Studies of shape phase diagrams of hot nuclei – GDR differential method

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Krakow

Plan of the talk

What **Why** **How**

- **Introduction:**

  Theoretical Guidance
  Experimental Observations

- The proposition:

  Differential technique
  Multiplicity measurements
  Some Case studies

- **Novel Detectors & Techniques:**

  Recent test results & Simulations

Collaborators

- *G. Anil Kumar*
- *D.A. Gothe*
- *H. C. Jain*
- *P. K. Joshi*
- *R. Palit*
- *M. Aggarwal*

Tata Institute of Fundamental Research, Mumbai

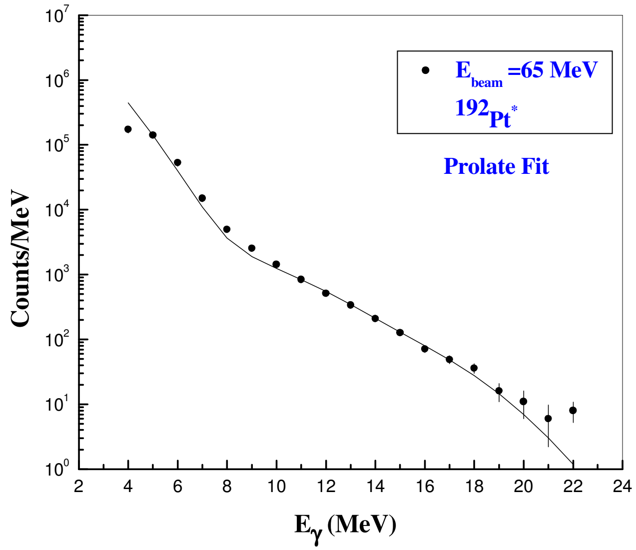
Adam Maj, *IFJ*,Krakow

Guergen Gerl, *GSI, Darmstadt*

Giant Dipole Resonance:

- *Small Amplitude High Frequency Vibration*
- *The GDR energy varies smoothly with the mass*
- *The width of the GDR is related to the damping of the vibration*
- *The collectivity is expressed by the appropriate sum rule*
- *The GDR splits in deformed nuclei. Tells us about nuclear shape*

GDR built upon excited states can probe Nuclear shape and reaction dynamics at high excitation.



Studies In Hot Nuclei Through GDR Observables

GDR PROPERTIES

Does the GDR centroid change with temperature and spin?
Does the GDR width saturate with temperature?
Effect of thermal and quantal fluctuations on Γ

Probing Nuclear Dynamics

- ✓ *Evolution of nuclear shapes at finite temperature and spin*
- ✓ *Nuclear dissipation: Fission hindrance and time scale*
- ✓ *Internal pair decay*
- ✓ *Nuclear Level Density*

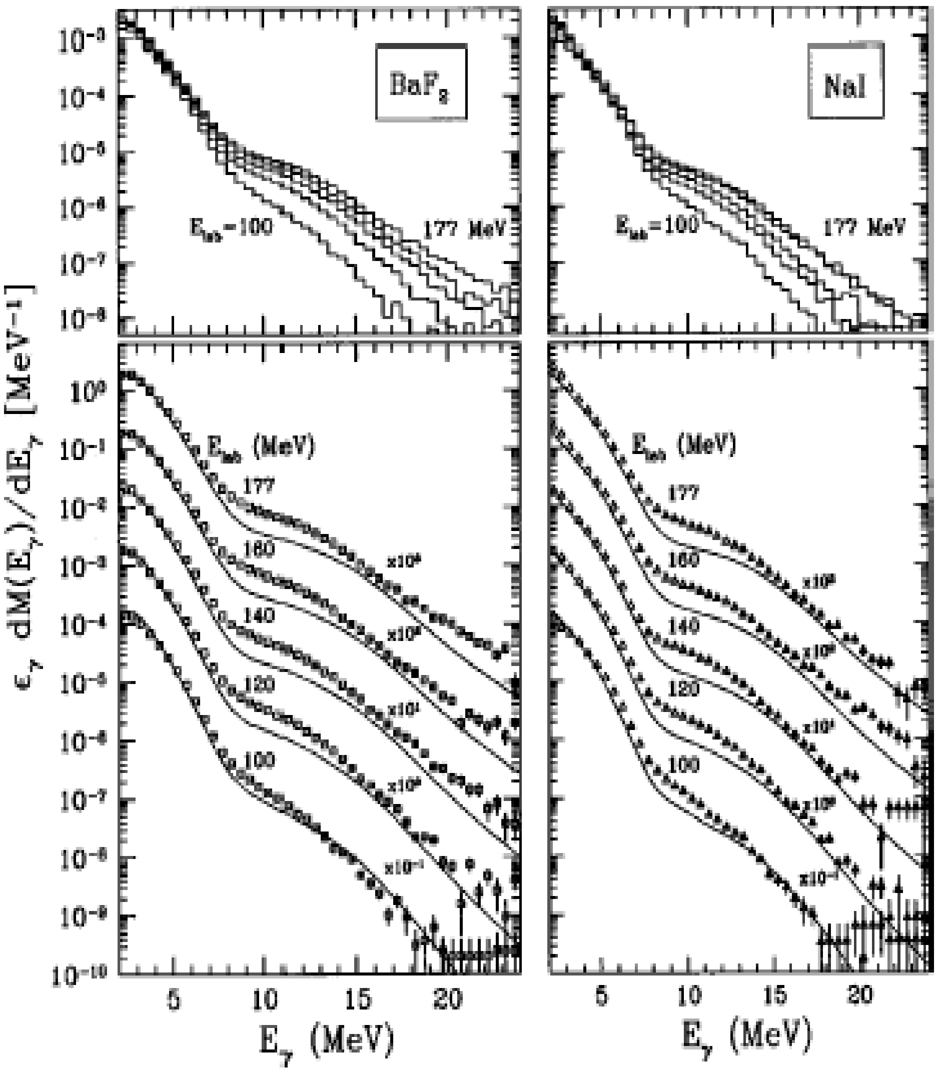
Entrance channel effect in HI fusion reactions
Isospin mixing at finite temperature

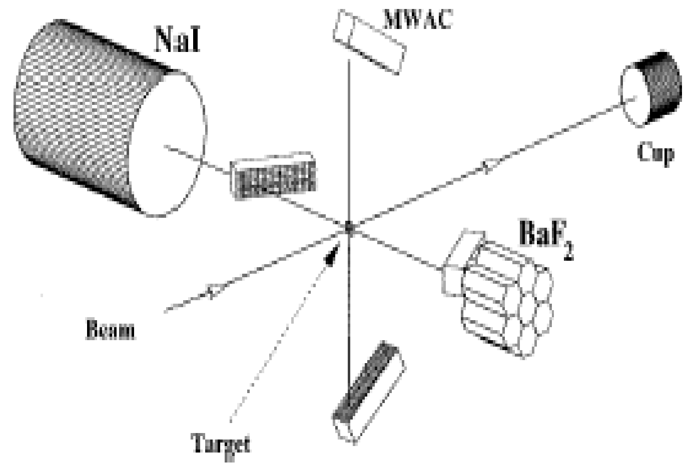
Does the GDR width saturate?

•kelly et al. PRL (1999)
Conclusion: The width continues to grow up to T~3.2 MeV in Sn mass region

•Wieland et al. PRL (2006) GDR γs and charged particles and heavy recoils
measured in coincidence up to 4 MeV at 300, 400,
500 MeV. Γ increases linearly with temperature.

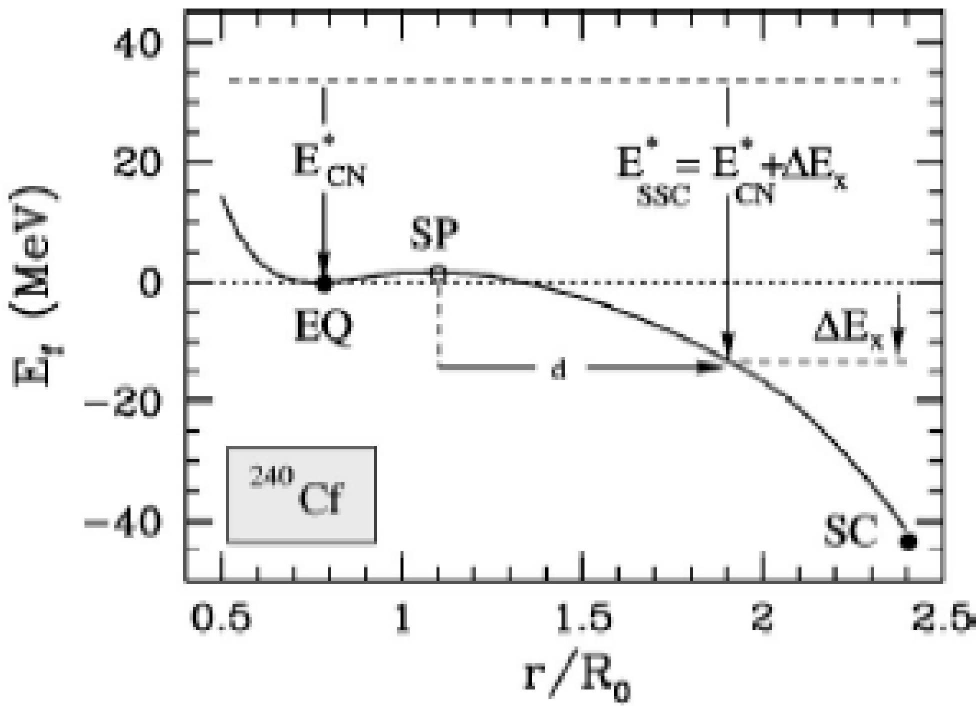
The variation of the width with excitation energy and the survival of collectivity remain cardinal issues in GDR decay studies





GDR and nuclear viscosity:

The Phenomenon of Fission Hindrance



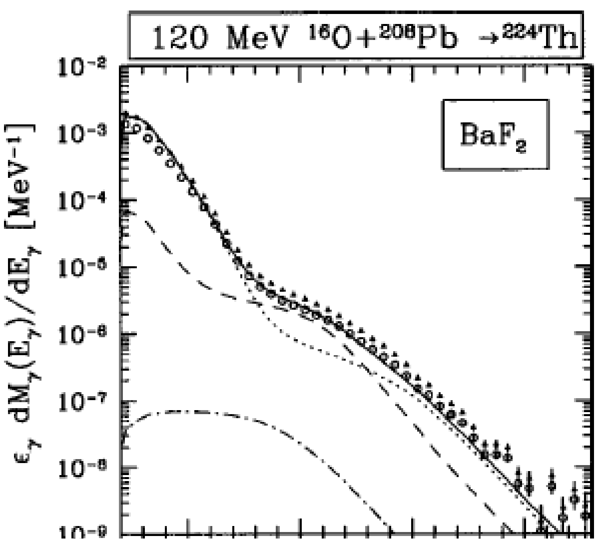
$$\Gamma_{\rm fiss}^{\rm BW}=\frac{1}{2\pi\rho_1(E_i,J_i)}\int_0^{E_i-E_b}\rho_2(E_i-E_b-E,J_i)\,dE,$$

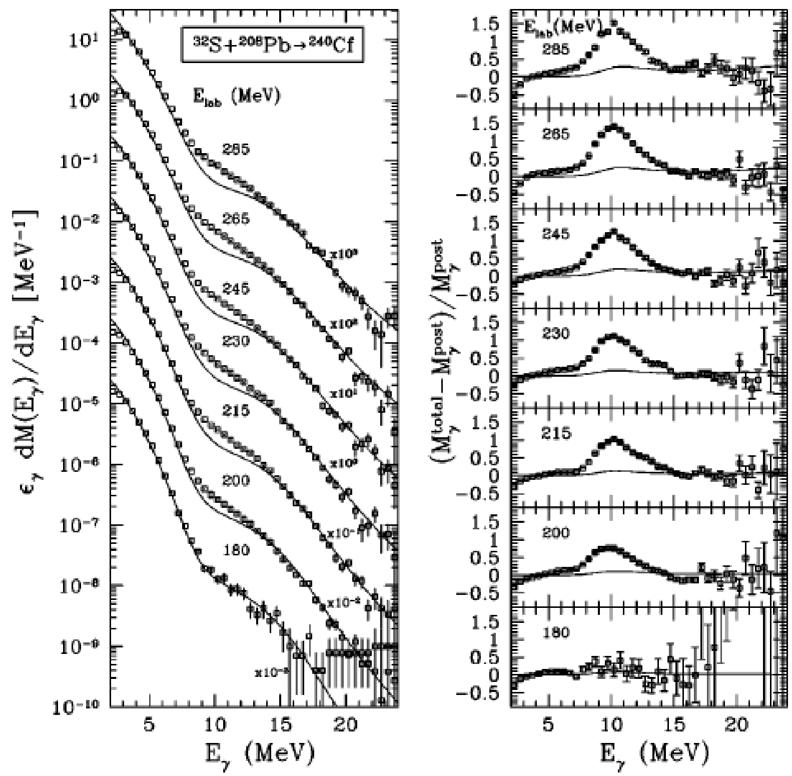
$$\Gamma_f^{\rm Kramers}=\Gamma_f^{\rm BW}[(1+\gamma^2)^{1/2}-\gamma]$$

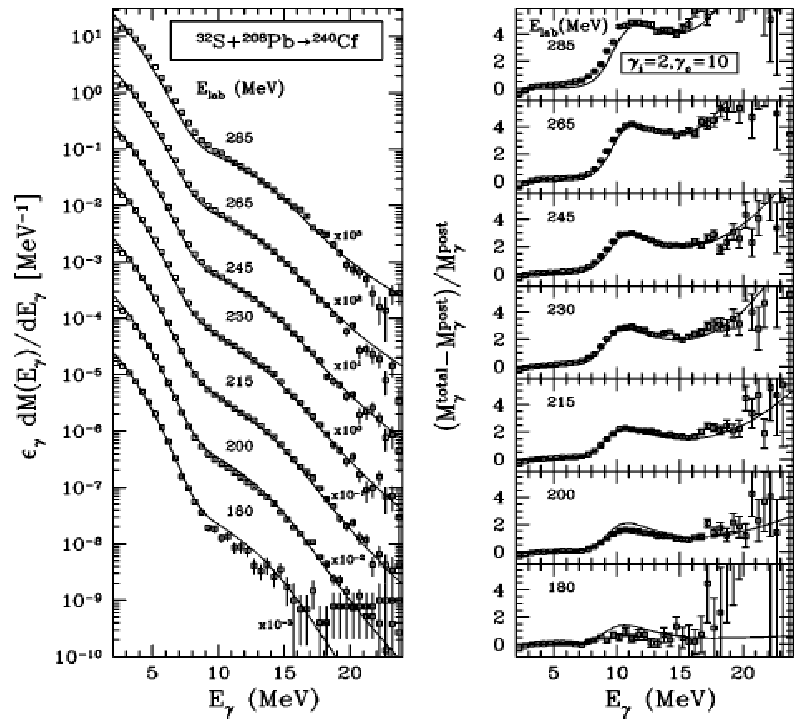
$$\tau_{\rm ssc}=\tau_{\rm ssc}^0[(1+\gamma^2)^{1/2}+\gamma].$$

$$\tau_{\rm ssc}^0=\frac{2}{\omega_0}R[(\Delta V/T)^{1/2}]$$

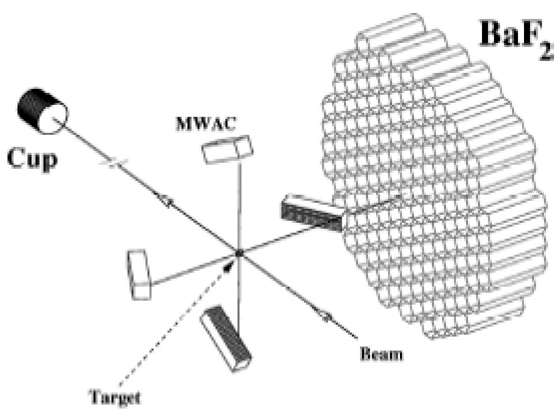
$$R(z)=\int_0^z \exp(y^2)\,dy\int_y^\infty \exp(-x^2)\,dx.$$







Phys. Rev C61, 044612
Phys. Rev. C61, 024613
Phys. Rev. C63, 047601
Acta. Phys. Hung.13
Phys. Rev. C63, 014611



No temperature dependence of viscosity Parameter.

Gamma rays measured in coincidence with fission fragments

Theoretical studies in hot-rotating nuclei and GDR decay:

•Calculation of Potential Energy Surfaces at finite temperature and spin

•Calculation of photo-absorption cross section or real time dipole response function at finite temperature.

Inclusion of fluctuation effects in both the above calculations.

Macroscopic or microscopic approaches.

Finite Temperature RPA calculations: Milano group

A.L. Goodman (FTHFBC calculations)

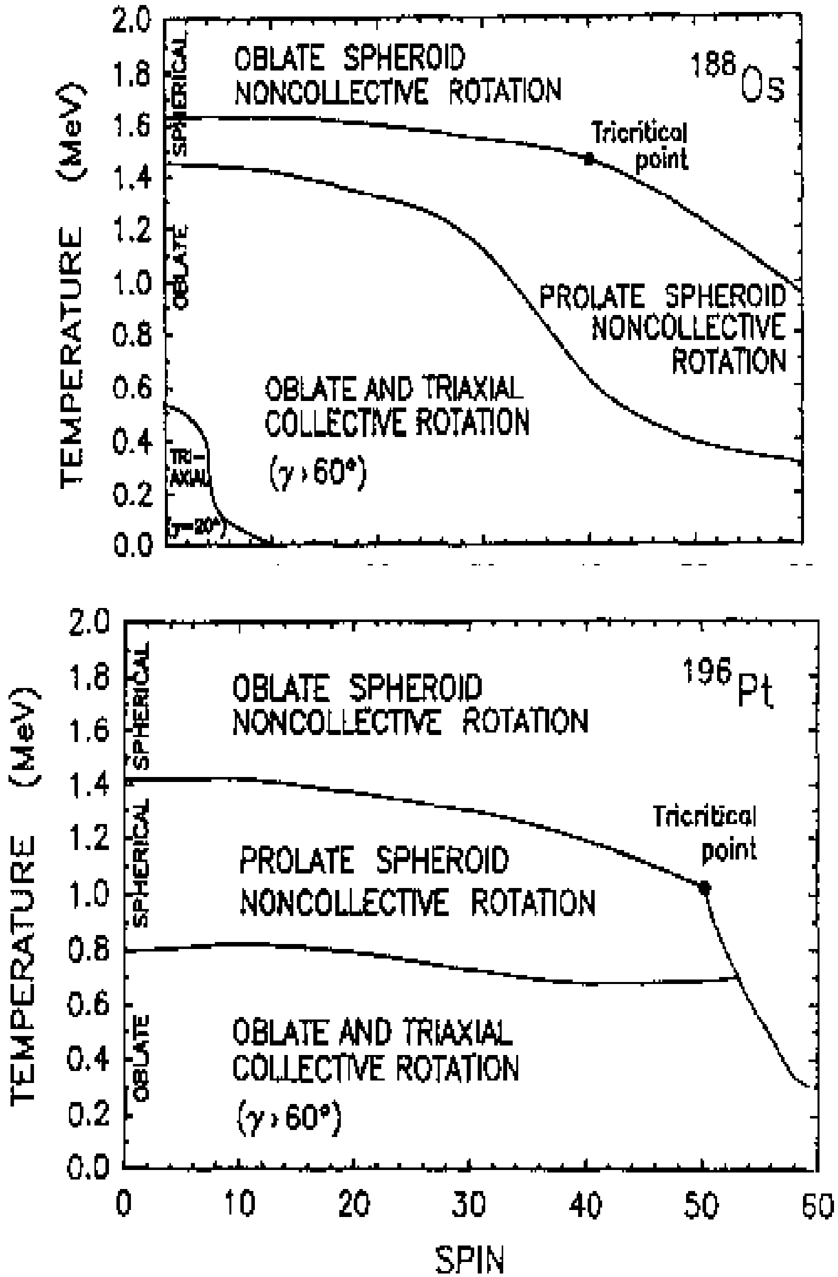
Ansari , Agrawal, Ring (SPA)
Egido and coworkers (SPA)

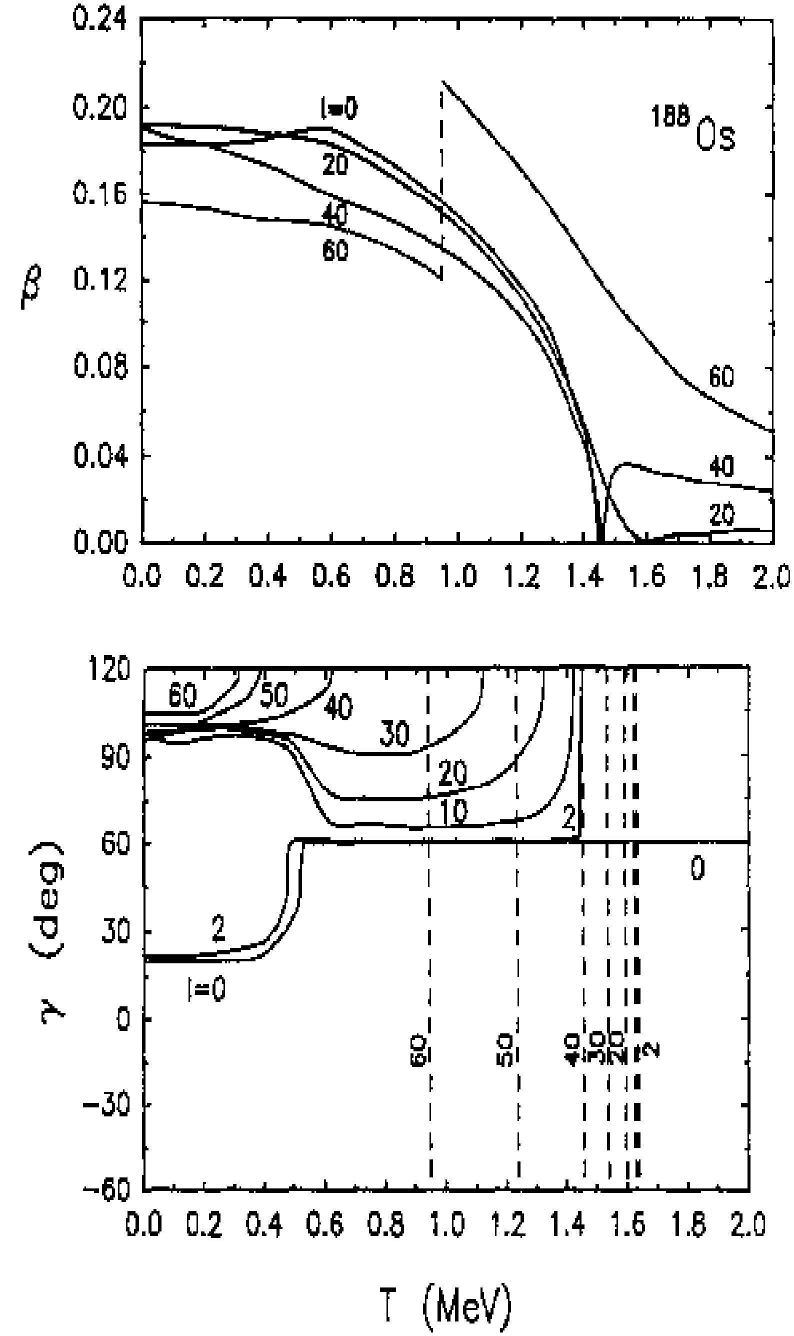
Alhassid and coworkers (Landau theory), thermal fluctuations, universal features

Pomorski & Dudek (LSD Model)(2003)
Application to GDR properties at high T, Jacobi Shape transitions (Maj-2001),

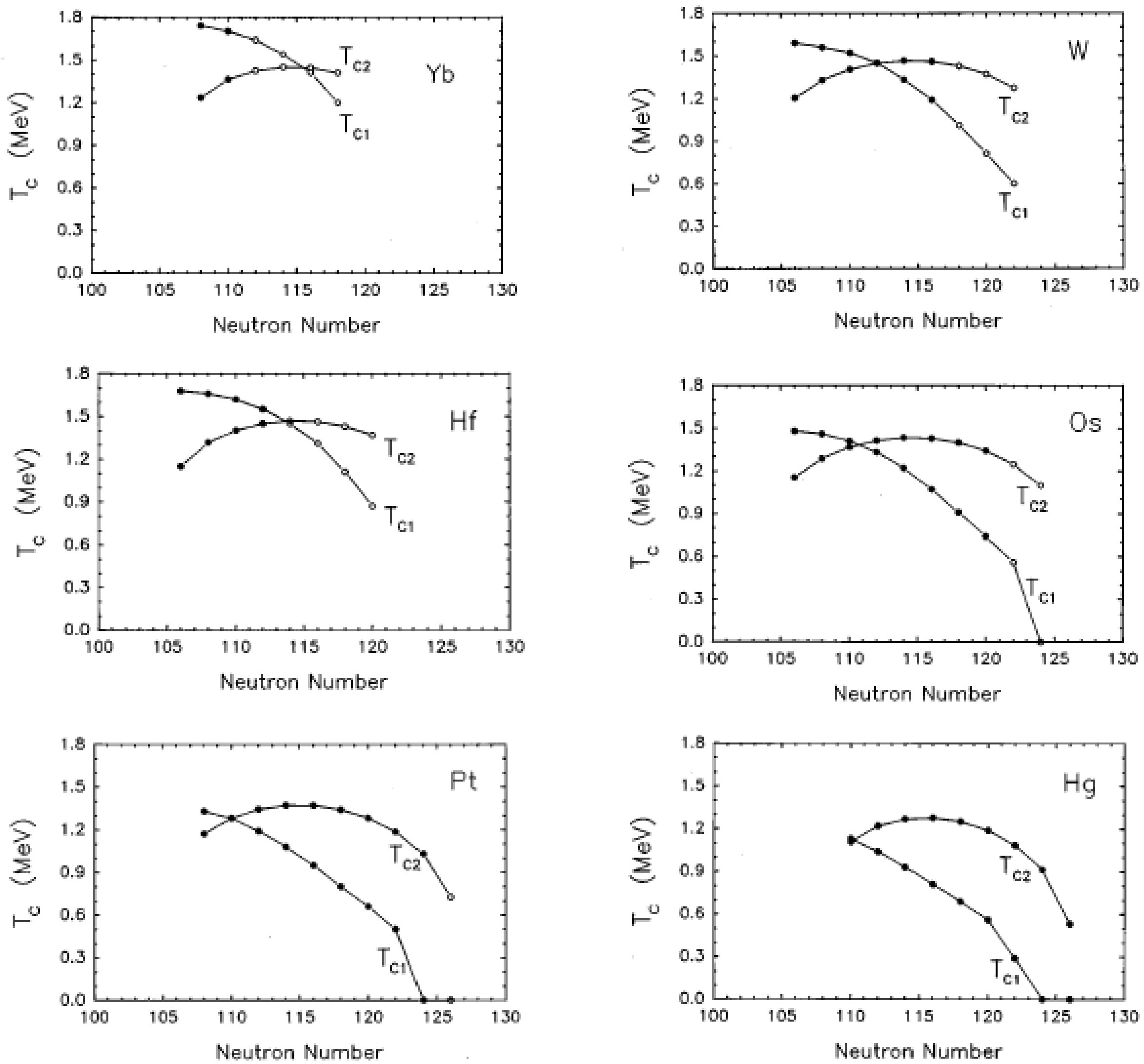
Brekiesz (2007) , influence of NLD parametrization on Γ , Mazurek et al. (2007)

Agarwal & Mazumdar (2009) PRC 80 Deformation and shape transition in hot nuclei





A.L. Goodman, Nucl. Phys. A611, (1996)



31 even-even Isotopes with
two critical Temperatures
TC1 & TC2.

TC1 < T < TC2 NCP
T > TC2 NCO

Goodman & Jin , 96

Radioactive nuclear beam (RNB) facilities will create new neutron-rich isotopes. Figure 1 in [12] shows the isotopes which could be produced with RNB facilities. Some of

Typical Detection Techniques:

High energy gamma rays spectrometer

Large NaI or BaF_2 detector
Or
Array of large detectors

Cosmic Ray Anti Coincidence Shield

Inclusive measurement

Angular momentum gating
Spin spectrometers

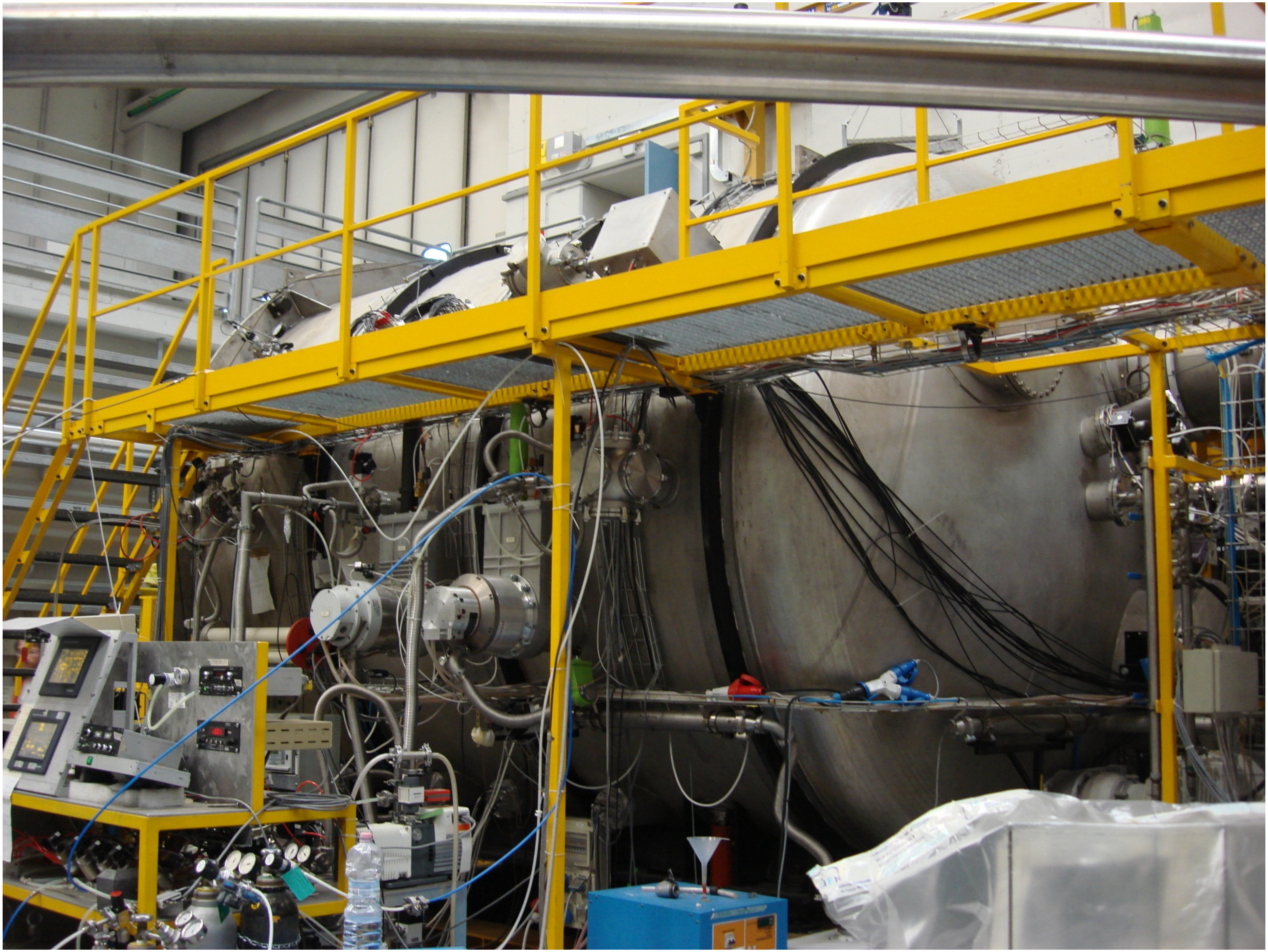
Detection of charged particles and ERs

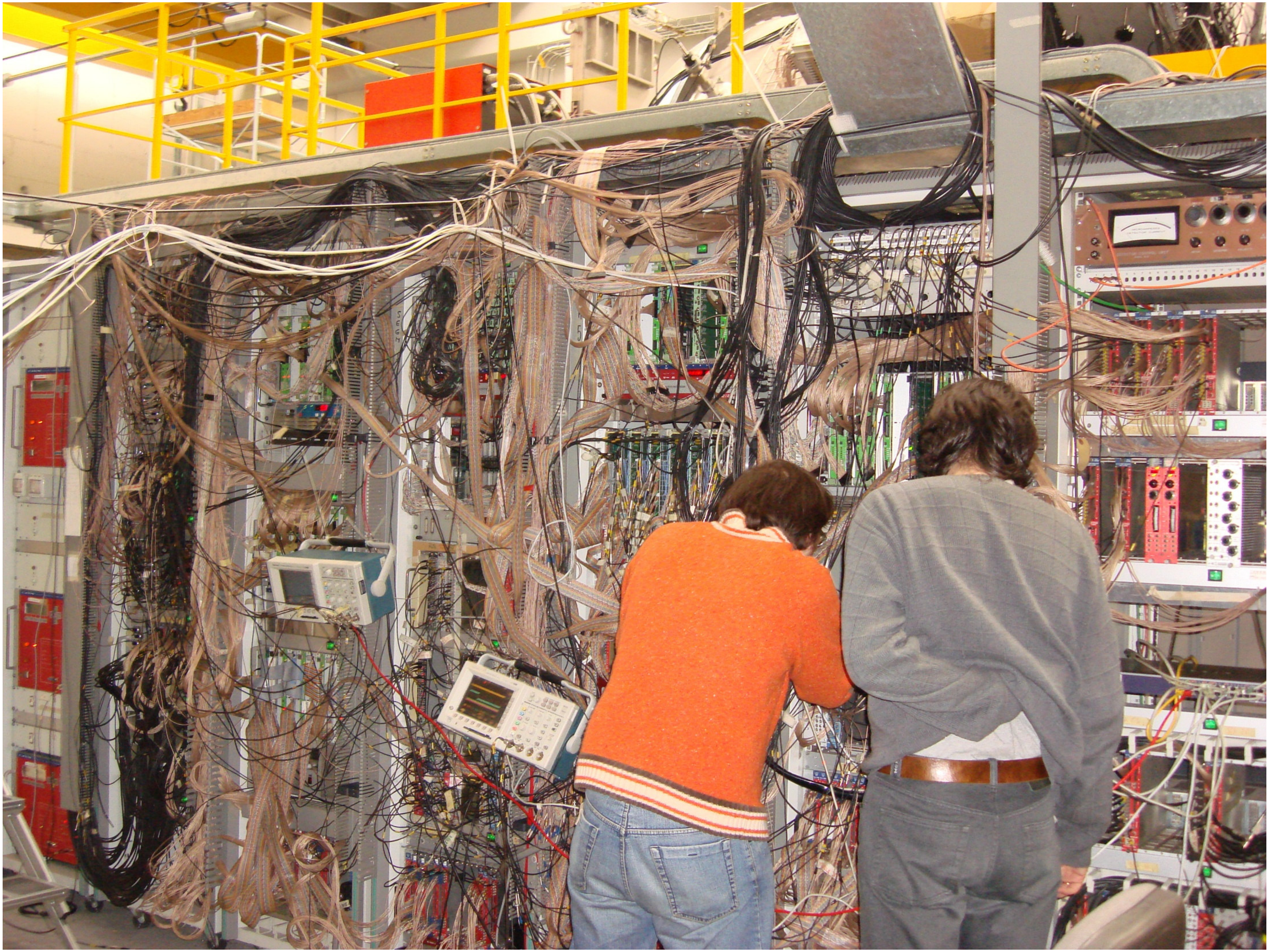
Detection of neutrons

Detection of Fission fragments

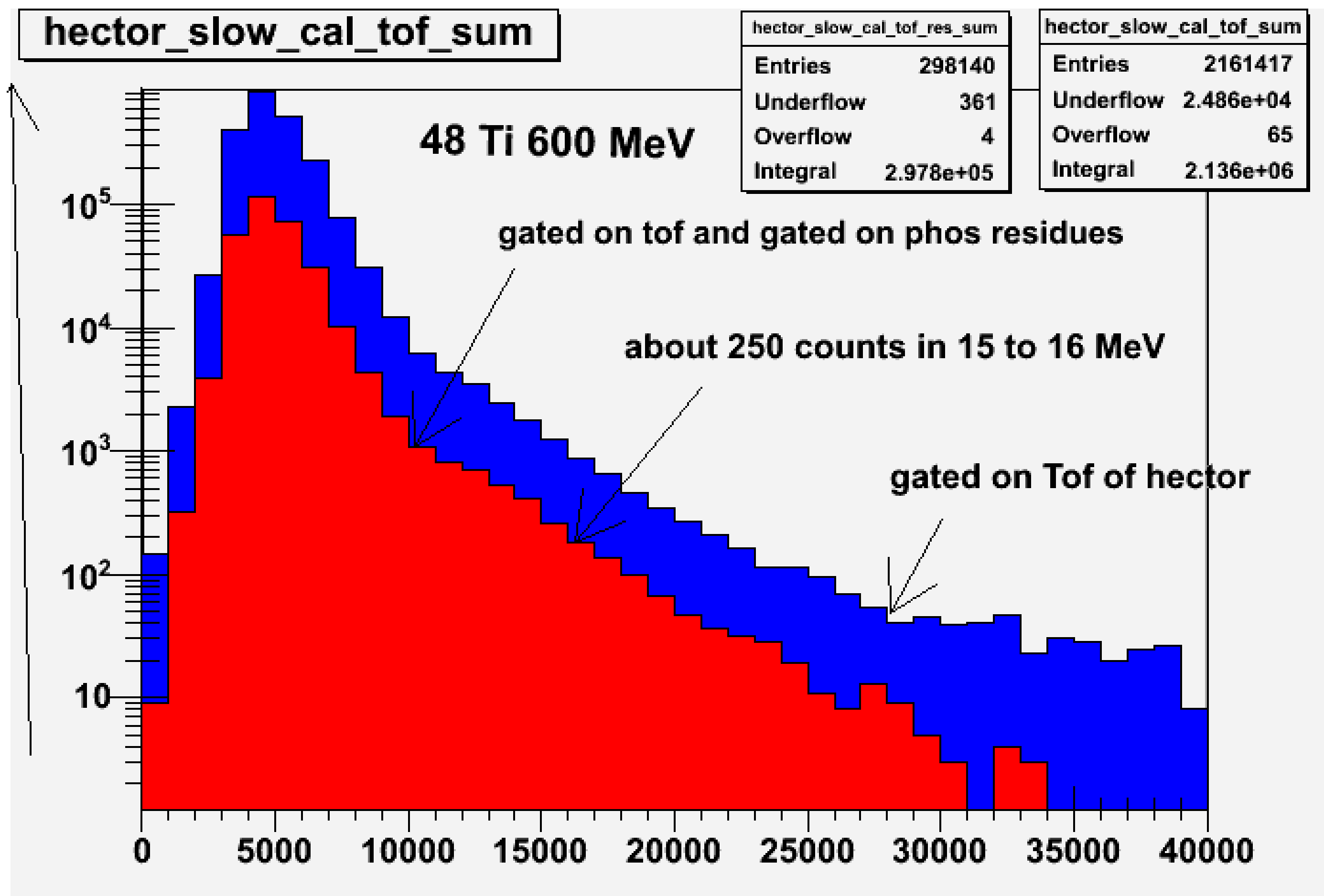
Exclusive measurement

5 – 50 MeV Gamma Rays





PRELIMINARY



" richness of our understanding reveals even greater richness of our ignorance "
Denys Wilkinson

The need for decoupling the temperature and angular momentum dependence

- Gating with ERs, FF, charged particles

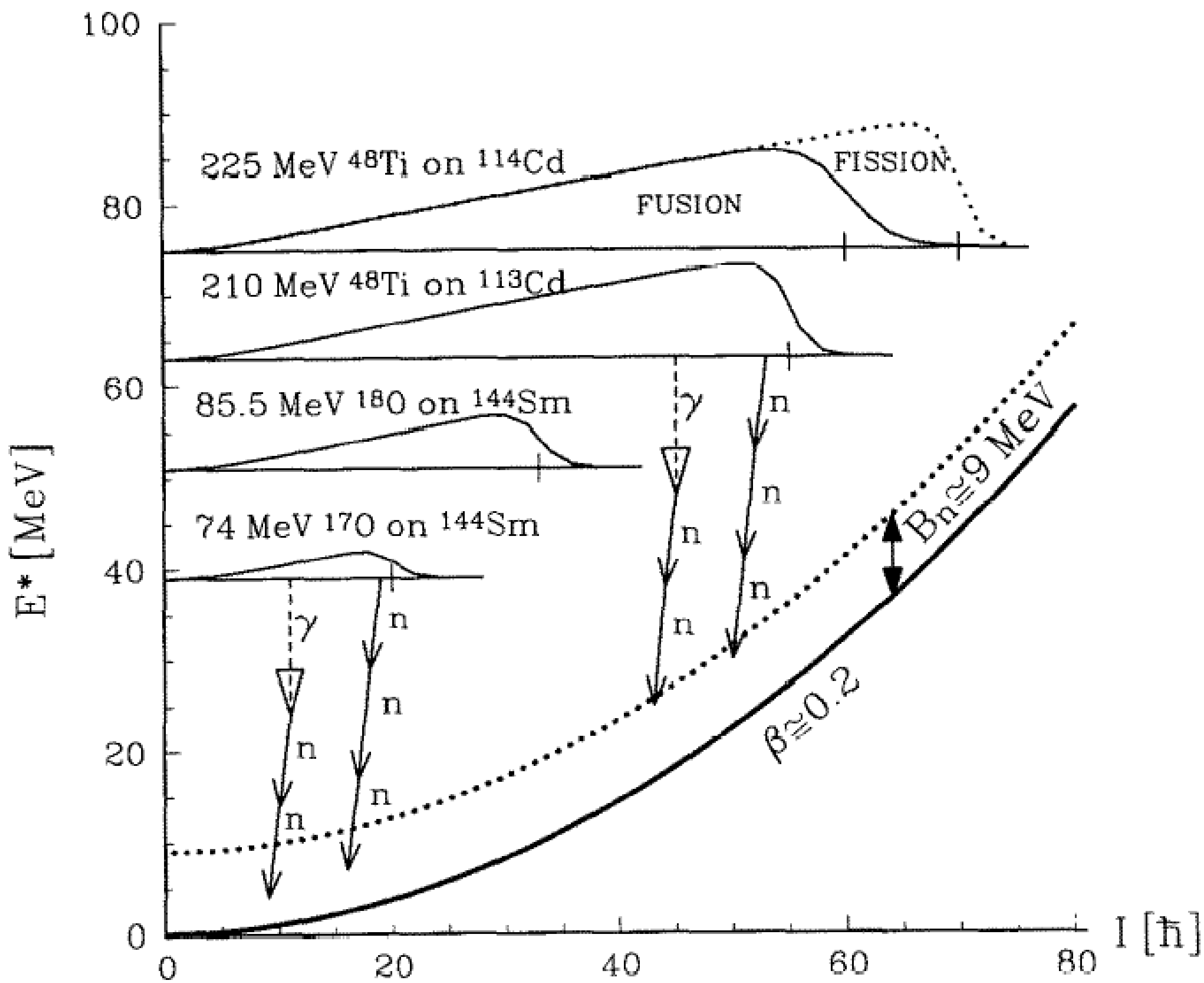
- Selection of temperature window
  - *Inelastic scattering*
  - *Differential Technique*

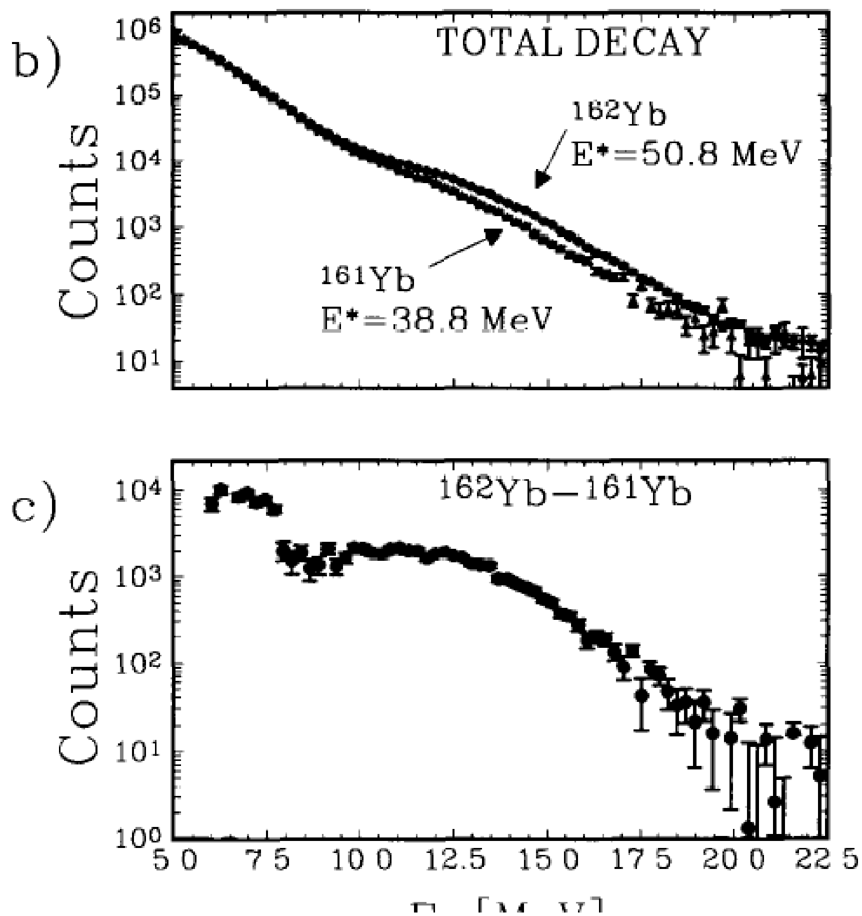
Ramakrishnan et al. (1996) GDR decay of ^{120}Sn by inelastic scattering of 40, 50MeV/A α

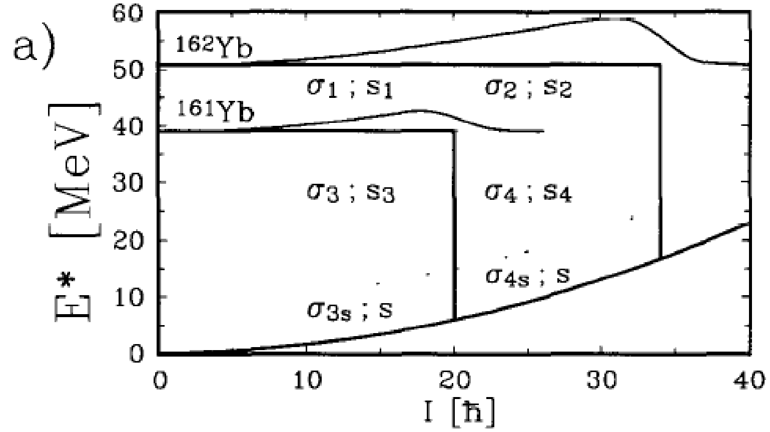
- Selection of Angular momentum

  High efficiency Sum–spin spectrometer

The Differential Technique







A. Maj *et al*. Nucl. Phys. A (1994)
A. Maj *et al*. Phys. Lett. B (1992)

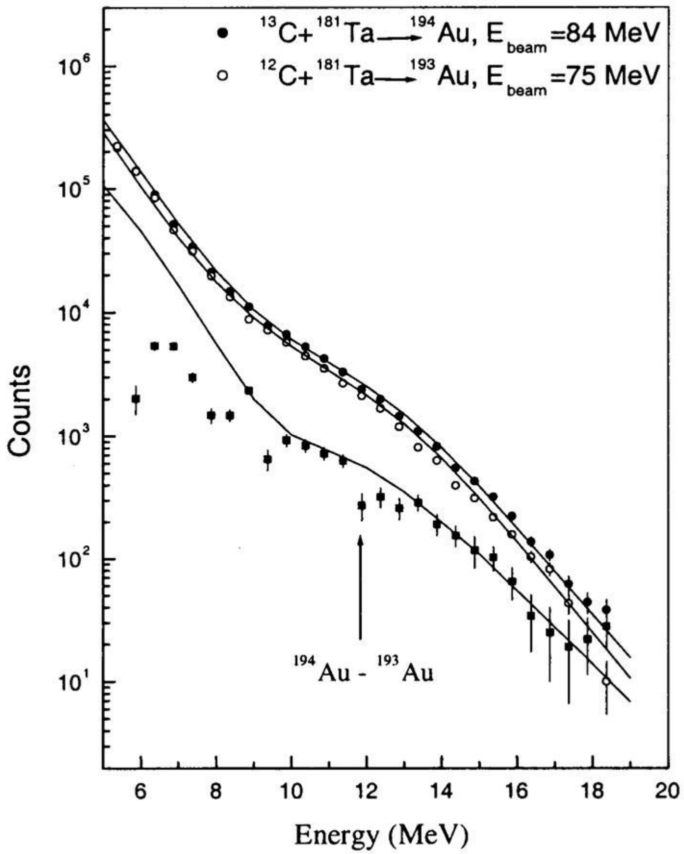
Reaction	E(beam) [MeV]	Target [mg/cm^2]	E^*(max) [MeV]	l_{max} [$\hbar$]	σ(fusion) [mb]
$^{17}O + ^{144}Sm$	74.0	2.2 (96.5%)	38.8	20	270
$^{18}O + ^{144}Sm$	85.5	2.2 (96.5%)	50.8	33	640
$^{48}Ti + ^{113}Cd$	210.0	1.3 (93.4%)	62.8	54	400
$^{48}Ti + ^{114}Cd$	225.0	1.1 (98.7%)	74.8	70 ($l_{fiss} = 60$)	610

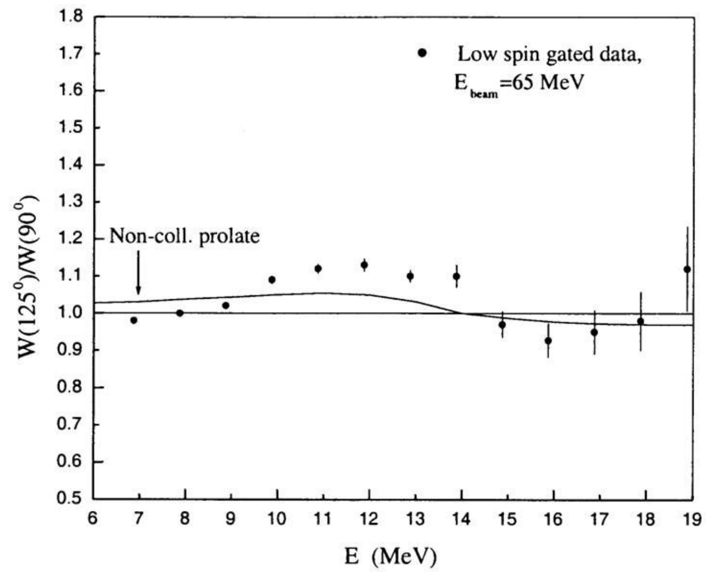
- To search for (rare) shape-phase transitions in nuclei at high excitation energy and angular momentum.
- To search for Giant Quadrupole Resonance (GQR) based on excited states.

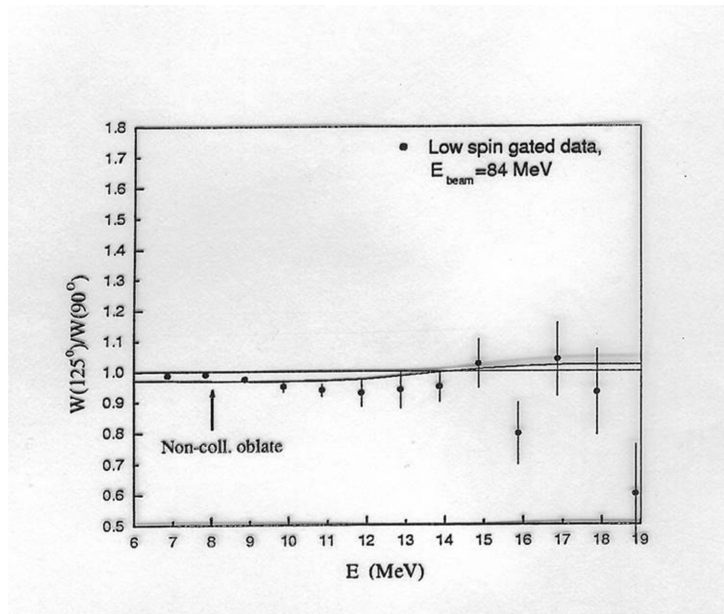
The nuclei chosen for exclusive measurements of high energy gamma rays:

^{194}Au **^{188}Os** ^{192}Pt ^{196}Hg

GDR decay from ^{194}Au

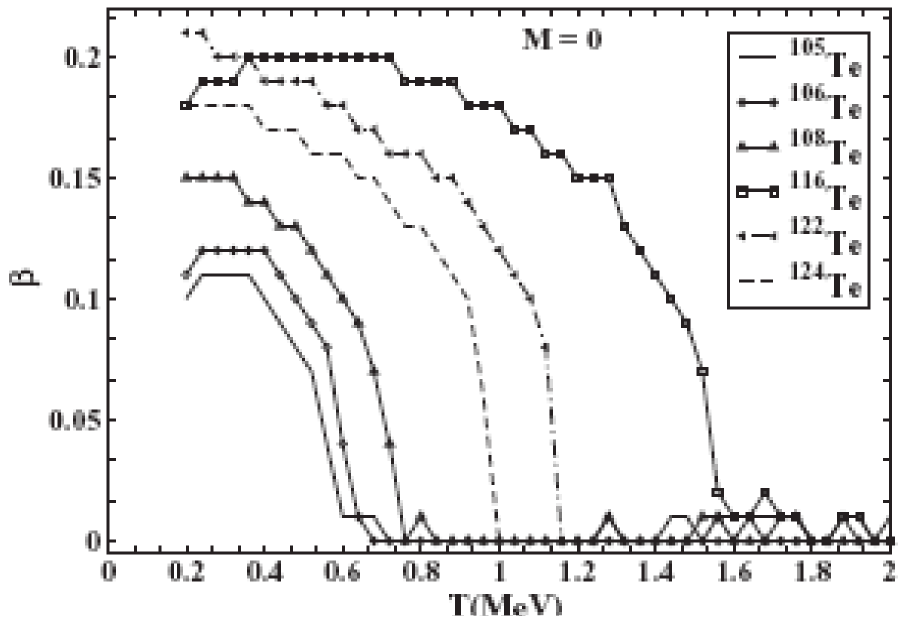






I. Mazumdar *et al.*, Nucl. Phys. A 731, 146 (2004)

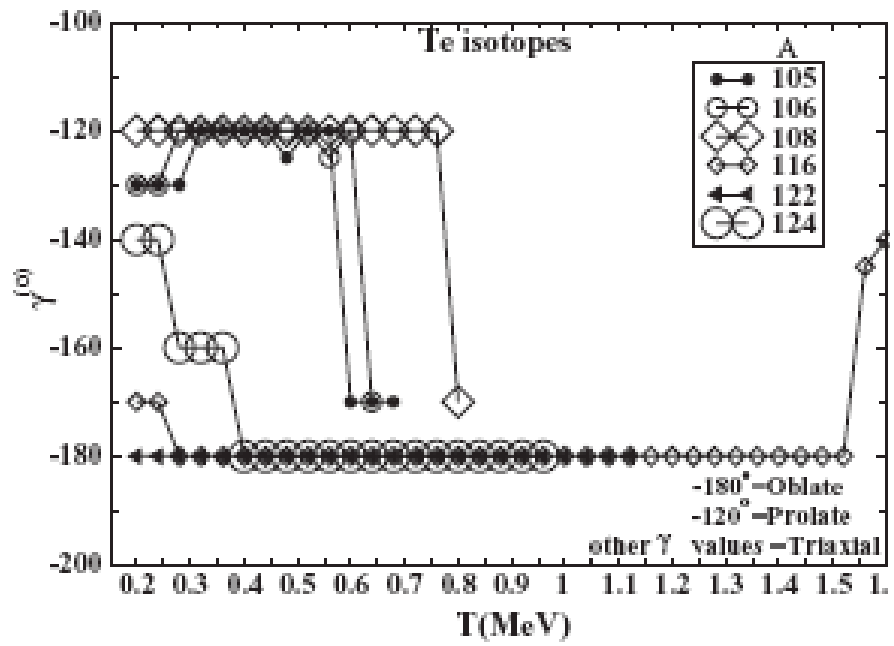
M. Agarwal, I. Mazumdar
Phys. Rev C 80 (2009)

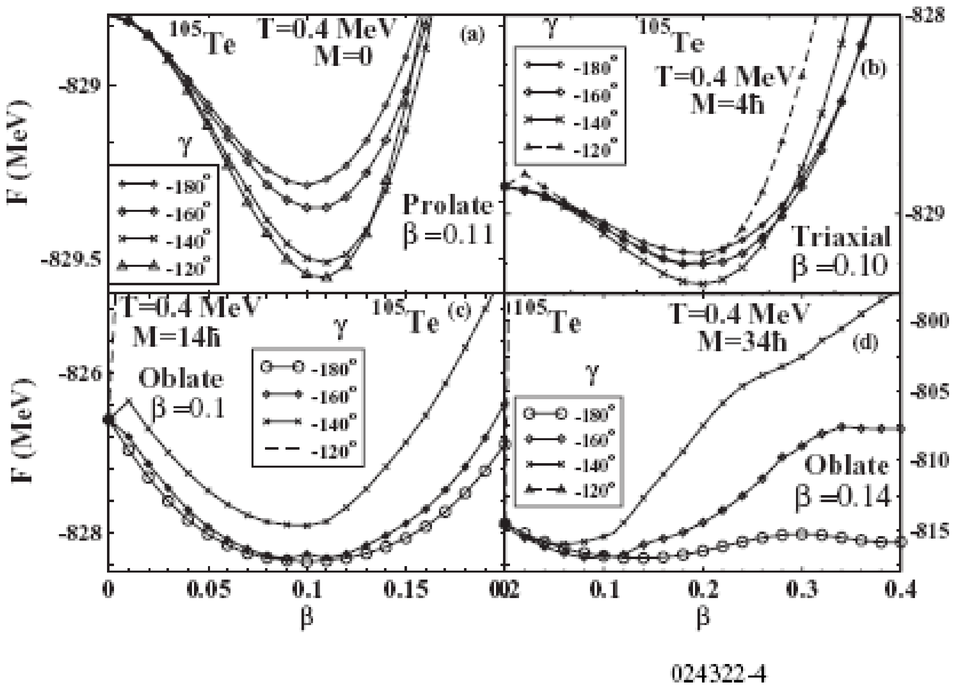


Ground state shapes and deformations

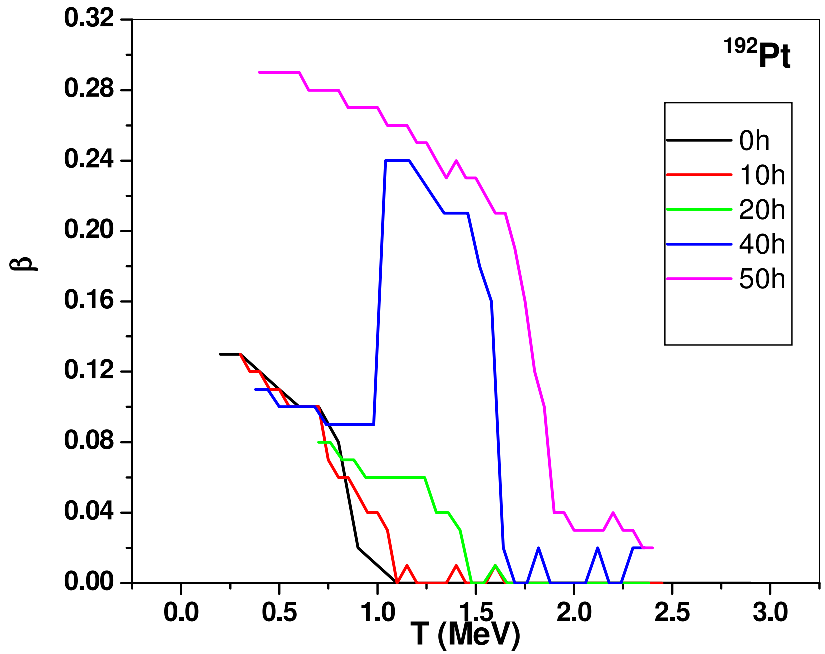
A = 103 – 124 (Proton drip line to stability)

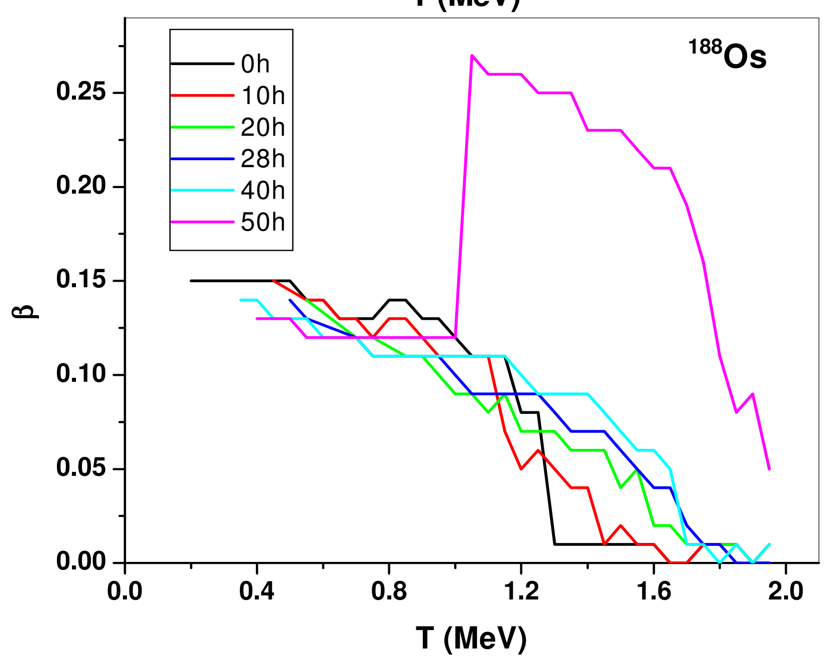
Critical Temperatures & shape evolutions for
^{105,108,116,122,124}*Te isotopes*



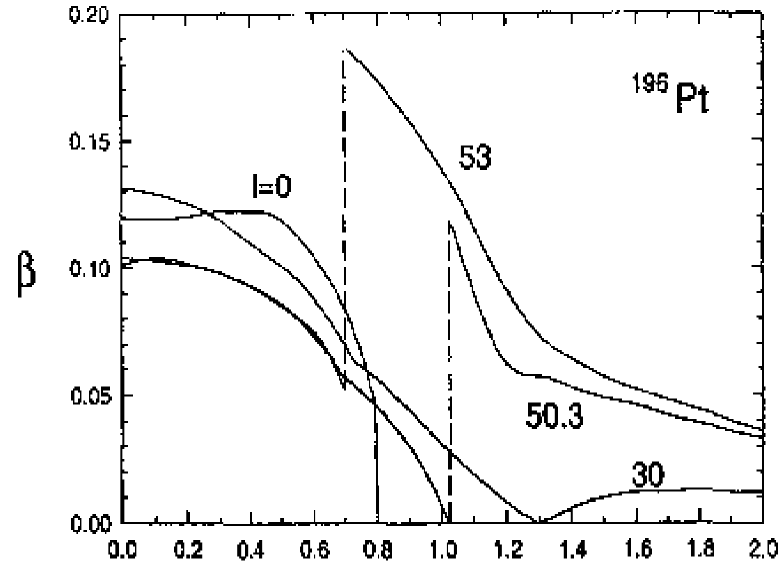


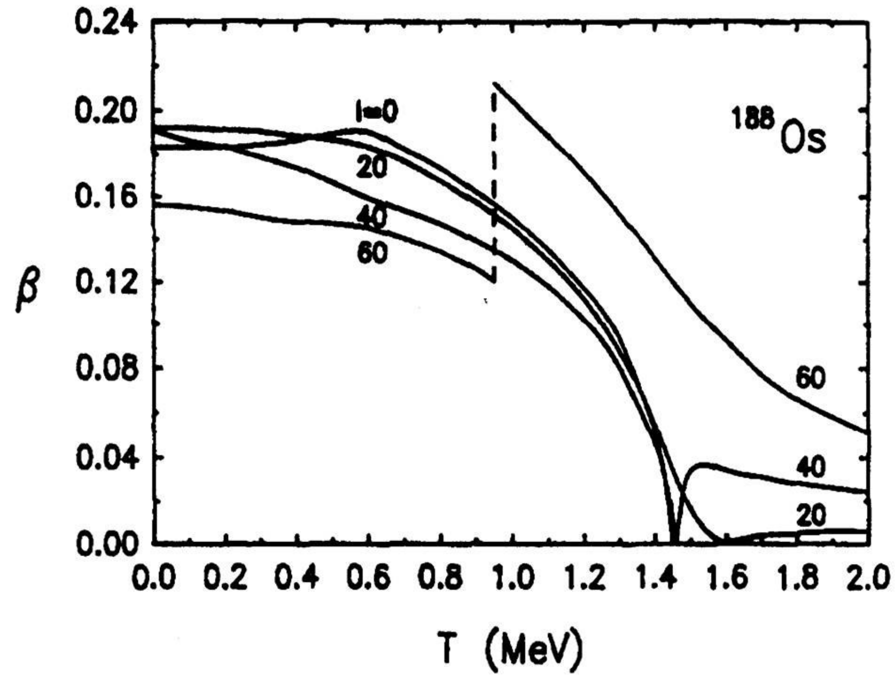
Aggarwal & Mazumdar





A.L. Goodman





Experiment

Reaction: $^{12}C + {}^{176}Yb \rightarrow {}^{188}Os^*$
E_{beam}: 65 MeV, 84 MeV (From TIFR 14MV Pelletron)
Target*: 1.2 mg/cm^2, self-supporting
Detectors: Large NaI Array + Annular Plastic shield
14 elements multiplicity filter

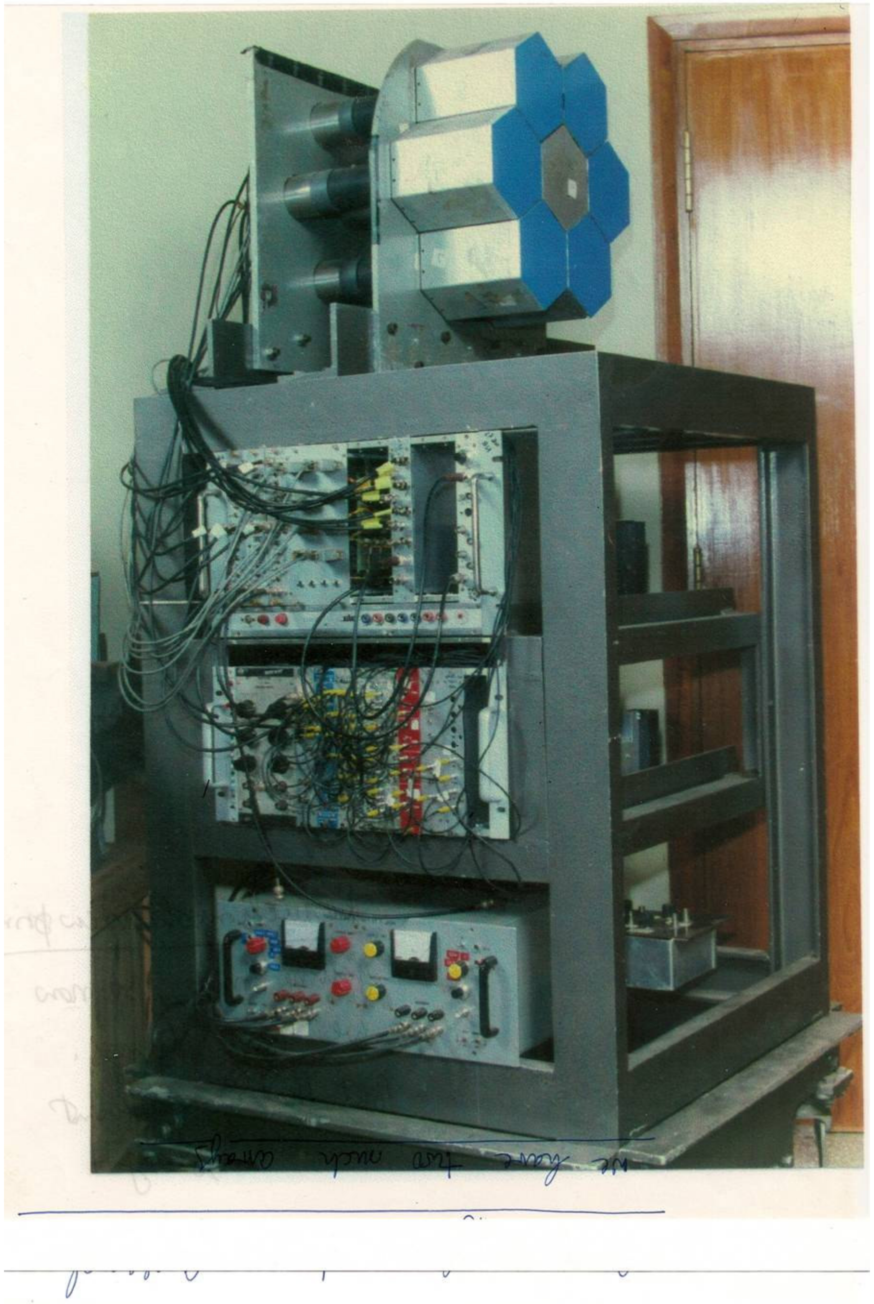
Spectra recorded at five angles w.r.t beam direction
Passive shielding of lead, paraffin etc.
n-γ separation by TOF (*Detector 75 cm from target*)
Pileup rejection by zero cross-over technique

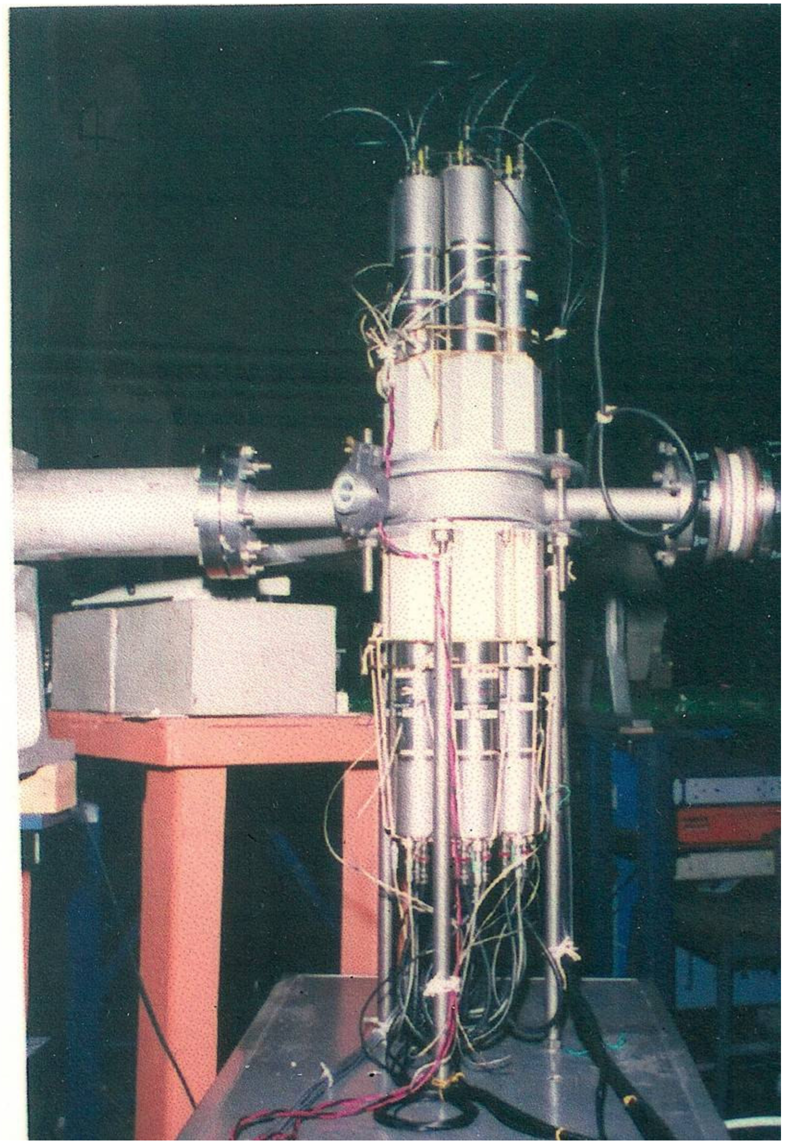
Cosmic ray background measured for extended period

Reaction: $^{13}C + {}^{174}Yb \rightarrow {}^{187}Os^*$ Target* 1.2mg/cm^2, self supporting
E_{beam} = 73 MeV

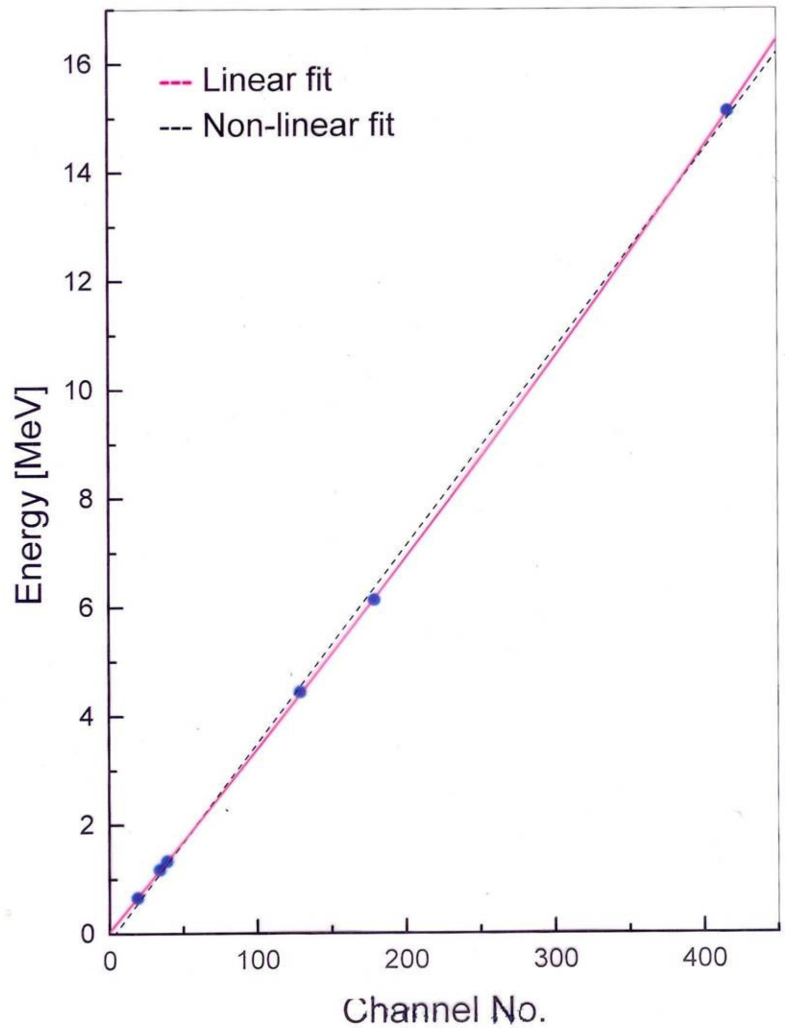
Mazumdar et al. (2007)
Acta phys. Pol.

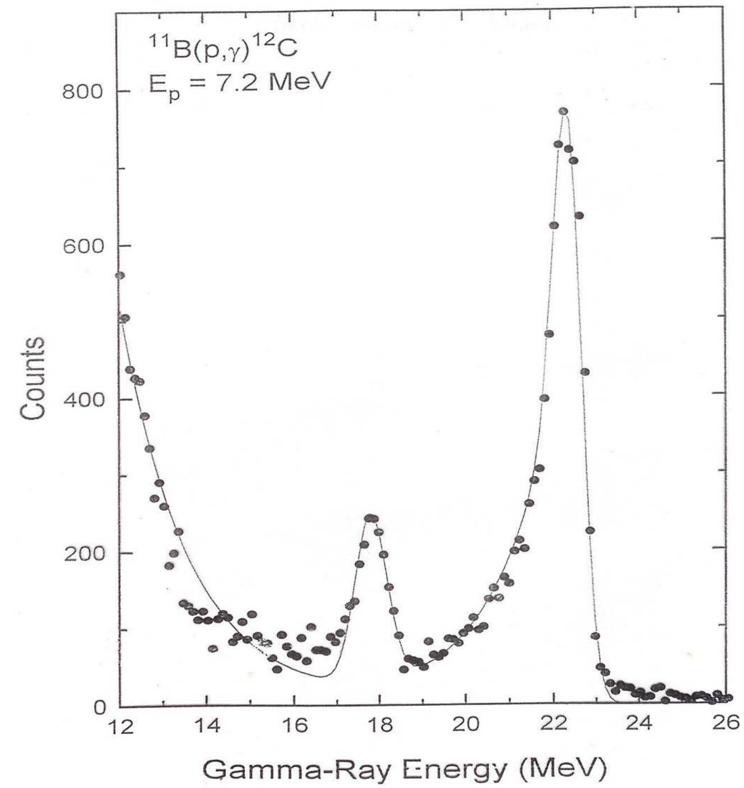
* *Courtesy: Andrjez Lipski, Nuclear Structure Lab, Stony Brook*

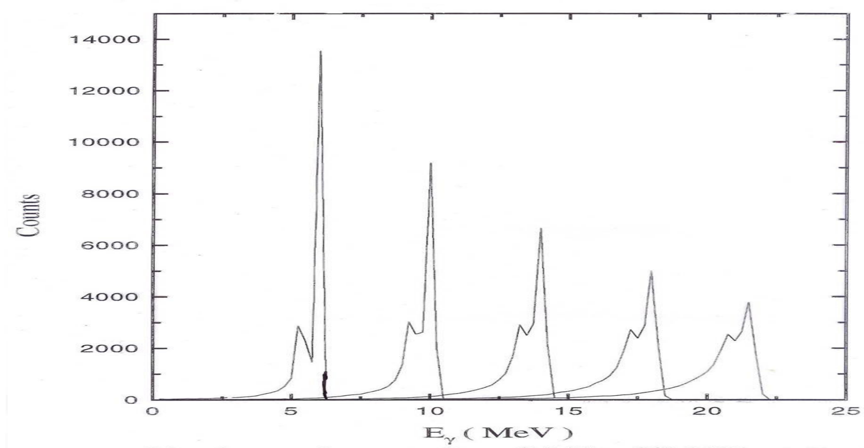




HIGRASP @ IUAC, Delhi (Formerly NSC),
Mazumdar *et al* NIM A417

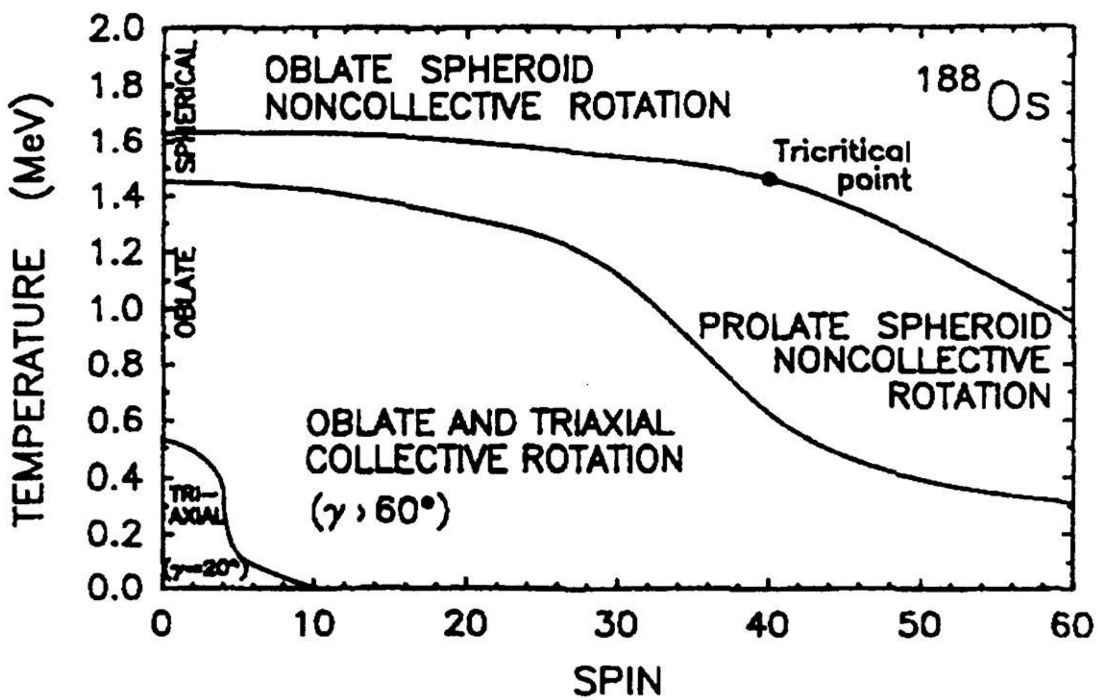




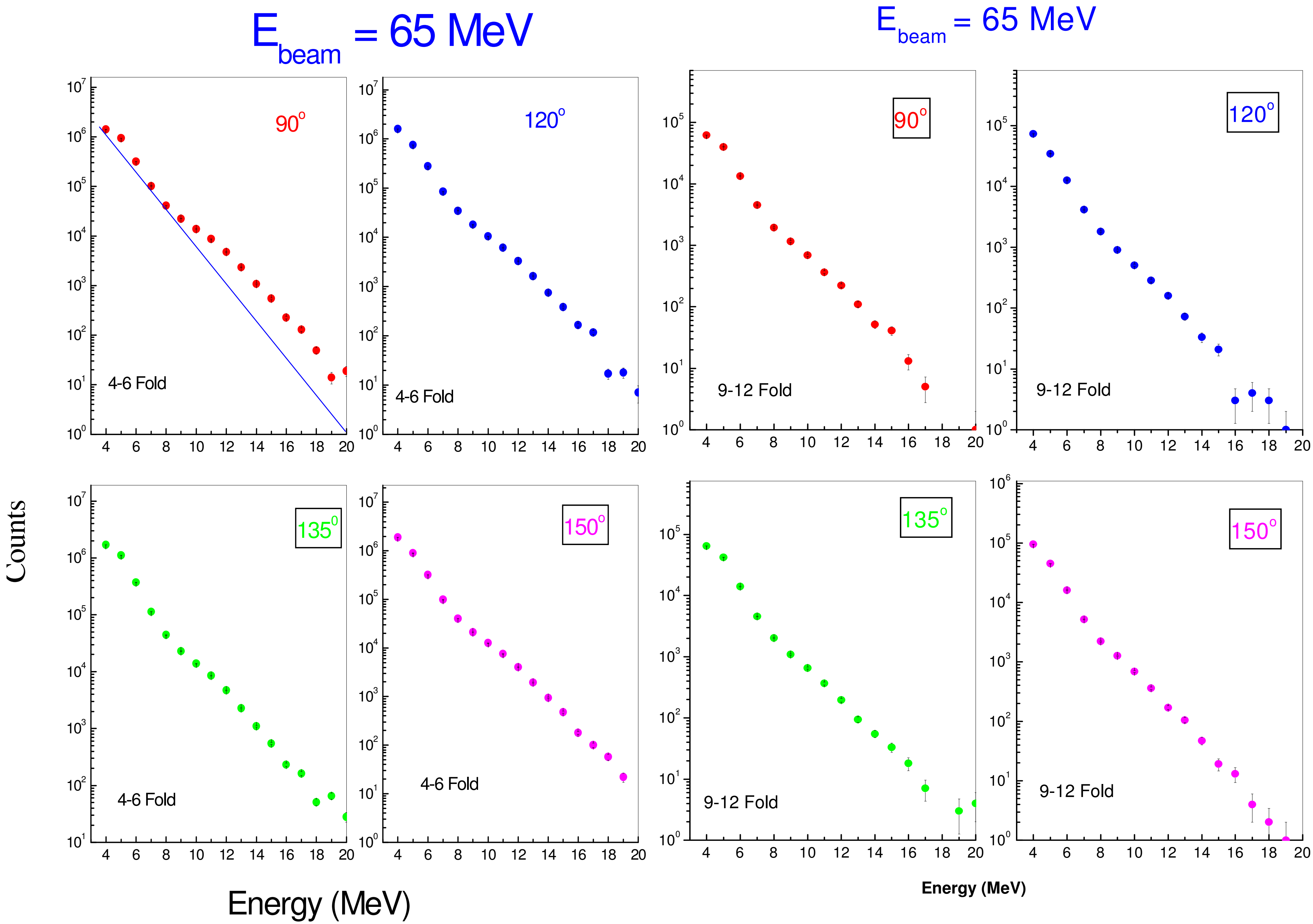


Lineshapes of γ - rays from 6MeV to 22MeV in steps of 4 MeV as calculated by EGS for the large NaI detector.

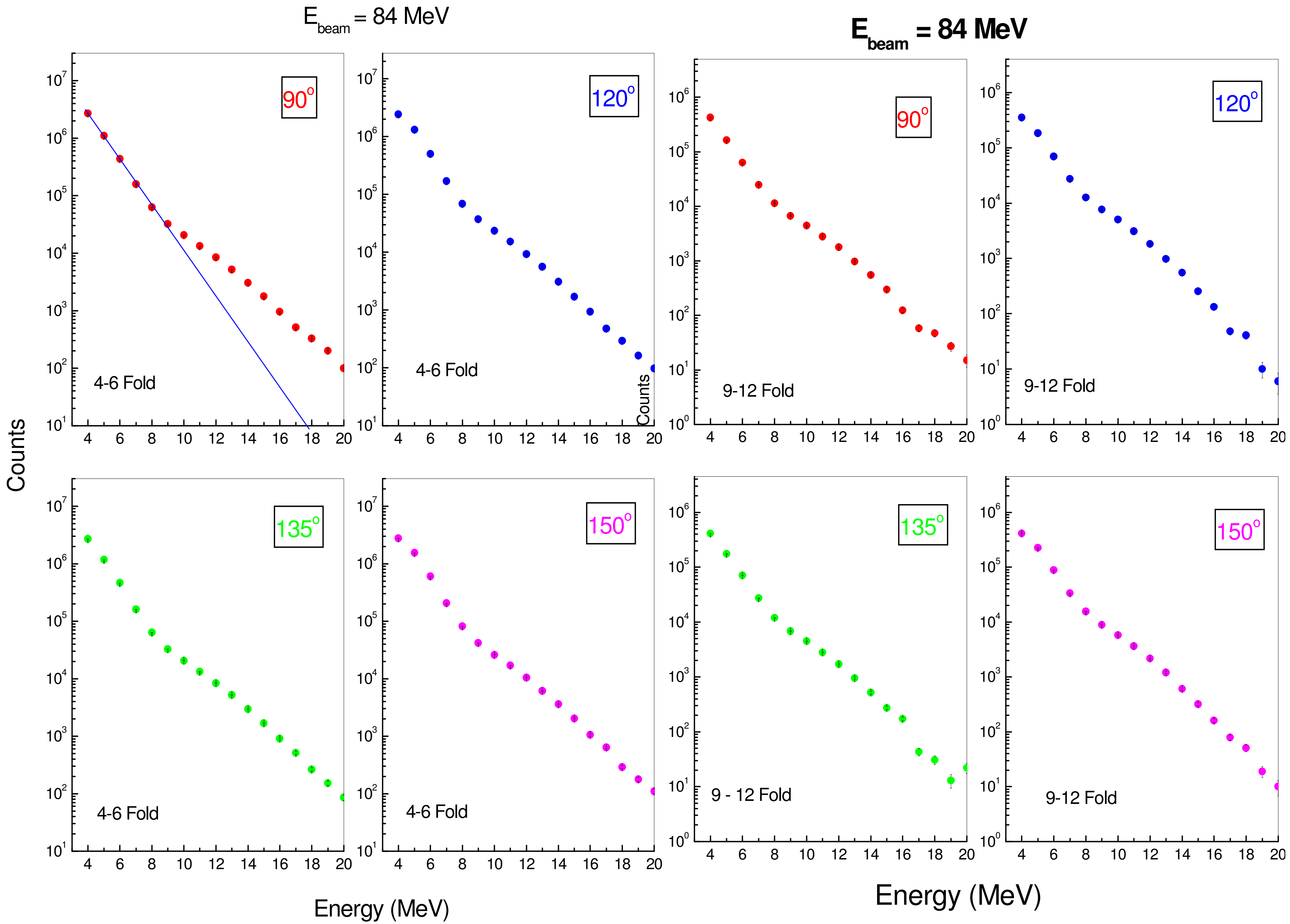
E_{beam} (MeV)	σ_{fusion} (mb)	E^* (MeV)	L_{max} (h)	<Erot> (MeV)	T_{eff} (MeV)
65	624	53	20	1.2	1.5
84	1326	71	37	3.8	1.8
73	718	57.5	30	2.45	1.6



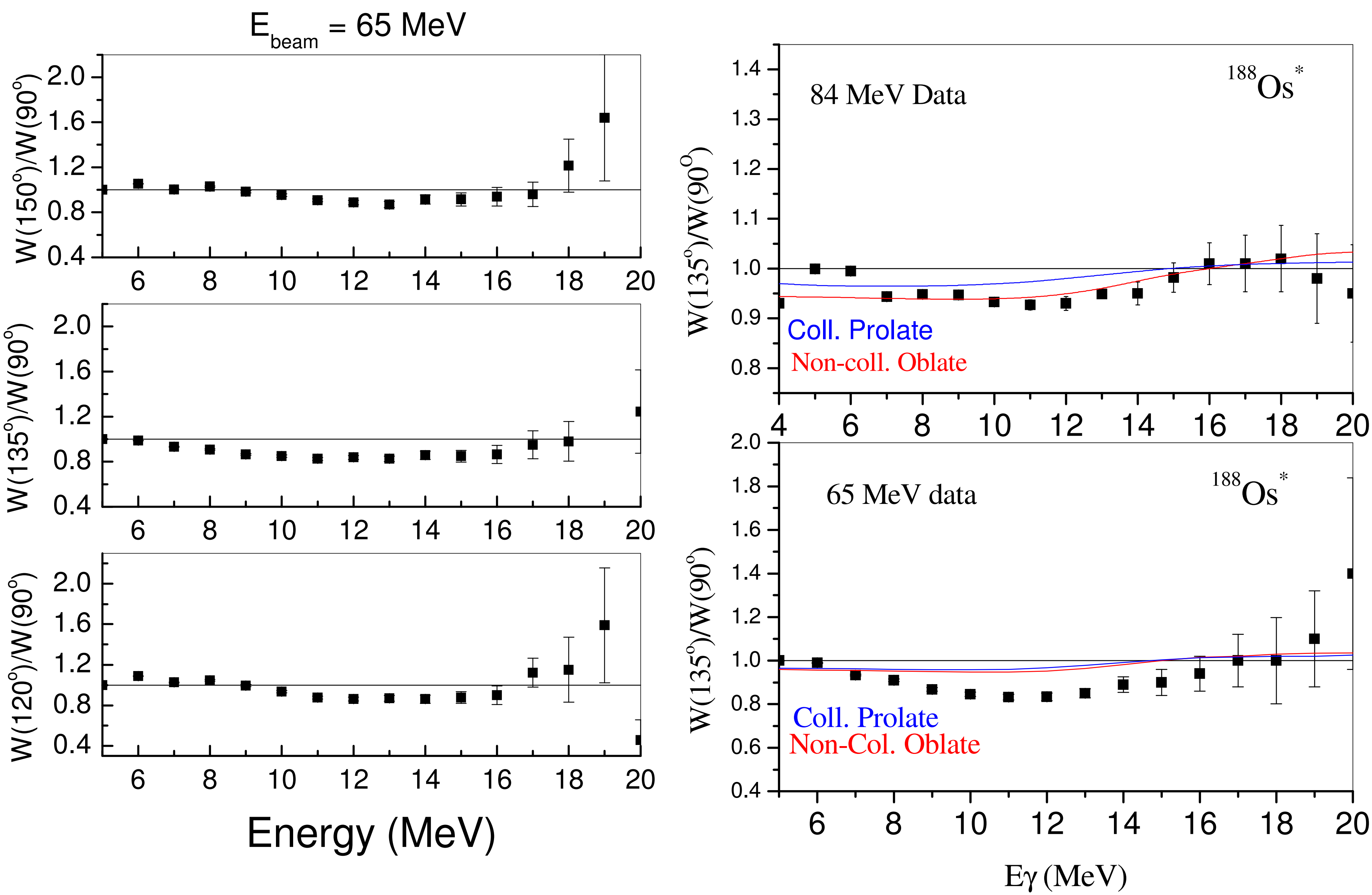
A.L. Goodman,
Nucl. Phys. A 611 (1996) 139



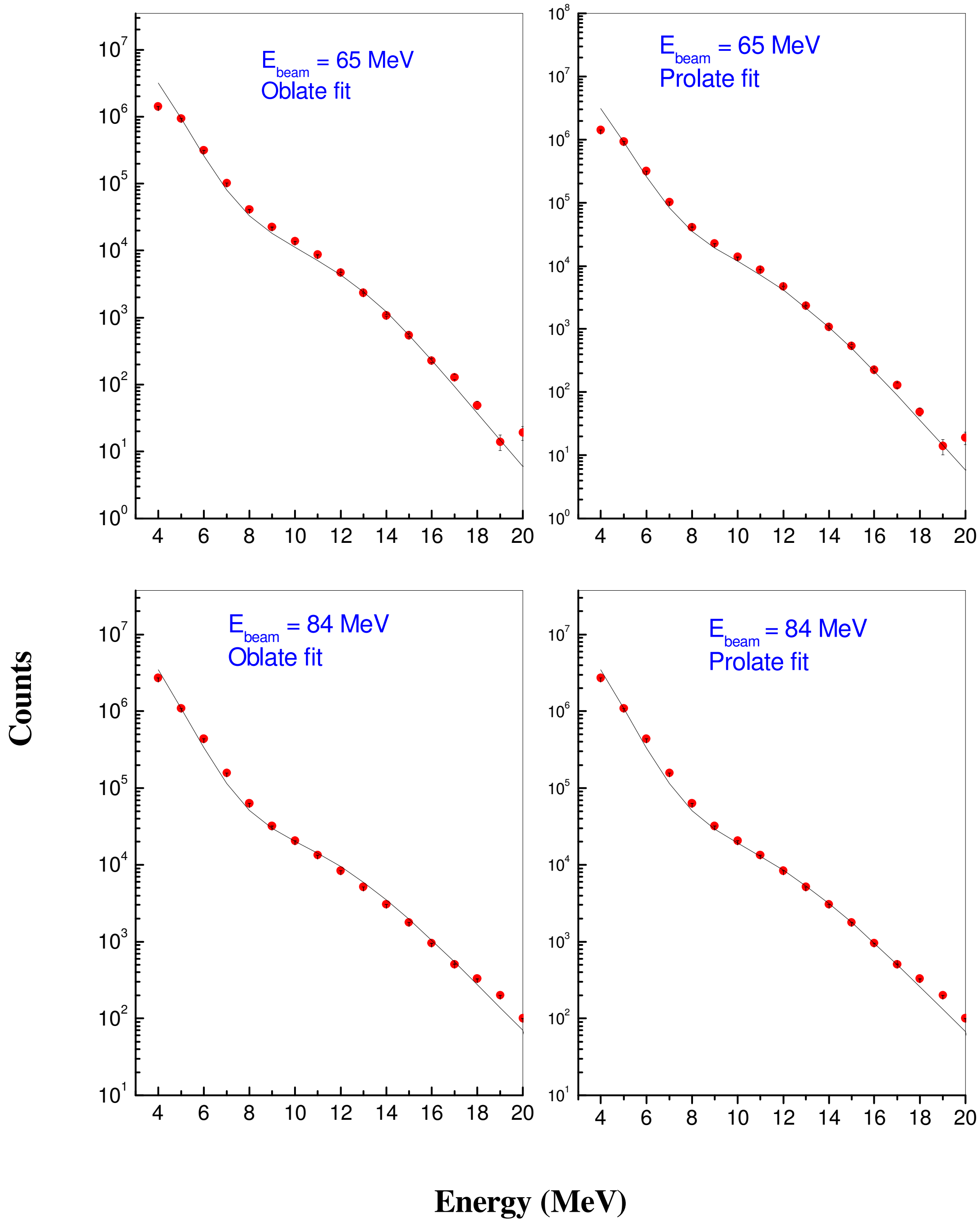
E_beam = 65 MeV
E_beam = 65 MeV
90°
120°
4-6 Fold
9-12 Fold
135°
150°
Counts
Energy (MeV)
Energy (MeV)



E_beam = 84 MeV
E_beam = 84 MeV
Counts
Counts
90°
120°
135°
150°
90°
120°
135°
150°
4-6 Fold
4-6 Fold
4-6 Fold
4-6 Fold
9-12 Fold
9-12 Fold
9 - 12 Fold
9-12 Fold
Energy (MeV)
Energy (MeV)



E_beam = 65 MeV
W(150°)/W(90°)
W(135°)/W(90°)
W(120°)/W(90°)
Energy (MeV)
84 MeV Data
188Os*
Coll. Prolate
Non-coll. Oblate
65 MeV data
188Os*
Coll. Prolate
Non-Col. Oblate
Eγ (MeV)



Cascade fits

- Ignatyuk-Reisdorf formalism for NLD.
- GDR width varied in successive steps.
- Constrained realistic fits not allowing the centroid to vary more than 500KeV from known systematics.
- Convoluted with response matrix of the array and normalized at 5 MeV.
- Fit parameters chosen after χ^2 minimisation and visual Inspection.

Deformation parameters extracted from CASCADE fits

E_{beam} = 65 MeV

Shape	E1	Γ1	E2	Γ2	S2
Prolate	12.0	7.0	15.0	9.0	0.67
Oblate	13.5	8.0	15.0	9.0	0.33
Spherical	13.5	9.5			

E_{beam} = 84 MeV

Shape	E1	Γ1	E2	Γ2	S2
Prolate	13.0	11.5	15.0	12.5	0.67
Oblate	13.5	10.5	16.0	12.0	0.33
Spherical	13.5	12.0			

E_{beam} = 65 MeV

	β	δ	a_o
Prolate	.26	1.12	8.0
Oblate	.12	1.12	8.0

E_{beam} = 84 MeV

	β	δ	
Prolate	.17	0.6	9.0
Oblate	.19	0.79	9.0

Summary

- Measurements on ^{188}Os have been carried out.

- Statistical model fits to all the spectra, all relevant parameters extracted

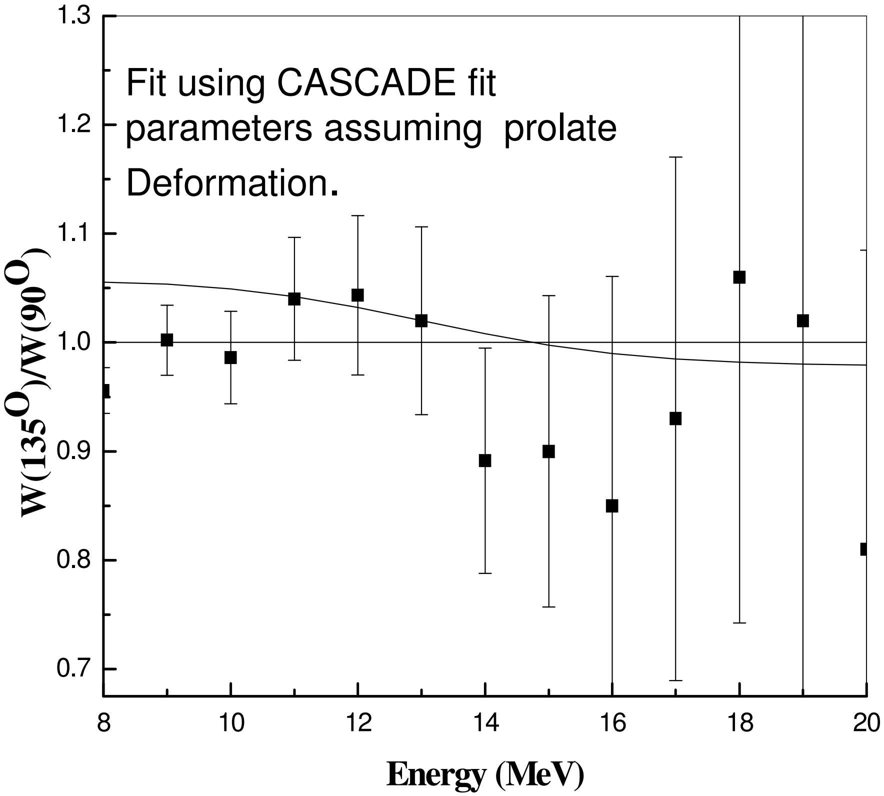
- Exact nature of deformation could not be determined unambiguously from line shape analysis, 84 MeV data is not fitted well considering spherical shape.

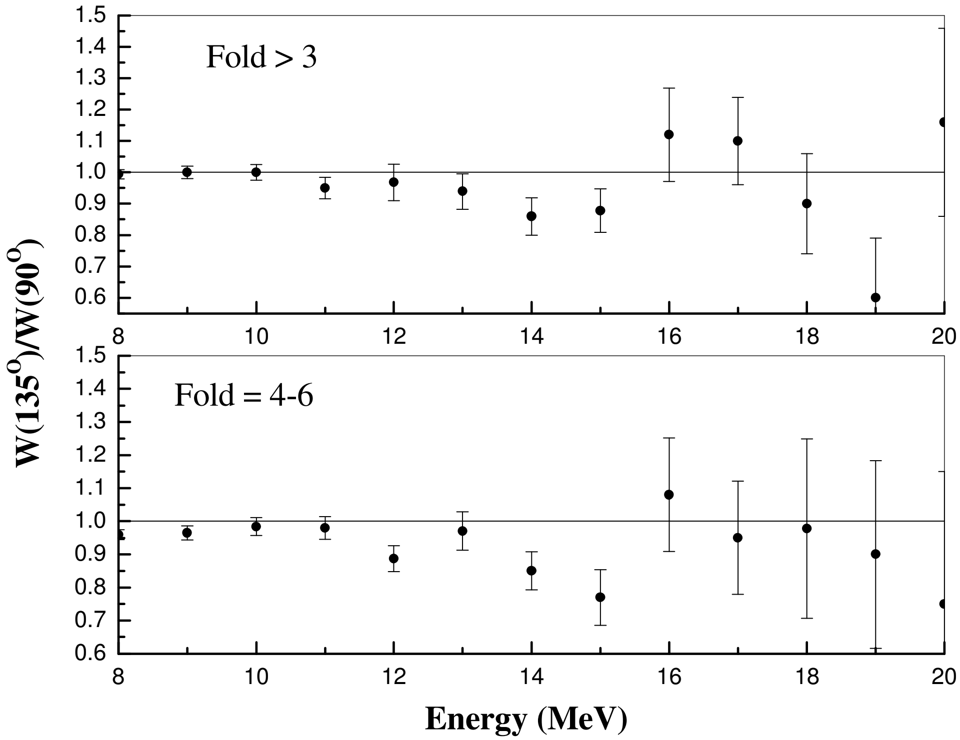
- Considerable angular anisotropy is observed at both the energies.

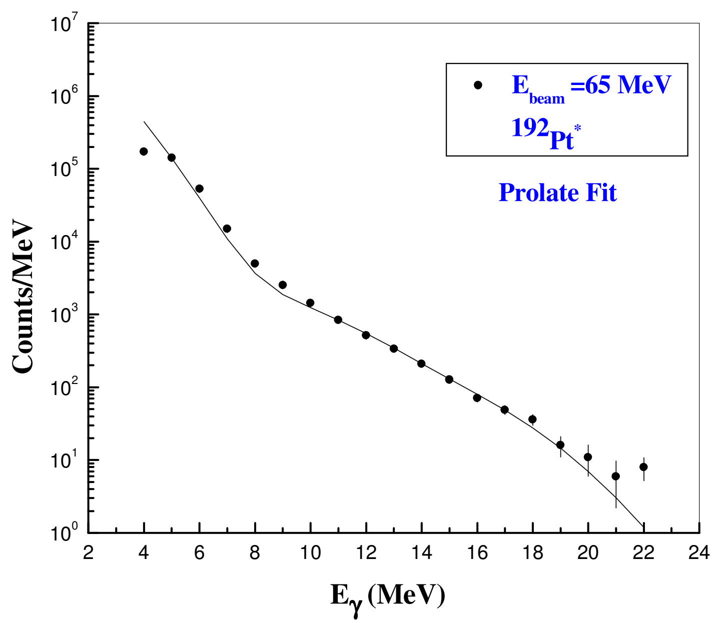
- The angular anisotropy at 84 MeV can be fitted well by calculated anisotropy with fit parameters corresponding to oblate deformation from statistical model analysis of the GDR line shapes . Seems to be in conformity with PES predictions of non-collective oblate phase. But shows larger deformation.

- Unlike ^{194}Au, no convincing evidence of non-collective prolate phase at lower energy. *May be both the energies probe same region in phase-space.*

- Considerable excess counts around the 20 to 28 MeV region even after complete Cosmic ray background subtraction.





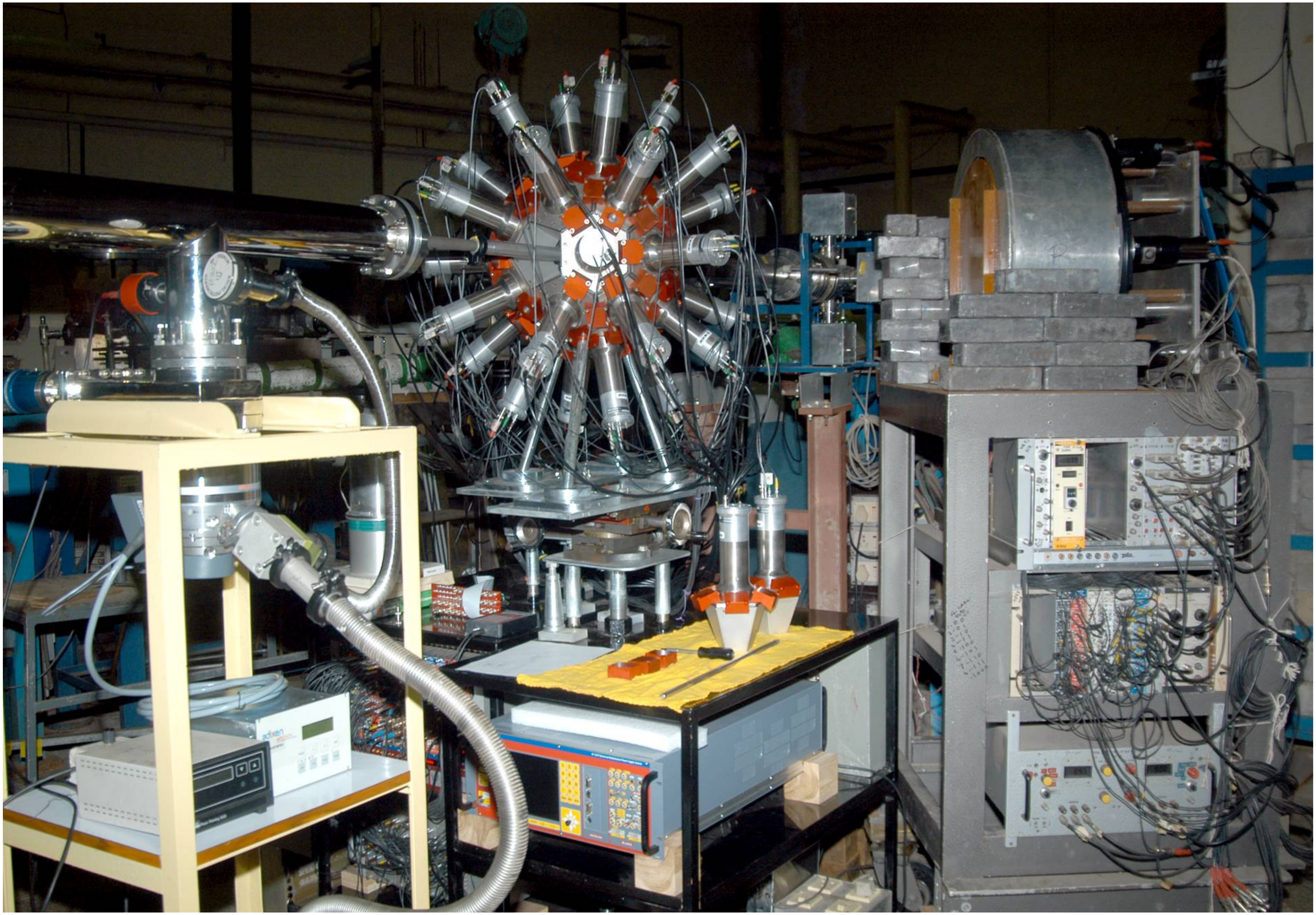


GDR decay from ^{192}Pt

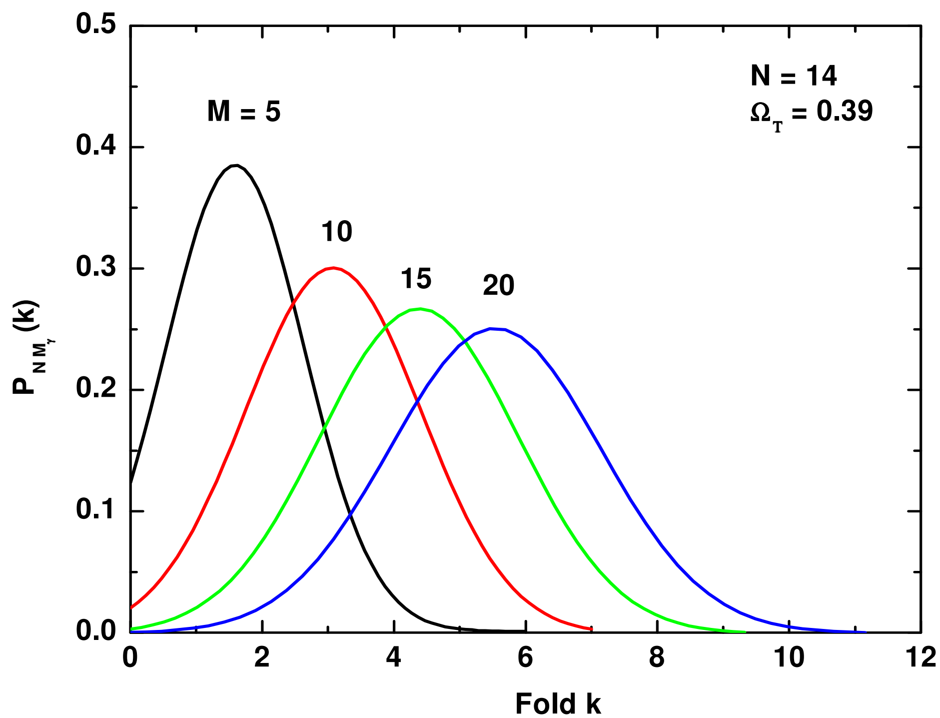
$^{12}C + ^{180}Hf \rightarrow ^{192}Pt$ @ 65 & 80 MeV

High energy γ-ray spectrometer
30 elements 4p spin spectrometer
Measurement of angular anisotropy

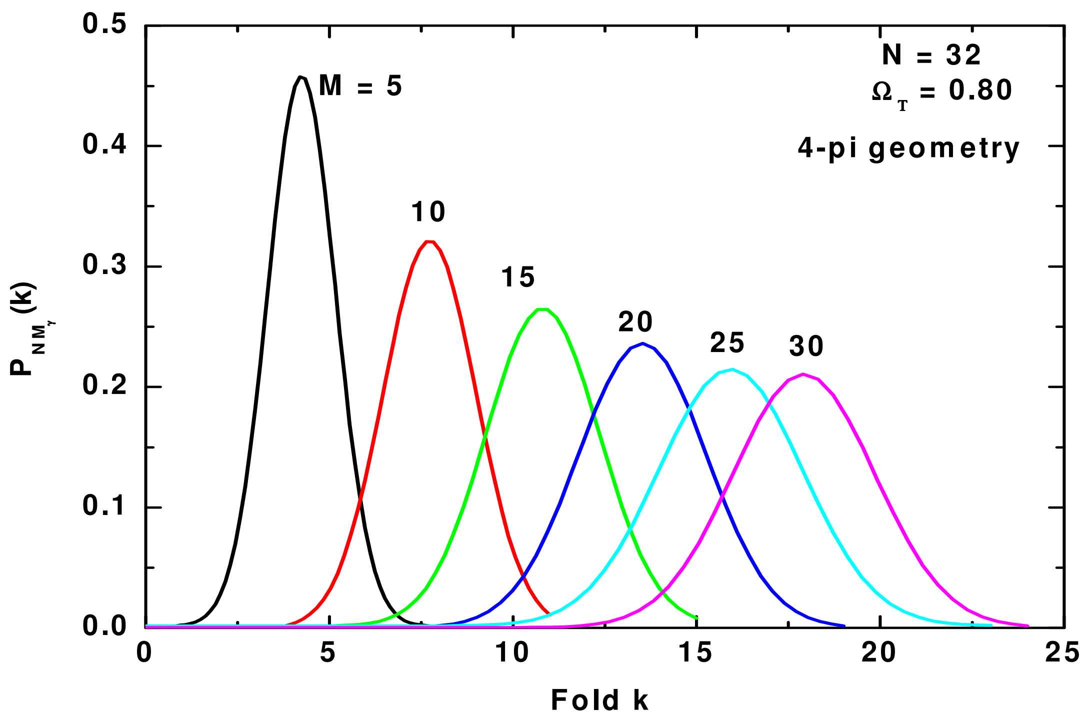
Mazumdar et al. 2009, Acta Phys. Pol.



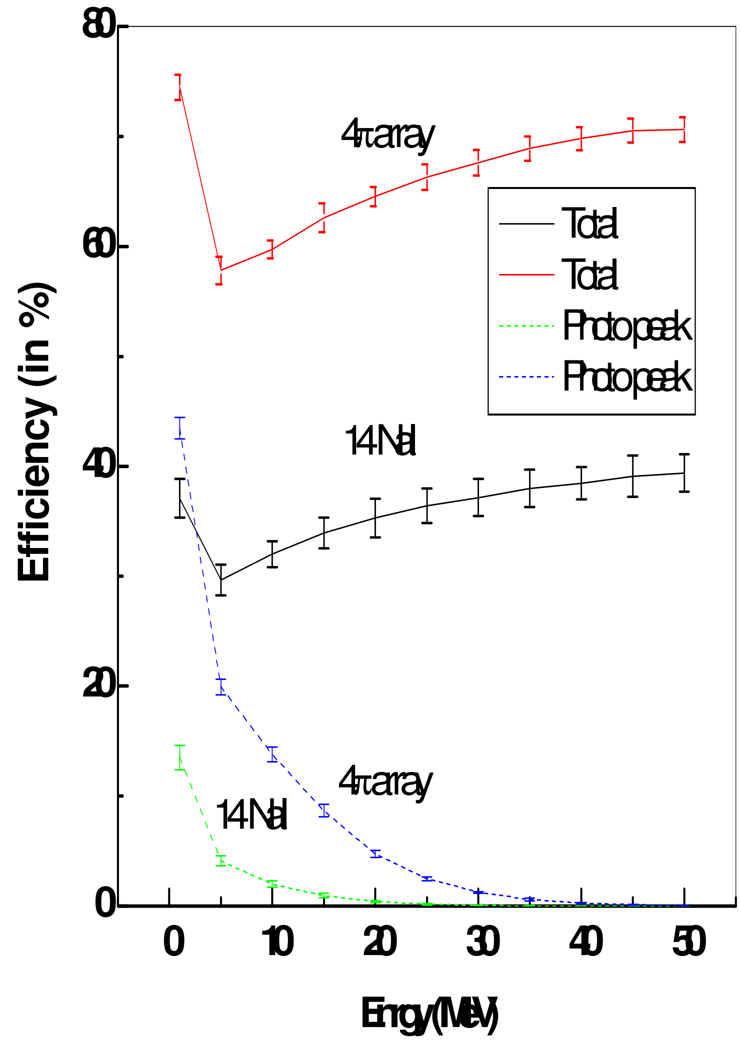
Mazumdar et al (In preparation),   Anil Kumar, Mazumdar, D.A. Gothe, NIM-A (In Press)



N = 14
Ω_T = 0.39
M = 5
10
15
20
$P_{NM_\gamma}(k)$
Fold k



N = 32
Ω_T = 0.80
4-pi geometry
M = 5
10
15
20
25
30
$P_{NM_\gamma}(k)$
Fold k



Efficiency (in %)
4π array
14 NaI
Total
Total
Photopeak
Photopeak
4π array
14 NaI

The Experiment:

$^{12}C + ^{184}W \rightarrow ^{196}Hg$
$^{13}C + ^{184}W \rightarrow ^{195}Hg$

E_{beam} = 65, 85 MeV ^{12}C
75 MeV ^{13}C

Current 3-5 pnA

The Arsenal

HIGRASP
Large LaBr3:Ce detector } GDR γs

32 elements 4π spin-spectrometer Low energy γs

HYRA ERs

E_{beam}	$\sigma_{residue}$	l_{max}	E^*	T_{eff}	$\sigma_{fission}$
85 MeV	**964 MB**	**36 h**	**73 MeV**	**1.8 MeV**	**23 MB**
65 MeV	**265 MB**	**16 h**	**54 MeV**	**1.5 MeV**	**0.2 MB**

Studies in Scintillator Detectors

Response of a 4π array *NaI*

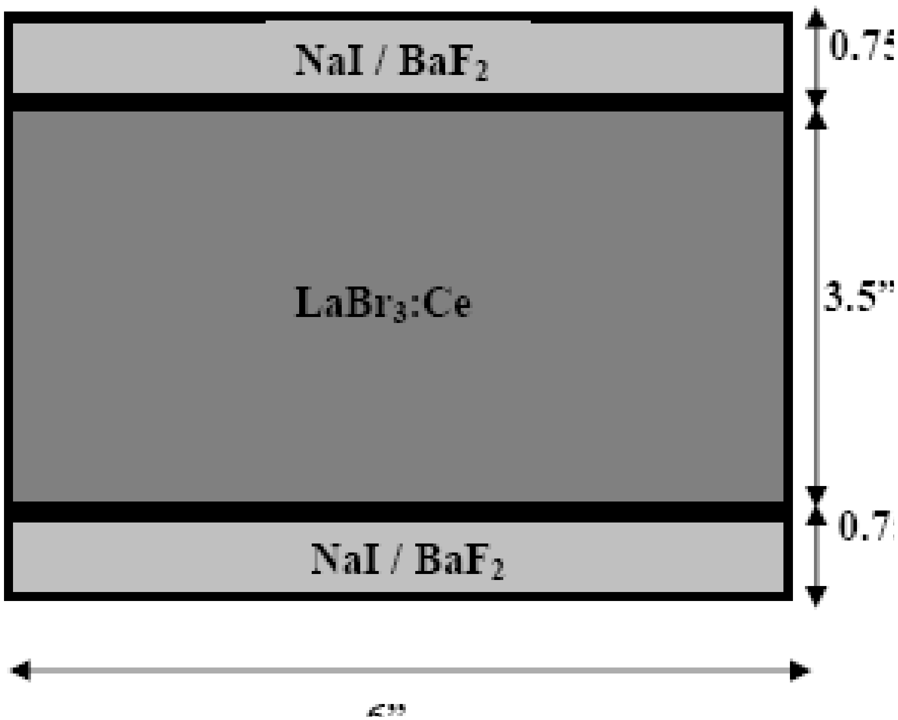
LaBr3:Ce

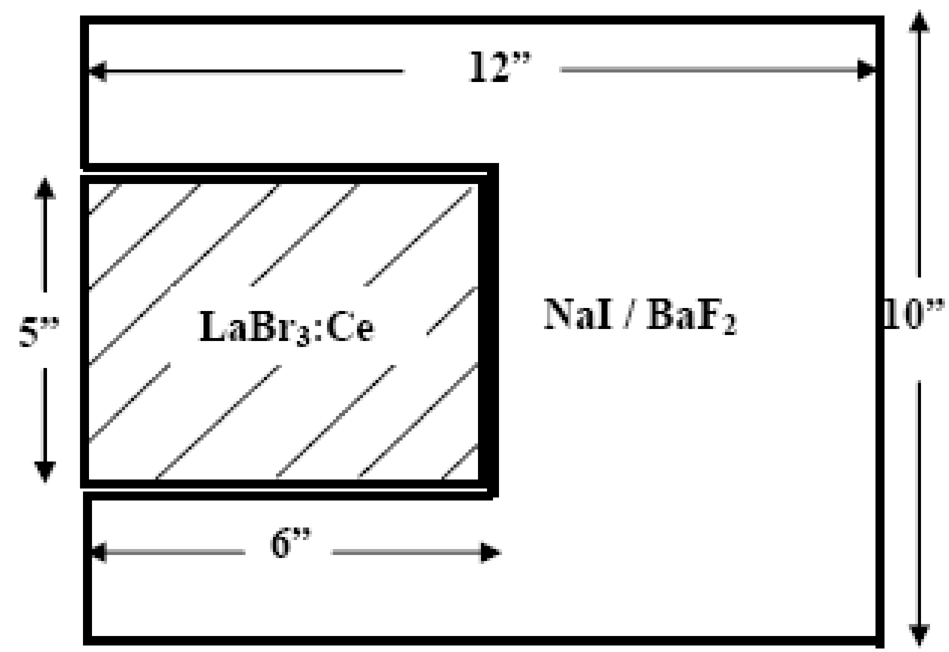
Performance of a small $LaBr_3$:Ce (*NIM-A, In Press*)

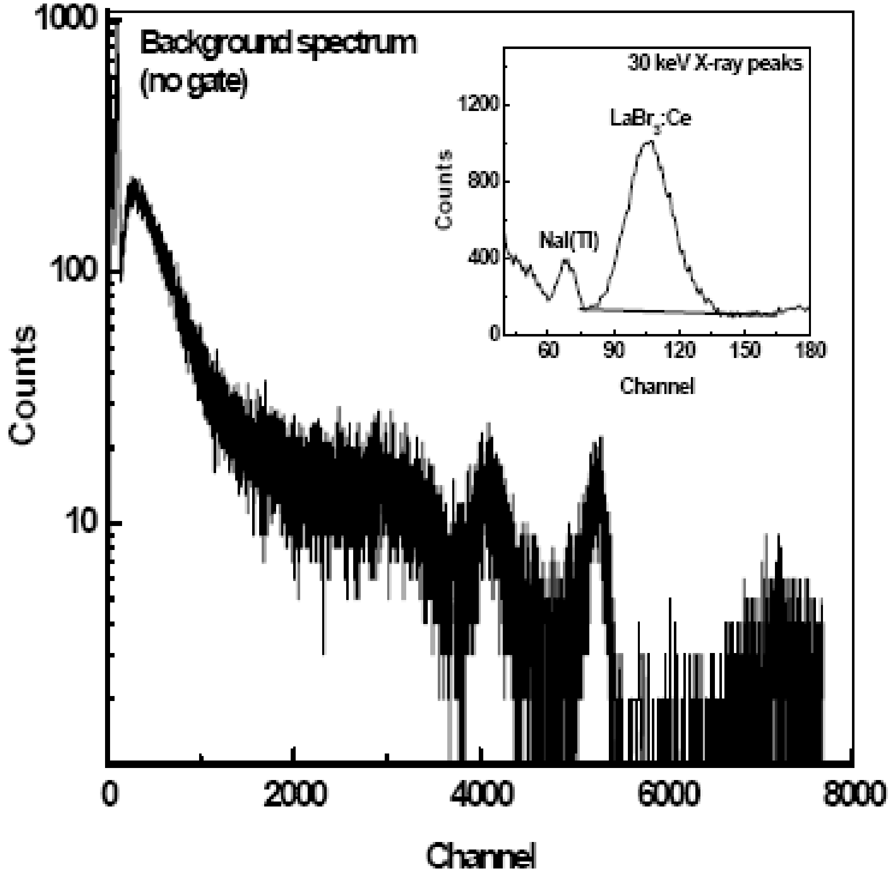
Proposition for combined scintillator assemblies

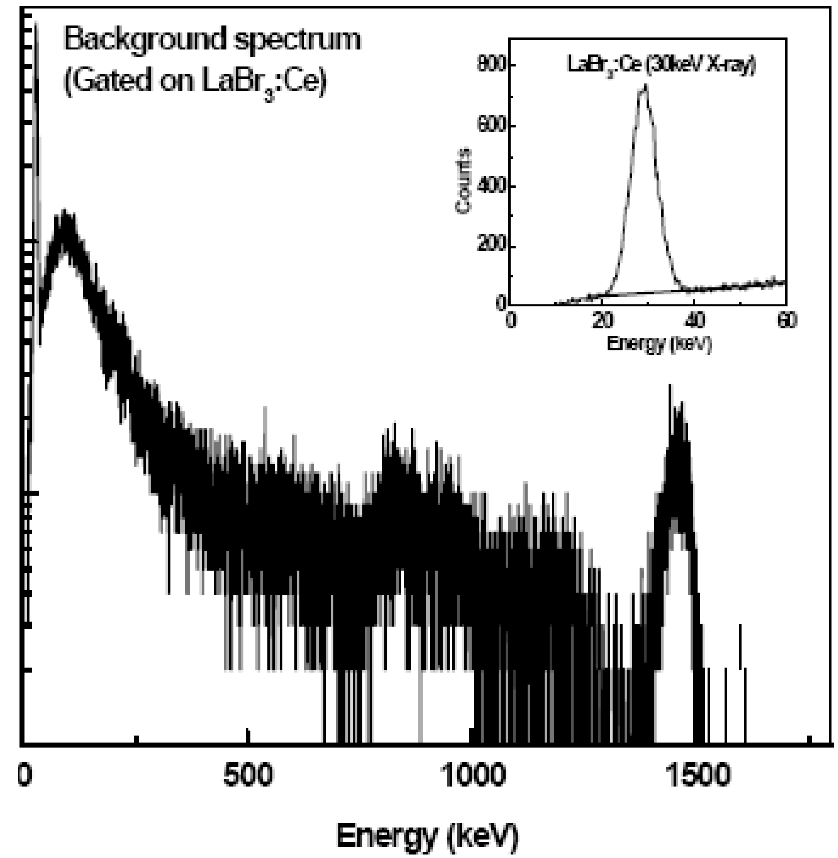
(*NIM-A, In Press*)

Performance of a Phoswich of $LaBr_3$:Ce+NaI(Tl)


NaI / BaF2
LaBr3:Ce
3.5”
NaI / BaF2


12”
5”
LaBr3:Ce
NaI / BaF2
10”
6”





<u>Pulse shape discrimination for a LaBr$_3$:Ce+NaI(Tl) Phoswich</u>

<u>Reduction of internal 30 keV radioactivity</u>


Thank You