

Optimizing the event selection for the total-body J-PET scanner with a brain PET insert: a simulation study

M Rädler^{1,2} and P Moskal^{1,2} on behalf of the J-PET Collaboration

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The poster features a central graphic of four atomic nuclei, each composed of purple and orange spheres, connected by a dashed orange line. A black dashed line with a zigzag pattern extends from the nuclei towards the right. The text '2nd Symposium on new trends in' is written in a yellow, curved font along the left side of the nuclei. The text 'Nuclear and Medical Physics' is written in a large, bold, yellow font on the right side. Below the main title, the dates '24-26 September 2025' are displayed in a yellow font. At the bottom, the host information 'Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University in Krakow, Poland' is written in a yellow font. The poster also includes logos for Jagiellonian University in Kraków, AGH, and Research University Excellence Initiative.

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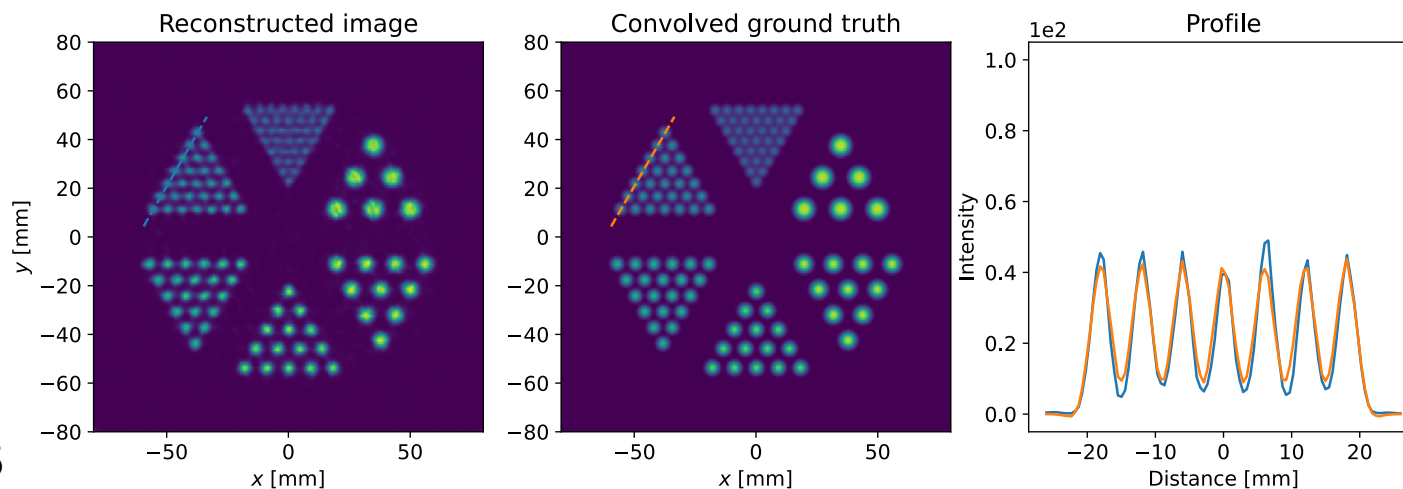
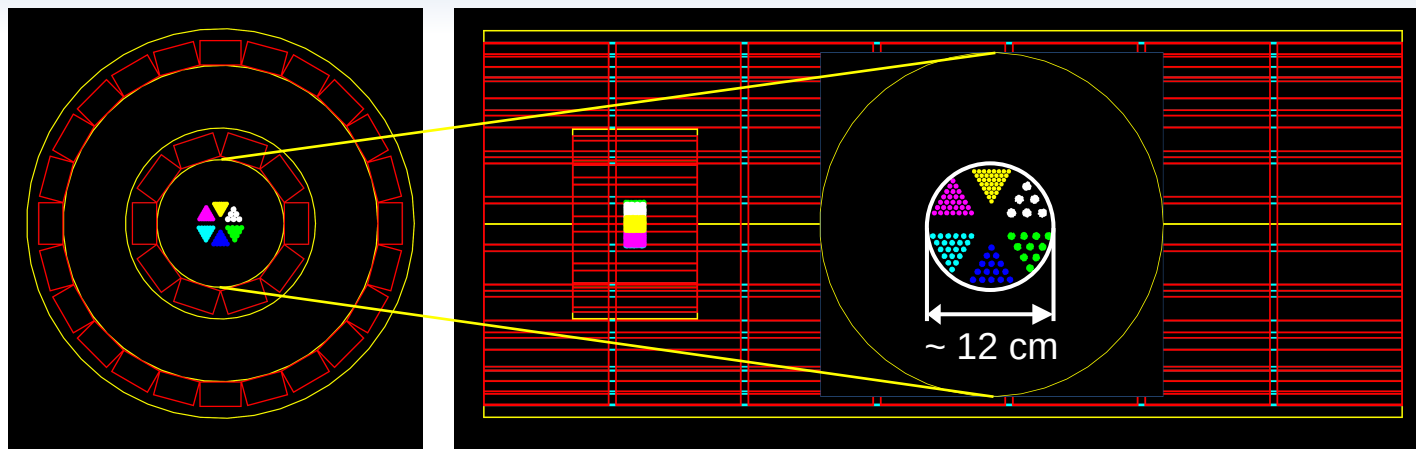
24-26 September 2025

2nd Symposium on new trends in Nuclear and Medical Physics

Faculty of Physics, Astronomy and Applied Computer Science,
Jagiellonian University in Krakow, Poland

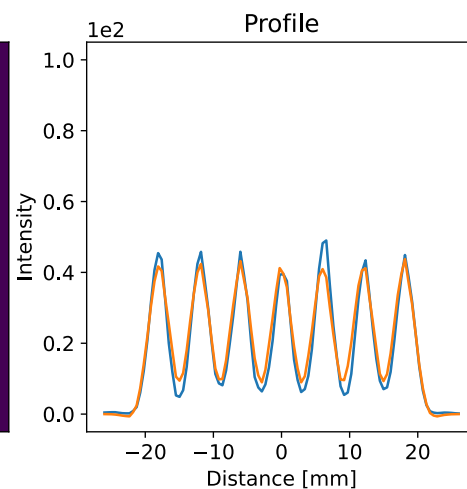
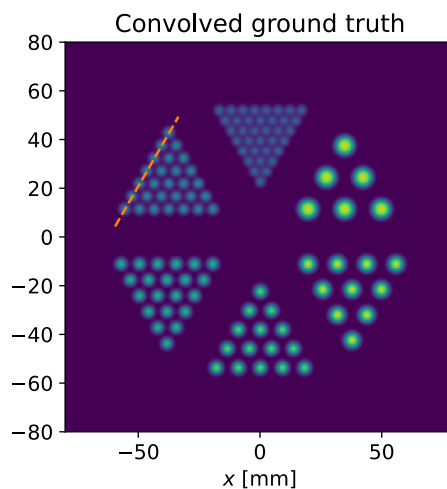
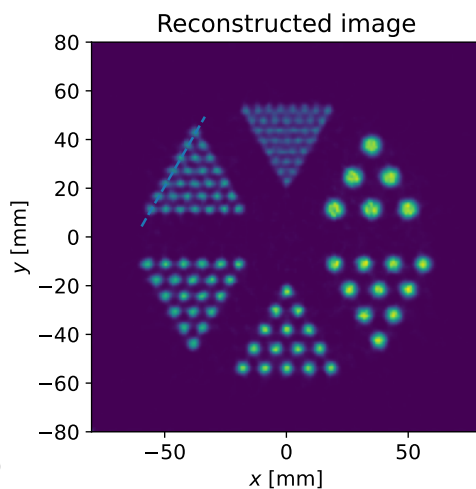
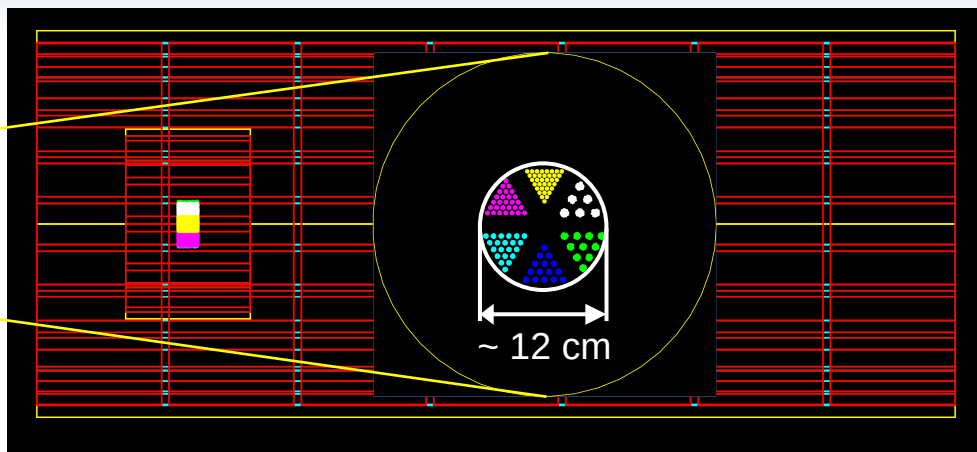
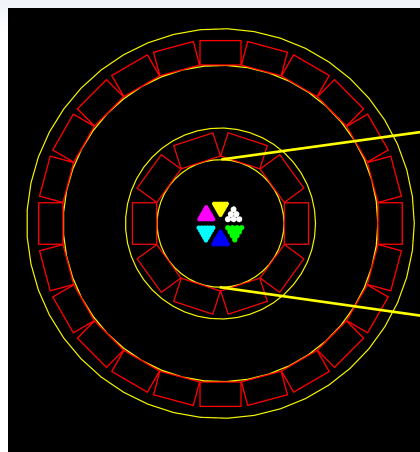
Introduction

Monte Carlo
simulations
and image
reconstruction
to analyze a
**brain PET
insert** for the
TB-J-PET



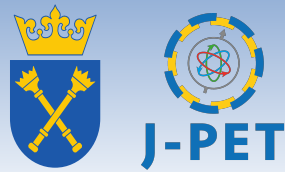
Introduction

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Event
selection

Outline



1. Event selection in J-PET and motivation
2. Monte Carlo simulation and data analysis
3. Results
4. Conclusions

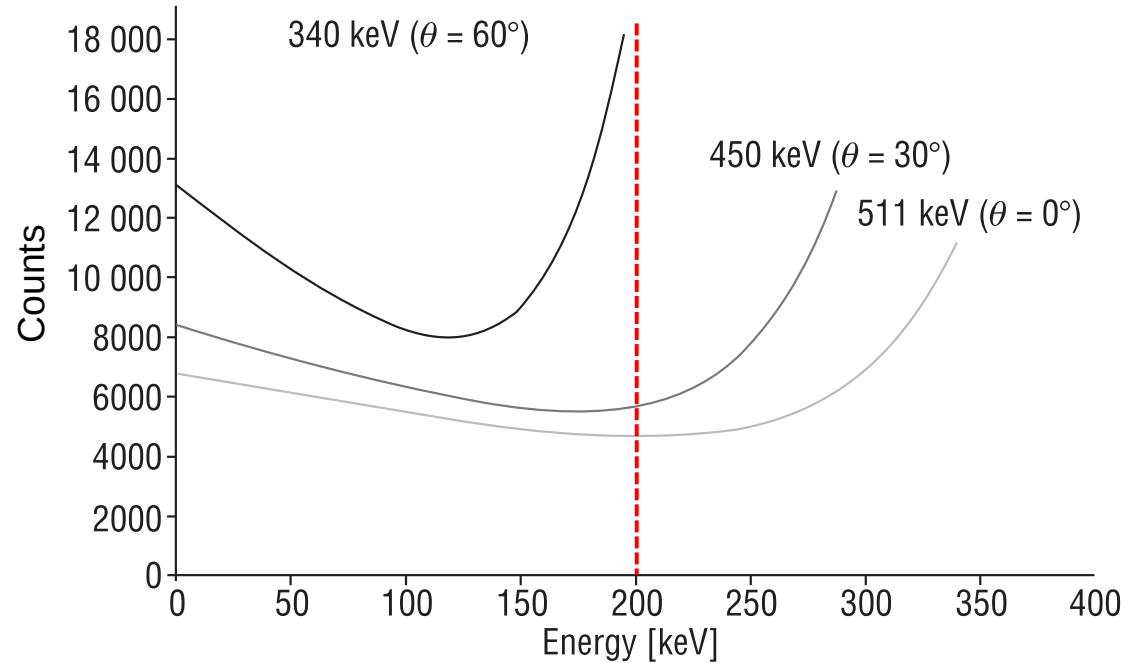
1.

Event selection in J-PET and motivation

200 keV minimum energy deposition



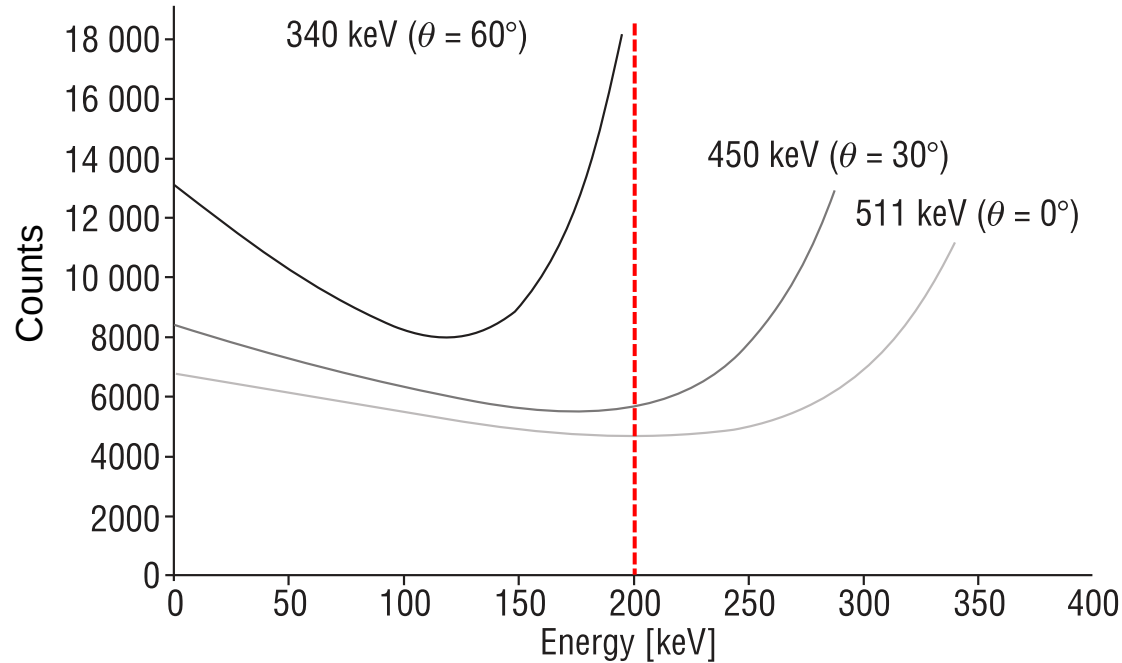
Reduce phantom scatters



P. Moskal et al. *Nuclear Medicine Review* 15 (2012)

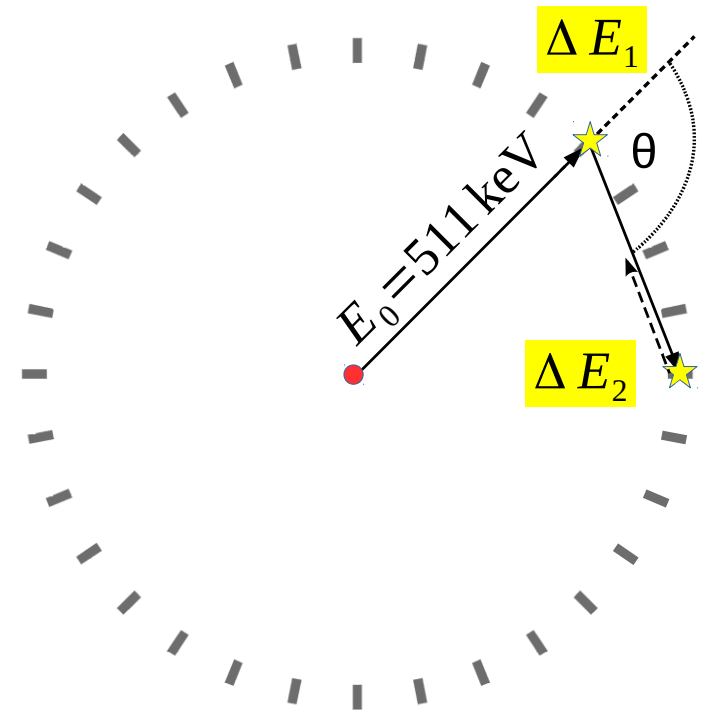
200 keV minimum energy deposition

Reduce phantom scatters



P. Moskal et al. *Nuclear Medicine Review* 15 (2012)

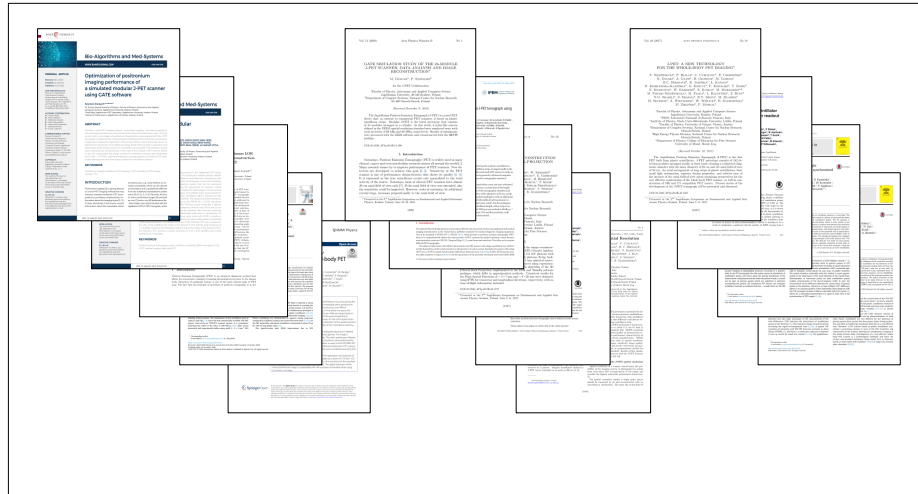
Reduce detector scatters



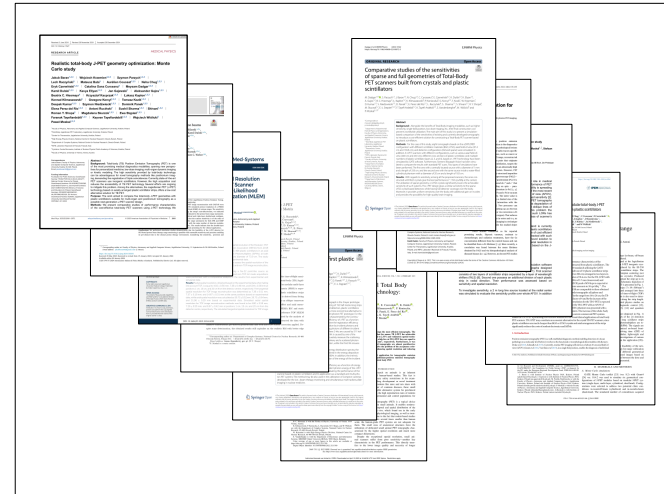
P. Kowalski PhD thesis (2021)

Simulation studies for J-PET

J-PET simulation studies using the 200 keV energy threshold



Direct references



Indirect references

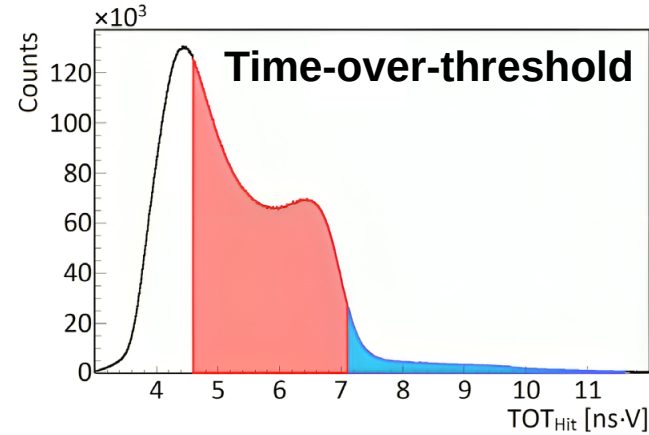
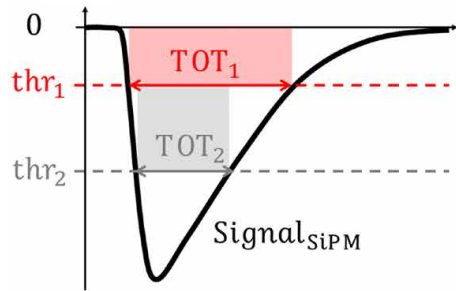


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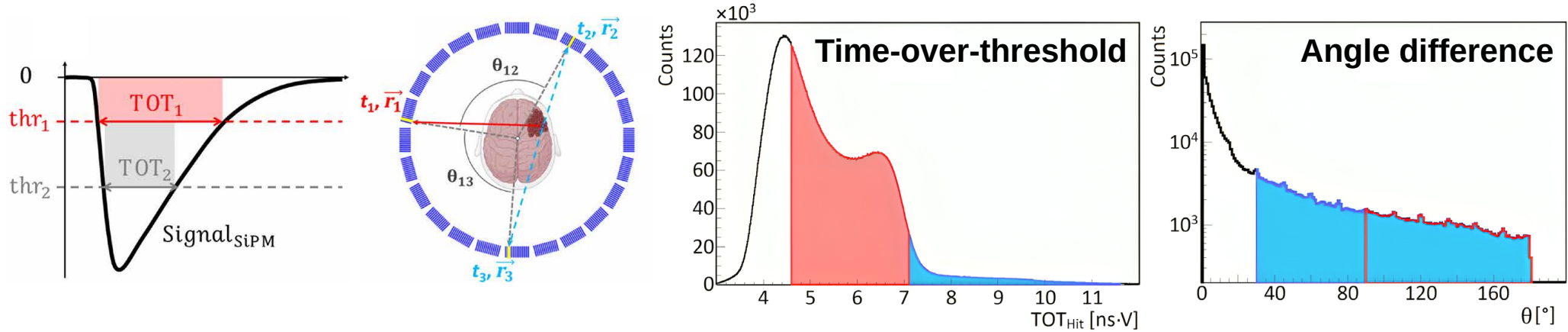
to one of ...

- P. Moskal et al. *Nuclear Medicine Review* 15 (2012)
- P. Kowalski et al. *Acta Phys. Pol. A* 127 (2015)
- P. Kowalski et al. *Acta Phys. Pol. B* 47 (2016)

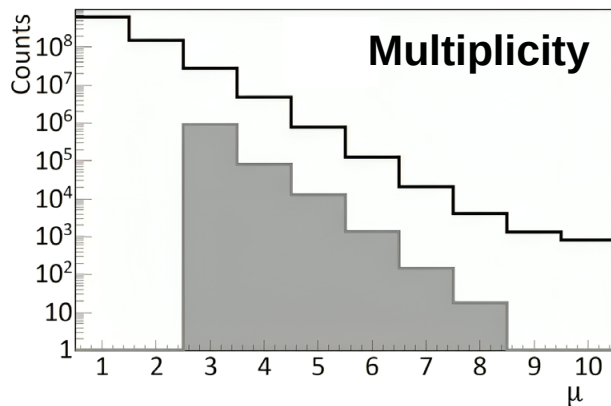
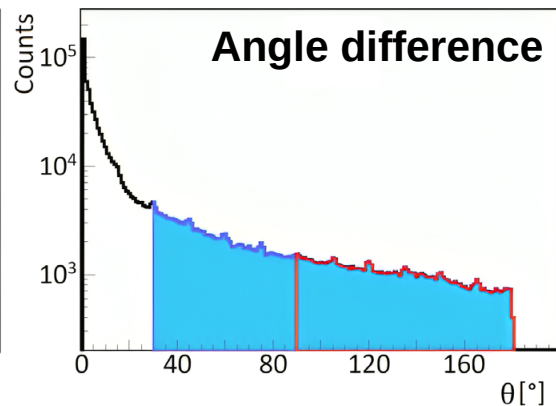
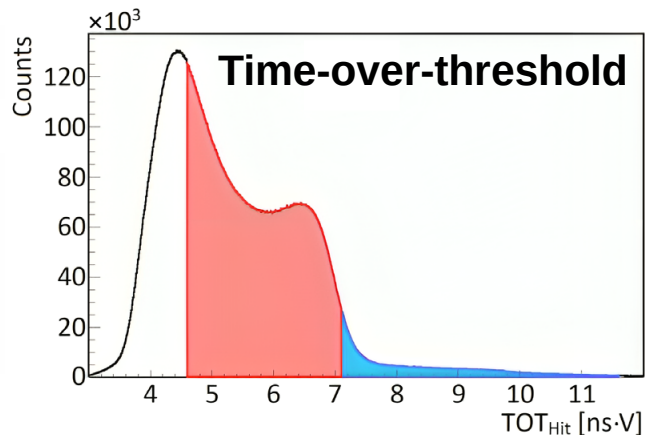
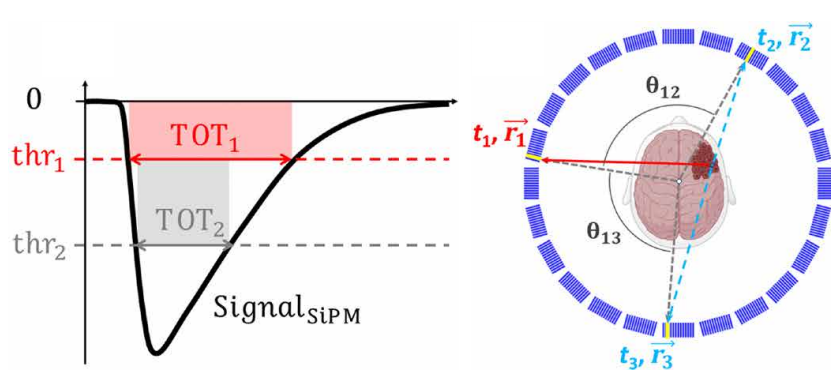
Event selection in experiment



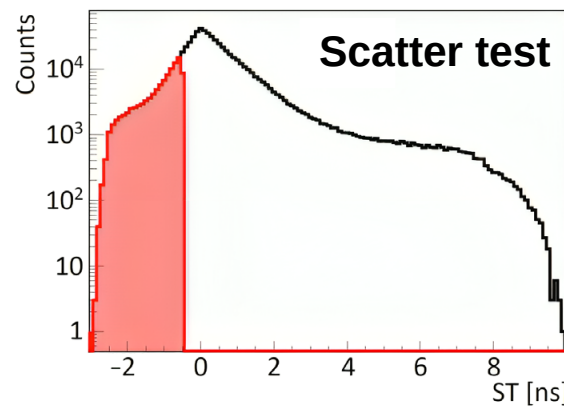
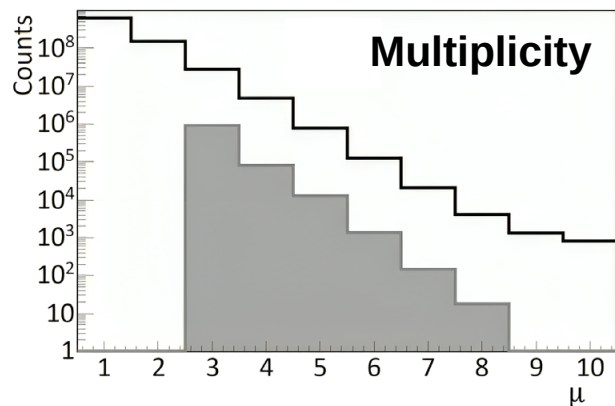
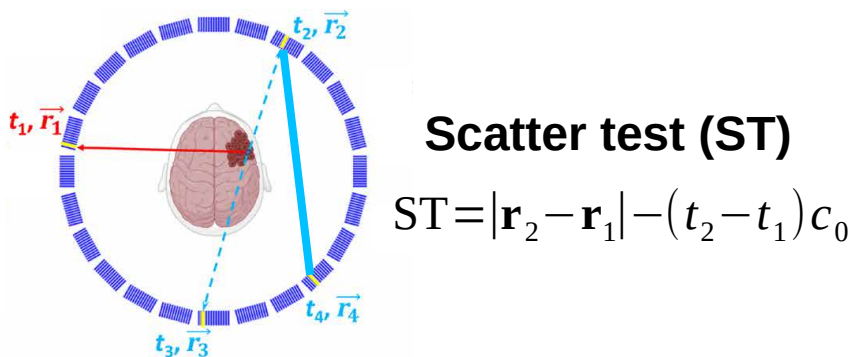
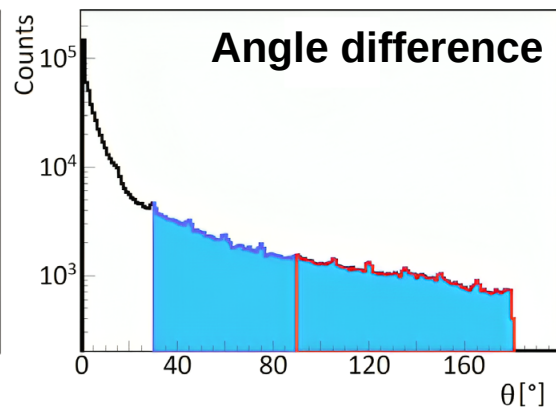
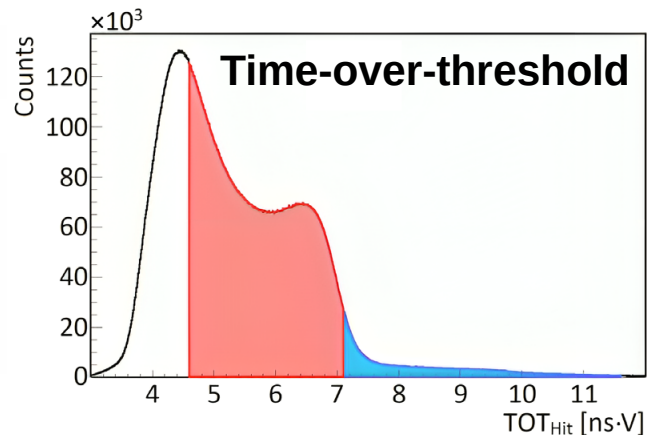
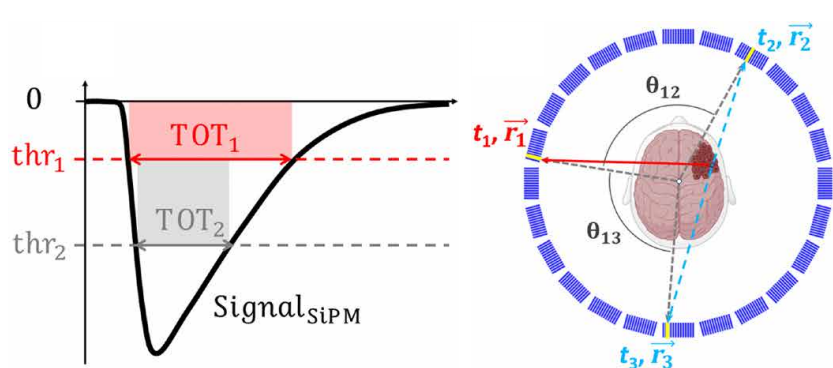
Event selection in experiment



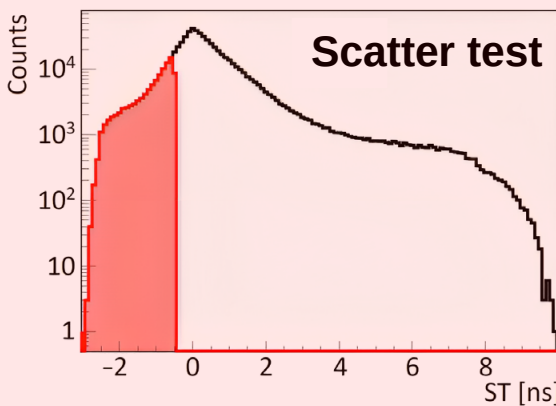
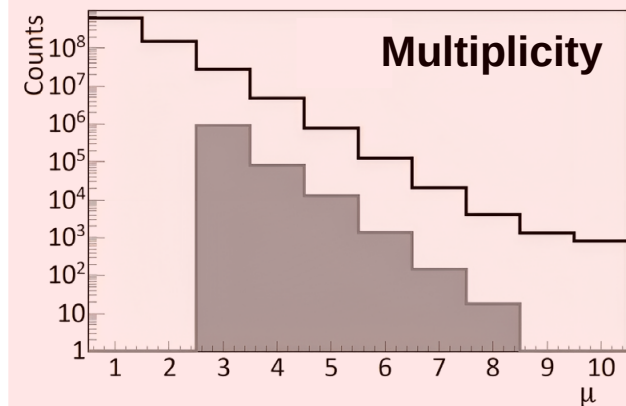
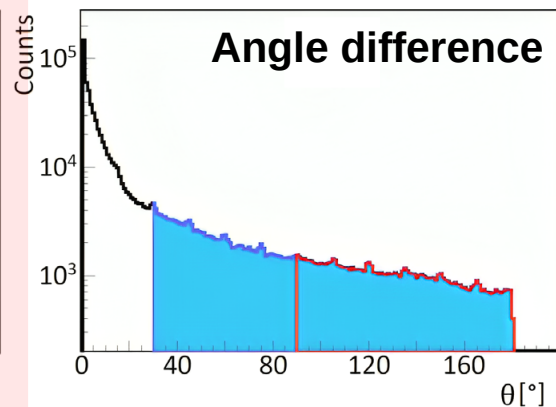
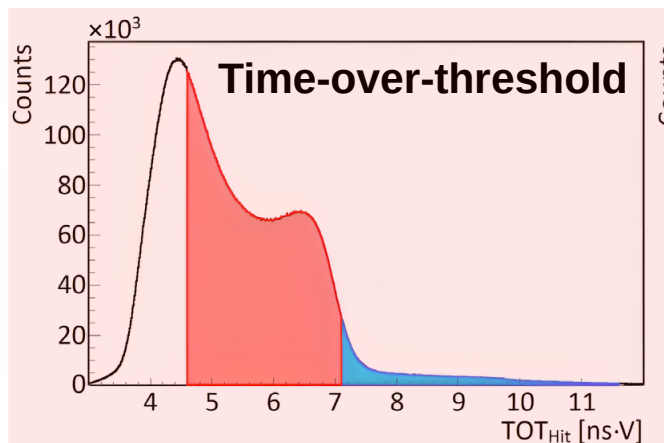
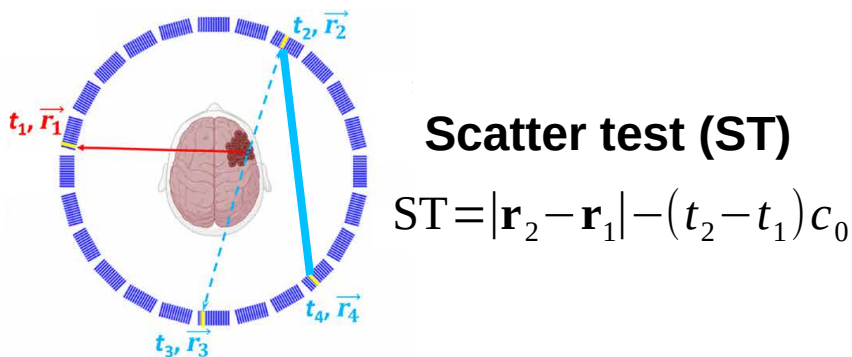
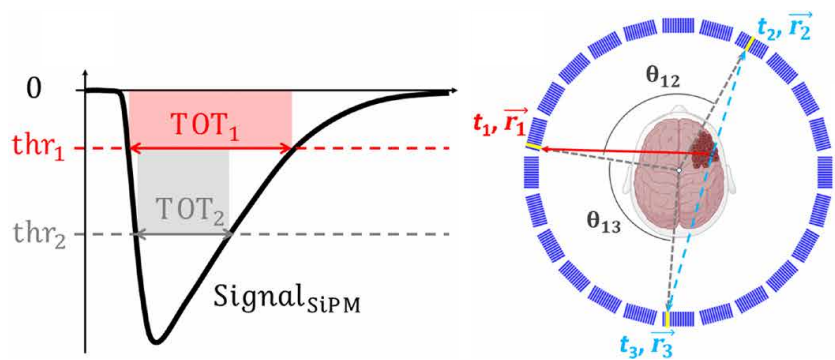
Event selection in experiment



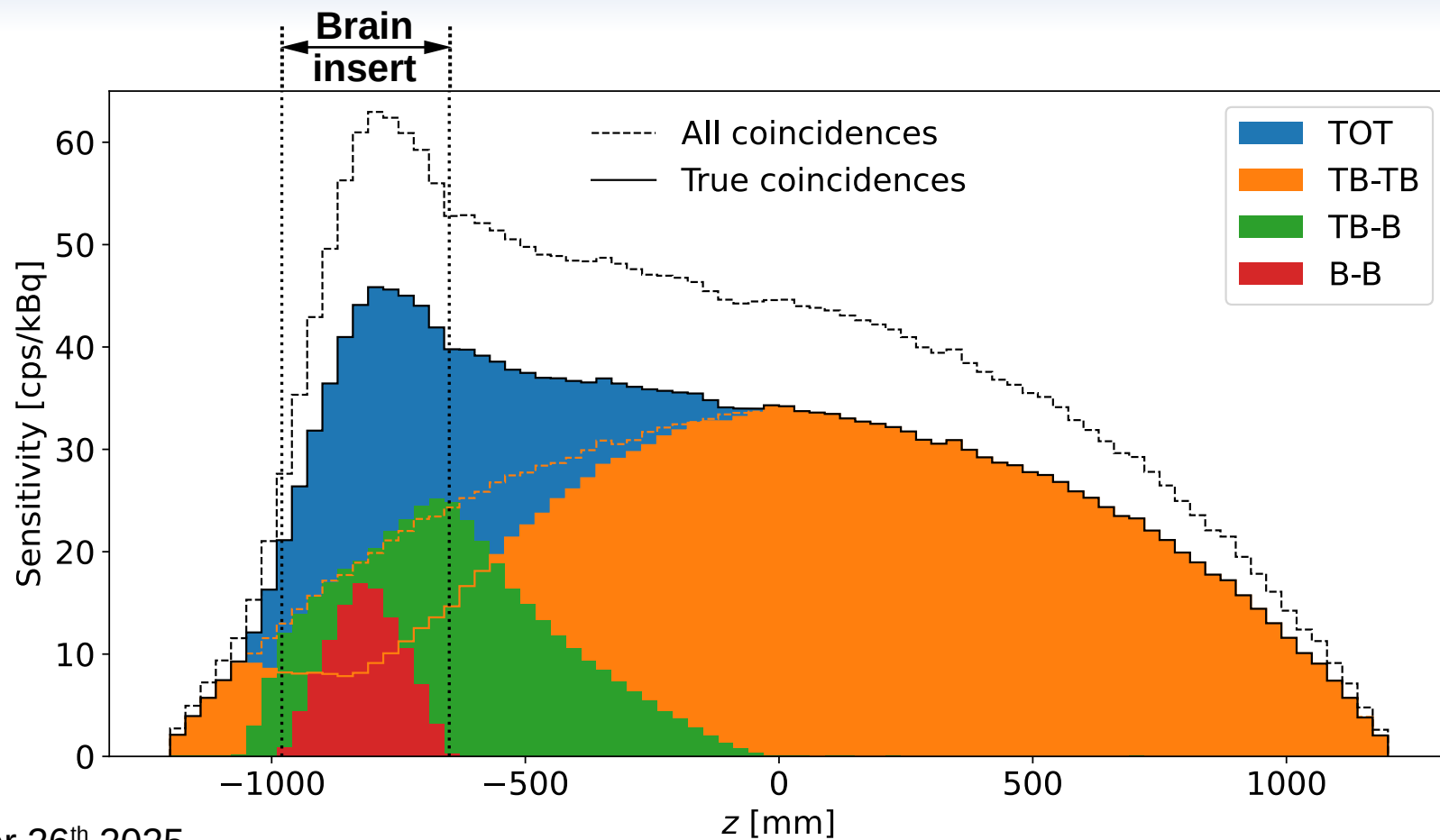
Event selection in experiment



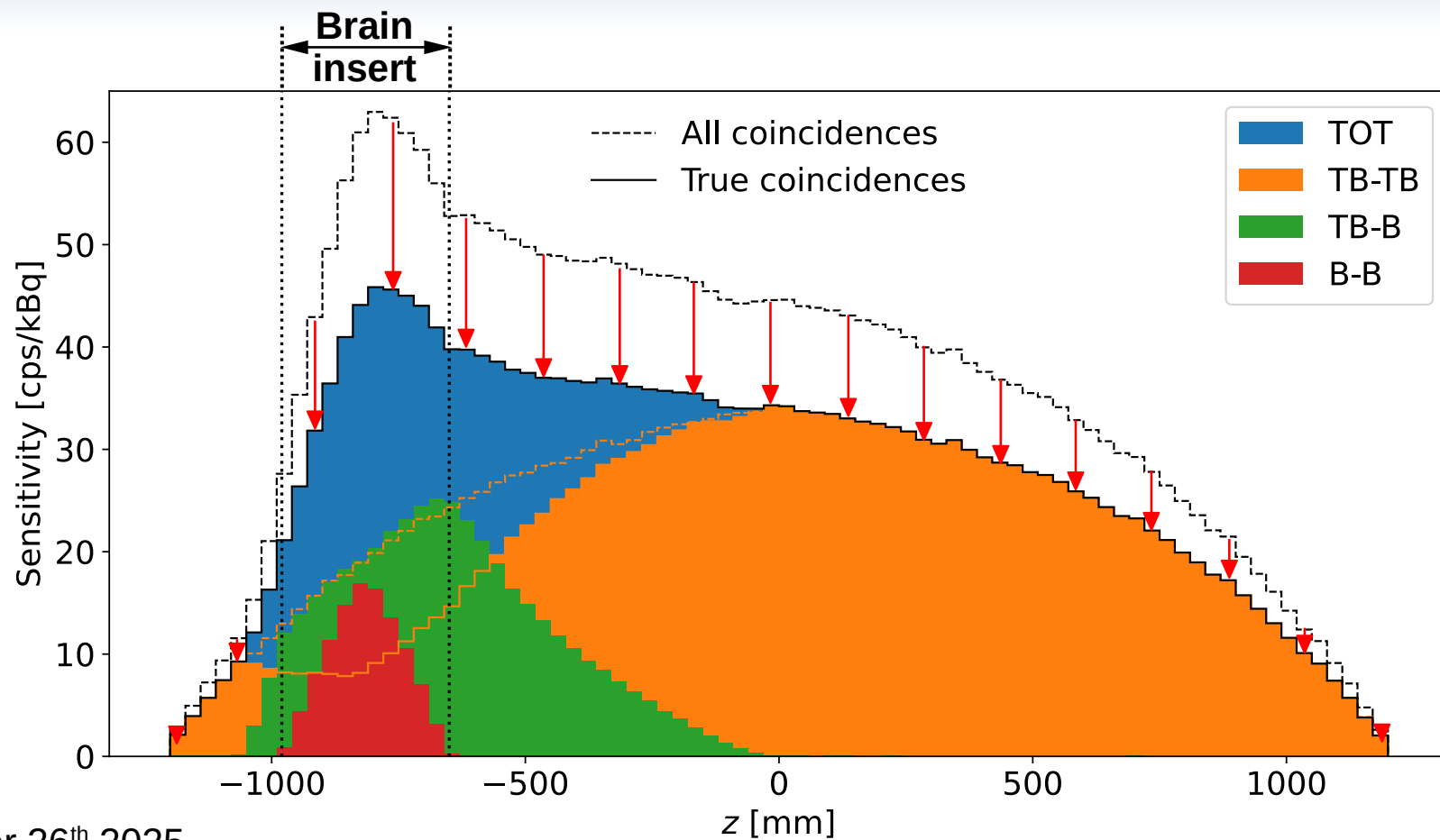
Event selection in experiment



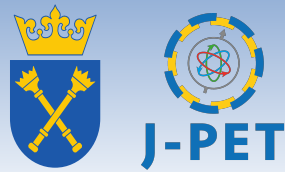
Motivation



Motivation



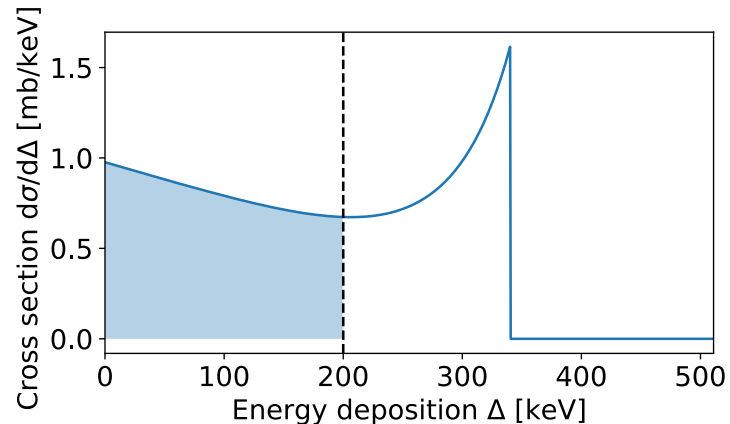
Motivation



- Sensitivity and spatial resolution strongly depend on the event selection policy

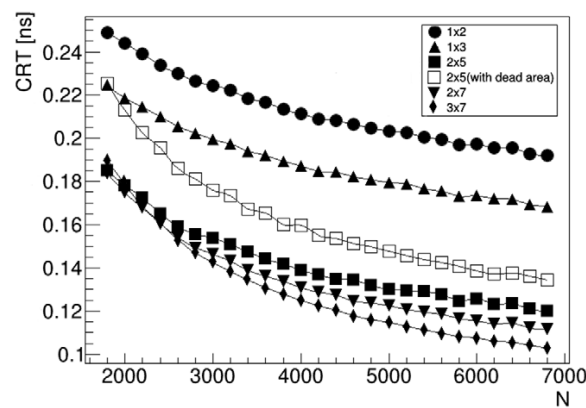
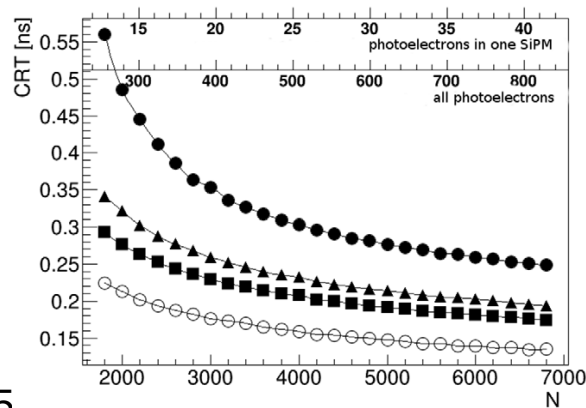
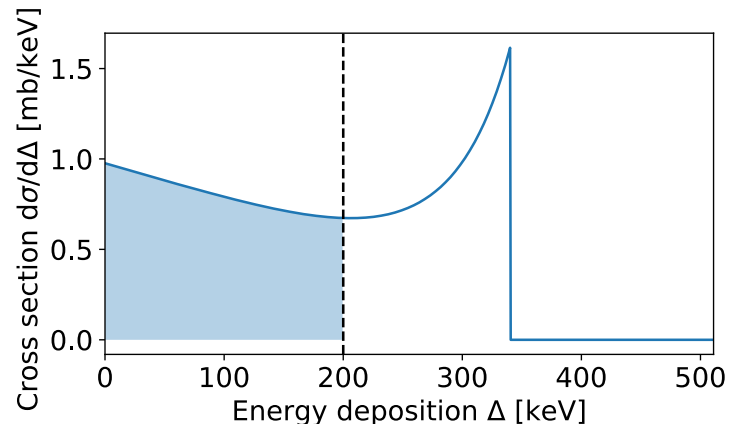
Motivation

- Sensitivity and spatial resolution strongly depend on the event selection policy
- False coincidences in the detector are caused by hits below 200 keV



Motivation

- Sensitivity and spatial resolution strongly depend on the event selection policy
- False coincidences in the detector are caused by hits below 200 keV
- **Aim:** to investigate a lower the energy threshold, combined with a time-based event selection policy

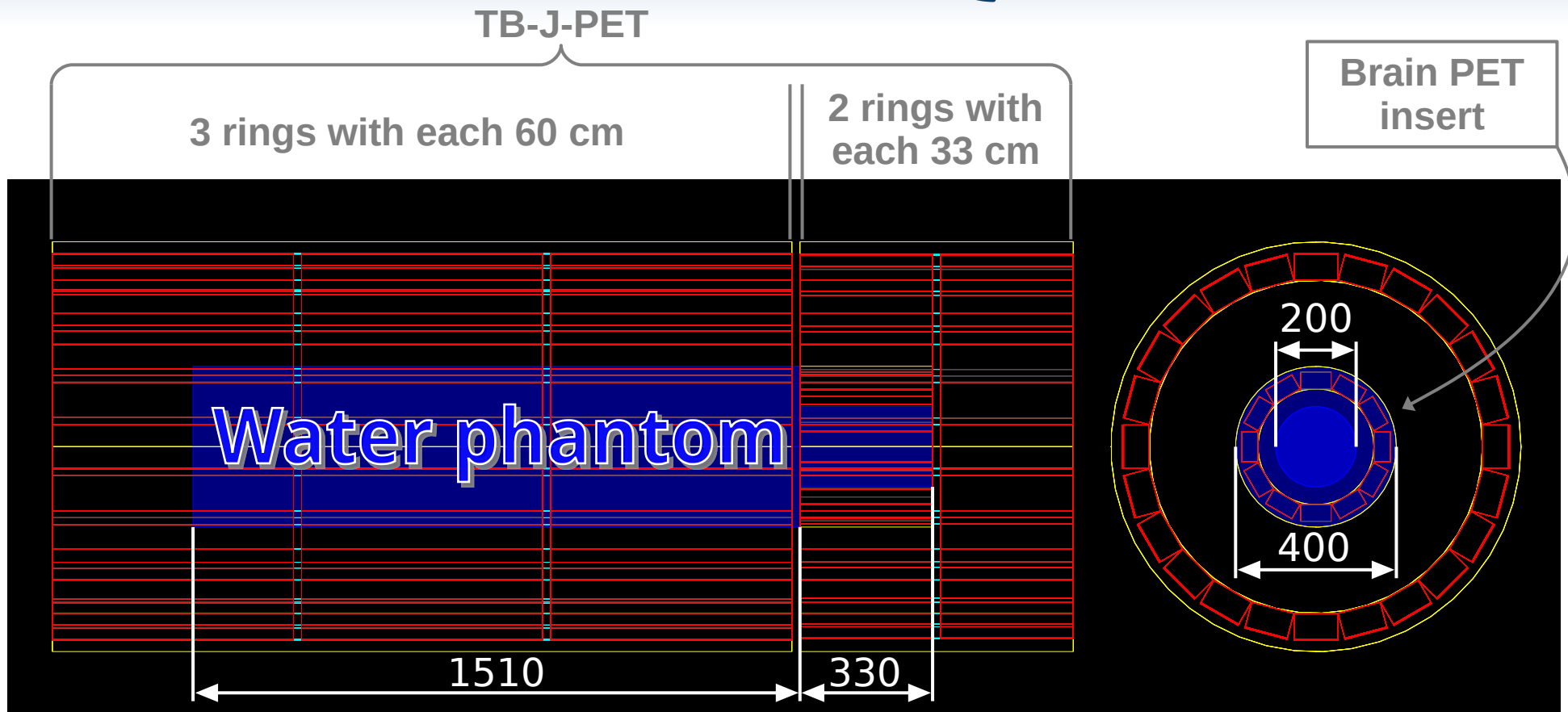
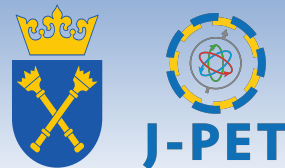


Moskal et al. *Phys. Med. Biol.* 61 (2016)

2.

Monte Carlo simulation and data analysis

Simulation geometry



Simulation settings

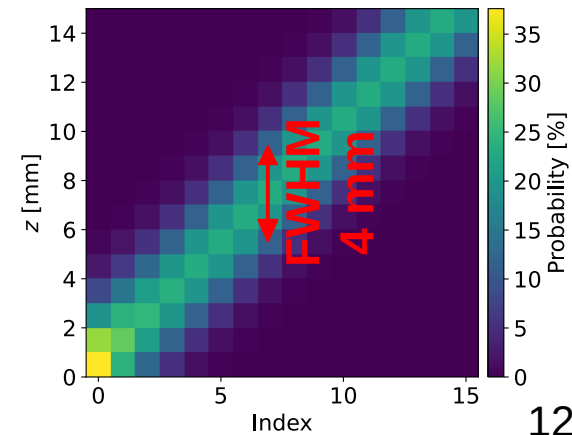
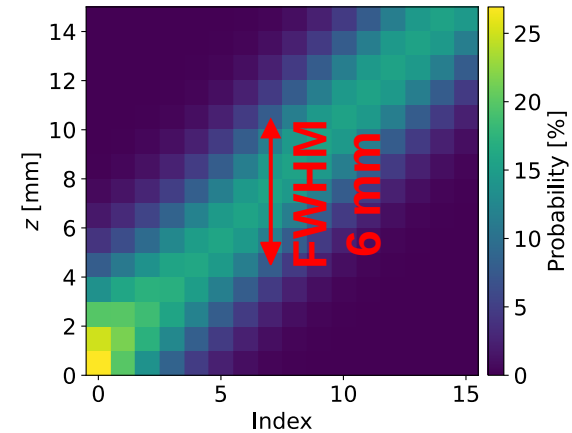


- Set the lower energy threshold to 50 keV
- Low total activity of 1 MBq to minimize the impact of random events
- Coincidence window 4 ns
- Export only coincidences but remove any further filtering by choosing the GATE policy takeAllGoods
- Time resolution $CTR = \{0, 200, 400, 600\}$ picoseconds

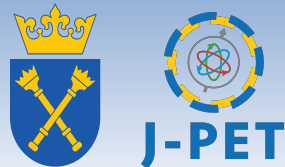
$$CTR = \sqrt{2STR^2 + S^2} \quad S = DOI_{\text{dimension}} / c_{\text{light}}$$

S: time spread due to geometry dimensions of the detector / DOI

- Blurring axial position according to the WLS dimensions



Simulation settings

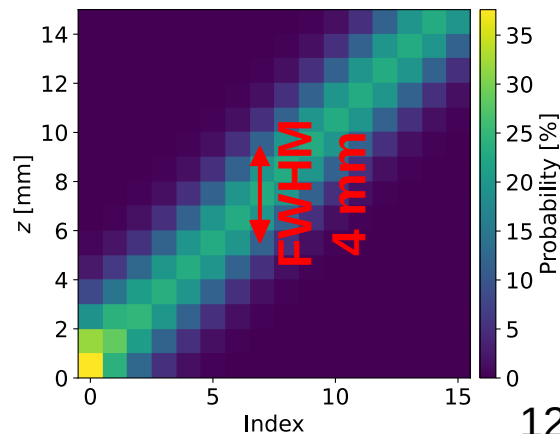
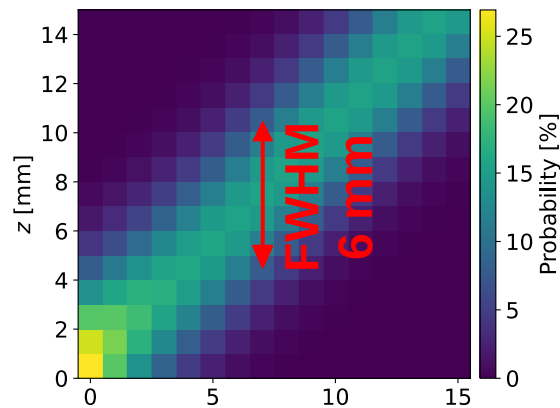


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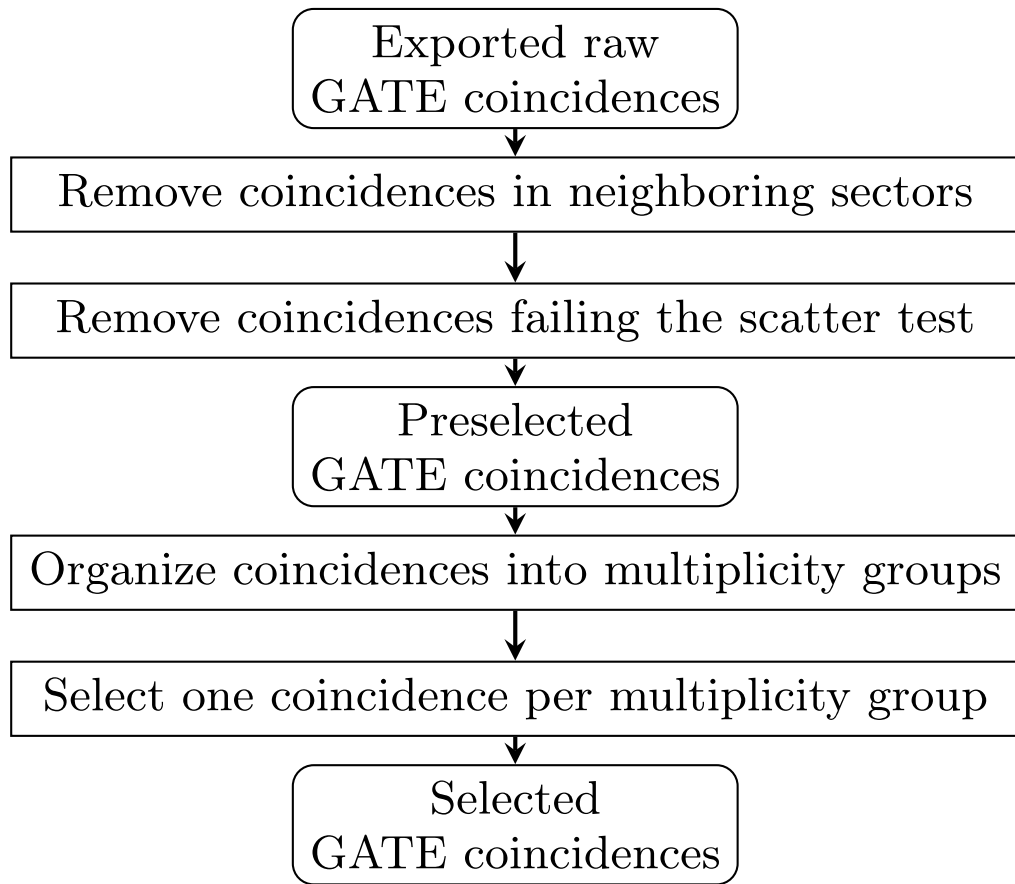
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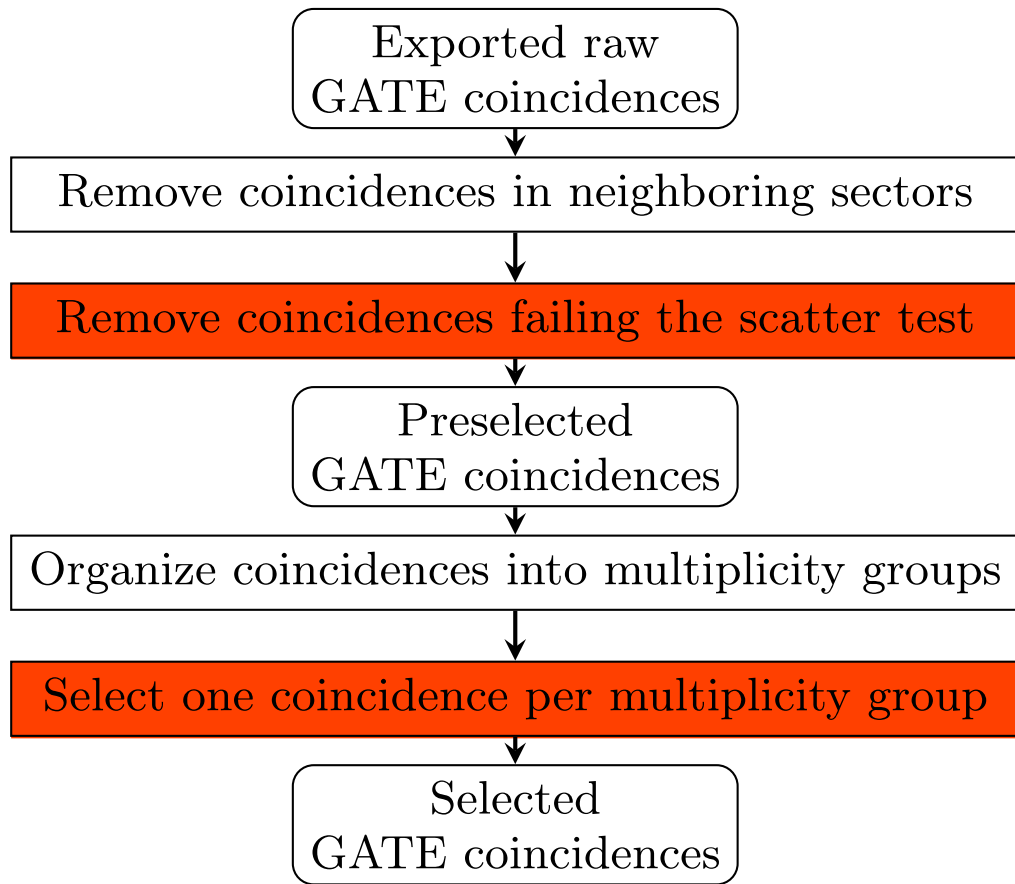
- Blurring axial position according to the WLS dimensions



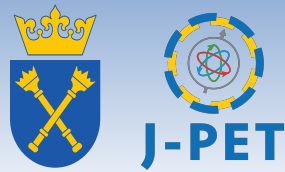
Data analysis



Data analysis



Event selection policies studied



Choose one
coincidence per
multiplicity group

Event selection policies studied

Choose one
coincidence per
multiplicity group

	Coincidences			
	C_0	C_1	C_2	C_3
	time →			
True/False	F	T	F	F
E_{\min} [keV]	100	70	170	200
$E_1 + E_2$ [keV]	350	250	380	400

Event selection policies studied

Choose one coincidence per multiplicity group

	Coincidences			
	C ₀	C ₁	C ₂	C ₃
	time →			
True/False	F	T	F	F
E _{min} [keV]	100	70	170	200
E ₁ +E ₂ [keV]	350	250	380	400

Lower energy threshold: 50 keV

Ideal		X		
Time-based: sel. → thresh.	X			
Time-based: thresh. → sel.	X			
Energy-based				X

Event selection policies studied

Choose one
coincidence per
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	Coincidences			
	C ₀	C ₁	C ₂	C ₃
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E _{min} [keV]	100	70	170	200
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Lower energy
threshold: 50 keV

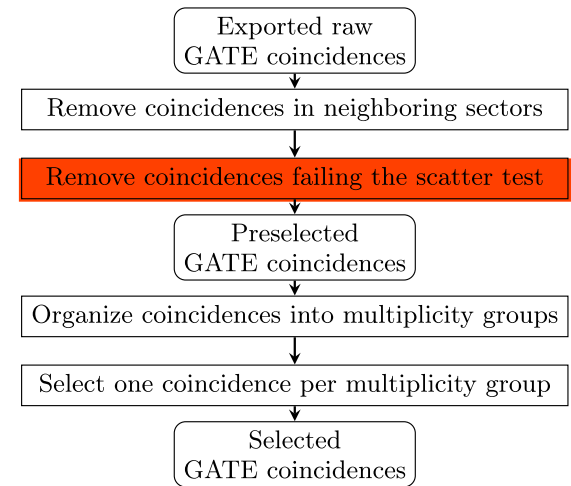
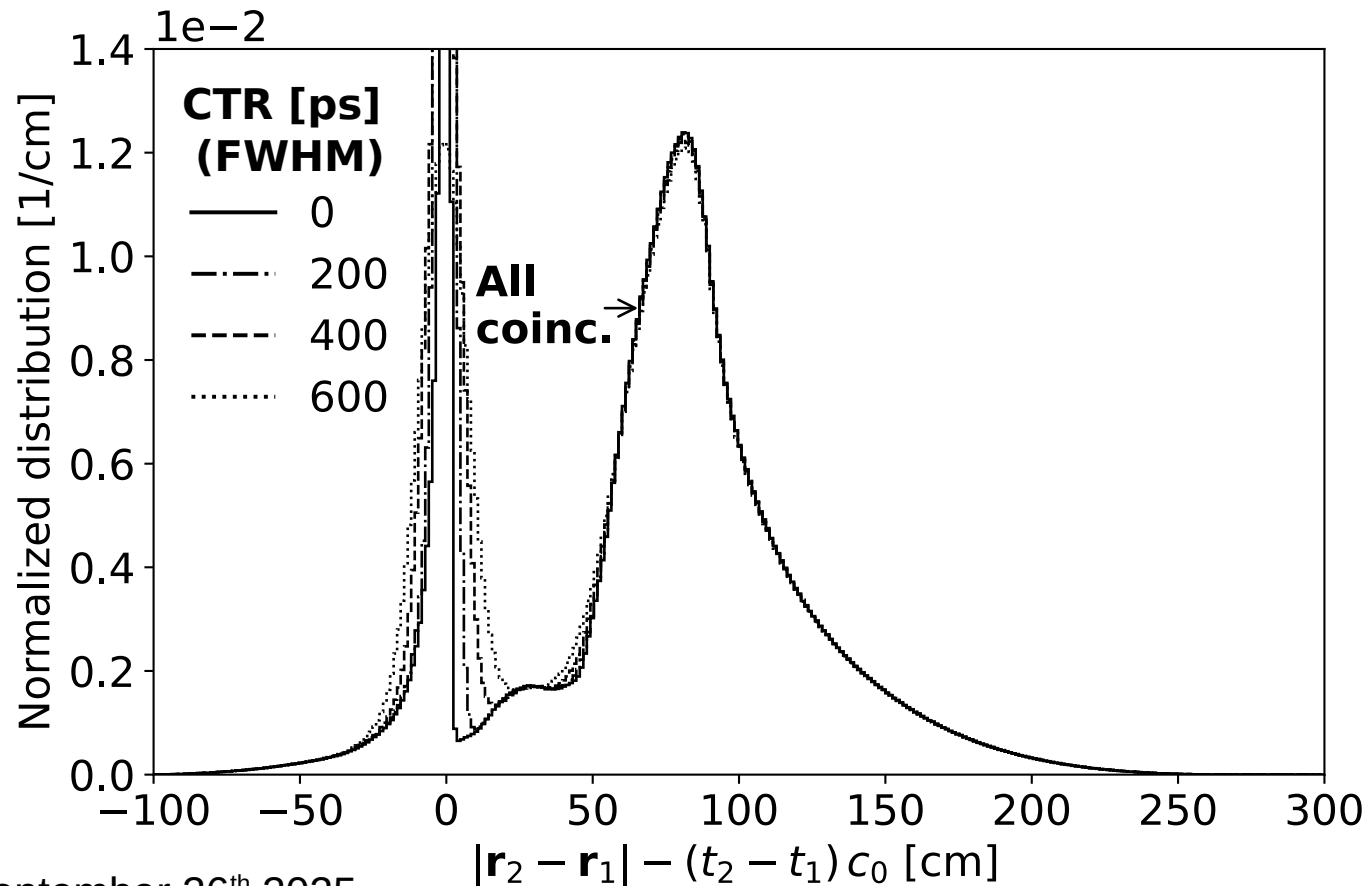
Lower energy
threshold: 150 keV

Ideal		X		
Time-based: sel. → thresh.	X			
Time-based: thresh. → sel.	X		X	
Energy-based				X

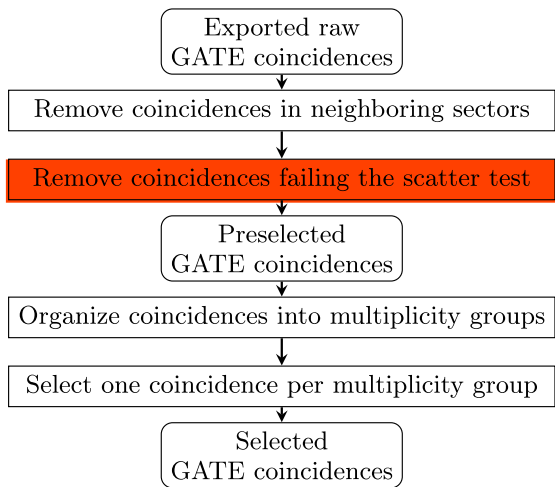
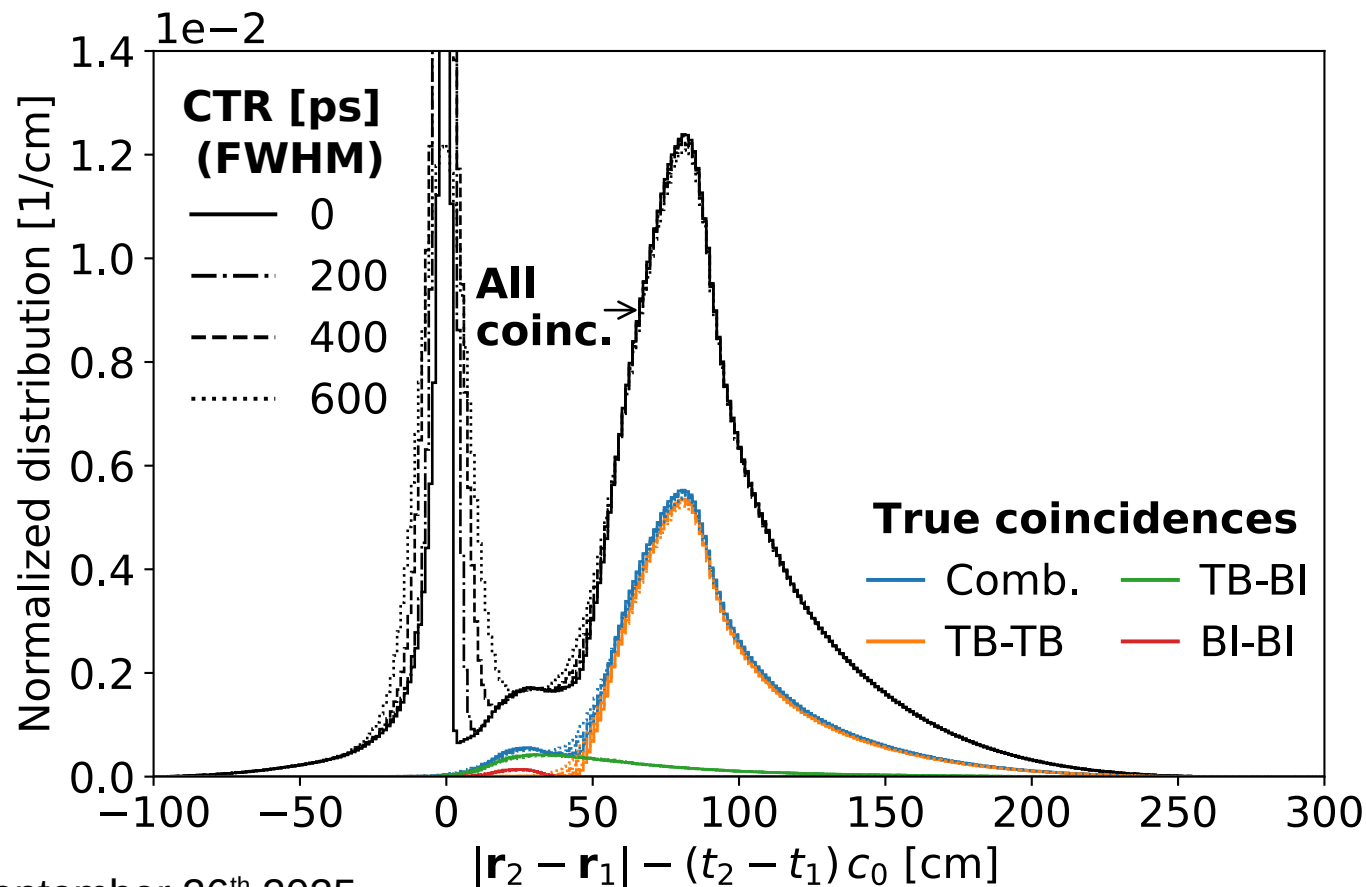
3.

Results

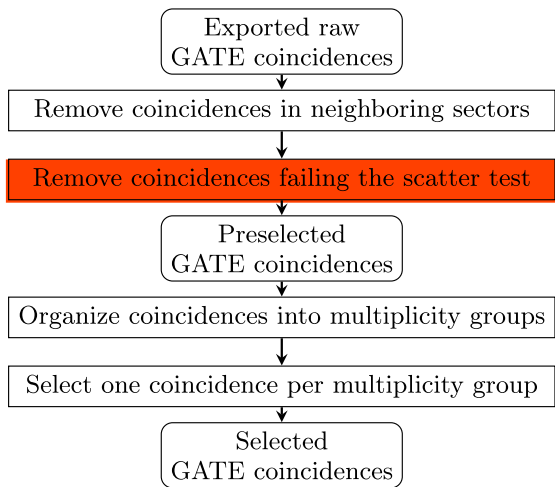
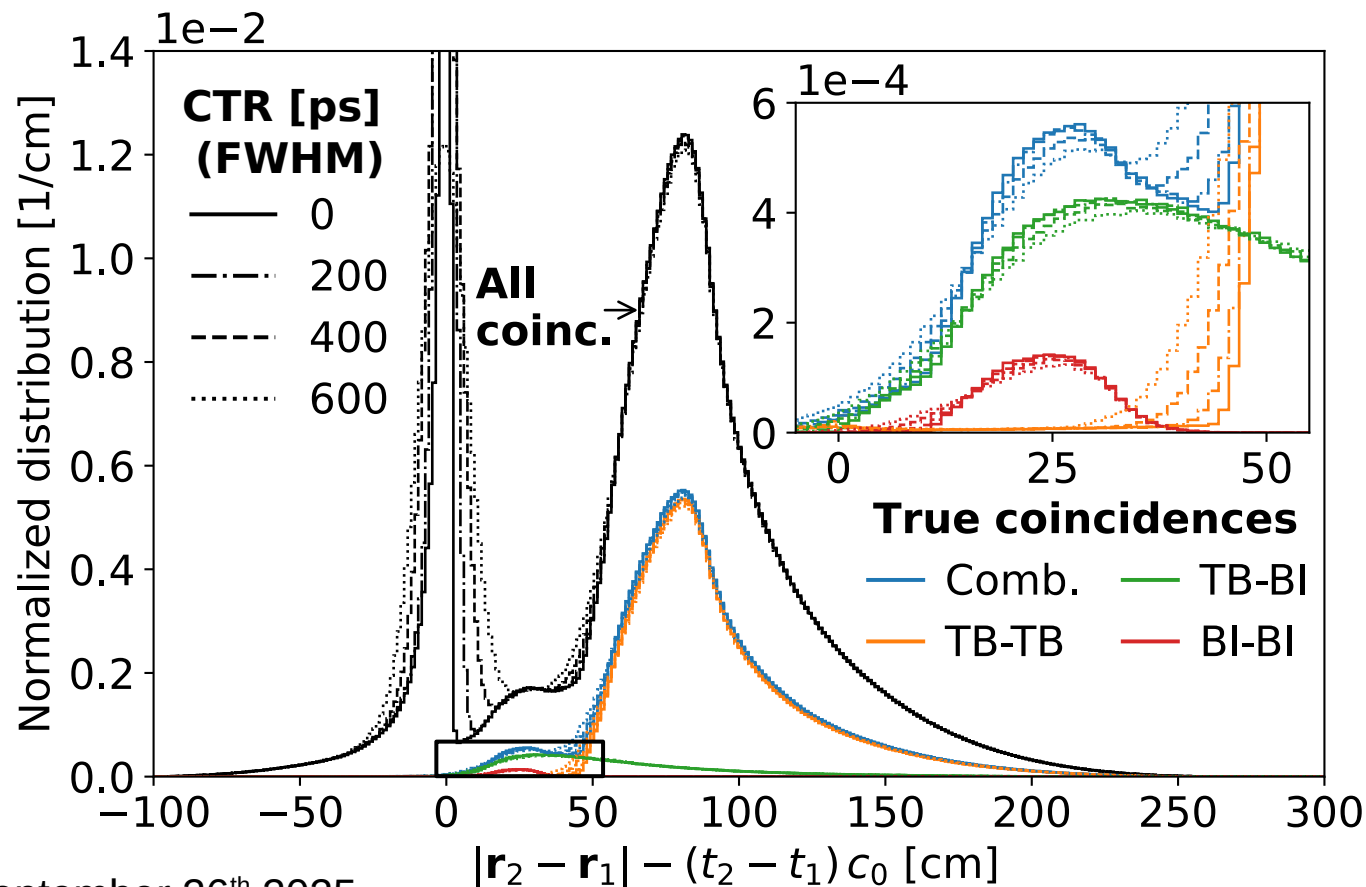
Scatter test w/o phantom



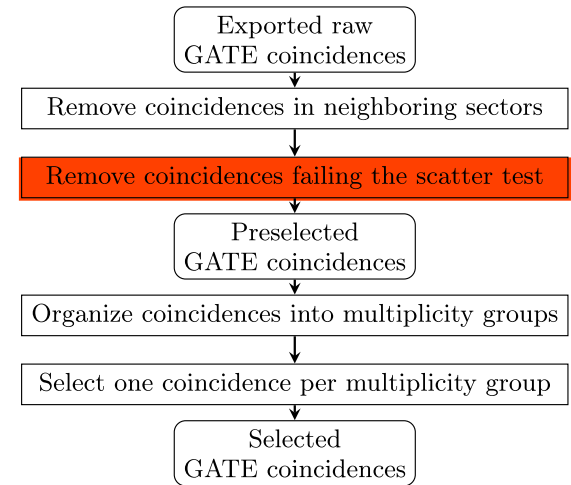
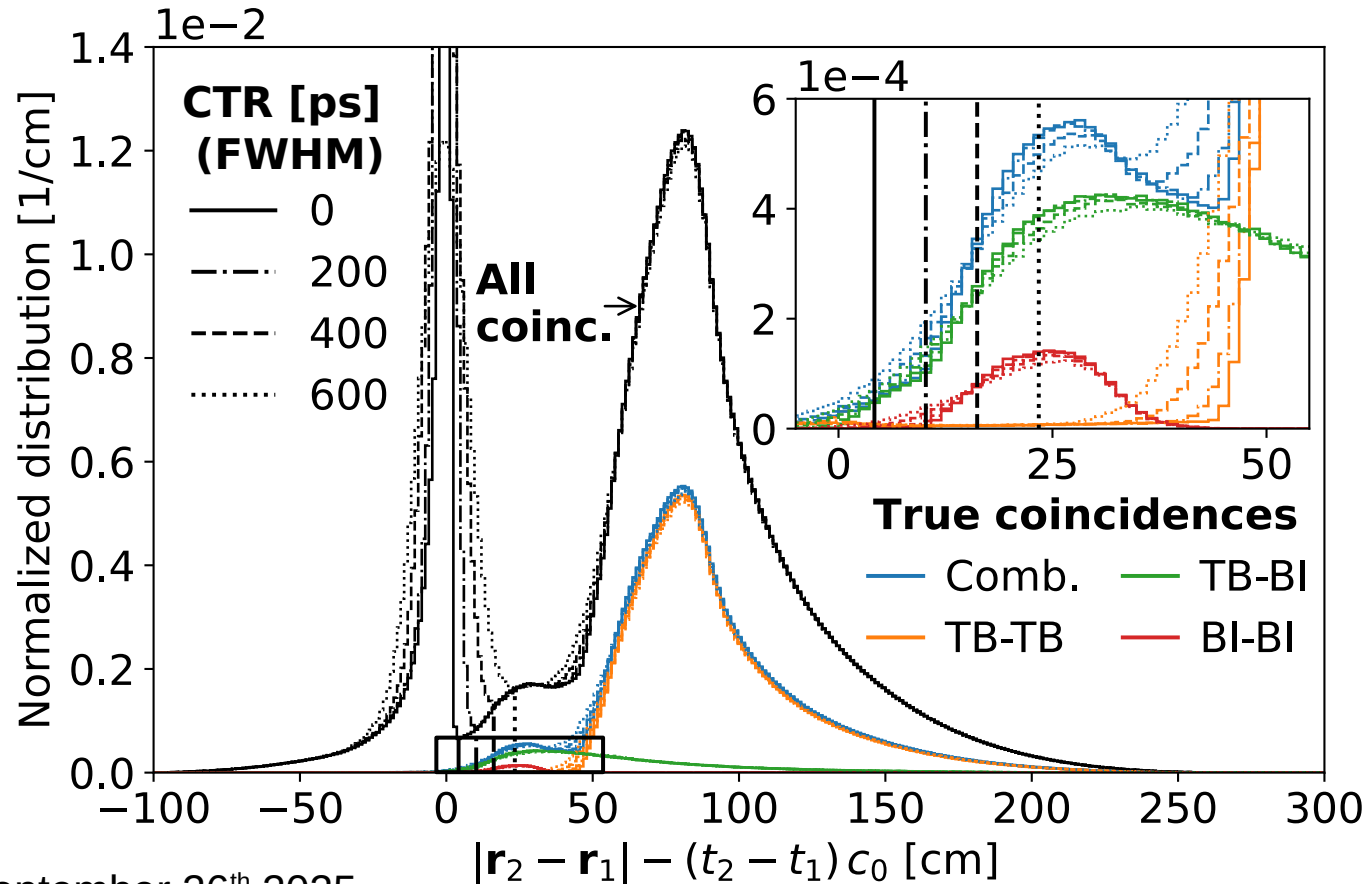
Scatter test w/o phantom



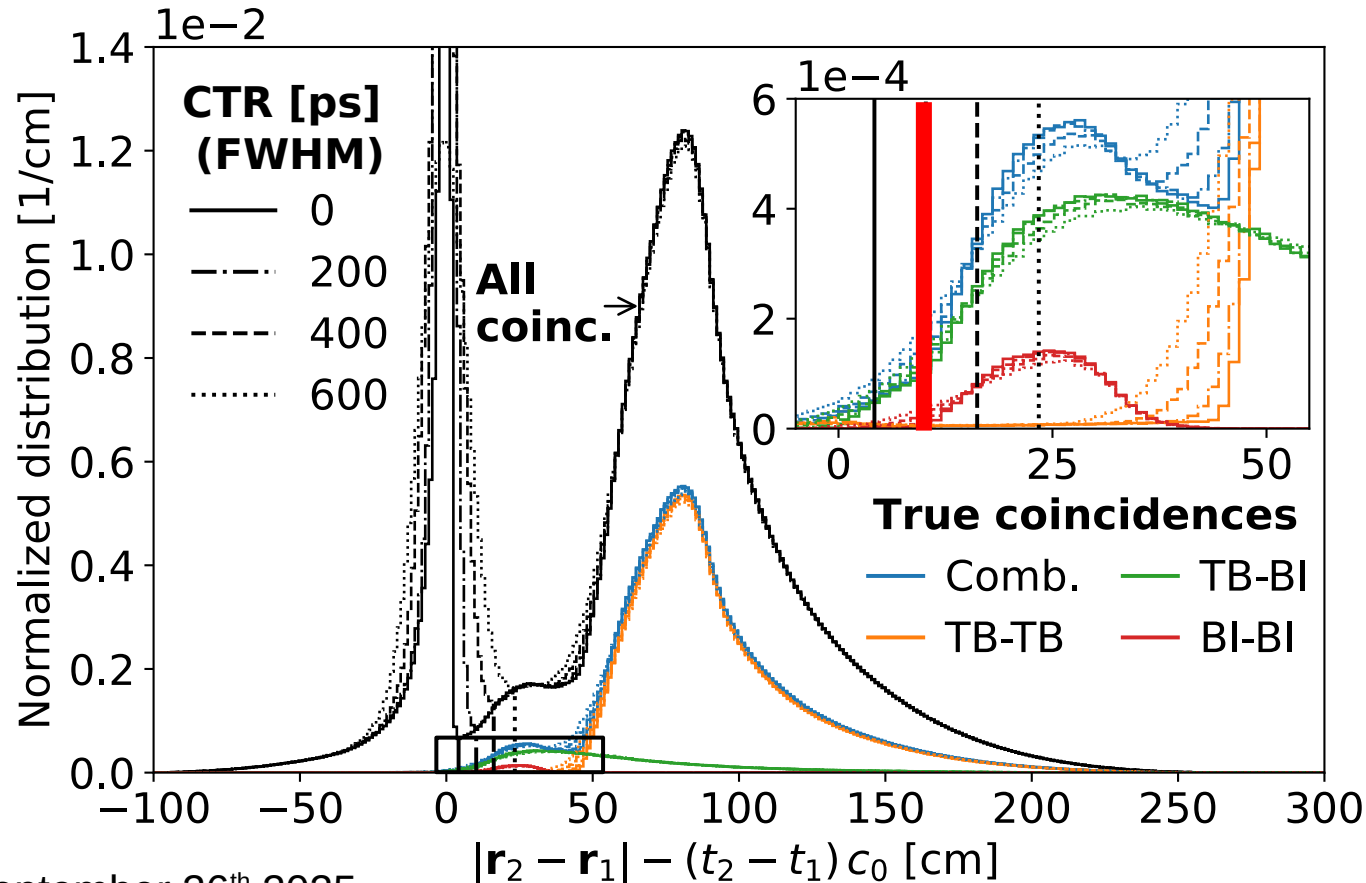
Scatter test w/o phantom



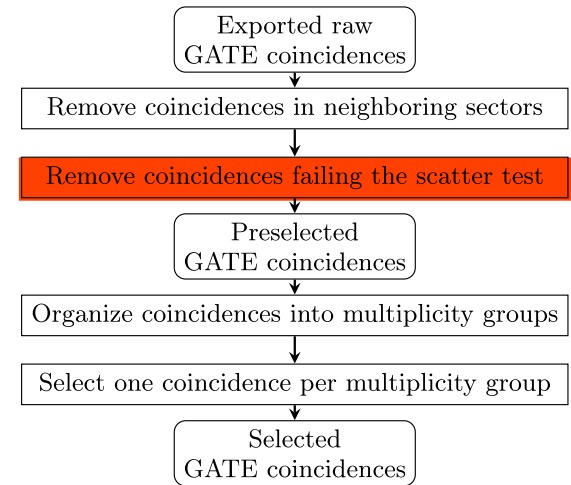
Scatter test w/o phantom



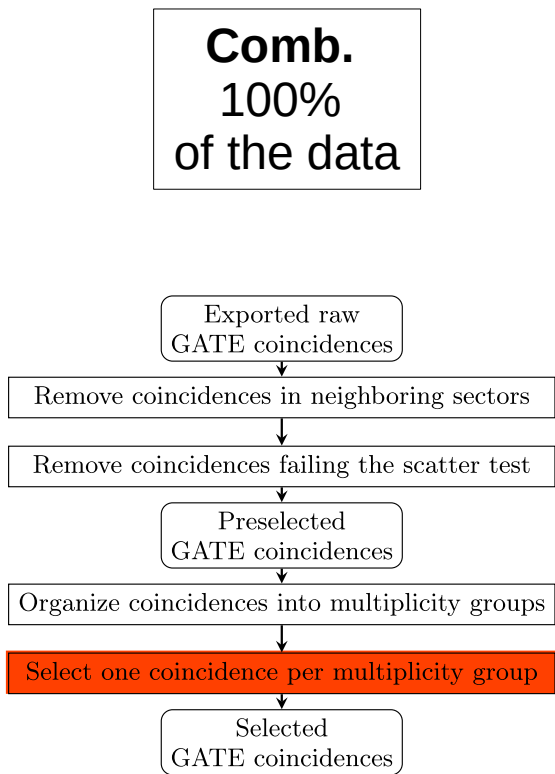
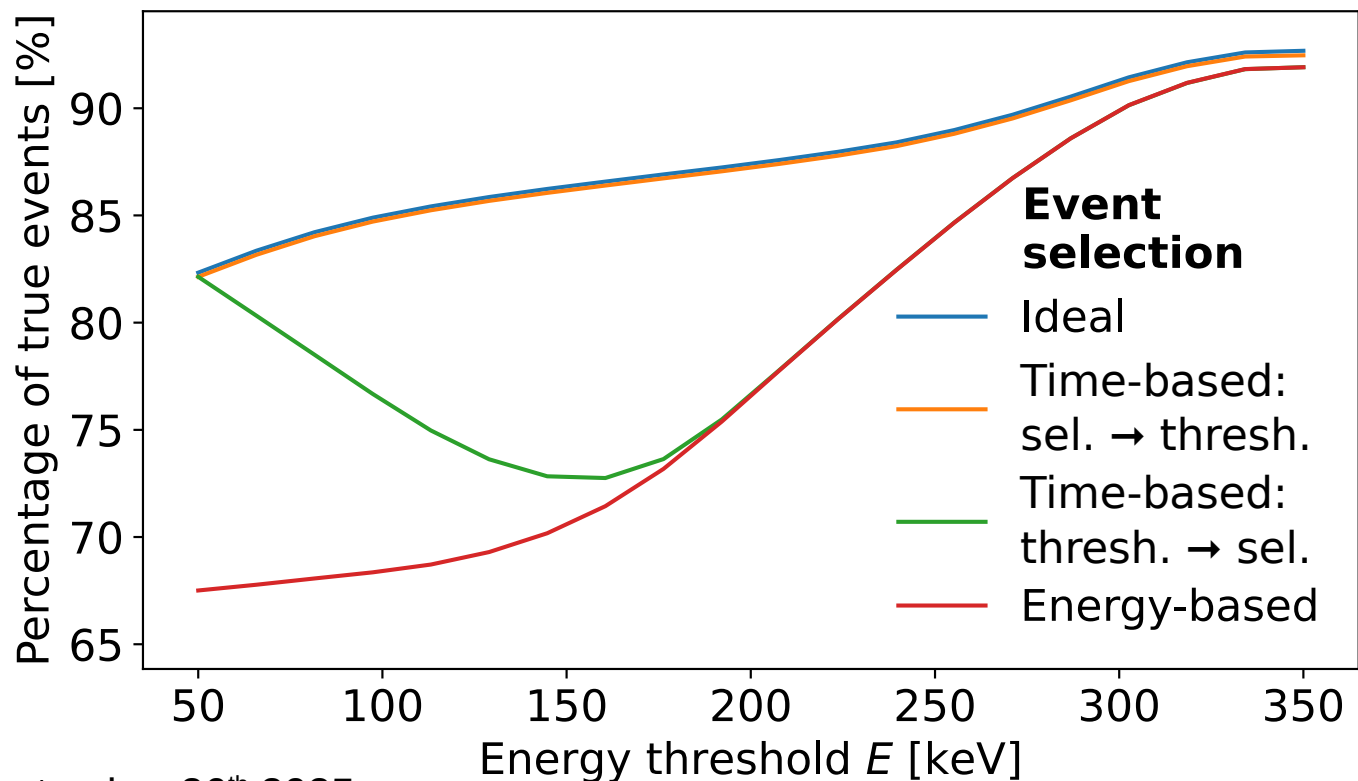
Scatter test w/o phantom



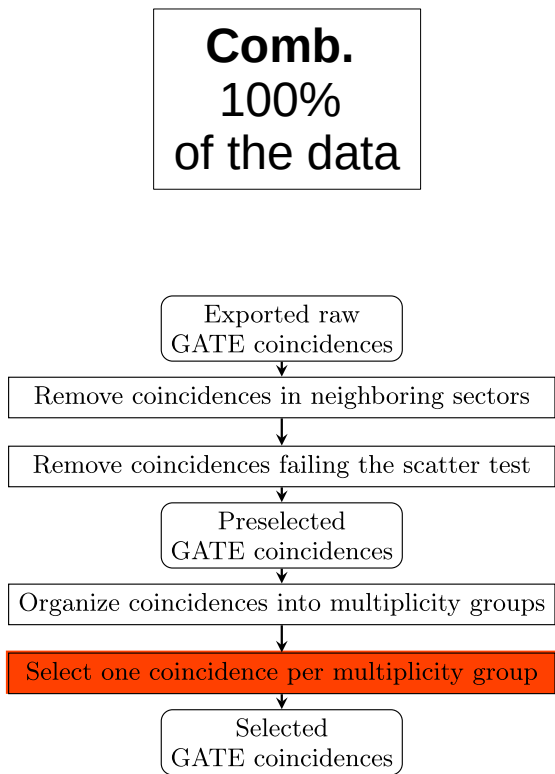
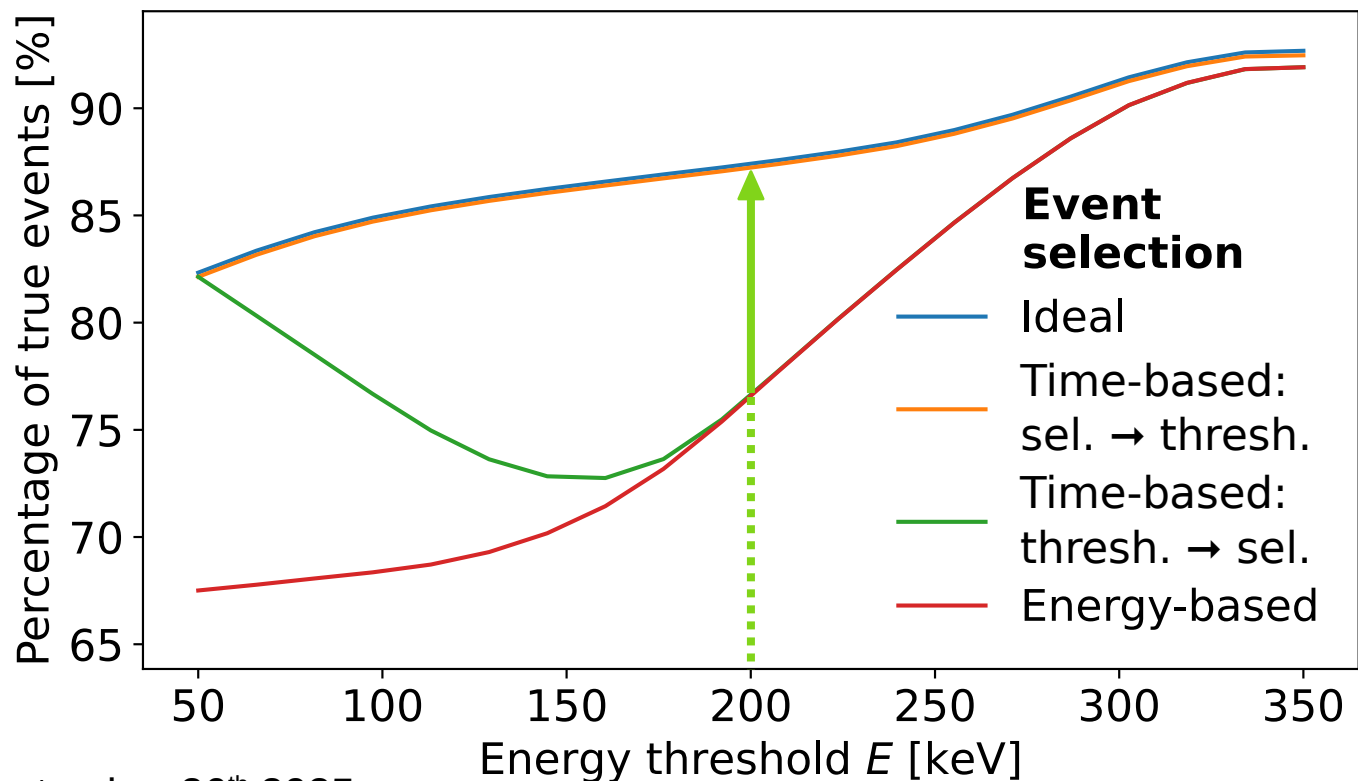
Threshold
max. at 10 cm



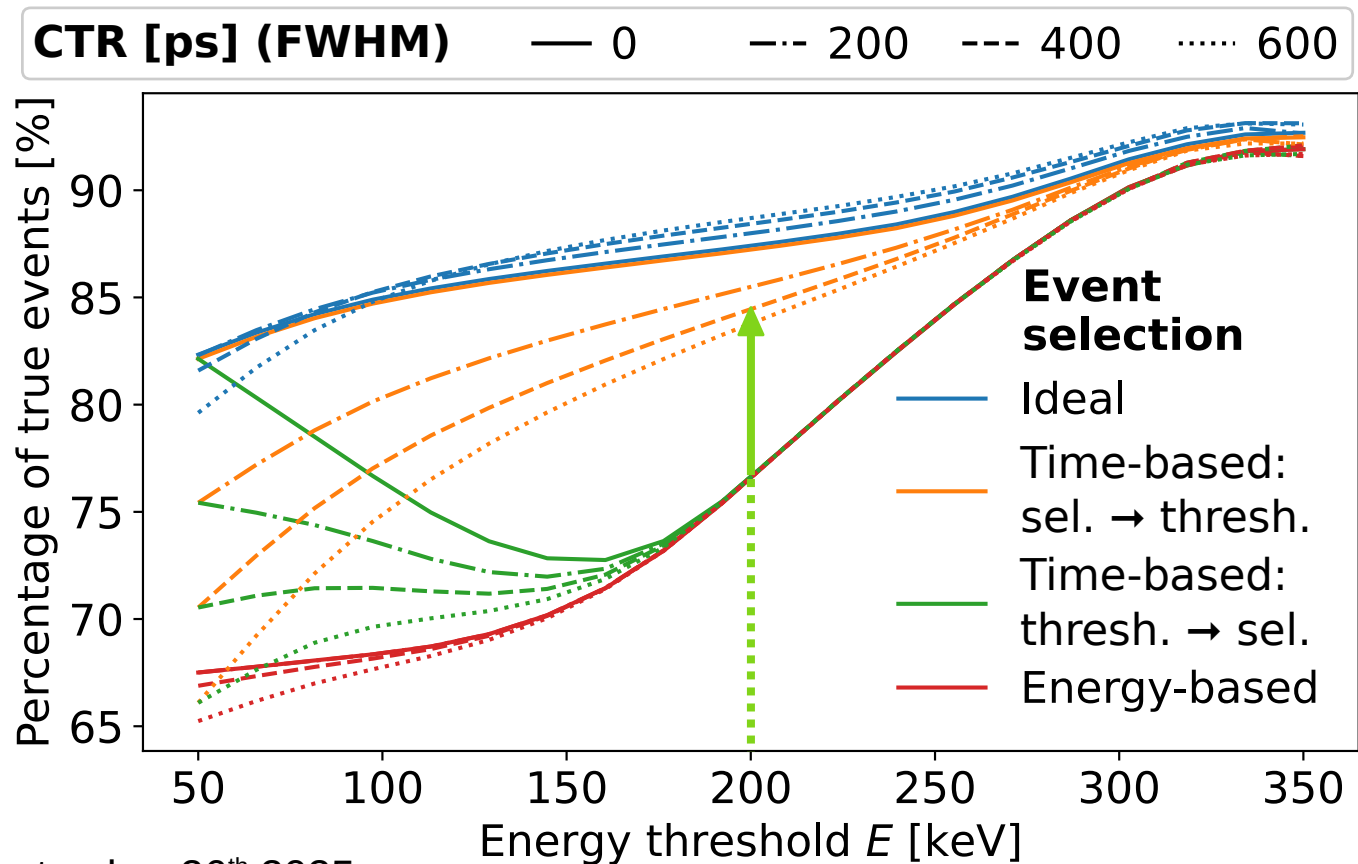
Performance analysis: w/o phantom



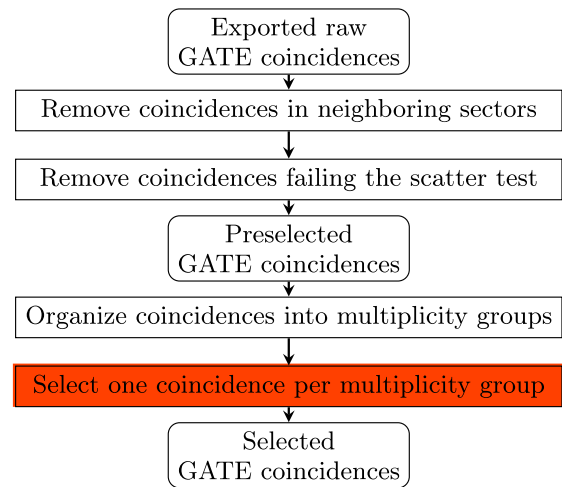
Performance analysis: w/o phantom



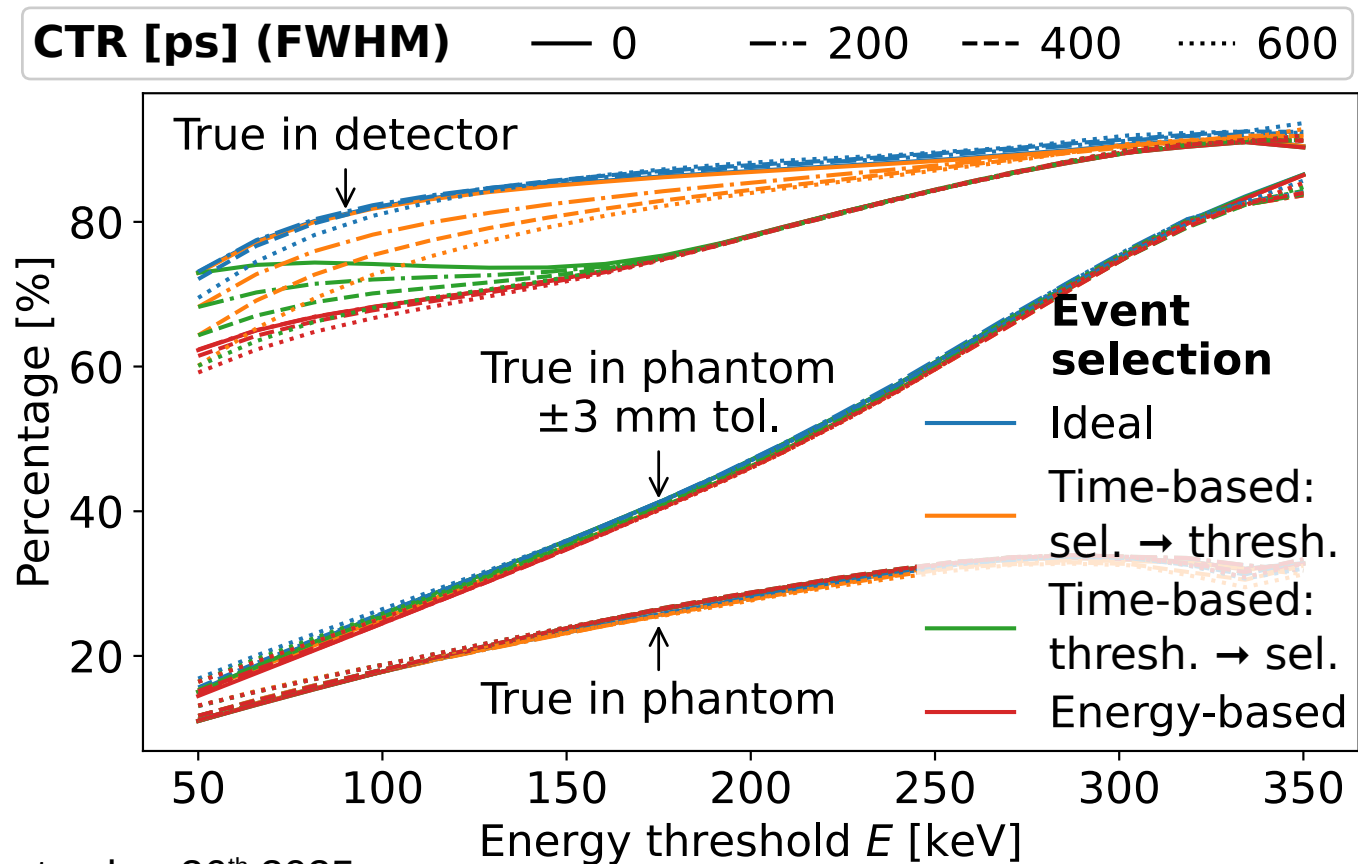
Performance analysis: w/o phantom



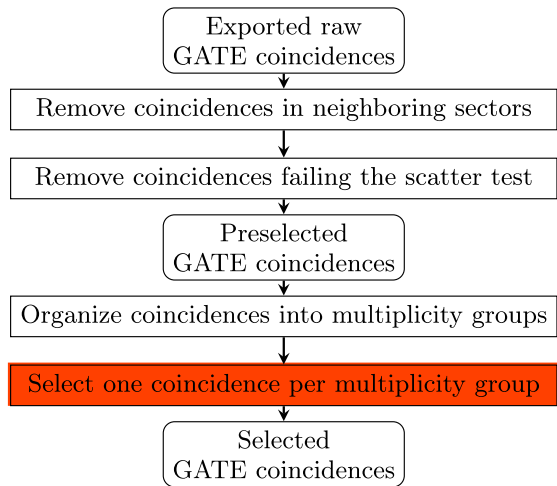
Comb.
100%
of the data



Performance analysis: w/ phantom

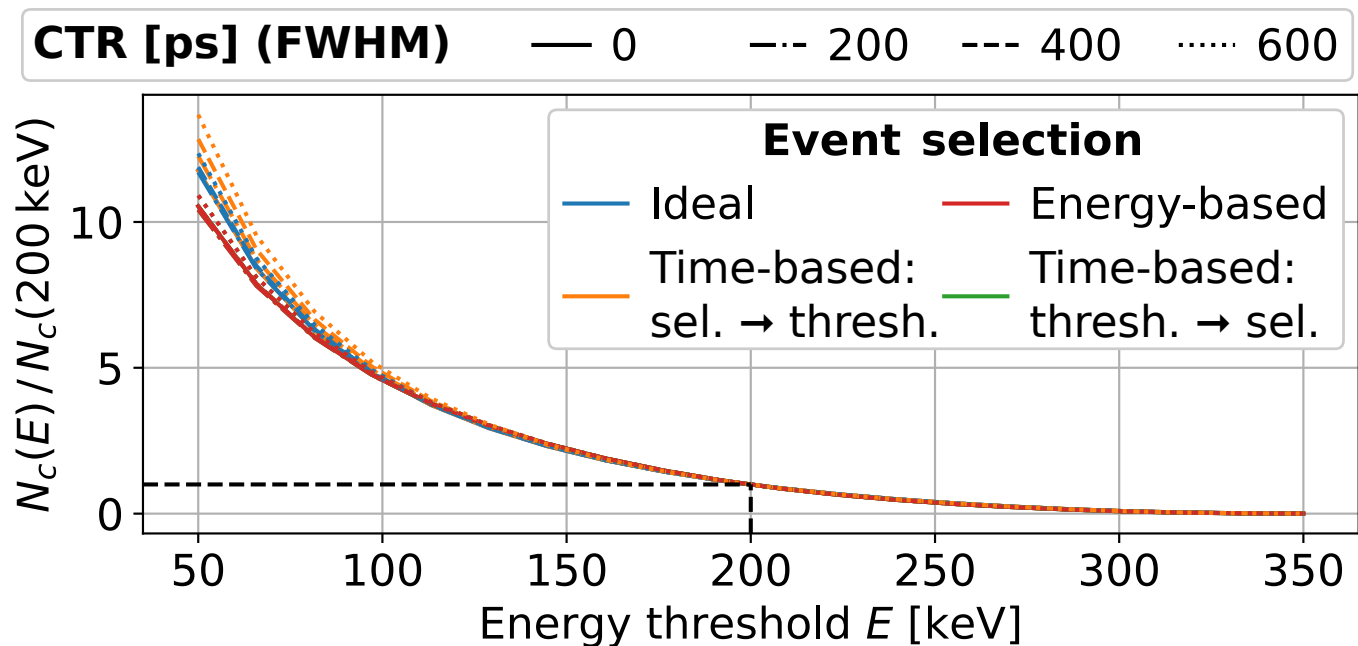


Comb.
100%
of the data

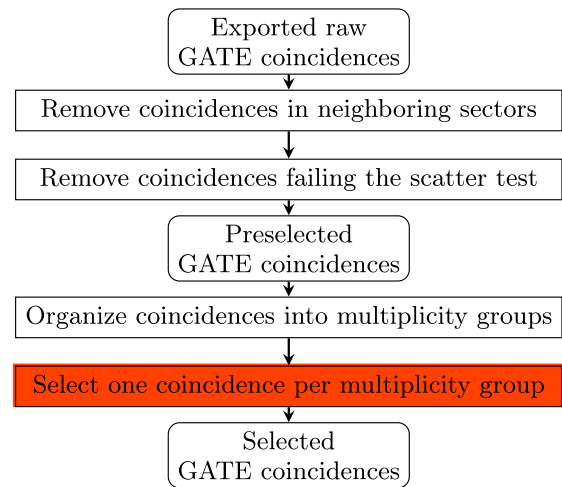


Performance analysis: w/ phantom

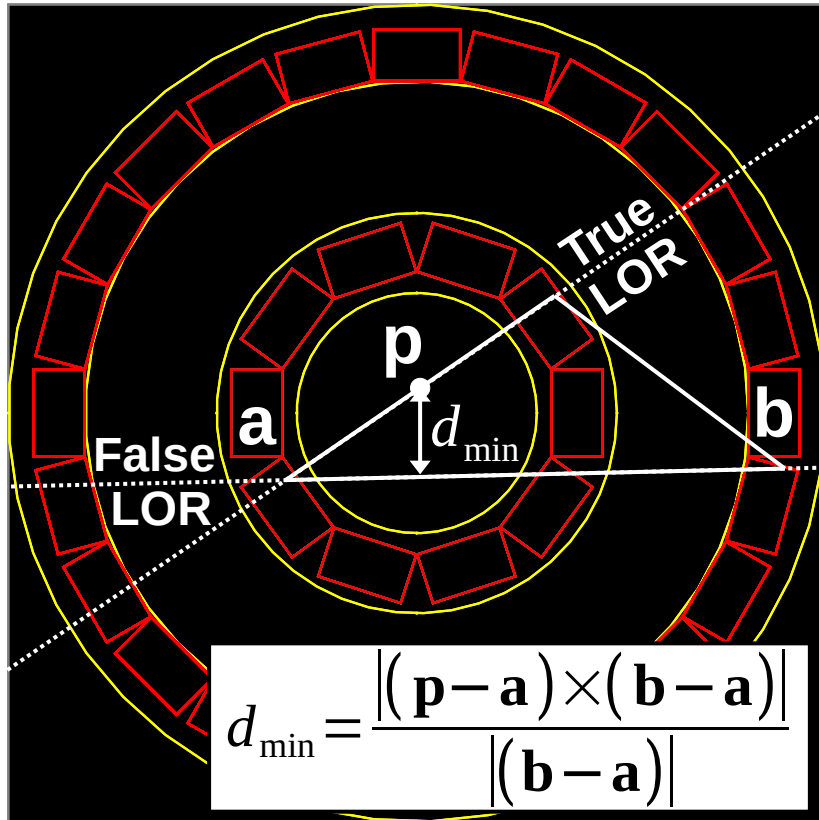
N_c : Number of coincidences ~ Sensitivity



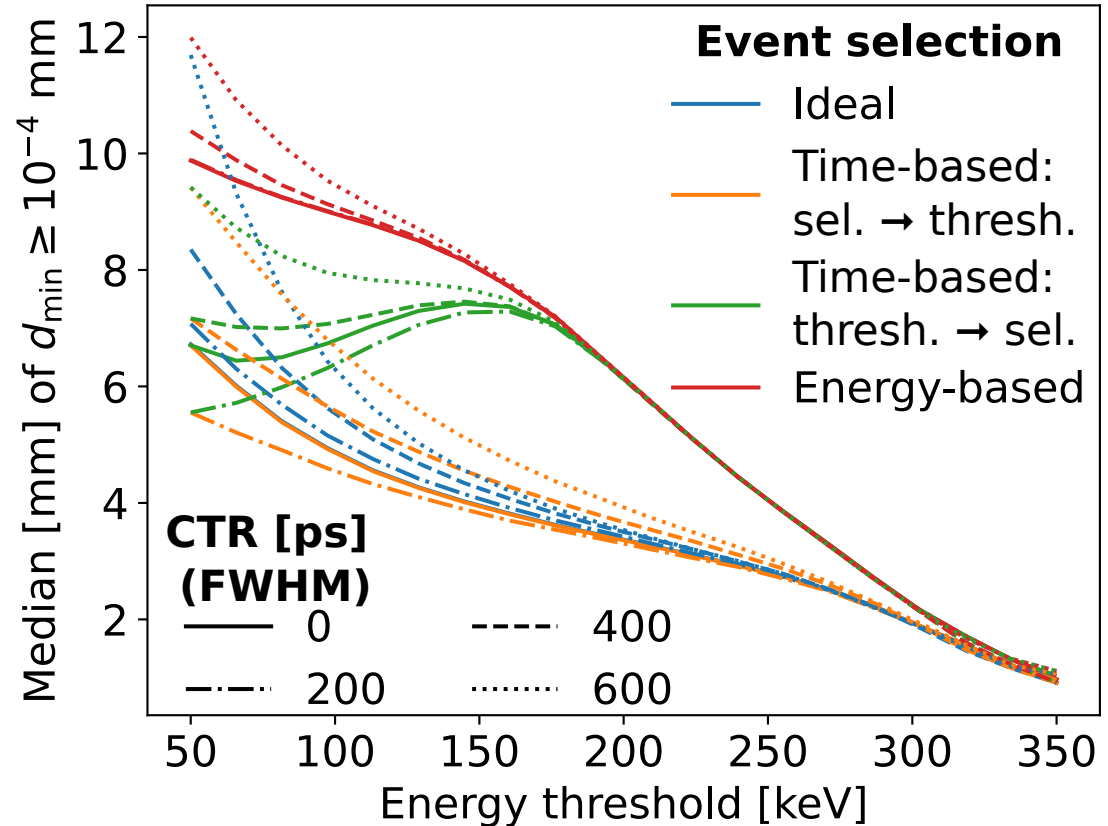
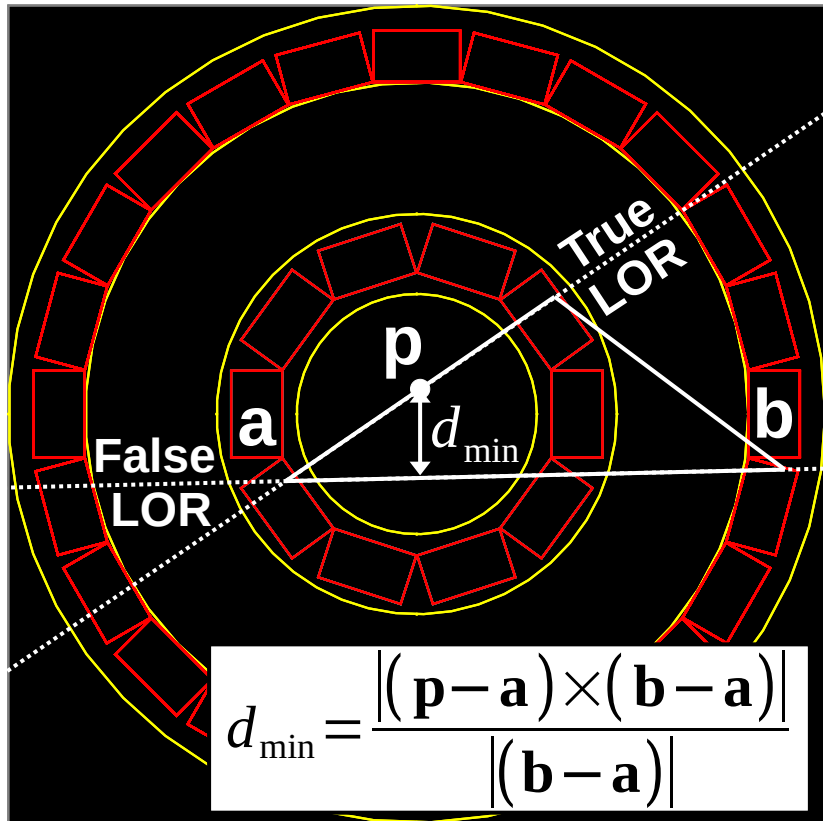
Comb.
100%
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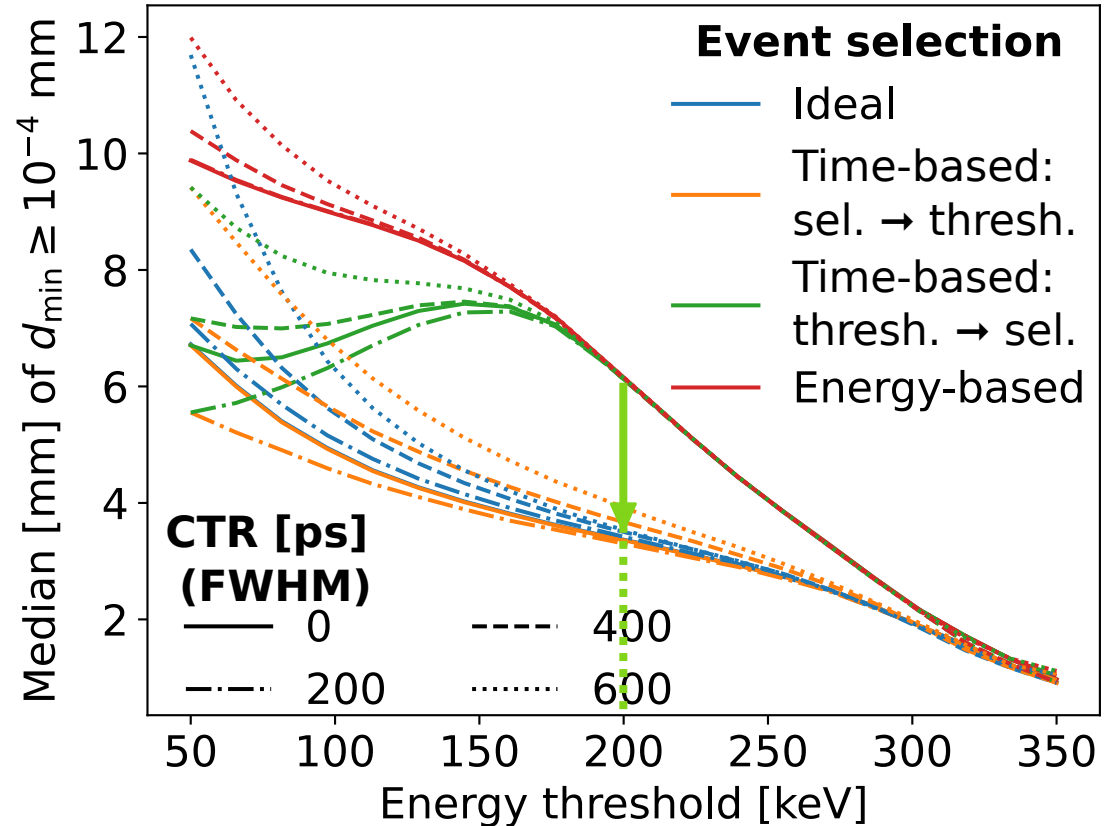
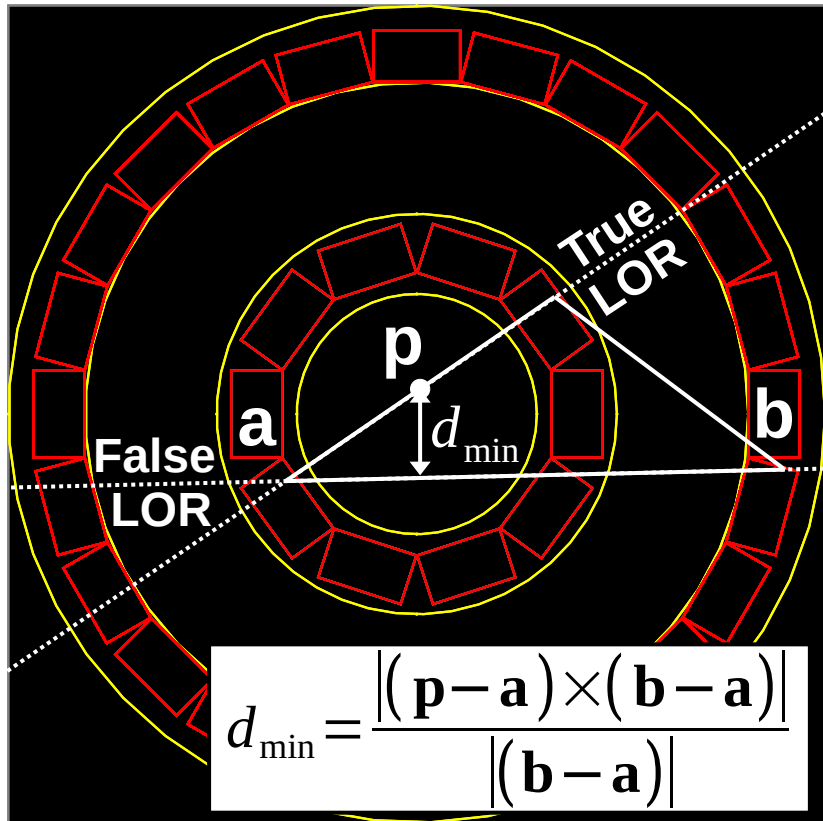
Error assessment



Error assessment



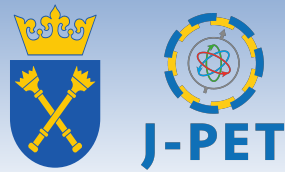
Error assessment



4.

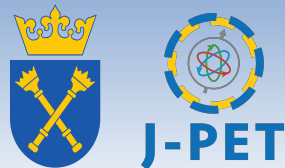
Conclusions

Conclusions



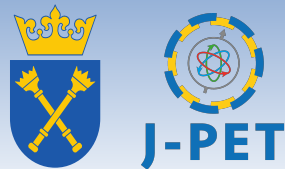
- Scanners close to the phantom pose limitations to the scatter test

Conclusions



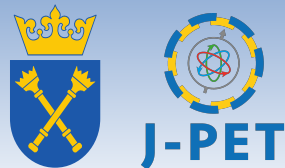
- Scanners close to the phantom pose limitations to the scatter test
- Thresh. → Sel. performs sub-optimally for time- and energy-based policies

Conclusions



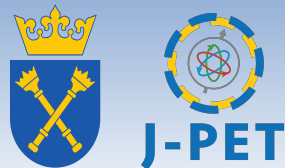
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- Sel. → Thresh. improves the accuracy, event with time resolution limitations

Conclusions



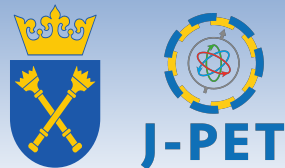
- Scanners close to the phantom pose limitations to the scatter test
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- Sel. → Thresh. improves the accuracy, event with time resolution limitations
- The increasing fraction of detector- or phantom-scattered events with a lower energy threshold needs to be compared to the significant rise in the number of events (sensitivity)

Conclusions



- Scanners close to the phantom pose limitations to the scatter test
- Thresh. → Sel. performs sub-optimally for time- and energy-based policies
- Sel. → Thresh. improves the accuracy, event with time resolution limitations
- The increasing fraction of detector- or phantom-scattered events with a lower energy threshold needs to be compared to the significant rise in the number of events (sensitivity)
- An analysis in the image domain with energy threshold-dependent scatter correction is necessary to further evaluate optimal event selection policy

Thank You for Your attention!



Thanks to the **J-PET** collaboration:

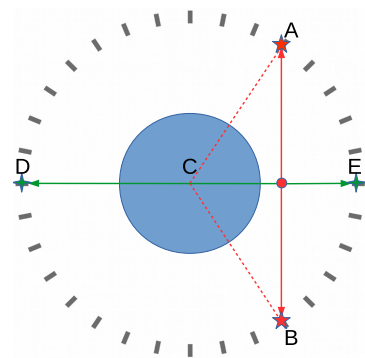
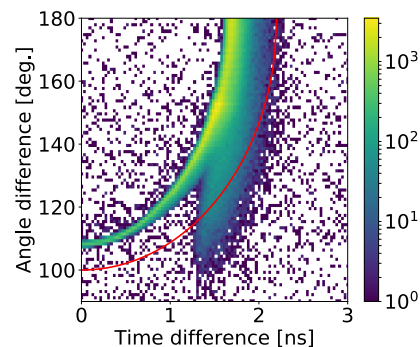
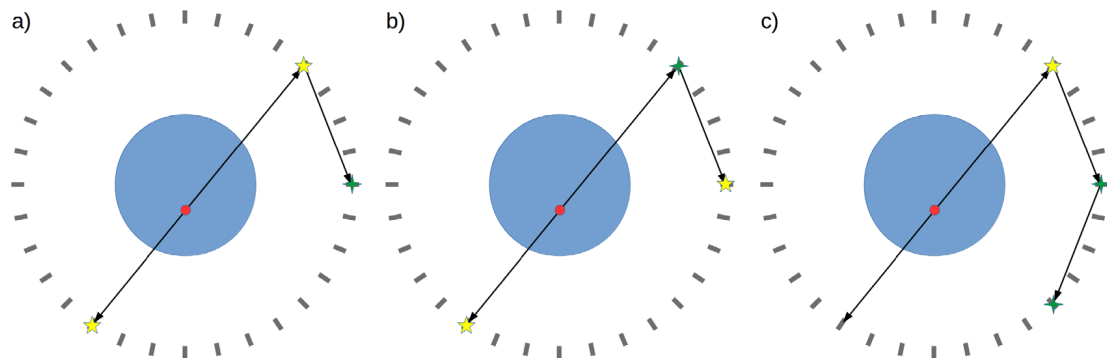
Supported by:



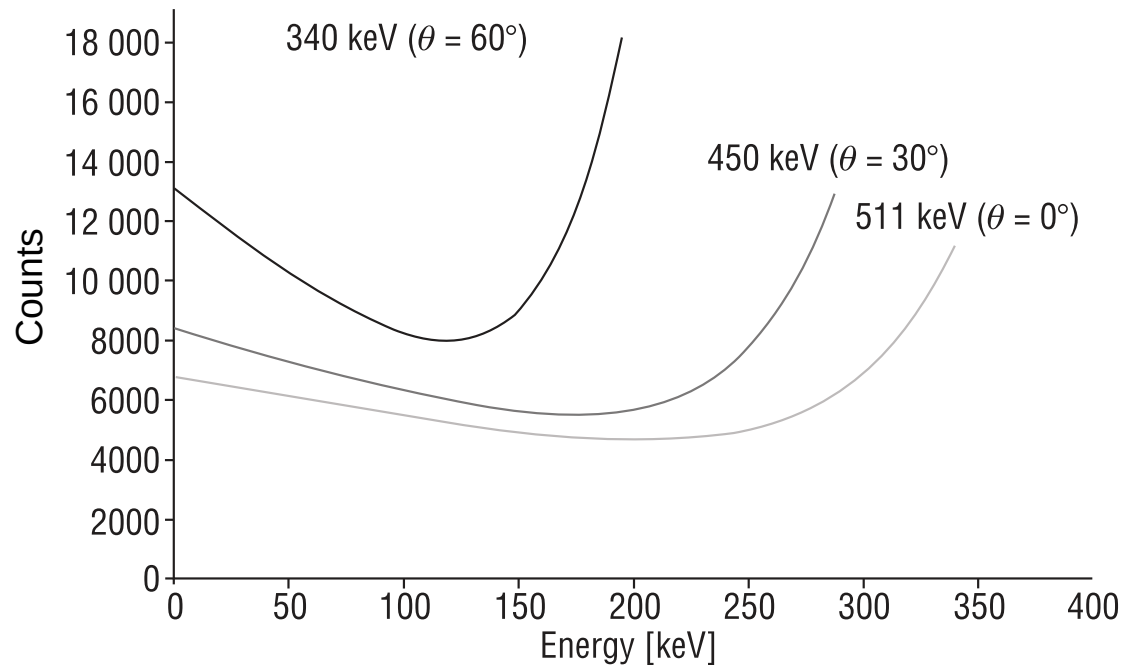
Backup

Event selection in MC simulations

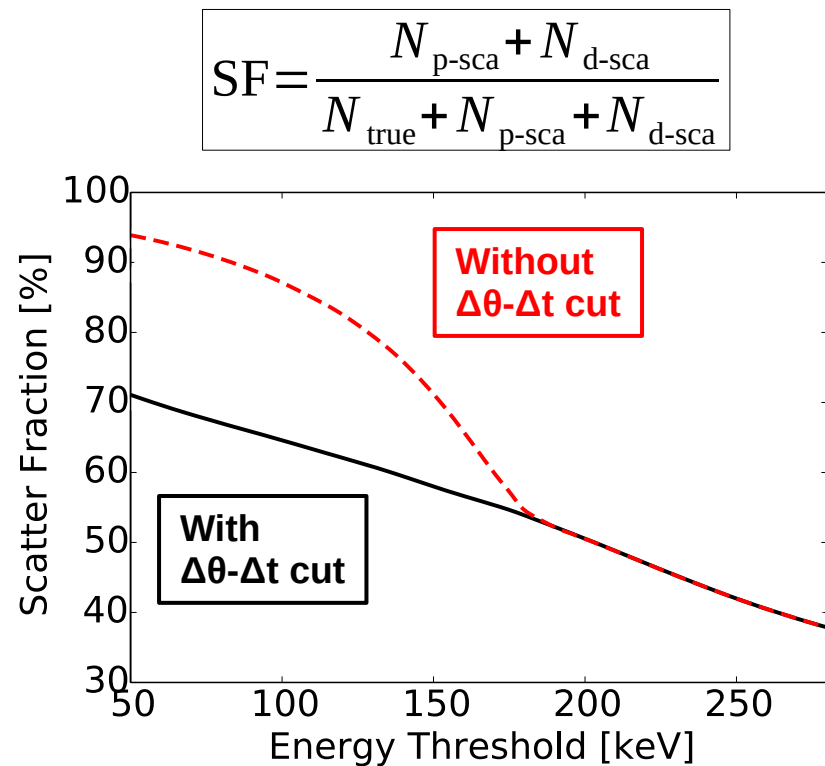
1. Only considering events with exactly two hits with $E > 200$ keV (and allowing more hits with $E < 200$ keV)
2. Cutting based on the correlation between the azimuthal angle difference and time difference (more relevant for larger activities)



Reason #1: phantom scatters



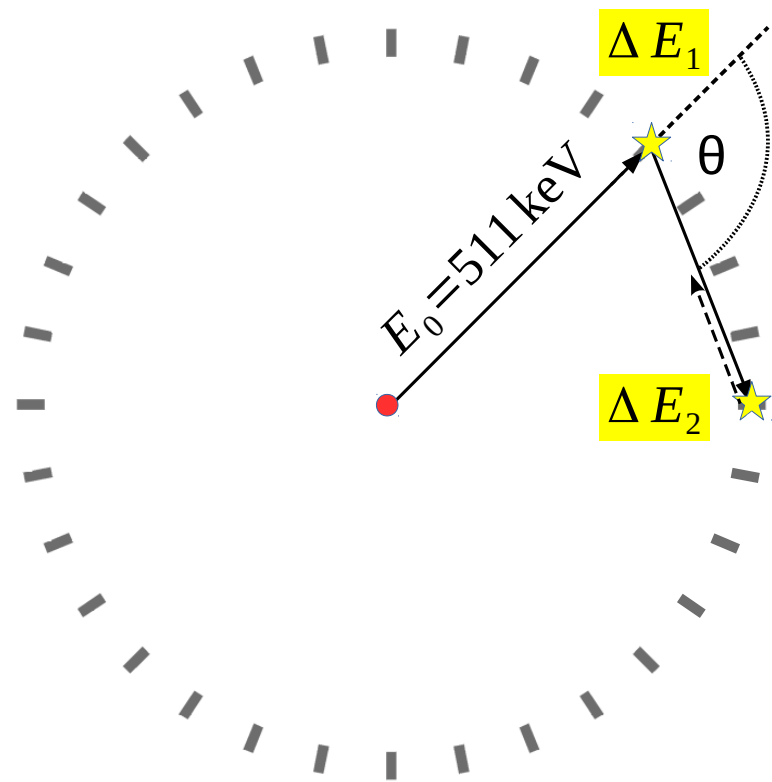
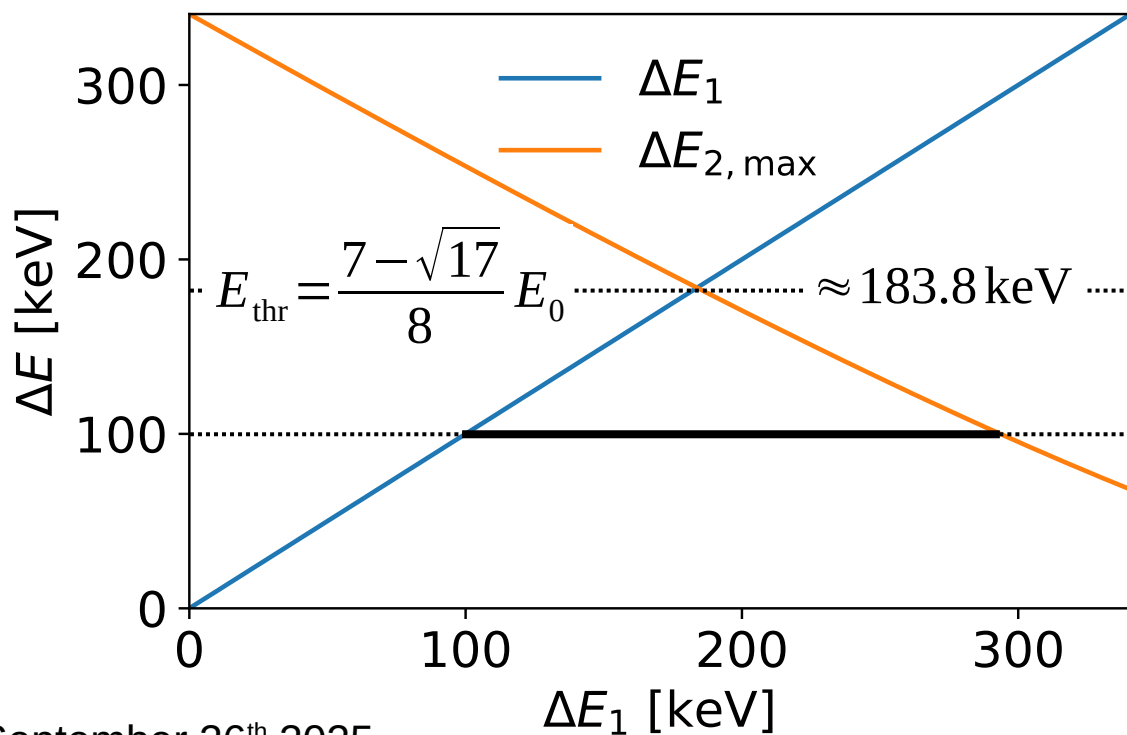
P. Moskal et al. *Nuclear Medicine Review* 15 (2012)



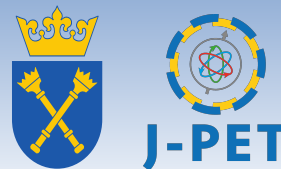
P. Kowalski et al. *Acta Phys. Pol. B* 47 (2016)

Reason #2: detector scatters

Which energy threshold can a single 511 keV photon exceed in two consecutive interactions?



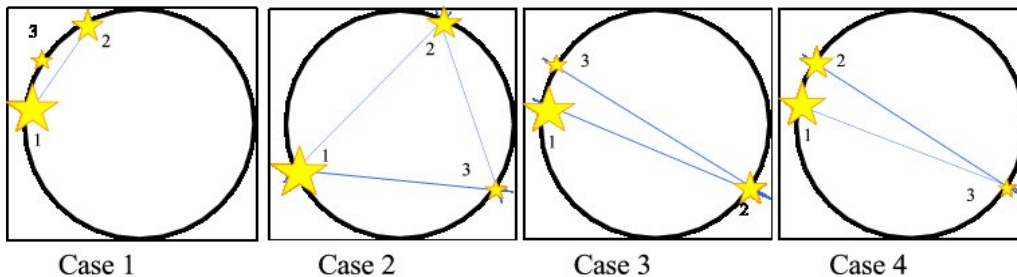
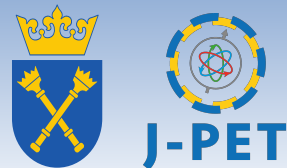
Simulation settings



Available multiple policies in GATE:

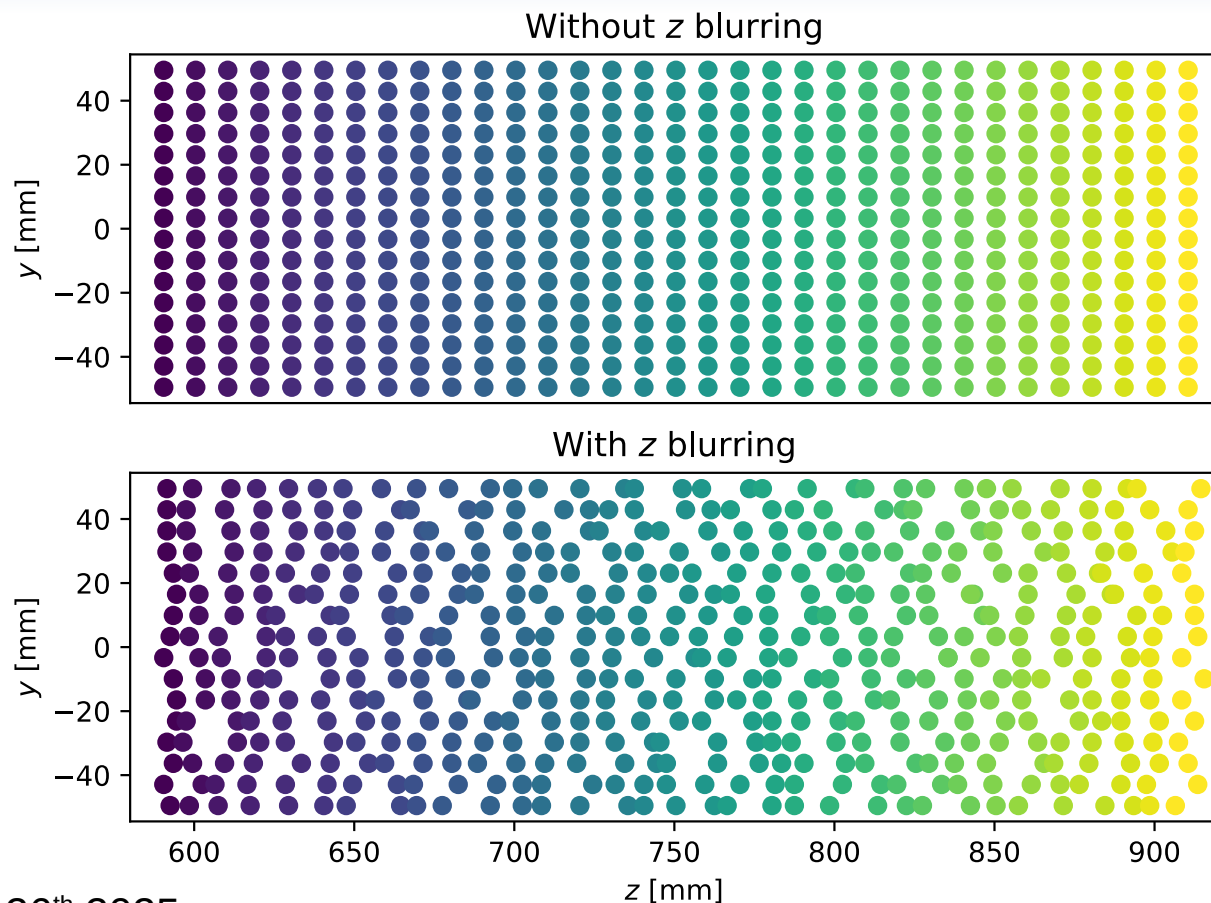
Policy name	Description
takeAllGoods	Each good pairs are considered
takeWinnerOfGoods	Only the good pair with the highest energy is considered
takeWinnerIfIsGood	If the pair with the highest energy is good, take it, otherwise, kill the event
takeWinnerIfAllAreGoods	If all pairs are goods, take the one with the highest energy
takeWinnerIfOnlyOneGood	If exactly one pair is good
killAllIfMultipleGoods	If more than one pairs is good, the event is seen as a real “multiple” and thus, all events are killed
killAll	No multiple coincidences are accepted, no matter how many good pairs are present

Simulation settings



Policy name	Case 1	Case 2	Case 3	Case 4
takeAllGoods	(1,2)	(1,2);(1,3);(2,3)	(1,2);(2,3)	(1,2);(1,3);(2,3)
takeWinnerOfGoods	(1,2)	(1,2)	(1,2)	(1,3)
takeWinnerIfIsGood	(1,2)	(1,2)	(1,2)	-
takeWinnerIfAllAreGoods	-	(1,2)	-	-
takeWinnerIfOnlyOneGood	(1,2)	-	-	-
killAllIfMultipleGoods	(1,2)	-	-	-
killAll	-	-	-	-

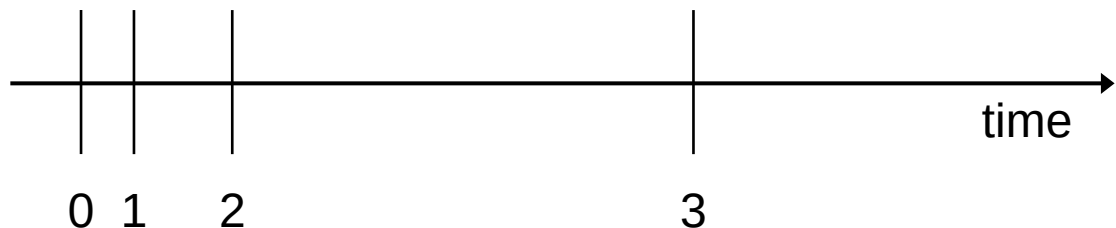
Axial blurring



Has a small impact on the scatter test when compared to the time resolution limitations

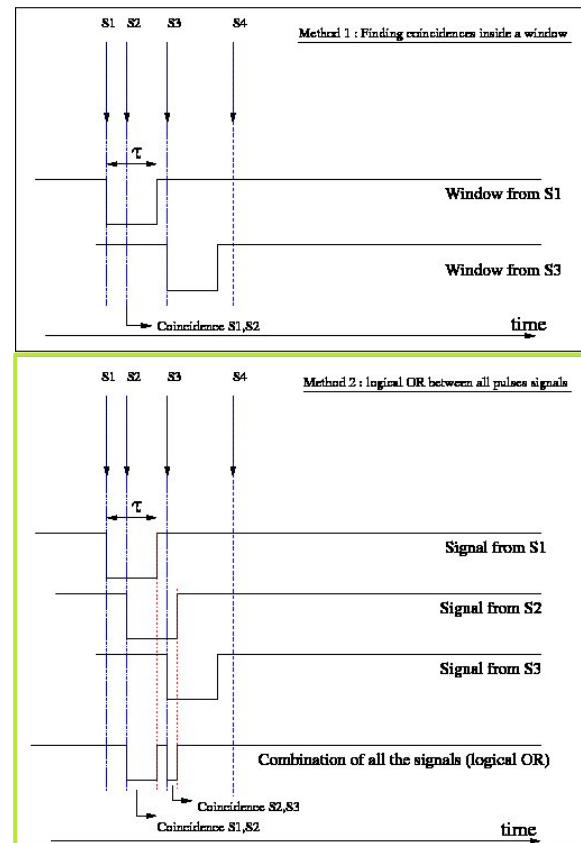
Event ordering

- Events are ordered based on time, but not based on the 'mid-time' $(t_1 + t_2)/2$
- For example consider 4 events:

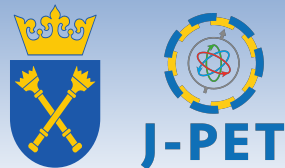


- If $t_3 - t_0 < 4$ ns, GATE orders as follows:

Event number	1	2	3	4	5	6
Hit number 1	0	0	0	1	1	2
Hit number 2	1	2	3	2	3	3

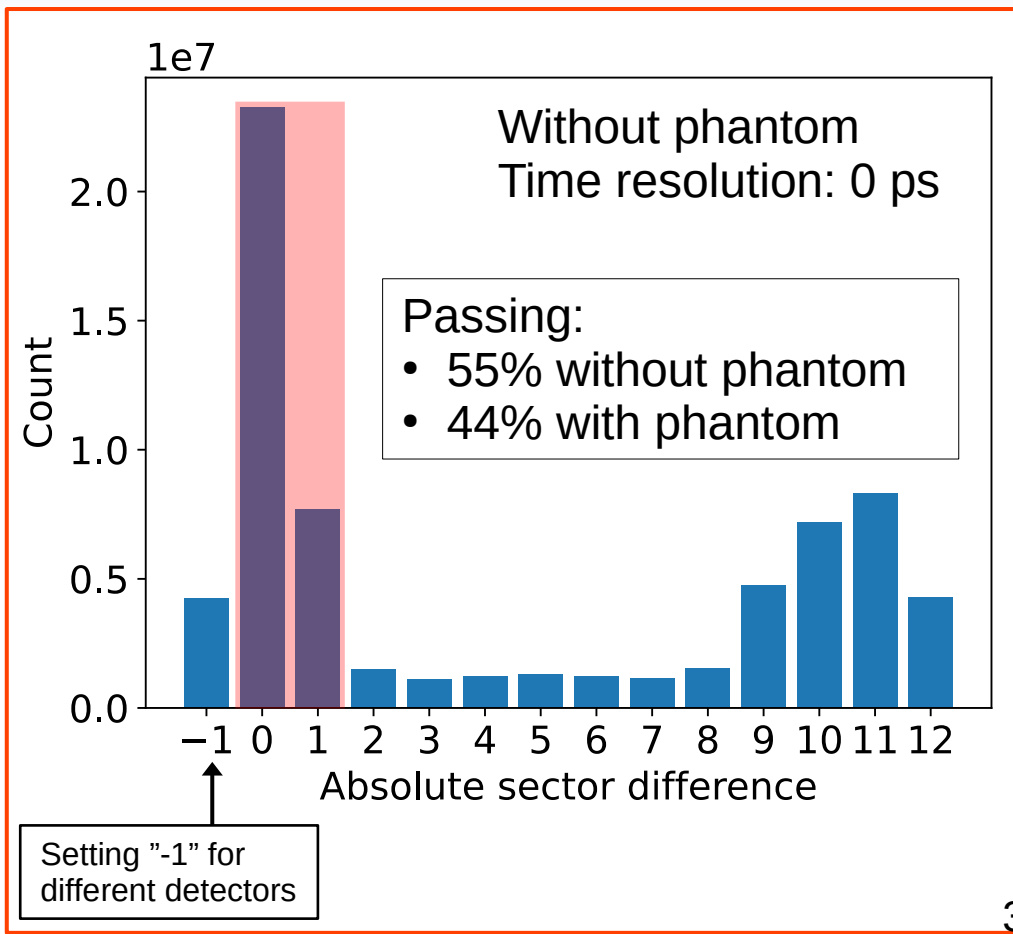
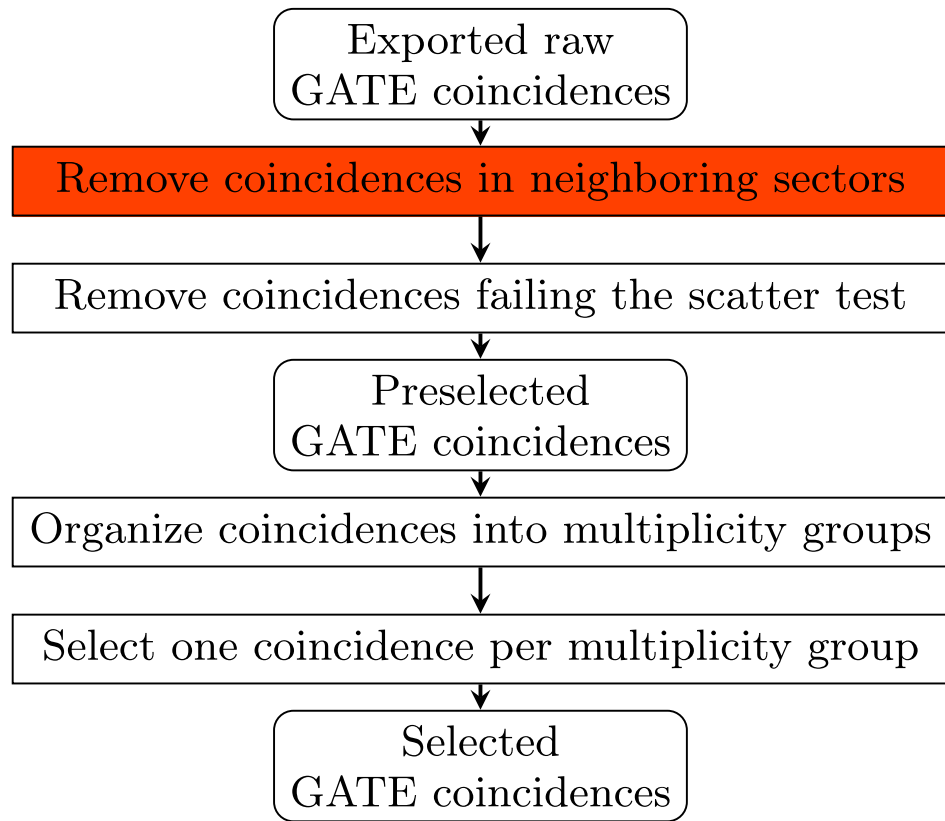


Event selection policies studied

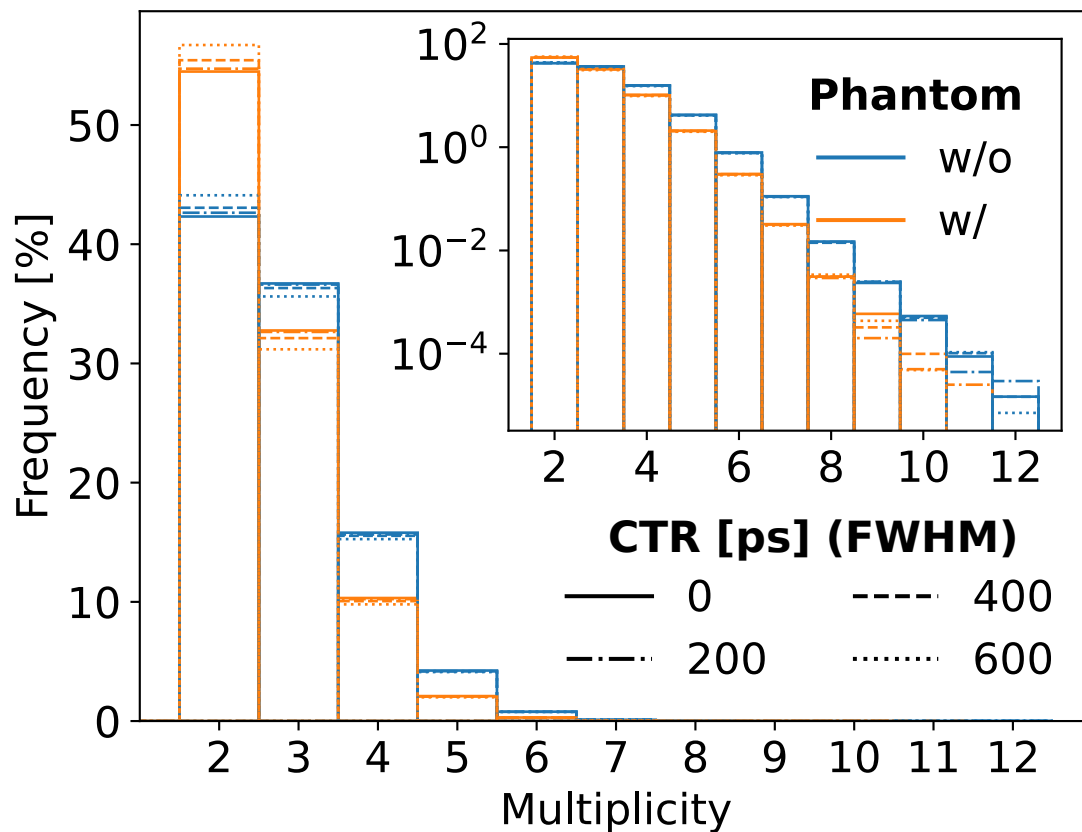


- Choose one coincidence per multiplicity group
- Investigating four policies:
 - **Ideal (for reference)**: If a true event is in the multiplicity group, choose it; otherwise choose the first coincidence
 - **Time-based: sel. → thresh.**: Choose the first one of the multiplicity group with data collected down to 50 keV
 - **Time-based: thresh. → sel.**: Choose the first one in the multiplicity group with data collected at the given energy threshold
 - **Energy based**: Choose coincidence with the highest total energy deposited ($E_1 + E_2$)

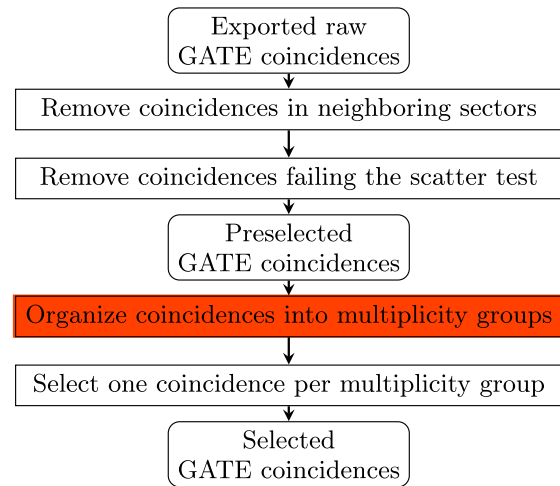
Data analysis



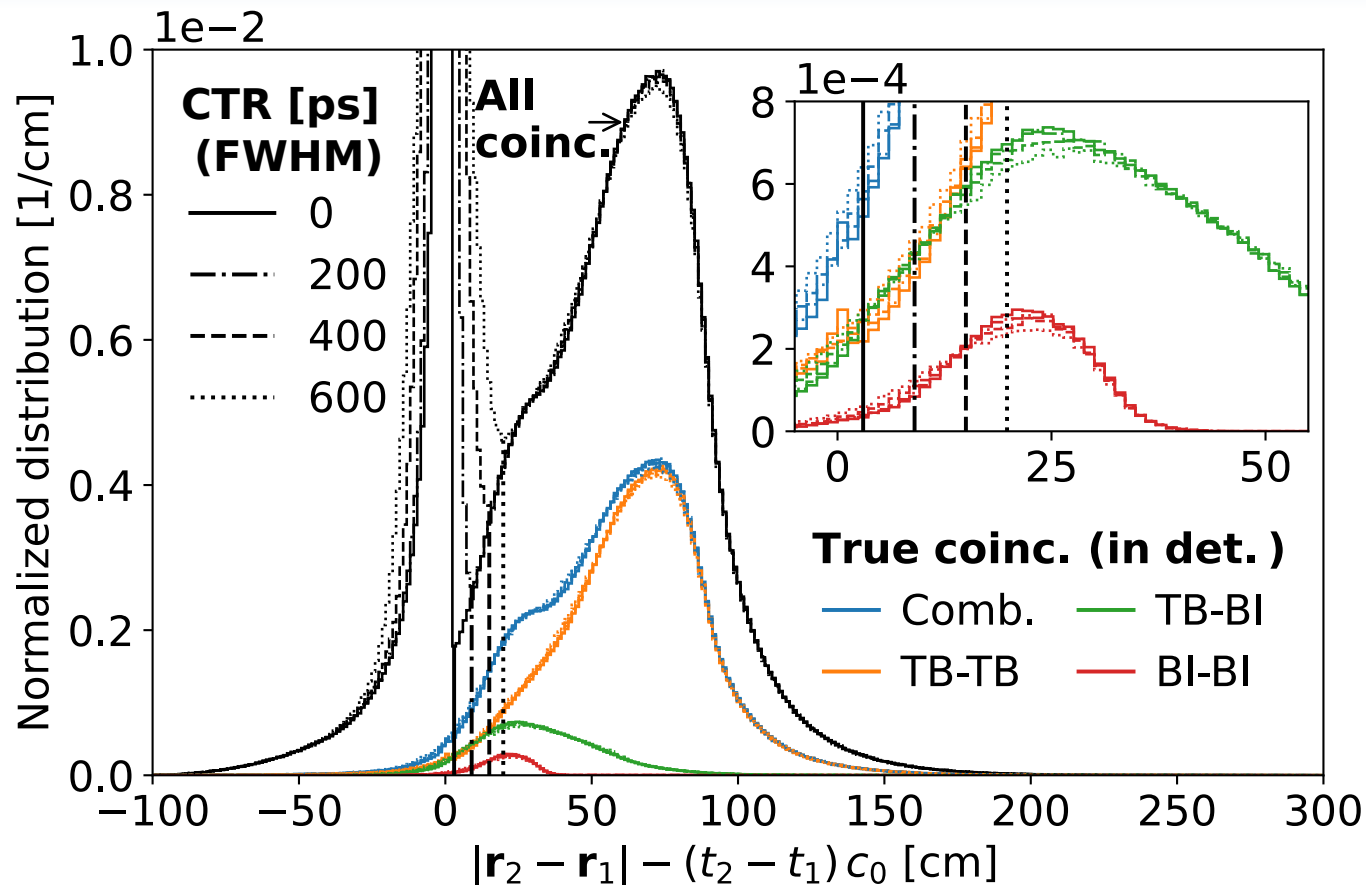
Multiplicity



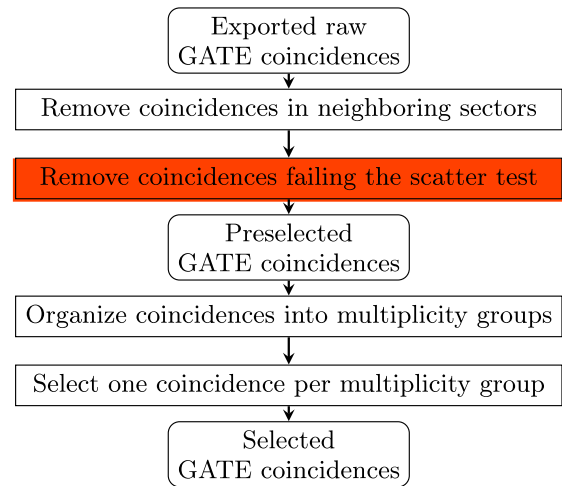
Threshold
max. at 10 cm



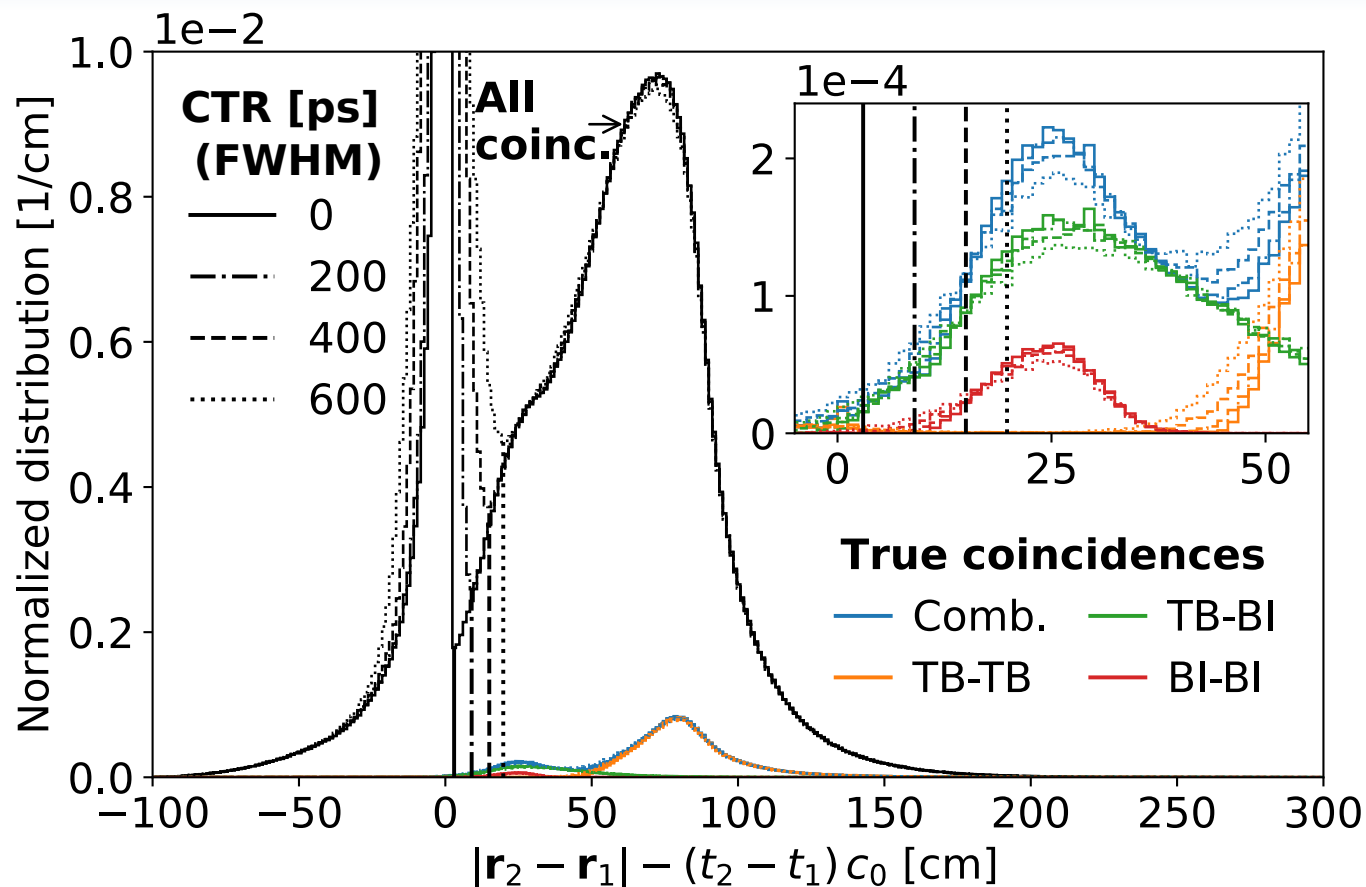
Scatter test w/ phantom



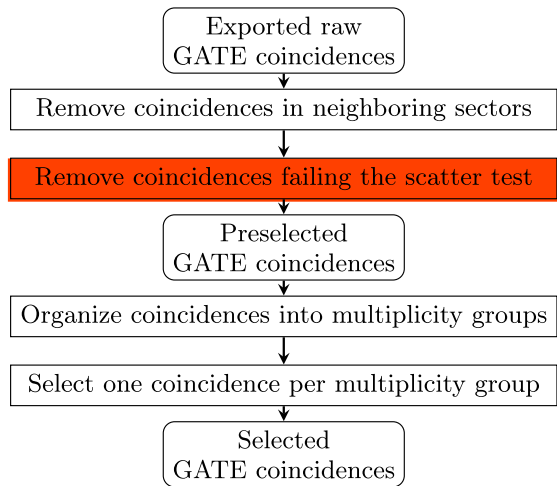
Threshold
max. at 10 cm



Scatter test w/ phantom



Threshold
max. at 10 cm



Scatter test: passing percentages

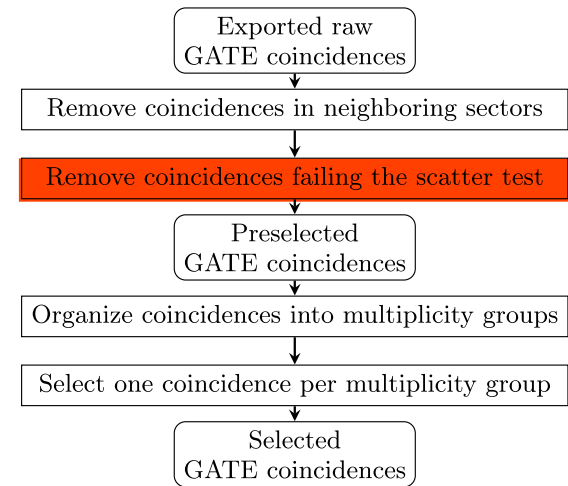
Without phantom

CTR [ps] (FWHM)	Passing scatter test [%]
0	73.14
200	72.70
400	73.17
600	74.62

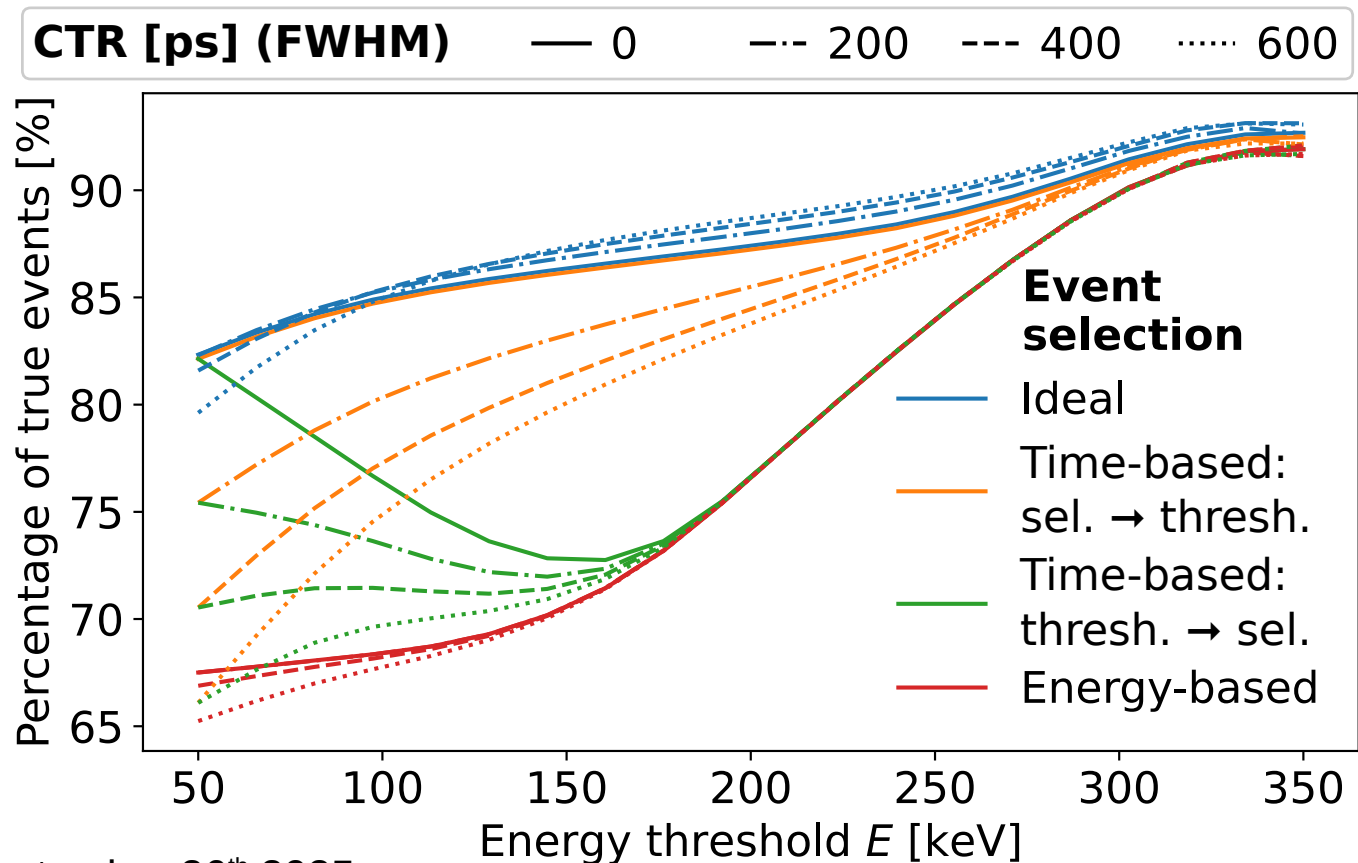
With phantom

CTR [ps] (FWHM)	Passing scatter test [%]
0	64.90
200	63.65
400	63.85
600	65.43

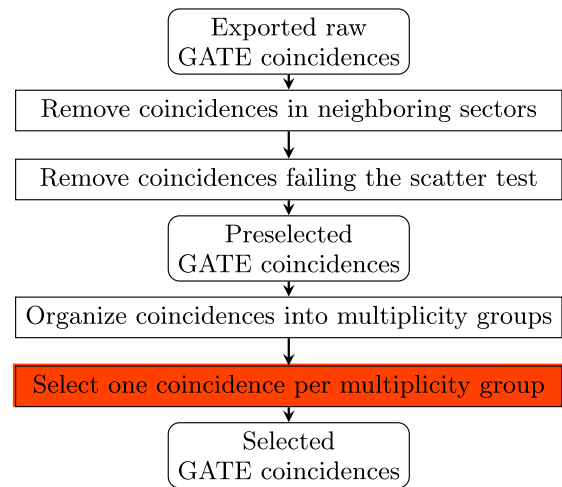
Threshold
max. at 10 cm



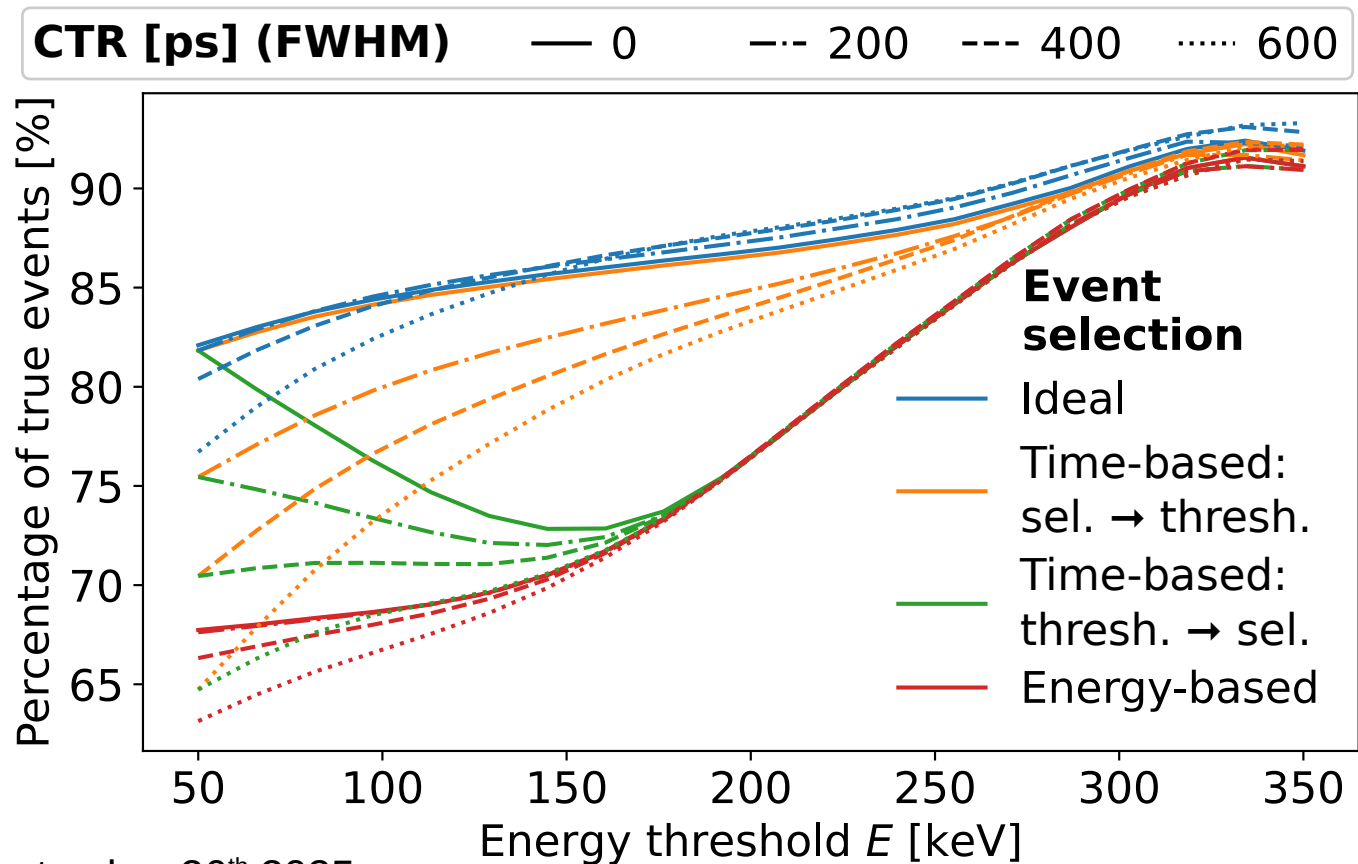
Performance analysis: w/o phantom



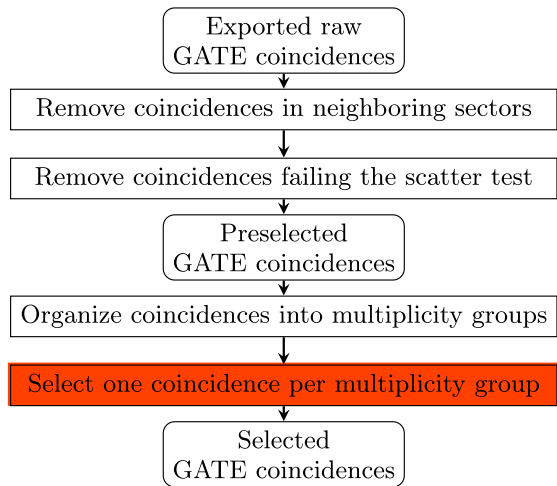
Comb.
100%
of the data



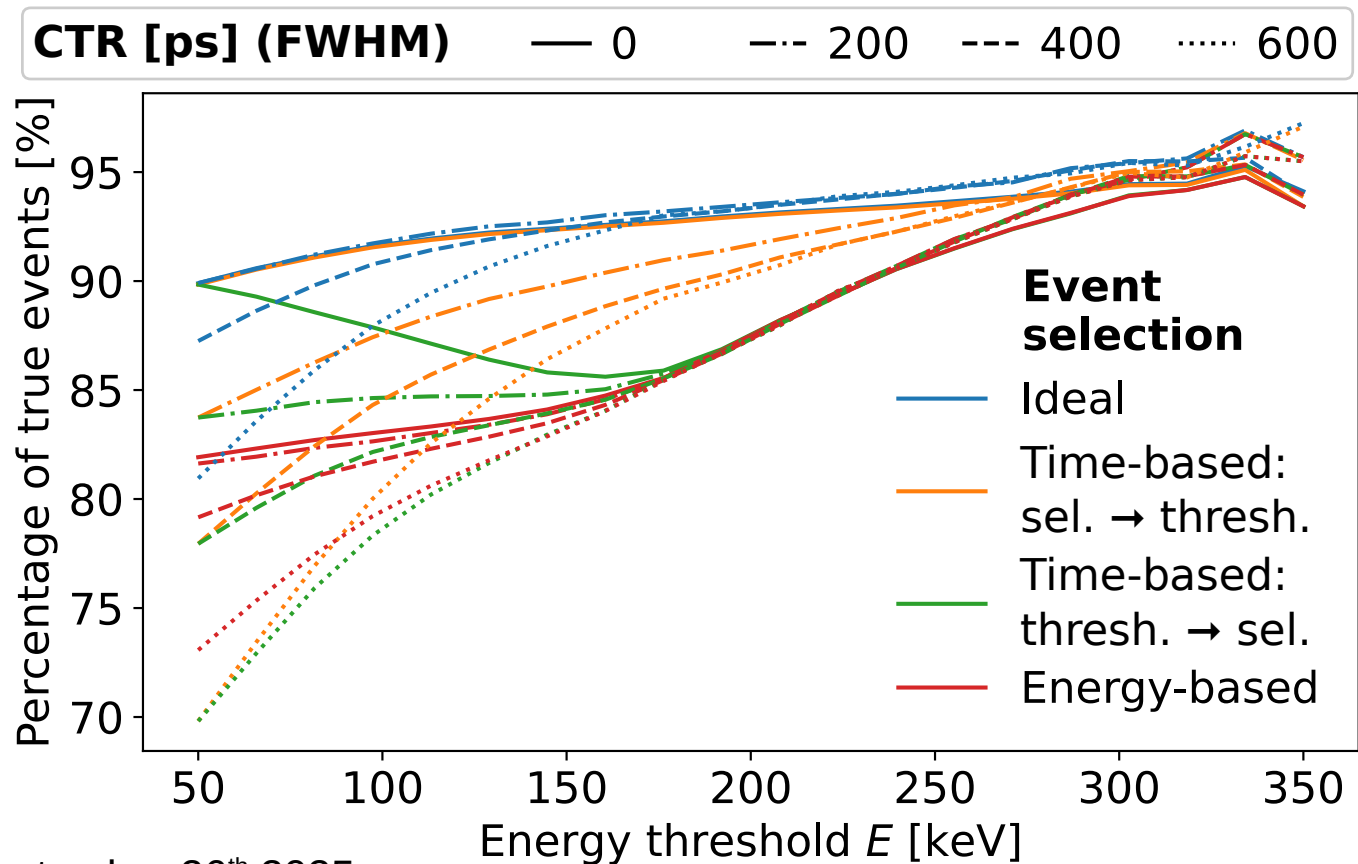
Performance analysis: w/o phantom



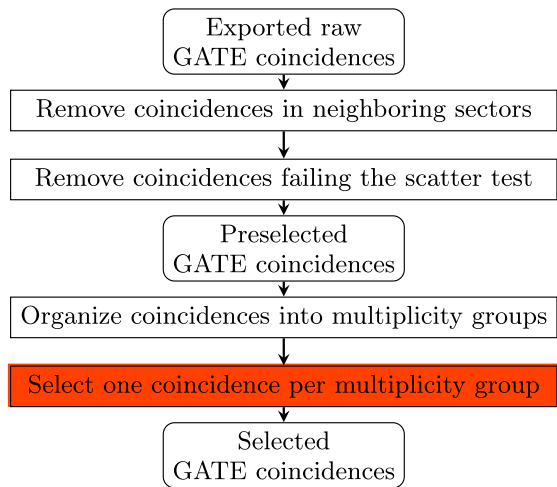
TB-BI
~ 9%
of the data



Performance analysis: w/o phantom

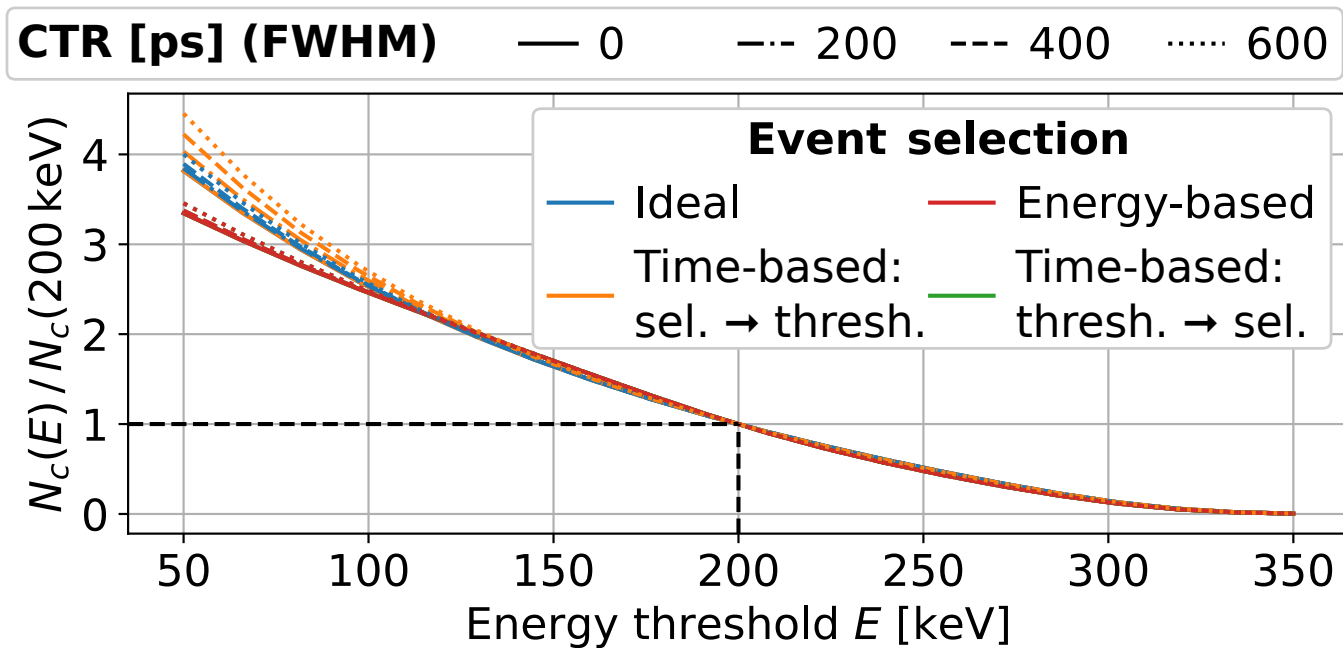


BI-BI
~ 0.5%
of the data

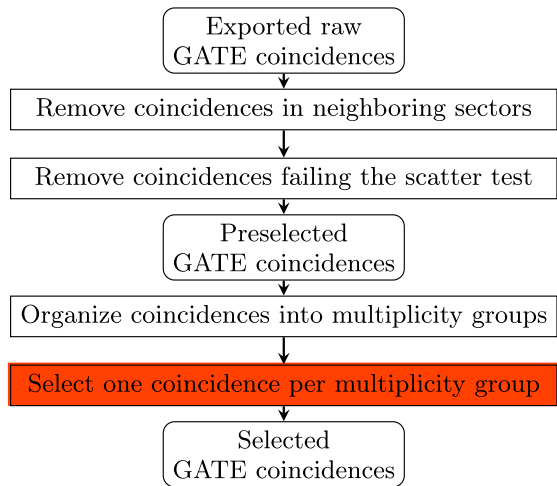


Performance analysis: w/o phantom

N_c : Number of coincidences ~ Sensitivity

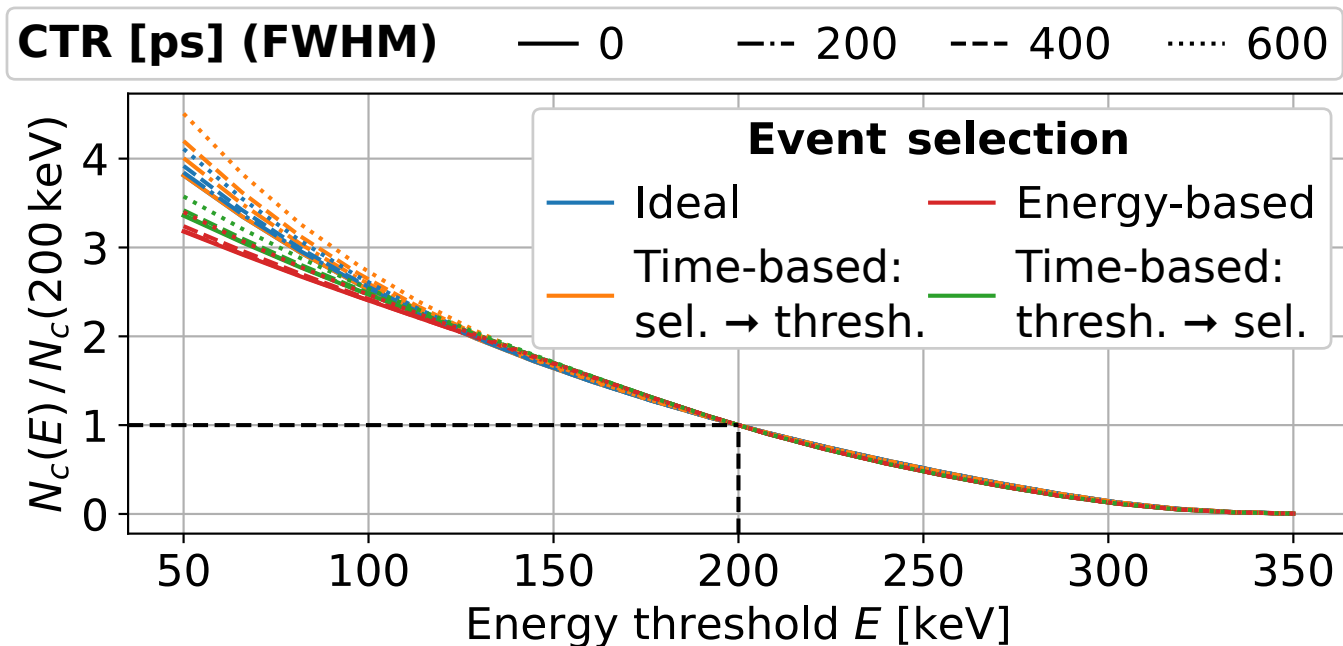


Comb.
100%
of the data

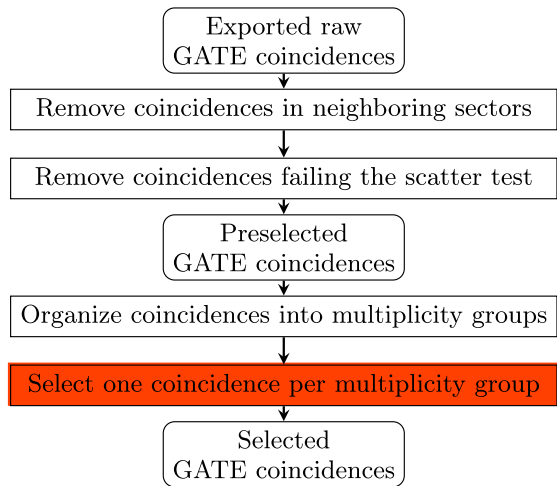


Performance analysis: w/o phantom

N_c : Number of coincidences ~ Sensitivity

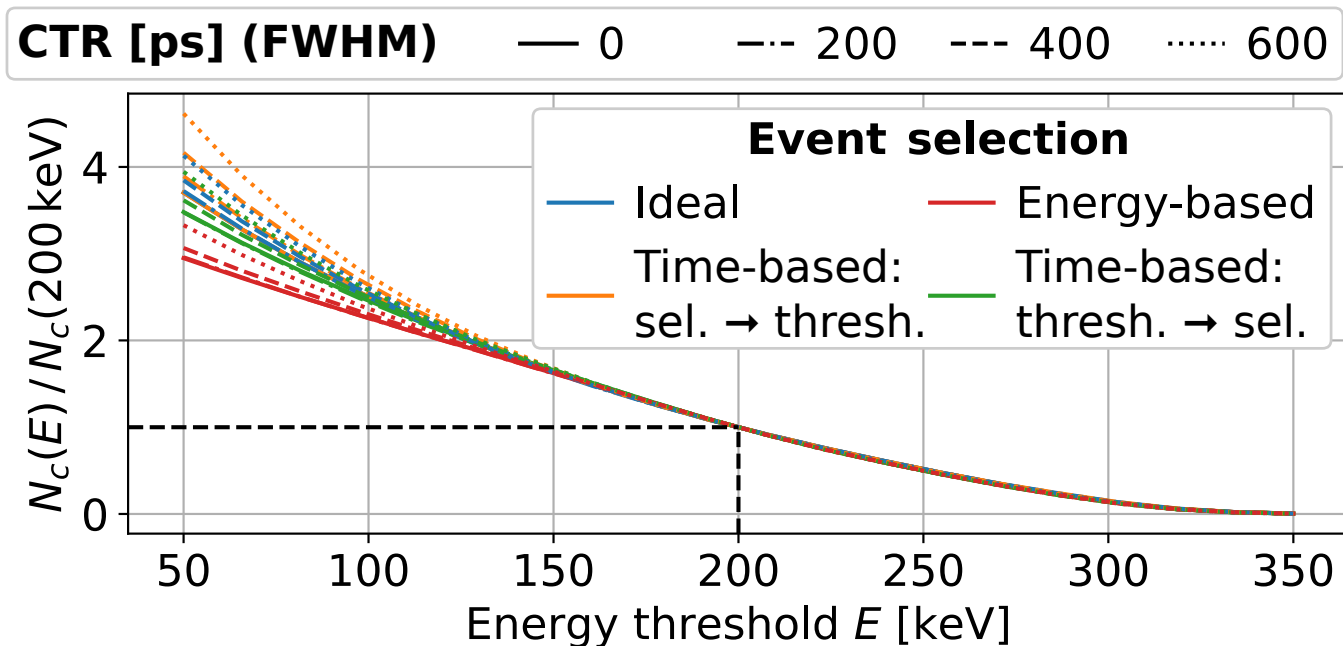


TB-BI
~ 9%
of the data

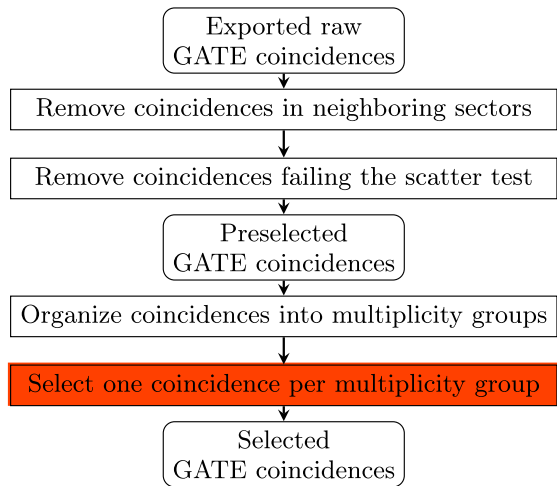


Performance analysis: w/o phantom

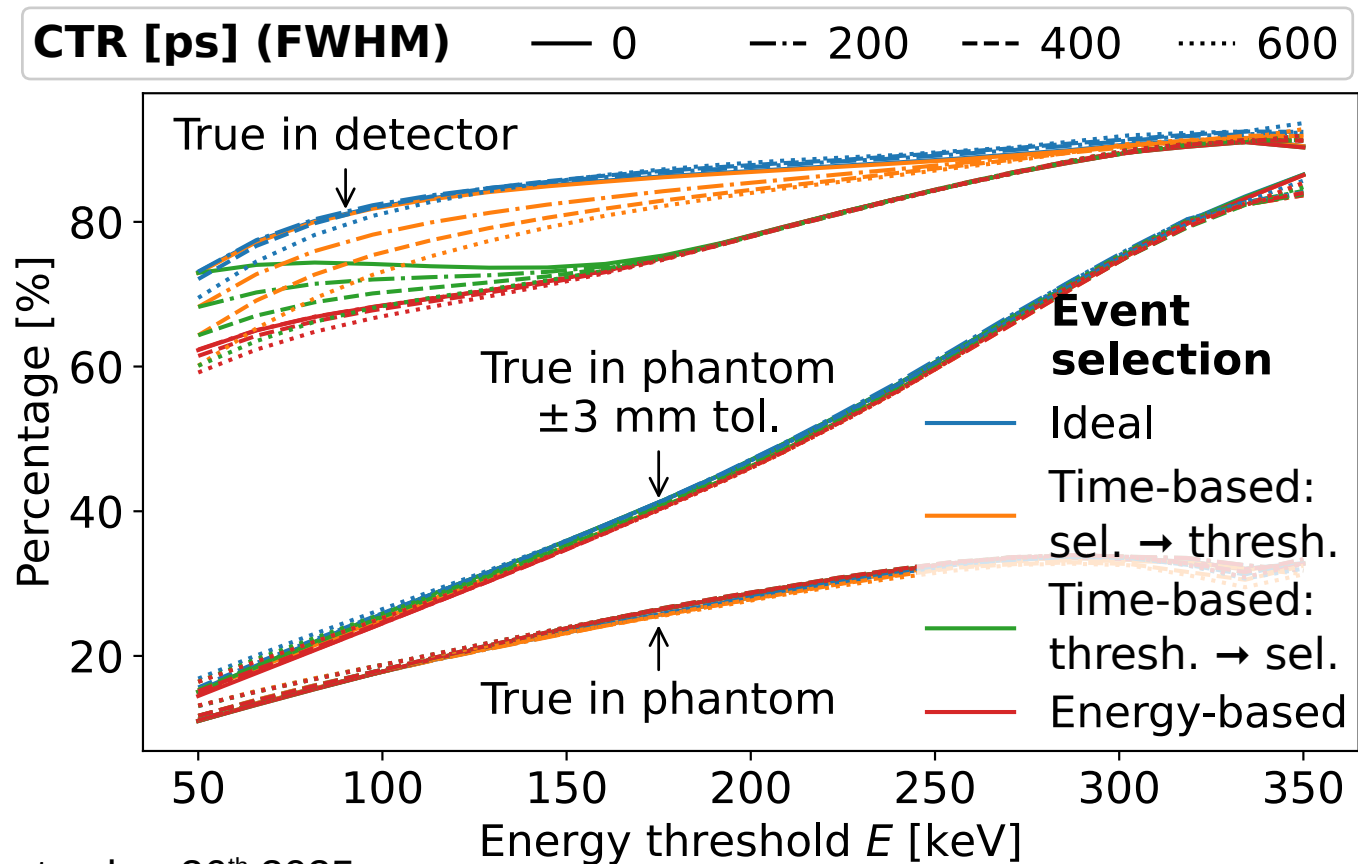
N_c : Number of coincidences \sim Sensitivity



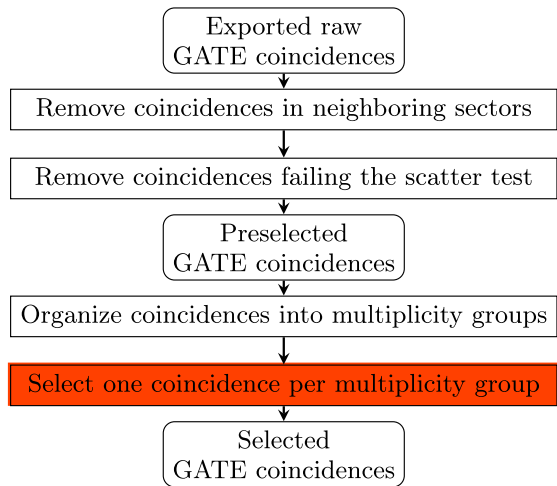
BI-BI
 $\sim 0.5\%$
of the data



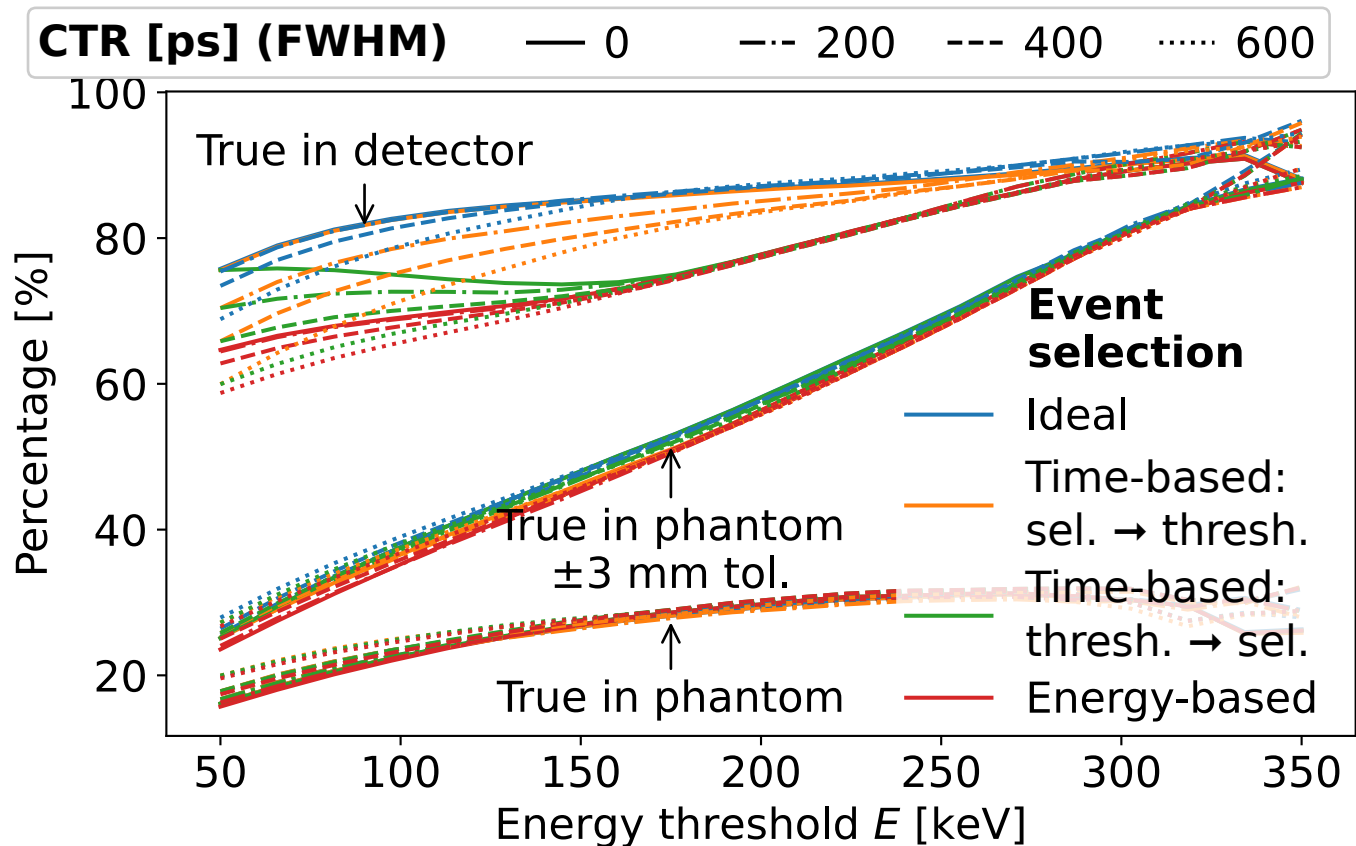
Performance analysis: w/ phantom



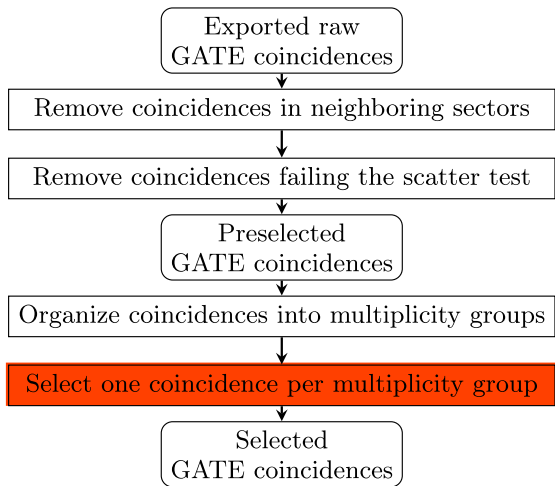
Comb.
100%
of the data



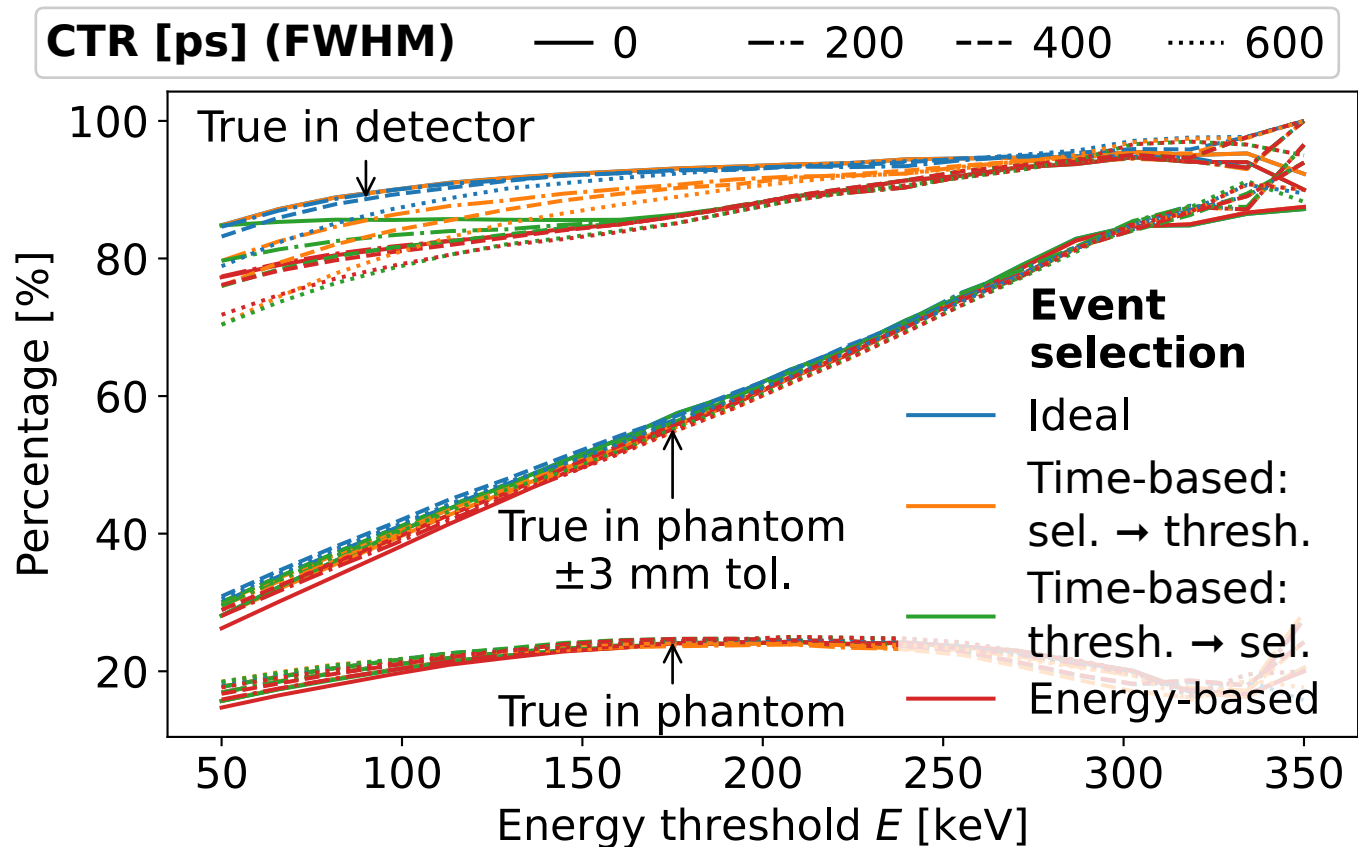
Performance analysis: w/ phantom



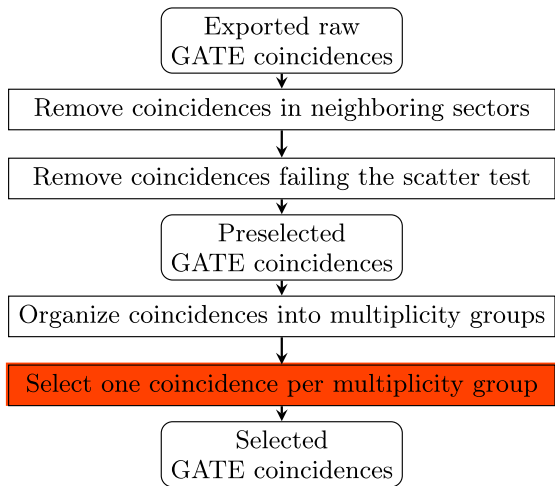
TB-BI
~ 9%
of the data



Performance analysis: w/ phantom

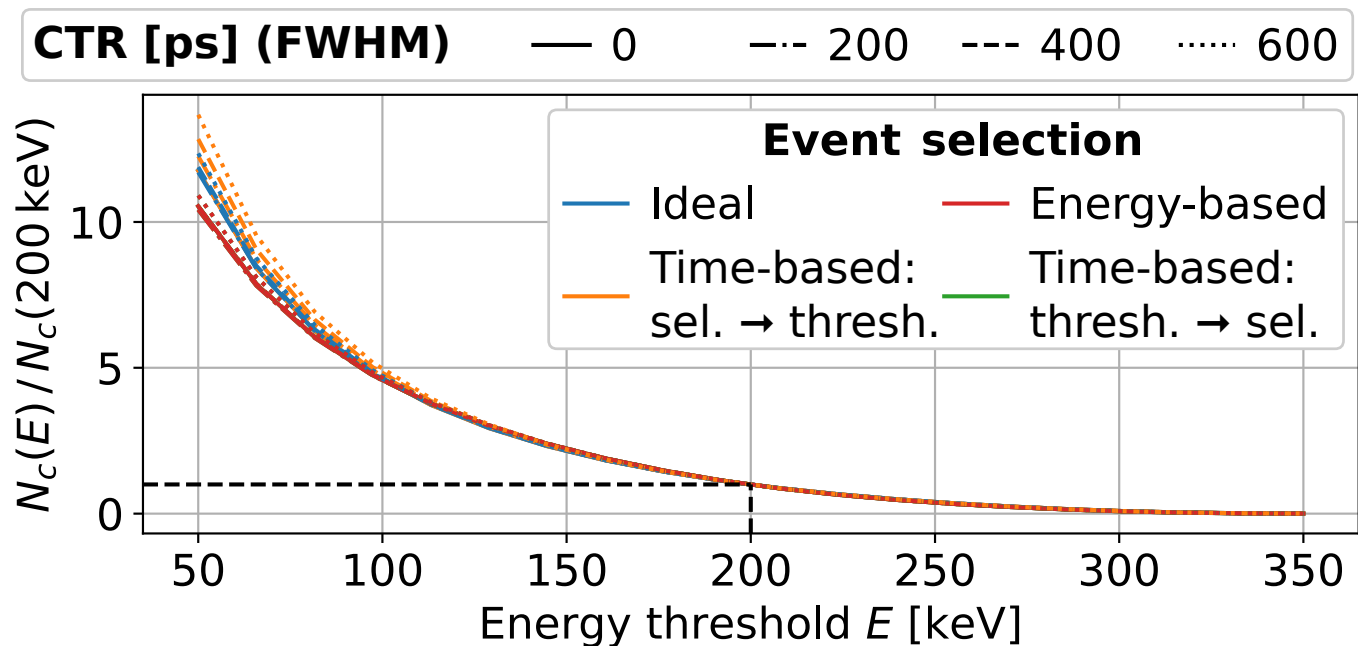


BI-BI
 $\sim 0.5\%$
of the data

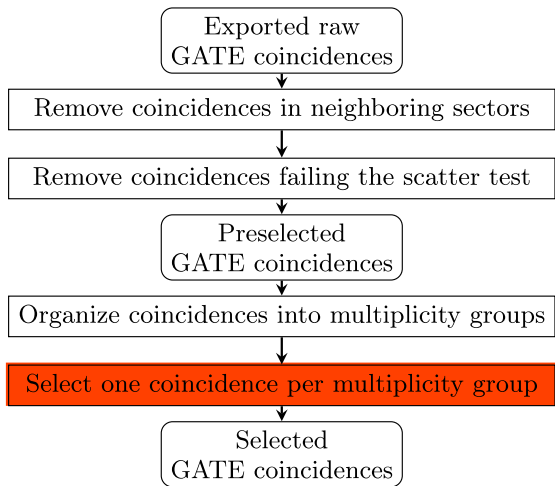


Performance analysis: w/ phantom

N_c : Number of coincidences ~ Sensitivity

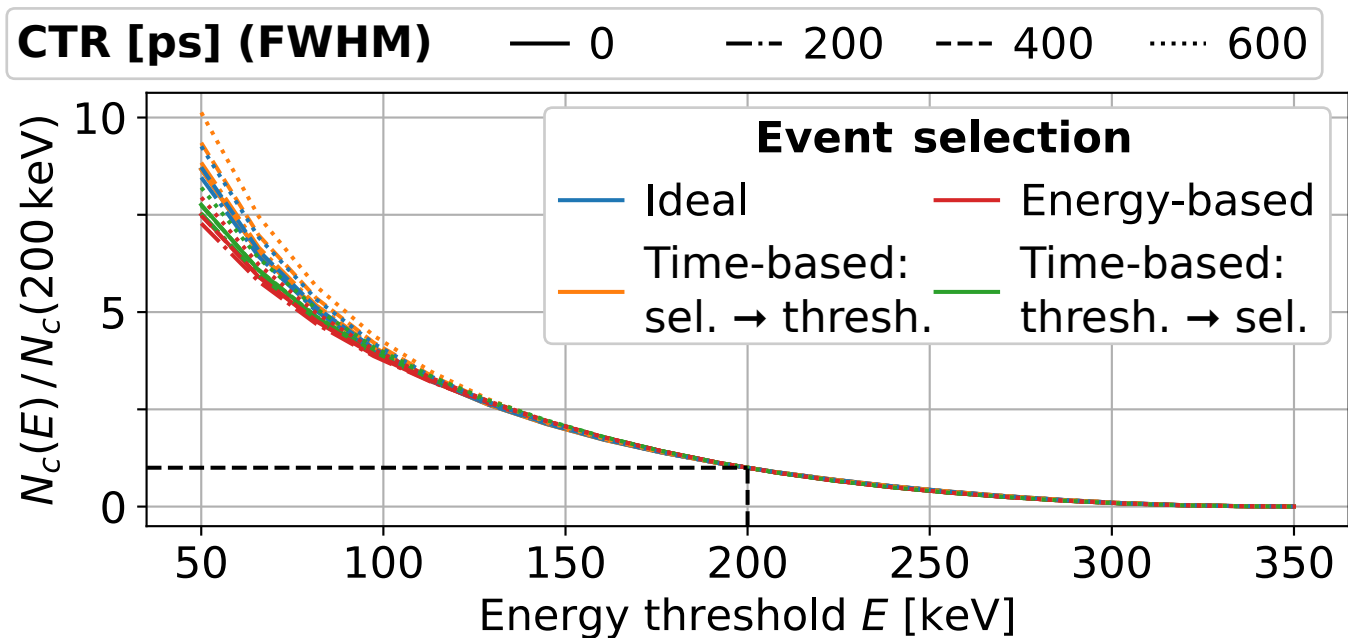


Comb.
100%
of the data

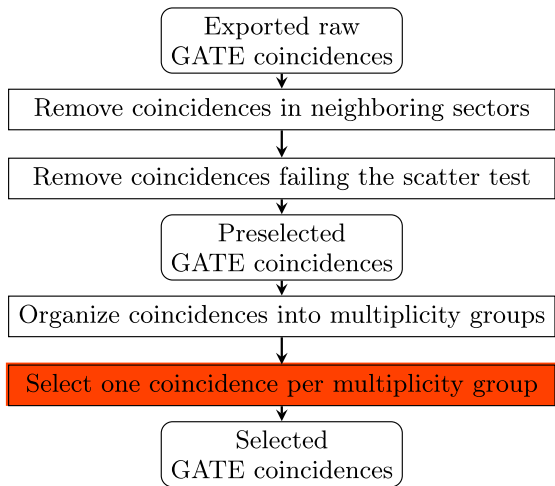


Performance analysis: w/ phantom

N_c : Number of coincidences ~ Sensitivity



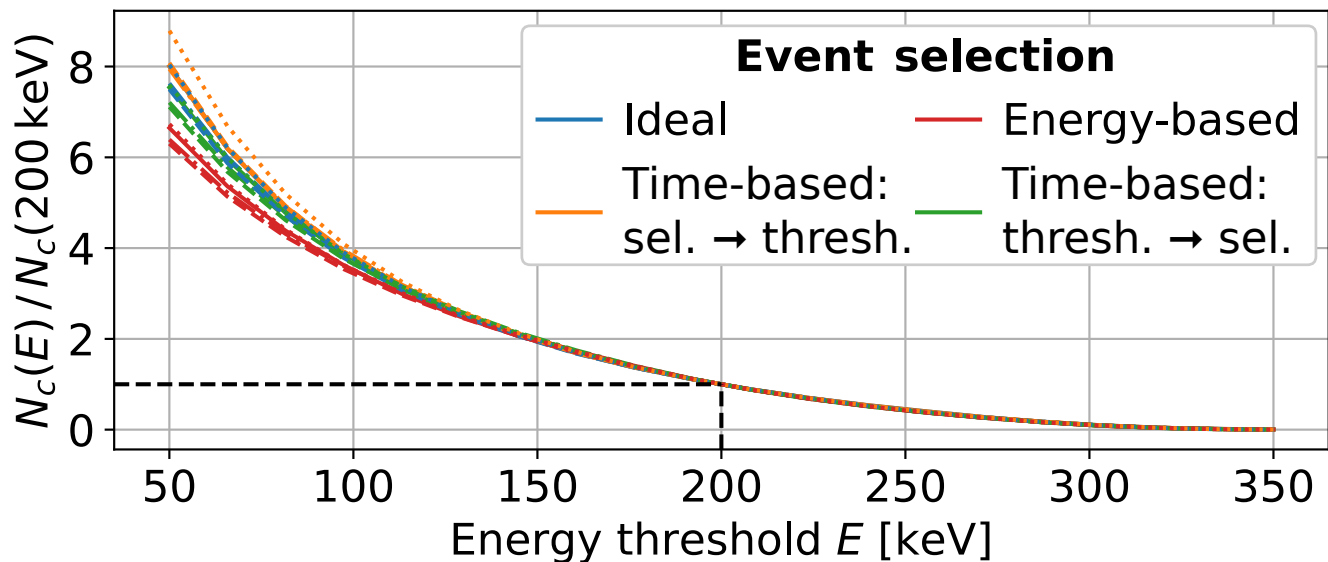
TB-BI
~ 9%
of the data



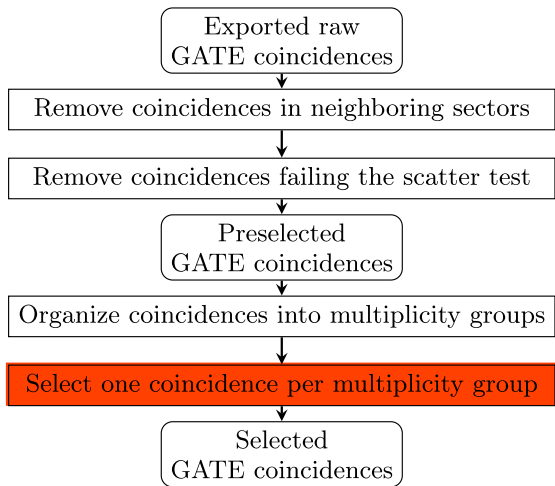
Performance analysis: w/ phantom

N_c : Number of coincidences ~ Sensitivity

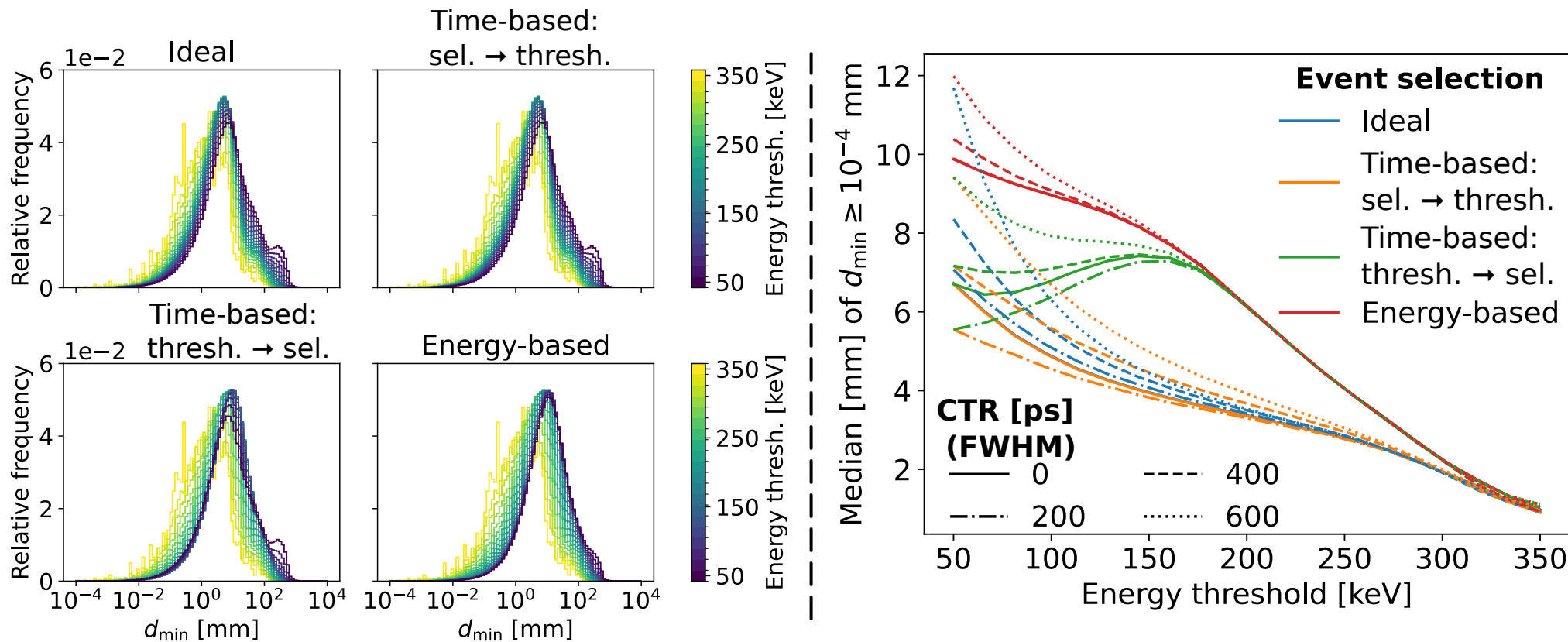
CTR [ps] (FWHM) — 0 - - - 200 - - - 400 600



BI-BI
~ 0.5%
of the data



Error assessment: w/o phantom



Error assessment: w/ phantom

