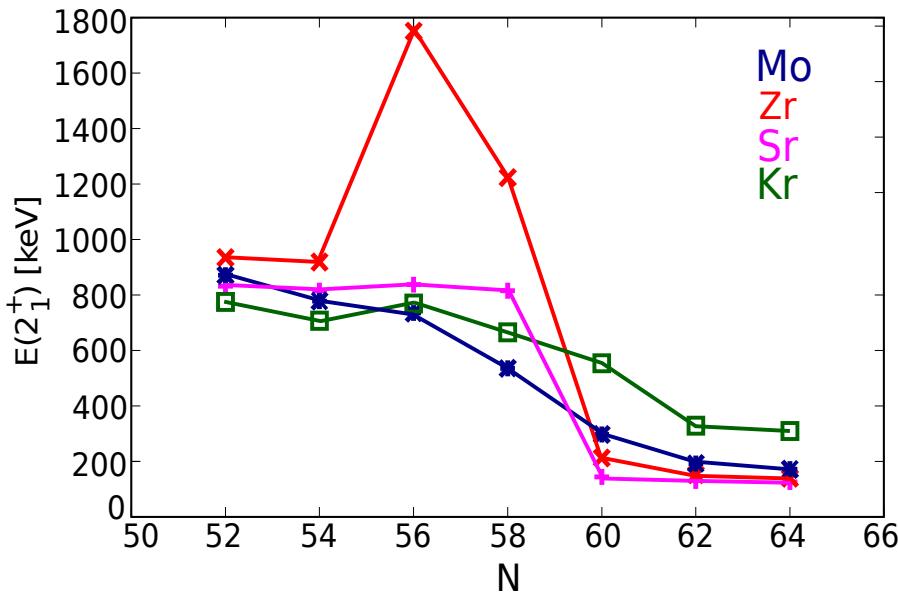
HFB+GCM(GOA) calculations  
with Gogny D1S force,  
J.P. Delaroche et al., PRC 81  
(2008)

Rich variety of nuclear shapes

- Rapid variations with (Z,N)
- Oblate and prolate minima  
→ shape coexistence

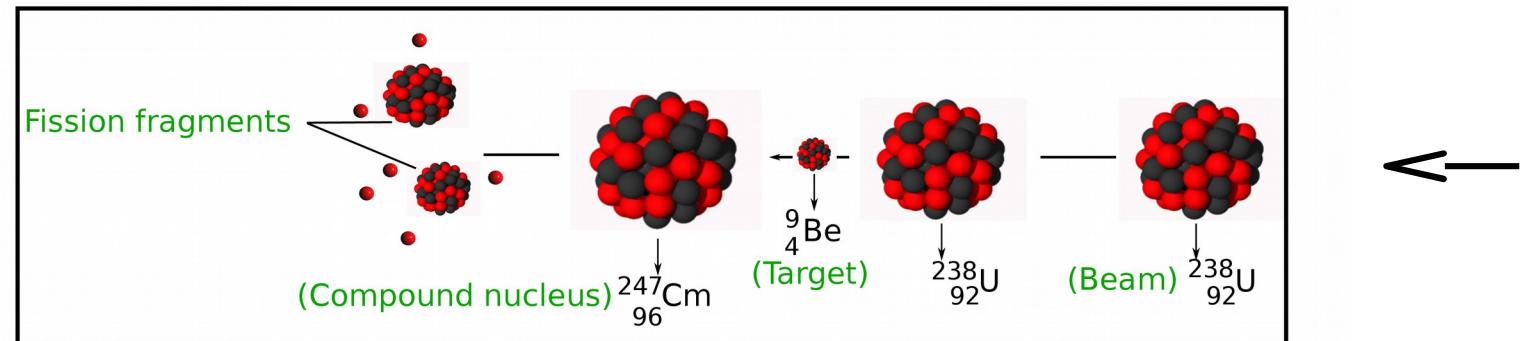


# Motivation



- Evolution of the  $2^+_1$  excitation energy as a function of neutron number in the  $A \sim 100$  region.
- Experimental evidence of shape transition at  $N=58-60$ .
- Experimental measurements of **lifetime** to determine **transition strengths ( $B(E2)$ )**.

# Experimental Procedure



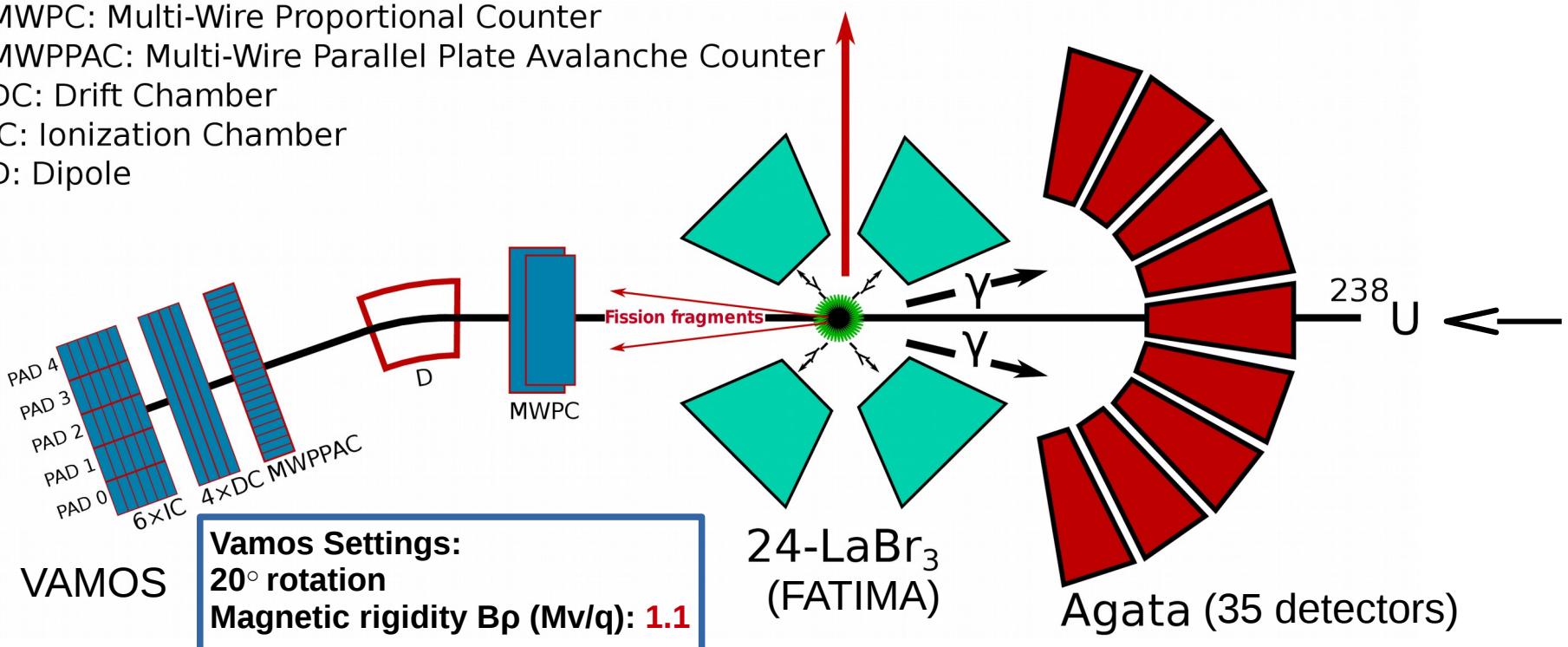
MWPC: Multi-Wire Proportional Counter

MWPPAC: Multi-Wire Parallel Plate Avalanche Counter

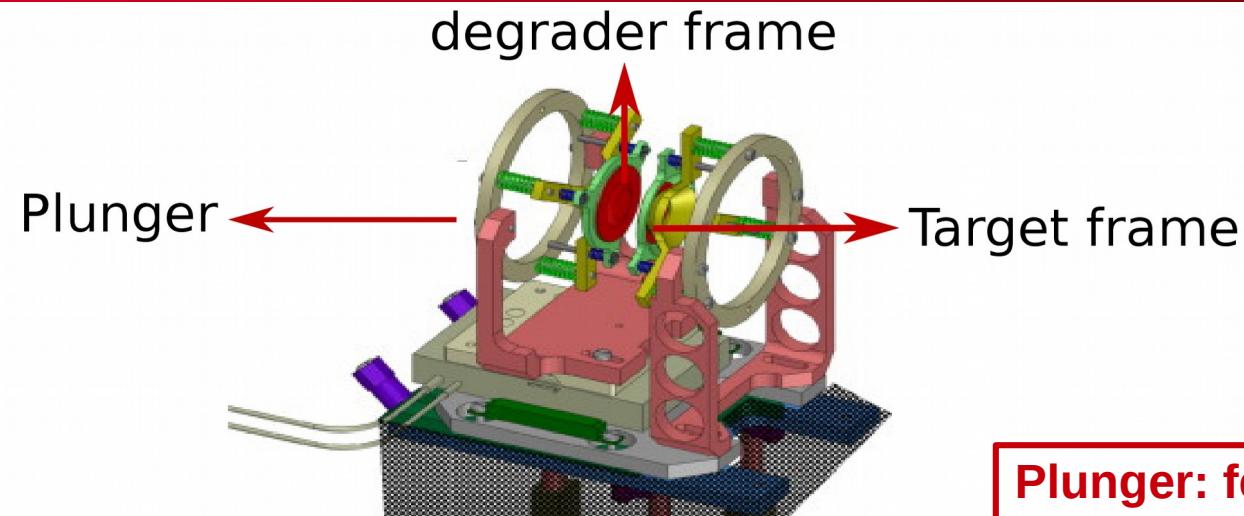
DC: Drift Chamber

IC: Ionization Chamber

D: Dipole



# Experimental Procedure



**Plunger: few ps-100 ps**  
**FATIMA: ~50 ps**

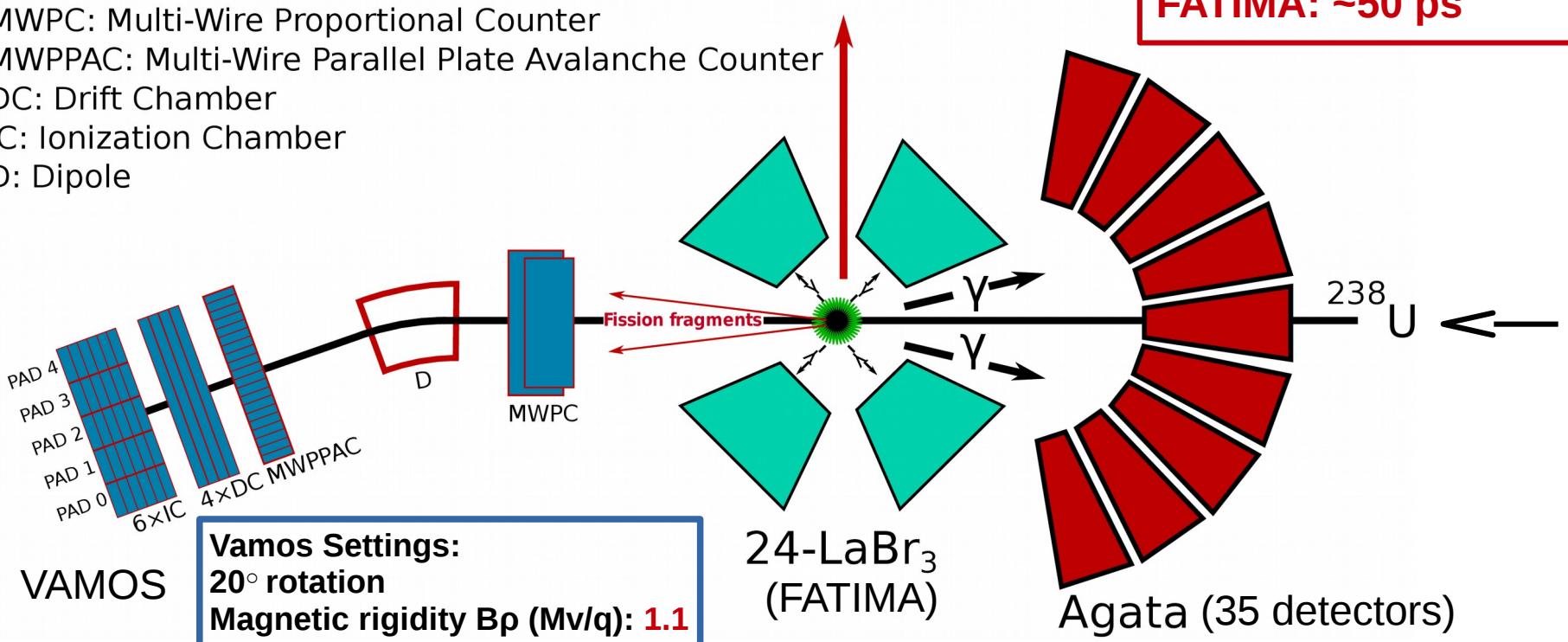
MWPC: Multi-Wire Proportional Counter

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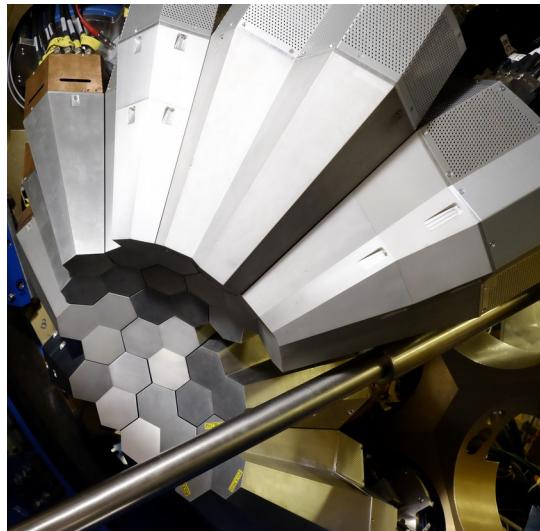
D: Dipole



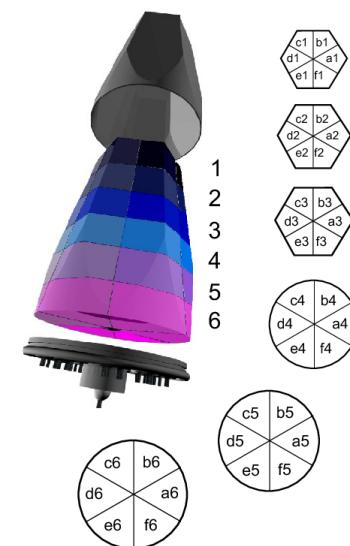
**AGATA** is an array composed of high-purity segmented germanium detectors.

## Strength of the array:

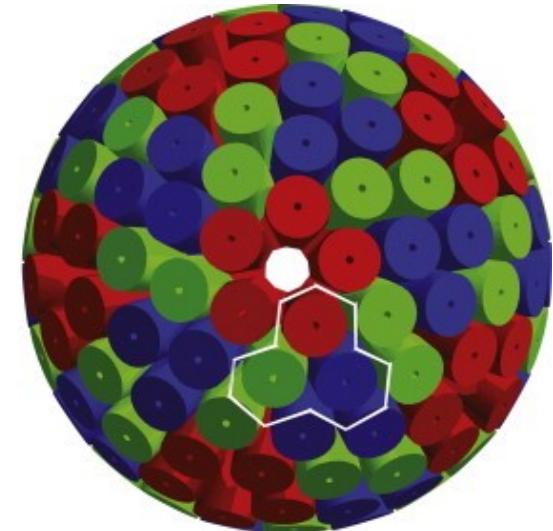
- Determine the interaction point of  $\gamma$  ray by comparing it to the measured signal shapes.
- Reconstruct the path of a Compton scattered  $\gamma$  ray inside the array.



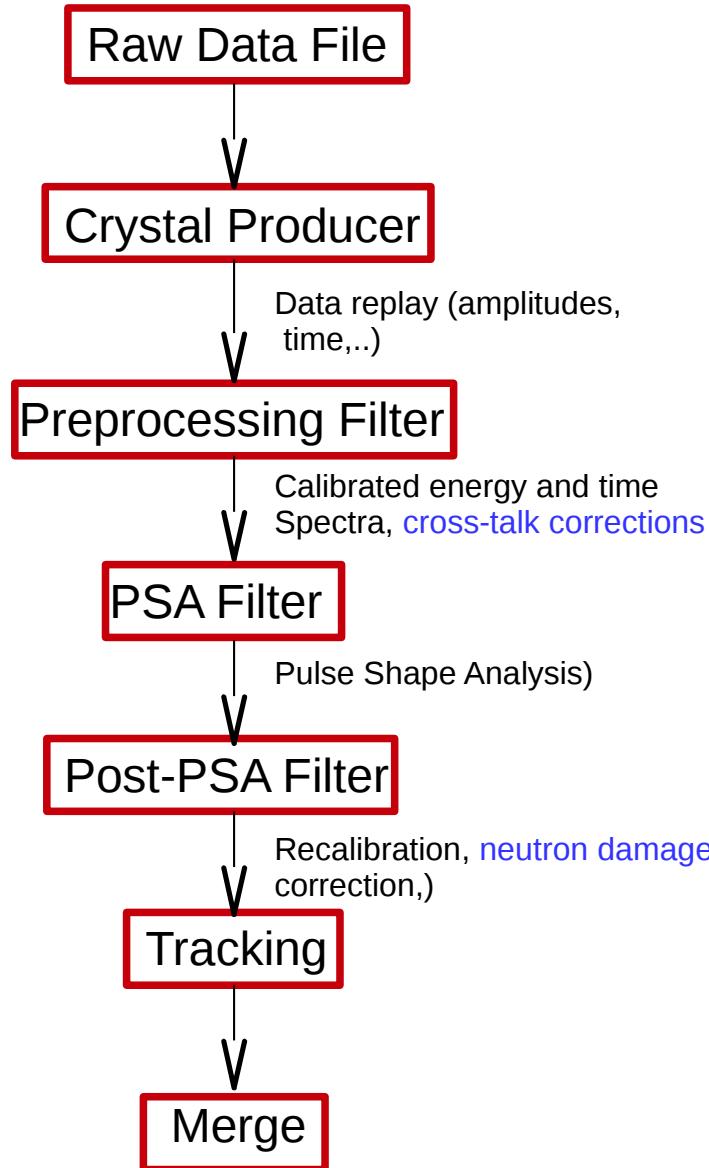
35 AGATA detectors were used in the present work



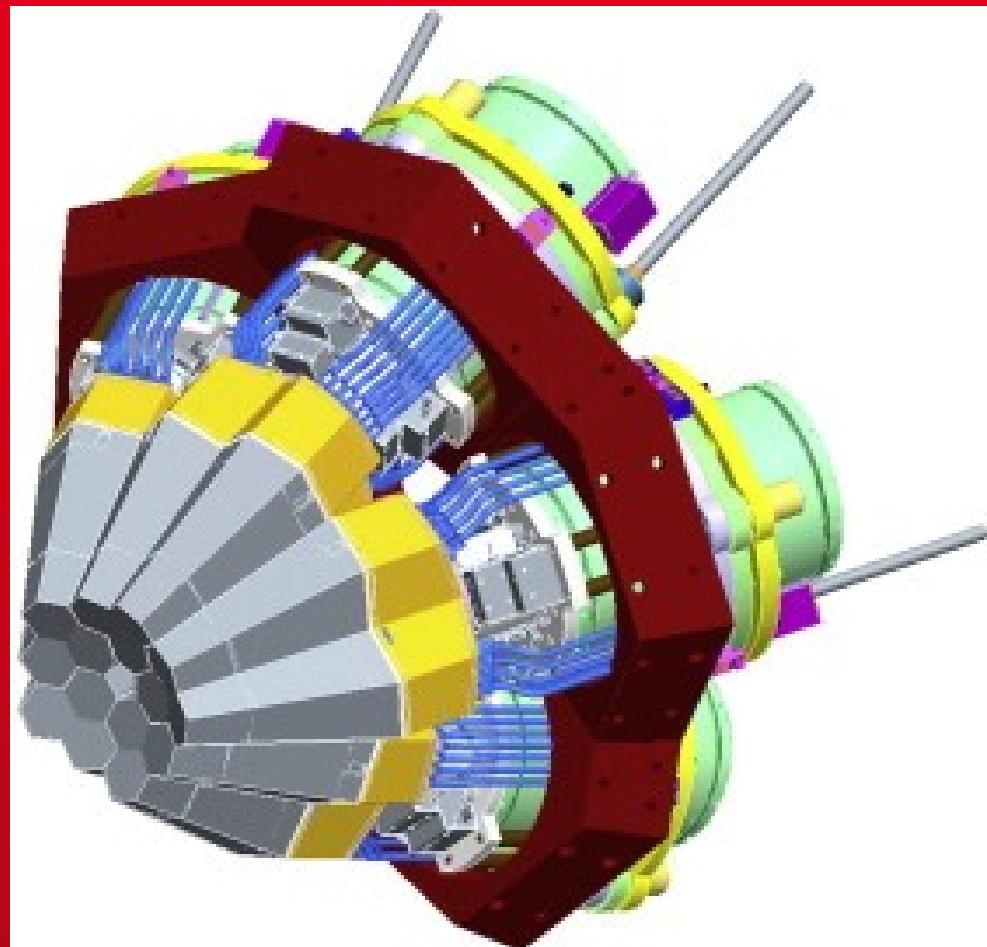
Each AGATA crystal is composed of 36-fold segments



AGATA project aims at reaching a  $4\pi$  solid angle

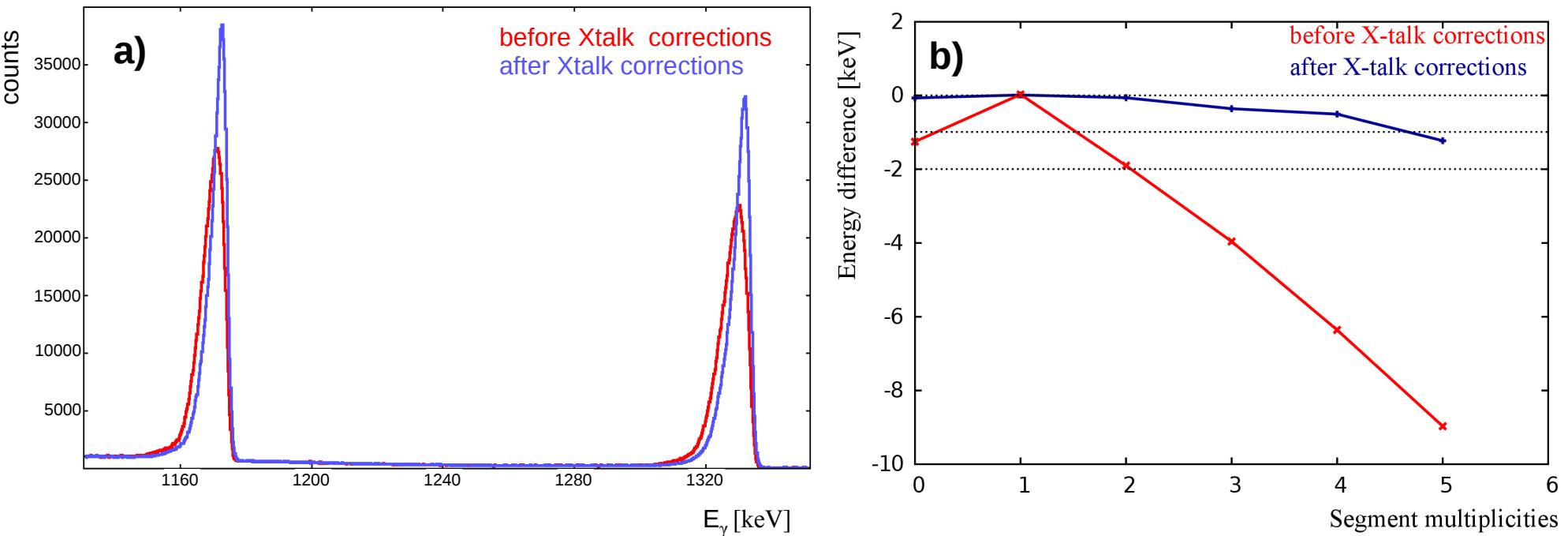


# AGATA ANALYSIS



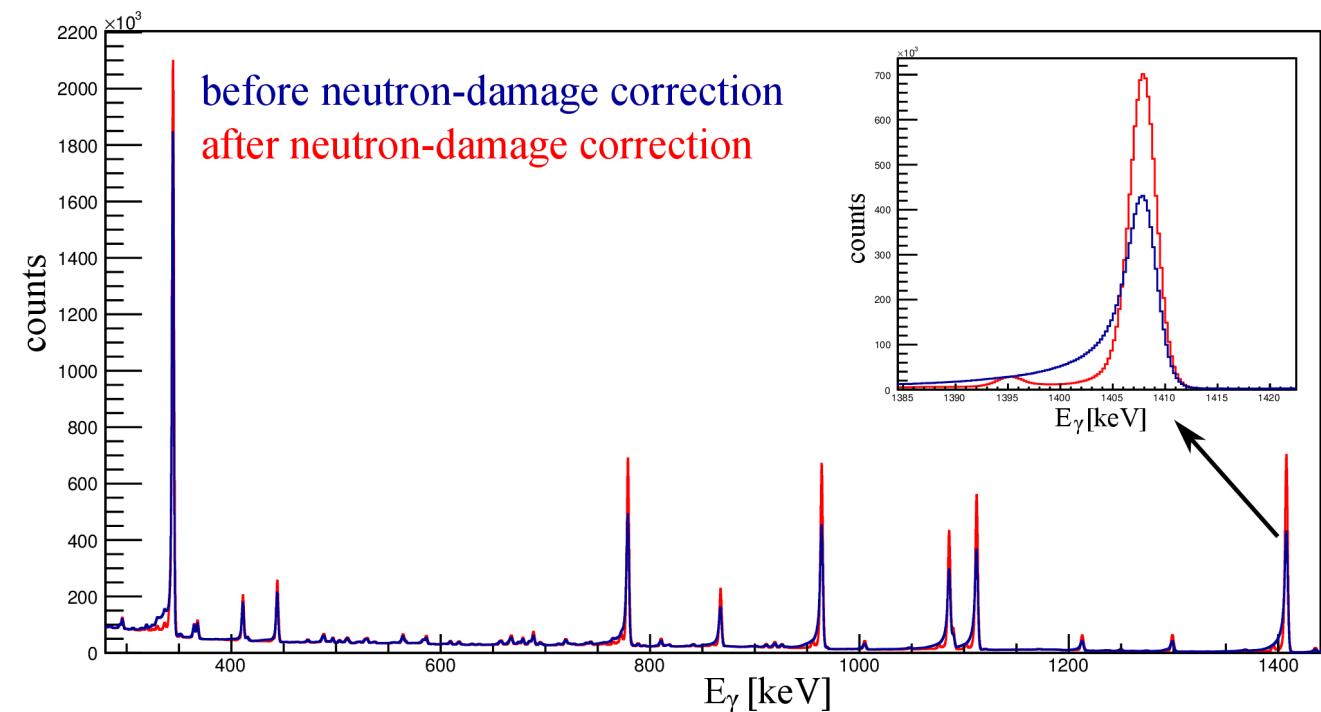
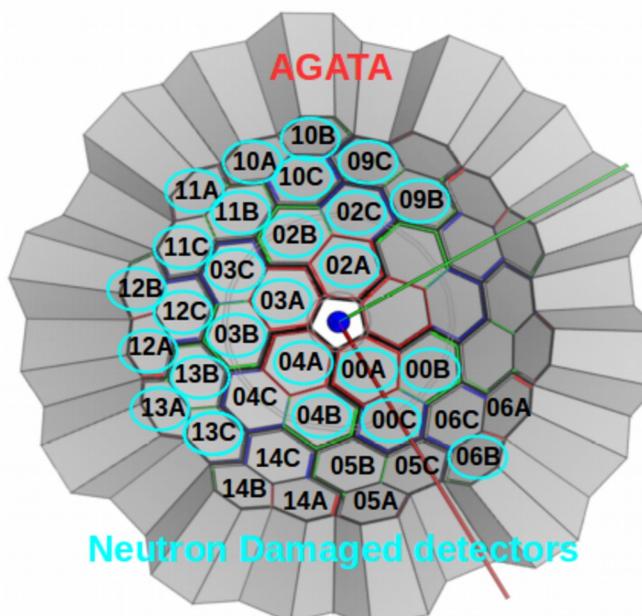
S. Ansari

# Cross talk correction



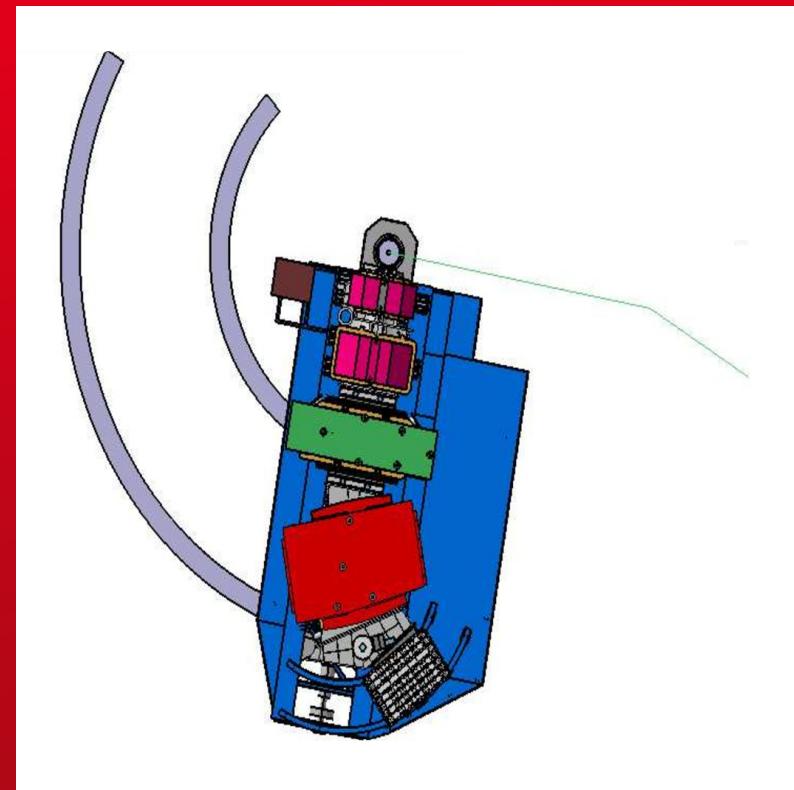
- Electronic cross talk effects are observed in segmented Ge detectors.
- Cross talk correction allows to recover the sum of hit energies.

# Neutron Damage Correction



- Interaction of neutrons with Ge crystals induces lattice defects.
- Lattice defects are more susceptible to trap holes than electrons.
- Neutron damage correction is possible from the knowledge of the interaction position and corrects for the deficiency of the charge collection.

# VAMOS ANALYSIS



S. Ansari

NUSPIN 2019 – 28-06-2019

Credit: P. Singh

# Vamos Analysis

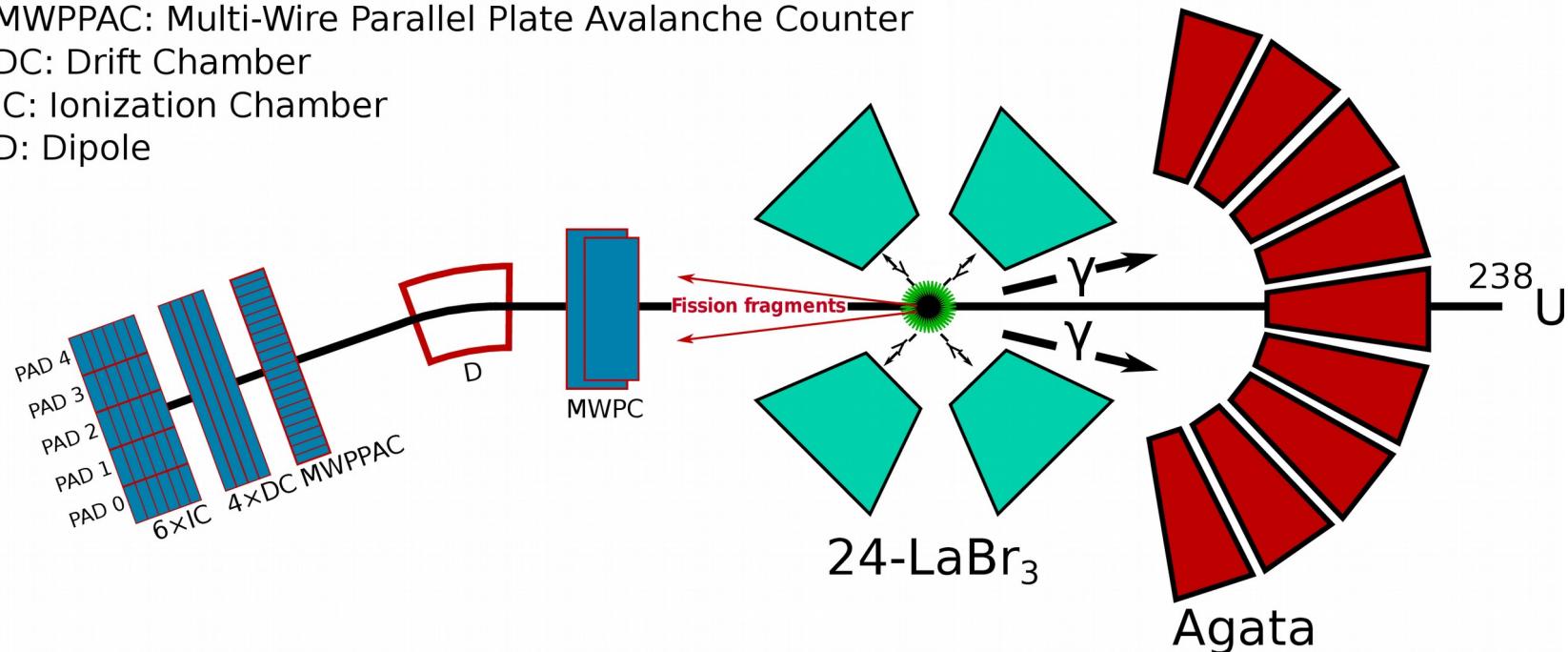
MWPC: Multi-Wire Proportional Counter

MWPPAC: Multi-Wire Parallel Plate Avalanche Counter

DC: Drift Chamber

IC: Ionization Chamber

D: Dipole



# Vamos Analysis



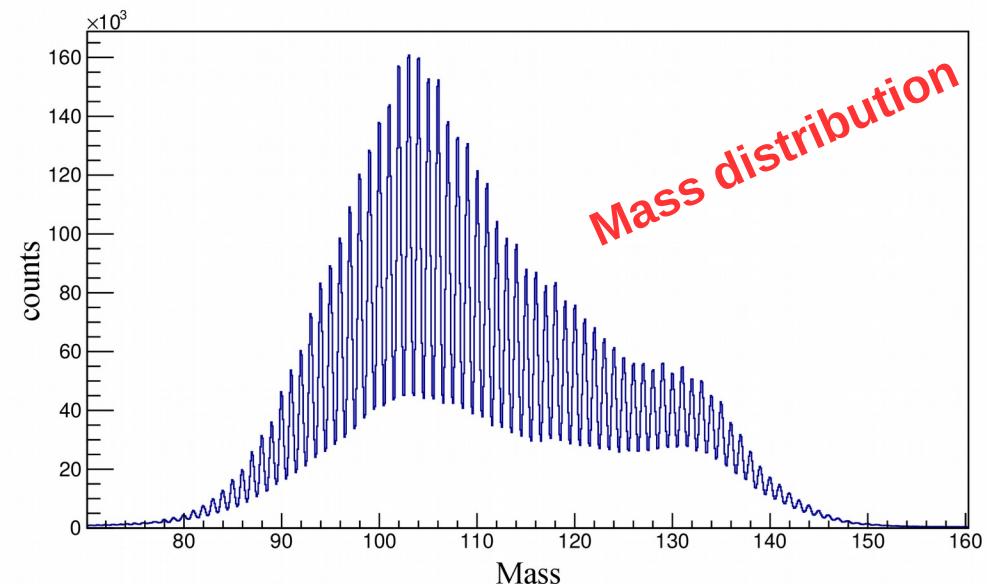
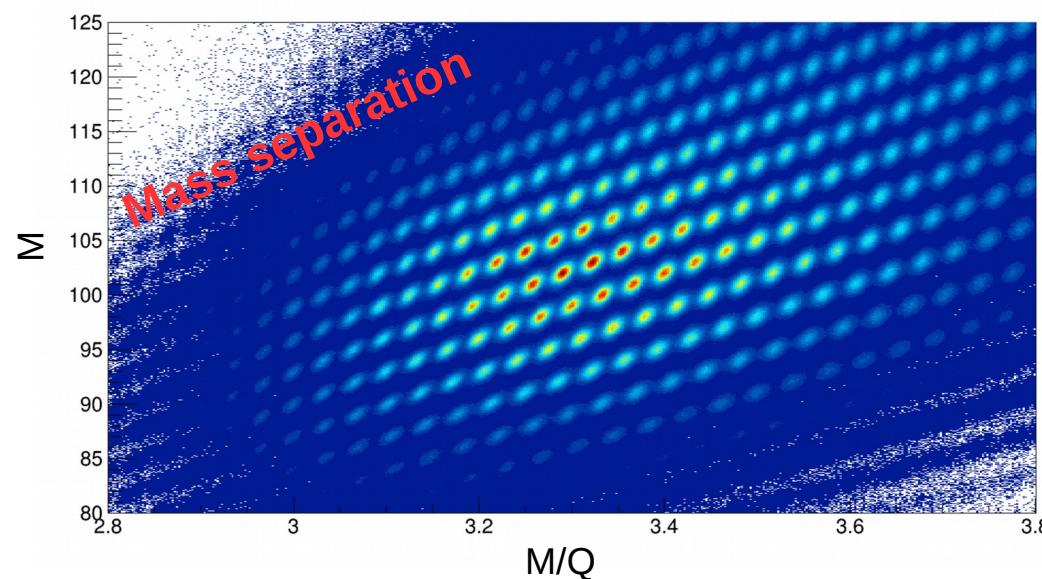
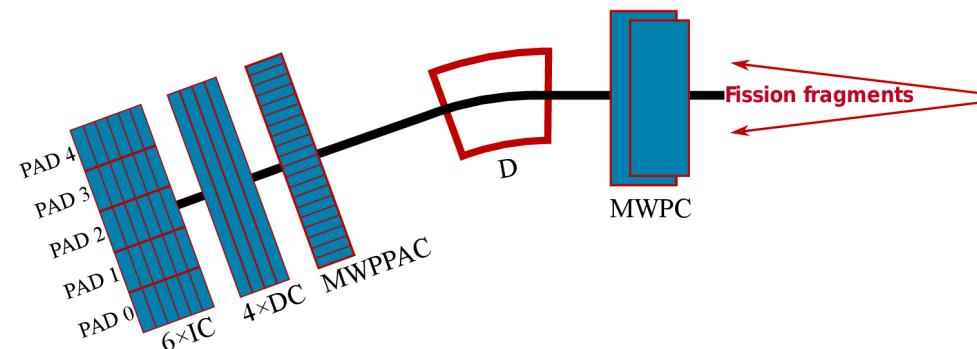
MWPC: Multi-Wire Proportional Counter

MWPPAC: Multi-Wire Parallel Plate Avalanche Counter

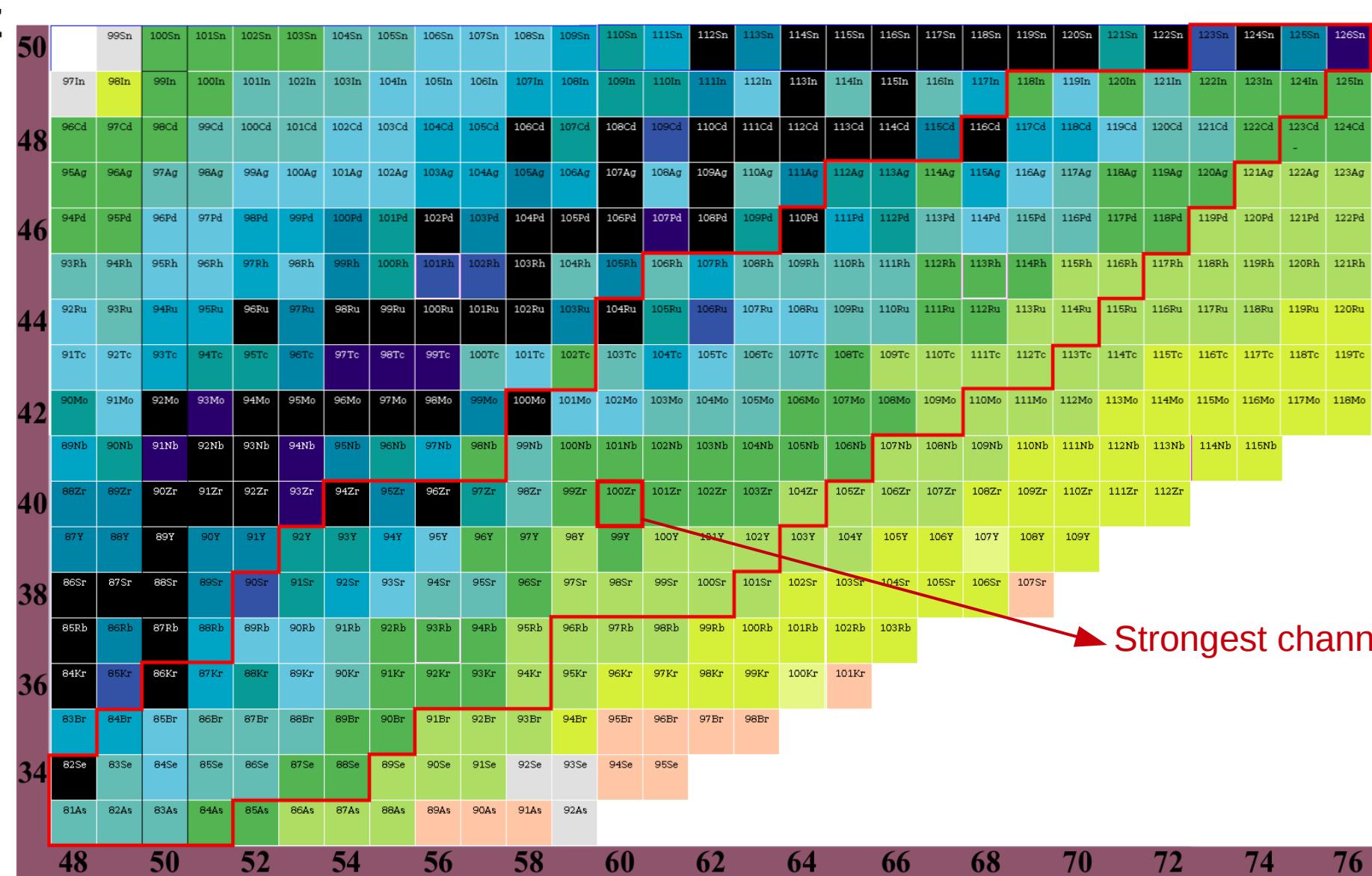
DC: Drift Chamber

IC: Ionization Chamber

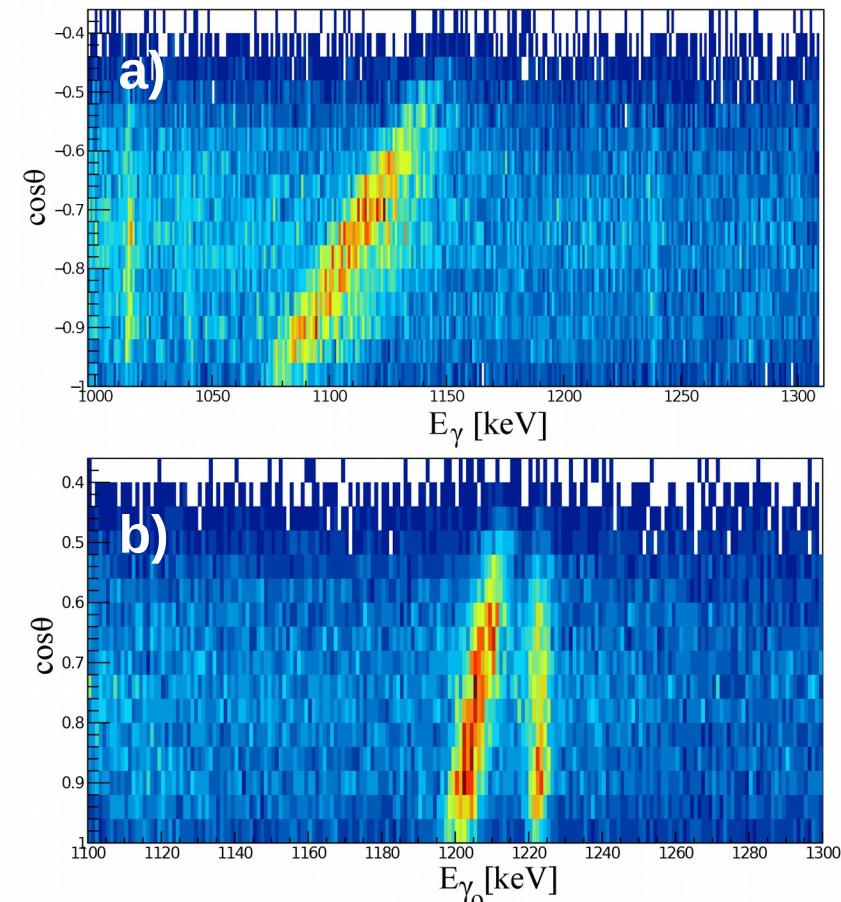
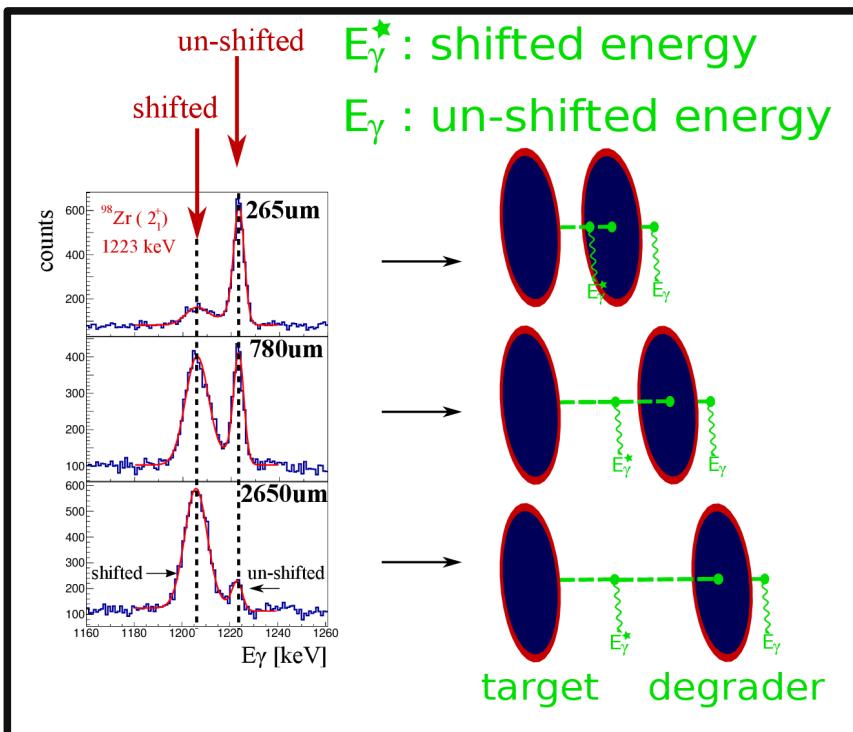
D: Dipole



# Which isotopes are accessible?



# Recoil Distance Doppler Shift method



$$E_{\gamma_0} = E_\gamma \frac{\sqrt{1-\beta^2}}{1-\beta \cos\theta}$$

- $E_\gamma$ : before doppler correction
- $E_{\gamma_0}$ : after doppler correction
- $\beta=v/c$
- $\theta$ : angle between recoil and  $\gamma$

a)  $\cos\theta$  vs  $E_\gamma$

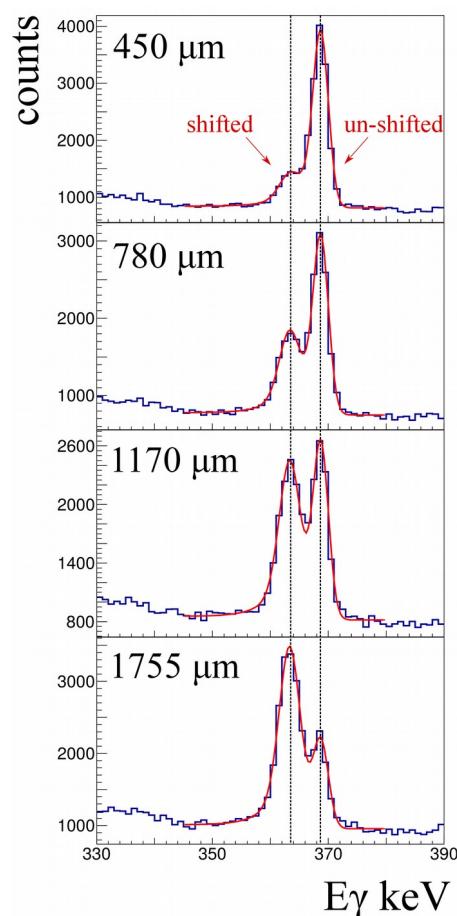
b)  $\cos\theta$  vs  $E_{\gamma_0}$

→ Left line:  $\gamma$  emitted before the degrader.

→ Right line:  $\gamma$  emitted after the degrader.

**$^{104}\text{Mo}$** 

DDCM (singles)

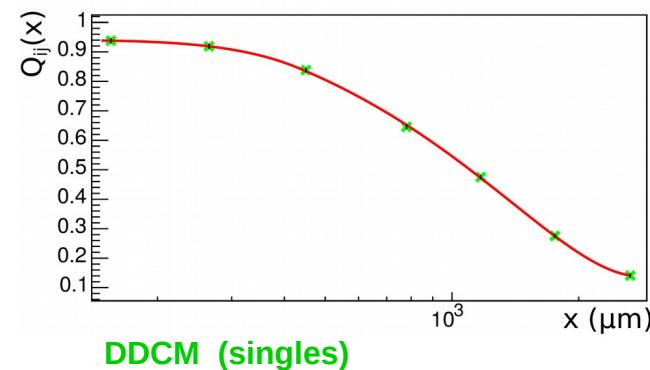
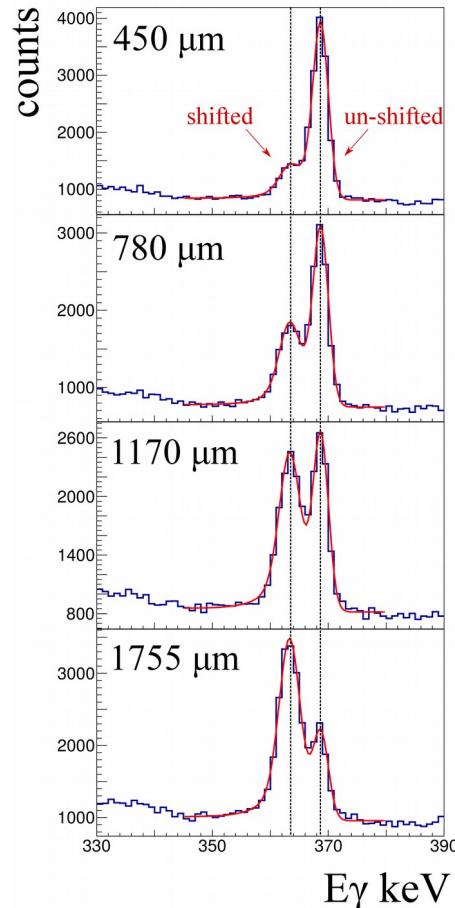


# Differential Decay Curve Method (DDCM)



**$^{104}\text{Mo}$**

**DDCM (singles)**



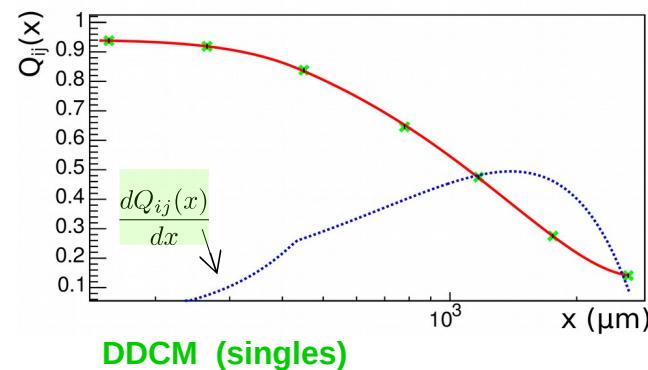
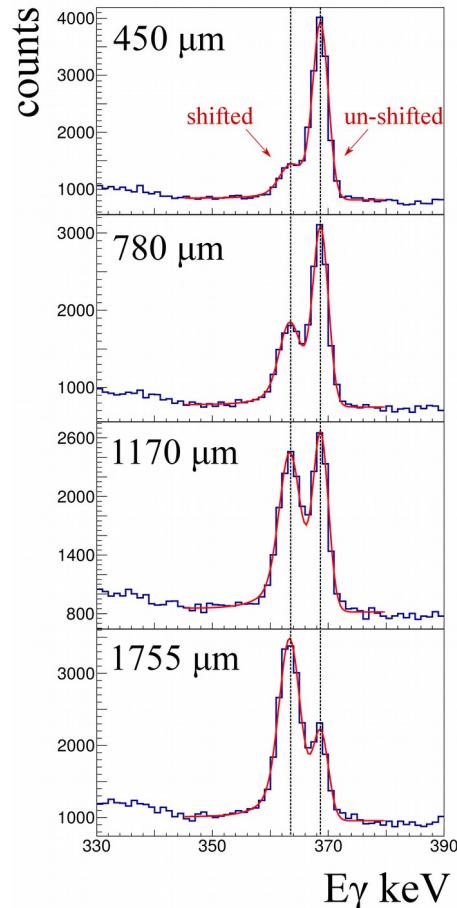
$$Q_{ij}(x) = \frac{I_{ij}^u(x)}{I_{ij}^u(x) + I_{ij}^s(x)}$$

# Differential Decay Curve Method (DDCM)



**$^{104}\text{Mo}$**

**DDCM (singles)**



$$Q_{ij}(x) = \frac{I_{ij}^u(x)}{I_{ij}^u(x) + I_{ij}^s(x)}$$

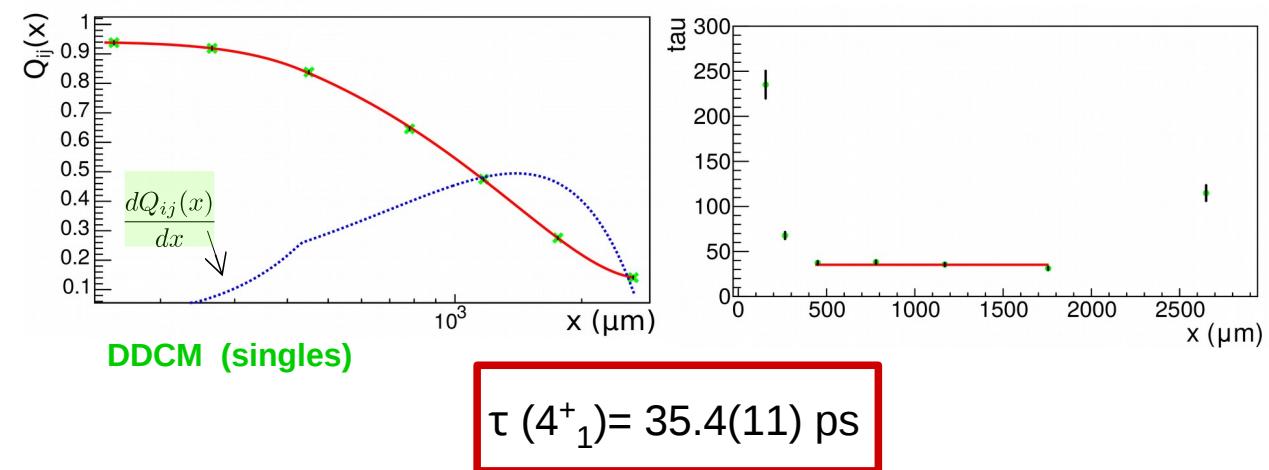
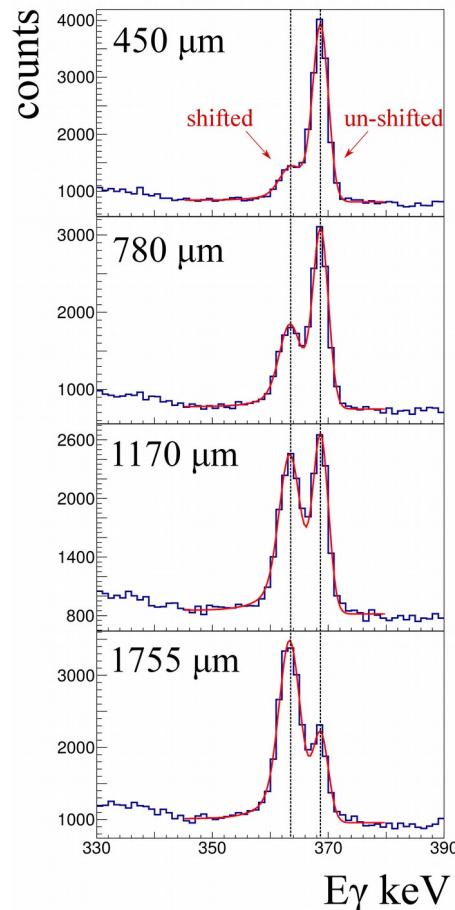
$$\tau_i(x) = -[v \frac{dQ_{ij}(x)}{dx}]^{-1} [Q_{ij}(x) - b_{ij} \sum_h \alpha_{hi} Q_{hi}(x)]$$

# Differential Decay Curve Method (DDCM)



**$^{104}\text{Mo}$**

**DDCM (singles)**

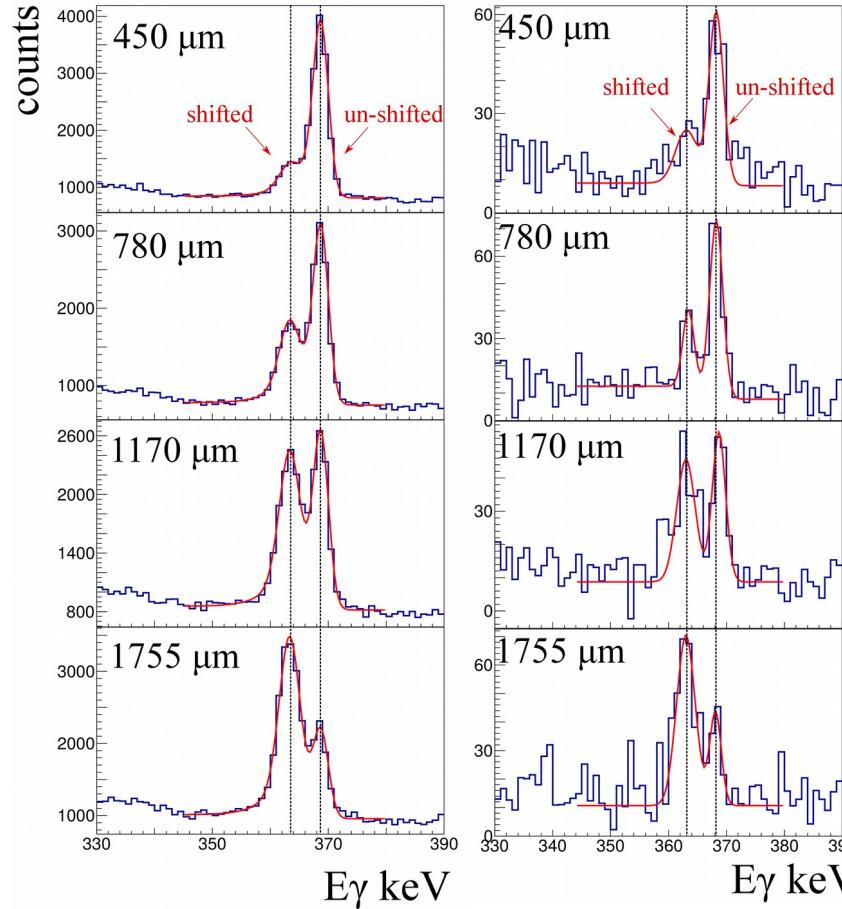


# Differential Decay Curve Method (DDCM)

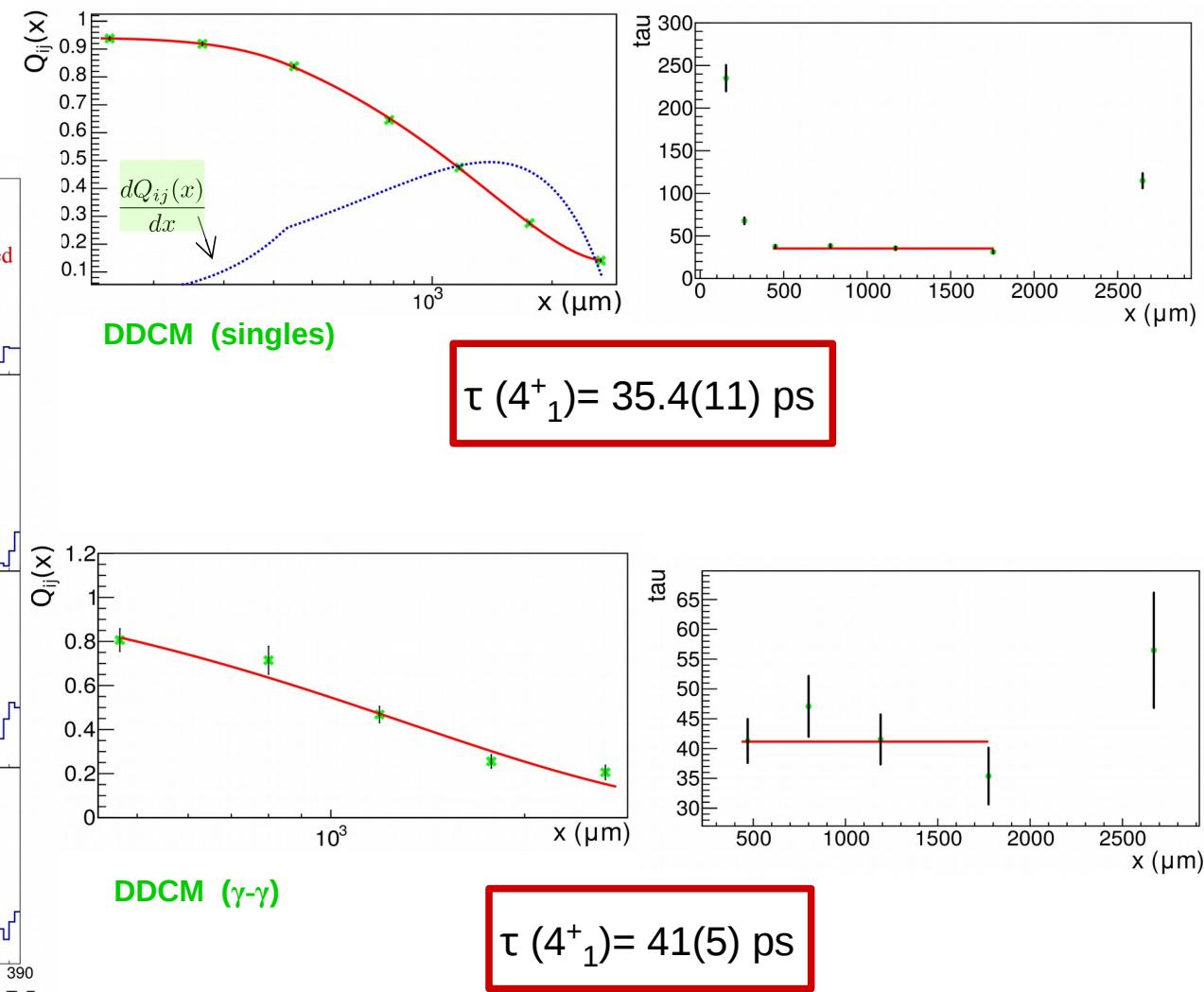


**$^{104}\text{Mo}$**

**DDCM (singles)**



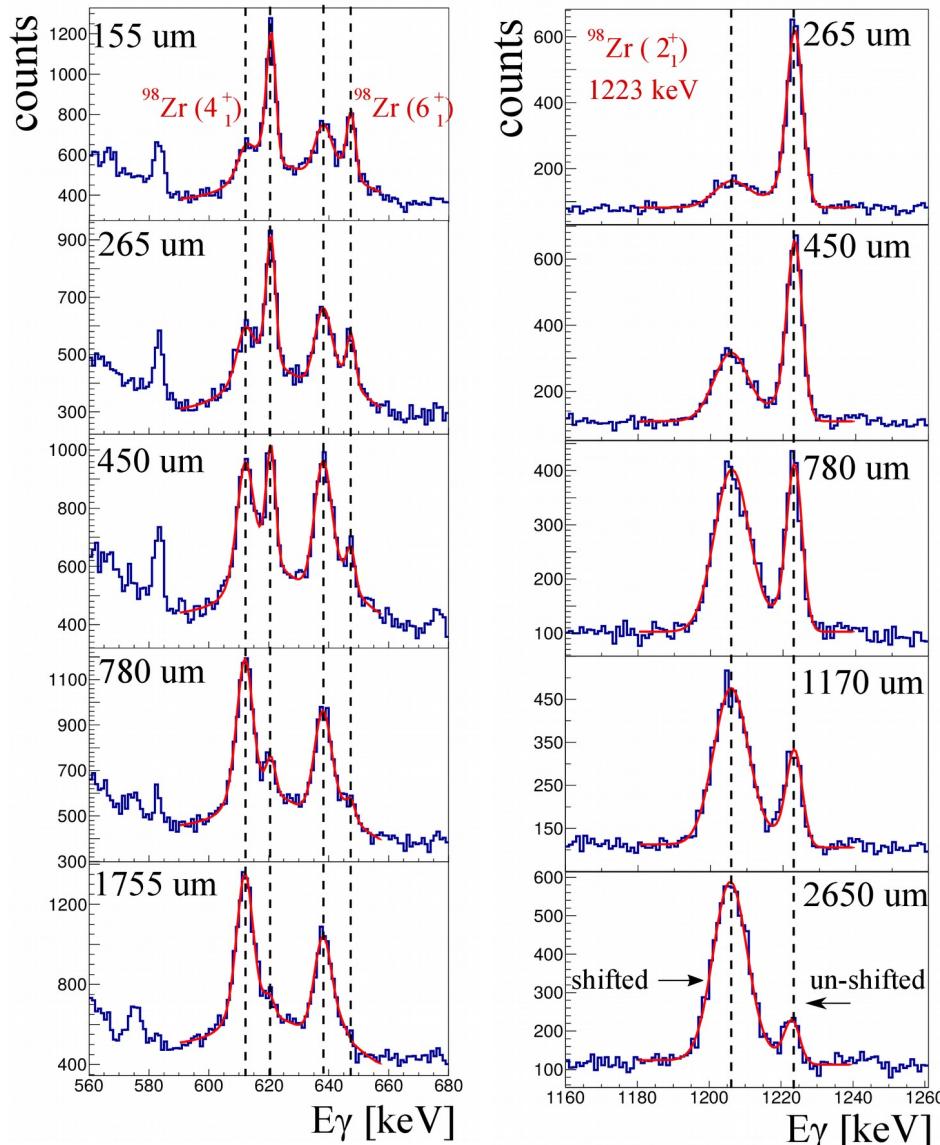
**DDCM ( $\gamma\gamma$ )**



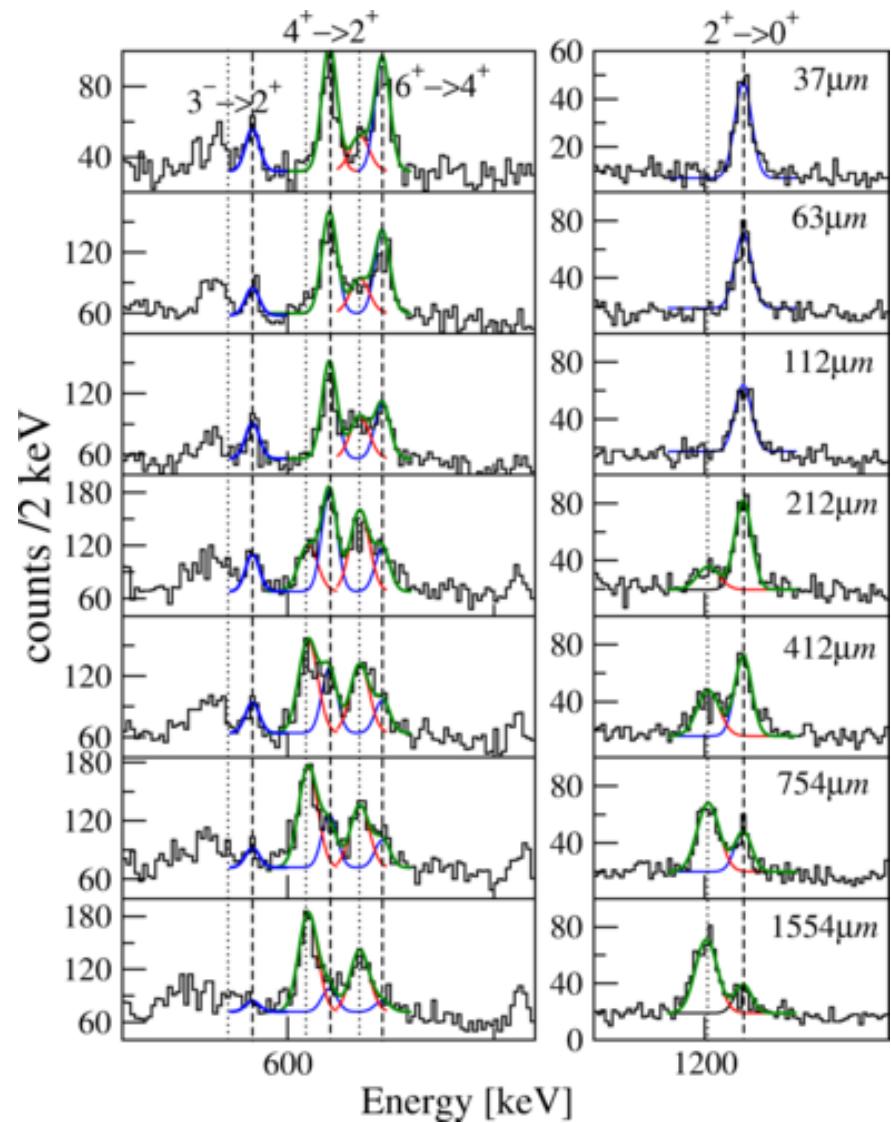
# Comparison of AGATA vs EXOGAM for $^{98}\text{Zr}$



## AGATA

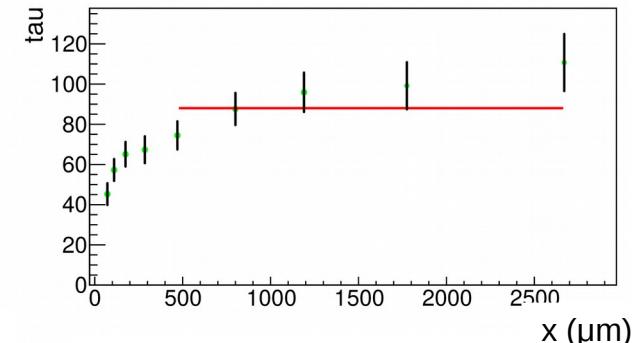
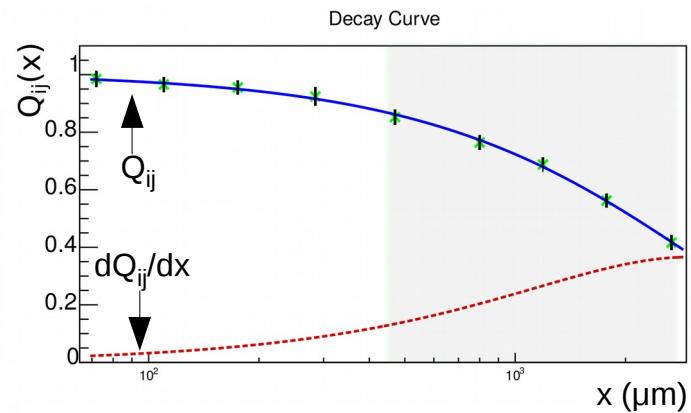
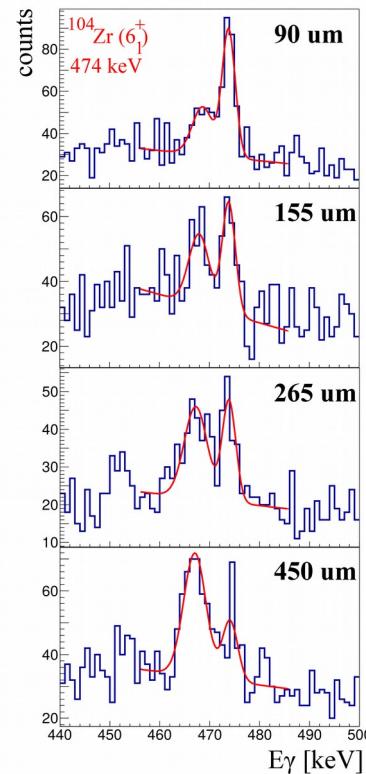
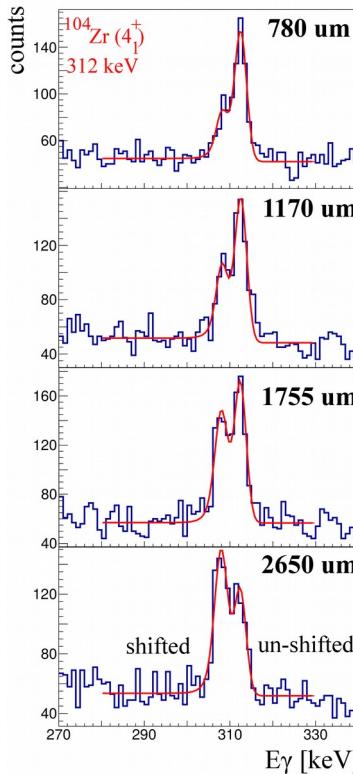


## EXOGAM

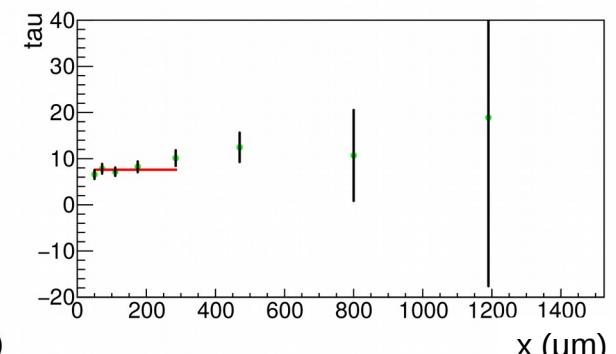
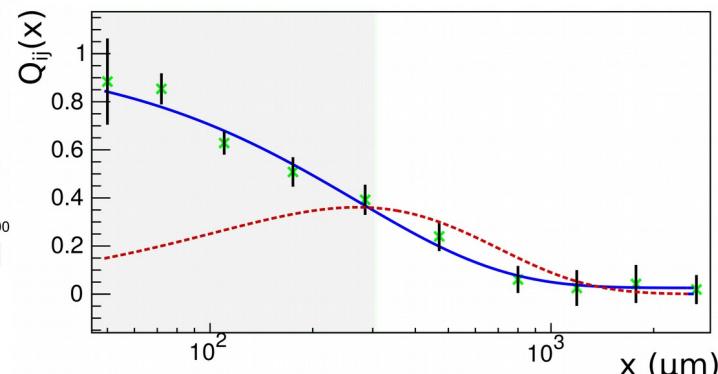


P. Singh et.al., PHYSICAL REVIEW LETTERS 121, 192501 (2018)

# Limits of observation ( $^{104}\text{Zr}$ )



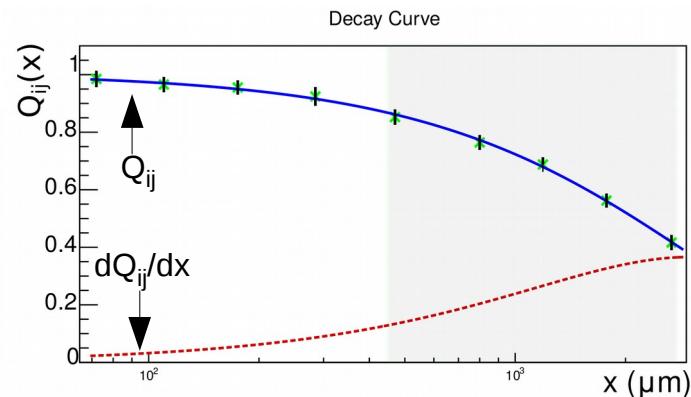
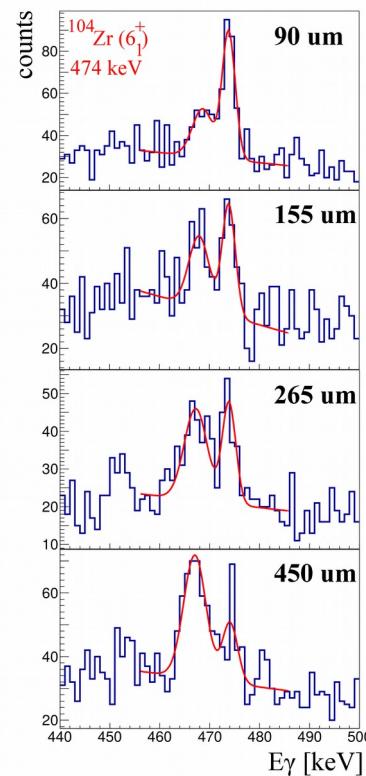
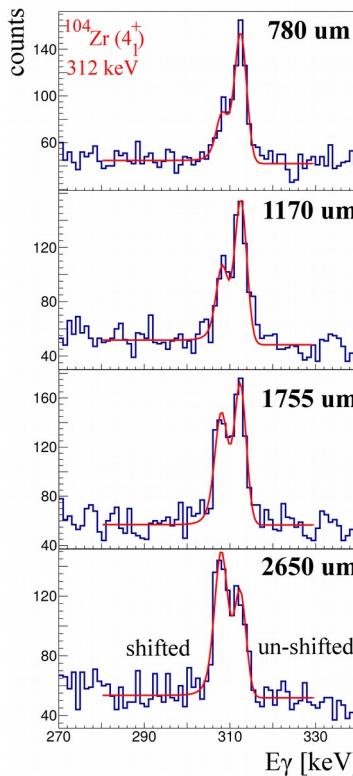
$$\tau (4^+_1) = < 90 \text{ ps}$$



$$\tau (6^+_1) = 7.7(5) \text{ ps}$$

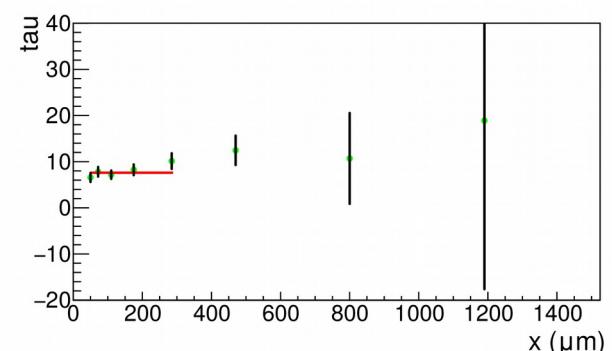
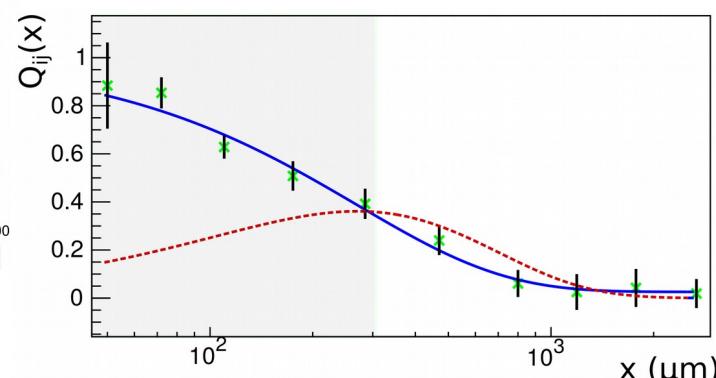
preliminary

# Limits of observation ( $^{104}\text{Zr}$ )



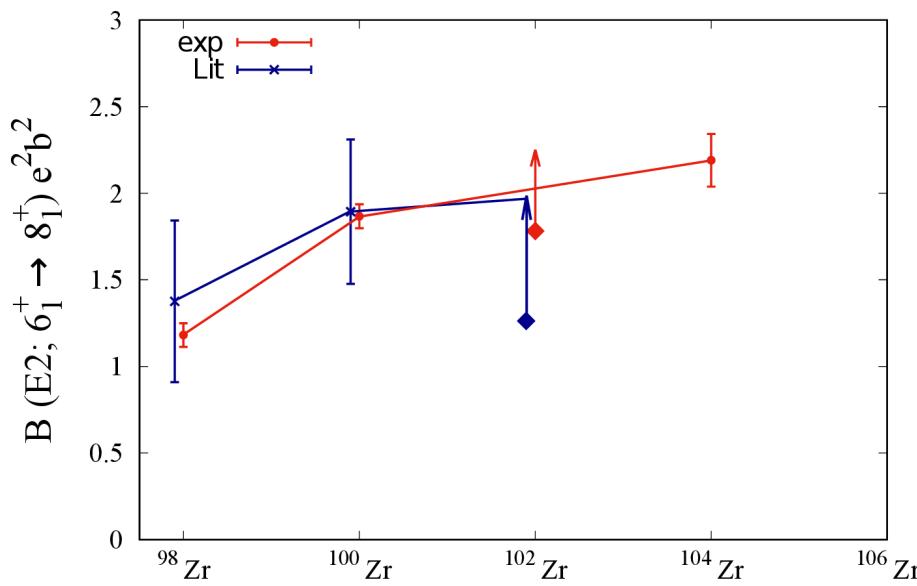
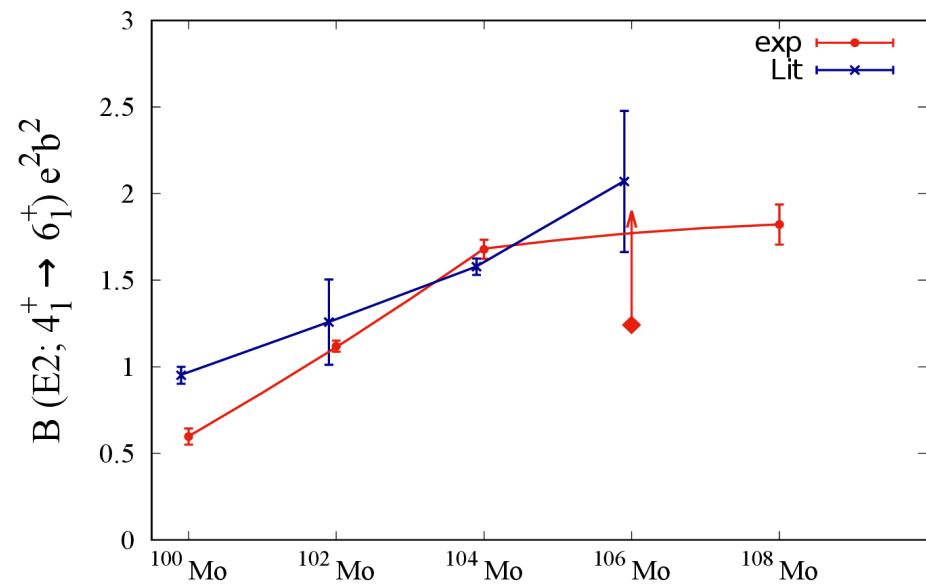
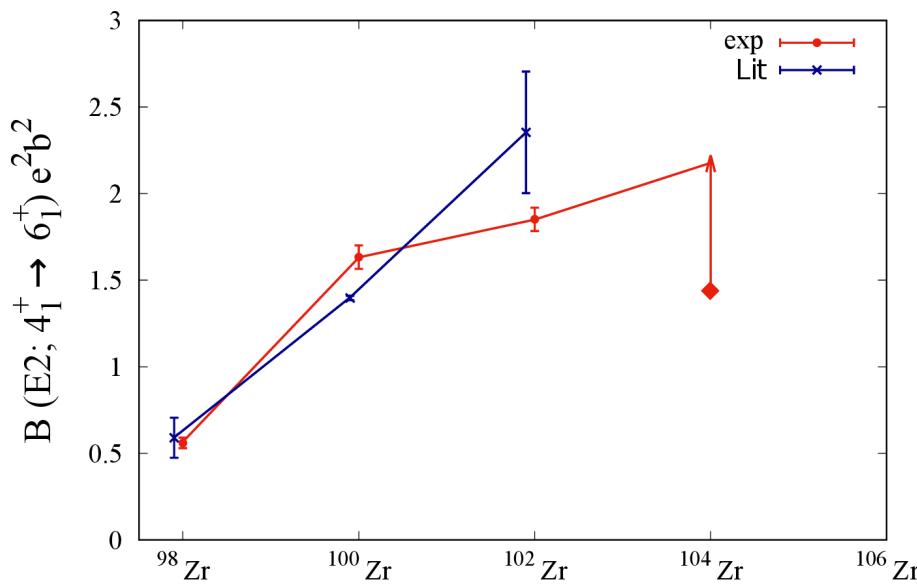
$$\tau (4^+_1) = < 90 \text{ ps}$$

Possible side-feeding  
from 4<sup>-</sup> state

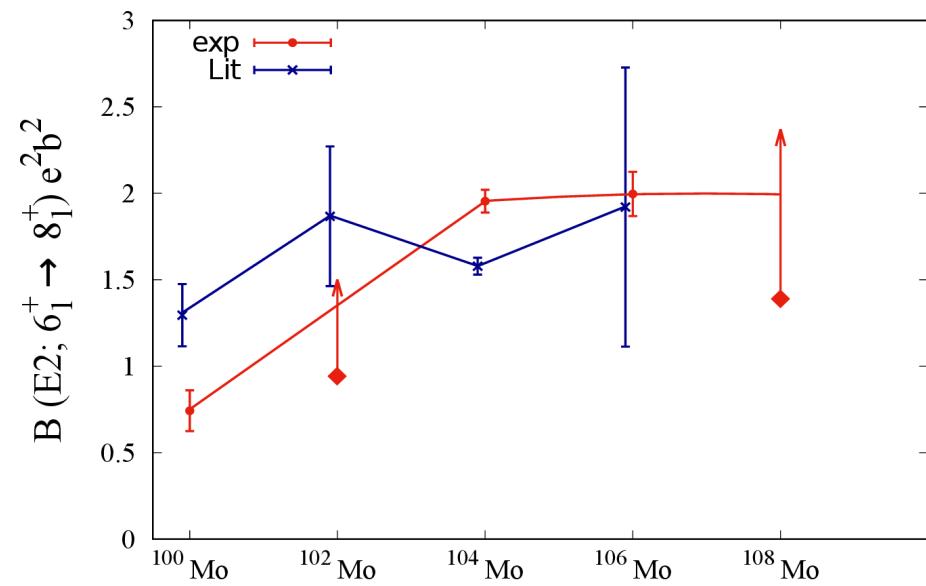


$$\tau (6^+_1) = 7.7(5) \text{ ps}$$

# Transition Strength



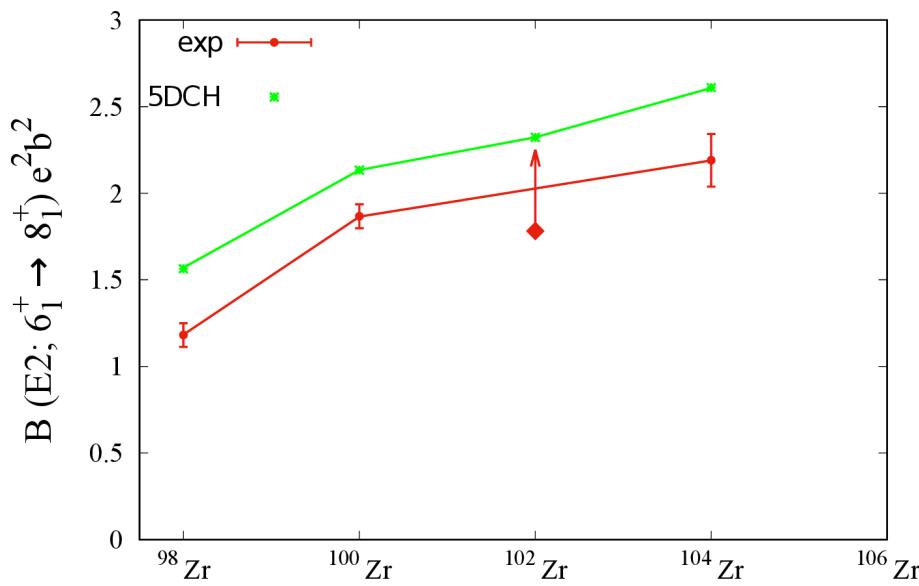
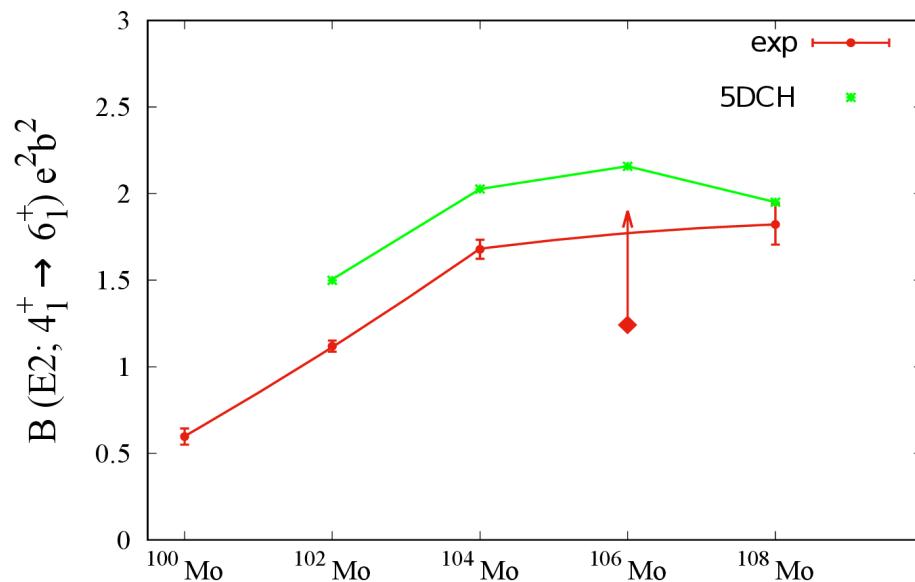
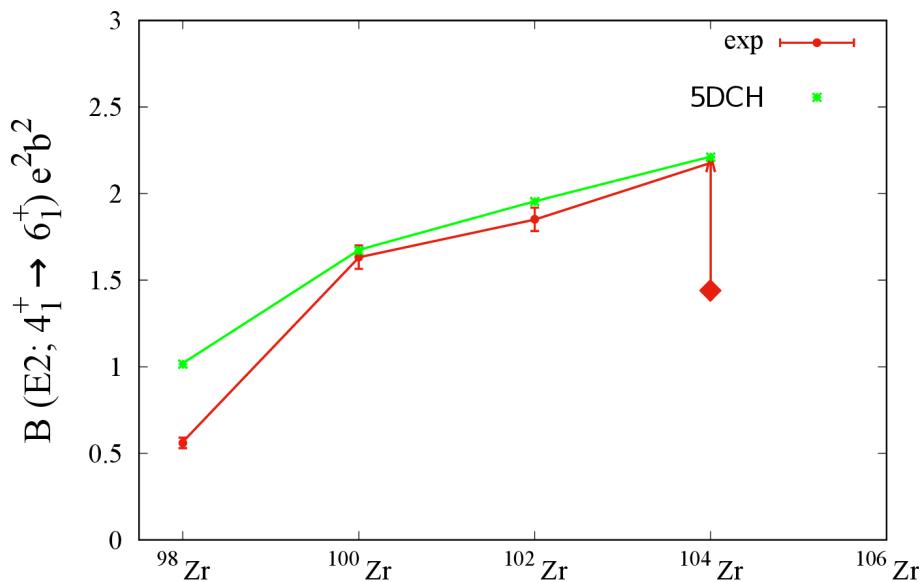
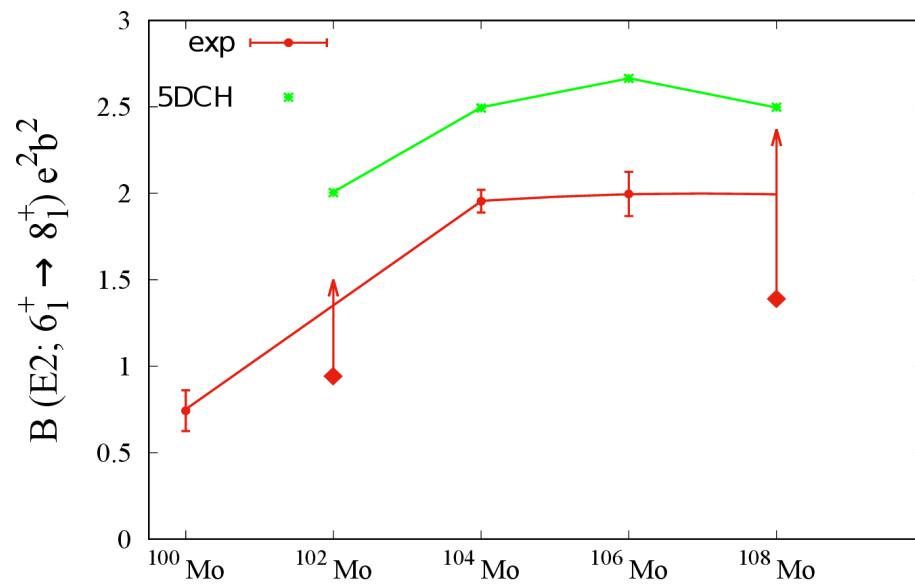
Zr



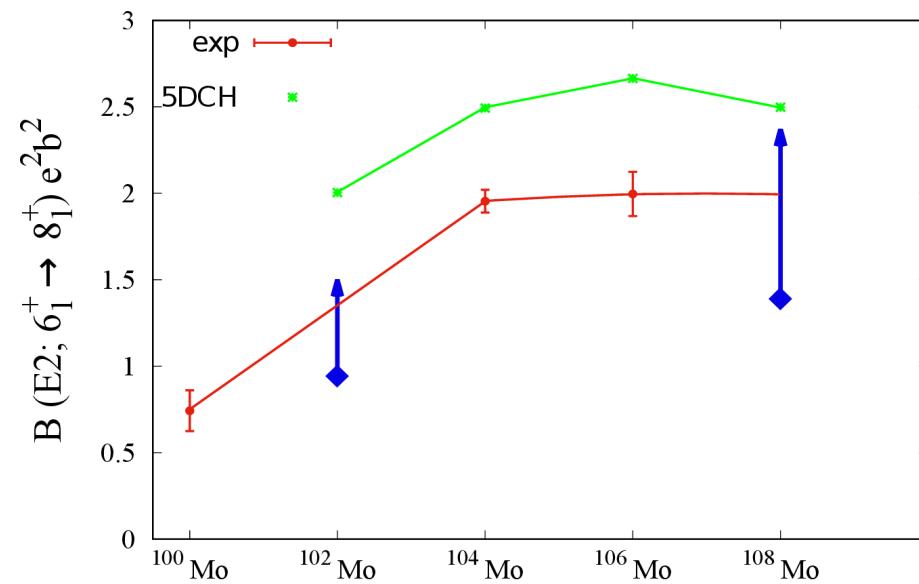
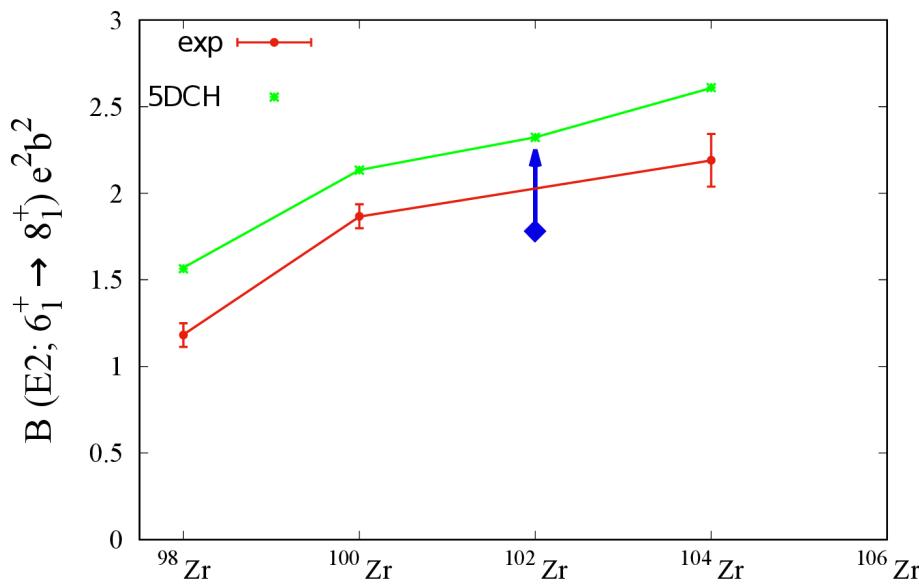
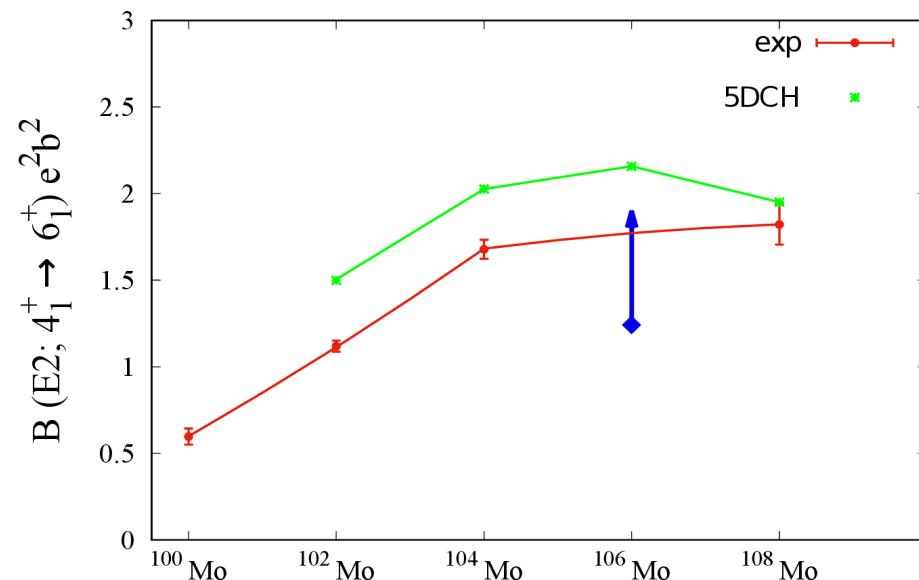
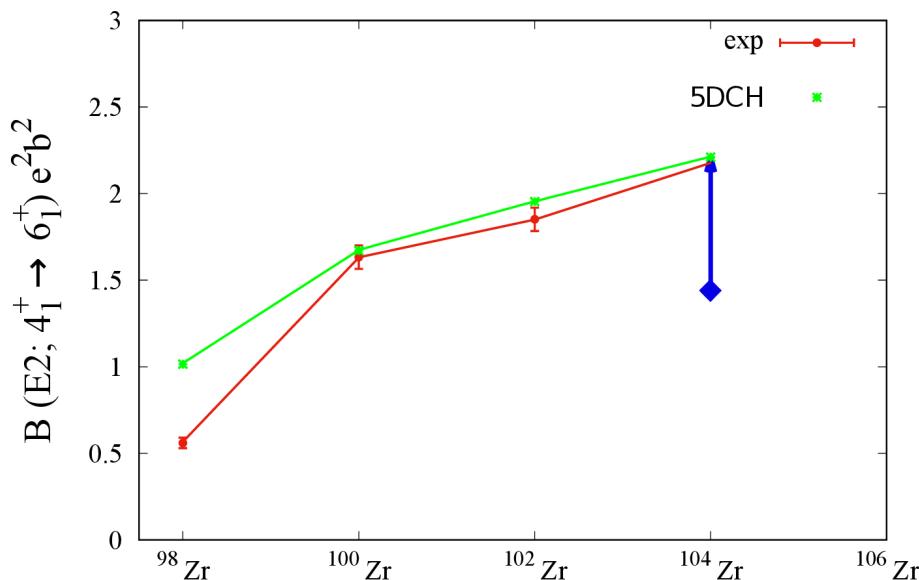
Mo

preliminary

# Transition Strength


Zr

Mo

# Transition Strength


Zr

**Work in Progress!**

Mo

- Fusion-Fission Experiment with AGATA & VAMOS
- Confirmation of Previous lifetime  
 $4^+_1 {}^{98}\text{Zr}$ ,  $4^+_1 {}^{102,104}\text{Mo}$ ,  $6^+_1 {}^{98,100}\text{Zr}$ ,  $6^+_1 {}^{106}\text{Mo}$
- **New lifetimes in  $4^+_1$  &  $6^+_1 {}^{104}\text{Zr}, {}^{104}\text{Mo}$**
- Potential in Ru, Pd, Sr ...
- B(E2) measurements are an important ingredient for Coulomb excitation measurements performed at CARIBU (104,106Mo, 110Ru, planned 100Zr,112Ru).
- Work in progress!



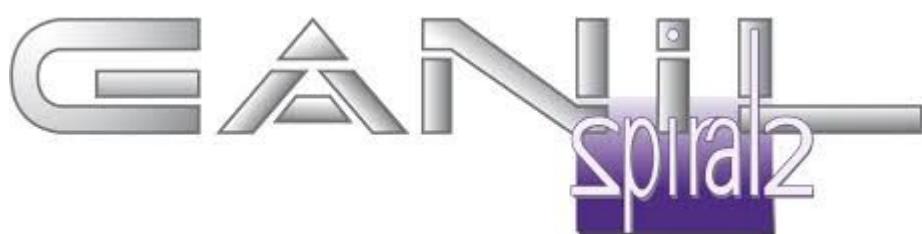
UiO : Universitetet i Oslo



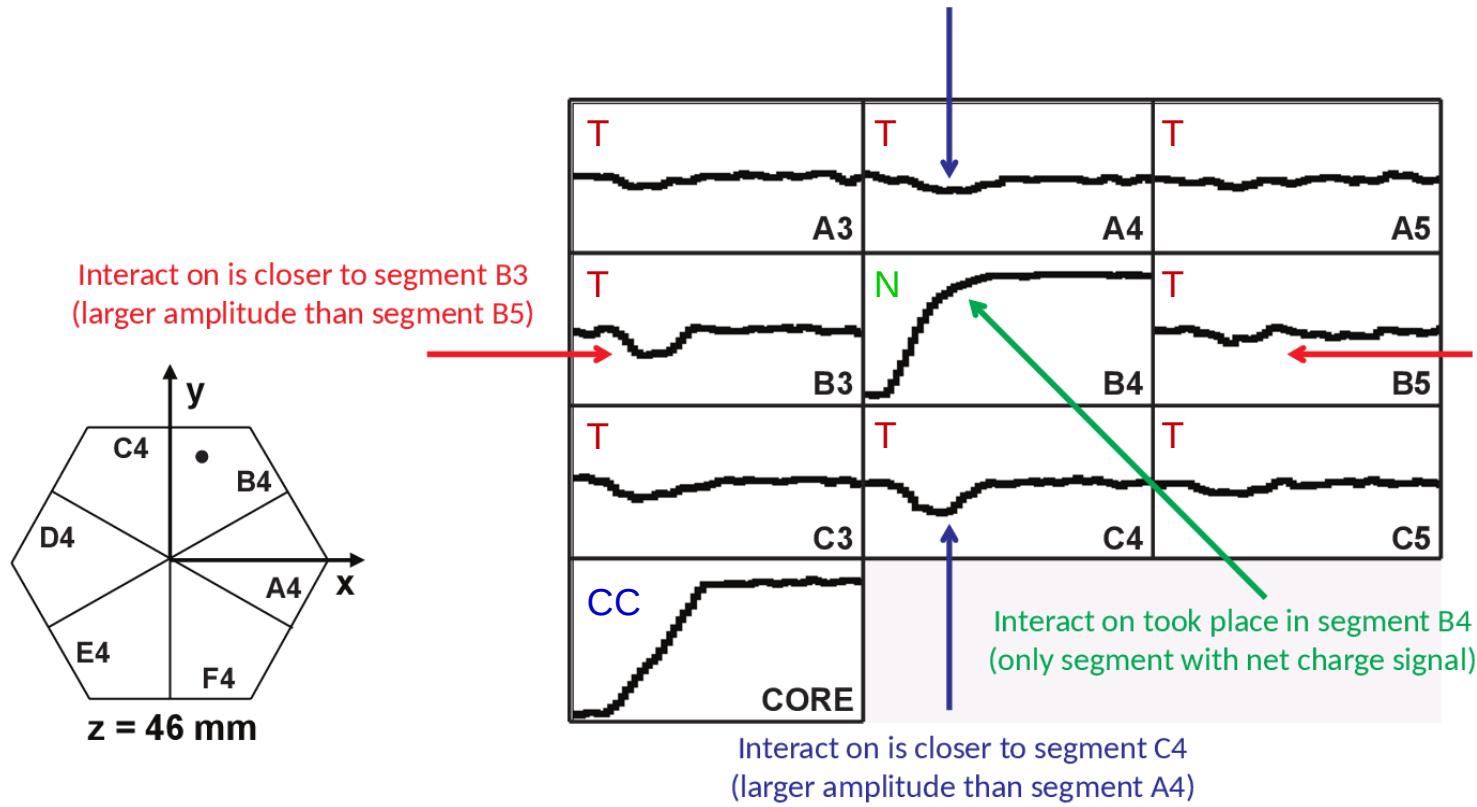
# THANK YOU



Universität zu Köln



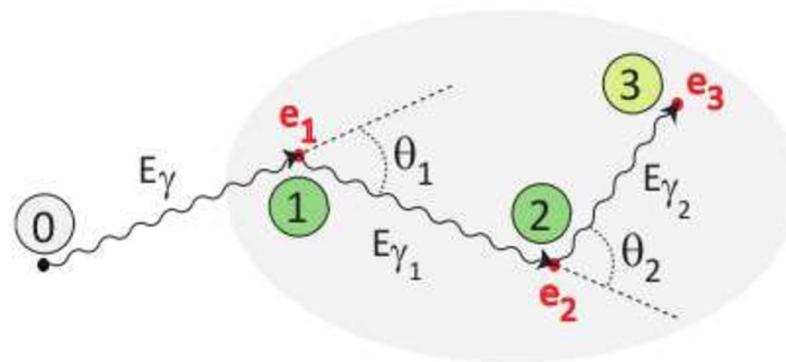
# Pulse Shape Analysis



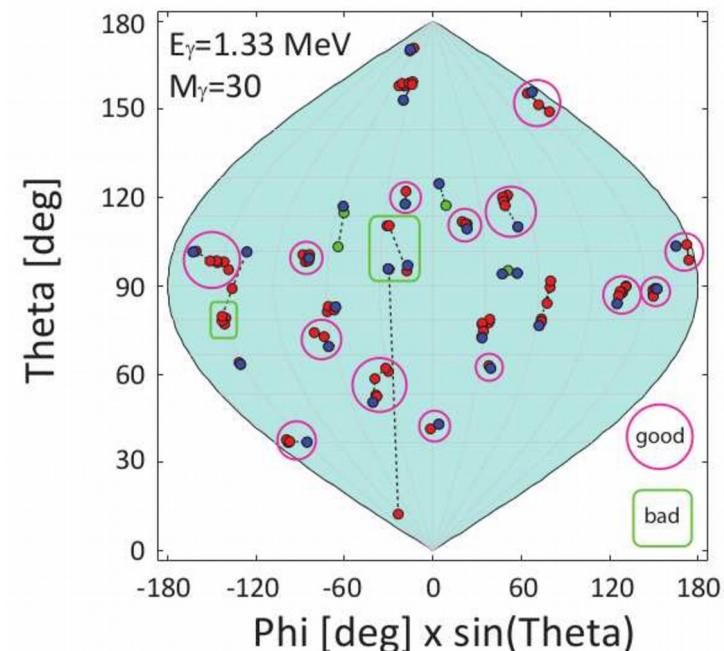
- $\gamma$  ray interacted at B4 and created the electron-hole pair.
- The signal shape for the Central Contact (CC) is different than the segment with Net charge (N), suggesting the presence of a “real”  $\gamma$  time in between.

# Tracking

- Multiple Compton scattering of a  $\gamma$  ray (energy  $E_\gamma$ )
- Start point: position 0 (the target)
- Compton scattered at 1 and 2 before fully absorbed in 3.



- Interaction positions and cluster identification in a  $4\pi$  germanium shell as considered by the tracking algorithm.



PC: Dino Bazzacco