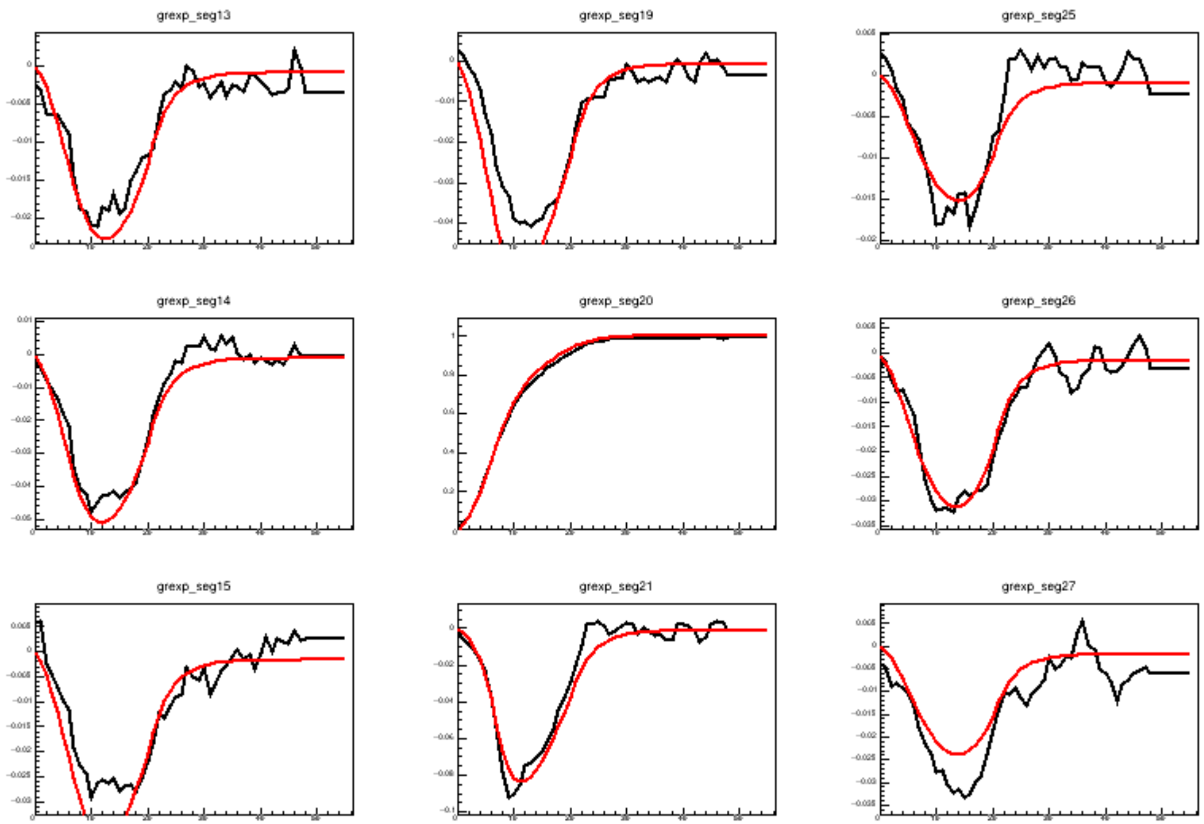
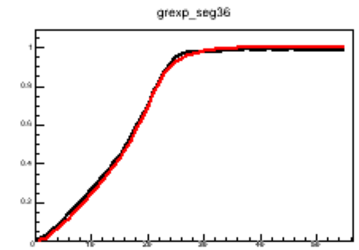
Exercise 3: Pulse-shape analysis (using chi2 minimisation)



The text file contains:

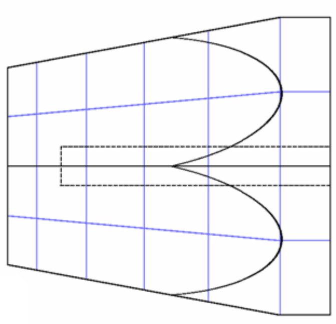
- in the 2nd column the recorded waveforms in 9 neighboring segments and the CC for a single measured event
- in columns 3rd - 11th it has the same information for 9 pre-calculated basis points

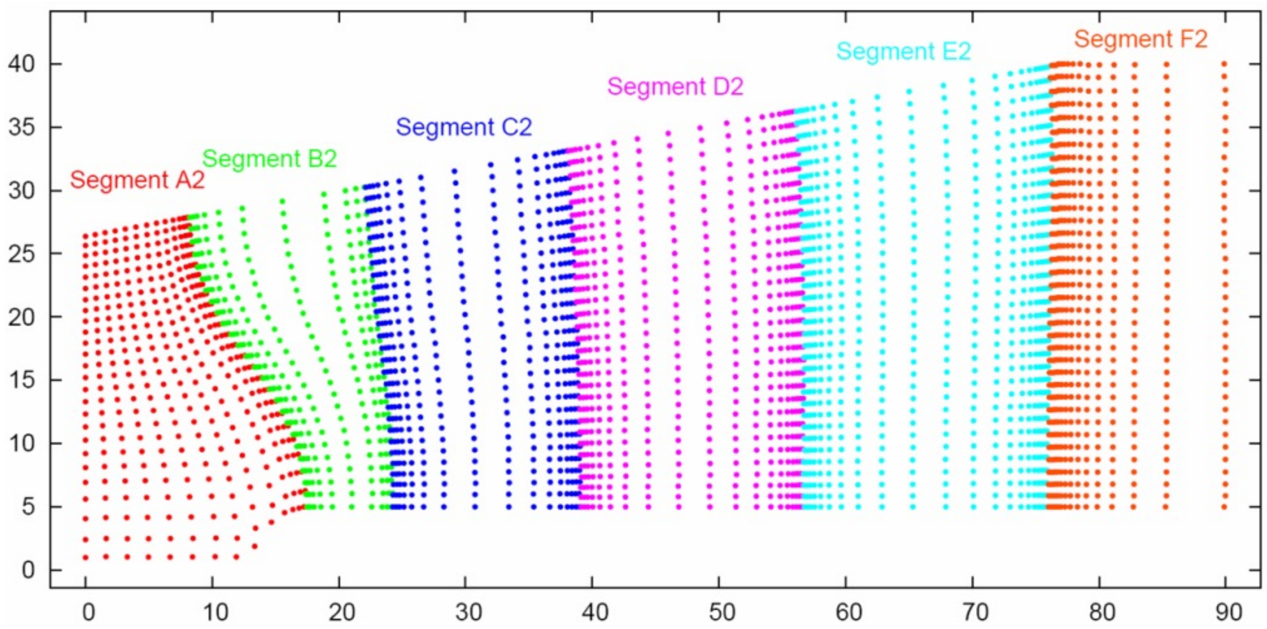


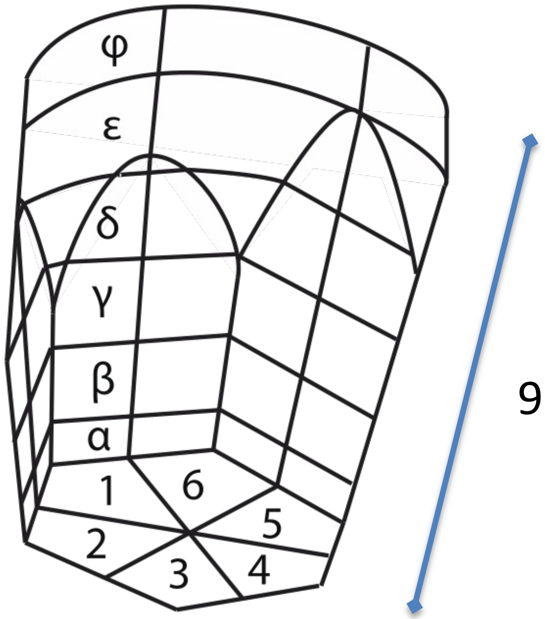
Compare the traces and extract the x, y, z interaction position (from the corresponding basis points) that gives the best-fit to the recorded data

Prepared by Sidon Chen

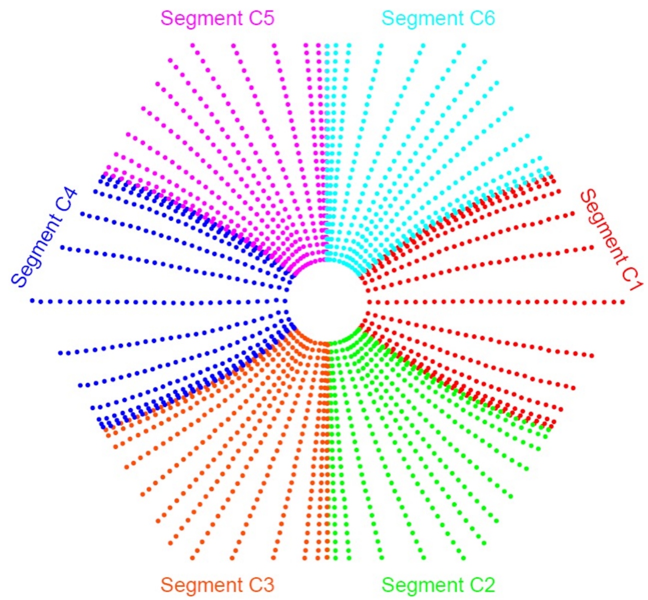
A realistic basis



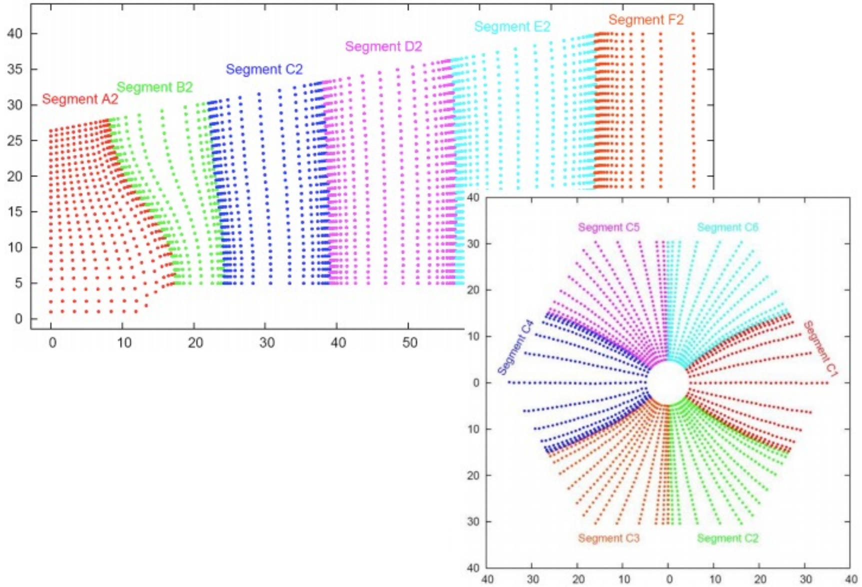


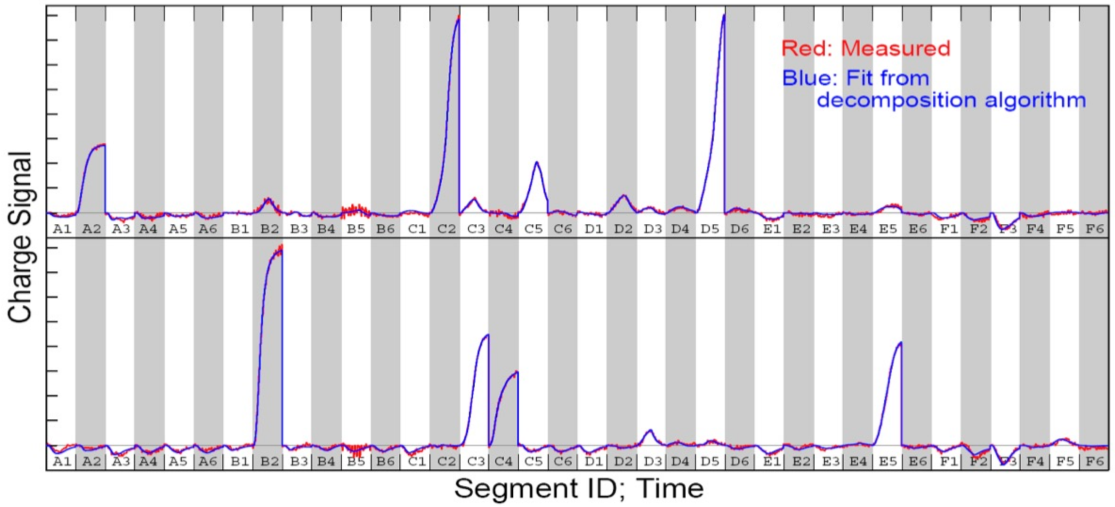


9 cm

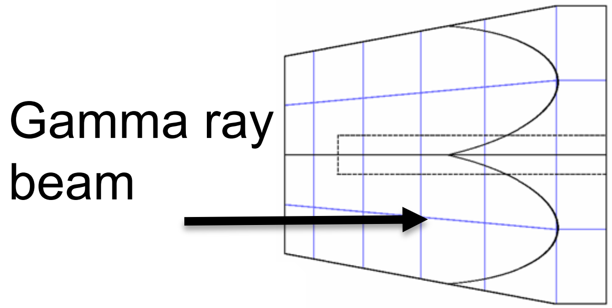


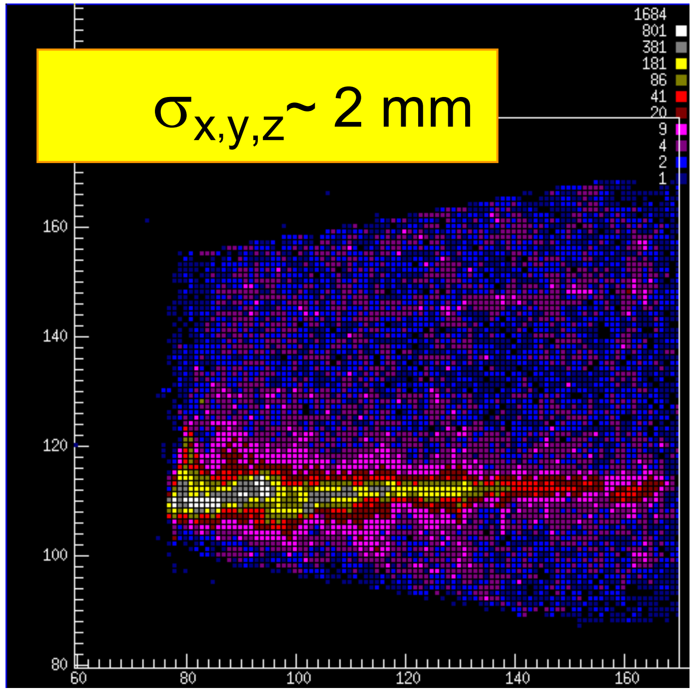
A realistic position reconstruction





Collimated source of ^{137}Cs 662 keV

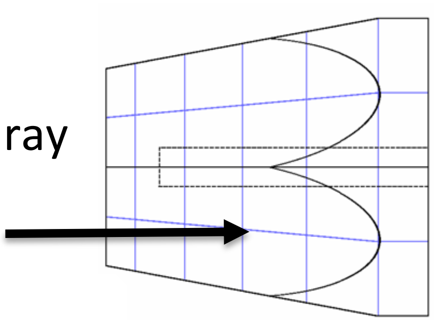




Position resolution

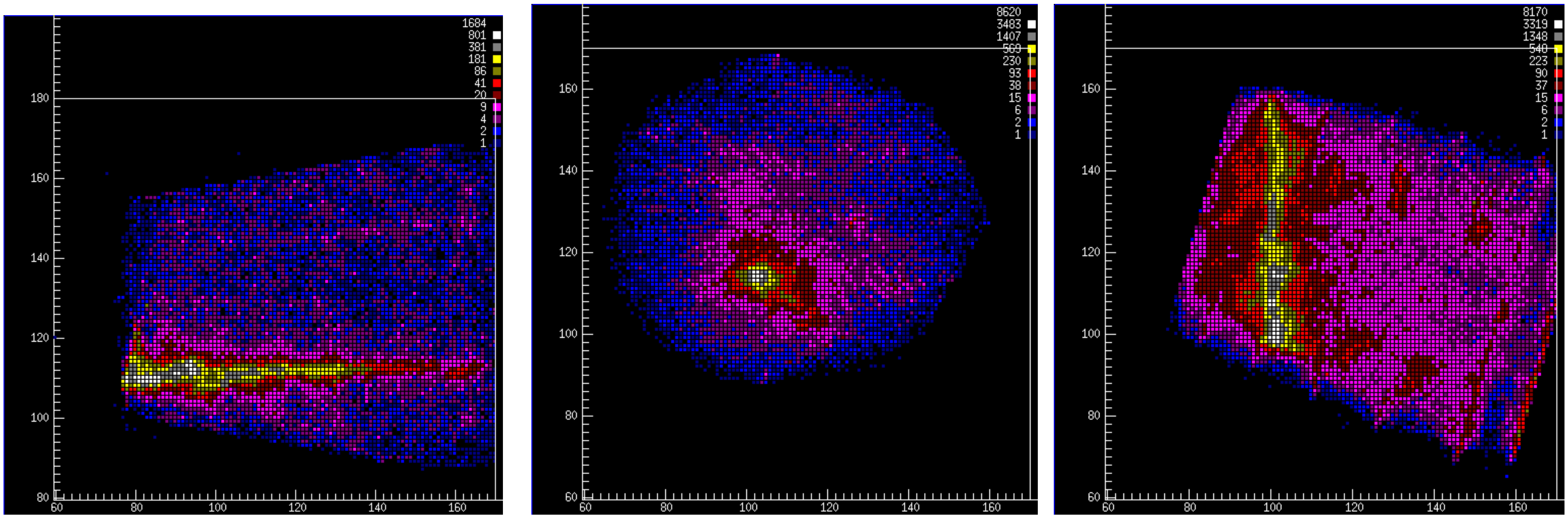
- Collimated beam of ^{137}Cs 663 keV
- Highest energy point from signal decomposition

Gamma ray beam



singles

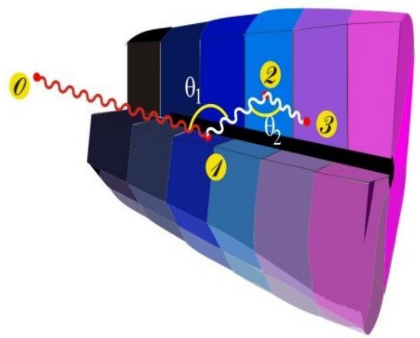
$\sigma_{x,y,z}$~ 2 mm



Gamma–Ray Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

Identified interaction points

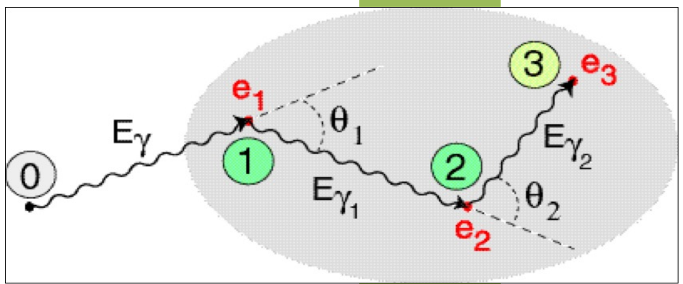
$(x,y,z,E,t)_i$

Pulse Shape Analysis to decompose recorded waves

3

4

Reconstruction of tracks evaluating permutations of interaction points



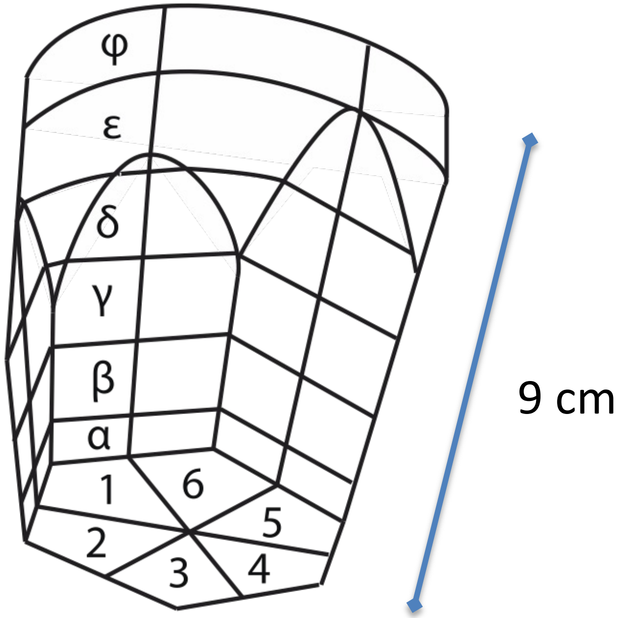
Reconstructed gamma-rays

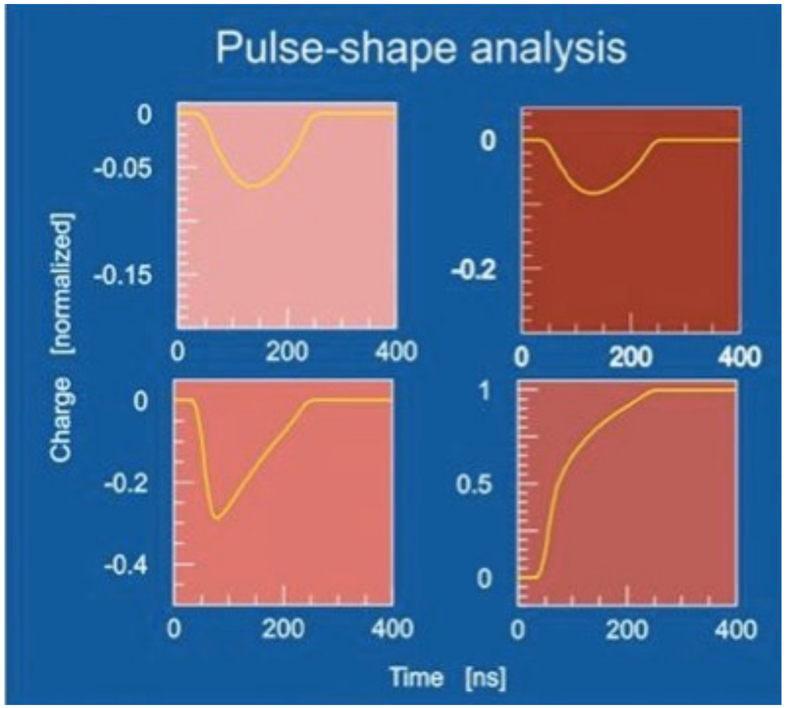
Gamma-ray tracking:
Principle of operation

A 3D position sensitive Ge detector

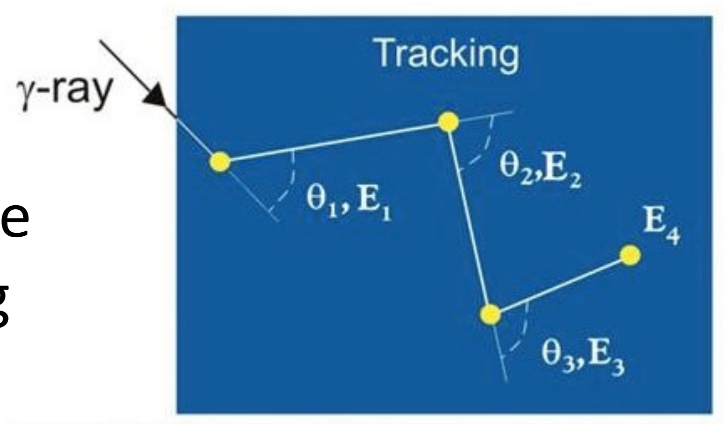
- Electrically segmented
- Pulse shape analysis

of position sensitive signals





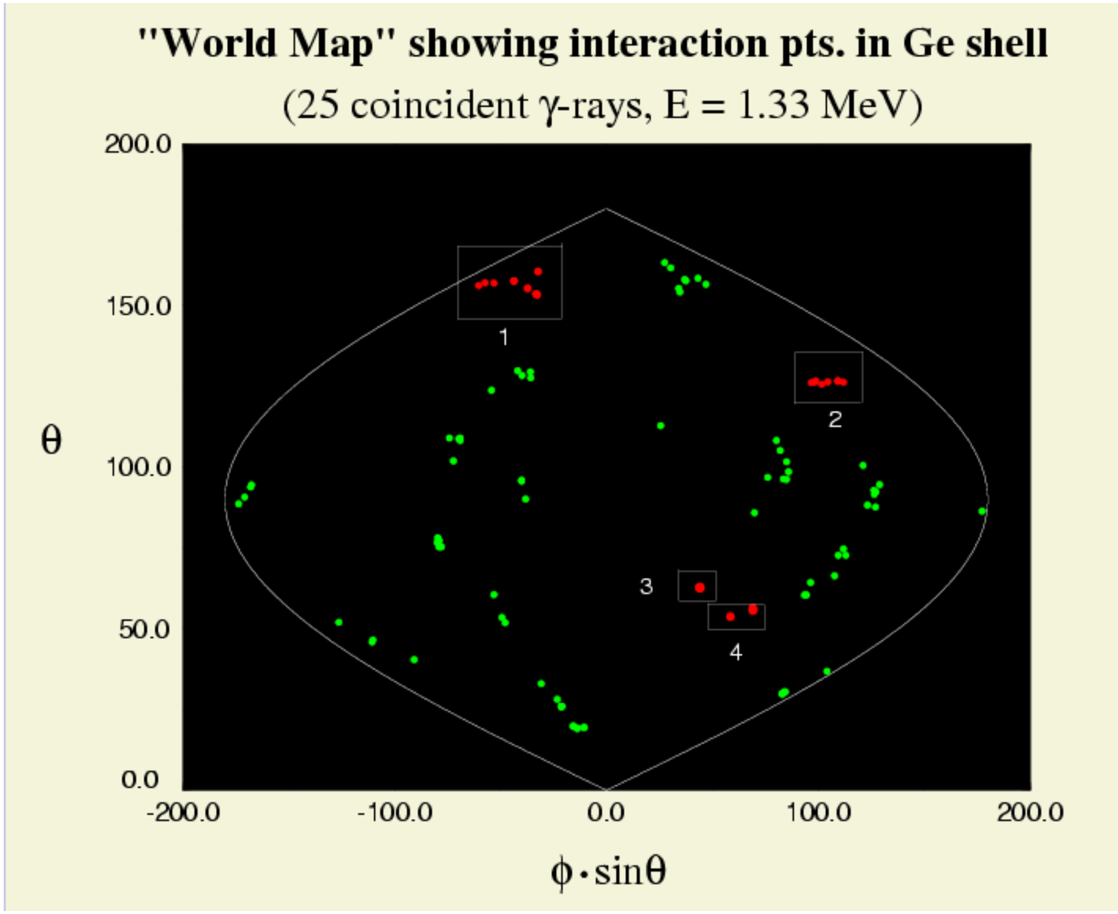
Determine interaction points

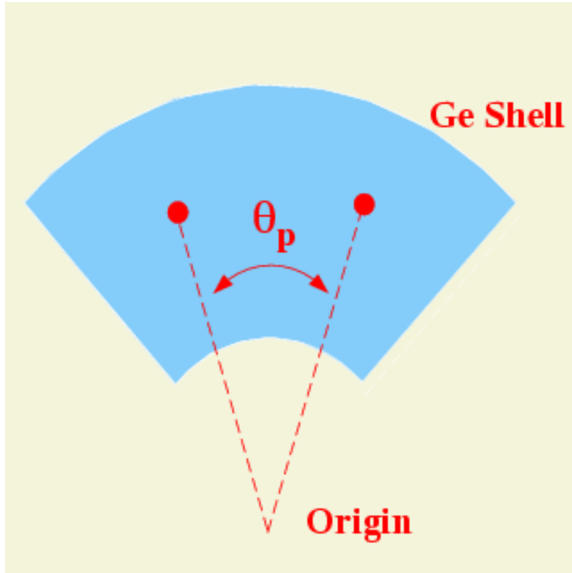


Determine scattering sequence

Tracking: clustering

First step in tracking is to find clusters of interaction points which likely belong to a single γ-ray scattering in the detector – based on opening angle into the Ge shell



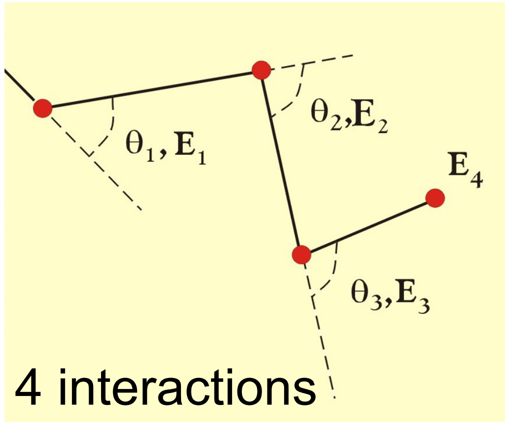


Any two points with $\Delta\theta < \theta_p$ are grouped into the same cluster. The process is repeated for every new point that joins the cluster

(Forward) Tracking

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_0 c^2}(1 - \cos(\theta))}$$

E_γ

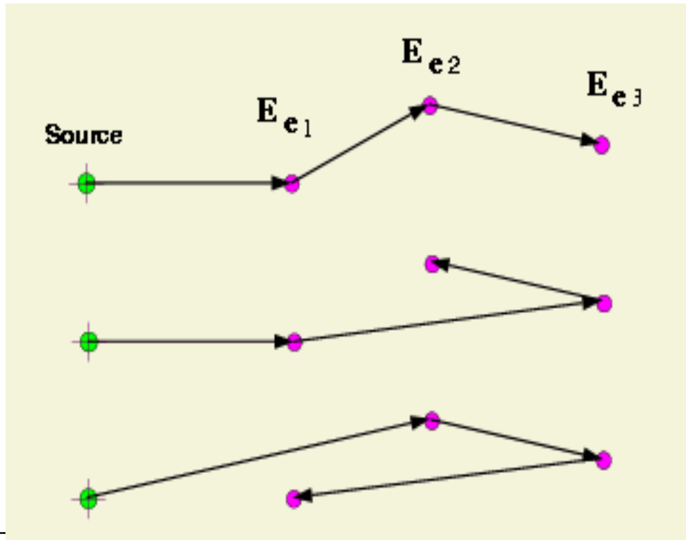


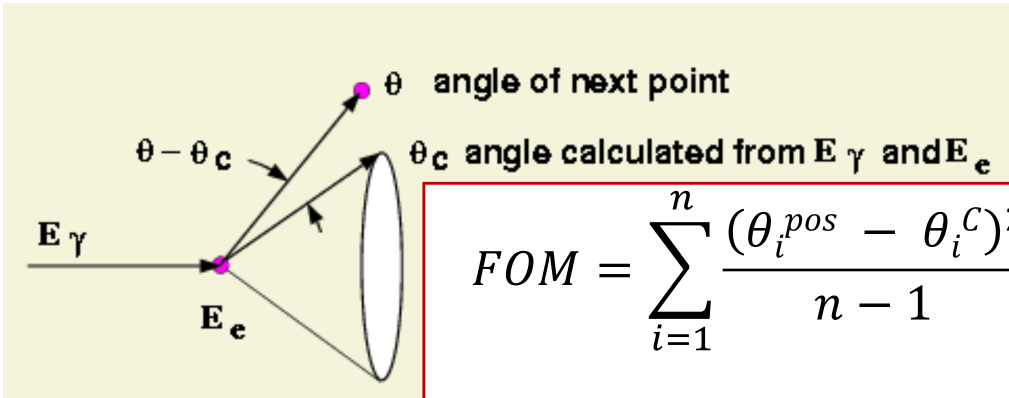
4! = 24 possible sequences

$$E_e = E_\gamma \left(1 - \frac{1}{1 + \frac{E_\gamma}{0.511}(1 - \cos\theta)} \right)$$

Assume:

- $E_\gamma = E_{e1} + E_{e2} + E_{e3}$
- γ-ray from the source

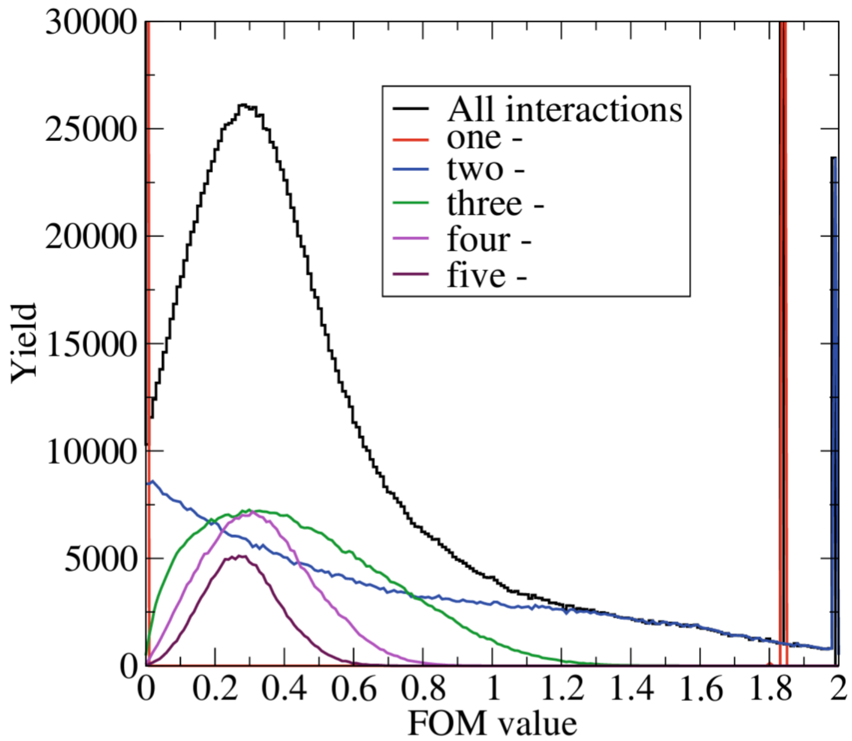


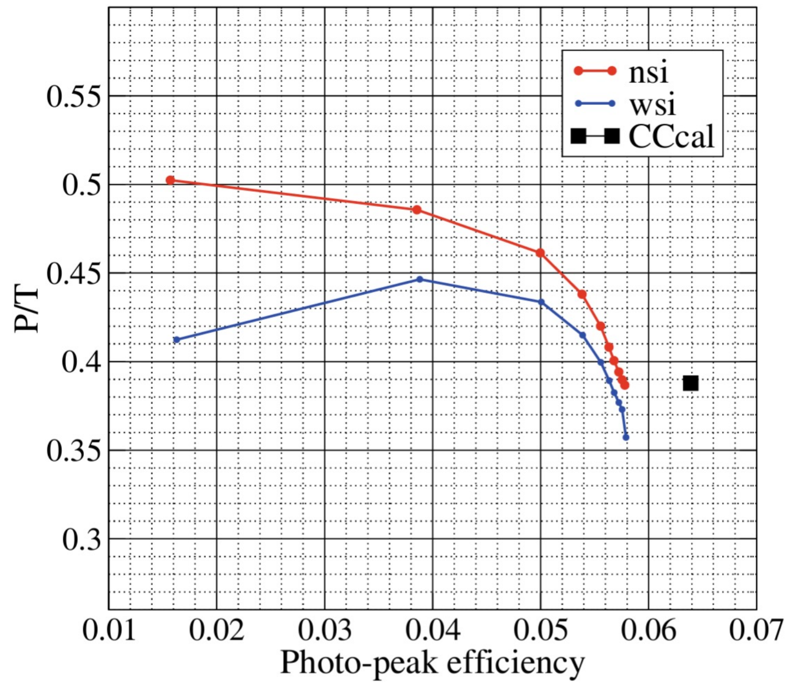


$$FOM = \sum_{i=1}^{n} \frac{(\theta_i^{pos} - \theta_i^{C})^2}{n-1}$$

Sequence with the minimum FOM:
→ chosen as correct scattering sequence
→ rejecting escaped (Compton) and wrong direction

The tracking Figure of Merit (FOM) “cut” and the “tradeoff”



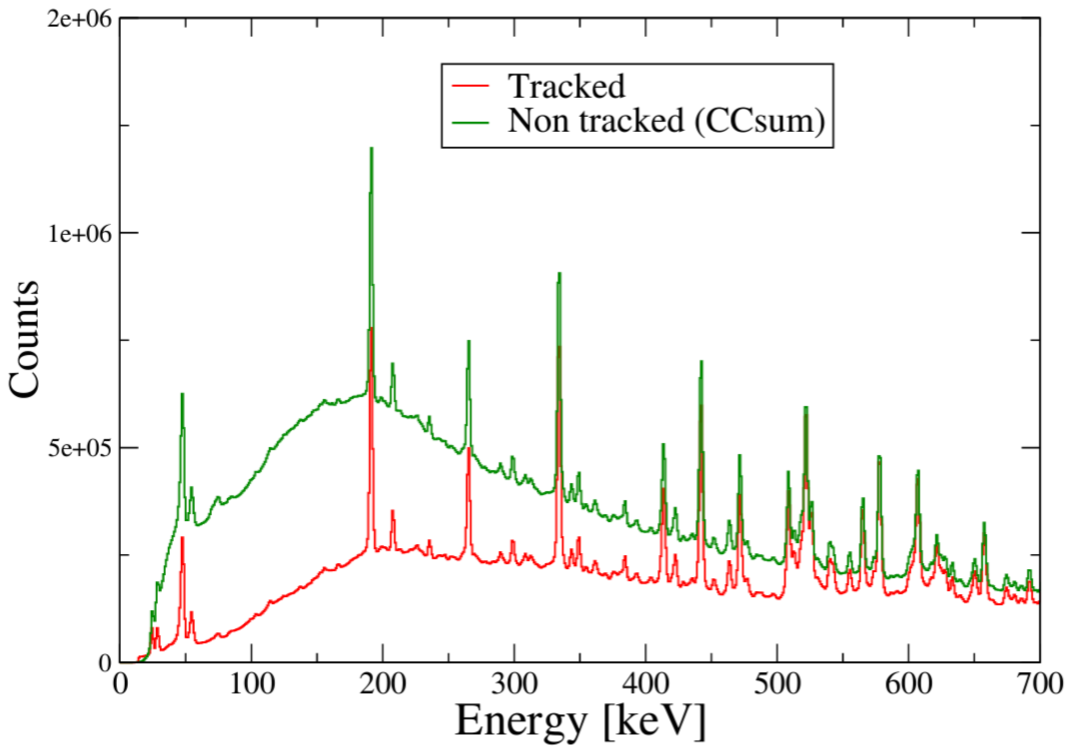


$$FOM = \sum_{i=1}^{n} \frac{(\theta_i^{pos} - \theta_i^{C})^2}{n-1}$$

The curves are provided for a range of FOM cuts from 0 to 0.2, 0.4, 0.6, ... 1.8, 2.0.
The lower curve includes single interactions (wsi) and the upper one is obtained without these interactions (nsi).

Korichi and T. Lauritsen, EPJ A (2019) 55: 121

Example of tracked and non tracked ^{158}Er source spectrum



Experimental data

Exercise 4: γ-ray tracking

A Geant4 simulation assumes a 2MeV gamma-rays emitted from 0.5c moving particles, and detected by 4Pai-AGATA array.

1,000,000 events are simulated.

The analysis is performed with OFT tracking and the Doppler correction is applied.

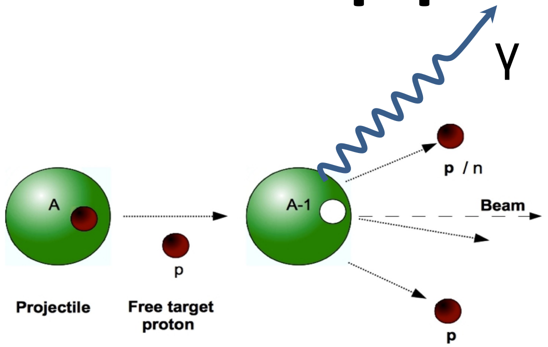
The branches in the tree are:

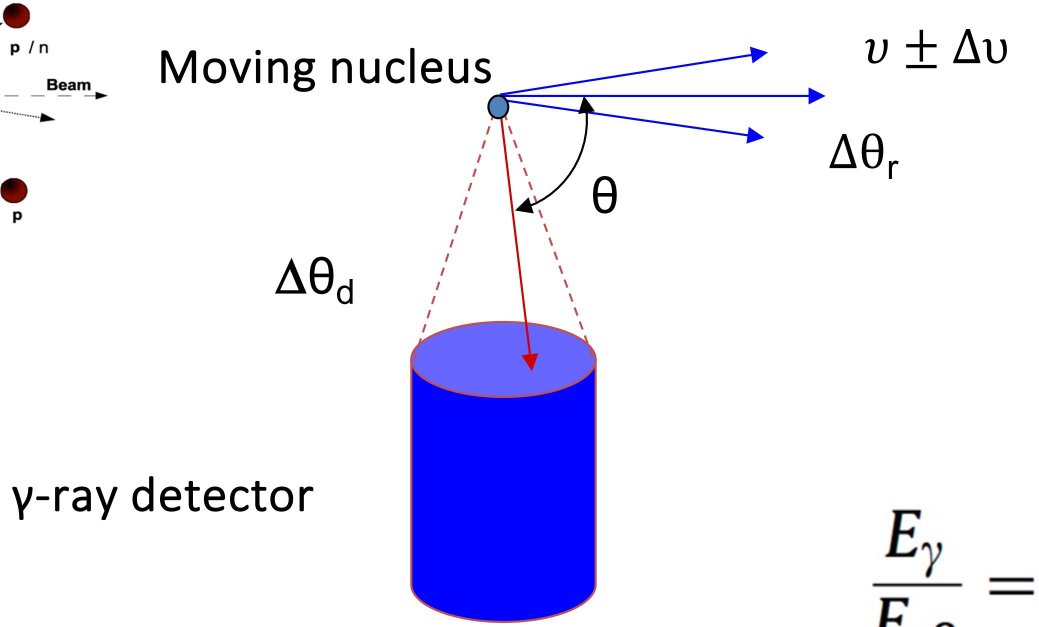
- **EntryID**: event id in simulation
- **Energy**: gamma energy without Doppler correction
- **EDopp**: gamma energy with Doppler correction (use this one)
- **FOM**: in the OFT tracking, the FOM is calculated as the probability, so large FOM means good tracking (opposite definition than in the slide above but same principle)
- **ninter**: number of interactions in one event

→ Task: Use the ROOT file to estimate the efficiency vs P/T for different FOM cuts.

Prepared by Sidon Chen

Doppler shift and broadening



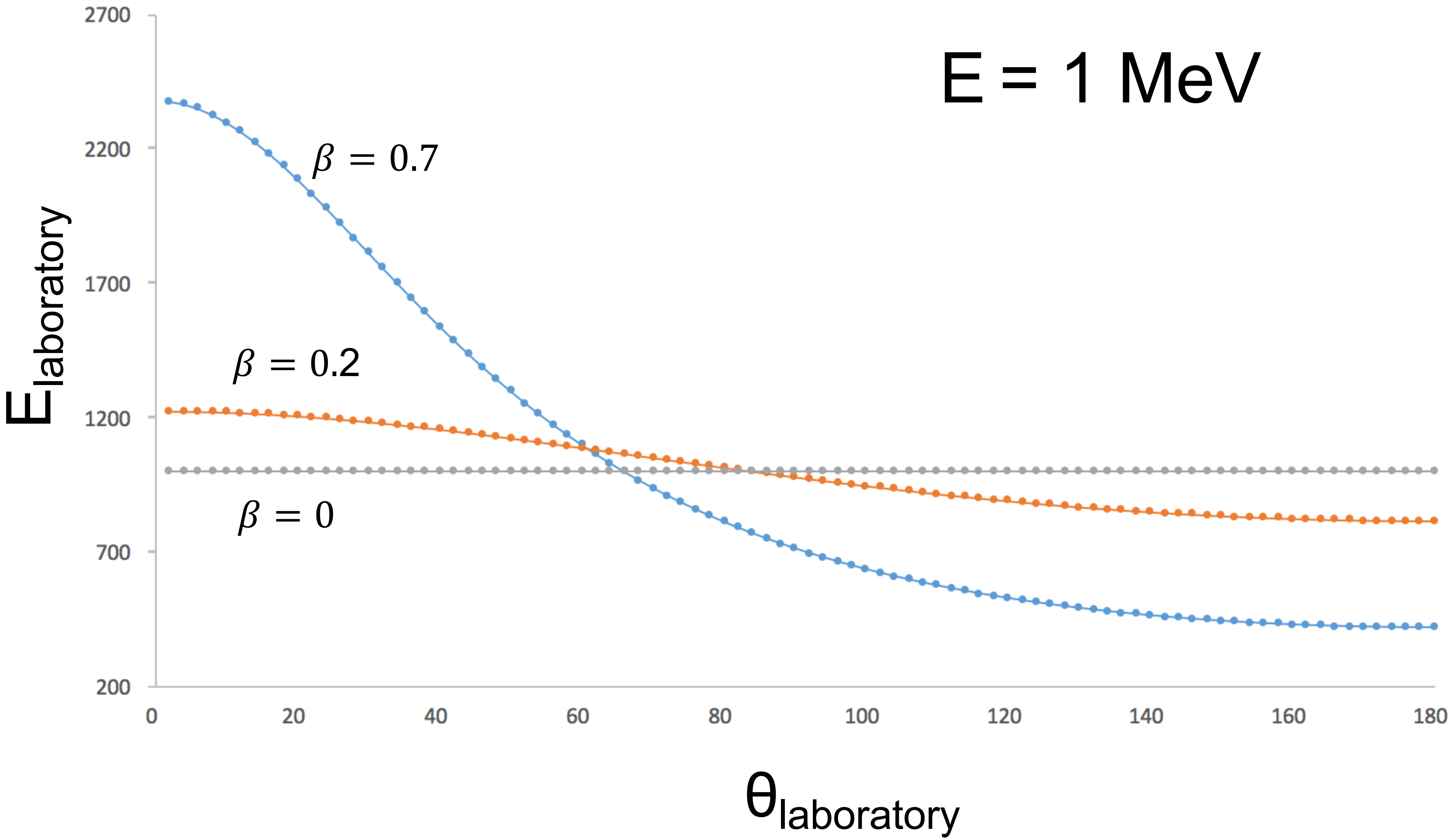


$$\frac{E_\gamma}{E_{\gamma 0}} = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\vartheta_\gamma}$$

Broadening of detected gamma-ray energy due to:

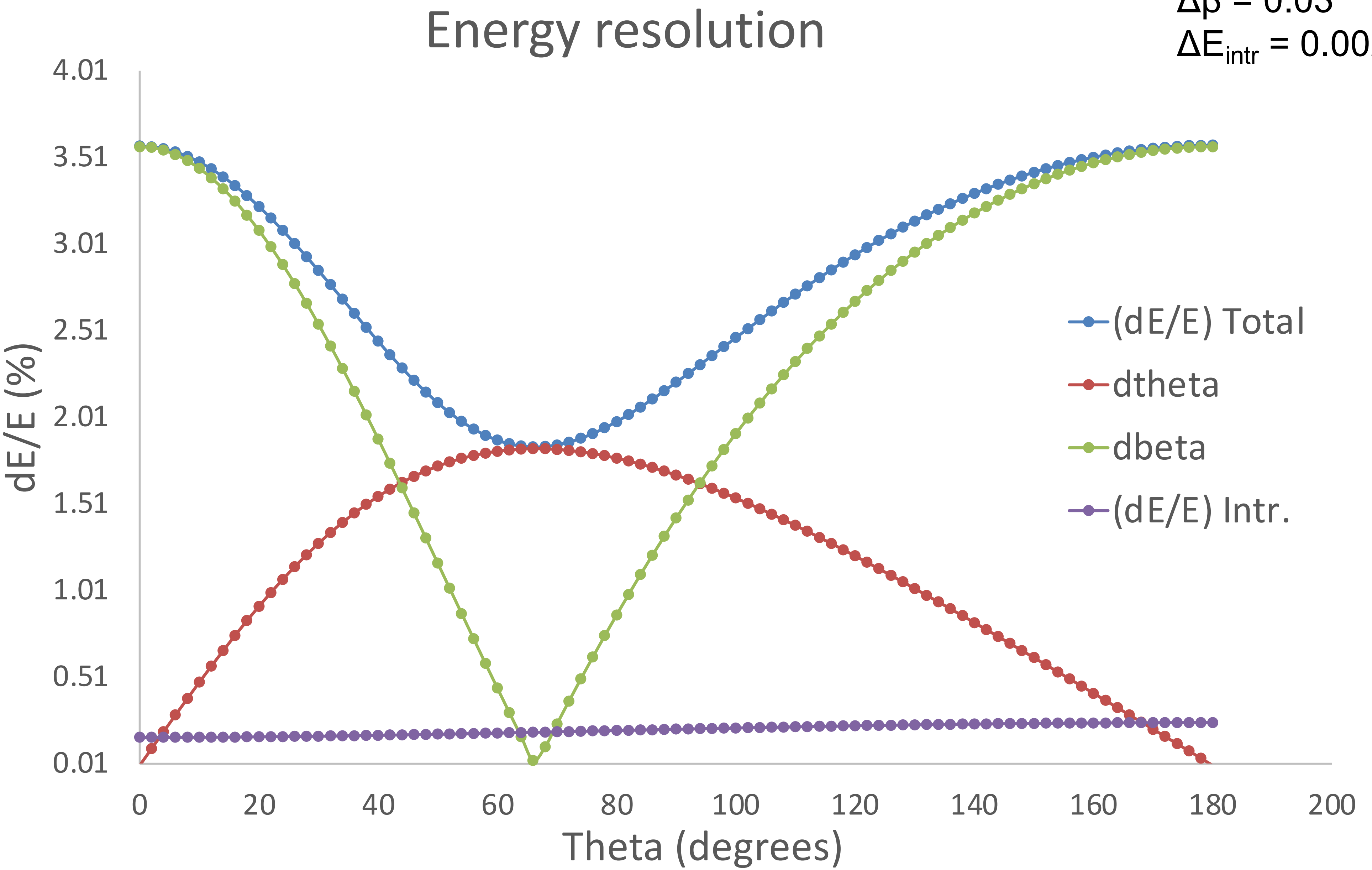
- velocity change in target (unknown interaction depth), momentum spread
- Δθ due to opening angle detector and trajectory of nucleus

Doppler Shift

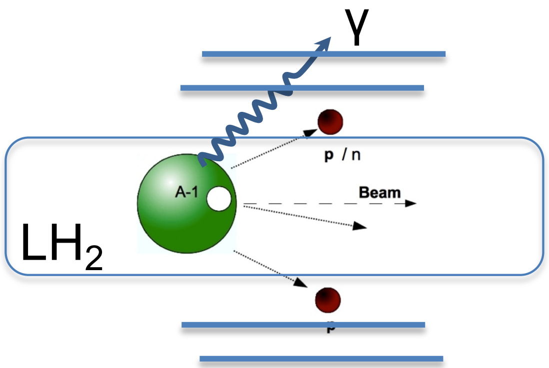


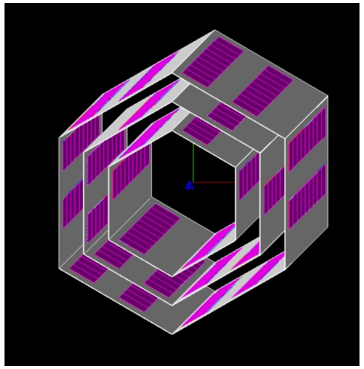
Doppler Broadening

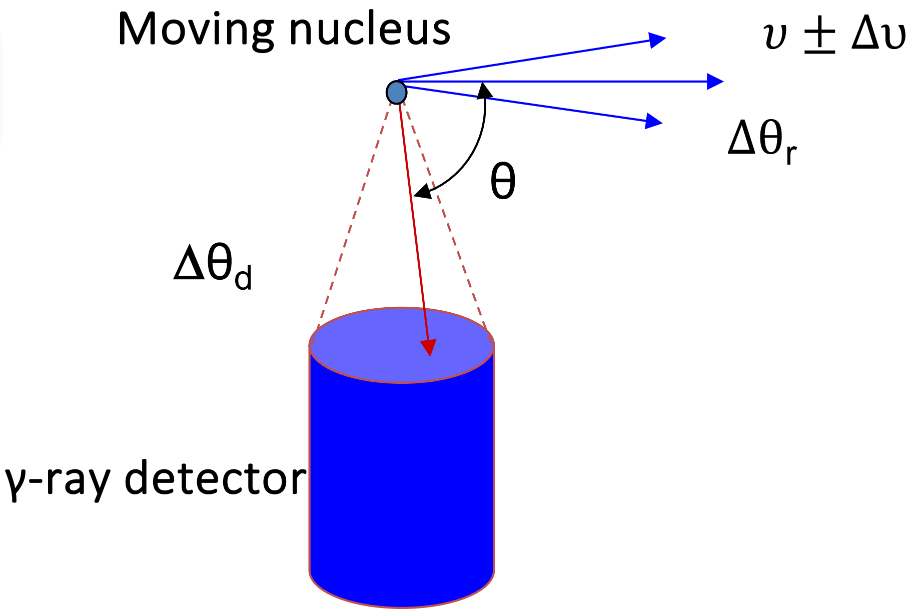
$\beta = 40\%$
$\Delta\theta = 2.4^o$
$\Delta\beta = 0.03$
$\Delta E_{intr} = 0.002$

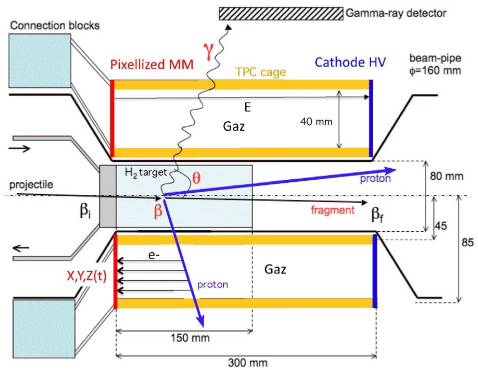


Doppler Broadening







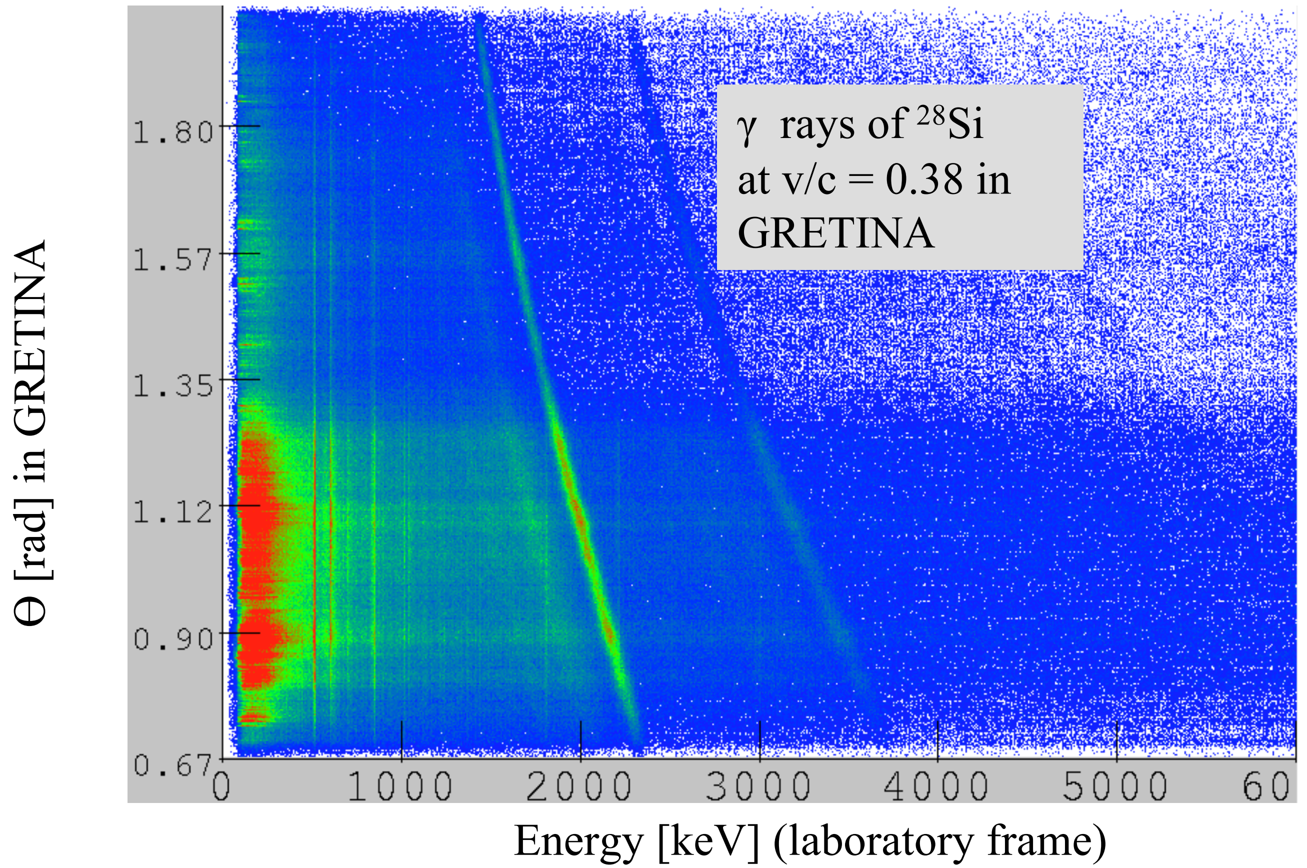


Broadening of detected gamma-ray energy due to:

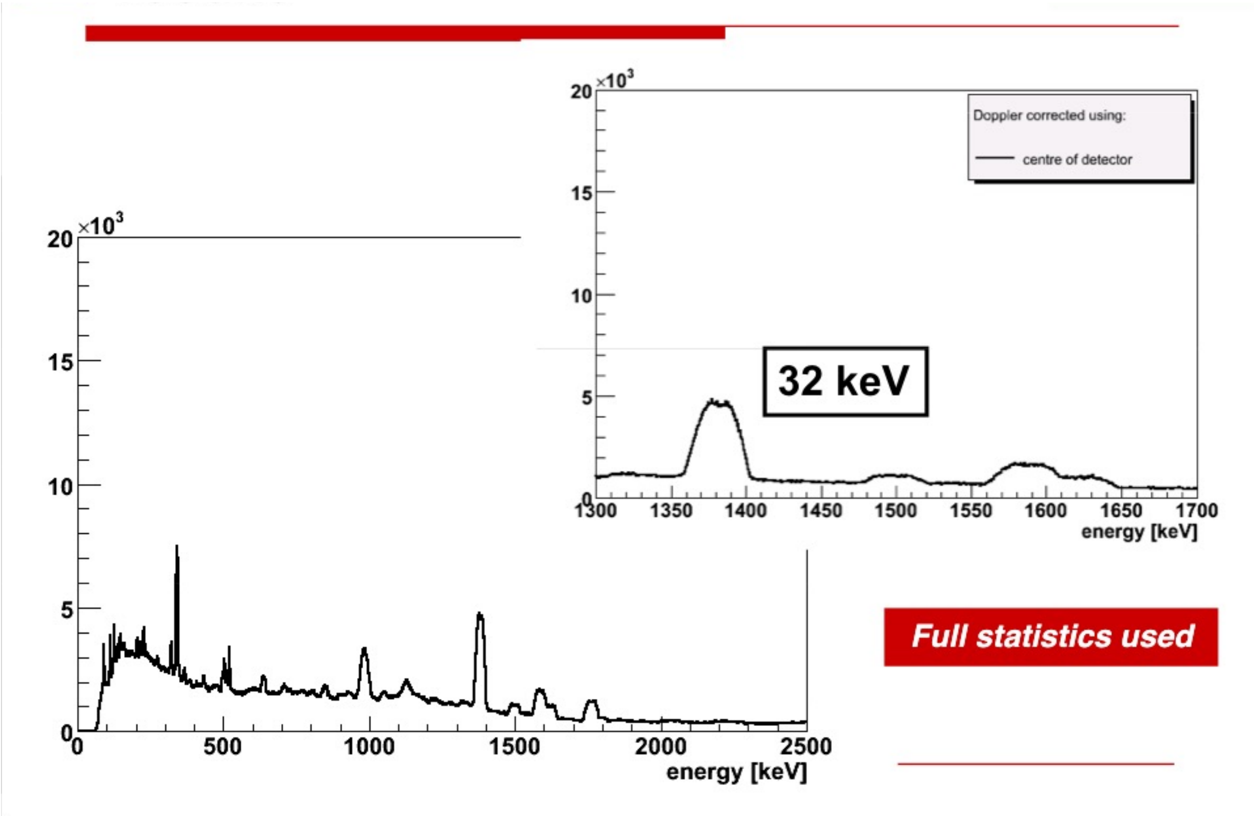
- velocity change in target (unknown interaction depth), momentum spread
  - E.g. thin target (or MINOS)
- Δθ due to opening angle detector and trajectory of nucleus
  - E.g. position resolution of gamma-ray detector and Spectrometer/detector

- **11007**—Weisshaar, D. et al. Commissioning of GRETINA + S800 at NSCL

^{28}Si from ^{36}Ar on 47 mg/cm^2 Be v/c = 0.38

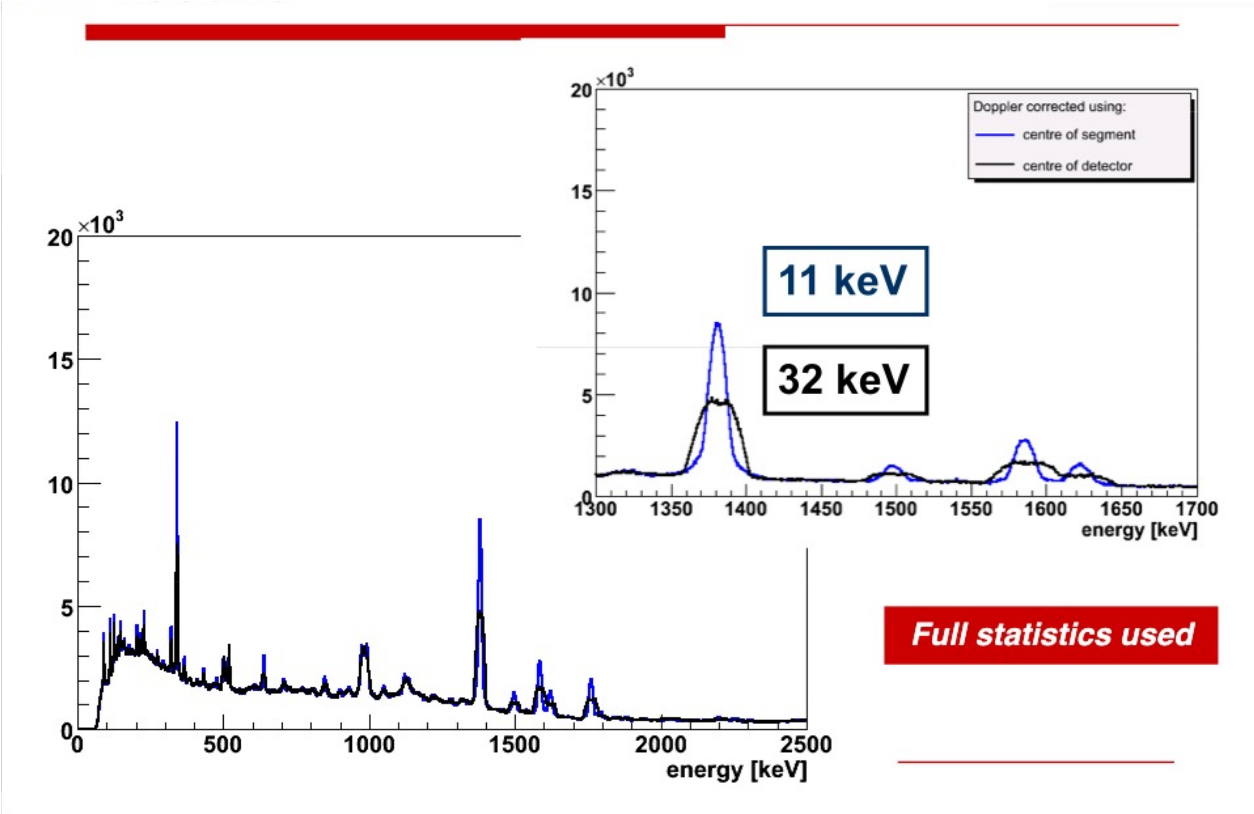


Doppler correction using position information



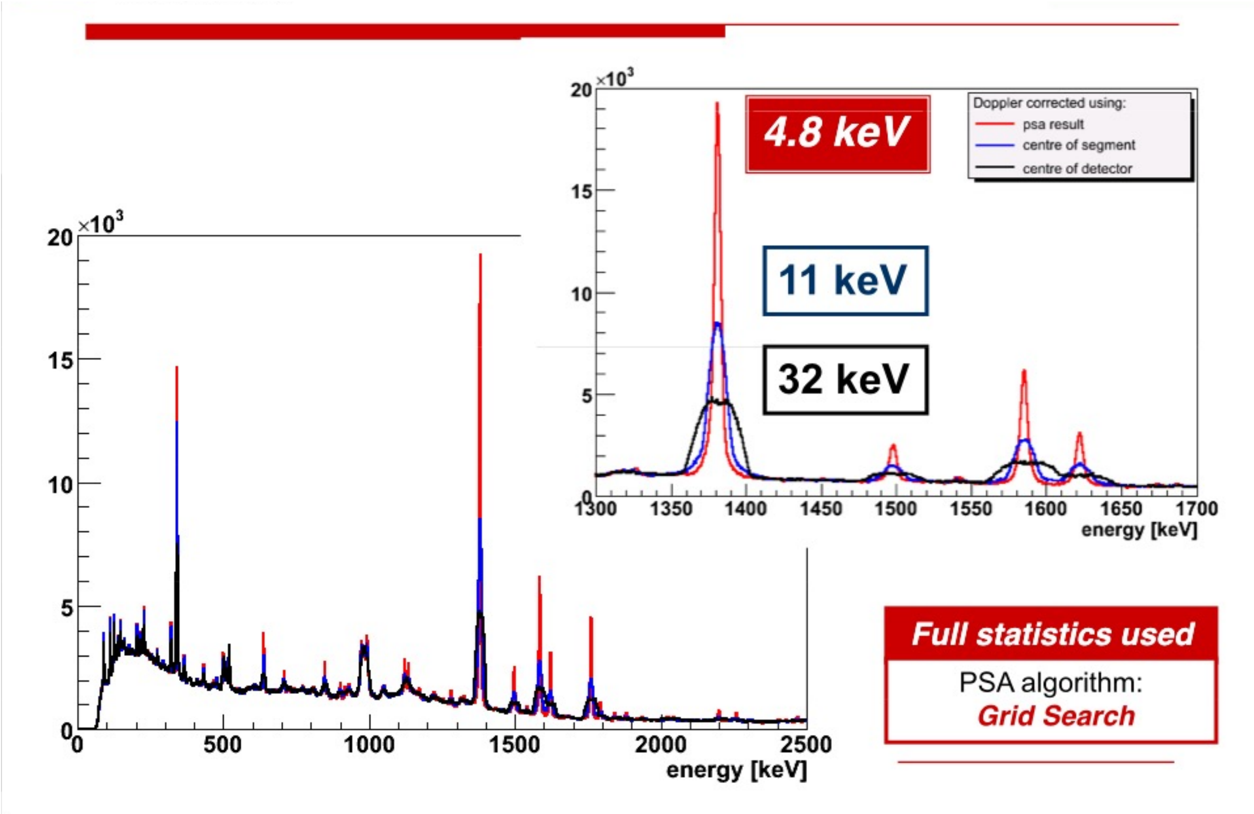
From F. Recchia, PSD8 conference

Doppler correction using position information



From F. Recchia, PSD8 conference

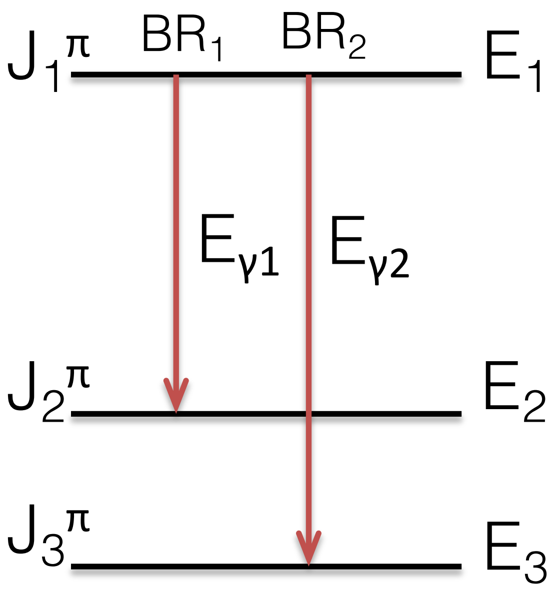
Doppler correction using position information



From F. Recchia, PSD8 conference

Properties of Gamma Decay

- Energies --> spacing between nuclear levels
- Lifetimes --> information about transition probabilities, links to nuclear matrix elements (structure!)
- Intensities --> experiment dependent – generally relates to transition probabilities (branching ratios)

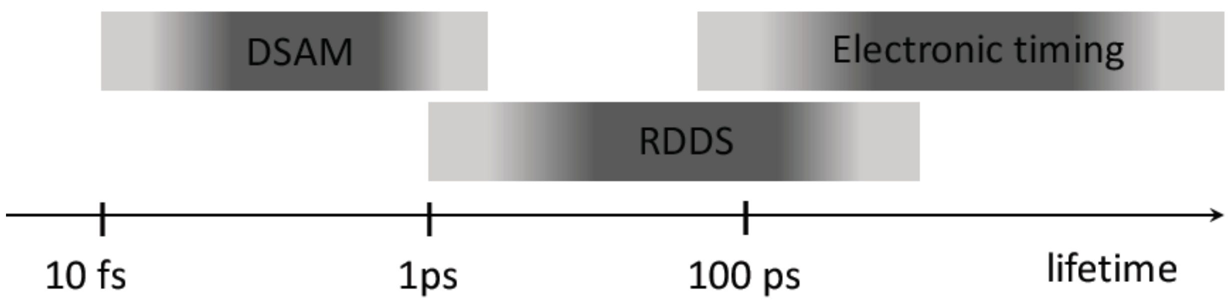


Lifetimes and Gamma Decay

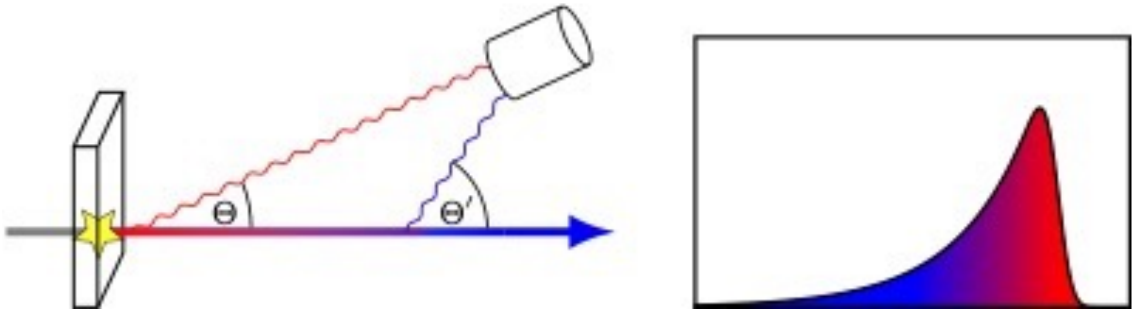
The bulk of electromagnetic (gamma) transitions have lifetimes of $10^{-15} - 10^{-9}$ s

Below a fraction of a nanosecond no clocks available for direct measurements

What do we do??



Lifetimes information in the line-shape of peaks



Due to applying a “wrong” Doppler correction by assuming
the “wrong” angle that the decays were emitted from the target position

Other more common life-time measurement methods also benefit
from position sensitive detectors and tracking arrays:

DSAM – Doppler shift attenuation method

Plunger method

Advantages of Tracking

Advantages of Tracking	
Efficiency	No solid angle lost to suppressors
Peak-to-background	Reject Compton events
Doppler correction	Position of 1st interaction
Polarization	Angular distribution of the 1st scattering
Counting rate	Many segments

bonus

Particularly important for experiments with fast secondary beams delivered by the fragmentation facilities

Summary

In this Lecture we discussed:

Background and motivation

Interactions of ionizing radiation with matter — γ rays

Detection technology — Semiconductors, HPGe arrays

Electronic readout and signal processing — position sensitive

Data analysis — for g-ray tracking

The self-calibration method
(if time allows…)