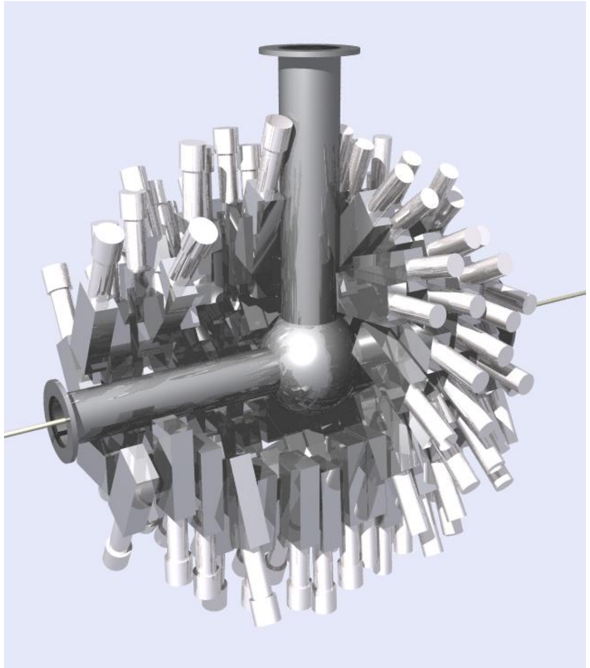
NaI(Tl) array for in-beam γ-ray spectroscopy

-DALI2-



- Introduction
  - DALI & DALI2
  - In-beam γ-ray spectroscopy
- Developments
  - Requirements
  - Solutions
  - DALI2
- Experiments
  - DALI
  - DALI2

TAKEUCHI Satoshi RIKEN Nishina Center

DALI & DALI2

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

→ For use in experiments with in-beam γ-ray spectroscopy technique.

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

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

  Publication : 21 papers

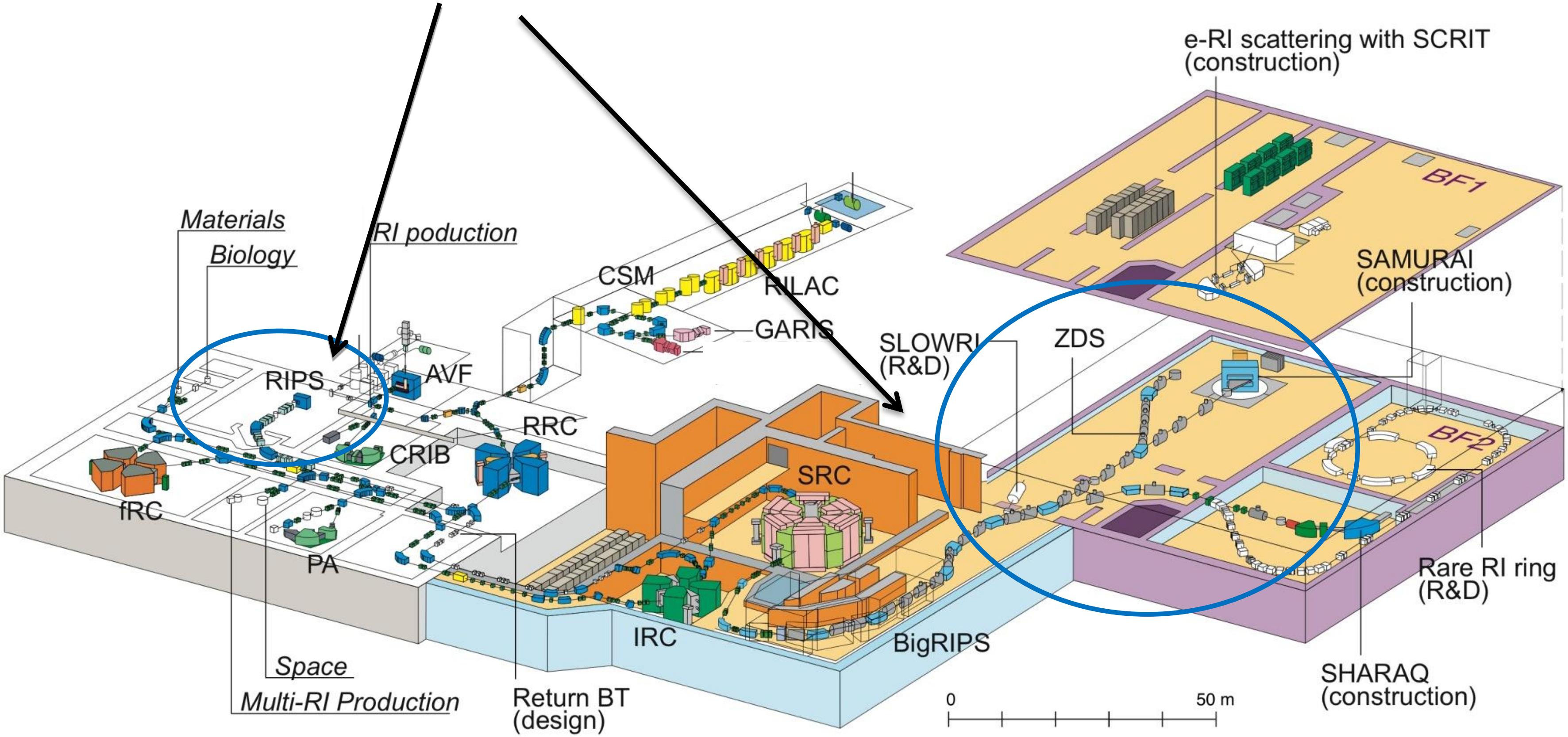
- **DALI2** (2002 -) by Rikkyo University and RIKEN

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

  Publicatino : 24 papers

RI Beam Factory

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



Performed at RIPS, BigRIPS/ZDS, and SHARAQ

Unstable nuclei

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

–Low beam intensity

–Low event rate (γ ray emission)

–Doppler shift [β = v/c ~ 0.3 (RARF) and β ~ 0.6 (RIBF)]

→γ ray energy depends on the emission angle.'

Typical beam intensity

RIPS (^{40}Ar ~50pnA)

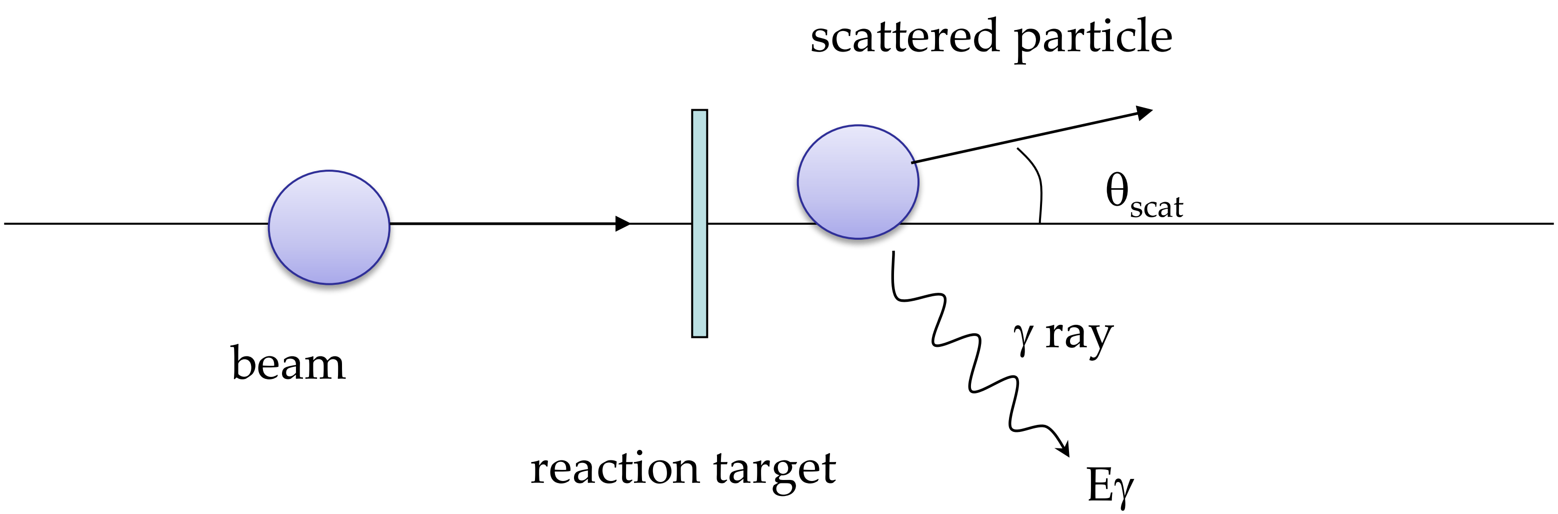
^{30}Ne 0.2 cps, ^{32}Mg 500 cps β ~ 0.3

BigRIPS (^{48}Ca ~100pnA)

^{30}Ne~ 300 cps, ^{42}Si ~10 cps β ~ 0.6

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.



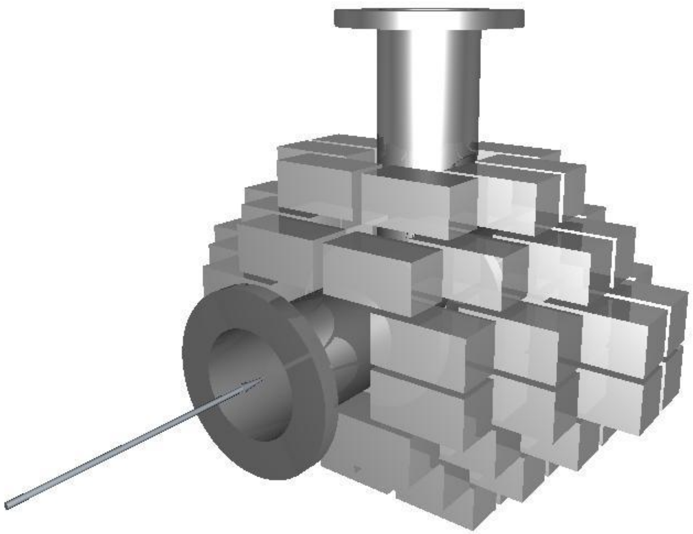
100 keV – 5000 keV

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

→ Nuclear structure or shape

Experiment at RIPS with DALI

DALI : Detector Array for Low Intensity radiation



60 NaI(Tl) detectors

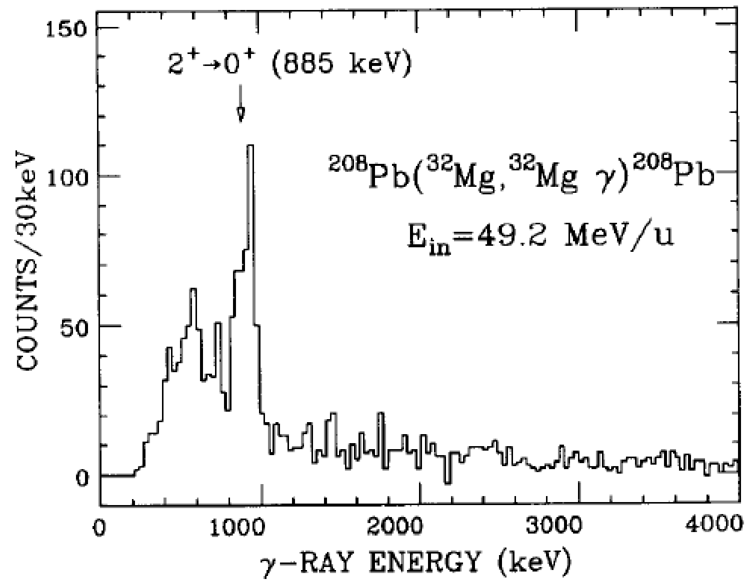
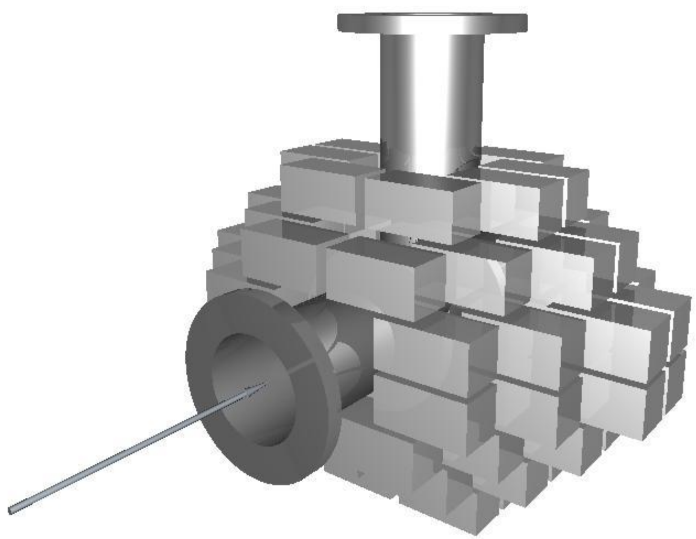


Fig. 1. Energy spectrum of γ rays emitted from the $^{32}Mg+^{208}Pb$ inelastic scattering at 49.2 MeV/u incident energy. The Doppler shift is corrected for.

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

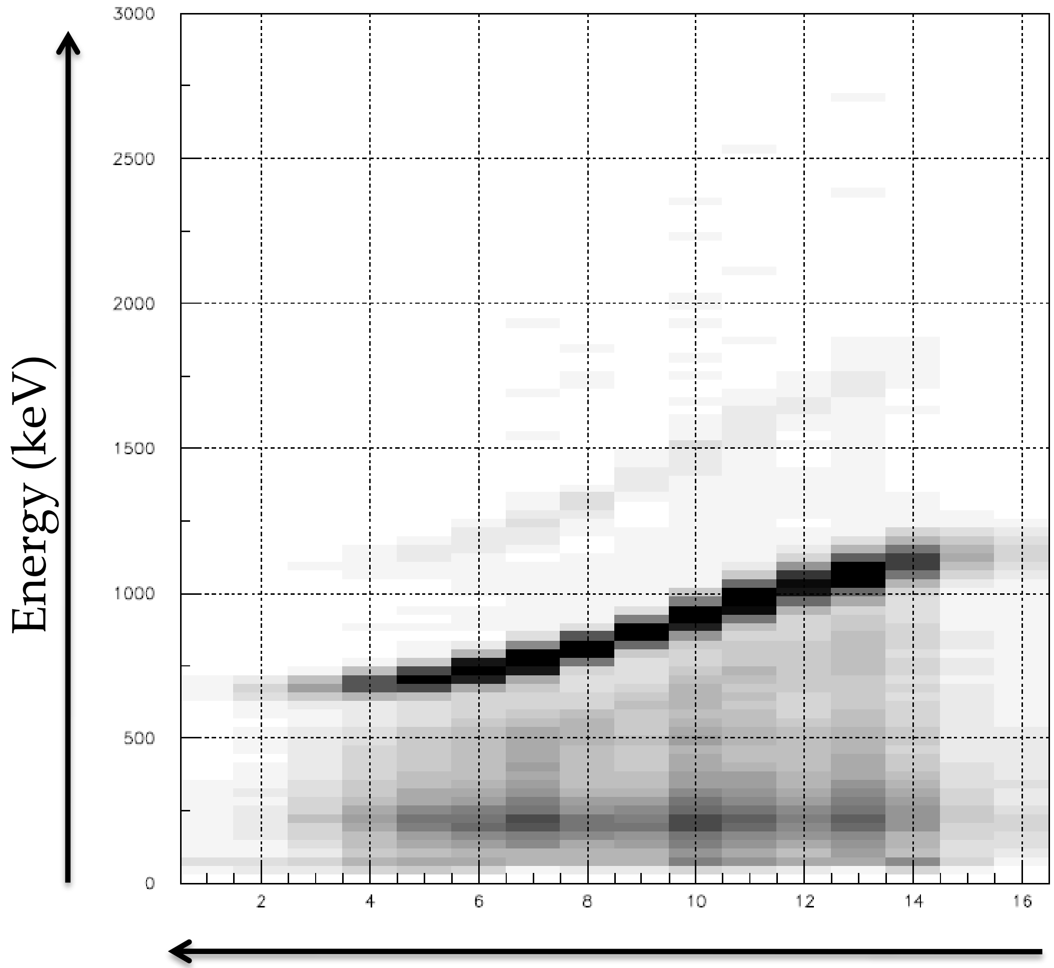
γ rays which we measure.

- 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

Corrections of Doppler shift effects

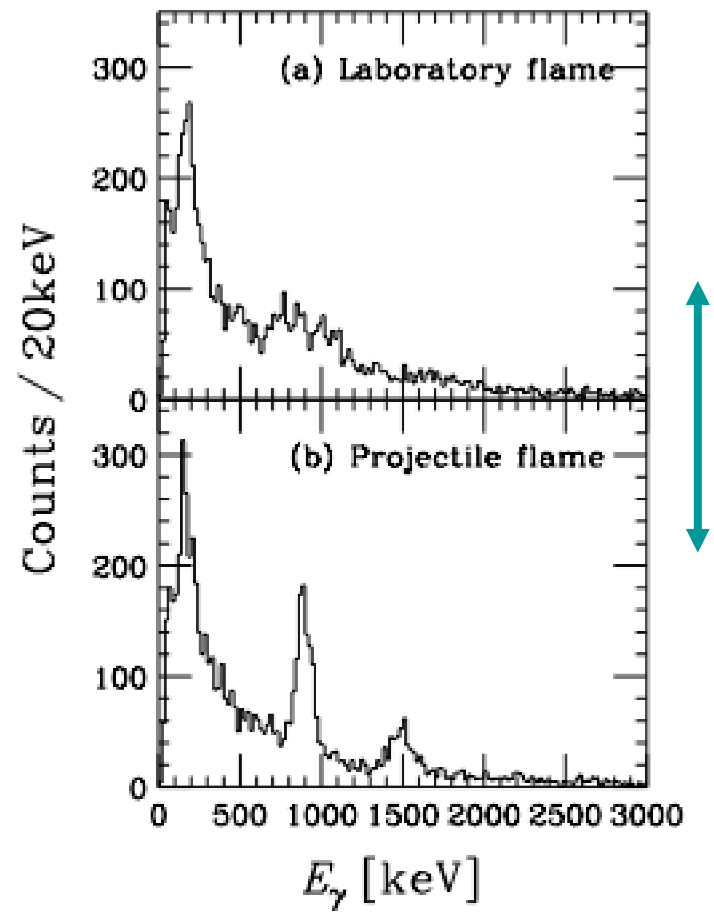


160°

20°

Emission angle

^{32}Mg(p,p′) b~0.3



γ 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

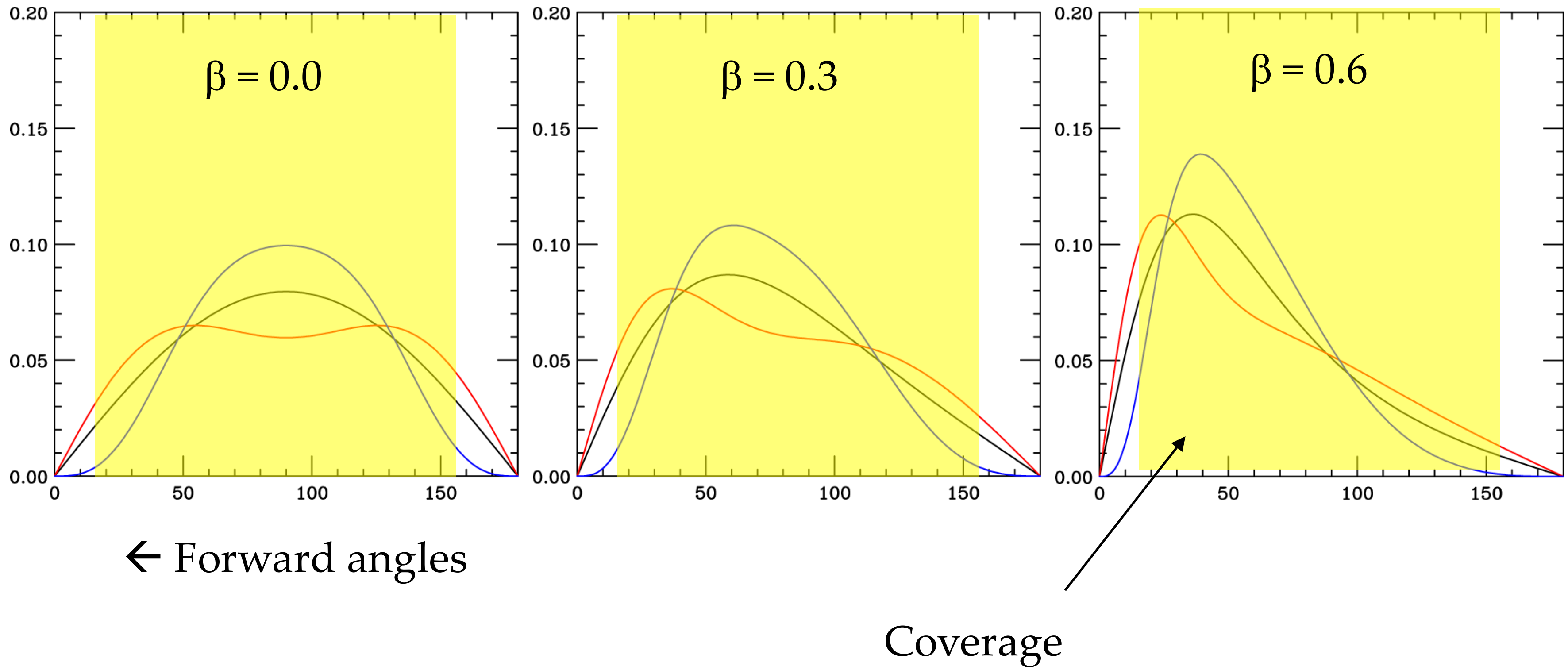
- Emission angle — Forward peak (Lorentz boost)

  → Detector arrangement

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

Angular distribution of γ rays

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



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

The policy of the design

γ ray energy	→ Excitation energy	← intrinsic resolution & granularity
γ ray yield	→ Transition strength	← large volume
γ ray distribution	→ Angular momentum	← granularity

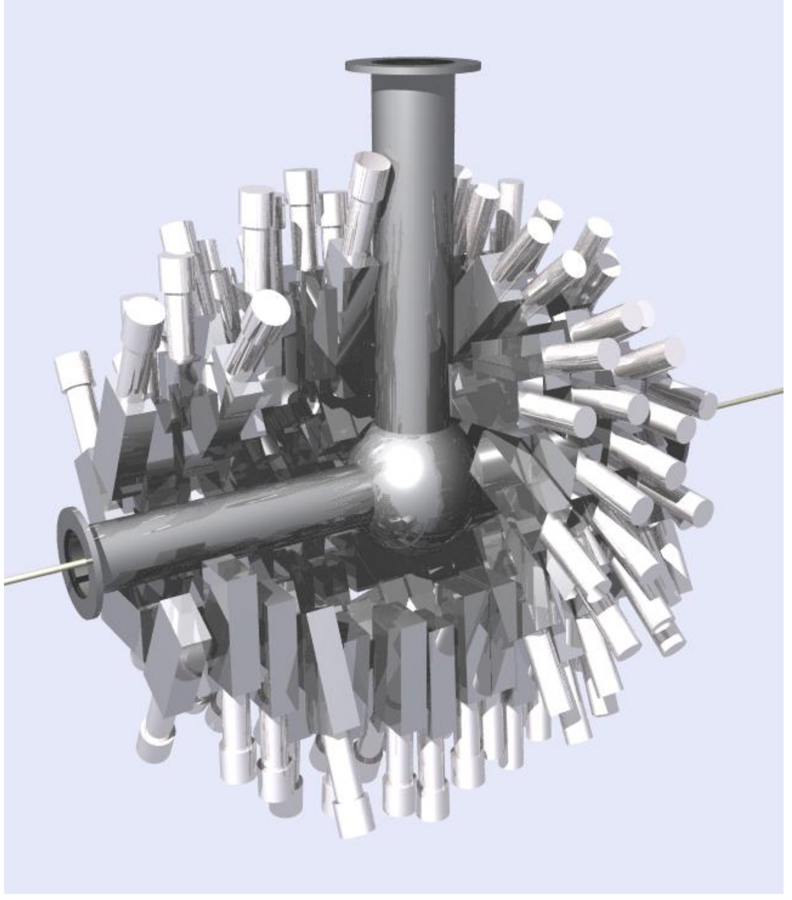
↓

High detection efficiency and high angular resolution array

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

~ 200 NaI(Tl) detectors

DALI2 (Detector array for Low Intensity radiation 2)



Collaboration : RIKEN Nishina Center & Rikkyo University

Specification

Rikkyo

- SAINT-GOBAIN x 80 detectors

  45 x 80 x 160 (mm)

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

PMT : HAMAMATSU R580

RIKEN

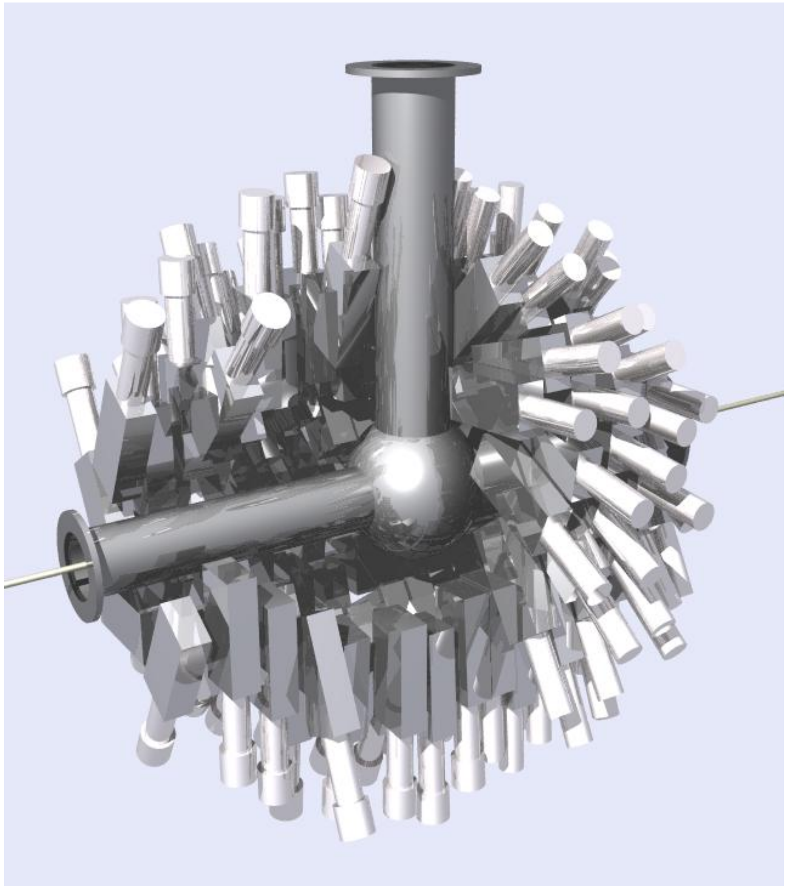
- SCIONIX x 80 detectors

  40 x 80 x 160 (mm)

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

+ BICRON detectors (from DALI)

- DALI2 – for RIBF exp.



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

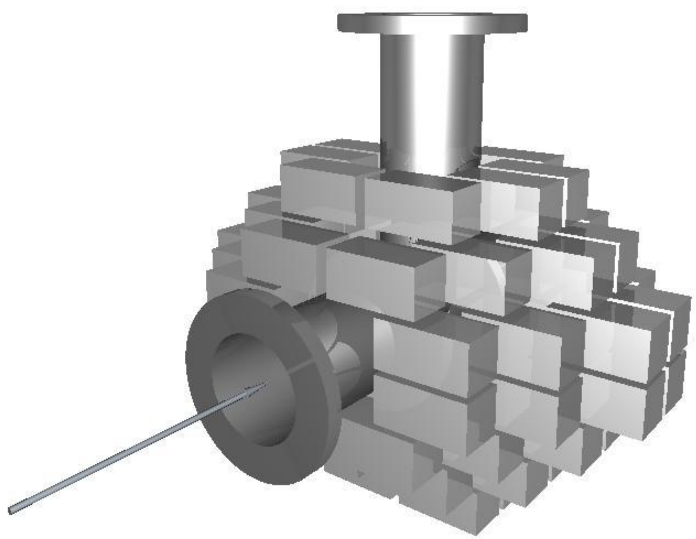
Ref. S.Takeuchi et al., RIKEN Accel. Prog. Rep. **36**(2003)148

Past experiments with DALI (2005-1994)

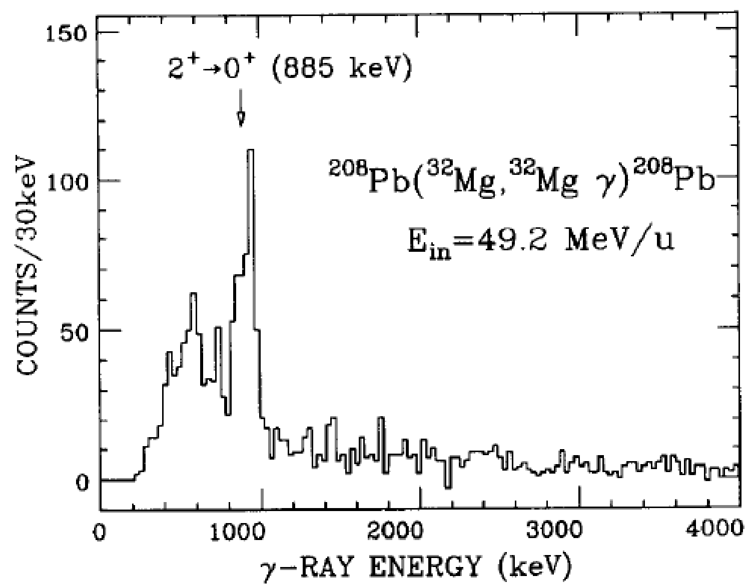
^{18,19}C knockout reaction	TITech, RIKEN	RIPS
^{20}Mg Coulex	Tohoku, Rikkyo, RIKEN	RIPS
^{28}Ne Coulex	CNS, RIKEN	RIPS
^{15,17}B(C,C')	TITech	RIPS
^{12}Be 0^{+} state	CNS, Rikkyo, RIKEN	RIPS
^{30}Ne(p,p')	RIKEN, Rikkyo	RIPS
^{14}O(α,α')	CNS, Rikkyo	RIPS
^{12}Be(α,α')	CNS, Rikkyo	RIPS
^{16}C(Pb,Pb')	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

Experiment at RIPS with DALI

DALI : Detector Array for Low Intensity radiation



60 NaI(Tl) detectors



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

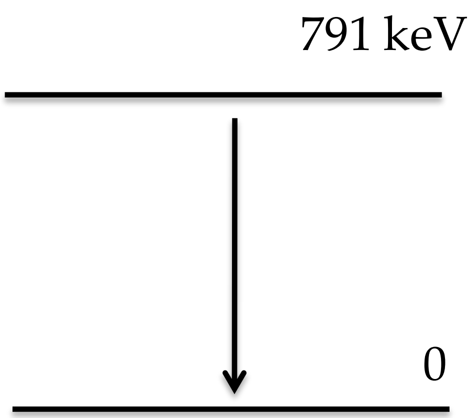
^{30}Ne inelastic scattering (@RIPS)

Physics Letters B 566 (2003) 84–89

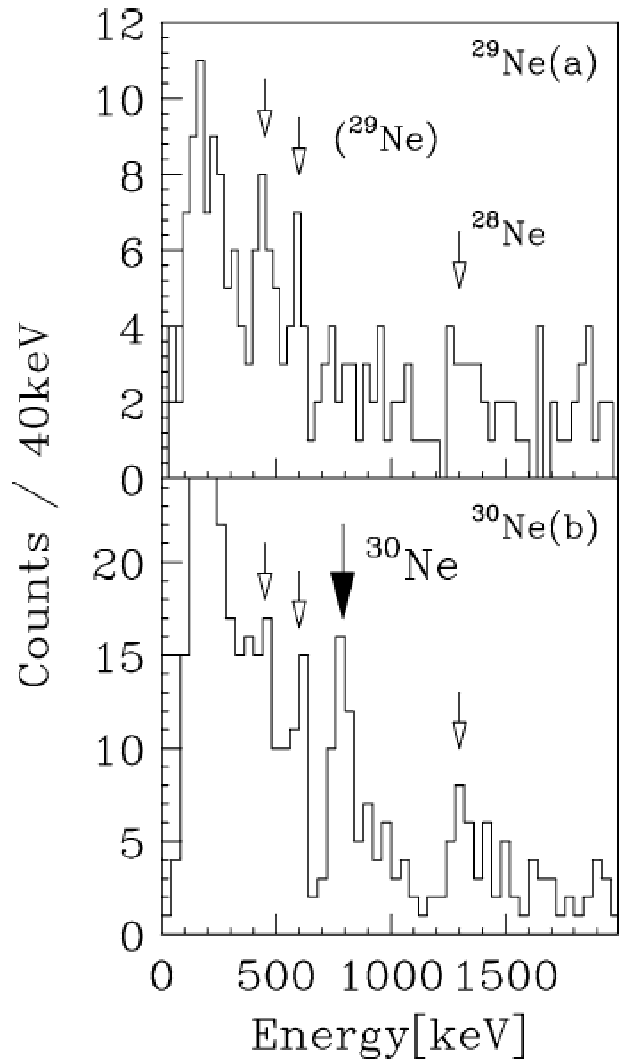
^{30}Ne beam : 0.2 counts / second

→ Very weak intensity

Identify peak with or without conditions of particle identifications.



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

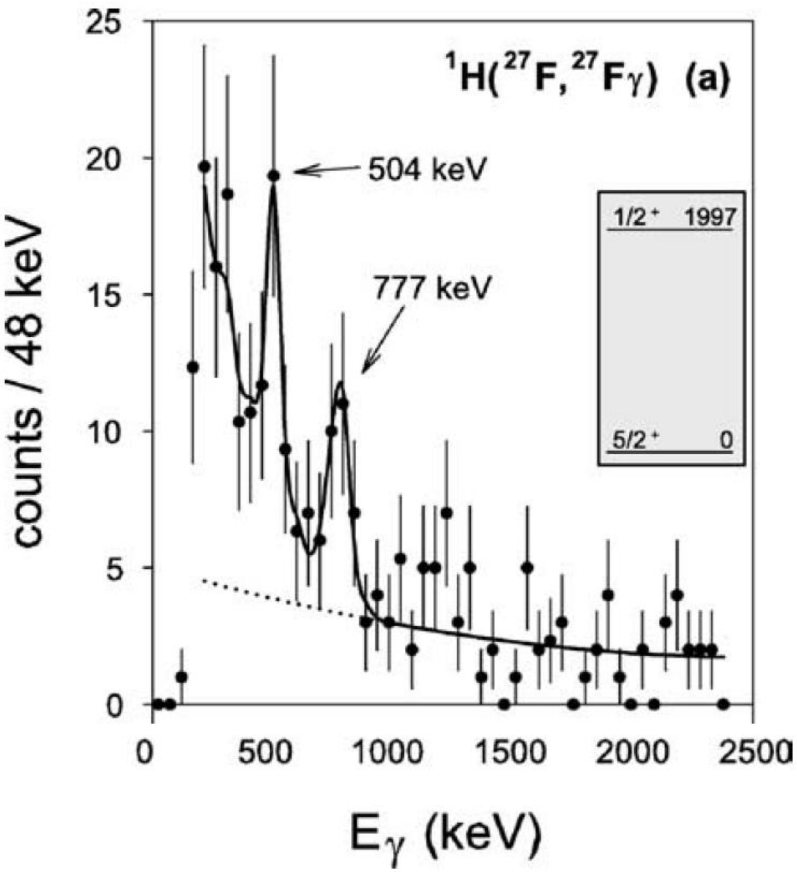


Past experiments with DALI2 (present-2002)

^{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
$^{78\text{-}82}$Ge Coulex	Tokyo, RIKEN	RIPS
^{28}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)

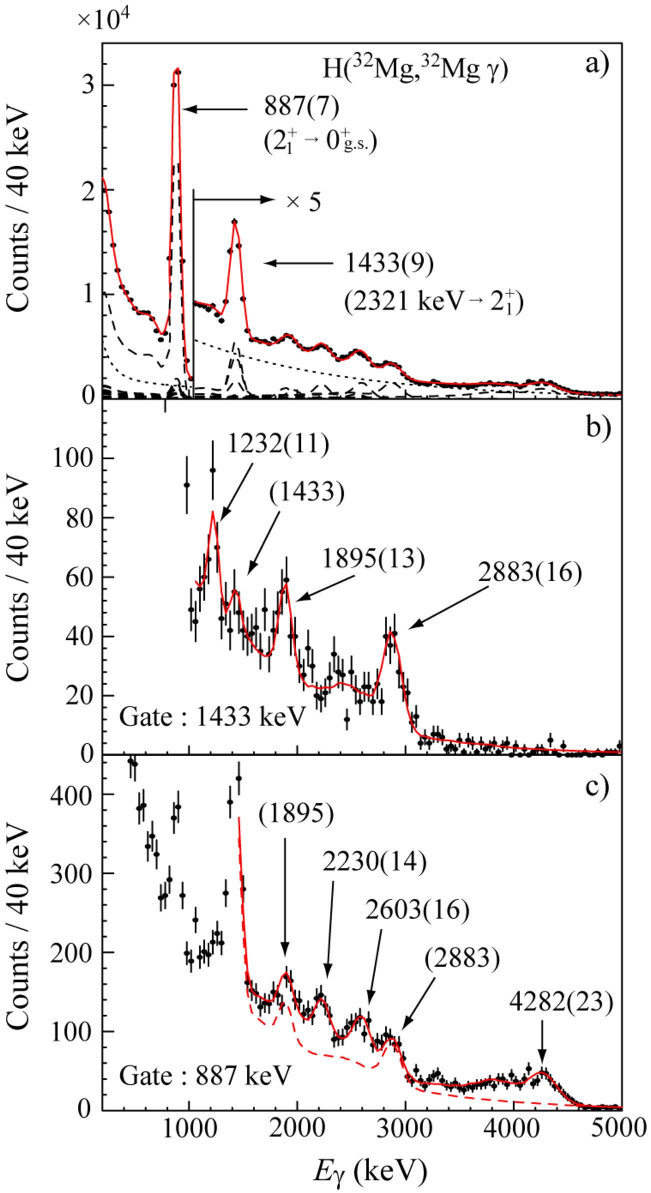
Physics Letters B 599 (2004) 17–22

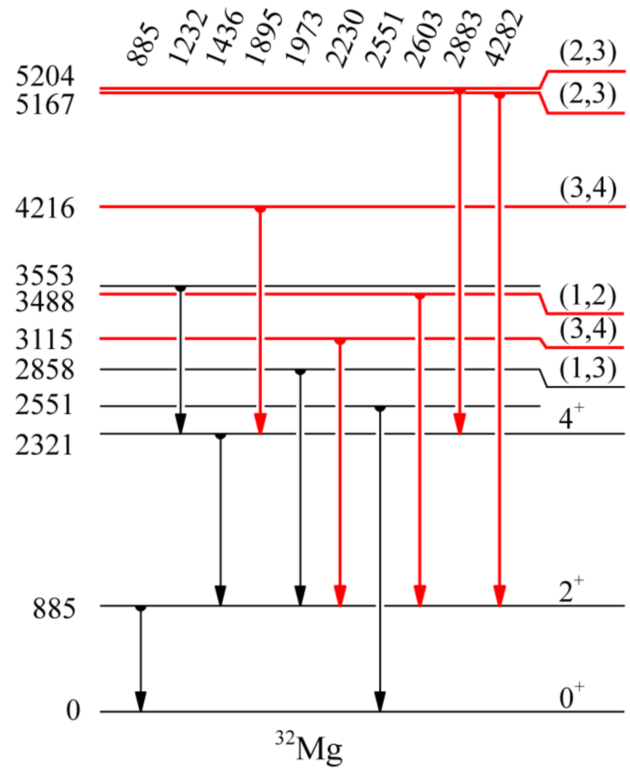


First experiment by using DALI2

^{27}F beam : 4 cps

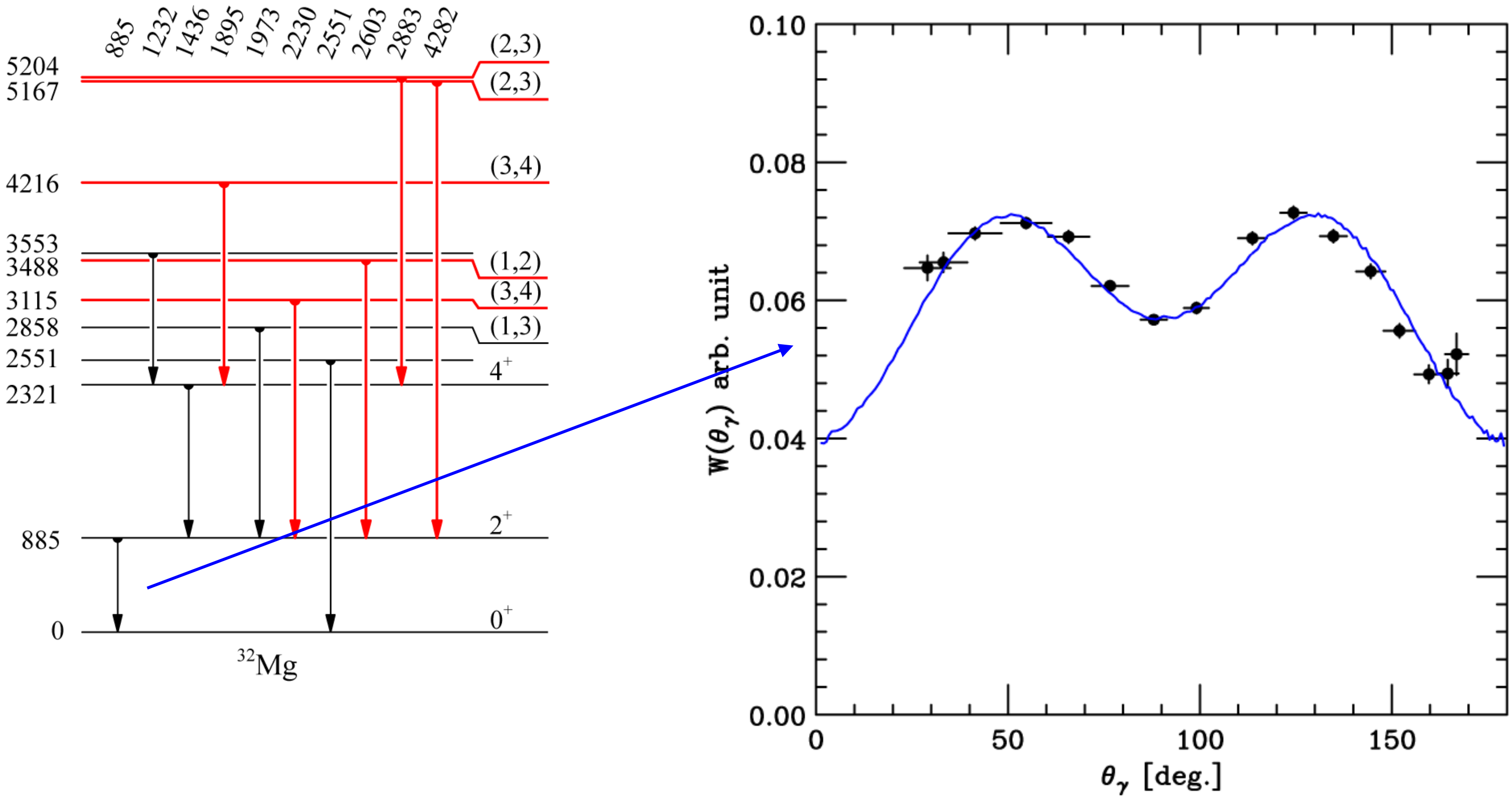
^{32}Mg inelastic scattering (@RIPS) PHYSICAL REVIEW C **79**, 054319 (2009)





Angular distribution of γ rays

Multipolarity = 2



^{32}Ne (@BigRIPS/ZDS)

PRL 103, 032501 (2009)

First experiment using DALI2 at RIBF

Eight hours measurements.

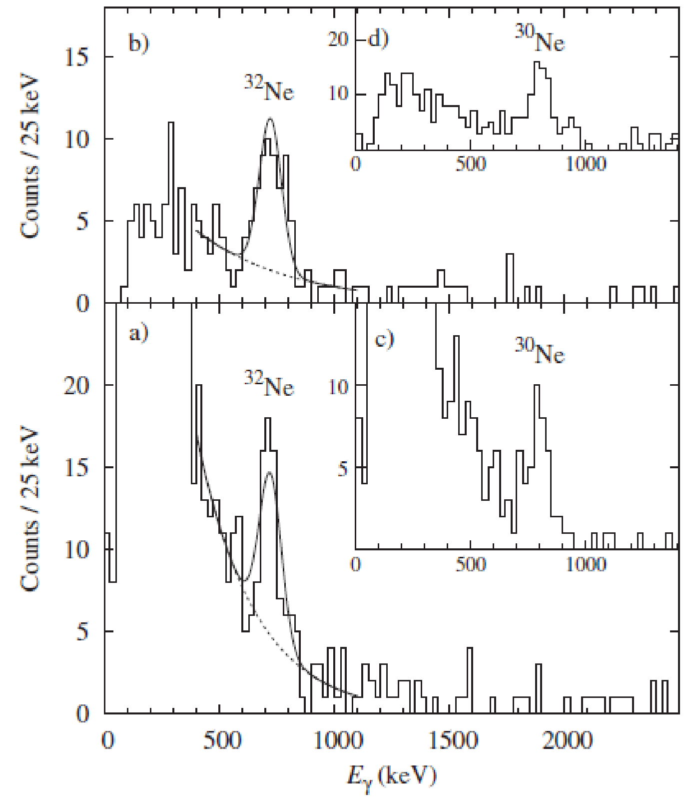
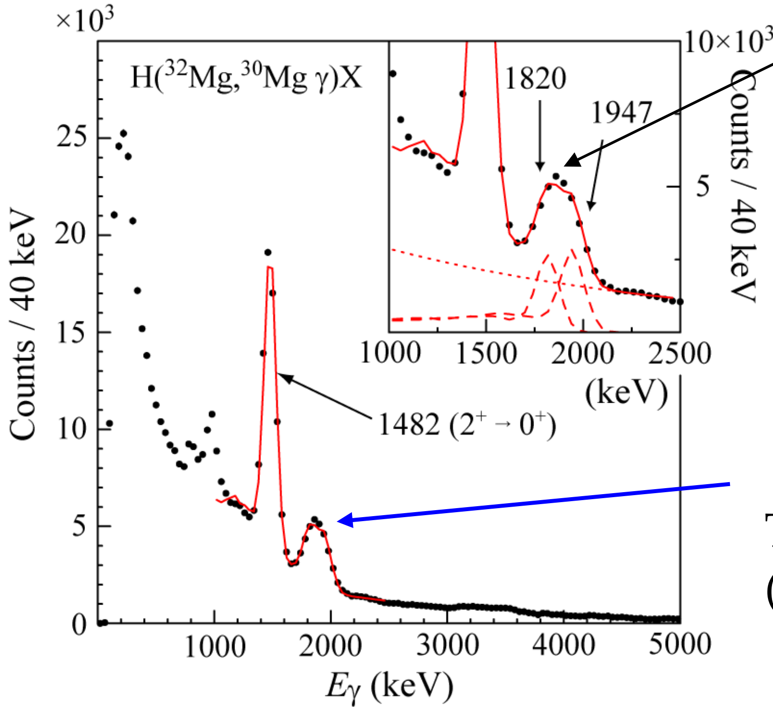


FIG. 2. Doppler corrected γ-ray energy spectra in coincidence ($\pm$5 ns) with ^{32}Ne (a),(b) and ^{30}Ne (c),(d). Panel (a) shows the results for inelastic scattering of ^{32}Ne and (b) the result for proton removal from ^{33}Na. The outcomes of the fitting procedure are shown by the solid (total) 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.

$^{32}Mg \rightarrow {}^{30}Mg$ (@RIPS)

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

One more γ line



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

Need more good resolution to separate γ lines

Next-generation array → SHOGUN

Efficiency (高効率)	larger volume high-z scintillator
Granularity (細分化)	small size scintillator enough length for γ rays
Flexibility (融通がきく)	easy rearrangement easy cabling

+ better intrinsic energy resolution

Efficiency	~ same as the present system or better
Energy resolution	< 3% @ ^{137}Cs energy
Angular resolution	< 3 degrees
Circuit	FADC+FPGA?
γ ray tracking	pulse shape analysis, if shape depends on depth.

$LaBr_3$(Ce) scintillator - BrilLanCe 380 by SAINT-GOBAIN

	Light output (%)	Decay time (ns)	Density (g/cm^3)	DE/E (%) @511keV
$LaBr_3$(Ce)	**130**	**26**	**5.3**	**3**
NaI(Tl)	**100**	**250**	**3.7**	**7**
LSO	50-75	41	7.4	12
GSO	20-30	30-60	6.7	9
BGO	20	300	7.1	14

$LaBr_3$(Ce) : good solution, but very expensive.

25mmϕ x 76mm → ~¥1,300,000 (without PMT) (2008) → **¥35,000 /cm^3**

NaI(Tl)

40mm x 80mm x 160mm → ~¥500,000 (with PMT) → **¥1,000 /cm^3**

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 in **the light-mass region**, especially for study of the first 2^+ state.

→ For **the heavier mass region** and more detailed studies, we have to develop a new device, SHOGUN.

When we can switch to SHOGUN?

How many people (or collaborations) do we need?

How much?

We continue to use DALI2 or other Ge arrays, until SHOGUN is available.