γ-ray Tracking with AGATA

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EGAN school, 1-3 October 2014

Outline

- Introduction & basic principles
- 2 tracking philosophies
- Limitations
- Description of OFT
- 3 “hands-on” examples (^{60}Co, high energy, “high” fold)
- Conclusion & outlook

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 incident and scattering directions (for Doppler correction & polarization measurements)

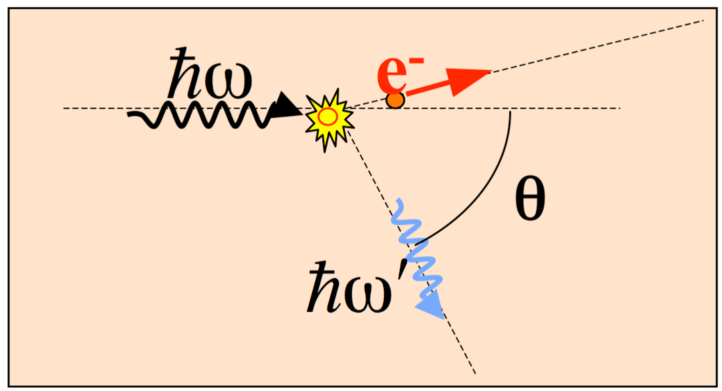
E_1, $(\theta,\phi)_{inc-1}$, $(\theta,\phi)_{sc-1}$
E_2, $(\theta,\phi)_{inc-2}$, $(\theta,\phi)_{sc-2}$
....
E_i, $(\theta,\phi)_{inc-i}$, $(\theta,\phi)_{sc-i}$

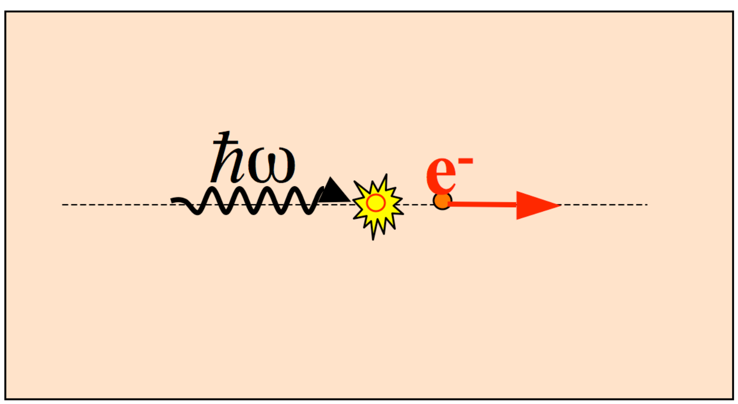
Processes in Germanium

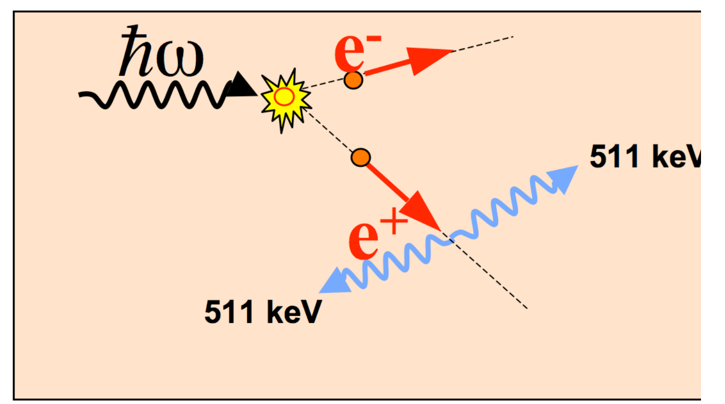
~ 100 keV ~ 10 MeV

γ-ray energy

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







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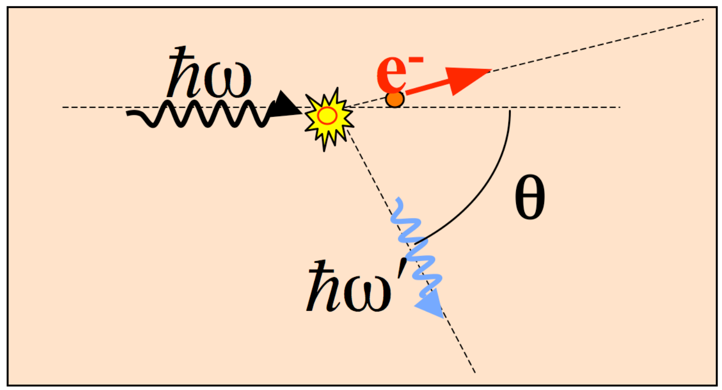
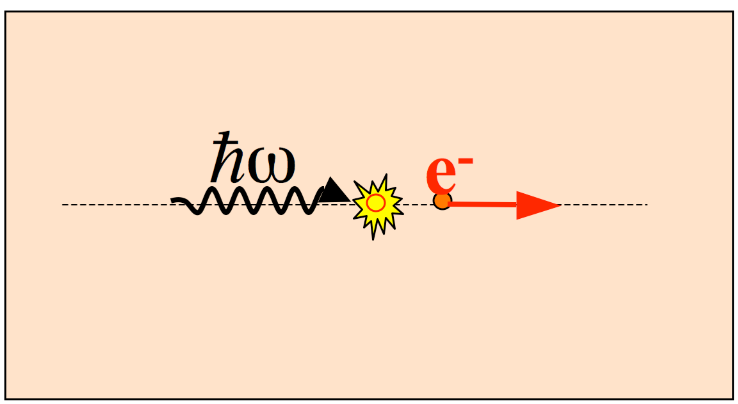
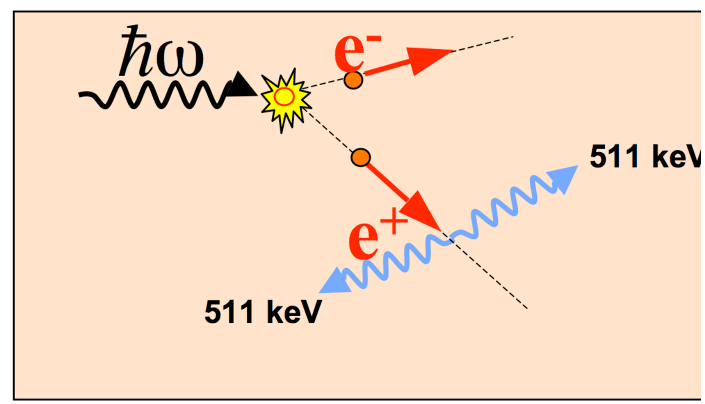
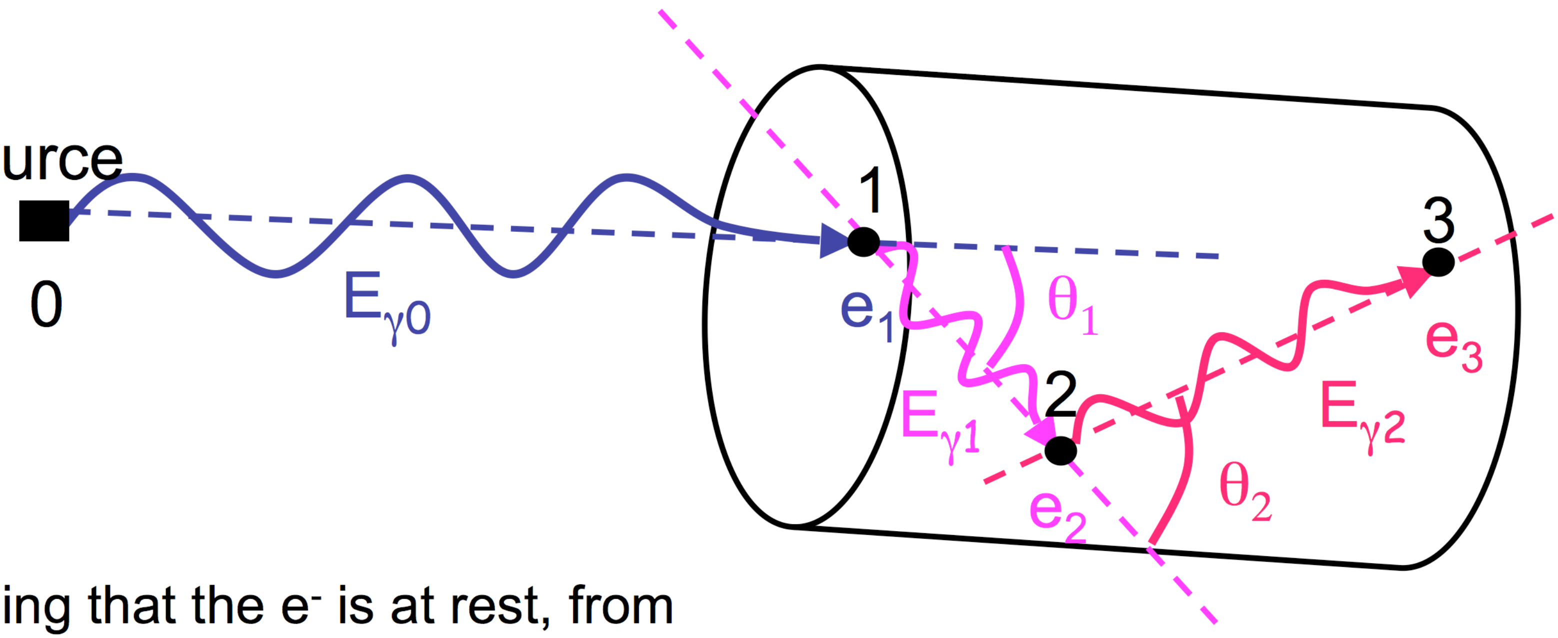
Photoelectric	Compton Scattering	Pair Production







Compton scattering



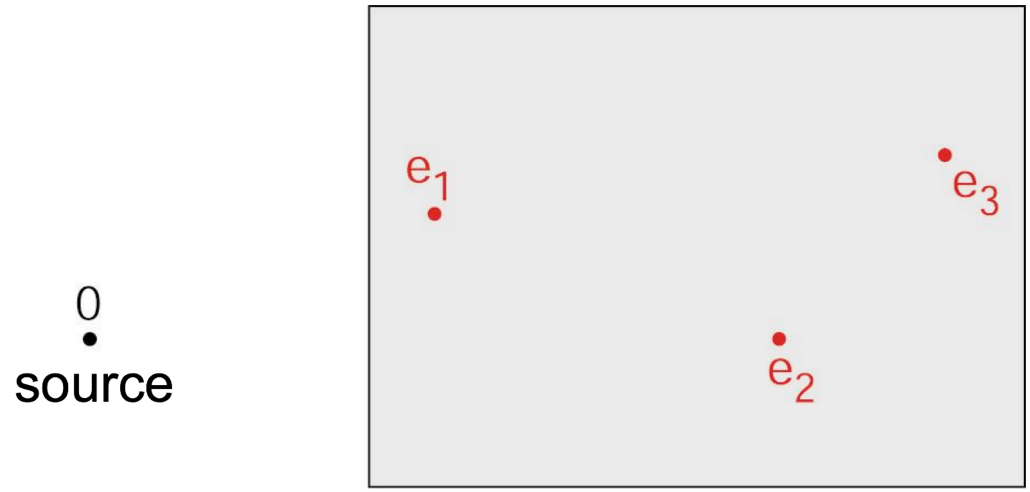
assuming that the e^- is at rest, from conservation of energy & momentum:

incident energy at i

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

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

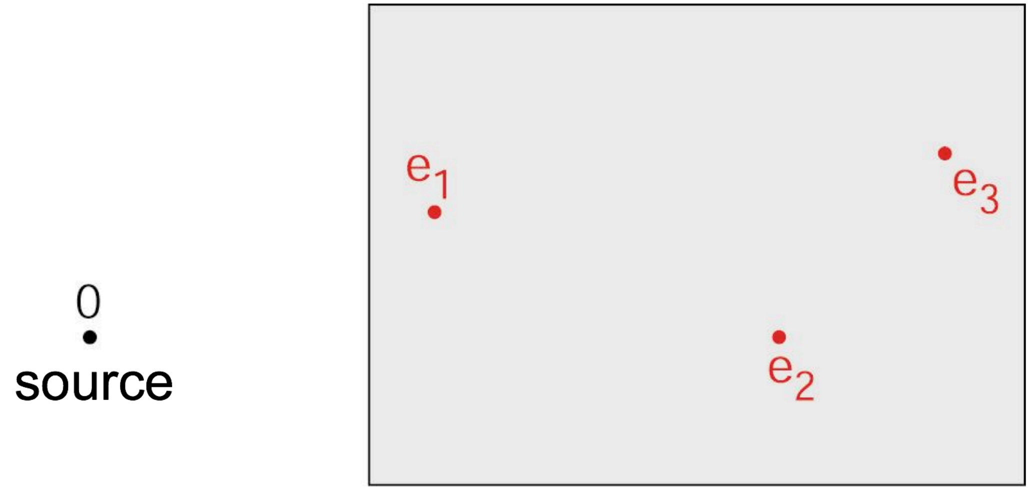
What tracking does



What tracking does

Questions :

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



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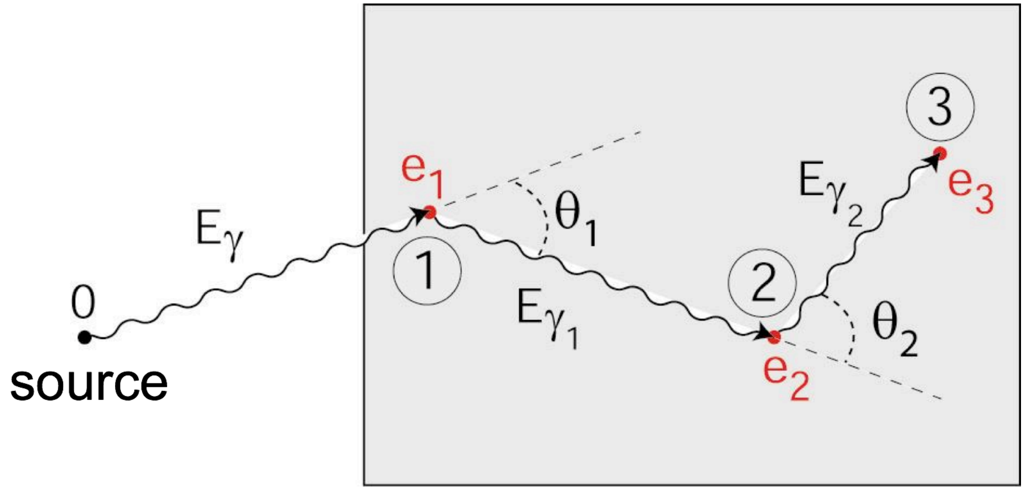

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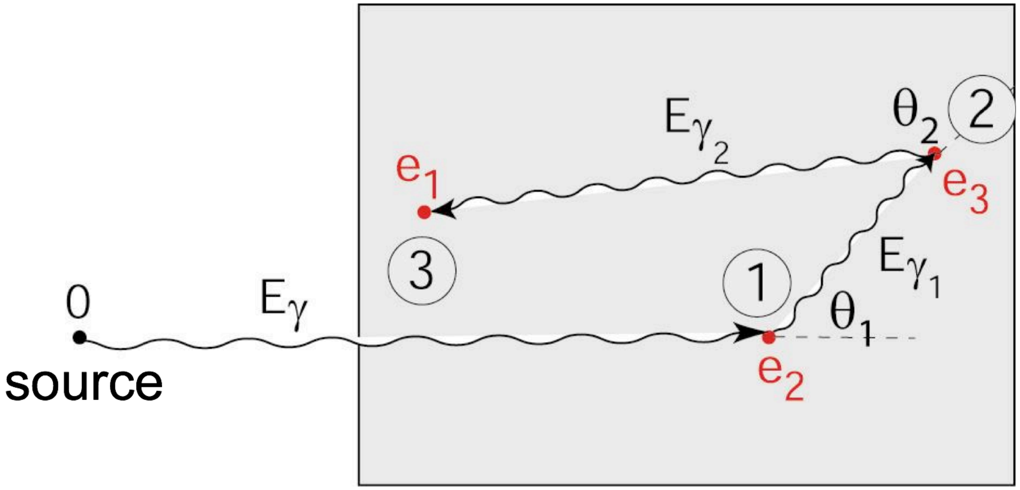

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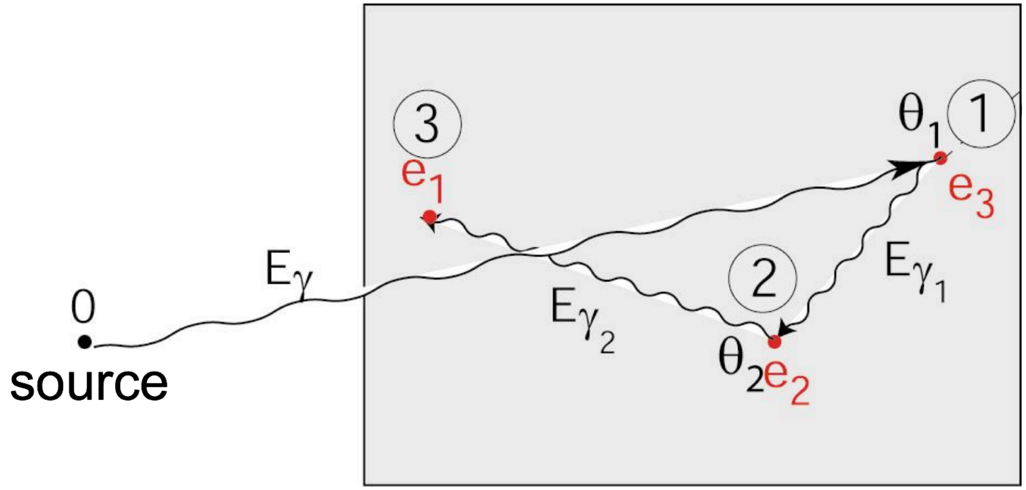

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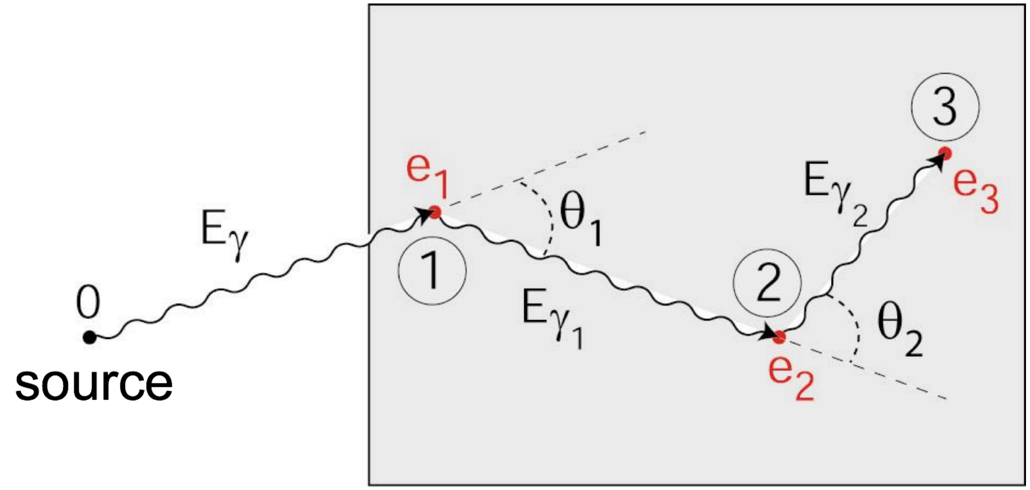

1) from source + interaction positions :

$$\cos(\theta_1) = \frac{\overrightarrow{01}\,.\,\overrightarrow{12}}{|\overrightarrow{01}|.|\overrightarrow{12}|} \Rightarrow E_{\gamma 1,pos} = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1 - \cos(\theta_1))}$$

from energy deposition + incident energy:

(incident energy = sum of energy depositions assuming that the event is complete)

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

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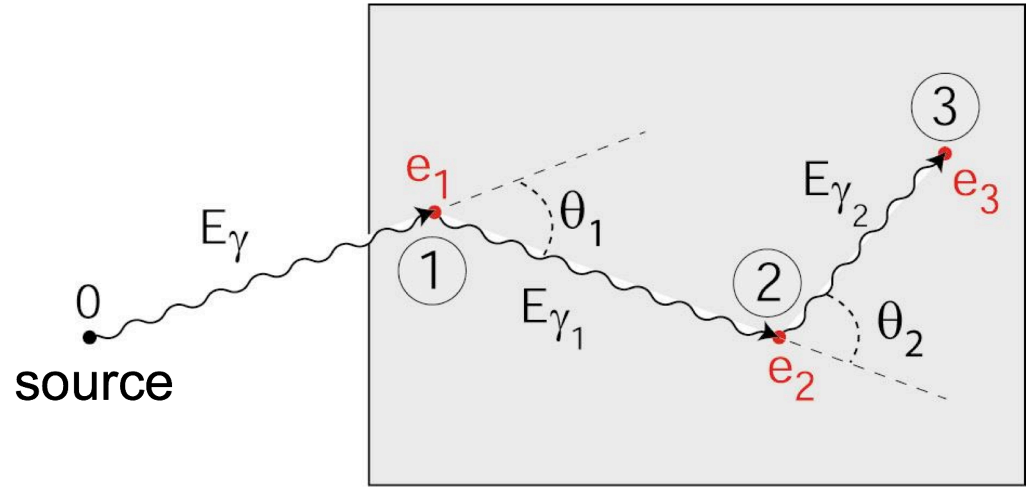

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2) $\Rightarrow$

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

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

What tracking does

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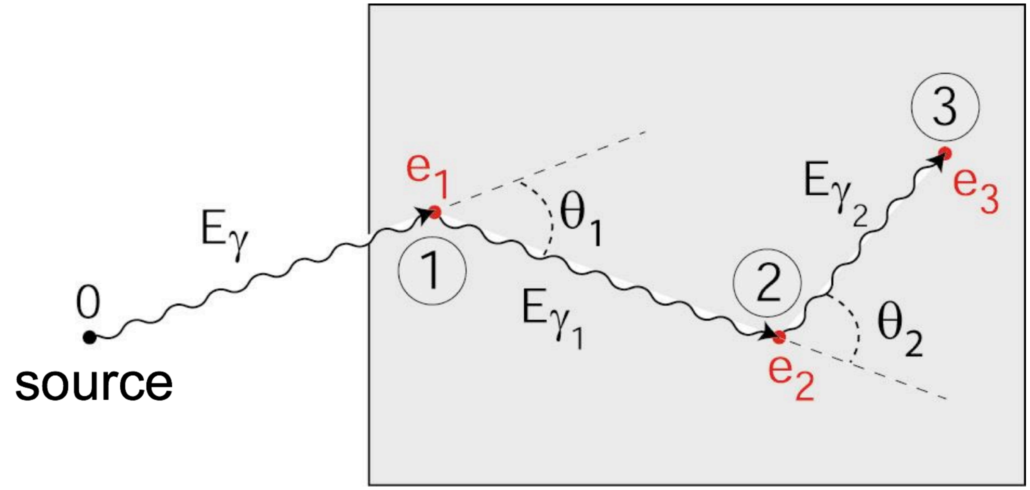

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$$E_{\gamma 1} = E_\gamma - e_1$$

2)

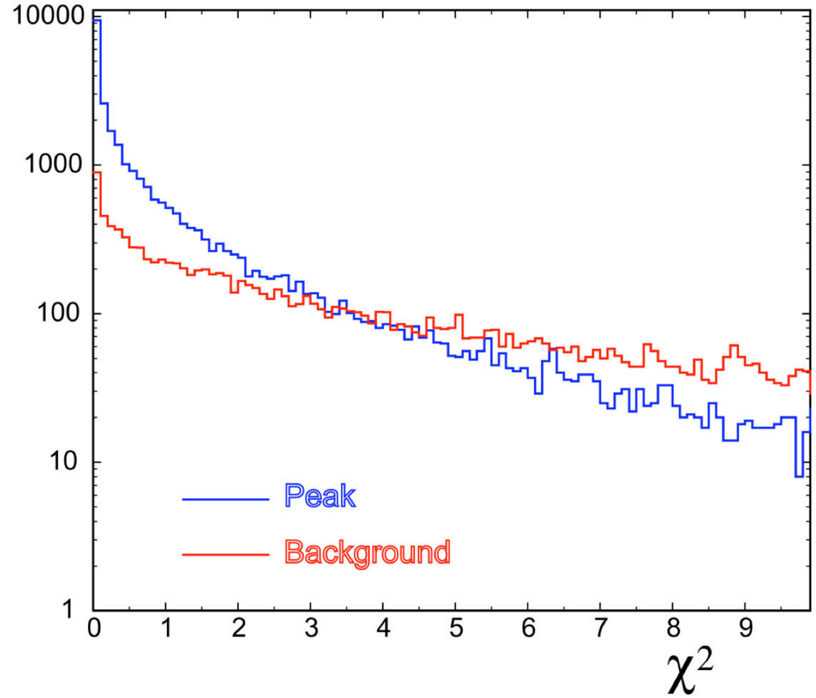
$$\Rightarrow E_{\gamma 2,pos} = \frac{E_{\gamma 1}}{1 + \frac{E_{\gamma 1}}{m_e c^2}(1 - \cos(\theta_2))}$$

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

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



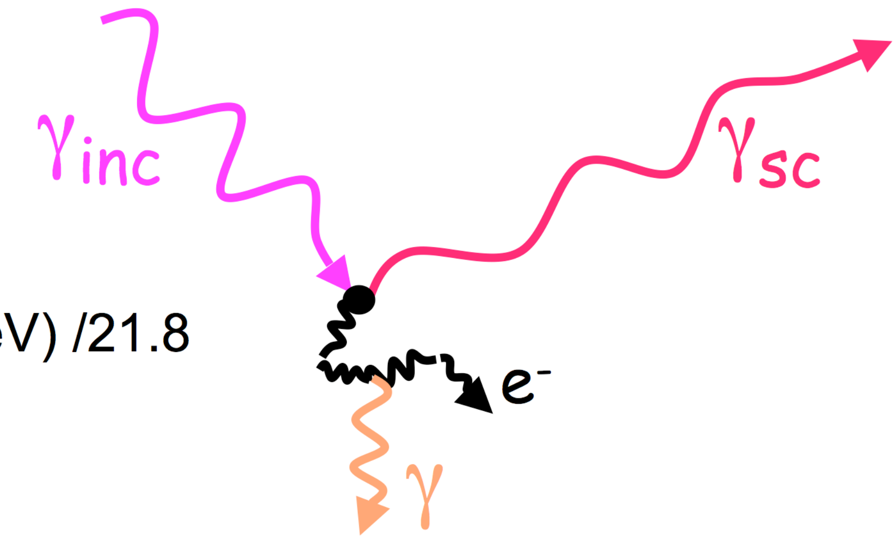
⇨ spectra will always contain background

⇨ 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 $\neq$ position of energy deposition

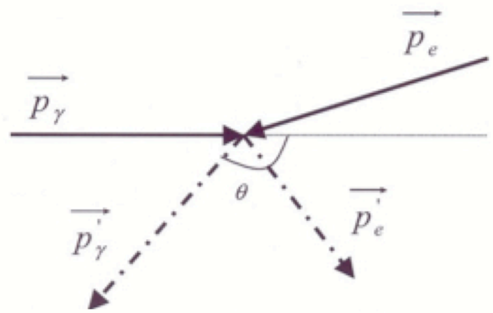


$\sigma_{ion}/\sigma_{Brem} \sim E_{e-}$ (MeV) /21.8

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

⇨ change in incident direction

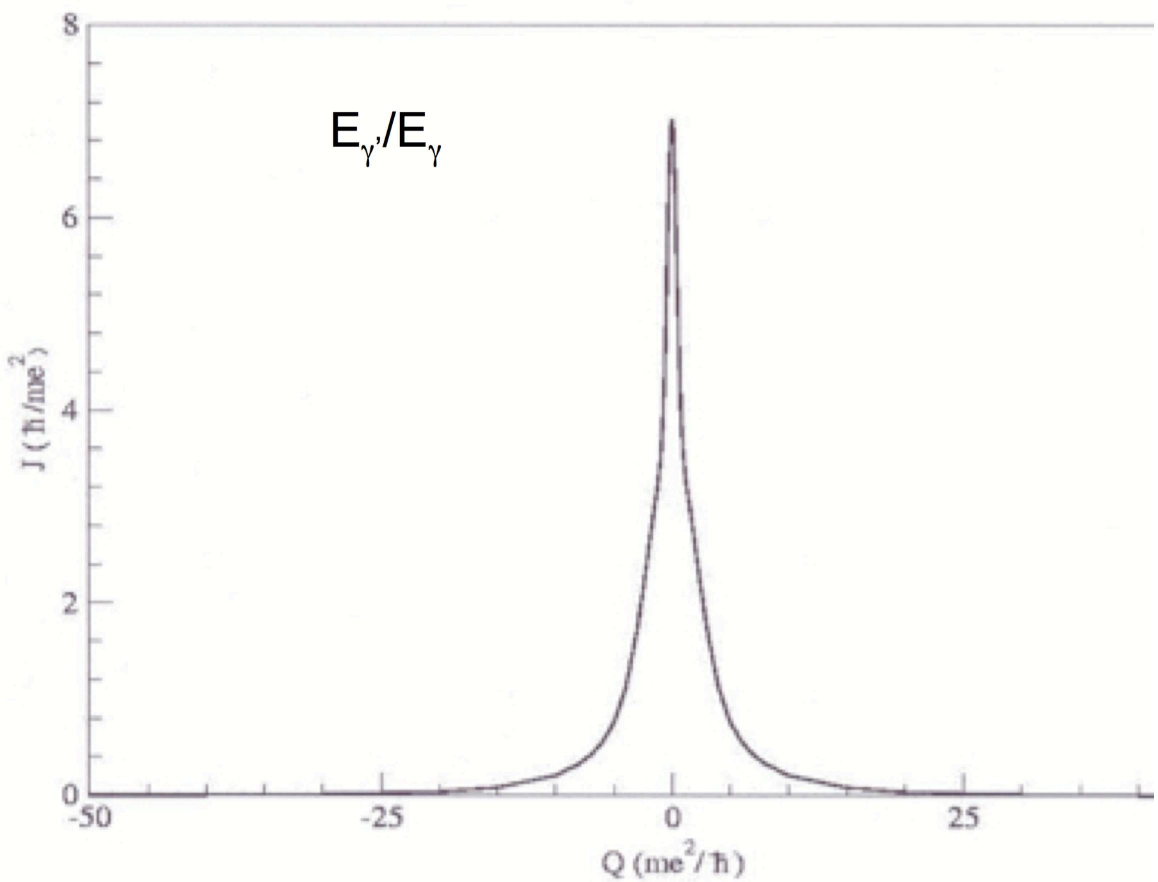
Electron Momentum Profile



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

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

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



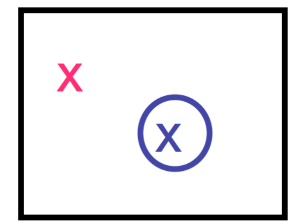
Low-Energy Compton Scattering for Geant4
by R. Marc Kippen www.batse.msfc.nasa.gov

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

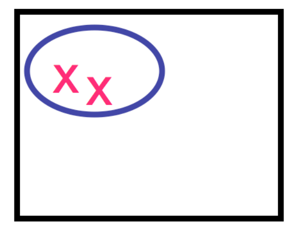
Some more complications

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

Clusterisation & Forward tracking

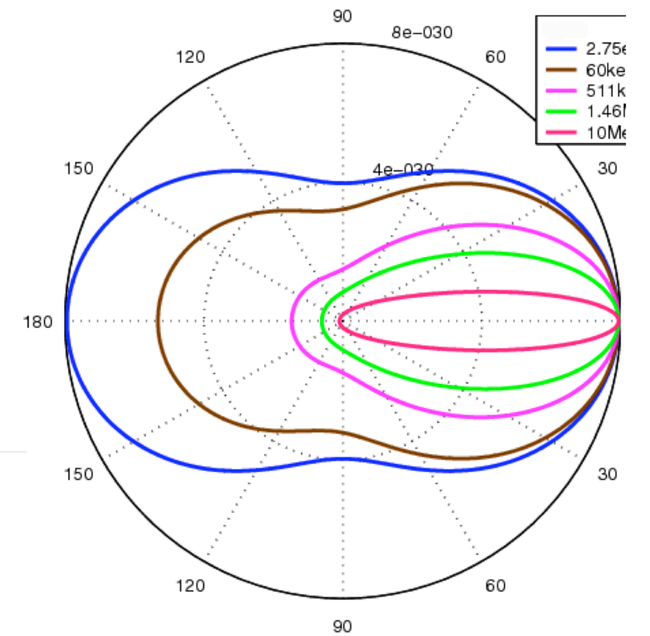
G. Schmidt *et al.*, Nucl. Instr. Methods 430 (1999) 69

* Forward peaking of Compton scattering (Klein-Nishina)

$$\frac{d\sigma}{d\Omega} = 0.5 r_e^2 (P(E_\gamma, \theta) - P(E_\gamma, \theta)^2 \sin^2(\theta) + P(E_\gamma, \theta)^3)$$

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

* Decreasing range as the photon loses energy



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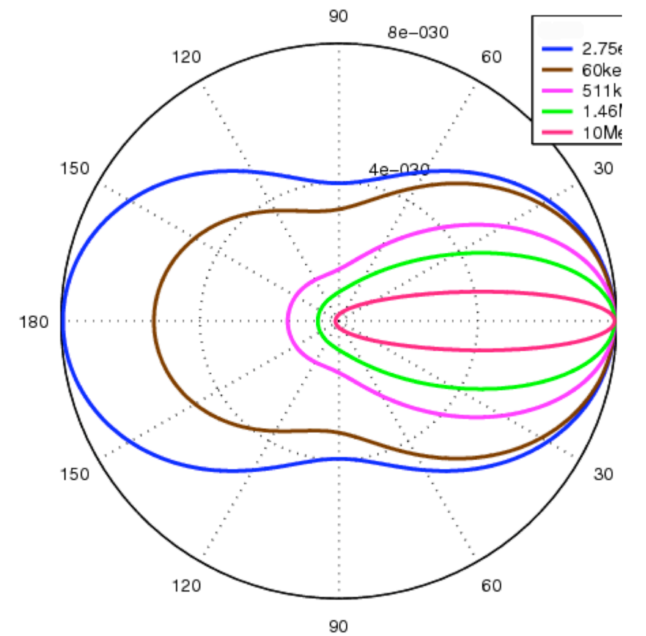
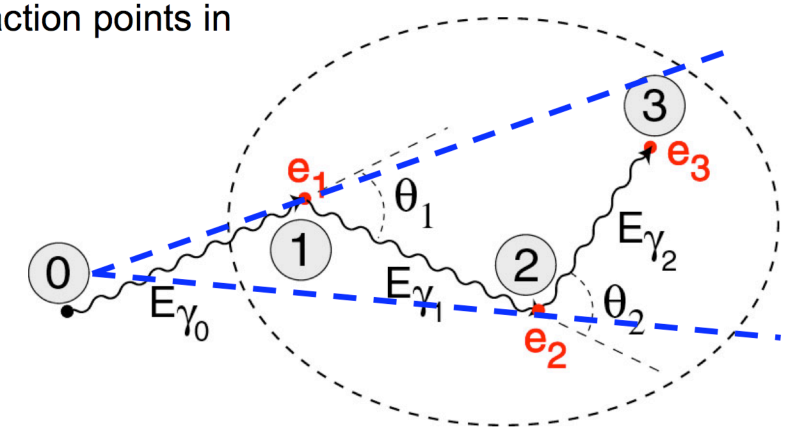
⇨ Clusterisation of interaction points in (θ,ϕ) space





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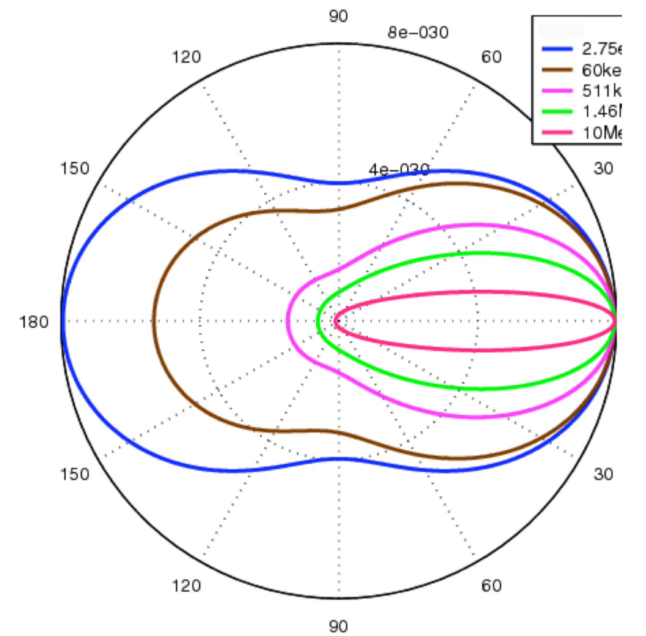
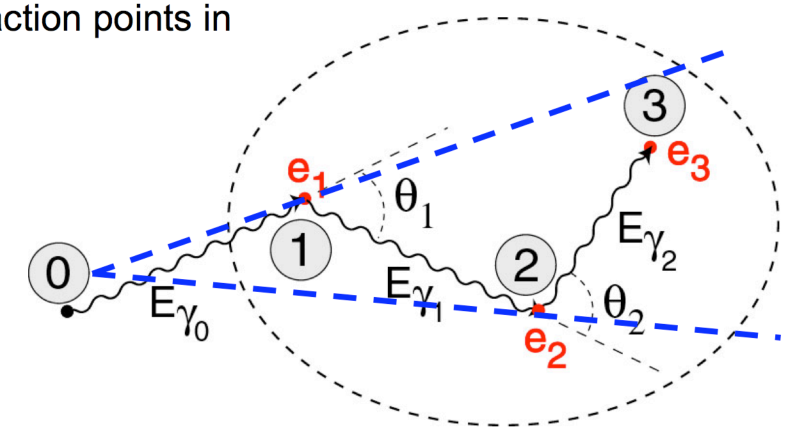




Interaction points with an angular distance ≤ α between each other (link alg.) or with respect to a given point (leader alg.) constitute a CLUSTER

2 algorithms available: Mgt (D. Bazzacco) and OFT (A. Lopez-Martens)

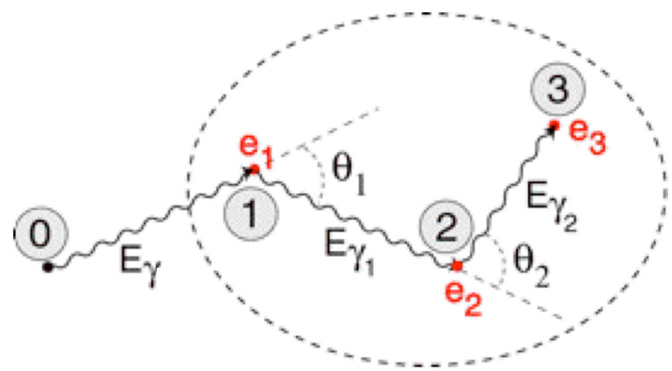
Forward tracking (OFT)

1. Create cluster pool => for each cluster, E_γ = sum of energy depositions in the cluster
2. Find most probable sequence of interaction points for each cluster

Which sequence satisfies best the Compton scattering rules ?

$$L = \prod_{n=1}^{N} P_n \exp^{-\left(\frac{E_{\gamma n} - E_{\gamma n,pos}}{\sigma_E}\right)^2}$$

Probability for Compton or photoelectric interaction and for travelling a given distance in Germanium



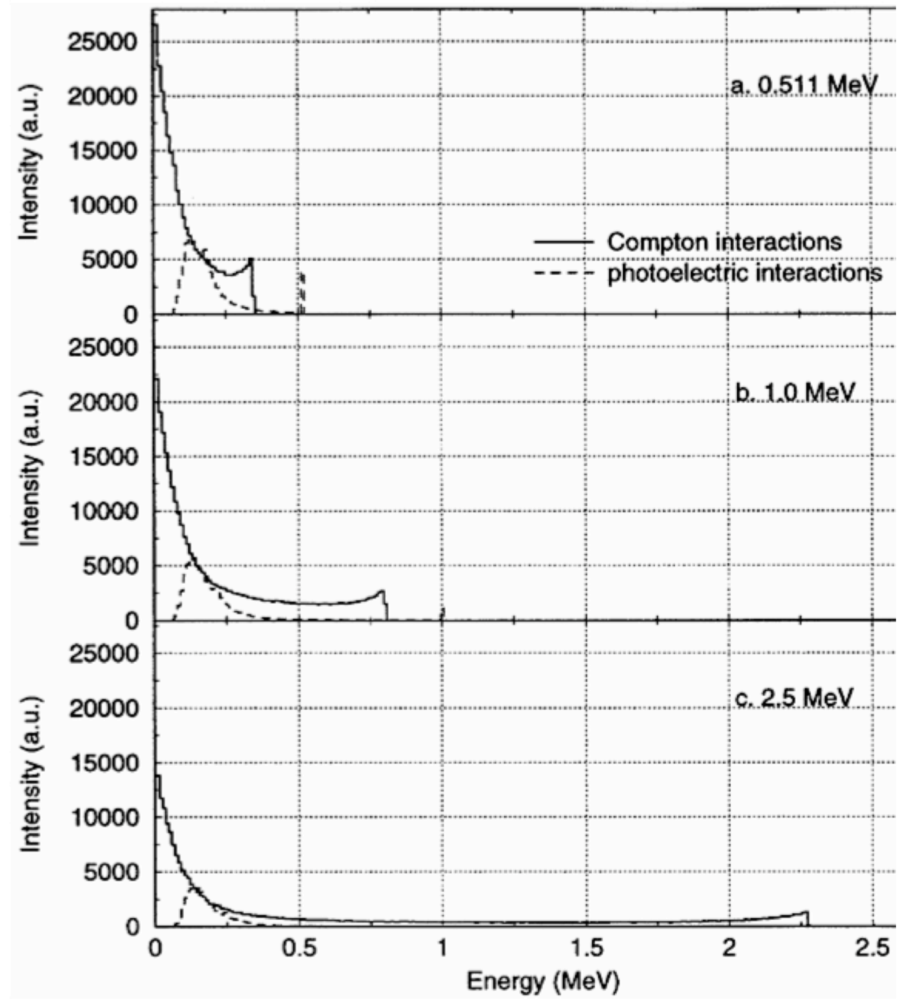
3. Accept or reject clusters on the basis of (2xN-1)th root of L

Backtracking

J. Van der Marel and B. Cederwall,Nucl. Instr. Meth. 437 (1999) 538

- Photoelectric energy deposition is ~ independent of incident energy

- Peaks around 100-250 keV



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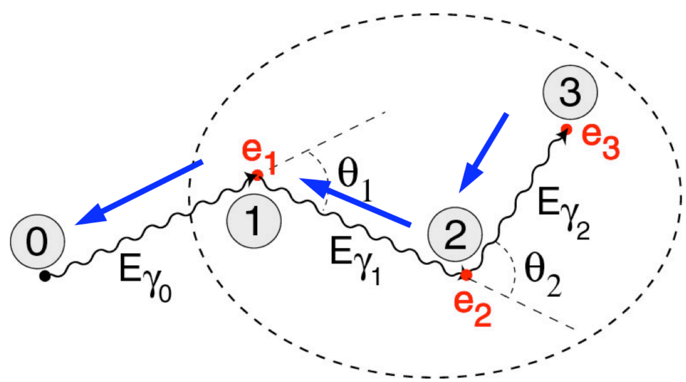
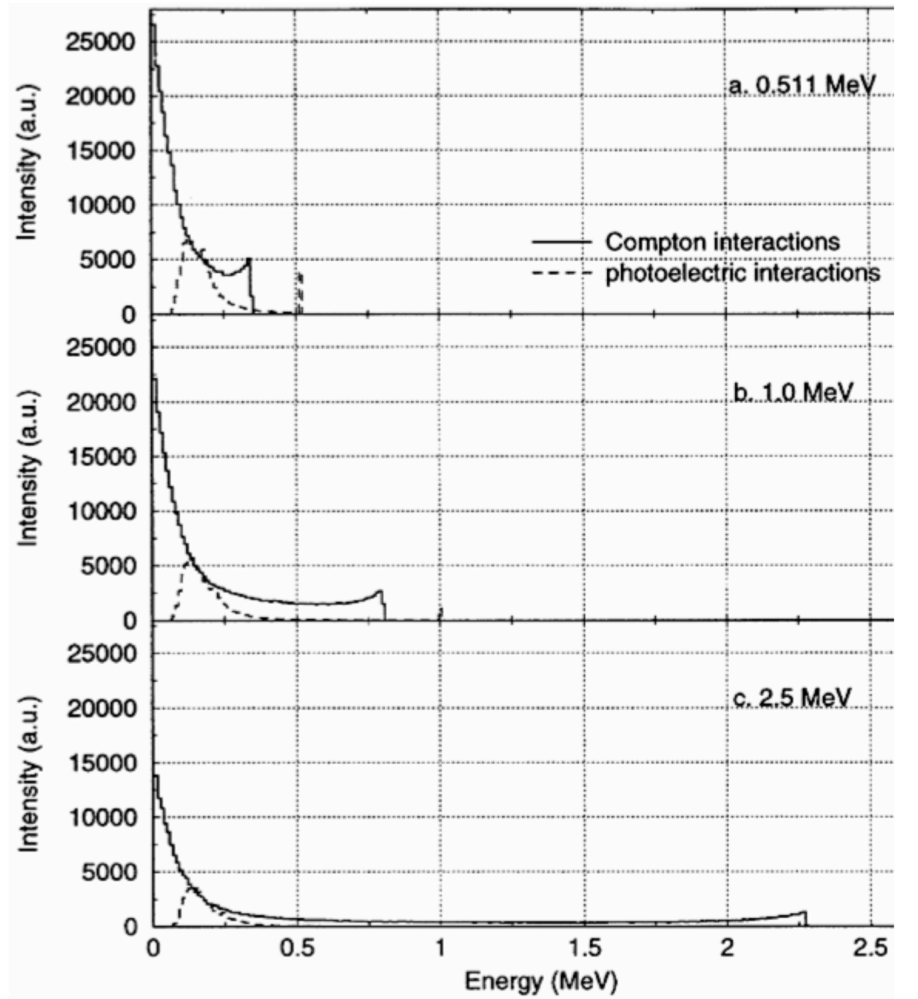
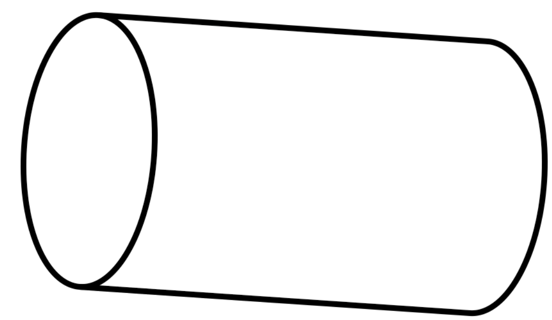




⇨ interaction points within a given deposited energy interval ($e_{min} < e_i < e_{max}$) will be considered as the LAST INTERACTION of a fully absorbed photon track

Bactracking



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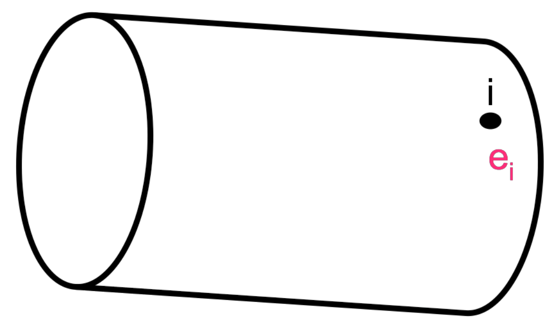


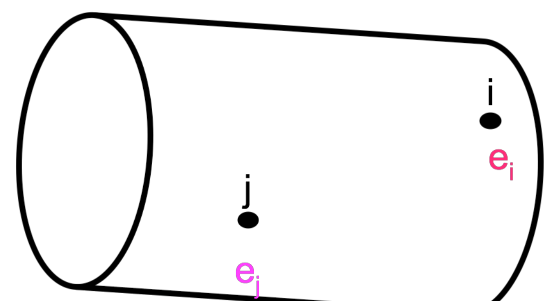
Bactracking

1. Create photoelectric interaction pool: $e_{min} < e_i < e_{max}$

2. Find closest interaction j to photoelectric interaction i:

distance between interaction points < $\lambda 1 \zeta$

$E_{inc} = e_i + e_j$, $E_{sc} = e_i$



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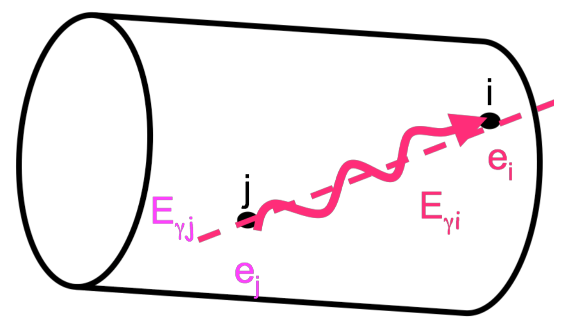

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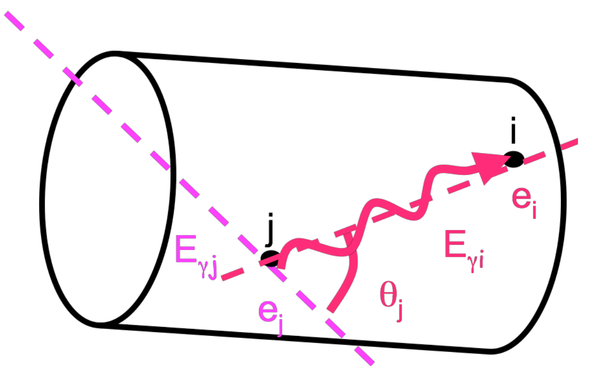
3. Find incident direction :

$\cos(\theta) = 1 - m_e c^2 (1/E_{sc} - 1/E_{inc})$



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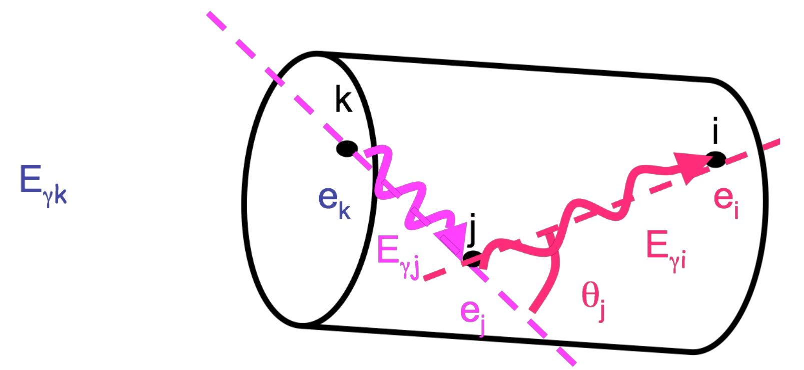

4. Find previous interaction k or source along direction

$|\cos(\theta_{energy}) - \cos(\theta_{geometry})| <$ limit
Prob(Compton interaction) > $P_{Comp,min}$
distance between interaction points < $\lambda 2$
$E_{inc} = e_i + e_j + e_k$, $E_{sc} = e_i + e_j$

Bactracking

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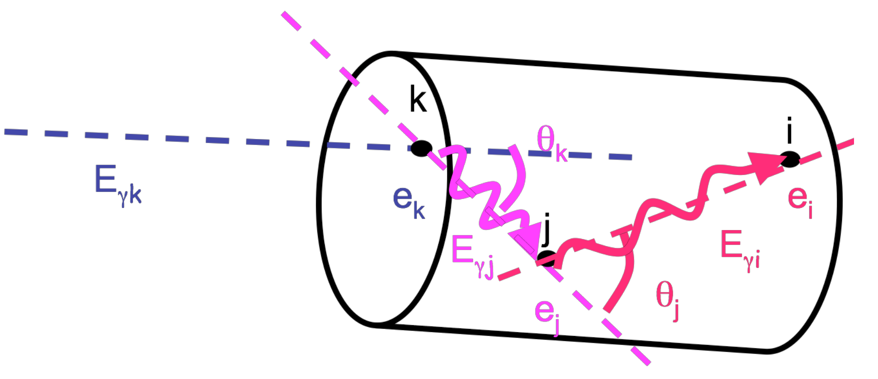

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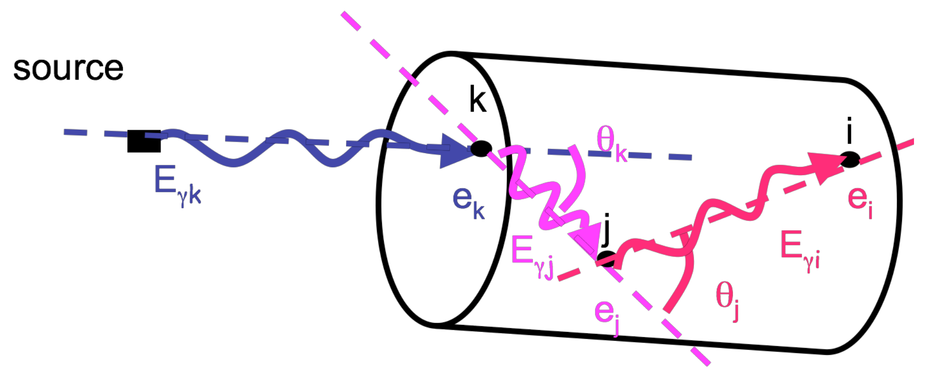

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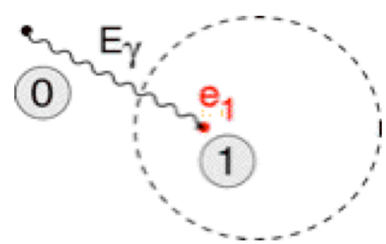
Common treatment

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 ?



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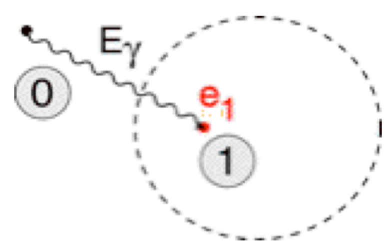
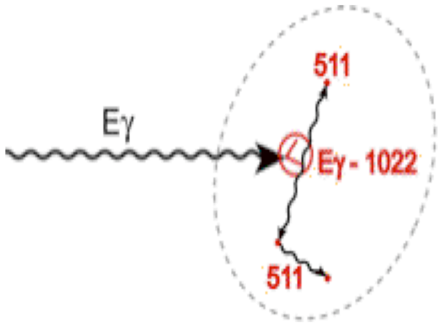


! ~20% of full absorption 1 MeV events end up in single interaction points

Common Treatment

2. Pair production interaction points:



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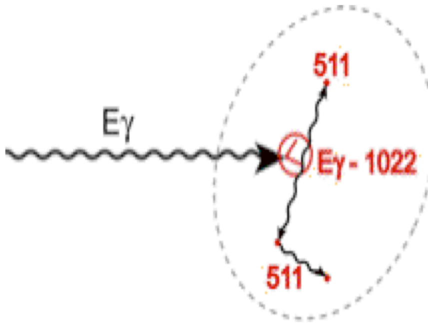

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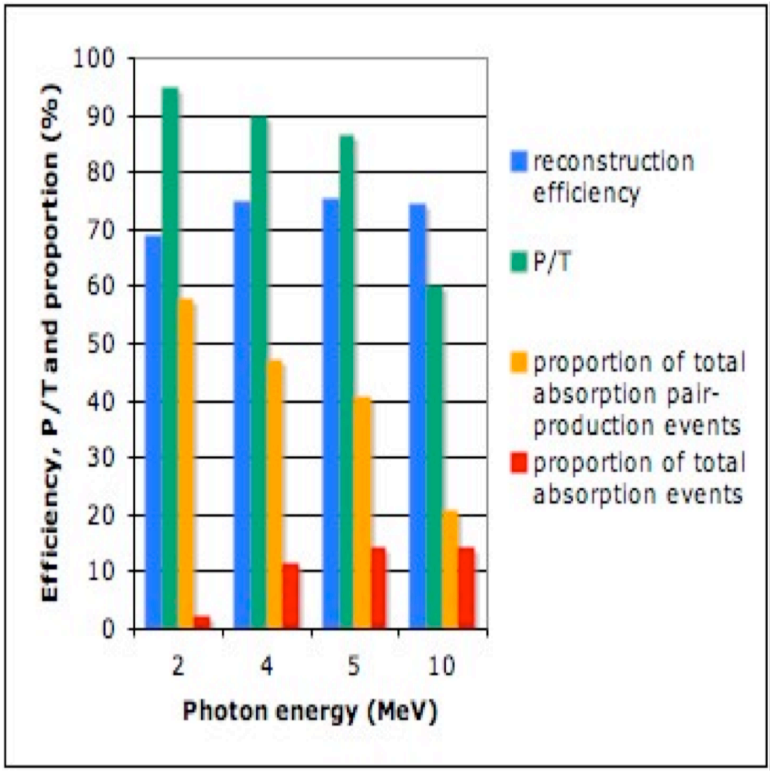
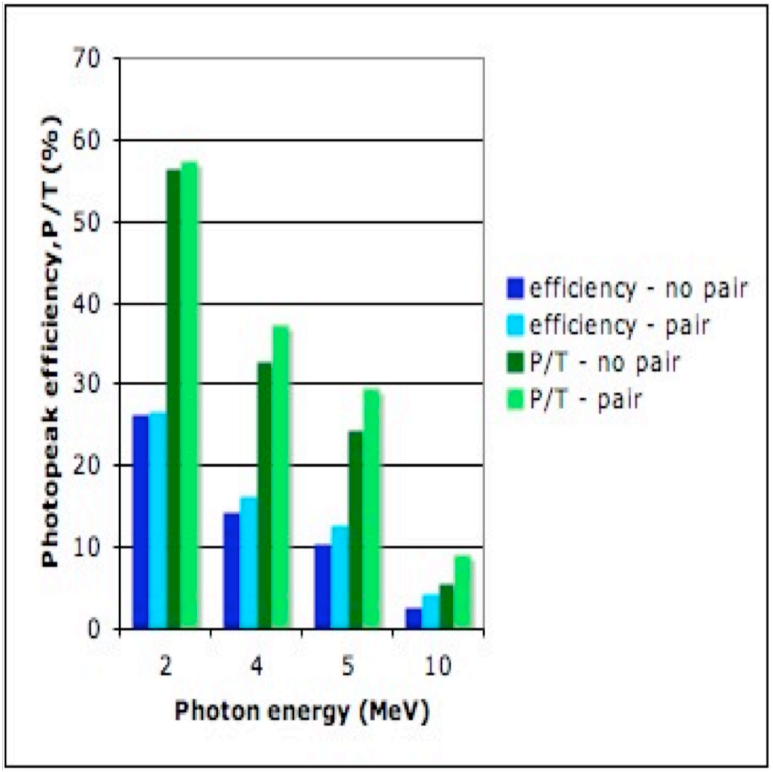
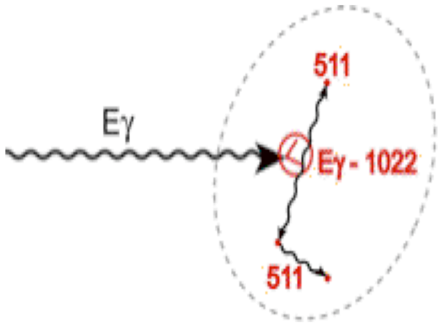
$$e_1 = E_\gamma - 2\, m_e c^2$$





Common Treatment

2. Pair production interaction points:



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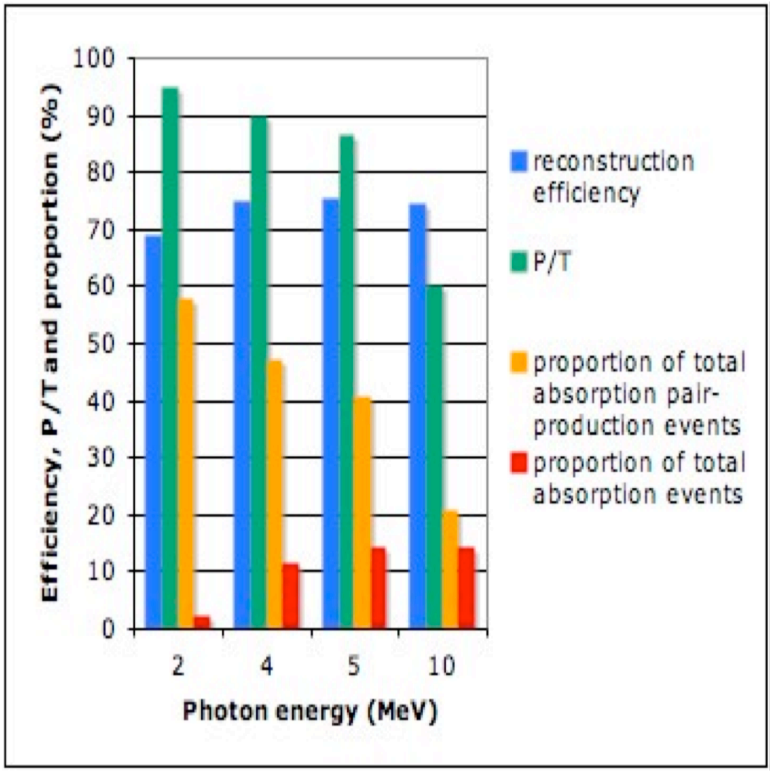
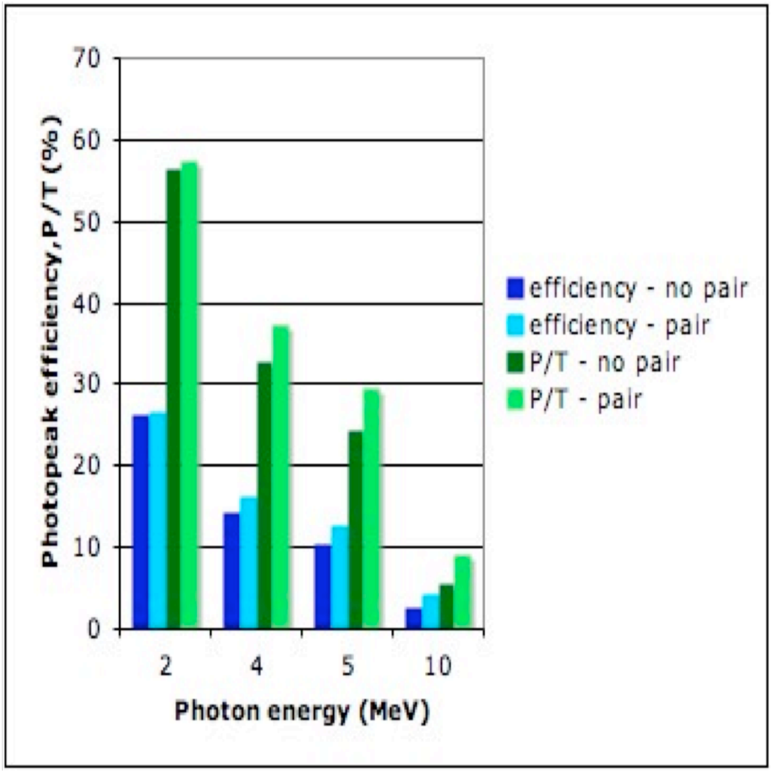
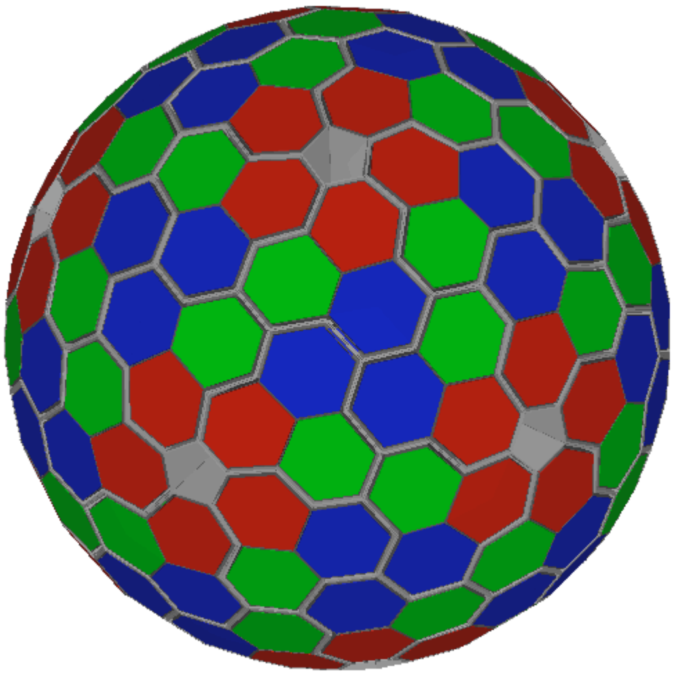




For the moment, only Mgt has the option to track pair-production events online

Simulation tool



(e_i, x_i, y_i, z_i) →

Simulation of PSA:
packing,
smearing,
energy threshold,
energy resolution

↓ $(e'_k, x'_k, y'_k, z'_k,)$

Tracking codes

↓

$(E_n$,incident + scattered directions)

Simulation of interactions of Mγ photons in a 4π shell or Agata (with the Agata Geant4 code)

E. Farnea et al., NIM A 621, 331 (2010)

Output Format

see agataManual.pdf for more info

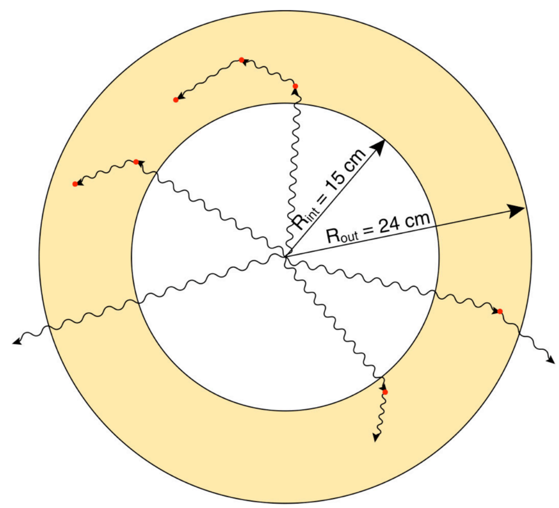
```
AGATA 7.3.0
OUTPUT_MASK 11100100
DISTFACTOR 1
ENERFACTOR 1
G4TRACKING 0
DATE Tue Feb 23 14:42:28 2010
GEOMETRY
AGATA
SUMMARY 235.008  329.202  180  3 6 6 6 6 6 6
TRANSFORMATION   0.000   0.000   0.000   0.000   0.000   0.000
PASSIVE 1
CAPSULES 1
ENDGEOMETRY
GENERATOR 0
ENDGENERATOR
GAMMA 1
660.0000
RECOIL   0.0000  0.0000  0.0000  0.0000  1.0000  0.0000
SOURCE       0       0    0.0000    0.0000    0.0000
$
 -1    660.000 -0.60338  0.67296  0.42786 0
108    14.739 -186.859  201.971  124.106 41
108    41.177 -181.561  213.797  137.505 51
108    11.067 -178.510  212.085  138.185 51
108   120.646 -178.501  212.081  138.187 51
110   149.312 -189.109  184.667  121.543 35
110    33.558 -189.109  184.667  121.544 35
108   123.471 -170.676  190.341  120.965 31
108   166.031 -170.685  190.351  120.974 31
```

Why does one use forward tracking ?

A. Lopez-Martens *et al.*, Nucl. Instr. Meth. A 533 (2004) 454

- Geant4 => Ph. Eff. = 76%

  P/T = 81%



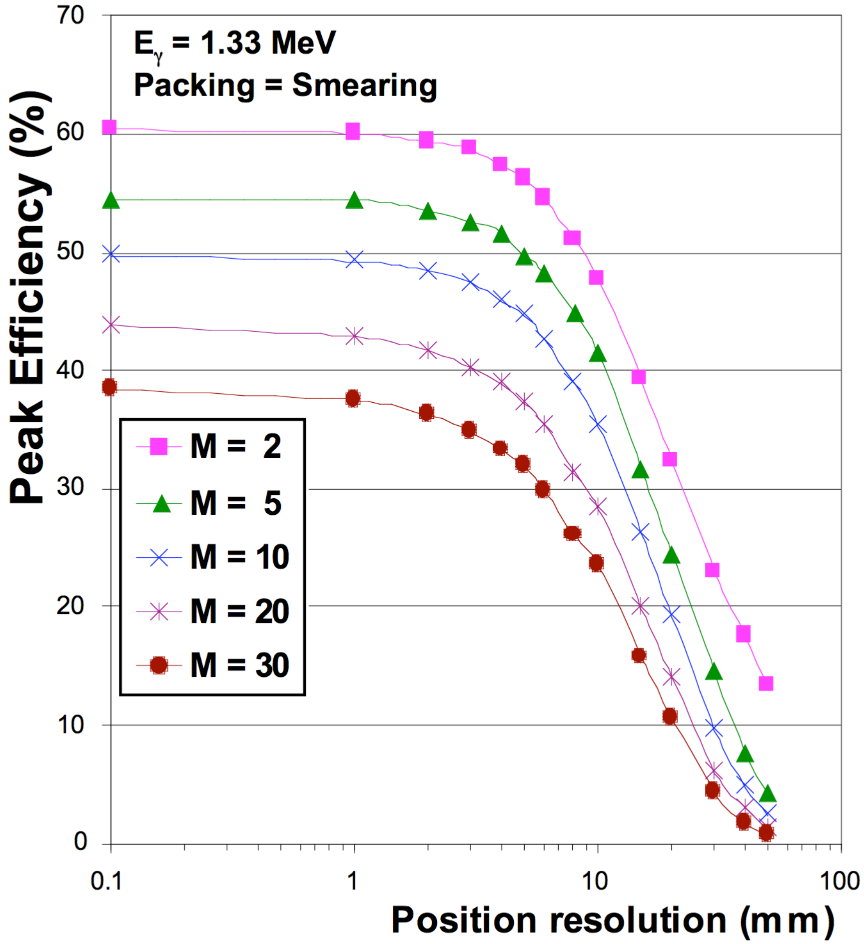
Photon Energy = 1 MeV
Multiplicity 1 and 30
Smearing - packing - energy threshold

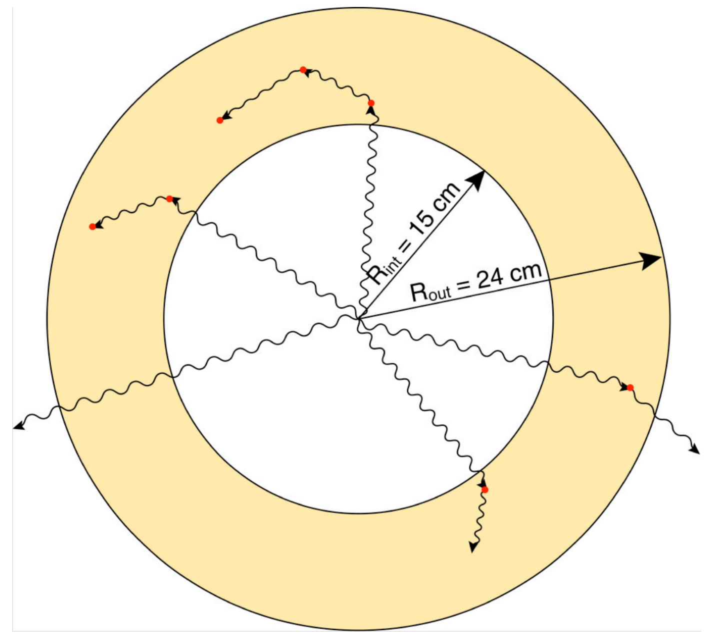
	Ph. Eff.	P/T
Forward-tracking	61.6 (33.9)	84.2 (57.7)
backtracking	40.3 (25.3)	67.0 (46.7)

Backtracking: the last points of the sequence are of low energy and close to each other

→ **bad position resolution and easily packed together**

Performances vs position resolution & gamma multiplicity





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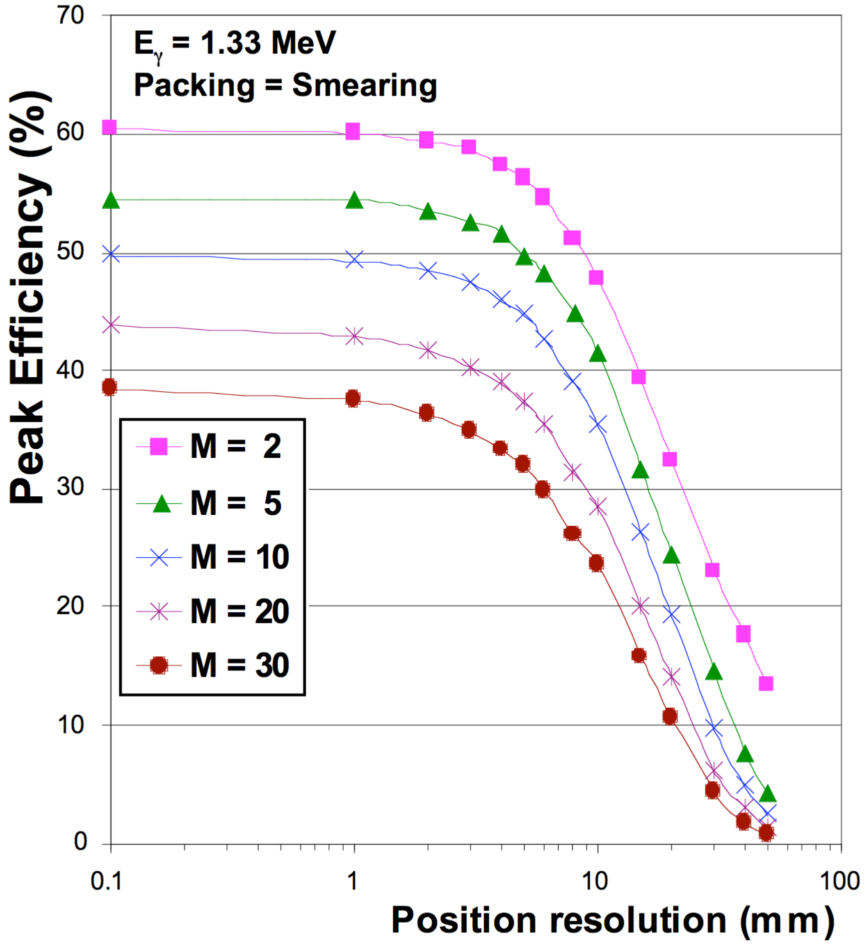
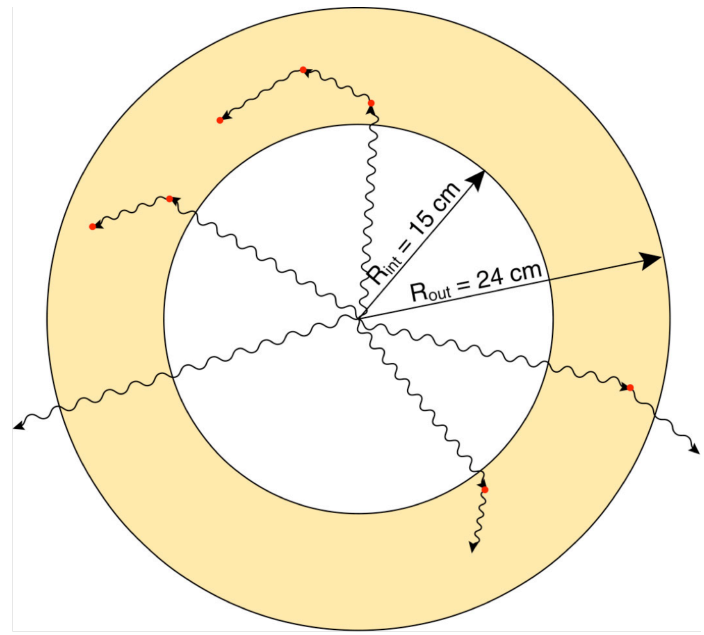
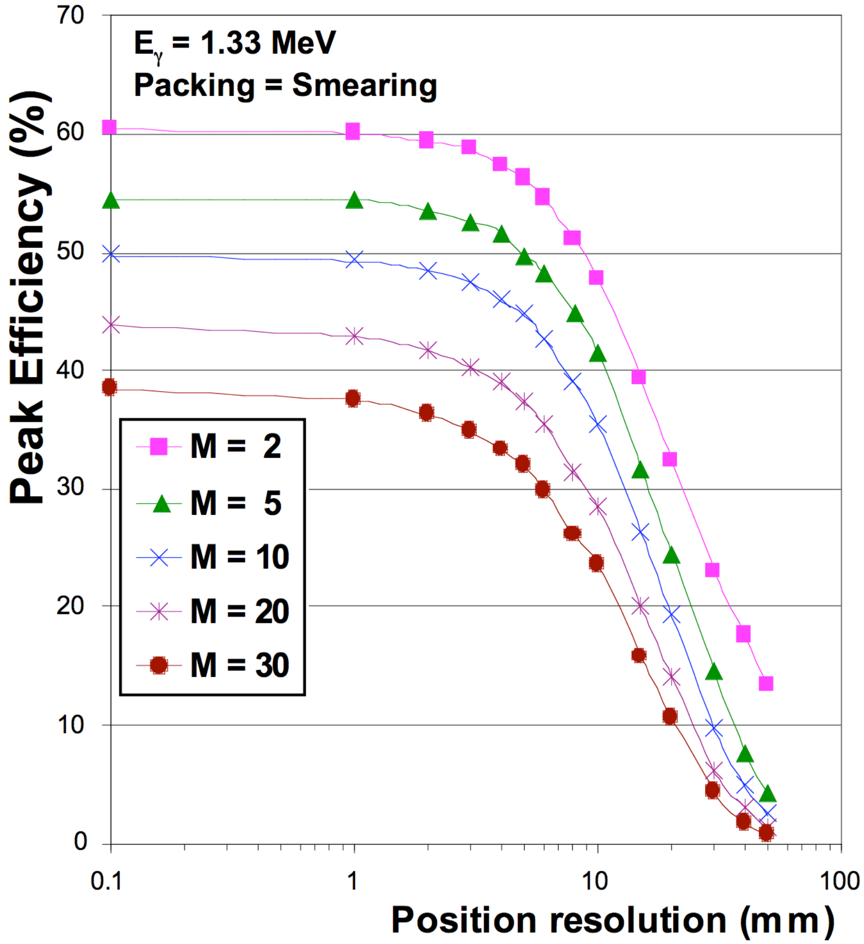
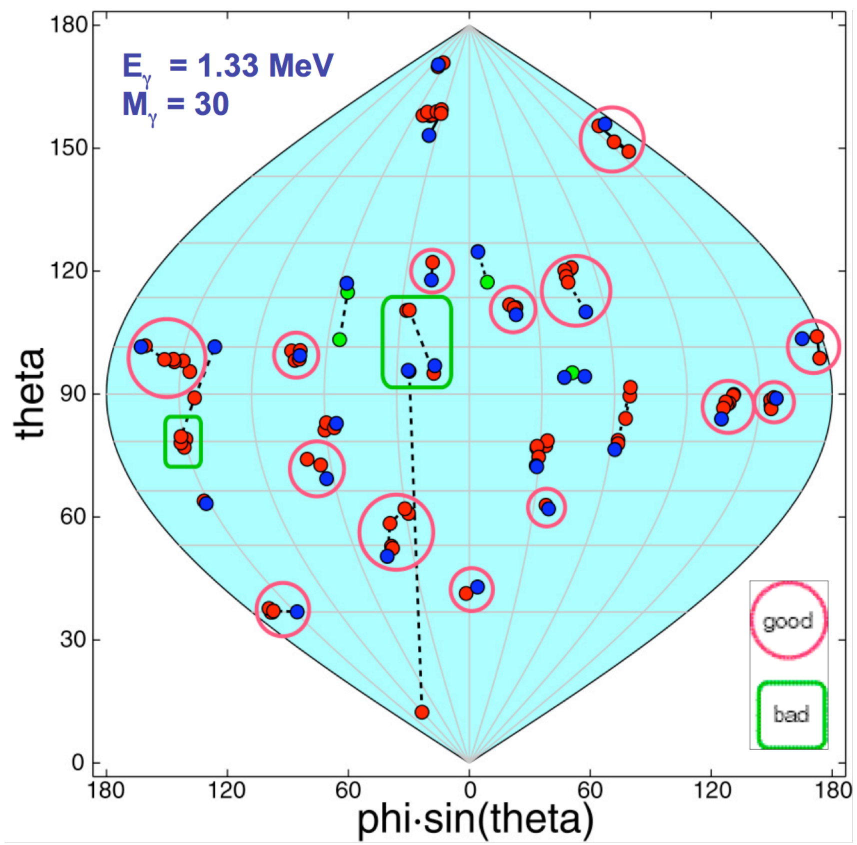




The biggest losses are due to multiplicity (mixing points)

Performances vs position resolution & gamma multiplicity





27 photons interacted - 24 with total absorptio
16 tracks reconstructed
14 good

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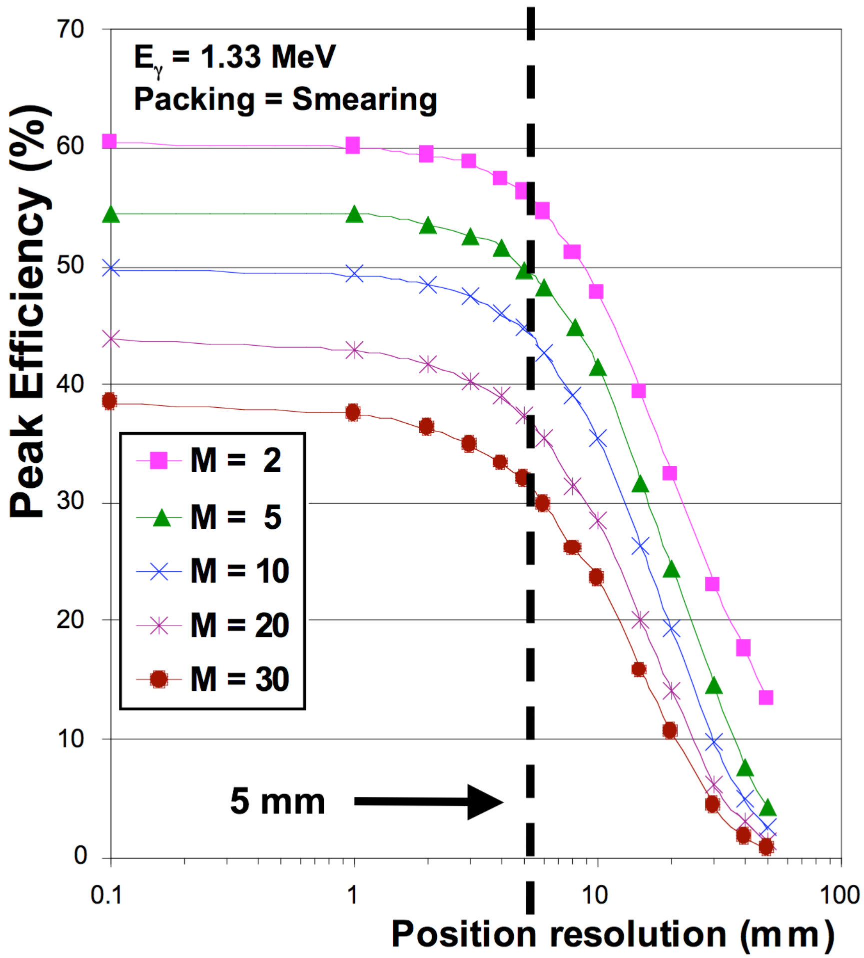
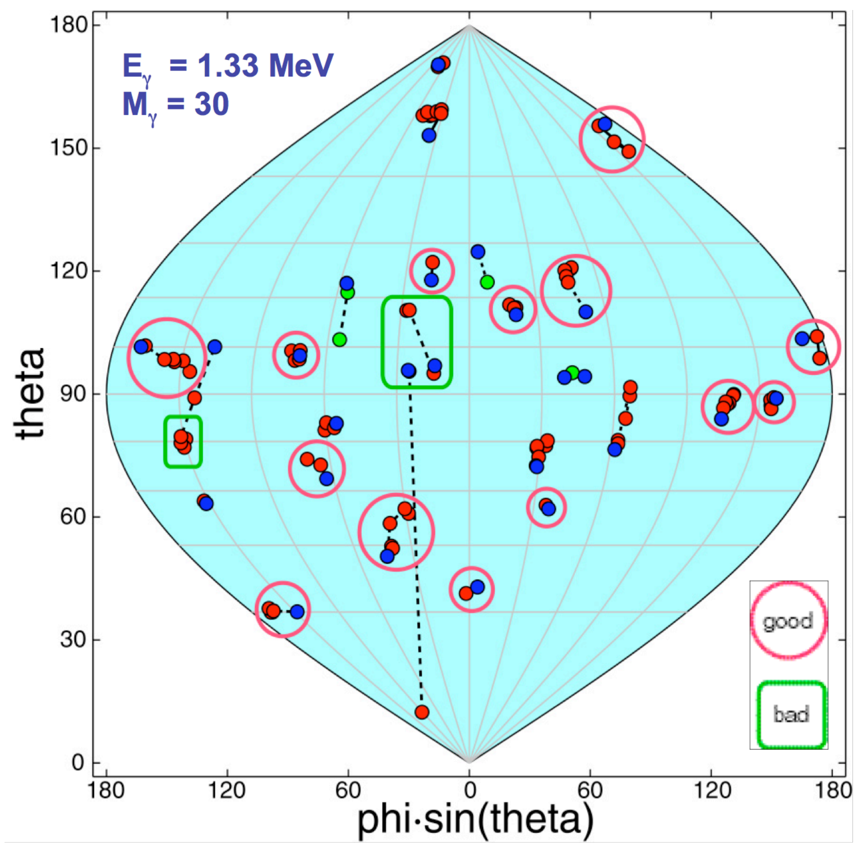
Performances vs position resolution & gamma multiplicity





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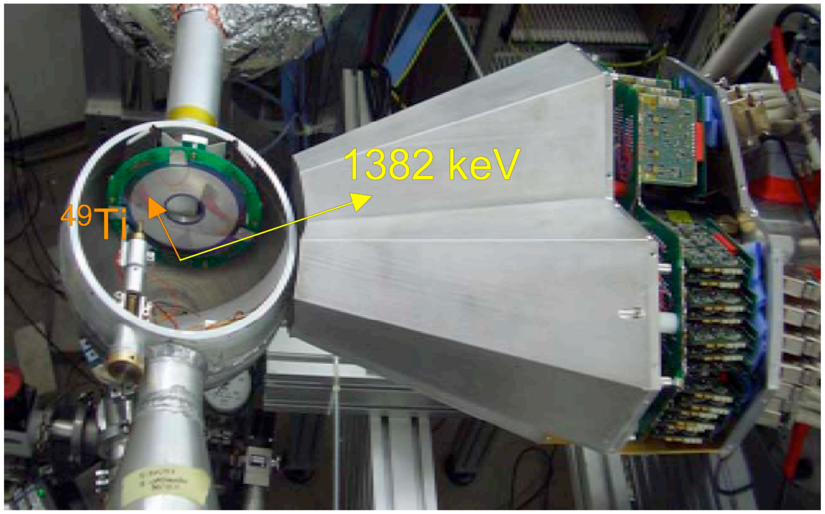
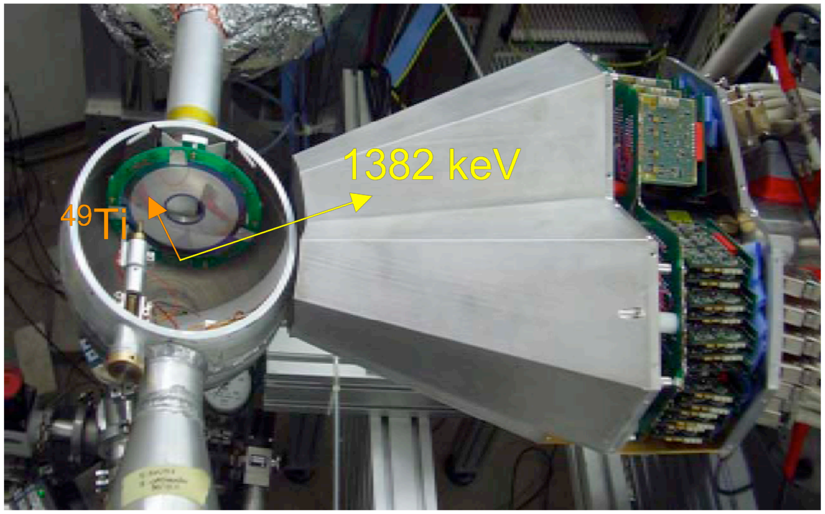
Deduced position resolution @ AGATA



REACTION CHANNEL: $^{48}Ti(d,p)^{49}Ti$

beam	^{48}Ti	100 MeV
target	^{48}Ti + ^{2}H	220 μg/cm^2
Si detector	thickness	300 μm
	segmentation	32 rings, 64 sectors
AGATA triple symmetric cluster		

Deduced position resolution @ AGATA



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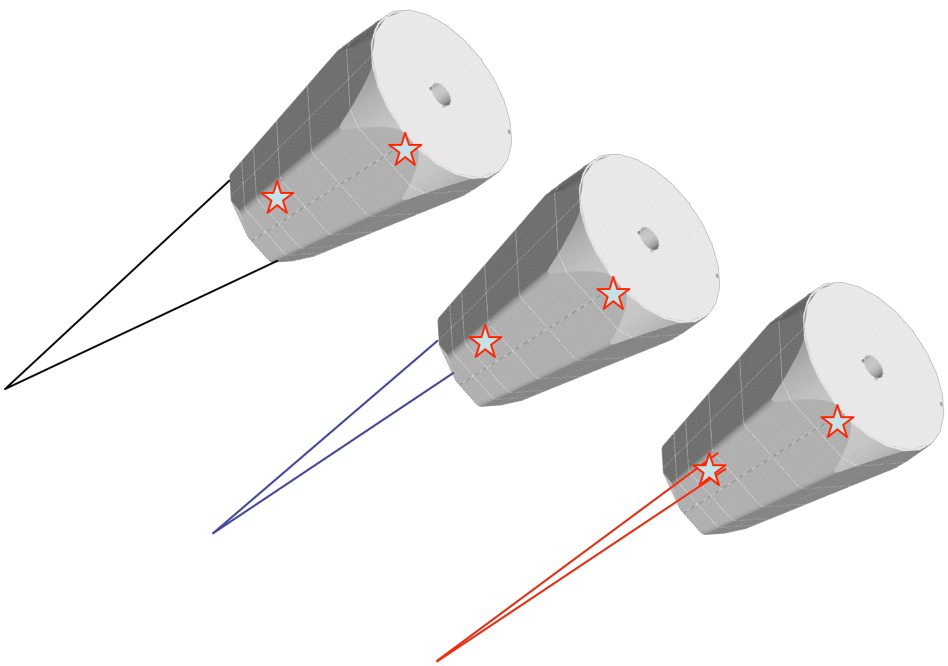
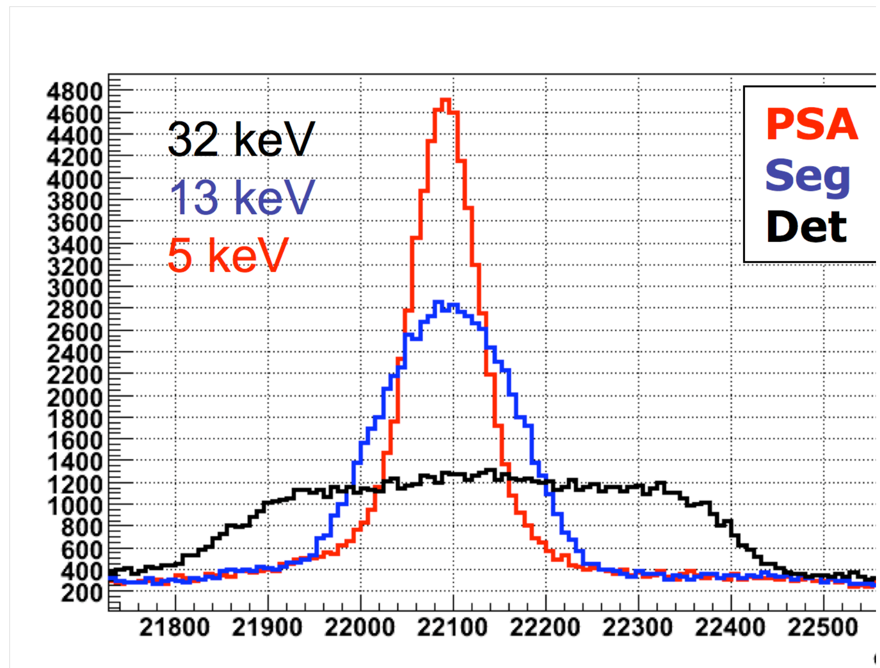
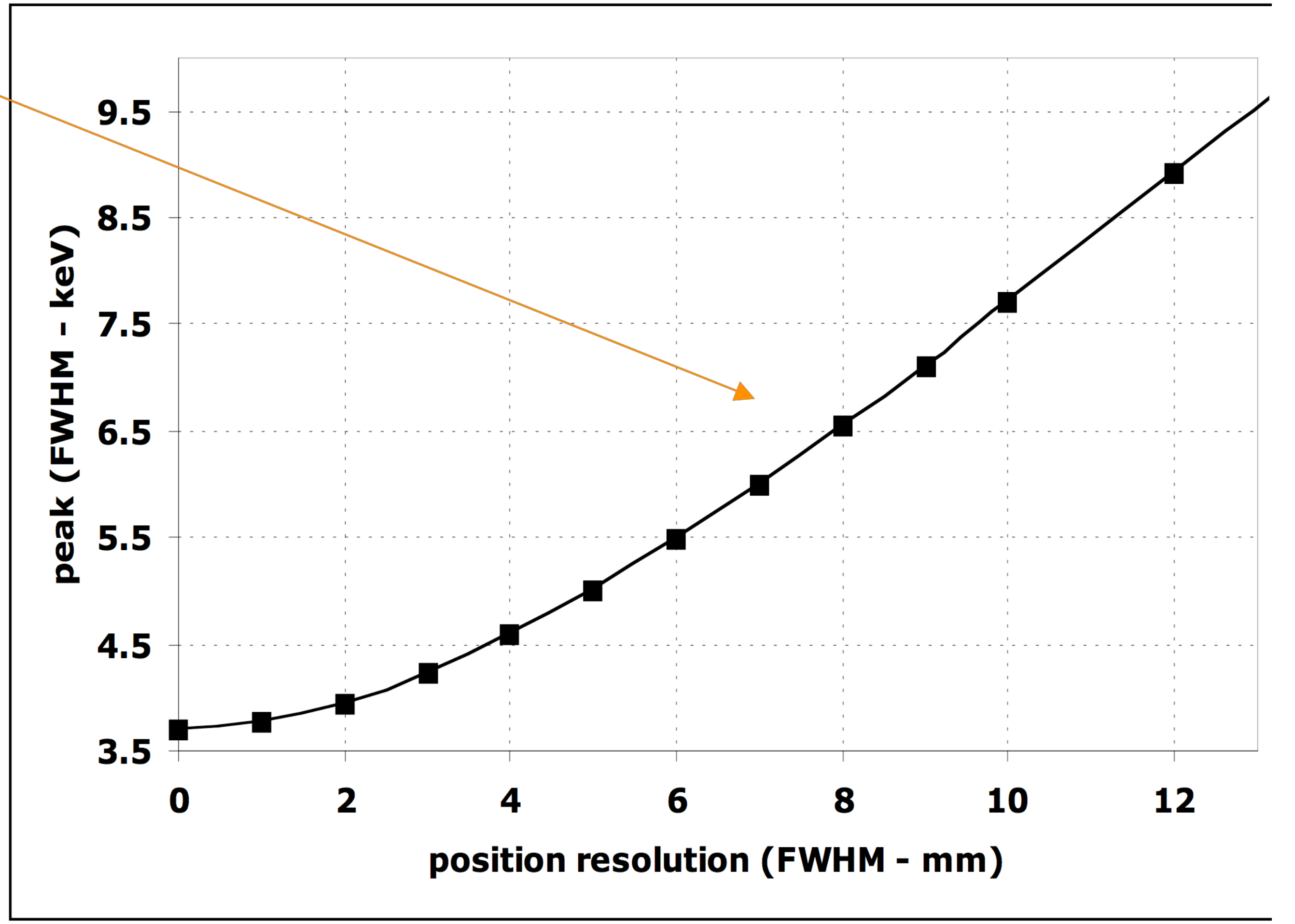




Deduced Position resolution

F. Recchia et al., Nucl. Instr. Meth. A 604 (2009) 5555

simulations
of the reaction
+
detector
responses



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simulations
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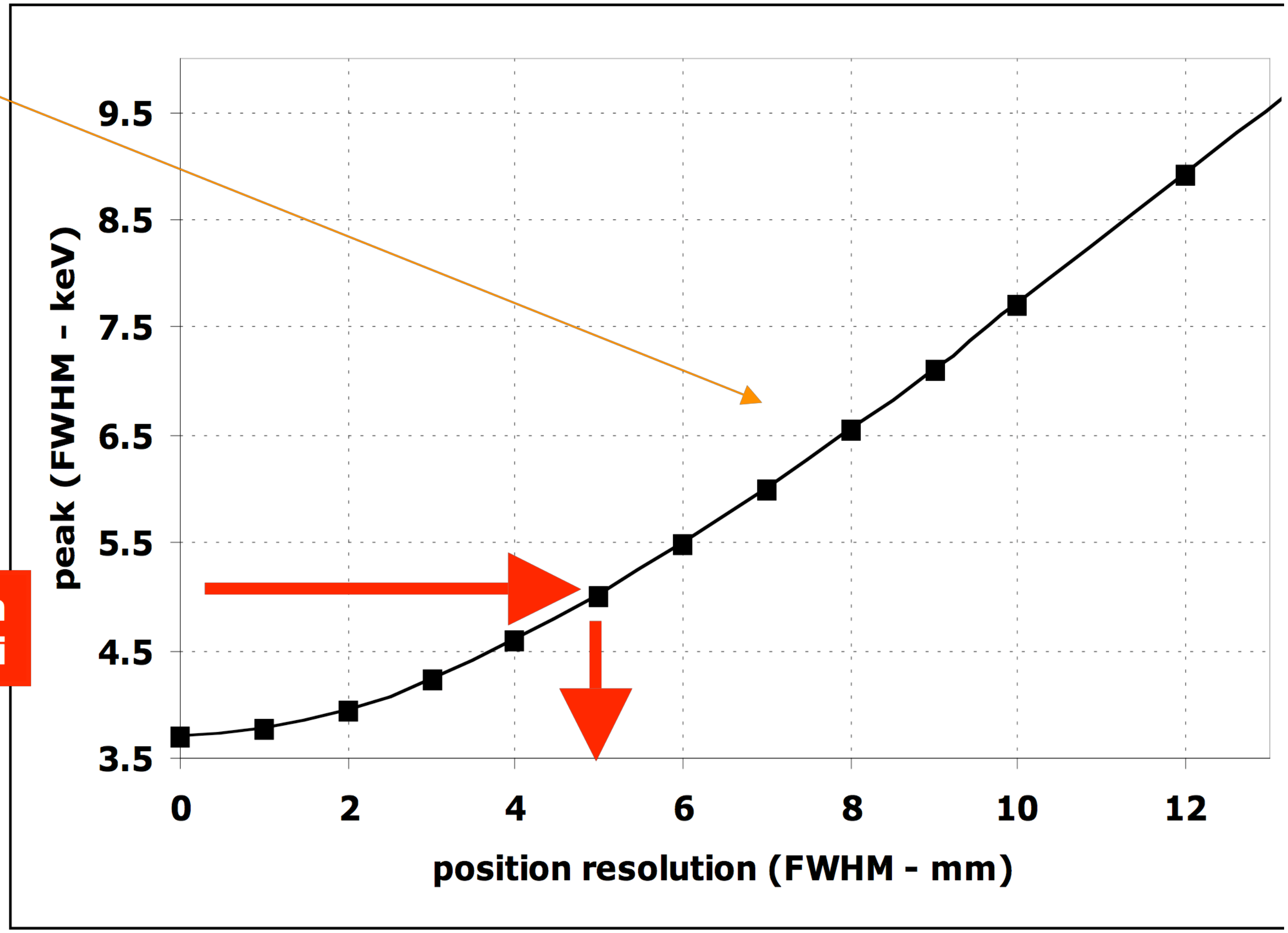
Grid Search
R. Venturelli



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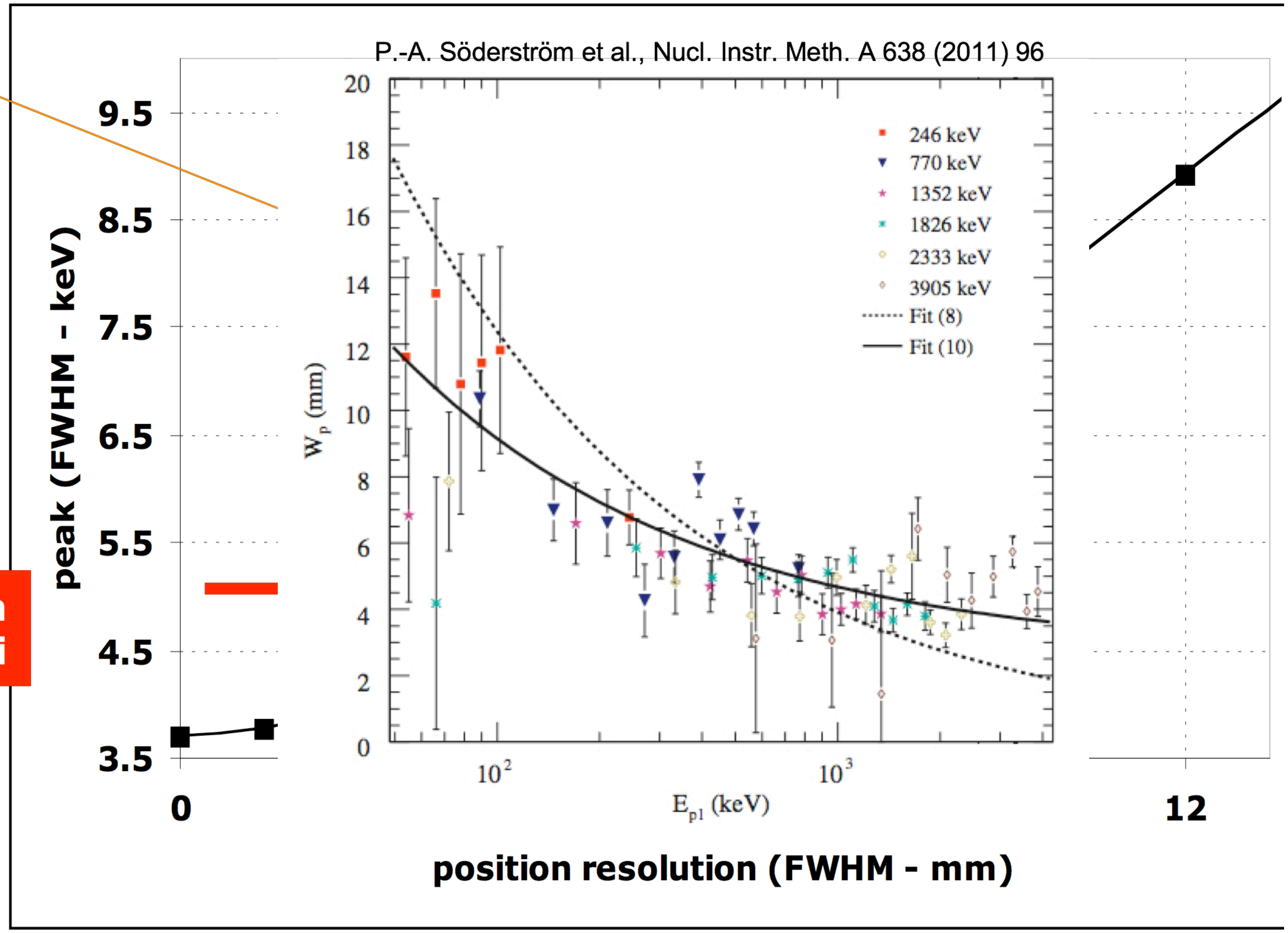

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simulations of the reaction + detector responses

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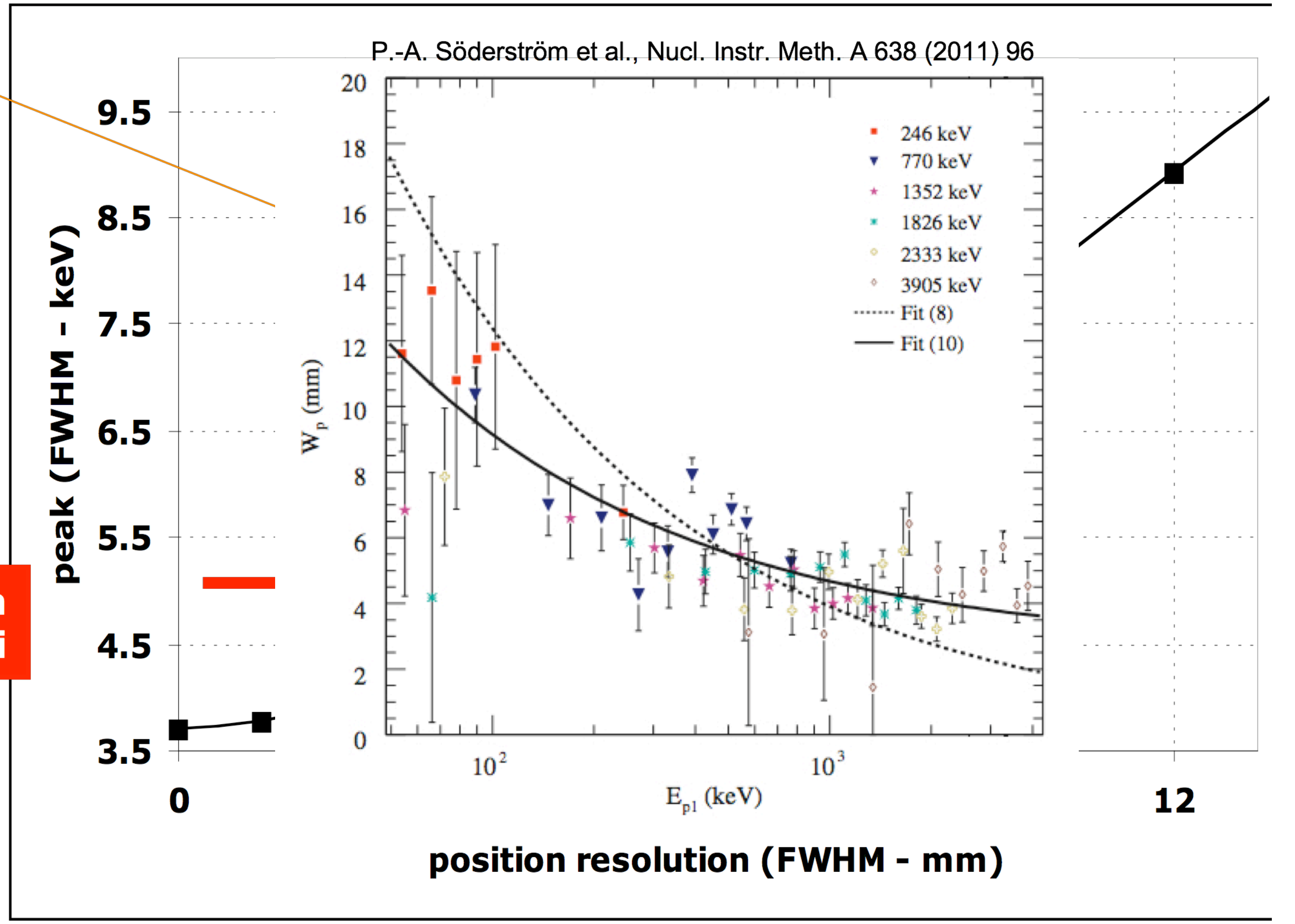

Is the position resolution the same in all directions?

(The Doppler correction is sensitive to mostly only x & y .....)

Deduced Position resolution

F. Recchia et al., Nucl. Instr. Meth. A 604 (2009) 5555

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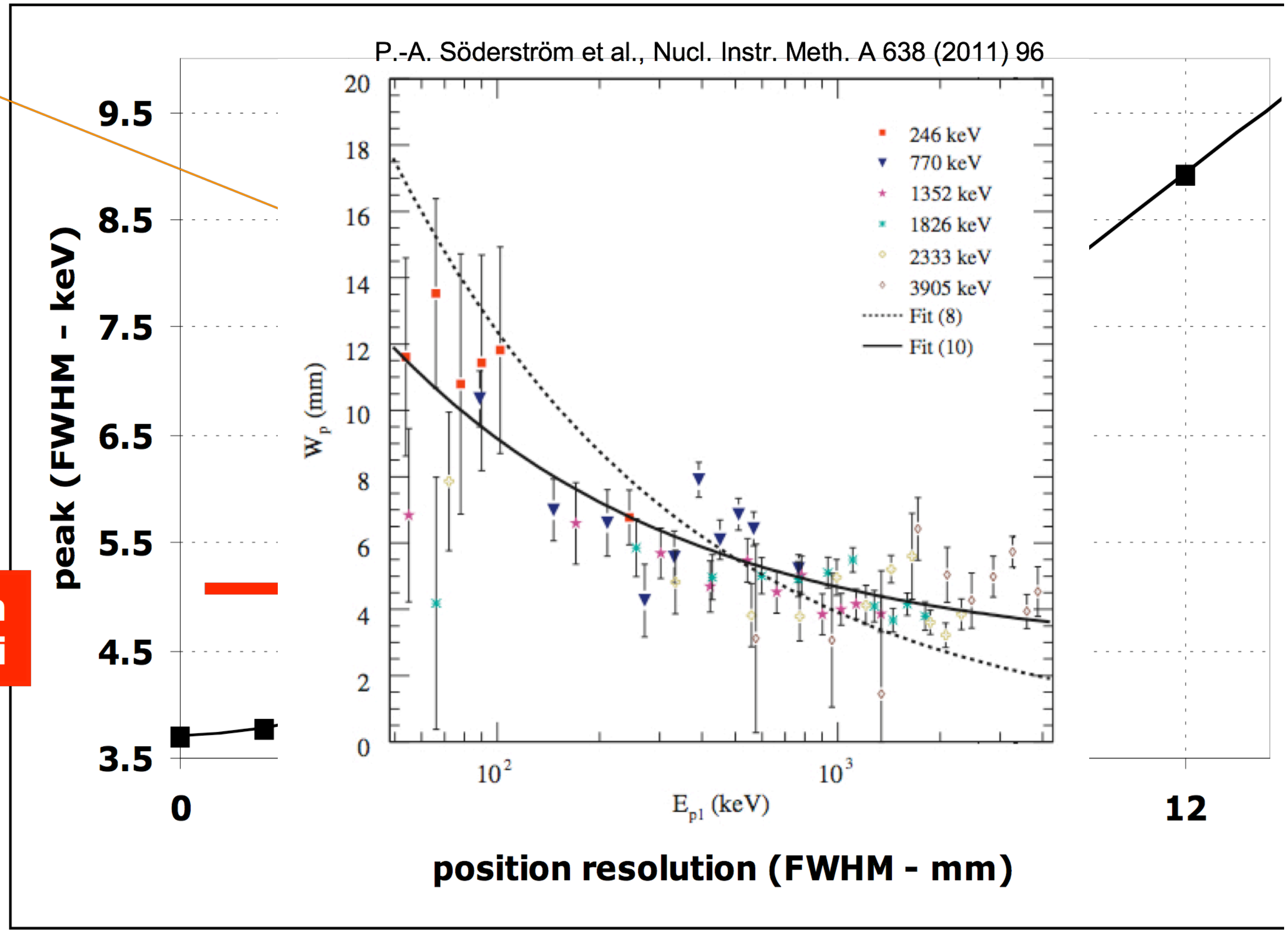

Is the position resolution the same in all directions?

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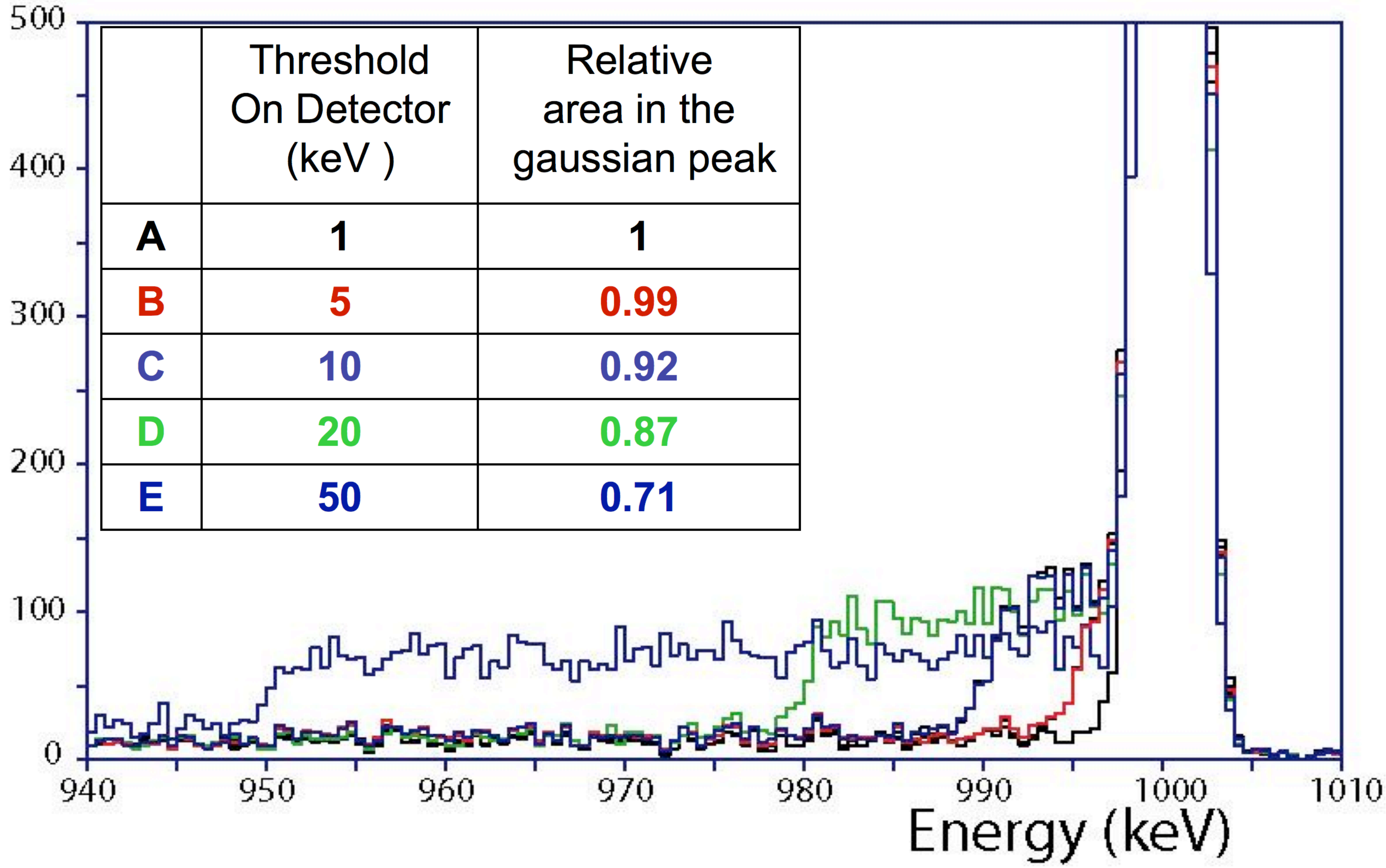
Other estimates: quality of Compton imaging by F. Recchia et al., & ^{22}Na position resolution measurement by S. Klupp et al.,

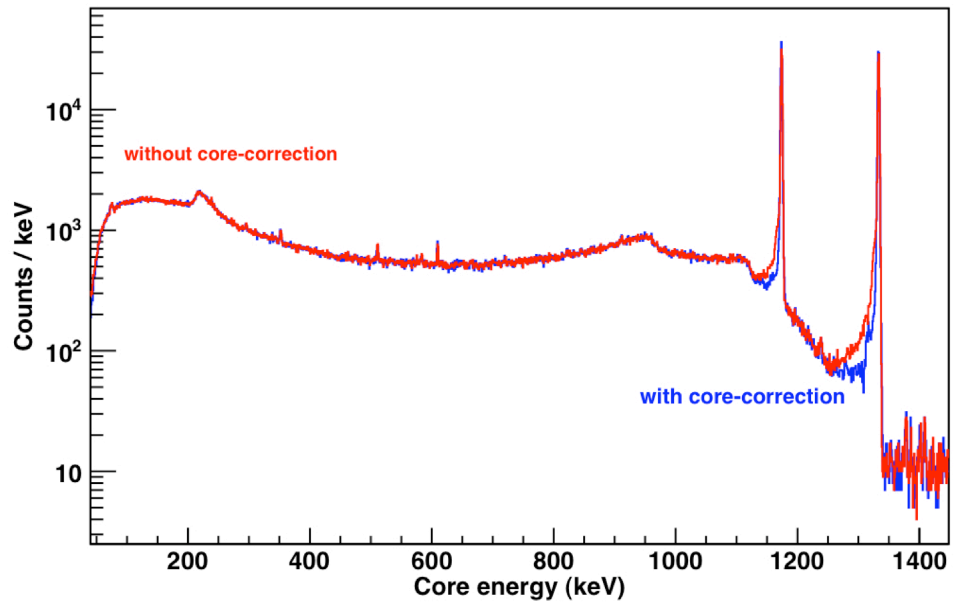
Effect of energy threshold



	Threshold On Detector (keV)	Relative area in the gaussian peak
A	1	1
B	5	0.99
C	10	0.92
D	20	0.87
E	50	0.71

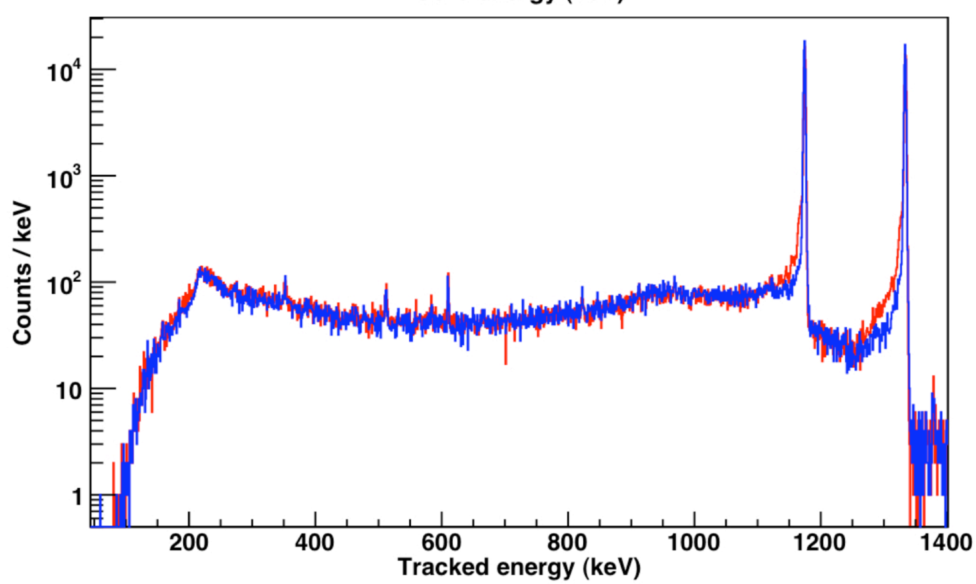
Core-energy correction

Sum of core spectra



E_{core}-Σsegments redistributed among segments

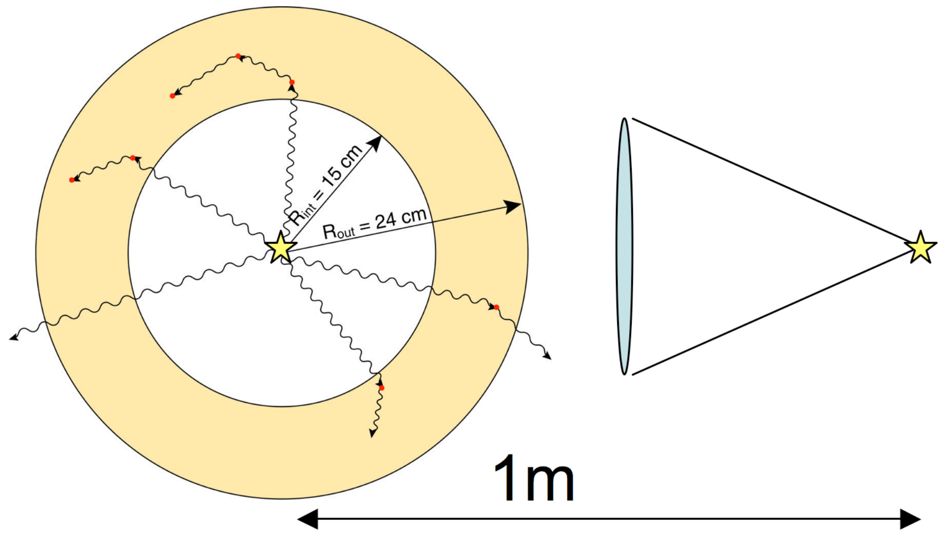
Tracked spectra (no single interactions)



+10% peak

+12% P/T

Background rejection



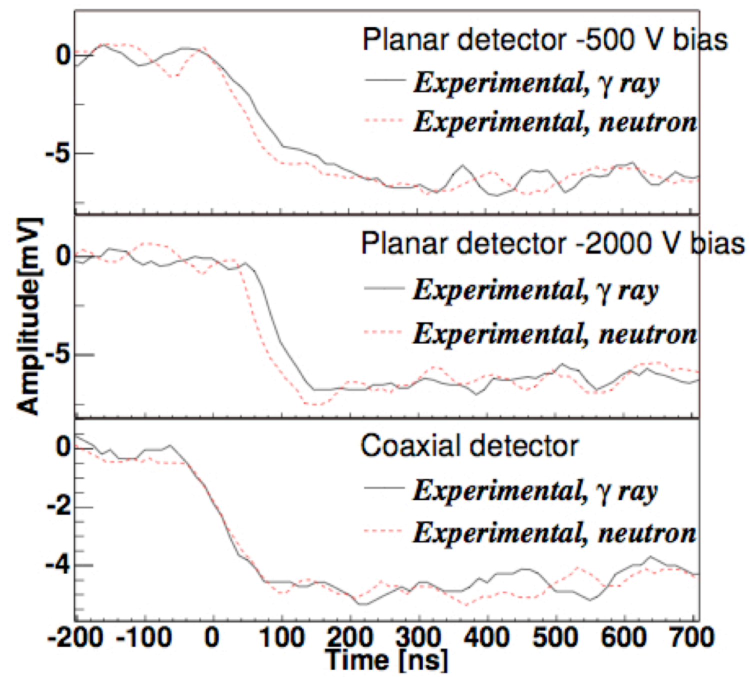
(same data used)	200 keV	500 keV	1 MeV
Centered source	P/T = 97.4% Tr. Eff = 90.5% Mgt: P/T=96.6% Tr. Eff = 95.3%	P/T=89.2% Tr. Eff. = 81.5 % Mgt: P/T=91.0% Tr. Eff = 94.5%	P/T=83.7% Tr. Eff = 80.1% Mgt: P/T=80.0% Tr. Eff = 92.7%
Off-centered source (1m from center)	P/T = 93.0% Tr. Eff = 1.6% Mgt: P/T=99.4% Tr. Eff = 57.4%	P/T=79.2% Tr. Eff. = 31.8% Mgt: P/T=77.3% Tr. Eff = 74.4%	P/T = 60.1% Tr. Eff = 40.1 % Mgt: P/T=66.6% Tr. Eff = 78.7%

Effect of neutrons

J. Ljungvall and J. Nyberg, Nucl. Instr. Meth. A 550 (2005) 379

Neutrons & Gammas

- similar signals
- similar distribution of interaction points



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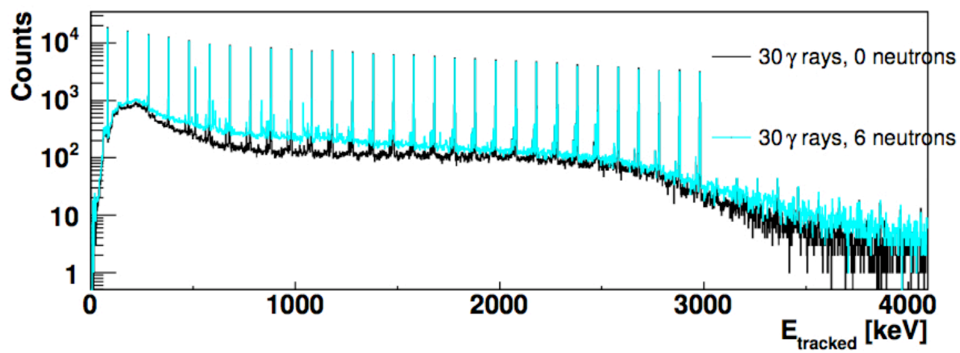

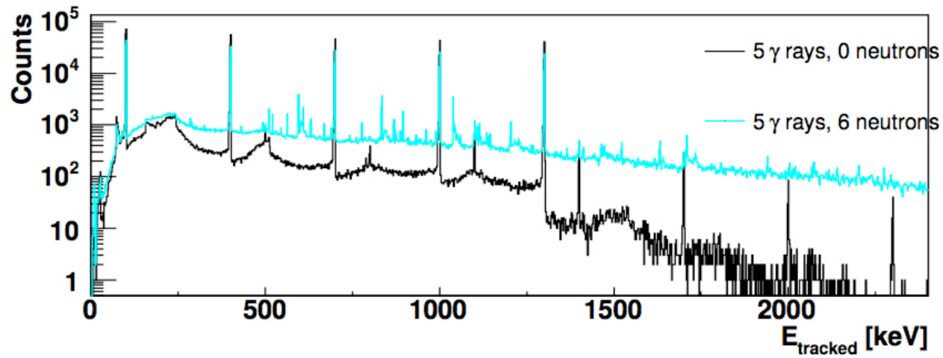

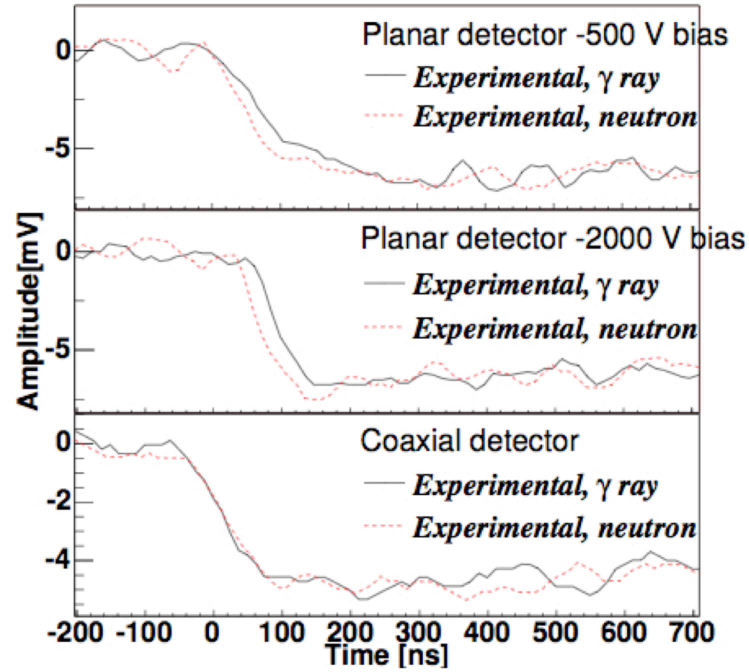

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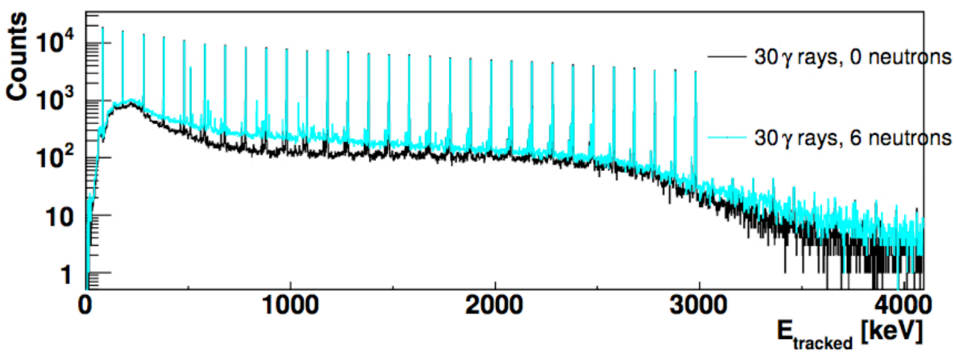
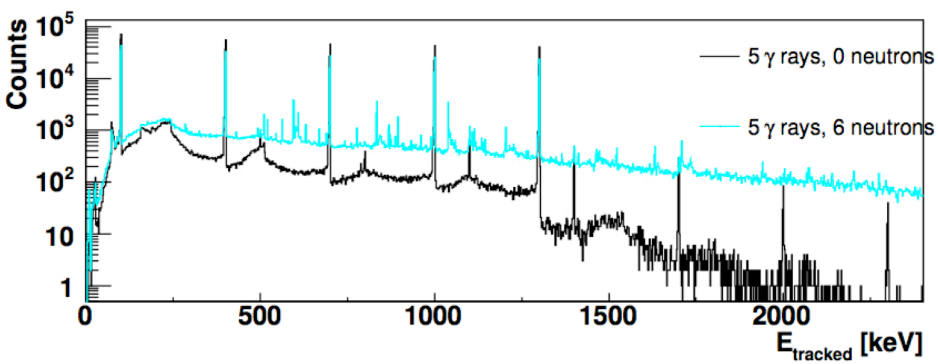
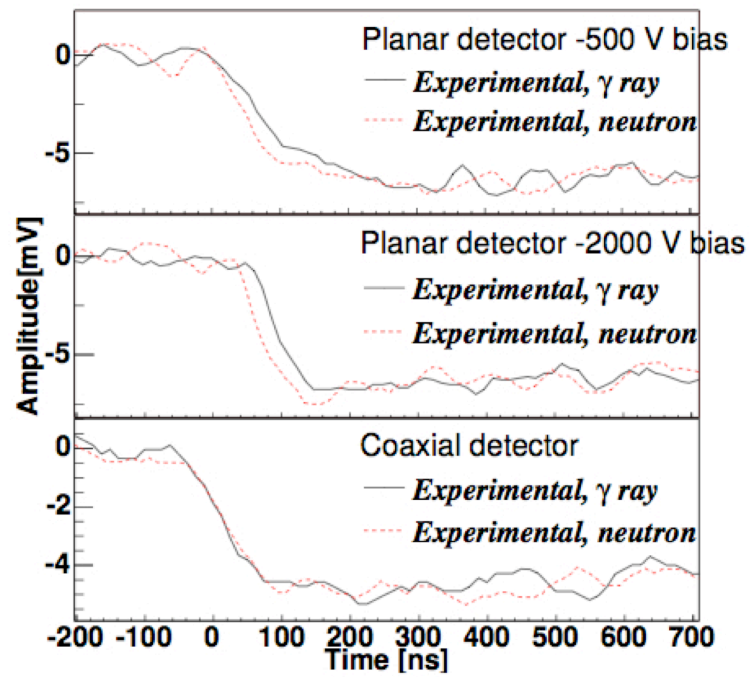






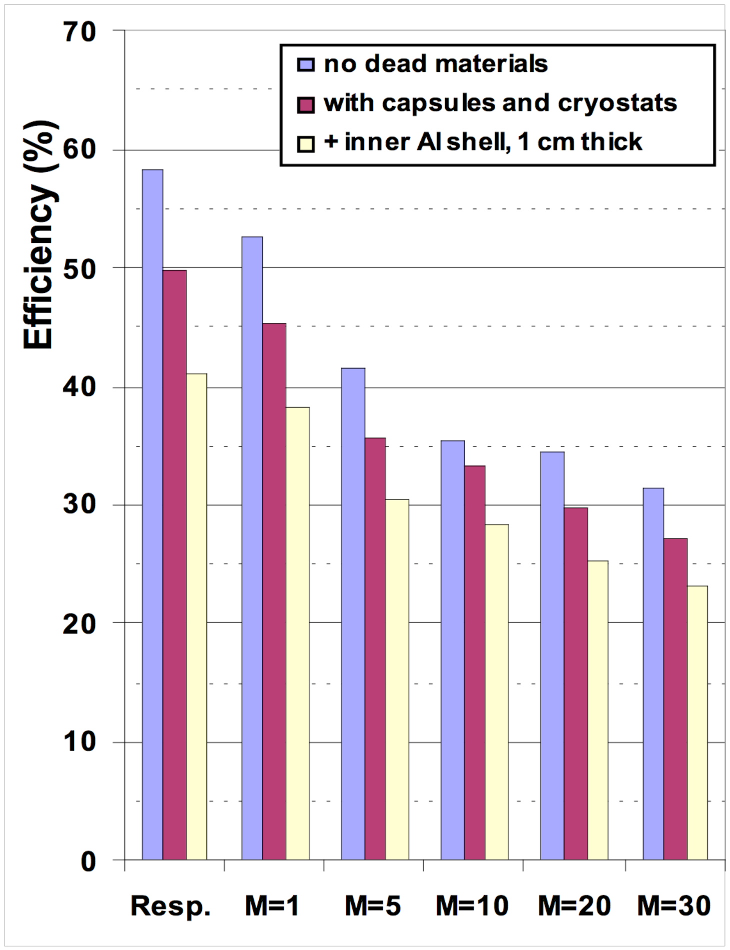
⇨ Large effect on P/T for low gamma multiplicities

⇨Ph. Eff = -1% /n

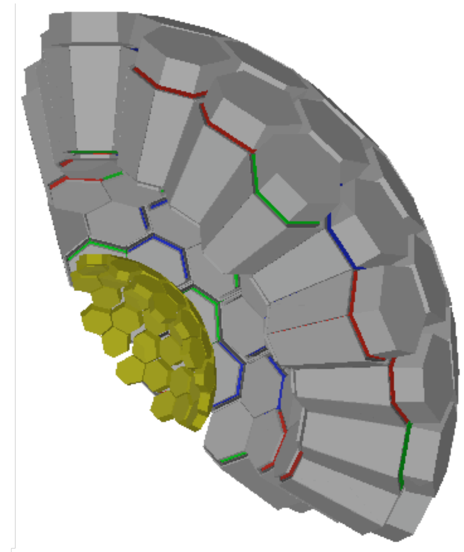
⇨ Can only discriminate n's and γ's with good timing (can also reduce some background due to inelastic reactions (n,n'γ) with tracking)

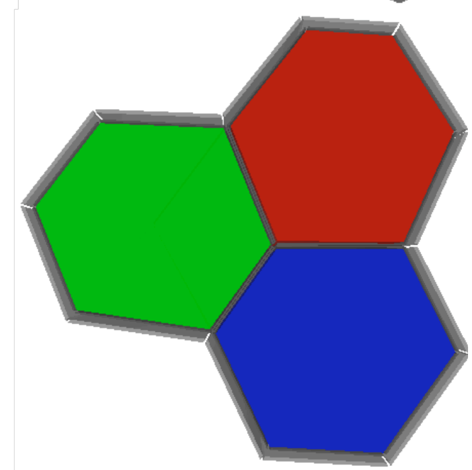
A. Ataç et al. Nucl. Instr. Meth. A 607 (2009) 554

Effect of encapsulation and other dead materials

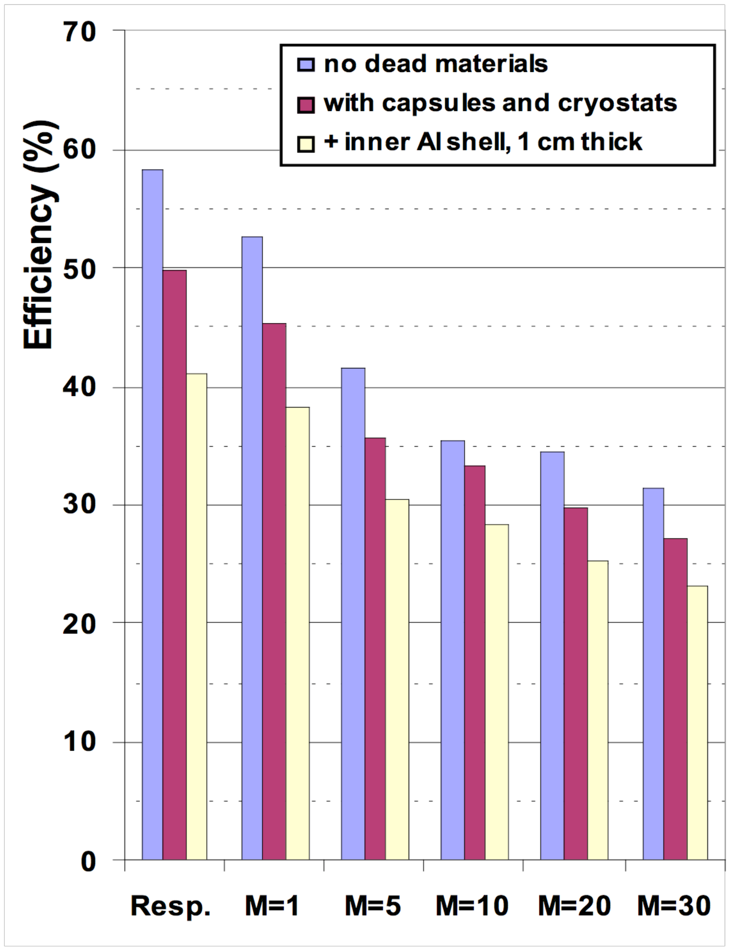


Thickness of	mm
Capsule side	0.8
Cryostat side front back	1.5 3.0 30
Inner “ball”	10





Effect of encapsulation and other dead materials



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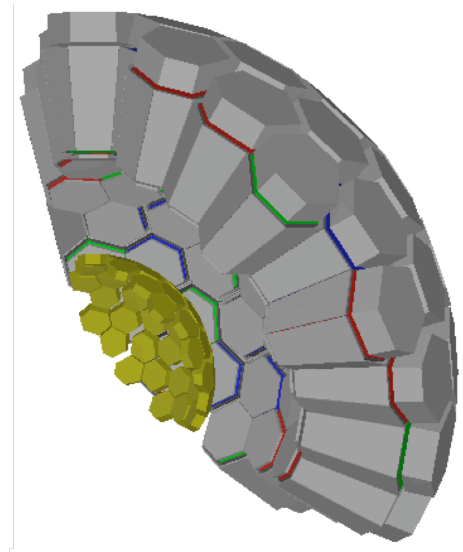
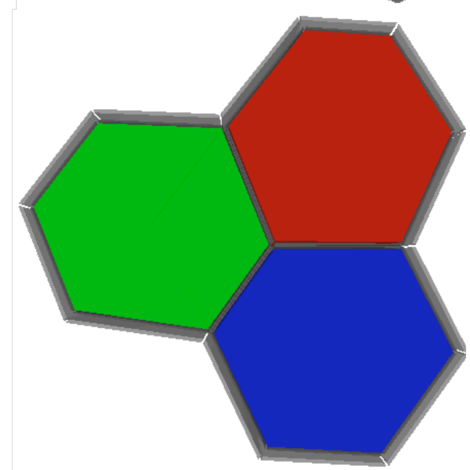
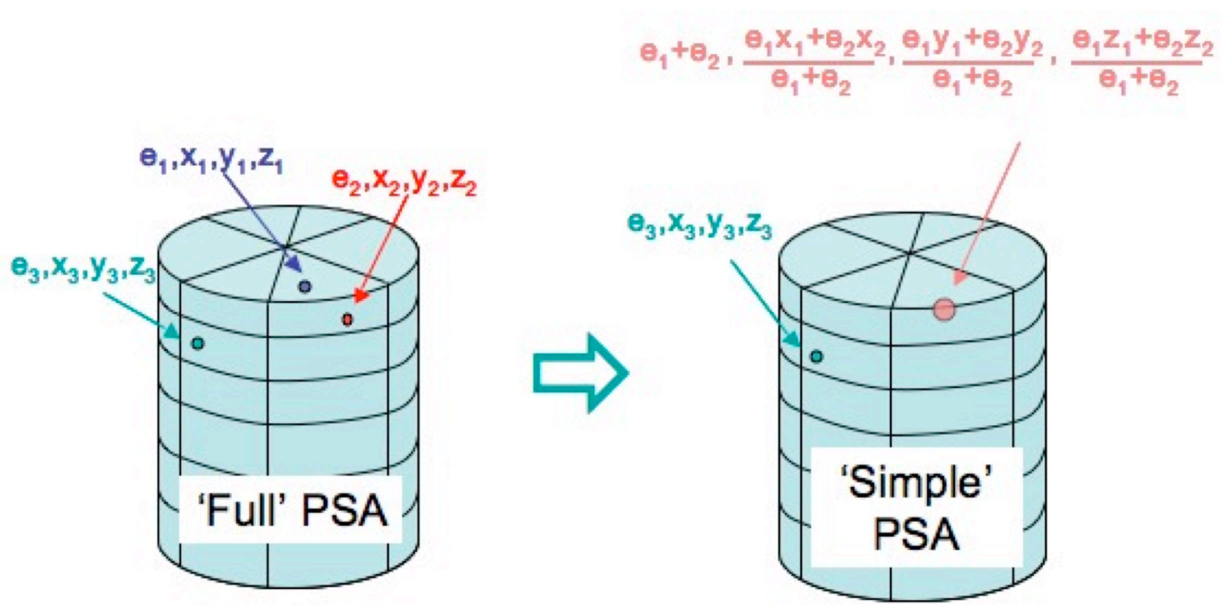


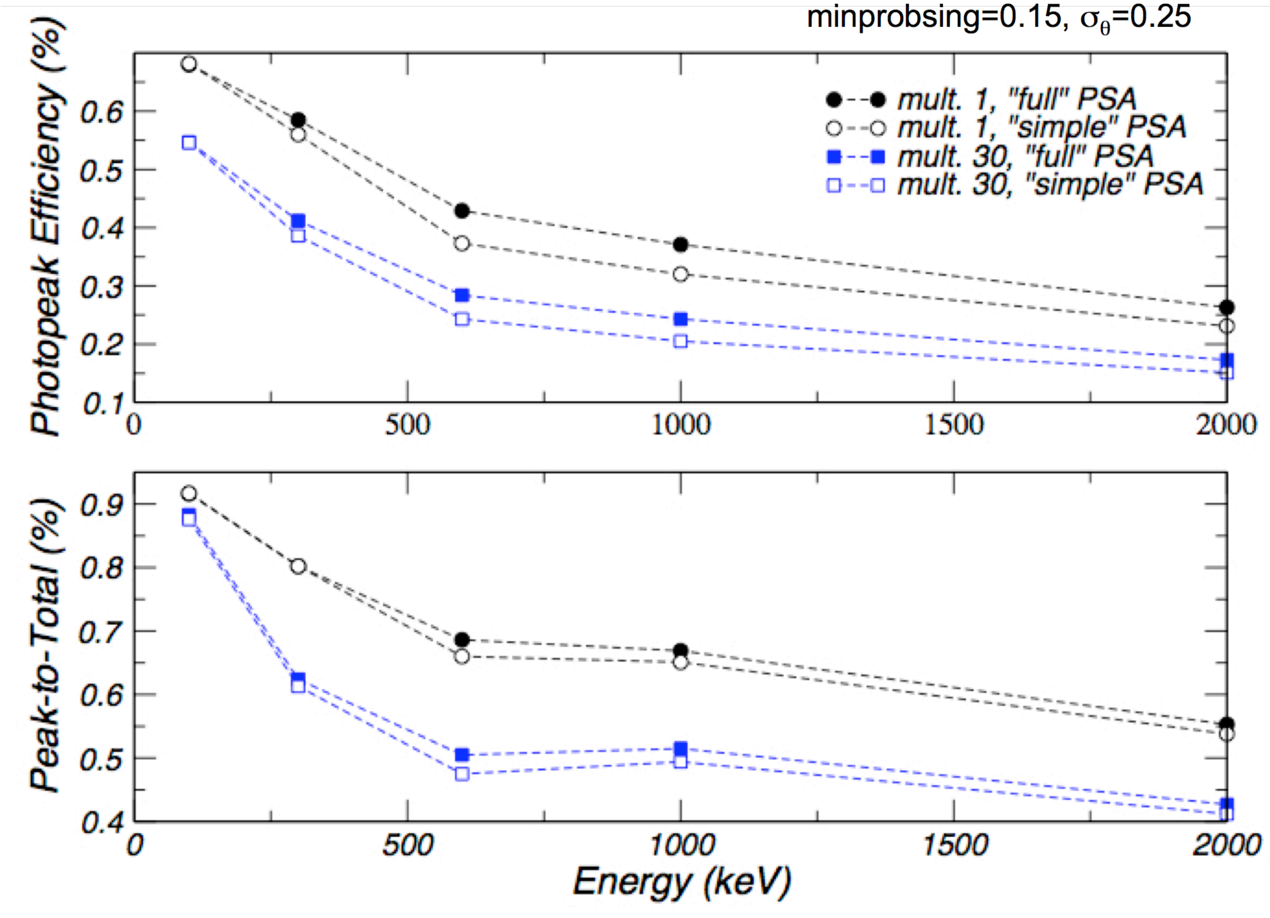


⇨ Careful design of ancillary devices !

Effect of simplified PSA



Effect of simplified PSA



How OFT works ?

- Reads in PSA hits (e[i],x[i],y[i],z[i], ndet[i], nseg[i]) from a Mgt_Hits or Oft_Hits file: can vary the number of events tracked at a time (mult) and the total number of events (totnumbofgammas)

- Requires energies in MeV and positions in cm:

```
e[ir]=1e-3*e[ir];

x[ir]=x[ir]/10.;
y[ir]=y[ir]/10.;
z[ir]=z[ir]/10.;
```

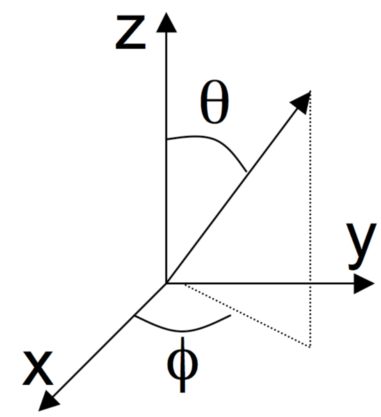
- Requires the knowledge of the position of the source (from file or hardcoded)

xsource
ysource
zsource

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

- Does NOT need to know the recoil velocity or direction (but it's handy to be able to Doppler correct to check if the experiment is going ok !)

How OFT works ?

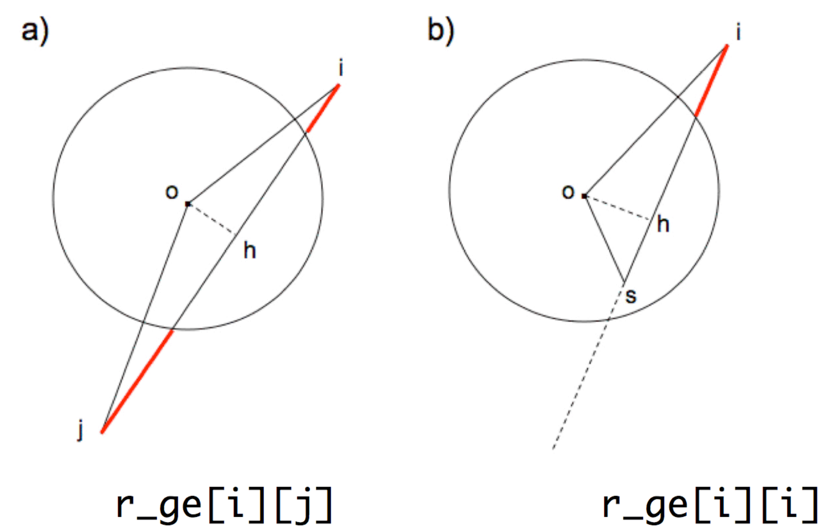


- Calculates angles and sorts points according to increasing θ

```
r[i][i] = sqrt(SQ(x[i]-xsource)+SQ(y[i]-ysource)+SQ(z[i]-zsource));
angtheta[i] = acos((z[i]-zsource)/r[i][i]);
angphi[i] = atan2((y[i]-ysource),(x[i]-xsource));
```

- Calculates effective distances in Ge between points and between points and source

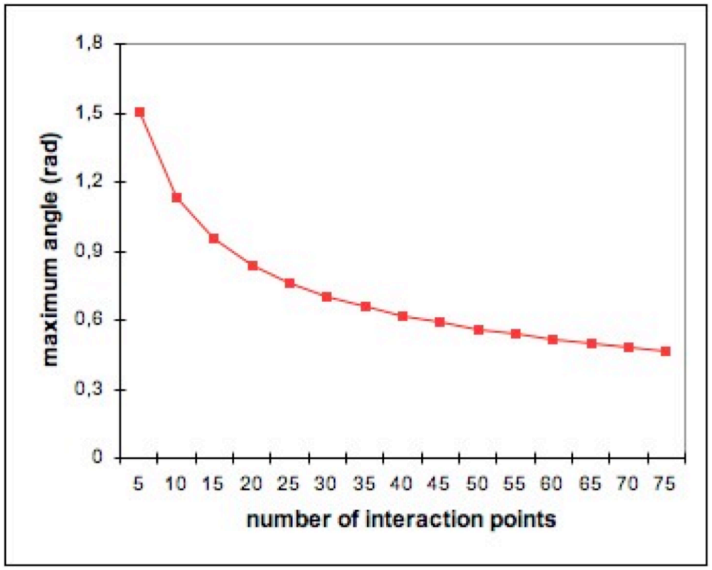
!!! assumes spherical geometry around (0,0,0) and no holes in the array



How OFT works ?

- Computes the maximum angular separation α_{max} between points in a cluster

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



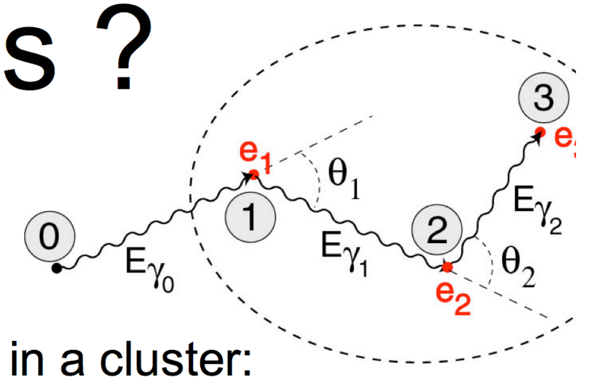
- Assigns interaction points i and j to the same cluster if:

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

- Loops on $\alpha < \alpha_{max}$ and find n different clusters ($\delta\alpha$=0.1 rad)

total energy: et[n]
number of interactions: numn[n]
with the interaction point id's: sn[n][numn[n]]

How OFT works ?



-if numn[i]=1, give the cluster the minimal probability minprobtrack

- Computes the figure of merit for all sequences of points in a 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 = etotale-e[i] and
escattern= etotale/(1+etotale/mc2 (1-cosθi))
```

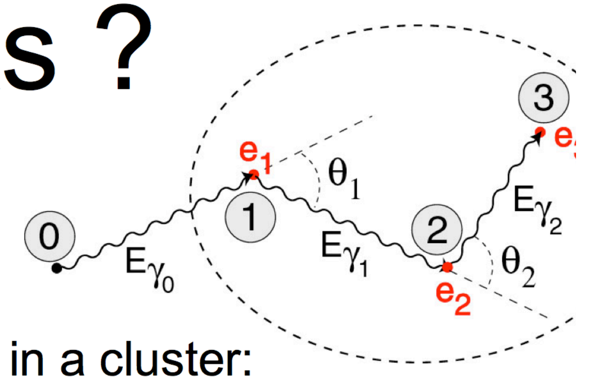
using the expression

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

```
deltaescn = SQ(escattern)*ercos/mec2;
deltaesc = sqrt((numn[i]+1)*SQ(eres));
```

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

How OFT works ?



-if numn[i]=1, give the cluster the minimal probability minprobtrack

- Computes the figure of merit for all sequences of points in a 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 = etotale-e[i] and
escattern= etotale/(1+etotale/mc2 (1-cosθi))
```

using the expression

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

```
deltaescn = SQ(escattern)*ercos/mec2;
deltaesc = sqrt((numn[i]+1)*SQ(eres));
```

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

σ_θ is related to the average position uncertainty in cm

How OFT works ?

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(etotale)/(sig_abs(etotale)+sig_pair(etotale)+sig_compt(etotale))
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(etotale))
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

5) the total probability for a sequence is the Nth square root of product of probabilities - where N=(numn[cluster]*2)-1

6) award the cluster n the probability of the best sequence:

```
probtot[n] = mincosdif
```

2 3 1 4 5
2 3 1 5 4
2 3 4 1 5
2 3 4 5 1
2 3 5 1 4
2 3 5 4 1
2 4 1 3 5

How OFT works ?

- 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)

- Clusters with numn[n]>1 are accepted or rejected if probtot[cluster]>minprobtrack

- Evaluates the figure of merit of the remaining single interaction clusters:

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

- Accepts cluster if probcomp > minprobsing

How OFT works ?

key parameters:
sigma_thet, minprobsing (and to lesser extent minprobtrack)

can switch off single interactions with
nodirect=1
can switch off pair production events with
nopair=1

source position and recoil velocity information read in from OFTinput file

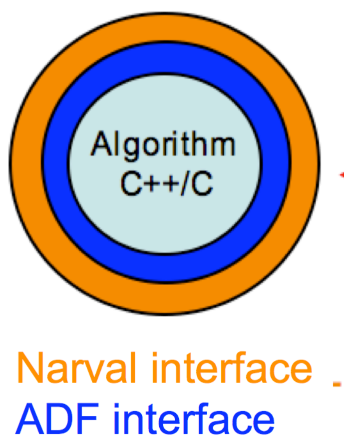
output spectra/statistics to a Root file and some spectra are also written to a Radware.sec file

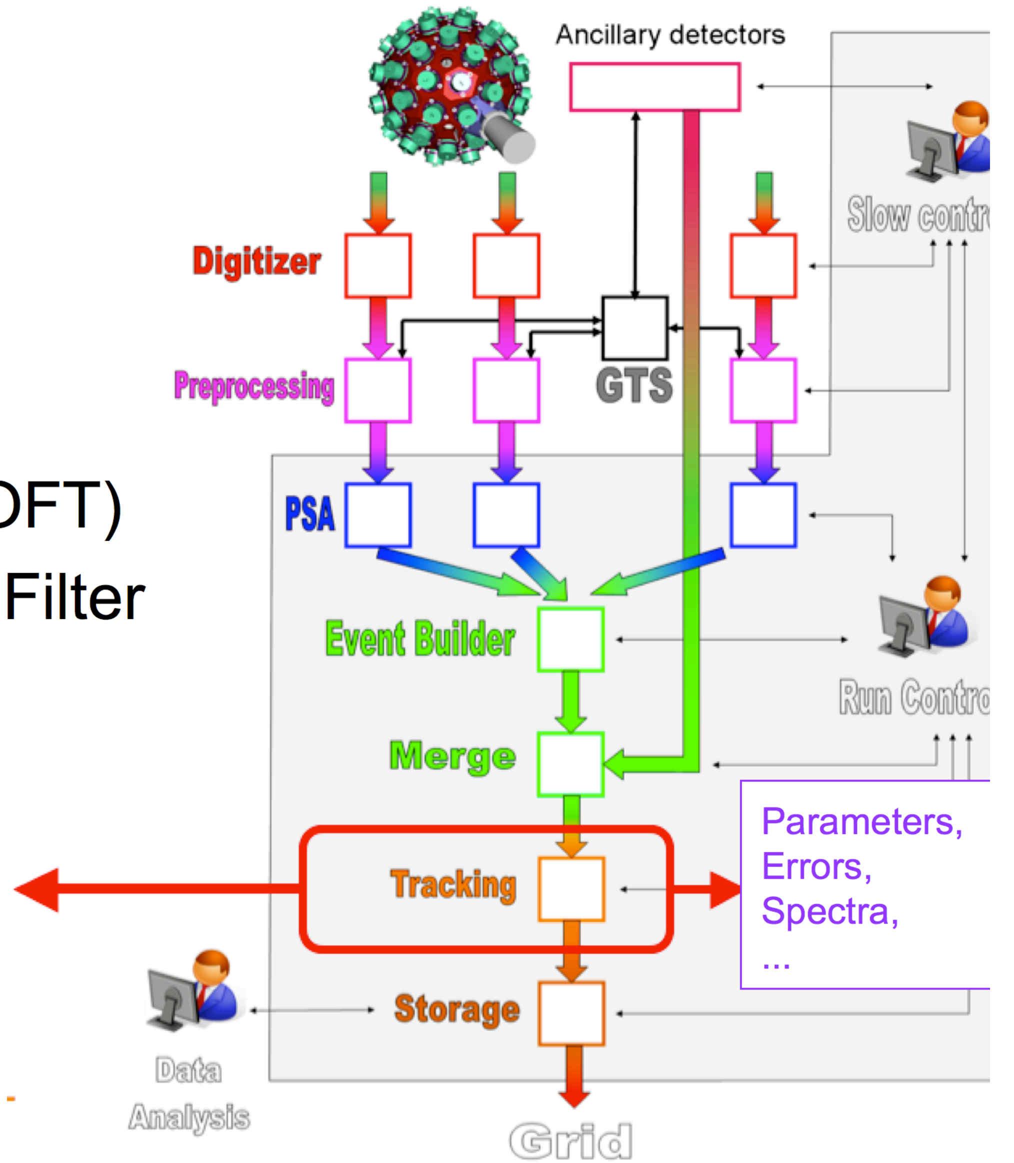
How is tracking done on-line

Tracking = Actor in Narval

Actor type = Filter

Tracking libraries (such as OFT) are called from the TrackingFilter « mother » class





Organization of TrackingFilter

The TrackingFilter « mother » class

- defines what type of data is tracked
- opens and reads configuration and setup files and initializes variables
- gets Event-built and merged data from the data flow
- decodes PSA data
- can write PSA data to an Agata-type file
- performs some preprocessing (geometrical transformations)
- processes the events (for OFT, this is defined in the « daughter » class: TrackingFilterOFT)
- performs some postprocessing (Doppler correction)
- can write tracked data to file
- puts the tracked data (currently the positions and energies of the 1st 2 interaction points in each track) into the data flow

The TackingFilter also return errors and message logs and it can transmit parameters and spectra to be monitored

OFT Tracking

the process() function fills the appropriate local data structures with the PSA data structure (FillOFTStructures()), processes the data (process_event()) and then moves the OFT data to the tracked data structure (MoveOFTStructures())

process_event: computes distances and angles between points and source, sorts positions according to increasing θ, computes all distance between points and calls the following functions:

- cluster_search: find the clusters (with a maximum of kmax points) for a given opening angle α, with $\alpha=\alpha_{min}+\delta\alpha$ up to α_{max}=f(number of interaction points nb_int)
- cluster_evaluation: using the Compton scattering formula, compute the figure of merit for each sequence of points in every cluster and determine the best sequence of points in each cluster. The comparison between geometrical angles and energy angles depends on the position uncertainties through sigma_thet
- cluster_sort_flag: sort the clusters according to the figure of merit and flags clusters, which have common points with better clusters
- cluster_validation: accept clusters if figure of merit > minprobtrack
- ! single_interaction: single interaction point clusters are treated last. They must be isolated (distance to closest point > 4cm) and the square root of the product of the depth and interaction probabilities must be >minprobsing

process_event returns tracked multiplicity (mult), total energy of track (etot), 1st (xfirst,yfirst,zfirst) and 2nd (xsecond,ysecond,zsecond) positions in track, number of points in track (nbtot) and figure of merit of track (probtot)

Practical (1)

GSI source data (from N. Lalovic)

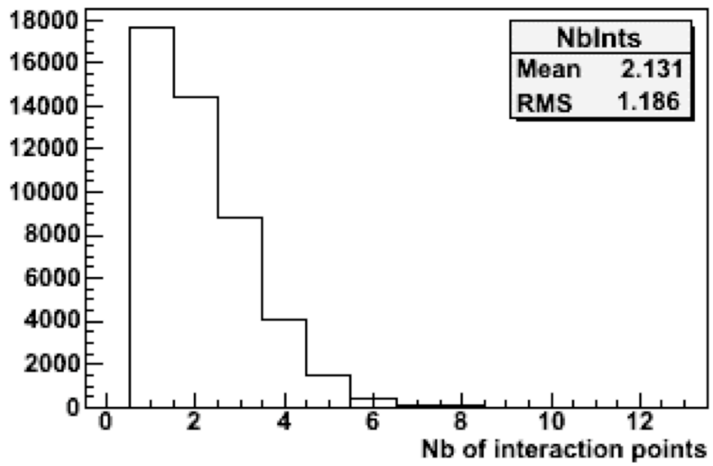
21 Agata detectors + 1 Euroball detector

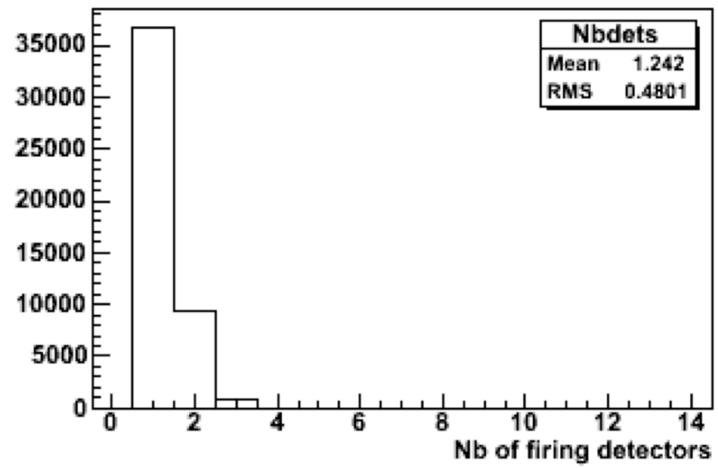
^{60}Co , source = (0,0,0)

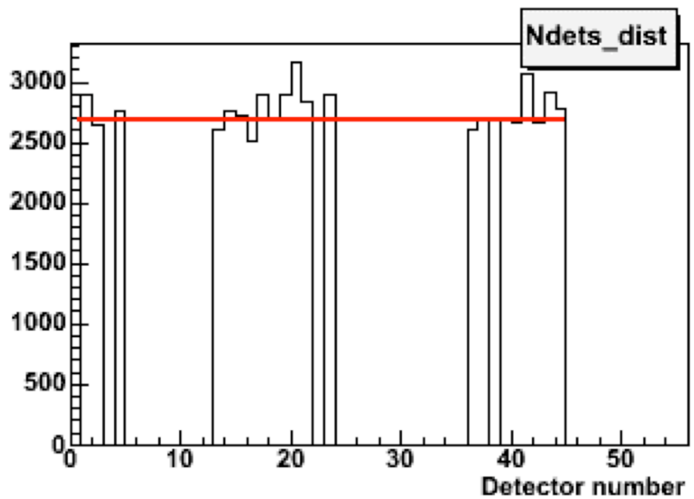
data written to Mgt_Hits file if presence of the 1332 keV line in the Euroball detector

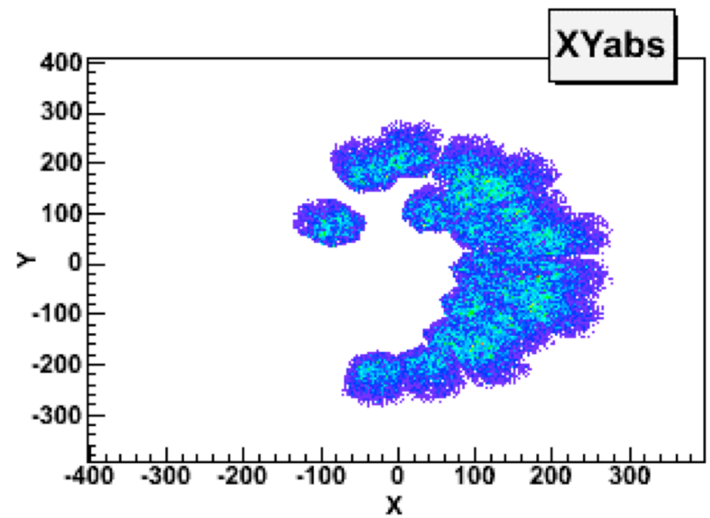
NB: you probably need to increase your stack size to run forward (ulimit -s 32000)

Statistics

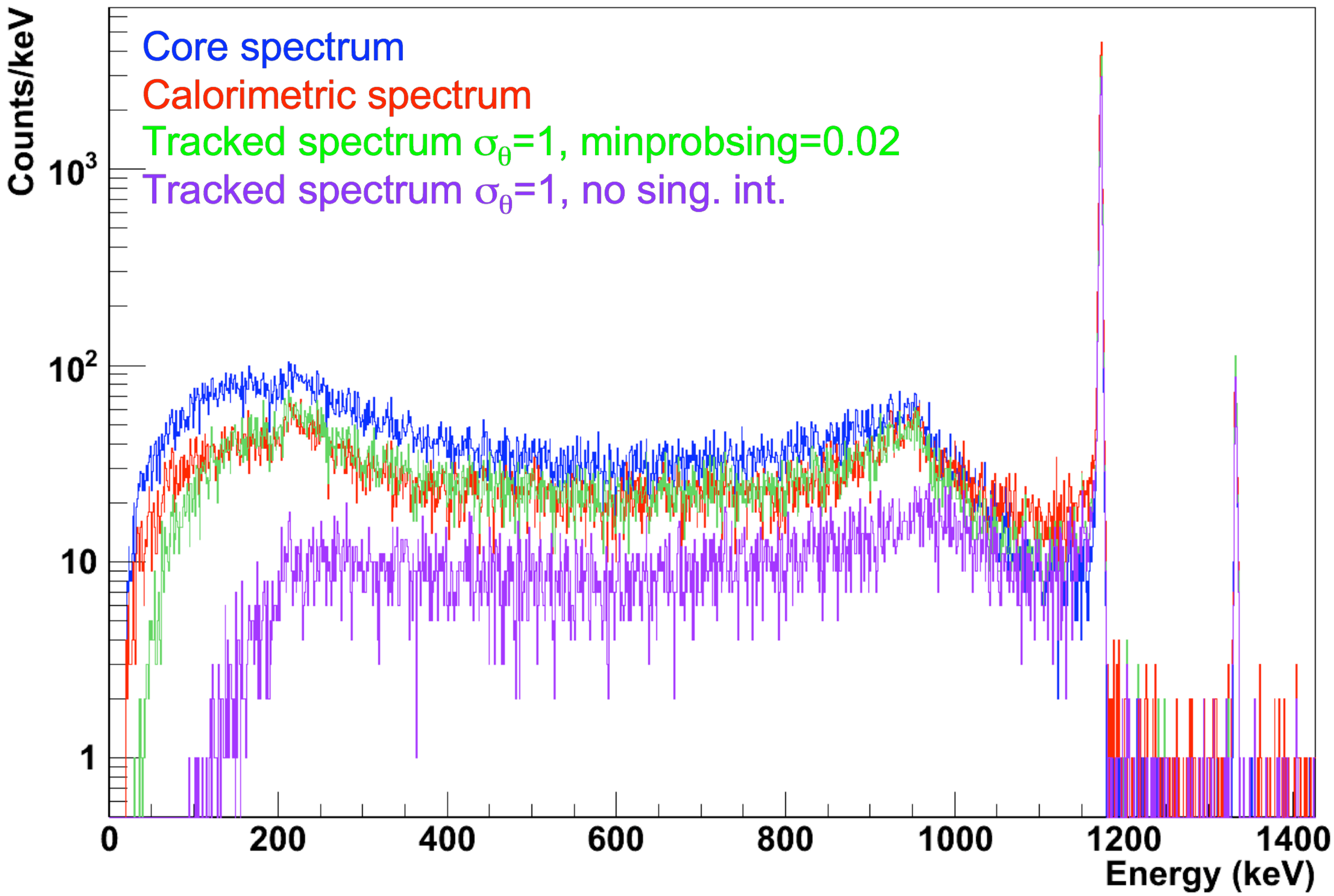

NbInts
Mean 2.131
RMS 1.186
Nb of interaction points


Nbdets
Mean 1.242
RMS 0.4801
Nb of firing detectors


Ndets_dist
Detector number

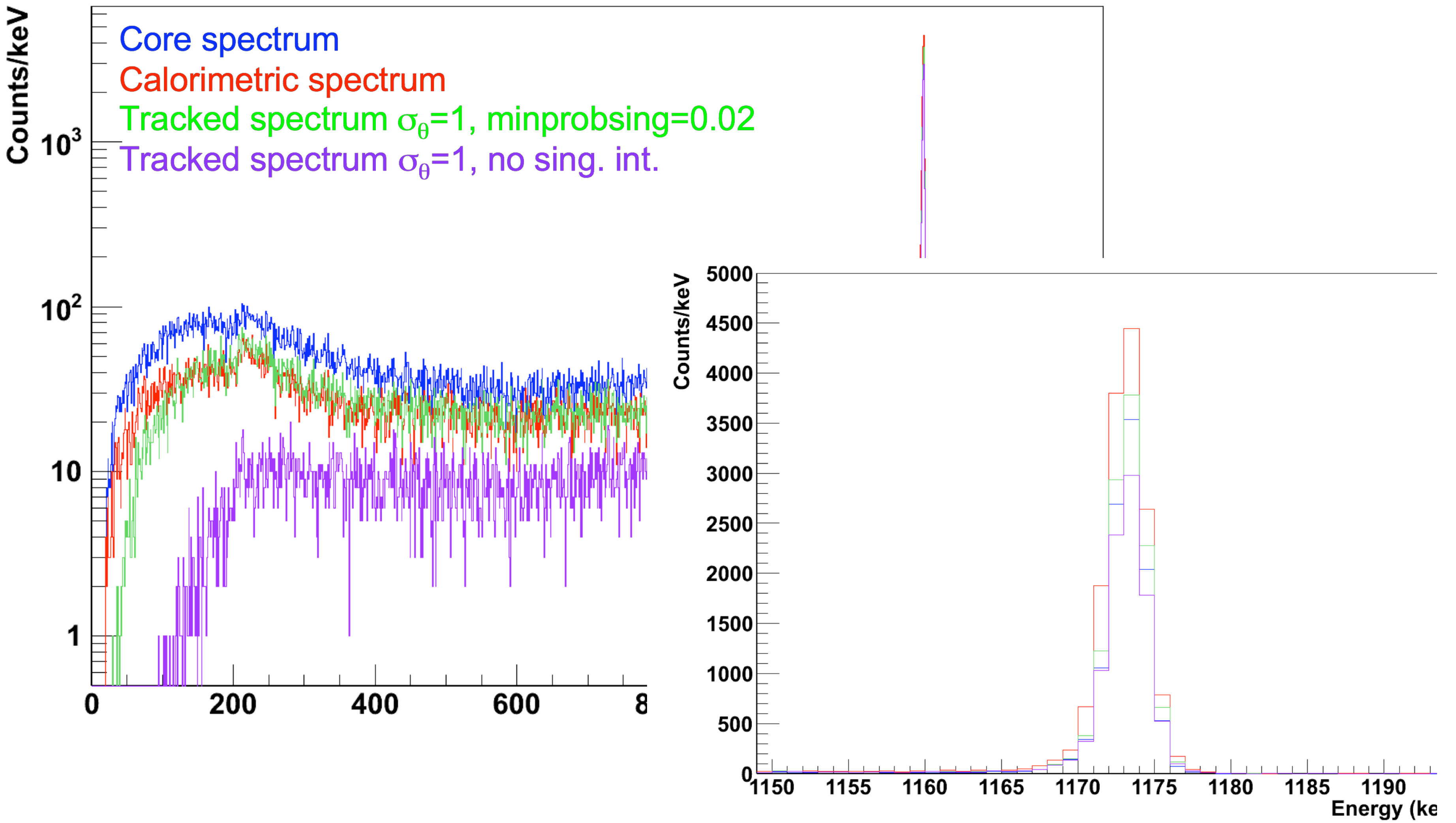

XYabs
Y
X

Spectra



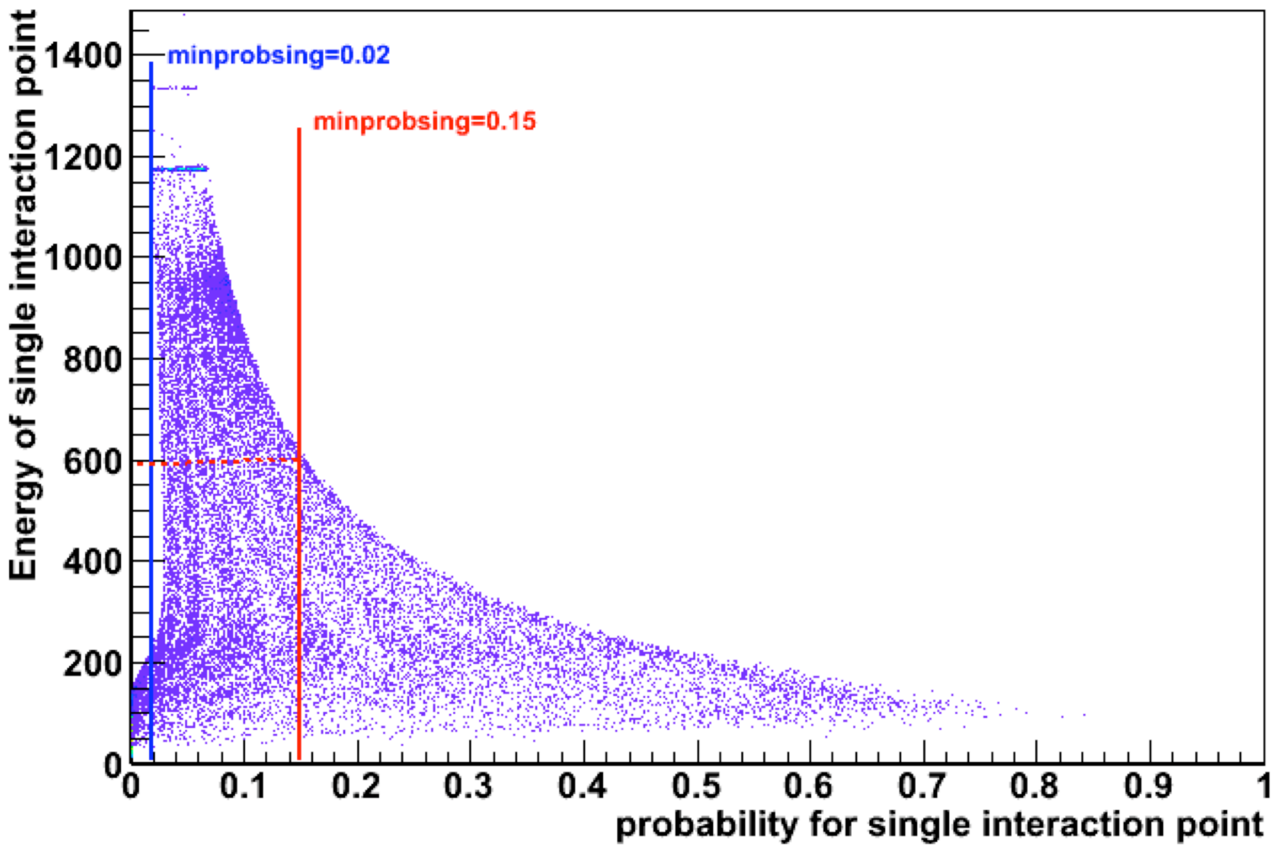
Counts/keV
10^3
10^2
10
1
Core spectrum
Calorimetric spectrum
Tracked spectrum σ_θ=1, minprobsing=0.02
Tracked spectrum σ_θ=1, no sing. int.
0
200
400
600
800
1000
1200
1400
Energy (keV)

Spectra

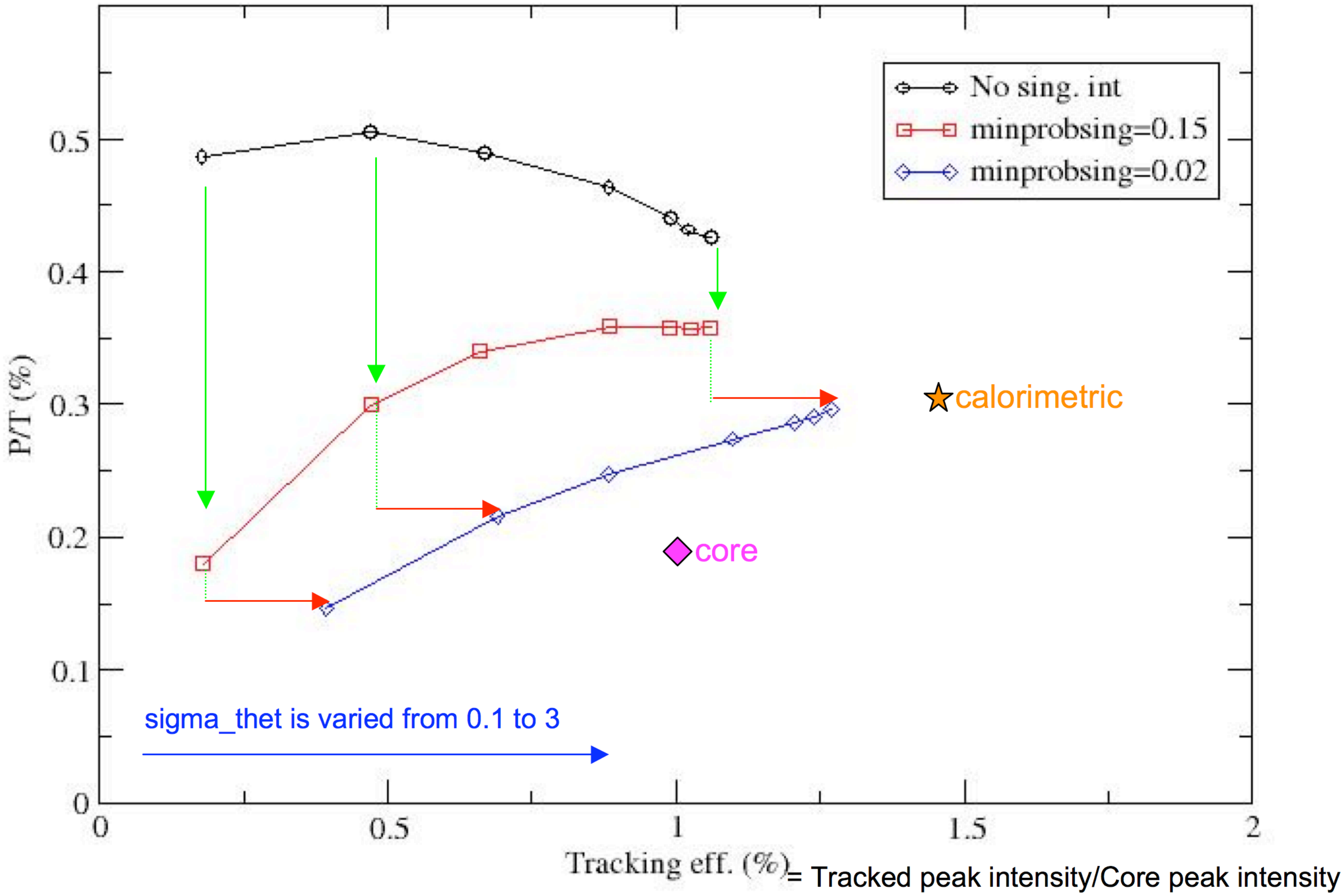


Core spectrum
Calorimetric spectrum
Tracked spectrum σ_θ=1, minprobsing=0.02
Tracked spectrum σ_θ=1, no sing. int.
Counts/keV
10^3
10^2
10
1
0
200
400
600
Counts/keV
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1150
1155
1160
1165
1170
1175
1180
1185
1190

Tuning single interactions

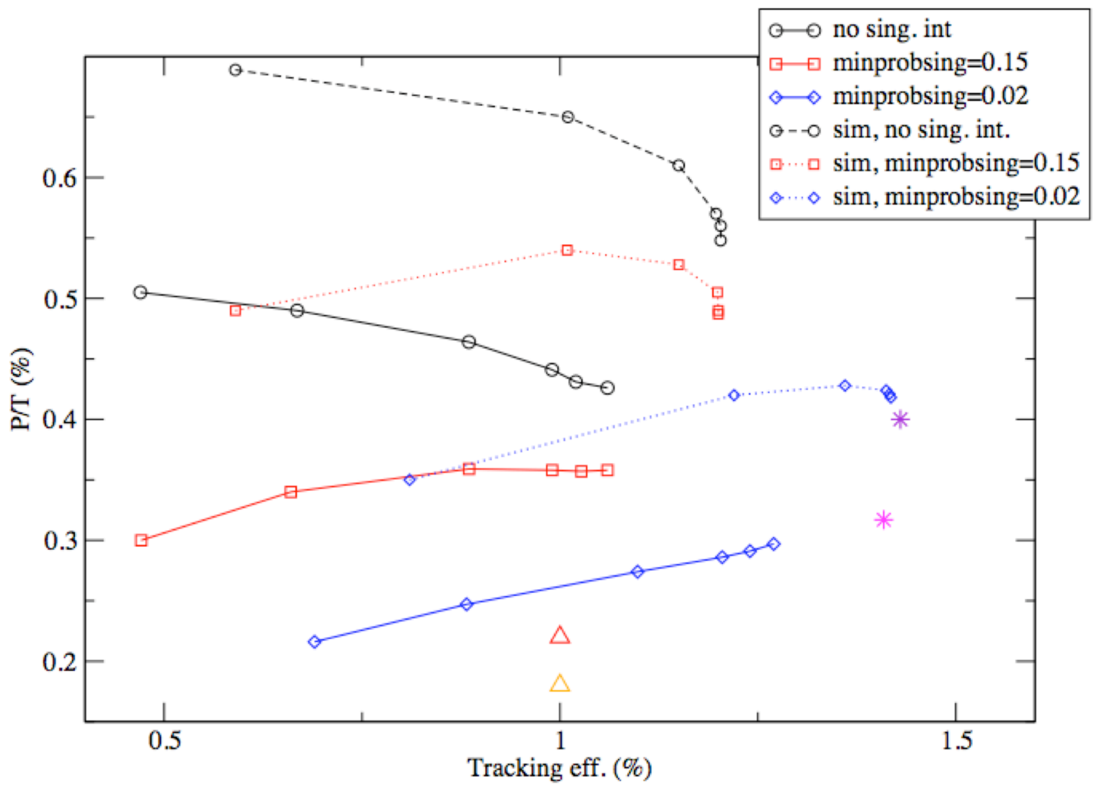


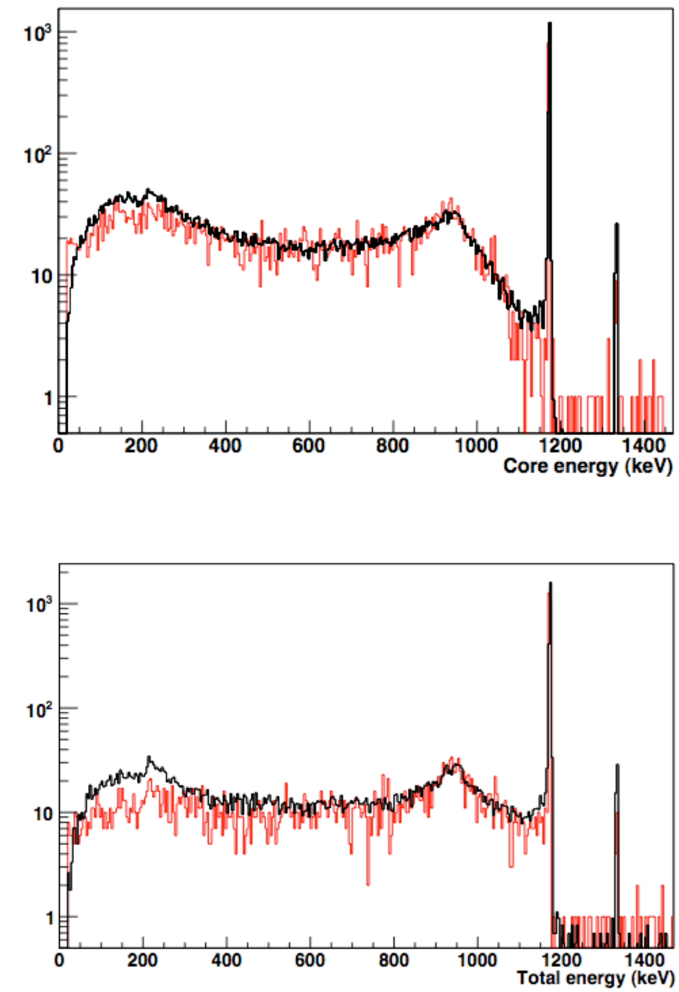
Results



★increase in background by including the single interactions
★gain in efficiency by extending the energy range of the single interactions

Comparison to simulations (J. Ljungvall)





There is still an unknown source of backscattering, which is responsible for the worse experimental P/T !

Practical (2)

Legnaro source data (from C. Michelagnoli)

Agata demonstrator (4 triple clusters)

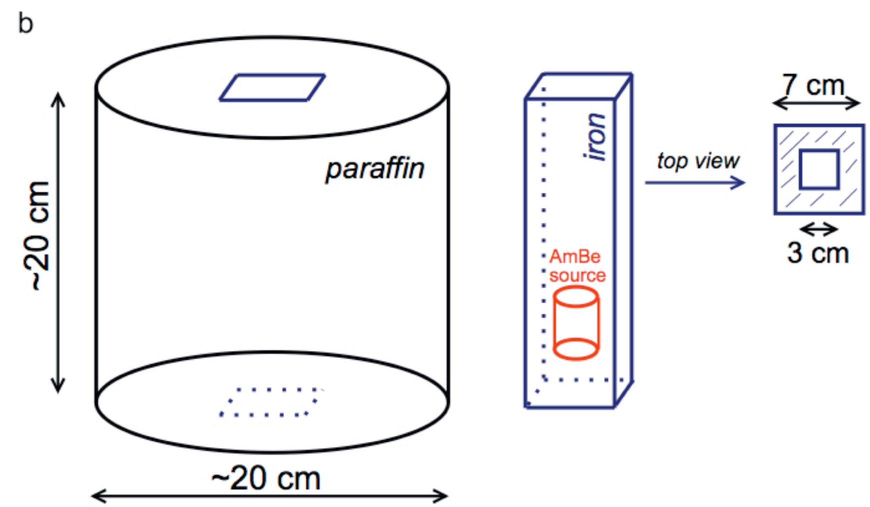
AmBe(Fe) high energy gamma-ray source

source=(0,0,+5 cm)

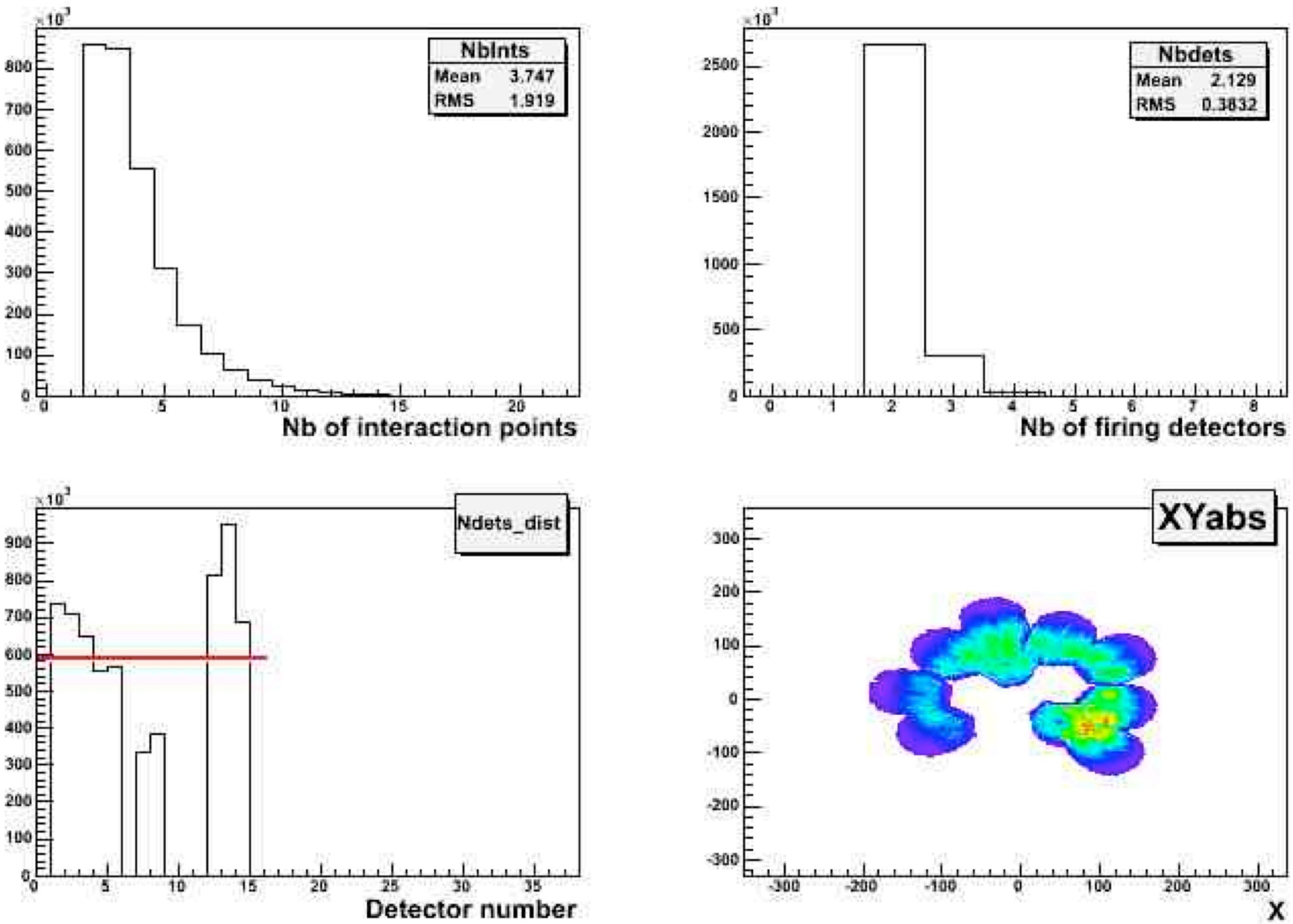
(!! the x pos. of the source is actually lower)

↓

might have some effect on the performance of OFT

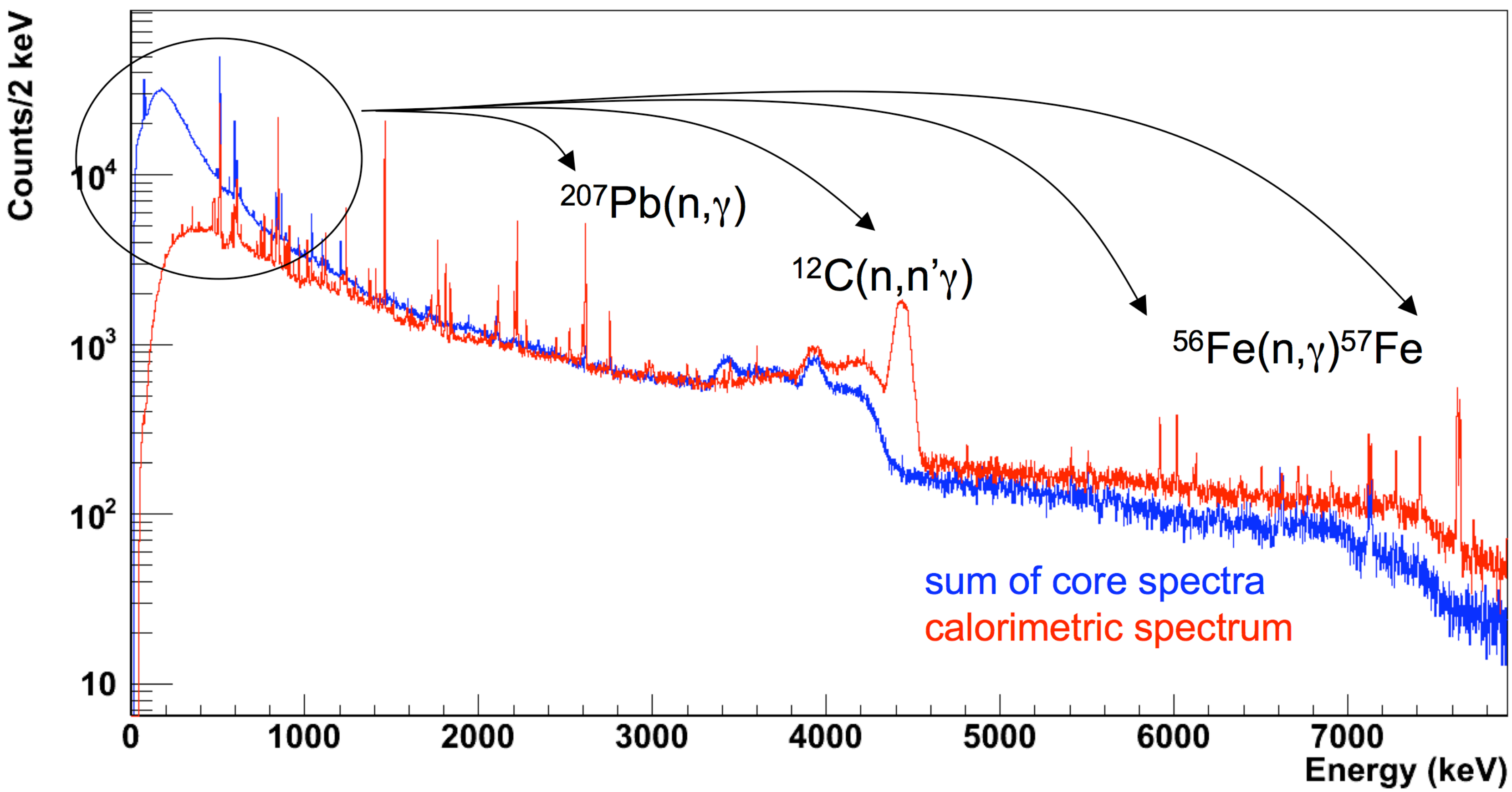


Statistics



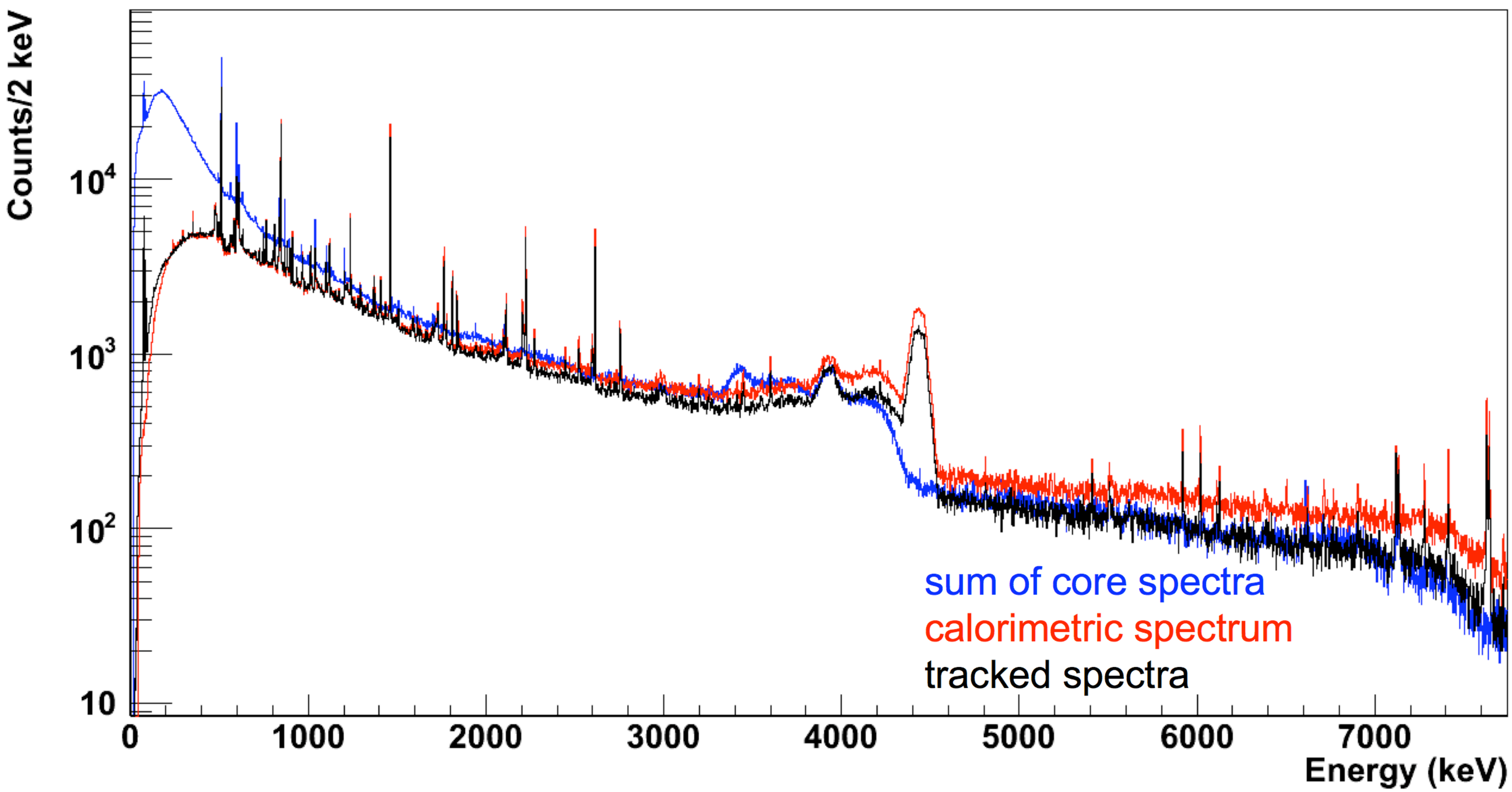
NbInts
Mean 3.747
RMS 1.919
Nb of interaction points
Nbdets
Mean 2.129
RMS 0.3832
Nb of firing detectors
Ndets_dist
Detector number
XYabs
X

Spectra

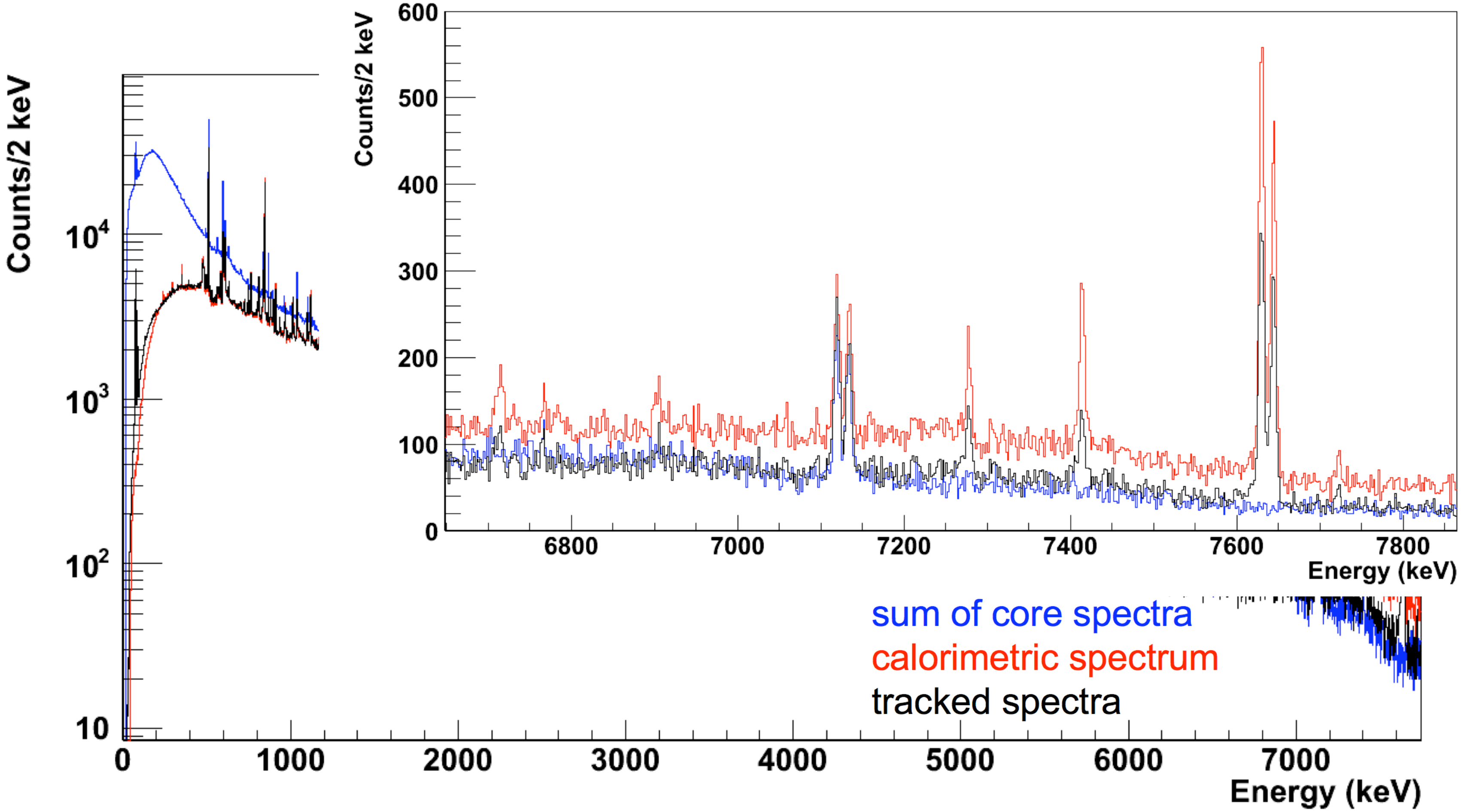


Counts/2 keV
10^4
10^3
10^2
10
0
1000
2000
3000
4000
5000
6000
7000
Energy (keV)
$^{207}Pb(n,\gamma)$
$^{12}C(n,n'\gamma)$
$^{56}Fe(n,\gamma)^{57}Fe$
sum of core spectra
calorimetric spectrum

Tracking at high energy



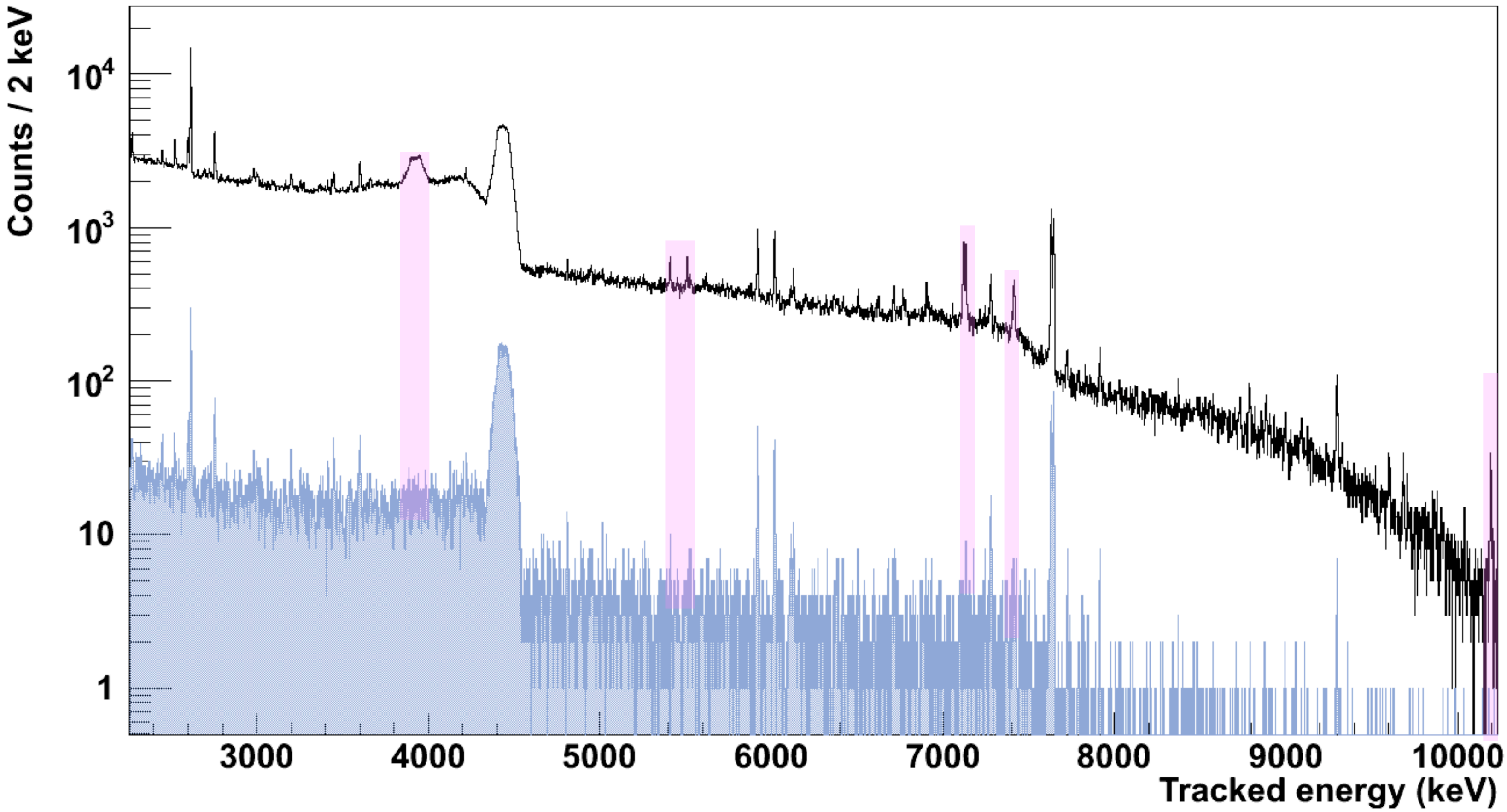
Tracking at high energy



σ_θ=3.0, minprobsing=0.02, source=(20,0,5) => ~ background is divided by 2

tracking eff. wrt calorimetric peak = ~70%

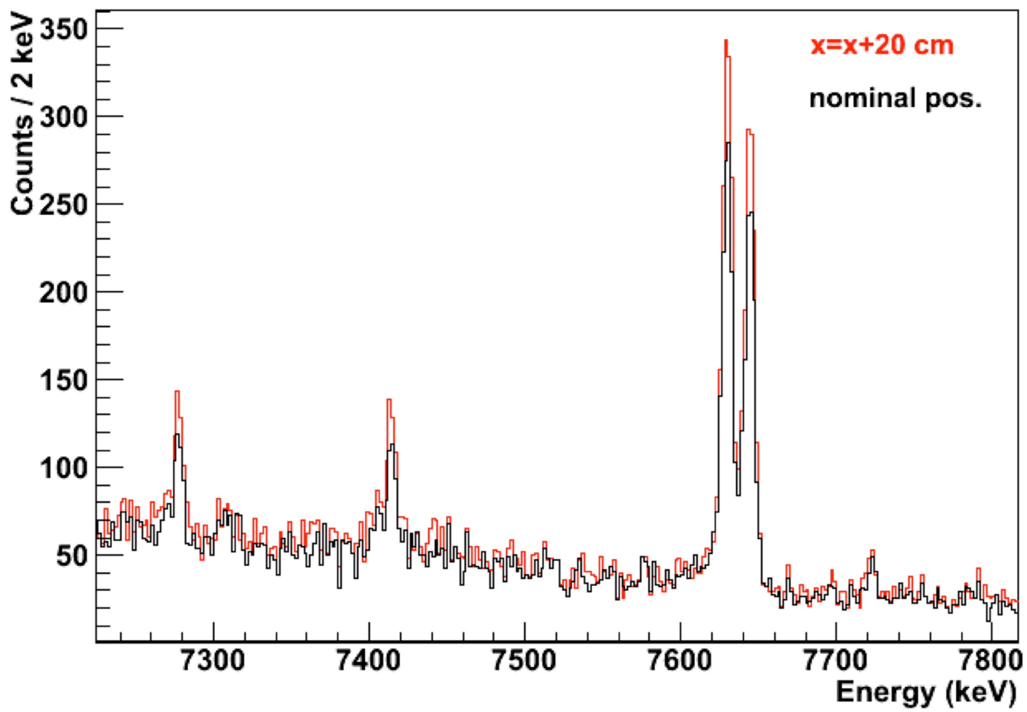
Compton vs Pair production

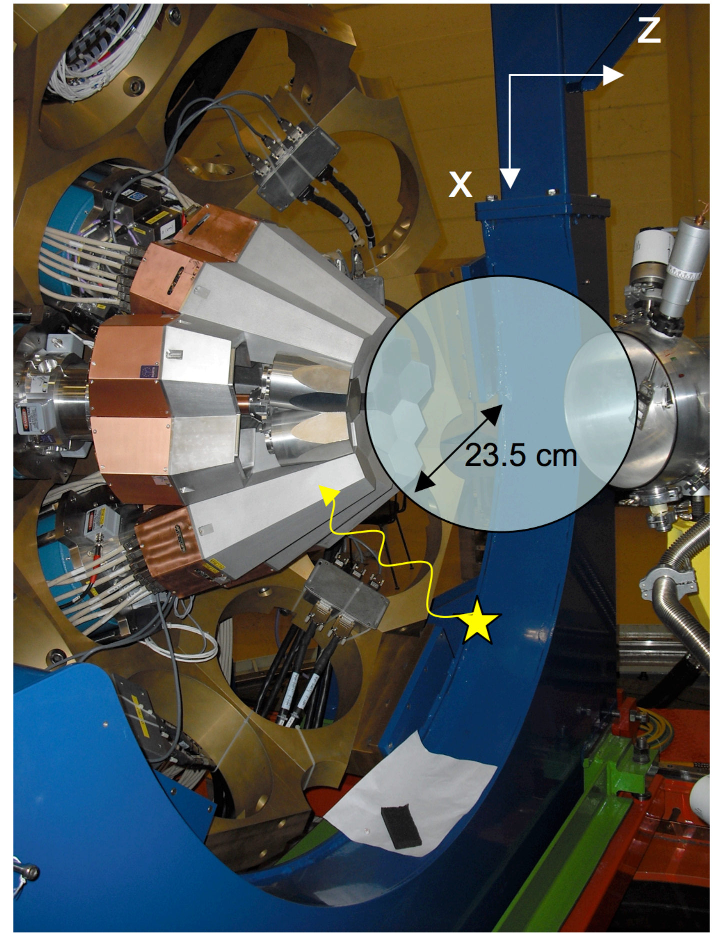


★at 7.6 MeV, reconstruction of pair-production events contributes to ~6% of the total photopeak eff. => Compton dominates !

★Algorithm can recognize escape and pileup peaks

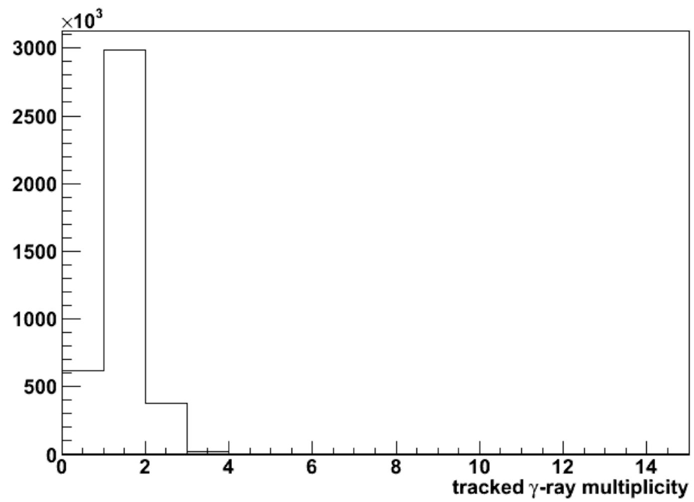
Position dependence....





source was probably lower - but issue with r_ge[i][j] & r_ge[i][i] calculations if the source is outside the inner radius of the shell

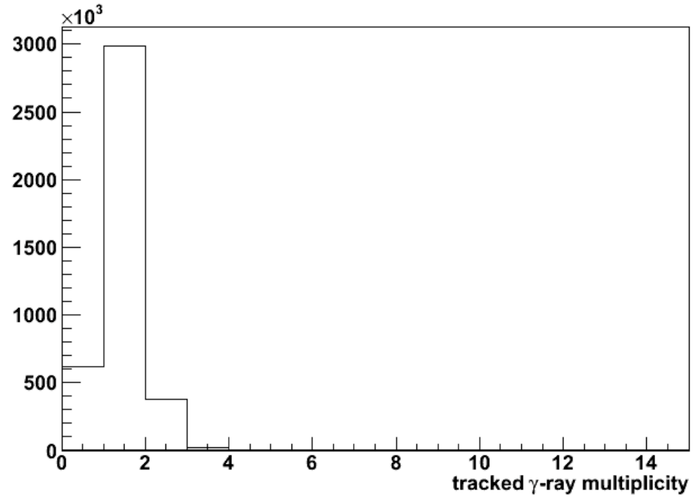
Calorimetric vs tracking



- multiplicity 1 events

⇒can sum everything in the array

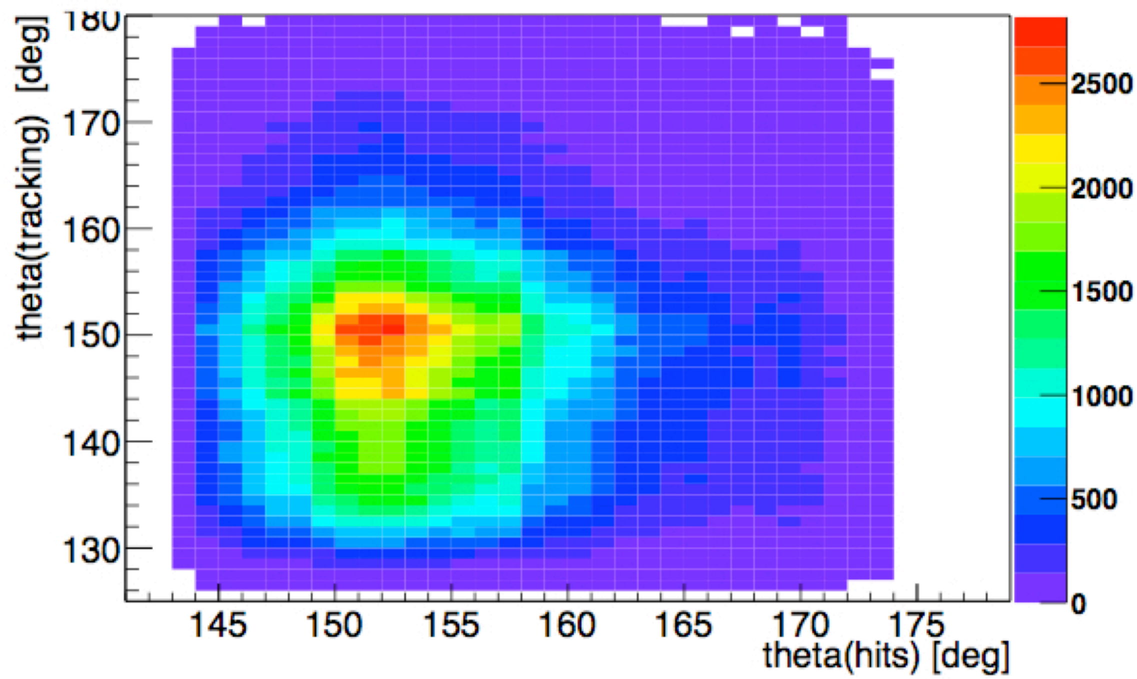
Calorimetric vs tracking



• multiplicity 1 events
⇒can sum everything in the array

C.Michelagnoli, PhD

• efficiency vs energy resolution in-beam....



Practical (3)

Fusion-evaporation reaction (from D. Mengoni)

$^{208}Pb(^{18}O,xn)^{226-xn}Th$

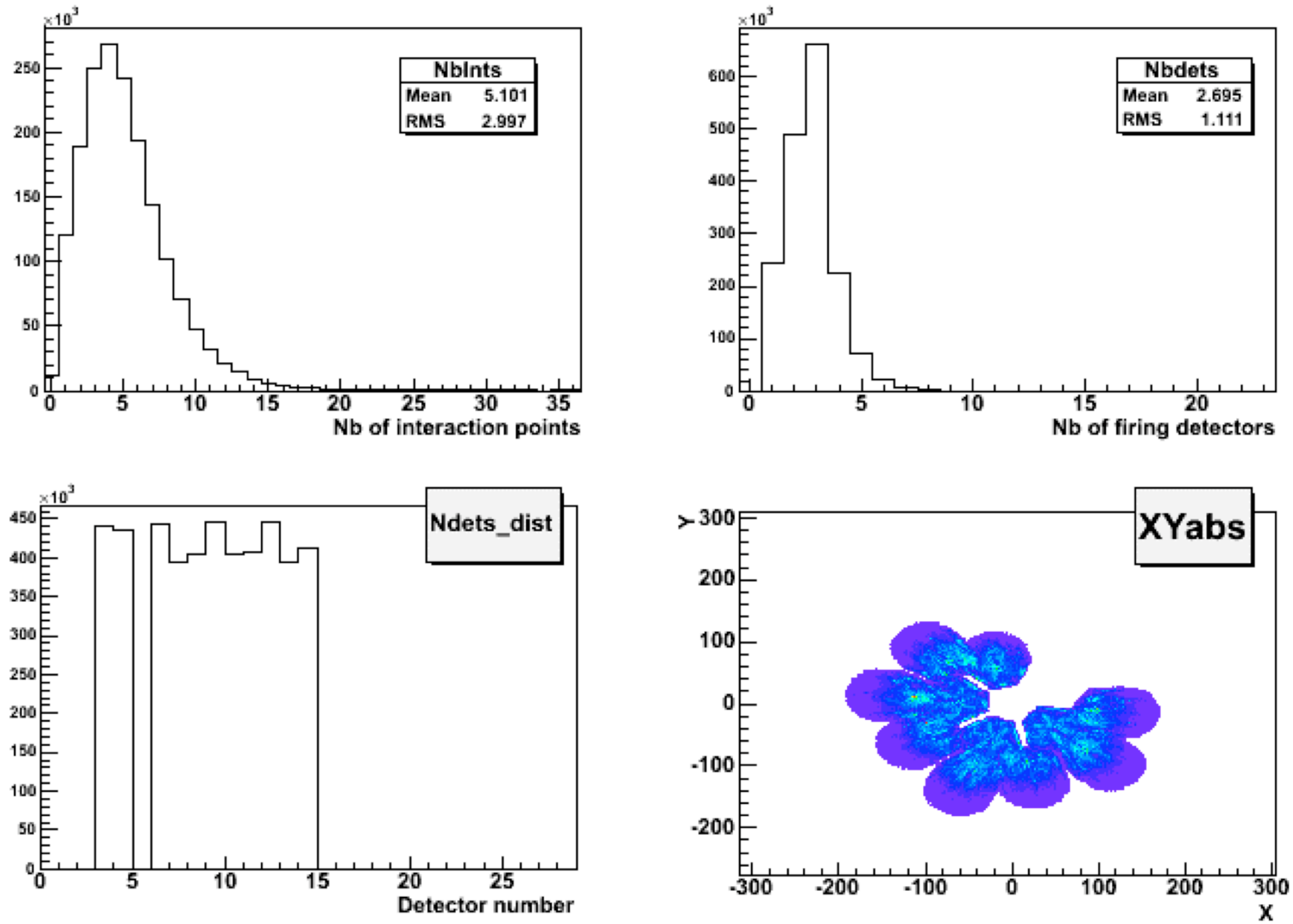
4 AGATA triple clusters

source=(0,0,-9.5cm)

recoil direction= (0,1,0)

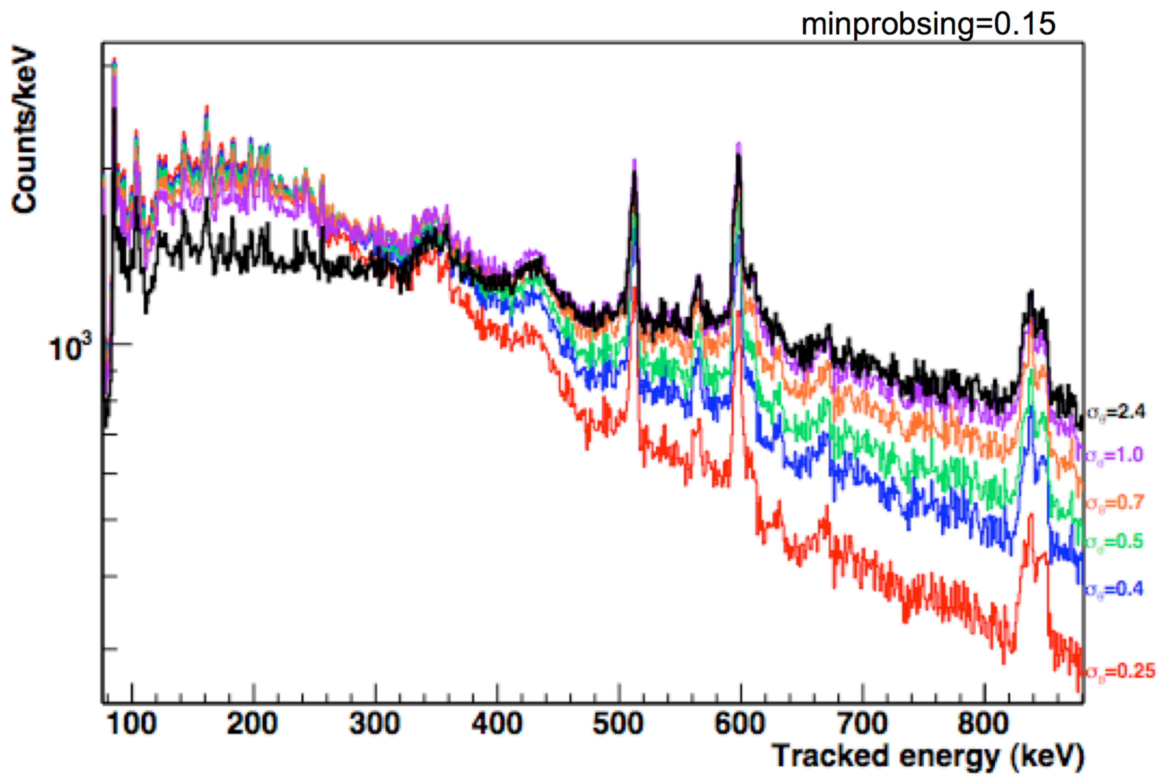
v/c=0.01

Statistics



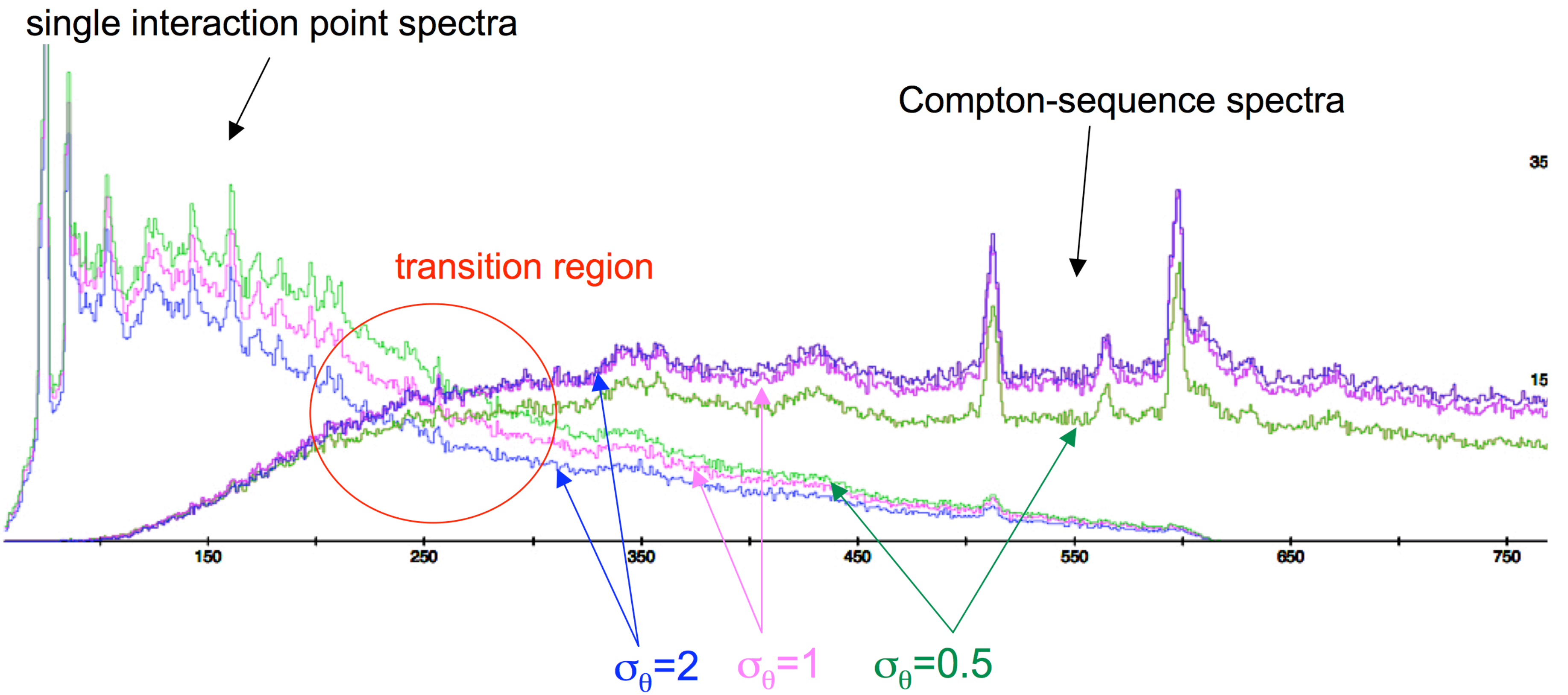
×10³
NbInts
Mean 5.101
RMS 2.997
Nb of interaction points
×10³
Nbdets
Mean 2.695
RMS 1.111
Nb of firing detectors
×10³
Ndets_dist
Detector number
XYabs
Y
X

Spectra

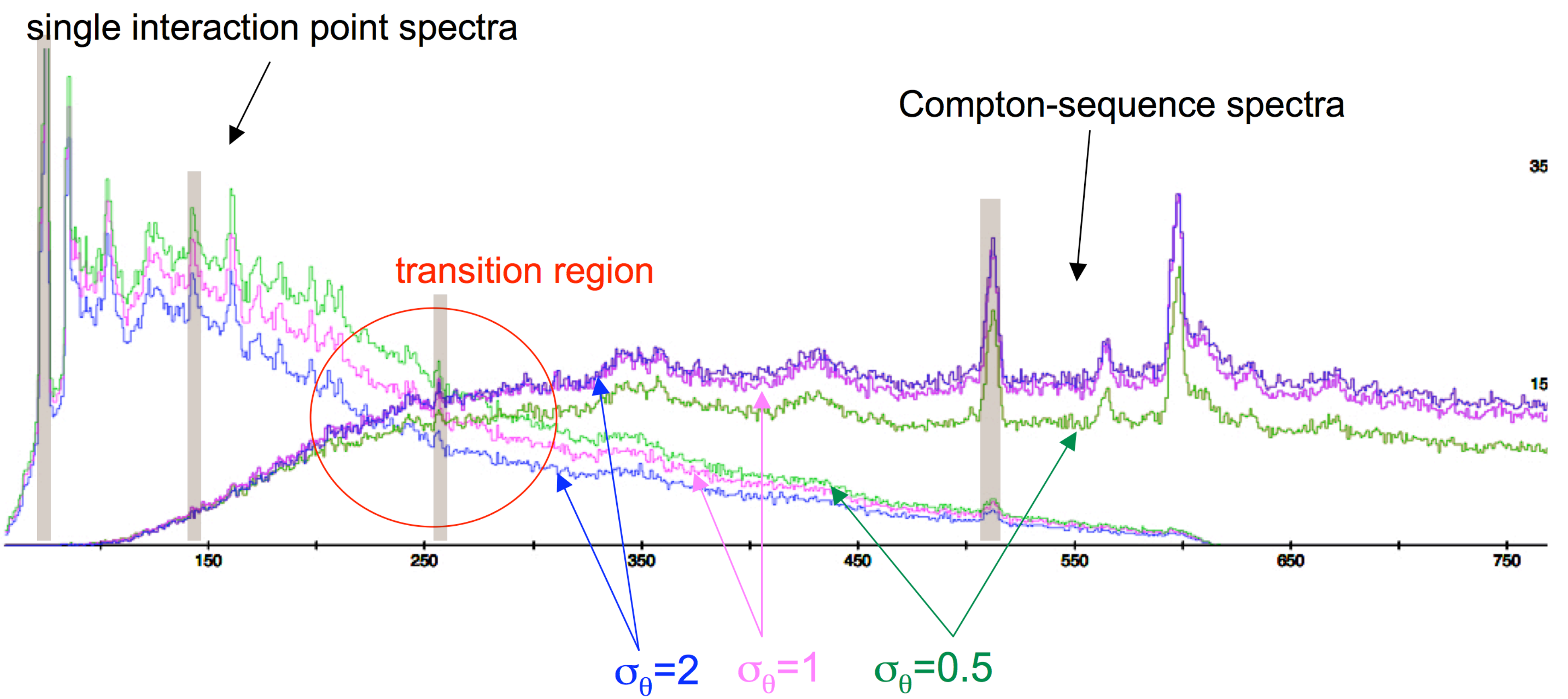


The ratio low/high energy of the spectrum changes !

Balancing Compton sequences and single interaction points in the same event

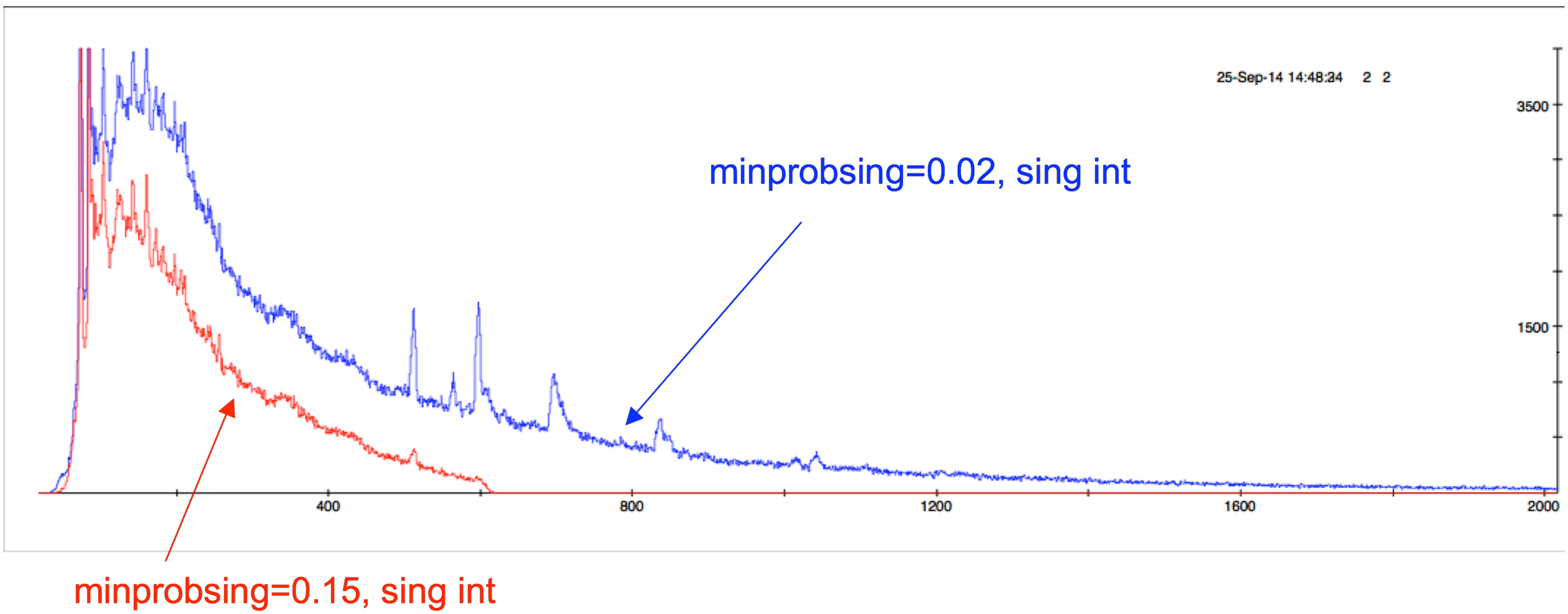


Balancing Compton sequences and single interaction points in the same event

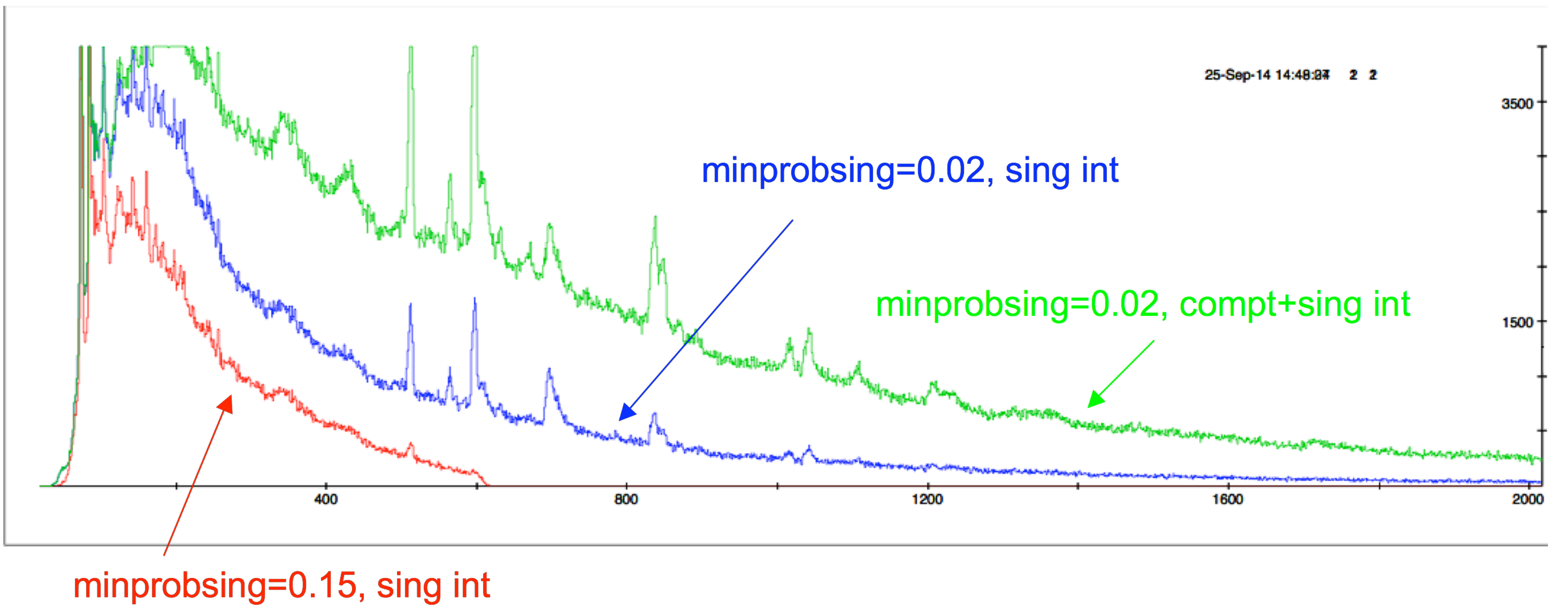


⇨ optimum for $0.7 < \sigma_\theta < 1$

Adding efficiency @ high energy



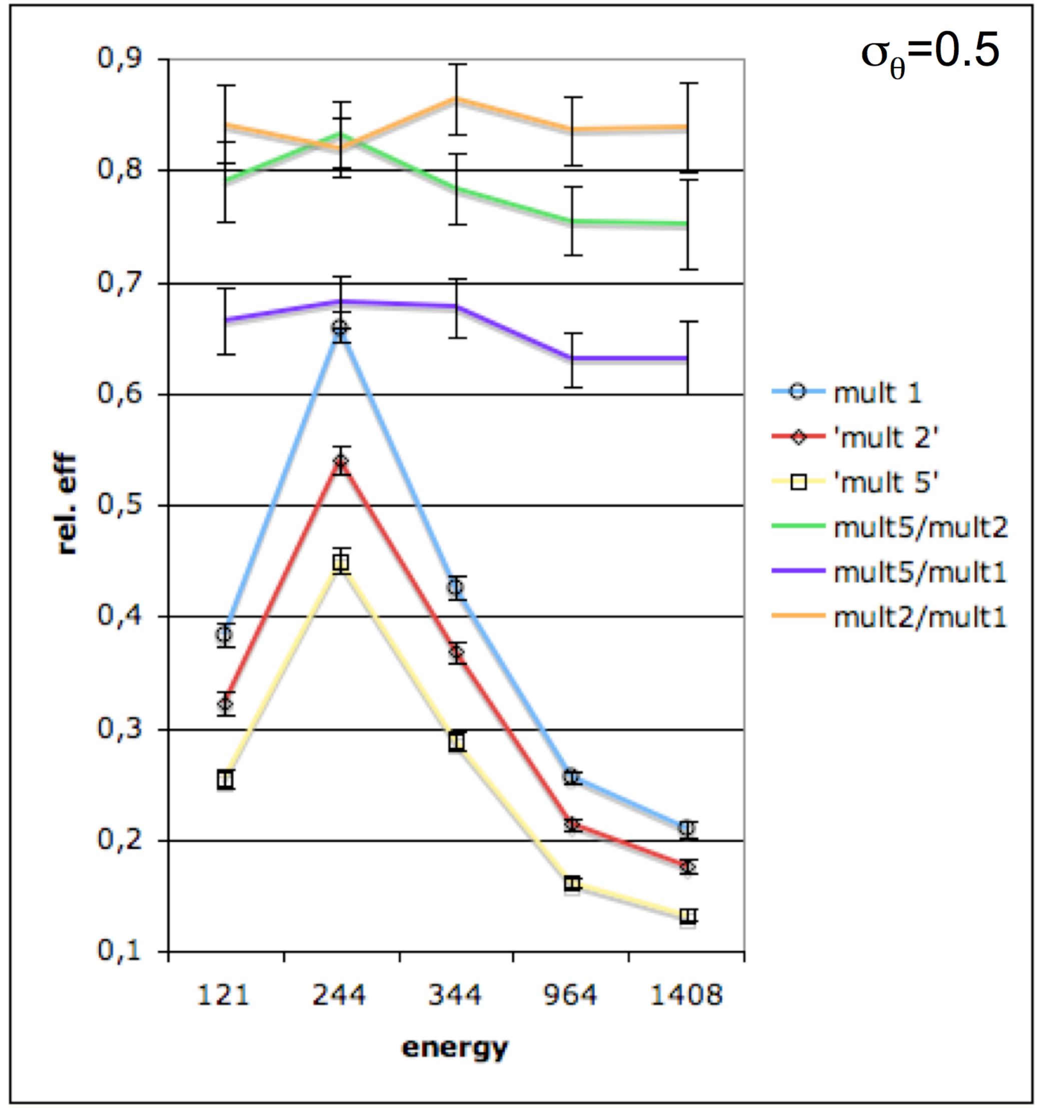
Adding efficiency @ high energy



Efficiency vs input fold

*^{152}Eu source run
*Concatenate events to simulate higher folds

(dirty source run due to activation...)



Conclusions & outlook

- tracking works !
- needs tuning for every experiment
- the algorithm can still be improved (energy dependent sigma_thet, clustering,...)
- still some open (in my mind) questions:
  - why is the experimental P/T not up to expectations ?
  - relative efficiency
  - response function to unfold for eg., to correct for summing....
  - ...