# CNS Ge Array for Spectroscopy of Fast Moving Exotic Nuclei

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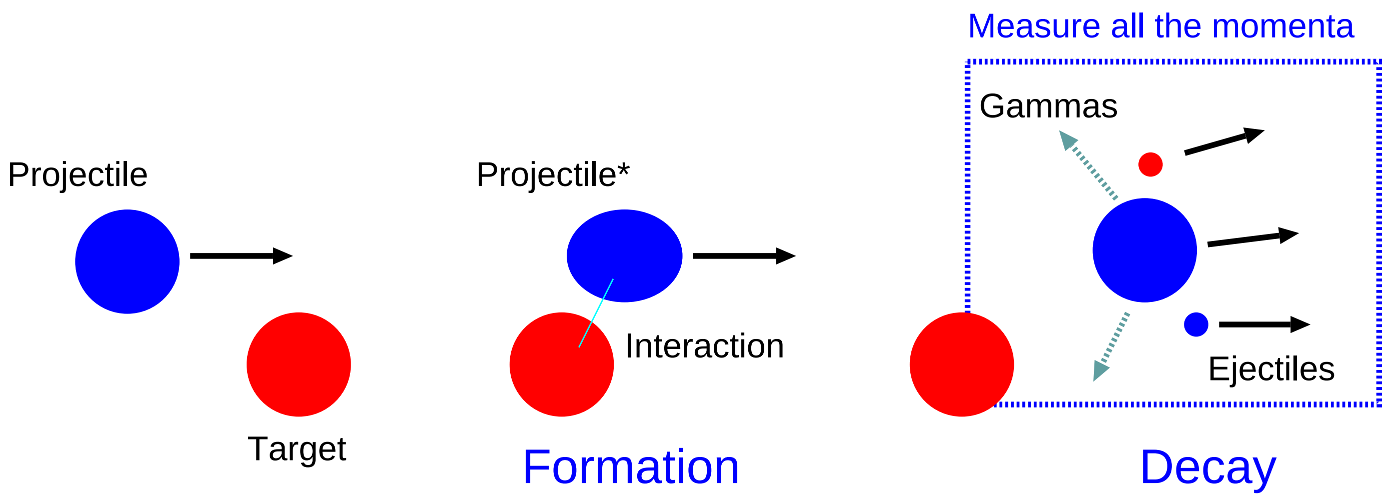
# Inverse Kinematics

## Formation of Excited States and Their Decays




**Direct reactions at incident energies above several tens of MeV**

**Target as a Physical Probe**

**Velocities of Ejectiles are almost same as that of projectile**

**Gamma-rays are Doppler-Shifted**

## Spectroscopy of Beam-Like nuclei with Targets as Probes

**Heavy Nuclei: Strong Coulomb Field**

- **Coulomb Excitation, Coulomb Dissociation**
  - **Isovector E1, E2, multi-step for heavier nuclei**

**Hydrogen, Deuterium**

- **Inelastic Scattering, Charge Exchange, Knockout**
  - **Isoscaler/Isovector, Spin Flip/non Flip, M1, Fermi, GT ...**

**$^{4}$He**

- **Inelastic Scattering, Nucleon Transfer**
  - **Isoscaler, Spin non Flip, ISE0, ISE1 ...**

**$^{6}$Li, $^{7}$Li**

- **Inelastic Scattering, Charge Exchange**
  - **Isovector, Spin Flip/non Flip, M1, GT ...**

**Other targets (C etc.)**

- **Inelastic Scattering, Knockout, Fragmentation**

# Doppler Shift of Gamma-Ray

## Transformation between CM and Lab system

$$
\begin{aligned}
E_L &= E_C \gamma (1 + \beta \cos\theta_C) \\
\cos\theta_L &= \frac{\beta + \cos\theta_C}{1 + \beta \cos\theta_C} \\
E_C &= E_L \gamma (1 - \beta \cos\theta_L) \\
\cos\theta_C &= \frac{-\beta + \cos\theta_L}{1 - \beta \cos\theta_L}
\end{aligned}
$$

$$
\begin{aligned}
\frac{d\Omega_C}{d\Omega_L} &= \frac{1 - \beta^2}{(1 - \beta \cos\theta_L)^2} \\
\frac{1}{E_C} \cdot \frac{\partial E_C}{\partial \theta_L} &= \frac{\beta \sin\theta_L}{1 - \beta \cos\theta_L} \\
\frac{1}{E_C} \cdot \frac{\partial E_C}{\partial \beta} &= \gamma^2 \cdot \frac{\beta - \cos\theta_L}{1 - \beta \cos\theta_L}
\end{aligned}
$$

**Good angular resolution is required for high resolution spectroscopy**

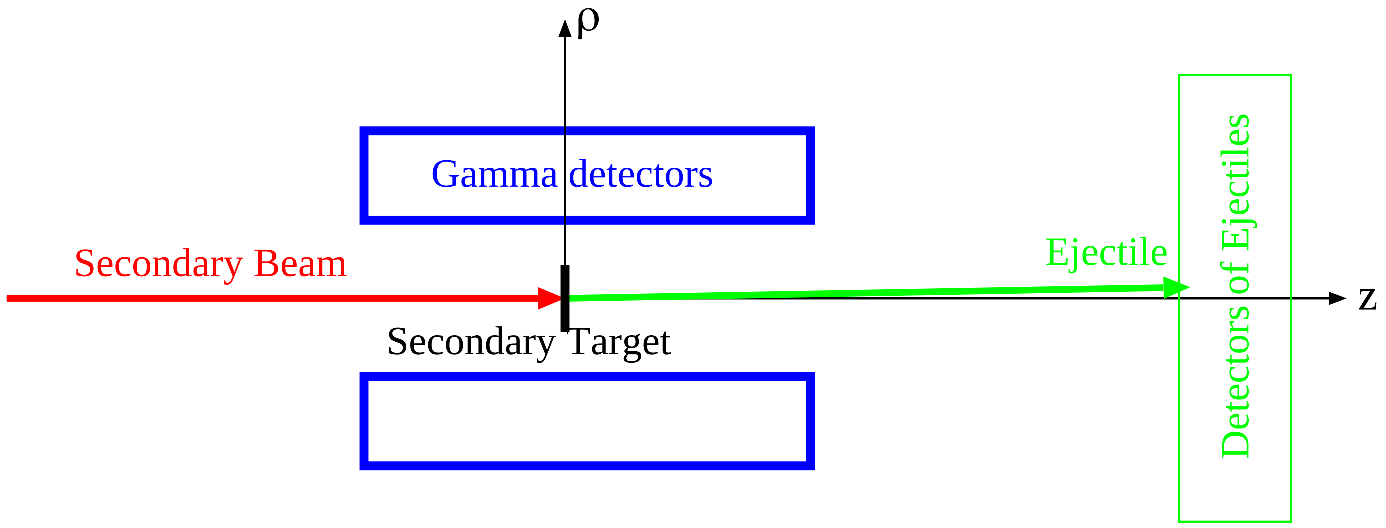
**Ideal Case**

**As large acceptance as possible,**

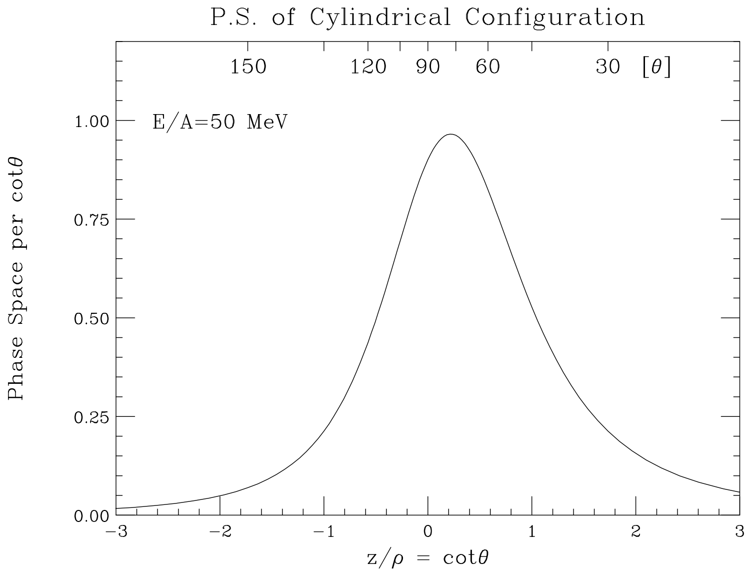
**but spaces for incoming beam and outgoing ejictiles**

$\Longrightarrow$ **TUBE covering around 90 degree**

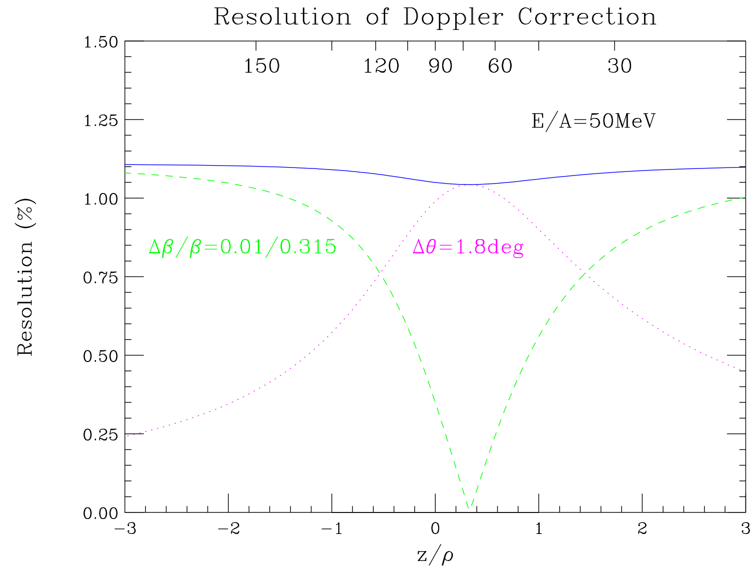
Ideal Configuration



## Phase Space




## Resolution of 1-2 degree needed




**$\Delta\beta$ = 0.01 corresponds to 50 $A$ MeV $^{12}$Be+ 250 mg/cm$^2$ Be target**

**50 $A$ MeV $^{32}$Mg+ 70 mg/cm$^2$ Be target**

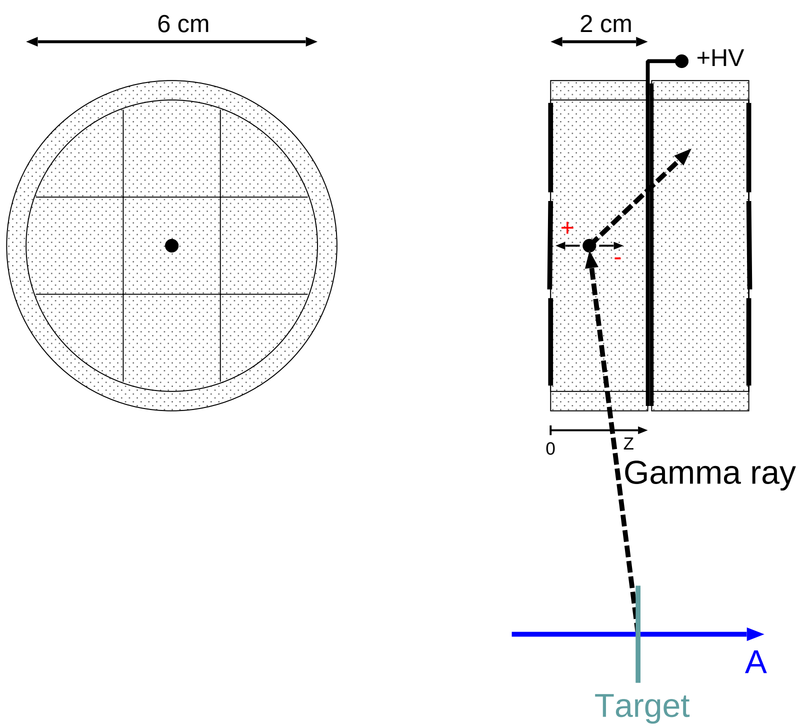
**50 $A$ MeV $^{68}$Ni + 30 mg/cm$^2$ Be target**

**200 $A$ MeV $^{68}$Ni+ 200 mg/cm$^2$ Be target**

## Detector

**Planar-type detector**

**Pulse-shape analysis to determine vertex points in the direction parallel to that of the Electric Field**




**Active Volume: $2^t \times 6^\phi$ cm$^3$**

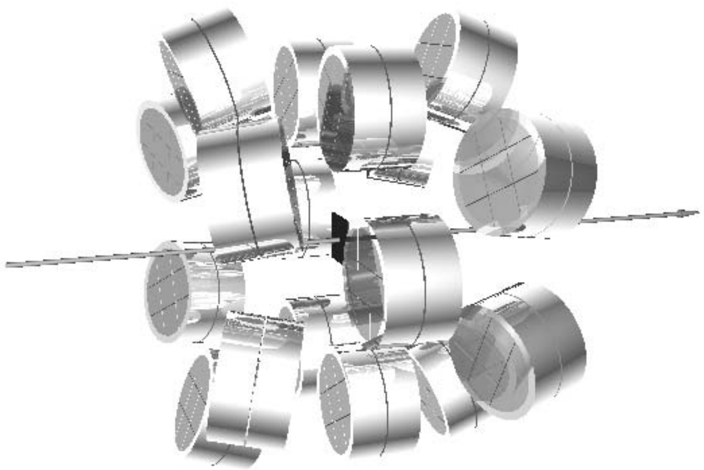
**Segmentation: $3 \times 3$**

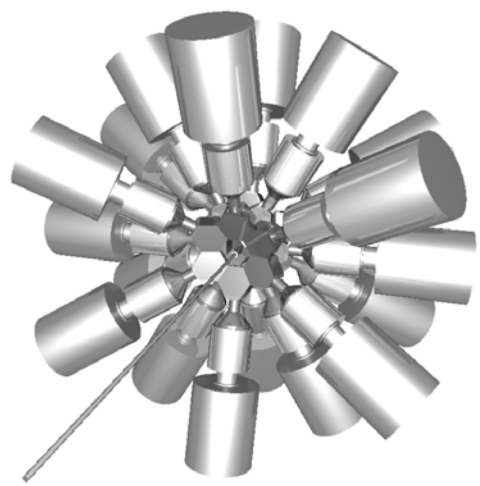
**2 crystals in 1 cryostat**

# CNS Ge Array

## Array Configuration

**Locates 18 detectors around 90 degree**



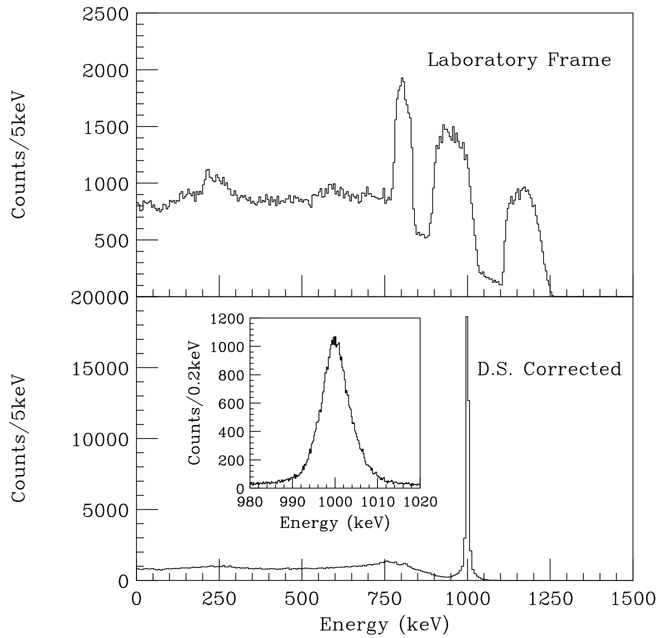


**all the detectors are ready NOW**

# Expected Performance

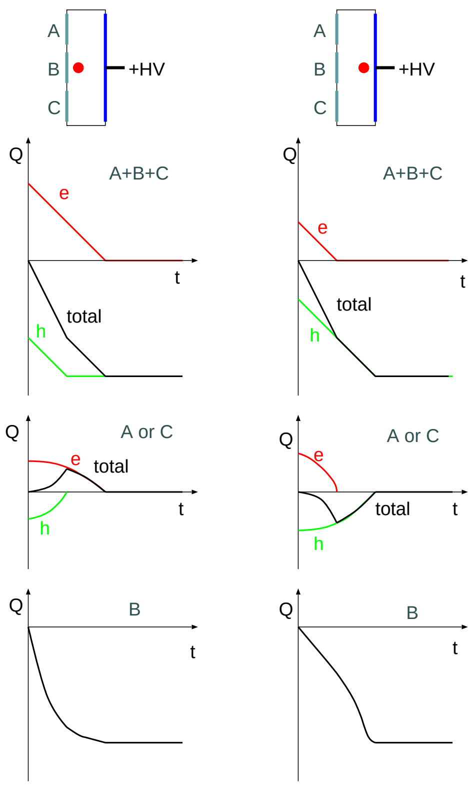
**For 1-MeV $\gamma$ from $\beta = 0.3$ Emitter**

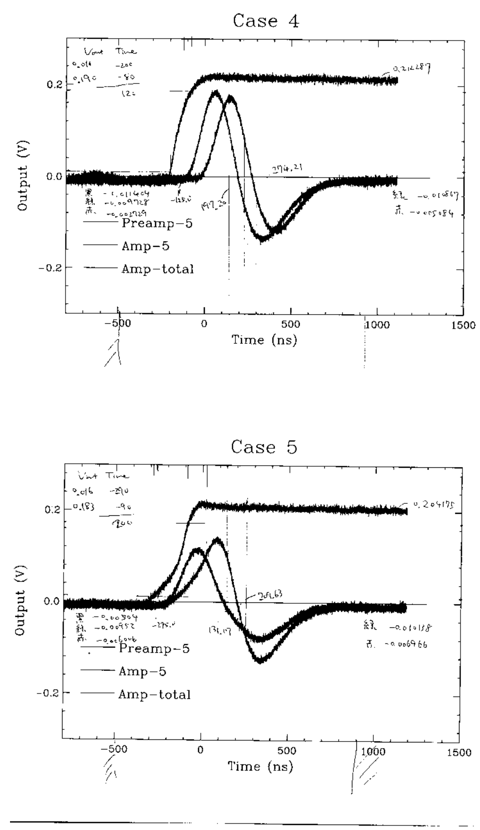
**Energy Resolution**
**for D.S. Correction**
**1% (FWHM), 2% (FWTM)**
**Total detection efficiency ($\varepsilon\Omega$)**
**5 %**



# Pulse Shape Analysis

Pulse Shape (saturated drift velocity)

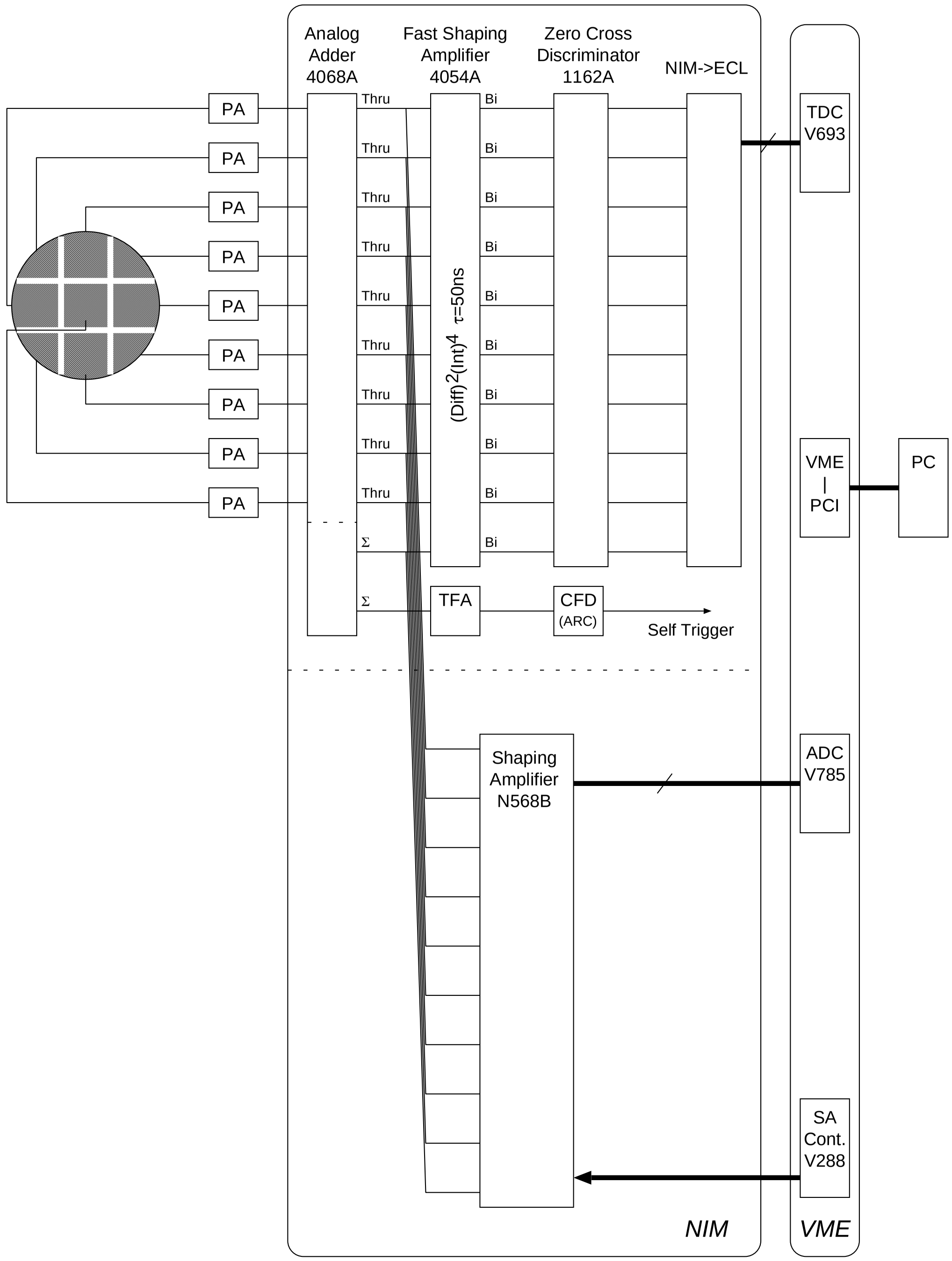



**Small Pixel Effect**

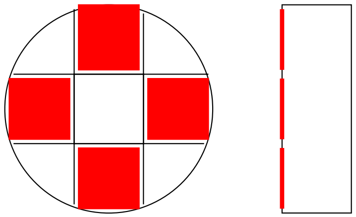
**Fast Shaping (Diff)$^2$(Int)$^4$ $\tau = 50$ns**

# Circuit Diagram



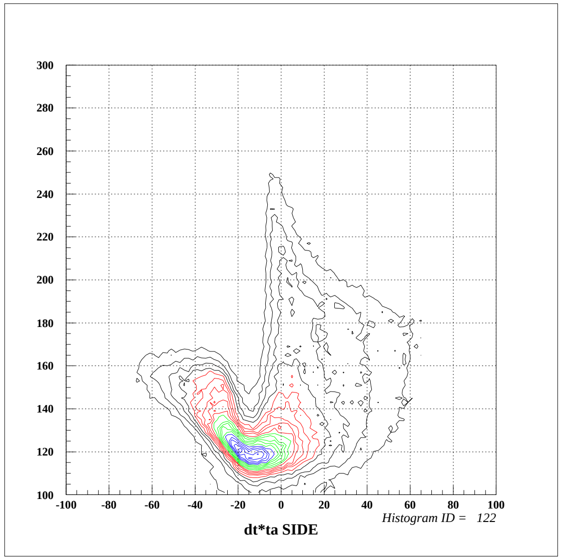
# Pulse Shape Analysis

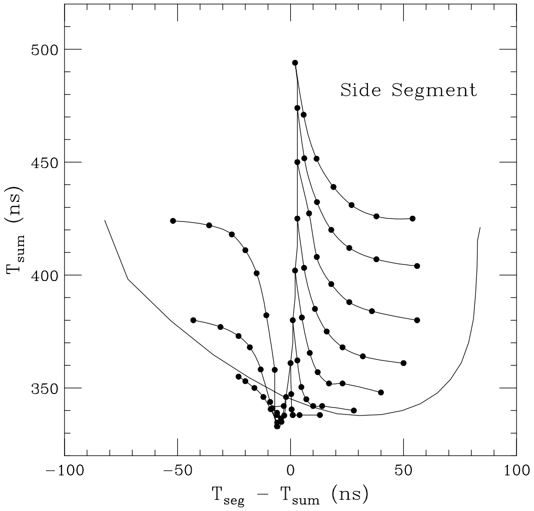
(Example)



**Experiment**

Simulation

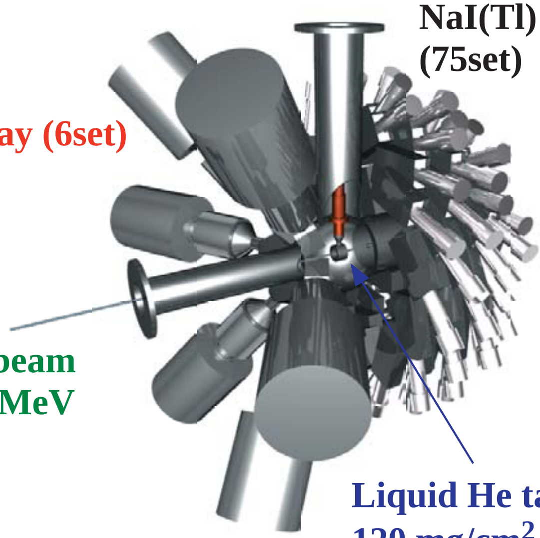


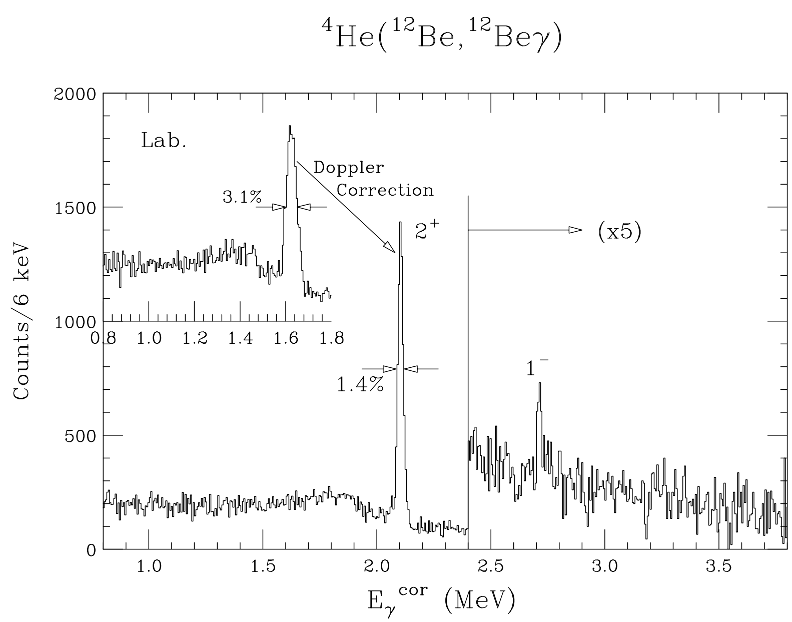

$T_{\mathrm{HIT}} - T_{\mathrm{SUM}}$ **vs.** $T_{\mathrm{SUM}}$

# First Experiment in July, 2002

## Setup



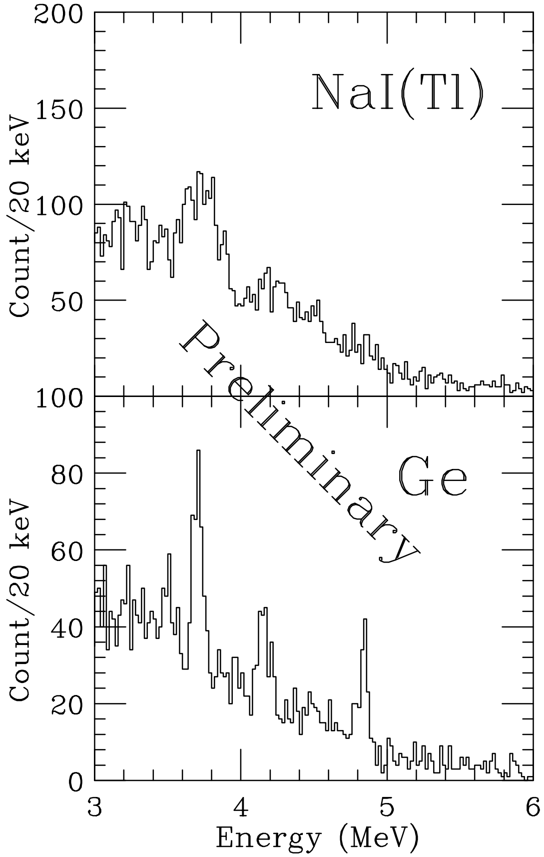

## $^{4}$He($^{12}$Be,$^{12}$Be$\gamma$) at 50 $A$ MeV




**about 5-mm position resolution was achieved for entire active volume**

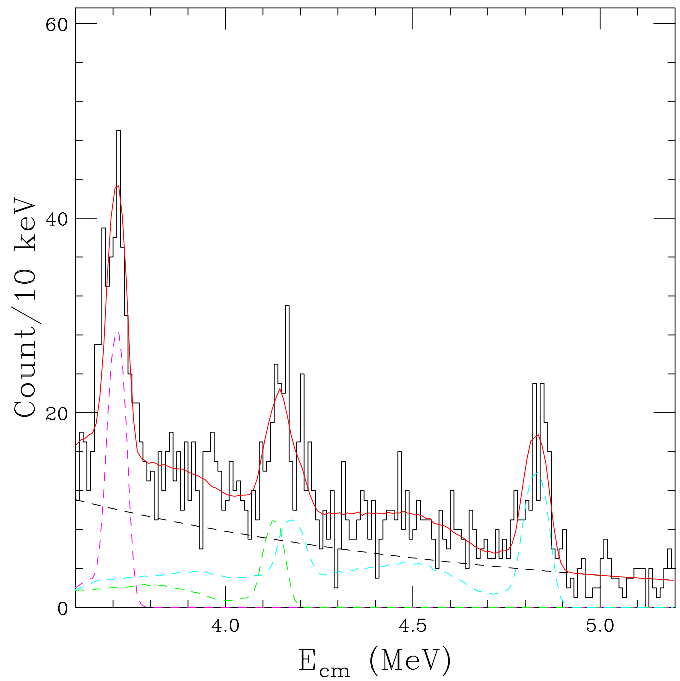
# $^{4}$He($^{12}$Be,$^{13}$B$\gamma$) at 50 $A$ MeV

## Comparison between NaI(Tl) and Ge




## Peak fitting using GEANT simulation

**$E_{decay}$ = 4829, 4131 and 3713 keV are assumed**



## General Characteristics of Planar Detectors

- **Simple structure of the electric field.**
- **By using small pixel effect, position information for depth can be extracted.**
- **In this sense, double sided strip detector may be a better candidate for 3-dimensional tracking.**
- **The insensitive edge region may be problem for determining efficiencies with high accuracy, which is required for High-multiplicity events.**

## Summary

- **CNS Ge array for $\gamma$ spectroscopy of fast moving exotic nuclei is NOW ready for operation**
- **Position information in a Ge crystal is derived from Pulse Shapes of “Hit” and “Sum” signals**
- **By using analog circuits for pulse-shape analysis at least 5-mm resolution for the $z$-direction was achieved, which will be improved**
- **Simplicity of the electric field and insensitivity at edge region are to be considered, the weight of which depends on the main purpose for a new detector system.**