The design of the beamline for the ENUBET experiment

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**NP06/ENUBET: Enhanced NeUtrino BEams from kaon Tagging**

Novel $\nu_e$ source from $K^+ \to e^+ \pi^0 \nu_e$ decays, lepton production at large angles is monitored at single particle level by calorimetric techniques, i.e. tagging the $e^+$ in an instrumented decay pipe

$\rightarrow O(10\%)$ flux uncertainty
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**NP06/ENUBET: Enhanced NeUtrino BEams from kaon Tagging**

Design optimized to reach a $O(1\%)$ precision on the $\nu_e$ flux $\rightarrow \nu_e$ flux prediction = e$^+$ counting

Two main steps:
- layout of the $\pi/K$ focusing and transport system with suitable proton extraction schemes
- special instrumented beamline capable of performing positron monitoring from decays of $K$ in a $\nu$ beam decay tunnel at single particle level
The Beamline

Requirements:

- Use of conventional magnets (normal-conducting, aperture < 15 cm)
- Keep under control level of background transported to the tunnel: fine tuning of shielding and collimators
- Maximize number of $K^+$ at tunnel entrance (looking for $K^+ \rightarrow e^+ \pi^0 \nu_e$)
- Small beam size: non decaying particles should exit the decay pipe without hitting the walls
- Minimize total length of the transferline (~20 m) to reduce kaon decay in the not instrumented region
Proton target design

Optimum particle production: primary proton beam = 400 GeV, secondary kaons momentum ~8.5 GeV.

Goal: maximise K production in region of interest.
- Optimization of transverse dimensions and length
- Test of different materials (Graphite, Beryllium, Inconel)

FLUKA + G4beamline simulations
→ maximise number of kaons of given energy (10% momentum bite) that enter a beamline with 20 mrad angular acceptance

Last version of the beamline:
Graphite target, L = 70 cm, R = 3 cm
Inconel target (L = 50 cm, R = 3 cm) is also being considered
Transfer Line design

Static TL, top view

Optics optimized with TRANSPORT.

Particle transport and interaction: full simulation with G4beamline

FLUKA: assess doses in the tunnel area where instrumentation will be placed, target studies

GEANT4: optimization of beamline elements, systematic uncertainties on the neutrino flux
Transer Line details

Reference beamline: 8.5 GeV, 10% momentum bite.
Focusing system: a quadrupole triplet before the bending magnets (14.8° bending)
→ Larger bending angle (w.r.t. original proposal) and increased length
→ Better collimated beam and reduced backgrounds

Improved shielding
- **W plug**: dumps low energy particles hitting the tagger, backgrounds reduced by large factors
- **W foil**: dumps low energy $e^+$ entering tunnel

**G4beamline**
Multi Momentum beamline

Neutrinos from reference beamline are peaked ~4 GeV (DUNE R.o.I, Region of Interest).

New beamline design: secondary multi momentum (4, 6, 8.5 GeV) → cover full range of interest (including the low-energy region, T2K/HyperK R.o.I.)

Optics optimization: TRANSPORT, G4beamline.

Contains detailed description of existing magnetic elements

First estimates of kaon fluxes and background are ongoing.
New design from G4beamline (feat. new proton target) → suppression of low energy $\nu_e$ from target region

Further reduction of background: optimization and final design of collimators and absorbers at the end of the transfer line (position, dimension and apertures) in progress with GEANT4

→ New genetic algorithm implemented to sample the parameter space

• Convergence in O(100) iterations

• Figure Of Merit = ratio $K^+$ entering tagger / background hitting tunnel  
  
  \[ \text{Figure Of Merit} = \frac{\text{signal}}{\text{background}} \text{ to be maximized} \]

GEANT4 - beamline optimization
GEANT4 - beamline optimization

→ FOM = \frac{\text{ratio } K^+ \text{ entering tagger}}{\text{background hitting tunnel}}

Preliminary

Scan of parameter space with FOM value in colour scale

Before implementation of new collimators

After optimization

Signal: kaons not affected

Background: pions and positrons - reduced

Convergence indicator

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Particle fluxes @ entrance of instrumented decay region

GEANT4 reproduces geometry and outcome of G4beamline simulation.
Contains information on particle decay along the beamline.

Flexibility of GEANT4 simulation:
- Map of different kinds of background entering the instrumented decay region
- Optimization of the beamline design
- Study of flux systematics

Spectra of particles at tagger entrance
Neutrino fluxes @ far detector

Flexibility of GEANT4 simulation:

- Detailed definition of signals, generation and path of different neutrino production mechanisms
- Even after instrumented decay region → far detector

Neutrino flux (weighted by energy) on a 6x6m² surface at 70m from the tagger exit
Summary

- ENUBET: reducing the flux related systematics → monitoring charged leptons in an instrumented decay tunnel
- Design of a transfer line: maximize $K^+$ and $\pi^+$ yield, minimize meson decays in the non-instrumented region.
- Step forwards in simulation:
  - Beamline design
  - Improved proton target design
  - GEANT4 simulation also for optimization studies
  - Doses estimation through FLUKA simulation
  - Multi Momentum beamline (4, 6, 8.5 GeV) → enhanced physics reach
- Next steps:
  - Finalize optimization