Mauro Mezzetto

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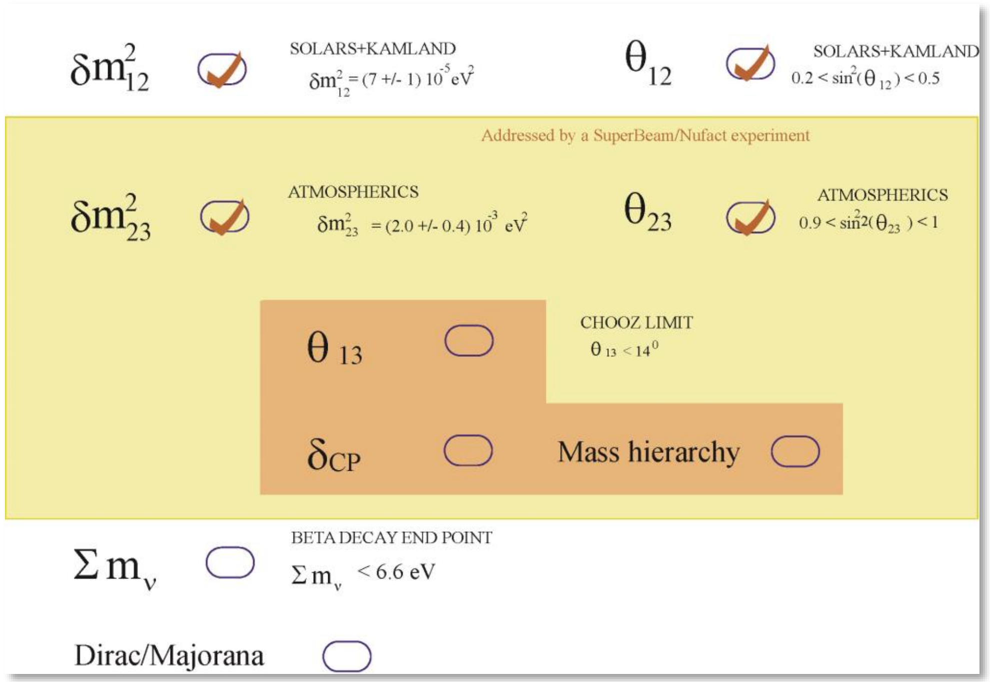
Status and perspectives of Neutrino Oscillation Experiments

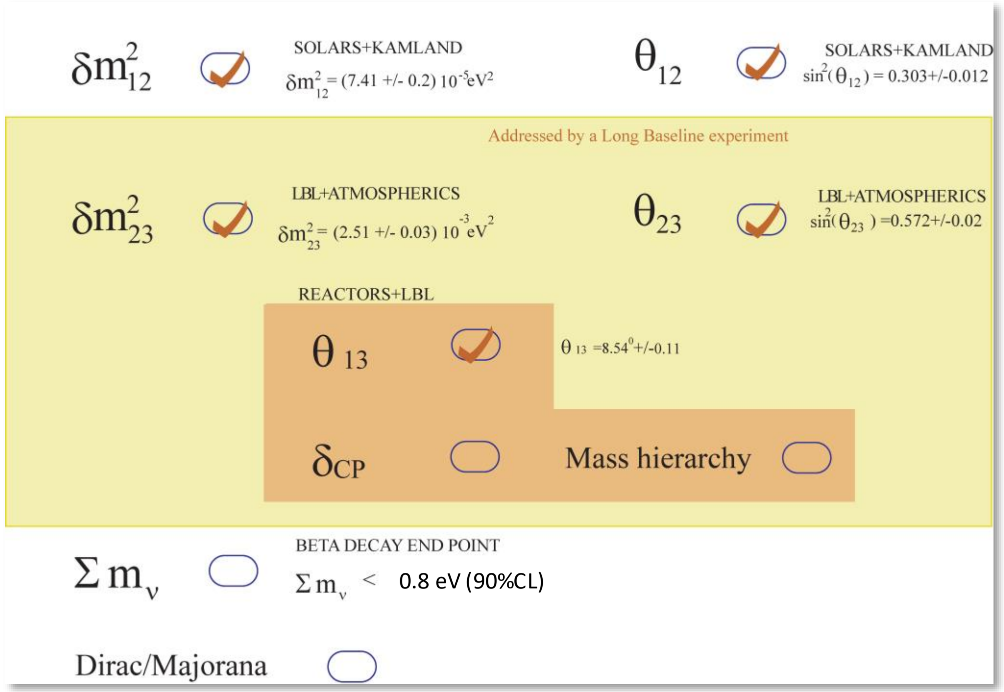
Muon4Future, Venice, 30/05/2025

Neutrino Physics in the past 20 years

2005



2025



Apparently not a great record (but have a look to the greatly increased precision).
So why several thousands of physicists are joining next generation long baseline experiments, which are among the priorities in hep in many countries (Italy included)?
Let's have a closer look to the achievements of neutrino oscillations physics

Major achievements in neutrino oscillations

Before 90's: detection of Solar Neutrinos (**Homestake**) and detection of SuperNova neutrinos (**Kamiokande**), awarded with the **2002 Nobel Prize** to Ray Davis and Masatoshi Koshiba *"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos* "

Low energy neutrino astronomy remains a pillar of the physics case of the far detectors of Long Baseline neutrino experiments

At the same conference, **Chooz** reported no evidence of reactor $\bar{\nu}_e$disappearance while **MACRO** reported a ~2.5σ signal of atmospheric neutrino oscillation

1998: **Super-Kamiokande** discoveries neutrino oscillations by studying atmospheric neutrinos. Awarded with the **2015 Nobel Prize** to Takaaki Kajita "***for the discovery of neutrino oscillations, which shows that neutrinos have mass***"

2002: **SNO** provides a model independent signature of solar neutrinos oscillations. Art McDonald shares the 2015 Nobel prize.

Gallex/GNO at LNGS had provided a model dependent evidence of solar neutrino disappearance

T2K and then **Double Chooz** reported early indications of non-zero θ_{13} values

2012: the reactor experiments **Daya Bay** and **RENO** provide the first observation of a non-zero value of θ_{13}. Awarded with the EPS-HEP prize in 2023. For a longer discussion of the θ_{13} saga you can read the long citation of the prize. SK, SNO, Kamland, Daya Bay and T2K awarded with the Breakthrough prize 2016

… from the photo album of Istituto Veneto.

M. Koshiba, 1988

Ray Davis 1990

Art Mc Donald, 2011

T. Kajita was here in 2007 and 2009, but this picture is taken in 2016 when he received a Laurea Honoris Causa by Padova University

Why neutrino oscillations matter

Neutrino oscillations → neutrinos are massive ($\Delta m^2 \neq 0$)

In two ν generations (α,β flavor, i,j mass eigenstates):

$$P(\nu_\alpha \to \nu_\beta, \alpha \neq \beta) = \sin^2(2\theta_{ij}) \sin^2(1.27 \frac{\Delta m^2_{ij}(eV^2) L(km)}{E(GeV)})$$

In the Standard Model neutrinos are **massless**

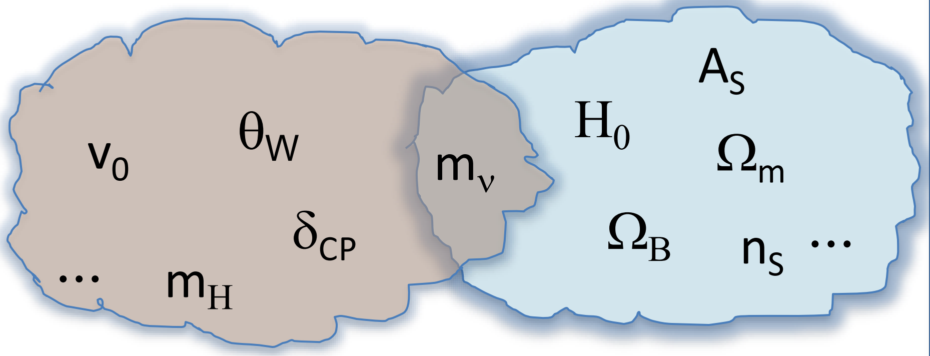
- Absence of right-handed neutrinos → **no Dirac mass for neutrinos**
- Lepton number is an accidental symmetry at the renormalizable level → given SM fields and gauge symmetry, lepton number cannot be violated at dimension 4 → **no Majorana mass can be generated**

New physics is required to give mass to neutrinos

- Neutrino masses are only parameter measurable both by hep and cosmology
- **A crucial test of consistency**

Standard model of particle physics

Standard model of cosmology



But …

Cosmology measures $\sum_i m_i$

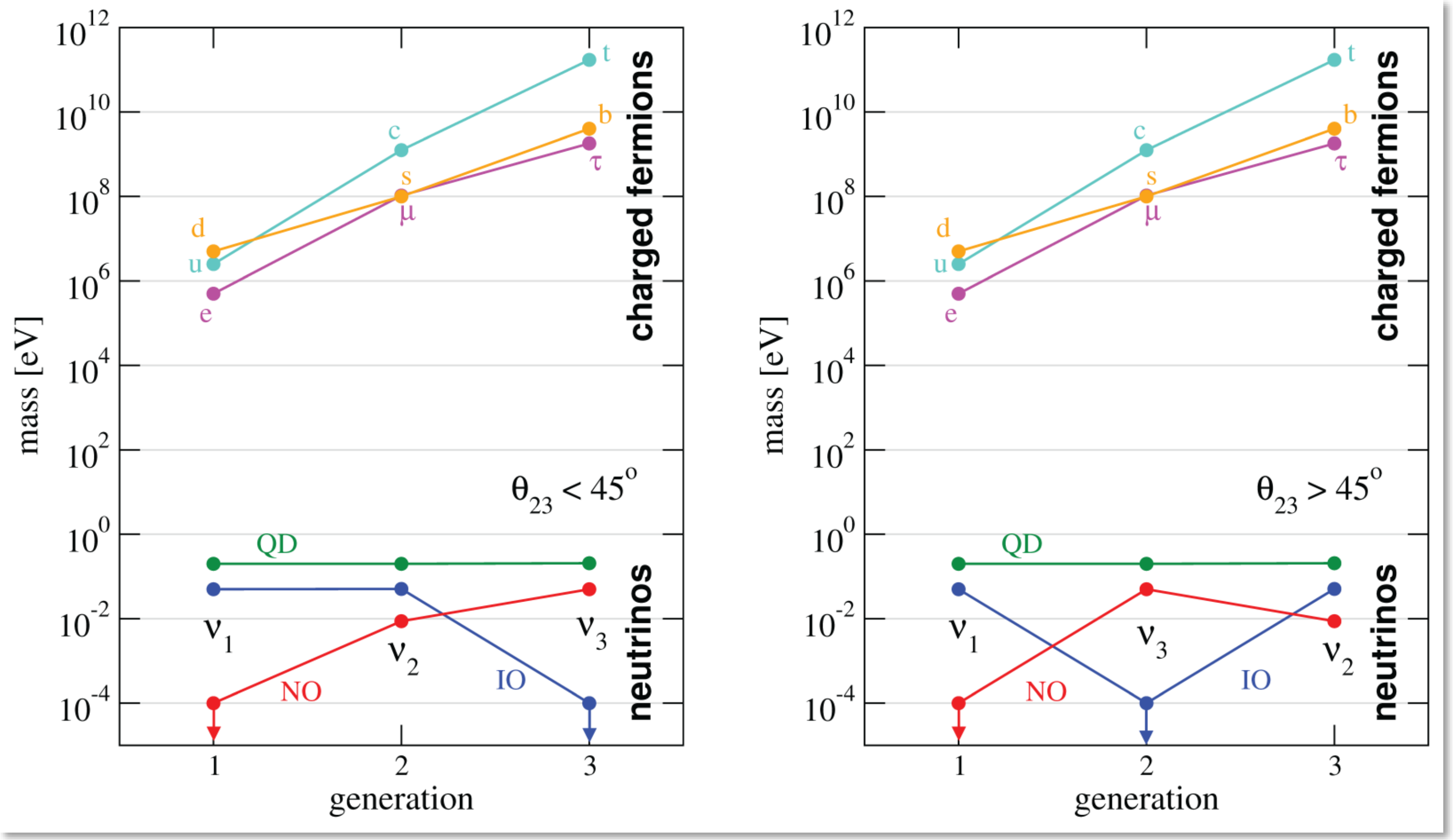
Double beta decay measures $\left|\sum_i U_{ei}^2 m_i\right|$

Direct searches measure $\left(\sum_i |U_{ei}^2| m_i^2\right)^{\frac{1}{2}}$

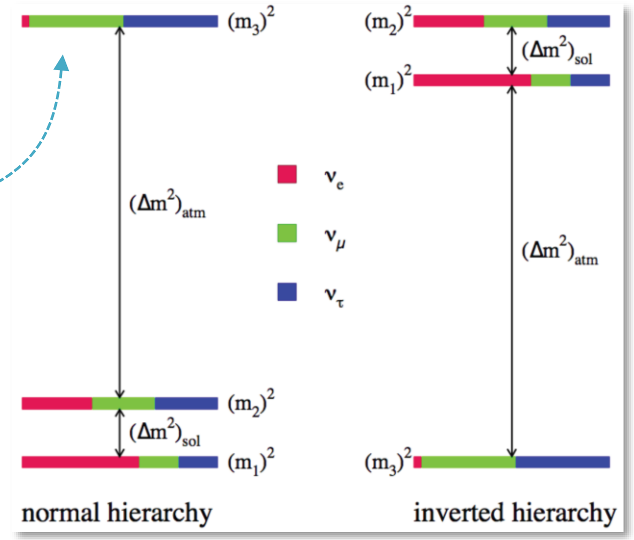
To **single out** individual neutrino masses you need to measure neutrino mass ordering.

What do neutrino oscillations still have to say about ν masses?

Neutrino oscillations cannot measure absolute neutrino masses, but can determine their pattern by measuring **neutrino mass ordering** (NMO) and the **octant** of θ_{23} (which decides if ν_3 is mostly ν_μ or ν_τ)

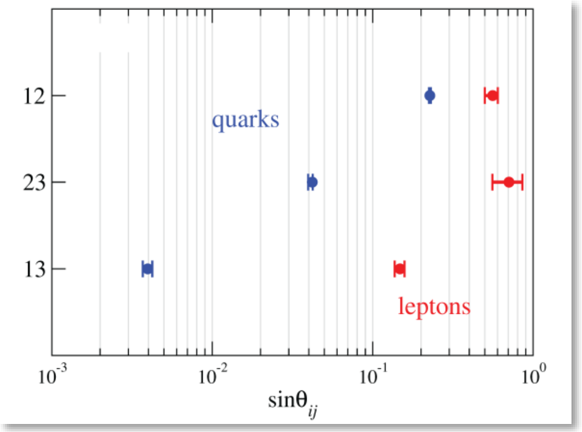


From T. Schwetz talk at EPS-HEP 2021



Neutrino mass ordering: normal (NO) or inverted (IO), measurable by Long Baseline experiments (the 1-2 ordering already decided by solar oscillations)

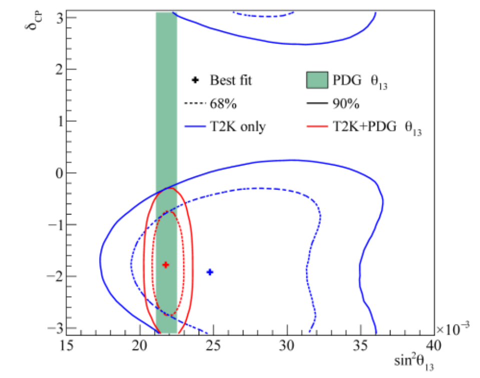
The **neutrino mixing** is also very different from quarks



Why θ_{13} matters

No way to decide next generation LBL strategy without knowing the θ_{13} value**:**
A "small" θ_{13} value (÷2) would have made conventional neutrino superbeams (the same neutrino beams of the '70s + brute force) useless: need for new concepts as neutrino factories or beta beams. Neutrino mass ordering searches would have been almost impossible.

θ_{13} as measured via $\bar{\nu}_e$ disappearance by reactor experiments breaks any θ_{13}-δ_{CP} degeneracy in LBL experiments and greatly improves their sensitivity



T2K: *Eur.Phys.J.C* 83 (2023) 9, 782

The Jarlskog invariant in neutrino oscillations:

$$J_\nu = \sin\theta_{13}\cos^2\theta_{13}\sin\theta_{12}\cos\theta_{12}\sin\theta_{23}\cos\theta_{23}\sin\delta_{CP}$$

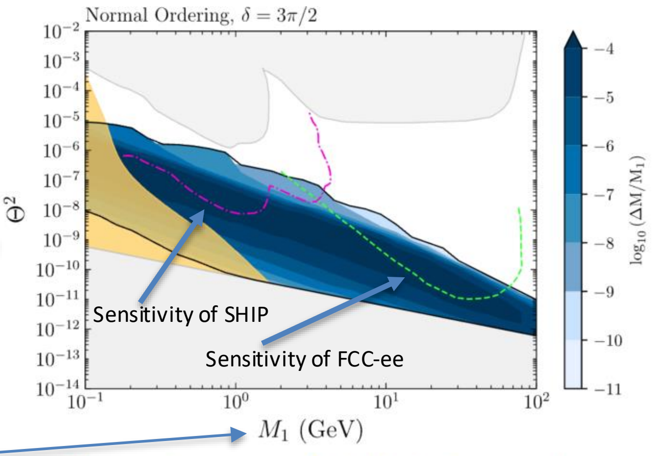
has a maximum value about three orders of magnitude bigger than the invariant in the quark sector

$J_\nu(\max) = 3.2 \cdot 10^{-2}$

$J_{quark} = 3.8 \cdot 10^{-5}$

opening the possibility of a role of neutrino oscillations in explaining the **matter-antimatter asymmetry** in the Universe through Leptogenesis.

Granelli, Pascoli, Petcov, Phys.Rev.D 108 (2023) 10, L101302



See-saw parameters

Parameter space of viable leptogenesis with CP violation coming only from δ_{CP}

Three generations of Long Baseline Experiments

Long baseline experiments produce intense ν_μ ($\bar{\nu}_\mu$) beams and detect them at the maximum of atmospheric oscillations.

Leading process are $\nu_\mu \rightarrow \nu_\tau$ oscillations, and so ν_μ disappearance, allowing to measure the atmospheric parameters θ_{23} and Δm^2_{23}

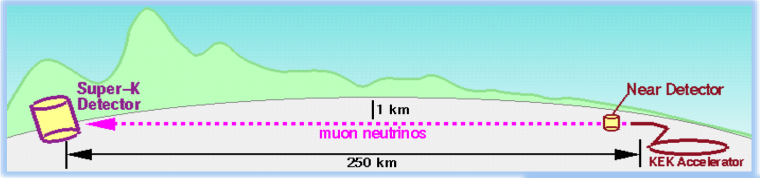
Subleading process are $\nu_\mu \rightarrow \nu_e$ oscillations, sensitive to θ_{13} and δ_{CP}

Subleading ν_e appearance formula

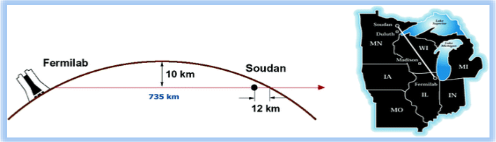
$$p(\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2\frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1-2s_{13}^2)\right] \quad \theta_{13} \text{ driven}$$
$$+ 8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$
$$\mp 8c_{13}^2 c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{CPodd}$$
$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$
$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1-2s_{13}^2) \quad \text{matter effect (CP odd)}$$

Disappearance formula

$$P(\nu_\mu \to \nu_\mu) \simeq 1 - 4\cos^2\theta_{13}\sin^2\theta_{23}[1 - \cos^2\theta_{13}\sin^2\theta_{23}]\sin^2\frac{\Delta m_{23}^2 L}{4E}$$



First Generation: **K2K** in Japan, aimed to **confirm** the Super-Kamiokande results with accelerator neutrinos by detecting ν_μ disappearance.

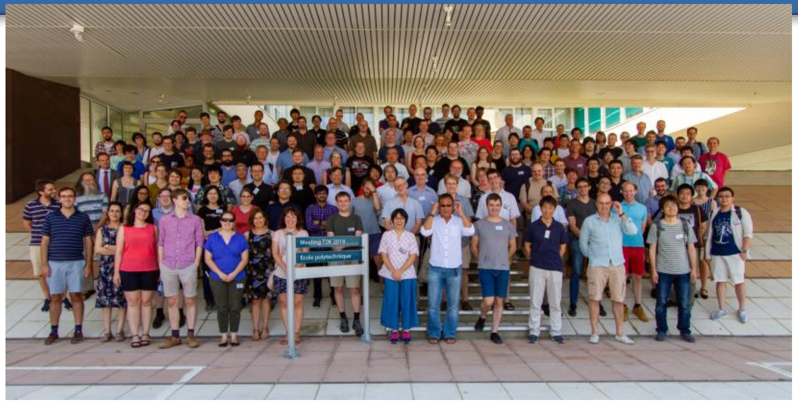


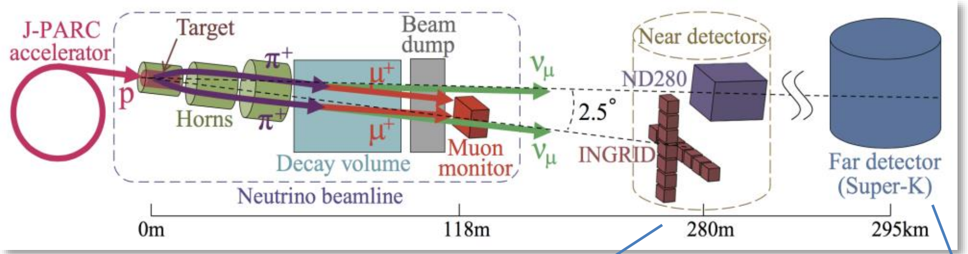
Second Generation: **Minos** in the States (ν_μ disappearance) and **Opera** at CNGS (ν_τ appearance), aimed to **improve** the Super-Kamiokande results.

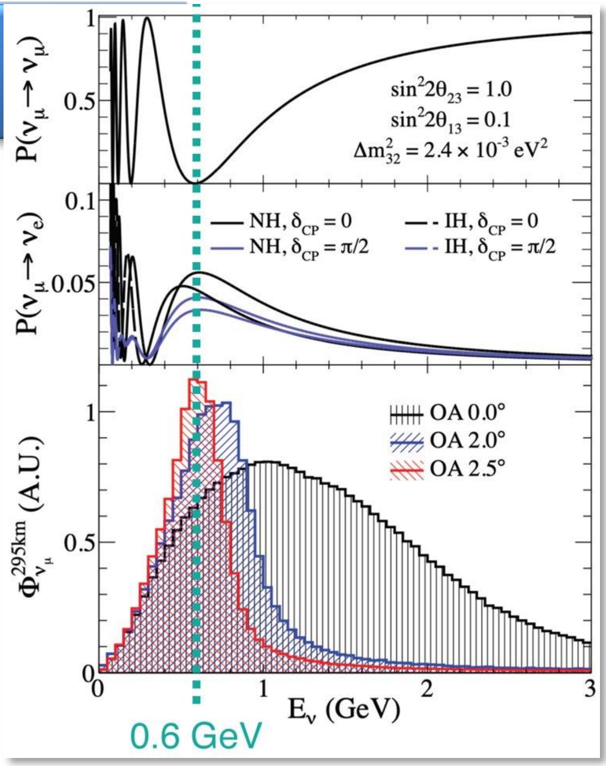
Third Generation: **T2K** in Japan and **NOvA** in the States. Sensitive to subleading processes, aimed to **measure θ_{13}** and **constrain CP violation** in the leptonic sector.

The T2K experiment

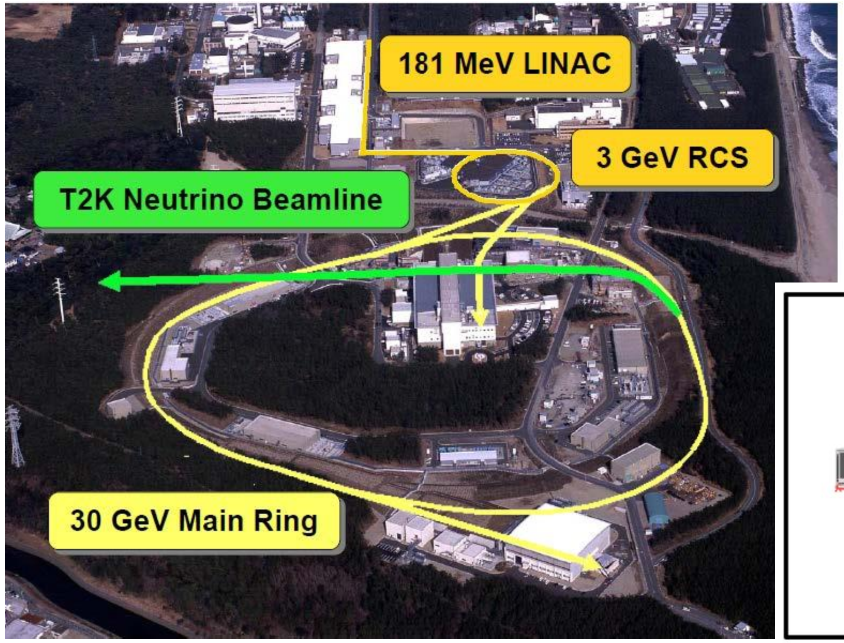
- T2K: Tokai to Kamioka (295 km baseline)
- Running since 2010
- ~575 members, 75 Institutes, 14 countries
- First indication of $\theta_{13} \neq 0$
- Precise measurements of the atmoshperic parameters θ_{23} and Δm^2_{23}
- Constrain the CP violation phase δ_{CP}
- Neutrino cross-section measurements

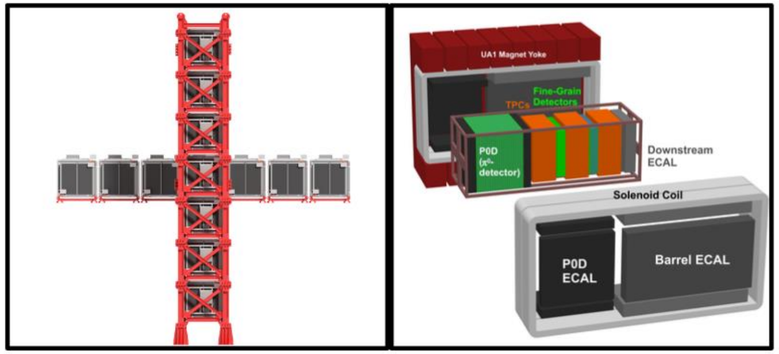


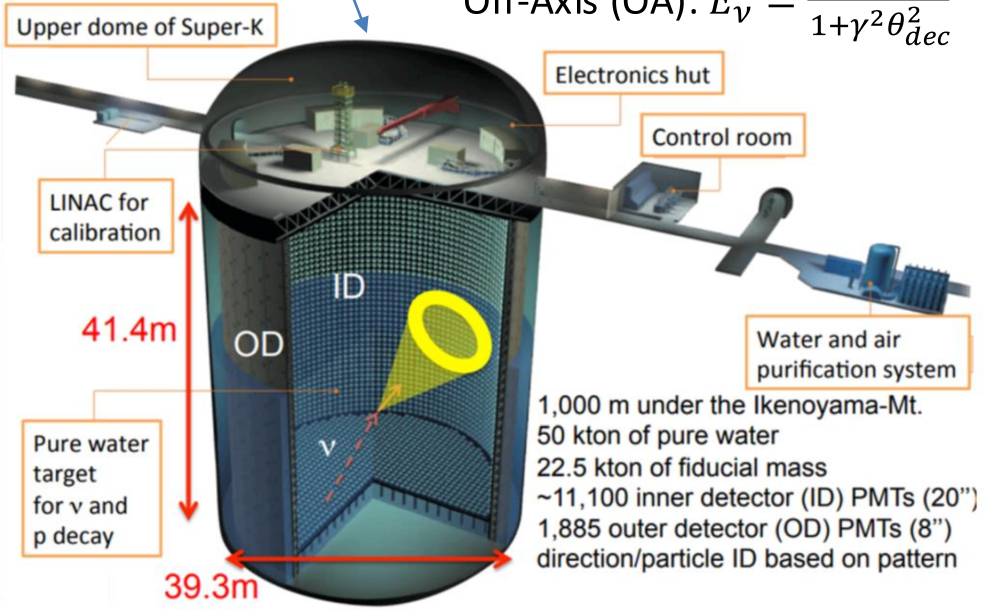


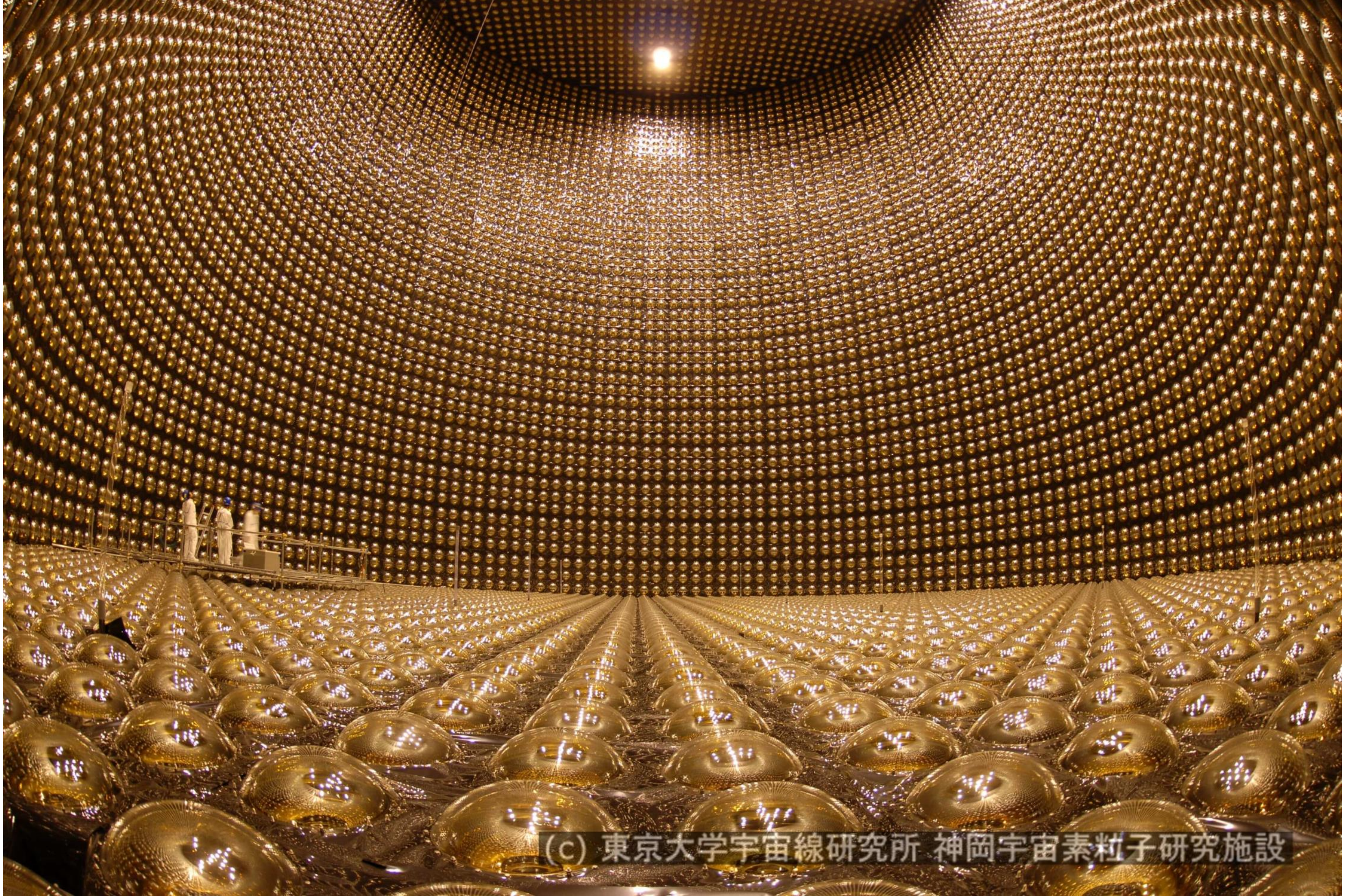


Off-Axis (OA): $E_\nu = \frac{0.43\, E_\pi}{1+\gamma^2\theta^2_{dec}}$



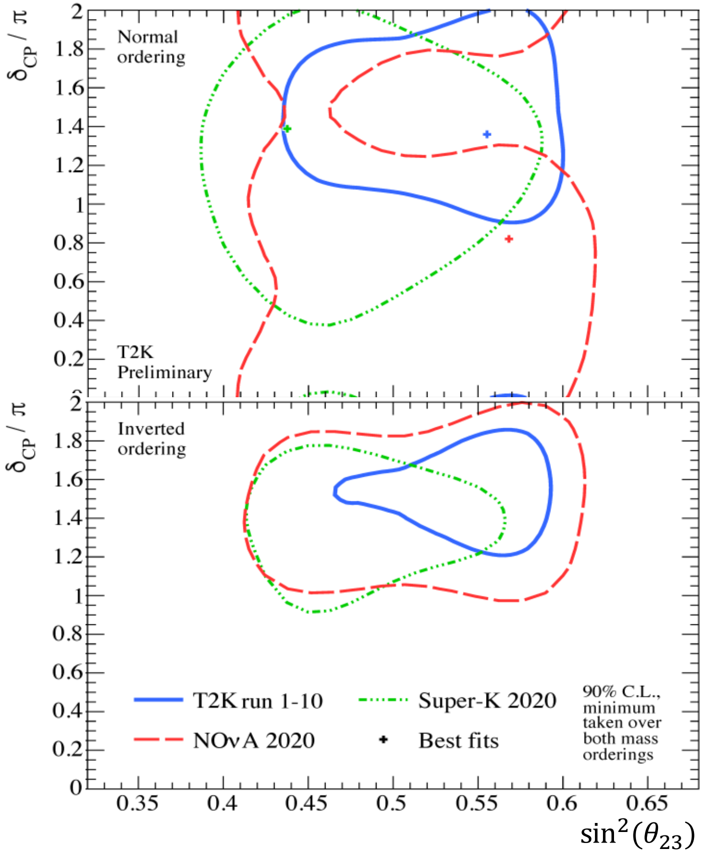





(c) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設

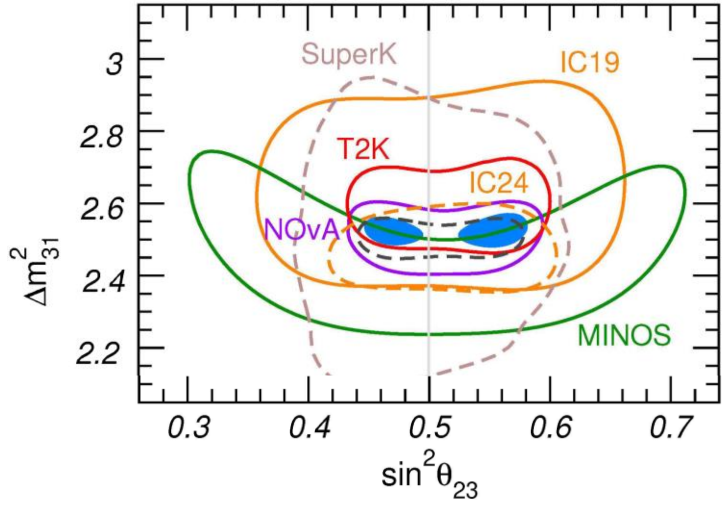
Present status of neutrino oscillations

T2K, Nova and Super-K results about δ_{CP}.
Tension in case of NO



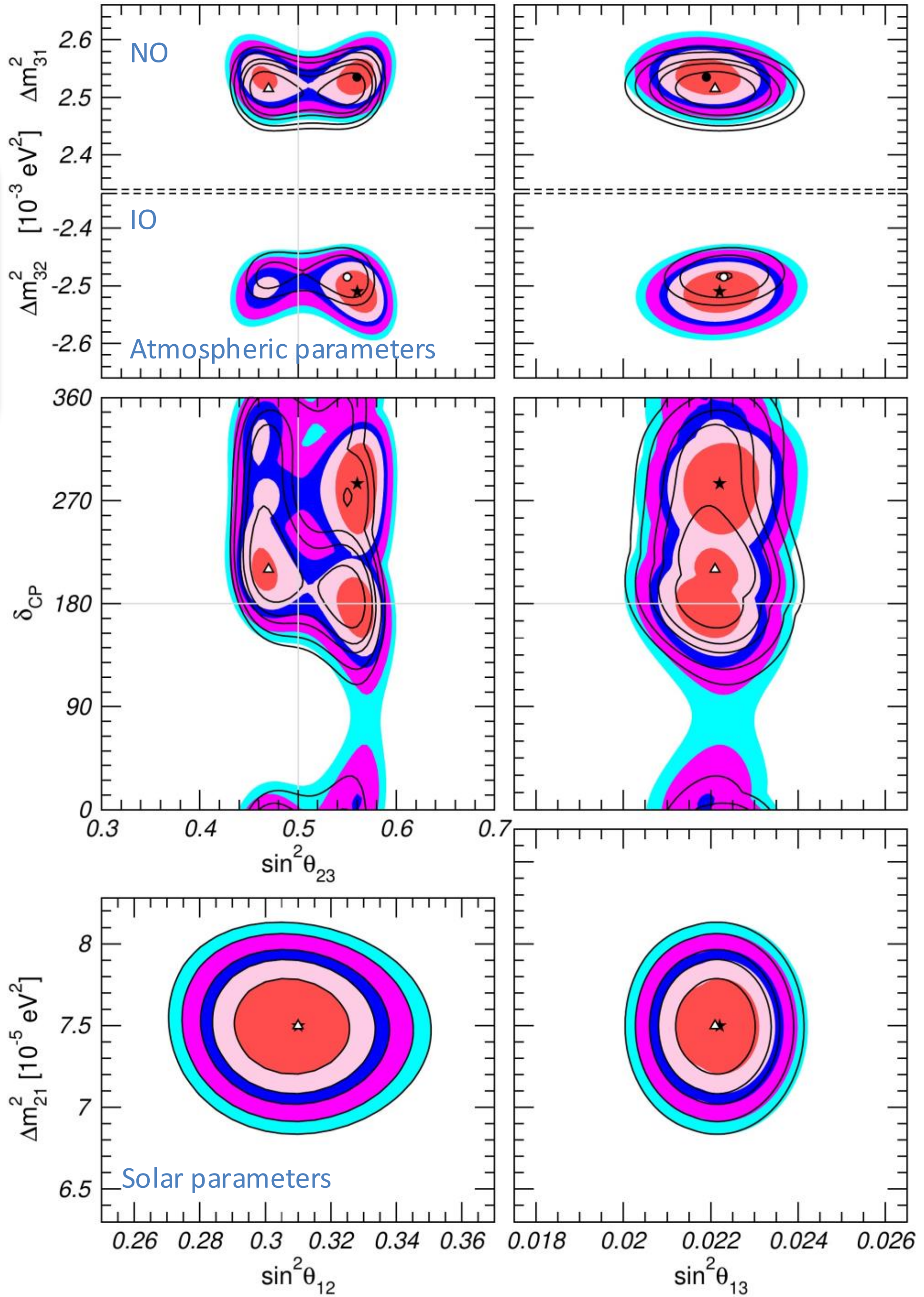
- Null CP violation disfavored at slightly less than 2σ (NO) or almost 3σ (IO)
- Normal Ordering slightly preferred
- The θ_{23} octant unstable in the global fits
- Oscillation parameters measured with a 5% precision or better

Atmospheric parameters as measured by different long-baseline and atmospheric experiments.



The different contours correspond to the two-dimensional allowed regions at 1σ, 90%, 2σ, 99%, 3σ CL

NuFIT 6.0 (2024)



$\sin^2\theta_{12} = 0.307 \pm 0.013$
$\Delta m^2_{12} = (7.53 \pm 0.18) \times 10^{-5}$
$\sin^2\theta_{23} = 0.534^{+0.021}_{-0.024}$ (IO)
$\sin^2\theta_{23} = 0.547^{+0.018}_{-0.024}$ (NO)
$\Delta m^2_{23} = (-2.519 \pm 0.033) \times 10^{-3}\ eV^2$ (IO)
$\Delta m^2_{23} = (2.437 \pm 0.033) \times 10^{-3}\ eV^2$ (NO)
$\sin^2\theta_{13} = (2.20 \pm 0.07) \times 10^{-2}$
$\delta_{CP} = 1.23 \pm 0.21\ \pi$ rad

PDG 2023

Main goals of next gen experiments: Dune, Hyper-K, Juno, atmospherics

CP violation: 5σ sensitivity for the widest possible range ($\geq 50\%$) of δ_{CP} values

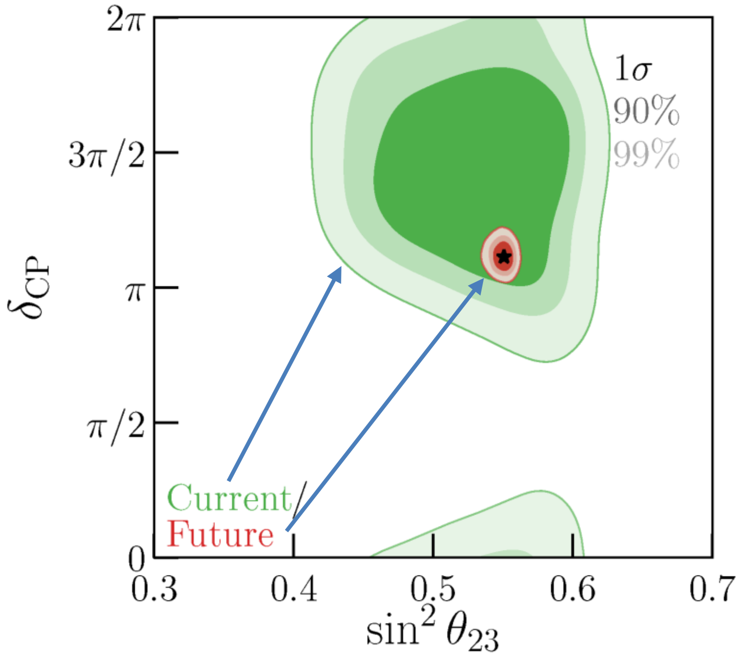
Mass Ordering: decide between Normal and Inverted Ordering at 5σ

Precision physics/Exotics: challenge the Standard Model (next slide)

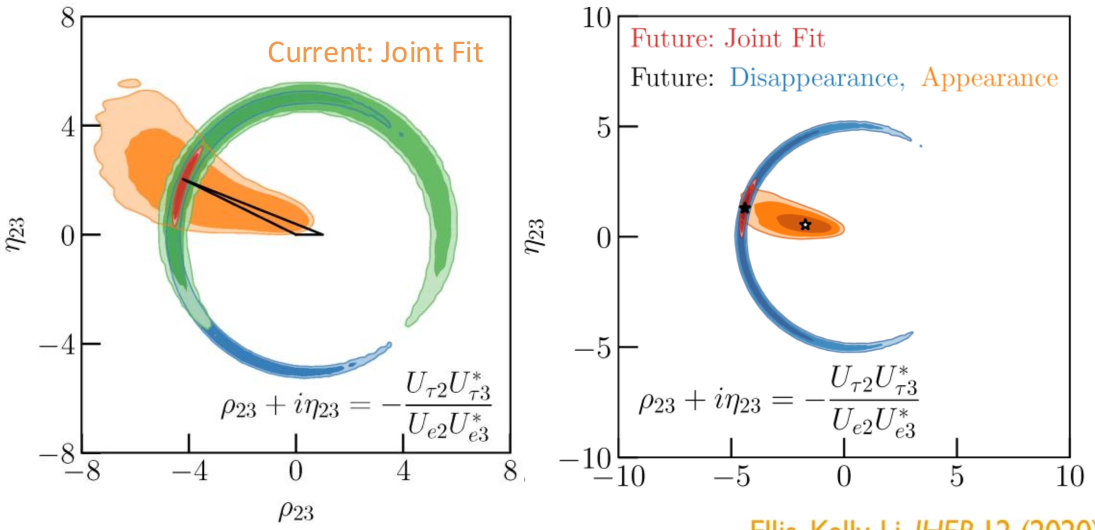
Astrophysics: the gigantic far detectors are excellent observatories for rare decays and astrophysical measurements

Precision physics → new physics

For instance by studying non-unitary leptonic mixing matrixes (LMM)



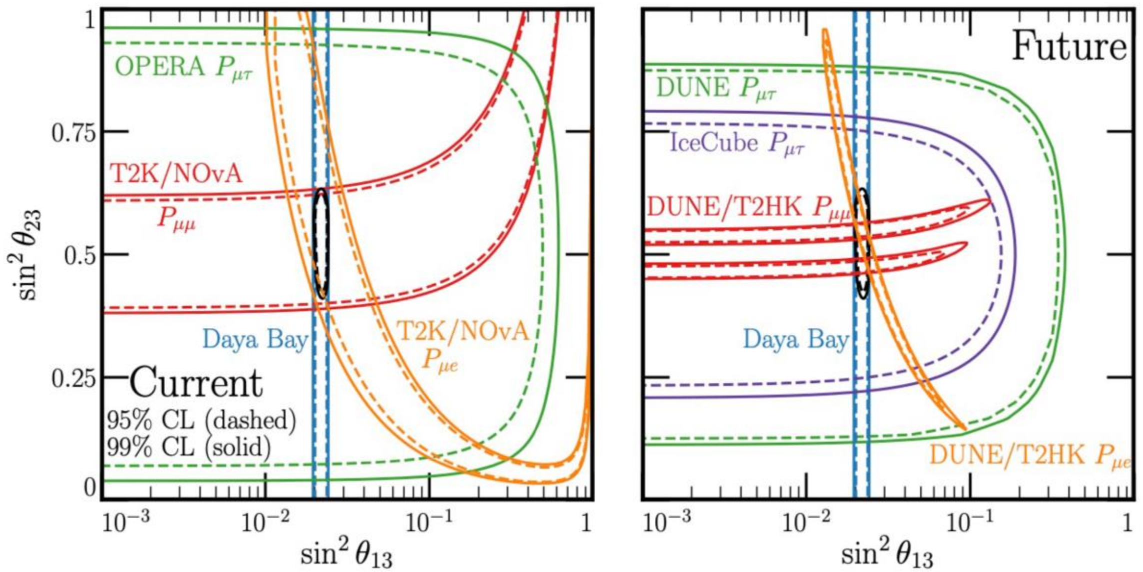
Current and future fit to atmospheric and CP oscillation variables, assuming as true value the best fit of present data.
From *Phys.Rev.D* 102 (2020) 11, 115027.



From *Phys.Rev.D* 102 (2020) 11, 115027.
Data are simulated with a non-unitary LMM, but analyzed assuming it is.

Another way to visualize possible checks with future sensitivities

Ellis, Kelly, Li, *JHEP* 12 (2020) 068



Other exotic searches

- Non Standard neutrino Interactions
- Neutrino decays
- Heavy neutrino decays
- Lorentz and CPT violations
- Sterile neutrinos
- ….

The JUNO experiment

Jiangmen Underground Neutrino Observatory, China, detecting $\bar{\nu}_e$ disappearance at reactors.

Liquid Scintillator Detectors

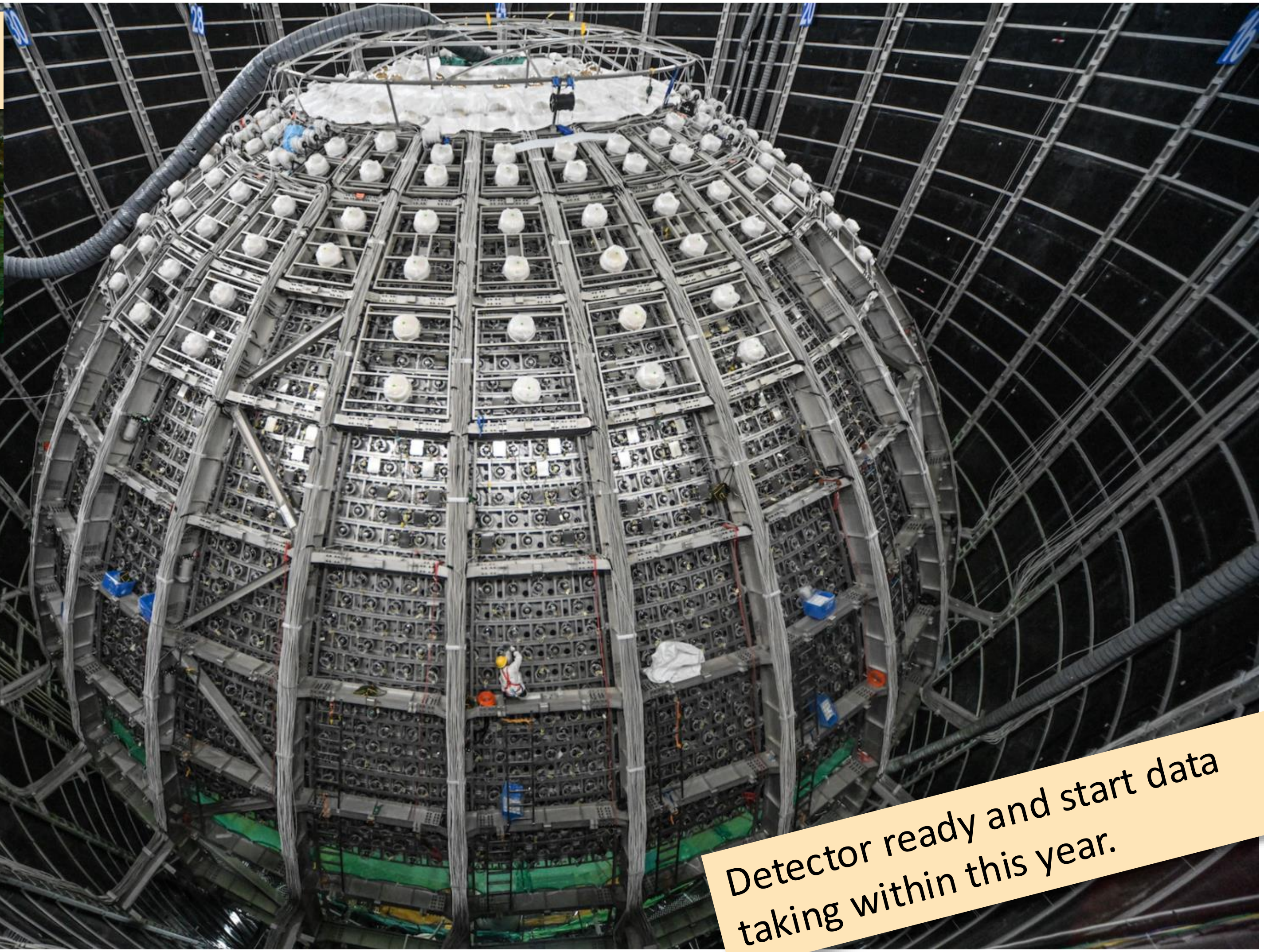
	Target mass	Energy resolution (σ)
Daya Bay	20 ton	8%/√E
Borexino	300 ton	5%/√E
KamLAND	1000 ton	6%/√E
JUNO	20 000 ton	3%/√E

Photo coverage: 78%
1600 p.e./MeV

74 institutes (8 INFN)
17 countries/regions
~700 collaborators

Signal rates

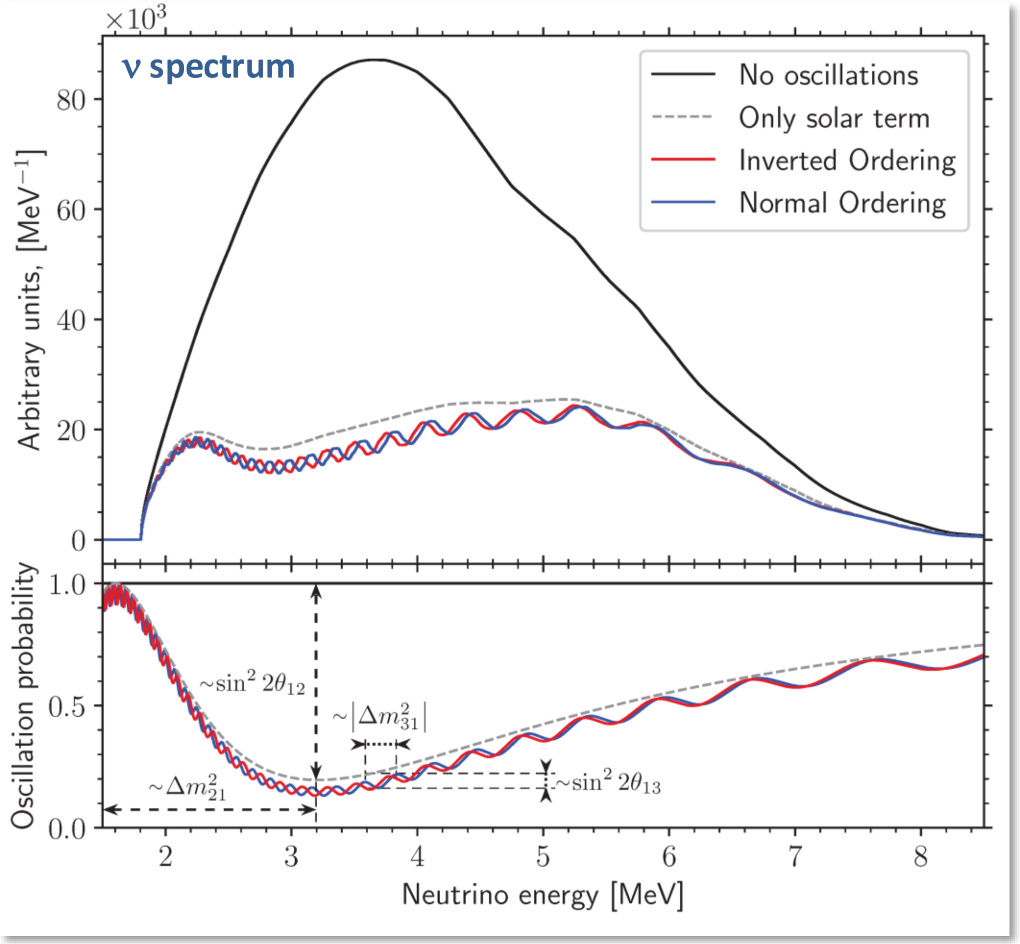
Neutrino source	Expected signal
Reactor	45 evts / day
Supernova burst	10^4 evts at 10 kpc
Diffuse supernova background	2-4 evts/ year
Sun ^{8}B (^{7}Be)	16 (490) / day
Cosmic rays	100+ / year
Earth crust & mantle	400 / year



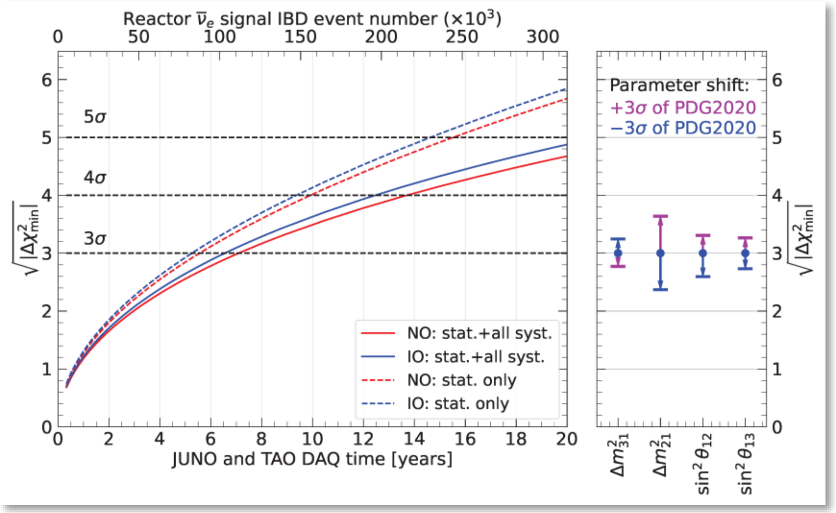
Detector ready and start data taking within this year.

Detect for the first time solar and atmospheric oscillation modes simultaneously

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{12}\, c_{13}^4 \sin^2 \Delta_{21} - \sin^2 2\theta_{13} \left(c_{12}^2 \sin^2 \Delta_{31} + s_{12}^2 \sin^2 \Delta_{32} \right)$$



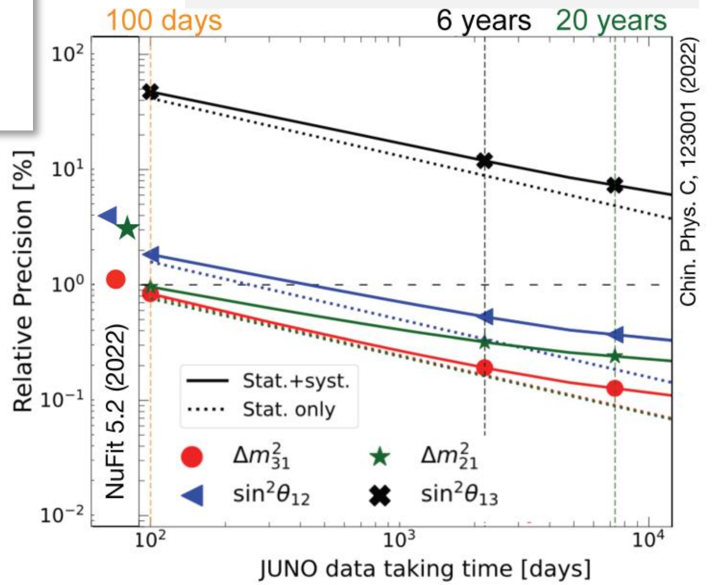
Sensitivity to NMO vs DAQ time



To measure NMO: decide if the oscillation pattern corresponds to the blue or to the red curve. Requires high statistics and extreme control of the energy scale.
Expected **3σ sensitivity in 7.1 years**.

From the detected spectrum is possible to extract several oscillation parameters…

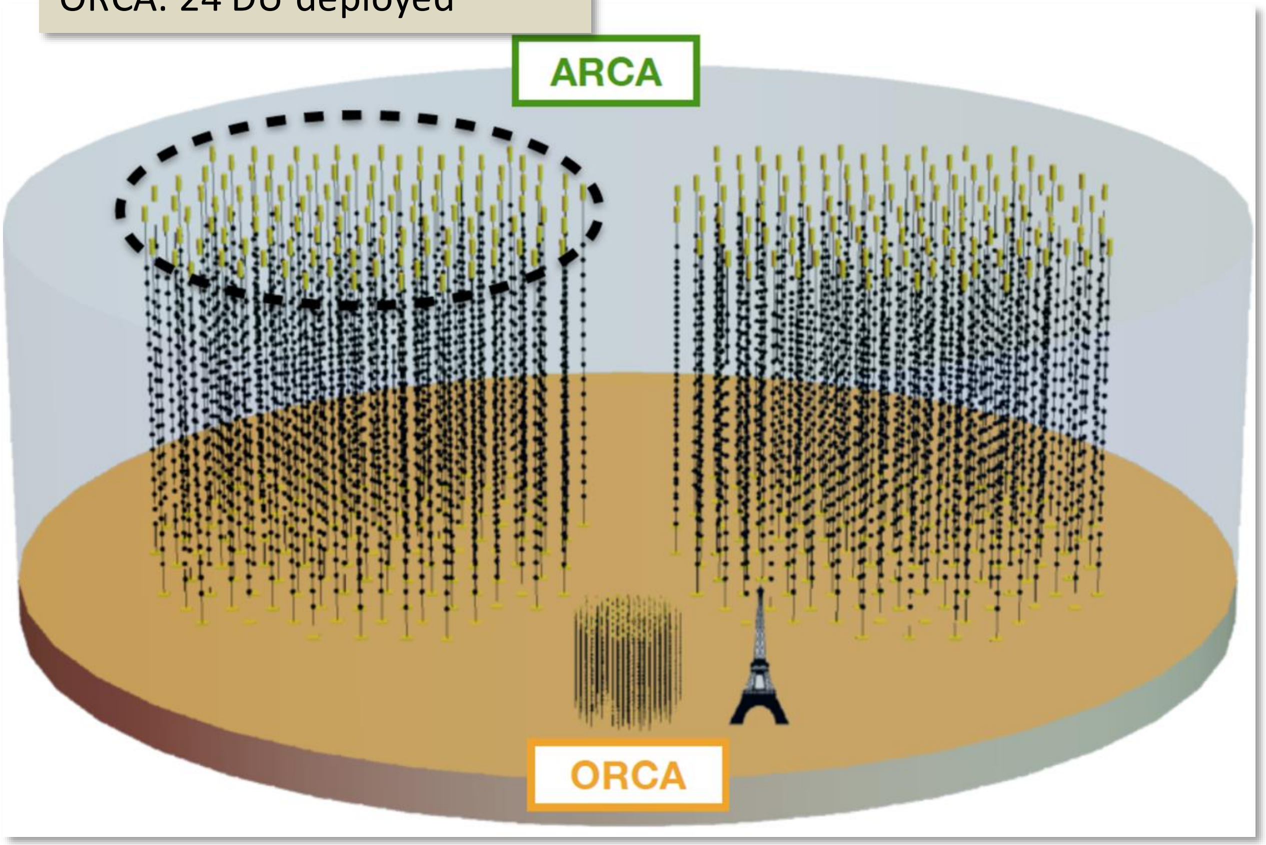
… whose accuracy will exceed present values



KM3NeT

2016 and 2020 ESFRI Roadmap
KM3NeT4RR: KM3NeT for Next Generation EU (PNRR)
14 countries, 47 institutions, ~ 300 collaborators

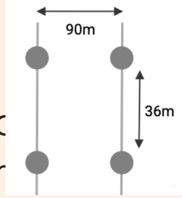
Status:
ARCA: 33 DU deployed
ORCA: 24 DU deployed



Detector Unit
(DU): 18 DOMs

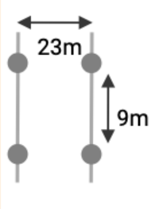
Optical Sensor
(DOM):
31 PMTs (3")

ARCA (**A**stroparticle **R**esearch with **C**osmics in the **A**byss)



- Depth ~3500 m
- Two blocks of 115 DU each (130 func
- Average distance between DU~90 m
- Vertical distance between DOMs ~36 m
- Volume (0.5 × 2) km3

ORCA (**O**scillation **R**esearch with **C**osmics in the **A**byss)



- Depth ~2500 m
- One block of 115 DU (50 funded)
- Average distance between DU ~20 m
- Average vertical distance btw DOMs ~9 m
- ≈8 Mton

Orca sensitivity to oscillation parameters

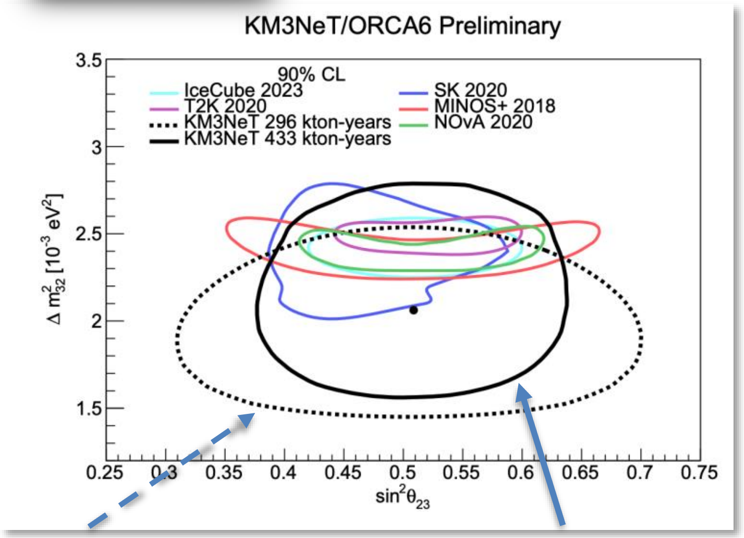
Neutrino mass ordering

Full Statistics

Δm^2_{32} vs $\sin^2\theta_{23}$

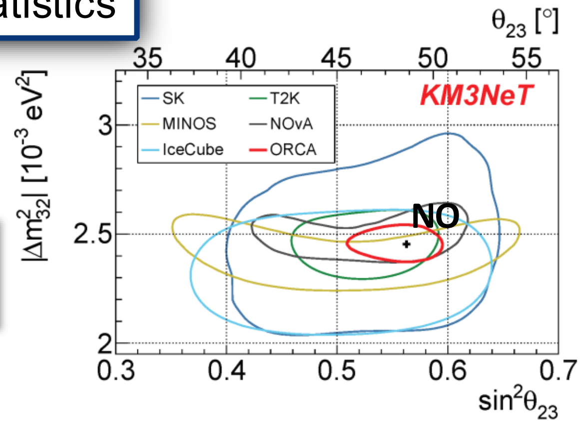
ICRC 2023
Neutel 2023

Will be updated next week @Neutrino 2024

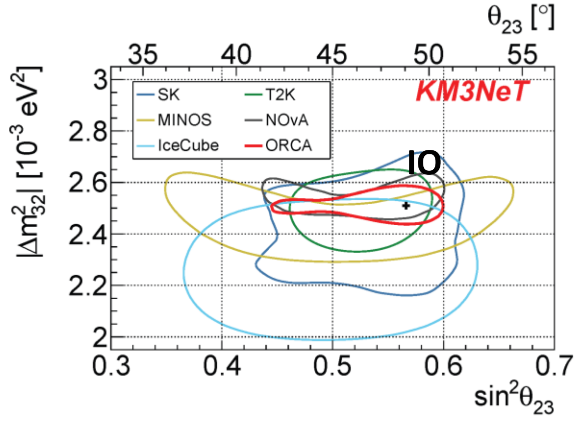


ORCA6 DUs 354days

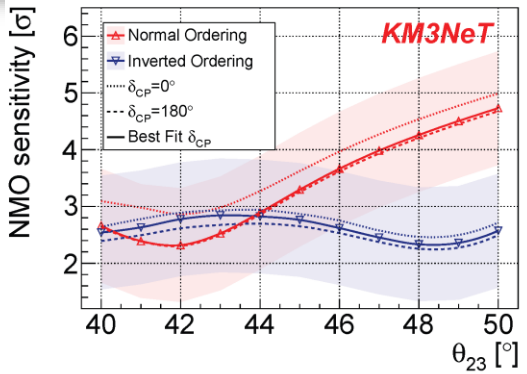
ORCA 6 DUs 510days

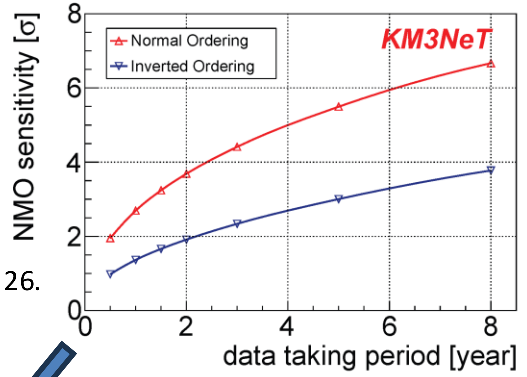


(a)

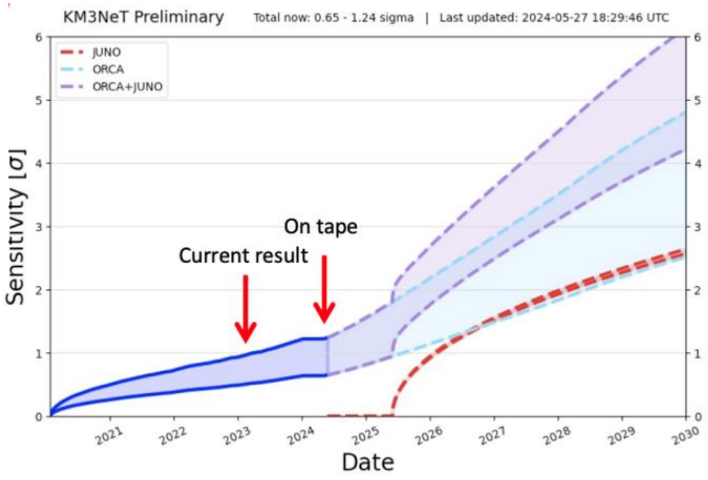


Three years of data taking. 115 DOMs. Educated guess about systematics



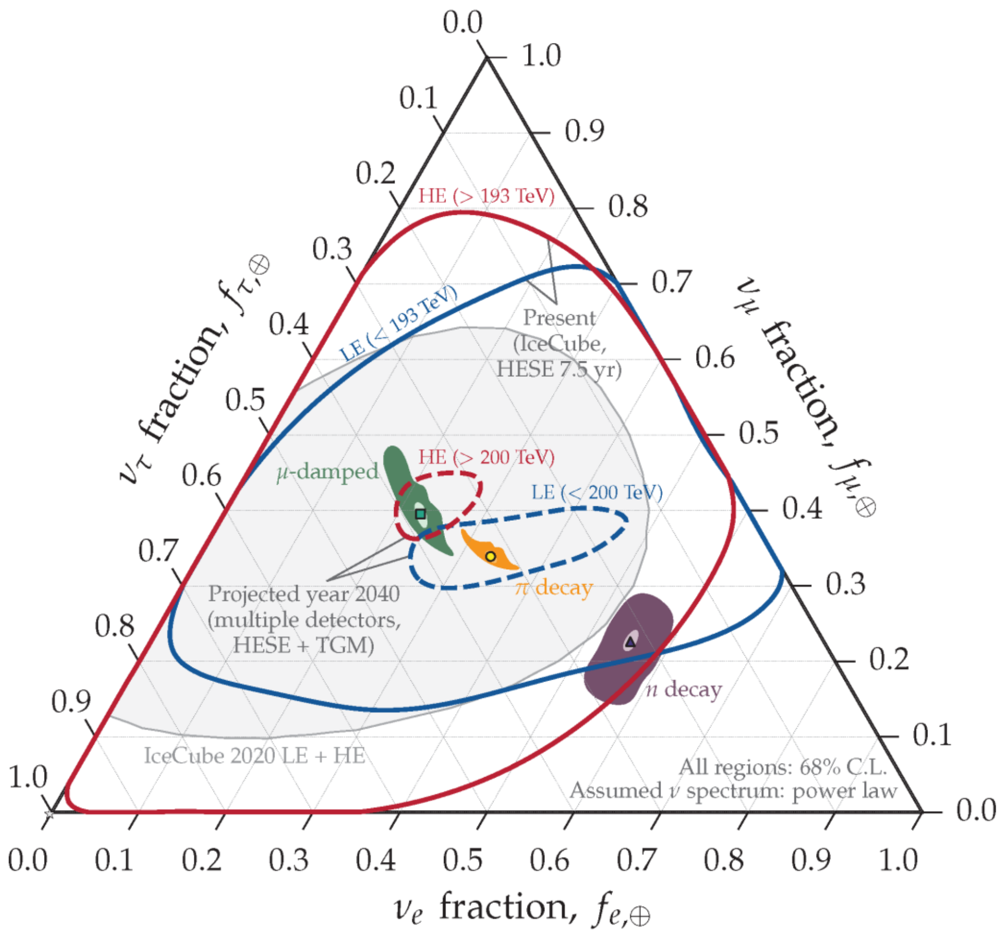


Eur.Phys.J.C 82 (2022) 1, 26.
θ_{23}=48.6° and δ_{CP}=221°



Most updated prediction following the deployment master plan, the error band considers both NO and IO and the range of the θ_{23} allowed values

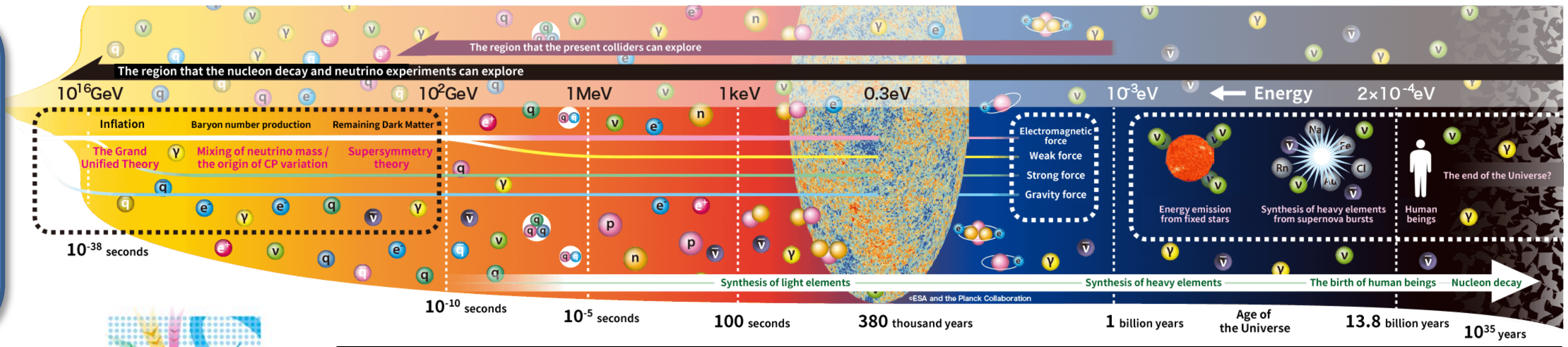
An example about the many different ways to look for new physics with oscillations at Neutrino Telescopes



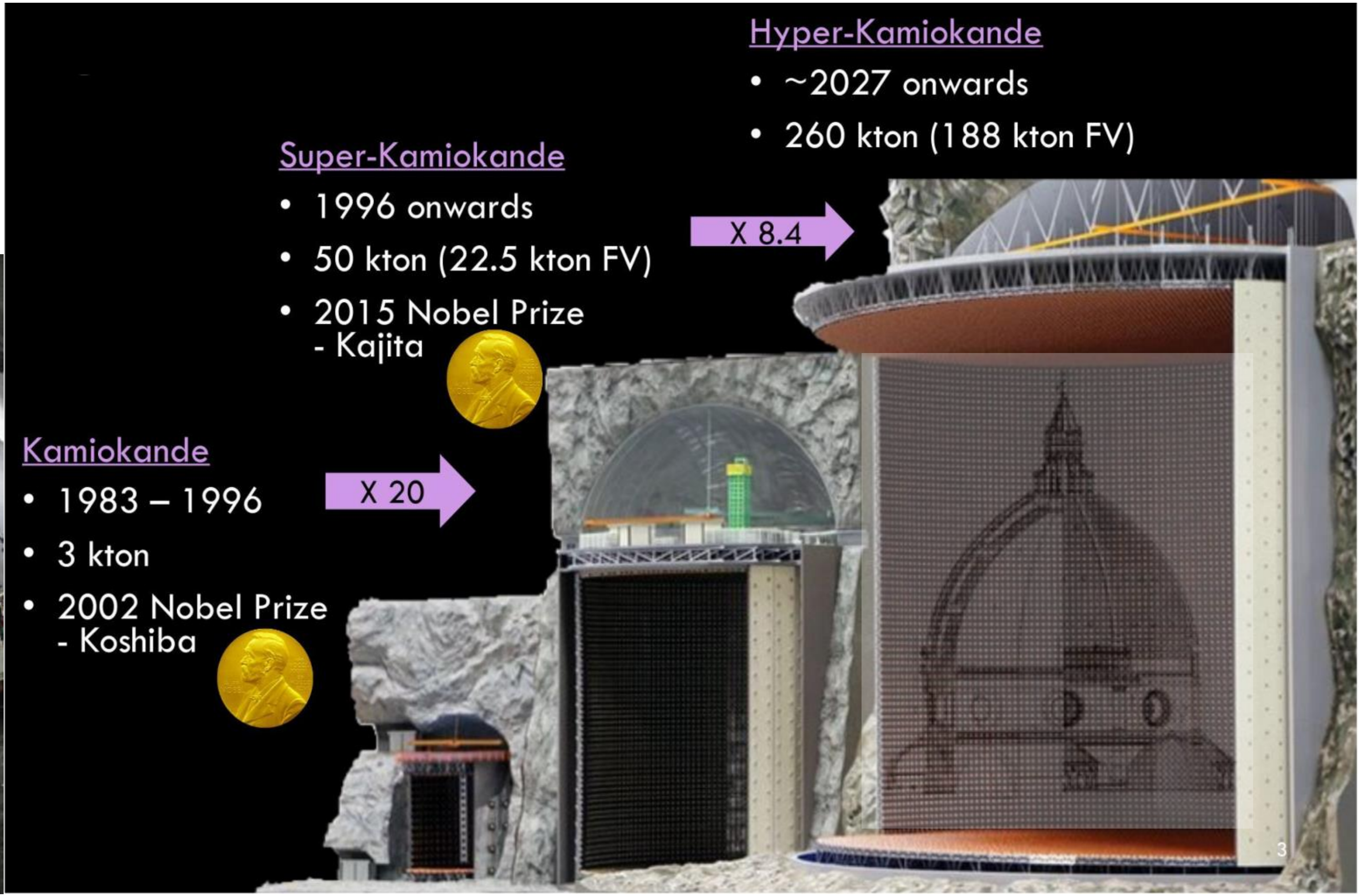
- Cosmic sources produce neutrinos with a well defined flavor composition
- Oscillations randomize the flavor composition in their travel, but not completely.
- If something happens different from oscillations, it will modify the composition at earth:signature for new physics
- Present precision is far from enough for these studies, but in the future, also combining several experiments, it will be possible to look for new physics signatures in this plane.
- The role of KM3NeT/ARCA could be crucial

Q.Liu et al., arXiv:2312.07649
This representation was first introduced by Fogli, Lisi et al., Phys.Rev.D 52 (1995) 5334

Hyper-Kamiokande

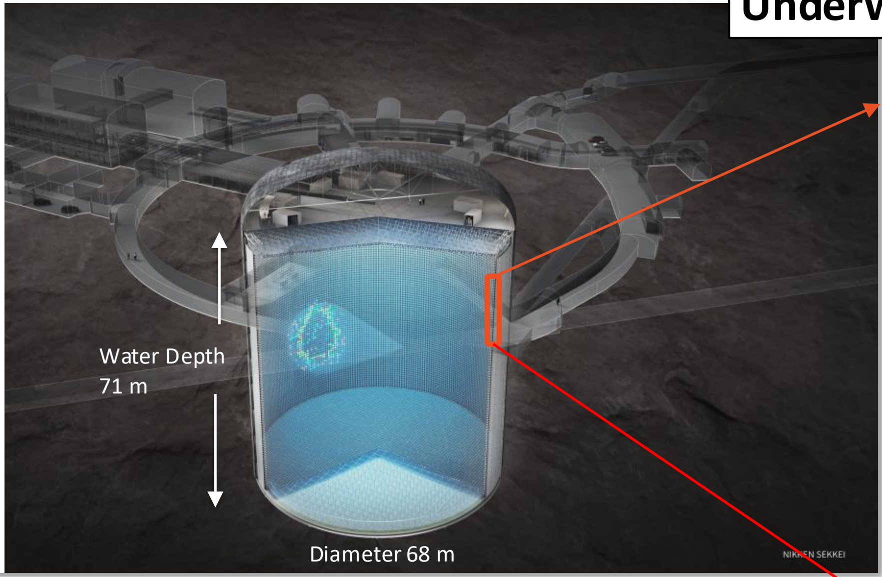


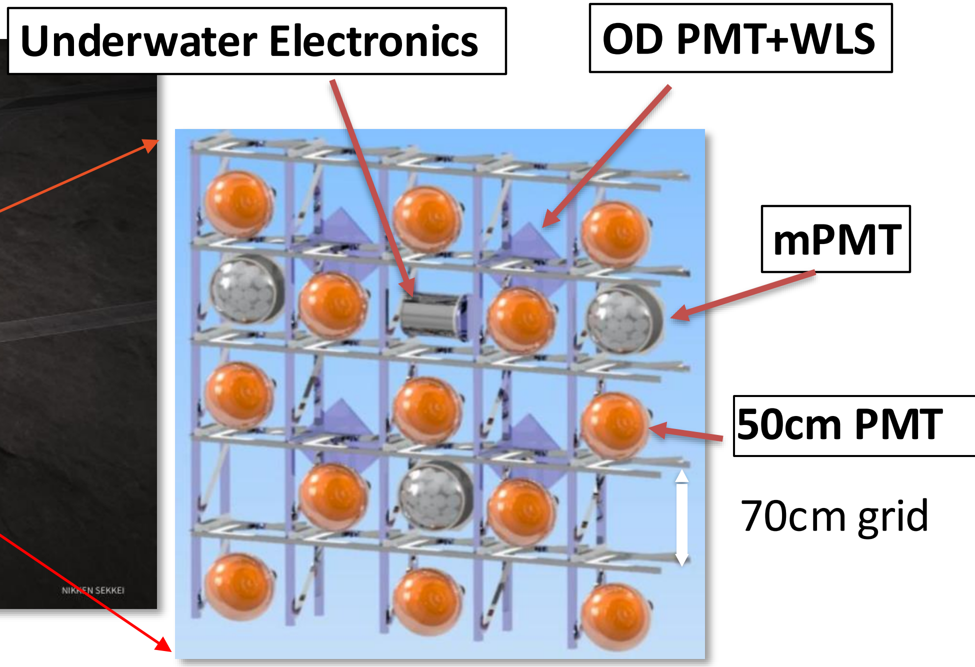
~600 collaborators
106 Institutes
22 Countries
(INFN: 6 sezioni ~ 10% of the collaboration)



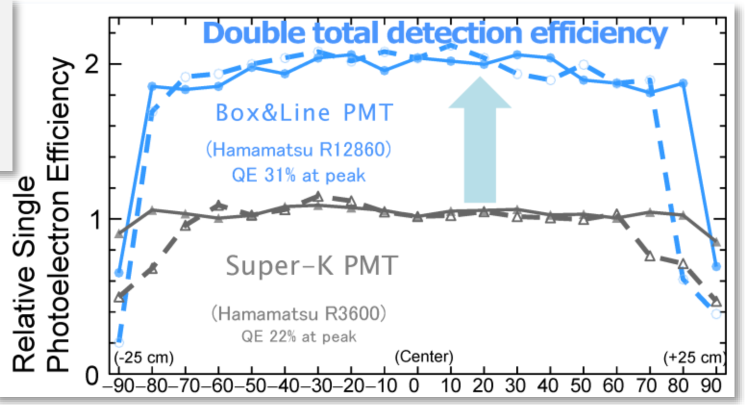
Hyper-K detector configuration

- **Inner Detector (ID)**
  - 64.8m diameter, 65.8m height
  - 40k PMTs, 50 cm, will be installed
  - 800 Multi-PMT modules will be integrated as hybrid configuration
- **Outer Detector (OD)**
  - 1m (barrel) or 2m (top/bottom) thick
  - 3-inch PMT + WLS plate
  - Walls are covered with high reflectivity Tyvek sheets



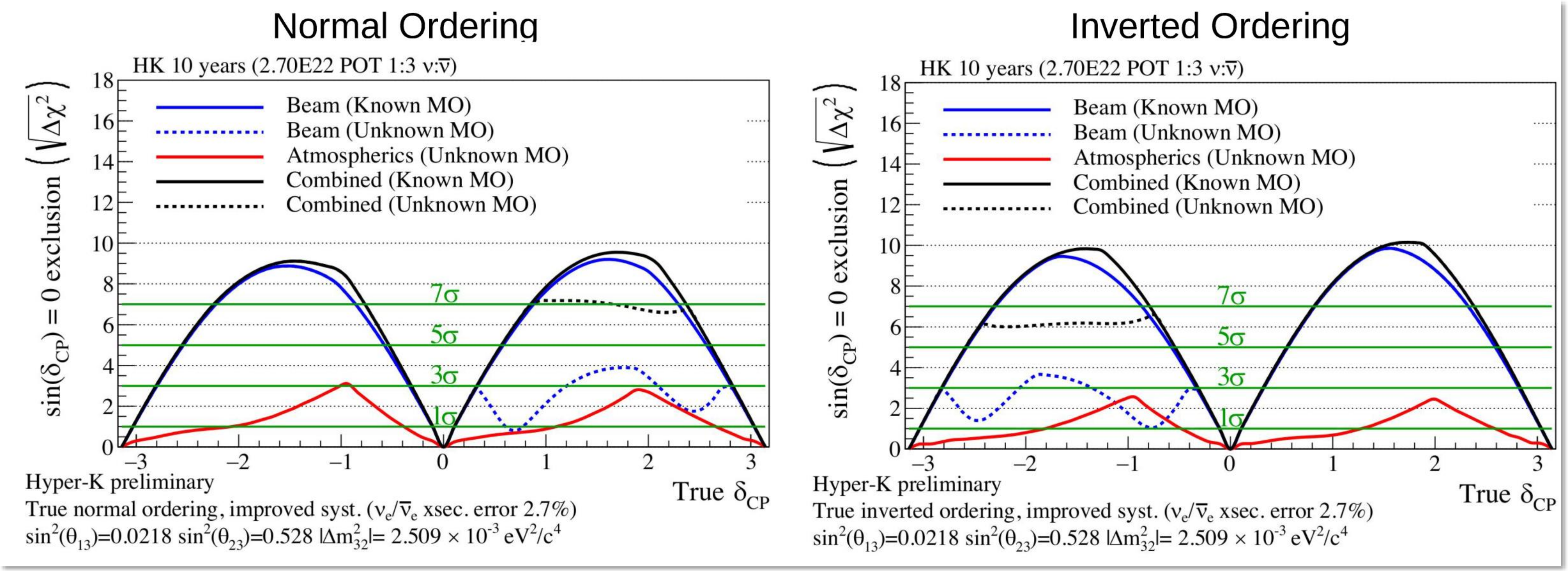


Half coverage (20%) versus Super-K but twice efficiency



CP violation sensitivity

It's important to stress that efficiencies, backgrounds, systematic errors come from more than 10 years of T2K analysis efforts



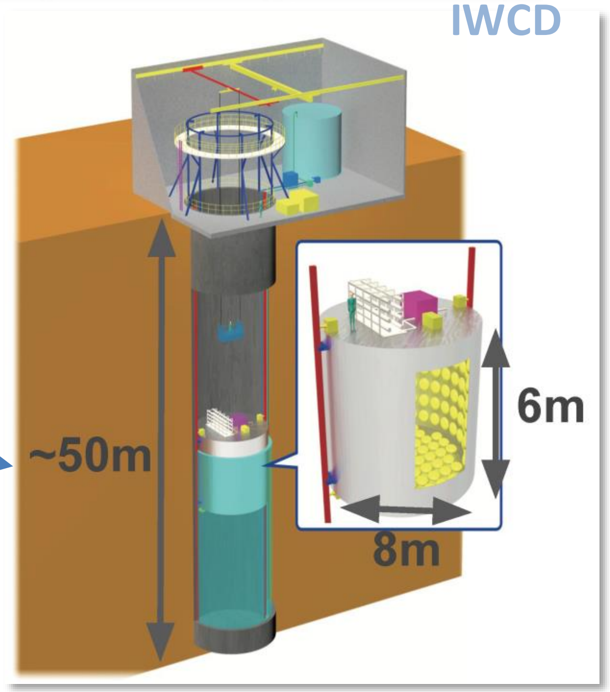
By combining beam neutrinos and atmospherics

- For maximal CP violation ($\delta_{CP}=-\pi/2$) 5σ sensitivity is reached in 3 years.
- In 10 years, CP conservation excluded at 5σ for 60% of δ_{CP} values.

Systematic Errors

T2K systematic errors for the ν_e appearance channel are 4.7% (initial goal was 5%).
Without the close detectors they would be ~13%.
Aim to reduce them to around 2% (full simulation undergoing):

- **ND280 redesigned and optimized** to better constrain systematic errors (already fully in place)
- A new Intermediate (0.75 km) Water Cherenkov Close Detector (**IWCD**) to further constrain systematic errors (ready for Hyper-K)
- More statistics (20x T2K) will allow close detectors to constrain ν-nucleus interaction models better (no assumptions on better models)
- Gadolinium doping can enhance efficiency and purity of antineutrinos' detection (will not be added on day one)
- Dedicated experiments like **Enubet** could reduce (anti-)ν_e cross section uncertainty further.



Total percentage error on sample event rates:

Error model	μ-like ν-mode	μ-like $\bar{\nu}$-mode	e-like ν-mode 0 d.e.	e-like $\bar{\nu}$-mode 0 d.e.	e-like ν-mode 1 d.e.	e-like $\nu/\bar{\nu}$ modes 0 d.e.
T2K 2020	3.0%	4.0%	4.7%	5.9%	14.1%	4.6%
Improved	1.2%	1.1%	2.1%	2.2%	5.2%	2.0%

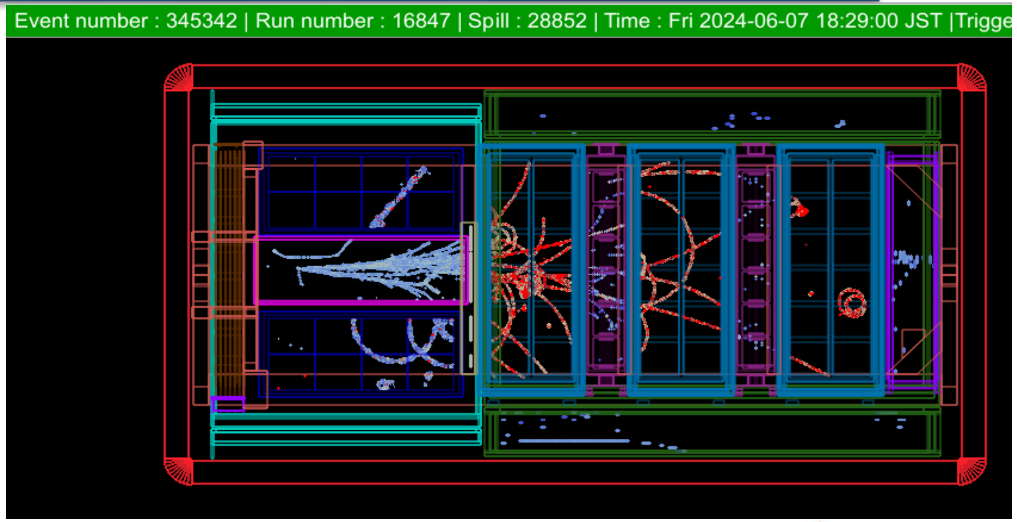
HK Expected event rate @ 10 years vs T2K today

$\nu : \bar{\nu}$ = 1:3 (T2K is 1:0.7), @ δ_{CP} = 0

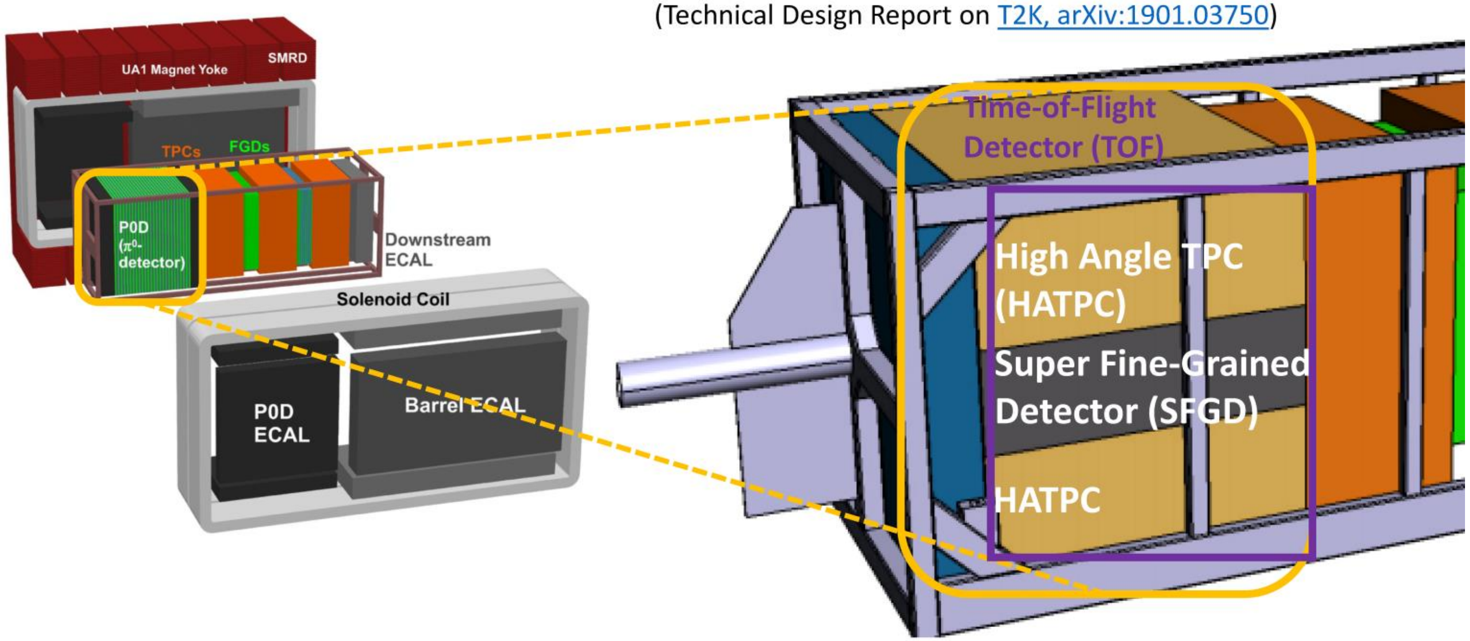
	HK	T2K
ν-mode, 1 ring μ-like	~8800	318
$\bar{\nu}$-mode, 1 ring μ-like	~12000	137
ν-mode, 1 ring e-like	~2100	94
$\bar{\nu}$-mode, 1 ring e-like	~1800	16
ν-mode, 1 ring e-like, 1 decay e-	~300	14

Near detector (ND280) upgrade

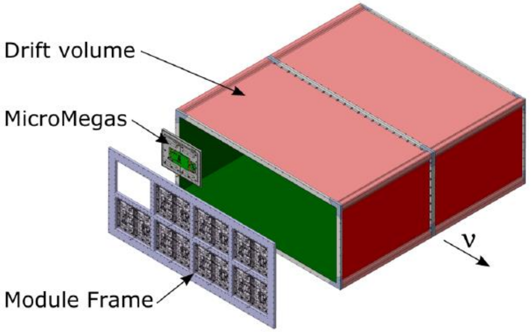
Almost in place now for T2K, will be re-used by Hyper-K
More (and more granular) mass for the neutrino interactions: **SFGD**
More angular acceptance: **High Angle TPCs**
Better veto for external tracks: **Time-of-flight**
Significant lower energy threshold for protons and much better neutron detection efficiency.
Inside the former UA1 and Nomad magnet.



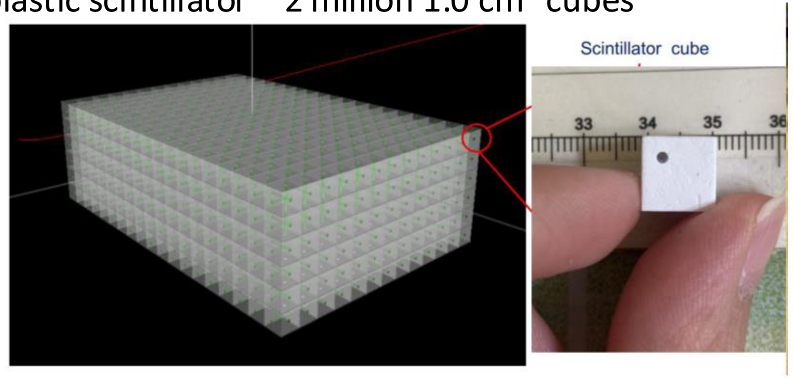
(Technical Design Report on T2K, arXiv:1901.03750)



HATPC



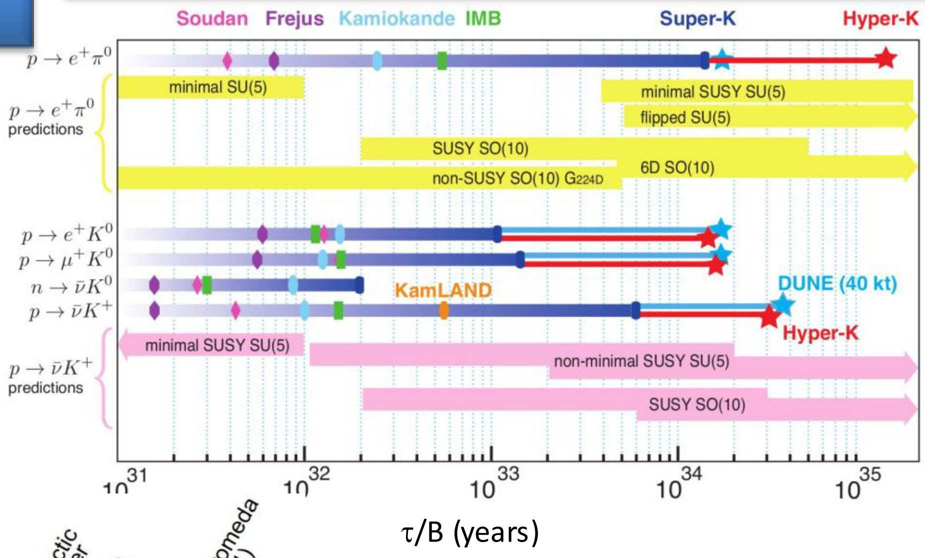
SFGD:
3D plastic scintillator ~ 2 million 1.0 cm^3 cubes



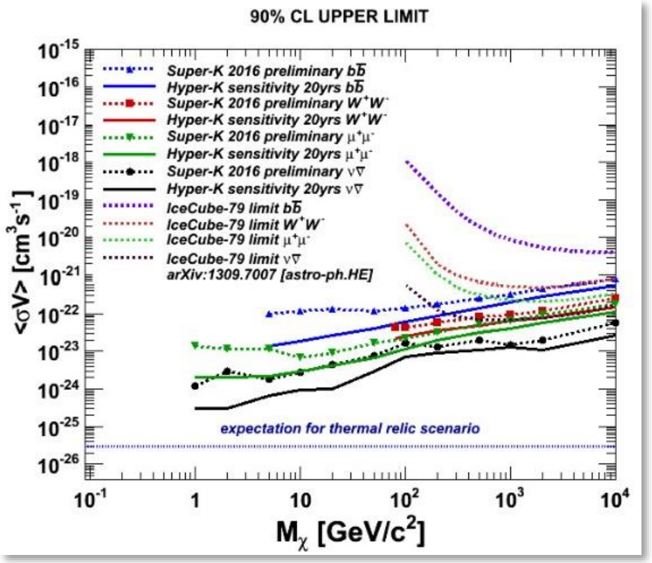
Rare decays and astrophysics in HK

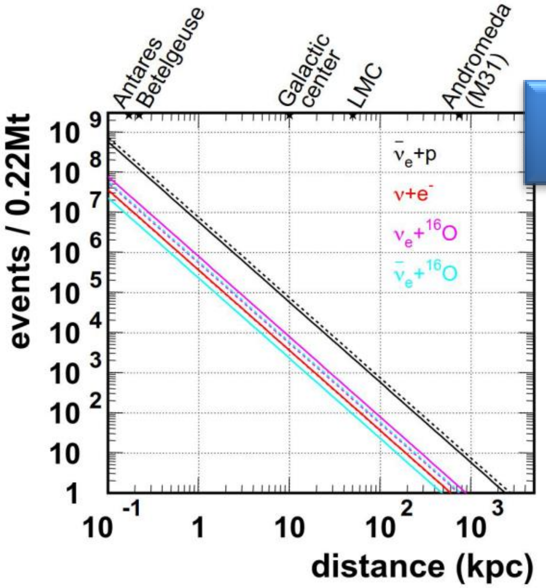
Great complementarity with DUNE and JUNO in most of these searches

Proton Decay

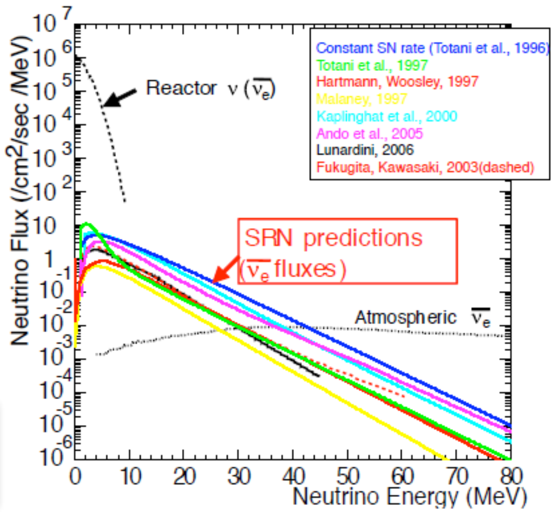


Indirect Dark Matter searches

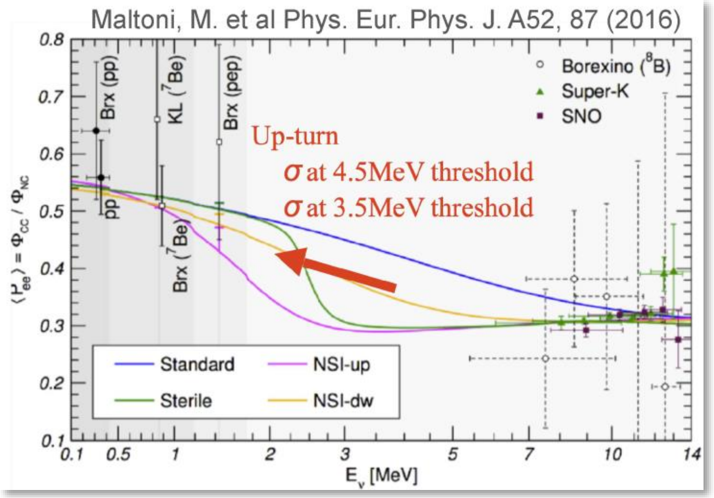




SuperNova burst ν



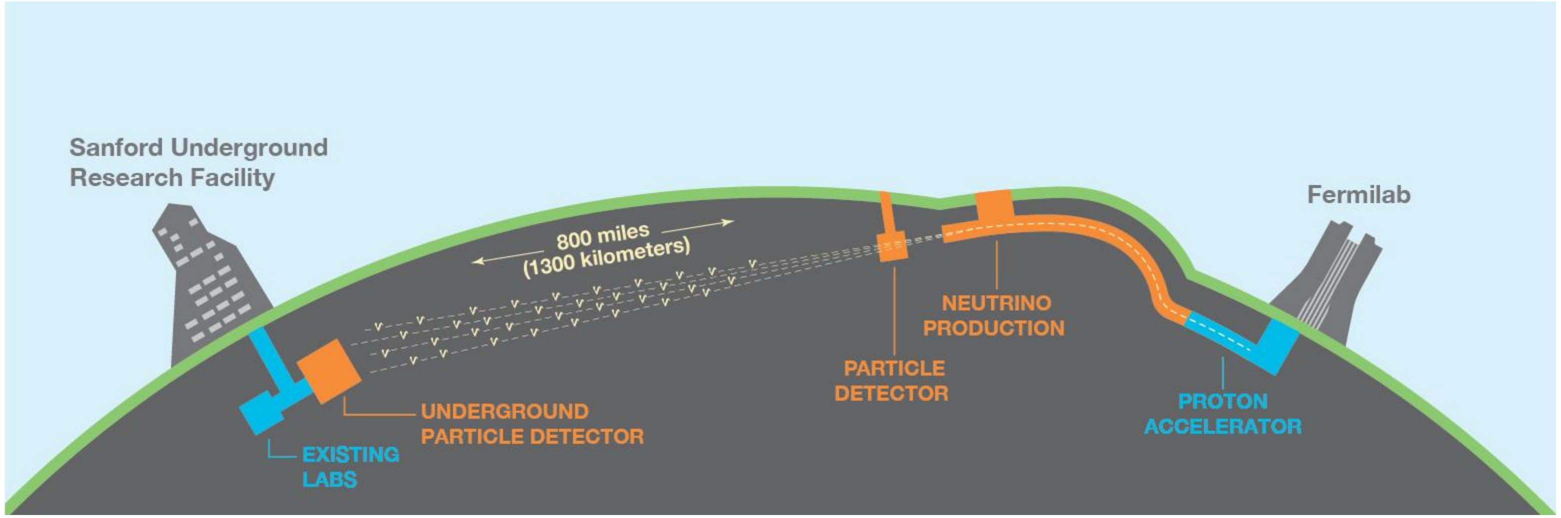
SuperNova relic ν



Solar ν

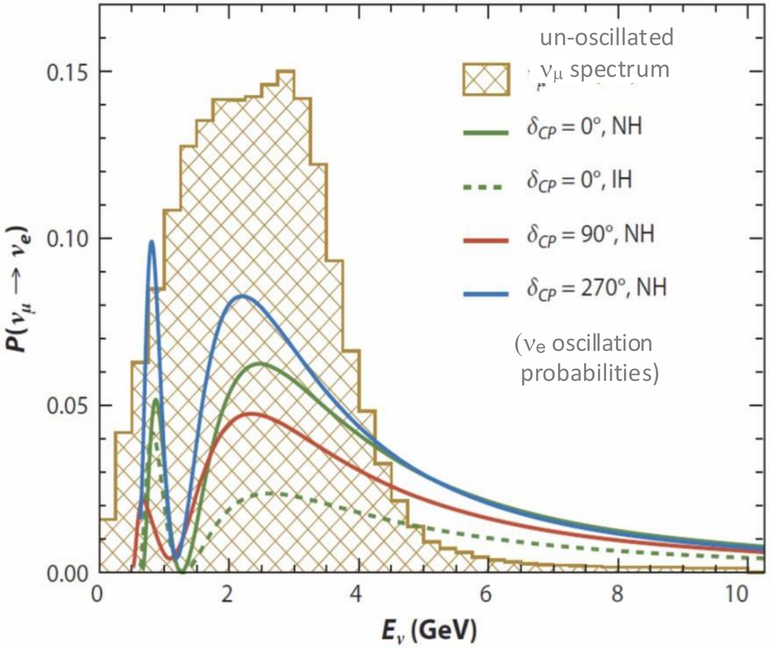
Low energy ν bursts

DEEP UNDERGROUND NEUTRINO EXPERIMENT



- 1450 collaborators
- 215 Institutes (11 INFN)
- 35 Countries

- On-axis
- Sensitive to first and second oscillation maxima
- Part of the spectrum above the tau creation threshold (~3.5 GeV)



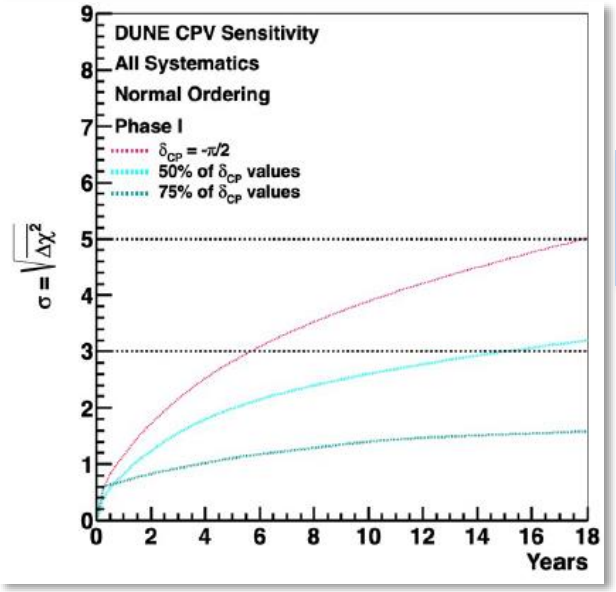
- *High precision measurements of neutrino mixing in a single experiment.*
- Determination of the neutrino mass ordering in the first few years.
- Observation and measurement of CP Violation in the neutrino sector.
- Test of the 3-neutrino paradigm (PMNS unitarity).
- Observatory for astrophysical neutrino sources (solar, atmospheric, supernova).
- Search for BSM physics.

Current status and future plans in a nutshell

- LBNF is being delivered in its entirety.
- DUNE Phase I:
  - FD (approved): 2 x 17 kt (total) LAr TPCs: one Horizontal Drift (ready in 2029), one Vertical Drift (ready in 2030).
  - ND (baseline TBC and approved by 2025): NDLAr with TMS; DUNE-PRISM; SAND on-axis.
- PIP II: ongoing construction, first beam in 2031, reaching 1.2 MW by end 2032.

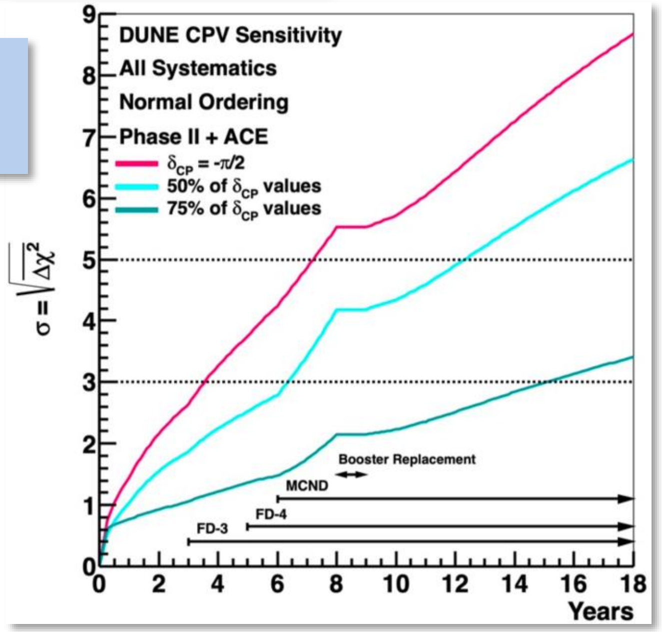
- Phase 2, as submitted to P5 (report due in early December):
  - DUNE ND plan: More Capable Near Detector (HPGAr TPC, magnet, calorimeter).
  - DUNE FD plan: FD3, FD4.
  - Fermilab plan: ACE: MIRT, Booster Replacement. Can provide up to 2.1 MW at DUNE start.

CP Violation and neutrino mass ordering

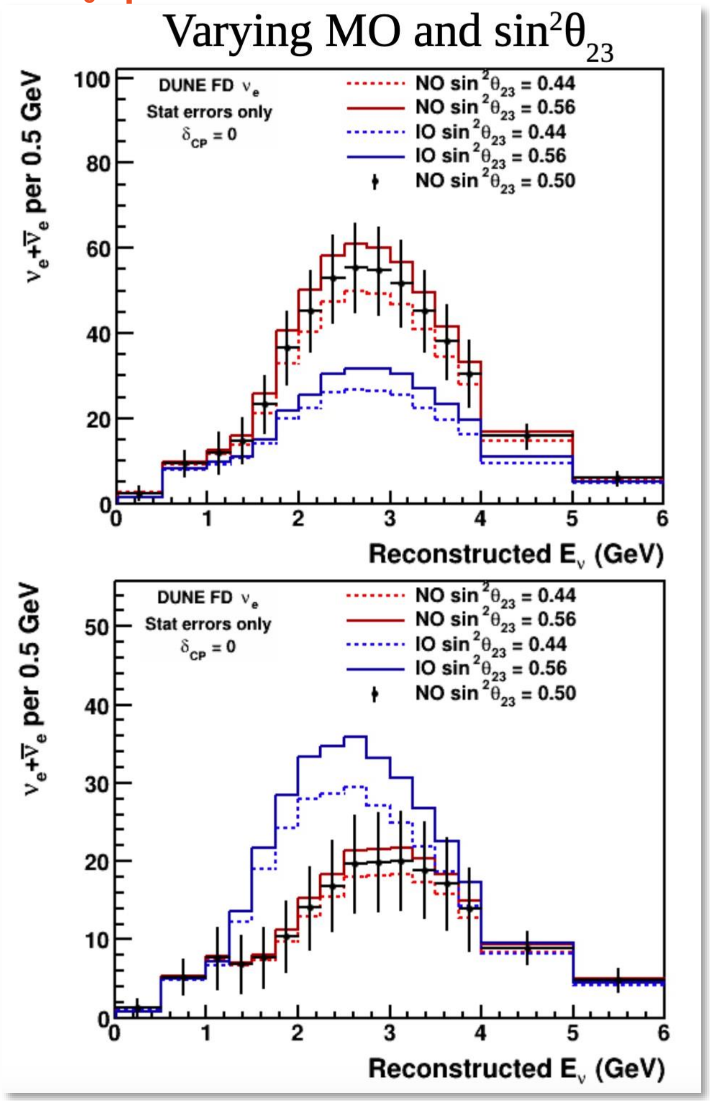


CPV sensitivity, Phase I

CPV sensitivity, Full Phase II



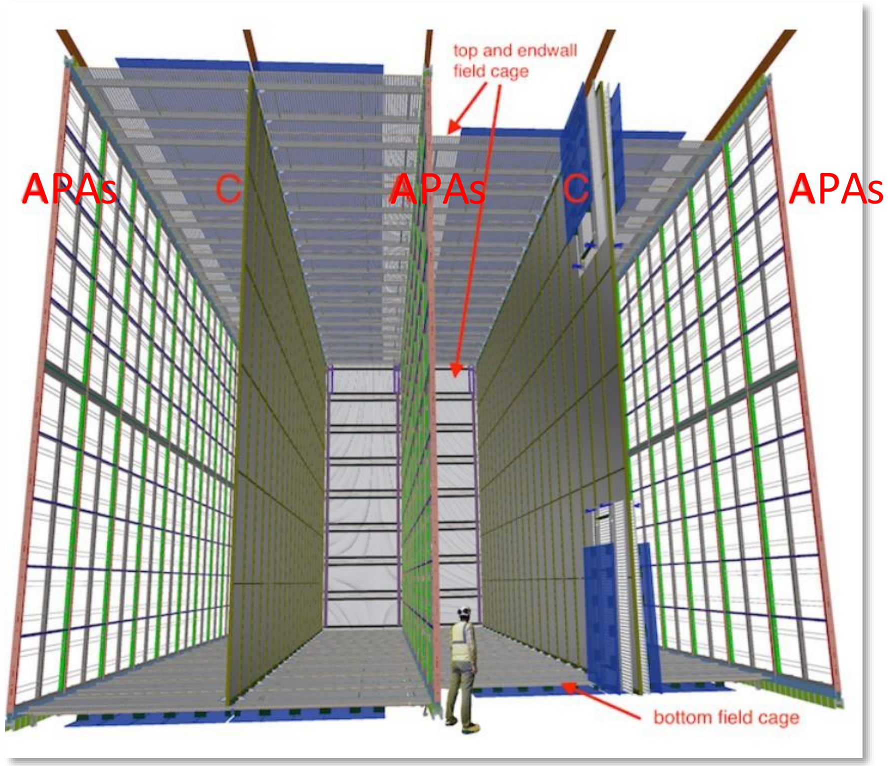
Determining Mass Ordering with DUNE Phase I, 4 yrs, using ν_e and anti-ν_e spectra.



Far Detectors

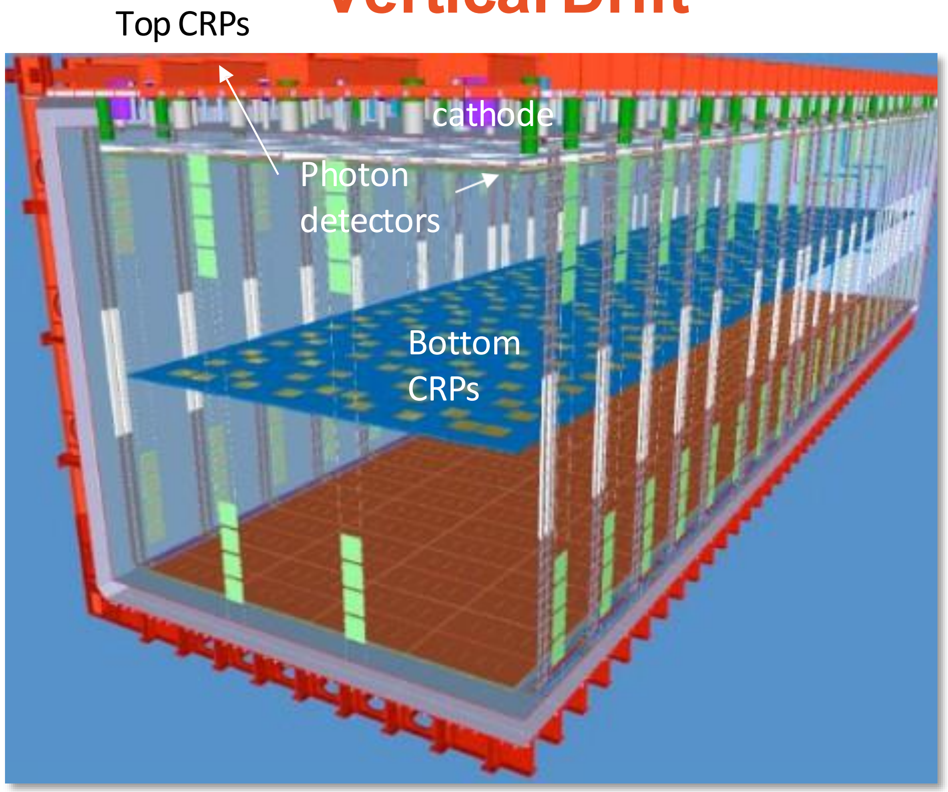
2 (max 4) LAr TPCs, 17 kt Argon total (10 kt fiducial) each one:

Horizontal Drift



- APA : based on a wire chamber technology
- Drift length ~ 350 cm -> ~ 180 KV on cathode
- ~ 9800 m^3 = ~ 13’661 tons of active LAr

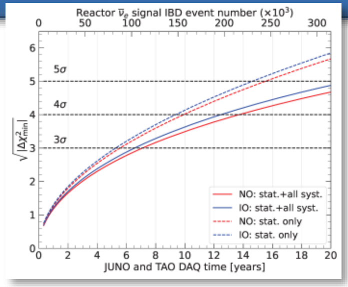
Vertical Drift



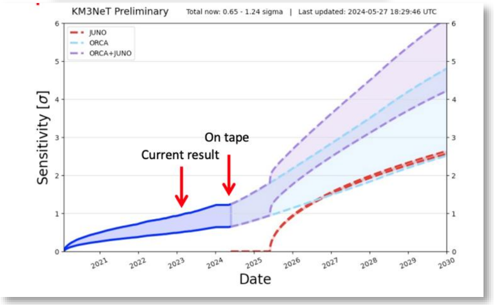
- CRP: based on perforated PCB technology
- Drift length ~ 640 cm → 300 kV on cathode
- Photon detectors on the cathode at 300 kV
- ~ 10180 m^3 = 14190 tons of active LAr

… The race for neutrino mass ordering (aka hierarchy)

NMO can only be +/-1, so sensitivity means wrong ordering rejection



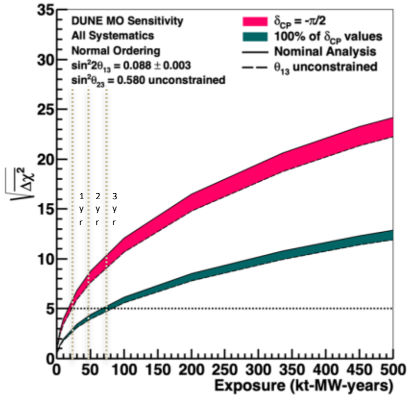
JUNO
arXiv:2405.18008



ORCA/KM3NeT

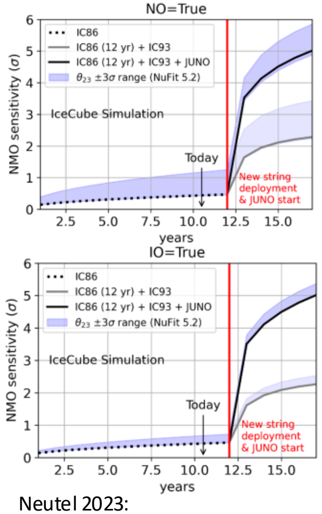
Most recent update of Eur.Phys.J.C 82 (2022) 1, 26.

DUNE Phase 1: 1yr=24 kt-MW

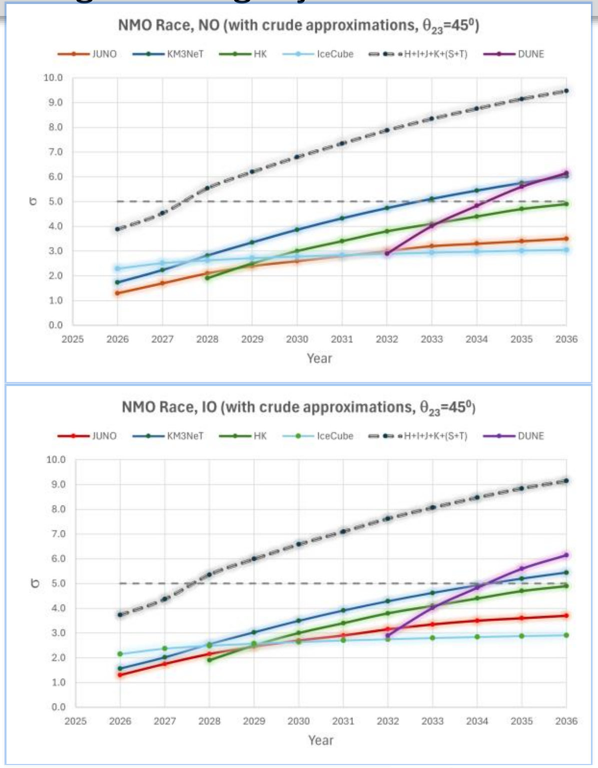


Vertical Drift TDR: arXiv:2312.03130

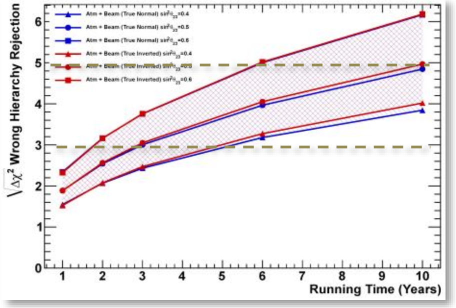
IceCube (+Upgrade)



Neutel 2023:
https://doi.org/10.5281/zenodo.10567782
Computed for θ_{23}=40°



H+I+J+K+(S+T): combination of HK, IceCube, JUNO, KM3NeT and joint analysis of SK and T2K at full statistics



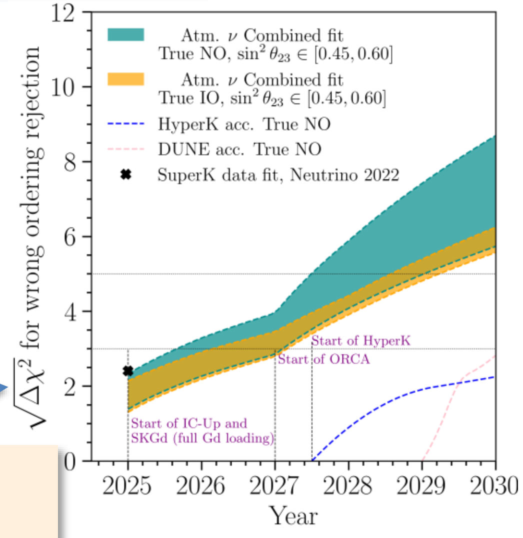
HK (mostly from atmospherics)
HK TDR arXiv:1805.04163

Nominal Starting Dates
2025: JUNO and IceCube Upgrade
2027: Hyper-K
2028: Full ORCA
2031: DUNE Phase I
(T2K joint SK @ full statistics :$\Delta\chi^2$=8)

Depend on:

- Assumptions on θ_{23} (atmospherics have terms ∝ $\sin^4\theta_{23}$)
- Assumptions on δ_{CP} (DUNE)
- True Ordering
- Degree of optimism in the calculation of systematic errors
- Performance of the detector (JUNO)
- Fiducial mass (ORCA)

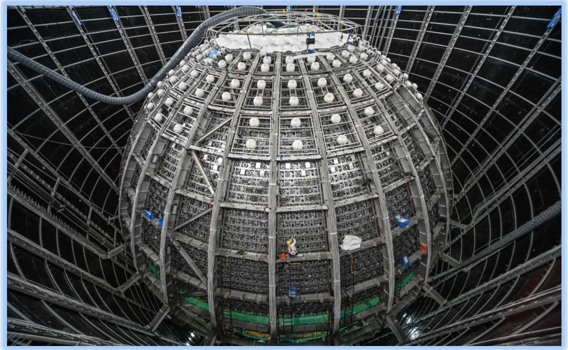
No way to display these curves in a single plot keeping the same assumptions, this is my best guess.



An independent study, considering only atmospheric neutrinos

Argüelles, Fernandez, **IMS** and Jin, PRX 13 (2023)

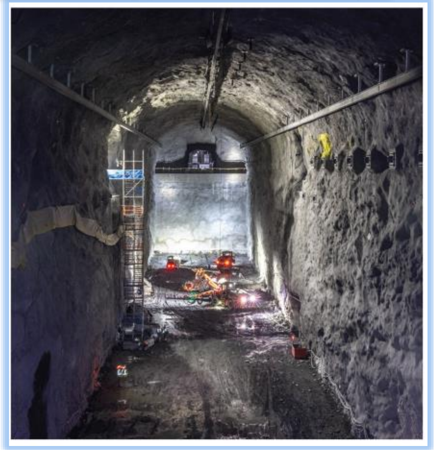
Conclusions



JUNO

KM3NeT

Hyper-K



DUNE

The outstanding achievements of neutrino physics in the past 25 years will allow exciting new neutrino physics for the next 25 (at minimum)

Both guaranteed signals and new physics searches will be performed

With a great complementarity between JUNO, ORCA, IceCube, DUNE and Hyper-K

The gigantic 3-liquids far detectors are the ultimate observatories for low-energy neutrino astronomy

If you like to hear about neutrinos nearby don't miss Neutrino Telescopes 2025, September 29th-October 3rd, Padova