Re Investigation of entrance channel effects in heavy ion fusion fission dynamics

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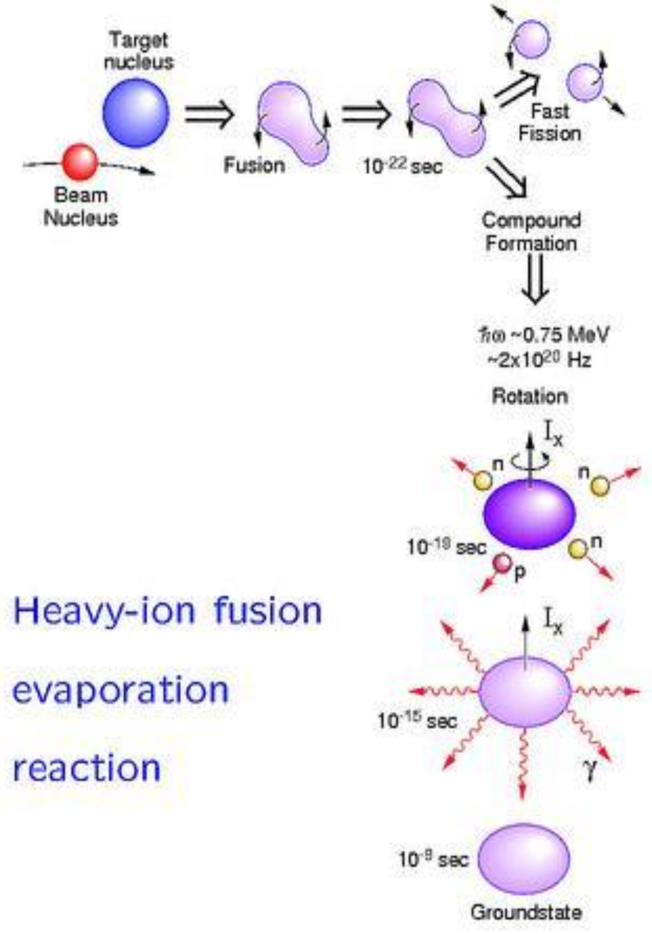


* Formation of compound nucleus.

* Statistical decay of the equilibrated system.

* Decay is independent of the mode of formation.

* Formation of compound nucleus is instantaneous

Theoretical calculation

- CASCADE, HICOL, PACE and MODEFF were used to perform theoretical calculations.
- There are two basic quantities that govern the flow of an evaporation cascade.
- (a) The spin dependent level densities, defining the available phase space.
- (b) The transmission coefficients that control access to this space.

Experimental Plans

$^{12}C + ^{64}Zn \rightarrow ^{76}Kr^{*}$

E_{Lab} = 85 MeV

E^{*} = 75 MeV

$\ell_{max.}$ = 39 $\hbar$

Target thickness = 1.0 mg/cm^2

$^{31}P + ^{45}Sc \rightarrow ^{76}Kr^{*}$

E_{Lab} = 120 MeV

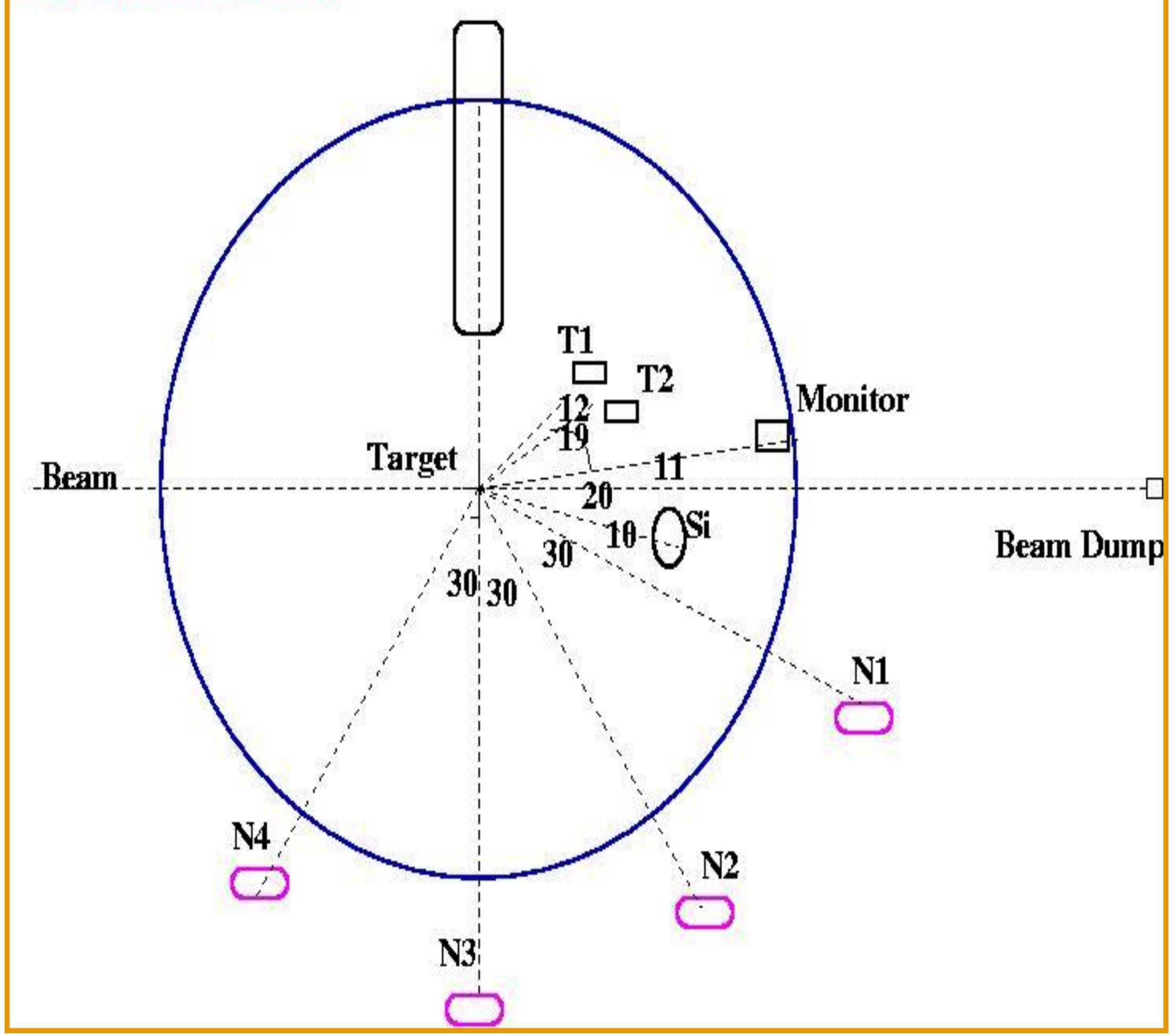
112 MeV

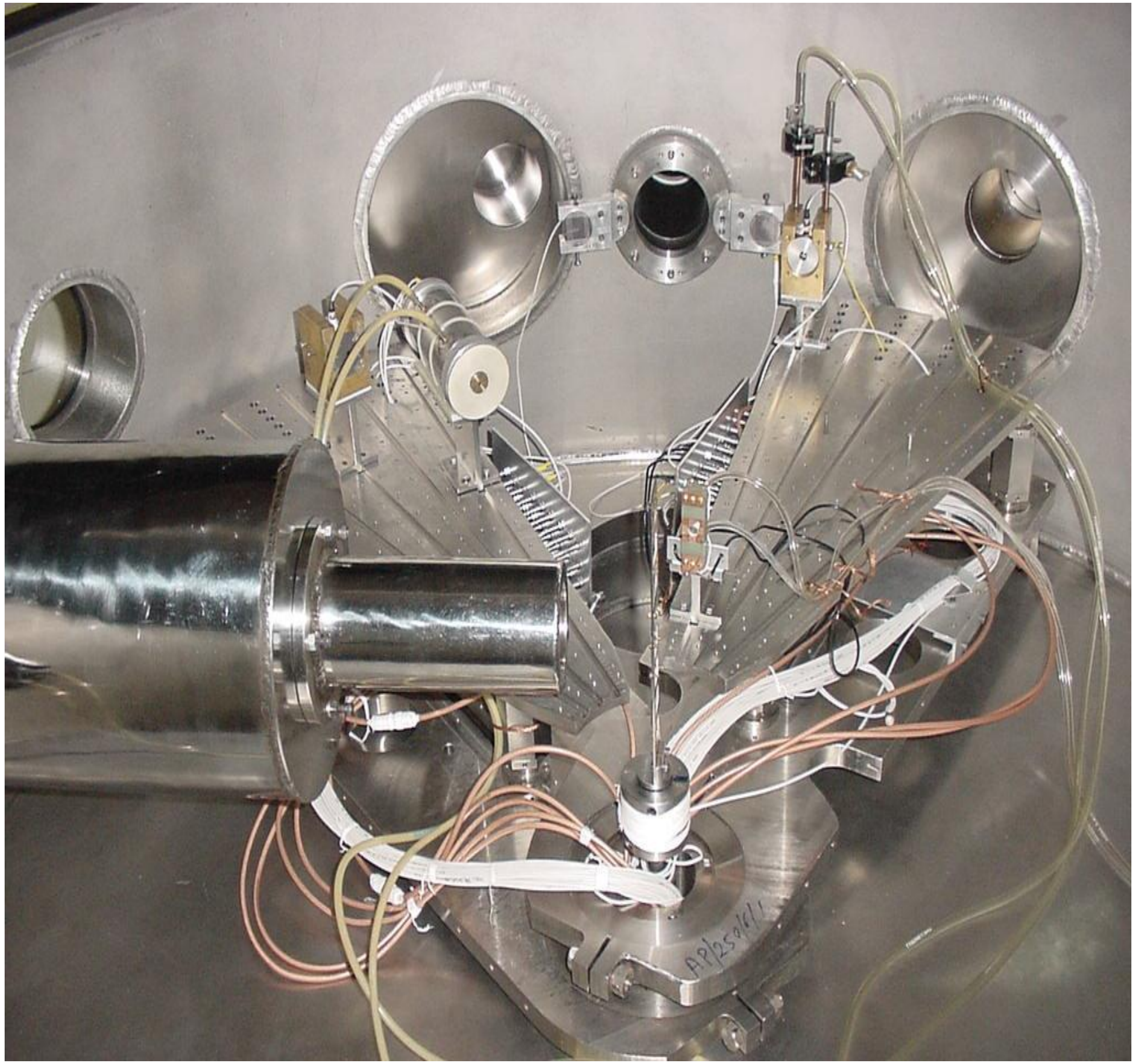
E^{*} = 75 MeV

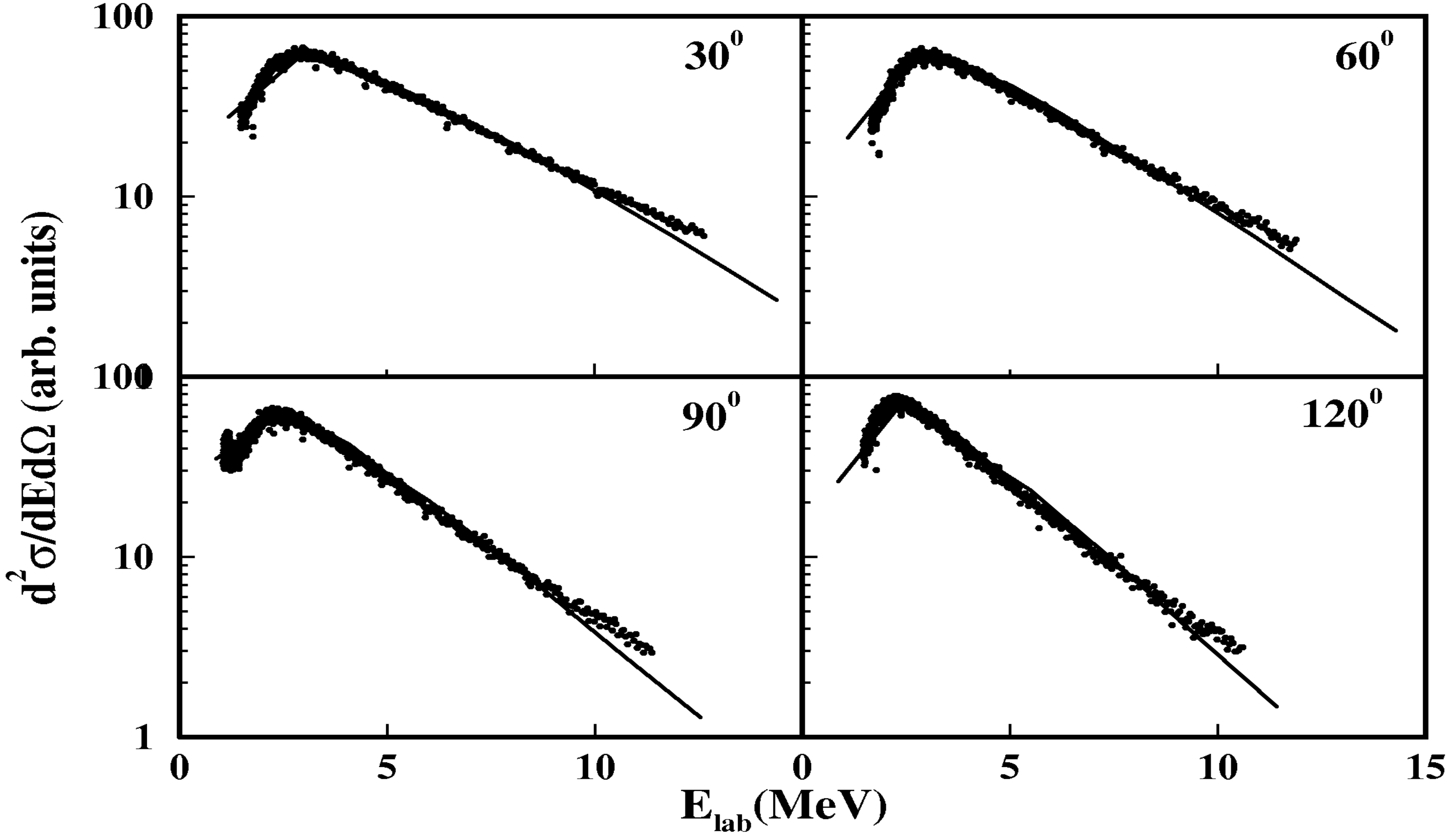
$\ell_{max.}$ = 39 $\hbar$

Target thickness = 1.0 mg/cm^2

Experimental Setup

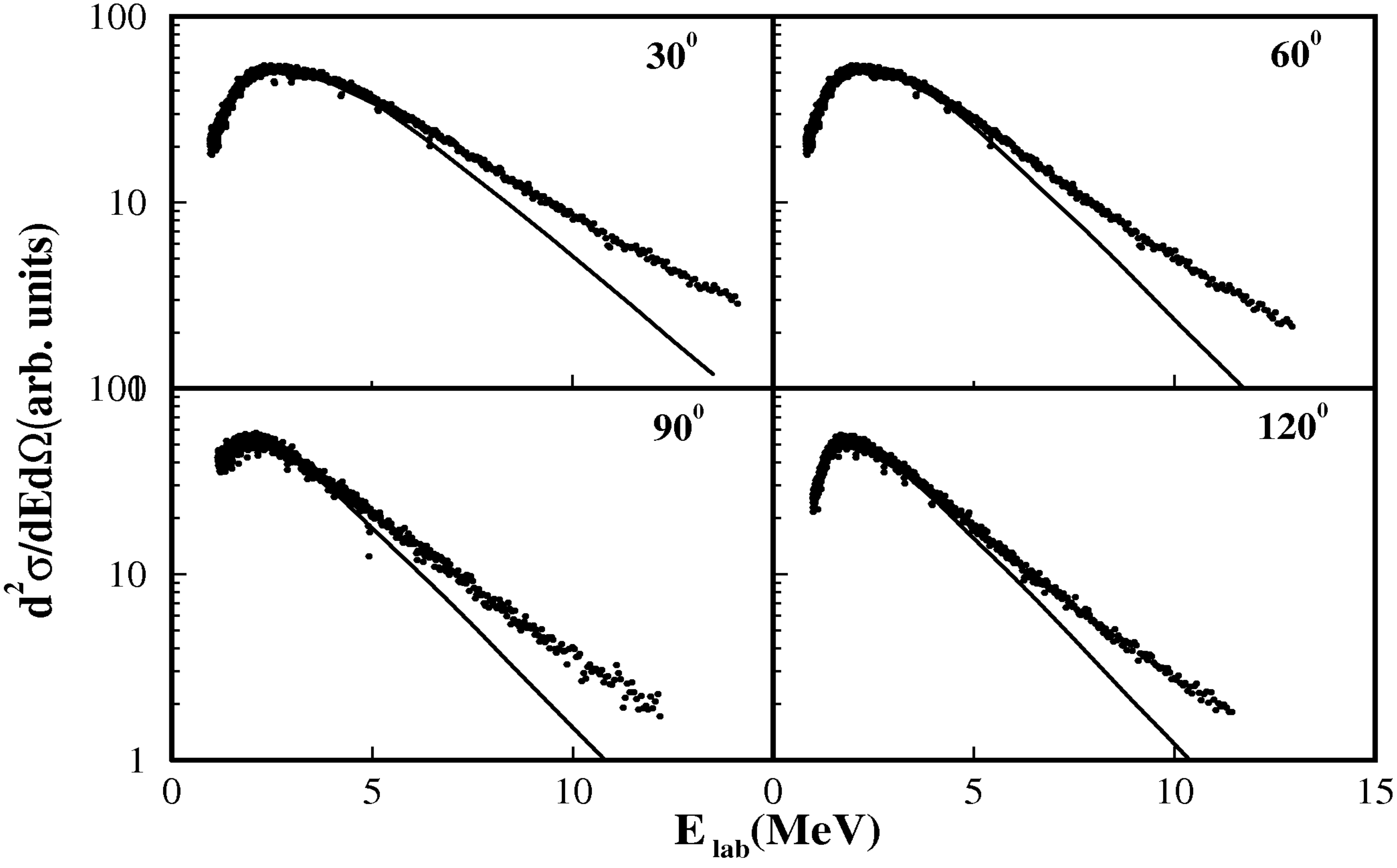




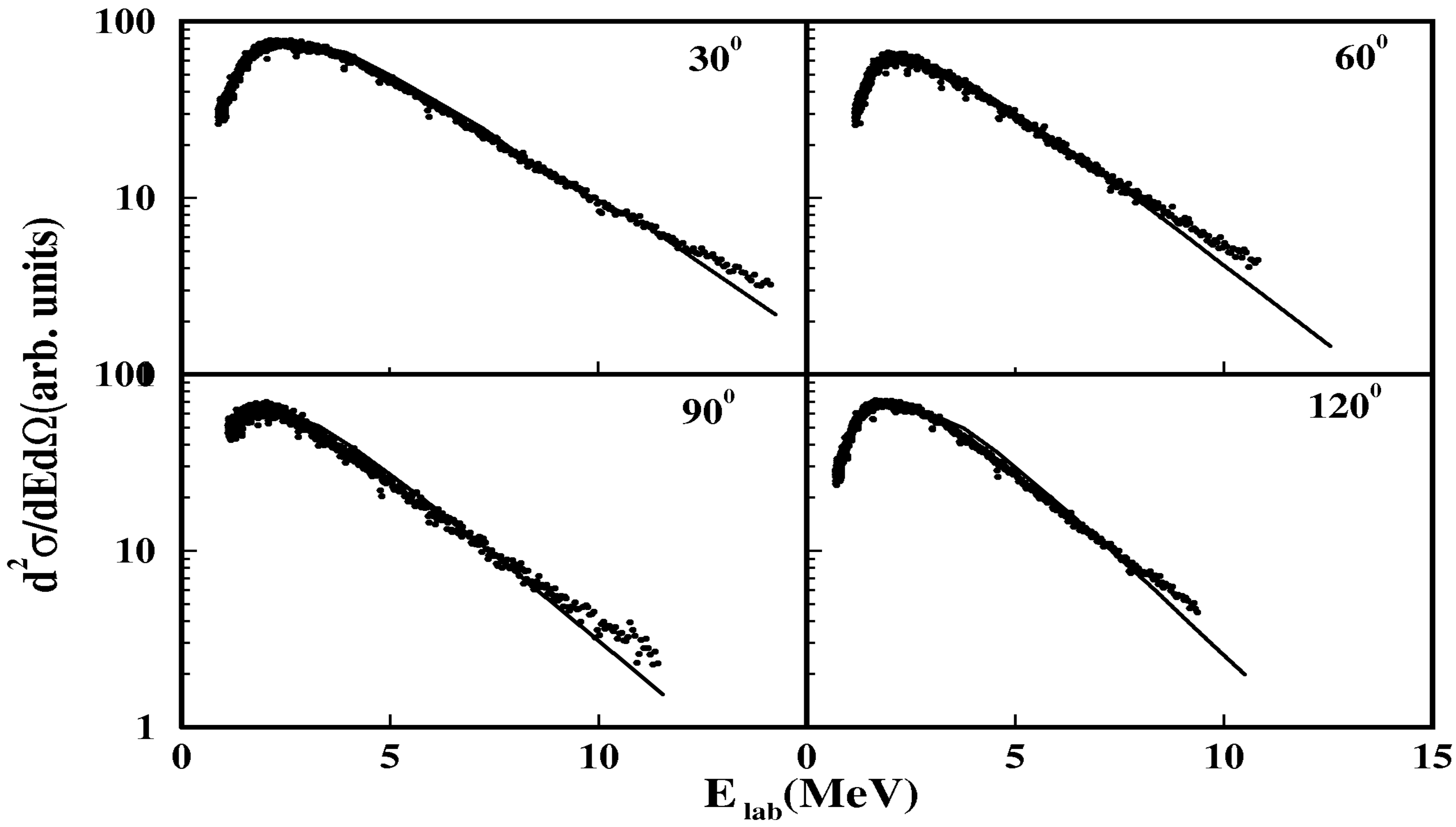


Comparison of the experimental neutron spectra (dots) with the statistical model (solid line) using r_0 = 1.25 and a = A/8 for the asymmetric reaction ^{12}C + ^{64}Zn with ℓmax = 39ℏ and E* = 75 MeV at E_{lab} = 85 MeV.

Ajay Kumar et al, Phys. Rev.C68.



Comparison of the experimental neutron spectra (dots) with the statistical model (solid line) using a = A/8 and r_0 = 1.25 for the symmetric reaction ^{31}P + ^{45}Sc with ℓmax = 39ℏ and E* = 70 MeV at E_{lab} = 112 MeV.



Comparison of the experimental neutron spectra (dots) with statistical model (solid line) using a = A/10 and r_0 = 1.25 for the symmetric reaction ^{31}P + ^{45}Sc with $\ell_{max} = 39\hbar$ and E^* = 70 MeV at E_{lab} = 112 MeV.

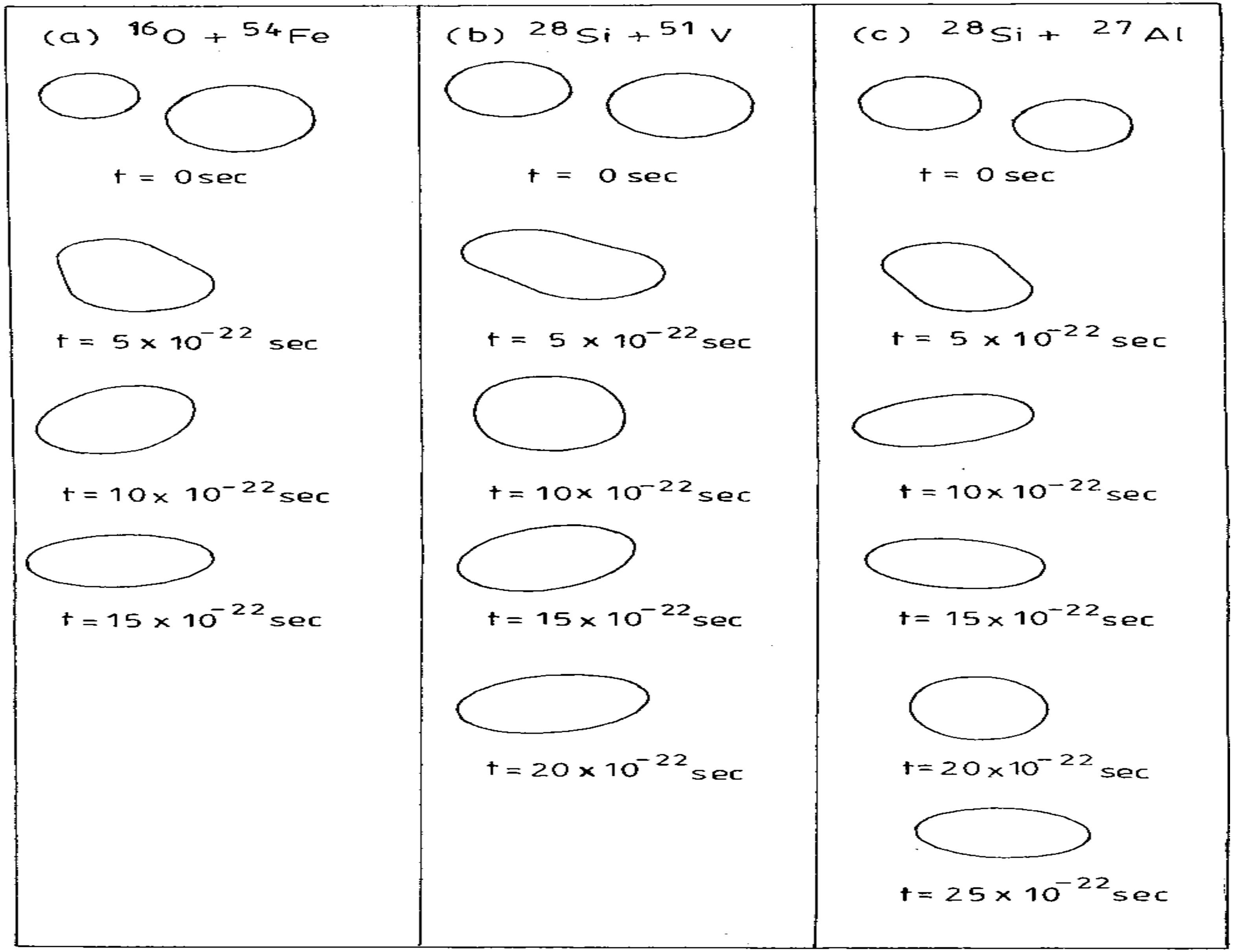
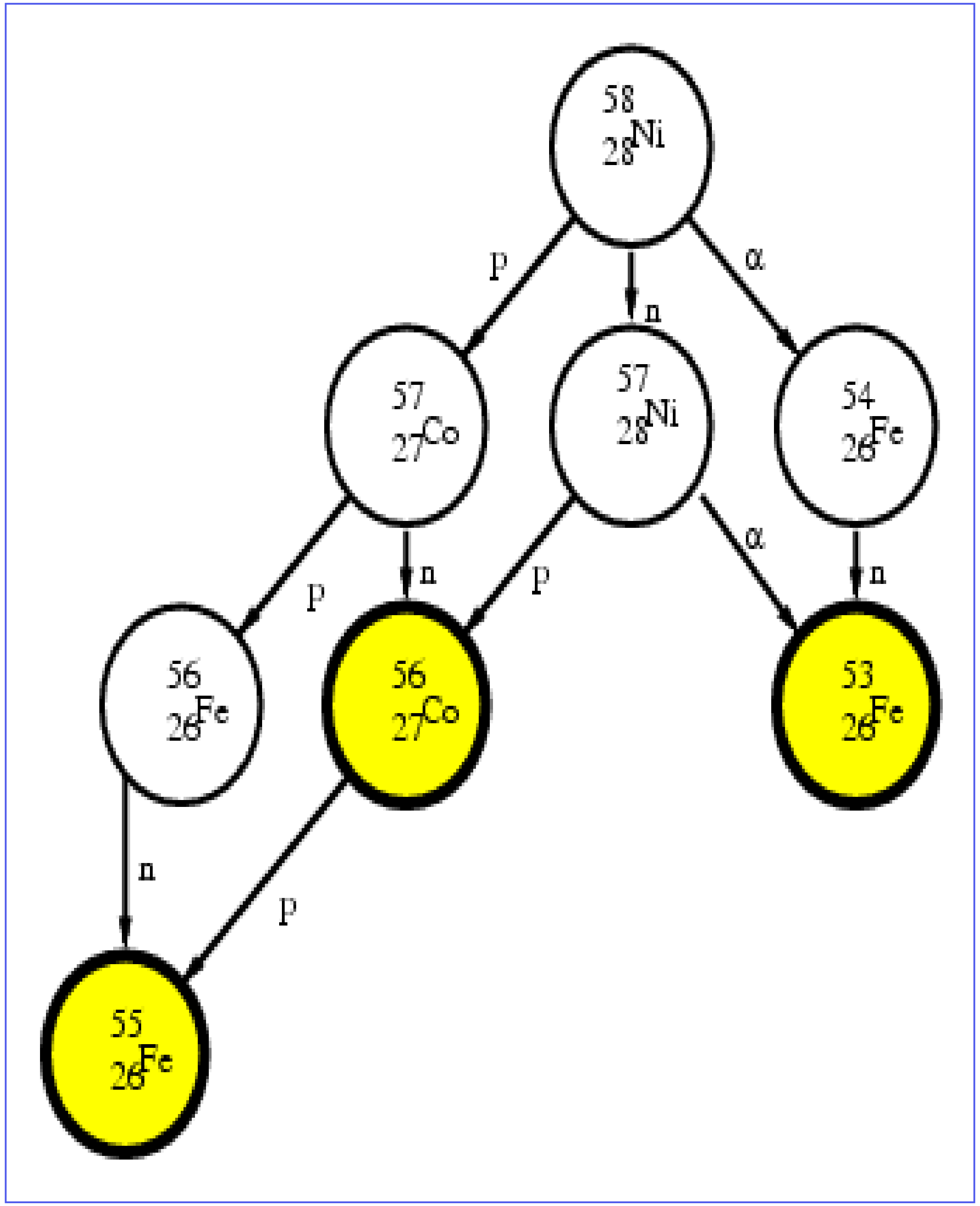


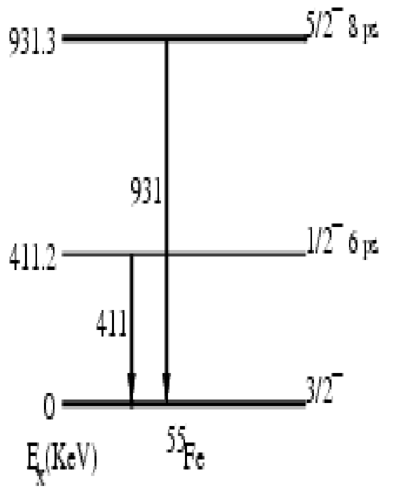
Fig. Time evolution for an angular momentum of 20 ħ for the reactions (a) ^{16}O+^{54}Fe at 110 MeV, (b) ^{28}Si+^{51}V at 140 MeV, and (c) ^{28}Si+^{27}Al at 140 MeV.

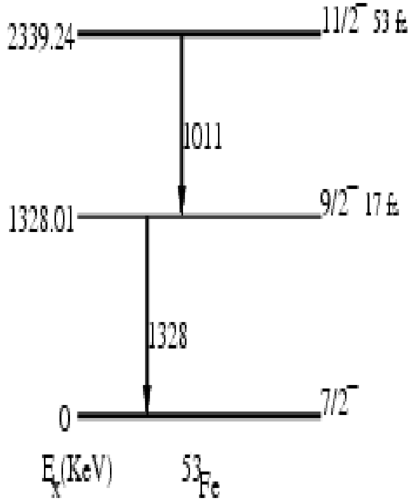
II .Experiment

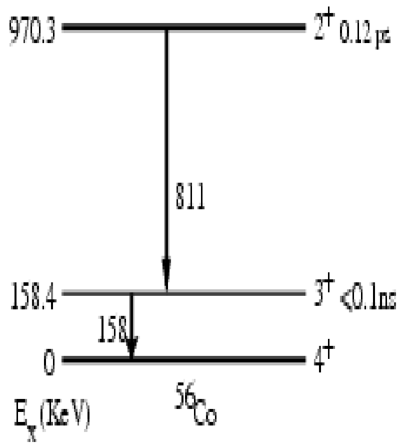
- $^{12}C + ^{46}Ti \rightarrow ^{58}Ni^*$
- E_{Lab} = 80 MeV
- E^* =79.5 MeV
- $\ell_{max.}$ =35 $\hbar$
- Target thickness = 0.8 mg/cm^2

- $^{31}P + ^{27}Al \rightarrow ^{58}Ni^*$
- E_{Lab} = 131 MeV
- E^* =79.5 MeV
- $\ell_{max.}$ =38 $\hbar$
- Target thickness = 1.0 mg/cm^2

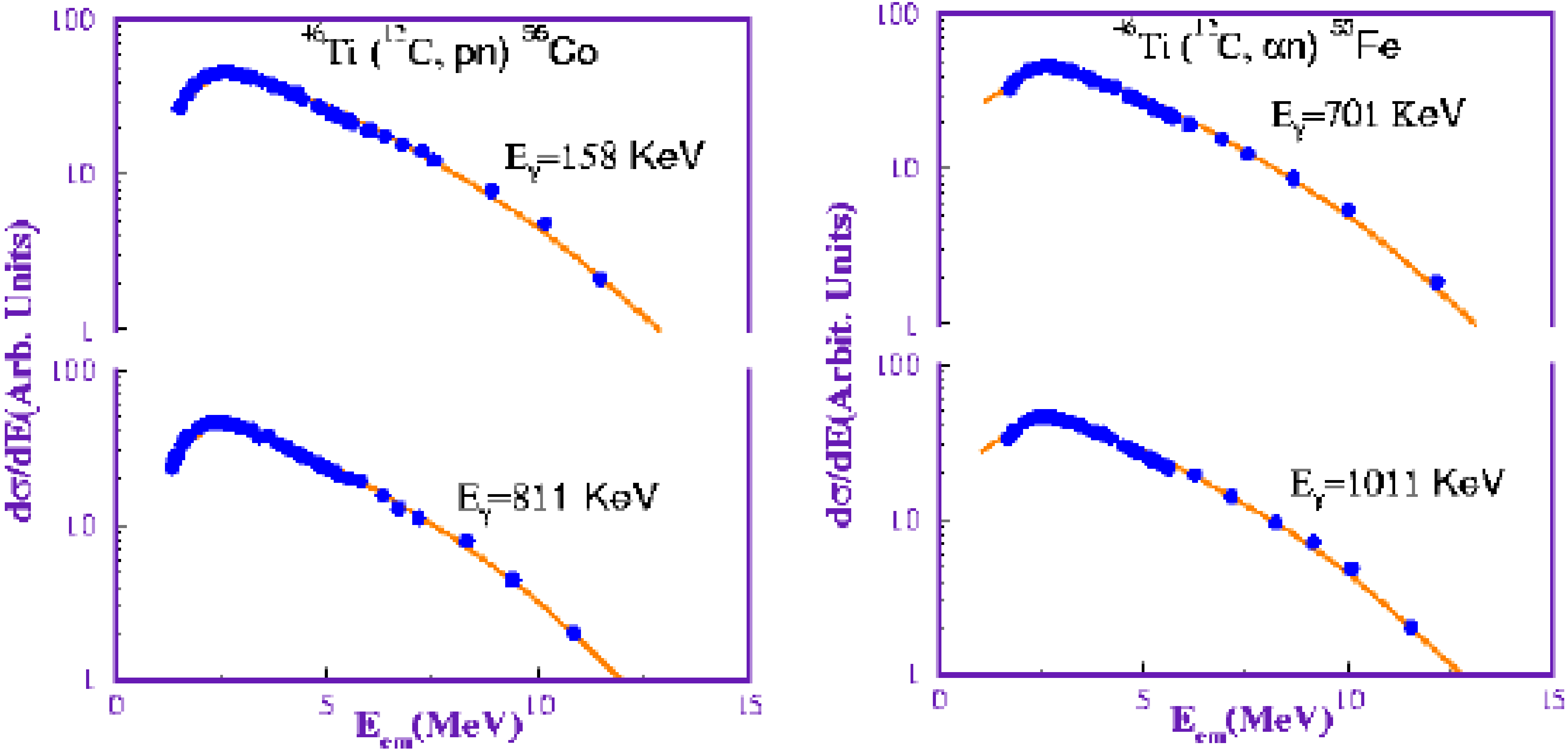




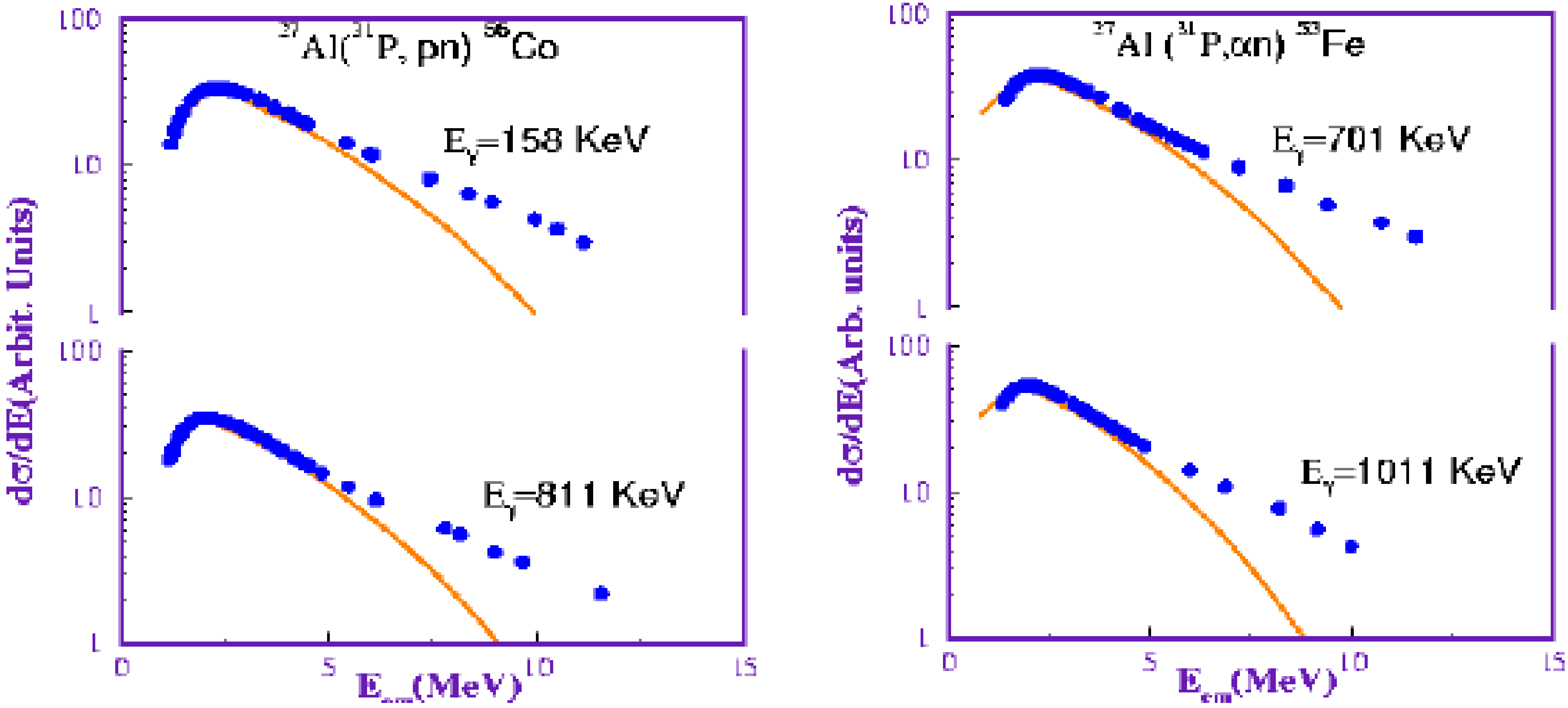




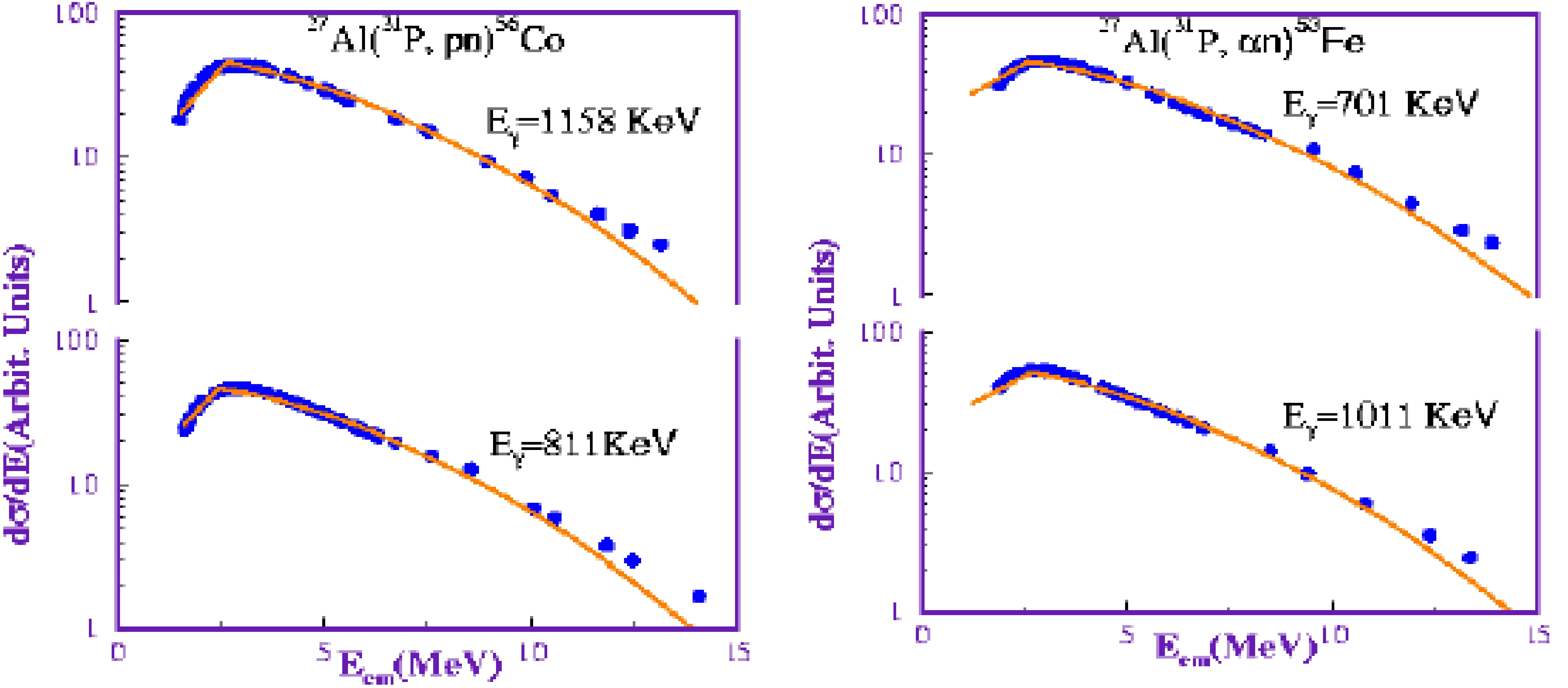
Ajay Kumar et al, Nucl. Phys. A798



Comparison of experimental neutron spectra with statistical model for the γ transitions observed in the final state nucleus ^{56}Co and ^{53}Fe, using r_0= 1.25, a = A/8 for the reaction ^{12}C + ^{46}Ti with ℓ_{max}= 34.5 $\hbar$, E* = 79.5 MeV at E_{lab} = 80 MeV.



Comparison of experimental neutron spectra with statistical model for the γ transitions observed in the final state nucleus ^{56}Co and ^{53}Fe, using r_0 = 1.25, a = A/8 for the reaction $^{31}P + ^{27}Al$ with ℓ_{max}= 38.2 ℏ , E* = 79.5 MeV at E_{lab} = 131 MeV.

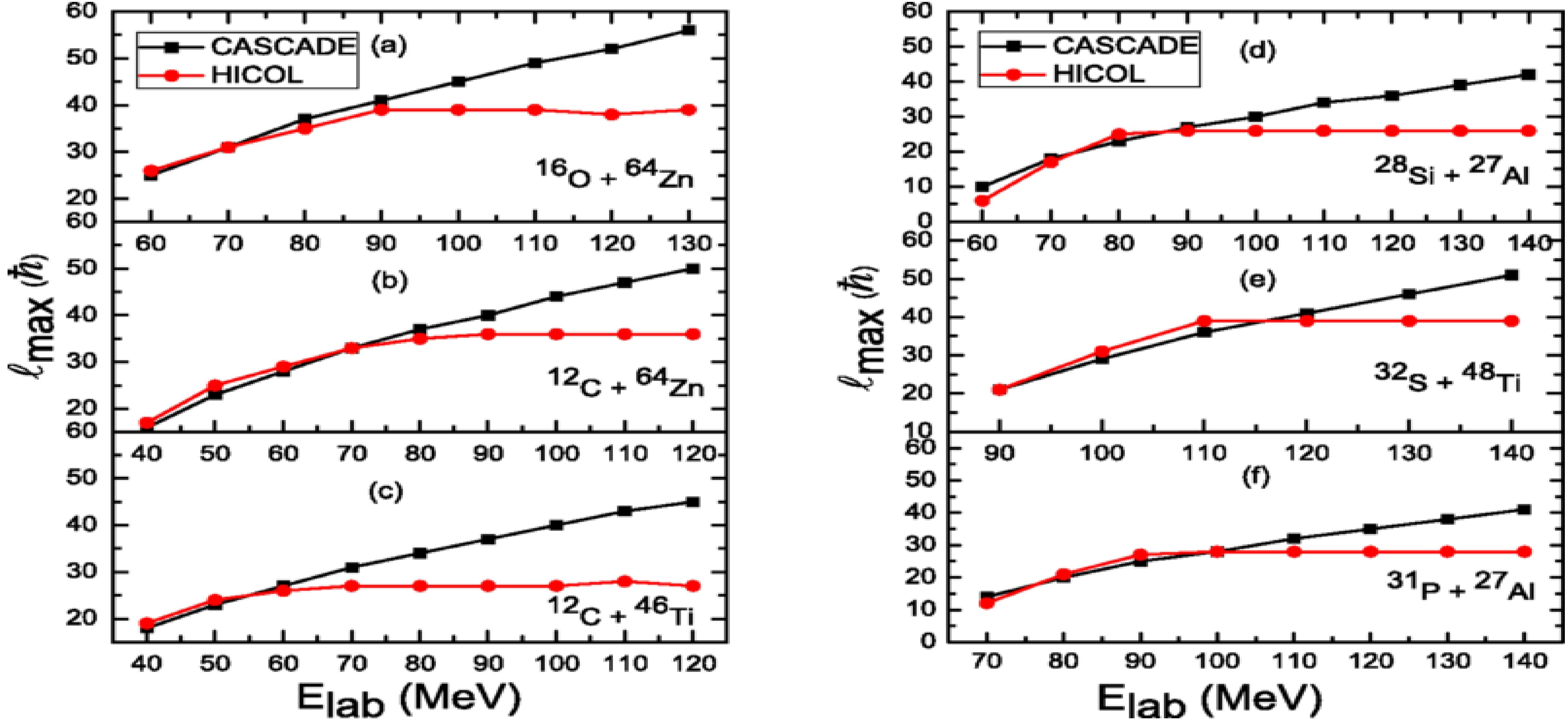


Comparison of experimental neutron spectra with statistical model for the γ transitions observed in the final state nucleus ^{56}Co and ^{53}Fe, using r_0 = 1.25, a = A/10 for the reaction ^{31}P + ^{27}Al with ℓ_{max}= 38.2 ħ , E* = 79.5 MeV at E_{lab} = 131 MeV.

The twist ……………

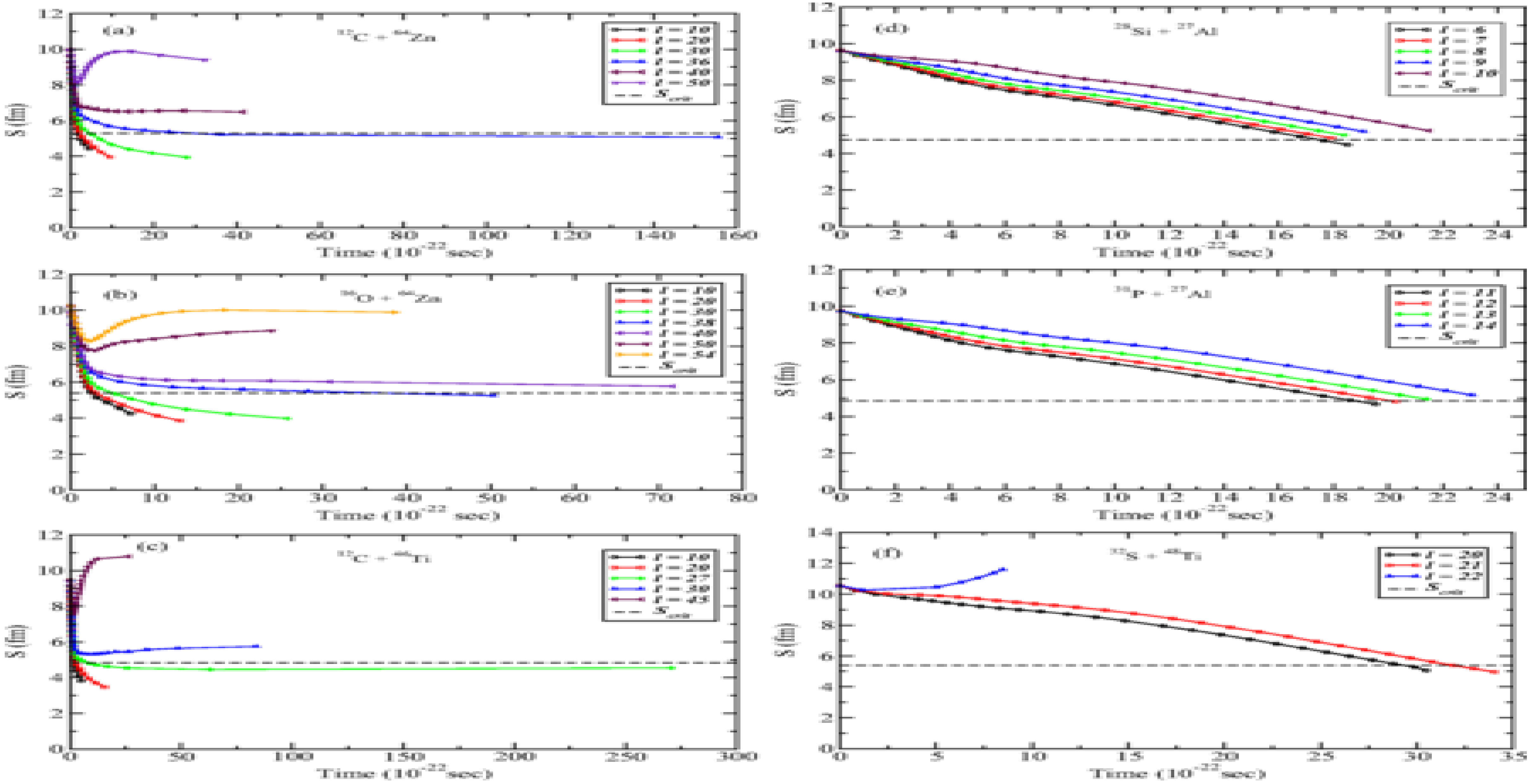
- Studies of evaporated particle energy spectra provide direct information about the main statistical model ingredients e.g. the nuclear level densities and barrier penetration probabilities.
- At higher excitation energy and angular momenta, measured light charged particle have characterized having lower average energy than predicted by statistical model.
- Dissipation influences the formation and decay of the compound nucleus in heavy-ion reactions.

$^{12}C + ^{64}Zn$	$^{28}Si + ^{27}Al$
$^{12}C + ^{46}Ti$	$^{32}S + ^{48}Ti$
$^{16}O + ^{64}Zn$	$^{31}P + ^{27}Al$

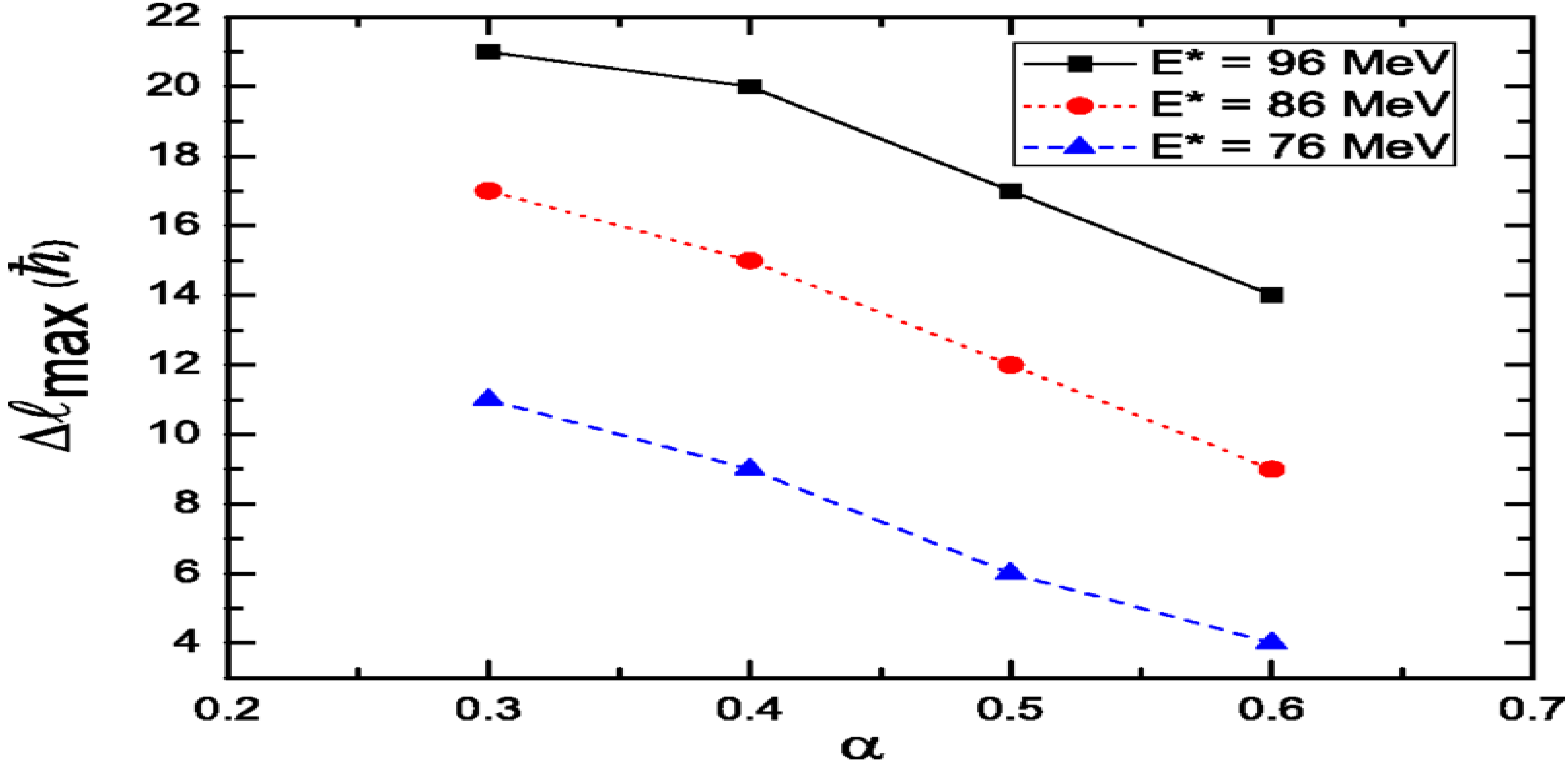


Variation of angular momentum l_{max} with respect to incident energy E_{lab} for asymmetric systems (a)–(c) and symmetric systems (d)–(f).

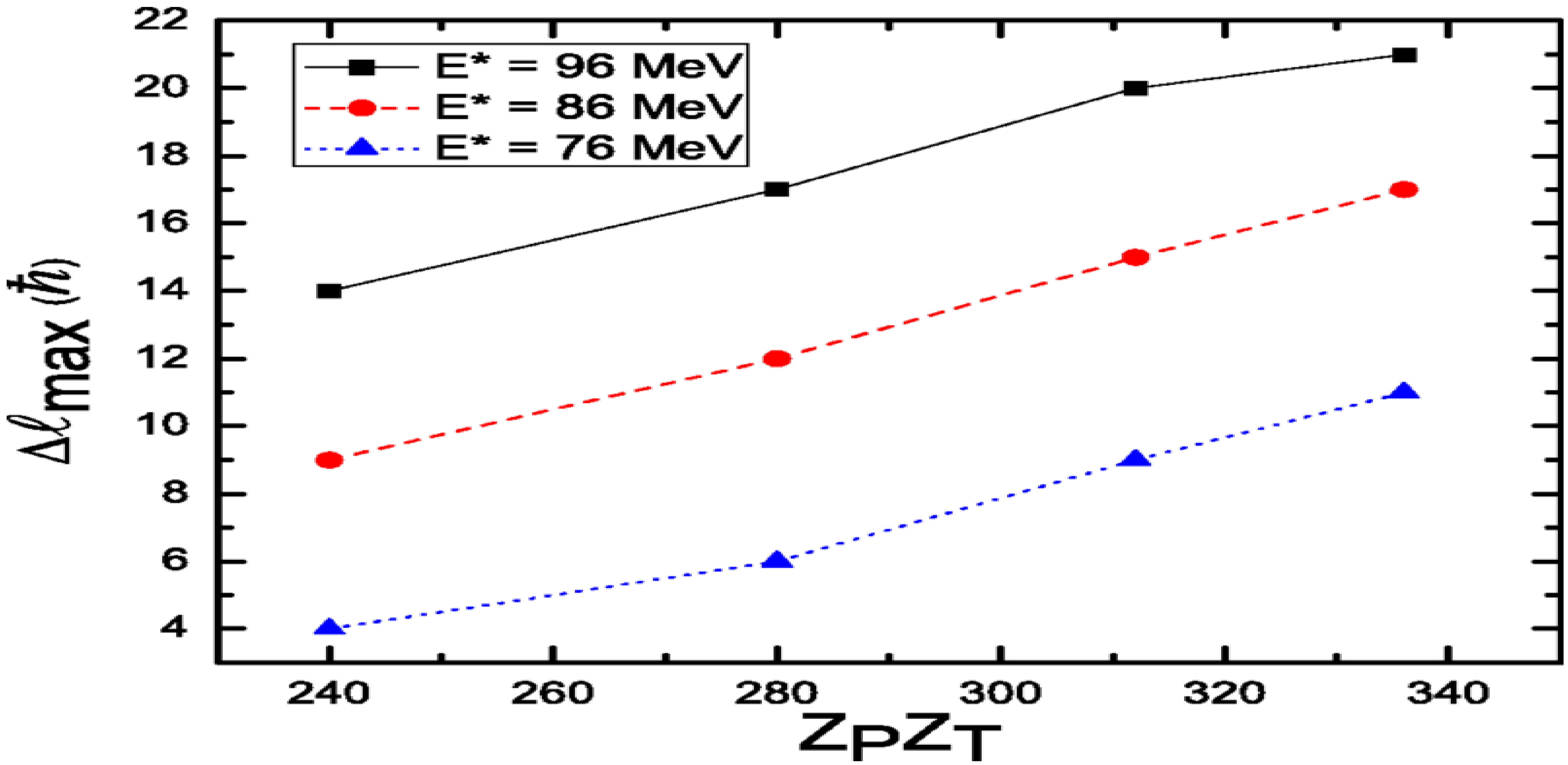
N. K. Rai and Ajay Kumar, Phys. Rev. C 98 (2019)



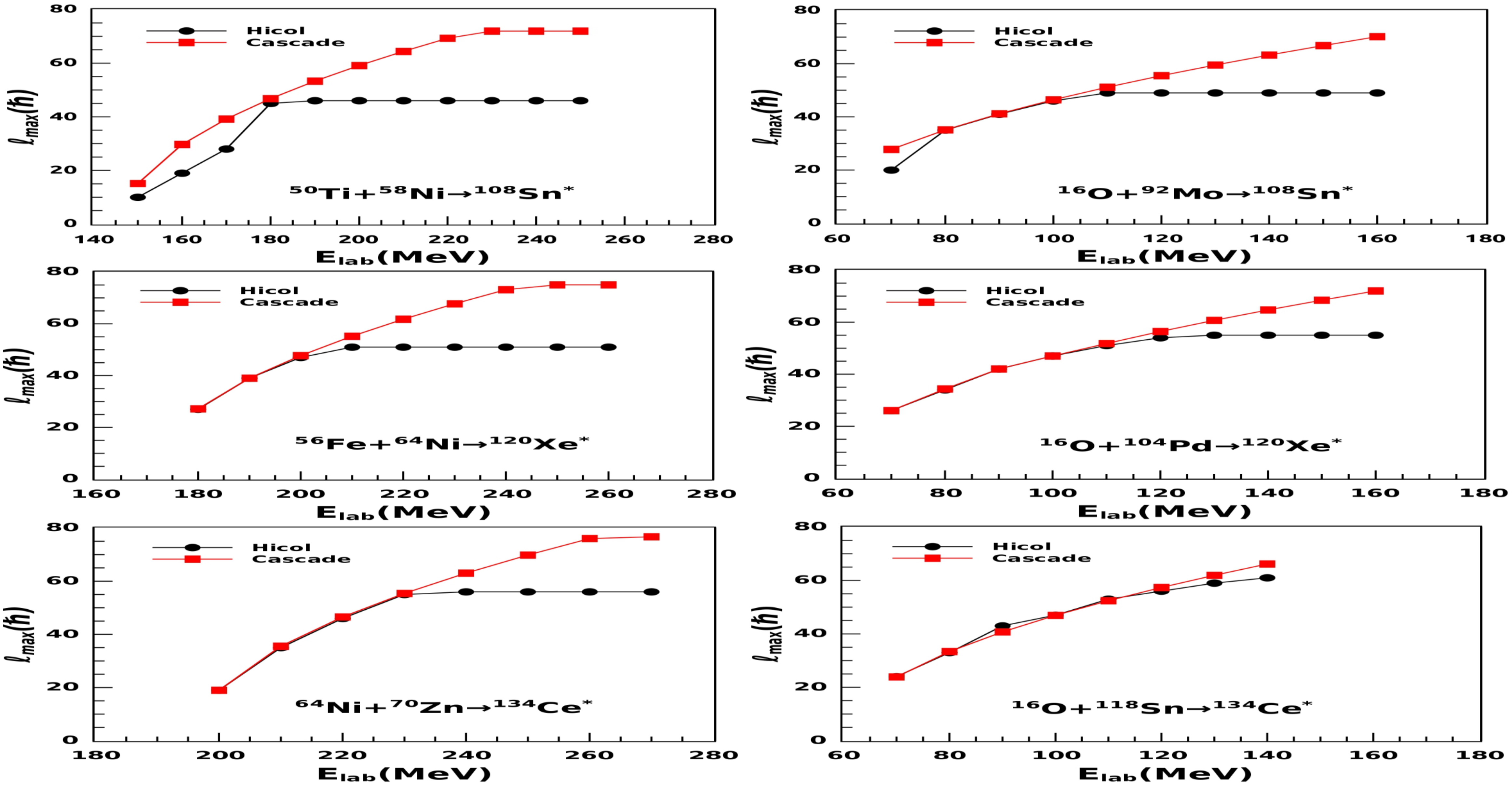
Calculated evolution of the separation (s) as a function of time for asymmetric systems (a)–(c) and symmetric systems (d)–(f).



Variation of angular momentum difference Δl_{max} with respect to mass asymmetry α for various target-projectile combinations, leading to the same compound nucleus ^{80}Sr at different excitation energies.

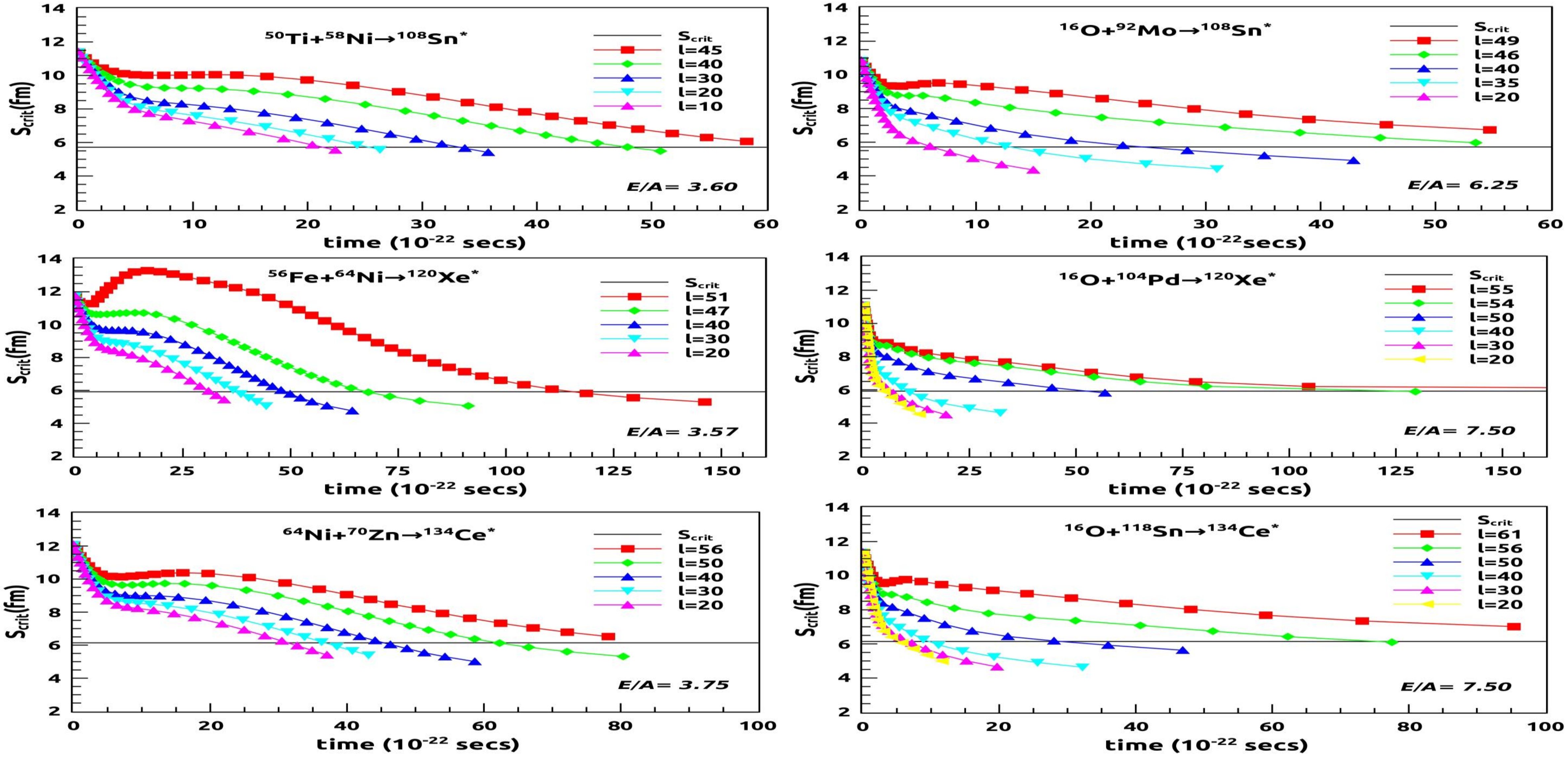


Variation of angular momentum difference Δl_{max} with respect to the charge product $Z_P Z_T$ for various target-projectile combinations, leading to the same compound nucleus ^{80}Sr at different excitation energies.

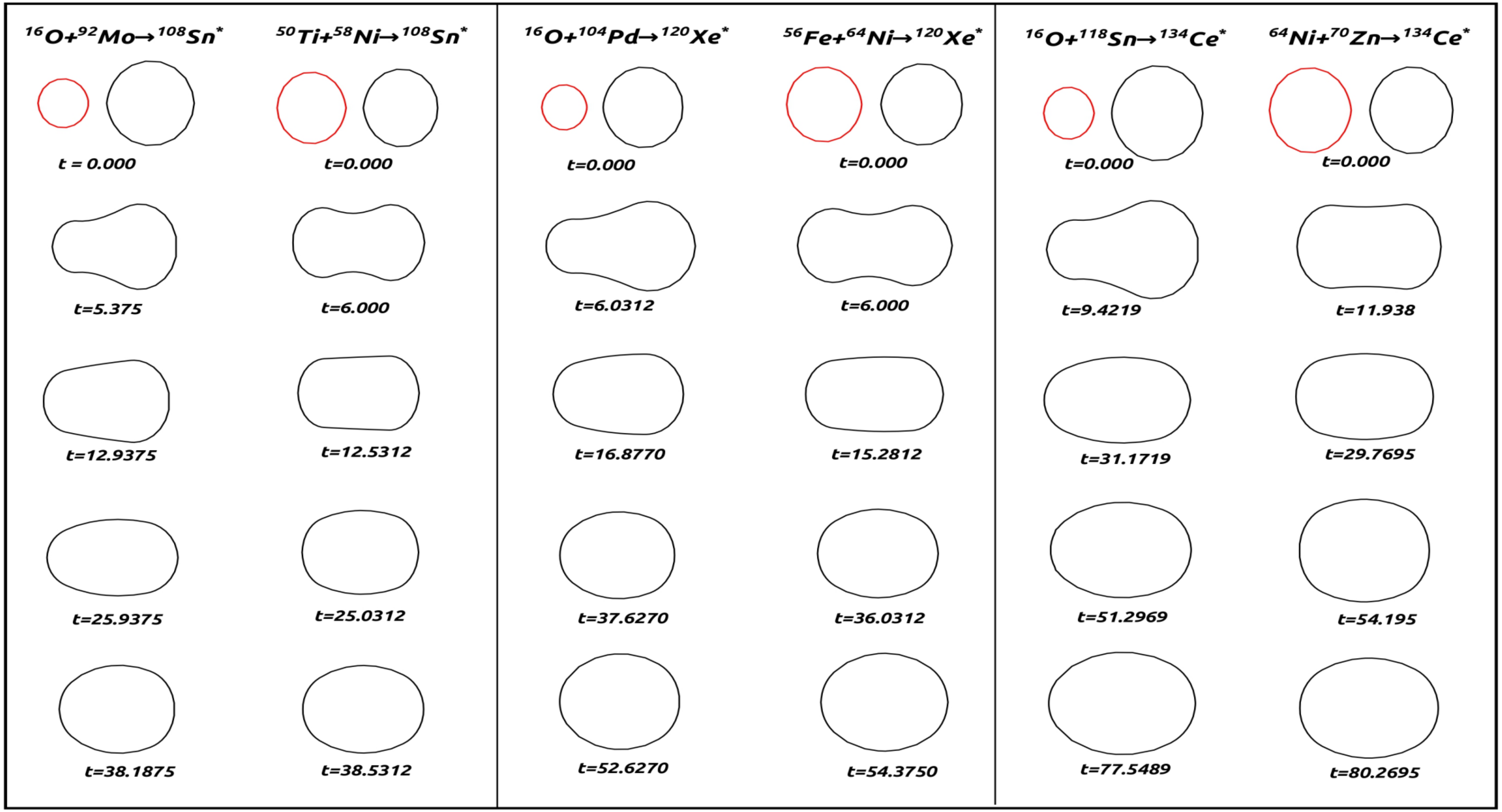


Variation of angular momentum ℓ_{max} with incident energy E_{lab} for ^{108}Sn, ^{120}Xe and ^{134}Ce compound nucleus.

Punit Dubey and Ajay Kumar, Under review in Phys Rev C



Calculated time evolution of the separation (S_{crit}) of the colliding nuclei w.r.t time for various ℓ values of ^{108}Sn, ^{120}Xe and ^{134}Ce compound nucleus.



Time evolution of the asymmetric and symmetric reactions forming ^{108}Sn, ^{120}Xe and ^{134}Ce compound nucleus for the angular momentum of 45 $\hbar$, 47 $\hbar$ and 56 $\hbar$ (time value is in 10^{-22} secs).

Role of dissipation in heavy ion fusion –fission dynamics

Details

pre- and post-scission neutron multiplicity for the reaction 18O + 186W populating the 204Pb at the three excitation energies 79.38 MeV, 74.82 MeV, and 70.26 MeV.

Here, we have selected the reaction 18O+186W because it has the nearly same value of entrance chan- nel mass asymmetry as the earlier studied system 16O +181Ta populating the CN 197Tl.

Experimental details

MWPCs of the active area 11 × 16 cm^2.

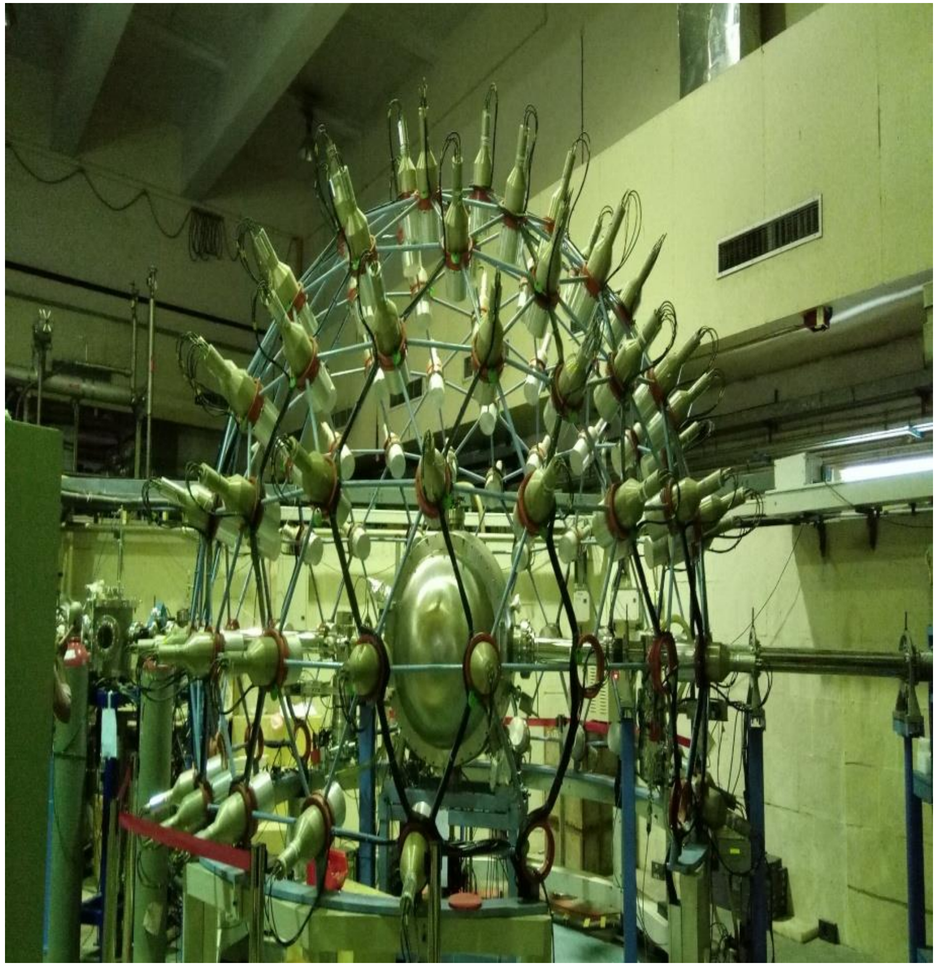
MWPC 1 was placed at the distance of 26 cm (35^o) and second was placed at the distance of 21 cm (126^o).

TOF of Fission fragments : Fast timing signal of the MWPCs wrt the beam

Two SSBD's @ ± 12.5^o w.r.t the beam directions to monitor the beam.

BC501: 100 neutron detectors, dimension 5 in. × 5 in.

NAND Facility @IUAC, New Delhi



18O @ repetition rate of 250 ns.

186W target of thickness 637 μg/cm^2 with carbon backing of 40 μg/cm^2.

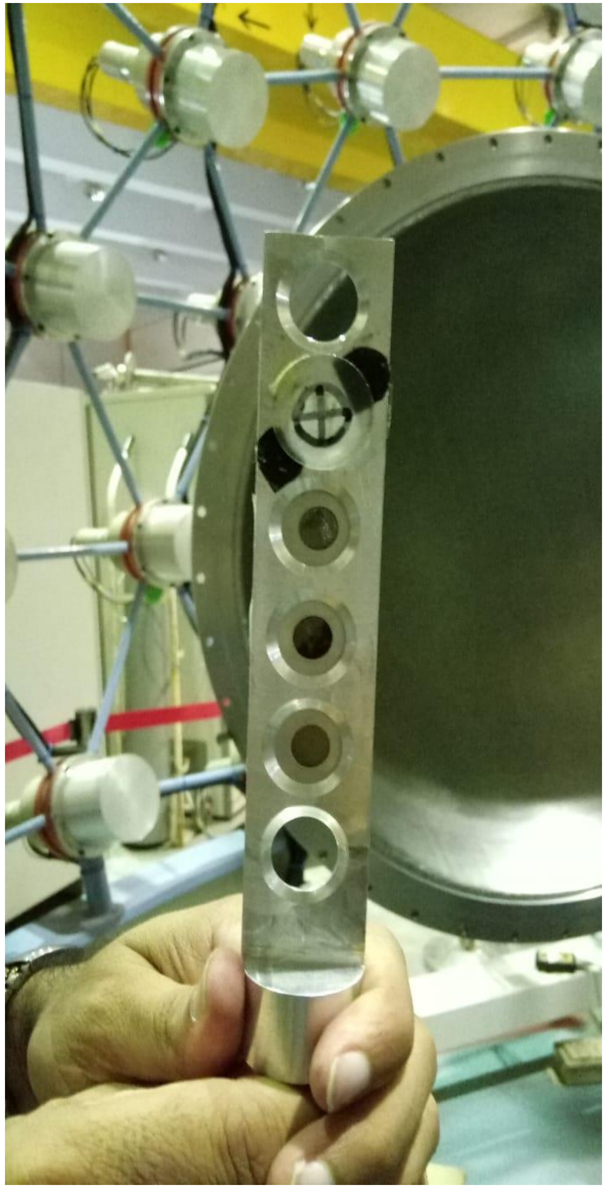
The threshold for the neutron detectors was kept at about 0.5 MeV by calibrating with the standard gamma sources (137Cs and 60Co)

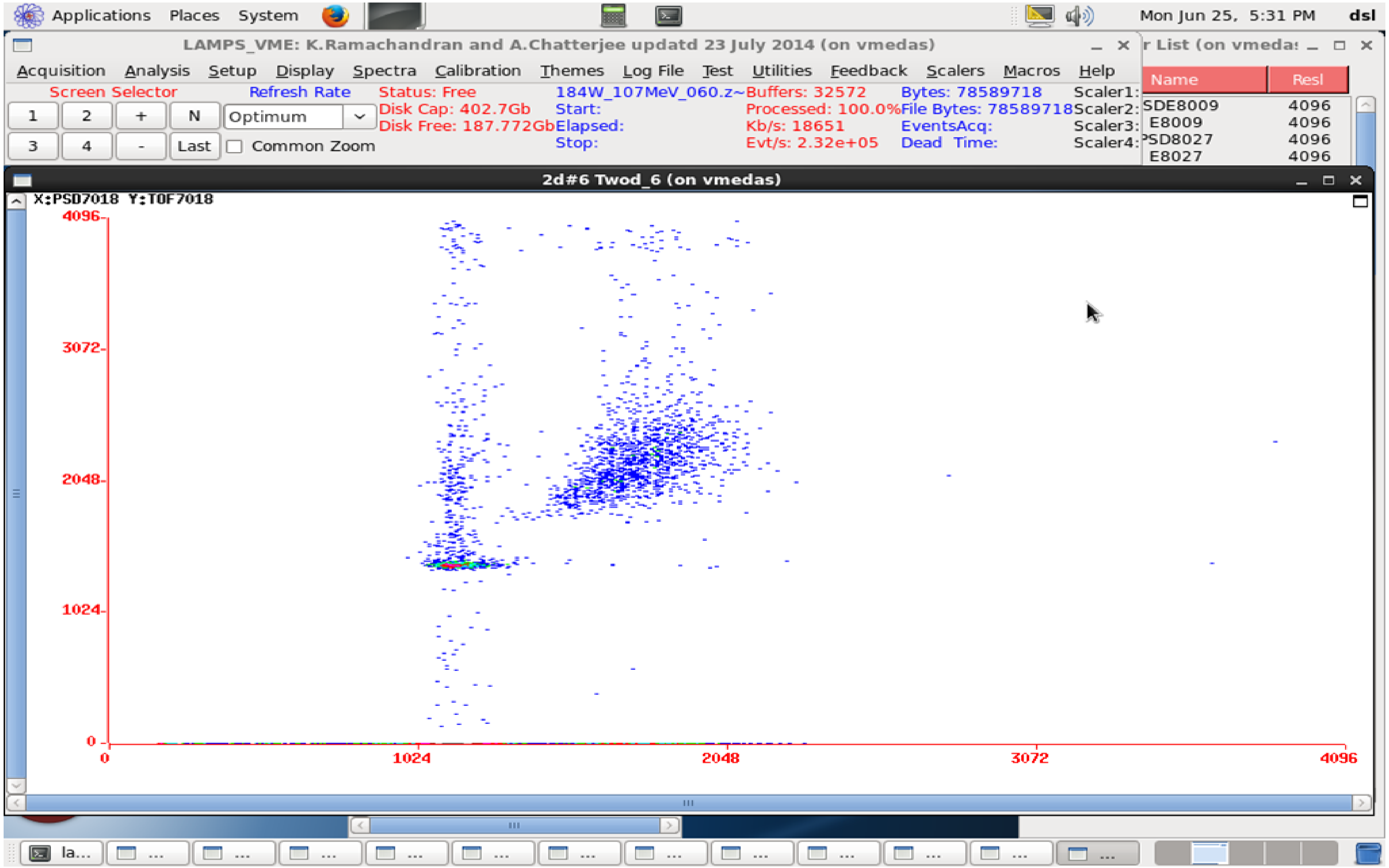
Beam dump was placed 4 m

The flight path was 175 cm.

n-gamma discrimination by zero crossing and TOF technique

The data acquisition was triggered by making the coincidence between the RF of the beam pulse and OR of the MWPCs.

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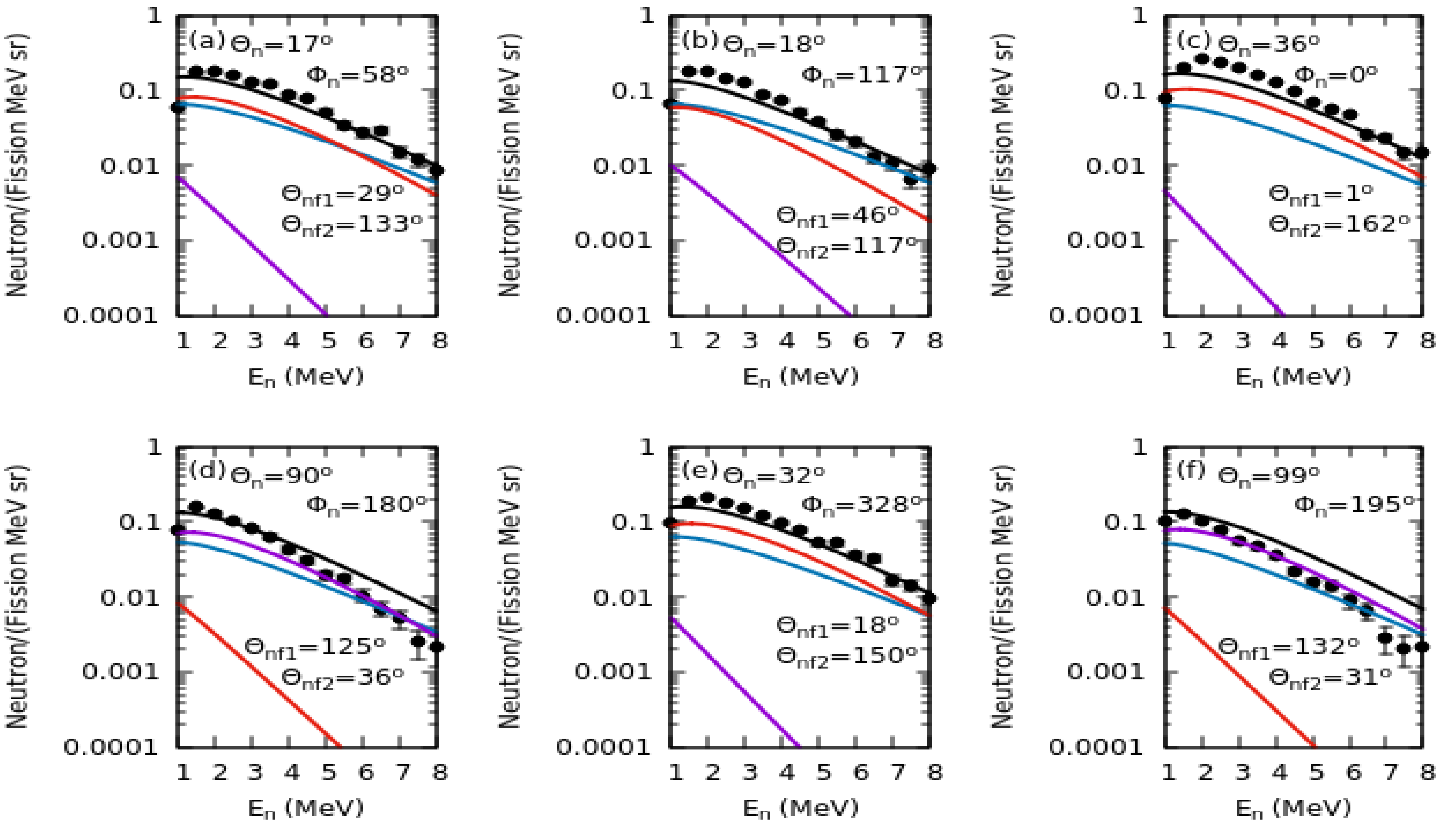
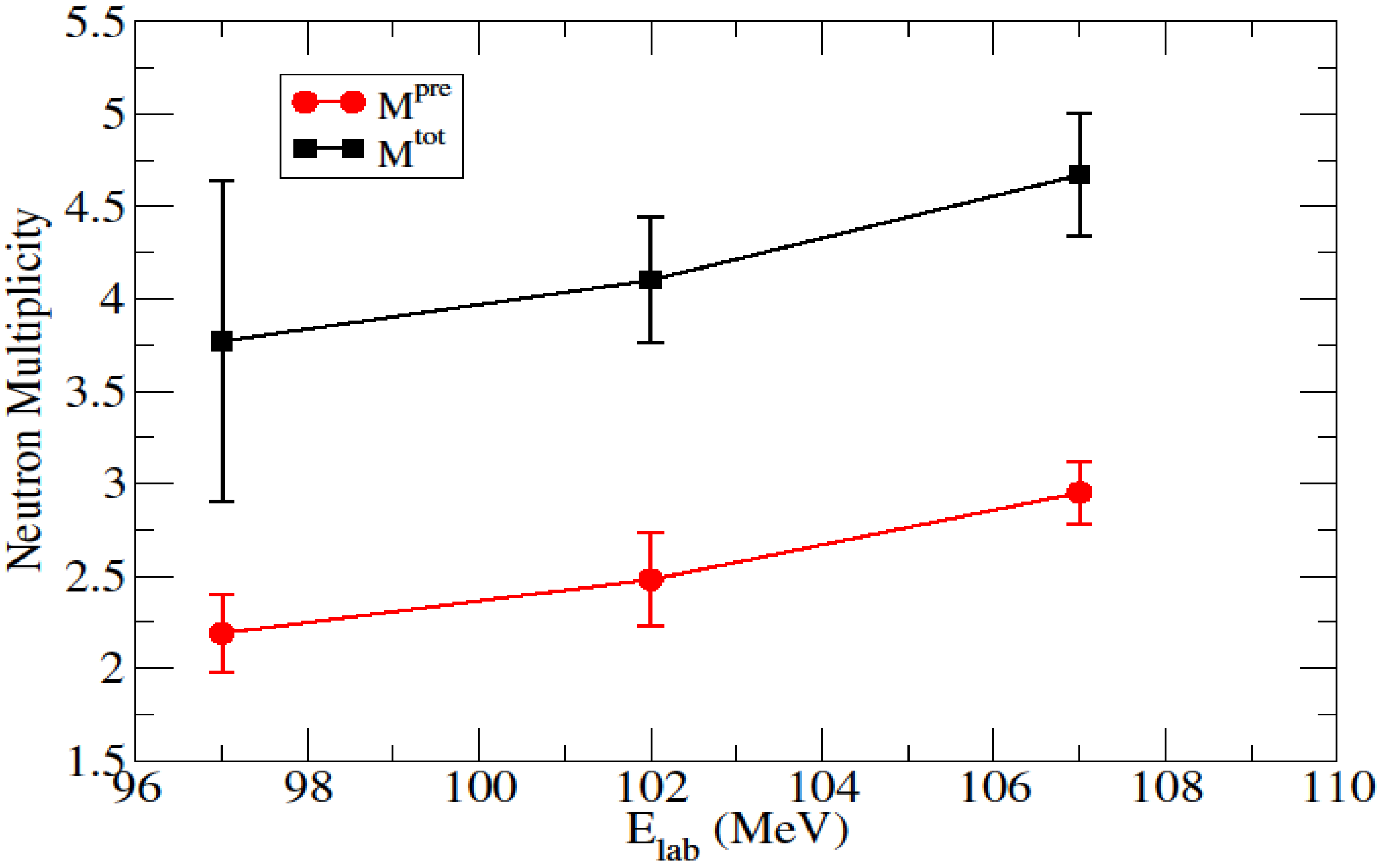


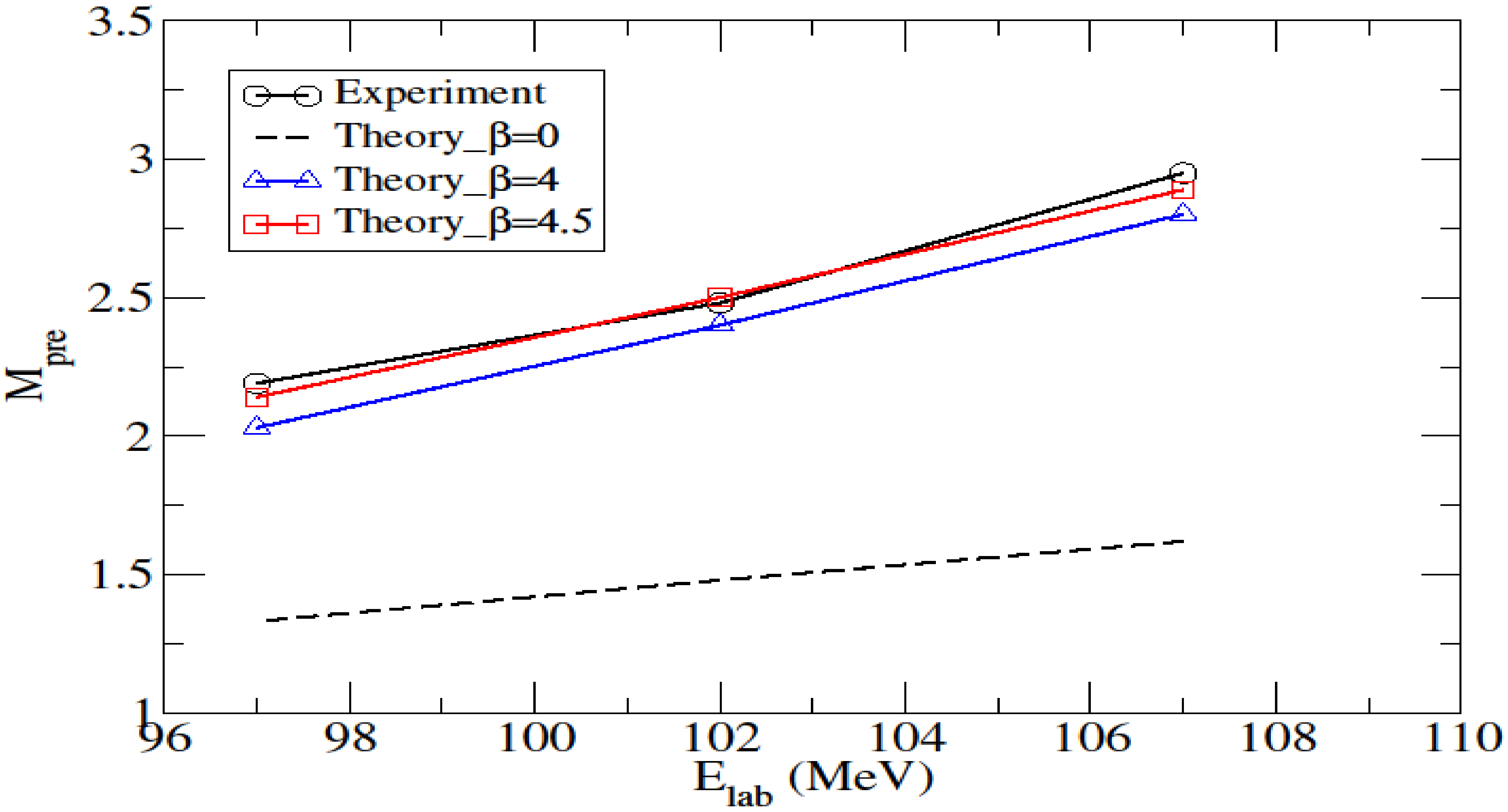
FIG. Neutron multiplicity spectra (filled circles) for the reaction 18O + 186W at Elab = 107 MeV along with the fits for the pre-scission (blue line) and post-scission contributions from the one fragment (red line) and other (violet line) are shown. The solid black line represents the total contribution and θnf refers to the polar angle of neutron detectors.

E*(MeV)	Mpre	Mpost	Mtot	T pre	T post
70.26	2.19 ±0.21	0.79 ±0.08	3.77 ±0.87	1.97 ±0.15	1.02 ±0.08
74.82	2.48 ±0.25	0.81 ±0.09	4.10 ±0.34	1.74 ±0.09	0.94 ±0.05
79.38	**2.95 ±0.17**	**0.86 ±0.06**	**4.67 ±0.33**	**1.83 ±0.09**	**0.92±0.05**

Experimentally measured values of neutron multiplicities and temperatures for the reaction 18O + 186W.

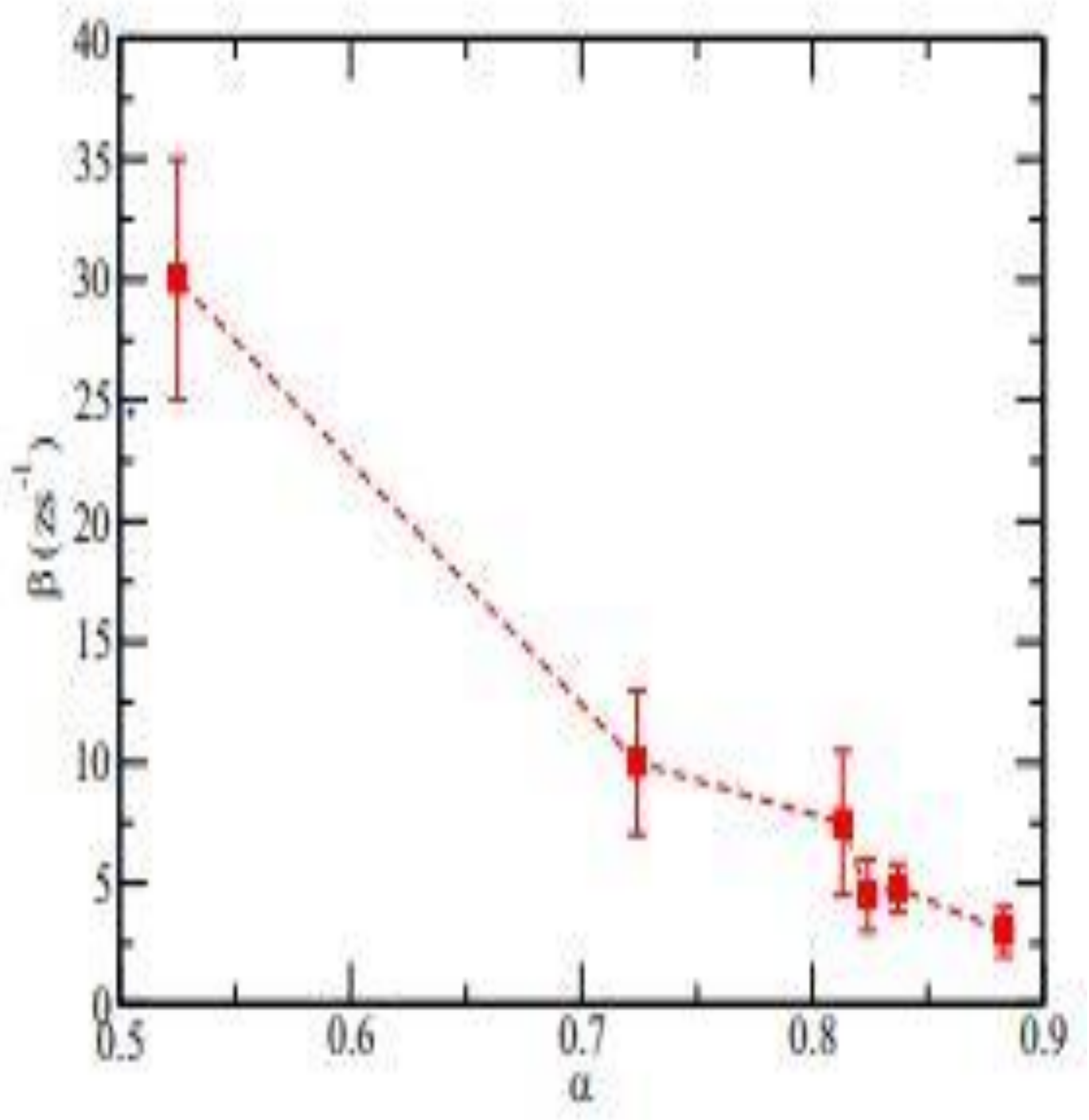


Experimental values of pre-scission and total neutron multiplicities for the reaction 18O + 186W



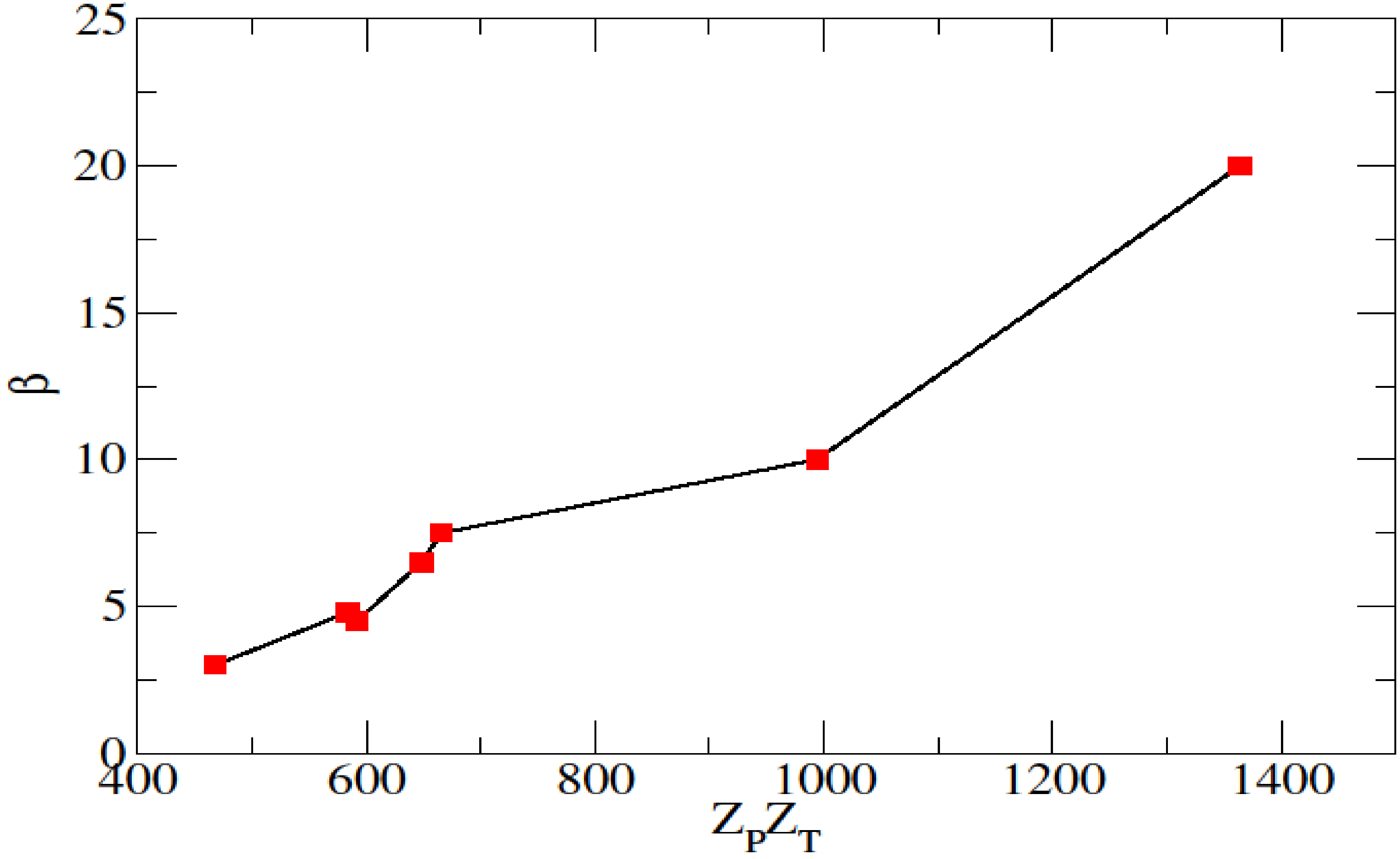
Experimental values of pre-scission neutron multiplicities for the reaction 18O + 186W and their comparison with the statistical model predictions.

N. K. Rai, Ajay Kumar et al, Phys. Rev. C 100, 2019



The systems are like 19F +178Hf @ 72 MeV, 19F + 184W @ 74 MeV, 16O + 181Ta @ 72 MeV, 28Si + 175Lu @ 73 MeV, 48Ti +154Sm @ 72 MeV 12C+194 Pt @ 76 MeV 18O+ 186W at 70 MeV [Present].

Variation of the dissipation parameter β with respect to the entrance channel mass asymmetry α.



Variation of the dissipation parameter β with respect to the Coulomb factor Z_P Z_T .

The Team at NAND

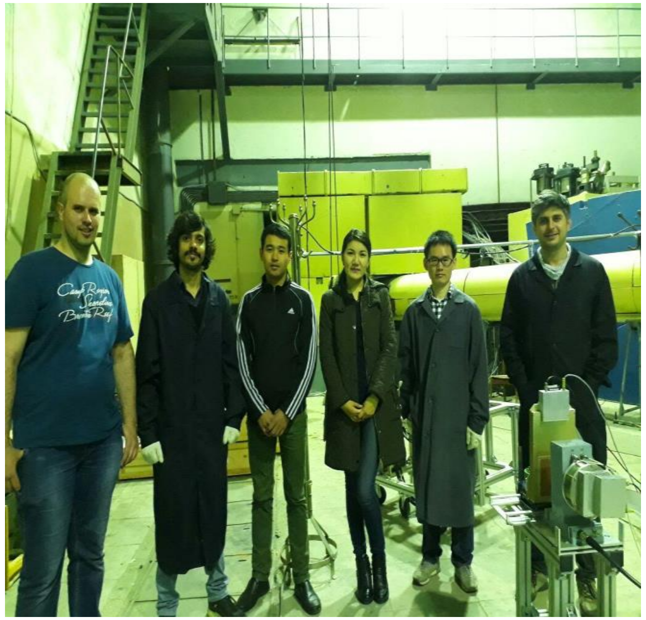
Conclusion

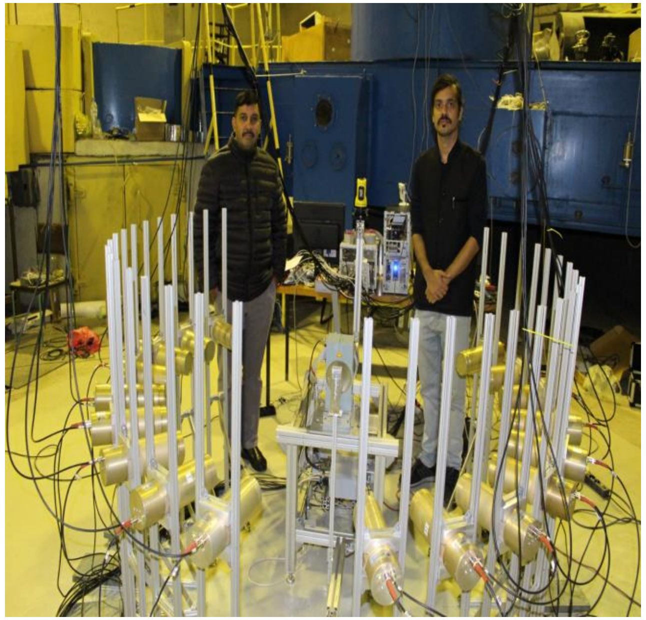
(1) The angular momentum hindrance (l_{max}) increases with the incident energy of the projectile for both symmetric and asymmetric systems, from which we conclude that the dissipation in the entrance channel increases with the projectile energy and causes the angular momentum hindrance in both the symmetric and asymmetric systems at the higher energy.

(2) Moreover, the dissipative behavior of the fusing nuclei is also compared with respect to the entrance channel parameters like mass asymmetry α and the Coulomb interaction term $Z_P Z_T$ at constant excitation energy and we observed that with increasing value of mass asymmetry it decreases almost linearly and it increases almost linearly when the Coulomb interaction term $Z_P Z_T$ increases.

(3) It will be interesting to study the dissipation for high mass region and higher incident energy as it shows extra ordinary variation of angular momentum.

Some pictures of the work under BHU-Russian Collaboration





Thanks