Tracking with OFT

AGATA data analysis workshop

21-24/01/2019

Orsay

Aim of tracking

Read for each event the list of deposited energies and positions of all the interactions points in AGATA

e_1, x_1, y_1, z_1
e_2, x_2, y_2, z_2
……
e_n, x_n, y_n, z_n

Disentangle the interaction points i.e reconstruct individual photon trajectories and extract photon energies and 1st & 2nd interaction positions (for Doppler correction & polarization measurements)

$E_1, (x,y,z)_{int\text{-}1}, (x,y,z)_{int\text{-}1}$
$E_2, (x,y,z)_{int\text{-}2}, (x,y,z)_{int\text{-}2}$
……
$E_i, (x,y,z)_{int\text{-}\iota}, (x,y,z)_{int\text{-}\iota}$

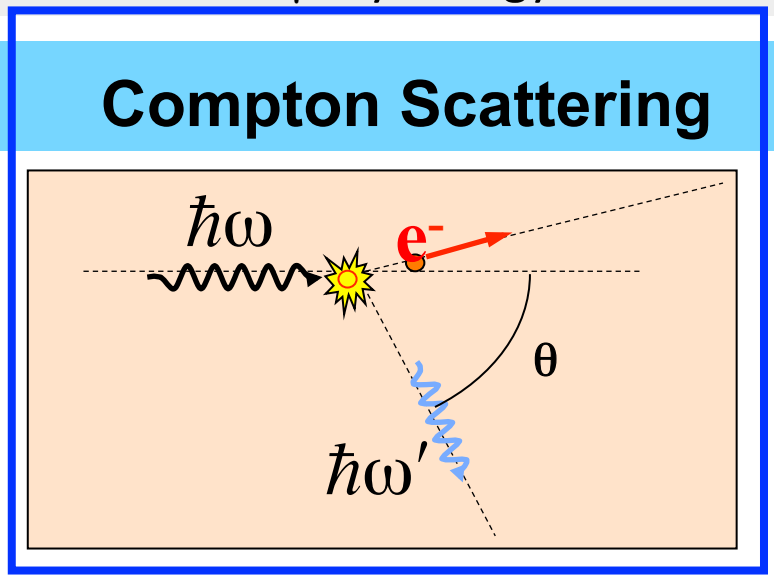
Processes in Germanium

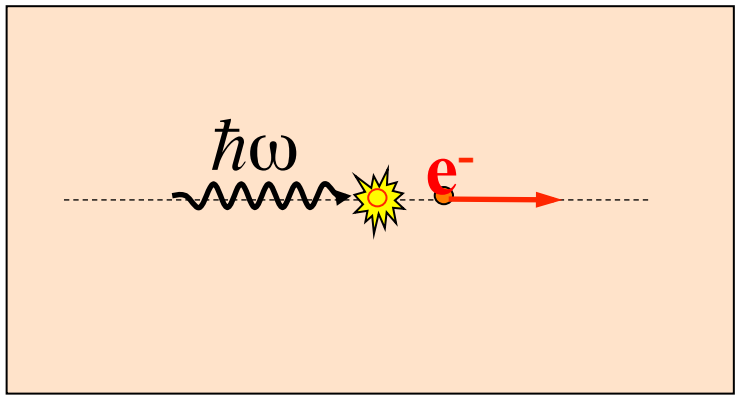
~ 100 keV

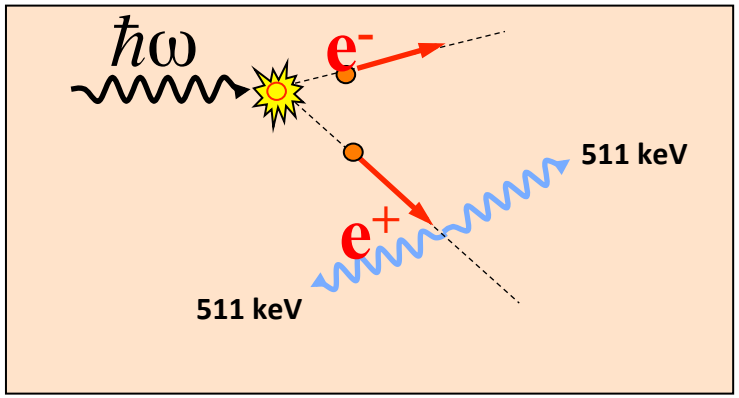
~ 10 MeV

γ-ray energy

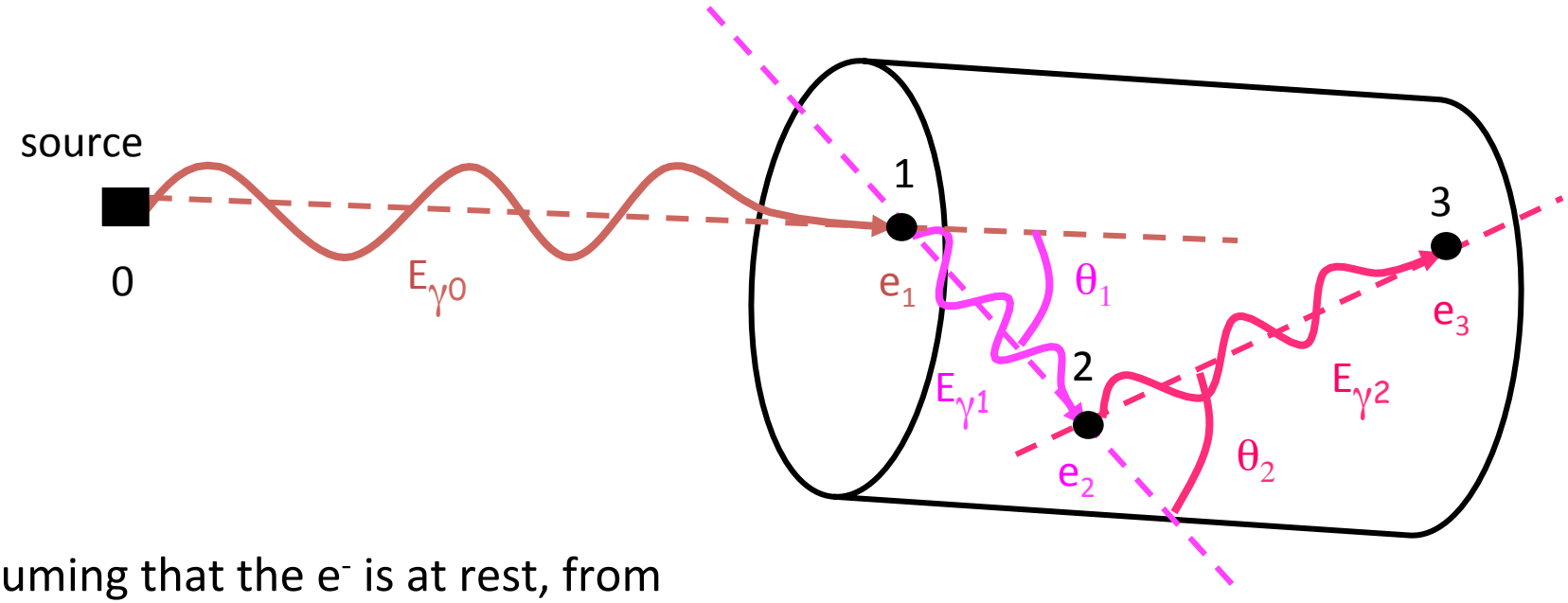
Photoelectric | **Compton Scattering** | **Pair Production**







Compton scattering



assuming that the e^- is at rest, from conservation of energy & momentum:

incident energy at i

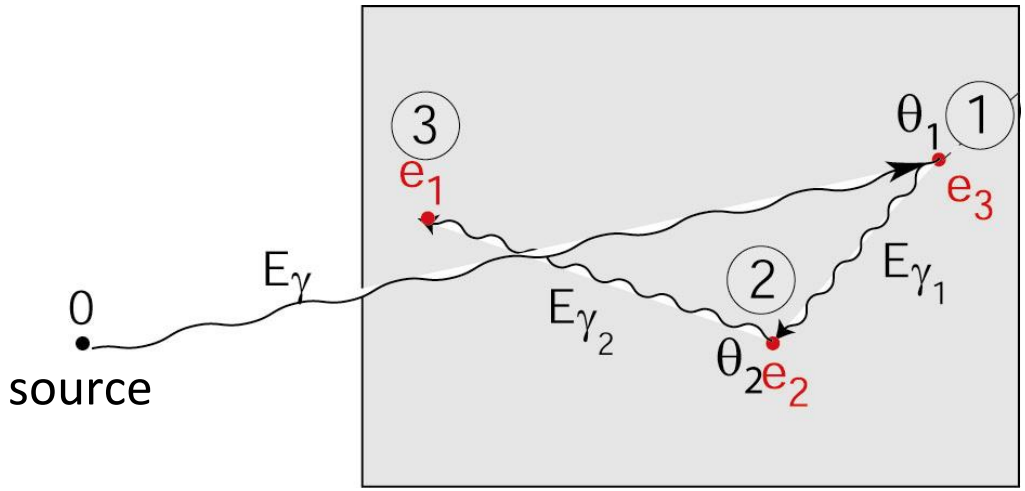
$$\cos(\theta_i) = 1 - m_e c^2 \, (1/E_{\gamma i} - 1/E_{\gamma(i-1)})$$

scattered energy at i = $E_{\gamma(i-1)} - e_i$

What tracking does

Questions :

1) Is the event complete : $\sum e_i = E_\gamma$
2) What is the right sequence



1) from source + interaction positions :

$$\cos(\theta_1) = \frac{\overrightarrow{01} \cdot \overrightarrow{12}}{|\overrightarrow{01}| \cdot |\overrightarrow{12}|}$$

$$E_{\gamma 1,pos} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1 - \cos(\theta_1))}$$

from energy deposition + incident energy:
(incident energy = sum of energy depositions assuming that the event is complete)

$$E_{\gamma 1} = E_\gamma - e_1$$

2)

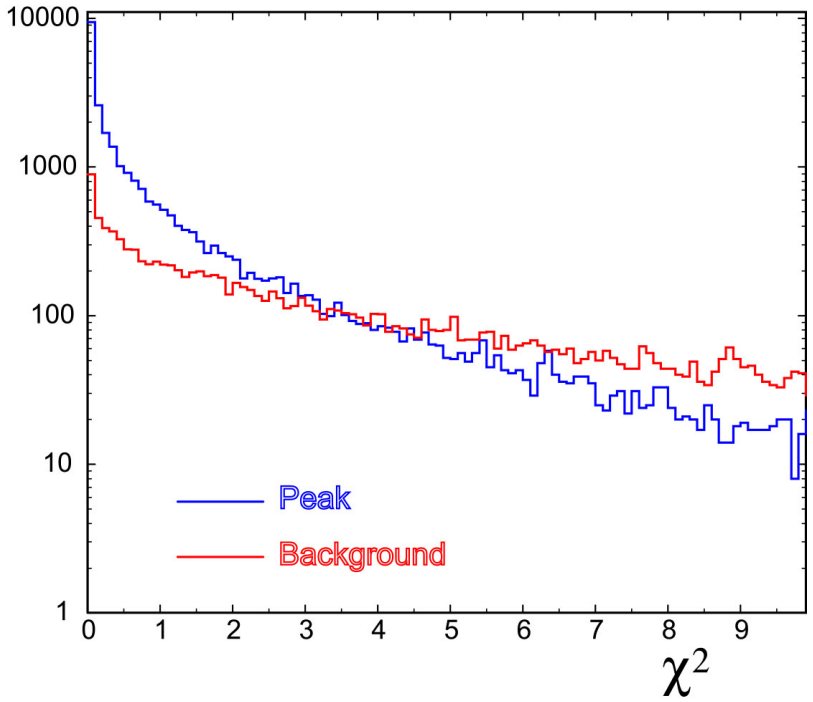
$$E_{\gamma 2,pos} = \frac{E_{\gamma 1}}{1 + \frac{E_{\gamma 1}}{m_e c^2}(1 - \cos(\theta_2))}$$

$$E_{\gamma 2} = E_{\gamma 1} - e_2$$

Track order = Permutation with best $\chi^2 = \sum_{n=1}^{2} \left[\frac{E_{\gamma n} - E_{\gamma n,pos}}{\sigma} \right]^2$ (or other figure of merit)

Full energy deposition or not ?

The identification is not 100% sure



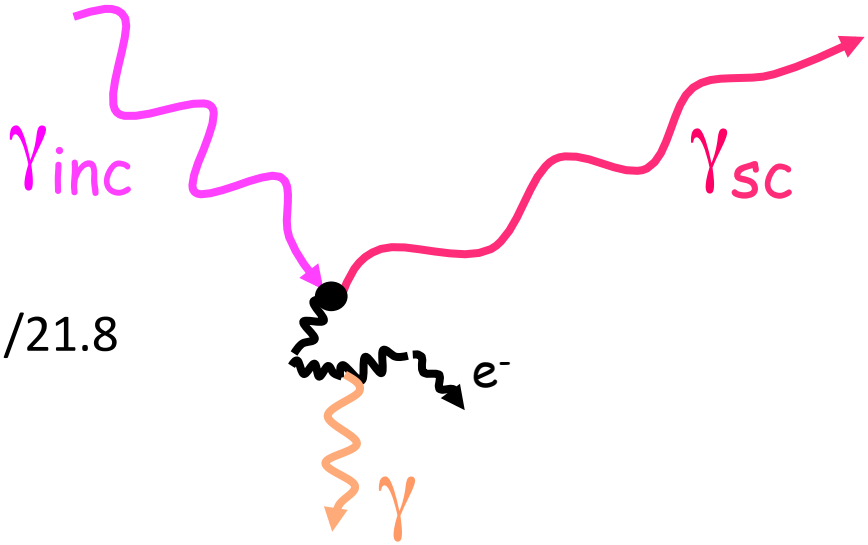
⇨ spectra will always contain background

⇨ Acceptance value determines the quality of the spectrum

⇨ Use R = Efficiency x P/T to qualify the reconstructed spectrum

What limits tracking performance ?

- Interaction position ≠ position of energy deposition

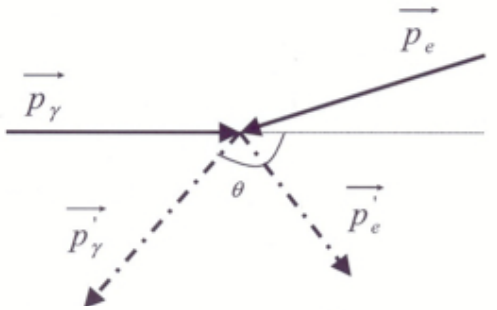


$\sigma_{ion}/\sigma_{Brem} \sim E_{e-}$ (MeV) /21.8

- Rayleigh scattering (relevant at low gamma energies and end of track)

⇨ change in incident direction

Electron Momentum Profile

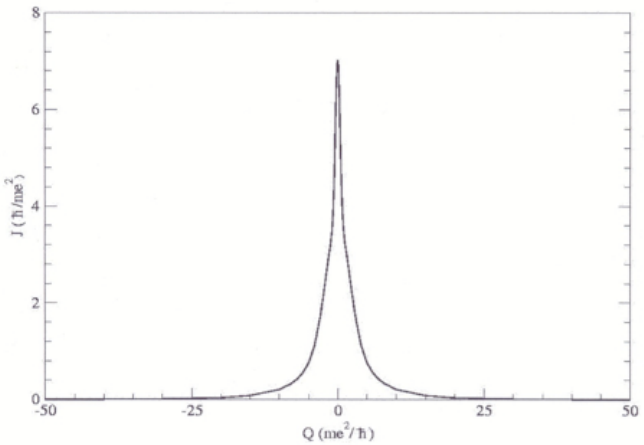


$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E'_\gamma} - \frac{1}{E_\gamma}\right) -$$

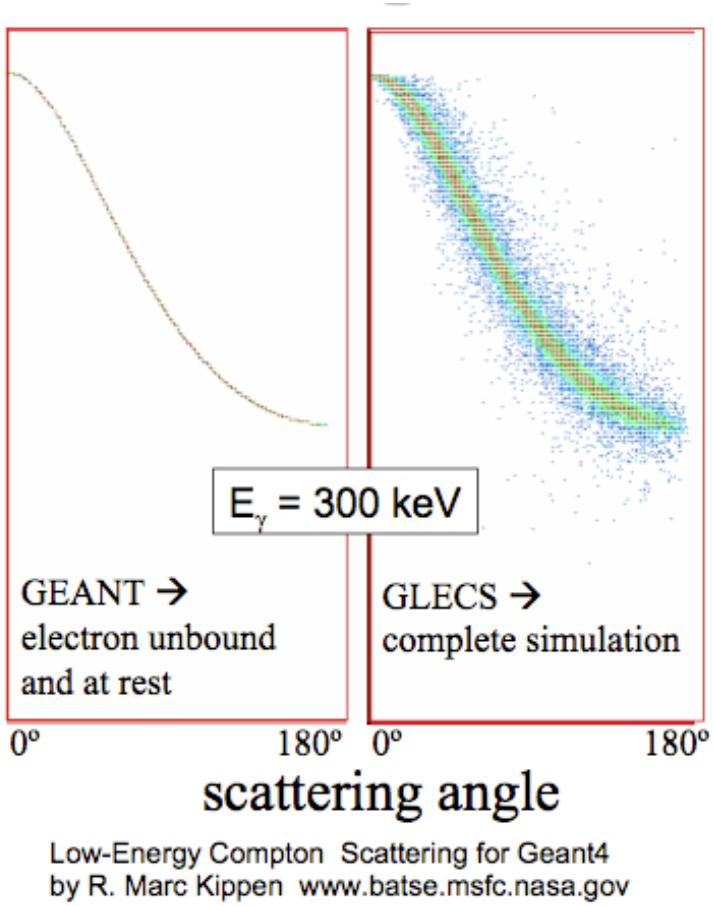
$$\frac{1}{E_\gamma E'_\gamma}\left(Q^2c^2 - Qc\left\{Q^2c^2 + 2m_e c^2\left(E_\gamma - E'_\gamma\right) + \left(E_\gamma - E'_\gamma\right)^2\right\}^{\frac{1}{2}}\right)$$

$$Q = -\vec{p}_e \frac{\overrightarrow{\Delta p_\gamma}}{\left|\overrightarrow{\Delta p_\gamma}\right|}$$

$$\overrightarrow{\Delta p_\gamma} = \vec{p}'_\gamma - \vec{p}_\gamma$$



$E_{\gamma'}/E_\gamma$

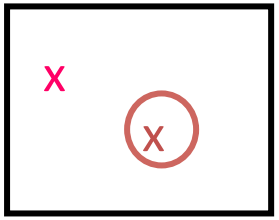


Biggs *et al.,* At. Data and Nucl. Data Tab. 3 (1975) 16

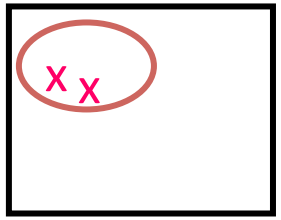
Some more complications

From Pulse Shape Analysis:

uncertainty in position of interaction $\delta p(e_i, x_i, y_i, z_i)$:

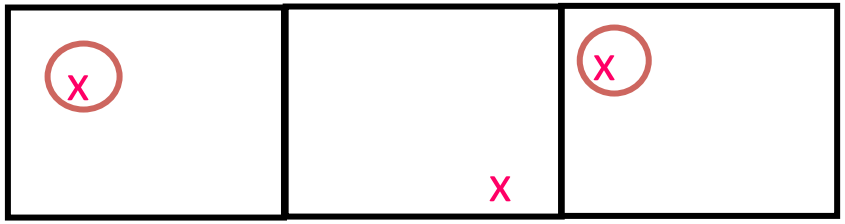


position resolution



From preamplifier:

energy threshold



From preprocessing:

energy resolution

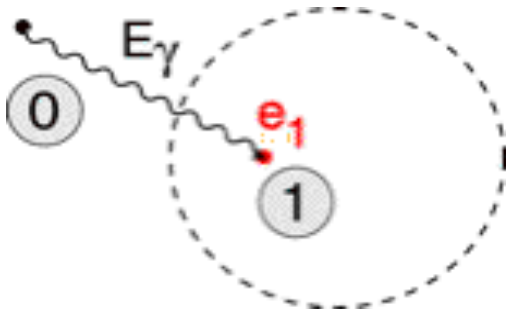
Not exactly tracking …

1. Single interaction points:

There is not much we can do....:

- Does the interaction point satisfy photoelectric conditions (interaction depth, energy) ?

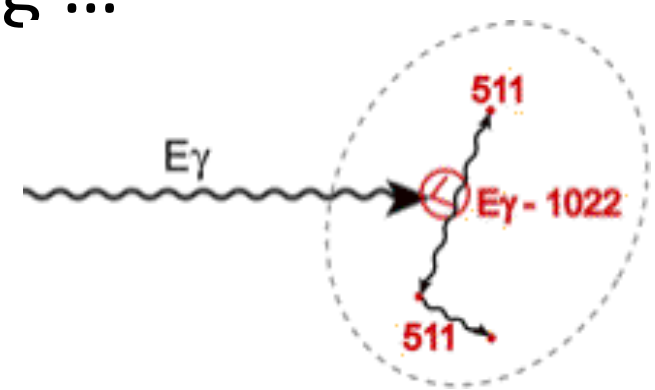
- Is the interaction point sufficiently isolated from other points ?



!! With the AGATA PSA algorithm: ~20% of full absorption 1 MeV events end up in single interaction points

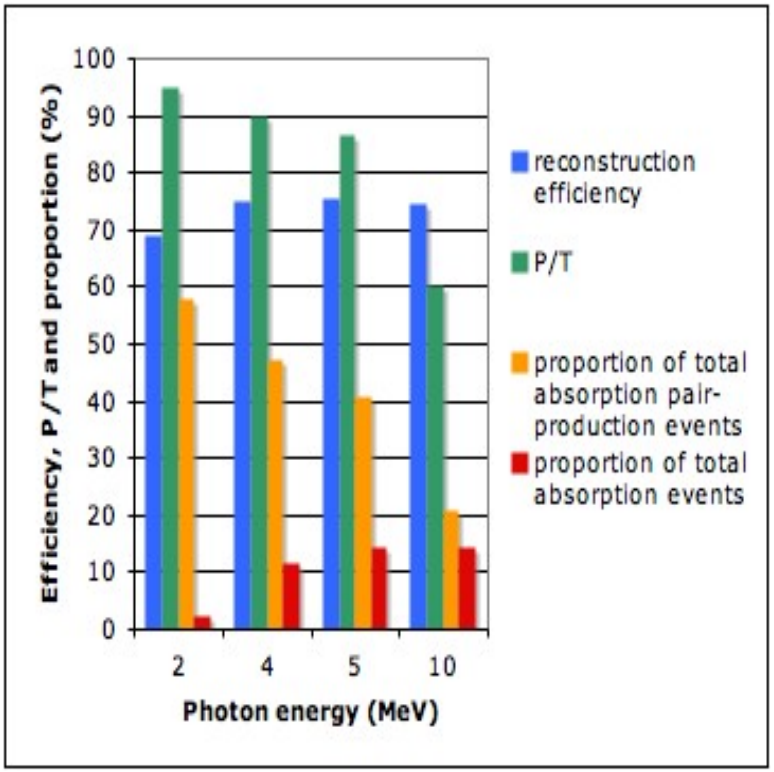
Not exactly tracking …

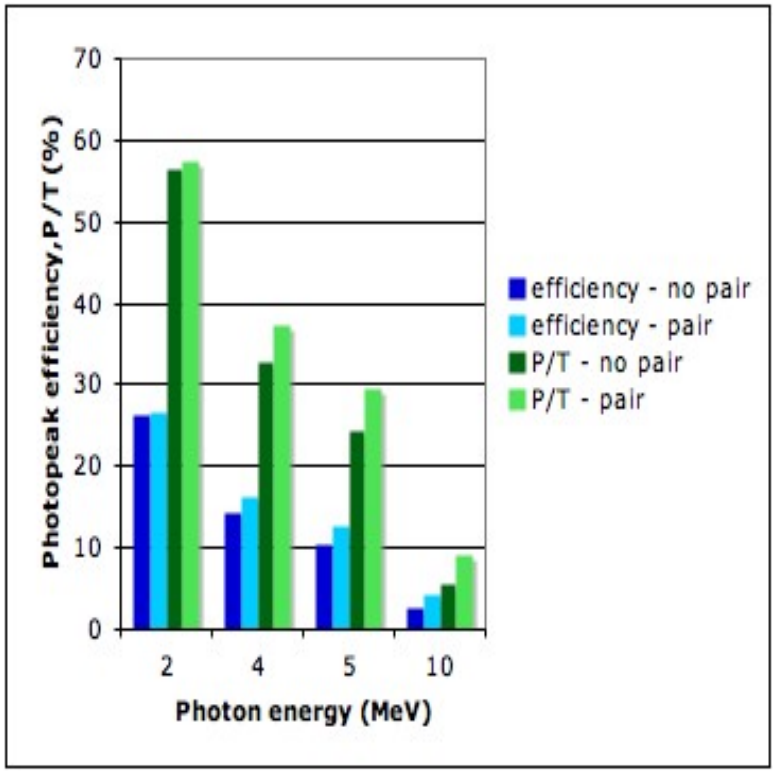
2. Pair production interaction points:



Do the interaction points correspond to a pair production event ?

$$e_1 = E_\gamma - 2\, m_e c^2$$





Inputs to OFT

- Requires 3(4) tracking parameters (OftParams from TrackingFilter.conf)

- Requires PSA hits e[i],x[i],y[i],z[i] within a given prompt coincidence time window

- Requires energies in MeV

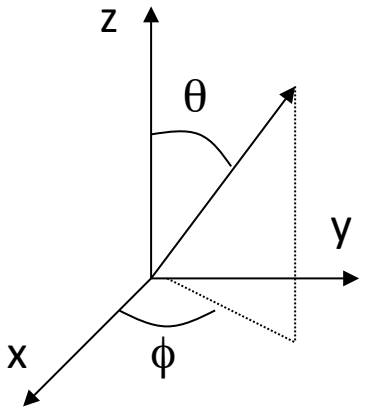
- Requires positions in the laboratory frame in cm

- Requires knowledge of the position of the source (SourcePosition from TrackingFilter.conf)

!! The source position is defined wrt to the center of the AGATA shell

- Does NOT require the recoil velocity or direction

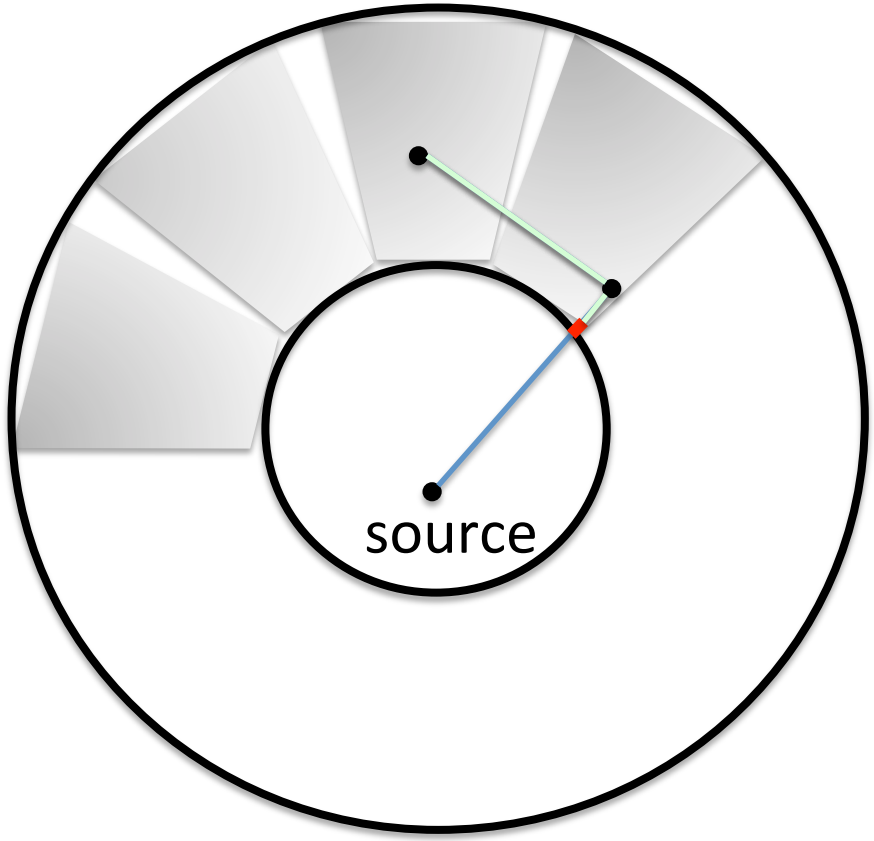
OFT – 1st steps



(i) Calculates angles and sorts points according to increasing θ

(ii) Calculates effective distances in Ge
between points and between points and source

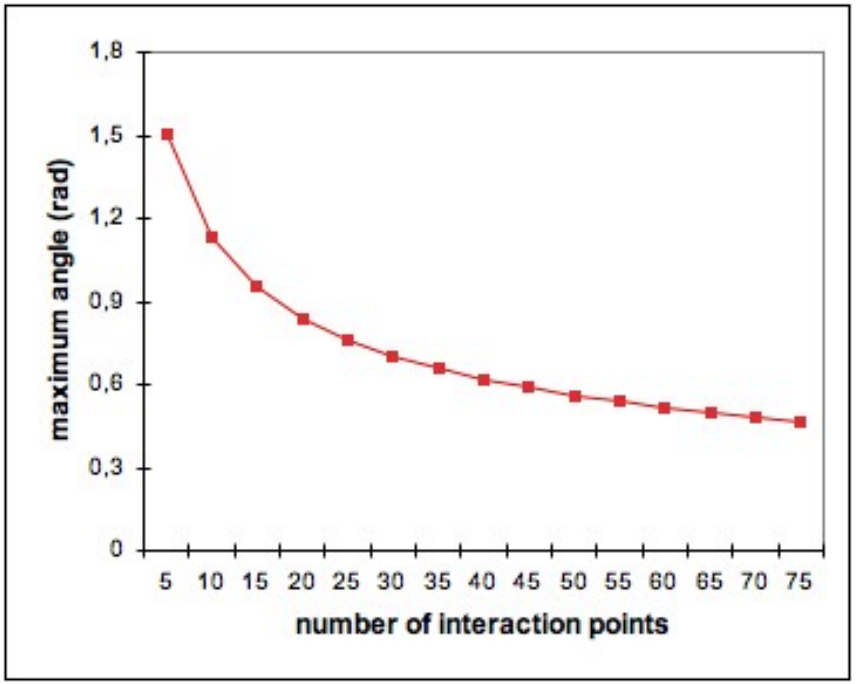
`r_ge[i][j]` `r_ge[i][i]`



OFT - clusterisation

(iii) Computes the maximum angular separation α_{max} between points in a cluster = f(intnumber)

```
power = pow(((intnumb+2)/3.),0.9);
alfamax=acos(1-2/power)/PARAM4;
```

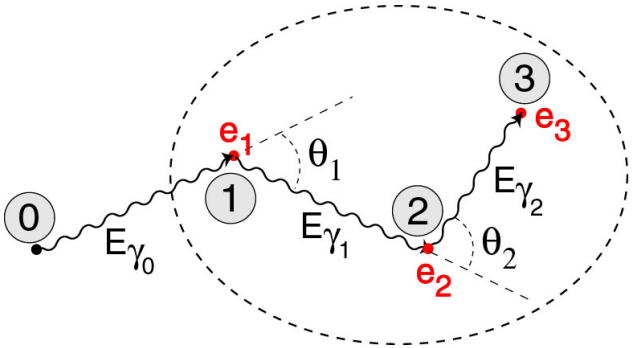


(iv) Assigns interaction points i and j to the same cluster if:

$$\left|\cos^{-1}\left(\sin\theta_j \sin\theta_i \cos\left(\varphi_j - \varphi_i\right) + \cos\theta_i \cos\vartheta_j\right)\right| \le \alpha$$

(v) Loops on α_{min}(=0.15) < α < α_{max} and find n different clusters ($\delta\alpha$=0.1 rad) with ecluster[n] total energy and intnumb[n] of interactions

OFT - tracking



(vi) If intnumb[i]=1, give the cluster the minimal probability minprobtrack=PARAM1

(vii) Computes Pair production probability for cluster

(viii) Computes the Compton tracking figure of merit for the cluster:

source -	i - j - k
`	i - k - j
	k - i - j
	k - j - i
	j - i - k
	j - k - i

1) compare scattered energies

```
escatter = ecluster-e[i] and
escattern= ecluster/(1+ecluster/mc2 (1-cosθi))
```

using the expression

```
exp(-2*SQ(escattern-escatter)/(SQ(deltaescn)+SQ(deltaesc)))

        deltaescn = SQ(escattern)*ercos/mec2;
        deltaesc = sqrt((intnumber+1)*SQ(eres));
```

$$er\cos = \sigma_\theta \sqrt{\left(\frac{\partial \cos\theta_1}{\partial x_0}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial y_0}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial z_0}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial x_1}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial y_1}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial z_1}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial x_2}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial y_2}\right)^2 + \left(\frac{\partial \cos\theta_1}{\partial z_2}\right)^2}$$

σ_θ is related to the average position uncertainty in cm = PARAM 3

OFT - tracking

2) multiply by the SQ of the probability to undergo a Compton interaction at i and the probability to Compton scatter at j (if j is the end of the track test for photoelectric interaction):

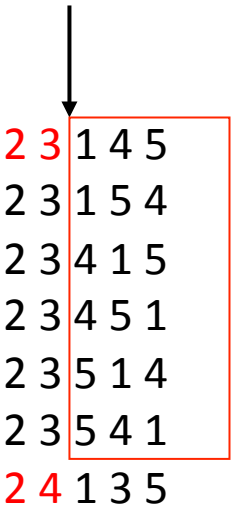
```
coef1=sig_compt(ecluster)/(sig_abs(ecluster)+sig_pair(ecluster)+sig_compt(cluster))
coef2=sig_compt(escatter)/(sig_abs(escatter)+sig_pair(escatter)+sig_compt(escatter))
```

3) multiply by the probability for ranges r_ge[i][i] and r_ge[i][j]:

```
lambda1=range_process(sig_compt(ecluster))
lambda2=range_process(sig_compt(escatter))
proba(lambda1,r_ge[i][i]) and proba(lambda2,r_ge[i][j])
```

4) skip the rest of a sequence after a bad scattering point and go to next sequence

5) Repeat for all the steps in the sequence: the total probability for each sequence is the Nth square root of product of probabilities - where N=(intnumber*2)-1



6) Award the probability of the best sequence or the pair production probability (& mechanism 2 or 3 respectively)

OFT – cluster validation

(ix) Clusters are sorted according to their figure of merit (clusters with smaller figure of merit than others and with at least one matching interaction point are flagged)

(x) Clusters with intnumb[n]>1 are accepted if probability[cluster]>minprobtrack = PARAM 1

(xi) Evaluates the figure of merit of the remaining unflagged single interaction clusters:

OLD METHOD

```
distance to closest interaction point > 4 cm
cross1=sig_abs(ecluster)
cross2=sig_abs(ecluster)+sig_compt(ecluster)+sig_pair(ecluster);
lambda=range_process(cross2);
probability = sqrt(proba(lambda,r_ge[0][0])*cross1/cross2;
```

- Accepts cluster if probability > minprobsing = PARAM 2 (& mechanism = 1)

NEW METHOD

```
if (proba(lambda,r_ge[0][0]) > f(ecluster)) probability= PARAM 2 + 1
else probability=0;
```

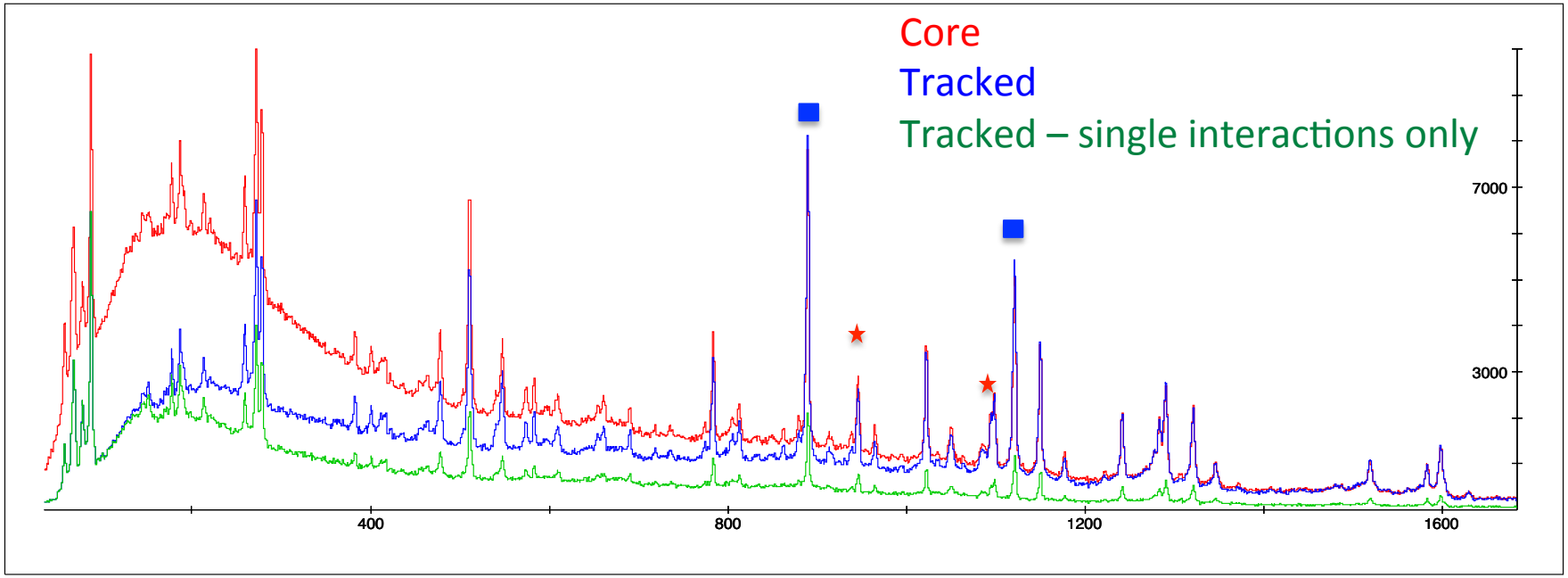
f fitted from data (hence PSA dependent)

OFT at work - singles

$^{36}Ar(^{40}Ca,2p\alpha)^{70}Se$

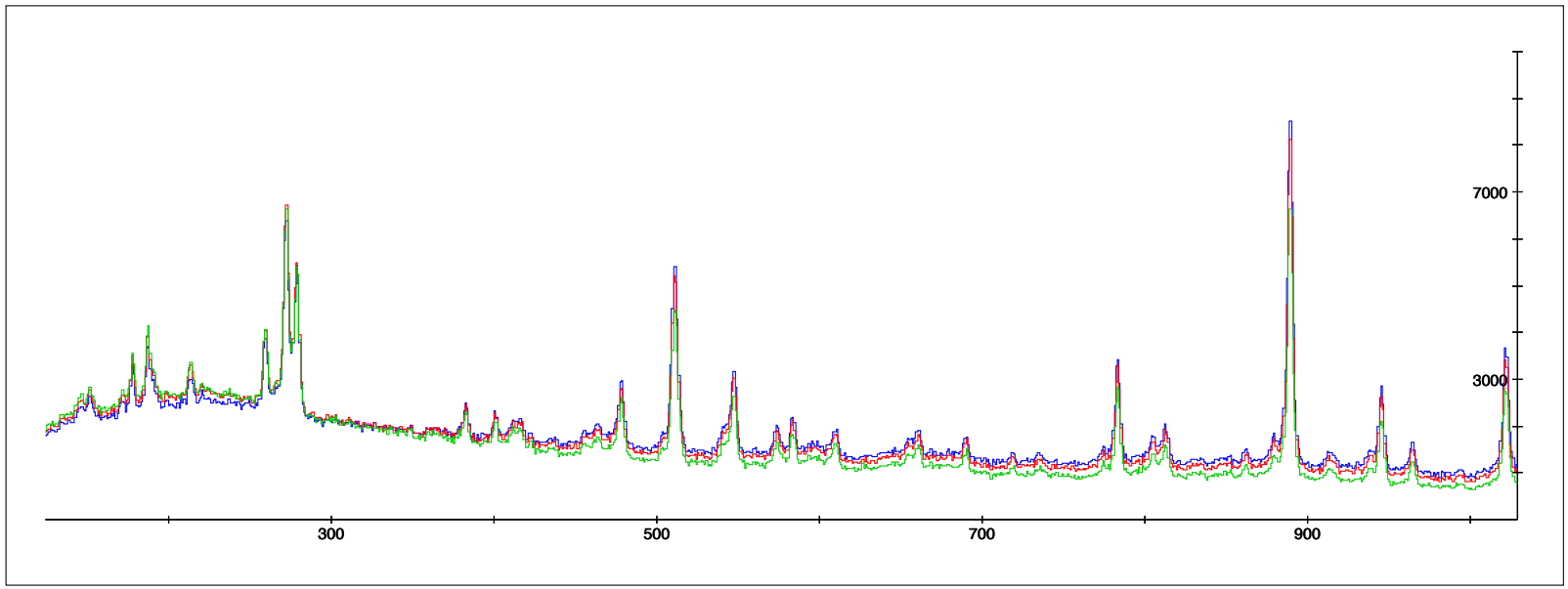
Contaminant reaction: $^{36}Ar(^{16}O,2p\alpha)^{46}Ti$

PARAM 1 = 0.05
PARAM 3= 0.8



Changing parameters

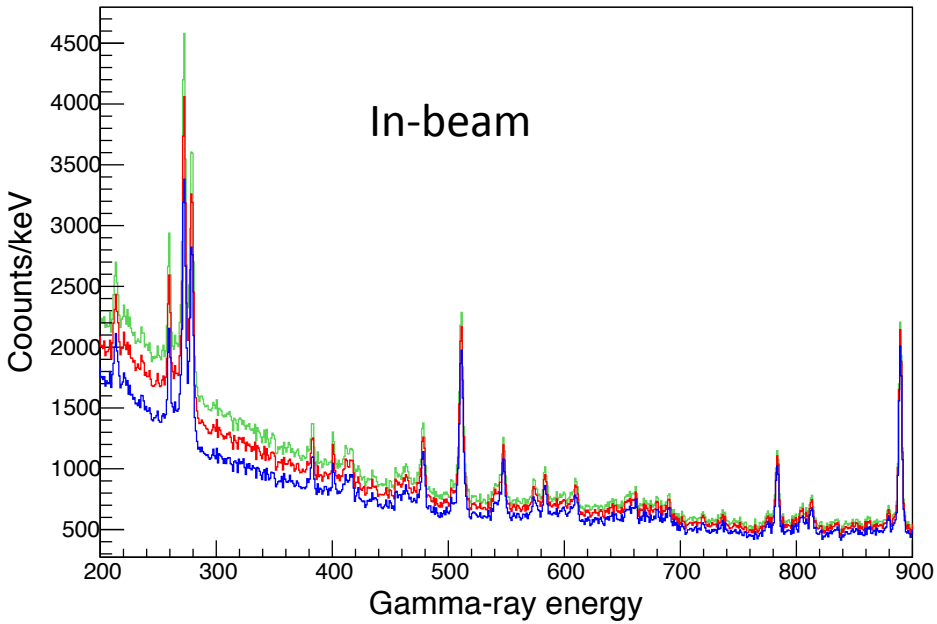
PARAM 3 = 1.6
PARAM 3 = 0.8
PARAM 3 = 0.4

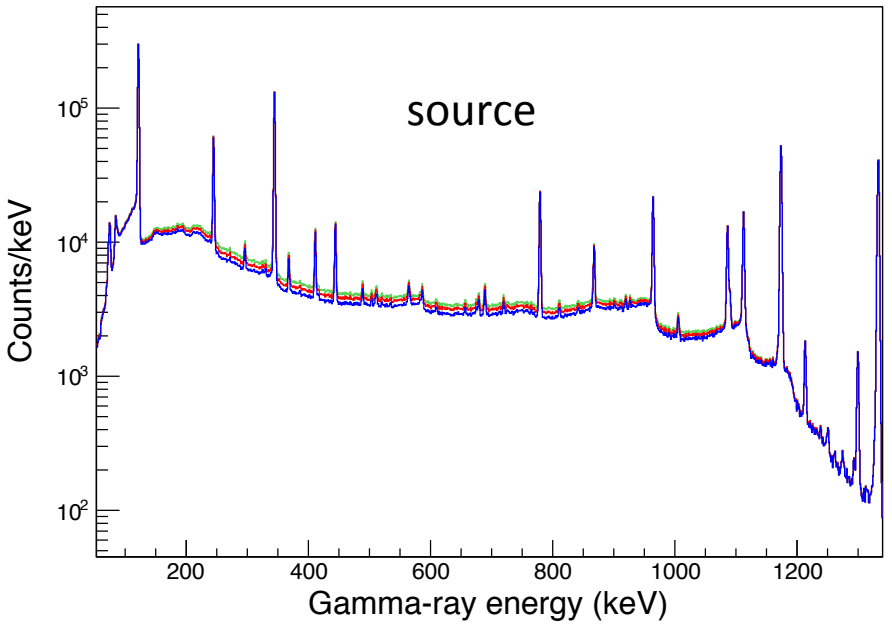


Optimum between gain at high energy and loss at low energy

Sing. Interactions in detail

« tracked » single interaction spectra as a function of different PARAM 3:

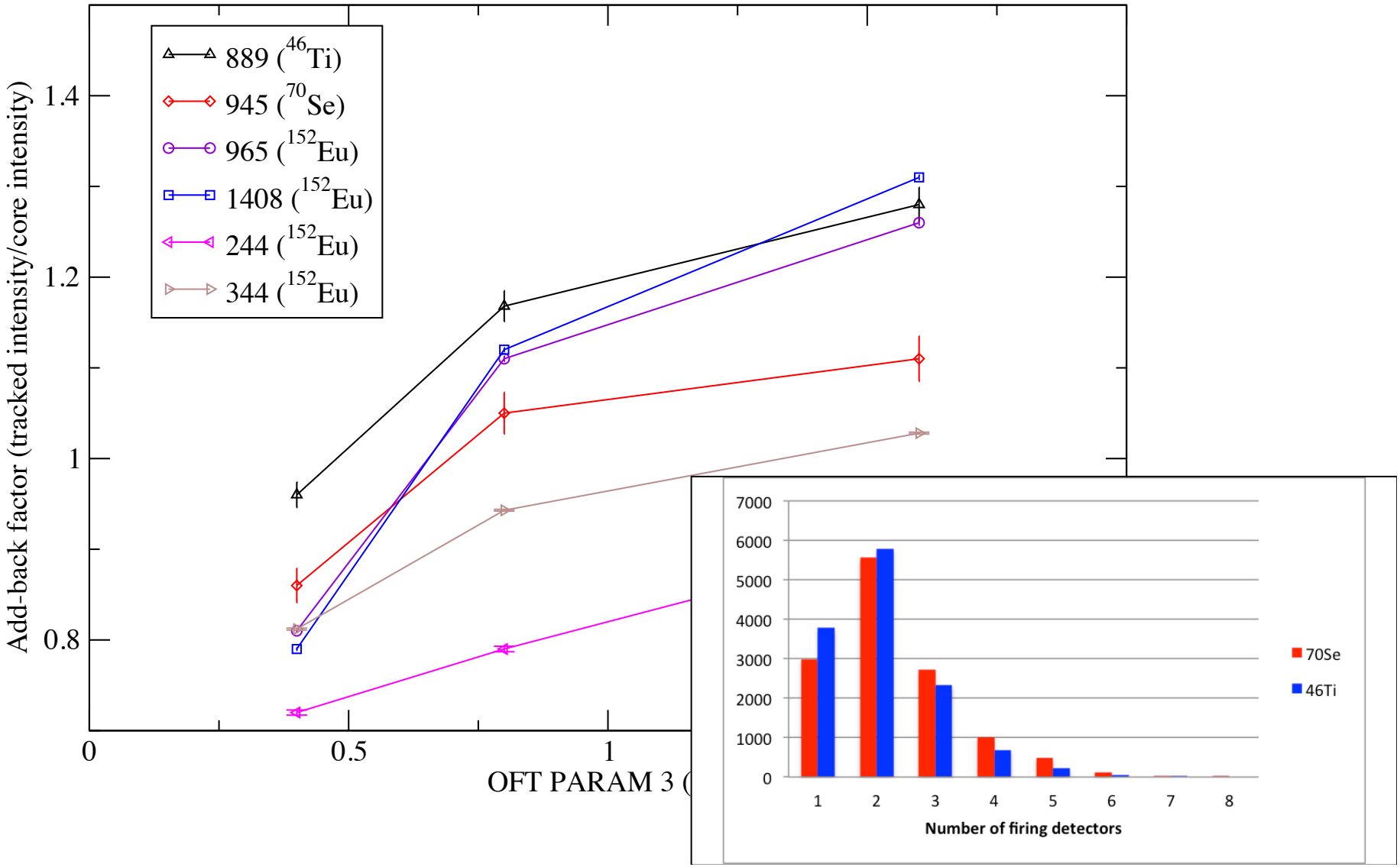




The behaviour depends on the gamma-ray multiplicity of the physical events

Add-back factors

(PARAM 1 = 0.05)



To Do

- Tune PARAM 3 & 4 to experimental conditions

- Issue of tracking time window to be solved for events with prompt and isomeric cascades (either by new builder possibilities or pre-tracking Filter)

- Errors on x,y and z should ultimately be given by PSA for every hit

- Mail for any help – or post query on forum