Detector for Exotic Nuclear Matter Studies

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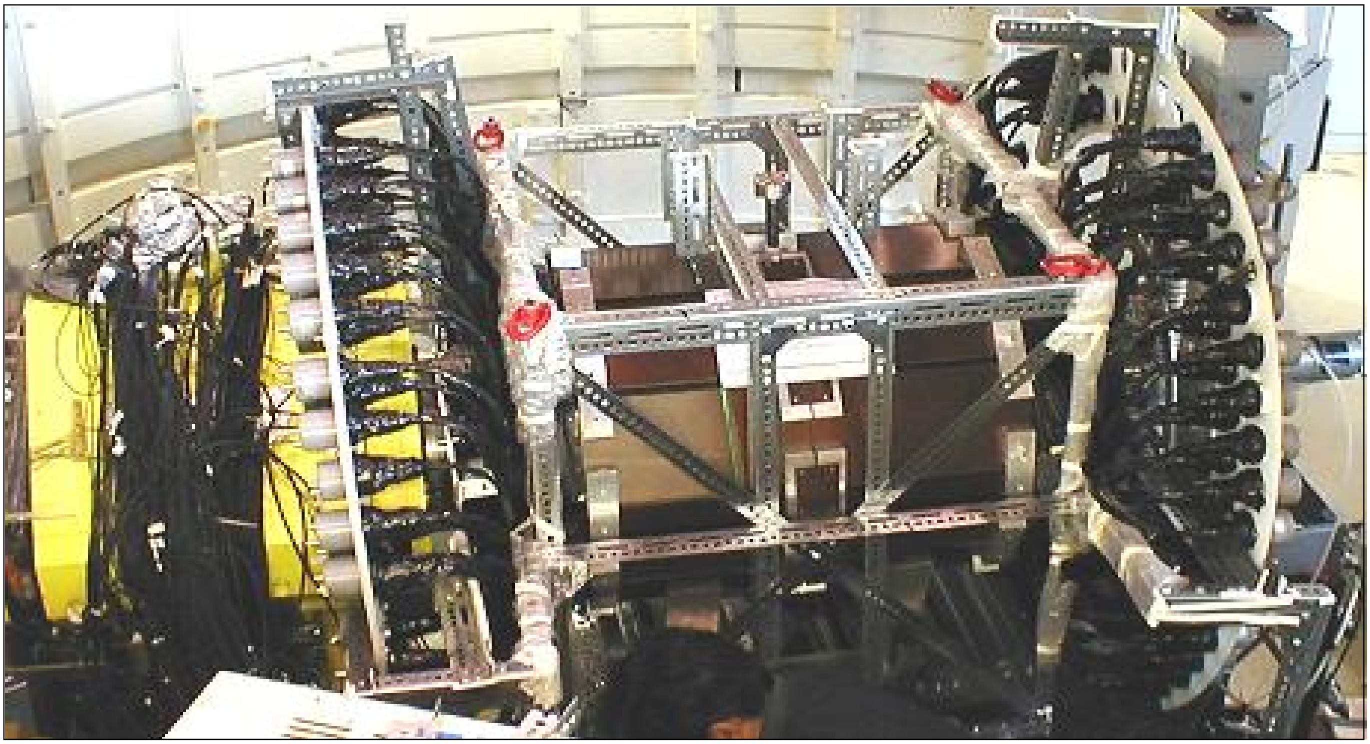
A large acceptance plastic scintillator detector “ENSTAR” with state-of-art fibre optics readout has been designed and built at BARC for studies of a new form of nuclear matter- ‘η-mesic’ nucleus($_{\eta}$A), a bound system of η-meson and nucleus. The η-mesic nuclei, which are solely the result of strong interactions, are a new kind of atomic nuclei and their research has fundamental significance in studying in-medium properties of hadrons, in particular, medium modification of meson masses. The information on the binding energy and width of such quasi-bound systems can be useful in understanding the origin of elementary particle masses. The experimental confirmation of the existence of such η-bound system will lead to new possibilities of studying the interaction between a nucleus and the short lived ($\sim 10^{-18}$s) η meson.

Beams of η-mesons cannot be obtained because of the very short life time of the η- meson. The only way to study eta-nucleus interaction is to produce eta mesons in a nuclear reaction where they appear as final state particles. It is planned to produce and study these η-mesic nuclei in several reactions e.g. $p + {}^{6}Li \rightarrow {}^{3}He + ({}^{4}He_{\eta})$, $p + {}^{12}C \rightarrow {}^{3}He + ({}^{10}B_{\eta})$ and $p + {}^{16}O \rightarrow {}^{3}He + ({}^{14}N_{\eta})$ at the multi-GeV hadron accelerator COSY, Juelich, Germany. The cooler synchrotron COSY, a medium energy accelerator, consists of a cyclotron as injector and a storage ring that delivers both protons and deuterons (un-polarized and polarized) up to a maximum momentum of 3.3 GeV/c with an option for cooled beam – that is a beam with a very small diameter and divergence. Several experimental stations are located inside the ring as well as at the extracted beam line. For the present experiment, which

Fig.1: ENSTAR detector



will be performed at the external target station, recoil free kinematics conditions will be used by choosing the momentum of the proton beam so that η is produced with very small momentum thereby increasing the probability of bound state formation. The estimated cross section for such events is only a few nano-barn, hence, a dedicated detection system is needed and has been set-up to achieve unambiguous signal for formation and decay of the - η nucleus bound state. The η -bound state decay is related to ‘$\eta + N' \rightarrow N^*(1488) \rightarrow N\pi$. The newly built detector ENSTAR (Fig.1) will register these decay products, namely, protons and pions while ^{3}He will be detected by a high resolution magnetic spectrometer BigKarl. The experimental set-up is shown in Fig.2.

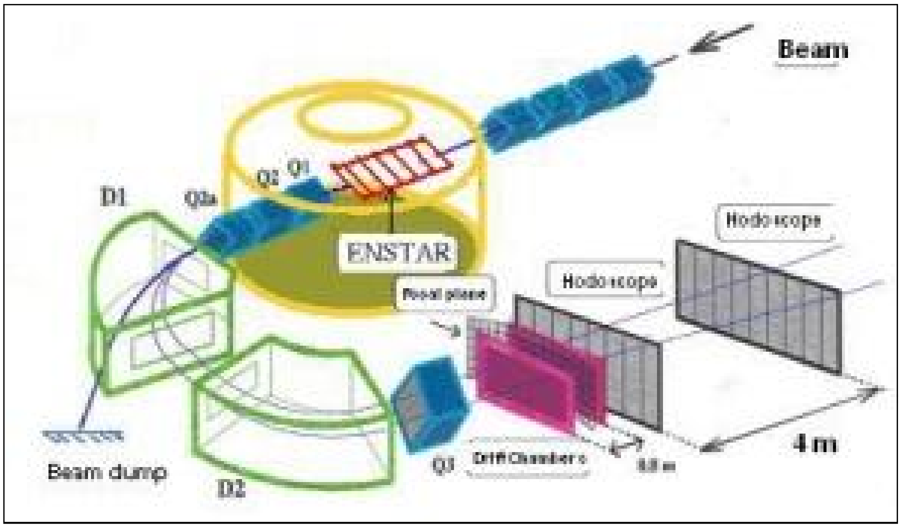


Fig 2 : The experimental setup

The ENSTAR will be mounted, as seen in the figure, around the target. A target ladder is at the centre of Detector ENSTAR. The spectrometer is equipped with, at its focal plane, two sets of multi-wire drift chambers for position information and two layers of scintillator hodoscopes for time of flight information. Triple coincidence between the ENSTAR and Bigkarl will ensure elimination of back-ground and selection of true events. The ENSTAR detector, in addition to the η -bound states search, will be used in many other experiments where ever the missing mass determination is to be done in coincidence with the decay products e.g., in the search for narrow nuclear Δ states in recoil free reactions where the decay products of Δ states will be detected by this detector.

Detector design and construction details

Detailed MonteCarlo phase space calculations have been performed for formation and decay of η-mesic nuclei and GEANT simulations are studied to generate the detector response to the decay products. The detector design is based on these simulation results. The detector, assembled around a carbon fibre beam pipe 83 mm φ (Fig.3), is made up of two identical cylinders

Fig.3 Scattering chamber made of 1.5 mm carbon fibre around which ENSTAR is assembled.

each consisting of three layers of plastic scintillator. The two cylinders are placed on either side of target leaving sufficient space for mounting of a solid target. A more complicated liquid target chamber can as well be accommodated with some modification in the detector support structure. Each layer of ENSTAR is divided into a number of pieces to obtain θ,φ information. The particle identification information can be generated from energy loss in various layers. A total of 122 pieces of different shapes and dimensions give three concentric cylinders on assembly (Fig.4). The overall dimension of ENSTAR is 700 mm in diameter and 780 mm in length.

Because of the complicated geometry of the present detector, the conventional method of use of light guides for scintillator readout was not practicable. Instead the idea of using wave length shifting (WLS) optical fibres are invoked. The WLS fibres absorb light that is produced in a scintillator volume (during the passage of a charged particle in a scintillation medium) and subsequently re-emit at a different wave length, hence the name wave length shifter. The light thus trapped in the fibre is guided by total internal reflection to

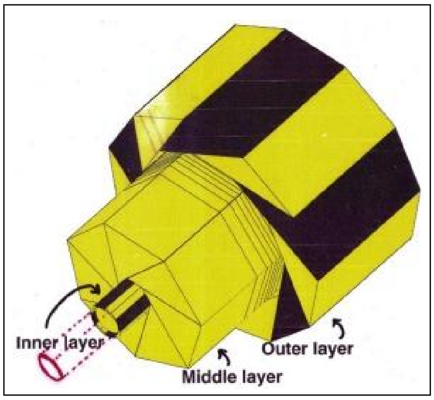


Fig.4. A schematic view of ENSTAR. Some parts of the detector are removed in this figure for better visualization of the inside part.

the open end of the fibre where it is finally read by photomultiplier tubes (PMT). The optical fibres with absorption spectrum that matches the emission spectrum of the scintillator are chosen and the PMTs that have enhanced sensitivity to the emission spectrum of the fibre are taken.

Scintillator grooving, fibre coupling and polishing

Efficient light collection requires good optical coupling between scintillators and WLS fibres. The fibres were coupled to the scintillators by machining grooves on the scintillators and fixing fibres on these grooves (Fig.5). The dimensions of the grooves are such that the fibres are embedded in the scintillators. The machining was done at the Central Workshop, BARC. A separate study was made for the optimization of number of fibres and grooves. The total length of optical fibre (diameter 1 mm) used is ~ 8 km.

A good surface finishing and polishing of both the ends of fibres, are a must and have been achieved by different techniques. At one end of the fibre that is attached to the scintillator, a highly reflective anodized aluminum sheet (known as EverBrite mirror) has been put to reflect back the light from this end. The other open end of all the fibres of individual scintillator pieces were bundled together and were glued inside a 2.54 mm diameter Perspex tube known as 'Cookie' which was then coupled to PMT. All 122 pieces are readout by separate PMTs. The scintillators are covered by a diffusely reflecting foil of Tyvek paper and were finally made light tight by black tedlar foils. The whole detector is assembled on a stainless steel stand sitting on a movable trolley. The complete structure along with PMTs connected was lifted by a crane for transporting and mounting inside the BigKarl target area.

ENSTAR test results

A number of test measurements have been carried out at BARC during the construction of the detector.

The in-beam testing of the detector in full assembled condition with its all 122 pieces is done at COSY, in several stages. Different nuclear reactions (pp elastic scattering, $pp\rightarrow d\pi^+$, p+'heavy target') are used as well as cosmic ray data are collected. Coincidence data (coincidence between ENSTAR and Bigkarl spectrometer, a 2-fold coincidence between different elements in ENSTAR) are also collected. The test results are satisfactorily good. The methodology is established for obtaining relative gains between different pieces and absolute calibration.

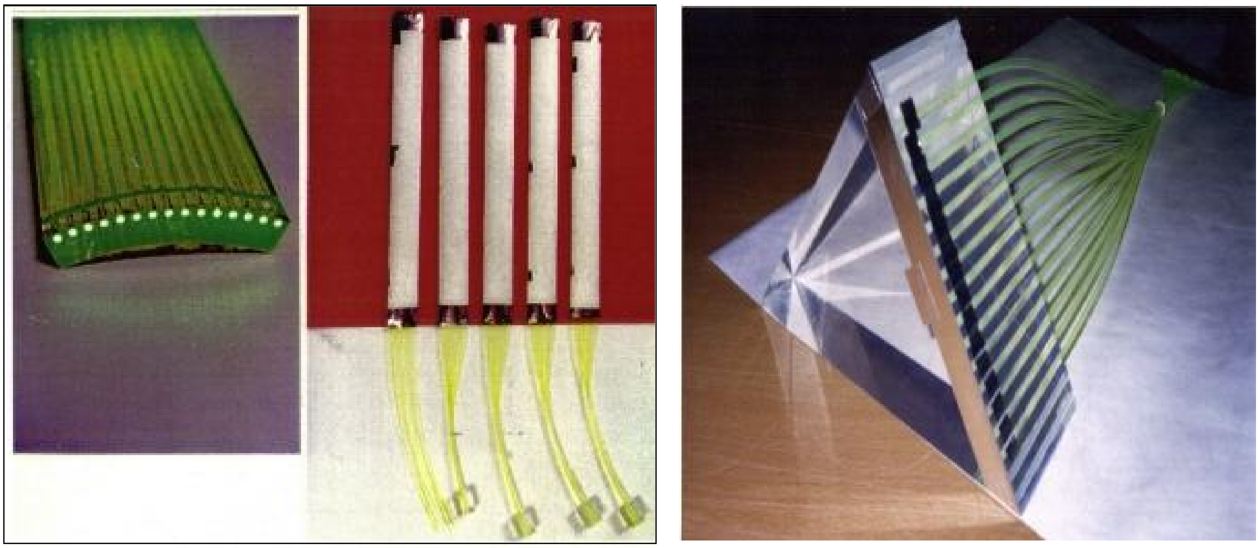


Fig.5 Some pieces of scintilattors with fibres coupled.