4π Heavy-Ion Detector for γ-ray Spectroscopy

C.Y. Wu, D. Cline, H. Hua, A. Hayes, and R. Teng

Nuclear Structure Research Laboratory, Department of Physics,
University of Rochester, Rochester, NY 14627

• General review of the particle-γ coincident technique.

• Current status of the heavy-ion detector.

• Future generation of the heavy-ion detector.
General review of the particle-\(\gamma\) coincident technique

1) Selectivity is required for the huge amount of \(\gamma\)-ray information gathered by the modern \(\gamma\)-ray detector arrays.

2) The detection of reaction products in coincidence with \(\gamma\) rays provides a unique selectivity for the \(\gamma\)-ray spectroscopic study.

3) Ideal detector for the detection of reaction products:
   - A large solid angle in a compact geometric environment.
   - Light mass to minimize the impact of the \(\gamma\)-ray detection.
   - Sufficient position, time, or energy resolution.
   - Stability under hostile environments, such as the high counting rate and the long duration of running time.
   - Resistance to the radiation damage.
Current status of the heavy-ion detector

1) **Physical characteristics:**
   - Position-sensitive parallel-plate avalanche counter.
   - Highly segmented with a $4\pi$ coverage.

2) **Measurements:**
   - Two-body kinematics that includes the measurements of angles for both reaction productions and their time-of-flight difference.

3) **Pseudo-parameters derived:**
   - Masses of both reaction products.
   - Recoiling velocities of both reaction products.
   - Q-value.
   - Time tag to distinguish between the prompt and delayed events.

4) **Performance:**
   - Time resolution: $\approx 500$ ps
   - Position resolution: $\approx 1^\circ$ in $\theta$ and $\approx 4.6^\circ$ in $\phi$.
   - $\gamma$-ray energy resolution: $< 1\%$. 
$^{208}\text{Pb} + ^{238}\text{U}$ at $E_{\text{lab}} = 1360$ MeV
\textsuperscript{118}Sn + \textsuperscript{162}Dy at \( E_{\text{lab}} = 780 \text{ MeV} \), \( 60^{\circ} \leq \theta_{\text{c.m.}} \leq 100^{\circ} \)

\( \Delta I = 0 \)

\( \Delta I = 1 \)

\( \Delta I = 2 \)

\( 116\text{Sn} \rightarrow ^{12}_{2}\text{Sn-like} \rightarrow ^{16}_{5}\text{Dy-like} \)

Counts / keV

E\(_{\gamma}\) [keV]
$^{170}$Er ($^{238}$U, $^{238}$U) $^{170}$Er

$E_{\text{lab}} = 1358$ MeV

$100^\circ \leq \theta_{\text{c.m.}} \leq 140^\circ$
$^{100}\text{Mo} + ^{136}\text{Xe}$ at $E_{\text{lab}} = 700 \text{ MeV}$
5) Physics program:
   • Coulomb excitation:
     a) Fragmentation of both two-phonon $\gamma$-vibrational and octupole-vibrational strengths.
     b) Exotic structure, such as the population of the high-$K$ isomeric bands and the rotationally aligned band.
     c) $X(5)$ symmetry.
   • Few-nucleon transfer reactions:
     a) Pairing degrees of freedom.
     b) Neutron-rich nuclei.
     c) Isomers.
   • Deep-inelastic reactions:
     a) Superdeformed minimum.
     b) Neutron-rich nuclei.
     c) Isomers.
   • Fission or fusion-fission reactions:
     a) Fission dynamics.
     b) Neutron-rich nuclei.
     c) Isomers.
Coulomb Excitation Paths of High-K Isomer Bands in $^{178}\text{Hf}$

- K=4$^+$ band
  - Yield $\sim 10^{-4}$
  - K-allowed transitions

- $\gamma$-band
  - Yield $\sim 10^{-4}$

- K=6$^+$
  - Yield $\sim 10^{-4}$
  - Coulomb Excitation Paths of High-K Isomer Bands

- K=8$^-$
  - Yield $\sim 10^{-4}$

- K=16$^+$
  - Yield $\sim 10^{-4}$
    - K-forbidden transitions
  - 31 yrs

- GSB
  - 4.0 s
Future generation of the heavy-ion detector

1) Required improvement:
   - The position resolution should match, at least, with that of GRETA.
   - High efficiency and large solid angle become more important for the low-intensity beam of RIA facility.

2) Current design parameters:
   - Six sectors in a sphere of 9-inch diameter.
   - Minimum flight path: 9.1 cm.
   - Angular coverage: $20^\circ < \theta < 83^\circ$.
   - Two-dimension read-out cathode board with the position resolution $< 3$ mm.