# Multi−Coincidence Spectroscopy of SHE using the TASISpec Setup


* The TASCA Separator
* The **TASISpec** Setup
* The GEANT4 Code
* First Experimental Results
* Next Approved Experiment

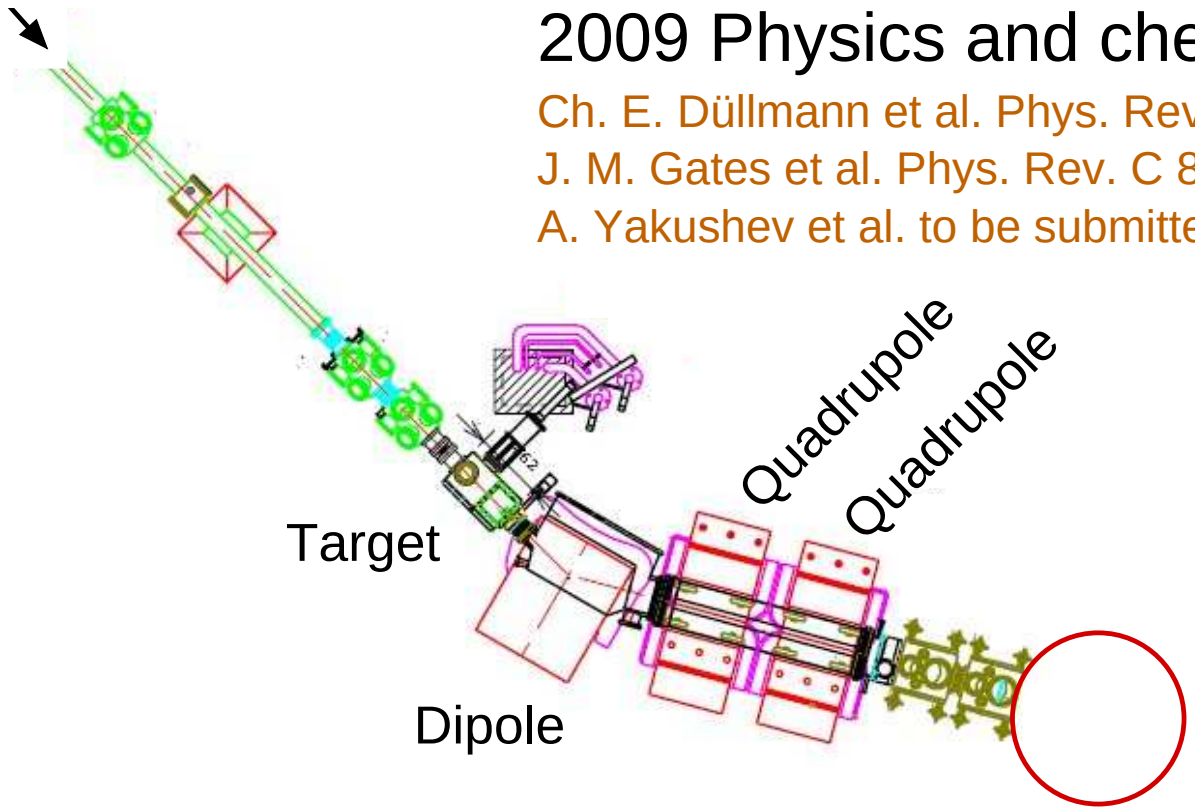
Lise−Lotte Andersson Helmholtz−Institute Mainz

Helmholtz Institute Mainz

# TASCA

## TASCA − TransActinide Separator and Chemistry Apparatus

UNILAC
beam




2005 Built

2006−2008 Commissioned

2009 Physics and chemistry of Z=114

Ch. E. Düllmann et al. Phys. Rev. Lett. 104, 252701 (2010)
J. M. Gates et al. Phys. Rev. C 83, 054618 (2011).
A. Yakushev et al. to be submitted.

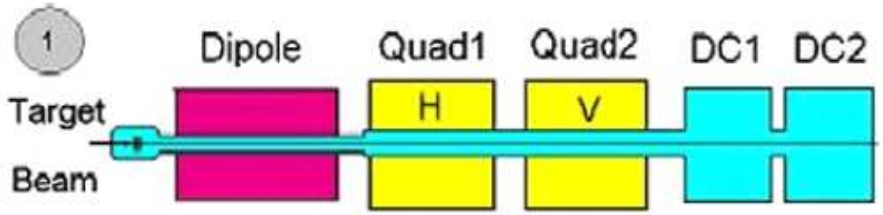
TASISpec

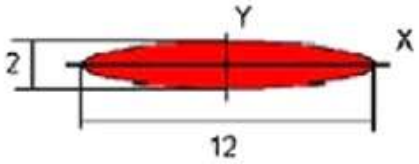
GSI

# The TASCA Separator at GSI

## Two available transmission modes

### High Transmission Mode (HTM)



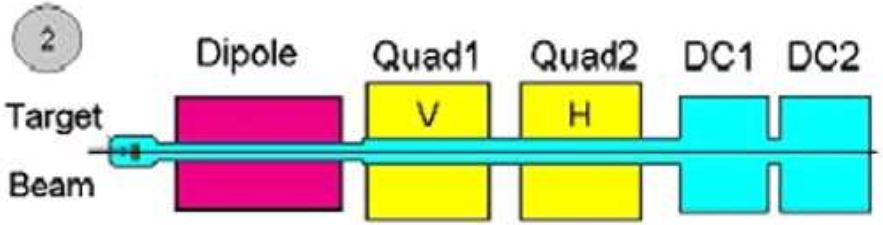

S = 18 (24) cm$^2$

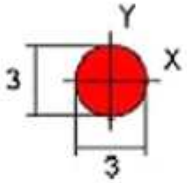
| Transmission | round | square |
|---|---|---|
| | 50% | 54% |

(60 ± 6)%

J. Gates et al. PRC 83 054618 (2011).

### Small Image−size Mode (SIM)




S = 7 (9) cm$^2$

(35 ± 4)%

| | |
|---|---|
| 30% | 36% |

A. Semchenkov et al. Nuclear Instrum. and Meth. Phys. Res. B 266 4153 (2008).

# The TASISpec Detector Set−up

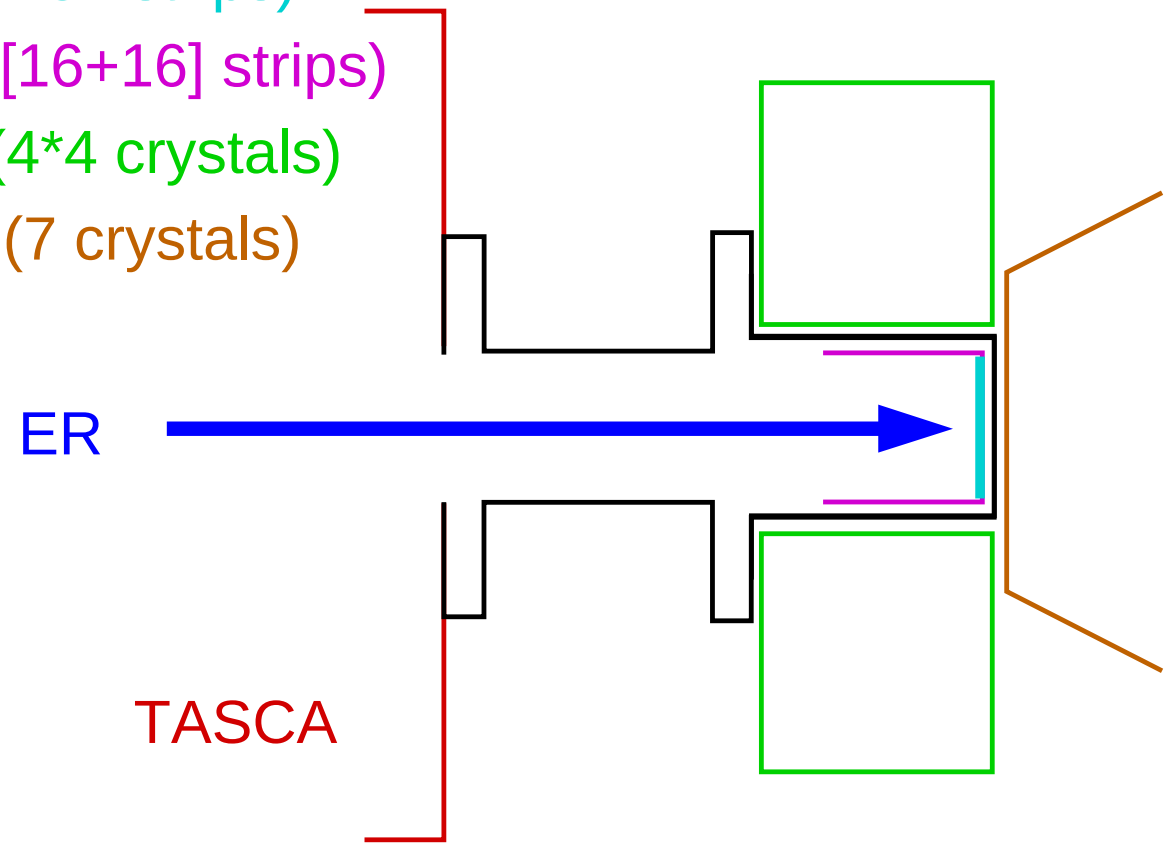
## TASCA in Small Image Mode Spectroscopy

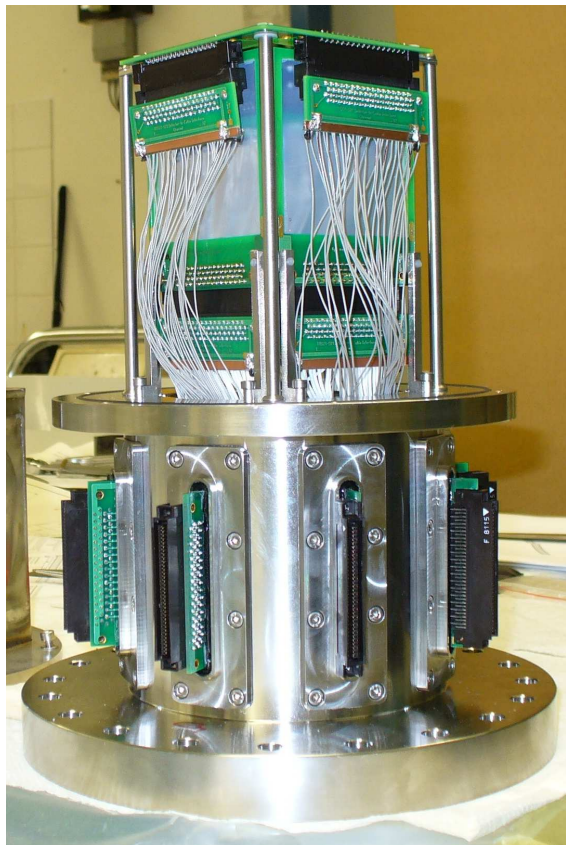
1 DSSSD (32+32 strips)

4 DSSSD (4*[16+16] strips)

4 Ge Clover (4*4 crystals)

1 Ge Cluster (7 crystals)



L−L Andersson et al., NIM A 622, 164 (2010)

LUND UNIVERSITY

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GSI

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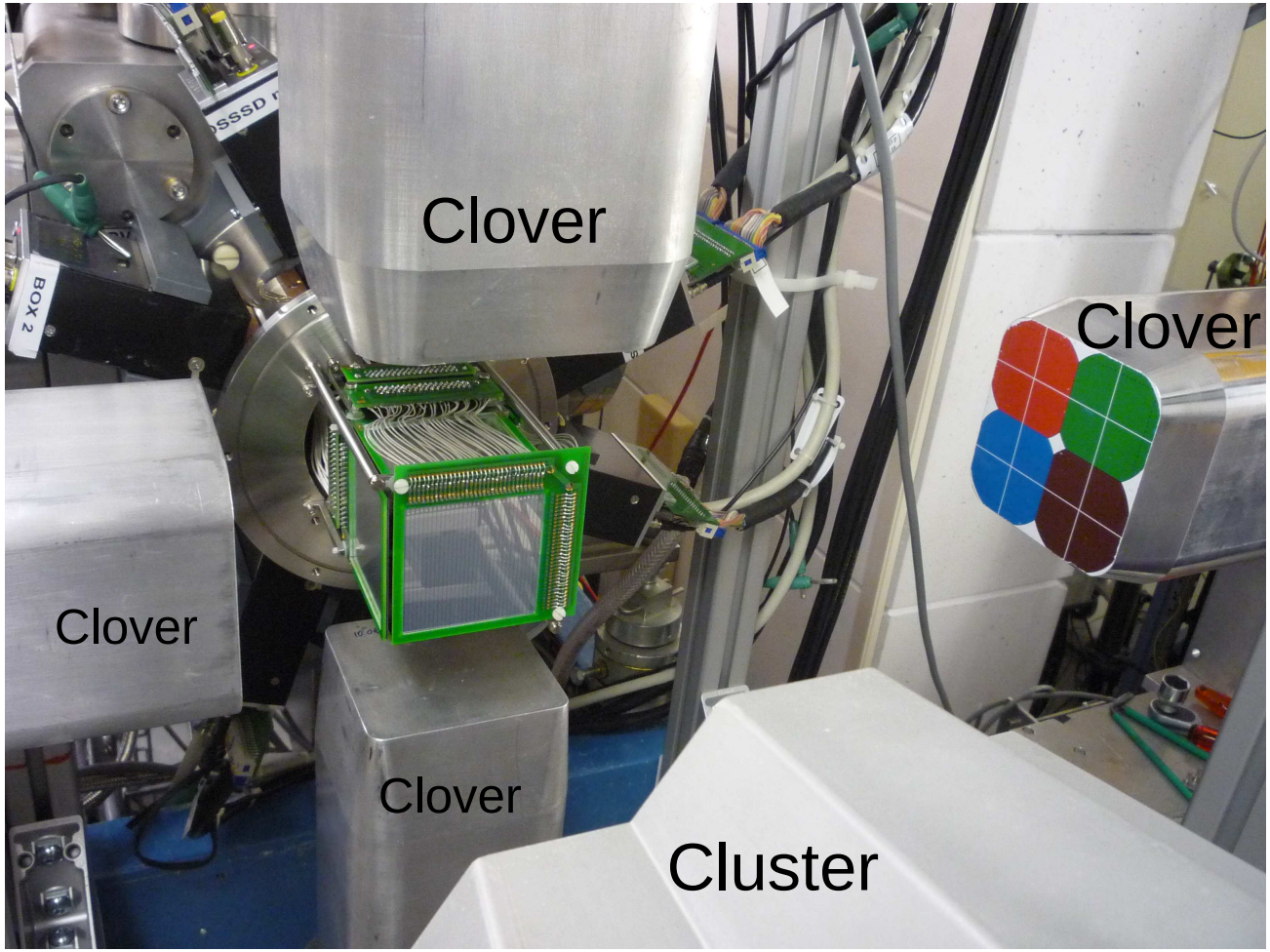
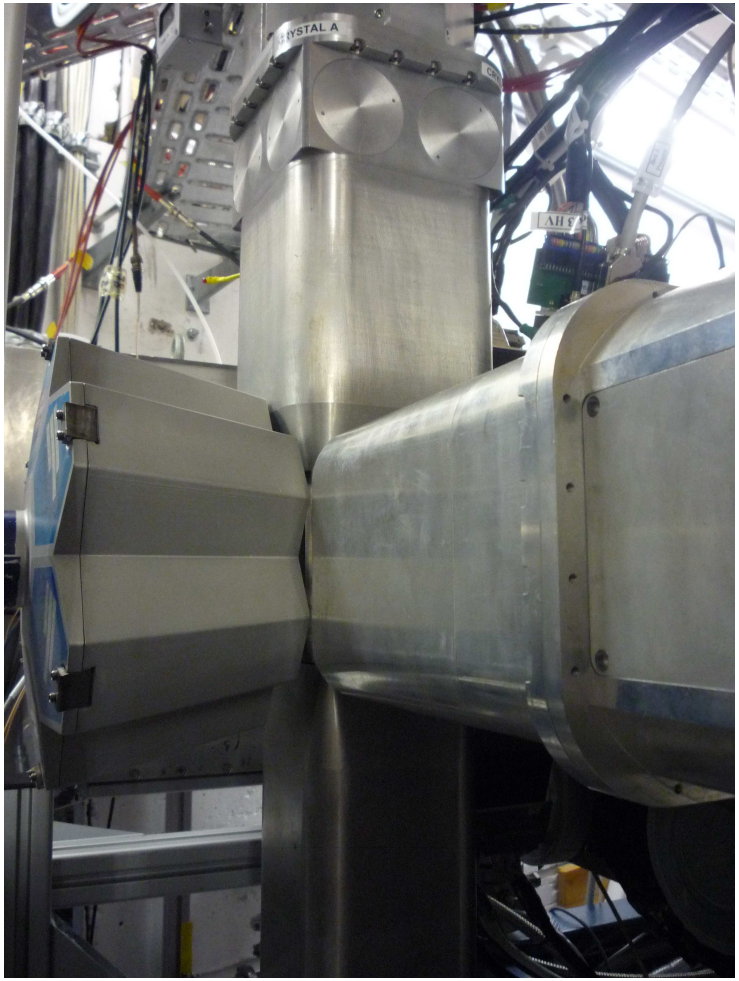
# The TASISpec Detector Set−up

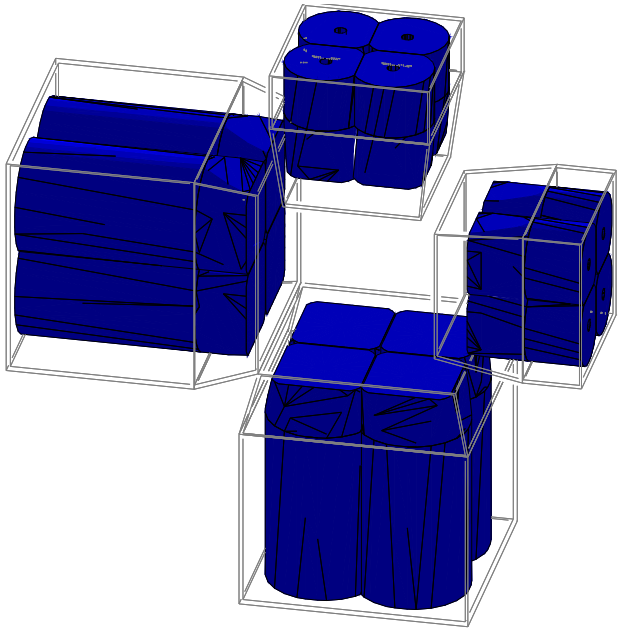
## Details of the construction

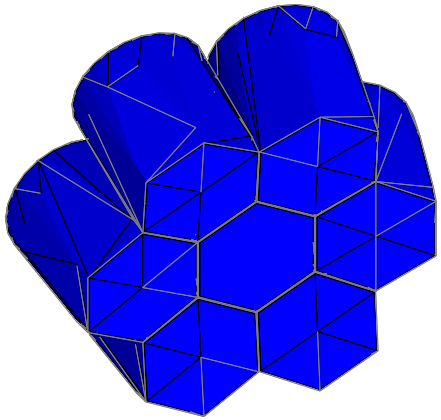


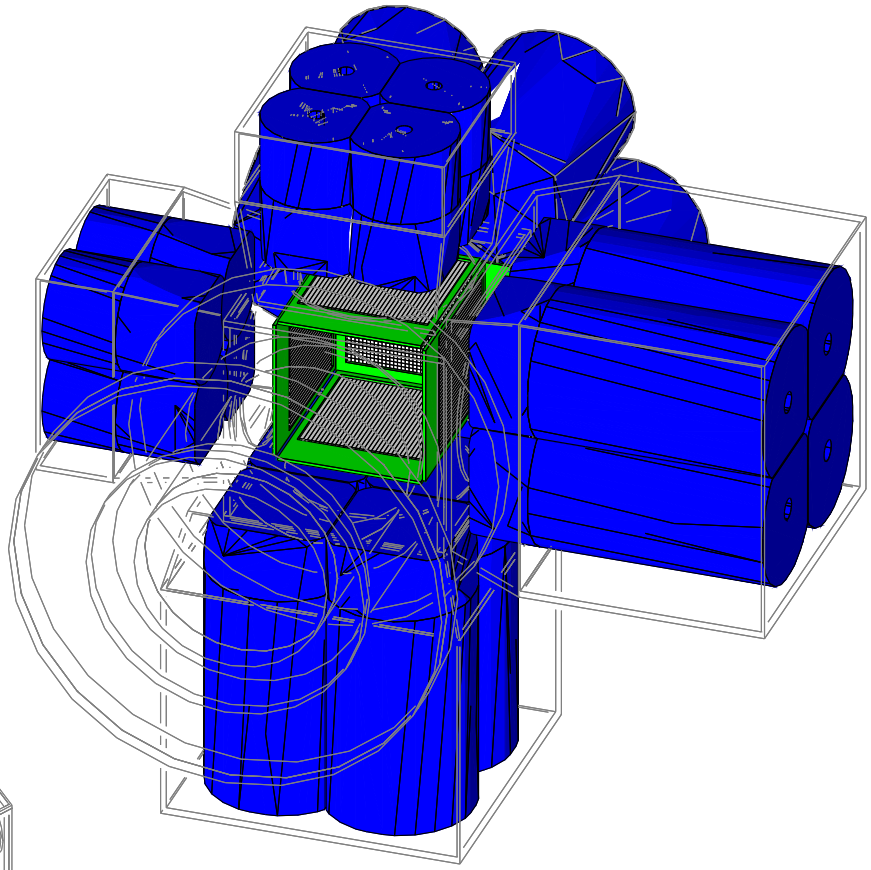



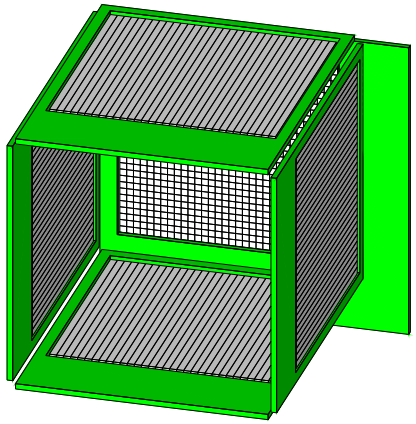
# The Full TASISpec Setup in Geant4

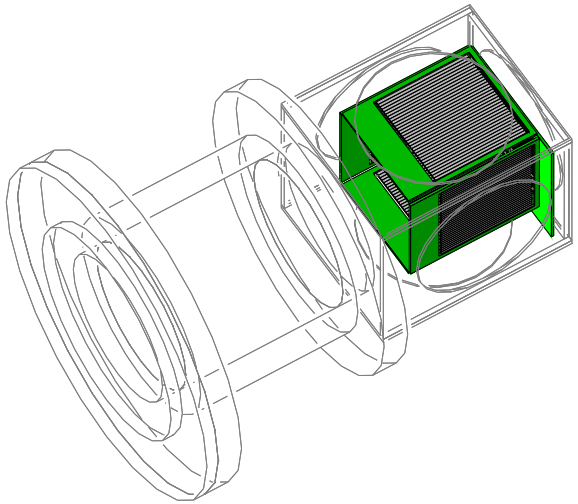
## Programmed (in great detail) by: L. G. Sarmiento











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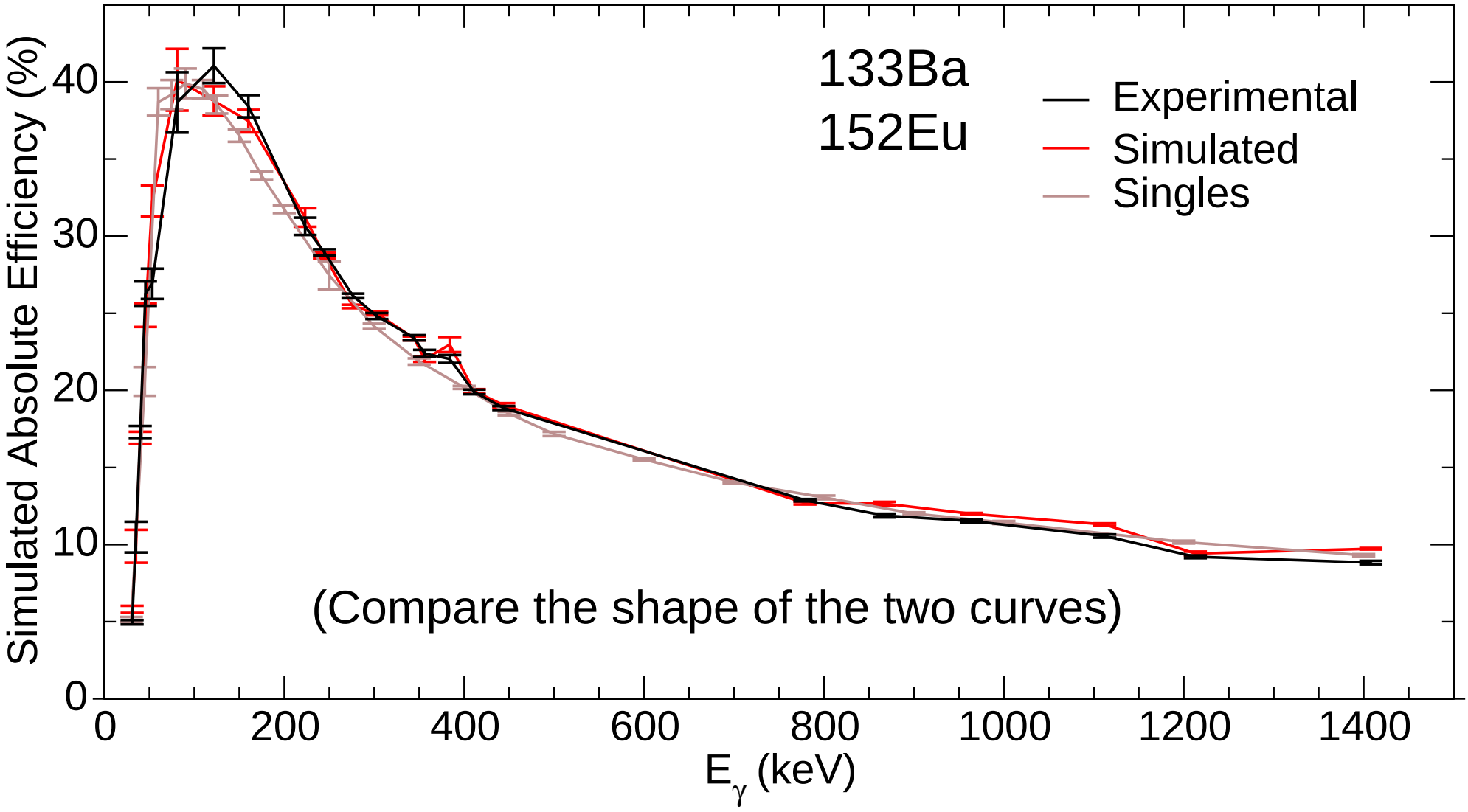
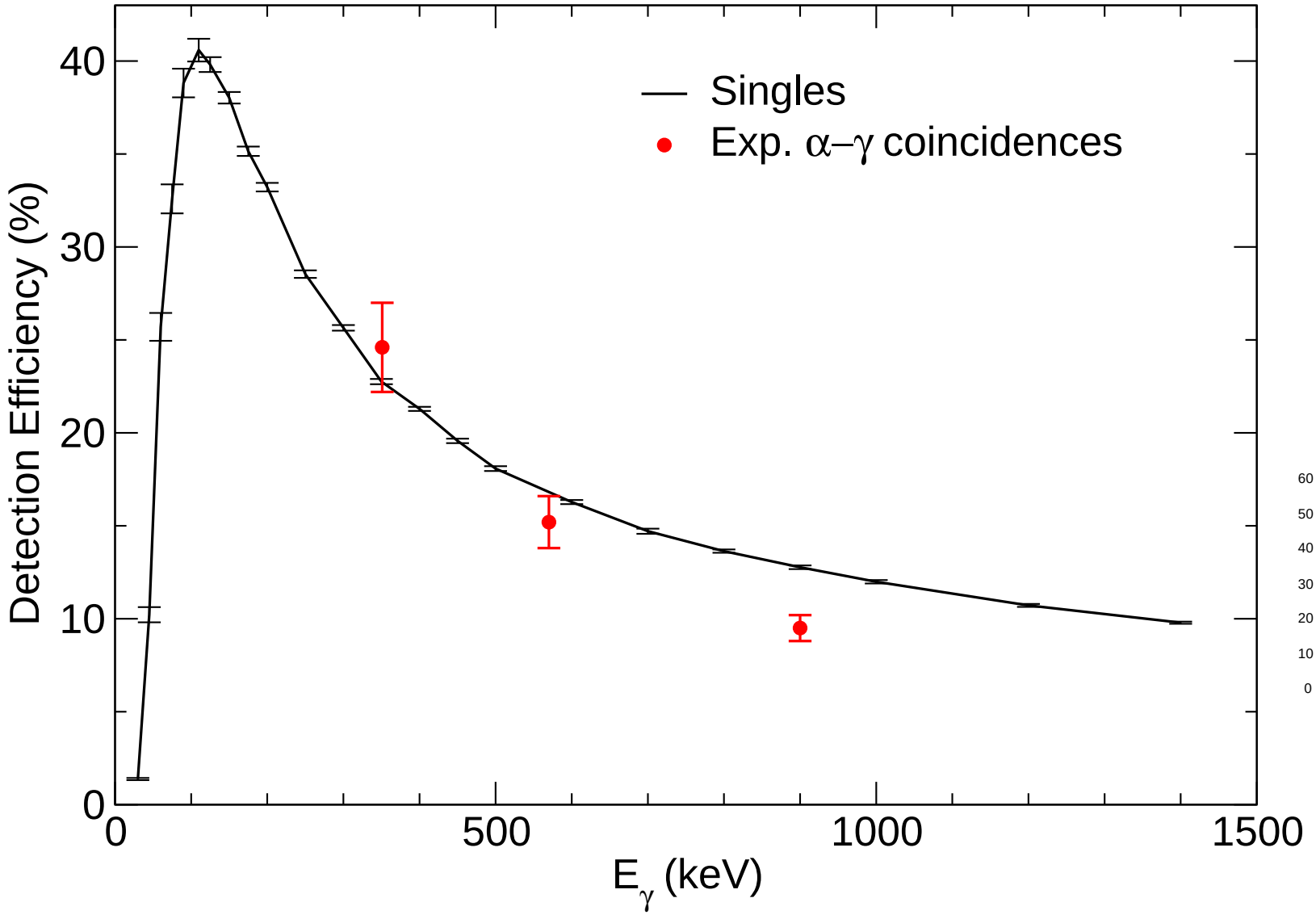
# Comparing Experiment With Simulations

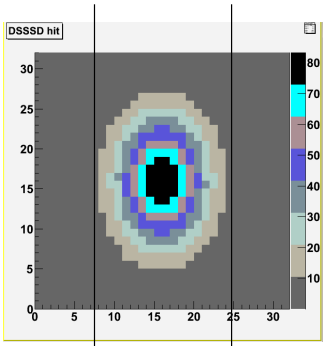
## Relative gamma−ray efficiency with source on holder

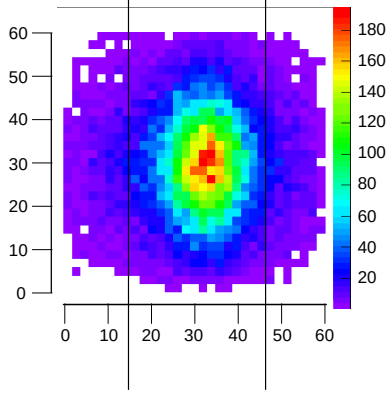


# Comparing Simulations With Experiment

## Gamma−ray efficiency obtained via alpha−gamma coincidences



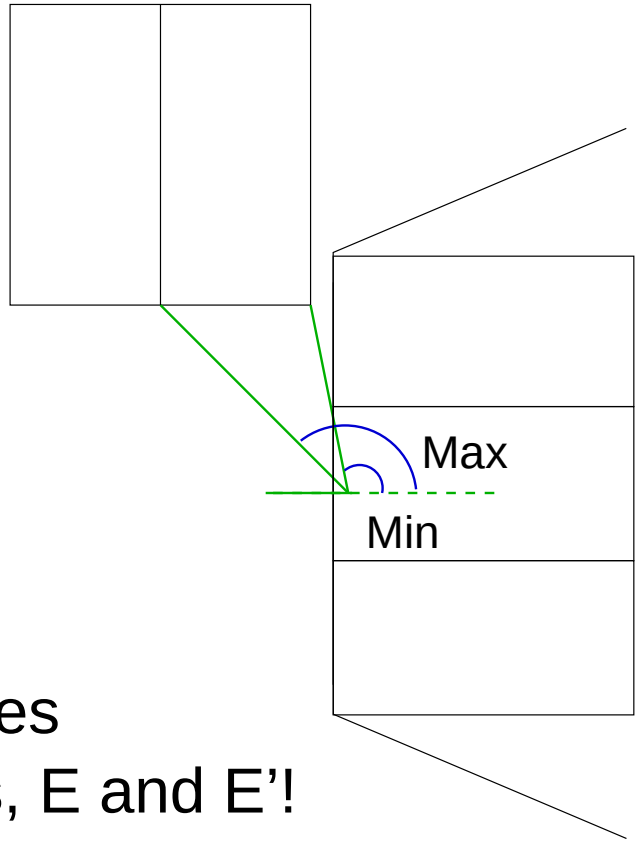
# Limiting Background and "False" Coincidences

## There are no Compton shields in the setup

1) Internal Add−back (between crystals in same detector)
2) Cross detector add−back (some combinations are more likely)

Compton Scattering:

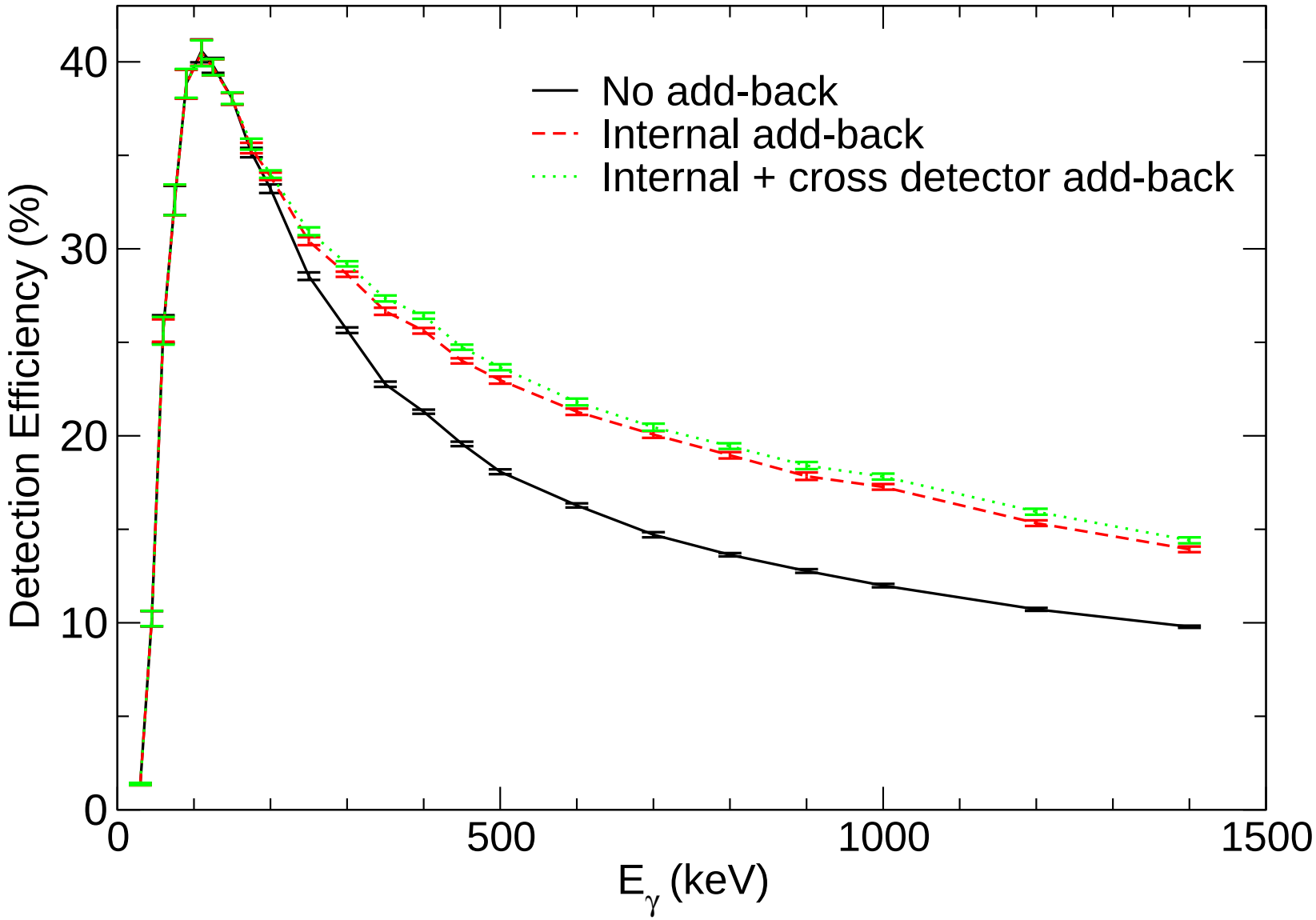
$$\frac{E' - E}{E * E'} = \frac{(1 - \cos\theta)}{m_e c^2}$$




Geometric limits of possible scattering angles
lead to restricted ratios for the two energies, E and E'!

# Simulating Addback Efficiencies

## Implanted nuclei decaying with a single gamma−ray



# TASISpec

The Next Step in Superheavy Element Spectroscopy

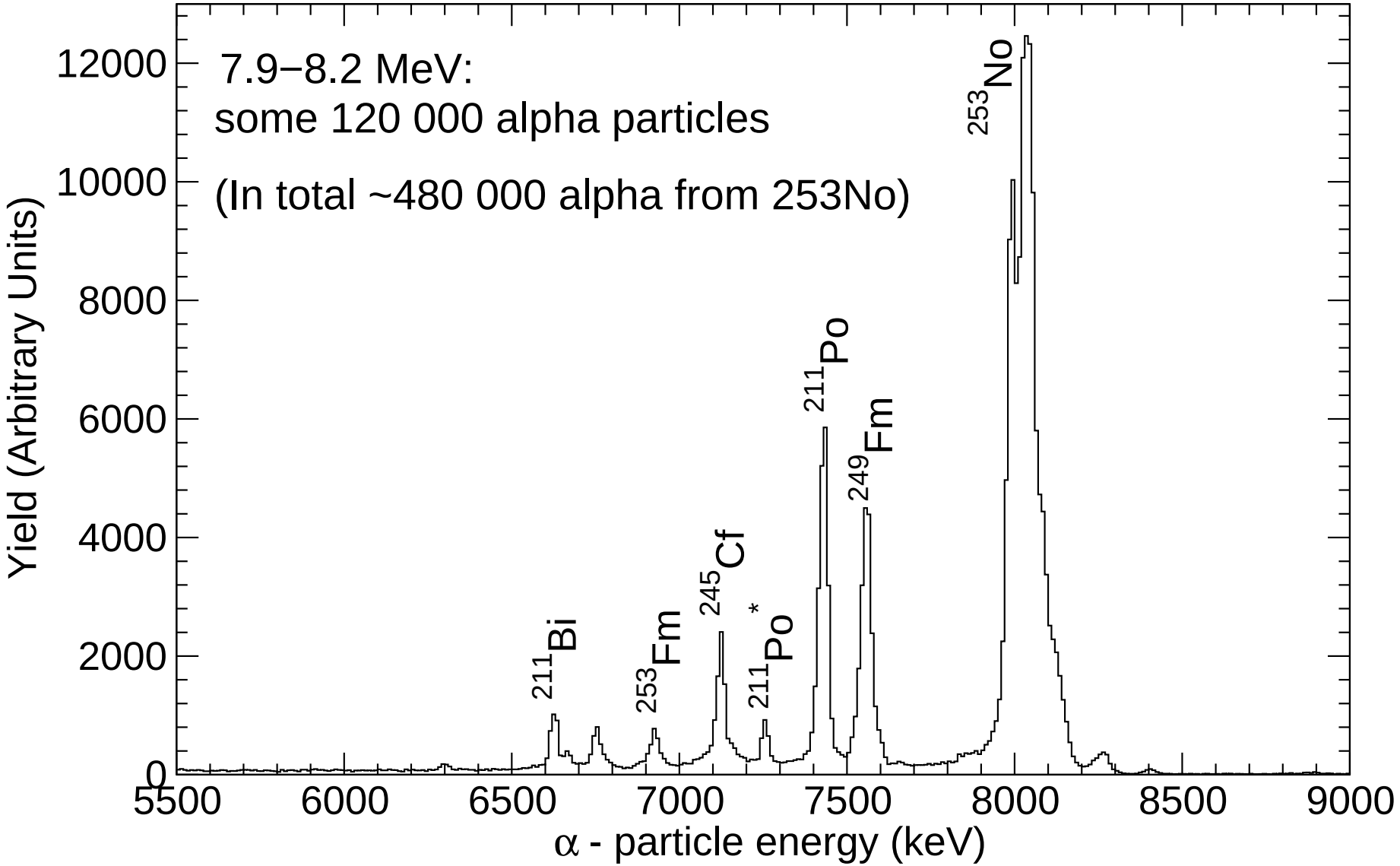
* First main beam experiment run in May

$$^{207}Pb(^{48}Ca, 2n)\,^{253}No$$

* Total beam integral 2.4E18
* Results from a subset of runs, corresponding to some 25% of the collected data

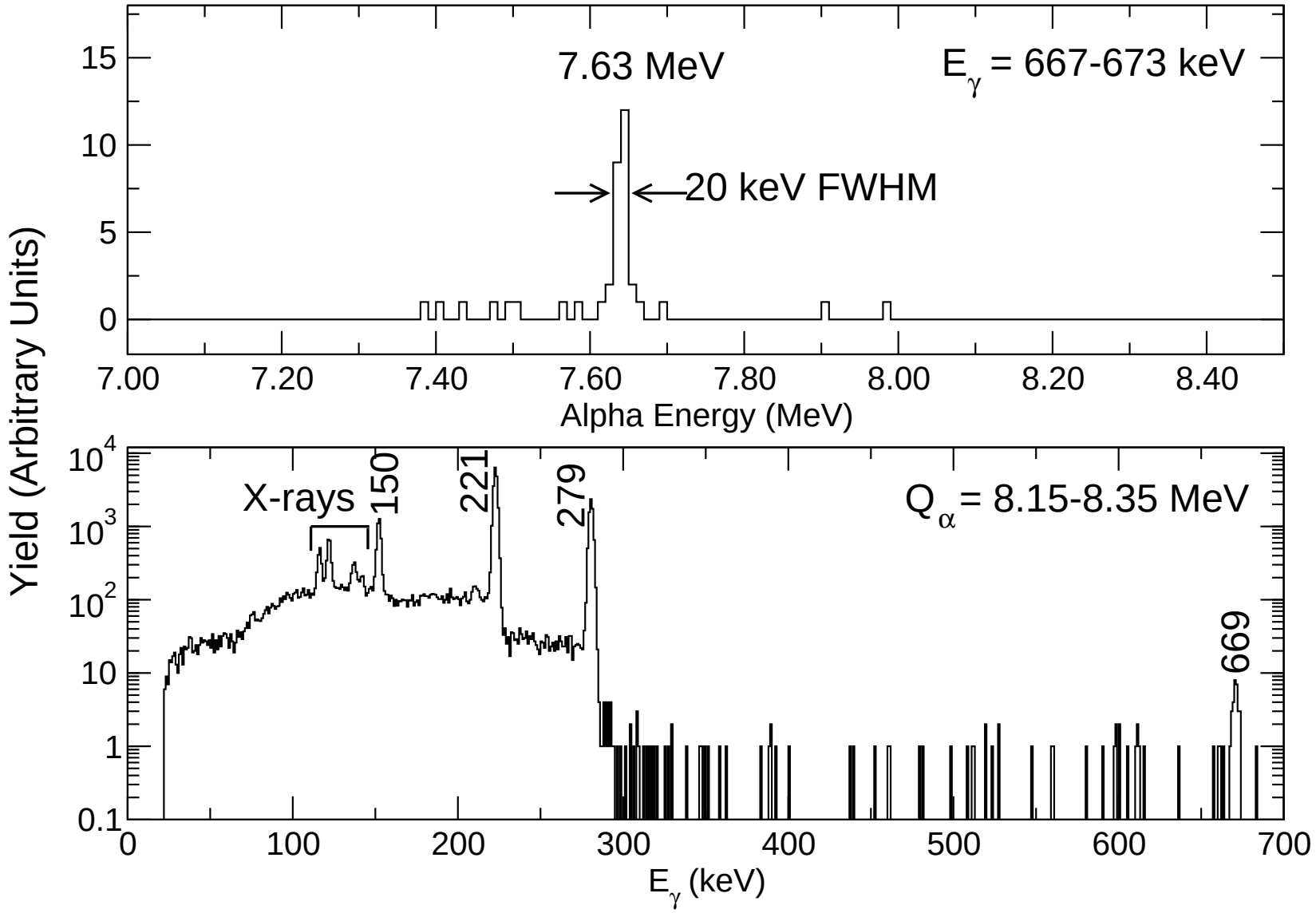
# Alpha Particles Detected in the DSSSD

## DSSSD p−side beam−off alpha spectrum



# Alpha Decaying 253No

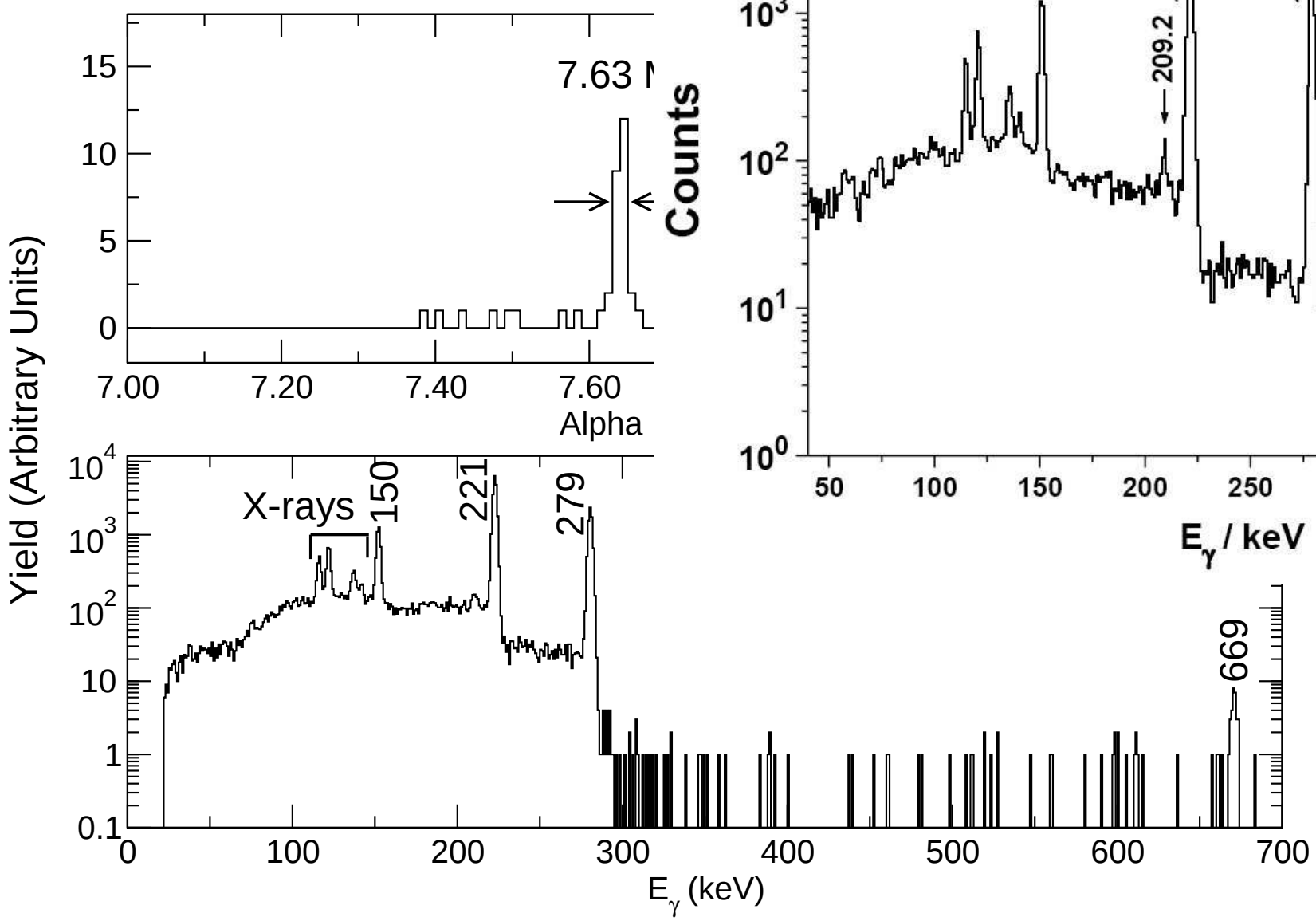
Gates clearly show new(ish) gamma−ray transition at 669 keV




A. Lopez−Martens et al. Nuclear Physics A 852, 15 (2011).

# Alpha d

## Gates clearly show new(i





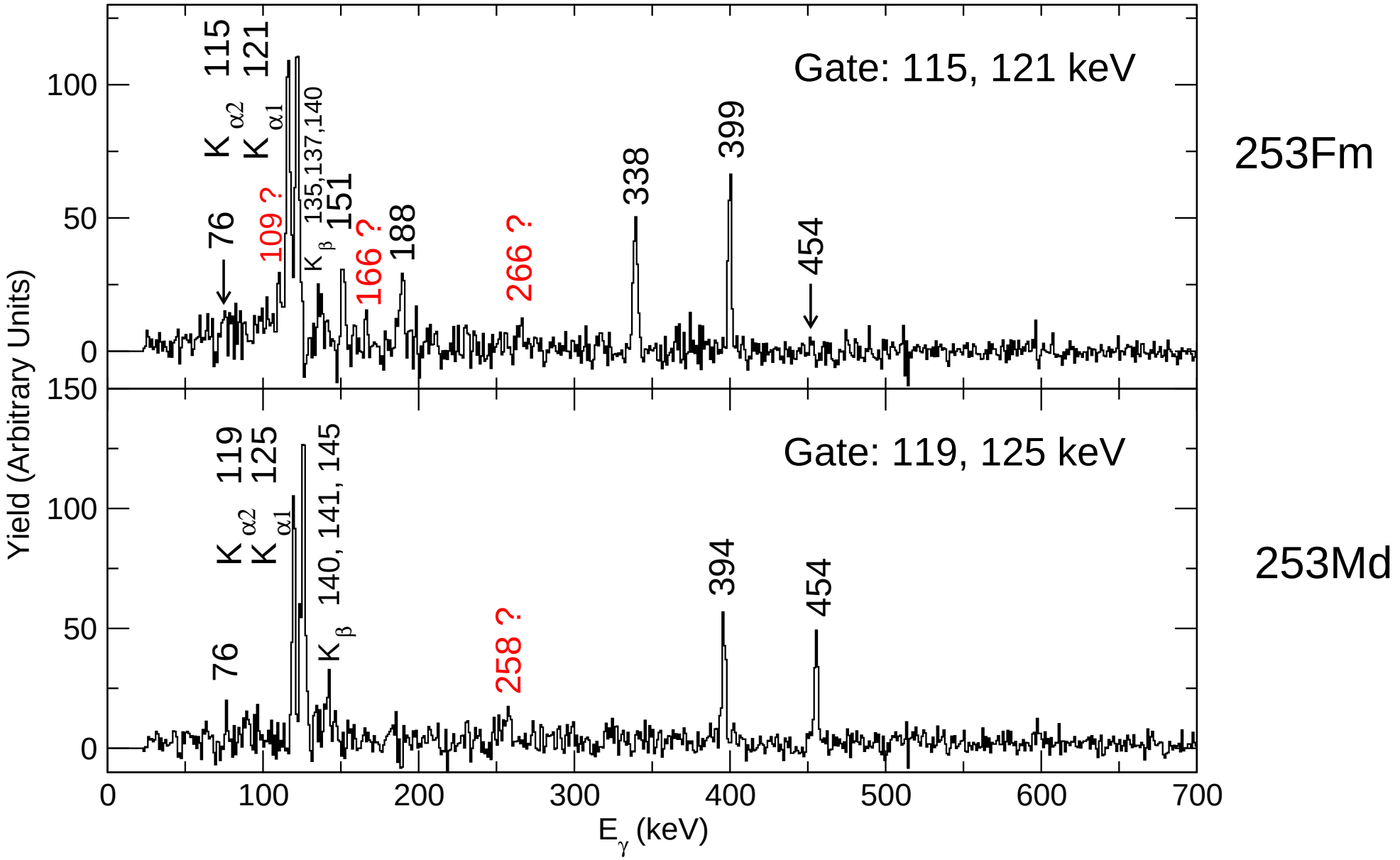


A. Lopez−Martens et al. Nuclear Physics A 852, 15 (2011).

F.P. Hessberger et al. Eur. Phys. J. D 45, 33 (2007).

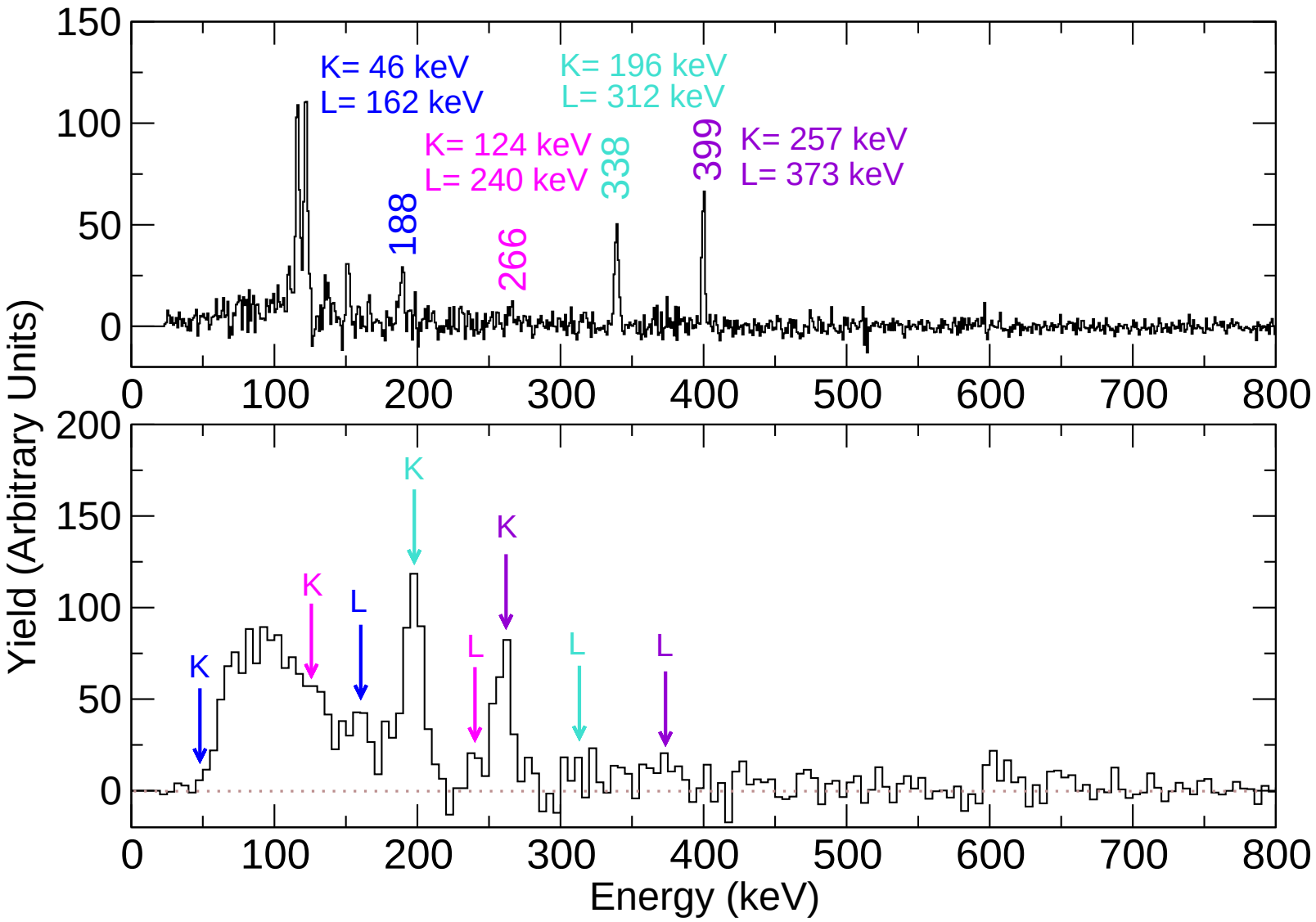
# Gamma−Gamma Coincidences

## Gated prompt on p−side DSSSD <600 keV + X−rays



# Conversion Electrons and Gamma Rays

## 253Fm comparison: All Ge detectors vs Si box detectors




Predicted by
BrIcc v2.2b

# TASISpec Flagship Experiment

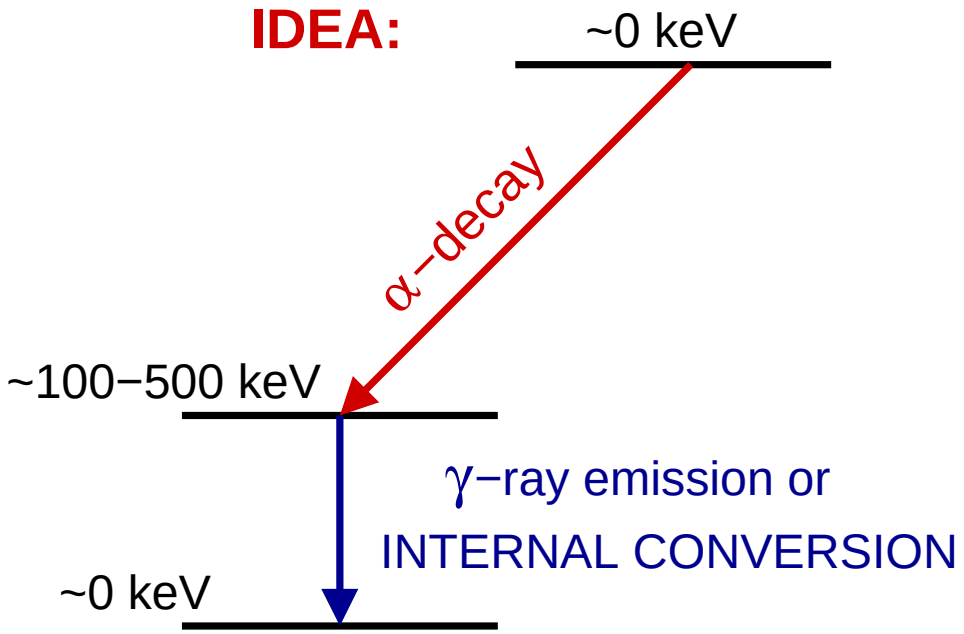
Fingerprinting E115 decay chains via X−rays
Direct measurement of proton number of the new SHE island!

8 weeks of beamtime approved at GSI.

1 α − X−ray coincidence detection per week expected.

Set−up and settings are prepared and **ready to run** at any time!

**IDEA:**





**=> K X−rays**

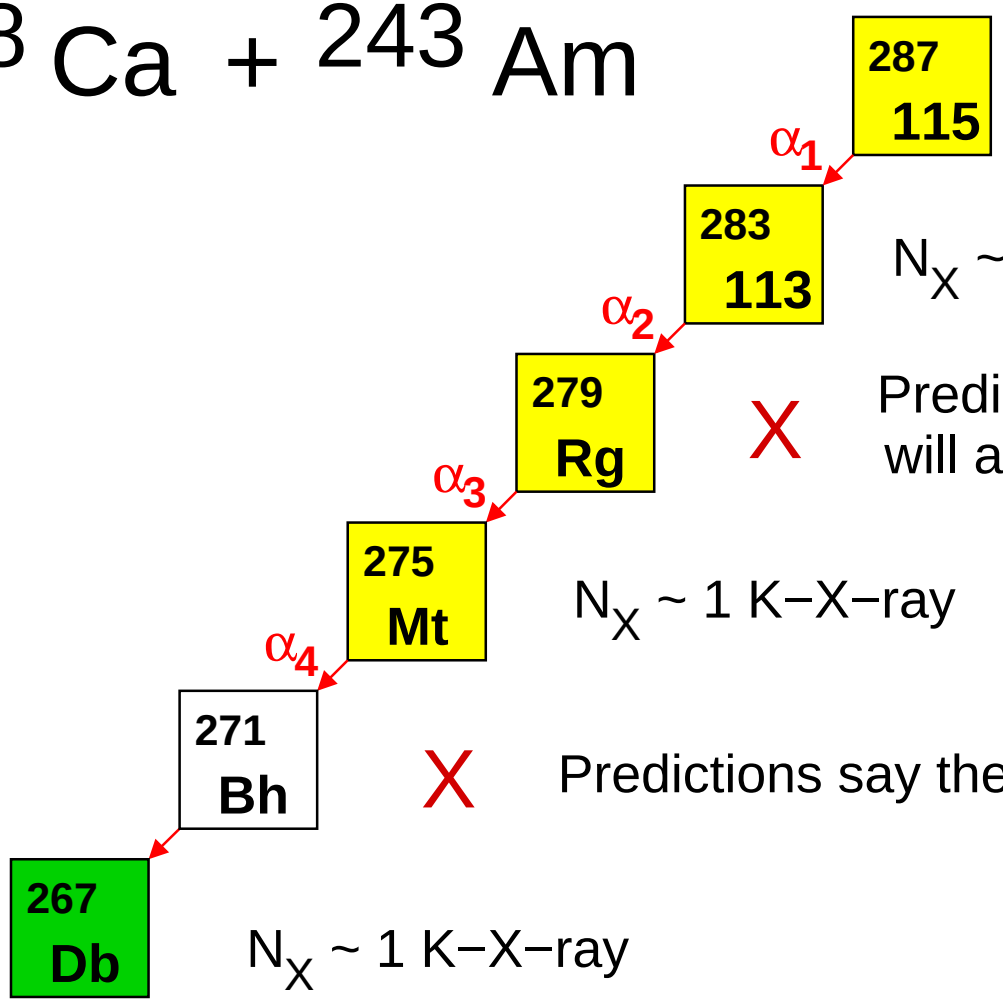
**Long decay chains of odd−A nuclei!**

**Spokesperson D. Rudolph (Lund University)**

# Predicted X−rays in the Decay Chain

## Numbers include realistic conversion factors

$^{48}Ca + ^{243}Am$




Expected to detect 8 decay chains

$N_X$ ~ 1 K−X−ray

X

Predictions say the populated excited state will alpha decay directly (not via groundstate)

$N_X$ ~ 1 K−X−ray

X

Predictions say the alpha populates the ground state

$N_X$ ~ 1 K−X−ray

**=> $N_X$ ~ 2−3 K−Xrays/chain!**

**=> TASISpec efficiencies; detect one alpha−X−ray coincidence/week!**

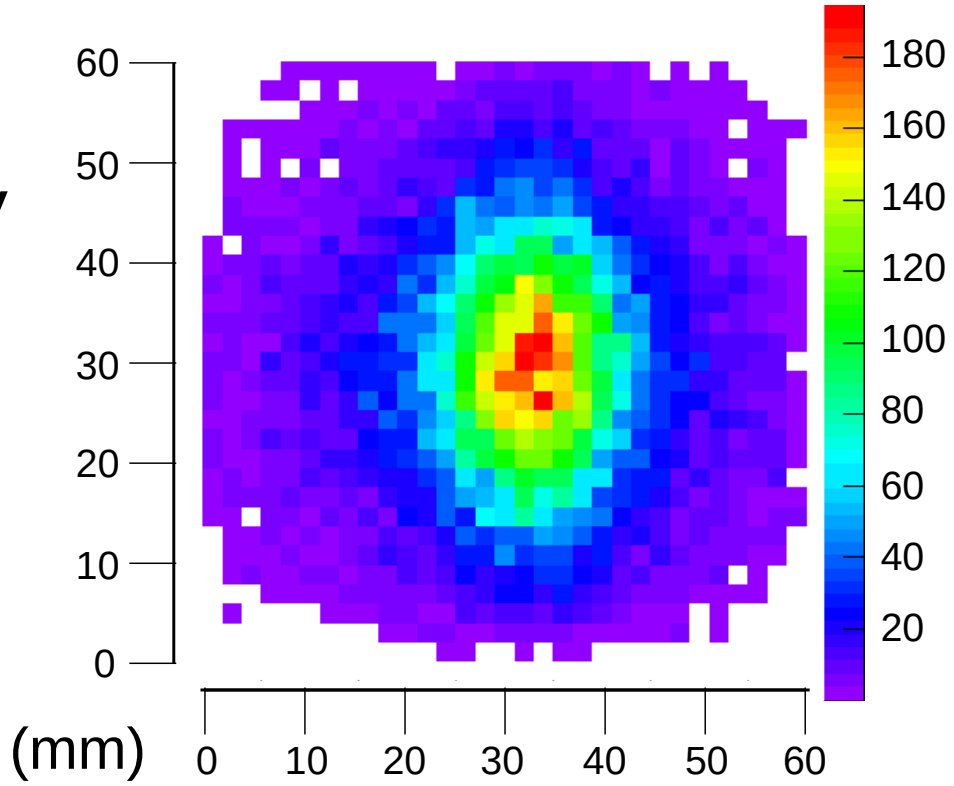
# TASISpec

## A versatile SHE spectroscopy setup!

* Small−image mode => compact focal plane
* High segmentation => 192 Si strips
  α−efficiency ~80%
* 4+1 segmented Ge detectors
  γ−efficiency ~40% @ 150 keV
* Multi−coincidence capabilities
  => suitable for SHE experiments

**Next up: E115!**

$^{253}$No alpha decays



# TASISpec

## Many thanks to the 'updated' collaboration:

TASCA @ GSI, DE

Helmholtz−Institut Mainz, DE

Lund University, SWE

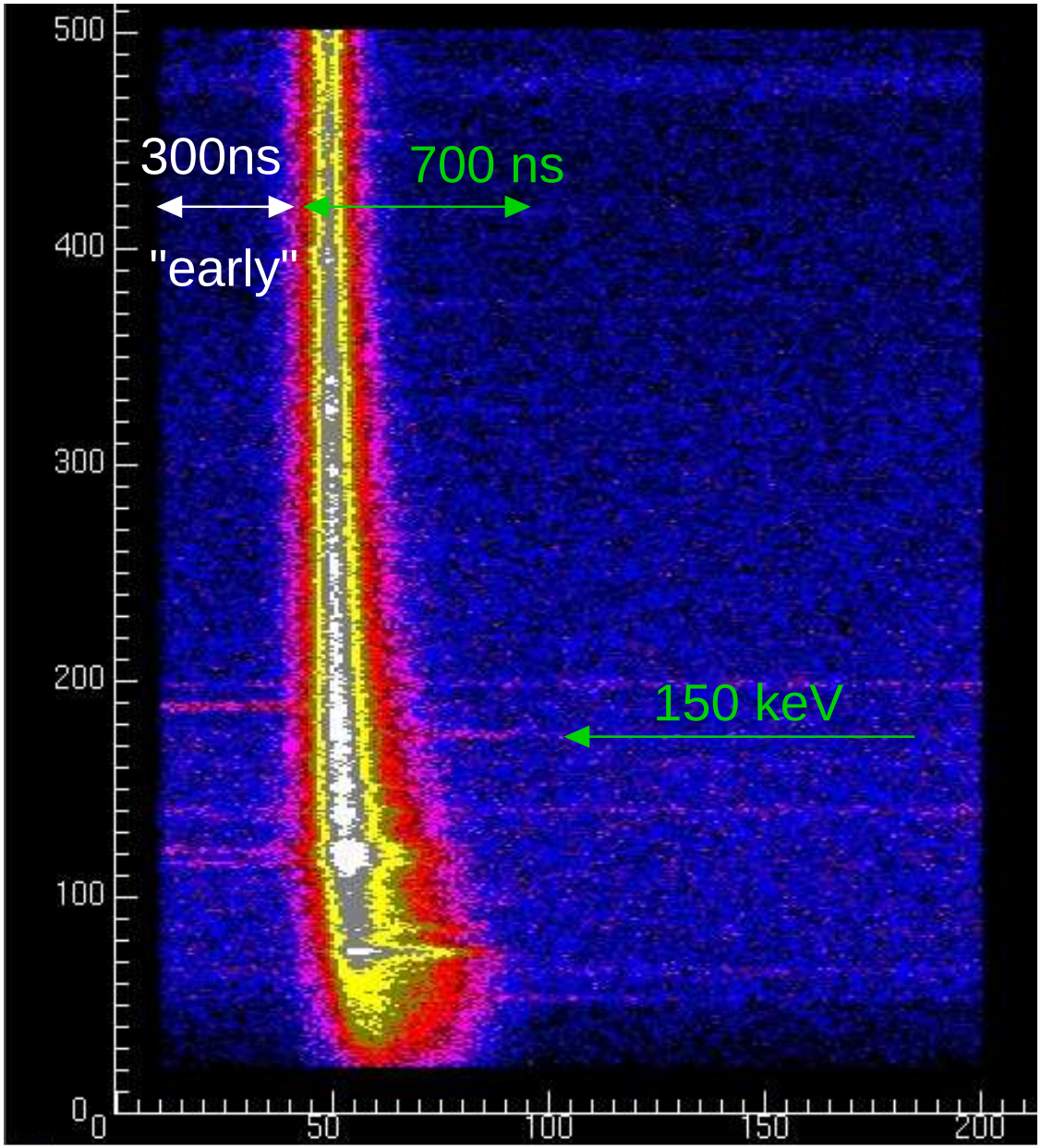
University of Liverpool, UK

Universidad Nacional de Colombia, CO

Universität Mainz, DE

# Early and Prompt Coincidences

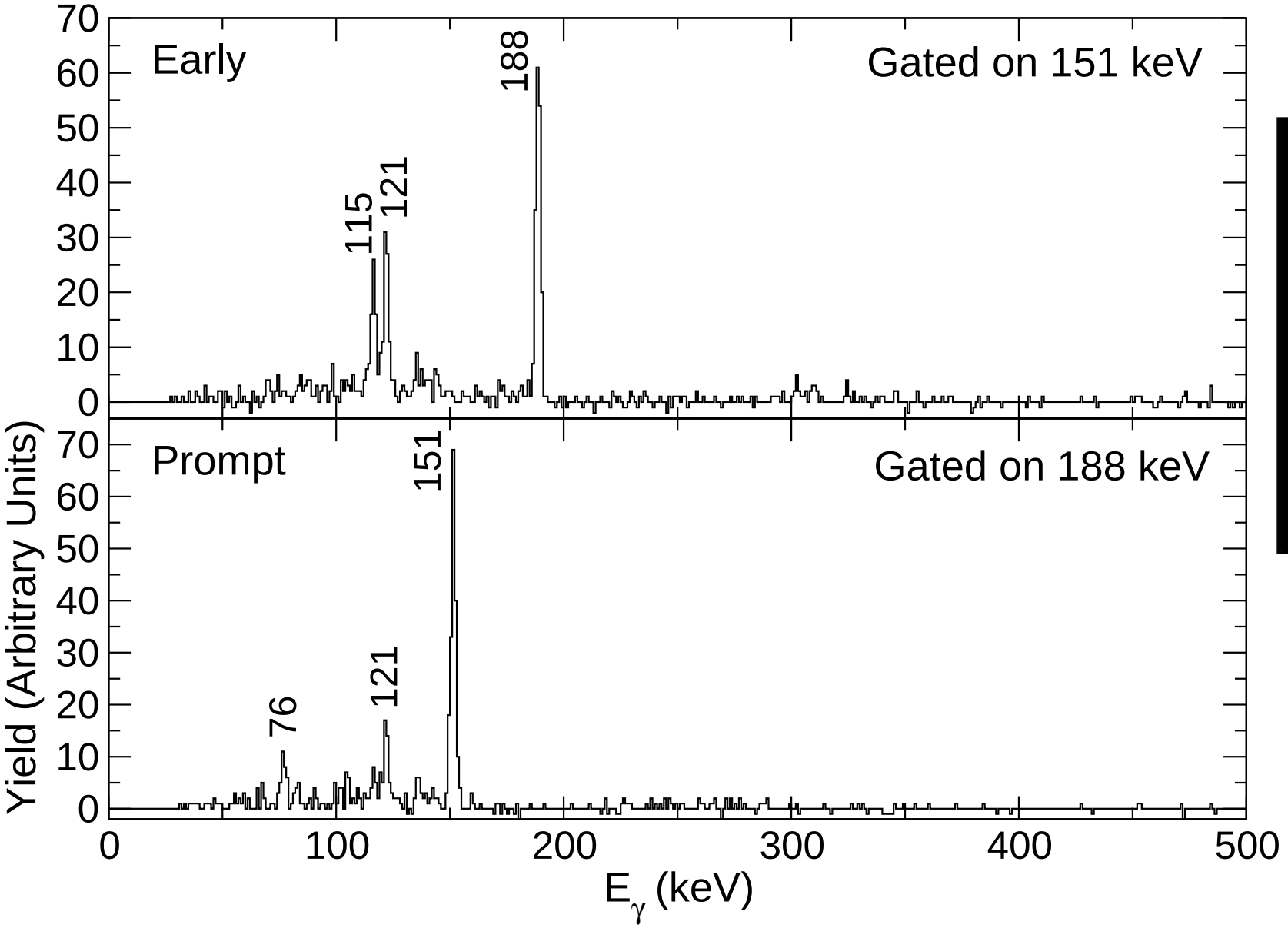
## Coincidences of electron and gamma looking at signal time differences

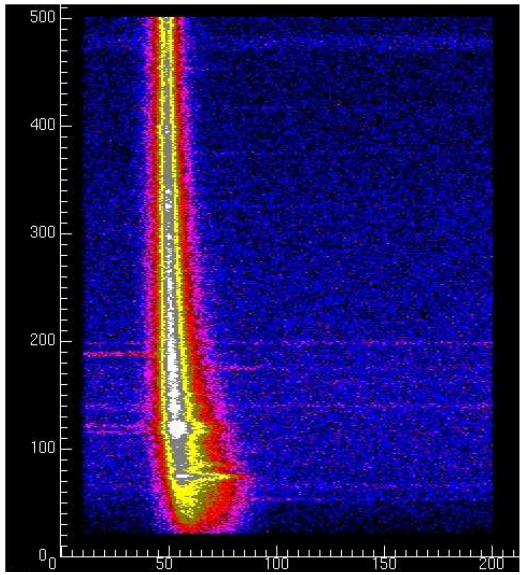



Time between Si and Ge signals

# Prompt and Early Coincidences

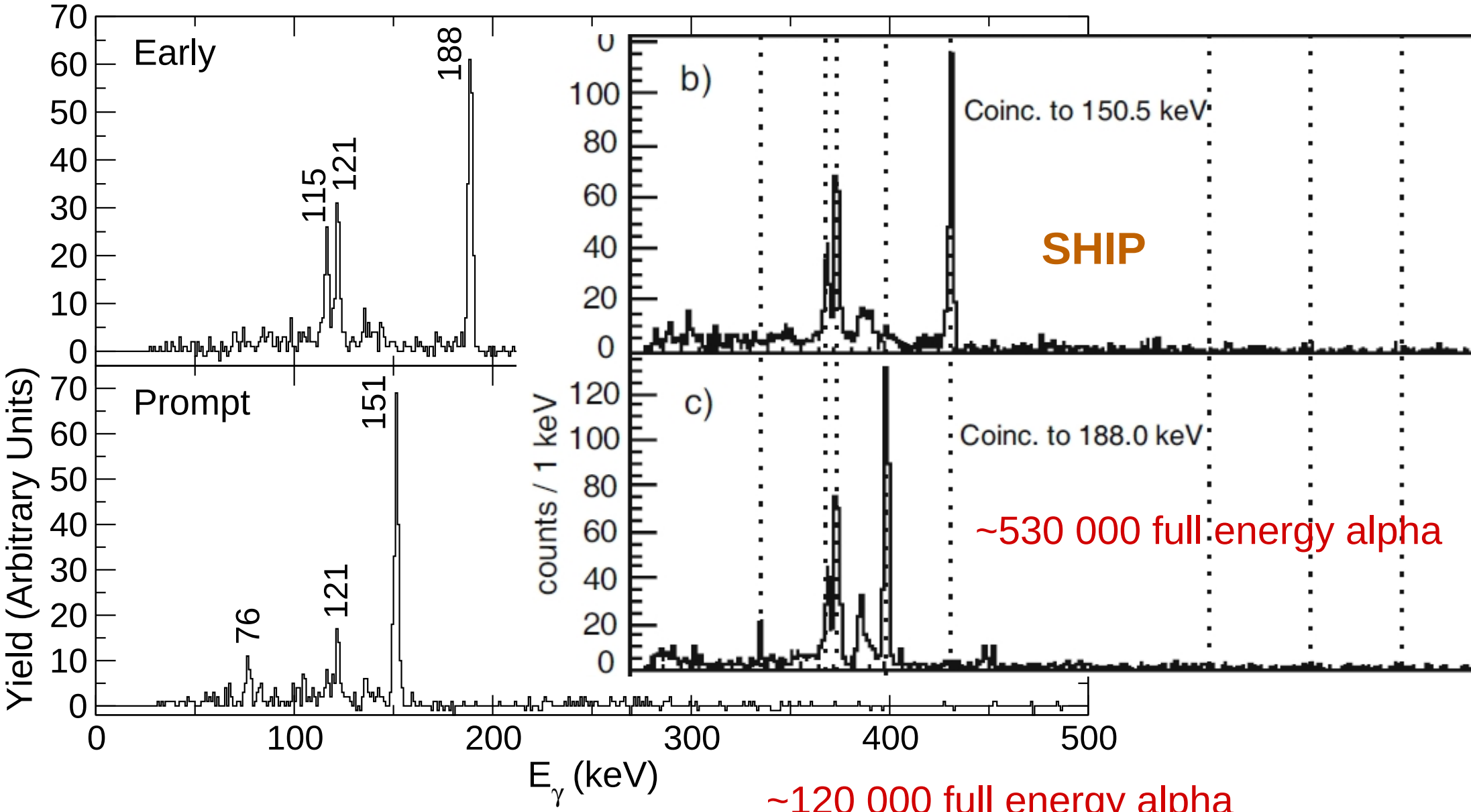
Coincidences of electron and gamma looking at signal time differences



# Prompt and Early Coincidences

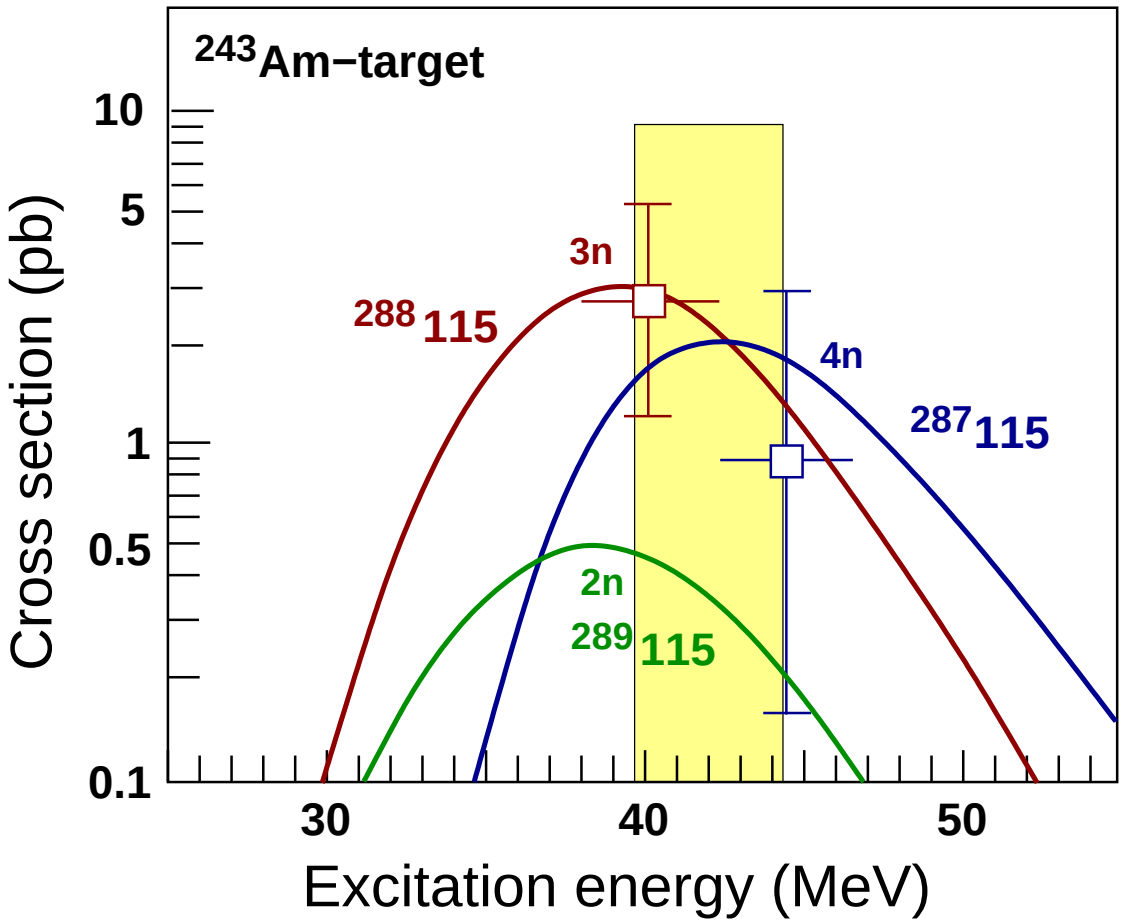
Coincidences of electron and gamma looking at signal time differences

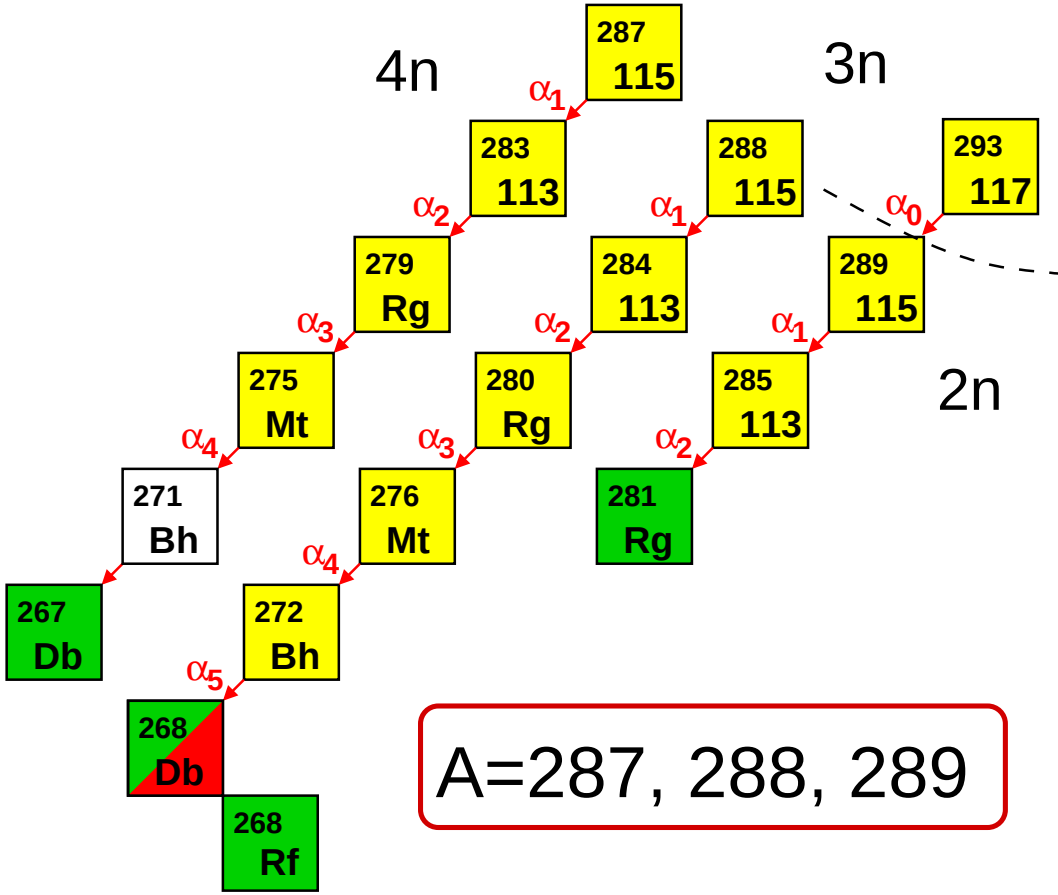



S. Antalic et al. Eur. Phys. J. A 47, 62 (2011).

# Three different E115 Isotopes Produced

## $^{243}$Am( $^{48}$Ca,xn) $^{291-x}$115 – 8 weeks approved!




A=287, 288, 289


Yu. T. Oganessian et al., PRC72, 034611 (2005)
Yu. T. Oganessian et al., JPG 34, R165 (2007)
Yu. T. Oganessian et al., PRL 104, 142502 (2010)
V. Zagrebaev, NPA734, 164 (2004).

# Aims of the Experiment

## To kill four birds with one stone!

1) 287−115 decaying with a chain of 5 alphas

   1.5 pb => 1 chain/week => 8 chains in total

   => 8*5 = 40 X−ray oppertunities

2) 289−115 confirm daughters in the 293−117 chanis from Dubna. Here ~0.5 pb

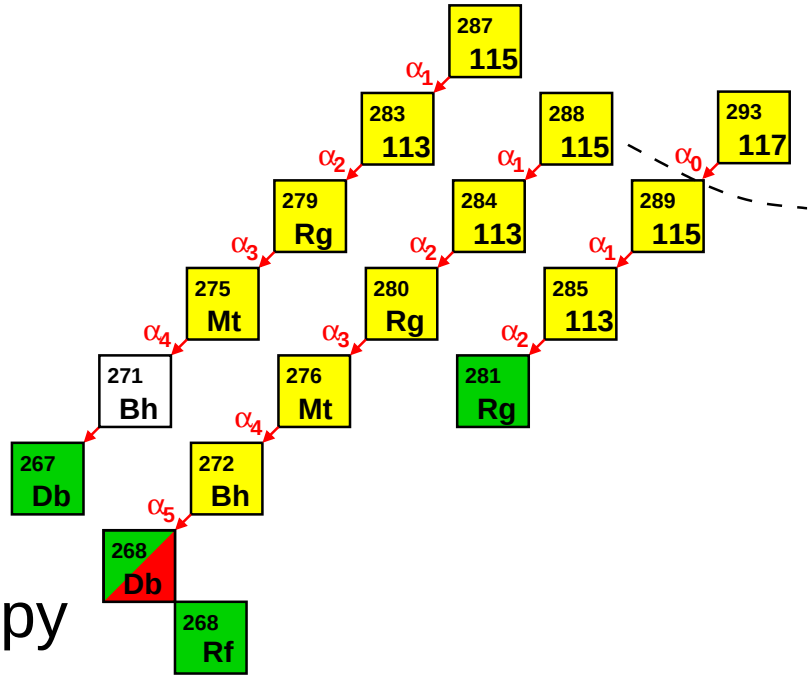
3) E115 alpha−gamma coincidence spectroscopy

   A=287, 288, 289

   Expected 20 decay chains =>100 oppertunities

   + Nuclear structure information

4) 287,288−115 confirmation of previous results



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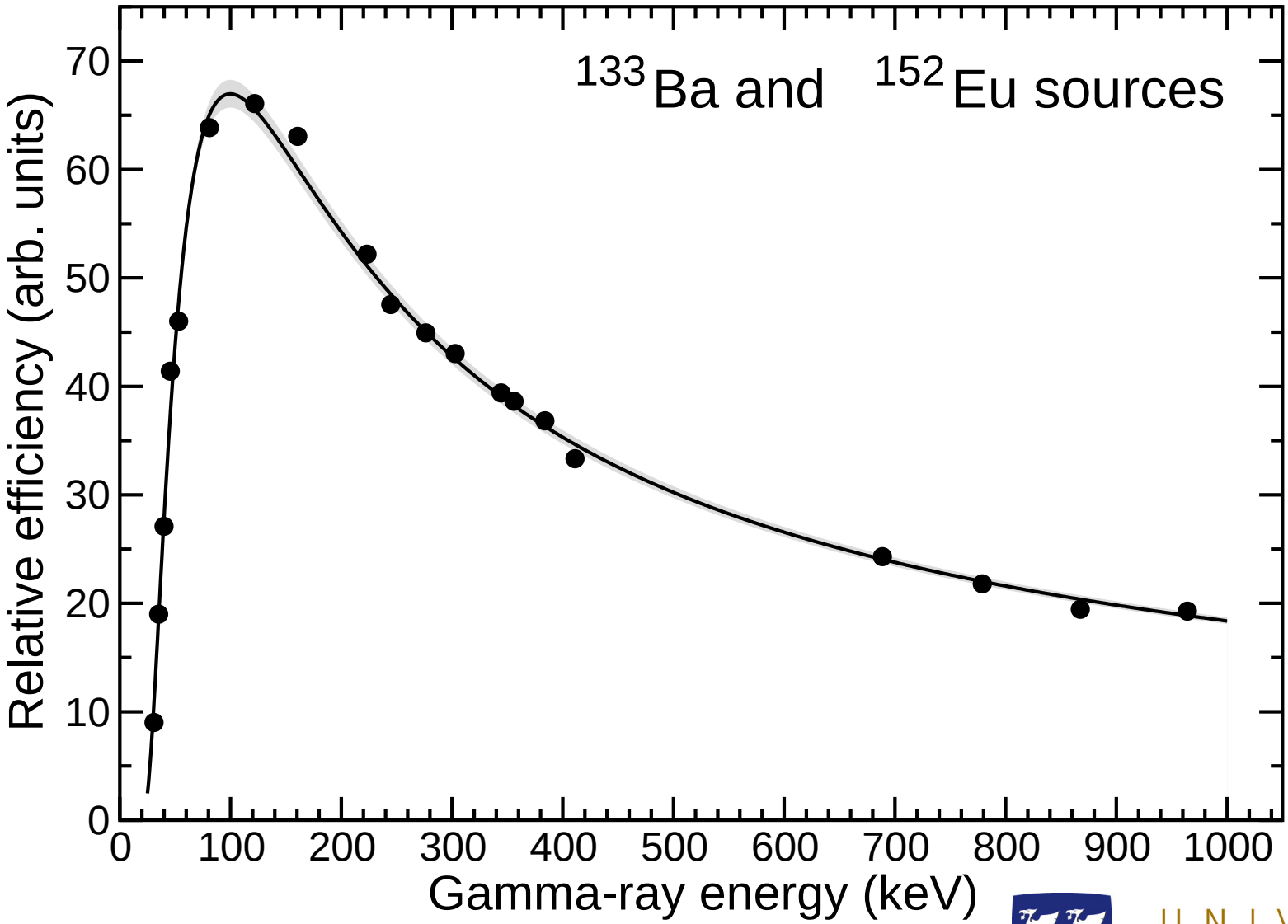
# Relative Gamma−ray Efficiencies

## Obtained using radioactive sources placed inside TASISpec




Lise−Lotte Andersson United Kingdom

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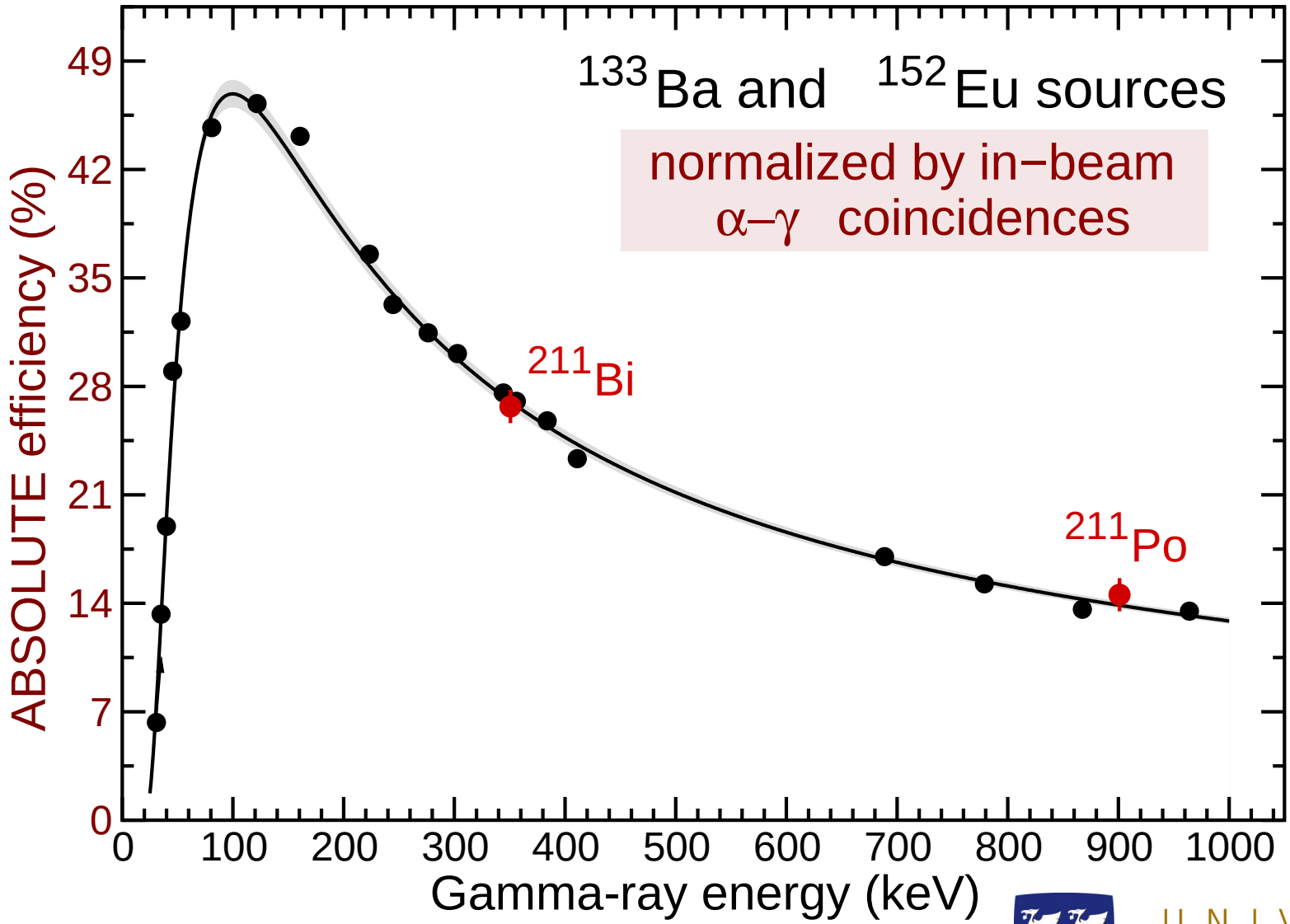
# Absolute Gamma−ray Efficiencies

## Obtained by comparing to values from our experiment

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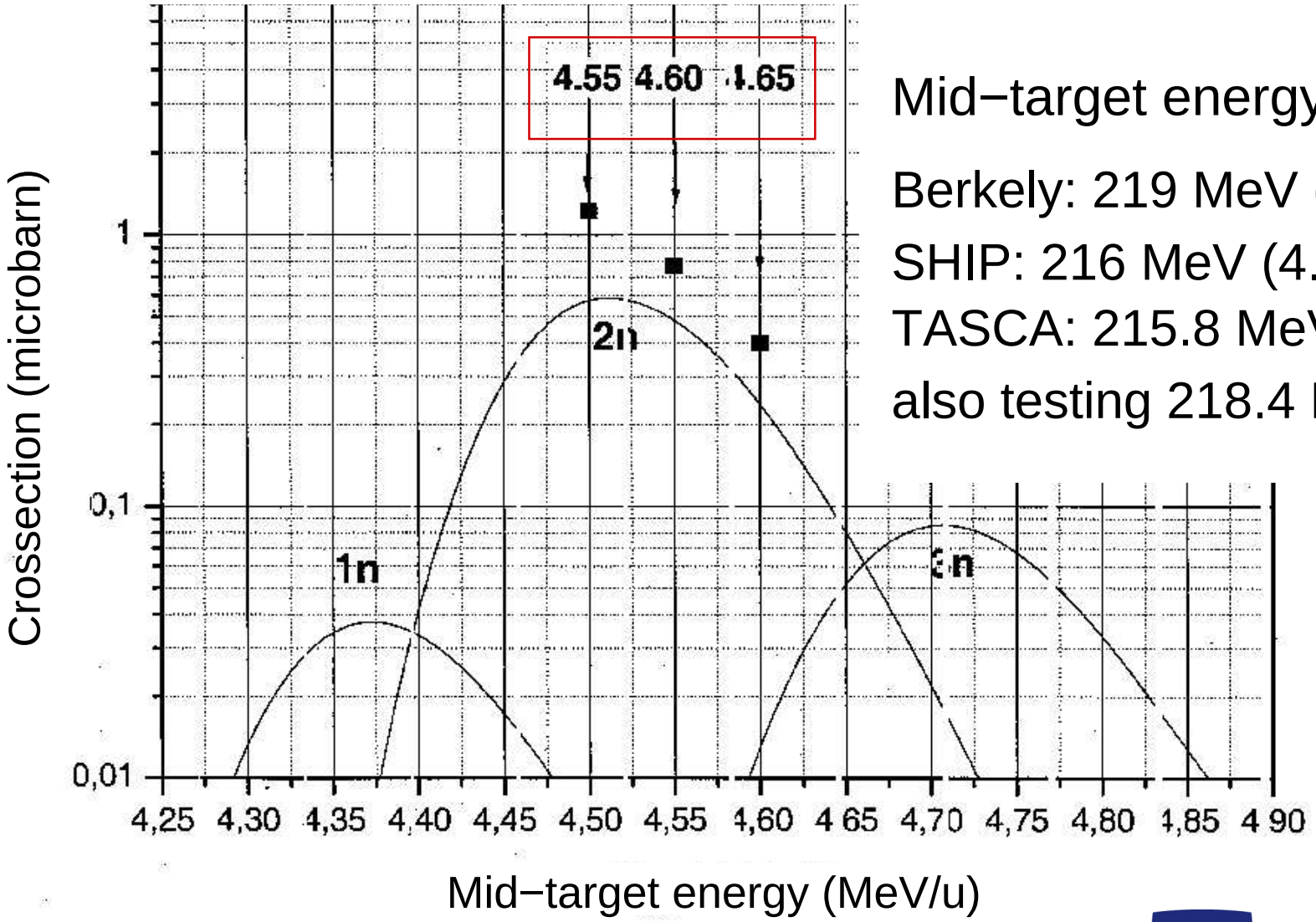
# Crossections for $^{253}$No

SHIP Aug 2007 (beginning of target energy)




Mid−target energy for 48Ca + 207Pb

Berkely: 219 MeV (4.56 MeV/u)

SHIP: 216 MeV (4.50 MeV/u)

TASCA: 215.8 MeV (4.50 MeV/u)

also testing 218.4 MeV (4.55 MeV/u)

HIVAP plot made by

F. Hessberger (thanks!)



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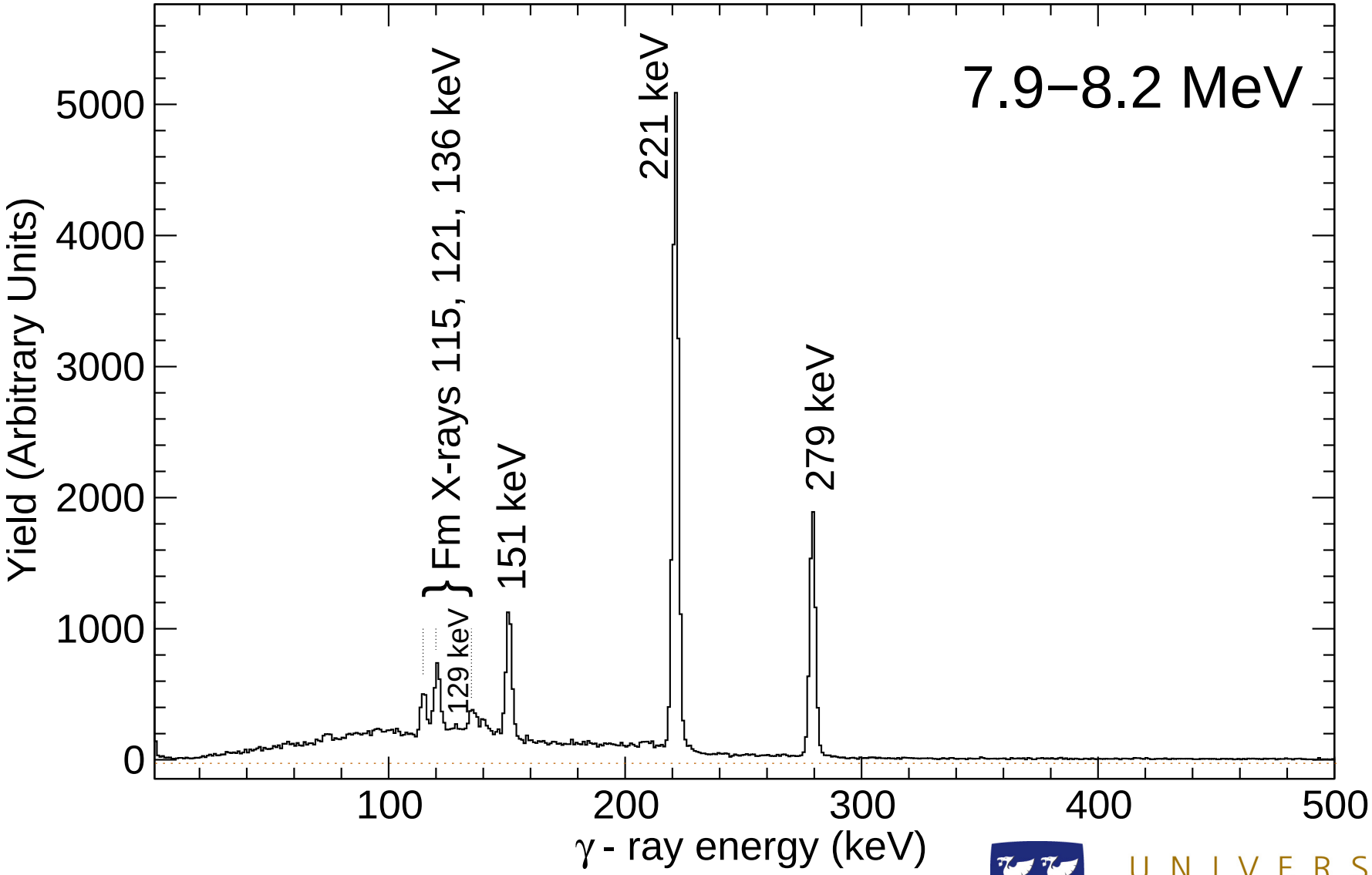
# Alpha−Gamma Correlations

## Gamma rays in prompt coincidence with 253No alpha

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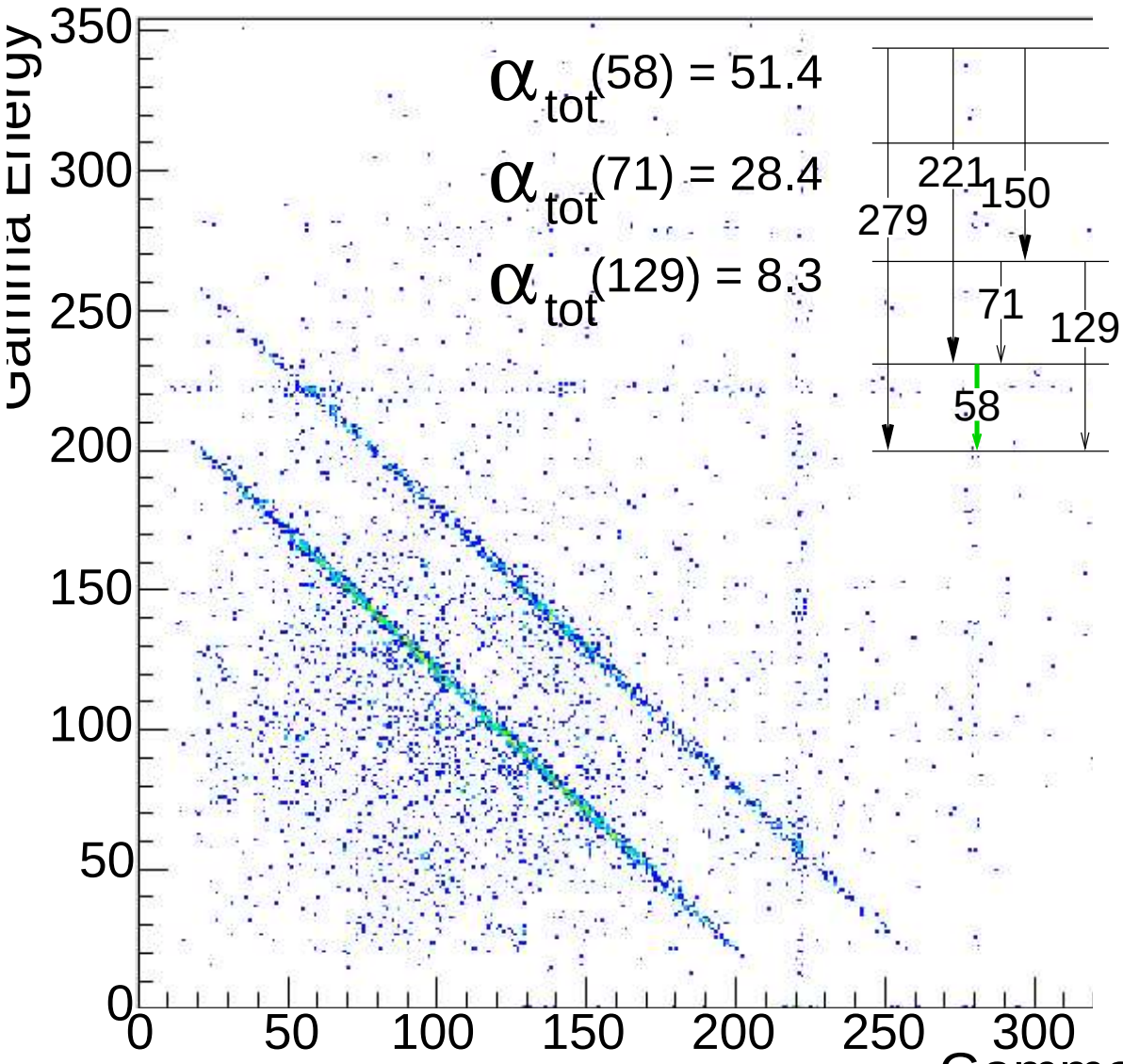
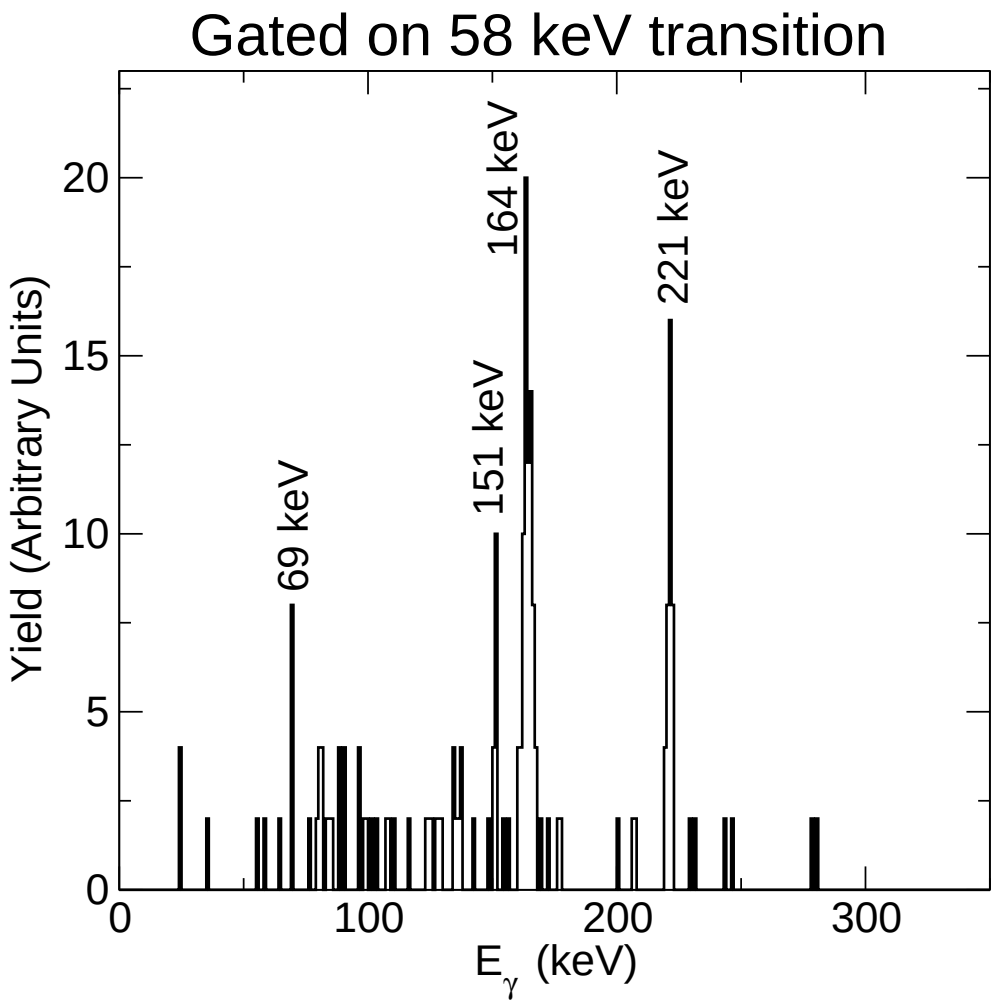
# Alpha−Gamma−Gamma Coincidences

## Addback + time gate

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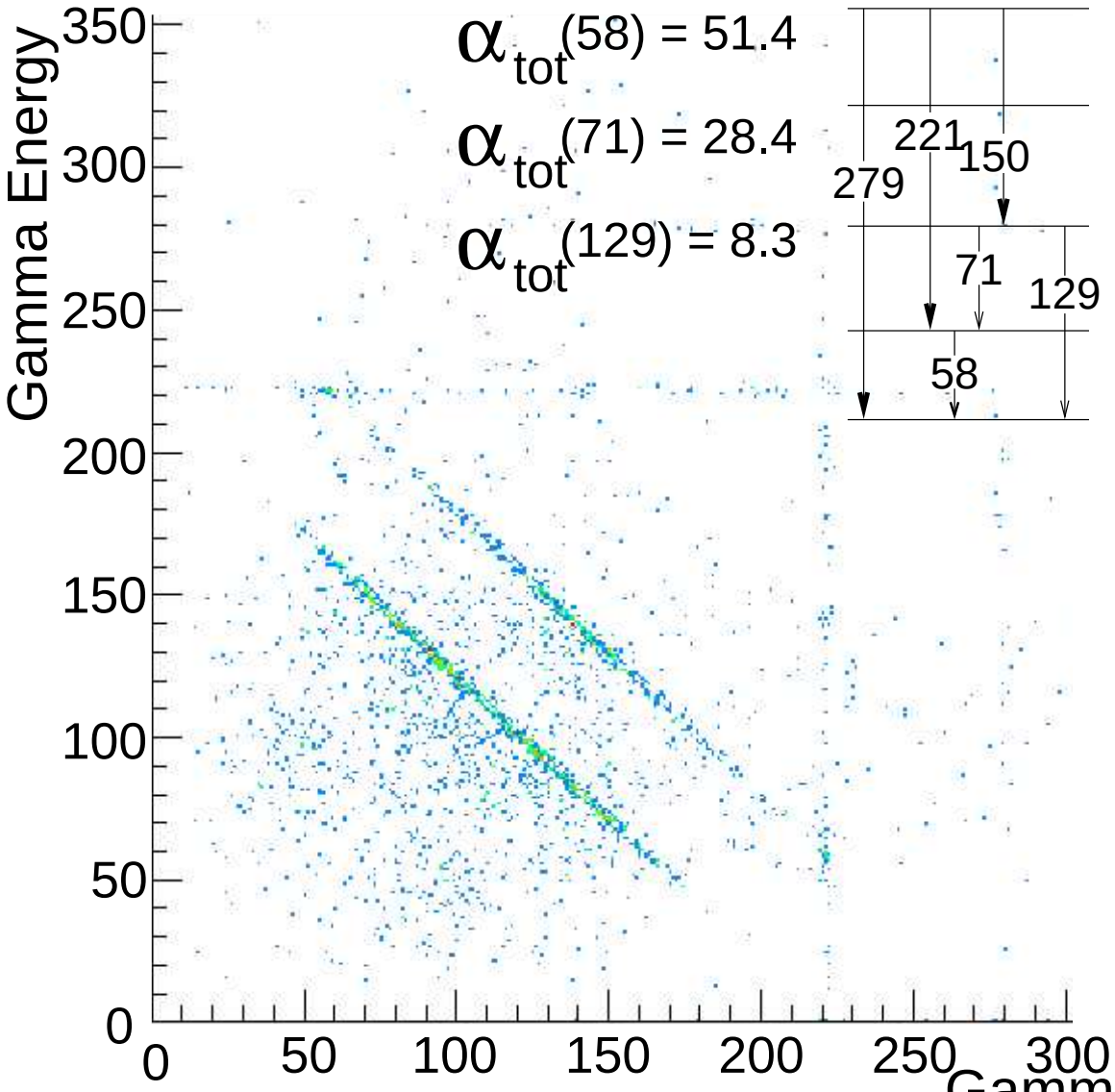
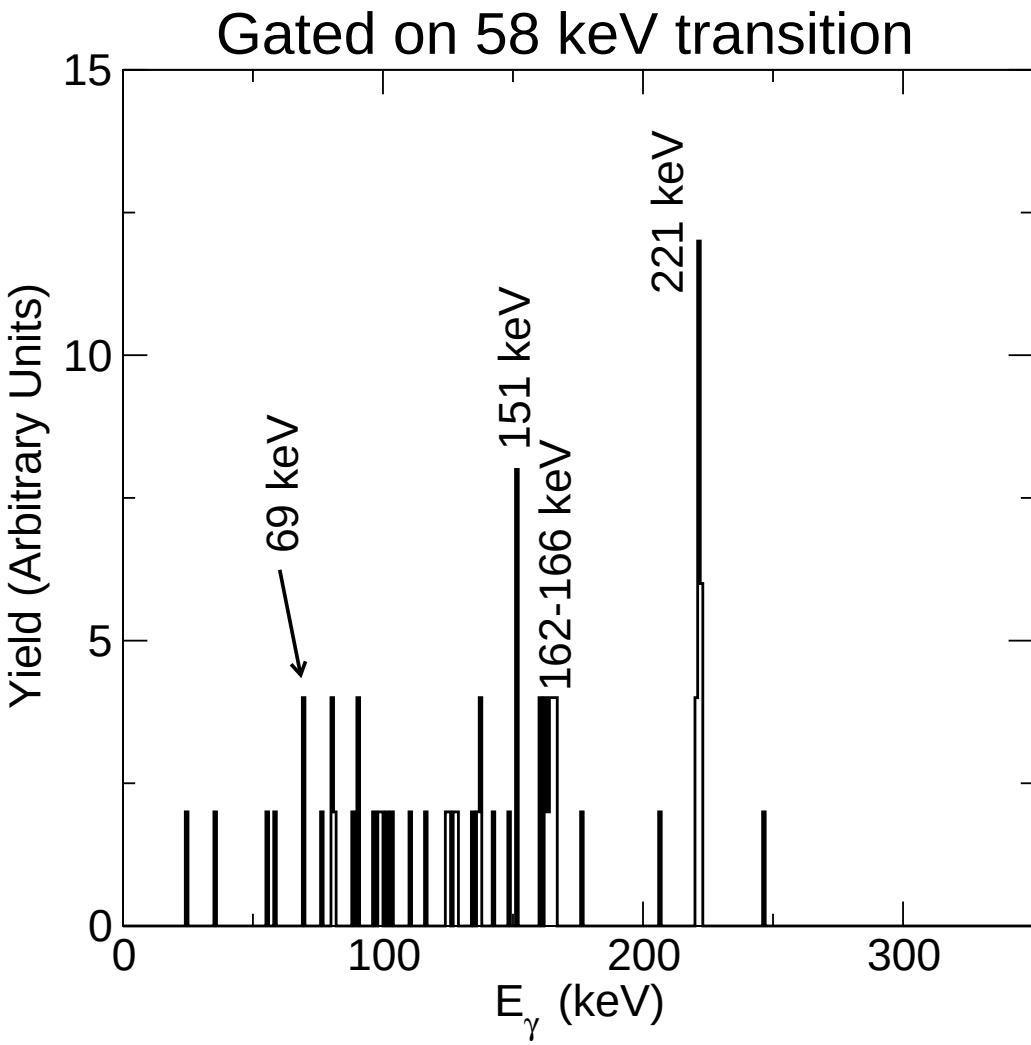
# Alpha−Gamma−Gamma Coincidences

## Addback + time gate + ONE crystal in each detector fireing

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# Looking at K−isomers

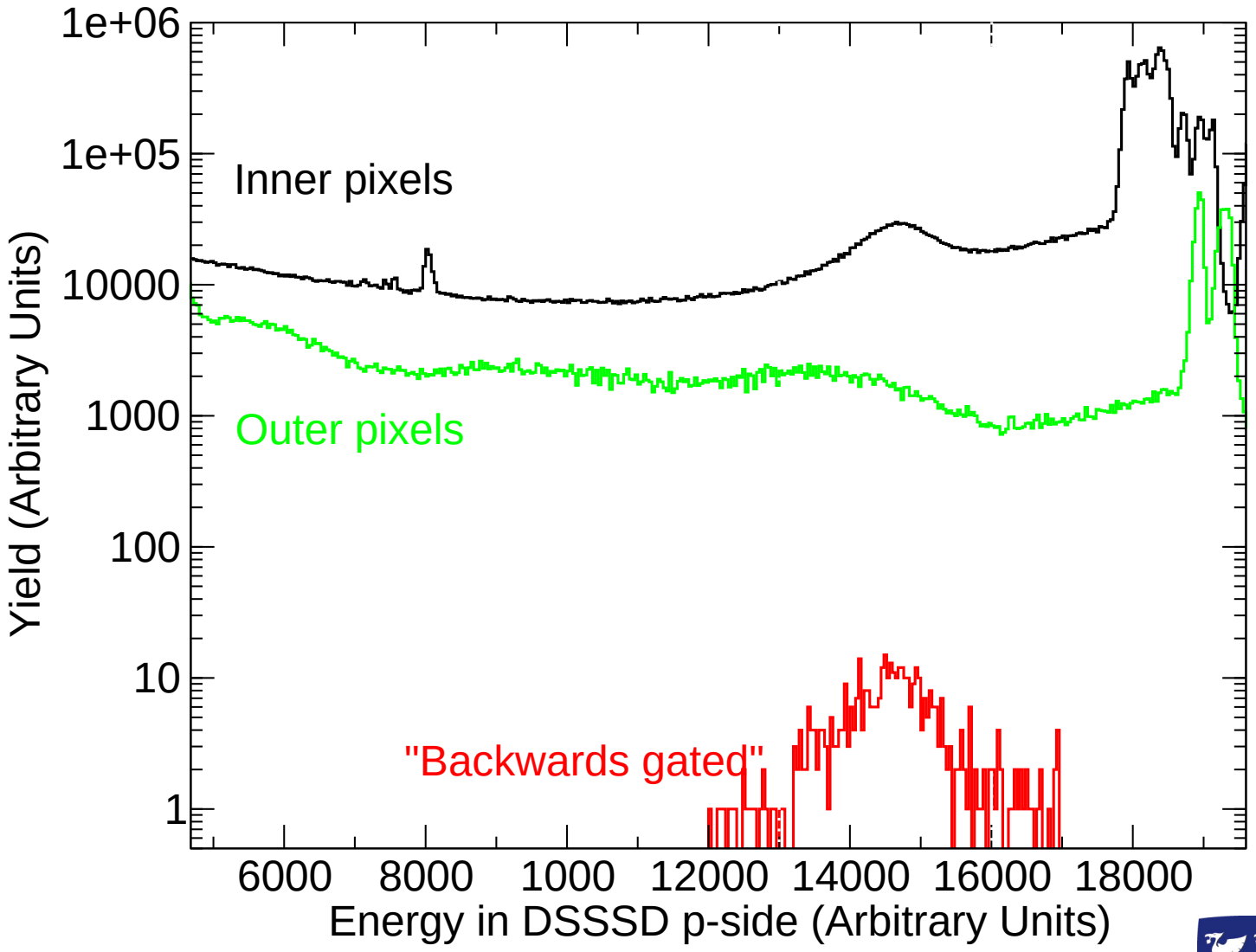
## To create an implant−electron−gamma spectrum

* Implant energy
* Electron energy
* Chose a time gate between implant and electron
* Chose a time between electron and gamma

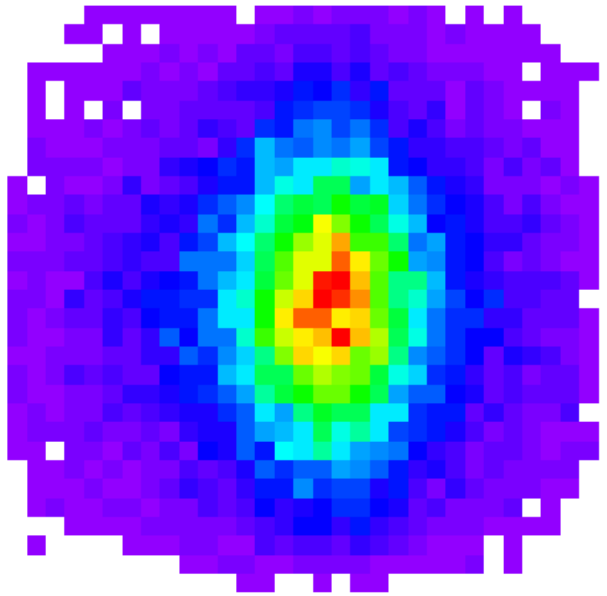
...et Voilà...?!

# Energy of the $^{253}$No Implants

## Beam On − implanted into the p−side of the DSSSD




DSSSD hit pattern
(gated on 253No alpha)



(beam off)

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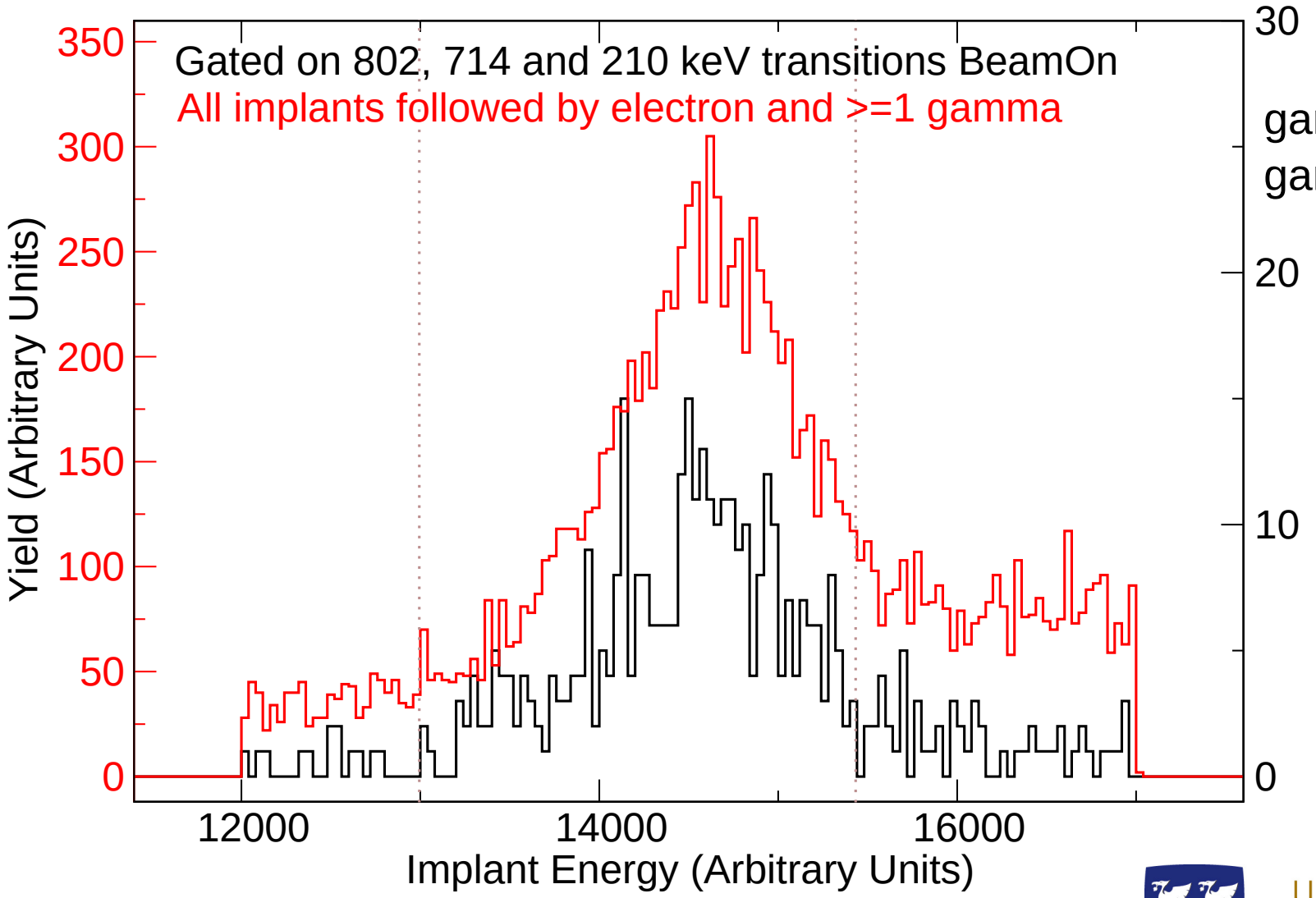
# Implant Energy Revisited

## Seems possible to narrow gate to improve cleanliness




gamma energy >10 keV
gamma time 44−60 "ticks"

Generous gate:
12−17 "MeV"
Tight gate:
13−15.5 "MeV"

(Thanks Fritz!)



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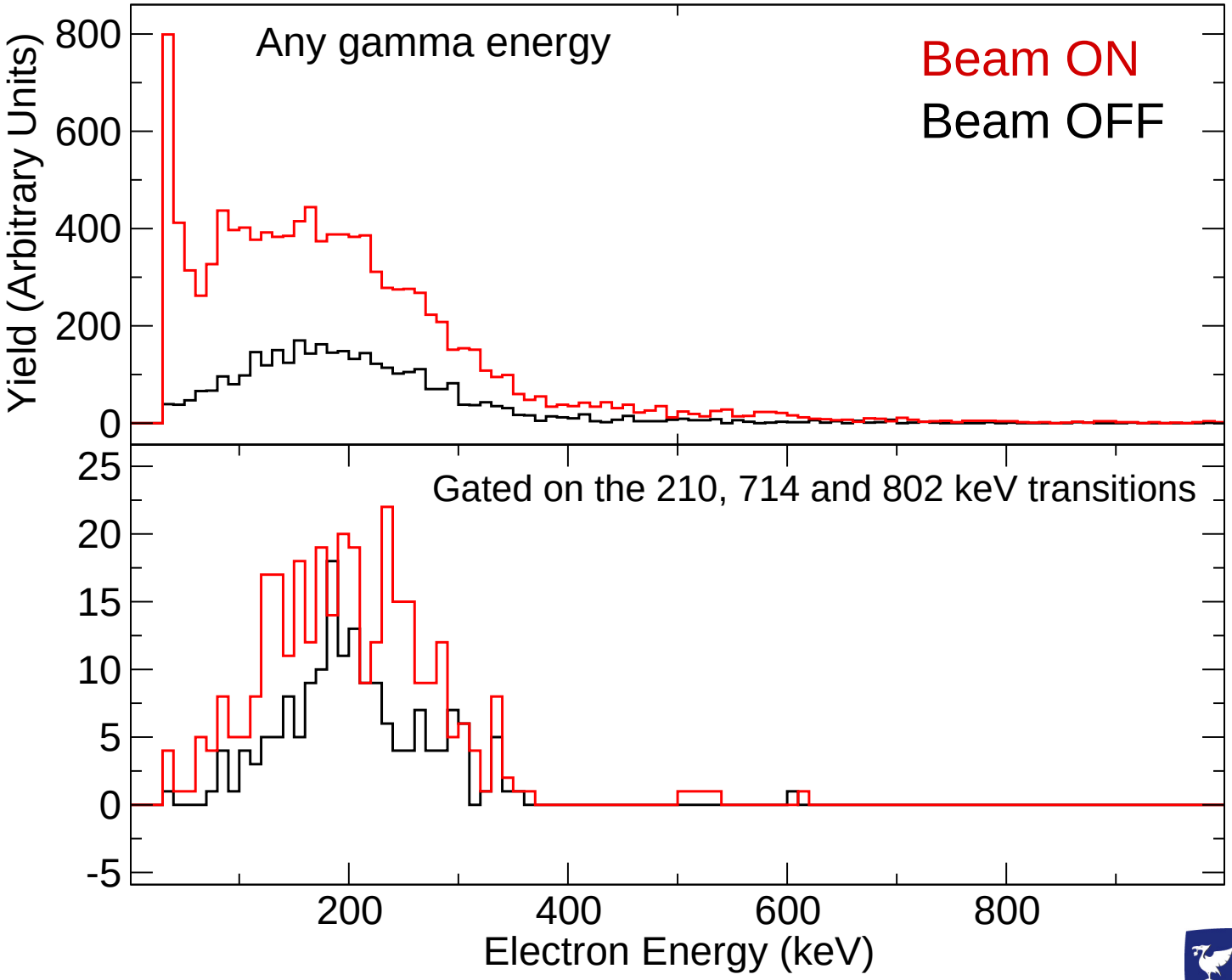
# Electron Energy

## Implant−electron correlation followed by at least 1 gamma ray




Generous gate:
30−2000 keV
Tight gate:
30−400 keV

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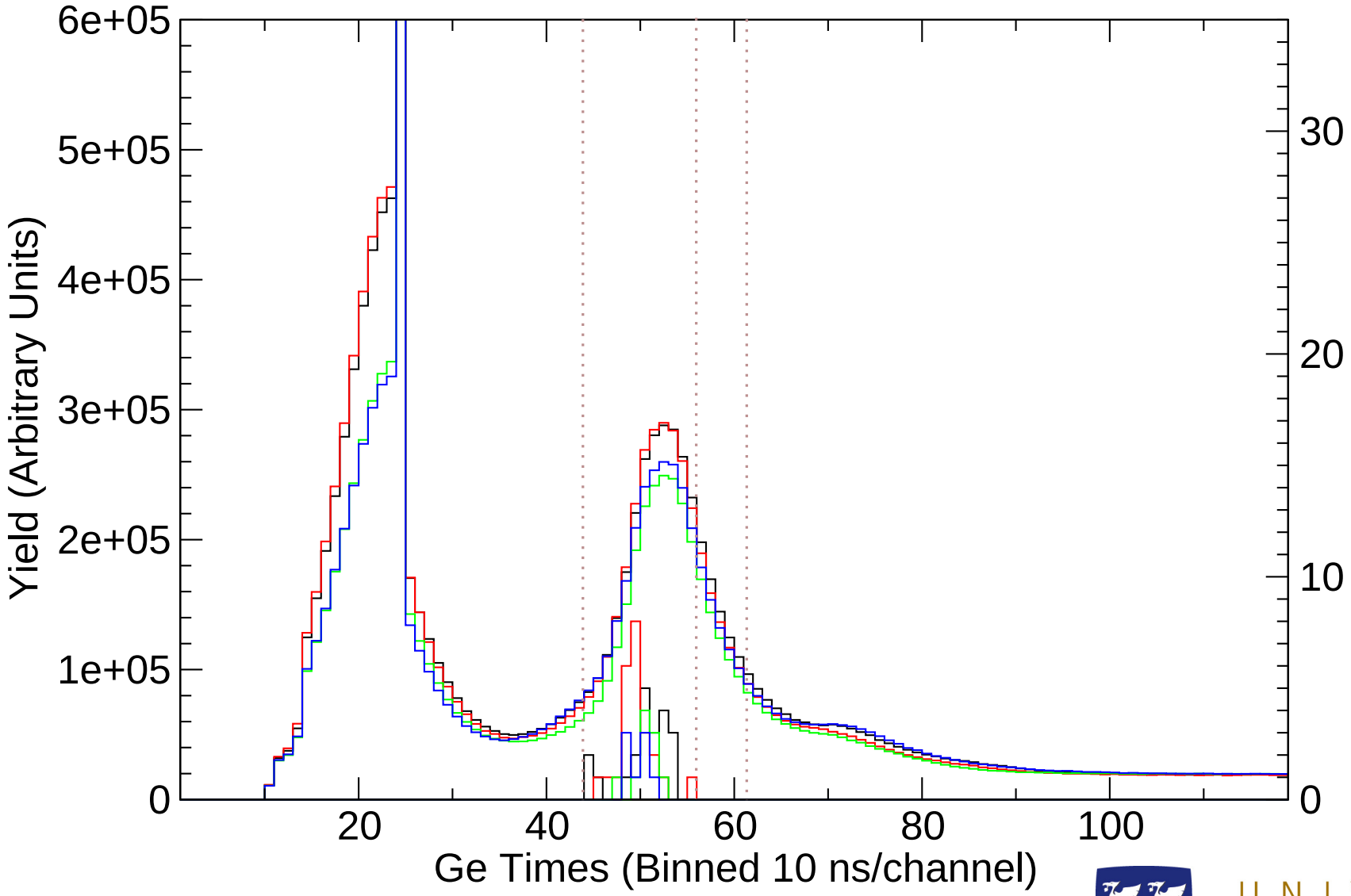
# Ge Times

## Times shown for 4 VEGA crystals + gated on 802 keV




Generous gate
440−600 ns
Tight gate:
440−550 ns

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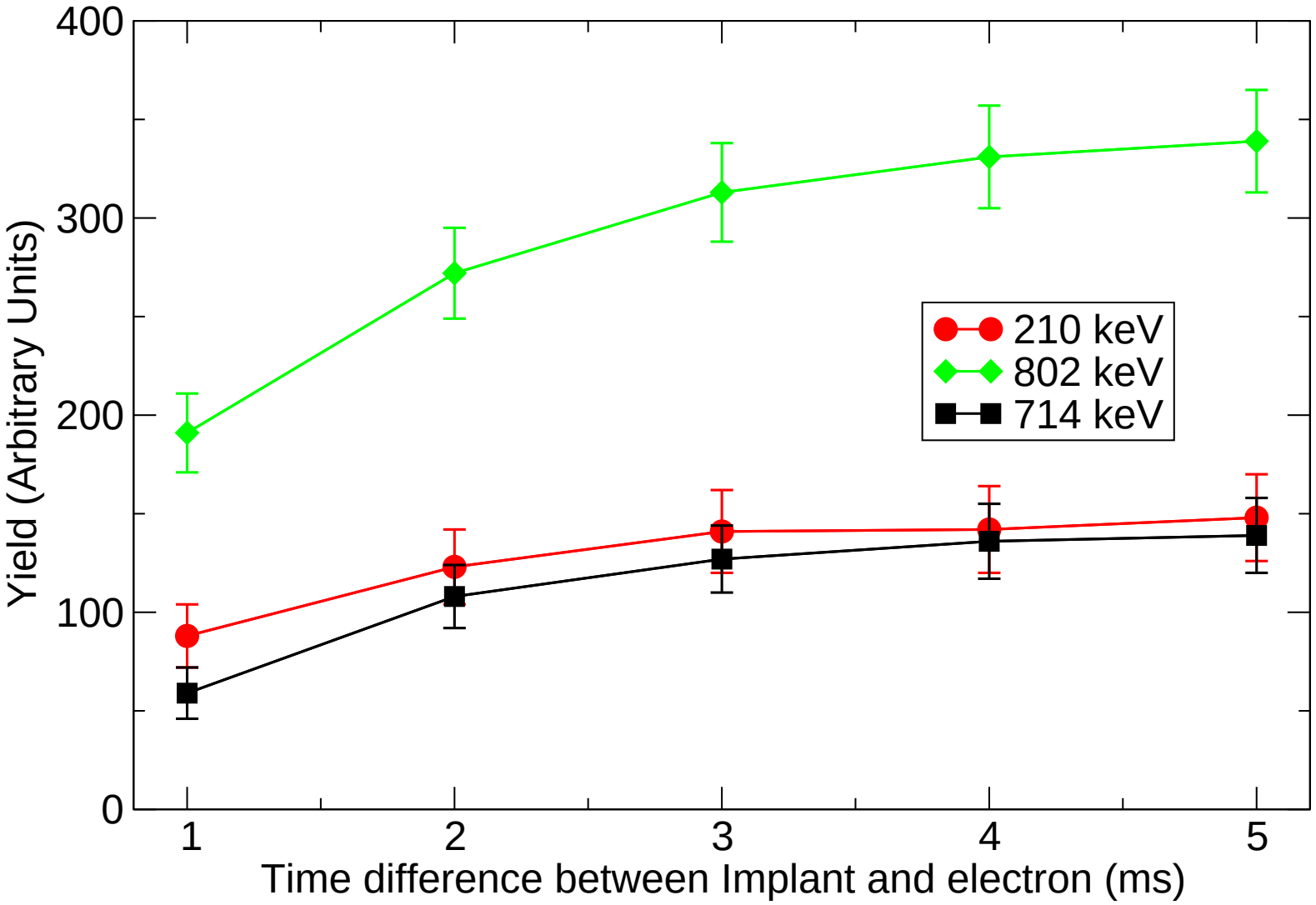
# Time Difference Between Implant−Electron

## Counts for the three intense peaks from the K−isomer




Previously: 3−5 ms

Seems reasonable also in this case!

Generous gate:
5 ms
Tight gate:
4 ms



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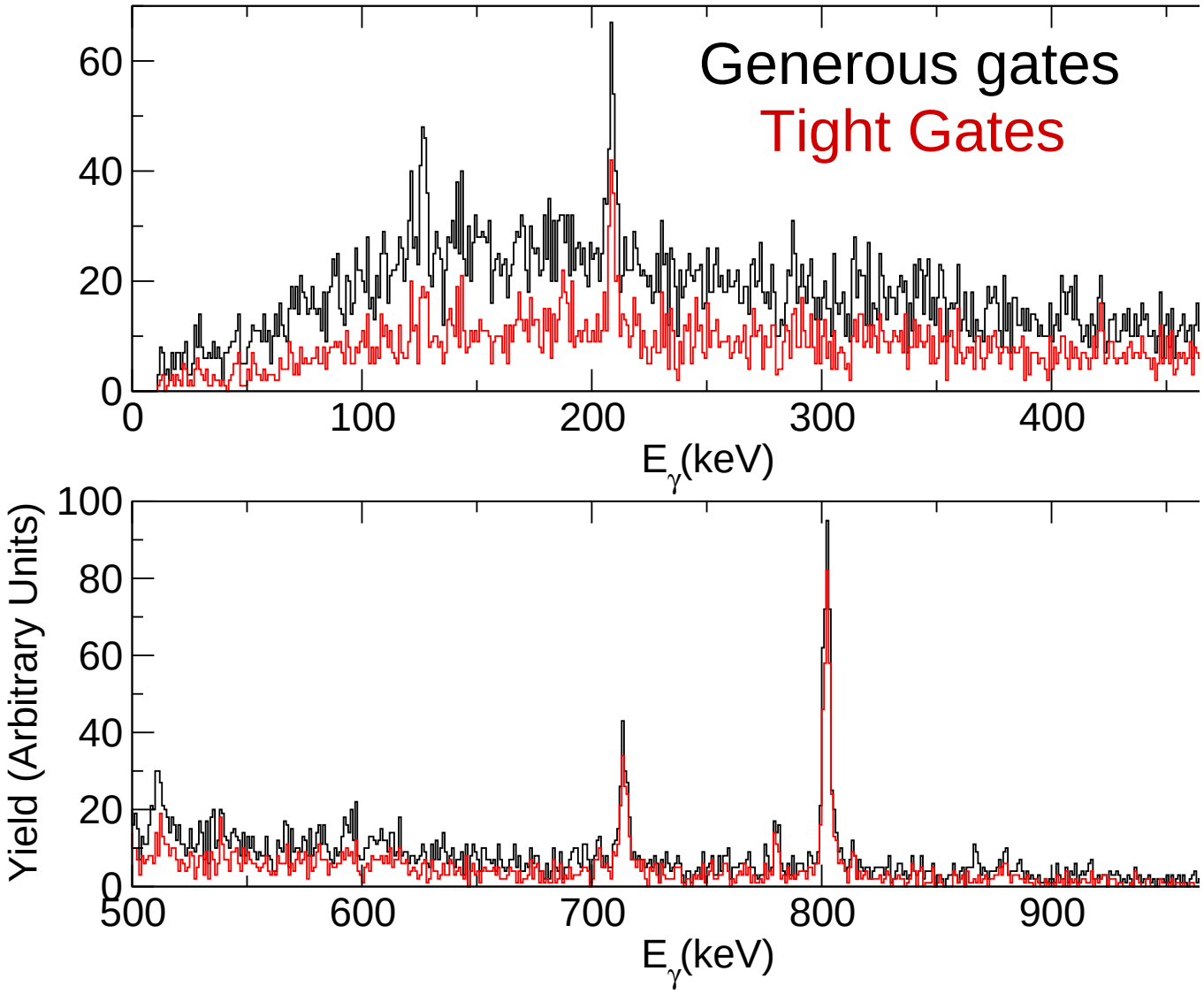
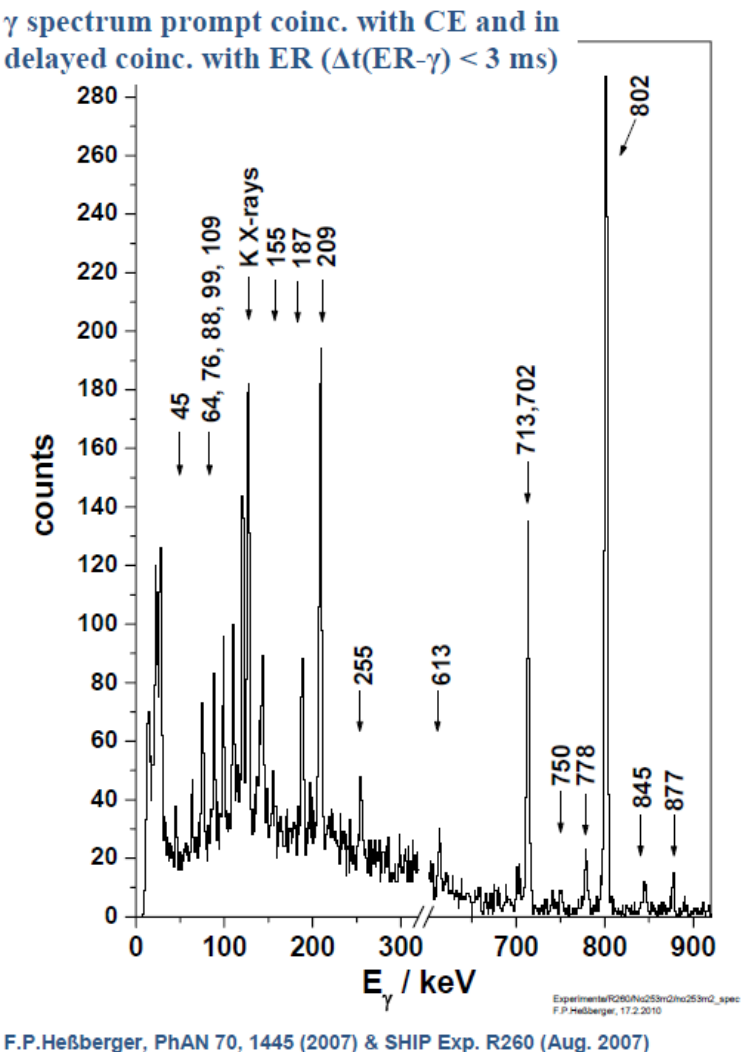
# The Final K−isomer Spectra

## ...and a comparison with Fritz spectrum from SHIP




F.P.Heßberger, PhAN 70, 1445 (2007) & SHIP Exp. R260 (Aug. 2007)

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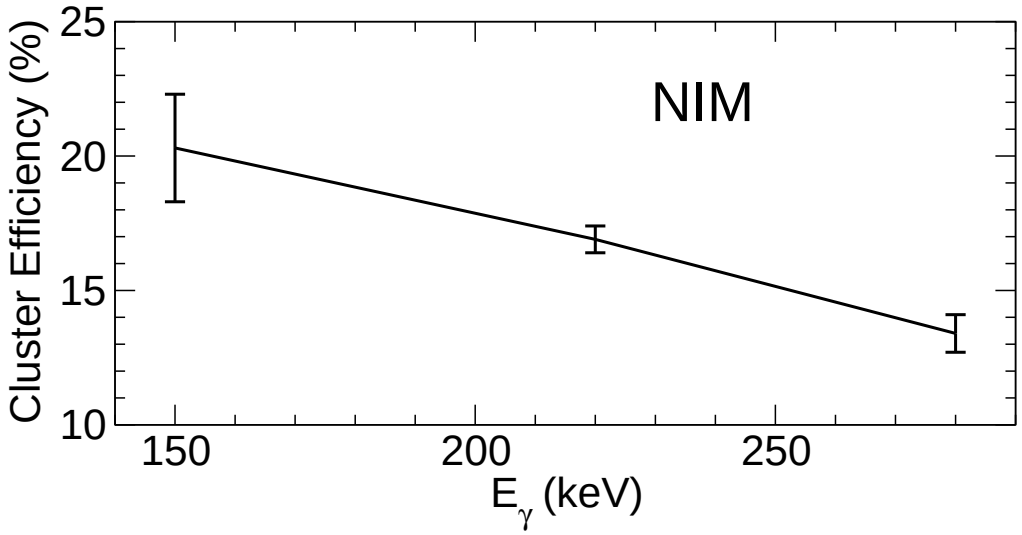
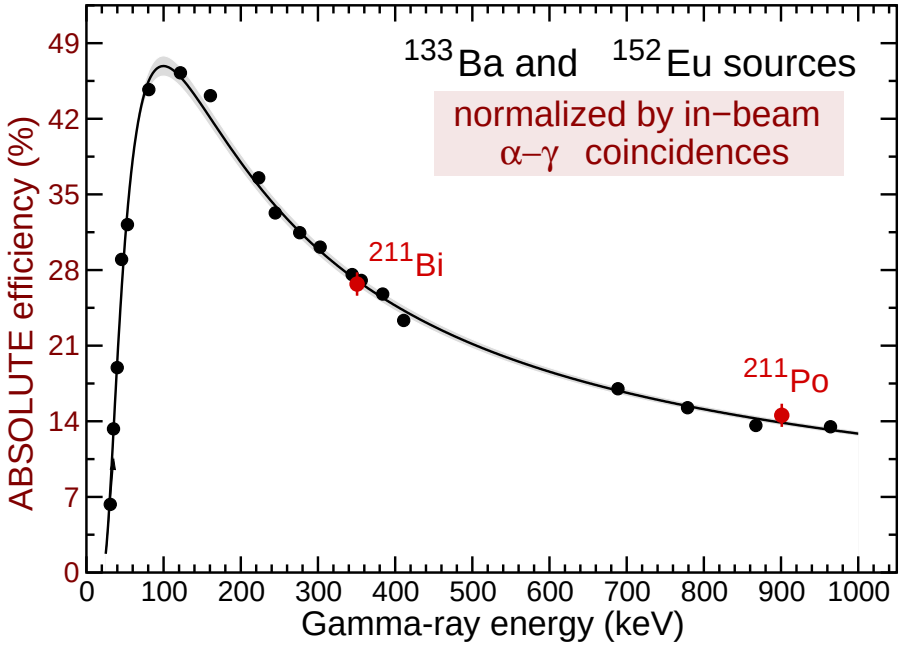
# Comparing Efficiencies

## My efficiencies does not add up. Why??




Run with 4.50 MeV/u beam energy




Alpha paticles: 104700 (7.96−8.1 MeV && n−side)

Clover: 4.1(3)%, 4.3(1)%, 3.2(2)%

Cluster: 10.1(7)%, 11.2(3)%, 8.2(4)%

Cluster: 20.3(20)%, 16.9(5)%, 13.4(7)% (NIM)

50(6)% 66(3)% 61(4)%

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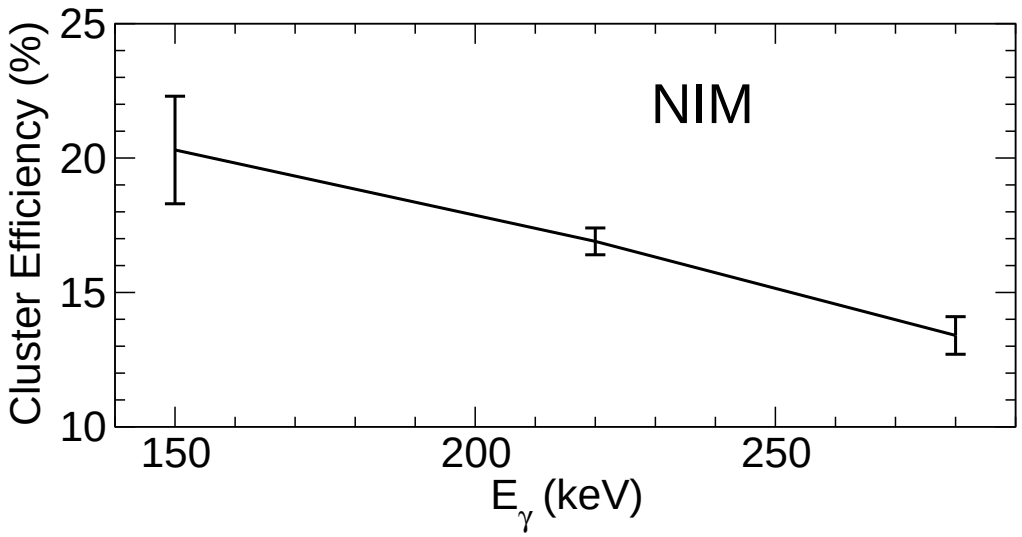
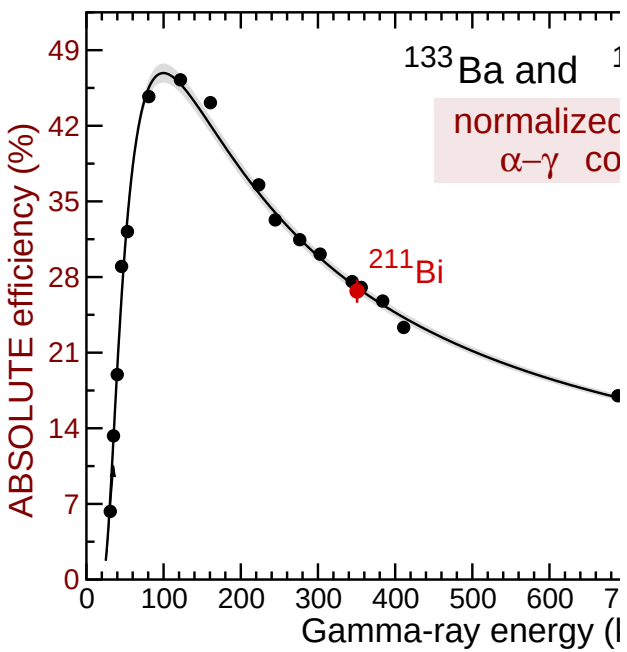
# Comparing Efficiencies

## My efficiencies does not add up. Why??

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50(6)% 66(3)% 61(4)%

THE BAD

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# Comparing Efficiencies

## Where do the data go? (Beam OFF only)

Looking at Cluster data to compare the numbers.

Good event requires:
Fast Trigger Count==1
No pileup flag
No re−trigger flag

From the events in the read−in structure:
100% comes trough to good/bad event sort
77% have fast trigger counter ==1 (the rest varies between 2−15)
77% have NO pileup flag (can only be YES or NO)
91 % have NO retrigger (can only be YES or NO)

**Related**

In total 70% are good events by these standards. Reasonable?

Henning says YES!

The numbers persist through the program!

# Comparing the results from the two beam energies

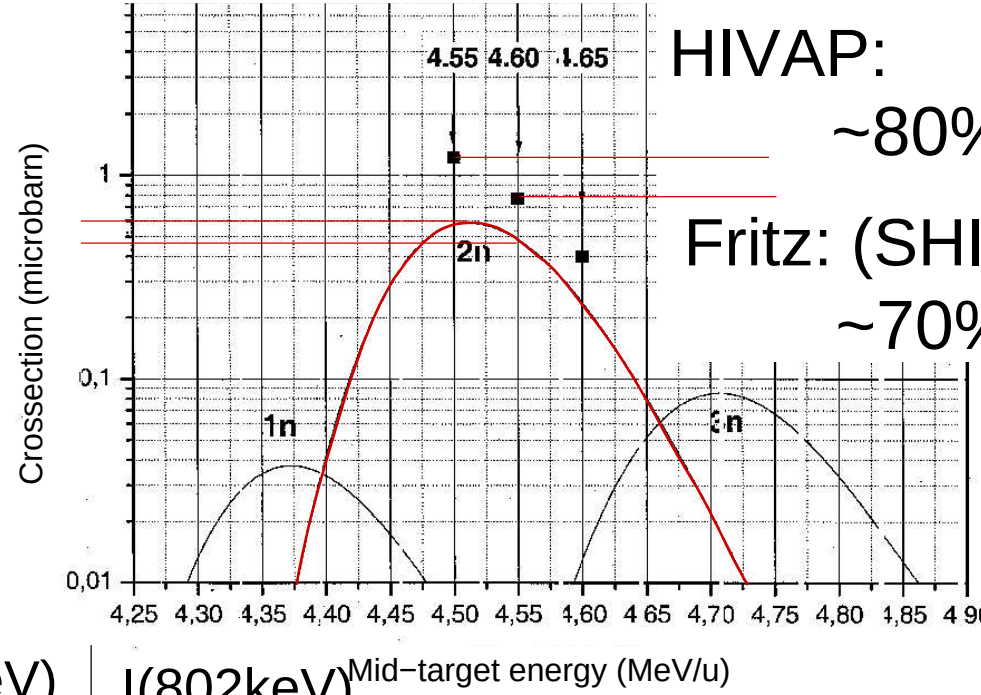
## Comparing mid target energy of 4.50 with 4.55 MeV/u

**Alpha particles: (7.9–8.2 MeV)**

(beam integral accounted for)

124 000
43 500

=> 70%




HIVAP: ~80%

Fritz: (SHIP) ~70%

Gates used: implant 12−17 MeV & electron 30−2000 keV
5 ms imp−electron, 440−660ns ge−time

| B Energy | B Integral | I(210 keV) | I(714keV) | I(802keV) |
|---|---|---|---|---|
| 4.50 | 6.02 E 17 | 142(18) | 146 (19) | 334(26) |
| 4.55 | 2.95 E 17 | 66(10) | 82(13) | 229(22) |
| Ratio: | 50% | 46(9)% | 56(11)% | 69(9)% |

142/334=0.43(6)

146/334=0.44(7)

66/229=0.29(5)

82/221=0.36(7)

Fritz:

0.50

0.43

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# A Summary of Difficulties

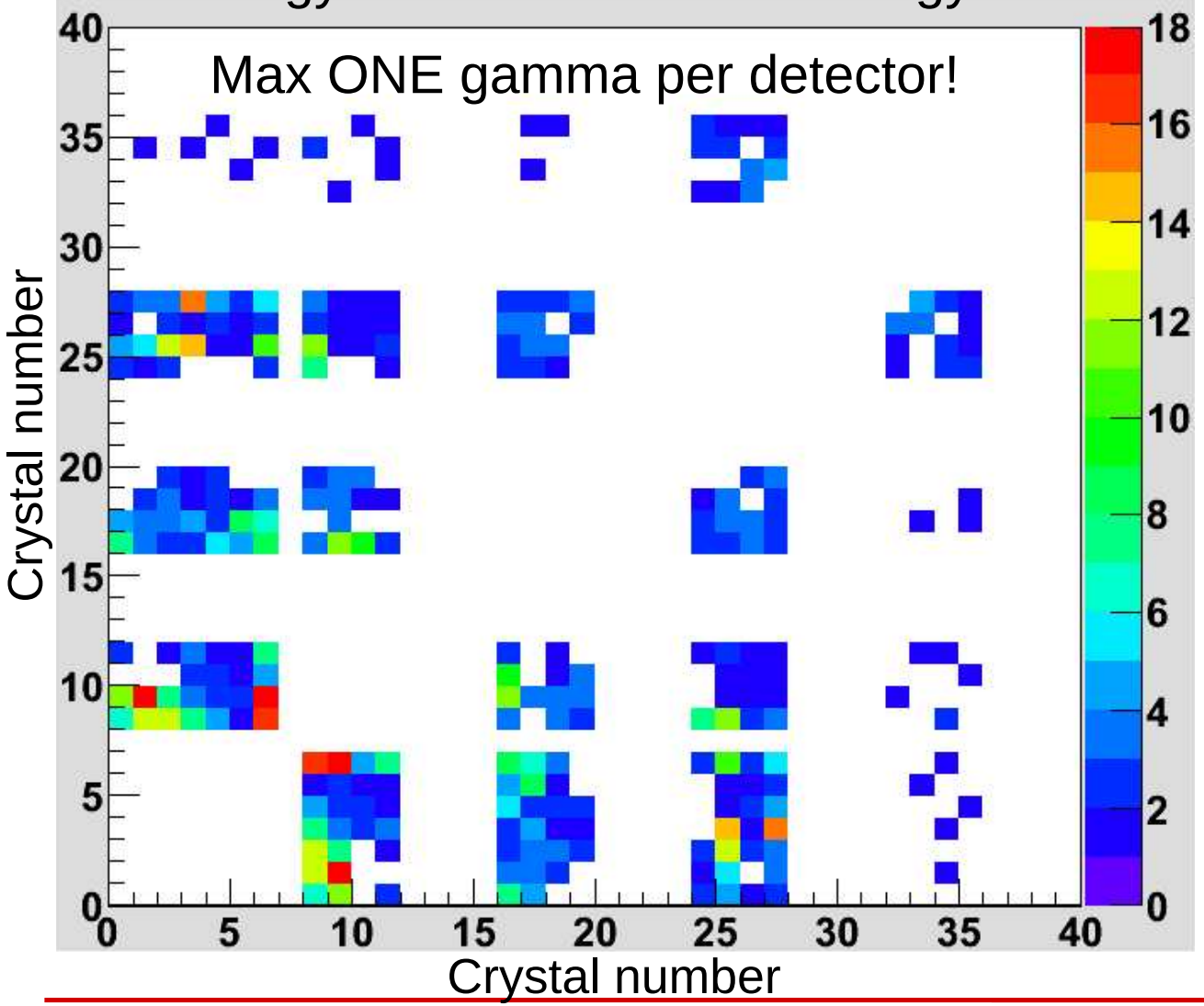
* Efficiency for the Ge not agreeing with previous measurements
  - Germanium?
  - Si−Ge correlations?
  - In the data or in the code?
  - Why are not all energies affected equally?
* Implant energy unknown. Can be bypassed!
* Scattering between the crystals??
  - Implement some kind of shielding in the future?

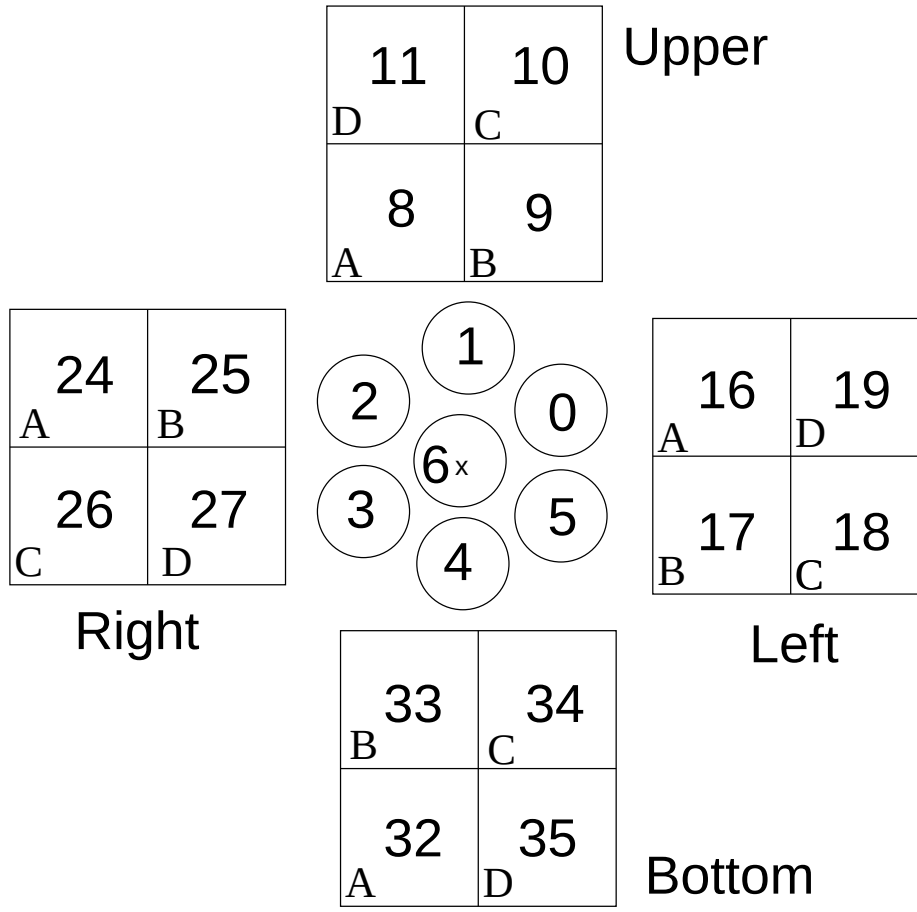
ALL INPUT IS GREATLY APPRECIATED!



# Scattering of Gamma Rays Between Crystals

Gates on 253No alpha on both p and n−side, Time gate of gamma
Single energy <200
Sum energy 218−225 OR Sum energy 276−282 keV

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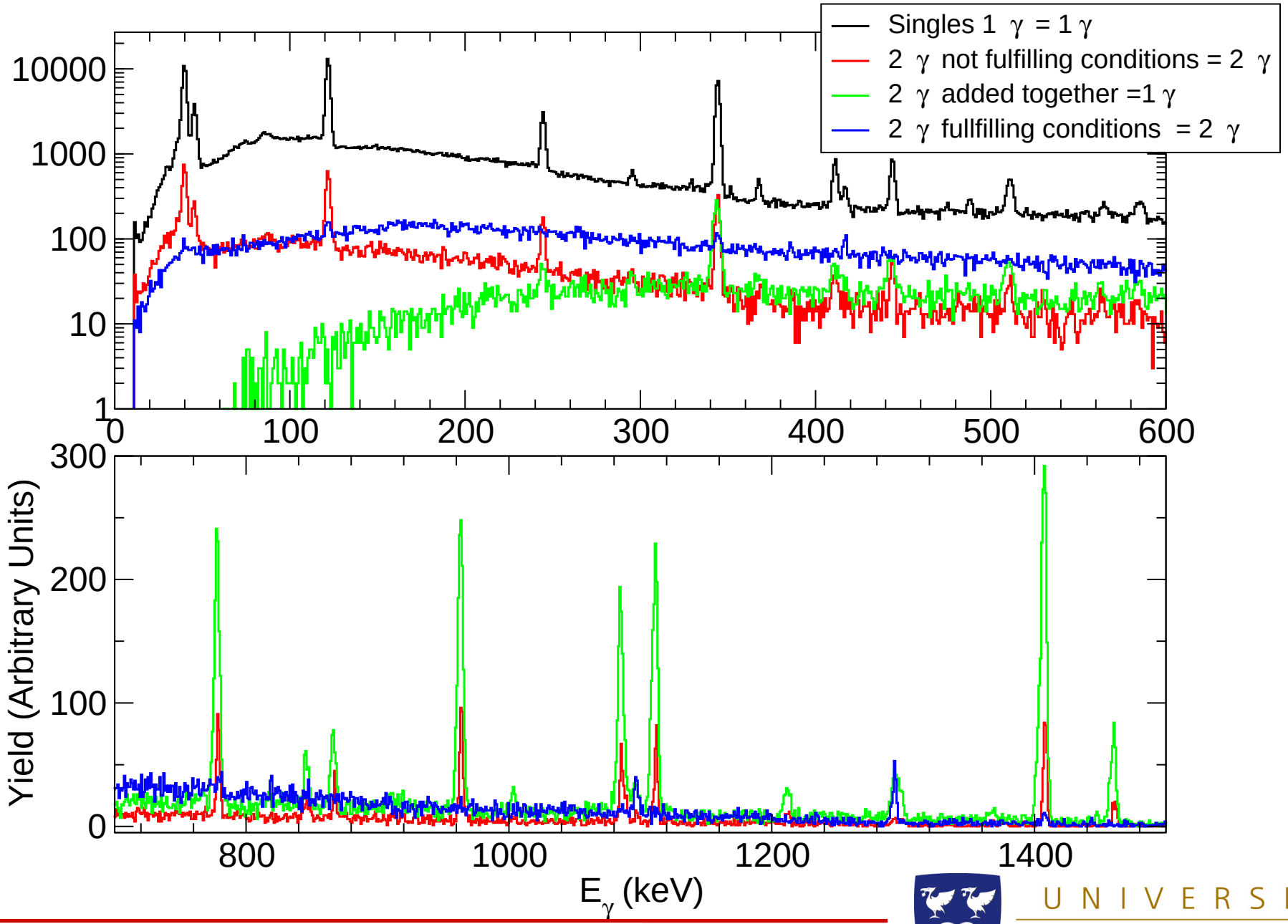
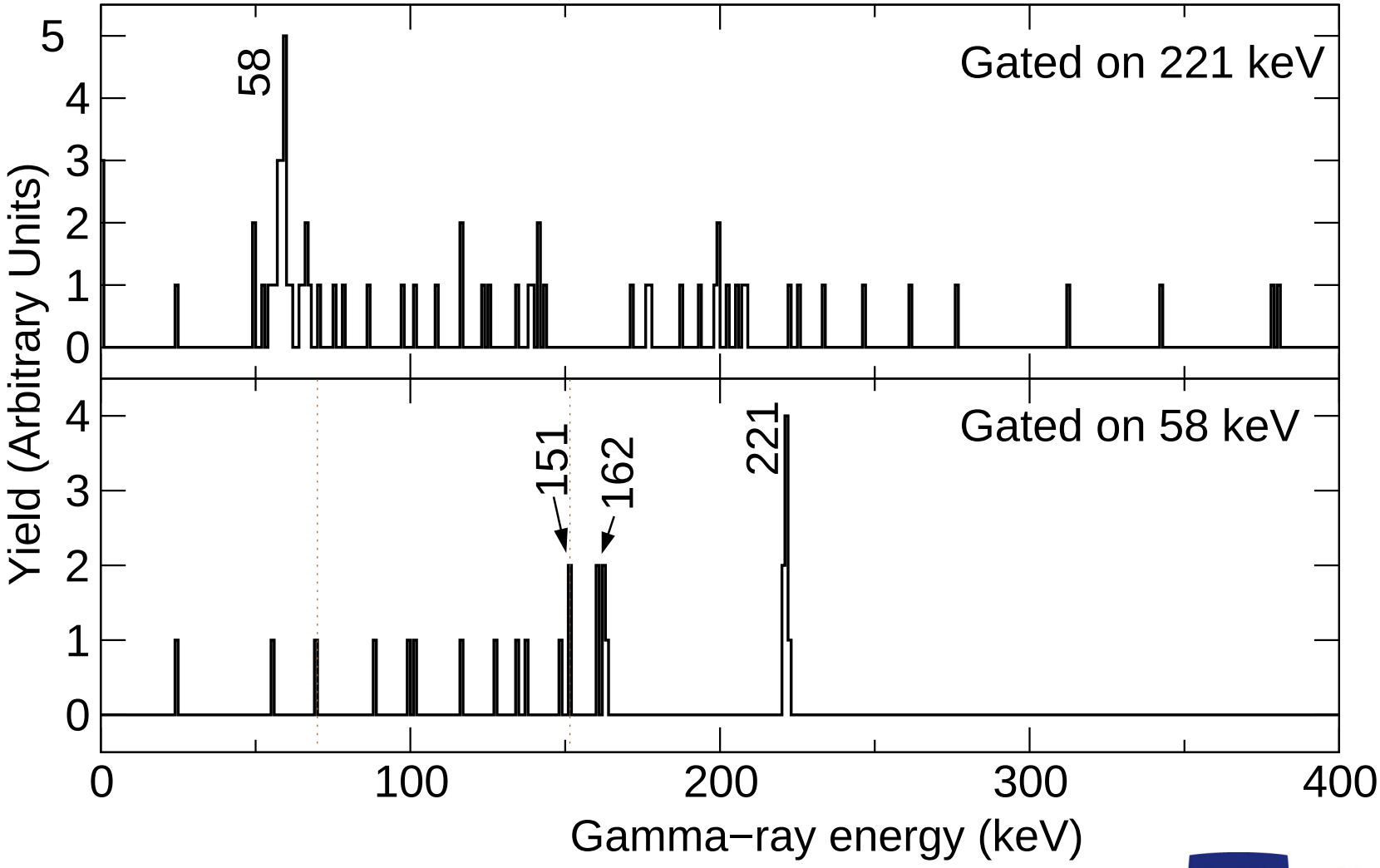
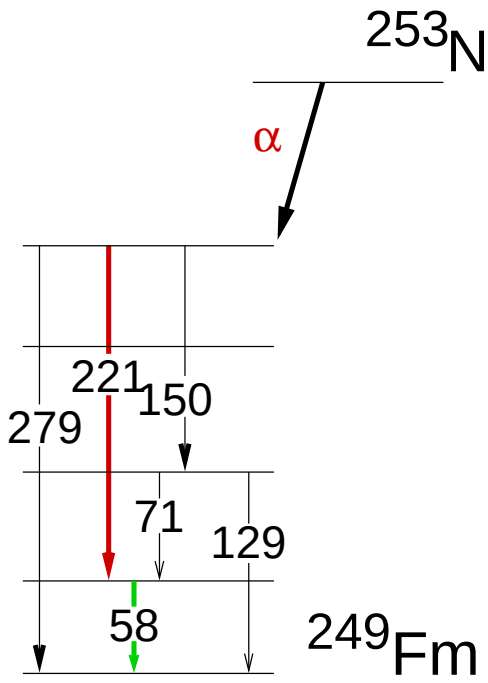
# Yes, the addback is working!



# Alpha−gamma−gamma Correlation

## 7.9−8.2 MeV Si energy, max 1 crystal in each Ge−detector fireing




$\alpha_{tot}(58) = 51.4$

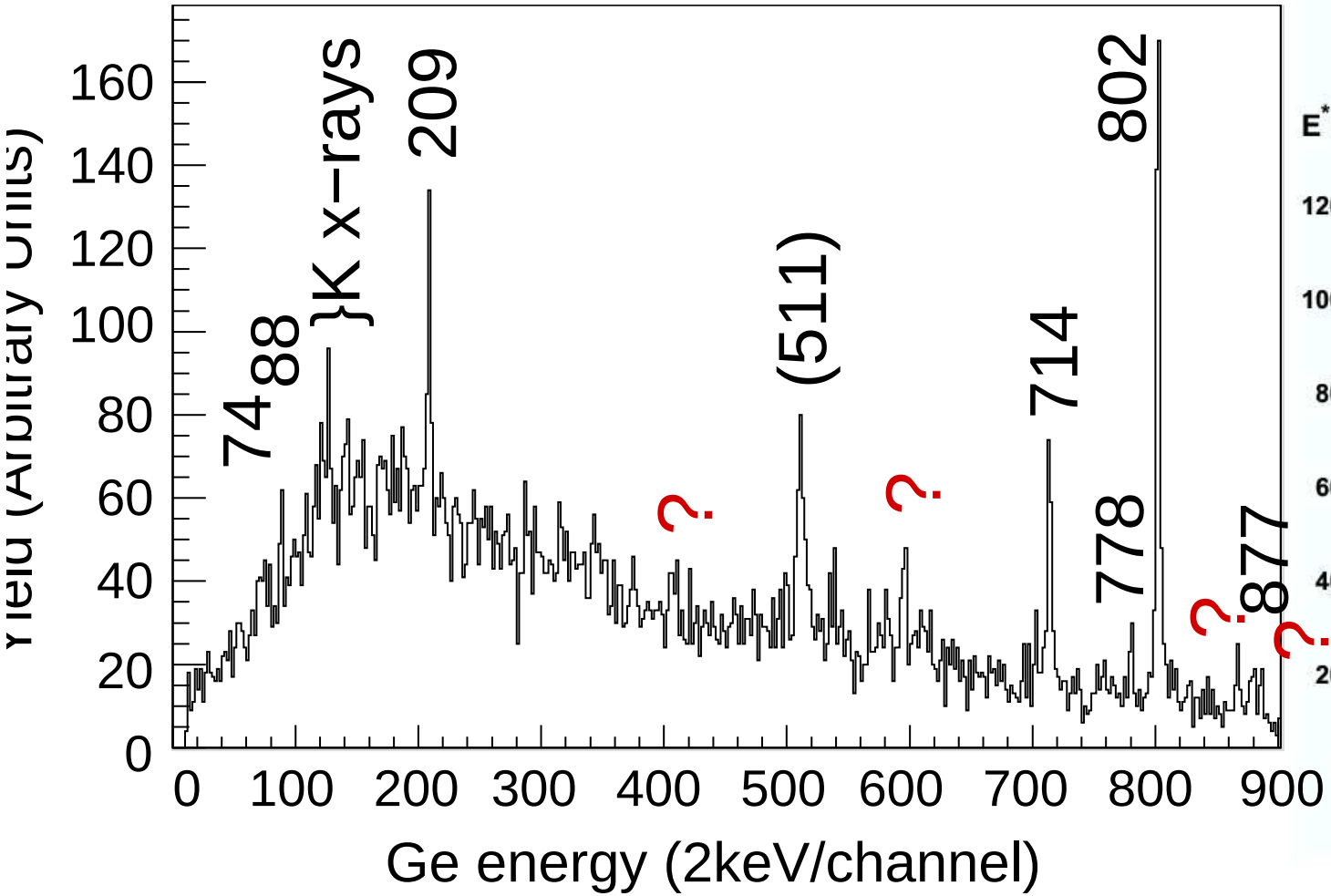
$\alpha_{tot}(71) = 28.4$

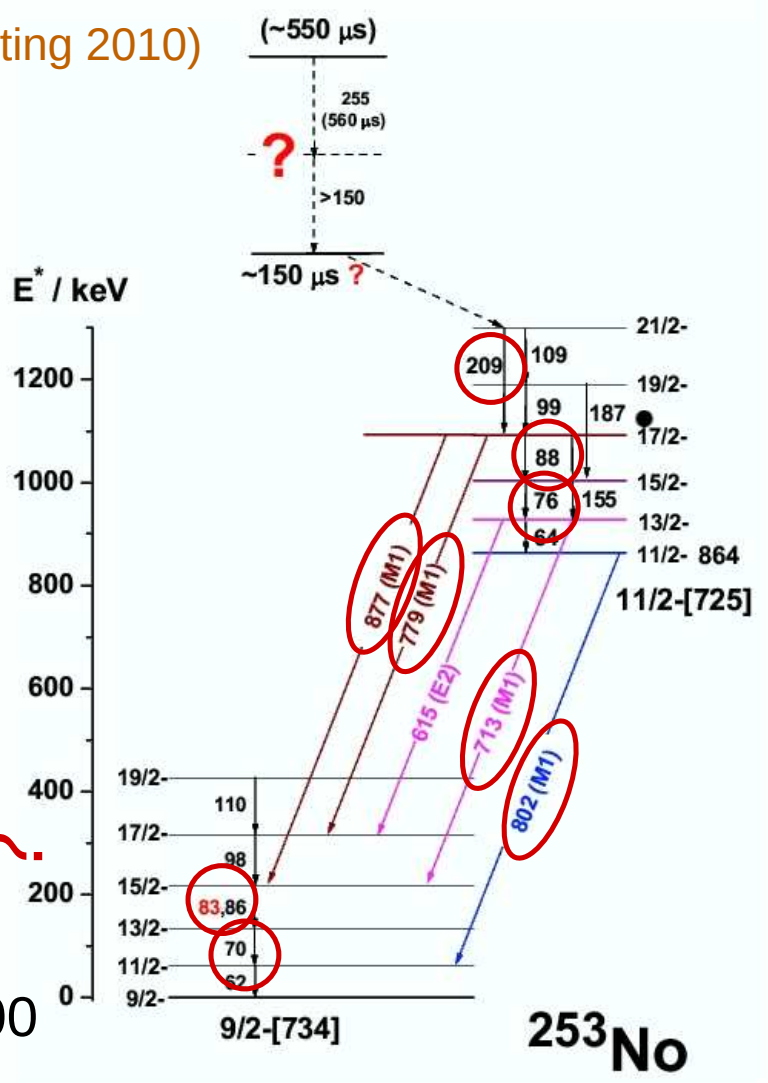
$\alpha_{tot}(129) = 8.3$

# Implant−electron−gamma correlations

## PRELIMINARY!!! 5ms ER−>electron, electron=40−450 keV

Level scheme borrowed from F. Hessberger (annual NUSTAR meeting 2010)

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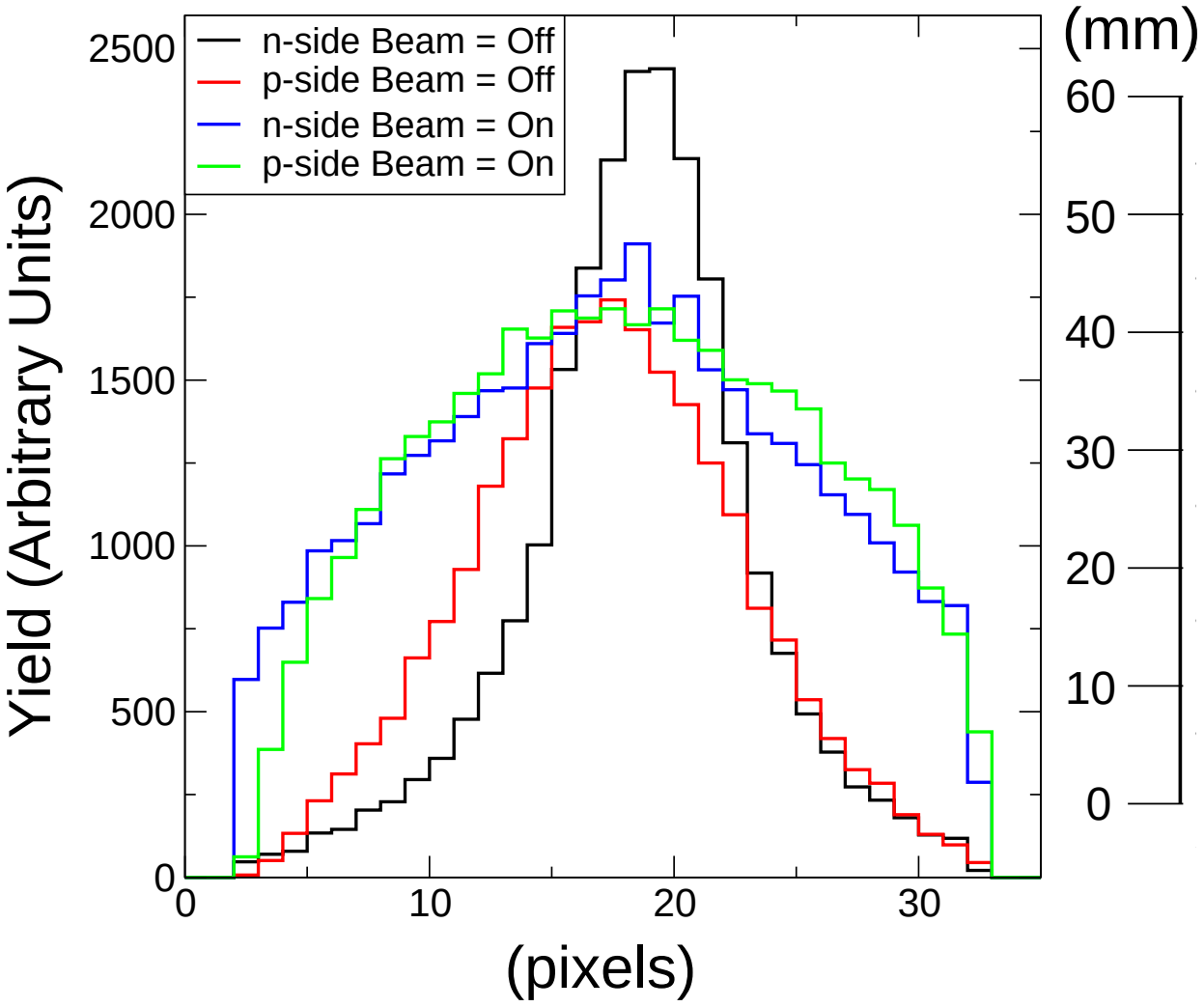
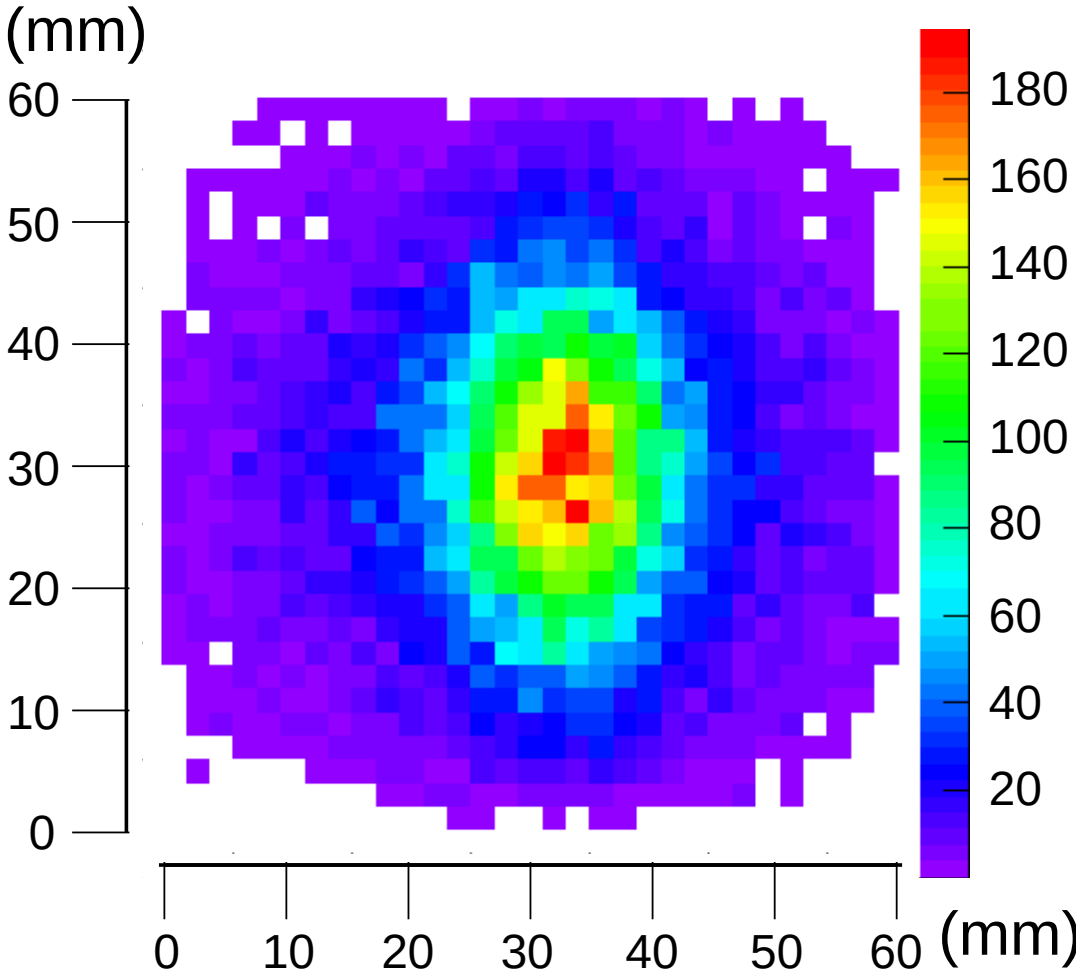
# DSSSD Implantation Profile

## Hitpattern in 1D and 2D for the DSSSD

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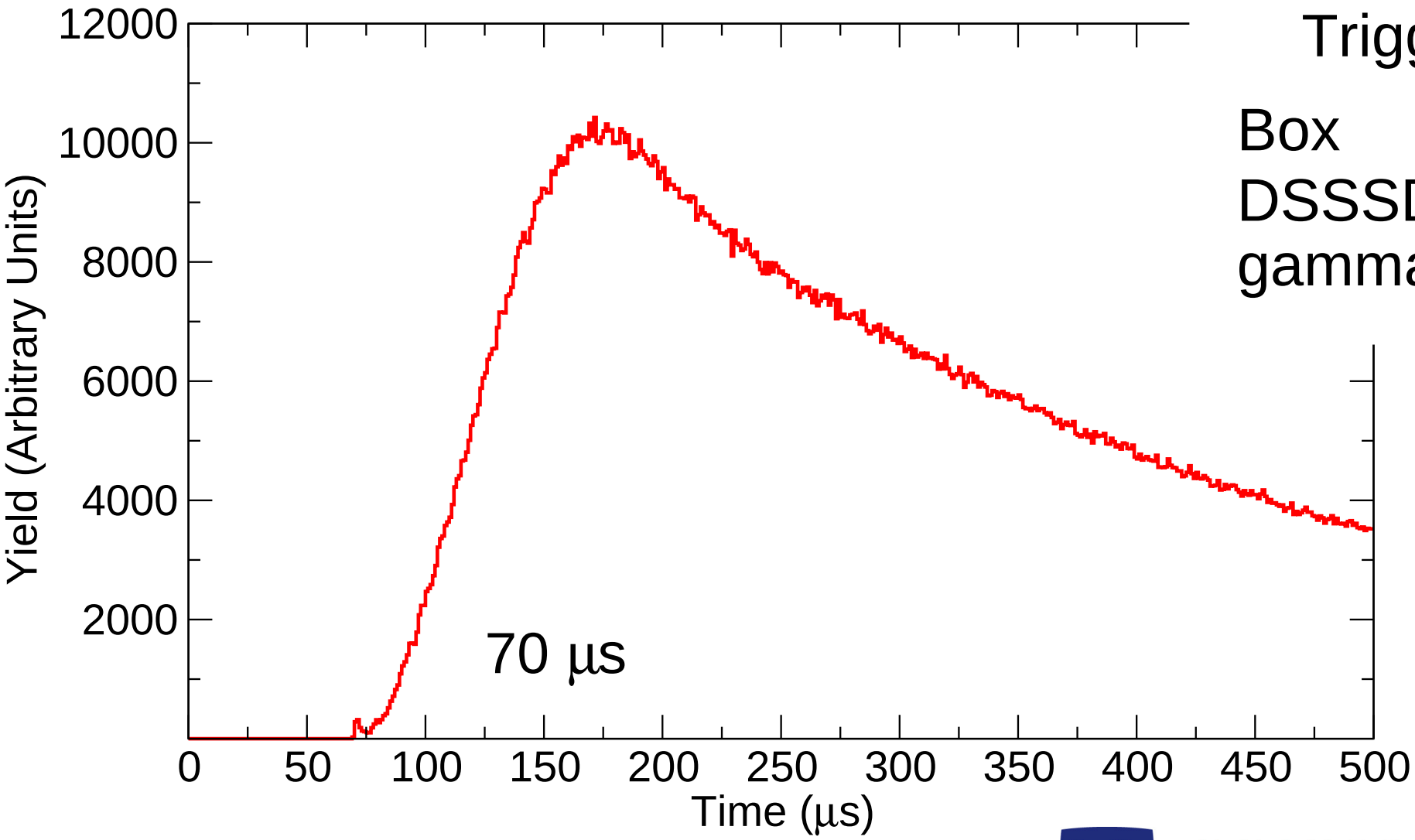
# Dead Time Using the Full Set−up

## Time difference between two subsequent incoming triggers




Triggers:

Box

DSSSD p OR n

gamma $\geq$ 3



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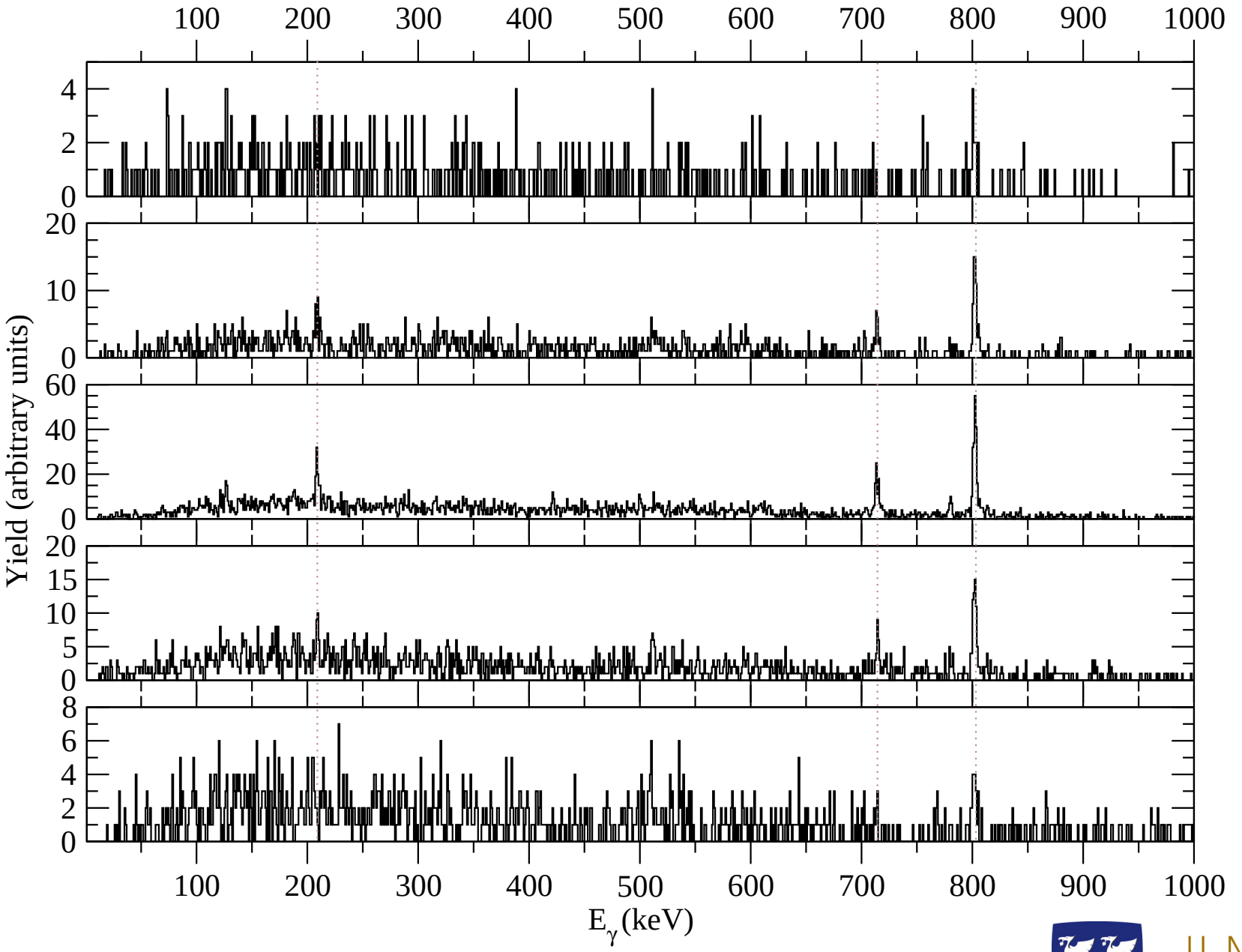
# Possible or Desired Improvements

## A setup under constant developement

* Thicker implantation detector (0.31 −> 0.52 −> 1.0 mm)
* 32−event block readout mode
* Pulse−shape electronics for DSSSD
* DSSSD for box

# Implant Energy Revisited



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# TASISpec

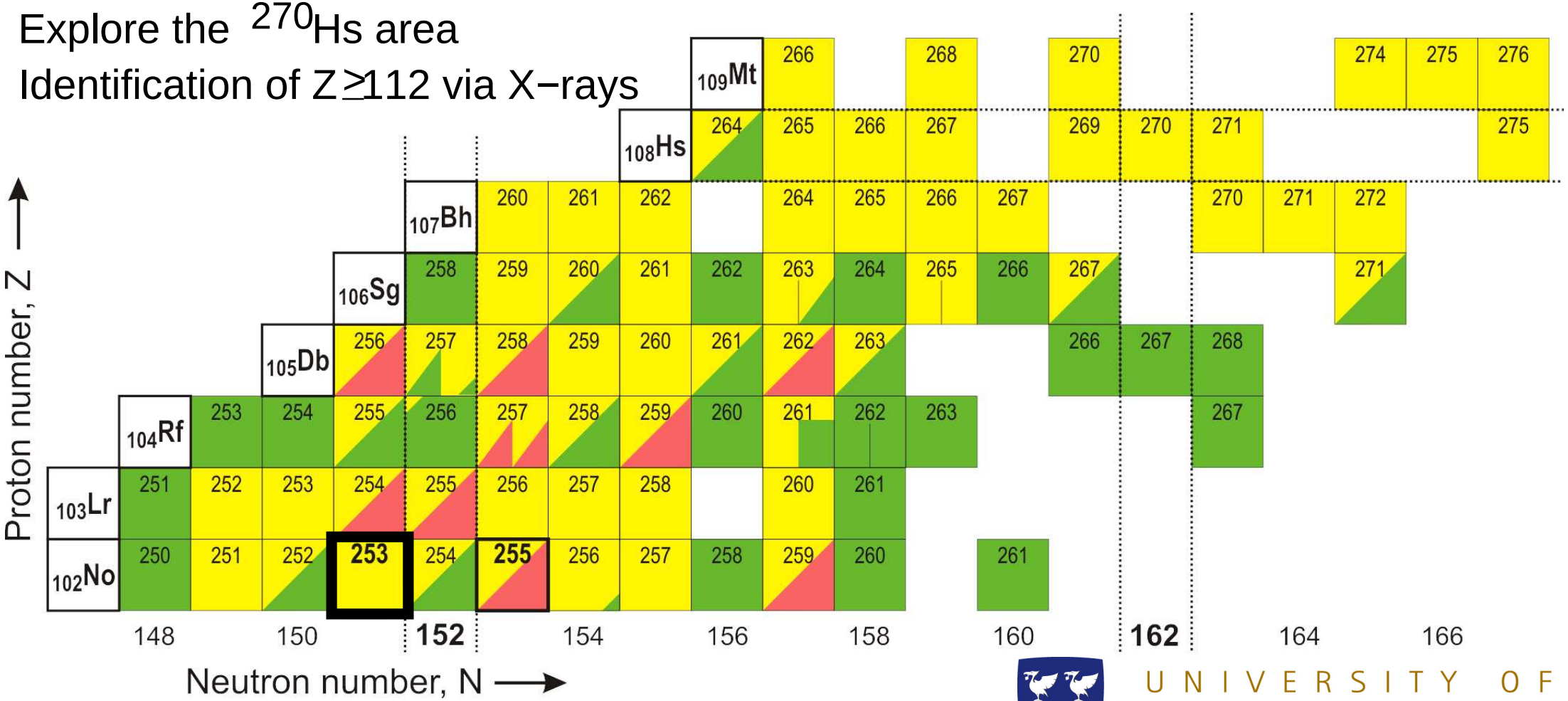
## A new tool to explore superheavy elements

Shell structure of the heaviest elements via coincidence spectroscopy

Define the $^{254}$No area ($^{253}$No experiment carried out in May)

Explore the $^{270}$Hs area

Identification of Z≥112 via X−rays





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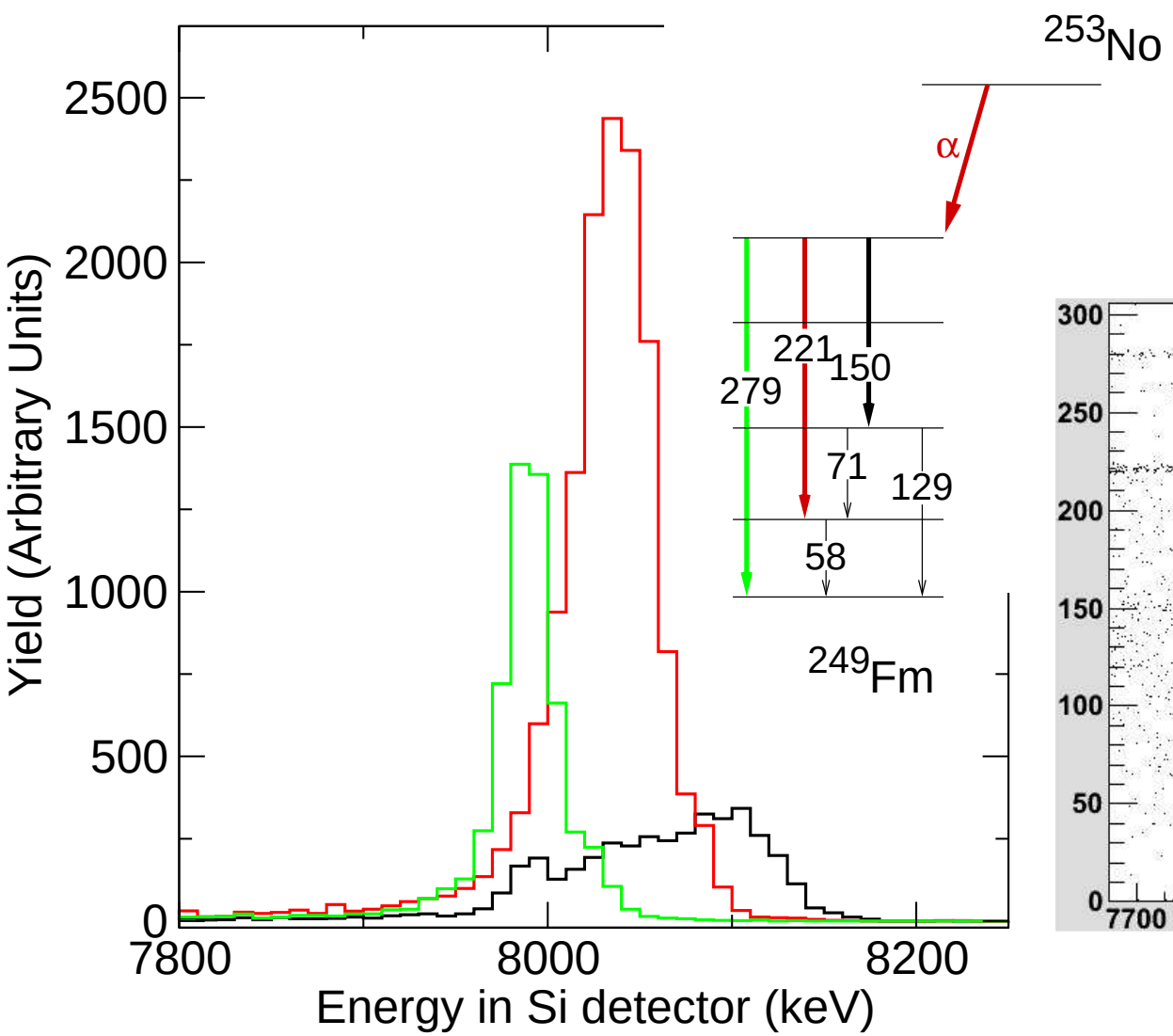
# Alpha−gamma Correlation

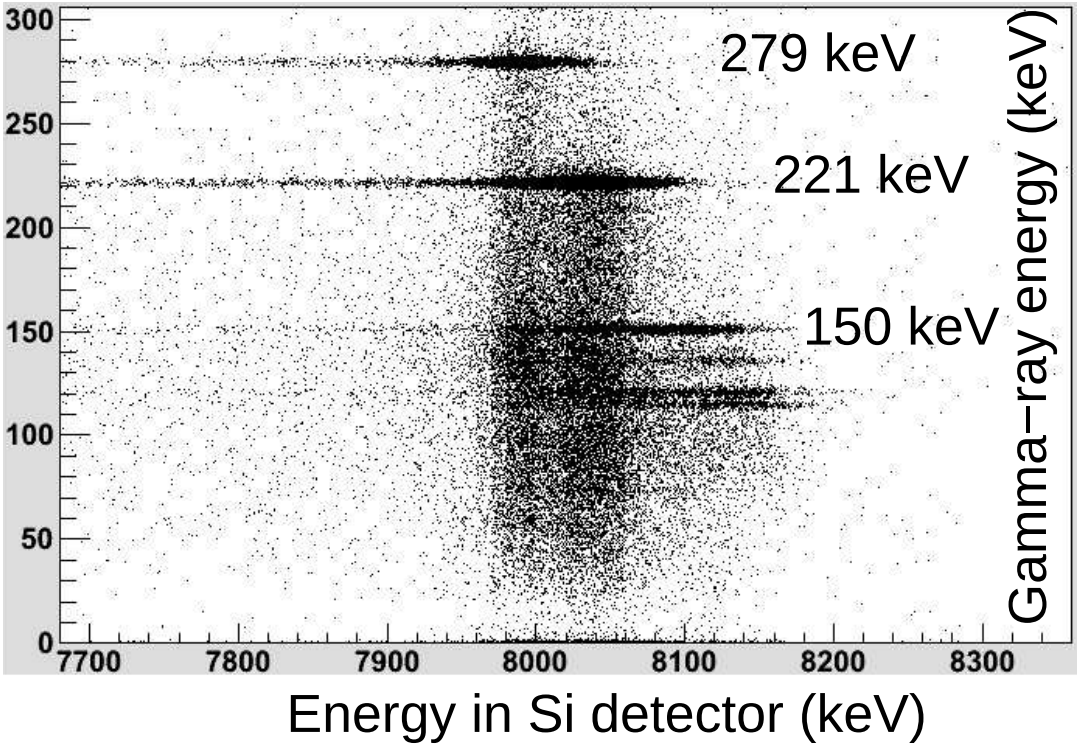
## Gating on gamma rays to see energy in Si detector




$\alpha_{tot}^{(58)} = 51.4$

$\alpha_{tot}^{(71)} = 28.4$

$\alpha_{tot}^{(129)} = 8.3$

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# First Main Beam Experiment

## Define K−Isomers in $^{253}$No

$$^{207}\mathrm{Pb}(^{48}\mathrm{Ca}, 2n)\,^{253}\mathrm{No}$$

* F.P. Hessberger; $\alpha$–$\gamma$ decay studies SHIP 2004
* F. P. Hessberger; isomeric $\gamma$ and CE decays SHIP 2007
* A. Lopez−Martens; isomeric $\gamma$ and CE decays Dubna 2007
* R.−D. Herzberg; in−beam studies JYFL 2002
* P. Reiter; in−beam studies ANL 2005