

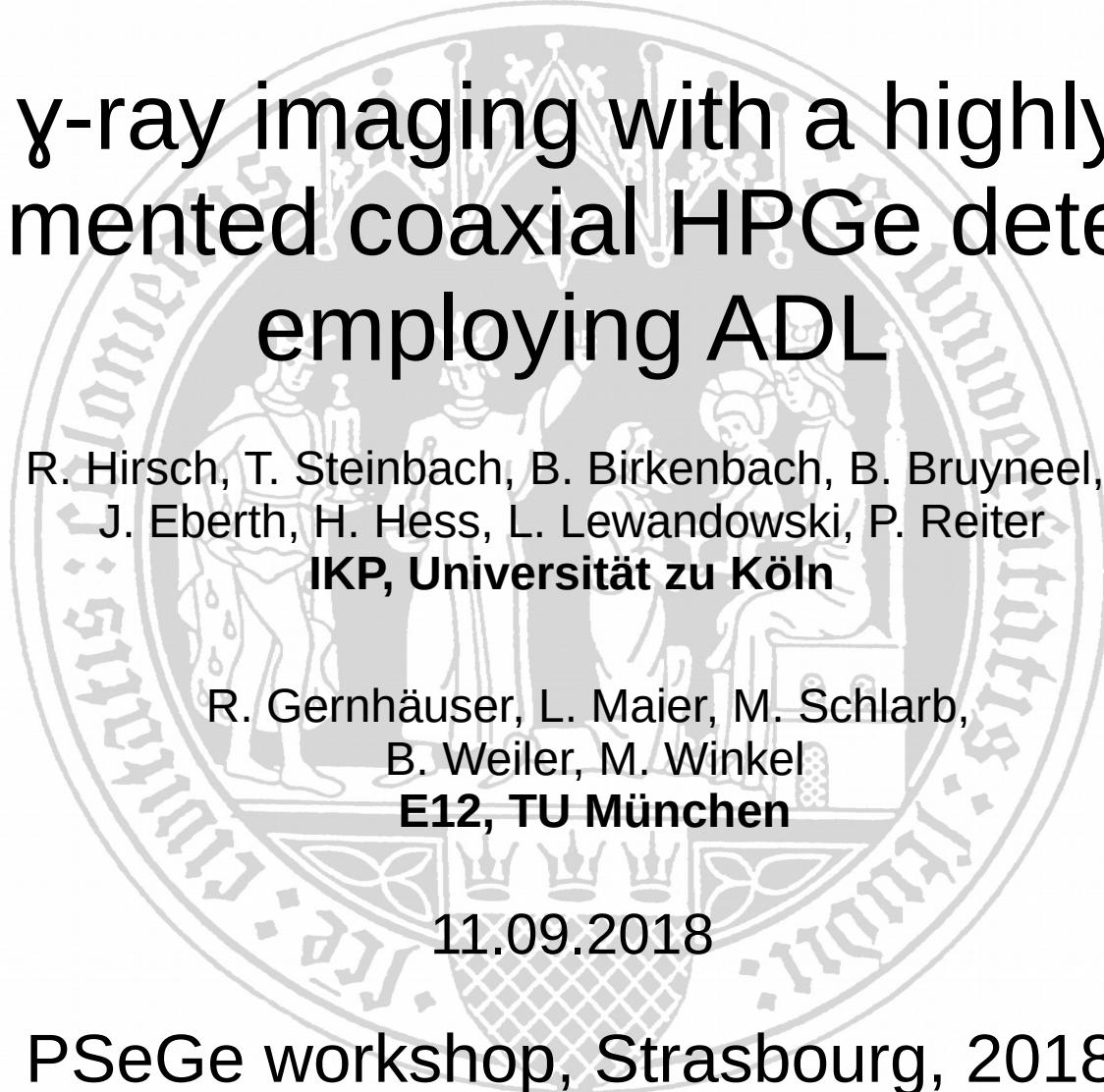
γ -ray imaging with a highly segmented coaxial HPGe detector employing ADL

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IKP, Universität zu Köln

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B. Weiler, M. Winkel
E12, TU München

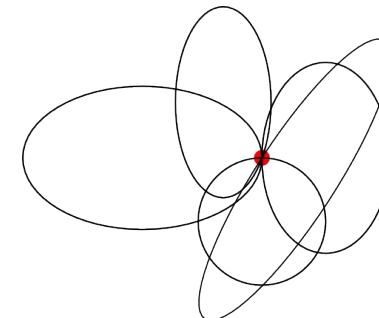
11.09.2018

PSeGe workshop, Strasbourg, 2018



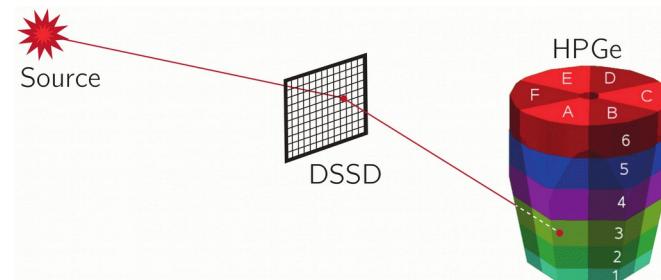
Overview

Compton camera principle



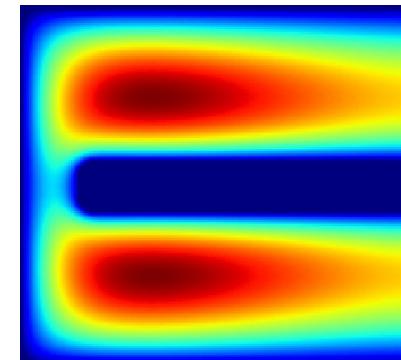
Experimental setup

- Detector setup
- Results



New HPGe Detector

- AGATA Detector Library
- Performance
- Status

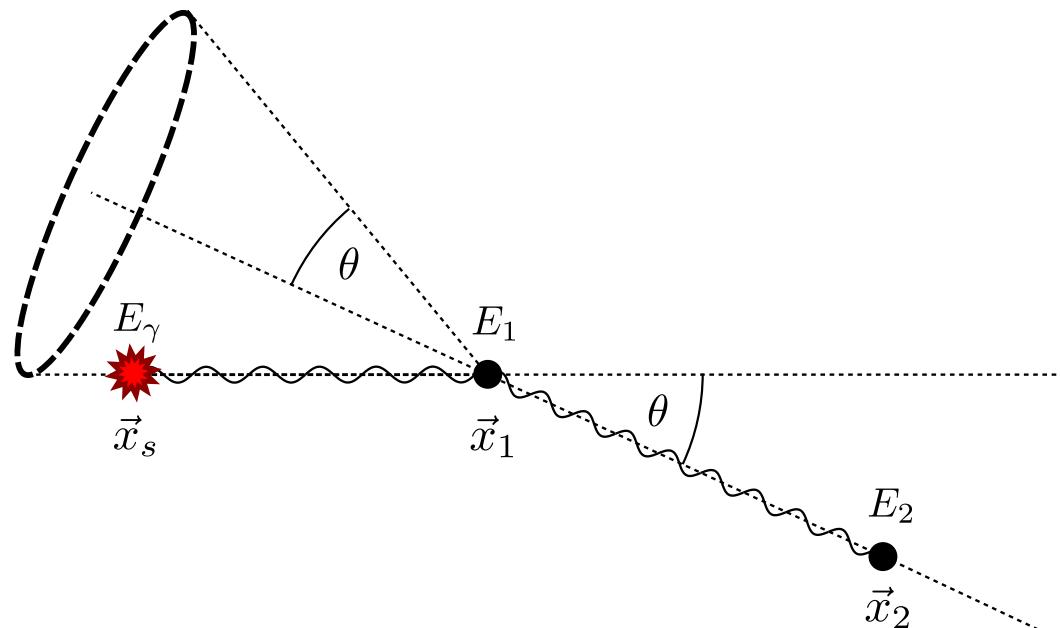


Compton camera principle

Imaging requires:

- Energy E_γ
- Energy loss due to Compton scattering E_1
- Interaction points and sequence
- Multiple events

$$\cos(\theta) = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma - E_1} \right)$$

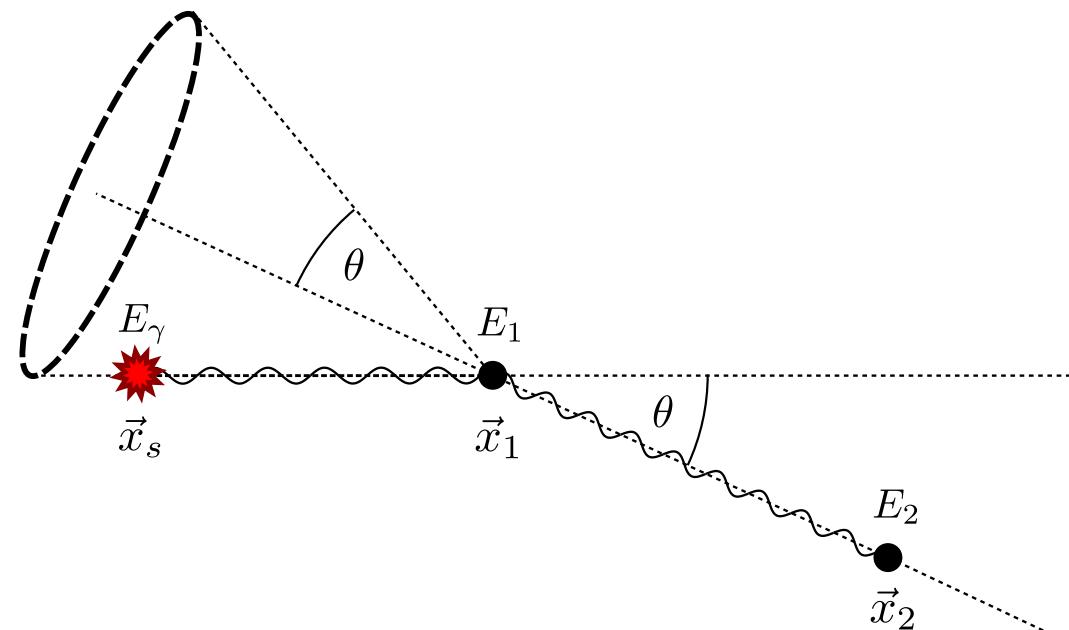
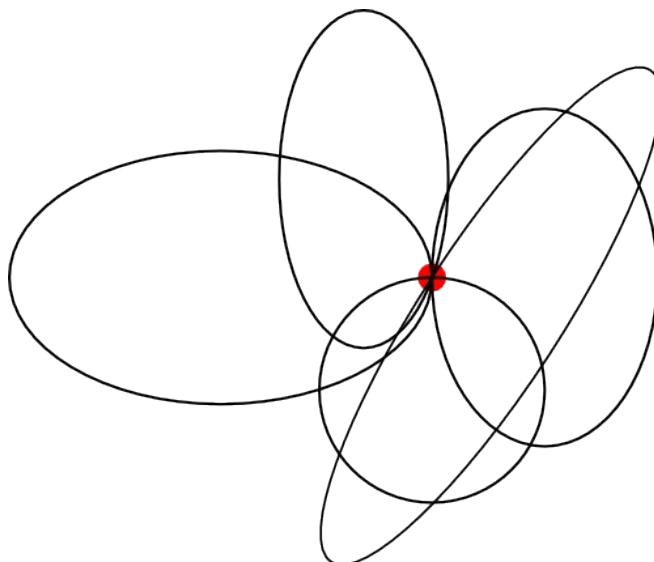


Compton camera principle

Imaging requires:

- Energy E_γ
- Energy loss due to Compton scattering E_1
- Interaction points and sequence
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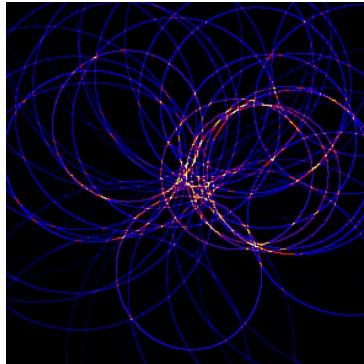
$$\cos(\theta) = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma - E_1} \right)$$



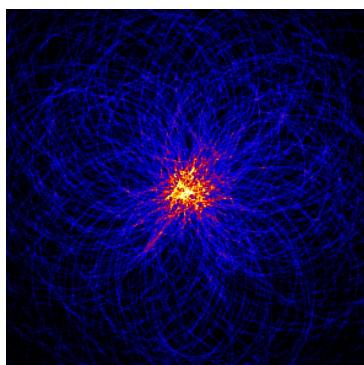
Compton camera principle

Imaging requires:

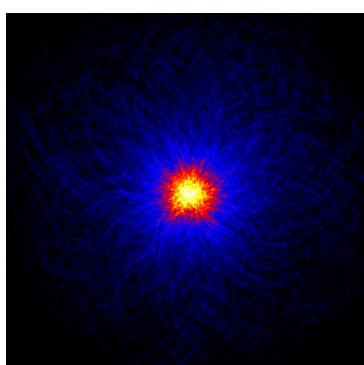
- Energy E_γ
- Energy loss due to Compton scattering E_1
- Interaction points and sequence
- Multiple events



50 events

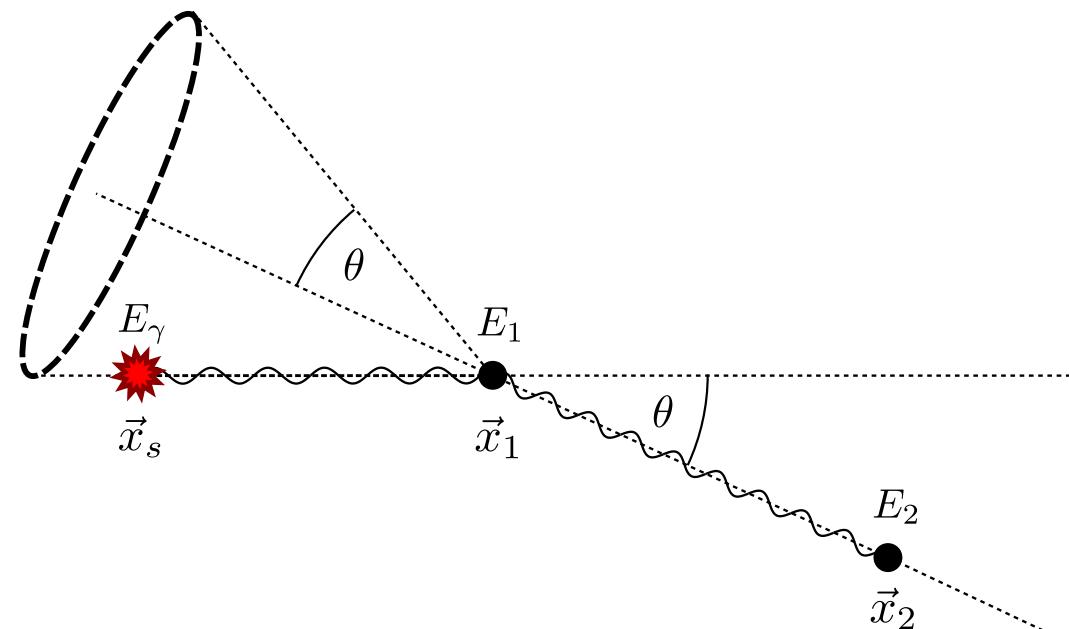


500 events

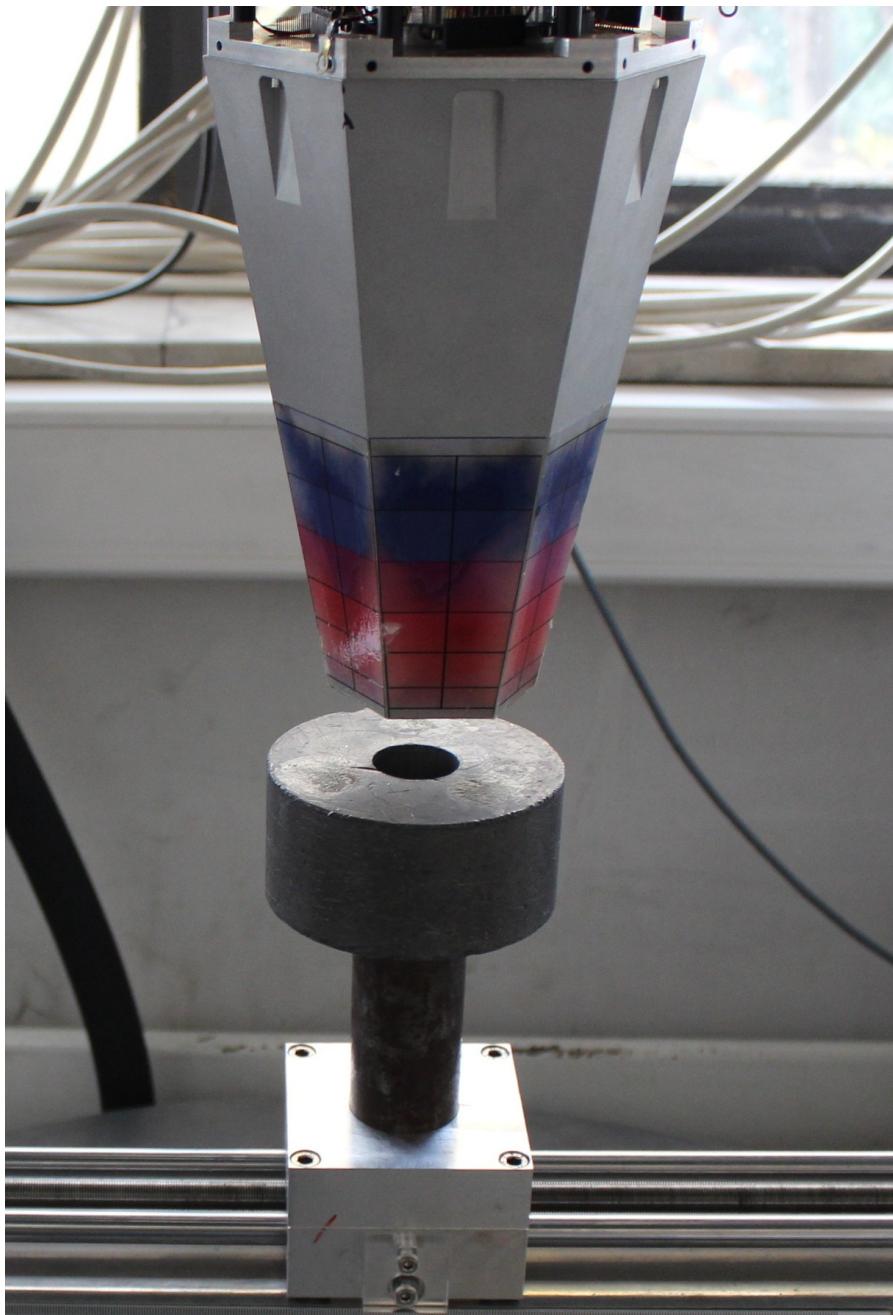


5000 events

$$\cos(\theta) = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma - E_1} \right)$$

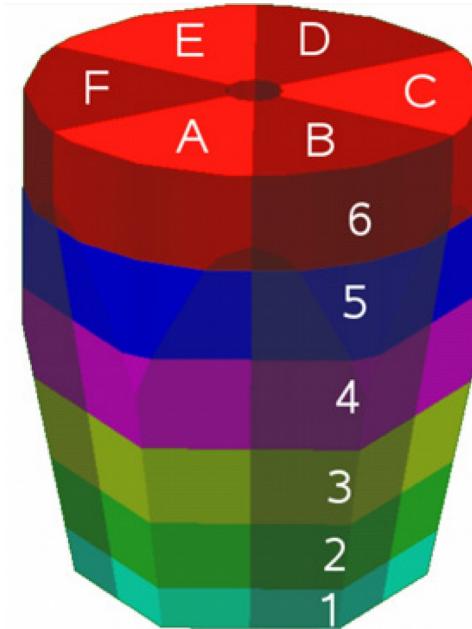


Detector setup



Highly segmented HPGe detector

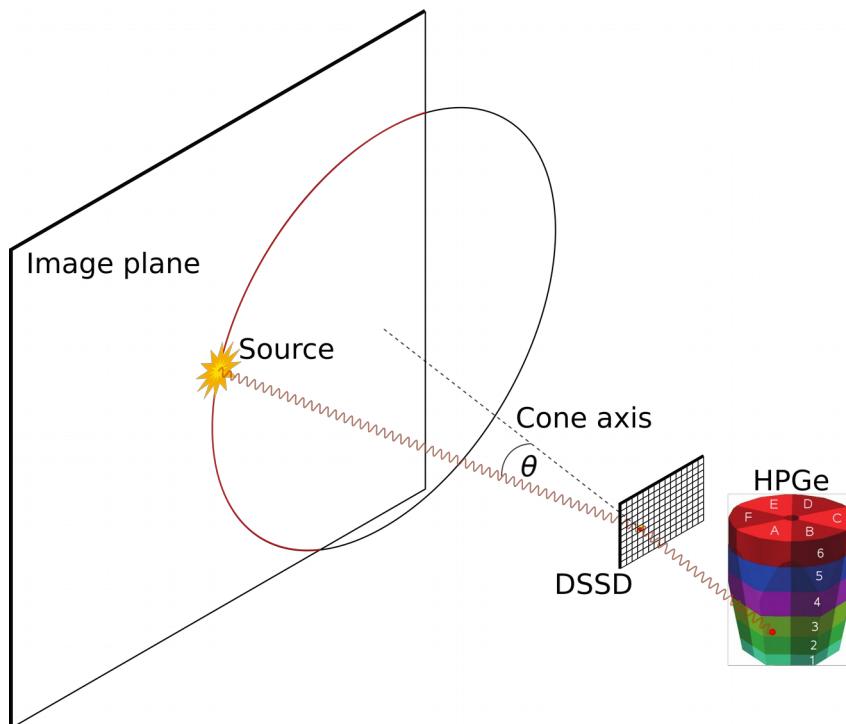
- AGATA detector S001
- $h=89\text{mm}$ $\varnothing=80\text{mm}$
- 71.1% efficiency
- 36 segments
- 10° symmetric hexagonal tapered
- Sub segment spacial resolution due to pulse-shape analysis (PSA)



Operation modes

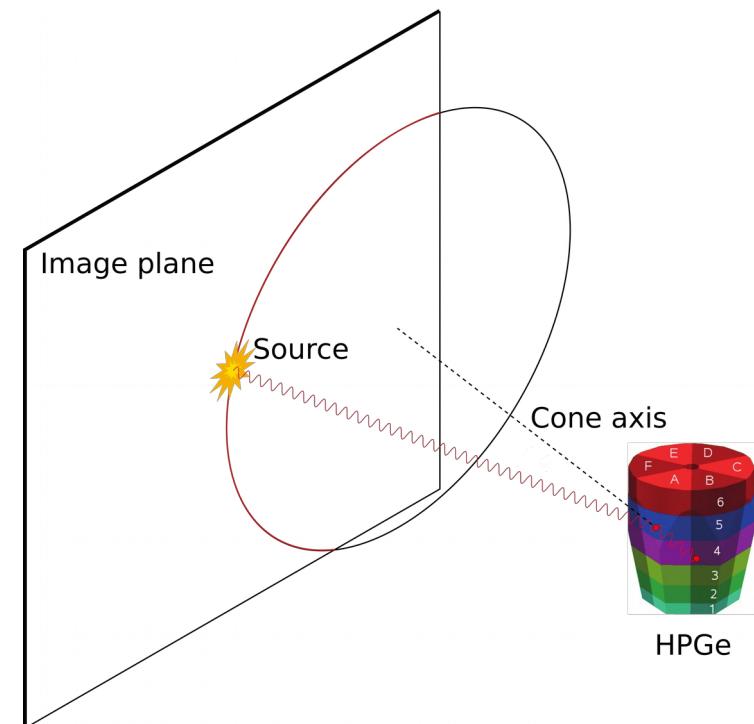
Coincidence mode DSSD + HPGe

- Excellent energy resolution
- High angular resolution
- Low efficiency
- Anisotropic sensitivity



HPGe stand-alone mode

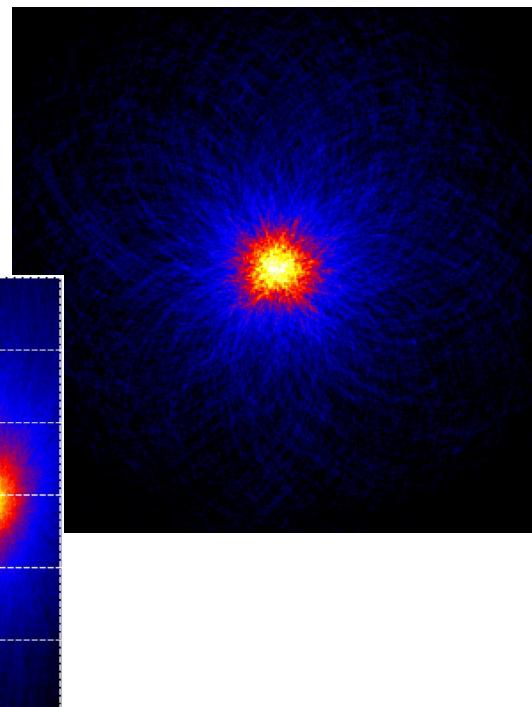
- Excellent energy resolution
- High efficiency
- Isotropic sensitivity
- Reduced angular resolution



Imaging results

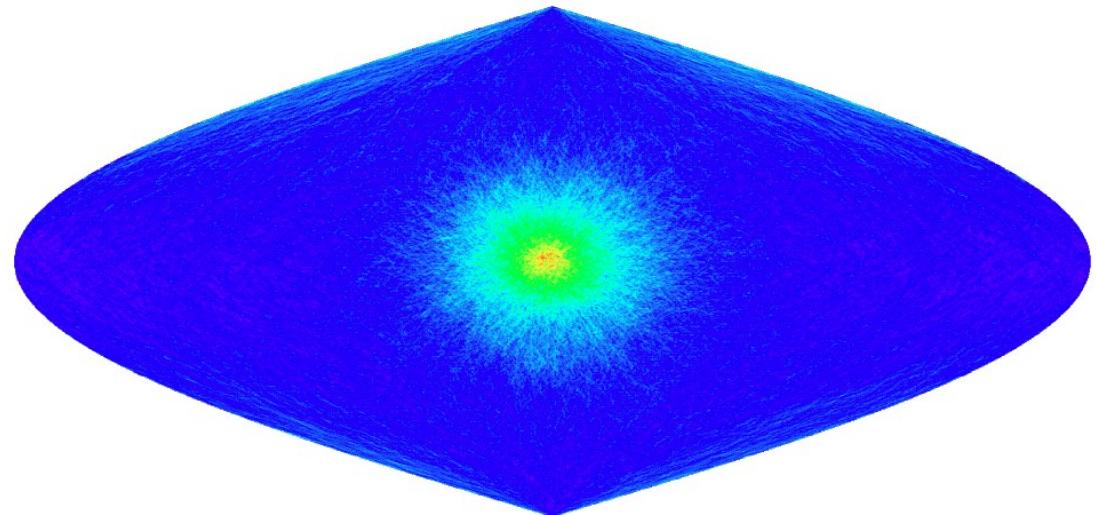
- **Coincidence mode**

- Angular resolution 4.6°
- Low efficiency (1.7×10^{-5})



- **HPGe stand-alone mode**

- Higher efficiency (up to 6.9%)
- Lower angular resolution (between 19° and 14°)



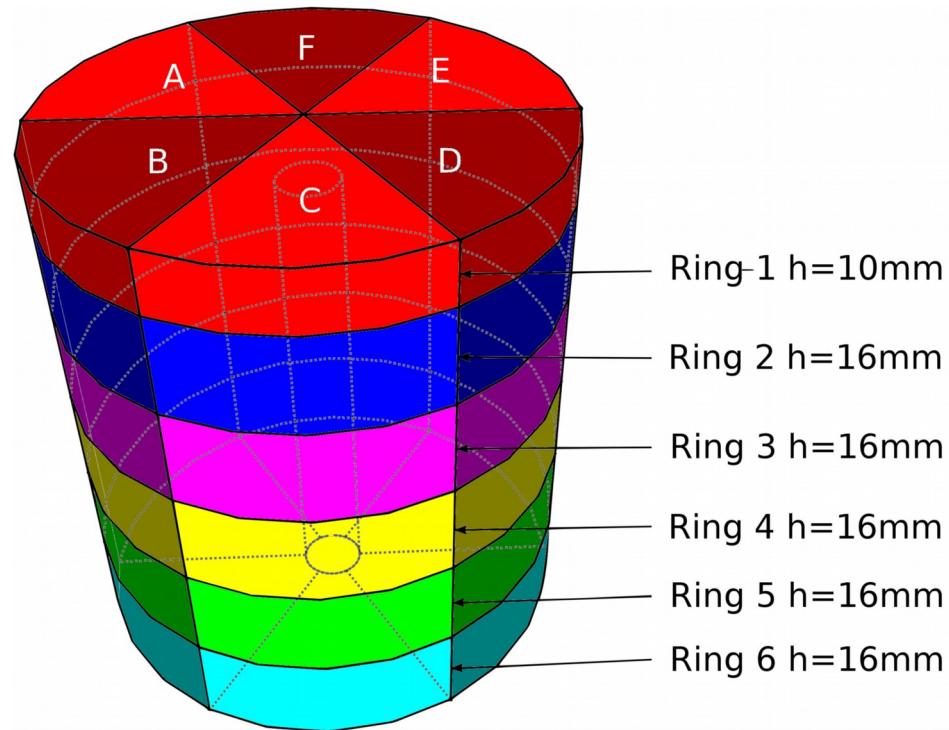
New HPGe-Detector



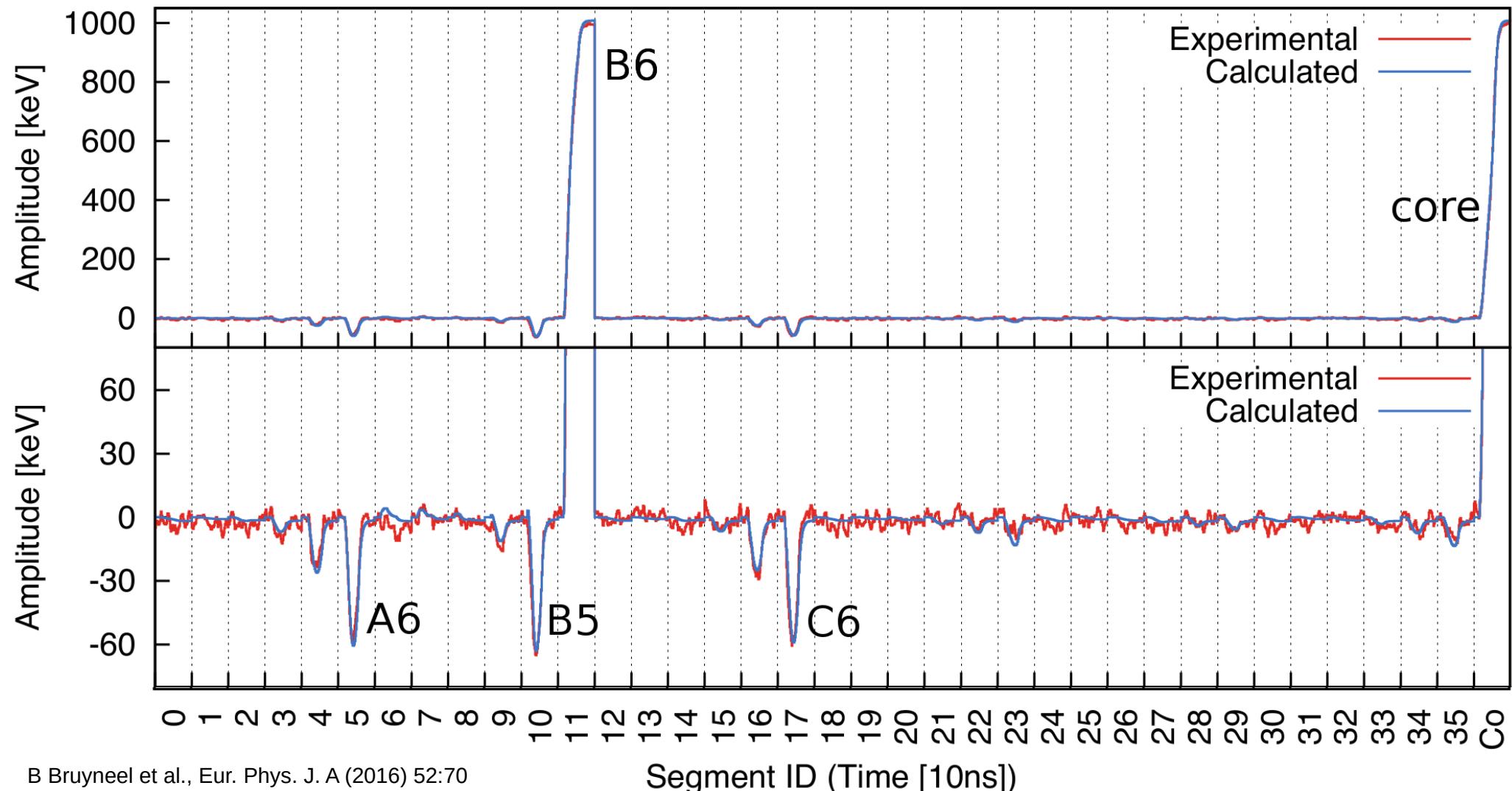
Canberra EGC-SEG36

- Closed-ended coaxial shape
- 36 segments
- $h=89.7\text{mm}$ $\varnothing=79.8\text{mm}$
- 109% efficiency

For comparison: Efficiency of AGATA/S001 71.1%



Pulse-shape analysis



B Bruyneel et al., Eur. Phys. J. A (2016) 52:70

Segment ID (Time [10ns])

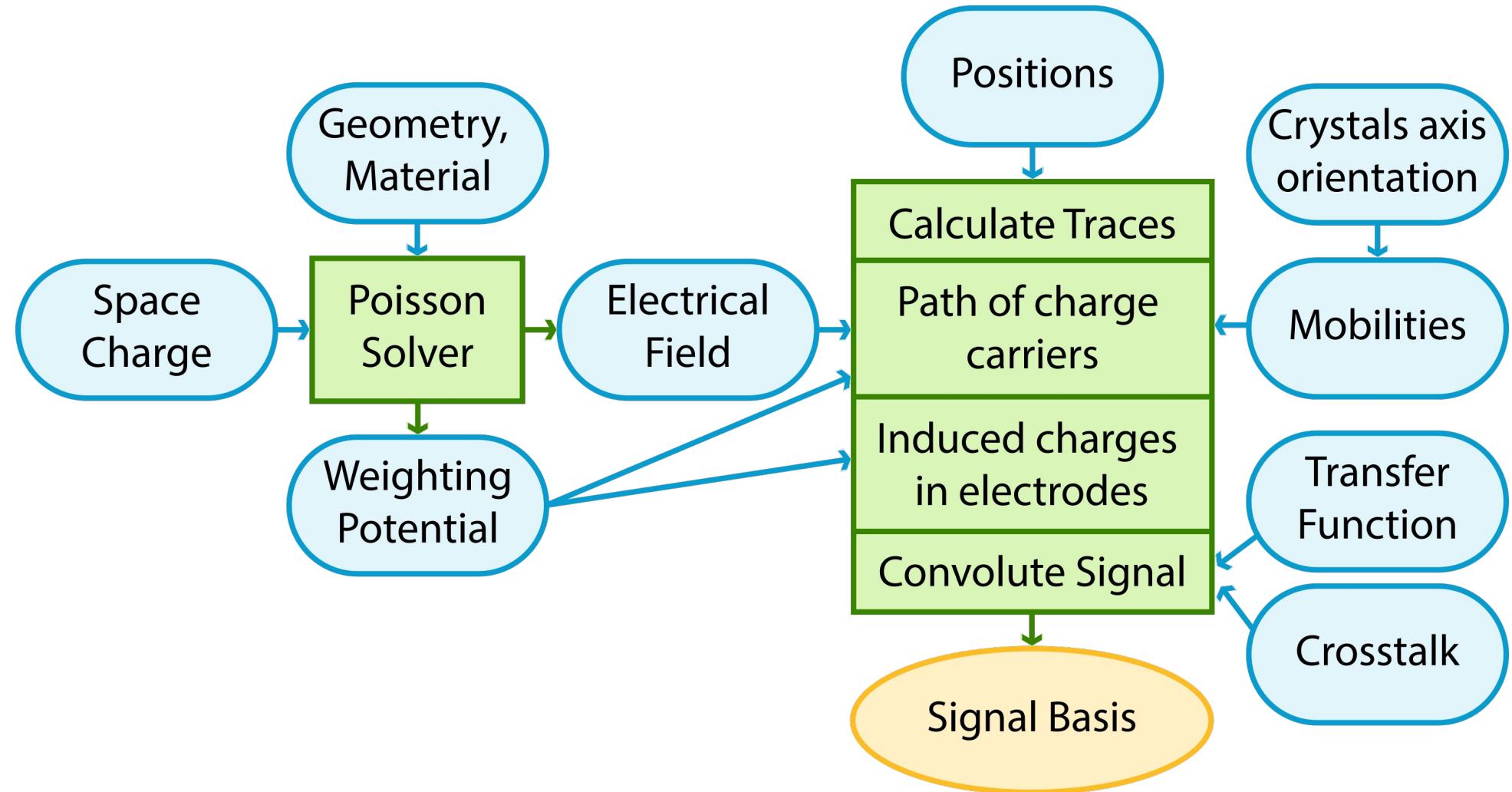
Database of simulated signals

- Grid of interaction points
- Simulated with ADL

Comparison of measured and simulated signals with AGAPRO

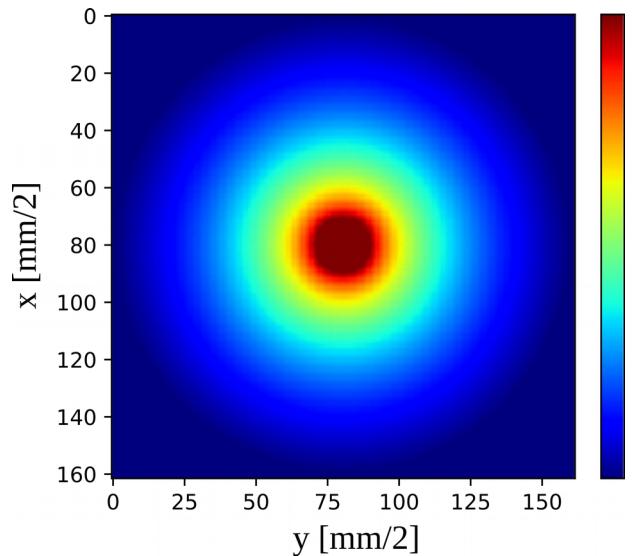
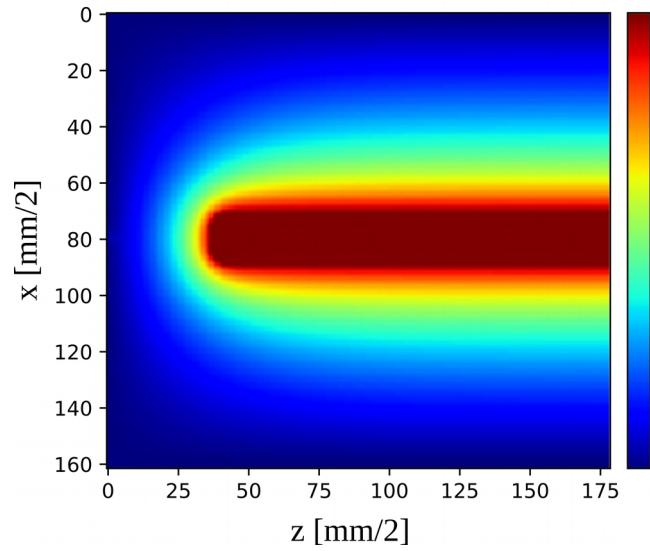
$$\text{Figure of Merit} = \sum_{i,j} |A_{i,j}^m - A_{i,j}^s|^p$$

AGATA detector library

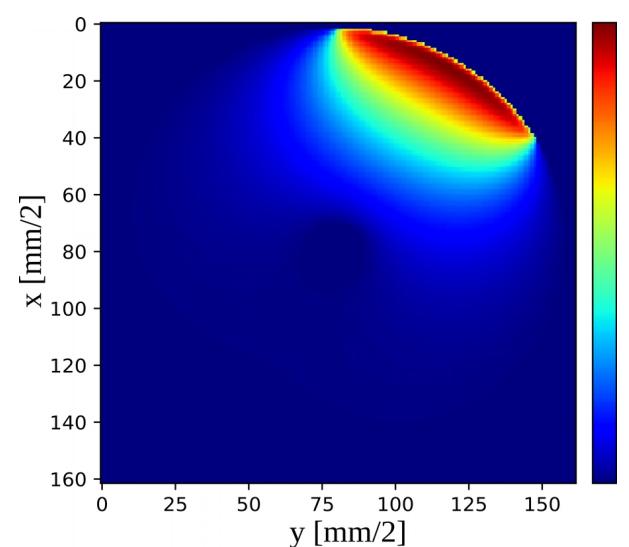
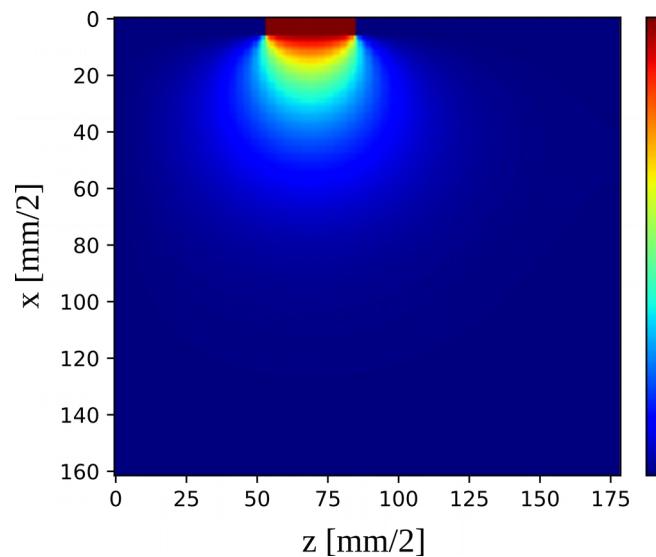


ADL3 – Weighting potentials

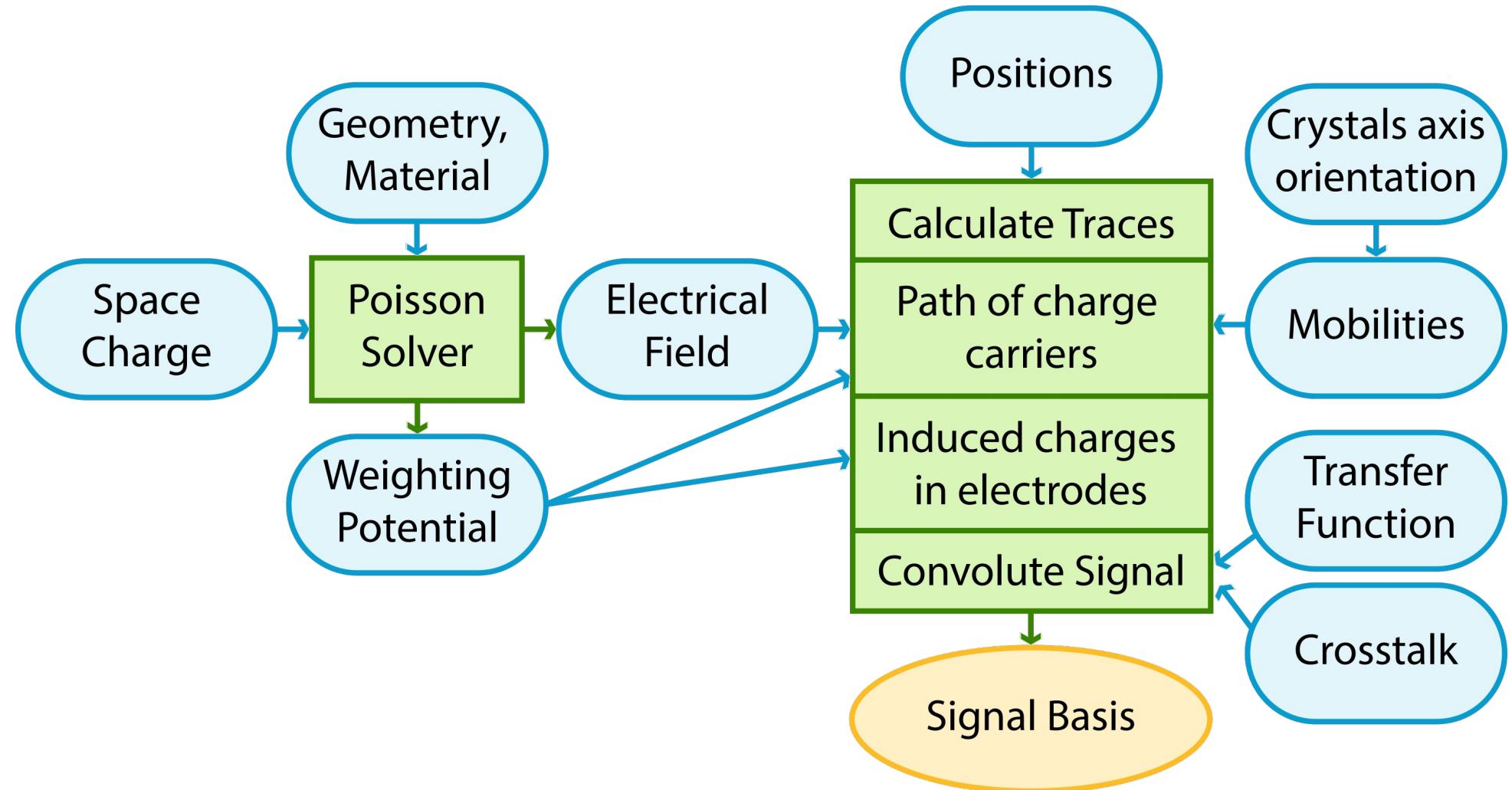
Core electrode



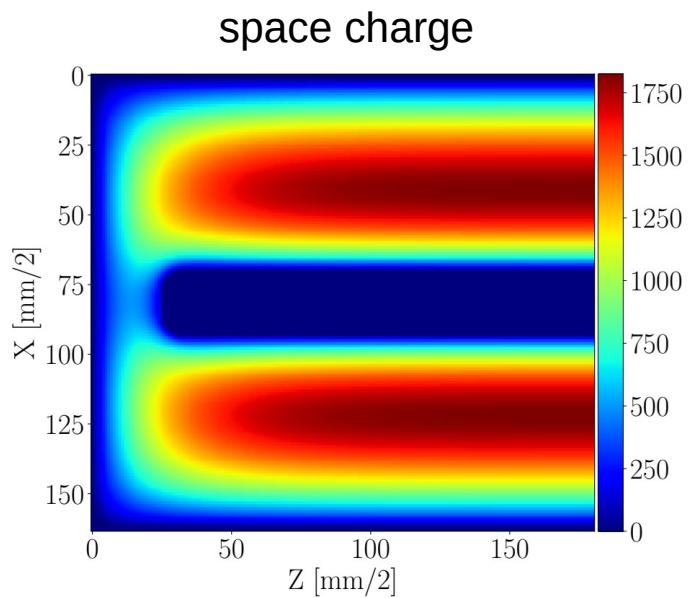
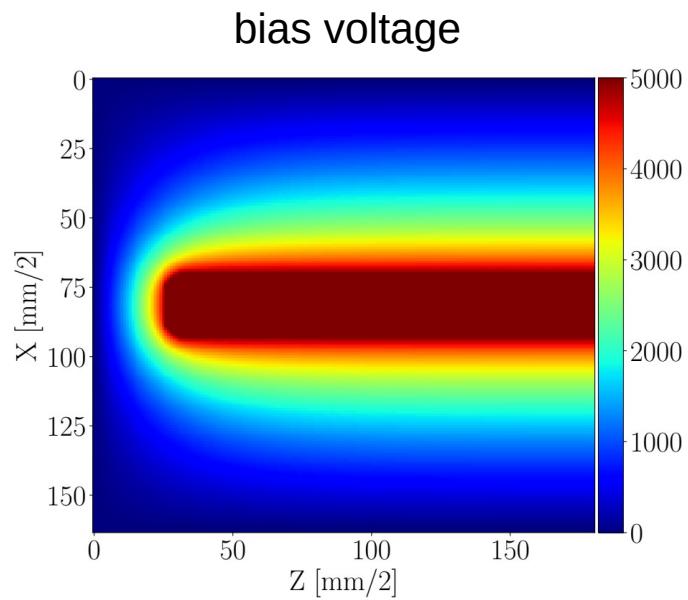
Segment C3



AGATA detector library



ADL3 Potential



Impurity concentration:

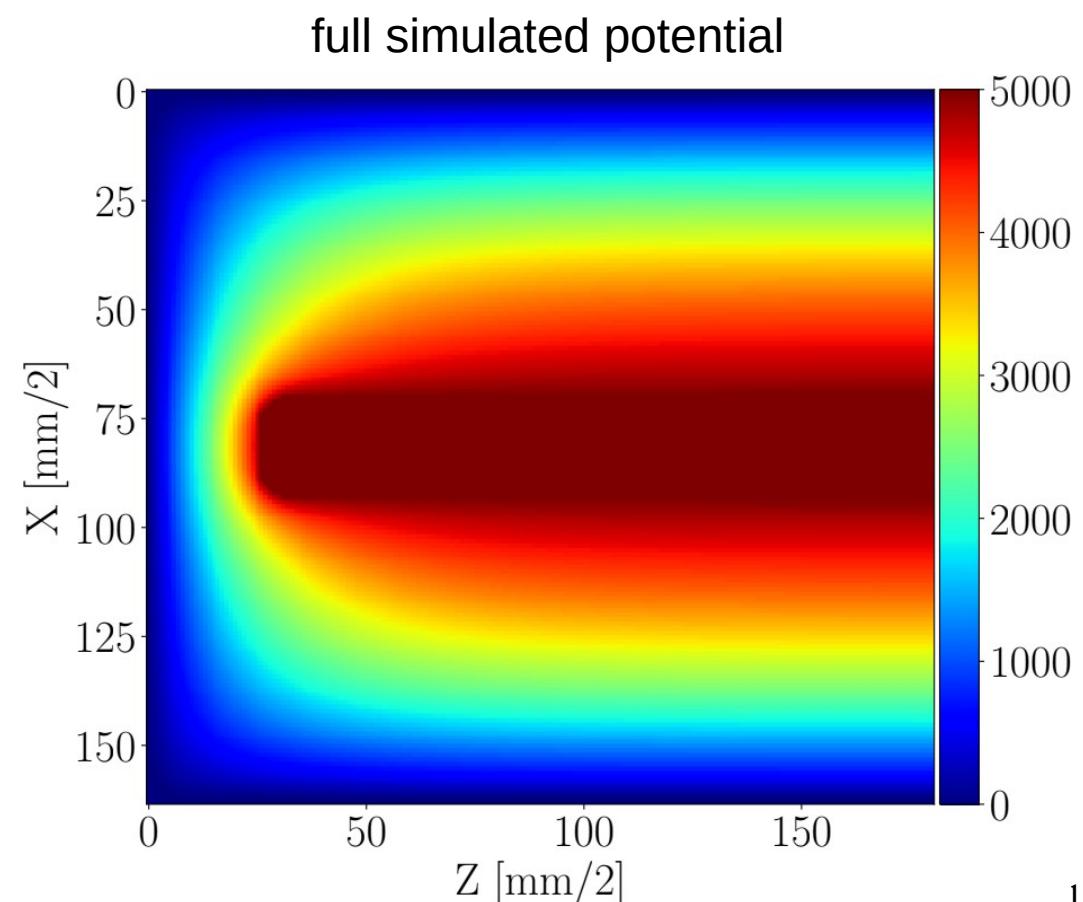
- $1.0 \times 10^{10} \text{ cm}^{-3}$

Bias Voltage:

- 5000V

Geometry:

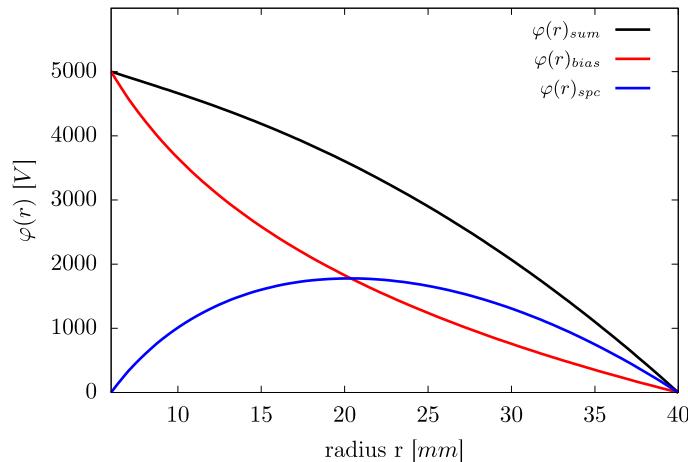
- $r_{\text{inner}} = 0.6\text{cm}$
- $r_{\text{outer}} = 4.0\text{cm}$
- $h = 8.95\text{cm}$



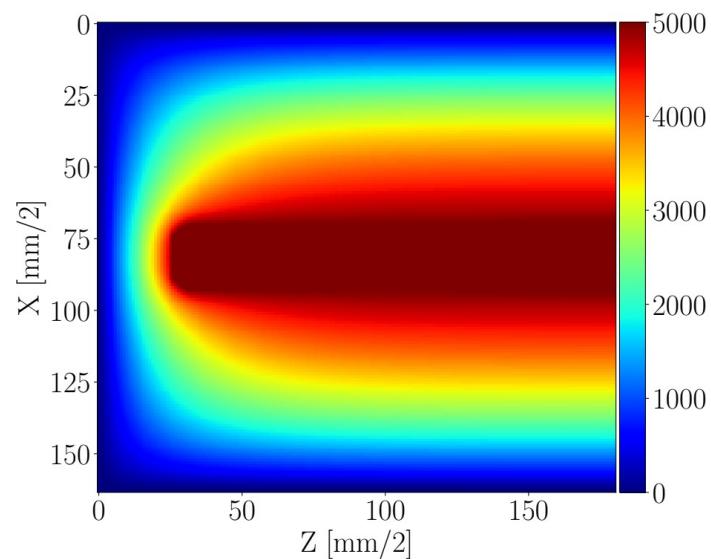
ADL3 Potential

true coaxial potential

$$\varphi(r) = 5000V \frac{\ln\left(\frac{r_2}{r}\right)}{\ln\left(\frac{r_2}{r_1}\right)} + \frac{\rho}{4\epsilon} \left((r_2^2 - r^2) - (r_2^2 - r_1^2) \frac{\ln\left(\frac{r_2}{r}\right)}{\ln\left(\frac{r_2}{r_1}\right)} \right)$$

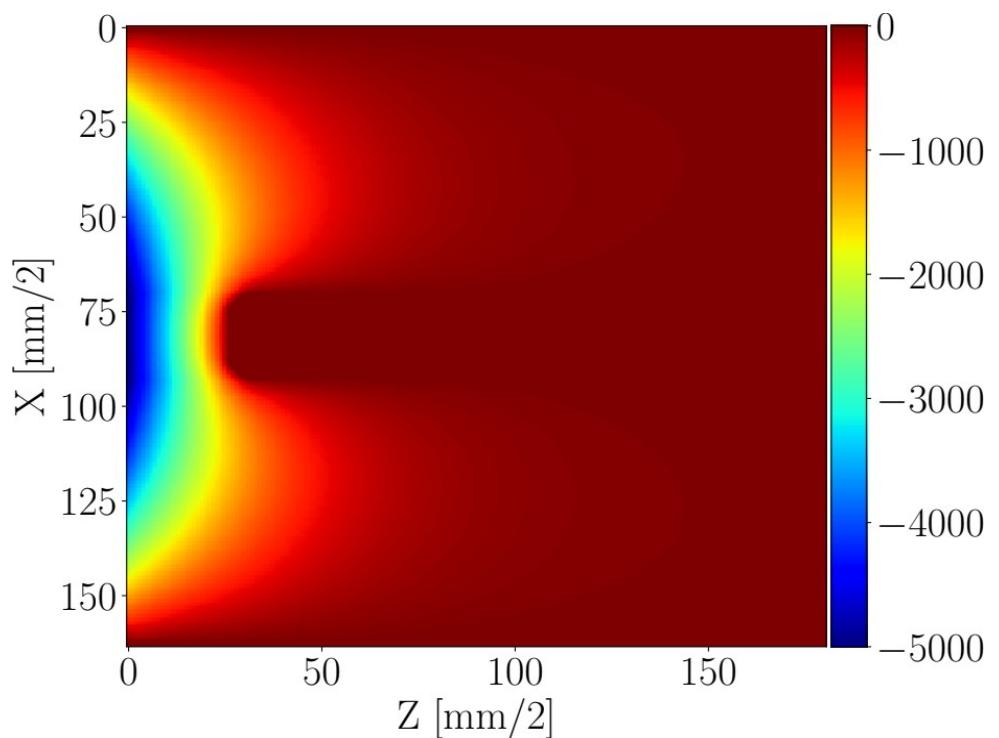


full simulated potential

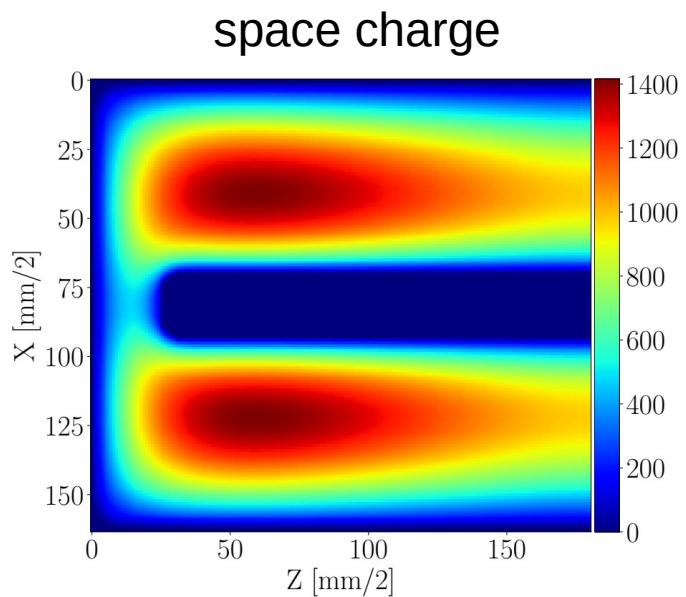
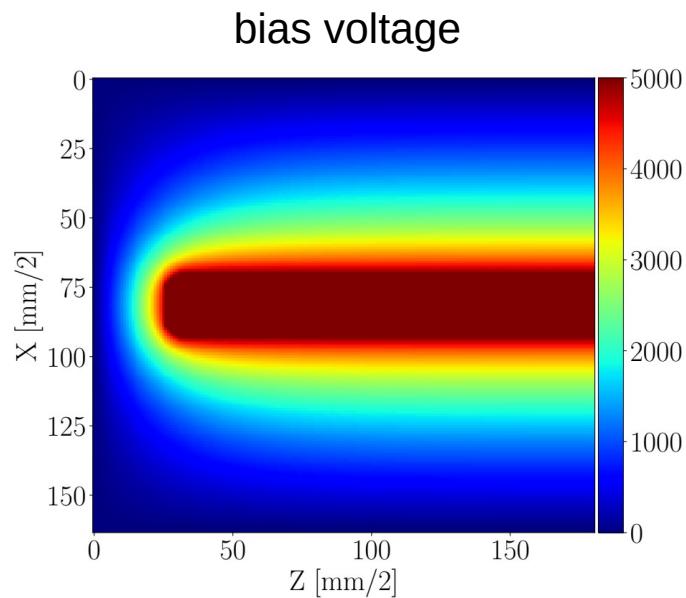


Difference:

- simulation
- true coaxial potential



ADL3 Potential



Impurity concentration:

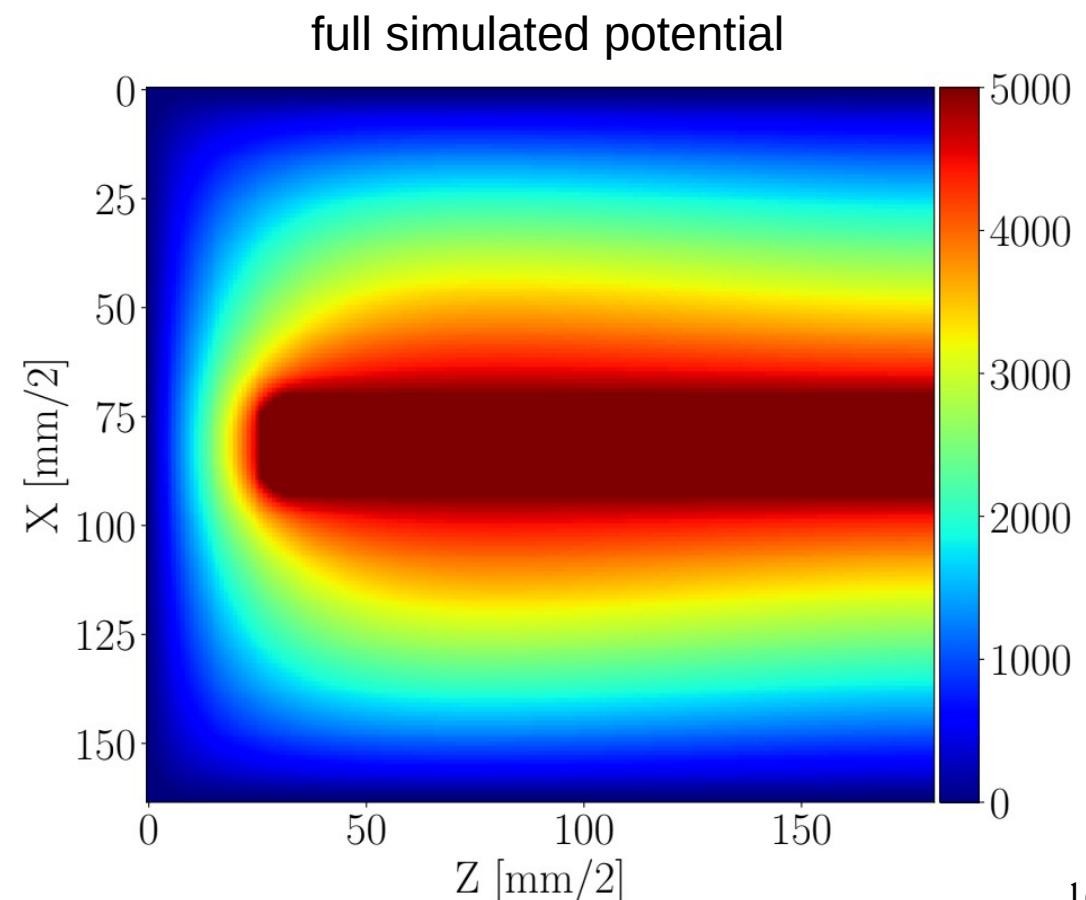
- front: $1.04 \times 10^{10} \text{ cm}^{-3}$
- back: $0.46 \times 10^{10} \text{ cm}^{-3}$

Bias Voltage:

- 5000V

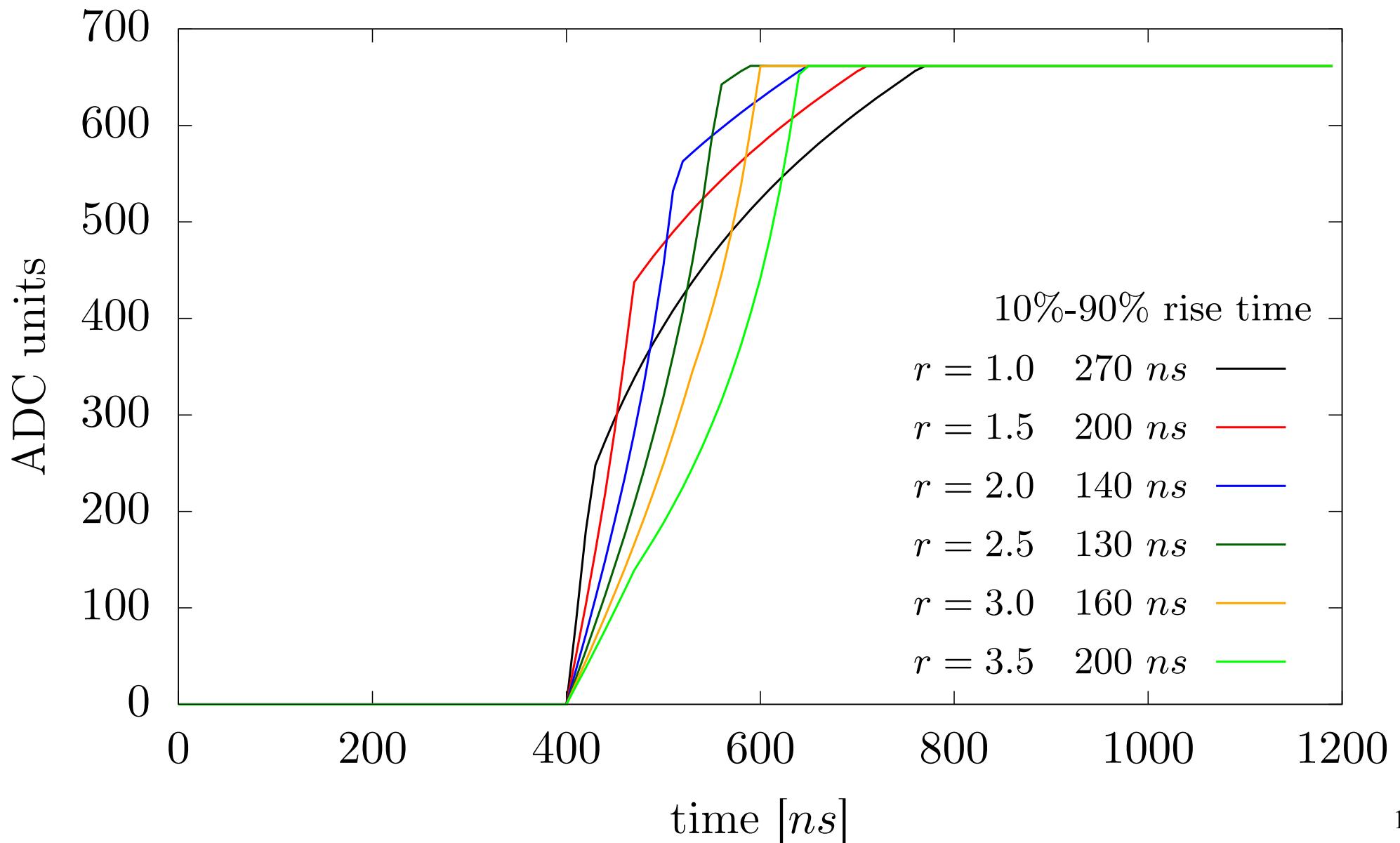
Geometry:

- $r_{\text{inner}} = 0.6\text{cm}$
- $r_{\text{outer}} = 4.0\text{cm}$
- $h = 8.95\text{cm}$



ADL3

Simulated Core Traces $E_{co} = 661.7\text{keV}$ hit in A3



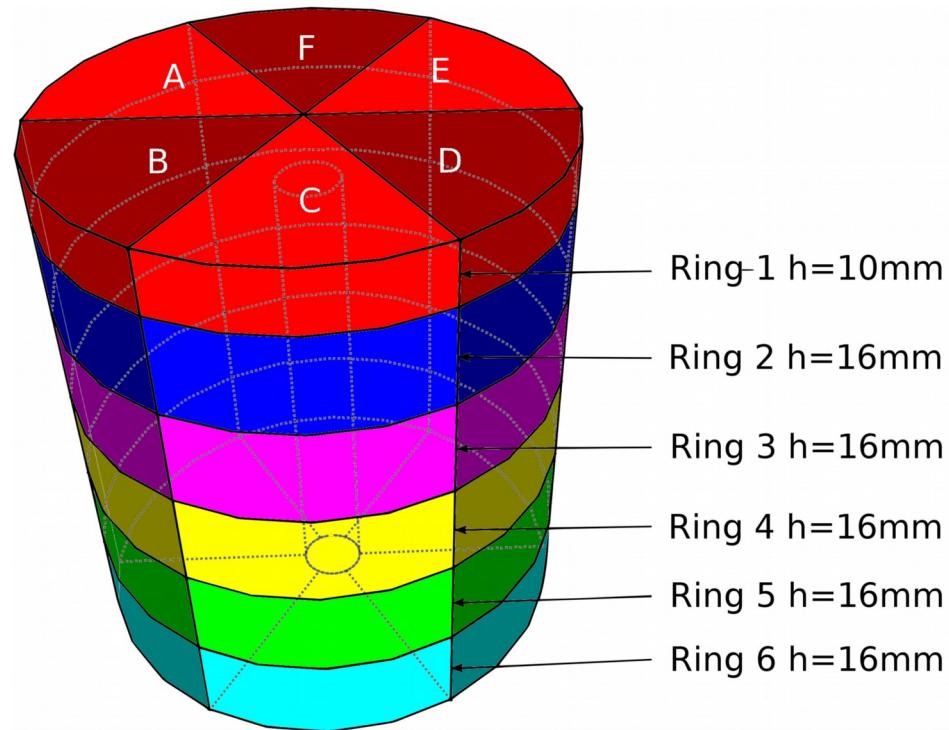
New HPGe-Detector



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For comparison: Efficiency of AGATA/S001 71.1%



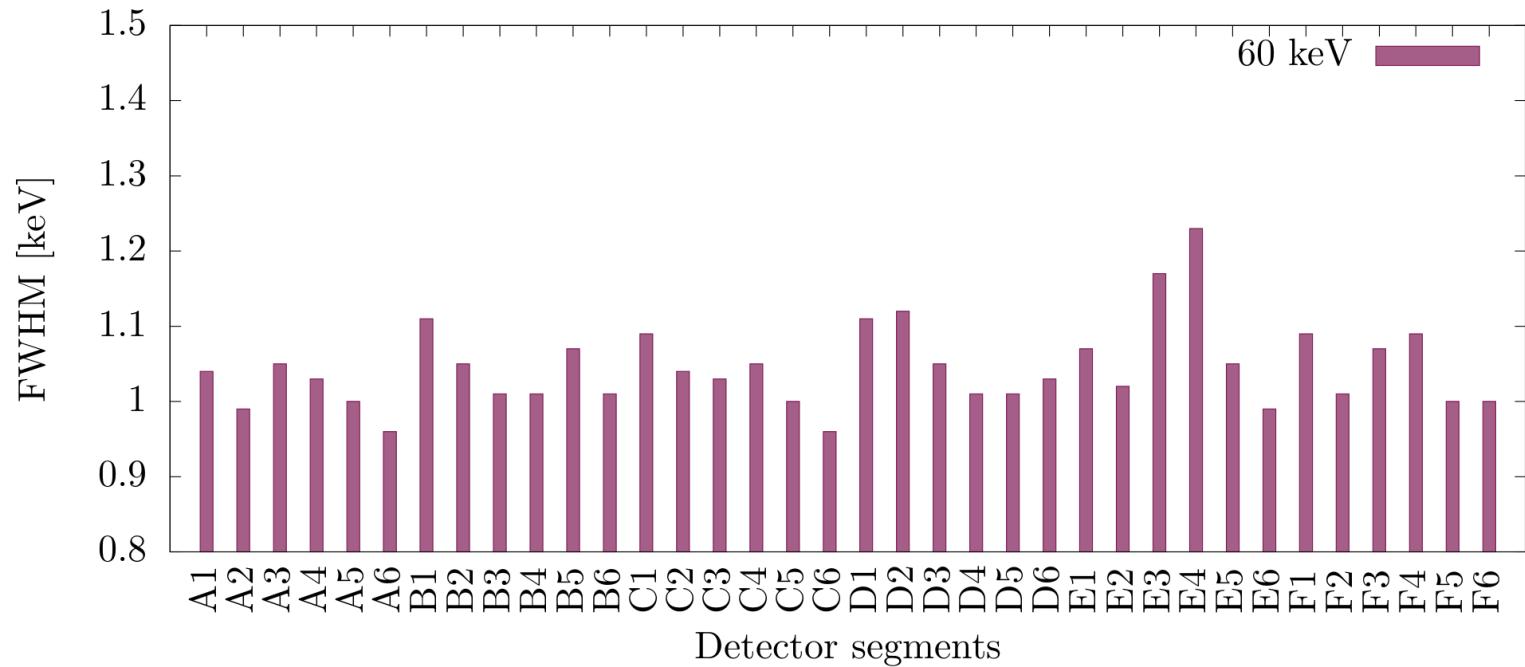
Energy resolution

Am-241

Specification:
 $\Delta E < 1.2 \text{ keV}$

Segments Avg.:
 $\Delta E = 1.045 \text{ keV}$

Core:
 $\Delta E = 1.00 \text{ keV}$

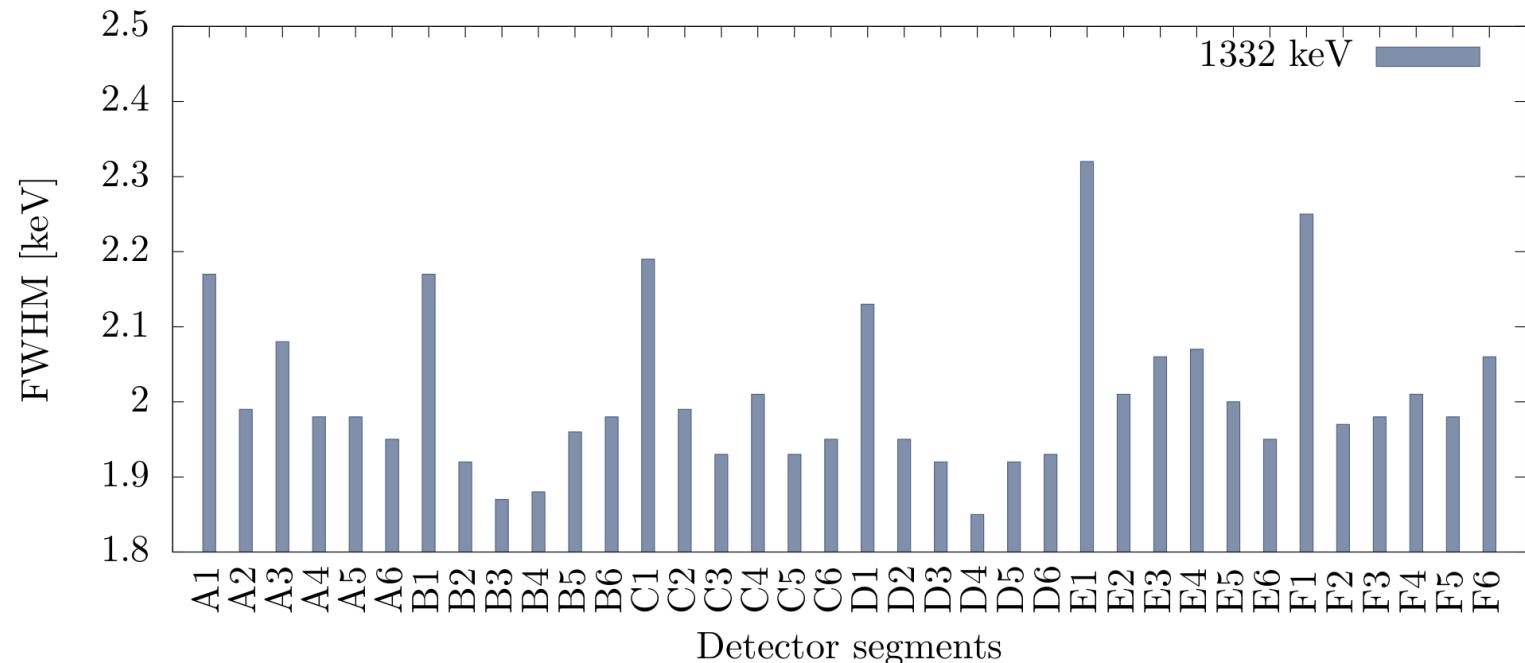


Co-60

Specification:
 $\Delta E < 2.1 \text{ keV}$

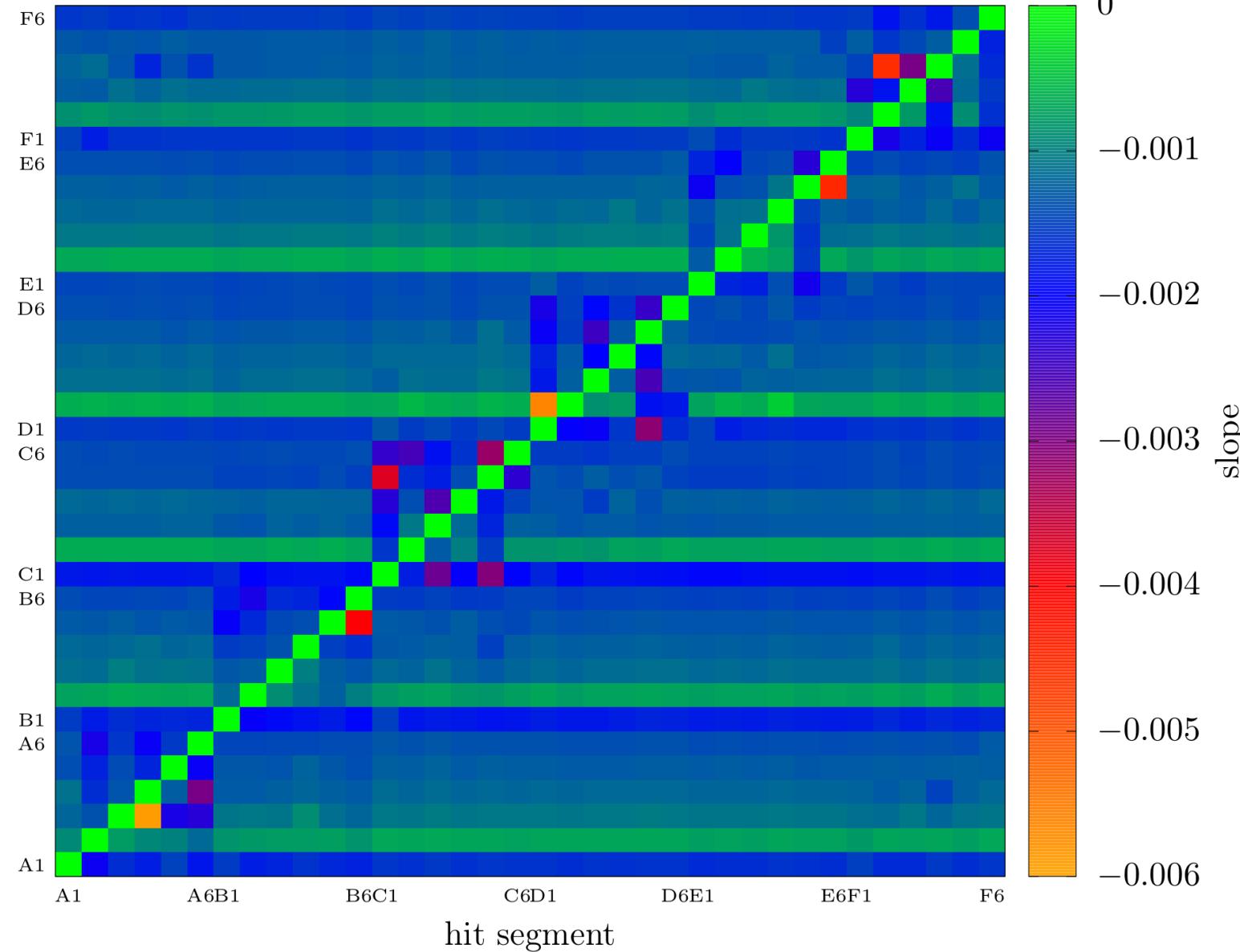
Segments Avg.:
 $\Delta E = 2.008 \text{ keV}$

Core:
 $\Delta E = 2.21 \text{ keV}$



Crosstalk measurement

Crosstalk parameter matrix



Crosstalk:

Single fold method

Parameters:

- Min.: 0.4‰
- Avg.: 1.3‰
- Max.: 5.9‰

0

-0.001

-0.002

-0.003

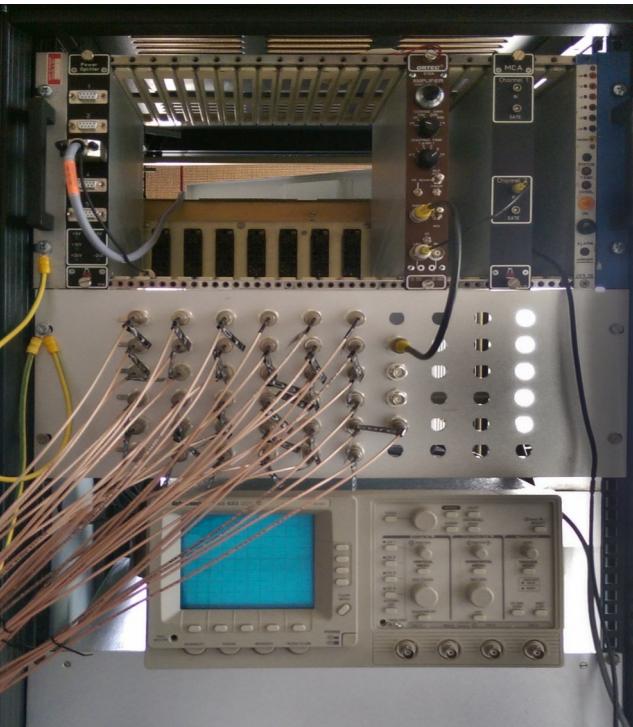
-0.004

-0.005

-0.006

slope

Energy resolution



Drop of energy resolution:

- Only core preamplifier $50\ \Omega$ terminated:
 $\Delta E = 2.19\text{ keV} @ 1332\text{ keV}$
- All 37 preamplifiers $50\ \Omega$ terminated:
 - $\Delta E = 2.84\text{ keV} @ 1332\text{ keV}$

Setup optimizations:

Detector readout:

- Patch panel / additional grounding
- NIM Crate / low voltage power supply

Cryostat (warm part):

- grounding
- low voltage power supply

After optimization:

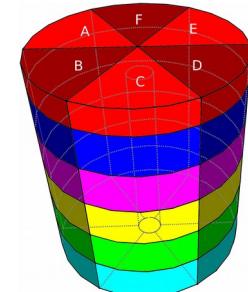
- Only core preamplifier $50\ \Omega$ terminated:
 - $\Delta E = 2.19\text{ keV} @ 1332\text{ keV}$
- All 37 preamplifiers $50\ \Omega$ terminated:
 - $\Delta E = 2.44\text{ keV} @ 1332\text{ keV}$



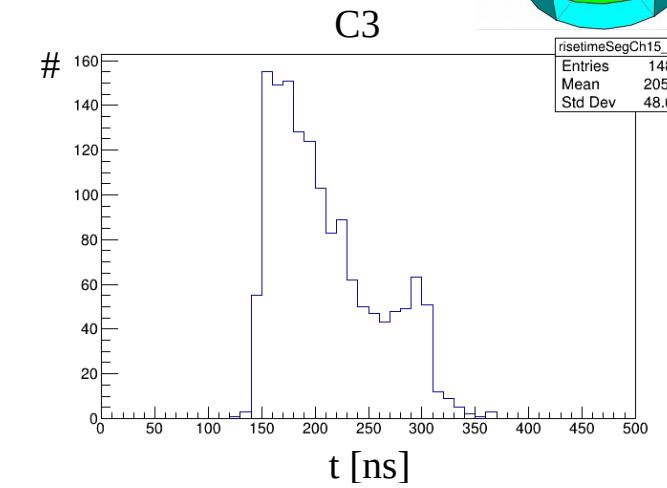
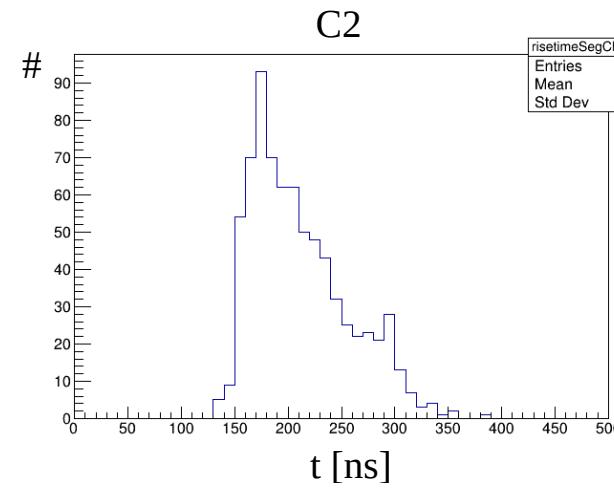
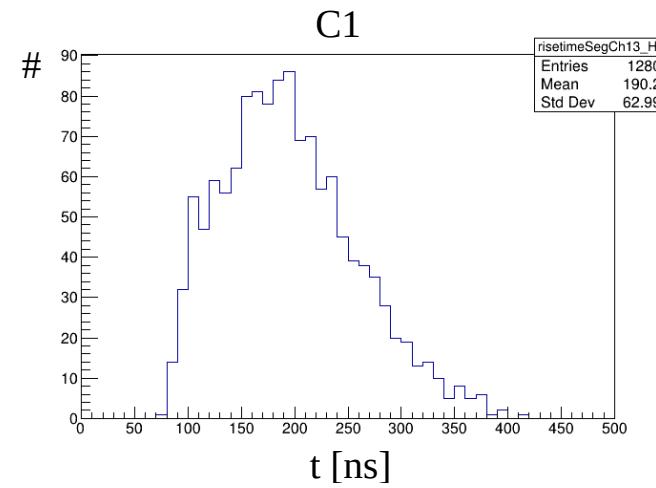
Rise time distributions

- Cs-137 Source
- Single segment hit
- Full energy deposition

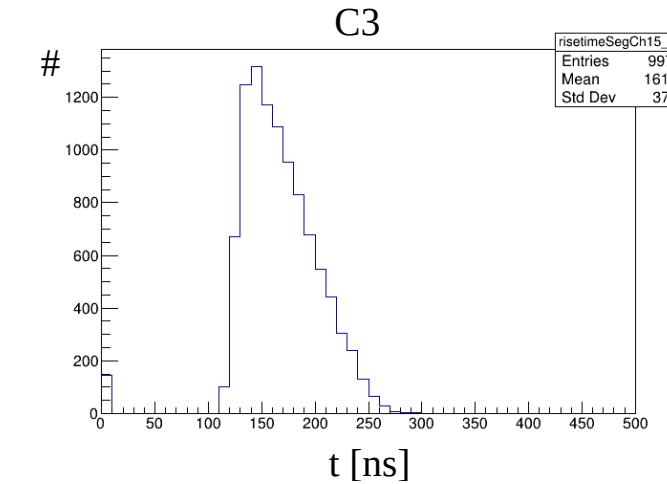
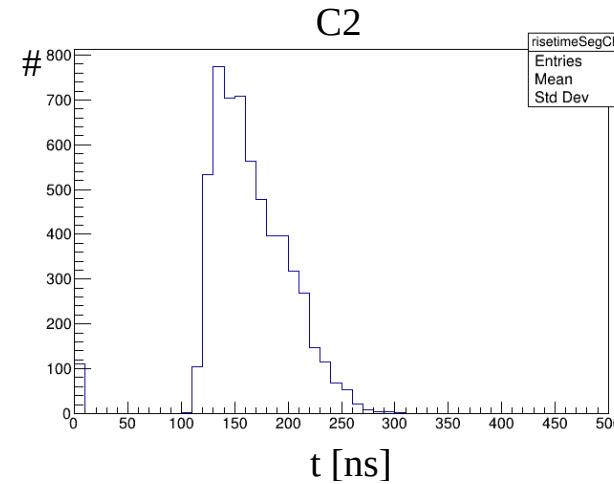
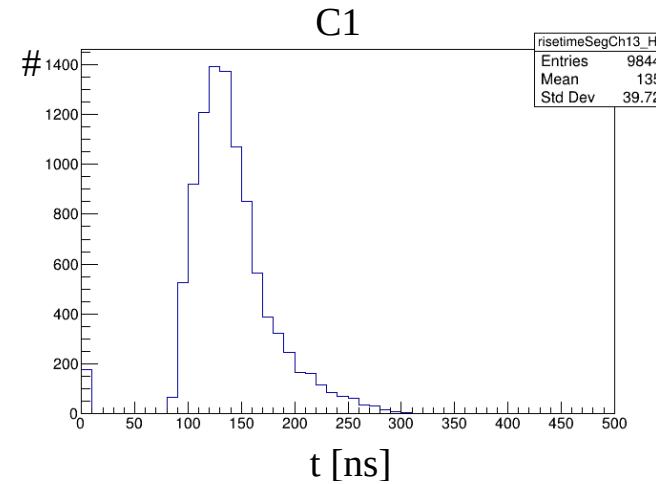
- Rise time 10%-90%
- Segment



EGC-Seg36



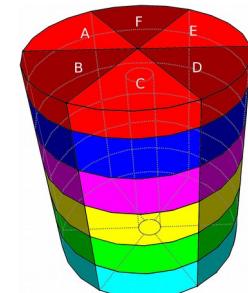
AGATA S001



Rise time distributions

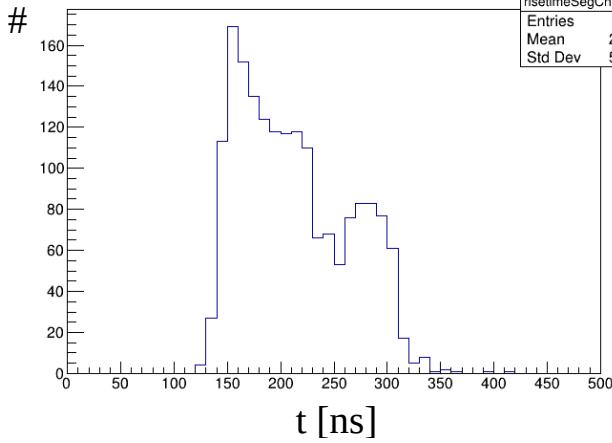
- Cs-137 Source
- Single segment hit
- Full energy deposition

- Rise time 10%-90%
- Segment



C4

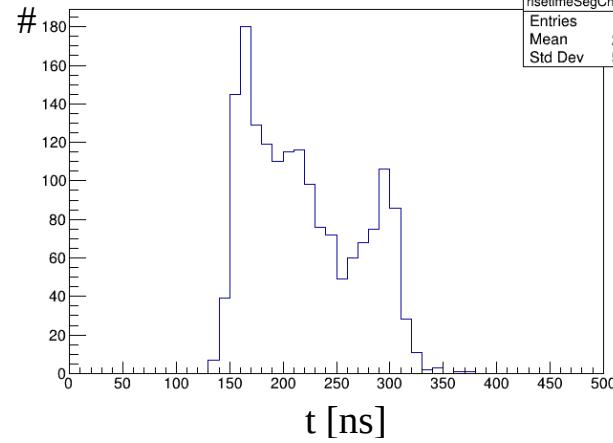
risetimeSegCh16_Hit		
Entries	1790	
Mean	207.8	
Std Dev	51.18	



EGC-Seg36

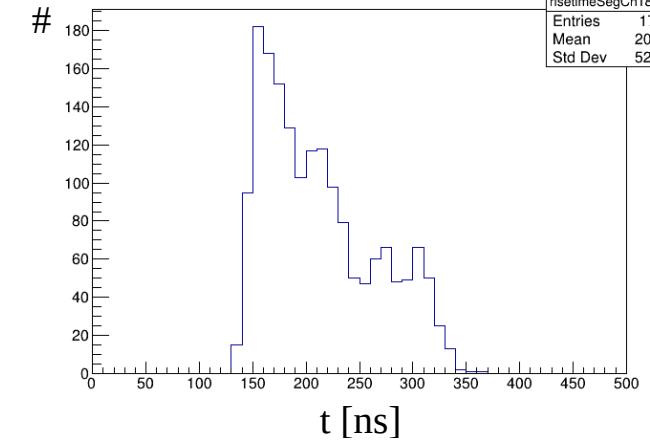
C5

risetimeSegCh17_Hit		
Entries	1696	
Mean	214.2	
Std Dev	50.99	



C6

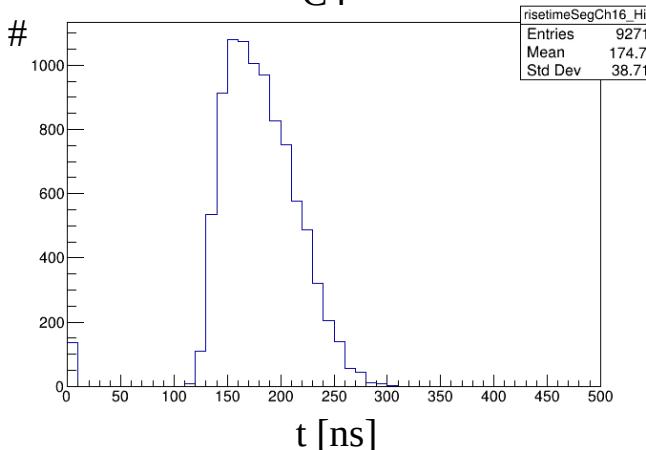
risetimeSegCh18_Hit		
Entries	1734	
Mean	207.5	
Std Dev	52.26	



AGATA S001

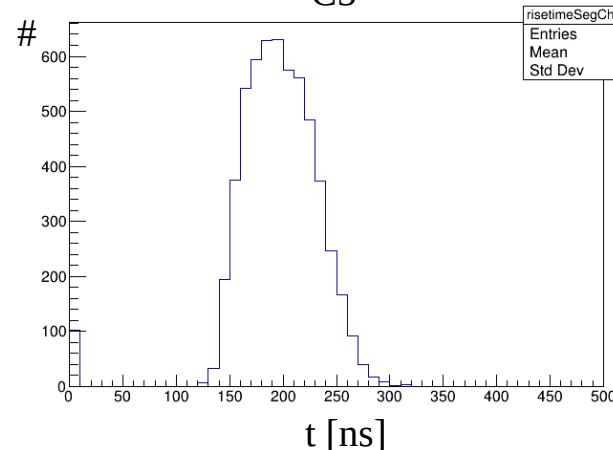
C4

risetimeSegCh16_Hit		
Entries	9271	
Mean	174.7	
Std Dev	38.71	



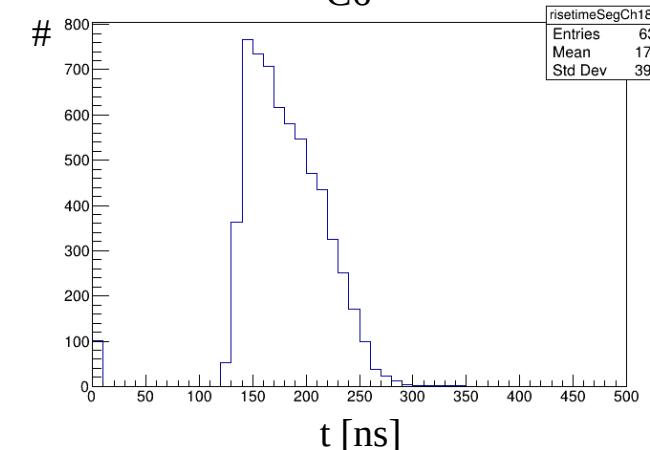
C5

risetimeSegCh17_Hit		
Entries	5674	
Mean	190	
Std Dev	40.41	



C6

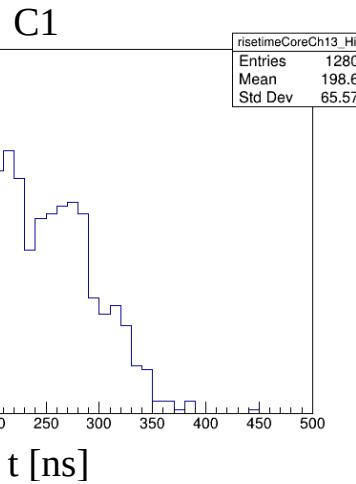
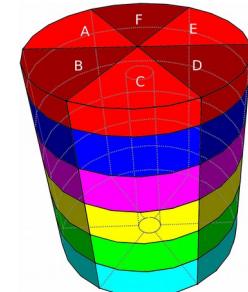
risetimeSegCh18_Hit		
Entries	6304	
Mean	174.5	
Std Dev	39.87	



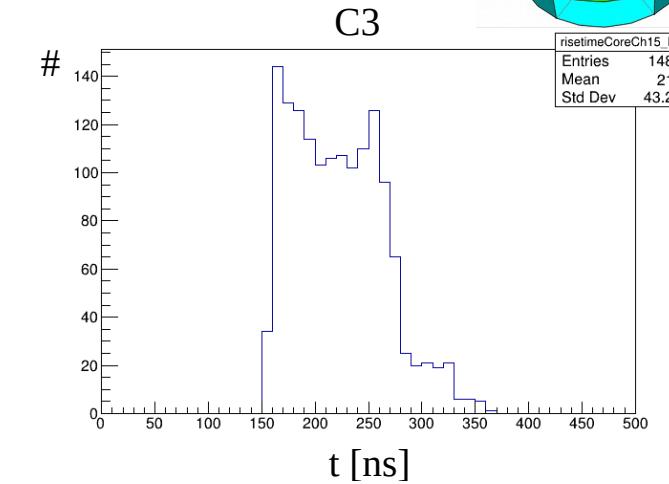
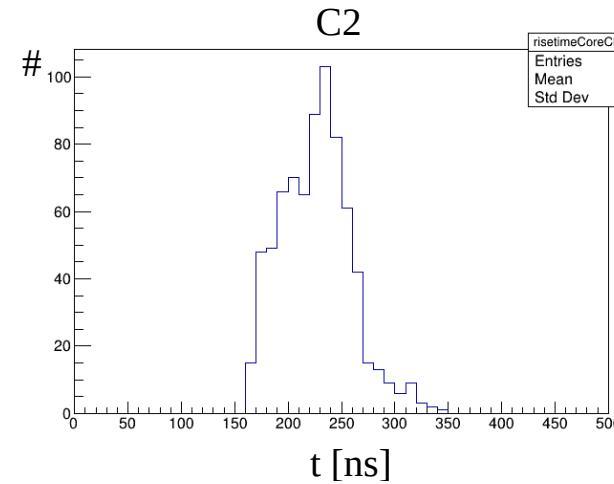
Rise time distributions

- Cs-137 Source
- Single segment hit
- Full energy deposition

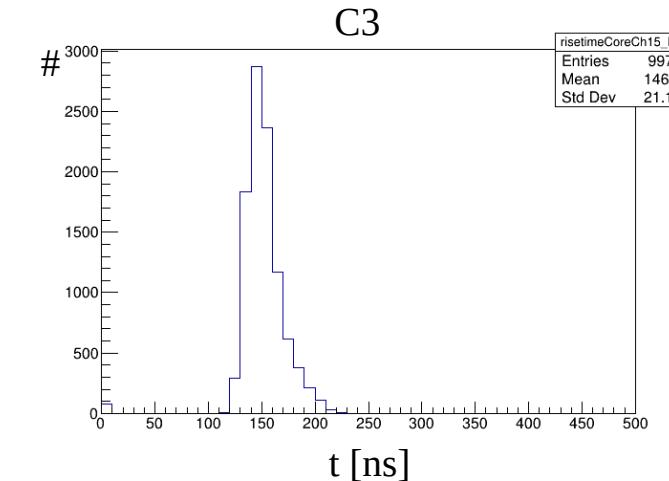
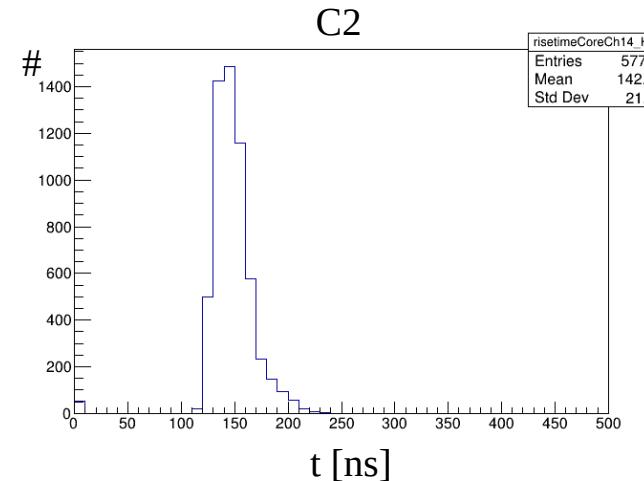
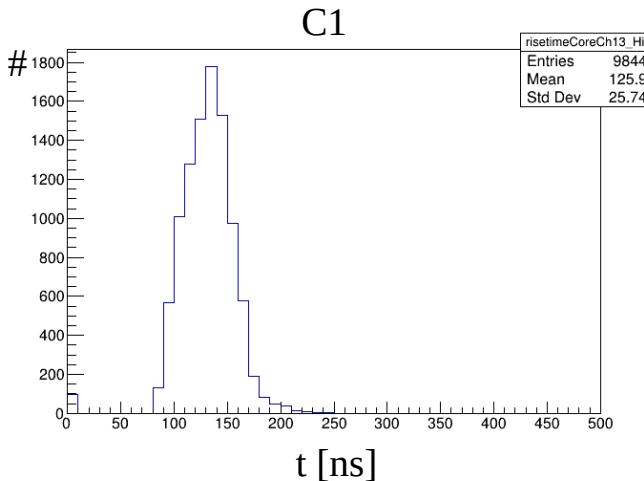
- Rise time 10%-90%
- Core



EGC-Seg36



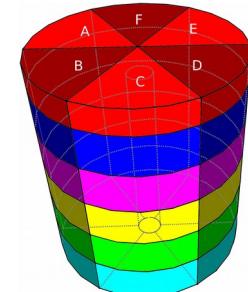
AGATA S001



Rise time distributions

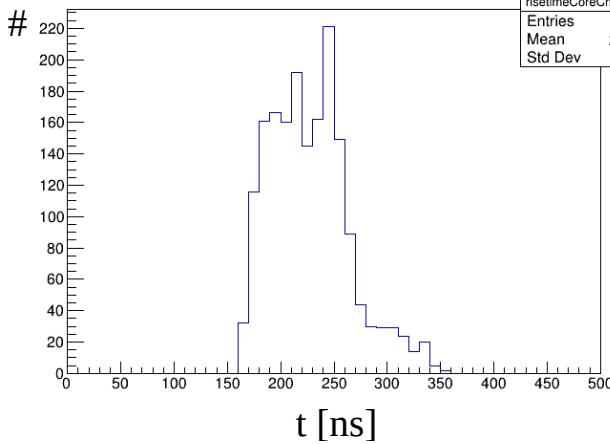
- Cs-137 Source
- Single segment hit
- Full energy deposition

- Rise time 10%-90%
- Core



C4

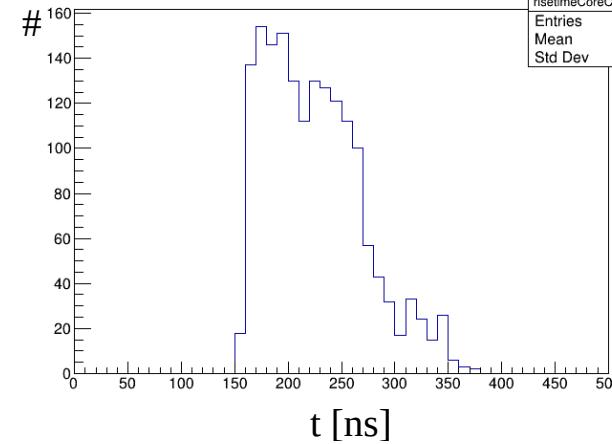
risetimeCoreCh16_Hit		
Entries	1790	
Mean	222.7	
Std Dev	37.31	



EGC-Seg36

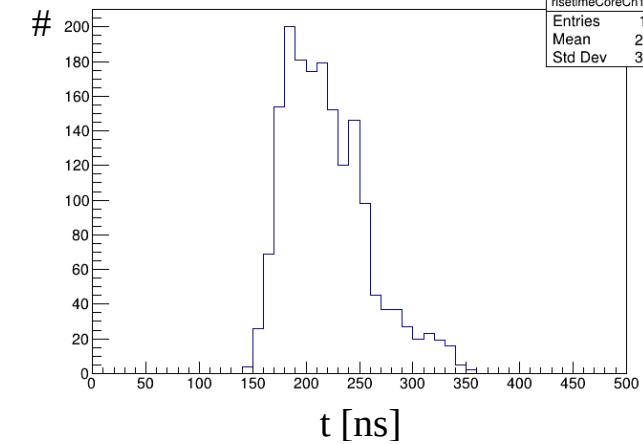
C5

risetimeCoreCh17_Hit		
Entries	1696	
Mean	220.3	
Std Dev	45.77	



C6

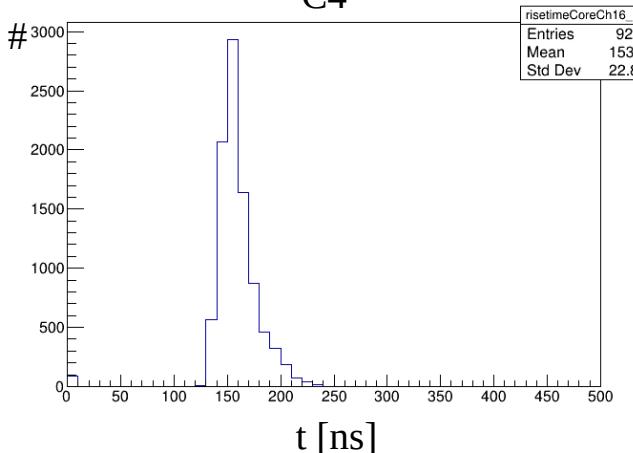
risetimeCoreCh18_Hit		
Entries	1734	
Mean	214.4	
Std Dev	39.42	



AGATA S001

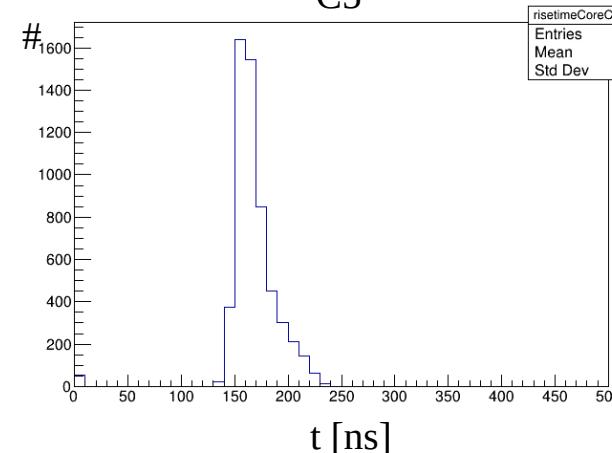
C4

risetimeCoreCh16_Hit		
Entries	9271	
Mean	153.5	
Std Dev	22.89	



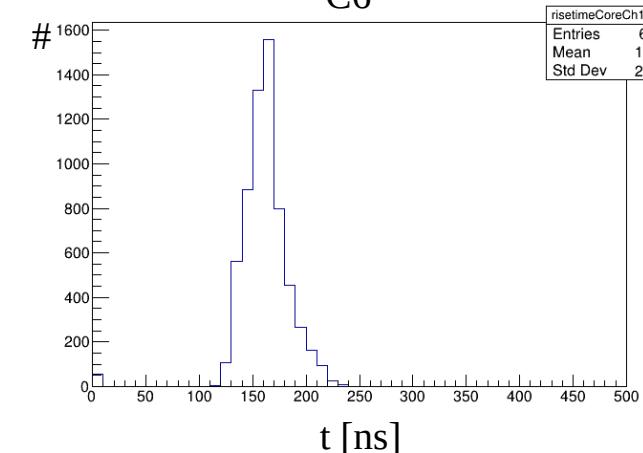
C5

risetimeCoreCh17_Hit		
Entries	5674	
Mean	162.5	
Std Dev	23.84	



C6

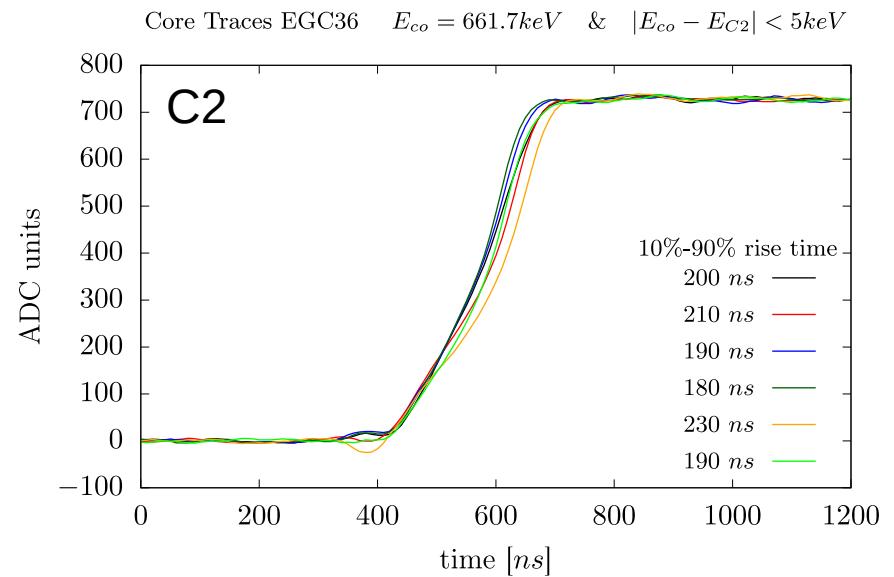
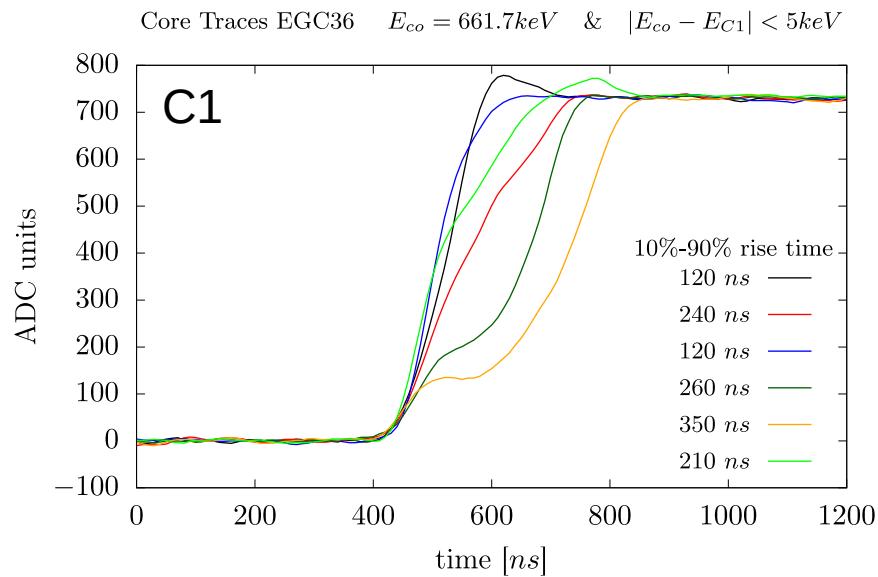
risetimeCoreCh18_Hit		
Entries	6304	
Mean	156.3	
Std Dev	24.12	



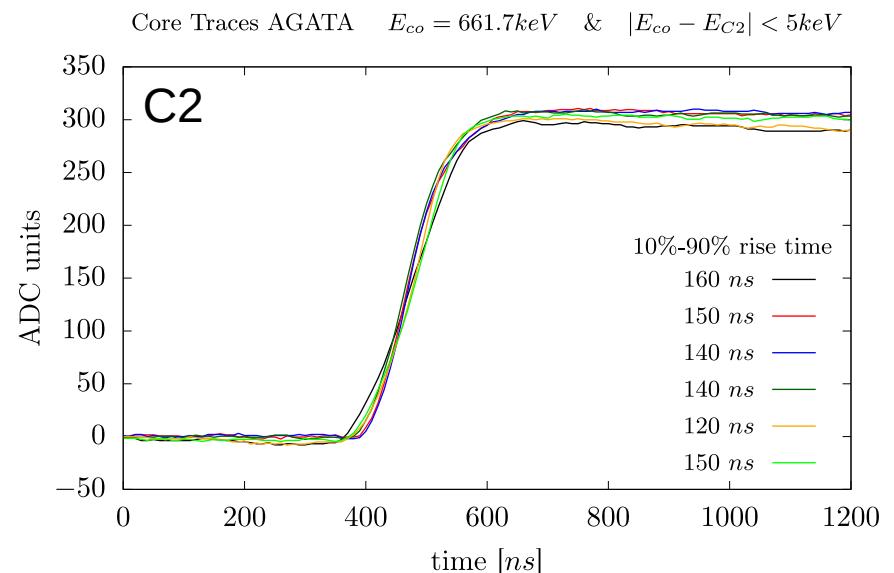
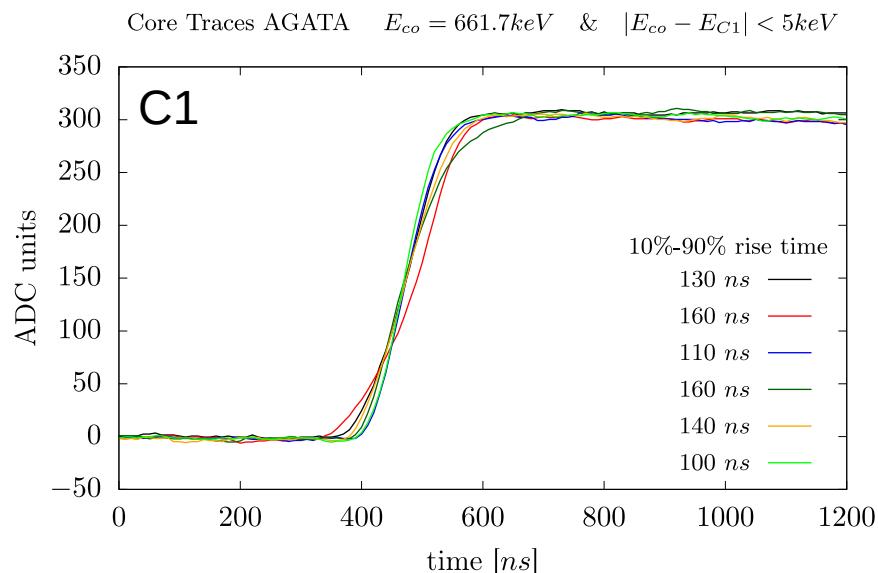
t [ns]

Traces hit segment C1/C2

EGC-Seg36

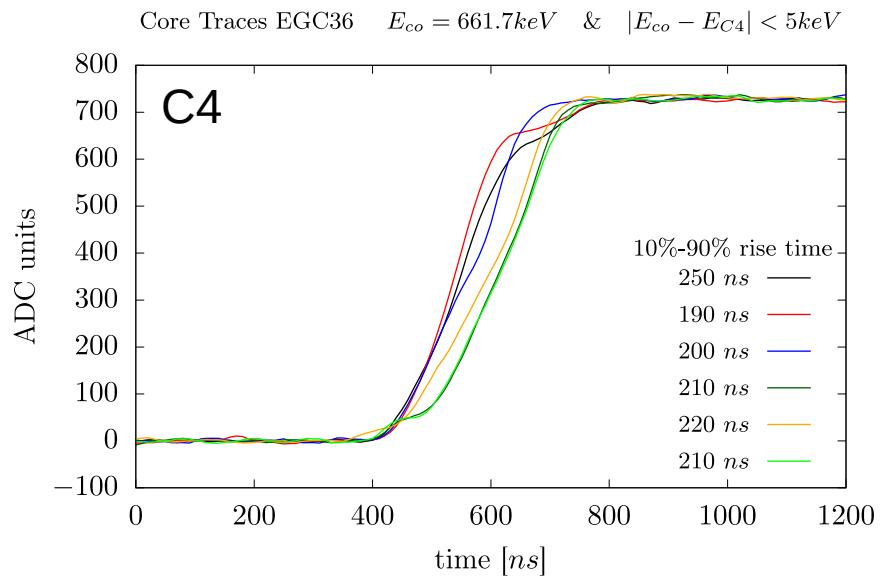
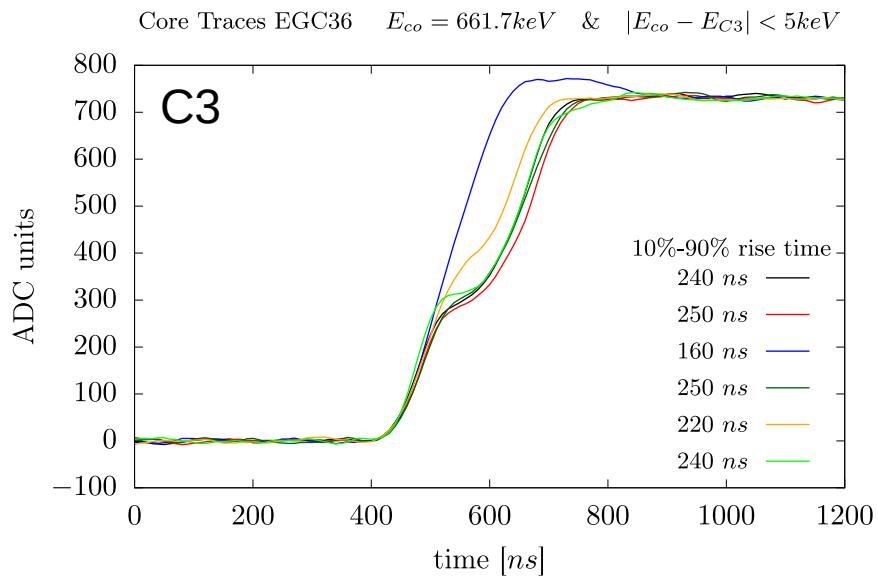


AGATA S001

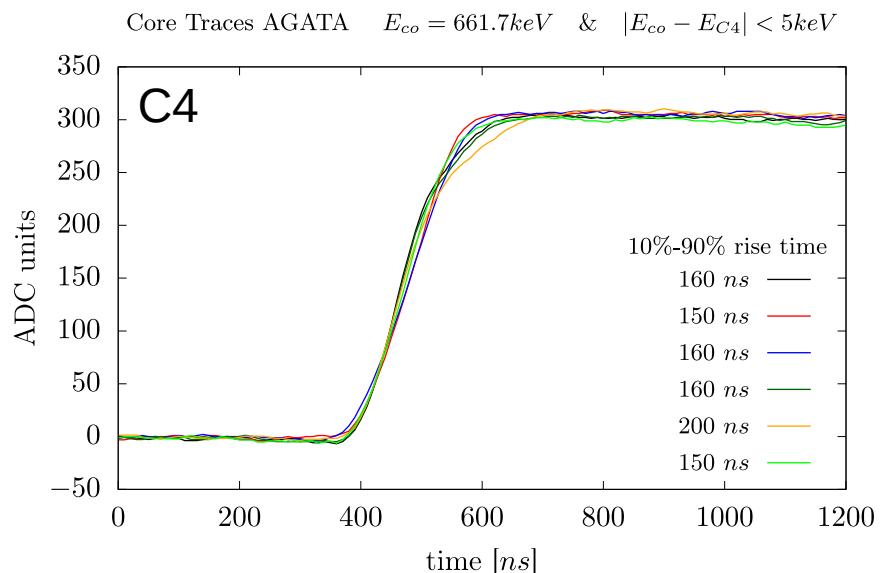
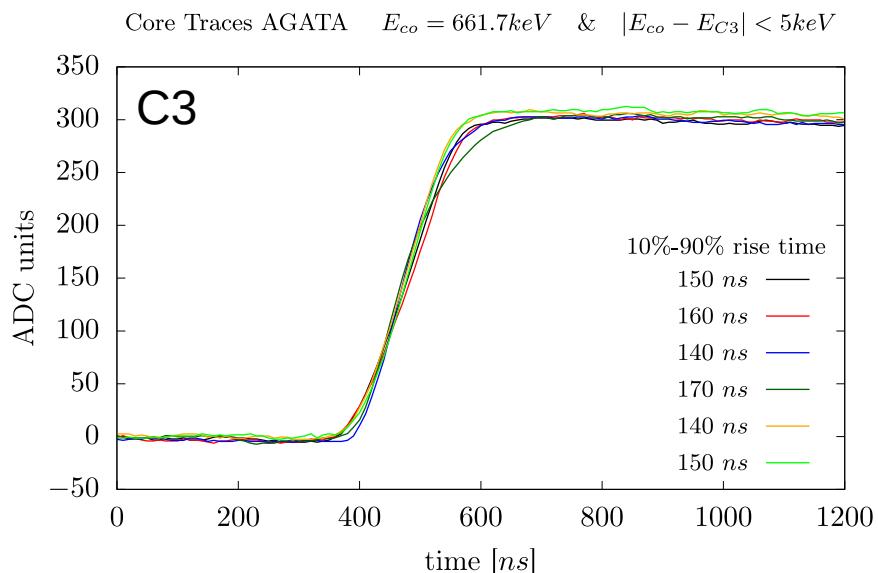


Traces hit segment C3/C4

EGC-Seg36

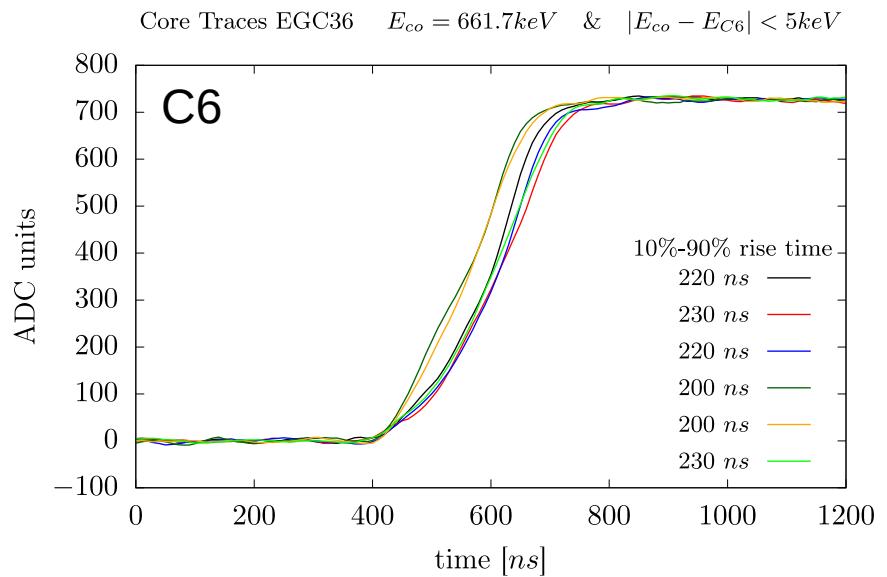
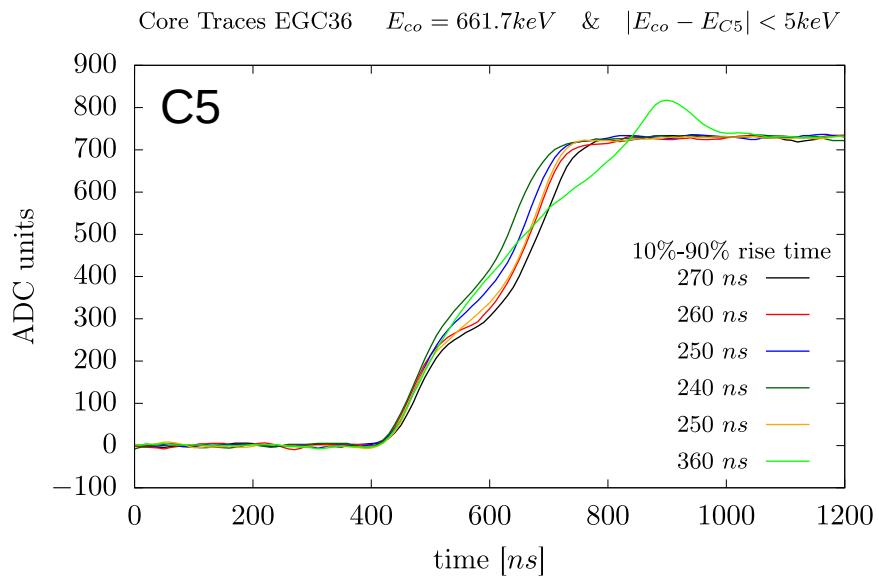


AGATA S001

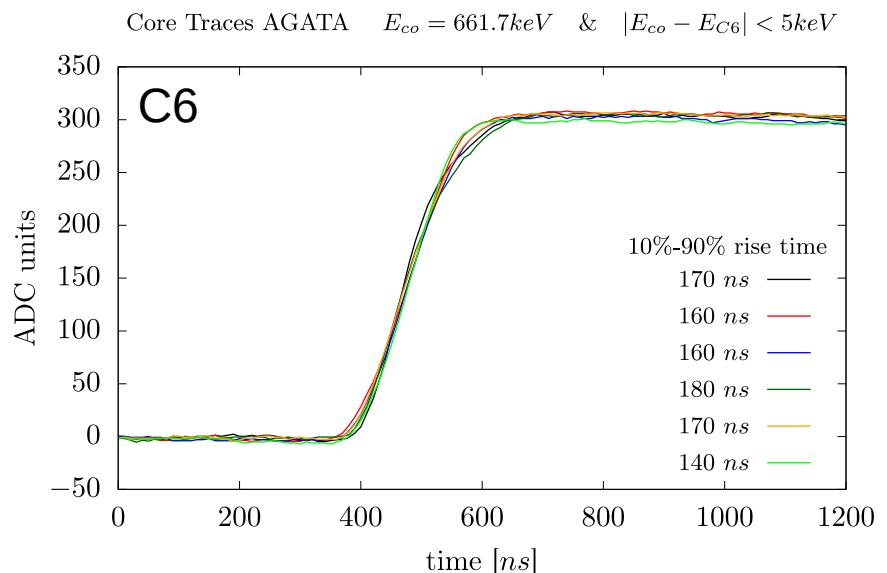
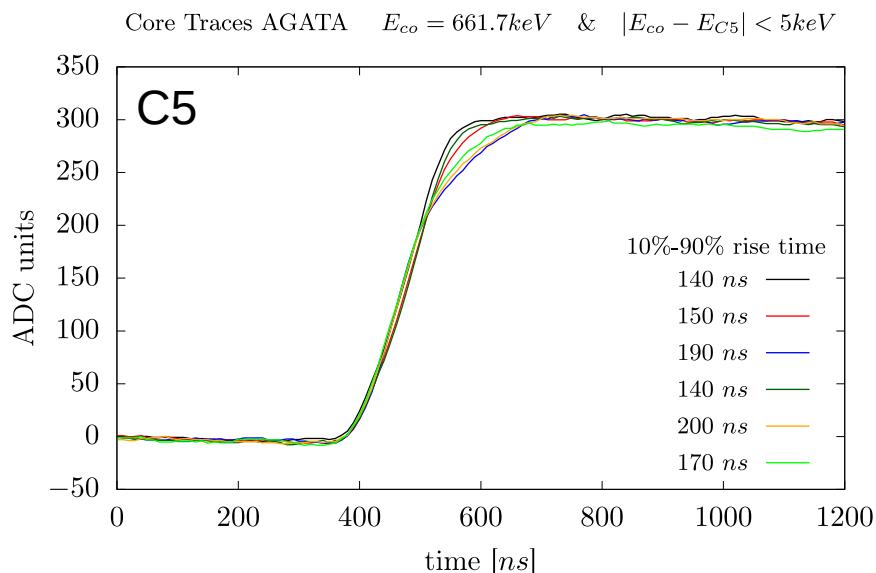


Traces hit segment C5/C6

EGC-Seg36



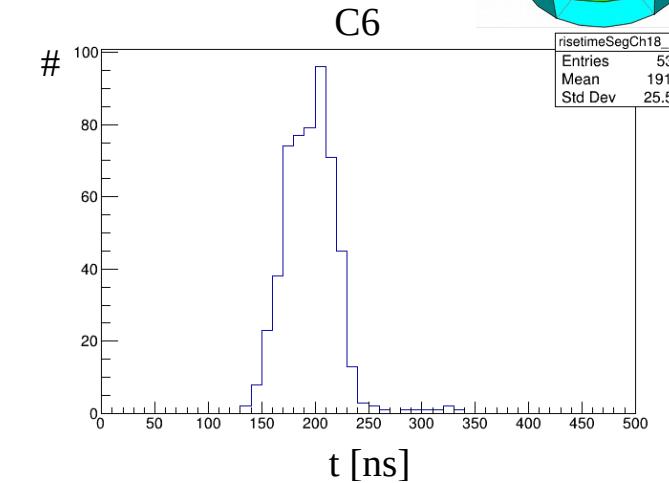
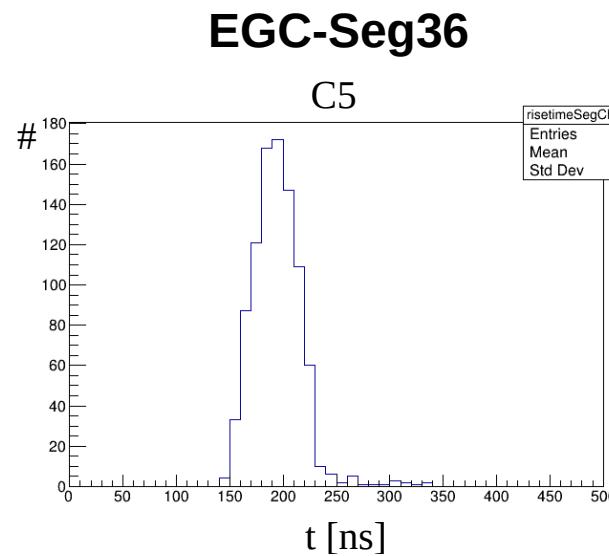
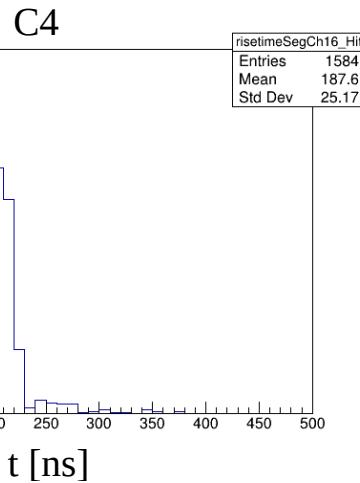
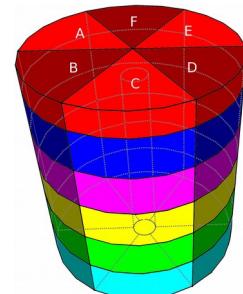
AGATA S001



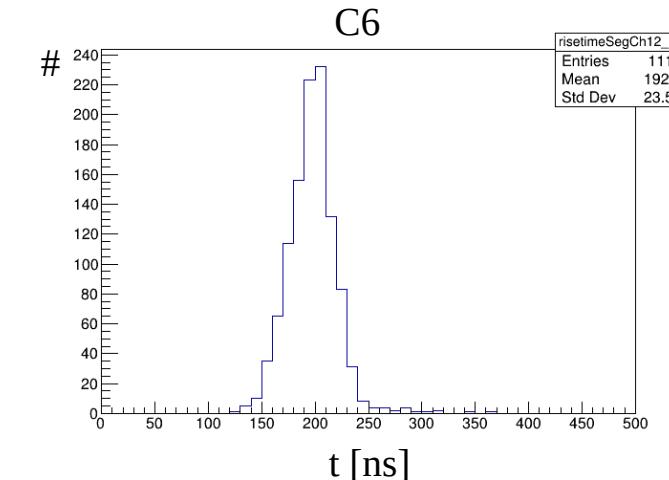
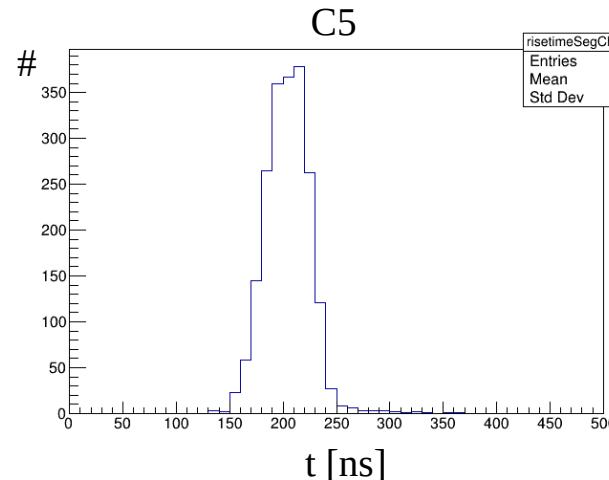
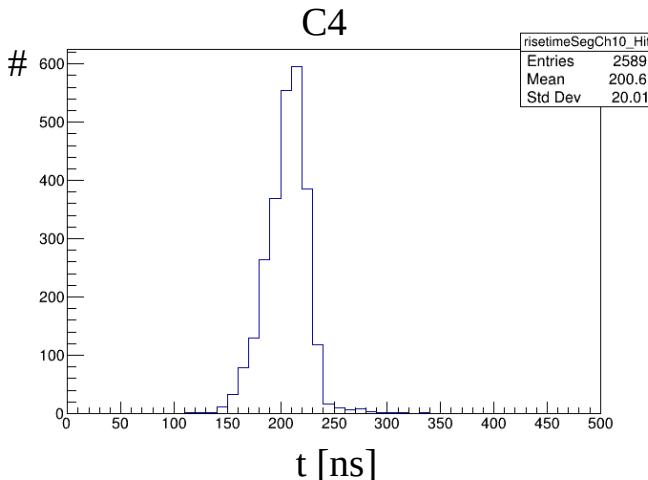
Rise time distributions

- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

- $r = 3.5\text{cm}$
- Rise time 10%-90%
- Segment



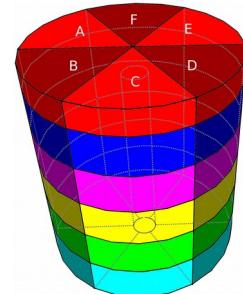
AGATA S001



Rise time distributions

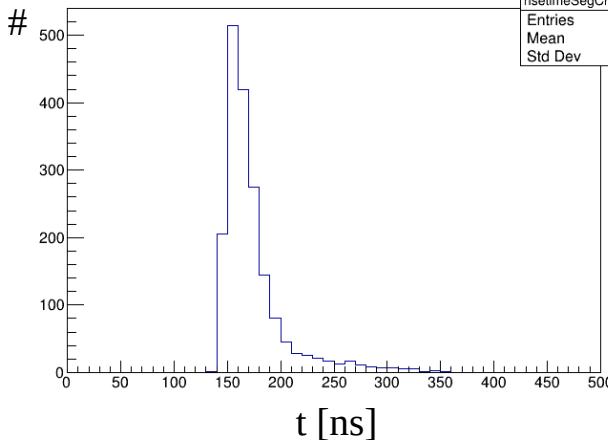
- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

- $r = 2.5\text{cm}$
- Rise time 10%-90%
- Segment



C4

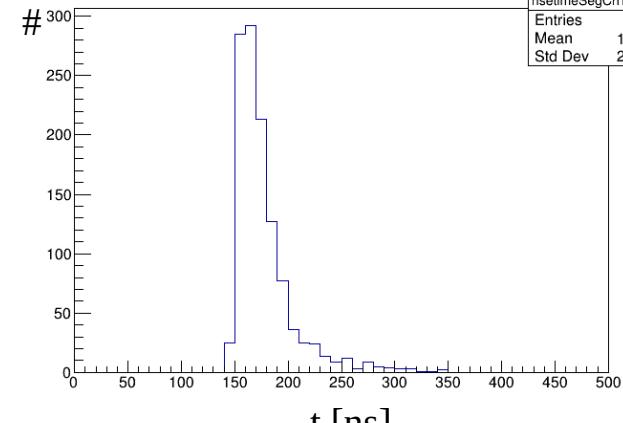
risetimeSegCh16_Hit		
Entries	1854	
Mean	168.5	
Std Dev	30.97	



EGC-Seg36

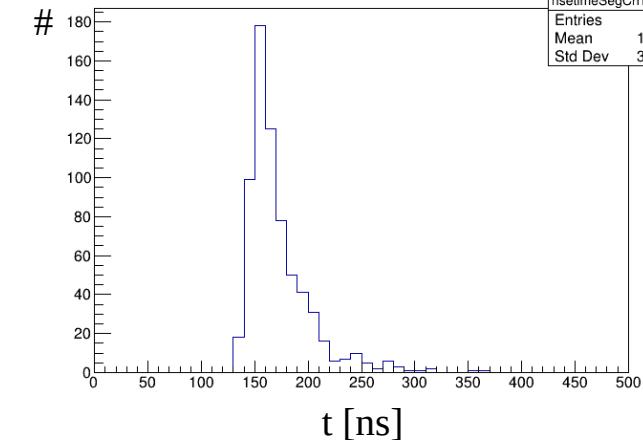
C5

risetimeSegCh17_Hit		
Entries	1171	
Mean	172.4	
Std Dev	28.55	



C6

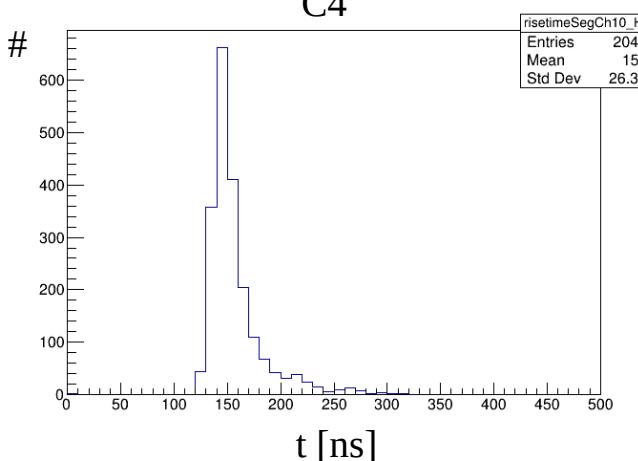
risetimeSegCh18_Hit		
Entries	681	
Mean	167.4	
Std Dev	30.76	



AGATA S001

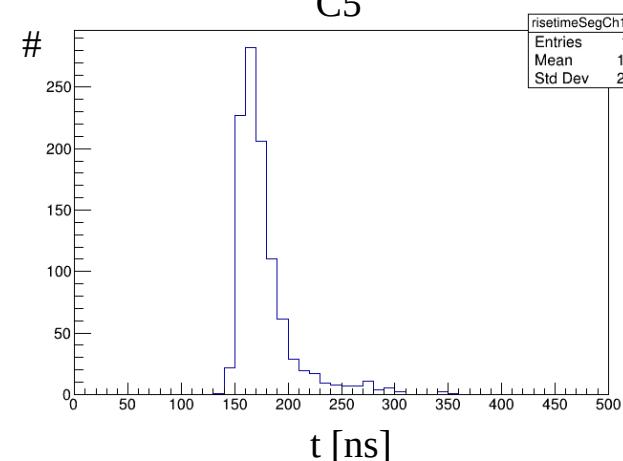
C4

risetimeSegCh10_Hit		
Entries	2045	
Mean	152	
Std Dev	26.36	



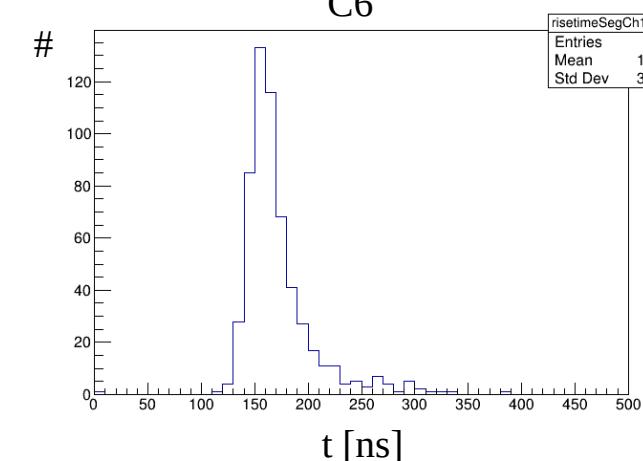
C5

risetimeSegCh11_Hit		
Entries	1030	
Mean	171.9	
Std Dev	27.85	



C6

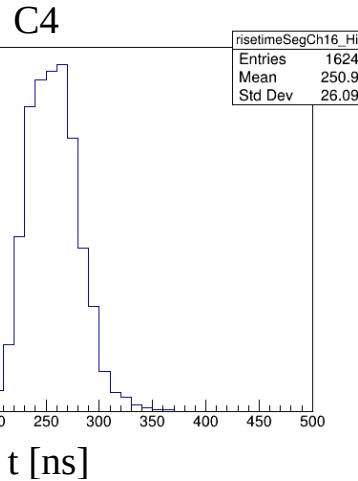
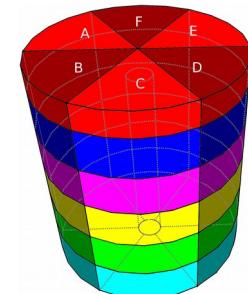
risetimeSegCh12_Hit		
Entries	578	
Mean	166.6	
Std Dev	34.34	



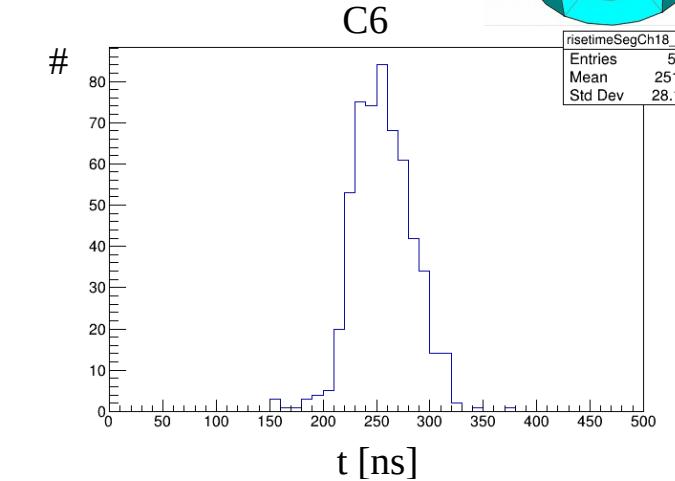
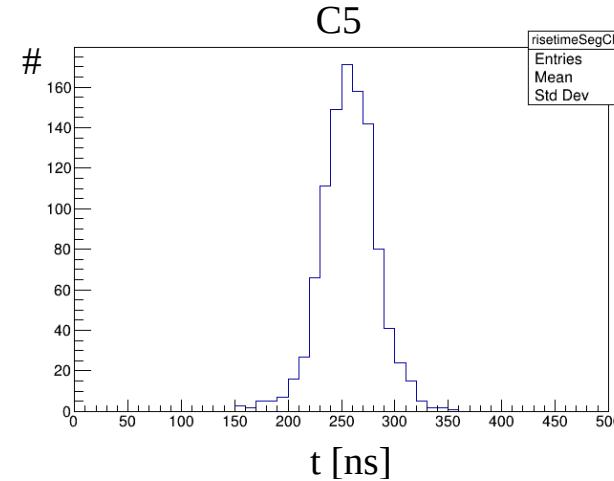
Rise time distributions

- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

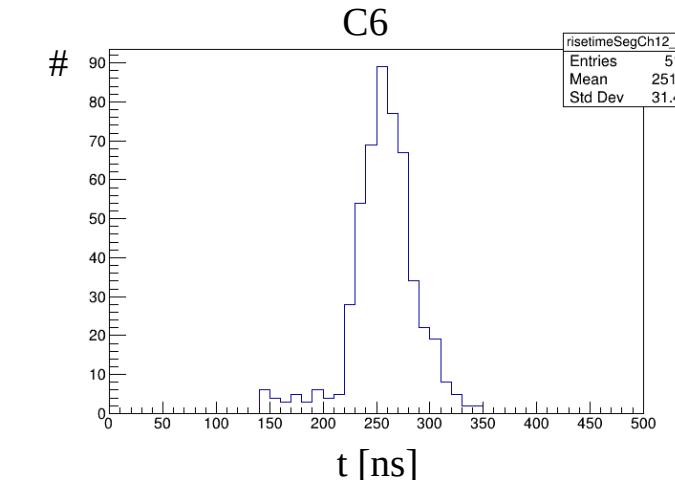
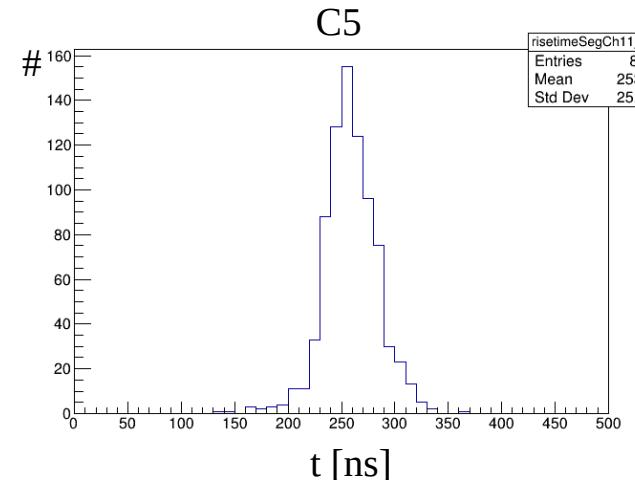
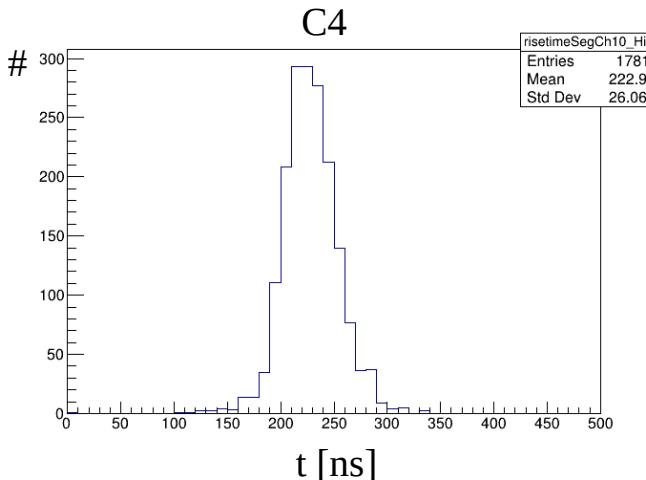
- $r = 1.5\text{cm}$
- Rise time 10%-90%
- Segment



EGC-Seg36



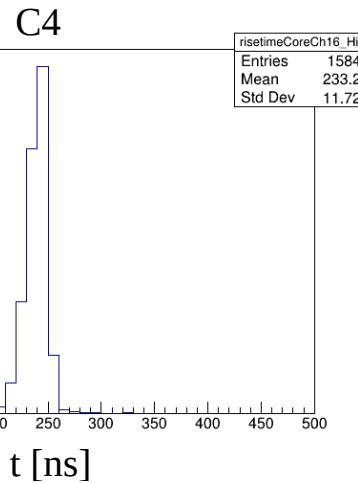
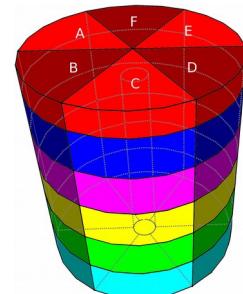
AGATA S001



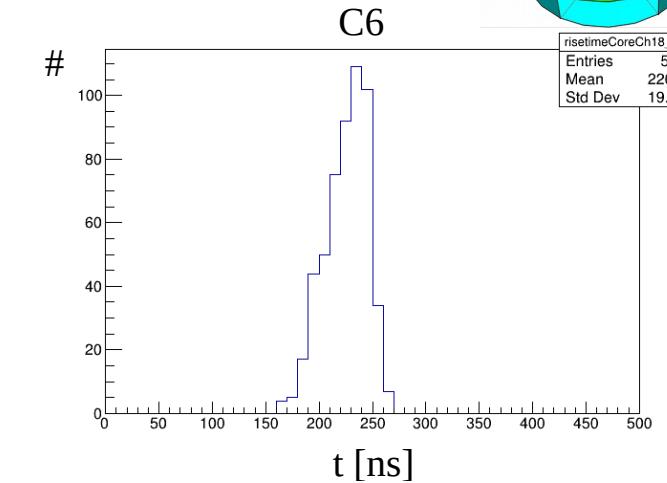
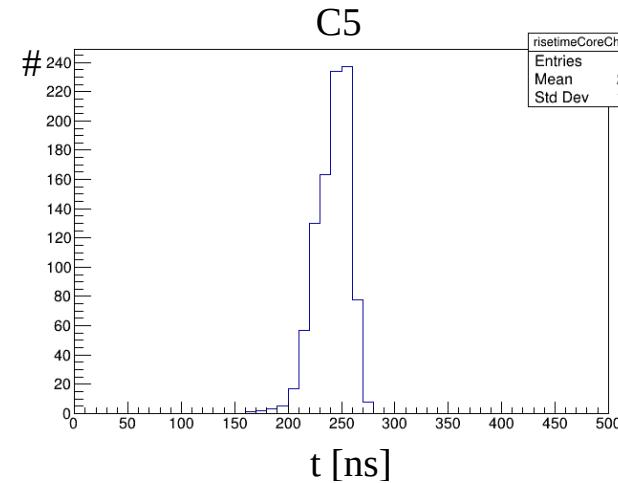
Rise time distributions

- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

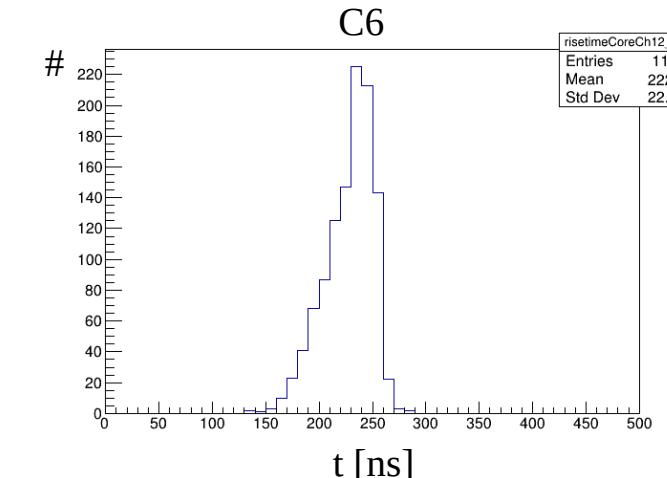
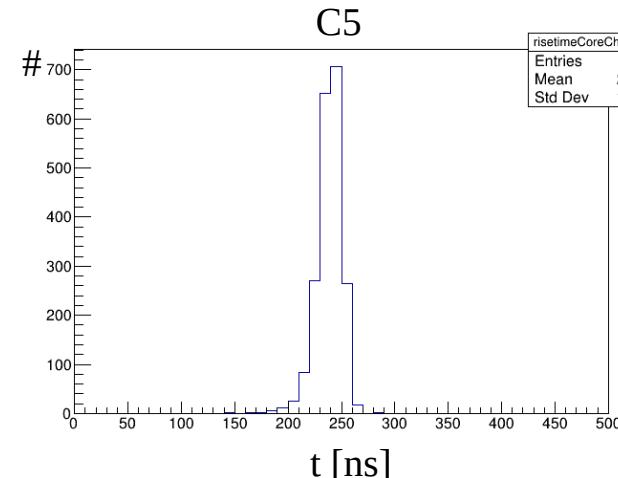
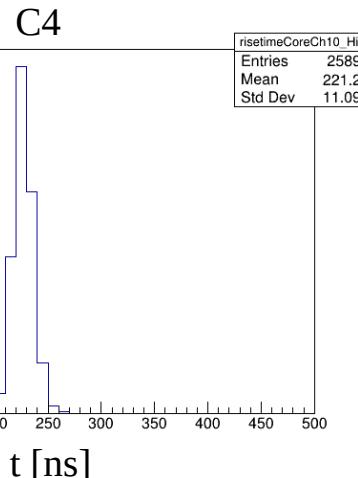
- $r = 3.5\text{cm}$
- Rise time 10%-90%
- Core



EGC-Seg36



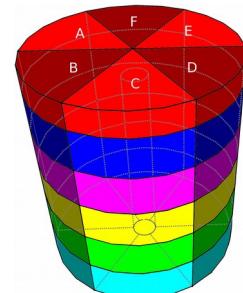
AGATA S001



Rise time distributions

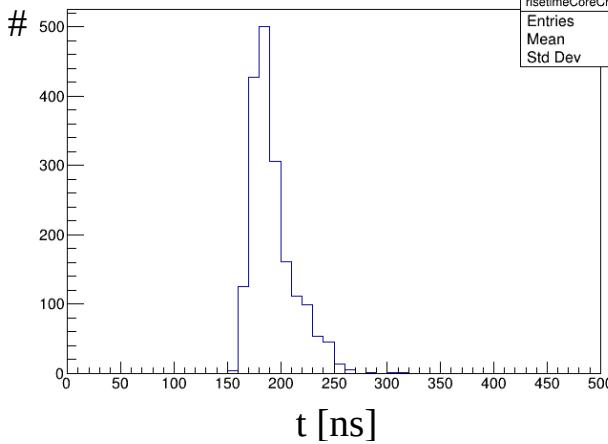
- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

- $r = 2.5\text{cm}$
- Rise time 10%-90%
- Core



C4

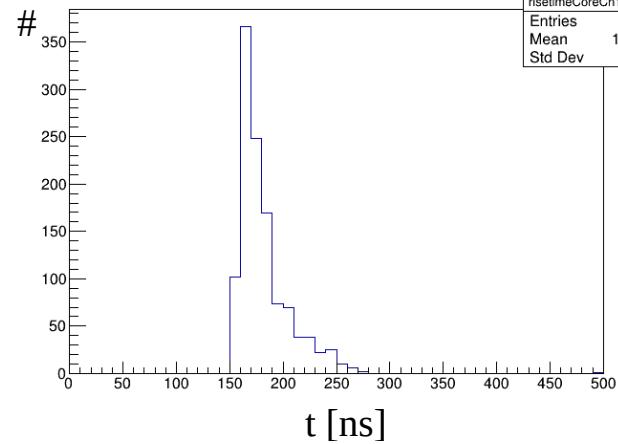
risetimeCoreCh16_Hit		
Entries	1854	
Mean	187.4	
Std Dev	20.54	



EGC-Seg36

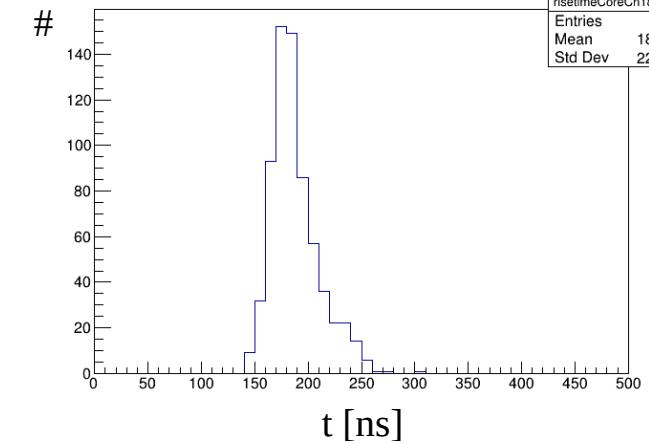
C5

risetimeCoreCh17_Hit		
Entries	1171	
Mean	176.8	
Std Dev	24.9	



C6

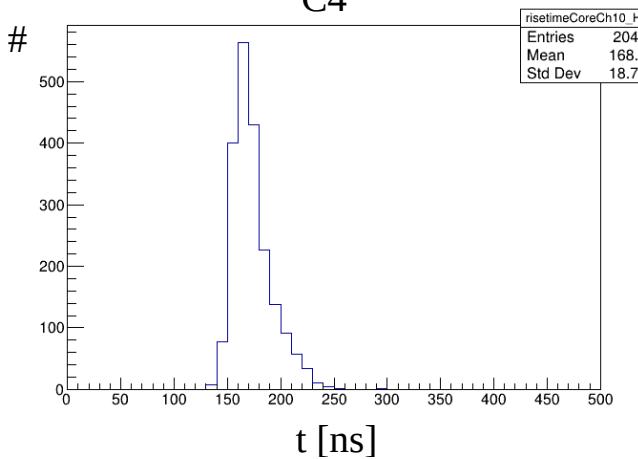
risetimeCoreCh18_Hit		
Entries	681	
Mean	182.8	
Std Dev	22.77	



AGATA S001

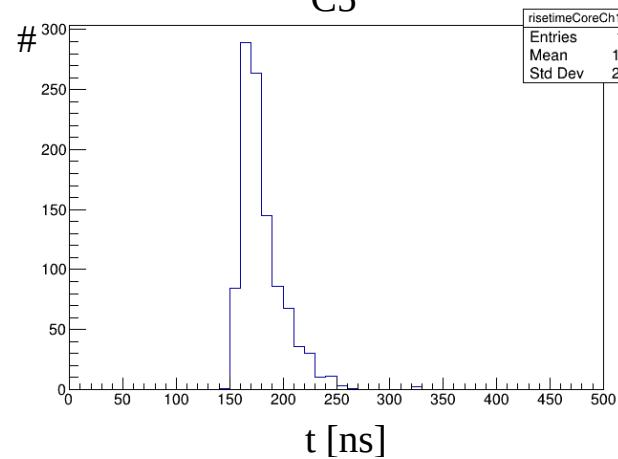
C4

risetimeCoreCh10_Hit		
Entries	2045	
Mean	168.4	
Std Dev	18.72	



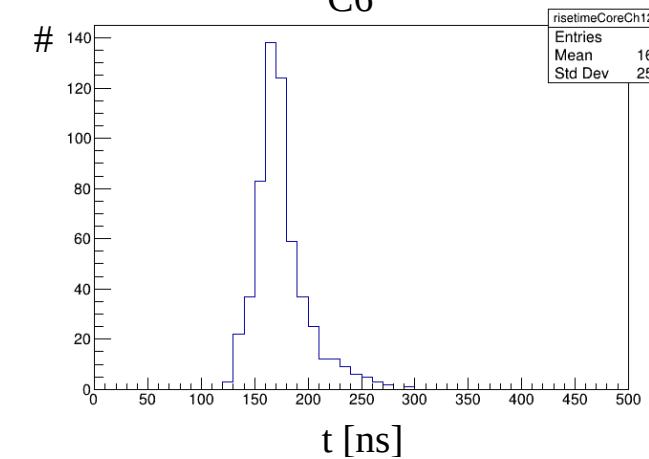
C5

risetimeCoreCh11_Hit		
Entries	1030	
Mean	175.4	
Std Dev	20.63	



C6

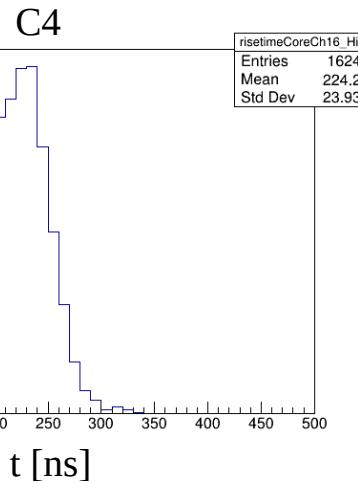
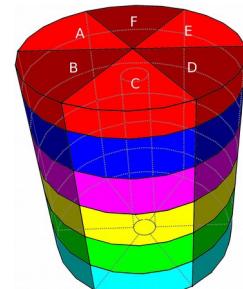
risetimeCoreCh12_Hit		
Entries	578	
Mean	169.9	
Std Dev	25.23	



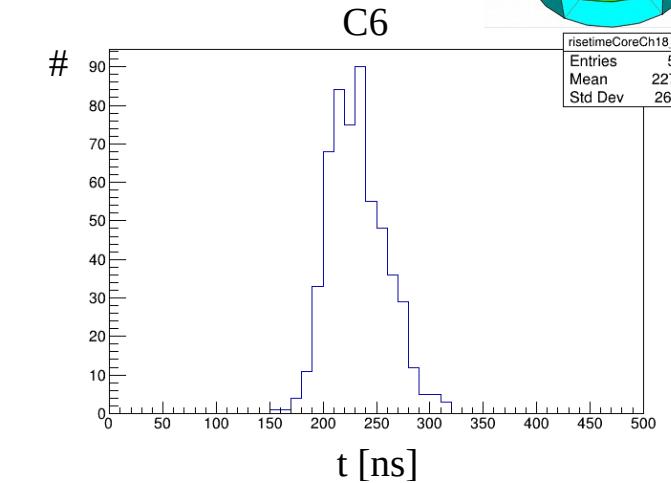
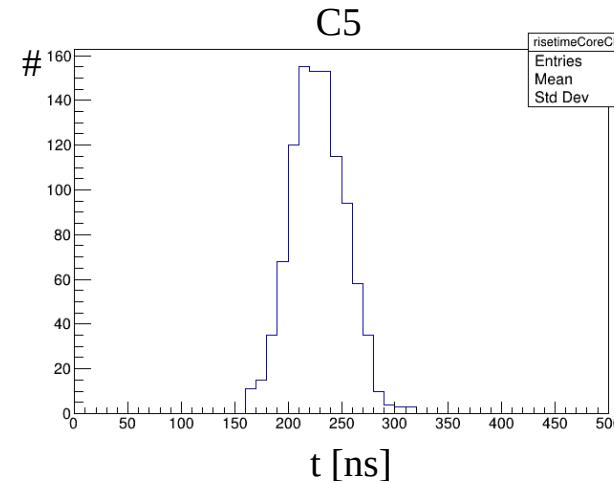
Rise time distributions

- Collimated Cs-137 Source
- Single segment hit
- Full energy deposition

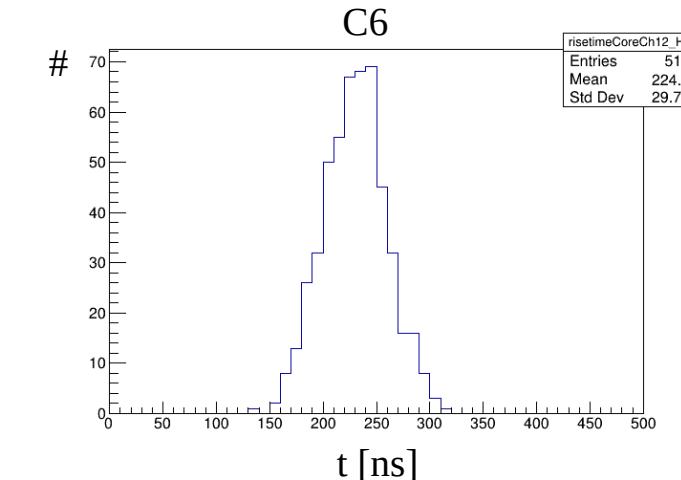
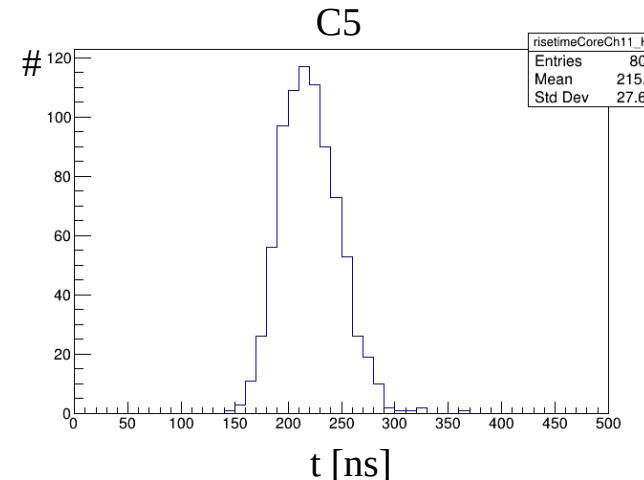
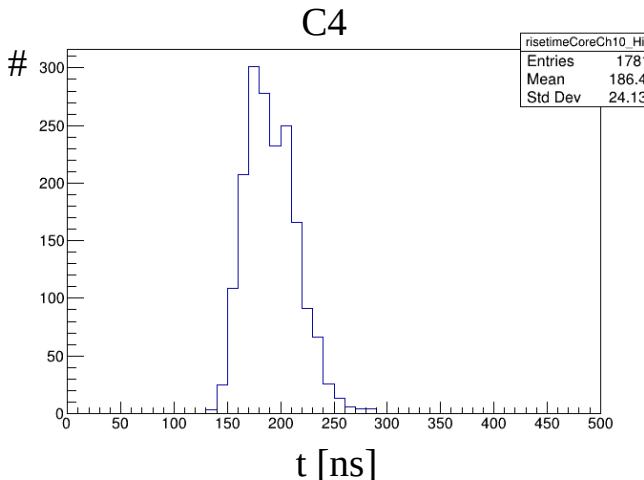
- $r = 1.5\text{cm}$
- Rise time 10%-90%
- Core



EGC-Seg36



AGATA S001



Summary and Outlook

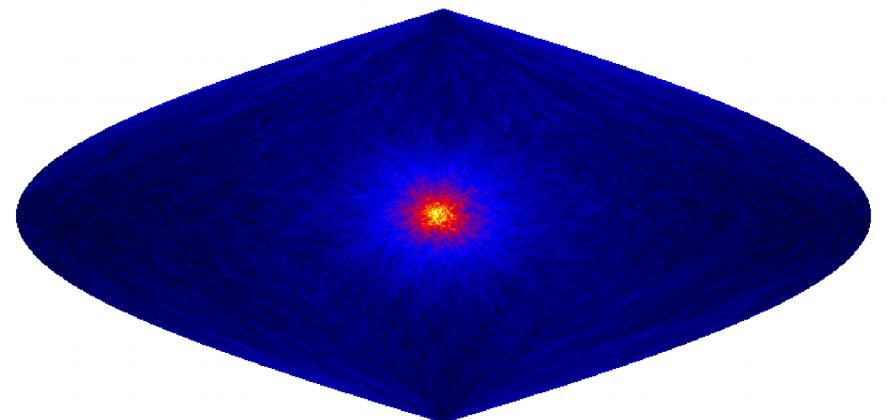
Detector Integration

- Characterization
- ADL Signal Basis
- Setup optimized
- Debugging

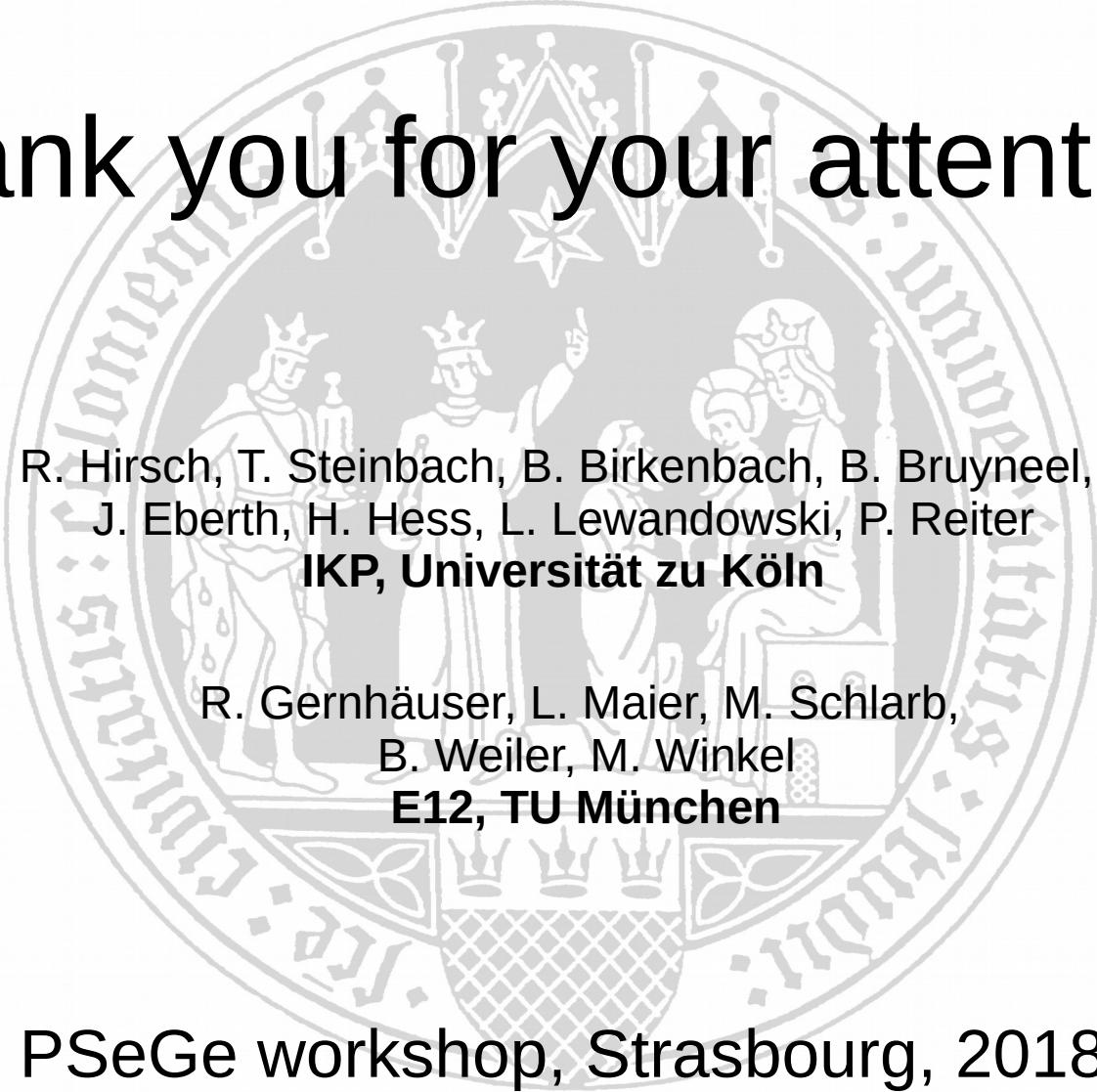


Pulse Shape Analysis

- ADL3 adjustments
 - Geometry
 - Impurity concentration
 - Mobilities
- Imaging performance



Thank you for your attention!



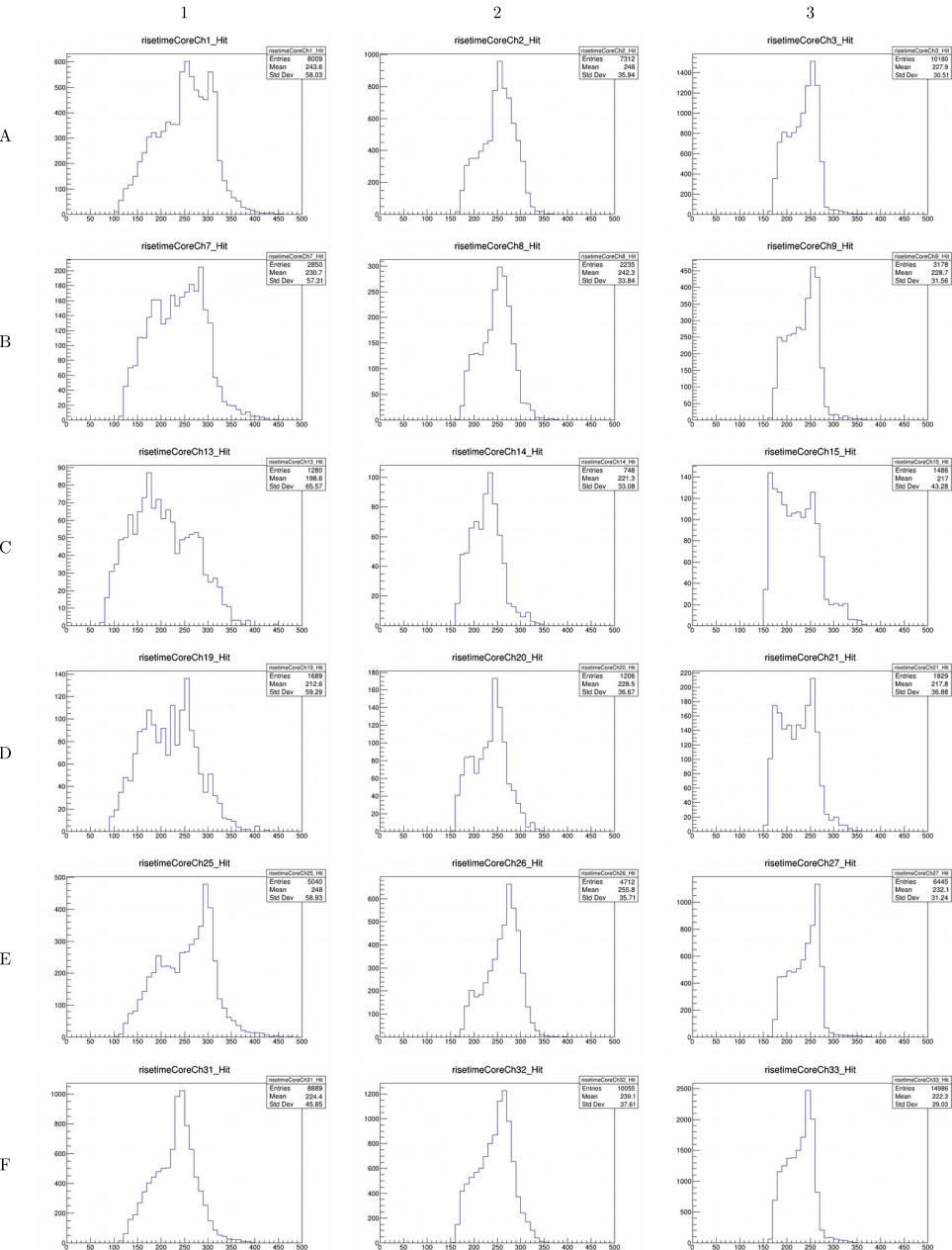
R. Hirsch, T. Steinbach, B. Birkenbach, B. Bruyneel,
J. Eberth, H. Hess, L. Lewandowski, P. Reiter
IKP, Universität zu Köln

R. Gernhäuser, L. Maier, M. Schlarb,
B. Weiler, M. Winkel
E12, TU München

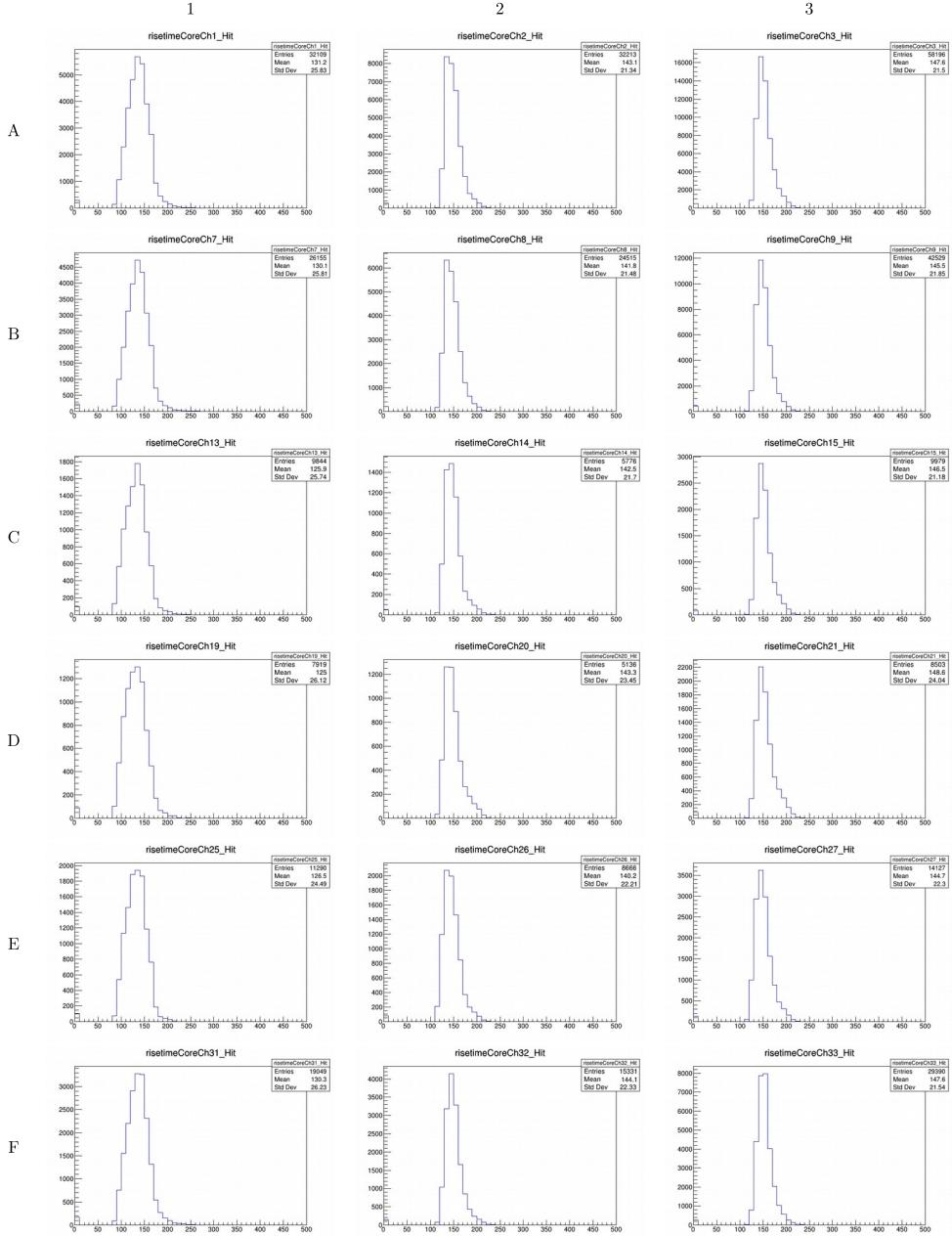
PSeGe workshop, Strasbourg, 2018

Core rise time distributions

EGC-Seg36

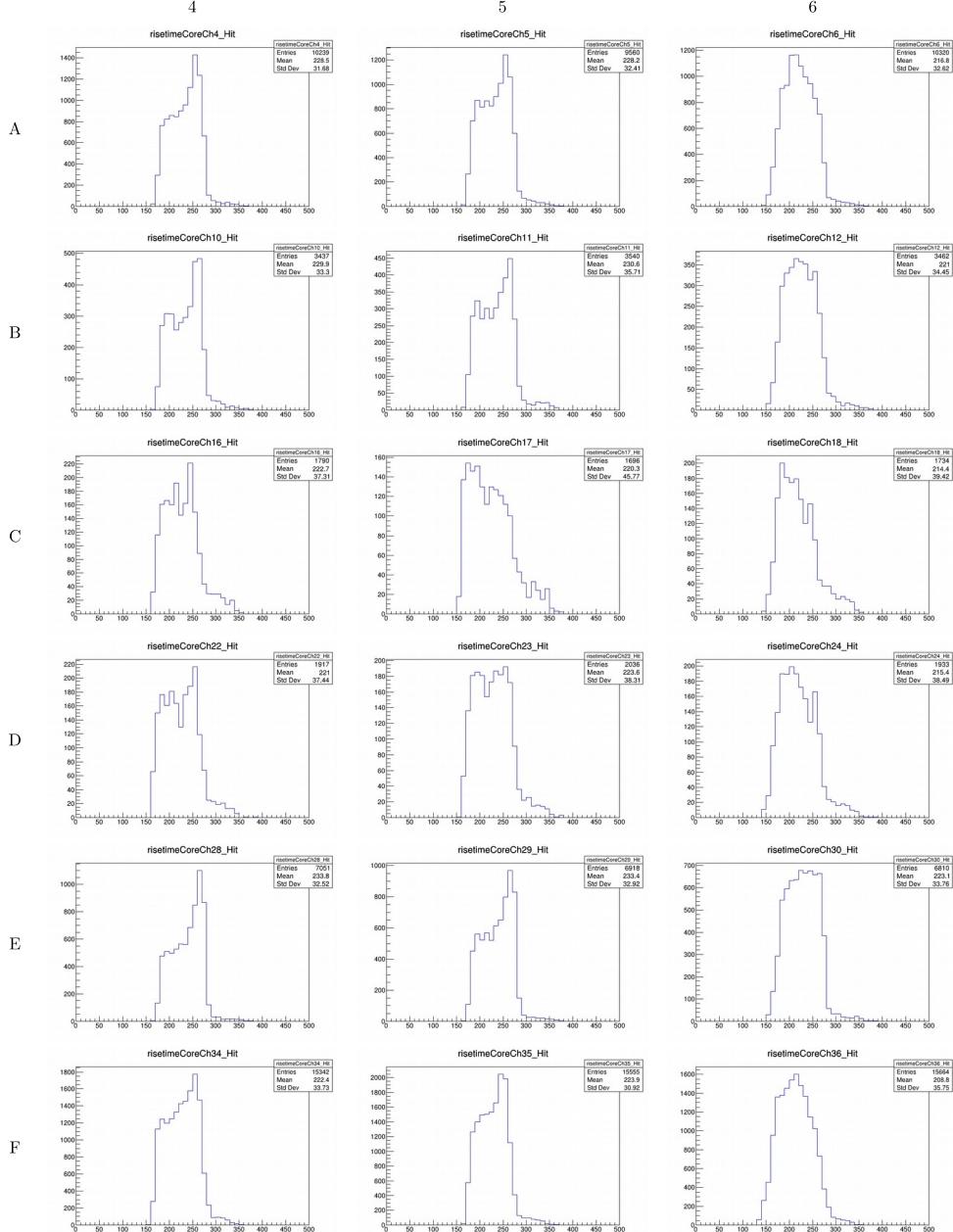


AGATA S001

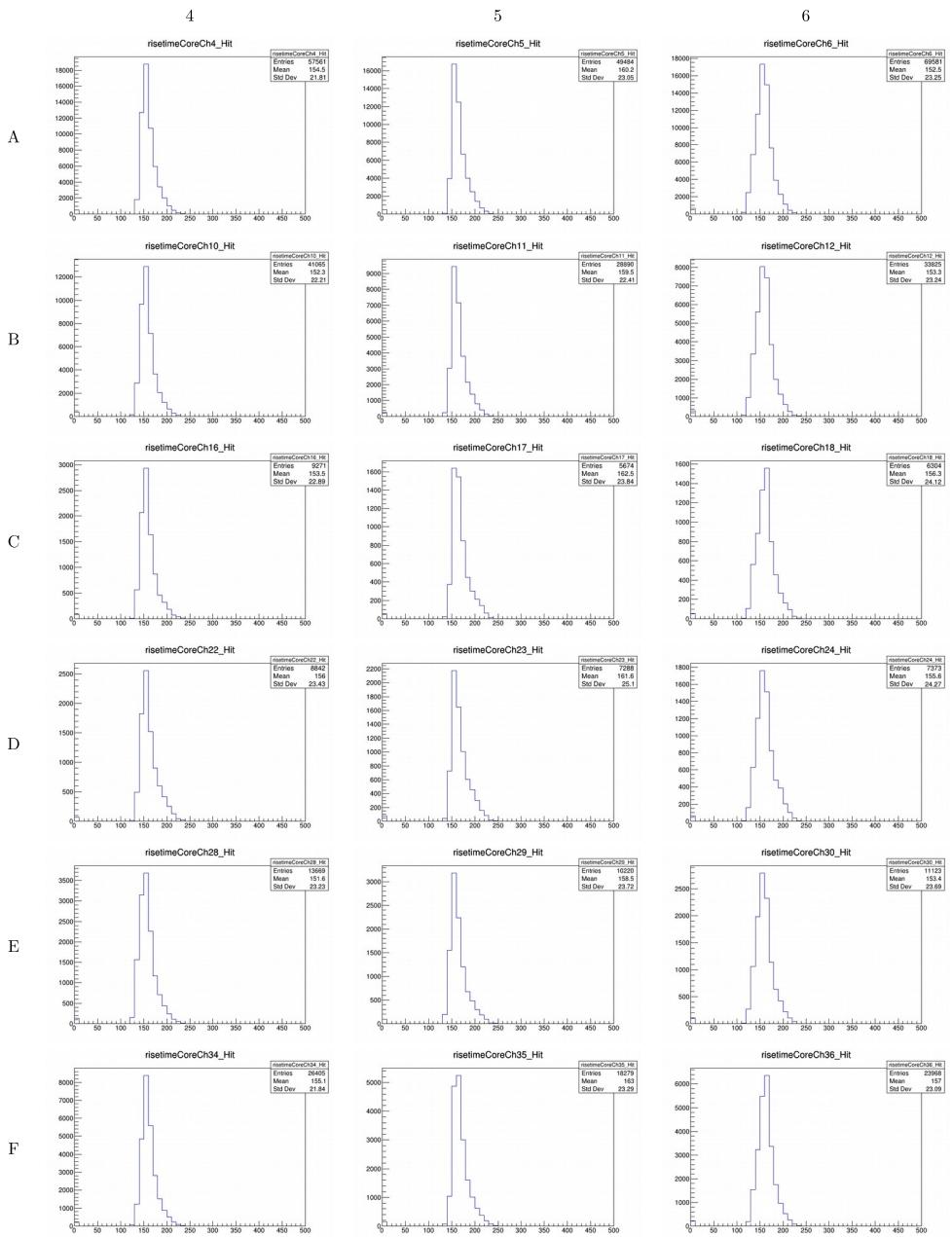


Core rise time distributions

EGC-Seg36



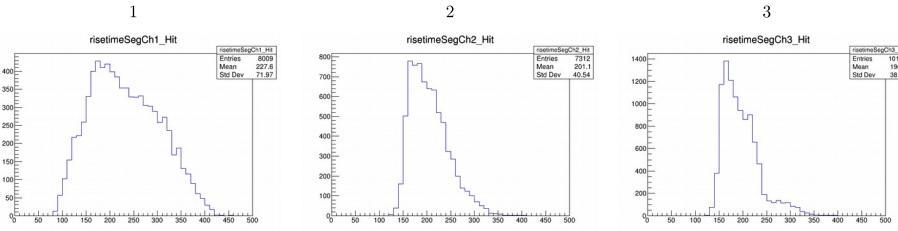
AGATA S001



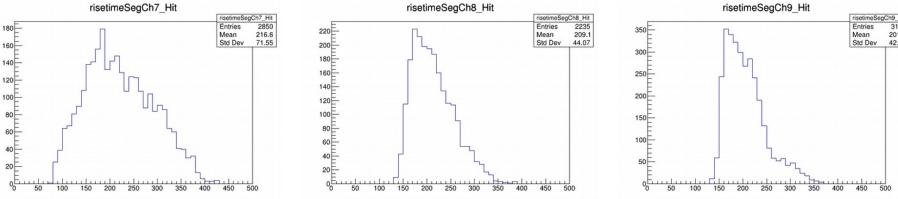
Segment rise time distributions

EGC-Seg36

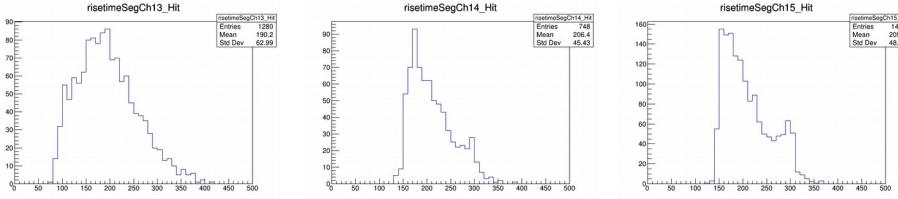
A



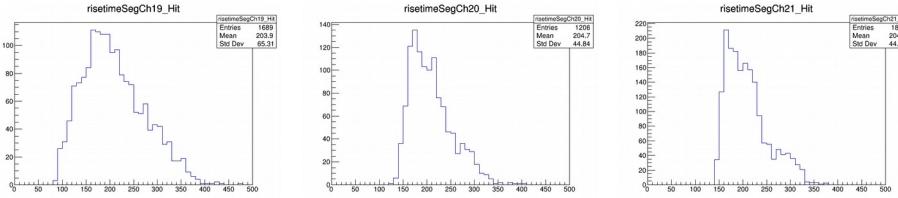
B



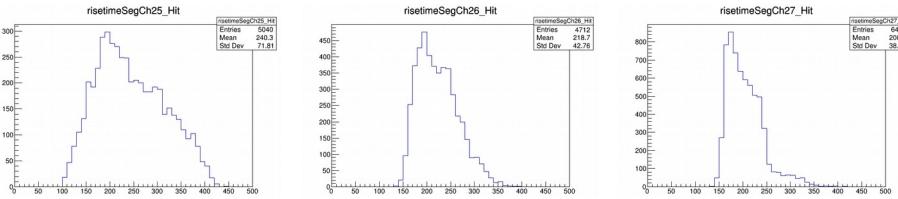
C



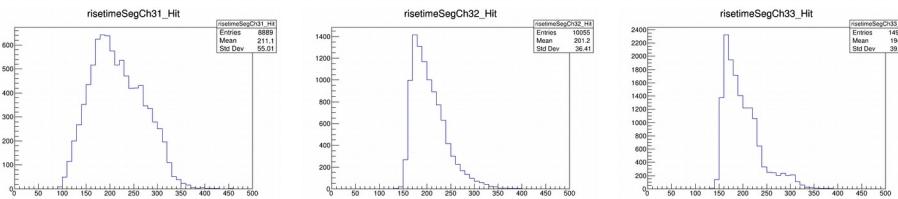
D



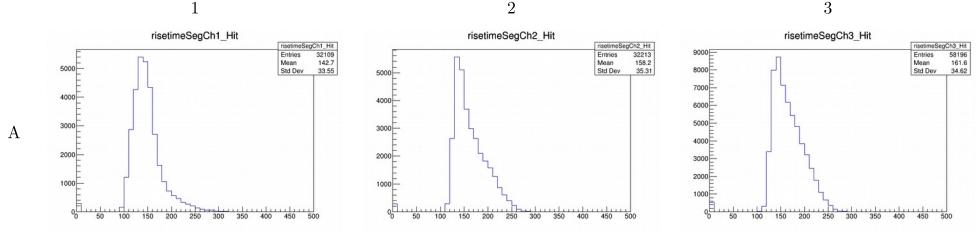
E



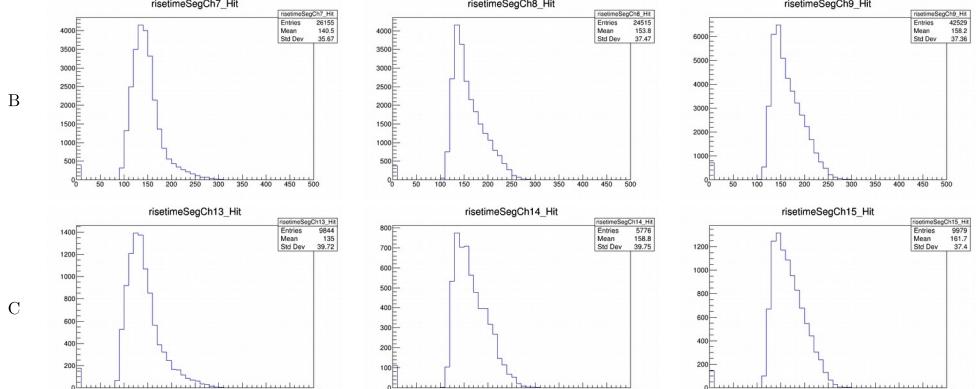
F



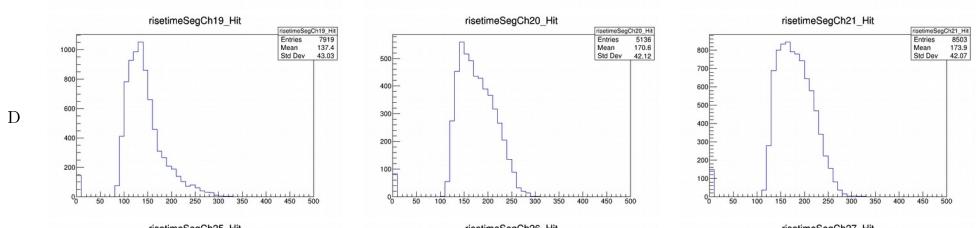
AGATA S001



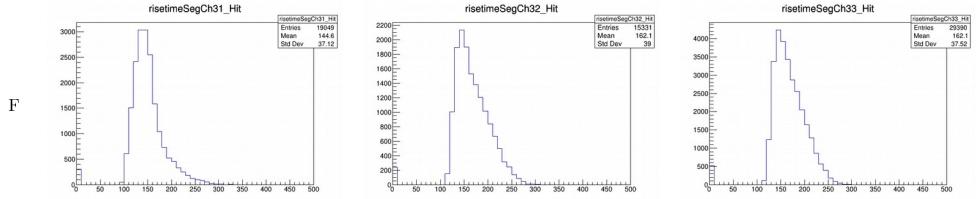
B



C

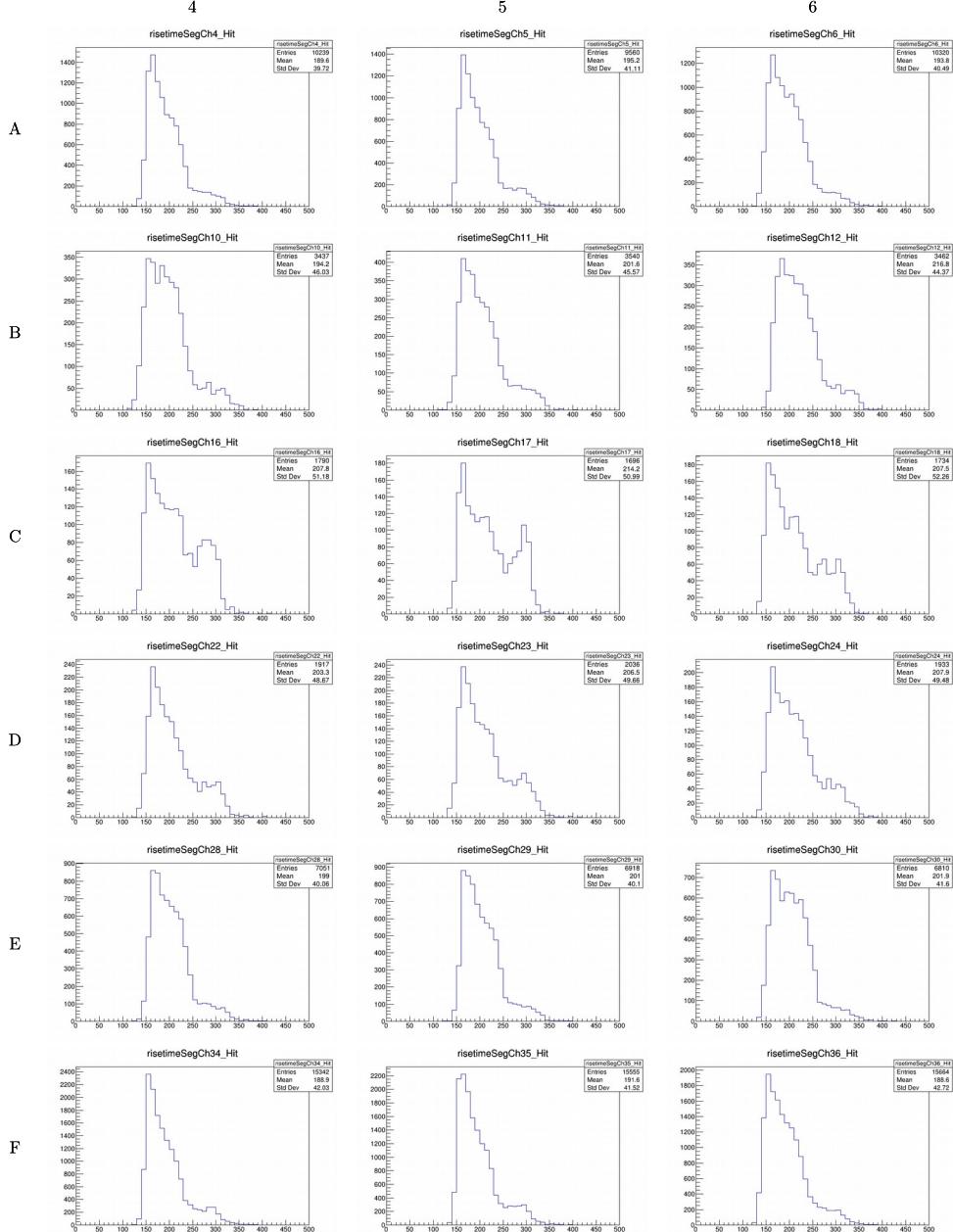


F

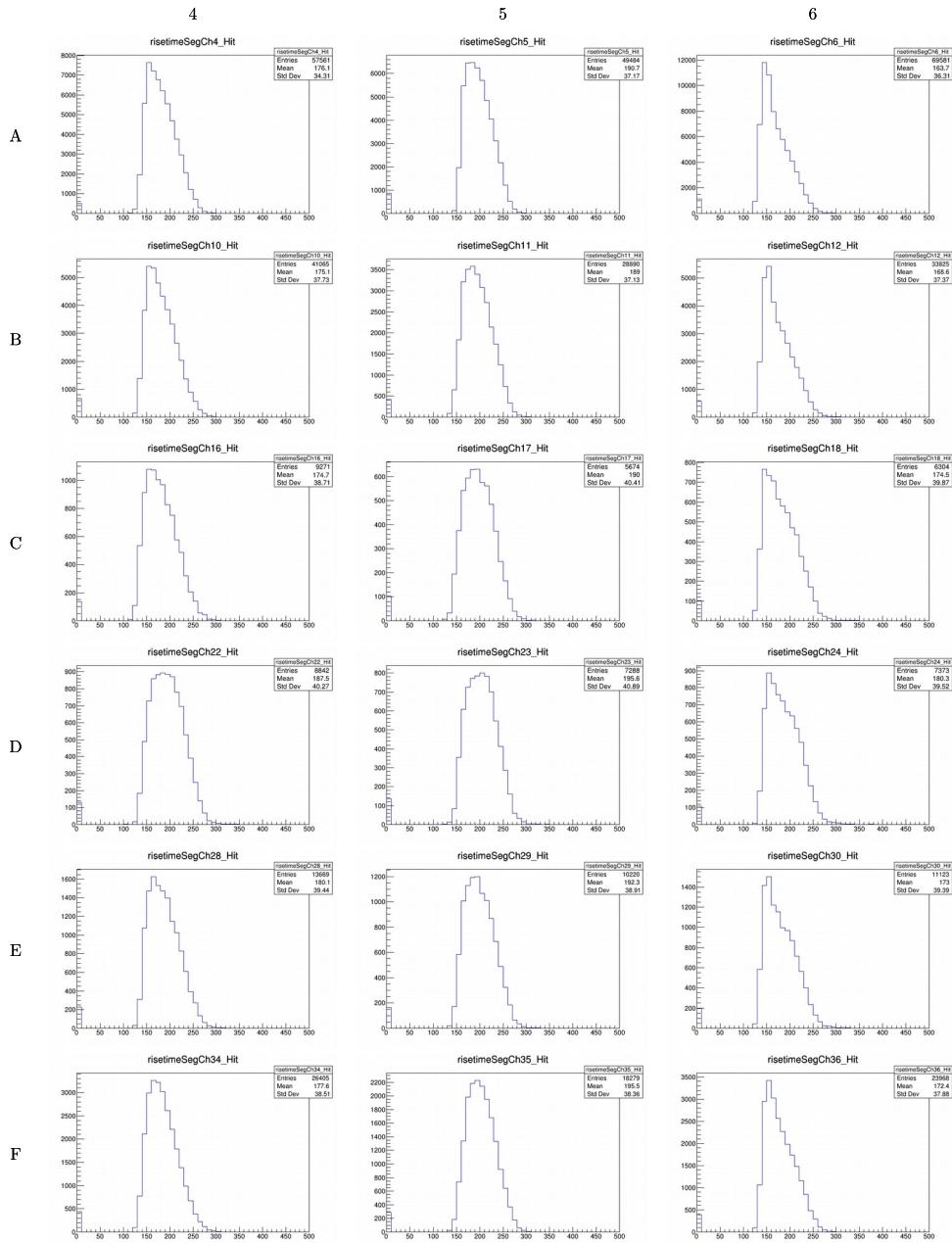


Segment rise time distributions

EGC-Seg36



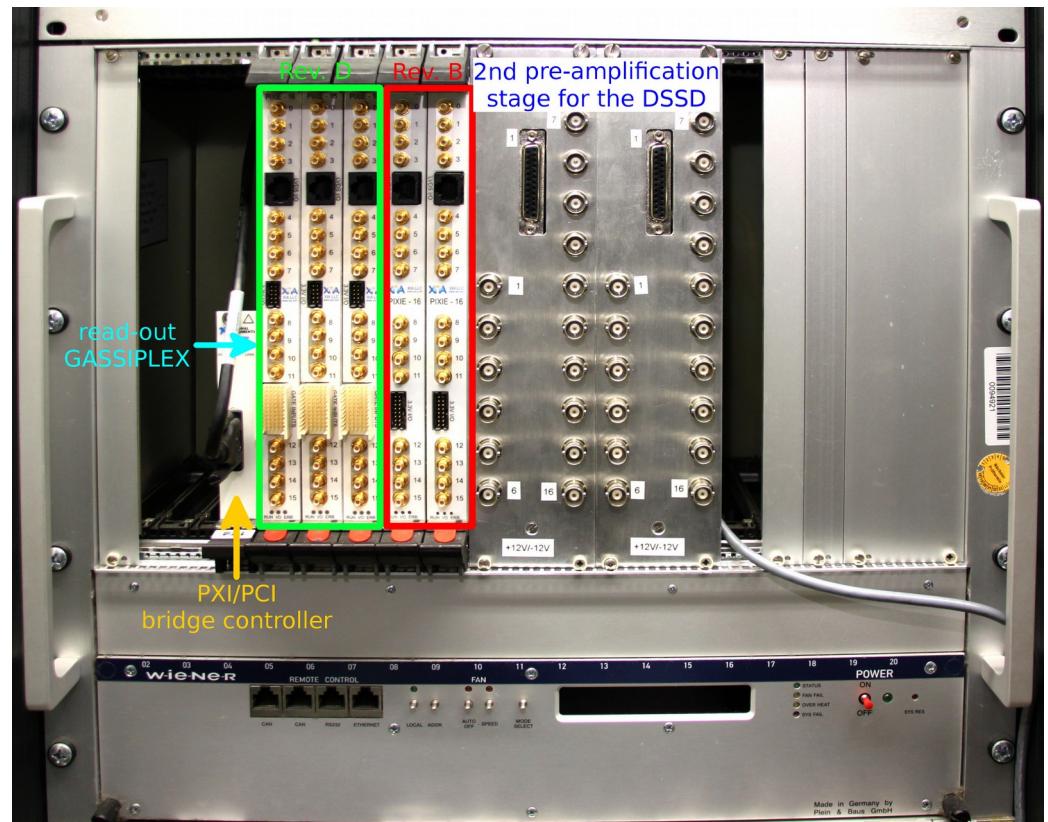
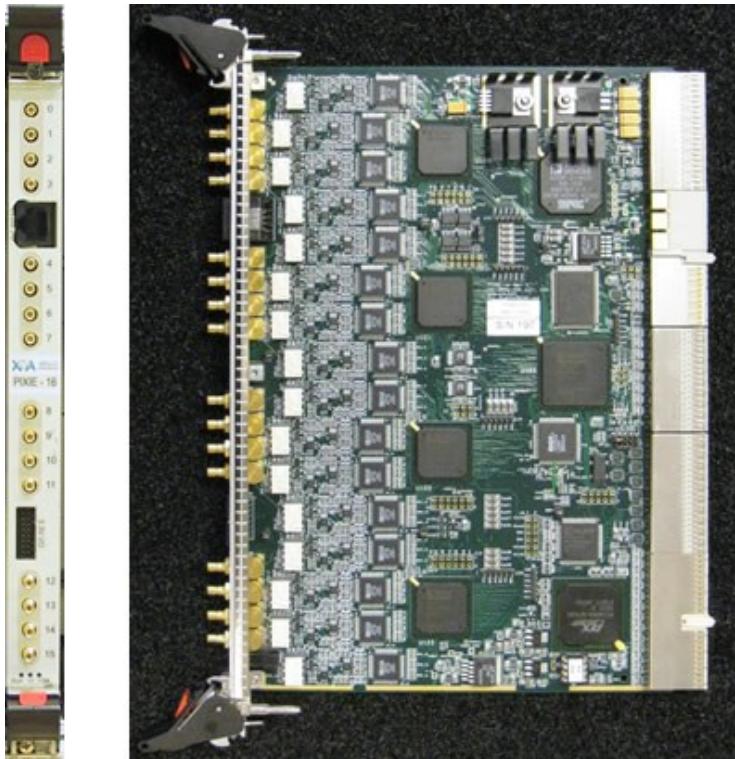
AGATA S001



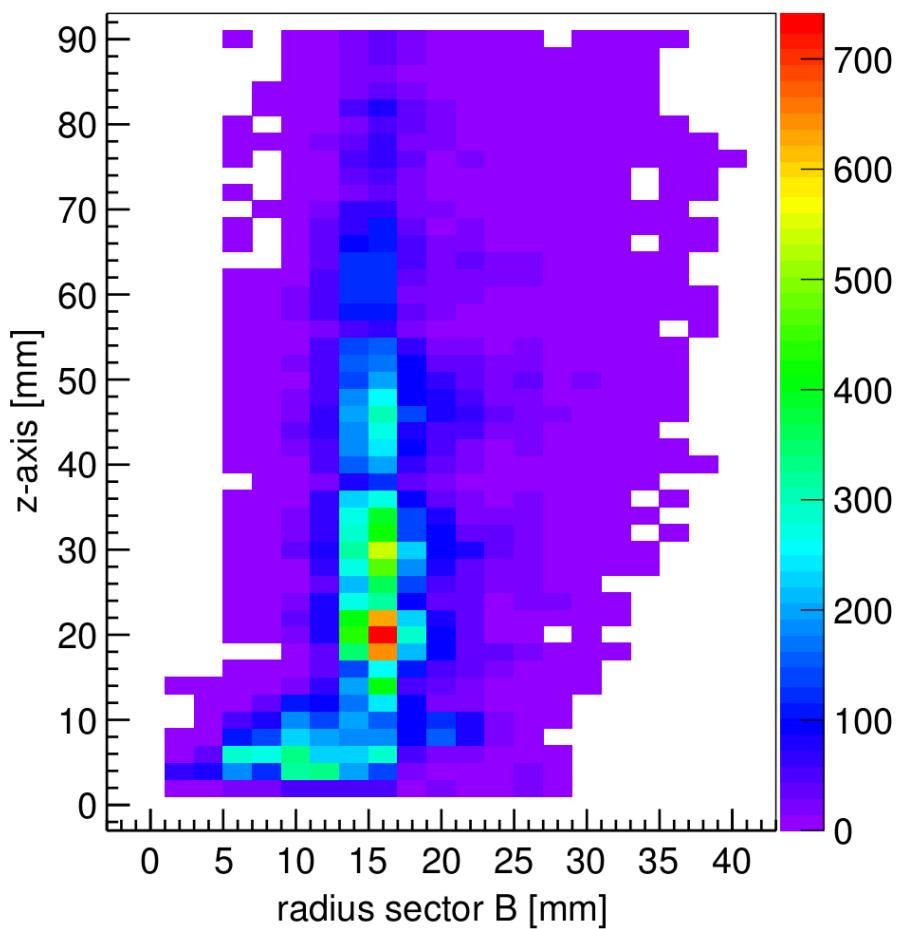
Digital electronics

Pixie-16 modules from XIA

- 16 channels per module
- 12-bit ADC
- 100-MHz sampling rate
- Custom firmware
- Data Converter to AGAPRO

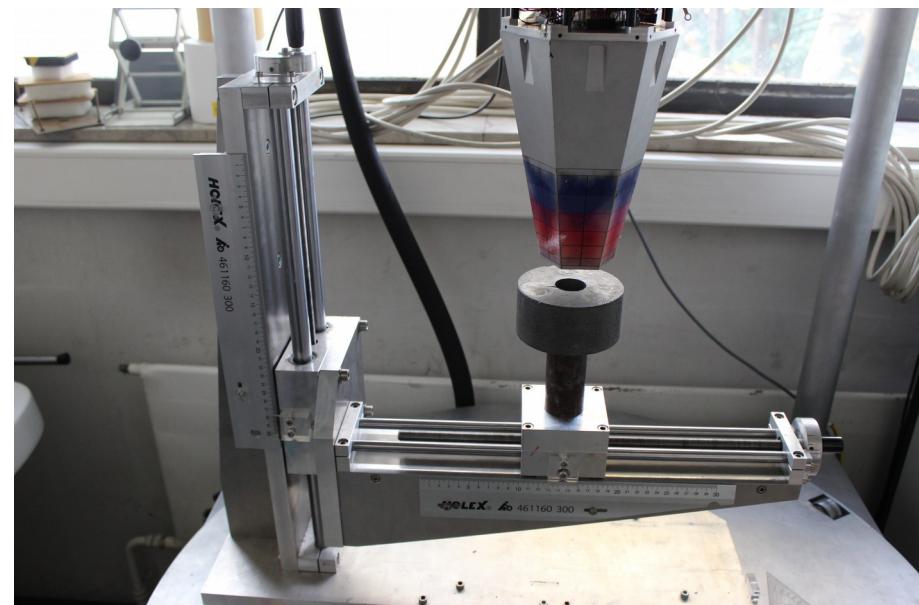
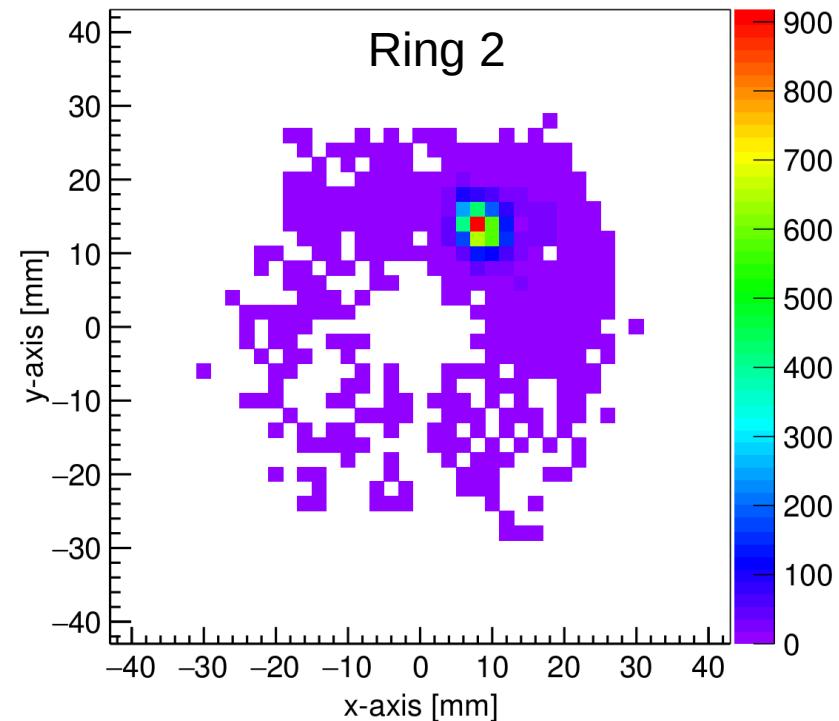


PSA results from AGAPRO



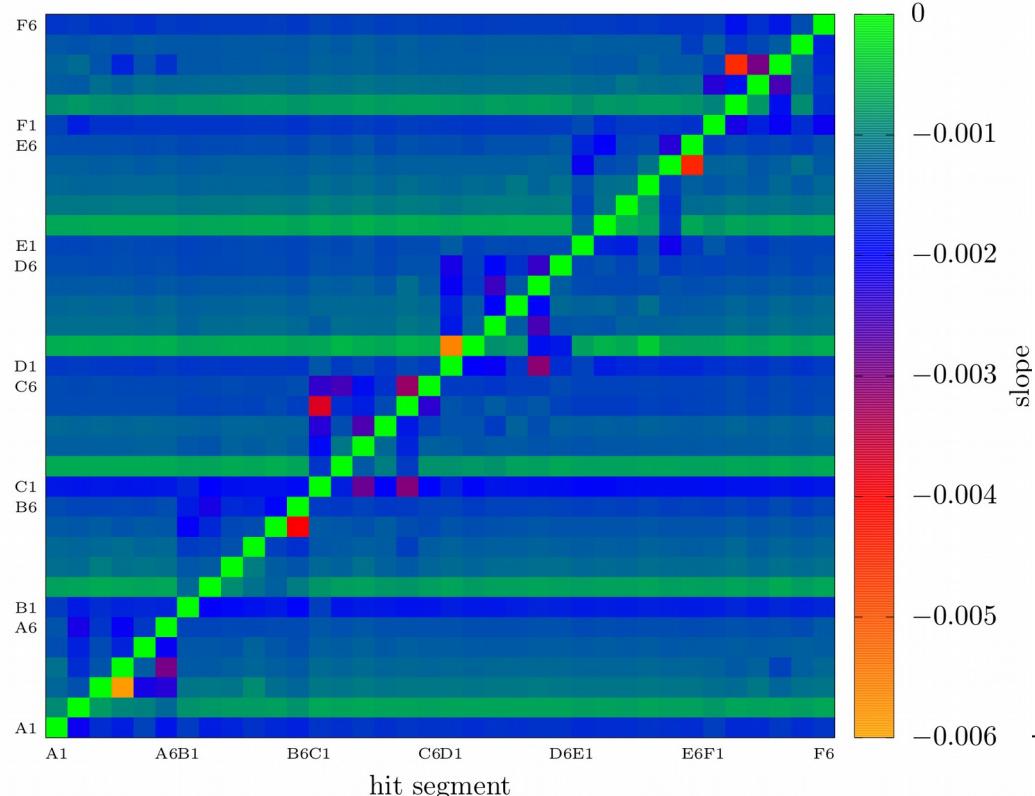
Collimated Cs-137 source

- At radius = 1.5 cm
- Middle of sector B



Crosstalk

Crosstalk parameter matrix



Crosstalk-correction
for AGAPRO

$x = \text{Energy}(26)$ $y = \text{Energy}(04)$

automated 1260 linear 2D fits

