Neutrino tagging method
Proof of principle at NA62

L. PETIT[1,2] on behalf of the NA62 collaboration

1 - Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France 2 - UTLN, IM2NP, STr team, Toulon, France

lpetit@cppm.in2p3.fr

Neutrino tagging method

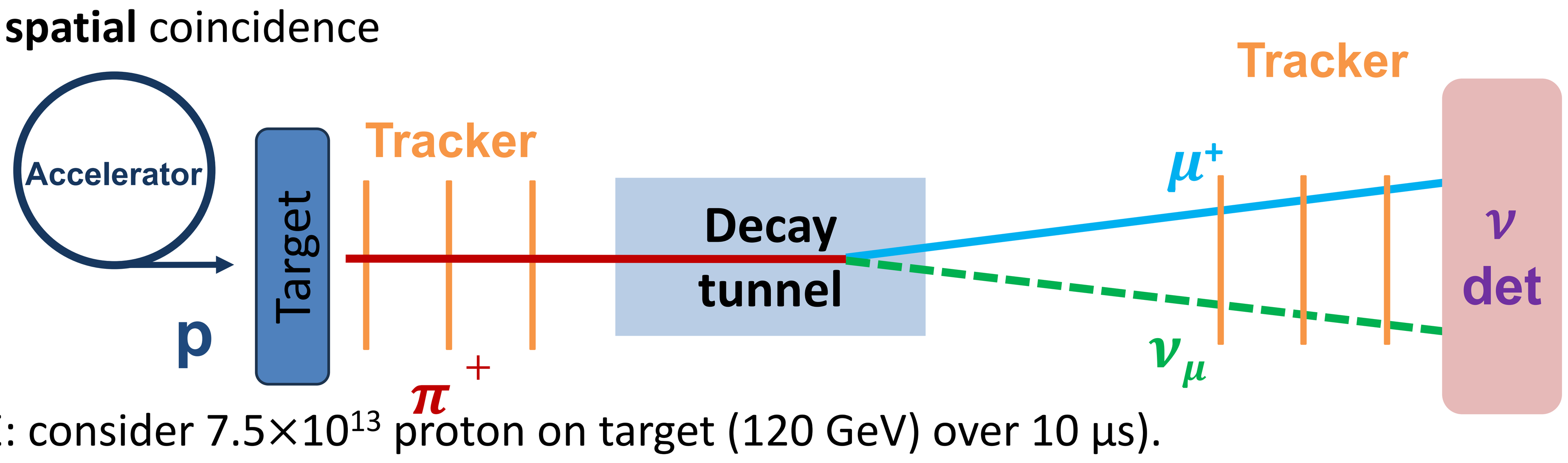
Context The next generation of long baseline neutrino experiments (DUNE**[1]**, HK**[2]**), will collect neutrino samples more than 10 times larger than their predecessors (NOVA**[3]**, T2K**[4]**). As a result, their measurements will start being dominated by systematic uncertainties, in particular those on the neutrino cross-sections. Thus, to fully exploit the potential of these experiments, the cross-section measurements precision should be improved from 5-10% down to 1%. To reach this precision, dedicated short baseline experiments with well characterized neutrino beam (<1% precision on the neutrino rate) are required **[5]**. Such precision could be obtained with the neutrino tagging technique **[6]**.

Principle of neutrino tagging: exploiting neutrino production mechanism $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$ [6]

- Beam line instrumented with silicon pixel detectors to measure the π and μ momentum, direction and time
- Kinematic reconstruction of the $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$ decay to estimate neutrino properties
- Association of each **detected** ν_{μ} with **tagged** ν_{μ} using **time** and **spatial** coincidence

Benefits

- **Beam characterization** (rate, energy, flavor, chirality)
- **Energy resolution** (20% for conventional experiments vs. <1% for neutrino tagging)



Technical and technological challenges

Particle rate in a neutrino beam line are extremely high (e.g. DUNE: consider $7.5{\times}10^{13}$ proton on target (120 GeV) over 10 µs).
Operating detectors in a neutrino beam line thus requires

- Dedicated beam line design operating in slow extraction **[12, 13]**
- High intensity pixel detectors:
  - state of the art technology (as the GTK silicon pixels of NA62 experiment **[7]**) can sustain 2MHz/mm^2
  - R&D for HL-LHC experiment aims to 100MHz/mm^2 **[8]**

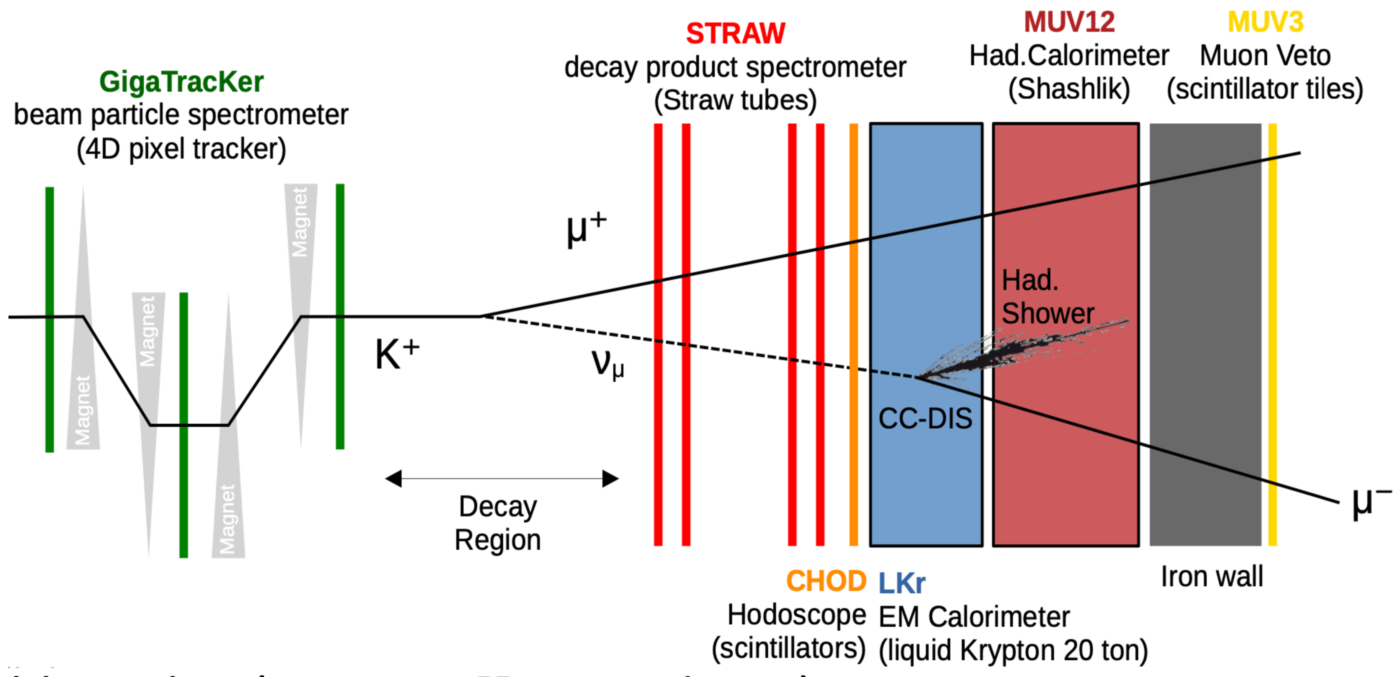
Proof of principle at NA62 [9]

NA62 experiment (CERN)

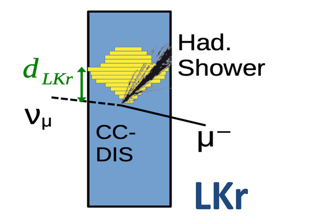
- Propose to measure very rare decay $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ (2016-2018 analysis results give a BR of $(10.6^{+4.0}_{-3.4}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$ **[10]**)
- Intense 75 GeV/c^2 **kaon** beam produces **neutrinos** through $K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$ decay
- $5{\times}10^{12}$ estimated $K^{\pm}$ decays per year **[11]**
- Two spectrometers reconstruct the **K** and the **µ**
- **Neutrino** detected by 20 ton of liquid krypton of the electro-magnetic calorimeter (LKr). Probability of a 40 GeV ν interaction ~10^{-11} **[9]**

Event topology

- Single muon track up to LKr
- Hadronic shower in LKr and MUVs
- Two well separated muons in the MUV3

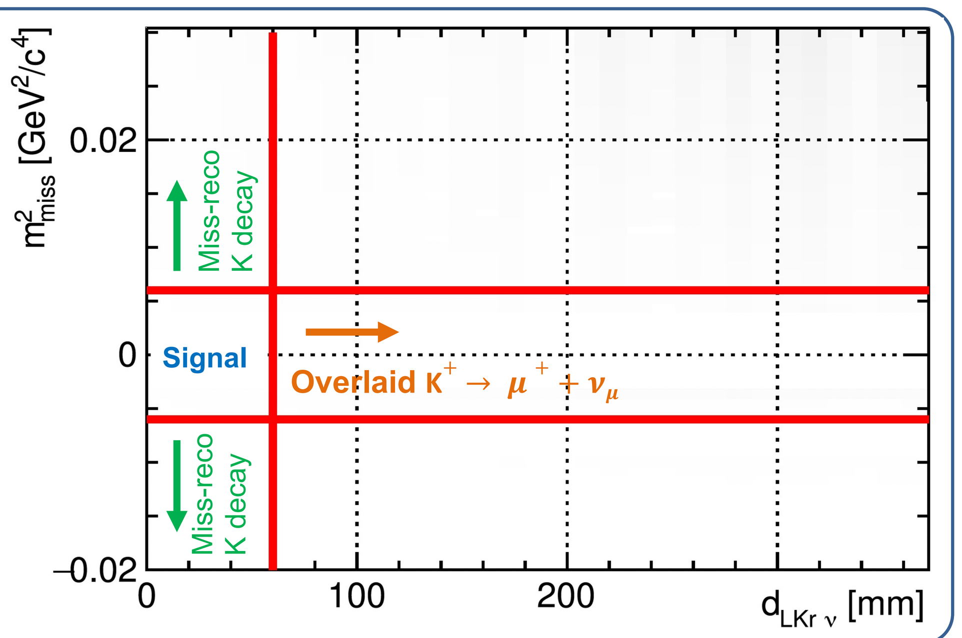


- $m^2_{miss} = |P_K - P_{\mu+}|^2$ compatible with 0 (ensures $K \rightarrow \mu\nu$ decay)
- Small values of dLKrv: distance between neutrino interaction in LKr and extrapolated position of the neutrino



Analysis strategy

- **Blind analysis:** event selection is optimized using data in the **two signal side bands** and simulated signal data
- Expected event yields obtained from a data driven analysis exploiting signal region side bands for the **background** and $K \rightarrow \mu\nu$ events (without neutrino interaction) for the **signal**



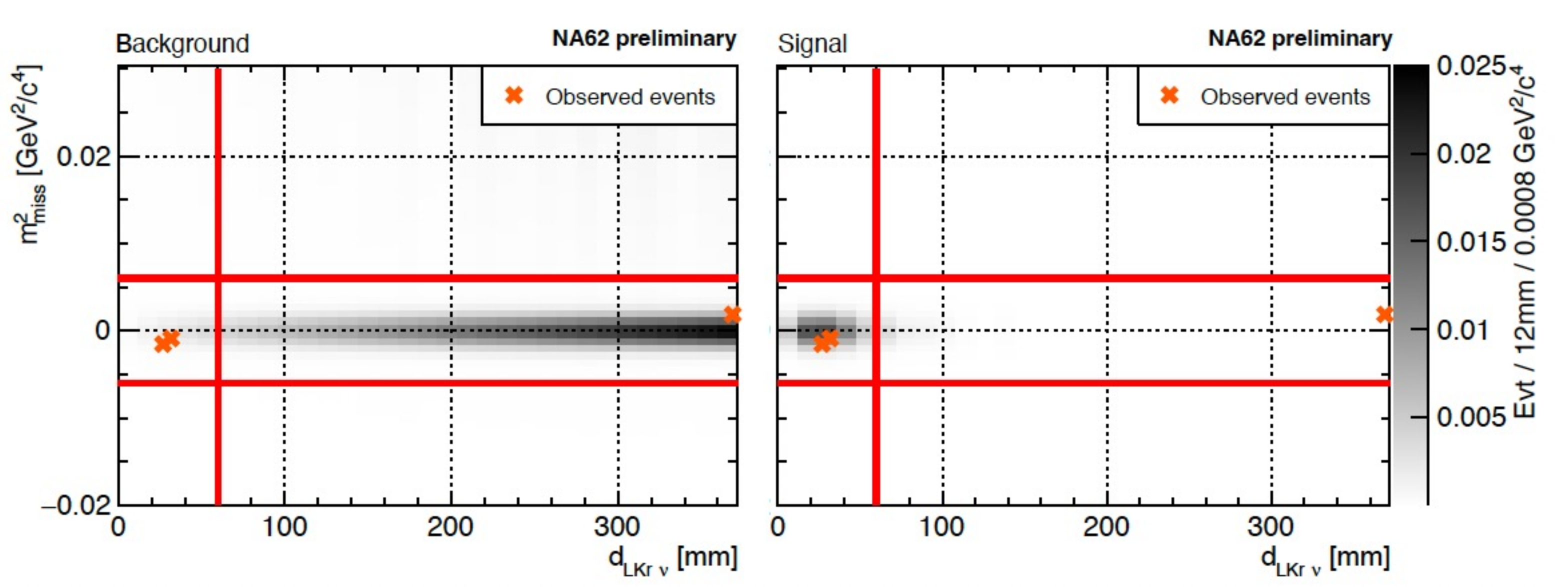
Results and perspectives [9]

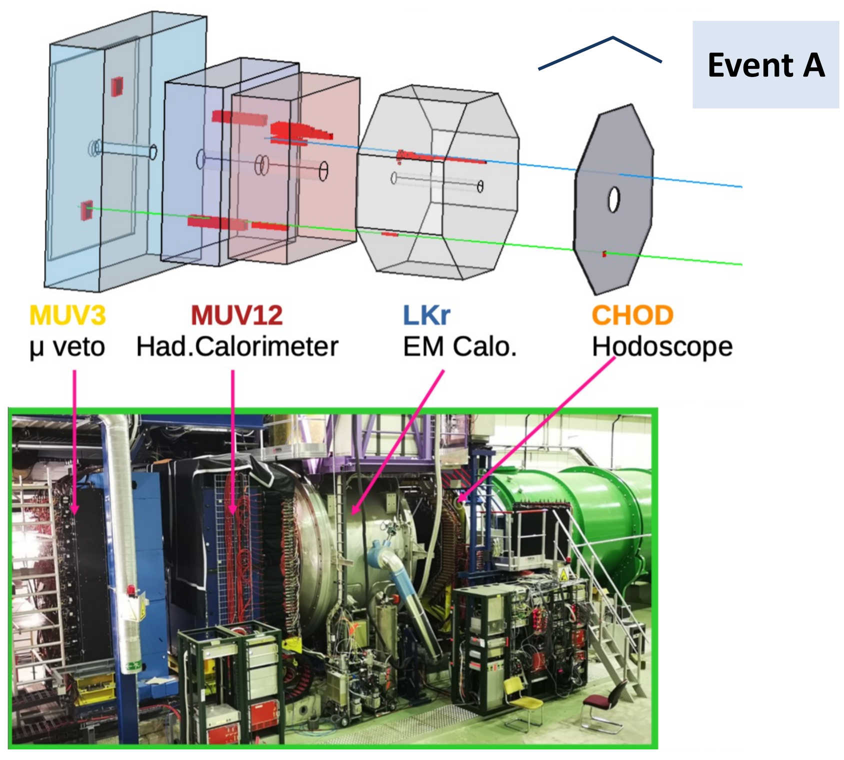
Tagged neutrinos in signal region
(Data collected in 2022)

Expected number of neutrinos:
$\mathbf{0.228} \pm 0.014_{stat} \pm 0.011_{syst}$

Expected number of background:
Mis-reco K: $\mathbf{0.0014} \pm 0.0007_{stat} \pm 0.0002_{syst}$
Overlaid: $\mathbf{0.04} \pm 0.02_{stat} \pm 0.01_{syst}$

Number of observed $K \rightarrow \mu\nu$ event :
$N_{K\mu 2} = 1.4873{\times}10^{11}$





Two tagged neutrino candidates detected for the first time !

Perspectives

- Data sample ~ 4 times larger : NA62 experiment will collect data until the end of 2025, this will allow to improve the accuracy of the 2022 dataset results
- Studies in collaboration with CERN Physics Beyond Collider have been initiated for a **SBL using proto-DUNE** and merging the neutrino tagging and ENUBET methods **[12]** to measure ν_{μ} and ν_{e} cross-sections and for a **proof of concept for a tagged LBL** ν beam line **[13]**

See Poster n°423 by M.A. Jebramcik !

[1] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics – Abi,B et al. (2020) [2] Hyper-Kamiokande Design Report – Hyper-Kamiokande Collaboration (2018) [3] Improved measurement of neutrino oscillation parameters by the NOvA experiment - The NOvA Collaboration (2022, Phys. Rev. D) [4] Measurements of neutrino oscillation parameters from the T2K experiment using 3.6 × 1021 protons on target – T2K Collaboration (2023, The European Physical Journal C) [5] A high precision neutrino beam for a new generation of short baseline experiments - Acerbi,F et al (2019) [6] Neutrino Tagging: a new tool for accelerator based neutrino experiments – Perrin-Terrin,M (2022, The European Physical Journal C) [7] The NA62 GigaTracKer: a low mass high intensity beam 4D tracker with 65 ps time resolution on tracks – NA62 Collaboration (2019, Journal of Instrumentation) [8] Framework TDR for the LHCb Upgrade II : Opportunities in flavour physics, and beyond, in the HL-LHC era – LHCb Collaboration (2021, CERN Report) [9] Bianca De Martino phd thesis: Experimental proof of principle of the Neutrino Tagging technique at NA62 (2023) [10] Measurement of the very rare K+→π+ν¯ν decay – NA62 Collaboration (2021, Journal of High Energy Physics) [11] Status and latest results from the NA62 Experiment at CERN - Patrizia Cenci (2012) [12] Design and performance of the ENUBET monitored neutrino beam, ENUBET Collaboration (2023, The European Physical Journal C) [13] NuTag: proof-of-concept study for a long-baseline neutrino beam - Baratto-Roldan,A et al (2024, The European Physical Journal C)