Gamma-ray calorimetry in Nuclear Physics experiments

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Outline

- **Introduction to calorimetry**

- **Gamma-rays detection**
  - **Gamma interactions**
  - **Detecting gamma-rays**
  - **Understanding a gamma-ray spectrum**

- **Gamma-ray emission in Nuclear Physics Experiments**
  - **Reactions and excited states**
  - **Some γ-ray calorimeters**
  - **Event reconstruction: addback**

- **Concluding remarks**

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Introduction

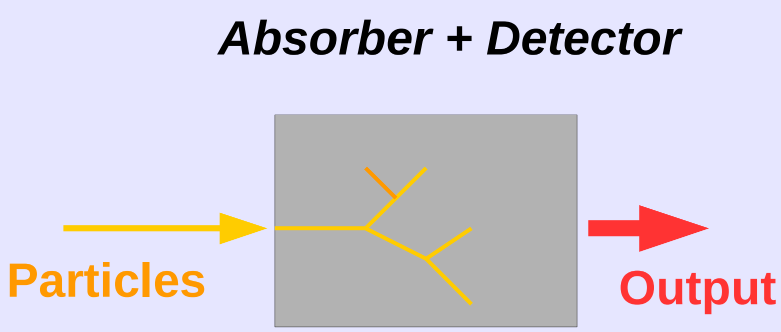
Calorimetry: act of measure transferences of energy.

Calorimeter: device to measure the energy of particle through total absorption.

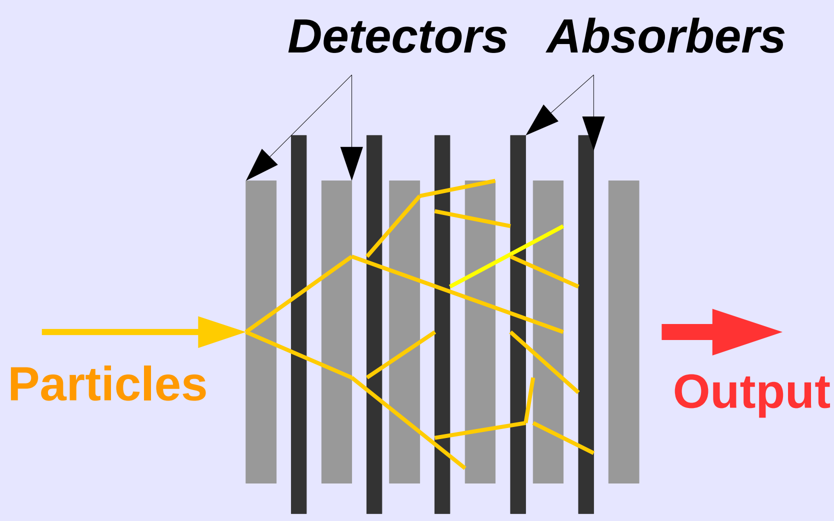
Basic idea: deposit the full energy in the medium (Shower formation).

Importance: know with precision the final states in particle collisions.

Calorimeter configurations:



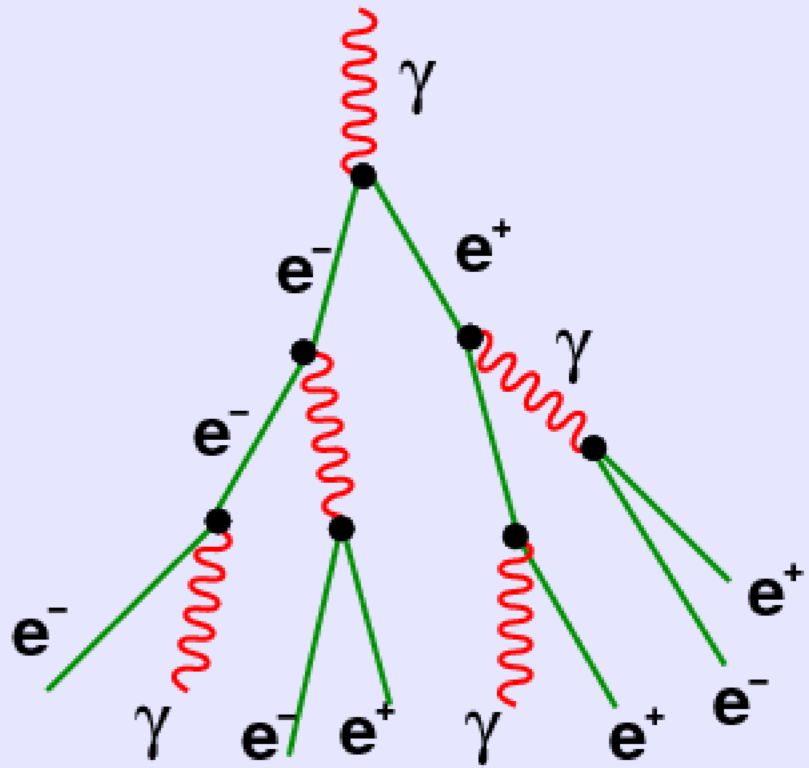
Homogeneous calo



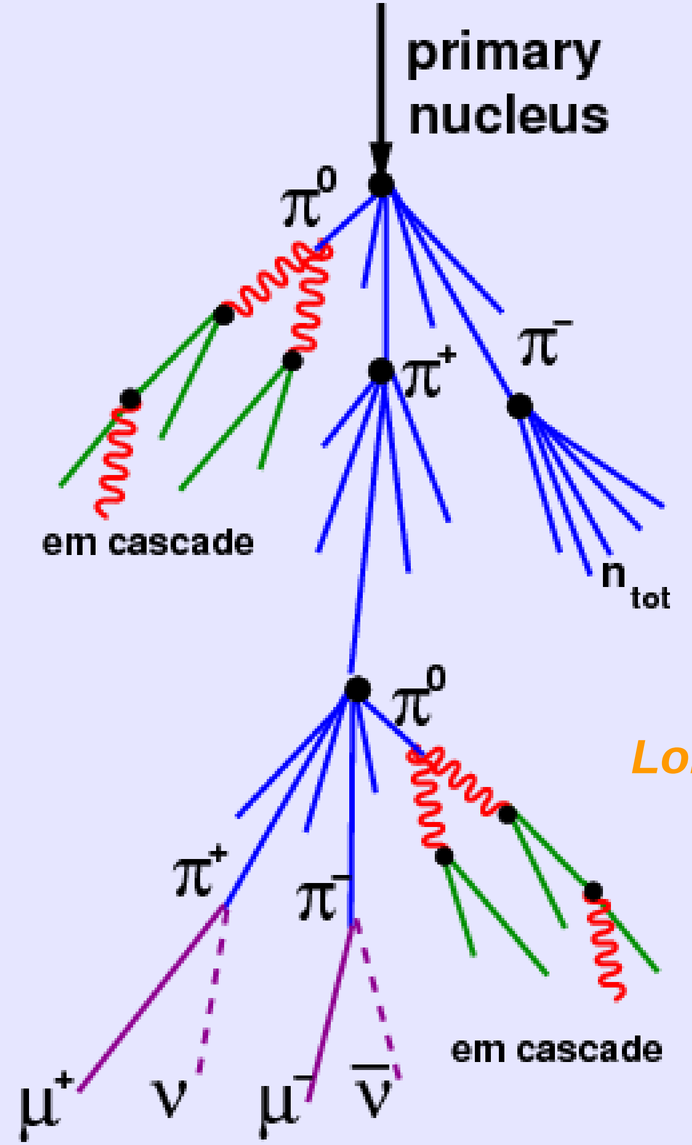
Sampling/segmented calo

Introduction

Electromagnetic showers
(electrons, positrons and gammas)



Short range



Long range

Hadronic showers

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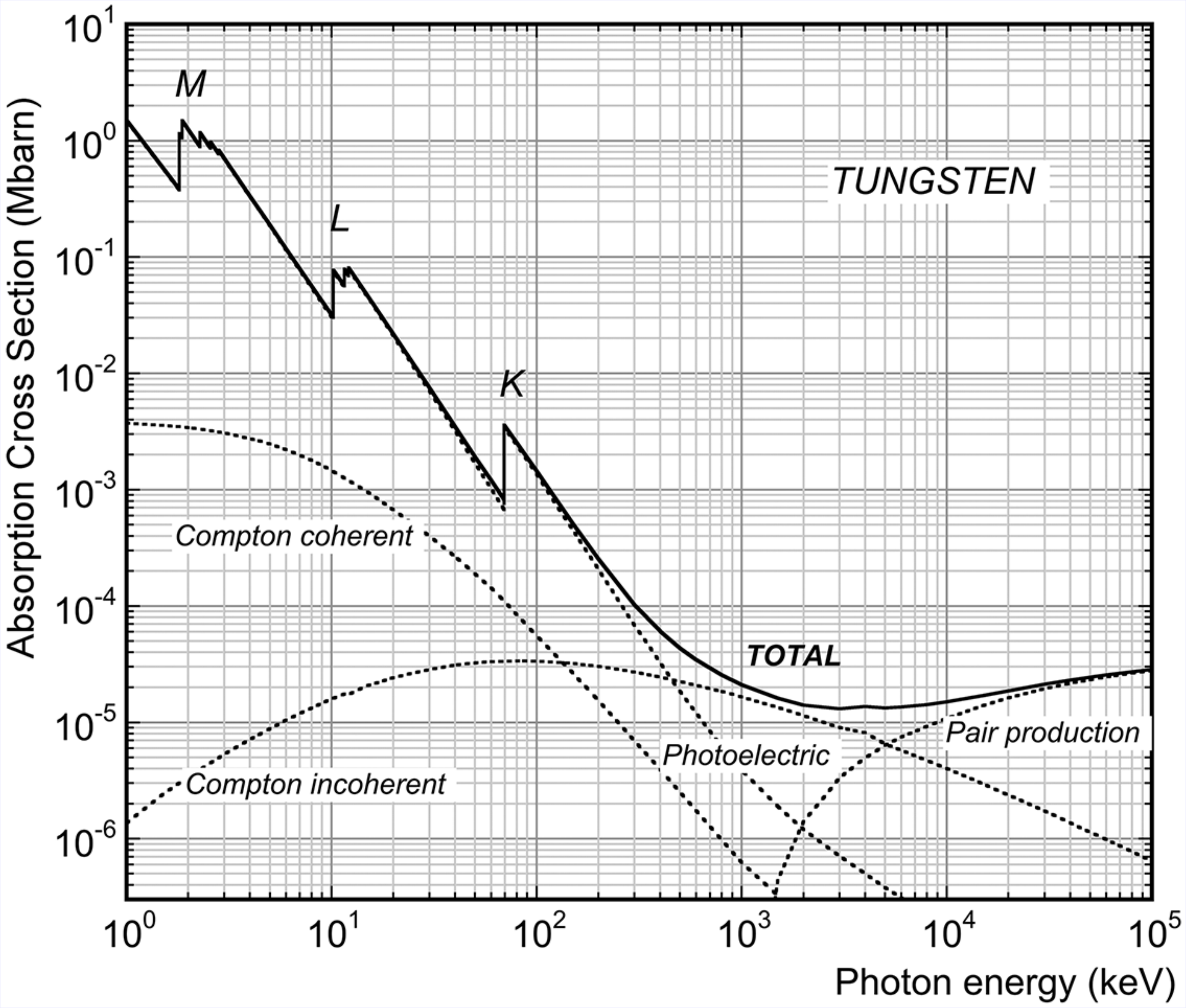
Gamma interactions

γ interactions cross-section diagram

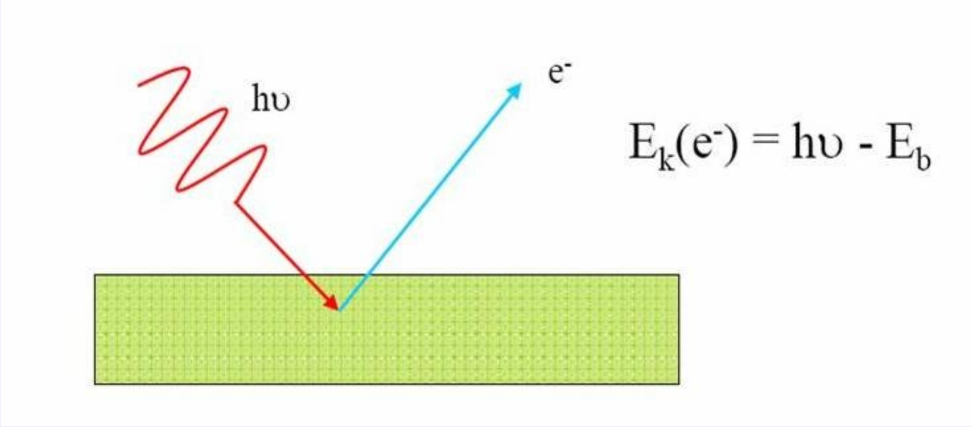
Photons interact with matter by <u>three</u> different processes

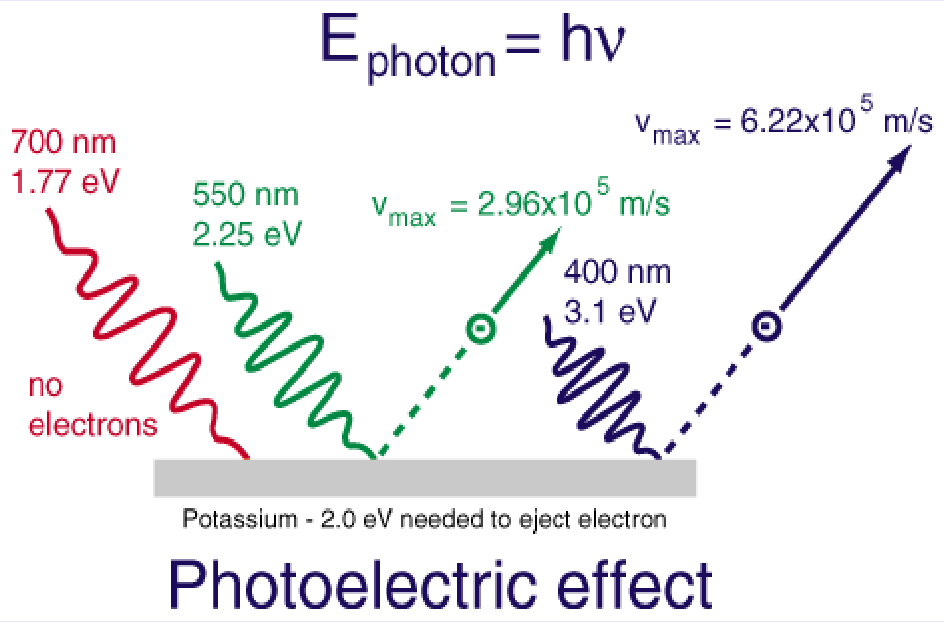


Gamma interactions

Photoelectric Effect

- **The incident photon extracts an electron from the medium**
- **Dominates at low energies (<1 MeV)**

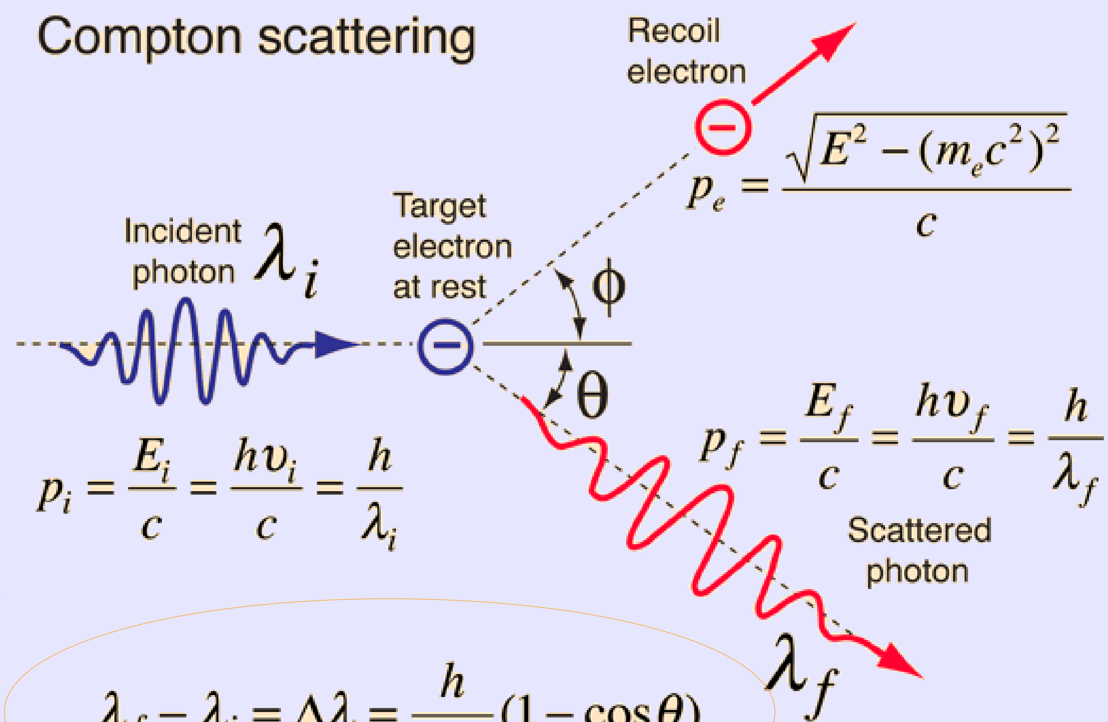




Gamma interactions

Compton Scattering

- **The incident photon "is scattered" and an electron is ejected at a given angle**
- **Becomes important at intermediate energies (~1 MeV)**



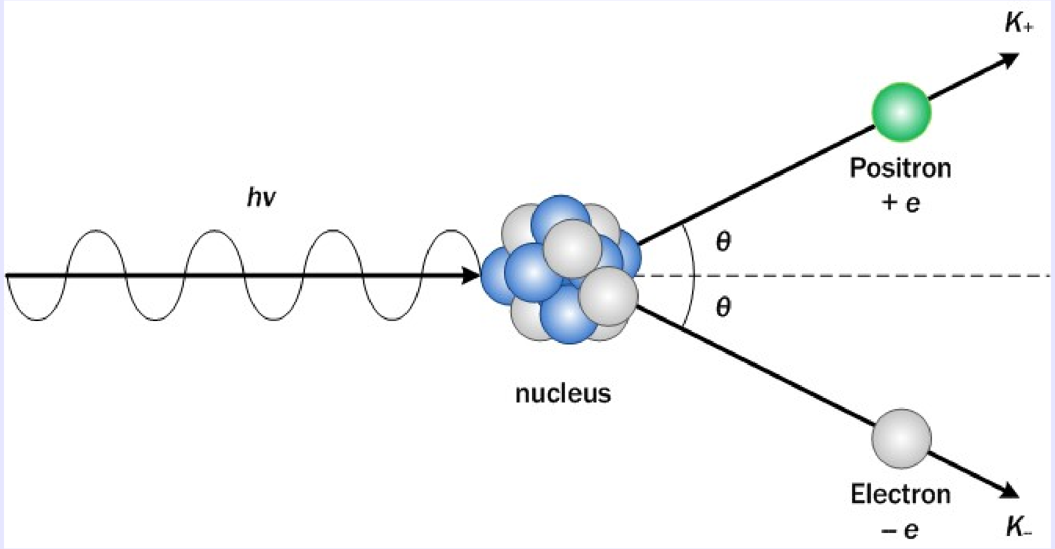
Maximum energy change in a single interaction

$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

Gamma interactions

Pair Production

- The incident photon interacts with the nuclear field and aa electron-positron is created
- Is the main contribution at high energies (>1 MeV)



Energy threshold!!

$E = h\nu = 1.022$ MeV

Detecting γ-rays

Two basic types of gamma-ray detectors:

Scintillating detectors

- Scintillating light produced after ionization
- Transparent to that light
- Organic (plastic), inorganic (NaI, CsI, BGO), ceramic (GAGG)
- Read-out with light sensors (PMTs, APDs, SiPMs)

Semiconductor detectors

- Electron-hole pairs are produced after ionization
- Very good resolution
- Silicon, Germanium, Cd-based

KEY FACTOR:

The output should be proportional to the energy deposited by the incident photons

Detecting γ-rays

Output pulses must be sorted by magnitude

Basic tools:
Multichannel Analyzers (MCA)
Analog-to-Digital Converters (ADC)

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HISTOGRAMS

Important parameter: Energy Resolution

$\sigma(E)$ = FWHM = 2.34σ

Fitting the photopeak to a Gaussian curve

→

R(%) = $\sigma(E)/E = a/\sqrt{E} + b/E + c$

Stochastic + noise + constant (calibration, materials, instruments...)

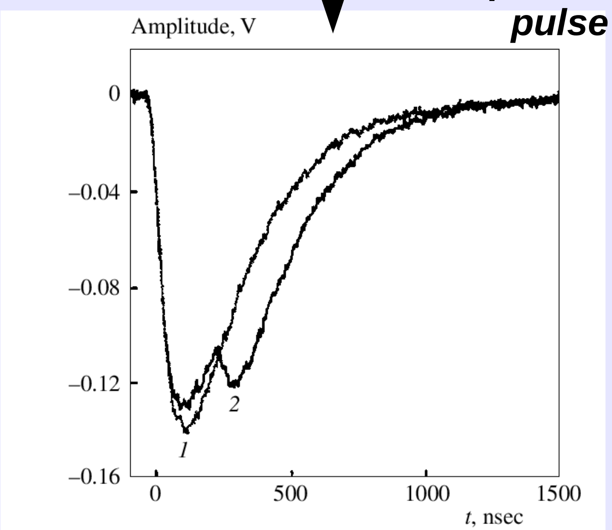
Detecting γ-rays

Detector

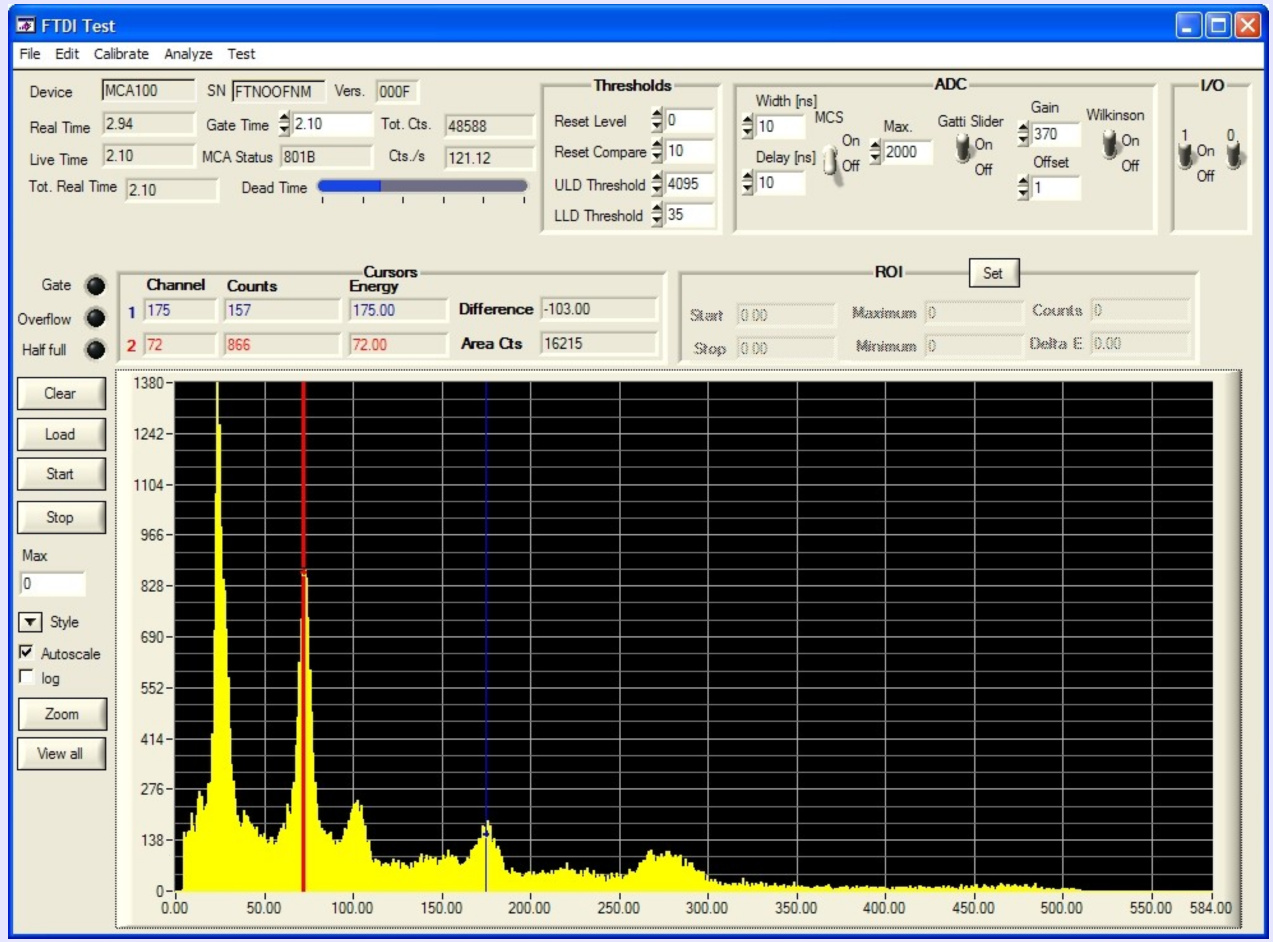
Current pulse

Amplification

Shaped voltage pulse

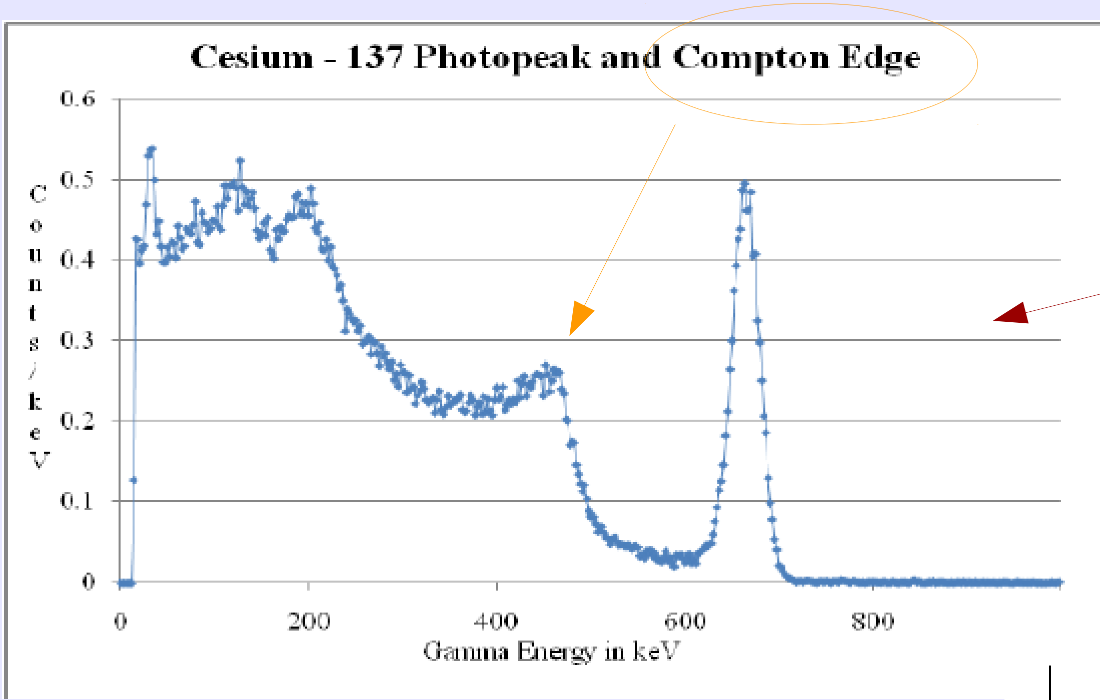


MCA



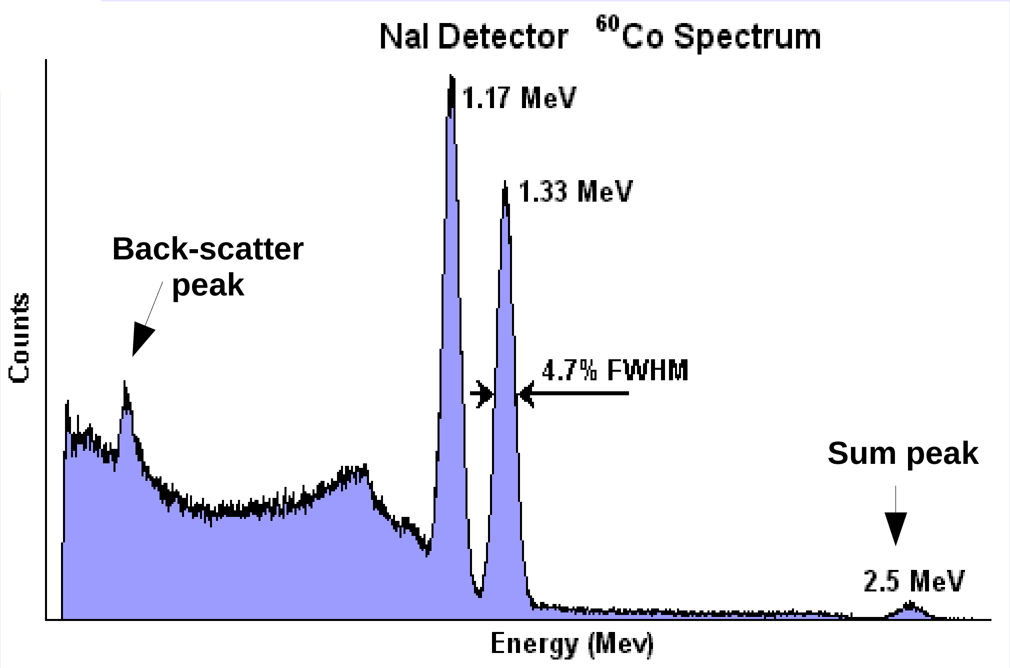
Sorted pulses by amplitude:
Histogram
Calibration linear with E

Understanding the spectrum

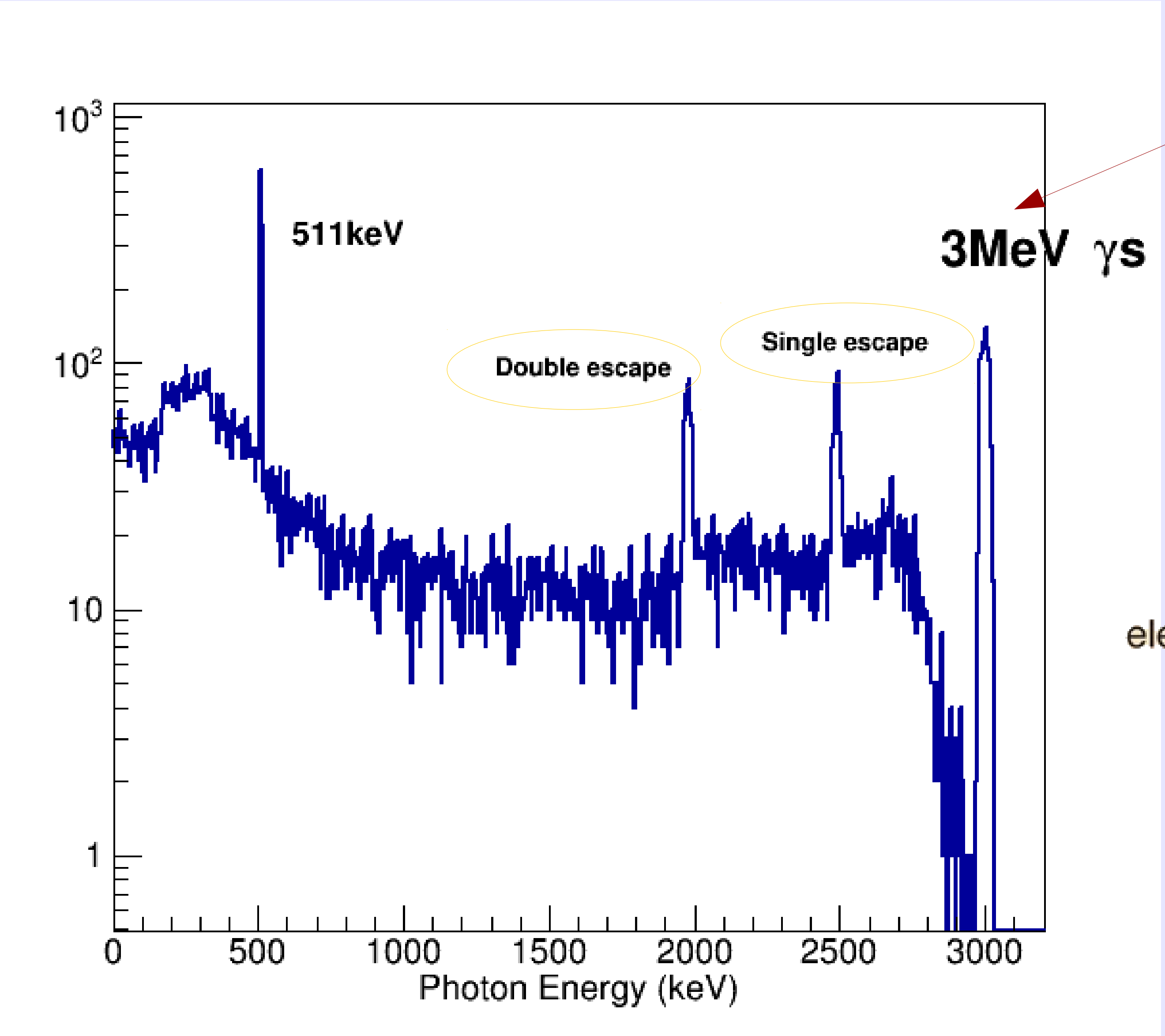


Mid-range energies: Compton domination

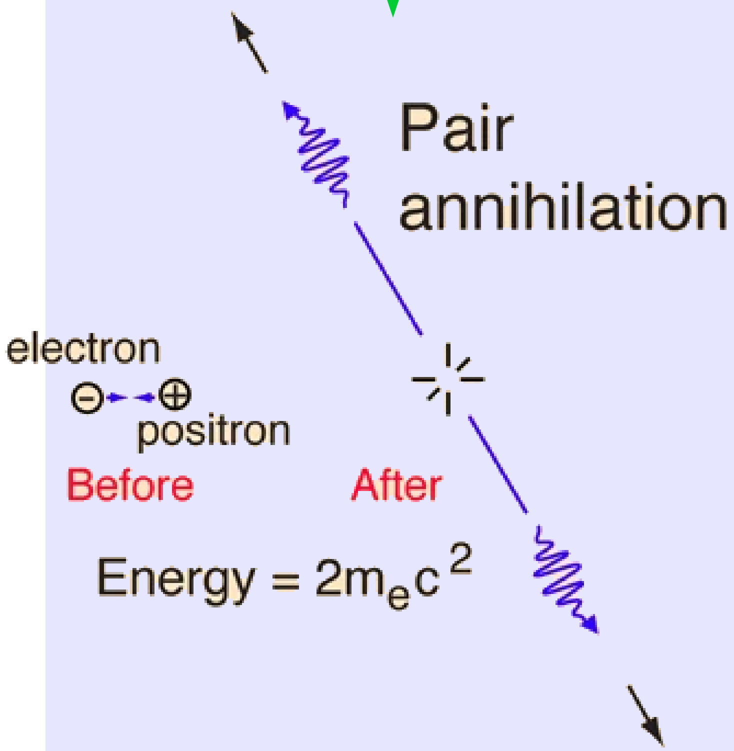
$$\Delta\lambda = \lambda_c\,(1 - \cos\vartheta)$$



Understanding the spectrum



e^+-e^- pair production



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Why gamma-rays?

Nuclear reactions have intermediate excited states

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Gamma emission

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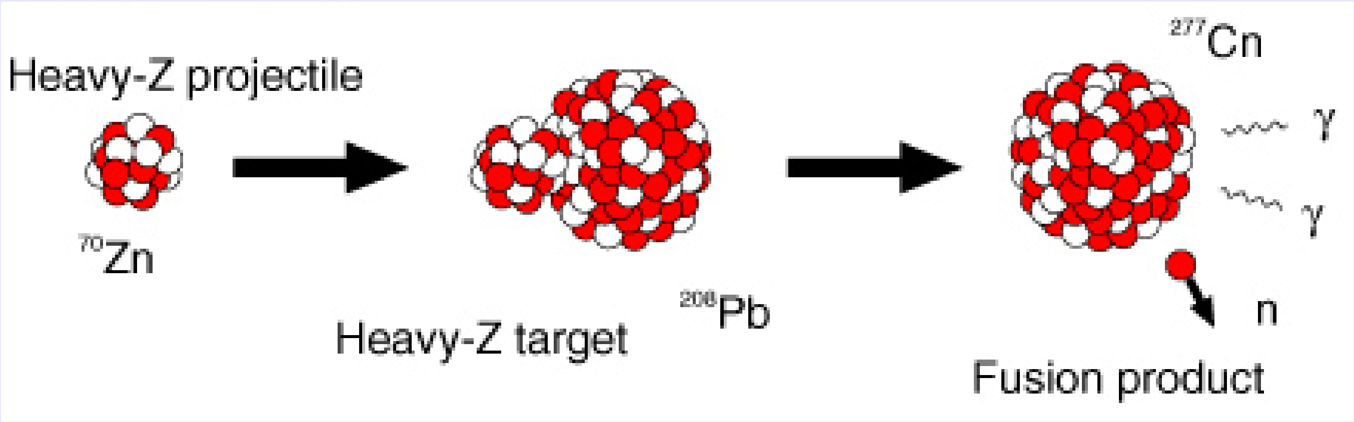
We can measure the energy, spin and parity of the excited states (EM transitions)

We can understand:

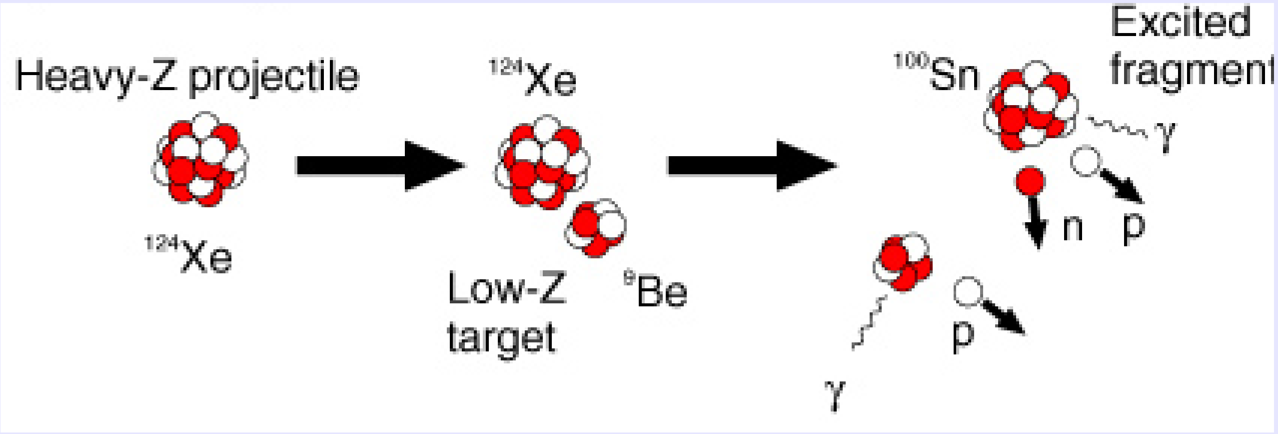
- **Collective excitations**
- **Phase transitions**
- **Nuclear structure and shell model**
- **EOS**

Nuclear Reactions

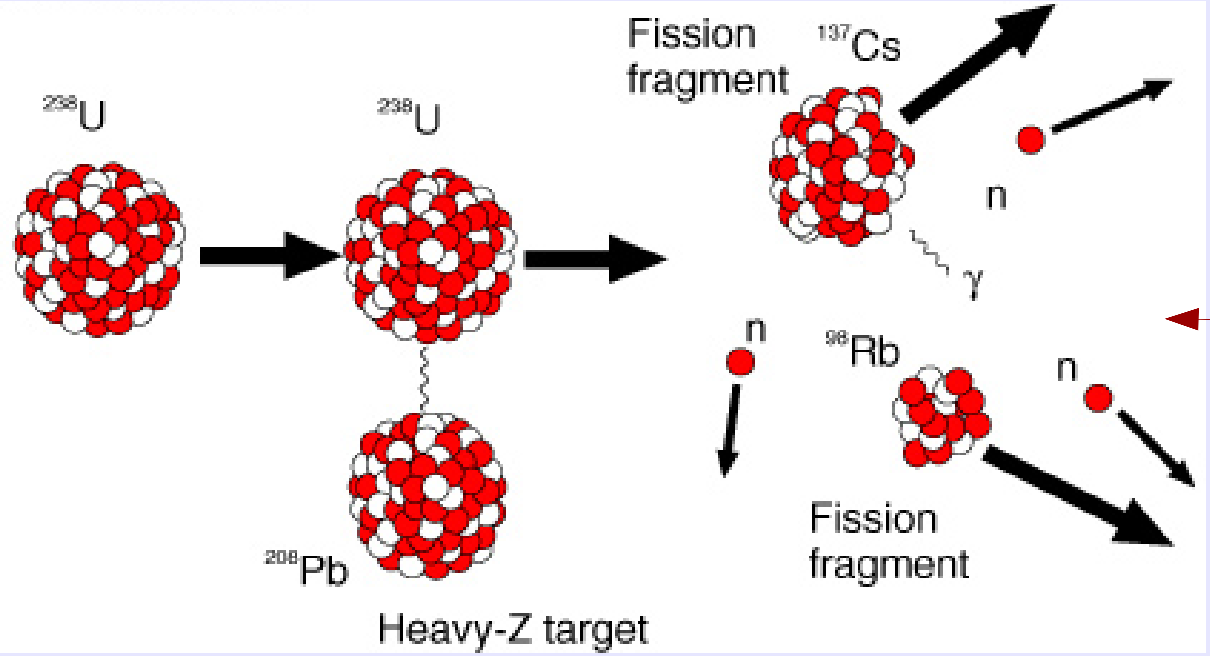


Nuclear Fusion

Nuclear Fragmentation

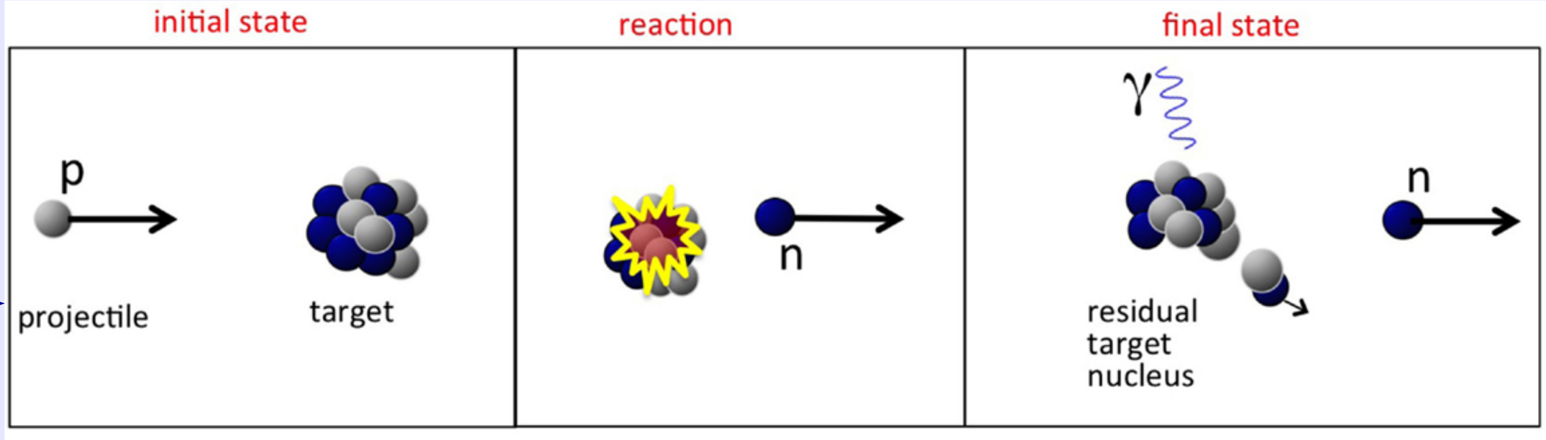


Nuclear Reactions

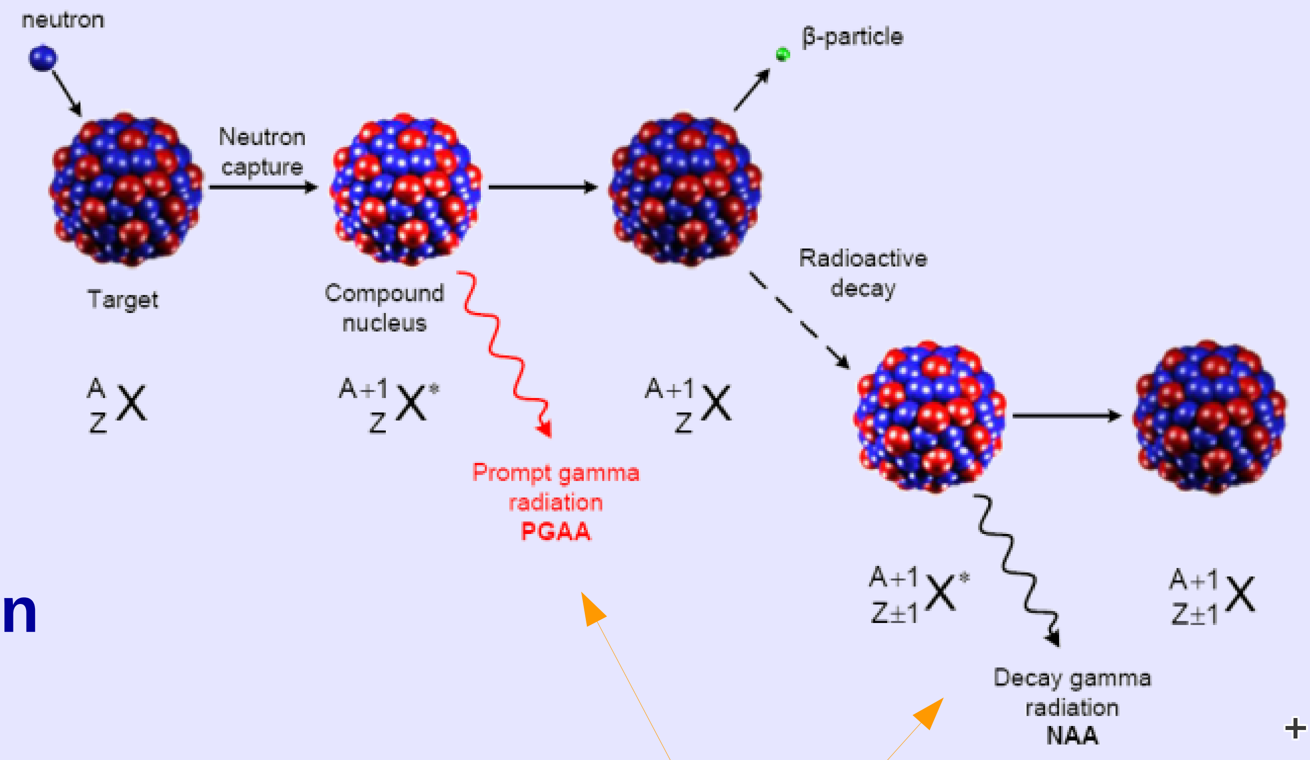


Nuclear Fission

Light projectile fragmentation



Nuclear Reactions



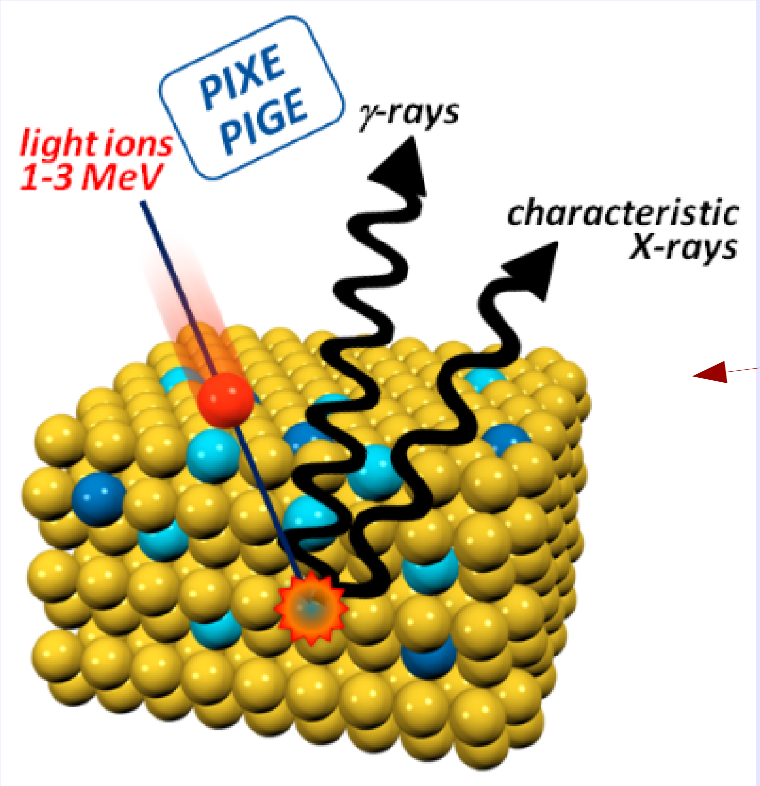
Beta delayed neutron emission

γ emission

Essential to:

- **Control reactions in Nuclear Power plants**
- **Stellar nucleosynthesis**
- **Nuclear Structure (n-rich nuclei)**

Nuclear Reactions

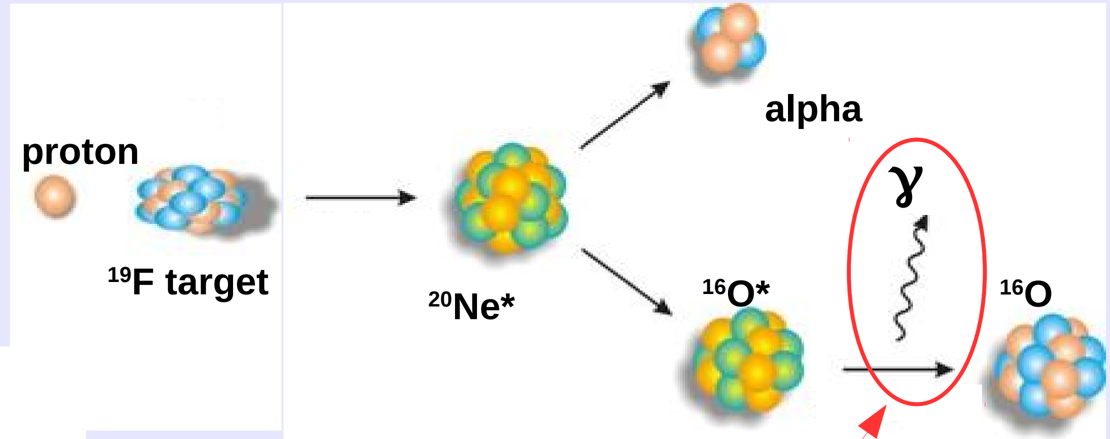


Proton induced X-Ray and Gamma emission

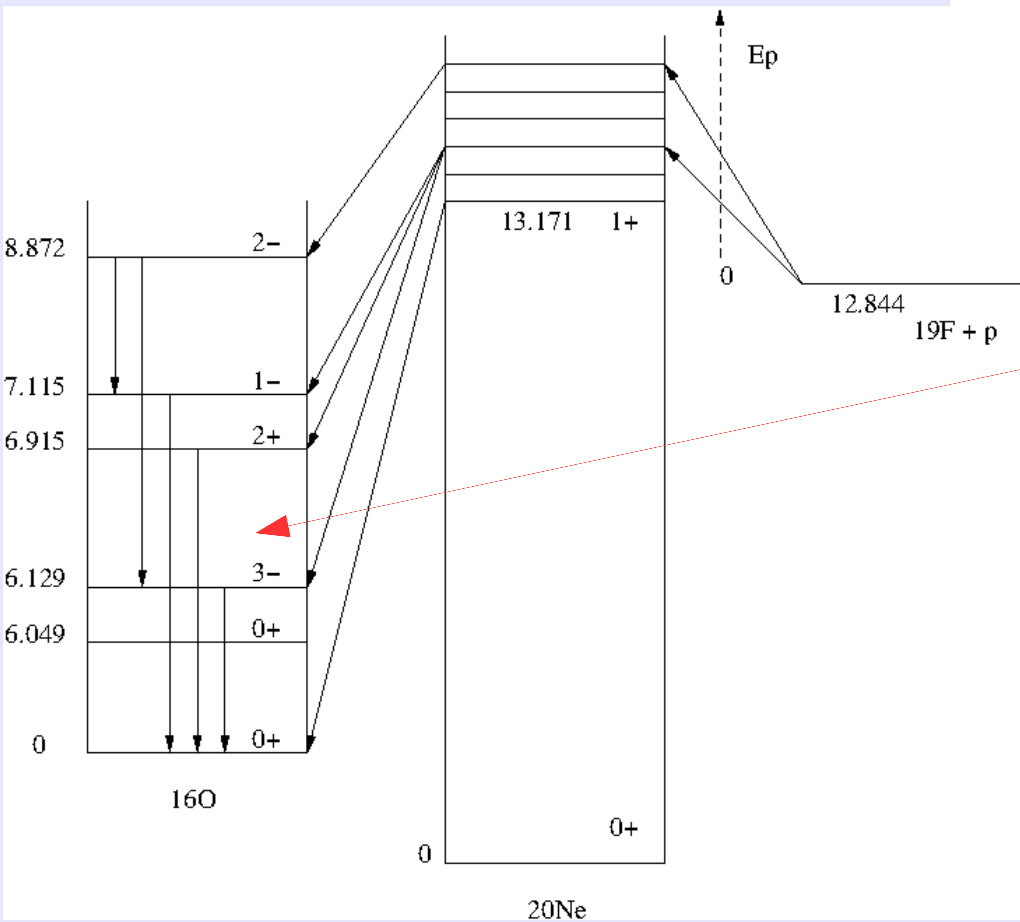
“Low scale” facilities (Tandem or Van de Graaff accelerators)

Nuclear Reactions

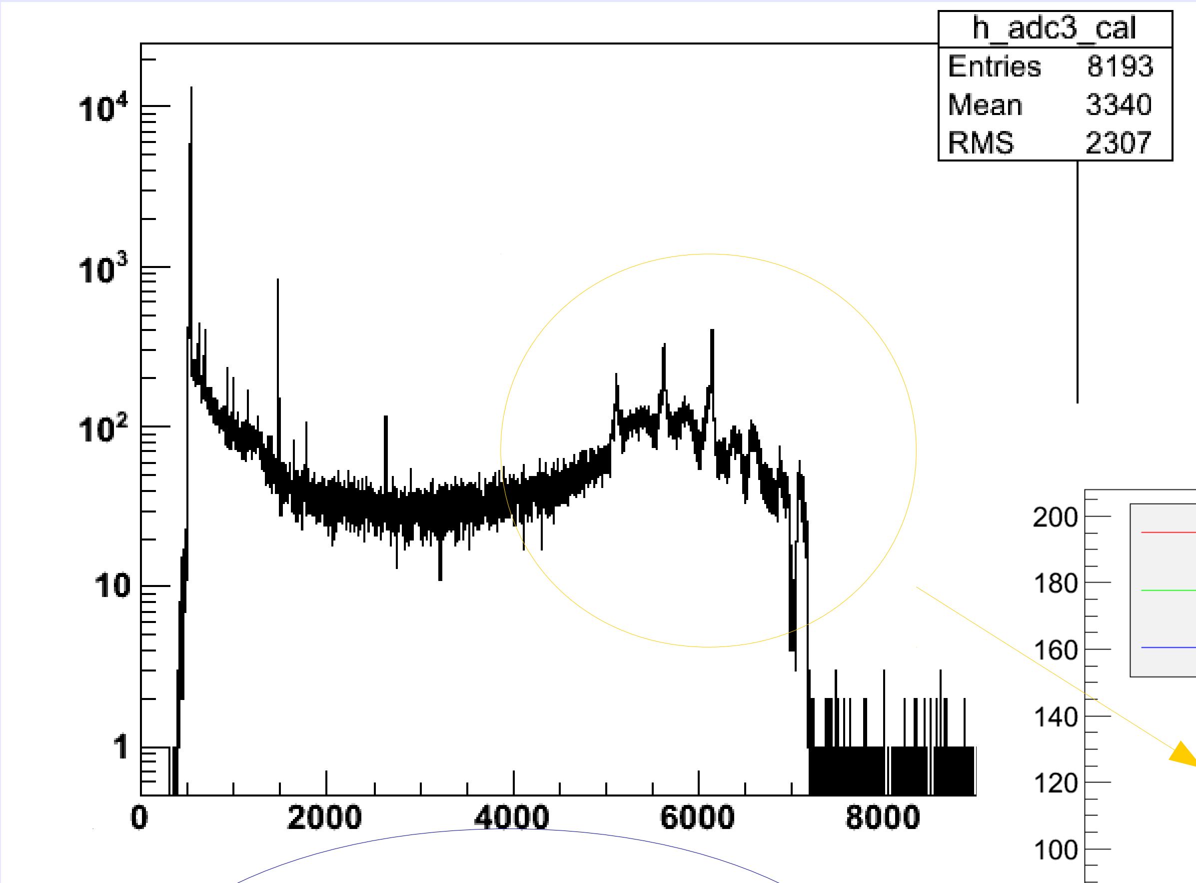
PIGE Reaction



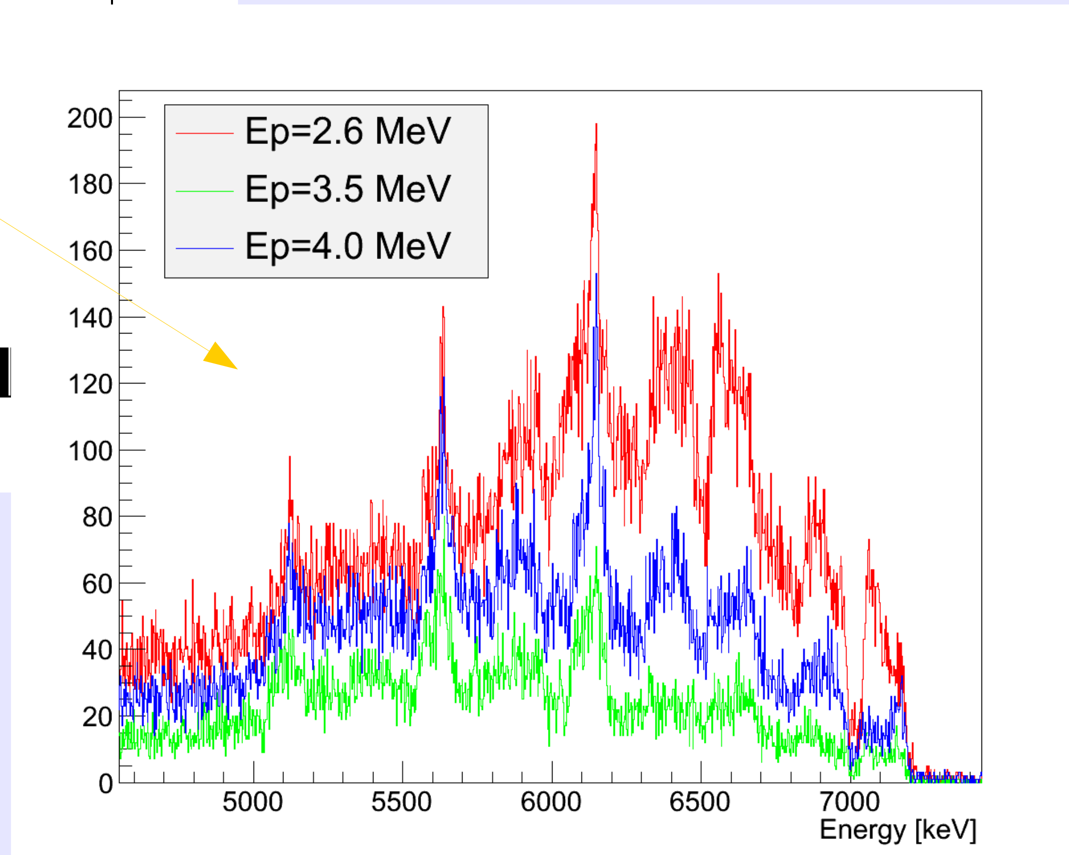
Gamma emission



Nuclear Reactions

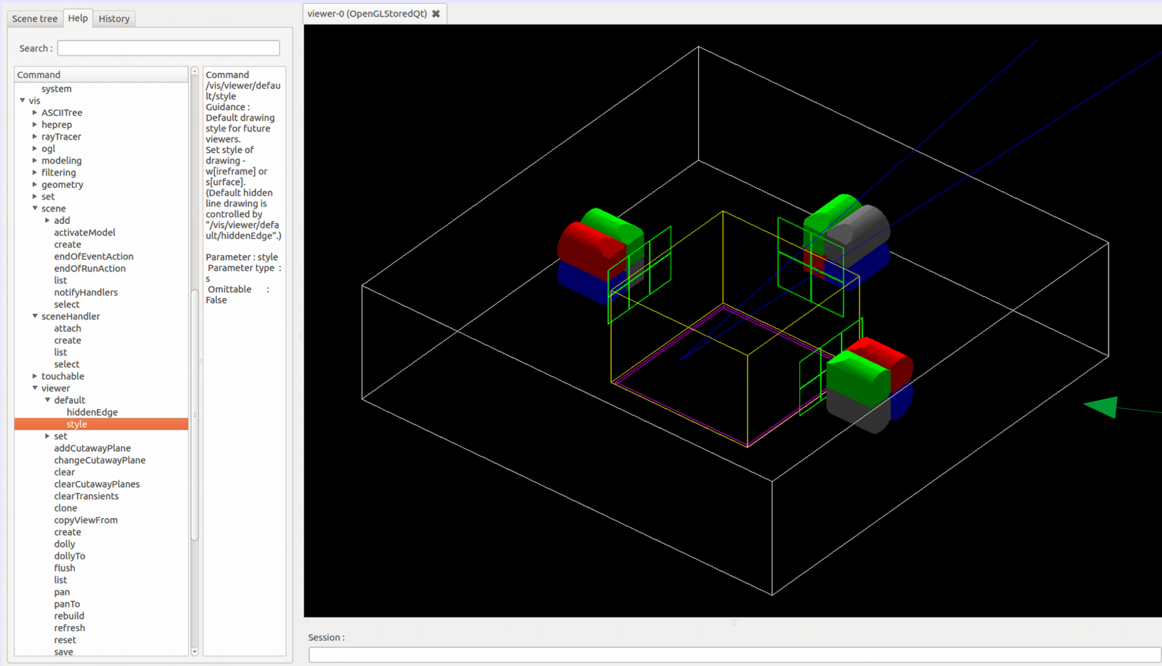


HE gamma rays!!!
Easy to produce



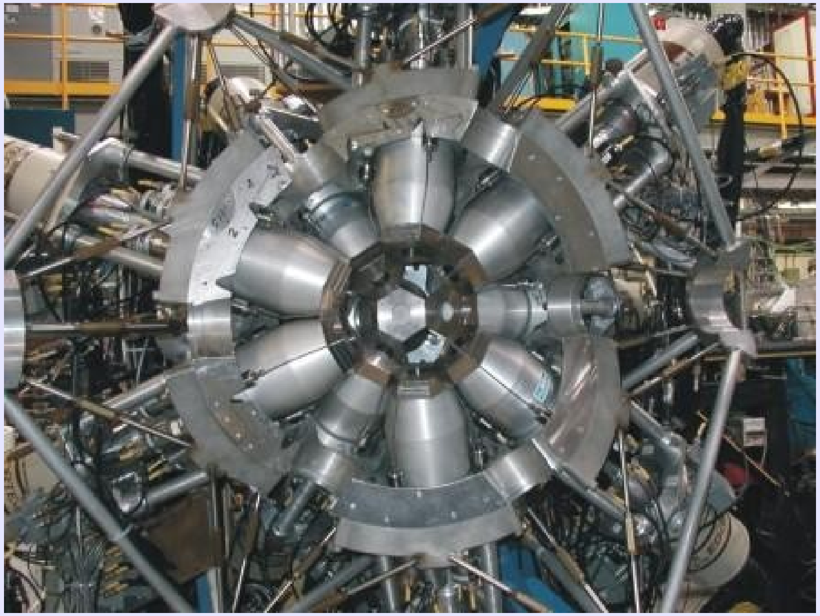
PIGE Reactions:
very powerful test beam candidates!

Some calorimeters



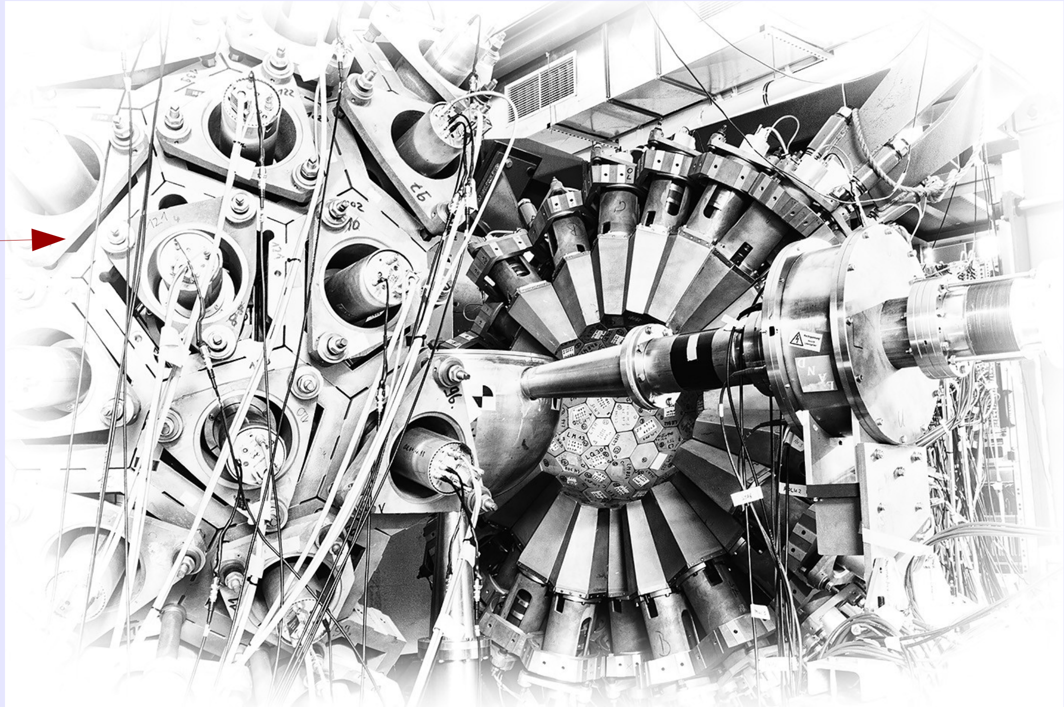
ACTAR @ GANIL (France)
3 Exogam clovers
(4 HPGe detectors each)

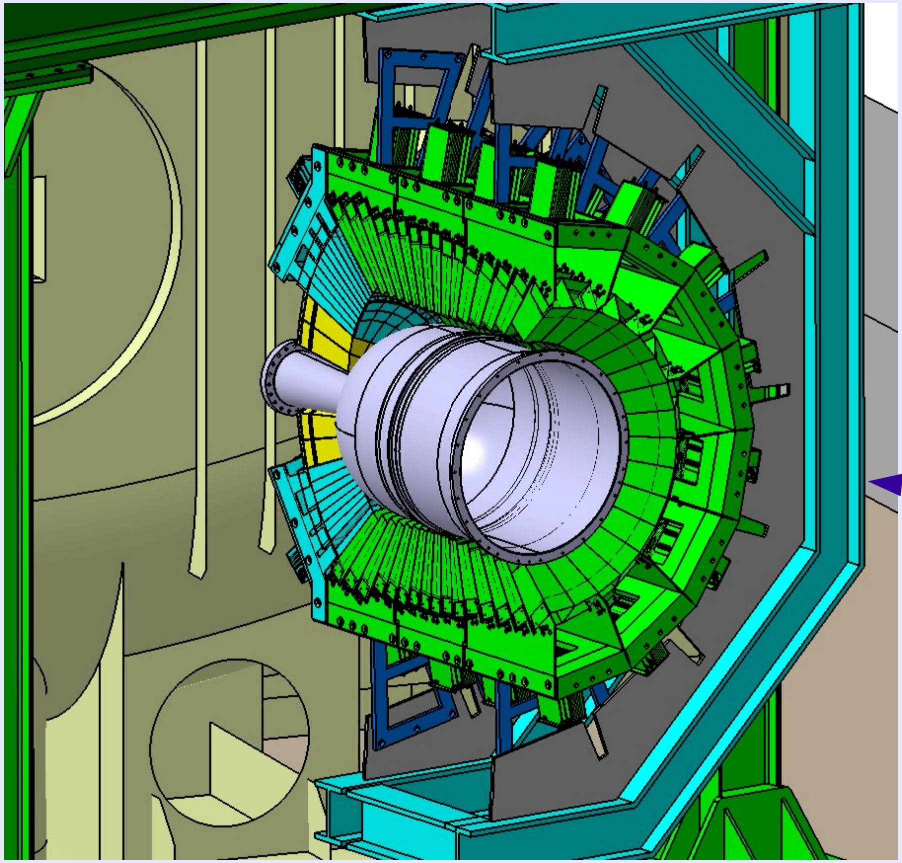
8π @ TRIUNF (Canada)
40 HPGe detectors



Some calorimeters

CrystalBall @ GSI (Germany)
162 NaI(Tl) crystals + PMTs





CALIFA @ FAIR (Germany)
2432 CsI crystals + APDs
96 LaBr3/LaCl3 + PMTs

Some calorimeters

- **All are segmented arrays!**
- **Wide range of gamma ray energies!**
- **Photons can fired more than one detection unit**

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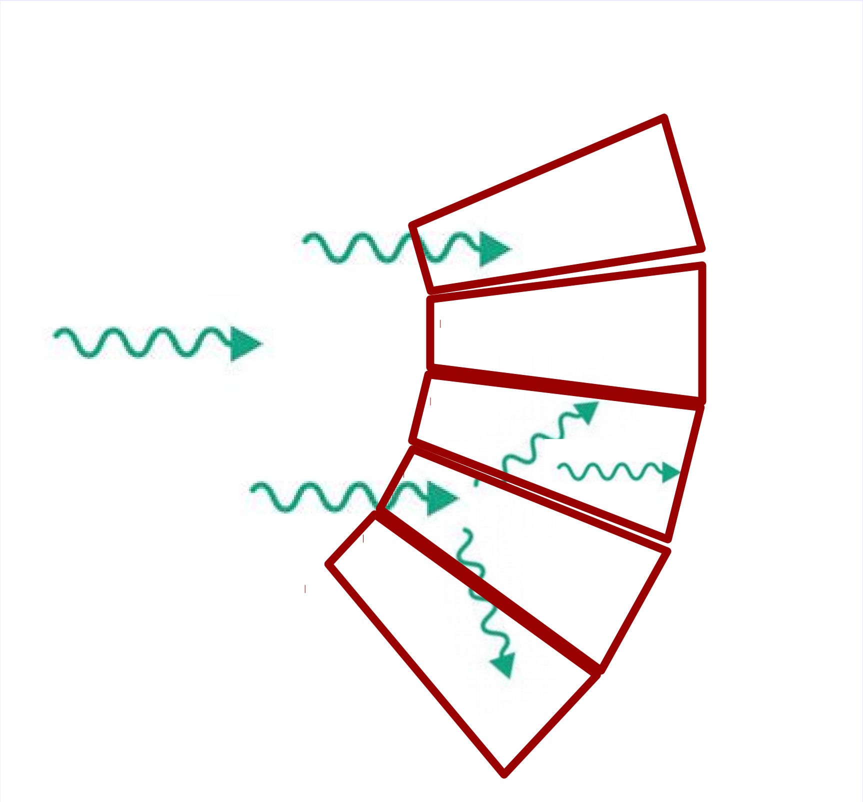
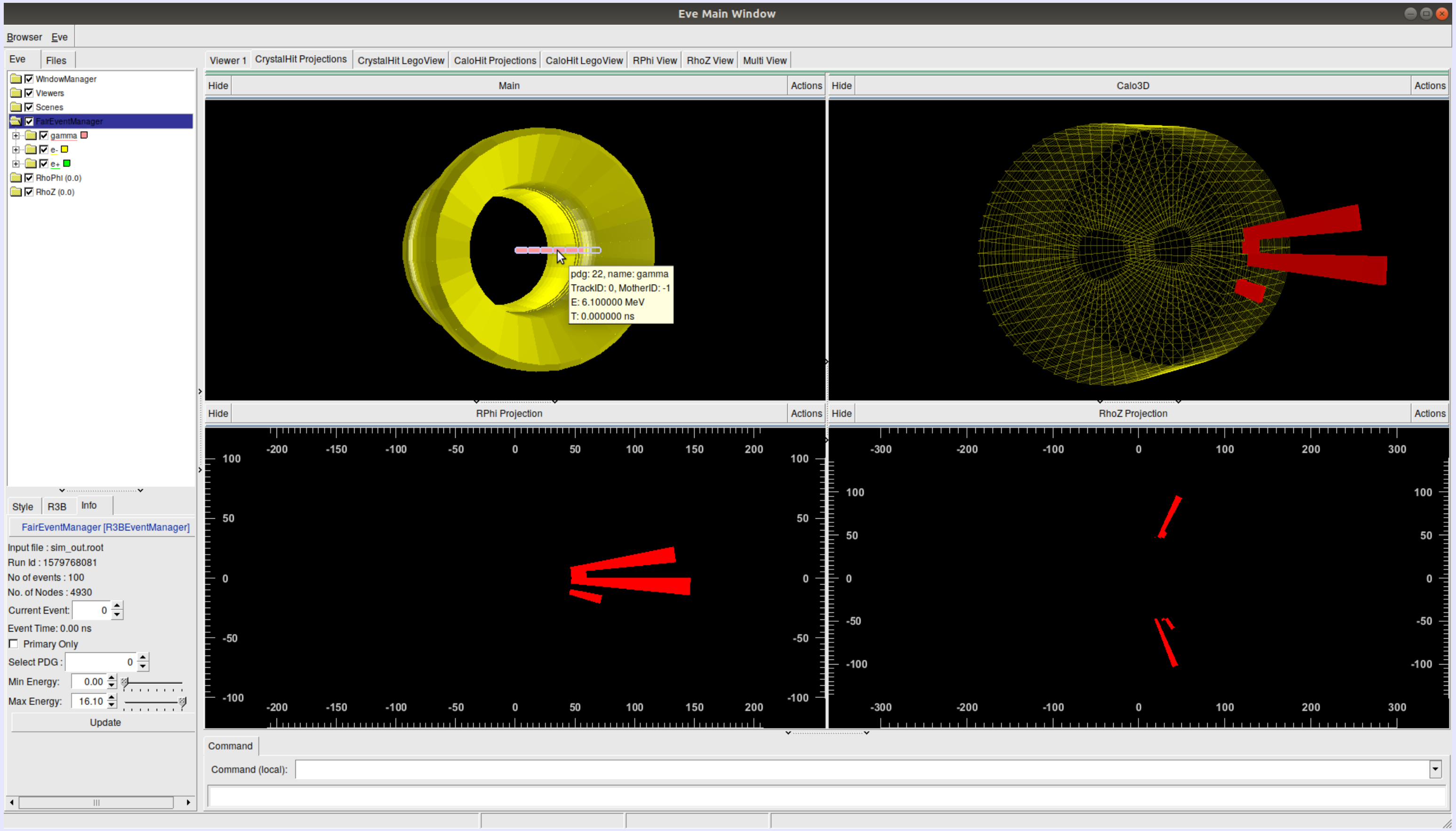
***Addback* procedures needed!!**

- **Sum over neighbors**
- **Cluster finding methods**
- **Deep/machine learning techniques like ANN**

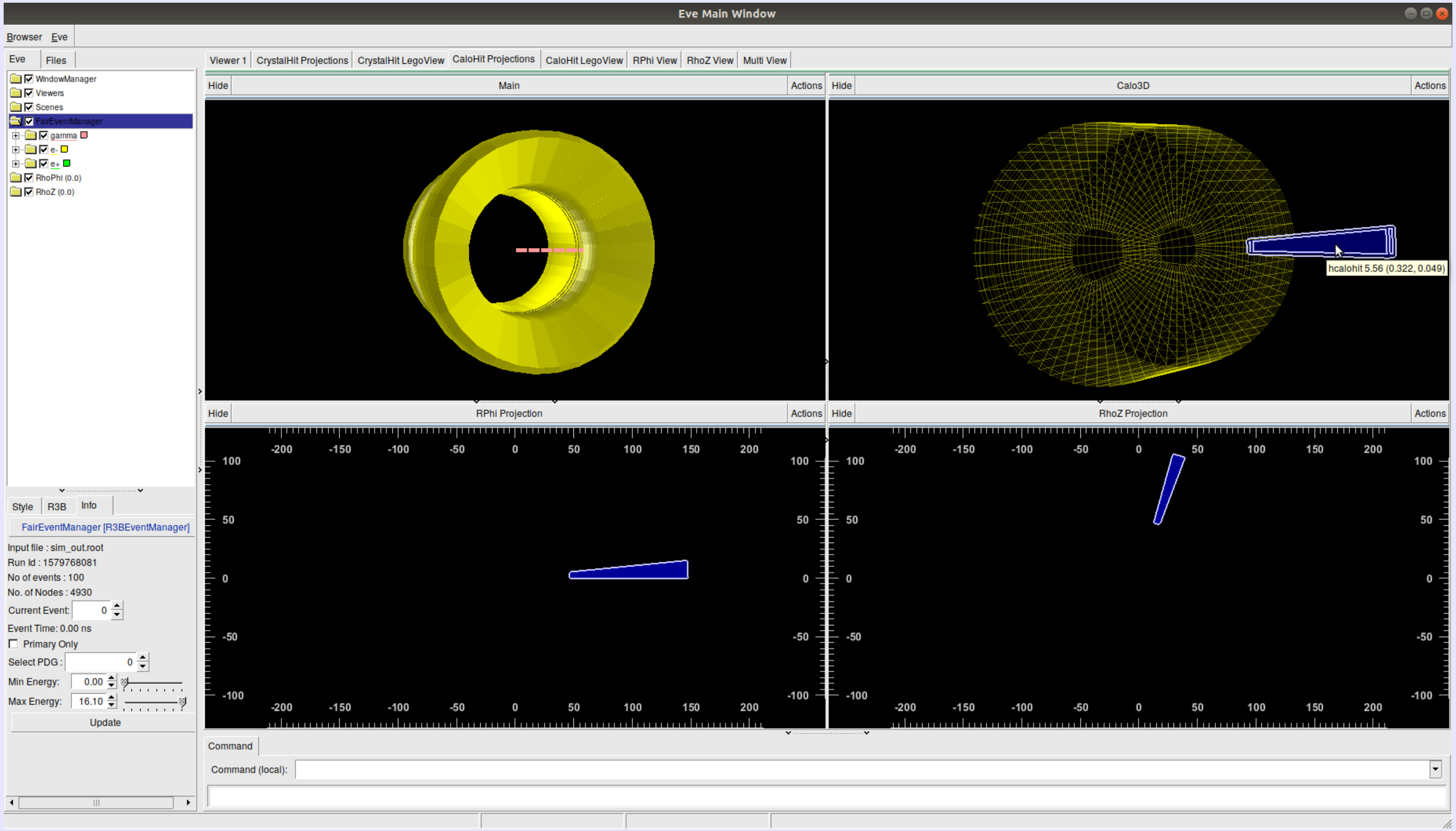


Event reconstruction



Single 6.1 MeV γ-ray → At least 6 crystals fired!!

Event reconstruction



After Addback procedure → ***All released energy at one location!!***

Final remarks

- **Nuclear Physics reactions produce gamma-rays**
- **Gamma-ray calorimetry is required**
- **A good understanding of gamma interactions in our detectors is needed**
- **Experimental setups involve different kind of detector systems and gamma detectors arrays**
- **Dedicated analysis techniques are mandatory: calibrations, addback...**

Thank you

for your attention!