Tracking

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GRETINA Software Working Group Meeting

LBNL, June 22-23, 2004

Outline

- **Tracking principle**
- **Status and results**
- **Future developments**

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 430 (1999) 69–83

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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A γ-ray tracking algorithm for the GRETA spectrometer

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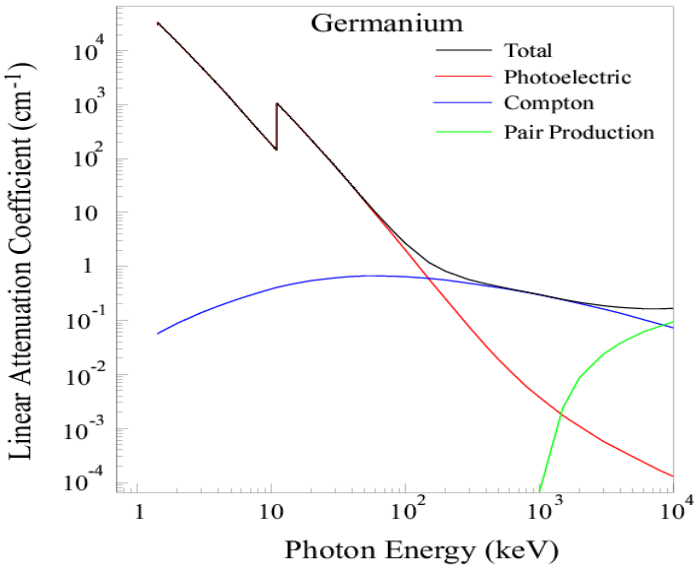
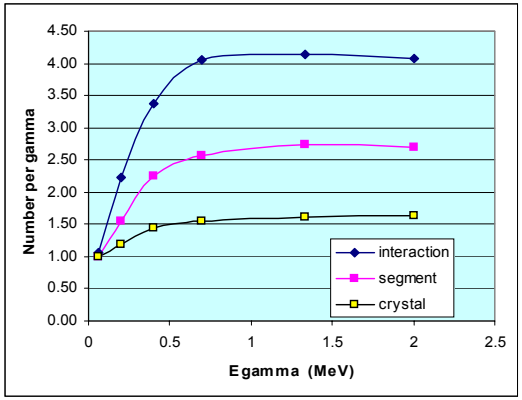
Received 12 November 1998; received in revised form 27 January 1999

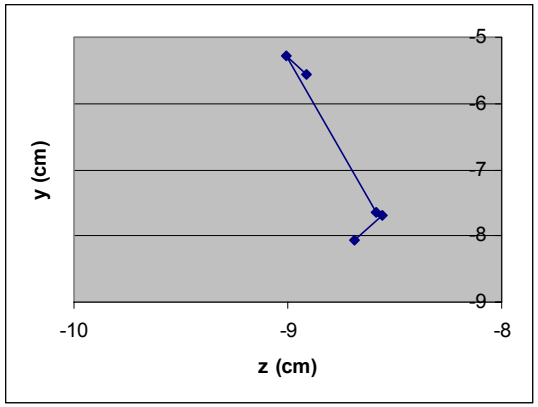
γ -ray interactions in Ge

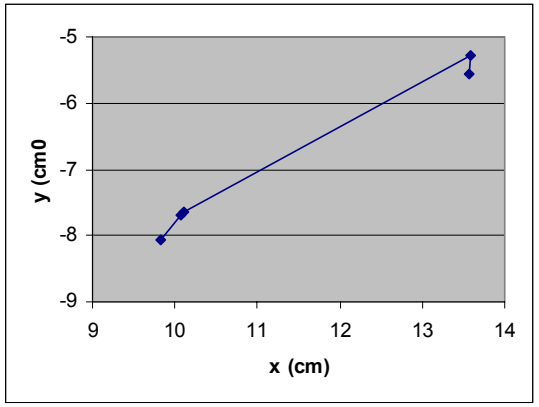


Example; 1.33 MeV
5 interactions: 4 Compton, 1 photo
Separation of interactions: 0.5 – 5 cm

x (cm)	y (cm)	z (cm)	E (MeV)
9.82	-8.07	-8.69	1.0184
10.07	-7.68	-8.56	0.0418
10.11	-7.65	-8.59	0.0044
13.58	-5.27	-9.01	0.1202
13.57	-5.55	-8.91	0.1452







Compton Tracking Principle

Assume 1) γ-ray starts from the source
2) full energy is deposited

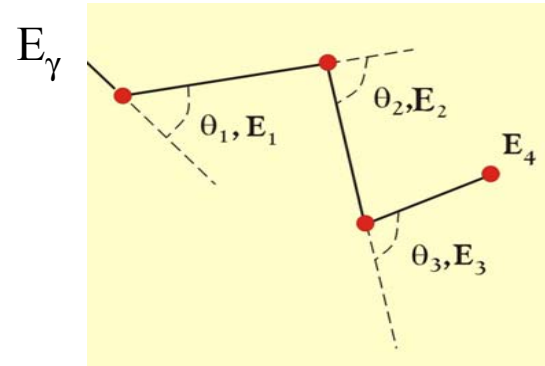
$$E_\gamma = E_{e1} + E_{e2} + E_{e3} + E_{e4}$$

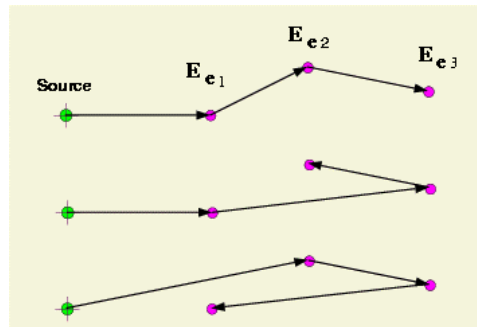
For N! possible permutations, check each interaction point for Compton scattering conditions

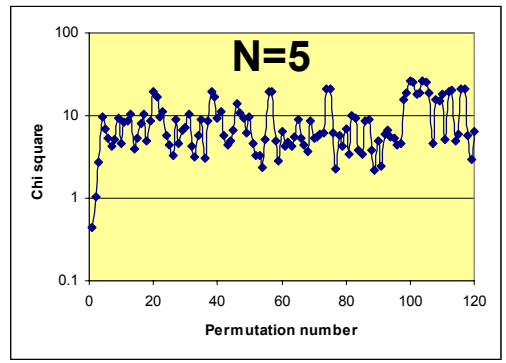
$$\cos\theta_C = 1 + \frac{0.511}{E_\gamma} - \frac{0.511}{E'_\gamma}$$

$$\chi^2 = \frac{1}{N-1}\sum_{i=1}^{N-1}\left(\frac{\theta^i - \theta_C^i}{\sigma_\theta^i}\right)^2$$

Select the sequence with the minimum $\chi^2 < \chi^2_{max}$
➔correct sequence
➔rejects Compton and wrong direction





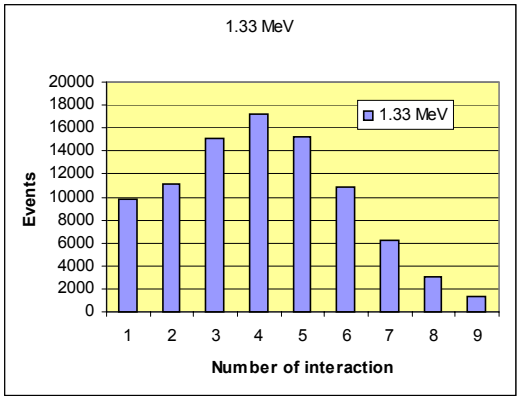


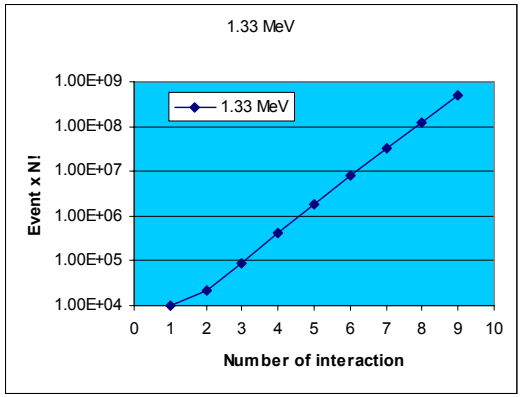
Tracking issues

single γ-ray

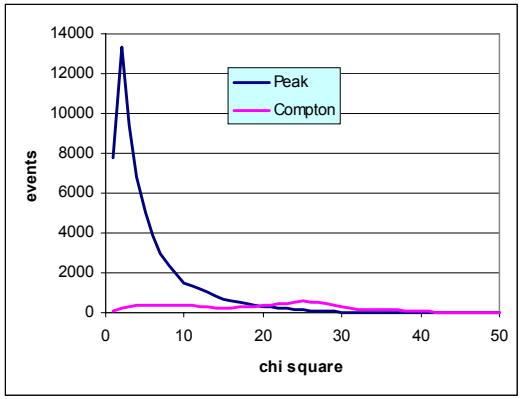
- **Computing time ≈ N!.** Cut off large N events, or better algorithm

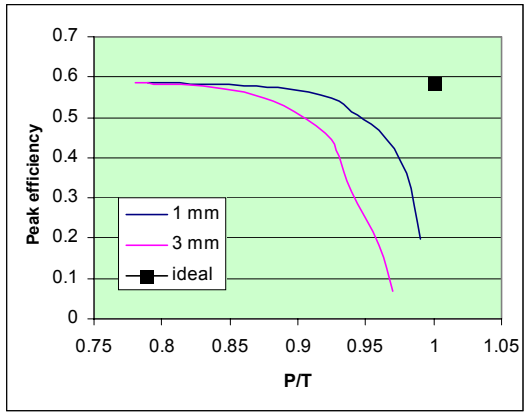
4 ! =	24
8 ! =	40,320
12! =	479,001,600

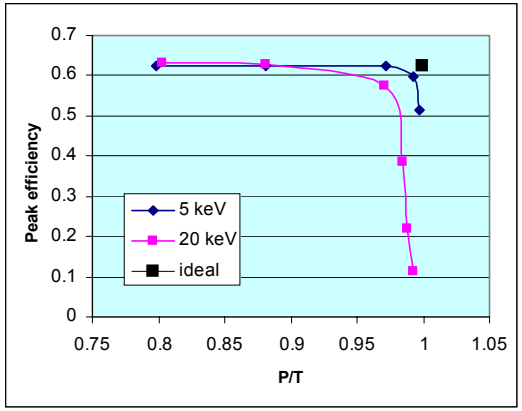




- **Finite position and energy resolutions**. Trade-off efficiency vs. P/T



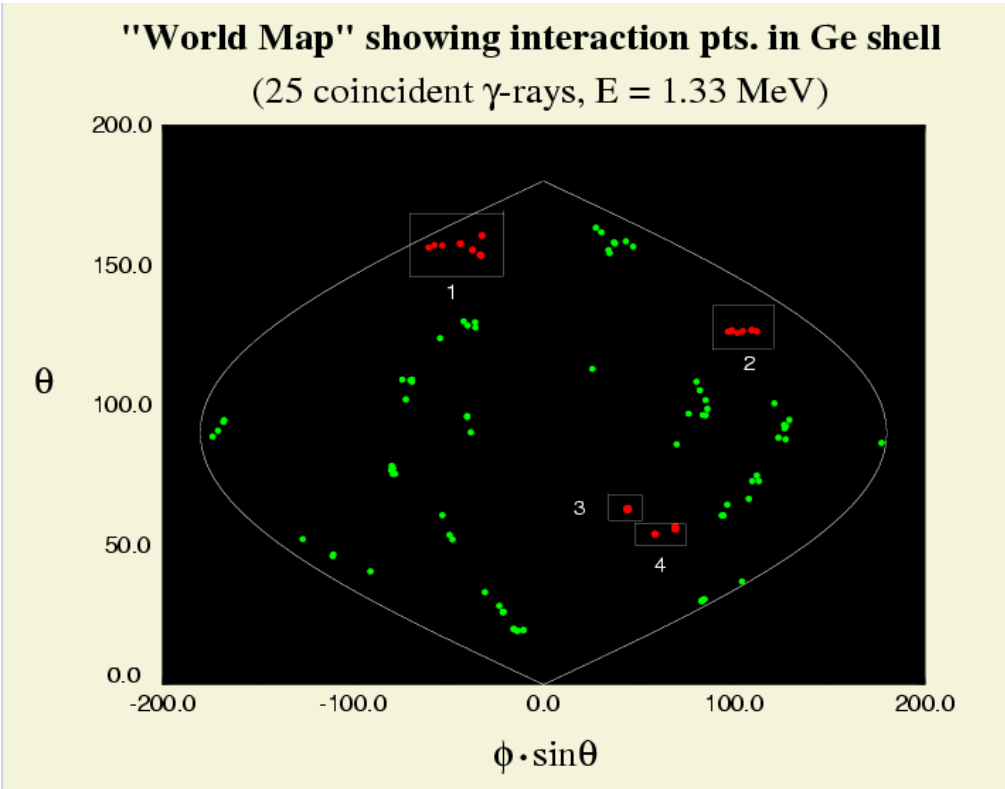


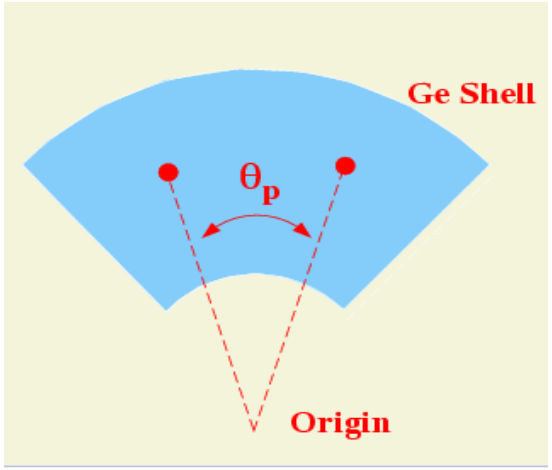


Tracking issues

multiple γ-ray

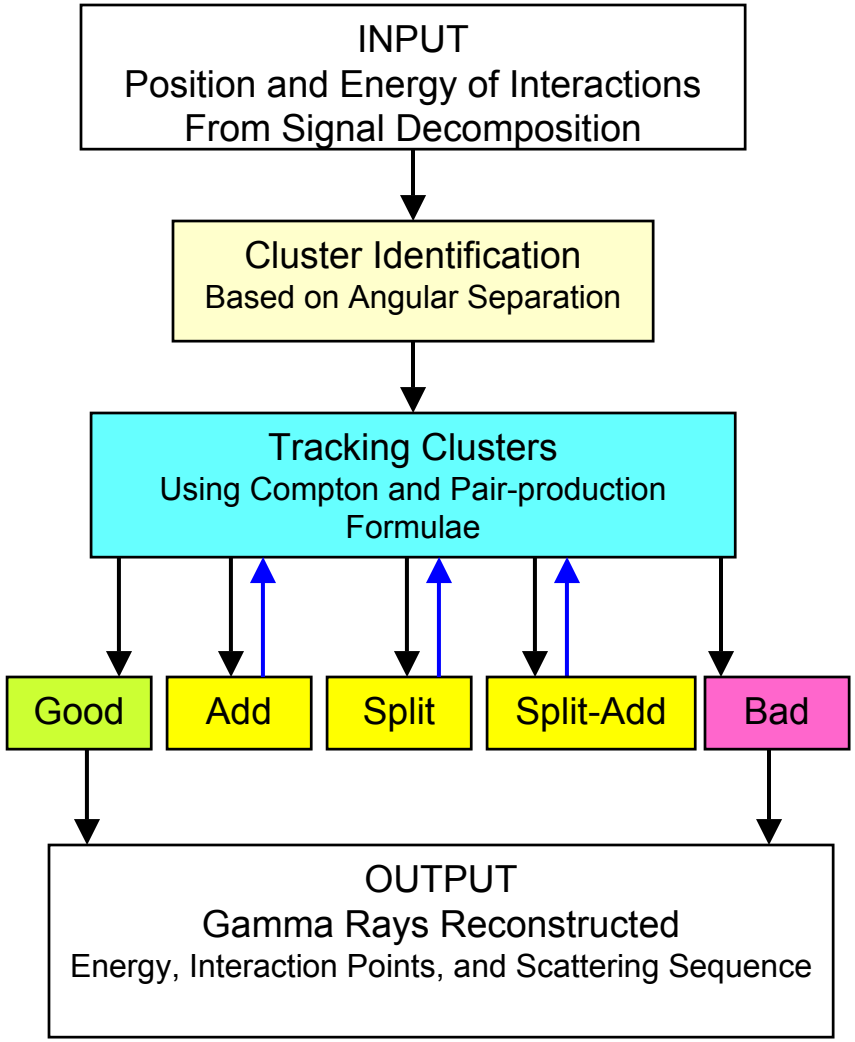
- **First step:** cluster creation





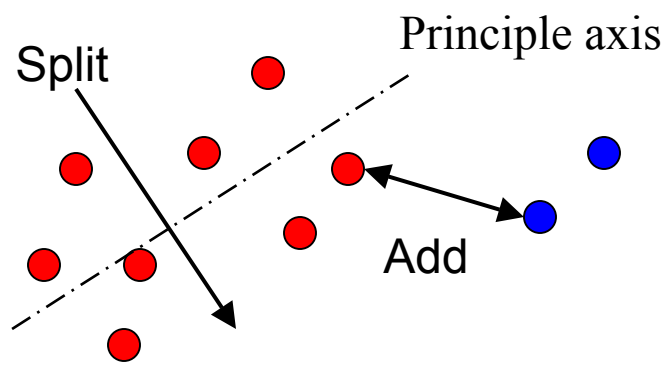
Any two points with θ < θp are grouped into the same cluster

Tracking algorithm



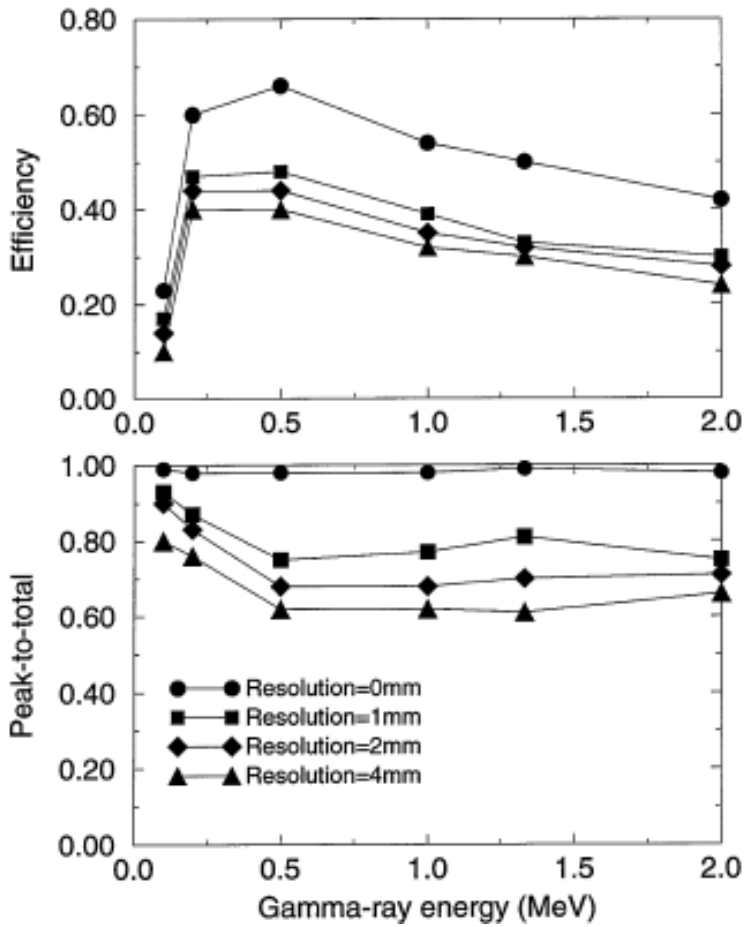
Split Clusters

- Use 3-D position of interactions
- Determine principle axes of cluster moment
- Split cluster perpendicular to the axes

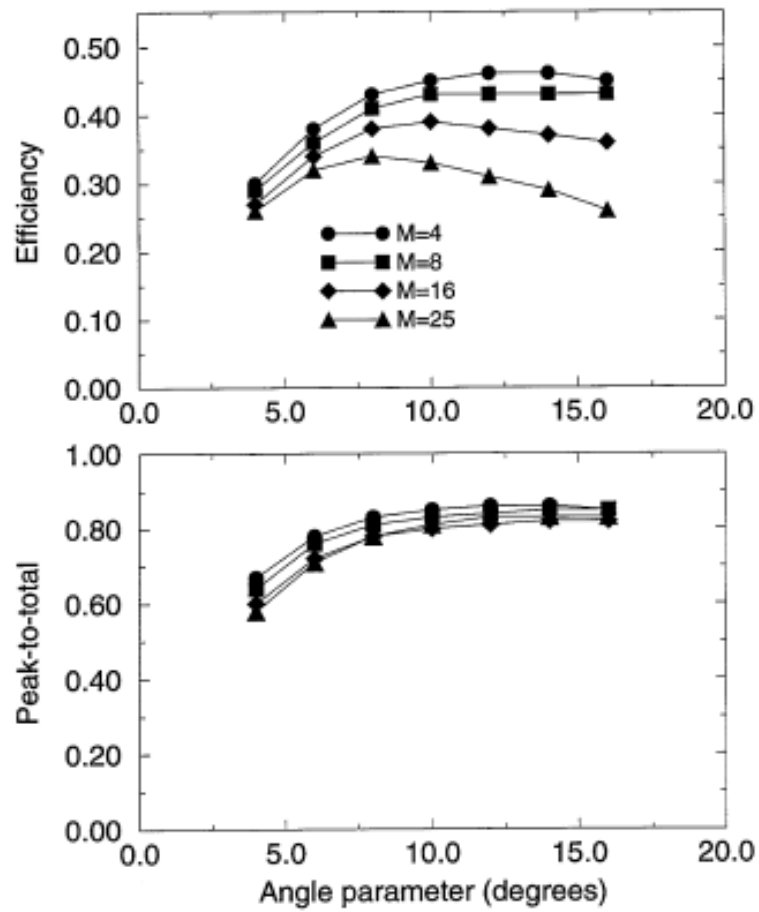


Tracking results

Mγ = 25, α =10°



Eγ = 1.33 MeV, Δr = 1 mm

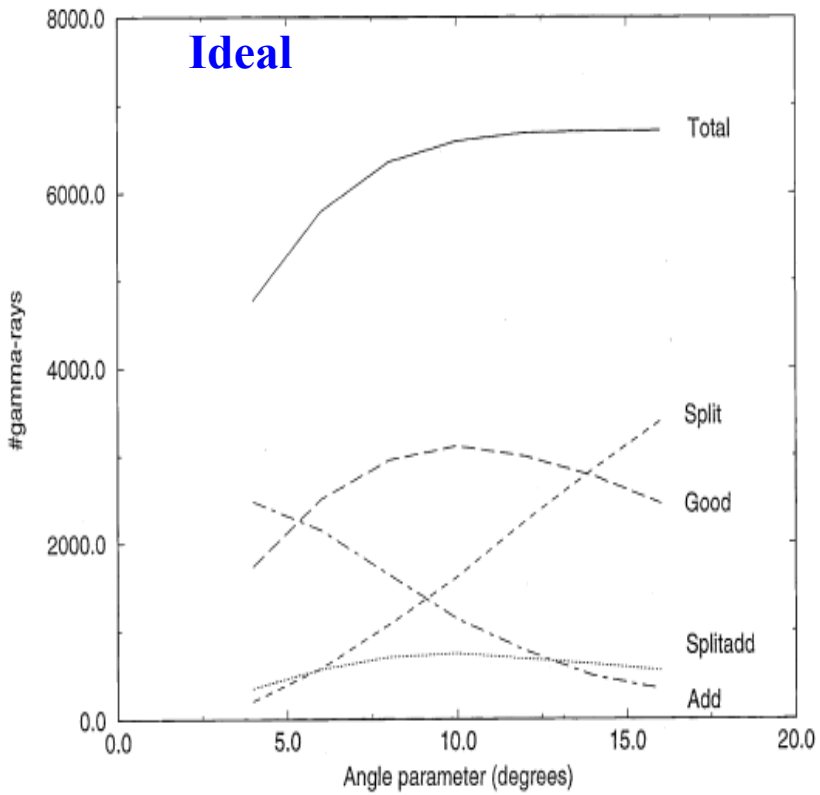


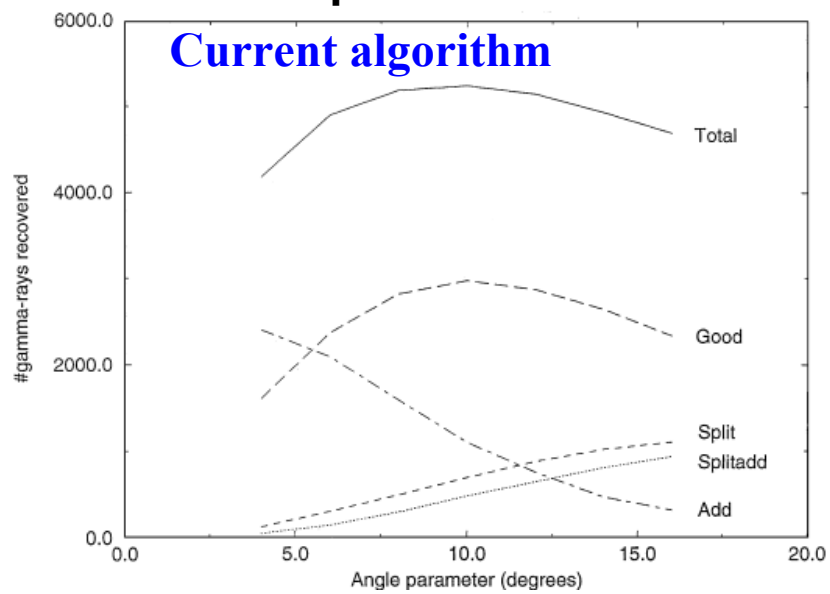
Tracking success rate

$E\gamma$ = 1.33 MeV, $M\gamma$ = 25, Δr = 0 mm

Success Rate
θ_p=10°

Good	100%
Add	96%
Split	44%
Split-add	67%

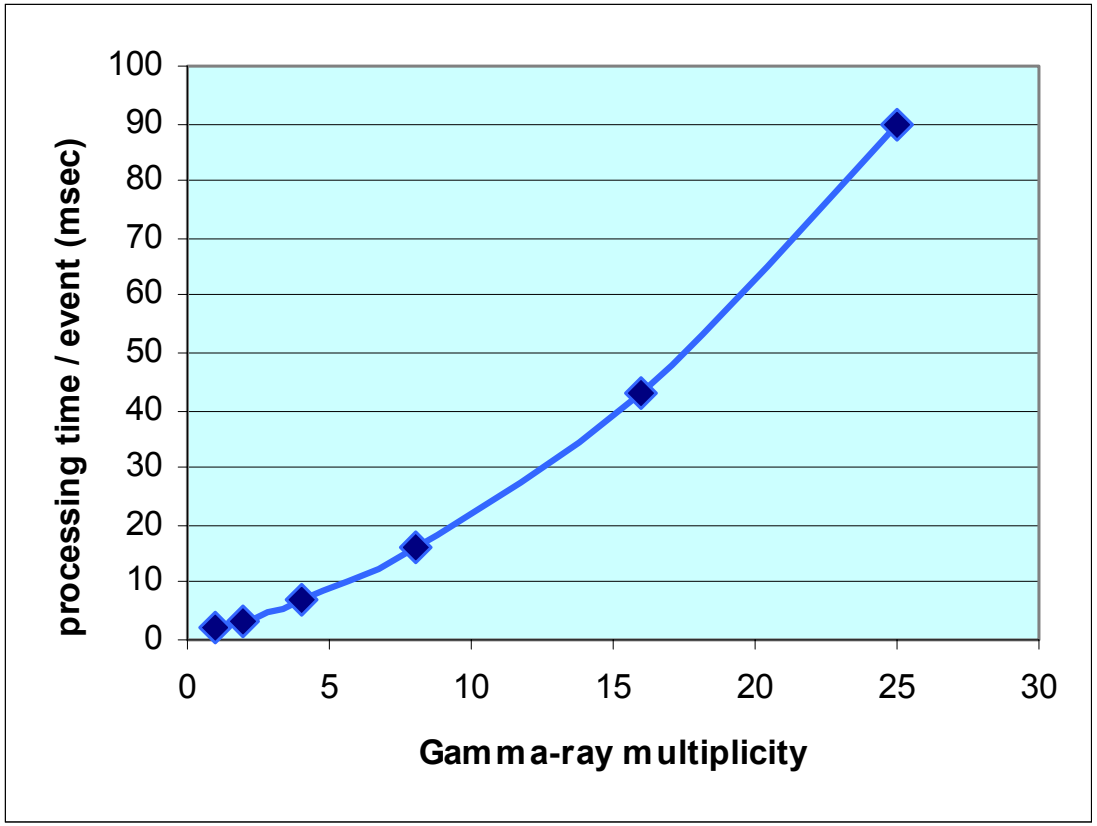




Tracking processing time

E_γ = 1.33 MeV, α = 10°, Δr = 1 mm

75 MHz SUN Sparcstation



Time distribution

For Mγ = 25

Cluster creation	10%
Initial tracking	20%
Add, tracking	30%
Split, tracking	35%
Split-add tracking	5%

For 25,000 γ rays
Need 100 75 MHz processors
= 10 modern processors

Tracking improvements

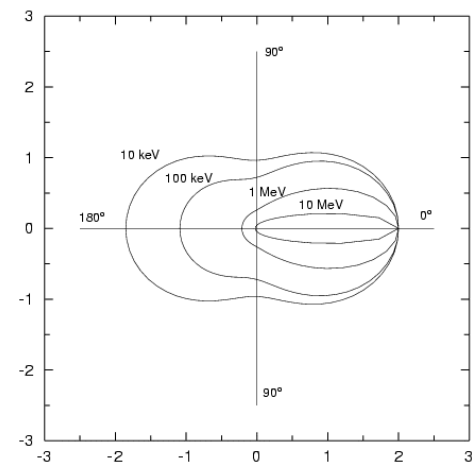
- Improve χ^2
- Speed up tracking
- Improve cluster creation and splitting
- Coupling with signal decomposition
- Correct for range of electron

Tracking improvements

Improve χ^2

- **Use angular distribution information**

$$\frac{d\sigma(\theta)}{d\Omega} = \frac{r_0^2}{2}\left(\frac{E'_\gamma}{E_\gamma}\right)^2\left(\frac{E_\gamma}{E'_\gamma} + \frac{E'_\gamma}{E_\gamma} - \sin^2\theta\right)$$



- **Use absorption length information**

$$\frac{dN}{dx} = \exp(x/a)$$

However, These are probabilistic formulae

Tracking improvements

Speed up tracking

- **Skip bad sequences (implemented)**

If $\chi^2 > \chi^2_{max}$ after the first scattering

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

Skip all permutations with the same sequence

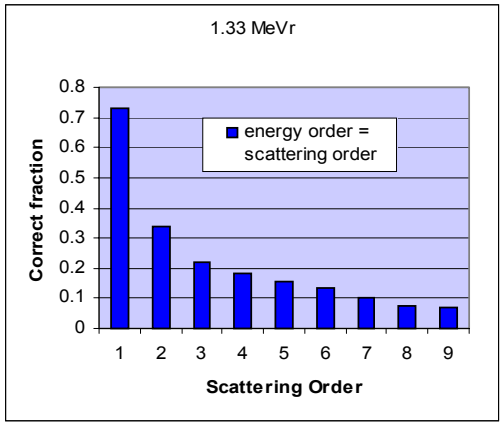
- **Calculate $\chi 2$ using points < total number of interactions (implemented)**

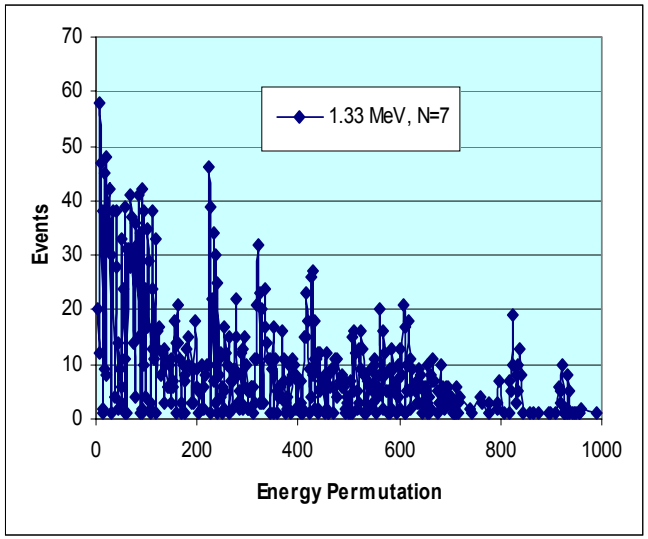
Time is reduced by a factor = N(N-1)(N-2)..(N-M)/N!

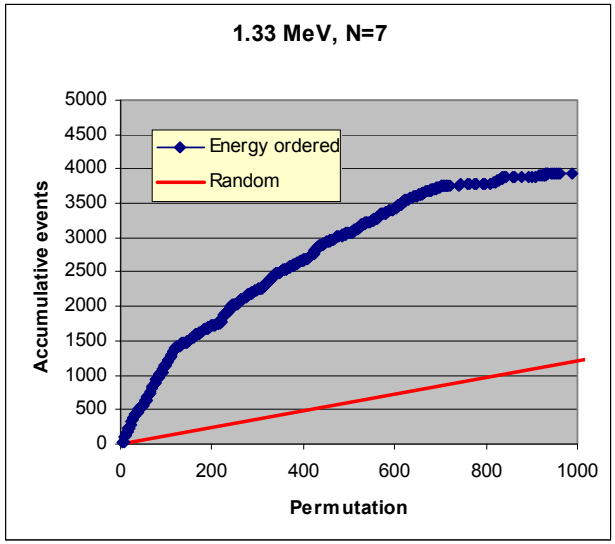
Tracking improvements

Speed up tracking

- Physics based permutation sequence
  - Order interactions by energy
  - Permute low energy points first
  - Examine fewer permutations than N!







1.33 MeV, N=7
7!=5040

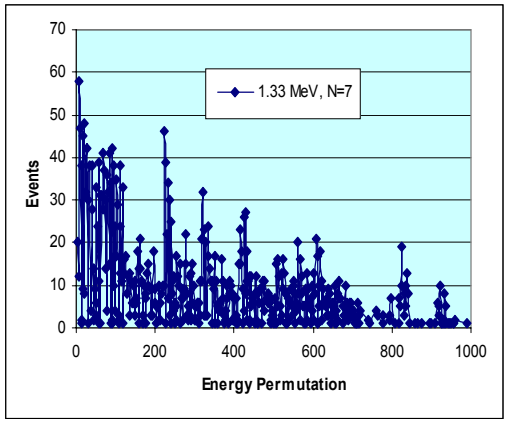
Permu.	Event
5%	33%
10%	50%
15%	62%
20%	65%

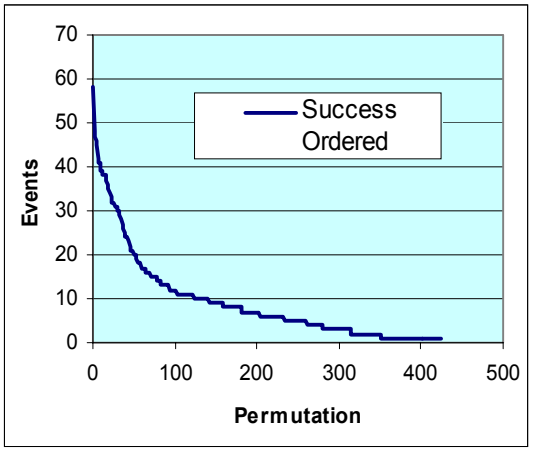
Another possible parameter — radial position of interactions

Tracking improvements

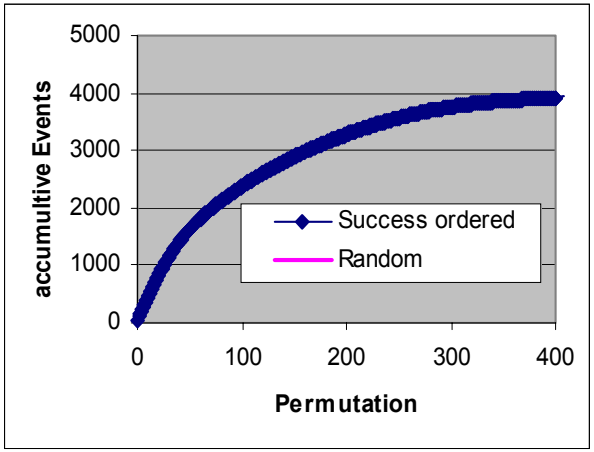
Speed up tracking

- Adaptive permutation sequence
  - Track energy ordered interactions (Learning mode)
  - Arrange permutation by success rate
  - Track with learned order of permutation (production mode)





1	2	3	5	6	7	4
1	2	3	7	5	6	4
1	2	3	5	7	6	4
1	3	2	5	6	7	4
1	2	3	6	5	7	4
1	2	4	5	7	6	3
1	2	6	5	7	4	3
1	2	5	4	6	7	3
1	2	6	4	5	7	3
1	2	5	7	4	6	3



1.33 MeV, N = 7

7! = 5040

Permu.	Event
3.4%	50%
5.0%	59%
7.0%	64%
8.4%	65%

Tracking improvements

Improve cluster creation and splitting

- Use physical properties of clusters in additional to geometrical information:
  - Number of interaction as a function of energy
  - Energy distribution of interactions
  - Use a learning algorithm

Tracking improvements

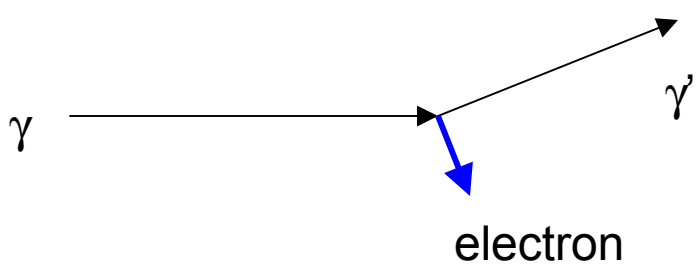
Coupling with signal decomposition

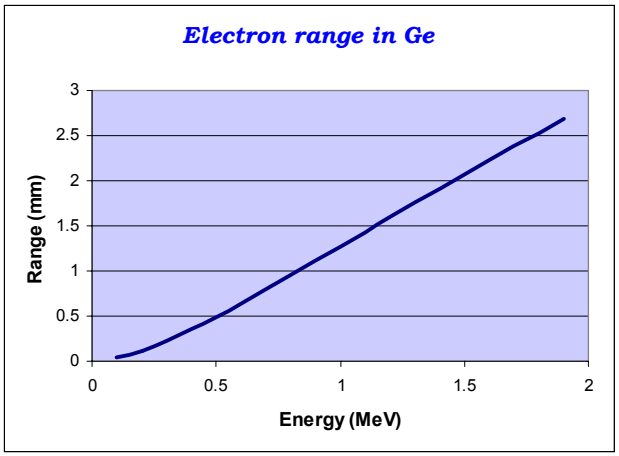
- Receive several possible decomposition results for a given event.
- Use tracking to determine the best set of interactions. (e.g. 1 point vs. 2 closely spaced points).

Tracking improvements

Correct for the finite range of electron

- The "position of the interaction" given by the signal decomposition is the centroid of the electron energy lost distribution.
- Tracking determines the direction and the magnitude of the electron velocity.
- Determine the correct position of interaction using the dE/dx of the electron.





Summary

- Current version of tracking algorithm can achieve 50% tracking efficiency for $M_\gamma = 25$ events.
- 10 current generation processors can handle 25,000 γ ray per second.
- Many opportunities exist for efficiency and speed improvement, especially in separation of overlapping clusters.