



Decay rate of o-Ps atoms

in the framework of J-PET detector

Sushil K. Sharma on behalf of the J-PET collaboration

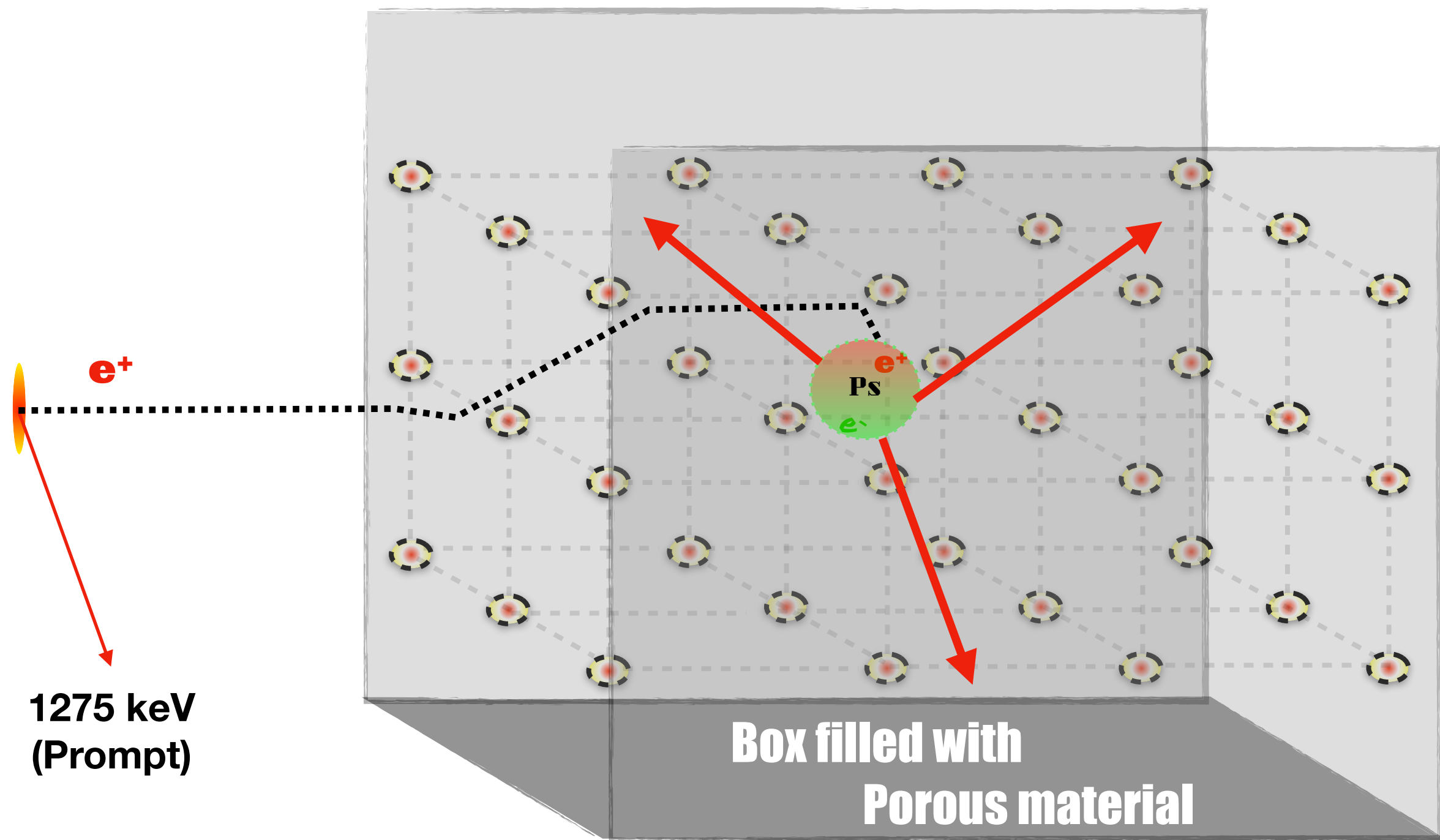
Presented in
workshop on “Investigating the Universe with exotic atomic and nuclear matter”
INFN Frascati, Italy



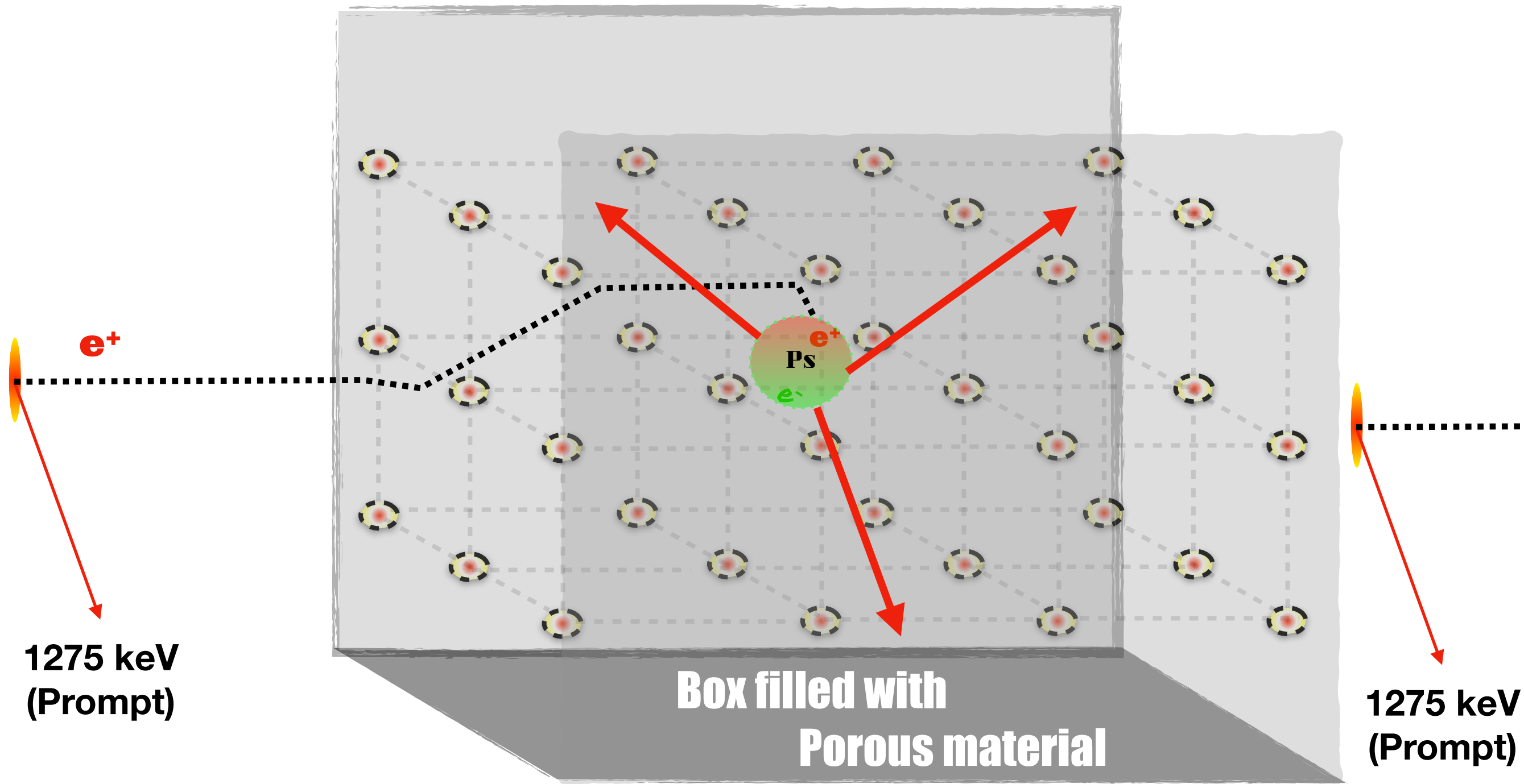


- Decay of o-Ps atom in XAD4 - **Event categorization**
- Lifetime of o-Ps atoms:
 - o-Ps -> 3 gamma
 - o-Ps -> 2 gamma (*pickoff, spin-flip*)
- Experimental set-up and Geant4 simulations
- Data analysis
- Results
- Summary

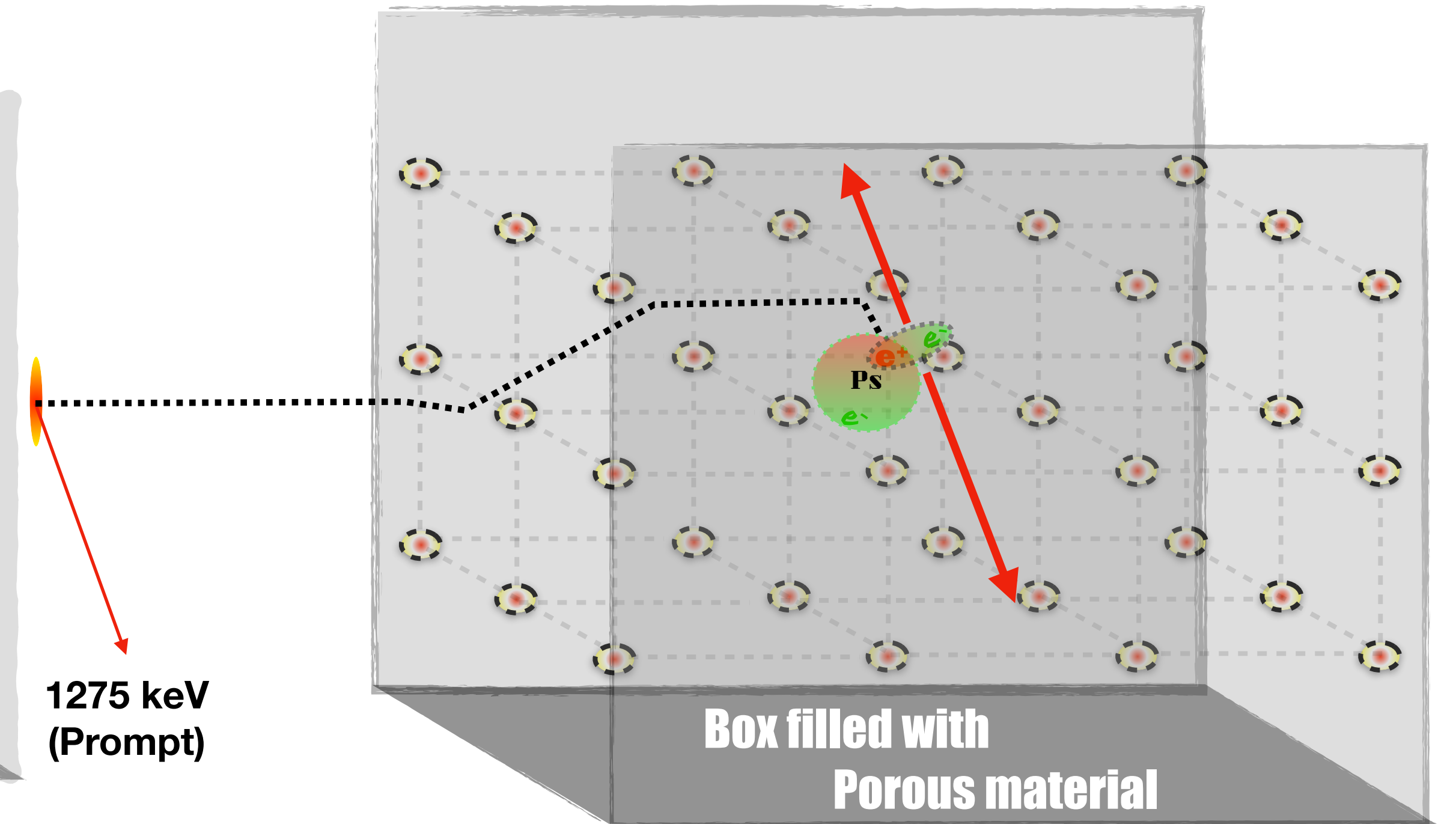
o-Ps atom's annihilation into 3γ



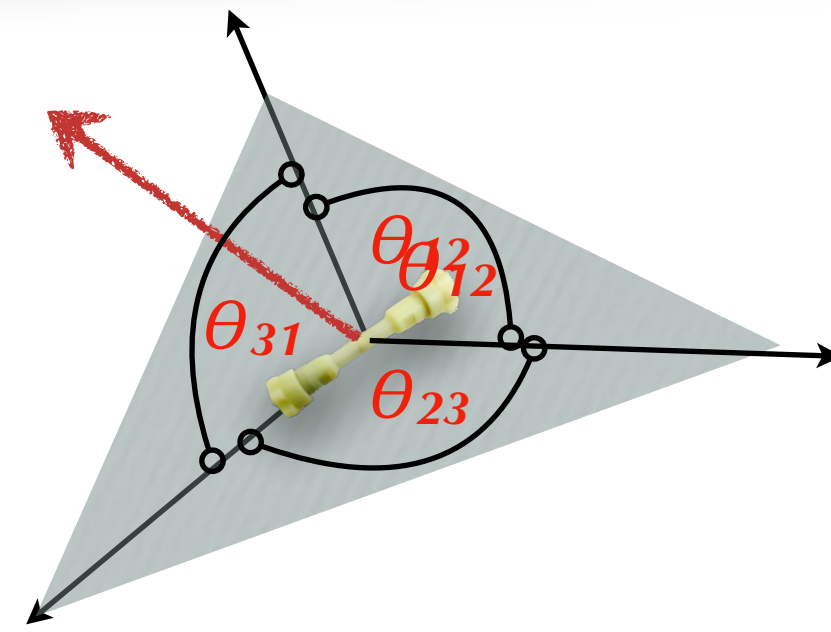
o-Ps atom's annihilation into 3γ



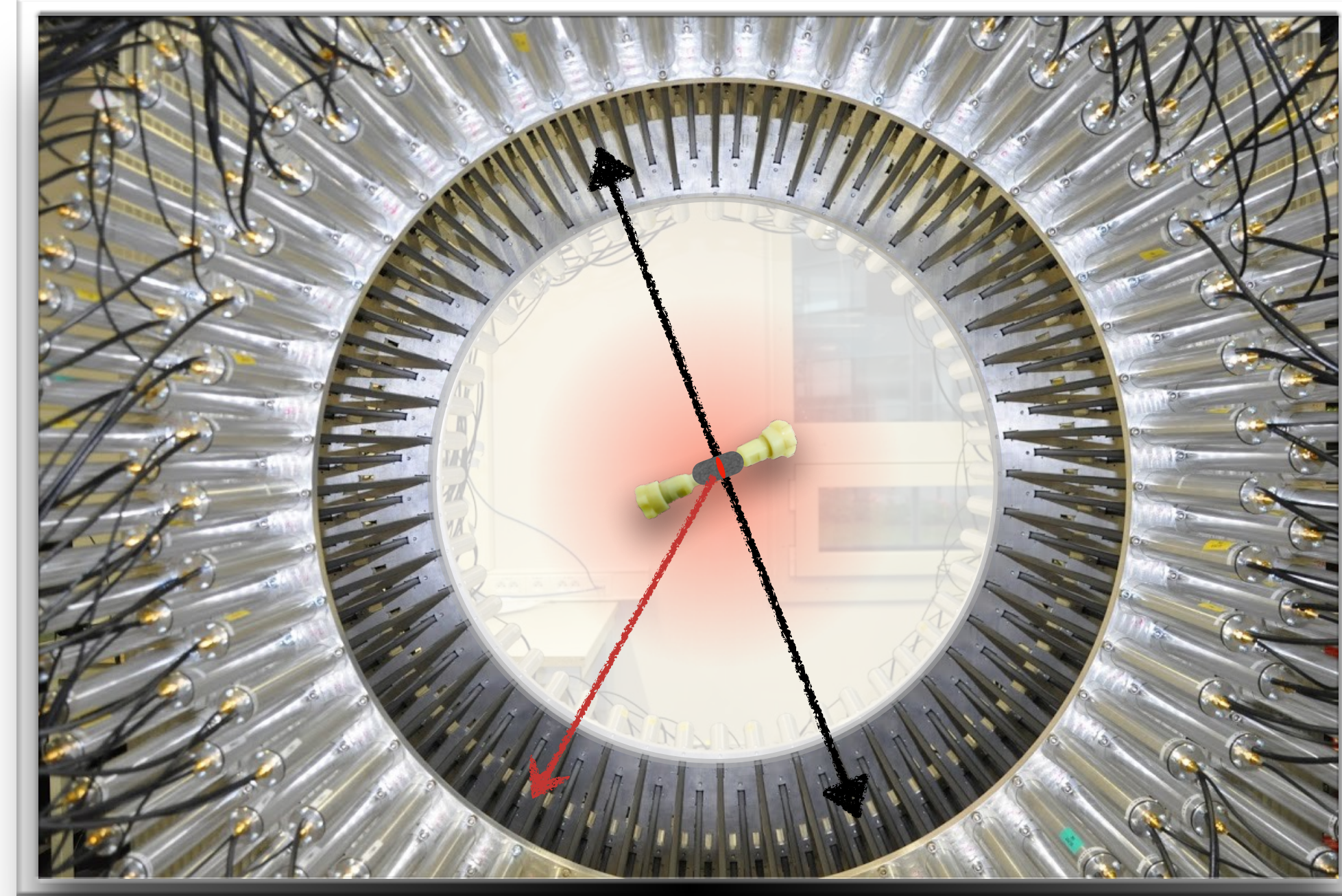
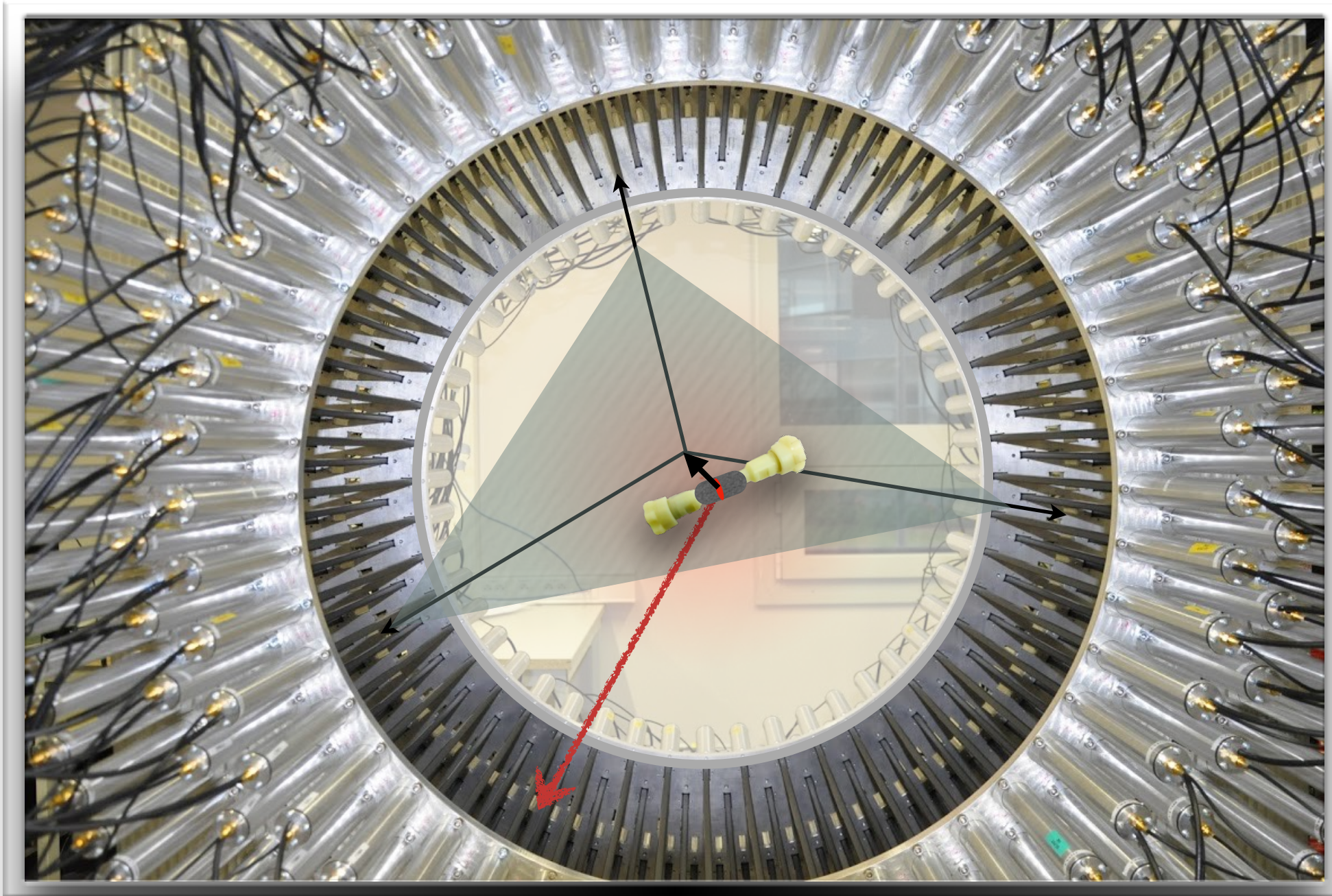
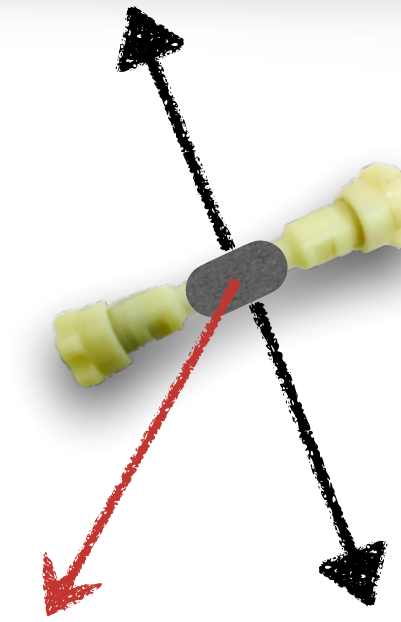
o-Ps atom's annihilation into 2γ (pick-off effect)

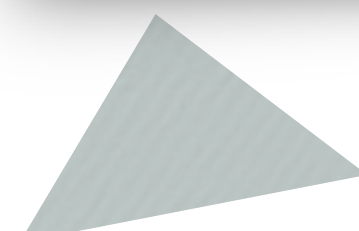



Events with 4 hit
1 prompt +
3 annihilation (o-Ps)

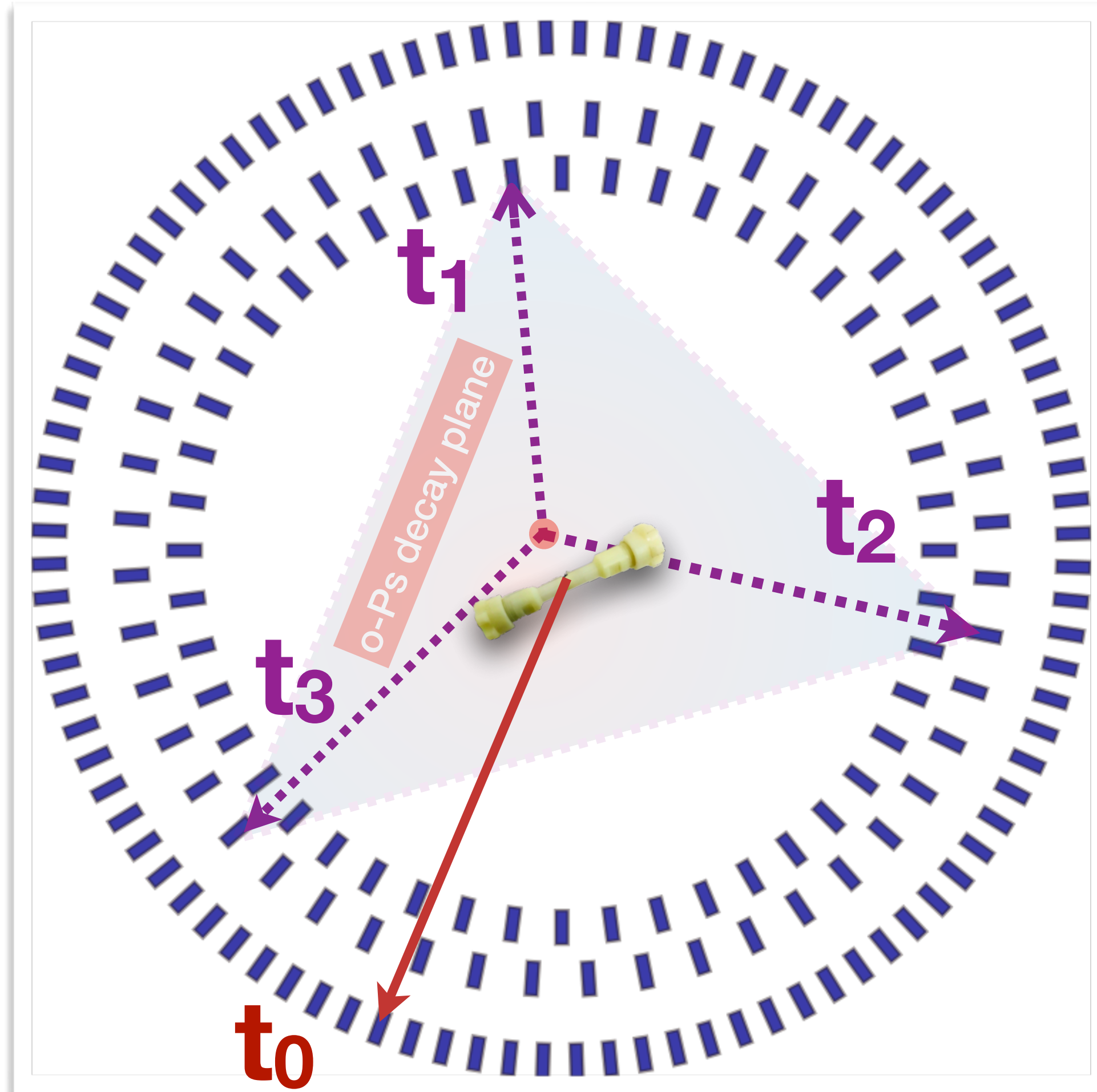


Events with 3 hit
1 prompt +
2 annihilation (B2B)



 Plane of annihilation photons from o-Ps
 \perp er distance of plane from the center of detector

J-PET prototype : 3 Layers (48, 48, 96)



t_0 = Emission time of Prompt photon

t_1 = Emission time of Ann. Photon 1

t_2 = Emission time of Ann. Photon 2

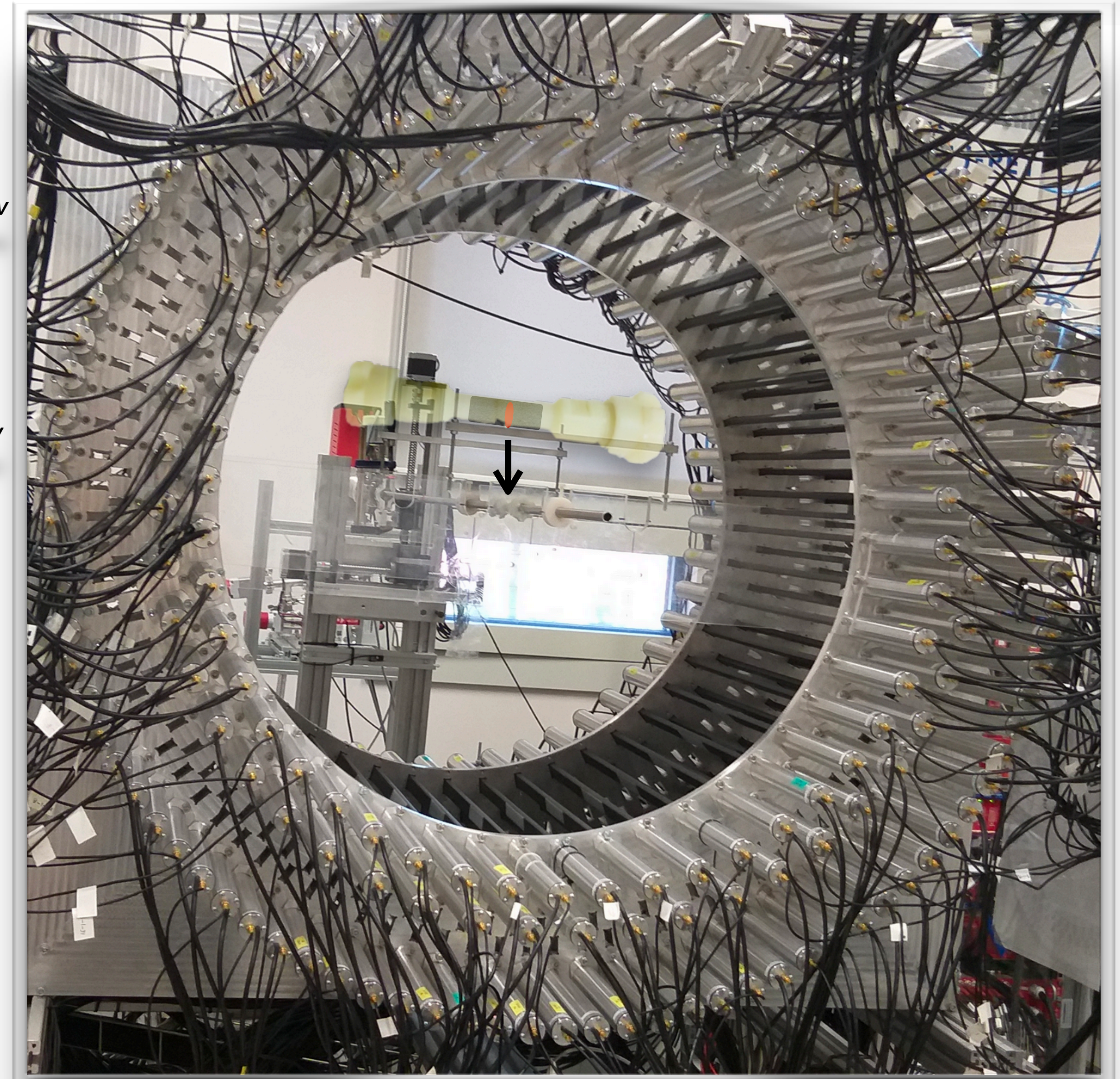
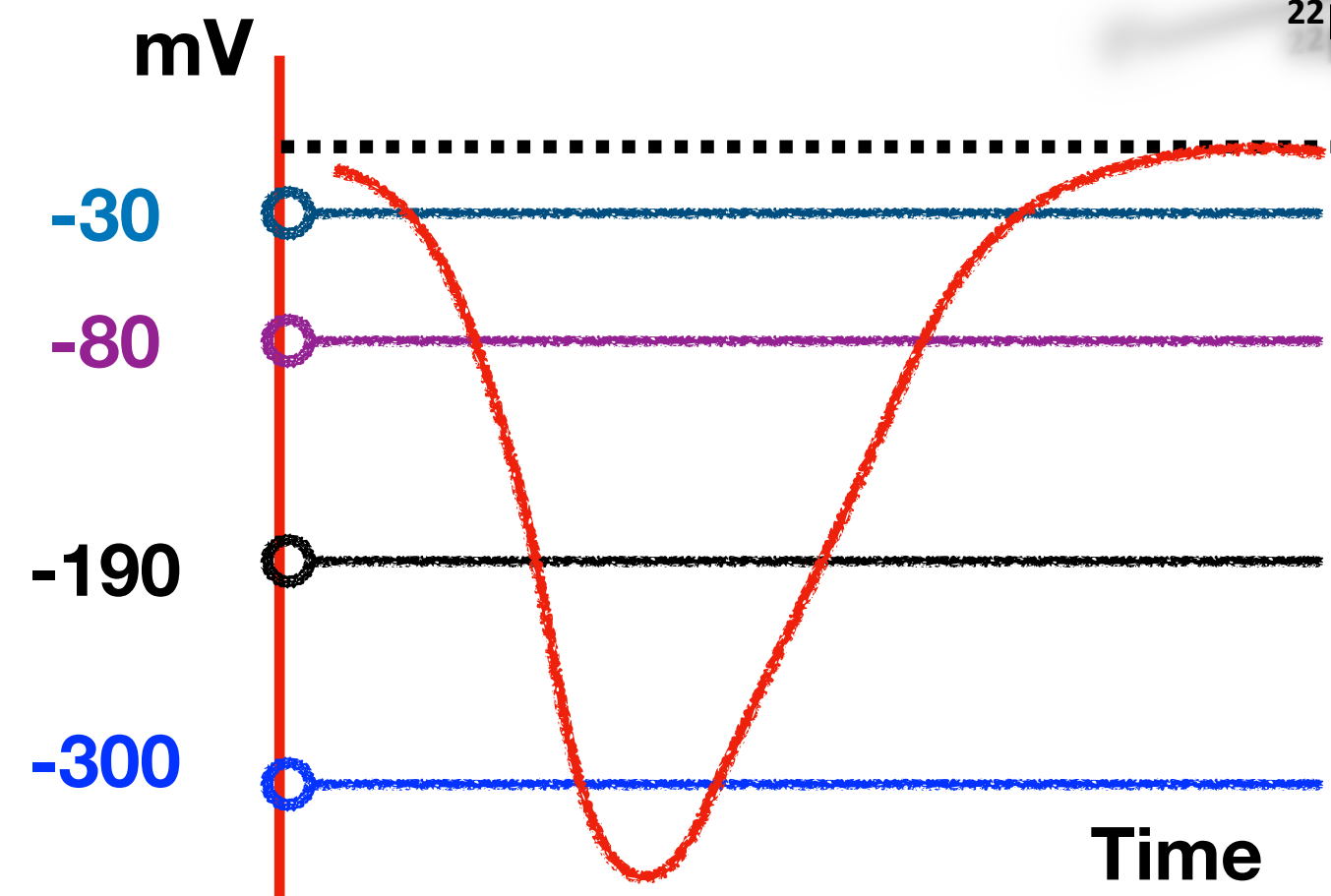
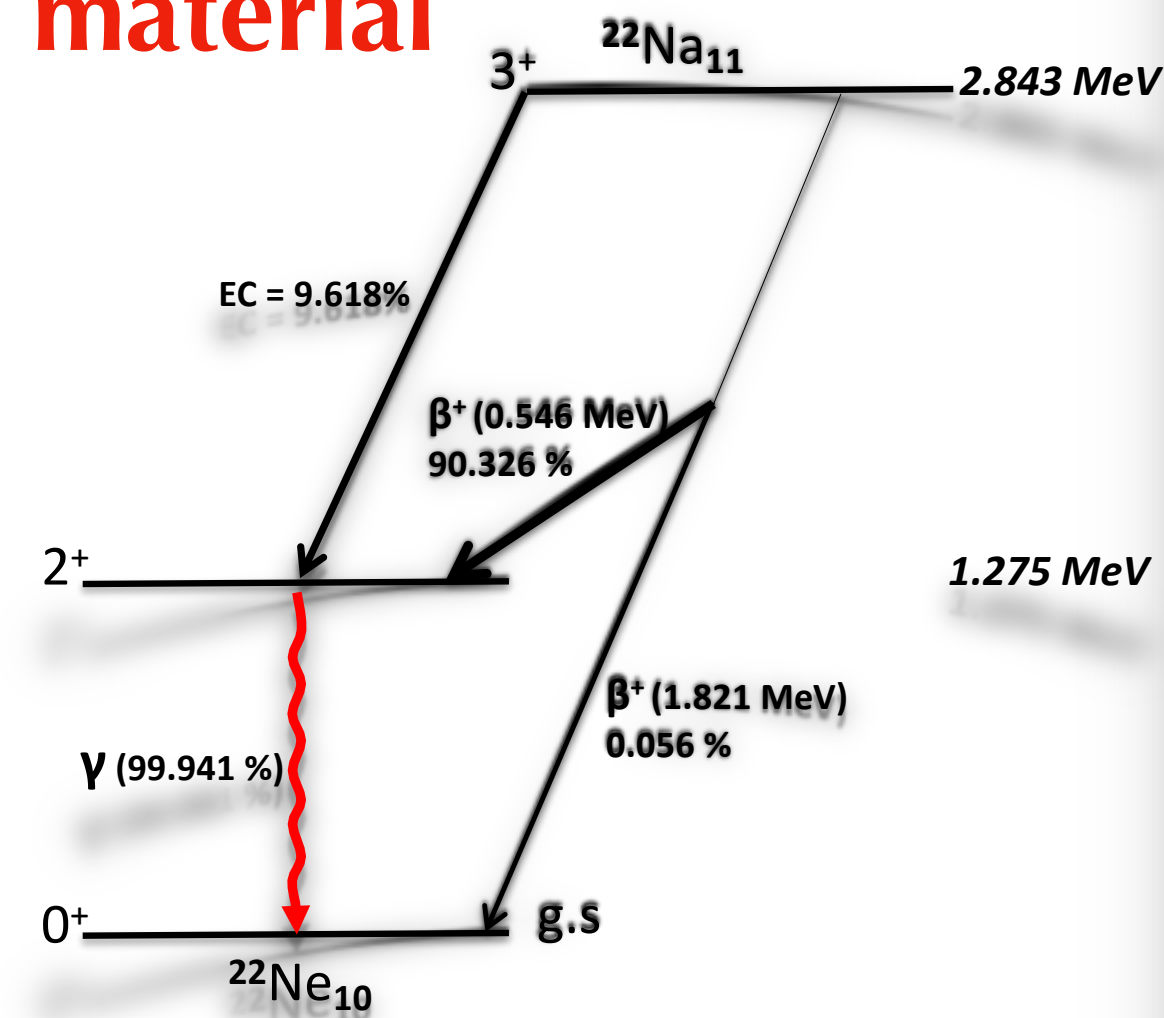
t_3 = Emission time of Ann. Photon 3

$$\text{Lifetime} = (t_1 + t_2 + t_3) / 3 - t_0$$

K. Dulski et. al., First exclusive measurement of ortho-positronium with the J-PET tomograph, *submitted to EPJ C for publication*.

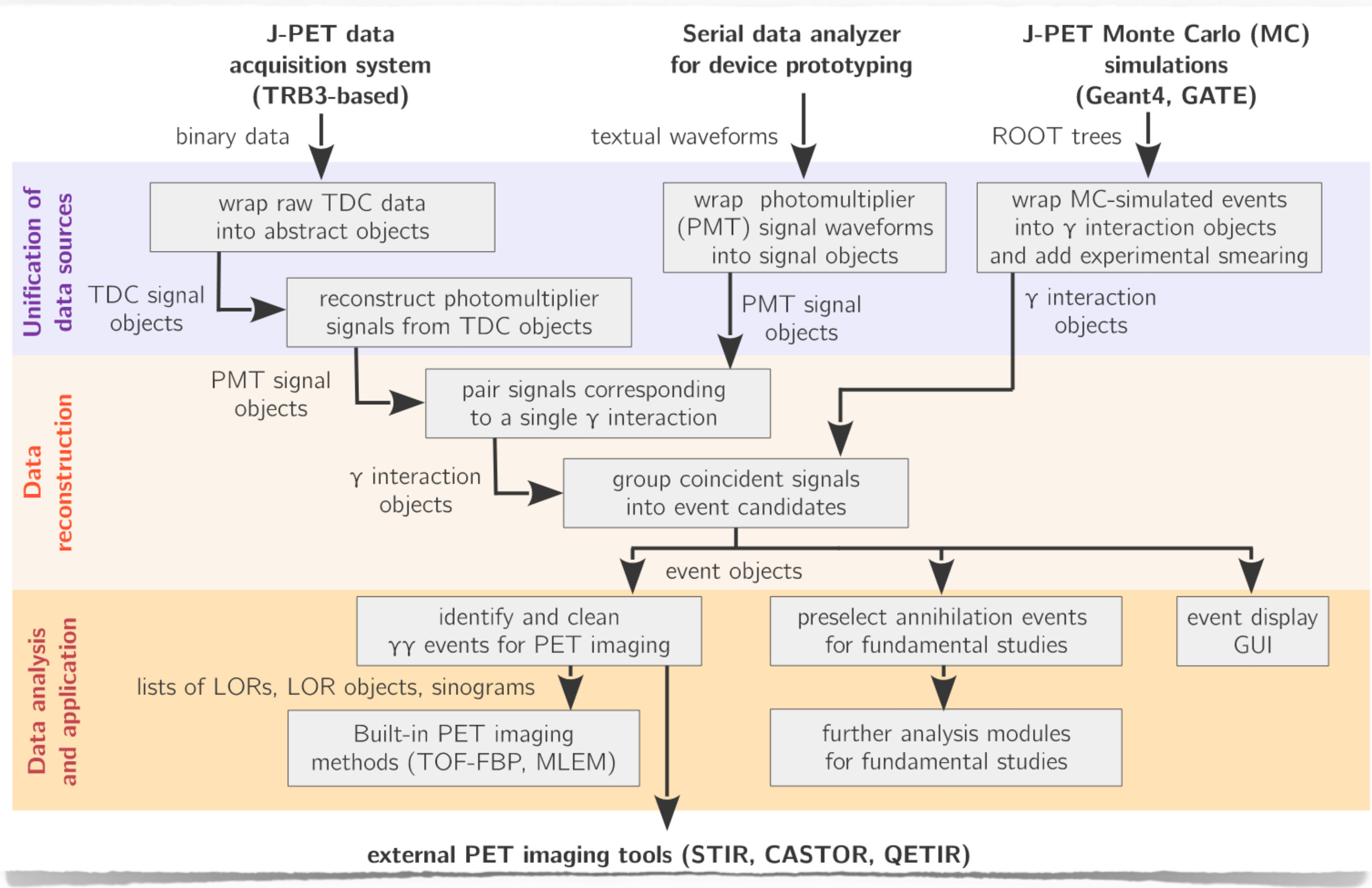
^{22}Na source is placed inside the plastic chamber sandwiched between **XAD4 material**

Decay scheme :



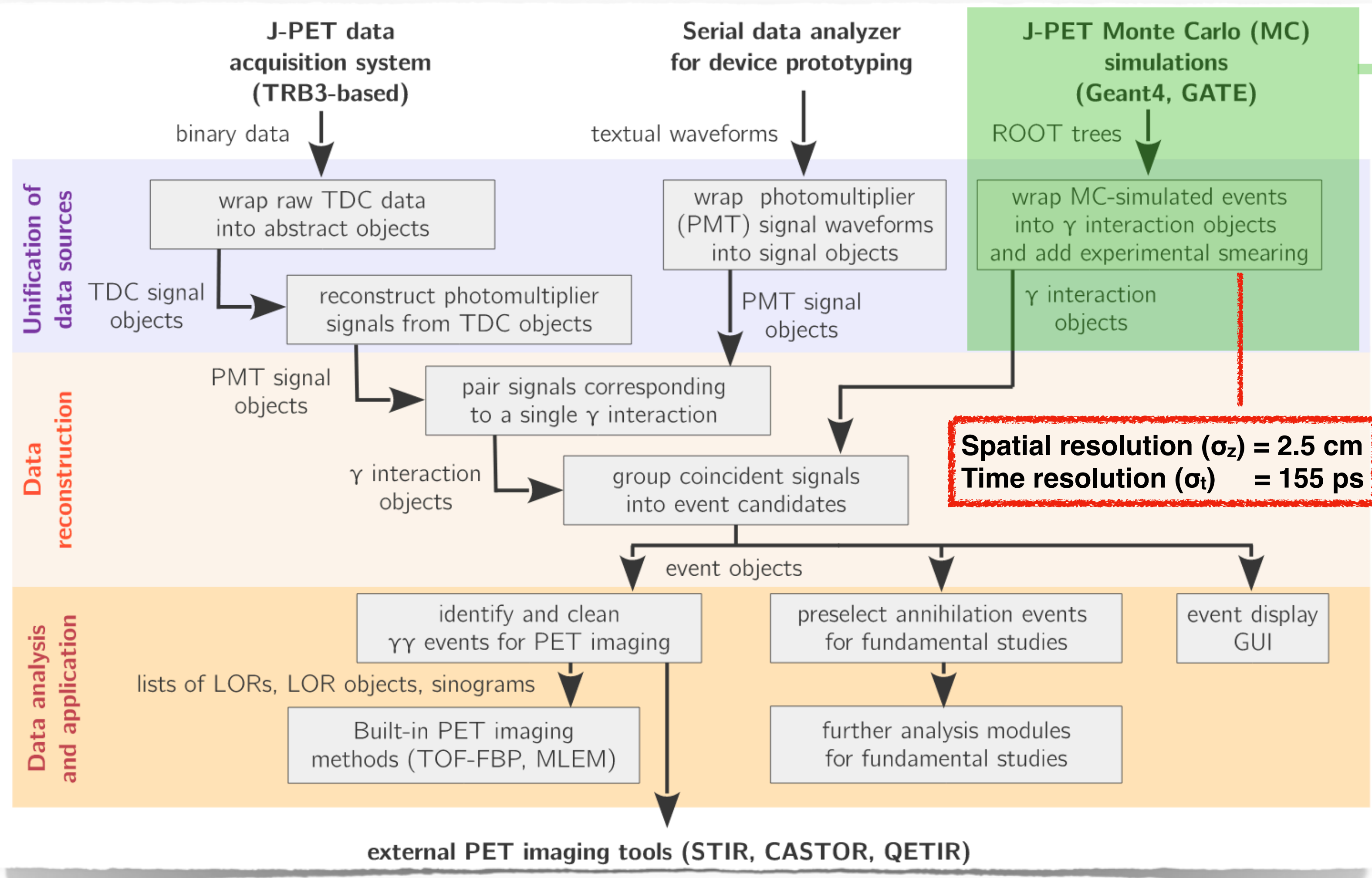


J-PET software



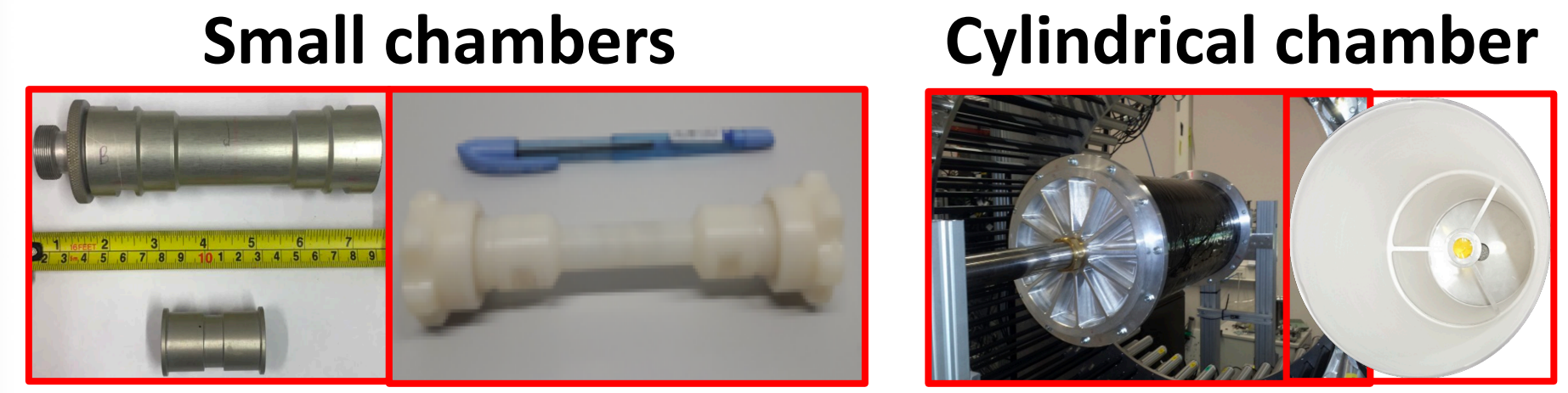
J-PET Framework architect for analyzing and comparing the Data with Simulations

W. Krzemien et. al., *SoftwareX* 11 (2020) 100487



Salient features of JPET MC package

- **Source** : Photons beams, Ps decays,...
- **Multiplicity tag** : tracking is easy for end users to identify the primary and scattered photons
- **Simulating various annihilation chambers:**



Spherical chamber

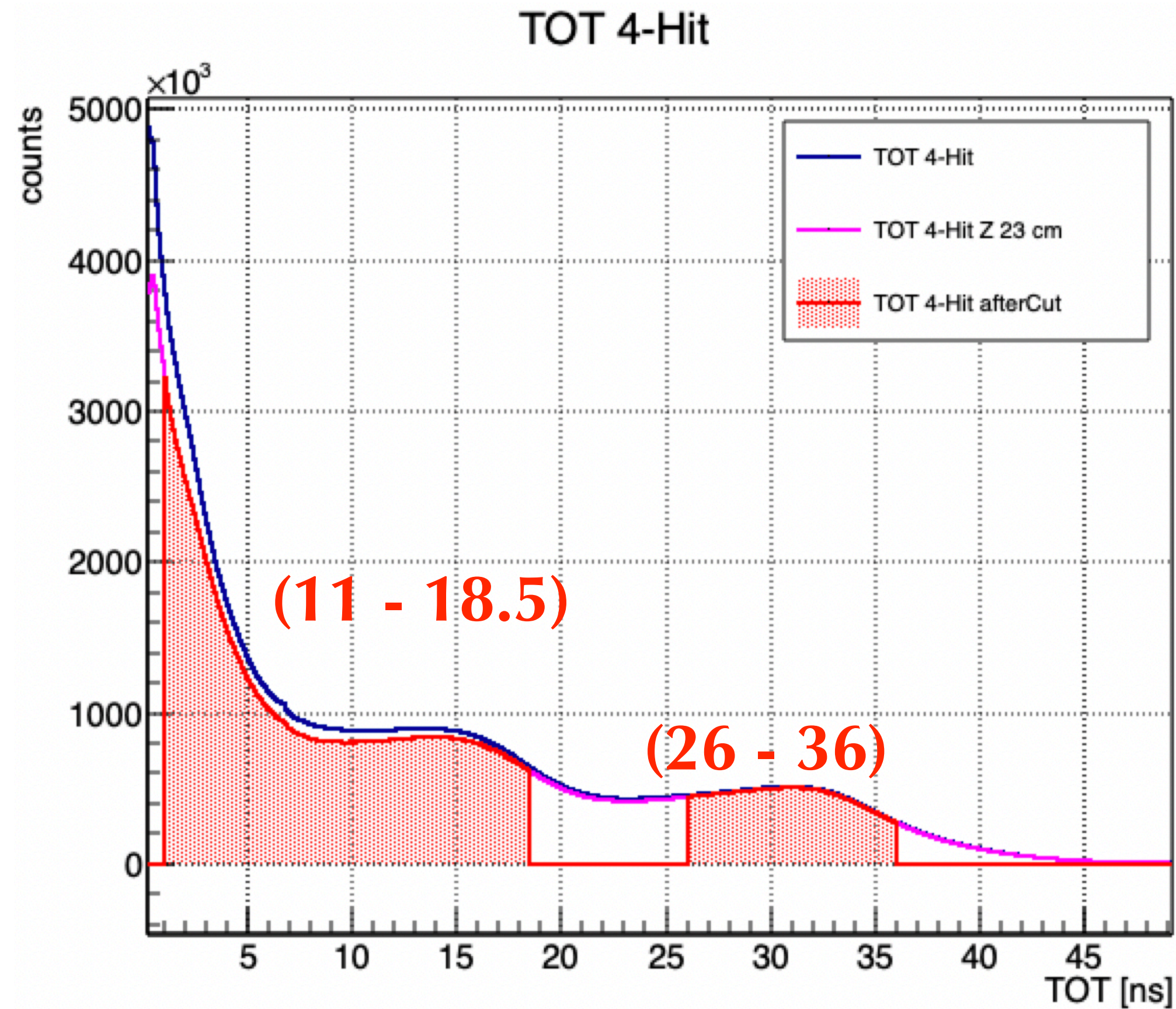


J-PET Framework architect for analyzing and comparing the Data with Simulations

W. Krzemien et. al., *SoftwareX* 11 (2020) 100487

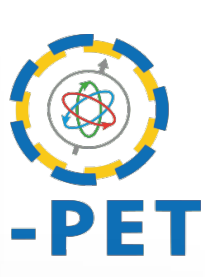


Experiment

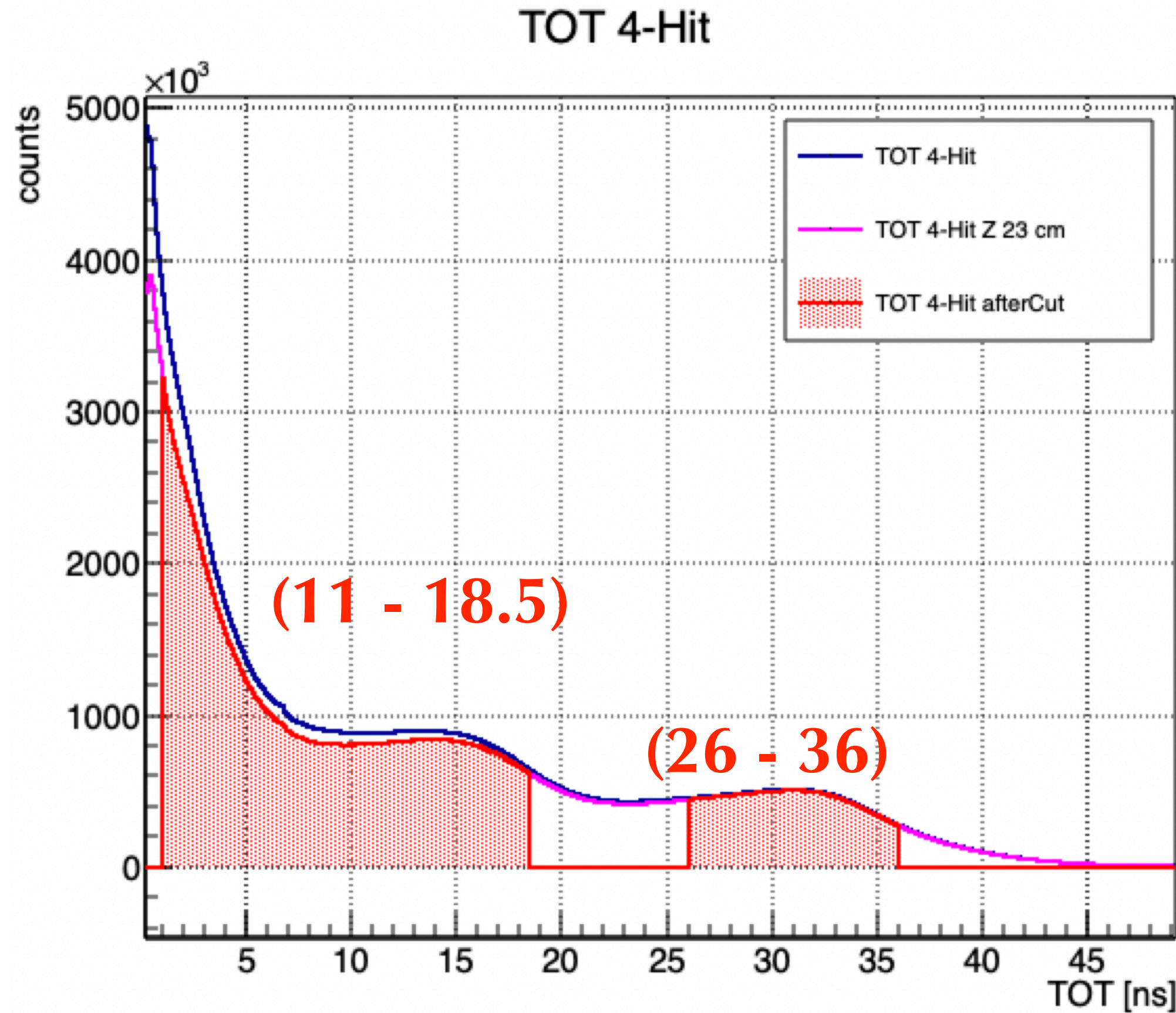




Selecting Annihilation and Prompt candidates



Experiment

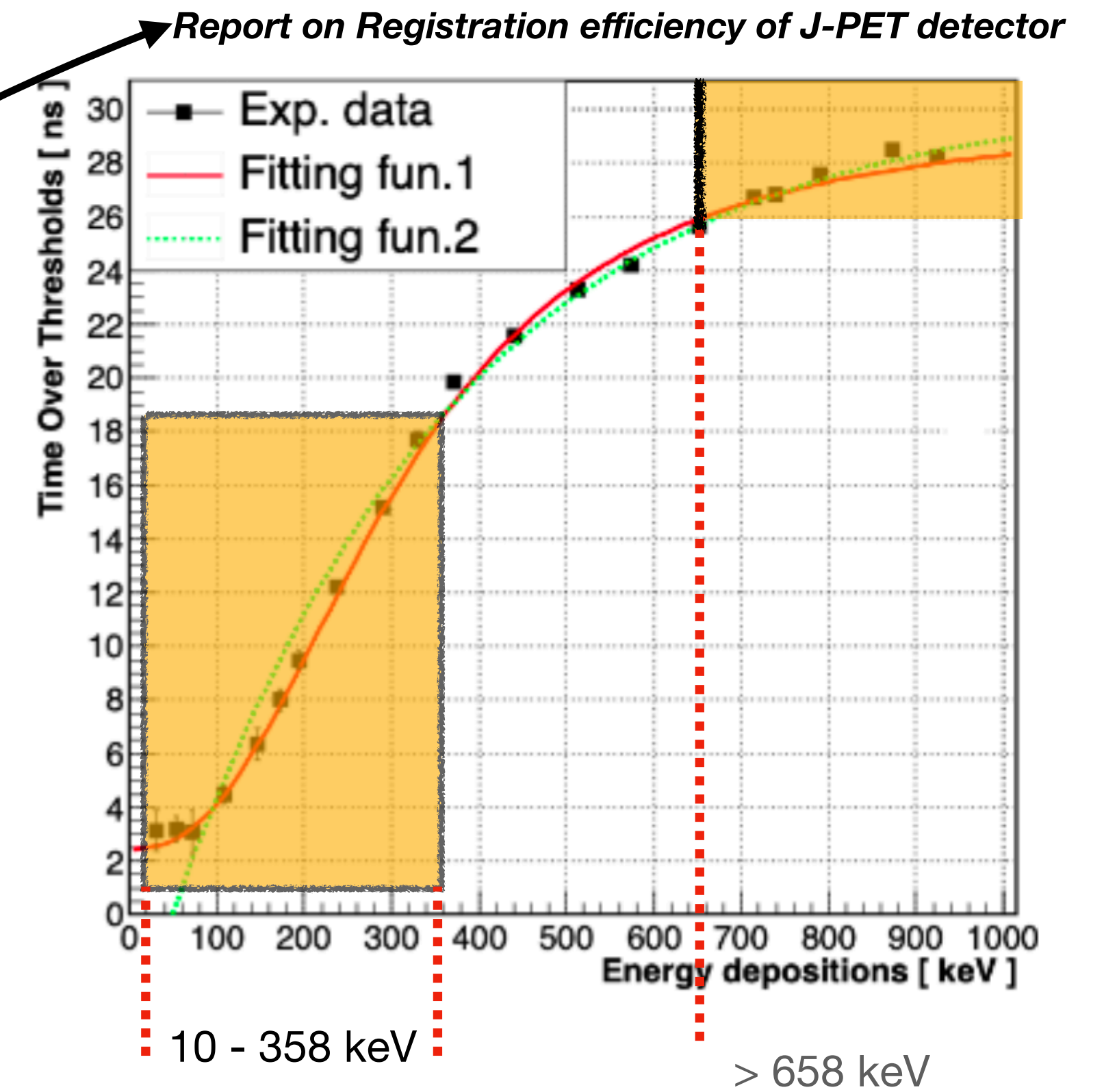


Simulation

Using Edep (TOT) and multiplicity tag of hit

(Hit multiplicity flags : Prompt: 1, o-Ps photons : 3)

$$Edep = A2 \cdot \left(\frac{A1 - TOT}{TOT - A0} \right)^{1/A3}$$



S. Sharma et. al., *European Journal of Nuclear Medicine and Medical Imaging* 7, 44 (2020)
 W. Krzemien et. al., *SoftwareX* 11 (2020) 100487

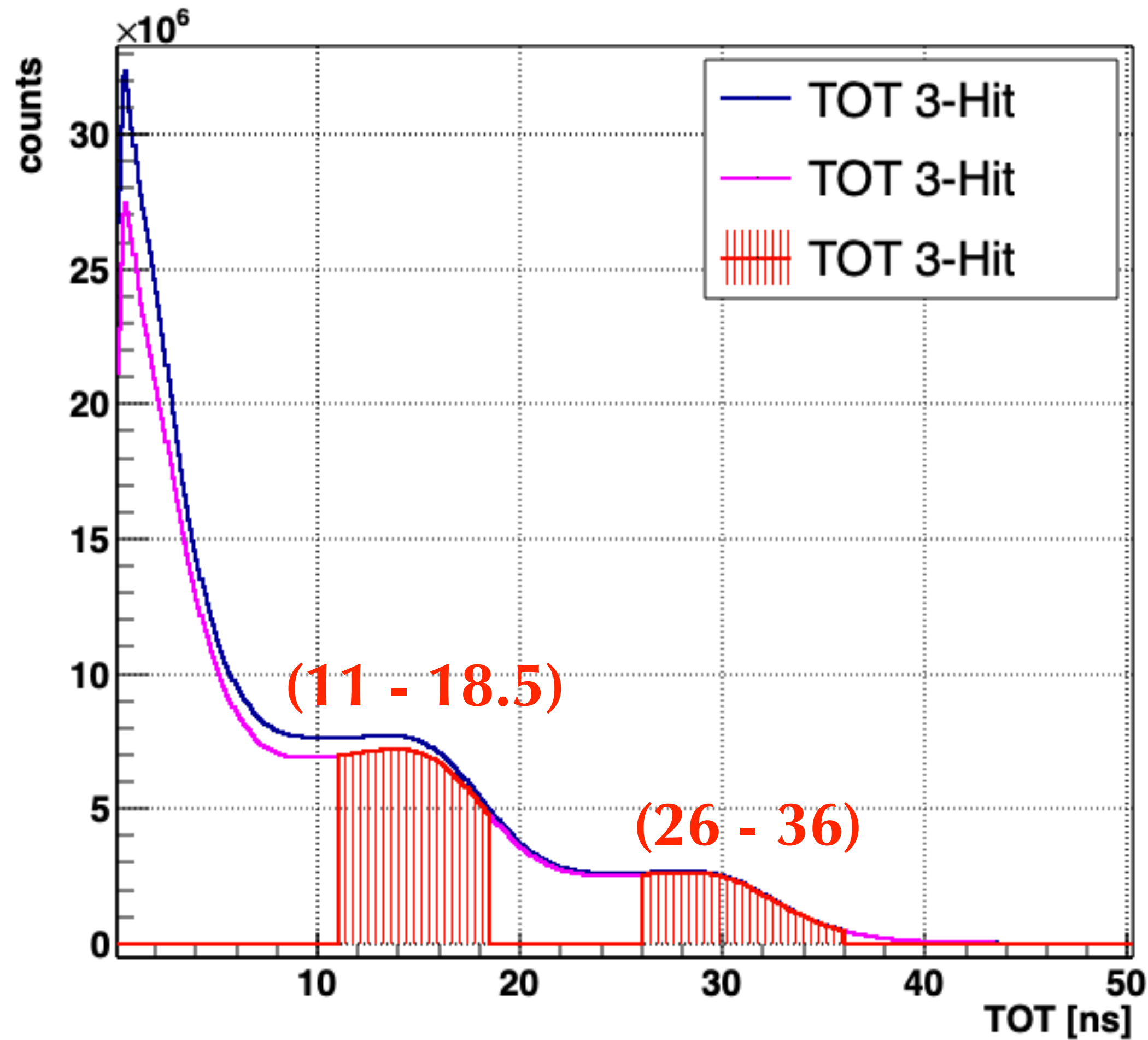


Analysis cut for lifetime spectra of o-Ps \rightarrow 3 photons

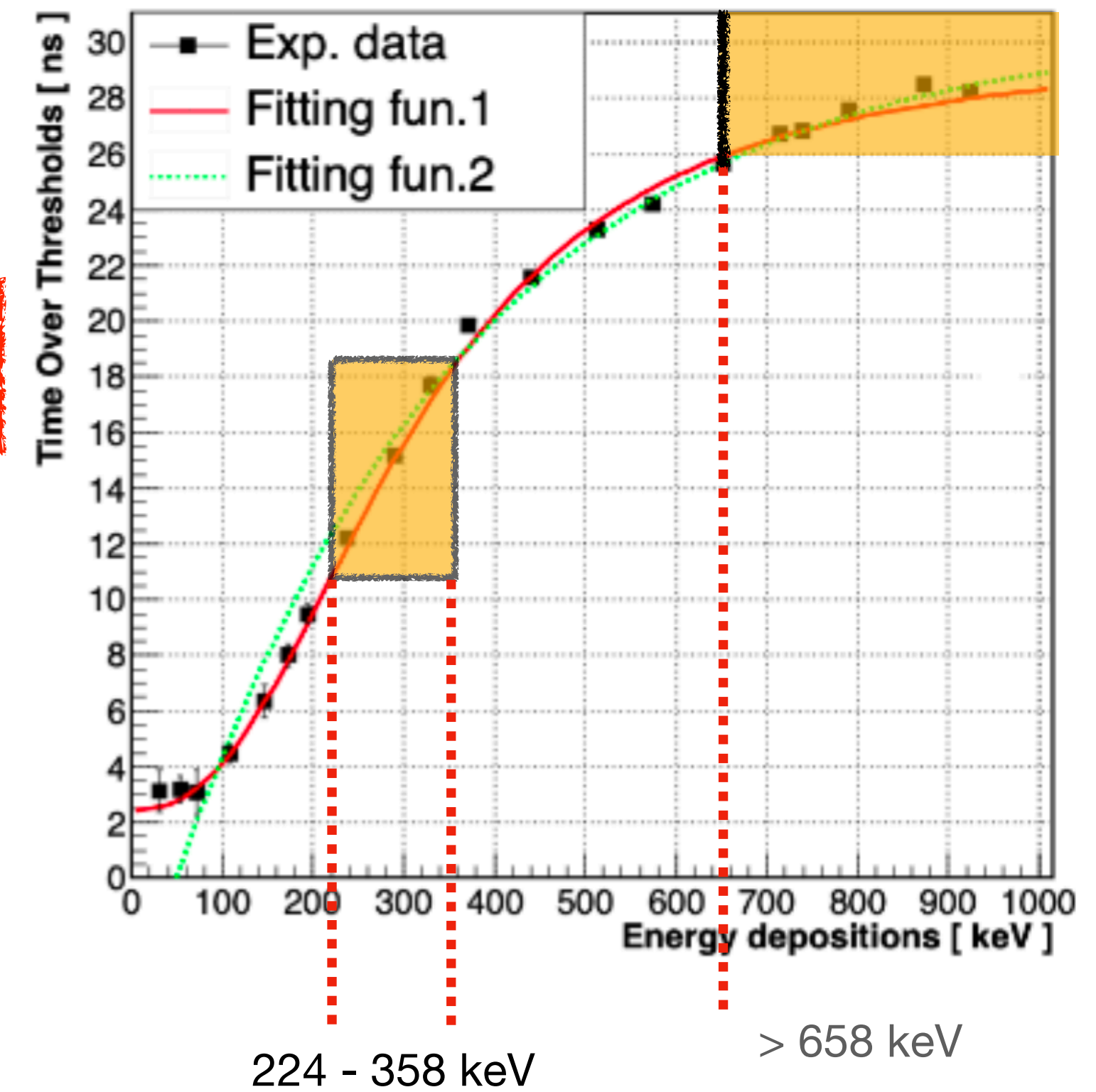


1. Distance of decay plane (O-Ps) from the center **3 cm**
2. time difference (Emission time) **1.5 nsec**
3. Cuts on angular correlation of the registered photons **$> 190^\circ$**
sum of two small. Angles (o-Ps candidates)

Selecting Annihilation and Prompt candidates



$$E_{dep} = A2 \cdot \left(\frac{A1 - TOT}{TOT - A0} \right)^{1/A3}$$



Hit multiplicity flags : Prompt: 1 , B2B photons : 2



 Distance of annihilation Point (B2B) from the center (**3 cm**)

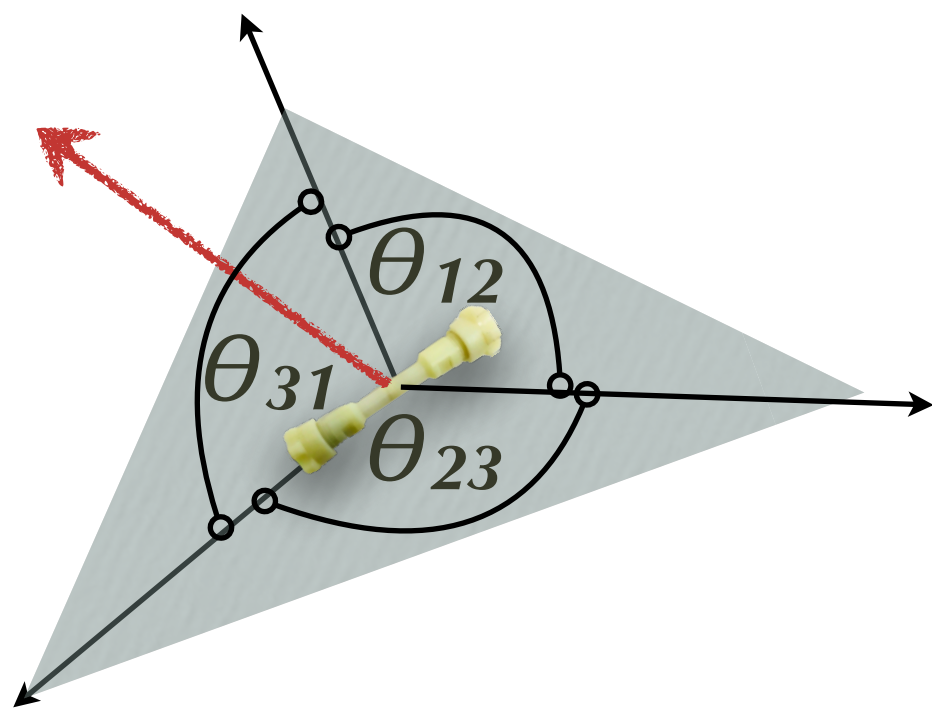
 *Time difference (Emi. time) between annihilation photons (1 ns)*

 Cuts on *angular correlation* of the registered photons:

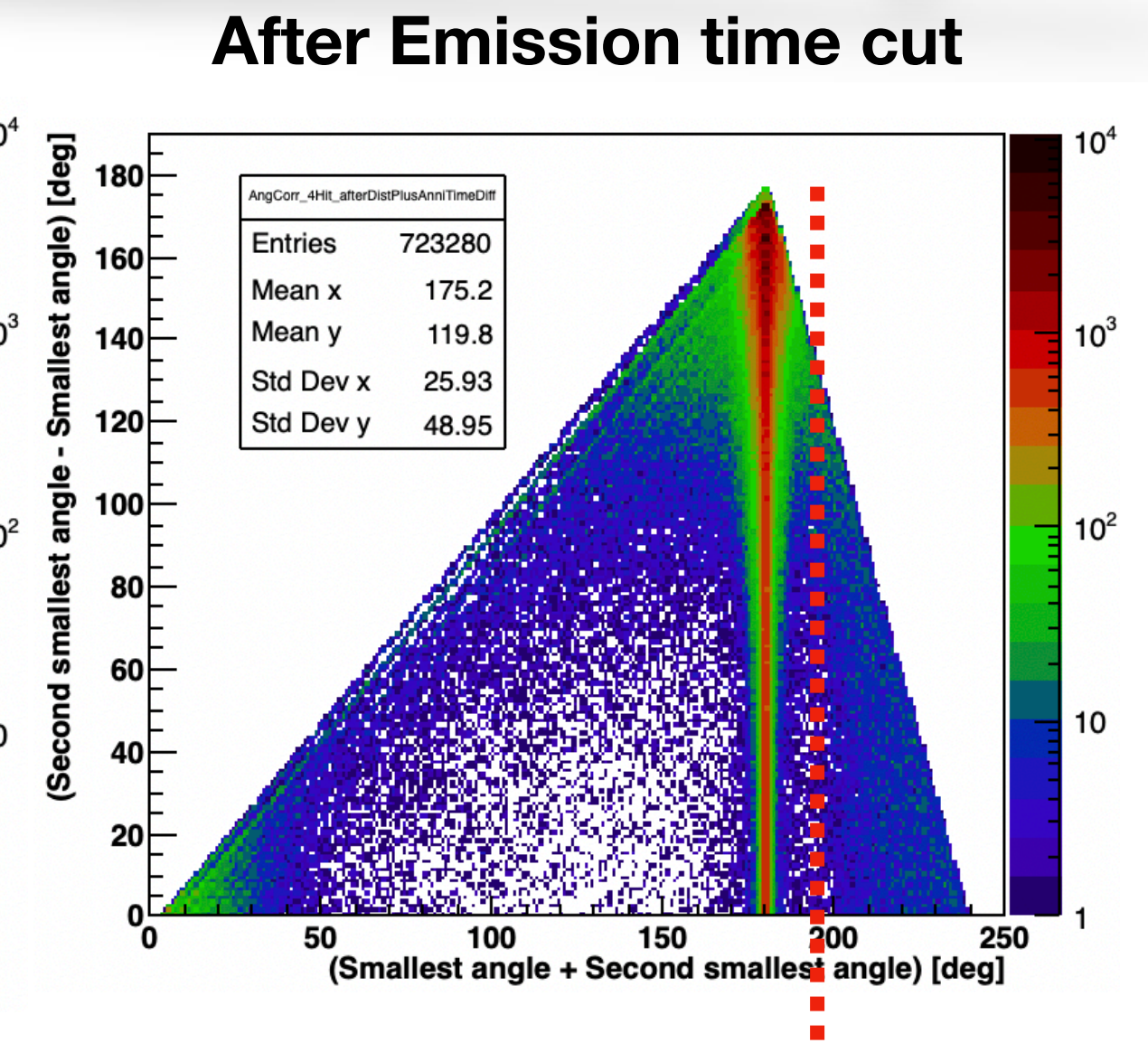
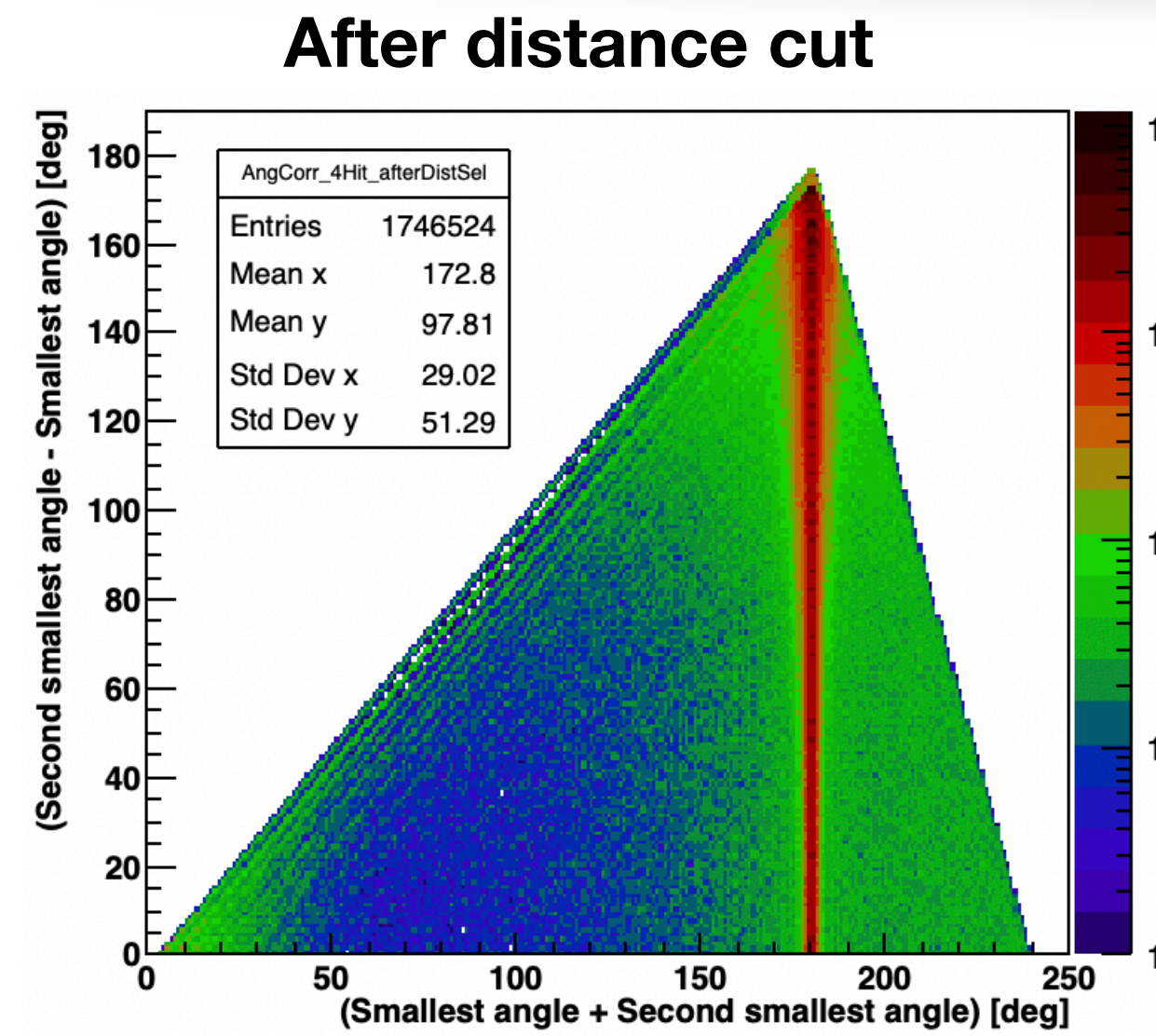
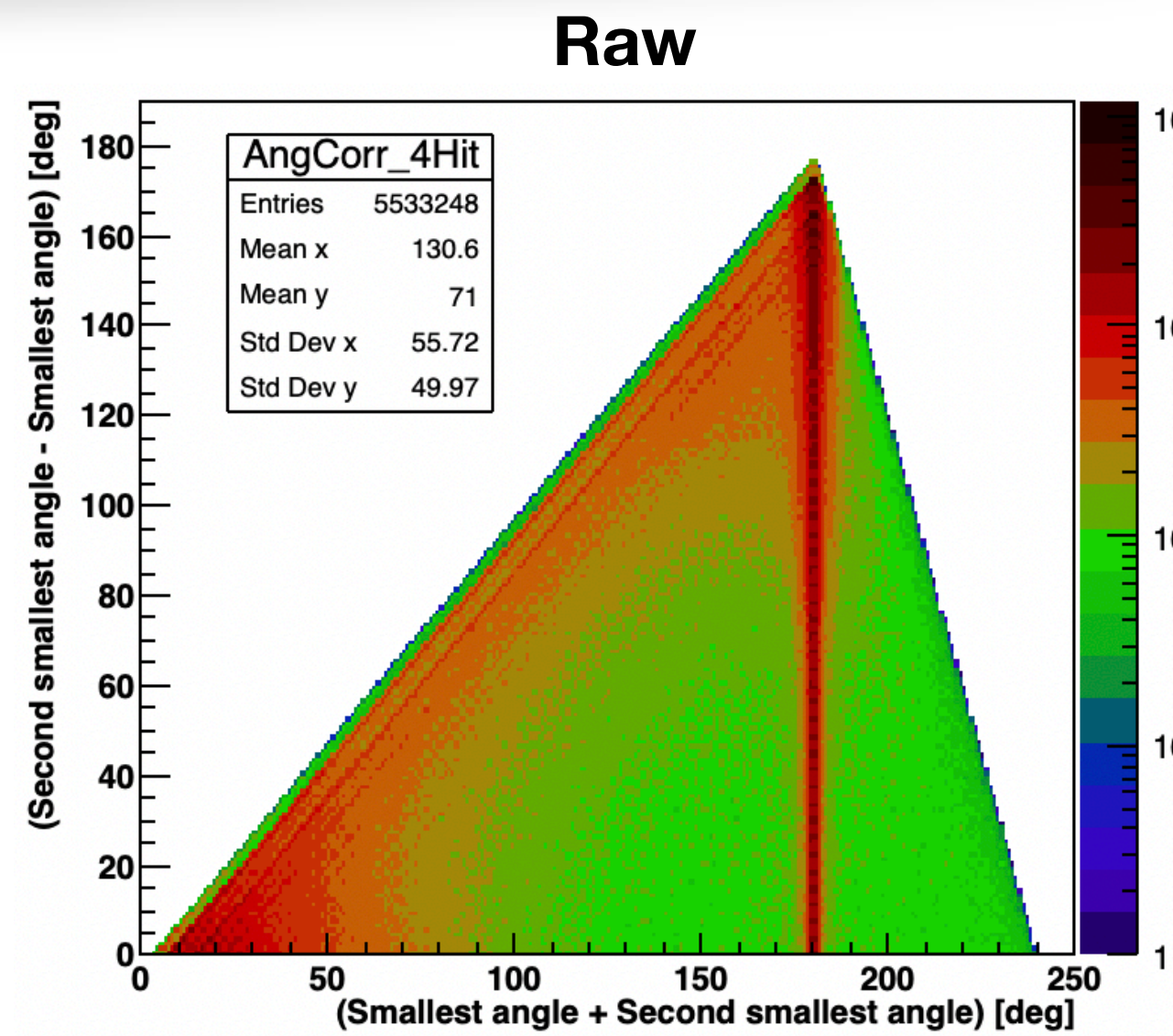
sum of two small. Angles : ($178^{\circ} - 182^{\circ}$) ;

Angular correction between hits

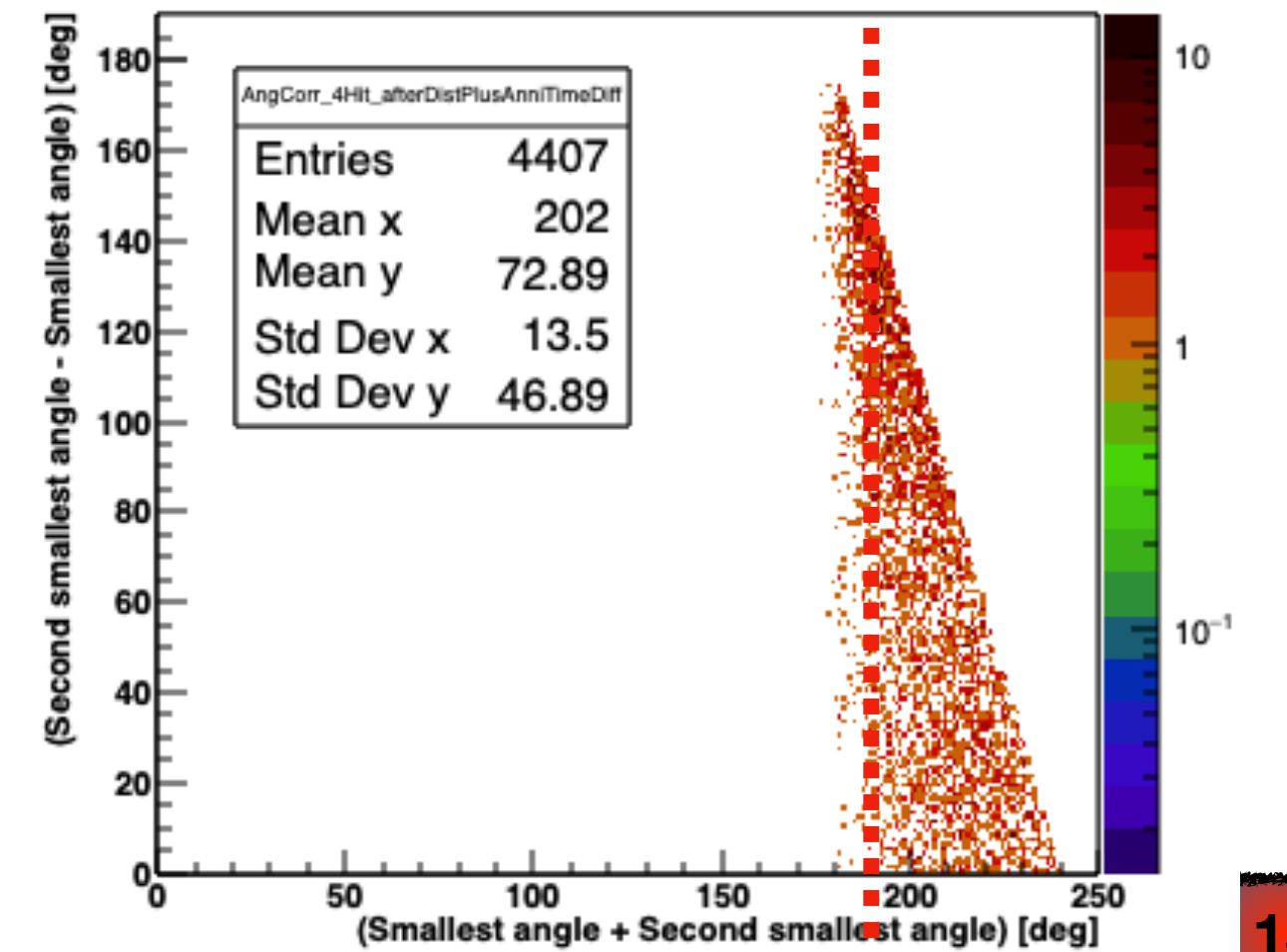
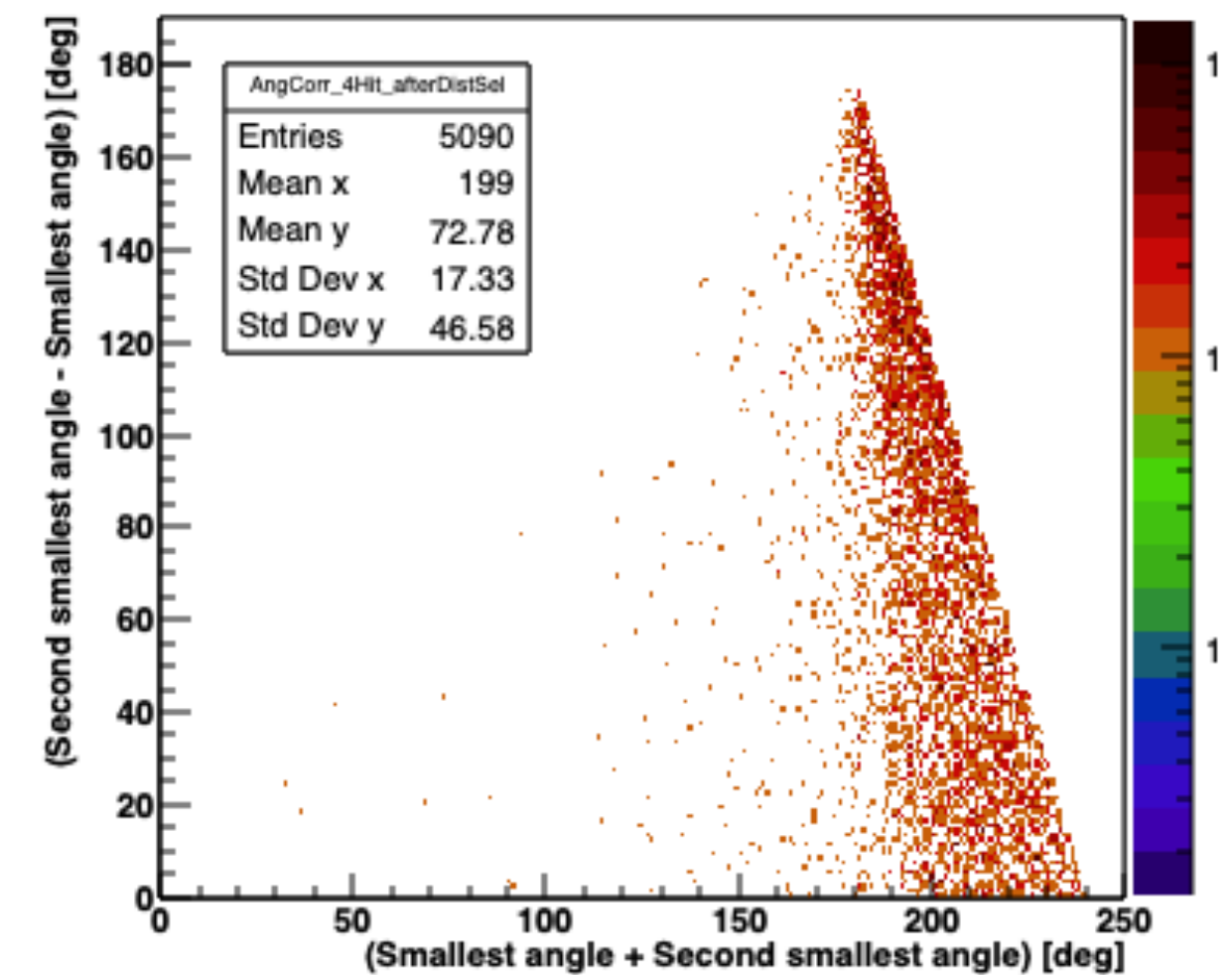
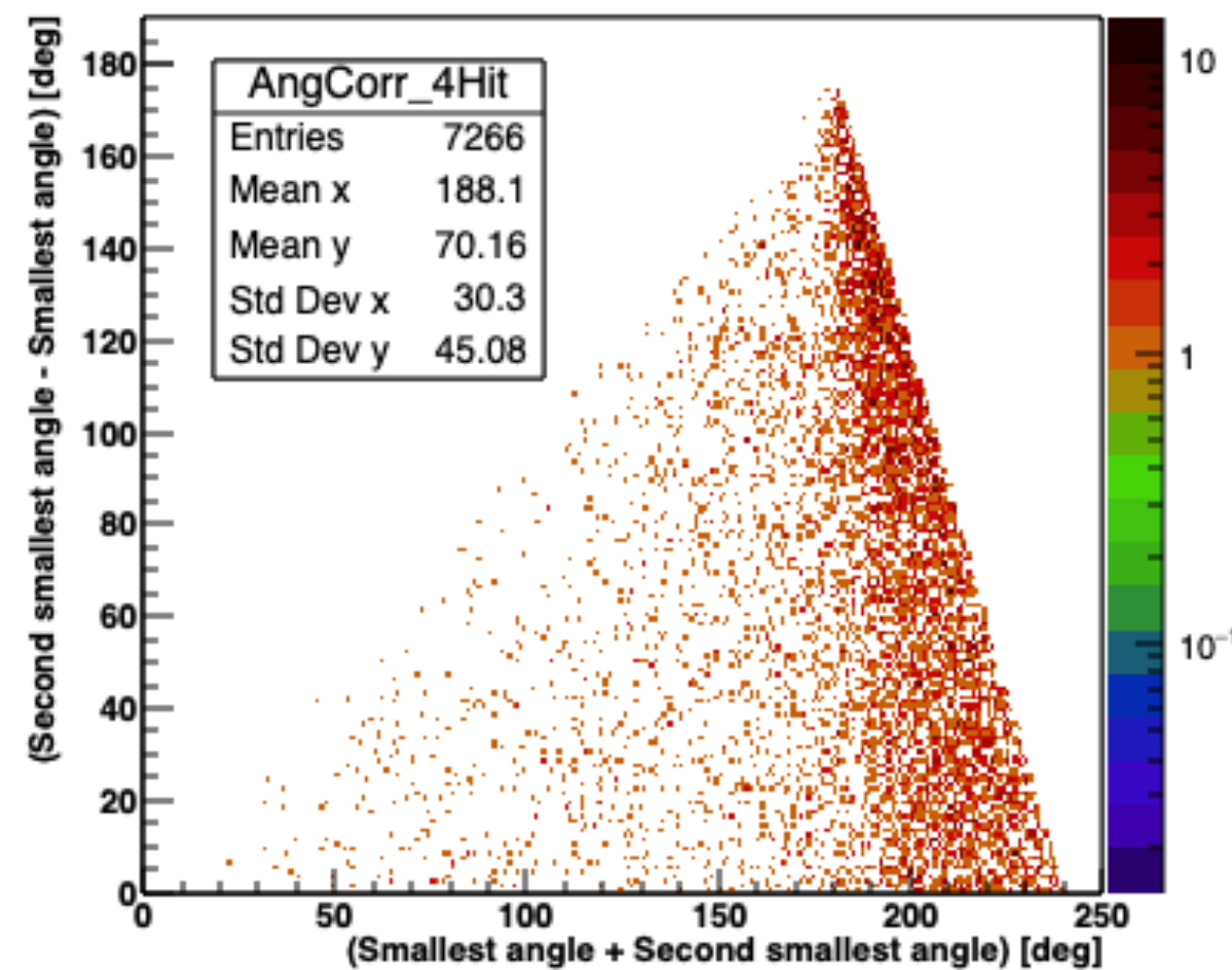
Angular (azimuth) correlation
b/w
3 anni. candidates



EXPERIMENT



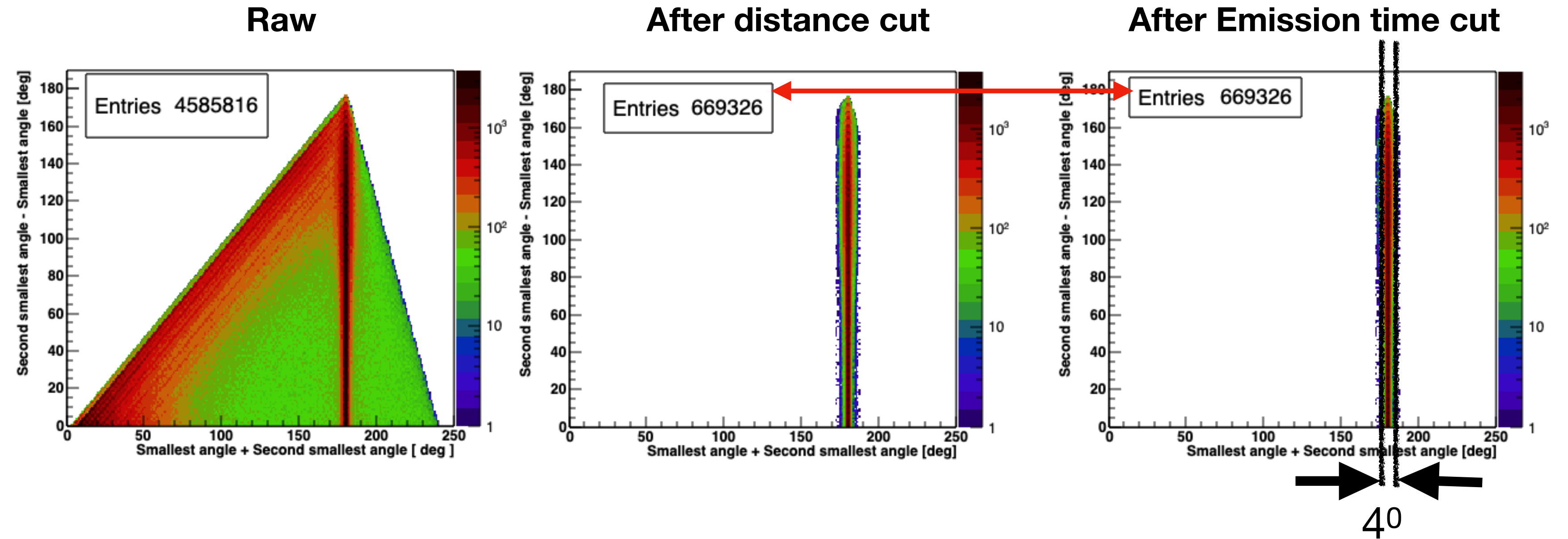
SIMULATIONS



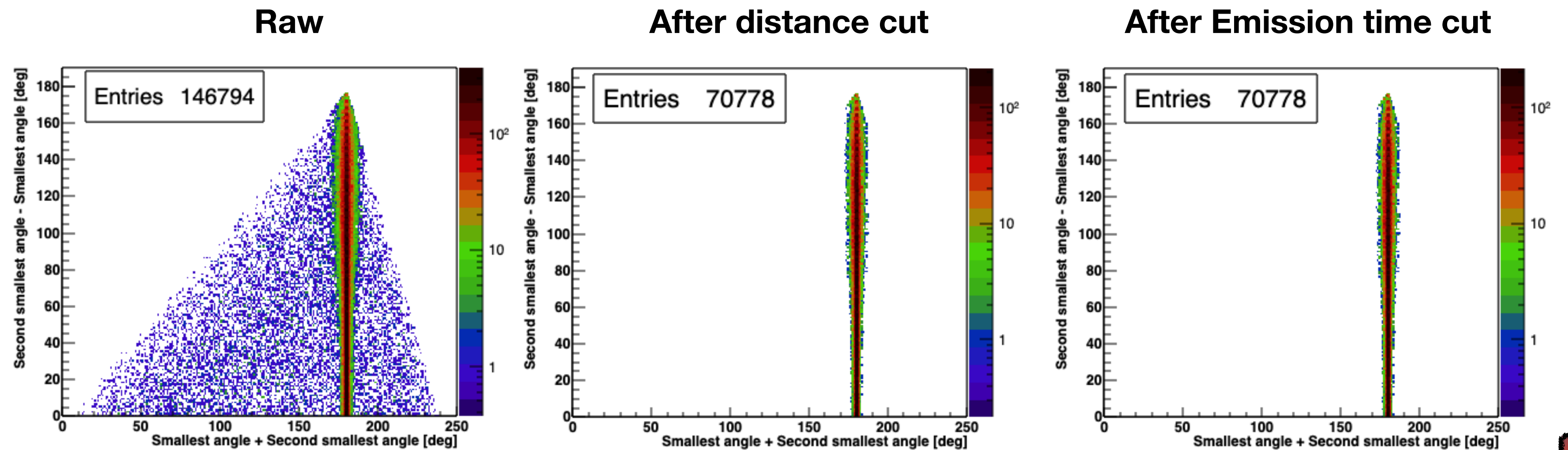
Angular (azimuth)
correlation
b/w
3 candidates

(1 prompt + 2 ann. Photons)

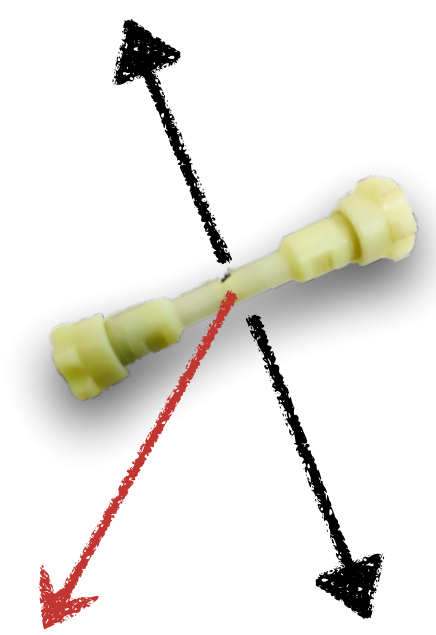
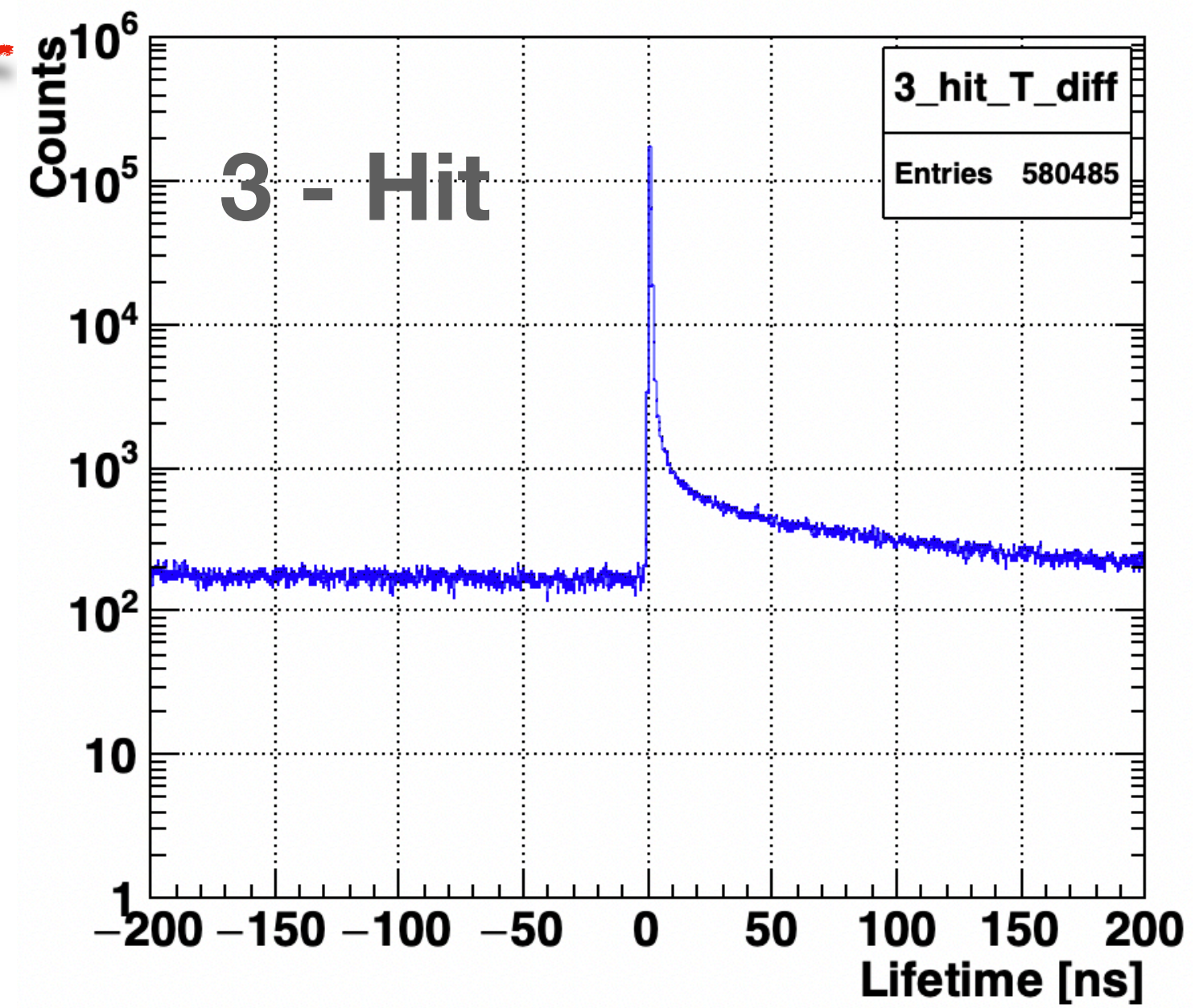
EXPERIMENT



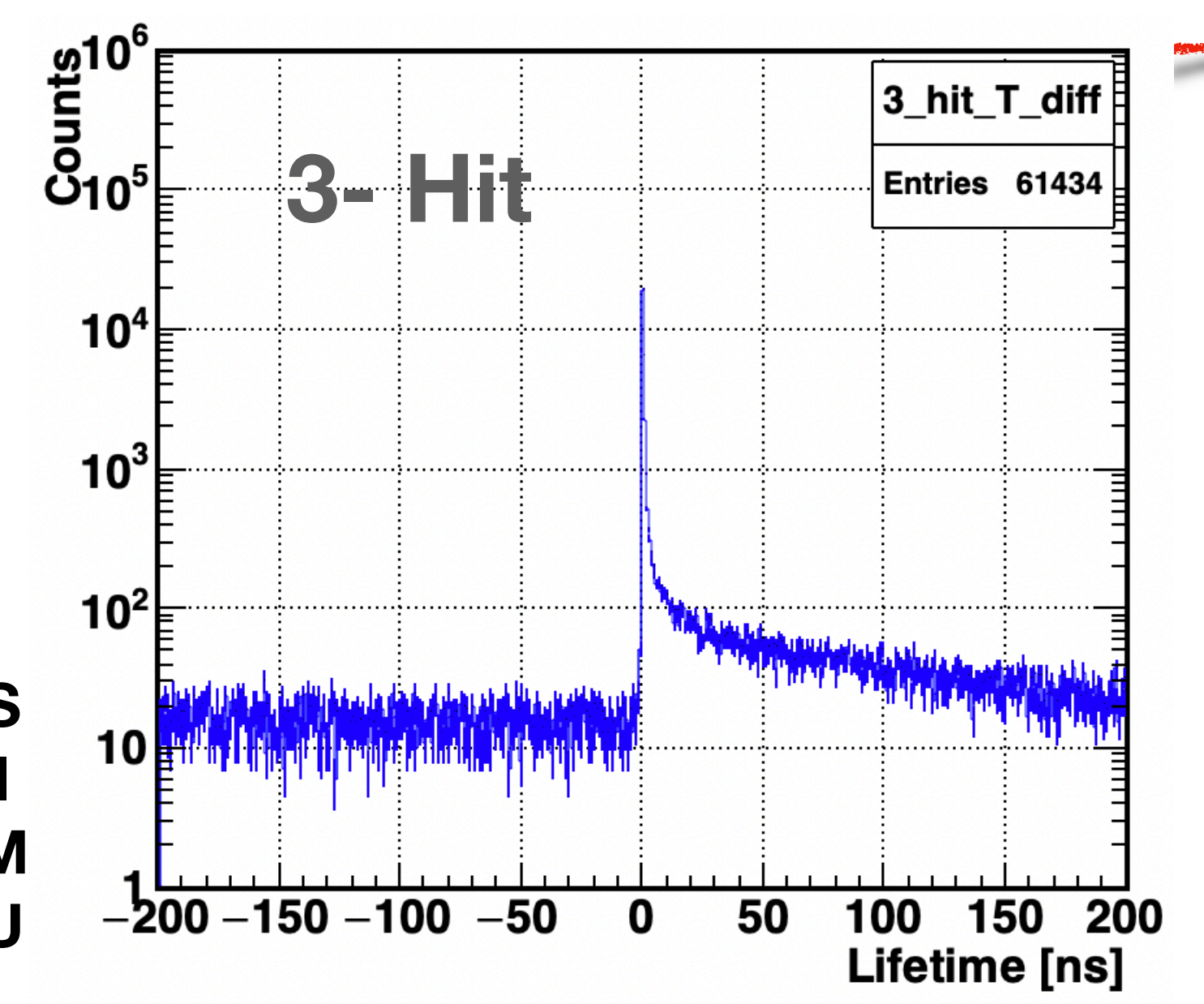
SIMULATIONS



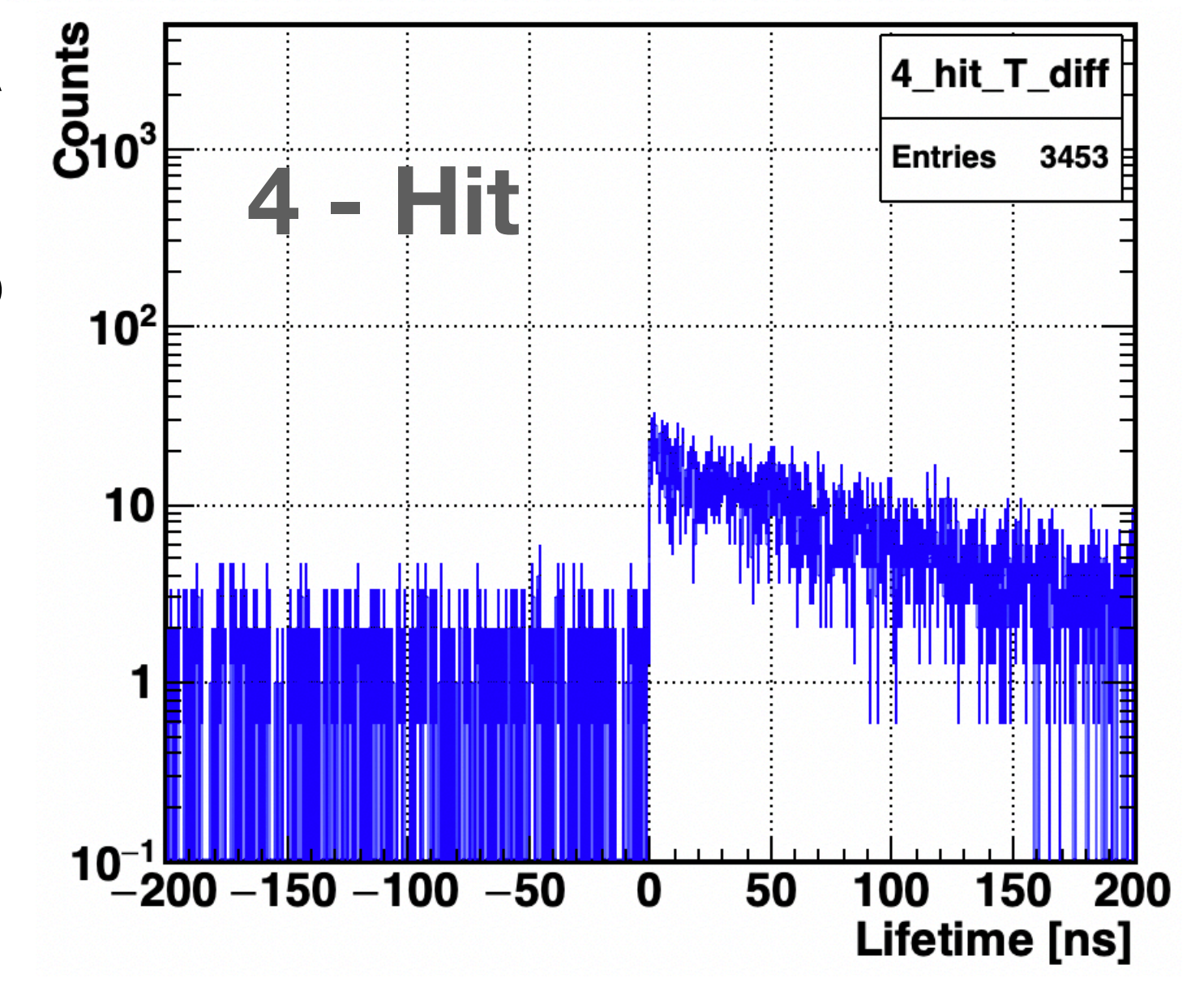
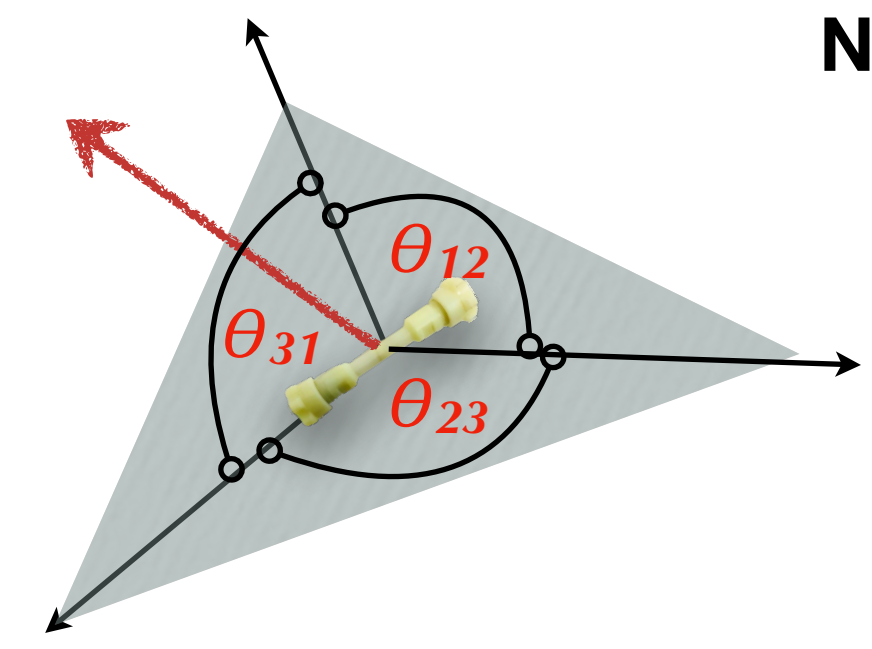
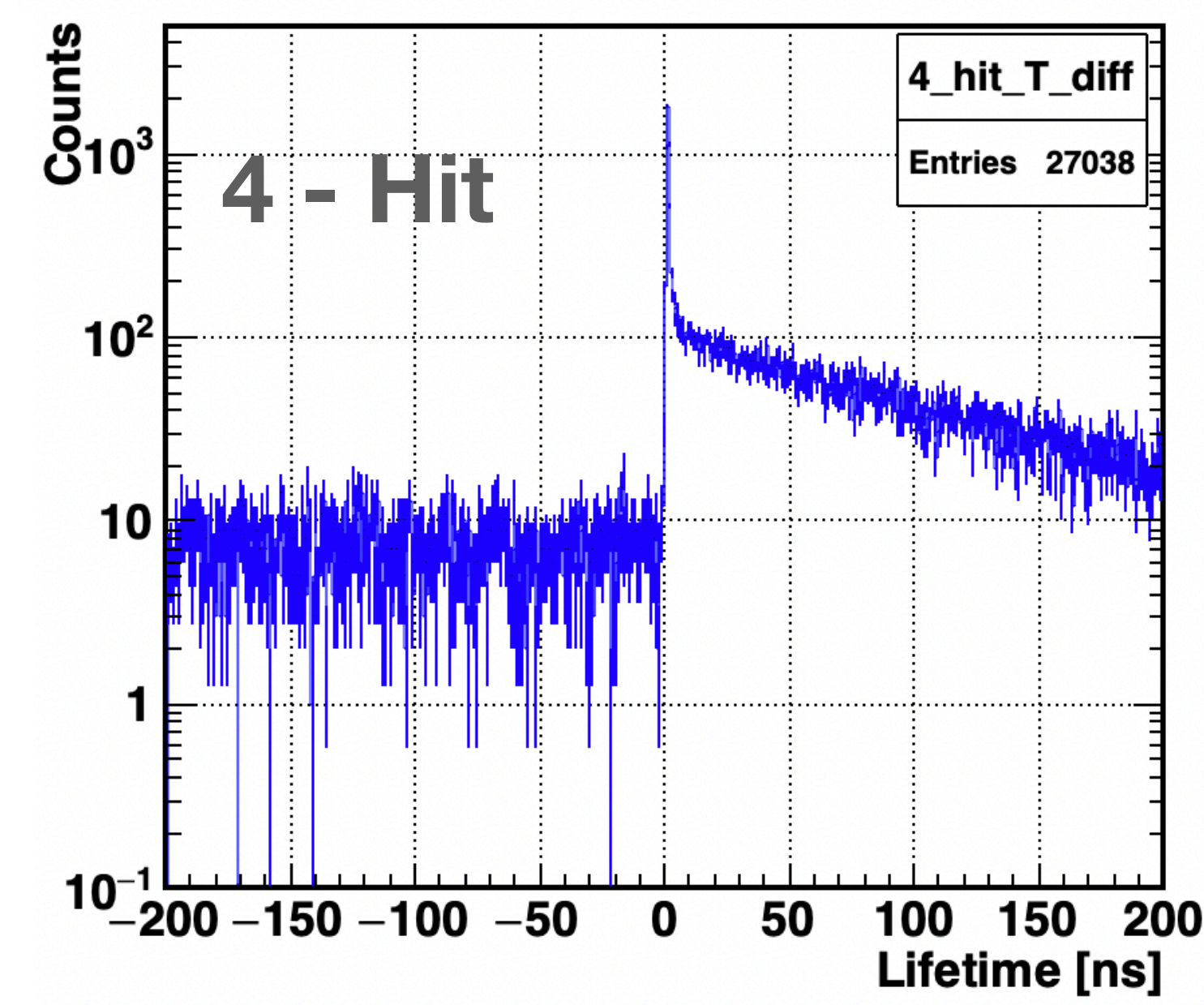
Lifetime spectra



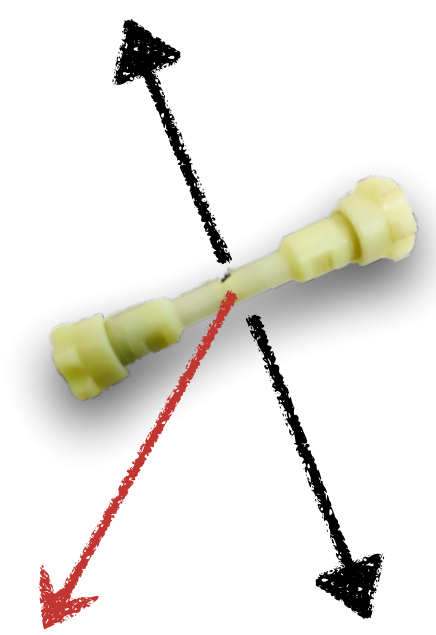
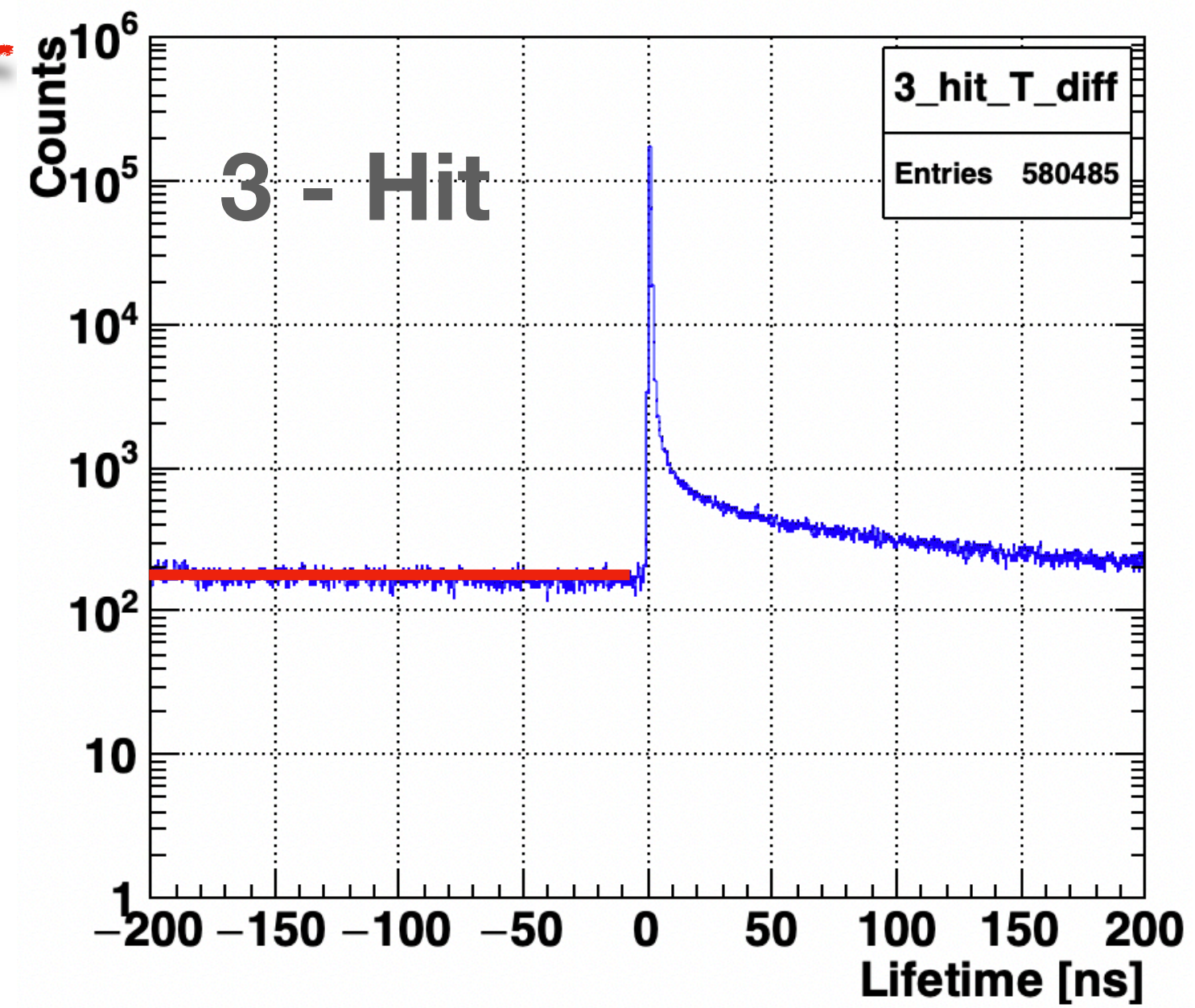
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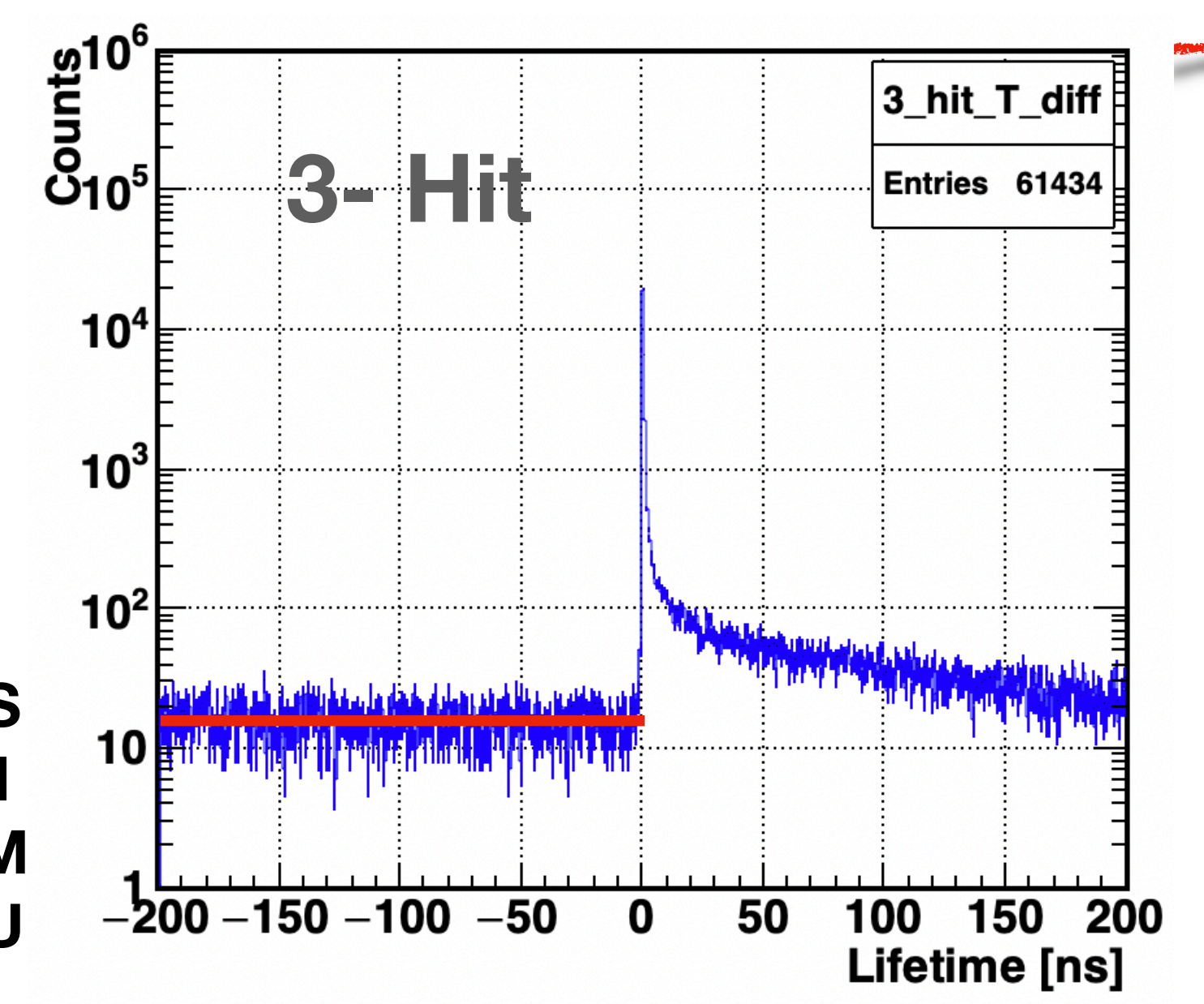
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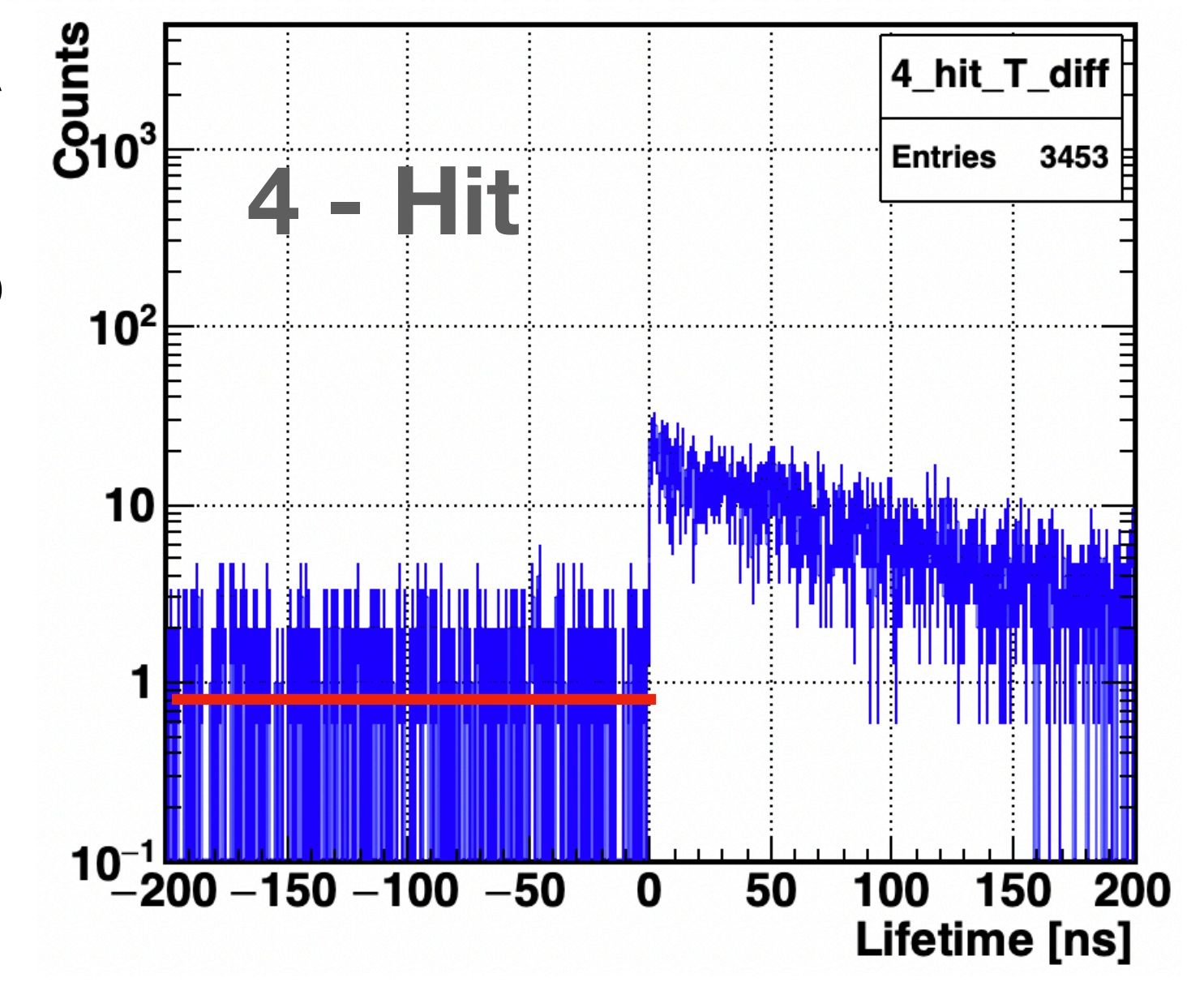
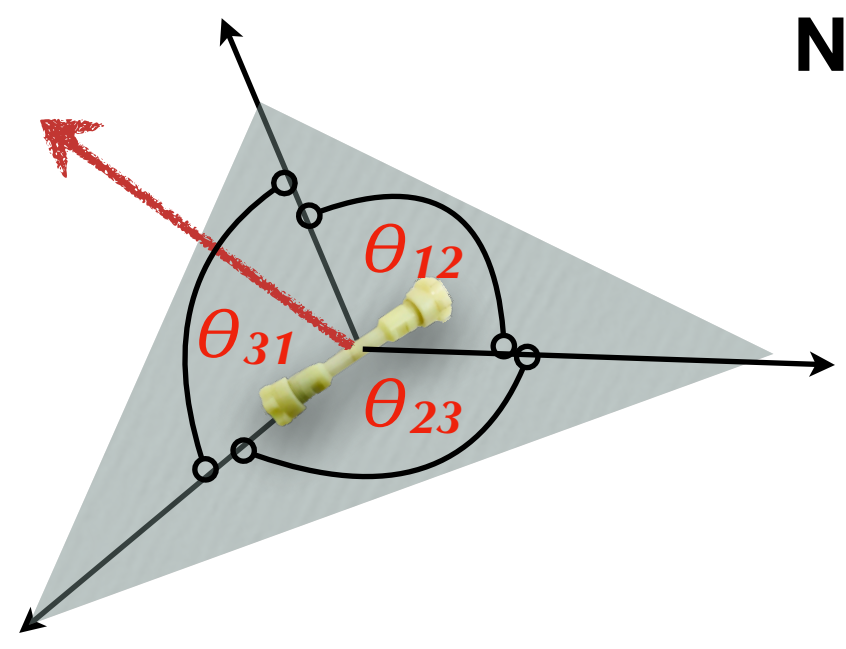
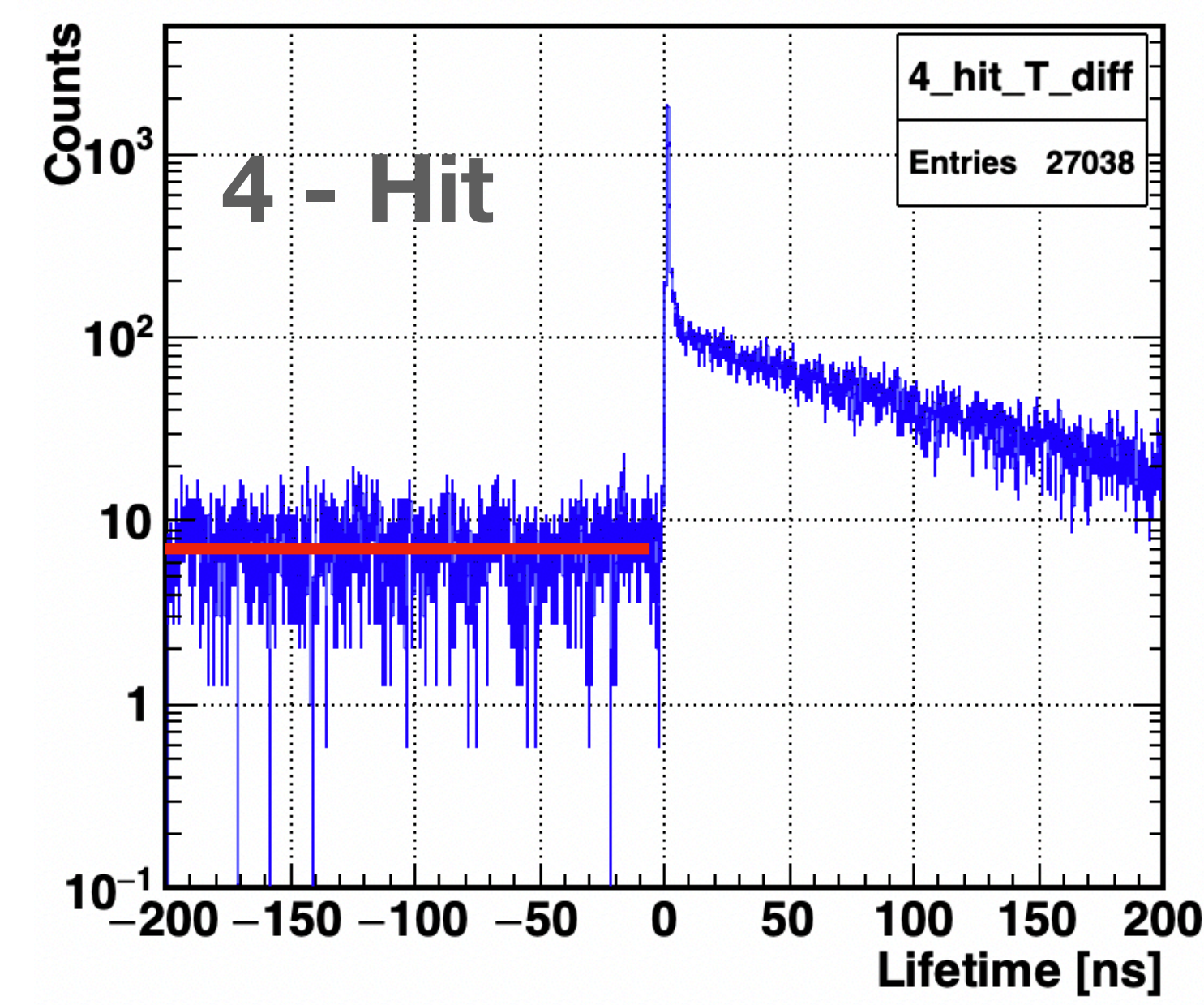
Lifetime spectra



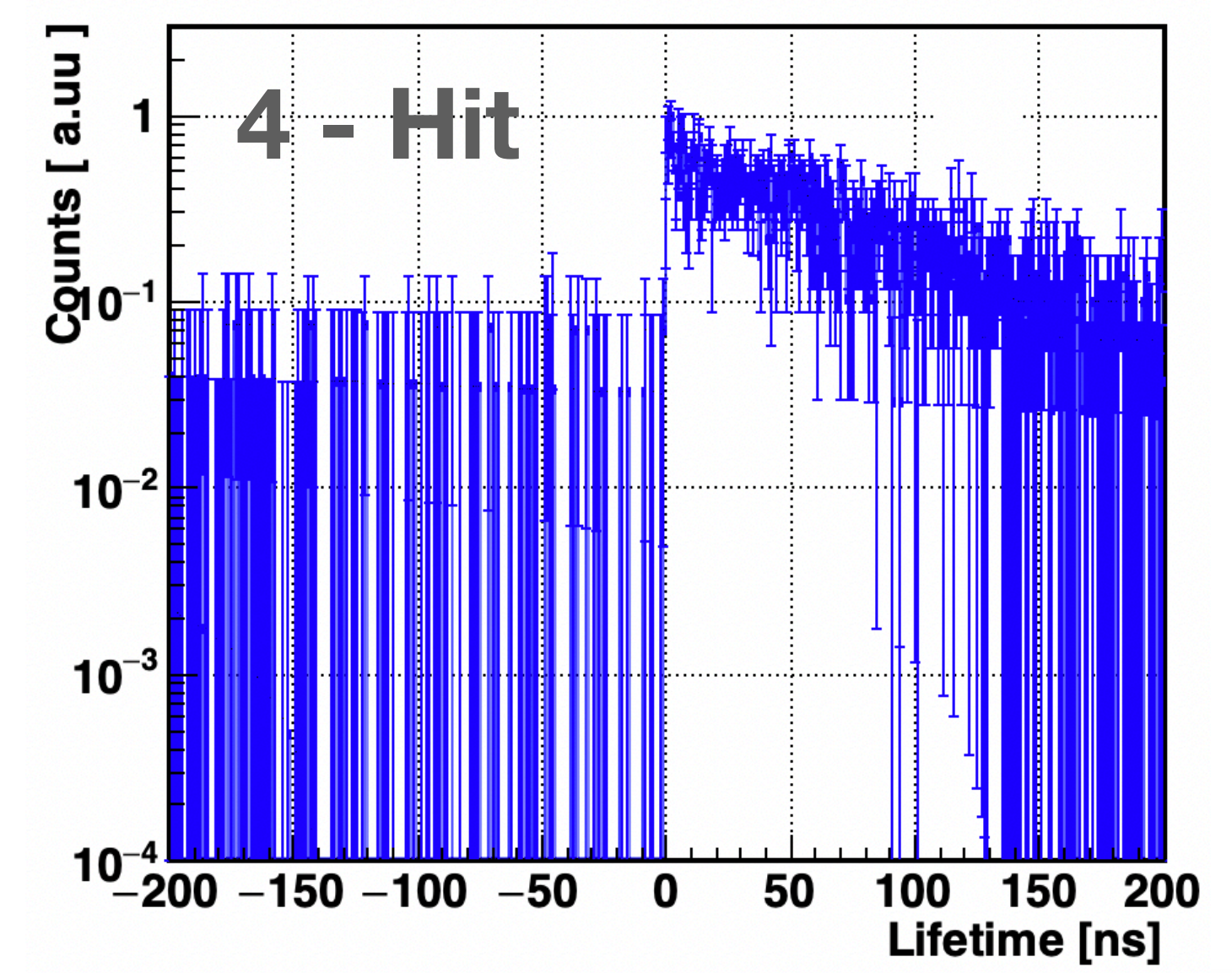
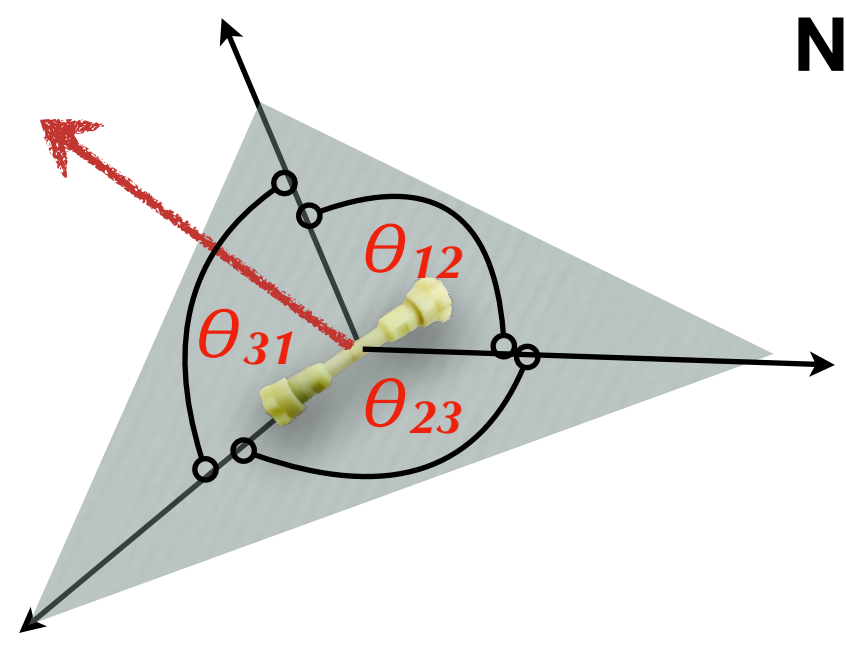
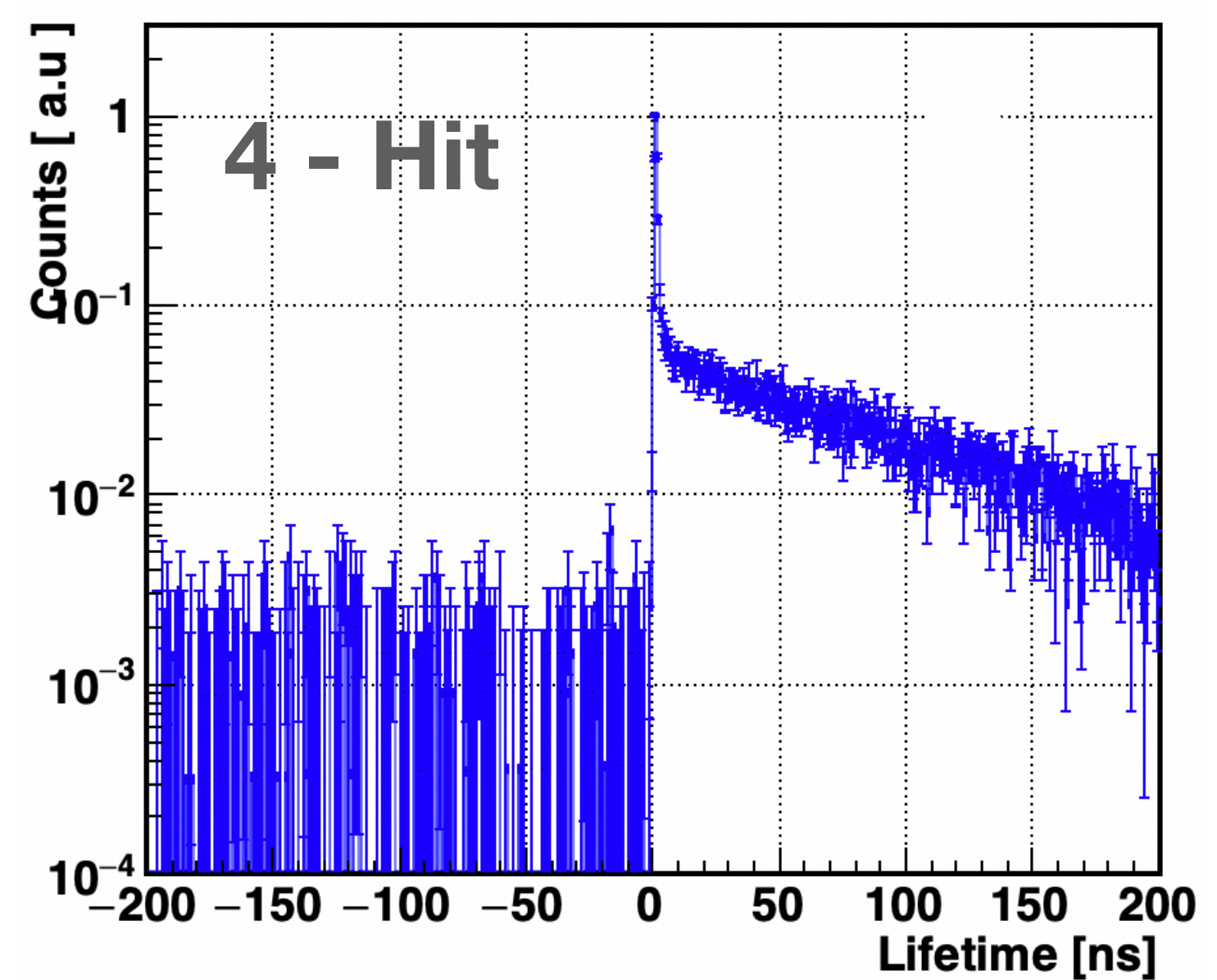
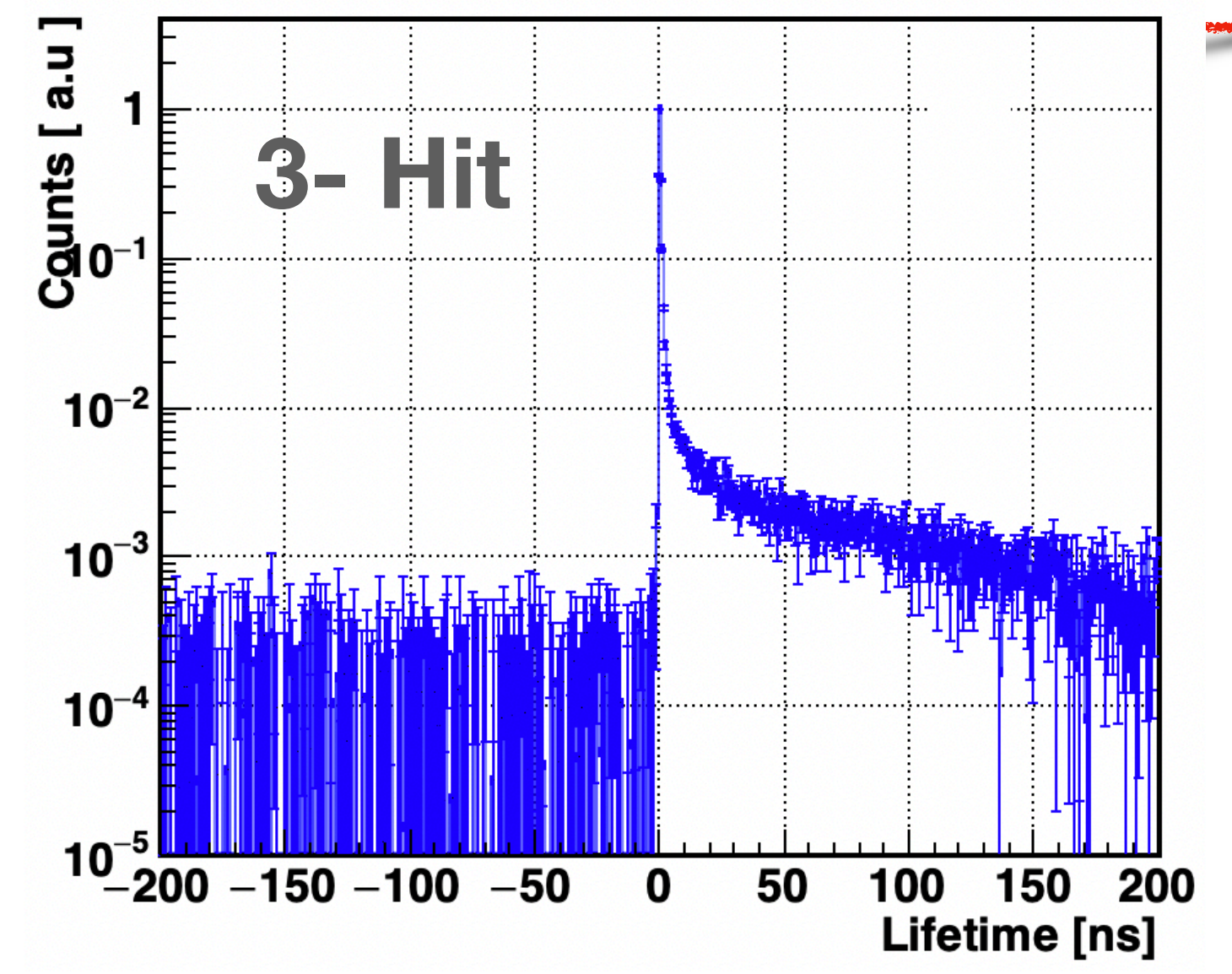
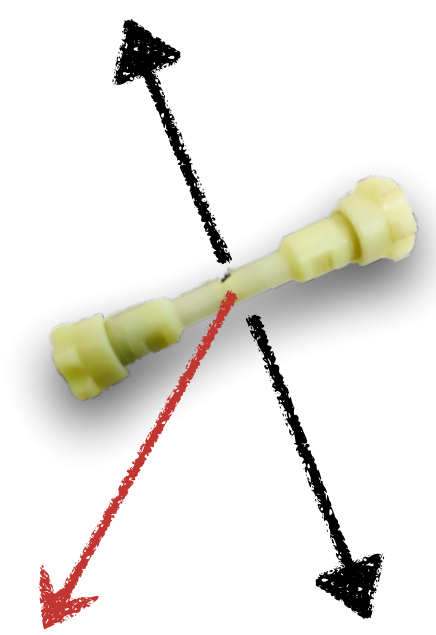
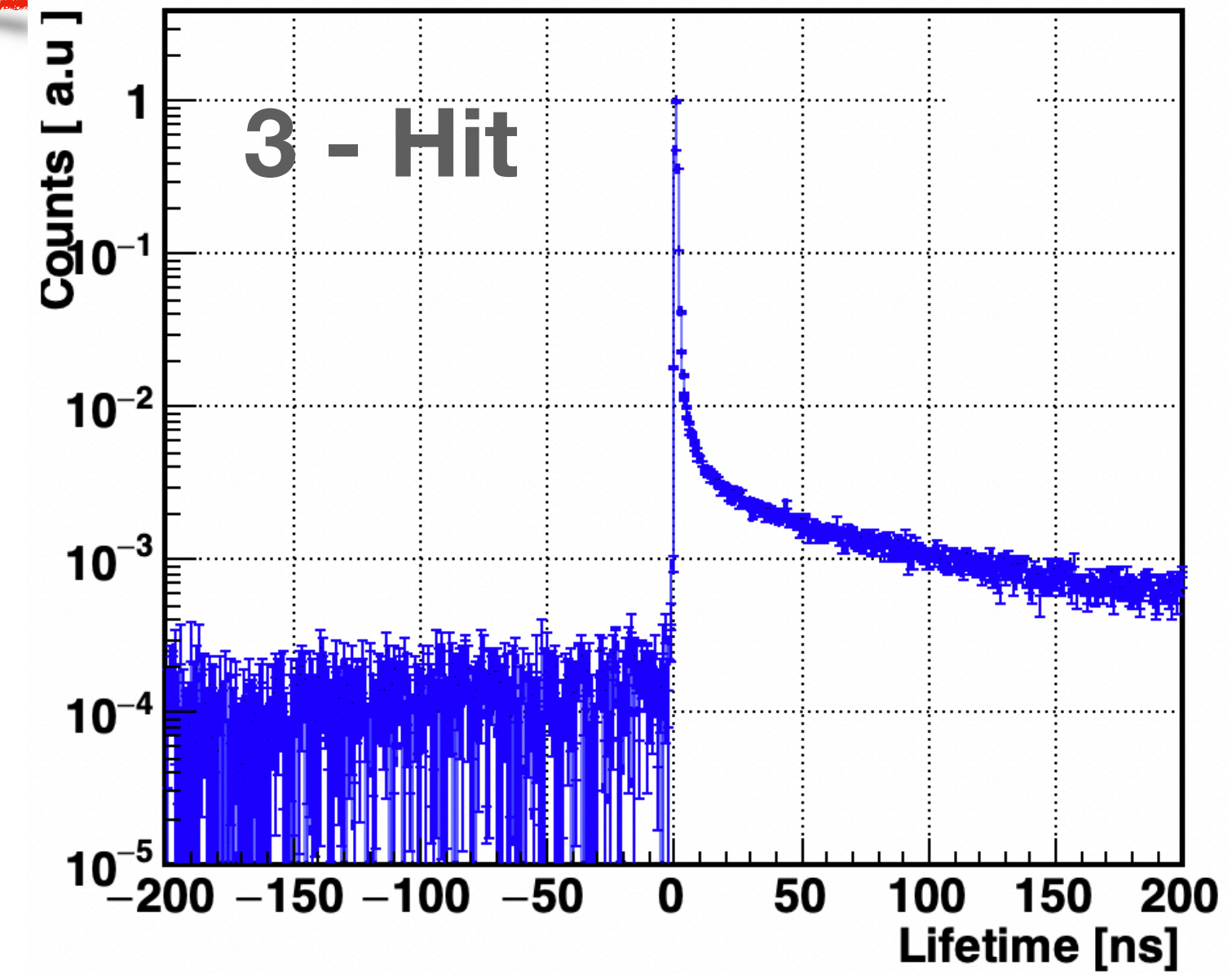
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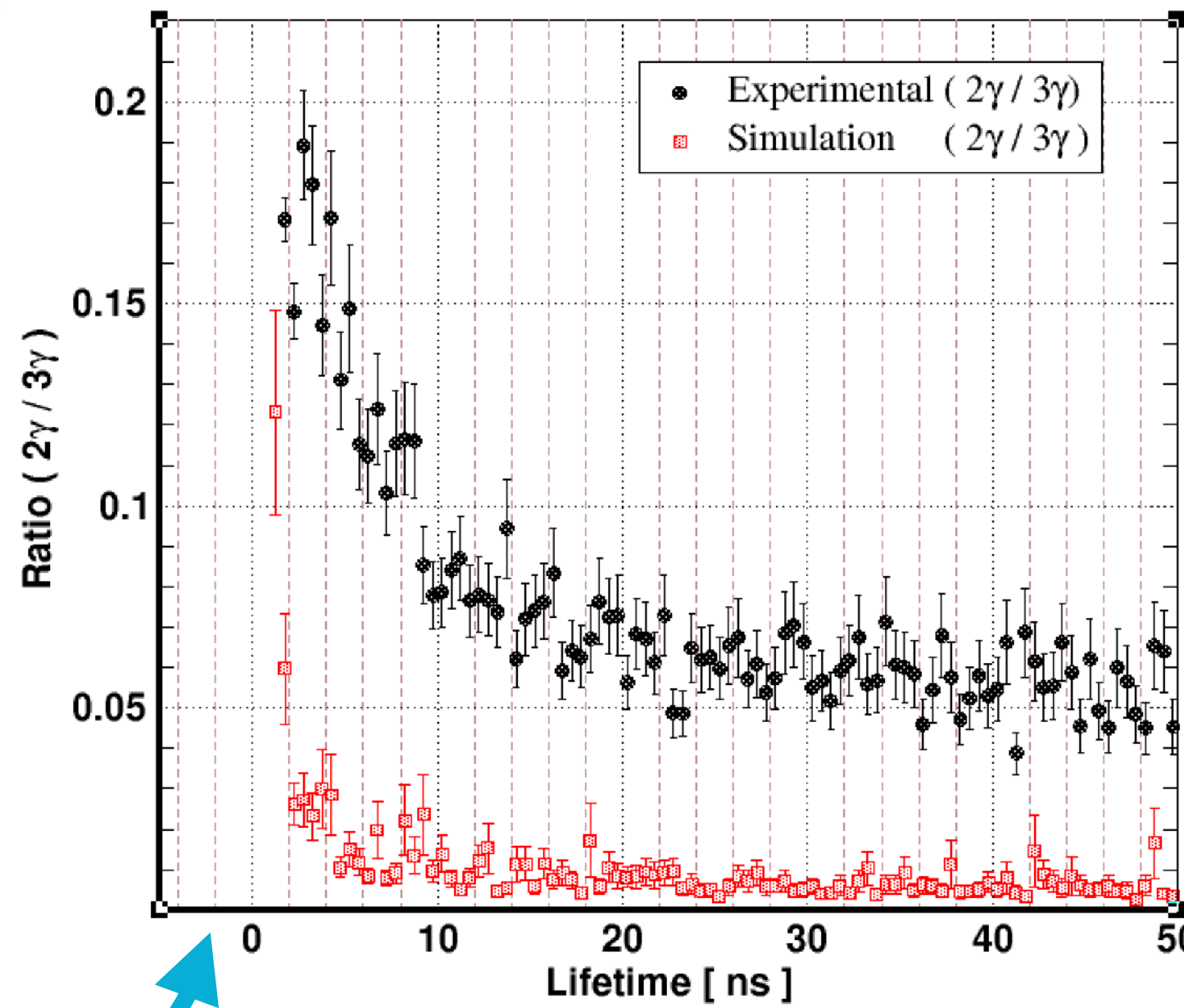
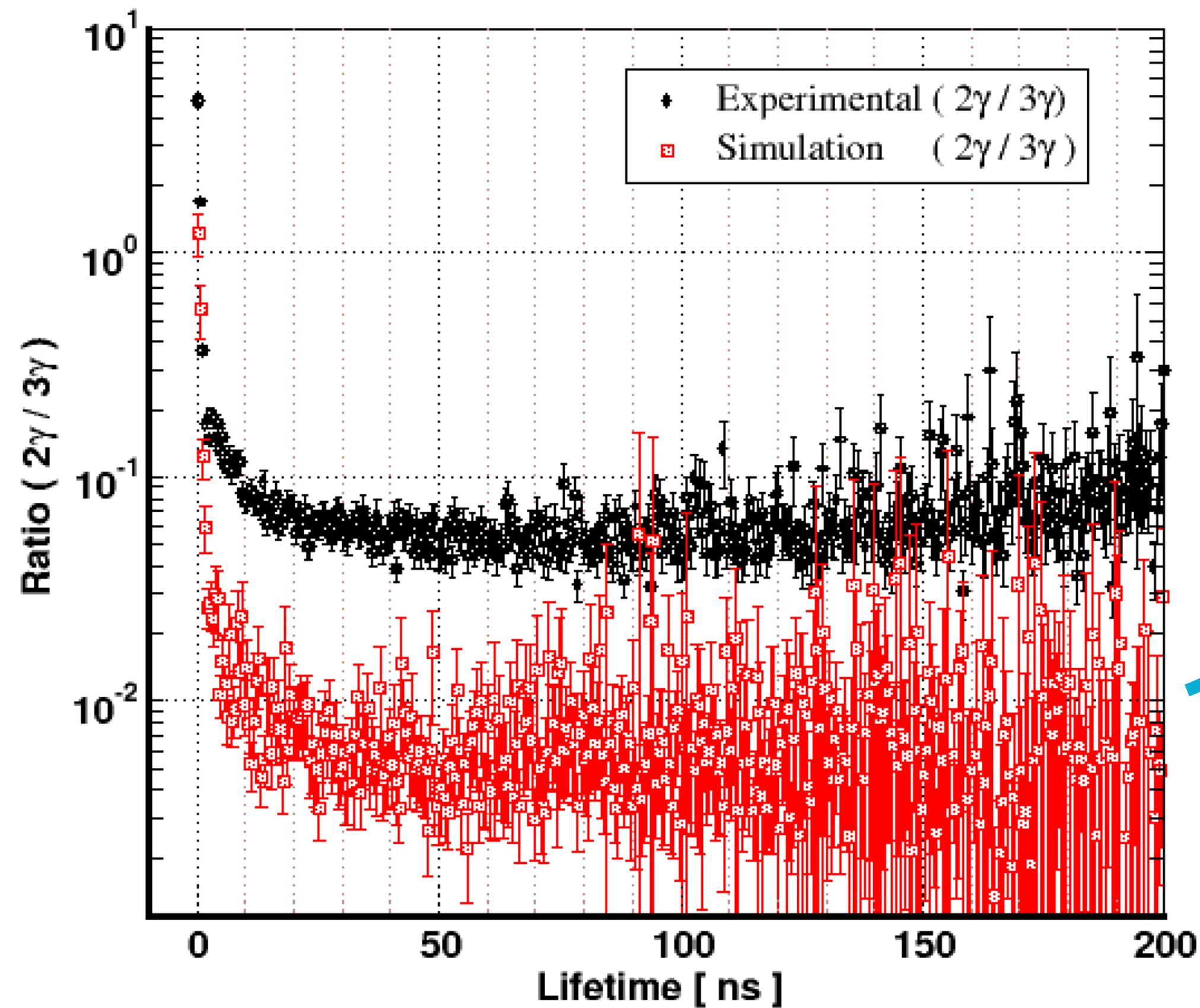


Lifetime spectra

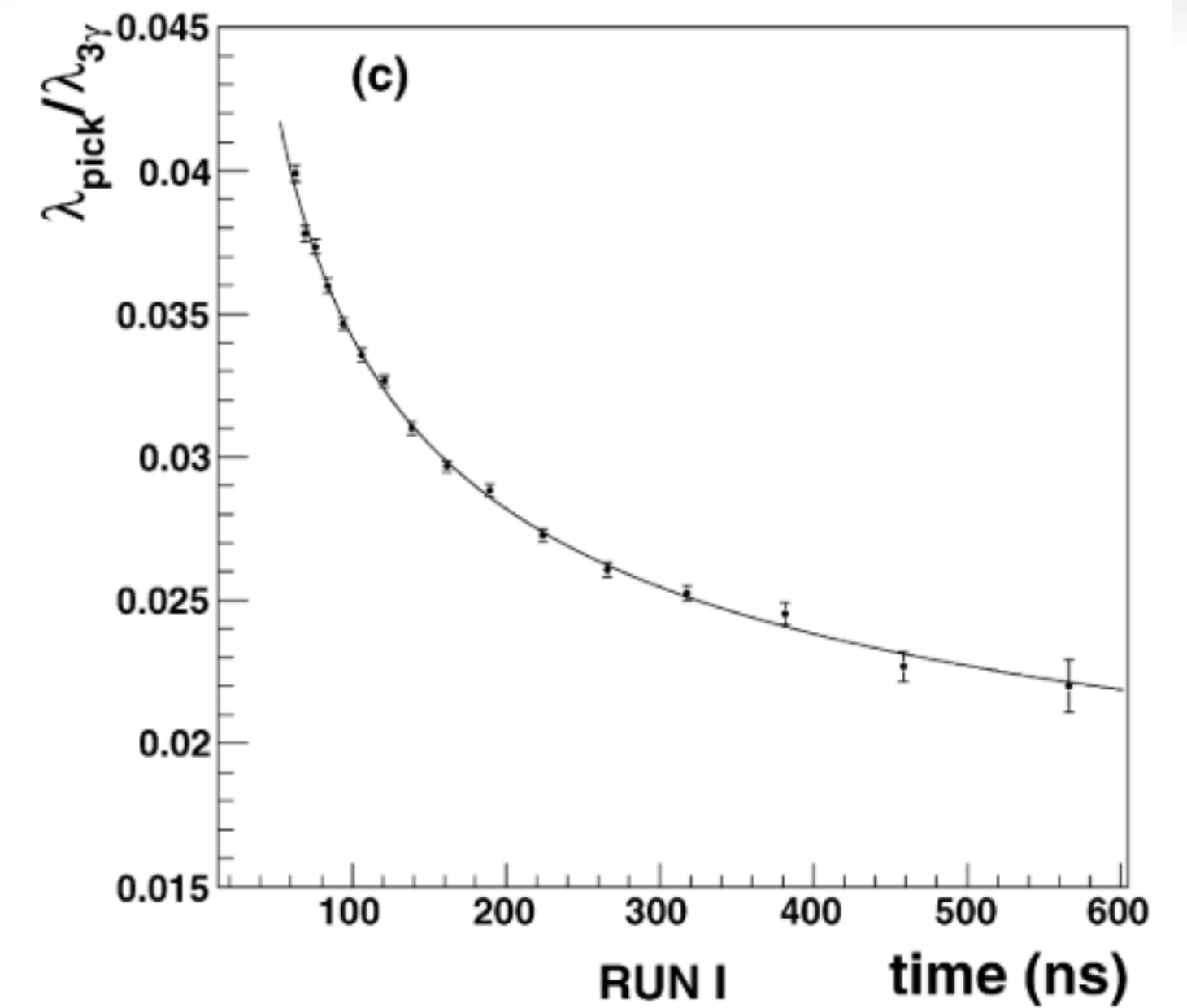


Ratio ($2\gamma / 3\gamma$)

Only positive values of ratios are shown



Extended scale unto 50 ns



Y. Karaoke, S. Asai et al.,
Physics Lett B 671 (2009) 219-223

In work reported by Y. Karaoke et al.,:

- Ratio of $\lambda_{pick(t)} / \lambda_{3\gamma}$ reported in literature is for SiO_2 material and used source was $^{68}\text{Ge-Ga}$ with $E_{\text{emend}} = 1.9 \text{ MeV}$.
- The pickoff contribution is estimated by subtracting the simulated o-PS energy specter from the measured o-PS spectra, for that they used HPGe detectors.



- ☑ J-PET detector allows to measure explicitly the lifetime spectra of the o-Ps atoms.
Kamil et. al., article submitted to EPJC
- ☑ **J-PET MC** allows to simulate the o-Ps events with the possibility *to select* the *probability density* for **various decay channels**. Comparing the *simulation results* with the *experimental measurement* allows us to understand the pickoff (t) process contribution in o-Ps decays in different aerogel materials.
W. Krzemien et. al., *SoftwareX* 11 (2020) 100487
- ☑ Efficiency corrections for the both process are still need to be implemented.
- ☑ The final estimation of the **Ratio ($2\gamma / 3\gamma$) as a function of time** can be concluded after the efficiency correction and optimization of the background reduction procedures.



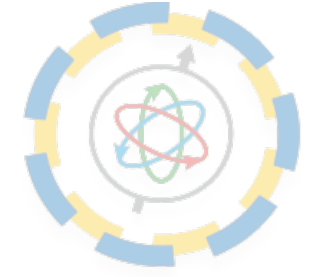
J-PET

J-PET

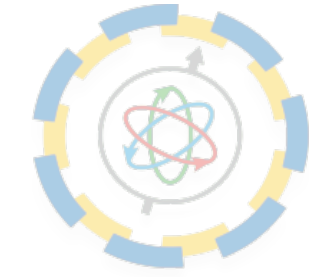
J-PET

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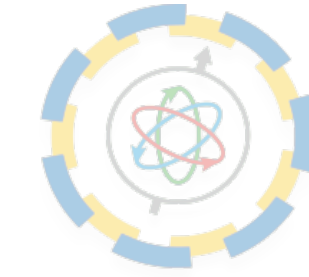
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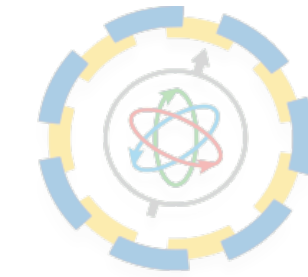
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J-PET



J-PET



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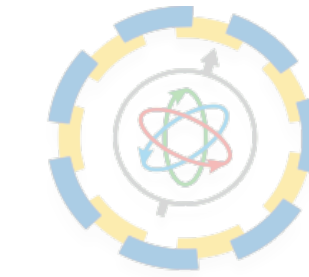
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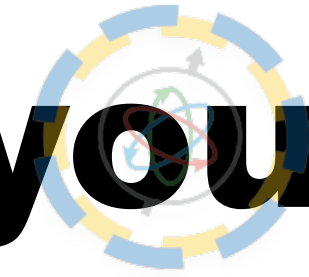
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J-PET

**Thank you
for your attention**



J-PET



J-PET



J-PET



J-PET

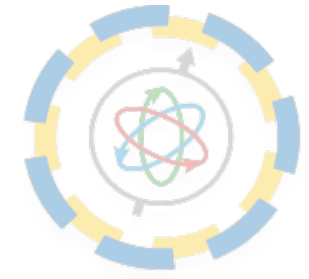
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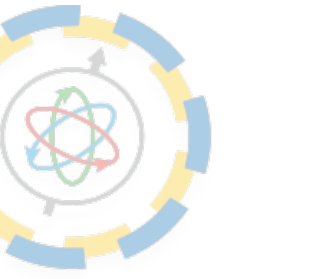
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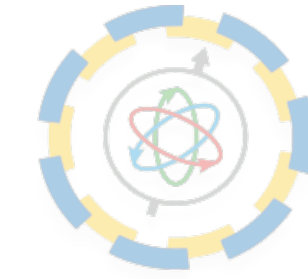
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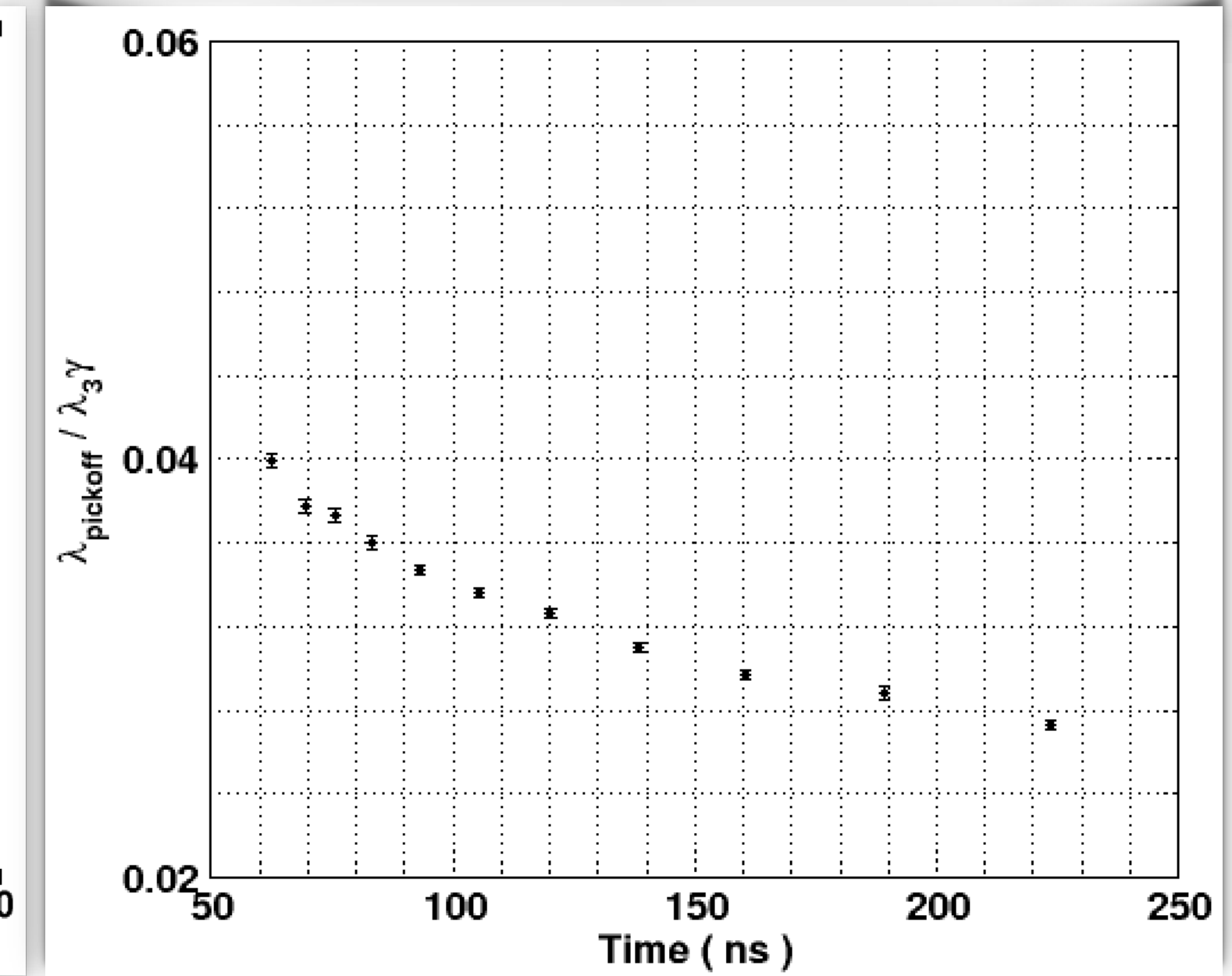
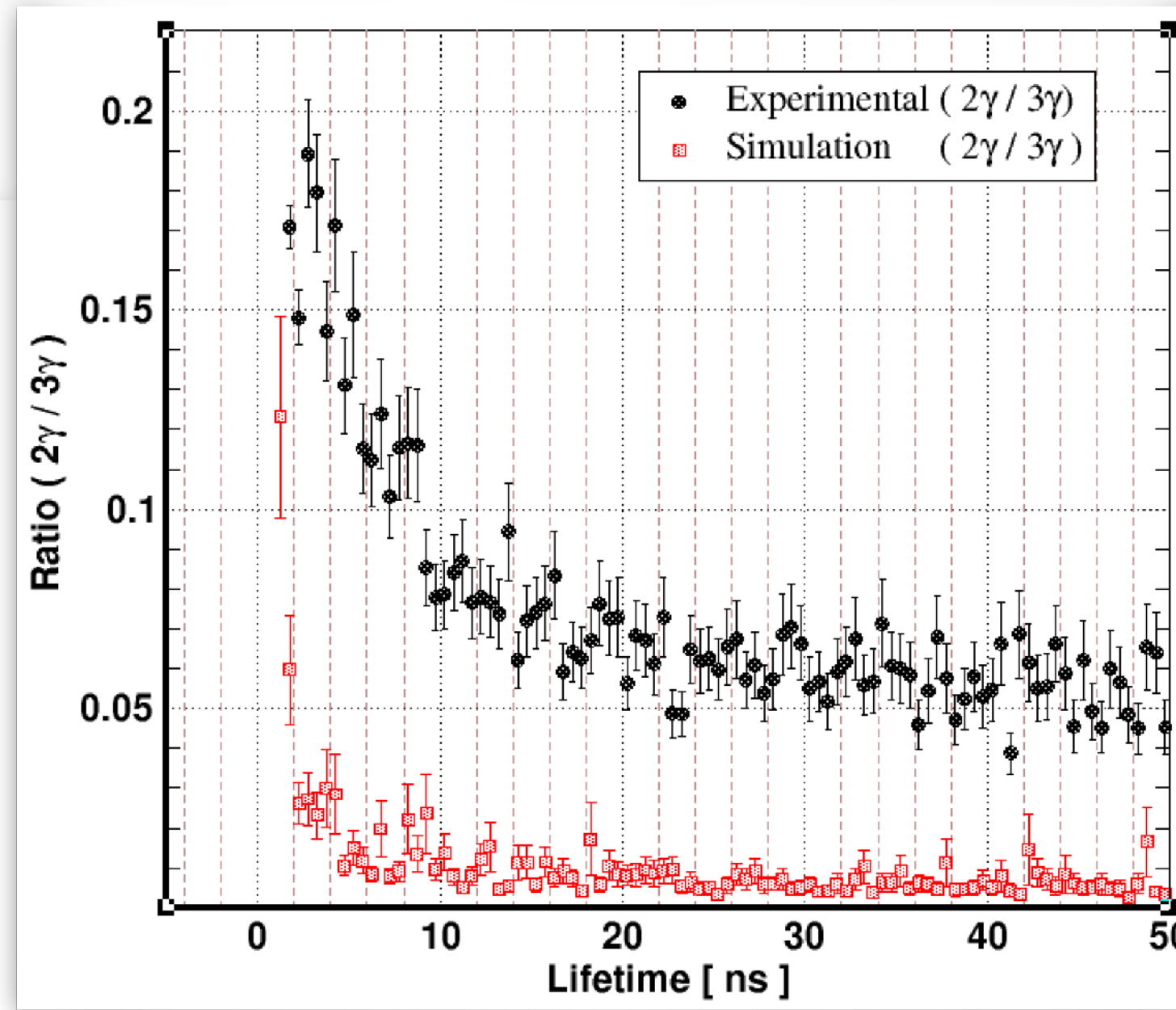
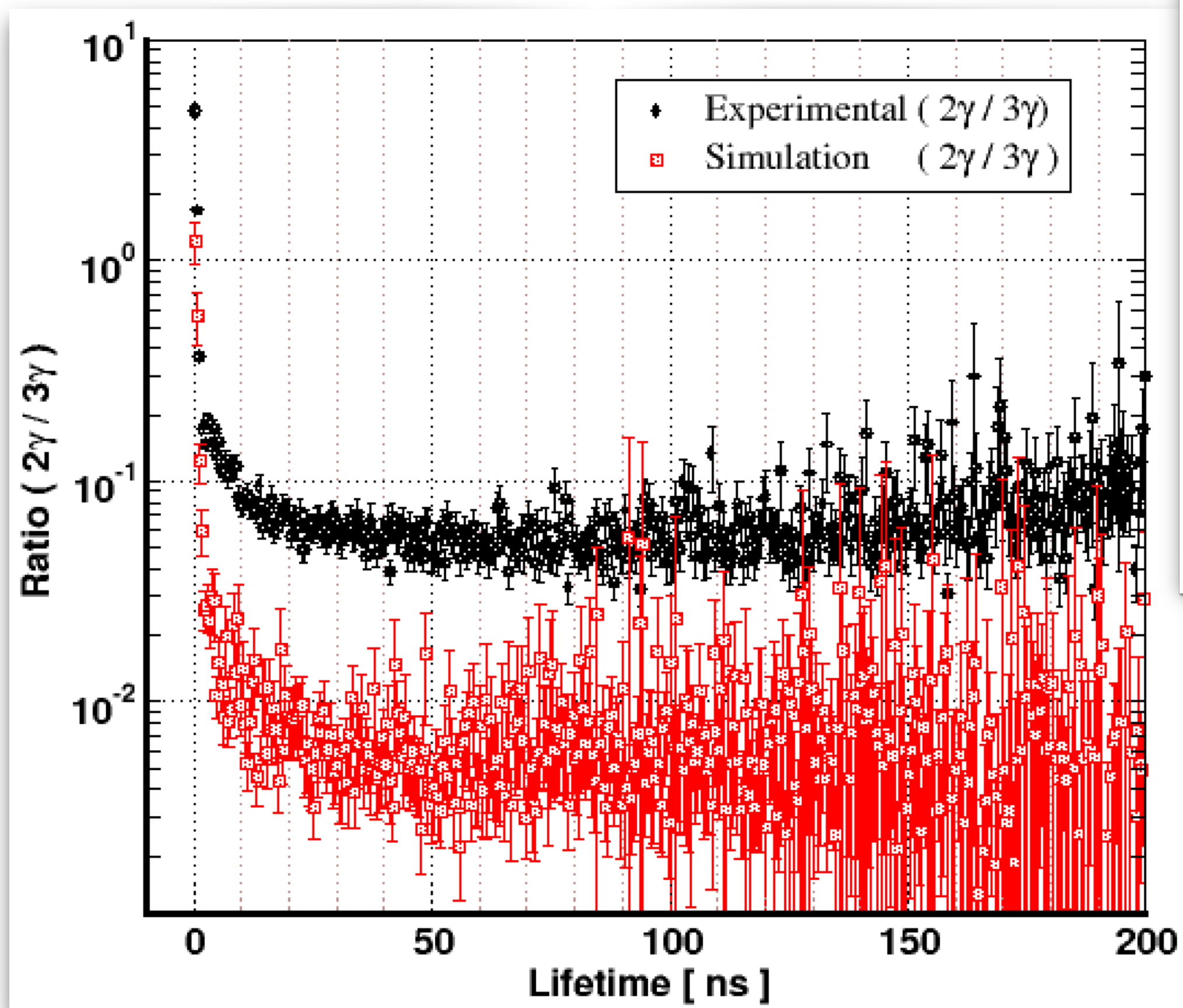
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Ratio ($2\gamma / 3\gamma$)



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