Input from Hyper_K and Enubet

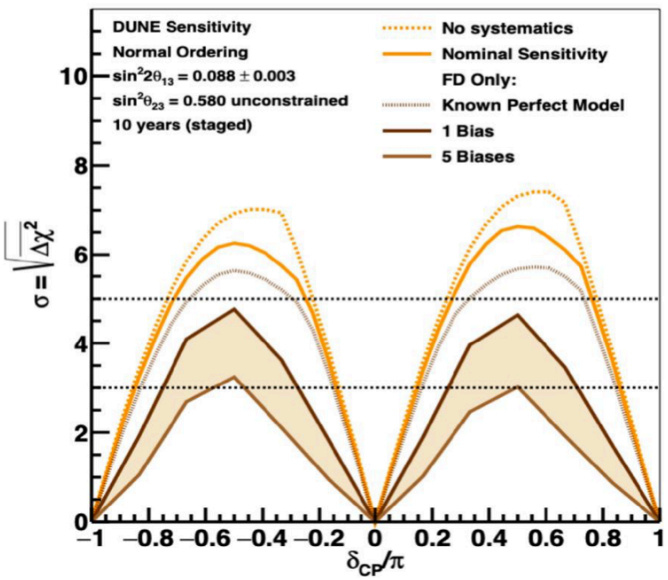
V. Berardi, N.F. Calabria, M.G. Catanesi, ***L. Magaletti***, E. Radicioni, R. Spina

The problem: ν-N x-sec

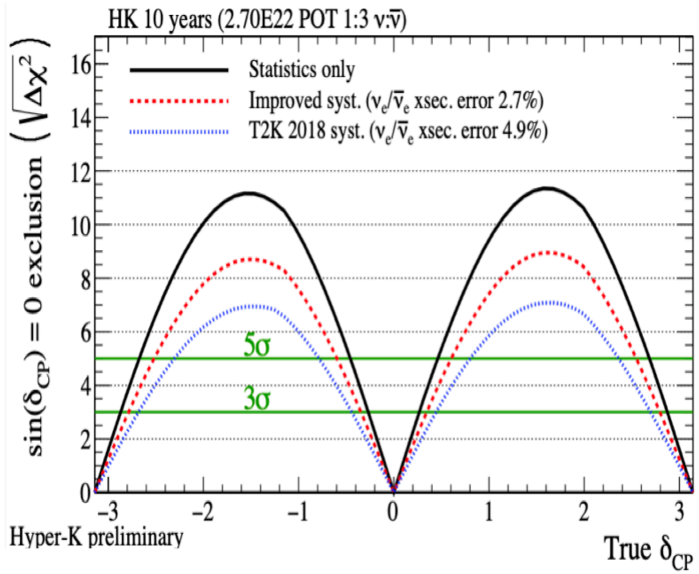
The knowledge of ν x-sec is stuck at 10-30% level. The needs of neutrino community is to push systematic uncertainties down to 1% level because:

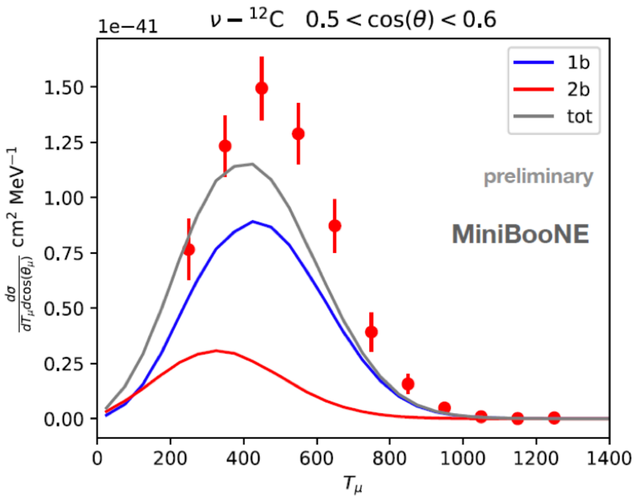
- Leading systematics for LBL experiments ⇒ ***Neutrino oscillations Physics***
- Limited possibility to validate nuclear electroweak effects ("nucleus and nuclear corrections") ⇒ ***Electroweak Physics***
- Neutrino generators based on different approaches still provide results with > 50% discrepancies ⇒ ***Nuclear Physics***

DUNE

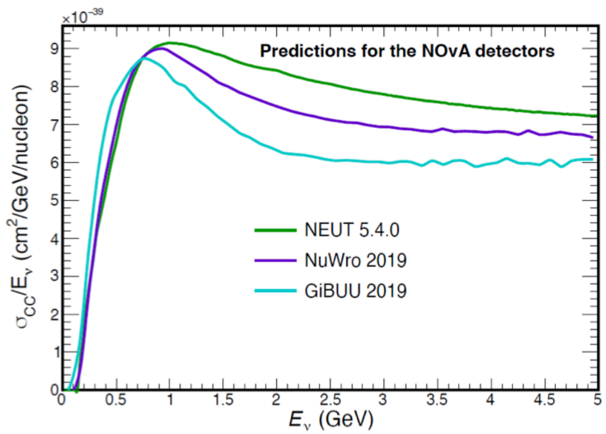


HyperKamiokande



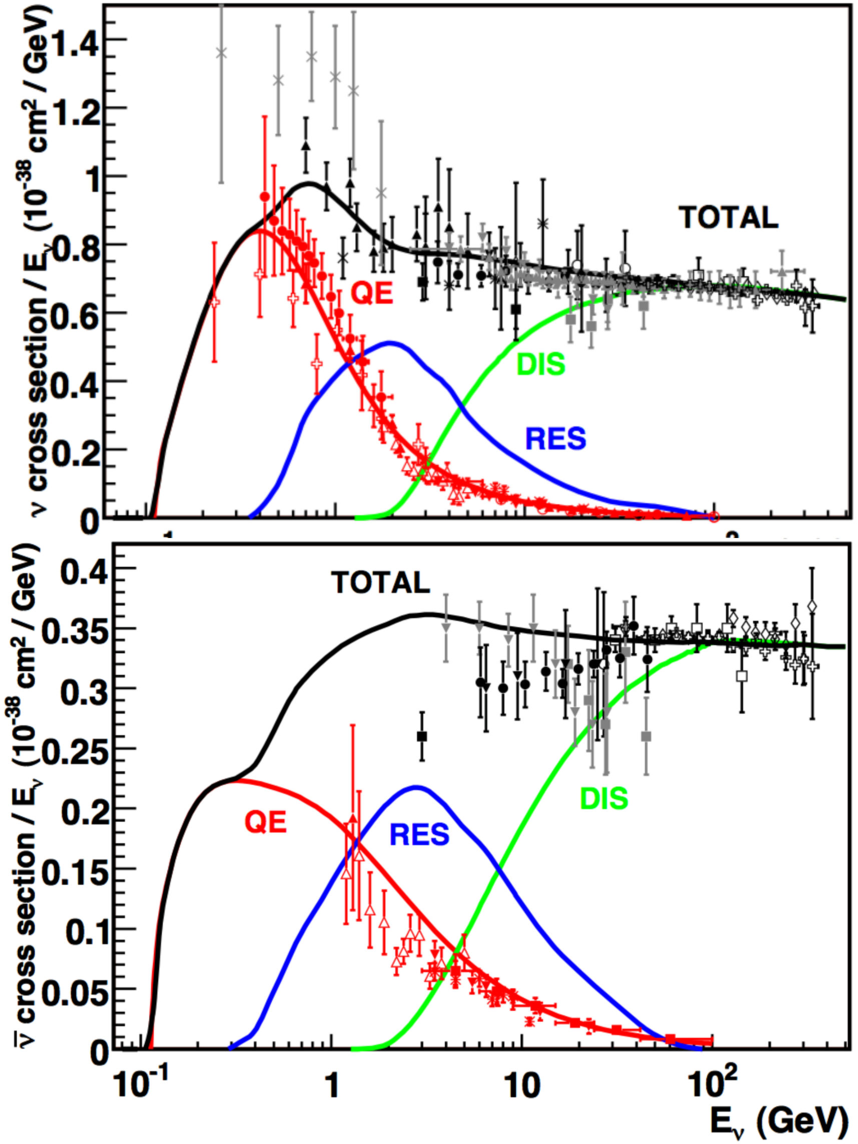


N. Rocco, Nufact2022



J. Paley, Nufact2022

Neutrino x-sec as a nuclear physics problem



- **CC0π dominant at T2K**

  → from the detector measurement (muon+proton) to the incoming neutrino energy

- **CC1π (+ DIS)**

  → how to disentangle Final State Interaction effects

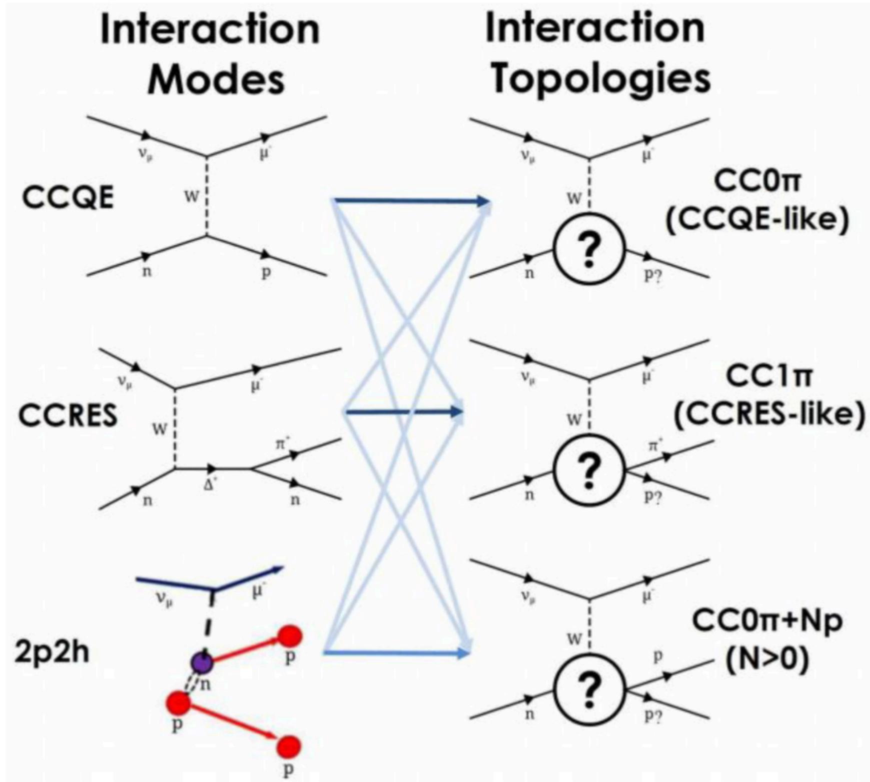
Impact on present and future oscillation measurements (δ_{CP}): $\bar{\nu}_\mu$

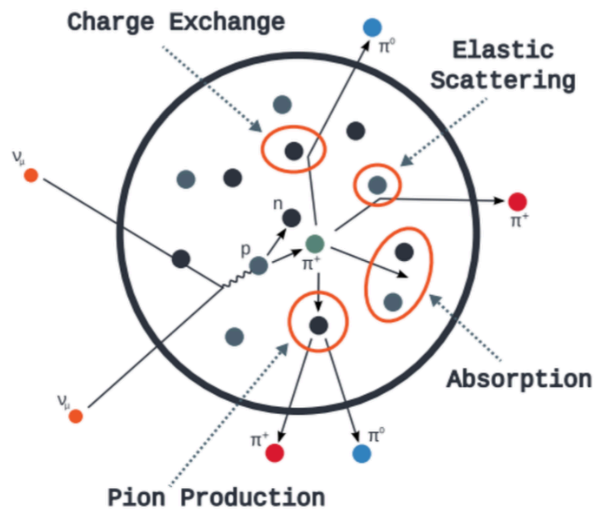
The measurement of δ_{CP} **crucially depends on the comparison of ν vs $\bar{\nu}$ oscillations:**

- bias on ν vs $\bar{\nu}$ x-sec directly reflect in bias on δ_{CP} measurement

Neutrino Interactions in the GeV region

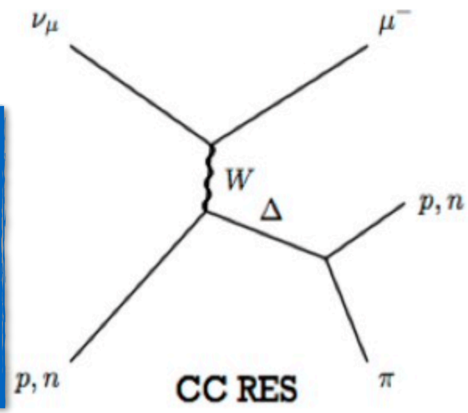
- Define signal by ‘topology’ (final state)
- Generally split by
  - ν flavour
  - interaction mode ($W^{\pm}/Z^{0}$)
  - π, proton multiplicity

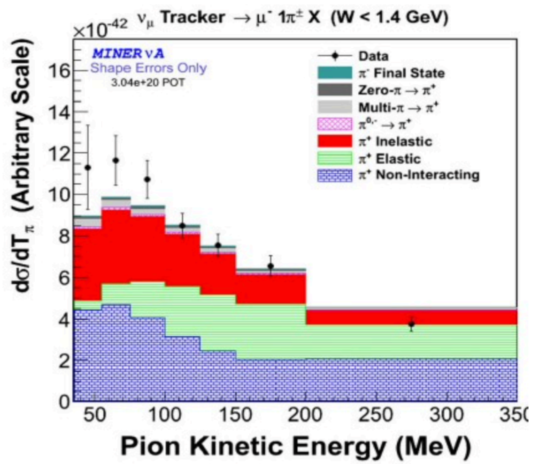




T. Golan, What is inside MC generators and why it is wrong. NuSTEC 2015

- **Large effects** from Final State Interaction (FSI): re-scattering of the π inside the nucleus (nuclear physics again!)
- **x-sec** and **FSI** have different A-dependence ⇒ ***important effect*** when extrapolation from ND and FD with different material

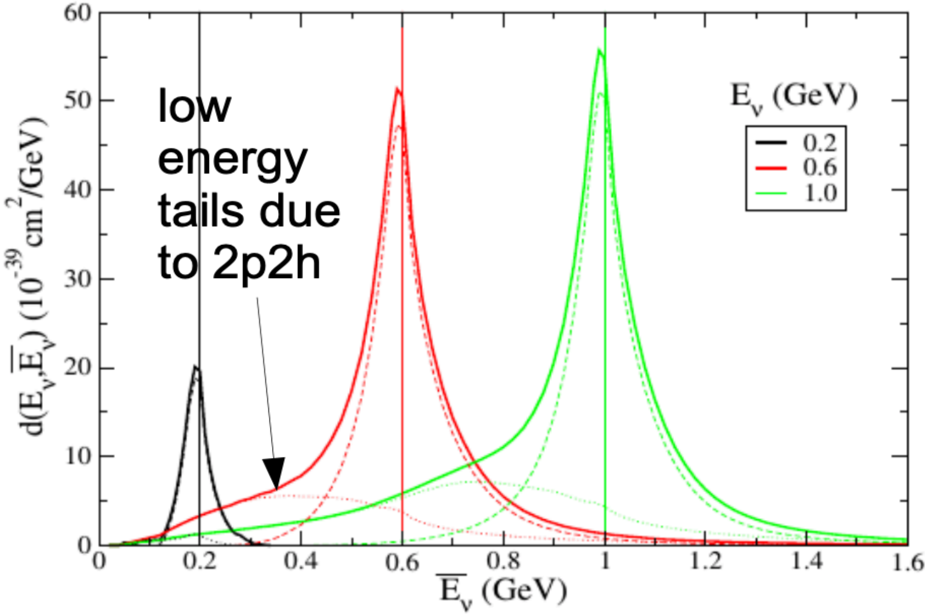




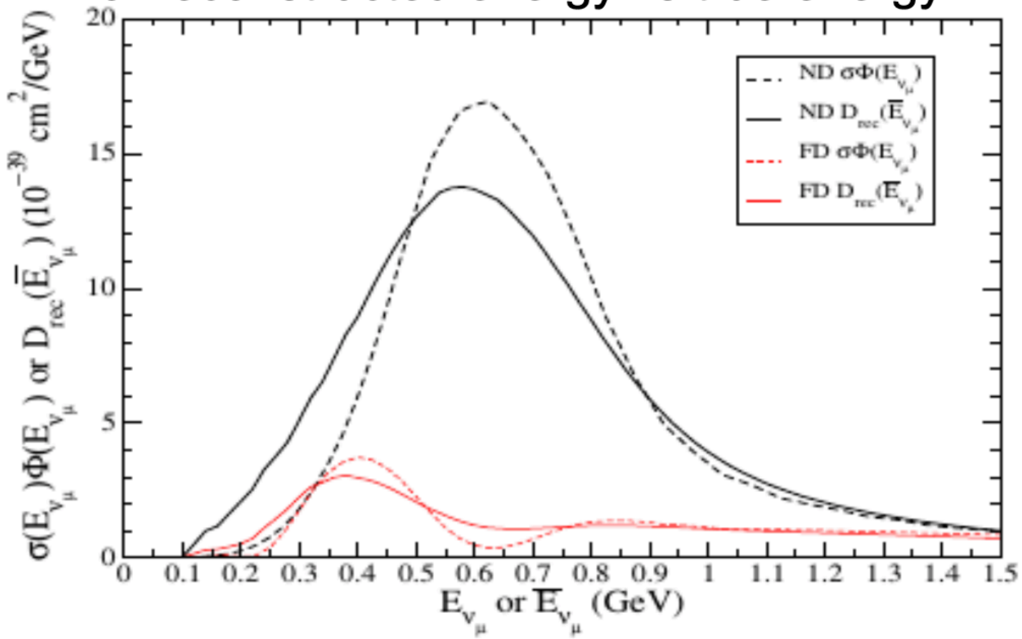
Why we need good models?

Neutrino oscillation goes like ~L/E$_\nu$ but we do not measure E$_\nu$! We measure the outgoing muon at SuperKamiokande and we infer the neutrino energy on the base of available models

Distribution of true energy for a given reconstructed energy



Near Detector and Far Detector spectra of reconstructed energy vs true energy



2p2h events fill the “dip” region sensitive to neutrino oscillation → **wrong modelling would cause bias on oscillation parameters**

What do we need to measure? What do we need to measure?

Uncertainties in ND→FD extrapolation :

✔ • different E_ν distribution (because of oscillation) ⇨ need to reconstruct the neutrino energy from the final state particles

Low energy hadrons $(p, n, \pi^{\pm})$ are very important!

✔ • different target ⇨ A-scaling: measure cross-sections on different targets (and/or on the same target of FD)

➔ • different acceptance ⇨ measurement of cross-section in the larger possible phase-space: increase angular acceptance of ND

4π is preferable

➔ • different neutrino flavor (because of oscillation) ν ($\bar{\nu}$) flux has typically a wrong sign component ⇨ measure cross-section asymmetries between different neutrino species (eg ν vs $\bar{\nu}$ important for for δ_{CP})

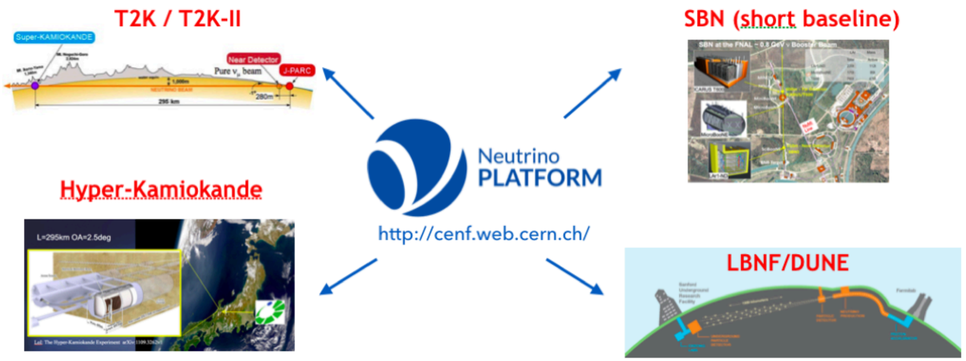
Neutrinos from accelerators

Neutrino related initiatives at CERN: overview

The CERN Neutrino Platform

- We are following the mandate give by the EU strategy in 2013: "pave the way ...."
- Main goal : compact the European groups around the projects of the future short and long Neutrino baselines
- CERN as a facility for R&D on future technologies (HW and SW) and partner in several neutrino research programs

The aim of all these activities is to improve our knowledge on $\nu - N$ x-sec



Prototypes for current and next generation near and far detectors:

NP07 → T2K near detector upgrade

NP04 → ProtoDUNE - Dual Phase

NP02 → ProtoDUNE - Single Phase

SPSC: **WCTE** (Water Cherenkov Test Experiment)

New ideas for improved future beams:

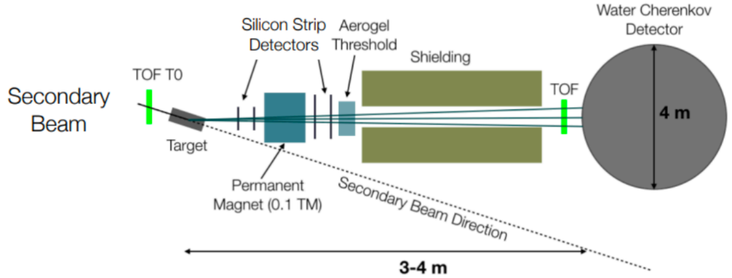
NP06 → ENUBET

Overall this approach is proving very effective with several successful and interesting activities !

Activities where **INFN-Bari is involved**

Water Cherenkov Test Experiment

- Propose a prototype water Cherenkov detector to operate in the T9 beam line in the East Area
- Study particles directly from secondary beam and with tertiary production configuration
- We propose a test experiment that is ~4 m diameter x 4 m tall
- **Particle fluxes of π±, p, μ, e in the 300 MeV/c-1200 MeV/c range**



CERN-SPSC-2020-005; SPSC-P-365: http://cds.cern.ch/record/2712416?ln=en

WCTE @ CERN

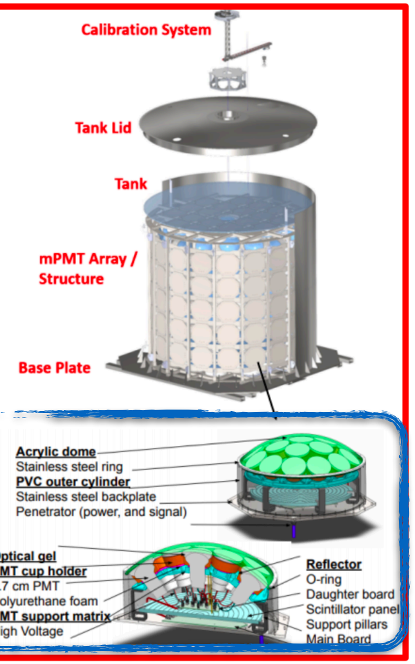
- **Control detector systematics**
- **Neutrino x-sec measurements:**
  - neutrons (key role in $\bar{\nu}$ scattering)
  - $\pi^{\pm}$ (FSI)

Huge effort from INFN-Bari
in the realization of multi-PMT:

- Comsol mechanical simulation
- Cover design
- Material studies

The WCTE Detector

- Detector is instrumented with 130 multi-PMT modules mounted on support structure
- Multi-PMT modules each contain 19 fast 8-cm diameter PMTs, their high voltage and readout circuits
- Installed inside stainless steel 304 tank
- Calibration deployment system to deploy sources throughout detector volume
- Filled with 50 ton deionized water



Enubet (NP06)

- Initial Proposal: A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015)
- ERC Project (2016-2022)

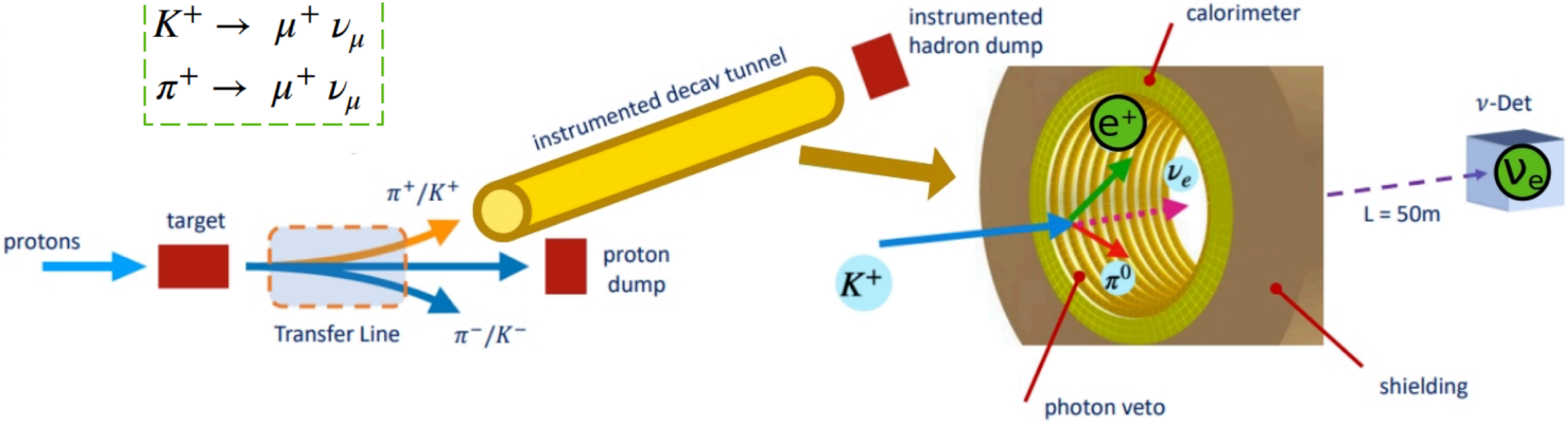
  Aim: Measure positrons from K_{e3} decay (in tunnel) to determine the ν_e flux

$$K^+ \to \pi^0 e^+ \nu_e$$

- CERN Neutrino Platform: NP06/ENUBET (2022-present), part of the Physics Beyond Colliders initiative

  Aim: Extend measurement to anti-muons from $K_{\mu 2}$ (in tunnel) and $\pi_{\mu\nu}$ (in dump) decays to determine the ν_μ flux

$$K^+ \to \mu^+ \nu_\mu$$
$$\pi^+ \to \mu^+ \nu_\mu$$

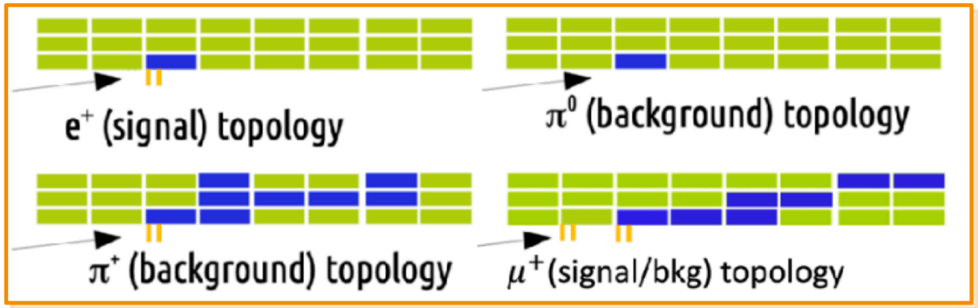


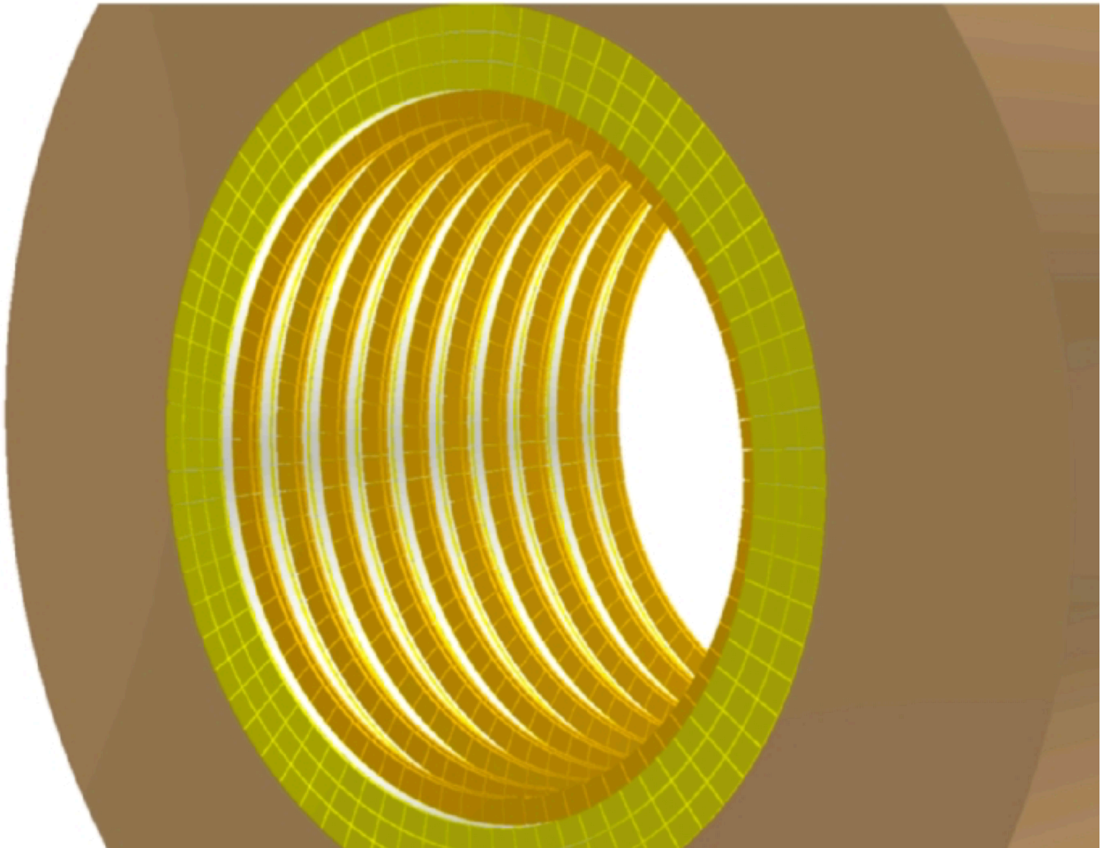
INFN-Bari involved in:
- Test beam @ CERN
- Data analysis

Enubet (NP06)

A decay tunnel instrumented with a calorimeter to **identify the leptons in the tunnel at single particle level**

PID based on the pattern of energy deposit in the calorimeter modules:





The Photon-Veto

- π^0 rejection and timing, time resolution of ~400 ps
- plastic scintillator tiles arranged in doublets forming inner rings

The Calorimeter

- e/π/μ separation
- **sampling calorimeter**: sandwich of **plastic scintillators** and **iron** absorbers
- 3 radial layers of **lateral readout** calorimetric modules (LCMs) longitudinal segmentation
- WLS-fibers/SiPMs for light collection/readout

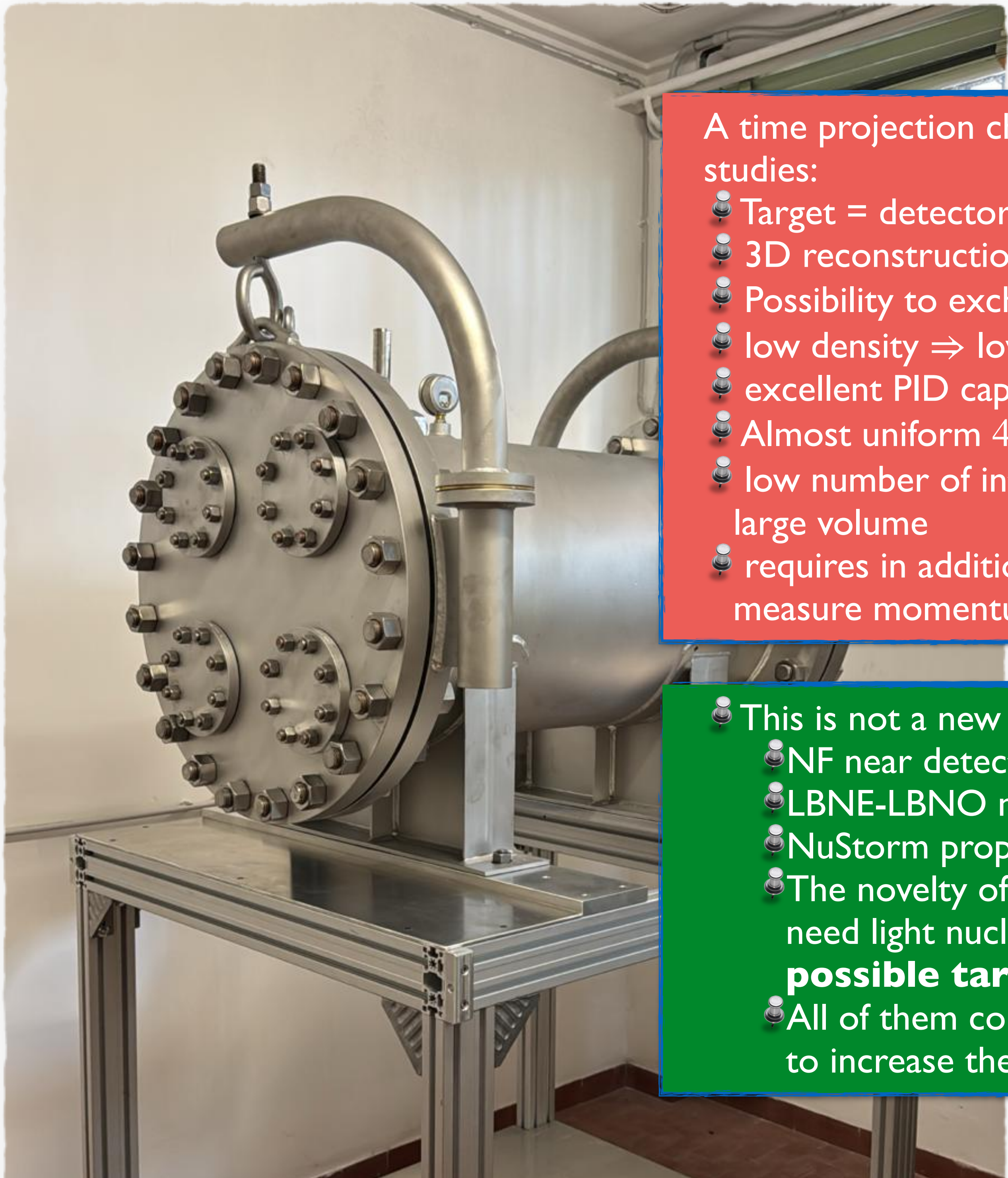
The Shielding

- 30 cm of borated polyethylene
- SiPMs installed on top → factor 18 reduction in neutron fluence

The goal of the Enubet project is to achieve knowledge of the neutrino flux at the 1% level

"By-pass" hadro-production, protons on target, beam-line efficiency uncertainties

High Pressure TPC as neutrino target



A time projection chamber is a good candidate for these studies:

- Target = detector.
- 3D reconstruction capabilities.
- Possibility to exchange targets ⇒ Nuclear dependencies
- low density ⇒ low thresholds
- excellent PID capabilities
- Almost uniform 4π acceptance
- low number of interactions ⇒ requires high pressure and large volume
- requires in addition a magnet or range detectors to measure momentum

- This is not a new idea (**Argon** as target):
  - NF near detector.
  - LBNE-LBNO near detector.
  - NuStorm proposal.
  - The novelty of the proposal and need for HK is the need light nuclei such as **He,Ne or CF4 as possible targets**. **(H?)**
  - All of them consider the option of a **High Pressure** to increase the number of events.

High-pressure Gaseous optical TPC's

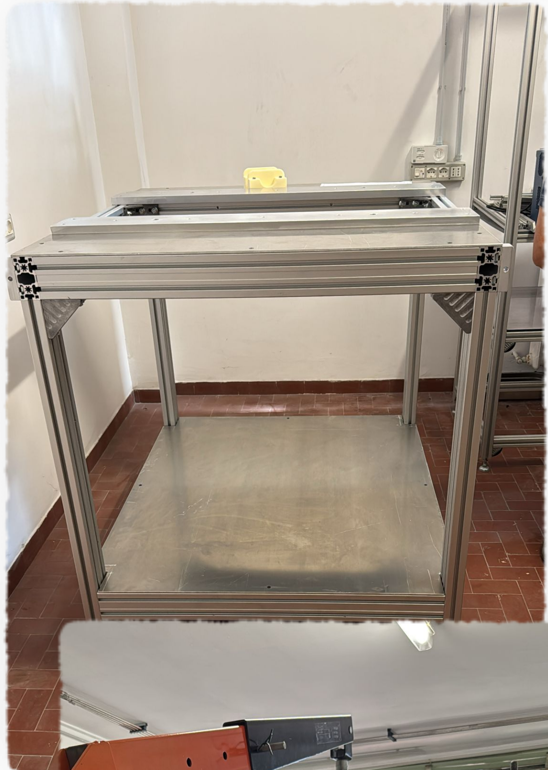
Advantages of gaseous TPC

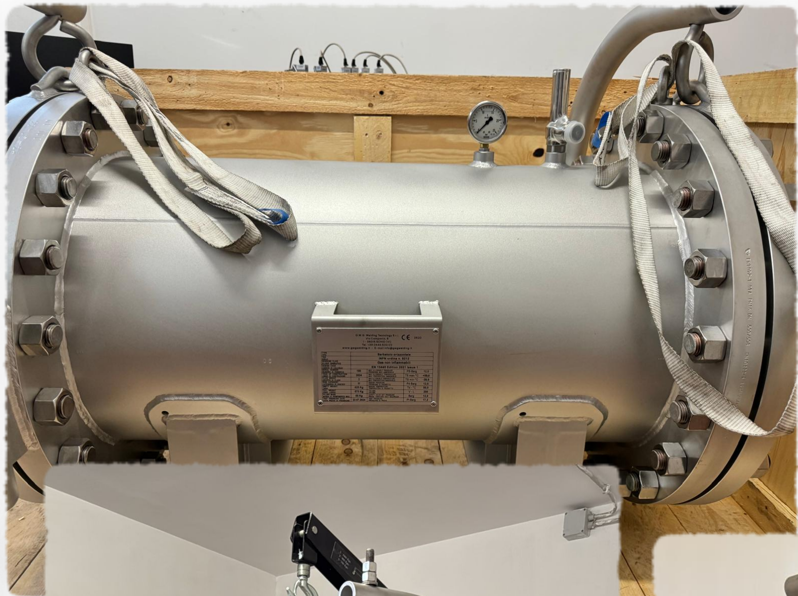
- Low target mass
- Single atom target
- Easy to scan different target materials : different gases.
- Low momentum detection threshold
- High pressure → higher target density → higher interaction rate.

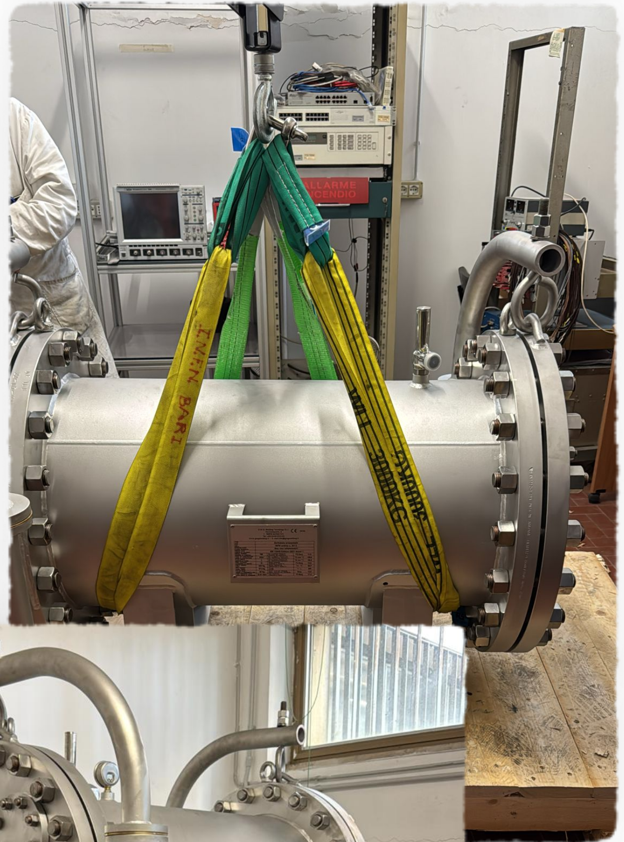
Advantages of optical TPC

- Fast developments in electronics
- High granularity
- Optics → high surface covered
- Read-out decoupled from active body
  - Facilitates access
  - No out-gassing
- Does not degrade fast with pressure.
- No gas mixture —> single nuclear target.

Vessel installation in Bari







Many thenks for design and vessel installation to our mechanical workshop!!!

Conclusions

- INFN Bari fully involved in current and future detector activities devoted to the next generation neutrino oscillation experiments (ND280 upgrade, mPMT for HK, Enubet, HP-TPC)
- HP-TPC project in both AIDA-INNOVA and DRD1
- HP-TPC useful for both Muon Collider and next generation neutrino oscillation experiments
- ND280++ meeting at CERN last July
- Workshop on Neutrinos@CERN (23-24 January 2025)

Workshop on Neutrinos@CERN

23–24 gen 2025
CERN
Europe/Zurich fuso orario

Inserisci il termine di ricerca

- Sintesi
- Accomodation
- CERN Wi-Fi Network
- Directions to and around CERN
- How to get to CERN
- Map CERN
- Iscrizione
- Calendario
- Videoconferenza
- VISA Instructions & other Practical information

Contact
neutrino.secretariat@ce...

This two-day workshop, fostered at CERN by the CERN Neutrino Platform and Physics Beyond Colliders, is aimed at discussing opportunities for performing neutrino physics experiments at CERN using existing, planned, and proposed facilities. The goal is to bring together neutrino physicists to explore these opportunities and provide input for the European Strategy for Particle Physics Update (ESPPU). The main themes of the workshop are:

- The need for dedicated CERN experiments in the DUNE and HyperKamiokande era, including short-baseline, beam dump, and hadroproduction experiments.
- Medium- and long-term plans for the ProtoDUNE detector complex and Neutrino Platform experiments.
- Neutrino physics with SHiP and the LHC far-forward projects (Forward Physics Facility etc.).

The workshop will take place on January 23-24, 2025 at CERN, concluding with a special session focused on input and proposals for neutrino-related experiments at CERN for the ESPPU.

If you are interested in proposing a contribution, please contact the organizers.

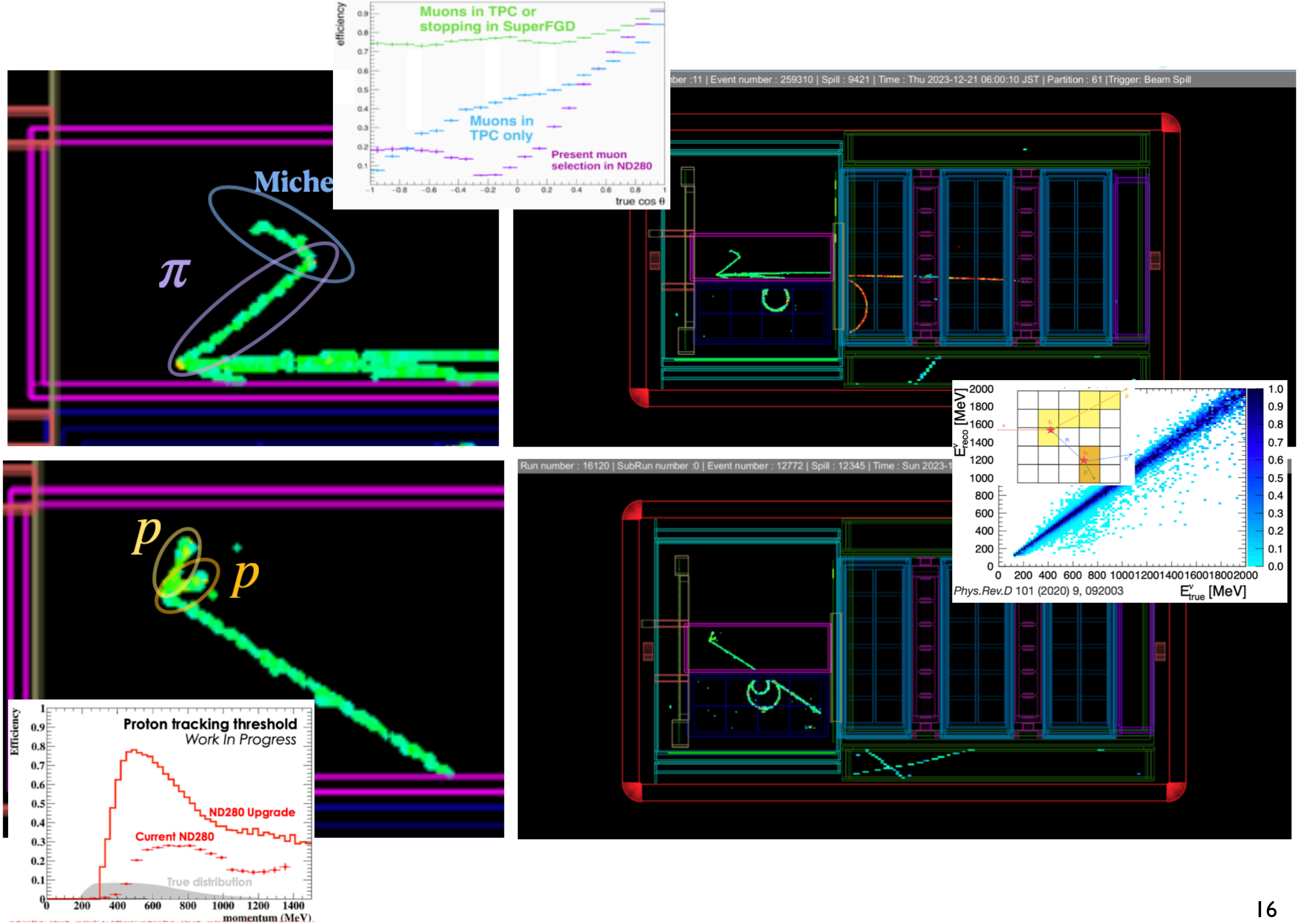
Inizio 23 gen 2025, 09:00
Finisce 24 gen 2025, 19:00
Europe/Zurich

CERN
40/S2-C01 - Salle Curie
Vai alla mappa

Filippo Resnati
Francesco Terranova
Gunar Schnell

Backup

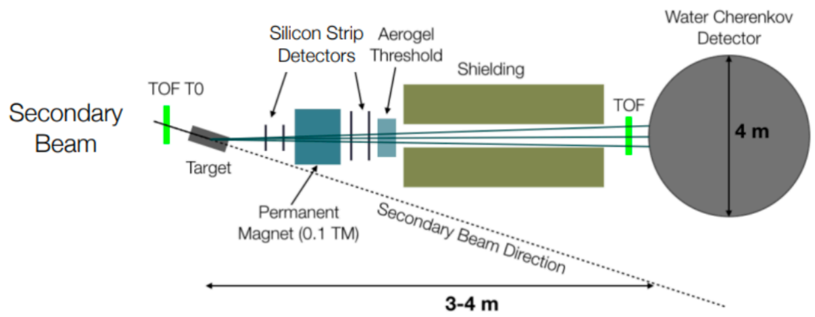
Some nice events from December 2023 in the upgraded ND280



WCTE @ CERN

Water Cherenkov Test Experiment

- Propose a prototype water Cherenkov detector to operate in the T9 beam line in the East Area
- Study particles directly from secondary beam and with tertiary production configuration
- We propose a test experiment that is ~4 m diameter x 4 m tall
- **Particle fluxes of $\pi^{\pm}$, p, μ, e in the 300 MeV/c-1200 MeV/c range**



CERN-SPSC-2020-005; SPSC-P-365: http://cds.cern.ch/record/2712416?ln=en 4

Neutrino x-sec mesurements:

- **neutrons** (key role in $\bar{\nu}$ scattering)
- $\pi^{\pm}$ (FSI)

Detector systematics

M. Hartz

- **Measurement of Cherenkov light production**
  - Currently used simulations are not consistent
  - Introduces systematic errors in event reconstruction
  - Can be measured with well characterized beam in WCTE
- **Study of energy scale calibration**
  - Muons crossing detectors used in Super-K to set energy scale
  - Systematic uncertainty of 2% needs to be reduced to 0.5% for Hyper-K
  - Can be studied with crossing muons of known energy in WCTE

- **Measurement of secondary neutron production**
  - In SK-Gd and Hyper-K, neutrons used for neutrino/antineutrino tagging, proton decay background tagging
  - Predicted rates sensitive to secondary production by pions/protons
  - Can measure secondary production in WCTE
- **Study of pion scattering**
  - T2K, Super-K and Hyper-K are using samples with pions in the final state
  - Reconstruction is challenging due to modeling of hadronic scattering with limited data on oxygen
  - Can directly measure water Cherenkov detector response to pions in WCTE

WCTE @ CERN

The WCTE Detector

- Detector is instrumented with 130 multi-PMT modules mounted on support structure
- Multi-PMT modules each contain 19 fast 8-cm diameter PMTs, their high voltage and readout circuits
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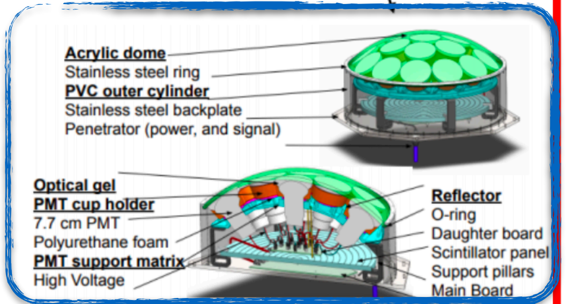
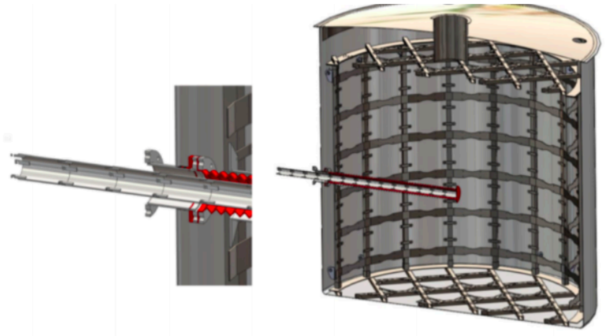
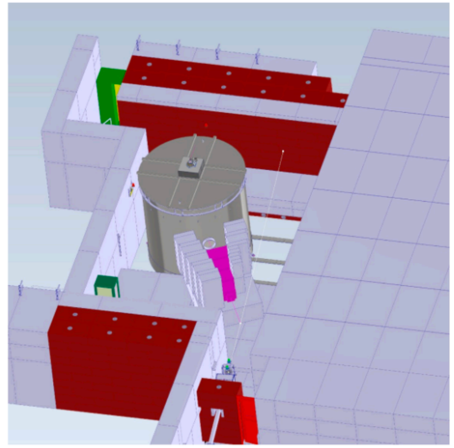


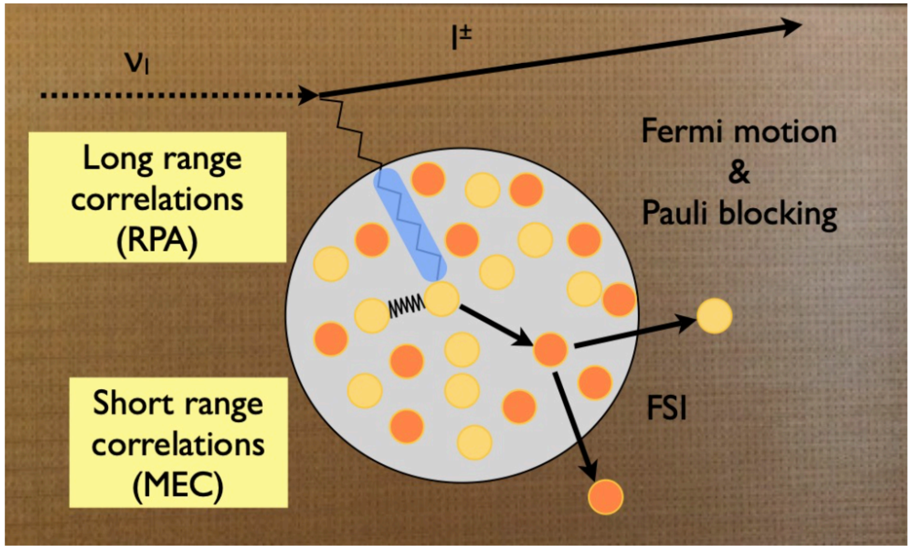




Huge effort from INFN-Bari in the realization of multi-PMT:

- Comsol mechanical simulation
- Cover design
- Material studies

Number of events (example)

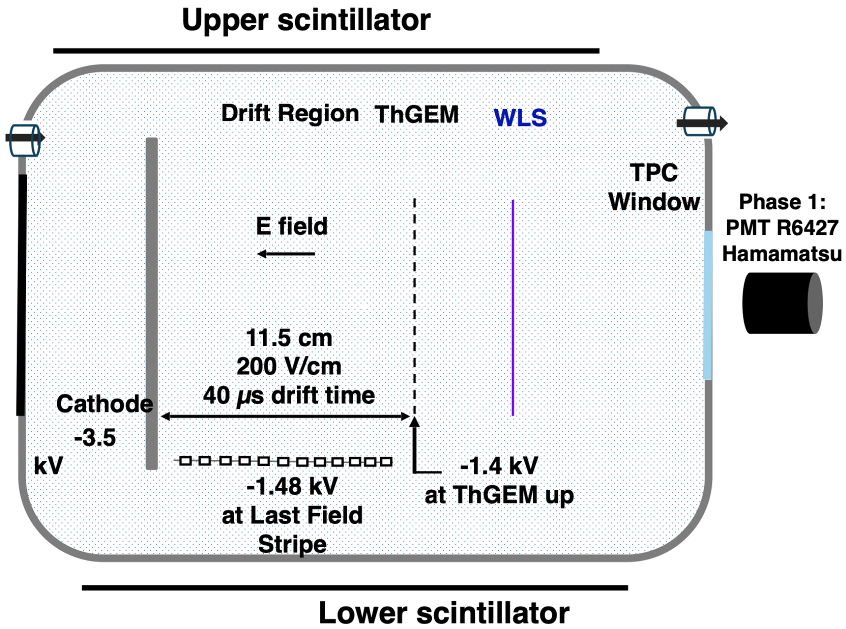


2x2x2 m^3 20°C	5 bars	10 bars
He	6.65 kg	13.3 kg
	520 evt/10^{21}pot	1040 evt/10^{21}pot
Ne	32.5 kg	67.1 kg
	2543 evt/10^{21}pot	5086 evt/10^{21}pot
Ar	66.5 kg	133 kg
	5203 evt/10^{21}pot	10406 evt/10^{21}pot
CF_4	146.3 kg	293 kg
	11450 evt/10^{21}pot	22893 evt/10^{21}pot

- As a cross-section experiment, HP-TPC allows to change the nuclear target addressing nuclear uncertainties systematics.

Scheme of $2 \times 2 \times 2\ m^3$ HP-TPC @UniGe with optical readout

- Primary ionisations in the drift region are guided to the amplification region by emectric field
- Amplification produces electron and photons
- Cameras image the amplification region and record a 2D projection of the electroluminescence photon
- Highly segmented readout $(100 \times 100\ \mu m^2)$ at low cost per pixel possible

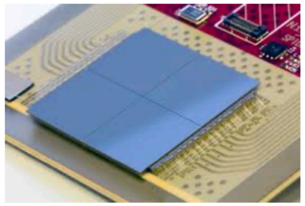


Readout ideas

Current CCD cameras do not allow to access the longitudinal coordinate due to their slow readout speed

The goal is to combine optical and charge readout ➔Full 3D tracking information (since the longitudinal coordinate can be reconstructed from charge signals) ➔ (TimePix or SIPM array)

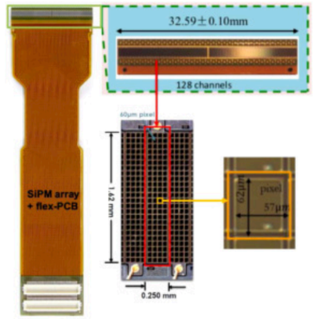
TimePix4



- Direct replacement of SiMP array
- High granularity
- Fast readout
- Excellent time resolution.
- Easy commercial access.
- Works with optics.
- Requires γ —> e^- conversion.

COMMON TECHNIQUE IN THE FIELD

sPAD



- High granularity, single photon.
- Fast readout —> digital.
- Excellent time resolution.
- Easy commercial access (Hamamatsu)
- Placed in front of PEN does not require optics —> Improve resolution.

NEW CONCEPT TO EXPLORE.

Sensitive to VUV?