

Systematic of Giant Monopole Energy and the Isotopic Dependence

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Nuclear matter compressibility is a
important physical quantity

- Supernova Collapse
- Neutron Stars
- Medium and high energy heavy ion collision
- Properties of nuclei
- Testing nuclear model from experimental results

The compression modulus of nuclear matter is defined by

$$K_{nm} = 9 \rho_0^2 \frac{d^2 E/A}{d\rho^2} \Big|_{n_0} = k_f^2 \frac{d^2 E/A}{dk_f^2} \Big|_{k_{f0}}$$

where n_0 is the equilibrium density and k_{f0} is the equilibrium Fermi momentum.

One cannot measure this quantity directly.

However, one can measure the energy of the compression mode giant resonance such as the isoscalar giant monopole resonance E_{GMR} , which can be related to the compression modulus for the nucleus of mass number A by the following formula

$$E_{GMR} = \sqrt{\frac{\hbar^2 A K_A}{m \langle r^2 \rangle_0}}$$

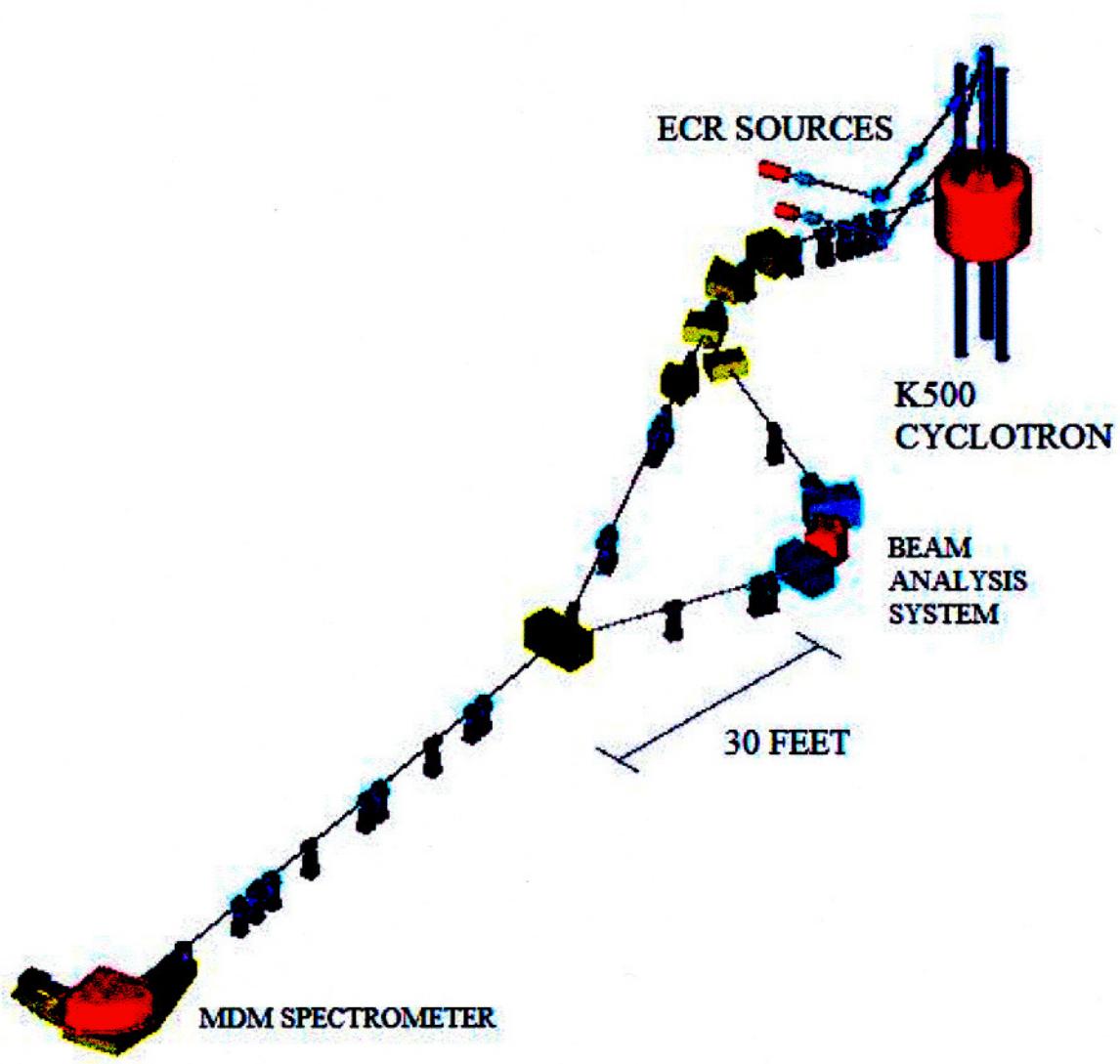
Where m is the nucleon mass.

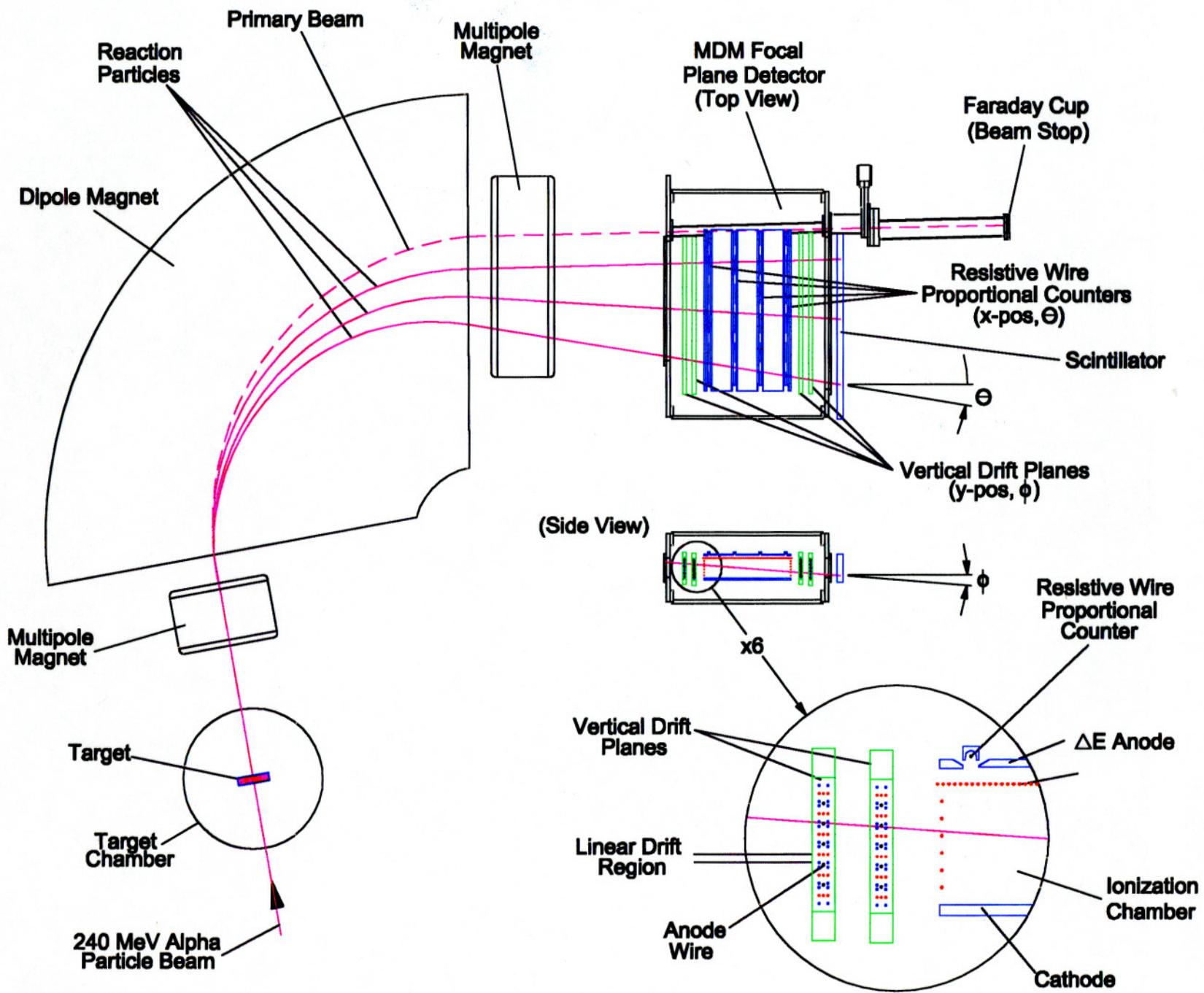
K500 Superconducting Cyclotron – 240 MeV α

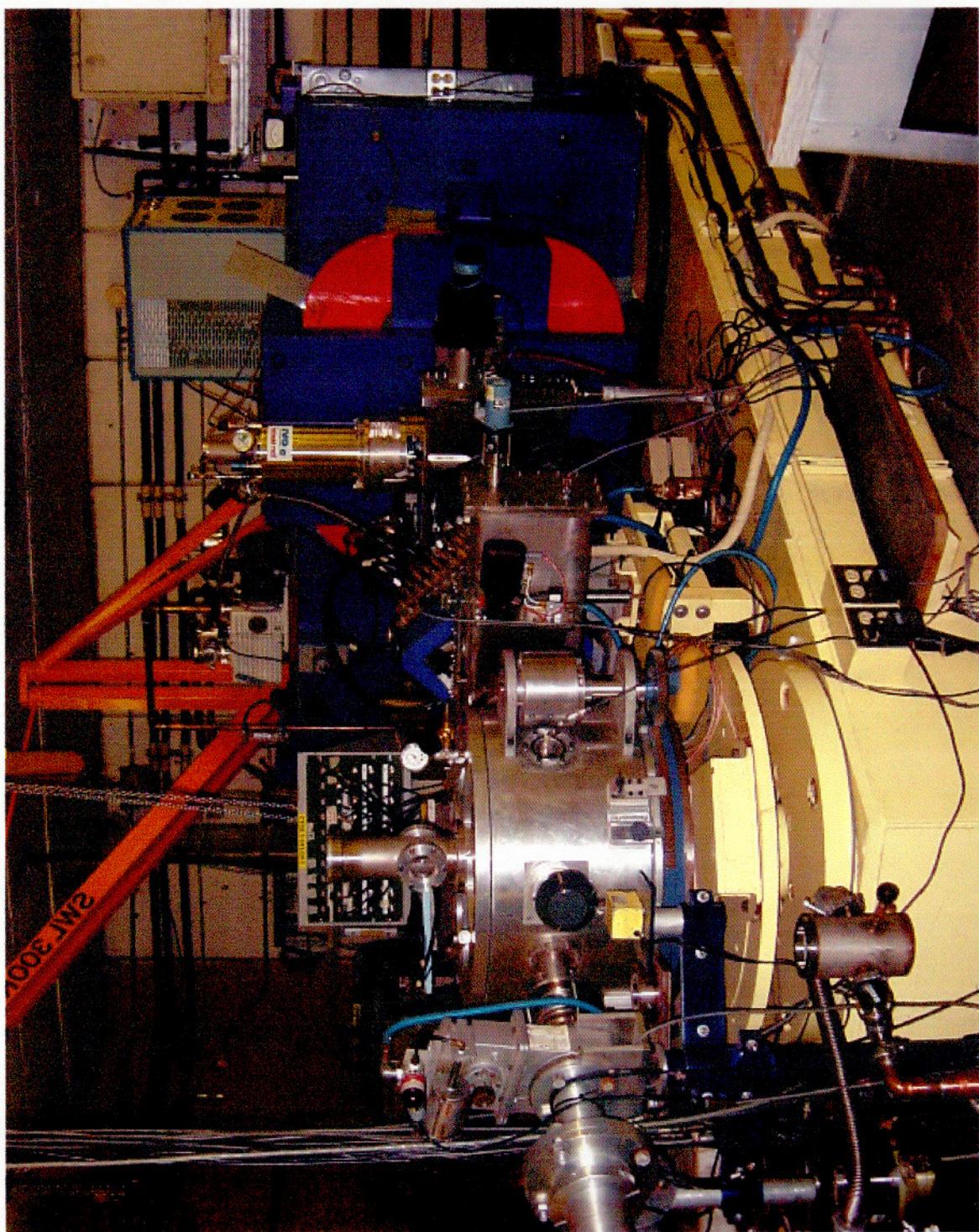
Beam analysis System (BAS) – to obtain high resolution and very clean beam from the cyclotron

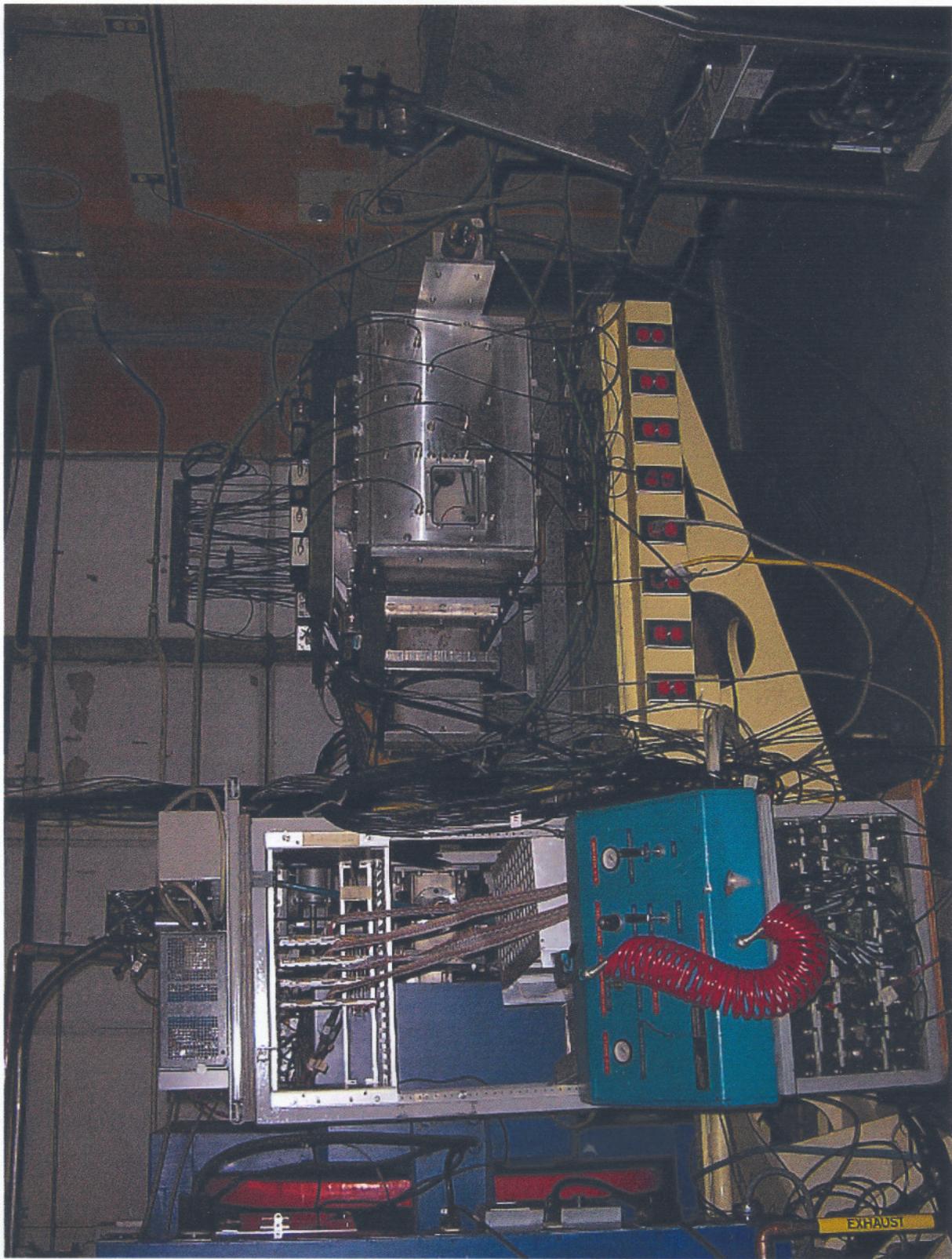
Broad Range Spectrometer (MDM) – multipole-dipole-multipole, able to measure large range of excitation region (60MeV).

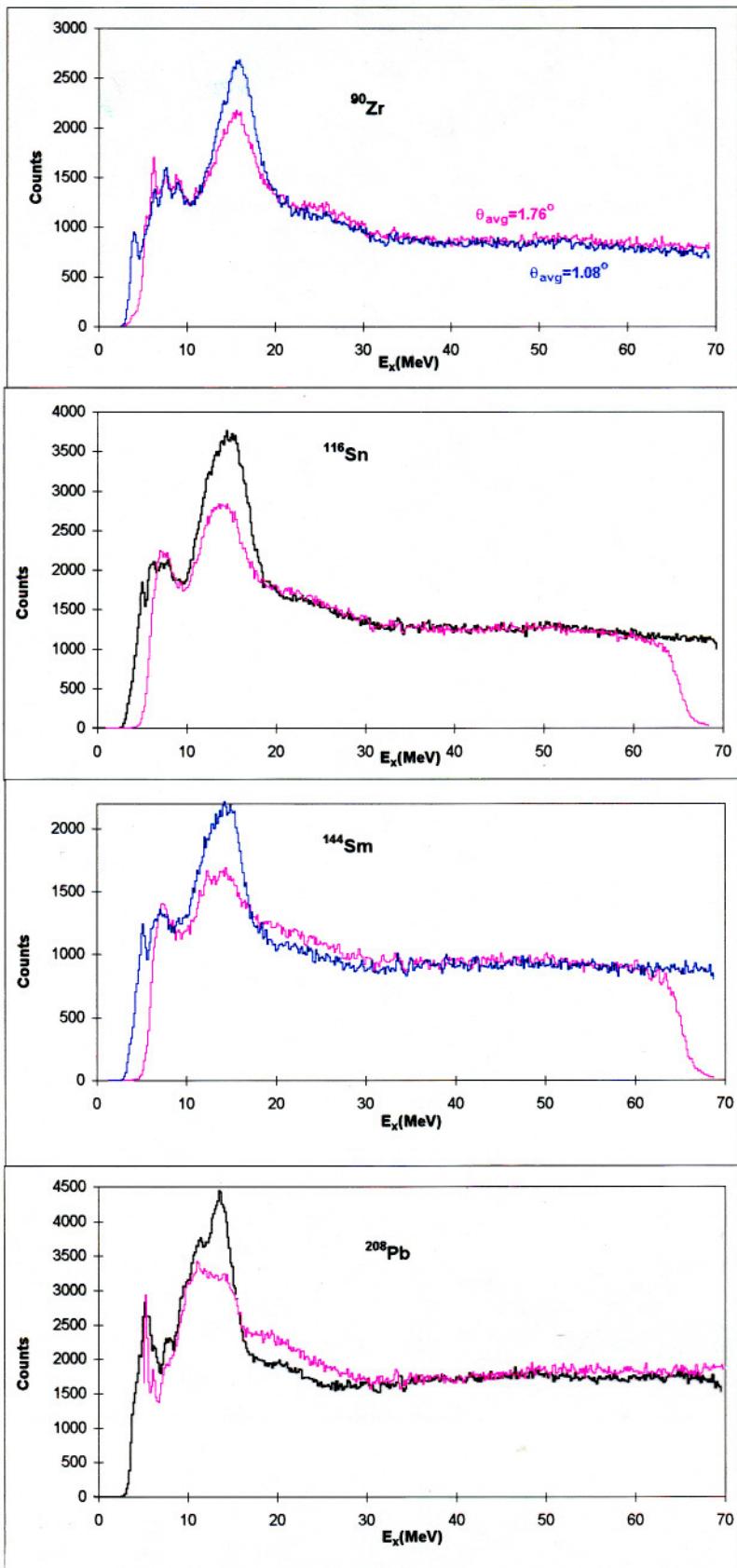
Raytrace Detector – high resolution, able to measure both θ (horizontal) and ϕ (vertical).

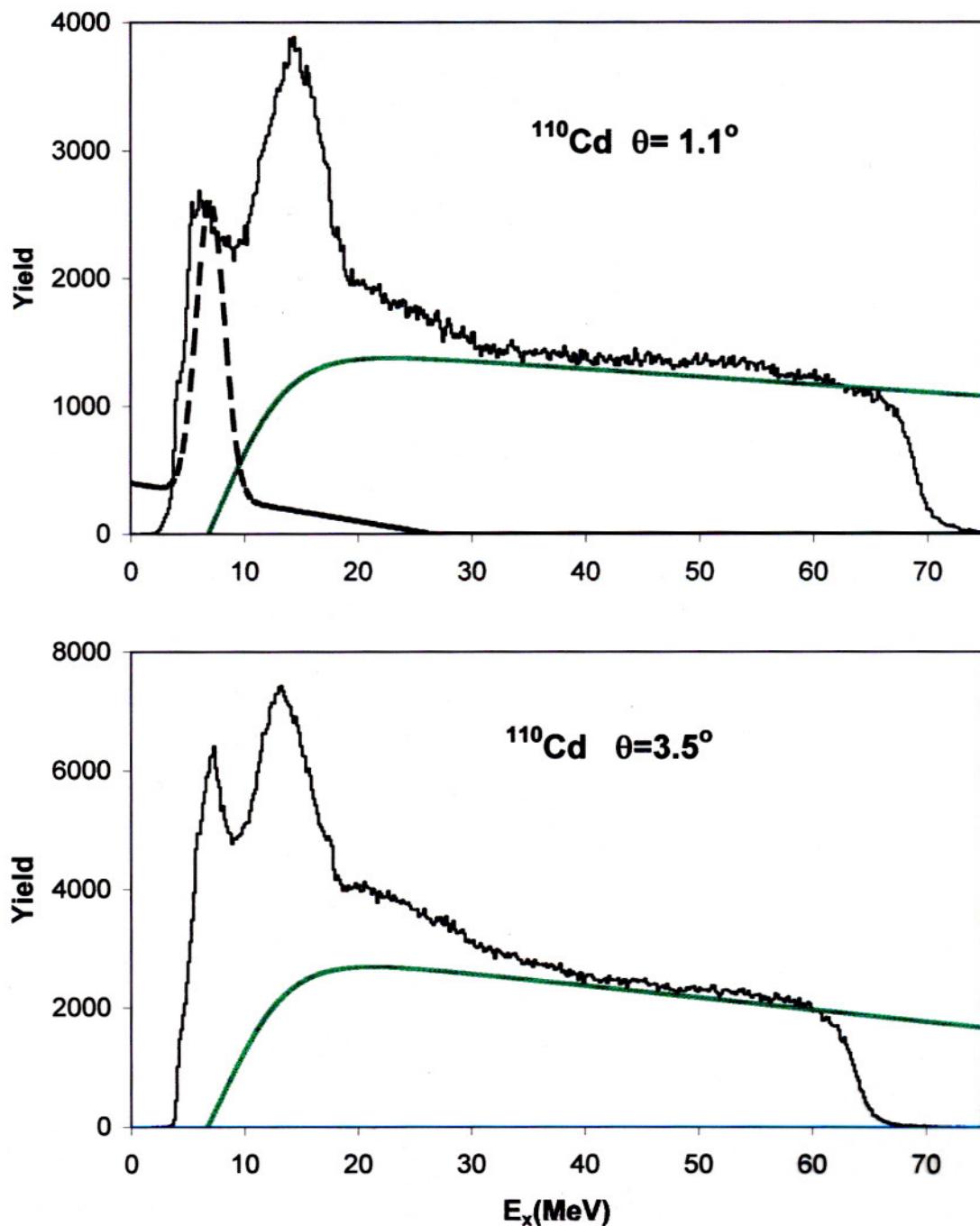


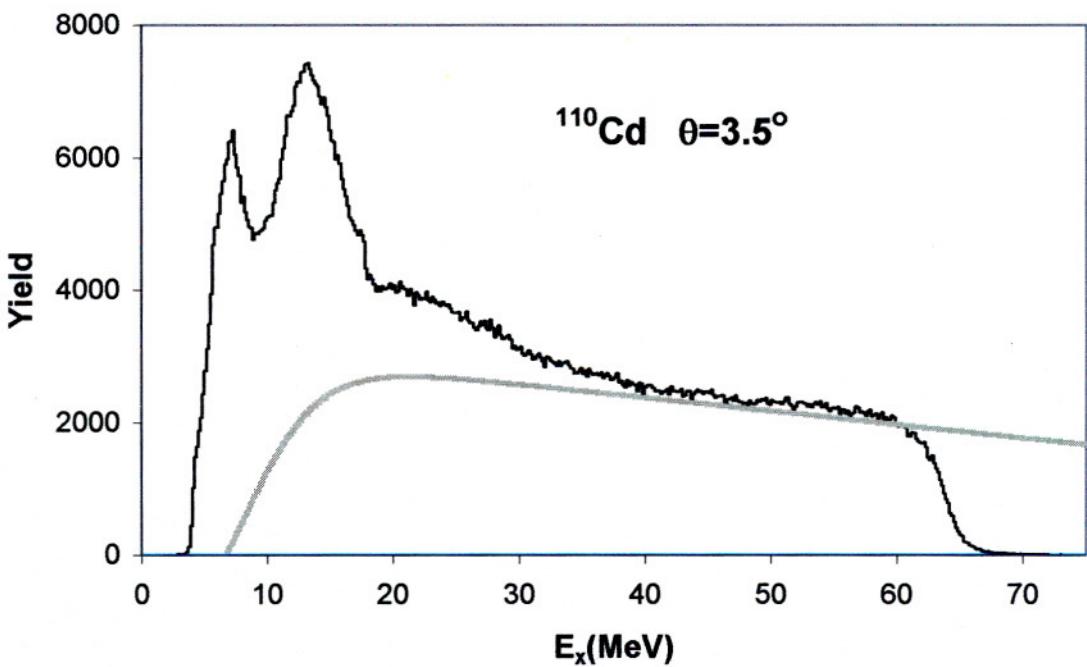
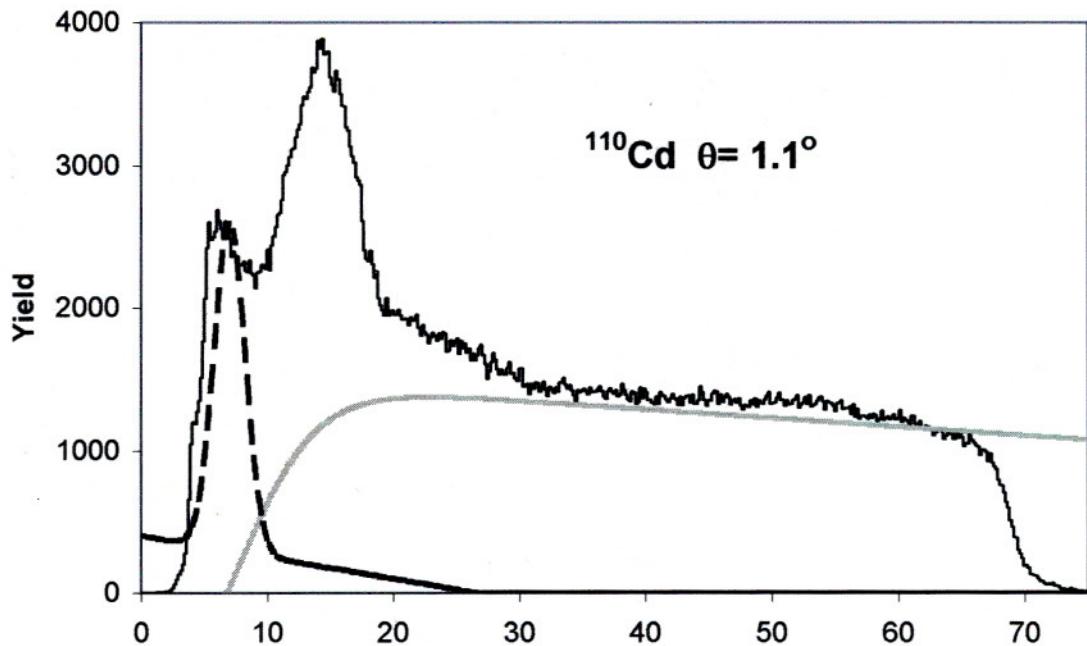




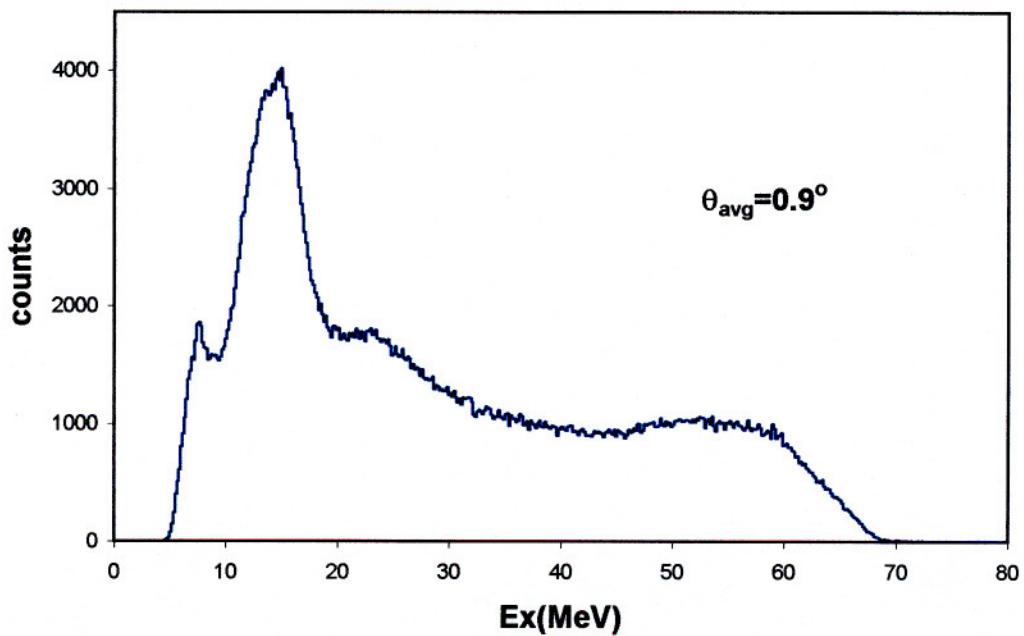
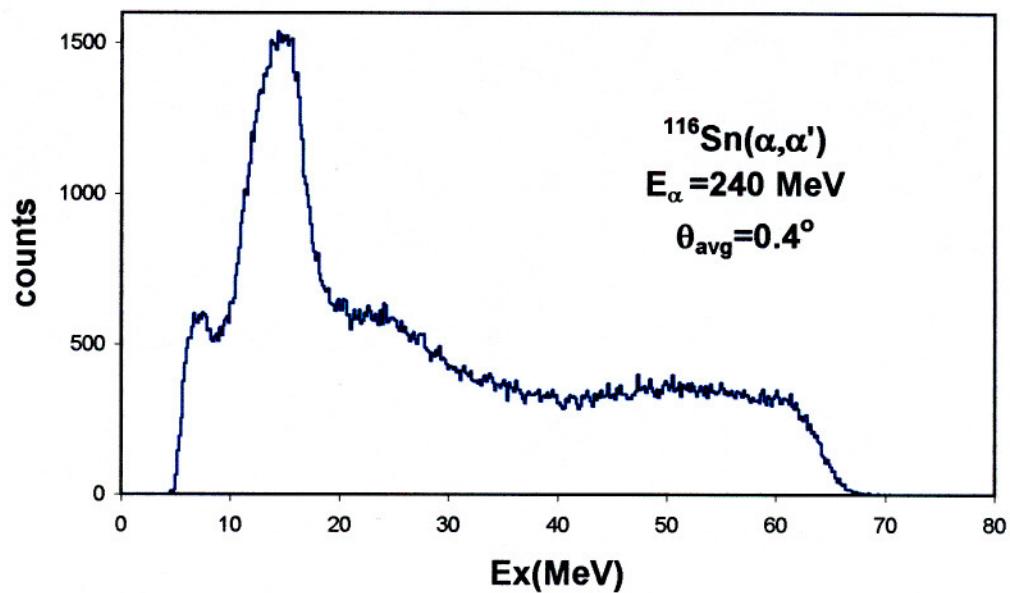


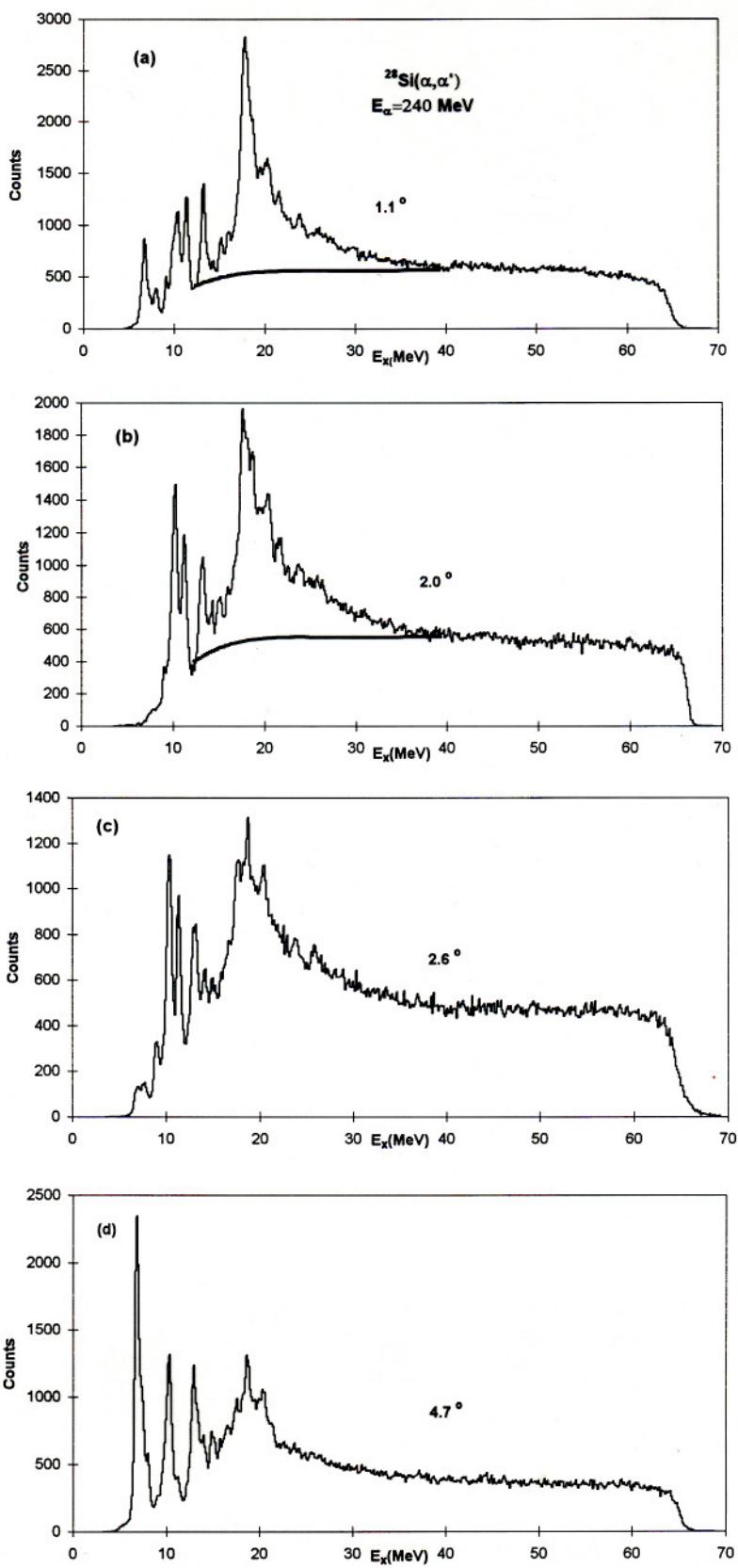






TAMU-2003





Analysis

Techniques

Slice analysis (multipole decomposition)

All multipoles ($L = 0$ to 4)

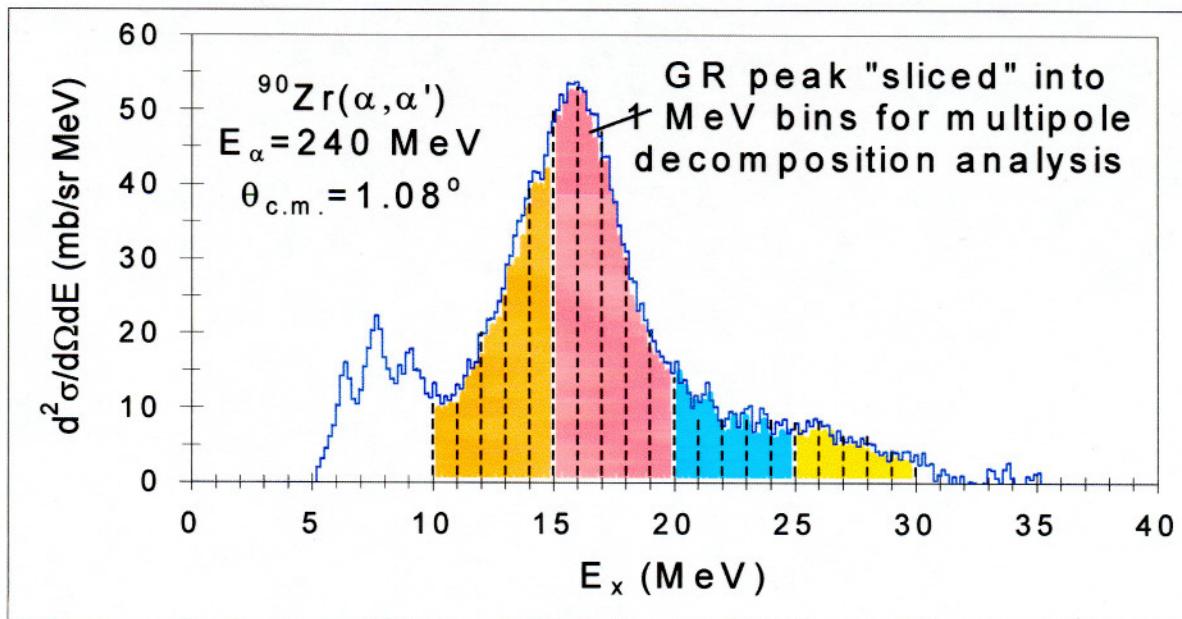
The multipole components of the giant resonance peak were obtained by dividing the peak into multiple regions (bins) by excitation energy and then comparing the angular distributions obtained for each of these bins to DWBA calculations.

The same analysis applied to the continuum, but only the $L=0$ components was included to the total strength.

The resolution of the bins varied from 150 keV to several MeVs.

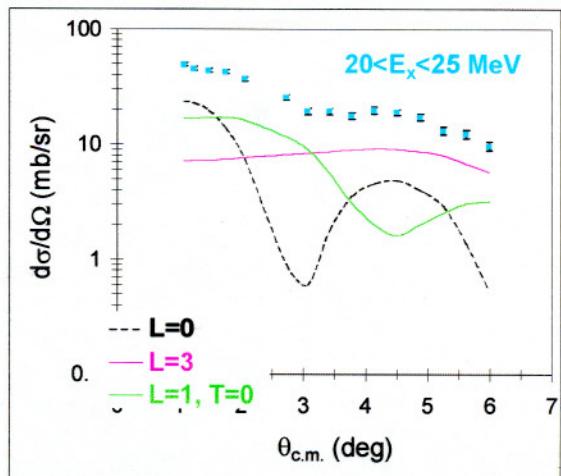
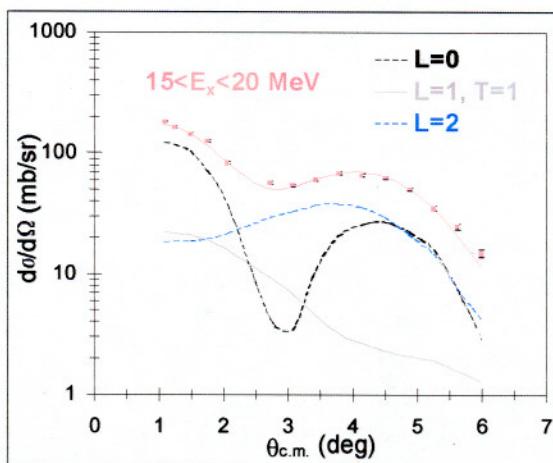
New: Choose a continuum and subtract it.

Divide the remaining peak AND the continuum into 1 MeV wide bins.



Fit the resulting angular distributions with a sum of isoscalar E0, E1, E2, E3 and E4 strength.

Include the known isovector E1 strength.



Because of the strong FORWARD PEAKING of the E0 angular distribution can identify the E0 strength in the peak AND in the "continuum".

Actual E0 strength distribution up to $E_x \approx 40 \text{ MeV}$.

No particular shape is assumed!

E0 strength obtained is independent of continuum choice.

DWBA Calculations - extract % EWSR

Folding calculations

Density dependent gaussian with Woods-Saxon imaginary term (Khoa and Satchler)

The folding model approach to the potentials is more basic and provides a direct and unambiguous link between the potentials and the underlying nuclear densities.

In this approach, the potentials are generated by folding an effective nucleon-nucleon interaction over the density distributions of the target and projectile.

The results from this approach can be very different to those obtained from the deformed potential model.

In our calculations, we use a hybrid folding model, in which

real potential : density dependent, single folding with Gaussian shape.

$$\begin{aligned}\overline{v_G}(s) &= -\nu \exp(-s^2/t^2), s = |\vec{r} - \vec{r}'| \\ \overline{v_{DDG}}(s, \rho) &= \overline{v_G}(s)f(\rho), f(\rho) = 1 - \alpha(1 + \beta)\rho(r')^\beta\end{aligned}$$

imaginary potential : Woods-Saxon shape

$$\text{Im } U(r) = -W/(e^x + 1), x = (r - R_w)/a_w$$

This model was used successfully to analyze the 240 MeV α data on ^{58}Ni as an initial test case by G. R. Satchler.
G. R. Satchler and Dao T. Khoa, Phys. Rev. C 55, 285(1997)

Single folding : average the interaction over the density distribution of the α particle.

use the same radial shape for both real and imaginary potentials, this results too strong absorption in the interior.

set imaginary potential to Woods-Saxon shape.

Density dependent : the strength of real interaction required To fit small angle scattering is too deep in the interior to reproduce correctly the rainbow features at large angle.

making interaction between α particle and target nucleon depend upon the density of the nuclear matter.

reduce the strength of the interaction as the density increasing, weakening the folded potential in the interior while leaving the peripheral values largely unchanged.

Gaussian shape : good fit to elastic data.

Transition density

$$g_0(r) = -\alpha_0'' \left[3\rho_t(r) + r \frac{d\rho_t(r)}{dr} \right] \quad \text{for GMR}$$

$$g_l^{BM}(r) = -\delta_l''' \frac{d\rho_t(r)}{dr} \quad \text{for } l \geq 2$$

$\rho_t(r)$ is the ground-state density of the nucleus

δ_l''' is the corresponding matter deformation length

G. R. Satchler, Nucl. Phys. A472, 215(1987).

$$g_1(r) = -\frac{\beta_1}{R} \left[3r^2 \frac{d}{dr} + 10r - \frac{5}{3} \langle r^2 \rangle \frac{d}{dr} + \varepsilon \left(r \frac{d^2}{dr^2} + 4 \frac{d}{dr} \right) \right] \rho_t \quad \text{for ISGDR}$$

$$\varepsilon = \left(\frac{4}{E_2} + \frac{5}{E_0} \right) \frac{\hbar}{3mA}$$

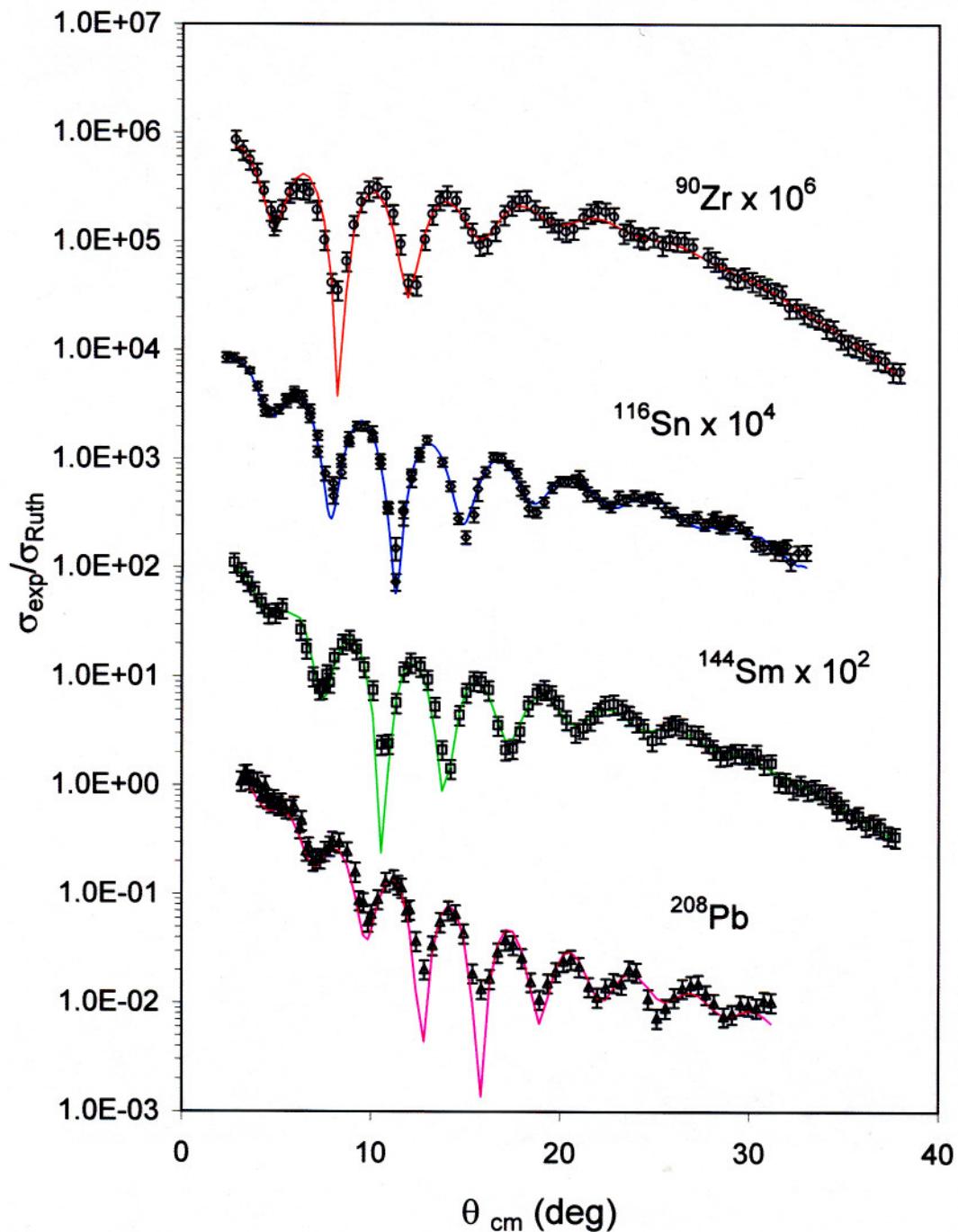
where E2 and E0 are quadrupole and monopole energies.

M. N. Harakeh and A. E. L. Dieperink, Phys. Rev. C 23, 2329(1981).

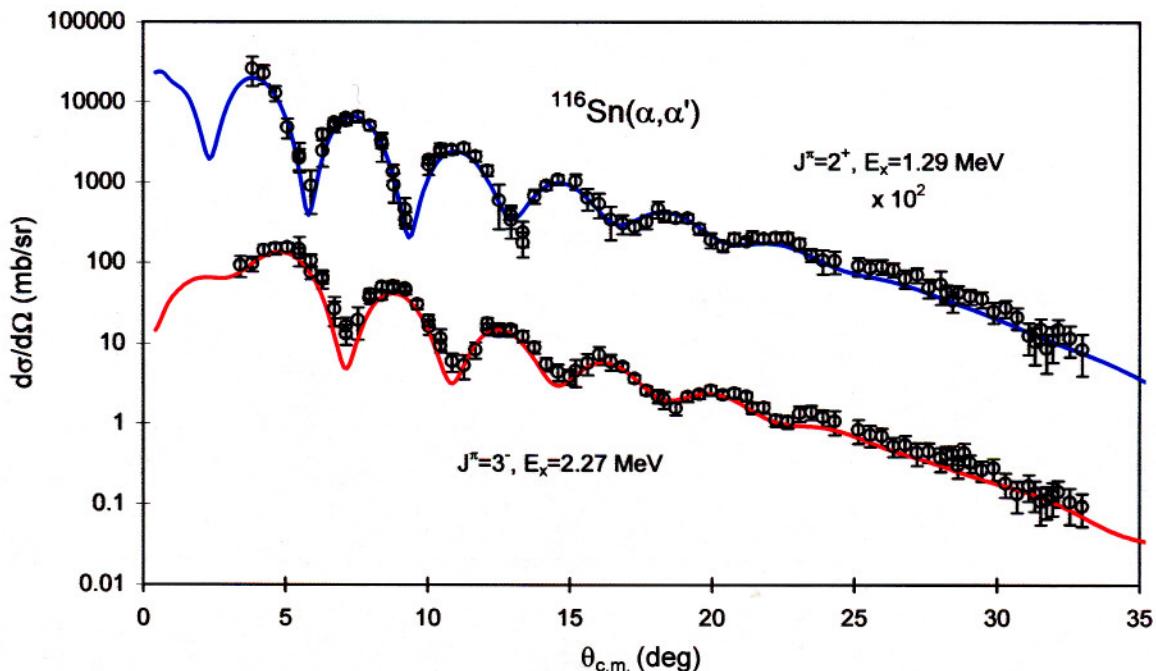
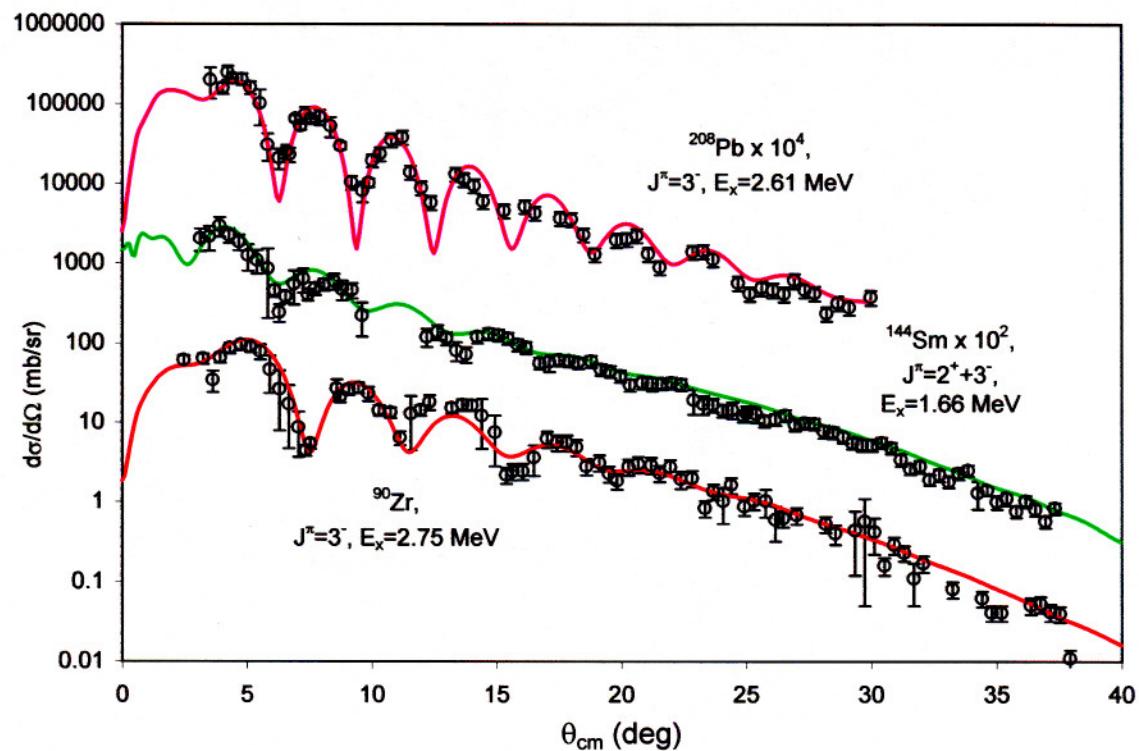
Folding model analysis of 240 MeV alpha scattering

$$U(r') = -v \int \rho(r') f(\rho) \exp(-s^2/t^2) d\tau - \nu W / (1 + \exp(r - R_w)/a_w)$$

where: $f(\rho) = 1 - \alpha \rho(r')^\beta$, $\alpha = 1.9 \text{ fm}^2$, $t = 1.88 \text{ fm}$ and $\beta = 2/3$



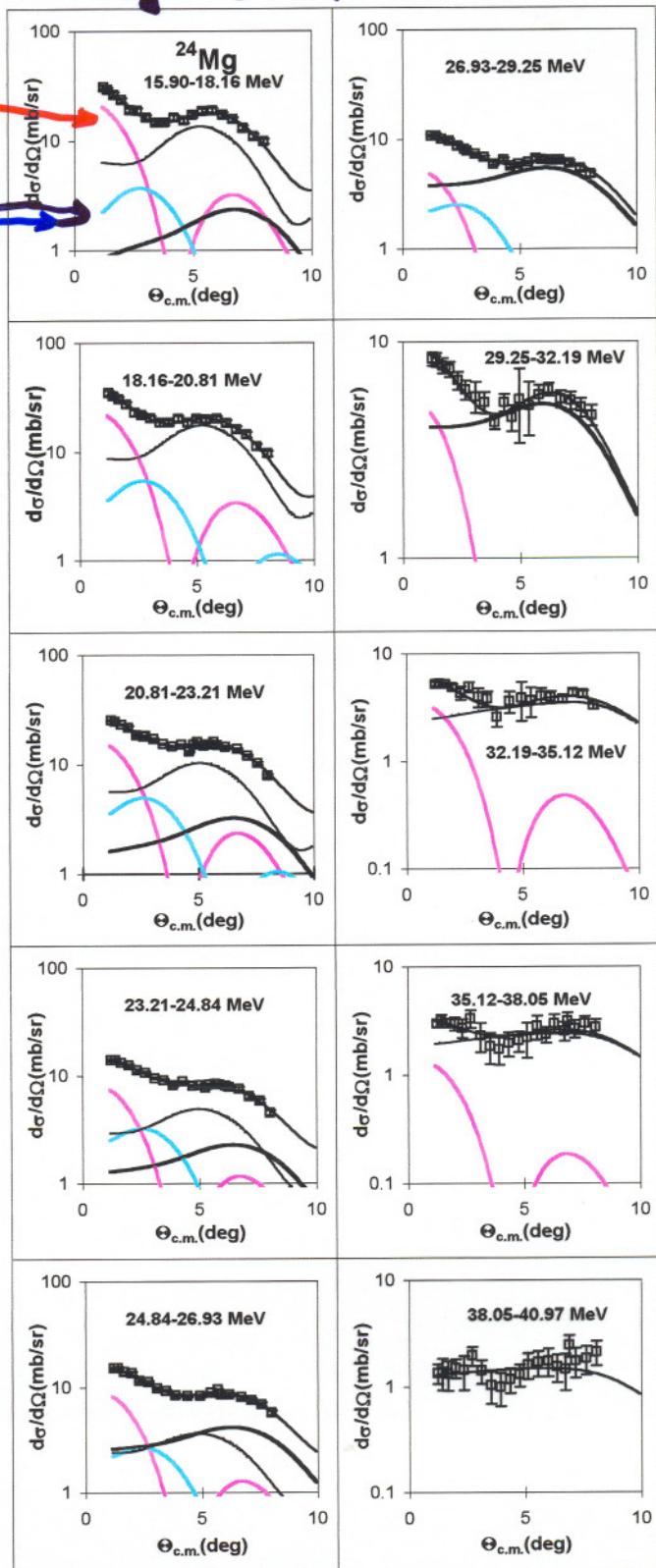
Folding model analysis of low-lying states:
 Calculations made using "electromagnetic values" for $B(E\gamma)$

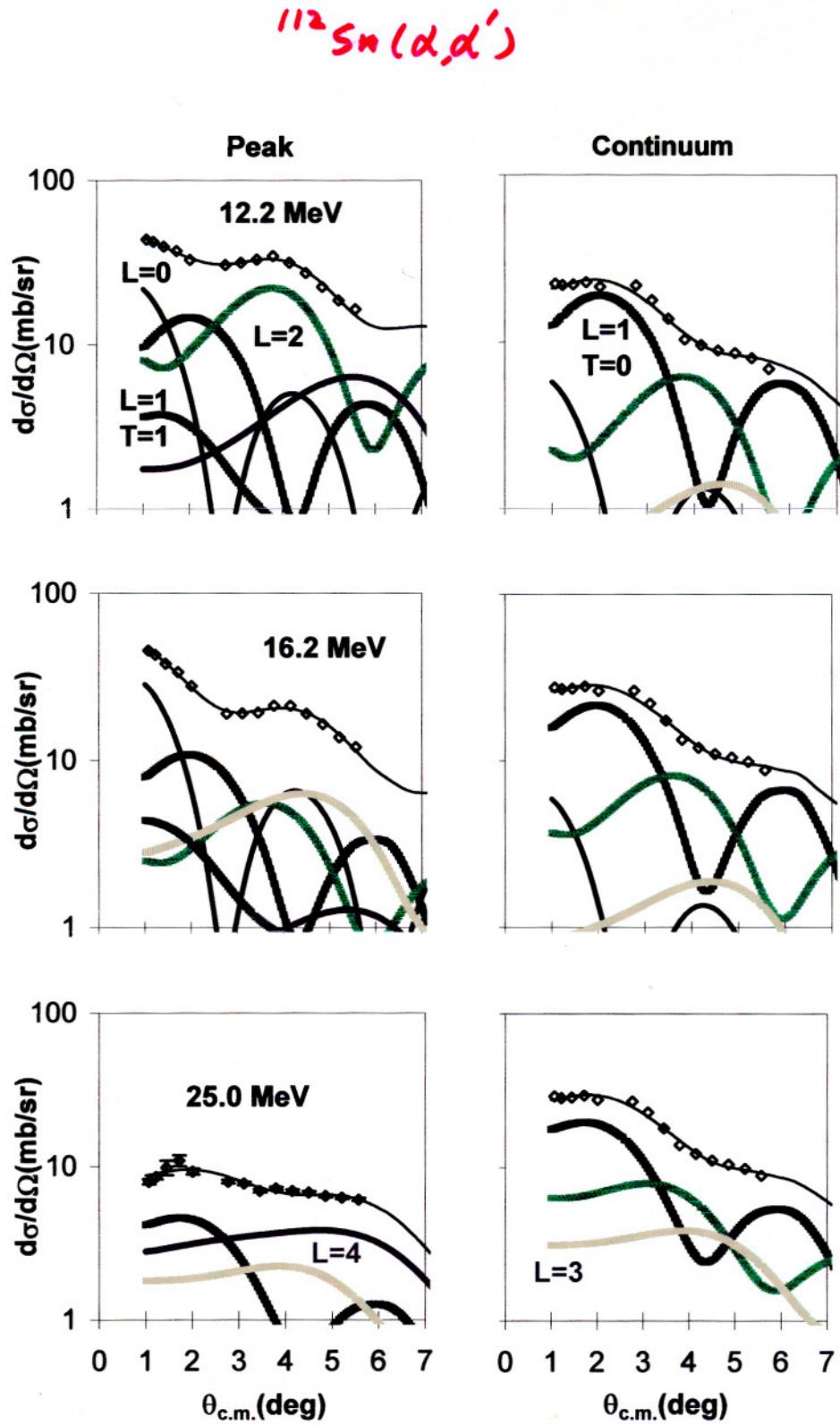


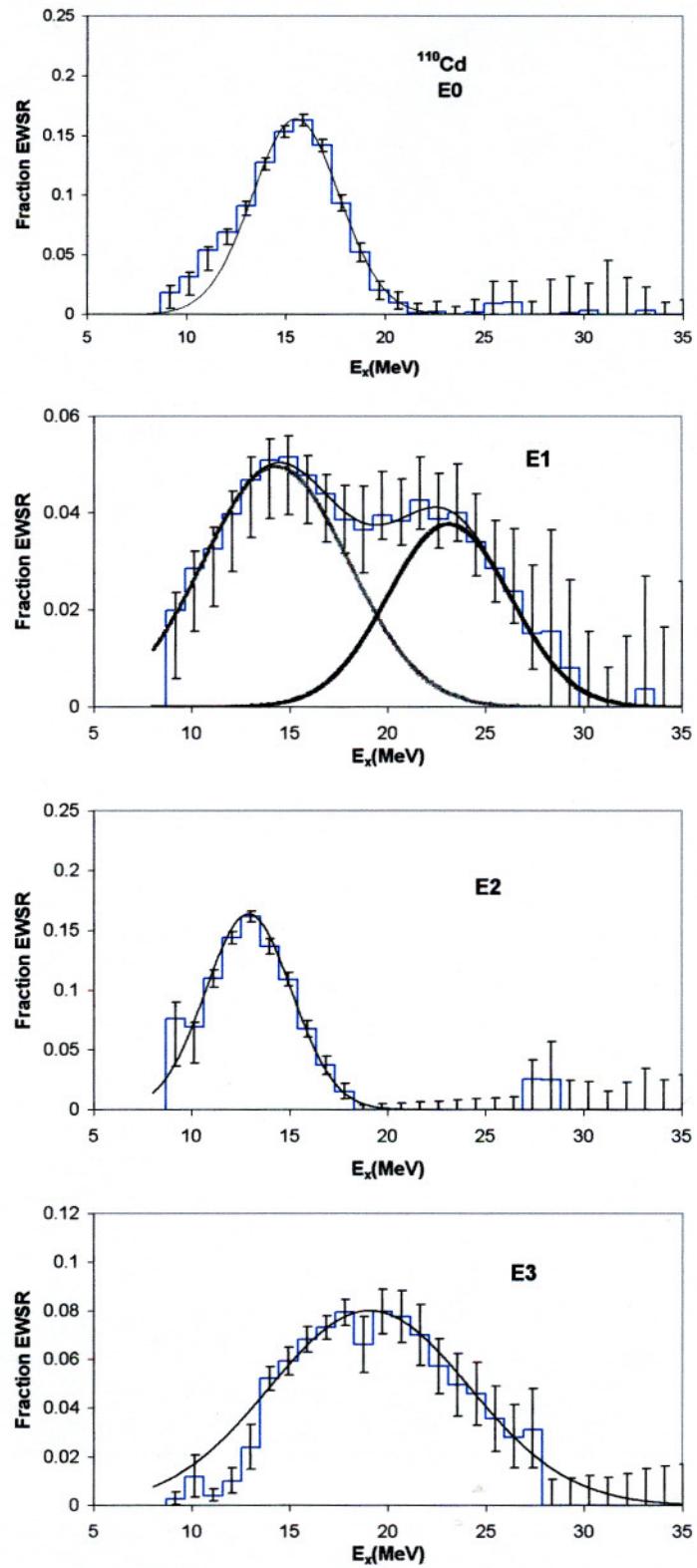
Slice Analysis - ^{24}Mg GR peak

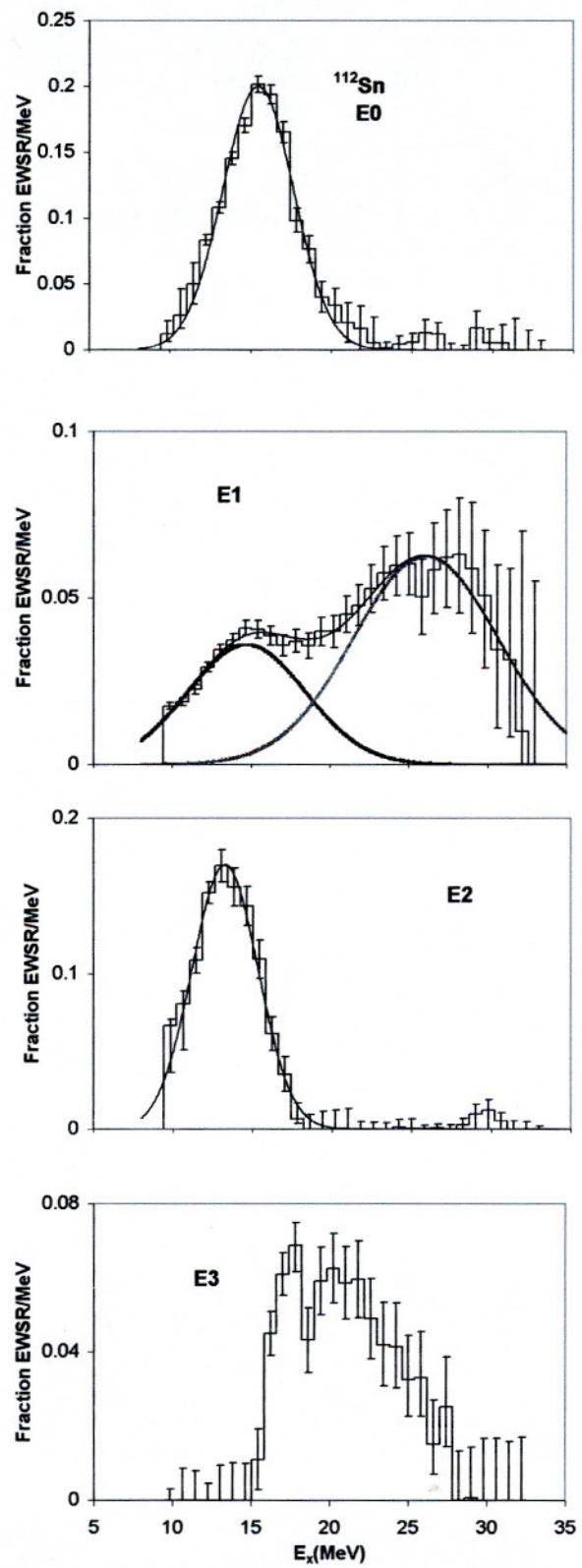
$L = \emptyset$

$T=0$ $t=1$

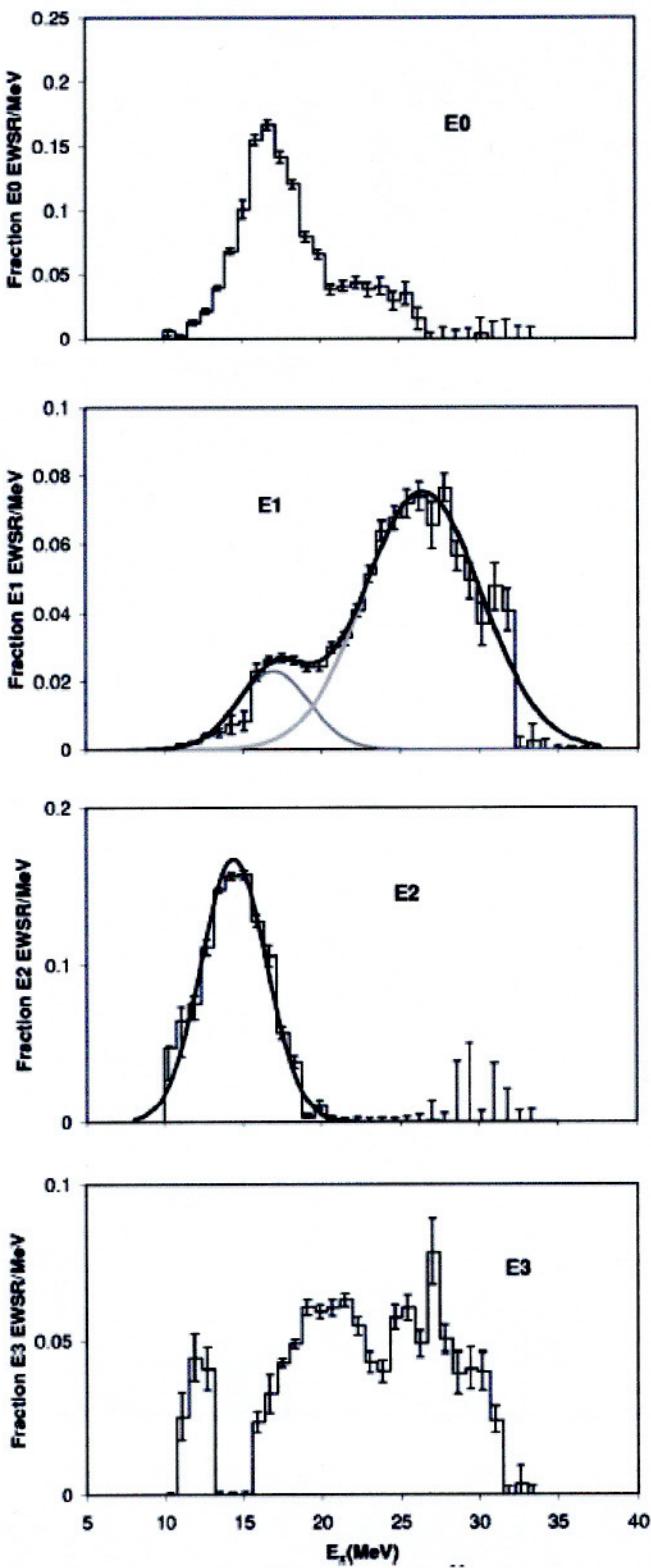


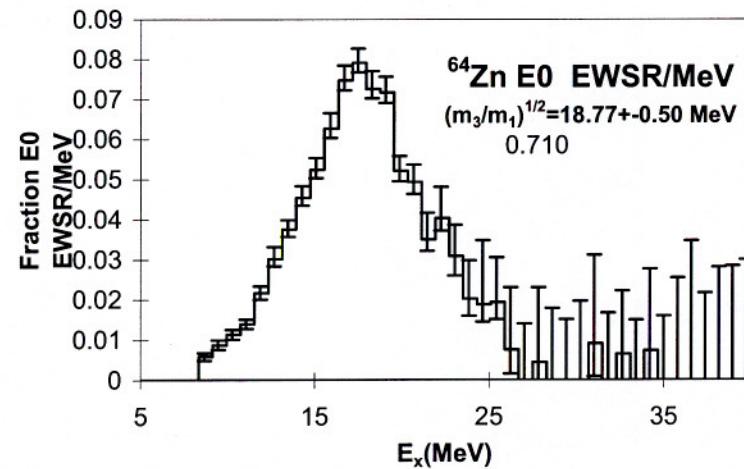
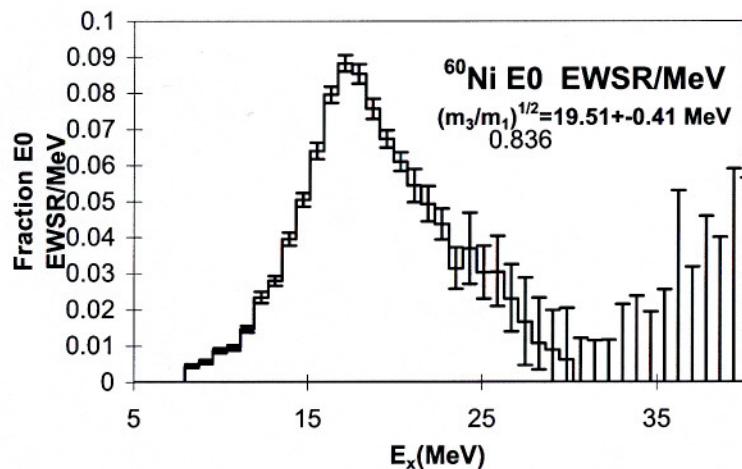
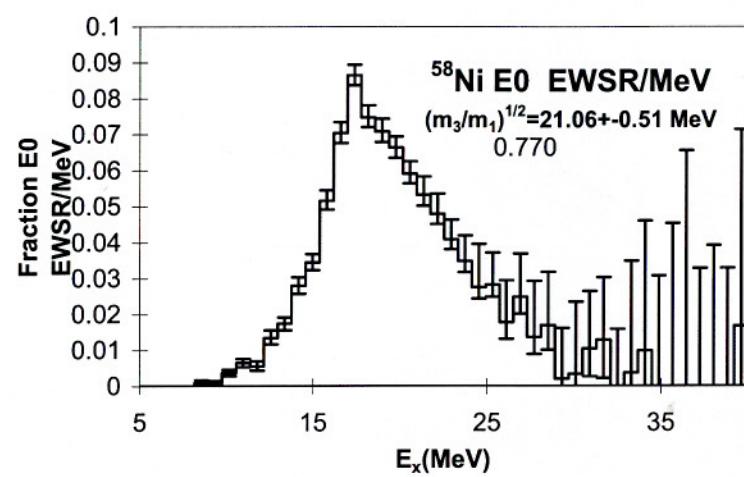
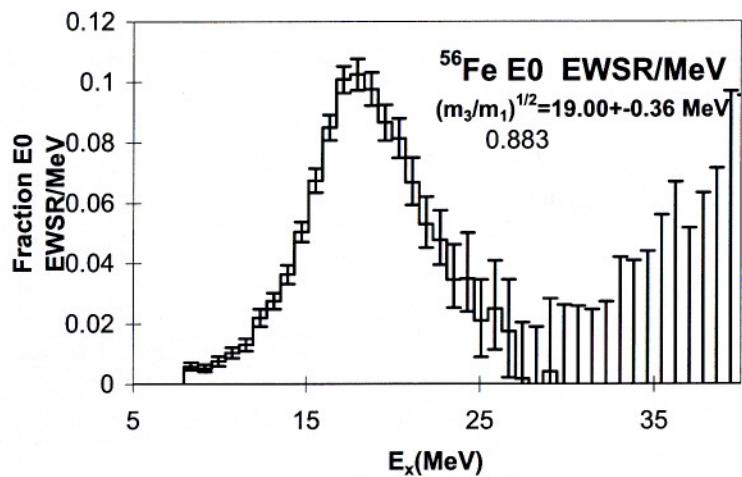


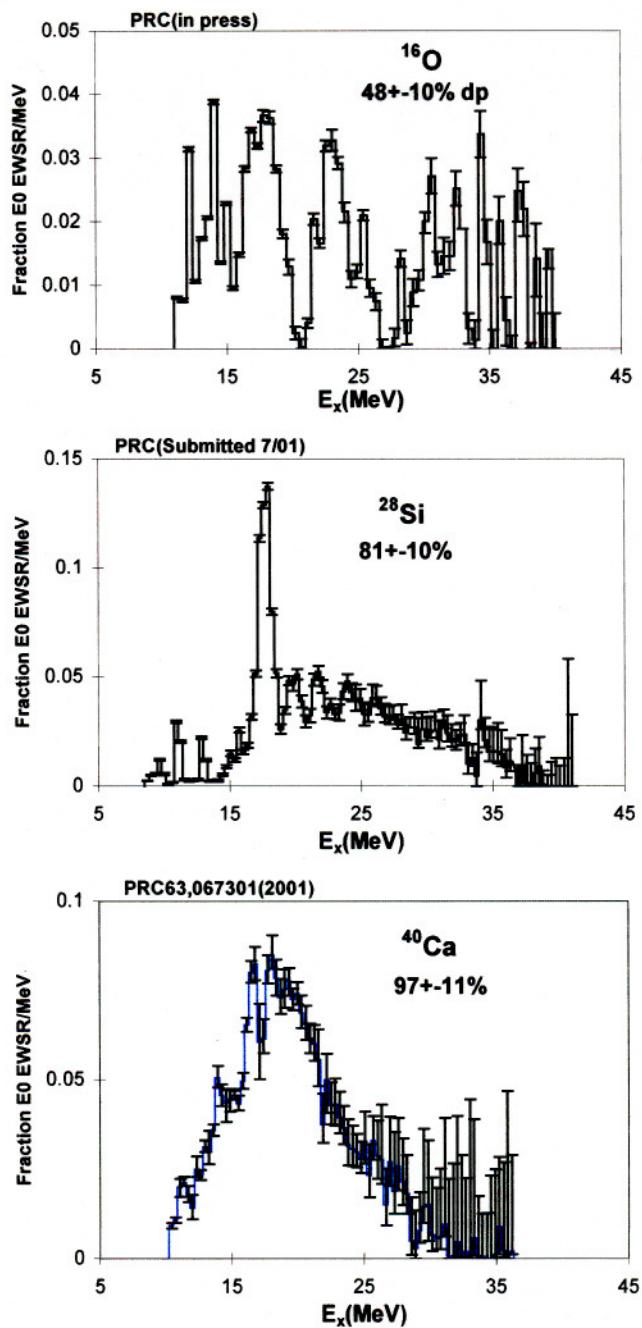


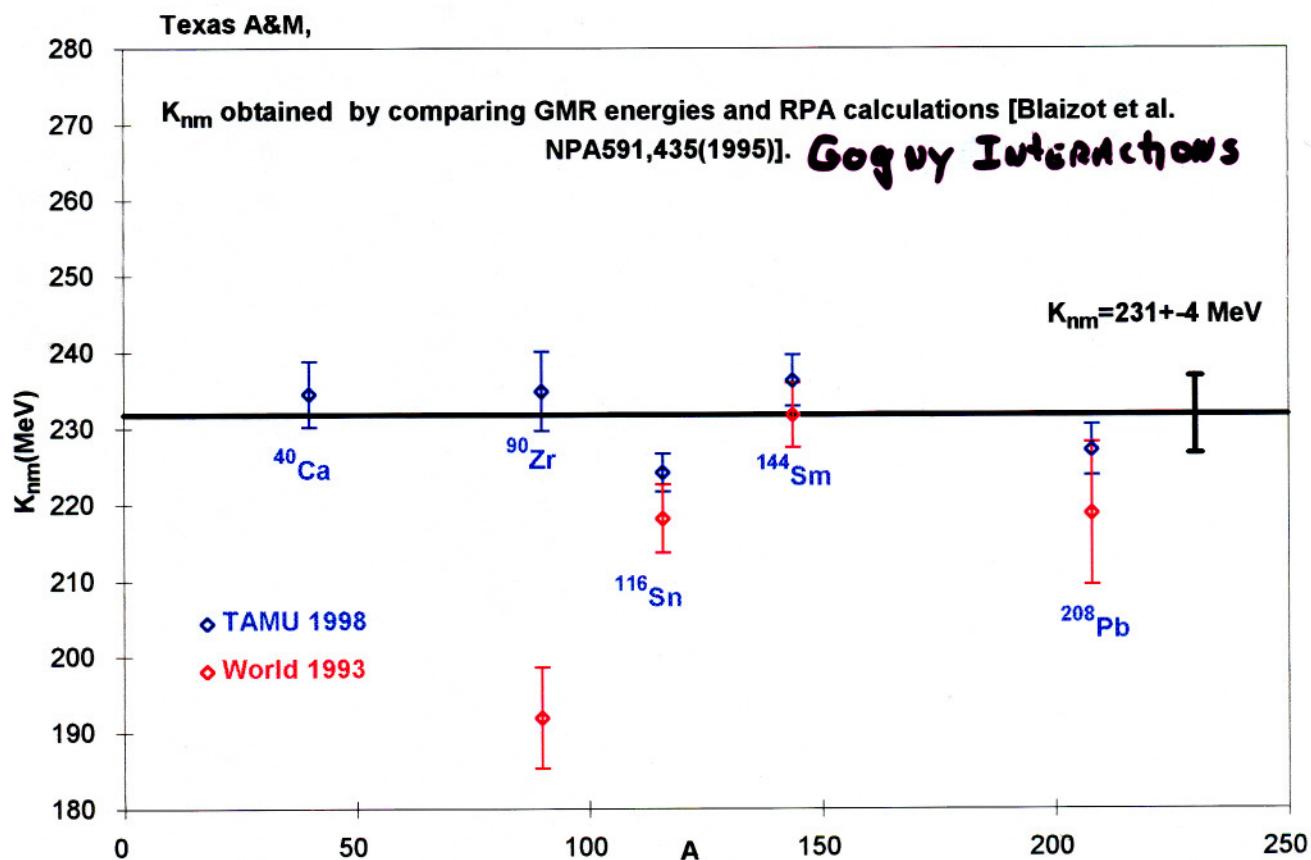


^{90}Zr









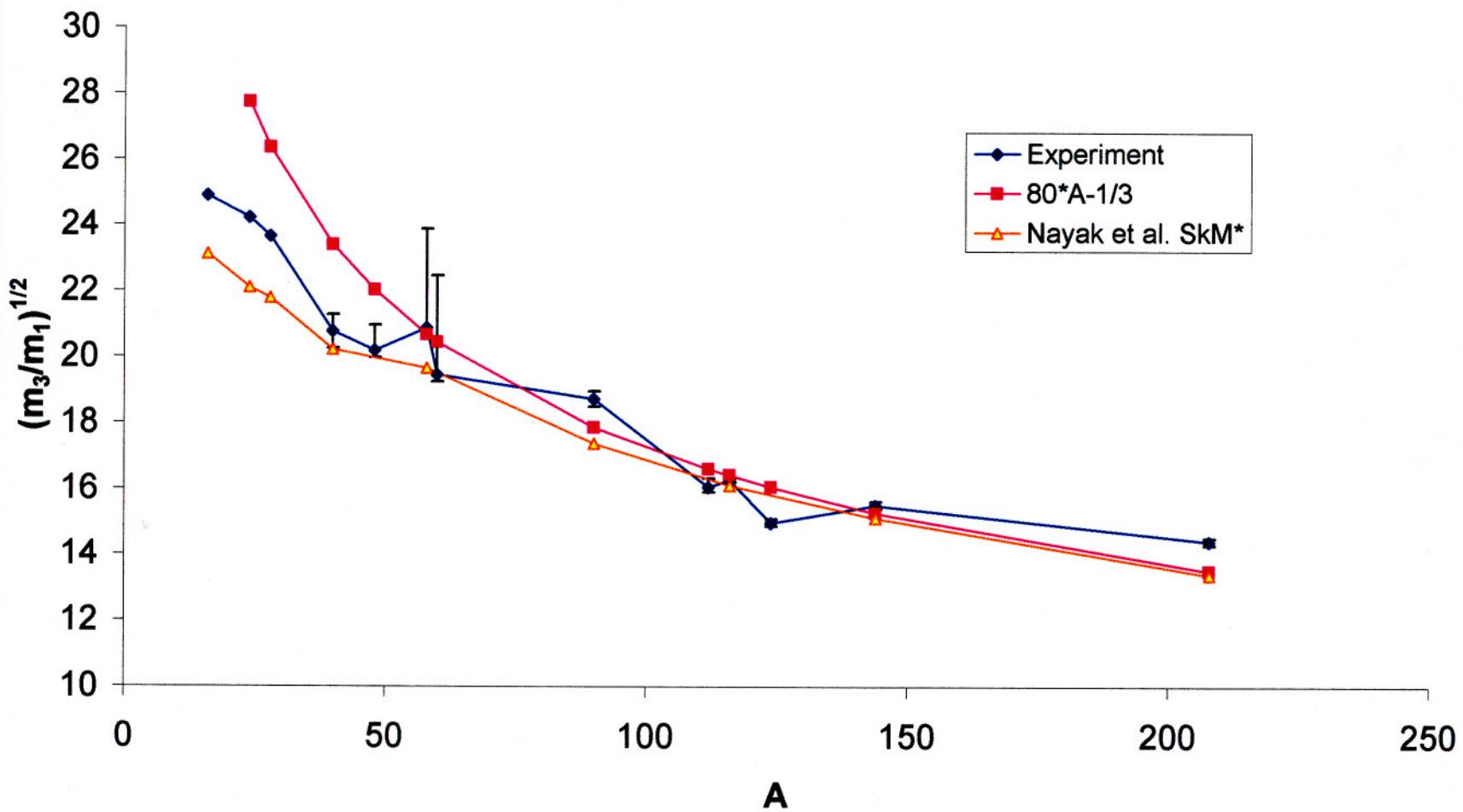
PRL 82, 691 (1999)

K_A can be expanded in volume, surface, symmetry, coulomb and higher order contributions in the following

$$K_A = K_{vol} + K_{surf} A^{-1/3} + K_{sys} \left(\frac{N-Z}{A}\right)^2 + K_{coul} \frac{Z^2}{A^{4/3}} + \dots$$

Rely on microscopic calculations to provide consistent determination of monopole energy and the nuclear matter parameters.

Giant Monopole Energies Using (α, α') at 240 MeV



Nayak et al. Nucl. Phys. A516, 62 (1990).

Within the framework of the scaling model, four different Skyrme-type forces, using extended Thomas-Fermi (ETF) approximation.

SkM* ($K_{nm}=217$ MeV), RATP ($K_{nm}=240$ MeV)

Michel Farine, J. M. Pearson, F. Tondeur, Nucl. Phys. A615, 135 (1997).

Generalized Skyrme-type forces with a term that is both density- and momentum-dependent. Semiclassical with corrections (no RPA). Fit E_{GMR} .

$K_{nm} \approx 215 \pm 15$ MeV

T. v. Chossy and W. Stocker, Phys. Rev. C 56, 135 (1997).

Parameter sets in nuclear relativistic mean-field theory.

$K_{nm} < 230$ MeV

35

$$K_A = K_V + K_{sf} A^{-1/3} + K_{vs} [(N-Z)/A]^2 + K_{Coul} Z^2 A^{-4/3} + \text{small term}$$

R. C. Nayak *et al.*, Nucl. Phys. A516, 62 (1990)

T. v. Chossy and W. Stoker, Phys. Rev. C 56, 2518 (1997)

30

25

20

15

10

E_{GMR} (MeV)

0

50

100

150

200

250

300

A

• EXP

— 80A^{-1/3}

— Nayak_SkM* (KV=216.6)

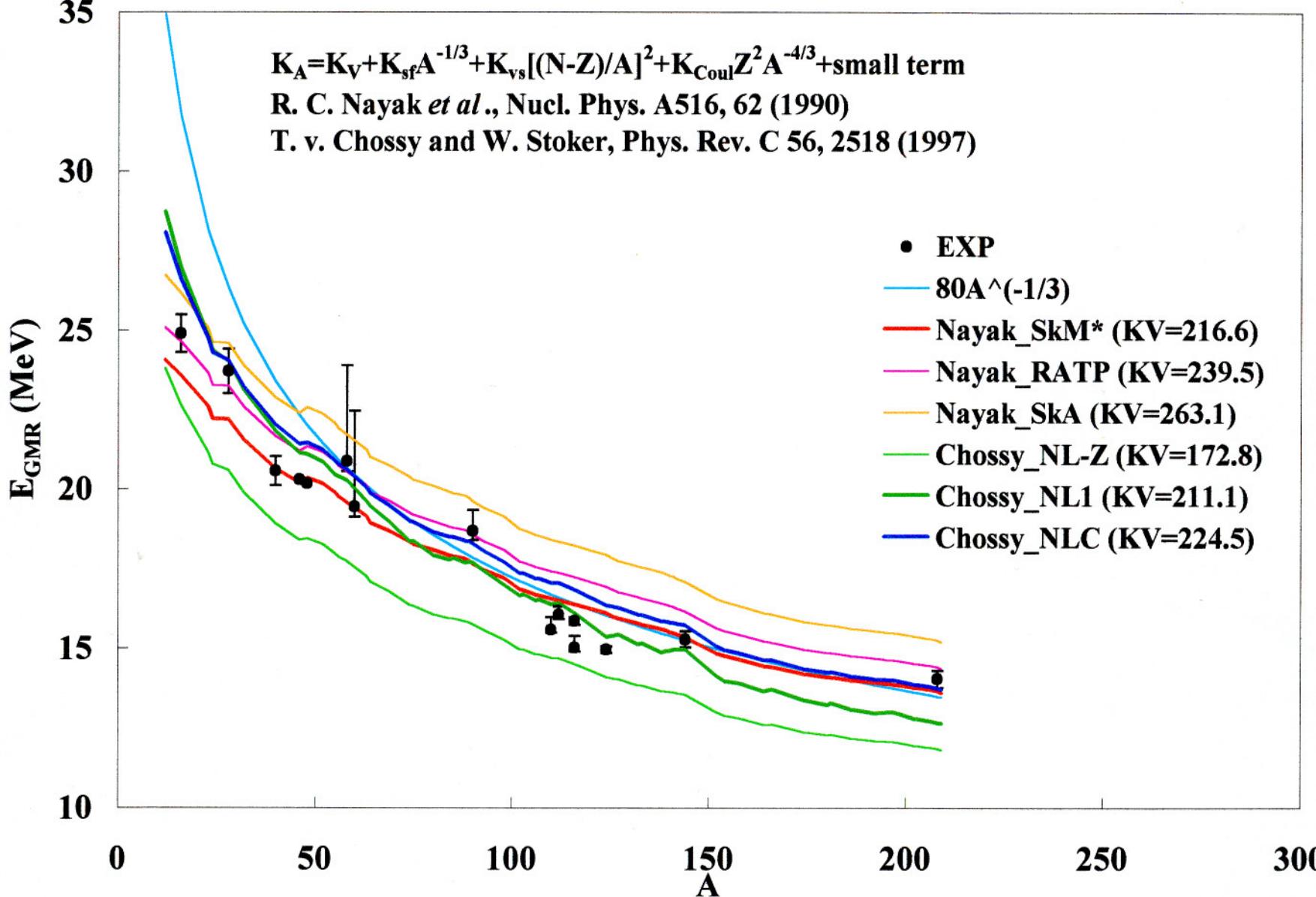
— Nayak_RATP (KV=239.5)

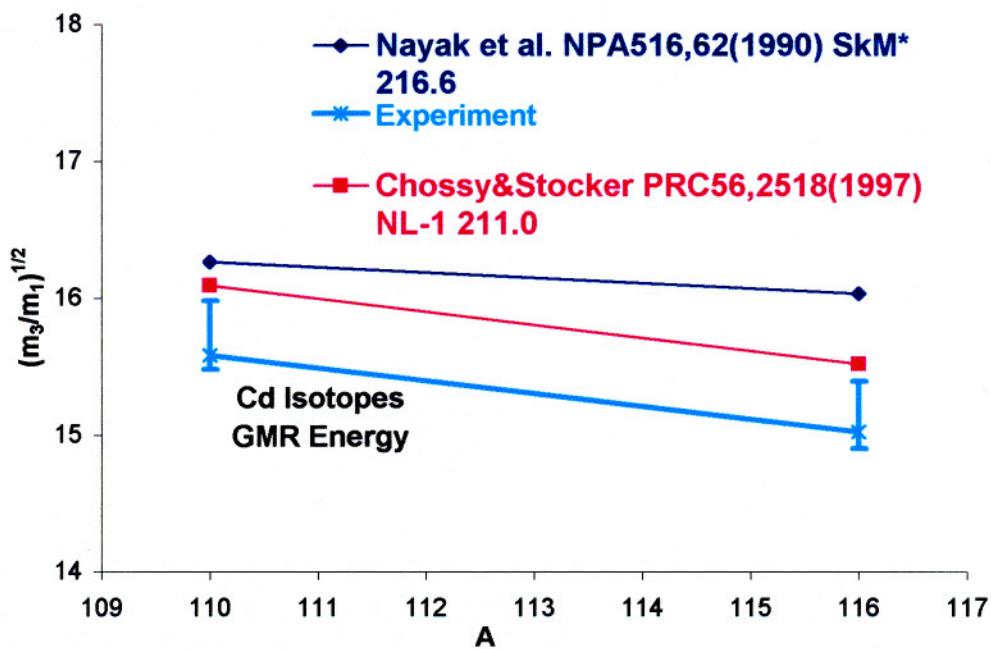
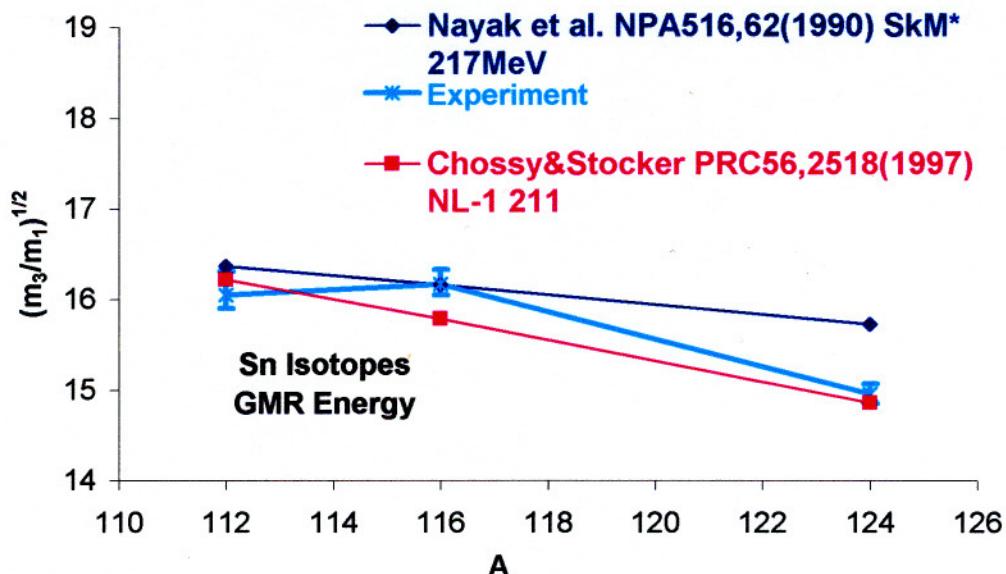
— Nayak_SkA (KV=263.1)

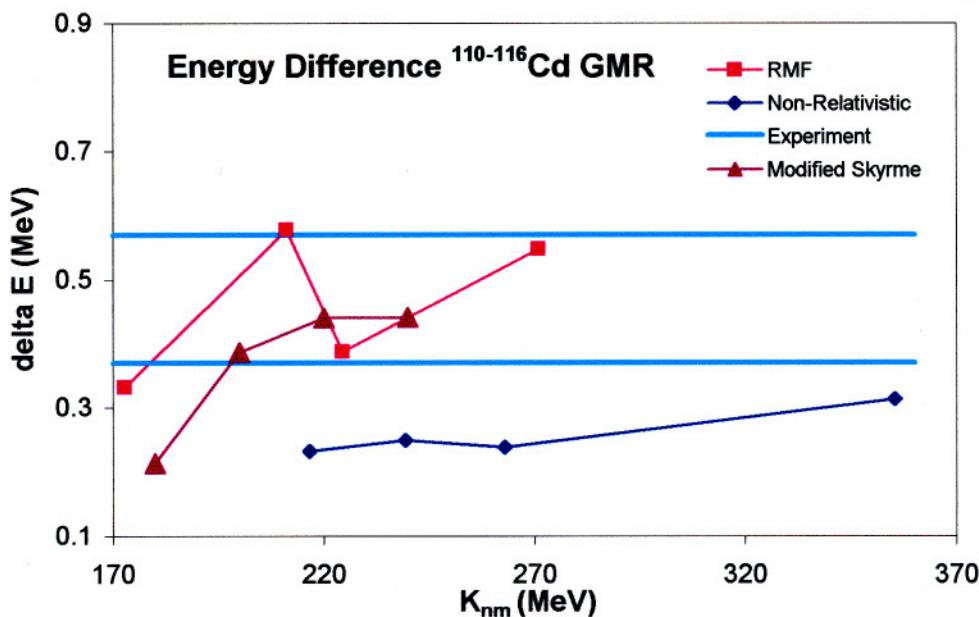
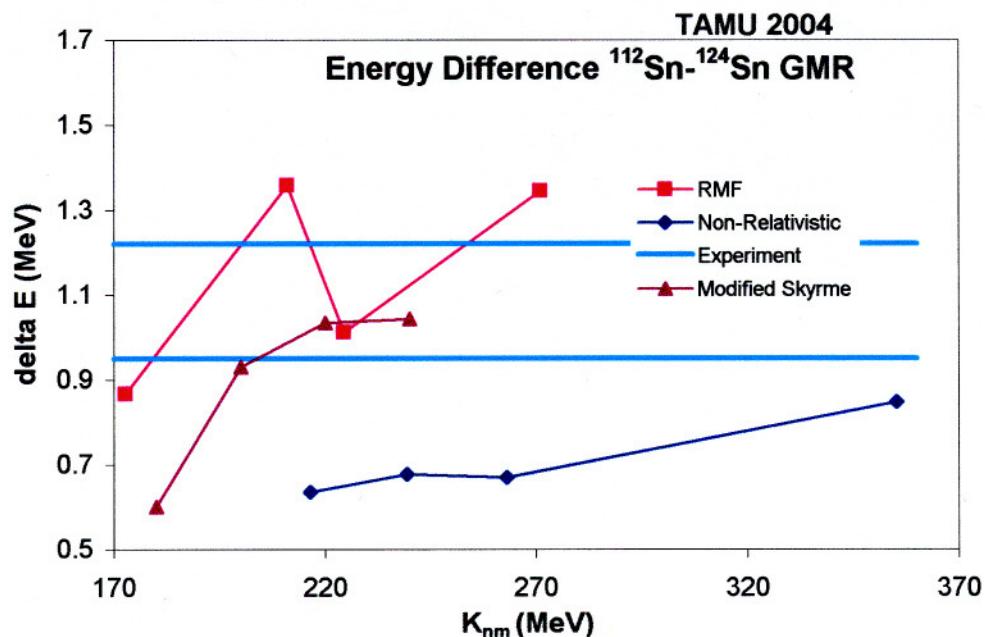
— Chossy_NL-Z (KV=172.8)

— Chossy_NL1 (KV=211.1)

— Chossy_NLC (KV=224.5)







In the past few years, high precision experimental data on giant resonances have been obtained from ^{12}C to ^{208}Pb using 240 MeV α particles from the Texas A&M K500 superconducting cyclotron.

- .100% E0 EWSR in heavy nuclei such as ^{90}Zr , ^{116}Sn , ^{144}Sm and ^{208}Pb have been found.
- .In light nuclei, nearly 100% E0 EWSR in ^{40}Ca , ^{28}Si and ^{24}Mg , and 50% E0 EWSR in ^{16}O have been located.
- .Using ^{208}Pb , ^{144}Sm , ^{116}Sn , ^{90}Zr and ^{40}Ca data a nuclear matter compressibility of 231 ± 5 MeV is obtained by comparing microscopic calculations using Gogny interaction.
- .Mass dependence using Leptodermous expansion.
- .Study the symmetry effect by measuring Cd and Sn.

Conclusions

- .In ^{112}Sn and ^{124}Sn , predictions using relativistic and non-relativistic (Skyrme or Skyrme-like) interactions with $K_{\text{nm}} \sim 221\text{-}216 \text{ MeV}$ result in energies consistent with the experimental energies.
- .In ^{110}Cd and ^{116}Cd , they are slightly above the experimental energies.
- .In more accurate energy difference between the E0 position in ^{112}Sn and ^{124}Sn is consistent with relativistic calculations for the NL-C parameter set ($K_{\text{nm}}=224.5 \text{ MeV}$) and with calculations using modified Skyrme interactions having $K_{\text{nm}}=220$ and 240 MeV .
- .Also it is true in energy difference between ^{110}Cd and ^{116}Cd .

**Using Leptodermous expansion to extract Nuclear
Matter Compressibility.**

High Risk !!

Need to be careful !!

Wrong!!

**What really needed is “REAL” Microscopic
Calculations for these Nuclei.**