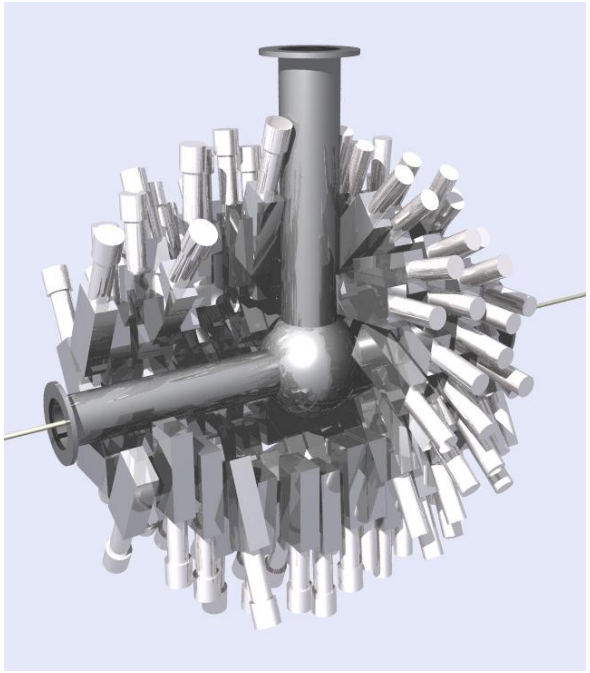
NaI(Tl) array for in-beam γ-ray spectroscopy -DALI2-



- Introduction
  - DALI & DALI2
  - In-beam γ-ray spectroscopy
- Experiments by
  - DALI
  - DALI2
- Summary/Memo/Information

TAKEUCHI Satoshi RIKEN Nishina Center

In-beam γ ray spectroscopy group :
N.Aoi, H.Scheit, J.Lee, P. Doornenbal, D. Steppenbeck, H.Wang, M.Matsushita, K.Li, S.T

DALI & DALI2

Detector **A**rray for **L**ow **I**ntensity radiation

→ For use in direct reaction experiments, mainly in-beam γ-ray spectroscopy experiments.

- **DALI** (1994 -) by Rikkyo University

  Collaborators : T.Motobayashi, Y.Yanagisawa, … (ST),…

  Publication : 21 papers

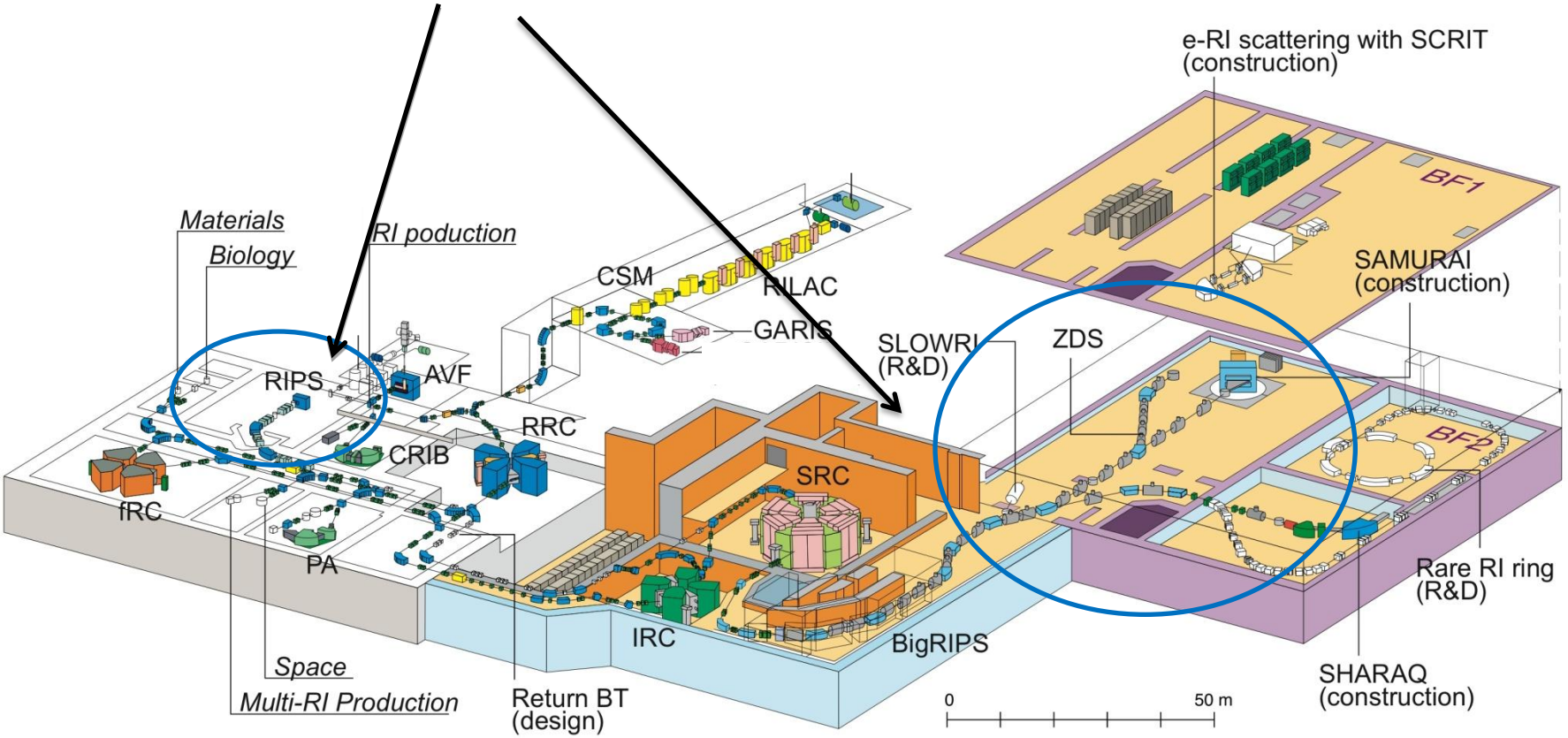
- **DALI2** (2002 -) by Rikkyo University and RIKEN

  Collaborators : ST, T.Motobayashi, N.Aoi, H.Murakami,
  Y.Togano, M.Matsushita, …,
  and in-beam γ-ray spectroscopy group in RIKEN.

  Publication : 24 papers

RI Beam Factory

Experiments by means of in-beam γ-ray spectroscopy.

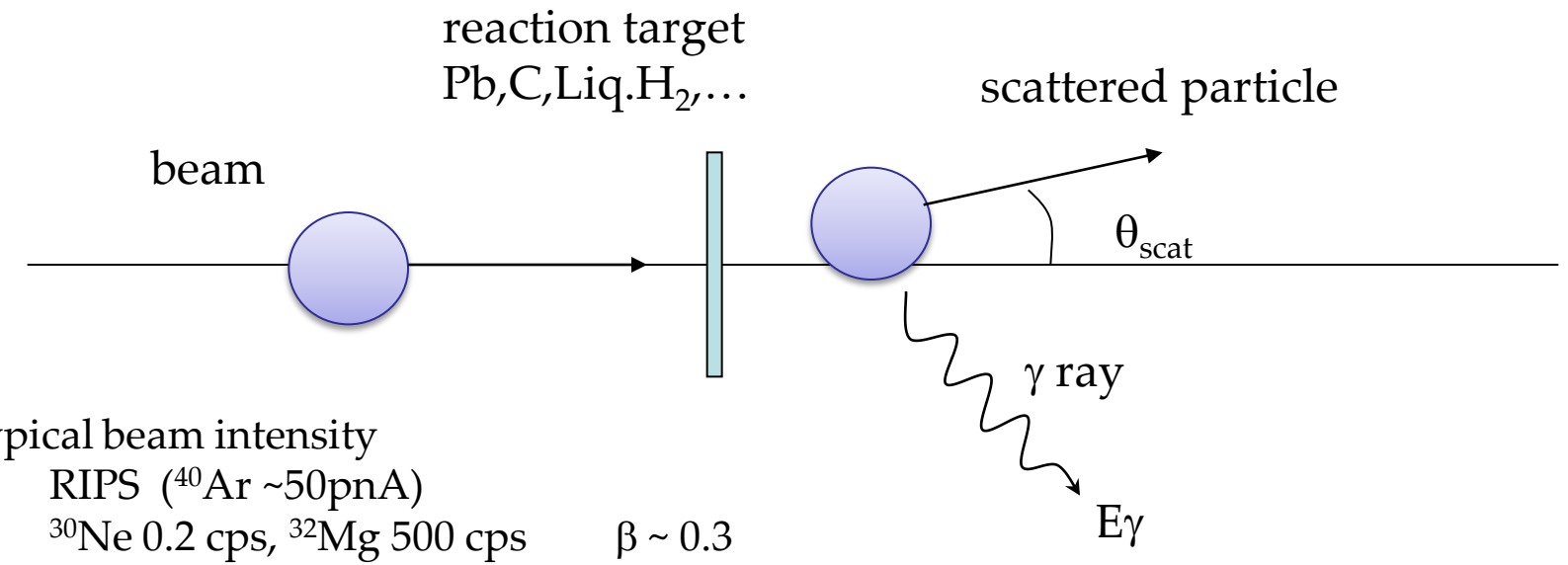


Performed at RIPS, BigRIPS/ZDS, and SHARAQ

Next… SAMURAI?

In-beam γ-ray spectroscopy

One of useful methods for study of stable or unstable nuclei by measuring de-excitation γ rays (and scattered particles).



Typical beam intensity

RIPS (^{40}Ar ~50pnA)
^{30}Ne 0.2 cps, ^{32}Mg 500 cps β ~ 0.3

BigRIPS (^{48}Ca ~100pnA)
^{30}Ne~ 300 cps, ^{42}Si ~10 cps β ~ 0.6

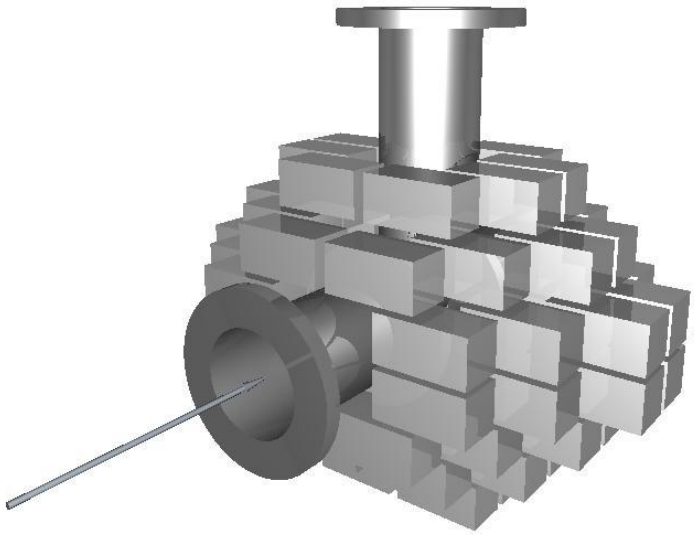
100 keV – 5000 keV

γ ray energy → Excitation energy
γ ray yield → Transition strength
γ ray distribution → Multipolarity

→ Nuclear structure or shape

Experiment at RIPS with DALI

DALI : Detector Array for Low Intensity radiation



60 NaI(Tl) detectors

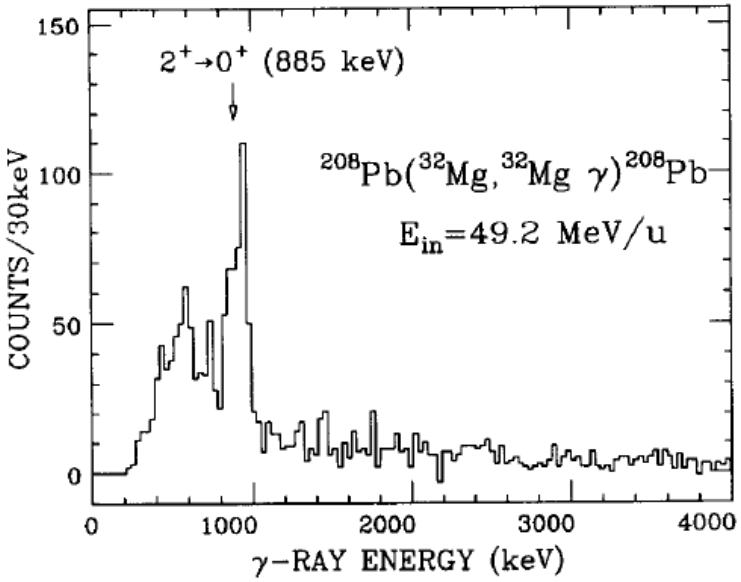
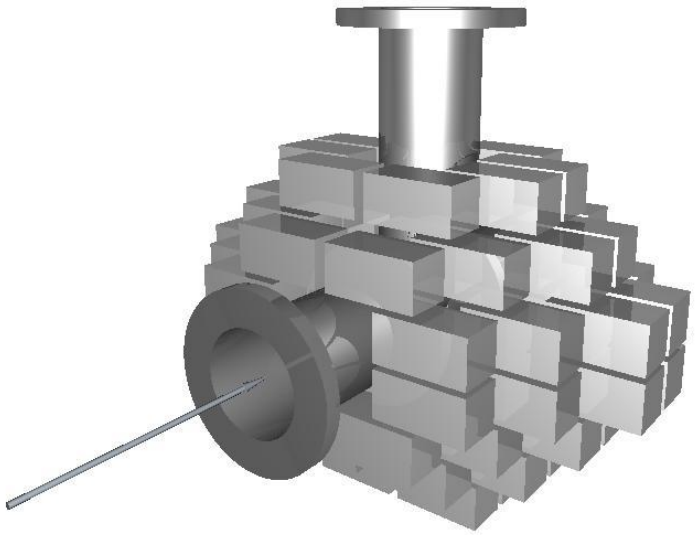


Fig. 1. Energy spectrum of γ rays emitted from the $^{32}Mg+^{208}Pb$ inelastic scattering at 49.2 MeV/u incident energy. The Doppler shift is corrected for.

T. Motobayashi et al. /Physics Letters B 346 (1995) 9-14

Experiment at RIPS with DALI

DALI : Detector Array for Low Intensity radiation



typical spec. of DALI-1

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

Now, ~40 detectors are available.

Past experiments with DALI (2005-1994)

^{18,19}C knockout reaction	TITech, RIKEN	RIPS
^{20}Mg Coulex	Tohoku, Rikkyo, RIKEN	RIPS
^{28}Ne Coulex	CNS, RIKEN	RIPS
^{15,17}B(C,C')	TITech	RIPS
^{12}Be 0^+ state	CNS, Rikkyo, RIKEN	RIPS
^{30}Ne(p,p')	RIKEN, Rikkyo	RIPS
^{14}O(α,α')	CNS, Rikkyo	RIPS
^{12}Be(α,α')	CNS, Rikkyo	RIPS
^{16}C(Pb,Pb')	ATOMKI, Rikkyo	RIPS
^{34}Si(d,d')	RIKEN, Rikkyo	RIPS
^{34}Mg Coulex	Tokyo	RIPS
^{15}O Coulex	Rikkyo, RIKEN	RIPS
^{34}Mg by fragmentation	Tokyo, Rikkyo	RIPS
^{12}Be(p,p'), ^{12}Be(Pb,Pb')	Tokyo, Rikkyo	RIPS
^{56}Ni Coulex	Rikkyo, Tokyo	RIPS
^{8}B Breakup	Rikkyo, Tokyo	RIPS
^{11}Be Breakup	Tokyo	RIPS
^{32}Mg Coulex	Rikkyo	RIPS

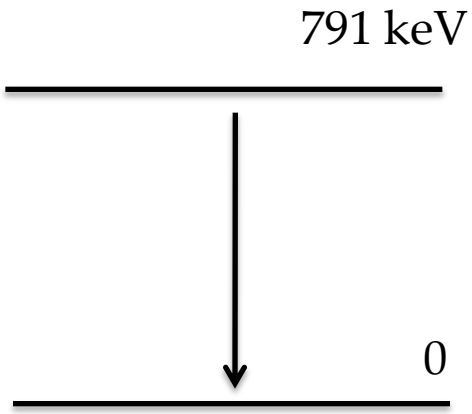
^{30}Ne inelastic scattering (@RIPS)

Physics Letters B 566 (2003) 84–89

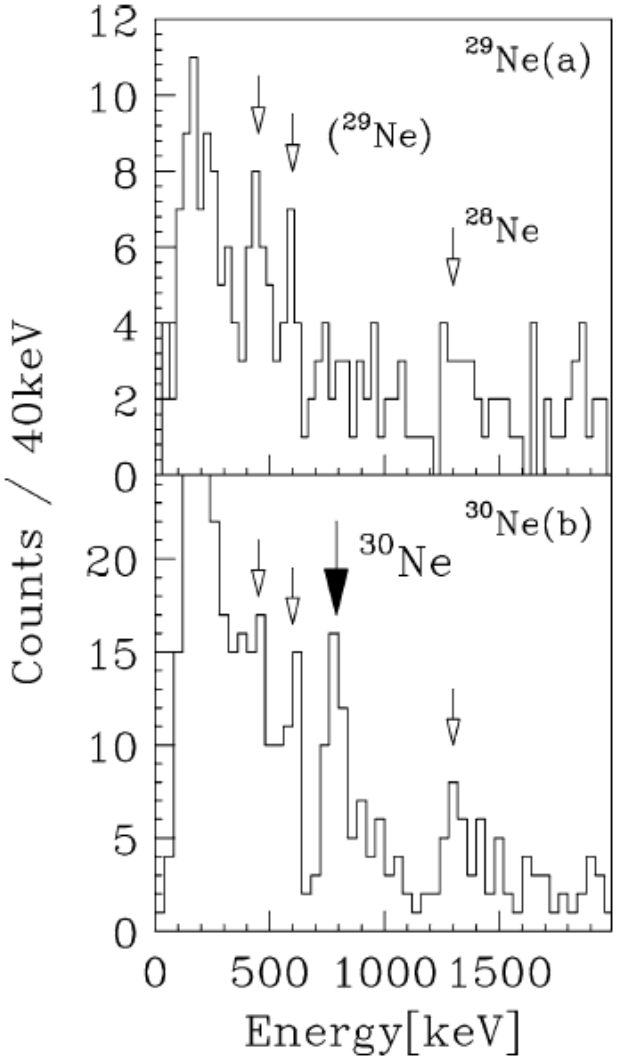
^{30}Ne beam : 0.2 counts / second

→ Very low intensity

Identify peak with or without conditions of particle identifications.



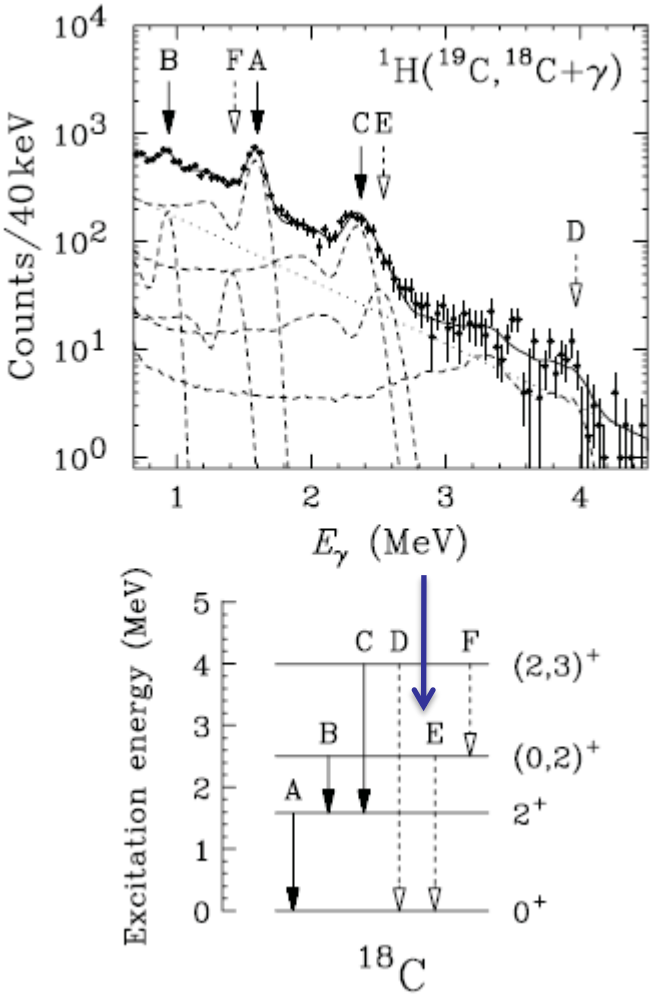
^{30}Ne (Z=10, N=20)

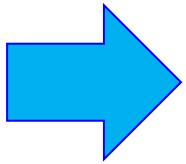


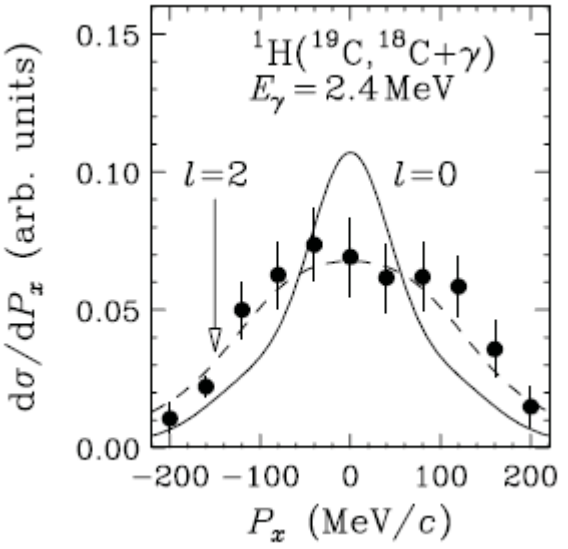
$^{19}C \rightarrow {}^{18}C + \gamma$ (@RIPS)

PHYSICAL REVIEW C **79, 014602 (2009)**

Identify excited states by measuring γ rays.

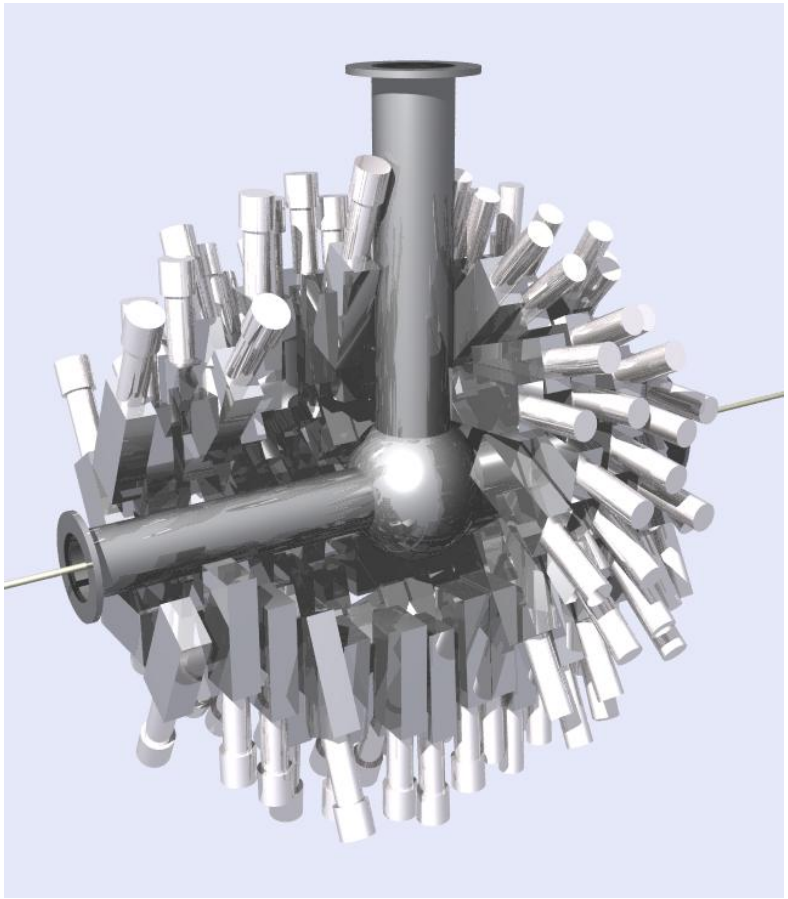






Transverse-momentum distribution of ^{18}C in coincidence with the 2.4-MeV γ ray.

DALI2 (Detector array for Low Intensity radiation 2)



Collaboration : RIKEN Nishina Center & Rikkyo University

γ rays which we measure.

- Energy range → 100 keV - 5000 keV in moving frame
  → **50 keV - 10000 keV in lab. Frame**
- Low event rate → High detection efficiency
- Doppler shifted → Angular resolution
- Forward peaking → Detector arrangement

Requirements

- high efficiency
- good energy resolution
- large granularity and flexibility

→ We chose NaI(Tl) detectors for development of DALI2.

Specification

Rikkyo

- SAINT-GOBAIN x 90 detectors

  45 x 80 x 160 (mm)

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

PMT : HAMAMATSU R580

RIKEN

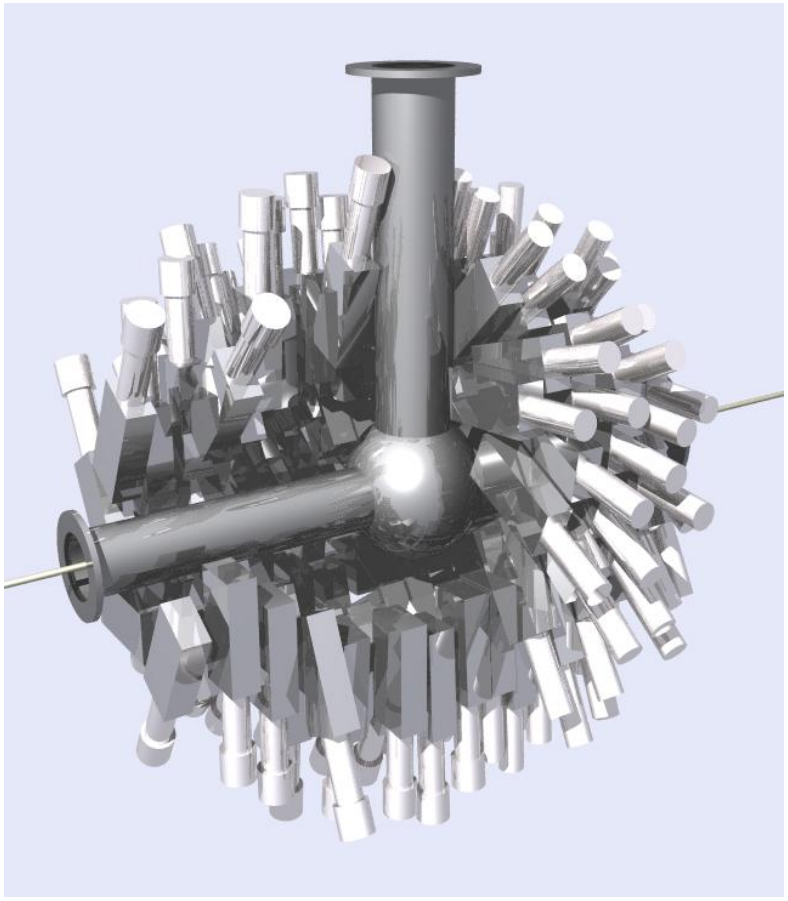
- SCIONIX x 84 detectors

  40 x 80 x 160 (mm)

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

+ BICRON detectors (from DALI)

- DALI2 – for RIBF exp.



Standard DALI2 specification

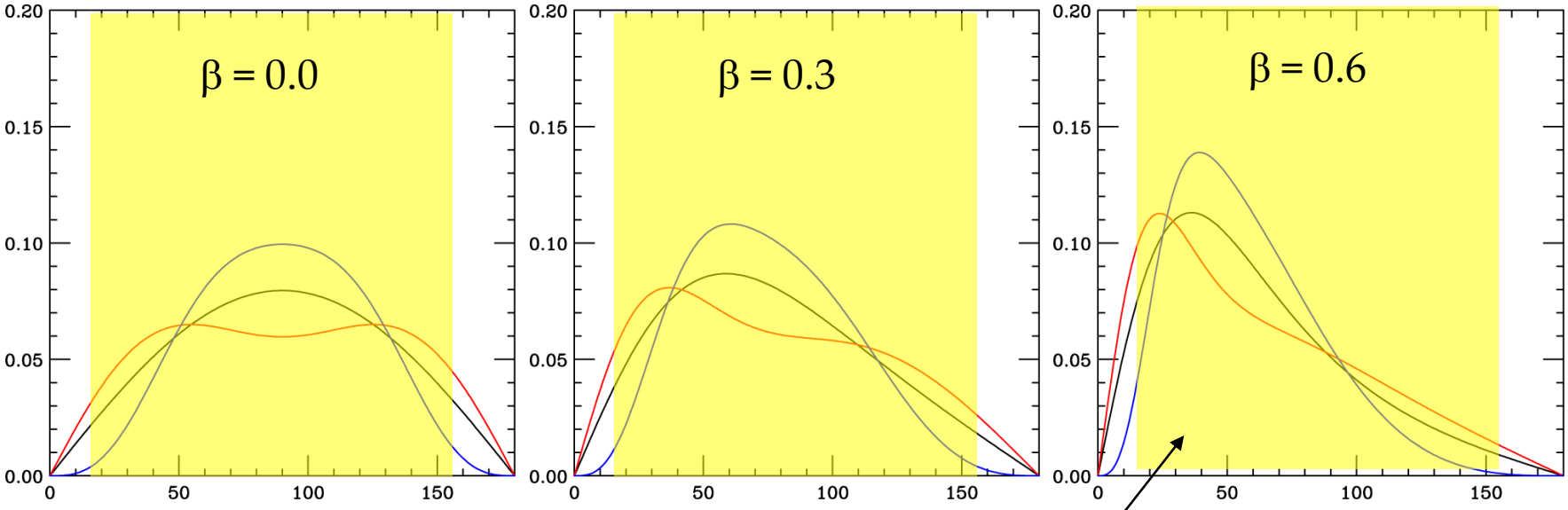
Arrangement	Hedgehog like
Size (cm^3)	4.5 x 8 x 16
# of Detectors	160
Volume	~ 90 liter
# of Layers	16
Angular resolution	~ 8 degree
Energy resolution (β~0.6)	10% @ 1MeV
Efficiency (β~0.6)	20% @1MeV (24%@1MeV (β~0.3))
Timing resolution	~ 2.5ns (FWHM)

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

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

Angular coverage of DALI2

Black : ΔL = 0
Red : ΔL = 1
Blue : ΔL = 2



← Forward angles

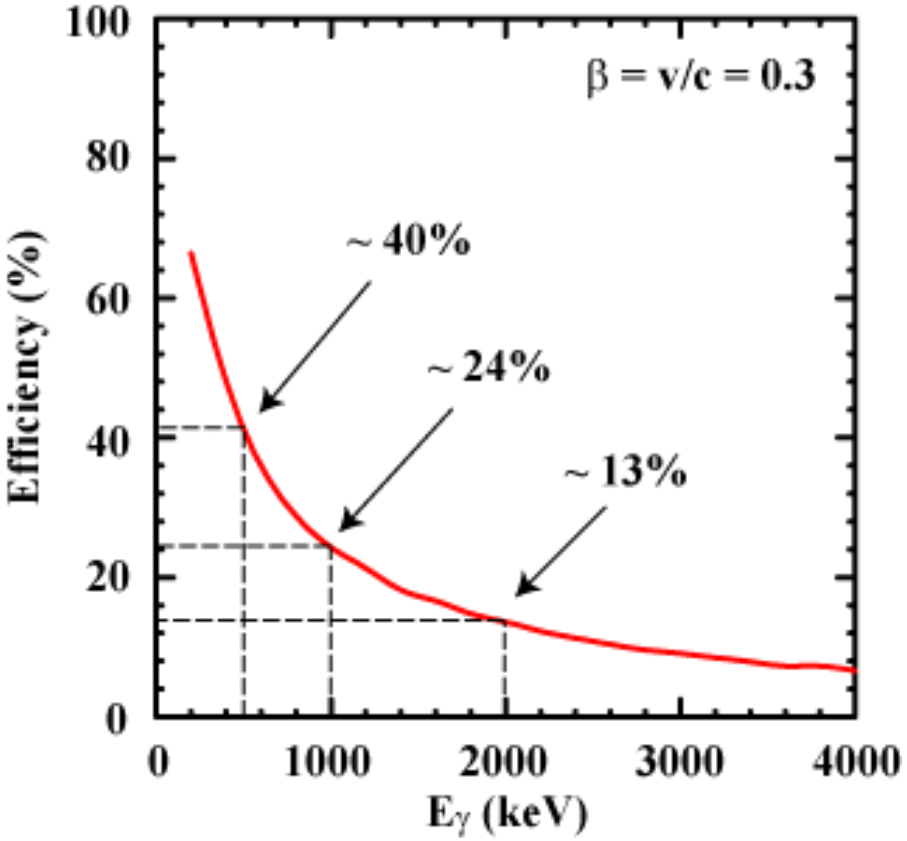
Angular coverage

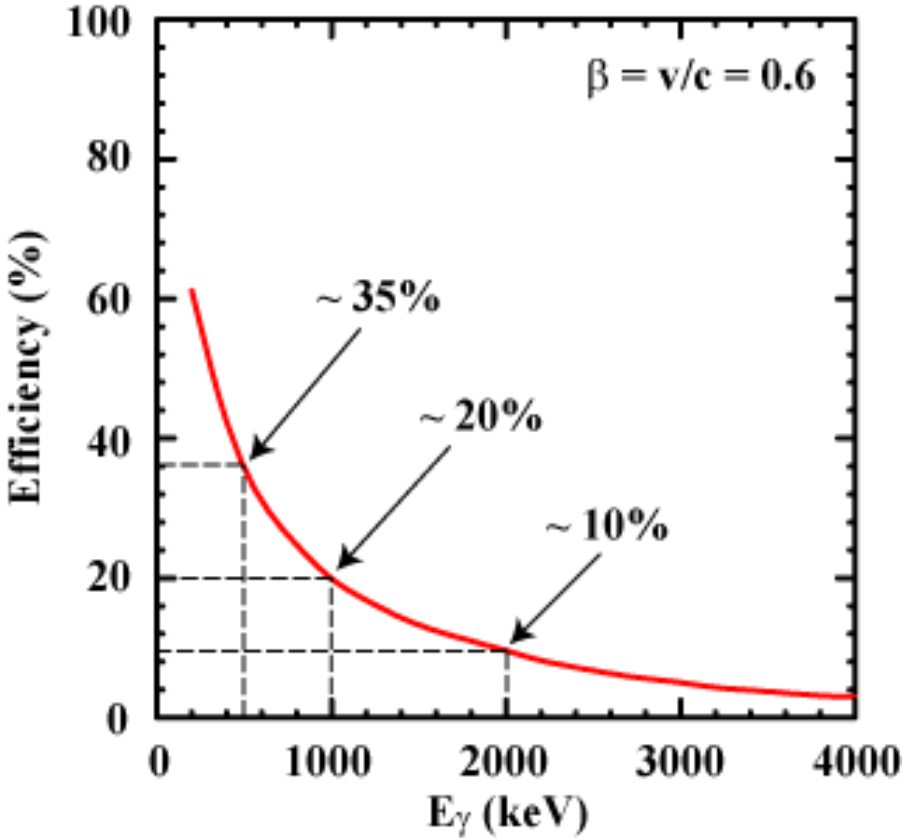
Efficiency depends on angular coverage and angular distribution of γ rays.

Efficiency curve

GEANT3 code

Without target, beam pipes





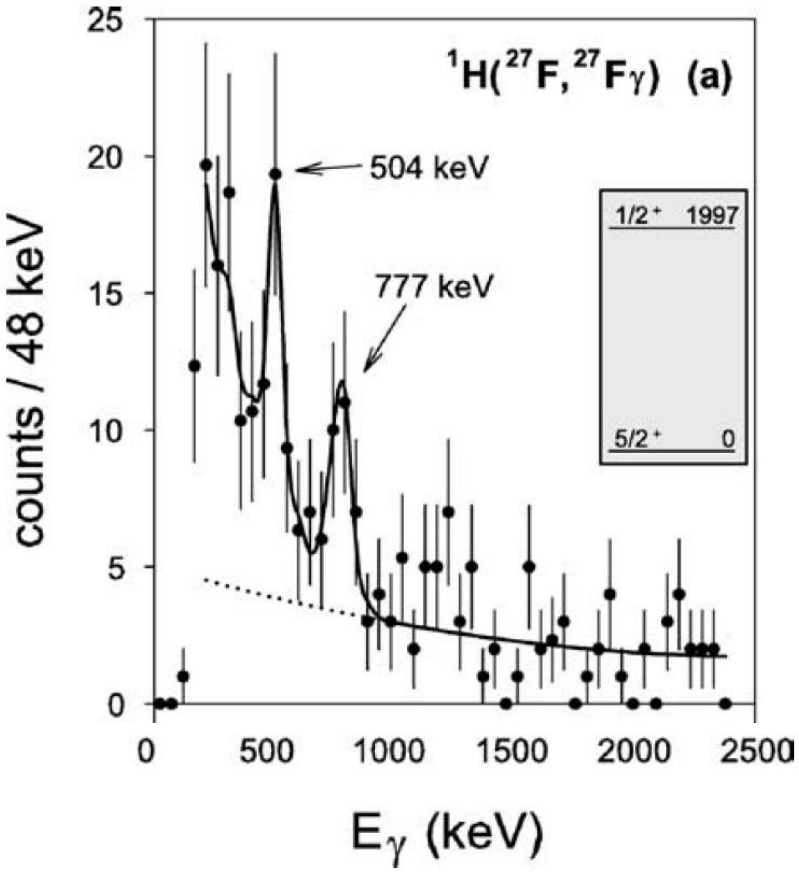
Energy resolution : 10%(FWHM)
for 1 MeV γ ray from β=0.6 nuclei

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

^{27}F inelastic scattering (@RIPS)

Physics Letters B 599 (2004) 17–22

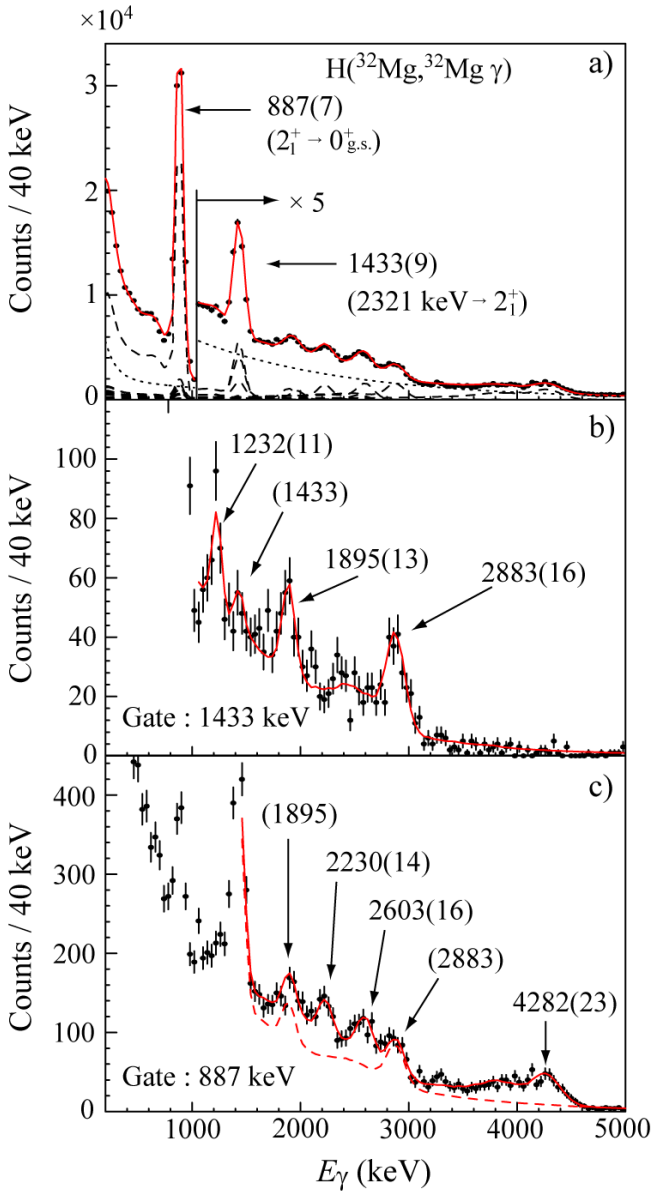


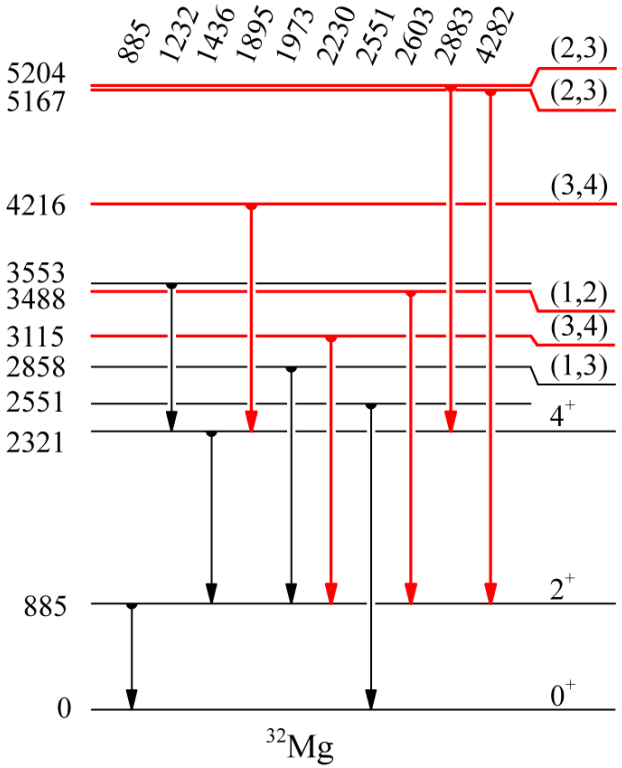
First experiment by using DALI2

^{27}F beam : 4 cps

^{32}Mg inelastic scattering (@RIPS)

PHYSICAL REVIEW C **79**, 054319 (2009)





^{32}Ne (@BigRIPS/ZDS)

PRL 103, 032501 (2009)

First experiment using DALI2 at RIBF

Eight hours measurements.

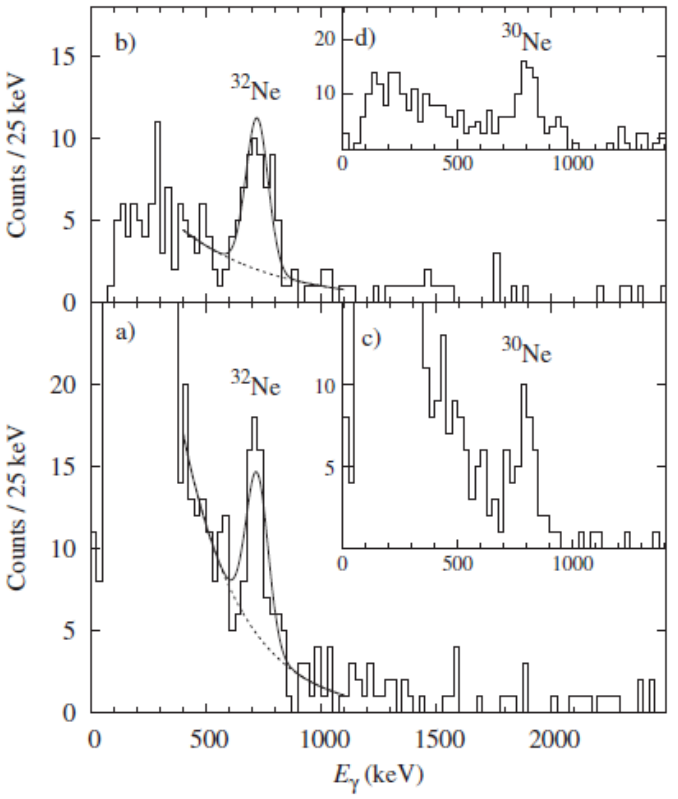
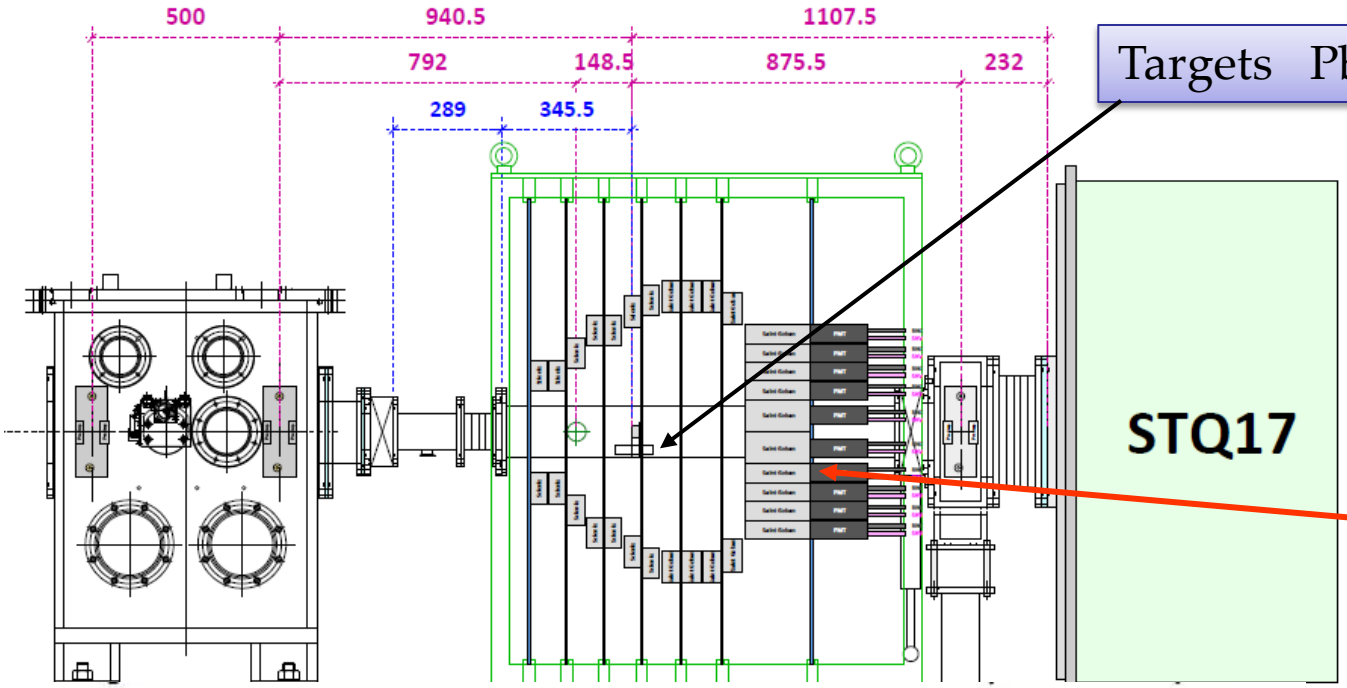


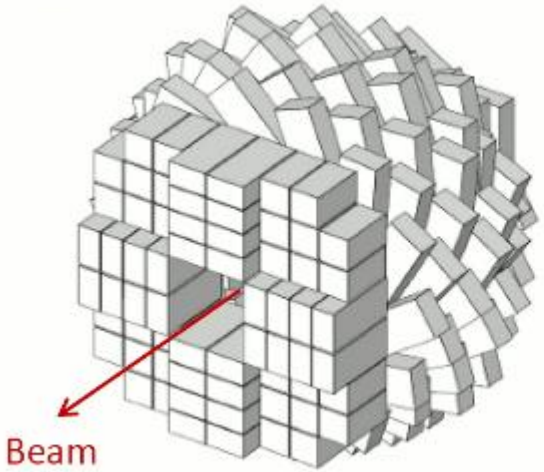
FIG. 2. Doppler corrected γ-ray energy spectra in coincidence ($\pm$5 ns) with ^{32}Ne (a),(b) and ^{30}Ne (c),(d). Panel (a) shows the results for inelastic scattering of ^{32}Ne and (b) the result for proton removal from ^{33}Na. The outcomes of the fitting procedure are shown by the solid (total) and dashed (background) curves. Here, both spectra were fitted simultaneously with the same peak position and peak width, but different peak areas and background parameters. The inset panels (c) and (d) show the results for inelastic scattering of ^{30}Ne and for $p2n$ removal from ^{33}Na, respectively, populating the first 2^+ state in ^{30}Ne.

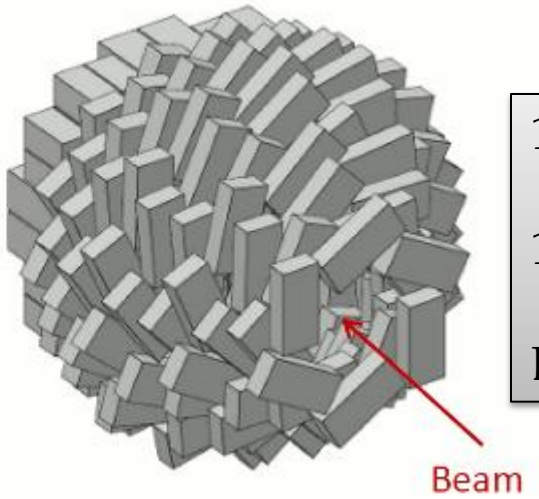
DALI2 configuration in the last experiments



Targets Pb, C, CH_2

`wall' consists of 5 rings.



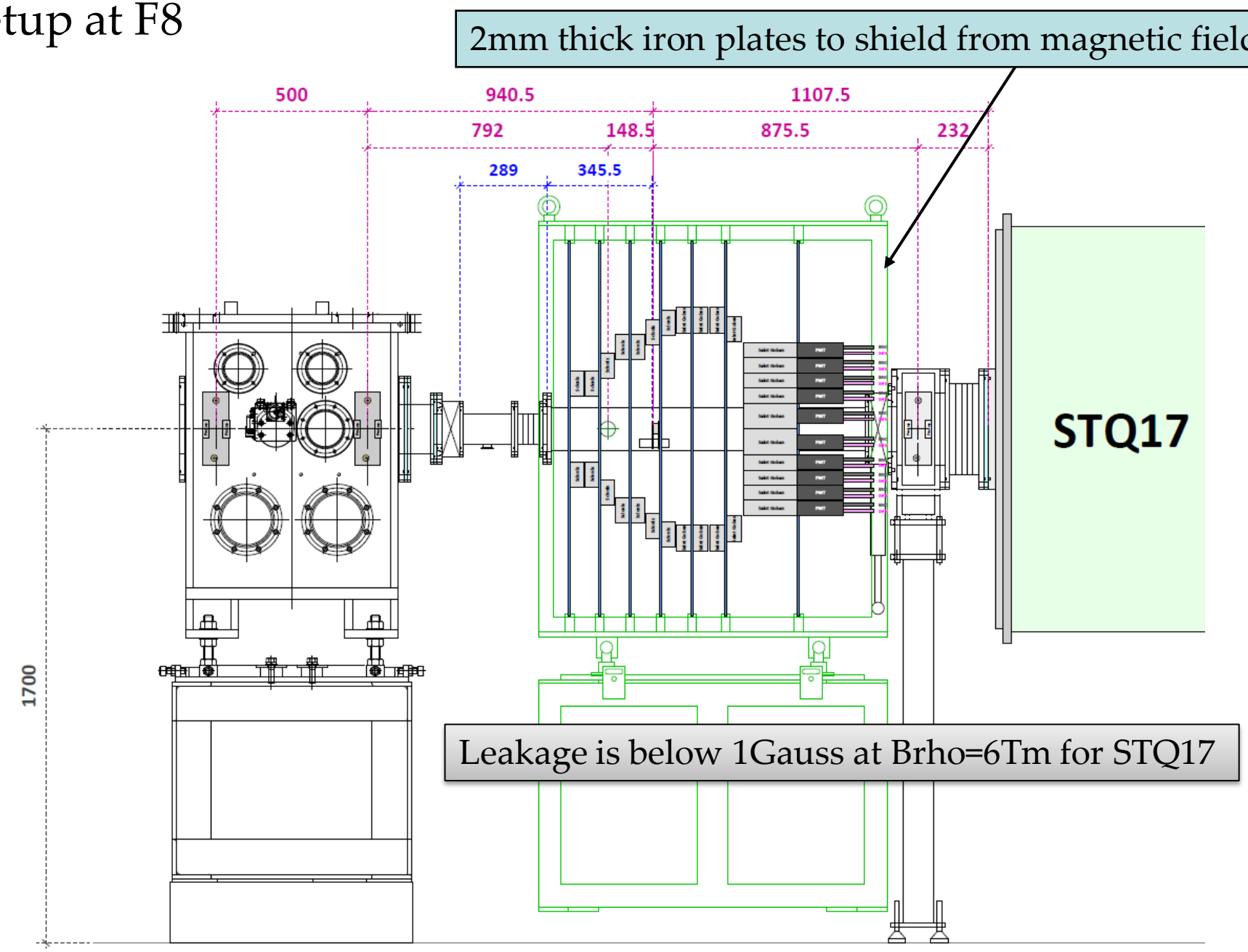


186 NaI(Tl) crystals

12 layers

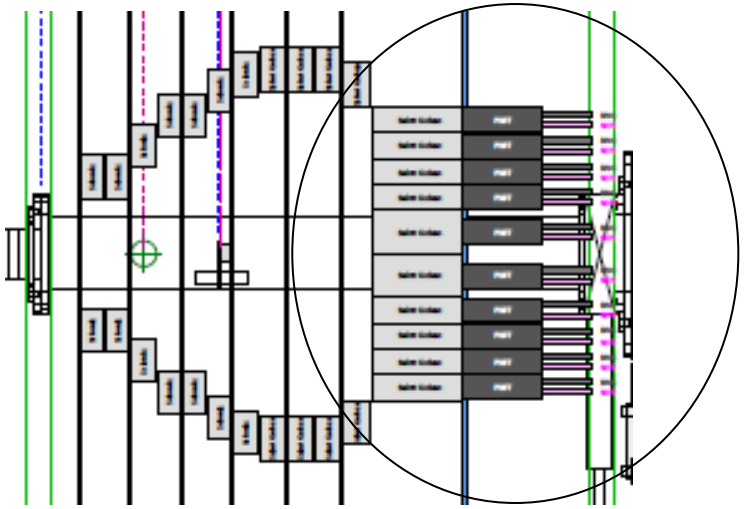
Eff. : ~ 25% for 1 MeV (β~0.6)

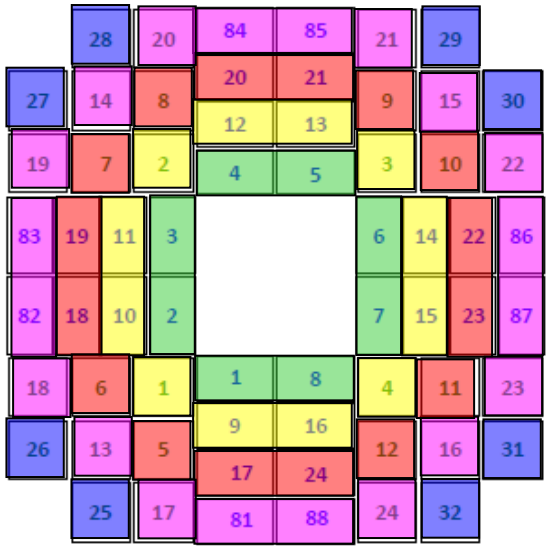
Setup at F8

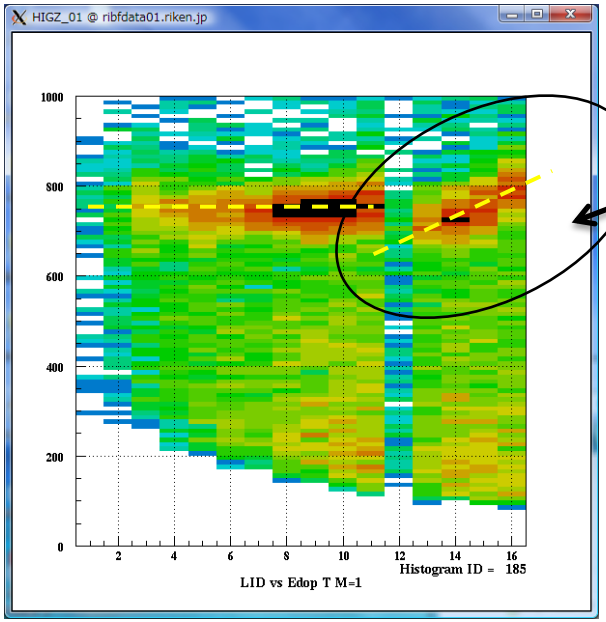

2mm thick iron plates to shield from magnetic field
500
940.5
1107.5
792
148.5
875.5
232
289
345.5
STQ17
1700
Leakage is below 1Gauss at Brho=6Tm for STQ17

Effects from magnetic field

Beam







May be effects from magnetic field

In order to correct this effect, we should measure calibrations for each Brho settings or make calibration using known energies of γ lines in the reactions.

Summary / Memo

DALI2 was developed for experiments performed at RIBF, by using 160-186 NaI(Tl) detectors.

→ DALI2 is a powerful tool for in-beam γ-ray spectroscopy.

Efficiency : ~20%
Energy resolution : ~10% (for 1MeV from β ~ 0.6)

For SAMURAI experiments, DALI2 may be **suitable or enough** for tagging final states in reactions.

Things to be considered,

use DALI2, use a part of DALI/DALI2
new frame?, new additional detectors?
is there enough space for current DALI2 frame?
how much magnetic leakage around reaction target position?
iron shields from magnetic field,
lead shields from atomic b.g., …

Summary / information from in-beam γ ray spectroscopy group

NOTICE! DALI2 is not a facility device.

So if you want to use DALI2, a part of DALI2, (or GRAPE (CNS Ge array)), please contact in-beam γ ray spectroscopy group.

→aoi@riken.jp, takesato@riken.jp, ideguchi@cns.s.u-tokyo.ac.jp (for GRAPE)

We are preparing drawings of detectors and frames and a simulation code.

Those information will be available on our website (to be published soon).