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**3<sup>rd</sup> Symposium on Positron Emission Tomography  
and  
1<sup>st</sup> Symposium on Boron Neutron Capture Therapy**

# **Time Over Threshold calibration in the framework of J-PET**

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



# Outline





## ⌘ Motivation





# Outline



- ⌘ Motivation
- ⌘ Experimental details





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- ⌘ Motivation
- ⌘ Experimental details
- ⌘ Event's selection





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- ⌘ Motivation
- ⌘ Experimental details
- ⌘ Event's selection
- ⌘ Results





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- ⌘ Motivation
- ⌘ Experimental details
- ⌘ Event's selection
- ⌘ Results
- ⌘ Summary & Outlook

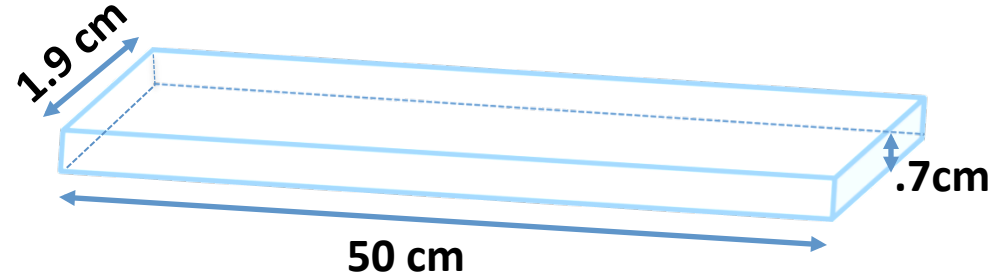




# Jagiellonian - **P**ositron **E**mission **T**omograph

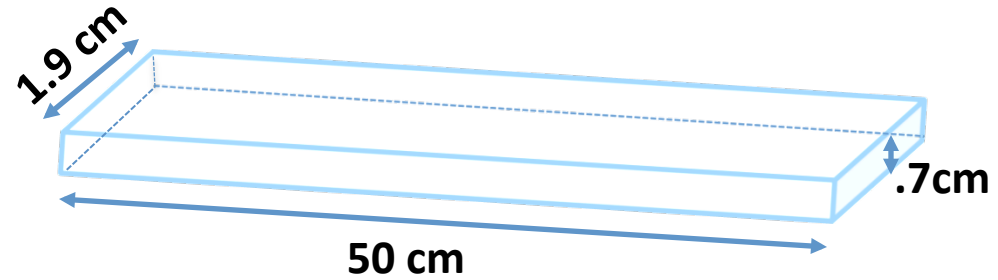






**192** plastic Scintillators





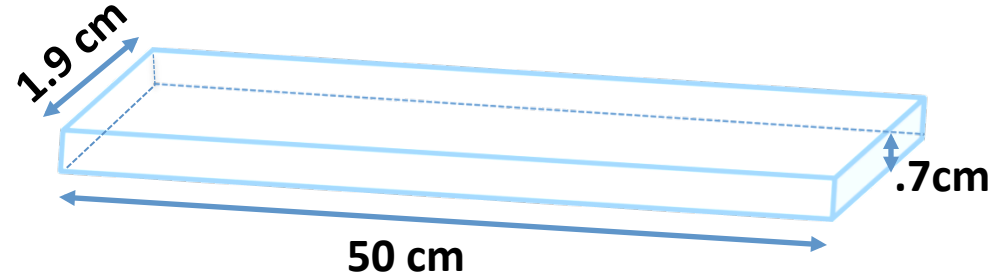
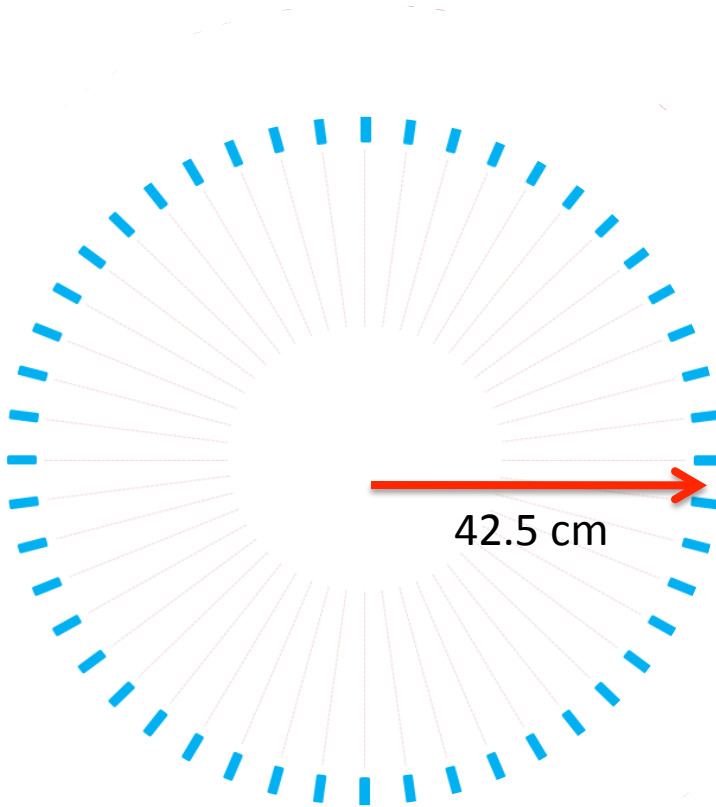
**192** plastic Scintillators

Arranged axially in **3 layers**





## 2-D front view J-PET



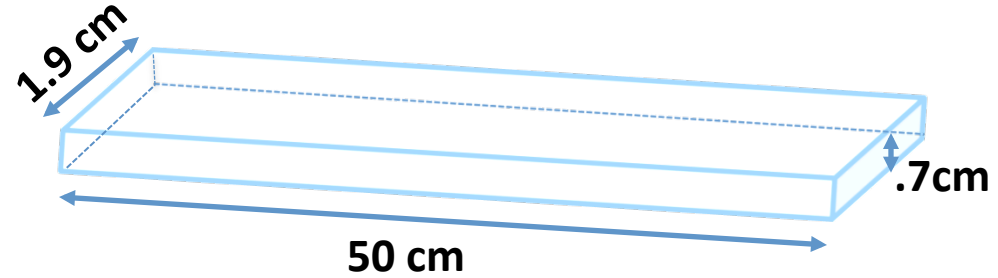
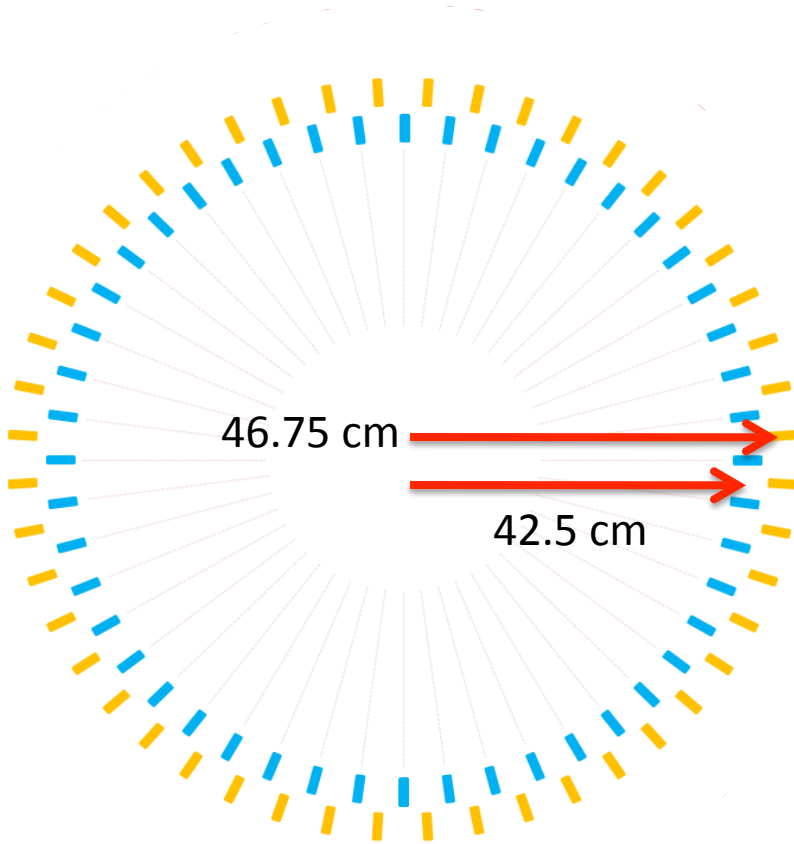
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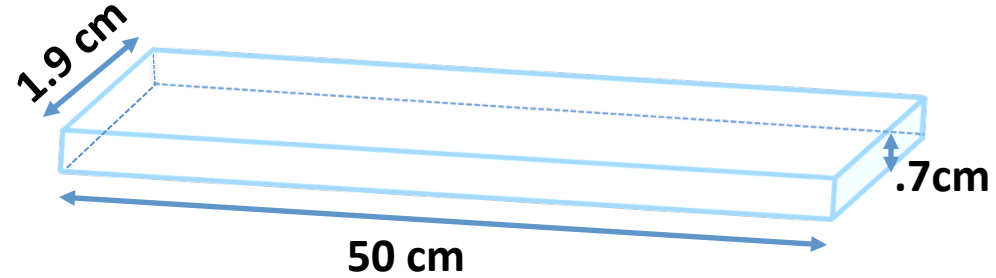
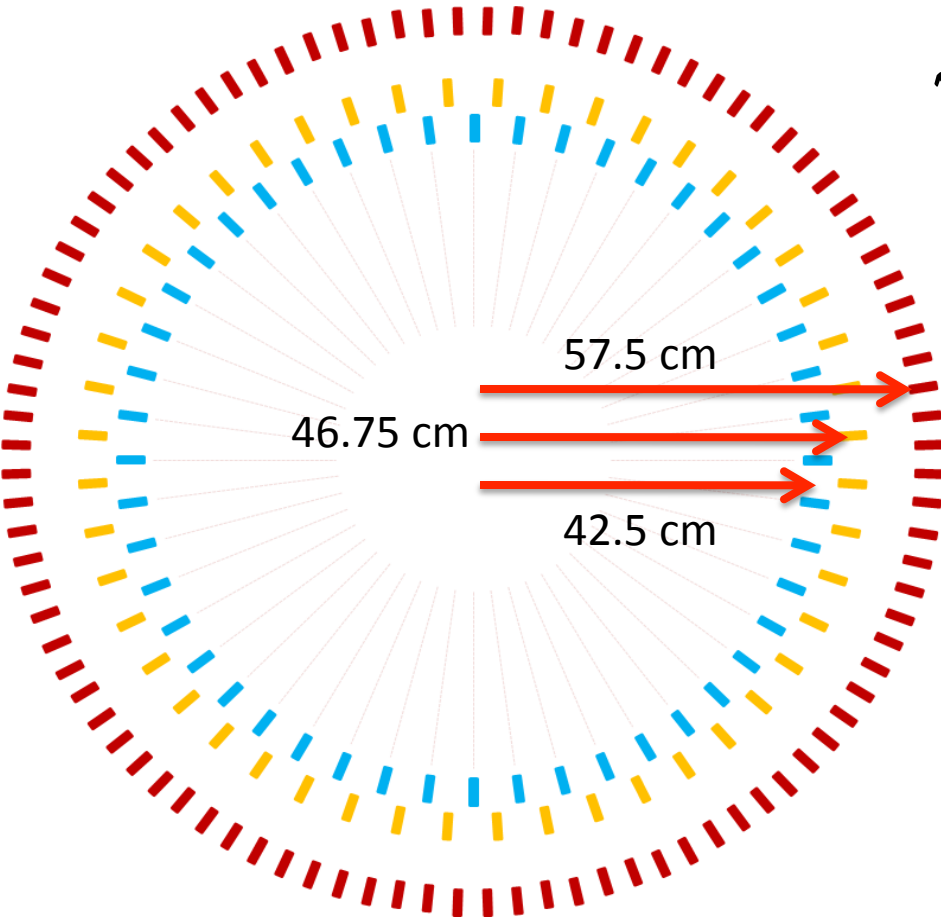
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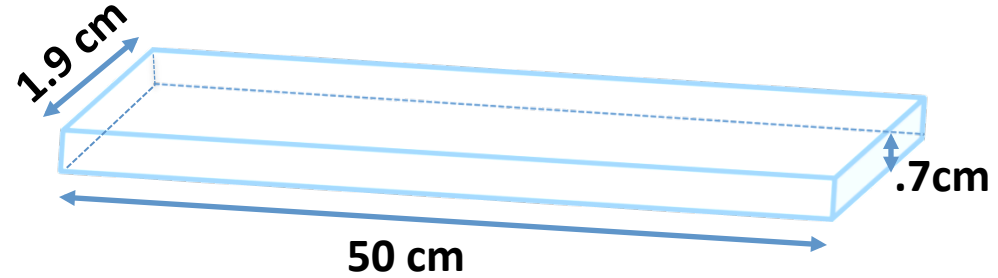
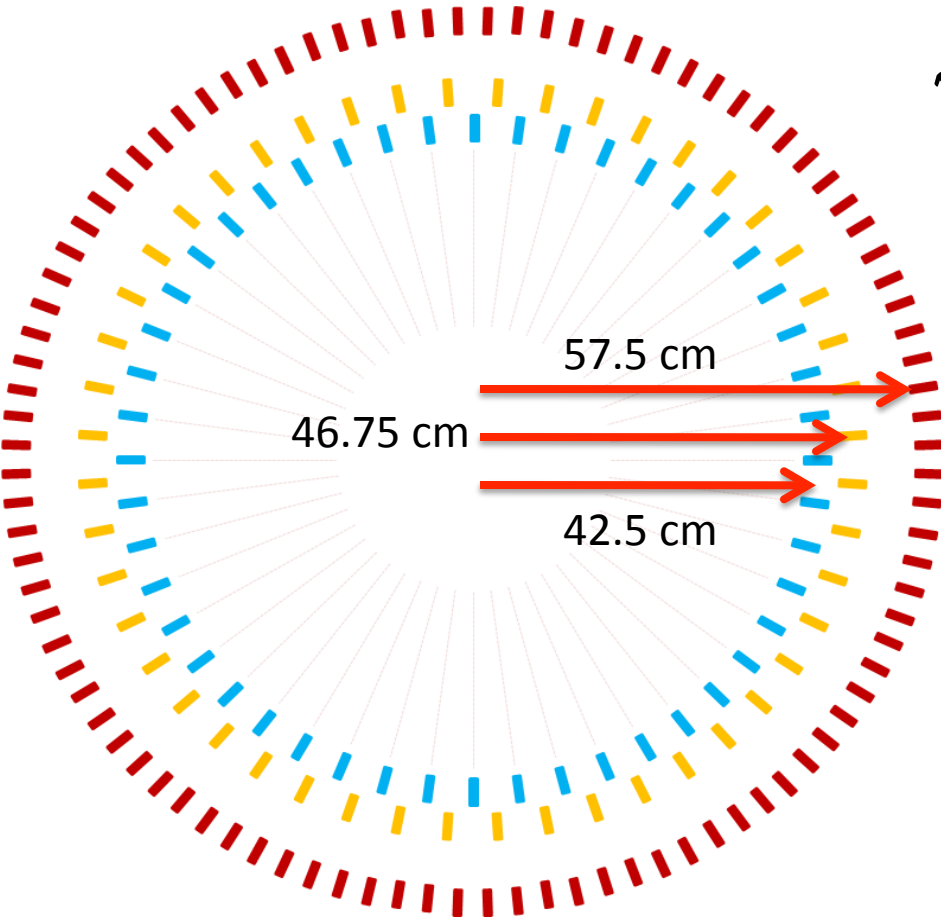
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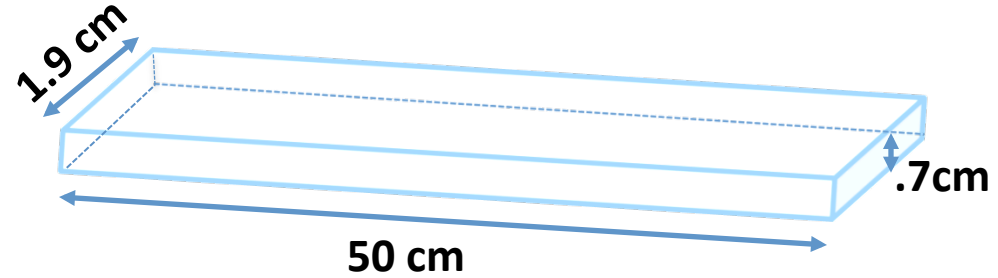
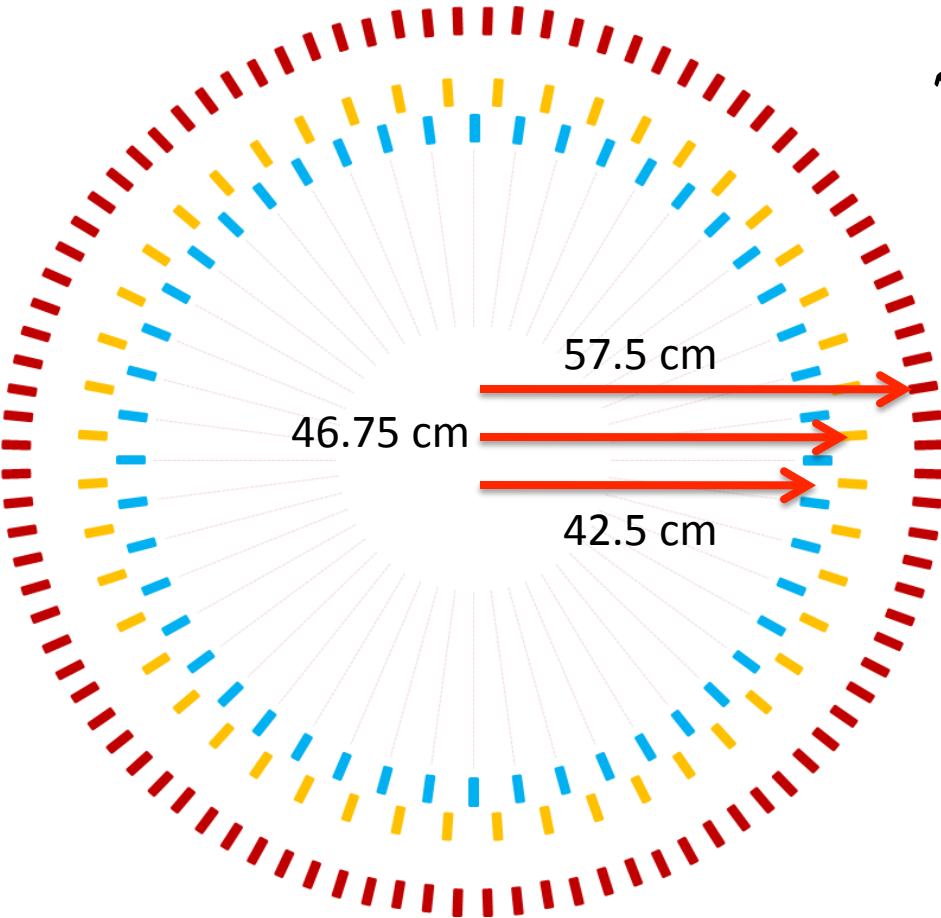
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**Key features :**





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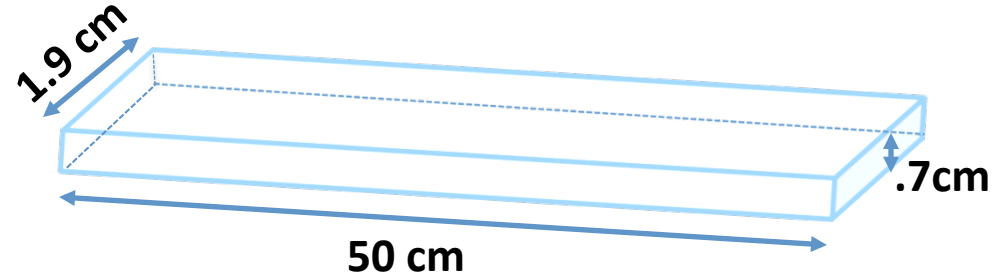
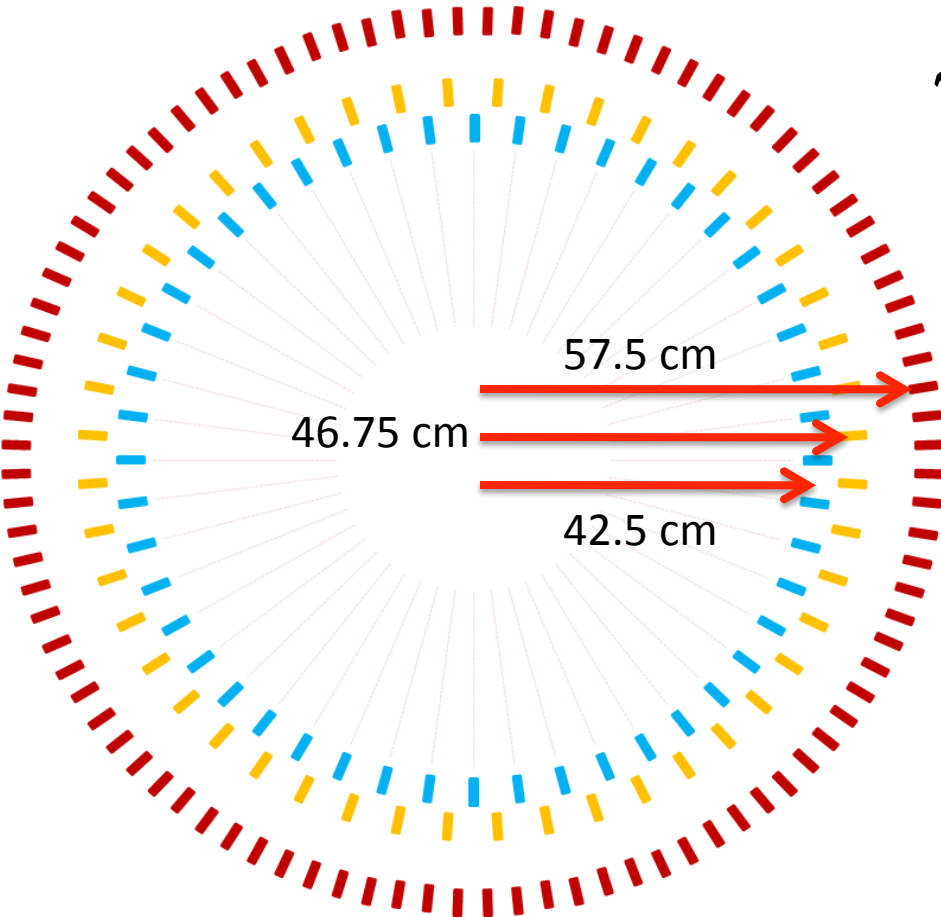
### Key features :

- ☑ Trigger less **DAQ**





## 2-D front view J-PET



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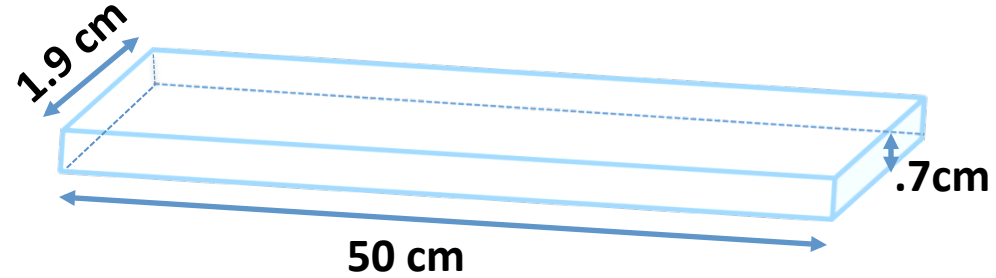
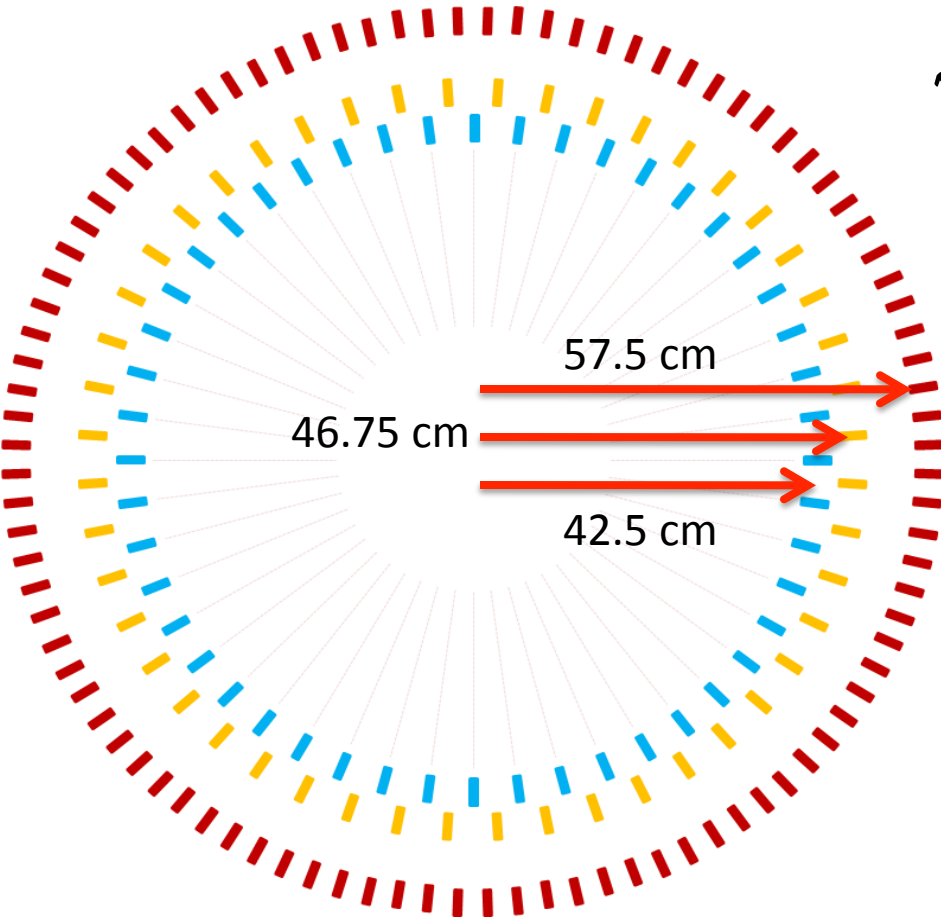
- ✓ Trigger less **DAQ**
- ✓ **TOT** as measure of energy deposition







## 2-D front view J-PET



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### Key features :

- ✓ Trigger less **DAQ**
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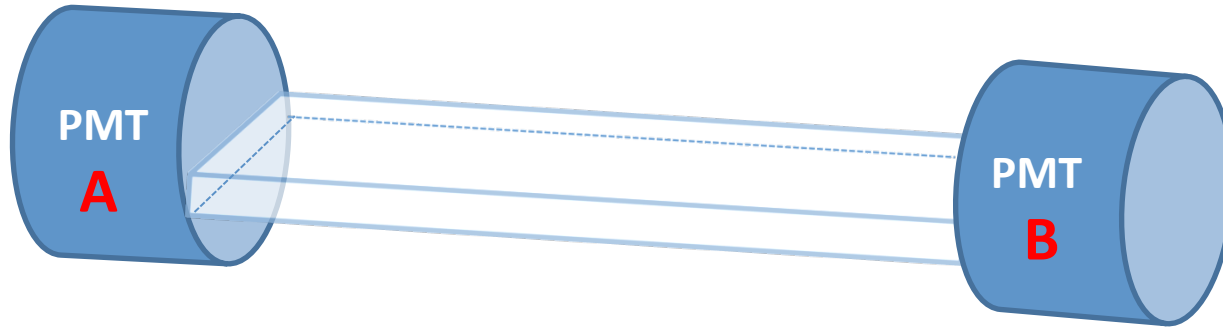


# Time-Over-Threshold & Energy deposition



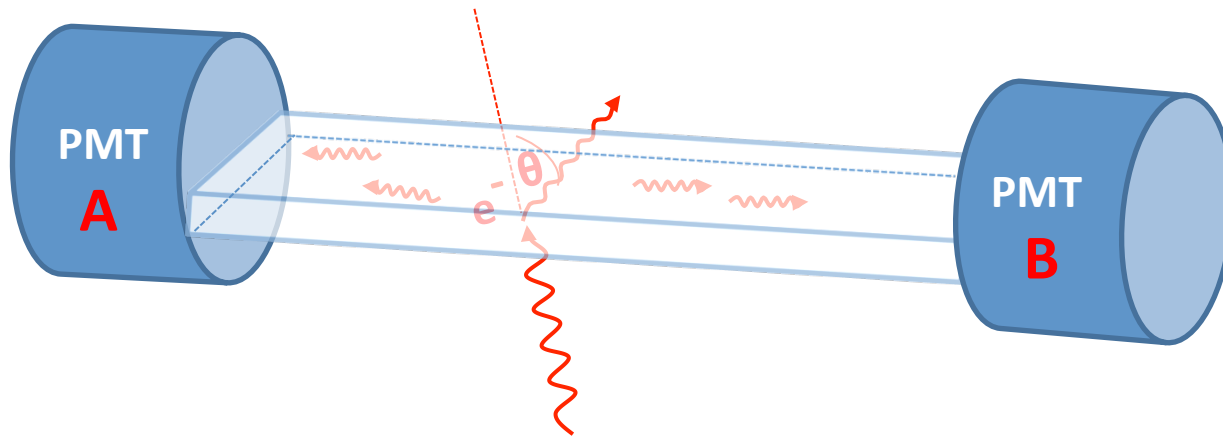


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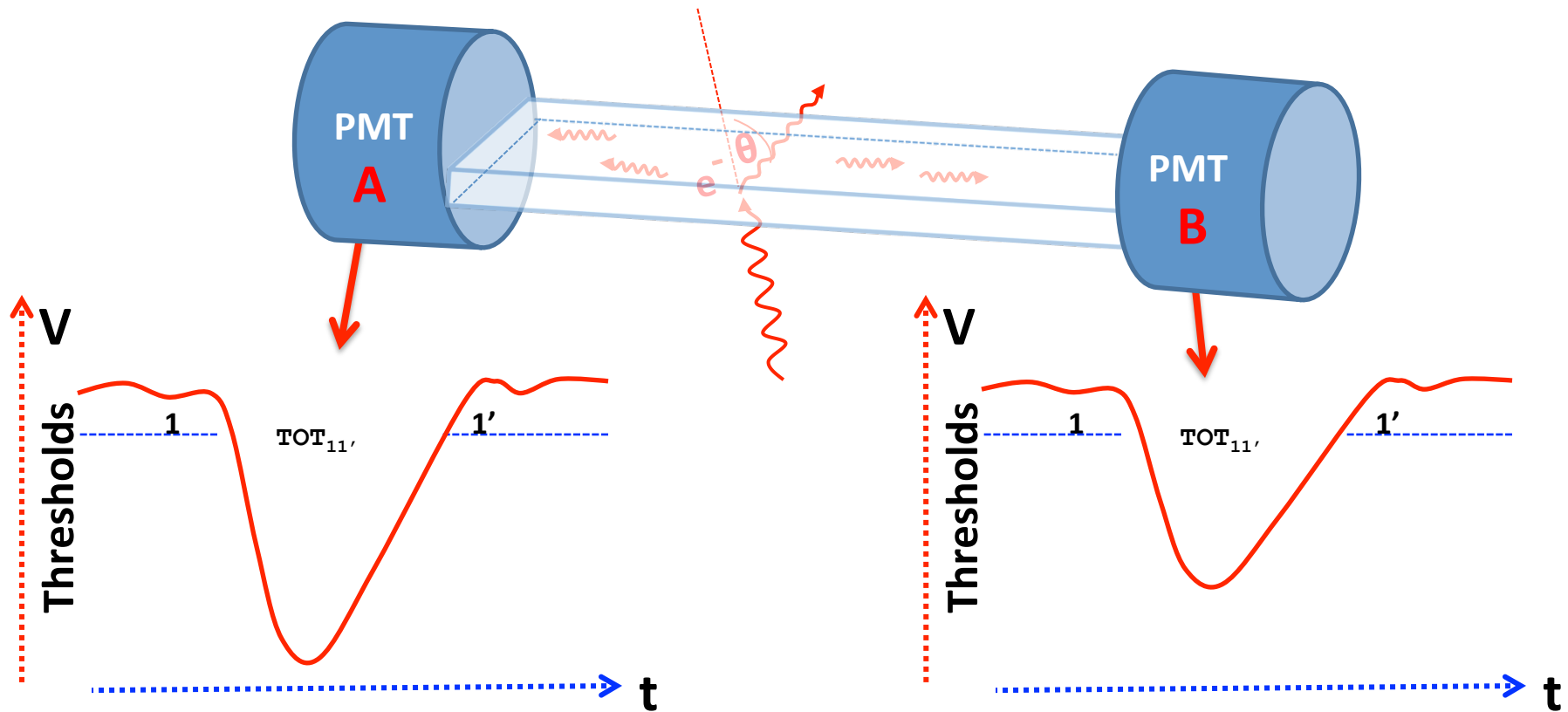


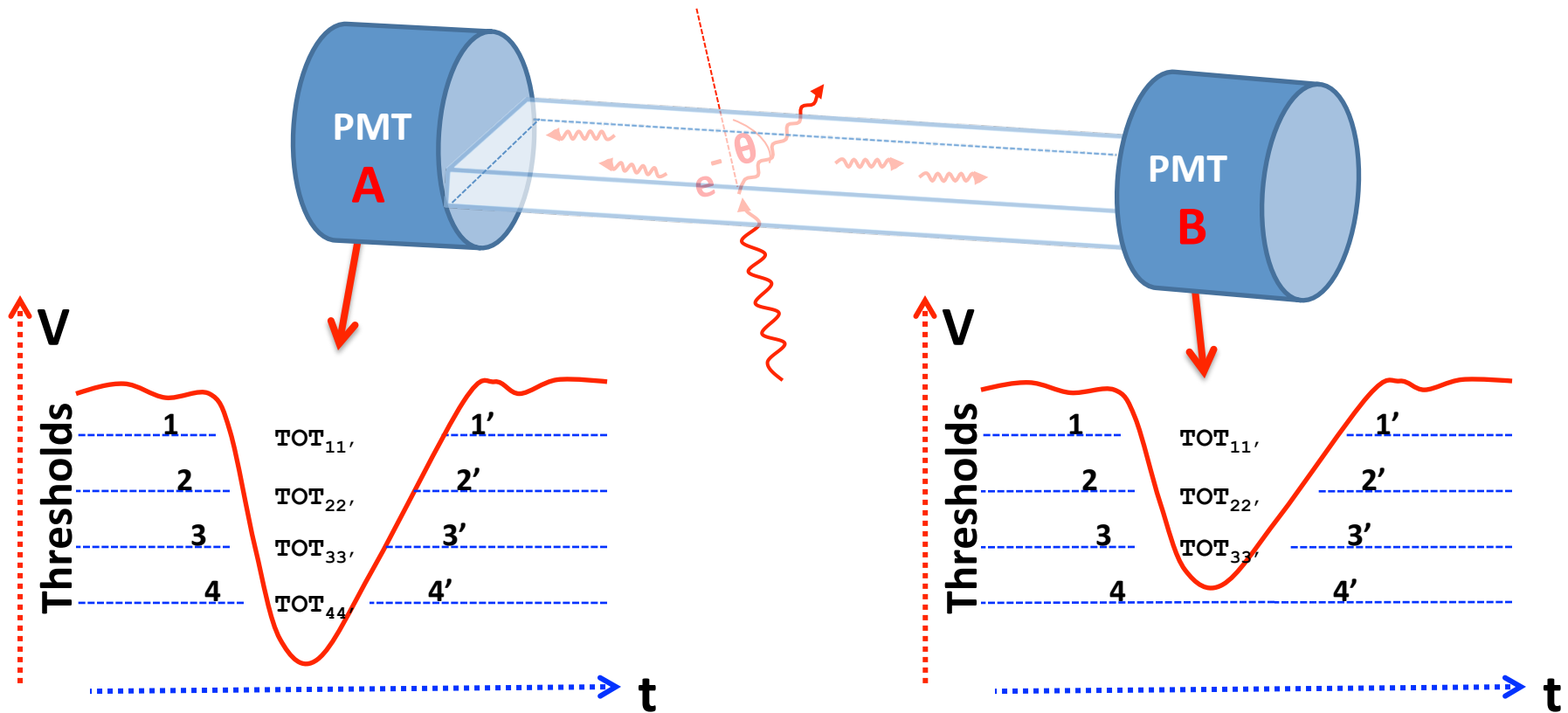
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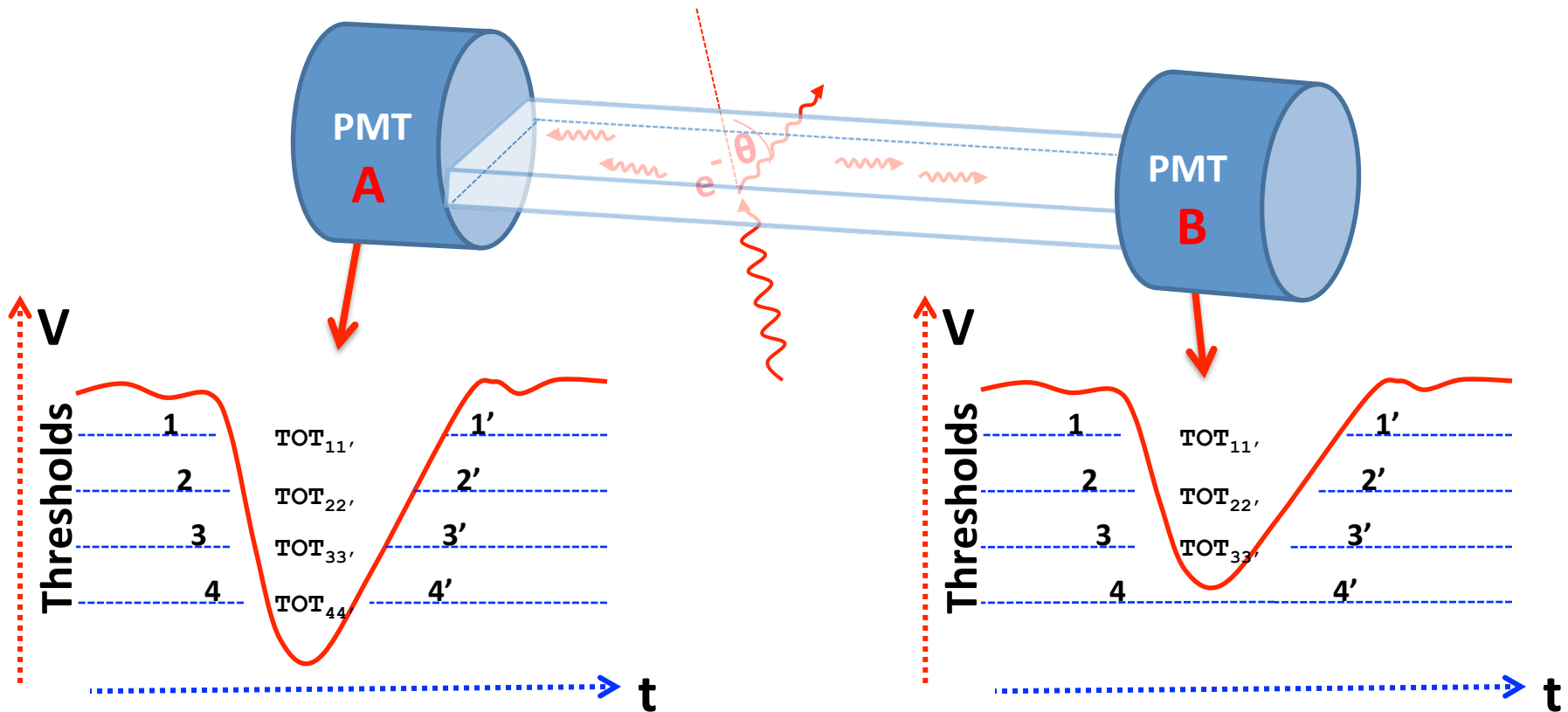
# Time-Over-Threshold & Energy deposition





Signals from each photomultiplier are probed at four thresholds.





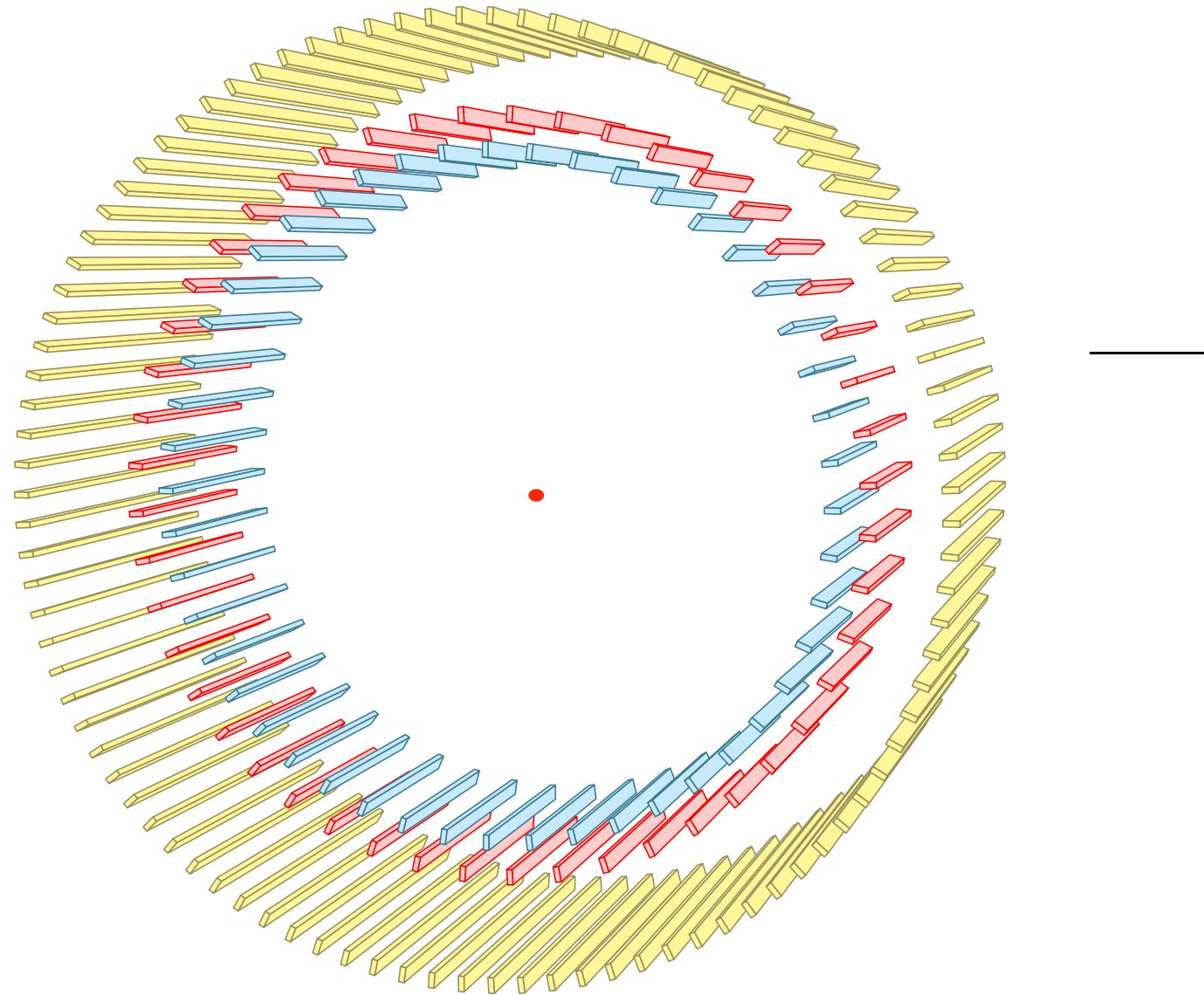
Signals from each photomultiplier are probed at four thresholds.

$$TOT = TOT_{\text{sum A}} + TOT_{\text{sum B}}$$





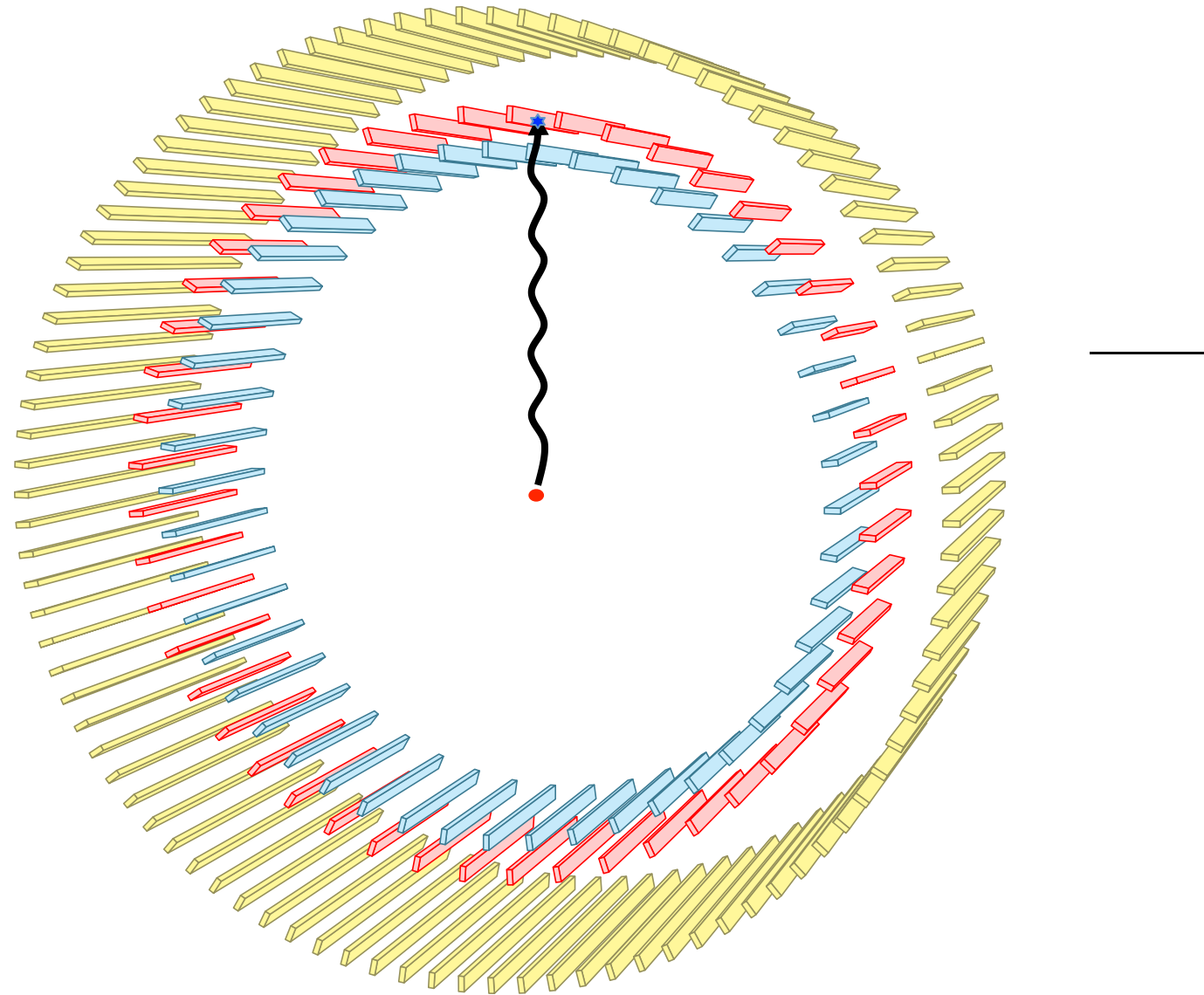
# Methodology :





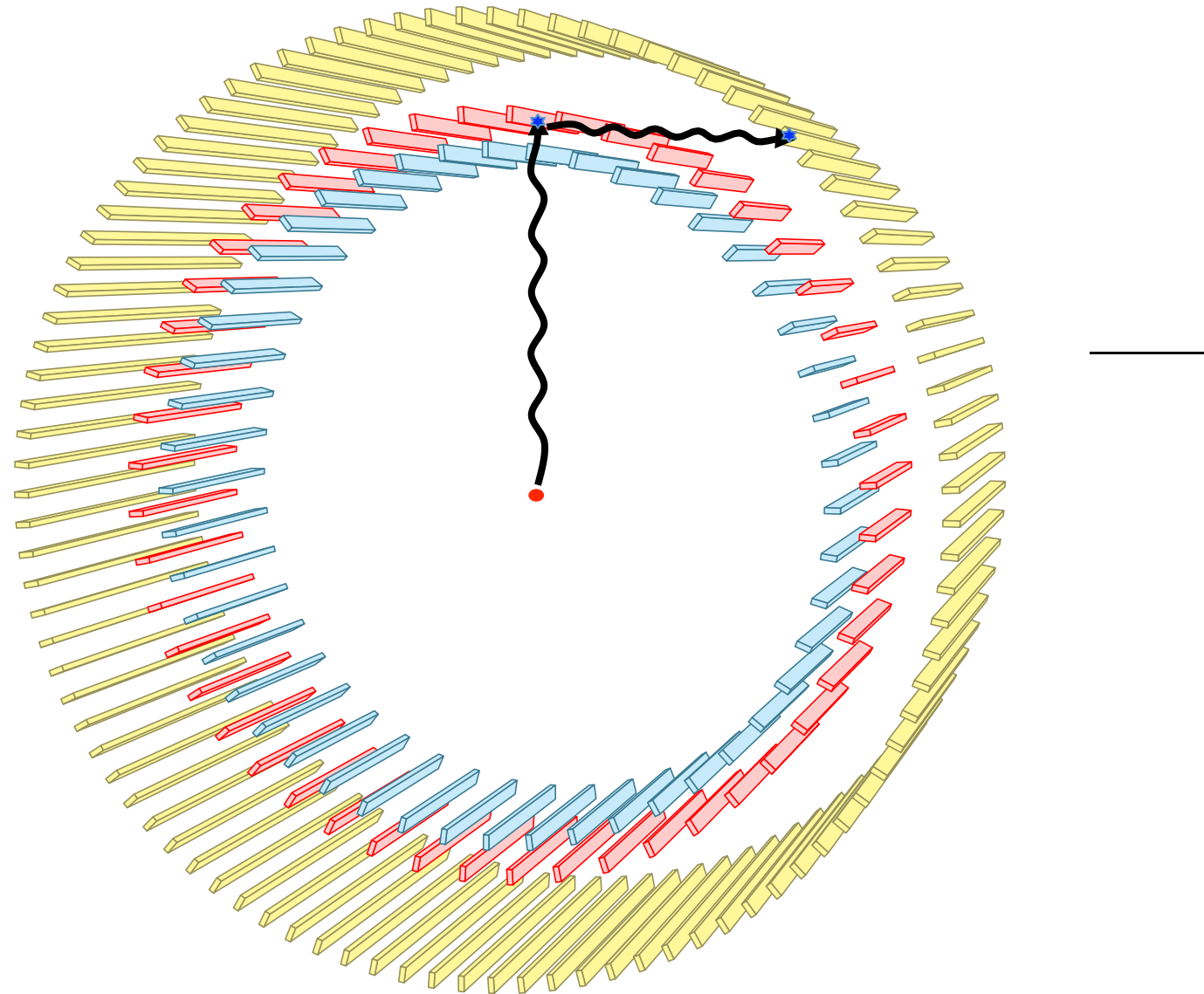


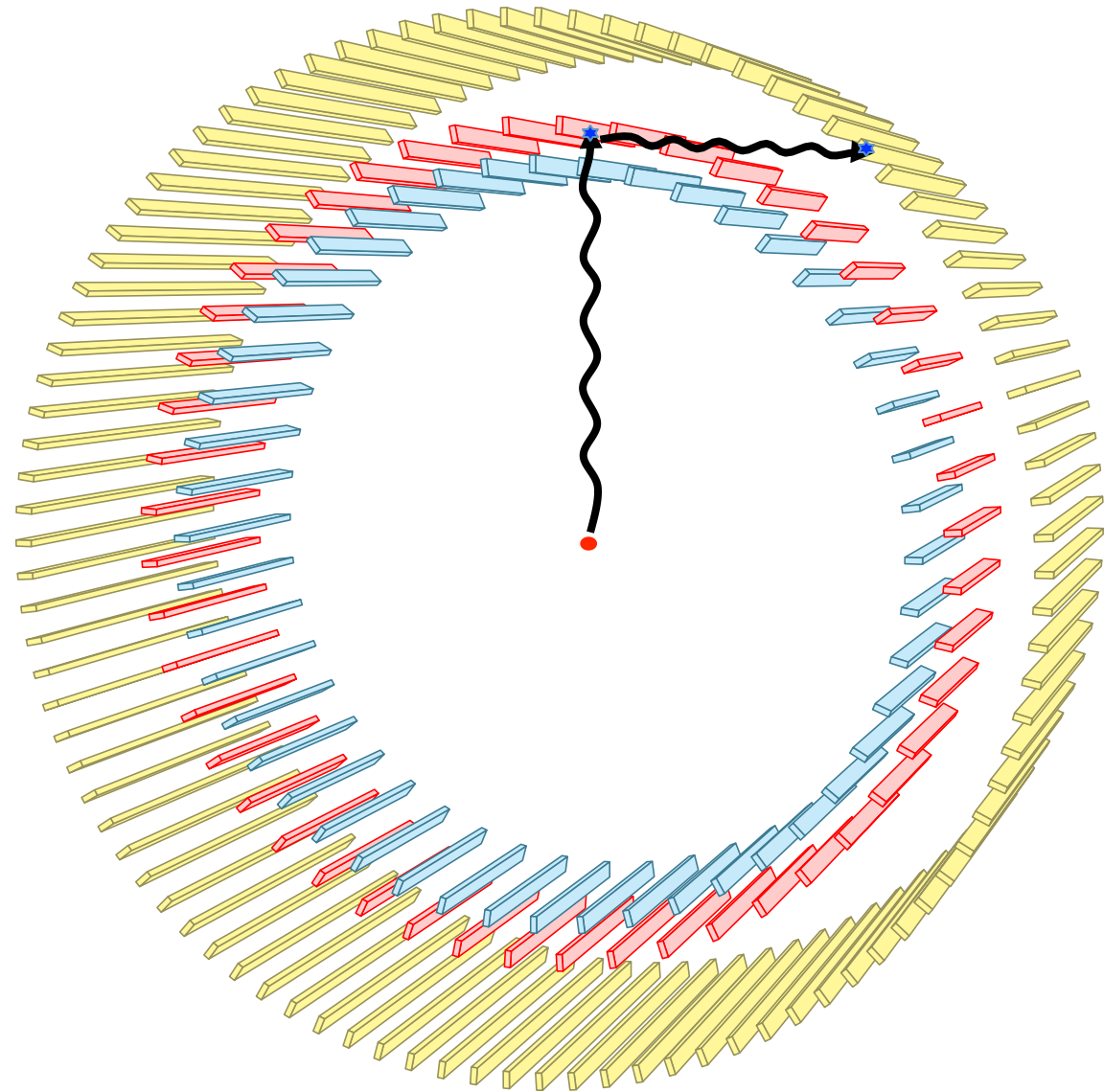
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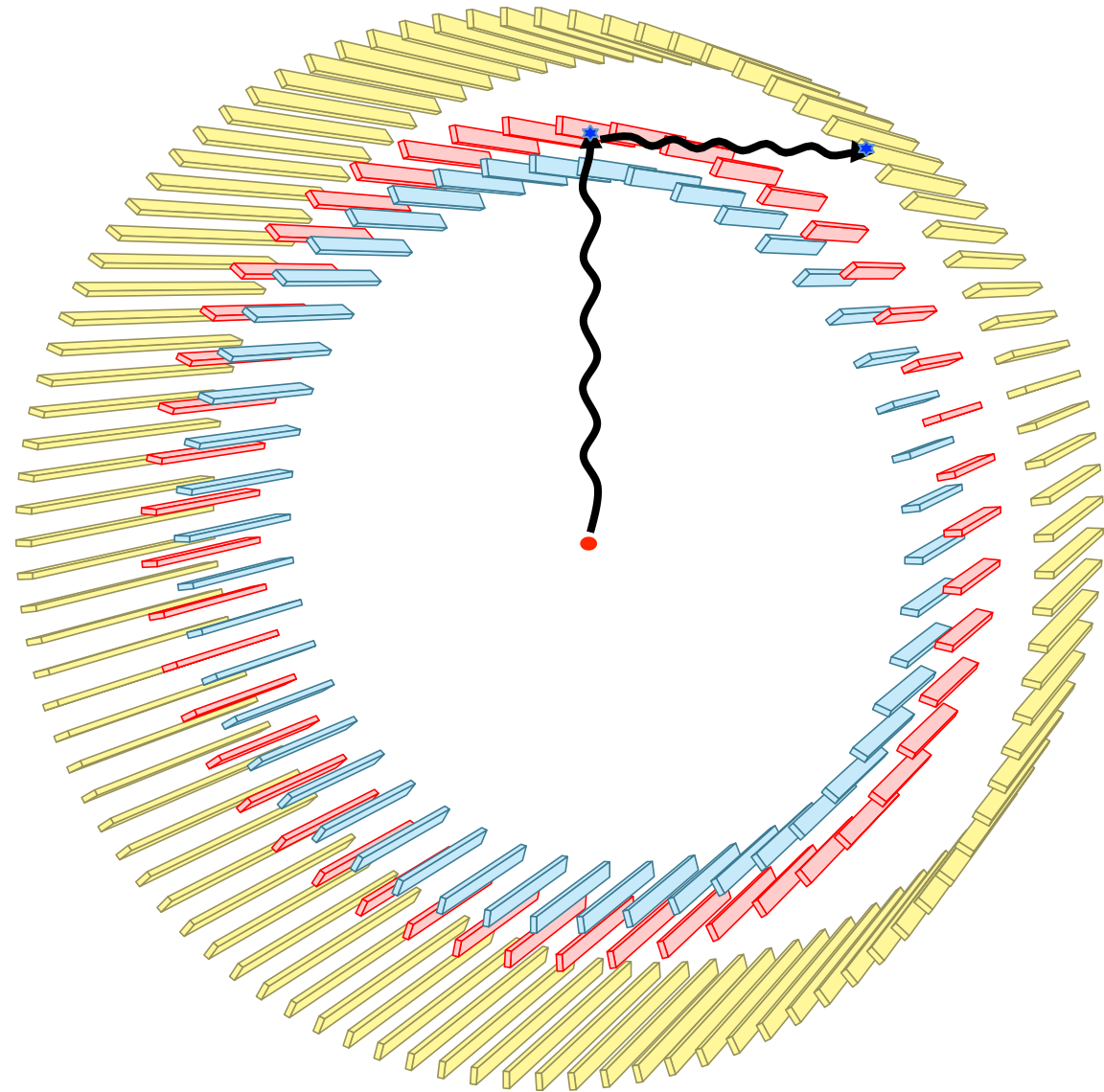




What we have :

\_\_\_\_\_

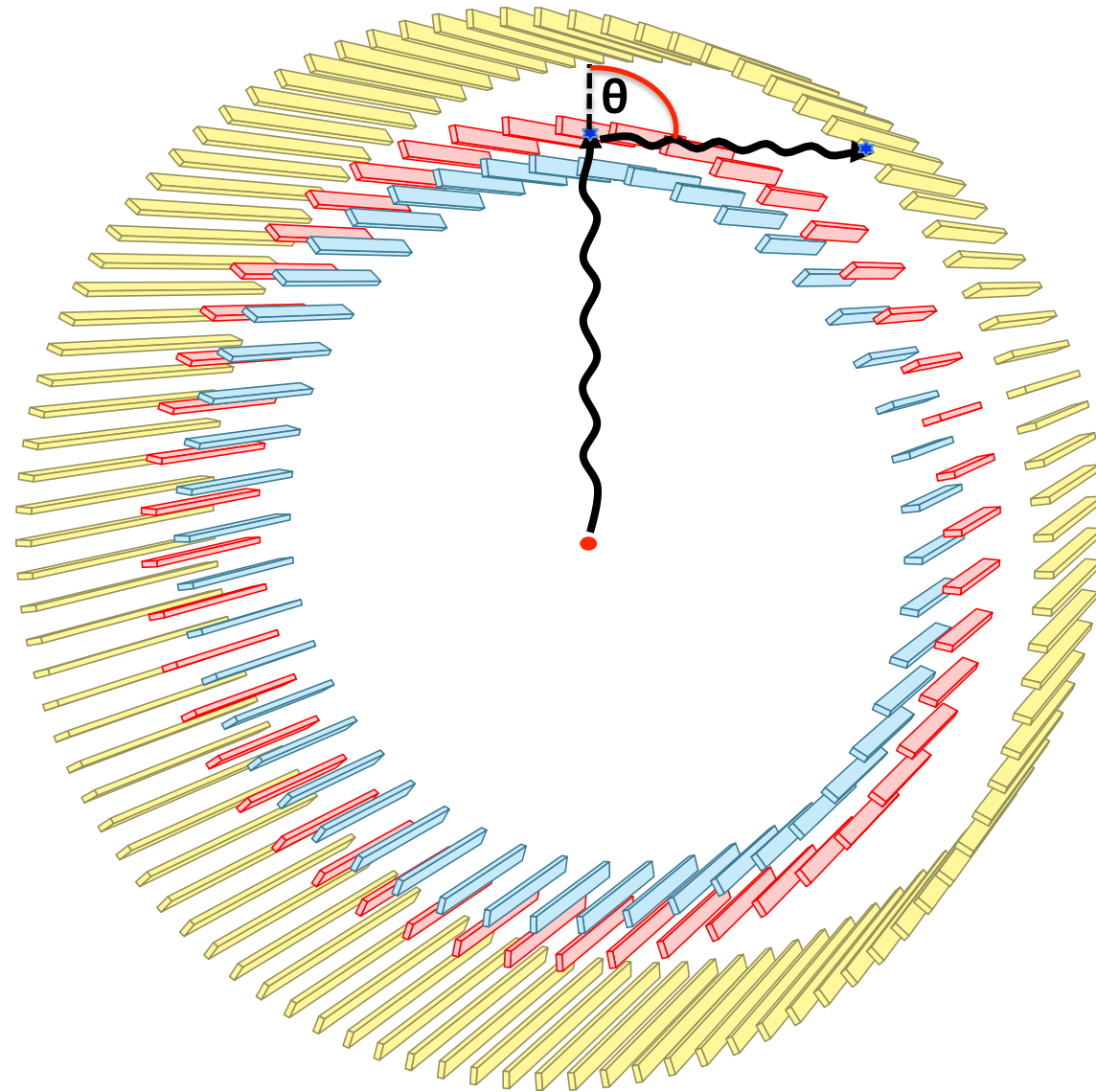




## What we have :

✓ Measured **TOT** values

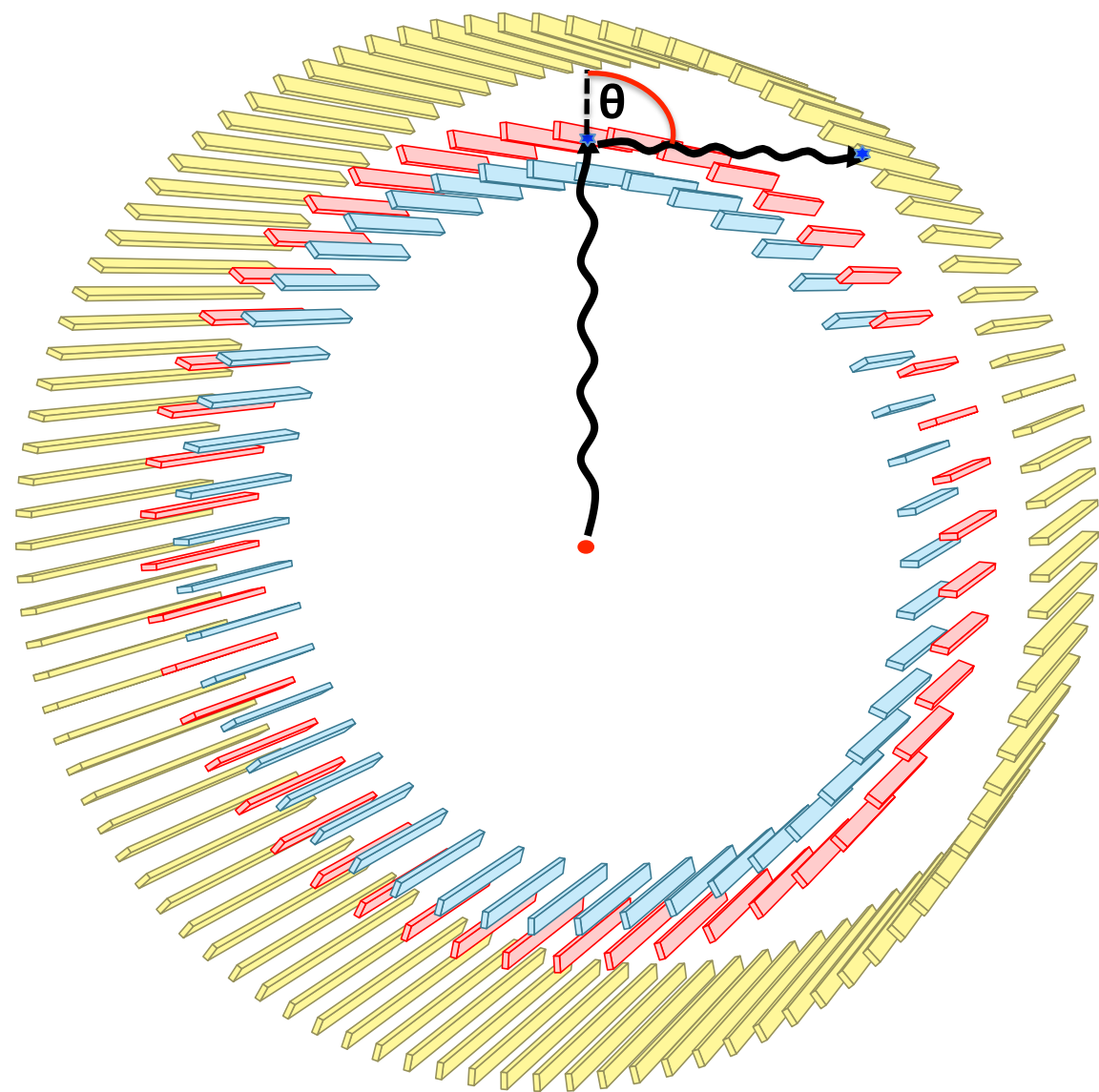




## What we have :

- ✓ Measured **TOT** values
- ✓ Hit positions of primary and scattered photon gives access to the  $\theta$  values



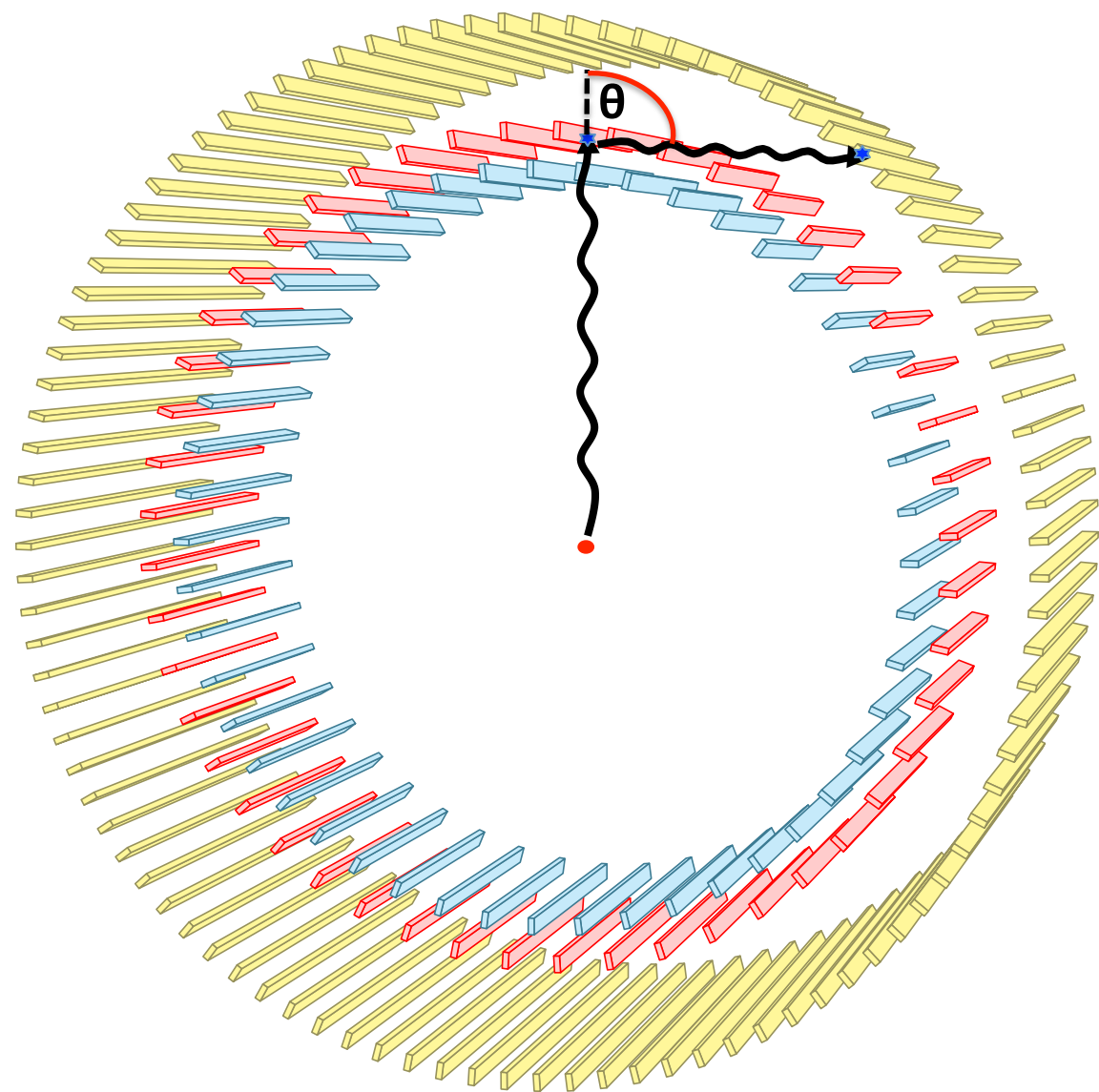


## What we have :

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## What is required :





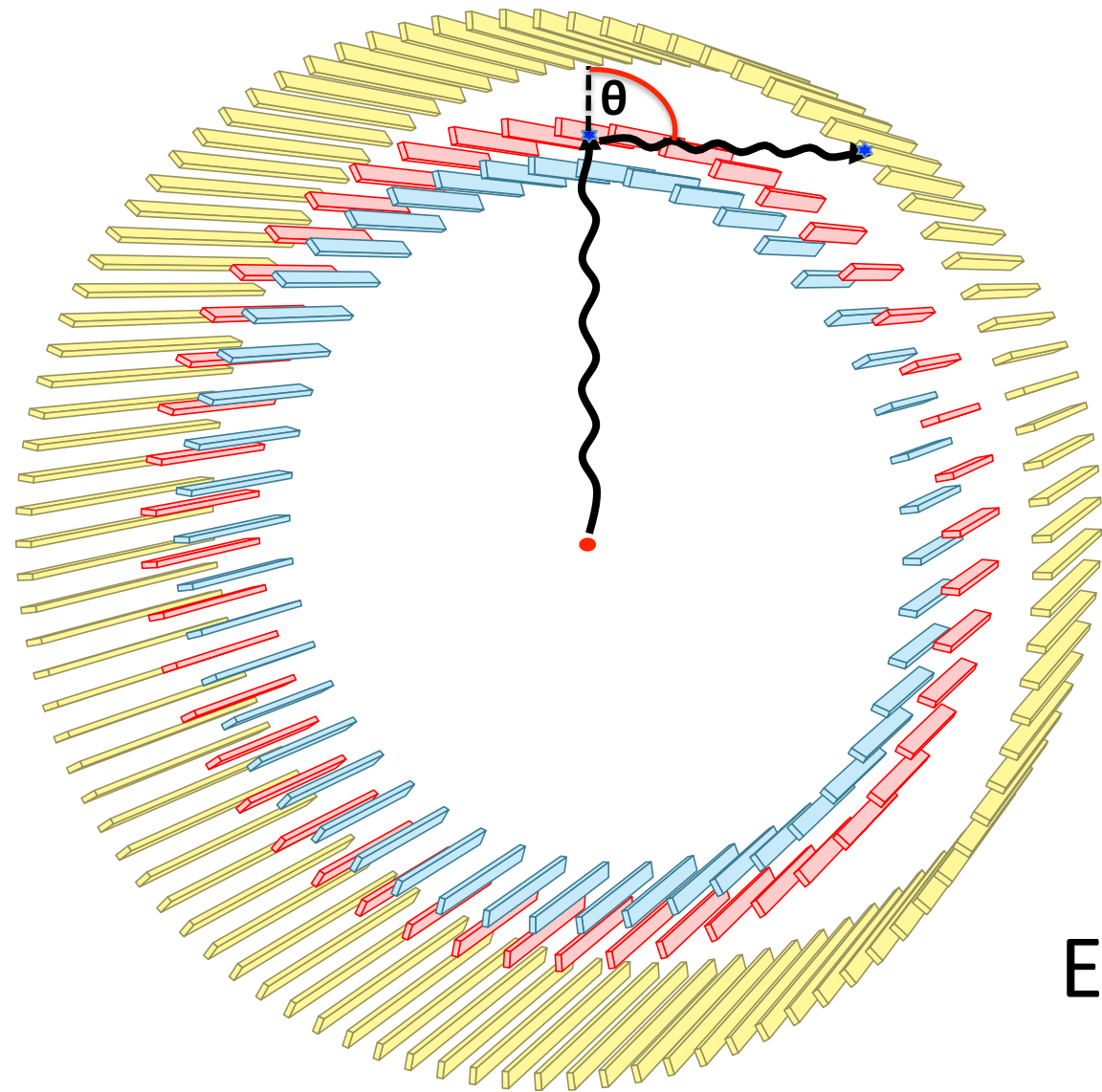
## What we have :

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## What is required :

- ✧ **Energy** of the **incident photon**
- ✧ True **scattering angle**





## What we have :

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- ✓ Hit positions of primary and scattered photon gives access to the  $\theta$  values

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- ✧ True **scattering angle**

$$E_{\text{dep}} = f(E_{\text{inc}}, \theta)$$







# Experimental details





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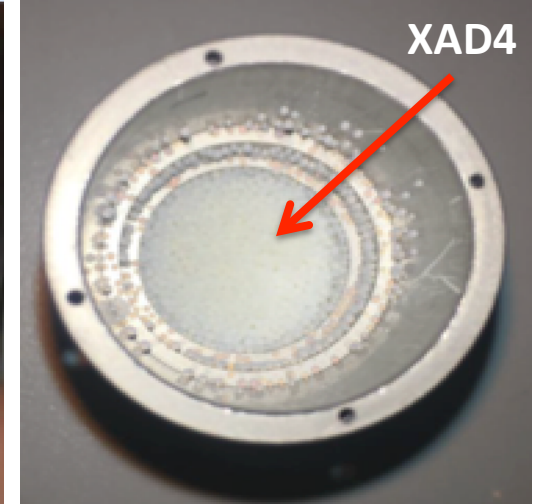
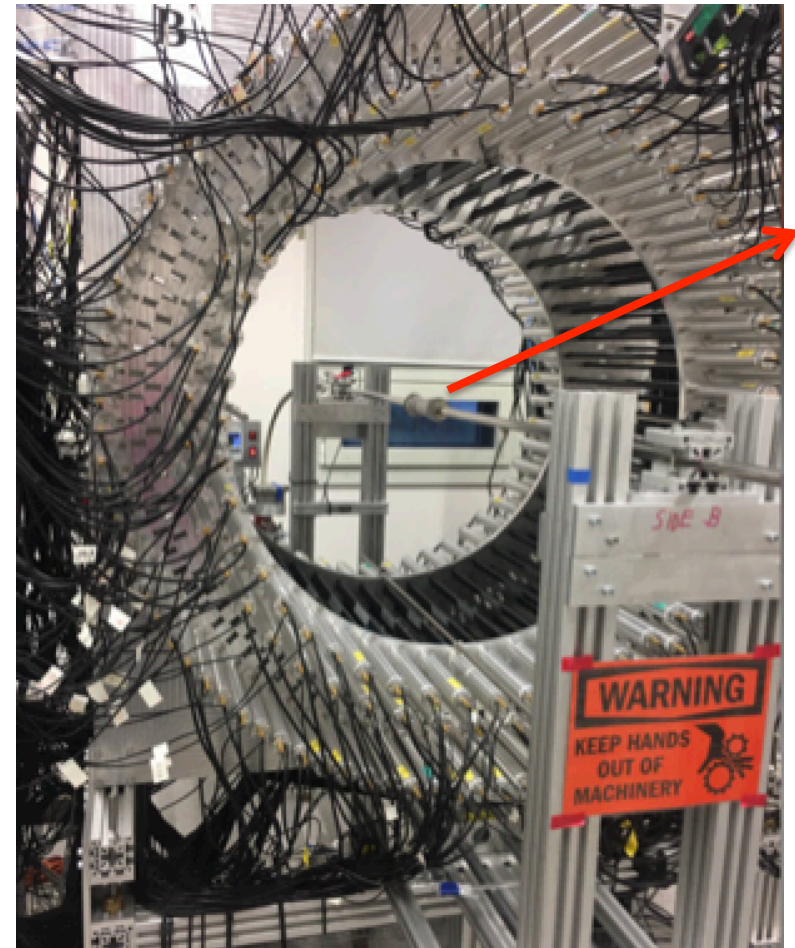
Small chamber in the center



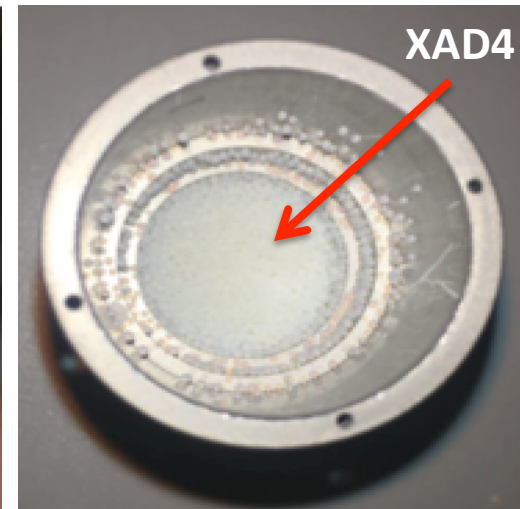
Small chamber in the center



## Small chamber in the center



## Small chamber in the center



## Run specifications :

Run number : 4 with small chamber

Total files analysed : **500 / 3500**

Velocity calibration : **Applied**

Time Calibration : **Applied**



# Events selection -



— —





# Events selection -



Analyzed : **3 Hit Events**

— —





# Events selection -



Analyzed : **3 Hit Events**

- In order to study *scattering of a photon*, two hits are sufficient.







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## Case 1

$e^+$  -  $e^-$  annihilation into  
two photons  
(**511 keV**)





# Events selection -



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## Case 1

$e^+$  -  $e^-$  annihilation into  
two photons  
(**511 keV**)

## Case 2

high energetic photons  
1274.6keV  
(**Prompt**)

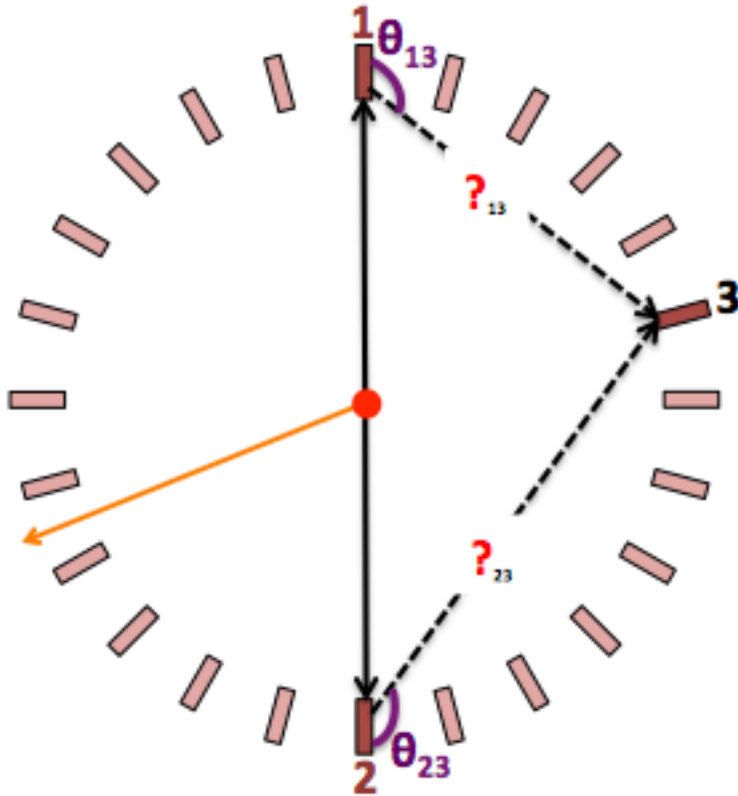




# 3 Hit Events ( Tagging 511 keV)



(hits are ordered in time)

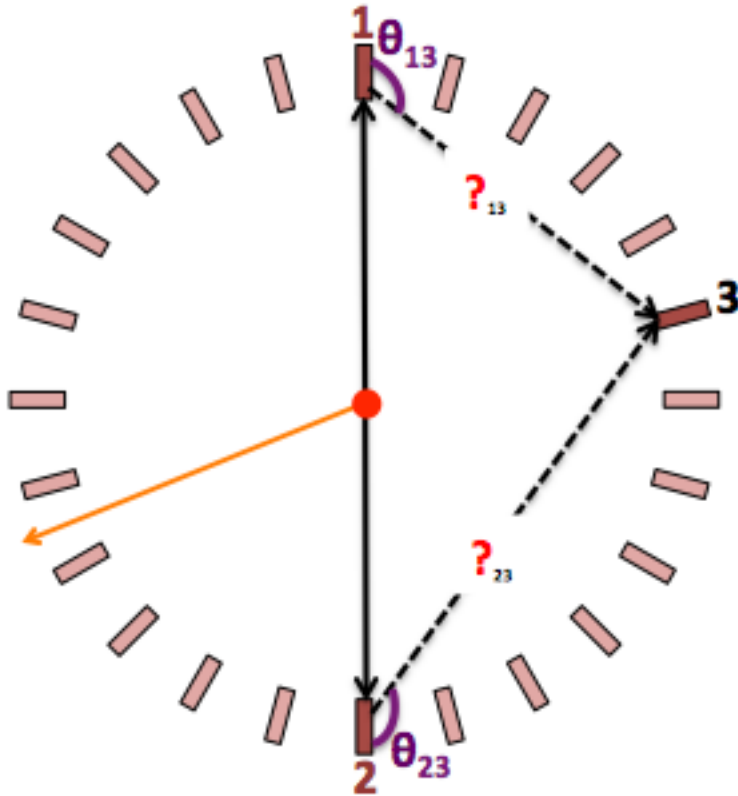




# 3 Hit Events ( Tagging 511 keV)



(hits are ordered in time)



- Two hits are Back-to-Back gamma

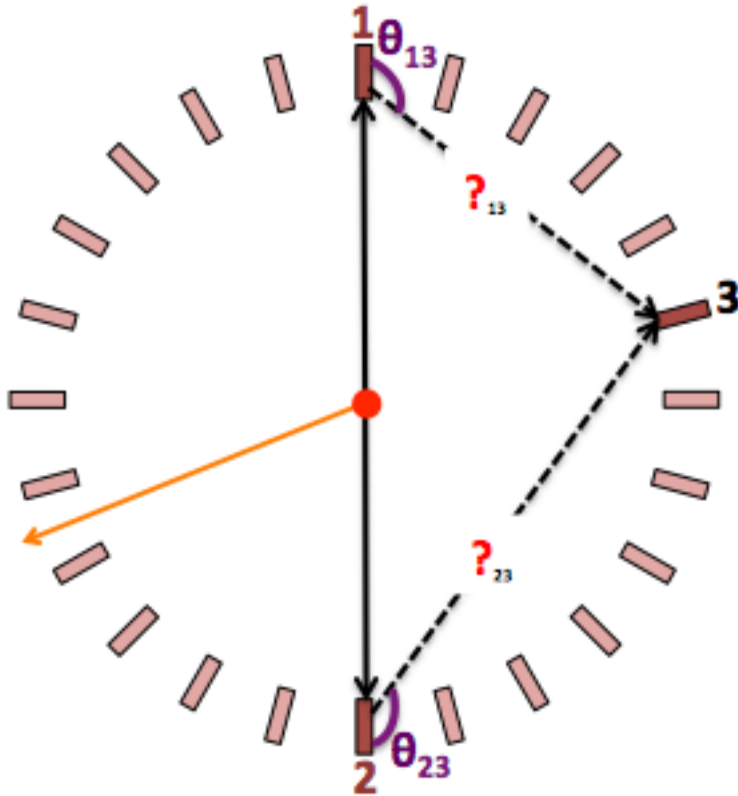




# 3 Hit Events ( Tagging 511 keV)



(hits are ordered in time)



- Two hits are Back-to-Back gamma
- 3<sup>RD</sup> Hit from the scattering of gamma either after Hit 1 or Hit2



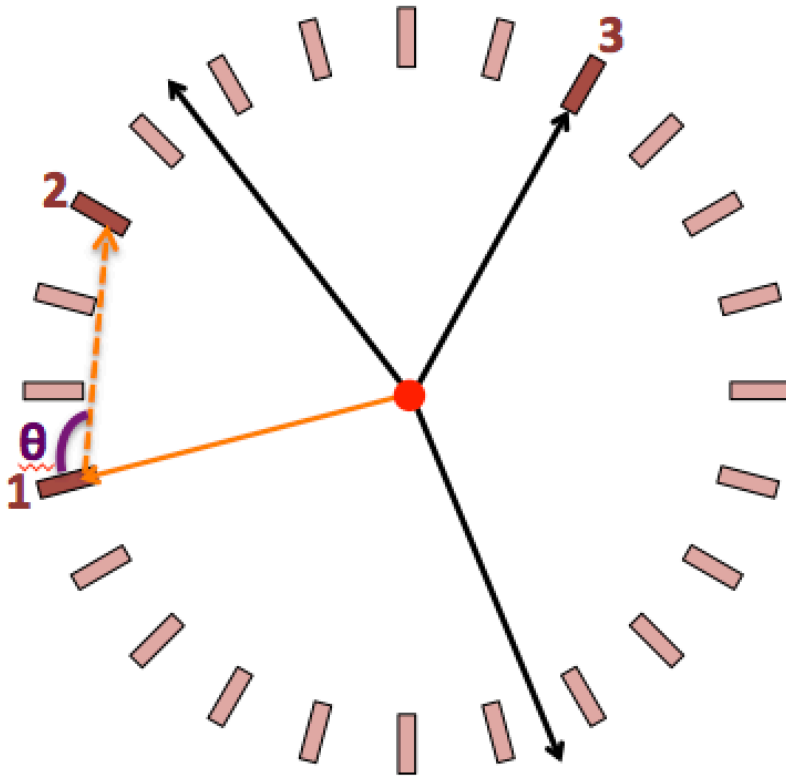


# 3 Hit Events ( Tagging **1274.6 keV**)



(hits are ordered in time)

Case 2: for 1274.6keV (Prompt)



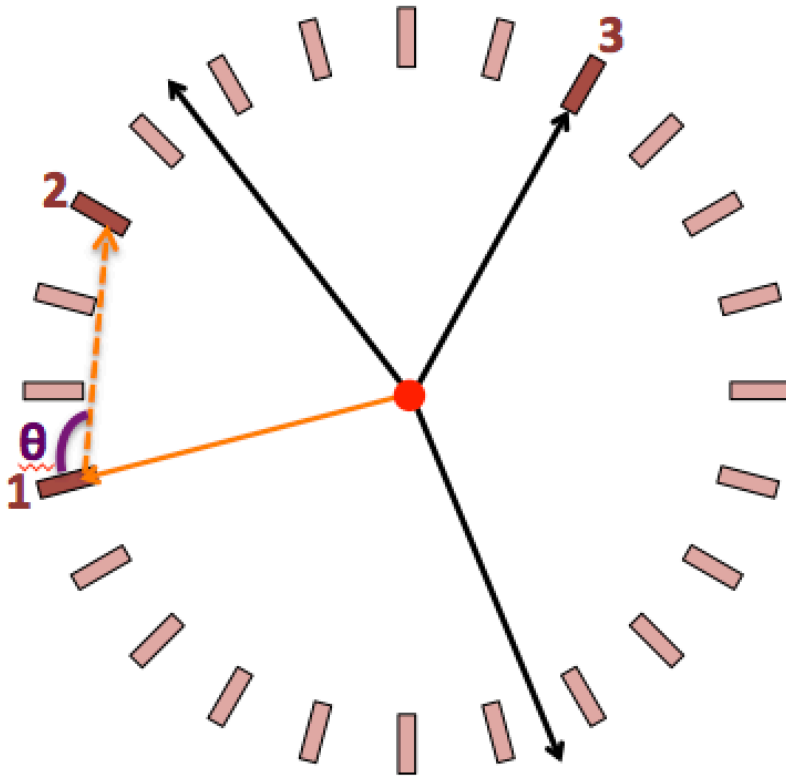


# 3 Hit Events ( Tagging **1274.6 keV**)



(hits are ordered in time)

Case 2: for 1274.6keV (Prompt)



- 1<sup>st</sup> Hit is prompt gamma

\_\_\_\_\_





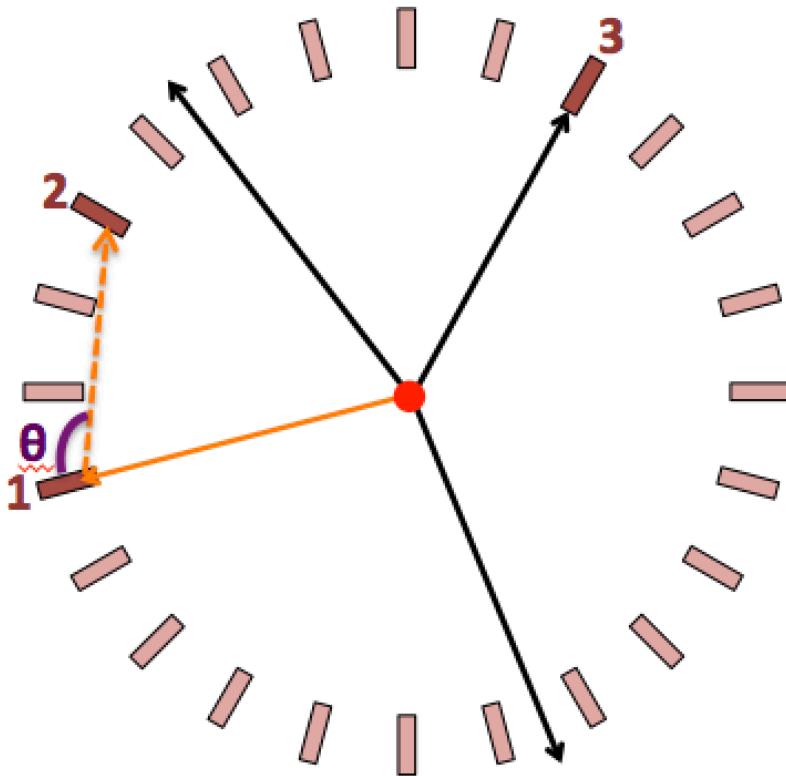


# 3 Hit Events ( Tagging **1274.6 keV**)



(hits are ordered in time)

Case 2: for 1274.6keV (Prompt)



- 1<sup>st</sup> Hit is prompt gamma
- 2<sup>nd</sup> Hit from the scattering of prompt gamma

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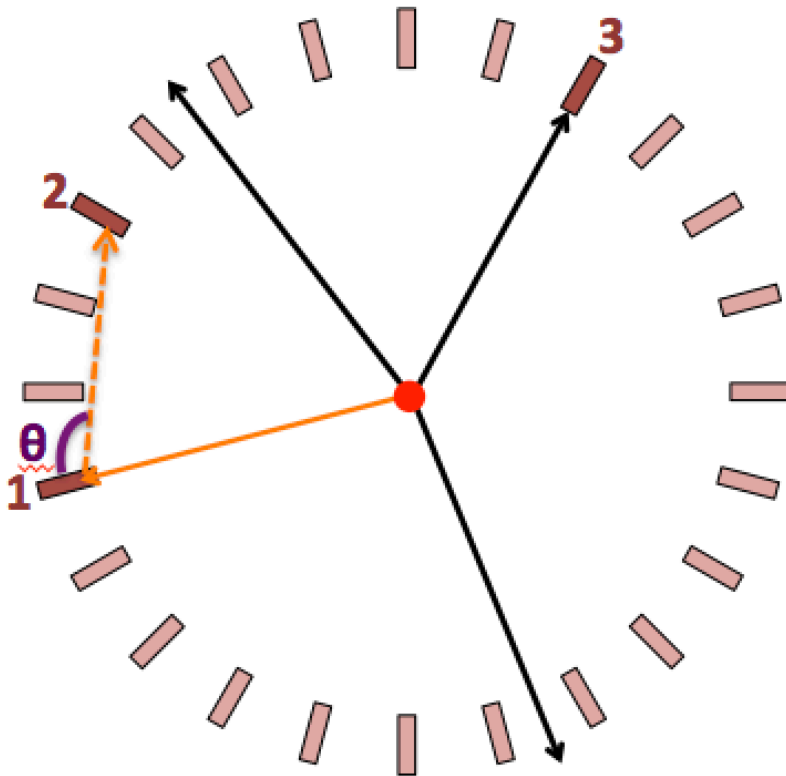


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- 1<sup>st</sup> Hit is prompt gamma
- 2<sup>nd</sup> Hit from the scattering of prompt gamma
- 3<sup>rd</sup> hit is assumed as one of the annihilation gamma from oPs decay as the time difference b/w 1<sup>st</sup> hit and 3<sup>rd</sup> hit is taken more than 10 ns



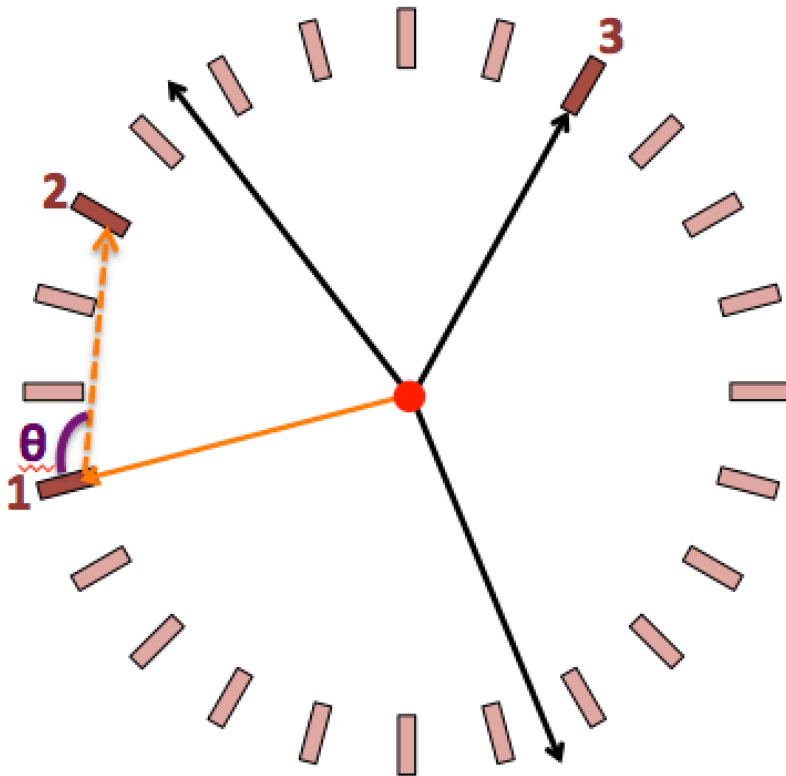


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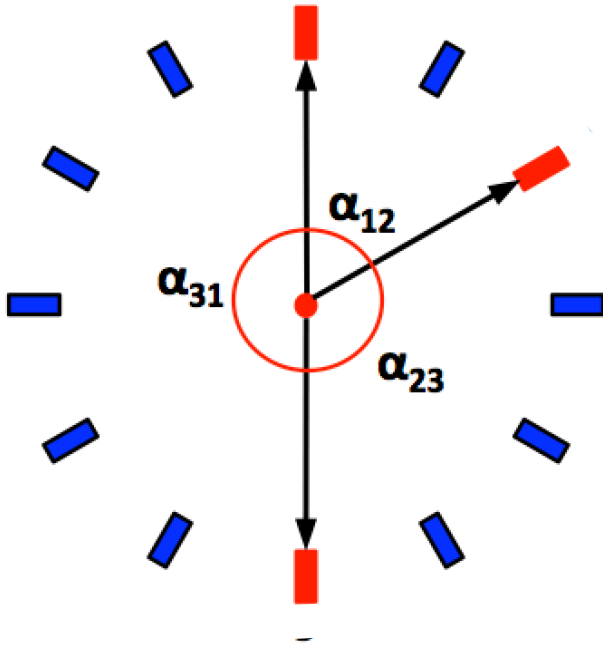


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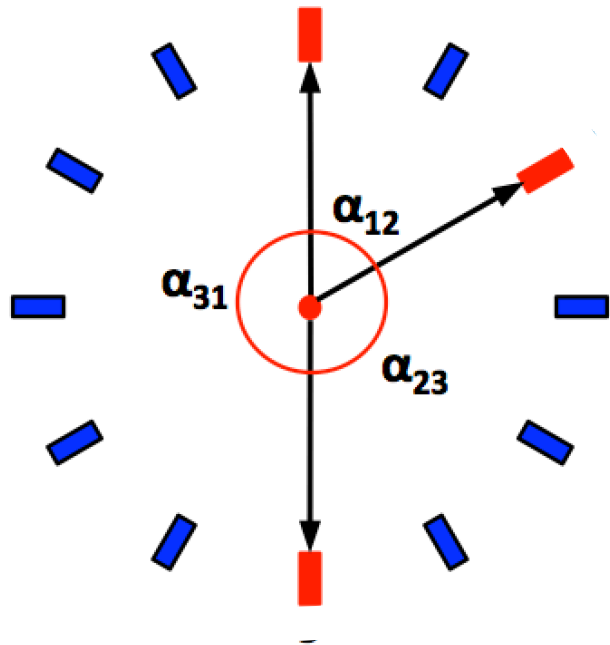


# 3 - Hit Angles



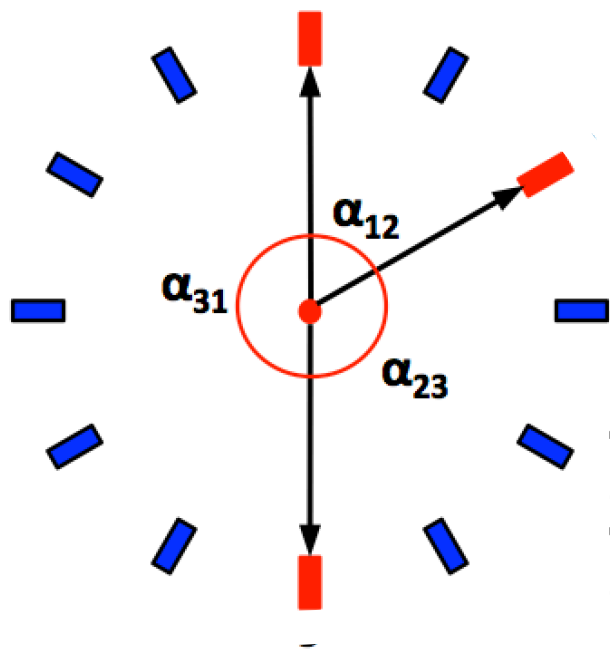


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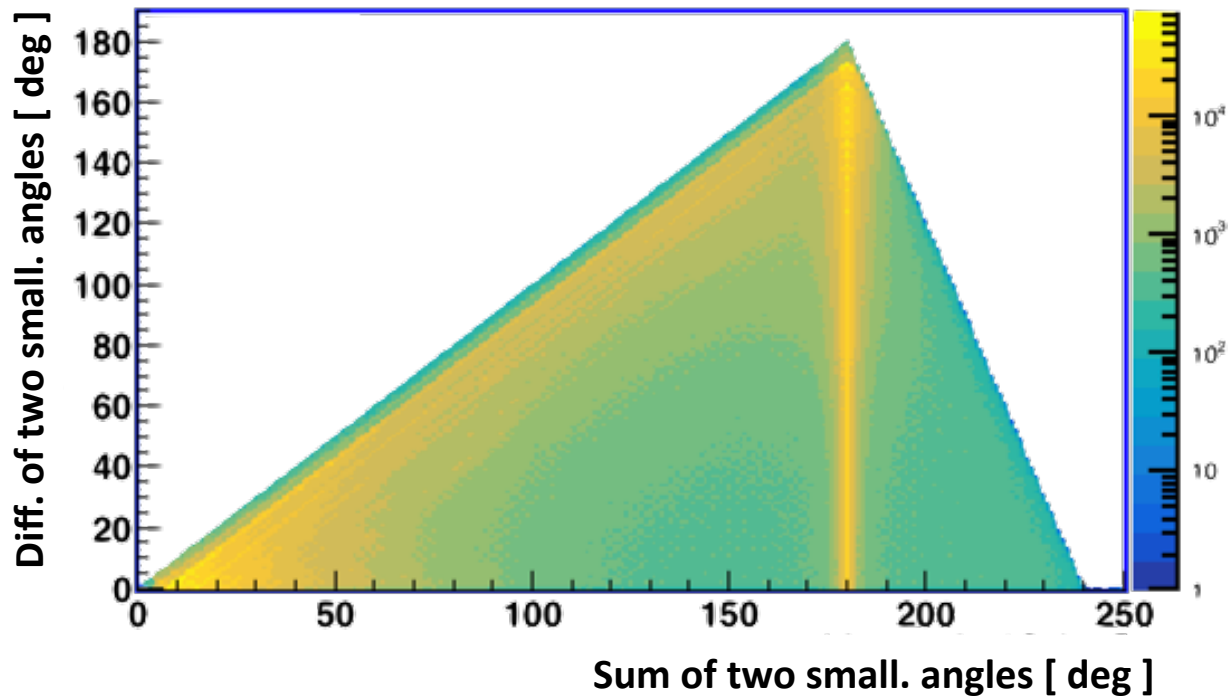


$$\alpha_{12} < \alpha_{23} < \alpha_{31}$$





$$\alpha_{12} < \alpha_{23} < \alpha_{31}$$





# Tagging the 511 keV photon



**Applied Cuts:**



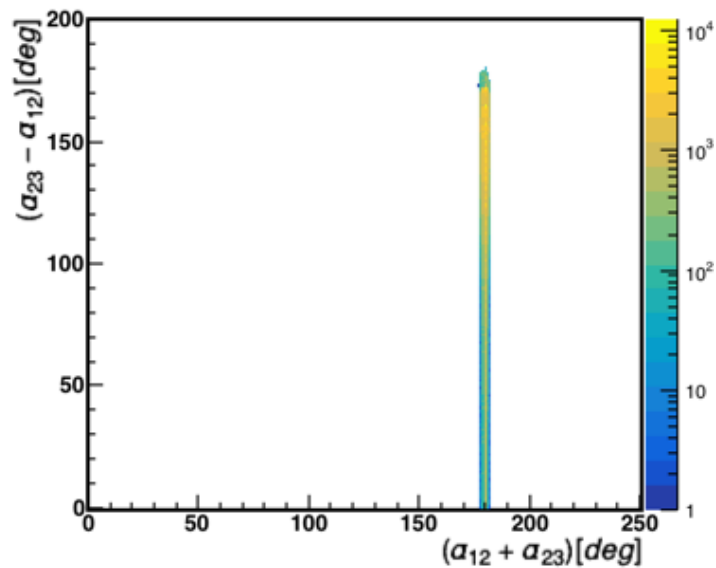


# Tagging the 511 keV photon



## Applied Cuts:

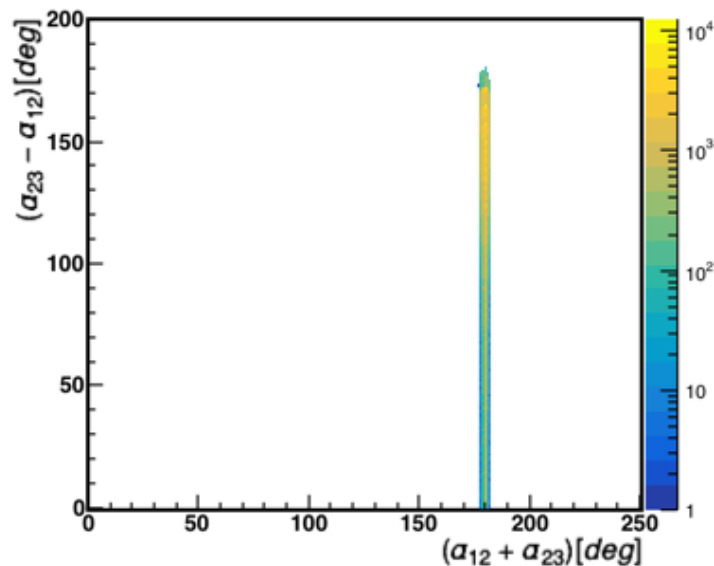
Hit 1 and Hi 2 are back to back (511keV)



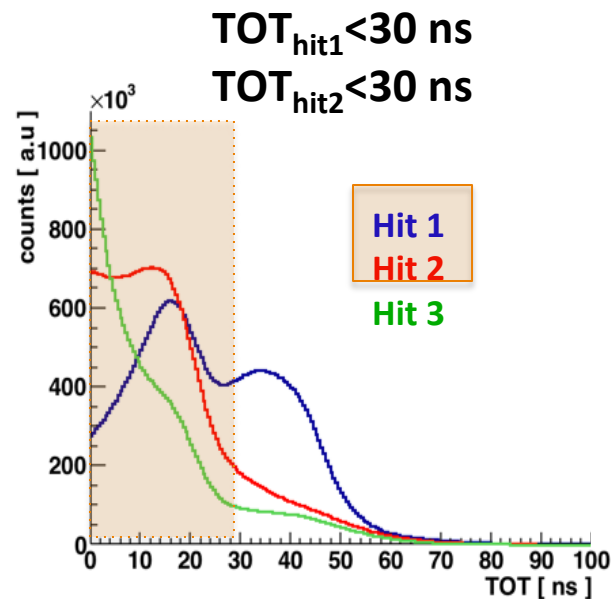


## Applied Cuts:

<sup>1</sup> Hit 1 and Hit 2 are back to back (511keV)

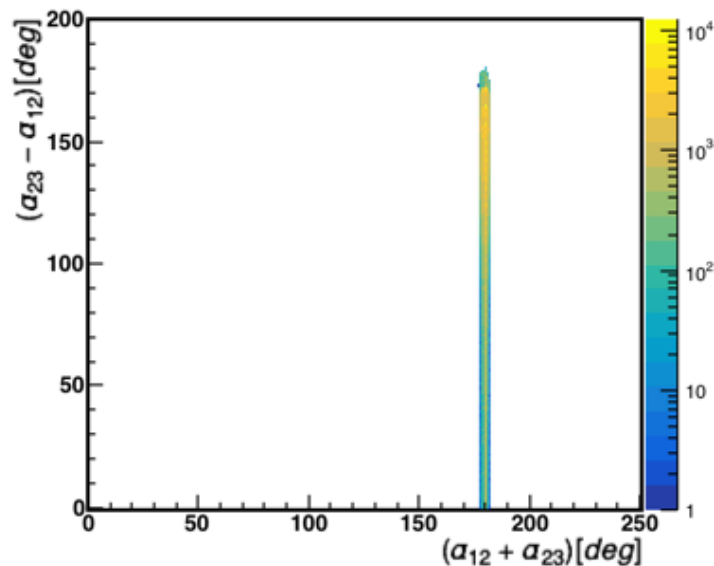


<sup>2</sup> TOT :

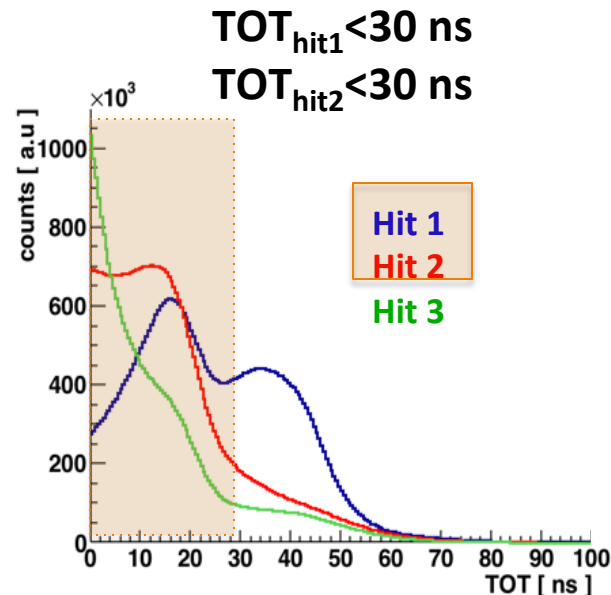


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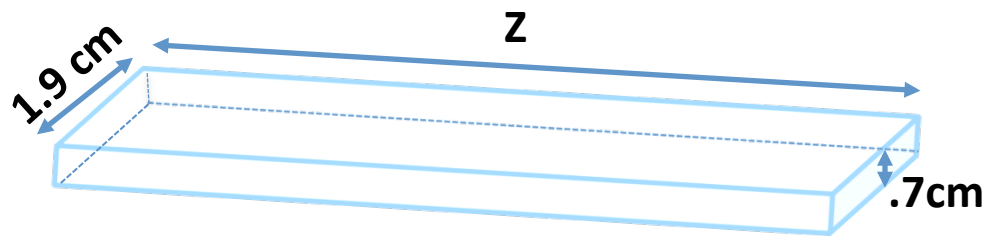


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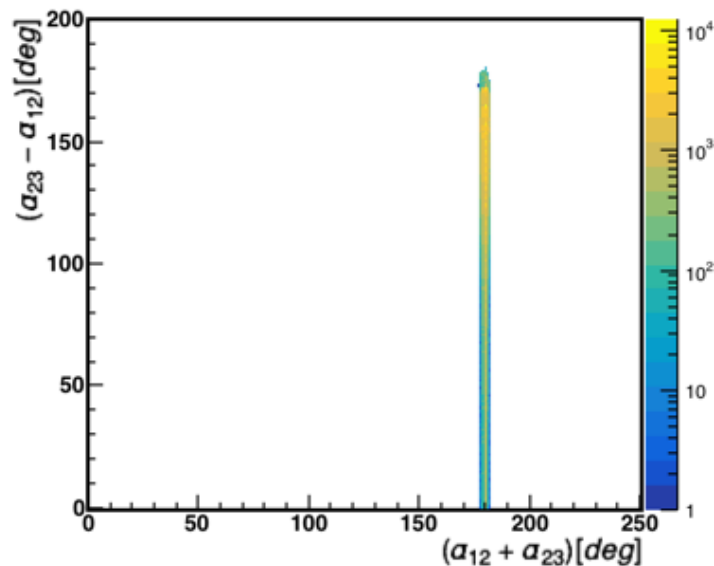
<sup>3</sup> Along Z :

$$\begin{aligned}
 -23 < Z_{hit1} < 23 \\
 -23 < Z_{hit2} < 23 \\
 -23 < Z_{hit3} < 23
 \end{aligned}$$

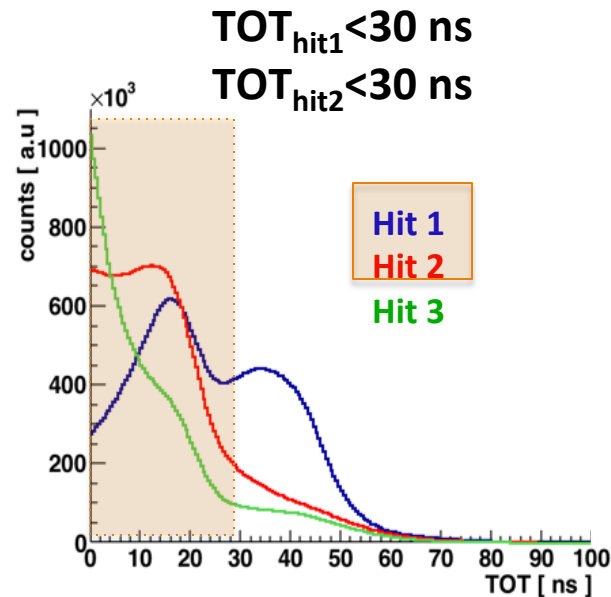


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2 TOT :

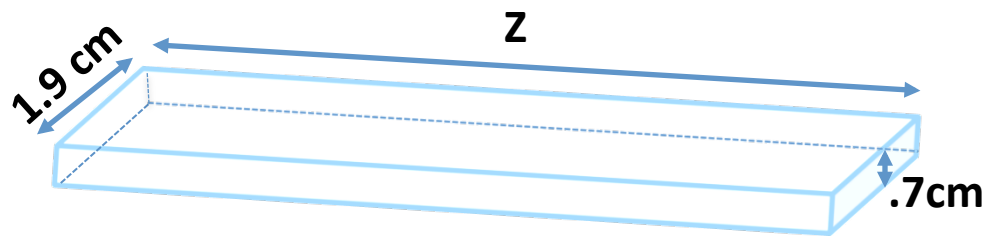


3 Along Z :

$$-23 < Z_{hit1} < 23$$

$$-23 < Z_{hit2} < 23$$

$$-23 < Z_{hit3} < 23$$



4 NO 2 hits in same scintillator



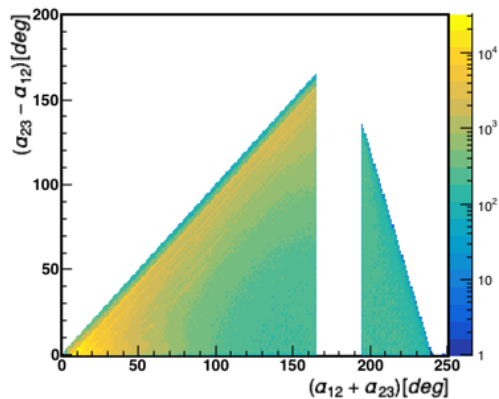


# Tagging the 1274.6 keV photon





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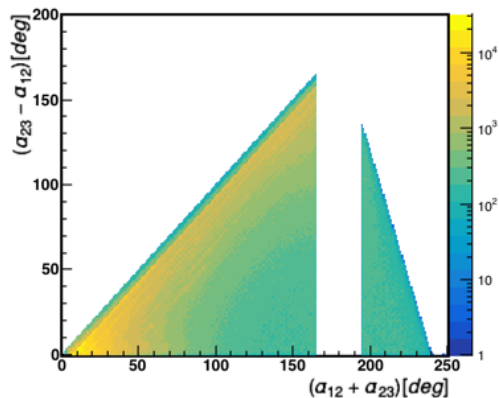


Cut on 3 Hits angles

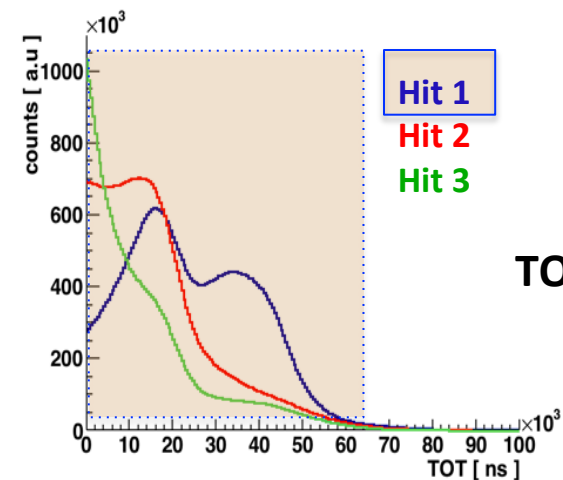




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Cut on 3 Hits angles

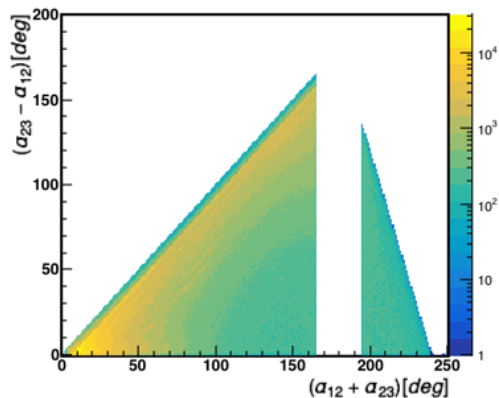


$TOT_{hit1} < 65 \text{ ns}$

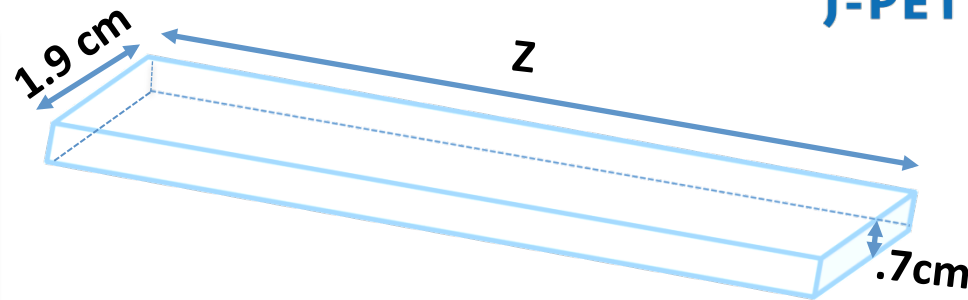




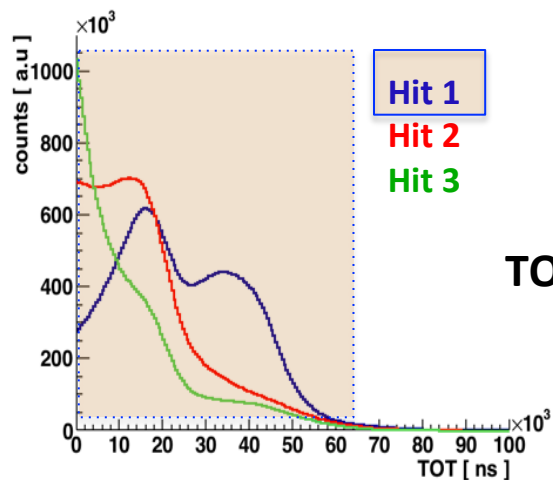
# Tagging the 1274.6 keV photon



Cut on 3 Hits angles



Along Z : for all hits  
 $-23 < Z < 23$

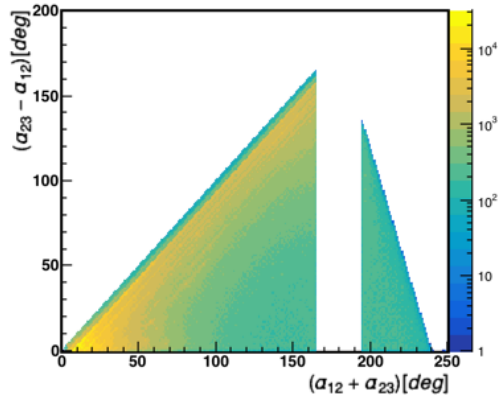


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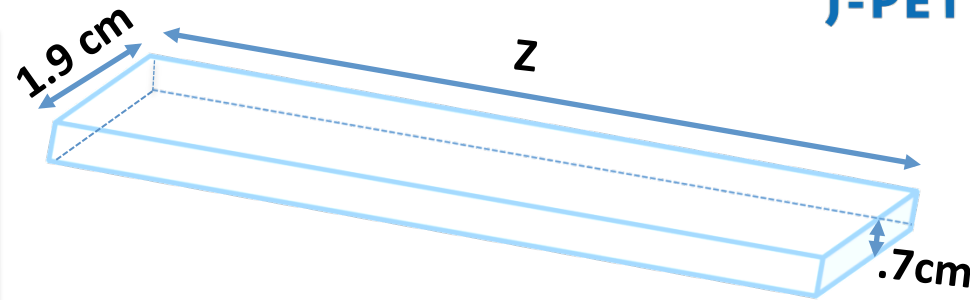




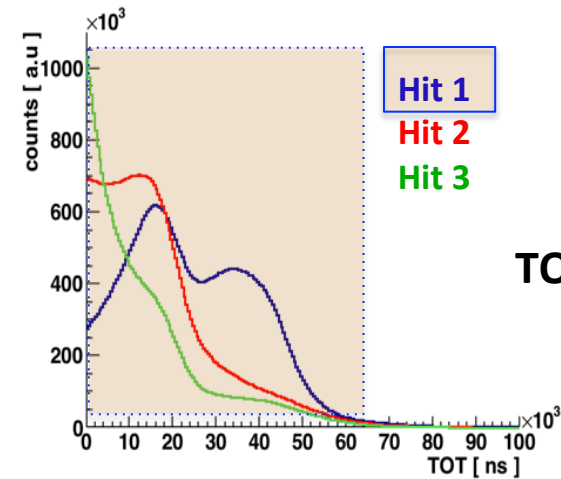
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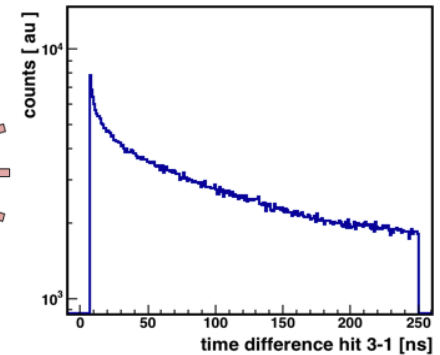
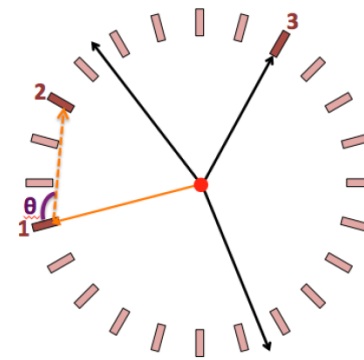
Cut on 3 Hits angles



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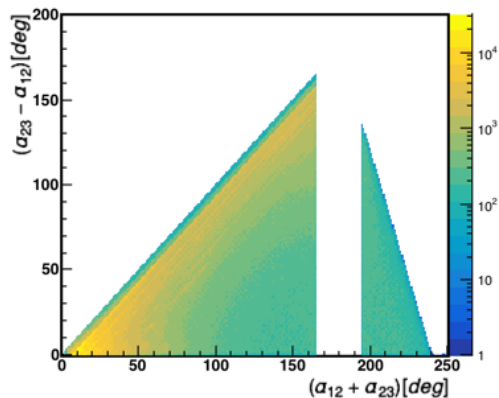
Time diff:  $Time_{hit3} - Time_{hit1} > 10 \text{ ns}$



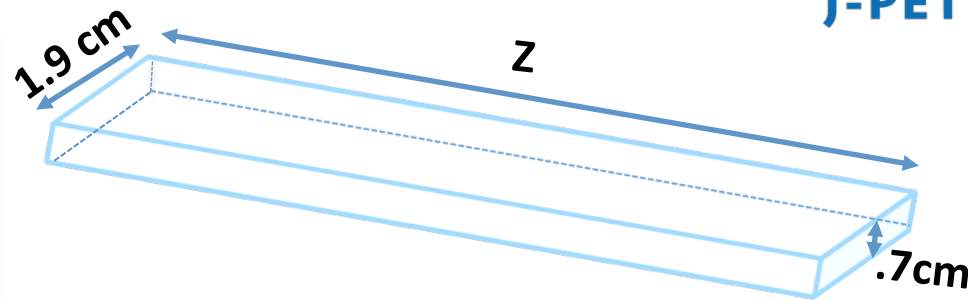




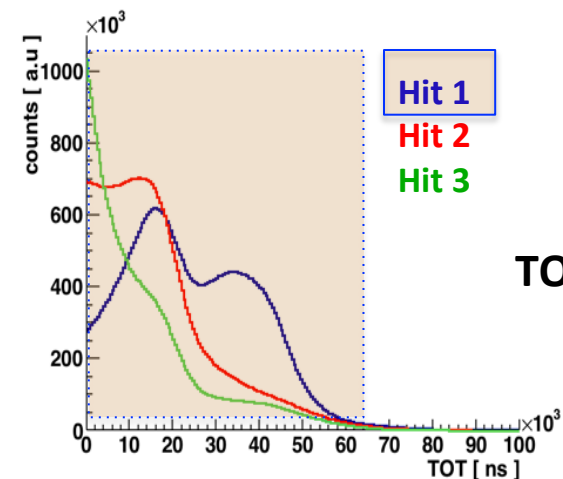
# Tagging the 1274.6 keV photon



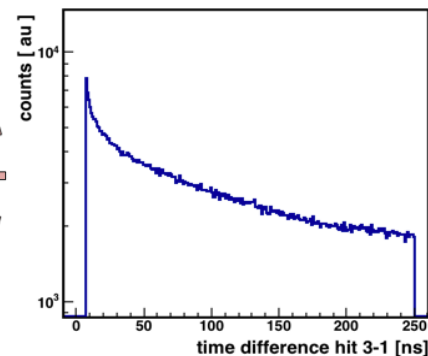
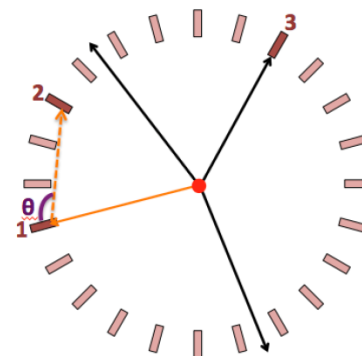
Cut on 3 Hits angles



Along Z : for all hits  
 $-23 < Z < 23$



$TOT_{hit1} < 65 \text{ ns}$



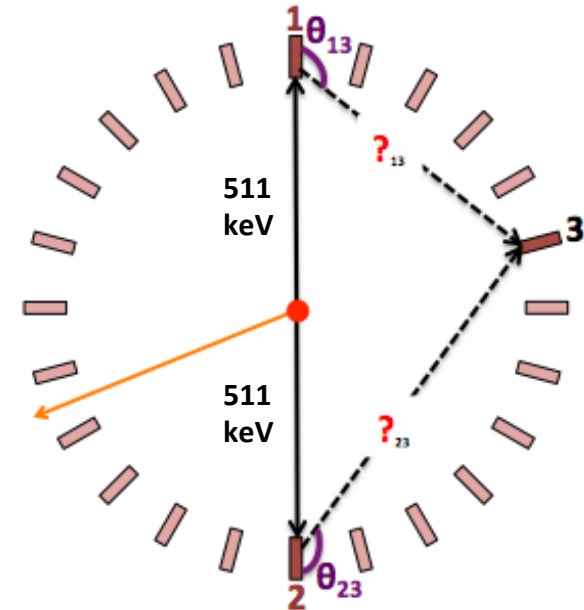
Time diff:  $Time_{hit3} - Time_{hit1} > 10 \text{ ns}$

**NO 2 hits** in same scintillator



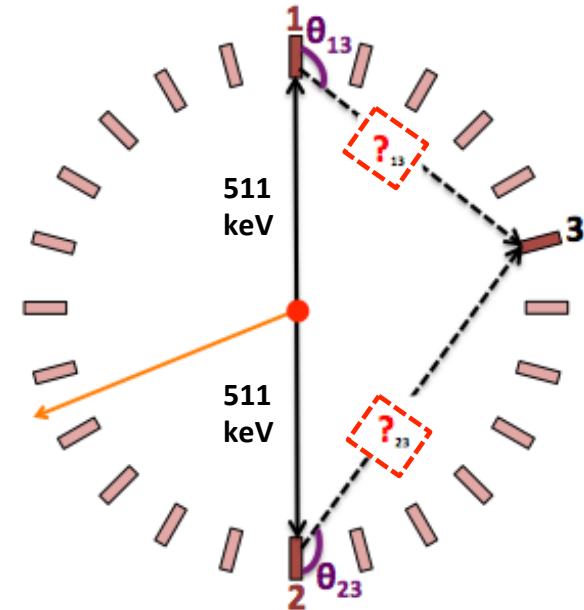


# Results – Scattering angle distribution (511 keV)





# Results – Scattering angle distribution (511 keV)

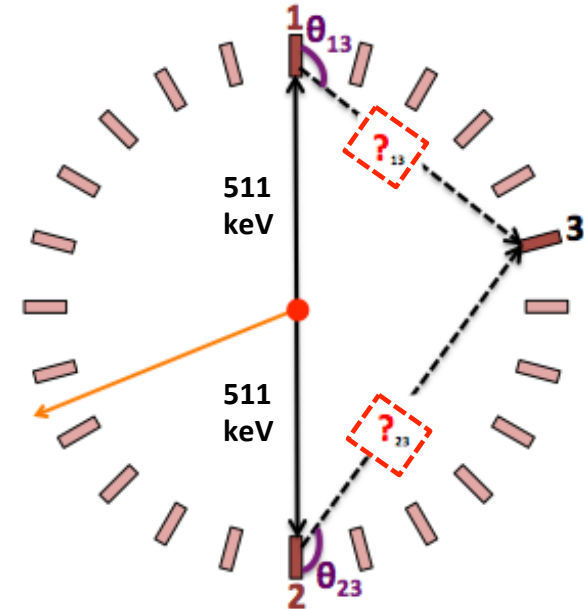




# Results – Scattering angle distribution (511 keV)



For the assignment of scattered hit to its origin, scatter test(S) was applied:



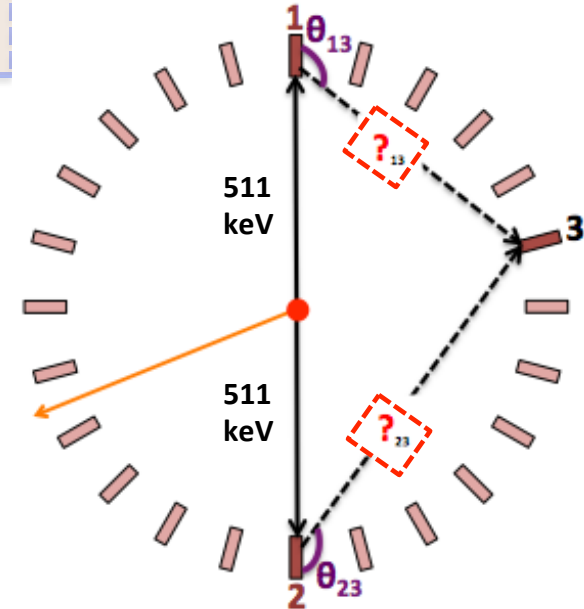


# Results – Scattering angle distribution (511 keV)



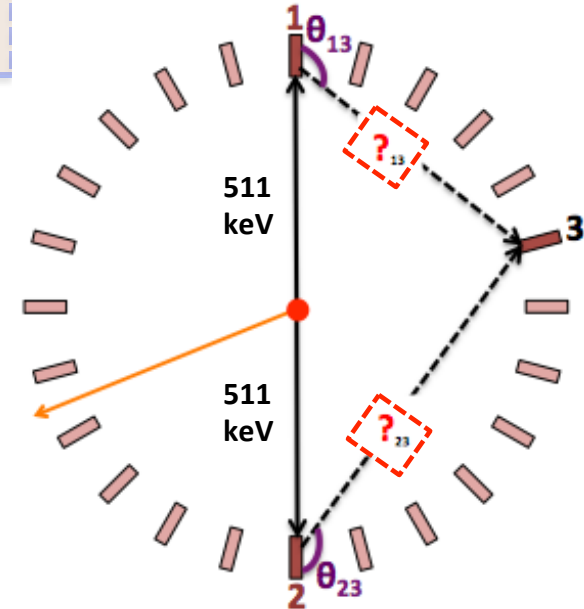
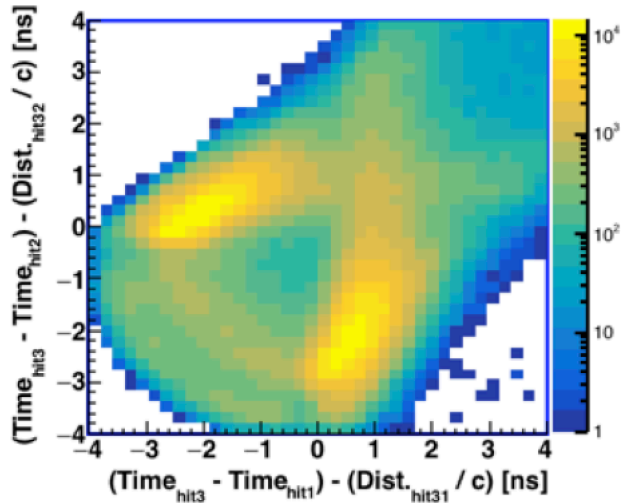
For the assignment of scattered hit to its origin, scatter test(S) was applied:

$$S = (\text{time}_{\text{scatter}} - \text{time}_{\text{origin}}) - \text{Distance}_{\text{scatter-origin}} / c$$



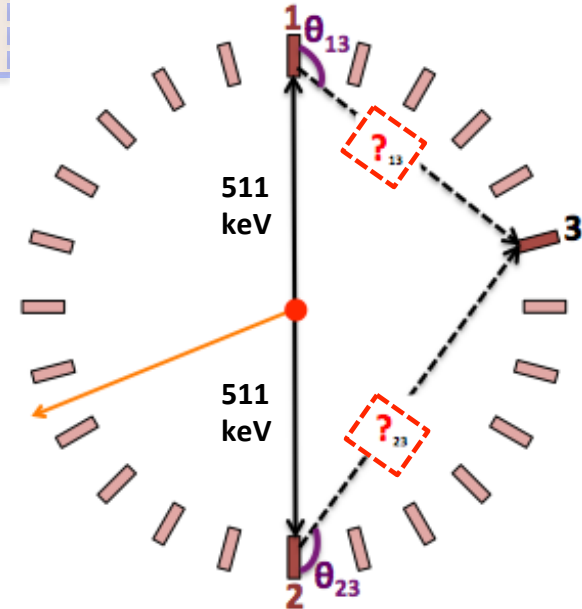
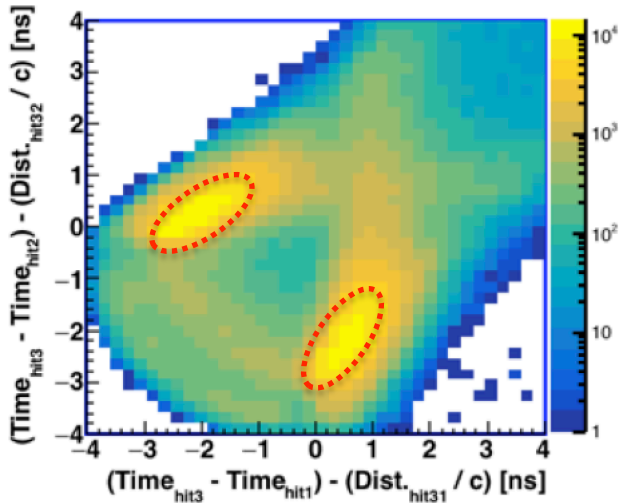
For the assignment of scattered hit to its origin, *scatter test*(S) was applied:

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$$S = (\text{time}_{\text{scatter}} - \text{time}_{\text{origin}}) - \text{Distance}_{\text{scatter-origin}} / c$$

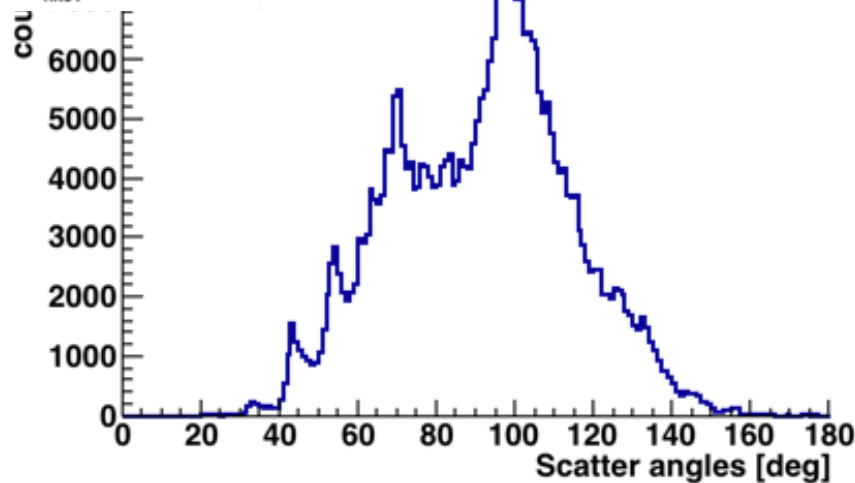
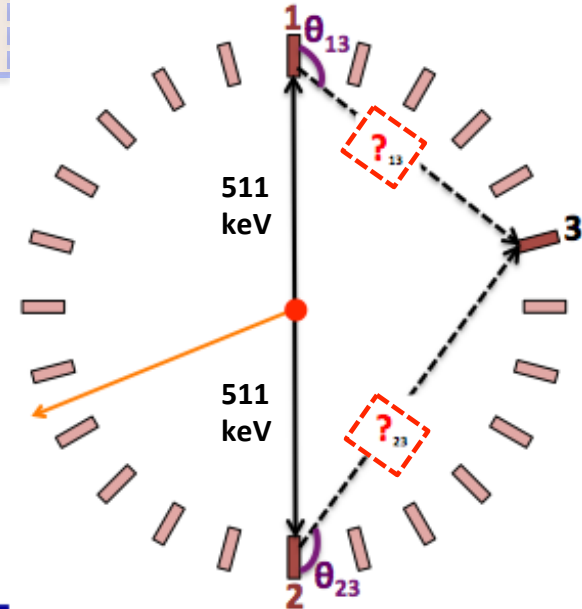
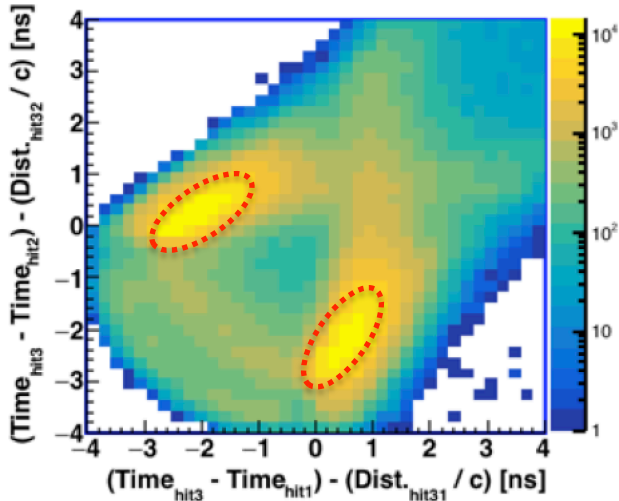


Selected scattered angles (  $\theta$  )



For the assignment of scattered hit to its origin, *scatter test*(S) was applied:

$$S = (\text{time}_{\text{scatter}} - \text{time}_{\text{origin}}) - \text{Distance}_{\text{scatter-origin}} / c$$



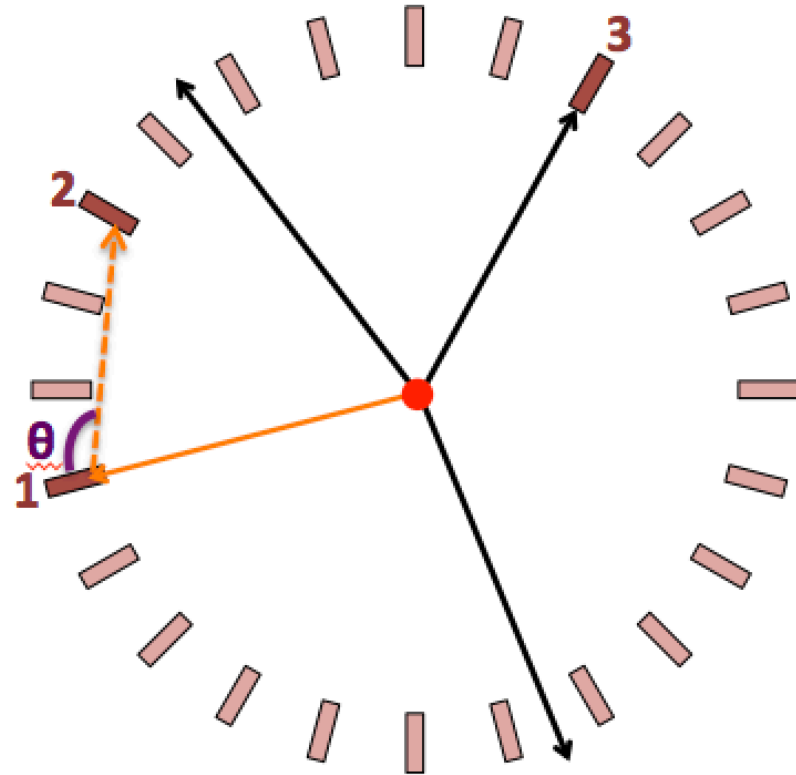
Selected scattered angles (  $\theta$  )



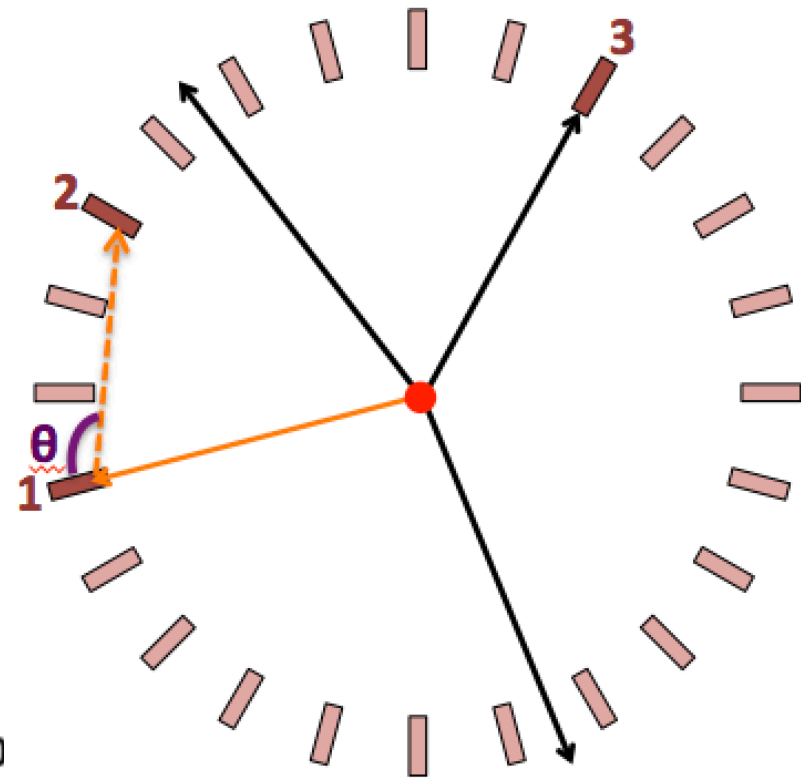
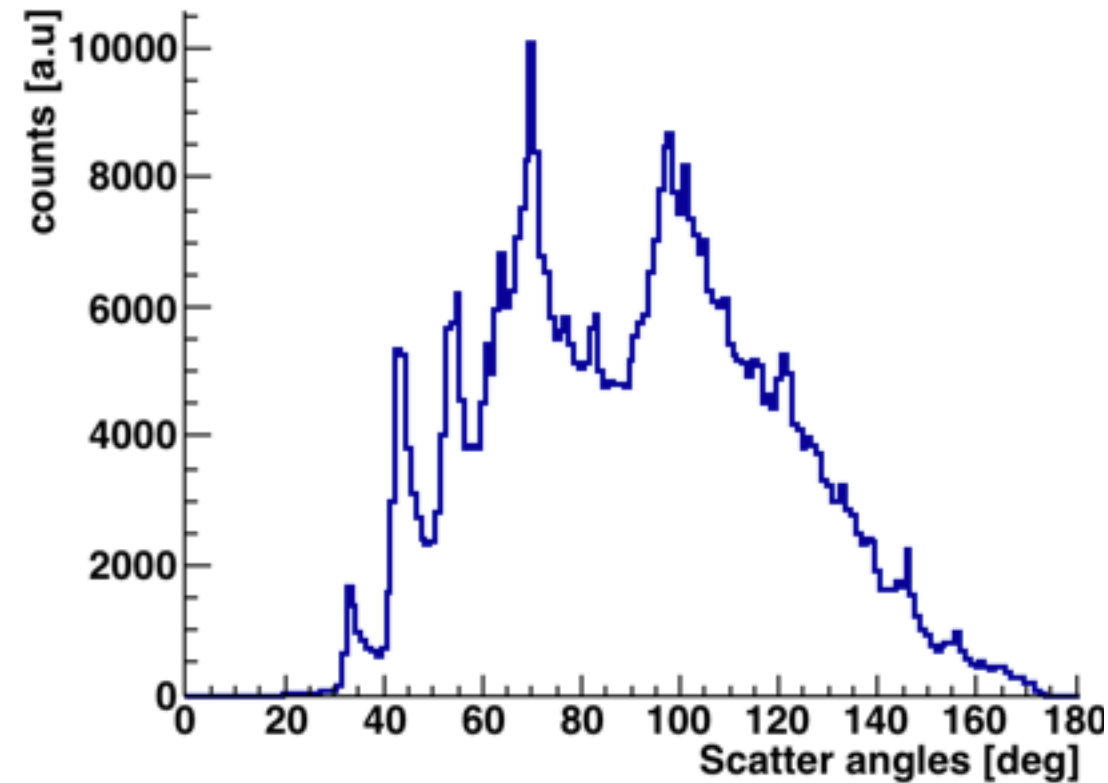




Selected scattering angles (  $\theta$  )



## Selected scattering angles ( $\theta$ )





# Results : Summed over 511 keV and 1274.6 keV



TOT spectra



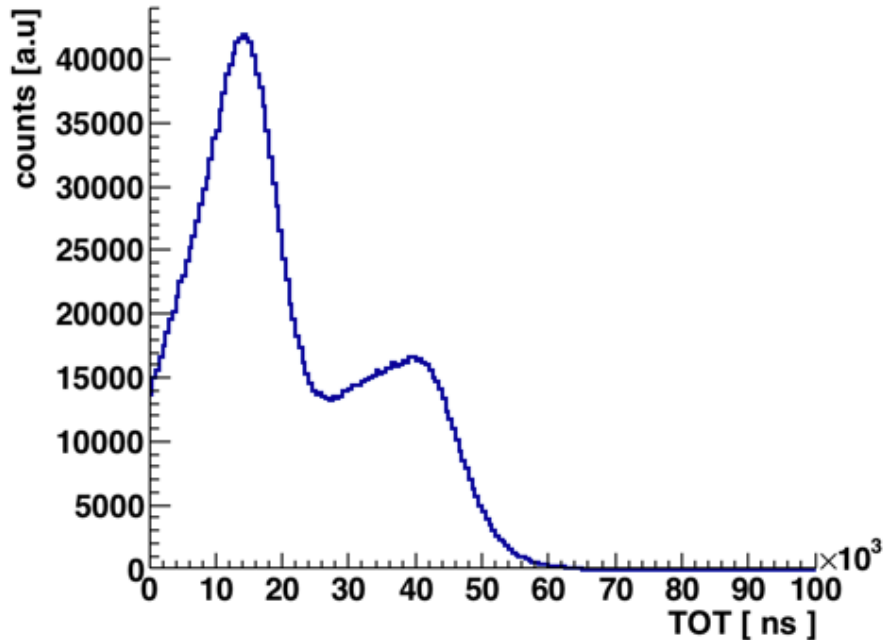
Scattered angles ( $\theta$ )





TOT spectra

Scattered angles ( $\theta$ )

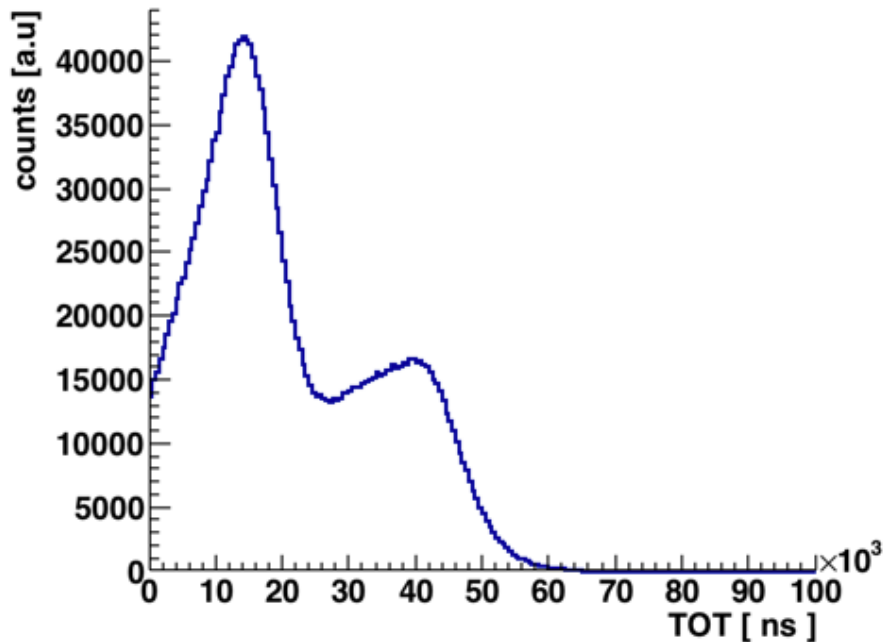




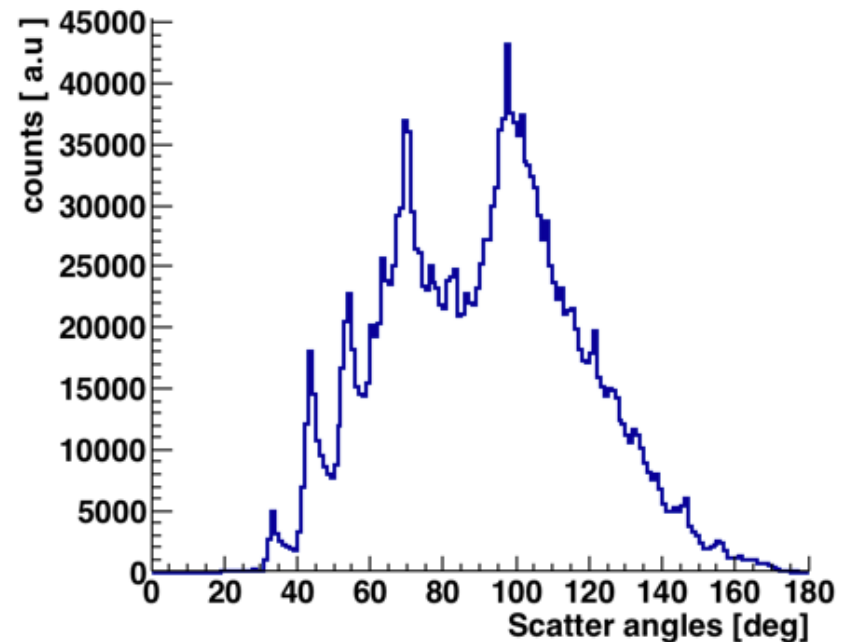
# Results : Summed over 511 keV and 1274.6 keV



TOT spectra



Scattered angles ( $\theta$ )





# Results : TOT vs Edep



Relationship between **TOT and Edep** individual for 511 keV and 1274.6 keV photons

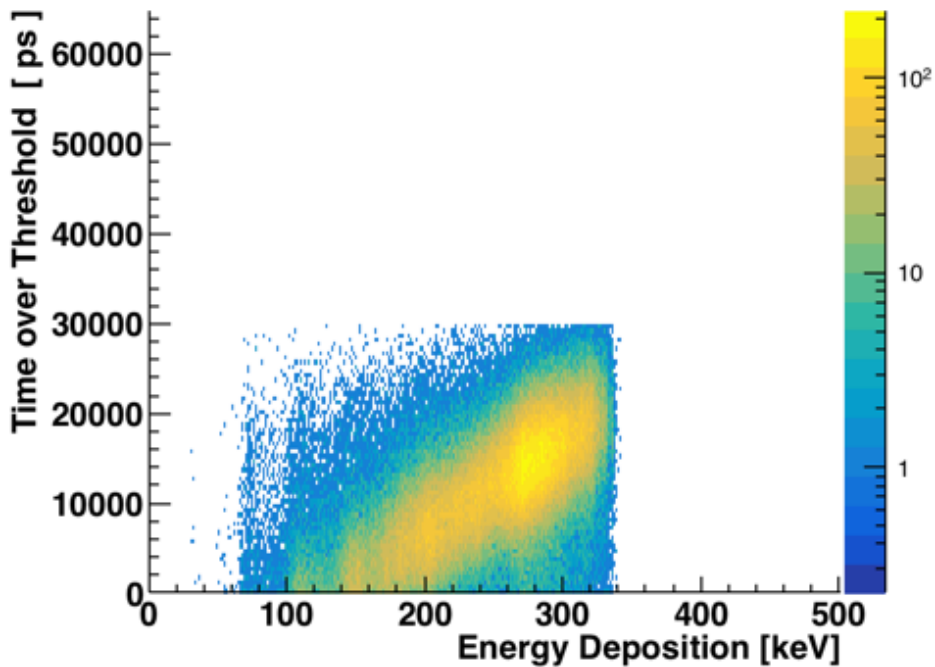




# Results : TOT vs Edep



Only for 511 keV



Relationship between **TOT and Edep** individual for 511 keV and 1274.6 keV photons

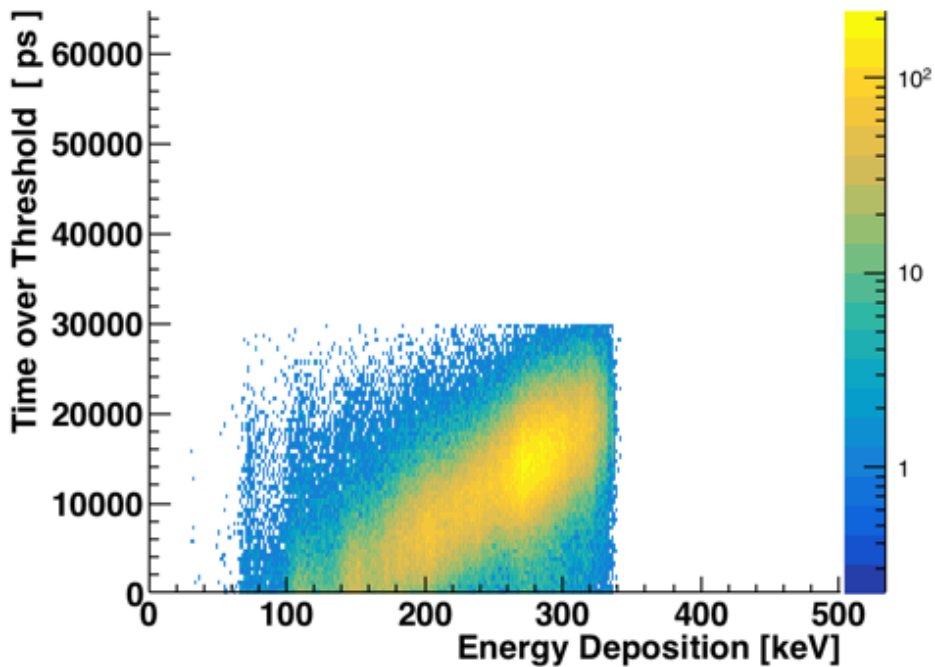




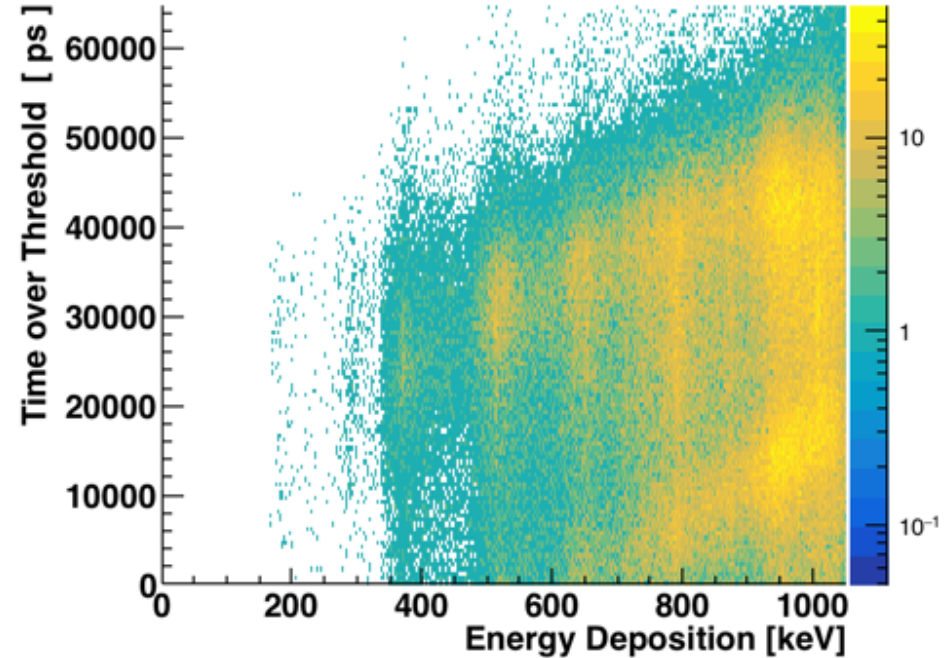
# Results : TOT vs Edep



Only for 511 keV



Only for 1274.6 keV



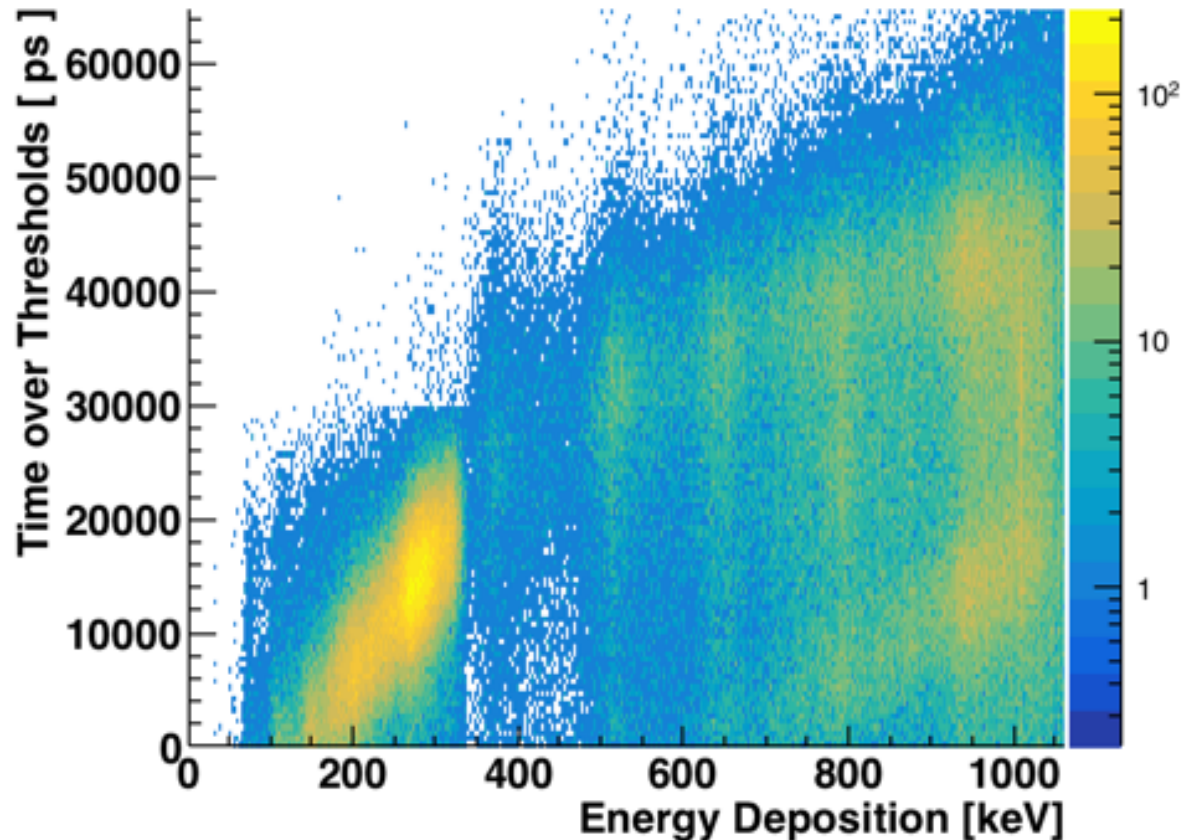
Relationship between **TOT and Edep** individual for 511 keV and 1274.6 keV photons







# Results : TOT vs Edep

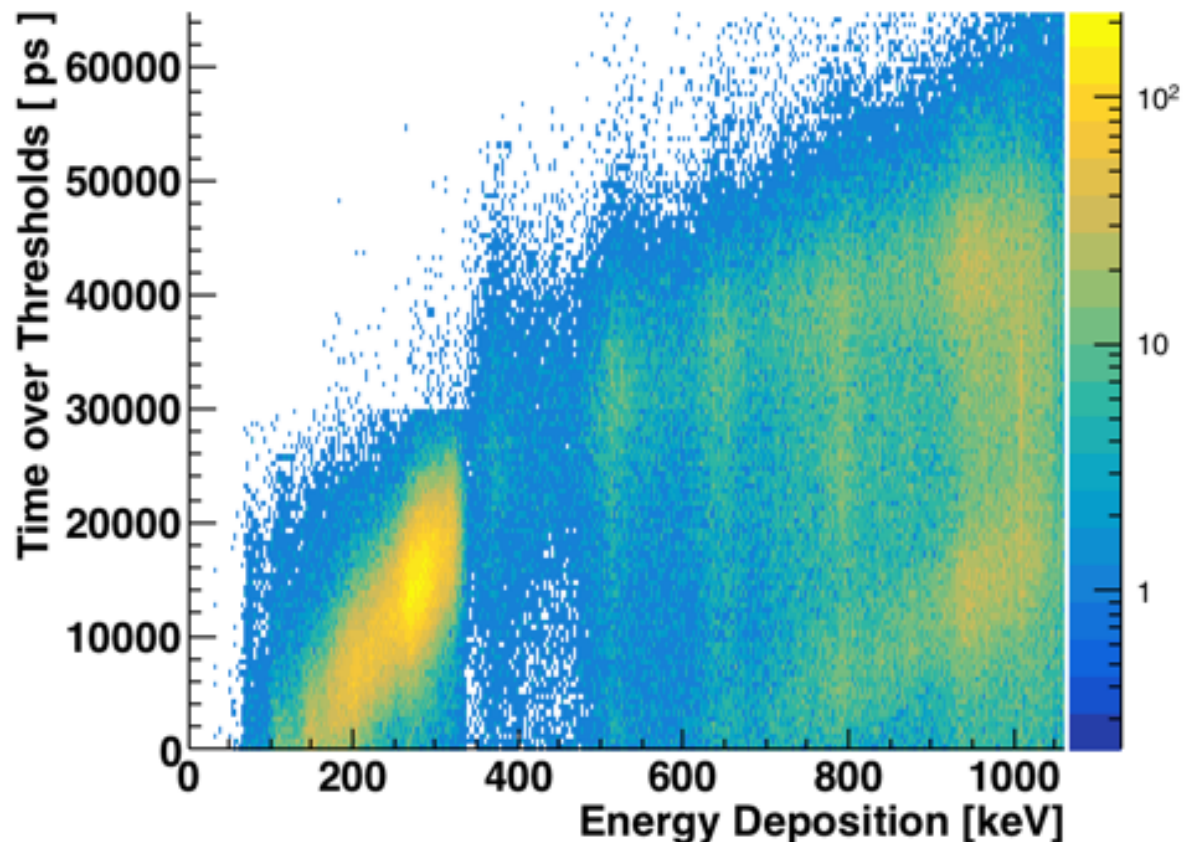


Relationship between **TOT and Edep** for **511 keV and 1274.6 keV photons together**





# Results : TOT vs Edep



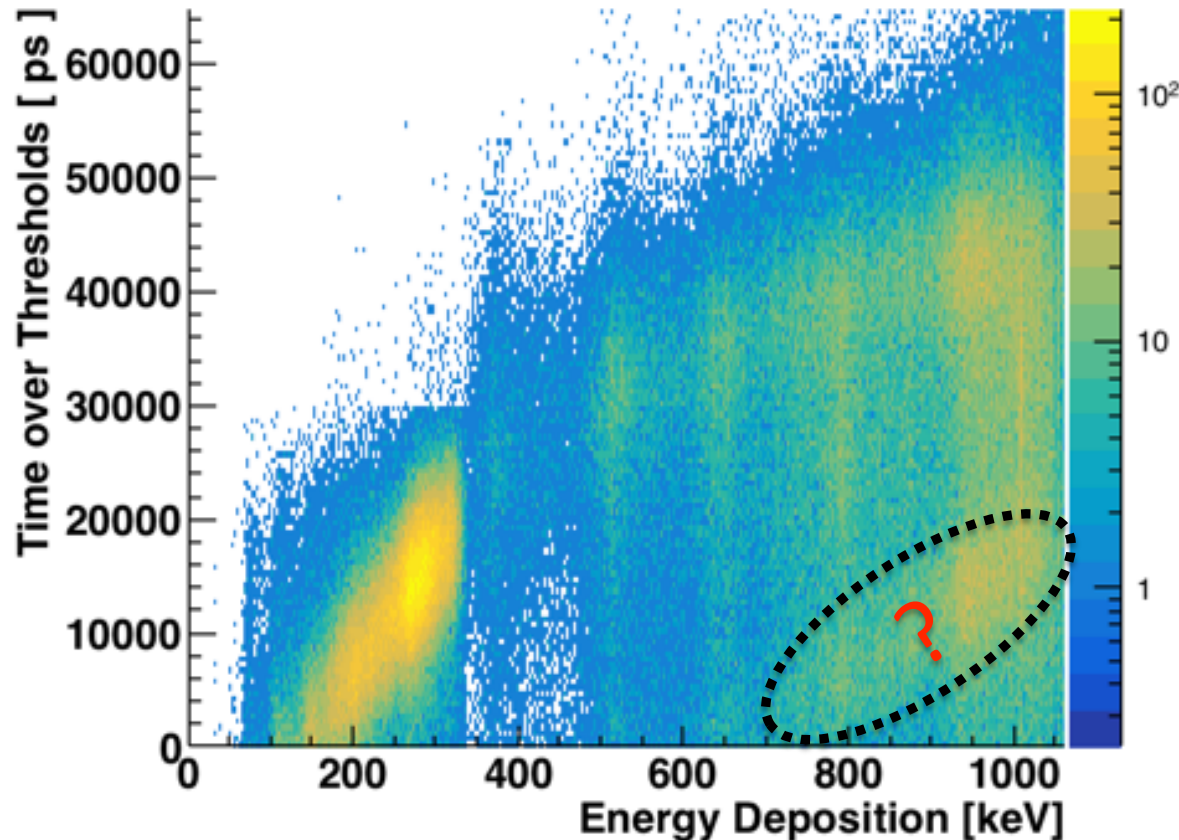
**There is an enhancement** in the value of **TOT** with the increase in the energy deposition.

Relationship between **TOT and Edep** for **511 keV and 1274.6 keV photons together**





# Results : TOT vs Edep



**There is an enhancement** in the value of **TOT** with the increase in the energy deposition.

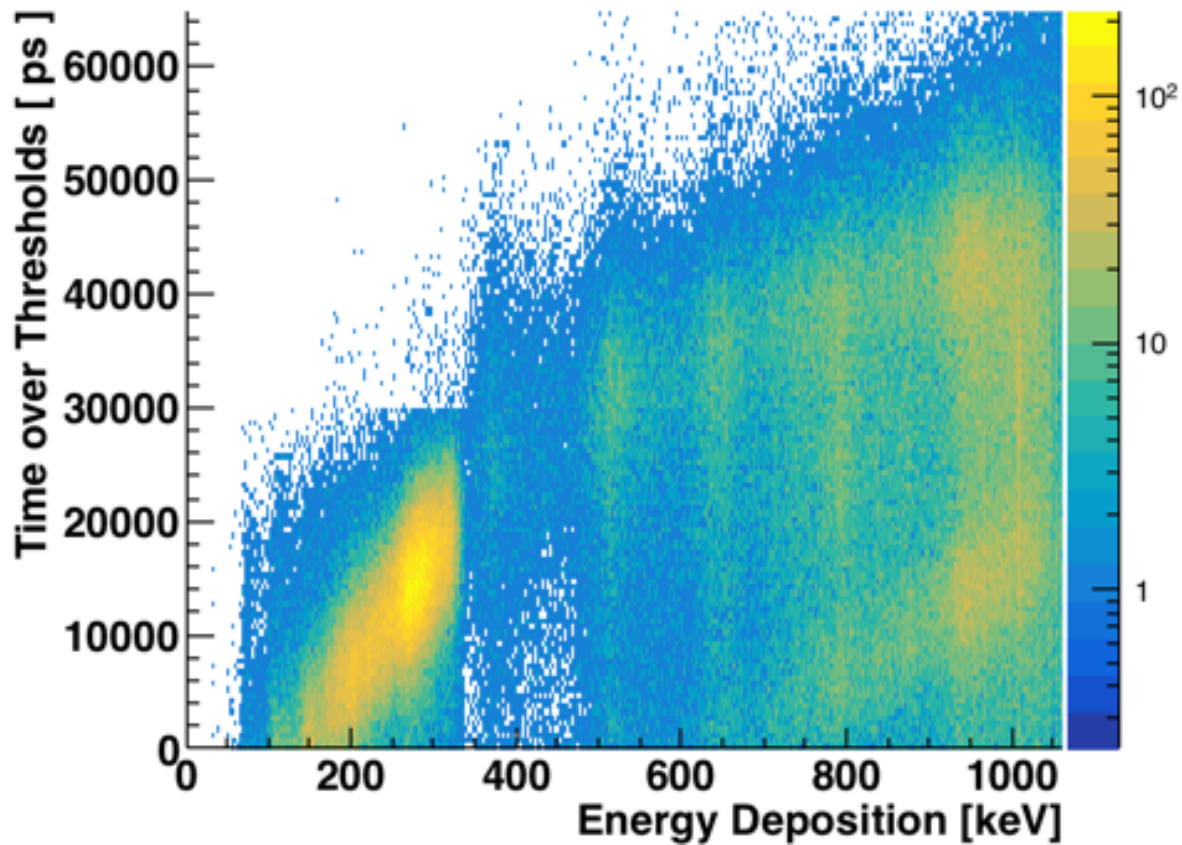
**However,** There is an additional contribution visible during the selection of prompt gamma ???

Relationship between **TOT and Edep** for **511 keV and 1274.6 keV photons together**



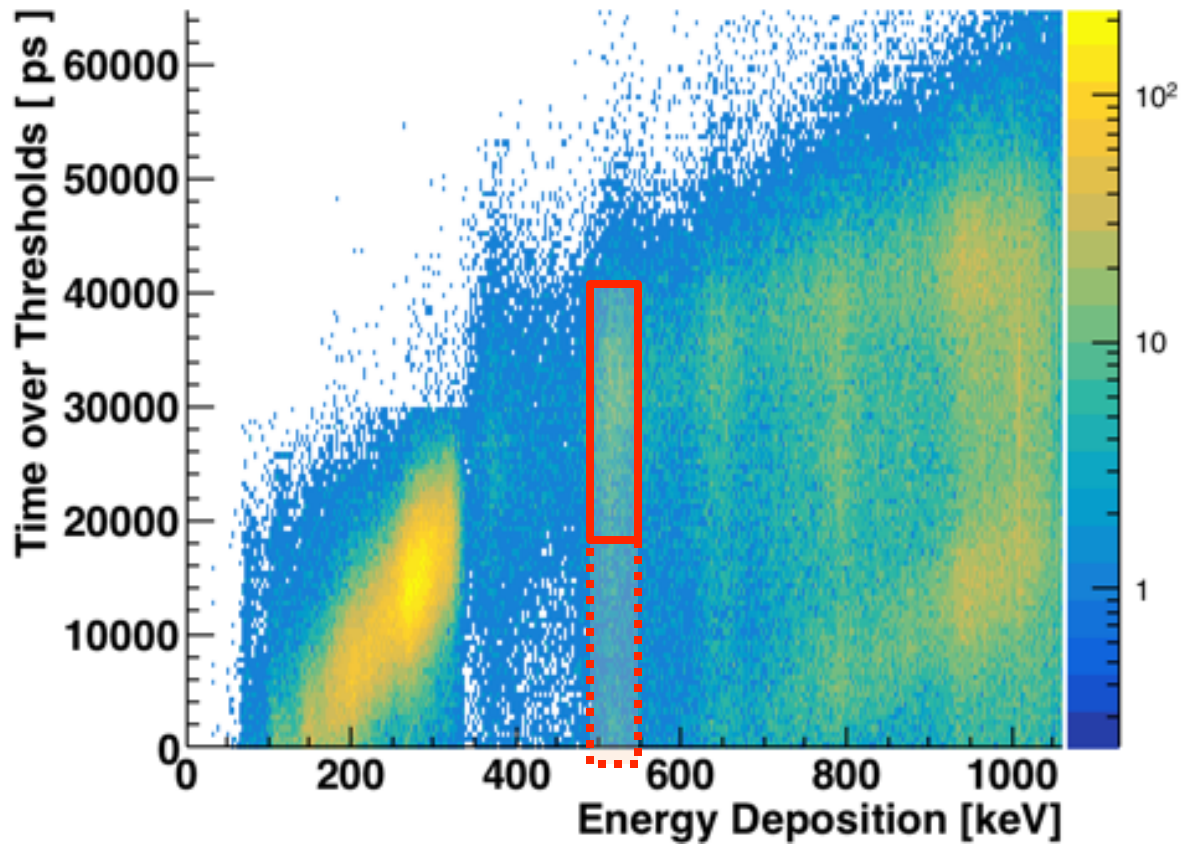


# Results : TOT vs Edep



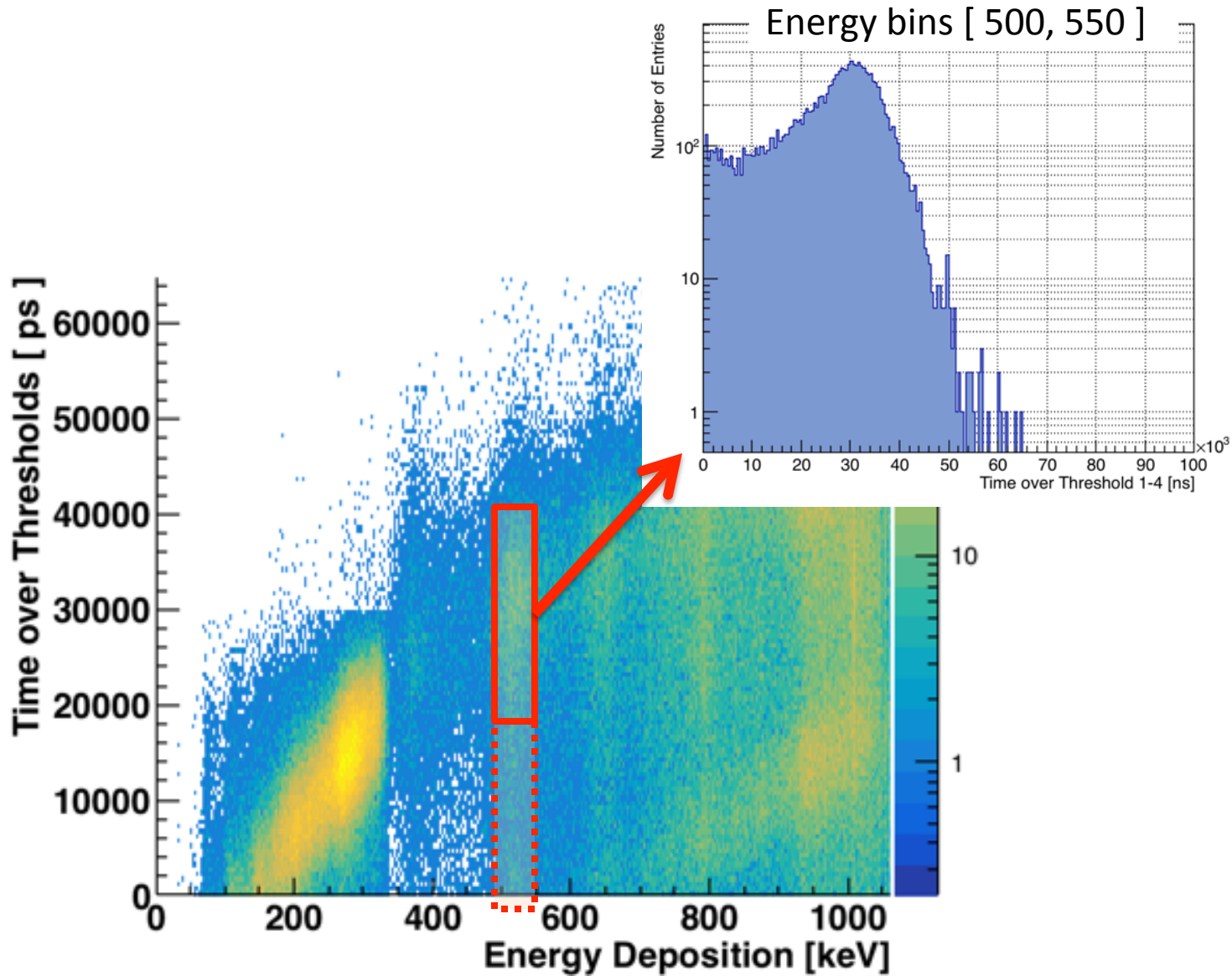


# Results : TOT vs Edep





# Results : TOT vs Edep





# Results : TOT vs Edep



Fitting of the TOT projections for most populated energy depositions :

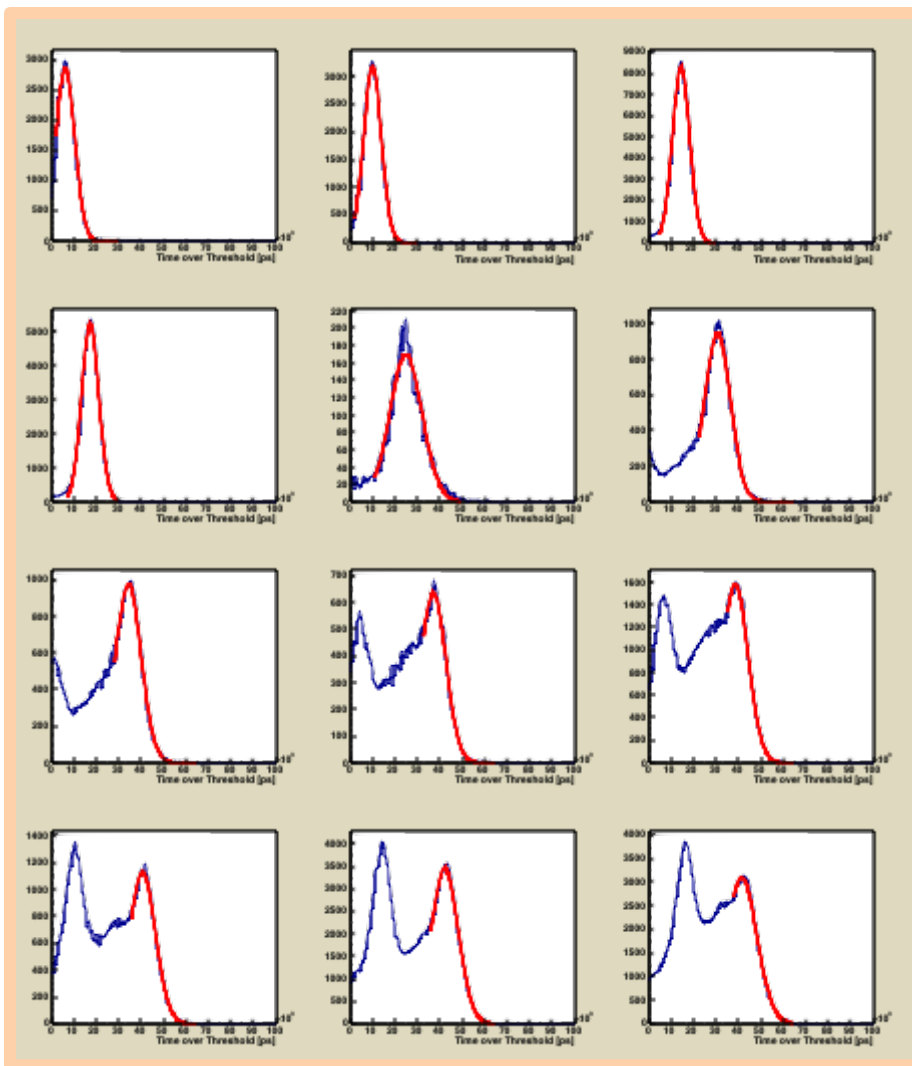




# Results : TOT vs Edep



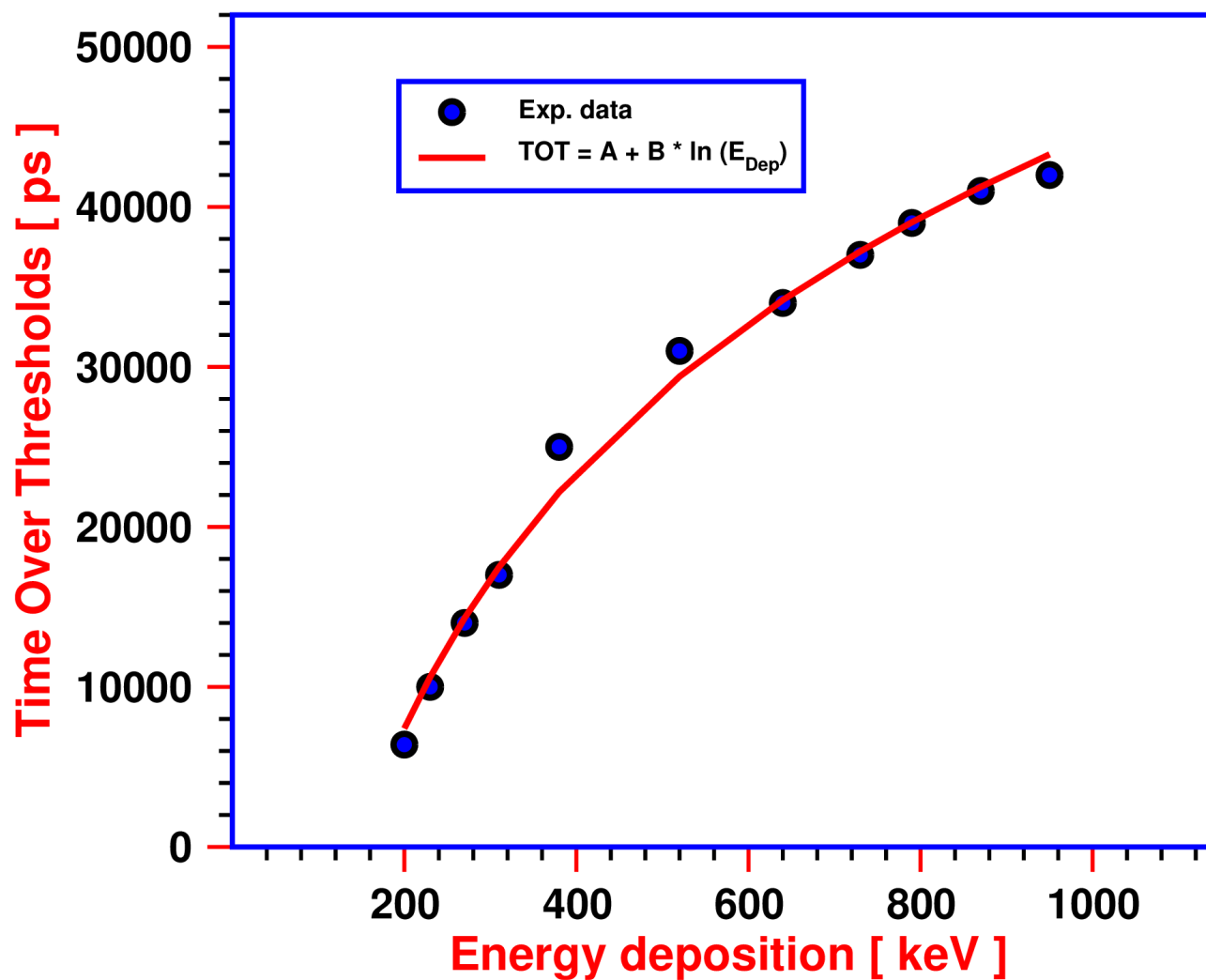
Fitting of the TOT projections for most populated energy depositions :







# Results : TOT vs Edep

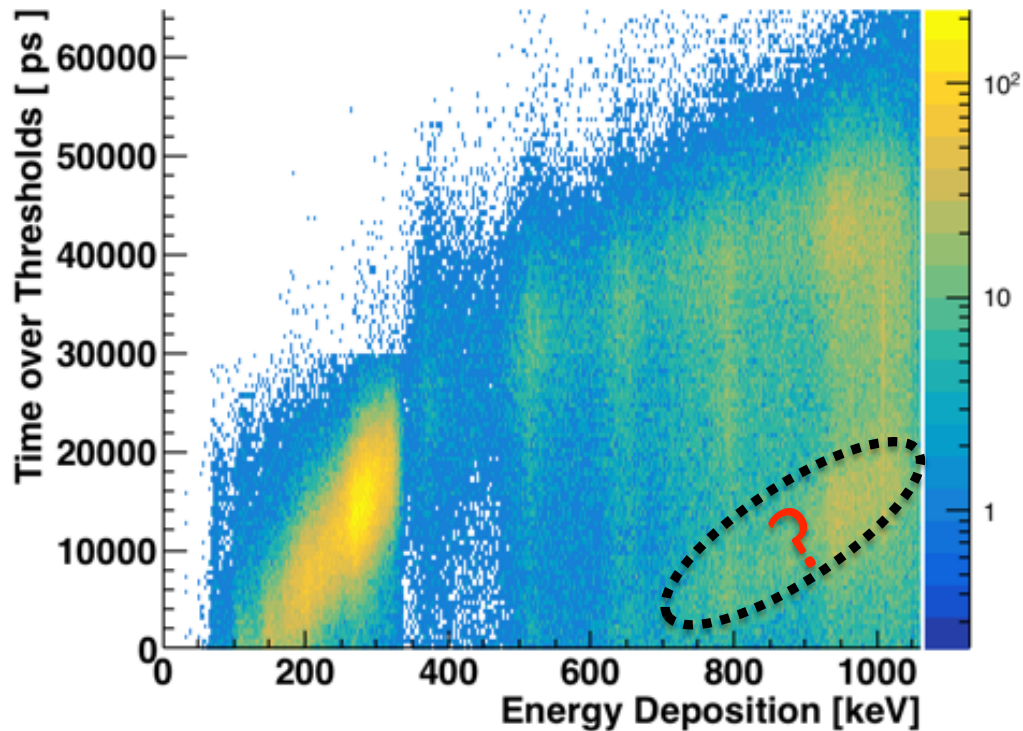




# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???



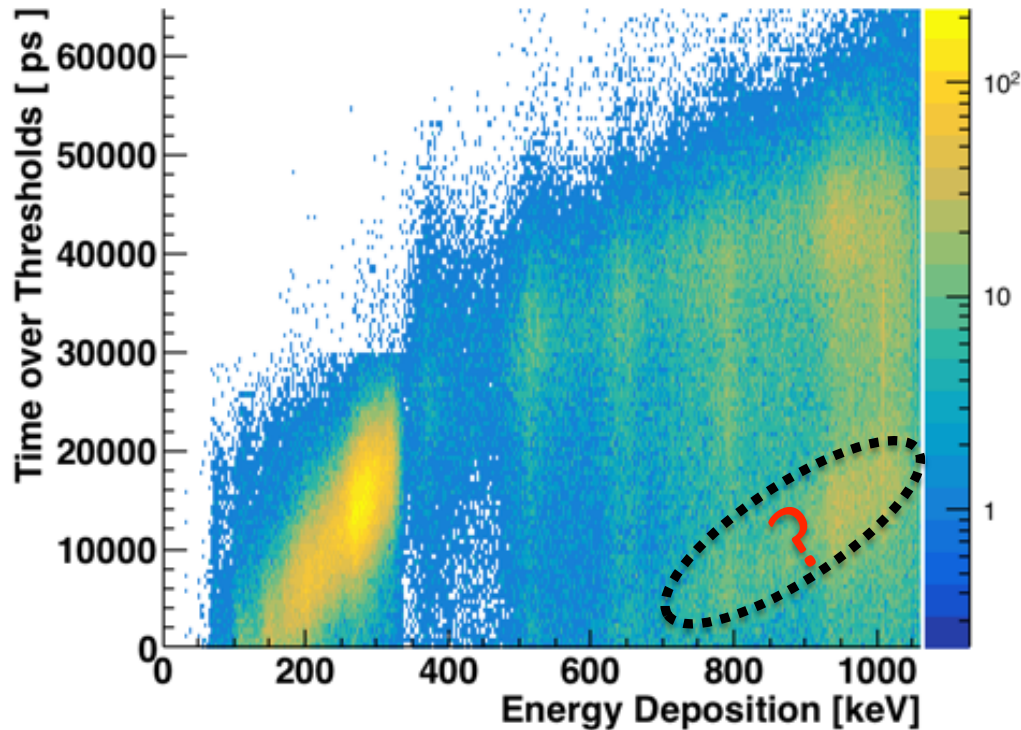


# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???

**Investigation procedure :**





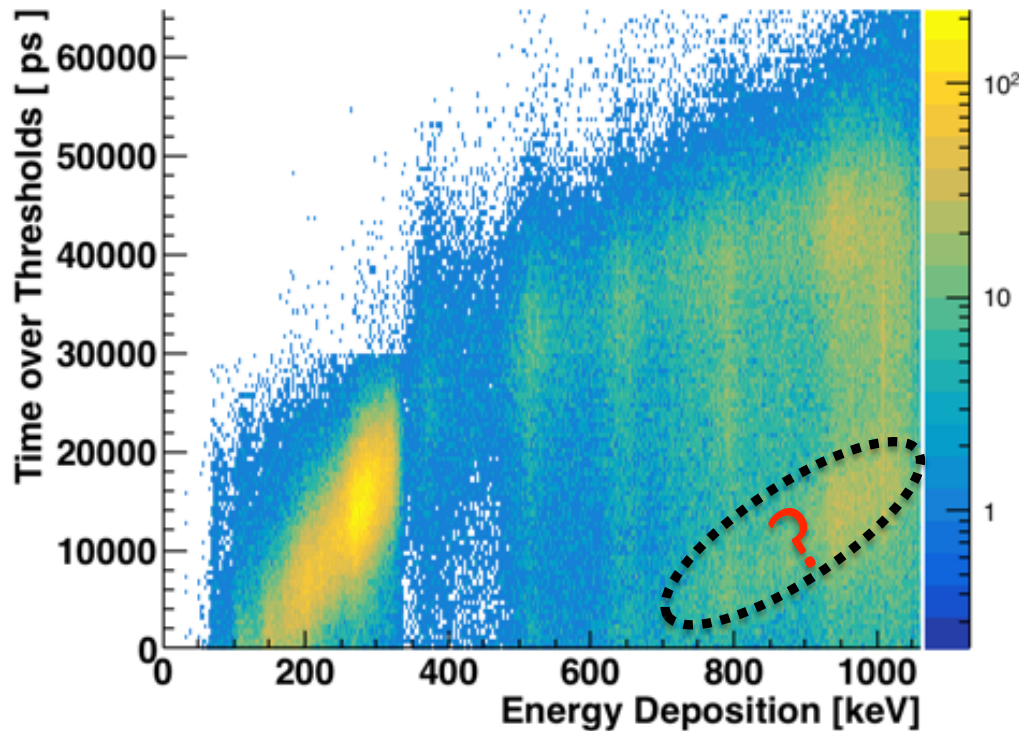
# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???

**Investigation procedure :**

For the calculated scattering angles ( $\theta$ ) for 1275 photon



—





# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???

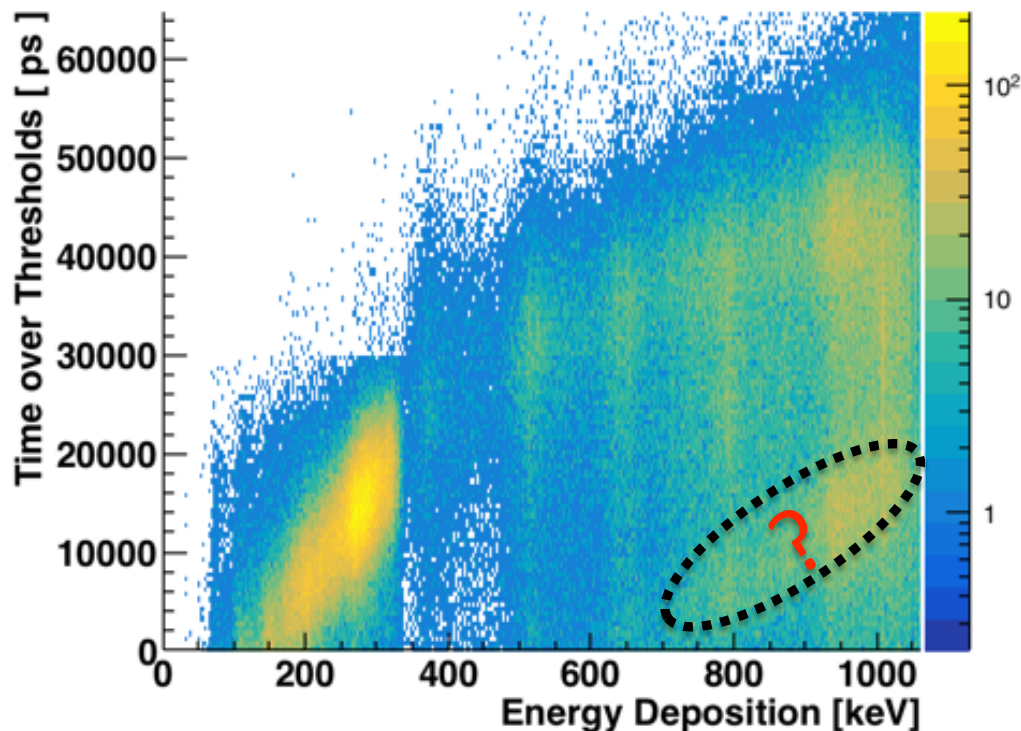
## Investigation procedure :

For the calculated scattering angles ( $\theta$ ) for 1275 photon

a). Estimate the Edep:

$$\text{Edep1} = f(511 \text{ keV}, \theta)$$

$$\text{Edep2} = f(1275 \text{ keV}, \theta)$$





# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???

## Investigation procedure :

For the calculated scattering angles ( $\theta$ ) for 1275 photon

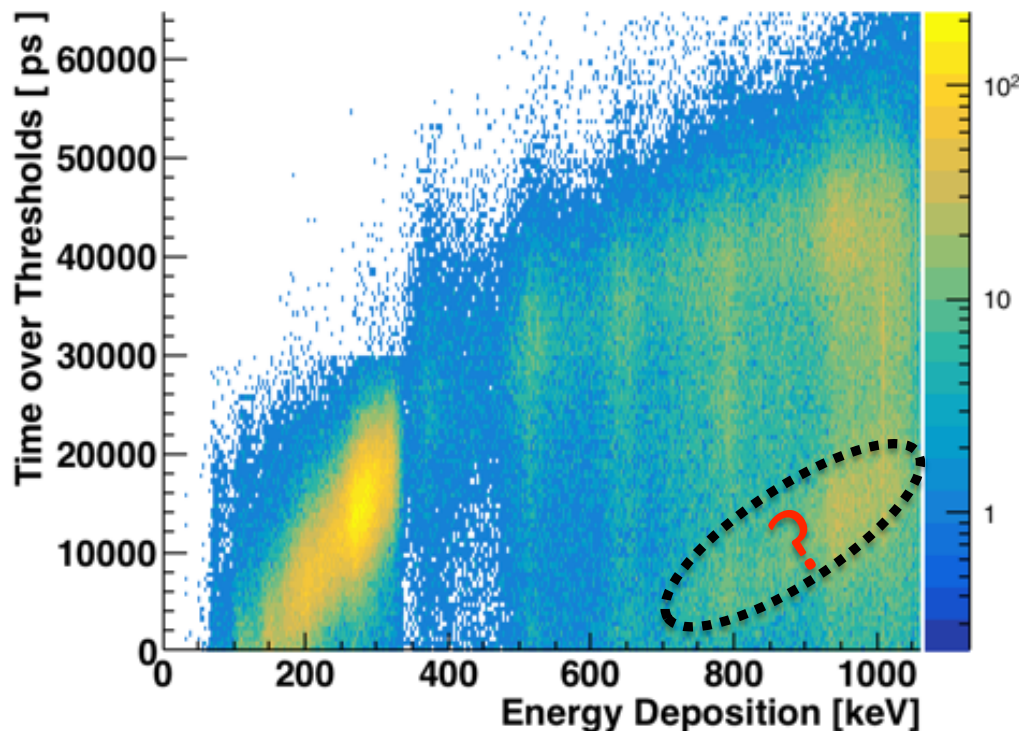
a). Estimate the Edep:

$$\text{Edep1} = f(511 \text{ keV}, \theta)$$

$$\text{Edep2} = f(1275 \text{ keV}, \theta)$$

b) cal. TOT value for Edep1

$$\text{using } \text{TOT} = A + B * \ln(\text{Edep1})$$





# Results : TOT vs Edep



Additional contribution visible during the selection of prompt gamma ???

## Investigation procedure :

For the calculated scattering angles ( $\theta$ ) for 1275 photon

a). Estimate the Edep:

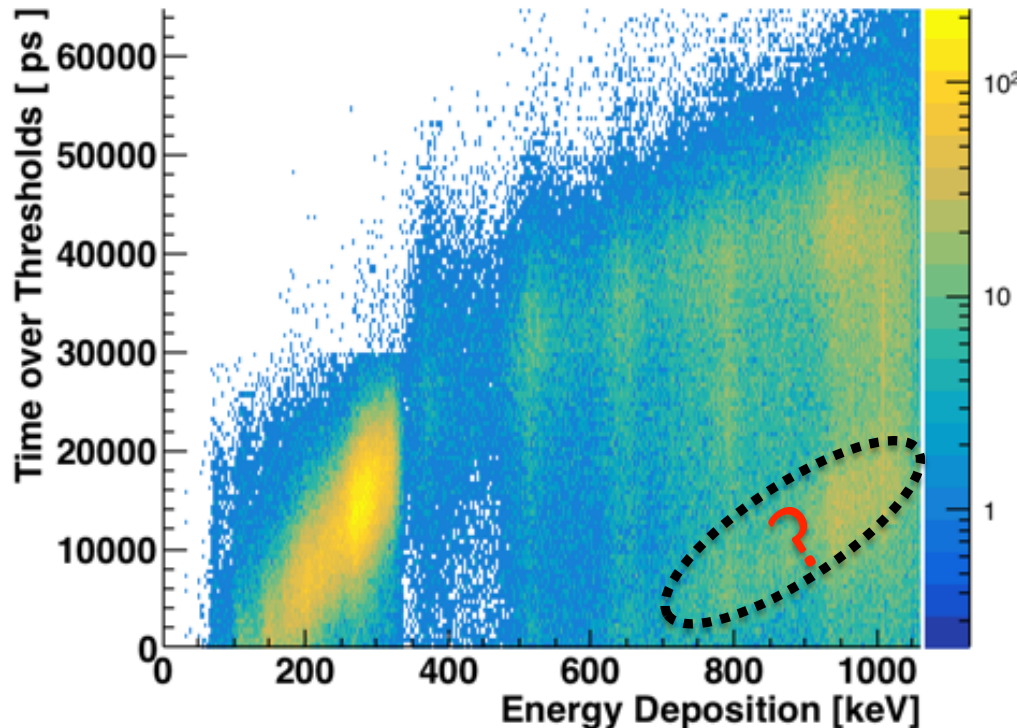
$$\text{Edep1} = f(511 \text{ keV}, \theta)$$

$$\text{Edep2} = f(1275 \text{ keV}, \theta)$$

b) cal. TOT value for Edep1

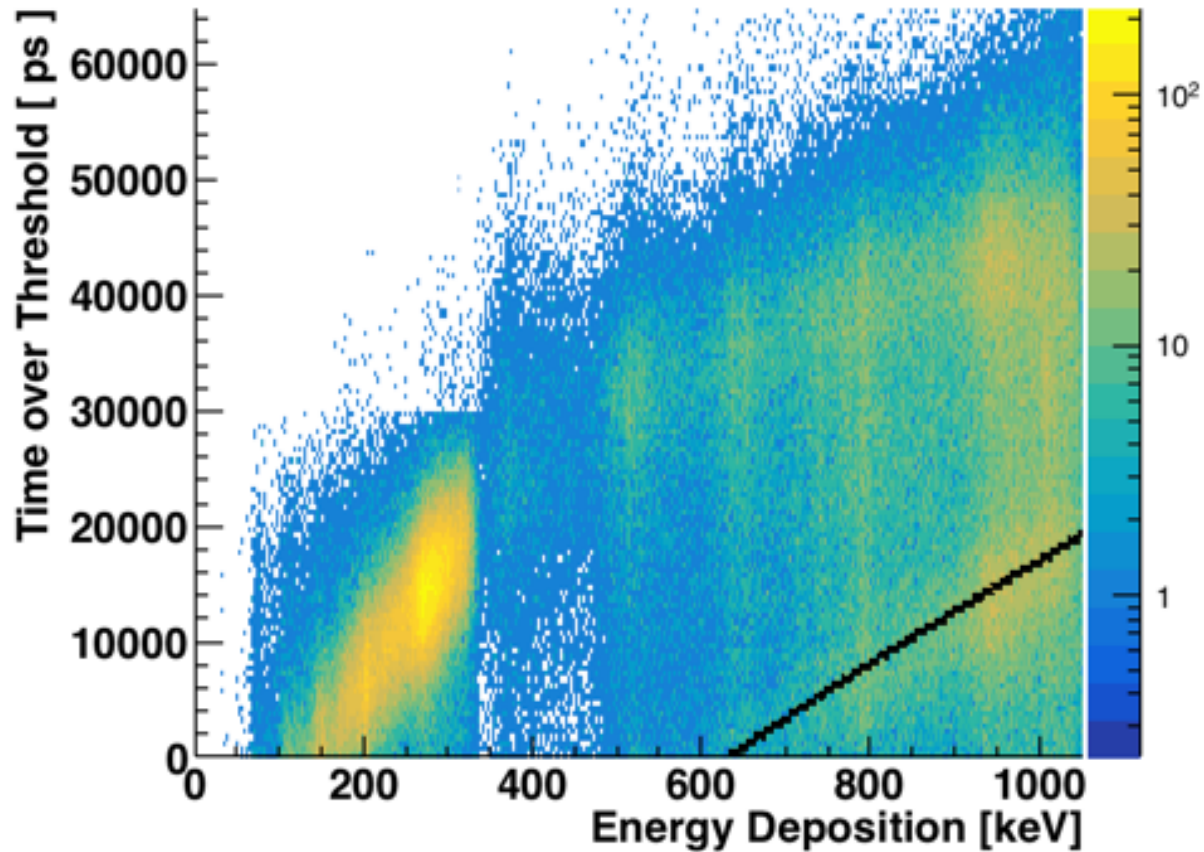
$$\text{using } \text{TOT} = A + B * \ln(\text{Edep1})$$

c). Fill the hist(Edep2, TOT)





# Results : TOT vs Edep



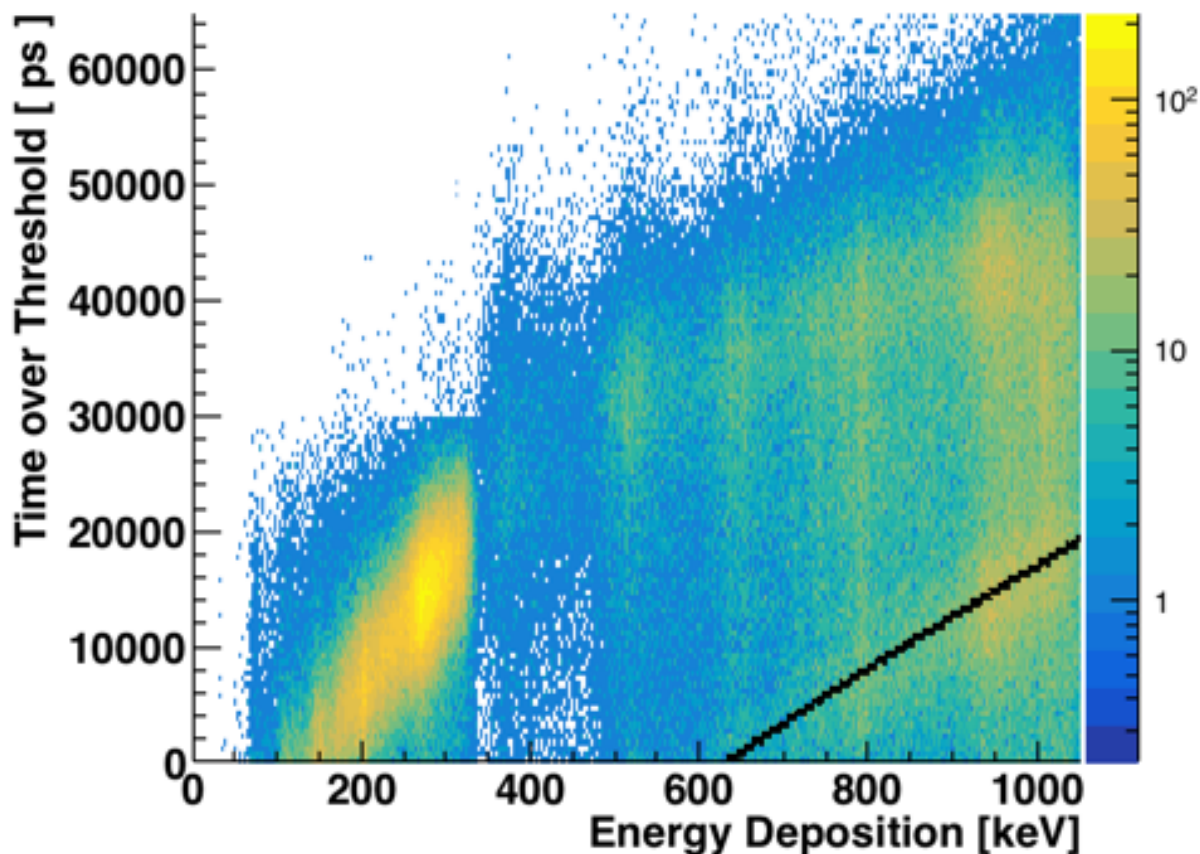
Black line shows the histogram filled with the discussed algorithm.







# Results : TOT vs Edep



**Black line** shows the histogram filled with the discussed algorithm.  
**Assuming** the contribution might be from **511 keV photon**,  
**FIT THE UNKNOWN REGION.**



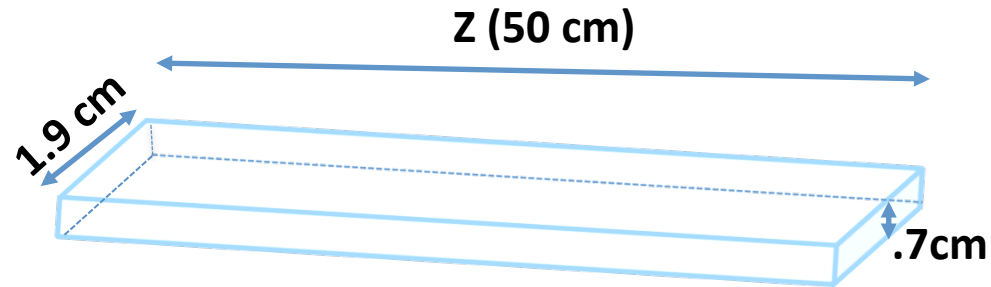


# TOT vs Edep ( for different hit Z – position)



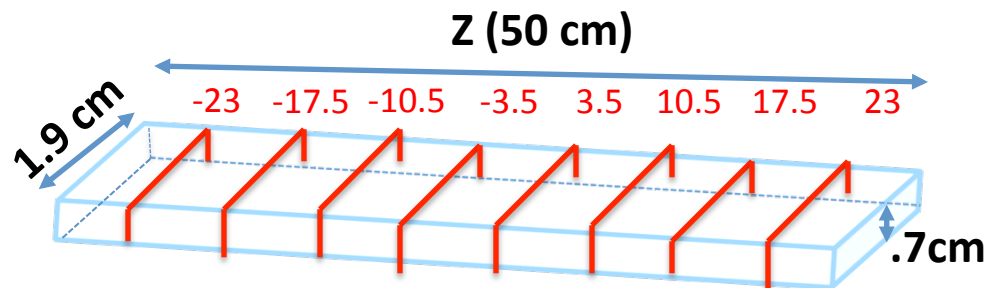


# TOT vs Edep ( for different hit Z – position)



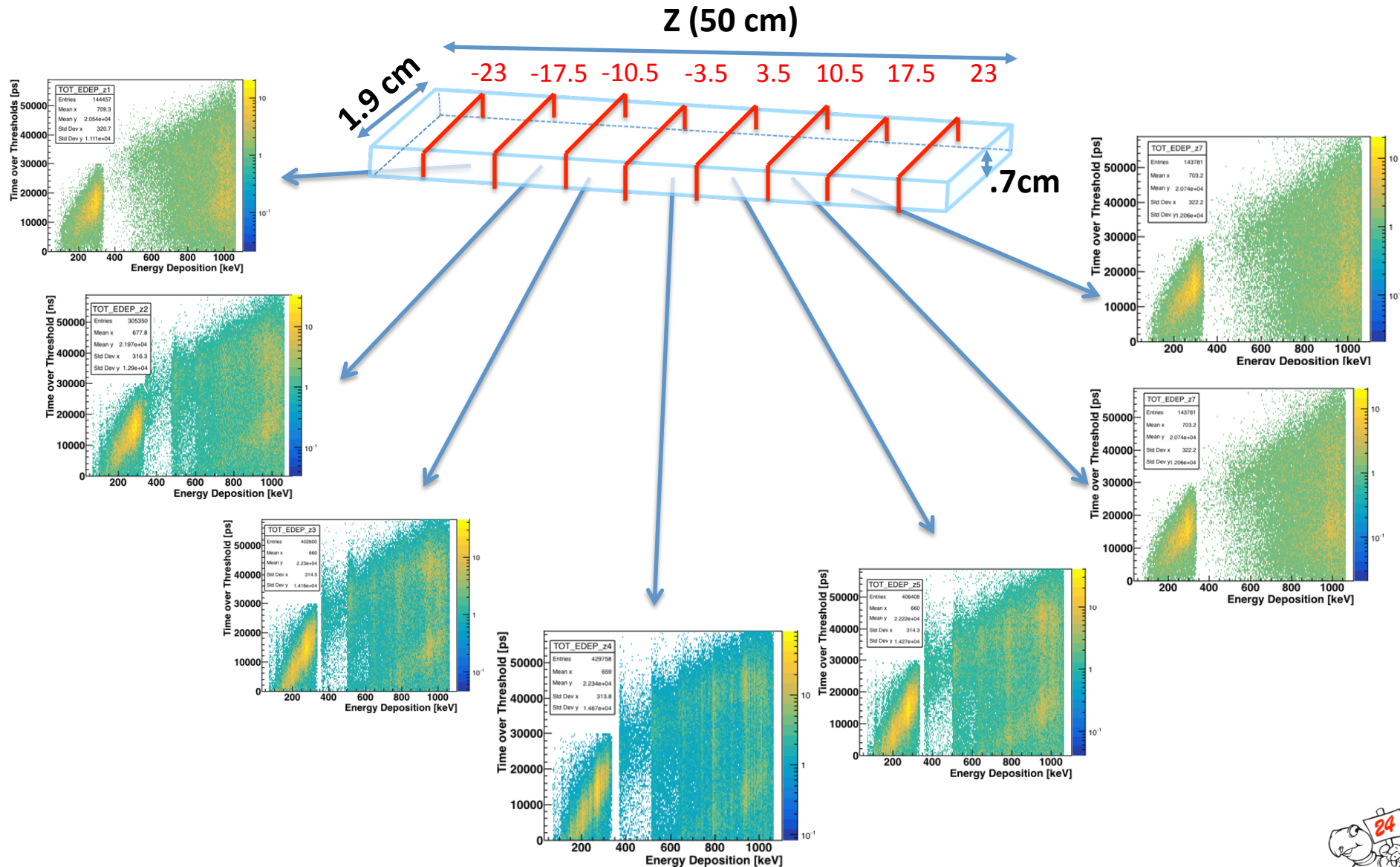


# TOT vs Edep ( for different hit Z – position)



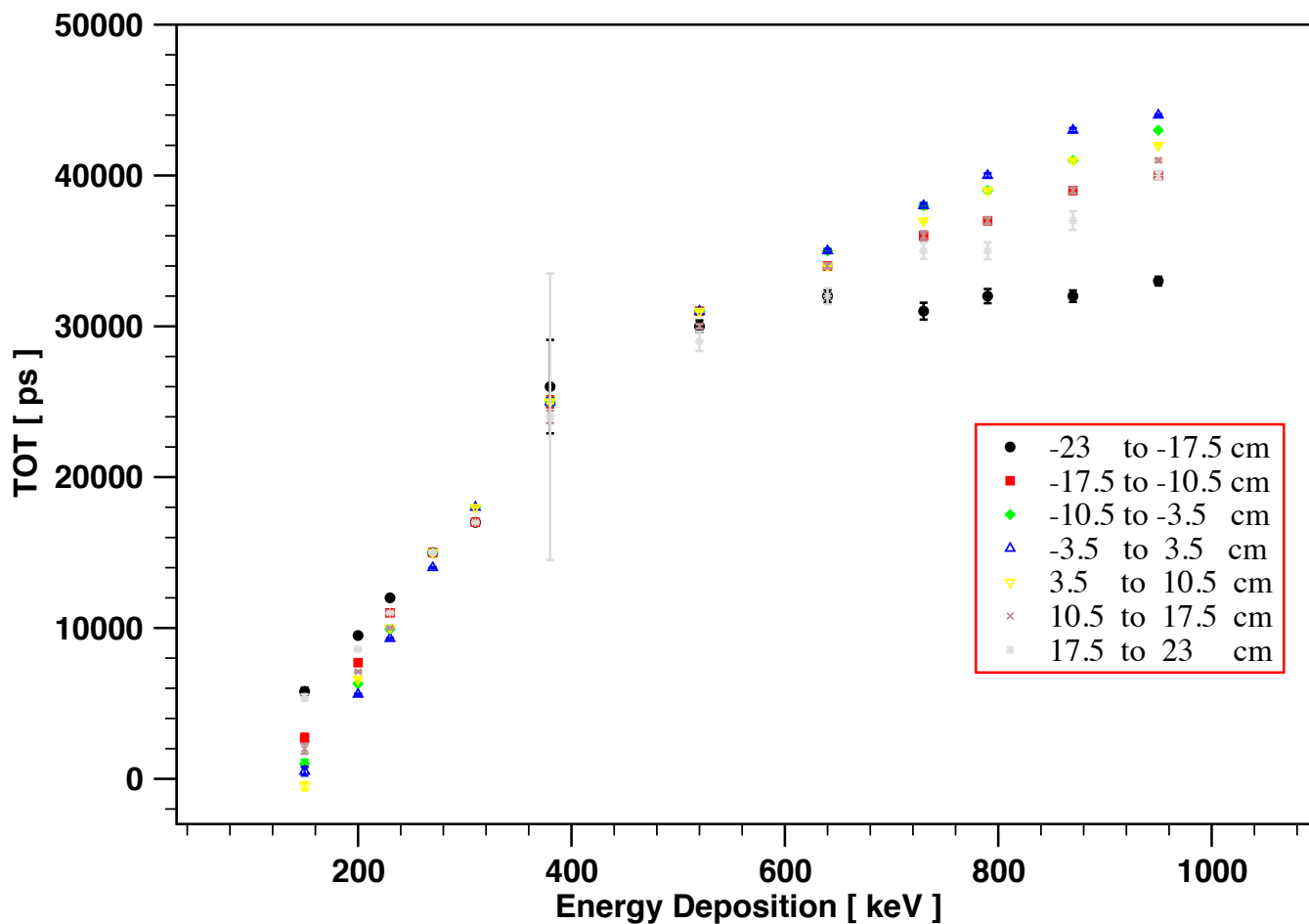


# TOT vs Edep ( for different hit Z – position)



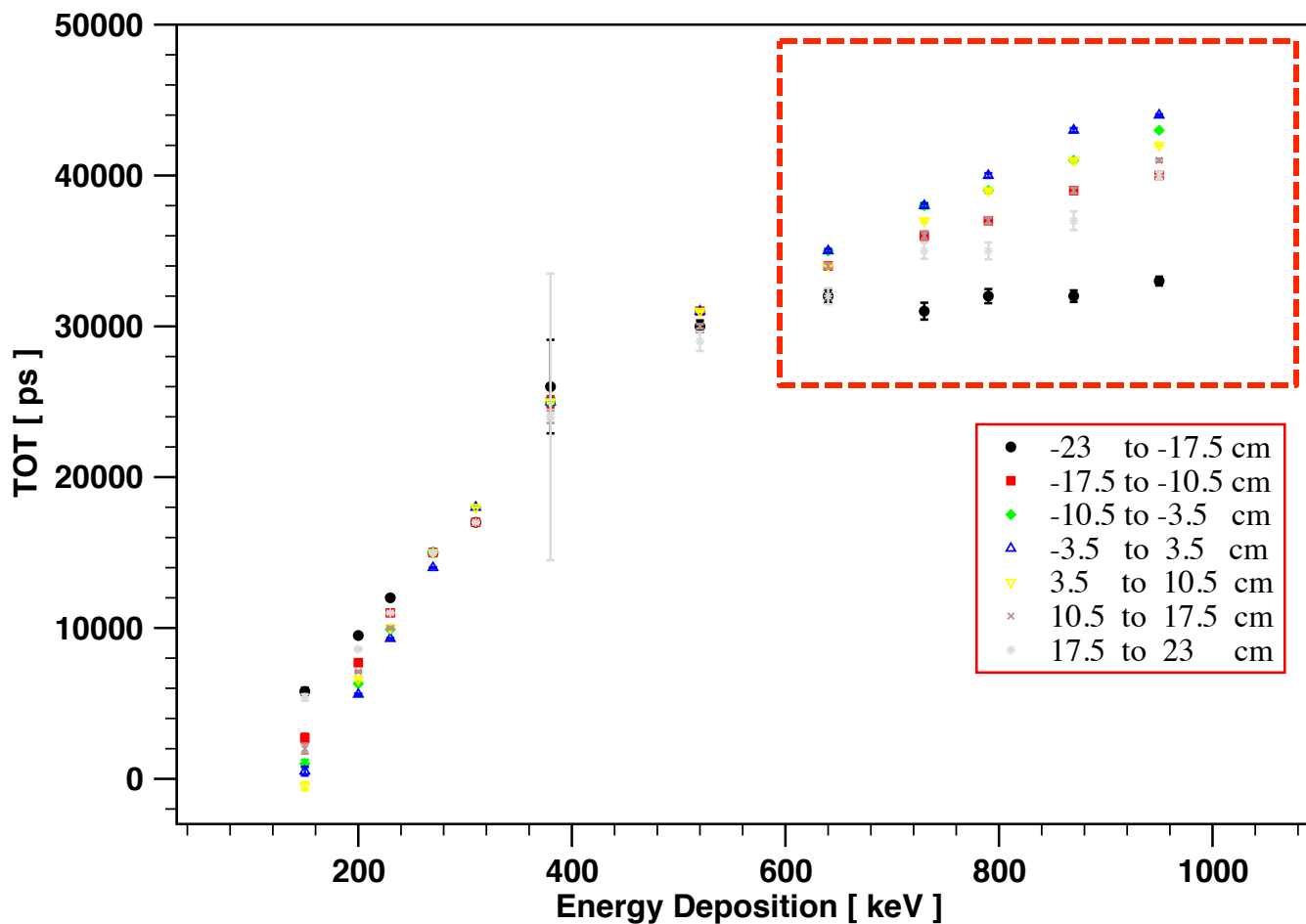


# TOT vs Edep ( for different hit Z – position)





# TOT vs Edep ( for different hit Z – position)





# Summary & Outlook



- ✓ An algorithm is developed to tag the photons of different energy and their scattering distributions are studied.
- ✓ Preliminary relationship between energy deposition by interacting photon and the corresponding TOT values is established.
- ❑ TOT vs Edep relationship has **Z – dependence** which is currently being investigated.







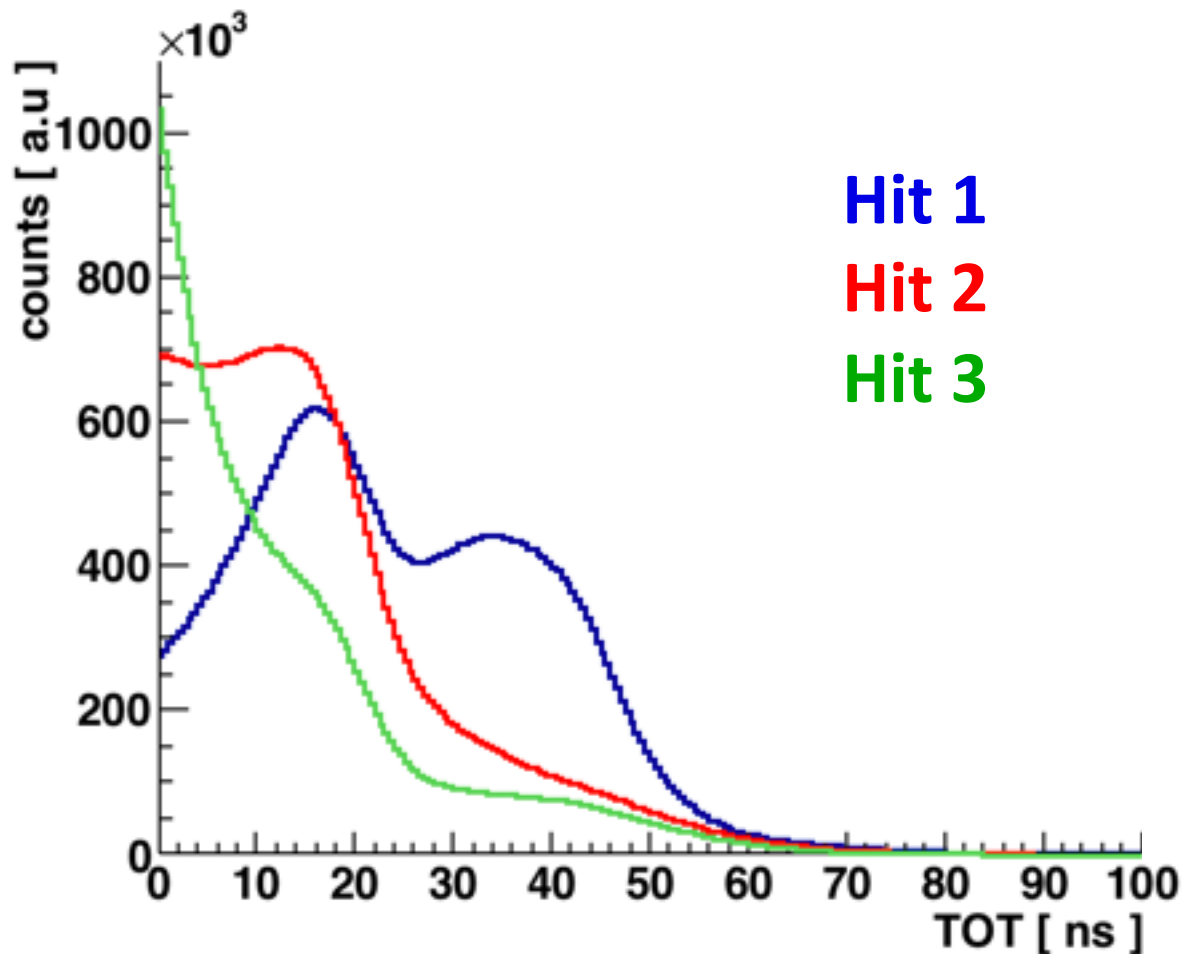


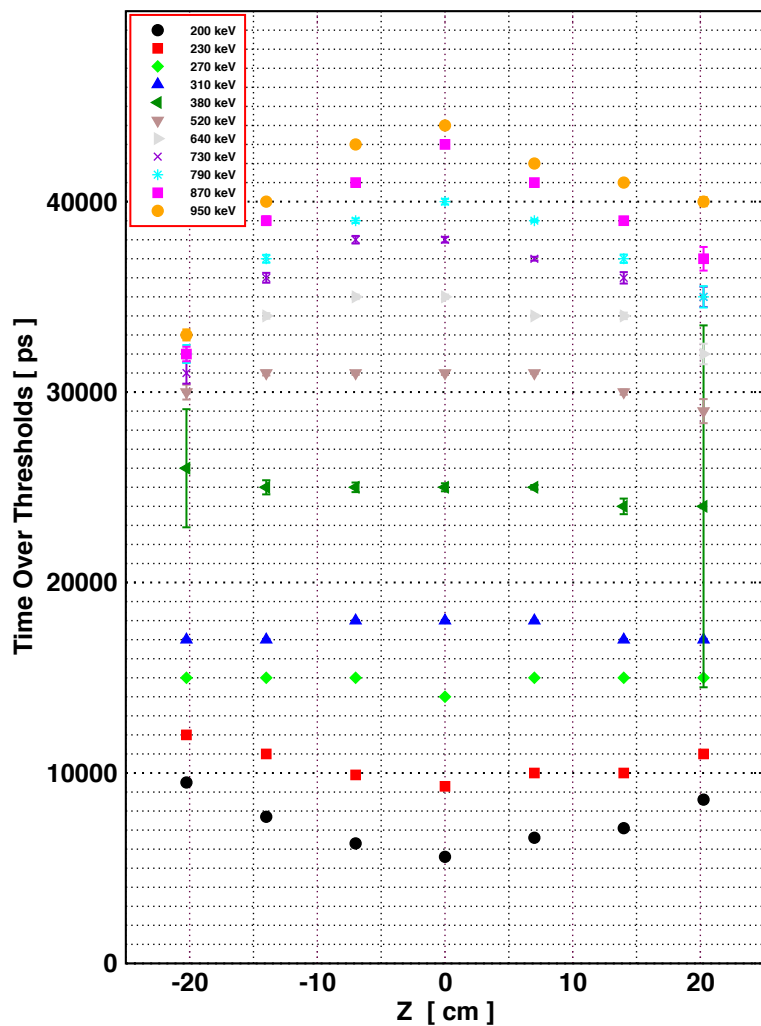
# Back-up slides





## TOT spectra – 3 Hits



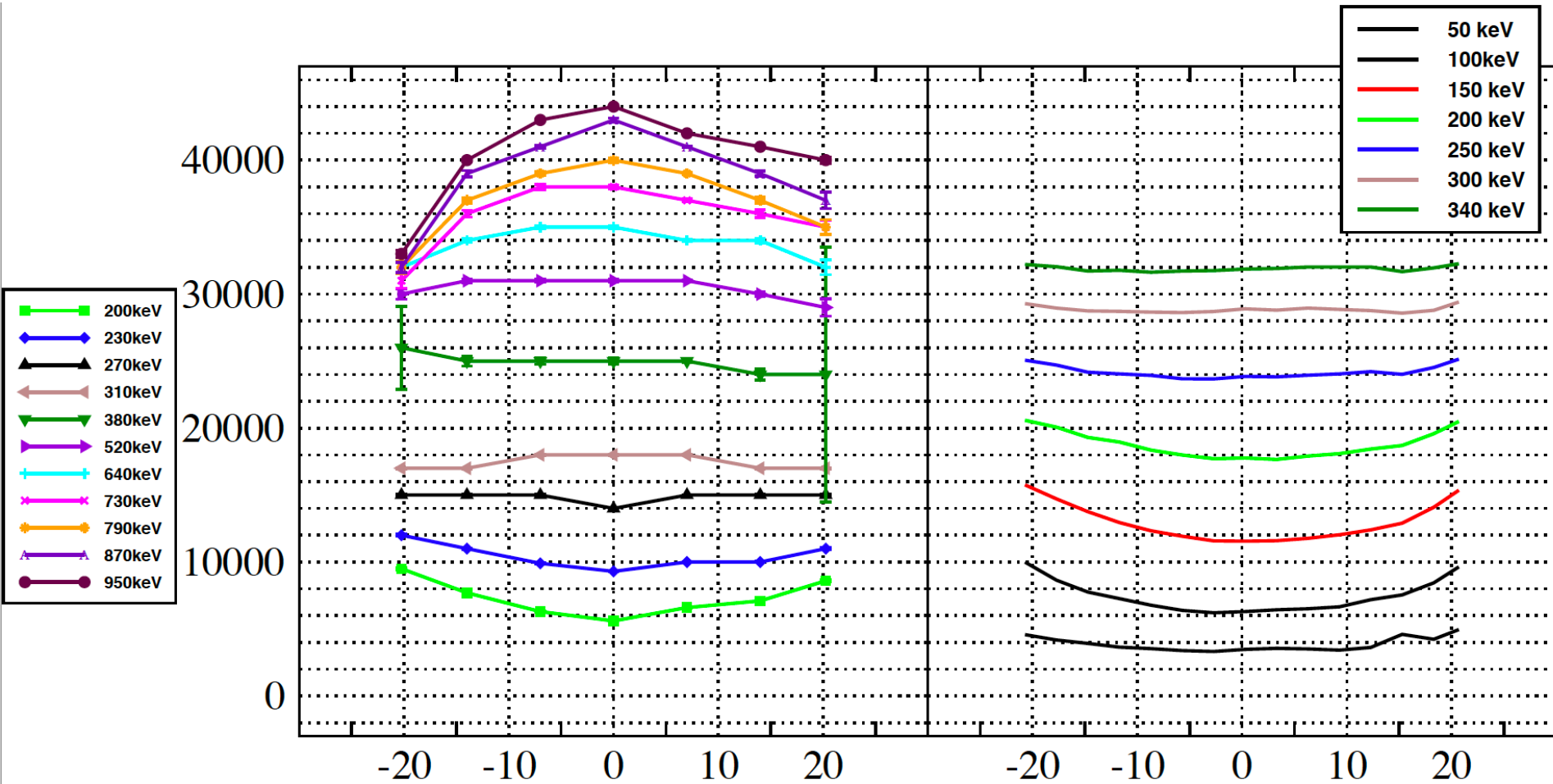


For different z-intervals , the center was chosen.





# Summary & Outlook





# Summary & Outlook

