Neutrinos!

Experimental Highlights

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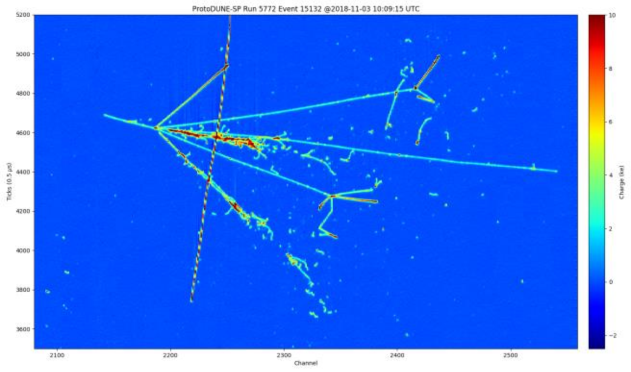
CERN, Geneva, Switzerland
31 August 2021

Corfu Summer Institute
21st Hellenic School and Workshops on Elementary Particle Physics and Gravity
Corfu, Greece 2021

Outline



Pion event in the ProtoDUNE at CERN

Speaker of today

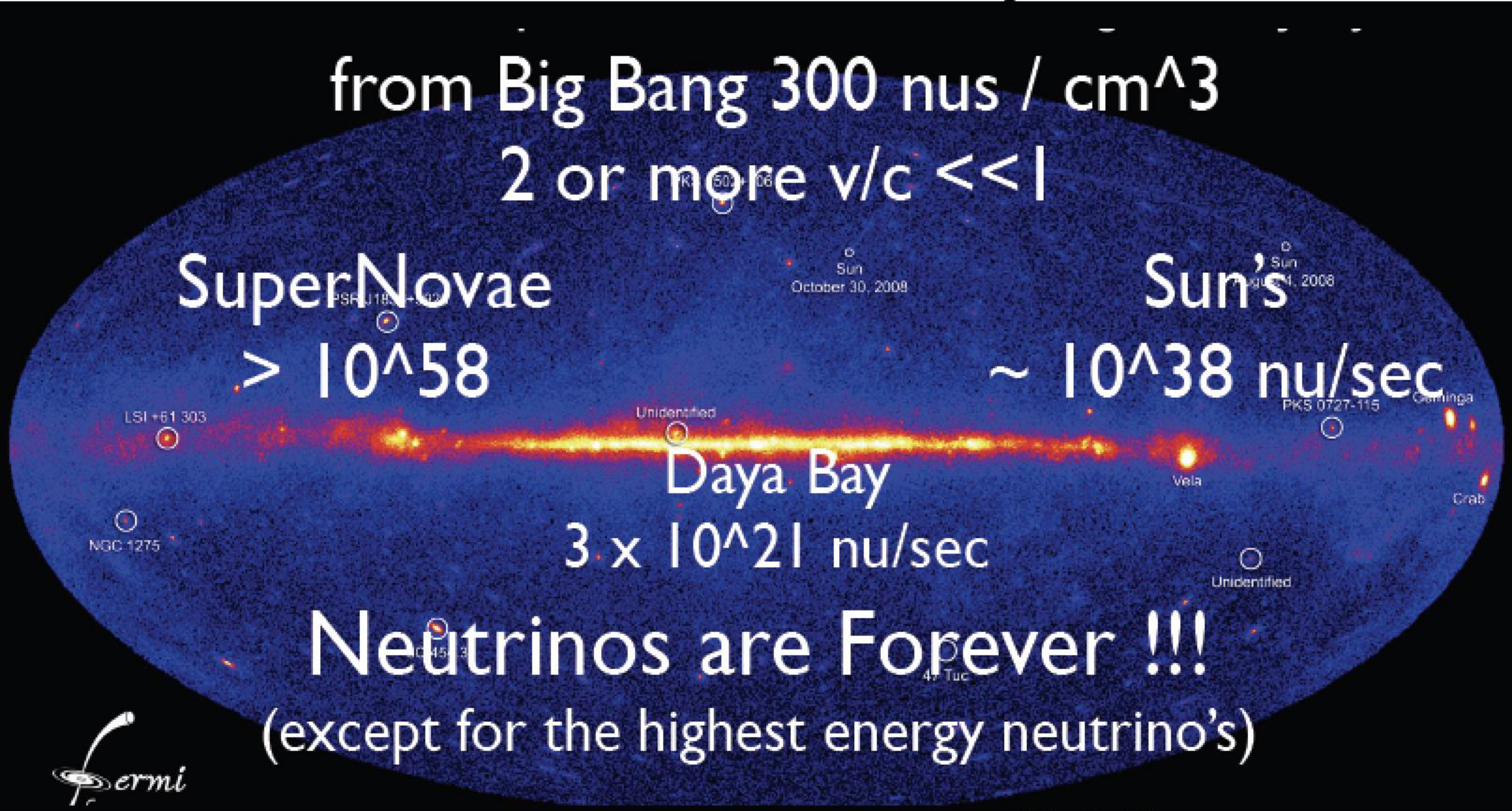
- Introduction to neutrinos
- Neutrinos oscillate and have mass
- Physics oscillation experiments
- Neutrino properties: mass and Majorana/Dirac nature
- Future experiments & CERN Neutrino Platform
- (Cosmic Neutrinos)
- (Sterile Neutrino Search)
- Neutrino experiments at the LHC
- Summary

Neutrinos

Neutrinos are still mysterious particles

- Have only (left handed) weak interactions
- Are mass-less in the (minimal) SM .. untill 1998
- Are the only neutral fermions in the SM
- Could be Majorana or Dirac fermions
- Neutrinos are produced everywhere
  - Solar neutrinos
  - Atmospheric neutrinos
  - Neutrinos from supernova explosions
  - Primordial neutrinos from the Big Bang
  - Nuclear reactor created neutrinos
  - Accelerator created neutrinos
  - Geoneutrinos, Radioactive decay, even from your body…

Neutrinos are Everywhere !



from Big Bang 300 nus / cm^3

2 or more v/c <<1

SuperNovae

> 10^58

Sun's

~ 10^38 nu/sec

Daya Bay

3 x 10^21 nu/sec

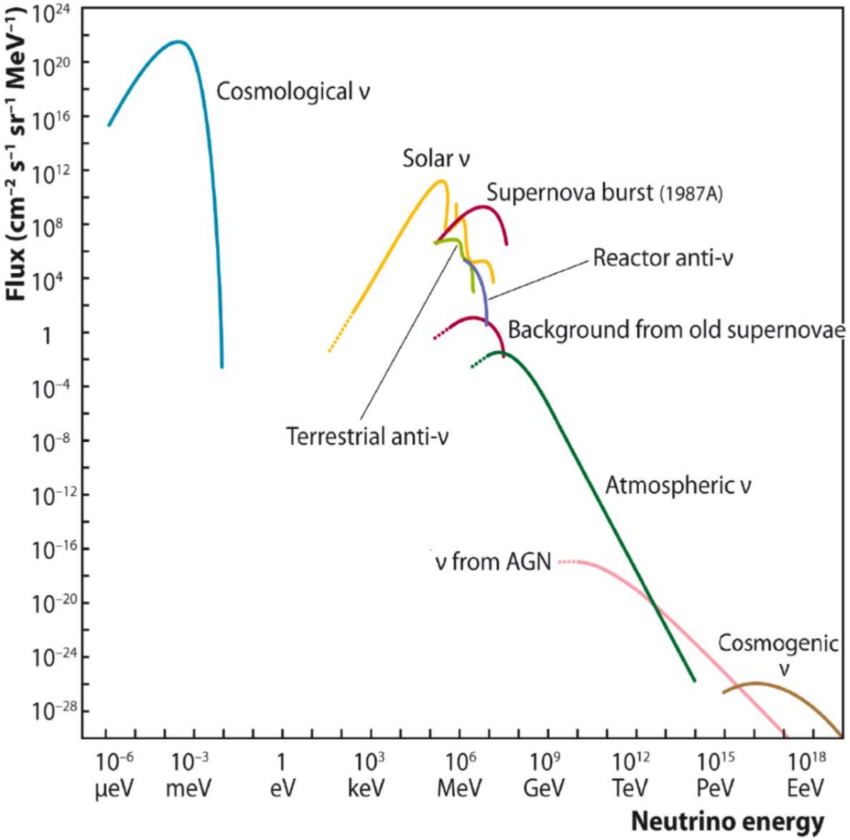
Neutrinos are Forever !!!

(except for the highest energy neutrino's)

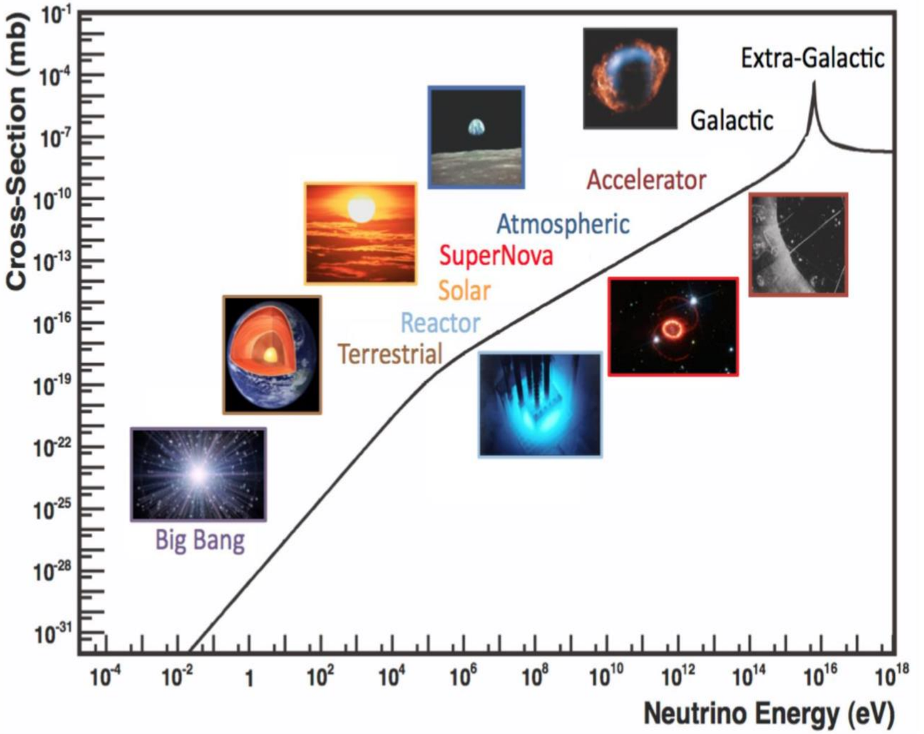
therefore in the Universe: $\frac{\partial N_\nu}{\partial t} > 0$

Neutrino Sources, Flux and Cross Sections

C. Spiering, arXiv:1207.4952



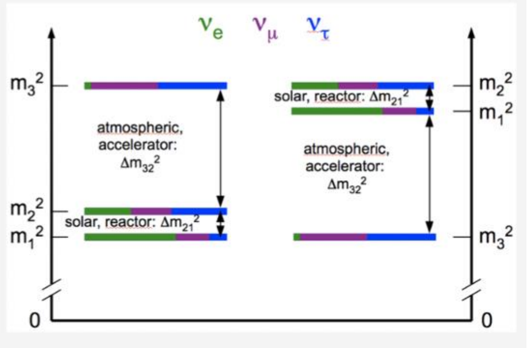
J. Formaggio, G.P. Zeller, arXiv:1305.7513



Cosmological and background from old supernovae neutrinos not yet observed!

Neutrinos

Neutrino experiments today -> Open Questions!



- Neutrino mass values?
- Neutrino mass hierarchy? Normal or Inverted?
- CP violation in the lepton sector? Are neutrinos key the baryon asymmetry in the Universe?
- Are neutrinos their own antiparticles? -> LNV processes
- Do right-handed/sterile/heavy neutrinos exist?
- Are there non-standard neutrino interactions?
- Neutrinos and Dark Matter?
- Testing of CPT..
- Neutrinos are Chameleons:
  They can change flavour!!

Neutrinos are an essential part of our Universe and our very existence, and can provide answers to some of the key fundamental questions today

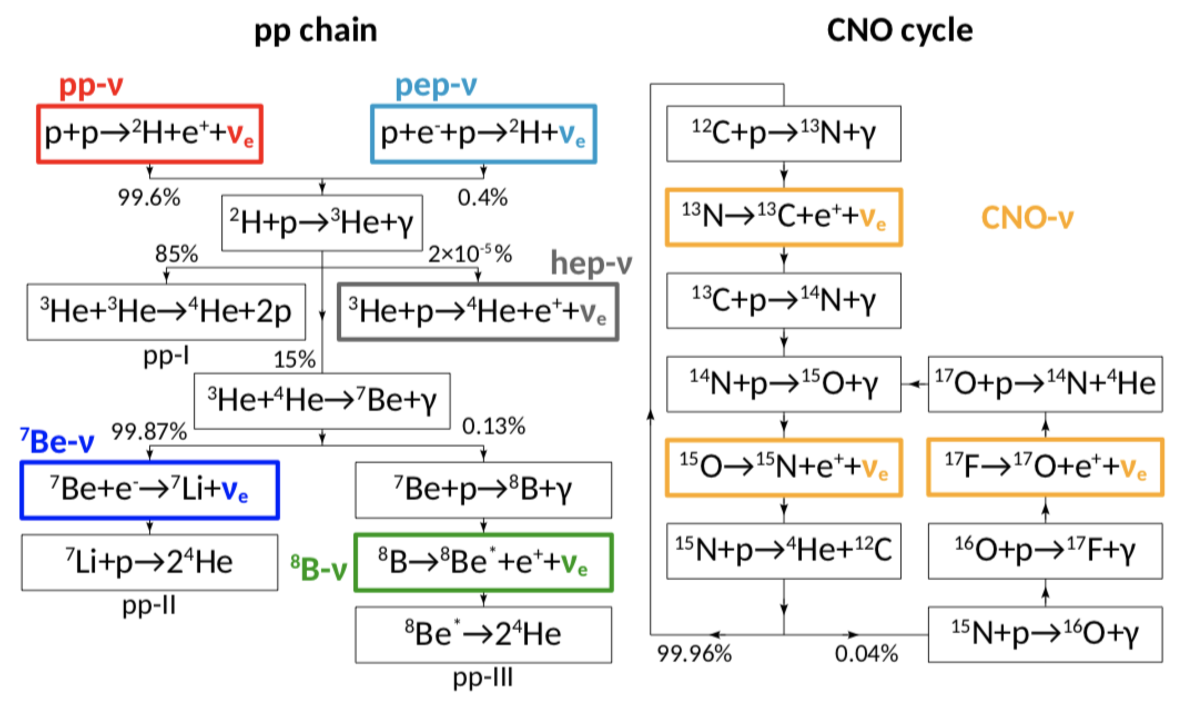
Neutrinos allow us to to look into the heart of the sun

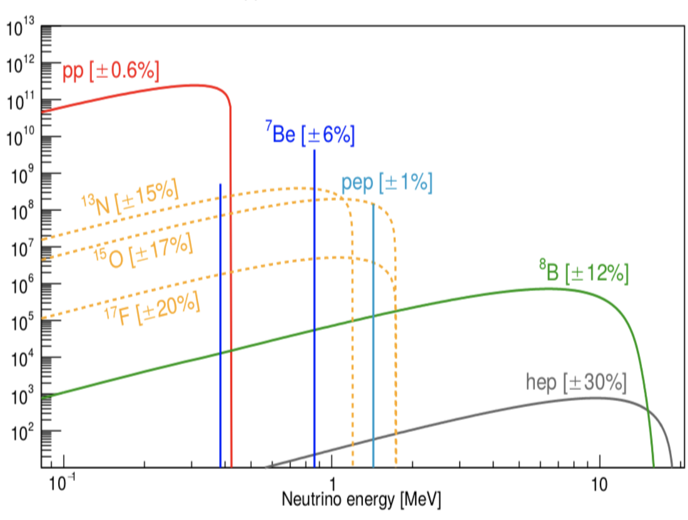
10^{38} neutrinos per second
are produced by the Sun

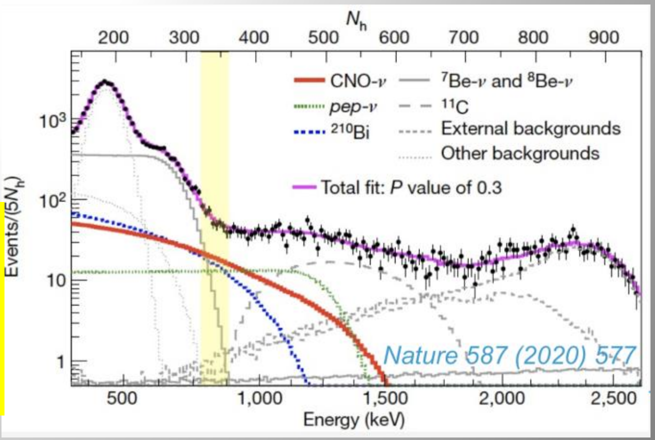
(with a flux of ~10^{11}/cm^2/sec at the Earth)

Solar Neutrinos

Neutrino measurements allow to understand how the sun works







2020: Borexino measured the CNO cycle ->
Nature 687 (220) 577

Neutrino Oscillations

Mixings and phases: **CKM→ PMNS** (Pontecorvo-Maki-Nakagawa-Sakata)

$$U_{\alpha i} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

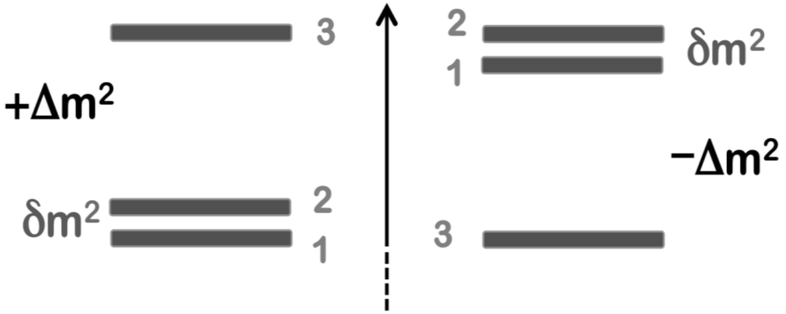
θ_{23} rotation θ_{13} rotation θ_{12} rotation

+ CPV "Dirac" phase δ

$$c_{ij} = \cos\theta_{ij};\, s_{ij} = \sin\theta_{ij}$$

Mass [squared] spectrum (E ~ p + $m^2/2E$ + "interaction energy")

"Normal" Ordering
N.O.



"Inverted" Ordering
I.O.

+ interactions in matter → effective terms ~ $G_F \cdot E \cdot$ density

In total 6 parameters to determine
- -3 angles
- -2 mass differences
- -1 CP violation phase

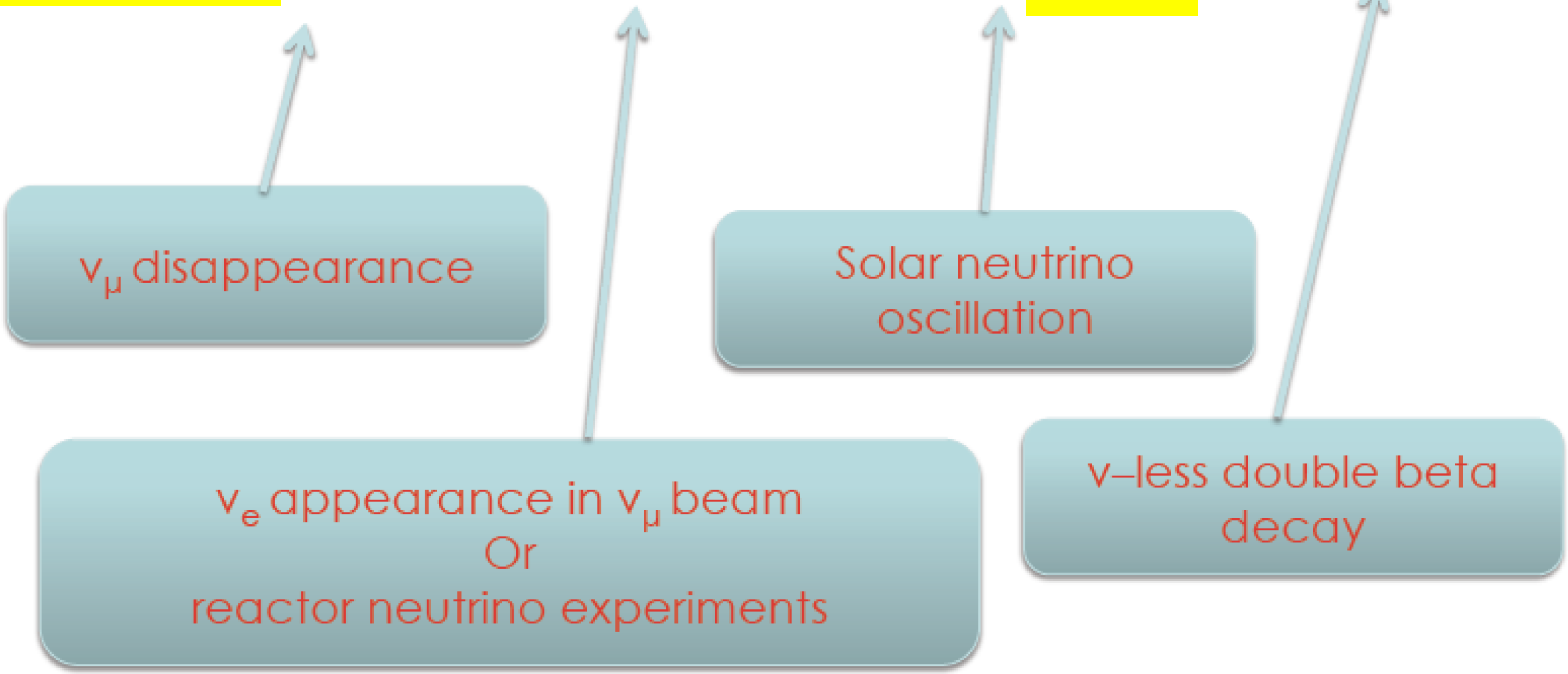
Neutrino Oscillations

$$c_{ij} = \cos\theta_{ij};\ s_{ij} = \sin\theta_{ij}$$

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & e^{i\delta_3} \end{pmatrix}$$

“Atmospheric”

“Solar”



ν_μ disappearance

Solar neutrino oscillation

ν_e appearance in ν_μ beam
Or
reactor neutrino experiments

ν–less double beta decay

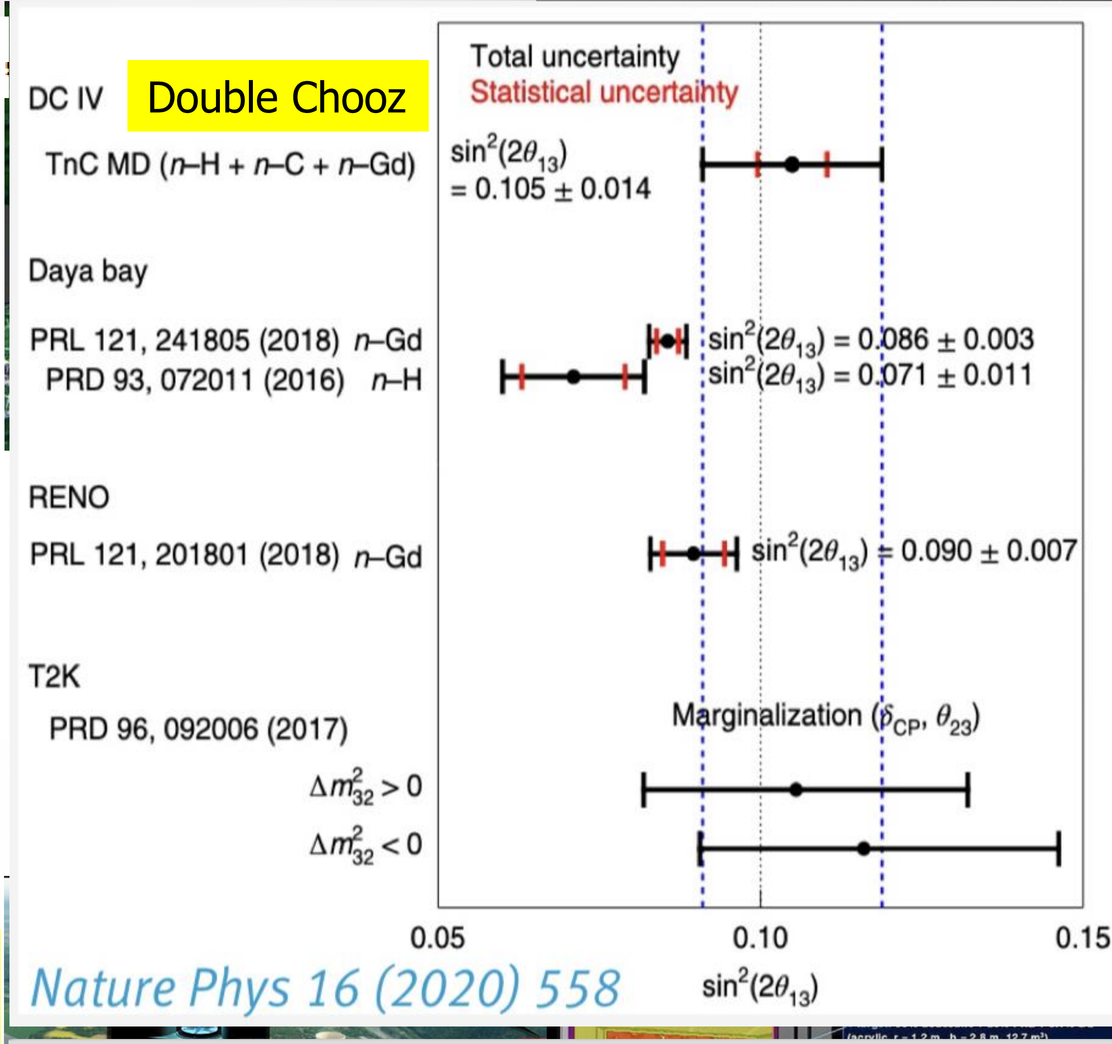
Short Baseline Experiments

Measuring the mixing angle θ_{13}

Daya Bay (China)
Eight anti-neutrino detectors
(liquid scintillator based)
within 2 km of 6 reactors

RENO (South Korea)
Two anti-neutrino detectors
(liquid scintillator based)
~up to 1.5 km of 6 reactors

Double Chooz (France)
Two anti-neutrino detectors
(liquid scintillator based)
within 0.4-1 km of the reactors



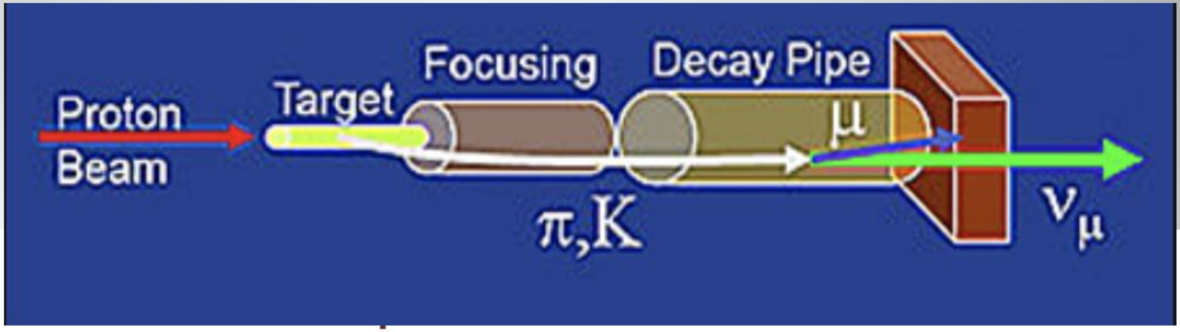
Nature Phys 16 (2020) 558

$$\sin^2\theta_{13} = 0.0220 \pm 0.0007$$

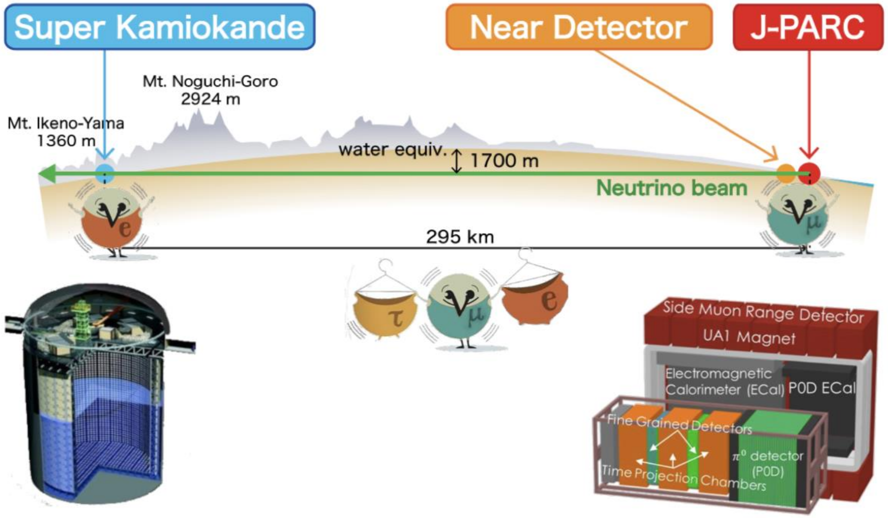
(PDG2021 using Double Chooz, Reno, Daya Bay)

Accelerator Based Neutrino Experiments

Neutrinos from accelerators

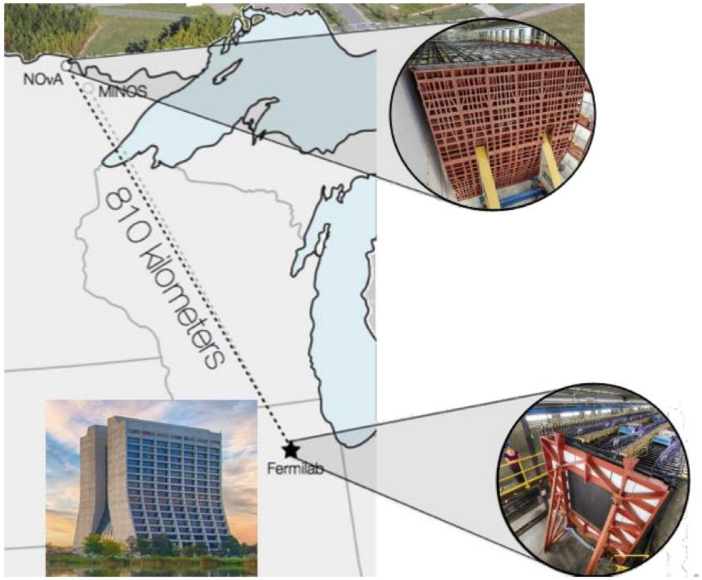


T2K



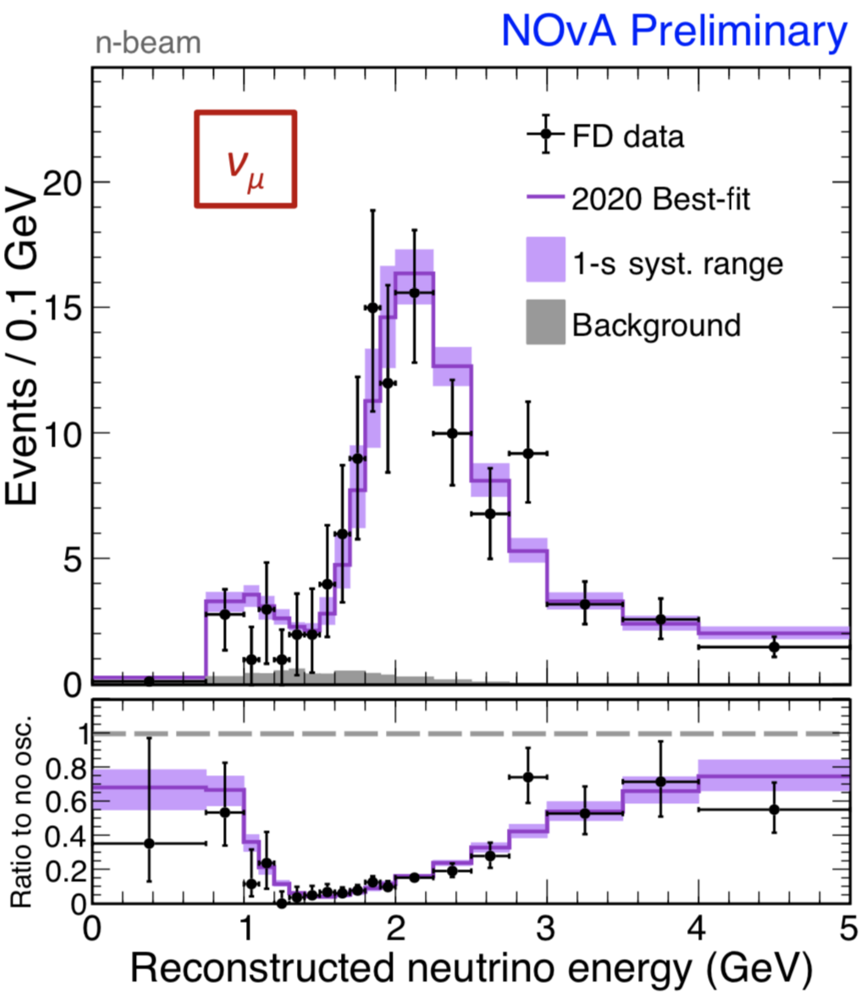
Baseline: 295 km
Peak E_ν: ~0.6 GeV (off-axis)
Near detector: ND280 (~2 T C/O targets, TPC tracking, magnetised)
Far detector: Super-K, 50 kT, Water-Cherenkov

NOvA

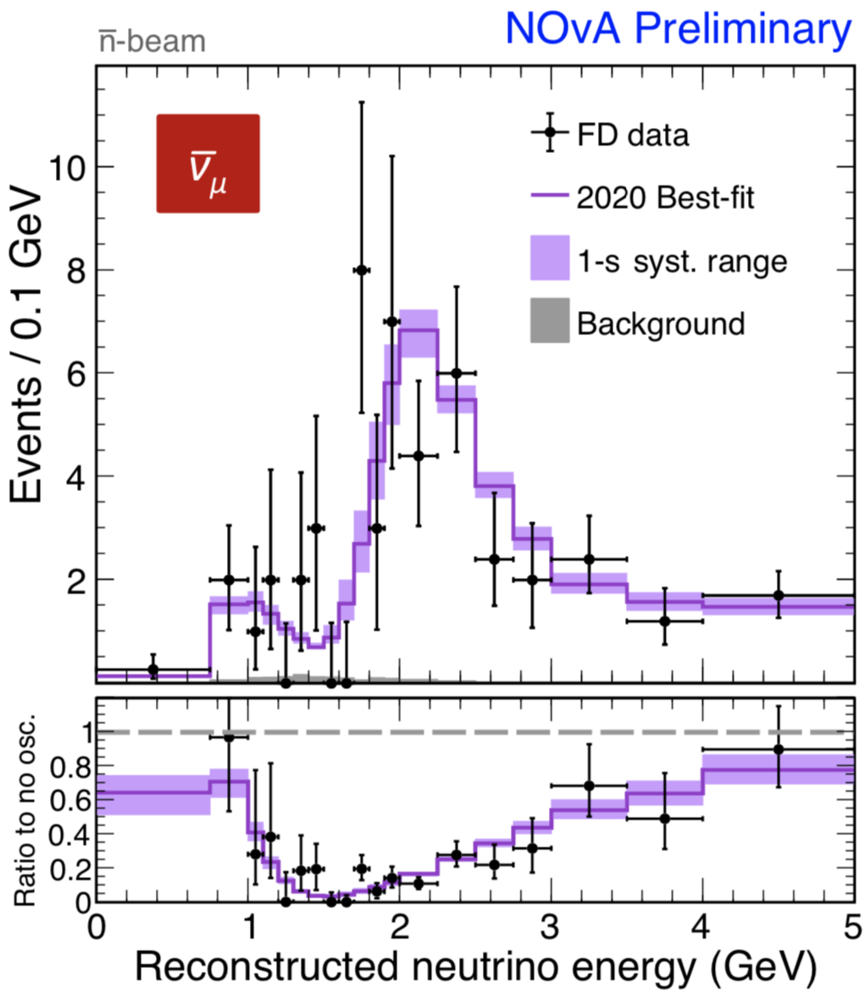


- Baseline: 810 km
- Peak E_ν: ~2 GeV (off-axis)
- Near detector: Scintillator tracker (300 T)
- Far detector: Scintillator tracker (14 kT)

Muon Neutrino Disappearance



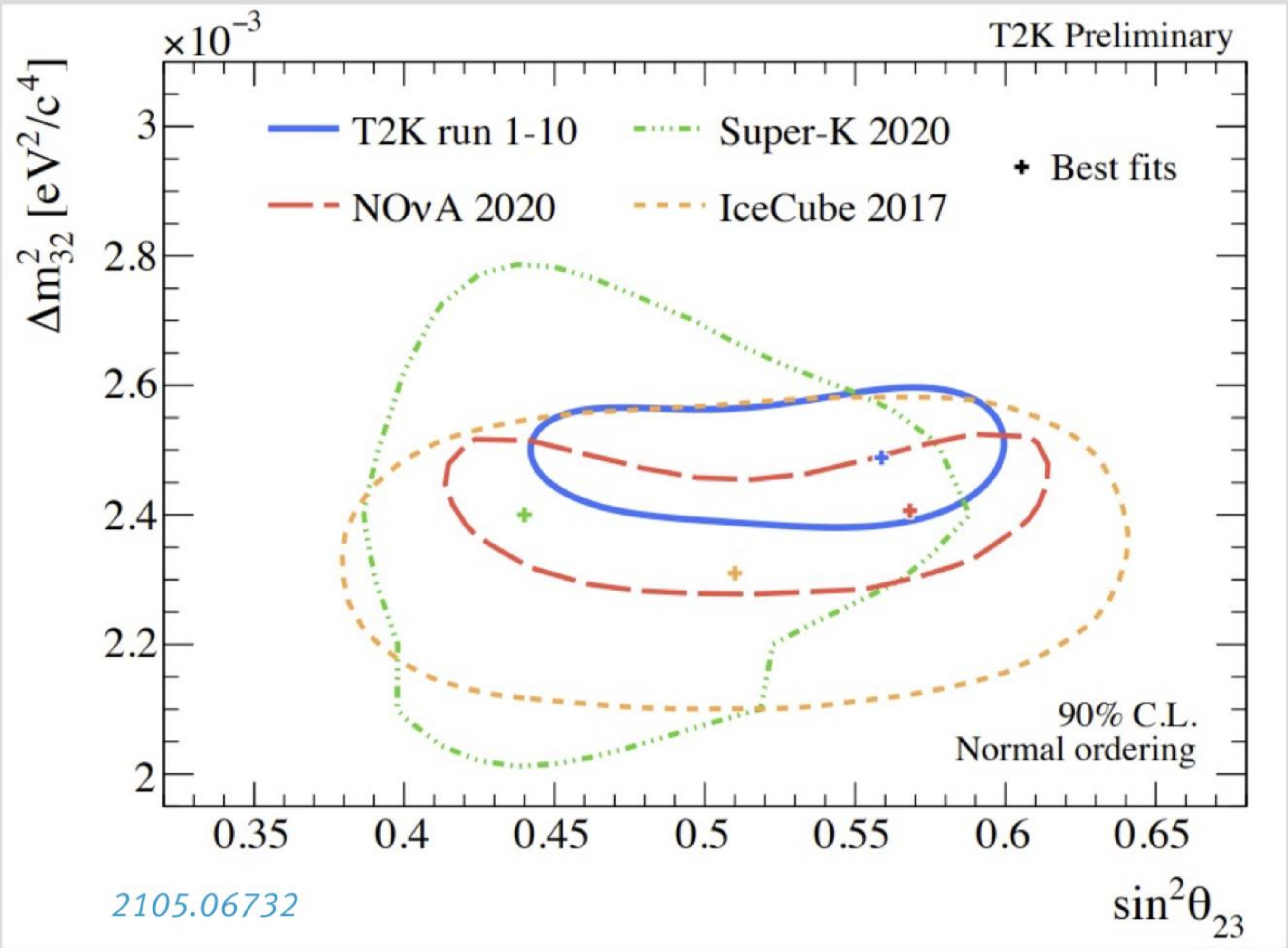
211 events, 8.2 background



105 events, 2.1 background

Neutrino Experiments

2105.06732



- Atmospheric parameter determinations by several experiments
- Results are consistent

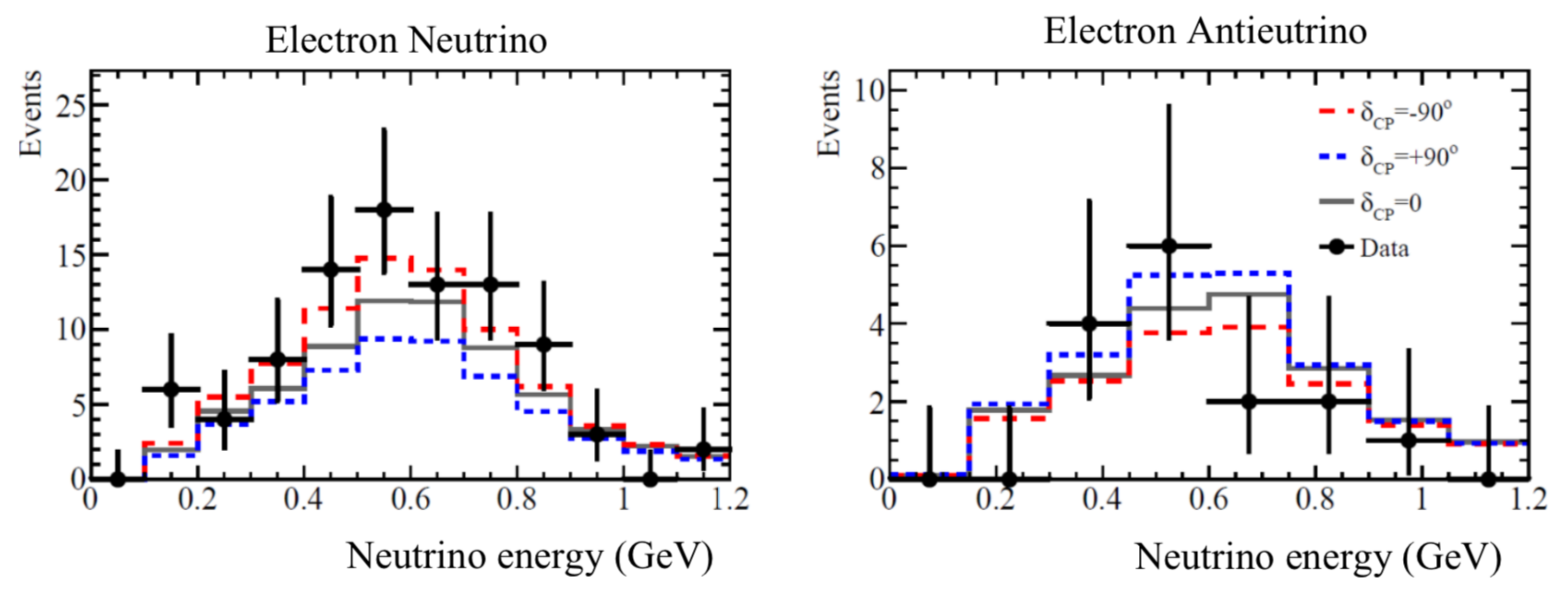
CP Violation: T2K Measurement

Do neutrinos and anti-neutrinos oscillate differently ?

Measured versus expected electron-(anti)neutrino events in SK as function of the assumed CP- angle

	Observed	Expectation	
		$\delta_{CP} = -90°$	$\delta_{CP} = +90°$
Electron neutrino	90	82	56
Electron antineutrino	15	17	22

δ_{CP}=0
~70
~20



CP Violation: T2K Result

The international journal of science / 16 April 2020

nature

THE MIRROR CRACK'D

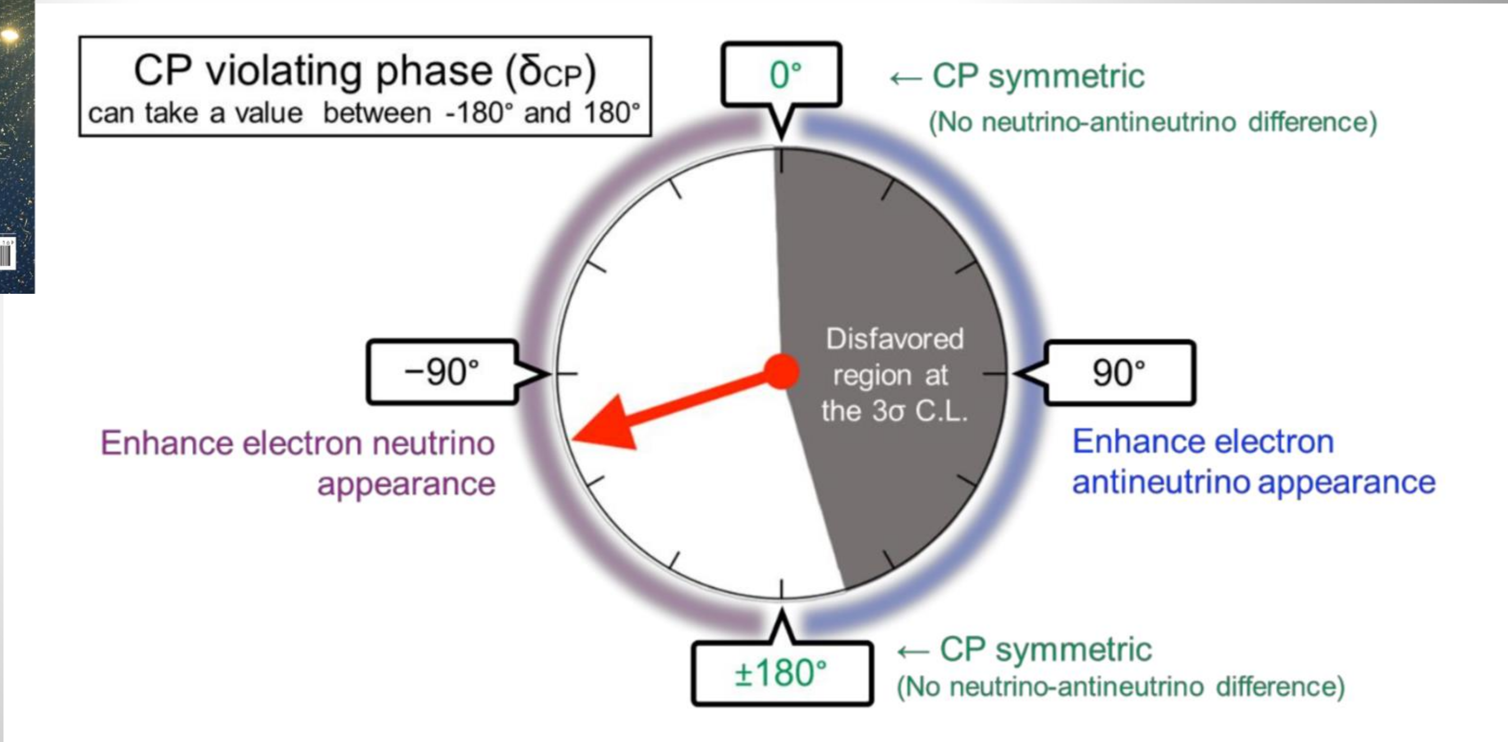
An indication of matter–antimatter symmetry violation in neutrinos

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

Nature Magazine April 16/4/2020
and arXiv:: 1910.03887



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

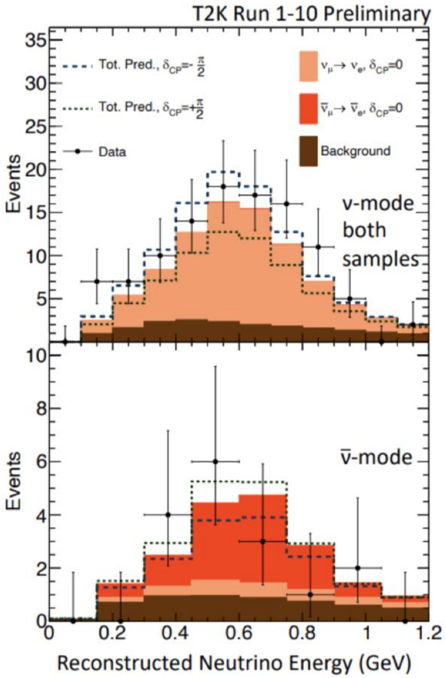
The gray region is disfavored by 99.7% (3σ) CL
The values 0 and 180 degrees are disfavoured at 95% CL

CP Violation Results

Updates from NOvA and T2K summer 2020..

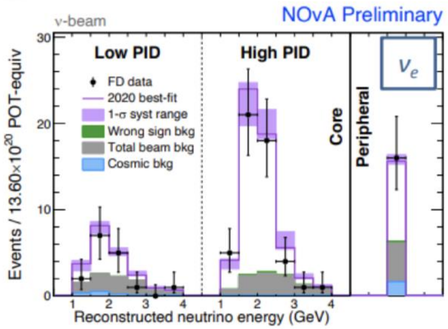
ν_e appearance data

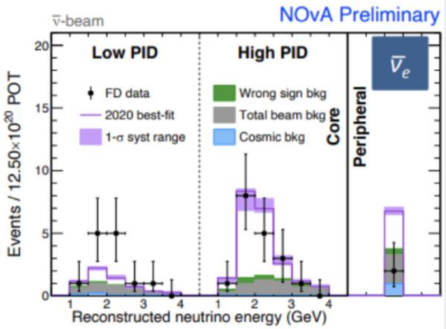
T2K



	$\delta_{CP}=-\pi/2$	$\delta_{CP}=0$	$\delta_{CP}=\pi/2$	$\delta_{CP}=\pi$	Data
FHC 1Re	97.62	82.44	67.56	82.74	94
RHC 1Re	16.69	18.96	20.90	18.63	16
FHC 1R ν_e CC1π^+	9.20	8.01	6.51	7.71	14

NOvA





Total Observed	82	Range
Total Prediction	85.8	52-110
Wrong-sign	1.0	0.6-1.7
Beam Bkgd.	22.7	
Cosmic Bkgd.	3.1	
Total Bkgd.	26.8	26-28

Total Observed	33	Range
Total Prediction	33.2	25-45
Wrong-sign	2.3	1.0-3.2
Beam Bkgd.	10.2	
Cosmic Bkgd.	1.6	
Total Bkgd.	14.0	13-15

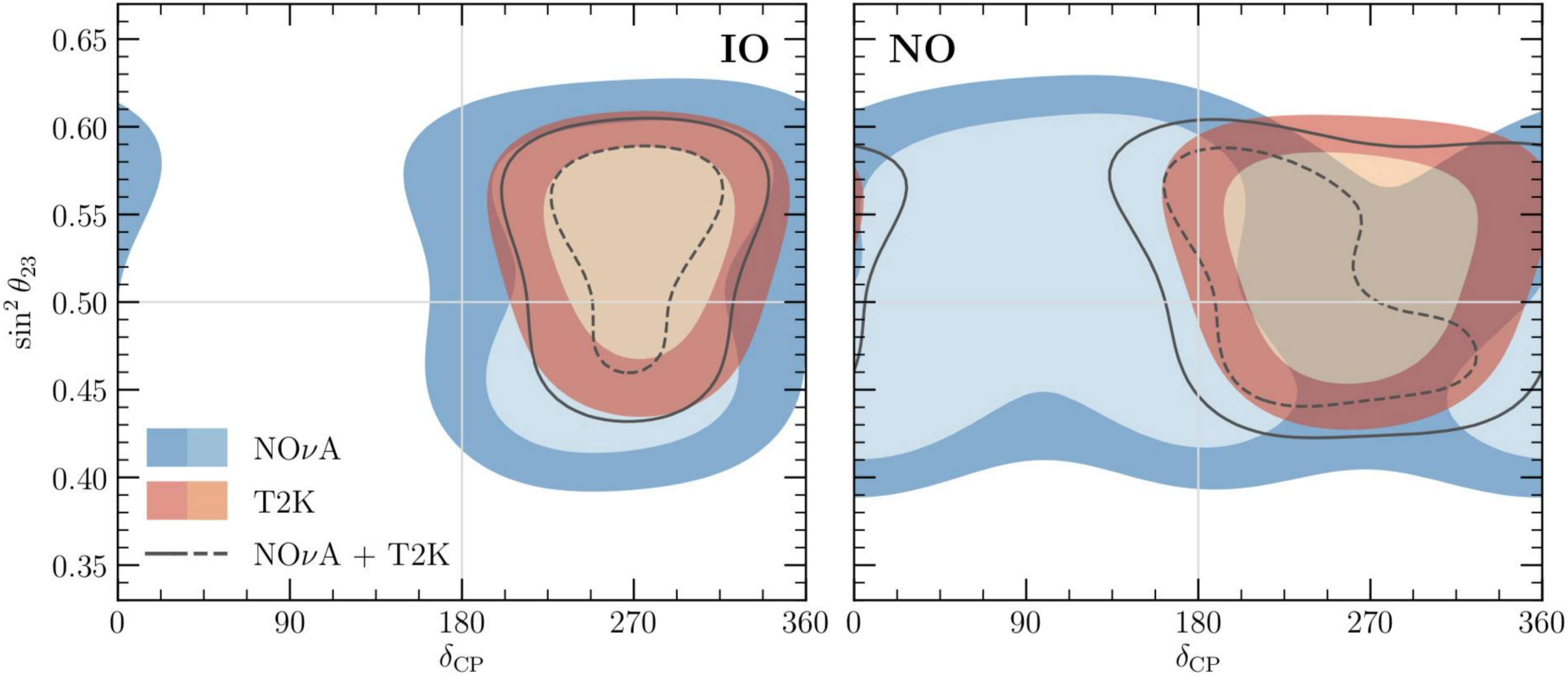
>4σ evidence of $\bar{\nu}_e$ appearance

CP Violation T2K/NOvA Results

Summer 2020 update

arXiv:2007.14792

NuFIT group

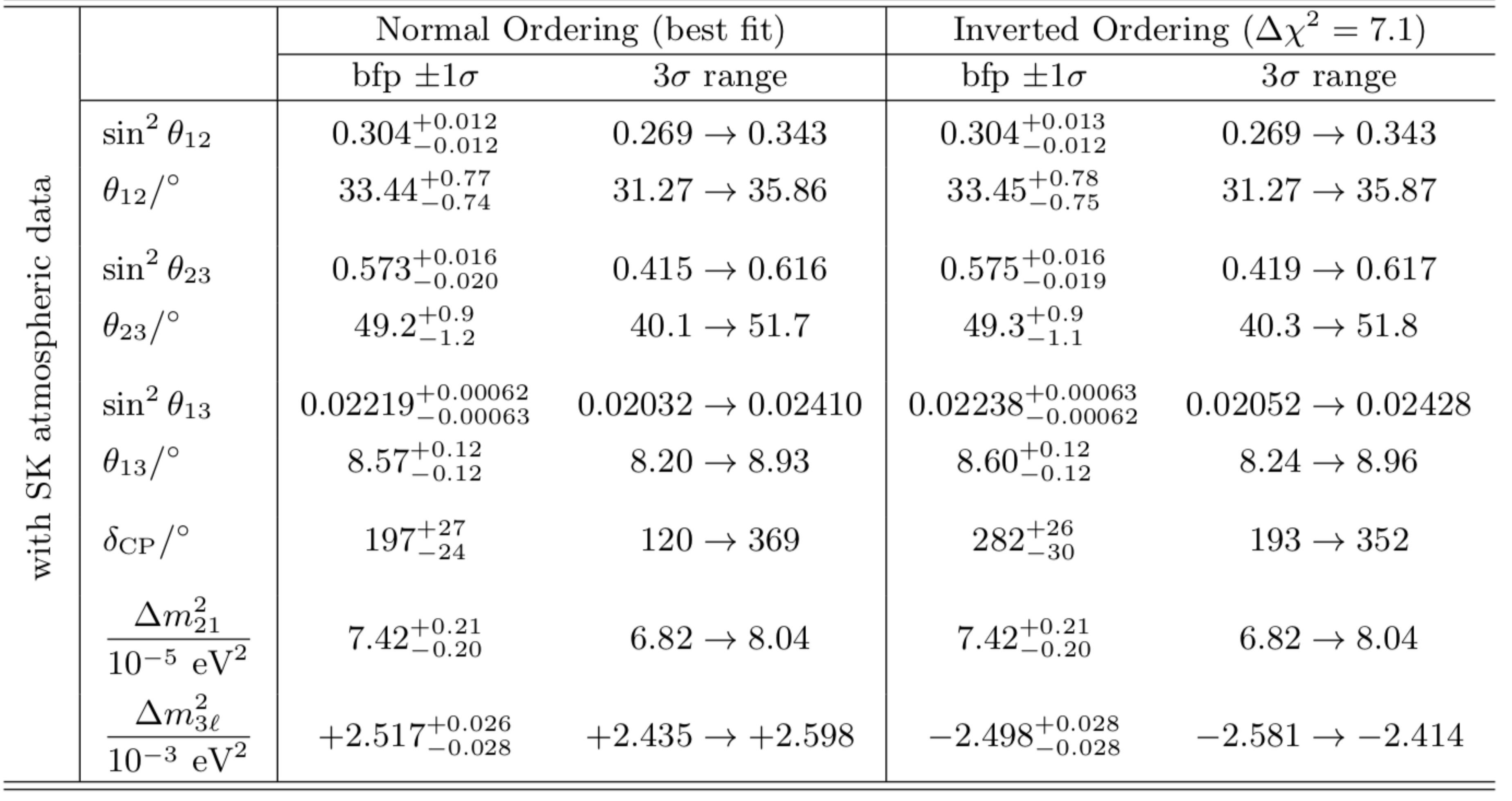


Some tension between NOvA and T2K results for NO mass ordering
-> more experimental data needed … (and coming..)

Taking all available data together…

arXiv:2007.14792

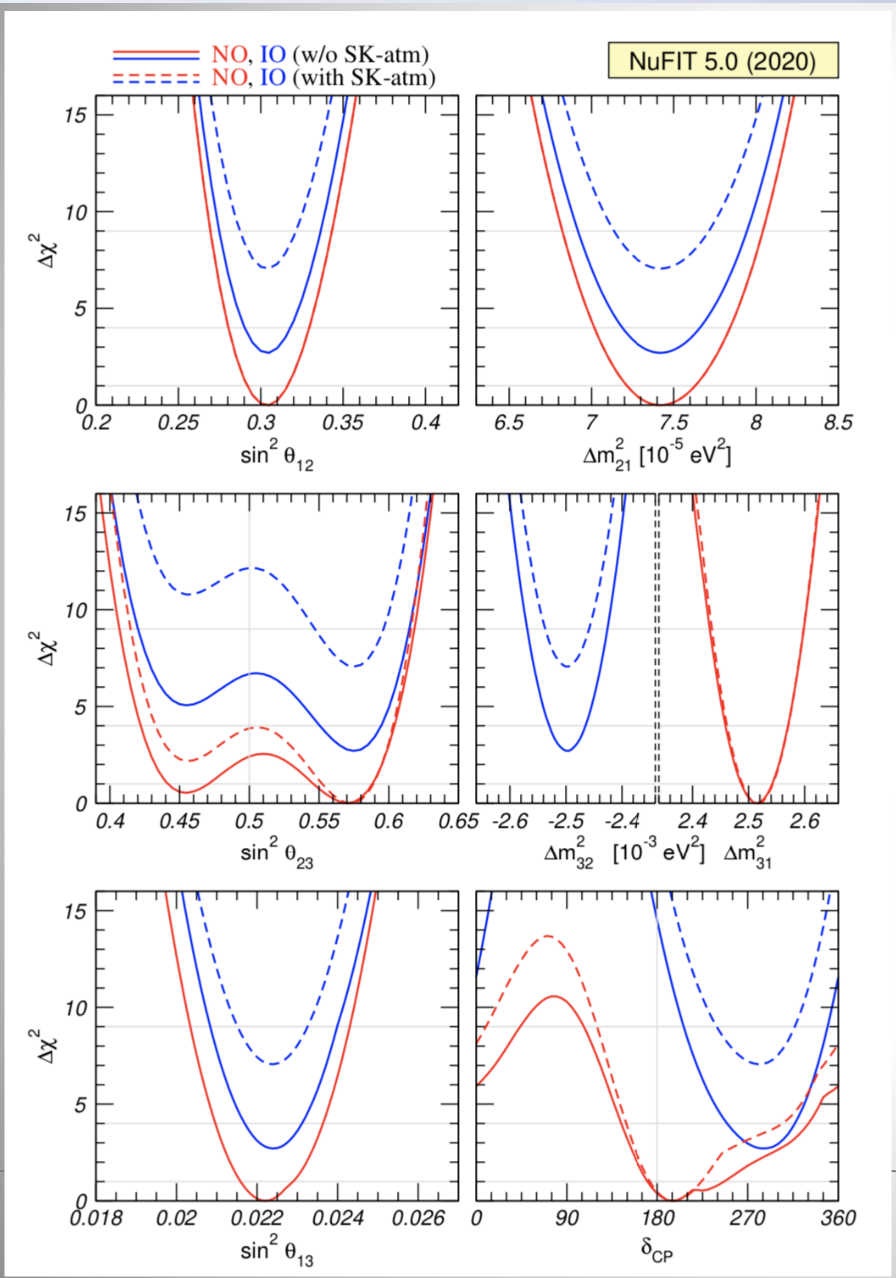
NuFIT group



		Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 7.1$)	
		bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range
with SK atmospheric data	$\sin^2\theta_{12}$	$0.304^{+0.012}_{-0.012}$	$0.269 \to 0.343$	$0.304^{+0.013}_{-0.012}$	$0.269 \to 0.343$
	$\theta_{12}/^\circ$	$33.44^{+0.77}_{-0.74}$	$31.27 \to 35.86$	$33.45^{+0.78}_{-0.75}$	$31.27 \to 35.87$
	$\sin^2\theta_{23}$	$0.573^{+0.016}_{-0.020}$	$0.415 \to 0.616$	$0.575^{+0.016}_{-0.019}$	$0.419 \to 0.617$
	$\theta_{23}/^\circ$	$49.2^{+0.9}_{-1.2}$	$40.1 \to 51.7$	$49.3^{+0.9}_{-1.1}$	$40.3 \to 51.8$
	$\sin^2\theta_{13}$	$0.02219^{+0.00062}_{-0.00063}$	$0.02032 \to 0.02410$	$0.02238^{+0.00063}_{-0.00062}$	$0.02052 \to 0.02428$
	$\theta_{13}/^\circ$	$8.57^{+0.12}_{-0.12}$	$8.20 \to 8.93$	$8.60^{+0.12}_{-0.12}$	$8.24 \to 8.96$
	$\delta_{\mathrm{CP}}/^\circ$	197^{+27}_{-24}	$120 \to 369$	282^{+26}_{-30}	$193 \to 352$
	$\dfrac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.42^{+0.21}_{-0.20}$	$6.82 \to 8.04$	$7.42^{+0.21}_{-0.20}$	$6.82 \to 8.04$
	$\dfrac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$	$+2.517^{+0.026}_{-0.028}$	$+2.435 \to +2.598$	$-2.498^{+0.028}_{-0.028}$	$-2.581 \to -2.414$

To explore Beyond the Standard Model ~ 10 times better precision needed

Taking all available data together…



arXiv:2007.14792

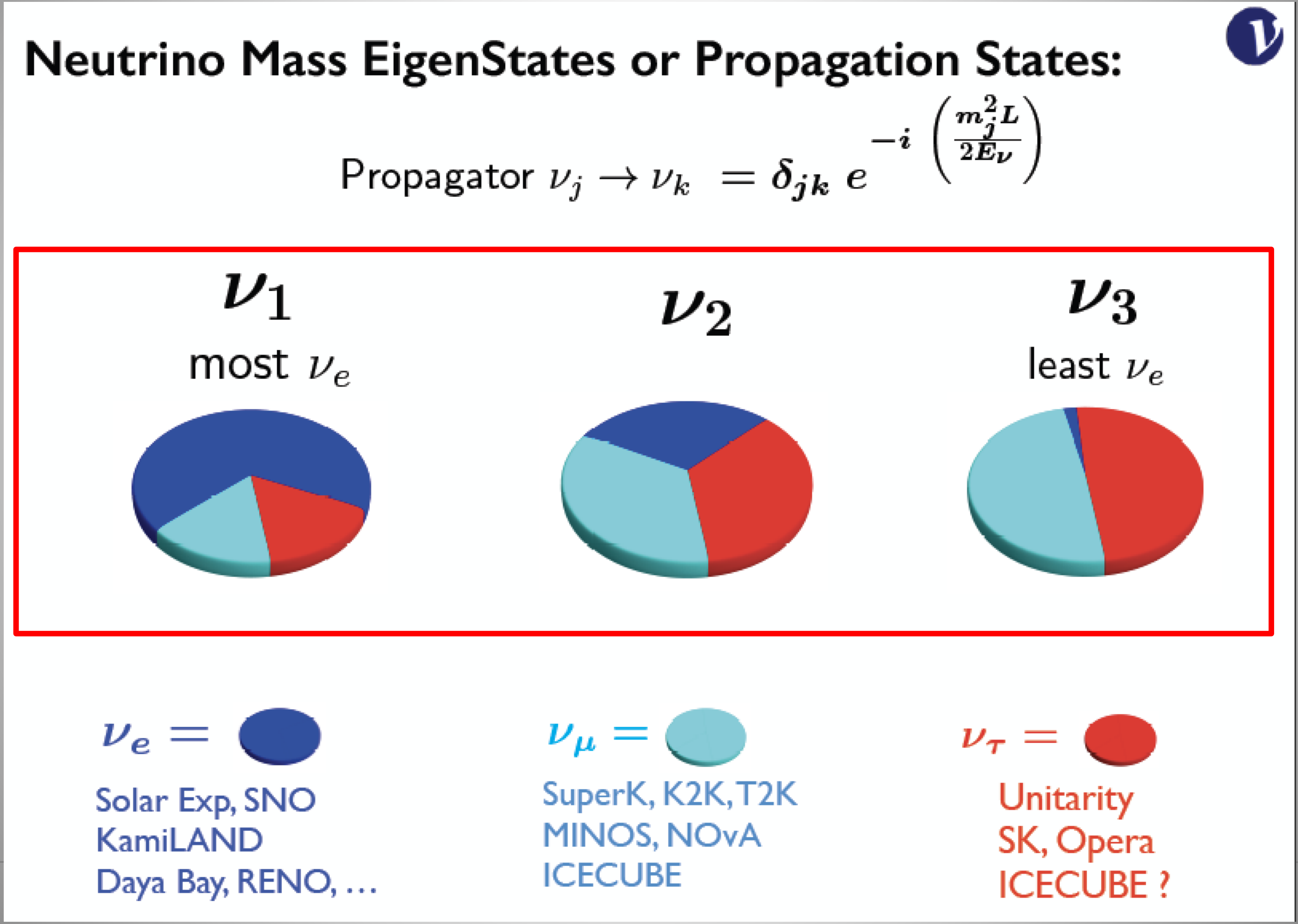
Minimized $\Delta\chi$ distribtions
for the 3 neutrino hypothesis
fit off all data

Inverse mass odering is disfavoured slightly compared to the normal mass ordering in the global fit by about 1.6 sigma (2.7 sigma when including SK)

Data mainly from reactors,
long baseline experiments,
atmospheric, solar neutrinos…

But the Jury is still out..

Neutrino Oscillations



Neutrino Mass EigenStates or Propagation States:

$$\text{Propagator } \nu_j \to \nu_k = \delta_{jk}\, e^{-i\left(\frac{m_j^2 L}{2E_\nu}\right)}$$

ν_1
most ν_e

ν_2

ν_3
least ν_e

$\nu_e =$ ●

Solar Exp, SNO
KamiLAND
Daya Bay, RENO, …

$\nu_\mu =$ ●

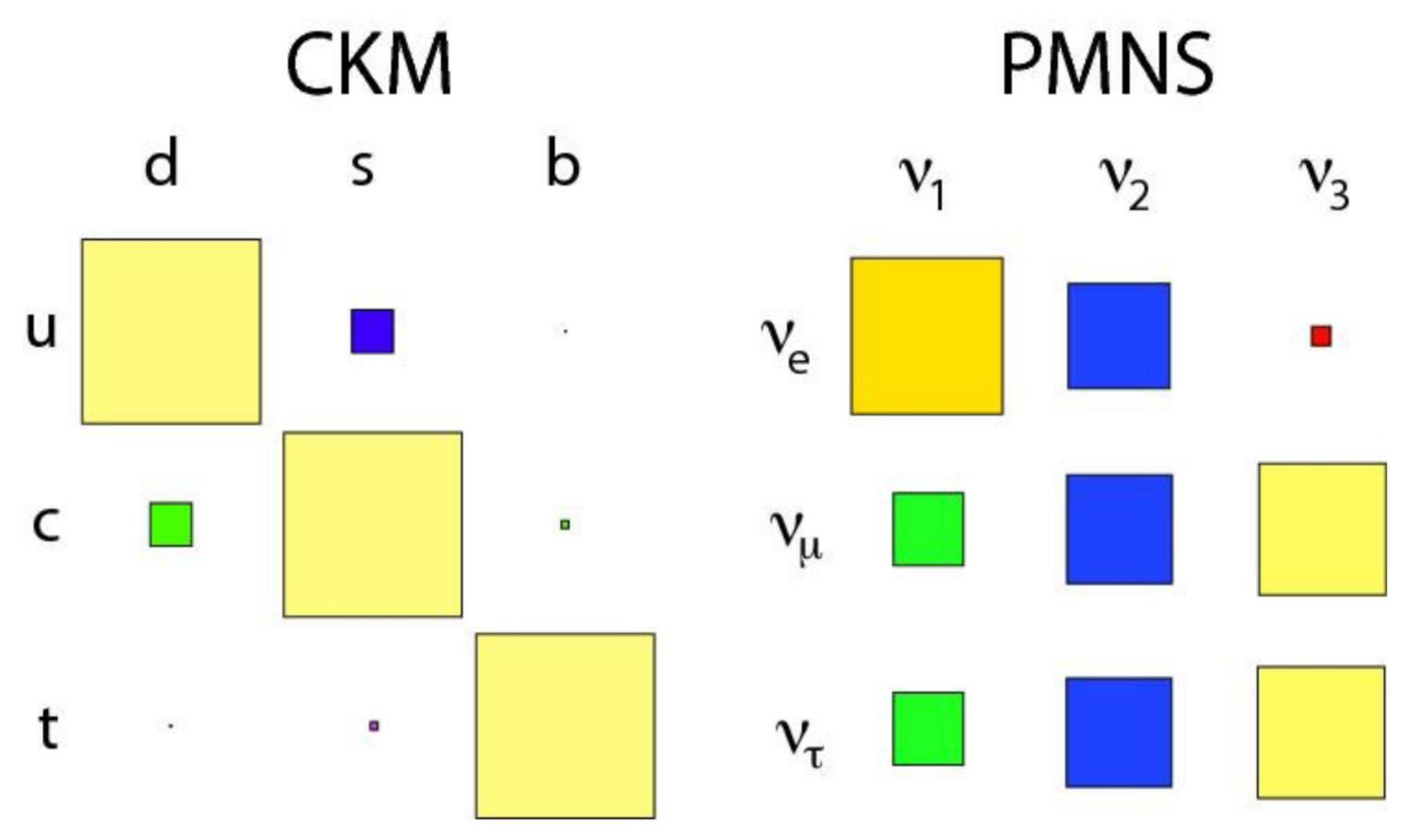
SuperK, K2K, T2K
MINOS, NOvA
ICECUBE

$\nu_\tau =$ ●

Unitarity
SK, Opera
ICECUBE ?

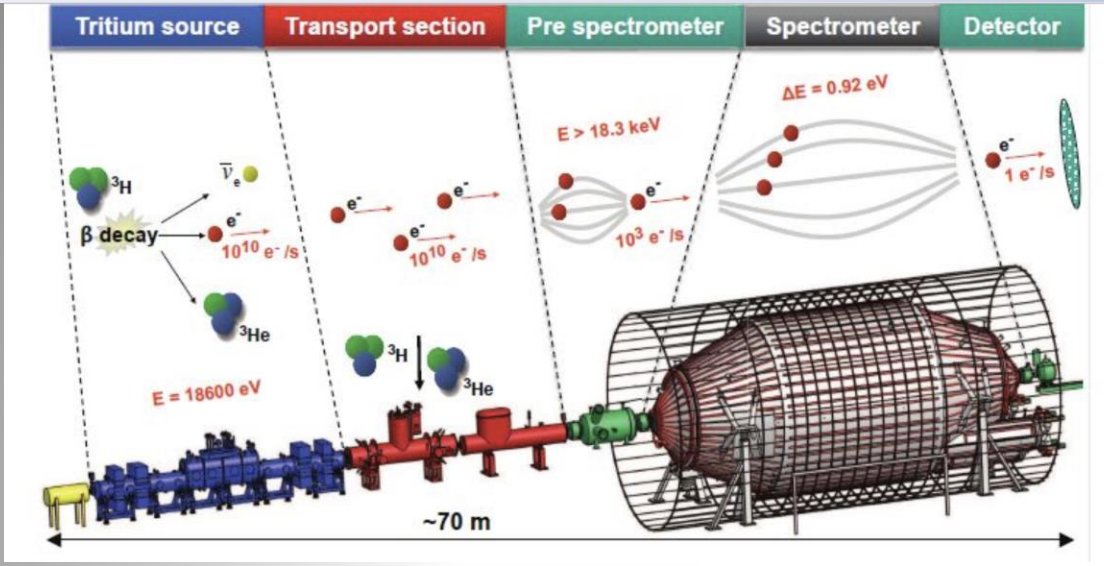
CMK vs PMNS

Why is Neutrino mixing so different from quark mixing?
What does that tell us?



The CKM matrix is almost diagonal, while the PMNS matrix is almost uniform.

KATRIN Experiment: the Mass of ν_e



The KArlsruhe TRItium Neutrino experiment (KATRIN) is designed to measure the mass up to projected sensitivity of 0.2eV

To achieve this, KATRIN will perform high-precision spectroscopy of the endpoint region of the tritium beta-decay spectrum.

Recent result $M\nu_e < 0.8$ eV (May 2021)

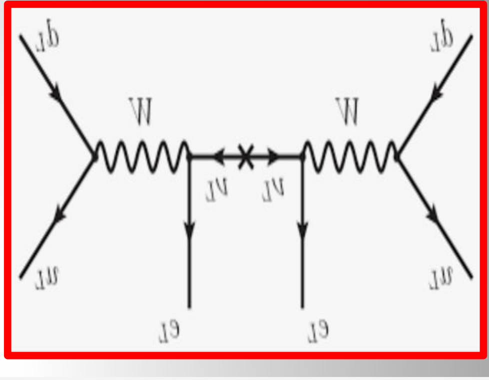
Neutrinoless Double Beta Decay

GERDA (GERmanium Detector Array) experimemt at LNGS (Gran Sasso/IT)

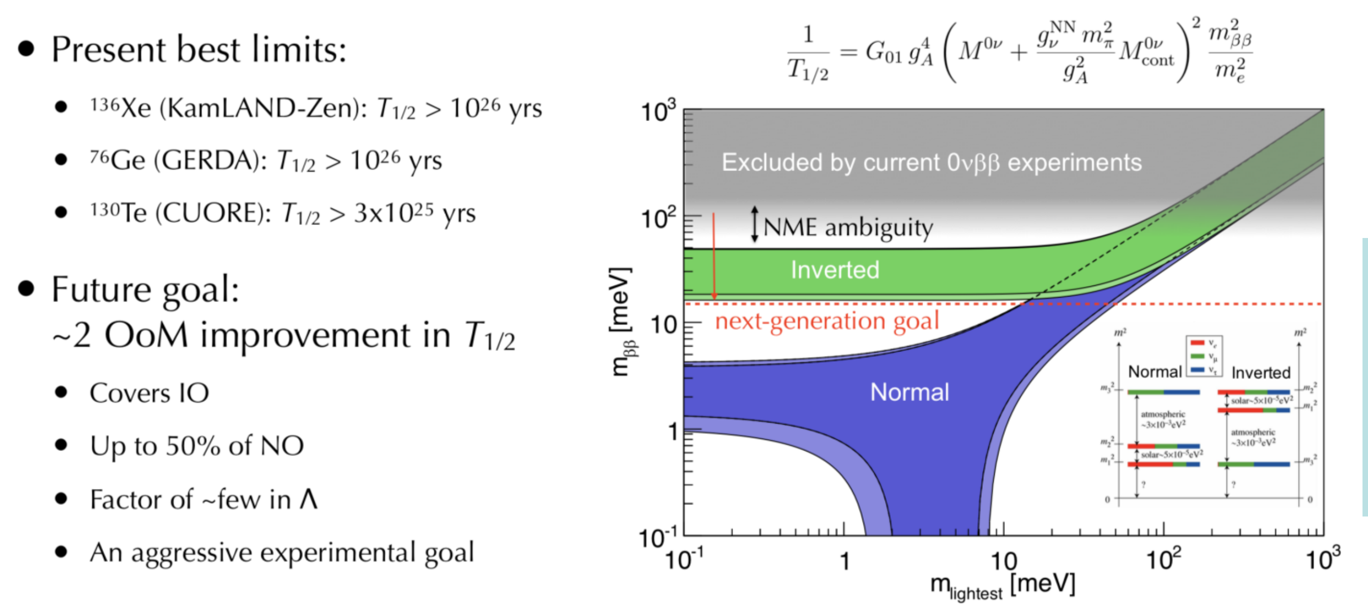
Final results: arXiv:2009.06079

127.2 kg.year exposure
between 2011-2019

Experiment now completed
No $0\nu\beta\beta$ signal observed ☹



upper mass limit: $m_{\beta\beta} < 79 - 180$ **meV**



- Present best limits:
  - ^{136}Xe (KamLAND-Zen): $T_{1/2} > 10^{26}$ yrs
  - ^{76}Ge (GERDA): $T_{1/2} > 10^{26}$ yrs
  - ^{130}Te (CUORE): $T_{1/2} > 3\text{x}10^{25}$ yrs
- Future goal:
  ~2 OoM improvement in $T_{1/2}$
  - Covers IO
  - Up to 50% of NO
  - Factor of ~few in Λ
  - An aggressive experimental goal

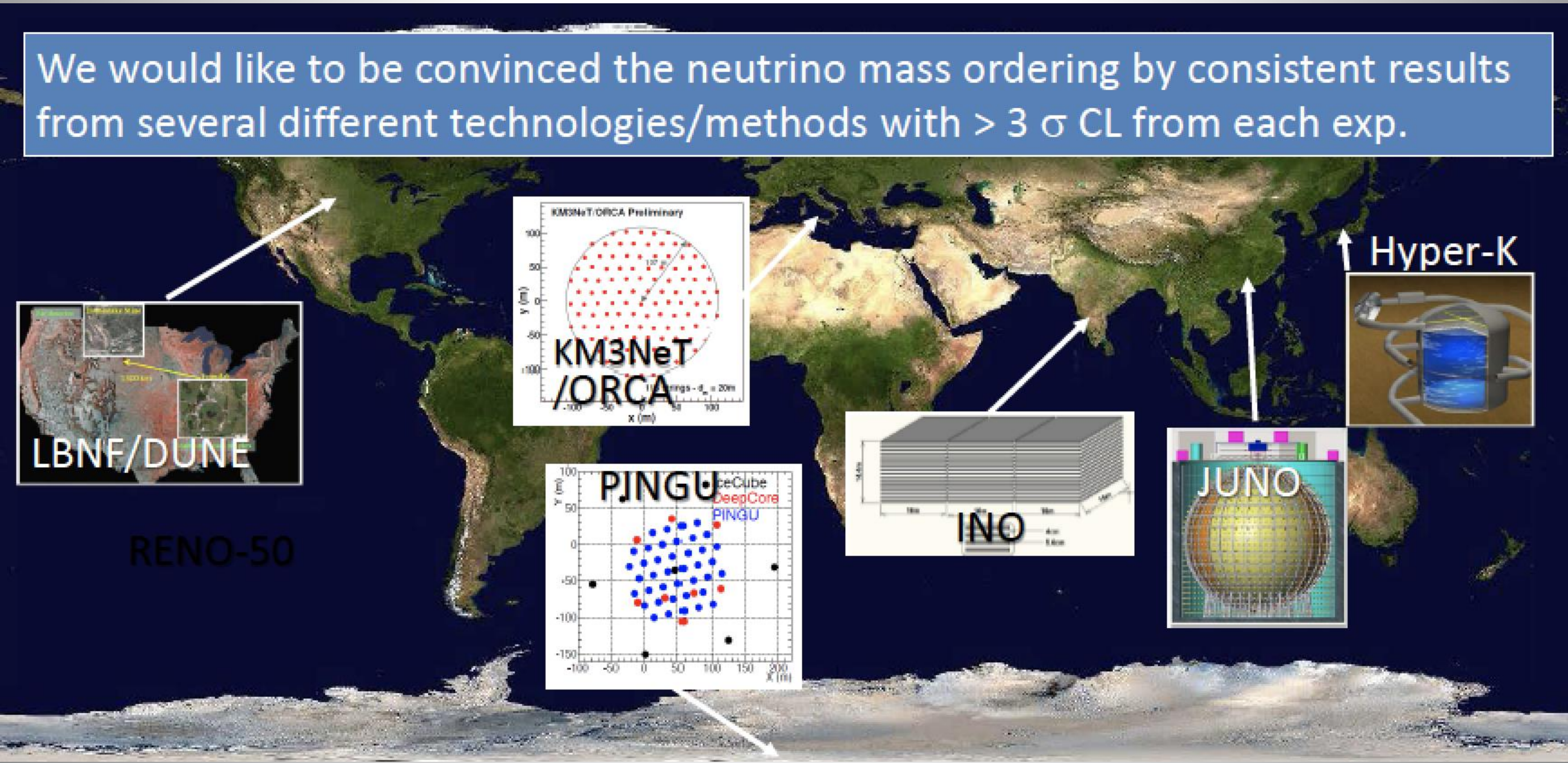
$$\frac{1}{T_{1/2}} = G_{01}\, g_A^4 \left(M^{0\nu} + \frac{g_\nu^{\rm NN}\, m_\pi^2}{g_A^2} M^{0\nu}_{\rm cont} \right)^2 \frac{m_{\beta\beta}^2}{m_e^2}$$

Many experiments operating, planned or in R&D: LEGEND SNO+, NEXT…

Future Neutrino Experiments

Eg. experiments that will contribute to the mass ordering question

We would like to be convinced the neutrino mass ordering by consistent results from several different technologies/methods with > 3 σ CL from each exp.



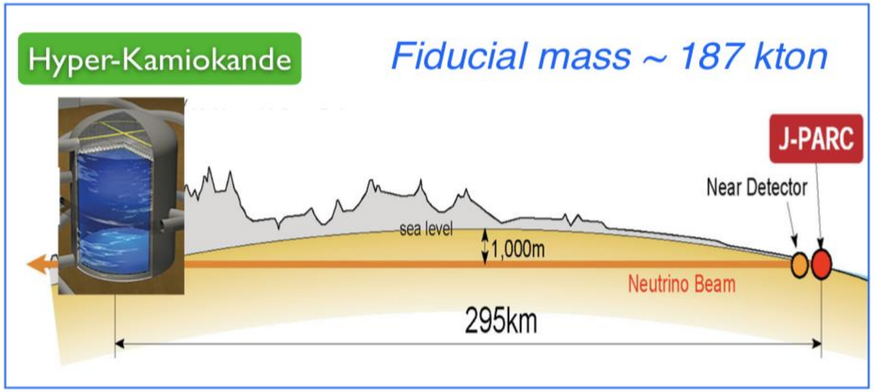
Future Neutrino Experiments

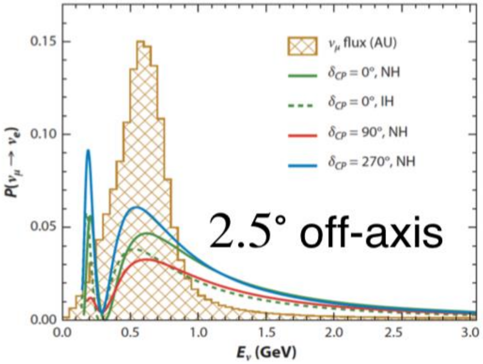
CERN

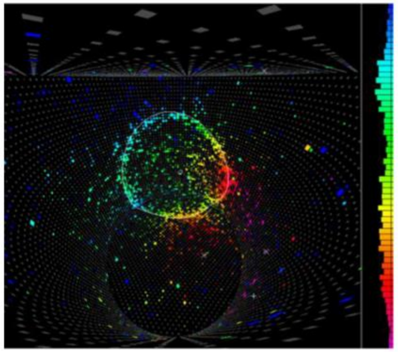
Long-baseline experiments: T2HK and DUNE

First data in 2027 (?)

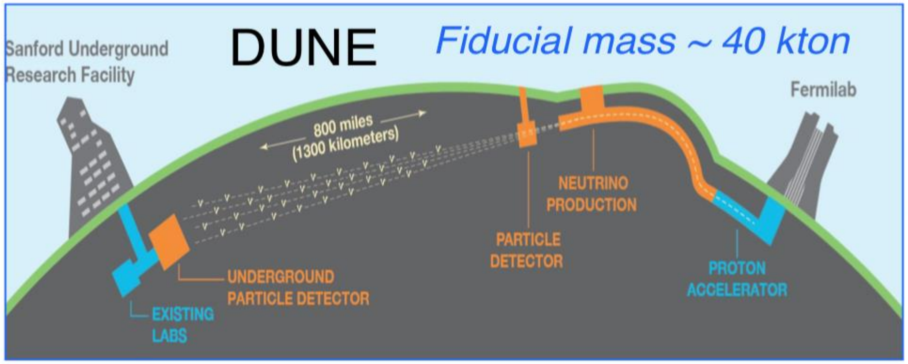
- Towards the measurement of the CP violating phase and Mass Hierarchy
  - ✦ Search for different $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation probabilities

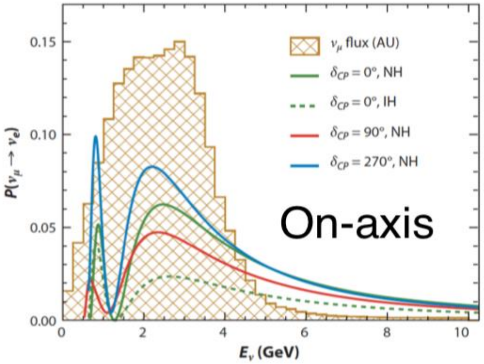


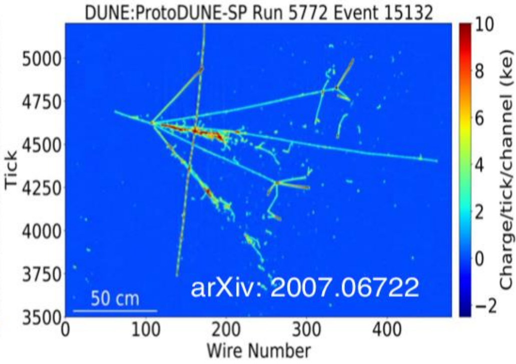




Annu. Rev. Nucl. Part. Sci. 2016. 66:47–71



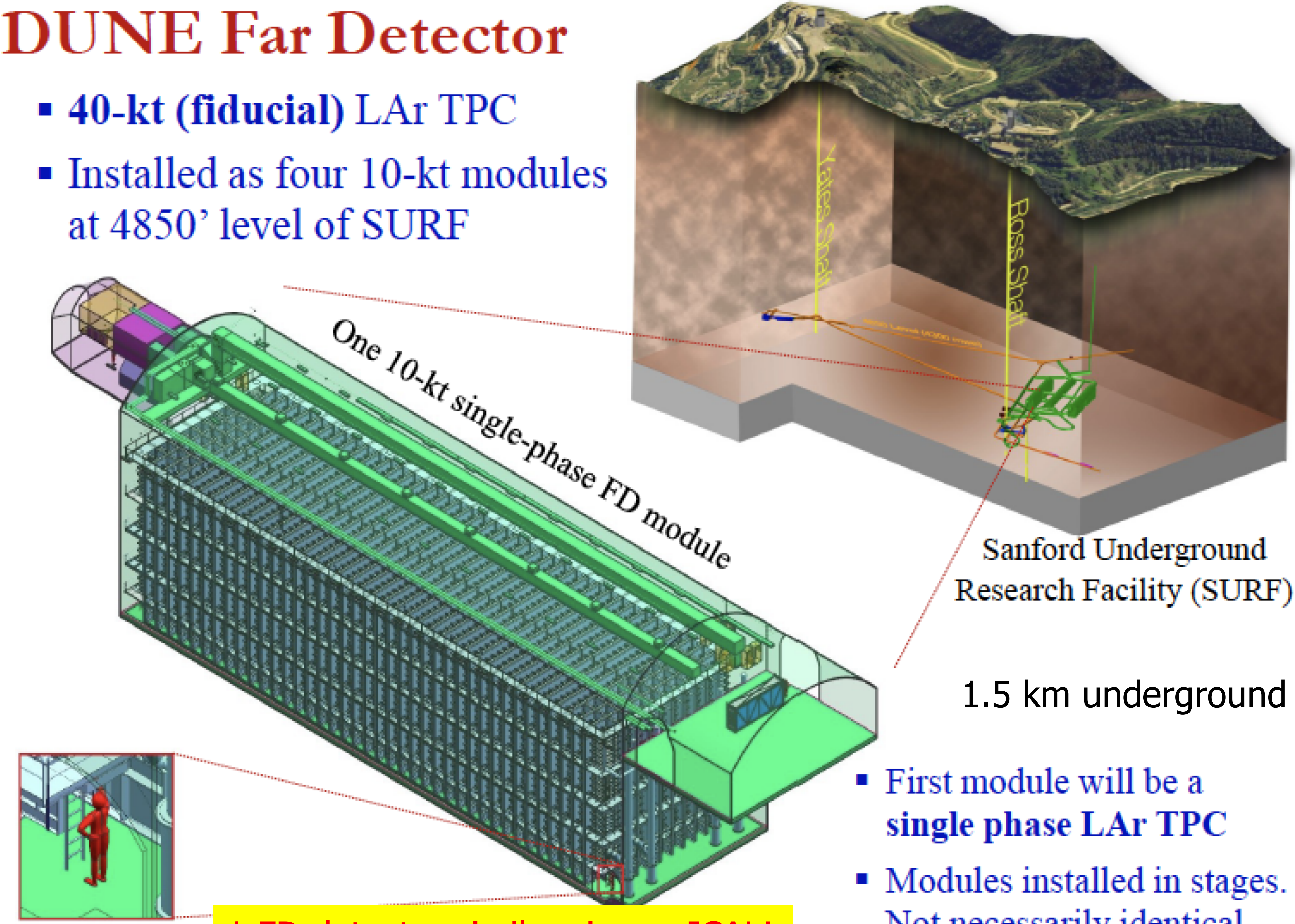




arXiv: 2007.06722

DUNE Far Detector

- **40-kt (fiducial)** LAr TPC
- Installed as four 10-kt modules at 4850’ level of SURF



1.5 km underground

- First module will be a **single phase LAr TPC**
- Modules installed in stages. Not necessarily identical

1 FD detector similar size as ICAL!

Neutrino Experiments and CERN

ProtoDUNE: Prototype at scale 1/25 of a DUNE far detector module

No neutrino beam since switching-off the LNS beam to Gran Sasso in 2015

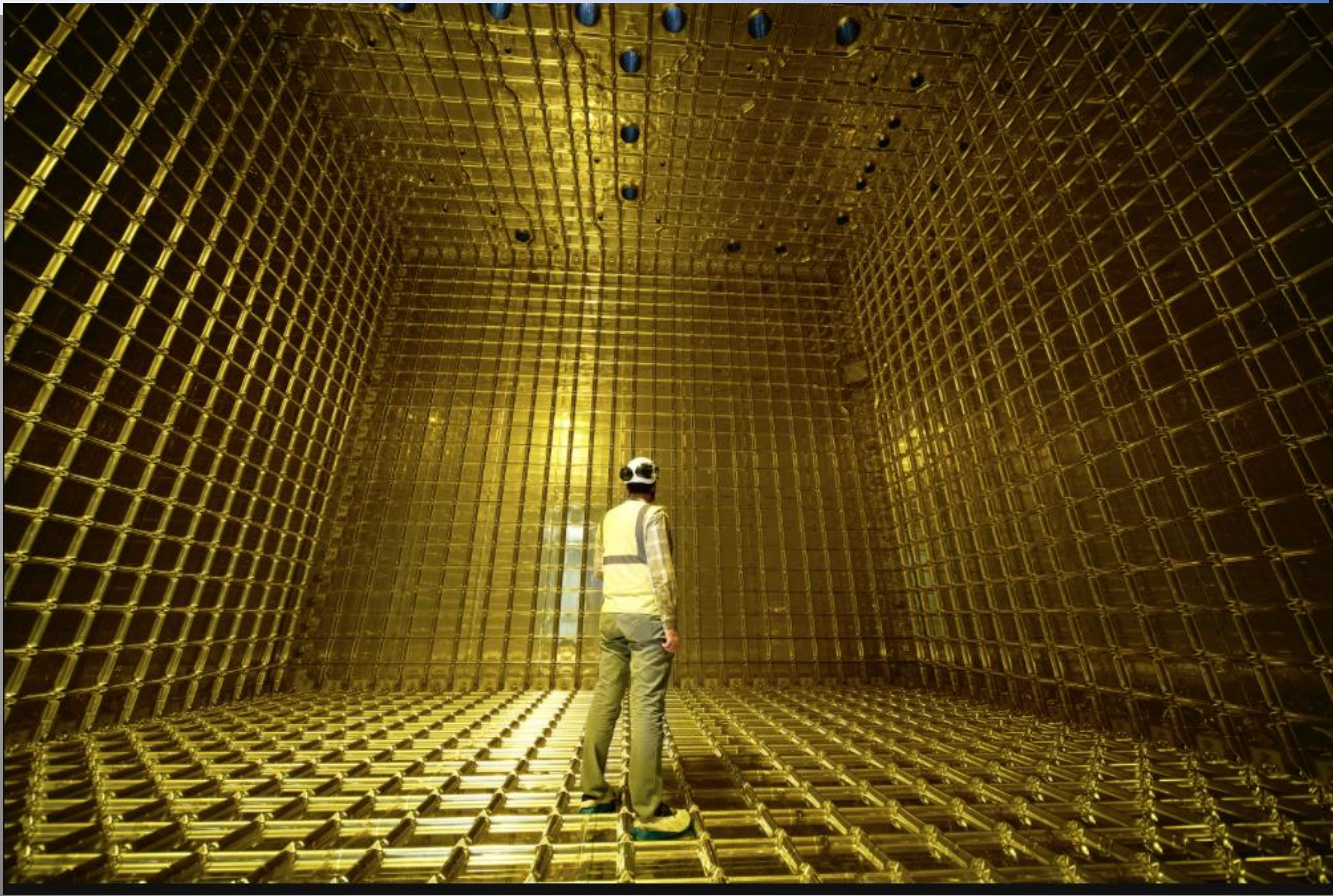
As of 2000: No neutrino experiments at CERN since CHORUS and NOMAD

In 2014, as a result of the European Strategy for Particle Physics at the time it was decided CERN would engage again in accelerator based neutrino experiments

- Creation of the Neutrino platform
- Creation of a Neutrino experimental Group in 2016 (and Theory forum)

2022: Neutrino experiments will be back at CERN … see later

The CERN Neutrino Platform



Present Status of NP Projects

7 MOUs signed:

- ✓ NP01: ICARUS overhauling + FNAL activities
- ✓ NP02: R&D on a double phase LAr TPC technology (protoDUNE DP)
- ✓ NP03: generic R&D on neutrino detectors and facilities
- ✓ NP04: R&D on a single phase LAr TPC technology (protoDUNE SP)
- ✓ NP05: Baby Mind muon spectrometer for a T2K near detector
- ✓ NP06: ENUBET, R&D on a neutrino beta beam
- ✓ NP07: ND280, a new T2K Near Detector

Cooperation agreements

- CERN participation in the USA LBNF/DUNE project
- CERN delivery in kind to USA of the first large LBNF cryostat
- CERN participation in the FNAL short baseline Neutrino program
- CERN technical participation in the Darkside project at LNGS

Other activities

- NP participation in the CERN FASER and SND@LHC project

The EHN1 Hall at CERN

Next step : ~800 ton LAr prototypes

SPS : new EHN1-1 experimental area

The NeutrinoPlatform hall

Virtual Visit to the Neutrino Platform

Recent visit on 12/8/2021

INTERNATIONAL NEUTRINO SUMMER SCHOOL 2021

2-13 AUGUST 2021

SPEAKERS:

–

Neutrino Astronomy Carlos Arguelles
Neutrinos in Cosmology Gabriela Barenboim
Making a Neutrino Beam Mary Bishai
Liquid Argon Detectors Flavio Cavanna
Neutrinos and Dark Matter Sandhya Choubey
Neutrino Interactions/Cross Sections Stephen Dolan
Direct Neutrino Mass Measurements Joe Formaggio
Future Vision for Neutrino Physics Sheldon Glashow

Neutrino Mass Models Andre de Gouvea
Neutrinoless Double Beta Decay Julia Harz
Reactor Neutrinos Patrick Huber
Water Cherenkov Detectors Tsuyoshi Nakaya
Neutrino Mixing & Oscillations Silvia Pascoli
Geoneutrinos Ingrid Semenec
CEvNS Kate Scholberg
Supernova Neutrinos Irene Tamborra

ORGANIZERS:

–

Albert De Roeck
Joachim Kopp
Claire Lee
Bibhushan Shakya

VIRTUAL:

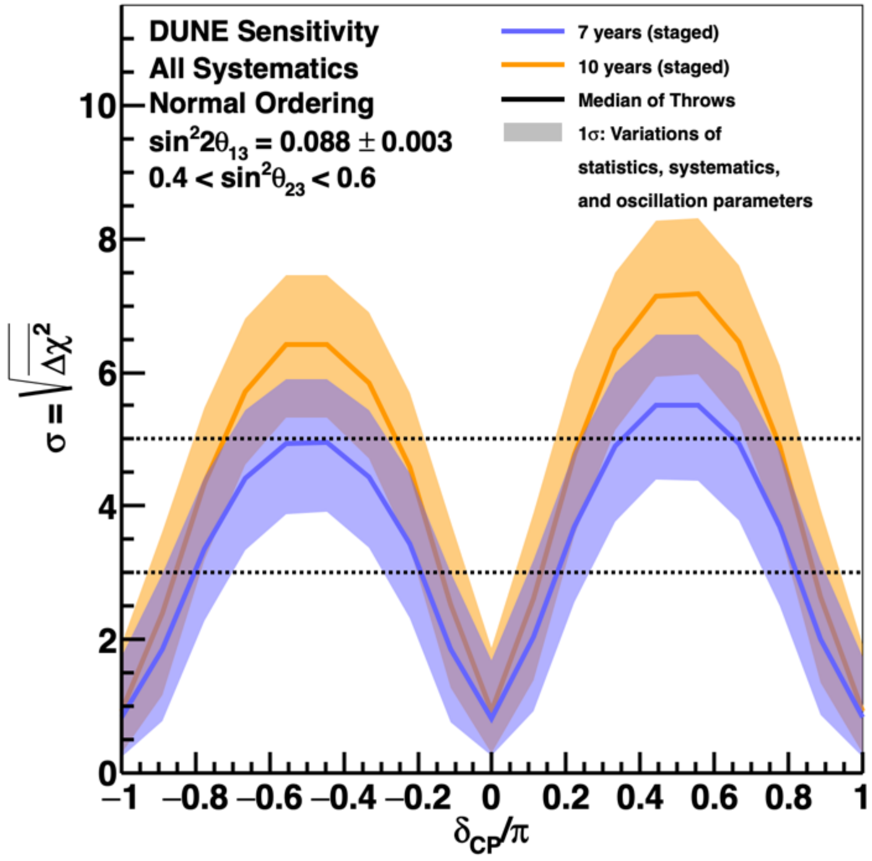
–

https://indico.cern.ch/event/1011452/
CERN-Neutrino-Summer-School-organisers@cern.ch

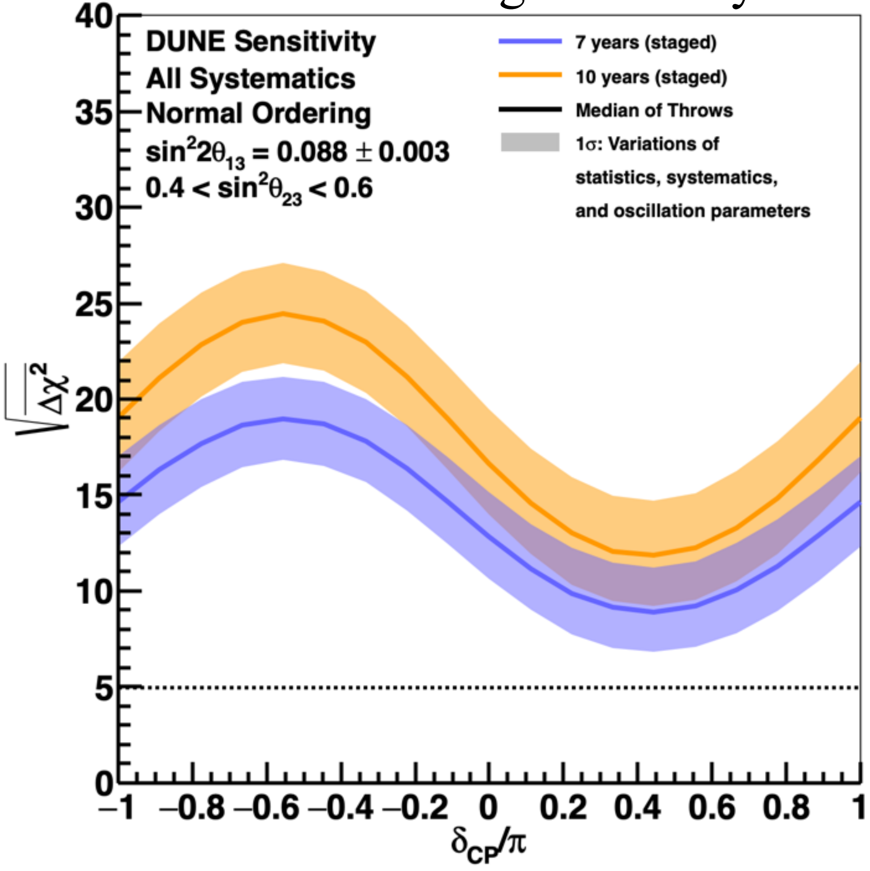
Video on the agenda of the school
https://indico.cern.ch/event/1011452/

CP Violation and Mass Ordering

*CP*v sensitivity



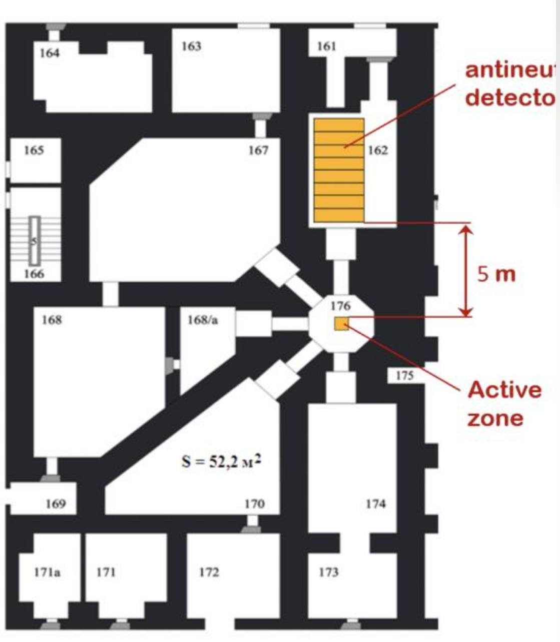
Mass ordering sensitivity



- Updated Sensitivity with realistic systematics and reconstruction
  - Move quickly to potential ***CP* violation discovery**
  - Rapid, definitive **mass ordering determination** (>5σ)

arXiv:2002.03005

Short baseline Reactor:Neutrino-4 Exp.



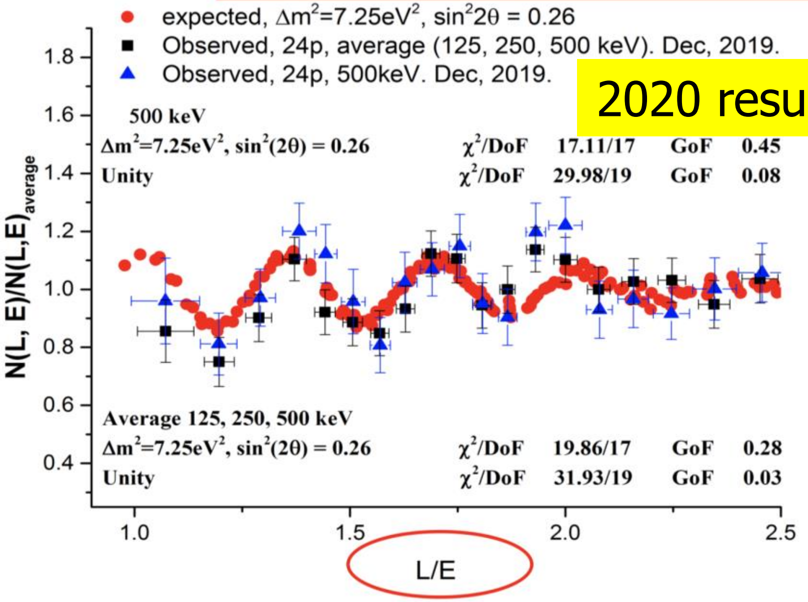
$2m^3$ liquid scintillator detector at a 90 MW reactor in Russia

3 years long measurement

2.8σ signific.

arXiv:1809.10561 (Jan 2020)

$$P(\tilde{\nu}_e \rightarrow \tilde{\nu}_e) = 1 - \sin^2 2\theta_{14} \; \sin^2\left(1.27 \frac{\Delta m^2_{14}[\mathrm{eV}^2] L[\mathrm{m}]}{E_{\tilde{\nu}}[\mathrm{MeV}]}\right)$$



2020 result

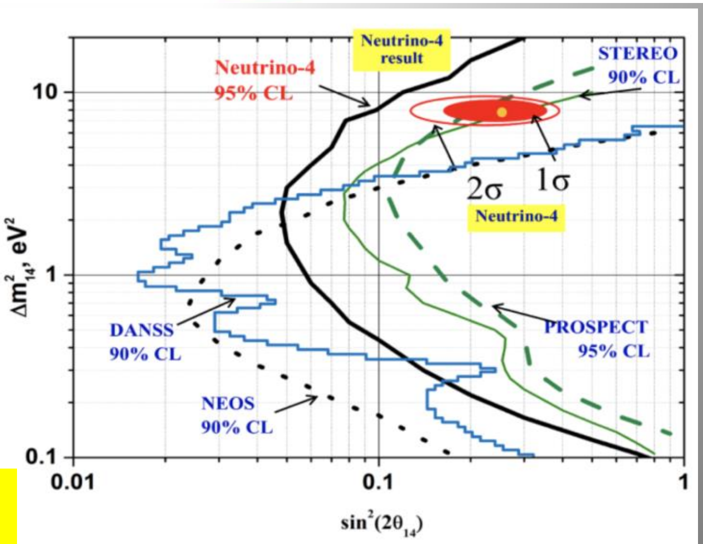
$$\Delta m^2_{14} = 7.25 \pm 0.13_{st} \pm 1.08_{syst} = 7.25 \pm 1.09$$

$$\sin^2 2\theta = 0.26 \pm 0.08_{stat} \pm 0.05_{syst} = 0.26 \pm 0.09(2.8\sigma)$$

Data analysis strongly critized

- Issues with the energy resolution
- Less biased approach -> ~2.2σ effect only
- “No-oscillation scenario” not excluded at 3σ

arXiv:2101.06785



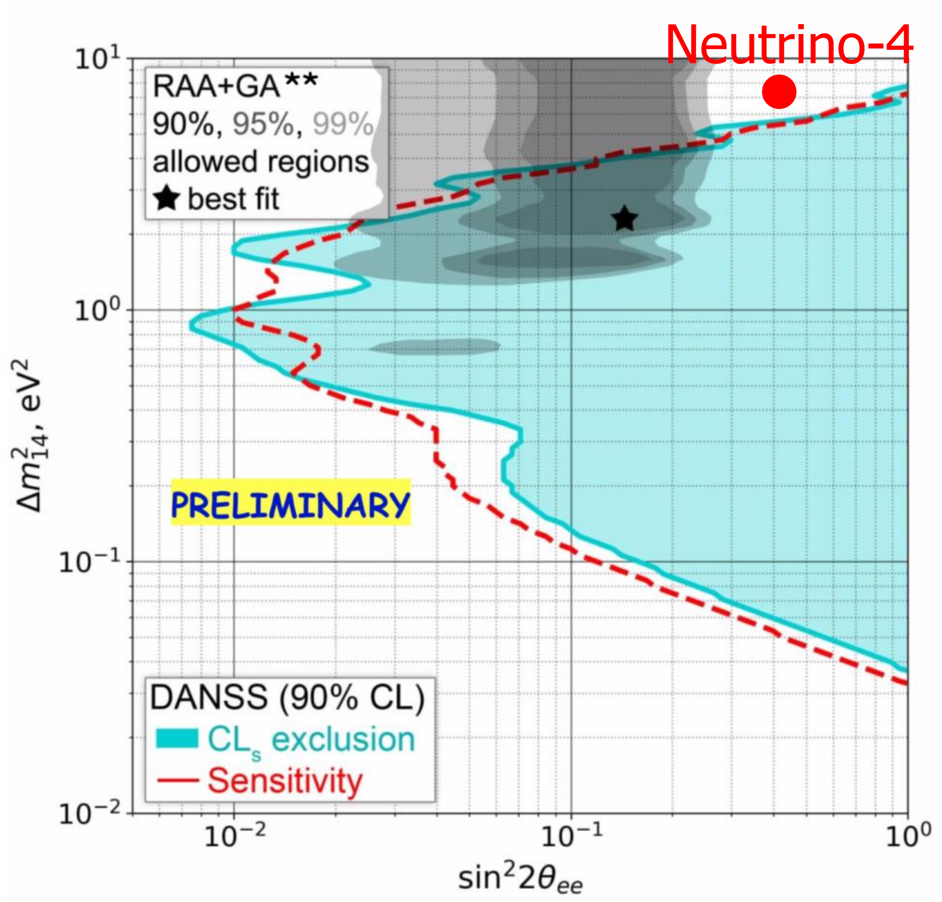
More discussion by Alexei on Friday

New Result from DANSS

EPS-HEP 2021

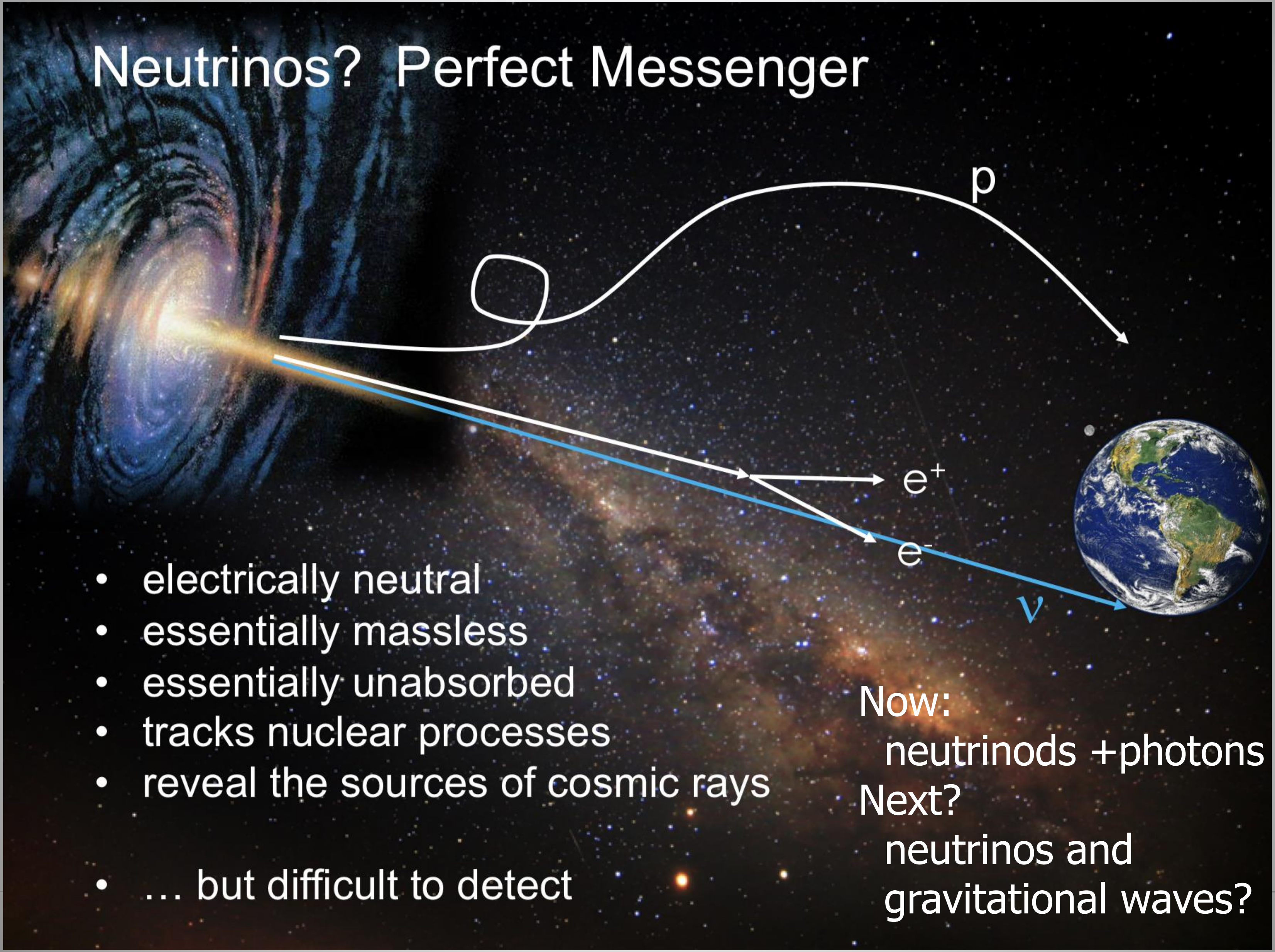
- DANSS records about 5 thousand antineutrino events per day with cosmic background ~1.7%, S/B>50

5.5 million IBD events were collected in 5 years



DANSS does yet cover up to Neutrino-4, but with the upgraded detector and 1-2 years additional data taking they will…

Multi Messenger Astronomy



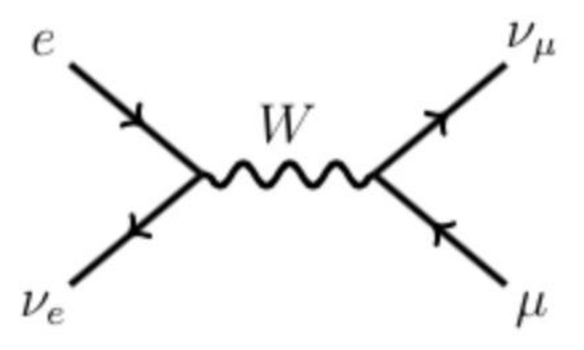
Neutrinos? Perfect Messenger

- electrically neutral
- essentially massless
- essentially unabsorbed
- tracks nuclear processes
- reveal the sources of cosmic rays

- … but difficult to detect

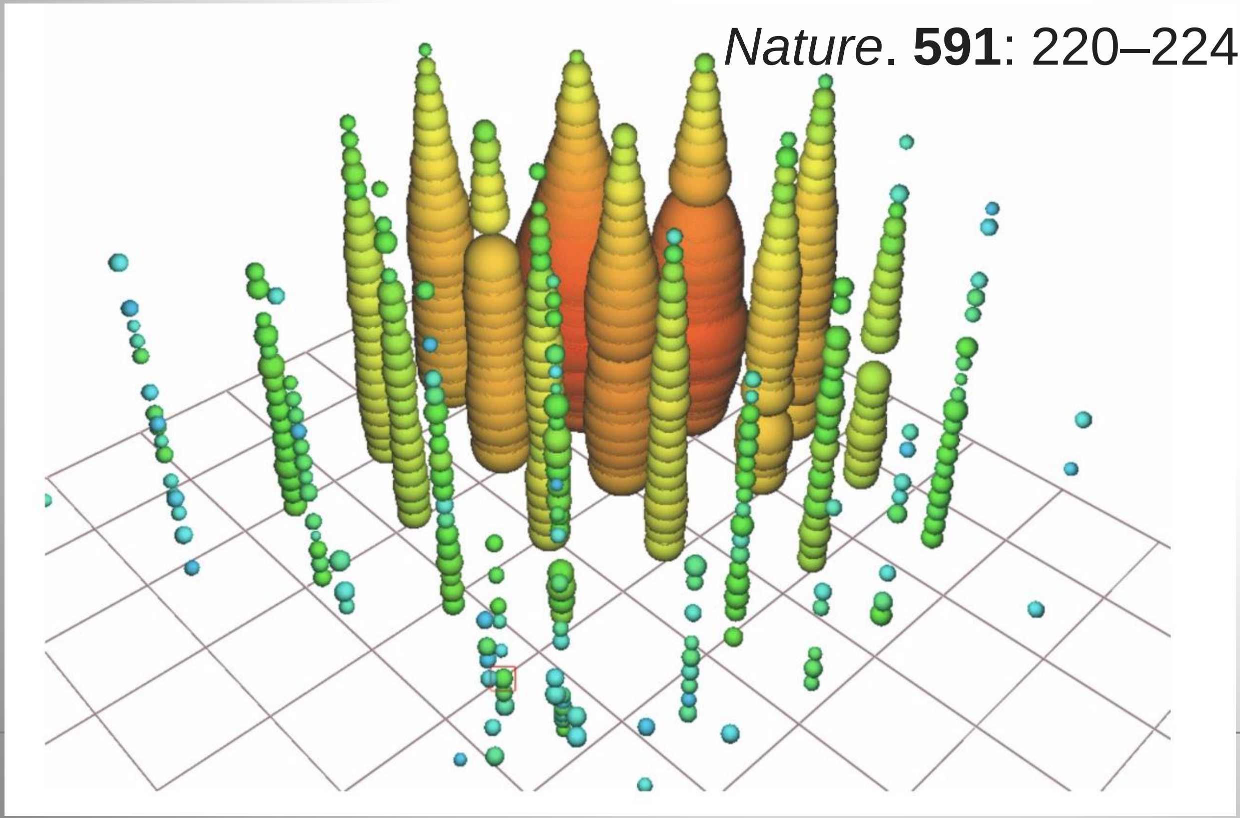
Now:
neutrinods +photons
Next?
neutrinos and
gravitational waves?

Observation of a Glashow Resonance



Scattering on electrons to form a W boson
Electron antineutrino with energy of ~6.3 TeV required

Event seen with an estmated energy of 6.05 TeV in IceCube (8/12/2016)



Nature. **591**: 220–224

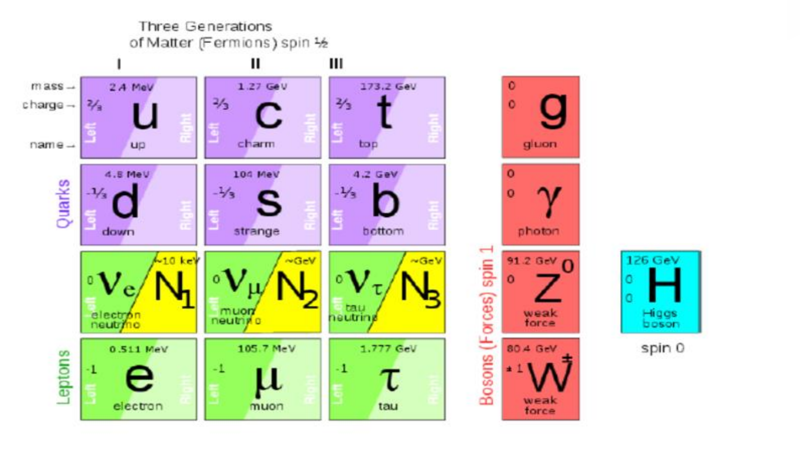
$$E_\nu = \frac{M_W^2 - (m_e^2 + m_\nu^2)}{2m_e} \approx \frac{M_W^2}{2m_e}$$

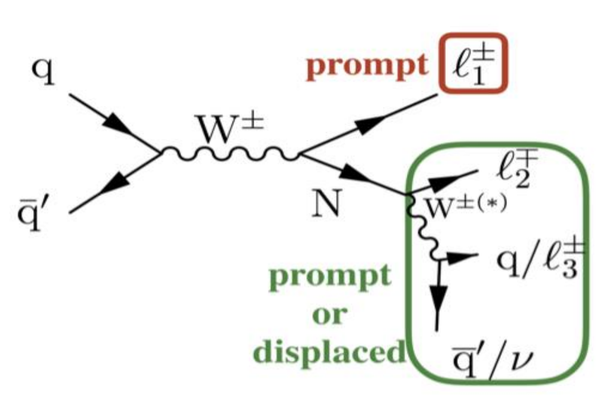
Neutrinos @ the LHC: Examples

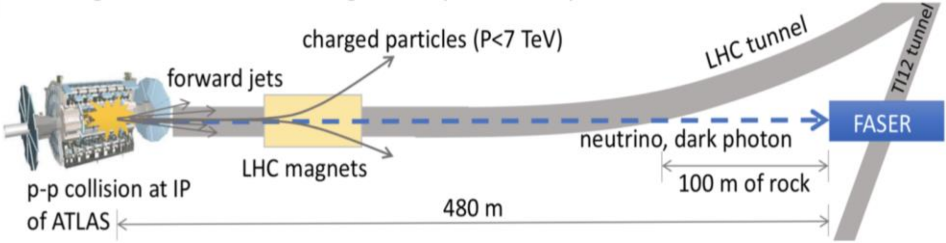
Searches for right-handed neutrinos at the LHC

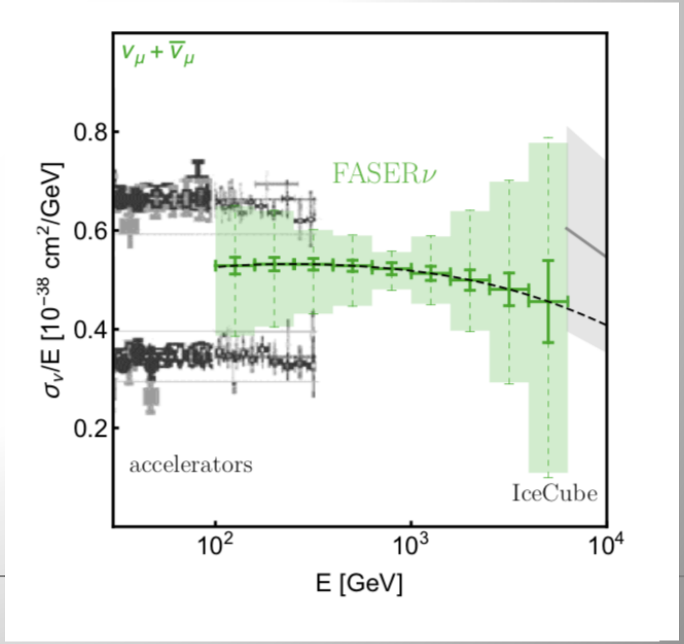
SND@LHC and FASER-Nu are 400m forward of the IPs and can study TeV-neutrinos with emulsion detectors

νMSM (Neutrino Minimal Standard Model)



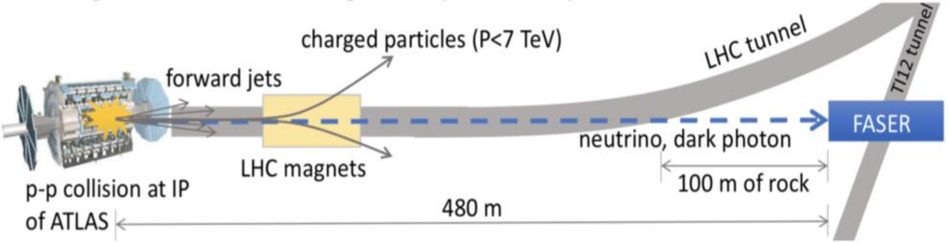






Neutrinos @ the LHC: SND@LHC

SND is 400m forward of the IPs and can Study TeV-neutrinos with emulsion and tracking+muon/calo detectors



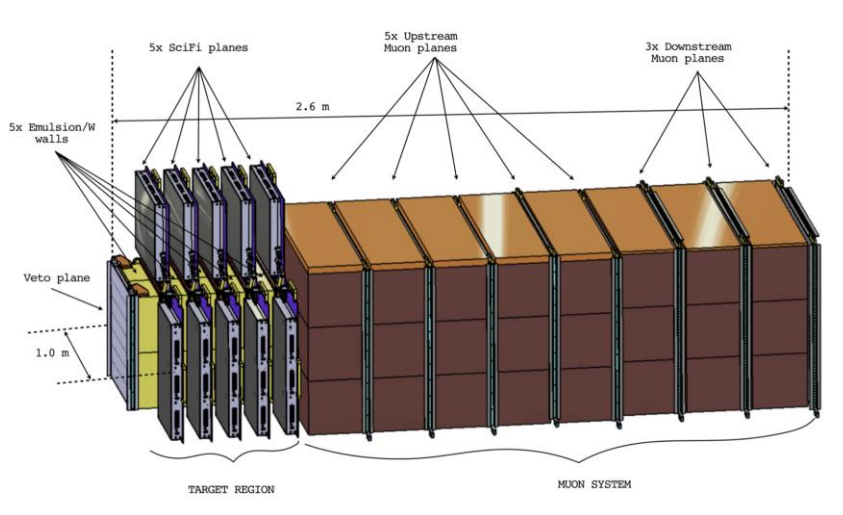
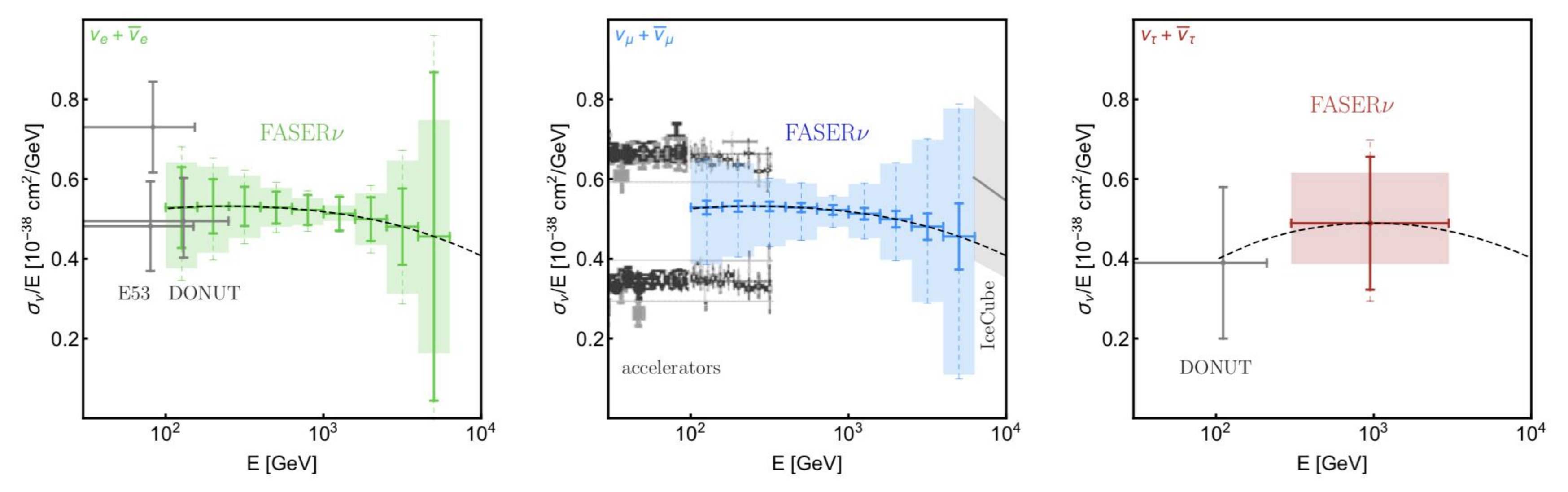


Figure 5: Layout of the proposed SND@LHC detector.

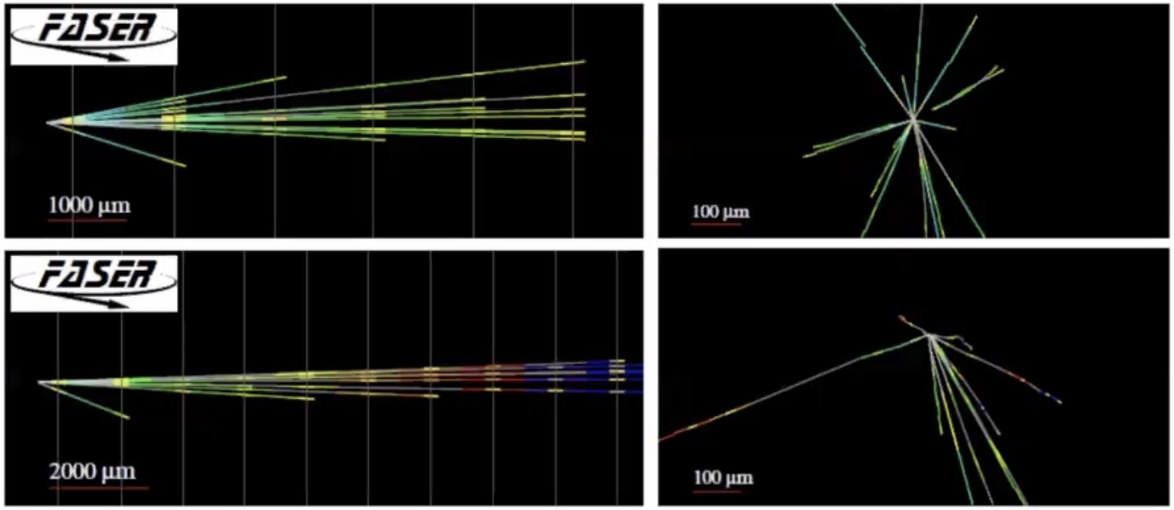
SND= Scattering and neutrino detector



First Observed neutrinos in FASER-ν

These are the first ever directly observed neutrinos at the LHC!!

Neutrino interaction candidates



Highlights the potential of the forward LHC location fro neutrino physics!

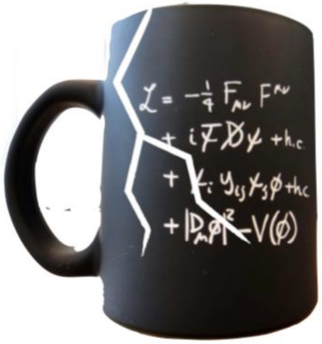
First neutrino interaction candidates at the LHC, arXiv:2105.06197

First neutrino interaction candidates at the LHC

(FASER Collaboration)

SUMMARY: Neutrinos

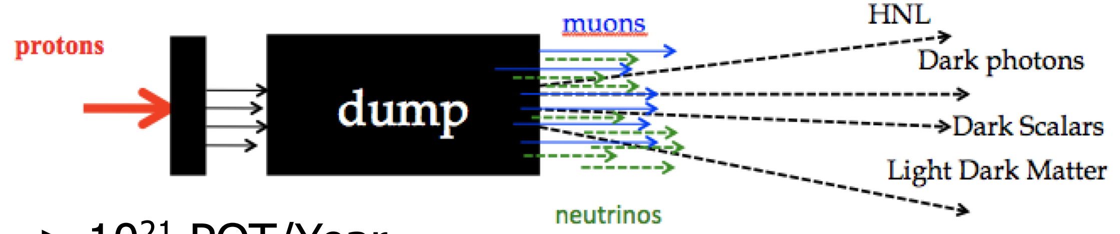
- Neutrinos studies is a vibrant field of research, and has still many open questions! Right-handed partners? Strong CP violation? More than 3 neutrinos? NS Interactions? Are neutrinos their own anti-particle?
- Now comes the age of neutrino precision physics with DUNE & T2HK and neutrino astronomy: look inside the sun, understand supernovae explosions, multi-messenger astronomy…
- Detailed study of PMNS oscillation parameters by experiments is key to the understanding
- Large experiments are really "observatories"
- The history of neutrino research showed many surprises. What surprise is waiting for us next??



Backup

NDs as Beam Dump Experiments

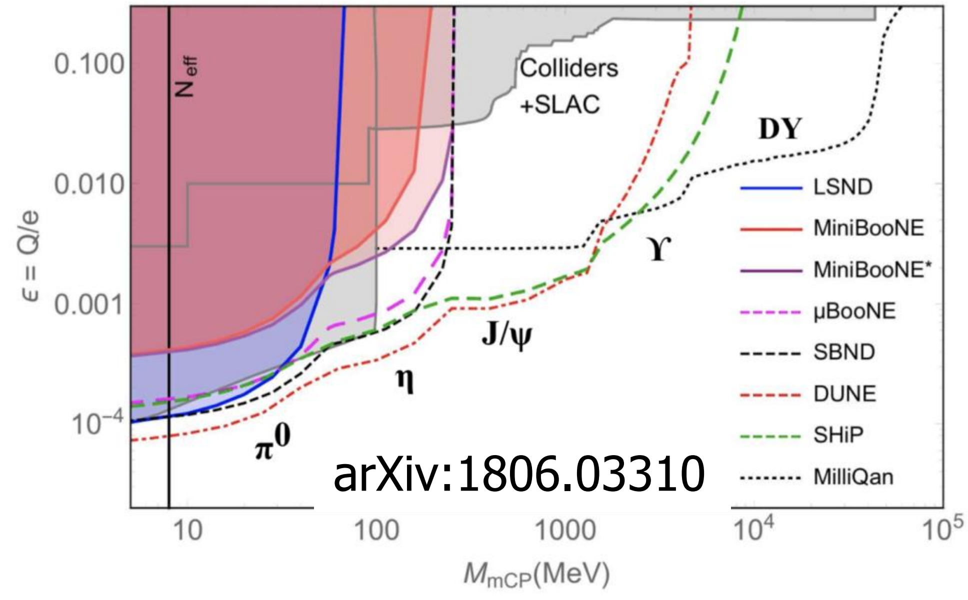
High intensity frontier for low mass particles with very weak couplings
->upcoming neutrino experiments (SBL, LBL) foresee very high intensity beams



> 10^{21} POT/Year

Near Detector:
few 100m away
from the dump

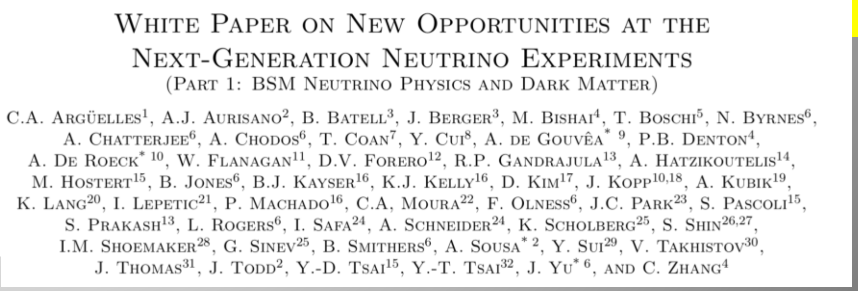
Example millicharges:



arXiv:1806.03310

These experiments can perform searches for low mass New Physics particles eg
- -HNL/sterile neutrinos
- -dark photons
- -ALPs
- -mini/millicharges

arXiv:1907.08311



White Paper on New Opportunities at the
Next-Generation Neutrino Experiments
(Part 1: BSM Neutrino Physics and Dark Matter)

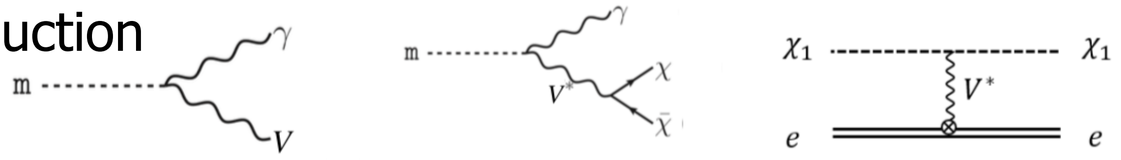
C.A. Argüelles[1], A.J. Aurisano[2], B. Batell[3], J. Berger[3], M. Bishai[4], T. Boschi[5], N. Byrnes[6], A. Chatterjee[6], A. Chodos[6], T. Coan[7], Y. Cui[8], A. de Gouvêa*[9], P.B. Denton[4], A. De Roeck*[10], W. Flanagan[11], D.V. Forero[12], R.P. Gandrajula[13], A. Hatzikoutelis[14], M. Hostert[15], B. Jones[6], B.J. Kayser[16], K.J. Kelly[16], D. Kim[17], J. Kopp[10,18], A. Kubik[19], K. Lang[20], I. Lepetic[21], P. Machado[16], C.A, Moura[22], F. Olness[6], J.C. Park[23], S. Pascoli[15], S. Prakash[13], L. Rogers[6], I. Safa[24], A. Schneider[24], K. Scholberg[25], S. Shin[26,27], I.M. Shoemaker[28], G. Sinev[25], B. Smithers[6], A. Sousa*[2], Y. Sui[29], V. Takhistov[30], J. Thomas[31], J. Todd[2], Y.-D. Tsai[15], Y.-T. Tsai[32], J. Yu*[6], and C. Zhang[4]

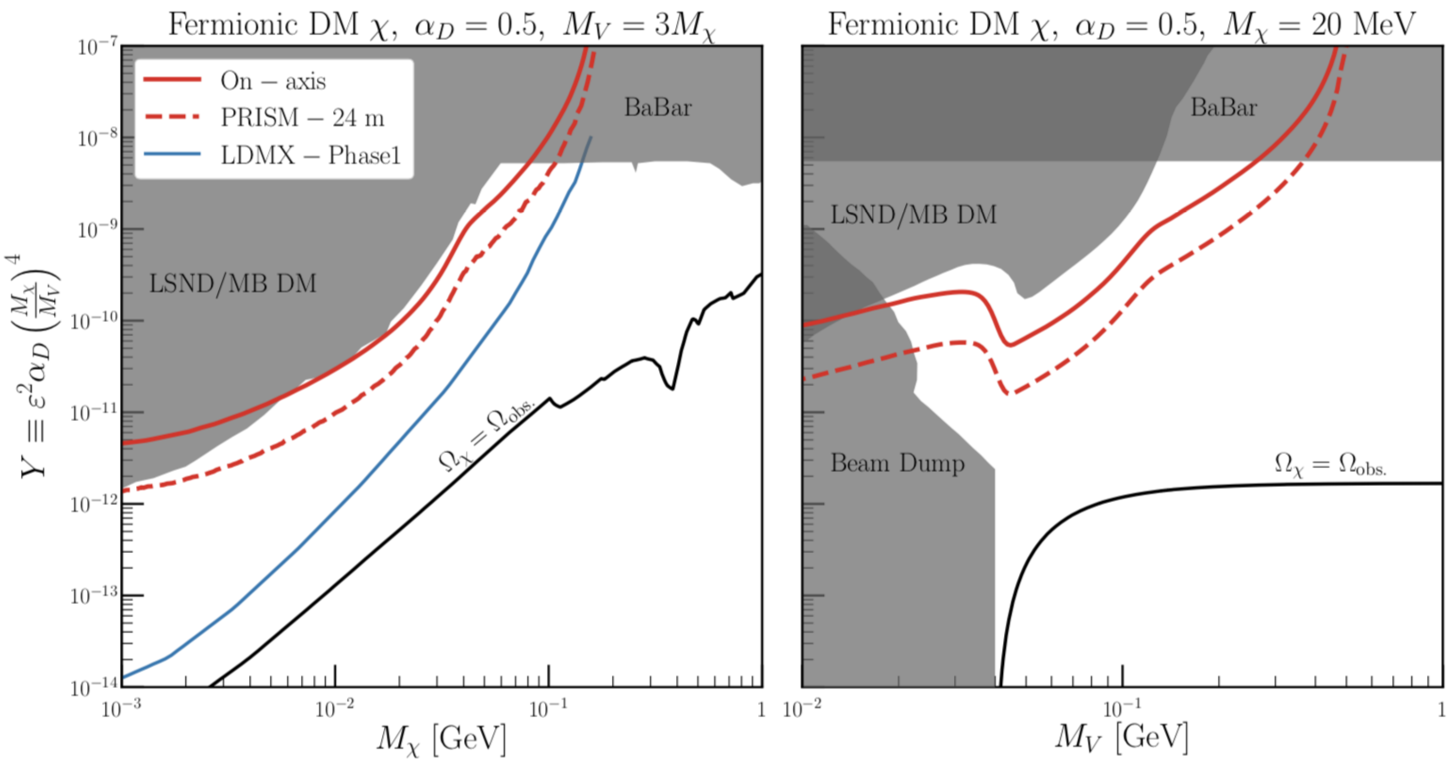
Searches for Low Mass Dark Matter

Light dark matter produced at the accelerator (meson decays)

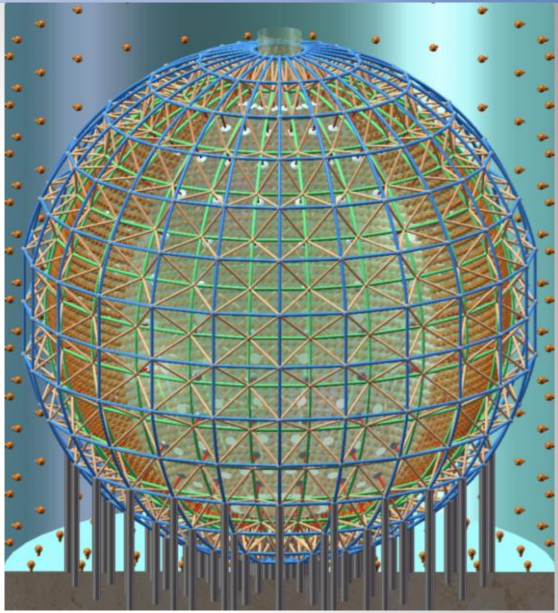
Production

Elastic scattering



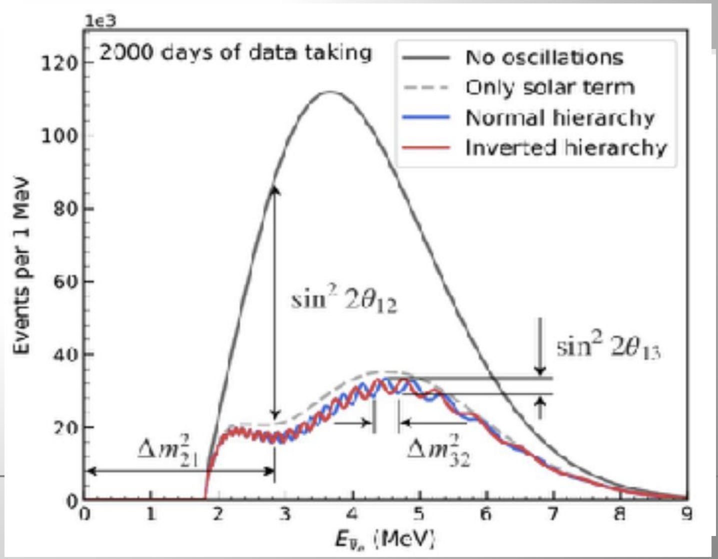


The JUNO Experiment



The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kton multi-purpose liquid scintillator detector (~20 times the size of present detectors, including 18000 20” PMTs) being built in a dedicated underground laboratory (700 m underground) in China and expected to start data taking end 2022/start2023

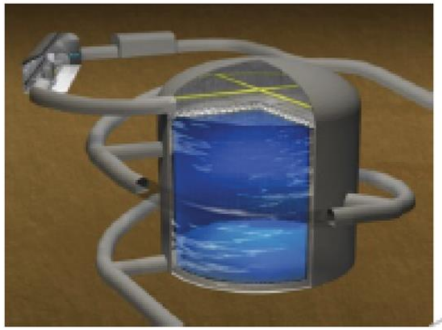
Determination of the neutrino mass ordering using electron anti-neutrinos from two nuclear power plants at a baseline of about 53 km. With an unprecedented energy resolution of 3% at 1 MeV, JUNO will be able to determine the mass ordering with a significance of 3 sigma within six years of running.
(4-5 sigma with acc. exp. and IceCube)



Hyper-Kamiokande

Upgrade of the Super-kamiokande experiment in Japan

First data in 2027



Hyper-K

J-PARC

Accelerator Complex

- ✓Gigantic neutrino and nucleon decay detector
  - ✓186 kton fiducial mass : ~10 × Super-K
  - ✓× 2 higher photon sensitivity than Super-K
  - ✓Superb detector capability, technology still evolving
  - ✓2nd oscillation maximum by 2nd tank in Korea under study
- ✓MW-class world-leading ν-beam by upgraded J-PARC
- ✓Project now is a priority project by MEXT's Roadmap

Sub-GeV ν beam