Particle/Gamma detectors in RIBF

Hideaki Otsu (RIKEN Nishina Center)

"Full deposition type calorimeter in particle and nuclear physics ~Practical utilization examples and applications~"

in ELPH, Tohoku University

2015/03/10
RIKEN Accelerator Research Facility
and RI Beam Factory Project

Fast RI beams

SHE (Z=110, 111, 112, 113)

~5 MeV/nucleon

RARF

pol. d beams

135 MeV/nucleon
for light nuclei

345 MeV/nucleon
up to U

1st beam in 2006

RI beams (<5 AMeV)

SRC+BigRIPS
High Intense primary beam to generate
high intense secondary beam
Nuclear Physics Frontier
+ High performance spectrometers
ZD/SHARAQ/SAMURAI

RIKEN Accelerator Research Facility
and RI Beam Factory Project
Challenges at the RIBF

Shell Evolution:
- magicity loss and new magicity

Dynamics of new “material”:
- Neutron-skin (halo)

R-process path: Synthesis up to U

EOS: asymmetric nuclear matter
- SN explosion, neutron-star
Physics explored by SAMURAI spectrometer

- Particle/Gamma detectors in RIBF
- Separation energy
- Neutron star
- N \geq Z
- Stable
- Gas phase
- Giant resonance
- Cluster degree of freedom at neutron rich nuclei
- Excitation energy
- Cluster correlation
- Soft mode
- 2n correlation
- N > Z
- Unbound state
- Explosive hydrogen burning
- Halo
- Skin
- Egg
- p/n decoupling
- Neutron excess
- Heavy element synthesis
- Unbound state
- Heavy element synthesis
- p/n decoupling
- 2n correlation
- Low density weak (no) binding
- Disappearance/Appearance of magicity
- Neutron excess
- Neutron star
- Particle/Gamma detectors in RIBF
Spectroscopy for unstable nuclei

- gamma ray spectroscopy
  - for bound states
    - extremely small branch from unbound state

- invariant mass spectroscopy
  - for unbound states
    - gamma rays detection is also needed for residue

- missing mass spectroscopy
  - independent for bound and unbound states
Primary beam up to U 345 MeV/u 15 pnA (=1.2kW) 2014/10
Secondary beam production
Be/W target 1-30 mm²
Isotope separation by $Bp + \Delta E(\text{Wedge})$
Particle/Gamma detectors in RIBF

2nd beam Tagging
F3-F7 TOF
F5 Bp tagging

ZeroDegree
SAMURAI
SHARAQ
SHARAQ-SDQ
SHARAQ-D1
SHARAQ-Q3
Particle/Gamma detectors in RIBF

F7-F11 TOF (L~30m)
F9 Bp tagging
F11 TKE

Secondary Target
e.g. Liq. H, He, Pb/Au/C
Particle/Gamma detectors in RIBF

TOF Target-FP

(L~8m)

Bp @ FP TKE

Secondary Target
e.g. Liq. H, He, Pb/Au/C
Super conducting ring cyclotron (SRC)

K=2600 MeV / 8300 ton

Accelerate $^d$ to $^{238}$U up to 345 A MeV
First beam on 2006/12,
First $^{238}$U beam on 2007

$^{238}$U $\sim$ 10 pnA on 2013

BigRIPS

Large acceptance secondary beam separator
with 9 Tm bending power
w/ Super conducting Quadrupole magnets
Aperture of 60 mrad x 80 mrad on target
corresponds to 50 % of fission fragments

Generate $^{125,126}$Pd on 2007/05
and over 20 new isotopes on 2008/11
Detectors for γ spectroscopy in RIBF

1. DALI2
2. DALI2 + X
3. Catana (Togano-san)
   (4. Eurica)
• Nuclear excitation (C target)  
  • \(E(2+, 4+\ldots)\) determination

• Coulomb excitation (Pb/Au target)  
  • \(B(E2\uparrow)\) determination

``Inverse kinematics of the ("\(\gamma\", \(\gamma\)\)) reaction``
In beam $\gamma$ spectroscopy with DALI

Data on 2008

$^{32}$Ne $2^+$ energy determination

Data on 2011

``Inverse kinematics of the ("$\gamma$, $\gamma'$) reaction"

$^{42}$Si $4^+ \rightarrow 2^+$ energy determination

Cumulative report are given in Pieter Doornenbal, Prog. Theor. Exp. Phys. (2012) 03C004
DALI2: A NaI(Tl) detector array for measurements of $\gamma$ rays from fast nuclei

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ABSTRACT

A NaI(Tl) detector array called DALI2 (Detector Array for Low Intensity radiation 2) has been constructed for in-beam $\gamma$-ray spectroscopy experiments with fast radioactive isotope (RI) beams. It consists typically of 186 NaI(Tl) scintillators covering polar angles from $\sim 15^\circ$ to $\sim 160^\circ$ with an average angular resolution of $6^\circ$ in full width at half maximum. Its high granularity (good angular resolution) enables Doppler-shift corrections that result in, for example, 10% energy resolution and 20% full-energy photopeak efficiency for 1-MeV $\gamma$ rays emitted from fast-moving nuclei (velocities of $v/c = 0.6$). DALI2 has been employed successfully in numerous experiments using fast RI beams with velocities of $v/c = 0.3$–0.6 provided by the RIKEN RI Beam Factory.

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DALI2

立教大学、理化学研究所の共同研究開発

- 高速（$b=0.3-0.6$）で飛行する原子核から放出されるガンマ線を測定
- ドップラーシフトを補正

→ 高検出効率、高角度分解能
- NaI(Tl)検出器を160個使用
- 160個の検出器を効率よく配置

これまでに、RARF,RIBFの実験に使用

<table>
<thead>
<tr>
<th>$\beta = v/c$</th>
<th>DALI ($\beta = 0.0$)</th>
<th>DALI ($\beta = 0.3$)</th>
<th>DALI2 ($\beta = 0.0$)</th>
<th>DALI2 ($\beta = 0.3$)</th>
<th>DALI2 ($\beta = 0.6$)</th>
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<tbody>
<tr>
<td>Number of detectors</td>
<td>~60</td>
<td>160</td>
<td>186</td>
<td></td>
<td></td>
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<tr>
<td>Number of layers</td>
<td>6–8</td>
<td>16</td>
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<tr>
<td>Angle coverage (degrees)</td>
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<td>~15°–~160°</td>
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<tr>
<td>Average $\Delta \theta$ (FWHM) (degrees)</td>
<td>10</td>
<td>7</td>
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<tr>
<td>$\Delta E/E$ (FWHM) (%)</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>10</td>
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<tr>
<td>Efficiency (%)</td>
<td>13</td>
<td>10</td>
<td>24</td>
<td>24</td>
<td>20</td>
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</table>
これまでの実験

2002年から実験に使用

RARF, RIBFで30実験以上

投稿論文は39編ほど出版済み。これからも数本出ます

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Beam</th>
<th>Energy (MeV/μ)</th>
<th>Target</th>
<th>Thickness (mg/cm²)</th>
<th>Observables</th>
<th>Reference</th>
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<td>H(³⁵⁺F, ²⁵⁺F)</td>
<td>²⁵⁺F</td>
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<td>levels, σ</td>
<td>[29]</td>
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<tr>
<td>H(³³⁺B, ¹⁷⁺B)</td>
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<td>[30]</td>
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</tr>
</tbody>
</table>

CD₃(²²⁺O, ²²⁺O) | ²²⁺O | 34.0 | CD₃ | 30 | σ, β | [37] |

<table>
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<tr>
<th>Reaction</th>
<th>Beam</th>
<th>Energy (MeV/μ)</th>
<th>Target</th>
<th>Thickness (mg/cm²)</th>
<th>Observables</th>
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<td>[44]</td>
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<td>[46]</td>
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<td>Na</td>
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<td>levels, σ, β</td>
<td>[50]</td>
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<td>Na</td>
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<td>levels, σ, β</td>
<td>[51]</td>
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<td>Na</td>
<td>210</td>
<td>levels, σ, β</td>
<td>[52]</td>
</tr>
</tbody>
</table>

論文出版時のリスト
Neutron number 34 makes exotic calcium–54 isotopes doubly magic

by S. Takeuchi
共同研究の枠組み

RIBFでDALI2などを使った実験を対象

17か国、110名

2015/2/23現在

http://www.nishina.riken.jp/collaboration/SUNFLOWER/index.html
**DALI2**

- DALI2 is "Calorimetric" device?

- Motobayashi (founder or originator of DALI/DALI2) answered "No", because of lack of efficiency

| Basic parameters of DALI and DALI2. The efficiencies and energy resolutions are for 1-MeV $\gamma$ rays. |
| --- | --- | --- | --- | --- |
| $\beta = v/c$ | DALI  |  | DALI2  |  |  |  |
|  | 0.0  | 0.3  | 0.0  | 0.3  | 0.6  |
| Number of detectors | $\sim 60$ |  | 160  |  | 186  |
| Number of layers | 6–8  |  | 16  |  |  |
| Angle coverage (degrees) | $\sim 50^\circ$–$\sim 150^\circ$ |  | $\sim 15^\circ$–$\sim 160^\circ$ |  |  |
| Average $\Delta \theta$ (FWHM) (degrees) | 10  |  | 7  |  |  |
| $\Delta E/E$ (FWHM) (%) | 10  | 12  | 7  | 8  | 10  |
| Efficiency (%) | 13  | 10  | 24  | 24  | 20  |
For E1 strength search on threshold region

- 8 x LaBr3 detectors were coupled with DALI (96 crystals) to cover high energy gamma up to 10 or 15 MeV.
- LaBr3(Ce) : 3.5''φ x 8'' (8.9cm φ x 20.3 cm depth)
- at θ = 30 degree(Lab)
Characterization of large volume 3.5” × 8” LaBr₃:Ce detectors


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ᶜInstitute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), P.O. Box 51, H-4001 Debrecen, Hungary
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Gamma rays
Energy resolution
Time resolution

ABSTRACT

The properties of large volume cylindrical 3.5” × 8” (89 mm × 203 mm) LaBr₃:Ce detectors were characterized using the Hamamatsu R10233-100ESL photo-multiplicator tube coupled to the Hamamatsu R10233-100ESL photo-multiplicator tube. The detectors were used in a 30 cm × 30 cm × 30 cm NaI detector, and the energy resolution and response linearity of the LaBr₃:Ce detectors were measured. The results were compared with those obtained using the same NaI detector. The LaBr₃:Ce detectors showed a higher energy resolution and a broader energy distribution than the NaI detector. The detectors also showed a higher energy resolution and a broader energy distribution than the NaI detector. The LaBr₃:Ce detectors showed a higher energy resolution and a broader energy distribution than the NaI detector. The detectors also showed a higher energy resolution and a broader energy distribution than the NaI detector.

Fig. 15. Top panel: the energy spectrum measured with the S/N M0249CS_B LaBr₃:Ce detector, the “LABRVD” active voltage divider, free running ADCs and digital processing, using the Am-Be-Ni source (see Section 4.1). Bottom panel: as a reference, the same energy spectrum measured using a HPGe detector.
LaBe3(Ce) properties

• Time response: very good:
• Linearity: very high
  → favorable for multi step energy deposition in material \( \gamma \) rays

<table>
<thead>
<tr>
<th>comparison to common scintillators:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl)</td>
</tr>
<tr>
<td>Light Output (1/keV)</td>
</tr>
<tr>
<td>Decay Time (ns)</td>
</tr>
<tr>
<td>( Z )</td>
</tr>
<tr>
<td>Density (g/cm(^3))</td>
</tr>
<tr>
<td>Temp. Coef. (%/K)</td>
</tr>
<tr>
<td>Max. Sc. Wavel. (nm)</td>
</tr>
<tr>
<td>Energy Res. (%)</td>
</tr>
<tr>
<td>Time Res. (ns)</td>
</tr>
<tr>
<td>Linearity</td>
</tr>
<tr>
<td>Hygroscopic</td>
</tr>
</tbody>
</table>

• for same detector volume

Heiko Scheit, RIBF ULIC Detector workshop

\[ \varepsilon_{FE} \propto \rho^{1.5} \times Z^{3.5} \]
132Sn, 70Ni, 24O with Au (Coulomb ex.) or Liq. He (Isoscalar Dipole) performed on Oct/Nov, 2014.

Dynamic range: \( E_g < 40 \text{ MeV} \rightarrow E_g(\text{CM}) < 26 \text{ MeV} \)

Time response of LaBr3(Ce): \( \sigma t < 0.3 \text{ ns for } E_g > 1 \text{ MeV} \) which enable us to separate \( \gamma \) from particles like p or n
DALI+LaBr3
LaBr3 efficiency estimation

CM 0.5 MeV
eff = 4.9%

CM 1 MeV
eff = 4.0%

CM 5 MeV
eff = 5.8%
(photo peak + single+double escape)

CM 10 MeV
eff = 5.8%
(photo peak + single+double escape)
DALI+LaBr3

- DALI+LaBr3 is "Calorimetric" device?
- for the moment: No, while the effort would continue to future project:

- SHOGUN1000

<table>
<thead>
<tr>
<th>fast beam setup ($v = 0.6c$)</th>
<th>$\frac{\Delta E}{E}$ (%)</th>
<th>$\epsilon_{\gamma}$ (%)</th>
<th>$\epsilon_{\gamma\gamma}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI(Tl) DALI2</td>
<td>10.0</td>
<td>23.5</td>
<td>5.5</td>
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<tr>
<td>RISING</td>
<td>1.9</td>
<td>2.8</td>
<td>0.08</td>
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<td>SHOGUN 1000</td>
<td>3.2</td>
<td>35.0</td>
<td>12.2</td>
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<table>
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<th>slow/stopped beam setup</th>
<th>$\frac{\Delta E}{E}$ (%)</th>
<th>$\epsilon_{\gamma}$ (%)</th>
<th>$\epsilon_{\gamma\gamma}$ (%)</th>
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<td>15.0</td>
<td>2.25</td>
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<tr>
<td>SHOGUN 1000</td>
<td>2.4</td>
<td>56.0</td>
<td>31.3</td>
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</table>
Total energy detector for particles in RIBF

(0. Why TKE detector is needed)
1. SAMURAI TKE
2. LaBr3 at ZD
Total Energy Detector (TED) for RI-beam experiments
Invariant mass spectroscopy: one example of RI beam experiment

RI beam
\(~\text{few 100 MeV/A}\)

excited nucleus

decay fragments

\((\Delta E, Bp, \text{TOF}) \rightarrow (A, Z, p_1)\)

- Excitation energy \(E_X\) or relative energy \(E_{rel}\)
  \(E_X = \sqrt{(E_f + E_N)^2 - (\vec{p}_f + \vec{p}_N)^2} - (M_f + M_N) + S_N\)

- Required resolution
  - Invariant mass: \(\sigma(E_{rel}) \sim 0.2\sqrt{E_{rel}}\) [MeV]
  - PID of heavy fragment: \(\sigma_{A/A} \sim 0.2/100\)

  *rigidity(f)*
  \(\sigma_R \sim \frac{1}{200}\)
  \(R \sim \frac{1}{200}\)
  \(\sigma_R \sim \frac{1}{700}\)
  \(R \sim \frac{1}{700}\)
  \(\sigma_R \sim \frac{1}{700}\)
  \(R \sim \frac{1}{1600}\)

  *velocity(N)*
  \(\sigma_\beta \sim \frac{5}{1000}\)
  \(\beta \sim \frac{5}{1000}\)
  \(\sigma_\beta \sim \frac{1}{1100}\)
  \(\beta \sim \frac{1}{1100}\)
  \(\sigma_\beta \sim \frac{1}{1100}\)
  \(\beta \sim \frac{1}{1100}\)

  *angle(N)*
  \(\sigma_\theta \sim \frac{1}{200}\)
  \(\theta \sim \frac{1}{200}\)
  \(\sigma_\theta \sim \frac{1}{200}\)

- TOF resolution
  \(\sigma_{\text{TOF}} \sim 0.3\text{nsec} \at L=10\text{m}\)
  \(\sigma_{\text{TOF}} \sim 50\text{psec} \at L=10\text{m}\)

- Excitation energy resolution
  \(E_X \sim 5\text{cm} \at L=10\text{m}\)

- Total energy resolution
  \(\sigma_T \sim \frac{1}{1000}\)
  \(T \sim \frac{1}{1000}\)
  \(T \sim \frac{1}{1000}\)

- Velocity resolution
  \(\sigma_\beta \sim \frac{0.6}{1000}\)
  \(\beta \sim \frac{0.6}{1000}\)
  \(\sigma_\beta \sim \frac{0.6}{1000}\)
  \(\beta \sim \frac{0.6}{1000}\)

- Possible realizations
  \(\sigma_{\text{TOF}} \sim 50\text{psec} \at L=10\text{m}\)
  \(\sigma_{\text{TOF}} \sim 50\text{psec} \at L=10\text{m}\)
  \(\sigma_{\text{TOF}} \sim 50\text{psec} \at L=10\text{m}\)
Total energy detector (TED) : type of scintillator

• Goal / Purpose
  • $\sigma_A/A \sim 0.2/100$ for PID $\leftrightarrow \sigma_T/T - 0.1 \sim 0.2\% @ T=20\sim30\text{GeV}$

• Scintillators tested
  • **NaI(Tl)** : 3" cube + 3"φPMT
    • $\sigma_T/T \sim 0.15\% @ 23\text{GeV} \ (290 \text{MeV/A}^{78}\text{Ge})$ OK
    • rate?($\tau \sim 200\text{nsec}$), non-uniformity?, PMT at low HV?, hydroscopic: casing(MgO+Al), radiation damage?
  • **CsI(Tl)** : 5cm-cube + PD + charge-sensitive PA
    • PD : 1x1, 1.8x1.8, 2.8x2.8 cm$^2$
    • $C_f$ of hybrid PA $\sim 100\text{pF}$ (low gain), oscillation
    • $\sigma_T/T \sim 0.4\%$ for $T = 7 \sim 20 \text{GeV} \ (\@ 250\text{MeV/A})$ X
    • rate?($\tau \sim 1\text{usec}$), worse resolution, PD for larger crystals?
  • **HP Ge** : 60mmφx35mm (semi planar)
    • PreAmp ($C_f=200\sim500\text{pF}$), self made, oscillation
    • HV bias : large leak
    • $\sigma_T/T \sim 0.35\% @ 3\text{GeV}$ X
CsI(pure) ?

- **CsI(pure) + PMT ?**
  - less light, fast decay time
  - small radiation damage
  - UV light
  - large temperature dependence: $\sim$% / deg
- Beam test using CsI(pure) 100x100x50mm$^3$ + 3"φ-PMT (HPK-R6233)
  - large saturation effect observed
  - pulse shape of heavy ion is different from $\gamma$, e, & proton
  - UV / non-UV window tested: no difference in resolution $\rightarrow$ PMT w non-UV window
  - PMT breeder: taper-type w high breeder current
  - $\sigma T/T=0.1\sim0.2\%$ was not achieved. THEN...
- enlarge total-energy difference using energy-loss for fragment with the same rigidity

\[ Ap_1(A) \sim (A+1)p_1(A+1) \]

\[ 69^{\pm1}\text{Cu (Z=29)} \]
\[ 294 \text{ MeV/A} \]

\[ \Delta T \]
\[ T_{A+1} \quad T_A \quad T_{A-1} \]

\[ AT(A) \sim (A+1)T(A+1) \]
prototype test  @HIMAC

CsI(pure, 100x100x50 mm$^2$) + 3"$\phi$ PMT

270 MeV/A ($\Delta p/p \sim 0.1\%$) with Al absorber

TED pulse height

$^{73}\text{As}$  $\Delta x / \sigma \sim 6.5$

$^{72}\text{As}$
Total Energy Detector (TED)

* Purpose: $\sigma_A \sim 0.2$ @ $A \sim 100$, $E_{tot} = 25 \sim 30 GeV$

* Configuration

  CsI(pure): 100x100x50mm$^3$ x 32
  effective area: 800mm(H) x 400mm(V)
  PMT: R6233HA (3”φ, non-UV) in light / magnetic shield box
Calibration using secondary beam

- Setup @HIMAC SB2

- Pulse height + position dependence for all 32 crystals
- RI beam: ~290 MeV/A, A~70
Pulse height : degrader thickness dependence @crystal center

- $^{69}\text{Cu}(z=29)$ 294 MeV/A, Al thickness = 0~17mm

![Graphs showing pulse height ratio and yield (reaction loss)](image)

- Pulse height ratio [%]
- RMS resolution [%]
- Yield (reaction loss) [%]

<table>
<thead>
<tr>
<th>Al thickness [mm]</th>
<th>0 mm</th>
<th>5 mm</th>
<th>10 mm</th>
<th>12 mm</th>
<th>13 mm</th>
<th>15 mm</th>
<th>16 mm</th>
<th>17 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(pulse height fraction)</td>
<td>(0.36%)</td>
<td>(0.42%)</td>
<td>(0.58%)</td>
<td>(0.69%)</td>
<td>(0.77%)</td>
<td>(1.12%)</td>
<td>(1.65%)</td>
<td>(3.19%)</td>
</tr>
</tbody>
</table>
Mass separation: degrader-thickness dependence @ crystal center

- \( ^{68,69,70}\text{Cu}(z=29) \) 294 MeV/A, Al = 0~17mm

- mass separation \( \sim 7\sigma \)
- but with low-energy tail
- adjustable by changing absorber thickness
- with energy resolution of \( \sigma_T/T \sim 1\% \)
Calibration: position dependence

- position dependence by extrapolating drift chamber track

- strange position dependence
  - data taken for all crystals
  - calibration procedure?

![Graphs showing pulse height vs. vertical position](image-url)
TED @SAMURAI17 exp.

• $p^{(^{132}\text{Sn},n)}$ exp. April-2014
Particle/Gamma detectors in RIBF

SAMURAI17
particle ID @ SAMURAI FP

- TKE detector response for distinguish charge states.
- In near future.

\[ Z \]

\[ \text{Counts} \]

\( \sigma_Z = 0.22 \)

\[ \text{Counts} \]

\( \sigma_{A/Q} = 0.14\% \)

\( 132\text{Sb}^{50+} \)

ROI

Plastic w/ position dependence correction

Particle/Gamma detectors in RIBF

\( 132\text{Sn}^{50+} \)

\( 50+ \)

\( 49+ \)

\( 49.5 < Z < 50.5 \)

\( 49 \)
Experiment for transmutation process setup

Beam Production

BigRIPS

Tagging

Secondary target CD$_2$, CH$_2$, C

LaBr$_3$(Ce)

Products PID

ZeroDegree
Particle Identification for $^{137}$Cs

**BigRIPS PID**

- Atomic number $Z$
- Mass-to-charge ratio $A/Q$
- $A/Q$ resolution $0.146 \times 10^{-2}$ (rms)
- $Z$ resolution 0.25

**ZeroDegree PID**

- Atomic number $Z$
- Mass-to-charge ratio $A/Q$
- $A/Q$ resolution $0.201 \times 10^{-2}$ (rms)
- $Z$ resolution 0.25
Charge states Identification by:

\[ {^{137}}\text{Cs} \rightarrow {^{137}}\text{XCs} \]

ZeroDegree PID

TKE detector @ F11
LaBr3(Ce) 76 φ x 76 [mm³]
Photo Dyode readout

Residue:

\[ {^{136,\ldots}}\text{Cs}, 160 \text{ MeV/u} @ \text{F11} \]
\[ E_{\text{total}} = 160 \times 136 \text{ MeV} \]
\[ \sim 22 \text{ GeV} \]
Charge states Identification by TKE response

Charge states ID by TKE

$Q=Z \quad 78\%$
$Q=Z-1 \quad 21\%$
$Q=Z-2 \quad 1\%$

$\sigma(E_t) \sim 100 \text{ MeV on } 20 \text{ GeV}
A \text{ resolution } 0.78 \text{ (RMS)}$

Enough for separate:
$\Delta A = 2$ ;
$^{133}\text{Cs}^{55+} \text{ from } ^{131}\text{Cs}^{54+}$

What makes the resolution:
#of photon $\rightarrow x$
*) rate dependence
Summary

- Gamma ray detectors, Particle total energy detectors in RIBF:
  - "Calorimetric" detector → Solid detector

- Gamma ray detector:
  - DALI → DALI + LaBr3
  - Still 10~20% coverage on efficiency
  - LaBr3 detector is promising for future device
    - Internal Background source
    - Patent ...

- Particle total energy detector:
  - CsI(pure) array on SAMURAI focal plane (Dispersive)
    - $\sigma(L)/L \sim 0.4\%$
    - with energy absorber $\sigma(A)\sim1/7$ @ $A\sim70$
  - LaBr3 on ZD focal plane (Achromatic)
  - Dynamic range : $\sim 250$ MeV/u x A (25 GeV @ A=100)
    - Rate latency problem
      - 1k cps : OK
      - 10k cps : get worse

CeBr3 (yesterday talk)
Summary (cont.)

• Calorimetric devices in RIBF which are not mentioned today:
  • neutron detectors for SAMURAI
    • NEBULA + neuLAND
    • $\varepsilon_{1n}$: 60% or more

• Possibility of TKE detector by Gas for HI in RIBF energies:
  • 200 MeV/u Z=55 particle: Range ~ 1.6 g/cm$^2$
    • Xe 1atm 2.7m : 1.6 g
    • Rn 1atm 1.6m
    • Multi sampling: Energy absorber
    • Quenching property is much different from that of solid material
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