Mass–TKE Correlations in the Fusion–Fission of the Compound Nucleus ^{206}Rn*

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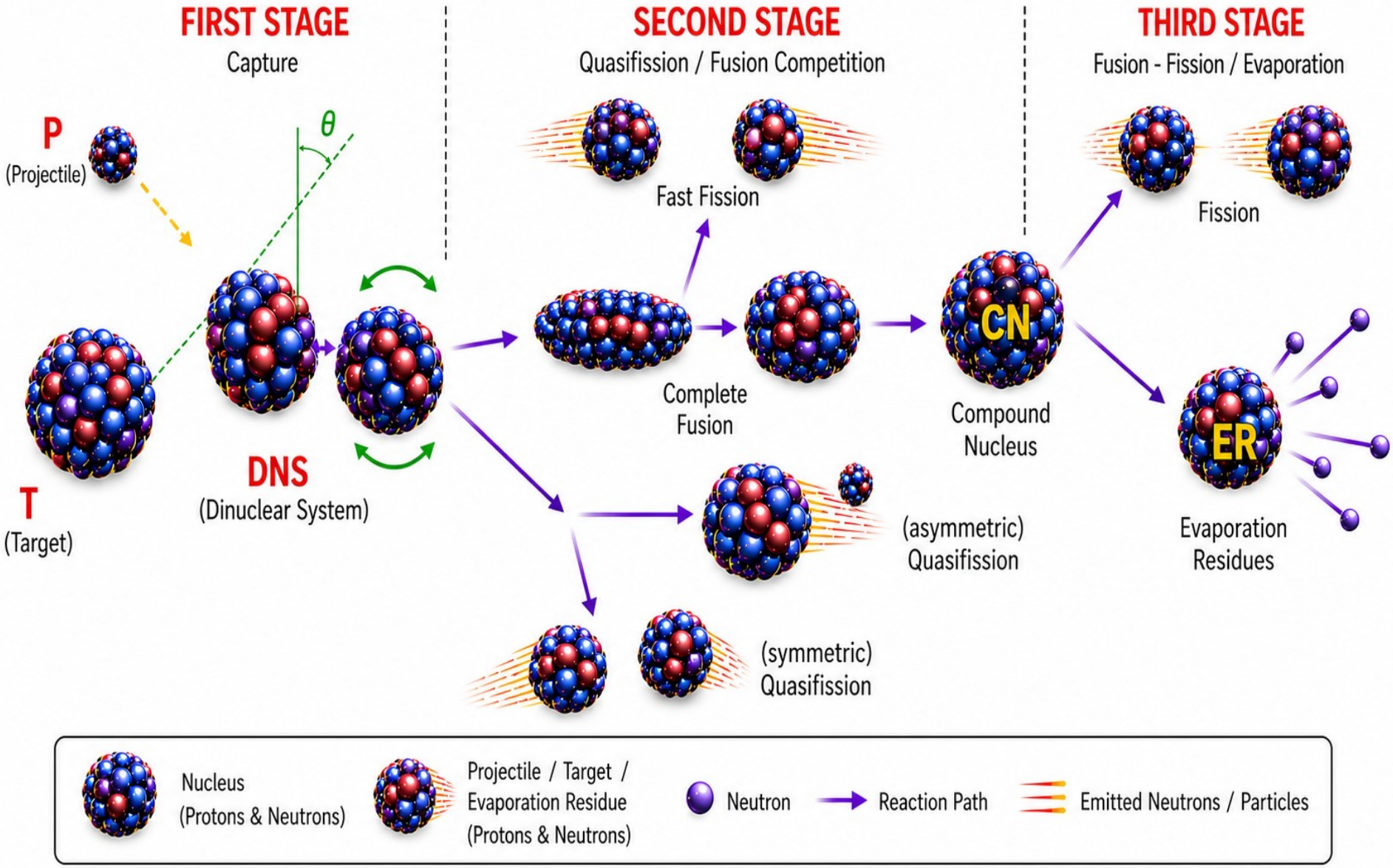
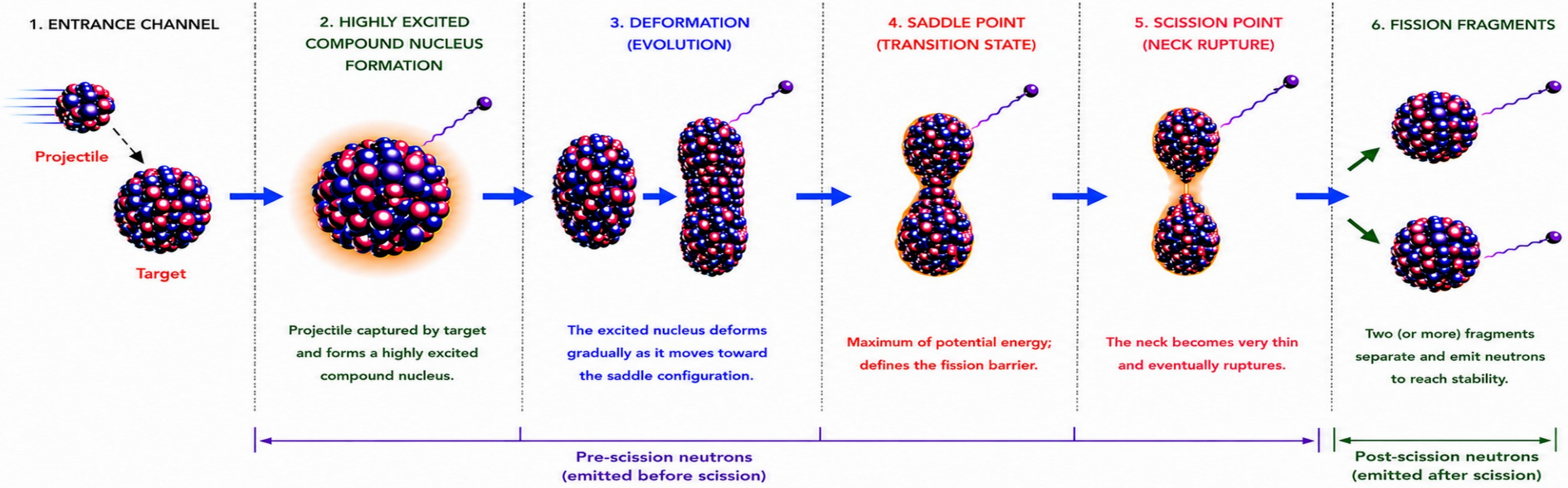
Outline

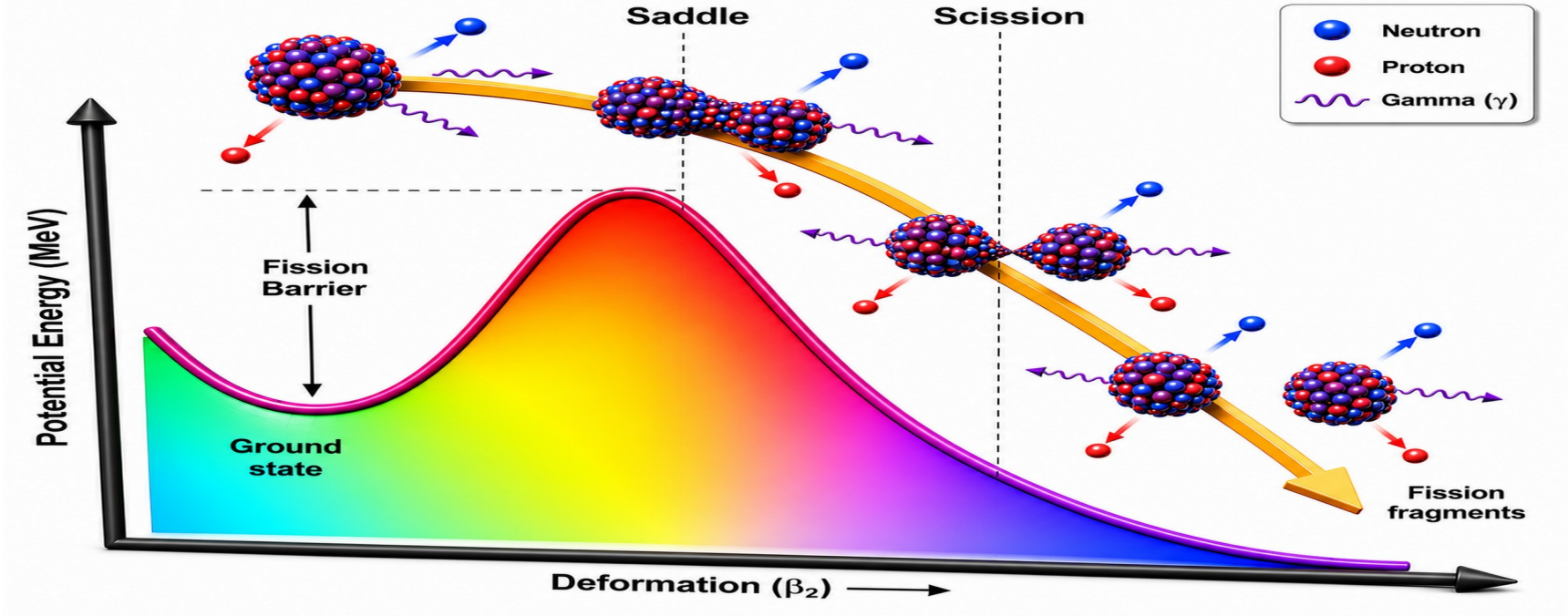
- Understanding Fusion–Fission Dynamics
- Scientific Motivation
- Experiment Setup & Data Analysis
- Results & Discussion
- Conclusion

HEAVY ION INDUCED REACTIONS

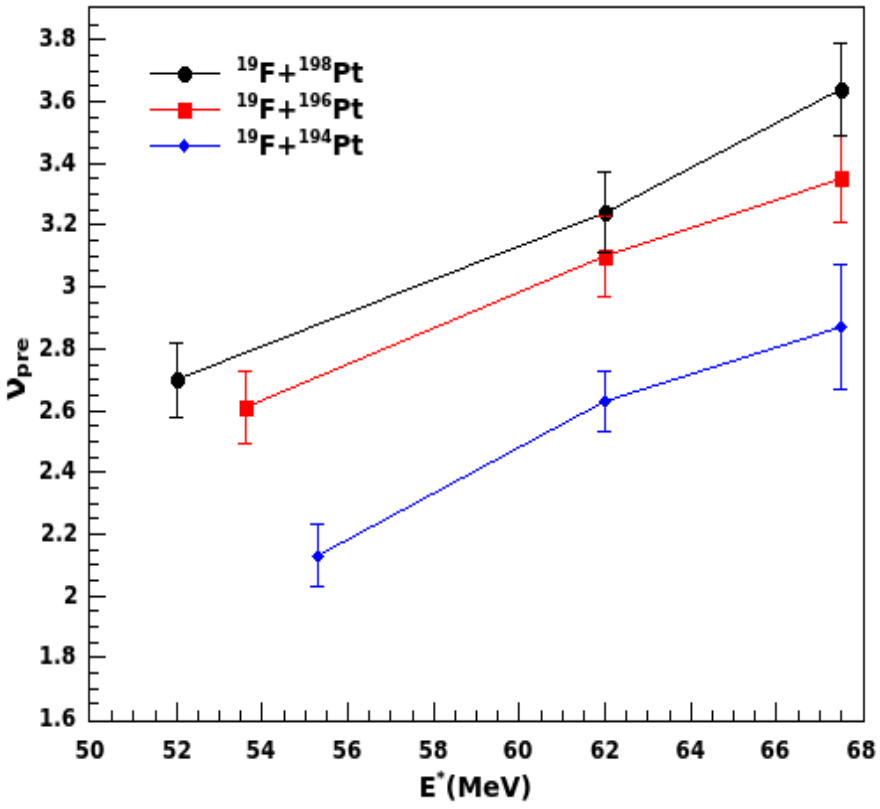


Heavy Ion Induced Fission



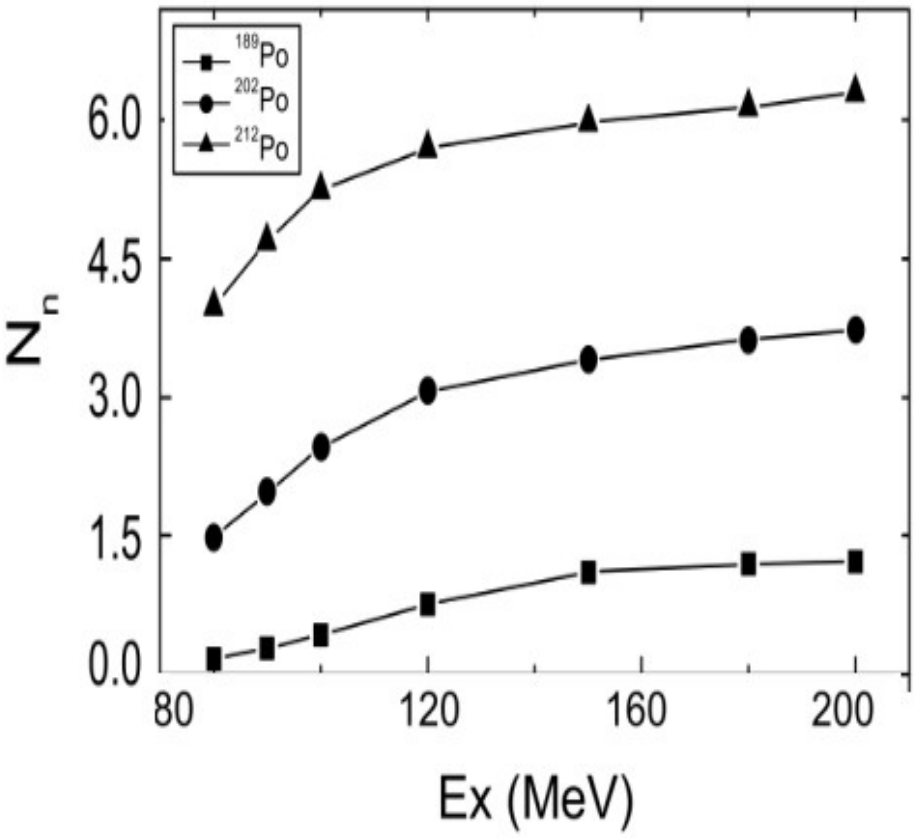


Scientific Motivation



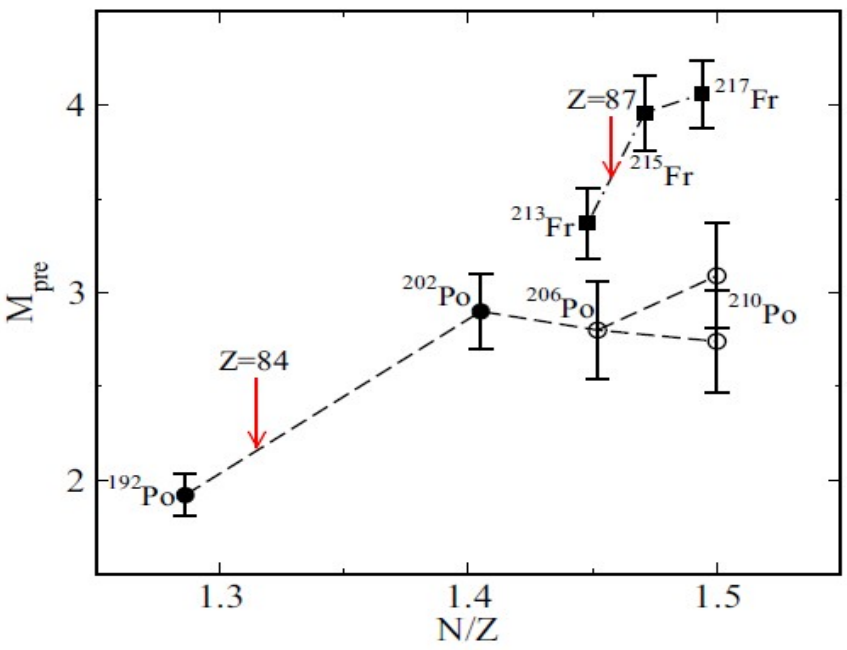
V. Singh *et. al.* PRC **86**, 014609 (2012)

Shell closure effect

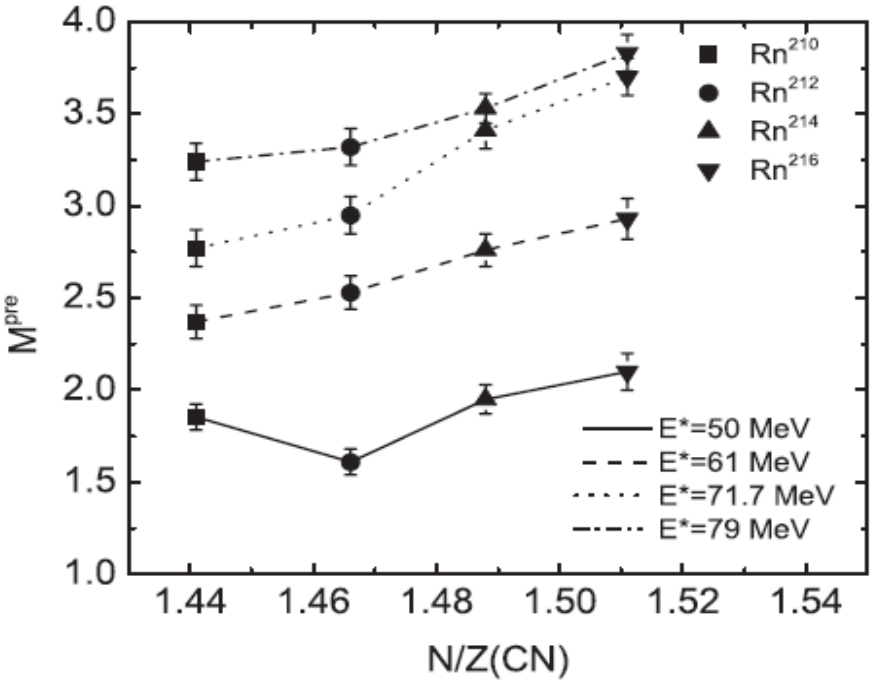


W. Ye, Eur. Phys. J. A **18**, 571 (2003).

Neutron multiplicity increases with an increase in the N/Z of the system.

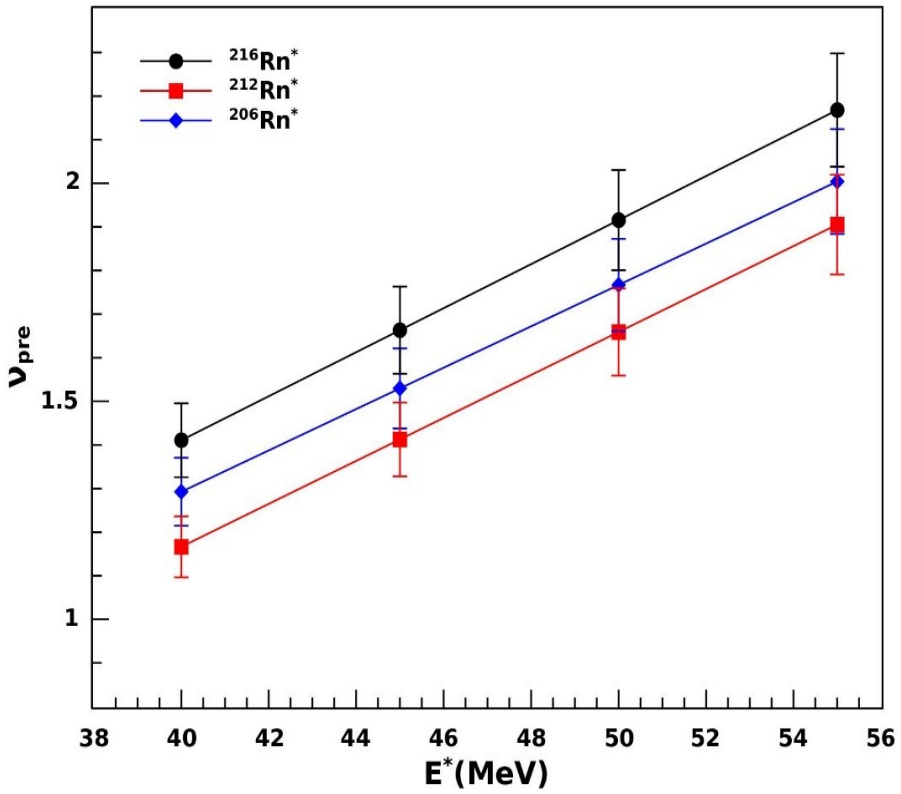


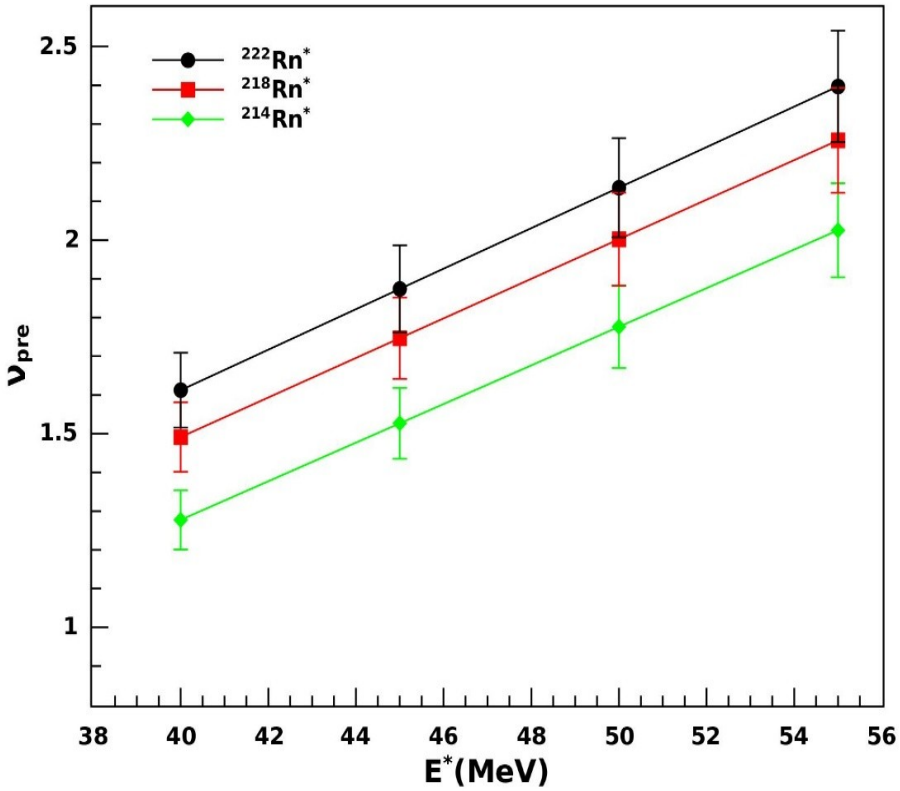
Ruchi Mahajan *et. al.* PRC **98**, 034601 (2018)



Rohit Sandal *et. al.* PRC **87**, 014604 (2013)

- In the N/Z dependence of M_{pre}, no specific trend at shell closure of N = 126 is observed
- N/Z value does not affect dissipation specifically.



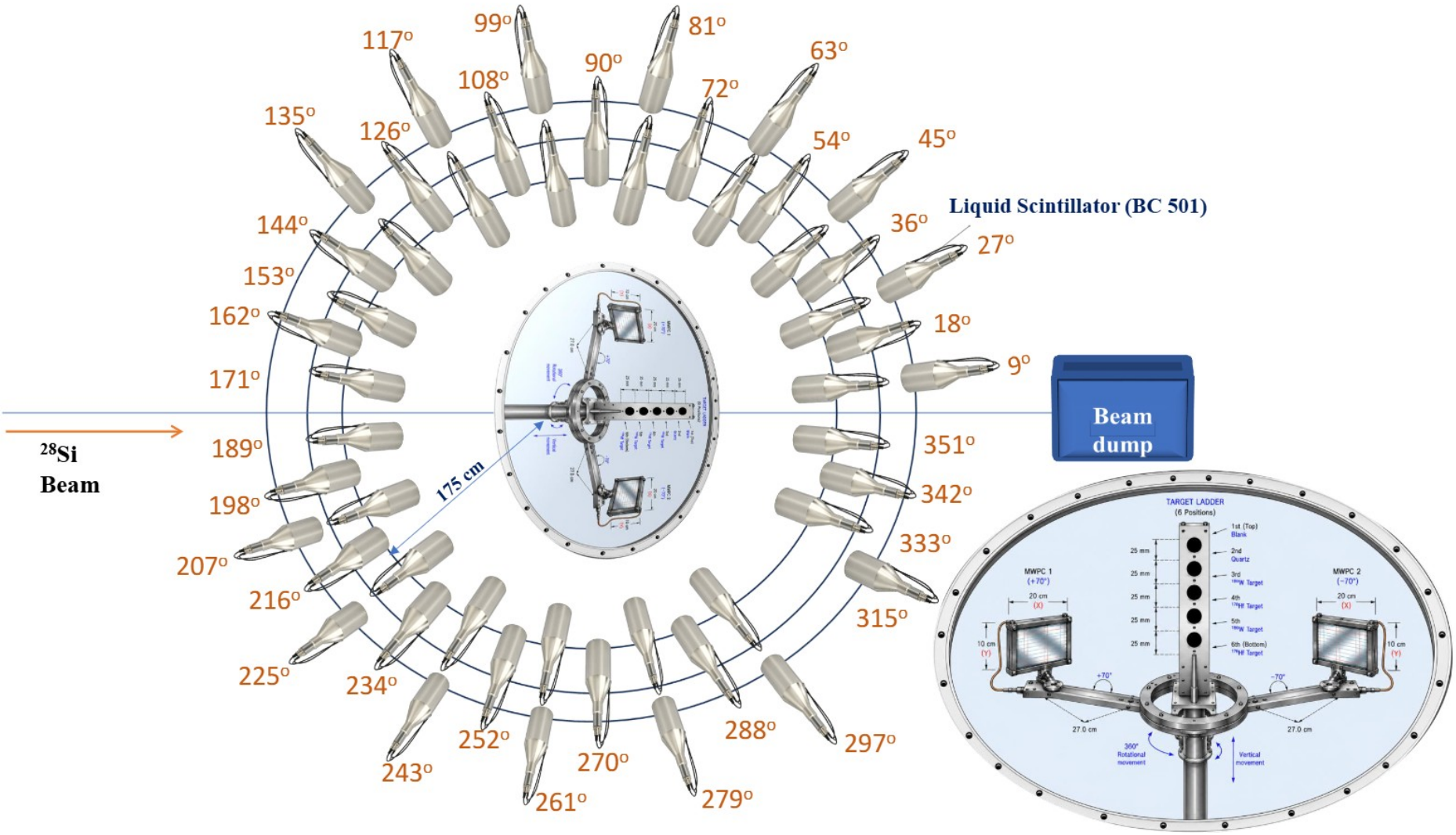


- Variation in neutron multiplicity w.r.t excitation energy using systematics by varying N/Z ratio near shell closure

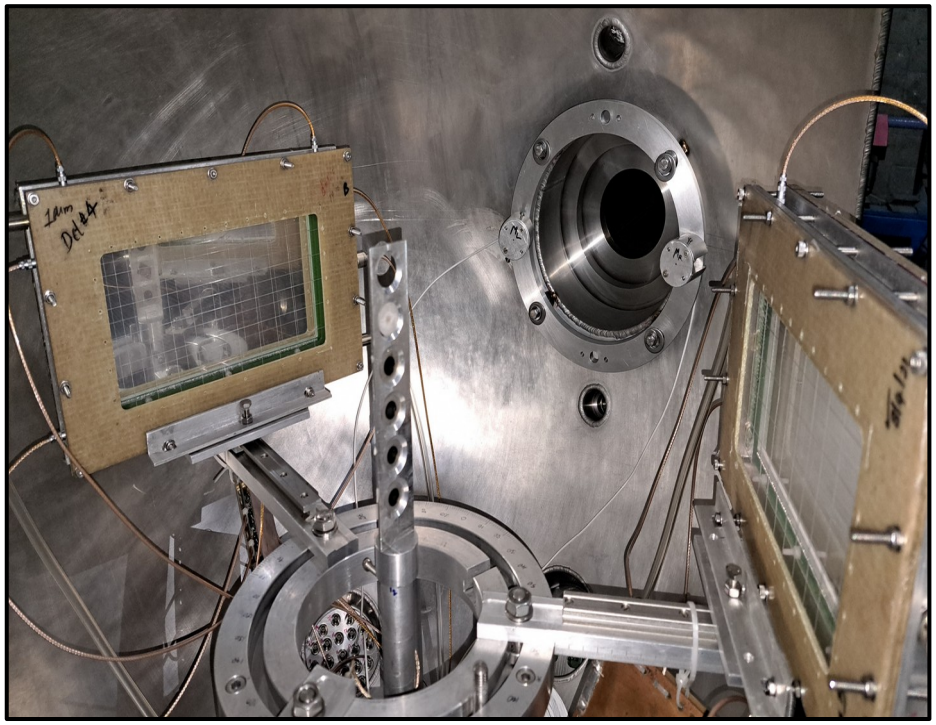
- Variation in neutron multiplicity w.r.t excitation energy using systematics by varying N/Z ratio away from shell closure

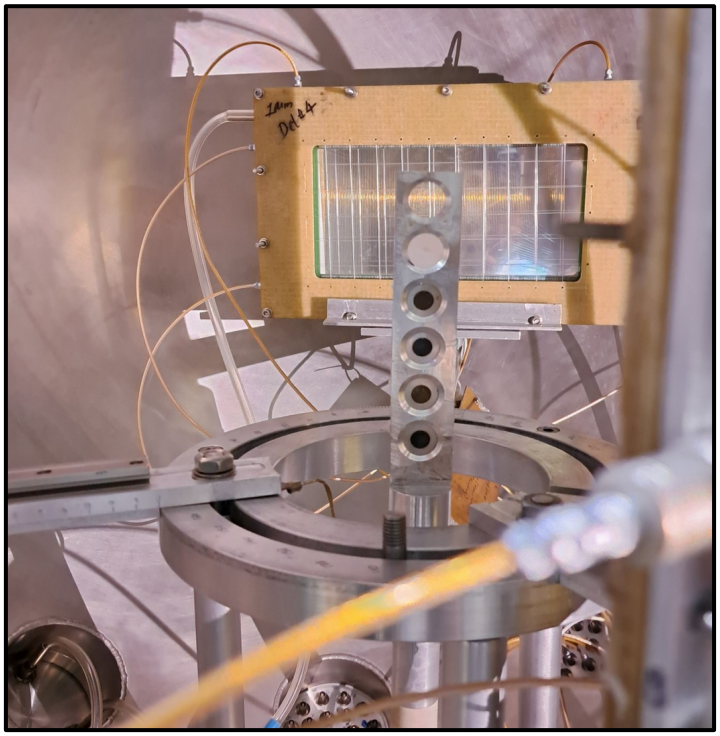
Punit Dubey, Ajay Kumar *et al*., J. Radioanal. Nucl. Chem., **333**, 5363 (2024)

Experiment Setup & Data Analysis

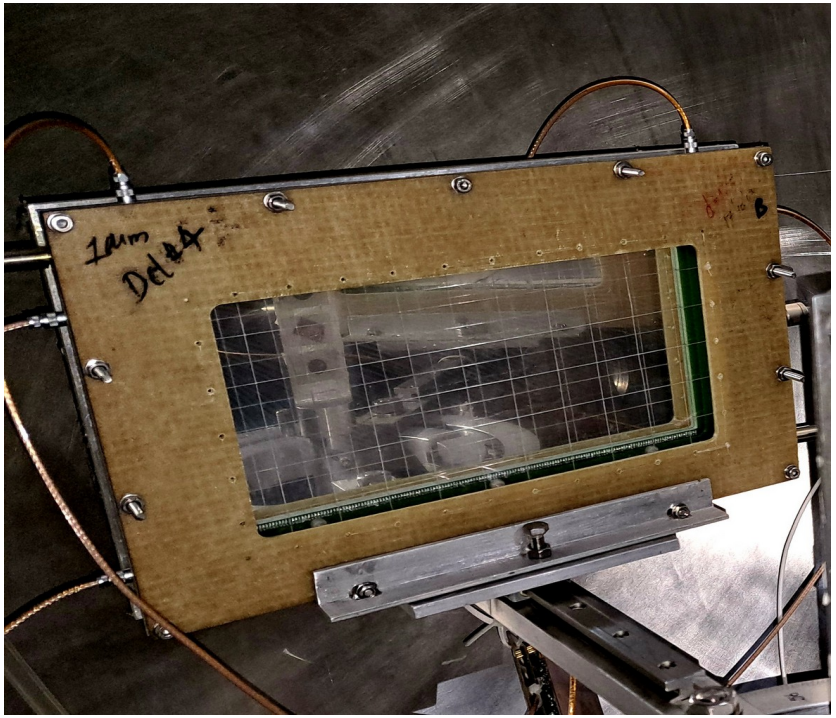


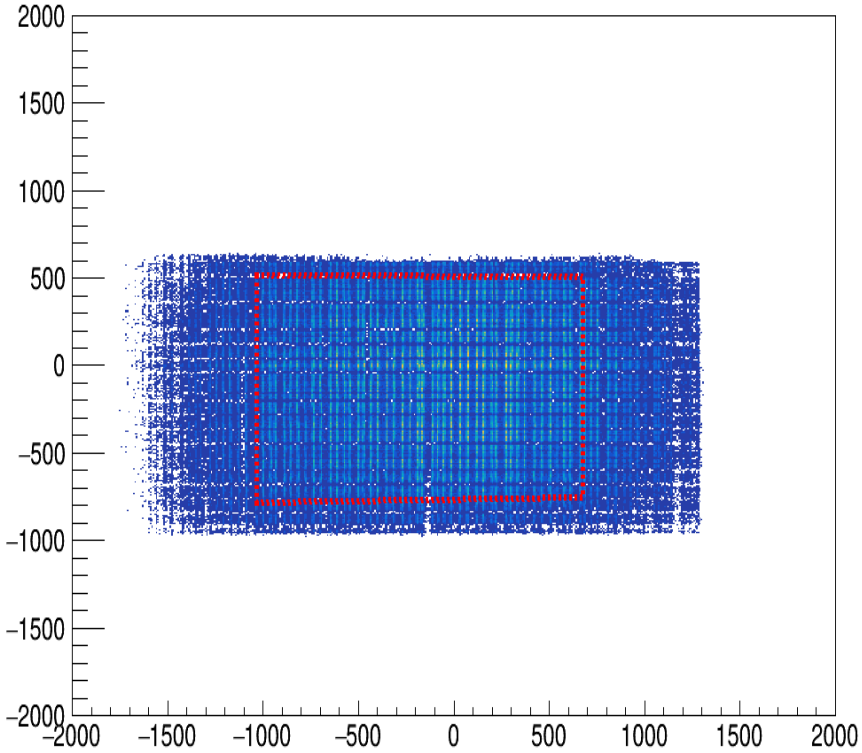
- Experimental setup (top view) used for measurement of neutron multiplicity in coincidence with fission fragments





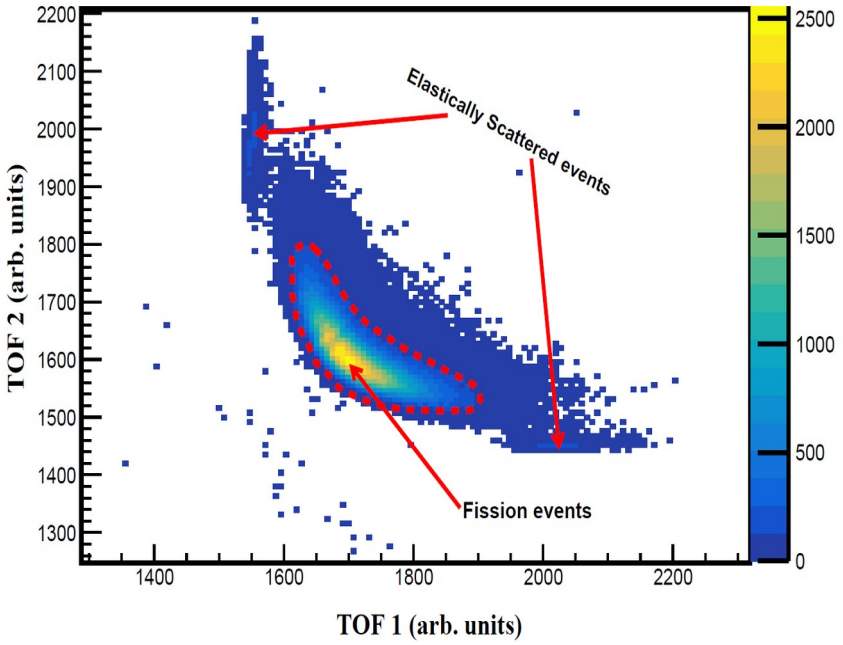
- Inside view of NAND scattering chamber

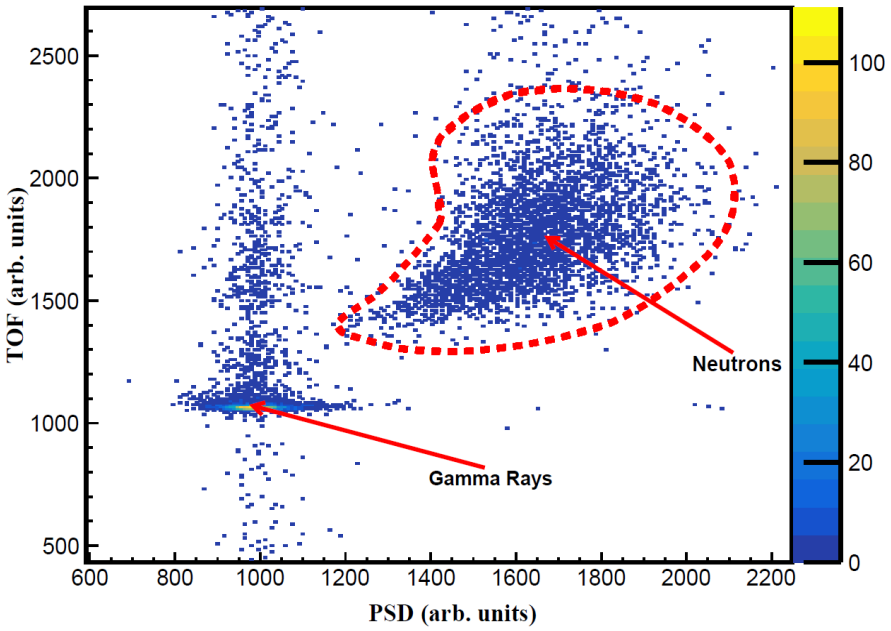




- MWPC Detector to detect fission fragments
- MWPC Detector graphical cut

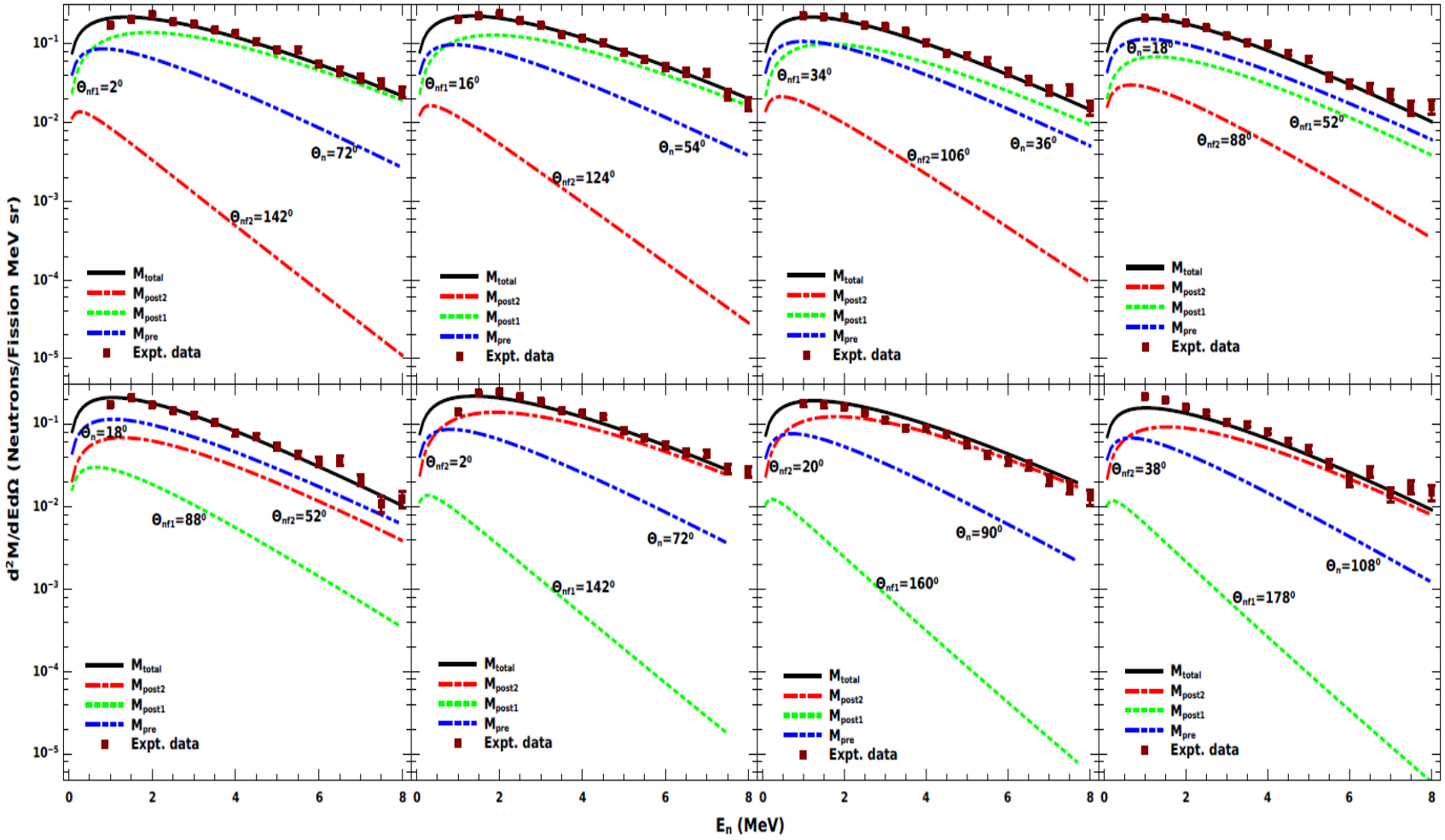
Results & Discussion





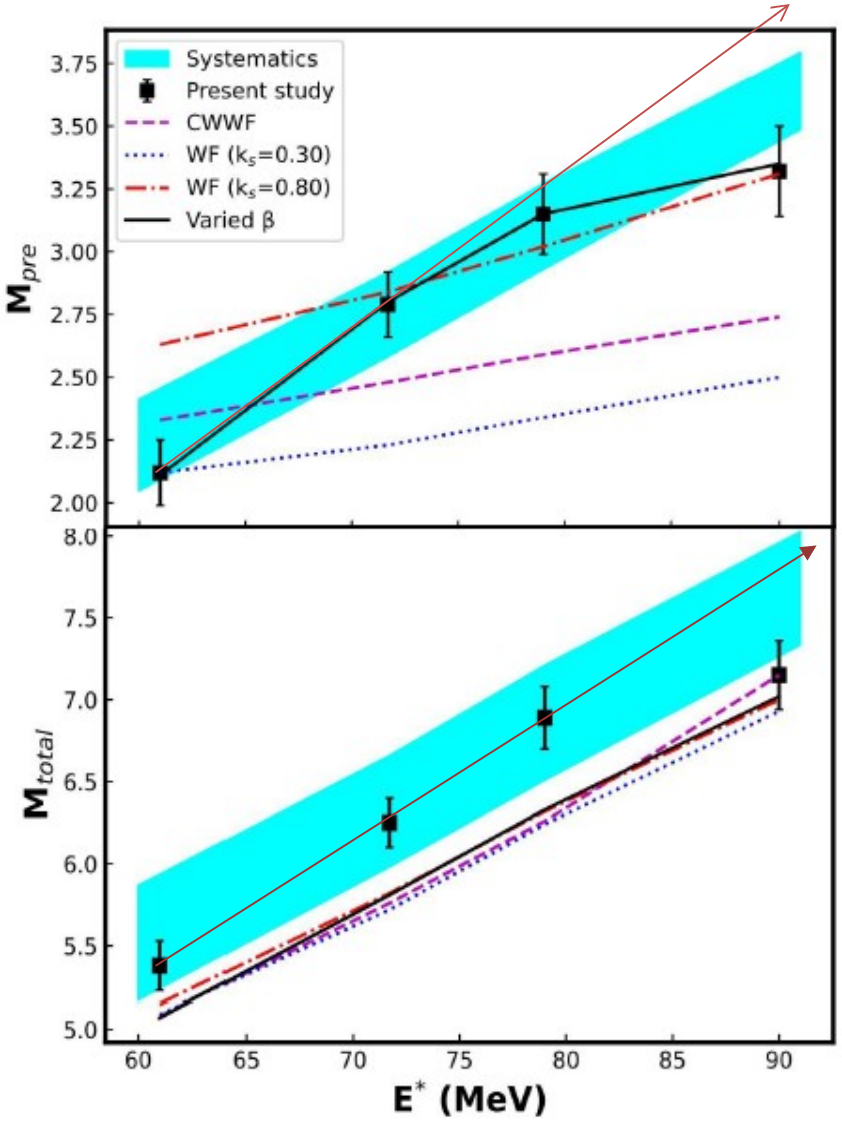
- Time correlation spectra of complementary fission fragments detected in the MWPCs
- PSD versus TOF spectrum of a neutron detector, for $^{28}Si+^{178}Hf$

Punit Dubey, Ajay Kumar *et al.*, Phys. Rev. C, **112**, L011602 (2025)

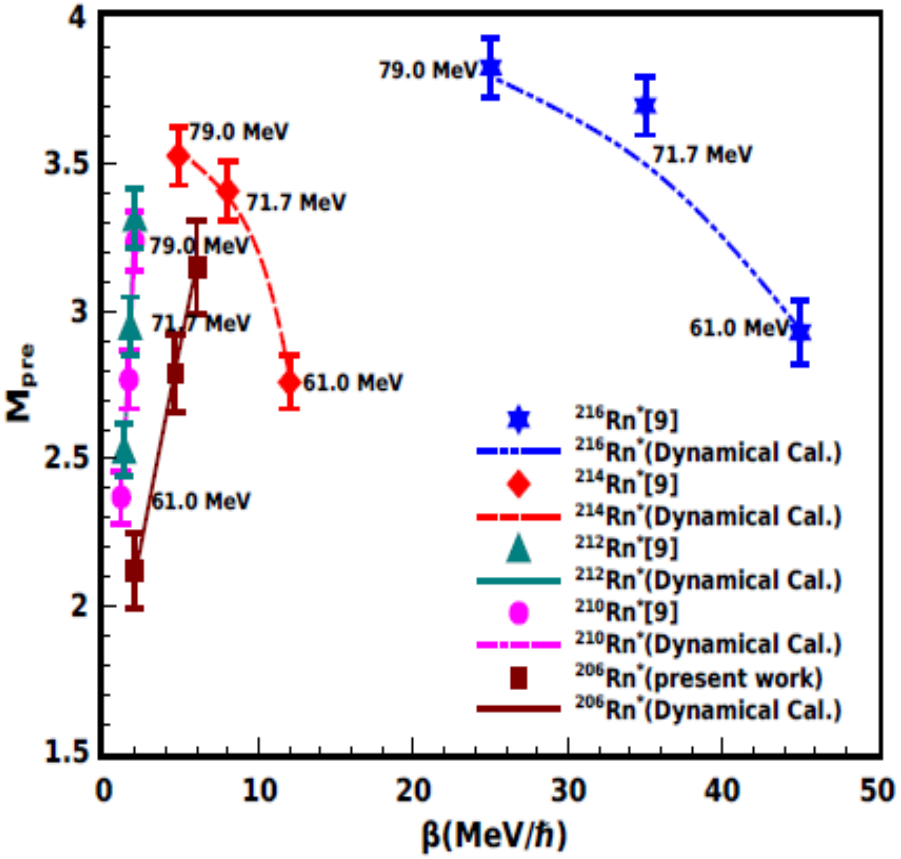


- Double differential neutron energy spectra for $^{28}Si+^{178}Hf$ at 79.0 MeV excitation energy along with the fits for the pre-scission (dot-dot-dashed curve) and post-scission from one fragment (dotted curve) and that from other (dot-dashed curve). The solid curve represents the total contribution.

Punit Dubey, Ajay Kumar *et al.*, Phys. Rev. C, **112**, L011602 (2025)



➢ Variation in pre-scission and total neutron multiplicity w.r.t excitation energy.



➢ Variation in β w.r.t M_{pre} for compound nucleus $^{206\text{-}216}$Rn* with increase in excitation energy.

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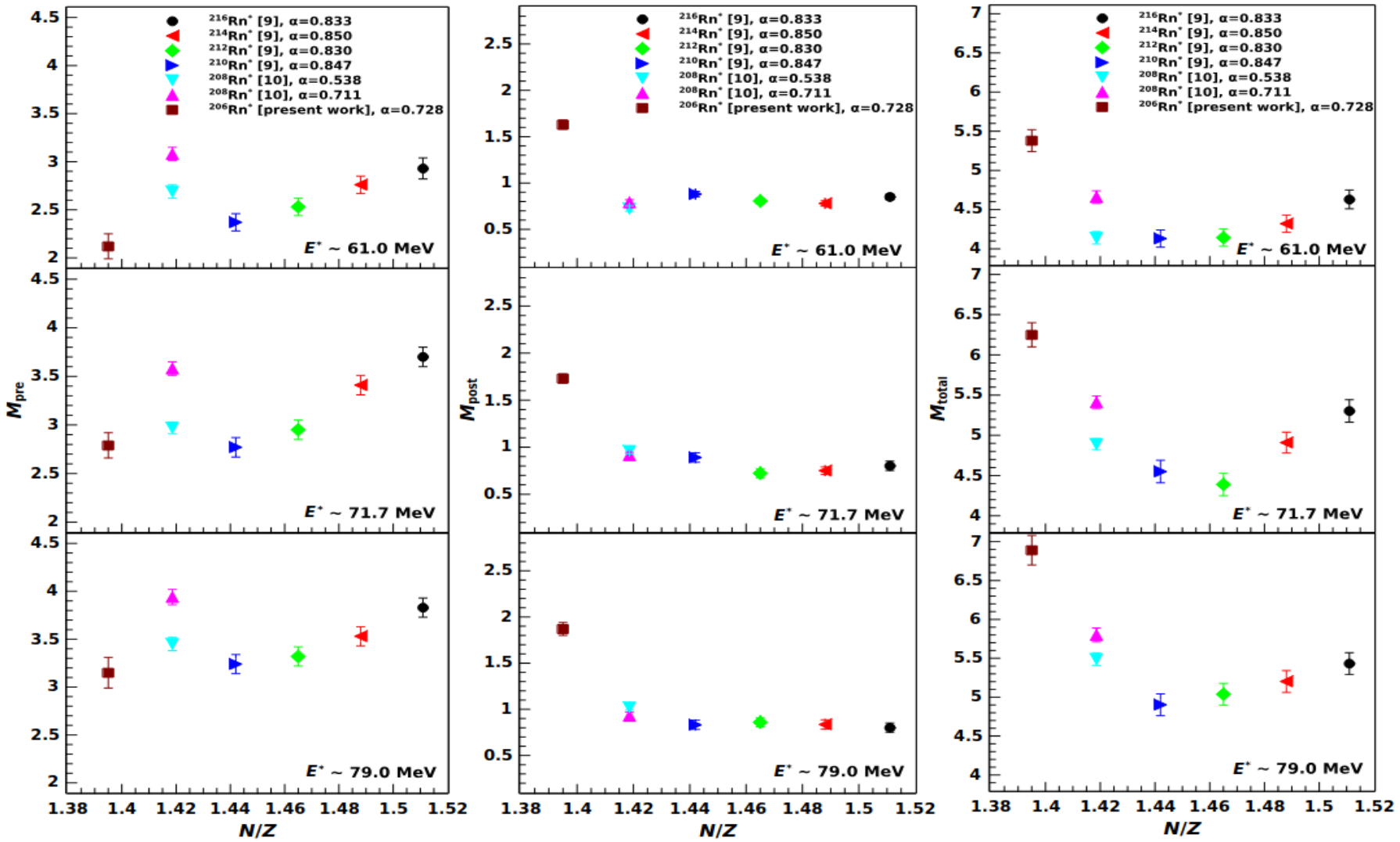
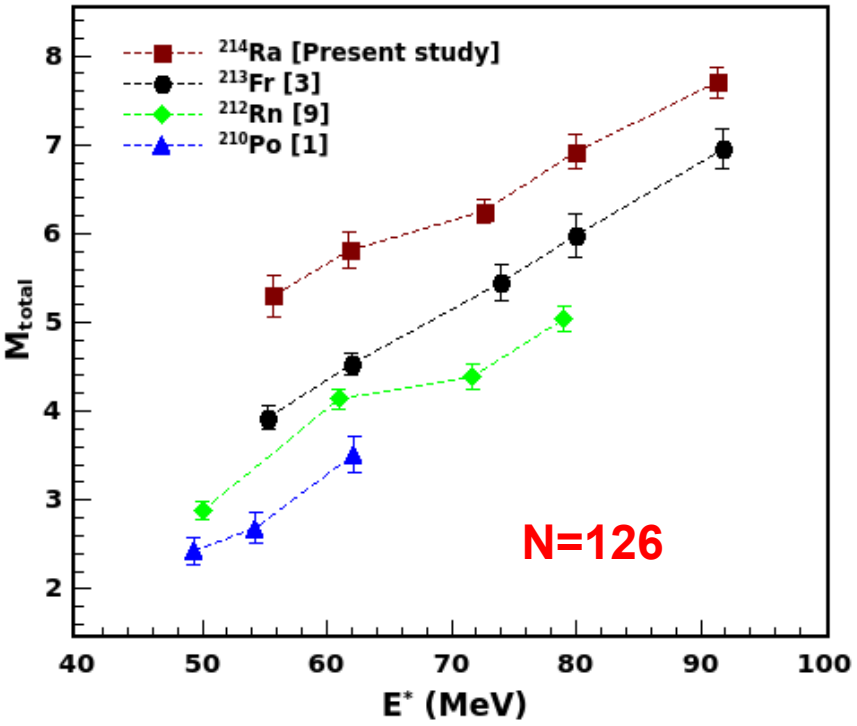


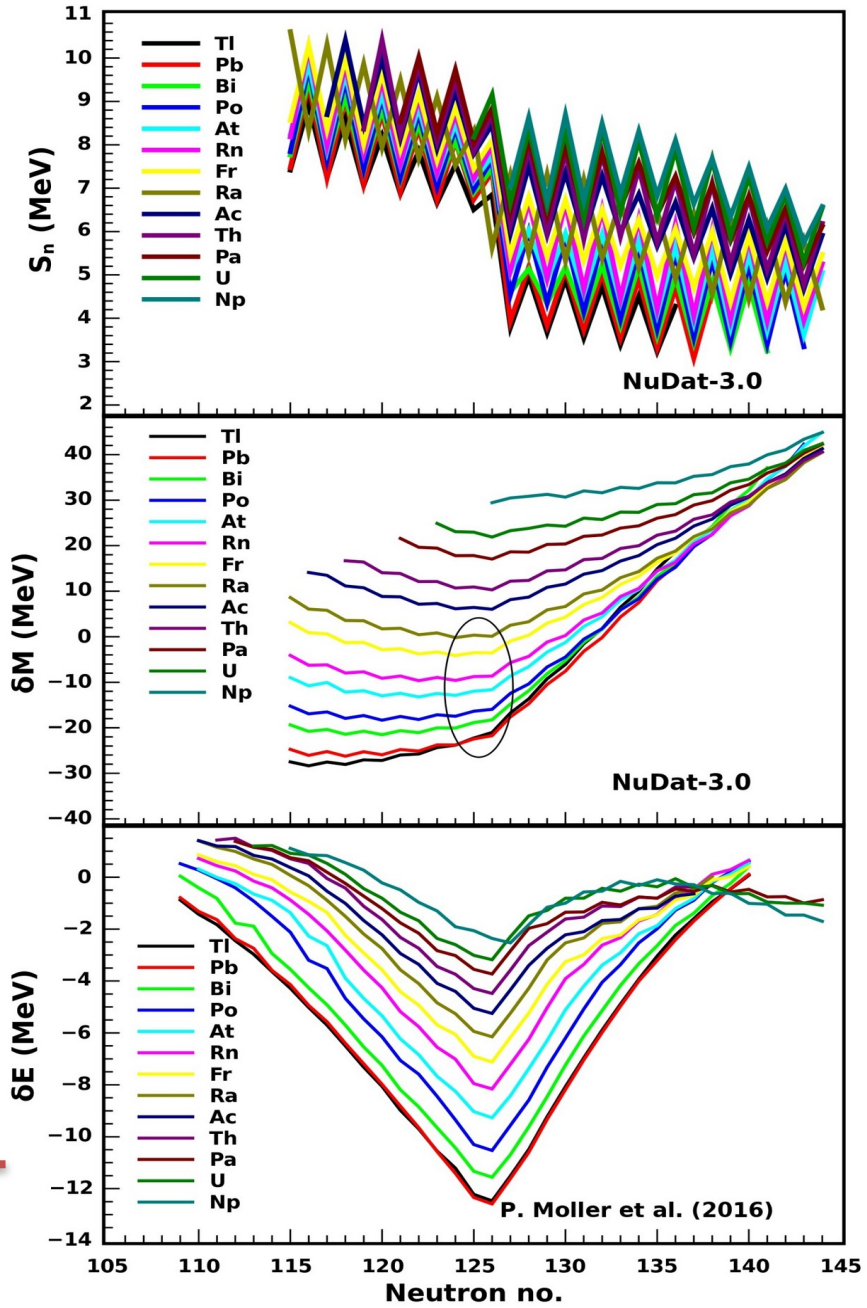
➢ Variation of M_{pre} (left), M_{post} (center), and M_{total} (right) with respect to the N/Z ratio for compound nuclei ^{206,208,210,212,214,216}Rn at excitation energies of 61.0, 71.7, and 79.0 MeV.

Punit Dubey, Ajay Kumar *et al.* Phys. Rev. C, **112**, L011602 (2025)

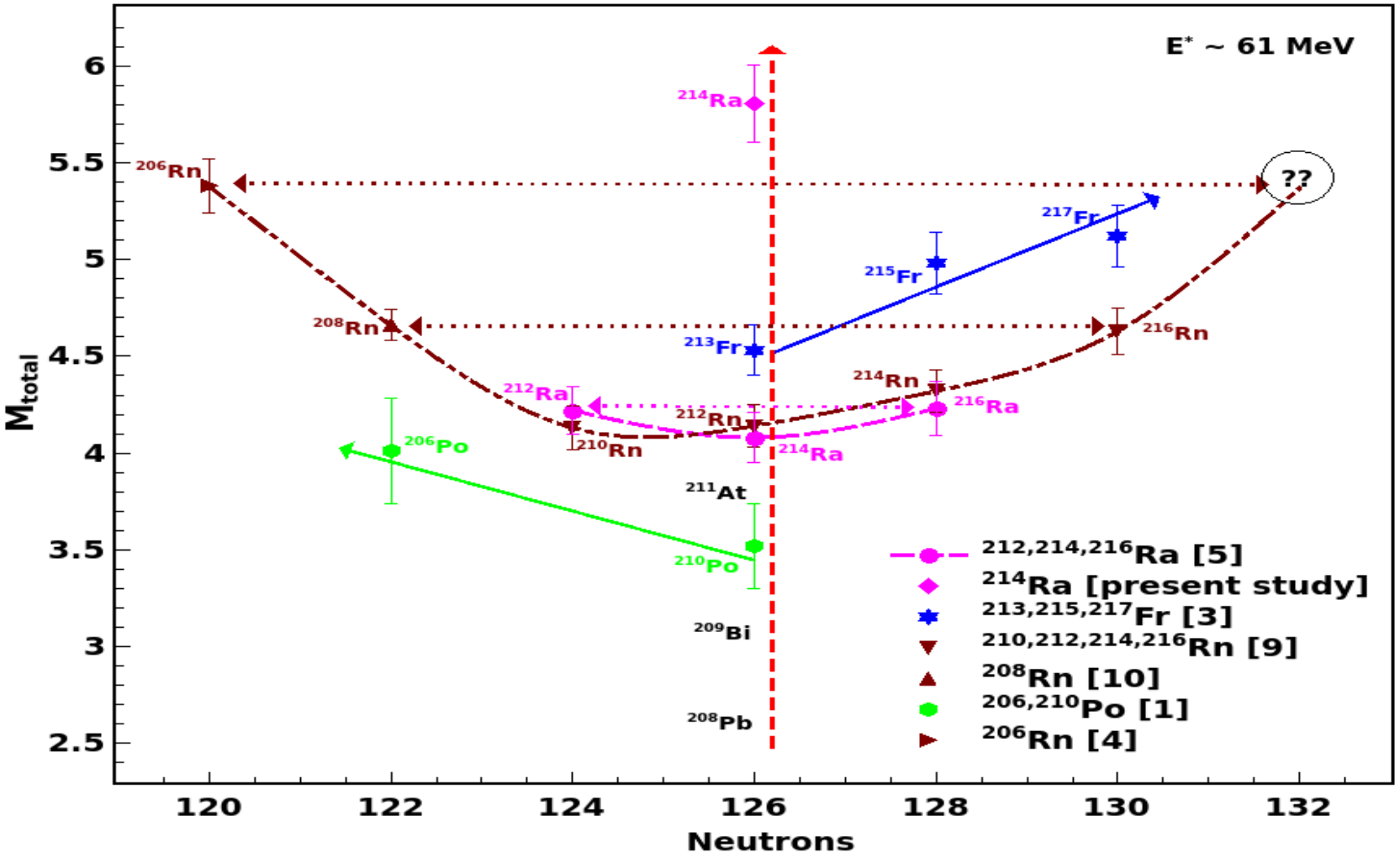


- Variation in M_{total} with increase in E^* for shell closure compound nucleus ^{210}Po, ^{212}Rn, ^{213}Fr and ^{214}Ra.

- Variation in S_n (top), δM (middle) and δE (bottom) with increases in Neutron no. for compound nucleus $Z = 81$ to $Z = 93$.



Punit Dubey, Ajay Kumar *et al.* Phys. Rev. C, **113**, 044602 (2026)



- Cross-correlation between neutron and proton shell closure with respect to M_{total} for pre-actinides.

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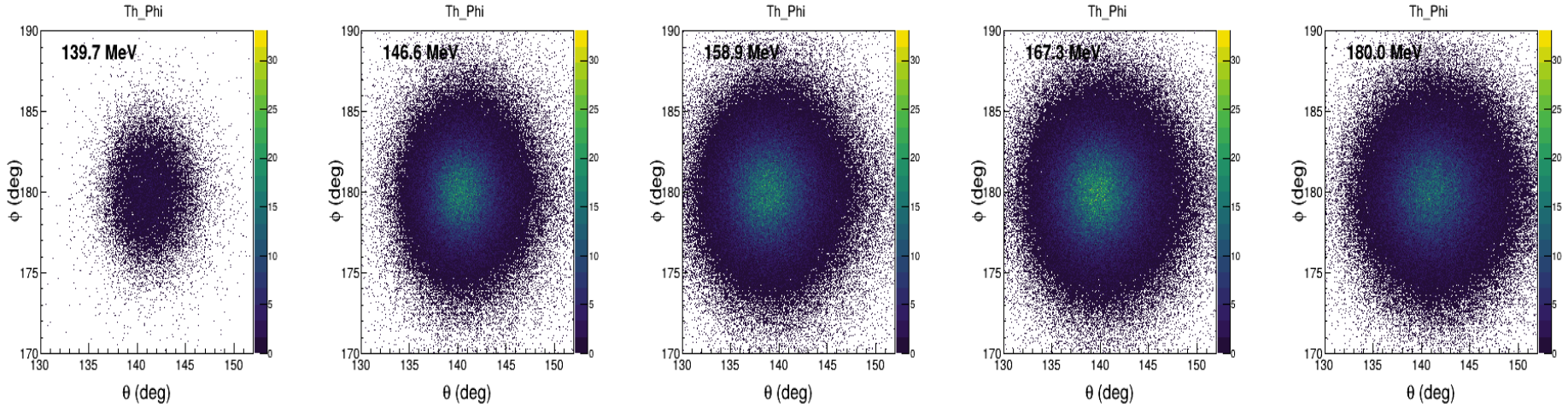
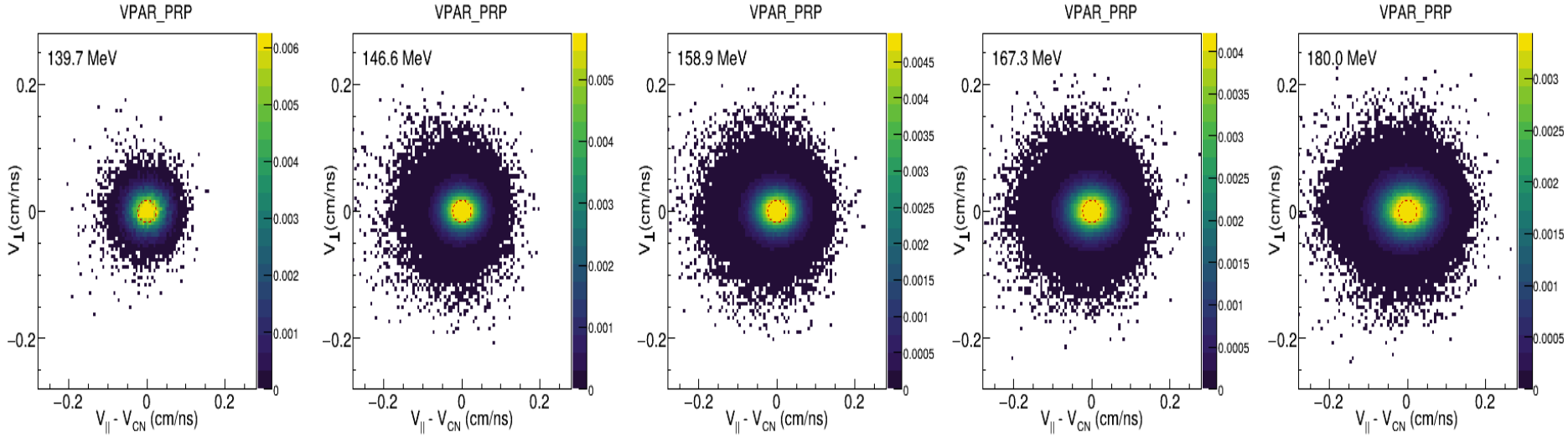
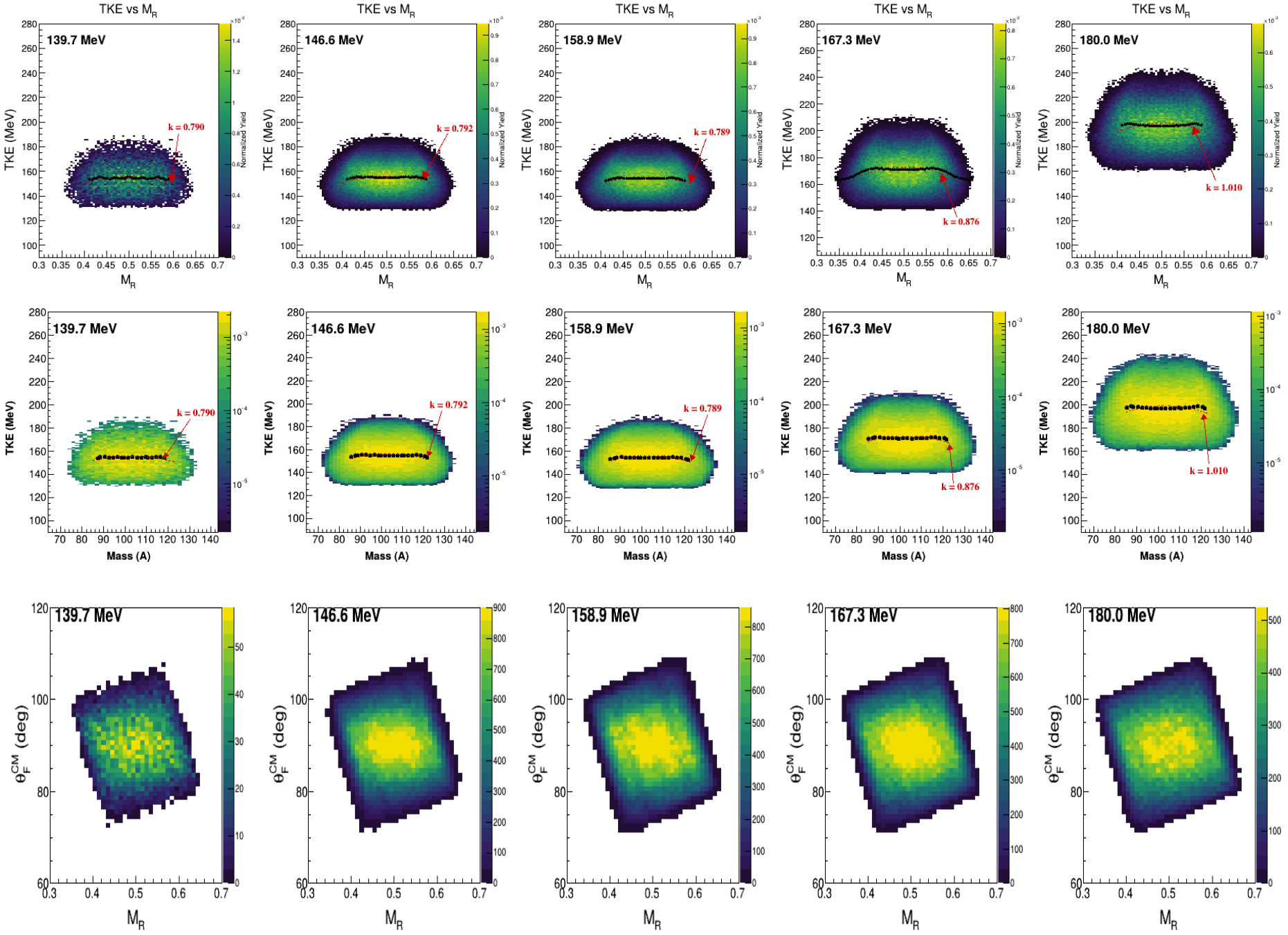
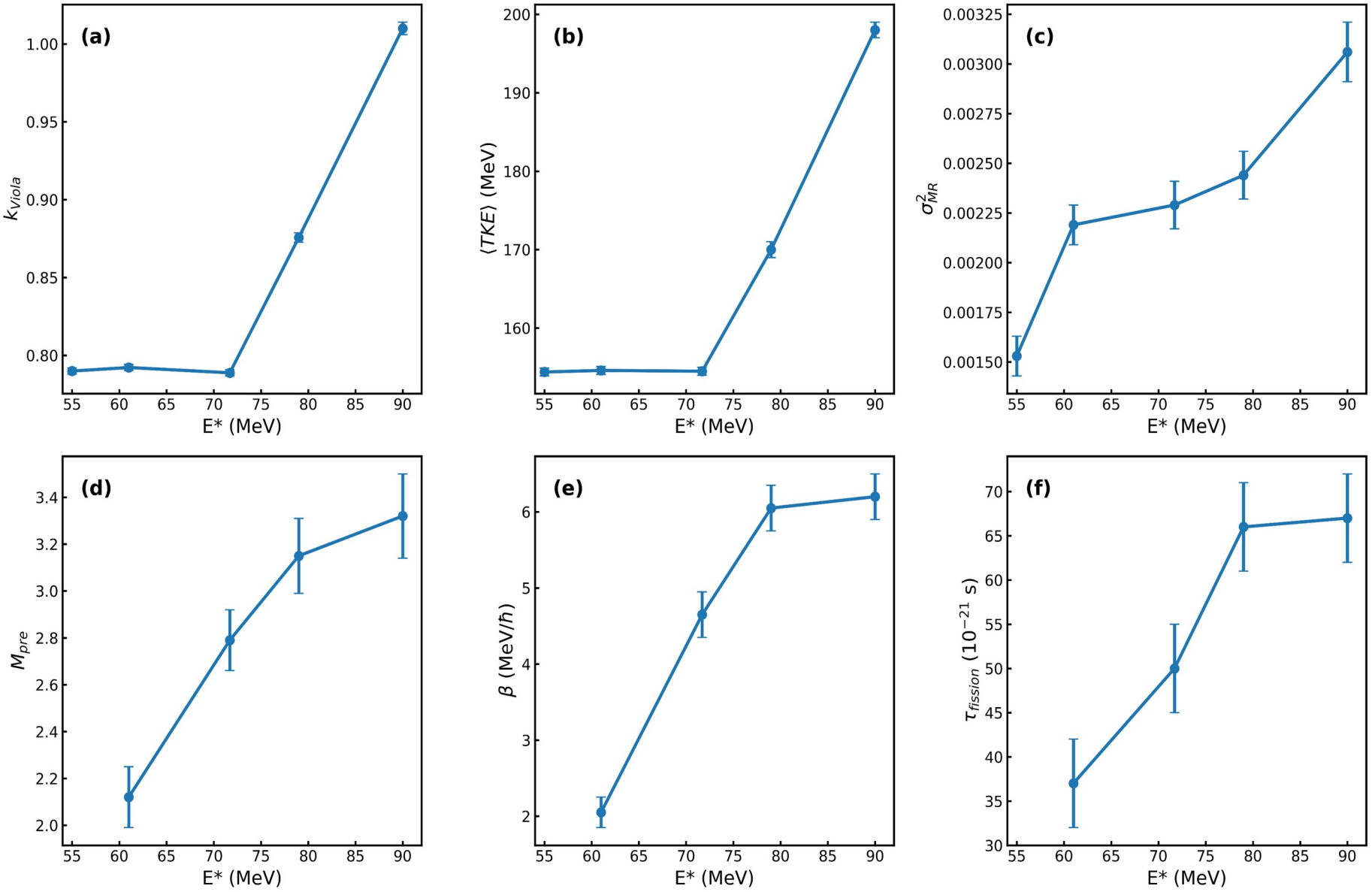
Mass-TKE Correlation






TKE vs M_R
139.7 MeV
k = 0.790
146.6 MeV
k = 0.792
158.9 MeV
k = 0.789
167.3 MeV
k = 0.876
180.0 MeV
k = 1.010
TKE (MeV)
M_R
Normalized Yield
Mass (A)
θ_F^CM (deg)


(a)
k_{Viola}
E* (MeV)
(b)
⟨TKE⟩ (MeV)
E* (MeV)
(c)
σ^2_{MR}
E* (MeV)
(d)
M_{pre}
E* (MeV)
(e)
β (MeV/$\hbar$)
E* (MeV)
(f)
$\tau_{fission}$ (10^{-21} s)
E* (MeV)

Conclusion

- The mass distributions of ^{206}Rn* exhibit persistent asymmetric fission over the explored excitation-energy range.
- A gradual increase in the symmetric component and σ_{MR}^2 with excitation energy indicates enhanced mass diffusion and damping of shell effects.
- The extracted Viola scaling parameter k shows a significant increase at higher excitation energies, suggesting a transition toward more compact scission configurations.
- The simultaneous increase in M_{pre}, dissipation strength β, and fission time scale $\tau_{fission}$ demonstrates stronger dissipative dynamics with increasing excitation energy.
- The observed enhancement in $\langle TKE \rangle$ above $E^* \sim 75$ MeV may indicate a change in the scission dynamics and possible onset of fast-fission-like contributions.
- Overall, the present study provides a coherent picture of the interplay between shell effects, dissipation, and dynamical evolution in the fission of ^{206}Rn*.

References

1. K. S. Golda *et al*., Nucl. Phys. A **913**, 157-169 (2013).
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4. Punit Dubey *et al*., Phys. Rev. C **112**, L011602 (2025).
5. M. Shareef *et al*., Phys. Rev. C **107**, 054619 (2023).
6. E. M Kozulin *et al.,* Yad. Fiz., **56**, 37-54 (1993).
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12. W. Ye, European Physical Journal A, **18**, 571 (2003).
13. Ruchi Mahajan *et. al.* PRC **98**, 034601 (2018).
14. Punit Dubey et al. arXiv:2508.12864v1 (Aug 2025).
15. J. Sadhukhan, **PhD thesis**, Homi Bhabha National Institute, Mumbai (2012).

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- I would like to express our gratitude to the operating staff of the Pelletron and LINAC facility at the Inter-University Accelerator Facility (IUAC) in New Delhi for providing a stable beam throughout my experiments.

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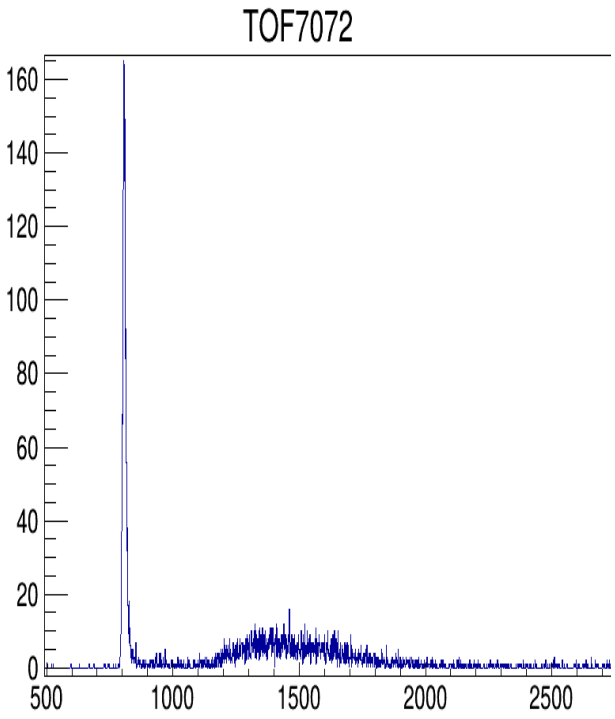
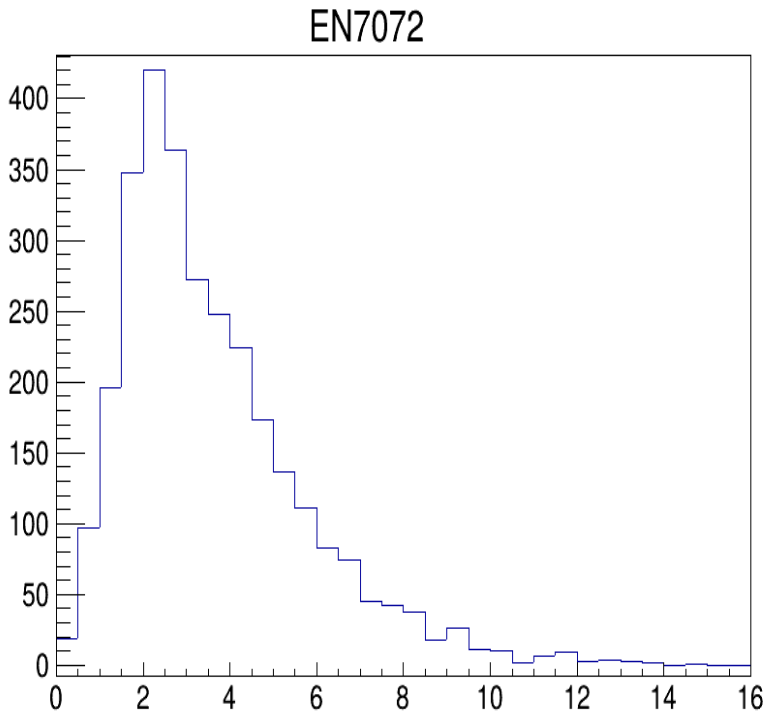
Thank You

Back-Up Slides

TABLE II. Characteristics of reactions studied in this work.

Proj.	Target	CN	$E_{c.m.}$ (MeV)	E^* (MeV)	$Z_1 Z_2$	α	α_{BG}	x_{eff}	$\sigma_{capture\text{-}fission}$ (mb)	P_{CN}
^{18}O	^{197}Au	^{215}At	92.8	60.5	632	0.833	0.788	0.413	834 ± 4	0.66
^{26}Mg	^{197}Au	^{223}Pa	130.1	60.4	948	0.767	0.833	0.524	749 ± 6	1.0
^{30}Si	^{197}Au	^{227}Np	148.3	60.2	1106	0.736	0.849	0.572	770 ± 10	0.06
^{36}S	^{197}Au	^{233}Am	165.1	60.1	1264	0.691	0.860	0.604	748 ± 10	0.13





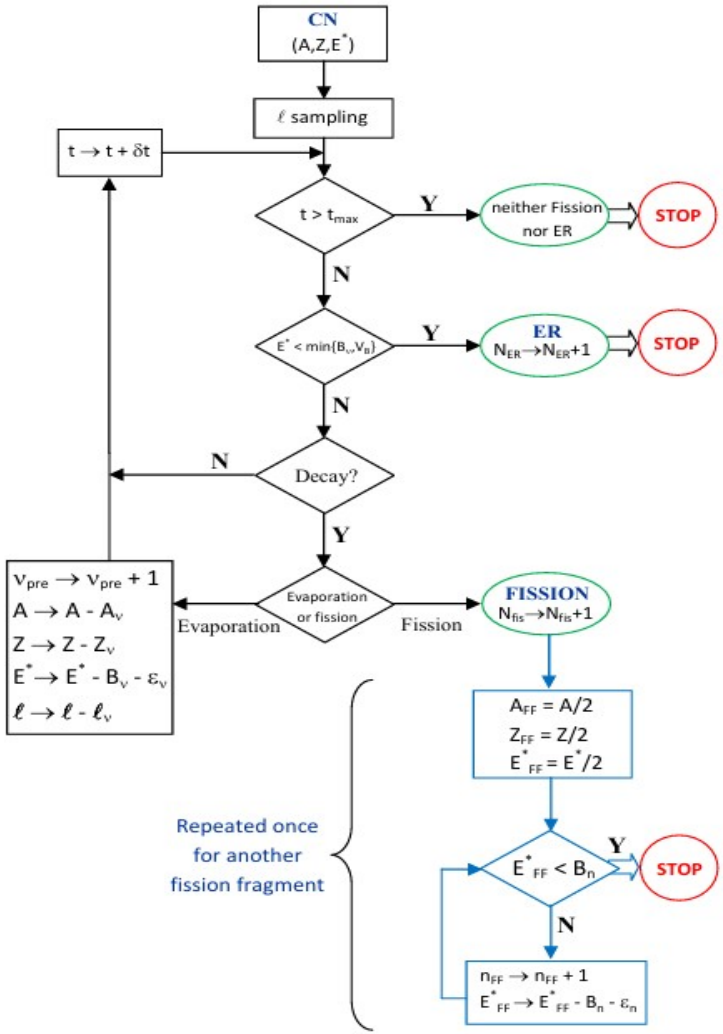
En	counts
0.0	19
0.5	97
1.0	196
1.5	348
2.0	420
2.5	364
3.0	272
3.5	248
4.0	224
4.5	173
5.0	137
5.5	111
6.0	83
6.5	74
7.0	45
7.5	42
8.0	38
8.5	18
9.0	26
9.5	11
10.0	10
10.5	2
11.0	7
11.5	9
12.0	3
12.5	4
13.0	3
13.5	2
14.0	0
14.5	1
15.0	0
15.5	0

Area = 2987

```
punit@punit-VivoBook-ASUSLaptop-X415EA-X415EA: ~/Punitdata/Fi...
gcc -Wall   -c -o mv_src_fit.o mv_src_fit.c
gcc -Wall   -c -o fit.o fit.c
gcc -o mv_src_fit mv_src_fit.o fit.o -lm
punit@punit-VivoBook-ASUSLaptop-X415EA-X415EA:~/Punitdata/Final_analysis/Final_178Hf/Output178Hf_180MeV/Mult_fit/WattEqn$ ./mv_src_fit
233 data points read in
----------------------------
Fit using fixed temperatures
Iter# 1, Chisq/DF=  8.08642
Iter# 2, Chisq/DF=  3.55072
Iter# 3, Chisq/DF=  3.55072
Mpre=4.09368 +- 0.171565, Mpost=1.494907 +- 0.0559637
----------------------------
Fit with variable temperatures
Iter# 1, Chisq/DF=  8.15705
Iter# 2, Chisq/DF=  3.31345
Iter# 3, Chisq/DF=  2.79787
Iter# 4, Chisq/DF=  2.78322
Iter# 5, Chisq/DF=  2.78289
Iter# 6, Chisq/DF=  2.78285
Mpre=3.30885 +- 0.188621, Mpost=1.922001 +- 0.0814437
Tpre=1.56031 +- 0.0757696, Tpost=1.288646 +- 0.041737
punit@punit-VivoBook-ASUSLaptop-X415EA-X415EA:~/Punitdata/Final_analysis/Final_178Hf/Output178Hf_180MeV/Mult_fit/WattEqn$
```

The kinematic effects on the energy and angular distributions of neutrons are assumed to originate from three moving sources (the CN and two fission fragments), and the corresponding neutron spectra are described by the Watt distributions [40],

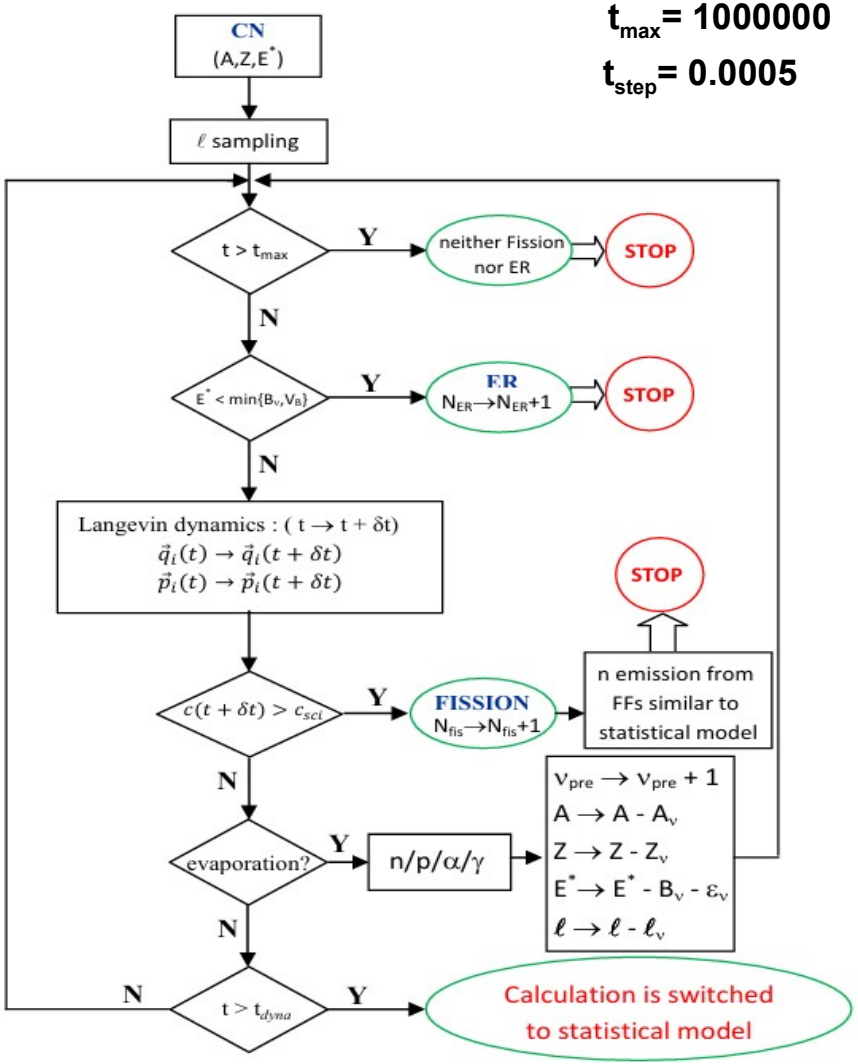
$$\frac{d^2M}{dE_n d\Omega_n} = \sum_{i=1}^{3} \frac{M_i\sqrt{E_n}}{2(\pi T_i)^{3/2}} \times \exp\left[-\frac{E_n - 2\sqrt{E_n E i/A_i}\cos\theta_i + E_i/A_i}{T_i}\right], \quad (1)$$



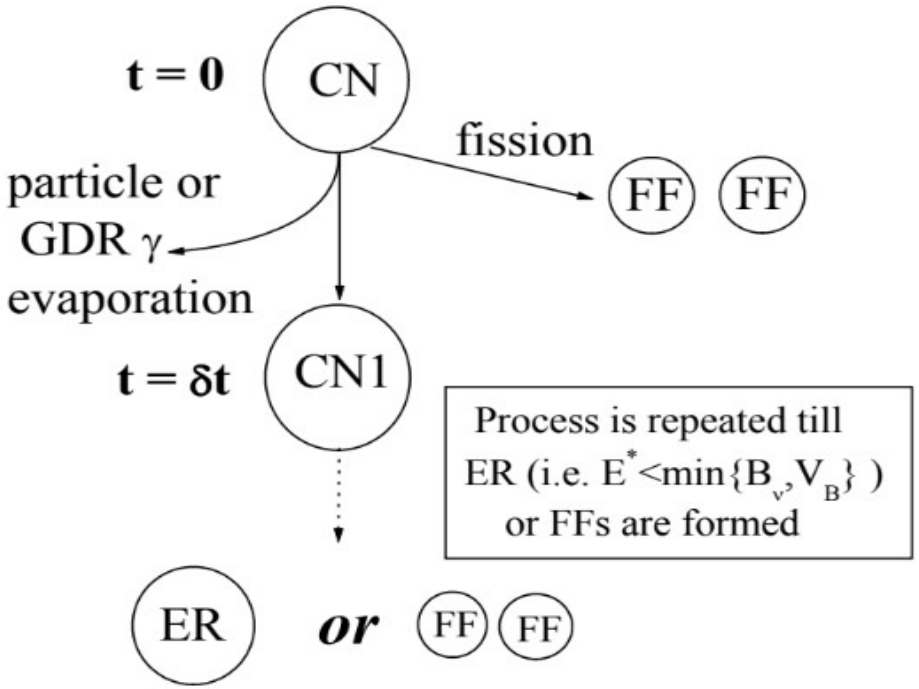
Statistical Model Flow Chart

t_{max}= 1000000

t_{step}= 0.0005



Dynamical Model Flow Chart



A schematic diagram of the decay of an excited CN.