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ENUBET —Enhanced NeUtrino BEams from kaon Tagging

G. Brunetti(*) on behalf of the ENUBET Collaboration
INFN, Sezione di Padova - via Marzolo 8, Padova, Italy

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Summary. — The ENUBET ERC-CoG project is funded (2016–2021) to prove lepton production monitoring in the decay tunnel of neutrino beams at single-particle level thus providing a 1% measurement of the flux at source. In particular, the three-body semileptonic decay of the kaons monitored by large angle positron production offers a fully controlled ν_e source at the GeV scale for a new generation of short baseline experiments. A new static focusing system has been validated in 2018, which is very promising in view of operating the system in time-tagged mode. Together with progresses in the design of the neutrino beamline, we report here also the performance of the positron tagger prototypes tested at CERN in 2017–2018.

1. – Introduction

Neutrino cross-sections play a crucial role in the oscillation physics of the next-generation $\nu_\mu \to \nu_e$ experiments and suffer from systematic uncertainties mainly due to the extimate of the flux. Flux uncertainties come from uncertainties in the full simulation of the beamline (which is an indirect procedure) and from limited knowledge of the hadro-production yields in the targets. The ENUBET project [1, 2] aims to develop a neutrino source based on tagging of large angle positrons from K_{e3} decays (*i.e.*, $K^+ \to e^+\pi^0\nu_e$) in an instrumented decay tunnel. A direct monitoring of the leptons produced in the decay tunnel allows to bypass uncertainties from proton-on-target, hadro-production and beamline efficiency and the ν_e flux prediction is directly inferred from positron counting. This technique may lead to a reduction of the systematic uncertainties on the knowledge of the initial neutrino flux to $\sim$1%, *i.e.*, one order of magnitude lower than present neutrino beams.

The decay tunnel to be implemented consists in a hollow cylinder with a length of 40 m and a 1 m radius. The expected rate at the detector (positron tagger) is 200 kHz/cm^2 and e/π separation at the < 3% level is needed to reject the pion background due to beam halo and to other kaon decay modes. This separation is achieved by means of

(*) E-mail: giulia.brunetti@pd.infn.it

longitudinally segmented calorimeters. Photons produced by π^0 decays are vetoed by plastic scintillator pads located just below the calorimeter. The photon veto also provides a precise timing of the positron (t_0). These requirements constrain the detector technology, that must be based on radiation hard components with $O(10\,\mathrm{ns})$ recovery time and a $10\,\mathrm{cm}^2$ granularity.

2. – The transfer line

The ENUBET transfer line has to focus and transport a collimated beam of pions and kaons with high efficiency, limited losses by decays and low beam-induced background. The optimization of the optics is performed with TRANSPORT [3] using a reference momentum of $8.5\,\mathrm{GeV}/c$ and a momentum bite of 10% while particle transport and interactions in the beamline are simulated with G4beamline [4]. Two options have been investigated: a horn-based beamline that employs a pulsed horn between the target and the transport line and a static system where the transport line is implemented directly after the target.

Though the horn-based solution would provide higher yields at the decay tunnel entrance one has to consider the horn pulse limit $<O$ (1–10) ms and the tagger rate limit that would be reached with $\sim 10^{12}$ POT/spill. The possibility of having multi-Hz accelerator extractions and a horn pulsing of 2 ms requires further machine studies, which are ongoing at CERN-SPS.

The static transfer line, on the other hand, only requires a single slow extraction and is beneficial in terms of pile-up effects in the tagger. Preliminary results obtained with the static option look very promising: by using a triplet-dipole-quadrupole scheme we obtain hadronic rates at the decay tunnel entrance that are 5–7 times better than the first estimate presented in [1]. Moreover, this solution would also offer the possibility of event-by-event tagging by coincidences between ν_e at a far detector and e^+ at the tagger. A schematic view of the static transfer line is shown in fig. 1. In table I are reported our expected rates for the two configurations.

3. – The positron tagger and detectors R&D

The reference design of the positron tagger is based on calorimetric units (UCM) made of five, 15 mm thick, iron layers, interleaved with 5 mm thick plastic scintillator tiles. The total thickness of the UCM module (10 cm) corresponds to $4.3\,X_0$ and its transverse size is $3 \times 3\,\mathrm{cm}^2$ providing e^+/π^+ separation. The readout is performed in shashlik

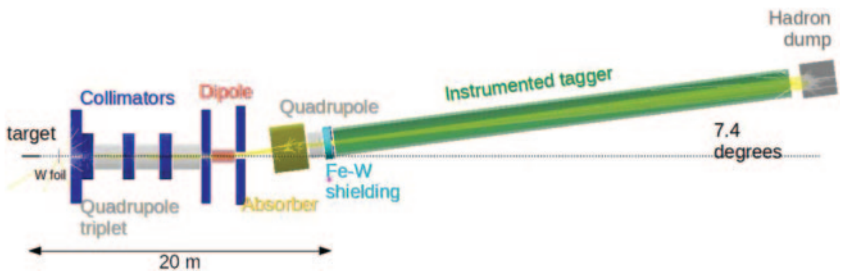

Fig. 1. – Schematics of the preliminary static line design. The secondary particles exiting a beryllium target are focused and transported to the decay tunnel with a system composed by a quadrupole triplet, a dipole that bends the reference beam by 7.4° and another quadrupole.

TABLE I. – *Preliminary expected rates of* π^+ *and* K^+ *at the decay tunnel entrance, in parenthesis are reported the initial estimate for the same rates as in* [1]. *The relative increase factor is shown in the last column.*

	π^+/POT $[10^{-3}]$	K^+/POT $[10^{-3}]$	Increase Factor w.r.t. [1]
Horn-based line	77.3 (33.5)	7.9 (3.7)	$\sim$2.2
Static line	26.7 (3.6)	2.05 (0.43)	5–7

mode through 9 WLS fibers coupled to silicon photomultipliers (SiPM). The photon veto (e^+/π^0 separation, π^0 rejection) is made of doublets of 5 mm thick plastic scintillator pads with a surface of $3\times3\,\text{cm}^2$, separated by a distance of 5 mm. A positron tagger prototype has been tested assembling 56 UCMs in a $7\times4\times2$ structure: in the longitudinal direction 7 UCMs sample the development of the electromagnetic and hadronic showers. The calorimeter (30.1 X_0 and 3.09 interaction lengths) was tested at CERN-PS T9 beamline in November 2016 [5]. The resolution of the calorimeter was measured in the 1–5 GeV energy range. The energy resolution measured for electrons was $(15.7\pm0.7)\%/\sqrt{\text{GeV}}$ and longitudinal profiles of partially contained pions are reproduced by the simulation at 10% precision (interactions in the instrumented decay tunnel and the detector response are simulated with GEANT4). The resolution and e/π discrimination were tested for particles impinging with a tilt angle from 0 to 250 mrad reproducing the conditions envisaged in the ENUBET decay tunnel.

During the lifetime of the experiment the SiPM will integrate a neutron fluence of $O(10^{11})$ 1 MeV-equivalent neutrons/cm^2. A dedicated irradiation campaign at the CN facility at INFN-LNL (Legnaro) was performed in June 2017 where neutron fluences up to 10^{12} n/cm^2 were integrated. UCM prototypes read out by the neutron irradiated SiPM boards were then tested at CERN-PS T9 beamline in October 2017. The calorimetric performance of the detector was not compromised by irradiation in the O(10^{11}) n/cm^2 regime: the energy response of the UCMs to a beam of π^-, e^- and μ^- showed that the ratio between the MIP peak and electron peak remains constant. During the beam test at CERN we were also able to perform the first measurement of the photon-veto time resolution ($\sim$400 ps) and the first 1 mip/2 mip separation using photon conversion from π^0 gammas.

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