F. Terranova (Univ. of Milano-Bicocca and INFN) on behalf of the ENUBET Collaboration

ENUBET: ERC Consolidator Grant. Jun 2016 - May 2021. PI: A. Longhin. Since April 2019, ENUBET is also a CERN Neutrino Platform experiment: NP06/ENUBET

The ENUBET Collaboration:  
60 physicists, 12 institutions  
Spokespersons: A. Longhin, F. Terranova  
Technical Coordinator: V. Mascagna
The rationale of eNUBET

To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied. Other important

ENUBET and NUSTORM  
(see also the European Strategy Physics Briefbook, arXiv:1910.11775)

ENUBET is aimed at
• Designing a narrow band neutrino beam at the GeV scale and measure at 1% the flux, flavor and (at 10%) the energy of the neutrinos produced at source

It is the core technology for
• A new generation of short-baseline experiments to achieve a 1% precision on the $\nu_e$ and $\nu_\mu$ cross sections and remove all the biases due the $\nu$ energy reconstruction
• It is essential to lower <3% the systematic budget of DUNE and HyperK and enhance remarkably their discovery reach (equivalent to doubling the DUNE mass!)
• Is the most natural follow-up of the previous generation of x-sect experiments (including the possibility to upgrade the ProtoDUNE or the SBN physics programme)
ENUBET will be the first “monitored neutrino beam” (*) where nearly all systematics are bypassed monitoring the leptons in the decay tunnel at single particle level.

(*) A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155
The new ENUBET beamline

Target simulation: OK
Transfer line:
- TRANSPORT/G4Beamline (optics and background shielding OK)
- FLUKA (doses and neutron shieldings ~OK)
- GEANT4 (systematics, in progress)

Proton dump: OK but engineering studies needed
Hadron dump: OK (with neutron shieldings NEW!)

See also: A. Longhin, Talk @ Neutrino 2020
Focusing with the Horn

“Slow burst extraction”: tested at the SPS in 2018. In 2019 we finalized the simulation with MAD-X to reach 2-10 ms extraction at 10 Hz in the flat top. **Final test: at SPS in 2022 (post LS2)**

Horn is being re-optimized for the new beamline. We will likely employ a parabolic horn. Current and shape of conductors are chosen in a broad phase space using genetic algorithms. **In progress**

Static focusing (no horn, 2s slow extraction): work carried on in 2017-2019. Adapt this option to the 2 dipole beamline: **in progress**

Paper: M. Pari, M. A Fraser et al, IPAC2019
Instrumentation of the decay tunnel

- Longitudinally segmented calorimeter (OK)
- SiPMs on top of the calo above a PE borated shield to reduce (x18) radiation damage OK
- Test of the photon veto (t0-layer) OK
- Custom digitizer: in progress

The choice of the technology is now final and it is extremely cost-effective

Lepton monitoring

Full simulation: detector response, pile-up, event building, PID algorithms (2016-2020) **OK**

Particle ID for the **positrons** is much better in the new beamline. **OK**

For the first time, we monitor **muons** and the beamline is flexible enough for dedicated runs in the region of interest for HyperK. **In progress**

**Muons from K ($\sim \nu_\mu$)**

**Positrons from K ($\sim \nu_e$)**

- **S/N = 2.1**
- **Efficiency: 24%**
  (dominated by geometrical eff.)

2020 highlight. First release at ICHEP2020
Physics performance

<table>
<thead>
<tr>
<th>Focusing system</th>
<th>$\pi$/pot ($10^{-3}$)</th>
<th>$K$/pot ($10^{-3}$)</th>
<th>Extraction length</th>
<th>$\pi$/cycle ($10^{10}$)</th>
<th>$K$/cycle ($10^{10}$)</th>
<th>Proposal (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horn</td>
<td>97</td>
<td>7.9</td>
<td>2 ms $^{(a)}$</td>
<td>438</td>
<td>36</td>
<td>x 2</td>
</tr>
<tr>
<td>“static”</td>
<td>19</td>
<td>1.4</td>
<td>2 s</td>
<td>85</td>
<td>6.2</td>
<td>x 4</td>
</tr>
</tbody>
</table>

To be updated with the new beamline In progress

The following results are given under the assumption of a **500 t neutrino detector** located 50 m from the hadron dump

$10^4$ fully reconstructed $\nu_e$ CC in about 1.5 y of data taking (TBC)

80% of the events directly monitored (positron in the decay tunnel)

10% from decay in the transfer line

10% low energy events from $K^0_L$ et al.
Muon neutrinos

Flux:
- Muons from $\pi$ monitored by the range-meter (useful for DUNE and HyperK)
- High energy muons monitored by $K_{2\mu}$ (useful for x-sect modeling and DUNE “tau runs”)

Energy:
- Since the momentum bite is <10% and the detector distance is small, strong correlation between the position of the neutrino vertex and its energy.
- We dubbed this technique “narrow-band off-axis technique” (*)
- We provide the $\nu$ energy on a event-by-event basis without relying on final state particles in $\nu_\mu$ CC

About $O(10^6)$ fully reconstructed $\nu_\mu$ CC per year

(*) F. Acerbi et al., CERN-SPSC-2018-034
The ENUBET Demonstrator

A realistic 2m long instrumented decay tunnel to be tested with beams of charged particles

SiPMs
n shield

Calo modules
[4.3 $X_0$ sampling, three layers in radial direction]

Photon veto
Conclusions and next steps

• **ENUBET is on schedule**: the design phase is over, the simulation are nearly completed and we are going to build the final demonstrator
• The physics performance are extremely appealing but we have to go through the complete study:
  • Optimization of the horn
  • Update of flux and spectra with the final beamline
  • Establish the final systematic budget for $\nu_e$ and $\nu_\mu$: **in progress** using the same techniques currently employed by T2K. We add the **ENUBET observables as additional priors** to defeat the flux systematics. We use the information on the **initial energy** to reduce the FSI systematics on cross section measurements
• The main tasks for 2021 are the construction of the **demonstrator** and the **full assessment of systematics**
• Beam-tests and machine studies are postponed to 2022 due to the COVID lockdown of the facilities (the ERC Project will be extended by one year, too)
• We aim at the final **Conceptual Design Report** by 2022

**We look forward to seeing ENUBET up and running in the DUNE/HyperK era!**