The evolution of the ENUBET beamline

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The ENUBET Project: Monitored Neutrino Beams

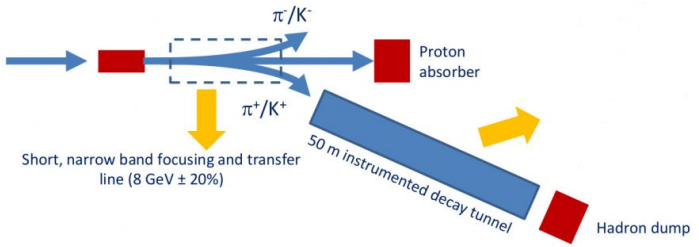
ENUBET's physics goal: overall error on the intensity of the produced neutrinos at the 1% level.

Technique for better neutrino flux and flavour control at production.
In conventional neutrino beams, ν_μ and ν_e are measured indirectly ⇒ Beamline simulation and hadron-production data.
Main flux uncertainties are given by hadrons re-interactions in the beamline apertures.

⇒ Direct Measurement: Number of neutrinos produced is measured counting the number of leptons produced at large angle inside the decay tunnel. (A. Longhin, L. Ludovici and F. Terranova, Eur. Phys. J. C 75 (2015) 155)

ENUBET (Enhanced NeUtrino BEams from kaon Tagging):

$K^+ \rightarrow \mu/e^+ \pi^0 \nu_\mu/\nu_e$ (Kμ3/Ke3) $K^+ \rightarrow \mu^+ \nu_\mu$ ($K_{\mu\nu}$)

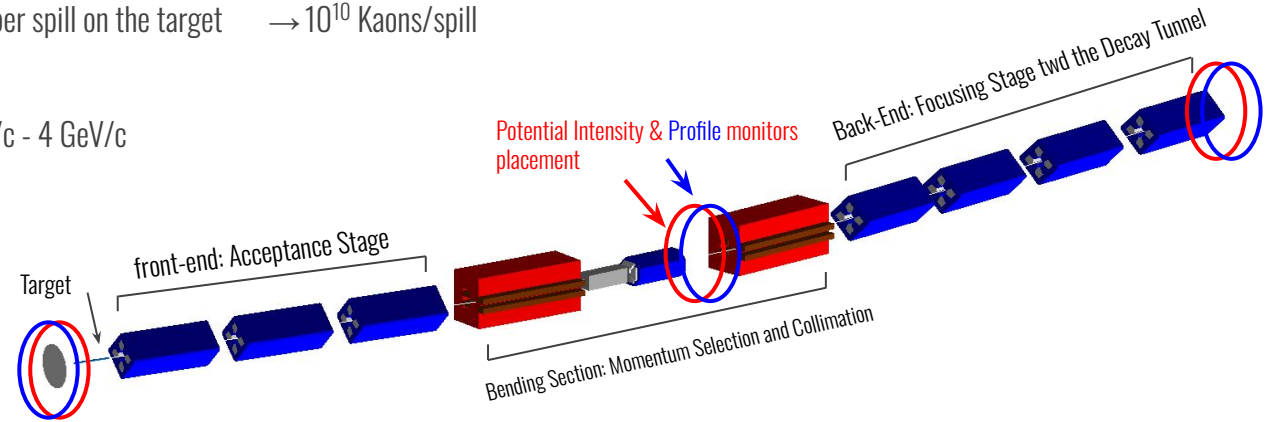


Enubet's reference beamline characteristics

A beam line that can transport a broader momentum range hadrons, i.e from 4 - 8.5 GeV/c with well defined momentum, but at the same time keep the narrow-band properties of the ν beam.

Layout summary:

- First quadrupole distance from the target: 30 cm
- Target 0.5° tilt from beamline to reduce background and primary re-interaction.
- 5 mm W absorber after collimation → to reduce the positrons bgk.
- ~4s slow extraction with 4.5×10^{13}~POT per spill on the target → 10^{10} Kaons/spill
- Short Secondary Beamline (29 m)
- Primary Momentum: 400 GeV/c
- Secondary Momenta: 8.5 GeV/c - 6 GeV/c - 4 GeV/c



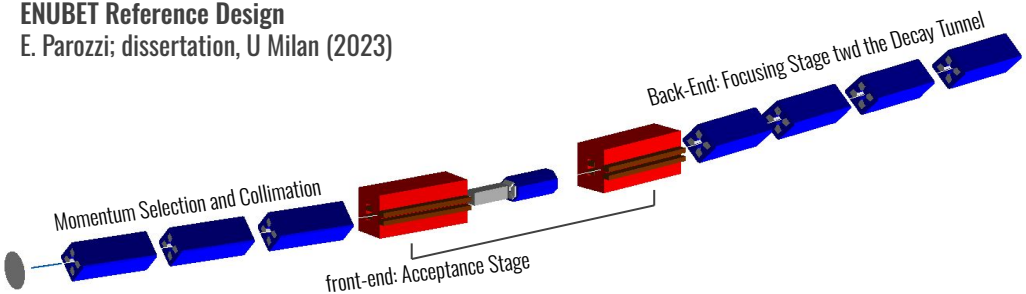
Evolution of the ENUBET beamline into the SBN beamline at CERN

- **ENUBET** is a "monitored" neutrino-beam experiment
- **NuTag**: Particle-by-particle reconstruction of the neutrino kinematics (two-body decay)

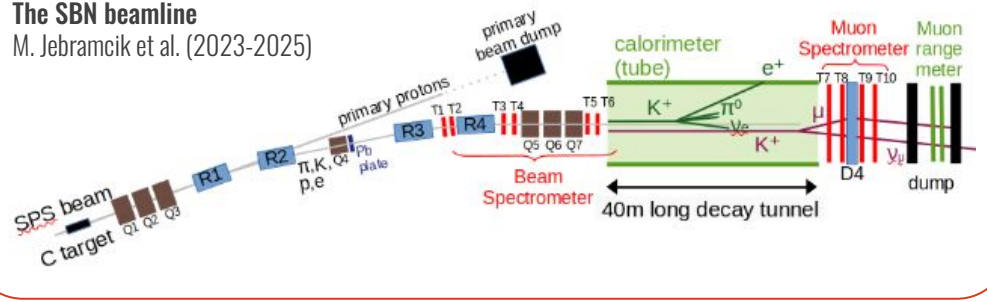
- **SBN**: The ENUBET-NuTAG merger that combines the two projects under the PBC framework to exploit their synergies

Aim of this study: Conducting of a conceptual feasibility analysis that considers all possible locations and the respective expenditures

ENUBET Reference Design
E. Parozzi; dissertation, U Milan (2023)



The SBN beamline
M. Jebramcik et al. (2023-2025)



fresh new name since 2 days!

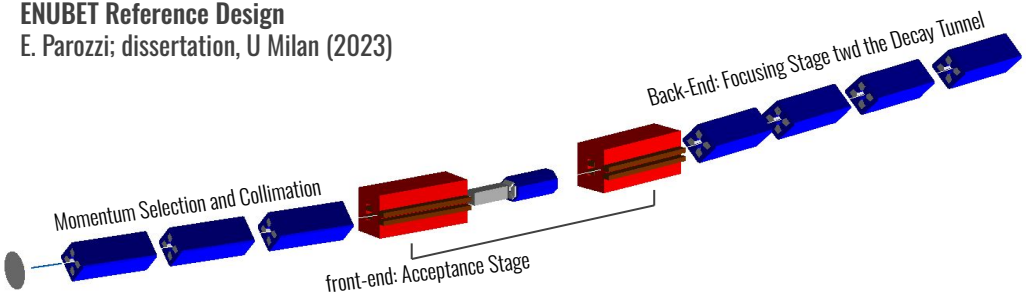
Evolution of the ENUBET beamline into the NuSCOPE beamline at CERN

- **ENUBET** is a "monitored" neutrino-beam experiment
- **NuTag**: Particle-by-particle reconstruction of the neutrino kinematics (two-body decay)

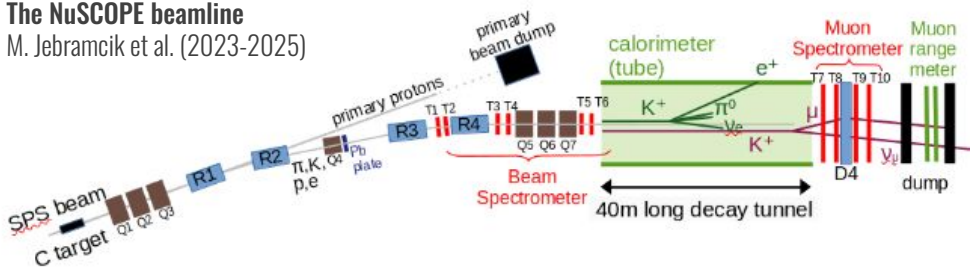
- **NuSCOPE**: The ENUBET-NuTAG merger that combines the two projects under the PBC framework to exploit their synergies

Aim of this study: Conducting of a conceptual feasibility analysis that considers all possible locations and the respective expenditures

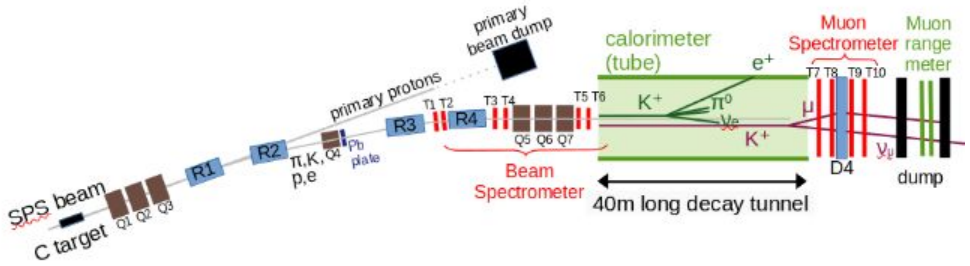
ENUBET Reference Design
E. Parozzi; dissertation, U Milan (2023)



The NuSCOPE beamline
M. Jebramcik et al. (2023-2025)



The NuSCOPE beamline characteristics at SPS Energy



The current beamline design is the product of an extensive optimization process at 400 GeV/c proton momentum

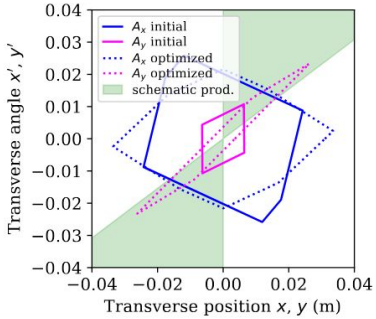
The beamline design merges the beamline requirements for both the ENUBET and the NuTAG proposals → pixel detectors in addition to calorimeter in decay tunnel

The beamline's meson production is maximized and the event rate is adjusted to meet the pile-up constraints of the NuTAG pixel detectors

Parameter	Value
Primary proton energy	400 GeV/c
Beamline momentum (mesons)	up to 8.5 GeV/c
Extraction type	slow: 4.8s or 9.6s from the SPS
Spill intensity	1.0E13 protons/spill
Event rate	1 – 2 THz
Instantaneous power	170 – 340 W
K^+ / π^+ per proton	1.3E-3 / 1.9E-2
K^+ / π^+ rate	up to 2.7 GHz / 40 GHz
Annualized proton requirement	2E18 – 3E18 protons/year
Total proton requirement (1% stat. error on ν_e x-section)	1.4E19 protons
Beamline length to decay tube	23 m
Bending magnet strength	1.8 T

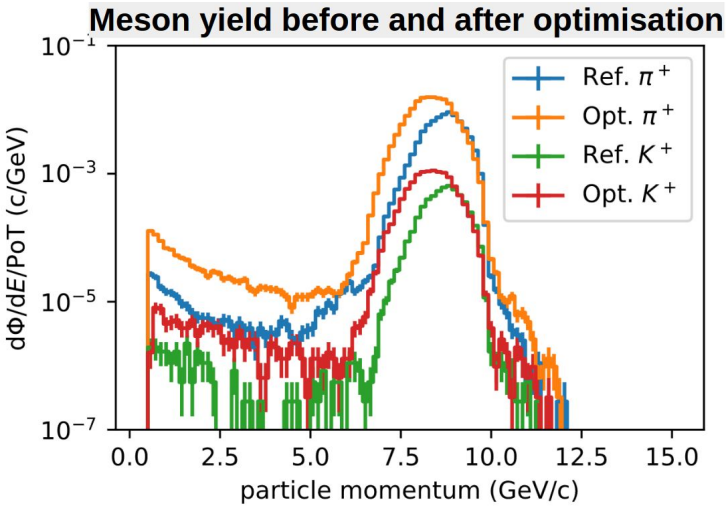
Meson yield comparison

The optimized design significantly enhanced the phase space acceptance of the beamline by employing a multi-objective genetic algorithm to simultaneously tune 26 parameters. This parallel optimization led to a substantial improvement in secondary particle yields, **increasing the K^+/π^+ fluxes by a factor 1.8**.



→ The required POT from the SPS was drastically reduced, enabling a more efficient and cost-effective operation while maintaining or exceeding performance targets.

Particle yield	ENUBET design	REF design	SBN (opt.)	SBN (opt.) PS energy
K^+ / PoT (10^{-4})	3.6	7.0	12.6	0.31
π^+ / PoT (10^{-2})	0.4	1.1	1.9	0.047

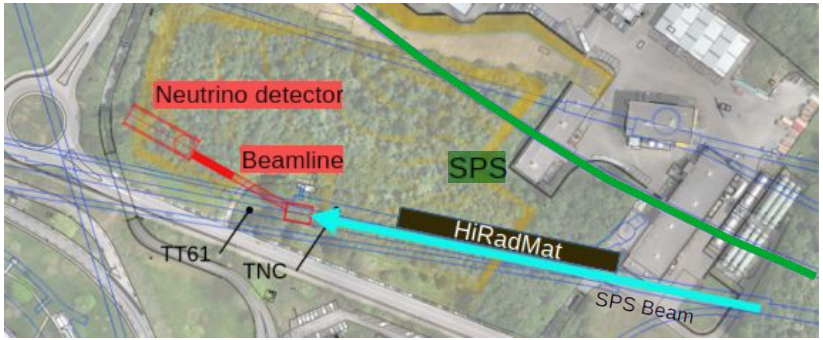


Possible integrations at CERN's SPS

Considerations of possible implementations are:

- **North Area existing halls: EHN1, EHN2 & ECN3**
  - ECN3 → SHiP
  - EHN1 & EHN2 too strong radiation protection constraints
- **LSS4 (AWAKE) and LSS6 (HiRadMat)**
  - lack of slow extraction setup
- **New facility: ECN4?**
  - existing studies and proposal for BDF/SHiP with a simpler target complex

Ongoing studies and considerations prove ECN4 to be a feasible solution together with parallel studies for a conceptual slow extraction at LSS6. The latter would have the advantage of being completely shielded by soil and the existing infrastructure.



Conclusion

- Successful beamline optimization. PoT requirement has shrunk significantly: 1.0E13 protons/spill with an annualized intensity of 2.0E18 – 3.0E18 PoT/year ← 25% of the TCC2 annual intensity
- Two comparable ways of implementing the beamline either in some new facility ECN4 in the North Area of the CERN campus or in the TT61/TNC region downstream of the SPS LSS6 straight section.
- 1% statistical uncertainty on the νe inclusive cross section within the envisaged time span of 5 years achieved.

For more details, Marc's presentation at Neutrinos@CERN: **https://indico.cern.ch/event/1460367/overview**

and ESPPU submission: **https://cds.cern.ch/record/2929199**