γ-ray tracking with AGATA

New perspectives for spectroscopy

- Introduction to AGATA
- Pulse shape analysis and γ-ray tracking
- Capabilities and opportunities

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Universität zu Köln

Final Symposium

of the Sino-German GDT Cooperation

Ringberg Castle 18.10. – 24.10.2015

Experimental Conditions and Challenges at future Radioactive Beam Facilities

EURISOL
FAIR
HIE-ISOLDE
SPES
SPIRAL2
...

- Low intensity
- High background
- Large Doppler broadening
- High counting rates
- High γ-ray multiplicities

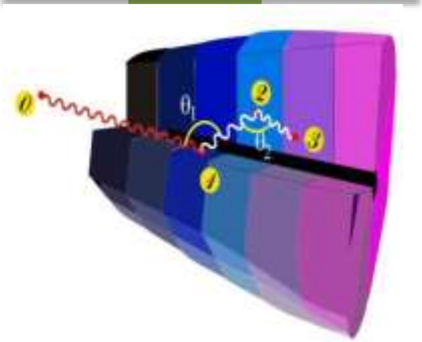
Need for γ-spectrometer based on γ-ray tracking

High efficiency
High sensitivity
High throughput
Ancillary detectors

Ingredients of Gamma-Ray Tracking

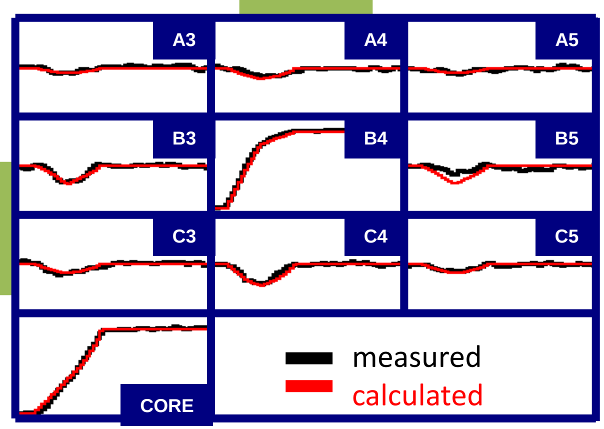
1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals



3

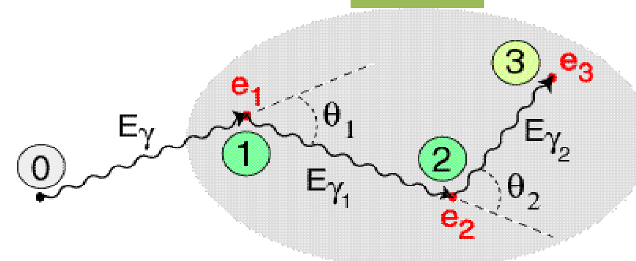
Pulse Shape Analysis to decompose recorded waves

Identified interaction points

$(x,y,z,E,t)_i$

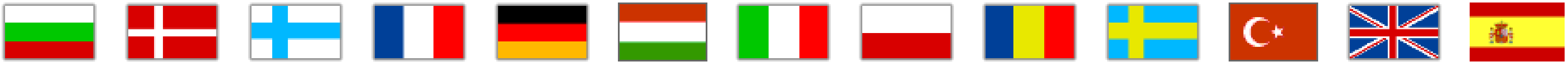
4

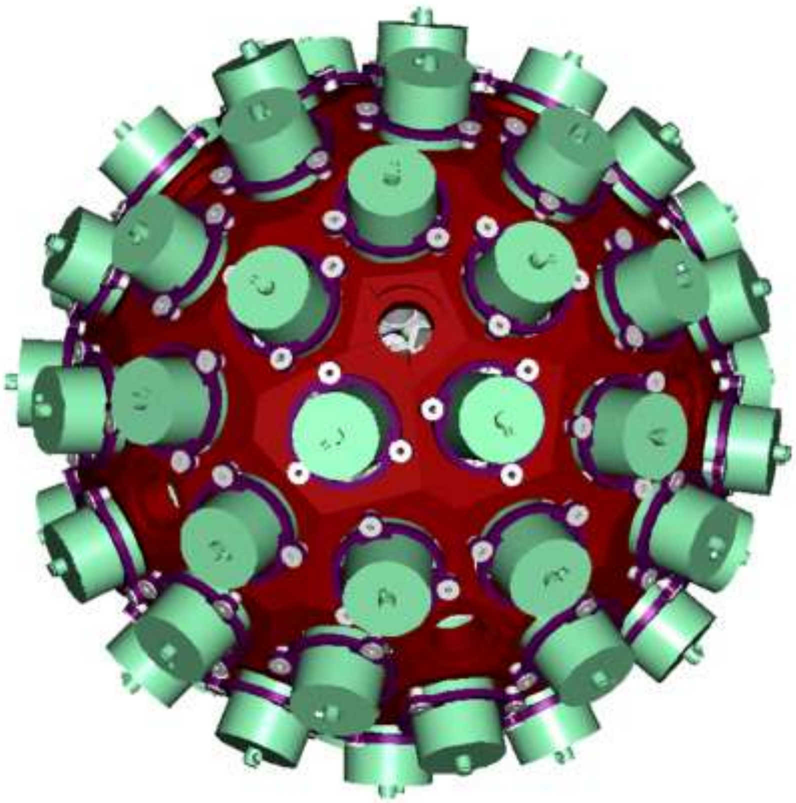
Reconstruction of tracks evaluating permutations of interaction points



Reconstructed gamma-rays

Advanced GAmma Tracking Array





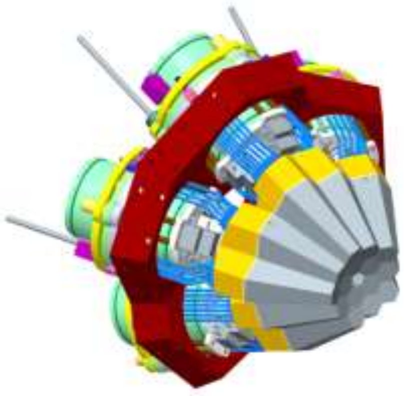
180 hexagonal crystals	3 shapes
60 triple-clusters	all equal
Inner radius (Ge)	23.5 cm
Amount of germanium	362 kg
Solid angle coverage	82 %
36-fold segmentation	6480 segments
Singles rate	~50 kHz

Efficiency: 43% (M_γ=1) 28% (M_γ=30)

Peak/Total: 58% (M_γ=1) 49% (M_γ=30)

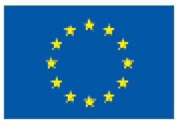
-6660 high-resolution digital electronics channels

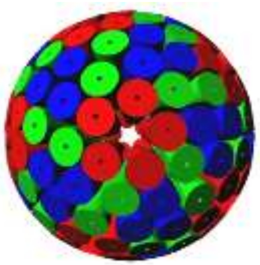
- needs proof of principle → demonstrator at Legnaro



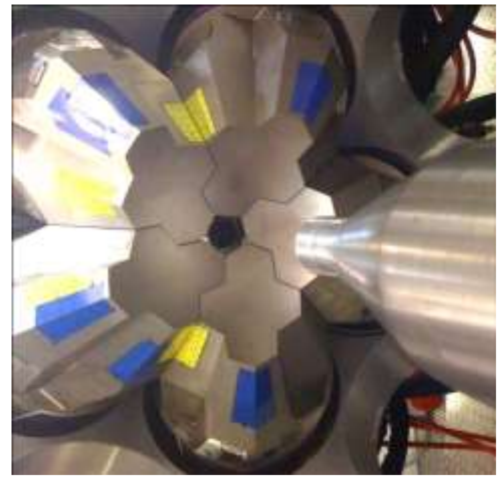
Two international collaborations

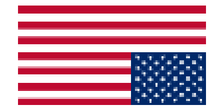
AGATA
(Advanced-GAmma-Tracking-Array)

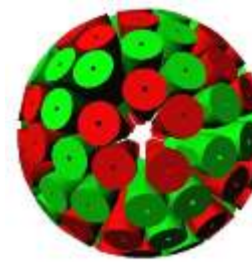




GRETA
(Gamma-Ray Energy Tracking Array)







@ GANIL, AGATA+VAMOS *2014→ 2018*
ongoing first experimental campaign

@ GSI, AGATA+FRS, PreSpec *2012 → 2014*

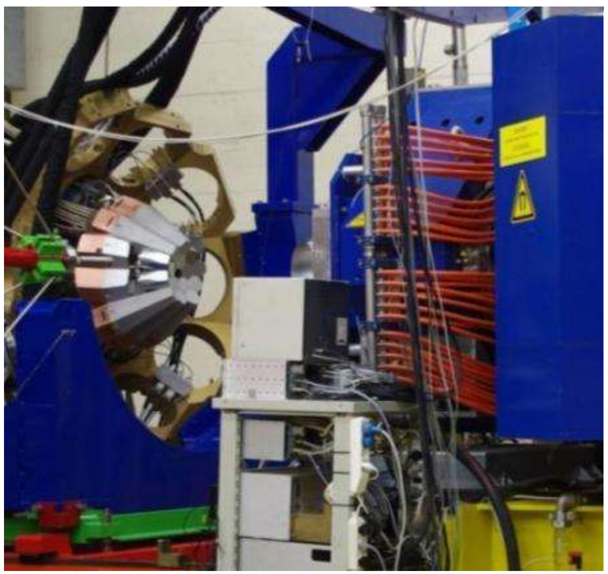
@ LNL, AGATA Demonstrator *2009 → 2012*
(+PRISMA, TRACE, DANTE, HELENA)

From the Demonstrator to AGATA 1π

LNL: 2009-2011
15 crystals (5TC)
Total Eff. ~6%

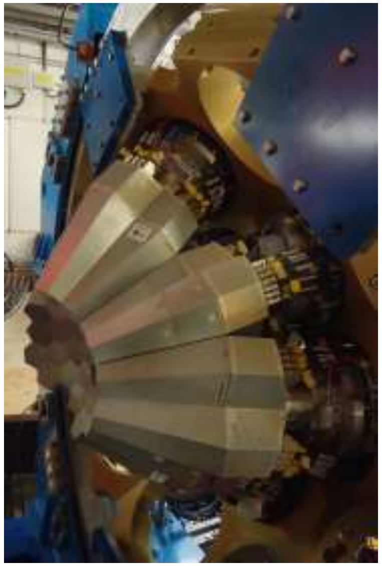
GSI: 2012-2014
24 crystals (3DC+6TC)
Total Eff.~9%

GANIL: 2014-2018
45 crystals (15 TC)
Total Eff. ~15%



Demonstrator + PRISMA

AGATA + FRS



AGATA+VAMOS

Status autumn 2015 delivered & ordered detectors: 42 crystals

AGATA Triple Cryostat

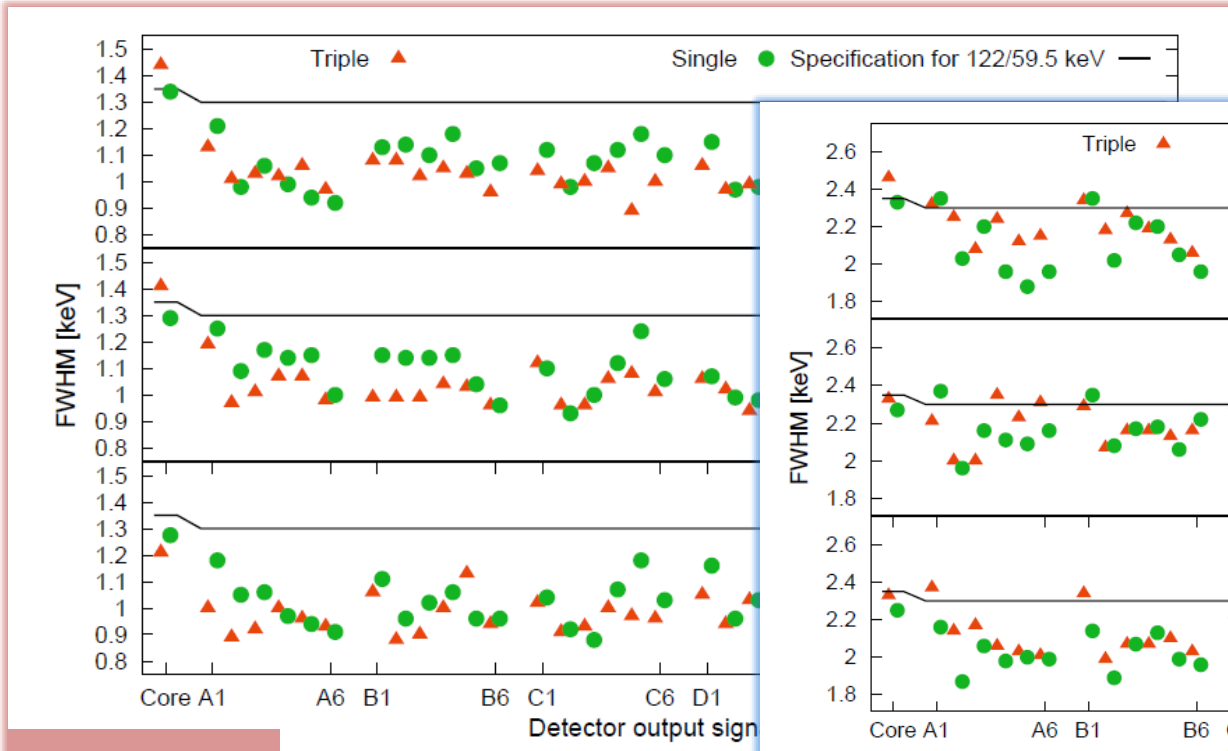
- integration of 111 high resolution spectroscopy channels
- cold FET technology for all signals

Challenges:

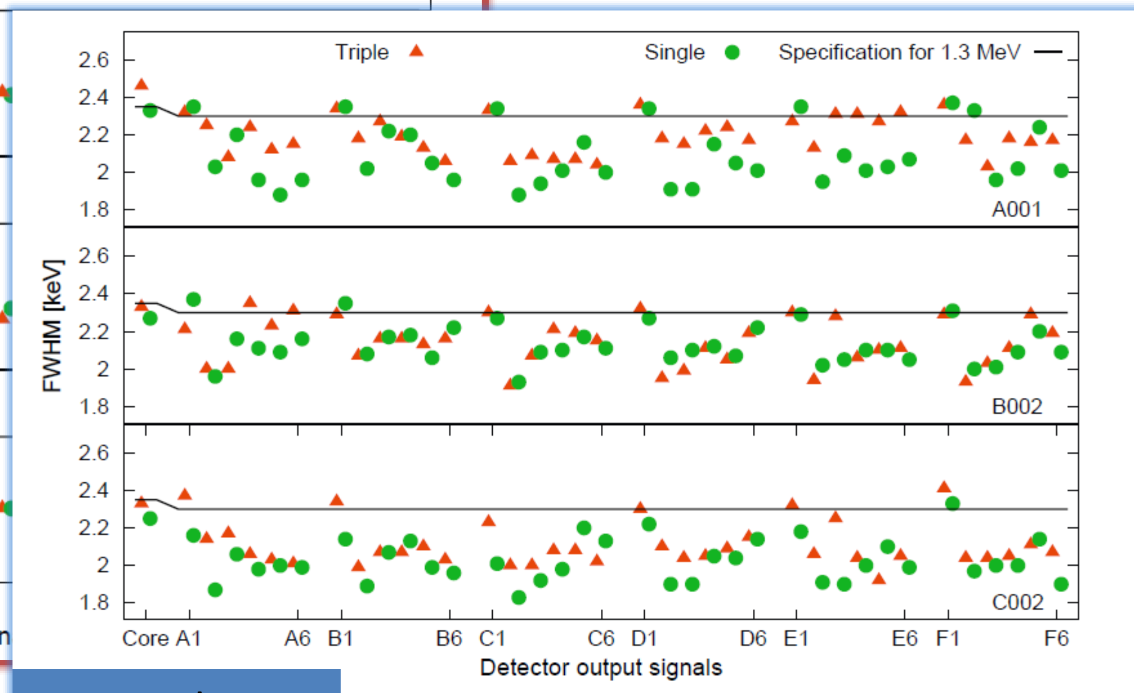
- mechanical precision
- LN2 consumption
- microphonics
- noise, high frequencies

- A. Wiens et al. NIM A 618 (2010) 223–233
- D. Lersch et al. NIM A 640(2011) 133-138

Performance: Energy resolution



@ 60 keV



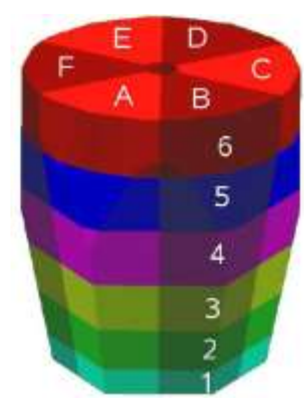
@ 1333 keV

Averages of the segment resolutions
@ **60 keV :**

A001:	1011 +/- 53 eV
B002:	1039 +/- 70 eV
C002:	965 +/- 63 eV

Averages of the segment resolutions
Measured in Cologne and Legnaro
@ 1333 keV :

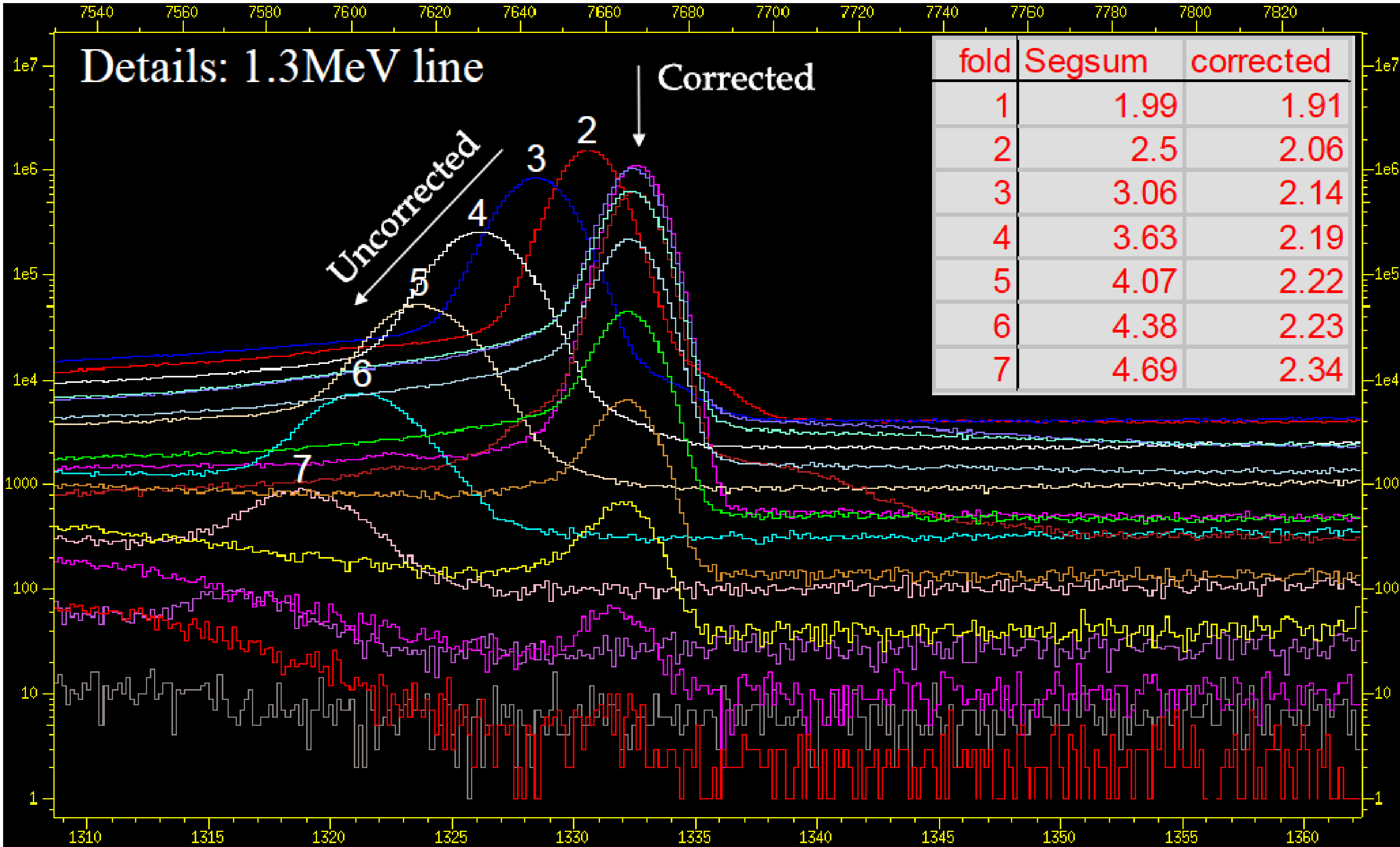
	IKP / Legnaro
A001:	2,19 keV / 2,00 keV
B002:	2,09 keV / 1,98 keV
C002:	2,1 keV / 1,94 keV



Segment labeling

Energy resolution & Cross talk

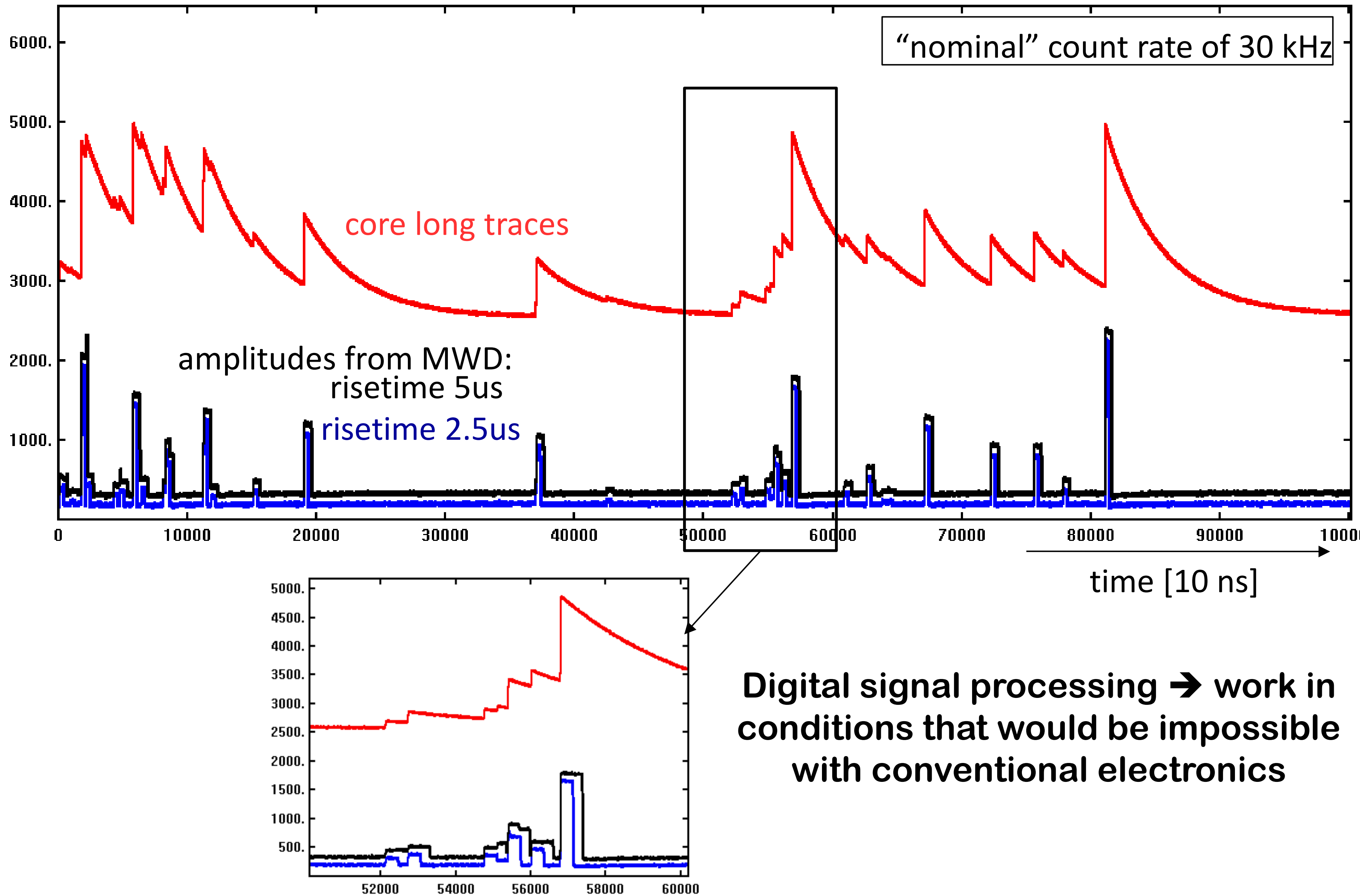
FWHM 60keV: 1.20 → 1.02 !



fold	Segsum	corrected
1	1.99	1.91
2	2.5	2.06
3	3.06	2.14
4	3.63	2.19
5	4.07	2.22
6	4.38	2.23
7	4.69	2.34

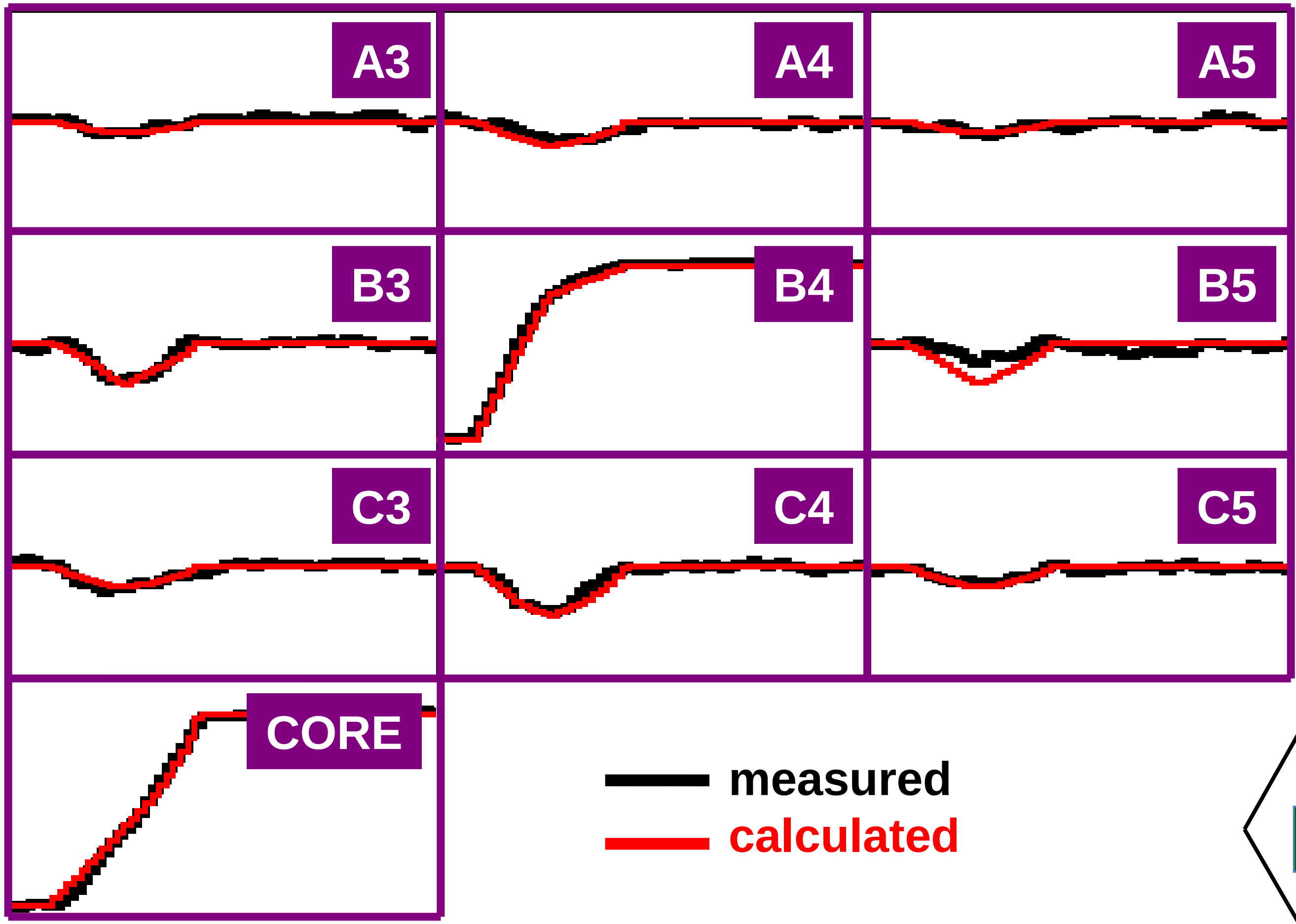
A. Wiens, et al.; *Eur. Phys. J. A (2013) 49: 67* B. Bruyneel, et al.; *Eur. Phys. J. A (2013) 49: 61*

Digital signal processing at high count rate



Digital signal processing ➔ work in conditions that would be impossible with conventional electronics

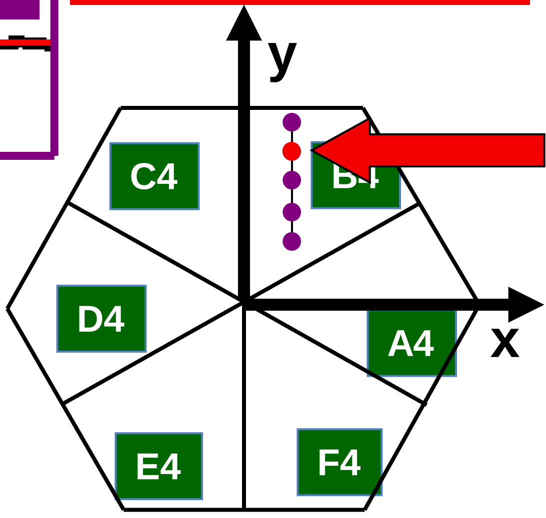
Pulse Shape Analysis concept



791 keV deposited in segment B4

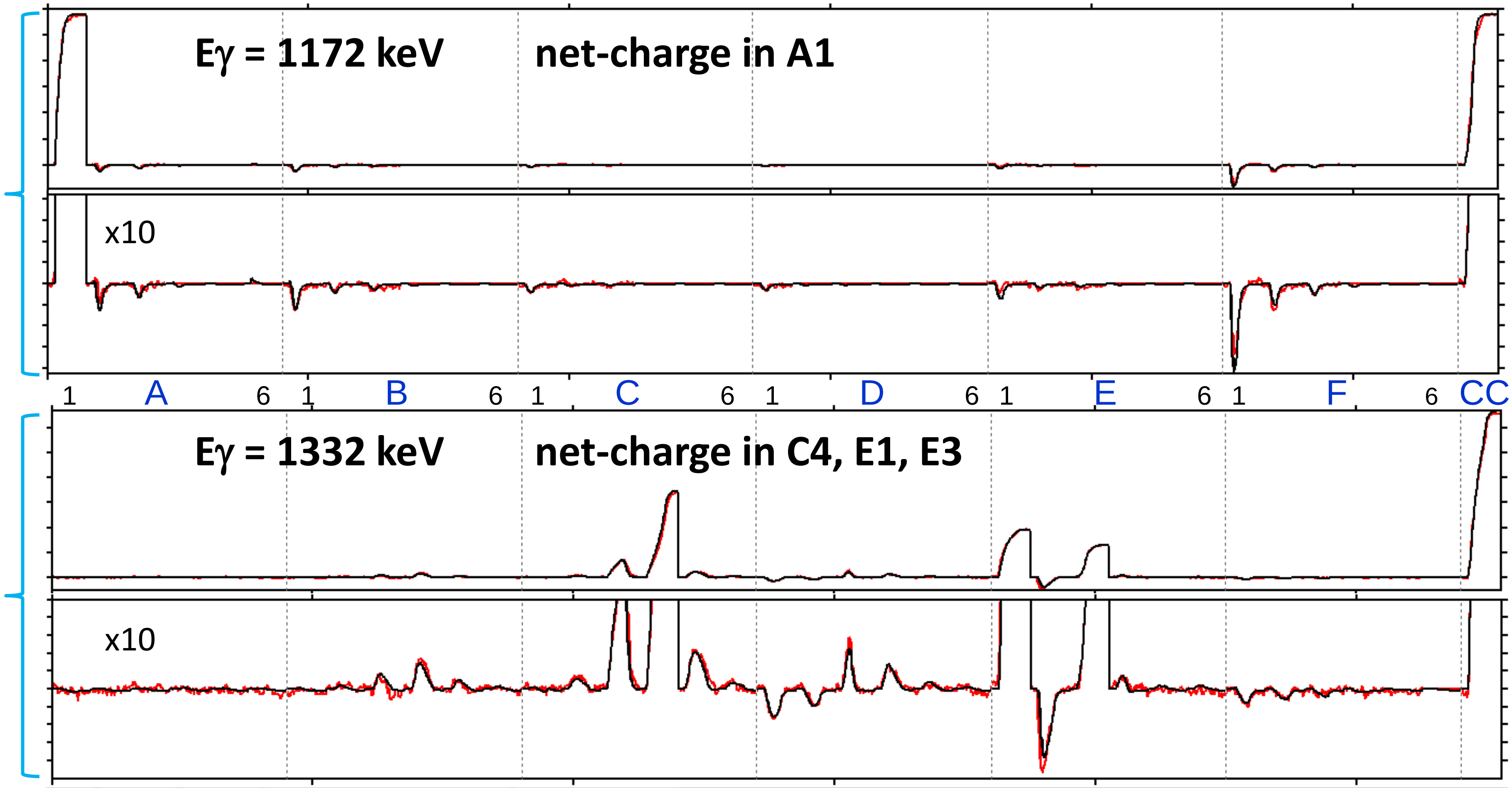
Result of *Grid Search* Algorithm

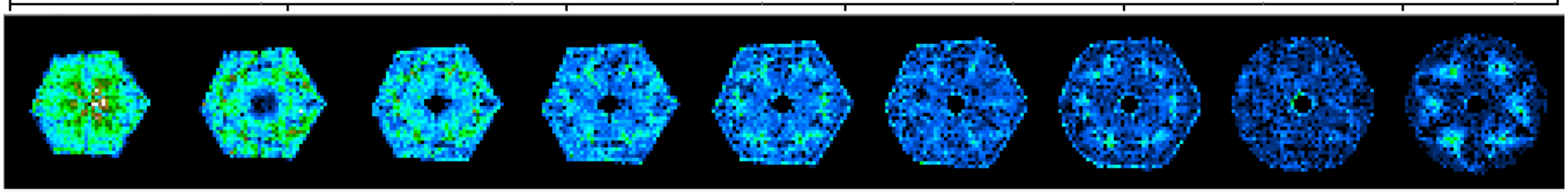
(10,25,46)



z = 46 mm

Pulse shape analysis two examples



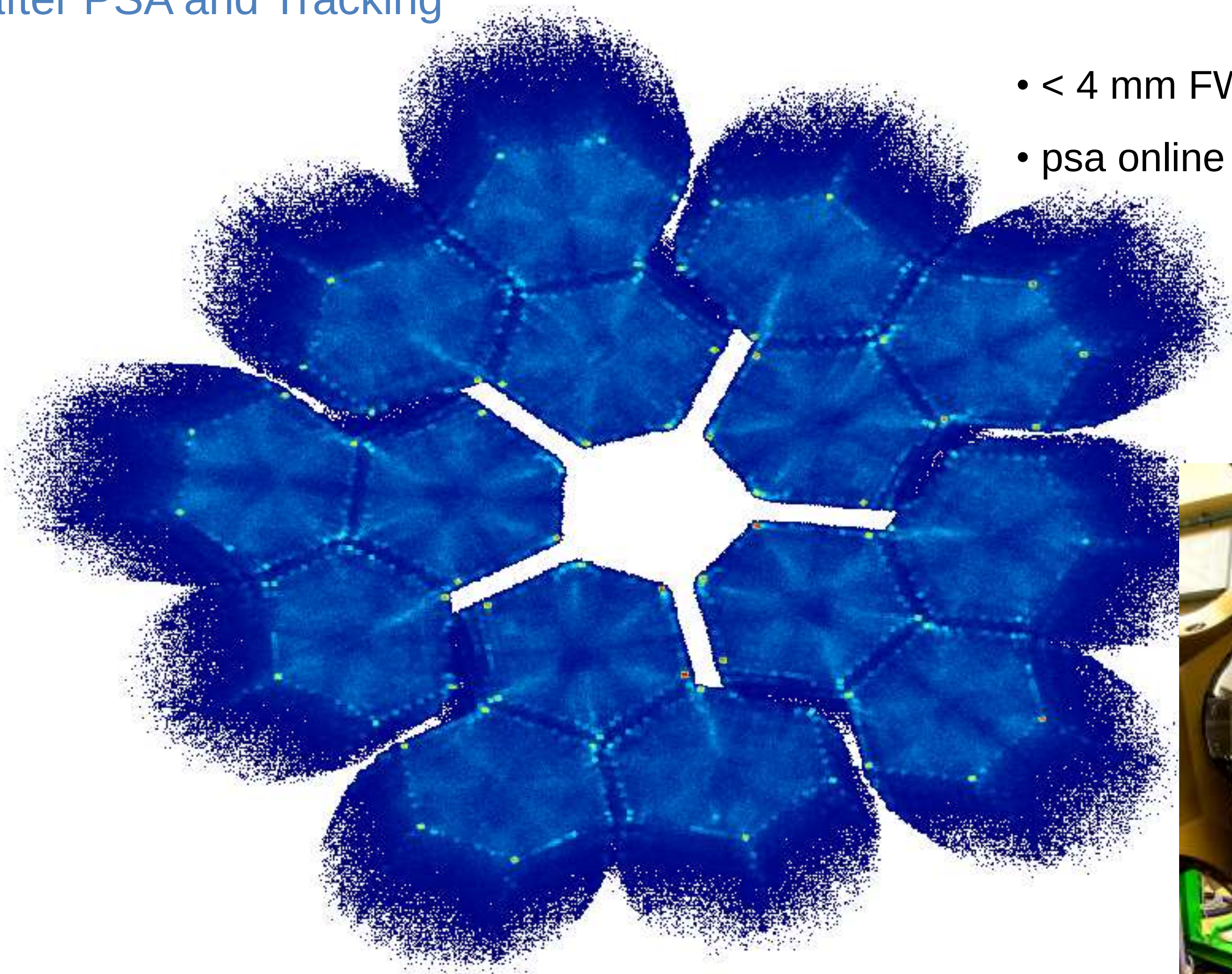


Tomography of interactions in the crystal: non uniformities due to PSA

Result of AGATA tracking

Reconstructed initial gamma rays with: - gamma ray energy
- 1st interaction position → Doppler correction
- 2nd interaction position → Polarization

1st interaction positions after PSA and Tracking



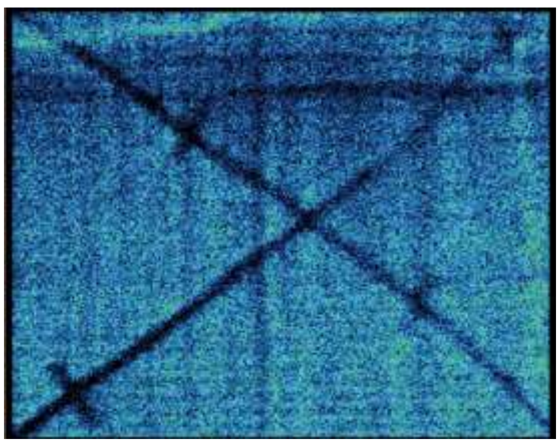
- < 4 mm FWHM resolution obtained
- psa online at rates > 15 kHz per crystal

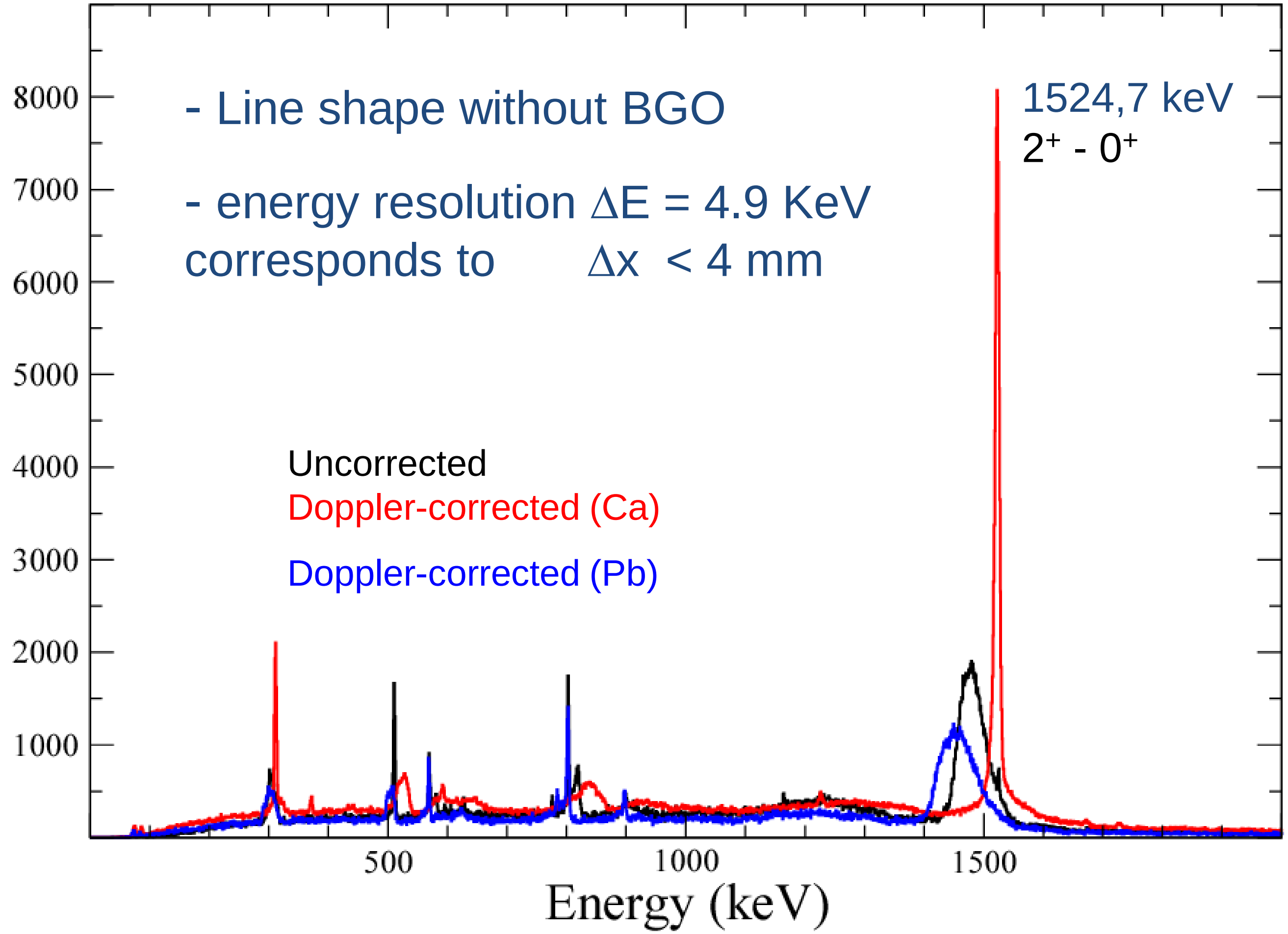
AGATA position resolution

^{42}Ca@170MeV + ^{208}Pb

Kinematical coincidences

Position sensitive MCP

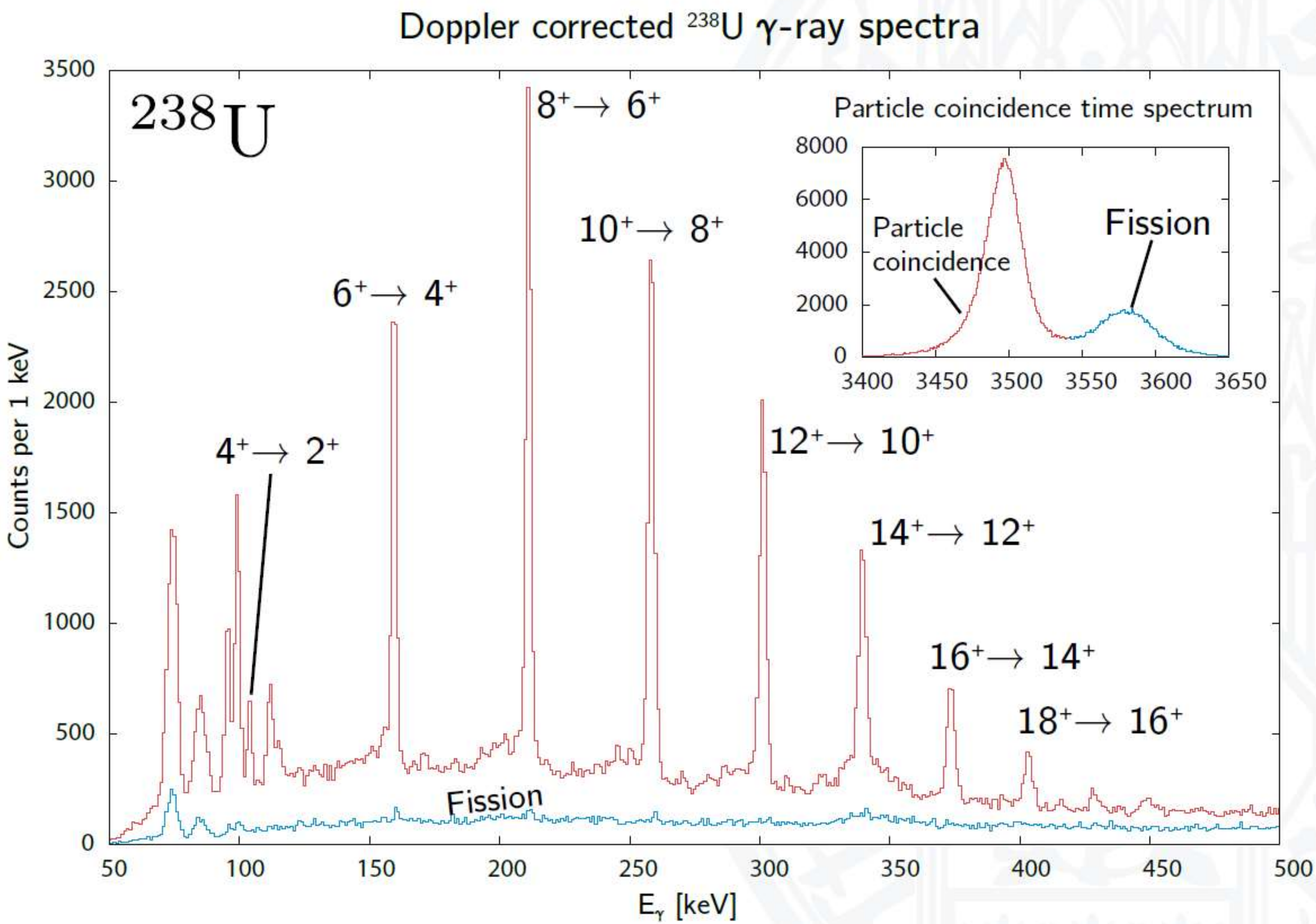




AGATA position resolution

Δx FWHM	Method	
5.2 mm	Doppler corr. meas.	F. Recchia et al. NIM A (2009)
4.0 mm	Doppler corr. meas	P.-A. Söderström et al. NIM A (2011)
3.5 mm	511keV source meas.	S. Klupp, M.Schlarb, R. Gernhäuser

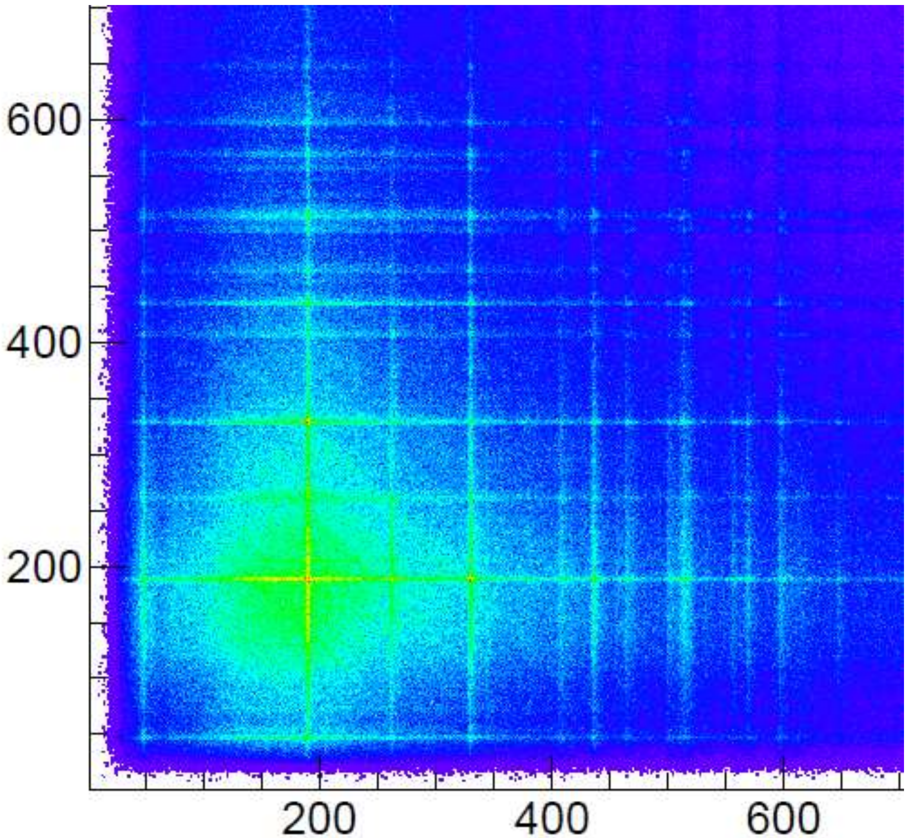
Line shape higher multiplicity events



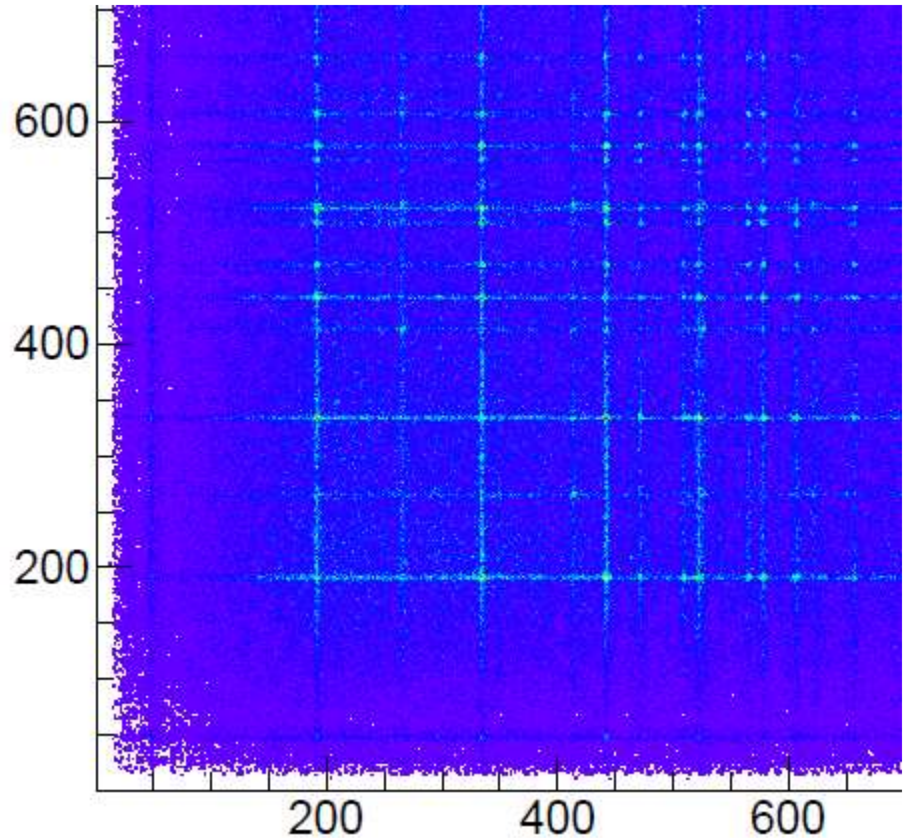
A. Vogt, et al.; Phys. Rev. C 92, 024619 (2015), B. Birkenbach, et al.; Phys. Rev. C accepted

Resolving power high multiplicity events

$^{40}Ar + ^{122}Sn \rightarrow ^{158}Er$ (24 capsules) Fold5 GANIL-June 2015



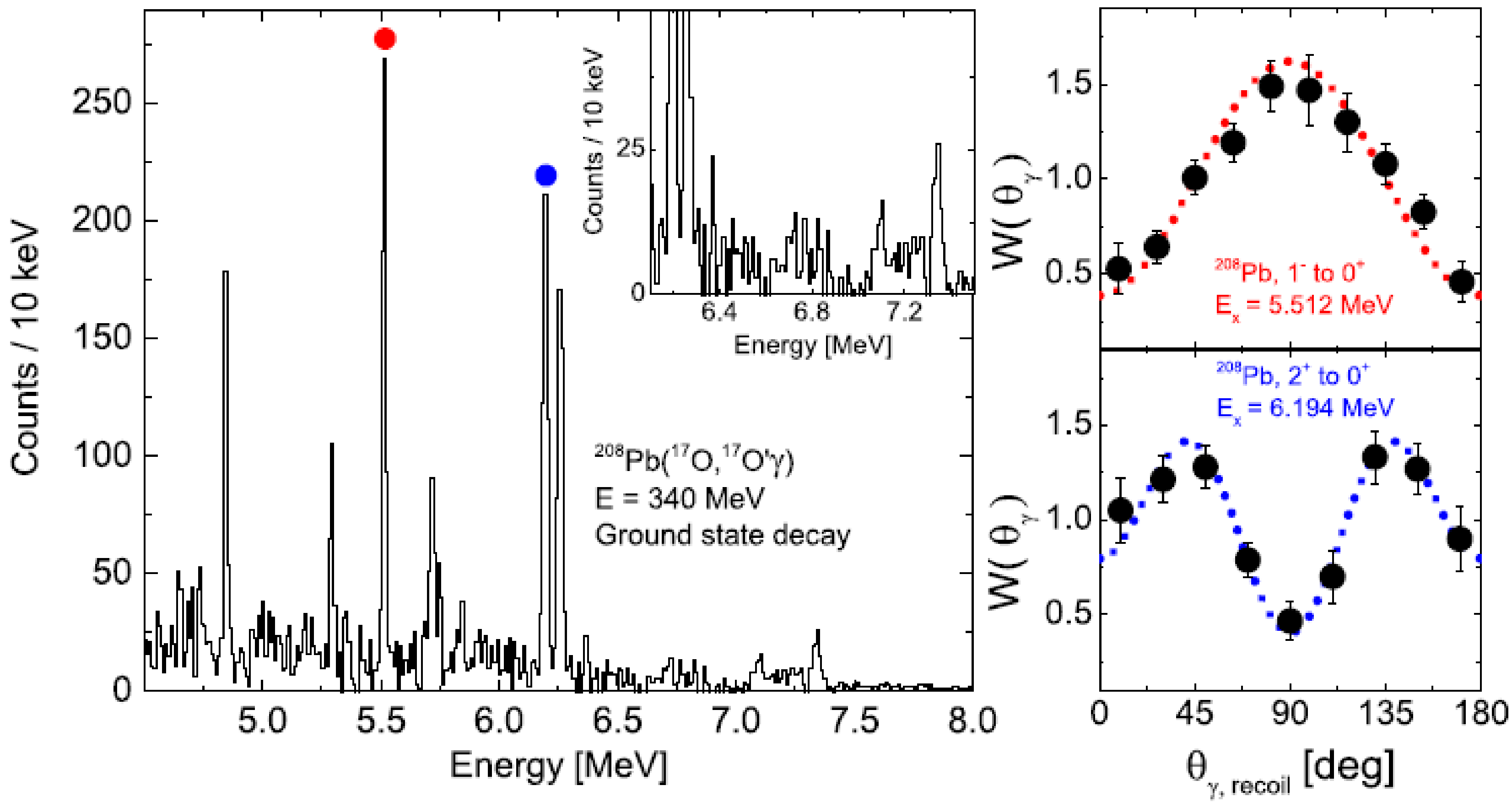
Before Tracking



After Tracking

A. Korichi, C. Michelagnoli, E. Clement

Line shape high γ-ray energy



Escape lines are identified and discriminated by γ-ray tracking

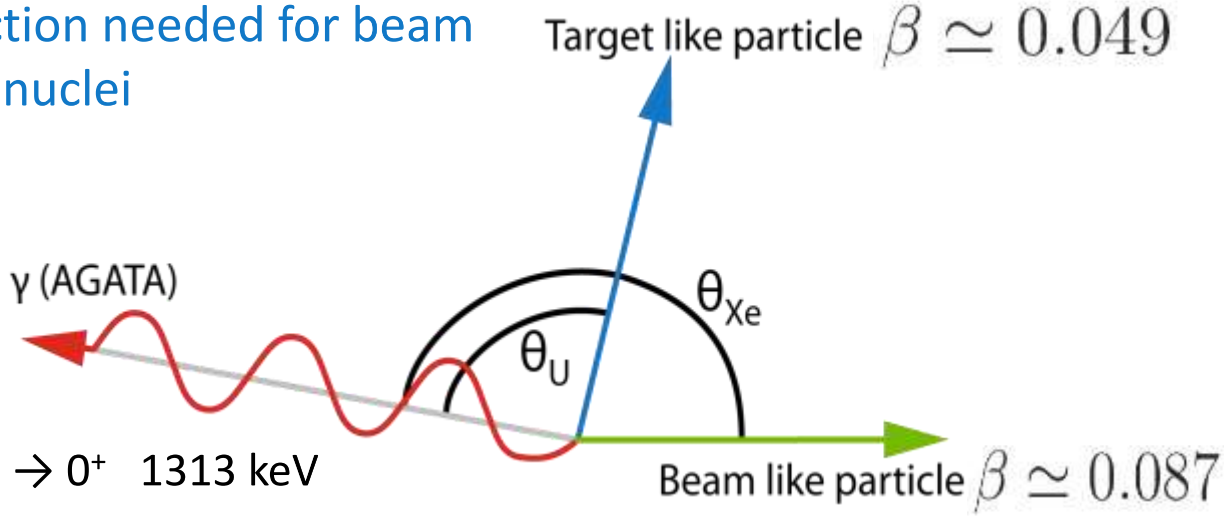
First interaction points yield angular distributions:

- E1 transition from the 1^- state at 5.512 MeV
- E2 transition from the 2^+ state at 6.194 MeV

F. Crespi, A. Bracco et al., Phys. Rev. Lett. **113**, 012501 (2014)

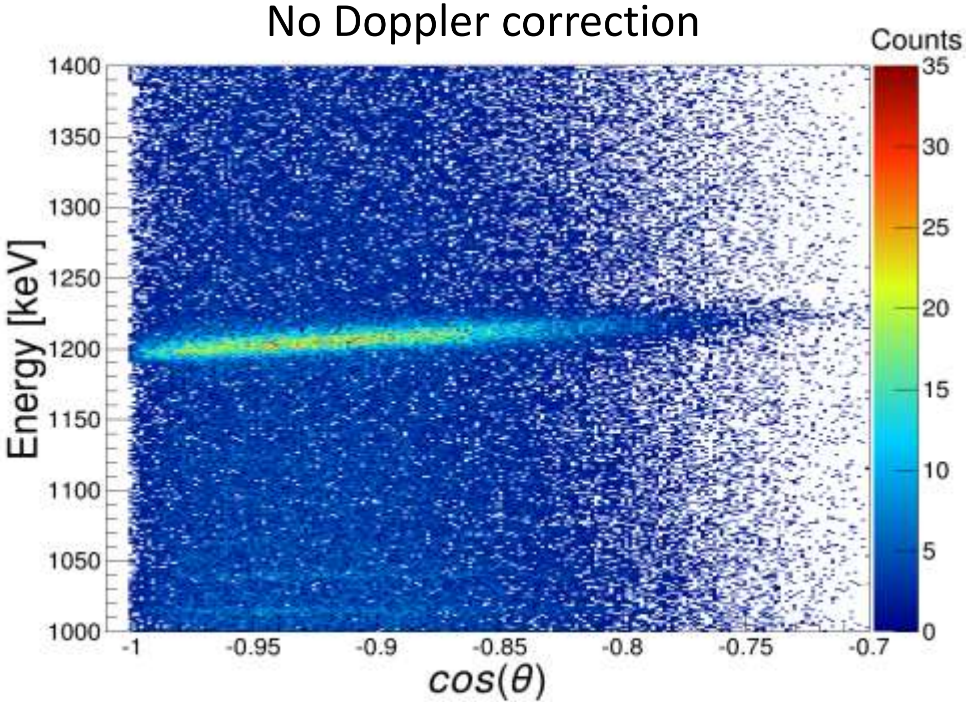
Position resolution & Doppler effects

Doppler correction needed for beam and target like nuclei

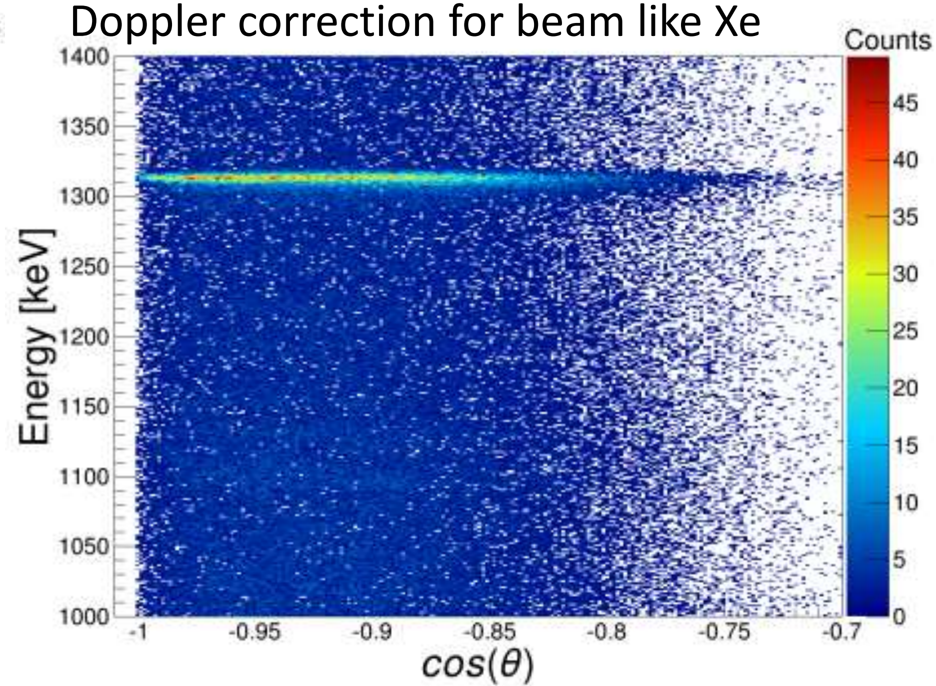


Example: ^{136}Xe: $2^+ \rightarrow 0^+$ 1313 keV

No Doppler correction

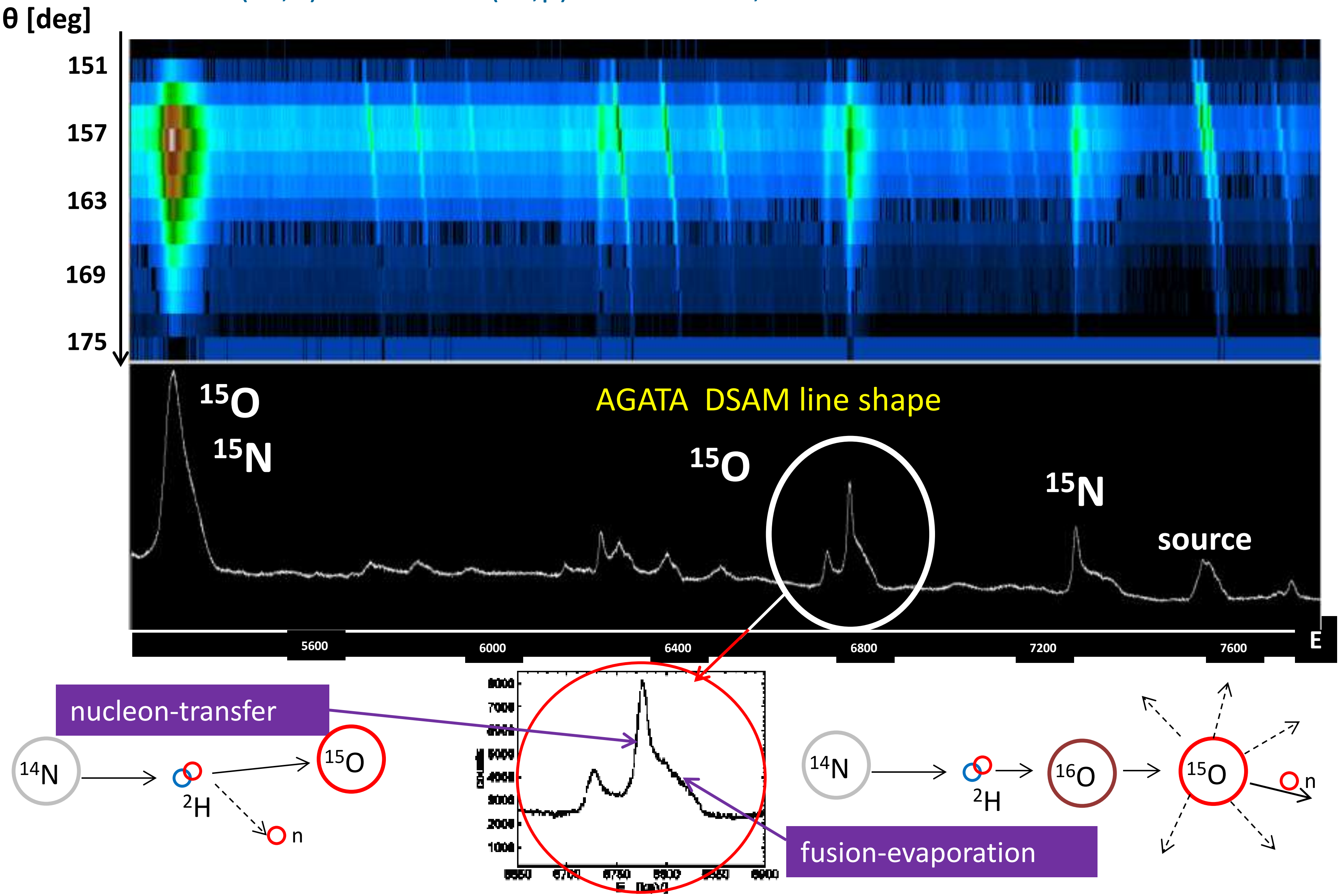


Doppler correction for beam like Xe



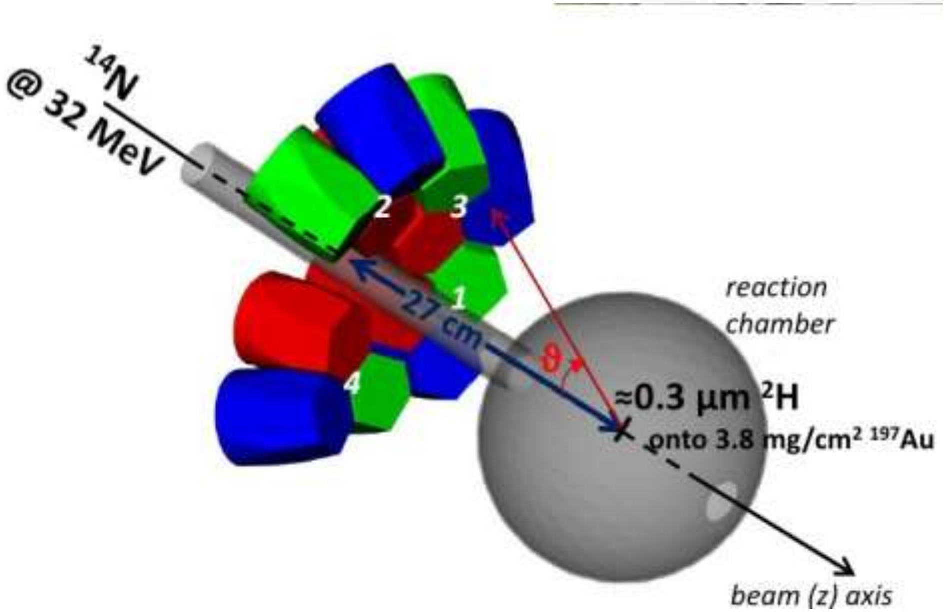
Lifetime of the 6.792 MeV state in ^{15}O

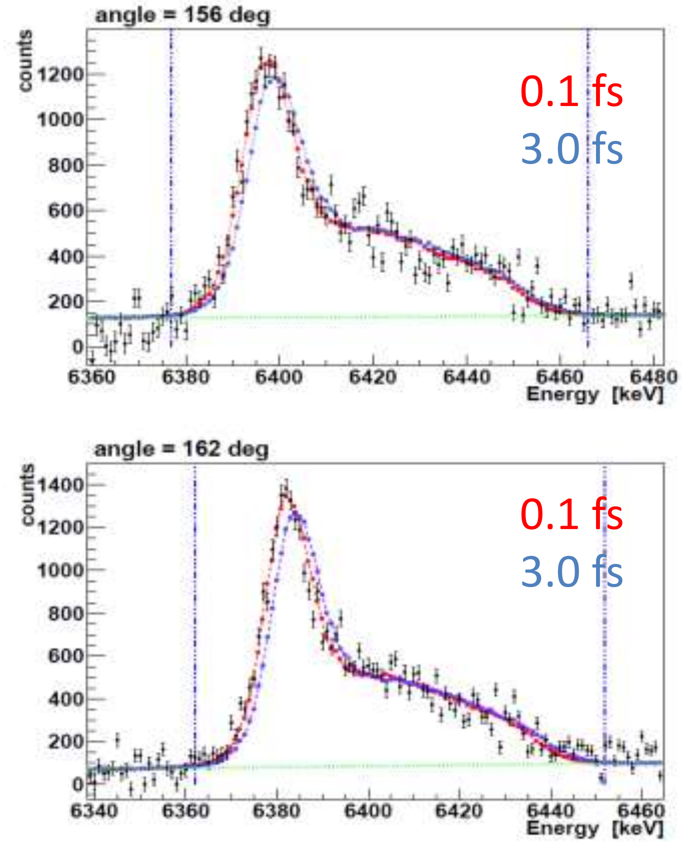
$^{14}N(^{2}H,n)^{15}O$ and $^{14}N(^{2}H,p)^{15}N$ reactions, inverse kinematics



Lifetime of the 6.79 MeV state in ^{15}O

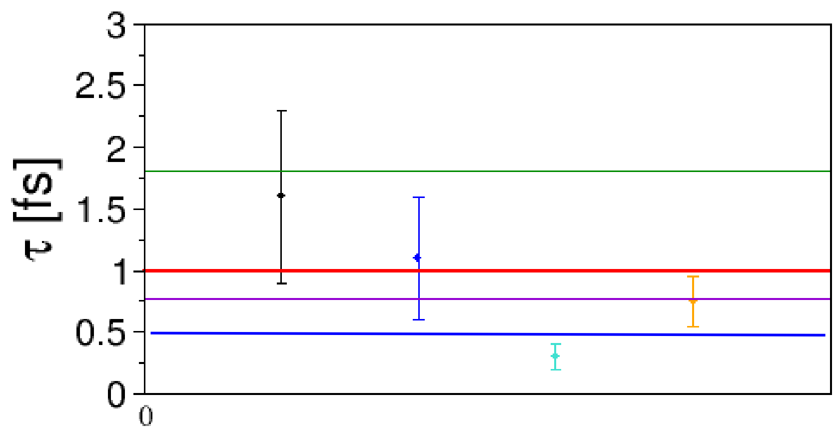
$^{14}N(^{2}H,n)^{15}O$ and $^{14}N(^{2}H,p)^{15}N$ reactions
inverse kinematics
Continuous DSAM lifetime measurement





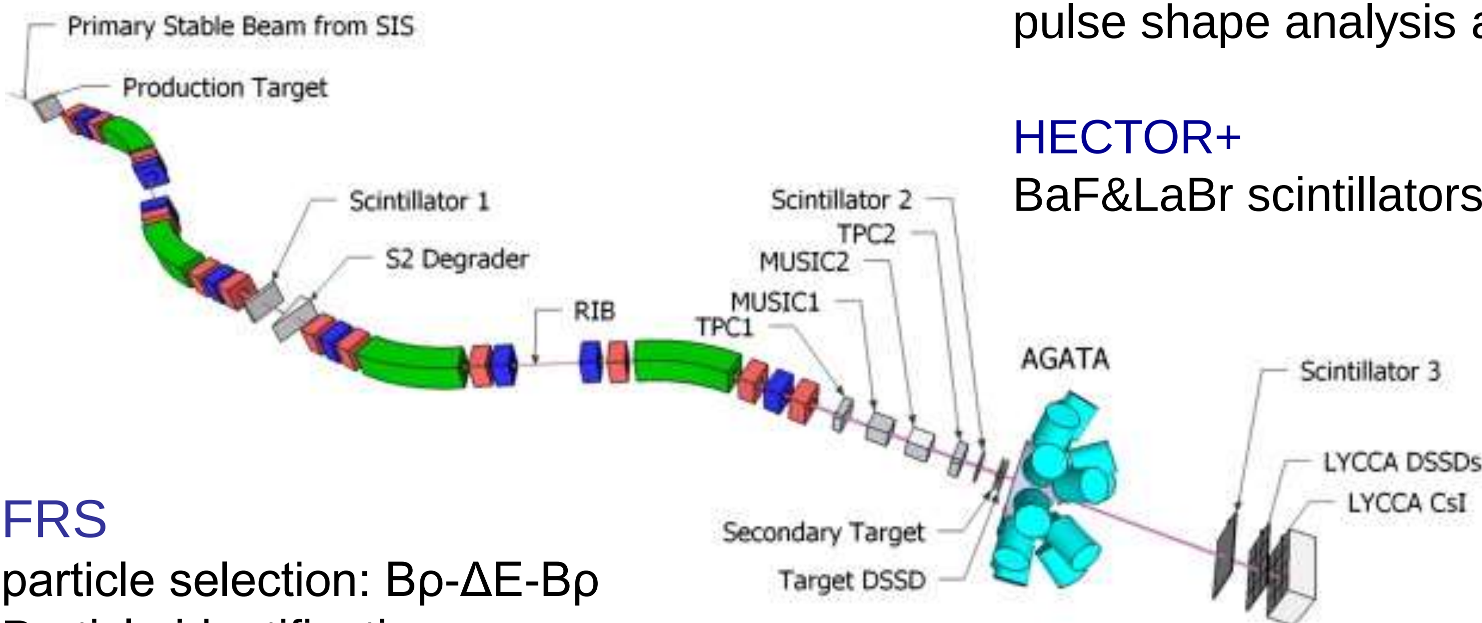
New upper limit of < 0.5 fs on the lifetime of the 6.79 MeV state in ^{15}O

Lower limit of the width of the state $\Gamma > 1.07$ eV



C. Michelagnoli et al., Phys. Rev. Let. accepted

PreSPEC-AGATA Setup @ GSI



AGATA
Triple & double cluster
pulse shape analysis and γ-ray tracking

HECTOR+
BaF&LaBr scintillators

FRS
particle selection: Bρ-ΔE-Bρ
Particle identification:
- TPC tracking detectors
- ToF measurement
- Energy-loss measurement

LYCCA
Outgoing particle tracking and identification:
- Z identification via E-ΔE
- Mass identification via E-ToF

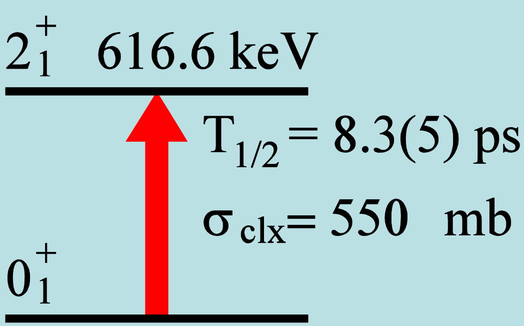
C. Domingo-Pardo et al., NIM A 694 297-312 (2012)

Coulomb Excitation @ relativistic energies

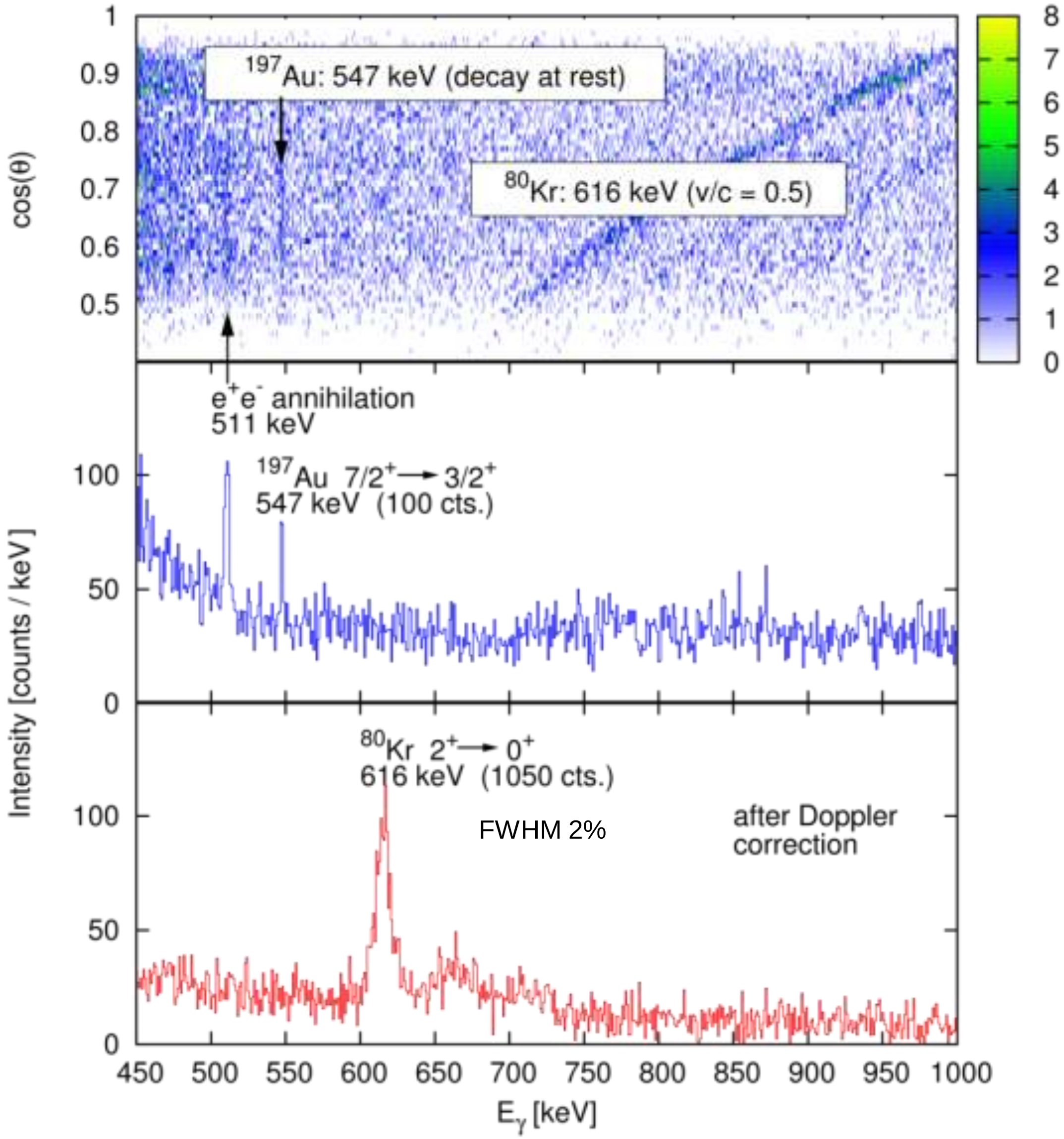
Reminder: Doppler effect

$$E_{\text{laboratory}} = E_{\text{rest}} \frac{\sqrt{1-\beta^2}}{1-\beta\cos(\vartheta_{\text{lab}})}$$

^{80}Kr

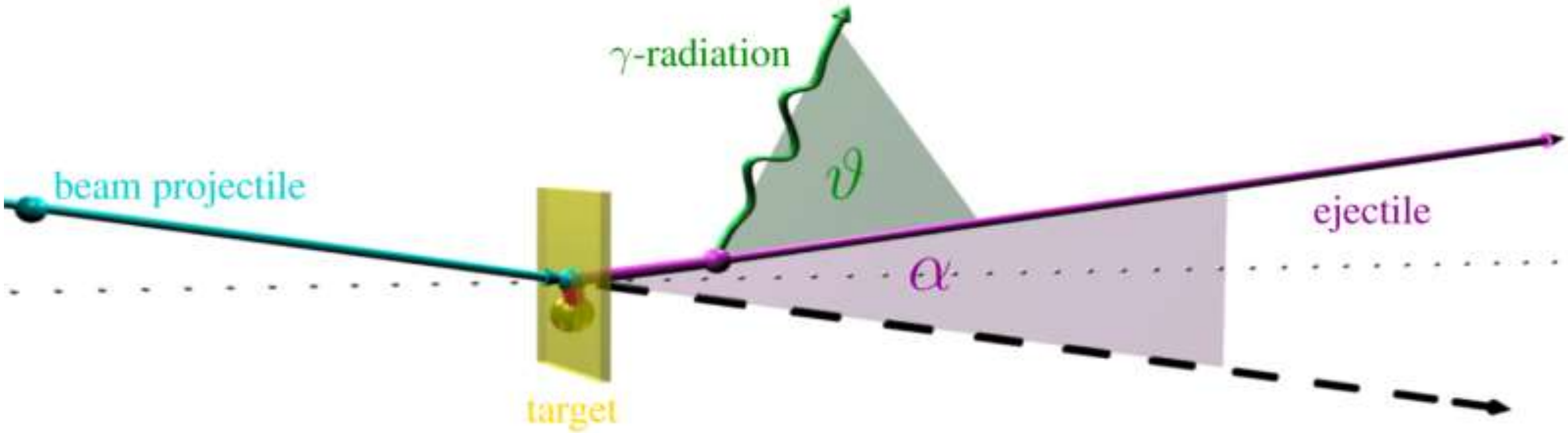


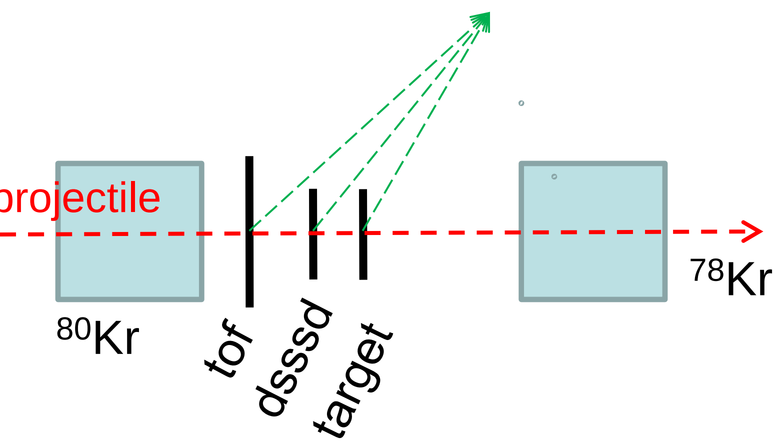
- large Coulex cross section
- no decay inside the target

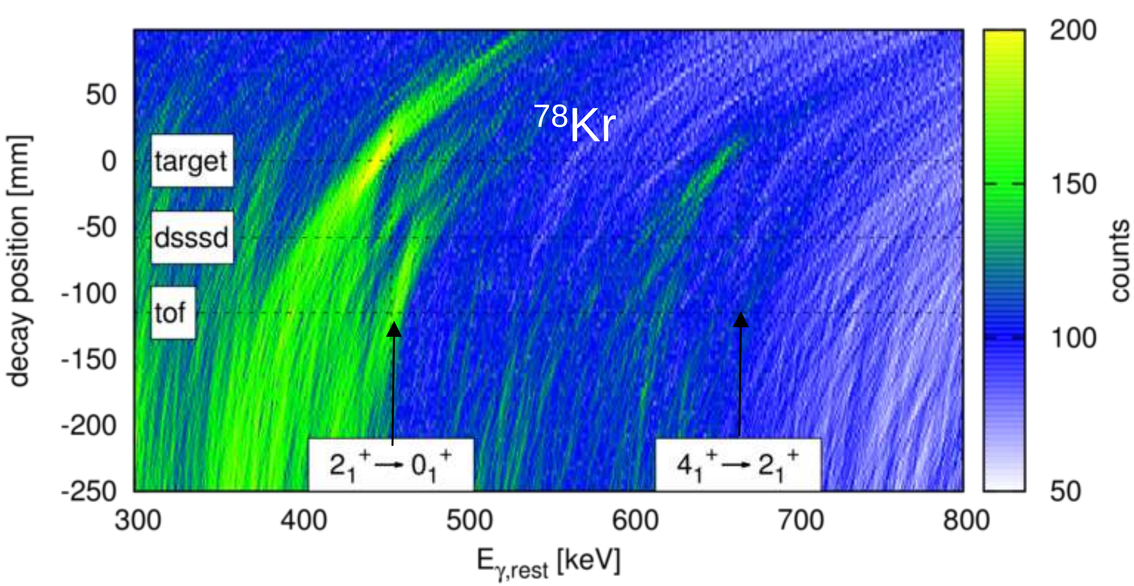


Michael Reese, TU Darmstadt

Location of Gamma Emission



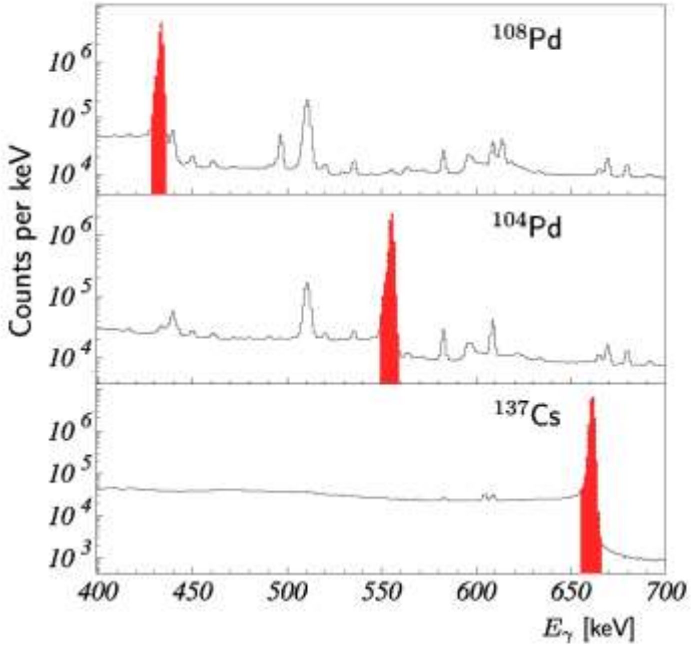


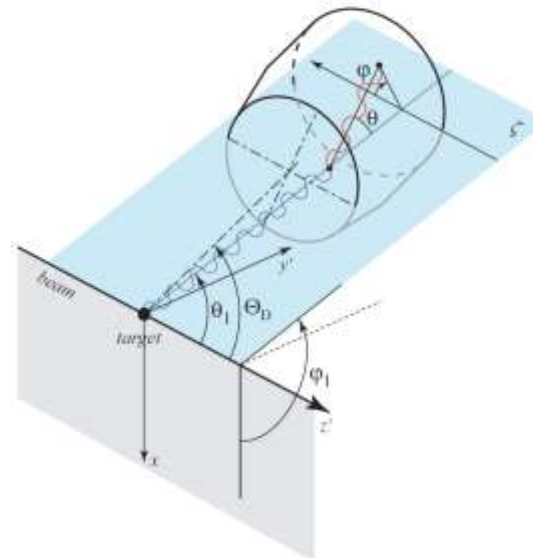


Michael Reese, TU Darmstadt

Analyzing power for γ-ray linear polarization

Partially-polarized 555.8-keV and 433.9-keV lines in ^{104}Pd and ^{108}Pd after Coulomb excitation.

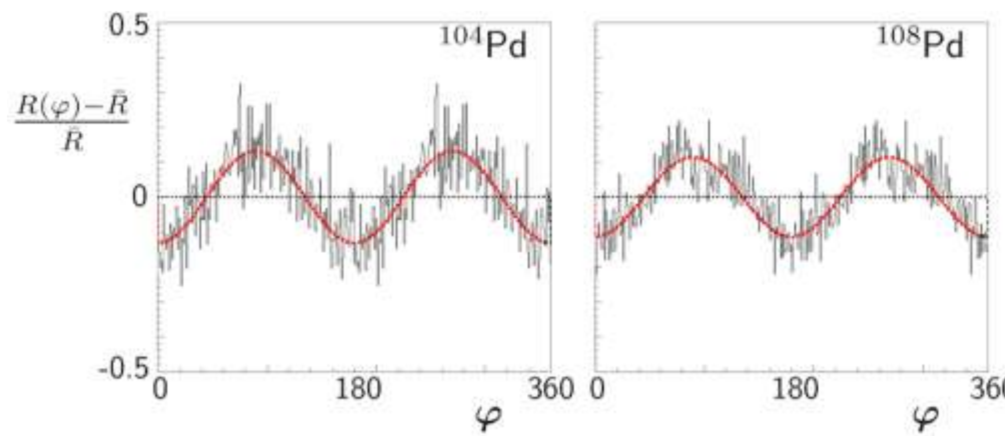




$$\bar{\sigma}_C(\theta,\varphi) = \frac{r_0^2}{4}\left(\frac{E'_\gamma}{E_\gamma}\right)^2 \left[\frac{E_\gamma}{E'_\gamma} + \frac{E'_\gamma}{E_\gamma} - \sin^2\theta \;\; (1 + P\cos 2\varphi)\right]$$

GOSIA

$$\frac{dN}{d\varphi} = a_0 + a_2 \cos(2\varphi) \; .$$



Analyzing power: A = 0.48

P.G. Bizzeti et al., Eur. Phys. J. A (2015) **51**: 49

Summary

- Status AGATA:
  - ✓ highly segmented HPGe detectors
  - ✓ digitizer & front-end electronics
  - ✓ pulse shape analysis & γ-ray tracking
  - ✓ position sensitive γ-ray detection: Δx~3-4 mm

- Improved conditions for in-beam γ-ray spectroscopy
  - energy resolution (reduced Doppler effects)
  - detection efficiency at higher energies
  - line shape (escape line suppression)
  - angular distributions from 1st interaction point
  - polarization sensitivity from 2nd interaction point
  - lifetime measurements
  - back ground suppression

Acknowledgements

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AGATA—Advanced GAmma Tracking Array

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ABSTRACT

The Advanced GAmma Tracking Array (AGATA) is a European project to develop and operate the next generation γ-ray spectrometer. AGATA is based on the technique of γ-ray energy tracking in electrically segmented high-purity germanium crystals. This technique requires the accurate determination of the energy, time and position of every interaction as a γ ray deposits its energy within the detector volume. Reconstruction of the full interaction path results in a detector with very high efficiency and excellent spectral response. The realisation of γ-ray tracking and AGATA is a result of many technical advances. These include the development of encapsulated highly segmented germanium detectors assembled in a triple cluster detector cryostat, an electronics system with fast digital sampling and a data acquisition system to process the data at a high rate. The full characterisation of the crystals was measured and compared with detector-response simulations. This enabled pulse-shape analysis algorithms, to extract