

The AGATA Array and Recent Results

- Introduction to AGATA
- pulse shape analysis and γ -ray tracking
- AGATA demonstrator at LNL
 - binary partners
 - lifetimes
 - high energetic γ -rays

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Institute of Nuclear Physics University of Cologne

ISOLDE Workshop and Users Meeting

15.12. – 17.12.2014



Experimental Conditions and Challenges at future Radioactive Beam Facilities

EURISOL
FAIR
HIE-ISOLDE
SPES
SPIRAL2
...

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

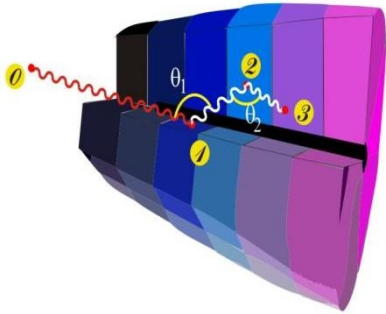
γ -spectroscopy profits
from improved detection
method: γ -ray tracking

High efficiency
High sensitivity
High throughput
Ancillary detectors

Ingredients of Gamma-Ray Tracking

1

Highly segmented
HPGe detectors



2

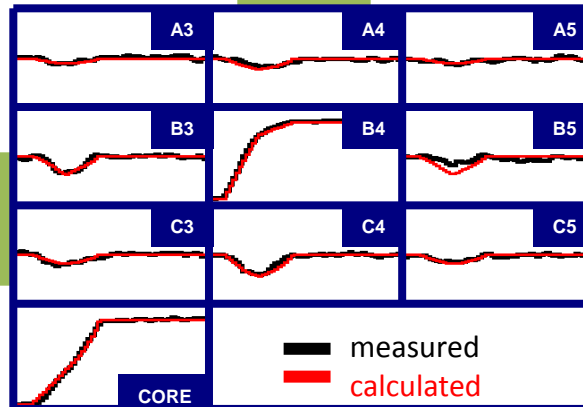
Digital electronics
to record and
process segment
signals

Identified
interaction points

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

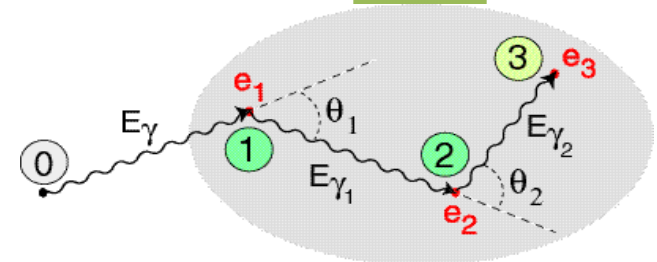
Pulse Shape Analysis
to decompose
recorded waves

3



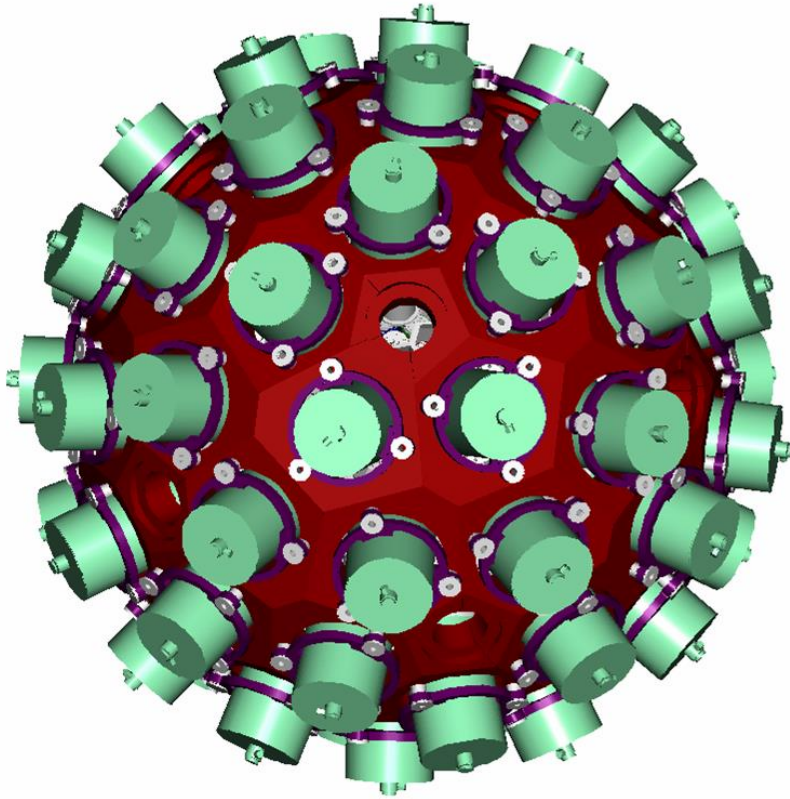
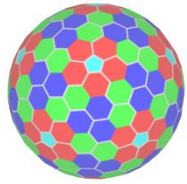
4

Reconstruction of tracks
evaluating permutations
of interaction points



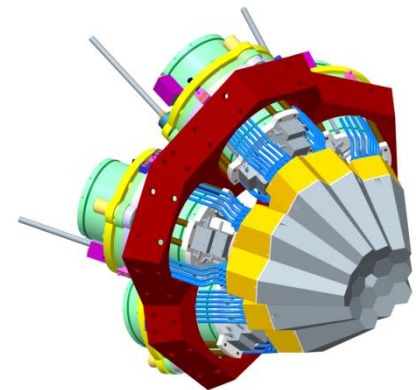
Reconstructed
gamma-rays

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% ($M_\gamma=1$) 28% ($M_\gamma=30$)
Peak/Total:	58% ($M_\gamma=1$) 49% ($M_\gamma=30$)

- 6660 high-resolution digital electronics channels
- needs proof of principle → demonstrator



From the Demonstrator to AGATA 1π

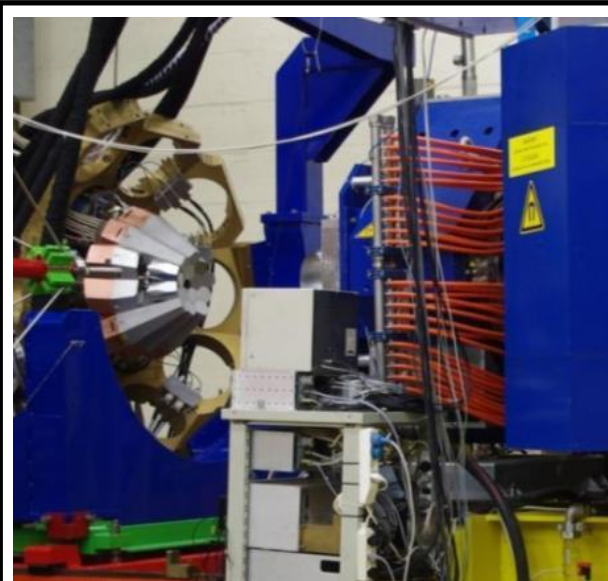
LNL: 2009-2011
15 crystals (5TC)
Total Eff. ~6%



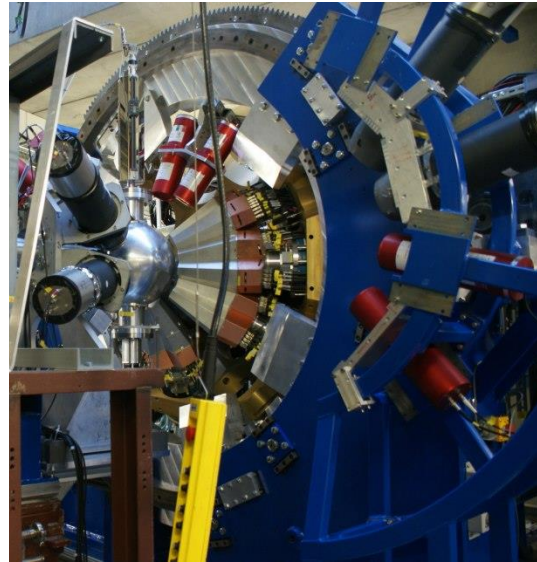
GSI: 2012-2014
24 crystals (3DC+6TC)
Total Eff. ~9%



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



Demonstrator + PRISMA



AGATA + FRS



AGATA+VAMOS

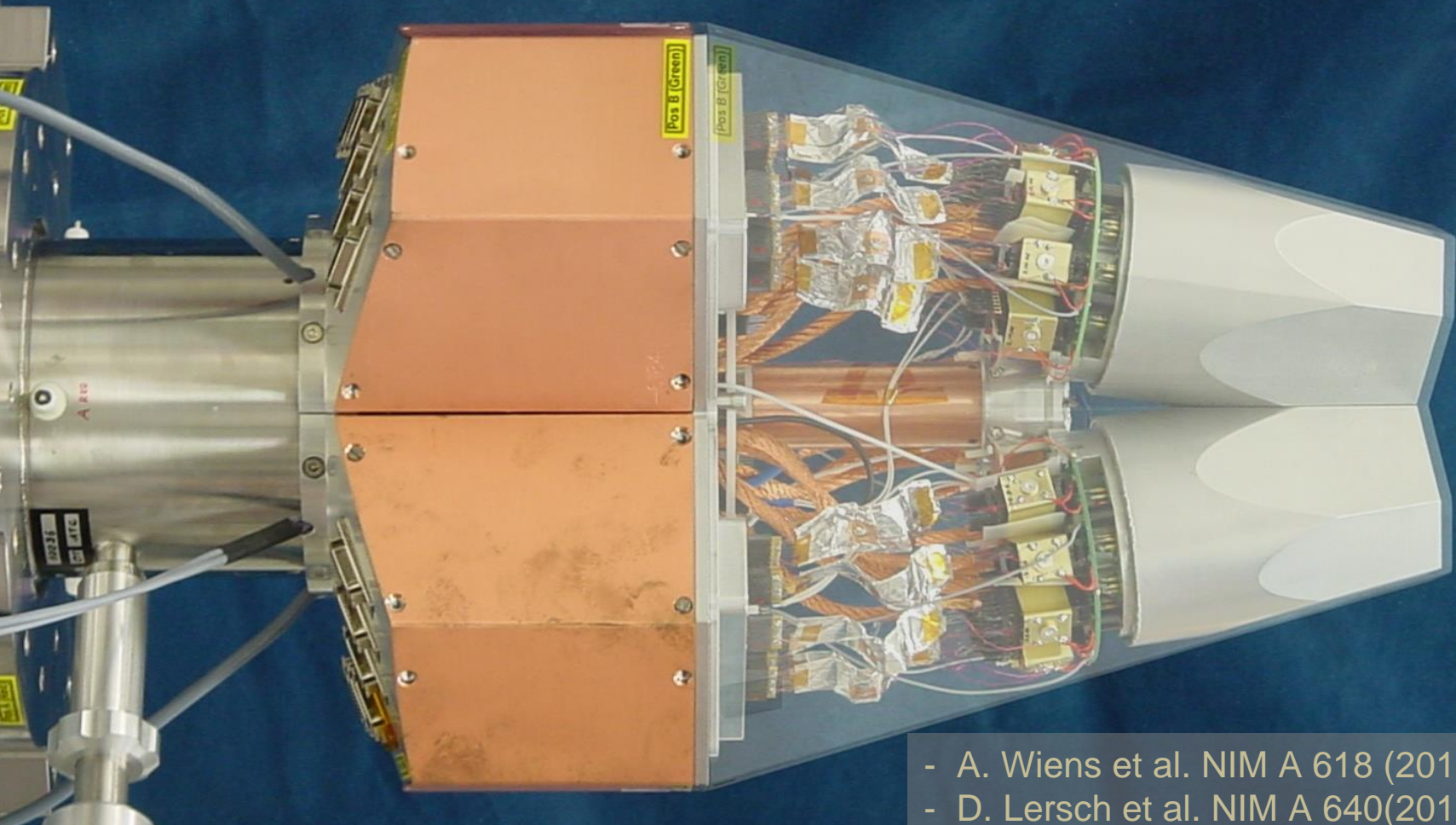
*delivered & ordered
detectors: 37 crystals*

AGATA Triple Cryostat

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

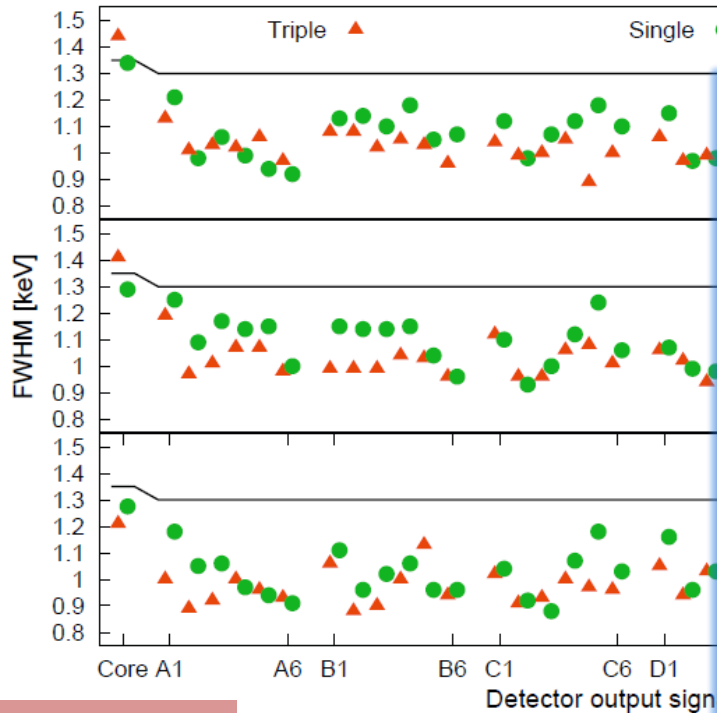
Challenges:

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

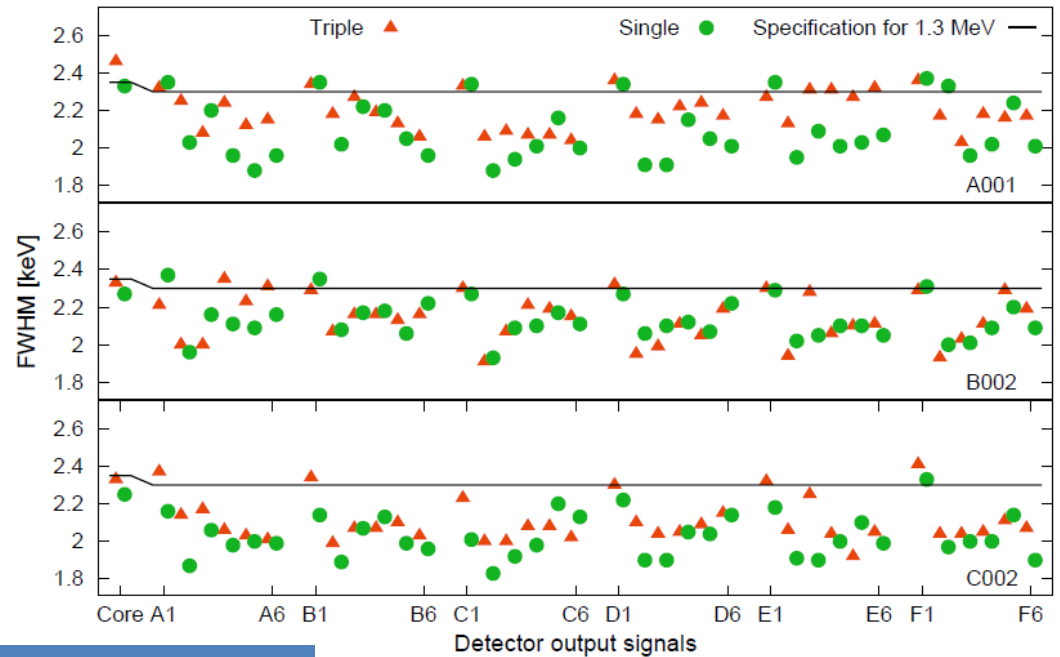


- A. Wiens et al. NIM A 618 (2010) 223–233
- D. Lersch et al. NIM A 640(2011) 133-138

Performance: Energy resolution



@ 60 keV



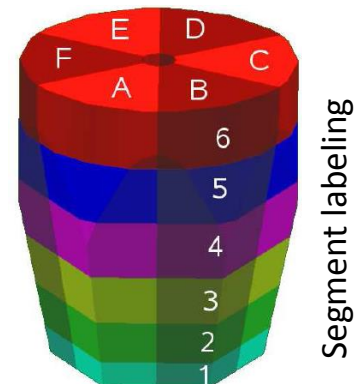
@ 1333 keV

Averages of the segment resolutions
@ 60 keV :

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

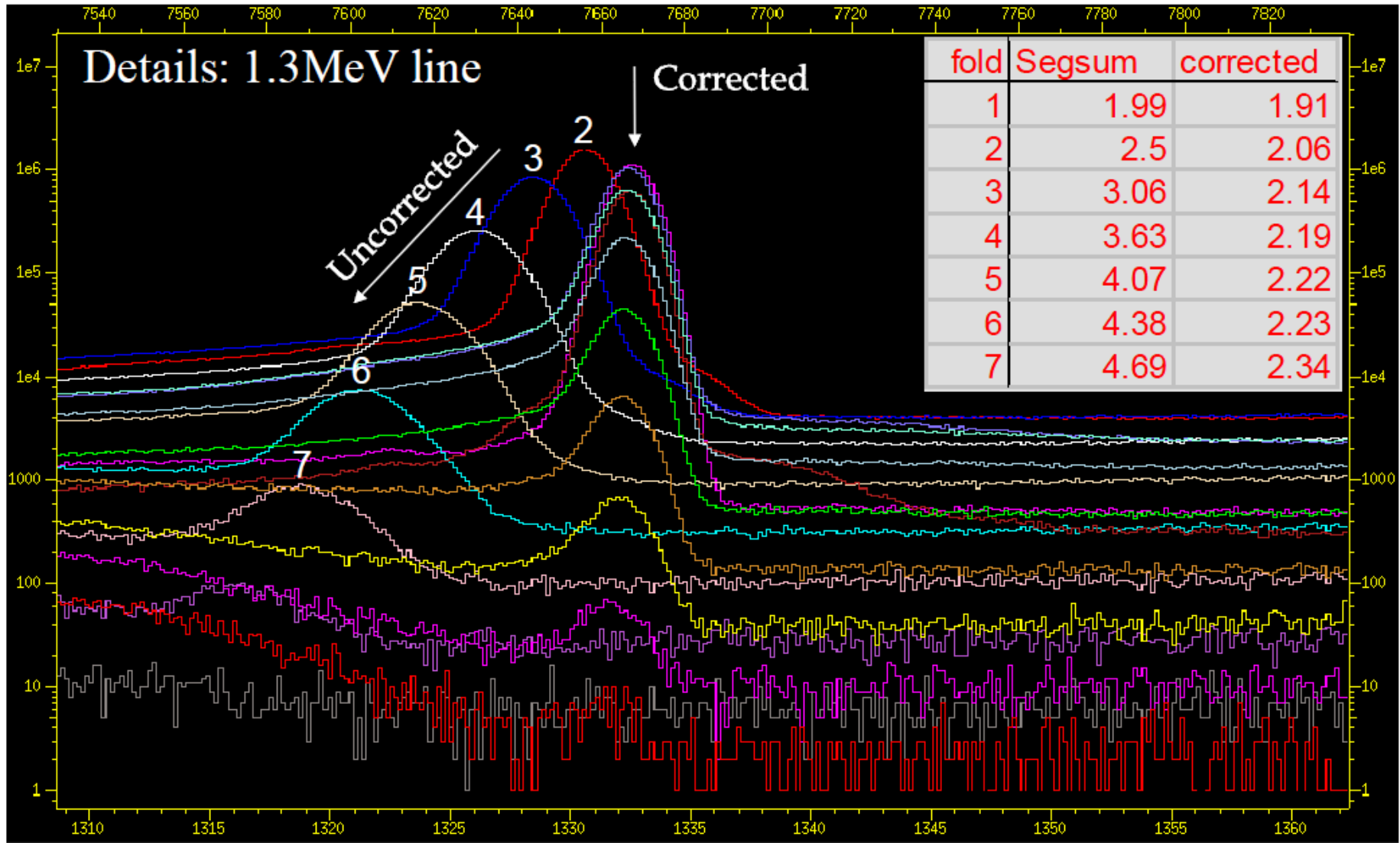
Averages of the segment resolutions
Measured in Cologne and Legnaro
@ 1333 keV :

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

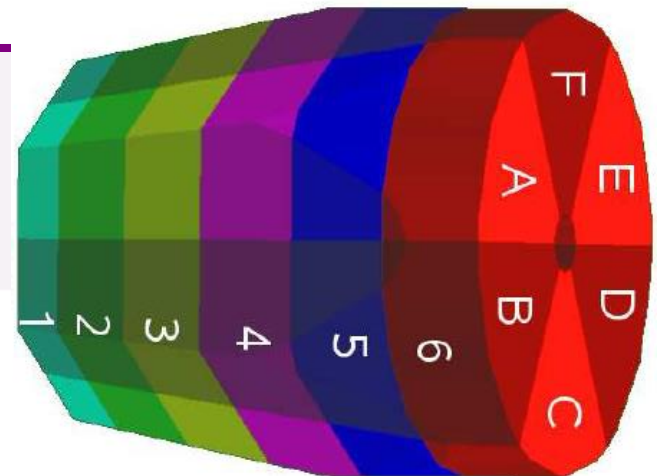
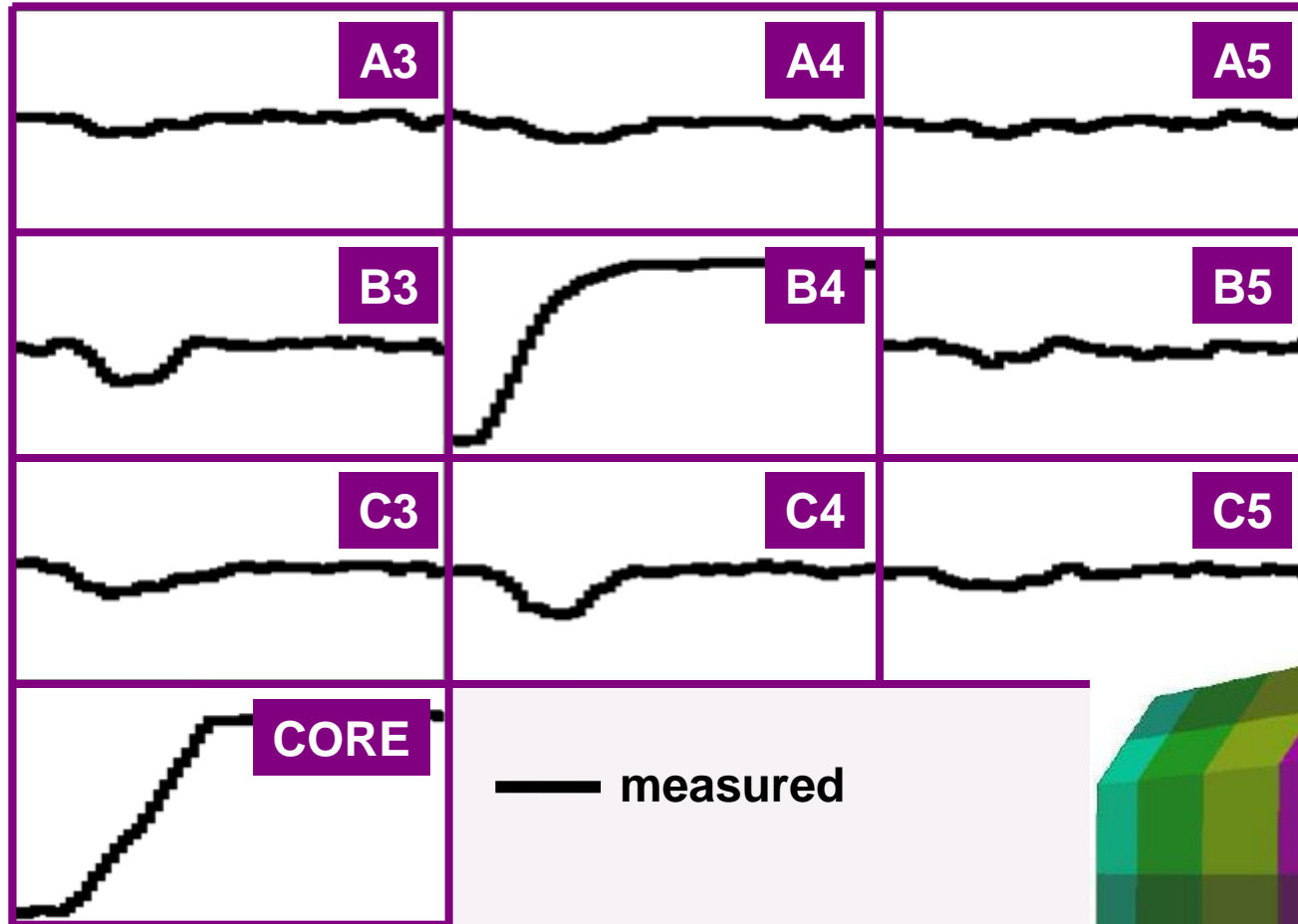


Energy resolution & Cross talk

FWHM 60keV: 1.20 → 1.02 !

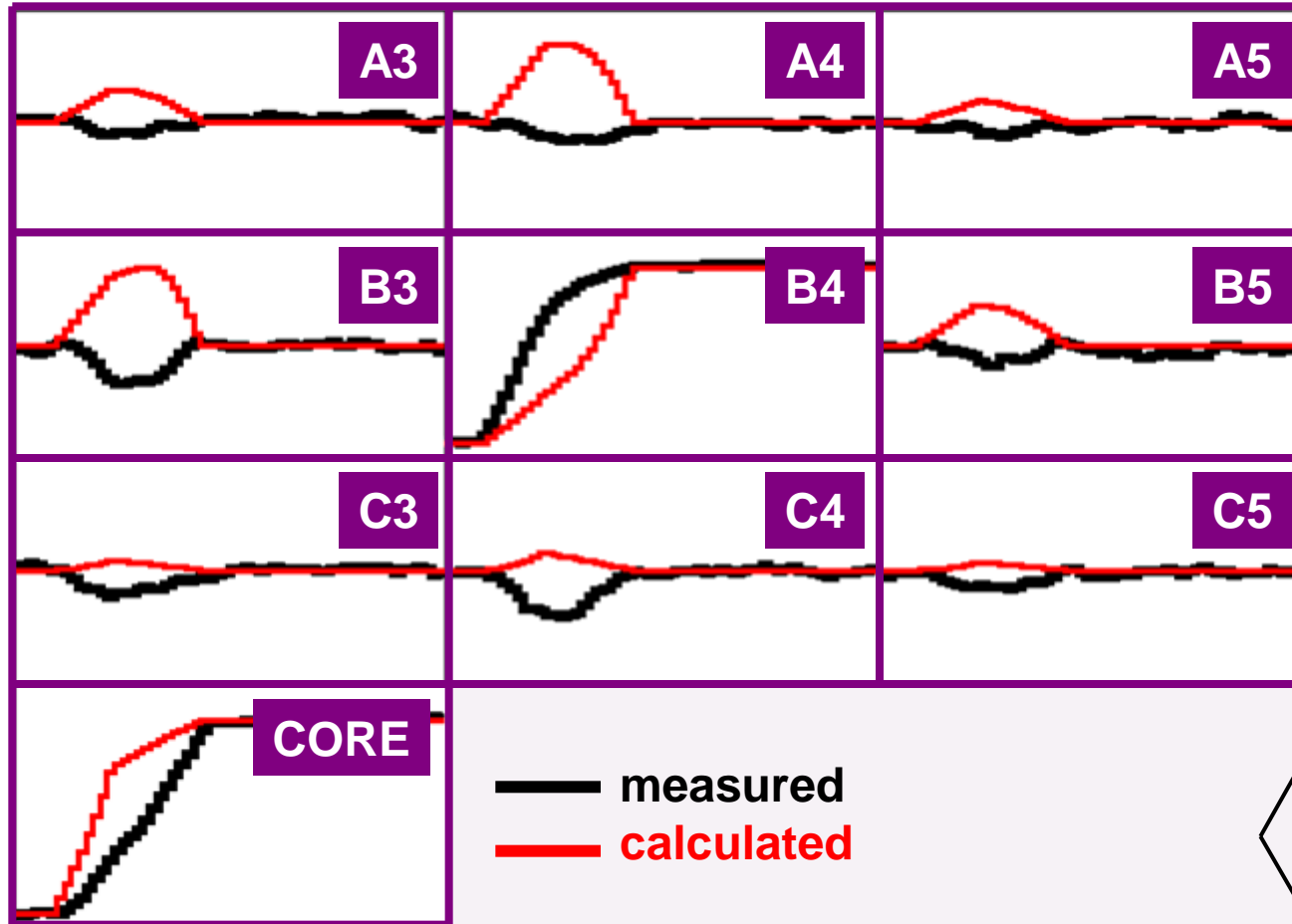


Pulse Shape Analysis concept

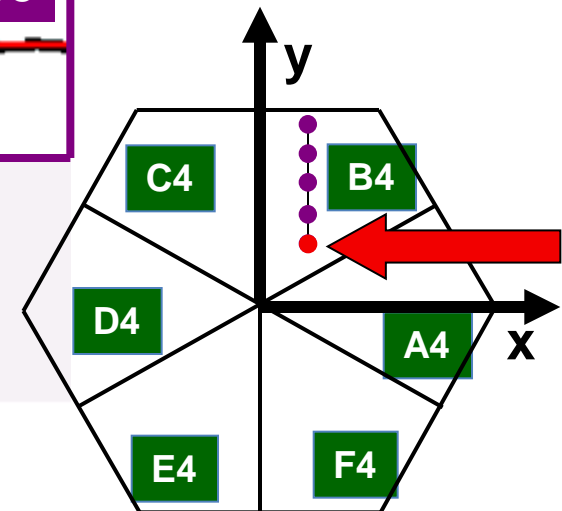


791 keV deposited in segment B4

Pulse Shape Analysis concept



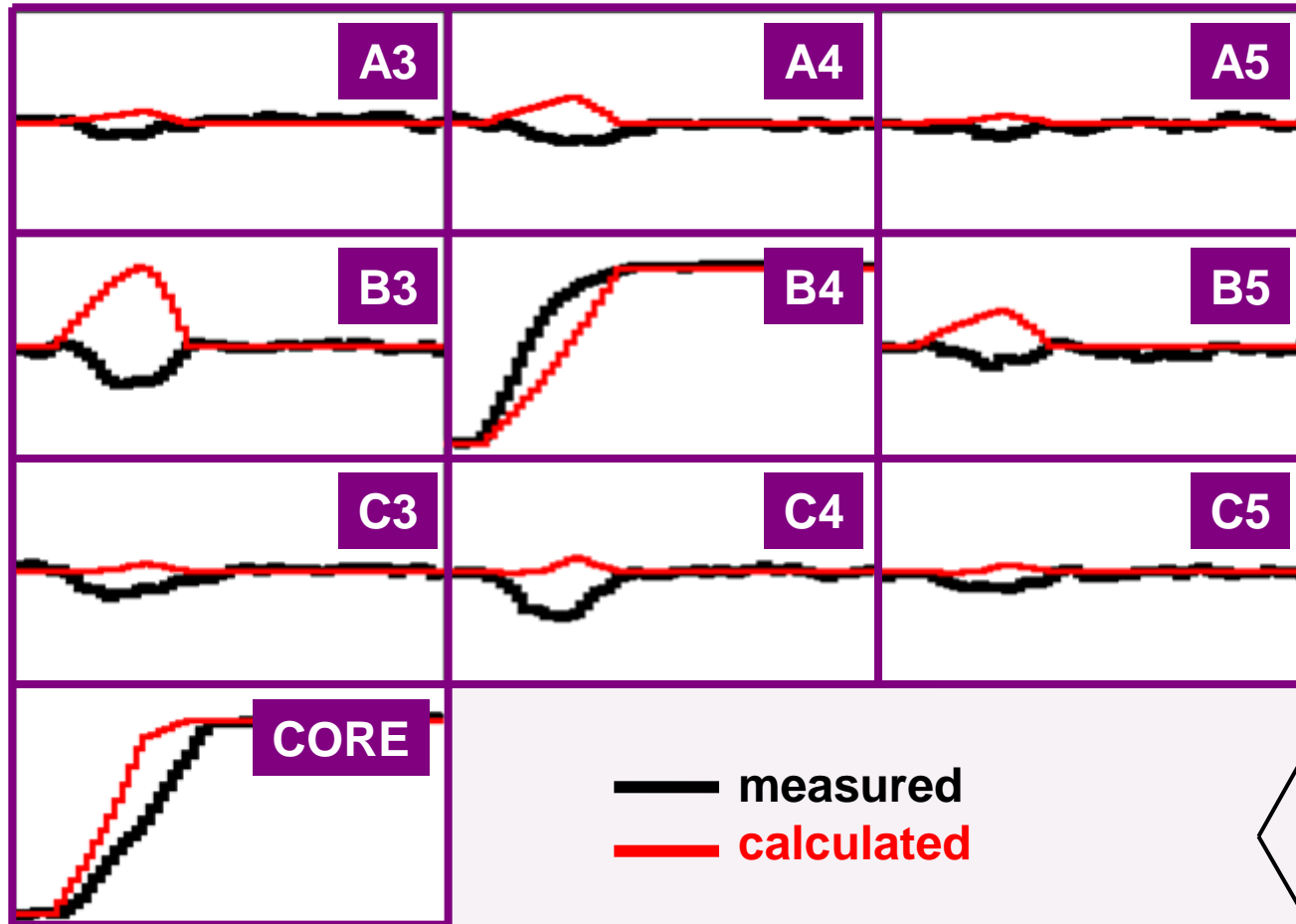
(10, 10, 46)



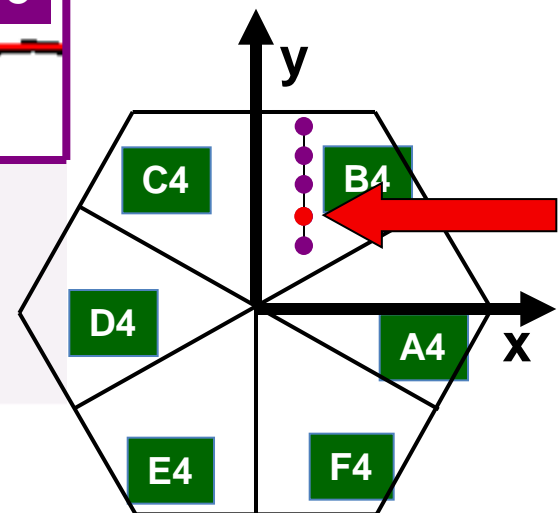
z = 46 mm

791 keV deposited in segment B4

Pulse Shape Analysis concept



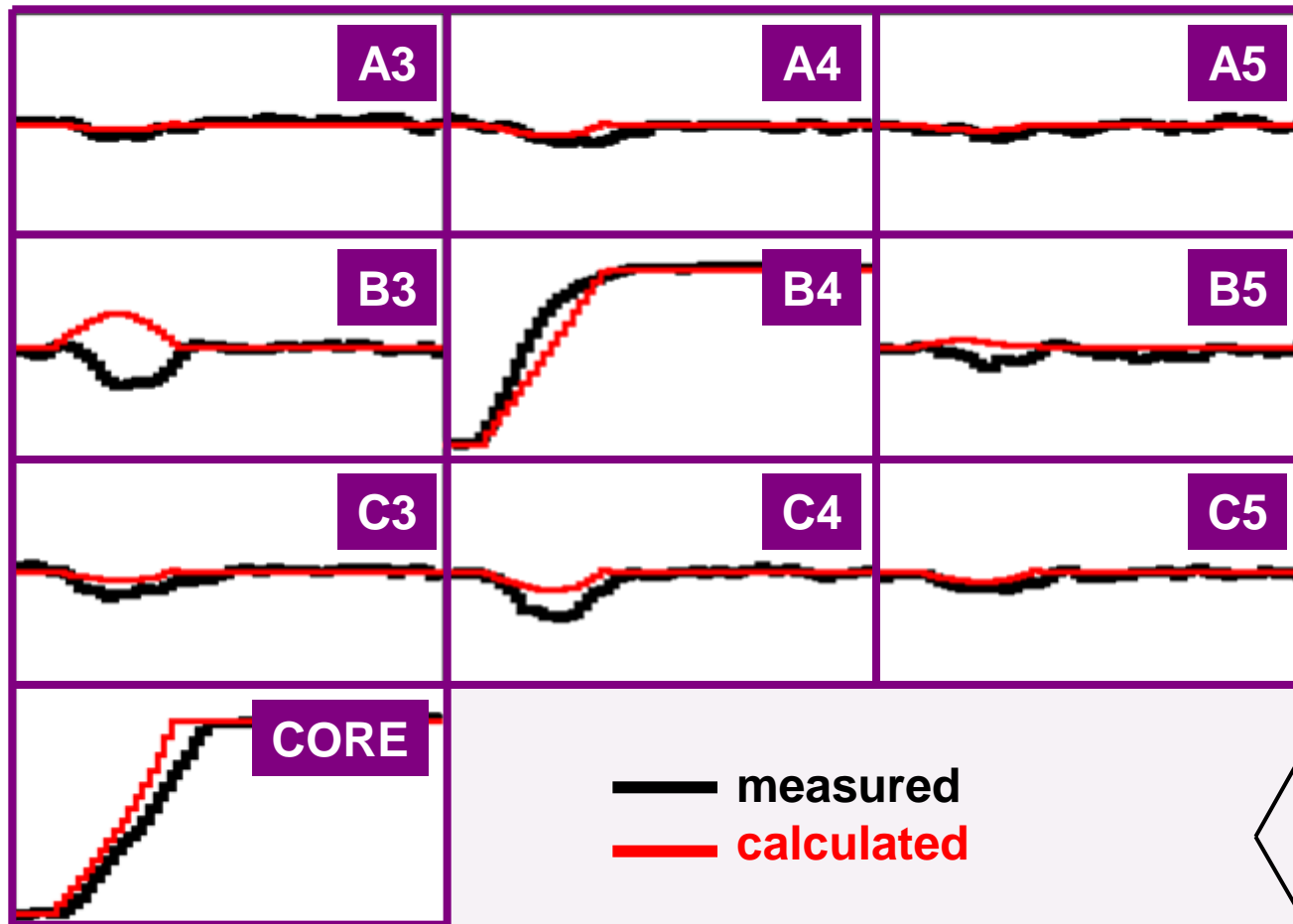
(10, 15, 46)



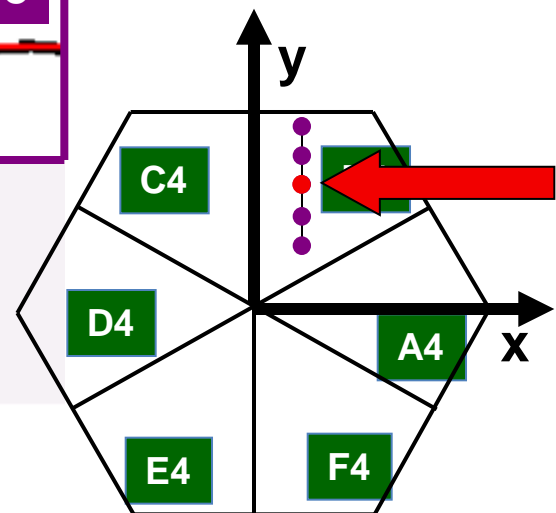
791 keV deposited in segment B4

z = 46 mm

Pulse Shape Analysis concept



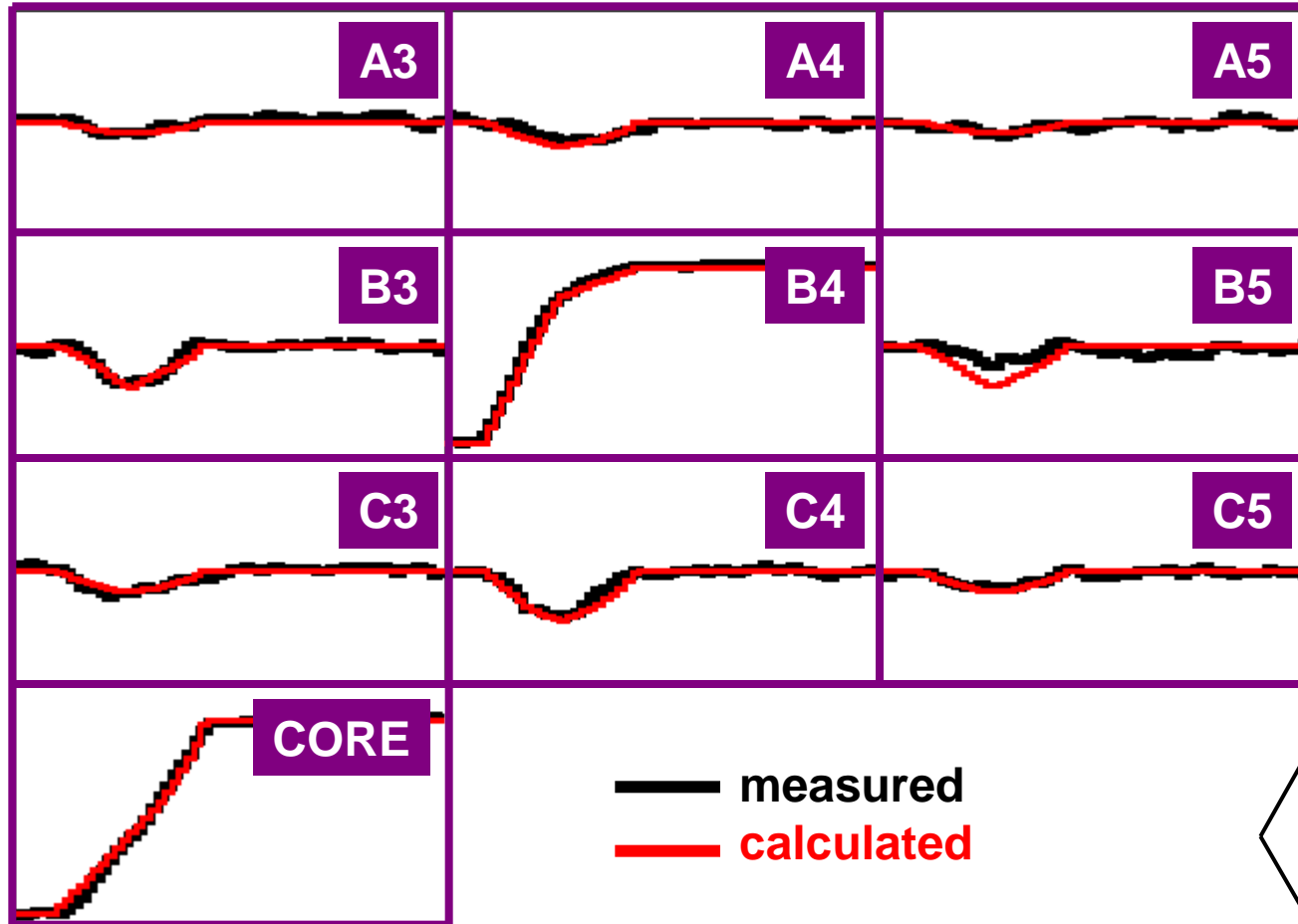
(10, 20, 46)



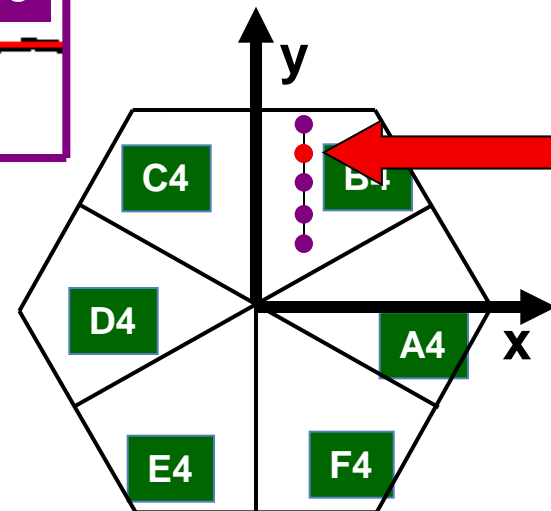
z = 46 mm

791 keV deposited in segment B4

Pulse Shape Analysis concept



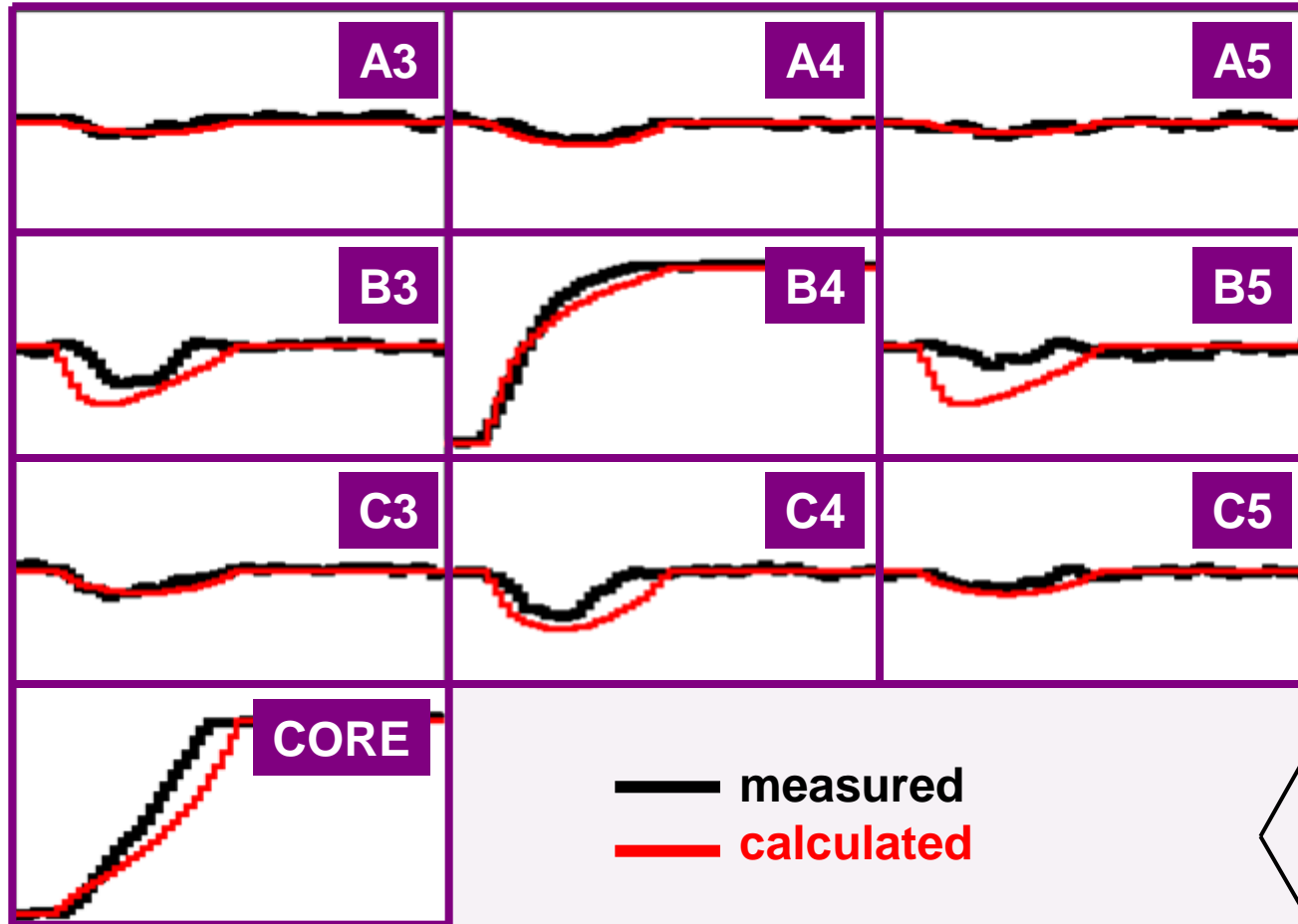
(10, 25, 46)



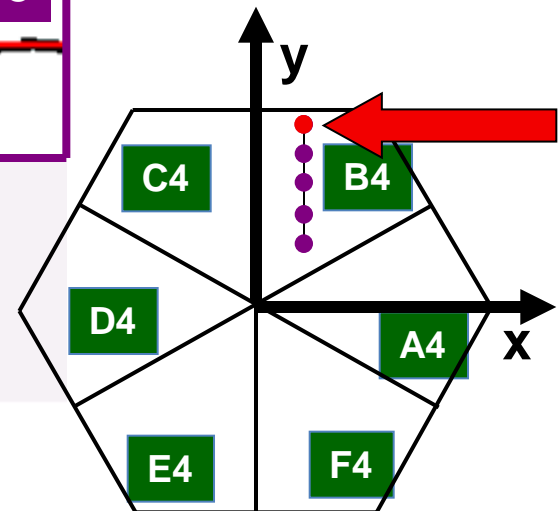
z = 46 mm

791 keV deposited in segment B4

Pulse Shape Analysis concept



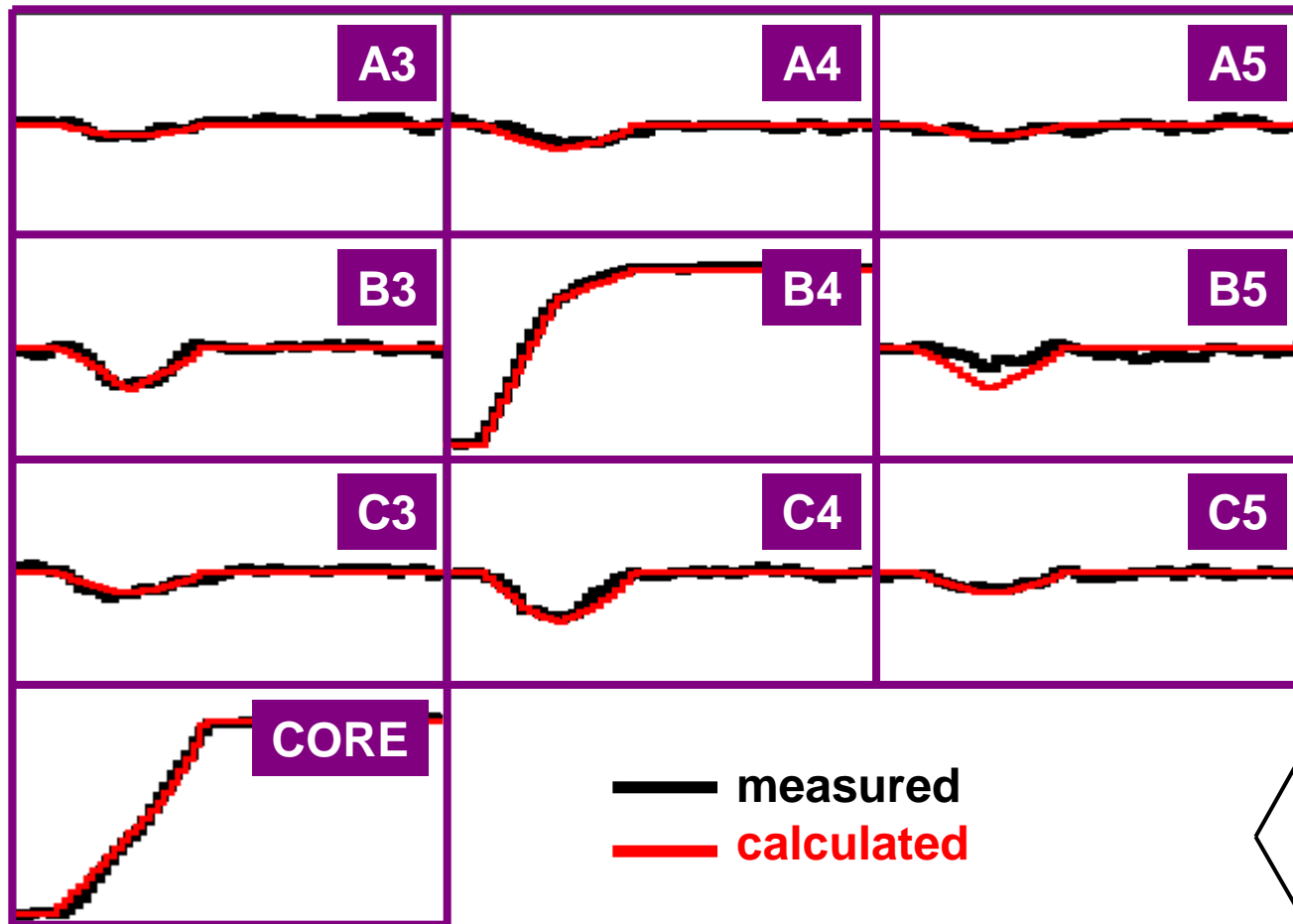
(10, 30, 46)



z = 46 mm

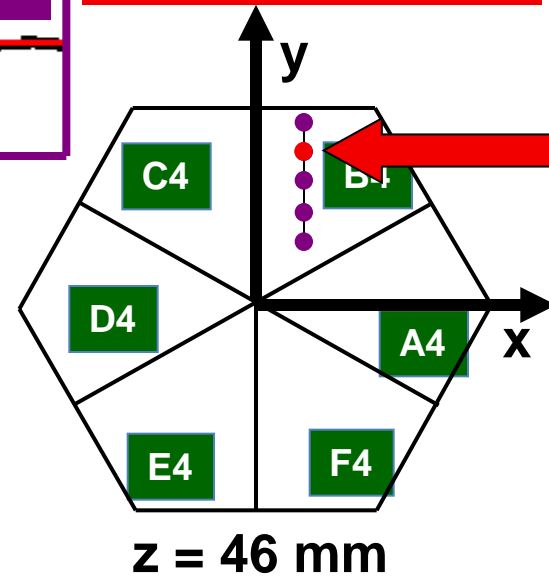
791 keV deposited in segment B4

Pulse Shape Analysis concept



**Result of
Grid Search
Algorithm**

(10, 25, 46)



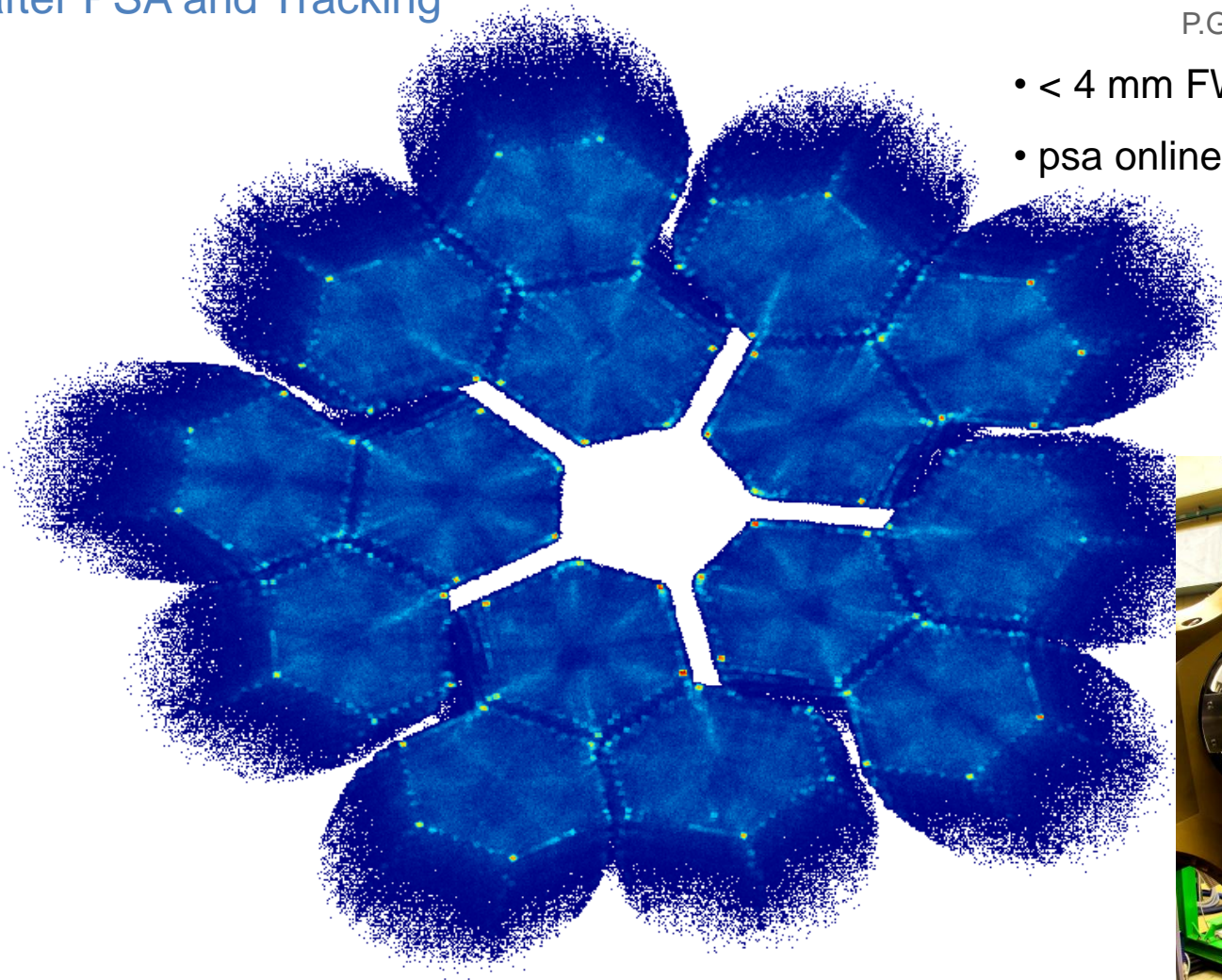
791 keV deposited in segment B4

Result of AGATA tracking

Reconstructed initial gamma rays with:

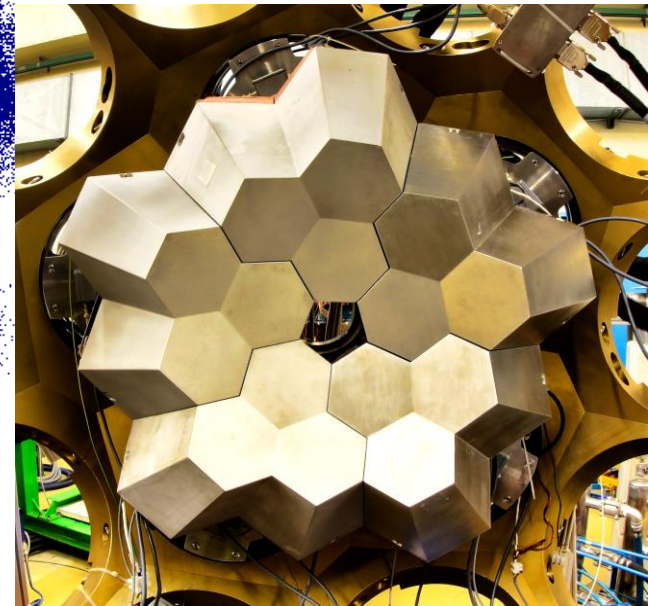
- gamma ray energy
- 1st interaction position → Doppler correction
- 2nd interaction position → Polarization

1st interaction positions
after PSA and Tracking



B. Alikhani, NIM A, 675(0):144 - 154, 2012.
P.G. Bizzeti, EPJA submitted

- < 4 mm FWHM resolution obtained
- psa online at rates > 5kHz per crystal

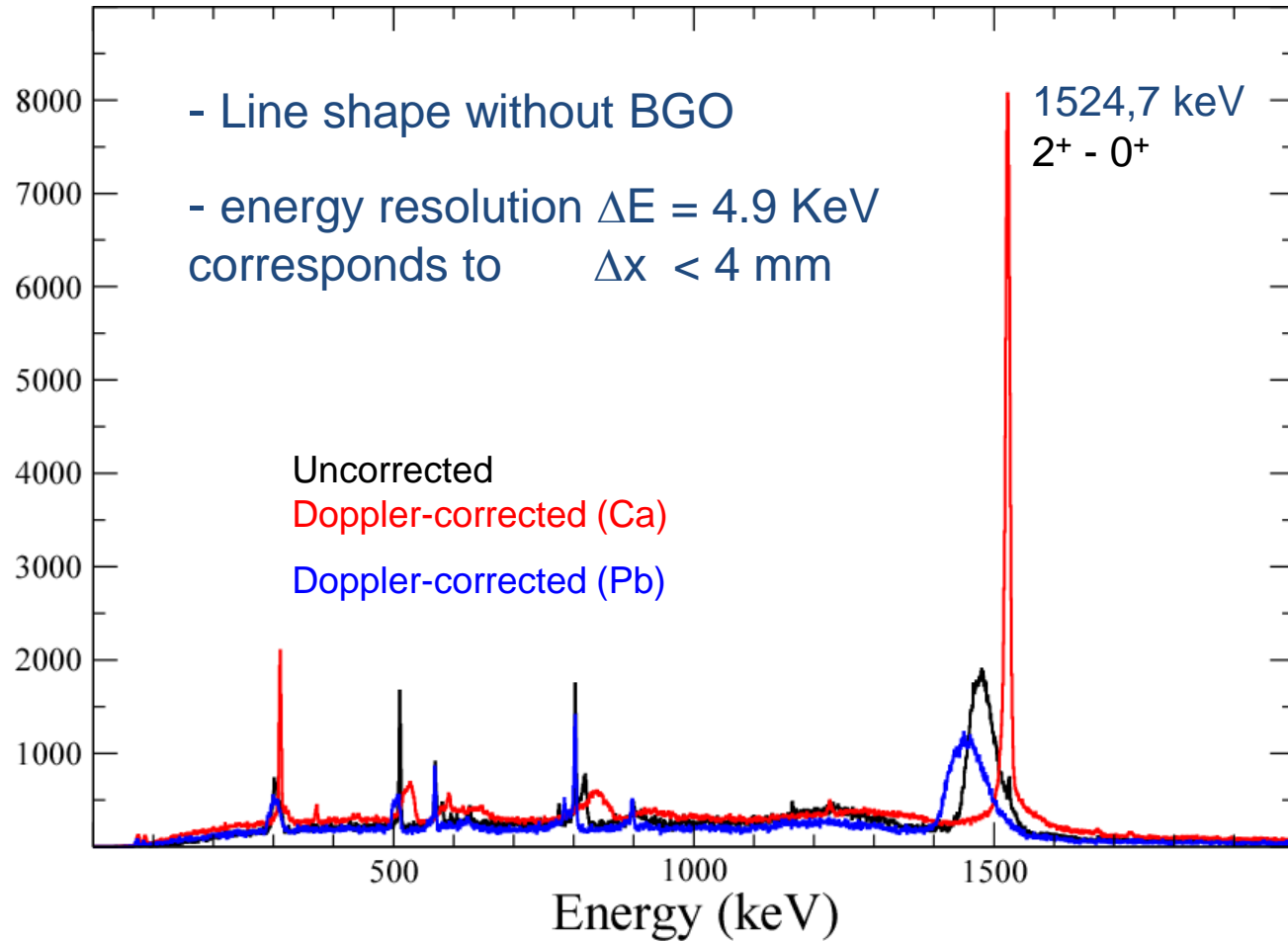
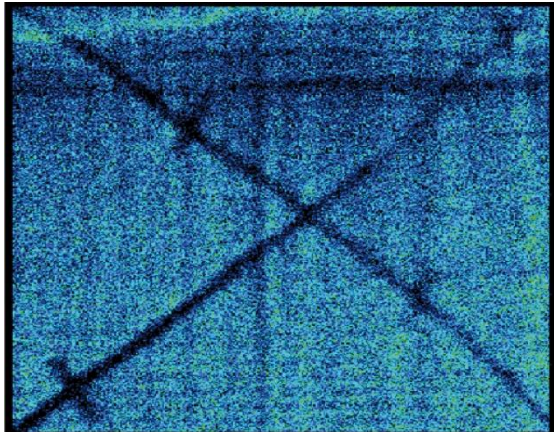


AGATA position resolution

$^{42}\text{Ca}@170\text{MeV} + ^{208}\text{Pb}$

Kinematical coincidences

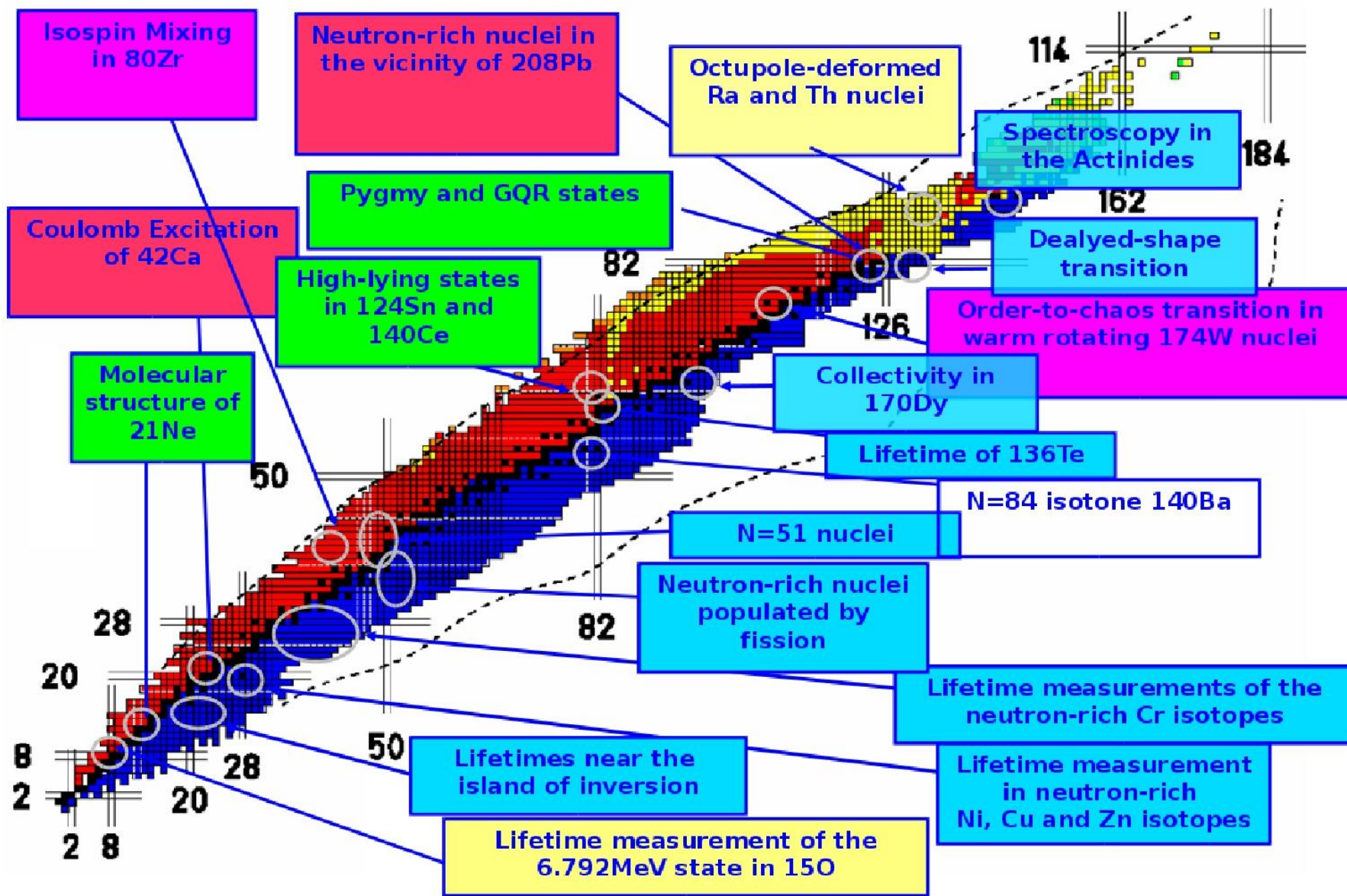
Position sensitive MCP



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

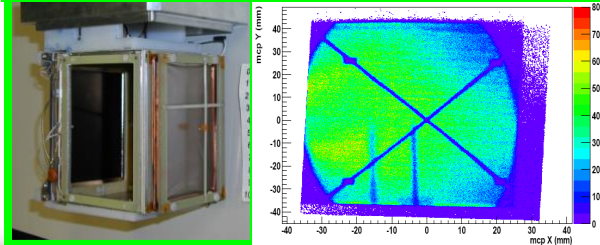
LNL EXPERIMENTS: 20 exps, 148 days, 3500 hs



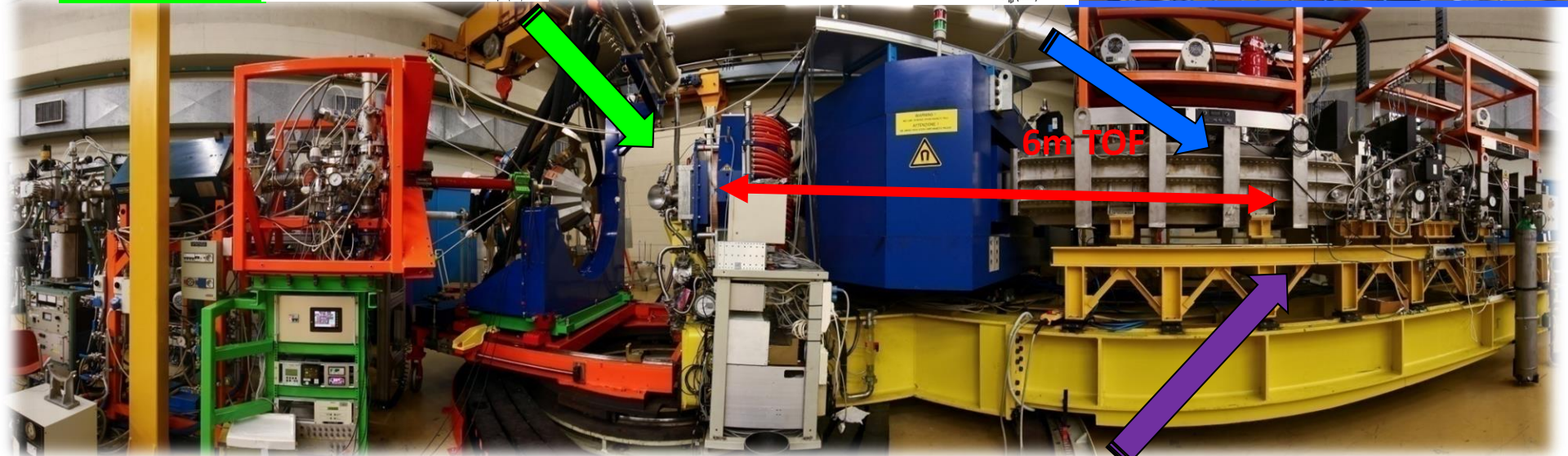
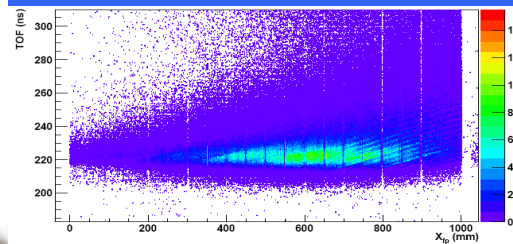
AGATA	PRISMA	TRACE	DANTE	HELENA	DSSSD
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PRISMA: Tracking Magnetic Spectrometer

MCP Start Det.: X,Y & T_i



MWPPAC X,Y & T_F

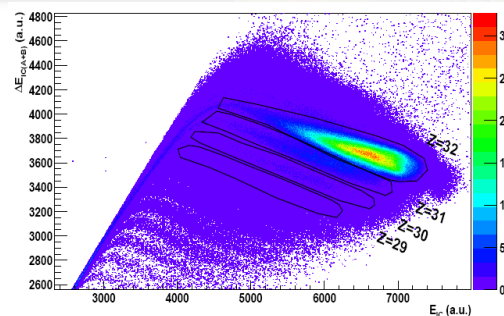


Large acceptance $\Omega = 80$ msr

Charge $\Delta Z/Z \approx 1/60$

Mass $\Delta A/A \approx 1/230$

Max. B $\rho = 1.2$ Tm



Ionisation Chamber $\Delta E - E$



LNL 11.22: Collective properties of n-rich actinides

A. Vogt, B. Birkenbach, K. Geibel, P. Reiter for LNL 11.22 and the AGATA collaboration



Universität zu Köln

Broad range of predictions for collective properties of U and Th nuclei

Shell Correction Energy

A. SOBICZEWSKI, I. MUNTIAN, Z. PATYK, PHYS. REV. C, 63 (2001) 034306

Alternative Parity States

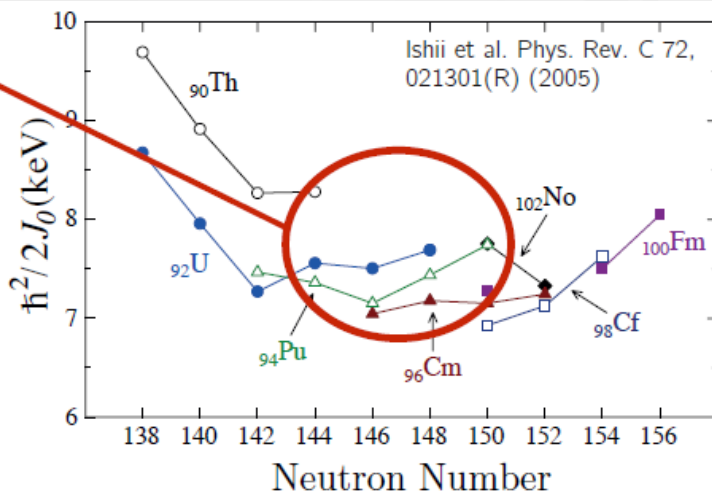
SHNEIDMAN, ET AL. PHYS. REV. C 74, 034316 (2006)

MF and beyond-MF methods, Gogny force

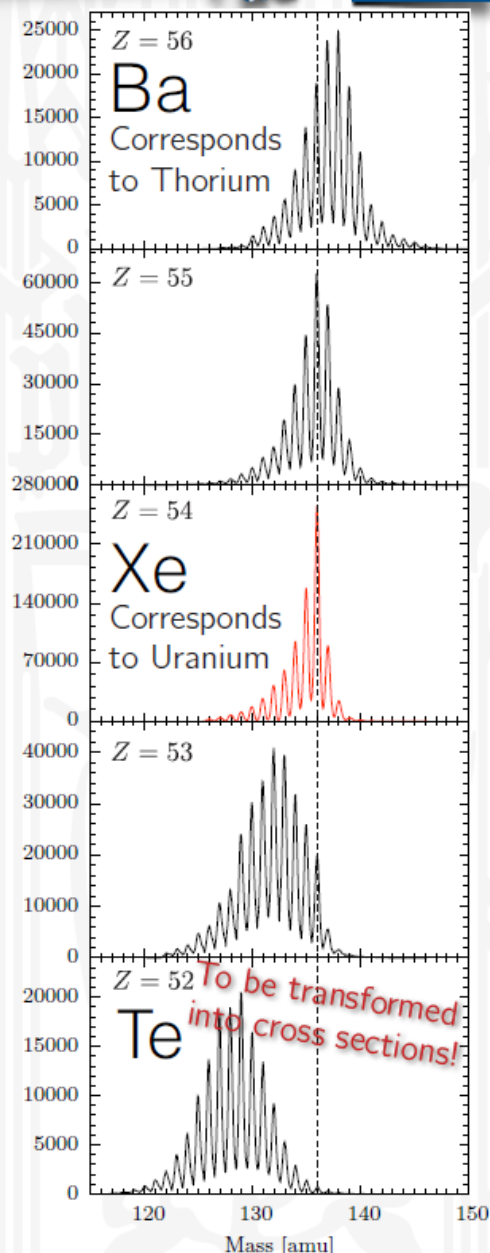
J.-P. DELAROCHE ET AL. NUCLEAR PHYSICS A 771 (2006) 103-168

Relativistic nuclear energy density functionals

D. VRETENAR, ET AL., INT. JOURNAL OF MODERN PHYSICS E (2010)



Measure target-like actinides in kinematic coincidence!



AGATA (x, y, z, E, Id)



²³⁸U target
1 or 2 mg/cm²

Target-like particle (U, Th, ...)

DANTE (x, y)

Doppler correction for both beam- and target-like spectra

$$E_\gamma = E_{\gamma,0} \frac{\sqrt{1 - \beta^2}}{1 - \beta \cos \theta}$$

Beam-like particle (Xe, Ba, ...)

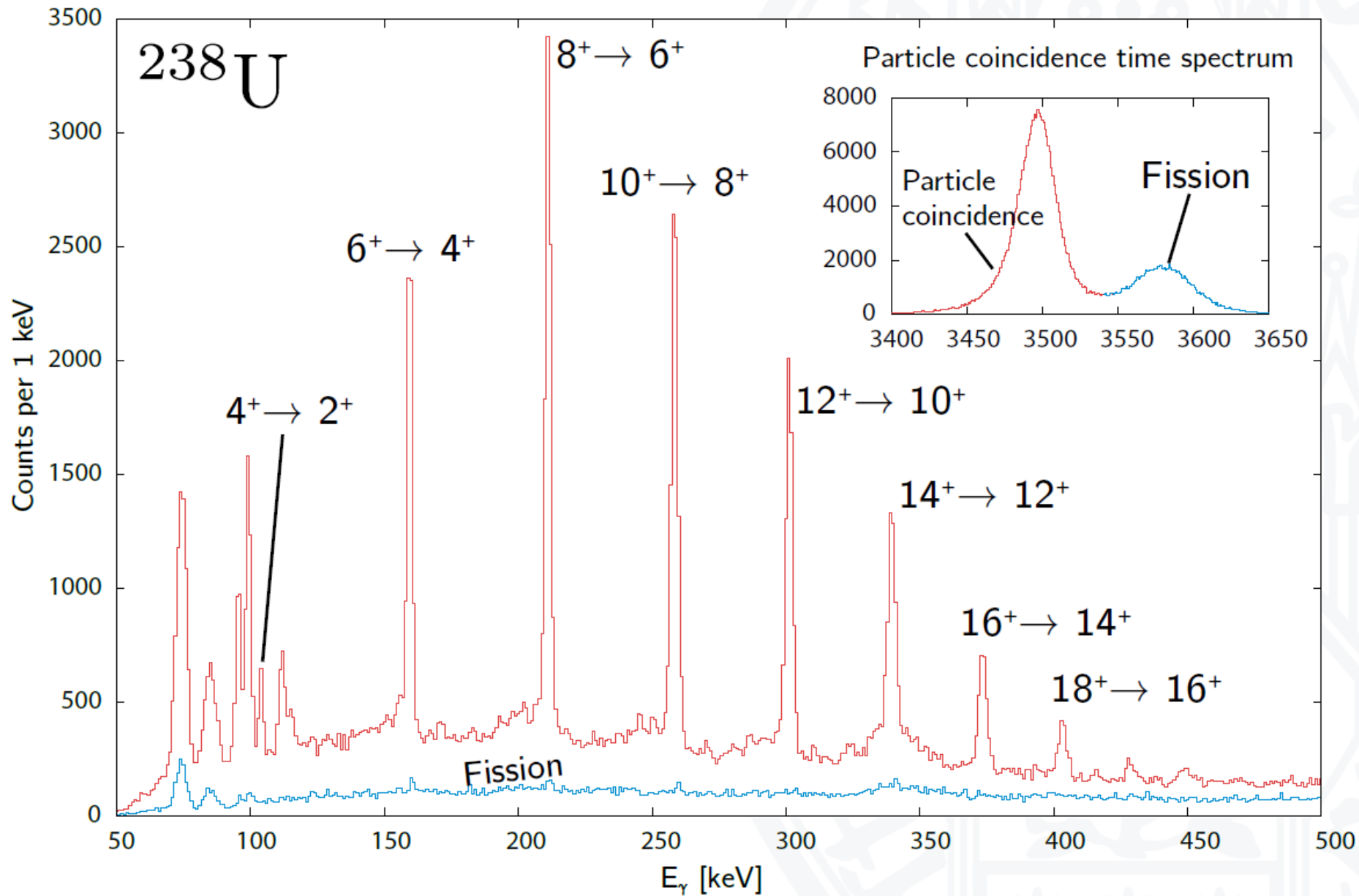
PRISMA (x, y, β , A, Z)

Beam (¹³⁶Xe, 1 GeV, 2 pnA)

Nb backing
1 mg/cm²



Doppler corrected ^{238}U γ -ray spectra

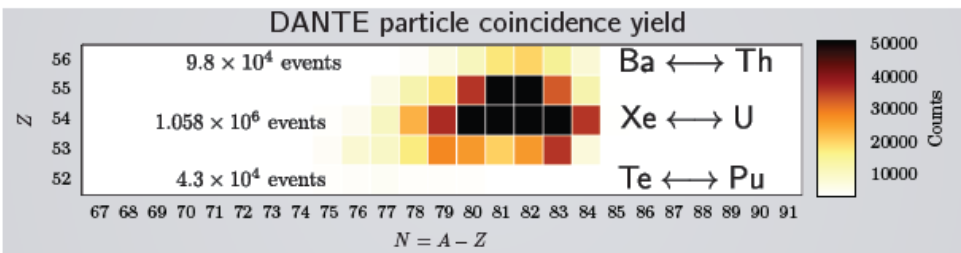


LNL 11.22: Collective properties of n-rich actinides

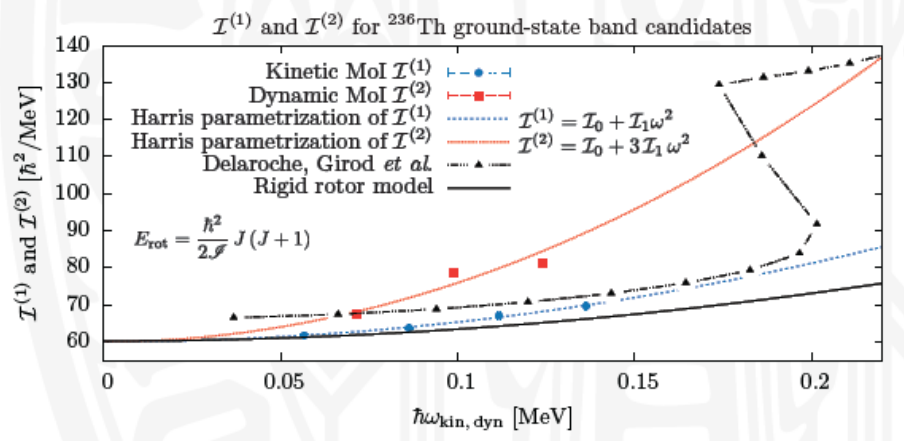
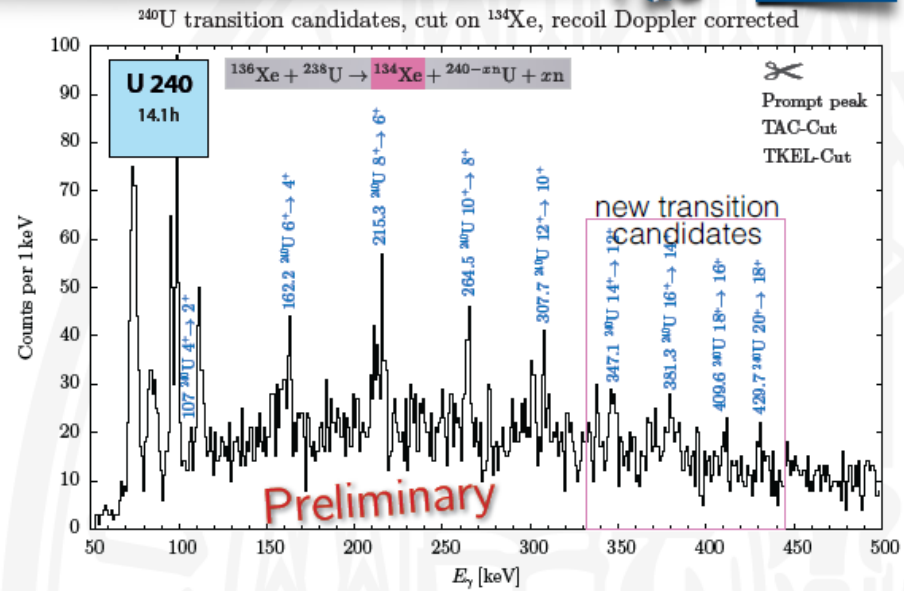
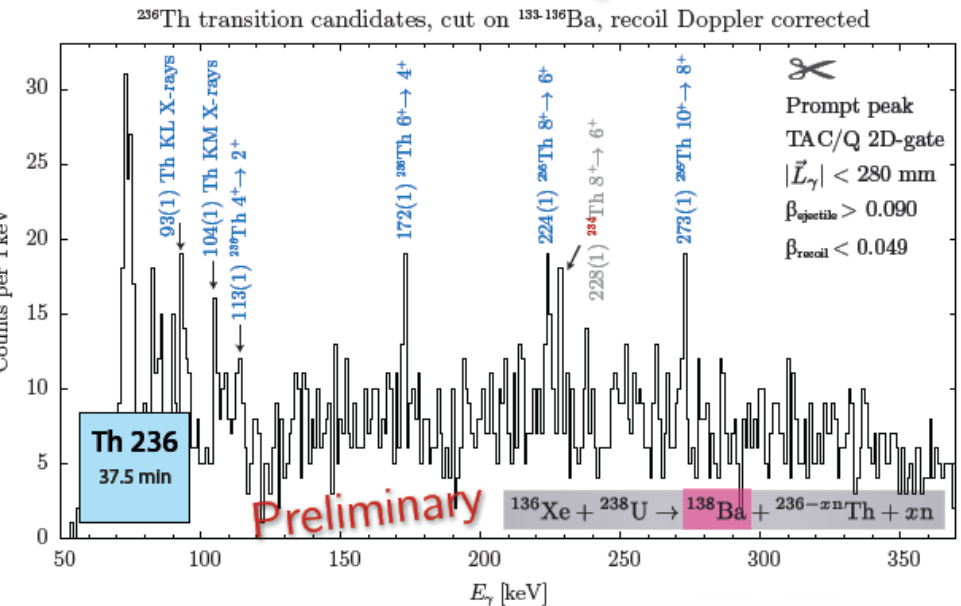
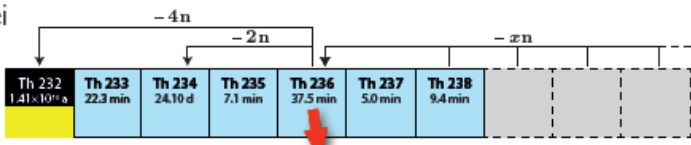
A. Vogt, B. Birkenbach, K. Geibel, P. Reiter for LNL 11.22 and the AGATA collaboration



- Recoil Doppler correction using binary-partner kinematics
- Particle coincidence between PRISMA and DANTE and Q-value used to suppress high fission background

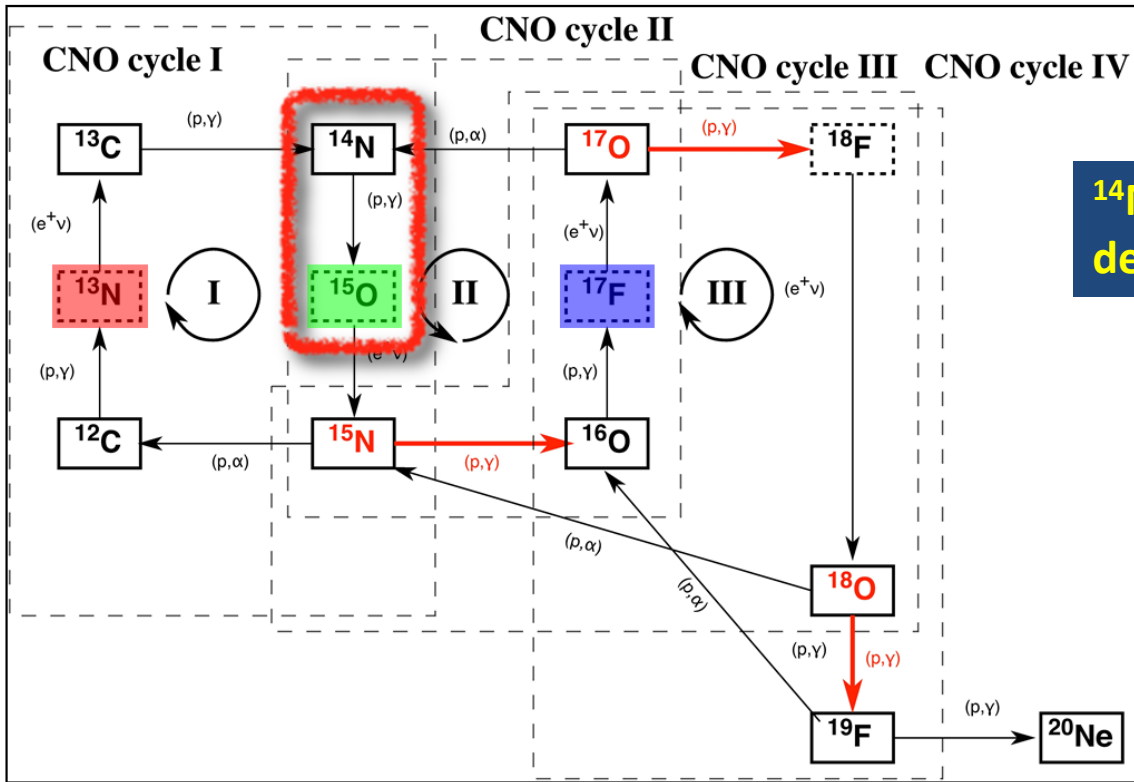


Severe n-evaporation for surviving Th nuclei gate on $^{133-136}\text{Ba}$ for surviving ^{236}Th



This work:	$I_0 = (60.25 \pm 0.09) \frac{\hbar^2}{\text{MeV}}$	$I_1 = (322 \pm 8) \frac{\hbar^4}{\text{MeV}^3}$
Ishii <i>et al.</i> 2007 Phys. Rev. C 72, 021301 (2005)	$I_0 = (62.6 \pm 0.2) \frac{\hbar^2}{\text{MeV}}$	$I_1 = (334 \pm 23) \frac{\hbar^4}{\text{MeV}^3}$
$\Delta E_{2^+ \rightarrow 0^+} = 2 \hbar\omega_{\text{kin}}^{2^+ \rightarrow 0^+} \simeq (49.7 \pm 0.3) \text{ keV}$	Ishii <i>et al.</i> 2007 $\Delta E_{2^+ \rightarrow 0^+} = (48.4 \pm 0.3) \text{ keV}$	

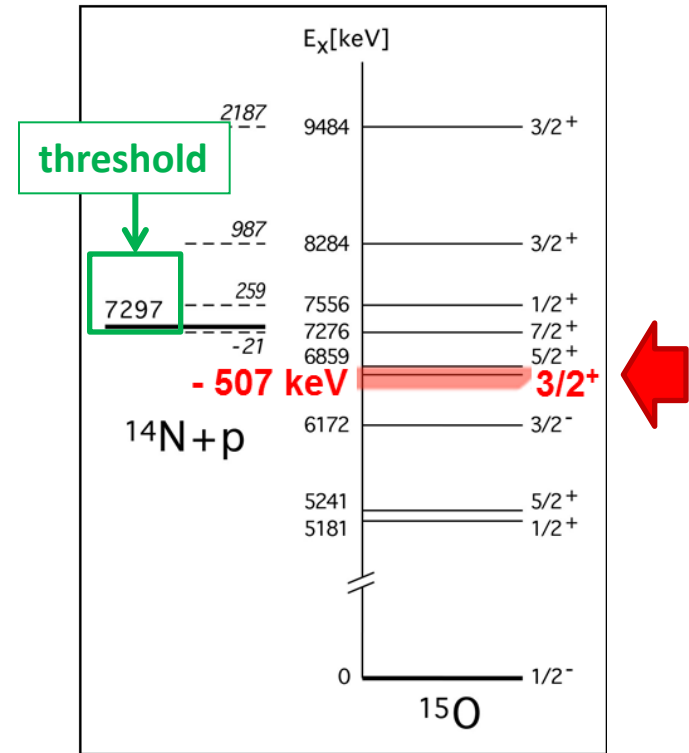
Stellar burning rates and the $^{14}\text{N}(p,\gamma)^{15}\text{O}$ reaction



$^{14}\text{N}(p,\gamma)^{15}\text{O}$ reaction is slowest, determines the overall rate

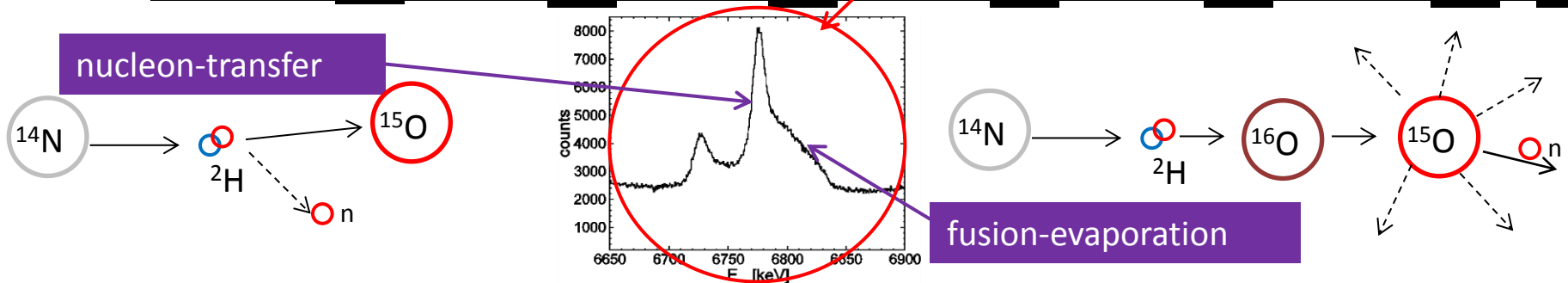
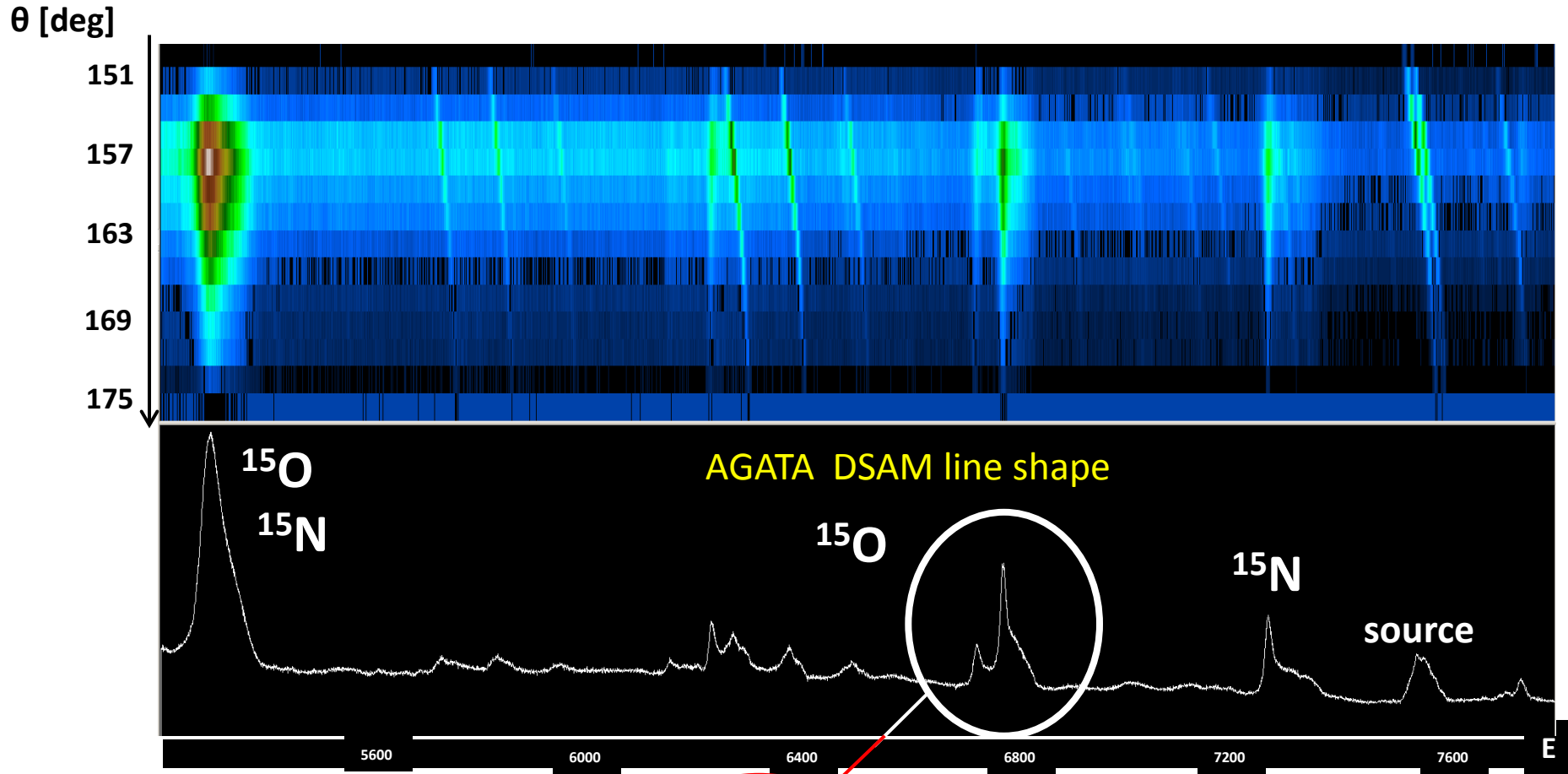
(C. Broggini et al., Annu. Rev. Nucl. Part. Sci. 2010. 60:53–73)

- cross section (astrophysical S-factor) in Gamow peak region relies on sub-threshold resonances
- corresponding to bound states in ^{15}O
- first excited $3/2^+$ state at 6.792 MeV in ^{15}O plays dominant role



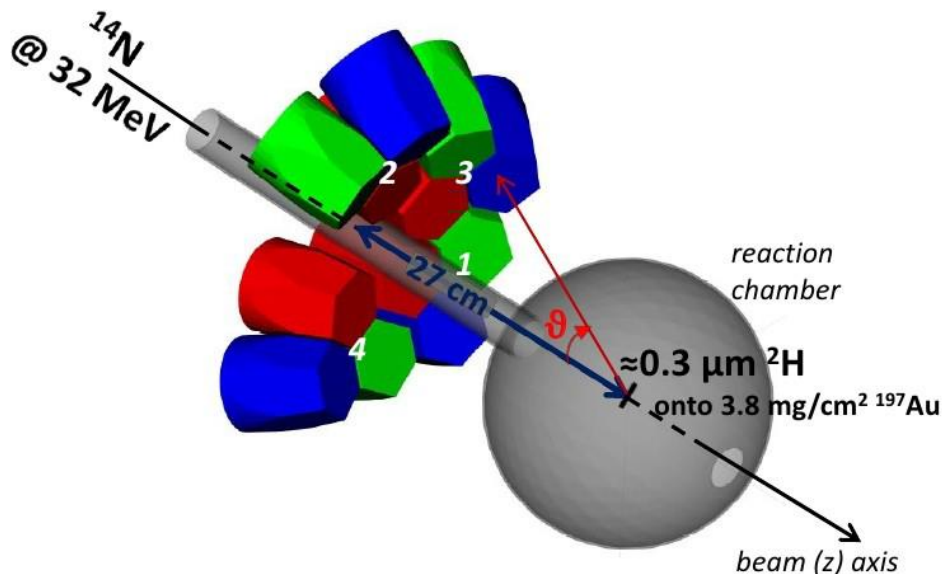
width of the resonance \longleftrightarrow lifetime of the excited nuclear level

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



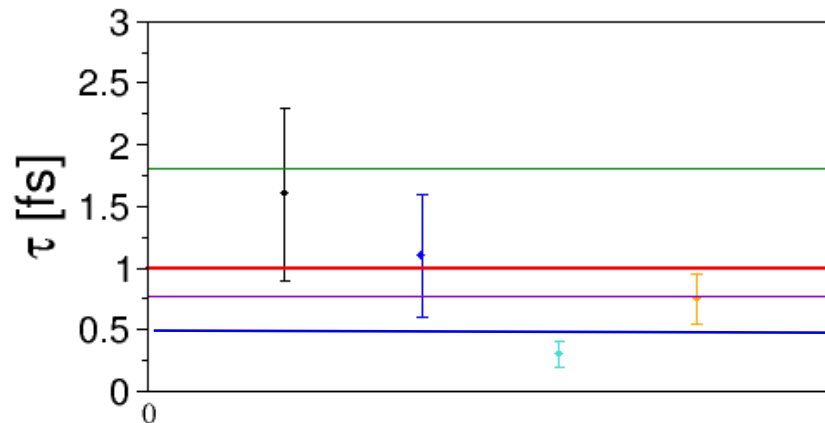
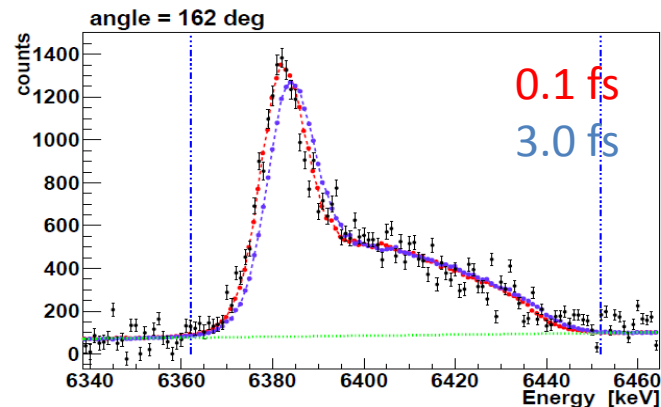
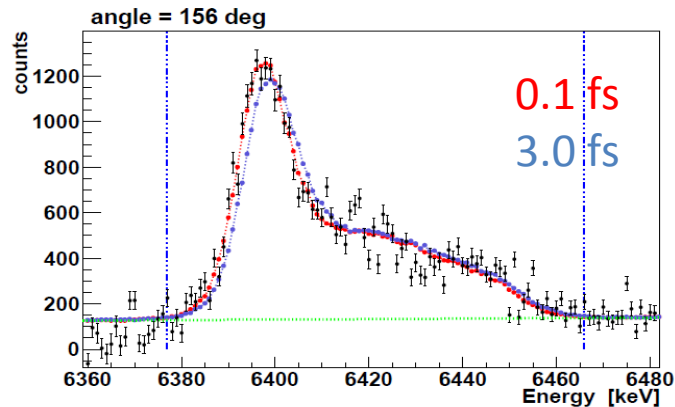
LIFETIME MEASUREMENT of 6.79 MeV in ^{15}O

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

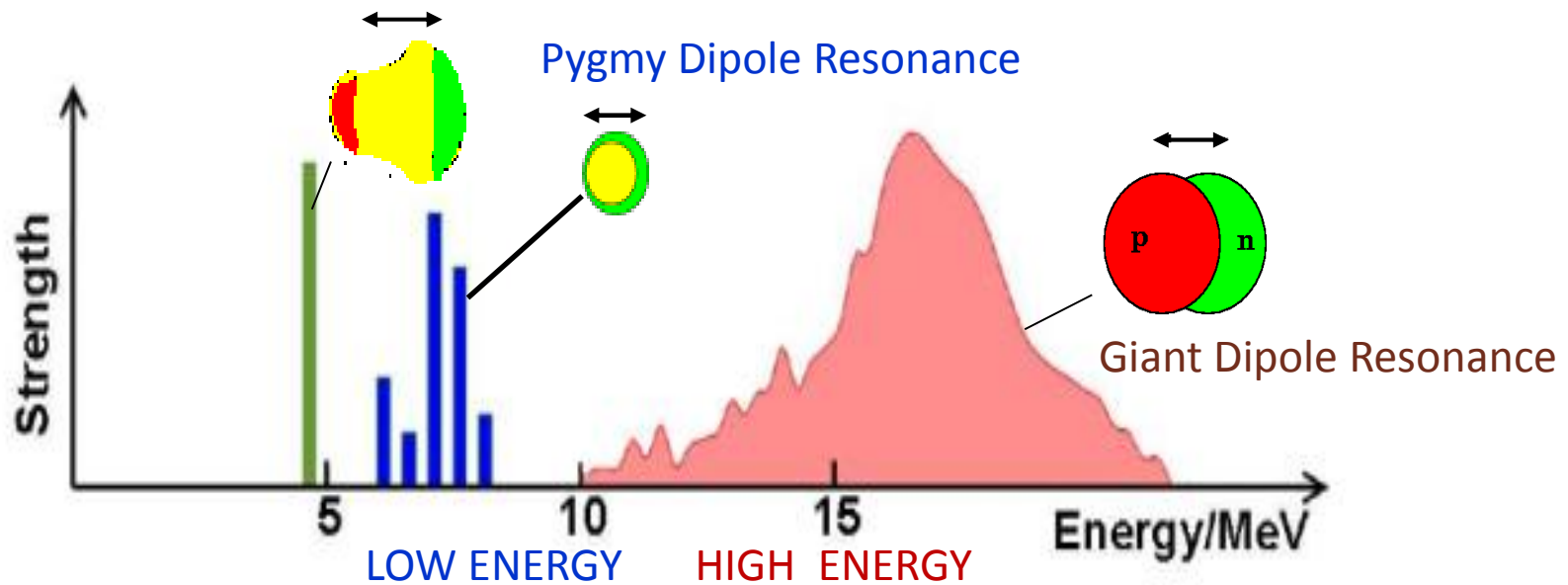


New upper limit of < 0.5 fs on the lifetime of the 6.79 MeV state in ^{15}O

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



Low lying E1 strength & Pygmy dipole resonance



Inelastic scattering of ^{17}O @ 20 MeV/u on different targets + γ -rays in coincidence

HECTOR+



TWO EXPERIMENTS PERFORMED:

Studied Nuclei: ^{208}Pb ^{90}Zr

R. Nicolini (Università di Milano /INFN)

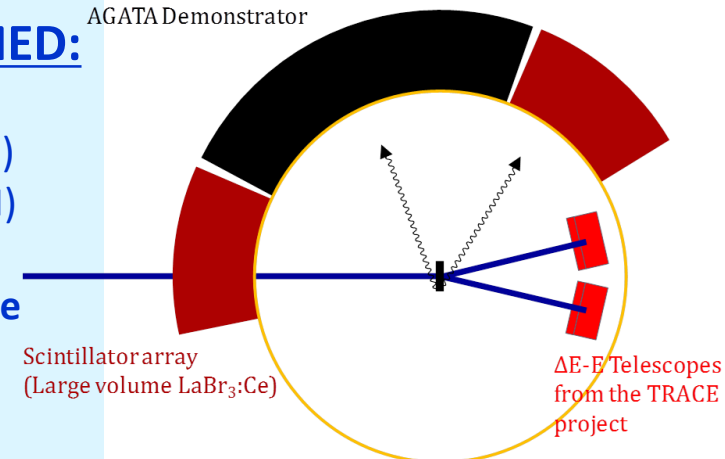
D.Mengoni (Università di Padova/INFN)

Studied nuclei: ^{208}Pb , ^{124}Sn , ^{140}Ce

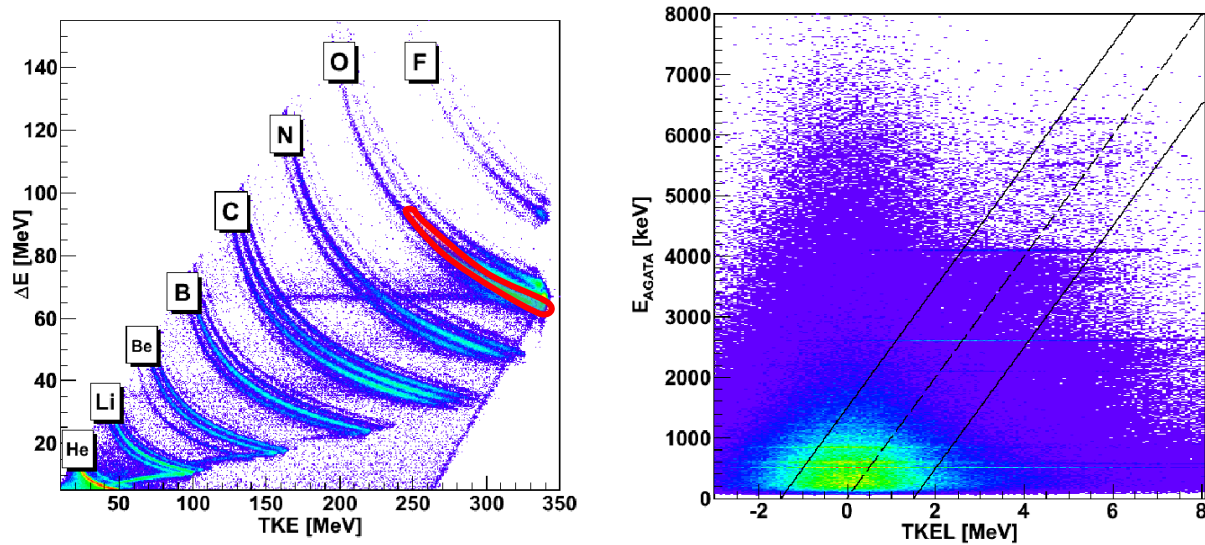
M. Kmiecik (IFJ PAN Kraków),

F. Crespi (Univ. di Milano/INFN)

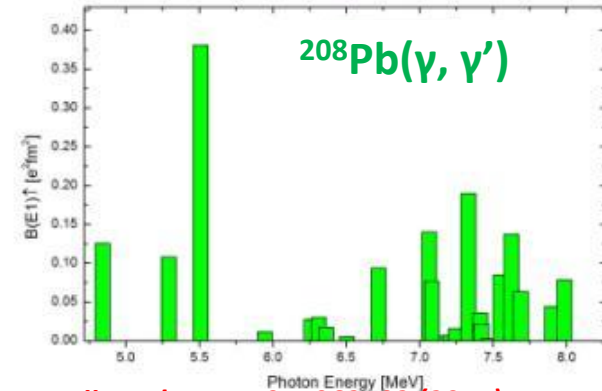
AGATA Demonstrator



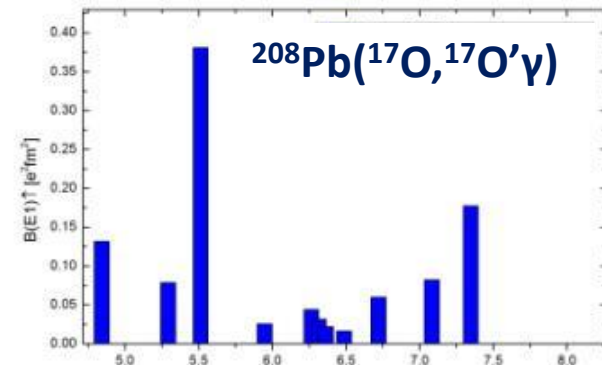
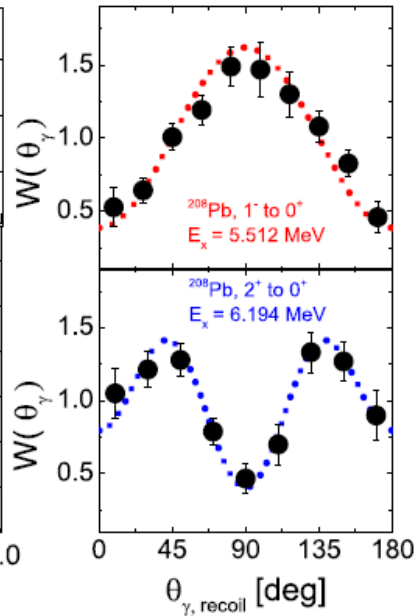
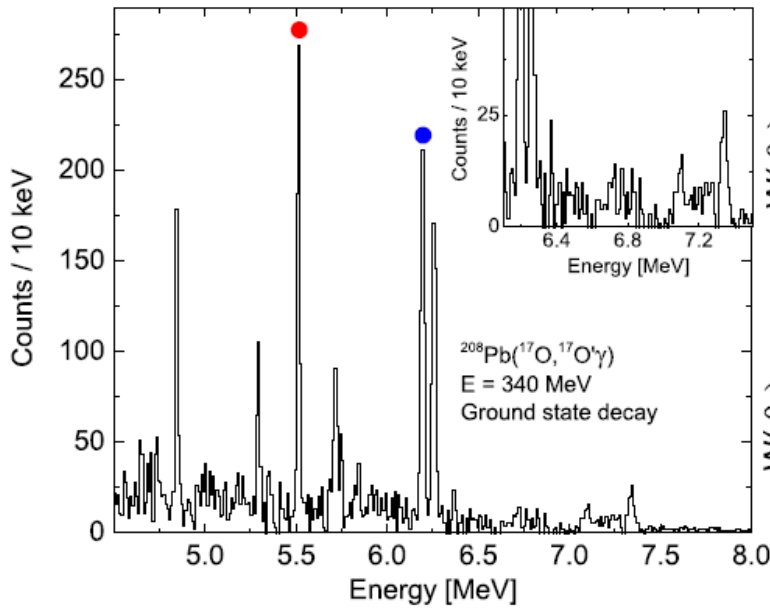
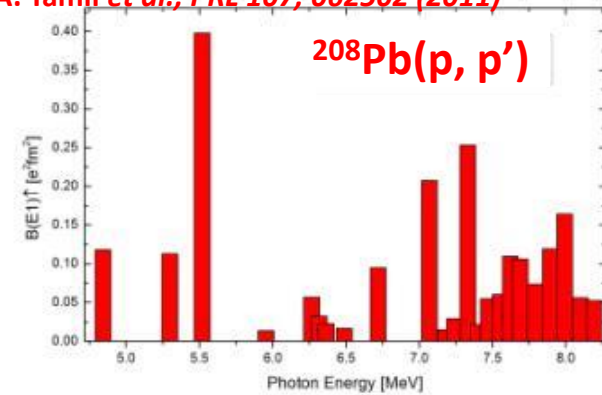
Pygmy dipole states in ^{208}Pb



N. Ryezayeva et al., PRL 89, 272502 (2002)



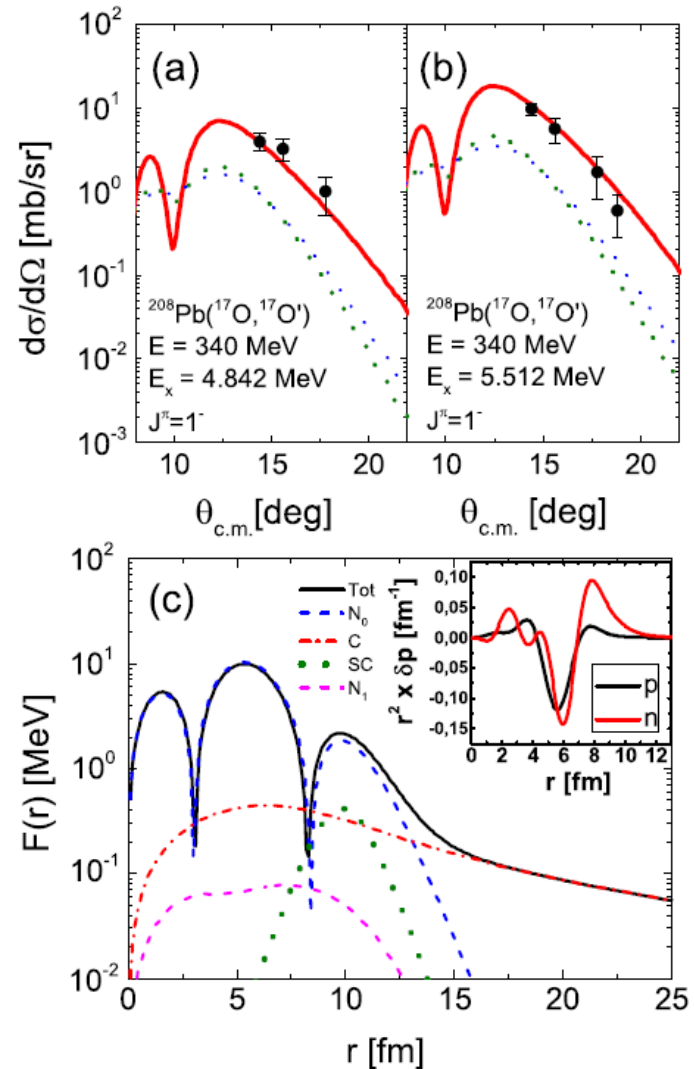
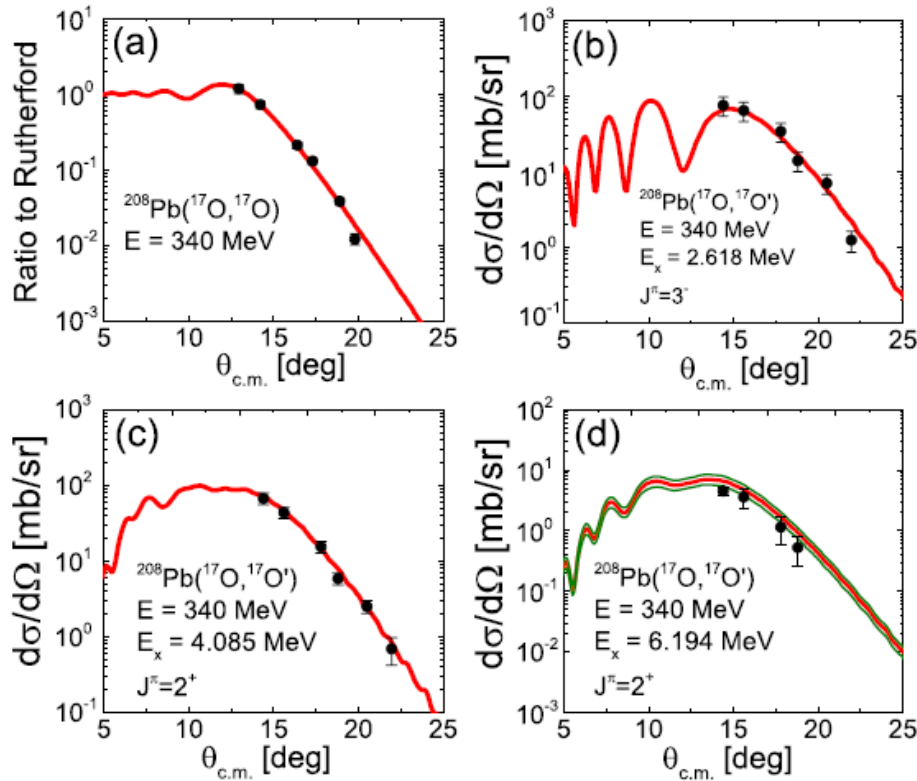
A. Tamii et al., PRL 107, 062502 (2011)



Different states are selectively populated in the isoscalar and isovector part of the GDR

Pygmy dipole states in ^{208}Pb

Differential cross sections for excitation of the 1^- @ 4.842 MeV and @ 5.512 MeV
DWBA calculations with microscopic form factor for isoscalar E1 excitation



F. Crespi, A. Bracco et al., Phys. Rev. Lett. **113**,012501 (2014)
see also AGATA results on ^{124}Sn
L. Pellegrini, A. Bracco et al. Phys. Lett. B **738** (2014) 519-523

Theory: E. Lanza et al., Phys.Rev. C **84** (2011) 064602

Summary

- Status AGATA:
 - ✓ 37 highly segmented HPGe detectors
 - ✓ digitizer & front-end electronics
 - ✓ pulse shape analysis & γ -ray tracking
 - ✓ position sensitive γ -ray detection: $\Delta x \sim 3\text{-}4$ mm
- Improved conditions for in-beam γ -ray spectroscopy
 - energy resolution (reduced Doppler effects)
 - efficiency at higher energies
 - polarization
- Physics campaigns
 - results from AGATA demonstrator at LNL
 - GSI campaign analysis ongoing
 - commissioning AGATA @ GANIL

