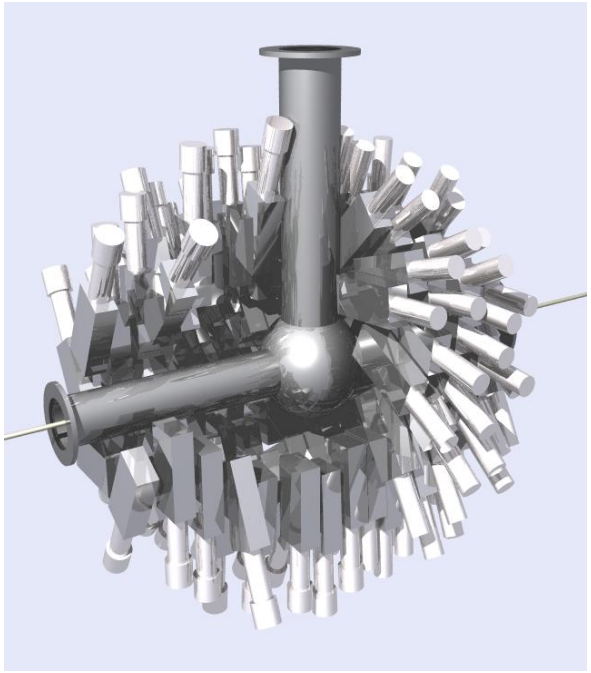
# DALI2

## – **D**etector **A**rray for **L**ow **I**ntensity radiation 2

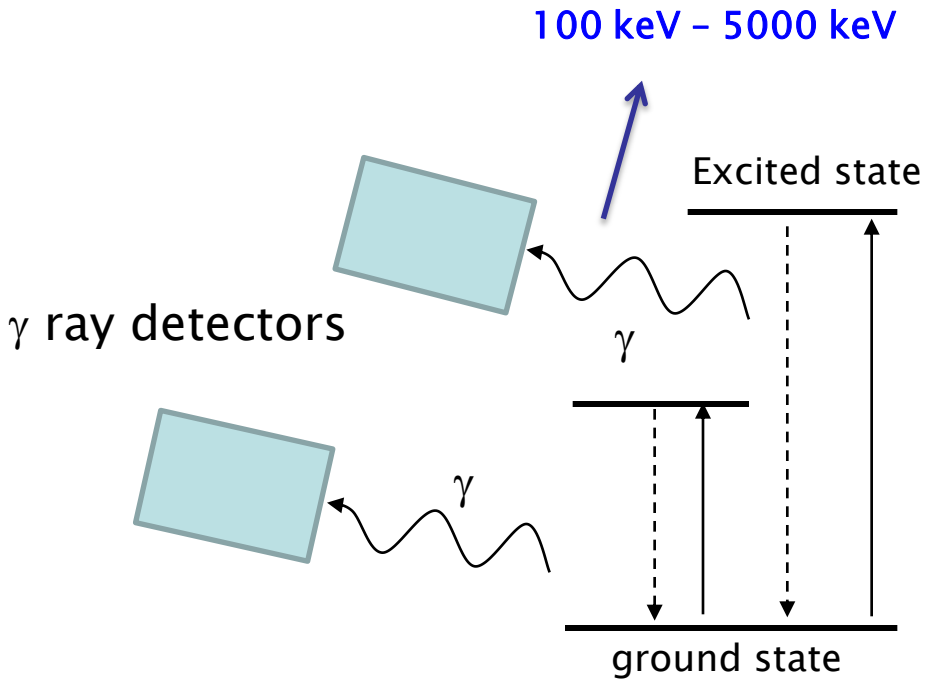


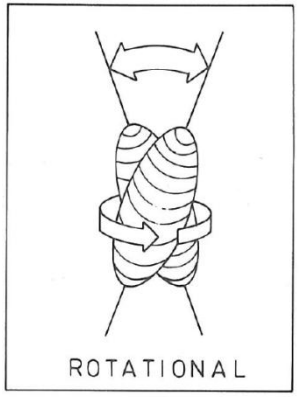
TAKEUCHI Satoshi RIKEN Nishina Center

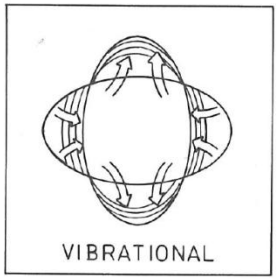
In-beam γ group : N.Aoi, H.Scheit, P.Doornenbal, D.Steppenbeck, J.Lee, M.Matsushita, W.He,L.Kouang,ST

# In-beam γ ray spectroscopy（インビームγ線核分光）

One of useful methods for study of stable or unstable nuclei by measuring de-excitation γ rays.



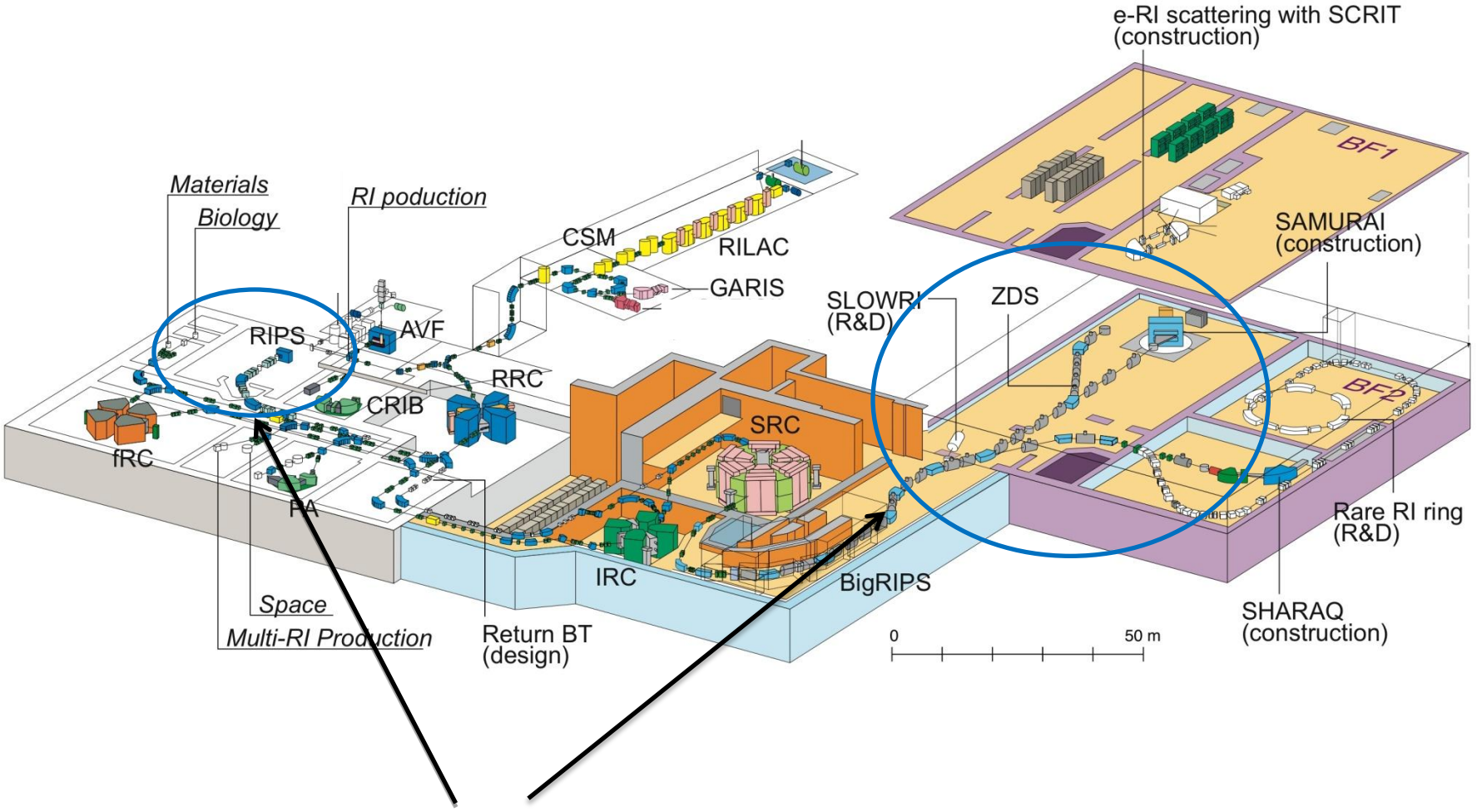




γ ray energy → Excitation energy
γ ray yield → Transition strength
γ ray distribution → Angular momentum

→ Nuclear structure or shape

Nuclei which we investigate are unstable…

# RI Beam Factory




Experiments by means of in-beam $\gamma$ ray spectroscopy.

# Unstable nuclei（不安定原子核）

- Decays to stable nuclei by β decay with a certain lifetime.
- Provided as fast secondary beams.

-Low beam intensity

- nuclei far from stability line → ~1cps
- Energy : ~200*A* MeV

-Low event rate (γ ray emission)

- with 2-3 g/cm$^2$ target : Pb, C, Be, $CH_2$, ...
  (size : ~ 30mmϕ)

- Typicaly, Δβ/β is around 10%

# $\gamma$ rays which we measure.

- Energy range — 100 keV – 5000 keV in moving frame
  **50 keV – 10000 keV in lab. Frame**
- Low intensity
  → High detection efficiency
- Doppler shifted

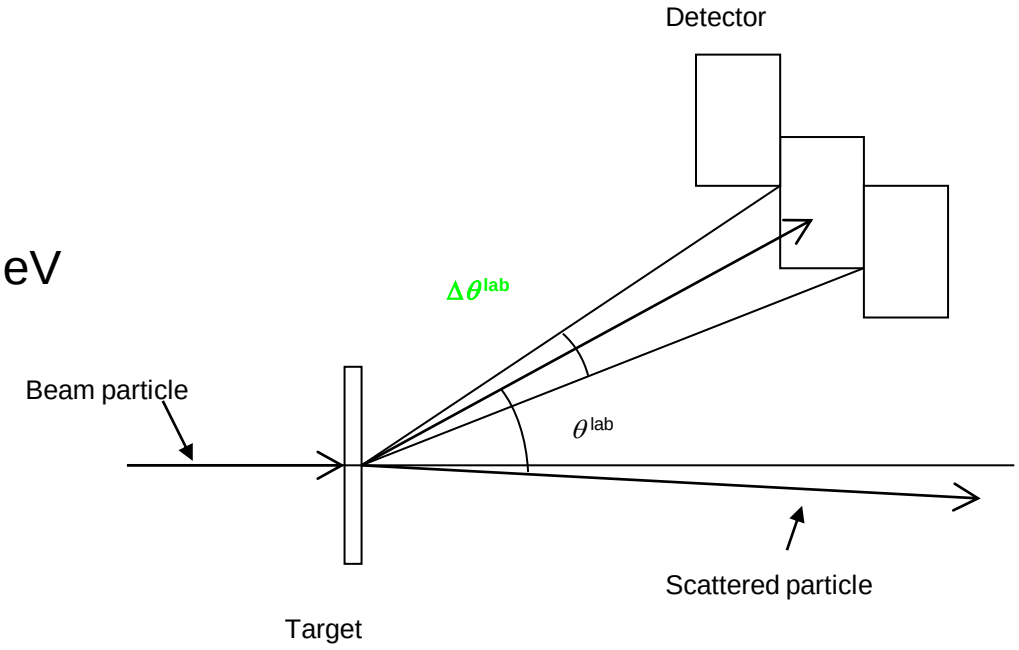
# Corrections of Doppler shift effects

Doppler shift [$\beta = v/c \sim 0.3$ (RARF) and $\beta \sim 0.6$ (RIBF)]

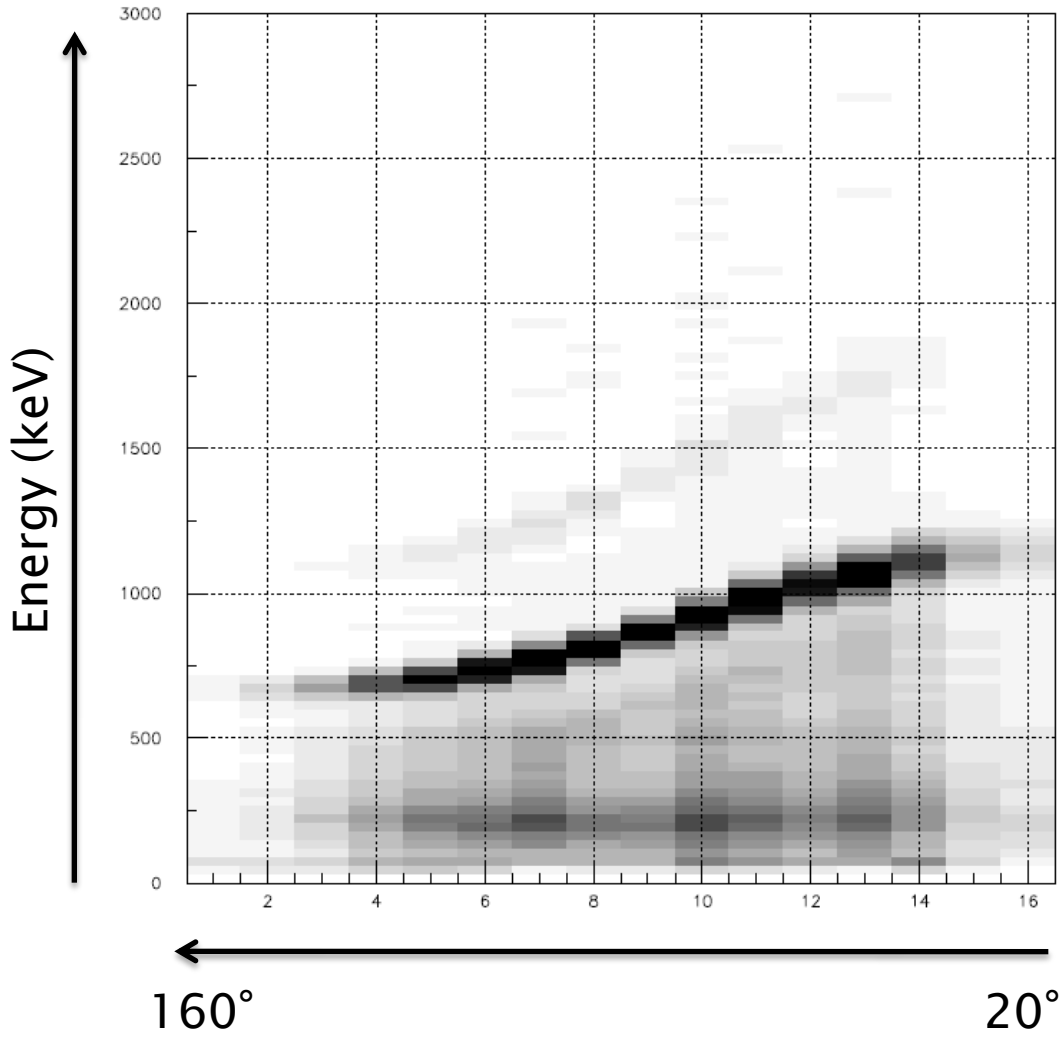
→ $\gamma$ ray energy depends on the emission angle.

→ High angular resolution

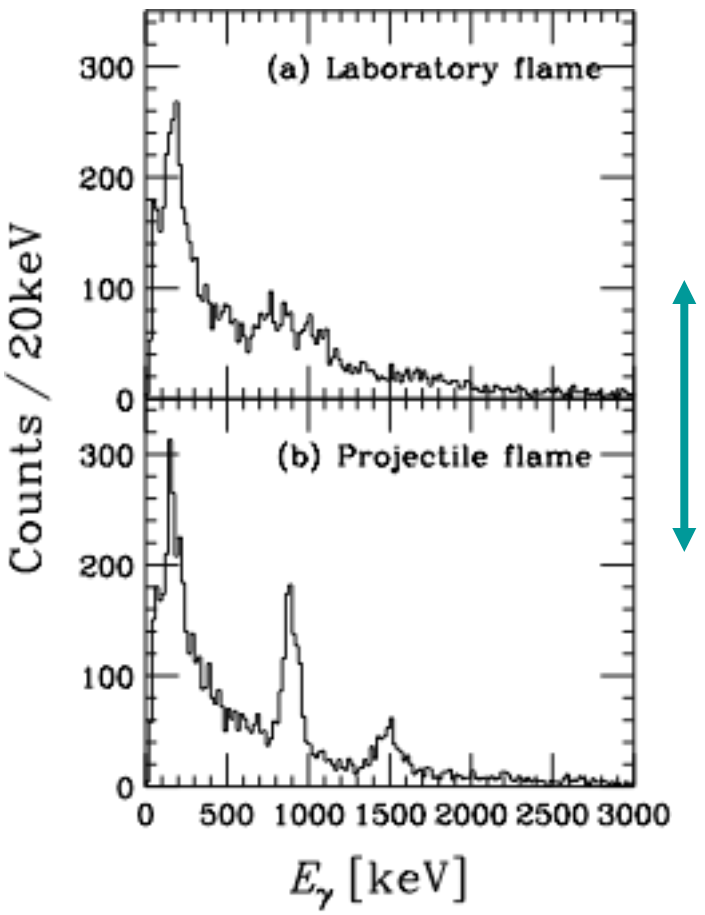
$E_{in} \sim 200A$ MeV




2-3 g/cm$^2$ at RIBF




$^{32}$Mg(p,p') β~0.3




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

# $\gamma$ rays which we measure.

- Energy range — 100 keV – 5000 keV in moving frame
  **50 keV – 10000 keV in lab. Frame**

- Low intensity (low event rate)
  → High detection efficiency

- Doppler shifted
  → Angular resolution

- Emission angle — Forward peak (Lorentz boost)
  → Detector arrangement

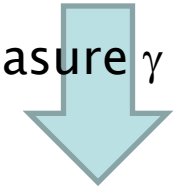
- Background
  → Timing resolution (to eliminate by time info.)

# The policy of the design

Efficiency (高効率)
Granularity (細分化)
Flexibility (融通がきく)

High detection efficiency and high angular resolution array

Measure γ rays

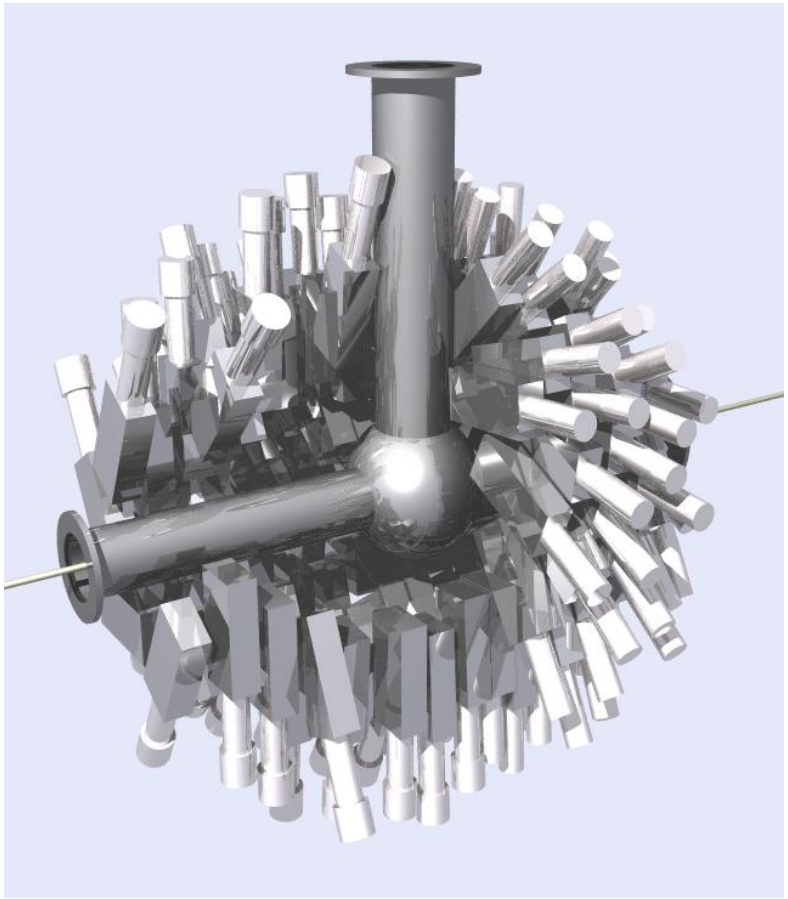


160 – 180 NaI(Tl) detectors

**γ ray energy** → Excitation energy
**γ ray yield** → Transition strength
**γ ray distribution** → Angular momentum

→ Nuclear structure or shape

# DALI2 (Detector array for Low Intensity radiation 2)



Collaboration : RIKEN Nishina Center & Rikkyo University

# Specification

DALI-2 detectors

- SAINT-GOBAIN x 90 detectors

  45 x 80 x 160 (mm)

  About 8%@662keV ($^{137}$Cs)

- SCIONIX x 84 detectors

  40 x 80 x 160 (mm)

  About 9%@662keV($^{137}$Cs)

DALI-1 detectors

- BICRON x ~50 detectors

  60 x 60 x 120 (mm)

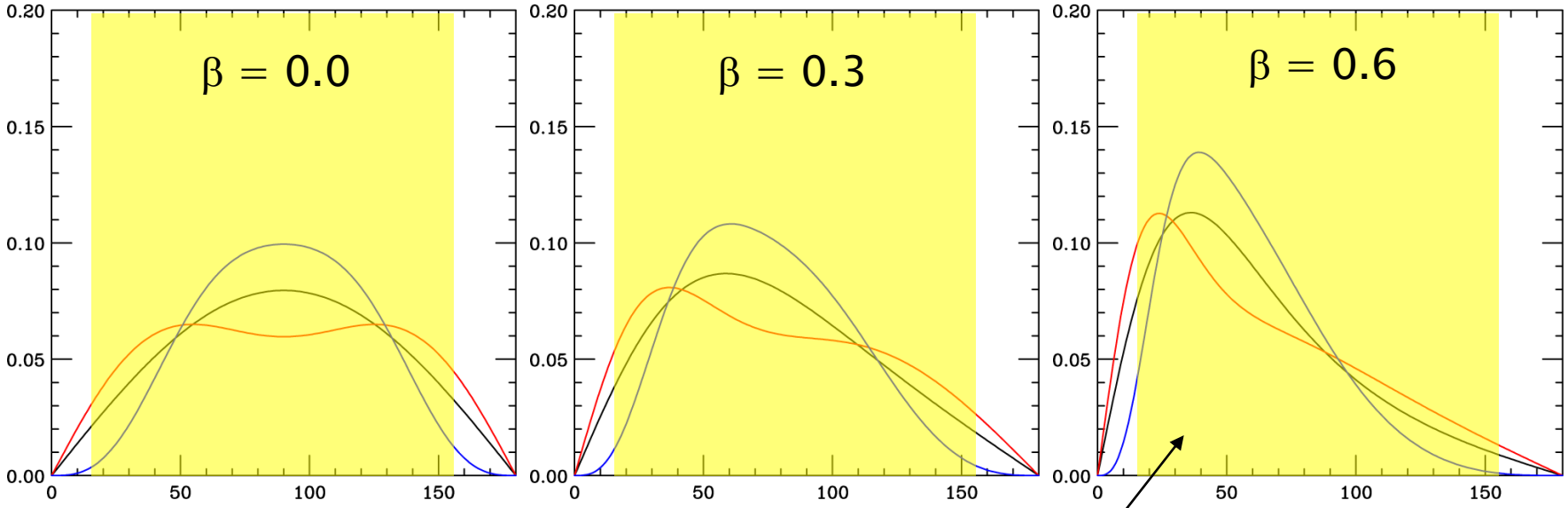
  About 8%@662keV($^{137}$Cs)

PMT : HAMAMATSU R580

# Detector configuration

Angular distribution of γ rays

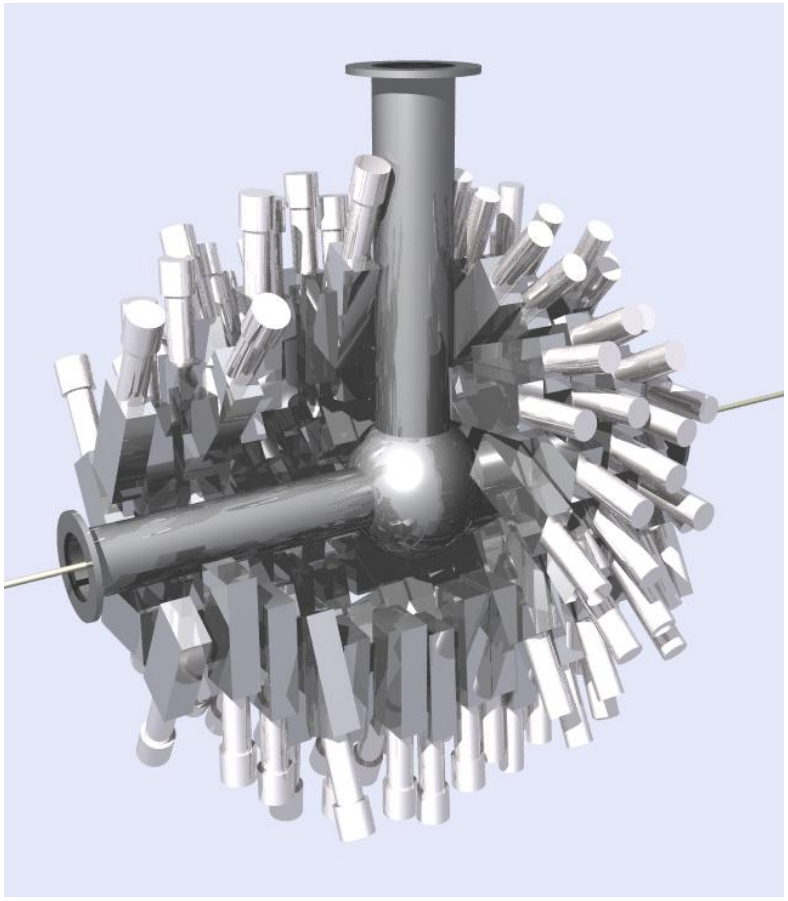
Black : $\Delta L = 0$
Red : $\Delta L = 1$
Blue : $\Delta L = 2$




← Forward angles

Coverage of DALI2

# – DALI2 – for RIBF exp.



## DALI2 specification

| | |
|---|---|
| Arrangement | Hedgehog like |
| Detector Size ($cm^3$) | 4.5 x 8 x 16 |
| # of Detectors | 160–180 |
| Volume | ~ 100 liter |
| # of Layers | ~16 |
| Angular resolution | ~ 8 degree |
| Energy resolution (β~0.6) | 10% @ 1MeV |
| Efficiency (β~0.6) | 20% @1MeV |
| Timing resolution | ~ 3ns (FWHM) |

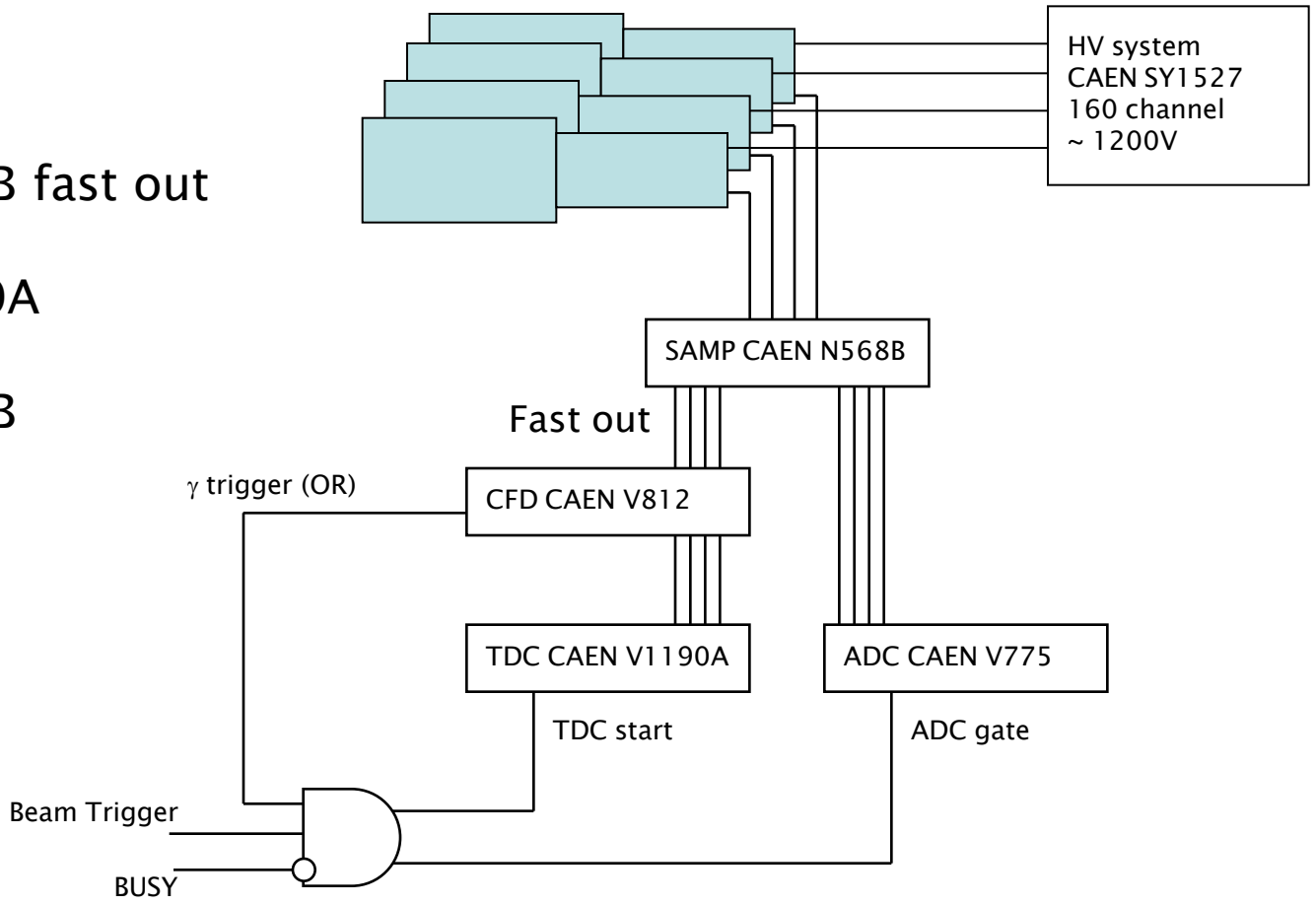
γ–ray energy
Emission angle of γ ray
→ For Doppler–shift corrections

Ref. S.Takeuchi et al., RIKEN Accel. Prog. Rep. **36**(2003)148

# Circuit

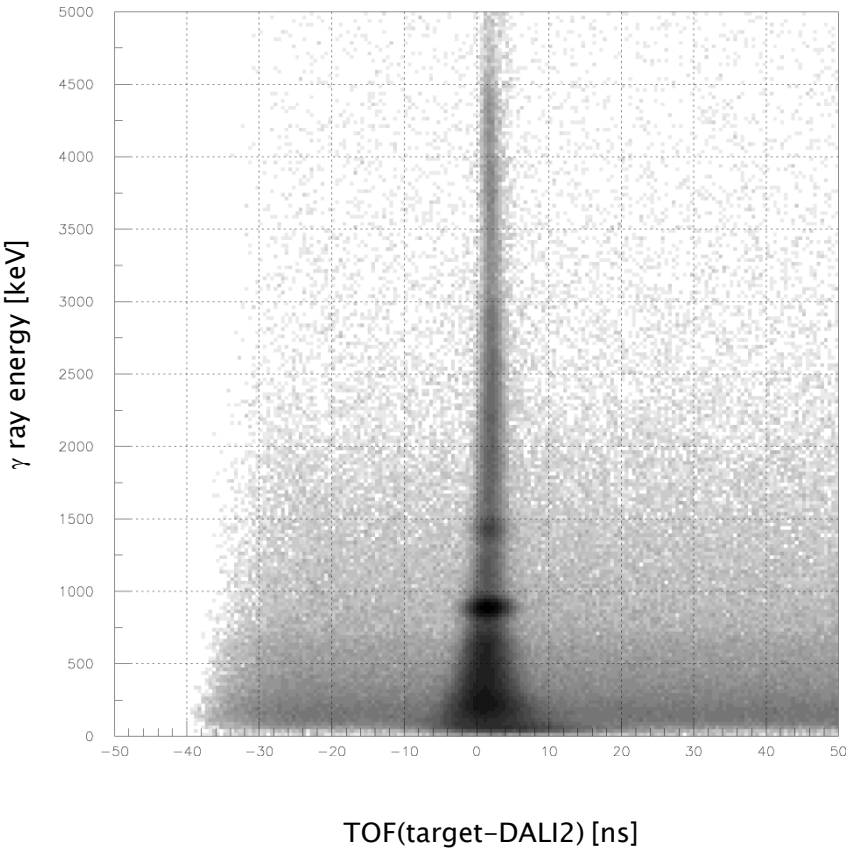
For Timing
- SAMP : N568B fast out
- CFD : V812
- TDC : V1190A

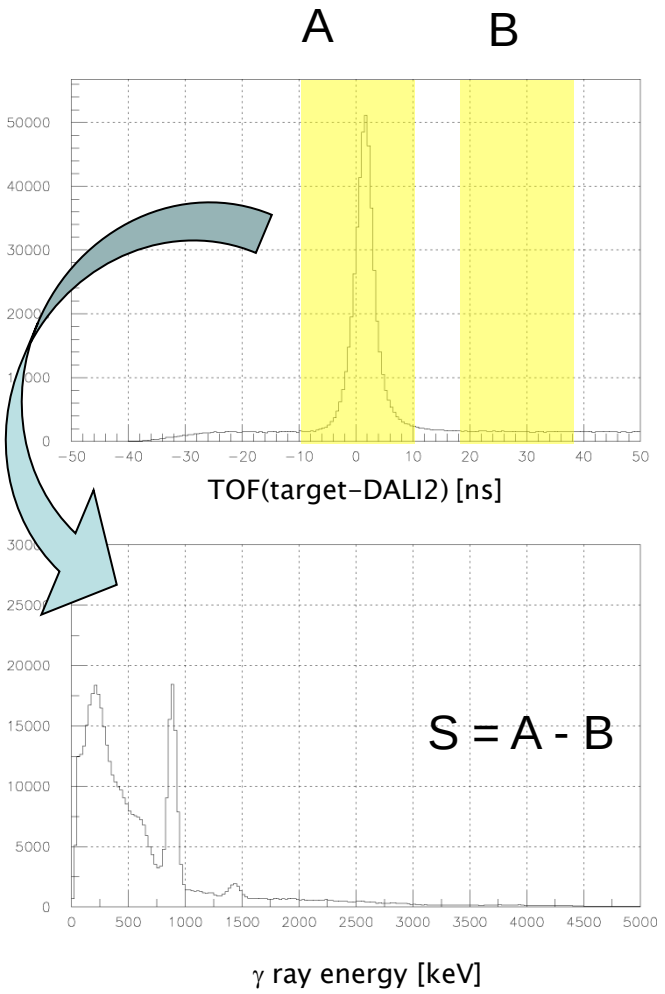
For Energy
- SAMP : N568B
- ADC : V785




| | | |
|---|---|---|
| γ trigger rate | : | 1 kcps to 200 kcps |
| Beam trigger rate | : | ~1 cps to 500 kcps |
| Coincidence rate | : | ~1 cps to 2-3 kcps |

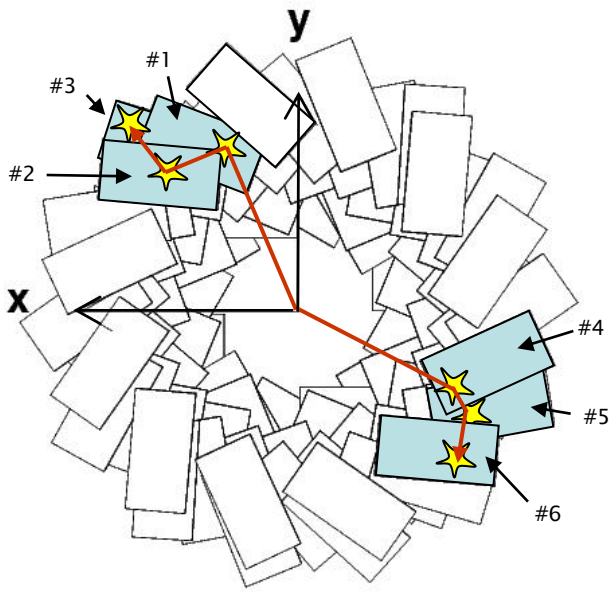
# γ ray spectra of in-beam γ ray spectroscopy



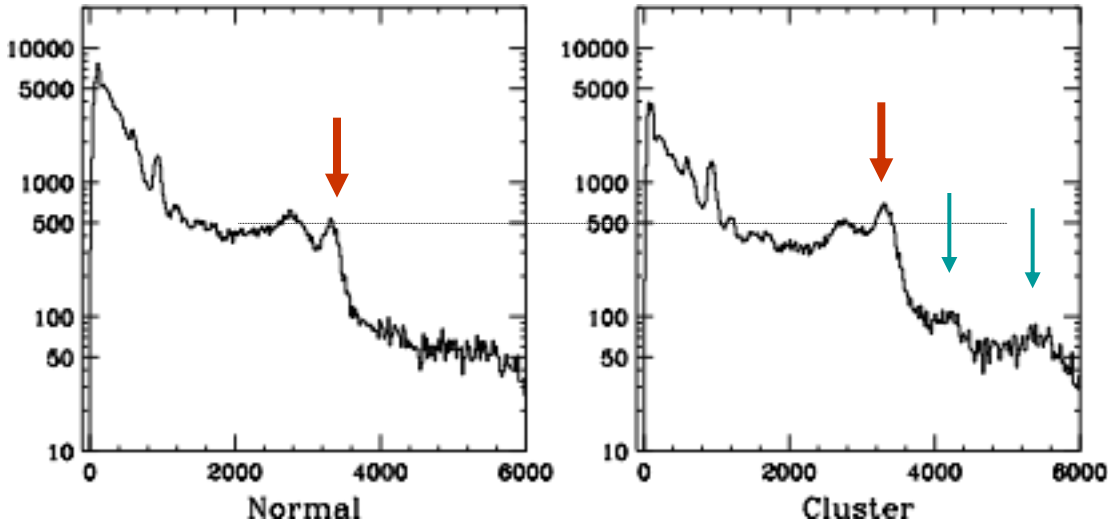

Timing resolution : ~ 3ns (FWHM) for 1MeV

# Add-back analysis




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

$^{34}Si$ + Liq.$H_2$

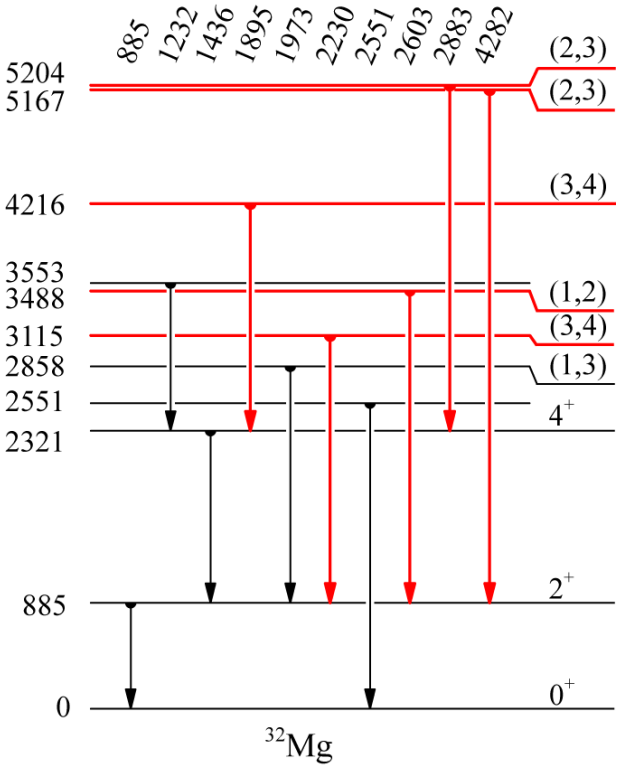


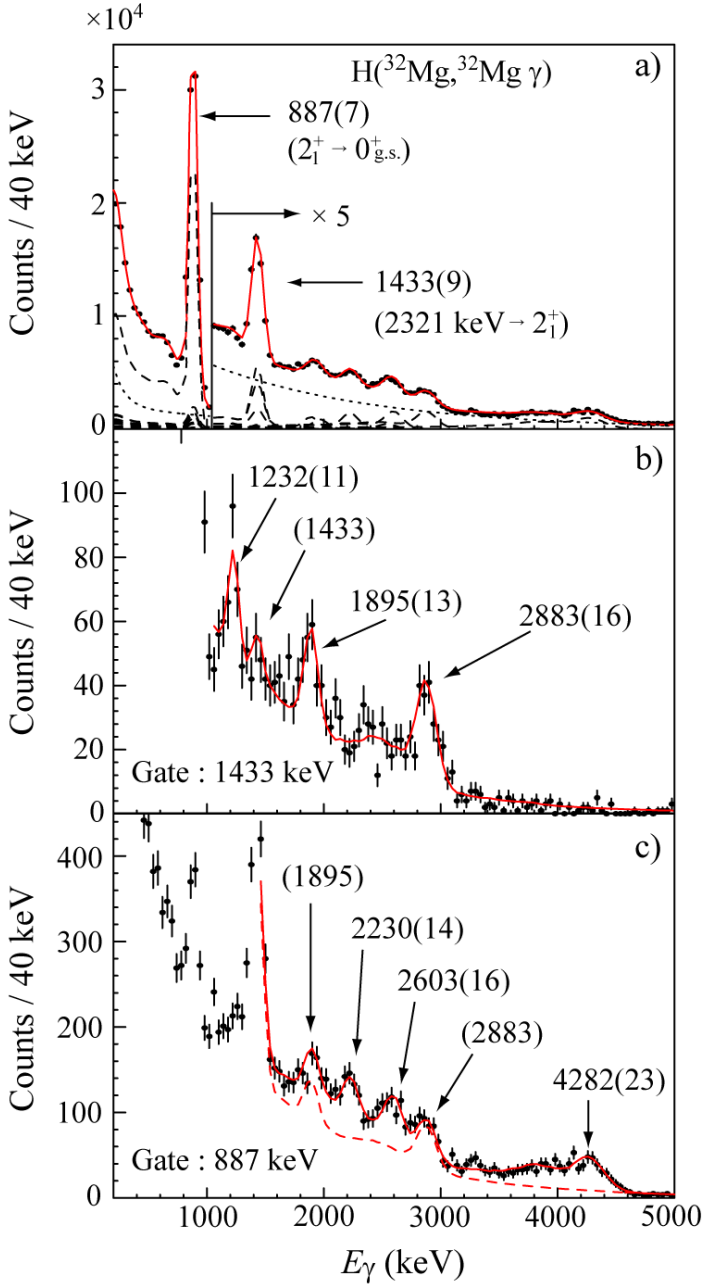

Cluster#1 = Det.#1 + Det.#2 + Det.#3

Cluster#2 = Det.#4 + Det.#5 + Det.#6

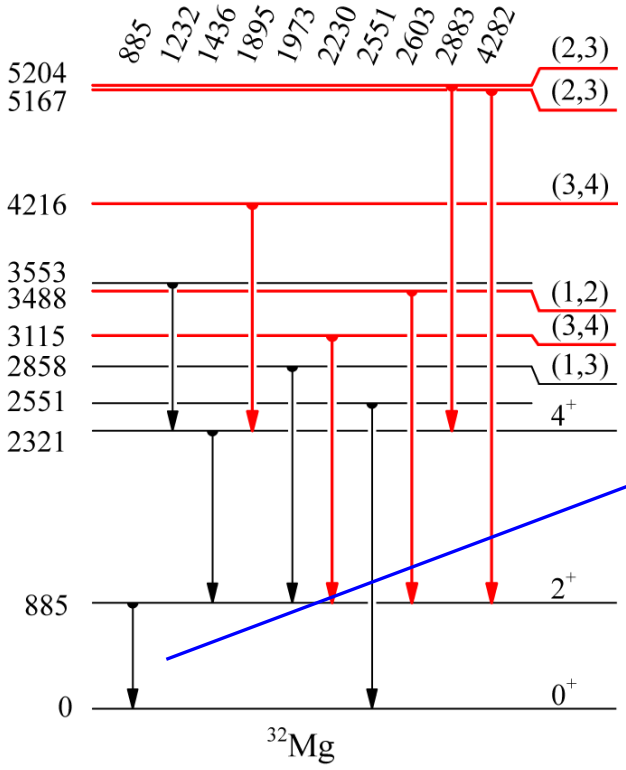
peak / B.G. improved

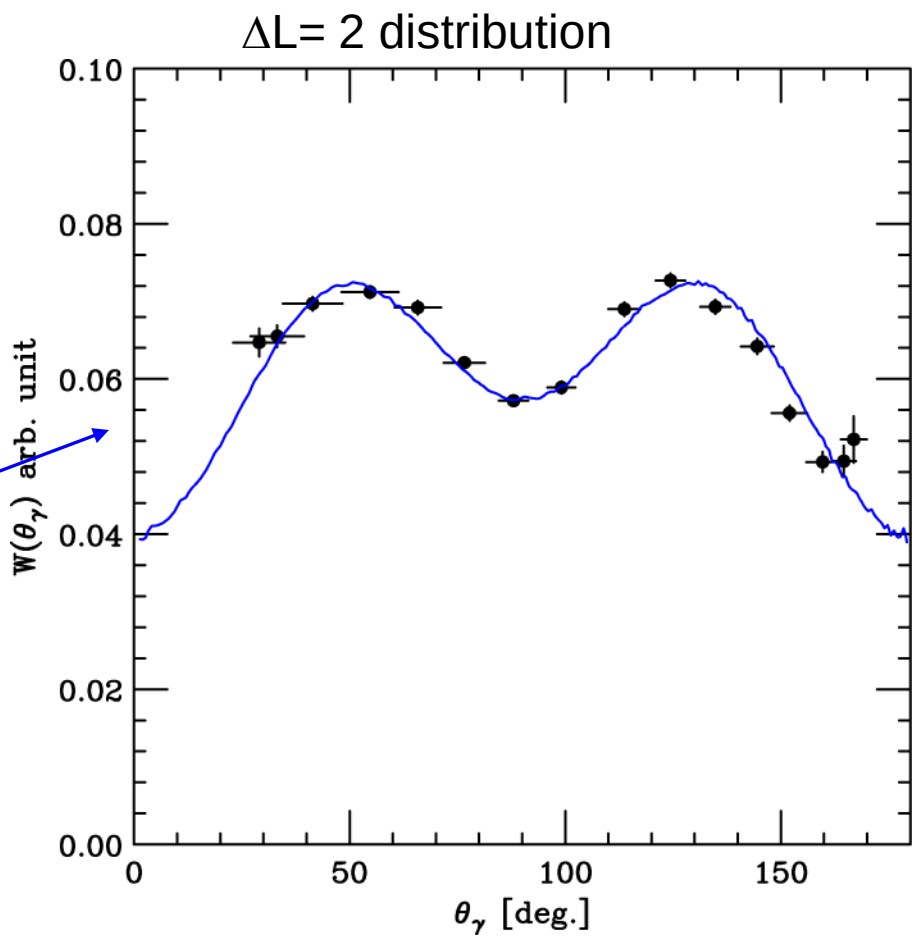
# $^{32}$Mg (Z=12, N=20)


885
1232
1436
1895
1973
2230
2551
2603
2883
4282
5204
5167
4216
3553
3488
3115
2858
2551
2321
885
0
(2,3)
(2,3)
(3,4)
(1,2)
(3,4)
(1,3)
4+
2+
0+
32Mg


×10^4
H(32Mg,32Mg γ)
a)
887(7)
(2+1 → 0+g.s.)
× 5
1433(9)
(2321 keV → 2+1)
Counts / 40 keV
b)
1232(11)
(1433)
1895(13)
2883(16)
Gate : 1433 keV
c)
(1895)
2230(14)
2603(16)
(2883)
4282(23)
Gate : 887 keV
Eγ (keV)

# Angular distribution of γ rays



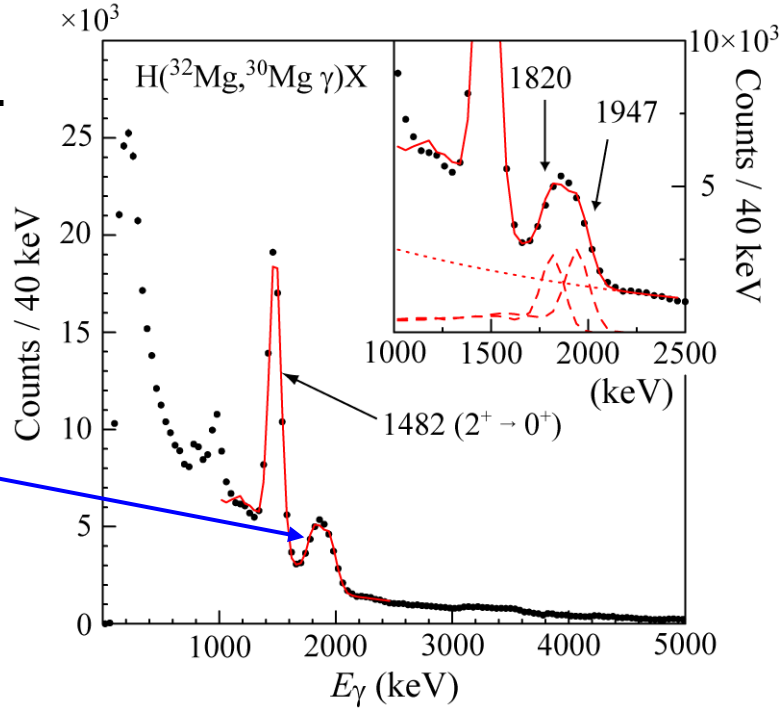
# Monte Carlo simulation by GEANT code

INPUT
- Geometry
- Energy resolution for each detector
- γ ray energy
- Velocity of nuclei

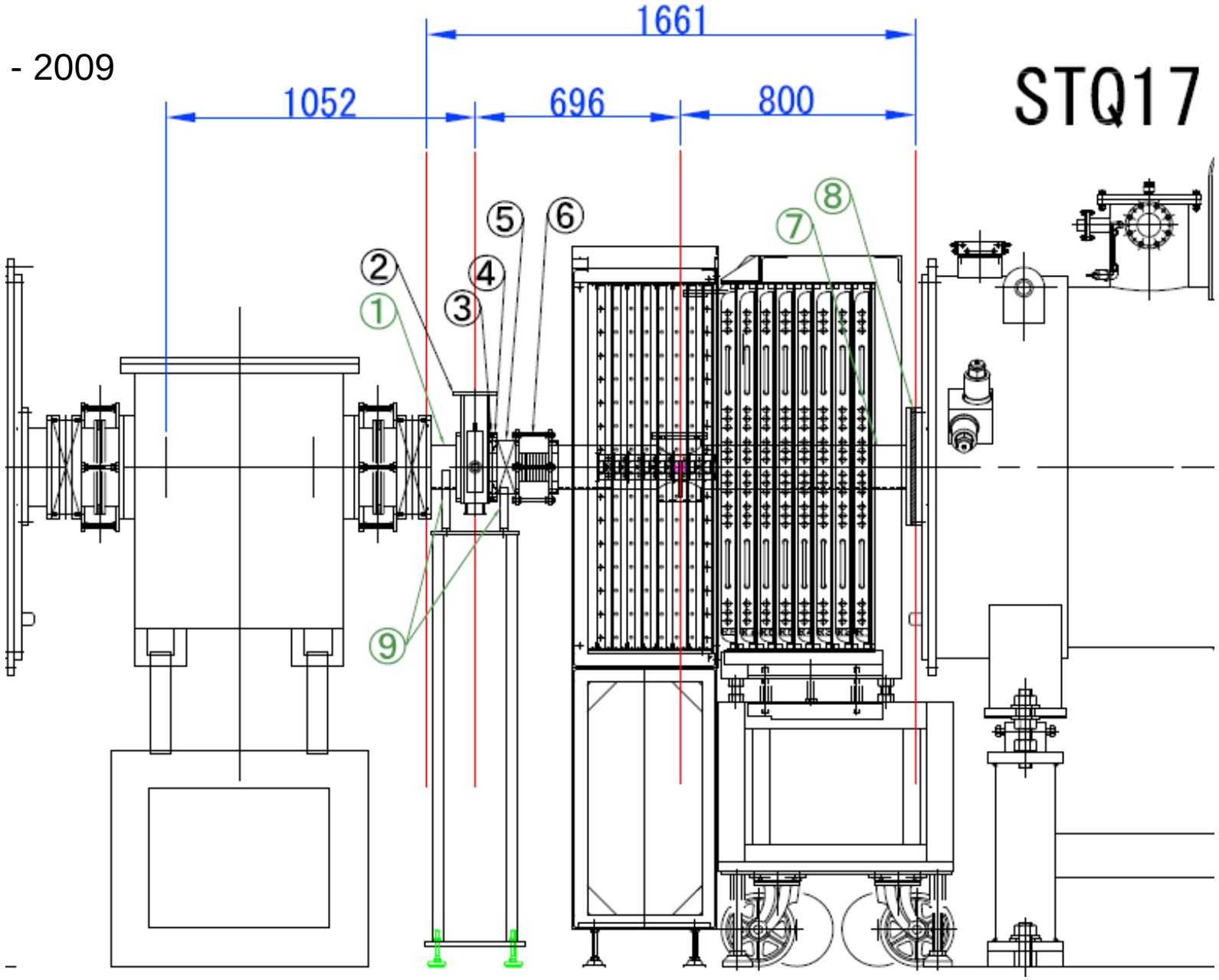
OUTPUT
- Response of the detector system for γ rays.

→ level scheme, transition strength, new γ lines, etc…

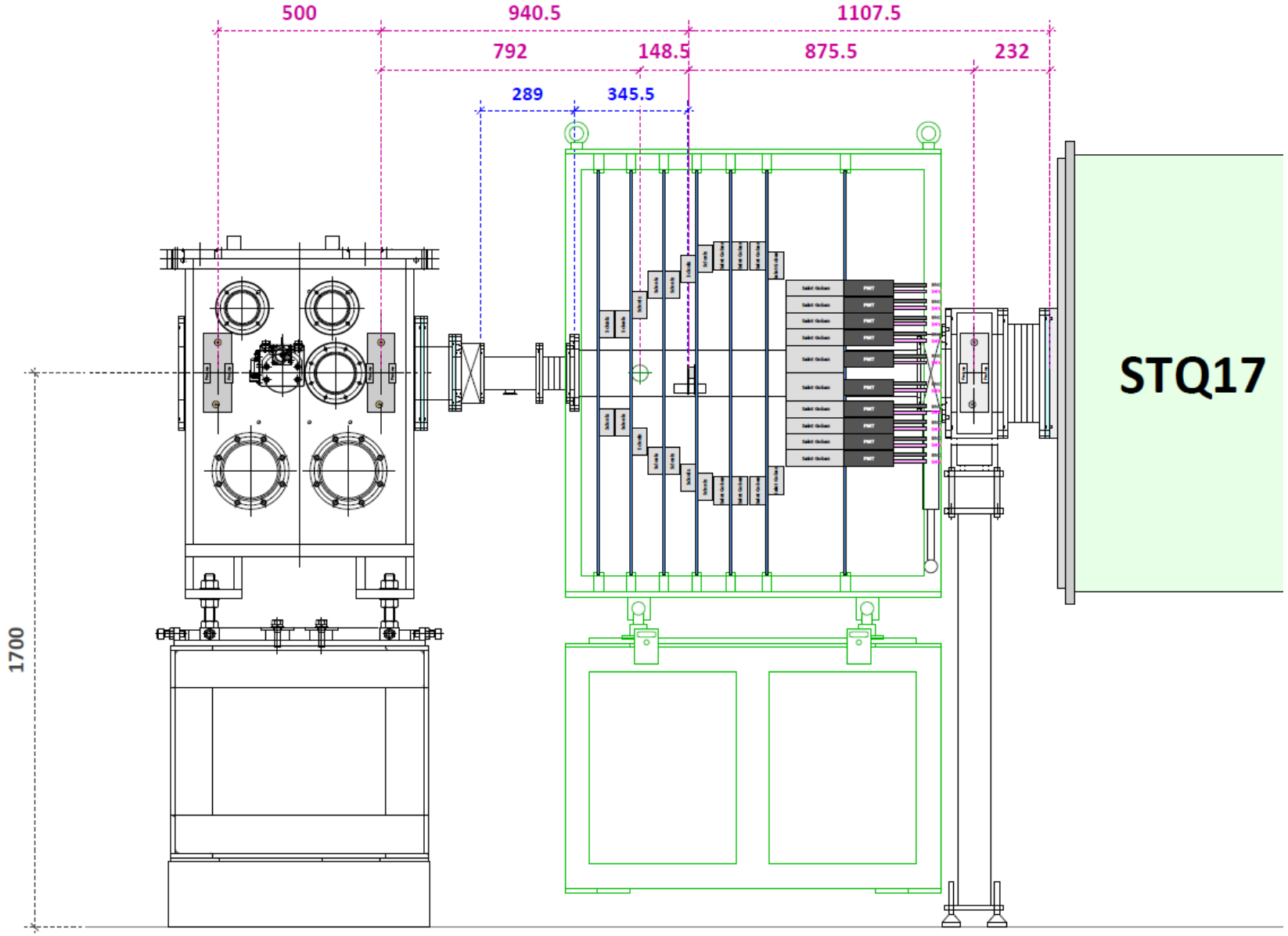
This line consists of two or more γ rays. (Width of this peak is wide.)

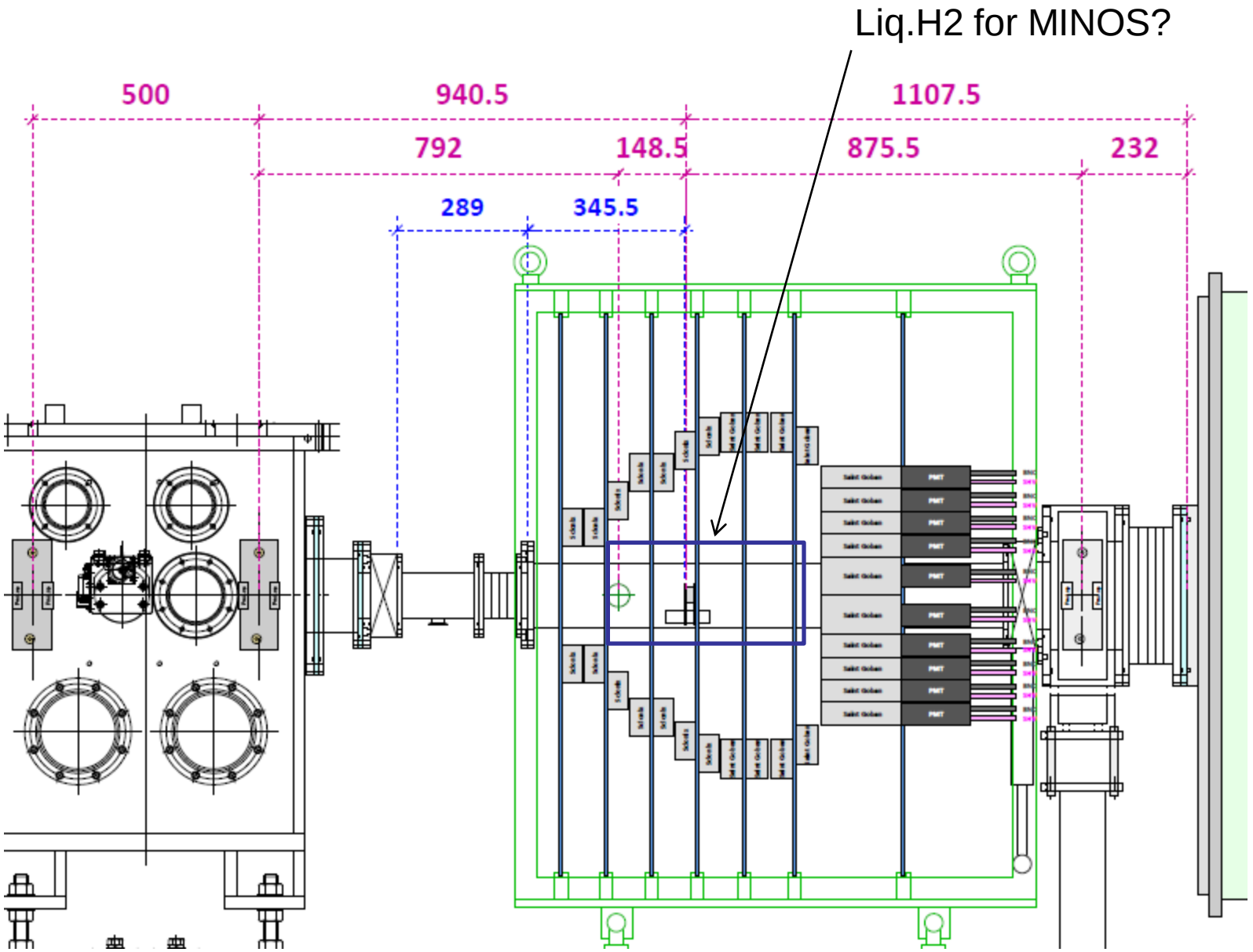


DALI2 - 2009



# DALI2 - 2010




Liq.H2 for MINOS?
500
940.5
1107.5
792
148.5
875.5
232
289
345.5

## Past experiments with DALI2 (present-2002)

| | | |
|---|---|---|
| $^{32}$Mg Coulex and inelastic scattering for reaction study | RIKEN | BigRIPS |
| A=130 region Coulex and nucleon removals for reaction study | RIKEN | BigRIPS |
| $^{32}$Ne inelastic scattering | RIKEN | BigRIPS |
| $^{20}$C(p,p'), $^{20}$C Coulex | ATOMKI, RIKEN | RIPS |
| $^{30}$Ne(p,p'), $^{36}$Mg(p,p') | RIKEN | RIPS |
| $^{34}$Si(p,p')$^{34}$Si$^{*}$ | RIKEN | RIPS |
| $^{32}$Mg(p,p')$^{32}$Mg$^{*}$ | RIKEN | RIPS |
| $^{60,62}$Cr(p,p') | Rikkyo, RIKEN | RIPS |
| $^{22}$O(d,p)$^{23}$O | ATOMKI, RIKEN | RIPS |
| $^{16,17,18}$C(p,p') | Tokyo, RIKEN | RIPS |
| $^{8}$B breakup with H, He, Pb | RIKEN | RIPS |
| $^{19}$C(p,p')$^{19}$C$^{*}$ | ATOMKI, RIKEN | RIPS |
| $^{78-82}$Ge Coulex | Tokyo, RIKEN | RIPS |
| $^{26}$Ne Coulex, Coulomb Breakup | Orsay, TITech, RIKEN | RIPS |
| $^{4}$He($^{22}$O,$^{23}$F$^{*}$) | CNS, RIKEN | RIPS |
| $^{16}$C(p,p')$^{16}$C$^{*}$ | ATOMKI, Tokyo, RIKEN | RIPS |
| $^{27}$F(p,p')$^{27}$F$^{*}$ | ATOMKI, Tokyo, RIKEN | RIPS |
| $^{54}$Ni,$^{50}$Fe,$^{46}$Cr. Coulex | Rikkyo, RIKEN | RIPS |
| $^{12}$Be(α,α')$^{12}$Be$^{*}$,$^{12}$Be(α,t)$^{13}$B$^{*}$ | CNS, Rikkyo, RIKEN | RIPS |