# Study of fission fragments mass distribution and prompt $\gamma$-ray spectrum in $^{28}$Si+$^{238}$U reaction

S. P. Behera[1],* P. C. Rout[1,2], A. Pal[1,2], R. Gandhi[1], G. Mohanto[1], S. De[1], A. Kundu[1,2], S. Joshi[1,2], A. Jhingan[3], S. Santra[1,2], K. Mahata[1,2], A. Shrivastava[1,2], R. G. Thomas[1,2], P. N. Patil[4], Vishal B.[5], R. Kujur[1], P. V. Patale[1], E. T. Mirgule[1], and B. K. Nayak[1,2]

[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[2] *Homi Bhabha National Institute, Mumbai - 400094, INDIA*
[3]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA*
[4]*Karnatak University, Dharwad - 580 003, India and*
[5]*Savitribai Phule Pune University, Pune - 411007, India*

## Introduction

The main objective of heavy ion induced fusion reaction is synthesis of super-heavy elements. The formation of the heavy elements depend on the penetration probabilities of the Coulomb barrier between two colliding nuclei, formation of a compound nucleus after the system is captured inside the Coulomb barrier, and survival of the exited compound nucleus against fission (fusion-fission) to produce evaporation residue (ER). In fusion-fission reaction using a heavy target and projectile, quasifission competes against fusion.

The measurement of gamma ray multiplicity in coincidence with the fragment mass has been investigated in heavy ion induced reaction on preactinide targets which shows a strong mass dependency in $^{40}$Ar+$^{154}$Sm ,$^{20}$Ne +$^{197}$Au systems [1]. The measurement of prompt fission gamma ray multiplicity on actinides are available only in thermal and fast neutron induced fission on $^{235}$U, $^{238}$U, $^{239}$Pu targets and the measurements are also limited to the heavy ion induced reaction with $^{238}$U. Recent measurement on mass and kinetic energy correlation in $^{36}$S, $^{48}$Ca and $^{48}$Ti induced reaction on $^{238}$U has been used to identify the fusion-fission and quasi- fission processes [2]. It would be interesting to measure the gamma ray multiplicity in heavy ion induced reaction with actinides targets around the Coulomb barrier.

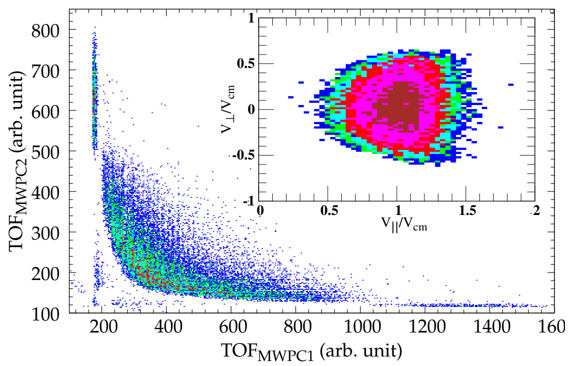


FIG. 1: A 2d spectrum between the TOF of MWPC1 and MWPC2 showing the fission, elastic and recoil events. In the inset, V$_{||}$/V$_{cm}$ versus V$_\perp$/V$_{cm}$ gated with the fission TOF gate

## Experimental details

The experiment has been performed using 161.1 and 180.0 MeV $^{28}$Si pulsed beam from the Pelletron Linac Facility (PLF), Mumbai, bombarding two actinide targets $^{238}$U and $^{232}$Th.A 100.0 $\mu$g/cm$^2$ thick $^{238}$U target with 10 $\mu$g/cm$^2$ carbon backing and 400 $\mu$g/cm$^2$ self supported $^{232}$Th are used in this experiment. Typical beam current is about 10.0 enA. In this experiment 2V (velocity) method has been used to determine the mass and total kinetic energy(TKE) distributions. Two PPAC detectors with an active area 4 cm $\times$ 4 cm have been placed at distance of 9.8 cm

*Electronic address: `shiba@barc.gov.in`

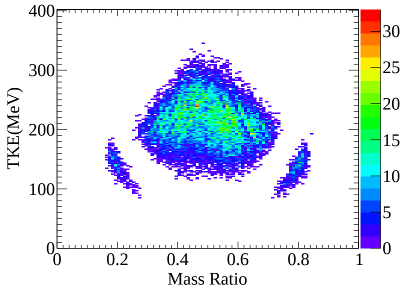


FIG. 2: TKE-mass ratios distribution of FF at beam energy of 161.1 MeV

with respect to target and used as start detectors. Two MWPCs with an active area of 12.5 $\times$ 7.5 cm$^2$ are placed at distance of 19.2 cm and 18.8 cm with respect to PPAC and used as stop detectors. Both the PPACs and MWPCs are placed symmetrically at $\pm 75°$ with respect to the beam direction in a 1.5 m diameter scattering chamber. Two SS cups with 3 mm thick window have been designed and fabricated to insert the $LaBr_3$(Ce) detector( dimension of 7.5 cm diameter and 15.0 cm thick cylindrical) for high energy gamma rays measurement. The $LaBr_3$(Ce) detectors are placed 18.2 cm and 15.9 cm from the target and the corresponding angles are 120° and 150° with respect to the beam direction. The TOF spectra are calibrated using precision time calibrator. The energy spectra of $LaBr_3$ are calibrated using radioactive gamma sources.

## Results and discussion

A typical time of flight spectrum between MWPC1 and MWPC2 is shown in Fig. 1 for the fission, elastic, and recoil like events. The folding angle, mass ratio and TKE spectra are derived using suitable TOF and position gates in MWPC1 and MWPC2 after the energy loss correction of fragments in the PPACs and entrance windows of MWPCs. Folding angles are found to be peaking at 148.3° and 147.0° for beam energies 161.1 MeV and 180.0 MeV, respectively. For full momentum transfer events, the ratio of parallel and perpendicular components of velocity with respect to center-of-mass velocity ($V_{c.m.}$) are found to

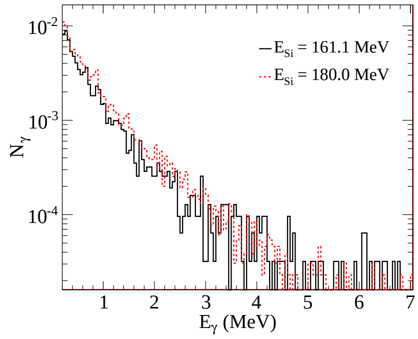


FIG. 3: Gamma rays emitted in coincidence with the FF for 161.1 MeV and 180.0 MeV beam energies.

be centered at 1 and 0, respectively as shown in the inset of Fig. 1. It is also found that the mass ratio of fragments peaks at 0.5. Figure 2 shows the fission fragments (FF) mass ratios versus the TKE at beam energy of 161.1 MeV. It is observed that the mean value of TKE distribution is about 214.0 MeV which compares well with Viola systematic. The efficiency uncorrected $\gamma$-rays energy spectra are obtained with FF-TOF and folding angle distribution gates. The typical gamma ray spectra per fission are shown in the Fig. 3. Further analysis is in progress to find out FF mass gated $\gamma$-rays multiplicity.


## Acknowledgments

We thank the PLF staff for smooth operation of the accelerator during the experiment.


## References


[1] R. P. Schmitt et al:, Nuclear Physics A **427** (1984) 614-638.

[2] E. M. Kozulin et al:, Physical Review C **94** (2016) 054613.