Beamtime proposal for the Pelletron beam cycle 2024

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2. Institution **:** BARC, Mumbai

3. Name of Local Collaborator **:** N/A

a) Consent of Local collaborator **:** N/A

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Title of Experiment: Fission Fragment mass and TKE distribution of ^{216}Rn [^{7}Li+ ^{209}Bi]

Beam Time Requirement (in number of shift): 18 shifts (6 days)

Beam, Energy(MeV) & Current (pnA): i) ^{7}Li beam, 30-42 MeV & 5pnA

Beam port and Experimental setup: Hall 1, 30 D.

If any hazardous or safety related material will be used in the experiment (eg Gas etc): N/A

Motivation of Experiment:

The low energy fission of preactinide nuclei remained less explored, as the increase in liquid drop fission barrier height with decreasing fissility drastically reduces fission probability at low energies. It also was expected that the liquid drop (symmetric) fission will dominate in the preactinide region. In 1980s, series of measurements were carried out by Itkis et al. [1] by bombarding p and α particles on stable preactinide targets. Symmetric fission was indeed found to dominate in this region.

However, recent unexpected observation of almost exclusive asymmetric fission in neutron-deficient ^{180}Hg [2] at low energy has put the focus back on this region. From the liquid drop as well as spherical shell gaps perspective, splitting into two symmetric doubly magic 90 Zr fragments (N = 50, Z = 40) should have been the most favored. Several other measurements [3 and Refs. therein] have firmly established the presence of asymmetric fission in this region. Our systematic study reveals that Z~36 plays a dominate role in asymmetric fission of pre-actinde nuclei and established the general dominance of proton shell in asymmetric fission [4]. However, there are conflicting experimental as well as theoretical results.

We had an ongoing experimental program to systematically explore the new kind of asymmetric fission observed in the preactinide region. Recently, we have investigated the fragment mass and total kinetic energy distributions in fission of ^{12}C+^{175}Lu → ^{187}Ir [5] and ^{7}Li + ^{197}Au → ^{204}Pb [3] reactions. While substantial presence of Z ~ 38 component was observed at all measured energies for ^{204}Pb, the liquid drop component was found to dominate in case of ^{187}Ir. Also good agreement was observed between the experimental and theoretical results for ^{204}Pb. The observed excitation energy dependence of asymmetric fission fractions for ^{204}Pb is compared with those for near−by nuclei and predictions of theoretical models to understand the damping of shell correction at large deformation. The TKE profiles for ^{204}Pb show deviations from the LD behavior around the standard fission modes (Z = 52–55) as observed in heavier preactinides earlier. Unlike the observed peculiarities in some of the neutron deficient light preactinides, the measured distributions of total kinetic energy and their profile do not show any departure from LD expectations corresponding to the new asymmetric mode(s).

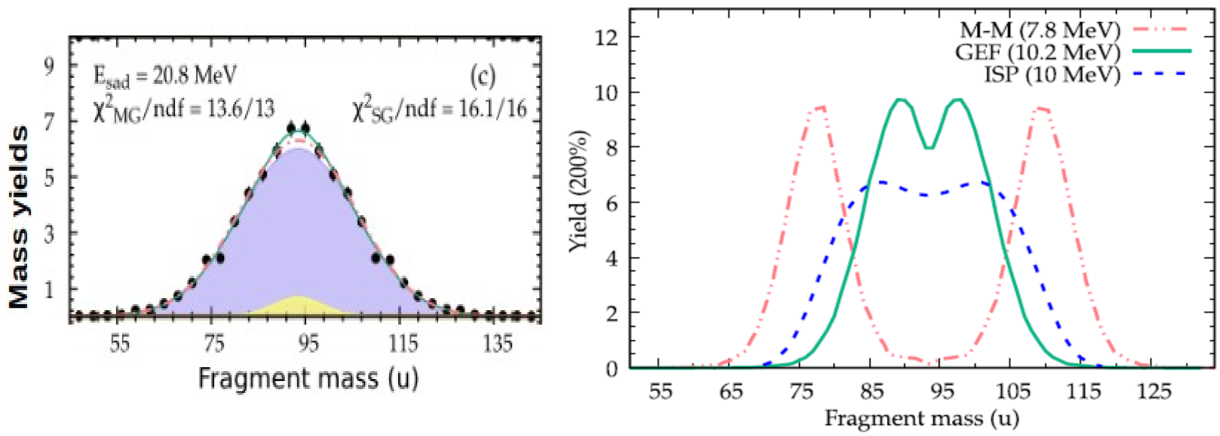

Fig 1 (left) The measured fission fragment mass distribution for $^{12}C+^{175}Lu \rightarrow {}^{187}Ir$ along with the Multi-Gaussian fit to extract the macroscopic and microscopic components. Fig 1(right) shows comparison of the available theoretical predictions for fission fragment mass distribution of ^{187}Ir.

Different models predictions and experimental results are found to differ significantly for ^{187}Ir. The measured fission fragment mass (Fig. 1 [left]) and total kinetic energy (TKE) distributions of ^{187}Ir were found to be dominantly symmetric [5]. Figure 1 (right) shows comparison of the available theoretical predictions for fission fragment mass distribution of ^{187}Ir. The predictions of the macroscopic-microscopic model (M-M) [6], GEF [7], and improved scission point model (ISP) [8] are shown in dot-dot-dashed, solid, and dashed lines, respectively. The numbers in the brackets represent the excitation energy above the saddle point. As can be seen from Fig. 1(right), the distributions (peak positions) predicted by different models differs significantly and all the theoretical models predict a substantial asymmetric contribution. It clearly shows that more studies are required to understand the evolution of the different contributions to the mass distribution across the preactinide region.

In this regard we intend to measure fission fragment mass and TKE distribution of ^{216}Rn populated in $^{7}Li+^{209}Bi$ reaction. Figure 2 (left) shows the GEF [7] prediction of fission fragment mass distribution for ^{216}Rn at 25.4 MeV compound nucleus excitation energy. The yields for asymmetric and symmetric modes are shown separately as red and blue histograms along with the total yield. Figure 2 (right) shows the GEF [7] prediction of symmetric fission fraction as a function of compound nucleus excitation energy. There is around 22% contribution from the asymmetric mode at 25.4 MeV compound nucleus excitation energy. As more studies are required to understand the evolution of the different contributions to mass distributions this measurement will be useful in constraining the state of the art theoretical models.

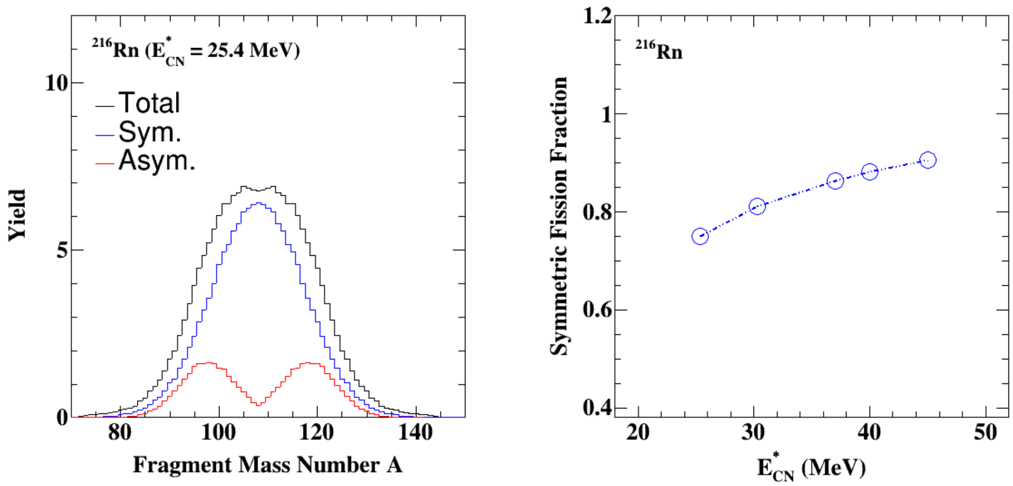

Figure 2 (left) : The GEF [6] prediction of fission fragment mass distribution for ^{216}Rn at 25.4 MeV compound nucleus excitation energy. The yields for asymmetric and symmetric modes are shown separately as red and blue histograms along with the total yield. Figure 2 : (right) The GEF [6] prediction of symmetric fission fraction as a function of compound nucleus excitation energy. There is around 22% contribution from the asymmetric mode at 25.4 MeV compound nucleus excitation energy .

References:

1. Itkis, M.G., Okolovich, V.N., Rusanov, A.Y. et al. Asymmetric fission of the pre-actinide nuclei. Z Physik A 320, 433–441 (1985)
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3. Vineet Kumar, K. Mahata, Sangeeta Dhuri, A. Shrivastava, K. Ramachandran, S. Pandit, V. V. Parkar, Arati Chavan, Abhinav Kumar, Satbir Kaur and P. C. Rout Phys. Rev. C **109**, 014613 (2024).
4. K. Mahata, C. Schmitt, S. Gupta, A. Shrivastava, G. Scamps, and K.-H. Schmidt, Phys. Lett. B **825**, 136859 (2022).
5. Sangeeta Dhuri, K. Mahata,, A. Shrivastava, K. Ramachandran, S. Pandit, V. Kumar, V. V. Parkar, P. C. Rout, Abhinav Kumar, Arati Chavan, Satbir Kaur and T. Santosh, Phys. Rev. C **106**, 014616 (2022).
6. P. Möller and J. Randrup, Phys. Rev. C **91**, 044316 (2015).
7. K.-H. Schmidt, B. Jurado, C. Amouroux, and C. Schmitt, Nucl. Data Sheets 131, 107 (2016).
8. A. V. Andreev, G. G. Adamian, and N. V. Antonenko, Phys. Rev. C 93, 034620 (2016).

Details of the measurement

As shown in Fig 1, two large area (12.5X7.5 cm^2) multi-wire proportional counters (MWPCs) will be placed in a scattering chamber of diameter 1.5 m at folding angle for the coincident detection of the fission fragments. From each detector, one timing and four position signals (two each of X and Y coordinates) will be fed into time to digital converter (TDC) after incorporating appropriate delays. The trigger or start signal will be generated by making an “AND” gate of radio-frequency (RF) signal, associated with the beam pulse from the accelerator, with the output of the “OR” gate of timing signals from MWPCs. Two monitor detectors will be placed at 20 degree in order to detect the elastically scattered beam particles. The data were acquired in event by event mode using a VERSA-Module Eurocard (VME) based multi parameter data acquisition system.

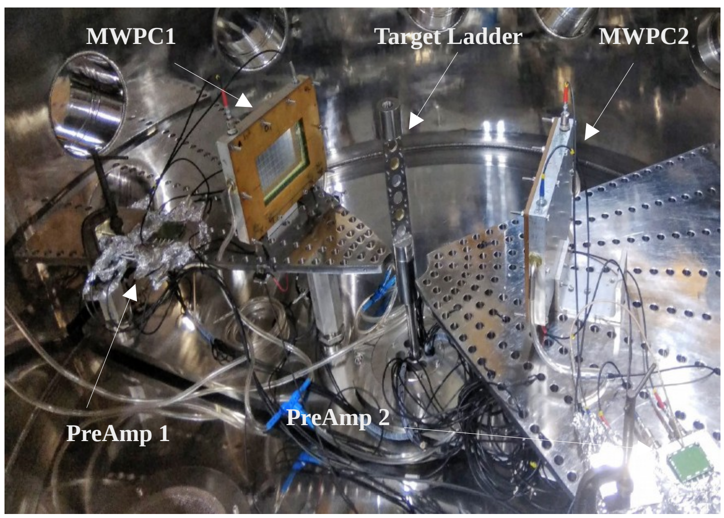

Fig 1: A typical detector setup inside general purpose scattering chamber. Similar setup will be used for the experiment.

The time of flight data and position information will be used to determine the fragment velocities. The emission angles, calculated from the position information will give the linear momenta. The correlations between folding and azimuthal angles, as well as between parallel and perpendicular components of the velocity onto the beam axis will be constructed to confirm the binary nature of the reaction. Pre-neutron fragment masses will finally be determined using the time-of flight (TOF) difference method. The total kinetic energies (TKE) will be obtained using the deduced masses and linear momenta. Assuming a time resolution of 500ps, we expect a resolution of 3-4 mass units.

Count Rate estimation:

For ^{7}Li pulsed beam 5 pnA, ^{209}Bi Target 200 μg/cm^2 thick

Vb = 31.46 MeV (lab frame) , Vb=30.44 MeV(CM frame), Bf = 13.62 MeV

E_{beam} (MeV)	E* (MeV)	$\sigma_{fission}$(mb)	Shifts required	~statistics
42	37.0	14.5	2 Including setup	106338
37	32.2	4.58	2	67176
33	28.3	1.14	4	33000
30	25.4	0.1	10	~7300

Total: 18 shifts

Request: As the experiments requires installing two MWPC inside the chamber along with gas handling system and requirement of pressure test, we would highly appreciate if we get at least two days access to scattering chamber in Hall1 before the experiment

Recent publications from previous experiments:

1. "Observation of asymmetric fission in ^{204}Pb at low excitation energies" Vineet Kumar, K. Mahata, Sangeeta Dhuri, A. Shrivastava, K. Ramachandran et. al. Phys. Rev. C **109**, 014613 (2024).
2. "Quest for understanding neutron emission in nuclear fission:The case of 210Po" Sangeeta Dhuri, K. Mahata, K. Ramachandran, P. C. Rout, A. Shrivastava, et. al. Phys. Rev. C **108**, 054609 (2023).
3. "Measurement of mass and total kinetic energy distributions for the $^{12}C+^{175}Lu$ system" Sangeeta Dhuri, K. Mahata, A. Shrivastava, K. Ramachandran, S. K. Pandit et. al. Phys. Rev. C **106**, 014616 (2022).
4. K. Mahata, C. Schmitt, S. Gupta, A. Shrivastava, G. Scamps, and K.-H. Schmidt, Phys. Lett. B **825**, 136859 (2022).