This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681647).

Status of the ENUBET monitored neutrino beam

M. Pari (University and INFN Padova)
on behalf of the ENUBET Collaboration

Istituto Nazionale di Fisica Nucleare

New Directions in Neutrino-Nucleus Scattering
NUSTEC Workshop, 15-18 March 2021

Overview

The ENUBET project: Enhanced NeUtrino BEams from kaon Tagging

ERC grant 2016-2022

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681647).

CERN Neutrino Platform experiment NP06/ENUBET

The ENUBET Collaboration: 60 Physicists, 12 Institutions

Goal:

Design of a monitored neutrino beam

↓

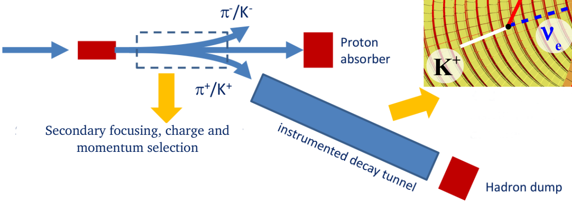
Reduction of neutrino flux systematics at the 1% level (additional: energy at 10%)

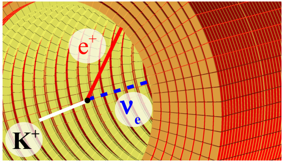
↓

Opening for high precision cross section measurement (1%)

Concept of monitored neutrino beam:

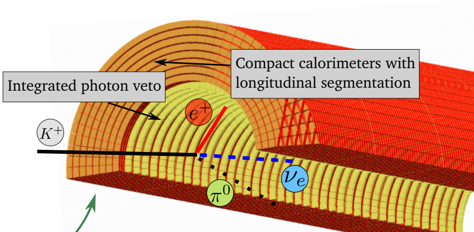
- Decay tunnel fully instrumented
- Direct estimation of neutrino flux from production vertex particles
- Bypassing high uncertainty hadro-production based flux extimation

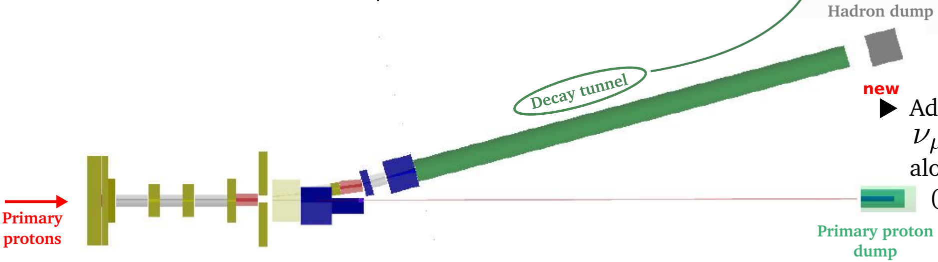




The ENUBET project

- Beamline (baseline option): **narrow band** beam at **8.5 GeV/c** secondaries with a **5-10% momentum bite**
- [*] **Ke3 ($K^+ \longrightarrow \pi^0 e^+ \nu_e$) main source of positrons** at the decay tunnel walls: possibility of **direct estimation of ν_e flux**
- new Muons at decay tunnel mainly from $\mathbf{K}_{\mu 2}$ ($\mathbf{K}^+ \longrightarrow \mu^+ \nu_\mu$) and $\mathbf{K}_{\mu 3}$: increased precision on $\nu_{\mu_\mathbf{K}}$ and $\nu_\mathbf{e}$ flux





- new Additional information on $\nu_{\mu\pi}$ from muon monitors along hadron dump (range-meter)

[*] A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155

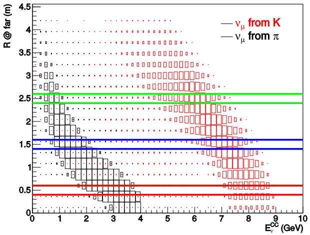
The ENUBET project

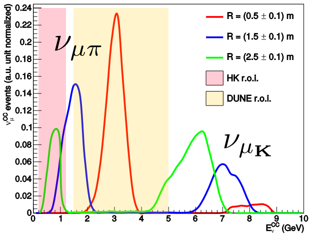
- Beamline (baseline option): **narrow band** beam at **8.5 GeV/c** secondaries with a **5-10% momentum bite**

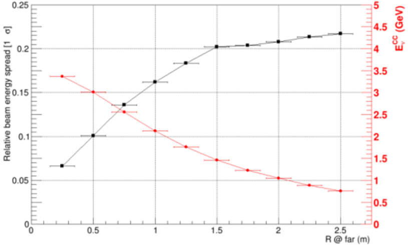
→ **Narrow-Band Off-Axis (NBOA) technique** [*]

- Full energy separation of ν_{μ_K} and $\nu_{\mu\pi}$ components
- Direct angle-momentum correlations from two-body decays

Estimation of neutrino energy from impact radius @detector







[*] F. Acerbi et al., CERN-SPSC-2018-034

The ENUBET beamline

Baseline option: **fully static beamline**

- Target and hadro-production: FLUKA ✓
- Transfer line:
  - optics optimization: TRANSPORT ✓
  - tracking & background: G4Beamline/G4 ✓
  - doses & neutron shielding: FLUKA ✓
  - systematics: GEANT4 **[in progress]**
- Neutron shielding added at hadron dump ✓
- Proton dump will require further eng. studies

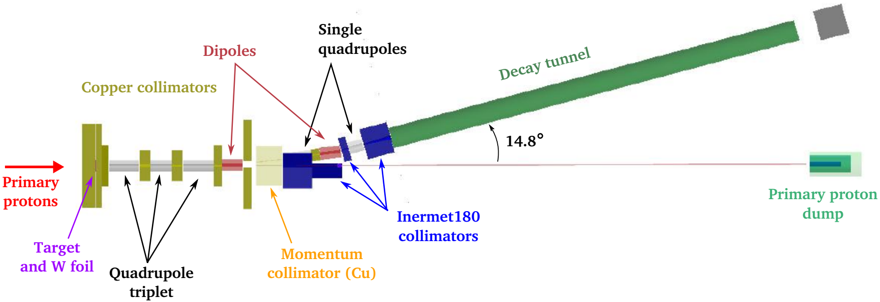
@SPS

π/pot (10^{-3})	K/pot (10^{-3})	Extraction length	π/cycle (10^{10})	K/cycle (10^{10})	Proposal [(c)]
19	1.4	2 s	85	6.2	**x 4**

new

Assuming 500 ton neutrino detector at 50 m and CERN-SPS as driver:

10^4 ν_eCC in ~2 years of data taking (preliminary)



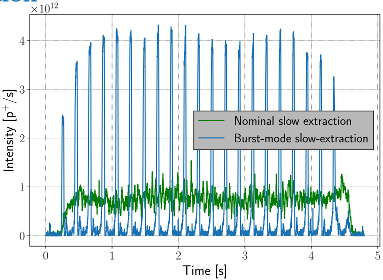
Static advantages:
- ✓ cost effective
- ✓ stable operation
- ✓ low rate

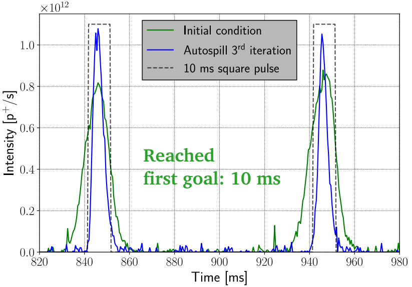
But:
potential flux increase from magnetic horn appealing →

Proton extraction studies

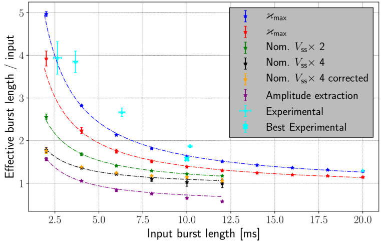
Dedicated slow extraction studies at CERN-SPS:
horn-compatible slow extraction

- From experimental campaign:
  - ⟶ Implemented **new pulsed slow extraction** (burst-mode)
  - ⟶ Optimized in operation down to **10 ms pulses @10 Hz**





- From simulations:
  - ⟶ **3-10 ms range of pulse lengths**

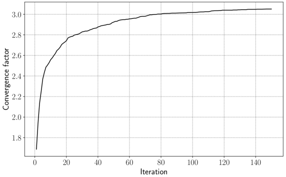


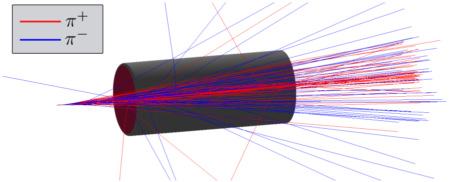
General extraction method: could be used for other applications (e.g. cosmic veto)

Magnetic horn

Developed optimization framework for the magnetic horn:

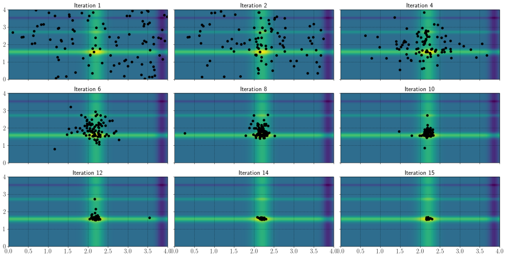
- Horn simulated with GEANT4 model
- Genetic algorithm used for optimization
- Hardware constraints enforced
- First candidates available

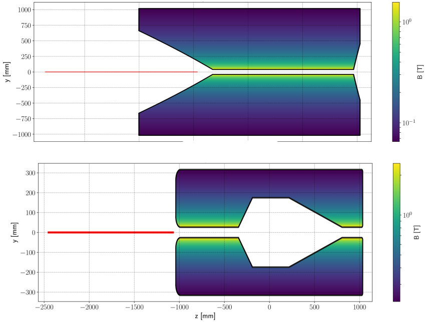




Next:

Strong dependence of flux-increase on beamline: dedicated beamline studies for horn option (branch-off)



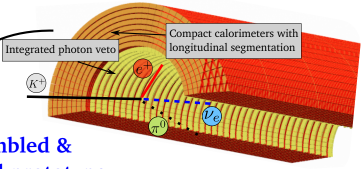


	K^+ gain at tunnel
Nominal beamline	1.6
Collimators opened to quad. apertures	6.8
All collimators opened but last one	4.7
All collimators opened but triplet ones	3.3

Decay tunnel instrumentation

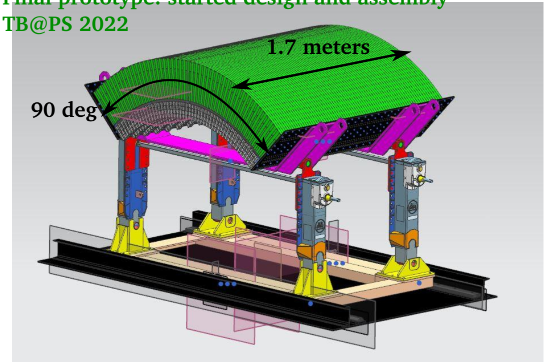
Instrumentation of decay tunnel [*]

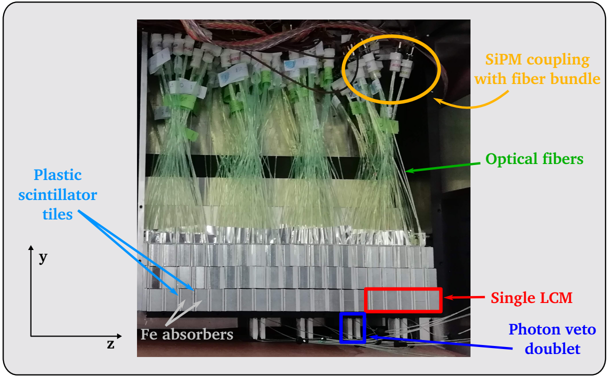
- After dedicated studies (simulations, prototyping, test beams):
  - → **Chosen final design**: longitudinally segmented calorimeters
  - → Lateral readout to SiPM (space for shielding: factor 18 reduction)
  - → Custom DAQ under development



Assembled & tested prototype

Final prototype: started design and assembly
TB@PS 2022





[*] JINST 15(2020)08, P08001; JINST 14 (2019) 02, P02029; NIM A 956(2020)163379

Full simulation of the instrumented decay tunnel in GEANT4:

→ Particle identification of each detected event based on deposited energies and photon veto.

→ More in detail: 15 parameters neural network trained over pure samples.

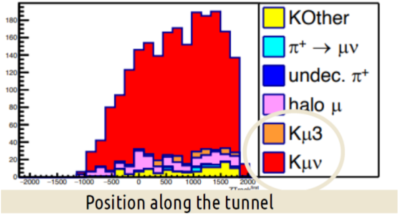
→ **Main results:**

For **muons**:

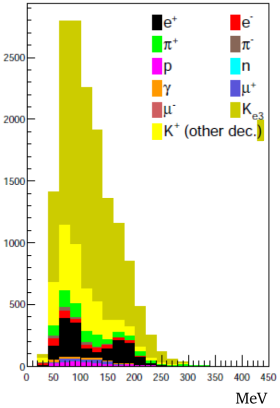
S/N: 6.1
Efficiency: 34%
(dominated by geometrical)

For **positrons**:

S/N: 2.1
Efficiency: 24%
(dominated by geometrical)



Visible Energy (NN)



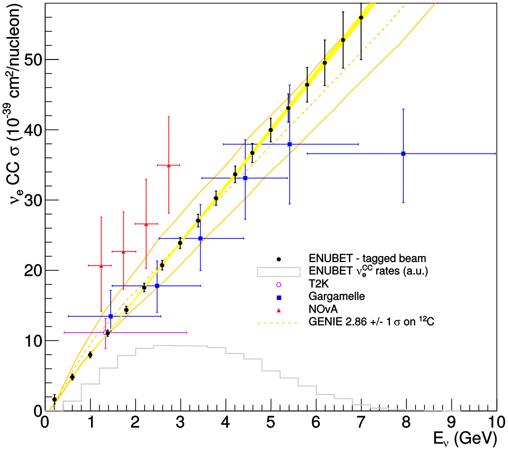
Conclusions and next steps

- Design phase of ENUBET terminated:
  - ⟶ Simulations nearly completed
  - ⟶ **A final demostrator of the tagger will be built and tested at the renovated CERN-PS East Area by 2022**
- Promising results up to now: **project on schedule**
- Fluxes and spectra will be updated with the final beamlines (baseline static, low-energy, horn option)
- **The final systematics on the neutrino fluxes (electron and muon) are under evaluation**

Thank you for your attention

Backup

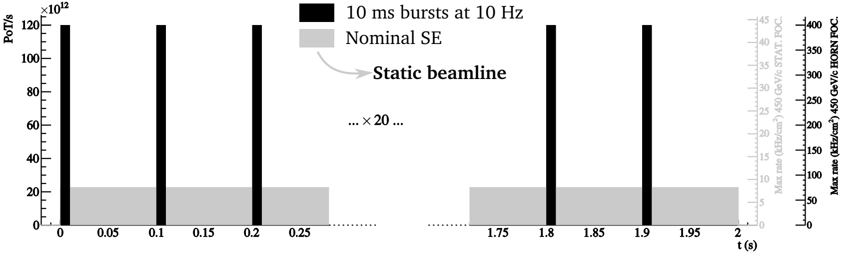
ENUBET: reach



The ENUBET beamline

Baseline option: **fully static beamline**

A tolerable pile-up level at tagger (< 500 kHz/cm^2):
fast extraction of protons impractical ⟶ **slow extraction required**



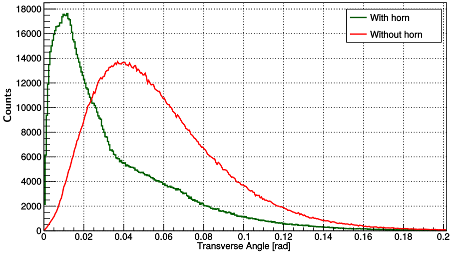
Two possible **slow-extraction** schemes compatible:

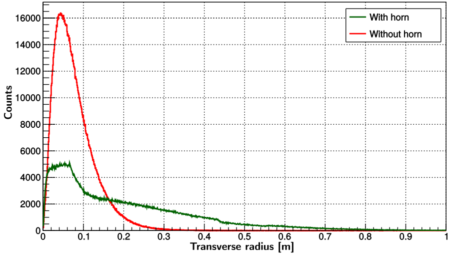
⟶ Static (standard)

⟶ Pulsed (novel)

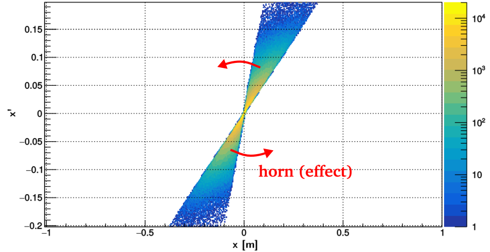
Could allow operation of magnetic horn: significant increase in flux.

Effect of horn on beam





Phase space after target



Phase space after horn