

# Neutrino Physics

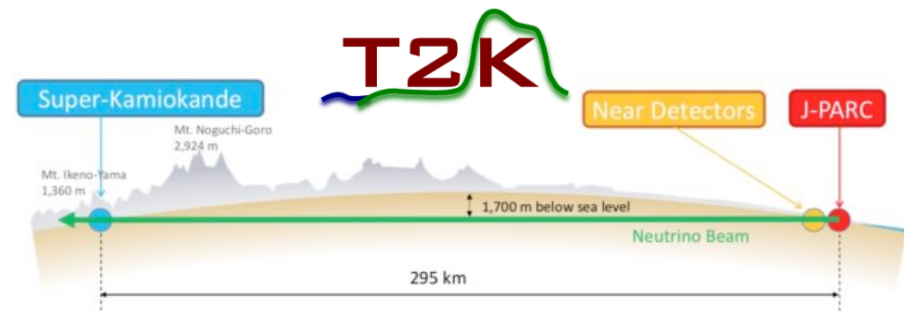
Yoshikazu Nagai



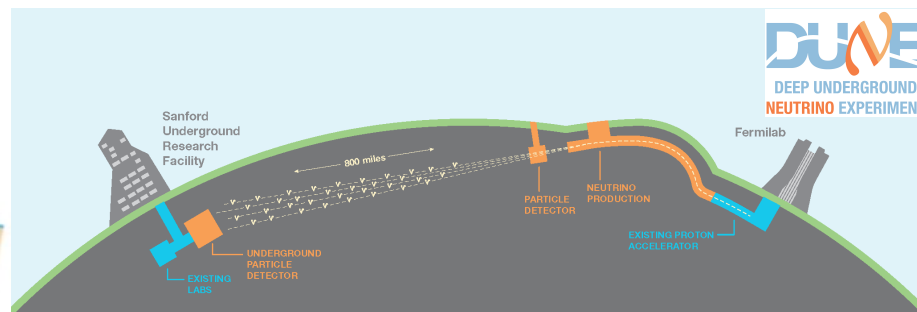
**ELTE**

Eötvös Loránd  
University

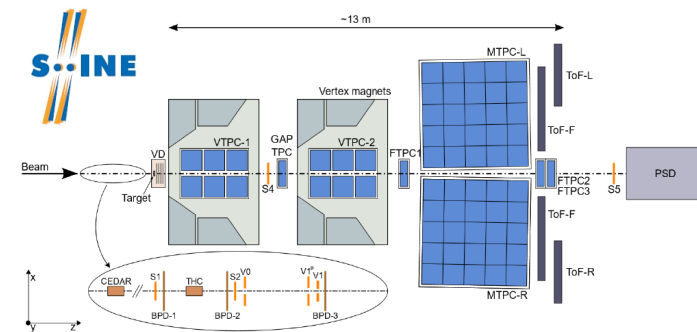
September 23, RECFA visit to Hungary



T2K (Running in Japan)



DUNE (Future in the US)

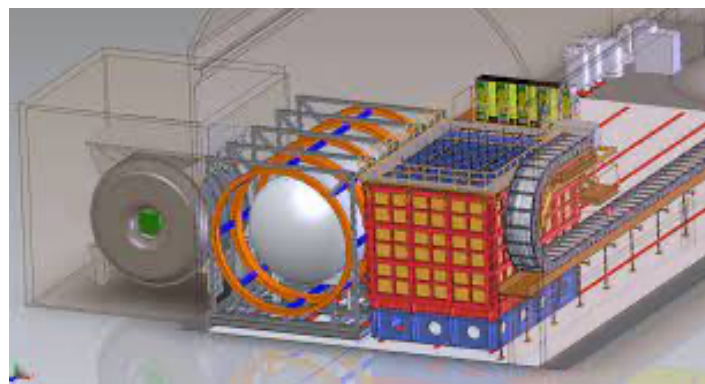


NA61/SHINE (Running at CERN)

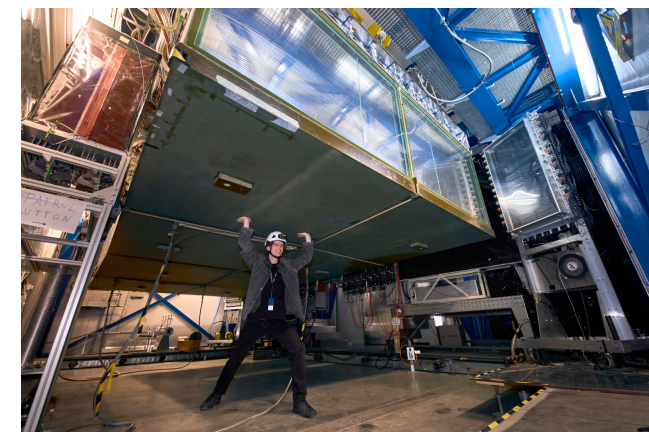
**ELTE is a member institute of three neutrino-related experiments since 2021.**  
**Research focus: Accelerator-based neutrinos**



T2K: Neutrino beamline



DUNE: Near Detector Complex



NA61/SHINE: TPC tracking chambers

# Resource, Personpower, Contributions

## Funding grants

- OTKA FK137812 (2021-2025): 40 MHUF (97k CHF)
  - Covers mainly travel of members
- TKP 2021-NKTA (2021-2025)
  - Covers Common funds and personnel costs

(OTKA: Hungarian Scientific Research Fund by NKFIH)

(TKP: Thematic Excellence Program Fund by NKFIH)

## Members

- Yoshikazu Nagai (PI) - DUNE, NA61/SHINE, T2K
- Pingal Dasgupta (Postdoc) - T2K
- Mahmoud Ibrahim (Master student) - DUNE

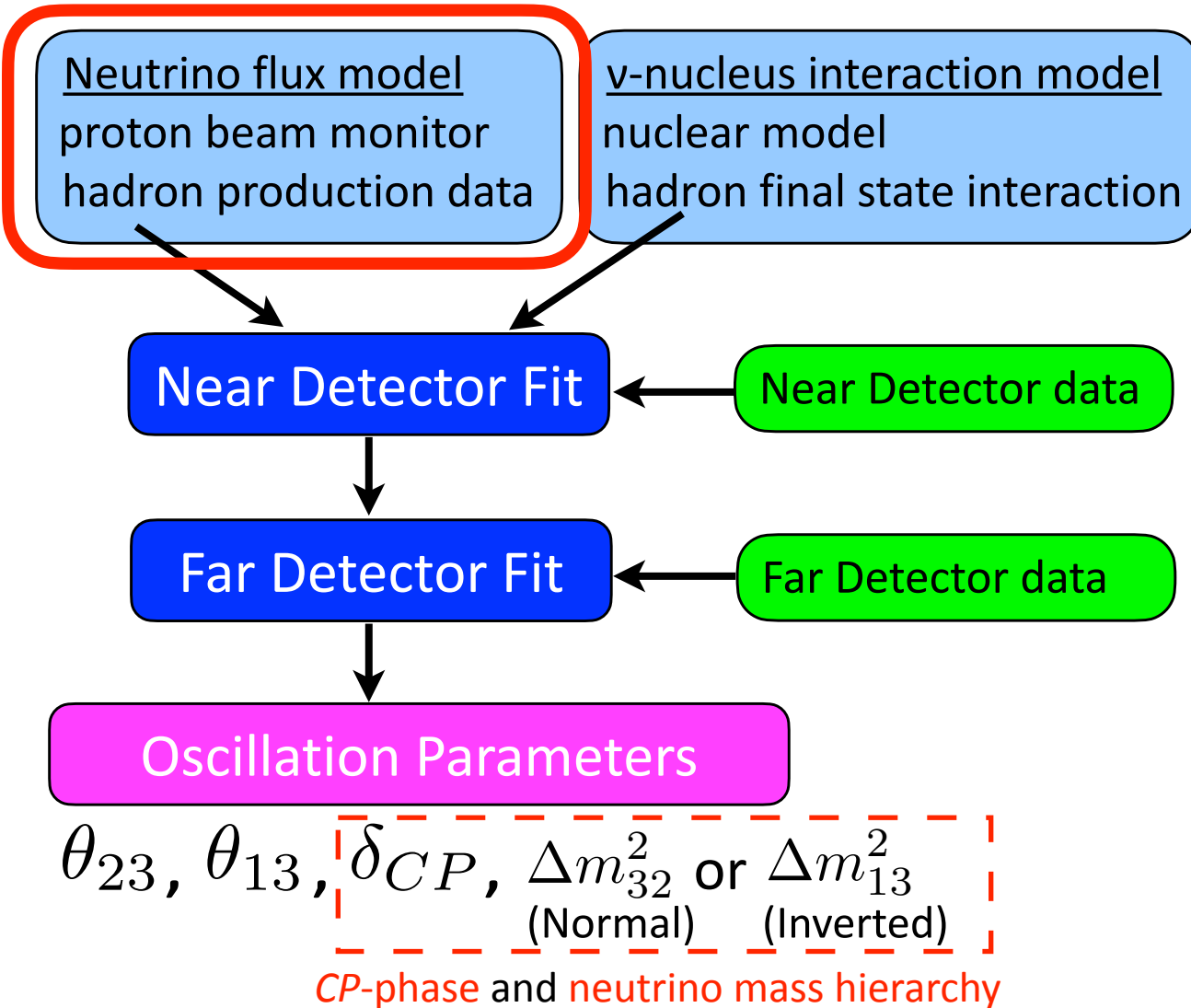
## Responsibilities within experiments

- T2K
  - Convener of beam MC working group
- NA61/SHINE
  - Physics Coordinator for neutrino run
  - Deputy convener of software working group
  - Convener of the low-Energy beamline working group

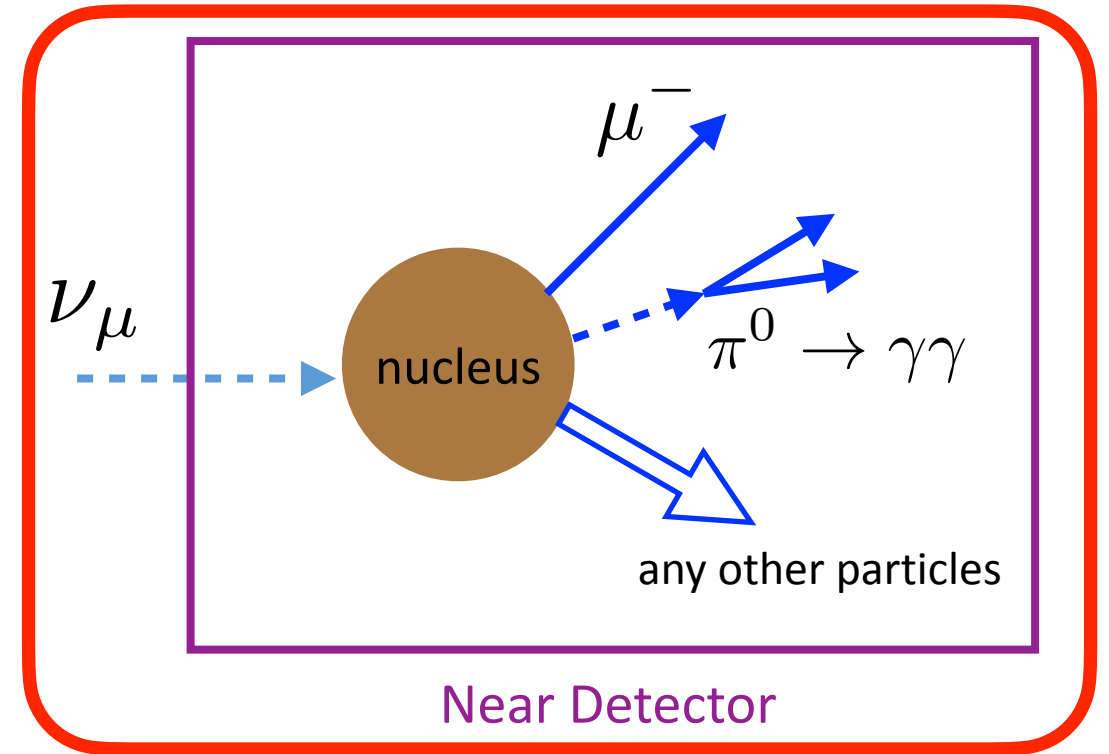


# Research Strategy

- Neutrino oscillation analysis



- Neutrino interaction measurement



Our focus: Flux and Near Detector

(for T2K and DUNE)

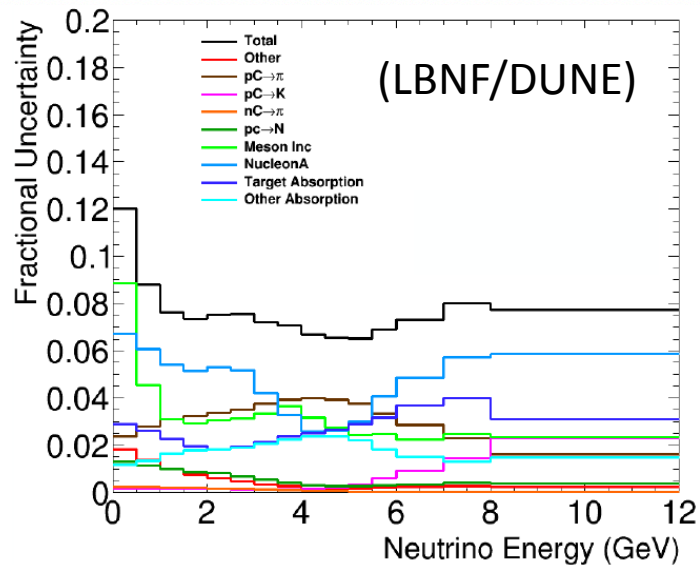
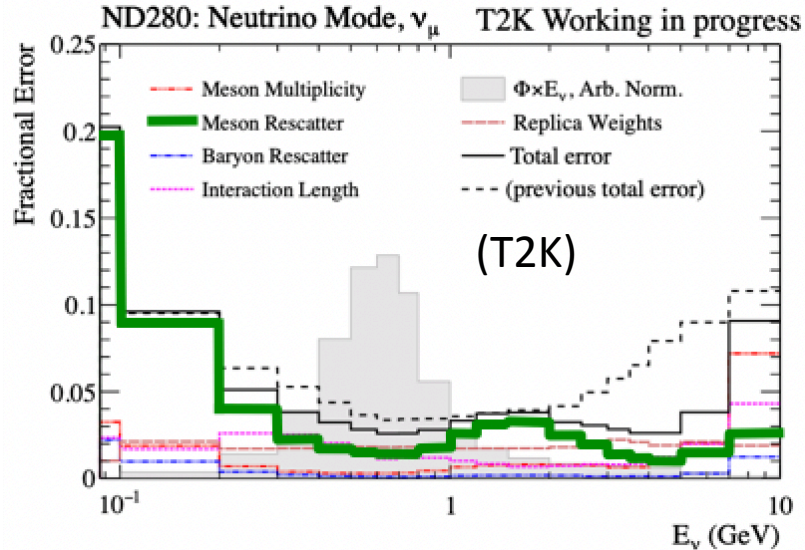
(for DUNE)

to measure the size of the *CP* phase  
in the current (T2K) and future (DUNE) experiments



# NA61/SHINE: Future Measurements for Neutrino

Demand for T2K and DUNE: flux uncertainty < 3%



Our contribution and plans

- Dedicated measurement for T2K
  - Complete data collection in summer 2022
  - Analysis next few years
- Dedicated measurement for DUNE
  - Foreseen in 2023-2025 (prototype target is under development)
- New initiative to build a low-Energy branch of H2 beamline
  - The project has been evaluated by CERN SPSC with positive remark
  - Foreseen construction during 2023 YETS at the earliest
  - Seeking funding sources (total project cost: ~1MCHF)

CERN-SPSC-2021-028: “Addendum to the NA61/SHINE Proposal: A Low-Energy Beamline at the SPS H2”

CERN-SPSC-2022-022: “Additional Information concerning the Low Energy Beam project”

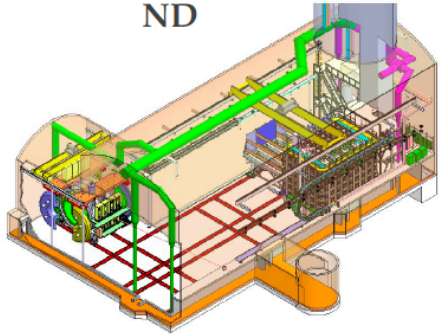
(In response to two submitted documents on June 2022)

The SPSC recognizes the scientific value of the improvements that the low energy beam line could bring to the knowledge of the neutrino cross sections and **recommends that the corresponding technical feasibility be studied in detail.**

Close collaboration with existing NA61 effort in Hungary  
(Covered by A. Laszlo’s talk)

# DUNE: Overview and Focus

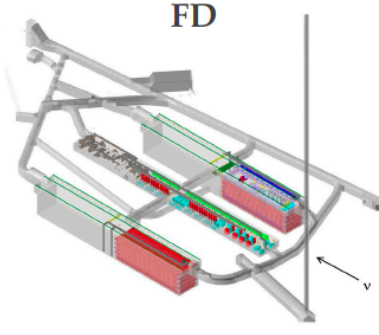
ND



## Phase I

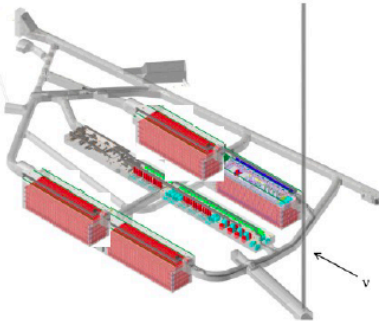
- FD: 2 x 17 kt LArTPC modules
- ND: ND-LAr+TMS (with PRISM) + SAND
- FD turns on late 2020s
- 1.2 MW capable beamline and ND by 2031

FD



## Phase II

- FD: 4 x 17 kt modules
- ND: ND-LAr+ND-GAr (with PRISM) + SAND
- Proton beam 1.2 MW to 2.4 MW



Our contribution: ND-GAr detector for Phase-II DUNE (ND-GAr = High-pressure gas Ar TPC)

ND-GAr will be responsible for:

- measurements of  $\nu$ -Ar interactions with unprecedented precision
  - very low threshold to charged hadrons compared to liquid Ar TPC
  - $4\pi$  acceptance with charge separation
- resolving interaction modeling uncertainties

Research activity

Improvement of event reconstruction using ML

- Identification of short photon tracks
- Improvement of primary  $\nu$ -Ar interaction vertices

Phenomenology theorists at ELTE actively study BSM physics scenarios that are suitable for DUNE Near Detector.

-> Possible future collaboration is foreseen !!

# Summary

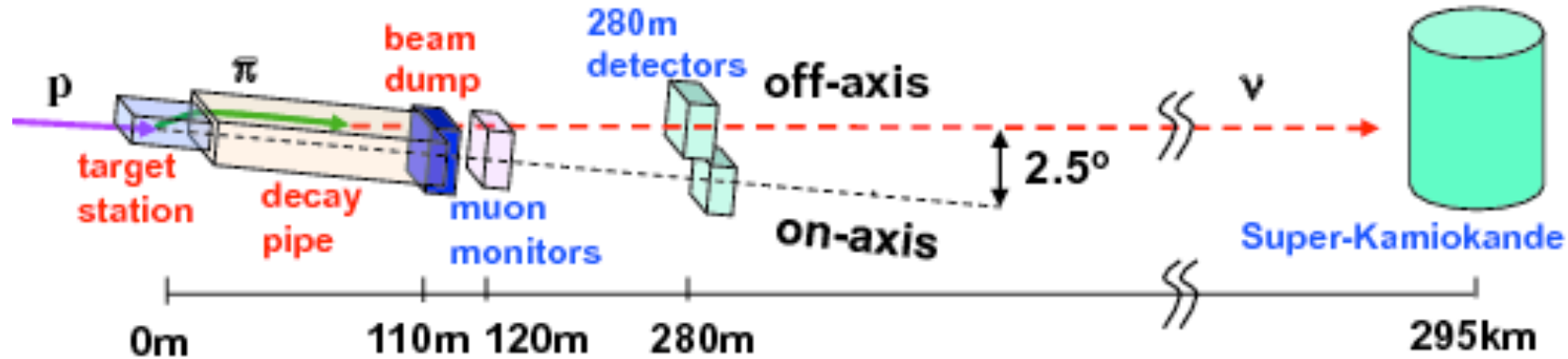
- ELTE has launched an experimental neutrino physics group recently
  - A member institute of the DUNE, NA61/SHINE, and T2K experiments to tackle neutrino CP violation through neutrino oscillation and to study neutrino interactions in detail
- The research program consists of two pillars:
  - Understanding neutrino flux for T2K and DUNE through extensive hadron production measurements with NA61/SHINE
  - Study for the next generation near detector for DUNE
- The challenge
  - Personpower (just one group from the entire Hungary)
  - Stable funding to cover common funds (relying on funding without a rolling-grant scheme)
  - Project funding to build a low-E beamline at CERN SPS H2
    - Consulting several funding possibilities in Europe, US and Asia



# Backup

# Long-baseline Neutrino (LBN) Experiments

example:  
T2K experiment



## Beamline

- Create intense  $\nu_\mu$  and  $\bar{\nu}_\mu$  beams by shooting proton beams on target, focusing hadrons, and letting them decay to neutrinos

$$\Phi_{\text{initial}}$$

## Near detector

- Flux and cross section constraint for far detector prediction
- Near detector physics measurements  
→ neutrino-nucleus cross sections, search for new physics, etc

$$N_{ND} \propto \int \Phi_{ND} \cdot \sigma \, dE_\nu$$

## Far detector

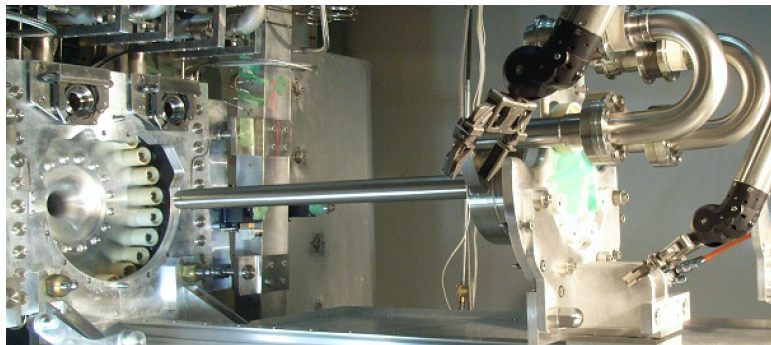
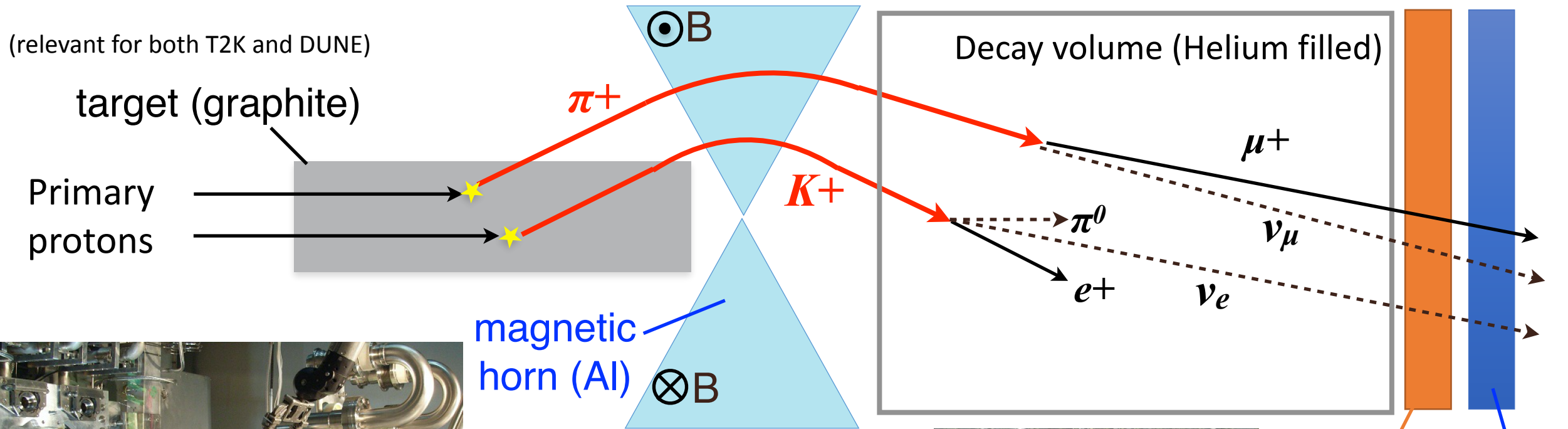
- Count  $\nu_e$  and  $\bar{\nu}_e$  appearance signals (measure the size of CP violation)
- Measure  $\nu_\mu$  and  $\bar{\nu}_\mu$  disappearance  
→ neutrino oscillations

$$N_{FD} \propto \int \Phi_{FD} \cdot \sigma \cdot P_{osc} \, dE_\nu$$

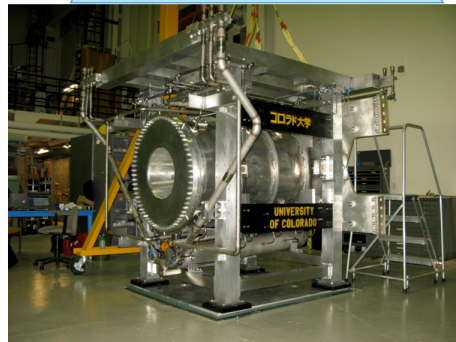
$$\propto \int R_{\frac{FD}{ND}} \cdot \Phi_{ND} \cdot \sigma \cdot P_{osc} \, dE_\nu$$

# Flux: Understanding Neutrino Beams

Hadron production of  $\pi^\pm$  and  $K^\pm$  through primary interactions in the target  
 —> Primary contribution to the flux, but huge uncertainty on hadron production



T2K target (90 cm, 1.9  $\lambda$ )

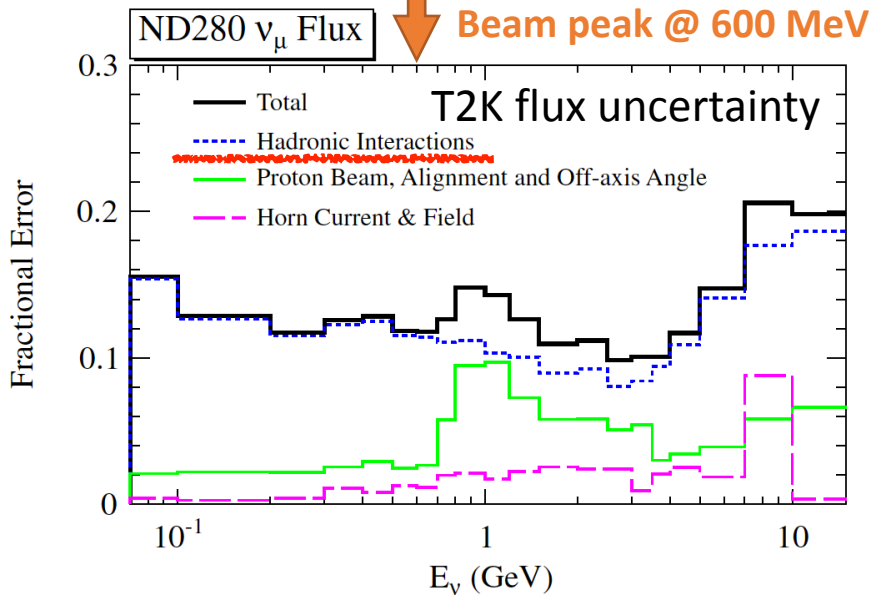


T2K decay volume (110 m)

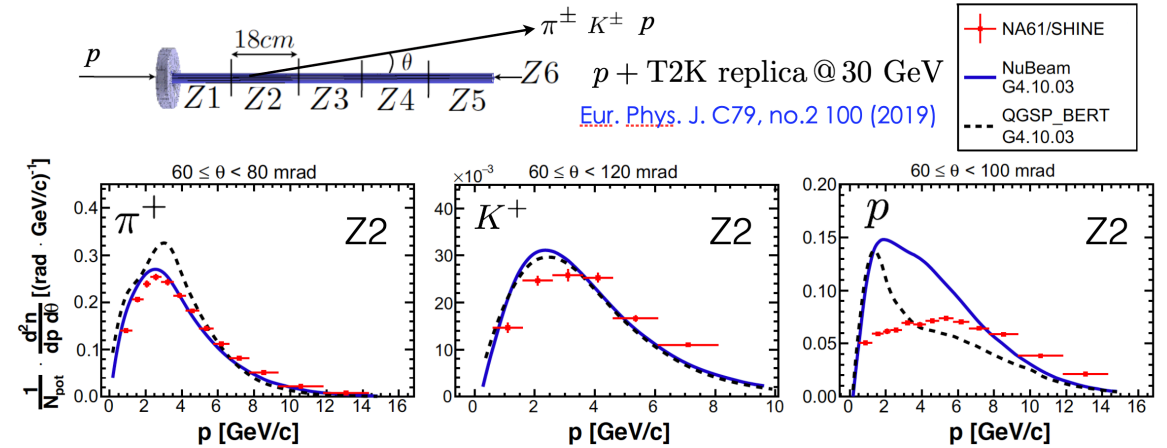


# NA61/SHINE: Hadron Production Measurements

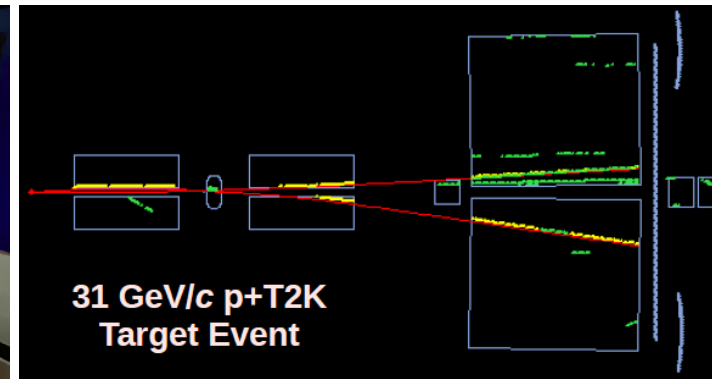
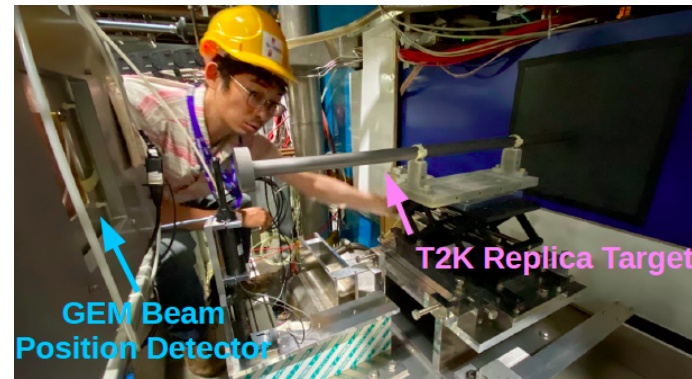
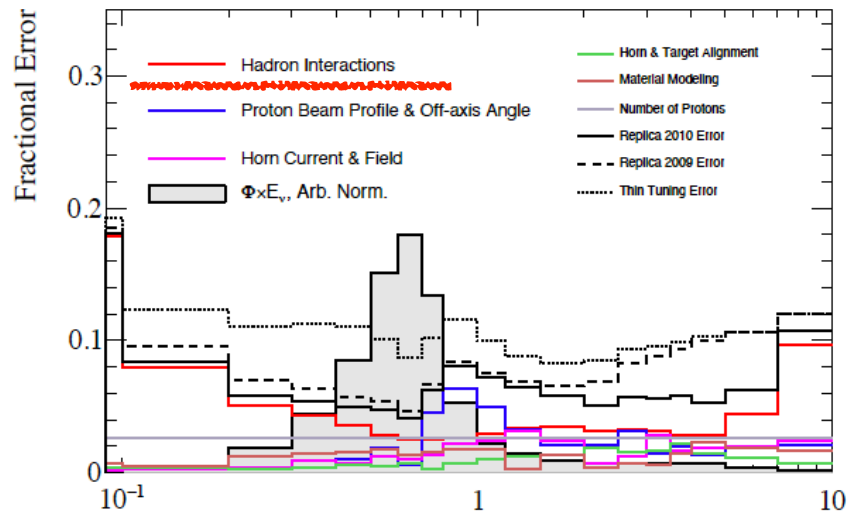
ND280  $\nu_\mu$  Flux **Beam peak @ 600 MeV**



(For T2K) Dedicated measurements with NA61/SHINE



(For T2K) More data has been collected in the summer 2022

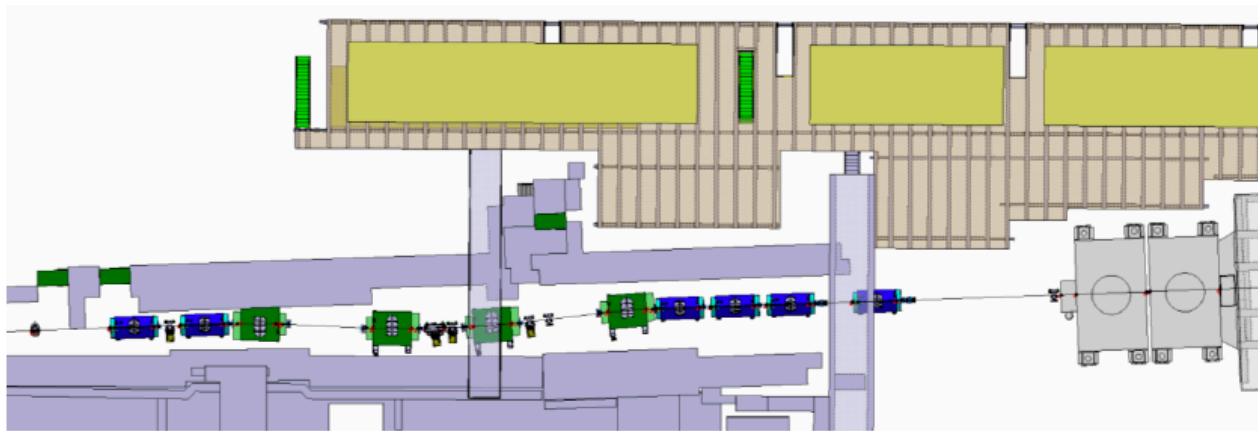


(For DUNE) Dedicated data collection in 2023-2025

Close collaboration with existing NA61 effort in strong interaction physics 11

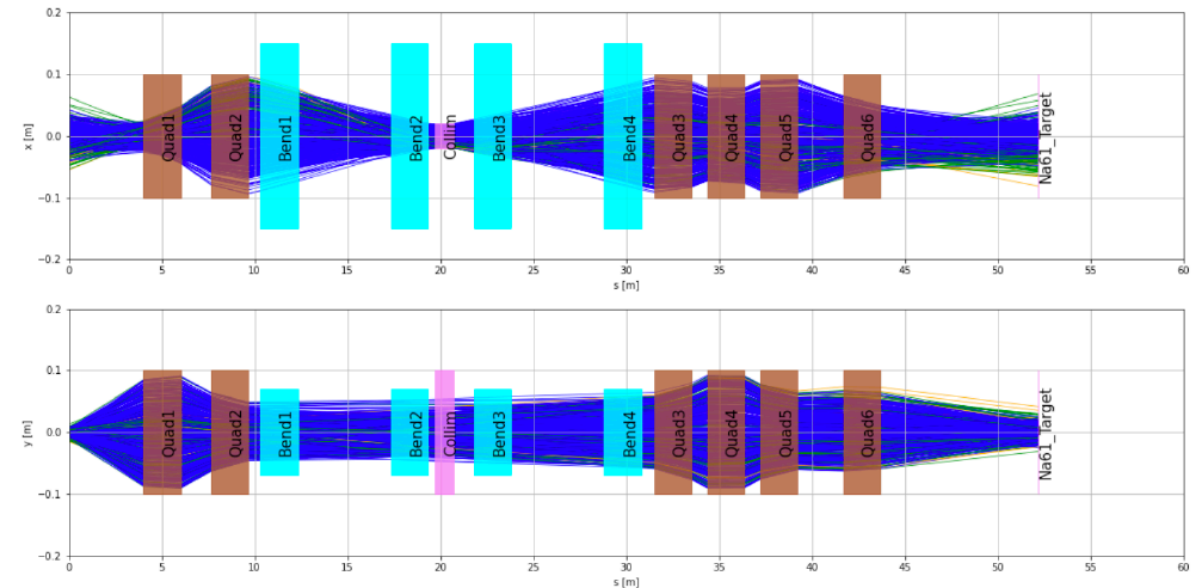
# Low-Energy Beamline at the CERN H2 beamline

- We are finalizing the design of new tertiary low-E beamline at CERN SPS H2-beamline
  - **Low-Energy = 2-13 GeV** → the lowest energy NA61 achieved was 13 GeV
  - proton, pion and kaon beams with good beam particle ID
- We have submitted two documents to CERN SPSC → **Positively evaluated**
  - Construction: during Year End Technical Stop (YETS) 2023 at the earliest
  - First beam in 2024 at the earliest



~45m

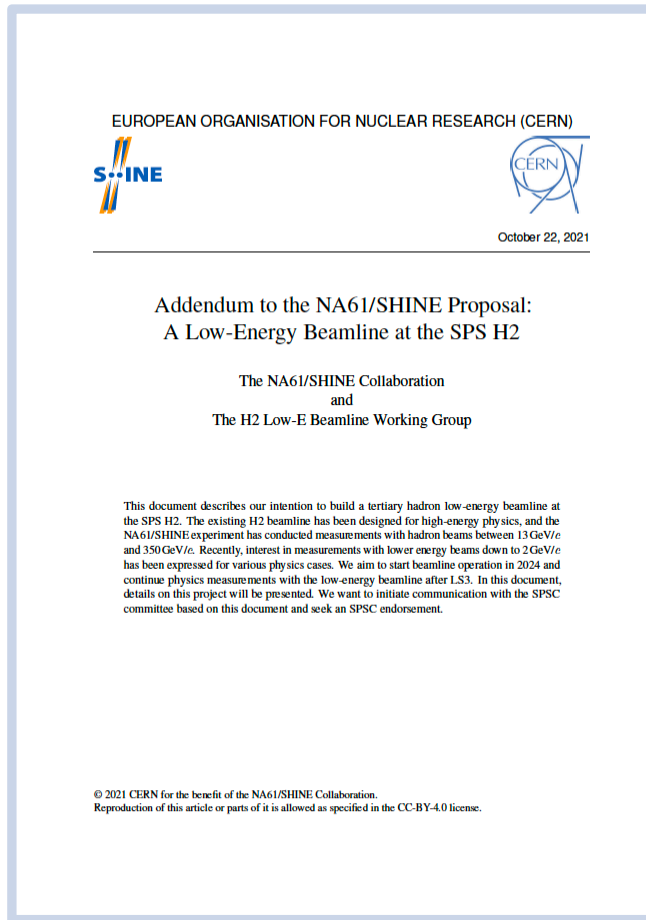
CAD rendering of beam area



beam particle tracking in low-E beamline

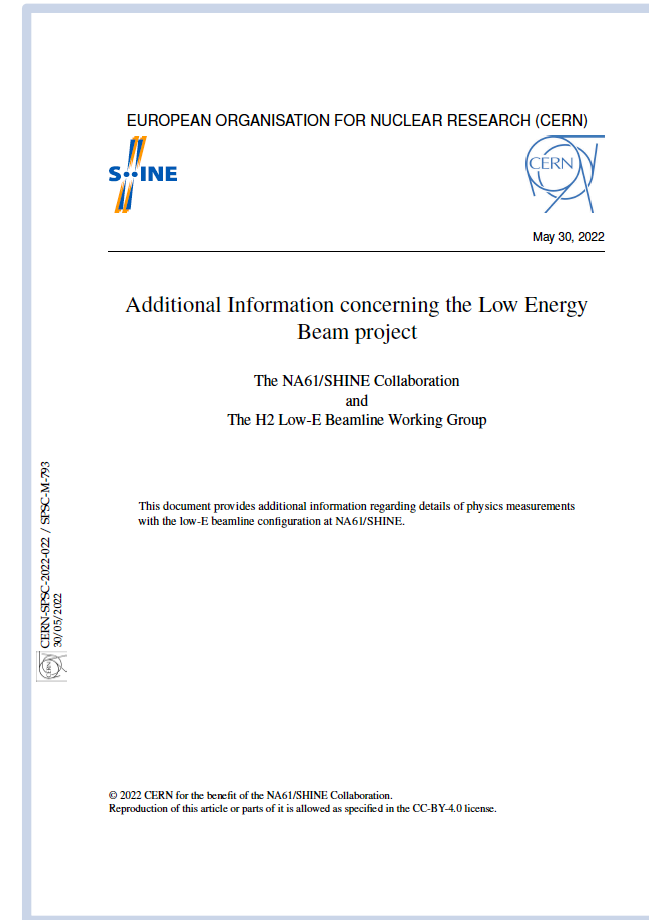
# Low-E beamline: Project Detail

## First SPSC document



<http://cds.cern.ch/record/2783037>

## Second SPSC document



<https://cds.cern.ch/record/2810696>