T2K phase I

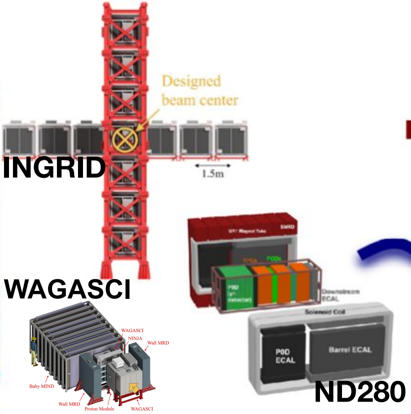
Margherita Buizza Avanzini,

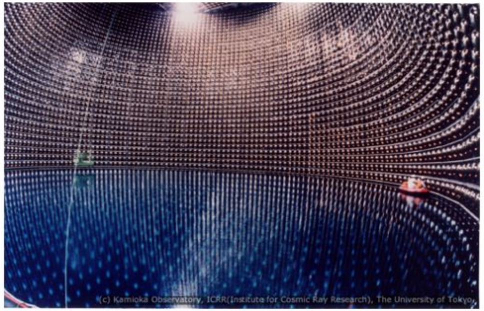
for the ILANCE, LPNHE and LLR Neutrino groups

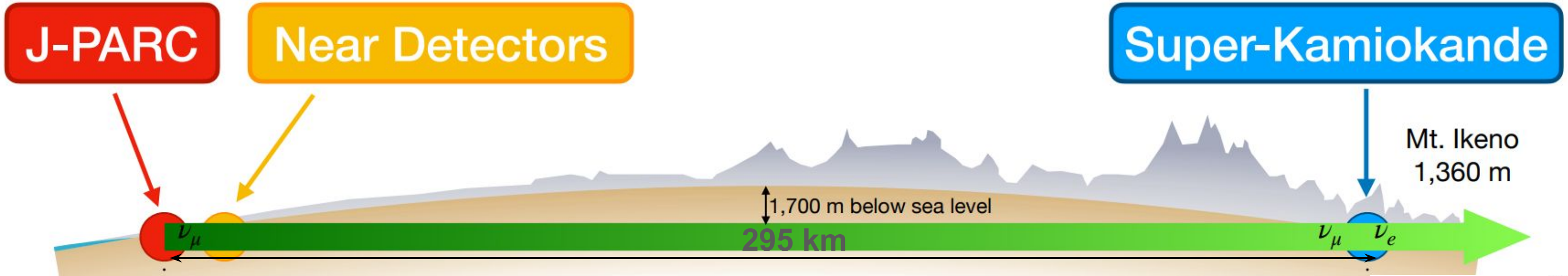
IN2P3 Physics Council

Oct. 26th 2021

The T2K experiment



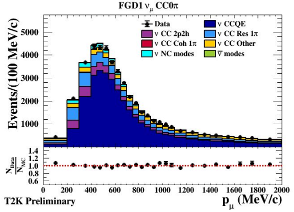


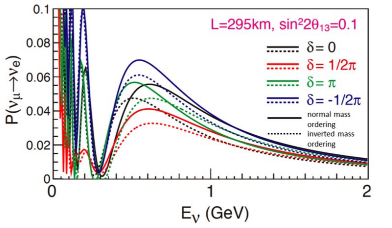


Tokai

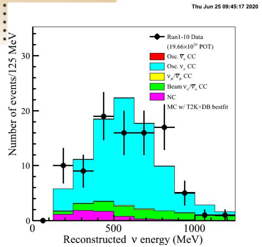
Kamioka

ν_μ beam

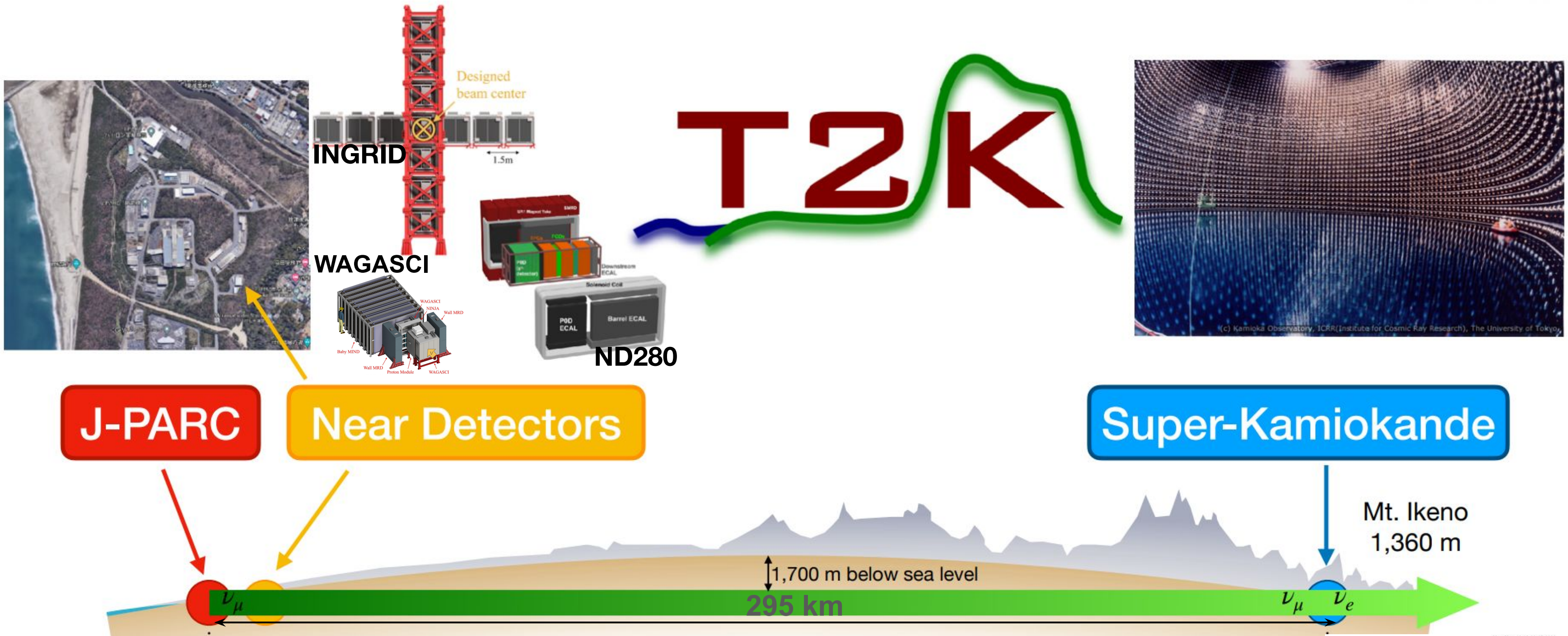




ν_e appearance



The T2K experiment



J-PARC

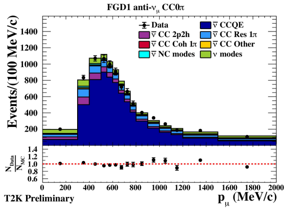
Near Detectors

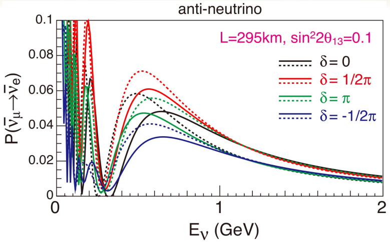
Super-Kamiokande

Tokai

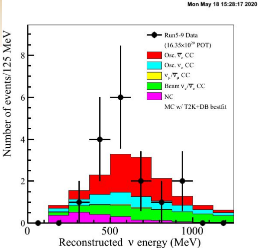
Kamioka

$\overline{\nu}_\mu$ beam





$\overline{\nu}_e$ appearance



The T2K milestones

IN2P3 joins T2K

T2K starts data taking

First anti-**ν** beam

IN2P3 joins ND280Up

WAGASCI /BM ready

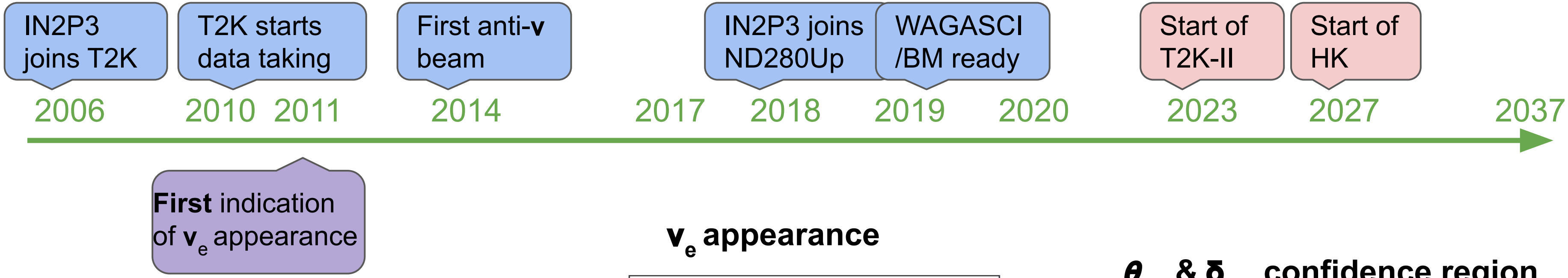
Start of T2K-II

Start of HK

2006 2010 2011 2014 2017 2018 2019 2020 2023 2027 2037

The T2K milestones

OA conveners from LPNHE (past) and LLR (present)


IN2P3 joins T2K
T2K starts data taking
First anti-**ν** beam
IN2P3 joins ND280Up
WAGASCI /BM ready
Start of T2K-II
Start of HK
First indication of **ν_e** appearance

Phys. Rev. Lett. 107, 041801 (2011)

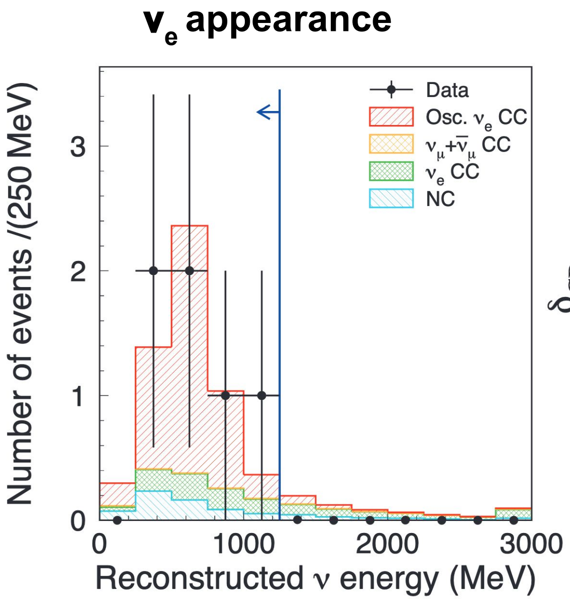
$1.43\ 10^{20}$ POT

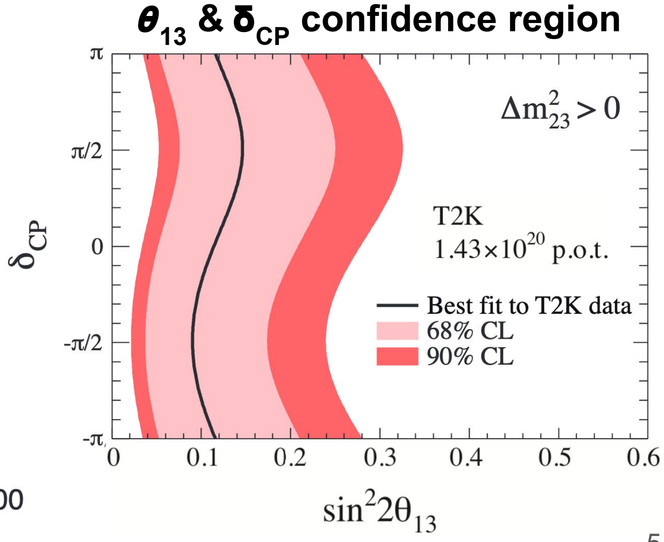
6 **ν_e** like events

$\theta_{13} \neq 0$ @ 2.5σ

First indication!

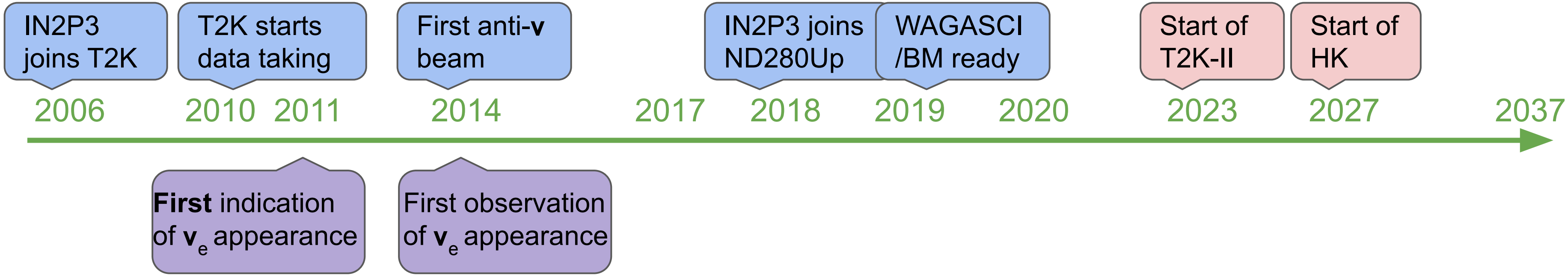
1,663 citations


ν_e appearance


θ_{13} & δ_{CP} confidence region

The T2K milestones

OA conveners from LPNHE (past) and LLR (present)



IN2P3 joins T2K — 2006

T2K starts data taking — 2010

First indication of ν_e appearance — 2011

First anti-**ν** beam — 2014

First observation of ν_e appearance — 2014

2017

IN2P3 joins ND280Up — 2018

WAGASCI /BM ready — 2019

2020

Start of T2K-II — 2023

Start of HK — 2027

2037

Phys. Rev. Lett. 112, 061802 (2014)

$6.57\ 10^{20}$ POT

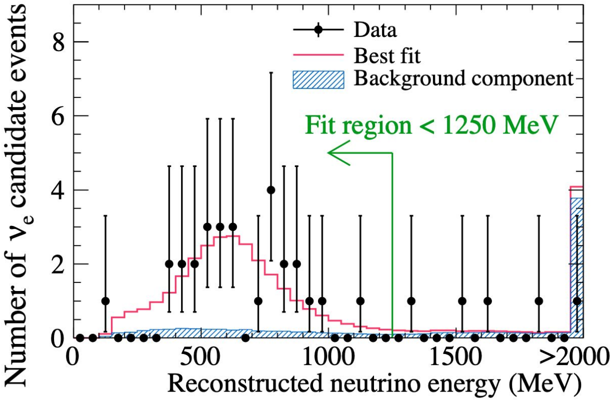
28 ν_e like events

$\theta_{13} \neq 0$ @ 7.3σ

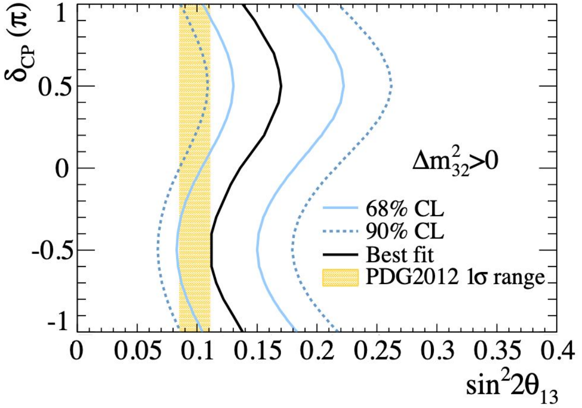
First observation!

BREAKTHROUGH PRIZE 2016
for ν_e appearance

ν_e appearance



θ_{13} & δ_{CP} confidence region



T2K was the only IN2P3 ν oscillation experiment awarded in this occasion

The T2K milestones

OA conveners from LPNHE (past) and LLR (present)

First indication of $\mathbf{\nu}_e$ appearance

First observation of $\mathbf{\nu}_e$ appearance

Precise measurement of Δm^2_{23} and $\sin^2\theta_{23}$

Phys. Rev. Lett. 112, 181801 (2014)

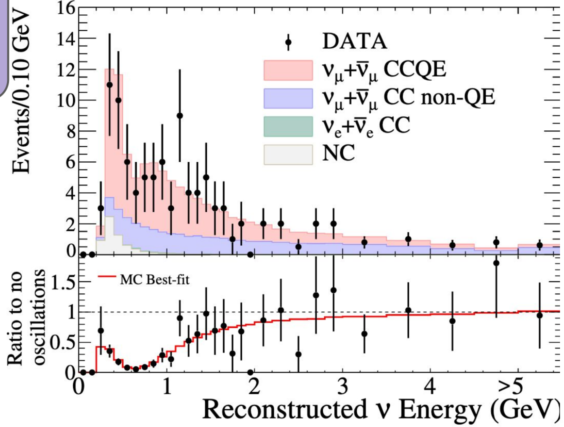
6.57 10^{20} POT

120 $\mathbf{\nu}_\mu$ -like events

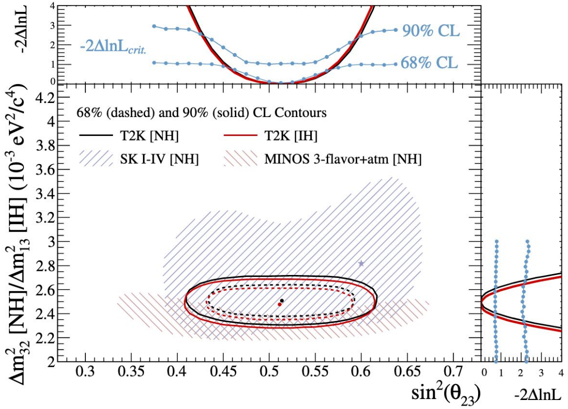
Δm^2_{23} = 2.51 ± 0.1 eV^2

$\sin^2\theta_{23}$ = 0.51 ± 0.55

ν_μ disappearance



θ_{23} & Δm^2_{23} confidence region



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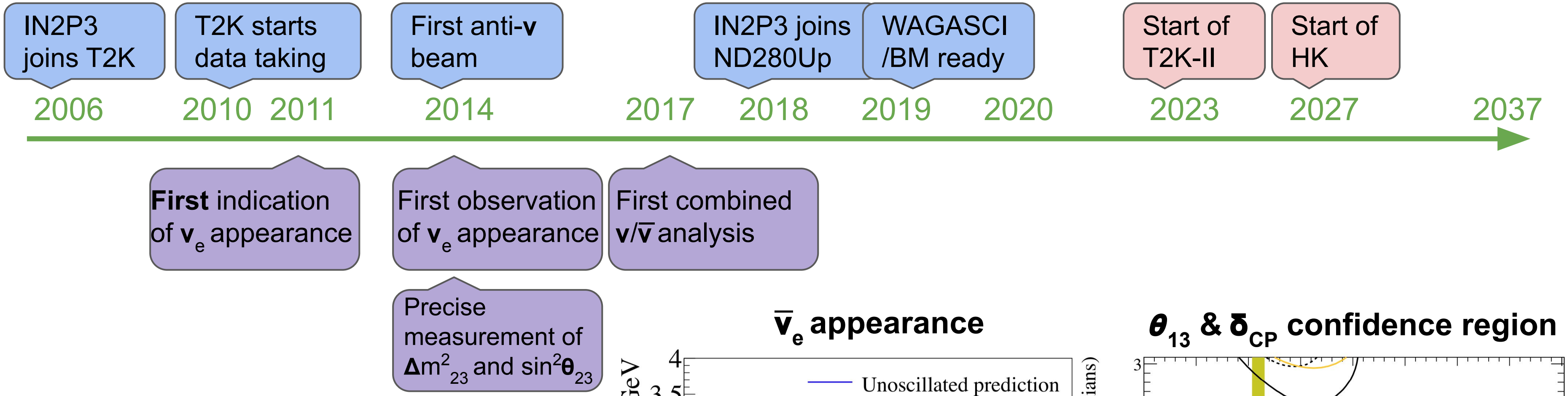


IN2P3 joins T2K

T2K starts data taking

First anti-ν beam

IN2P3 joins ND280Up

WAGASCI /BM ready

Start of T2K-II

Start of HK

2006 2010 2011 2014 2017 2018 2019 2020 2023 2027 2037

First indication of ν_e appearance

First observation of ν_e appearance

First combined $\nu/\bar{\nu}$ analysis

Precise measurement of Δm^2_{23} and $\sin^2\theta_{23}$

Phys. Rev. Lett. 118, 151801 (2017)

ν_μ mode: 7.48 10^{20} POT

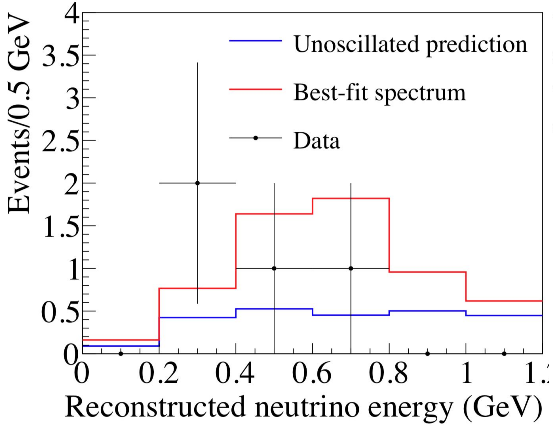
$\bar{\nu}_\mu$ mode: 7.47 10^{20} POT

32 ν_e -like events in ν_μ mode

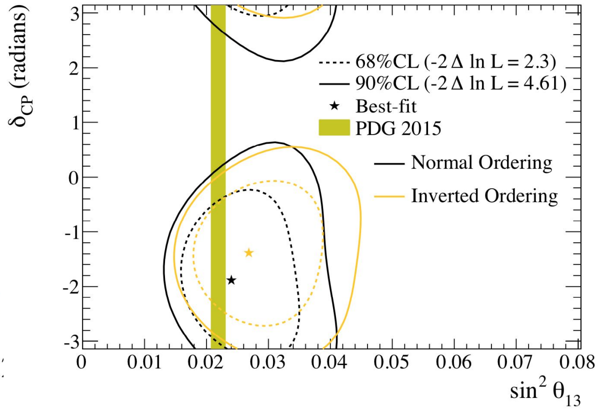
4 $\bar{\nu}_e$ -like events in $\bar{\nu}_\mu$ mode

δ_{CP} conservation excluded @90% CL

$\bar{\nu}_e$ appearance



θ_{13} & δ_{CP} confidence region



The T2K milestones

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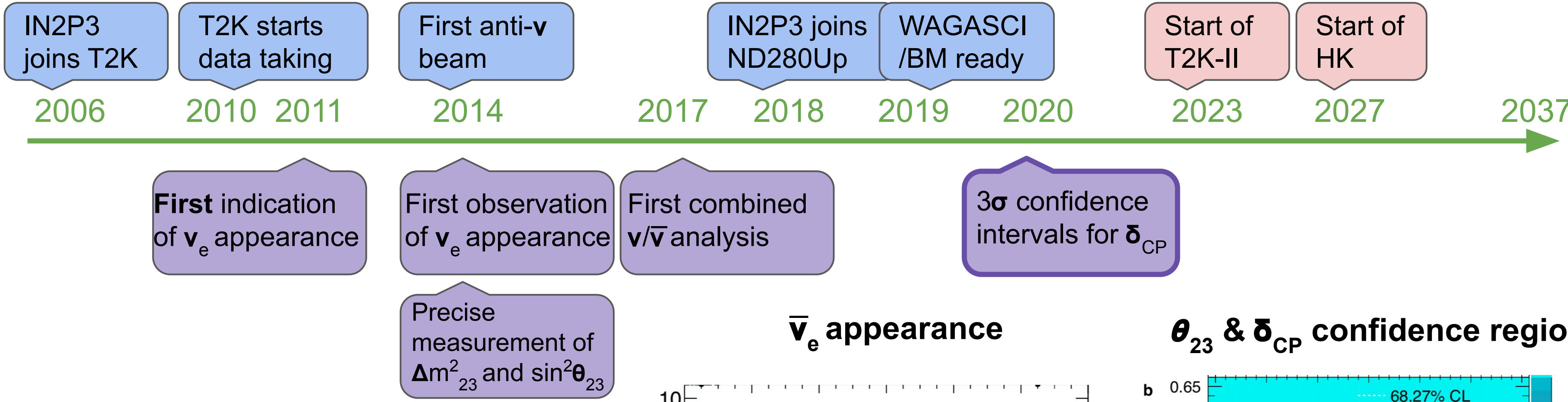

IN2P3 joins T2K

2006

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2011

First indication of ν_e appearance

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First observation of ν_e appearance

Precise measurement of Δm^2_{23} and $\sin^2\theta_{23}$

2017

First combined $\nu/\bar{\nu}$ analysis

IN2P3 joins ND280Up

2018

WAGASCI /BM ready

2019

2020

3σ confidence intervals for δ_{CP}

Start of T2K-II

2023

Start of HK

2027

2037

Nature 580, 339-344 (2020)

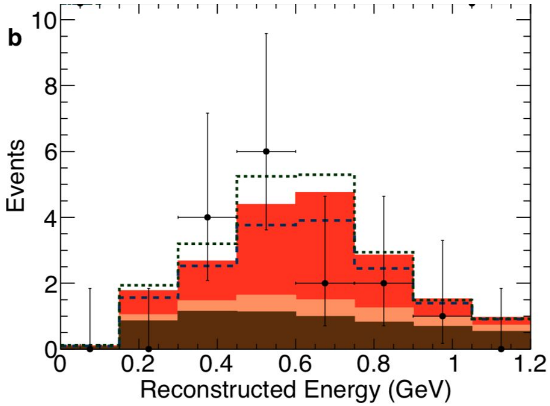
ν_μ mode: 1.49 10^{21} POT

$\bar{\nu}_\mu$ mode: 1.64 10^{21} POT

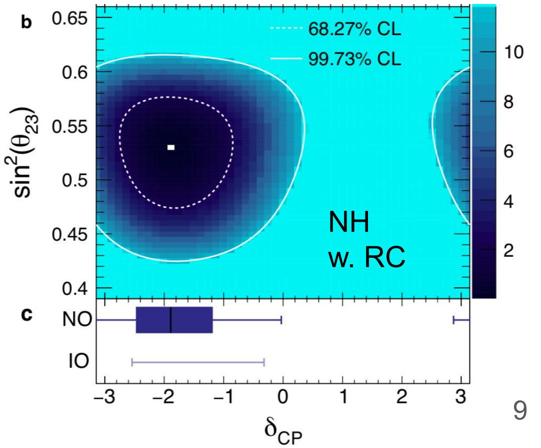
75+15 ν_e-like events in ν_μ mode

15 $\bar{\nu}_e$-like events in $\bar{\nu}_\mu$ mode

$\bar{\nu}_e$ appearance



θ_{23} & δ_{CP} confidence region



T2K on the cover of Nature

For the first time, 3σ intervals for δ_{CP}, conservation excluded at ~2σ

The international journal of science / 16 April 2020

nature

THE MIRROR CRACK'D

An indication of matter–antimatter symmetry violation in neutrinos

Coronavirus The models driving the global response to the pandemic

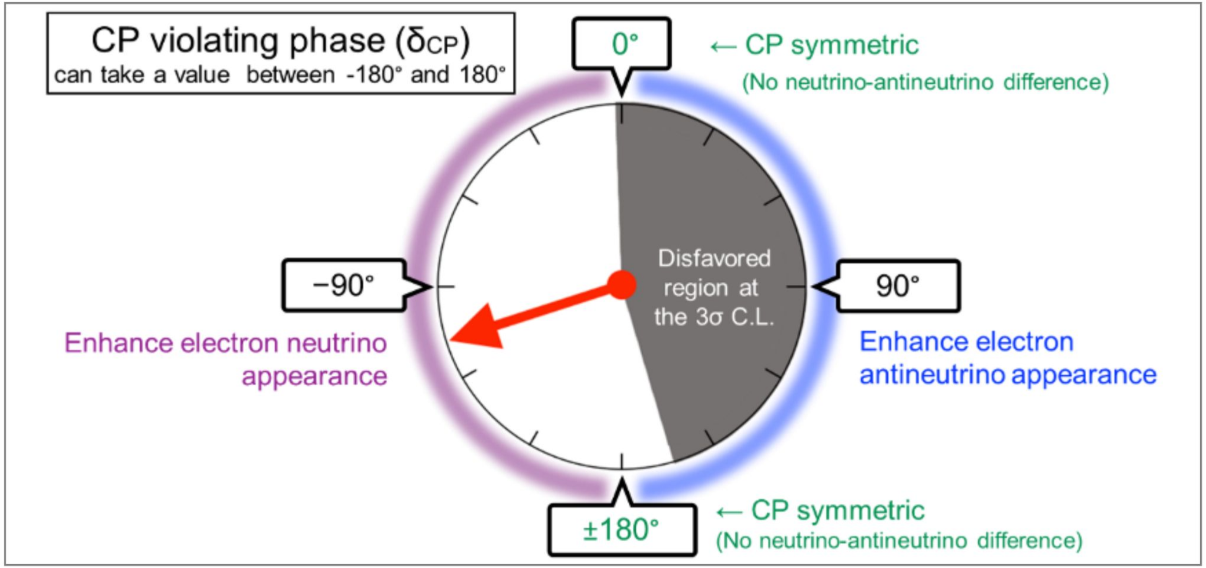
Hot source Remnants of primordial nitrogen in Earth's mantle

Origin of a species Revised age for Broken Hill skull adds twist to human evolution

Vol. 580 No. 7803 £10.00 nature.com

Nature, vol. 580, p. 339–344 (**2020**)

Hints toward a maximal CP violation!



CP violating phase (δ_{CP})
can take a value between -180° and 180°

0°

← CP symmetric
(No neutrino-antineutrino difference)

−90°

Enhance electron neutrino appearance

Disfavored region at the 3σ C.L.

90°

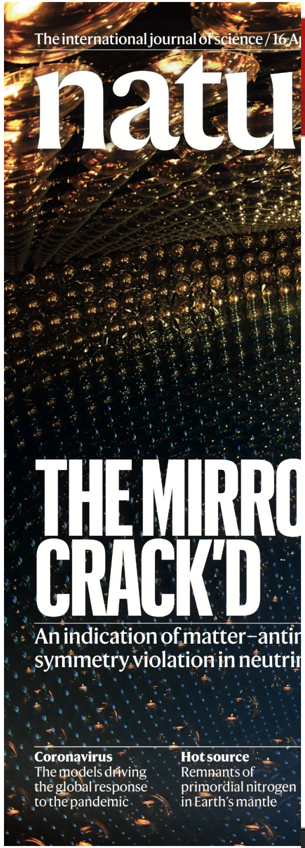
Enhance electron antineutrino appearance

±180°

← CP symmetric
(No neutrino-antineutrino difference)

T2K on the cover of Nature

For the first time, 3σ intervals for δ_{CP}, conservati



The international journal of science / 16 A

natu

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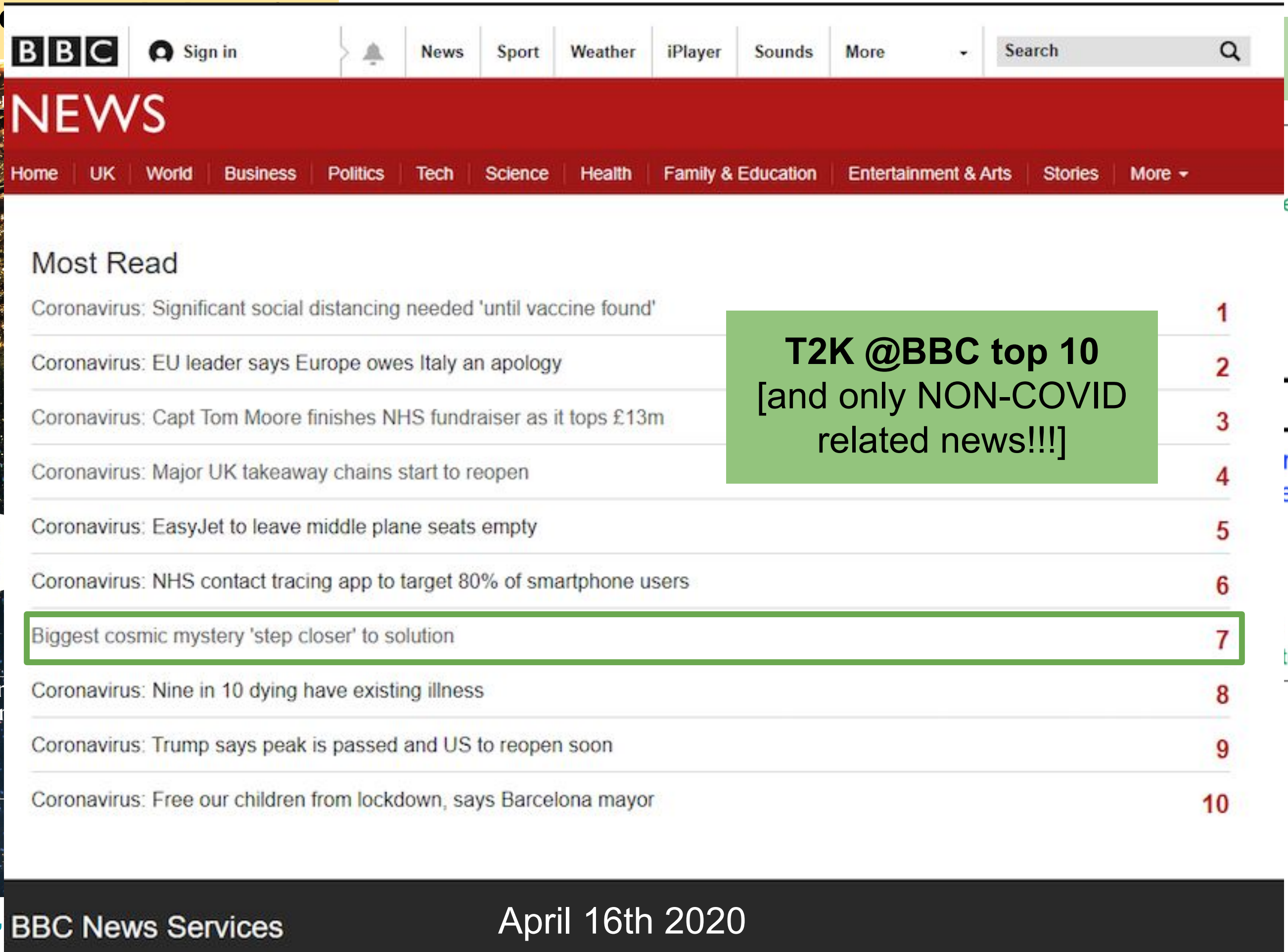

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Coronavirus: Nine in 10 dying have existing illness	8
Coronavirus: Trump says peak is passed and US to reopen soon	9
Coronavirus: Free our children from lockdown, says Barcelona mayor	10

T2K @BBC top 10
[and only NON-COVID related news!!!]

April 16th 2020

eutrino difference)

nce electron
eutrino appearance

trino difference)

The T2K milestones

OA conveners from LPNHE (past) and LLR (present)

- 2006: IN2P3 joins T2K
- 2010: T2K starts data taking
- 2011: First indication of ν_e appearance
- 2014: First anti-**ν** beam
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- 2017: First combined $\nu/\bar{\nu}$ analysis
- 2018: IN2P3 joins ND280Up
- 2019: WAGASCI /BM ready
- 2020: 3**σ** confidence intervals for δ_{CP}
- WE ARE HERE
- 2023: Start of T2K-II
- 2027: Start of HK
- 2037

T2K results @ Neutrino2020

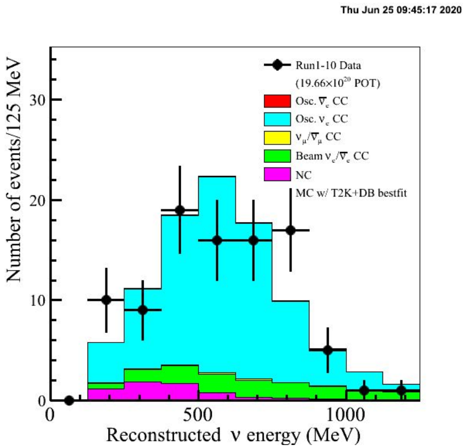
ν_μ mode: 1.97 10^{21} POT

$\bar{\nu}_\mu$ mode: 1.64 10^{21} POT

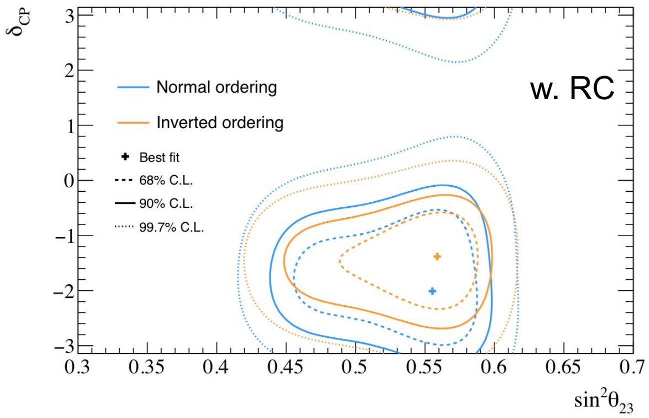
94+14 ν_e-like events in ν_μ mode

16 $\bar{\nu}_e$-like events in $\bar{\nu}_\mu$ mode

ν_e appearance



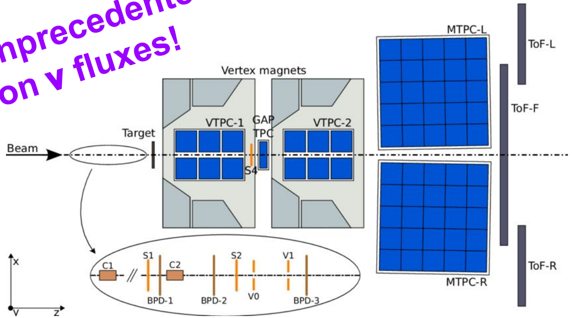
θ_{23} & δ_{CP} confidence region

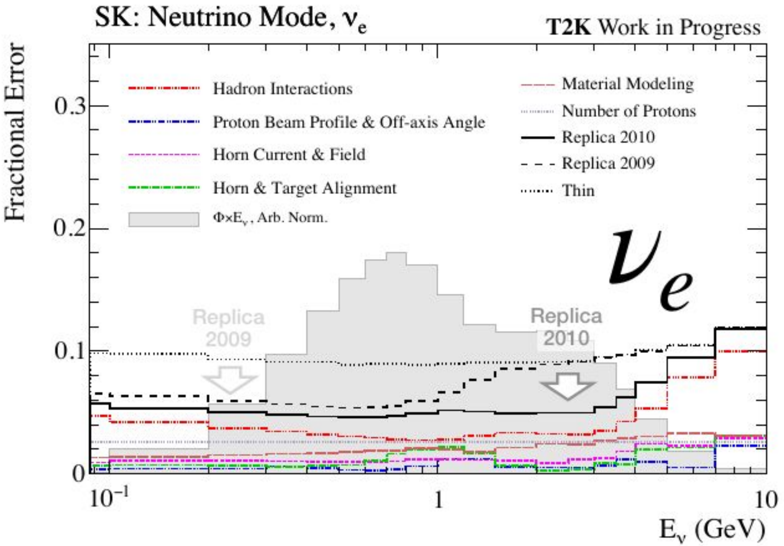


NA61/SHINE: Neutrino flux for T2K

NA61/SHINE analysis coordinator from LPNHE

Reached unprecedented precision on ν fluxes!





NA61/SHINE, a multipurpose detector @ CERN : precision hadron production measurements for T2K (and FNAL) neutrino fluxes predictions

Took data for T2K in 2007 with a thin target and in 2009 and 2010 with replica target

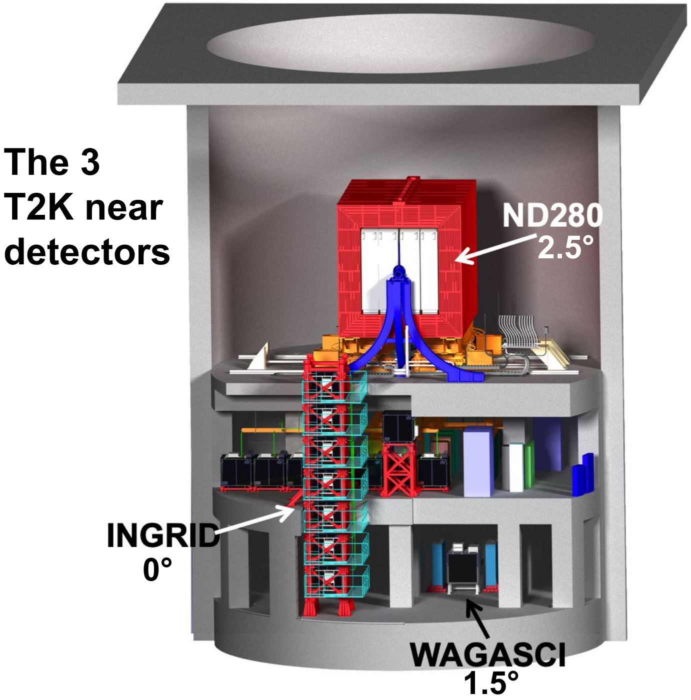
Thin target flux prediction used in T2K until 2019 (all oscillation and cross section analyses) → **flux uncertainty reduced from 25% to 10%**

Since 2020 we are using **replica target data from 2009** → further flux uncertainty reduction down to **5% for low (<1GeV) ν energy** for both OA and xsec!

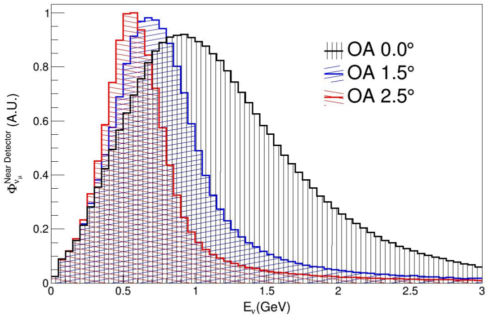
Flux prediction from T2K **replica target 2010** → further reduction of flux uncertainties down to **~5% also at high ν energy!**

Future improved measurements with T2K replica target and eventually a new T2K target will be crucial for T2K-II and HK

Neutrino cross sections @T2K



The 3 T2K near detectors



T2K near (but also far) detectors are also used to provide neutrino cross sections measurements
Since its beginning: ~25 cross section related publications

T2K is one of the world leading experiment (also) in this field

Currently, the cross section analysis strategy is devoted to:

- Promote **combined measurements** (multiple signal samples, multiple detectors, multiple fluxes)
- Explore **nuclear effects**: like 2p2h or FSI
- Provide new measurements on **water target**, thanks to FGD2 and more recently, WAGASCI

The ultimate goal is to provide material to help validating (or not) theoretical models and thus to help to **reduce uncertainties in the oscillation analyses** (for T2K, for T2K-II and for HK).

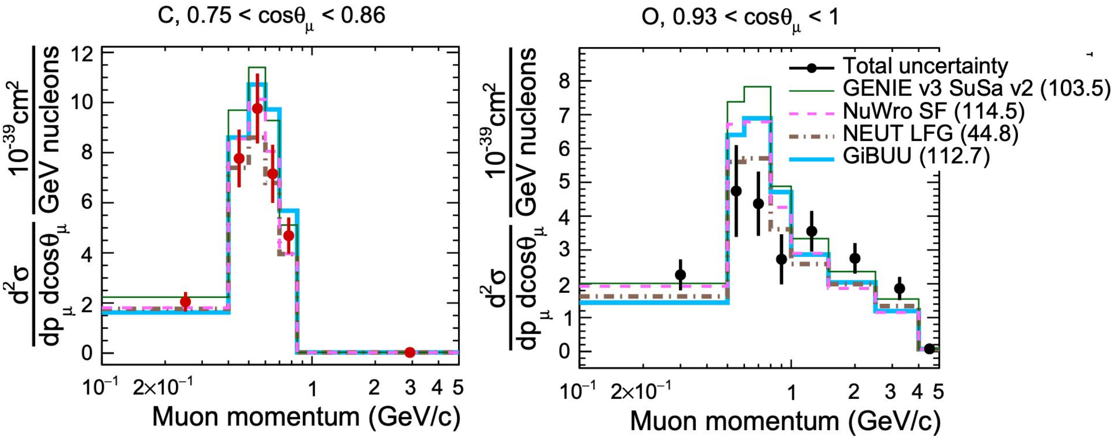
Major improvements expected with ND280 upgrade!

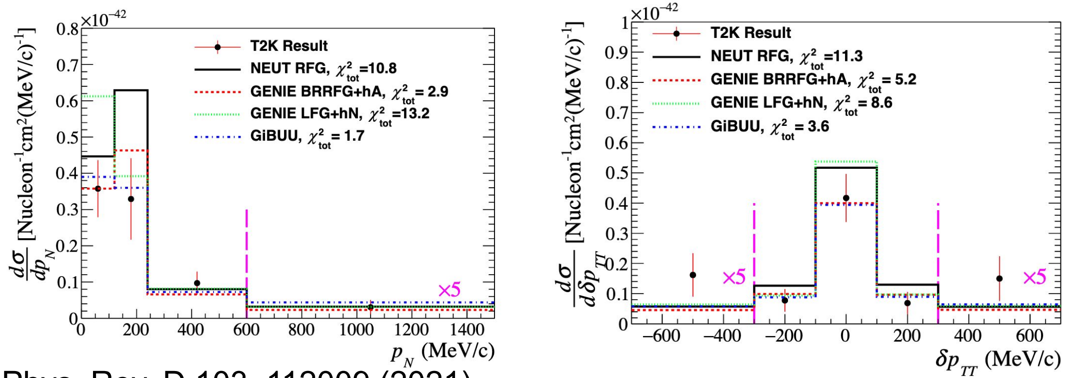
WAGASCI elec. convener +
XSEC convener from LLR

Neutrino cross sections @T2K: recent highlights

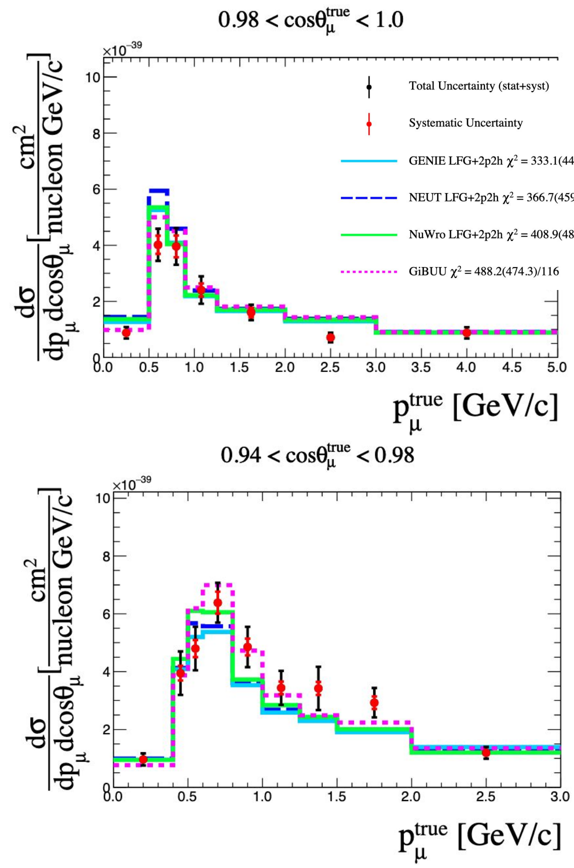
XSEC convener from LLR

Phys. Rev. D 101, 112004 (2020)





Phys. Rev. D 103, 112009 (2021)

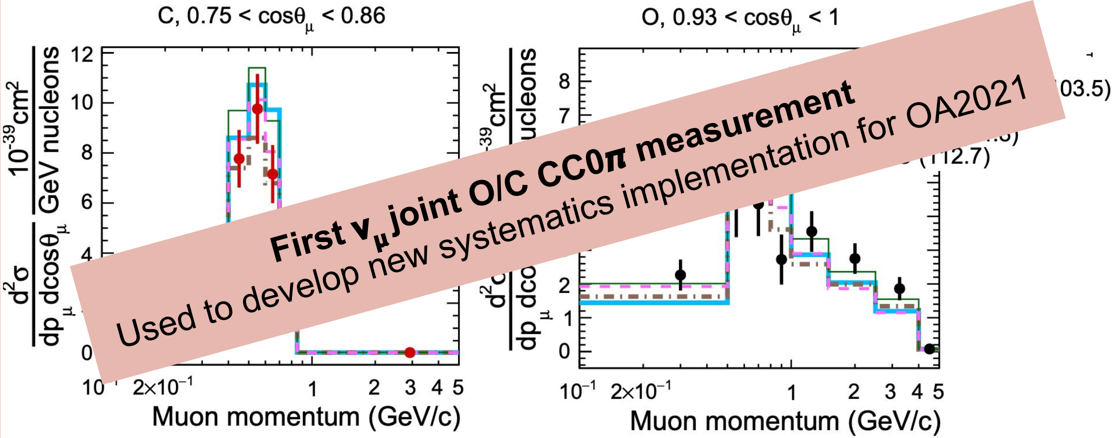


Phys. Rev. D 101, 112001 (2020)

Neutrino cross sections @T2K: recent highlights

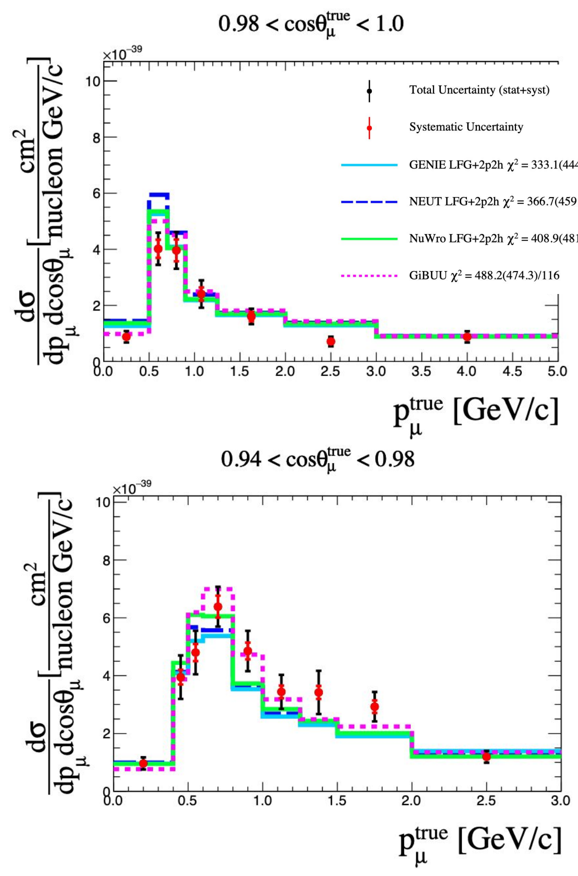
XSEC convener from LLR

Phys. Rev. D 101, 112004 (2020)



First ν_μ joint O/C CC0π measurement

Used to develop new systematics implementation for OA2021



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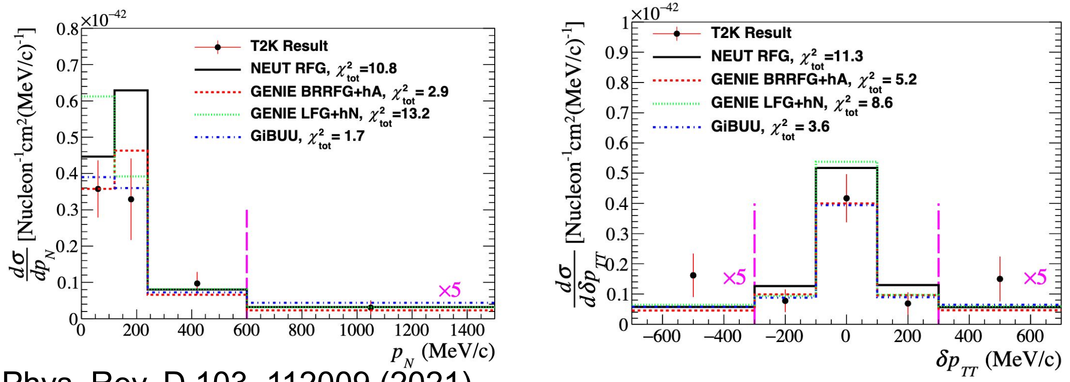

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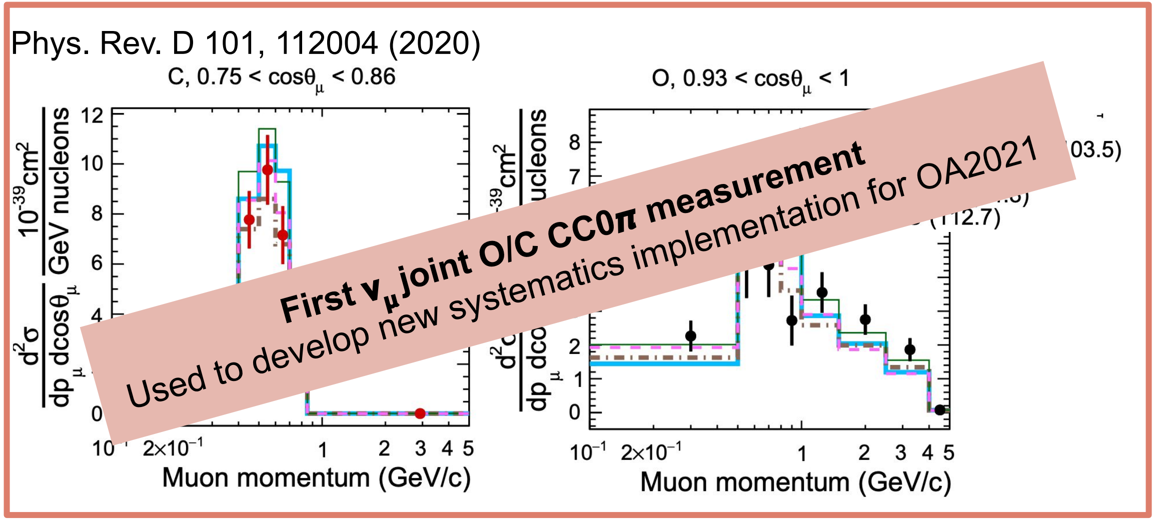

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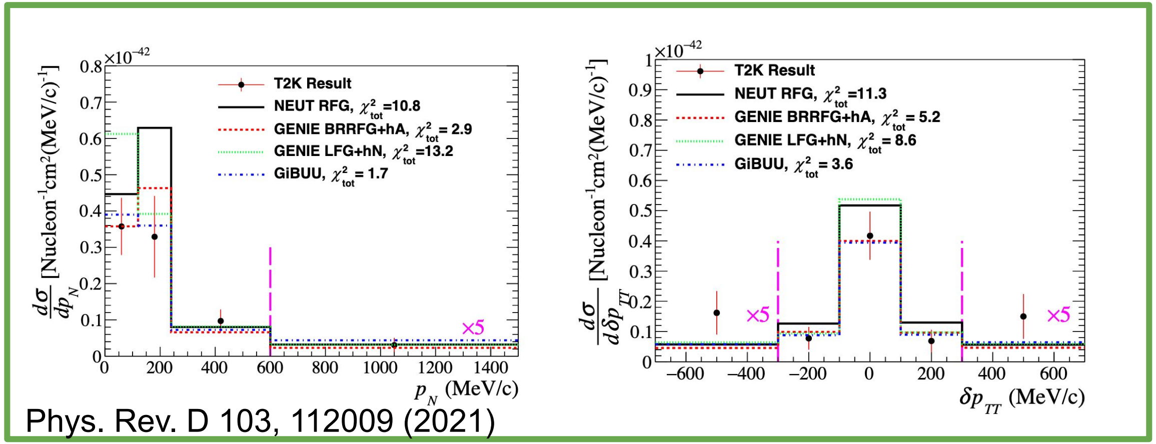

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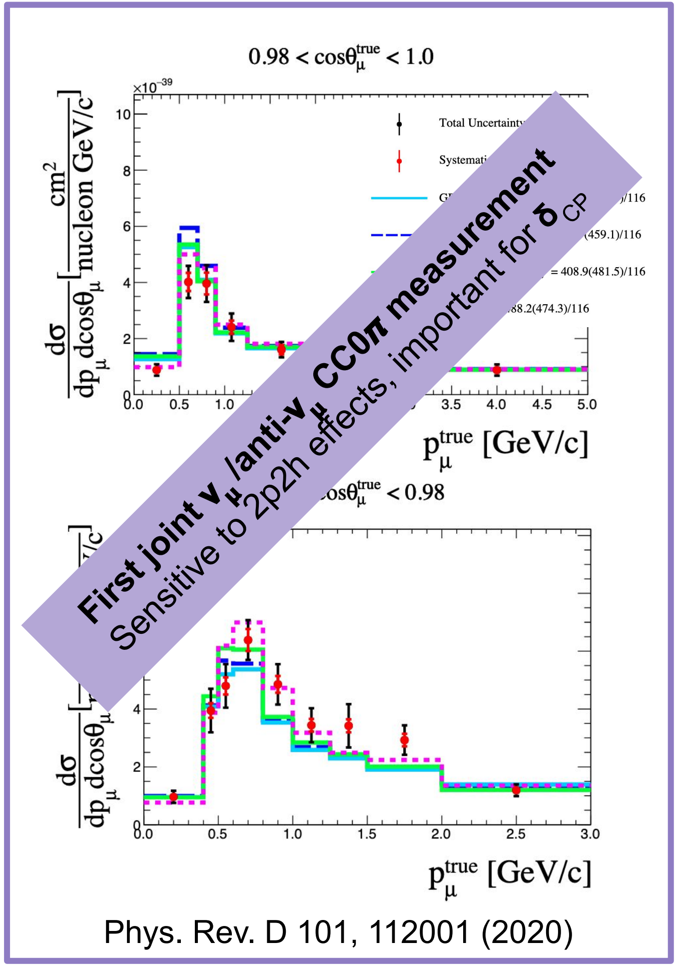

First joint ν_μ/anti-ν_μ CC0π measurement

Sensitive to 2p2h effects, important for δ_{CP}

Phys. Rev. D 101, 112001 (2020)

Neutrino cross sections @T2K: recent highlights

XSEC convener from LLR

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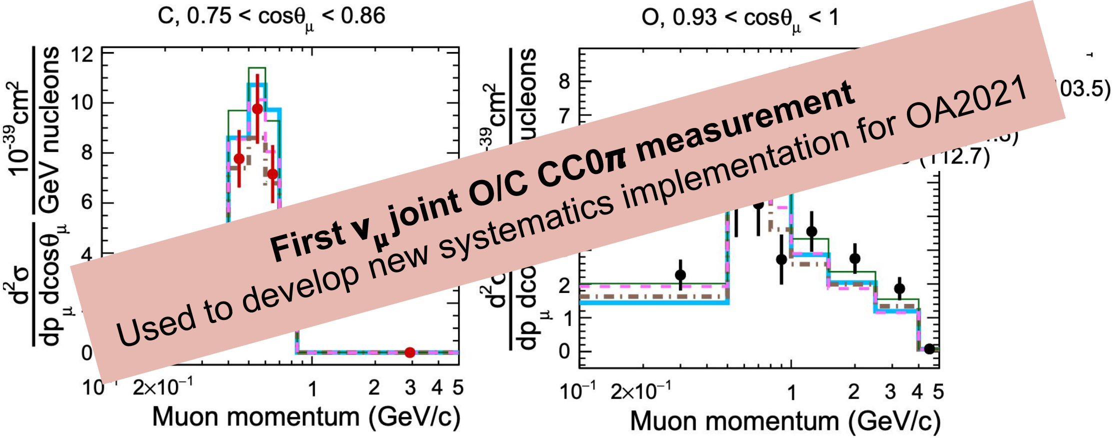

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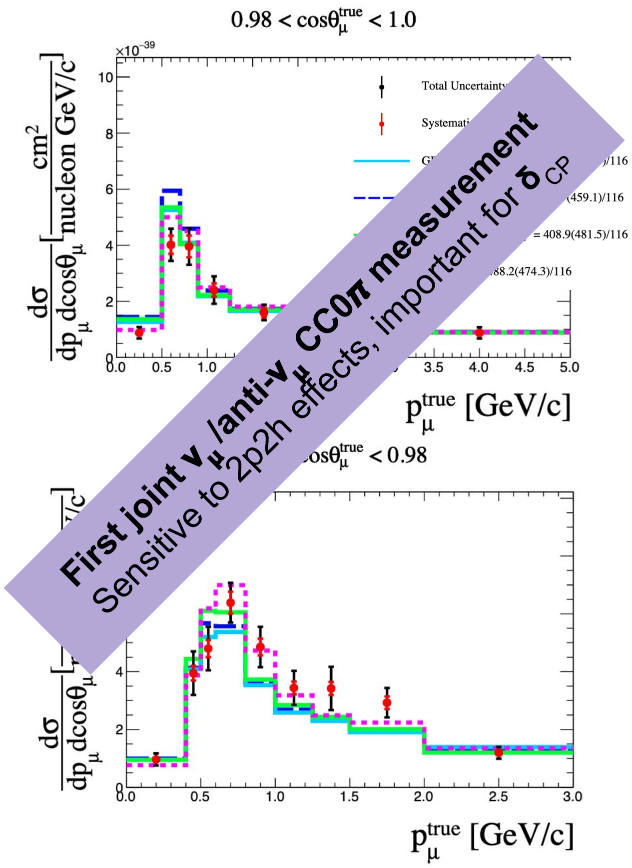

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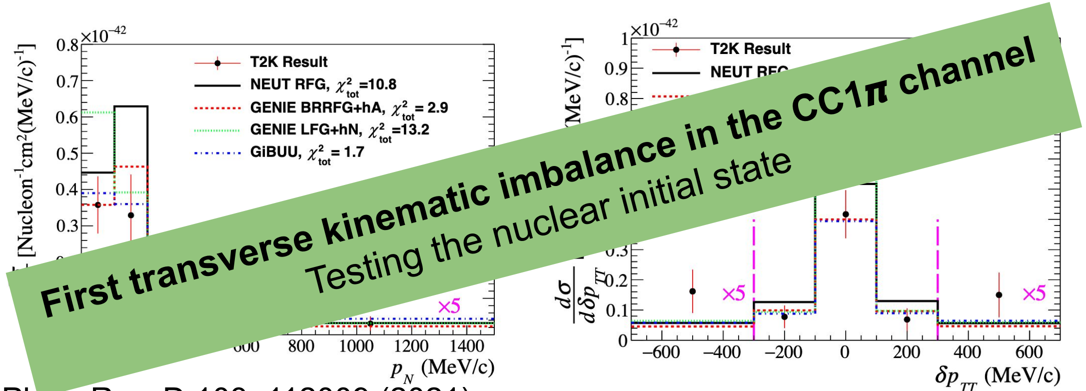


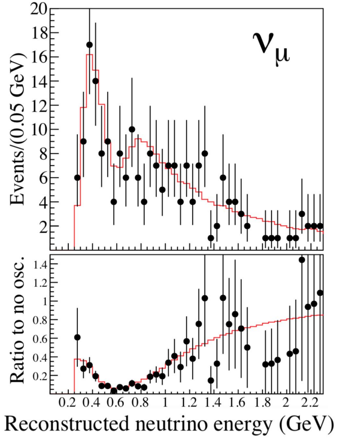
First transverse kinematic imbalance in the CC1π channel

Testing the nuclear initial state

Phys. Rev. D 103, 112009 (2021)

T2K-I: what we have learned?

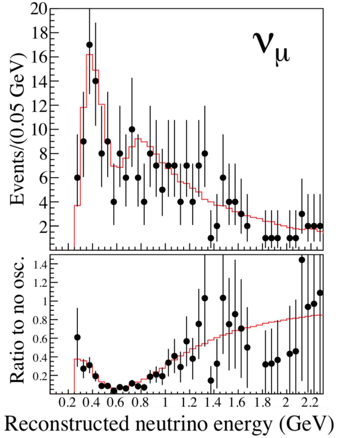
1. **T2K** is a super exciting experiment, that provided major results since its beginning and is now the **world leading experiment** for the precision measurement of **ν_e appearance, δ_{CP} , Δm^2_{23} and θ_{23} and neutrino cross sections**



2. This is the result of an **extremely accurate design of the experiment** :
   - off-axis beam to maximize the appearance,
   - NA61/SHINE to reduce flux uncertainty,
   - near detector suite (magnetized) to characterize the unoscillated flux,
   - well controlled and already fully successful far detector

T2K-I: what we have learned?

1. **T2K** is a super exciting experiment, that provided major results since its beginning and is now the **world leading experiment** for the precision measurement of **ν_e appearance, δ_{CP}, Δm^2_{23} and θ_{23} and neutrino cross sections**



2. This is the result of an **extremely accurate design of the experiment** :
   - off-axis beam to maximize the appearance,
   - NA61/SHINE to reduce flux uncertainty,
   - near detector suite (magnetized) to characterize the unoscillated flux,
   - well controlled and already fully successful far detector
3. To improve **δ_{CP}** measurement we need more **statistics** (currently ~11% stat. err. on the main **ν_e** appearance channel) → **T2K-II** + accelerator upgrade [Claudio]
4. **Systematics** currently dominated by **neutrino interaction** related uncertainties (3.2% over a total of 4.7% in the main **ν_e** appearance channel). Presently we do not have a theoretical model correctly describing the neutrino interaction final states, even for the most “simple” channel (aka CC0π) → need of more sophisticated models AND more precise measurements → only possible with **new detectors**! [see Claudio’s talk]

French groups have acquired a leading expertise in neutrino oscillation, precious for HK and DUNE era

More exciting results expected with the second phase of T2K, first, and HK, later: δ_{CP} @3σ by 2027 and @5σ by ~2030

Status&physics potential of the T2K joint fits

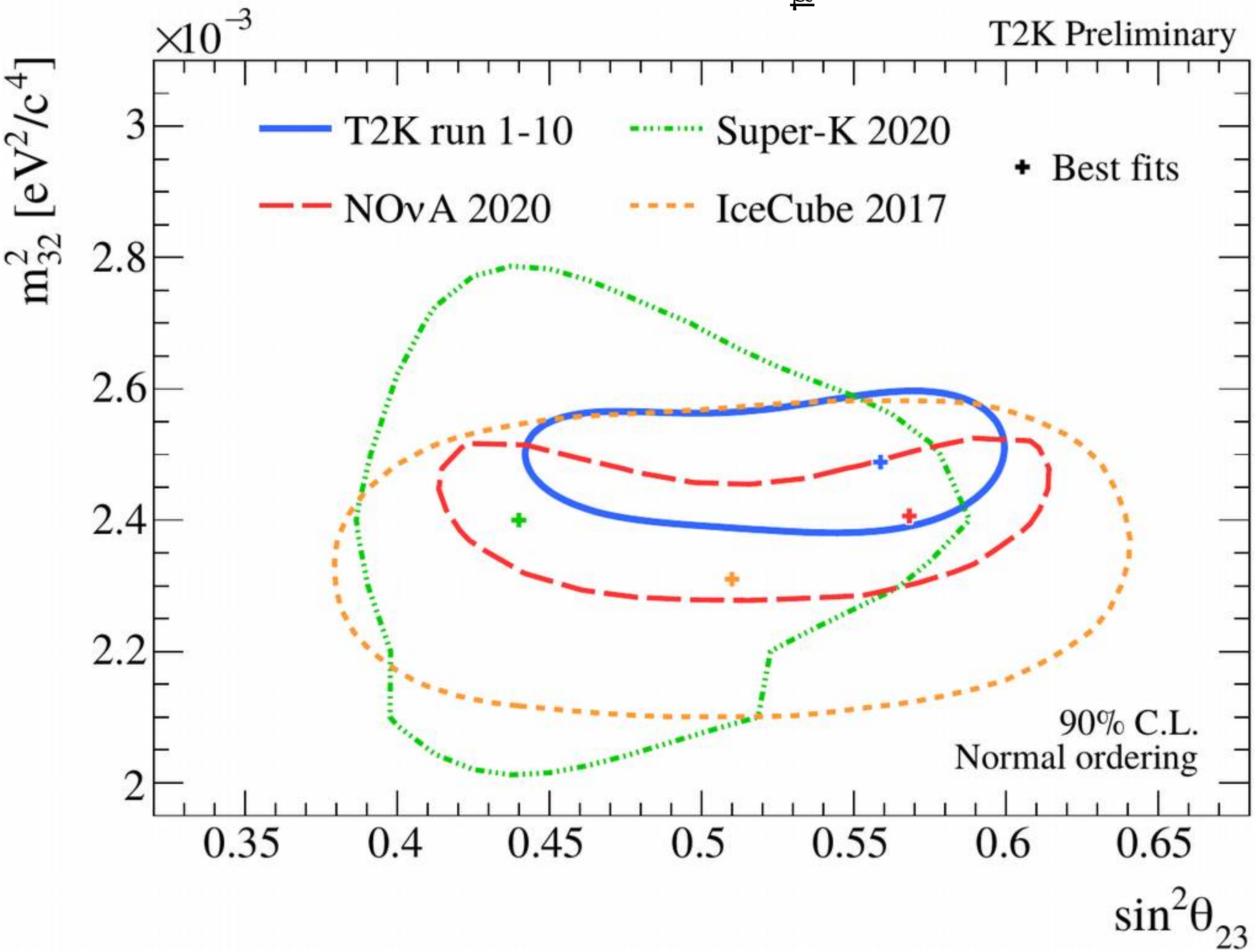
Benjamin Quilain

(Laboratoire Leprince-Ringuet, CNRS/Ecole polytechnique)

Conseil Scientifique de l'IN2P3, 2021/10/26

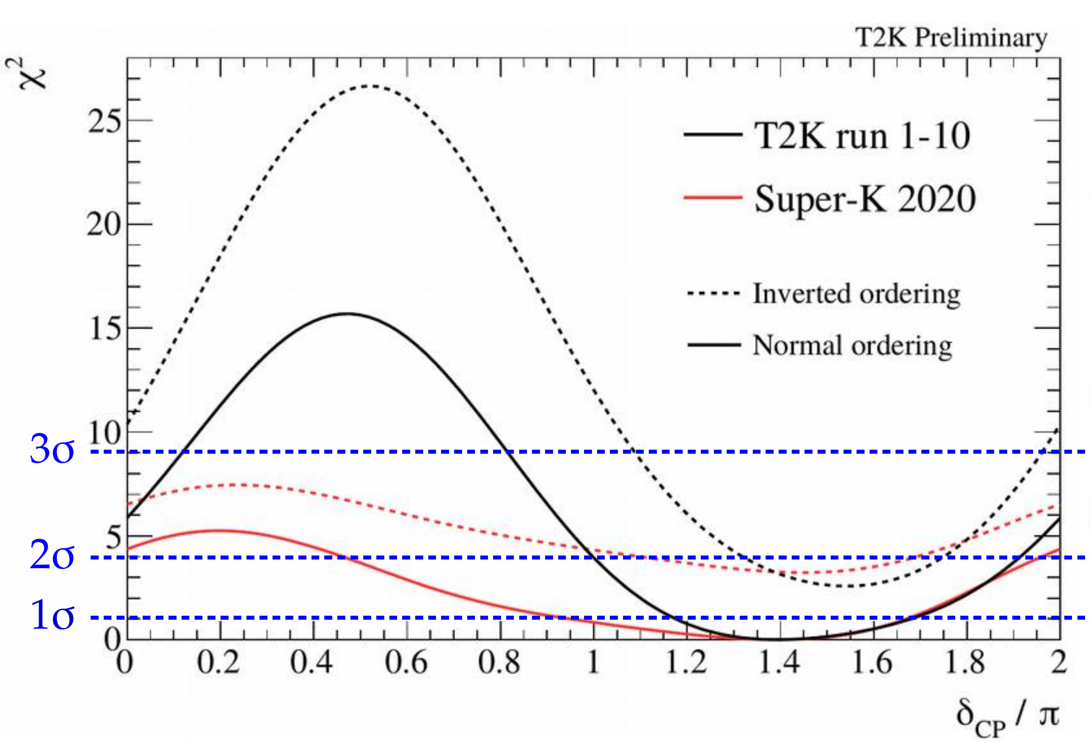
Atmospheric parameters

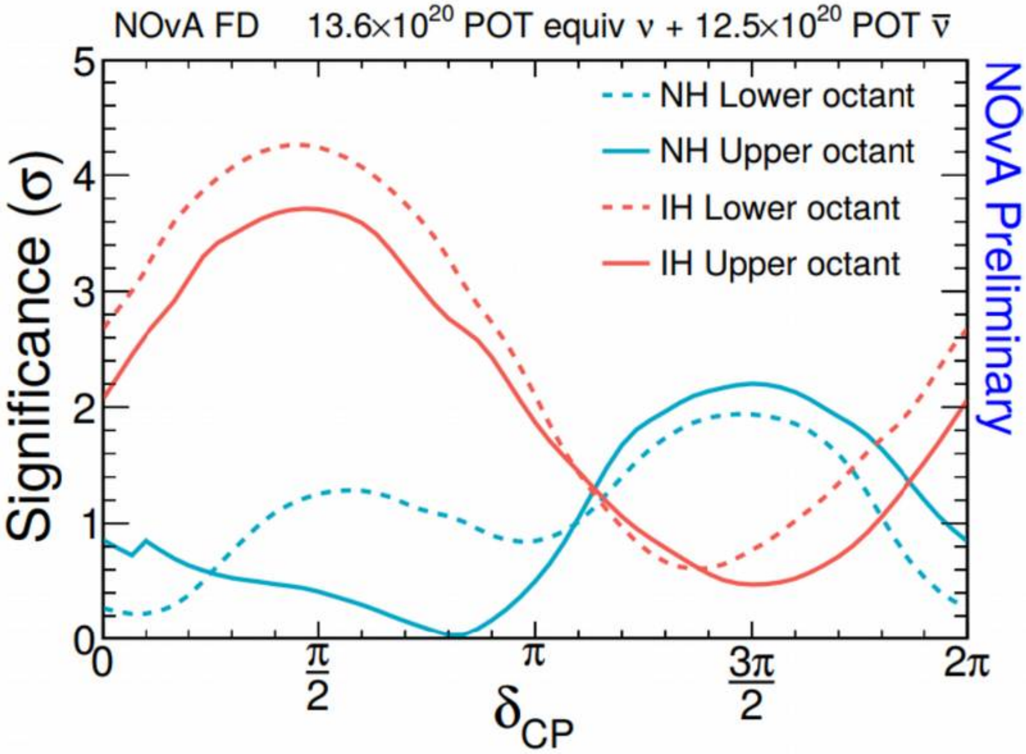
Sensitivity drawn by ν_μ disappearance



- All recent experiment are compatible w/ maximal mixing : $\sin^2 \theta_{23} = 0.5$.
- No significant disagreement in $|\Delta m^2_{32}|$.
- T2K : world leading constraint on θ_{23} and $|\Delta m^2_{32}|$.

δ_{CP} and mass-hierarchy





- Normal ordering favoured by T2K (1.8σ) and SK (1.7 σ).
  & Maximal CP violation $\delta_{CP} = 3\pi/2$ favoured by T2K, SK whatever MO.

- Nova favours no MO significantly.
  → Nova also favours $\delta_{CP} = 3\pi/2$, but if IO assumed…
  → Nova largely compatible with CP conservation if NO.

Solve these tensions ? → Joint fits + Accumulate more statistics

CP symmetry vs Mass ordering in T2K

ν_e / $\bar{\nu}_e$ appearance in T2K

1. $\sin^2(2\theta_{13})$: Leading term

2. CP violation effect:

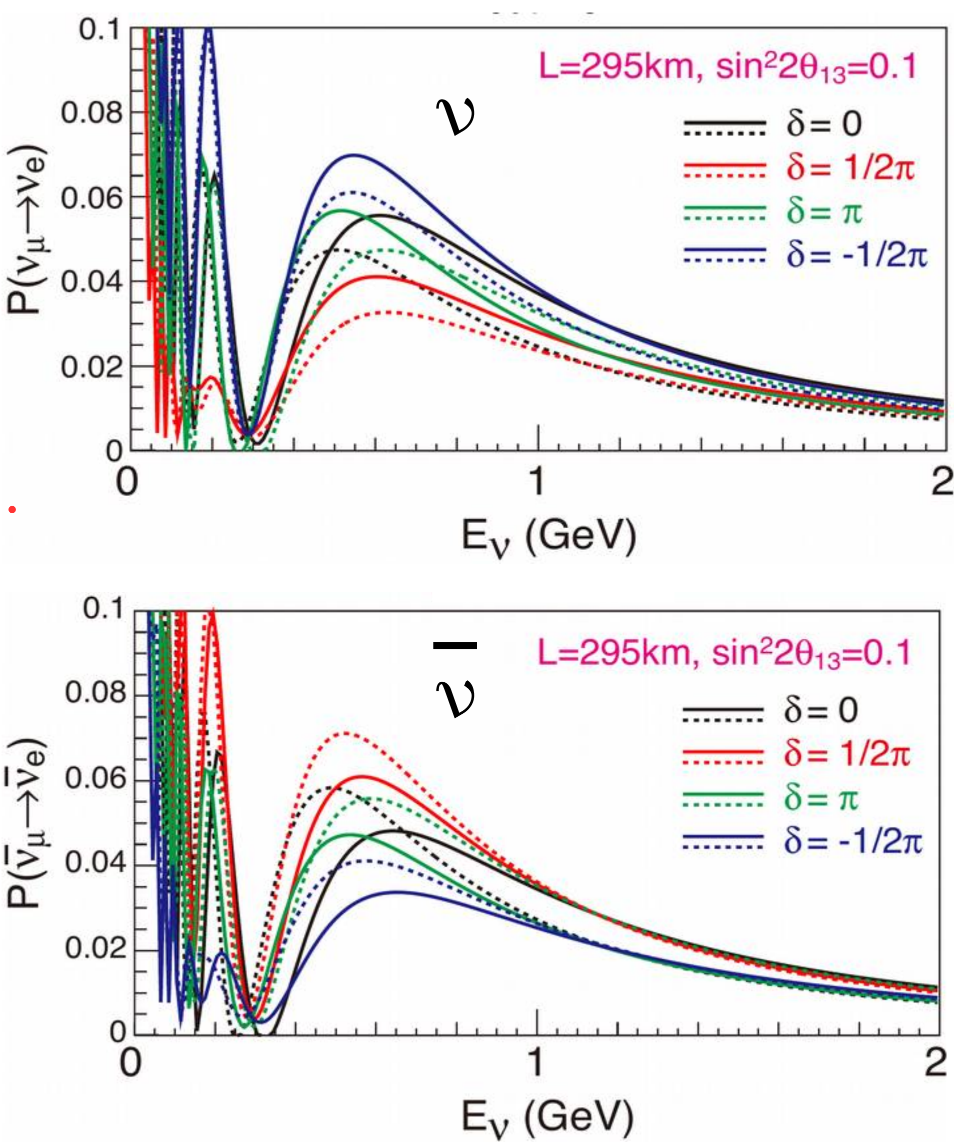
→ If $\delta_{CP} = -\pi/2$: $\uparrow \nu_\mu \rightarrow \nu_e$ & $\downarrow \bar{\nu}_\mu \rightarrow \bar{\nu}_e$.

→ ~27% @T2K ($\sin^2(2\theta_{23})=1$)

3. Mass ordering effect :

→ If NH : $\uparrow \nu_\mu \rightarrow \nu_e$ & $\downarrow \bar{\nu}_\mu \rightarrow \bar{\nu}_e$.

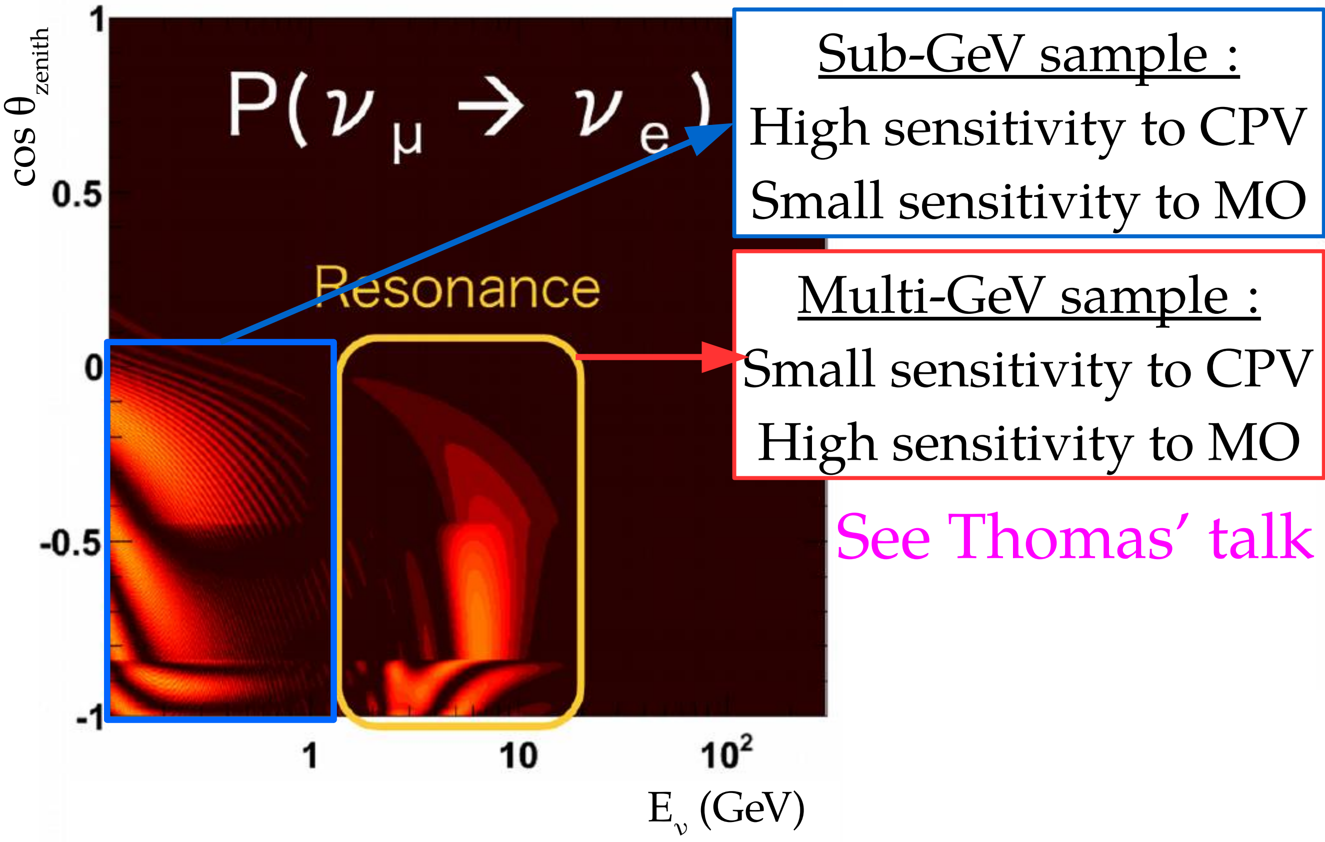
→ ~10% @T2K ($\sin^2(2\theta_{23})=1$)



→ Clear degeneracy in T2K betwen δ_{CP} and Mass hierarchy.

→ Resolving it in SK would be nice !

Atmospheric neutrinos



<u>Sub-GeV sample :</u>
High sensitivity to CPV
Small sensitivity to MO

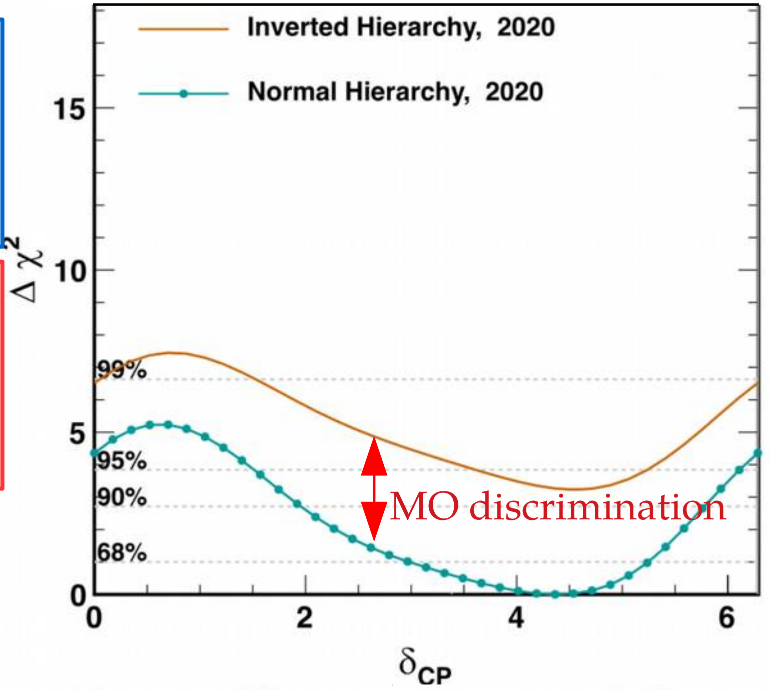
<u>Multi-GeV sample :</u>
Small sensitivity to CPV
High sensitivity to MO

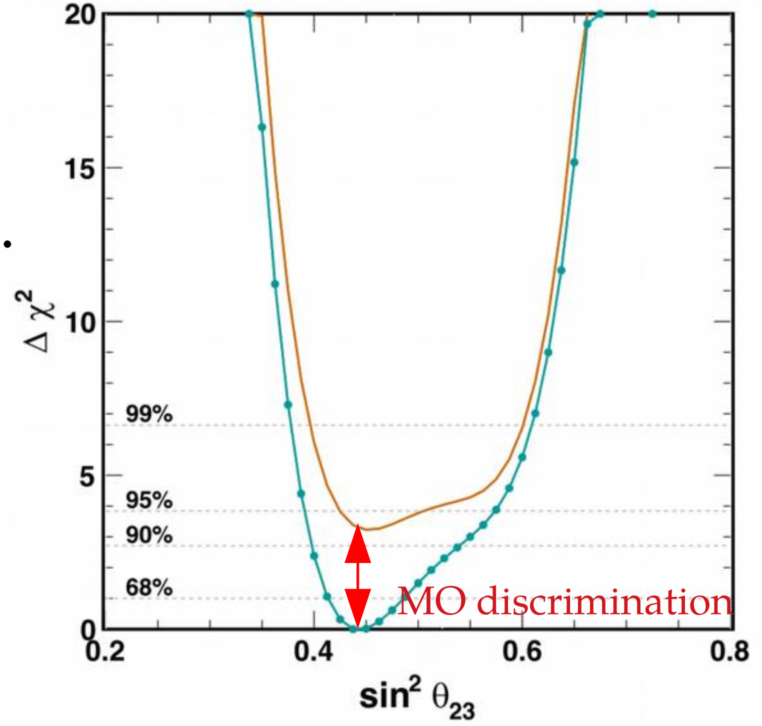
See Thomas' talk

- Great δ_{CP} / MO decoupling in atmospheric ν.

- But MO sensitivity highly depends on θ_{23}…

  … which world-leading measurement is T2K





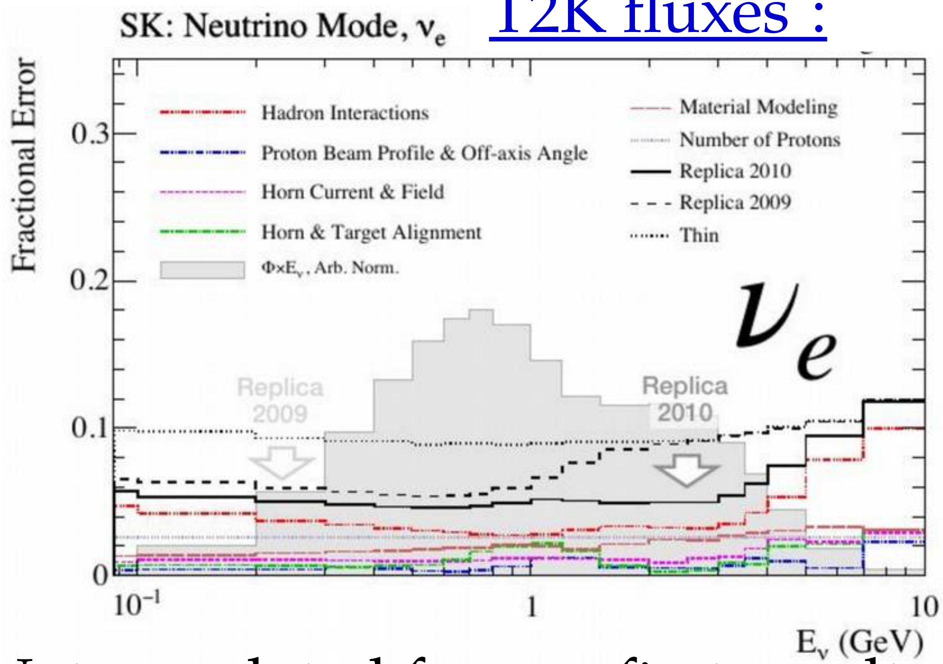
Flux systematics

Number of events = $\overset{\text{Incident } \nu \text{ :}}{\left(\nu \text{ flux models}\right)} \times \overset{\text{Interacting } \nu \text{ :}}{\left(\nu \text{ cross-section models}\right)} \times \overset{\text{Detected } \nu \text{ :}}{\left(\text{SK detector model}\right)}$

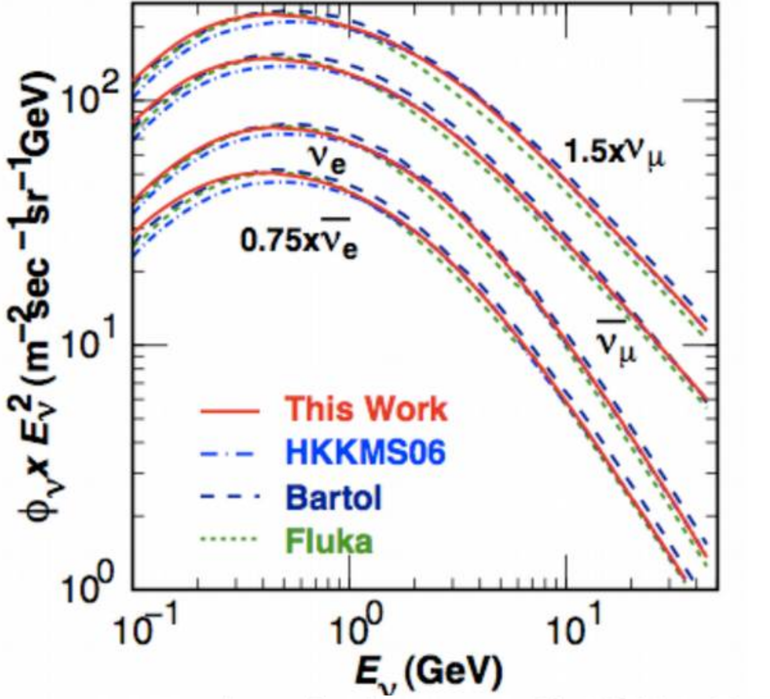
- Ongoing work : tune SK flux model to hadronic data used in T2K

- T2K flux model : uses hadronic models & NA61/SHINE tuning
- SK flux model : uses on Honda flux i.e. BESS&AMS data + Muon flux measurements

T2K fluxes :



Super-K fluxes :



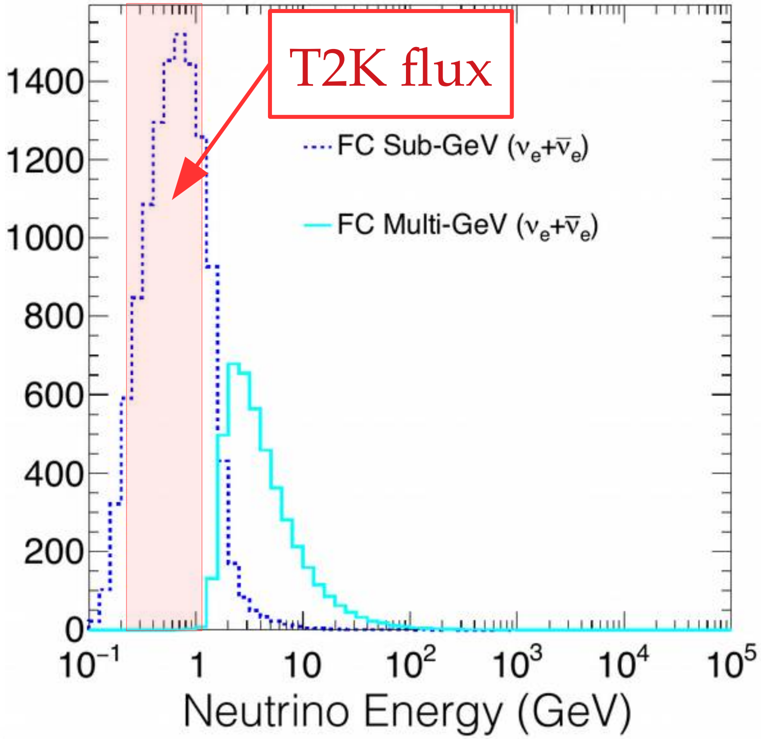
M. Honda et al., Phys.Rev., D83:123001, 2011

→ Not correlated for our first result

Cross-section systematics

Cross-section models partially unified :

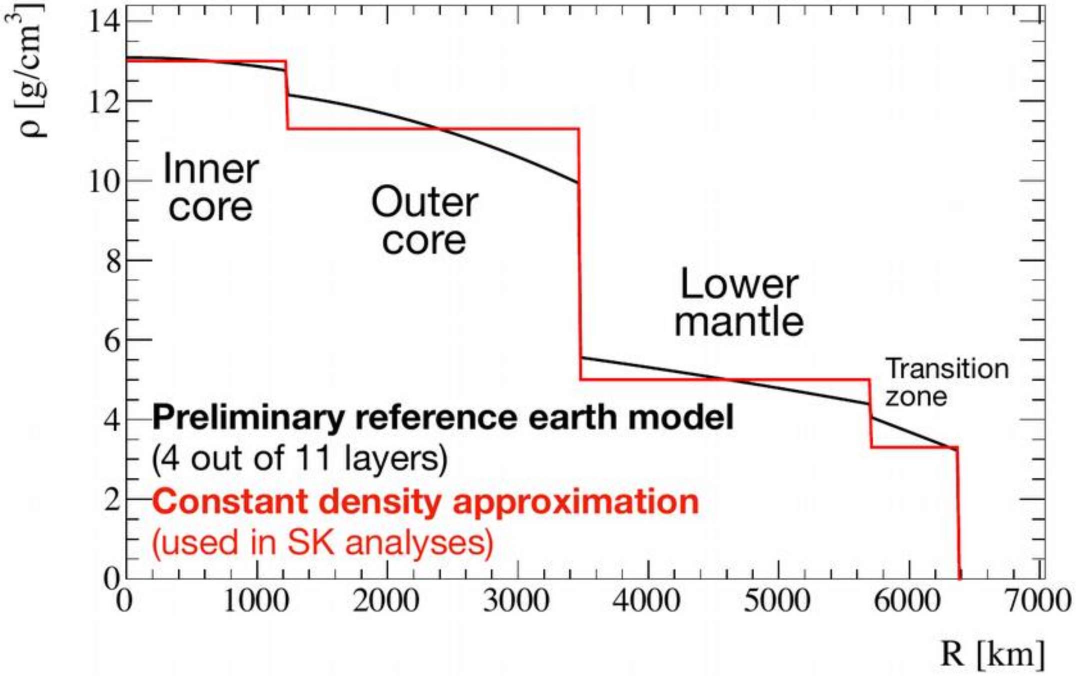
- Same NEUT model used.
- Sub-GeV atmospheric & T2K beam ν have unified error treatment
  → Constrained by ND280.
- Multi-GeV samples still uses ≠ treatment.



Detector uncertainty treatment is being unified for 1st analysis

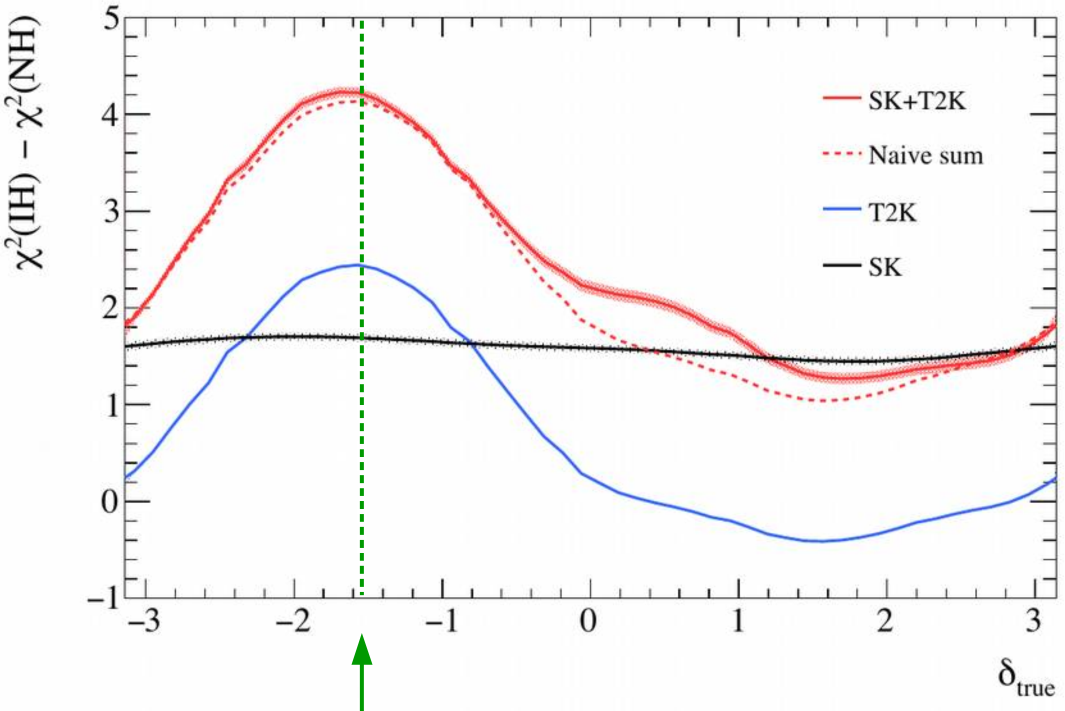
→ Not in sensitivity shown today.

Oscillation models in the Earth has been refined for SK.

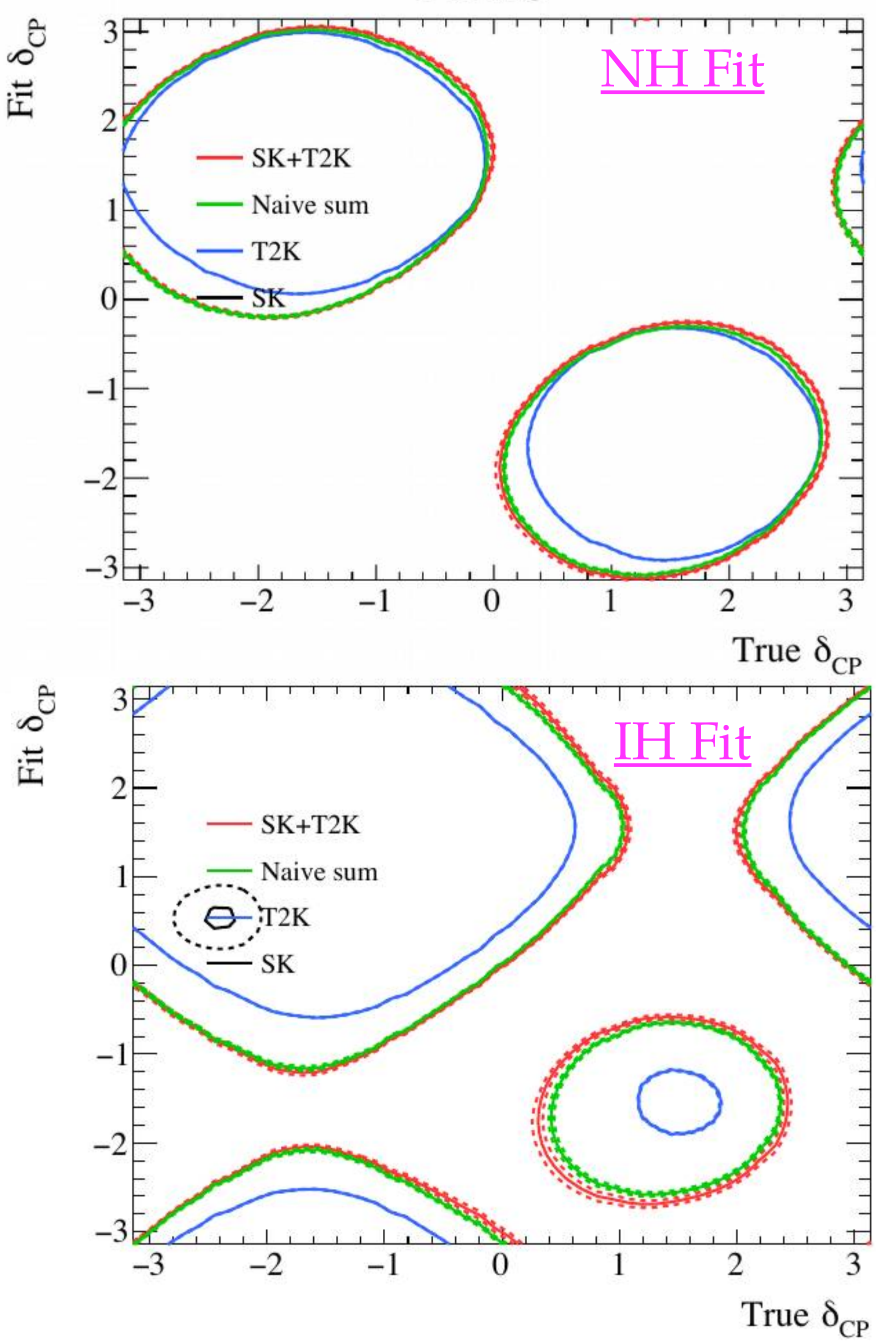


First sensitivity results

Sensitivity to MO (True NH)



2σ δ_{CP} exclusion (True NH)



- MO sensitivity ↑ to > 2σ at $\delta_{CP} = -\pi/2$.

  → Please remember that data constraints exceed sensitivities in T2K.

- CPV 2σ exclusion regions significantly enlarged wrt T2K.

Conclusions

- T2K, SK and Nova are leading the field in terms on CPV and MO.
  → But there are relative tension between Nova and T2K/SK.
  → Joint fits are elegant answers to this puzzle : T2K/Nova & T2K/SK.

- The T2K/SK joint fit received more attention so-far.
  → Large correlations between all systematic uncertainties.
  → Large difference in baseline allows to resolve δ_{CP}/MO degeneracy.

T2K constraint on θ_{23} → Improves → SK constraint on MO → Breaks MO/δ_{CP} degeneracy → T2K constrains δ_{CP}

- 1st sensitivity very promising for both MO and CPV
  → Though only cross-section models have been partially unified.
  → First official results in 2022: please stay tuned.

- All joint fit are built for long terms : much more powerful if stat. ~ syst.
  → Will show full potential in T2K-II (Claudio) and Hyper-K (Mathieu).
  → Unique probe to PMNS Unitarity, on top of CPV and MO.

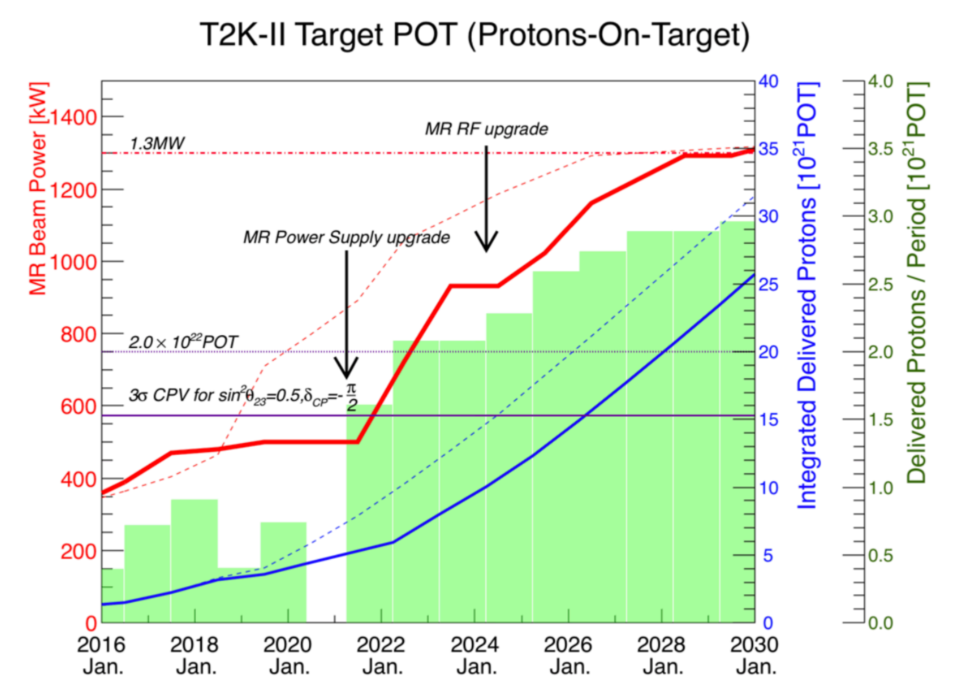
T2K-II and the ND280 Upgrade

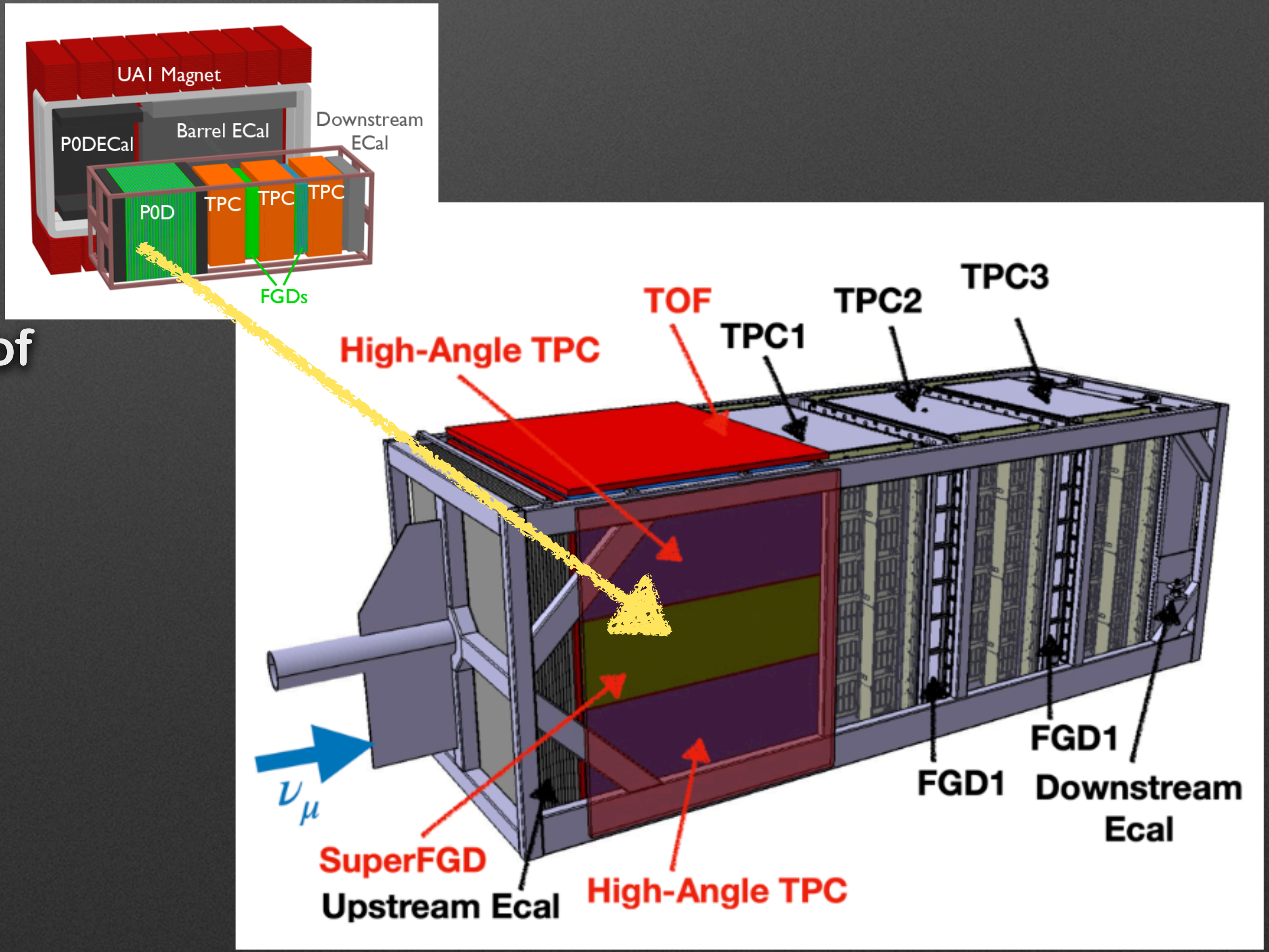
Claudio Giganti (LPNHE)
for the ILance, LLR and LPNHE groups

IN2P3 Scientific Council
26/10/2021

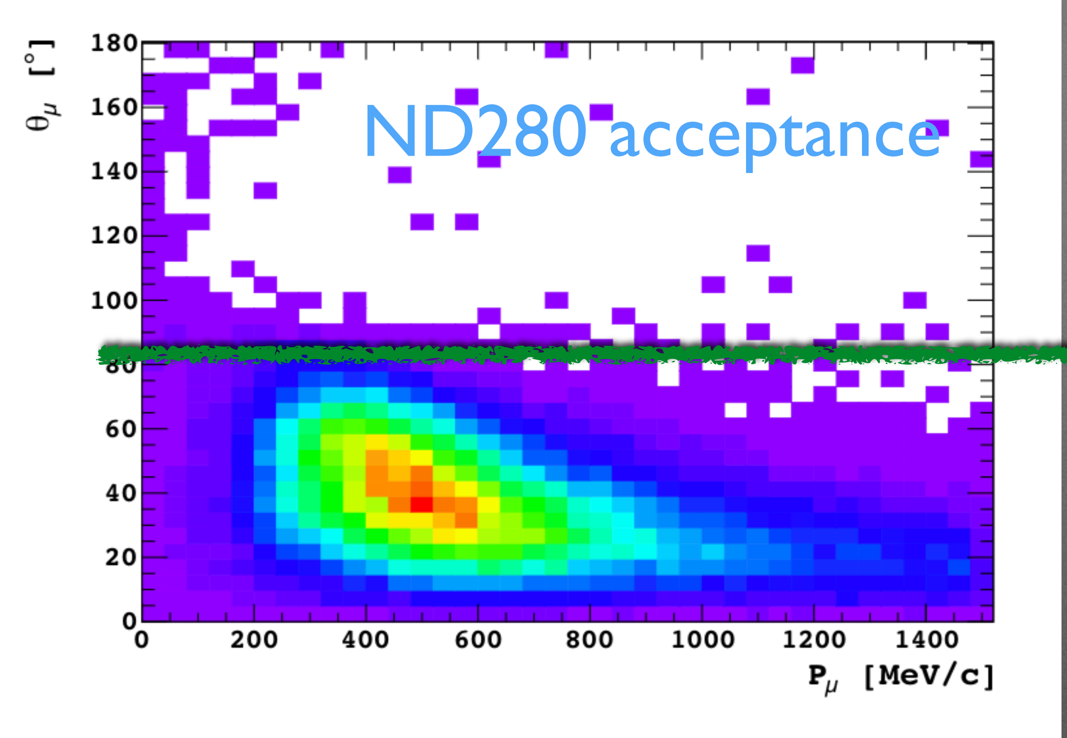
T2K-II

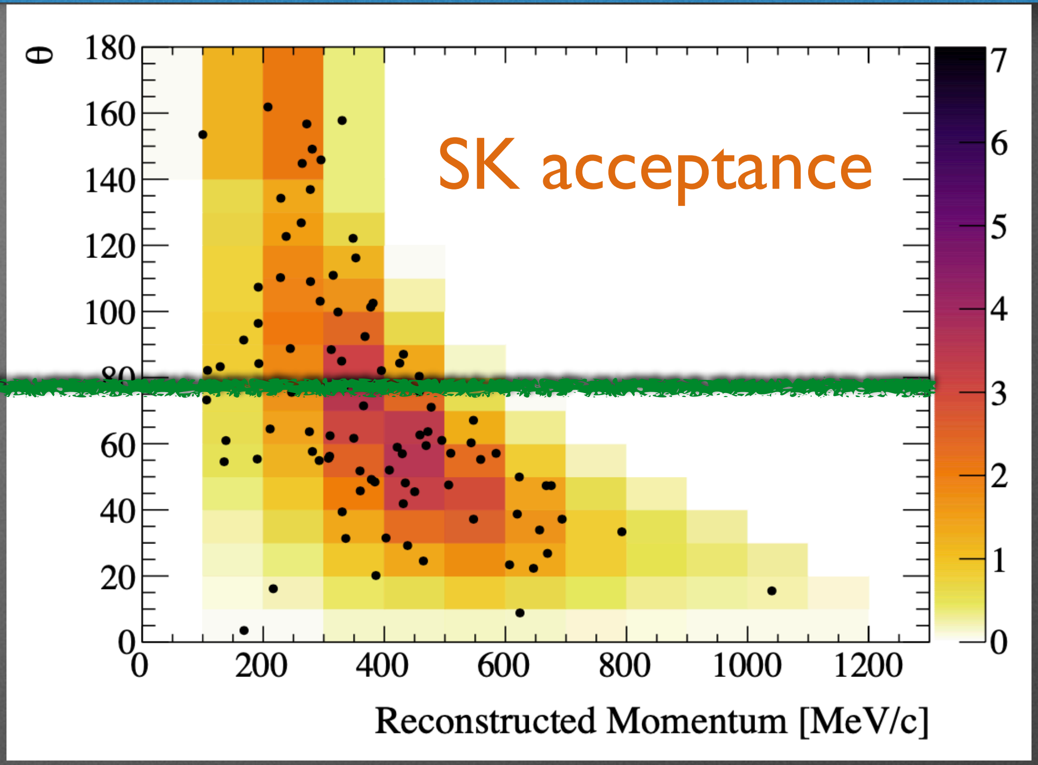
- **T2K-II**: extension of T2K running time in the period 2022 - 2027
  - 2027: Beginning of Hyper-Kamiokande
- Collect $>10x10^{21}$ POT → 3σ sensitivity to CPV if $\delta_{CP}=-\pi/2$
- T2K-II consists in two hardware projects:
  - **Beamline upgrade** → double repetition rate and increase power **from 500 kW to 1.3 MW**
  - **Off-axis Near Detector upgrade** → reduce systematics uncertainties to cope with additional statistics
  - After the upgrades we will collect 4 months of data per year until the beginning of HK
- T2K-II will ensure that Hyper-Kamiokande will have
  - 1.3 MW beam
  - Fully functioning and well understood Near Detector from day-1



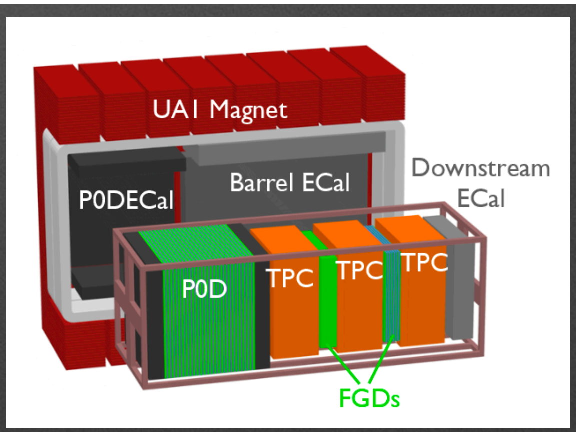


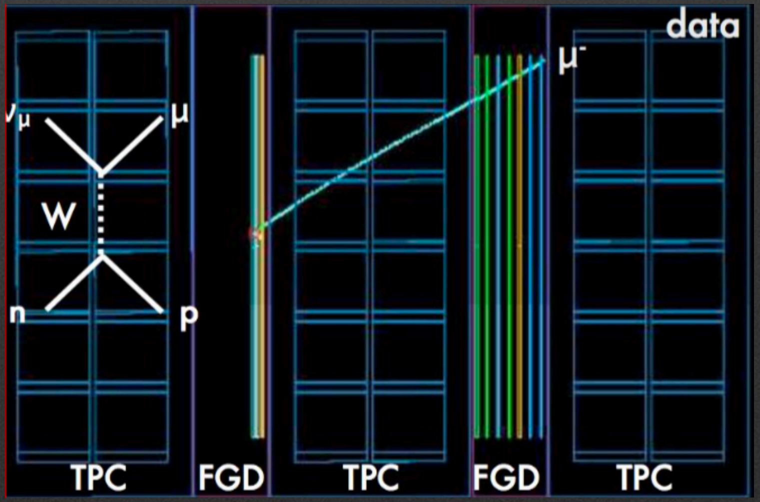
ND280 limitations



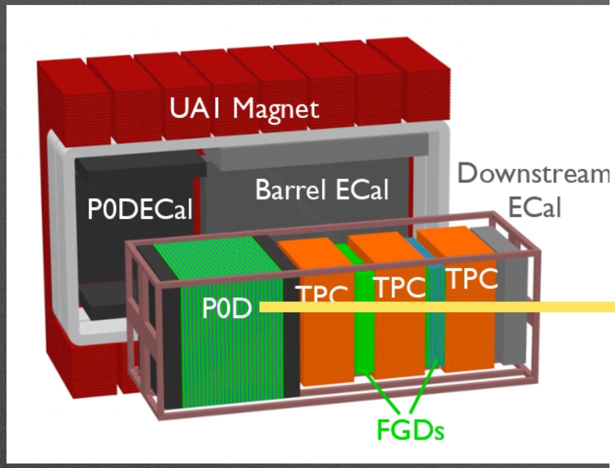


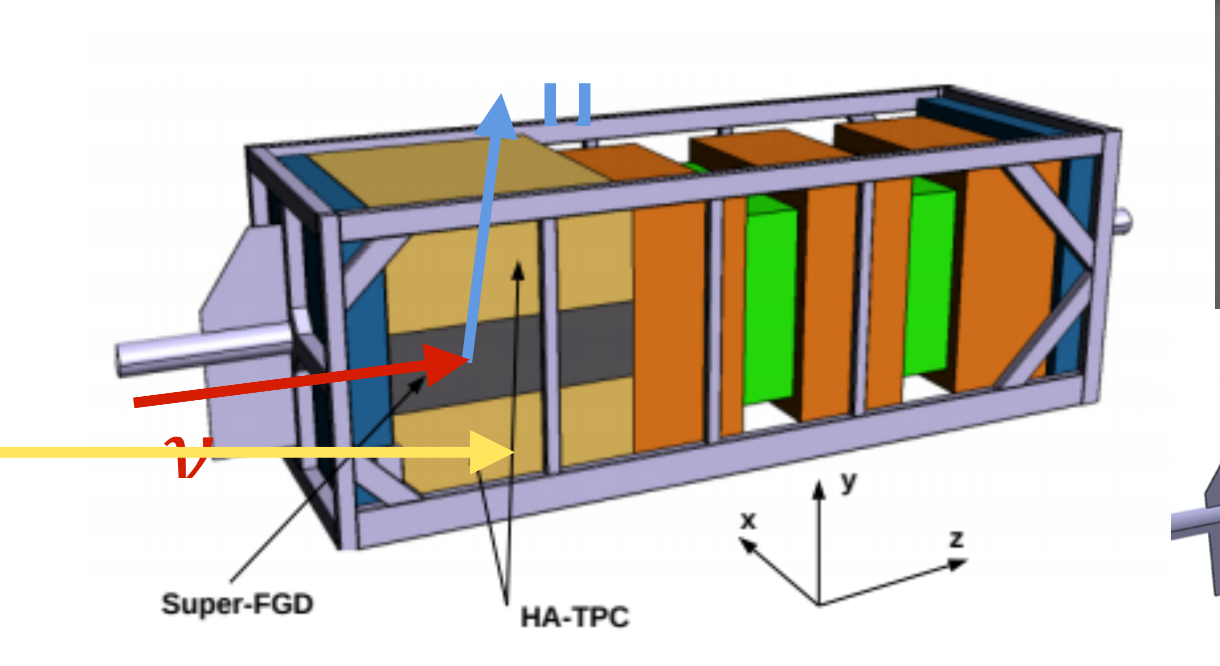
- ND280 has been used for all T2K Oscillation Analyses since 2010
- Main strength of ND280 : magnetized detector → separate ν from $\overline{\nu}$ (cannot be done in SK)
- Main limitations:
  - Reduced angular acceptance → only forward going muons are selected with high efficiency
  - Low efficiency to reconstruct the hadronic part of the interaction → only the muon kinematics is used in the oscillation analysis

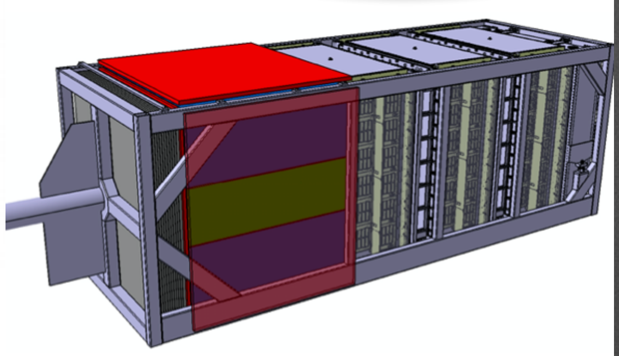




ND280 Upgrade







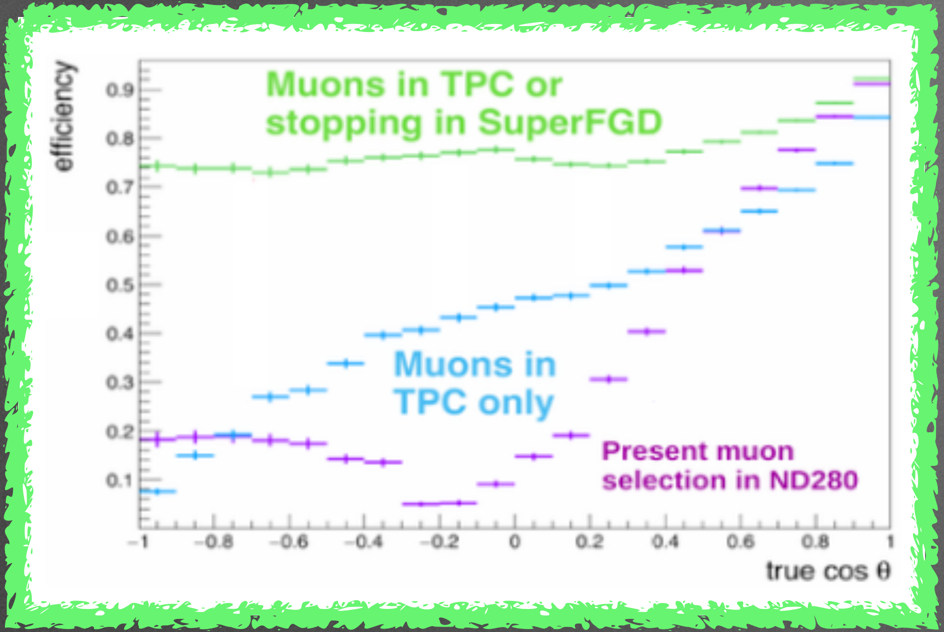
NP-07 at CERN NP

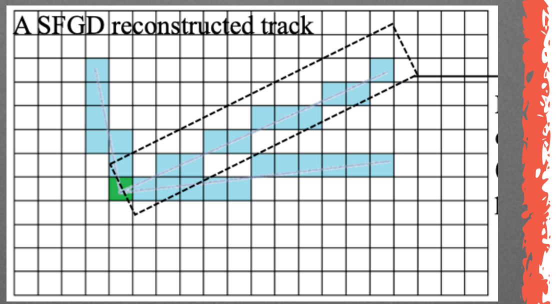
- One horizontal highly segmented target (**Super-FGD**) formed by 2 millions 1cm^3 cubes → Improve reconstruction of hadronic part of the interaction and of low momentum particles
- Two new **High Angle TPCs** → Improve reconstruction of high angle particles
- 6 **Time Of Flight** planes → Reduce backgrounds entering from outside the Super-FGD
- IN2P3 groups responsibilities:
  - Front-End electronics cards for HA-TPC and Super-FGD (based on CITIROC chip)
  - Reconstruction development and sensitivity studies
  - Overall coordination of the ND280 Upgrade

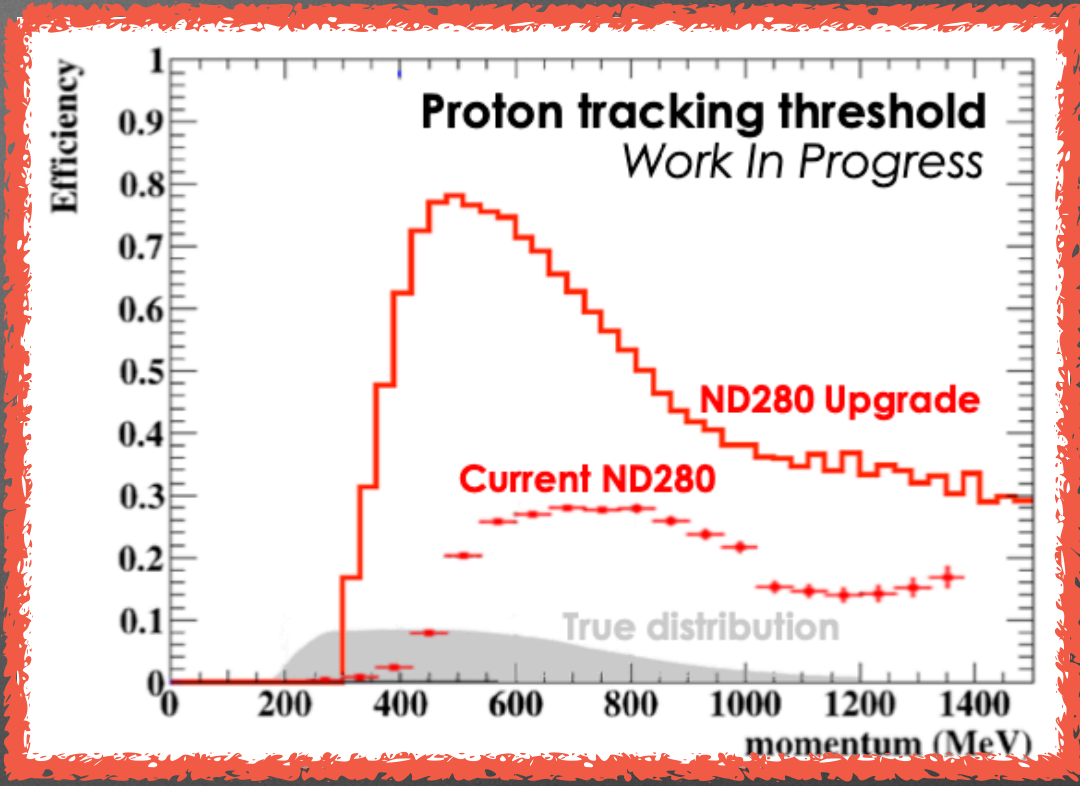
IN2P3 investment ~600 k€

ND280 Upgrade performances

Protons → threshold down to 300 MeV/c
(>500/c MeV with current ND280)



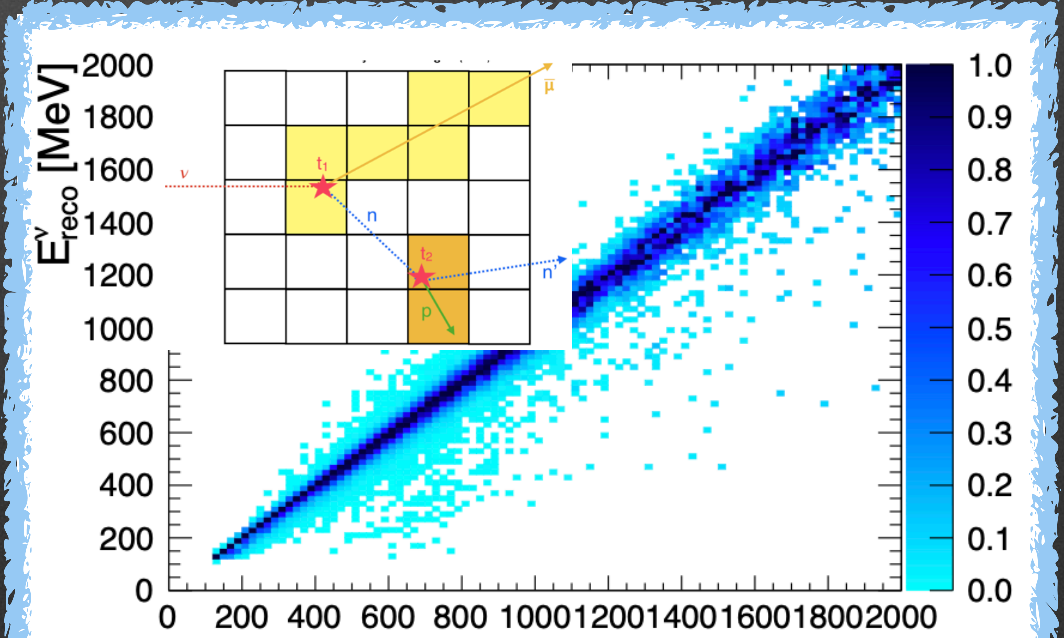




- High-Angle TPCs allow to reconstruct muons at any angle with respect to beam

- Super-FGD allow to fully reconstruct in 3D the tracks issued by ν interactions
→lower threshold to reconstruct protons

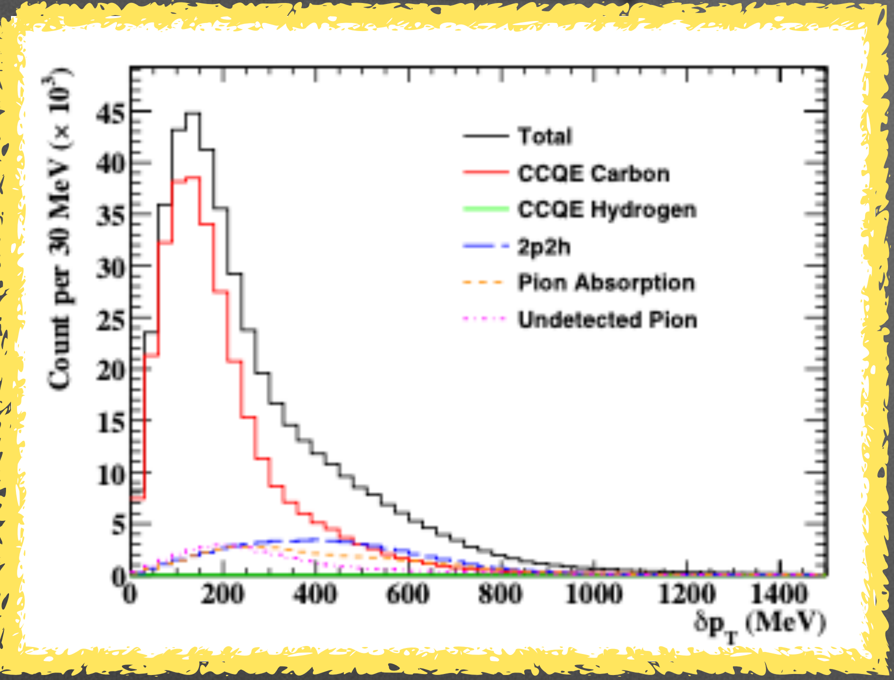
- Neutrons will also be reconstructed by using time of flight between vertex of $\overline{\nu}$ interaction and the neutron re-interaction in the detector



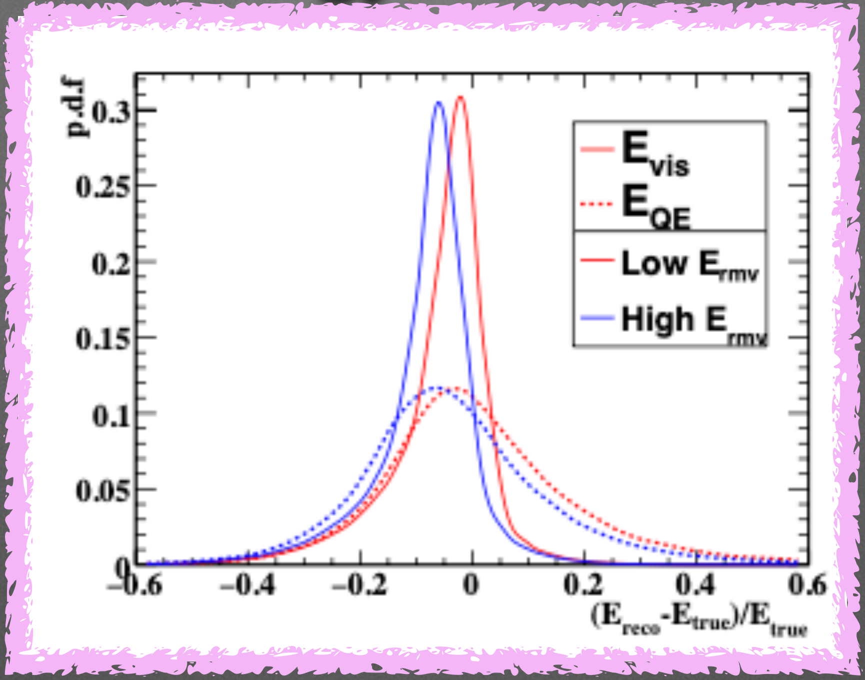
Phys.Rev.D 101 (2020) 9, 092003

Exploiting hadronic informations

Reconstructed δp_T

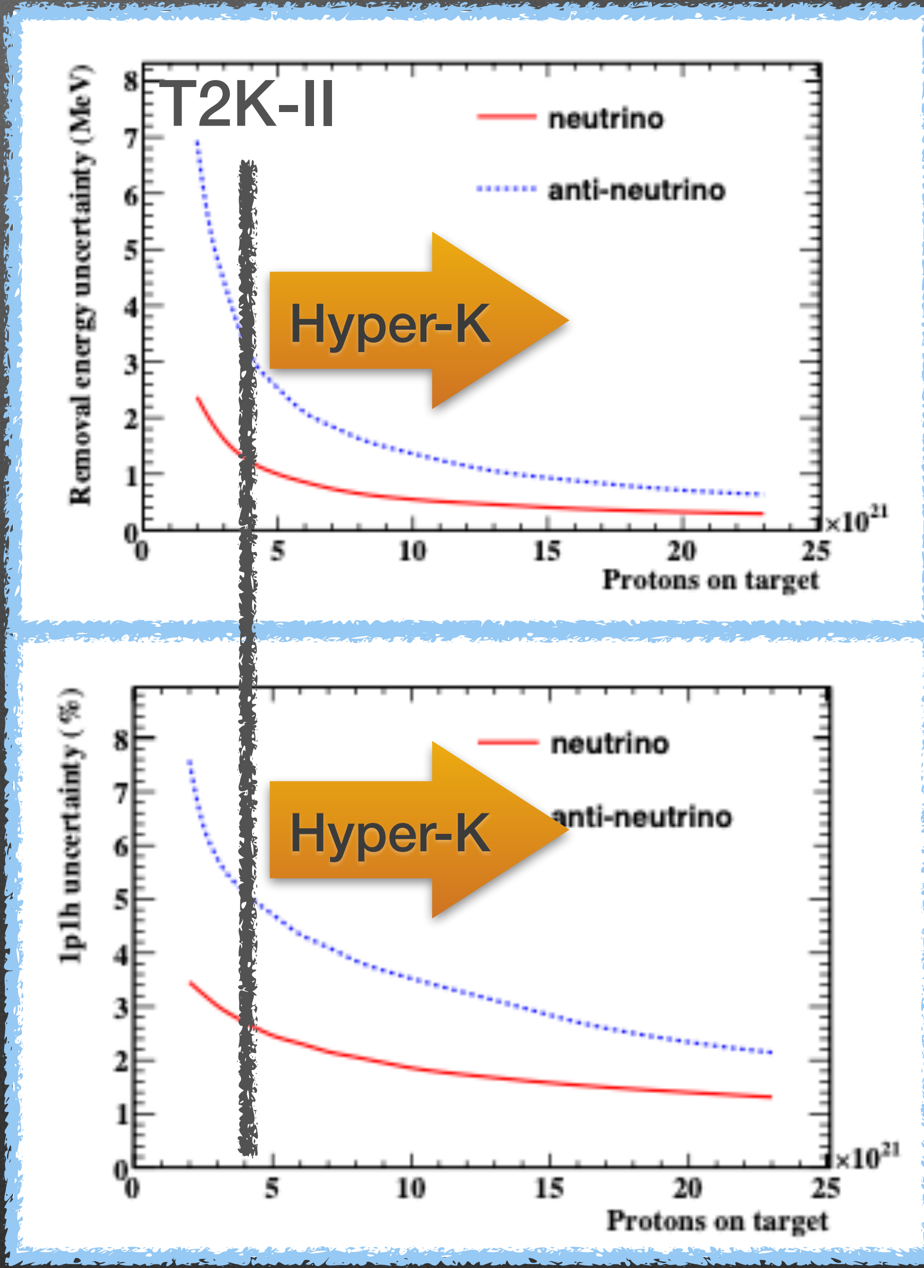


ν energy resolution



arXiv:2108.11779
submitted to PRD

Uncertainty on the removal energy vs POT

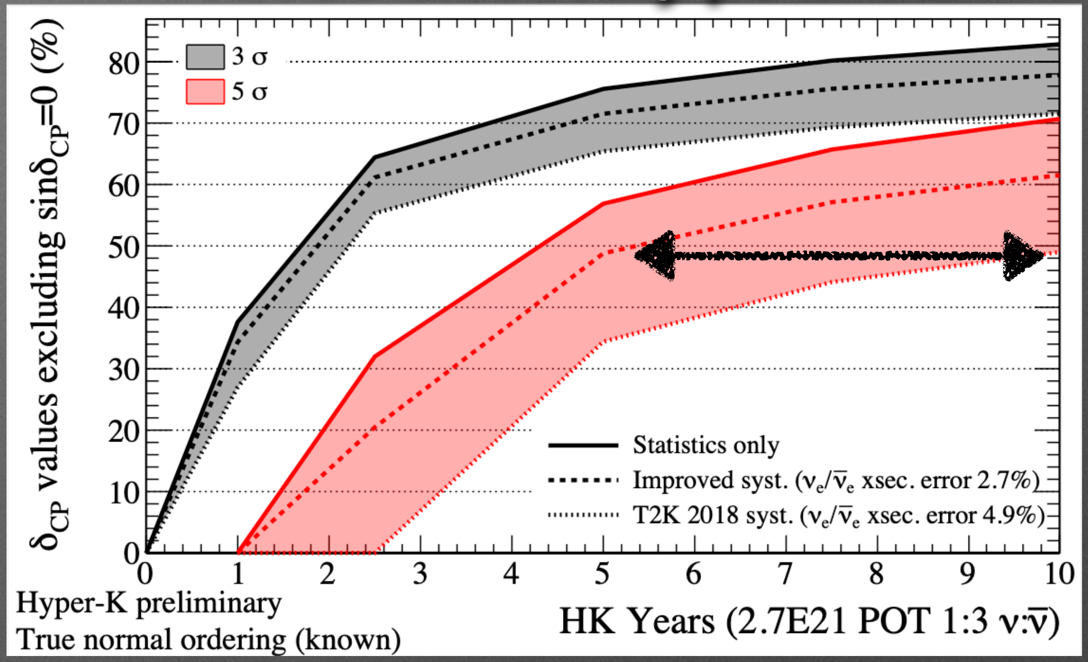


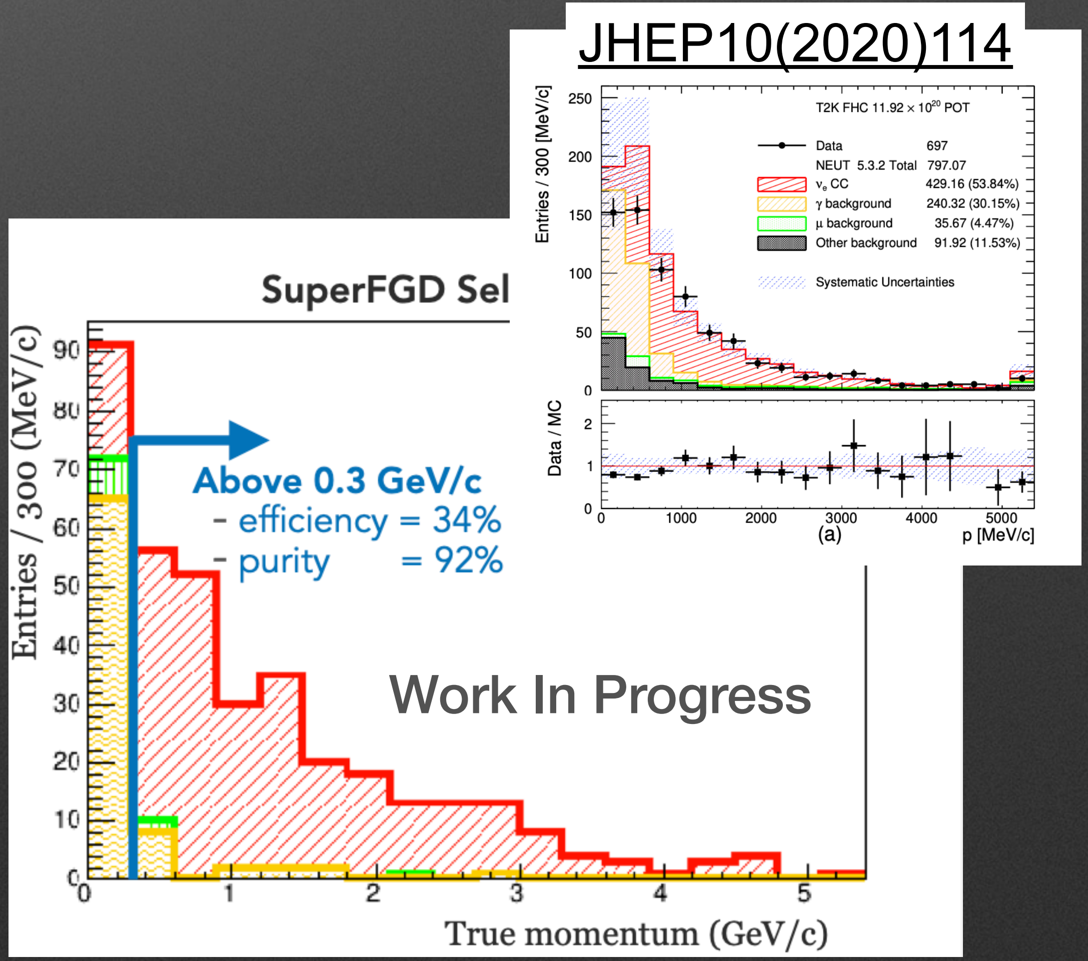
- Analyses done so far by ND280 mostly exploited the μ kinematics
- Reconstruct muons and protons (neutron) emitted in ν ($\overline{\nu}$) QE interactions
  - Reconstruct variables in the transverse plane → more sensitive to nuclear effects → $\delta p_T = |p_T{}^{\mu} - p_T{}^{p(n)}|$
  - $E_{vis} = E_{\mu} + T_{p(n)}$ → where T is the kinetic energy
    - Evis better estimator of the neutrino energy than QE formula
- ND280 Upgrade will exploit these variables to better constraint cross-section systematics
  - Benefit of the upgrade for T2K-II but also for Hyper-K

ν_e in the ND280 Upgrade

- One of the main systematics in the quest for CPV are the uncertainties on ν_e (and $\overline{\nu}_e$) cross-sections
- This measurement is particularly difficult in ND of LBL experiments → the beam contains ~1% of ν_e
- ND280 already did few measurements of ν_e cross-sections with a purity of ~55%
- Thanks to the superior capabilities of ND280 Upgrade we expect to sensibly improve this measurement → 90% purity vs 55% purity for the same efficiency
- ND280 is magnetized → possible to measure ν_e and $\overline{\nu}_e$

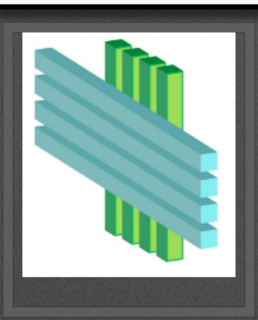
HK 5σ discovery potential



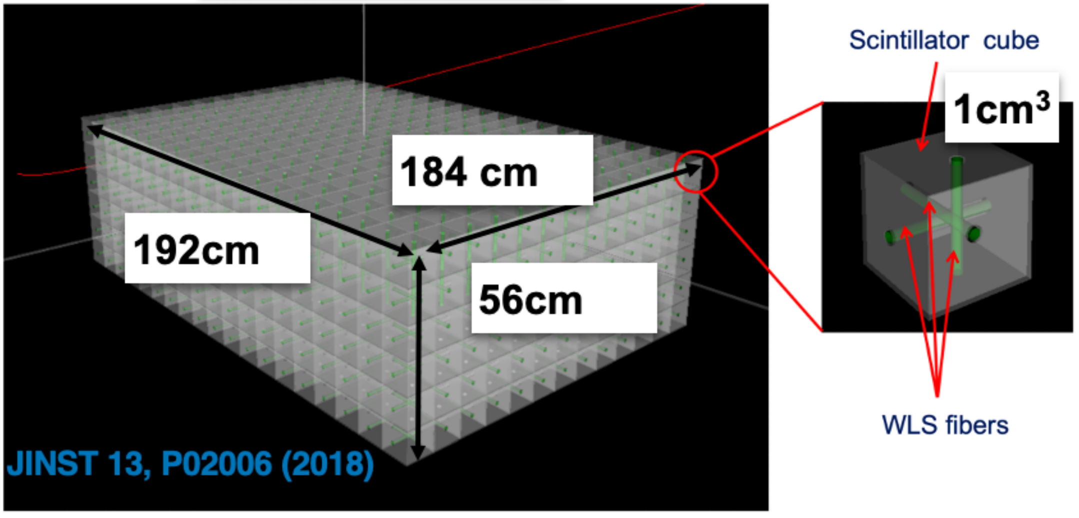


Super-FGD

FGD concept

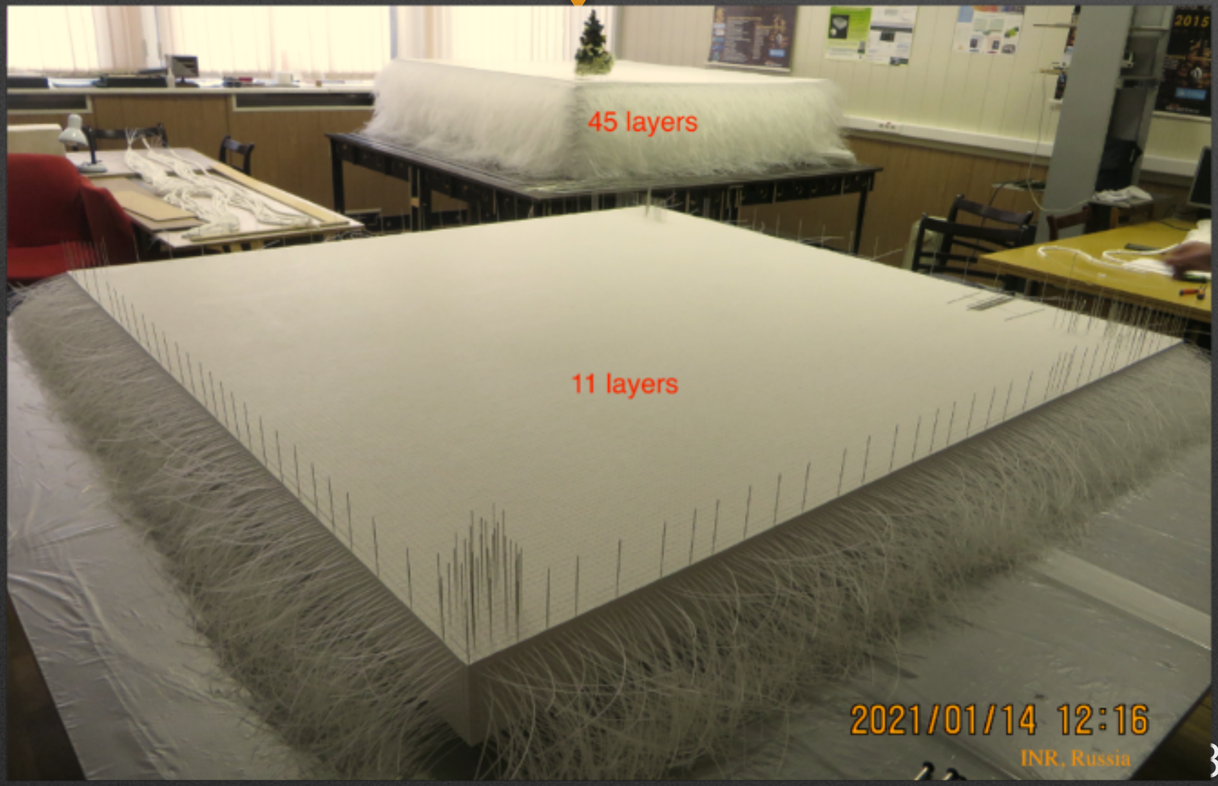


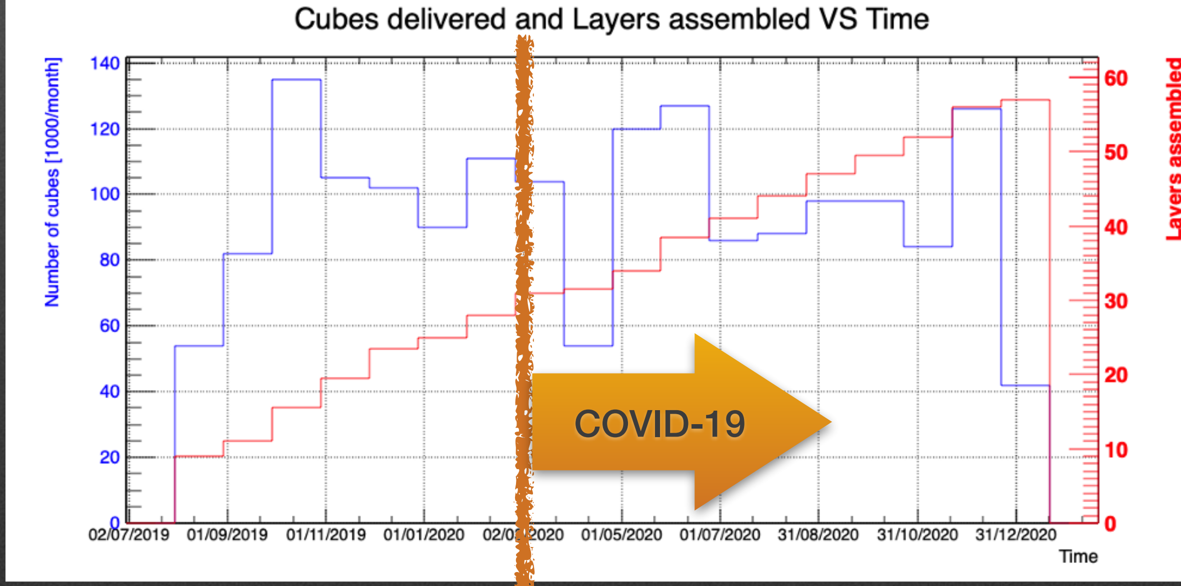
SuperFGD concept



- 2 millions $1cm^3$ cubes → **assembled in 56 x-y layers**
- Light in each cube is collected by 3 WLS (3 views)
- Light carried by the WLS is read by **56k MPPCs** mounted on PCB
- **Electronics** based on CITIROC chips

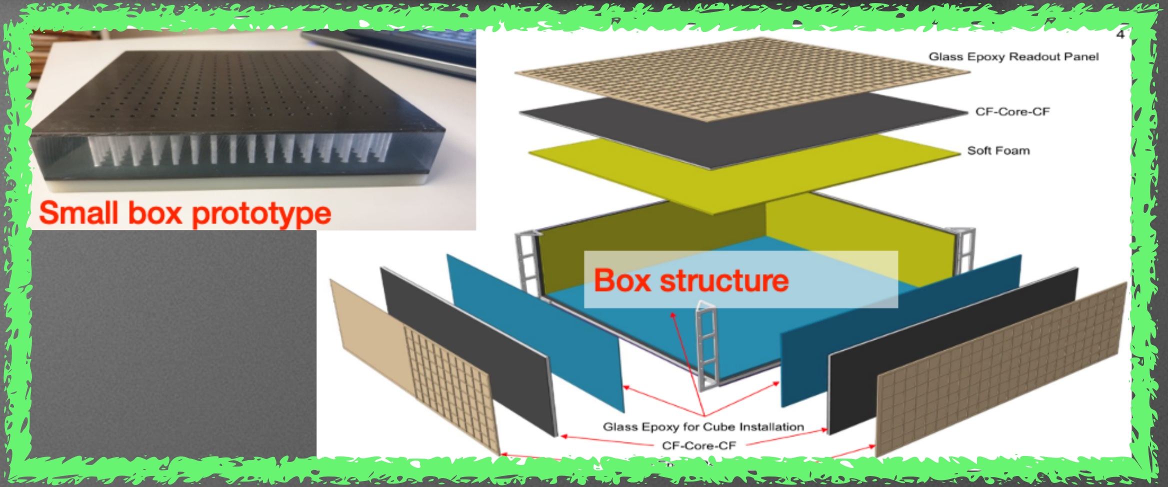
From drawings
to reality



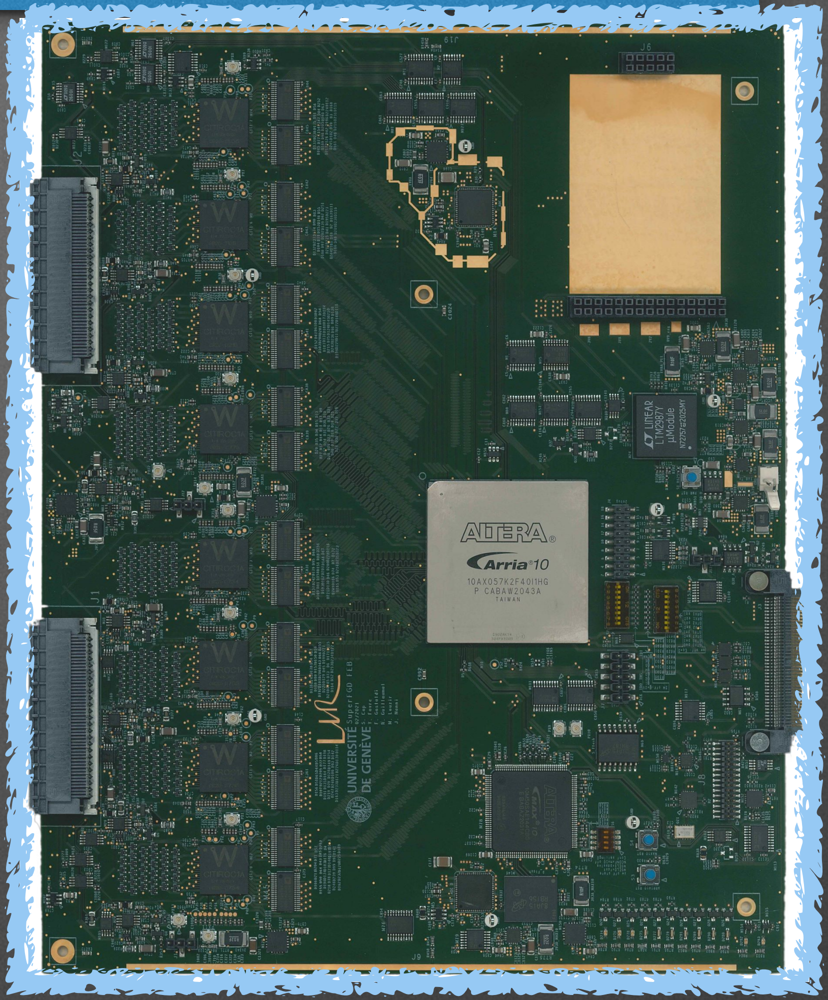


Super-FGD status

- Mechanical box in which cubes will be inserted is being produced
  - Box will arrive at J-PARC in March 2022
- Once the box is there we will install cube layers inside and then we will
  - Install wavelength shifting fibers
  - Install MPPC (64 MPPC per PCB)
  - Install the calibration system
  - Ready for the installation of the electronics by Summer 2022

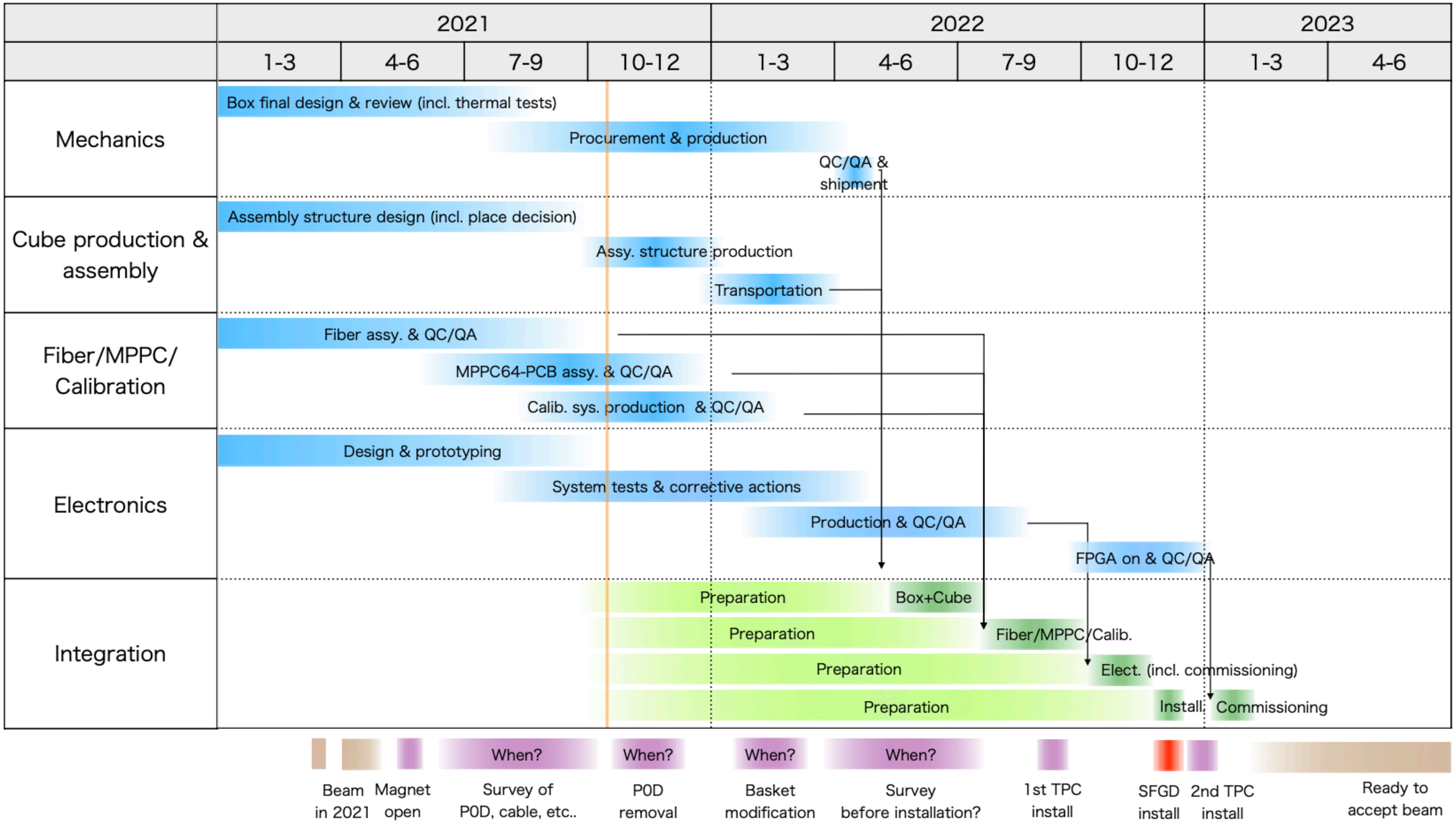


Super-FGD electronics

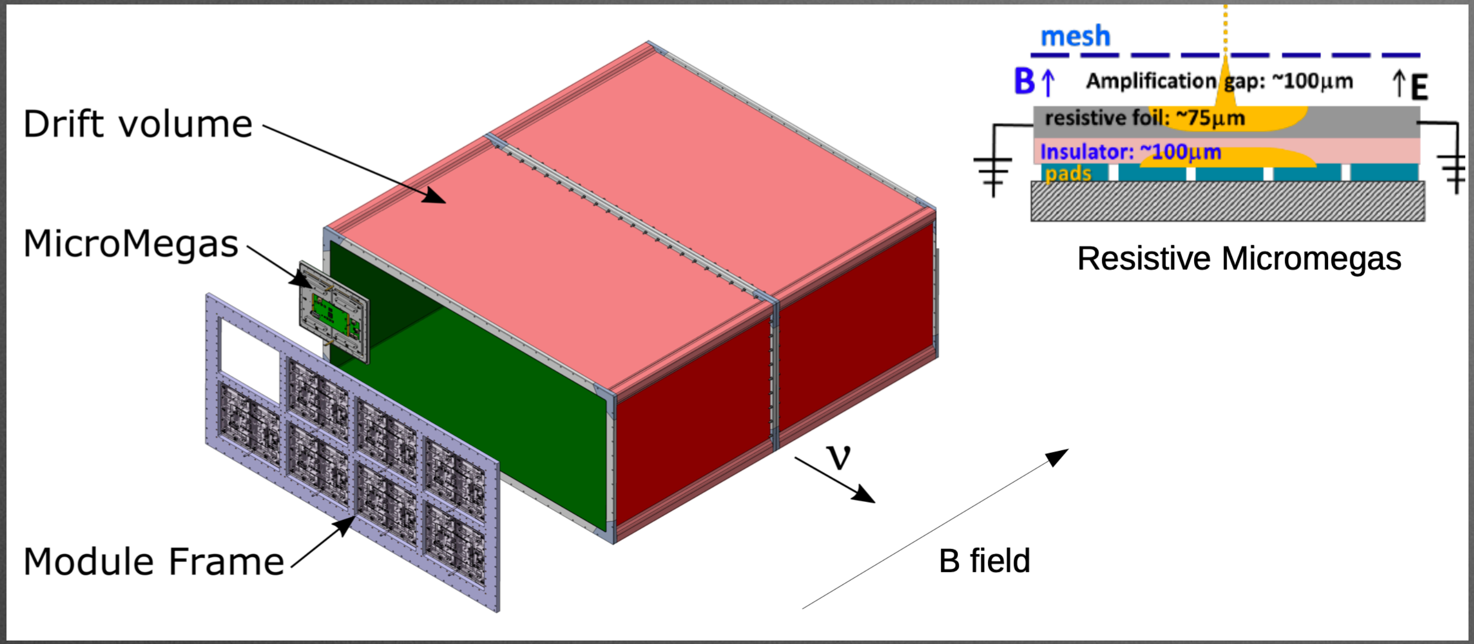


- Back-End electronics → US institution
- Front-End electronics → LLR + University of Geneva
- Super-FGD electronics based on the CITIROC chips
  - 8 CITIROC chips per board
  - ~230 boards to be produced
- First prototype has been produced and is being validated
- Production of the remaining boards might be delayed due to worldwide shortage of FPGA
  - Delivery of FPGA expected in September 2022 → trying to mitigate the impact of this delay
  - In the worst case the Super-FGD electronics will be ready by the end of 2022

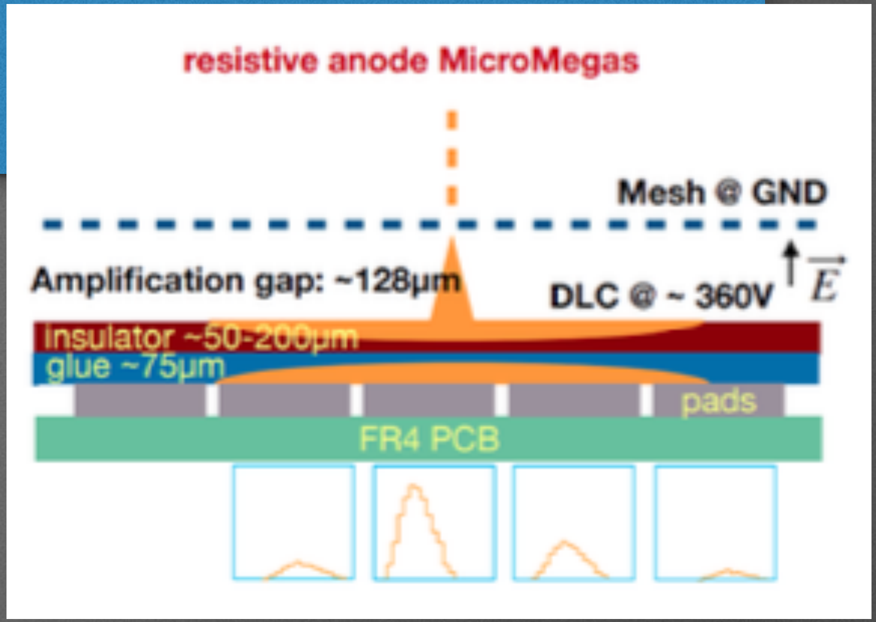
Super-FGD schedule



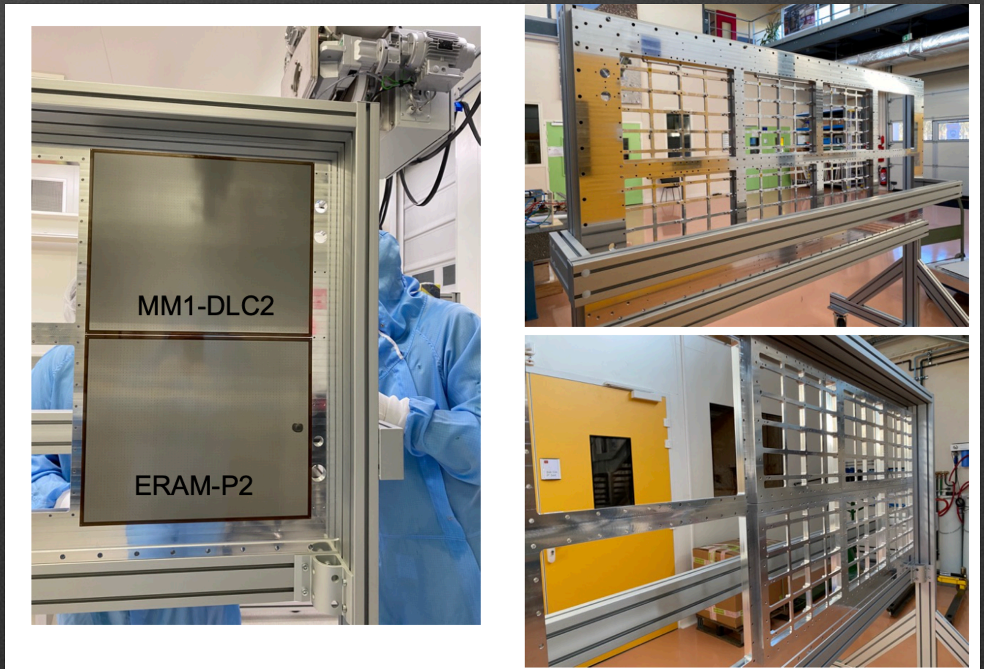
HA-TPC



- TPC operated at atmospheric pressure
- Design similar to the one of the existing ND280 TPCs
- Main differences: use of resistive MicroMegas (ERAM modules) and thin field cage



- Resistive MM → charge is spread over several pads
- Improve the spatial resolution by comparing charge in the different pads
- Reduce risk of sparks

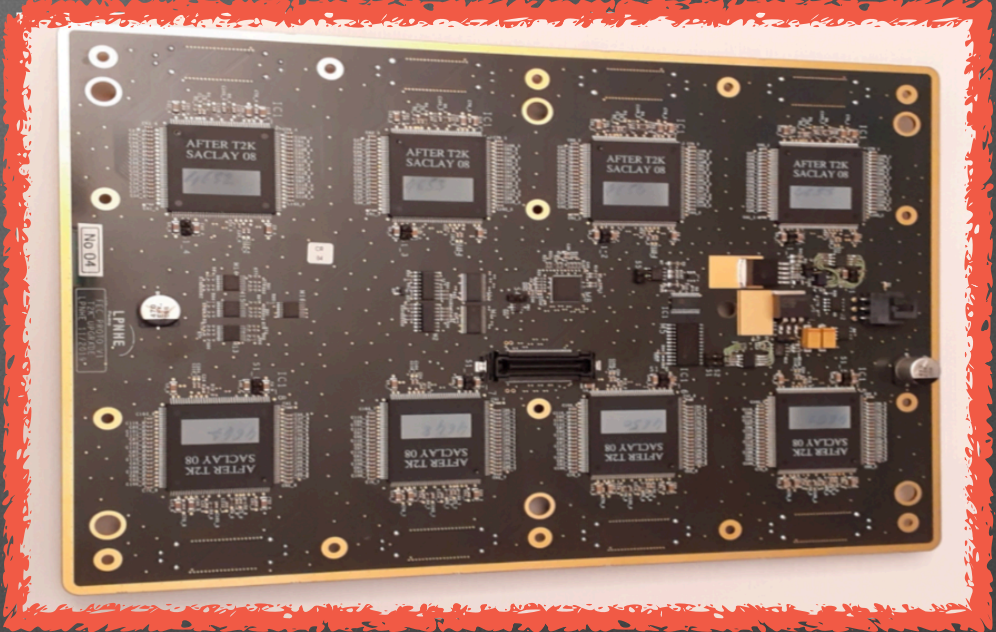


HA-TPC electronics

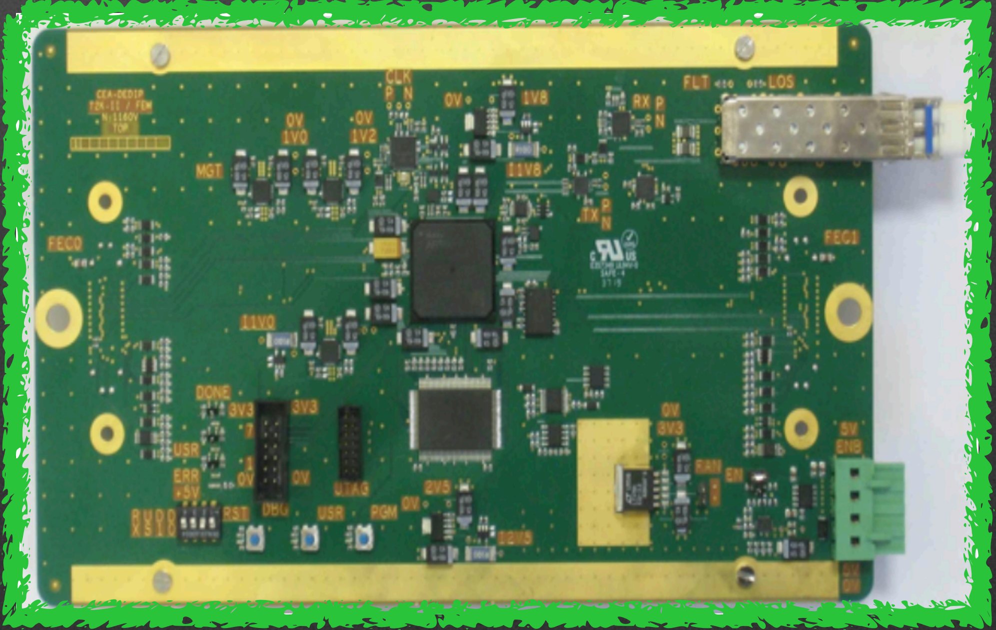
LPNHE+IRFU

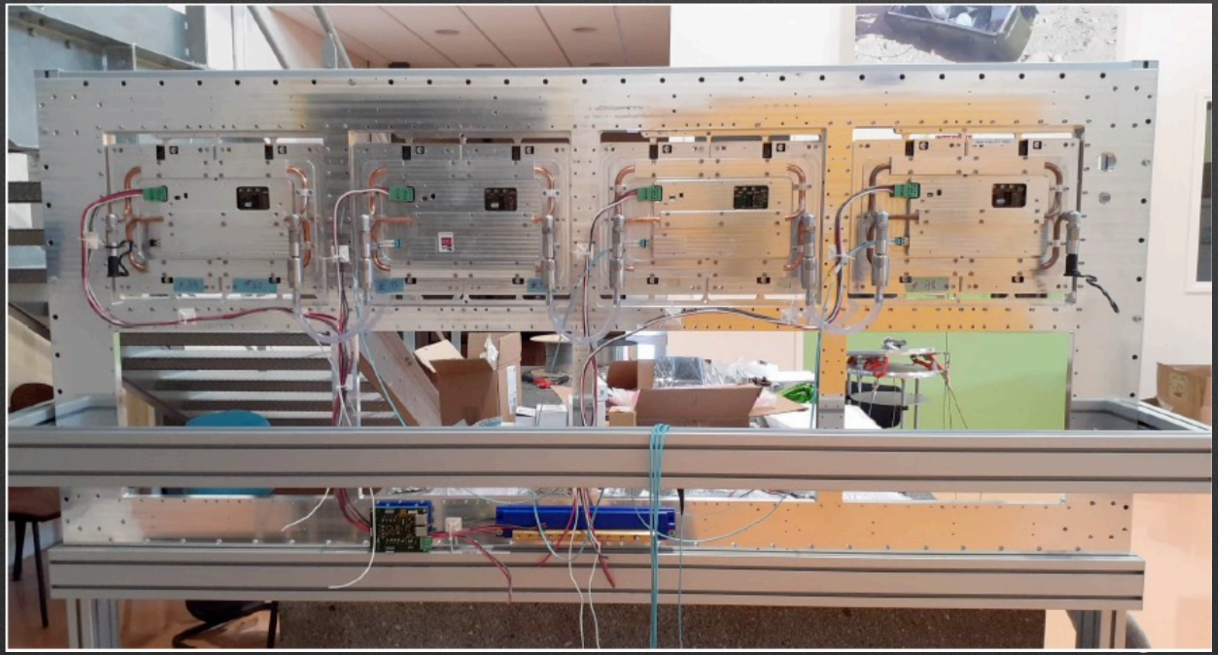
- Electronics based on the AFTER chips that were designed for T2K
- 8 chips embedded on the Front-End-Cards that will be mounted parallel to the ERAM modules (2 FECs for each ERAM) → LPNHE responsibility
- The FECs are connected to a FEM (Front-End Mezzanine) card and then the signal is sent to the back-end electronics
- Full electronics chain (FEC, FEM, TDCM, DAQ) tested during recent DESY Test Beam
- Production of 72 FECs at Ouestronic (Rennes) completed in 2021

FEC



FEM

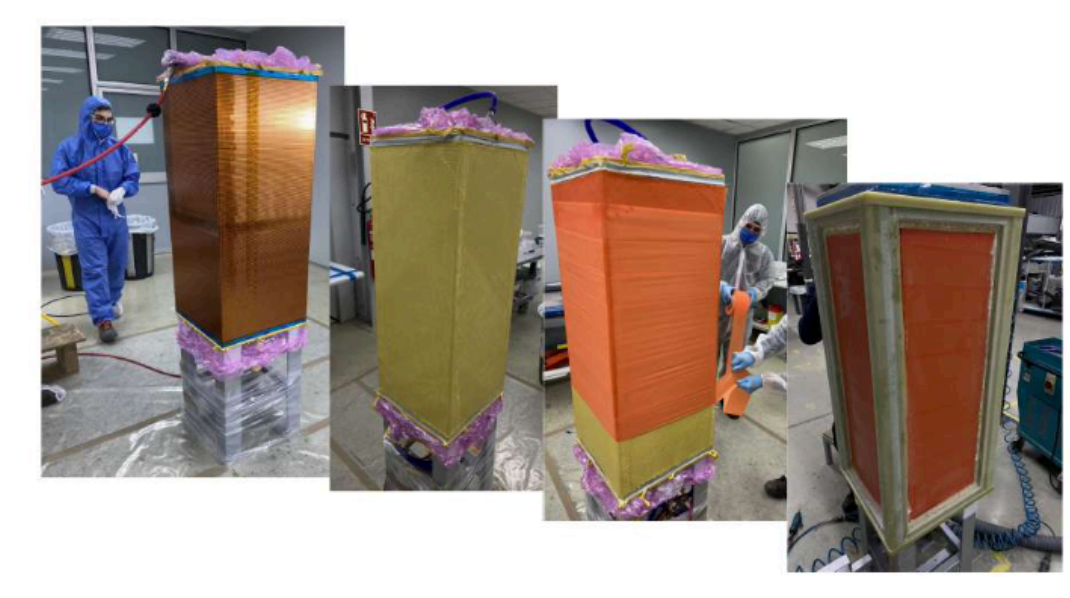


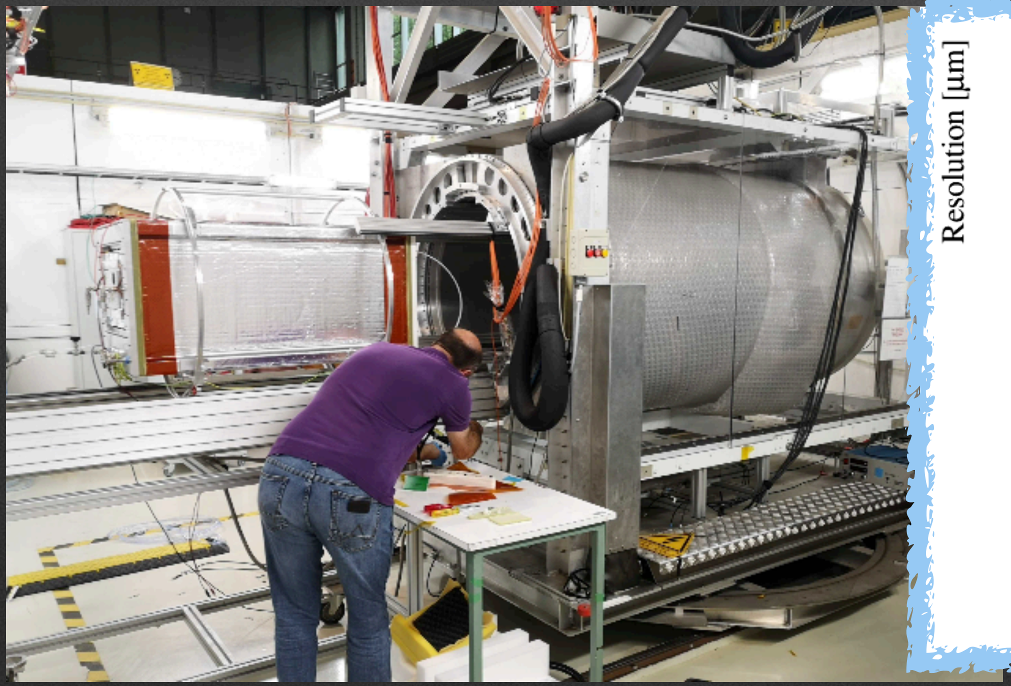


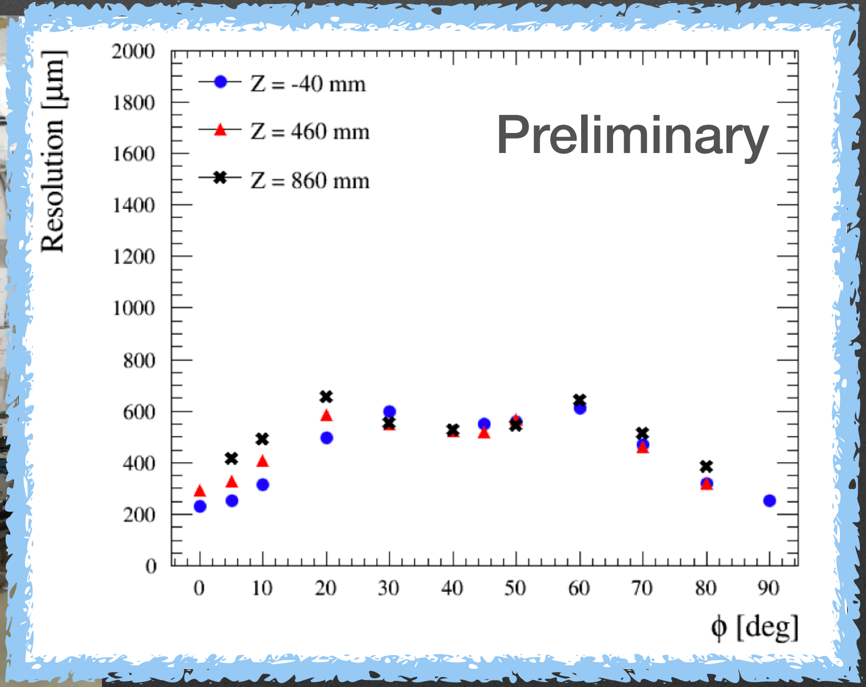
DESY Test Beam

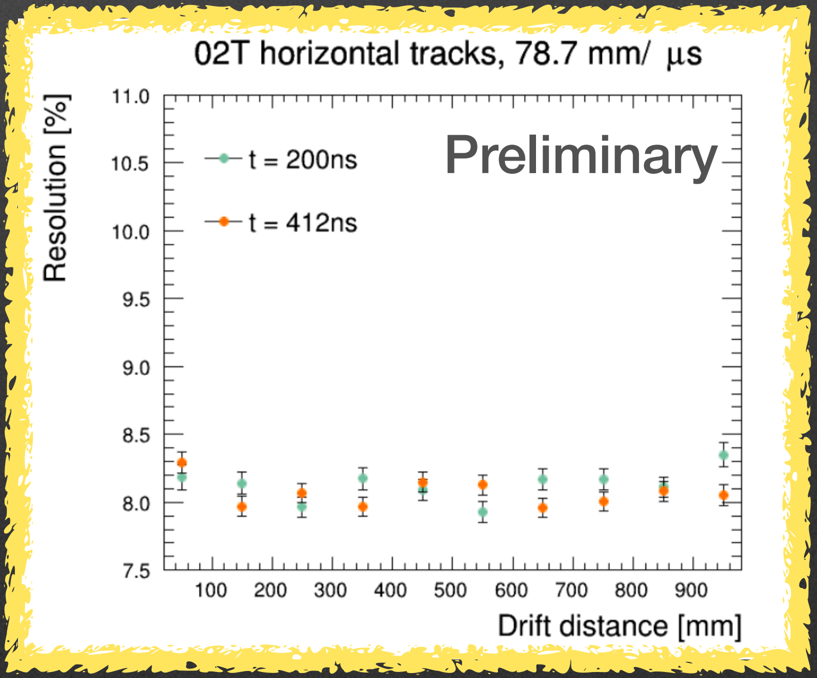
- 2 field cage prototypes have been produced in order to fix design of the field cage
- Instrumented with 1 ERAM module and final HA-TPC electronics
- Test Beam at DESY in July 2021
- Preliminary analysis show performances better than our requirements:
  - Spatial resolution between 200 and 600 μm (depending on angle and drift distance)
  - dE/dx resolution ~8% for tracks crossing one ERAM module

2019 test beam data:
arXiv:2106.12634
submitted to NIM









HA-TPC Schedule

- First half of the field cage has been produced at NEXUS and will be delivered at CERN in November

- 8 ERAM modules needed to instrument first half of the TPC are being produced at CERN and will be tested on the new Field cage

- Assembly the ERAM modules and the electronics on field cage in November

  - Commissioning with cosmics

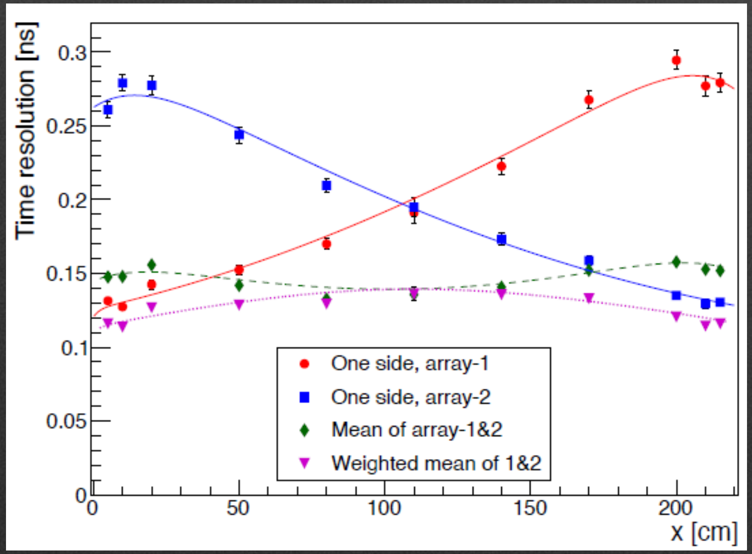
- The remaining 3/4 of HA-TPCs will be delivered in the next months (2 months of production time for each 1/2 FC)

  - Ready for installation at J-PARC in the second half of 2022

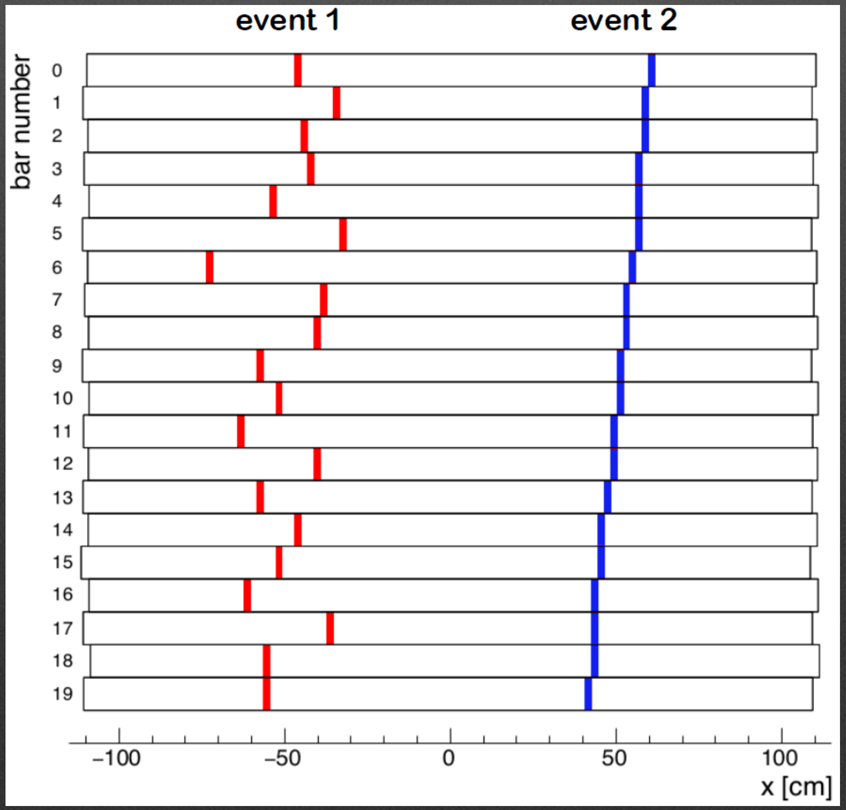
TOF

- The 6 TOF modules have been assembled and tested at EHN1 at CERN
- Cosmics tests done with one full module to confirm all channels are working and perform preliminary calibration and alignment
- Assembly of the TOF modules on the baby-basket done at CERN

Time resolution 140 ps



Shower Track

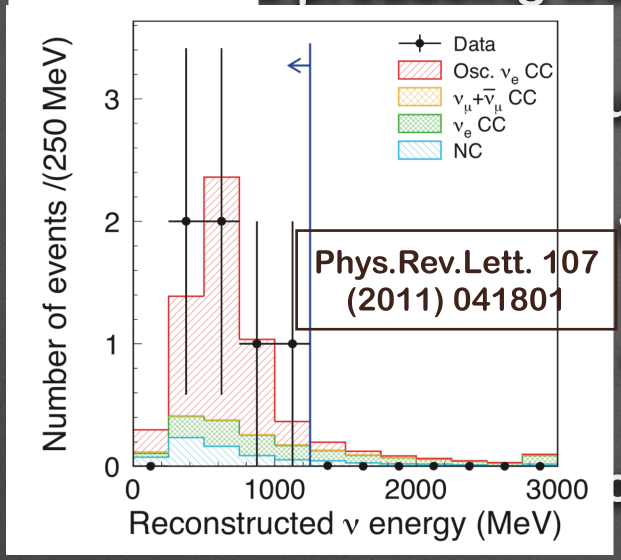


Conclusions

- T2K is producing world leading measurements in the neutrino field since 2010
    - Recent paper published on Nature observed first hints of CP violation in the leptonic sector
- Close collaboration with Super-K to perform joint analysis of beam+atmospheric ν
- The phase-2 of T2K will start in 2022
    - 3σ observation of CP violation by 2027 for large values of δ_{CP}
- ND280 Upgrade will be a crucial part of the physics programme of T2K-II
    - We will install the detectors at J-PARC in 2022
    - Great step forward in the understanding of neutrino-nucleus cross-section
- Well recognized expertises of IN2P3 groups in T2K (OA conveners, x-sec Convener, ND280 Upgrade coordination, …)
- Starting from 2027 ND280 will be the near detector of Hyper-Kamiokande
    - Contribute to the exciting physics that will be produced by HK → see Mathieu's talk
    - Systematics uncertainties under control from day 1 of HK

Conclusions

2011



Phys.Rev.Lett. 107 (2011) 041801

2019

The international journal of science / 16 April 2020

nature

THE MIRROR CRACK'D

An indication of matter–antimatter symmetry violation in neutrinos

Coronavirus The models driving the global response to the pandemic

Hot source Remnants of primordial nitrogen in Earth's mantle

Origin of a species Revised age for Broken Hill skull adds twist to human evolution

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  - …e exciting physics … → see Mathieu's talk
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T2K - T2K-II - Hyper-K : Seamless and exciting programme of detectors construction, world leading measurements, and discoveries since 2005 and until 2040 (and beyond…)

2022