ND280 upgrade design and resistive Micromegas

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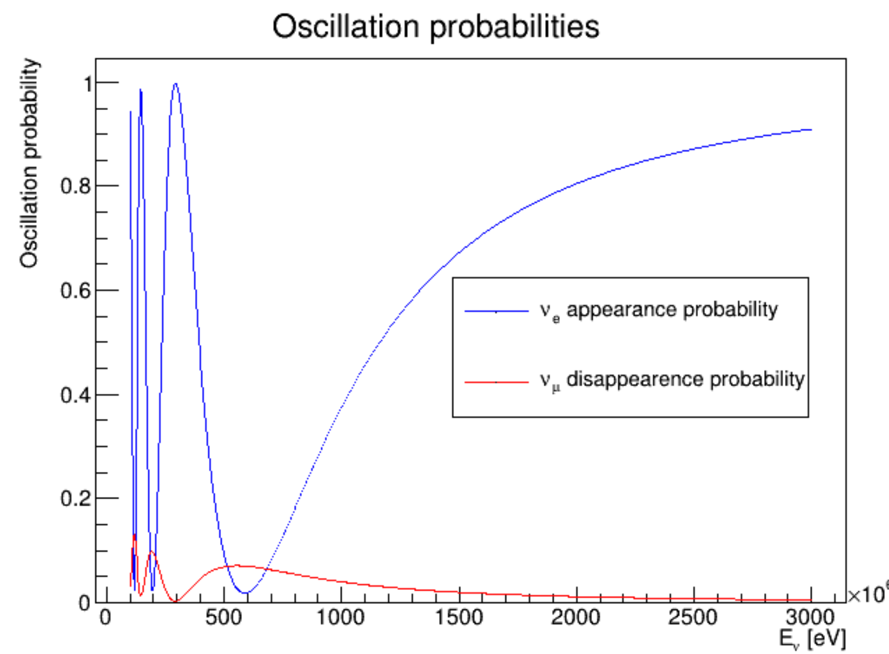
Outline

- A bit of context
- T2K: ND280 10 years ago
- Future T2K: How to overcome actual limitations?
- Focus on High-Angle TPC

Why studying neutrinos?

- In flavour physics, neutrino sector remains the less constraint one. With many open-questions that may be linked to Standard Model limitations
  - Neutrino mass origin, mass hierarchy, CP-violation, sterile neutrino…
- Most of those measurements could be performed by studying neutrino oscillation:
  - Mechanism describing the flavour evolution of neutrino as function of their energy and distance propagation: $P_{\nu_\alpha \to \nu_\beta}(L, E)$
- Depends on:
  - Three mixing angles driving oscillation amplitudes
  - Two (3) Mass-squared differences driving oscillation frequencies
  - One CP-violation phase.

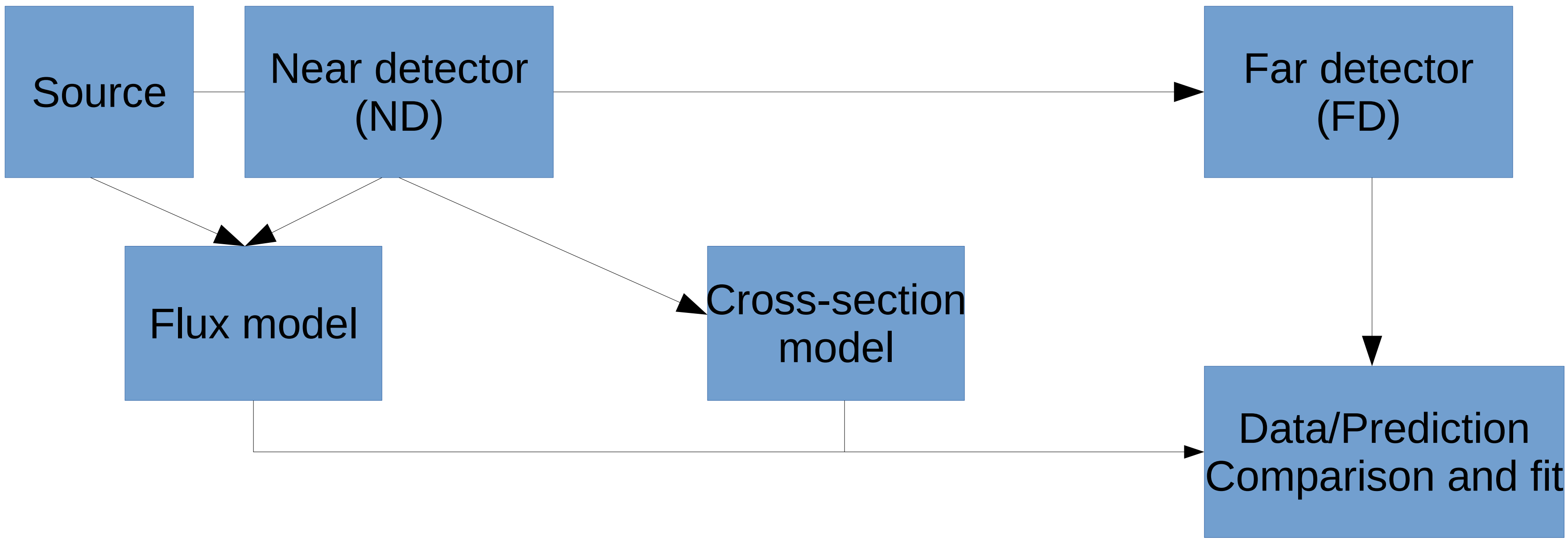


Muonic neutrino oscillation probability for T2K (295 km)

A lot of parameters to constraint!

Oscillation analysis strategy

- Measurement of neutrino oscillation implies to compare measurement before and after oscillation
  - Using prediction to know how many neutrinos are produced
  - Using a measurement before neutrinos start to oscillation
  - And ideally using both approaches!



Near detector measurement is fundamental!

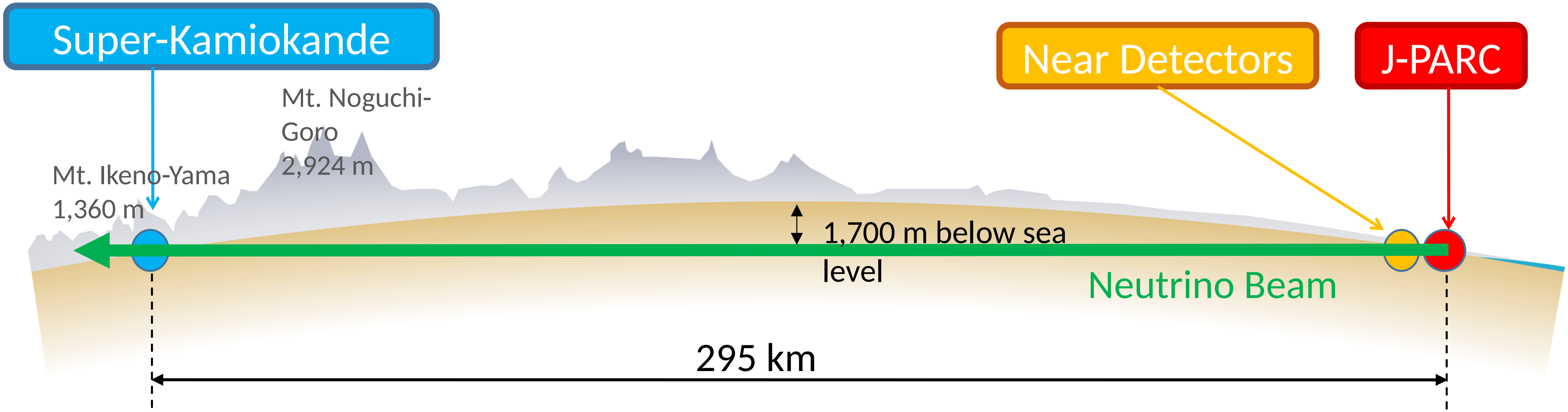
Oscillation analysis strategy

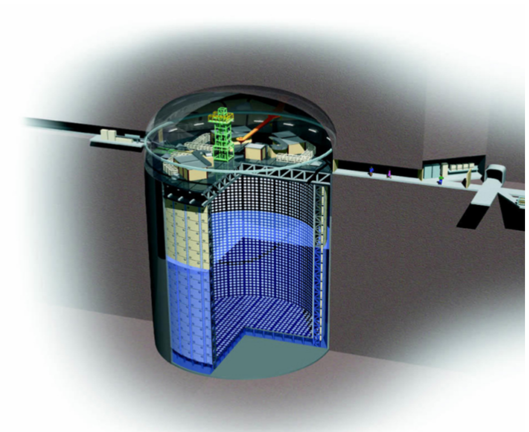
- Since oscillation discovery, a worldwide effort has been put on the measurement of all parameters

Experiments	Dominant	Important
Solar experiments	θ_{12}	$\Delta m^2_{21}, \theta_{13}$
Reactor LBL	Δm^2_{21}	θ_{12}, θ_{13}
Reactor MBL	$\theta_{13}, \lvert\Delta m^2_{31,32}\rvert$	
Atmospheric		$\theta_{23}, \lvert\Delta m^2_{31,32}\rvert, \theta_{13}, \delta_{CP}$
Accelerator LBL	$\theta_{23}, \lvert\Delta m^2_{31,32}\rvert, \delta_{CP}$	θ_{13}

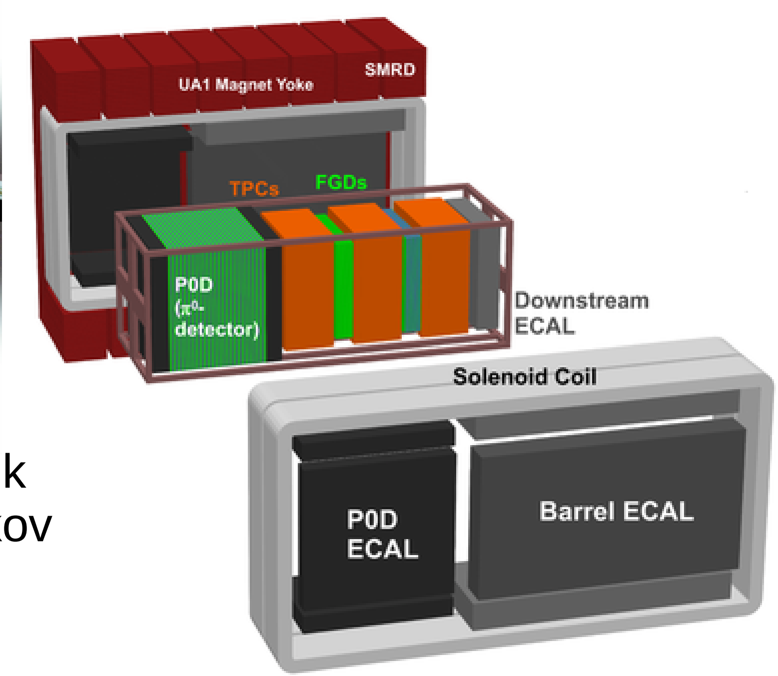
- Neutrino oscillation field is now entering in the precision era thanks to T2K, NovA..
  - Fundamental to measure the others: like CP-violation phase
- As long-baseline accelerator based experiments are the most sensible to CP, important projects have been developed: DUNE, HK.
  - **ND280 upgrade is born in this context**

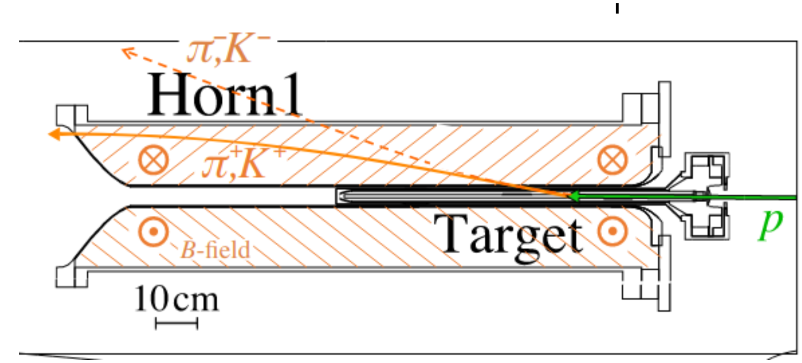
T2K: Tokai to Kamioka





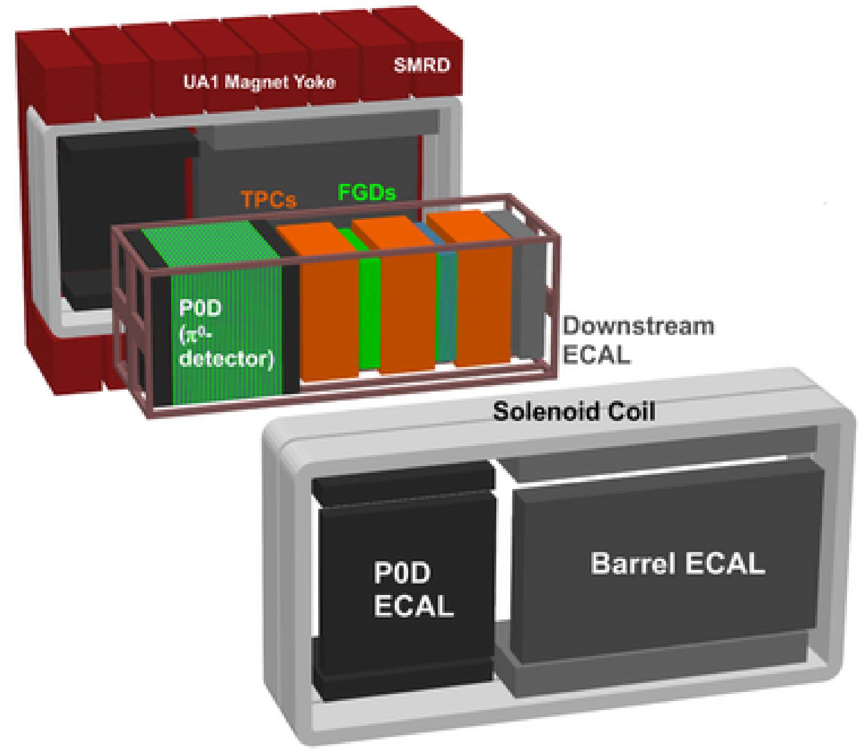
- Large pure water tank
- Reading out cherenkov light with PMTs





- Proton of 30 GeV on graphite target
- Producing pions, kaons decaying into (anti) neutrinos

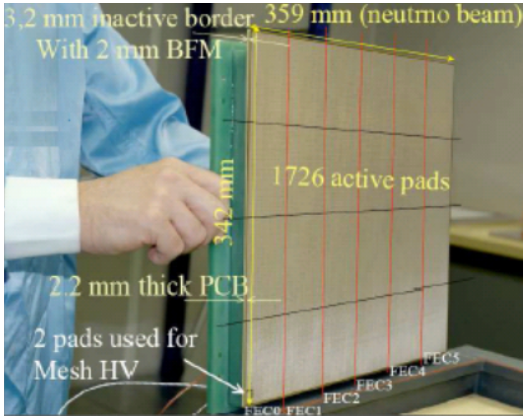
ND280 design

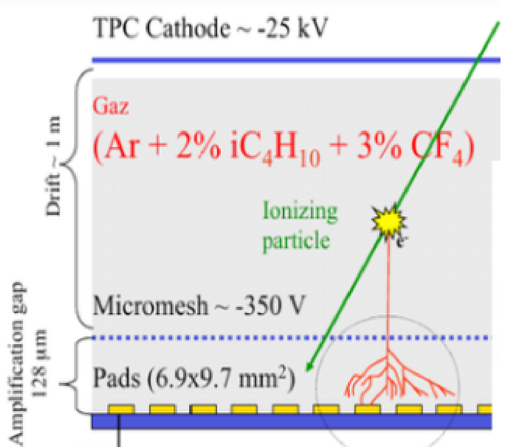


- Goals: measure beam spectrum and flavor composition before oscillations
  - Constraint Flux and X-section models
  - Need to measure both leptonic and hadronic (low efficiency → was not designed for) part of nu interactions
- Design:
  - **FGD:** 2 Fined grained detectors composed of plastic scintillator with layers of waters
    - Nu-target + precise determination of primary vertex
  - **TPC:** 3 Time Projected Chamber based on Micromegas technology
    - Momentum and charge particle measurements + PID
  - **P0D:** Upstream detector opimised for neutral pion detection
  - All detectors are surrounded by an electromagnetic calorimeter and a 0.2T magnet

ND280 TPCs

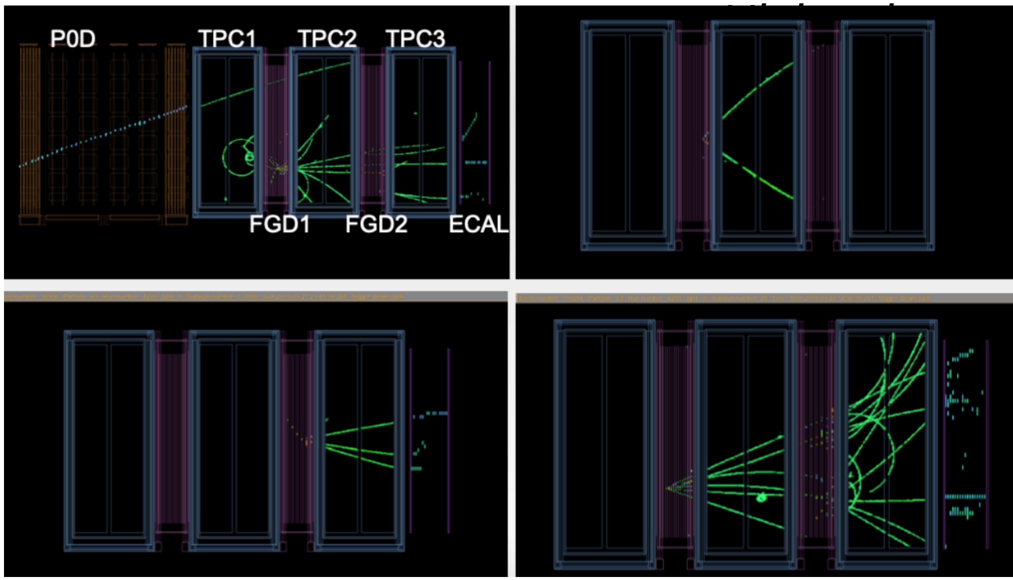
- Requirements:
  - Resolution on momentum better than 10% at 1GeV → Implies a spatial resolution better than 700um
  - dE/dx resolution better than 10% to measure nue beam contamination
- Details:
  - Total active area 9m2
  - Gas mixture Ar(95)/CF4(3)/iC4H10(2)
  - Electronics: 120k channels to readout
    - 6 front-end + 1 mezzanine for each module
- Operated since 2009 with no observation of performance degradation!



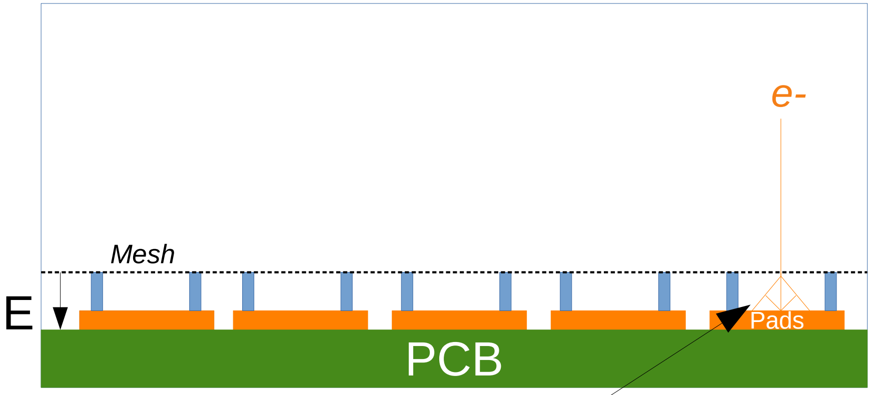


TPC with MicroMegas

- Time projected Chamber:
  - Charged particles ionise gas molecules producing free electrons
  - Application of an intense electric field to drift electrons to readout planes
  - 3D reconstruction 2D on readout planes + 1D with drift time



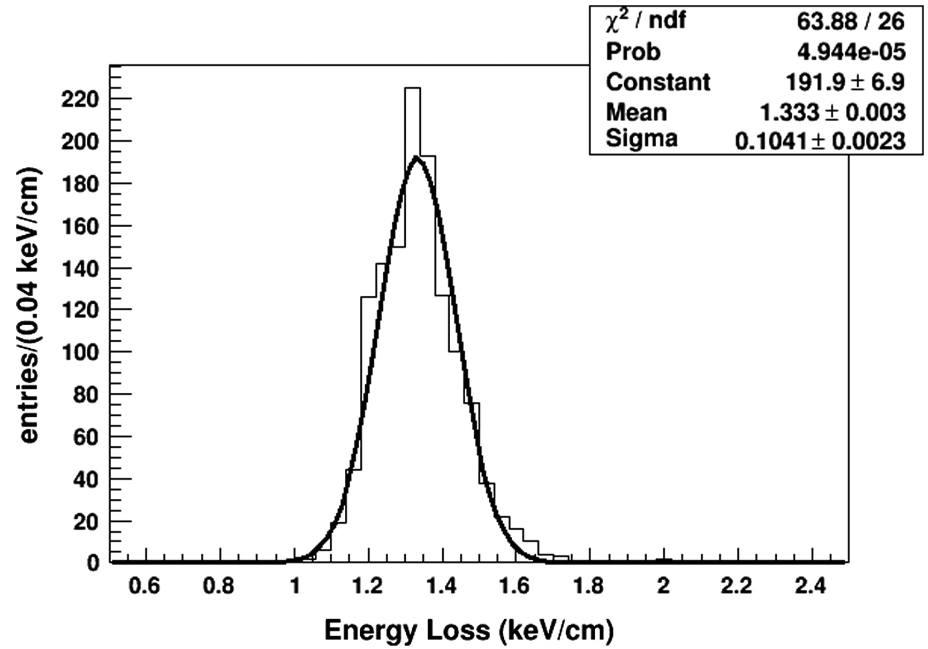
- Micromegas as readout system:
  - Few um above readout plane a mesh supported by pillars apply a strong electric field
  - When free electrons reach the **mesh**, an avalanche is created
    - Amplification gap – Gain: 10^3-10^4
  - Charges are collected thanks to pads



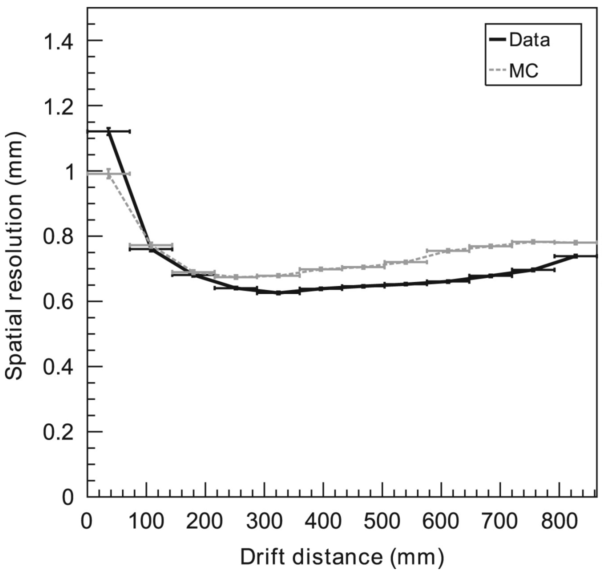
ND280 TPCs

➢ <u>Performances:</u>

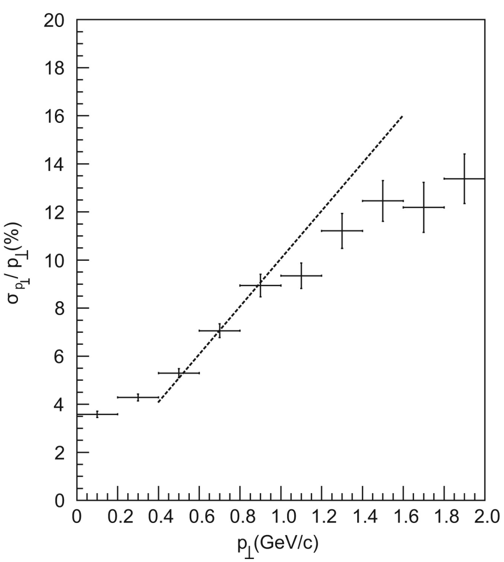
- ➢ Spatial resolution better than 700um
- ➢ dE/dx resolution better than 10% to measure nue beam contamination



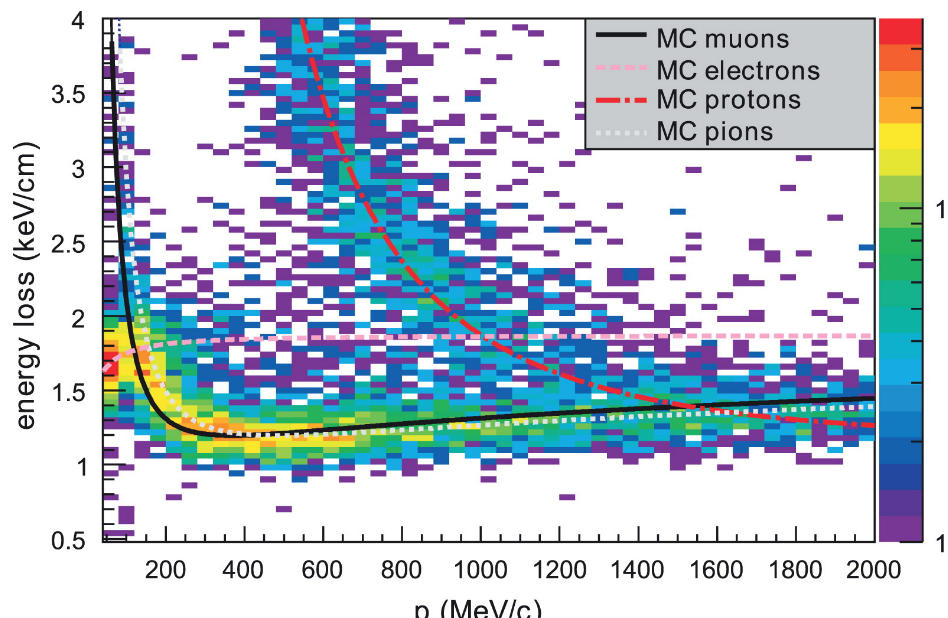
Spatial resolution



Momentum resolution



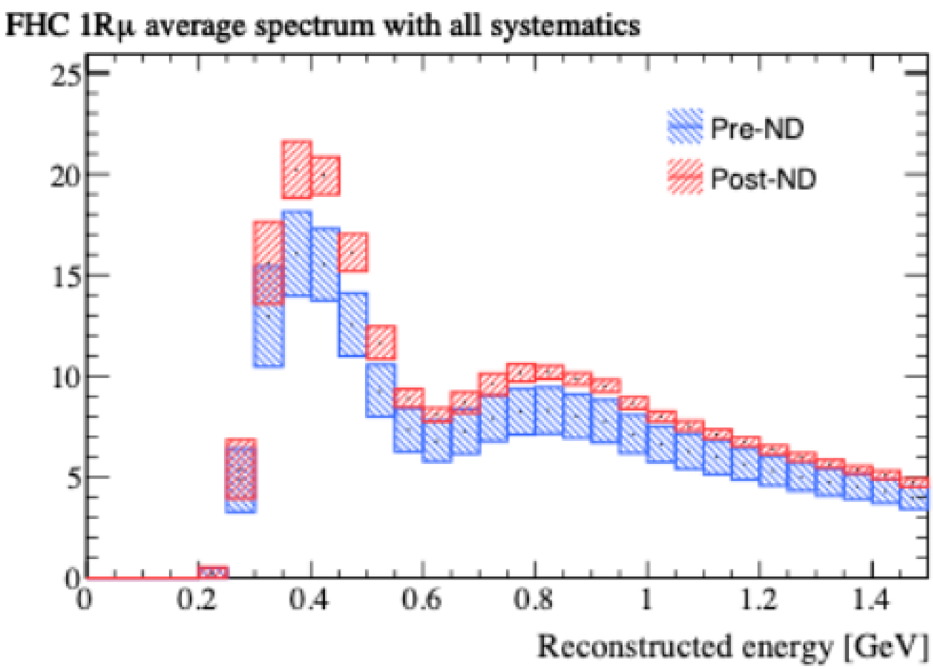
*dE/dx separation → **8%***

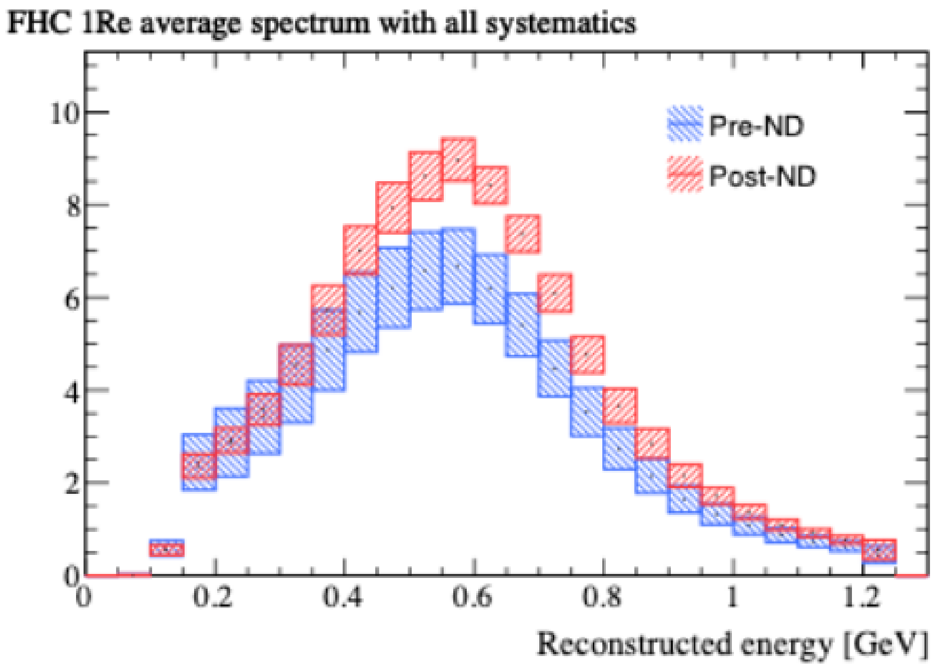


All requirements achieved!

Impacts on far detector analysis

- A lot of study are performed with the near detector allowing to better constraint far detector analysis:
  - Clear impact on FD rate and shape neutrino events





Future T2K

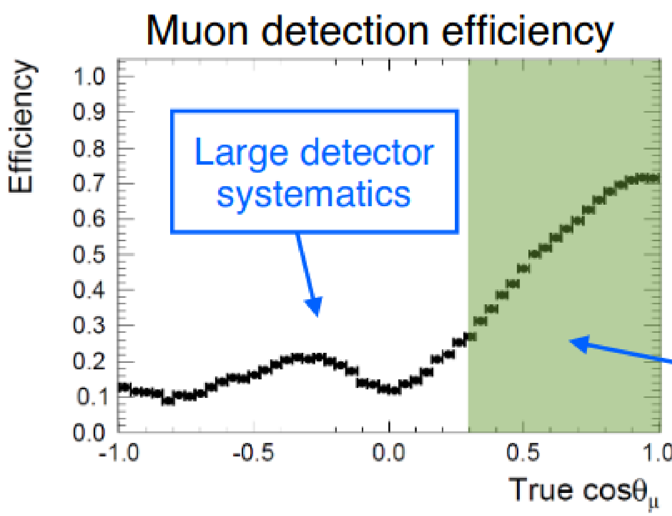
- T2K provided leading measurement of oscillation PMNS but analysis is still dominated by statistical uncertainties
  - Upgrade of the beam ongoing!
  - Hyper Kamiokande ongoing!

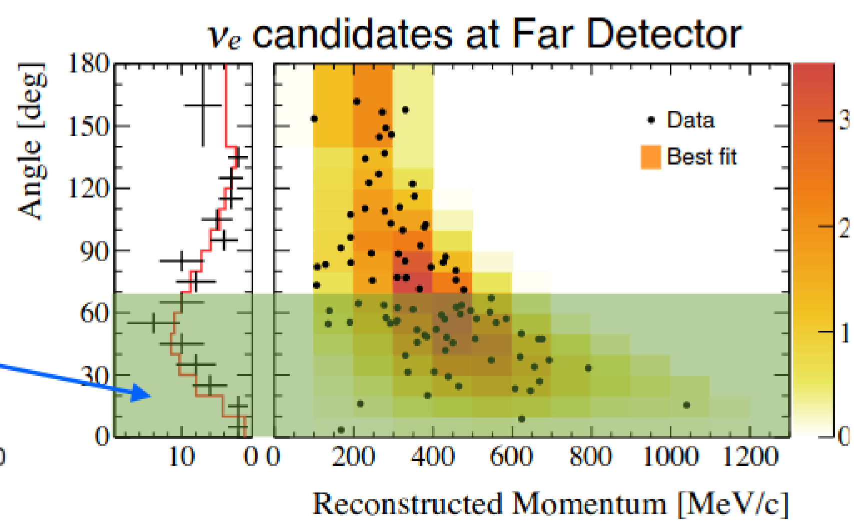
- Systematic will become important, requires more detailed studies to constraint them
  - Upgrade of the Near detector!

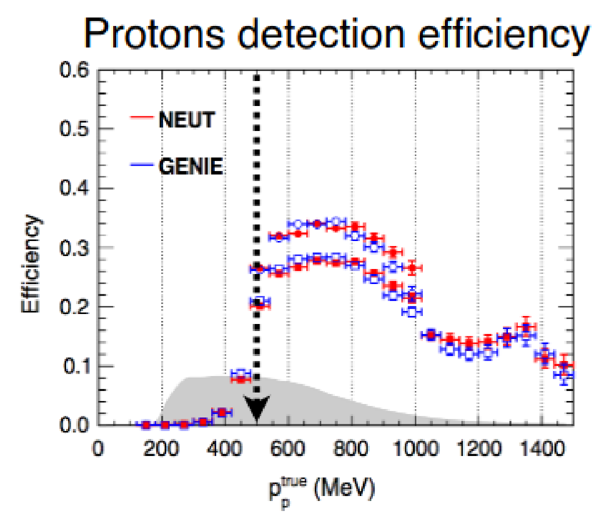
- Goals:
  - CP-violation at 3 sigmas if equal to -pi/2 (5 sigmas with HK)
  - Error on theta23 below 1.7 for maximal mixing
  - Error on mass-squared difference 23 below ~1%

ND280 upgrade

- Limitations
  - Increase angular acceptance: SK (4pi) whereas ND280 mostly forward
  - Better reconstruction efficiency of the hadronic component

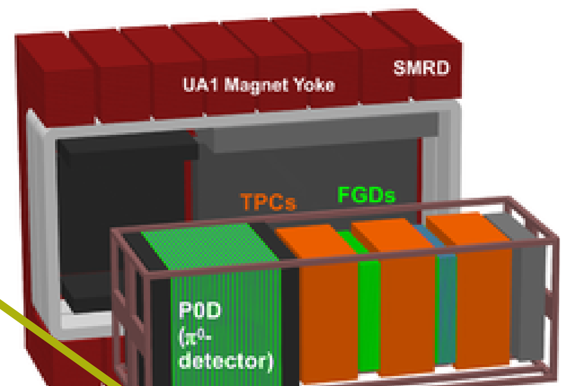


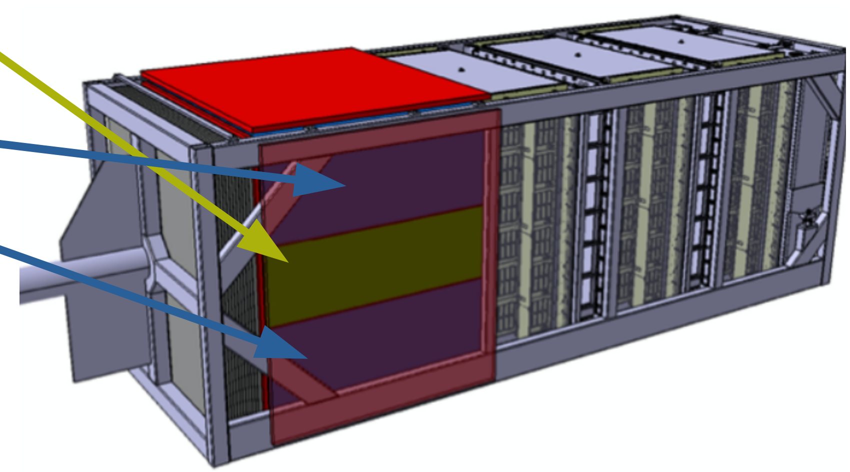




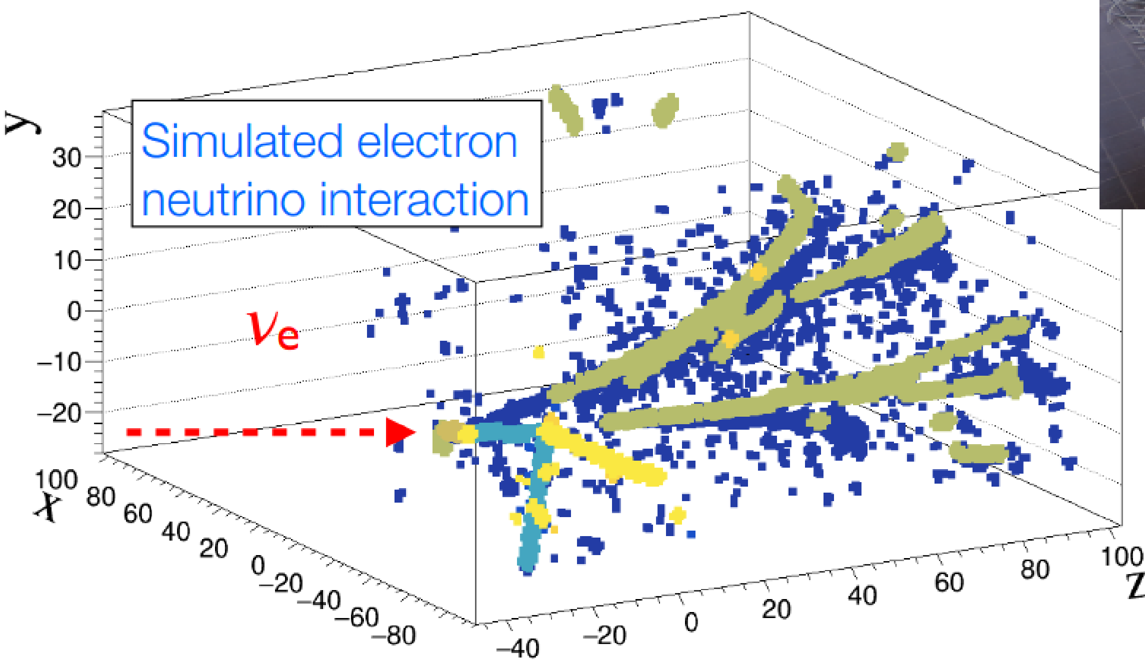
ND280 upgrade

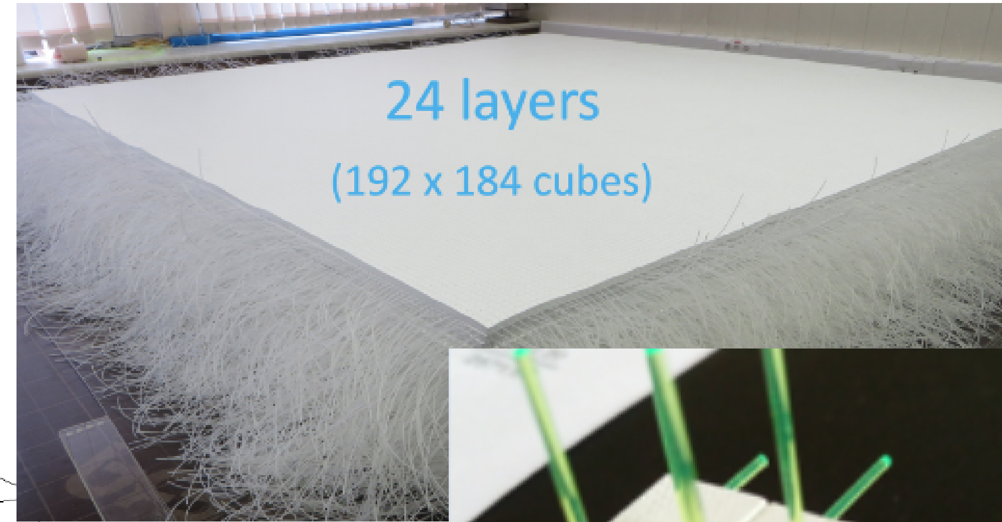
- <u>Limitations</u>
  - Increase angular acceptance: SK (4pi) whereas ND280 mostly forward
  - Better reconstruction efficiency of the hadronic component
- <u>Solutions</u>: Remove P0D detector and add a new target plus 2 new TPCs
  - **Super-FGD:** Highly segmented target of 2 millions scintillator cubes readout by a 3D network a WLS → Higher statistics, primary vertex position, reconstruction of outgoing hadrons
  - **HA-TPC:** High Angle TPC below and on the top of SFGD → improving angular acceptance
  - **TOF:** The whole is surrounded by plastic scintillator planes to tag outside background.

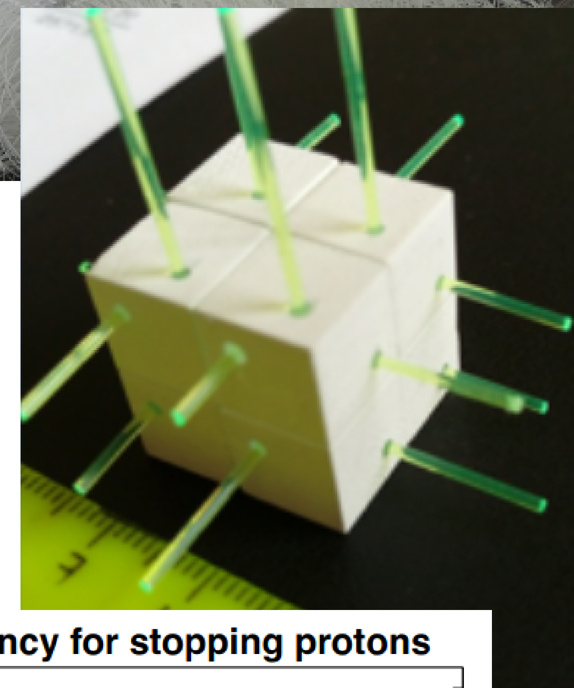


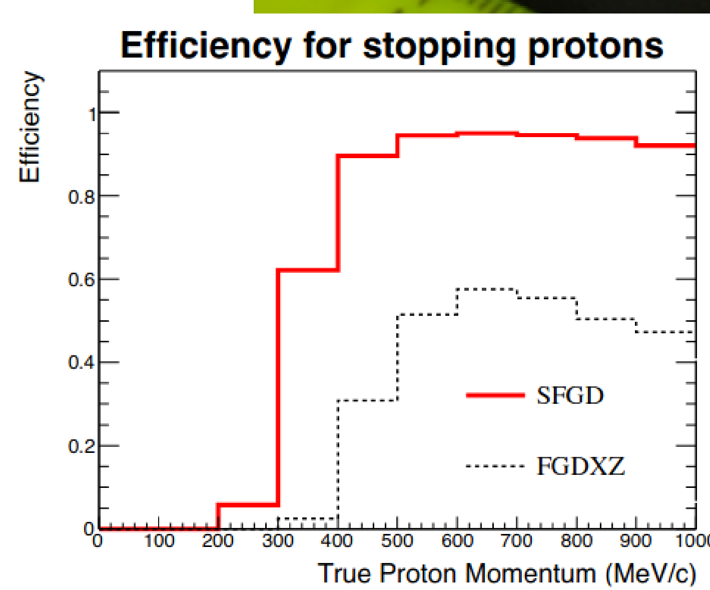


Super-FGD







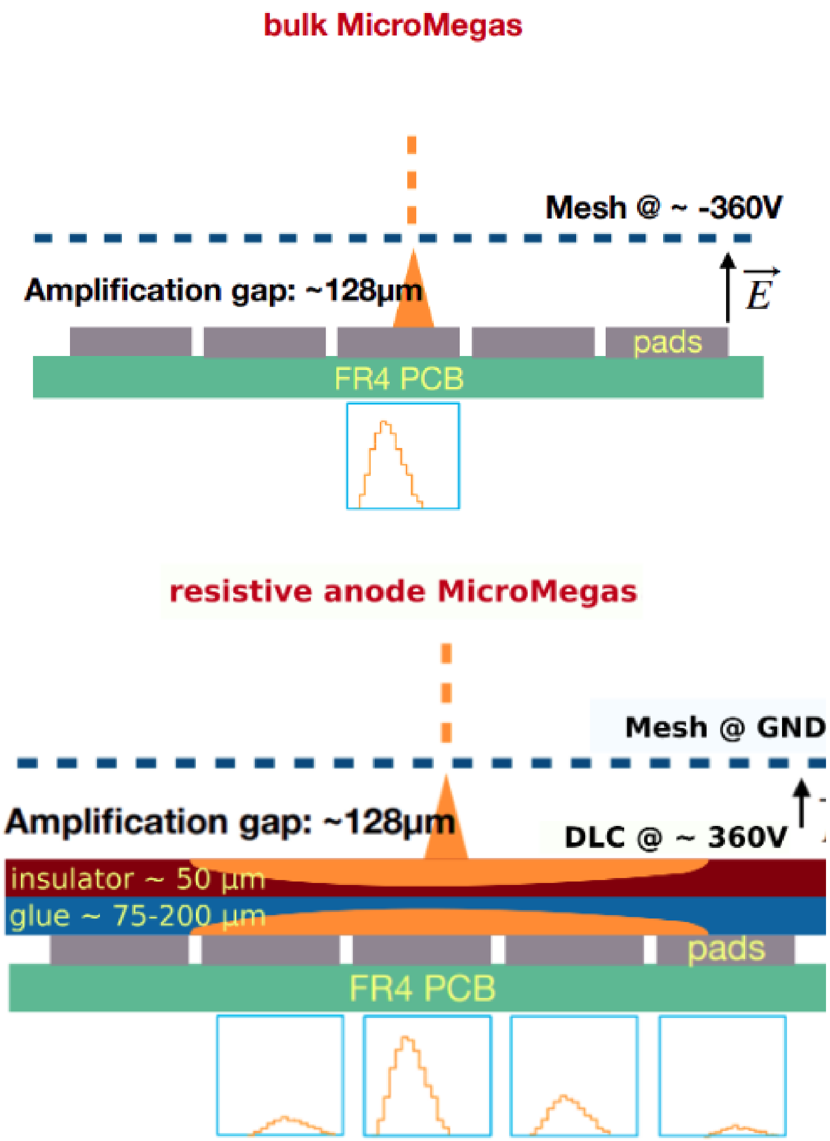


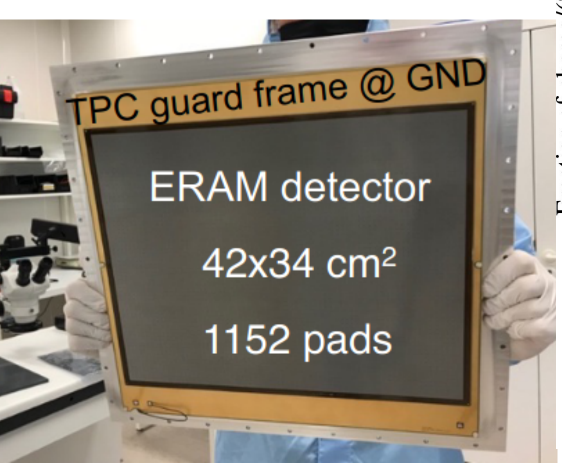
- Polystirene-based plastic scintillator
- Cube of 1cm side: High granularity!
- Allow to reconstruct proton down to 300 MeV/c (500 MeV/c previously)

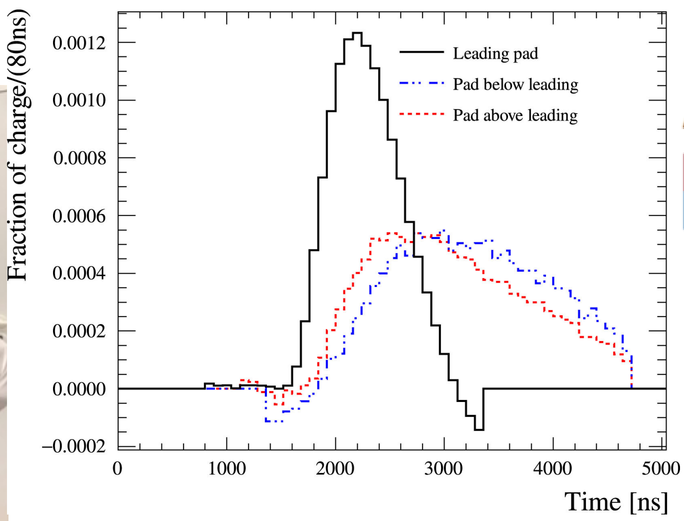
Will give crucial information on hadronic component!

Encapsulated Resistive MicroMegas

- Between pads and amplification gap add a resistive layer made of DLC (Diamond Like Carbon)
  - Allows charge spreading in X and Y as function of time depending on resistivity values
- Advantages:
  - Better resolution with less channels
  - Reduce risk of sparks
  - Mesh at ground allowing better electrical field uniformity







Prototype and test beam

Intensive detector characterisation w/ cosmic & beam test

- Define final design: Resistivity, glue thickness…

- R&D for ILC project
- First prototype tested with cosmics data at Saclay
- Test beam at CERN in 2018
- Second one tested during beam test at DESY in 2019
- DESY + CERN test beam in 2021
- Design fixed and production launched!



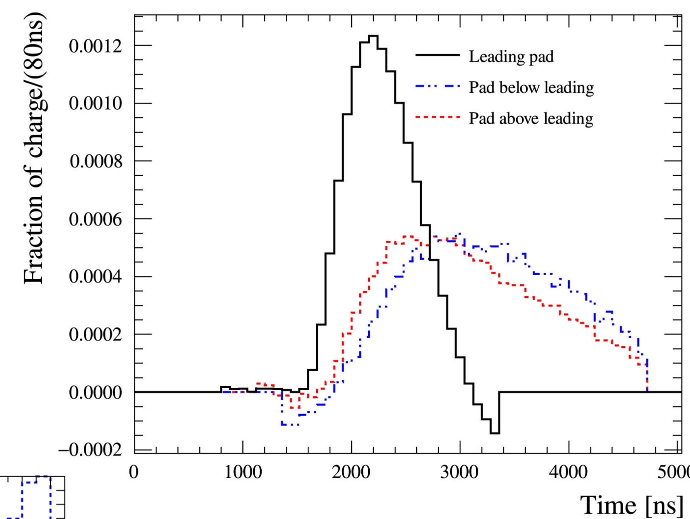
Track reconstruction with PRF

- Instead of using a center of charge method to determine track positions, use the Pad Response Function.
  - Neighbouring pad contributes to the event thanks to the charge spreading
- Take advantage of it by looking at ratios:

$$\frac{Q_{pad}}{Q_{ratio}} = PRF(x_{track} - x_{pad})$$

- This function could be parametrised and used in a chi-square to find positions:

$$\chi^2 = \sum_{pads} \frac{\frac{Q_{pad}}{Q_{cluster}} - PRF(x_{track} - x_{pad})}{\sigma}$$



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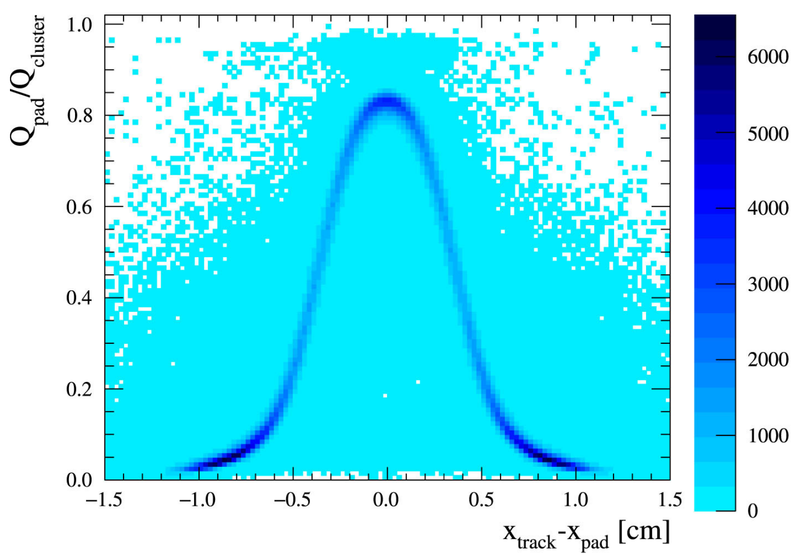
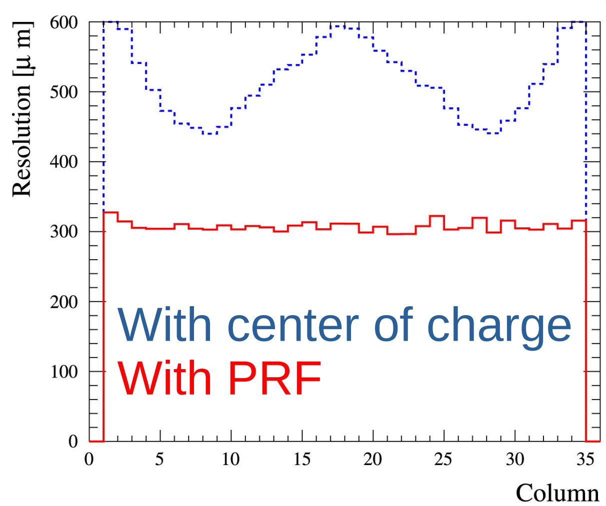


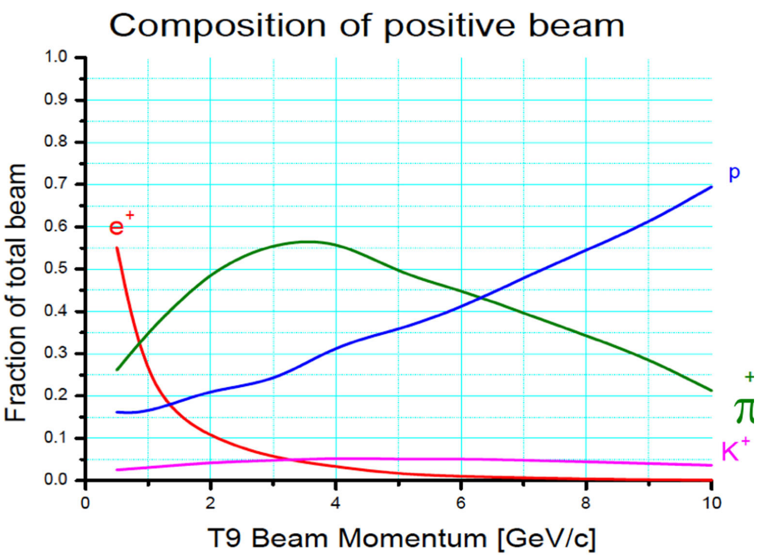


a)

Great spatial resolution even w/ 33% less pads

dE/dx resolution

- dE/dx resolution determine the ability to identify the type of particles
- The previous TPCs allow to reach a resolution better than 10%
- Test beam allows to test it since the beam is composed of several particles
- Find a resolution **better than 10%** for e- and proton, expected to be <7% if two modules are crossed



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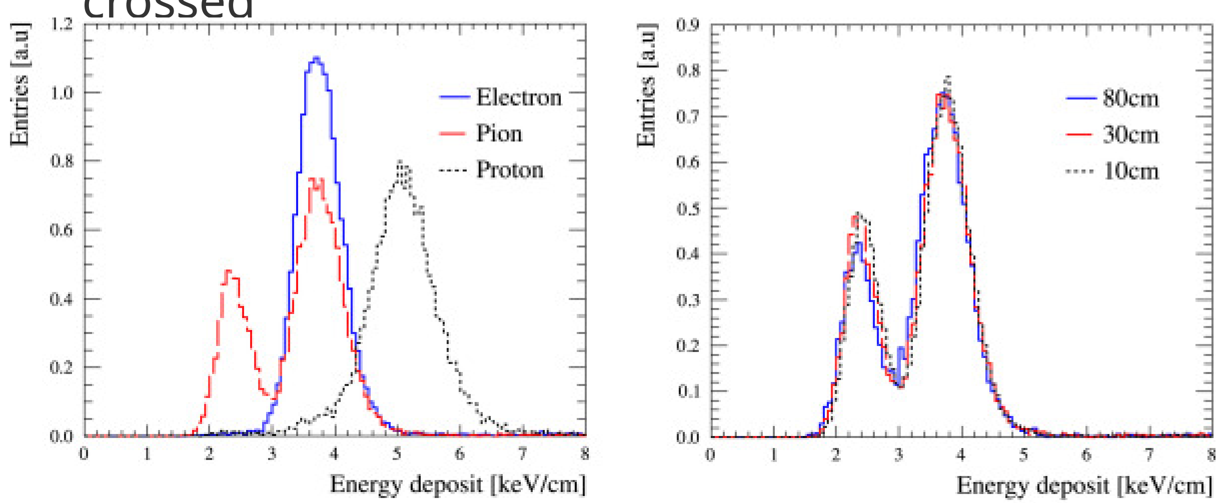
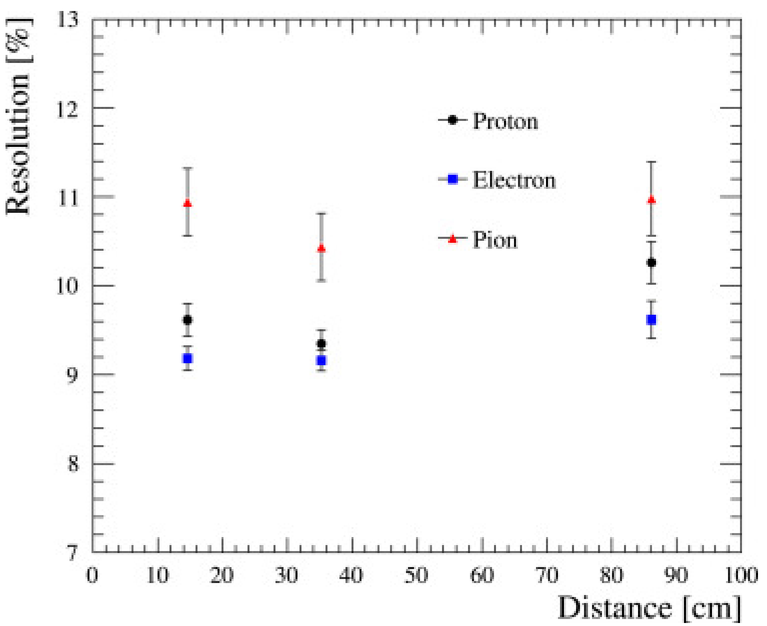
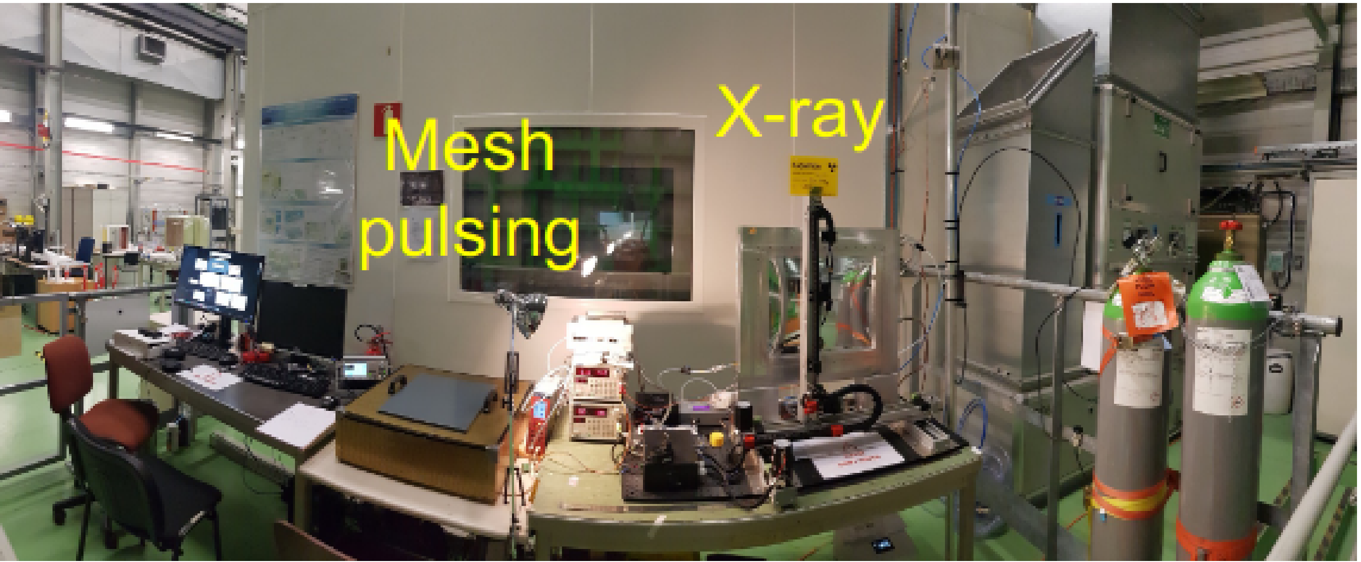


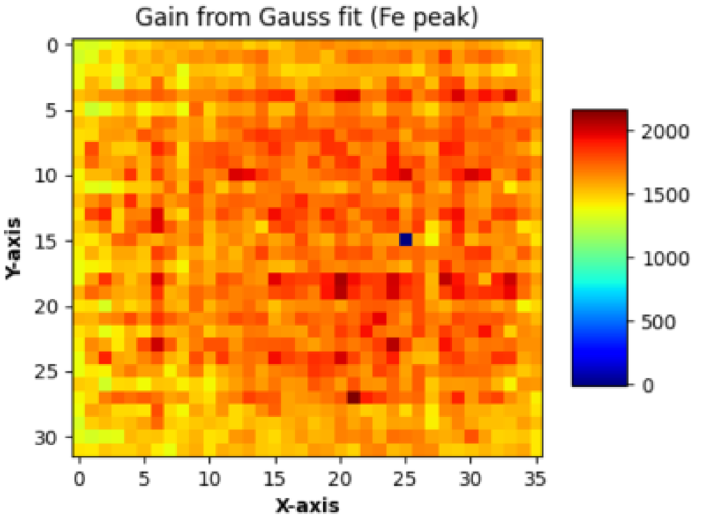
(a) (b)



Production and quality control

- Production of all ERAM modules ongoing
- Systematic characterization of detector response and electronic:
  - Mesh pulsing to test electrical response of detector
  - X-ray scan of the whole detector to extract gain and resolution
  - Thanks to a X-ray test bench @ CERN controlled remotely: 1 module fully scanned per week!





Conclusion

- T2K has produced high quality date since 10 years and is leading measurement of some oscillations parameters
  - This performance is possible thanks to a near detector allowing to better constrain far detector flux and interaction models
- With beam upgrade and Hyper Kamiokande systematic uncertainties will become the limitations
- The ND280 upgrade has been designed to answer to those limitations
  - With the new High-Angle TPCs and the usage of resistive micromegas the angular acceptance will increase
  - The ERAM modules have beeb characterized thanks to several prototypes and test beam campaign.
    - Performance requirements are reached even with less channels thanks to the resistive layer and charge spreading.
- Final design has been optimized and currently the production and characterization is ongoing. *Stay tuned for physics results in the near future!*