4π Heavy-Ion Detector for γ-ray Spectroscopy

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- **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-γ coincident technique

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

2) The detection of reaction products in coincidence with γ rays provides a unique selectivity for the γ-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 γ-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 4π coverage.

2) Measurements:

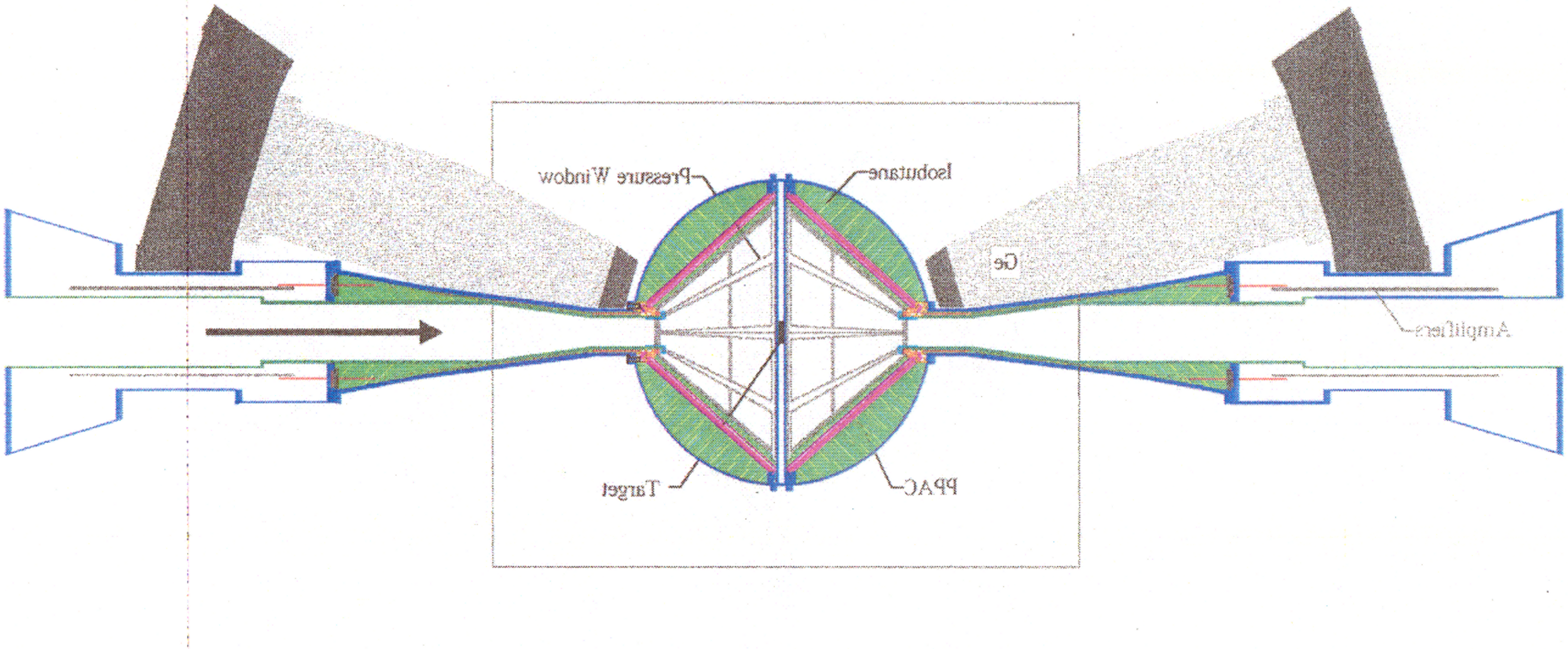
- Two-body kinematics that includes the measurements of angles for both reaction productions and their time-of-flight difference.

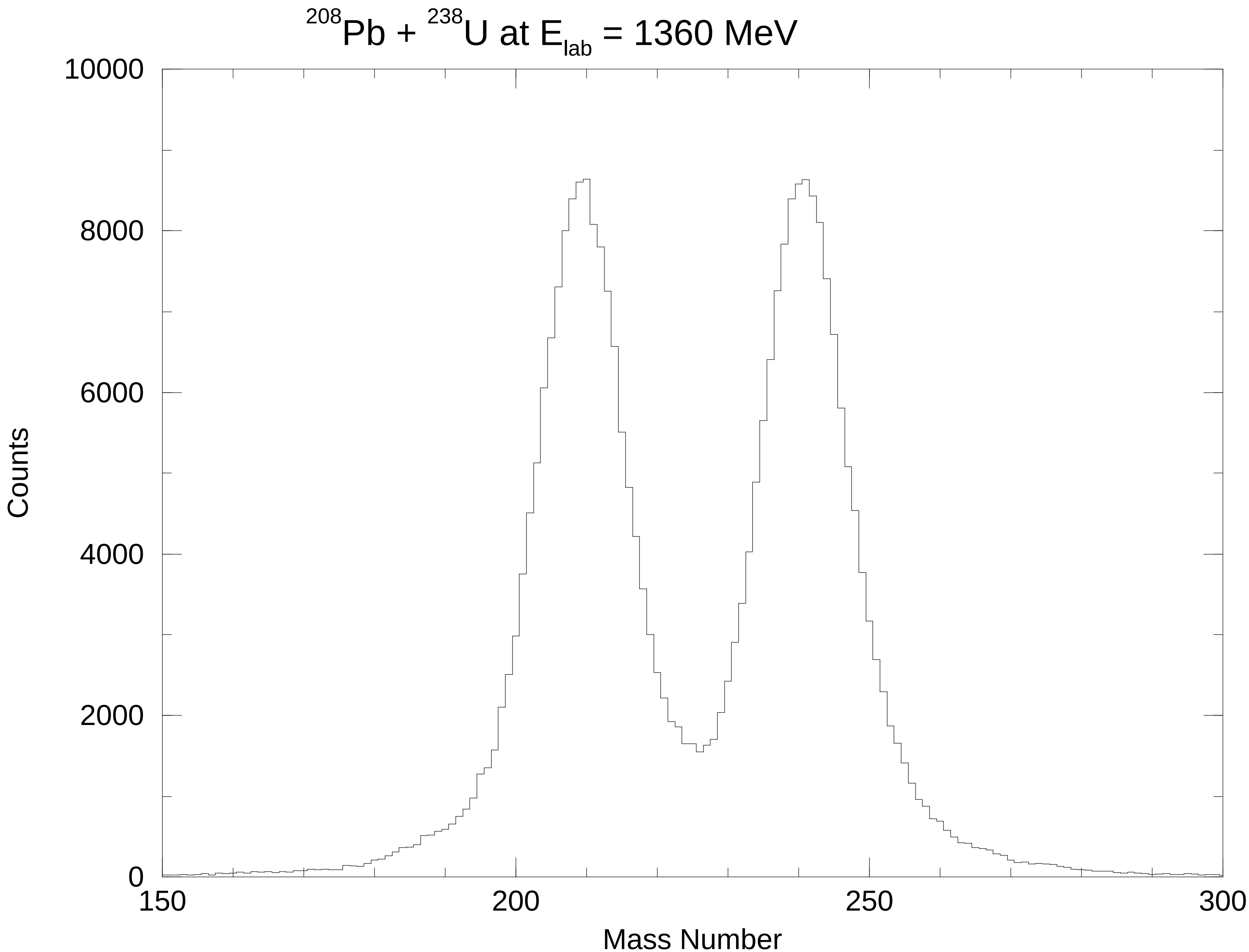
3) Pseudo-parameters derived:

- Masses of both reaction products.
- Recoiling velocities of both reaction products.
- Q-value.
- Time tag to distinguish between the prompt and delayed events.

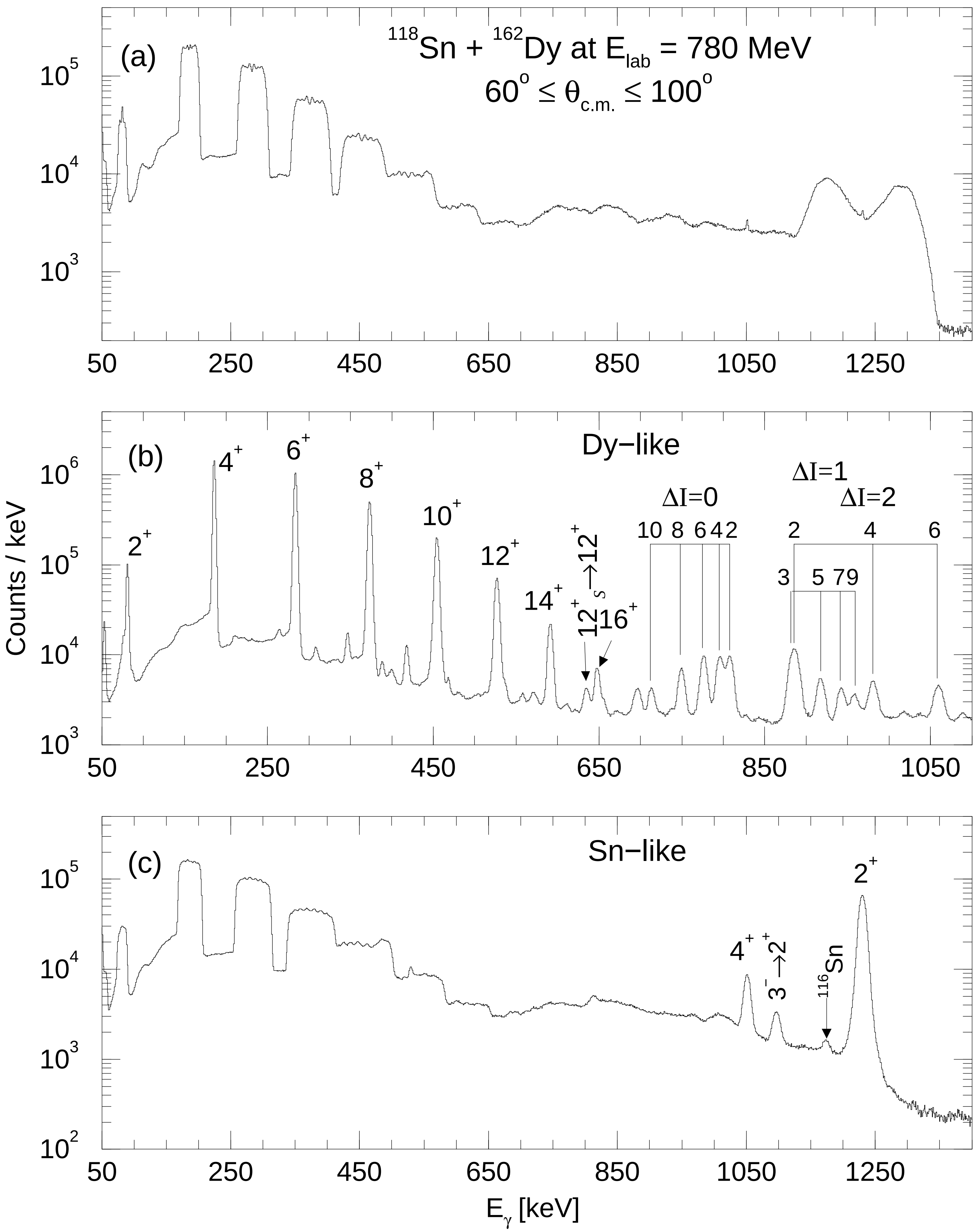
4) Performance:

- Time resolution: $\approx$500 ps
- Position resolution: $\approx 1^\circ$ in θ and $\approx 4.6^\circ$ in ϕ.
- γ-ray energy resolution: $<1\%$.

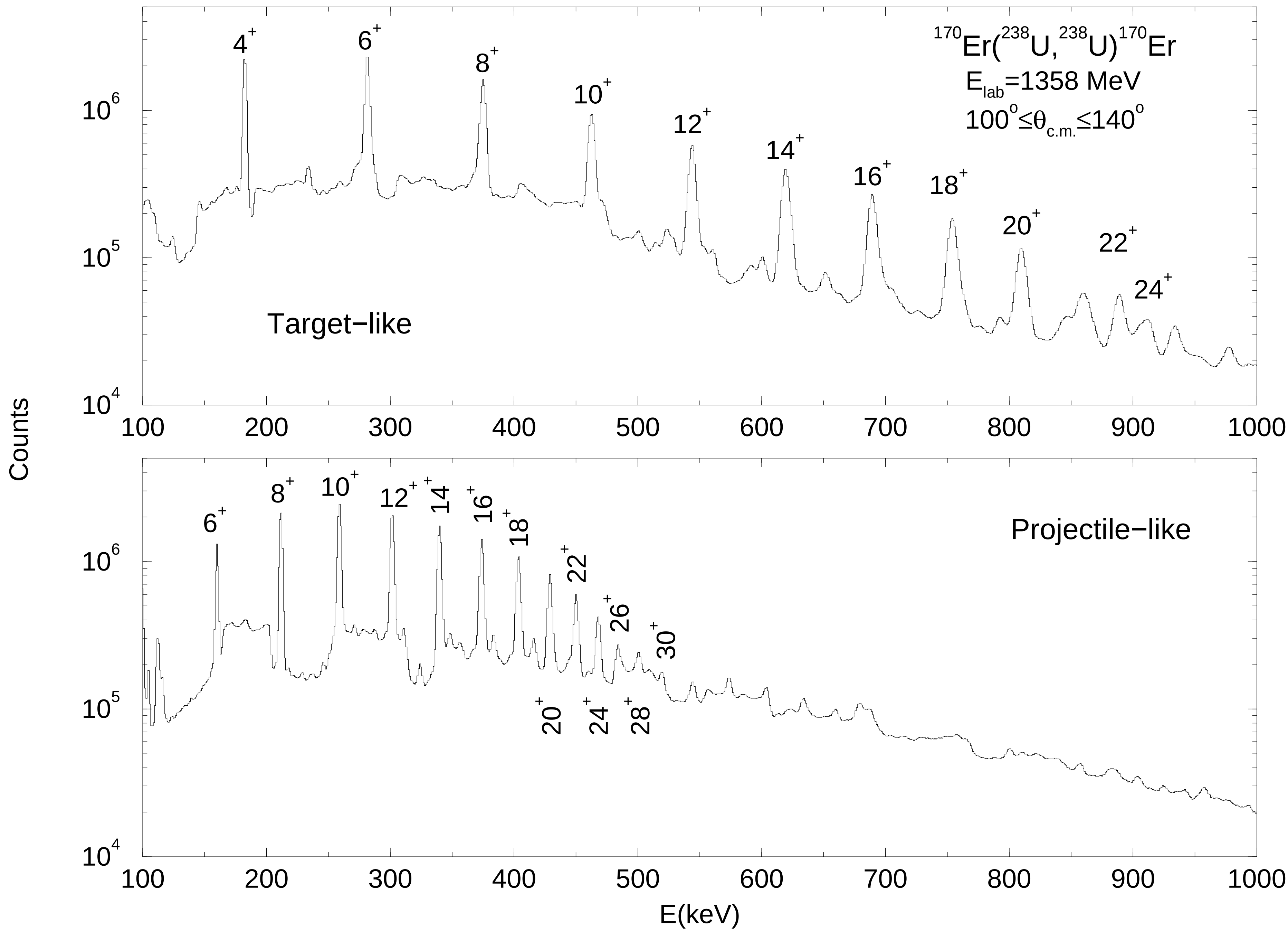

Pressure Window
Isobutane
Ge
Amplifiers
Target
PPAC



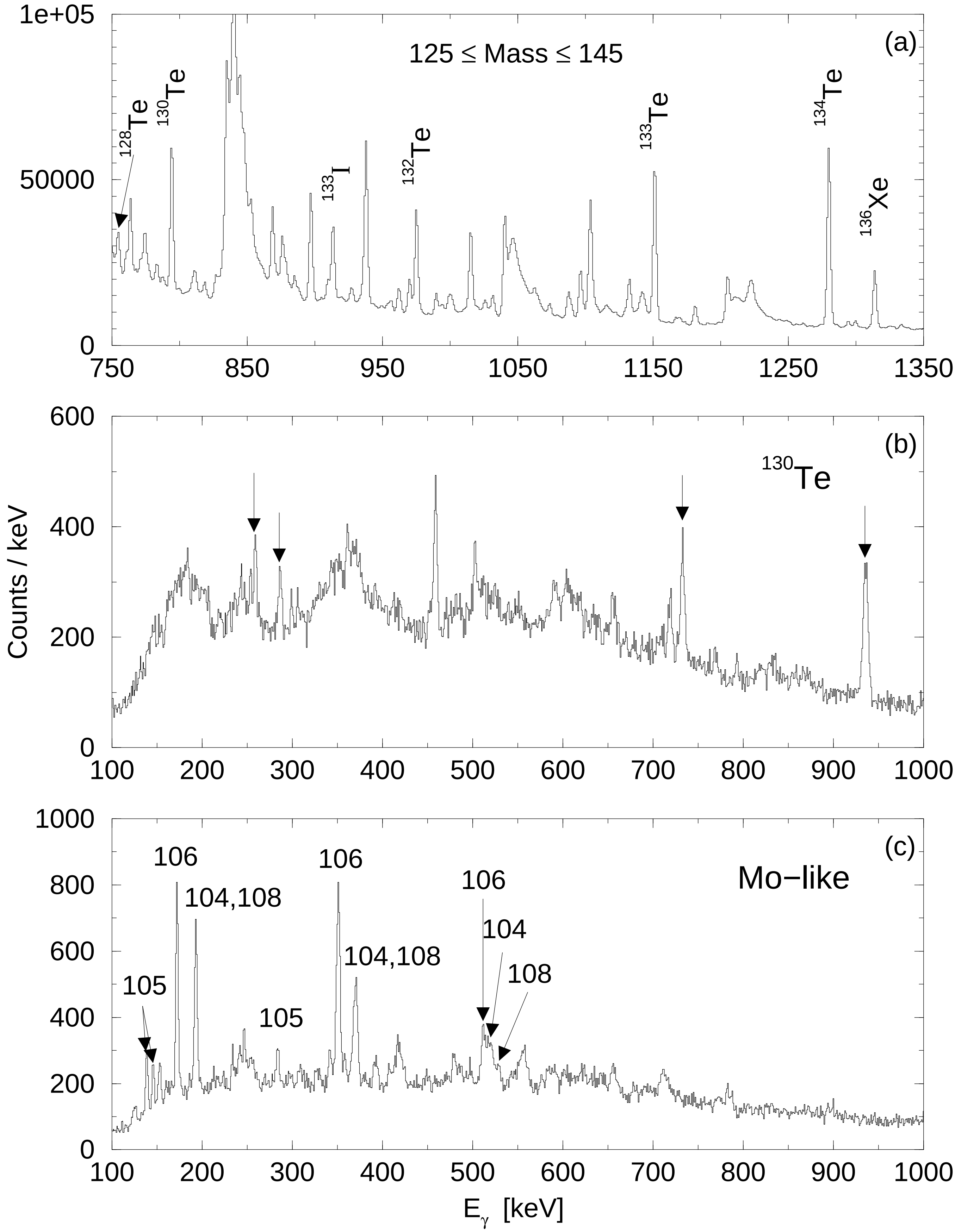
208Pb + 238U at Elab = 1360 MeV
Counts
10000
8000
6000
4000
2000
0
150
200
250
300
Mass Number



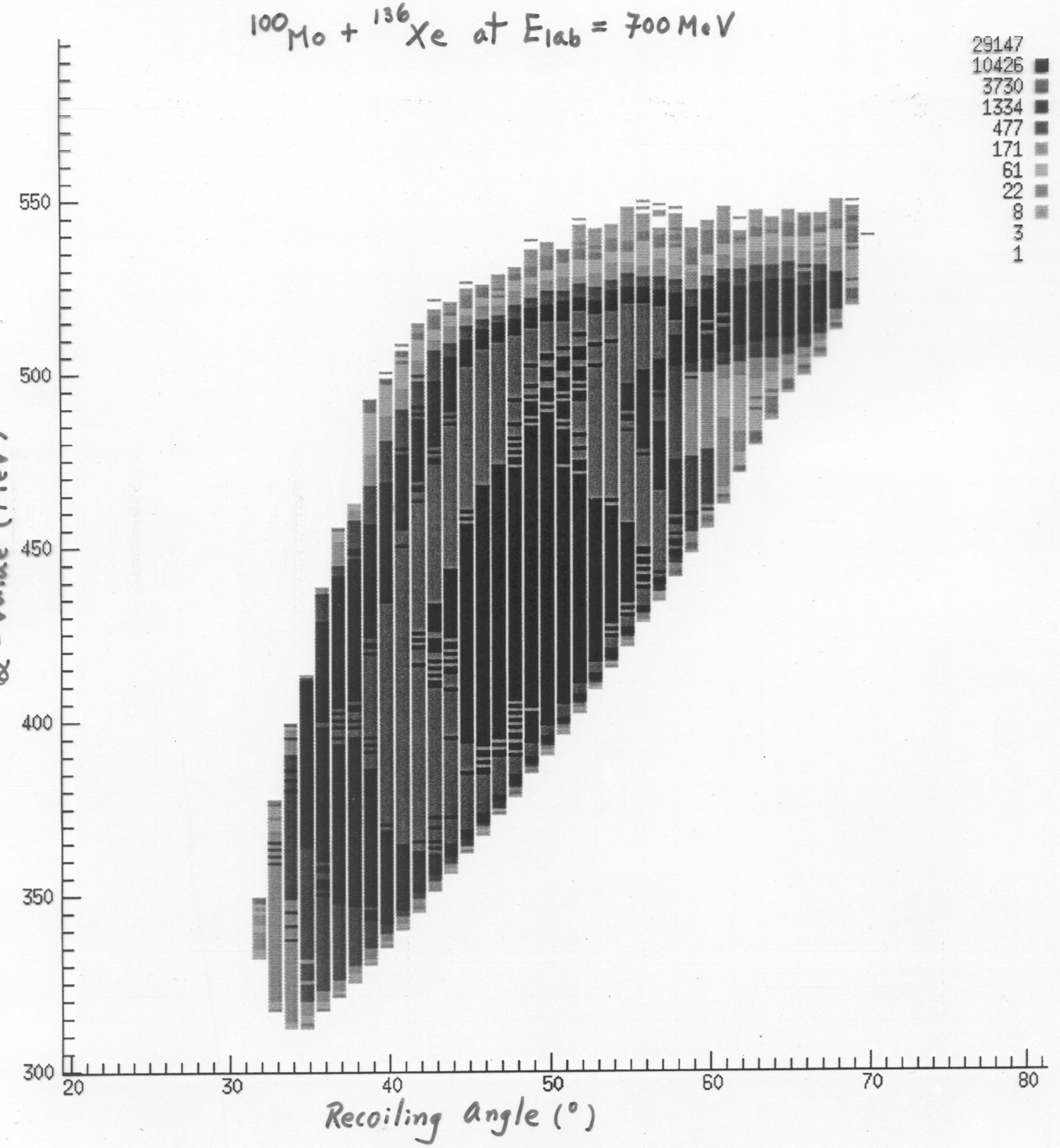
(a)
118Sn + 162Dy at Elab = 780 MeV
60° ≤ θc.m. ≤ 100°
(b)
Dy−like
2+
4+
6+
8+
10+
12+
14+
12+s→12+
16+
ΔI=0
10 8 6 4 2
ΔI=1
ΔI=2
2 4 6
3 5 79
(c)
Sn−like
4+
3−→2+
116Sn
2+
Counts / keV
Eγ [keV]

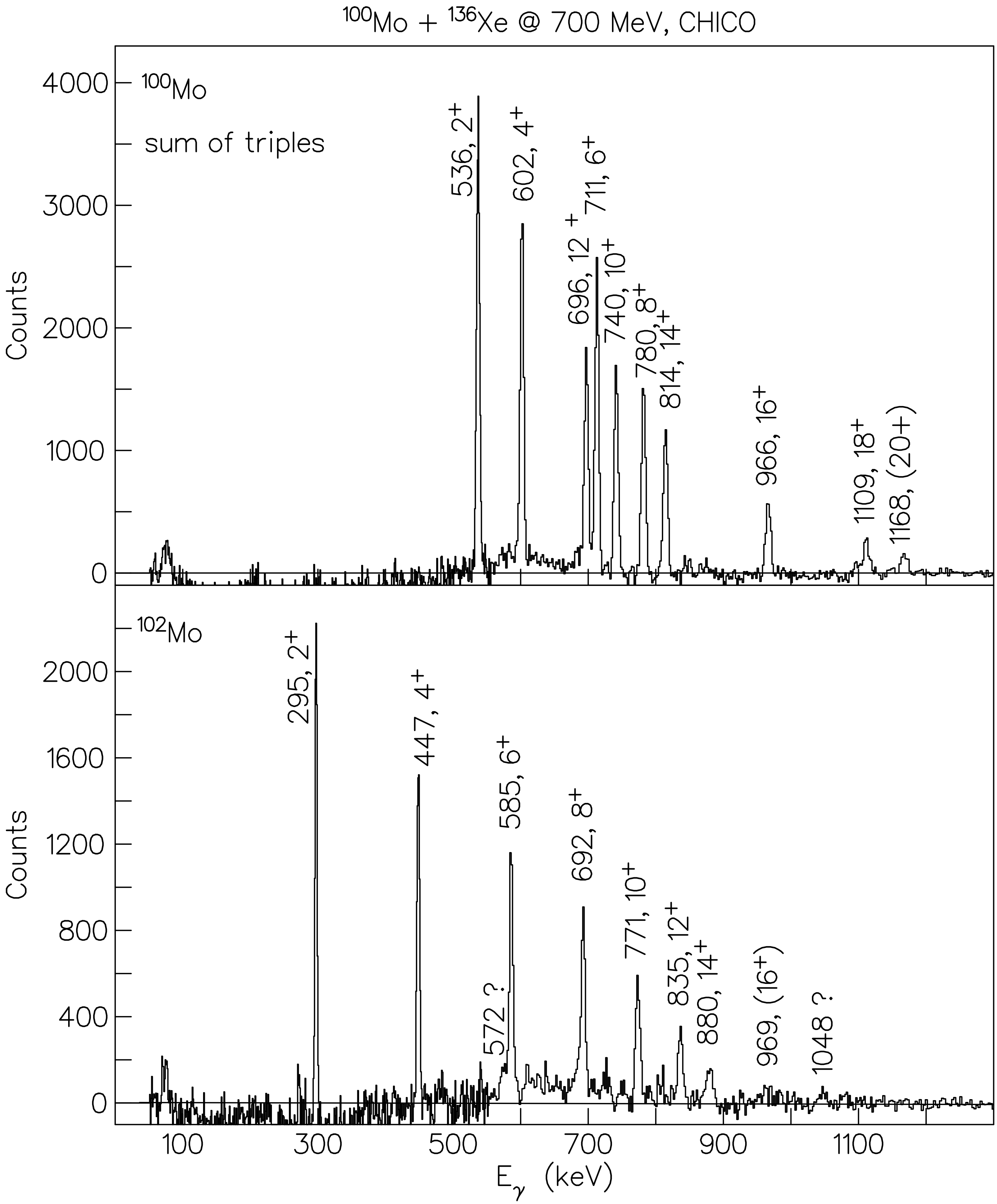


^{170}Er(^{238}U,^{238}U)^{170}Er
E_{lab}=1358 MeV
$100^o \leq \theta_{c.m.} \leq 140^o$
Target−like
Projectile−like
4^+ 6^+ 8^+ 10^+ 12^+ 14^+ 16^+ 18^+ 20^+ 22^+ 24^+
6^+ 8^+ 10^+ 12^+ 14^+ 16^+ 18^+ 20^+ 22^+ 24^+ 26^+ 28^+ 30^+
Counts
E(keV)



1e+05
50000
0
750
850
950
1050
1150
1250
1350
125 ≤ Mass ≤ 145
(a)
128Te
130Te
133I
132Te
133Te
134Te
136Xe
600
400
200
0
Counts / keV
(b)
130Te
100
200
300
400
500
600
700
800
900
1000
(c)
Mo−like
106
104,108
106
104,108
106
104
108
105
105
E γ [keV]


$^{100}Mo + ^{136}Xe$ at E_{lab} = 700 MeV
29147
10426
3730
1334
477
171
61
22
8
3
1
Q - value (MeV)
550
500
450
400
350
300
20
30
40
50
60
70
80
Recoiling angle (°)



$^{100}Mo + ^{136}Xe$ @ 700 MeV, CHICO
^{100}Mo
sum of triples
536, 2^+
602, 4^+
711, 6^+
696, 12^+
740, 10^+
780, 8^+
814, 14^+
966, 16^+
1109, 18^+
1168, (20+)
Counts
4000
3000
2000
1000
0
^{102}Mo
295, 2^+
447, 4^+
585, 6^+
572 ?
692, 8^+
771, 10^+
835, 12^+
880, 14^+
969, (16^+)
1048 ?
2000
1600
1200
800
400
0
100
300
500
700
900
1100
E_γ (keV)

5) Physics program:

- Coulomb excitation:

    a) Fragmentation of both two-phonon γ-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.

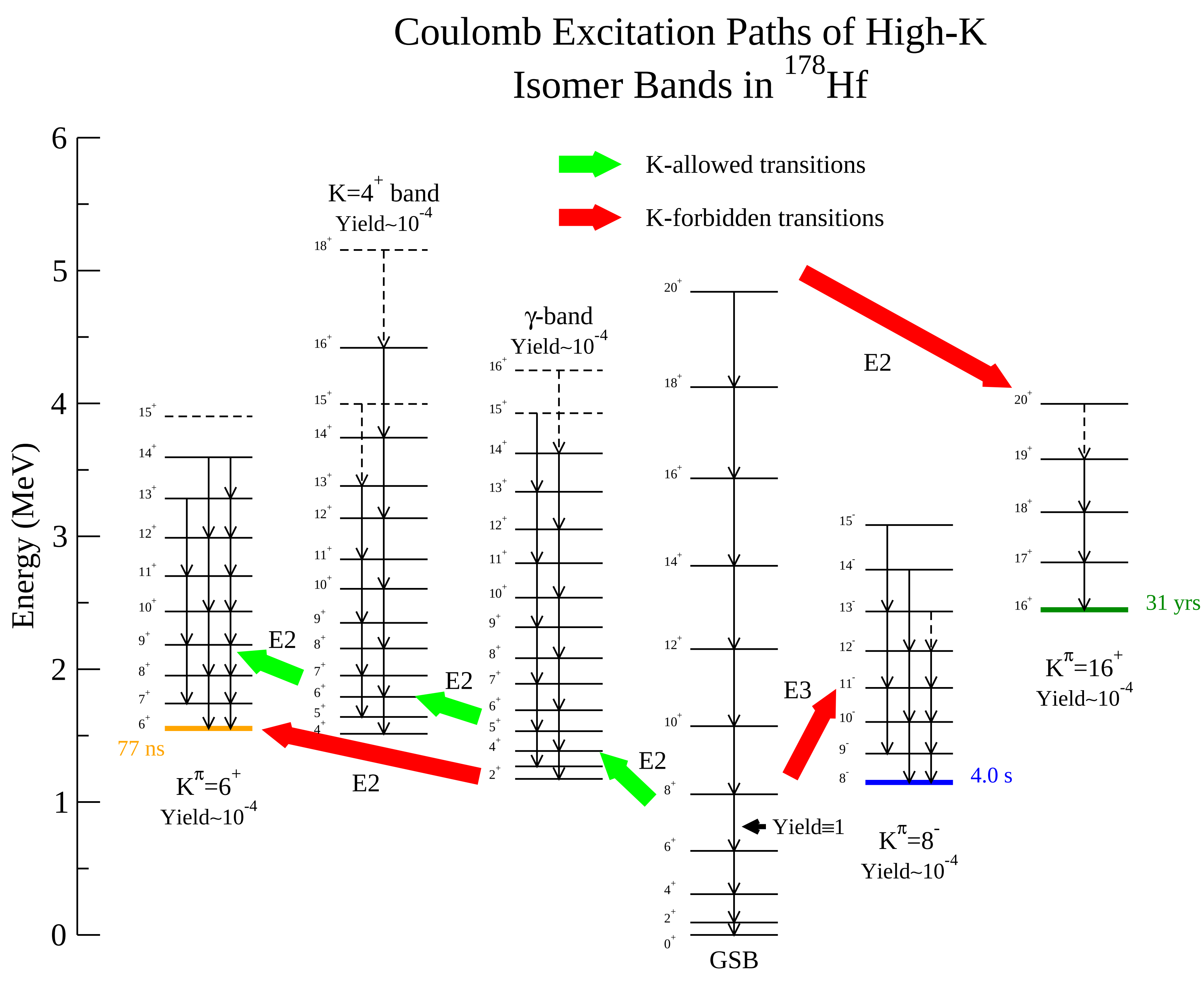
    c) Isomers.

- Fission or fusion-fission reactions:

    a) Fission dynamics.

    b) Neutron-rich nuclei.

    c) Isomers.



Coulomb Excitation Paths of High-K Isomer Bands in ^{178}Hf
Energy (MeV)
0
1
2
3
4
5
6
K-allowed transitions
K-forbidden transitions
K=4$^+$ band
Yield~10^{-4}
γ-band
Yield~10^{-4}
K^π=6$^+$
Yield~10^{-4}
77 ns
K^π=8$^-$
Yield~10^{-4}
4.0 s
K^π=16$^+$
Yield~10^{-4}
31 yrs
GSB
Yield≡1
E2
E3

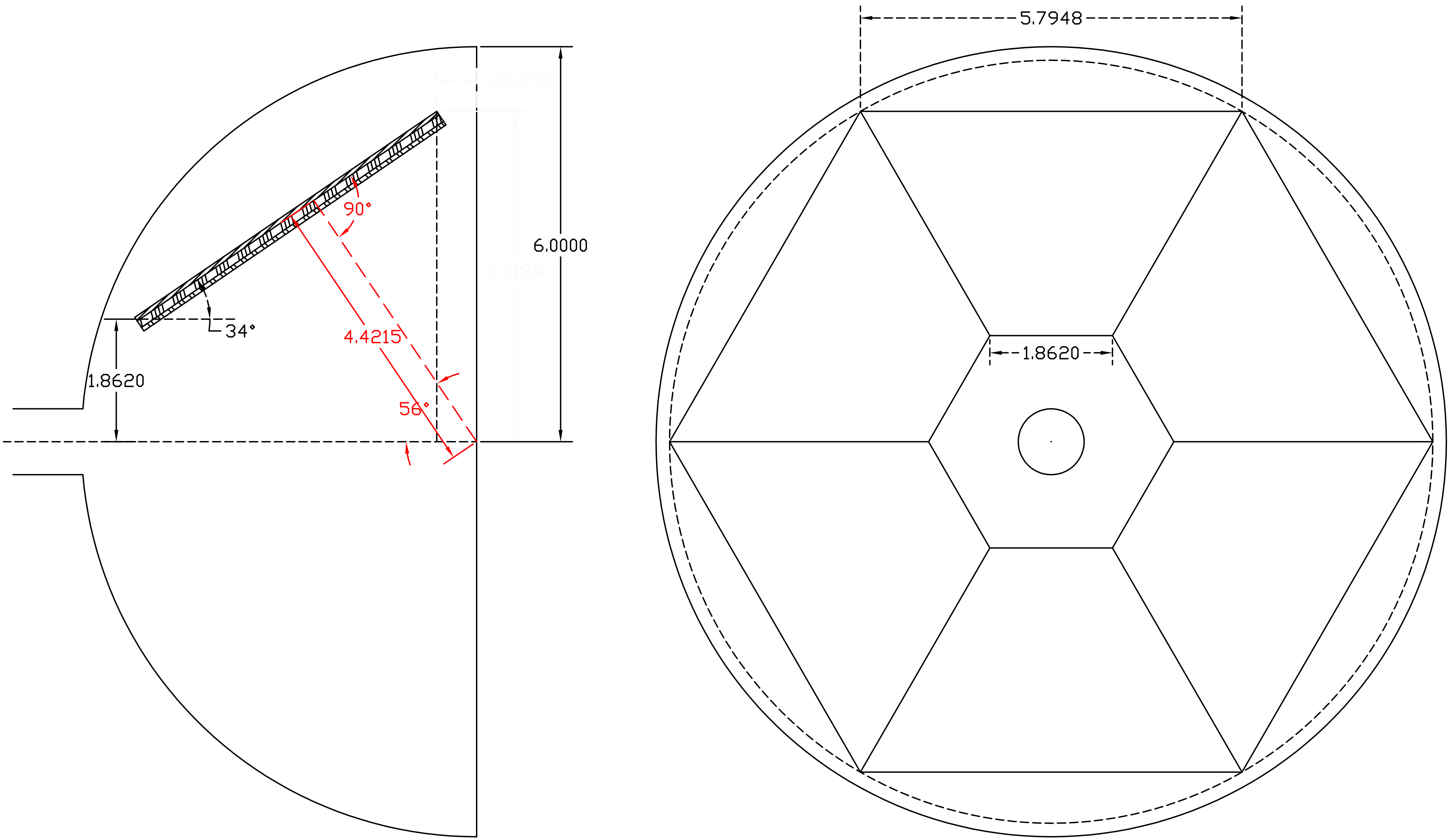
Future generation of the heavy-ion detector

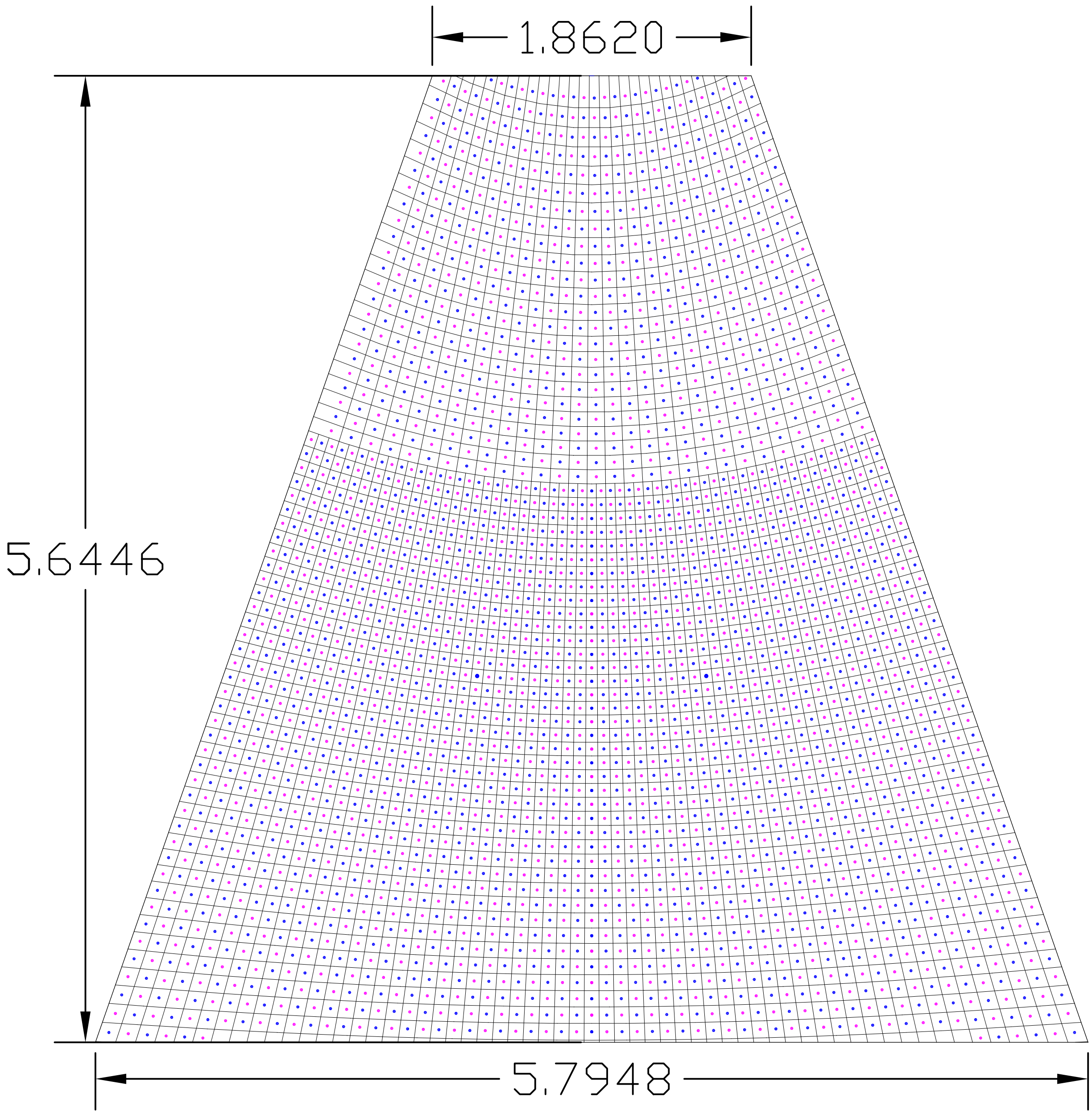
1) Required improvement:

- 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.


0.6052
6.0000
90°
5.0184
34°
4.4215
1.8620
56°
5.7948
1.8620



1.8620
5.6446
5.7948