Decay Detector For The Study of Isoscalar Giant Monopole Resonances

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Outline

- Giant resonances
- Isoscalar Giant Monopole Resonance
- Nuclear Matter Incompressibility
- Unstable Nuclei
- Decay Detector
- Scintillator Light Output

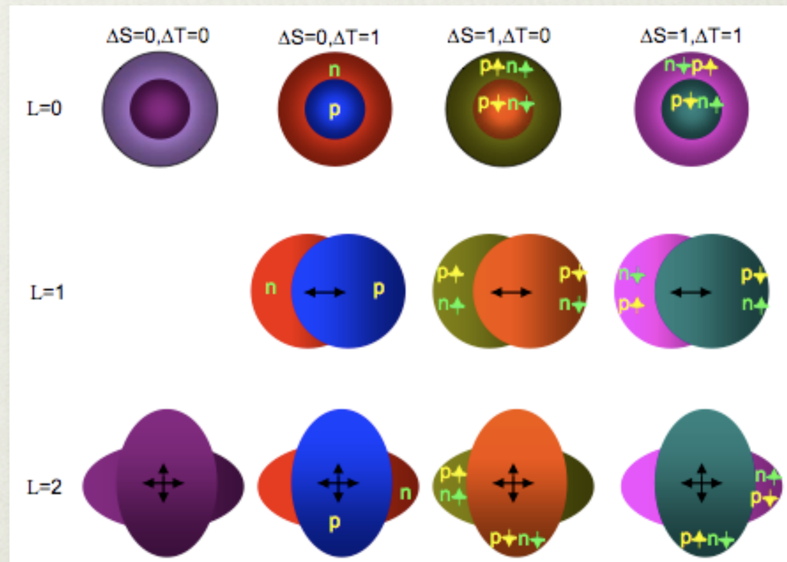
What Is A Giant Resonance?

- Appearance of high frequency resonances observed in C at 30MeV, Cu at 22MeV, Ta at 16 MeV, and Th and U at 16-18MeV during nuclear photo-disintegrations
- 1948 - Edward Teller and Maurice Goldhaber proposed the idea of a dipole vibration
- Collective oscillation of the nucleons
- Energy Weighted Sum Rule (EWSR)

$$S(Q) \equiv \sum_n (E_n - E_0) \left| \langle n | Q | 0 \rangle \right|^2$$

Isoscalar Giant Monopole Resonance (ISGMR)

- Isovector – neutrons and protons move out of phase with one another
- Isoscalar – neutrons and protons move in phase with one another
- Monopole is a spherical oscillation
- One of two compression modes
- “breathing mode”



Ref. Xinfeng Chen, “Giant Resonance Study By ^{6}Li Scattering”

Classical Description

- Liquid Drop Model
- Protons and neutrons are treated as two separate and independent fluids
- Giant resonance can be thought of as oscillations in the density and shape of these fluids

Nuclear Incompressibility

- E_{GMR} can be determined from the study of ISGMR
- Incompressibility of the nucleus is found from E_{GMR}
- Incompressibility of the nucleus is extrapolated to find the nuclear matter incompressibility, K_{nm}
- Analogous to the spring constant
- Nuclear Matter Equation of State
  - Supernova collapse
  - Neutron Star

Unstable Nuclei

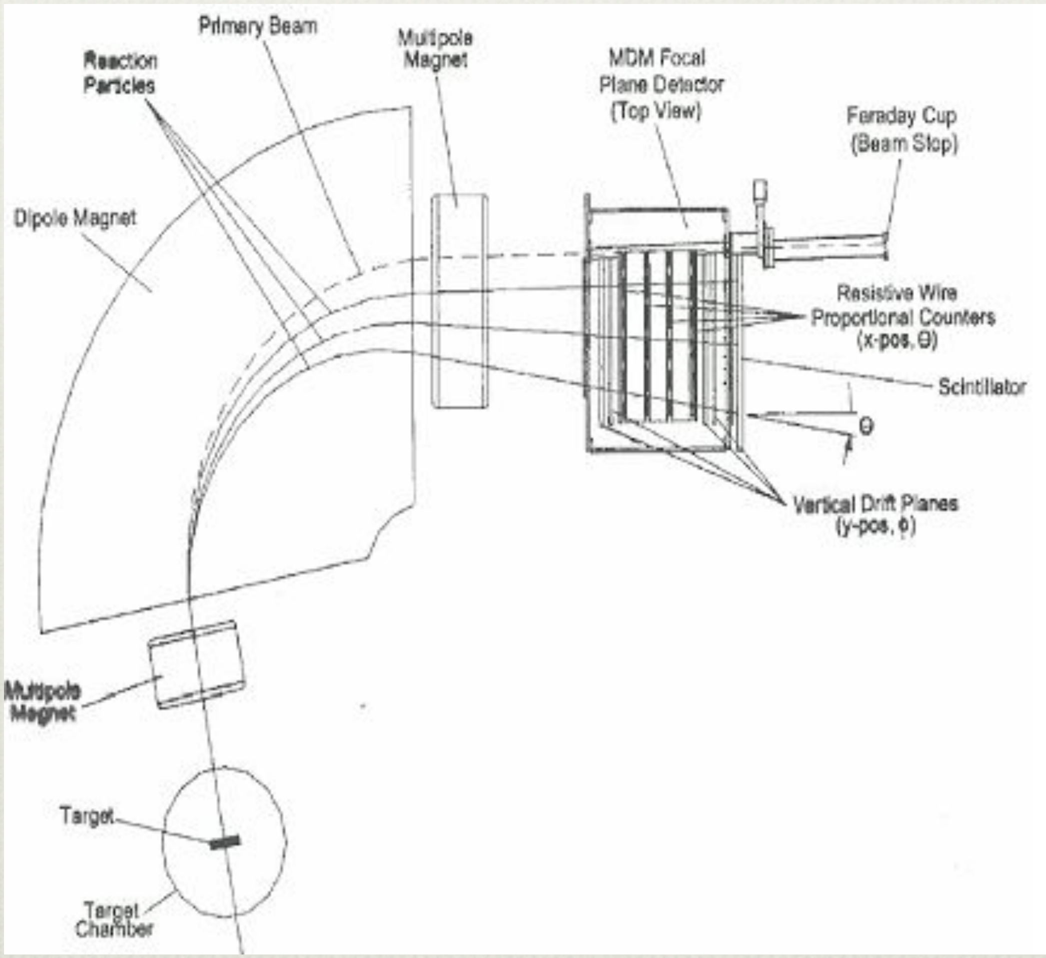
- We have an established systematic for stable nuclei
  - 236±5 MeV
- Might enable the determination of the dependence of nuclear incompressibility on (N-Z)/A
- Study the inverse kinematics
  - Normal kinematics:

$$^{26}Si(^{6}Li,^{6}Li)^{26}Si*$$

  - Inverse kinematics:

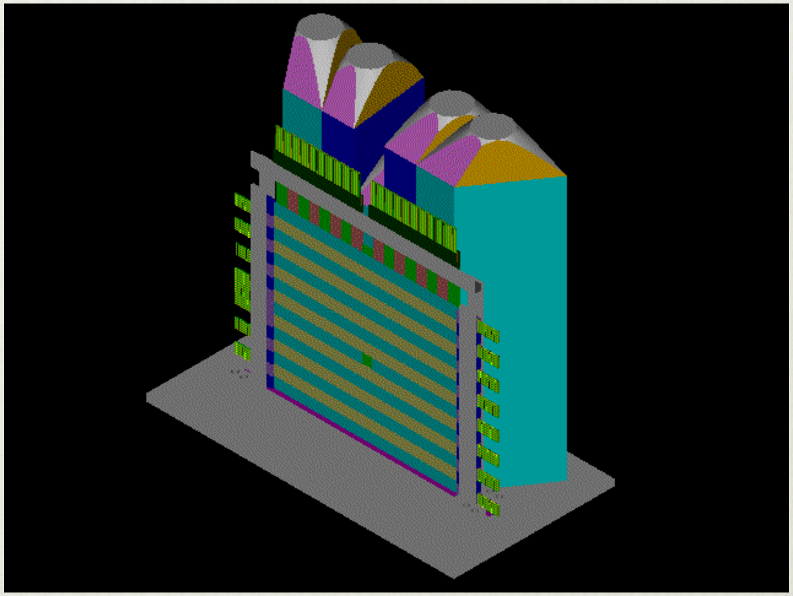
$$^{6}Li(^{26}Si,^{26}Si*)^{6}Li$$

Experimental Setup



Decay Detector

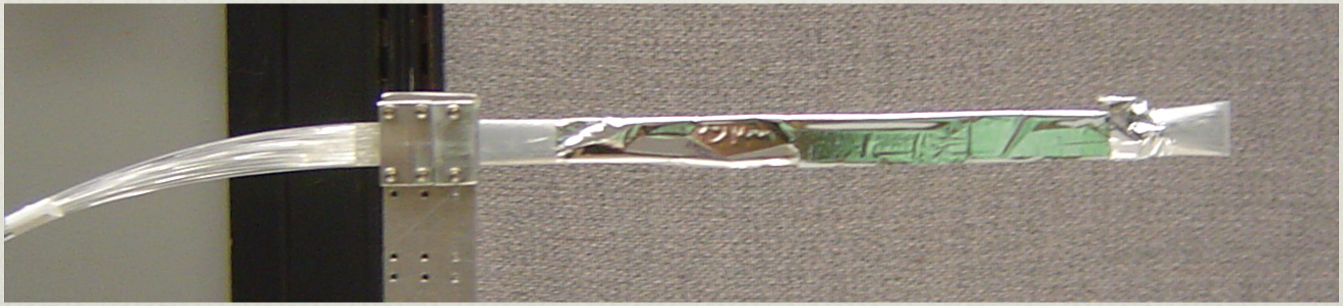
- Composed of a layer of 1 mm thick plastic scintillator strips arranged horizontally followed by a layer of 1 mm thick scintillator strips arranged vertically in front of 5 block scintillators



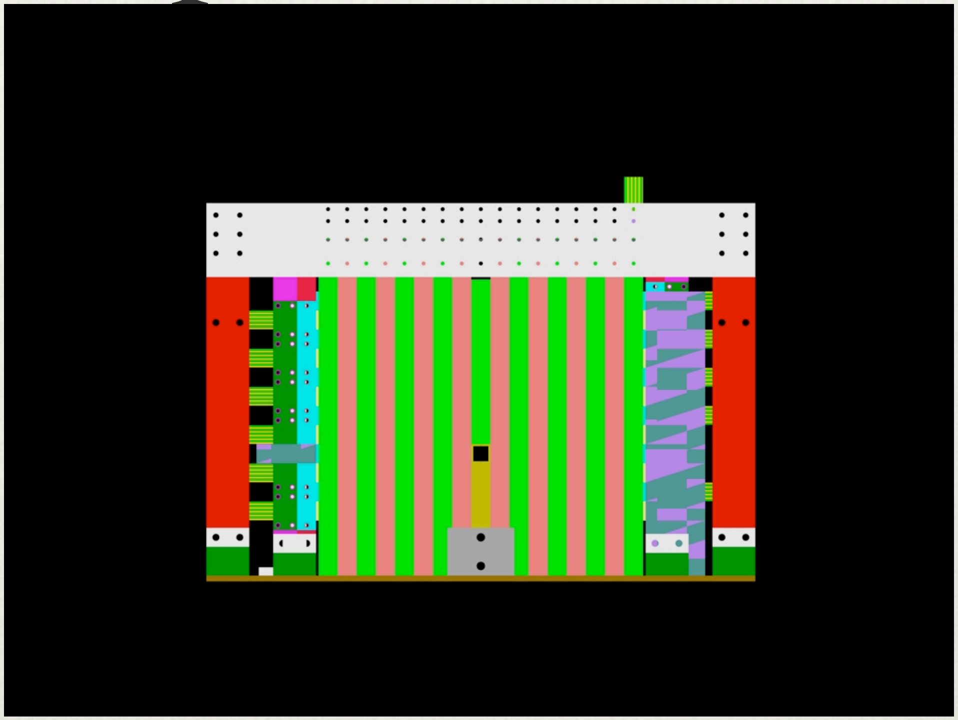
Drawing by Dr. Y. Tokimoto

Decay Detector Cont.

- Scintillator emits a photon signal
- Optical fibers carry the signal to a photomultiplier tube (PMT)
- Photon's energy is converted to an electrical signal and is amplified
- Strip scintillators and block scintillators are also used to ID particles



Strip Scintillators



- Angle and energy loss through strips is know
- 4×4 degree angular resolution

Light Output

- Stopping power – energy loss per unit length (dE/dx)
  - Bethe-Bloch Formula
- 2 Methods for predicting the light output
  - Birks semi-empirical formula
  - Energy Deposited By Secondary Electrons (EDSE)

Bethe-Bloch Formula

$$-\frac{dE}{dx} = 2\pi a_0^2 m_e c^2 n_e \frac{Z^2}{\beta^2}\left[\ln\left(\frac{2m_e c^2\gamma^2\beta^2 W_{\max}}{I^2}\right) - 2\beta^2 - \delta - 2\frac{C}{Z}\right]$$

$$\beta = \frac{v}{c}$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Approximation of the Bethe-Bloch Formula

- More convenient formula (can be integrated analytically)

$$-\frac{d\varepsilon}{dx} = \frac{Z^2}{m} \frac{1}{(1+\mu)} \frac{\kappa}{(\varepsilon + \varepsilon_0)^\mu}$$

- ε is the kinetic energy divided by rest mass

$$\varepsilon \equiv \frac{T}{mc^2} \approx \beta$$

- μ, κ, and ε_0 are parameters that are fit to the data from SRIM

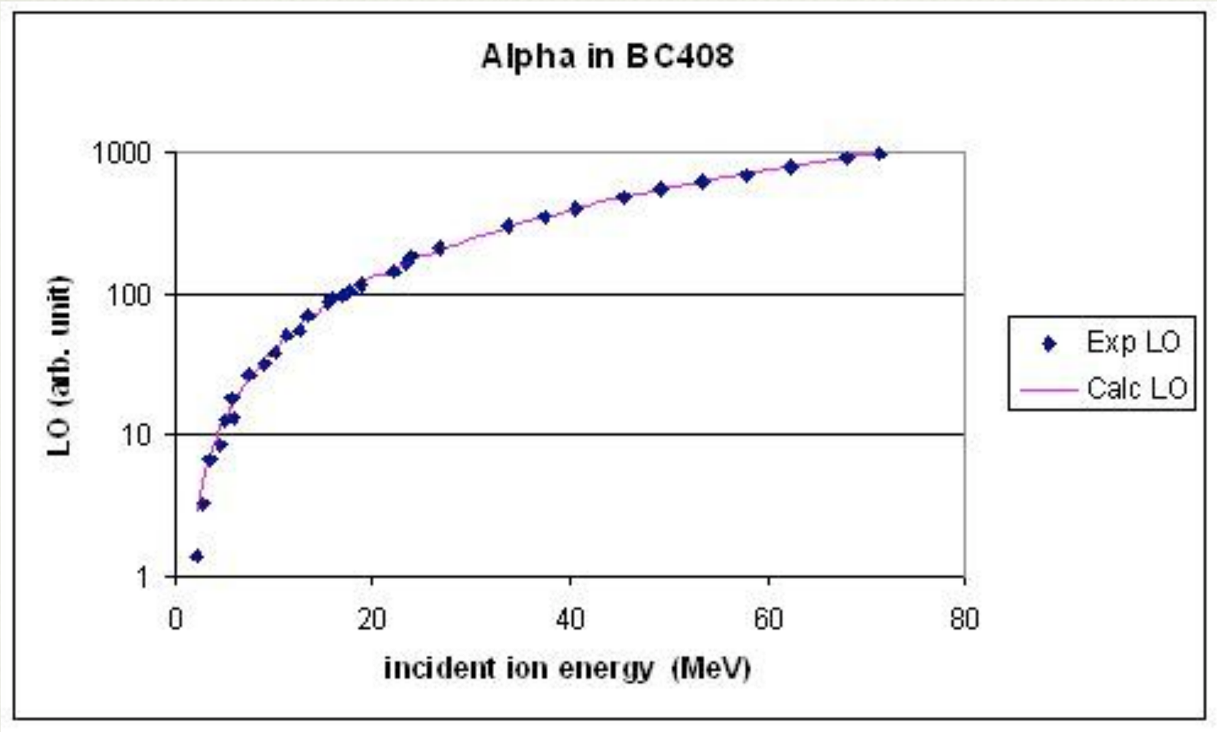
Birks Semi-empirical Formula

- Non-linear relationship to the stopping power at low energies

$$\frac{dL}{dx} = \frac{C_0 \frac{dE}{dx}}{1 + C_1 \frac{dE}{dx}}$$

- C_0 is the proportion of molecules that contribute to the light output
- C_1 is the proportion of molecules that are quenching sites
- C_1 is restricted to non-negative numbers

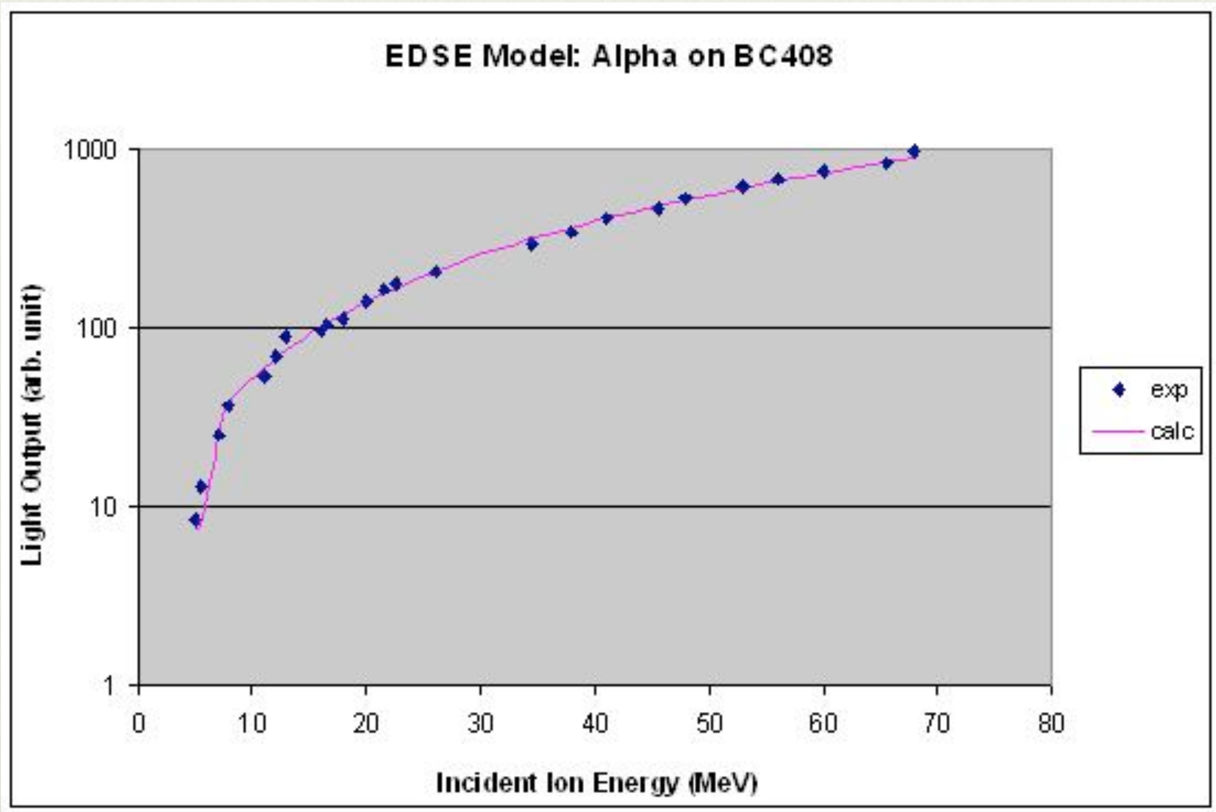
Birks Formula



Experimental data was taken from “Response of Plastic Scintillator Detectors to Heavy Ions, Z ≤ 35, E ≤ 170 MeV” Becchetti et al

- $Z = 2$
- $m = 3727.3$
- $\mu = 0.8519753$
- $\kappa = 6.8988548$
- $\varepsilon_0 = 0.0178087$
- $C_0 = 44.888741$
- $C_1 = 0.0099879$
- $\chi 2/n = 0.267635$

Energy Deposited By Secondary Electrons (EDSE) Model



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References

- Becchetti et al., Nuclear Instruments and Methods 138 (1976) 93-104
- R.J.M. Snellings et al., Nuclear Instruments and Methods in Physics Research A 438 (1999) 368-375
- M. Goldhaber and E. Teller, Phys. Rev. 74 (1948) 1046-1049