中間エネルギー直接反応を用いたエキゾチック核の核分光

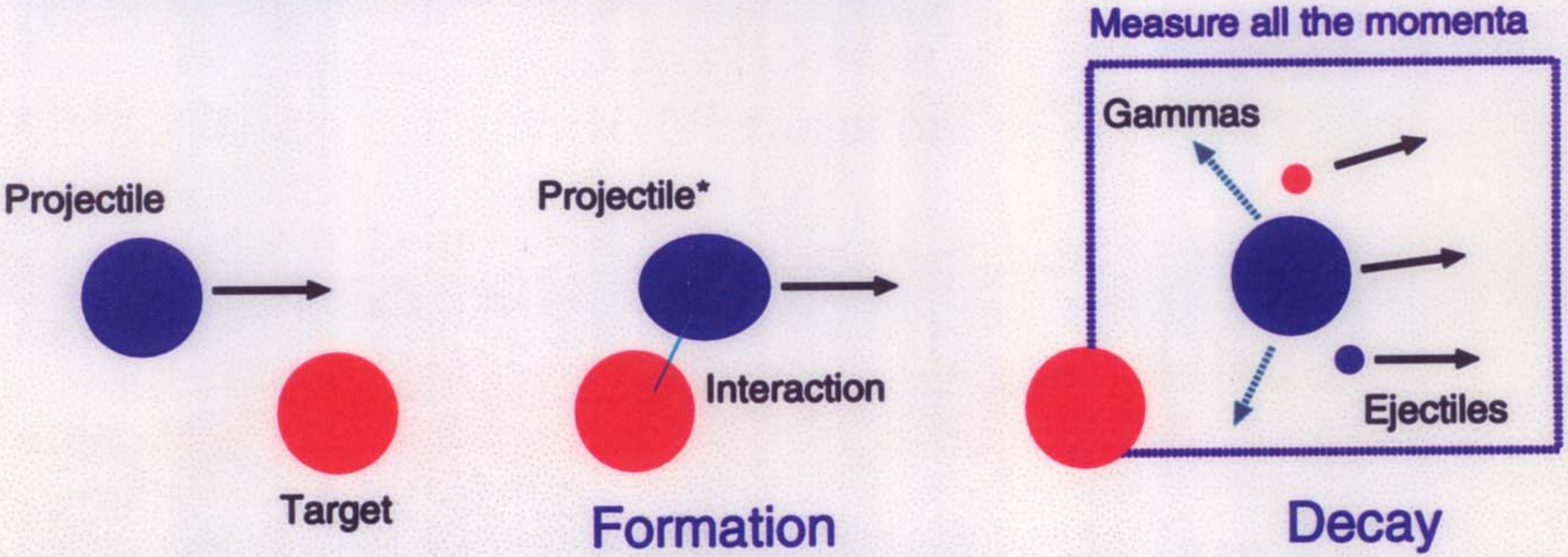
東大CNS　下浦　享

Menu

- In-beam Spectroscopy of Exotic Nuclei
  - Inverse Kinematics
  - Probes for Direct Reactions
- Spectroscopy of Neutron-Rich nuclei (12Be, 14Be, 32Mg, 34Mg)
- CNS Ge-Array for High Resolution Gamma-ray Spectroscopy

Inverse Kinematics

■ Formation of Excited States and Their Decays



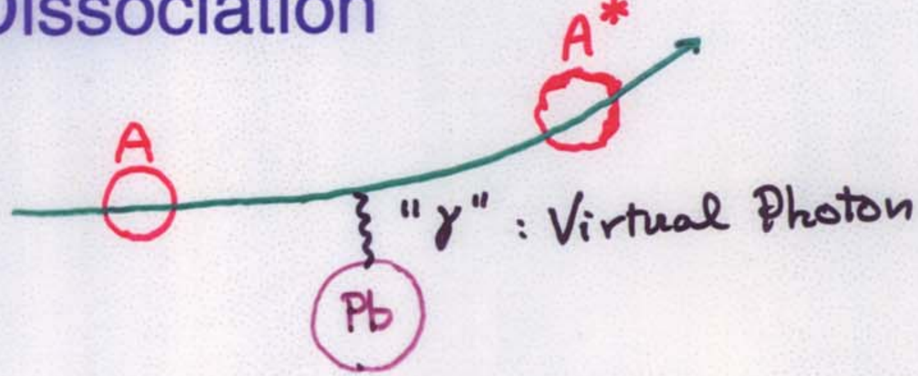
- Direct reactions are important for incident energies above several tens of MeV: Target as a Probe
- Velocities of Ejectiles are almost same as that of projectile
- Gamma-rays are Doppler-Shifted

Spectroscopy of Beam-Like nuclei with Targets as Probes

- Heavy Nuclei: Strong Coulomb Field
  - Coulomb Excitation, Coulomb Dissociation
    - Isovector, E1/E2
- Hydrogen, Deuterium
  - Inelastic Scattering
  - Charge Exchange Reaction
    - Isoscaler/Isovector, Spin Flip/Non-flip
  - Knockout
- Herium-4
  - Inelastic Scattering
    - Isoscaler, Spin Non-flip
- Any target
  - Inelastic Scattering
  - Knockout
  - Fragmentation

Selectivities

■ Coulomb Excitation, Coulomb Dissociation



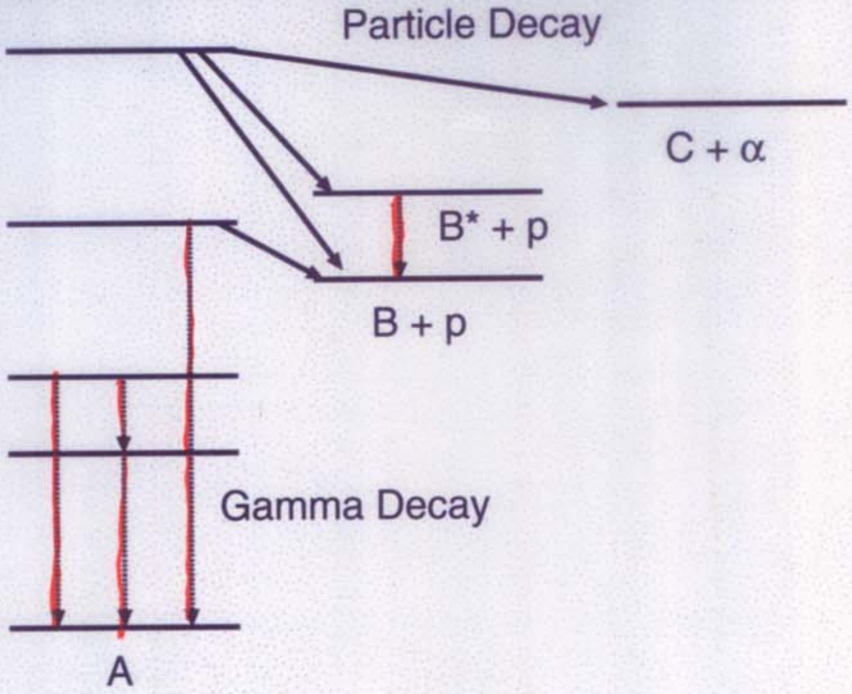
- Number of virtual photons
  - E1 > E2 > E3 ...
  - M1 > M2 ...
- Interaction with Protons only
  - Isovector Excitation

■ Nuclear Excitation

- Interaction with Protons and Neutrons
  - Isoscalar Excitaion ....
  - E1 << E2

  note: Isoscalar E1 Excitation is Higer order
- Higher angular momentum may be transferred
- Proton/Deuteron can make spin-excitation ; (p,n) : $\Delta S = 0, 1$; (d,2n) : $\Delta S = 1$
  IAS GT (d,2p) GT
- Helium-4 cannot make spin-excitation / isospin-excitation
  ISGMR, ...
-

Decays of Excited States



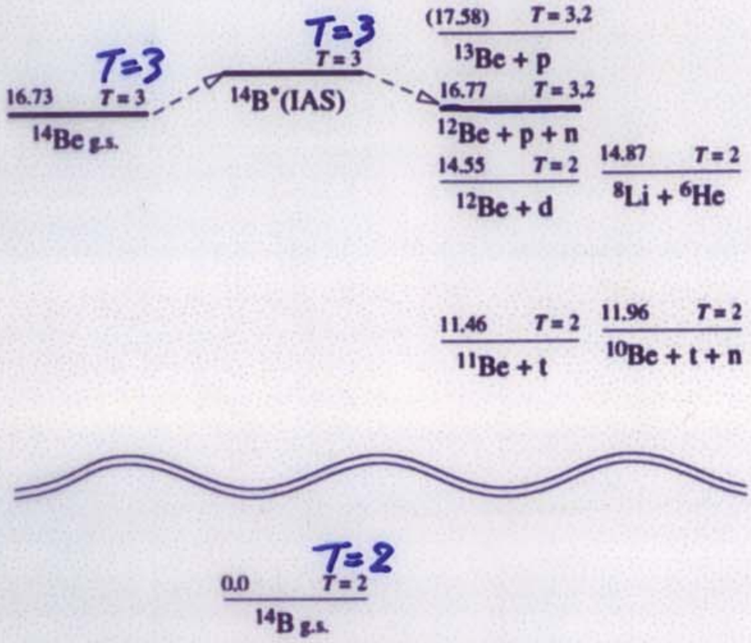
- Momenta of all the decay particles including gamma rays ->
  Excitation energy (from invariant mass)
- Particle-particle, particle-gamma correlation ->
  Spins and Parities
- Selectivities of Decay Process

"High resolution Gamma detectors"

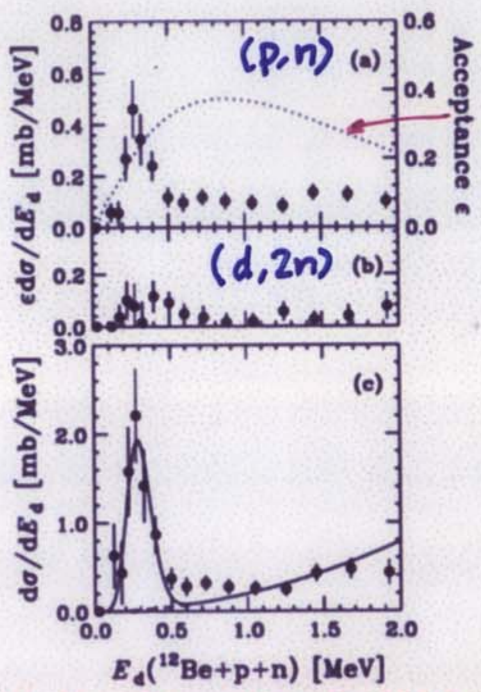
$^1H(^{14}Be, ^{14}B^*[IAS])n$ at 74 A MeV

Rikkyo-CNS-Tokyo-RIKEN

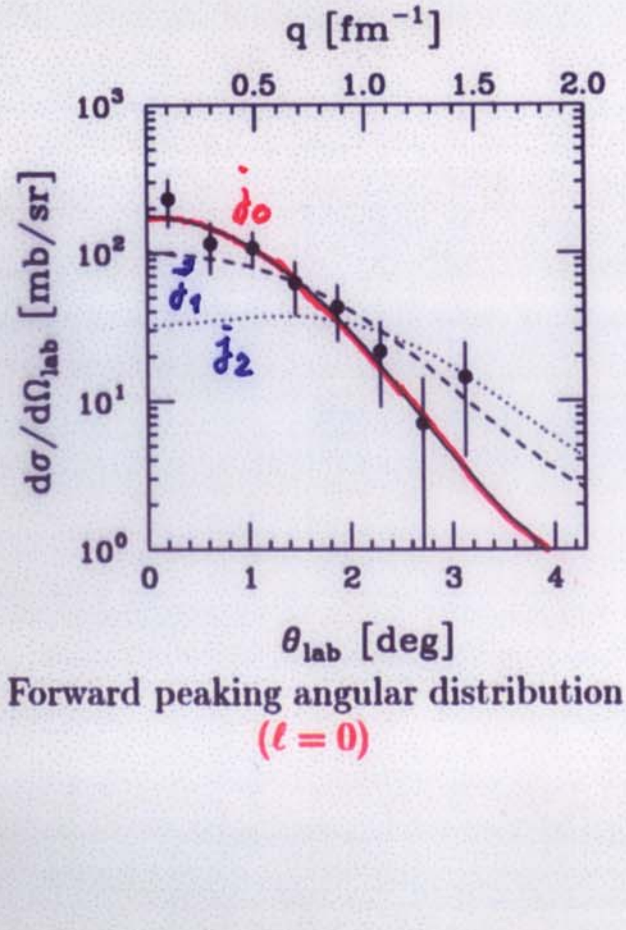
Takeuchi et al., Phys. Lett. B515 (2001) 255



Only the ^{12}Be+p+n channel has $T = 3$ among various open channels



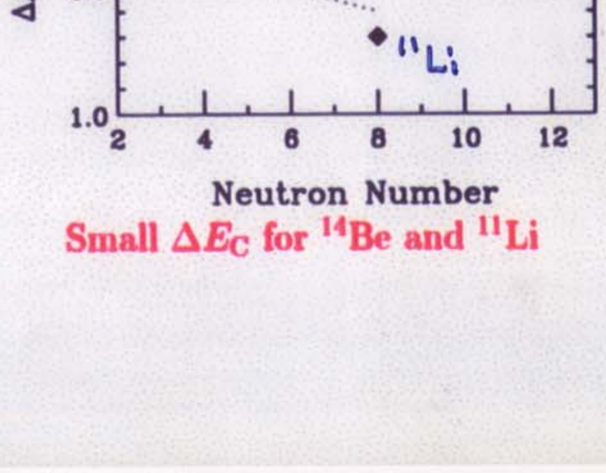
No Fermi transition for (d,2n)



Forward peaking angular distribution

$(\ell = 0)$

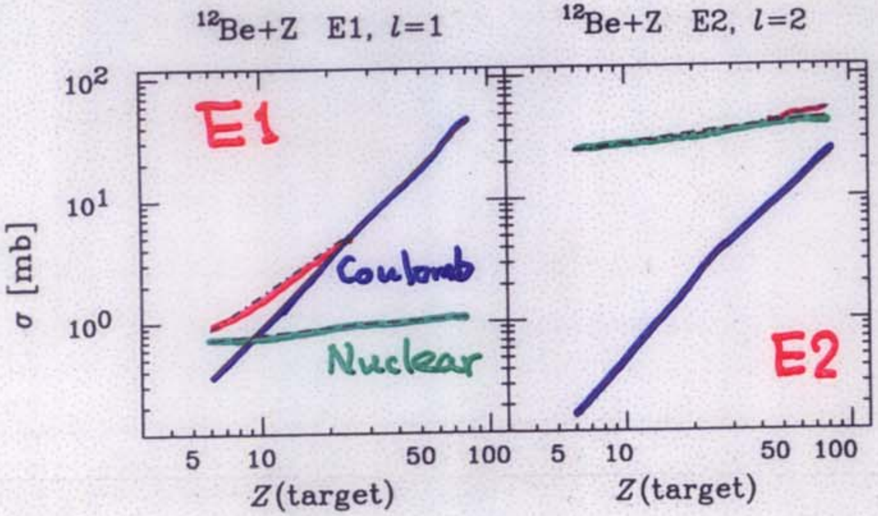
$$E_x\left(^{14}B^*\,(T=3)\right) = 17.06 \pm 0.02 \text{ MeV}$$
$$\text{FWHM}\,(\simeq \Gamma) = 0.11 \pm 0.05 \text{ MeV}$$
$$\Gamma_{sp}\,(\ell = 0) = 0.24 \text{ MeV}$$
$$\Gamma_{sp}\,(\ell = 2) = 0.001 \text{ MeV}$$

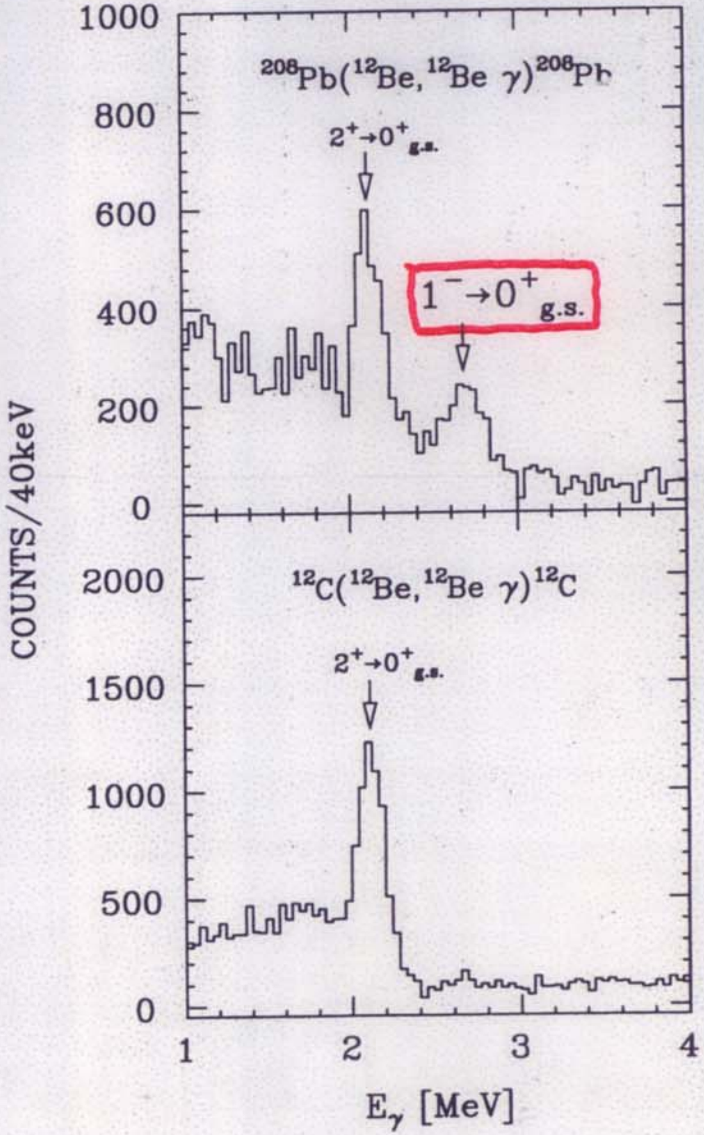


Small ΔE_C for ^{14}Be and ^{11}Li

Low-lying intruder 1^- state in ^{12}Be

Iwasaki et al., Phys. Lett. 491B (2000)8





1^- state at $E_x = 2.7$ MeV

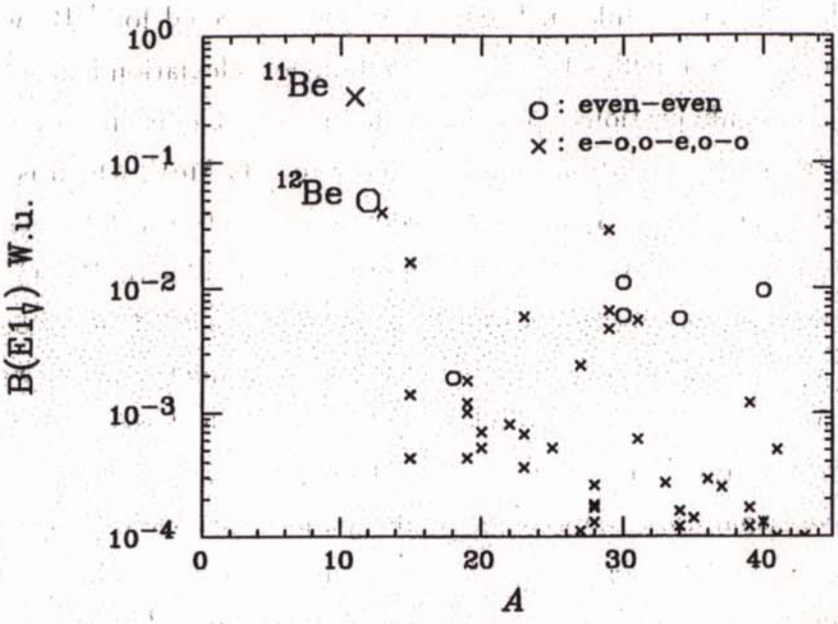


Figure 5.5: E1 transition strength observed between the ground state and the bound excited state in light nuclei. The γ-decay strength is plotted as a function of mass number A. The open circles represent the data obtained for even-even nuclei, while the cross symbols show the data for the other nuclei.

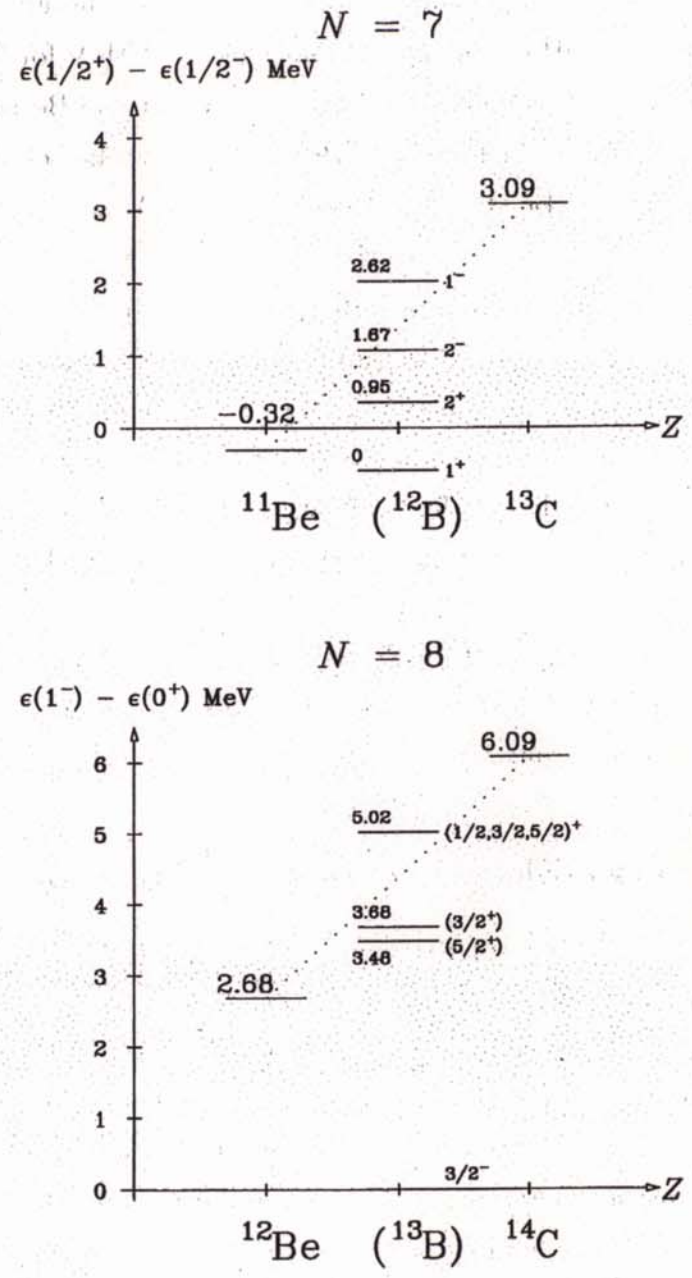
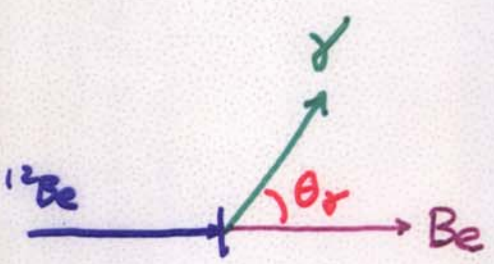


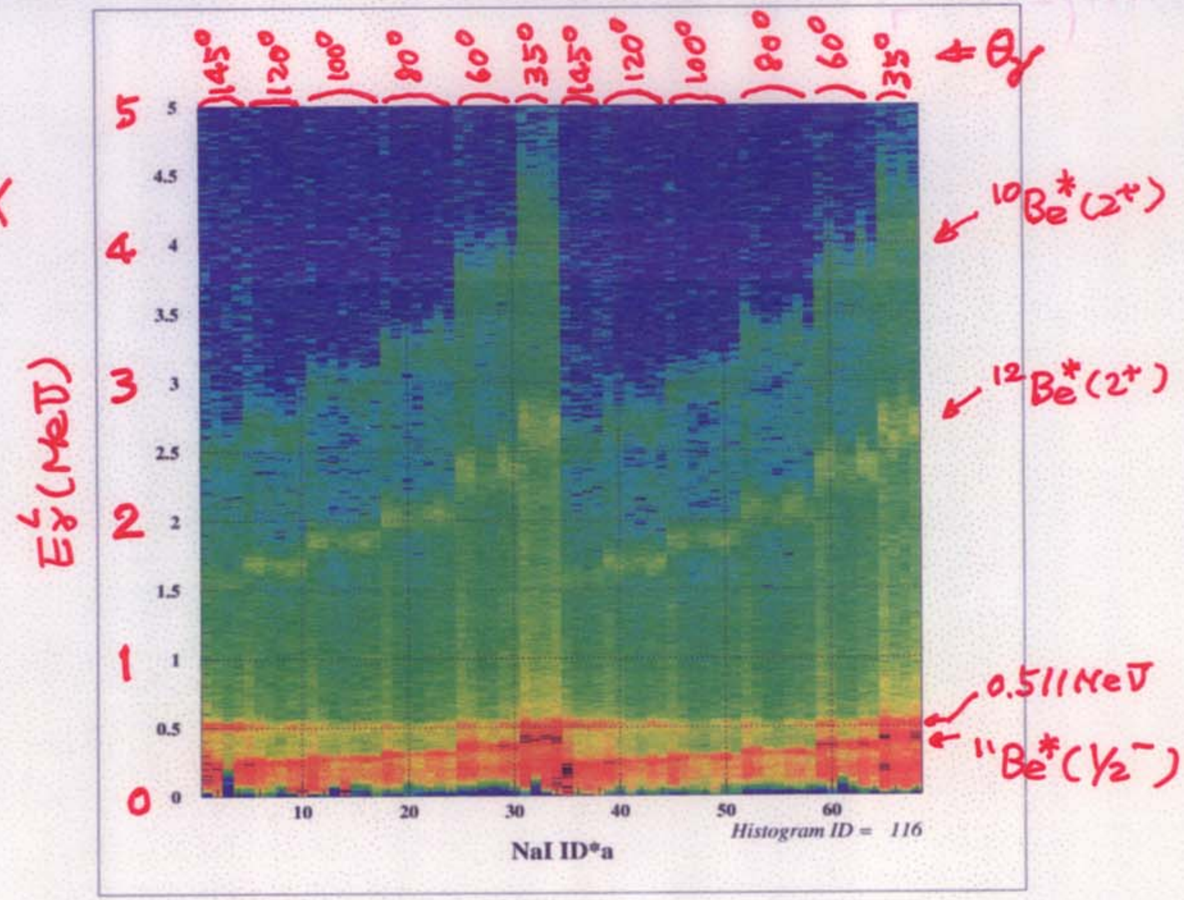
Figure 5.4: Energy levels in the Be and C isotopes with the neutron number N=7 and N=8. In the top panel, the energy differences between the $1/2^+$ state and the $1/2^-$ state are plotted as a function of Z. The bottom panel shows the plots of the excitation energies of the lowest 1^- states. The relevant levels in the B isotopes are also plotted.

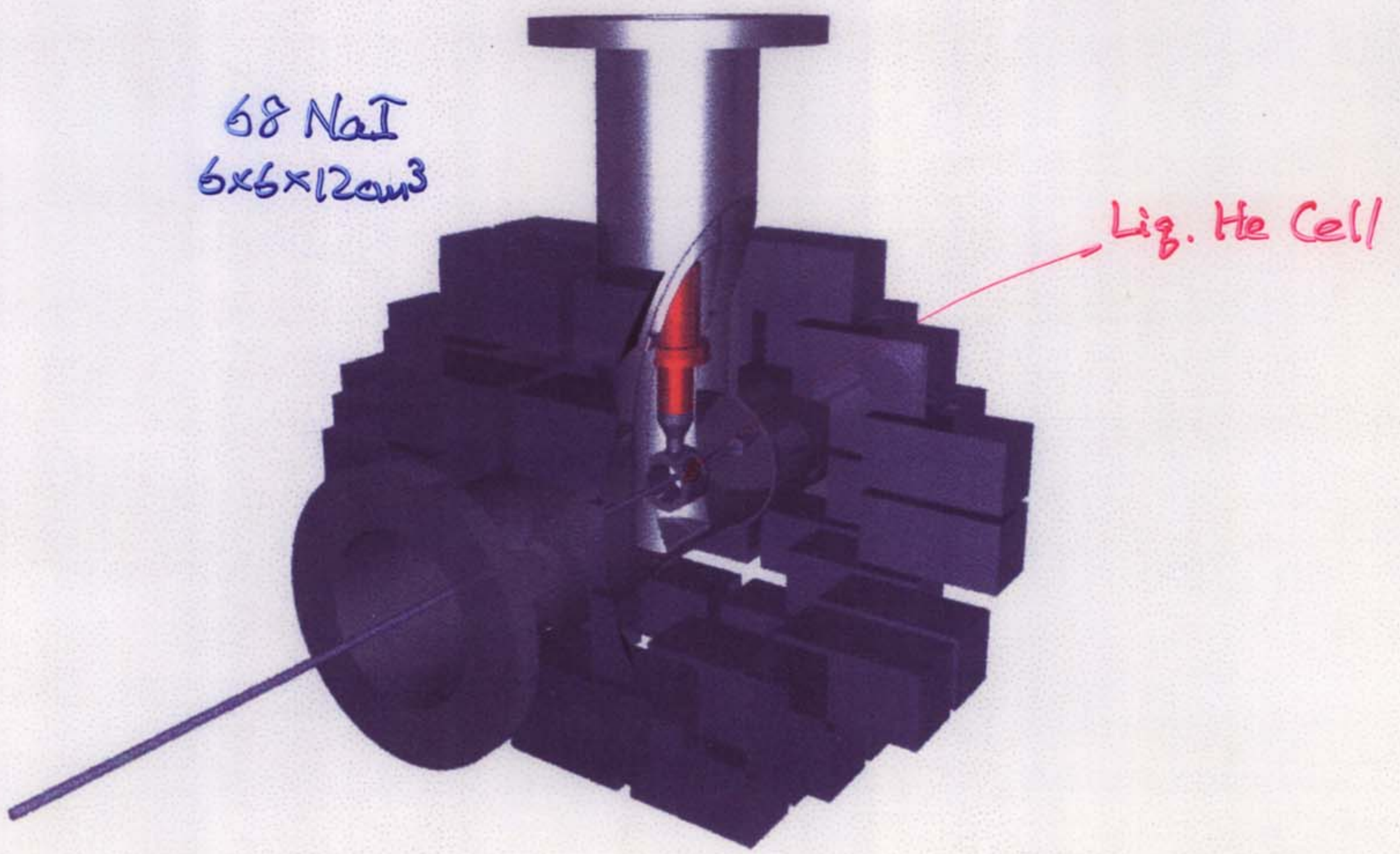
Example : NaI(Tl) array

- Scattering angle vs. Energy deposited in detectors (data)
  - 2.1 MeV gamma-rays from in-flight 12Be* are shifted
  - about 0.2 MeV (FWHM) resolution after D.S. corrected
  - 0.5 MeV gamma-rays from positron annihilation are not shifted

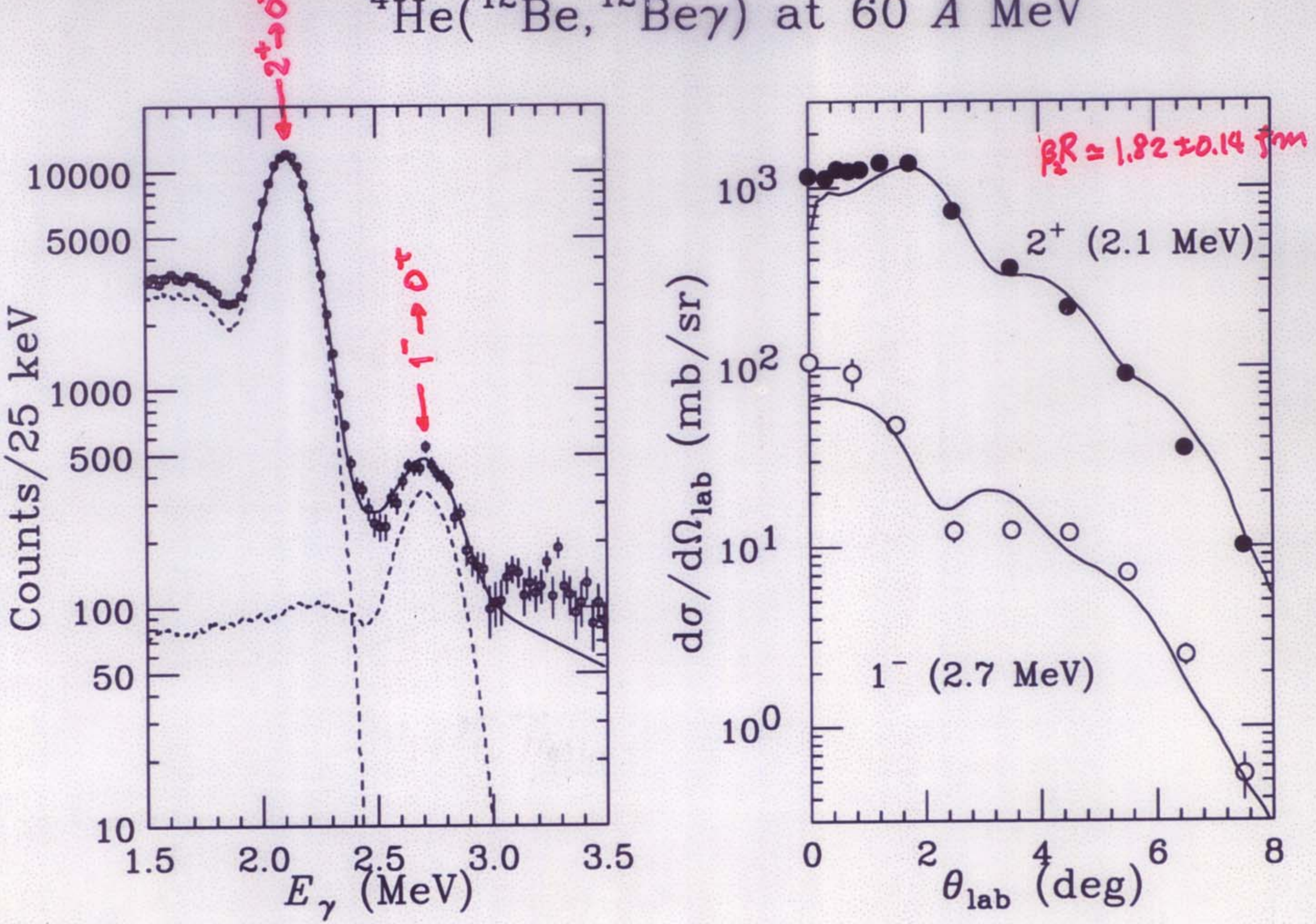
$^{12}Be + ^{4}He \rightarrow {}^{A}Be + \gamma + X$






68 NaI
6×6×12cm3
Liq. He Cell

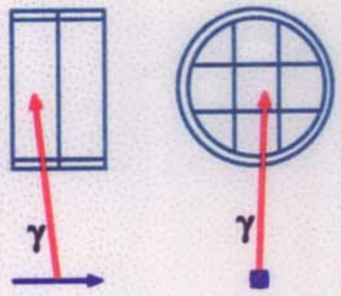
$^4He(^{12}Be, ^{12}Be\gamma)$ at 60 *A* MeV



Germanium Array

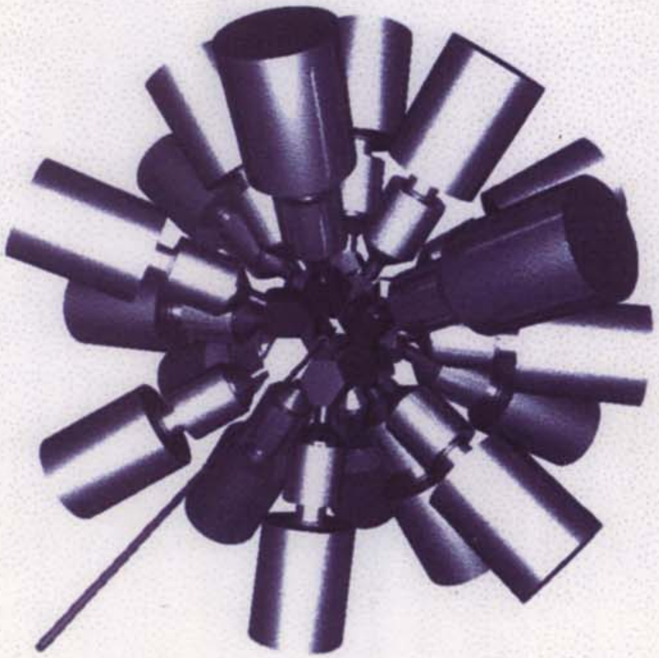
Geometry

crystal
planar type : direction of γ-ray // electrode
active volume : 2cm² × 6cm⁰
segmentation : 3× 3
2 crystals in the same cryostat = 1 detector
18 detectors (36 crystals) :
around 70, 90, 110 degree
radius of "ring" (Ge center) : 11 cm



Performance

angular resolution : 1 deg (pulse shape analysis)
full-energy-peak efficiency at 1 MeV : 5 %
intrinsic energy resolution : < 3 keV for 1 MeV
energy resolution of Doppler shift correction:
8 keV for 1 MeV γ from β=0.3 particle



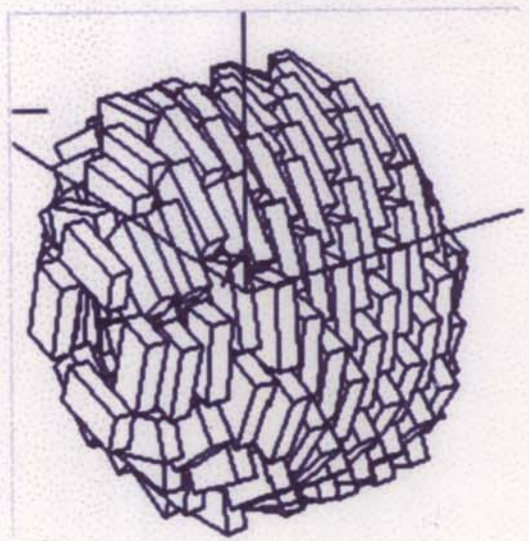
NaI(Tl) Array

Geometry

crystal
4cm ×8cm ×16cm
160 crystals
radius of "ball" (NaI center) : 30 cm

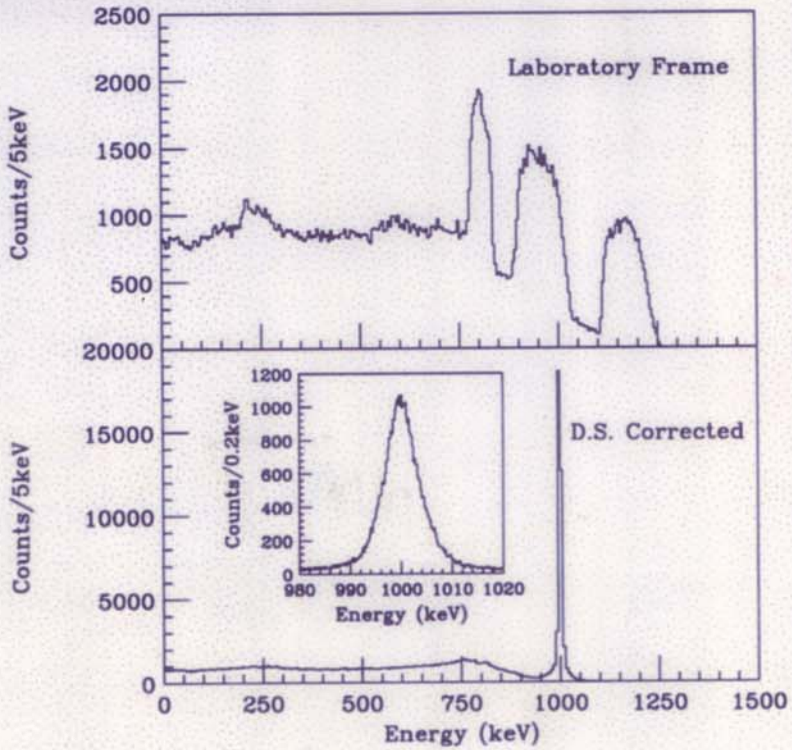
Performance

angular resolution : 8 deg
full-energy-peak efficiency at 1 MeV : 30 %
intrinsic energy resolution : 70 keV for 1 MeV
energy resolution of Doppler shift correction:
70 keV for 1 MeV γ from β=0.3 particle



Performance (Simulation)

- Energy Resolution after Doppler-Shift Corrected (v/c = 0.3)
  - 8 keV (FWHM) 17 keV (FWTM) for 1-MeV gamma
- Total Detection Efficiency (epsilon x Omega)
  - 5 % (All) 3.4 % (more than single hit)
- Peak-to-Total Ratio
  - 23 % (All) 42 % (more than single hit)



Assuming

1st Hit = Hit w/ Maximum Pulse Height

$\Delta X = \Delta Y = 2$ cm

$\Delta Z = 1$ mm