In-beam γ ray Experiments

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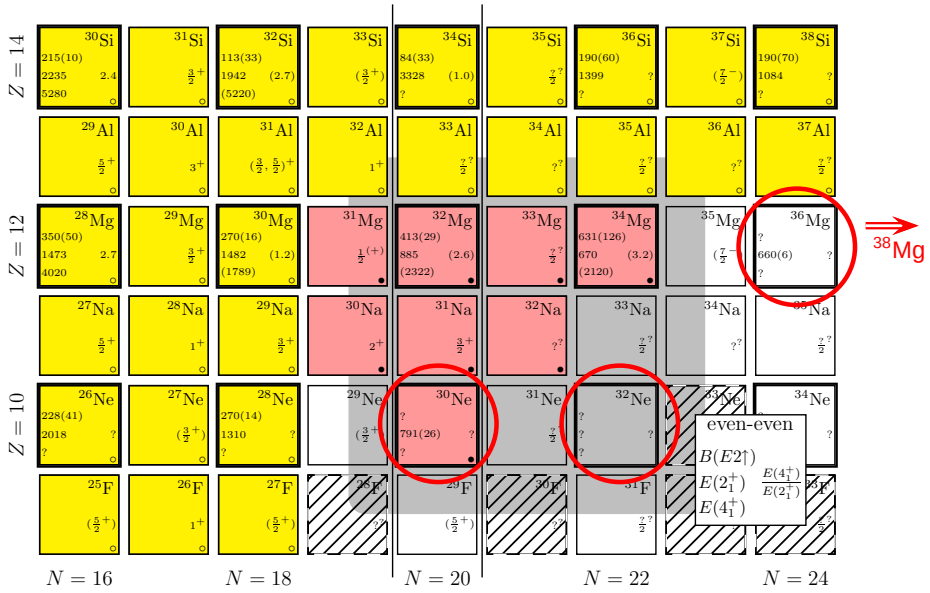
Outline

- List of approved in-beam γ ray experiments
- Overview of in-beam γ ray results 2008: 8 hours
  - DALI2 γ ray spectrometer (NaI(Tl) based)
- GRAPE γ ray spectrometer (HPGe based)
- SHOGUN γ ray spectrometer ($LaBr_3$(Ce) based)
- Things to consider
  - mainly due to high beam energy
- RIBF user group meeting in Hawaii

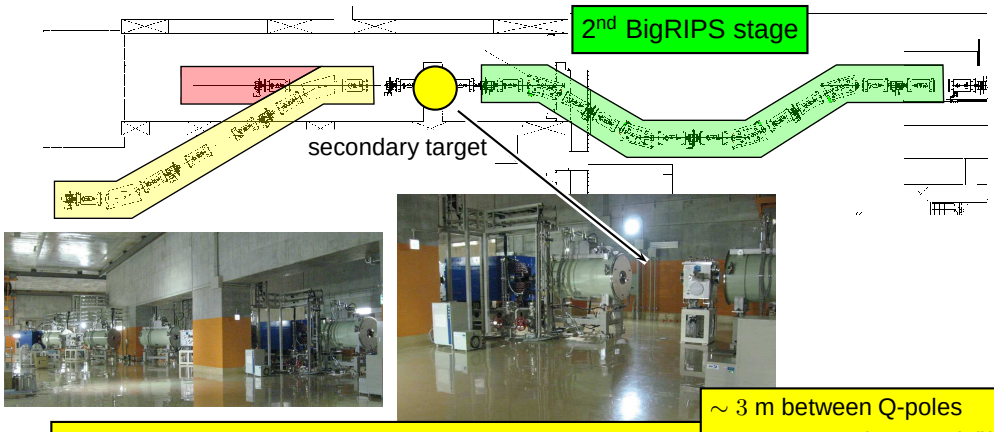
List of In-Beam γ ray Experiments

prim. beam	interest	spokesperson	days
^{16}O, ^{20}Ne, ^{36}Ar	?	**L. Trache**	3
^{48}Ca	$B(E2\uparrow)$: ^{42}Si	S. Takeuchi	3
^{48}Ca	$B(E2\uparrow)$: ^{30}Ne, ^{36}Mg, $E(2^+)$: ^{32}Ne,^{38}Mg,...	**H. Scheit**	10
^{48}Ca	$E(2^+)$: ^{40}Mg	**P. Fallon**	3(+3)
^{48}Ca	^{33}Mg	**D. Bazin**	4
^{70}Zn, ^{76}Ge	lifetime near ^{64}Cr	E. Ideguchi	4
^{86}Kr	?	Sohler/Elekes	?
^{86}Kr	$B(E2\uparrow)$: ^{52,54}Ca $E(2^+)$: ^{54}Ca	S. Takeuchi	2
^{124}Xe	$B(E2\uparrow)$: near ^{100}Sn	P. Doornenbal	7
^{238}U	?	Zs. Dombradi	3
^{238}U	$B(E2\uparrow)$, $E(2^+)$ near ^{132}Sn	**N. Aoi**	10
^{238}U	$B(E2\uparrow)$, $E(2^+)$ near ^{78}Ni	K. Yoneda	10

Island of Inversion



Experimental Setup



~ 3 m between Q-poles
- DALI2 array (180 NaI(Tl))

0° Spectrometer ZeroDegree
- **particle ID** after secondary target
- fragment momentum distribution
- various modes of operation

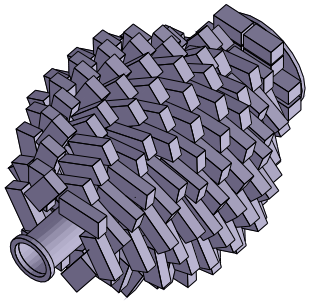
mode	$p/\Delta p$	Δp	Ang. Accep.
Large Accep.	1240	$\pm 3\%$	± 45 mrad(V) ± 30 mrad(H)
High res.(achrom)	2120	$\pm 3\%$	± 20 mrad(V) ± 30 mrad(H)
Dispersive	4130	$\pm 2\%$	± 20 mrad(V) ± 30 mrad(H)

DALI2

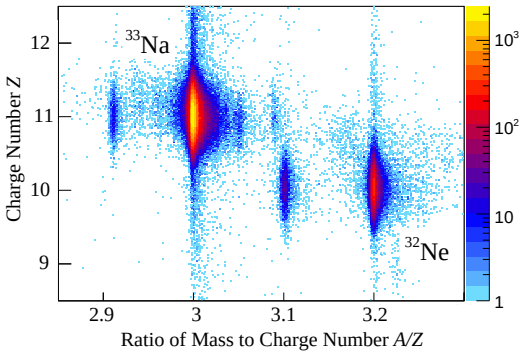
- 182 NaI(Tl) detectors
- θ coverage: 11°–165°
- $\epsilon_\gamma \approx 20\%$
- $\Delta E/E = 6\%$ (1 MeV) $\quad 11\%$ ($\beta = 0.6$)
- target: 2.54 g/cm^2 C
- S. Takeuchi *et al.*, RIKEN Prog. Rep. 36, 148 (2003)





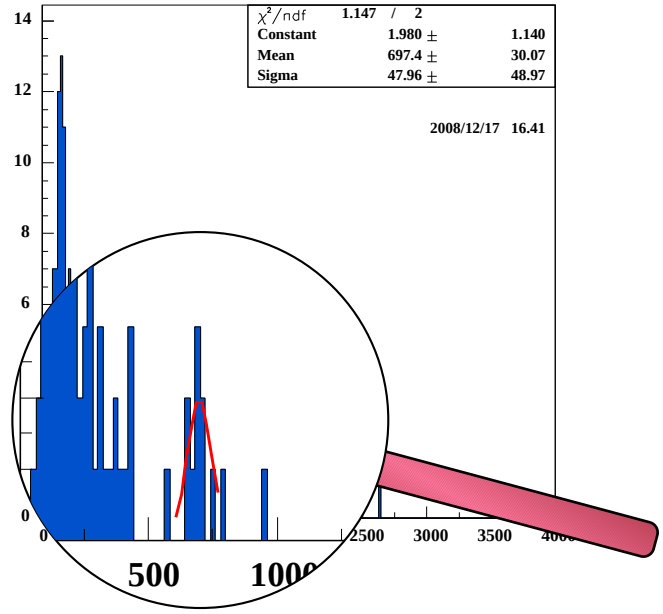


PID Before Secondary Target

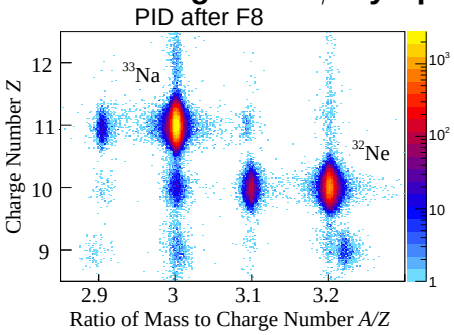


- ΔE–$B\rho$–TOF method
  - $Z \propto \Delta E$ $\quad \Delta Z = 0.5$ (FWHM)
  - $A/Q \propto$ TOF $\quad \Delta A = 0.06$ (FWHM)
- ^{32}Ne: 5/s $\quad E \approx 230$ MeV/u
- ^{33}Na: 30/s

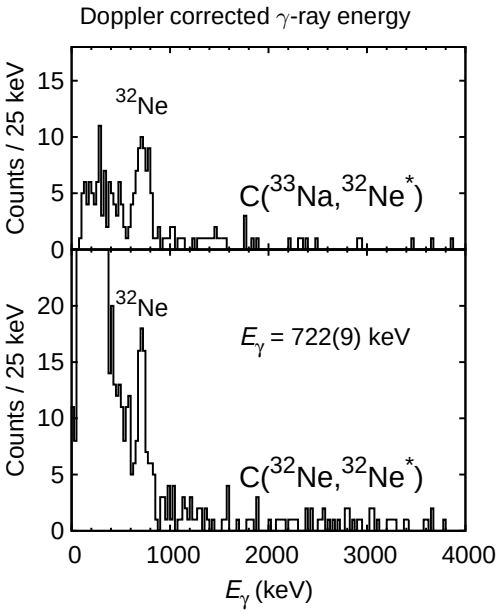
First New In-Beam γ ray Transition at the RIBF



PID After Target and γ ray Spectra

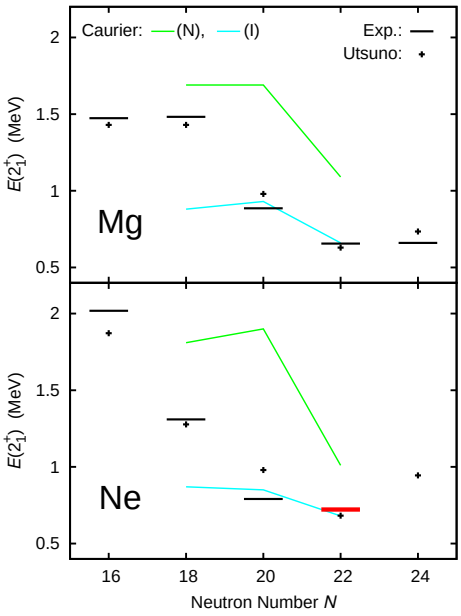


- C(^{32}Ne,^{32}Ne*), C(^{33}Na,^{32}Ne*)
- ^{32}Ne: 5 pps, 225 MeV/u
- F8 target: $^{nat.}$C (2.54 g/cm^2)
- DALI2 array: 182 NaI(Tl) detectors
- total data taking: 7 hours



$E(2^+)$ as Function of N

- lowest $E(2^+)$ of Ne isotopes
- very good agreement with Utsuno et al., PRC 60, 054315 (1999)
- very good agreement with Intruder calculation of Caurier et al., NPA 693, 374 (2001)
- ^{32}Ne belongs to the "Island of Inversion"



P. Doornenbal, H. Scheit *et al.*
Phys. Rev. Lett. 103, 032501 (2009)
arXiv:0906.3775

Next In-Beam γ Campaign

- Nov. 2009: 6 days U (Aoi-san, Yoneda-san)
- Dec. 2009: 7 days ^{48}Ca (Scheit-san, Takeuchi-san)
- RIBF beam time for in-beam γ ray experiments

year	time	
2007	0	
2008	8	hours
2009	15	days

- RIPS still operational

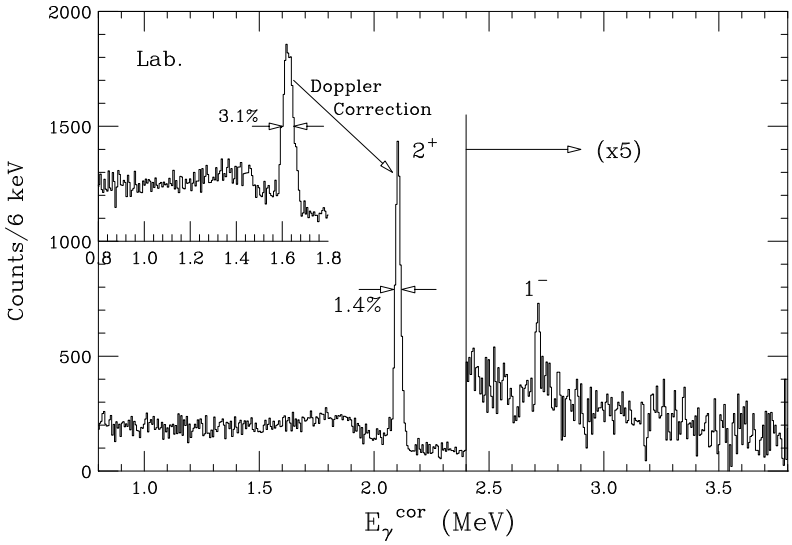
CNS GRAPE

- **G**amma-**R**ay detector **A**rray with **P**osition and **E**nergy sensitivity
- 18x2 planar segmented Ge detectors
- High Resolution 2.5 keV intrinsic resolution for 1.3 MeV
- High Sensitivity $\epsilon\Omega \sim 5$ % for 1 MeV
- Position Sensitive: Resolution after Doppler Correct. 1 %
- Goal: 1 mm position resolution for z-direction



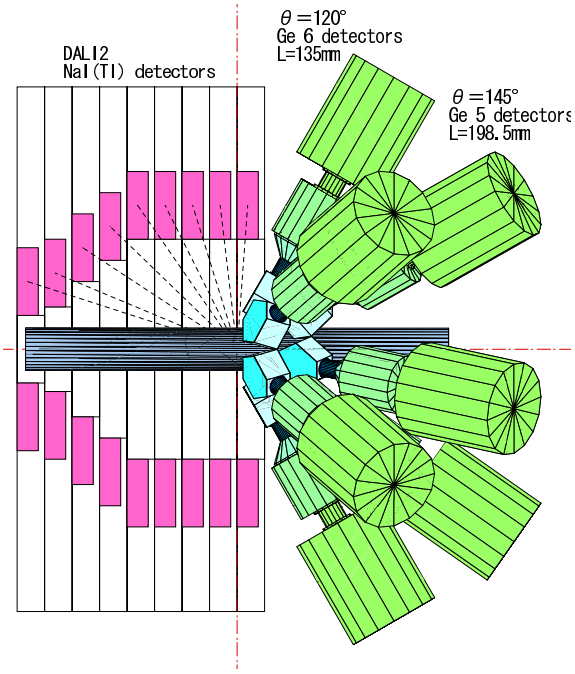


In-Beam Resolution



- ^{4}He(^{12}Be,^{12}Be*) $\beta = 0.3$ $\Delta z \approx 3.4$ mm (FWHM)
- new digital electronics since 2009

Recoil Distance Setup at F8



H. Scheit, In-Beam γ Experiments JUSEIPEN Workshop, Sep. 9-10, 2009 – 16

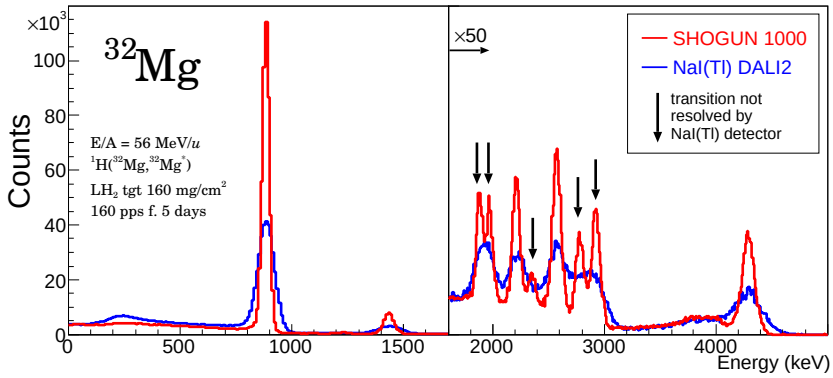
SHOGUN 17

Next Generation Fast Beam γ Spectrometer

- need higher precision
  - better energy resolution than NaI(Tl) DALI2: 10%
  - higher efficiency than HPGe GRAPE: 5%
  - better timing than NaI(Tl) or HPGe
- new "magic" scintillator material $LaBr_3$(Ce)
  - high light yield (~ 60% more than NaI(Tl))
  - fast decay time constant: 16 ns
  - time resolution: ~ 100 ps
  - high density: 5.1 g/cm^3
  - combines good properties of HPGe, NaI(Tl) and BaF

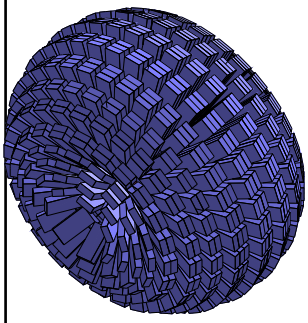
H. Scheit, In-Beam γ Experiments JUSEIPEN Workshop, Sep. 9-10, 2009 – 18

Simulation: SHOGUN 1000 and DALI2



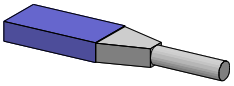
Simulation by P. Doornenbal
based on experimental data of
S. Takeuchi *et al.*, PRC 79, 054319 (2009)

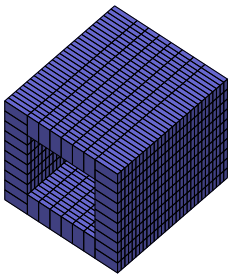
Possible Configurations



fast beam setup ($v = 0.6c$)			
	$\frac{\Delta E}{E}$ (%)	ϵ_γ (%)	$\epsilon_{\gamma\gamma}$ (%)
NaI(Tl) DALI2	10.0	23.5	5.5
RISING	1.9	2.8	0.08
SHOGUN 1000	**3.2**	**35.0**	**12.2**

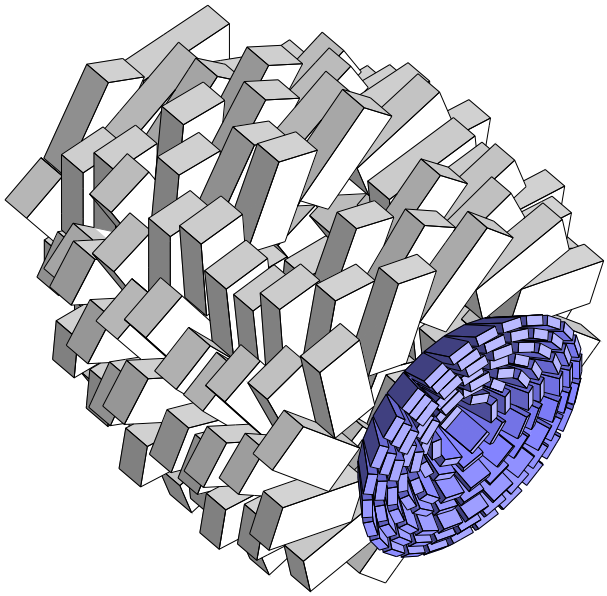
$8 \times 4 \times 1.5$ cm^3





slow/stopped beam setup			
	$\frac{\Delta E}{E}$ (%)	ϵ_γ (%)	$\epsilon_{\gamma\gamma}$ (%)
RISING	0.2	15.0	2.25
SHOGUN 1000	2.4	**56.0**	**31.3**

SHOGUN 100 and DALI2



SHOGUN

- **S**cintillator based **H**igh-res**O**lution **G**amma-ray spectrometer for **U**nstable **N**uclei
- advantages: fast beam
  - high (optimum) resolution
  - high efficiency
  - fast timing
  - **easy operation**
  - **very low running cost**
- advantages: slow/stopped beam
  - high efficiency (esp. $\gamma\gamma$)
  - "**prompt flash**" is no problem: high segmentation is not needed
- international **collaboration** (?)

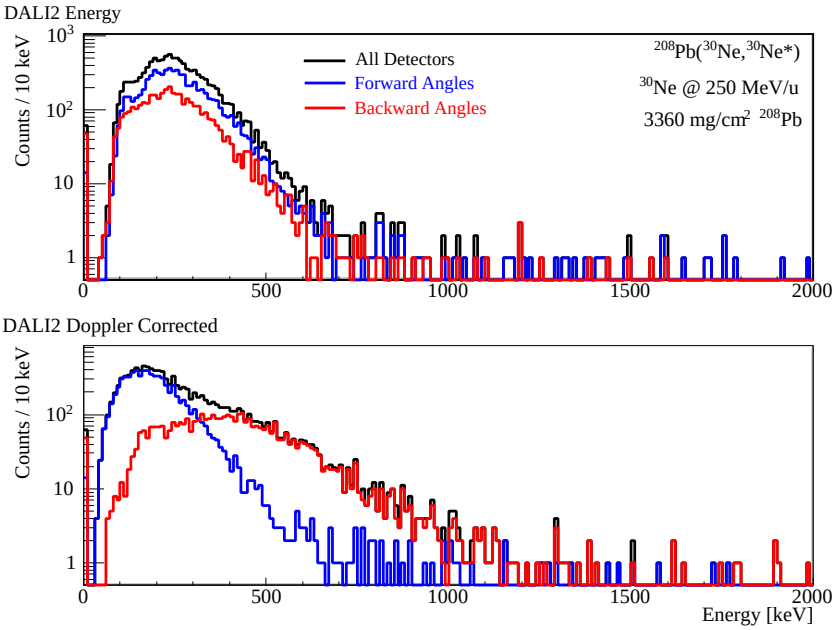
Issues at High Beam Energies

- $E = 150 \ldots 250$ MeV/u
- Doppler shift and **Doppler Broadening**
- atomic **background**
  - back-scattered electrons

$$E^{e^-}_{\max} = \frac{1}{500} E/A \qquad (\beta \to 2\beta, \quad m \to \frac{1}{2000} m)$$

  - **isotropic** in **laboratory** system
  - scales with Z_t^2

Atomic Background



Issues at High Beam Energies

- thick targets **1–2 cm** (!)
  - compare: 1 mm position resolution of γ ray detector
  - additional Doppler broadening:
    changing beam energy due to energy loss
- lifetime of excited state
  - 100 ps = 1–2 cm flight path (!)
  - unknown decay position
  - if decay after the target: velocity is exactly known
  - Doppler correction must take that into account

Other Issues

- charge states: for high-Z beams
  - measure TKE
- for absolute measurements
  - isomeric ratios can be large
  - must be measured

Other 28

RIBF User Group

- please join the RIBF user group
  - RIBF User Guide -> Users Group -> Users Group Registration
  - **http://ribfwww.riken.go.jp/exp/RIBF_uec_eng/**
- there will be a RIBF user group meeting during the
  APS/JPS meeting in Hawaii
  - please let me know any wishes

Summary

- many in-beam γ ray experiments already approved
- main devices for in-beam γ ray spectroscopy at the RIBF
  - DALI2
  - GRAPE
  - NB: both are not user devices; contact owner (!)
- RIBF with BigRIPS and ZeroDegree is fully operational
- first in-beam γ-ray study in 8 hours
  - ^{32}Ne: $E(2^+)$ = 722(9) keV (in “Island of Inversion”)
- next generation γ ray spectrometer: SHOGUN