The NP06/ENUBET experiment: a monitored neutrino beam
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The idea of monitored $\nu$-beams

ENUBET (Enhanced NeUtrino Beam) from kaon Tagging; a narrow-band beam for the precision era of $\nu$ physics:
- Knowledge of absolute $\nu_e/\bar{\nu}_e$ flux at 1% level;
- Energy of the neutrino determined at 10% level;
- High precision (8% 1%) in the flavour composition;

- Monitor positions from $K_{\ell 2}$ decays with a fully instrumented decay tunnel (tagger); $\nu_e$ flux determination from $\nu_\mu$ counting;
- Extend to the monitoring of muons from $K_{\ell 3}$ and $\pi^0$ decays for the $\nu_\tau$ flux determination;
- AVOIDS uncertainties from Protons-on-Target (POT), hadron-production, beam line efficiency;

Proton target & Transfer Line design

Layout (G4Beamline) of the two latest static transfer lines (8.5 GeV particle beam optimisation) + tagger + dumps:

- Large bending angle of $14.8^\circ$ (2 dipoles);
- better collimated beam and reduced background from muons;
- reduced $\nu_\mu$ from early decays in detector;

Shielding:
- absorbers & rock volumes included in complete simulation (optimised with FLUKA and GENIA4);
- tungsten block at target entrance for TLR6;
- in progress: optimisation/design of collimators + absorbers of last section of TLR6;
- tungsten foil downstream target to suppress positron background;

Target optimisation (FLUKA & G4Beamline):
- scan in the geometry parameter space and test of different materials (graphite, beryllium, inconel) to maximise $K_{\ell 3}$/production in region of interest;
- TLR6 employs optimised graphite target ($L = 70 \text{ cm} \times R = 3 \text{ cm}$);
- inconel target ($L = 50 \text{ cm} \times R = 3 \text{ cm}$) under consideration;

Graphite target length/radius scan

Calorimeter prototyping: test-beams and final demonstrator

Lateral readout schematic representation

Sampling calorimeter with lateral WLS fibers for light collection

Calorimeter with +/− separation capabilities
- Sampling calorimeter: plastic scintillator (0.5 cm) + Iron absorbers (1.5 cm);
- Three nested layers of Lateral Compact Modules (LCM): $3 \times 3 \times 10 \text{ cm}^3$ with longitudinal segmentation; light collection/readout: WLS fibers & SiPM;

Photon veto allows +/− separation
- plastic scintillator tiles; $3 \times 5 \text{ cm}^2$-like arranged in doubles forming inner rings;
- time resolution of $\leq 400 \text{ ps}$;

New light readout scheme with front grooves instead of lateral grooves driven by large scale scintillator production (safer production and more uniform light collection);
- validated with GEANT4 optical simulation;
- measuring efficiency maps of tiles with similar geometry ongoing @ INFN-Bologna;
- scintillators in production phase (~10000 pieces) with UNPLAST in collaboration with INR group;
- pre-demonstrator prototype with 3 LCMs (ENUBED) under test with cosmic-rays @ INFN-LNS;

Lepton PID performance and $\nu$-flux systematics assessment

Full Geant4 simulation of the detector (validation for $\nu_e$ reconstruction by prototype tests at CERN during 2016-2018):
- particle propagation and decay from transfer line to detector;
- $\nu_e$ flux systematics assessment: leptons measured @ calorimeter are related to neutrinos flux @ detector;

$\nu$-flux systematics assessment: leptons measured @ calorimeter are related to neutrinos flux detector

Analysis chain:
1. Event builder: identify LCM with energy deposit as seed of the event. Cluster neighbour LCM deposits compatible with particle;
2. signal/background separation: multivariate analysis (MLP-NN from TMVA) exploiting energy pattern deposition in calorimeters, event topology and photon-veto energy deposition variables;

Example distributions for muon impact point along calorimeter wall

Toy MC experiment: fit muon data (black points) with signal templates (coloured) and background (binned).

$K_{\ell 3}$ reconstruction: $+\Delta \nu_{e}/-\Delta \nu_{e}$

$K_{\ell 2}$ reconstruction: $+\Delta \nu_{e}/-\Delta \nu_{e}$

exploit Monte-Carlo (MC) simulations to compute template distributions for lepton physics observables measured by calorimeter;
- build a signal+background model (using RooFit): include a prior hadron-production (HP) and TL related systematic uncertainties;
- perform fit of toy-MC experiments to study the a posteriori systematic uncertainties and assess the corresponding uncertainties;
- propagate the a posteriori systematic uncertainties to the $\nu$-flux;
- built models from toy HP model & mock kinematical observables: multiverse method to propagate systematics from HP to observables;
- tested RooFit model on 500 toy-MC experiments: after fit $\Delta \nu_{e}$ from a $\sim 15 \%$ initial error (preliminary result on toy-model);
- next: build model based on real HP data and MC templates (work in progress);

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