High precision neutrino cross section measurements with ENUBET: assessment of systematics in monitored neutrino beams

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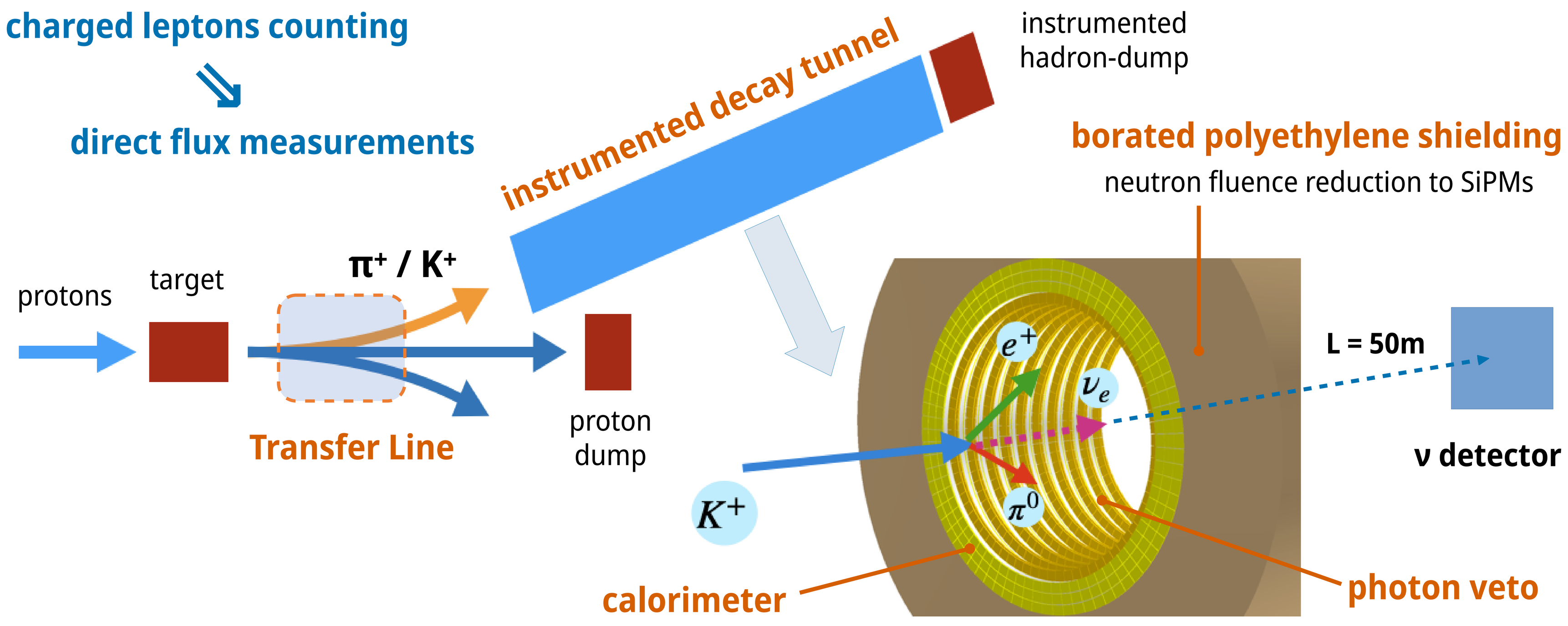
The concept of monitored neutrino beams

Monitored neutrino beams are a novel technology with a superior control of neutrino flux at source designed to provide high-precision neutrino cross-section measurements at the GeV scale with a total uncertainty of 1%.
The goal of cutting down the flux uncertainty to 1% can be achieved through the monitoring of charged leptons produced in association with neutrinos by instrumenting the decay tunnel of a conventional narrow-band neutrino beam.

The **ENUBET** project (**E**nhanced **N**e**U**trino **BE**ams from kaon **T**agging) is aimed at designing and experimentally demonstrating the concept of monitored neutrino beams:

- knowledge of absolute ν_e / ν_μ **flux** at **1% level** ⇨ **sensitivity increase equivalent to build larger mass detectors**
- ν_μ **energy** at **10% level** (narrow band off-axis)
- knowledge of flavour composition at 1% level

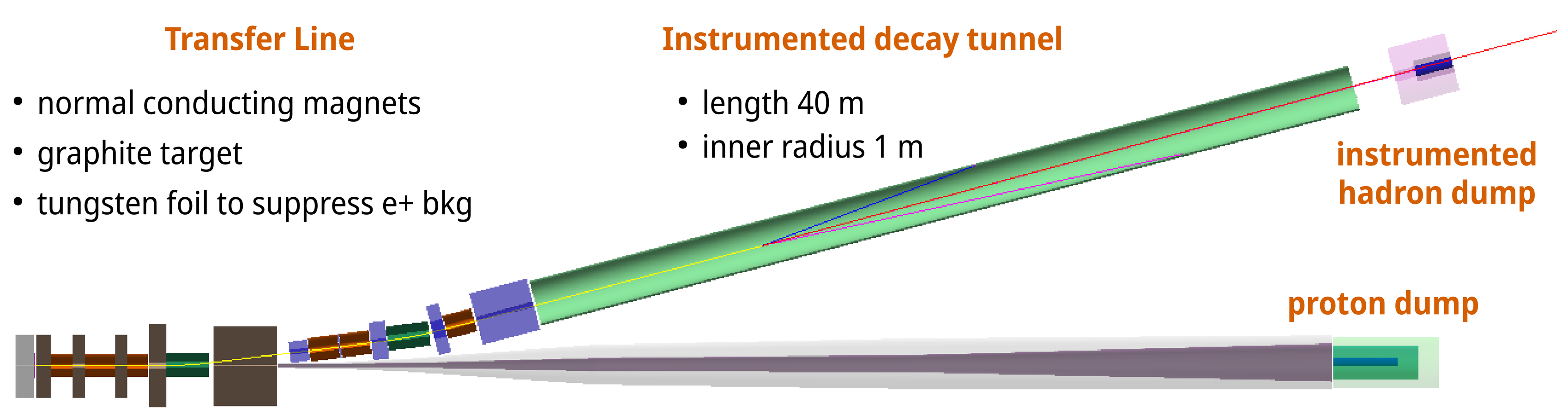


- The **ENUBET ERC** project focused on measuring **positrons** from K_{e3} ($K^+ \to e^+ \pi^0 \nu_e$) with an instrumented decay tunnel (tagger) ⇒ ν_e **flux** determination from e^+ **counting**
- The **CERN NP06/ENUBET** experiment aims at providing a full constraint on the ν flux measuring also **muons** from $K_{\mu\nu}$ ($K^+ \to \mu^+ \nu_\mu$) by means of the instrumented decay tunnel and from $\pi_{\mu\nu}$ ($\pi^+ \to \mu^+ \nu_\mu$) by instrumenting the hadron dump as a range meter ⇒ ν_μ **flux** determination from μ^+ **counting**

The beamline design

The transfer line relies on static focusing elements and does not employ a magnetic horn.

- **Slow proton extraction** ⇒ continuos extraction of full intensity in few seconds (~ 2 s)
  - lepton rate at tagger reduced to sustainable level (< 100 kHz/cm²)
  - static elements: dipoles and quadrupoles ⇒ cost-effective and operationally stable
- **Narrow-band beam**: selection of secondary mesons K^+ / π^+ with **p = 8.5 GeV/c ± 10%**
  optimized for DUNE r.o.i. (E_ν ~ 3 GeV)



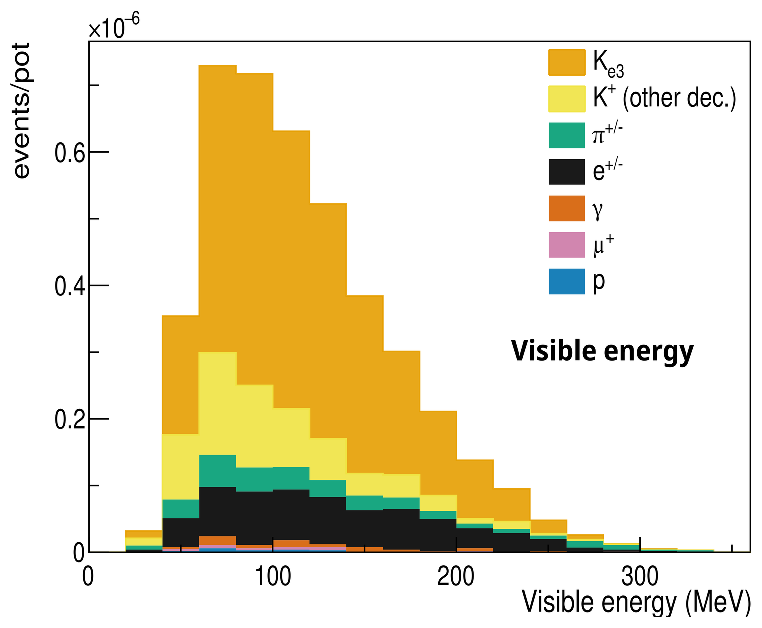
Lepton reconstruction in the instrumented tunnel

- **Calorimeter** with $e^+/\pi^+/\mu^+$ separation capabilities: 3 radial layers of longitudinally segmented sampling calorimeter modules (LCMs).

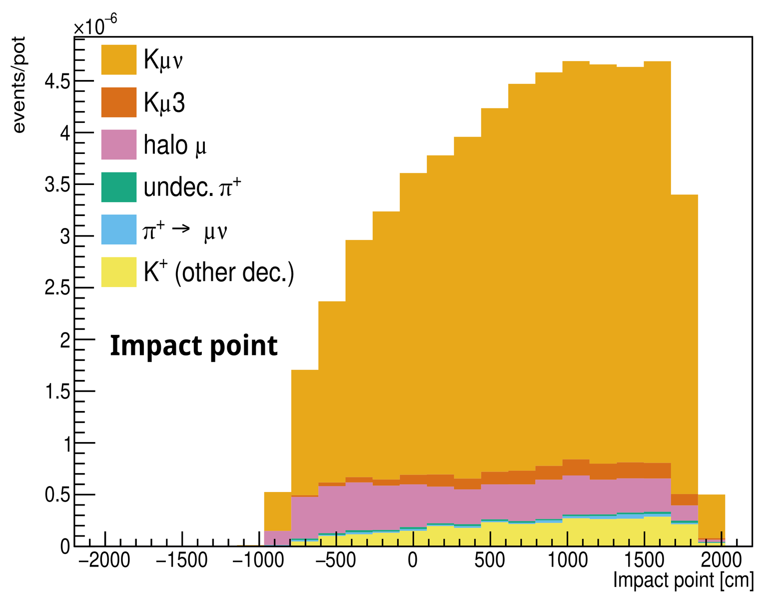
See **poster #61** for more info on instrumentation and prototype tests !

Event reconstruction and PID :

1. **Event builder**: identify LCM with energy deposit as seed for the event and cluster neighbour deposits compatible with particle.
2. **Selection**: multivariate analysis based on energy deposition pattern and event topology.



K_{e3} : ε = 20% & S/N = 2

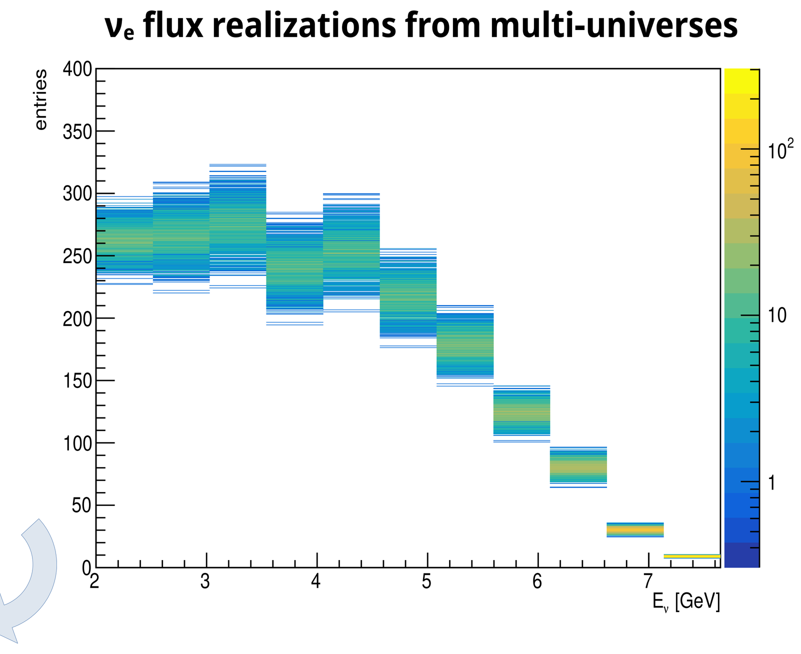


$K_{\mu\nu}$: ε = 35.6% & S/N = 5.2

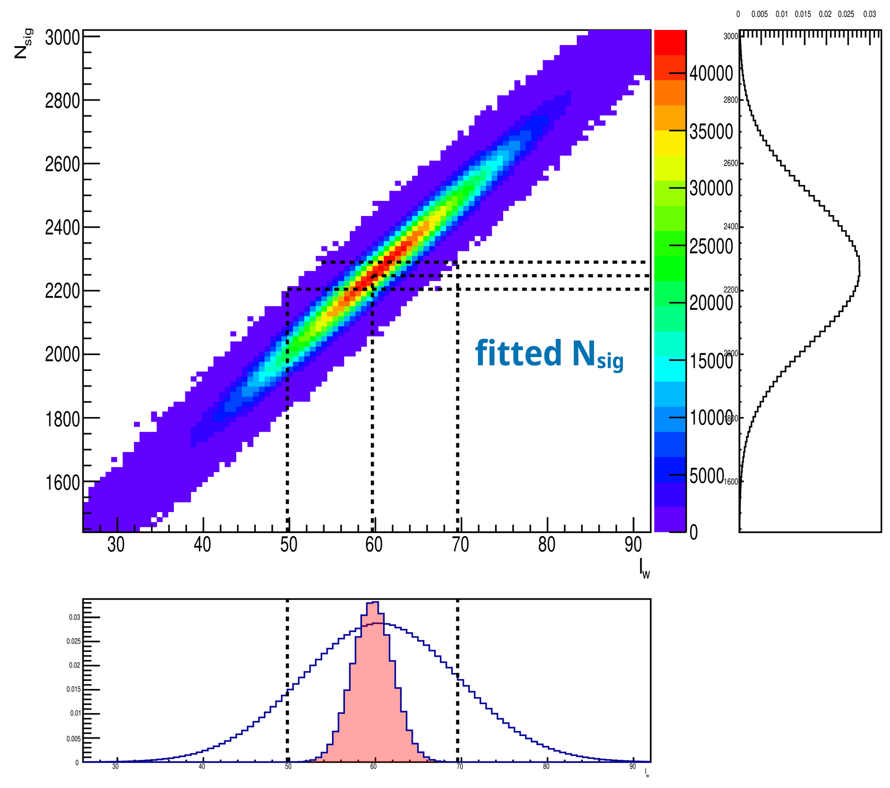
The assessment of flux systematic uncertainties

- The leading source of systematics on ν cross-sections comes from the poor knowledge of the initial flux, generally known with a precision worse than 10%.
- The main systematic uncertainties on ν flux are the poor knowledge of the **yields of secondary hadrons produced at the target**, **beamline geometry** and **detector-related effects**.
- Hadro-production data from NA20 and NA56/SPY are used to reweight MC events giving origin to neutrinos.
- The propagation of uncertainties to physics observables and to ν flux at detector is carried out by means of the **multi-universes method**.

ν_e flux realizations from multi-universes



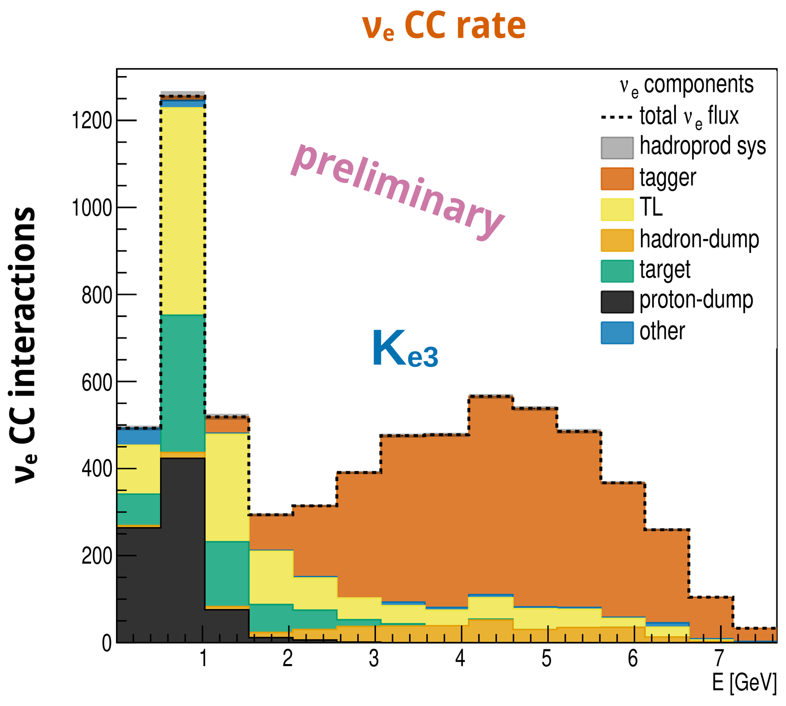
- The assessment of ν flux systematics budget before and after using the **lepton monitoring** is based on a **fit model** where :
  - POIs are related to the hadro-production
  - NPs parametrize beamline geometry and detector-related uncertainties.

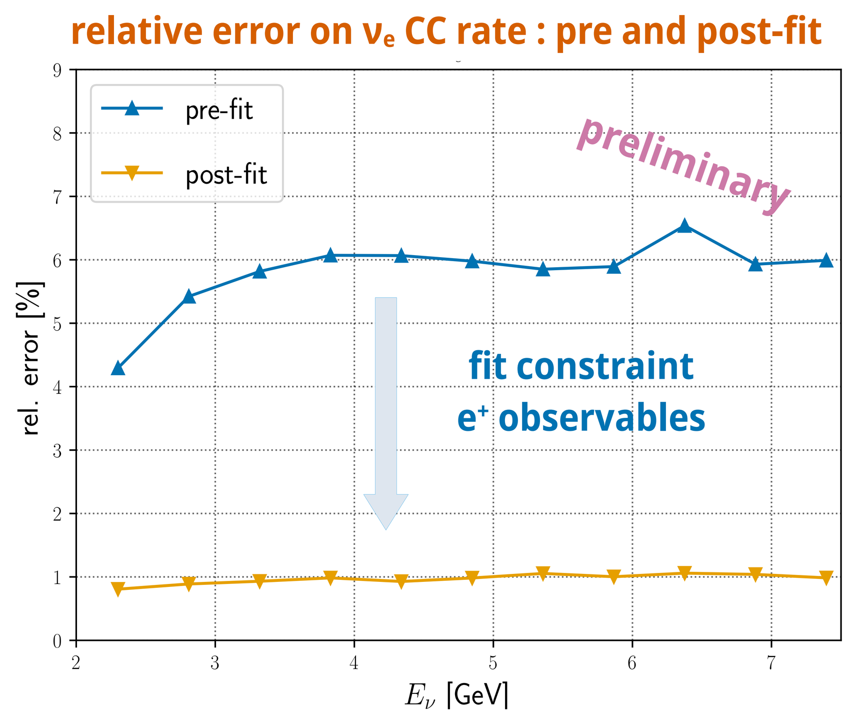


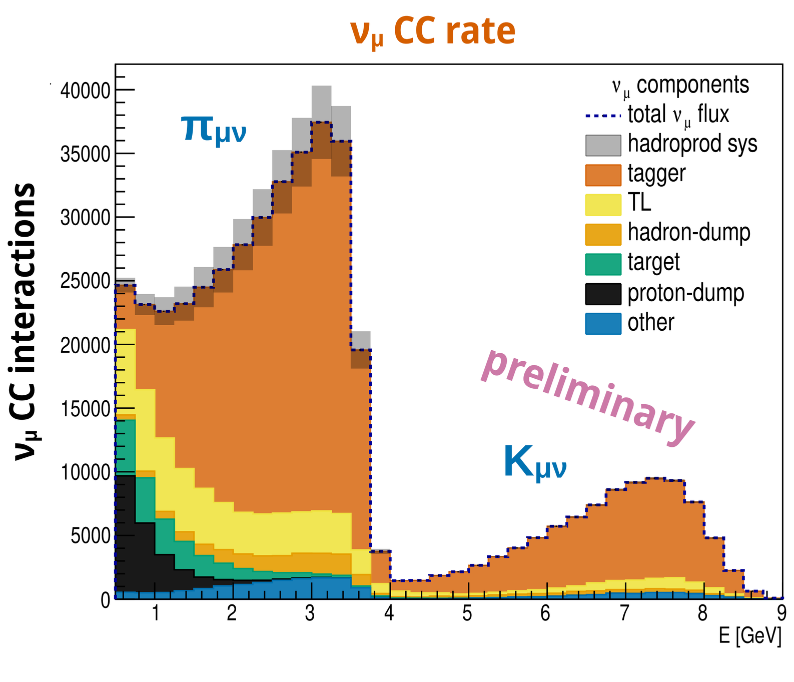
constrained hadro-production weight maps

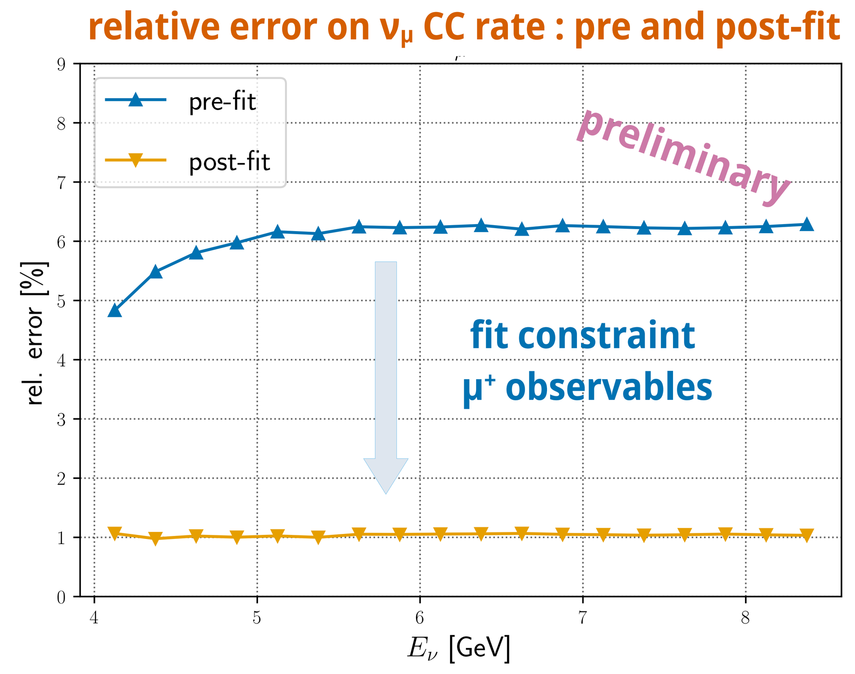
- A set of synthetic data derived from Geant4 is used to perform an extended likelihood fit to lepton observables.
- **Fit results are used to derive a constraint to set on the ν flux.** Precisely, the fit to lepton observables is used to set constraints on the hadron yields and, in turn, on the expected ν flux.

- Considering 4.5 · 10¹⁹ 400 GeV protons on target (pot) and a moderate mass neutrino detector of the size of ProtoDUNE (500 ton LAr) located at 50 m from tunnel end.









- **The constraint set on ν flux using charged lepton monitoring enhance precision at O(1%) level.**
- The Collaboration has started concentrating efforts on a proposal of a short-baseline neutrino beam to be implemented at the CERN North Area possibly using the ProtoDUNEs neutrino detectors.

References:

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