BARC-COTTON-SINP Nuclear Astrophysics Beamline at FRENA

Rasna Baruah[1], A Banerjee[2], J. J. Das[1*], V. M. Datar[3], P. C. Rout[4], S. Santra[4]
[1]*Department of Physics, Cotton University, Guwahati, Assam*
[2]*Saha Institute of Nuclear Physics, Kolkata, WB*
[3]*former Raja Ramanna Fellow, IMSc, Chennai, TN*
[4]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai, MH*

1. Introduction

The Facility for Research in Experimental Nuclear Astrophysics (FRENA) has been built around a 3 MV tandem accelerator capable of delivering beams with high intensities, of the order of several tens to a few hundreds of micro-Amperes (μA). The accelerator was recently commissioned [1]. BARC has taken up a program to develop a dedicated nuclear astrophysics beam line (NABL) and a gas target for FRENA [2]. A collaboration of BARC-COTTON-SINP is jointly working on these developments. As experimental nuclear astrophysics is new to India, we studied the challenges involved and formulated a plan to overcome these. In this paper, we present our efforts in designing the NABL and the essential experimental facilities in the beam hall.

2. Challenges in nuclear astrophysics measurements

At a fundamental level, for any overground laboratory (OL), the data quality of measurements requires to match with those of deep underground laboratories (UL). This necessitates the use of a recoil mass spectrometer (RMS) to match the huge suppression of cosmic ray background at an UL. This is apparent when we look at other experimental facilities of OLs: e.g. St George @ Notre Dame, Dragon @TRIUMF or ERNA @ INFN Napoli etc. making an RMS @ FRENA essential.

We encounter an additional challenge due to FRENA being a tandem accelerator where the minimum beam energy is ~500 keV which exceeds the Gamow peak energy of most reactions. We are trying to address this by choosing to perform the studies using inverse kinematics reactions (IKR) [3]. However, implementing it requires increasing the beam energy by 10 times which complicates the beam line design and increases the cost.

In nearly all nucleosynthesis scenarios, reactions proceed through radiative capture process (RCP) of H or He. As both of these are gases, a gas target is also required. Thus, an accurate and precise measurement of RCP is the primary goal of UL/OL facilities. At UL it is performed by measuring the high energy gamma rays emitted from deexcitation of the compound nucleus using 4π gamma spectrometers. In OL, the same is done by directly detecting the deexcited compound nucleus using an RMS. The main challenge in OGL measurements is use of high intensity beam because of extremely low cross-sections. This demands high beam rejection ratio of the RMS in IKR. As beam rejection is achieved using several sections of optically dispersive elements (E, B or ExB) the dimensions of the RMS become huge and accommodating inside available space in the beam hall becomes the most important issue.

3. Approach of the collaboration

In designing the NABL, our key considerations were to ensure meeting the performance documented by Rolfs et. al. in [4]. In this article, the concepts and hardware required in the beam line optics for successfully performing radiative capture measurements in inverse kinematics are described. In particular, during the study of $\alpha(^{12}C,^{16}O)\gamma$ reaction at Bochum using ERNA (European Recoil separator for Nuclear Astrophysics), the background of stable ^{16}O beam from the accelerator played havoc which was overcome by using 2 velocity filters (VF) one before and another after the analyzing

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*jibanjdas@cottonuniversity.ac.in

magnet. It reduced the ^{16}O contamination from a level of 1x10^{-11} to a level of 2x10^{-29}. Incidentally, this was also described by Rolf in his lectures in SLENA-2006 workshop. This was the reason of adding VF1/VF2 in the NABL. The other strategy we adopted was to use existing concepts and designs already in use elsewhere keeping modifications to a minimum. It was only done to ensure that all the necessary equipment can be laid out within the FRENA beam hall space.

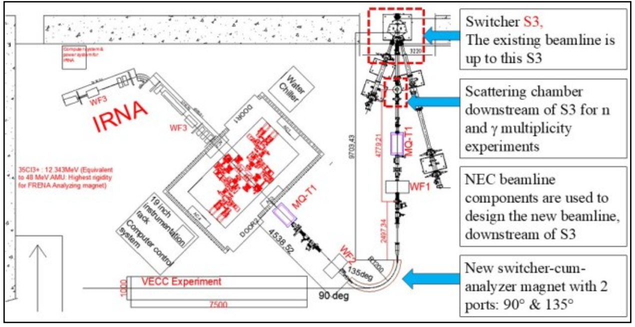
Finally, we also decided to make (i) the model in ready to procure/install configuration and (ii) workout support infrastructure and utilities requirements for the facility laid out. This involved making to the scale CAD design of the entire facility (NABL, gas target, the RMS and utilities) along with ion optical simulations. This was a two-year effort leading to an implementable design and a firm quotation with installation schedule [5].

4. Results and discussions:

The beam line optics was simulated first developing the CAD model of the ion optical elements, beam diagnostics and beam line hardware. These were obtained from the NEC, USA. Then the ion optical simulation is performed using the latest version of the ion optical simulation code GICOSY (GSI). The beam related specifications were taken from the FRENA design reference [6]. In Fig.1 the layout of the entire facility is shown. The NABL starts downstream of the S3 (switcher) and ends on the gas target. We tried to accommodate a 2nd generation RMS like St George, Dragon or ORNL-RMS but it was not successful due to space constraints but were able to accommodate ERNA type of design with appropriate choice of parameters of the 135° analyzer magnet. We also incorporated a thin wall scattering chamber in our model for n and γ multiplicity measurements using FRENA beam.

5. Acknowledgements:

The work was supported by V M Datar endowment fellowship to Cotton. We also acknowledge Nabajyoti, Dimpal, Bhargab, Hritik and Monuj for their help.



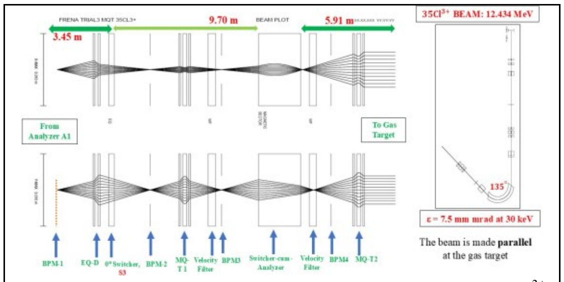
Switcher S3,
The existing beamline is up to this S3

Scattering chamber downstream of S3 for n and γ multiplicity experiments

NEC beamline components are used to design the new beamline, downstream of S3

New switcher-cum-analyzer magnet with 2 ports: 90° & 135°

Fig. 1: The layout of the NABL, gas target and IRNA in FRENA beam hall. Simulation of ERNA is not yet done. In this design, the CAD model of beam line components & hardware given by NEC was used.



35Cl^{3+} BEAM: 12.434 MeV

ε = 7.5 mm mrad at 30 keV

The beam is made **parallel** at the gas target

Fig. 2: Ion optics simulation of the 135° beamline for Cl^{3+} beam downstream of S3 to the gat target. Parallel trajectories are postulated at the target to minimize the scattering of beam from edges of several collimators of the differential pumping sections.

6. References

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