# nuSCOPE – A monitored & tagged neutrino beam at the CERN SPS for high-precision measurements

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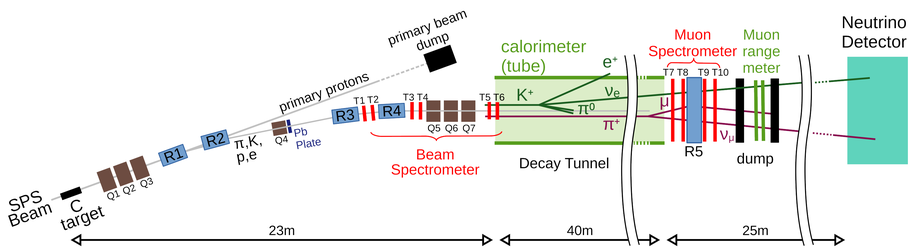
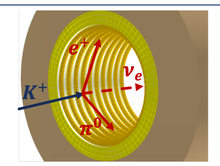
## Rethinking how to make a neutrino beam

**nuSCOPE** is a proposed experiment at CERN combining the efforts of the ENUBET & NuTAG collaborations.
A change of paradigm in neutrino beam design: *momentum-select the parent mesons, measure their kinematics and those of their decay products to infer neutrino energy on an event-by-event basis* → a monitored and tagged beam.

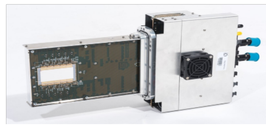
- 400 GeV p from CERN SPS → 8.5 GeV momentum-selected $\pi/K$ secondary beams.
- Slow extraction ($\sim$ 10s); need $\mathcal{O}(1\,\text{kt})$ detectors very close to the decay point.
- Nominal exposure: $1.4\times10^{19}$ POT in 5 years, fully compatible with other fixed target experiments (e.g. SHiP)
- Reference detectors: 500 t LAr ($\sim$ProtoDUNE/ICARUS) & 100 t water ($\sim$ 2×WCTE).

Precision measurement facility spanning: neutrino cross-section measurements, short-baseline oscillations, muon, pion and kaon physics.




Monitoring



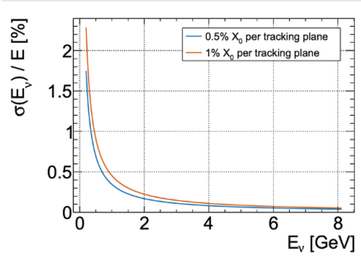
Tagging

## Monitoring: flux uncertainty <1%

- The decay tunnel is instrumented to count the charged decay products of the mesons that produce neutrinos.
- This pins the absolute flux to <1%, versus the ∼5–10% of conventional beams today.
- A full decay-tunnel section was tested at the CERN T9 beam. *EPJ C 83, 964 (2023).*
- Offers tight control over $\nu_\mu$ and $\nu_e$ fluxes.

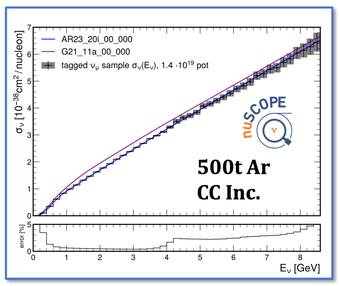
## Tagging: $E_\nu$ event-by-event

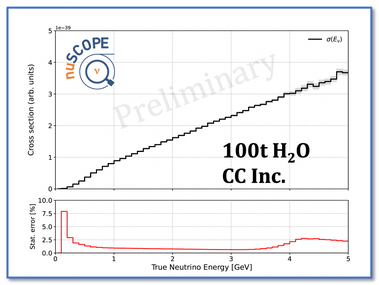
- Silicon trackers relate each $\nu$ to its parent meson → <1% $E_\nu$, event-by-event.
- A first tagged-$\nu$ candidate was seen by NA62 thanks to state-of-the-art detectors (NA62-GTK). *PLB 863 (2025) 139345*
- Expect ∼ 80% tagging efficiency for $\nu_\mu$ below ∼5 GeV.




## Total charged-current (CC) $\sigma$ measurement

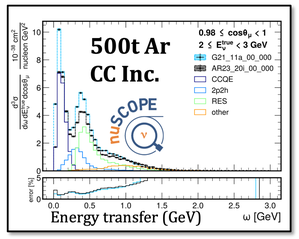
- Expect $\sim 7.6 \times 10^5$ $\nu$ interactions in which $E_\nu$ is known on an event-by-event basis with <1% uncertainty.
- Total CC $\sigma$ measurement for broad range of energies with %-level precision.

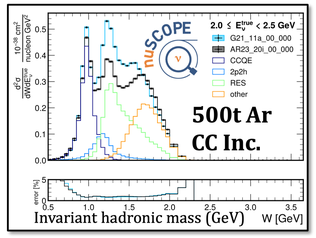



## Electron-scattering-like $\nu$ measurements

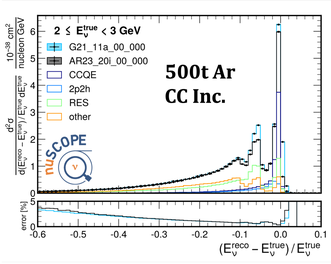
- A priori knowledge of $E_\nu$ gives access to variables like energy transfer and hadronic mass, just as in electron-scattering measurements.
- High statistics for multi-differential measurements at the <1% level.

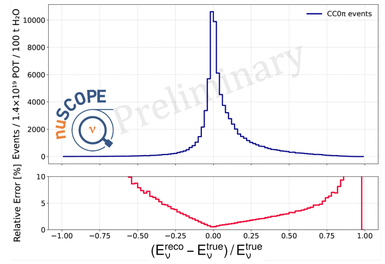



## Measuring the neutrino-energy bias

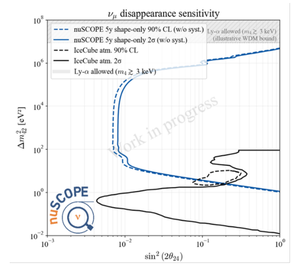
- With $E_\nu$ known on an event-by-event basis we can measure the true−reconstructed energy relation directly → direct constraints for oscillation measurements.
- Calorimetric (LAr) & kinematic (water Cherenkov) → measure neutrino energy smearing due to nuclear effects.

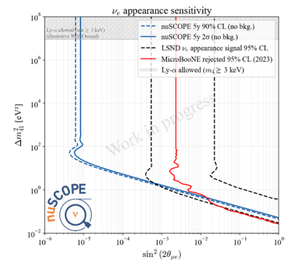



## Short-baseline (sterile-$\nu$) oscillations *arXiv:2606.14263*

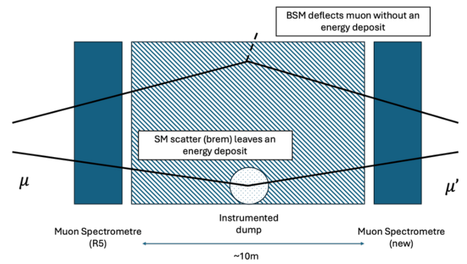
- Event-by-event knowledge of $L/E$ and neutrino flavor.
- Sensitive to very fast short baseline oscillations.




## A muon & meson program: nuSCOPE → muSCOPE (in collab. with Y. Soreq and R. Plestid)

- The same silicon trackers and the high muon flux downstream ($\sim 10^{16}$ $\mu$ in 5 years) make nuSCOPE a potential high-precision $\mu$ experiment in its own right.
- Could enable searches for dark sector processes (e.g. missing energy searches, bump hunting).
- Huge, well-known $\pi/K$ flux for other BSM measurements.




## Take-away messages and next steps

- nuSCOPE proposes a novel precision measurement facility delivering neutrino beams known with <1% flux uncertainty and neutrino energy known with <1% uncertainty on an event-by-event basis.
- Several candidate locations identified at CERN in collaboration with Accelerator Division and Physics Beyond Colliders.
- One facility, many measurements: cross sections, nuclear physics, sterile-$\nu$ & BSM, muon/meson physics.
- Studies ongoing to broaden the case — *get in touch to get involved!*
- Aim to submit an Expression of Interest to the CERN SPSC by the end of the year – welcoming new collaborators!