# Detector Array for Low Intensity radiation

## DALI and DALI2

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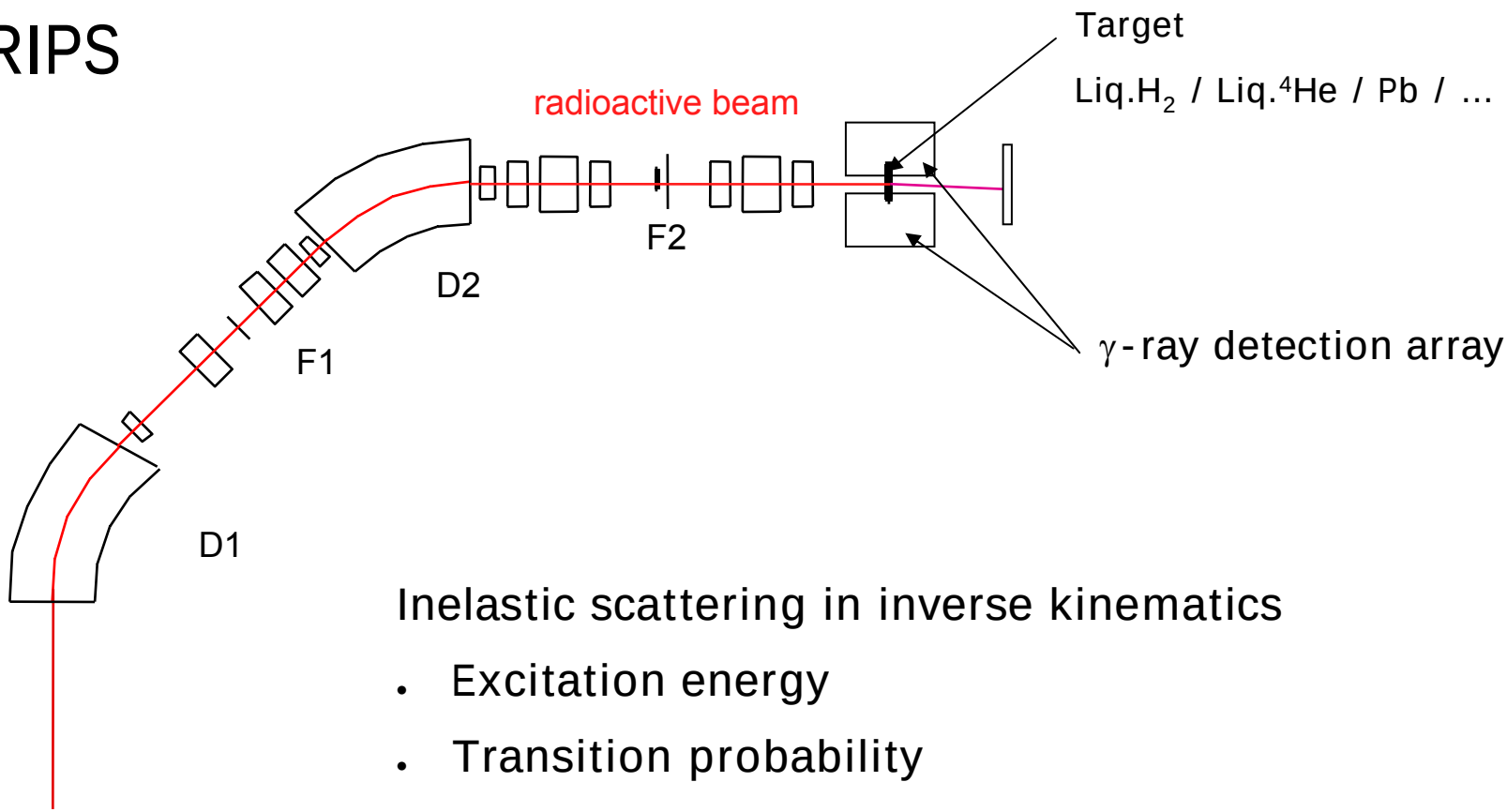
# γ-RAY SPECTROSCOPY WITH UNSTABLE NUCELI

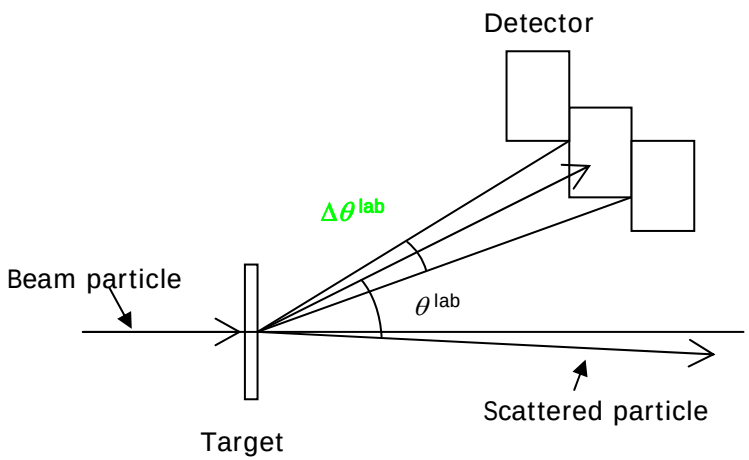
RIPS



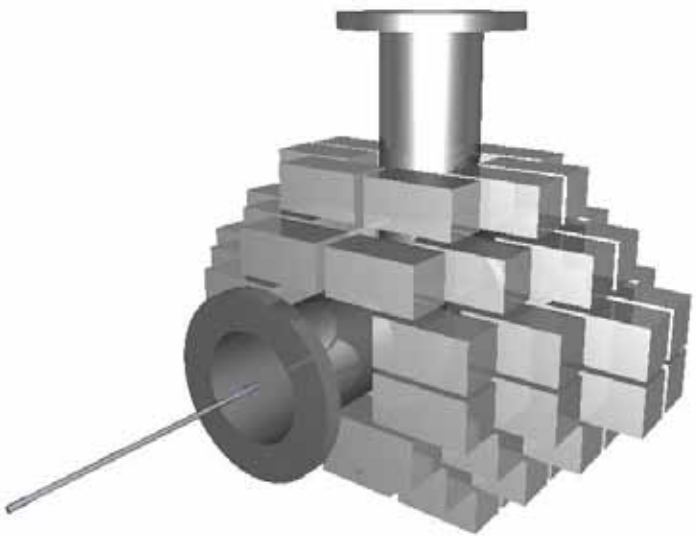

Inelastic scattering in inverse kinematics

- Excitation energy
- Transition probability
- Angular distribution for particle-γ

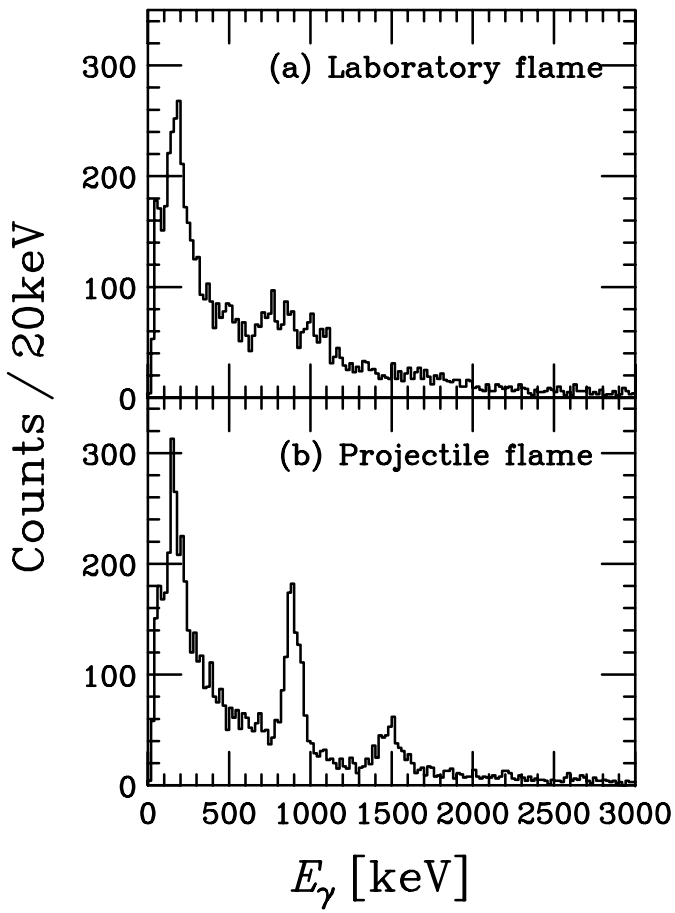
- Unstable nuclei
  - Low Beam intensity
    - → High detection efficiency
- Fast secondary beams
  - RARF ($\beta$ ~ 0.3) and RIBF ($\beta$ ~ 0.6)
    - → Doppler Shift
      Depending on the emission angle
    - → High angular resolution for High energy resolution



# DALI



$^{32}$Mg(p,p') β~0.3




H.Hasegawa, Master's thesis, Rikkyo Univ., 2003

Previous system (typical spec.)

- up to 68 NaI(Tl) detectors
- angular resolution : ~15 degree
- efficiency : about 15% for 1MeV

# DEVELOPMENT of A NEW ARRAY

## MOTIVATION:

- For More neutron-rich nuclei : Low Intensity
- For using at RIBF : Fast beam

## REQUIREMENTS:

- Higher Efficiency
- Higher Angular Resolution

  ⇔ • High Energy Resolution

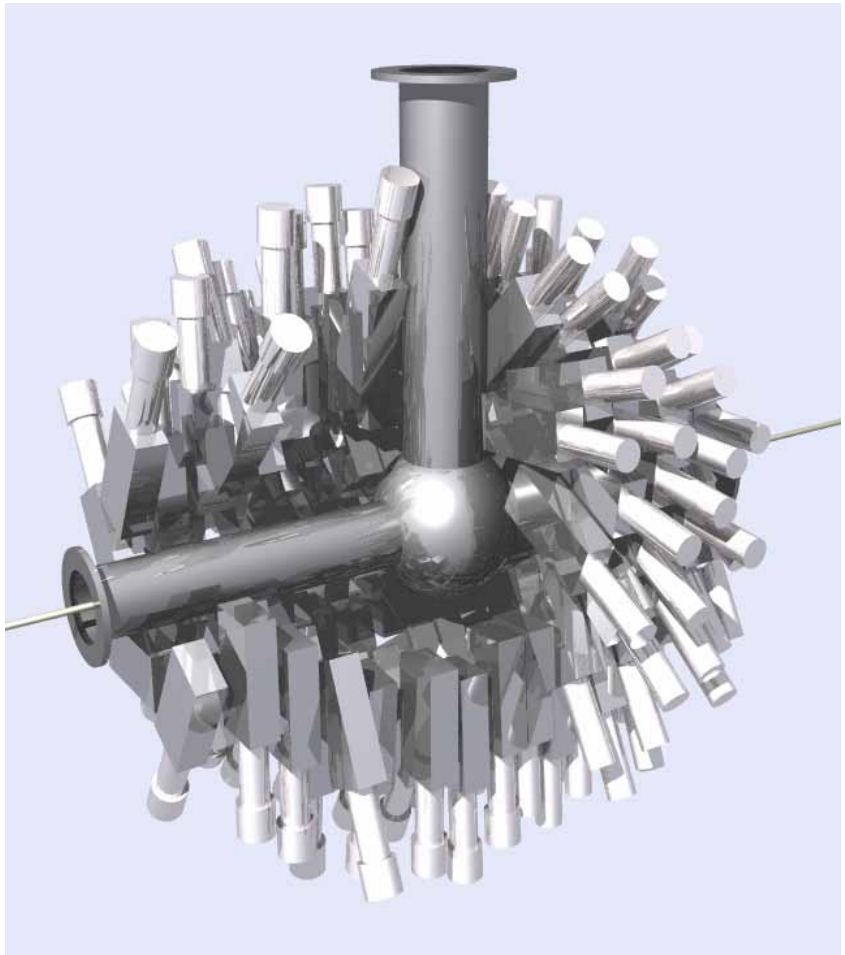
  • Angular Distribution measurements

↓

160 NaI(Tl) Detectors

Large Volume and Many Segments

# OVERVIEW - DALI2 -



160 NaI(Tl) detectors

Each detector
- 4.5 x 8 x 16 ($cm^3$)
- $\Delta E/E$ ~ 9% @ 662keV

Array
- 16 layers
- 6~14 detectors in each layer

# SPECIFICATION

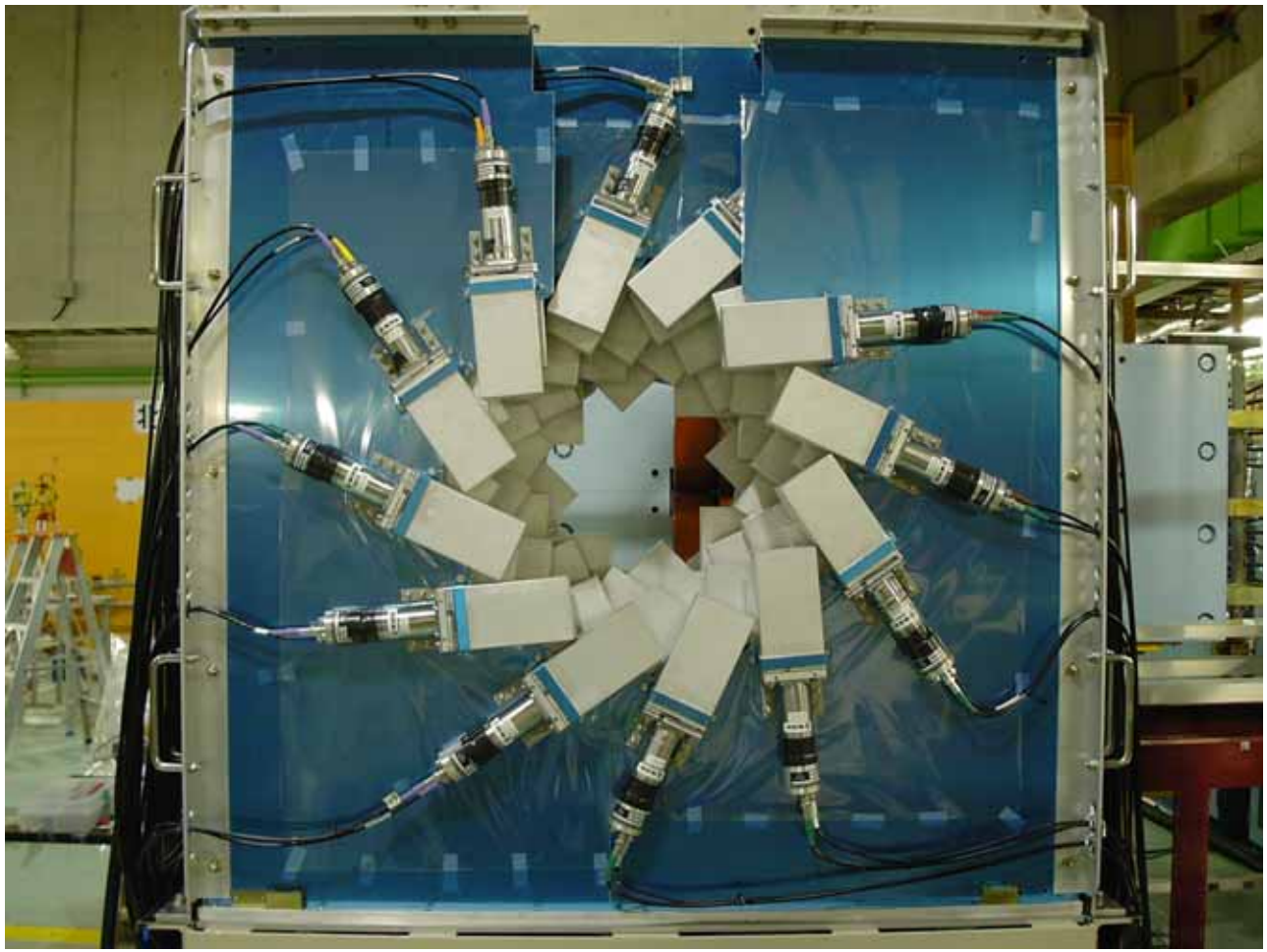
SAINT-GOBAIN x 80 detectors

- 45 x 80 x 160 (mm)
- About 8%@662keV ($^{137}$Cs)

SCIONIX x 80 detectors

- 40 x 80 x 160 (mm)
- About 9%@662keV($^{137}$Cs)

# Half of DALI2



# EXPERIMENT ROOM (E6 RIPS beam-line)

# DALI  and DALI2 

| | DALI | DALI2 |
|---|---|---|
| Arrangement | Brick wall like | Hedgehog like |
| Size | 6 x 6 x 12 ($cm^3$) | 4.5 x 8 x 16 ($cm^3$) |
| # of Detectors | 68 | 160 |
| Volume | ~ 30 liter | ~ 90 liter |
| # of Layers | 6 – 8 | 16 |
| Angular resolution | ~ 15 degree | ~ 8 degree |
| Energy resolution ($\beta$~0.3) | 12% @ 1MeV | 8% @ 1MeV |
| Efficiency ($\beta$~0.3) | 15% @1MeV | 21% @1MeV |

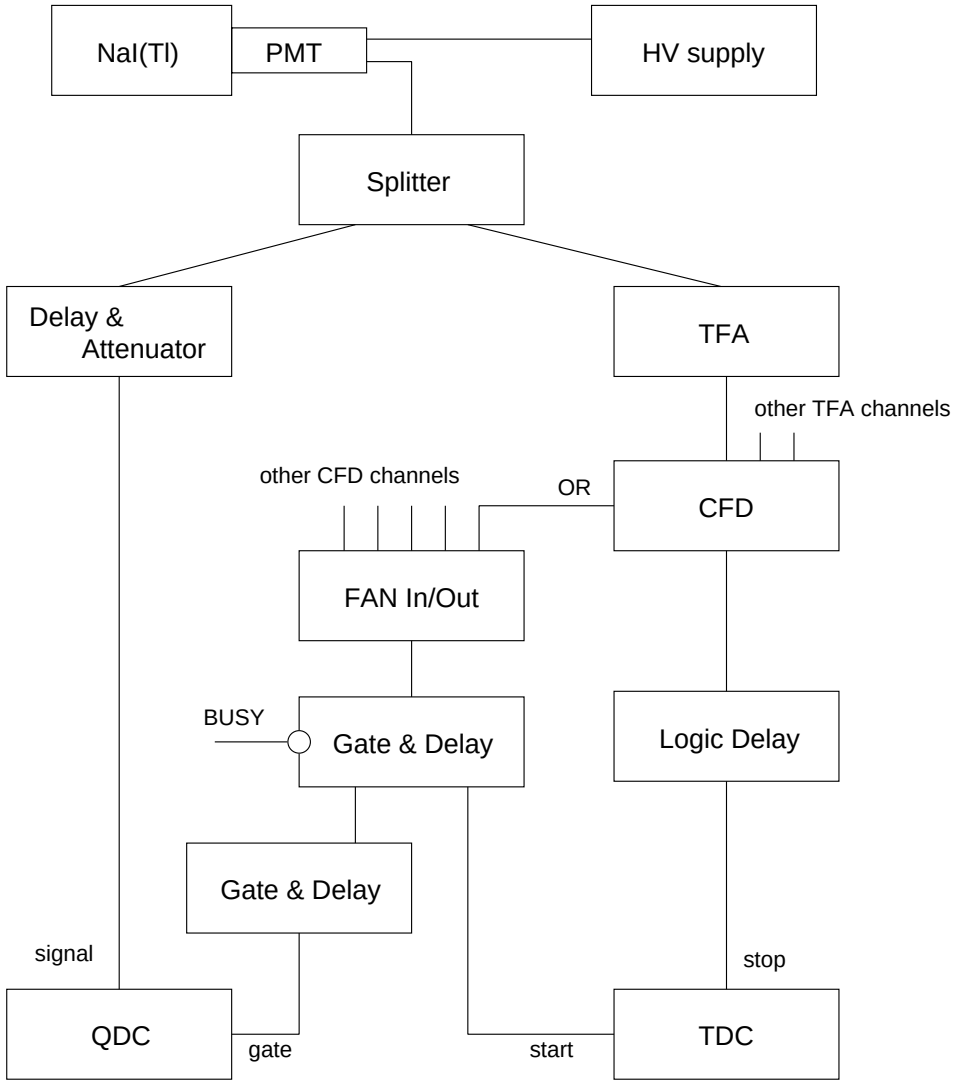
# CIRCUIT

Att. : 6-10dB or NONE

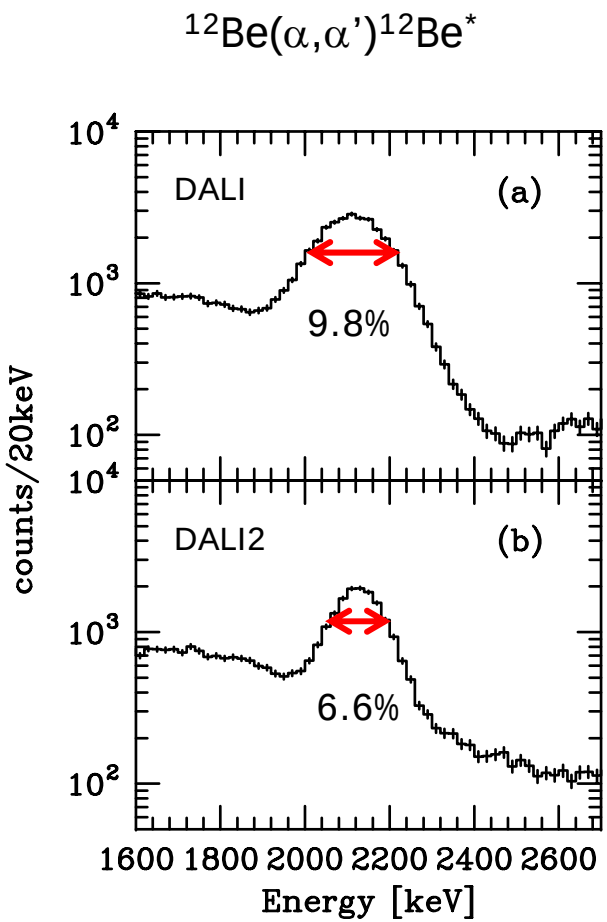
TFA : rise time ～ 50ns

QDC : GATE Width 500ns

Dynamic range
~100kev – ~5MeV



# IMPROVEMENT of ENERGY RESOLUTION




Eγ = 2100 keV, β ~ 0.3

(a) : DALI (Δθ~15°)

ΔE/E = 9.8% (FWHM)

(b) : DALI2 (Δθ~8°)

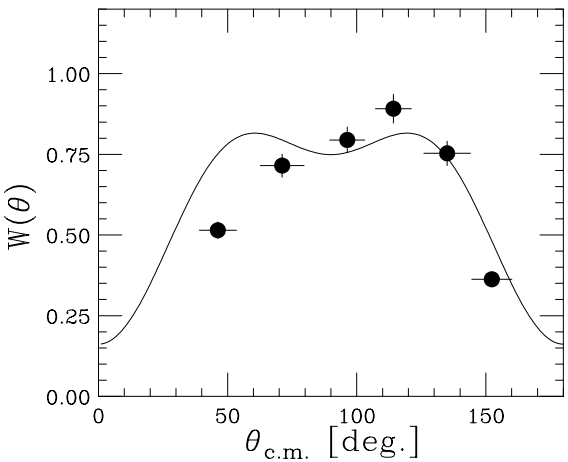
ΔE/E = 6.6% (FWHM)

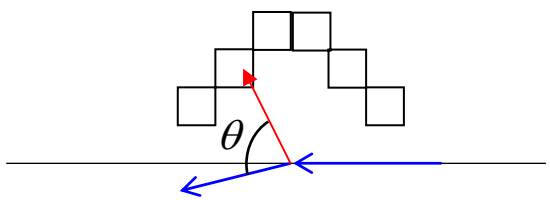
# IMPROVEMENT of ANGULAR DISTRIBUTION

## DALI

$^{36}$Si(Be,Be')$^{36}$Si*

E(2+) = 1399 keV

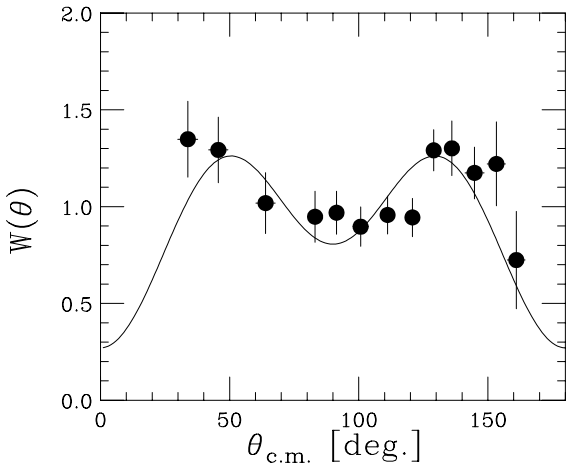


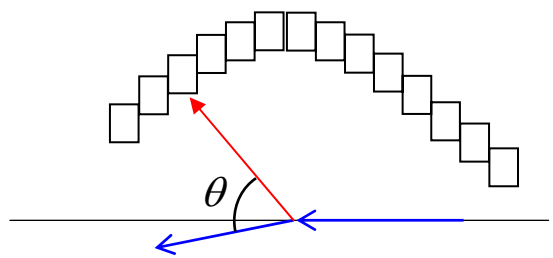




## DALI2

$^{16}$C(p,p')$^{16}$C*

E(2+) = 1766 keV



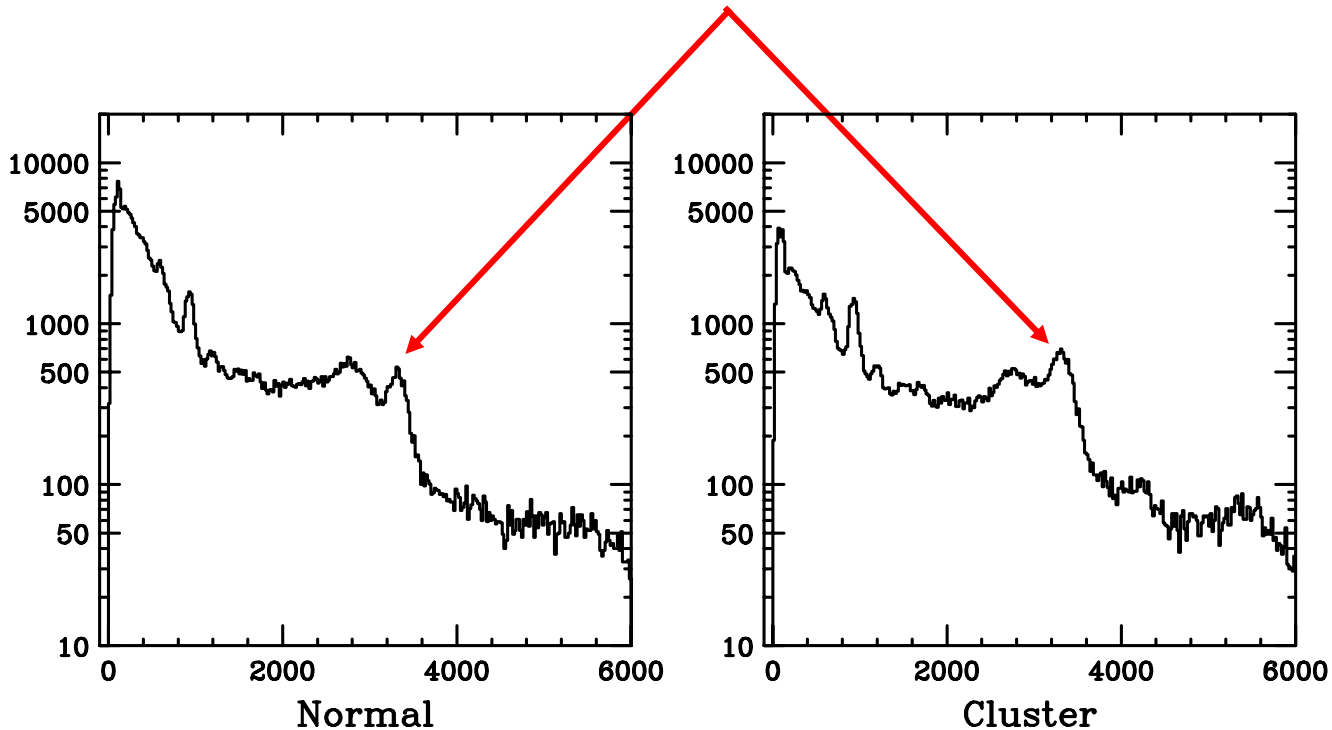



# PAST EXPERIMENTS with DALI2

- $^{12}$Be(**α**,**α**')$^{12}$Be$^{*}$,$^{12}$Be(**α**,t)$^{13}$B$^{*}$ (CNS, Rikkyo, RIKEN)
- $^{54}$Ni,$^{50}$Fe,$^{46}$Cr Coulex (Rikkyo, RIKEN)
- $^{27}$F(p,p')$^{27}$F$^{*}$,$^{16}$C(p,p')$^{16}$C$^{*}$ (ATOMKI, Tokyo, RIKEN)
- $^{4}$He($^{22}$O,$^{23}$F$^{*}$) (CNS, RIKEN)
- $^{26}$Ne(Pb,Pb)$^{26}$Ne$^{*}$ (Orsay, TIT, RIKEN)
- $^{78\text{-}82}$Ge Coulex (Tokyo, RIKEN)
- $^{19}$C(p,p')$^{19}$C$^{*}$ (ATOMKI, RIKEN)
- $^{22}$O(d,p)$^{23}$O (ATOMKI, RIKEN)
- $^{64}$Cr(p,p')$^{64}$Cr$^{*}$ (Rikkyo, RIKEN)
- $^{32}$Mg(p,p')$^{32}$Mg$^{*}$, $^{34}$Si(p,p')$^{34}$Si$^{*}$ (RIKEN)

# EXAMPLES - $^{34}Si(p,p')^{34}Si^*$ -

$^{34}Si^*$ $E_x(2^+)$ = 3326 keV




**解析方法によっては、収量が1.3倍になる。**

# Efficiency and Resolution

GEANT3 simulation

with target chamber and holder

$\beta$ = 0.3(RARF), 0.6(RIBF)

$E\gamma$ = 0.5, 1.0, 2.0 MeV

| | 0.5 MeV | 1.0 MeV | 2.0 MeV |
|---|---|---|---|
| Eff. ($\beta$=0.3) | 34% | 21% | 12% |
| Res. ($\beta$=0.3) | 11.6% | 8.0% | 6.5% |
| Eff. ($\beta$=0.6) | 31% | 18% | 8% |
| Res. ($\beta$=0.6) | 14.8% | 12.3% | 9.8% |

# SUMMARY

- We have developed DALI2 for in-beam $\gamma$-ray spectroscopy with fast unstable nuclei (@RIBF).
- The performance is improved compared with DALI.
  - Energy Resolution $\Delta E/E \sim 8\%@1MeV$
  - Detection Efficiency $\varepsilon \sim 21\%@1MeV$
- Several experiments have already done with DALI2 and we are planning experiments with low intensity beam and/or measuring $\gamma$-$\gamma$ coincidence.

# 課題

## RIBF仕様の配置を検討

### 検出器数の増加　(前方をカバー、角度分解能をさらにあげる)

DALI1＋DALI2 -> DALI3?

総数　：　２００個くらいか？

### 読み出し回路の検討

時間信号はそのまま回路を増やす

トリガー生成が早い

アナログは、SAMP -> ADC

アナログとゲートの関係が楽。

# DOPPLER SHIFT and BROADENING

$$E_\gamma^{\mathrm{proj}} = \gamma\left(1-\beta\cos\theta^{\mathrm{lab}}\right)E_\gamma^{\mathrm{lab}}$$

$$\left(\frac{\Delta E_\gamma^{\mathrm{proj}}}{E_\gamma^{\mathrm{proj}}}\right)^2 = \left(\frac{\beta\sin\theta^{\mathrm{lab}}}{1-\beta\cos\theta^{\mathrm{lab}}}\right)^2\left(\Delta\theta^{\mathrm{lab}}\right)^2 + \left(\frac{\beta\gamma^2\left(\beta-\cos\theta^{\mathrm{lab}}\right)}{1-\beta\cos\theta^{\mathrm{lab}}}\right)^2\left(\frac{\Delta\beta}{\beta}\right)^2 + \left(\frac{\Delta E_\gamma^{\mathrm{lab}}}{E_\gamma^{\mathrm{lab}}}\right)^2$$

Detector arrangement

Beam velocity or Target thickness

Intrinsic resolution