Simulation of non-destructive detection of explosives by Prompt Gamma Neutron Activation Analysis(PGNAA)

Heavy Ion Meeting
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  - Effect of Timing constraints
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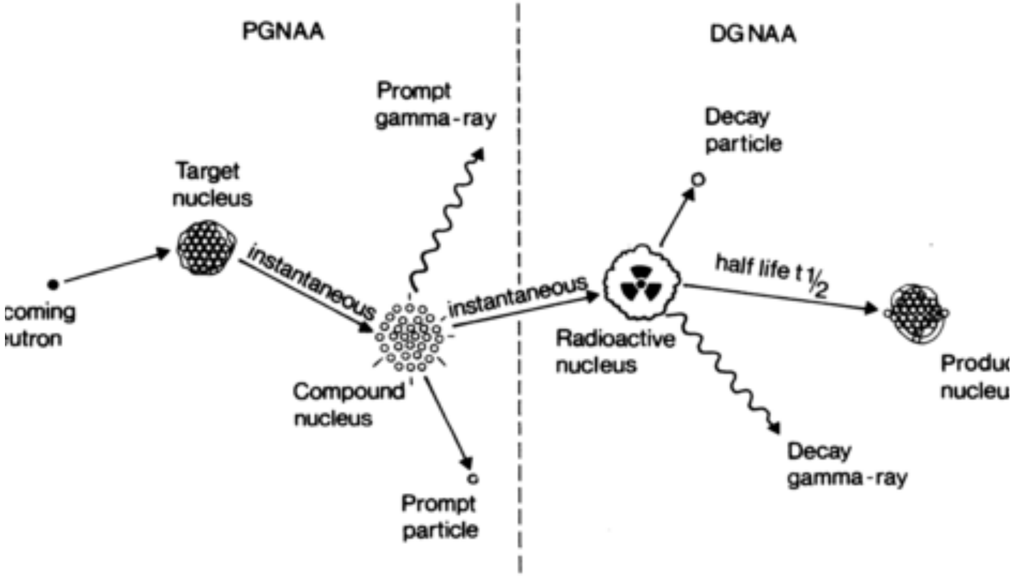
- Summary

Introduction to PGNAA

- PGNAA is a useful method to detect the concentrations of the various composite elements of a sample by measuring the prompt gammas.
  - Application : on-line measurements in the coal mining industry, environmental research, and searching for landmines as part of homeland security.



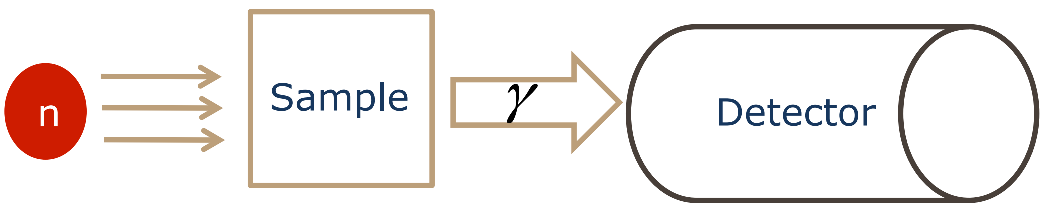
- Advantage :

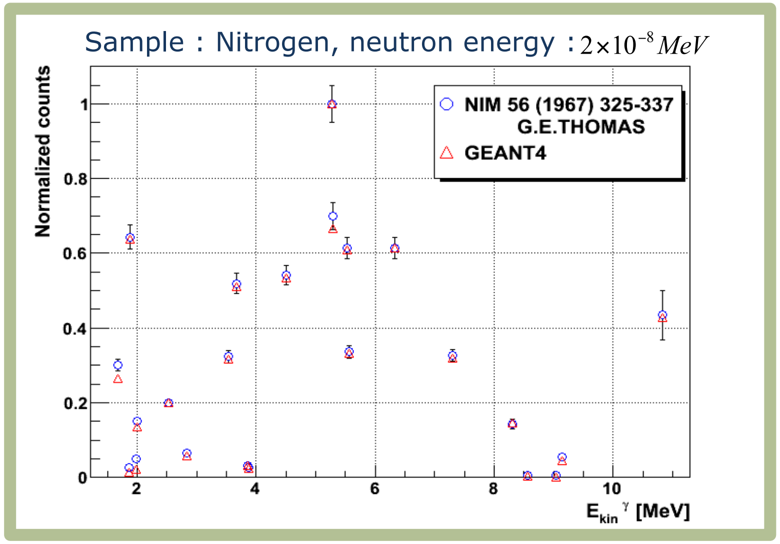
PGNAA can detect several elements in a compound simultaneously and measure gamma in real time.

- Disadvantage:

Low signal to background

Introduction to PGNAA





- Main parts of PGNAA
  - Neutron source
    : reactor, ^{252}Cf, neutron generator , **laser accelerator** D + D -> n + ^{3}He
    (pulsed neutron beam generator has the advantage of regulating the time gate for data taking)
  - Detection system
    :gamma ray detector (scintillator, semiconductor), DAQ system

Explosives classification

- Explosives are differentiated by measuring C/O and C/N elemental ratios. (strong correlation exists between the concentrations of O and N in explosives)

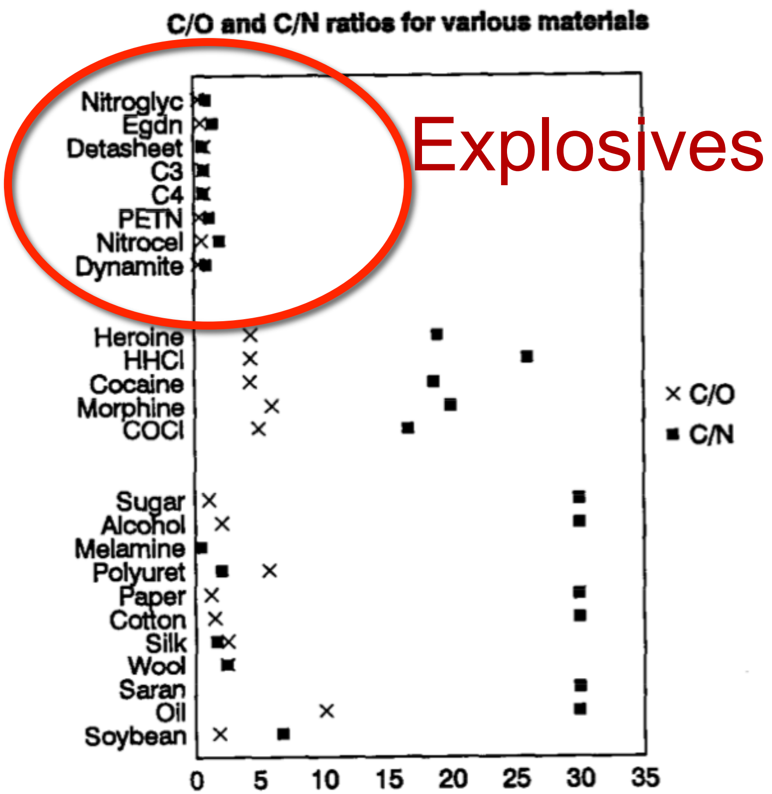
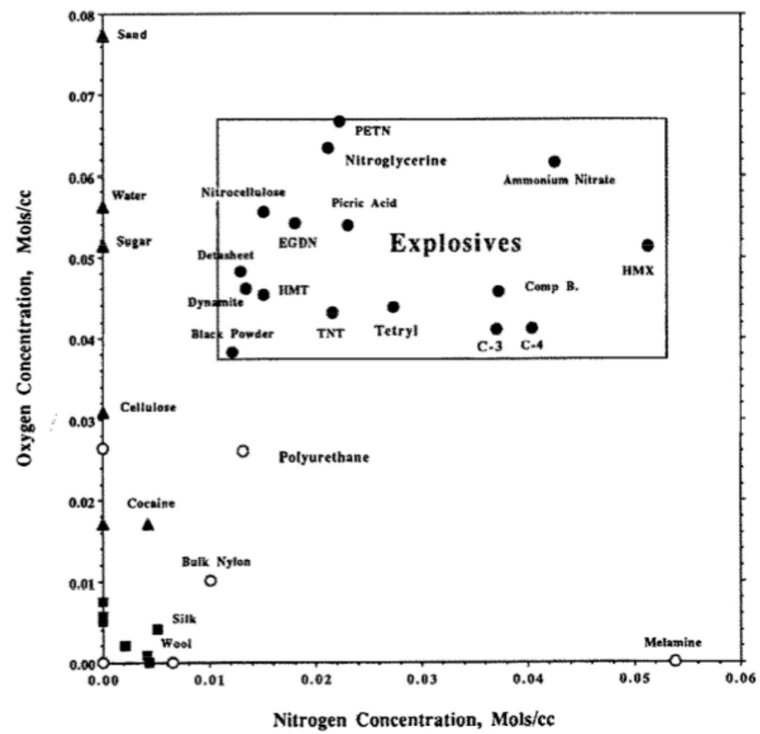


Fig. 2. C/O and C/N ratios for three categories of materials: explosives, drugs and miscellaneous.

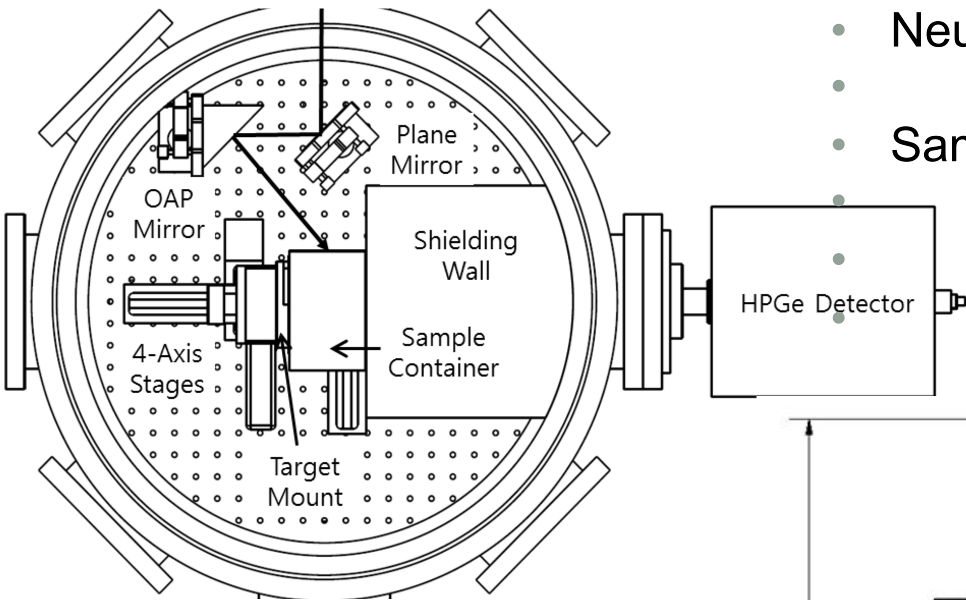


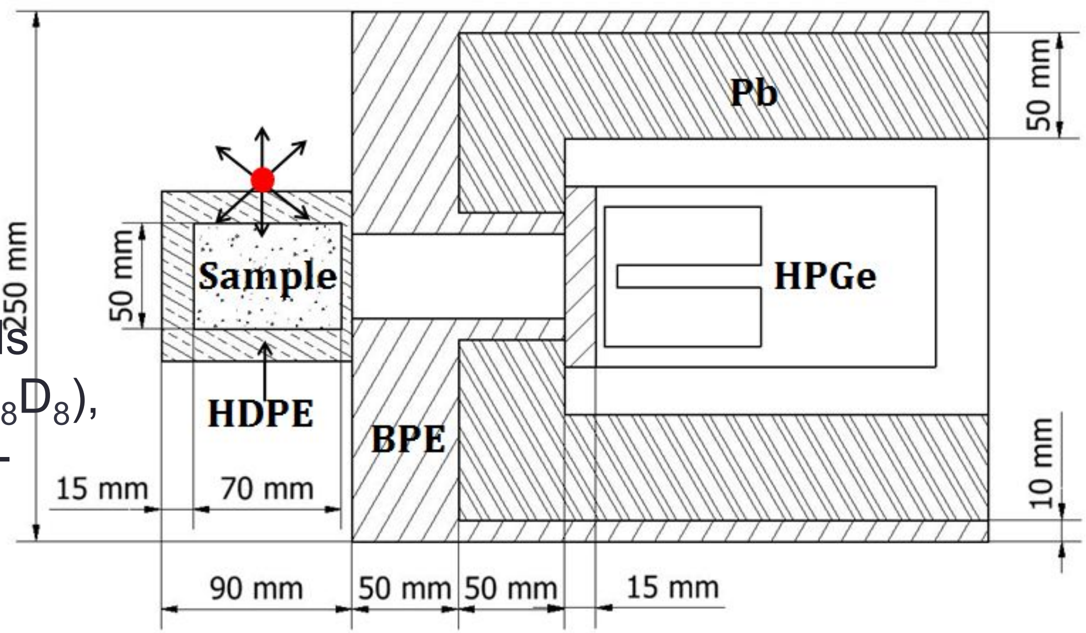
orrelation between the nitrogen density and the oxygen density for the materials in fig. 1. All explosives are found within a phase space that contains no non-explosive.

George Vourvopoulos, NIMB 89(1994) 388-393 Lee Grodzins, NIMB 56/57 (1991) 829-833

Setup of the PGNAA system in GEANT4

- Gamma shielding material : 5 cm thick Pb
- Neutron shielding material : 5cm thick 30 % BPE
- (Borated Polyethylene)
- Sample comtainer material : HDPE
- (High Density Polyethylene)
- Sample material : Trinitrotoluene (TNT) $H_5C_7N_3O_6$



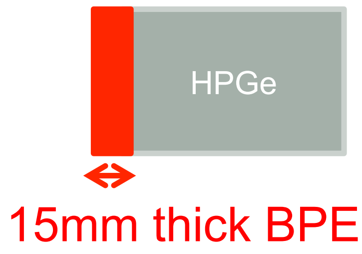


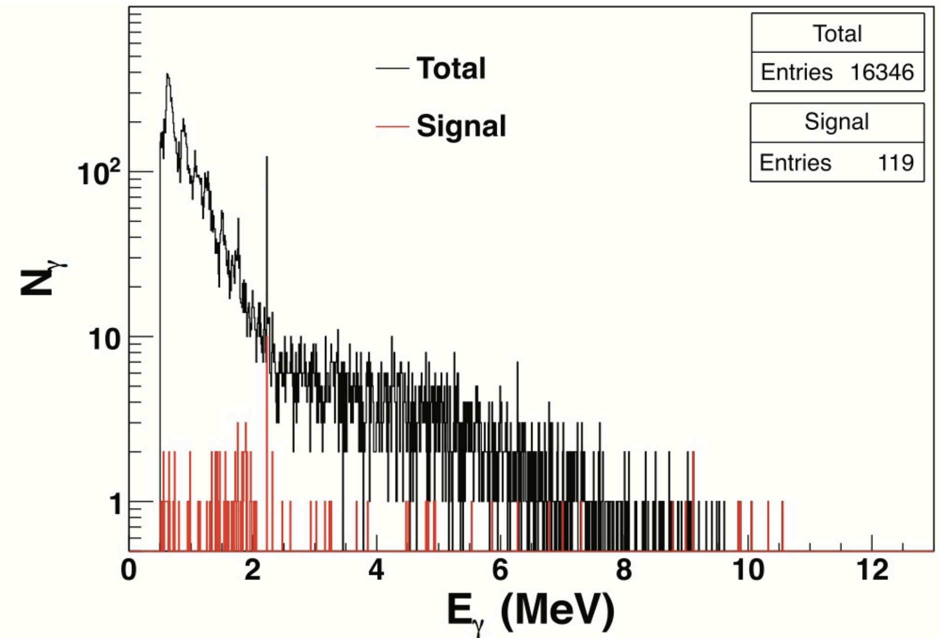
When intense laser beam bombards the deuterated polystyrene target(C_8D_8), neutrons are produced by deuteron-deuteron reactions.

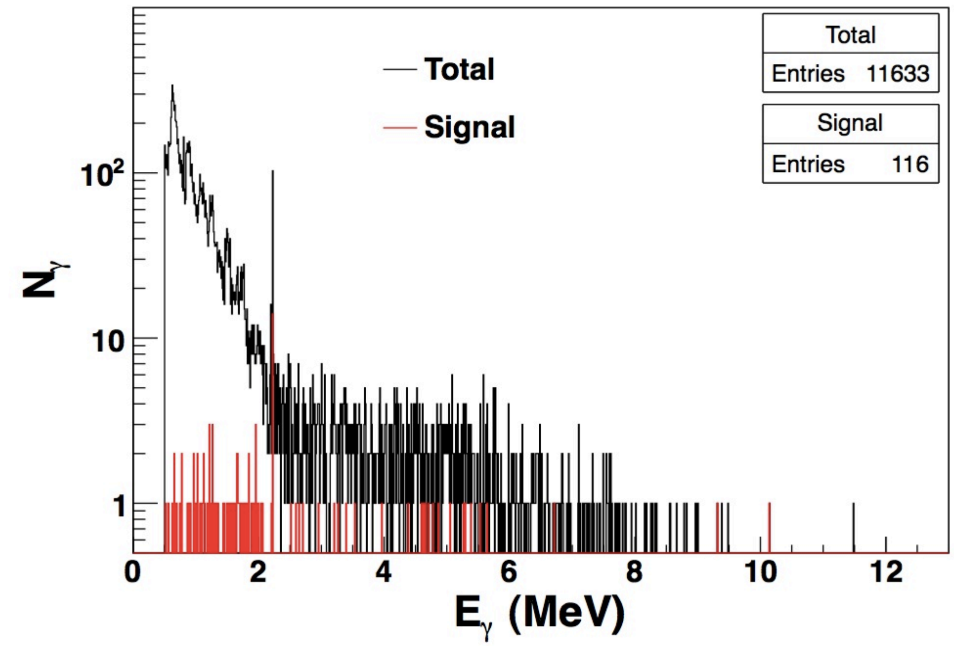
- maximum frequency : 10 Hz

Effect of the BPE shielding

- Compared the effect of neutron shielding window in the entrance of the HPGe detector
- Simulation conditions
  - Emitted neutron energy : 2.4 MeV
  - Emitted neutron direction : 4π
  - Number of simulated neutrons : 10^8
  - Sample : TNT($C_7H_5N_3O_6$)

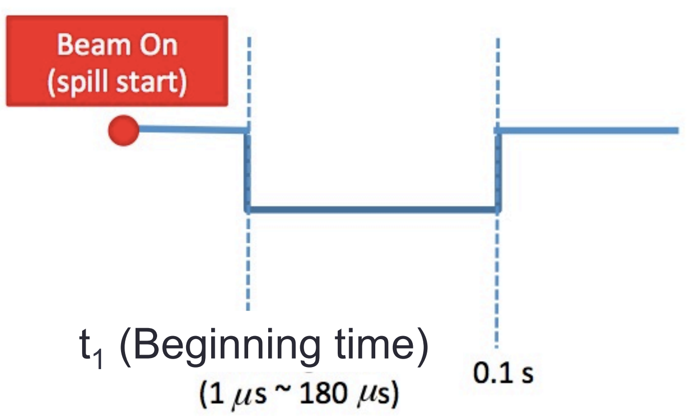


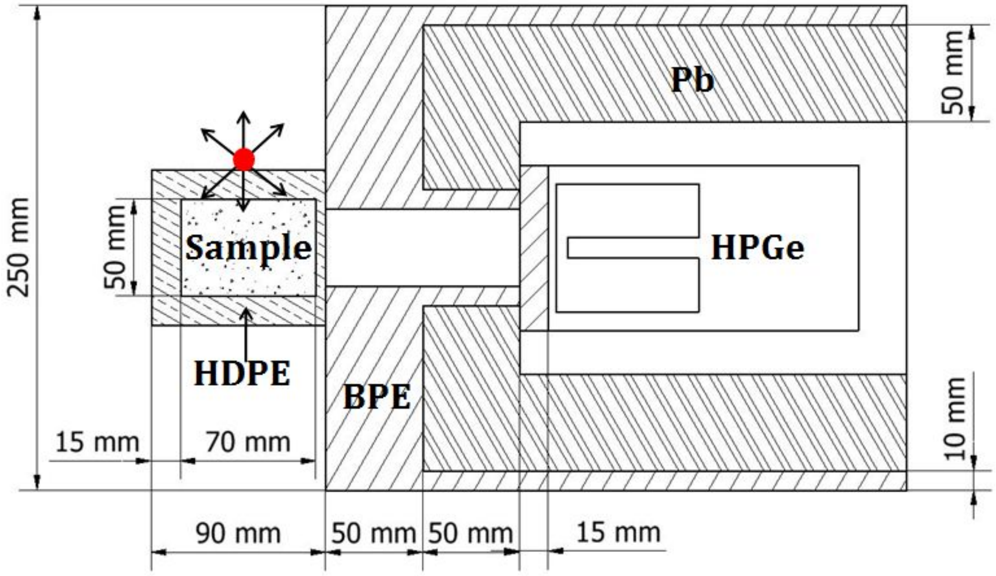




Effect of the timing constraint

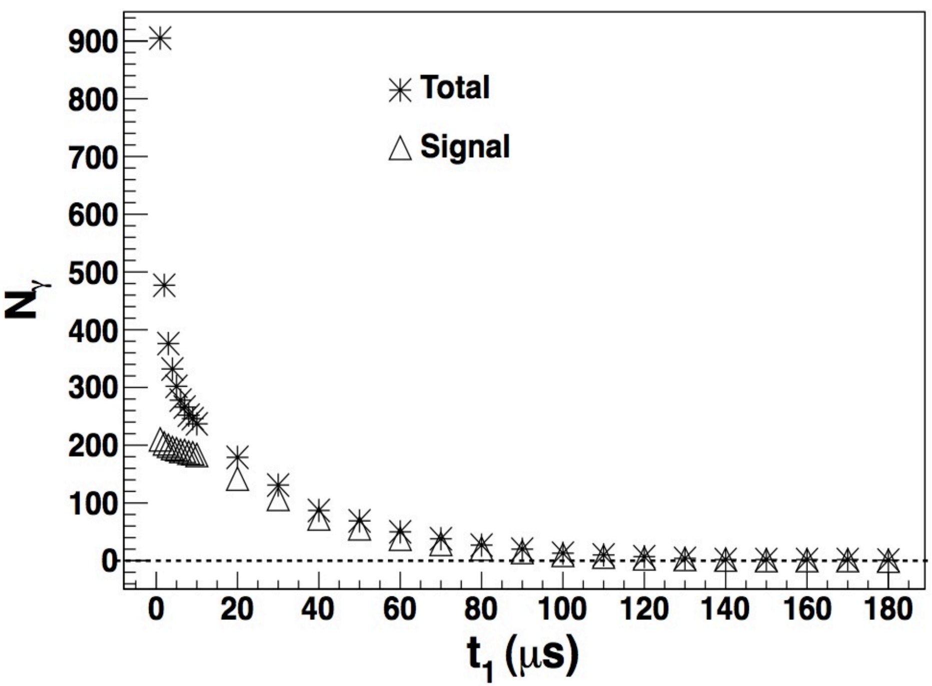
- Emitted neutron energy : 2.4 MeV
- Emitted neutron direction : 4π
- Number of simulated neutrons : 10^9
- Neutron shielding material : 5cm thick 30 % BPE
- Sample : TNT($C_7H_5N_3O_6$)
- BPE thickness in front of detector : 15 mm

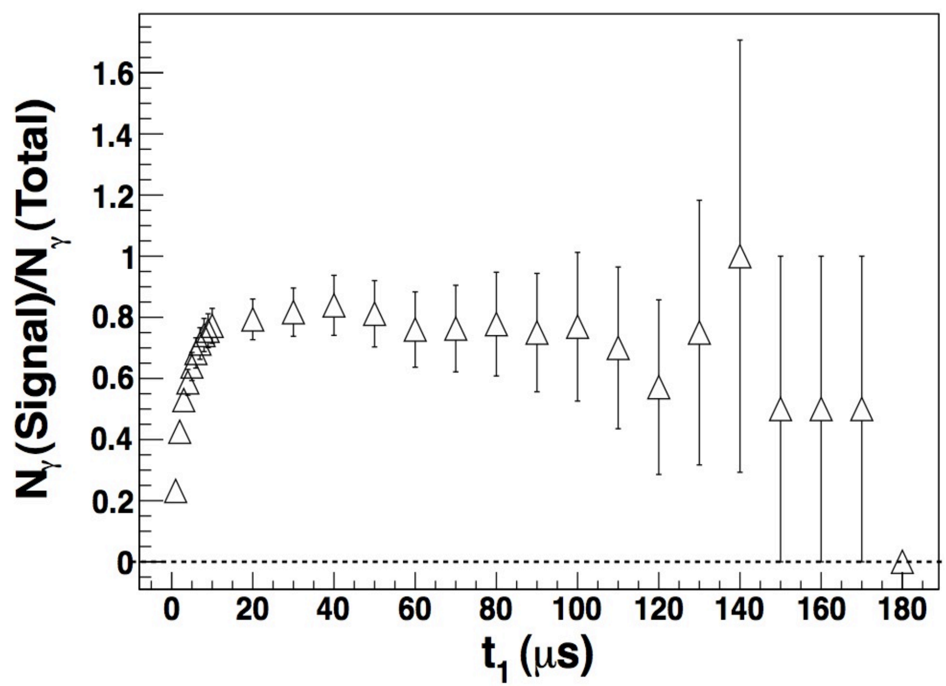




Effect of timing constraint

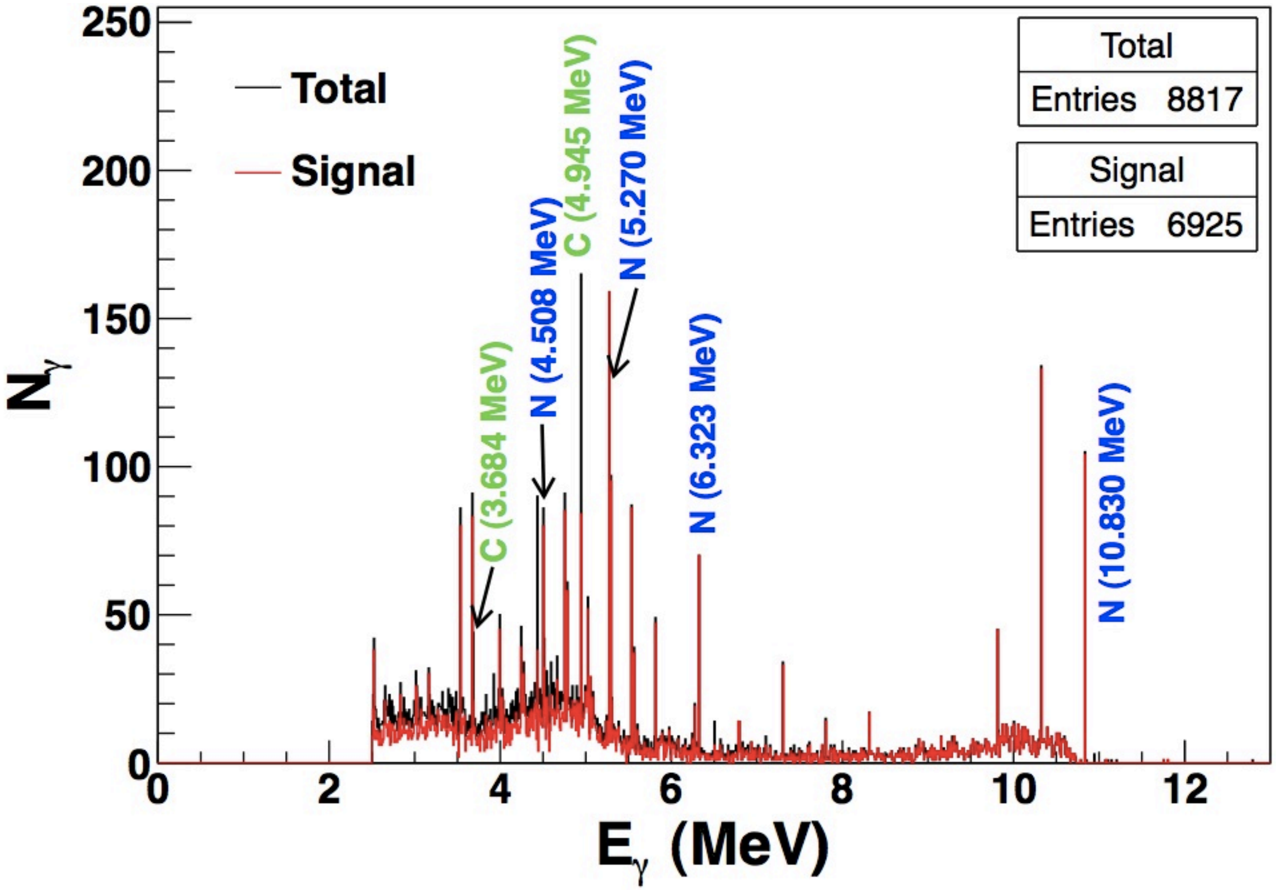
- Left figure shows the comparison of the signal and total gamma counts.(background are concentrated in a few μs after the generation of the neutron beam)
- Right figure shows that the fraction of the signal count increases up to about 10 μs and then saturates.





Energy spectrum for the TNT sample

- Total number of neutrons is $4*10^{10}$
- Applied time window from 10 to 100 μs
- Applied the cut-off for Eγ at 2.5 MeV



Estimated ratios of composite elements

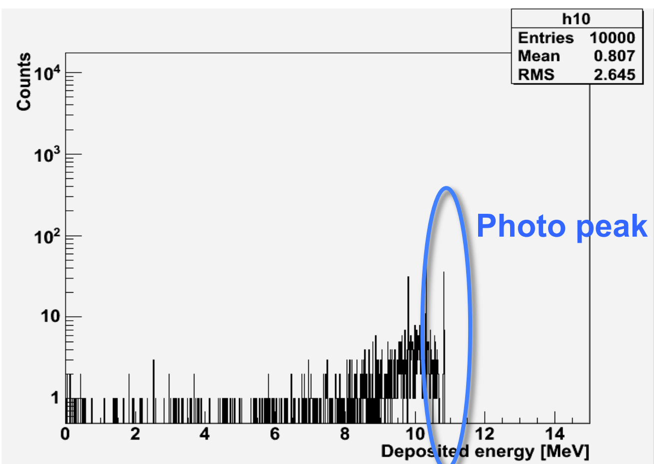
- Measured counts of gammas, N_γ, for each characteristic photo peak is closely correlated with the proportion of the corresponding element in the sample.

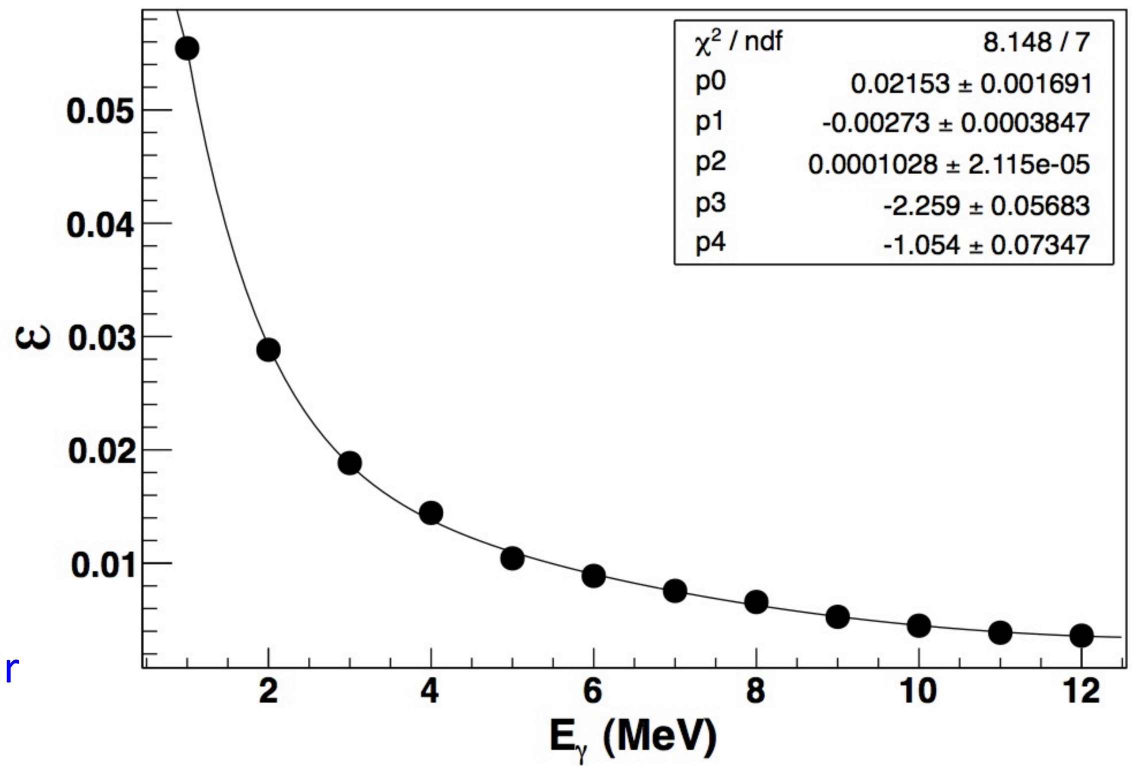
$$\frac{n_A}{n_B} = \frac{\sigma_B(E_n) I_B(E_\gamma) \varepsilon(E_\gamma)}{\sigma_A(E_n) I_A(E_\gamma) \varepsilon_A(E_\gamma)} \times \frac{N_{\gamma A}}{N_{\gamma B}}$$

- n : number of atoms
- N_γ : measured gamma counts
- $\sigma(E_n)$: neutron absorption cross section for the neutron energy E_n
- $I(E_\gamma)$: branching ratio to prompt gammas with energy E_γ
- $\varepsilon(E_\gamma)$: detection efficiency of the HPGe detector at E_γ

Photo-peak efficiency

- Figure shows the photo-peak efficiency of the HPGe detector to gammas as a function of the gamma energy between 1 and 12 MeV.

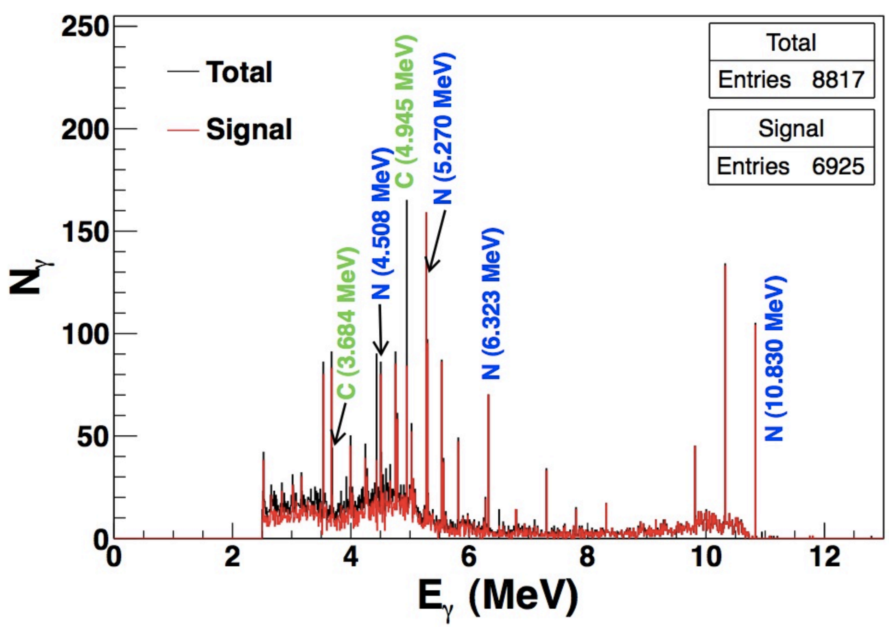


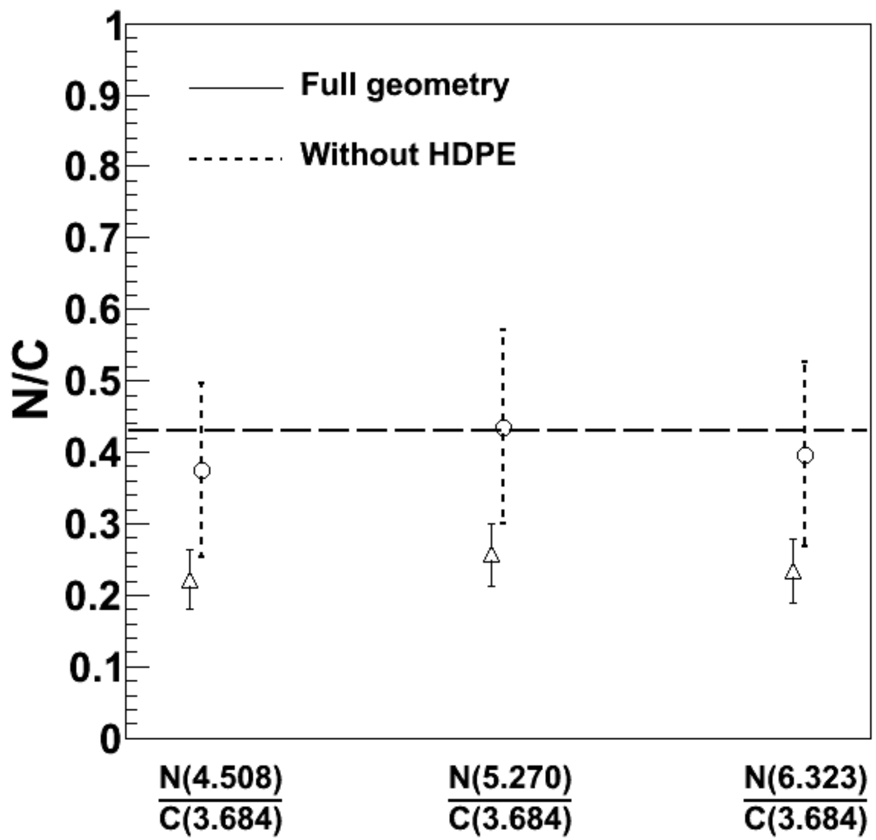


At high gamma ray energies, pair production is very significant.

Estimated ratios of N and C of the TNT

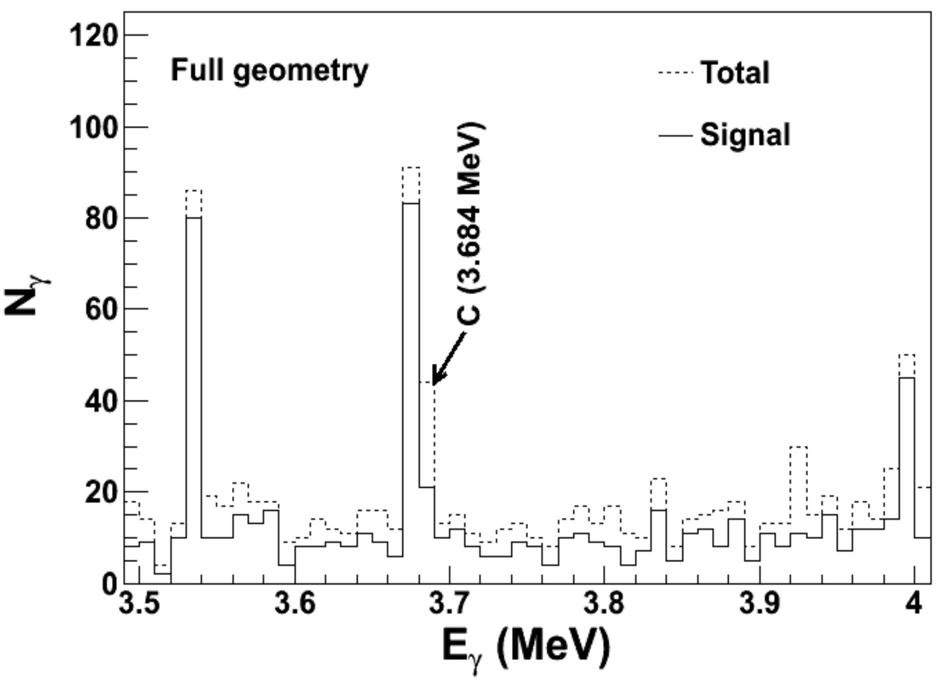
- The discrepancy between the simulated ratios for the full geometry and true ratio is caused by the relatively large background level for the peak at 3.684 MeV from C. (The dashed line at 0.43 indicates the true ratio of N and C in the sample)

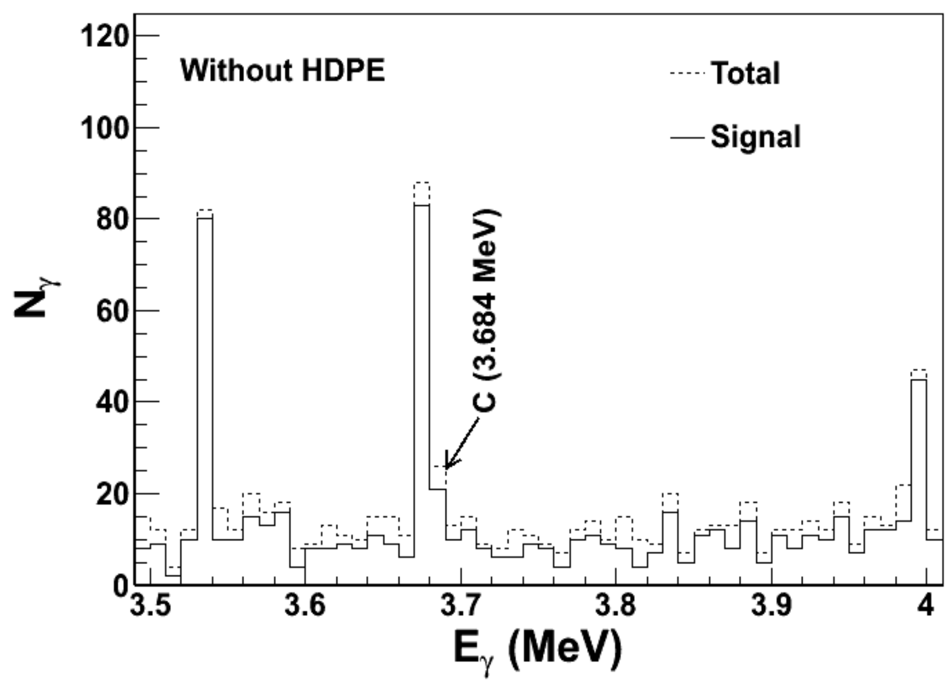




Background by sample container

- Compared the energy spectra of gammas with and without the sample container.
- By removing the HDPE sample container, the background events of C line are markedly reduced.





Summary

- The PGNAA system is a useful tool to non-destructively measure the composition of elements in the sample in real time.
- BPE window reduces the background significantly. But the signal peaks from the sample are not yet identifiable.
- Spectrum allows us to estimate the number of gammas corresponding to each characteristic photo peak when a proper time window has been imposed.(Background concentrated in a time span of a few microsecond.)
- The yield ratio of nitrogen to carbon in a TNT sample is investigated in detail. Estimated ratios without HDPE container agree well with the nominal value within statistical error.

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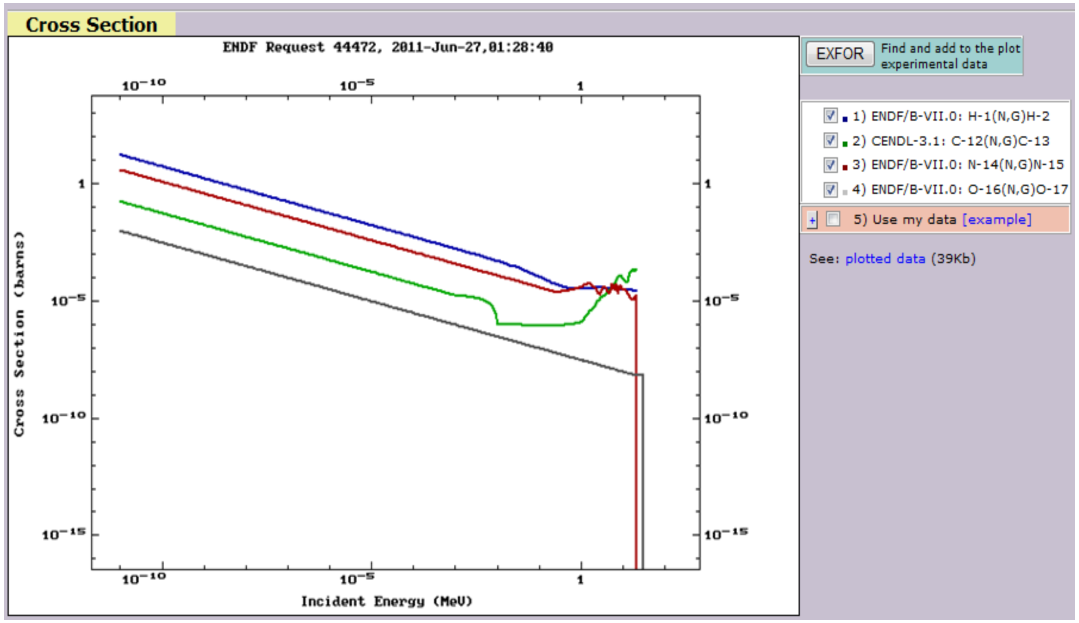

	Energy [MeV]	Intensity (I)	$\sigma(E_\gamma, E_n)$
C	3.683	32.10	0.109
C	4.945	67.64	0.229
N	5.269	29.73	2.230
N	5.297	21.02	1.577
N	6.322	17.78	1.334
N	10.829	14.12	1.059
O	3.271	18	1.66×10^{-4}

- Neutron capture cross-sections of C, N, O at thermal neutron are 3.38×10^{-3}, 7.53×10^{-2} and 1.91×10^{-4} [barn] respectively.
- Intensity : number of gamma rays per 100 neutron captures.

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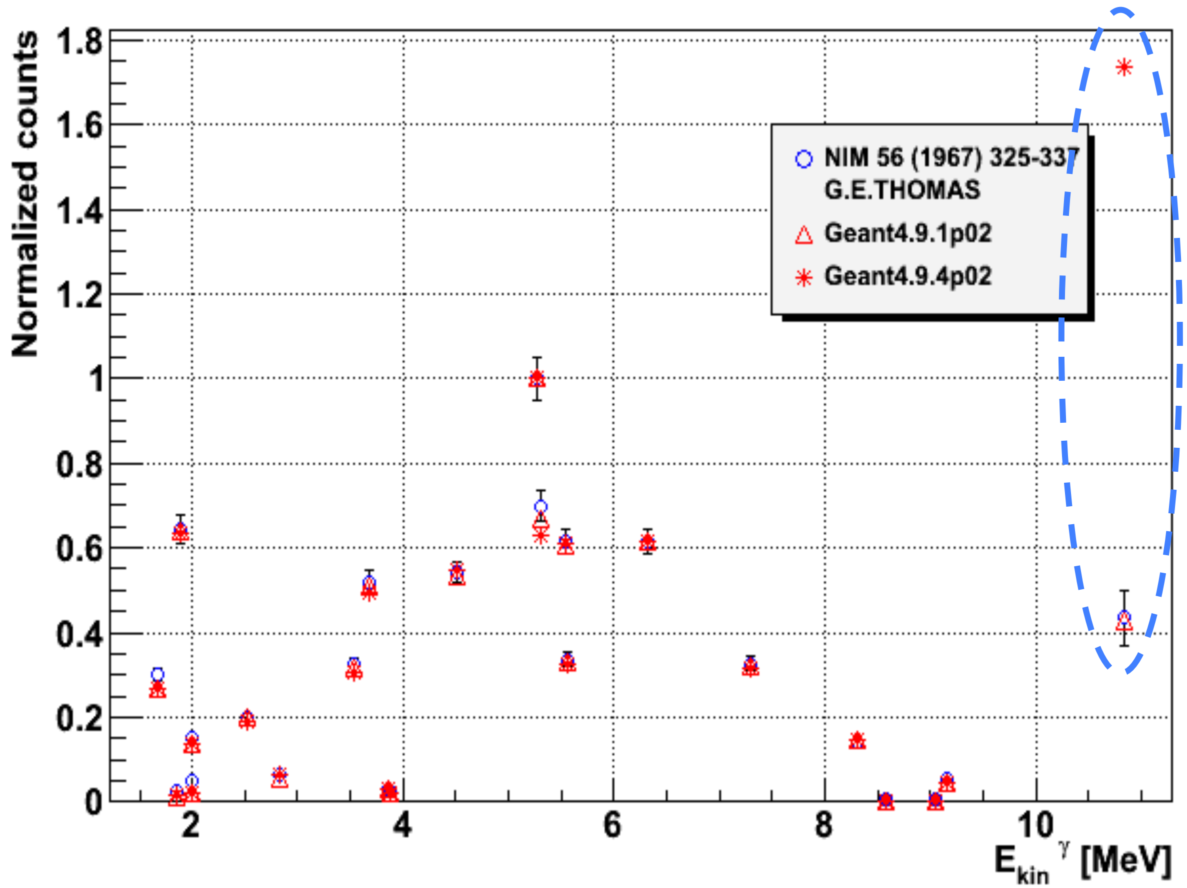
- Same source file results under condition of two different GEANT versions (geant4.9.1p02, geant4.9.4p02)



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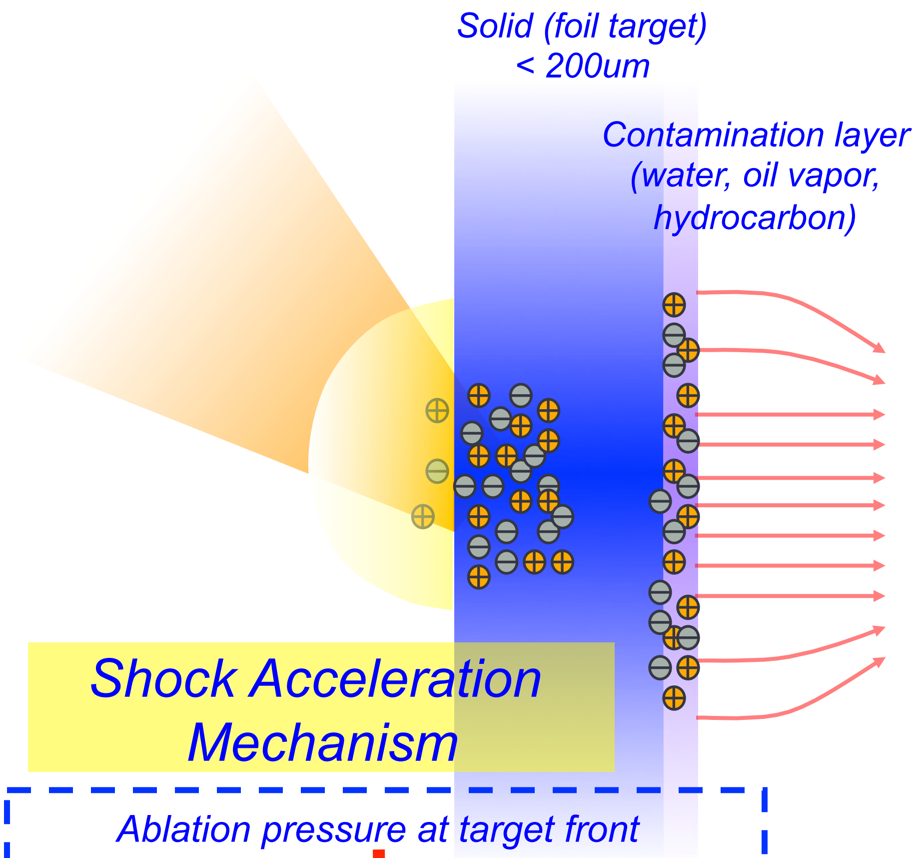

Shock Acceleration Mechanism

Ablation pressure at target front

↓

Induce Shock and reflected by dense plasma

↓

2 Acceleration of ions at front side

Target Normal Sheath Acceleration Mechanism

Pre-pulse
(contrast ratio: $10^{-5\sim-6}$: $>10^{12}$W/cm^2)

↓

Generation of preplasma
ionization: multiphoton, tunneling, collisional

↓

Interaction of main pulse with preplasma ($>10^{18}$W/cm^2)

↓

Ponderomotive acceleration of electrons

↓

Charge separation → ES field

↓

1 Acceleration of ions at rear side

$D + D \rightarrow n + {}^{3}He$