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

4. Name of Collaborator: K. Mahata, A. Shrivastava, K. Ramachandran, S. K. Pandit, V. V. Parkar, S. Mukhopadhyay, L. S. Danu, A. Kumar, P. C. Rout, S. Kaur, P. Mishra, P. Patale

Title of Experiment: Fission Fragment mass and TKE distribution of ^{194}Hg [^{19}F+ ^{175}Lu]

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

Beam, Energy(MeV) & Current (pnA): i) ^{19}F beam, 85-105 MeV & 2pnA

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:

Nuclear fission, discovered in 1938, represents one of the most substantial cases of nuclear transformation. In a decade since the discovery of asymmetric split in β-delayed fission of ^{180}Tl [1] the fission of the preactinides has witnessed considerable development both theoretically as well as experimentally [2]. However, an extensive understanding of the role of shell effects on the fission process in preactinides and its connection with shell effects in actinides is a vital question in nuclear fission studies. In the early fission studies of preactinides ($Z < 89$), the split was primarily thought of as symmetric due to weak shell corrections to the macroscopic potential for these nuclei [3]. However, later investigations showed mass distributions deviating significantly from a single Gaussian, indicating the presence of asymmetric fission which was not expected from the viewpoint of the liquid drop model (LDM). A systematic investigation of the experimental data in preactinide region has provided evidence of the dominant proton shell effect for Z ~ 34-38 in the light fragment and Z ~ 44-46 in the heavy fragment driving the asymmetric fission in $A < 200$ nuclei [4]. Thus, it has been recently put forth that similar to the actinides, asymmetric fission in preactinides is also driven by proton shells. However, the proton and neutron shells driving different fission mode has not been unambiguously identified for the lighter preactinides.

We had an ongoing experimental program to systematically explore the new kind of asymmetric fission observed in the preactinide region. Figure 1. (left) shows recent observation of asymmetric fission in fission fragment mass distributions of ^{204}Pb (populated in ^{7}Li+^{197}Au reaction) by our group [5]. Around 20-27% contribution of asymmetric fission is observed at low excitation energies. The measured asymmetric fission fraction is in agreement with GEF [6] and BSM model [7] calculations.

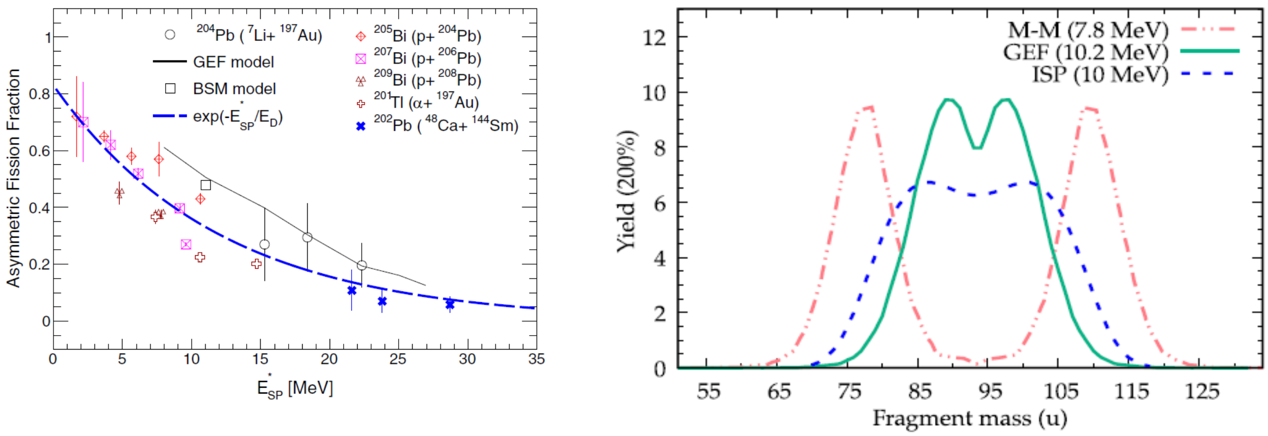

Fig 1 (left) The measured asymmetric fission fractions for ^{204}Pb as a function of excitation energy at the saddle point compared with the predictions of the GEF [6] and BSM [7] models. The experimental asymmetric fission fractions results for nearby nuclei are also shown for comparison. The blue dashed line corresponds to a fit considering all the data points with an exponentially falling function [exp(-E_{SP}^{*}/E_D)] with a damping parameter E_D = 12 MeV. Fig 1(right) shows comparison of the available theoretical predictions for fission fragment mass distribution of ^{187}Ir.

A combined fitting of the data, along with nearby nuclei, with an exponentially falling function [exp(-E_{SP}^{*}/E_D)] revel the value of damping parameter E_D = 12 MeV. In another experiment we measured fission fragment mass and total kinetic energy (TKE) distributions of ^{187}Ir populated in ^{12}C+^{175}Lu reaction [6]. 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) [7], GEF [6], and improved scission point model (ISP) [7] 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 predicted by different models differs significantly and all the theoretical models predict a substantial asymmetric contribution. However the measured fission fragment mass and total kinetic energy (TKE) distributions of ^{187}Ir can be described reasonably well using single Gaussian fits [8]. It clearly shows that more studies are required to understand the evolution of the different contributions to the mass distribution across the preactinide region, especially in case of lighter preactinides.

In this regard we intend to measure fission fragment mass and TKE distribution of ^{194}Hg populated in ^{19}F+^{175}Lu reaction. Figure 2 (left) shows the GEF [6] prediction of fission fragment mass distribution for ^{194}Hg at 52 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 [6] prediction of symmetric fission fraction as a function of compound nucleus excitation energy. There is around 20% contribution from the asymmetric mode at 52 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 theoretical models.

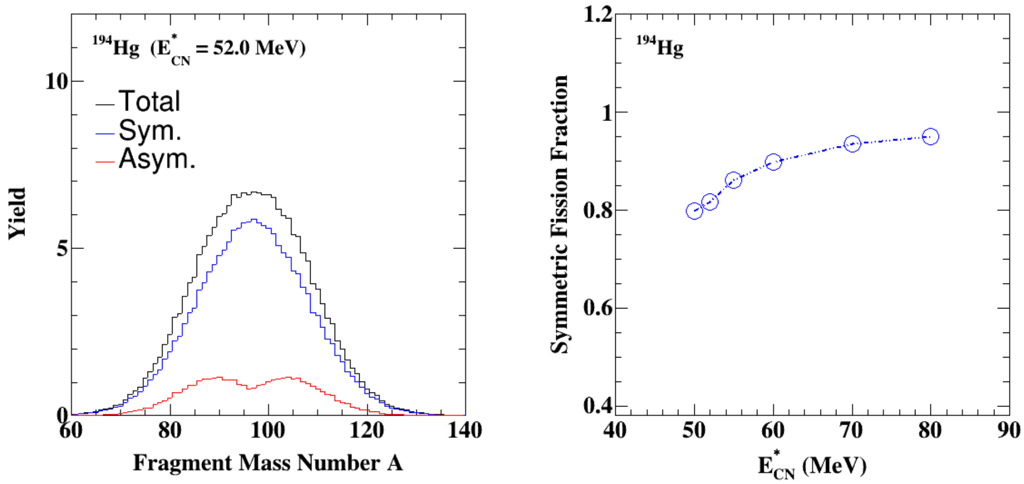

Figure 2 (left) : The GEF [6] prediction of fission fragment mass distribution for ^{194}Hg at 52 MeV compound nucleus excitation energy. The yields for asymmetric and symmetric modes are shown separately as red and blue histograms along with the total yield. Figure 2 : (right) The GEF [6] prediction of symmetric fission fraction as a function of compound nucleus excitation energy. There is around 20% contribution from the asymmetric mode at 52 MeV compound nucleus excitation energy.

References:

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2. A. N. Andreyev, K. Nishio, and K.-H. Schmidt, Rep. Prog. Phys. **81**, 016301 (2018).
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4. K. Mahata, C. Schmitt, S. Gupta, A. Shrivastava, G. Scamps, and K.-H. Schmidt, Phys. Lett. B **825**, 136859 (2022).
5. 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).
6. K.-H. Schmidt, B. Jurado, C. Amouroux, and C. Schmitt, Nucl. Data Sheets 131, 107 (2016).
7. A. V. Andreev, G. G. Adamian, and N. V. Antonenko, Phys. Rev. C 93, 034620 (2016).
8. 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).
9. P. Möller and J. Randrup, Phys. Rev. C **91**, 044316 (2015).

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.

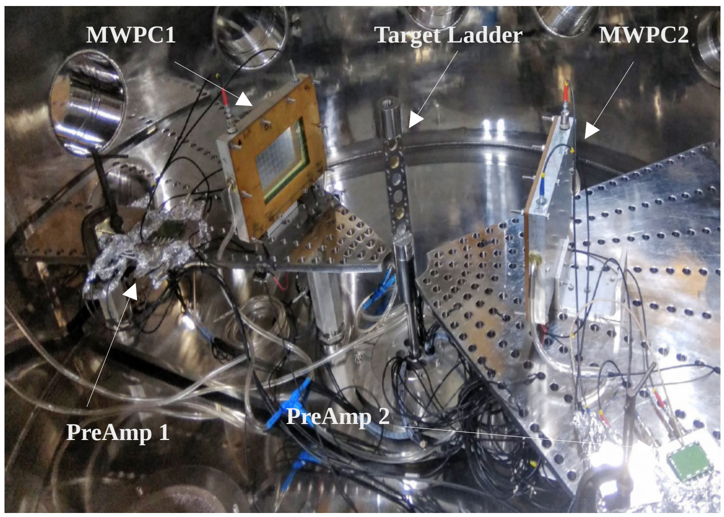

Fig 1: A typical detector setup inside general purpose scattering chamber. Similar setup will be used for the experiment.

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. Assuming a time resolution of 500ps, we expect a resolution of 3-4 mass units. The total kinetic energies (TKE) will also be obtained using the deduced masses and linear momenta.

Count Rate estimation:

For ^{19}F pulsed beam 2 pnA, ^{175}Lu Target 200 μg/cm^2 thick

Vb = 84.57 MeV (lab frame) , Vb=76.11 MeV(CM frame), Bf = 18.20 MeV

E_{beam} (MeV)	E* (MeV)	$\sigma_{fission}$(mb)	Shifts required	~Statistics
105	70.0	40.7	1 Including setup	~1M
94.0	60.0	4.1	1	~1M
88.0	55.0	0.5	6	~12000
85.0	52.0	0.17	10	~6500

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. “Evidence for the general dominance of proton shells in low-energy fission”, K. Mahata, C. Schmitt, S. Gupta, A. Shrivastava, G. Scamps, and K.-H. Schmidt, Phys. Lett. B **825**, 136859 (2022).
5. “Competing asymmetric fusion-fission and quasifission in neutron-deficient sub-lead nuclei”, Shilpi Gupta, K. Mahata, A.Shrivastava, K.Ramachandran, S.K.Pandit, et. al. Phys. Lett. B **803**, 135297 (2020).