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I neutrini nella strategia particellare (oscillazioni, massa, ββ0ν)

Goals
Results
Perspectives

Neutrino oscillations
Sterile neutrinos
Double Beta Decays
Direct mass measurements

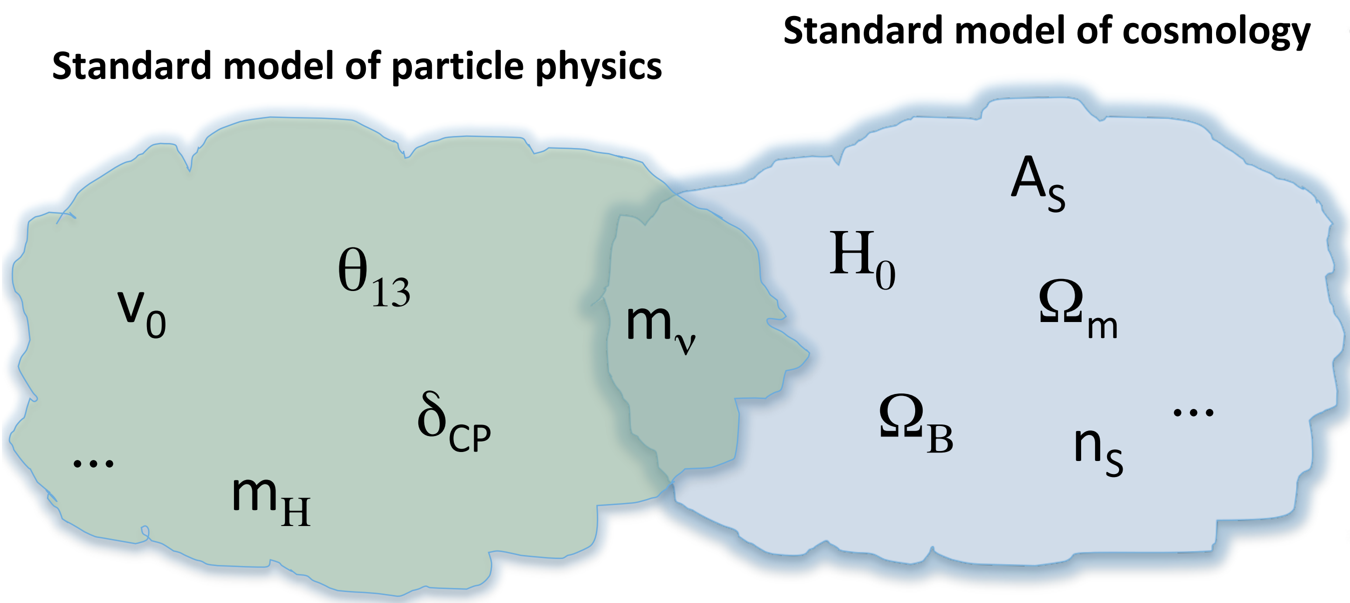
Ringrazio per la collaborazione: O. Cremonesi, E. Previtali, R. Brugnera, S. Bertolucci, A. Guglielmi, G. Catanesi, G. Ranucci, P. Sapienza, F. Terranova, A. Longhin, M. Laveder, L. Stanco, A. Cocco, A. Nucciotti

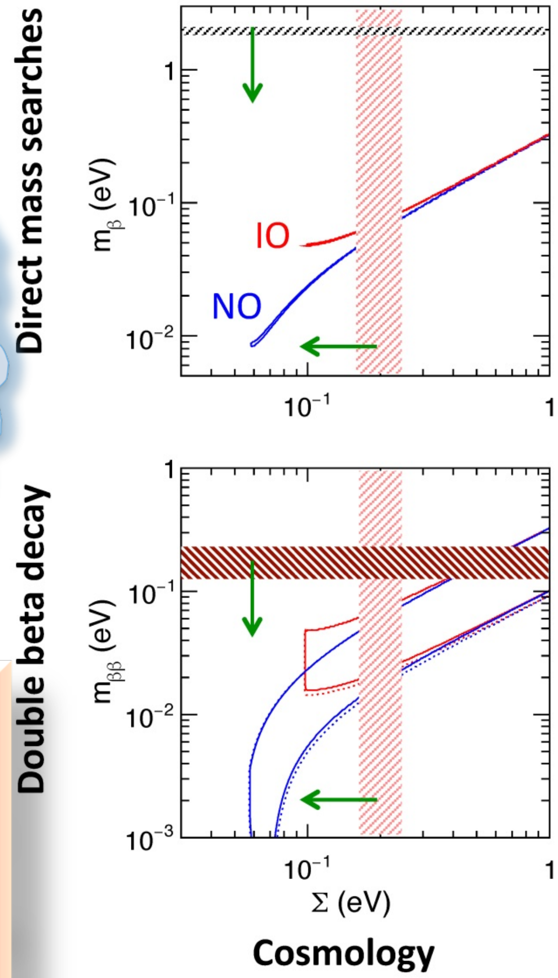
Naturalmente la fisica dei neutrini e’ gestita dalla CSN2,e il suo ruolo e’ fondamentale

Fisica delle Particelle, verso la nuova Strategia Europea, INFN, 6-7 Settembre 2018

The importance of measuring m_ν

- The only parameter measurable both by hep and cosmology
- **A crucial test of consistency**





Cosmology measures $\sum_i m_i$

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

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

To compare hep with cosmology, neutrino oscillations parameters must be known, in particular mass ordering (MO)

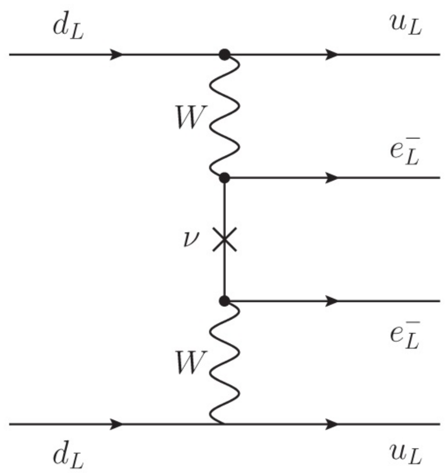
The importance of measuring δ_{CP}

- Matter/antimatter asymmetry in the Universe requires CP violation
- CP violation in the quark sector has been measured the first time 54 years ago, but this violation doesn't help very much in understanding what happened soon after the big-bang ($J^{CKM} \approx 3 \times 10^{-5}$)
- Through leptogenesis, theory link the ν −mass generation to the generation of baryon asymmetry of the Universe as suggested by Fukugita and Yanagida already in 1986.
- The Dirac phase δ_{CP} can be one of the ingredients of these mechanisms (and $J^{PMNS} \approx 0.033 \sin\delta_{CP}$)
- So it's mandatory to measure its value
- … also because it's one of the few unknowns of the Standard Model (together with neutrino masses)

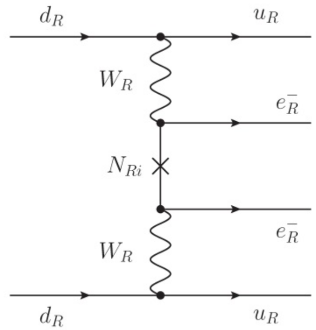
Sterile neutrinos

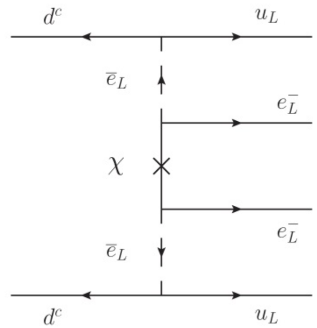
- Several experimental anomalies in neutrino experiments could be explained (not in a very consistent way) with eV sterile neutrinos
- Heavy sterile neutrinos (heavy neutral leptons) are good candidates as particles beyond the standard models. Not covered in this talk.

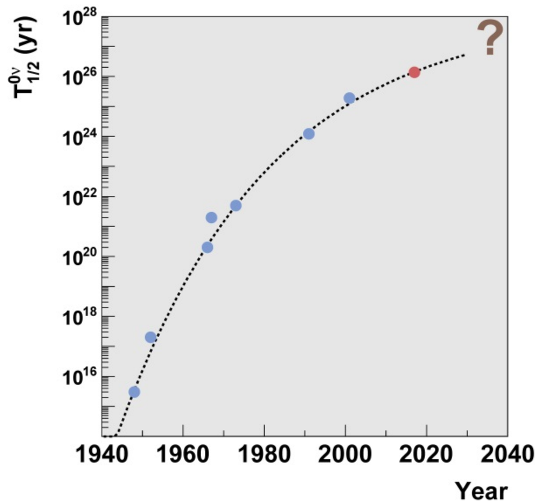
Neutrinoless Double Beta Decays



- The only experimental way to decide if neutrinos are Majorana particles
- A way to measure neutrino masses
- A way to observe leptonic number violation(ΔL=2)
- Additional CP violating phases
- **A portal to new physics**
- … and a very challenging experimental effort







Not discussed in this talk

The CNO cycle and the metallicity of the sun

- A critical parameter to compute star luminosity and lifetime
- Estimates from sunlight spectroscopy and helioseismology disagree: 1.3% vs 1.8%
- Could be fixed by precisely measuring solar neutrinos, in particular the CNO cycle
- The only experiment (ever) in the word is Borexino

Neutrinos and Multimessenger Physics

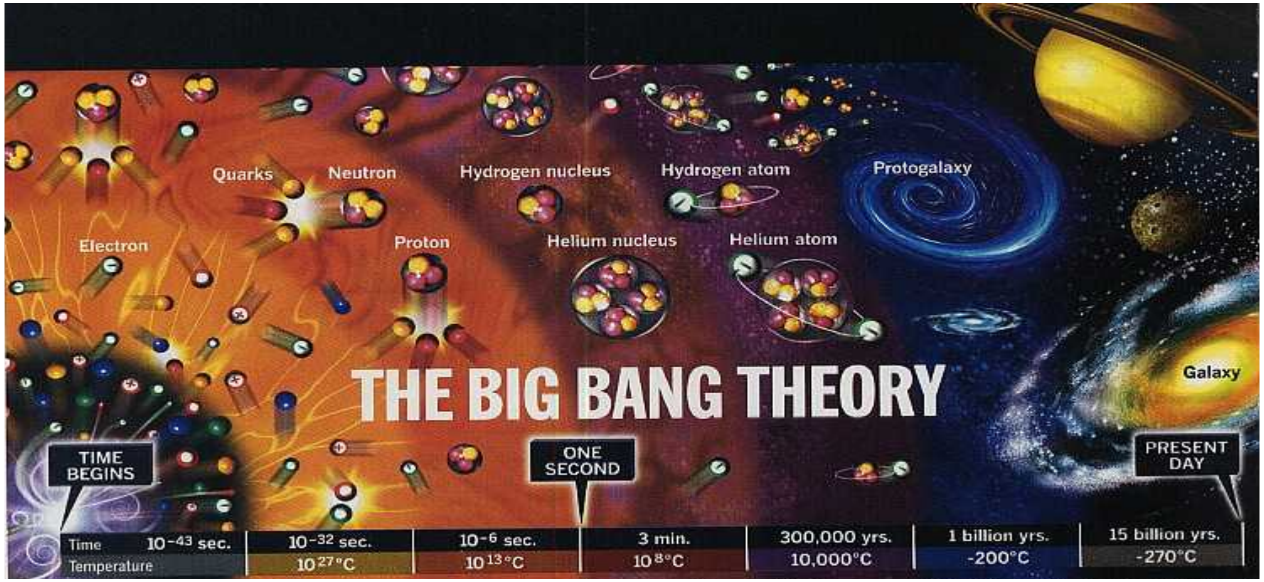
- In spite of the spectacular TXS 0506+056 event measured by IceCube and gamma ray telescopes …
- … the INFN effort in Km3Net
- … and the "Neutrino Telescopes" conference cycle we run at Venice since 1988

SuperNovae Neutrinos

- Hoping they wait the restart of Ligo/Virgo and SK

RELIC Neutrinos

A very hot topic in a strategy discussion, even if not exactly particle physics

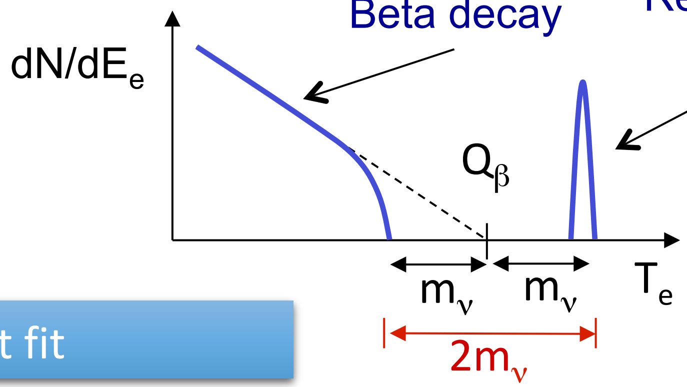


Neutrinos decouple (CνB)

Neutral atoms (CMB)

Neutrino Capture on beta decaying nuclei has no threshold on incoming particle energy

E.Baracchini et al. arXiv:1808.01892
A.G.Cocco et al. JCAP 06(2007)015
A.G.Cocco et al. Phys.Rev. D79(2009)053009



Needs tritium and an underground lab: LNGS can't fit

Recap: neutrino oscillations

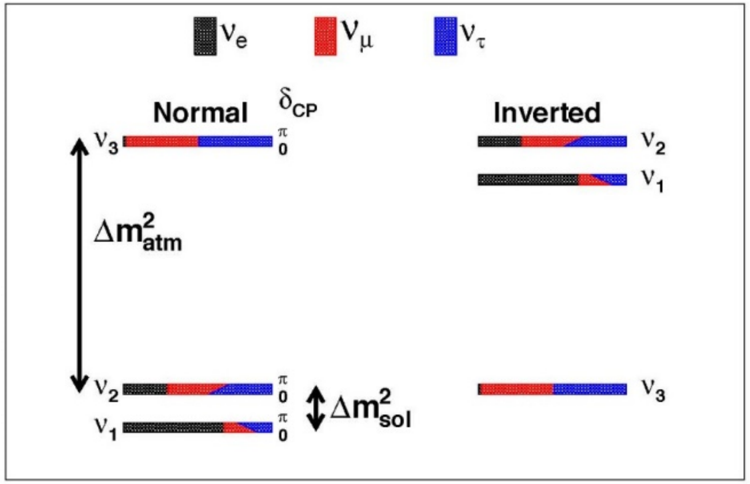
$$U_{3\times3} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

https://globalfit.astroparticles.es/

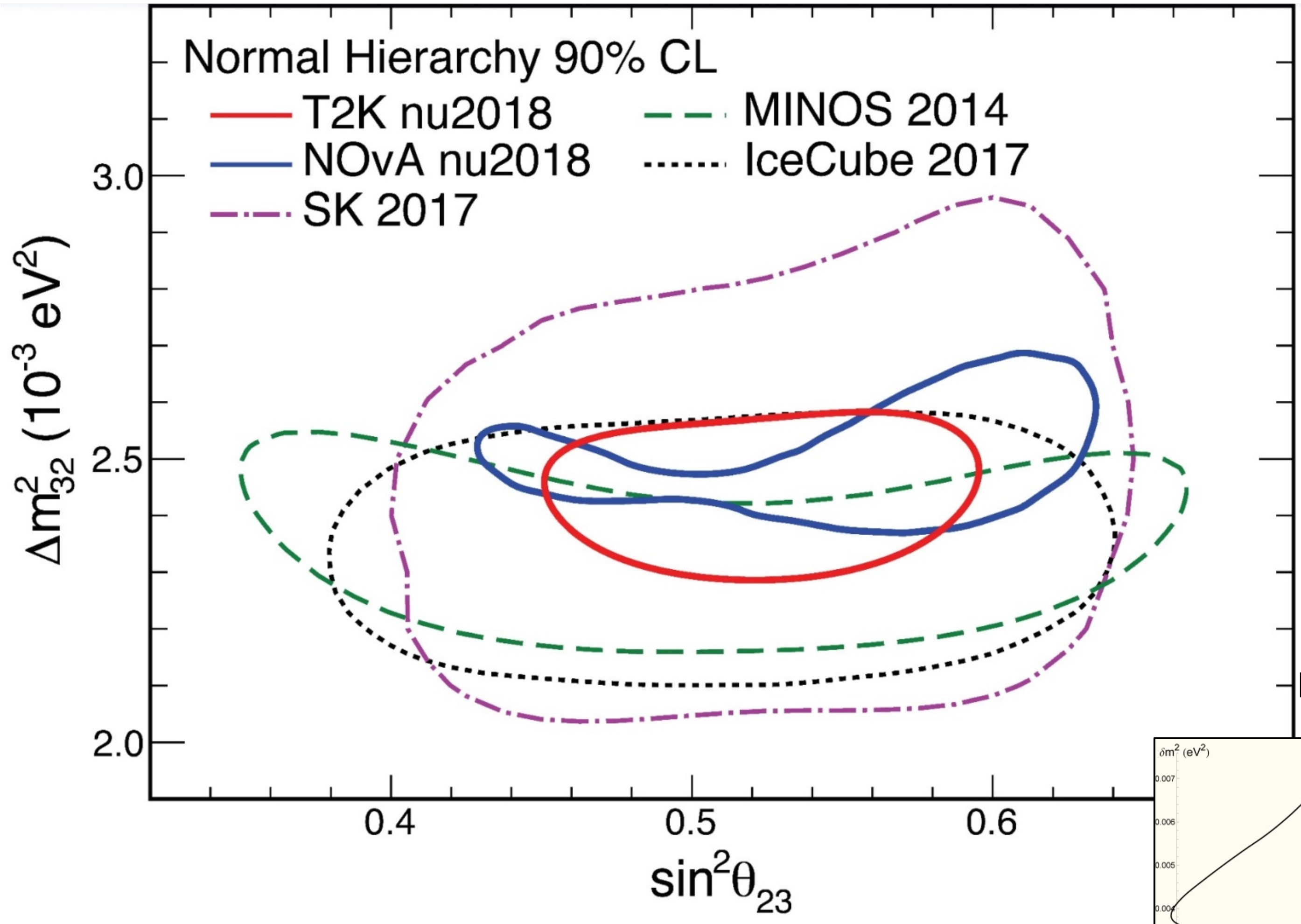
parameter	best fit $\pm$ 1σ	3σ range	relative 1σ uncertainty
Δm^2_{21} [10^{-5}eV^2]	$7.55^{+0.20}_{-0.16}$	7.05–8.14	2.4%
$\lvert\Delta m^2_{31}\rvert$ [10^{-3}eV^2] (NO)	2.50±0.03	2.41–2.60	1.3%
$\lvert\Delta m^2_{31}\rvert$ [10^{-3}eV^2] (IO)	$2.42^{+0.03}_{-0.04}$	2.31-2.51	
$\sin^2\theta_{12}/10^{-1}$	$3.20^{+0.20}_{-0.16}$	2.73–3.79	5.5%
$\sin^2\theta_{23}/10^{-1}$ (NO)	$5.47^{+0.20}_{-0.30}$	4.45–5.99	4.7%
$\sin^2\theta_{23}/10^{-1}$ (IO)	$5.51^{+0.18}_{-0.30}$	4.53–5.98	4.4%
$\sin^2\theta_{13}/10^{-2}$ (NO)	$2.160^{+0.083}_{-0.069}$	1.96–2.41	3.5%
$\sin^2\theta_{13}/10^{-2}$ (IO)	$2.220^{+0.074}_{-0.076}$	1.99–2.44	
δ/π (NO)	$1.32^{+0.21}_{-0.15}$	0.87–1.94	10%
δ/π (IO)	$1.56^{+0.13}_{-0.15}$	1.12–1.94	9%

deSalas et al, 1708.01186 (May 2018)

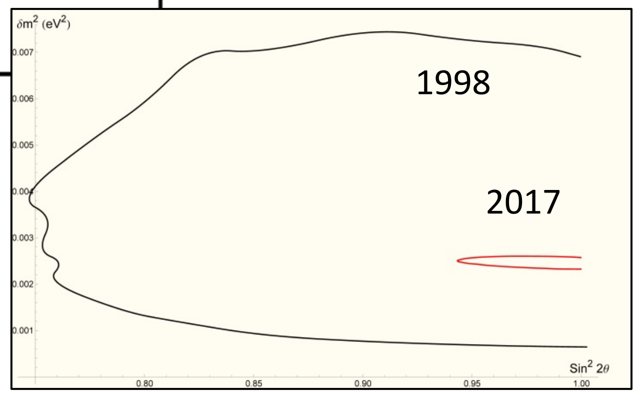
Neutrino Mass Ordering



Atmospheric Parameters



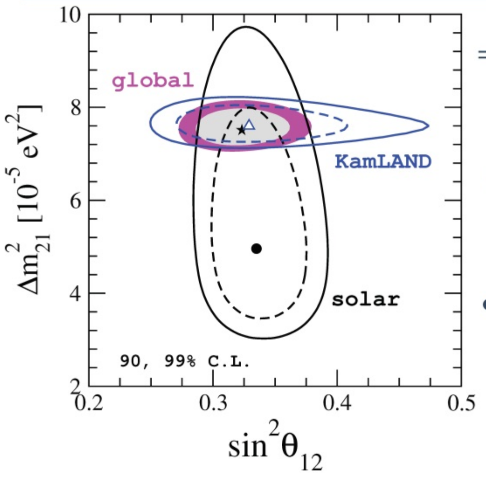
Progress since the discovery



Solar Parameters

From M. Tortola talk at Neutrino 2018

Tension between solar and KamLAND



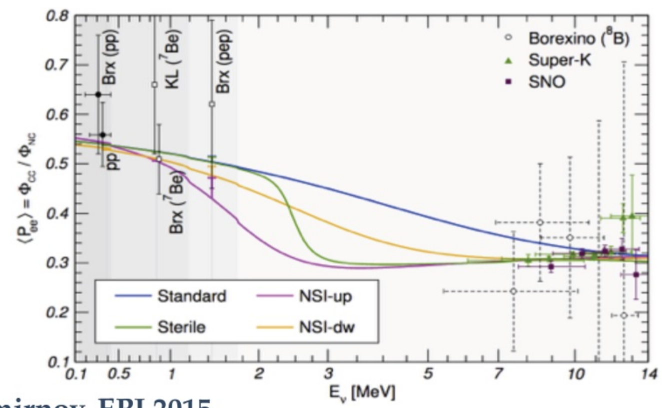
$\Rightarrow$ 2σ tension between preferred value of Δm^2_{21} from KamLAND and solar data

- Δm^2_{21} preferred by KamLAND predicts steep upturn at solar spectrum and smaller D/N asymmetry
- More precise measurements of Δm^2_{21} by reactor (JUNO,RENO-50) and solar experiments may help.

- NSI (ε ~0.3) can reconcile solar and KL data

$\Rightarrow$ flatter spectrum at intermediate E-region

$\Rightarrow$ larger D/N asymmetries can be expected

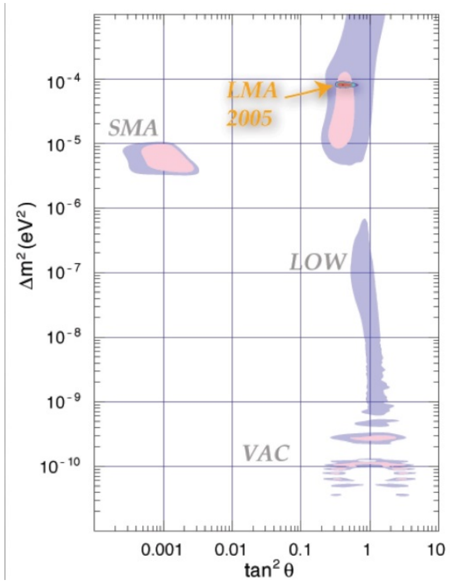


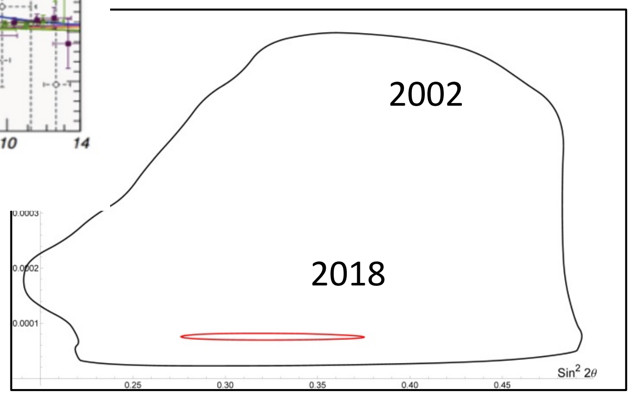
Escrihuela et al, PRD80 (2009)

Coloma et al, PRD96 (2017)

Maltoni & Smirnov, EPJ 2015

Solar neutrinos: 1998 vs today

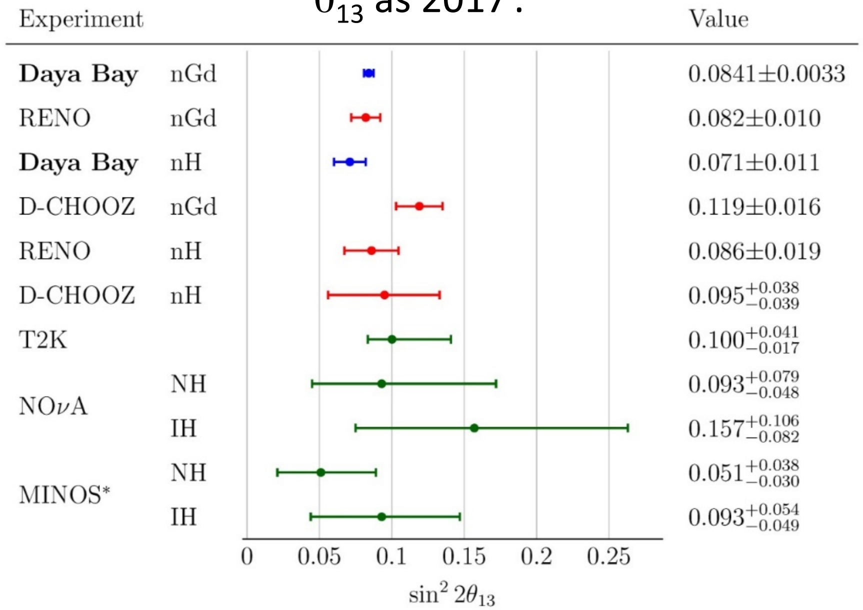




The large value of θ_{13} changed the worldwide strategy on neutrino oscillations

- Reactors could precisely measure θ_{13} (better than accelerators)
- The precise value of θ_{13} as measured by reactors improved significantly the sensitivity of accelerator experiments in measuring CP violation
- Several different methods for measuring neutrino mass ordering became possible (Juno, Orca, IceCube)
- High sensitivity (5σ) next generation experiments to measure CP violation could start without any R&D on new concepts for neutrino beams (Dune, Hyper-Kamiokande)
- Since they were no more necessary, R&D activities on new concepts for neutrino beams had been suddenly stopped.

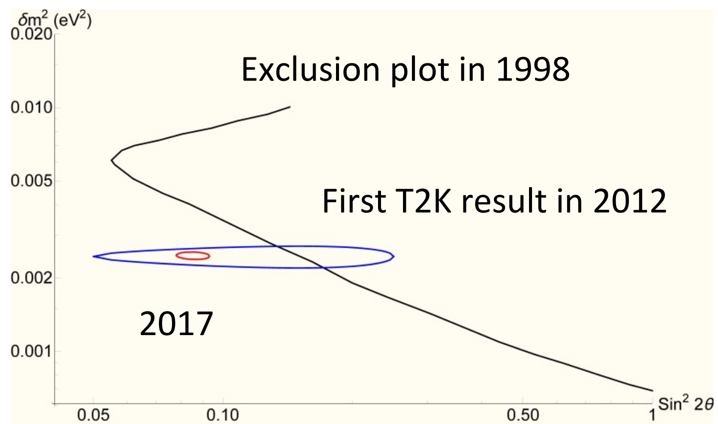
θ_{13} as 2017 .



Latest result by Daya Bay at Neutrino 2018

$$\sin^2 2\theta_{13} = 0.0856 \pm 0.0029$$

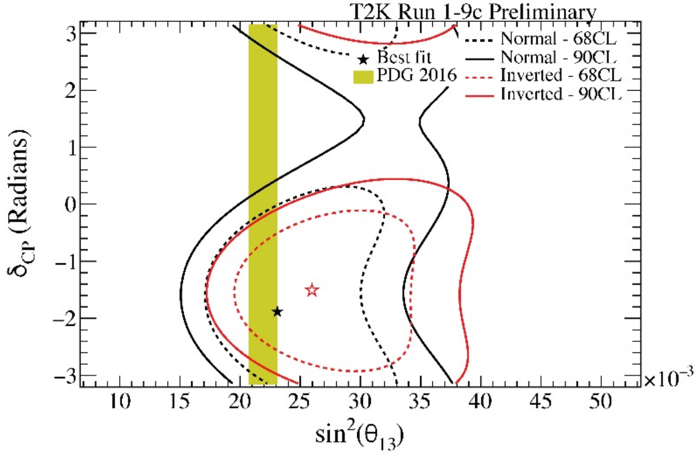
$$|\Delta m^2_{ee}| = (2.52 \pm 0.07) \times 10^{-3}\ \mathrm{eV}^2$$



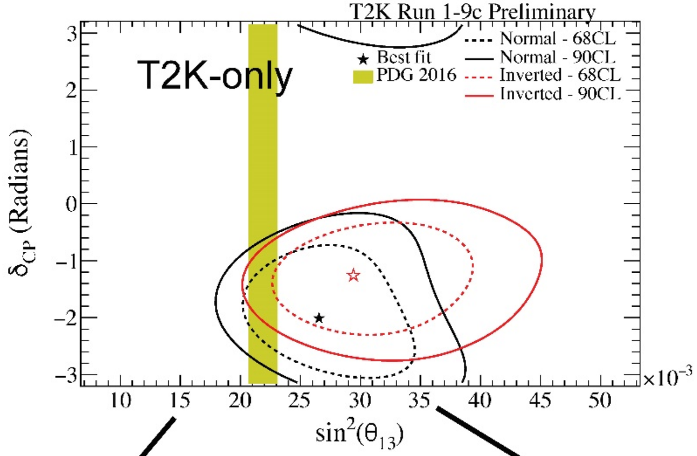
Latest T2K results: arXiv:1807.07891

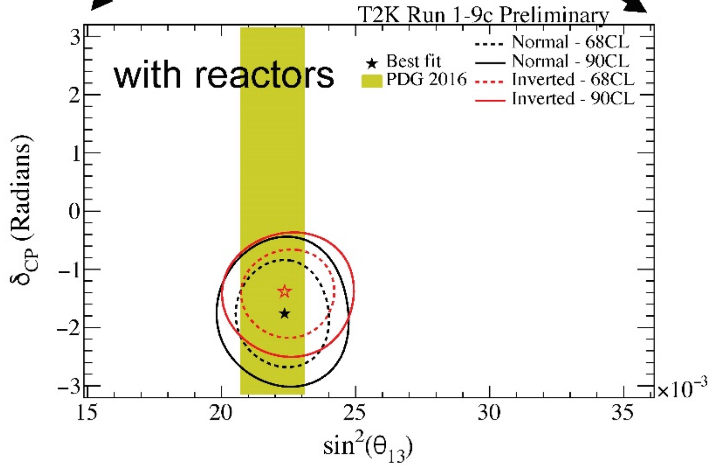
δ_{CP} vs. $\sin^2\theta_{13}$

SENSITIVITY



DATA FIT

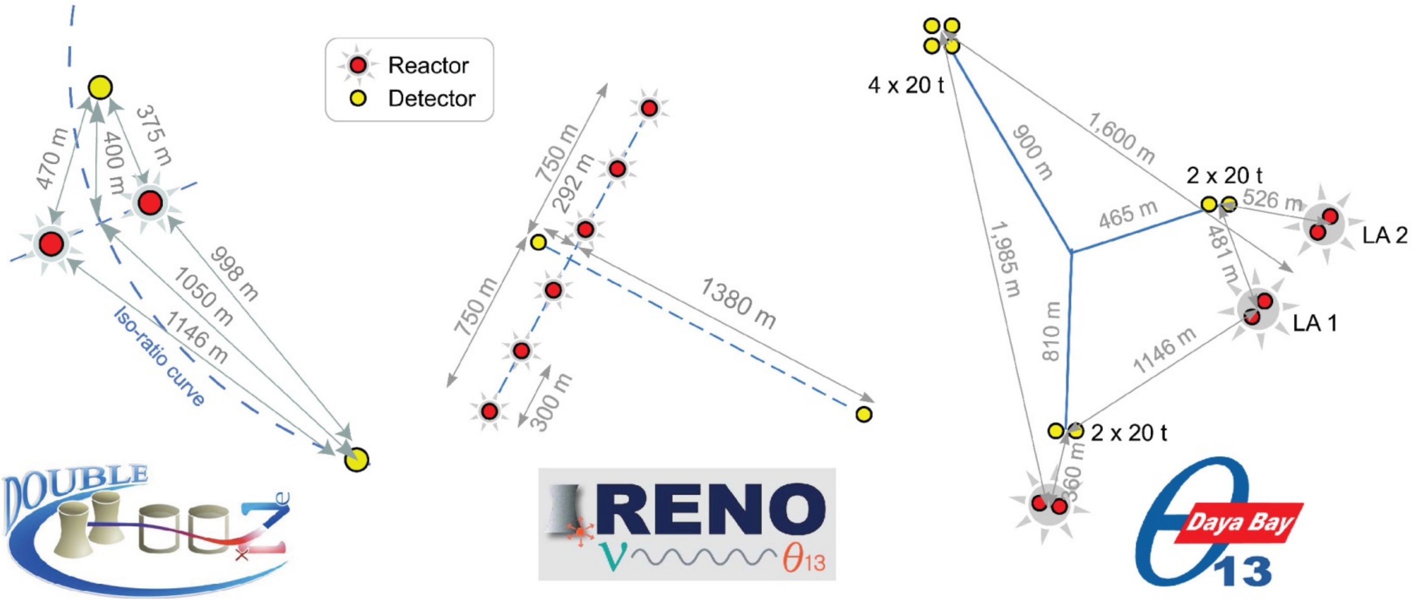




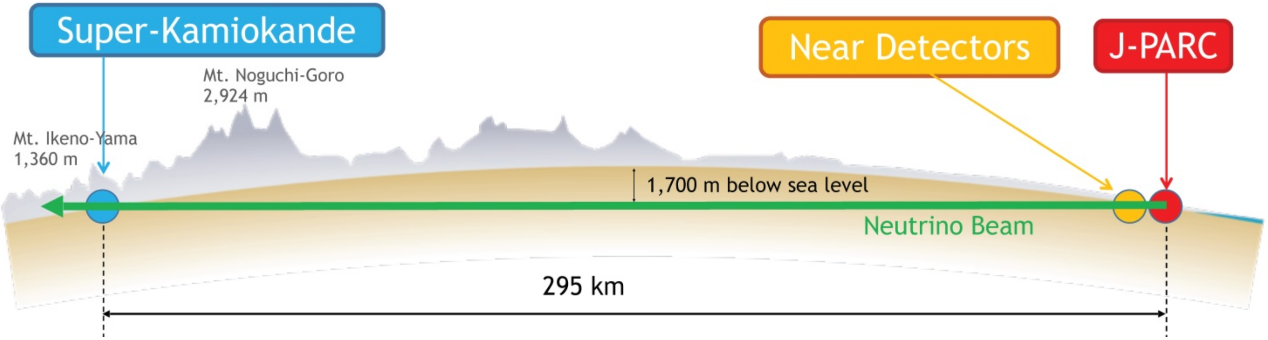
- sensitivity assumptions:
  - $\sin^2\theta_{13}$= 0.0219 (2016 PDG)
  - $\sin^2\theta_{23}$ = 0.528
  - NH, δ_{CP} = -1.601

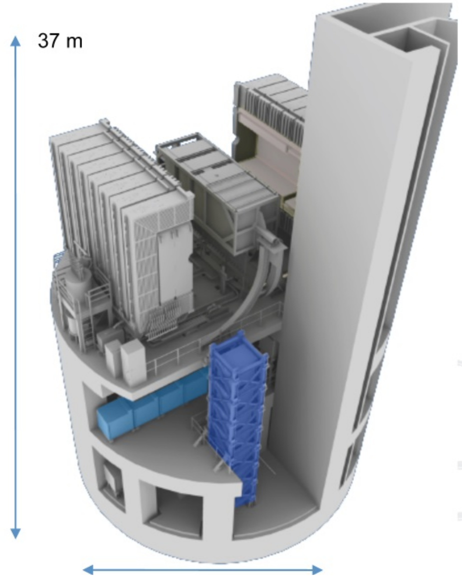
Reactor experiments

Setup	P_{Th} [GW]	L [m]	m_{Det} [t]	Events/year	Backgrounds/day
Daya Bay	17.4	1700	80	$10 \cdot 10^4$	0.4
Double Chooz	8.6	1050	8.3	$1.5 \cdot 10^4$	3.6
RENO	16.4	1400	15.4	$3 \cdot 10^4$	2.6



The T2K project



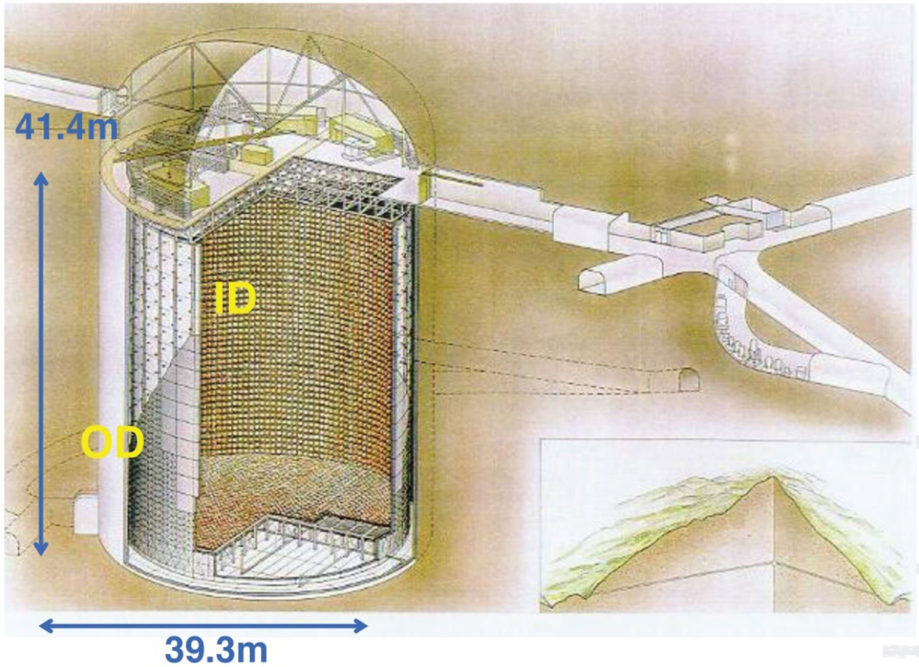


Powerful (0.5 MW at today) neutrino beam from J-Parc 30 GeV/c proton synchrotron

A set of close detectors both on and off-axis. In particular ND280 at 280 m from the target, off-axis.

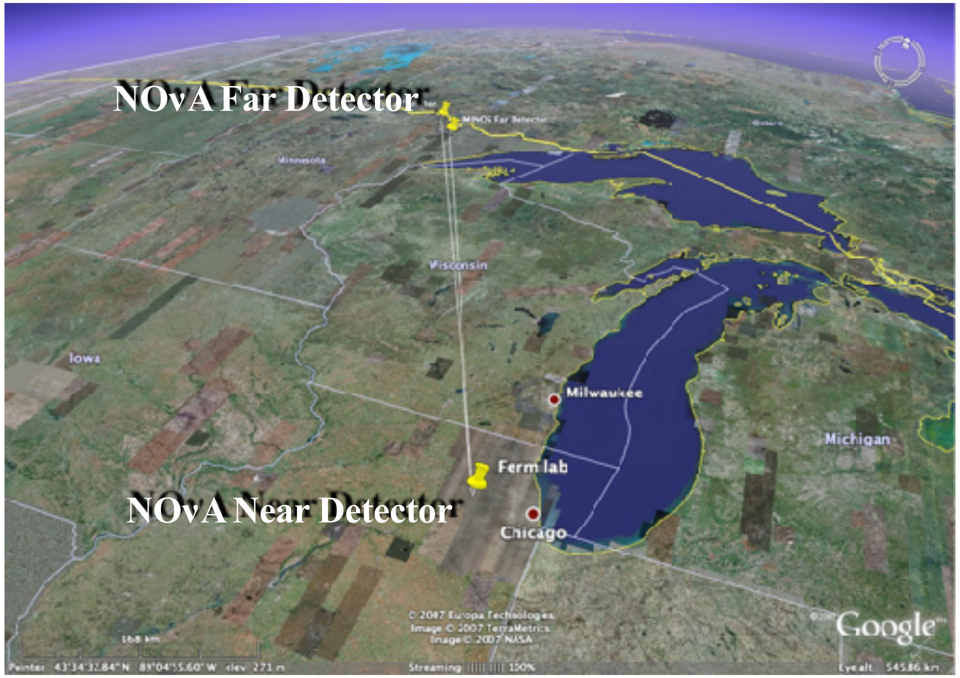
SK as far detector, 295 km off-axis

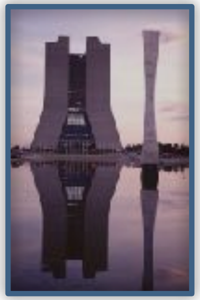
Data taking started in 2009.



The Nova experiment

- Upgraded NuMI **beam of muon neutrinos or antineutrinos** at Fermilab running at 700kW.
- Highly active liquid scintillator **14- kton detector** off the main axis of the beam.
- Functionally identical detectors: Near Detector (ND) site at Fermilab and Far Detector (FD) 810 km away at Ash River,
- NOvA observes **disappearance of muon neutrinos and antineutrinos, appearance of electron neutrinos and antineutrinos** and potential suppression of neutral current interactions.
- 4σ evidence of $\overline{\nu}_e$ appearance presented at Neutrino 2018

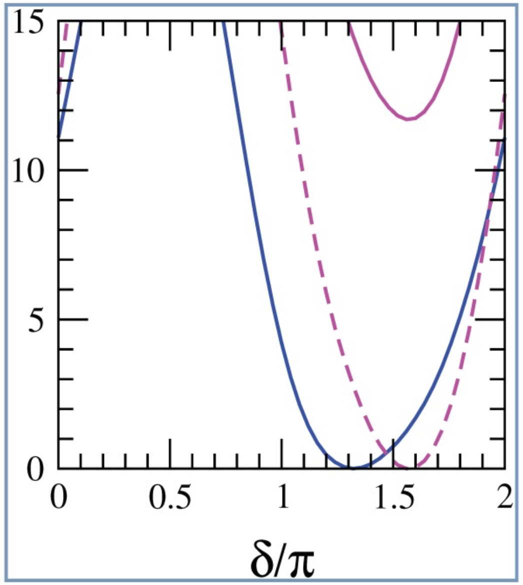




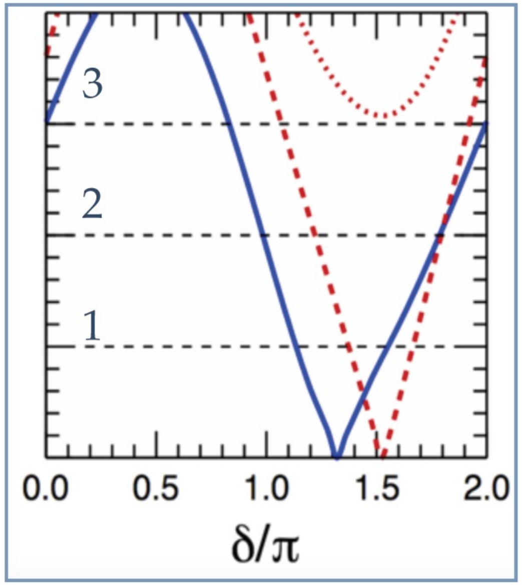
← longest baseline →

Status of CP and Mass Ordering

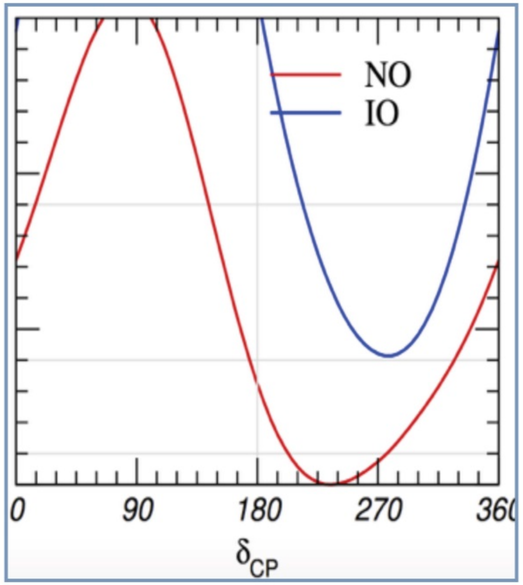
Δχ², Valencia [1708.01186]



Nσ, Bari [1804.09678]



Δχ², NuFit v3.2

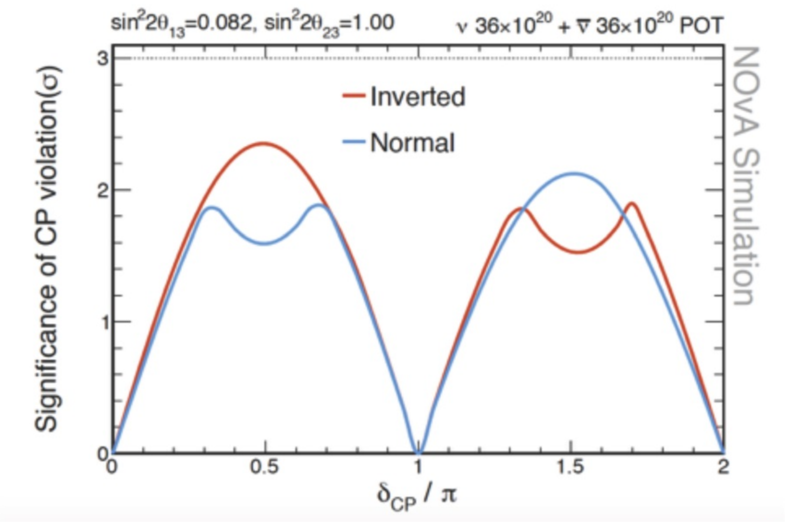


SK-atm not included

- Global fits exclude CP conservation at 2σ
- SK, T2K and Nova favor NO at 2σ
- **Global fits favor NO at 3σ**

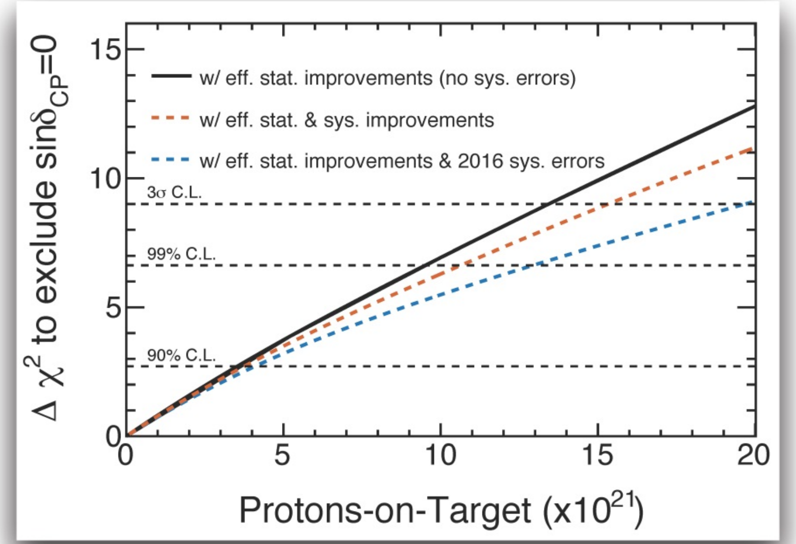
Running experiments CP sensitivity projection

NOνA



- by 2024:
  > 2σ sensitivity on CP violation at max CP violation (π/2 & 3π/2)

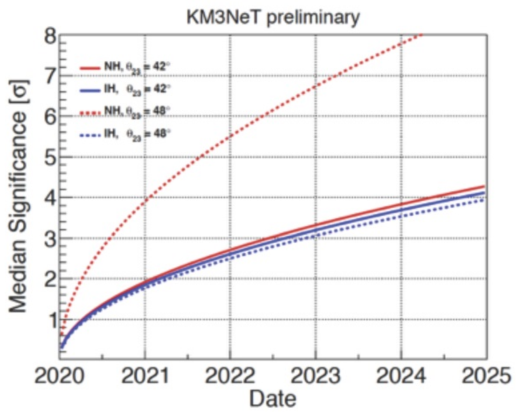
T2K-II **Abe et al, 1609.04111**



- by 2026 (20×10^{21} POT):
  > 3σ sensitivity on CP violation

"Short term" sensitivities in MO

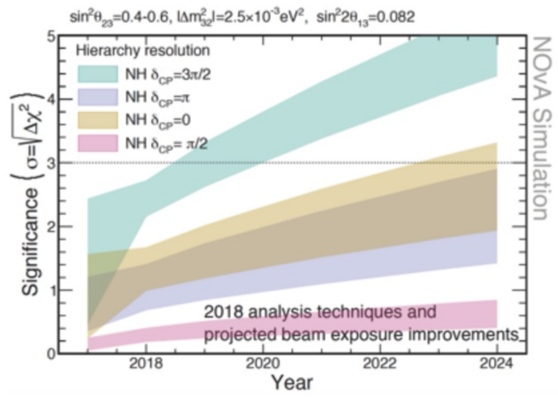
ORCA — **Adrian-Martinez et al, 1601.07459**



- by 2023: 3σ determination of MO

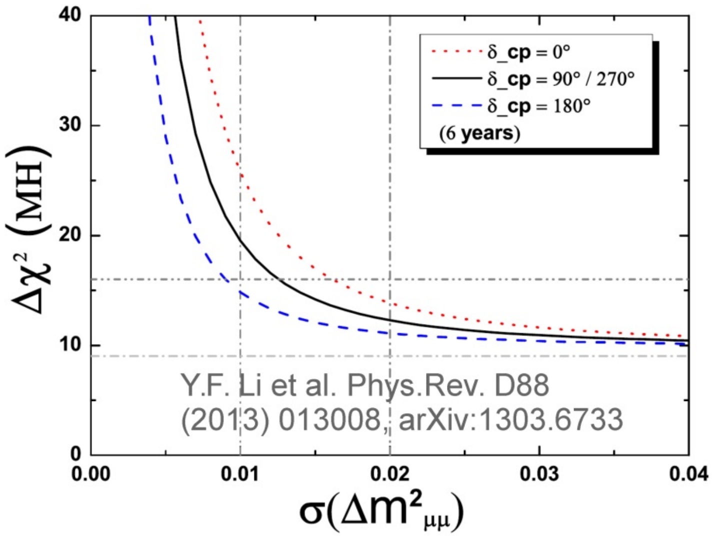
(similar results for PINGU)

NOνA — **Neutrino 2018**



- by 2020: 3σ sensitivity (NO and δ=3π/2)
- by 2024: 3σ sensitivity for 30/50% of δ

JUNO ⇒ 3σ sensitivity on mass ordering after 6 years



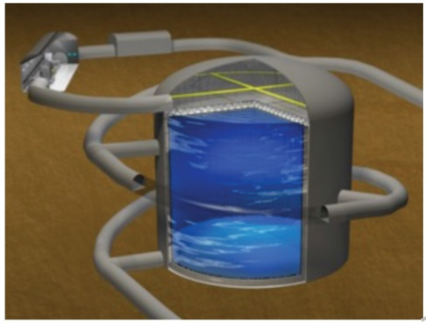
Third generation Long Baseline Experiments

Gigantic detectors with three liquids are under way:

- Liquid scintillator: **Juno** and **SNO+** are in construction
- Water**: Hyper-Kamiokande** selected as top project by Mext.   And also **IceCube Gen 2 , Km3net/Orca**
- Liquid Argon: **Dune** is approved and partially funded

Great complementarity in many astrophysics measurements (SN, relic SN, solar and atmospheric neutrinos, indirect DM searches etc.) and **proton decay**

Hyper-Kamiokande

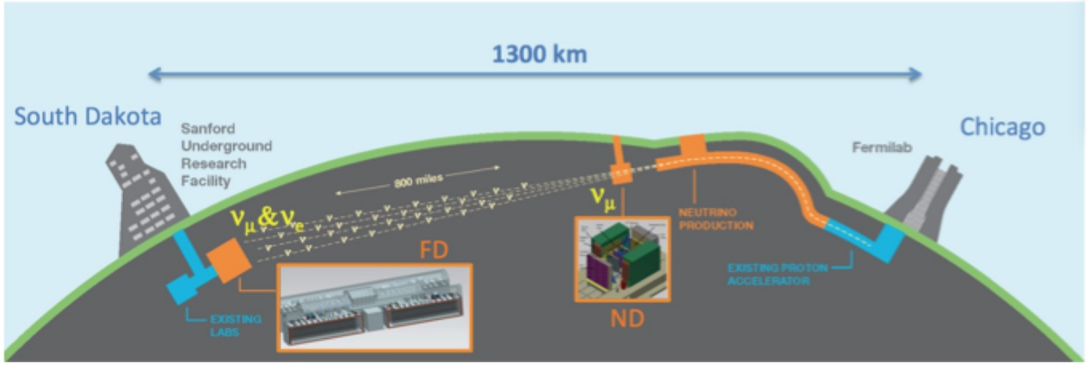


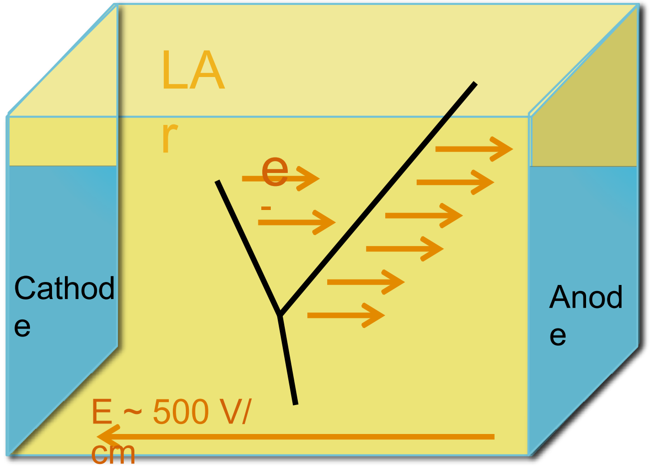
Hyper-K

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
  - ✓Aiming to start construction in FY2019, operation in FY2026

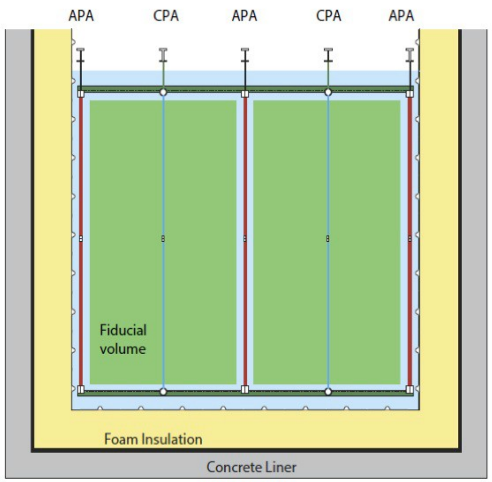
Latest news (31/8): approved but not yet funded by MEXT



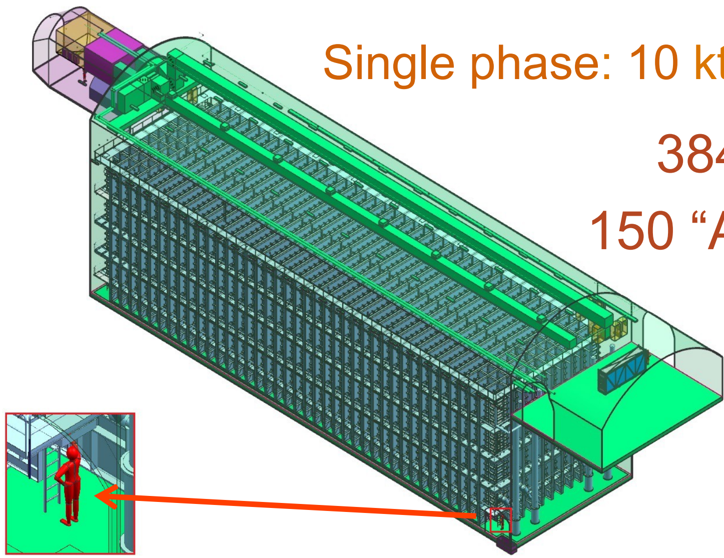


- 4 10-kt (fiducial) liquid argon TPC modules
- **Single-** and dual-phase detector designs (1st module will be single phase)
- Integrated photon detection
- Modules will not be identical

Single phase: modular wire-plane readout



Single phase: 10 kt module



384,000 readout wires

150 “APAs” (2.3 m x 6 m)

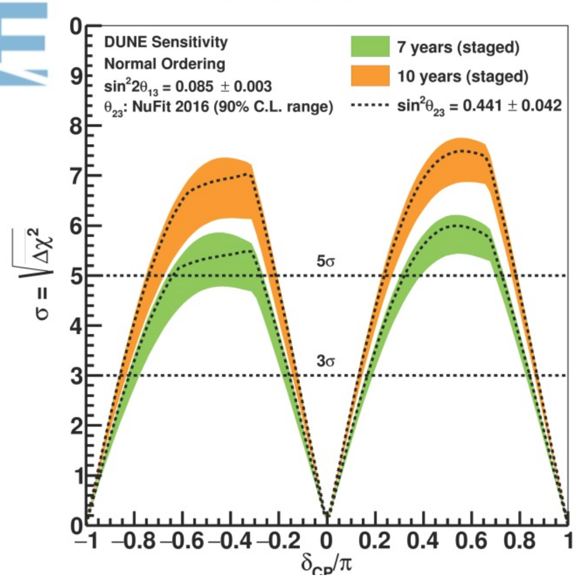
12 m high

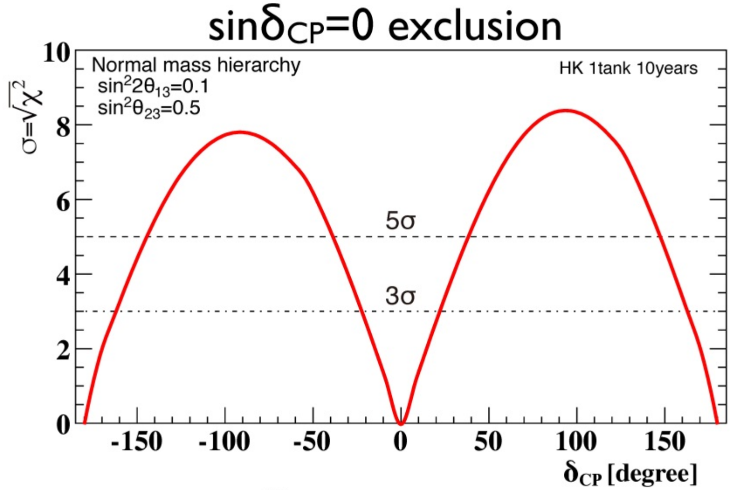
15.5 m wide

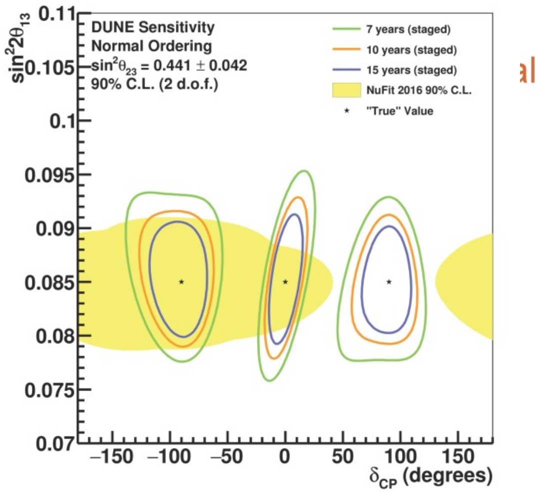
58 m long

Dune and HK CP Sensitivity

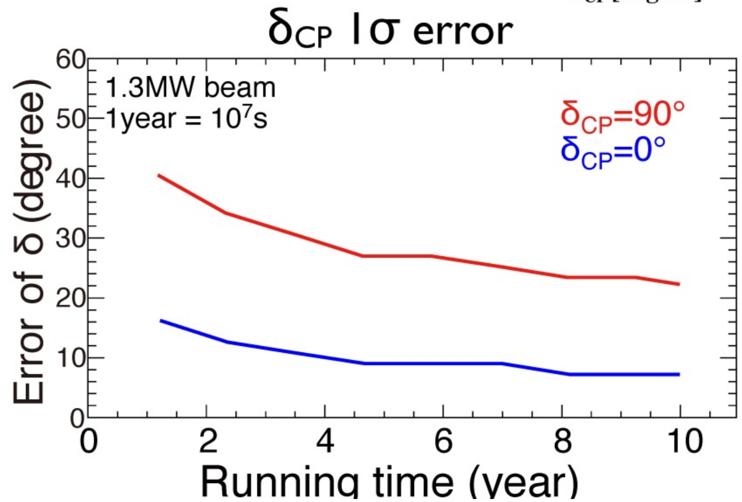
CP Violation







Simultaneous measurement of neutrino mixing angles and δ_{CP}



Proton decay

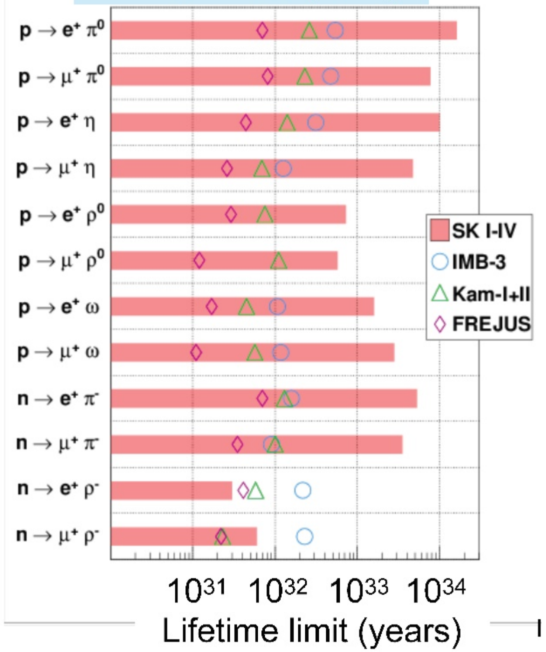
- The initial goal of KamiokaNDE
- … and probably the main goal of HK
- In the meantime the project won 2 Noble prizes on neutrinos
- Goal: push the sensitivity to 10^{35} yr

SK limits

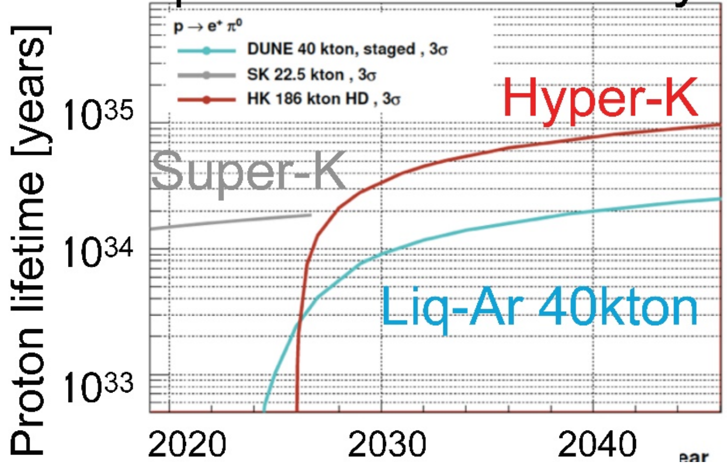
PRD 90, 072005 (2014)

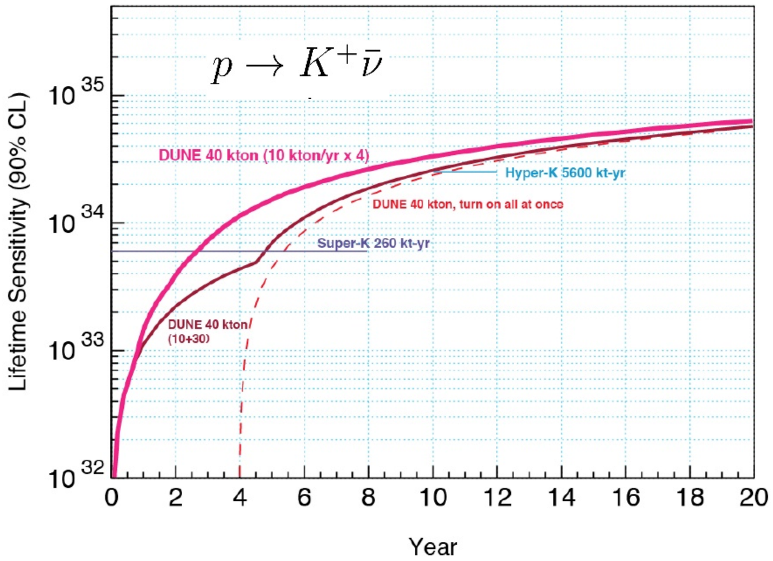
- $p \to \nu K^{+}$
  - $\tau_p/Br > 5.9 \times 10^{33}$ yrs

PRD 96, 012003 (2017)



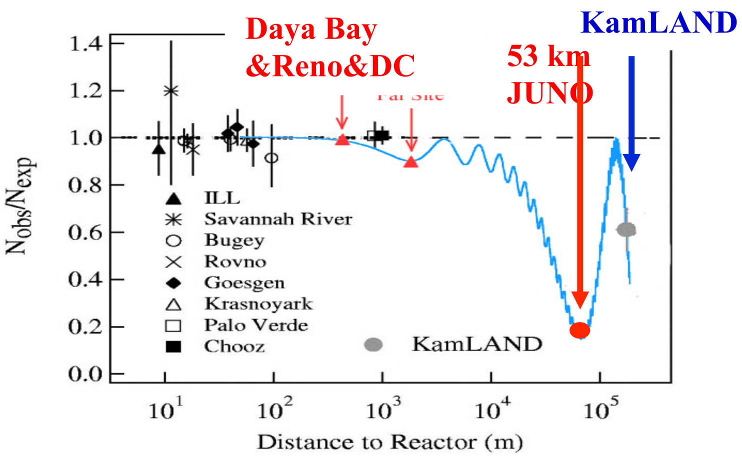
$p \to e^{+}\pi^{0}$ 3σ discovery

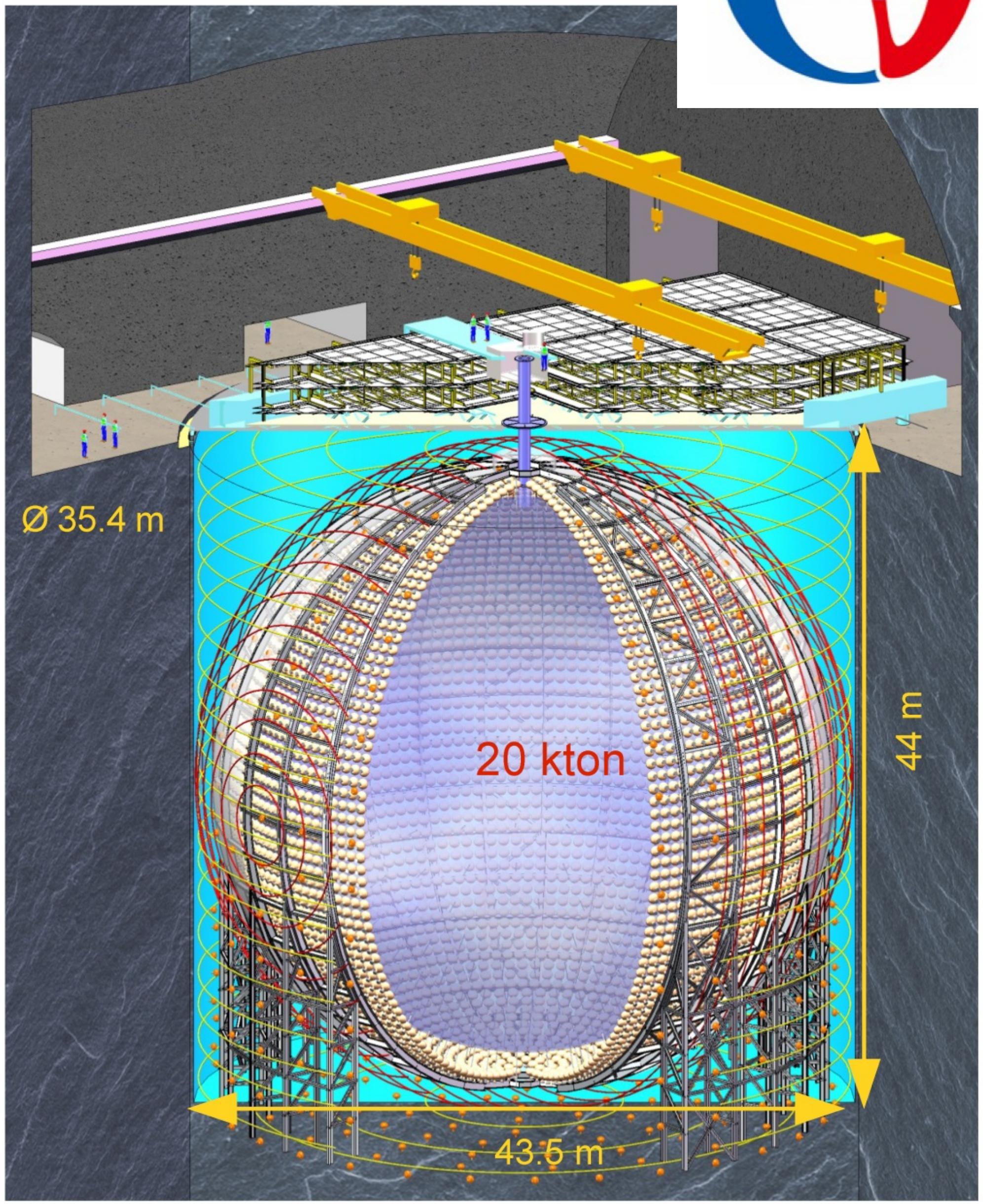




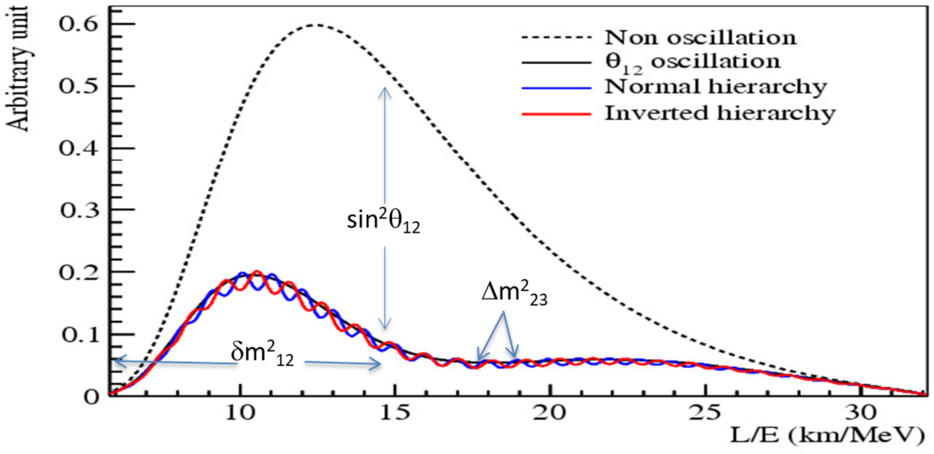
Juno

- **Central detector**
  - Acrylic sphere with liquid scintillator
  - PMTs in water buffer
  - 78% PMT coverage
- **Water Cherenkov muon veto**
  - 2000 20" PMTs
  - 35 ktons ultra-pure water
  - Efficiency > 95%
  - Radon control → less than 0.2 Bq/m^3
- **Compensation coils**
  - Earth magnetic field <10%
  - Necessary for 20" PMTs
- **Top tracker**
  - Precision muon tracking
  - 3 plastic scintillator layers
  - Covering half of the top area





Juno physics summary



- **~3 % energy resolution-the greatest challenge**
- Rich physics possibilities
  - **Mass hierarchy**
  - **Precision measurement of 3 mixing parameters**
  - **Supernovae neutrinos**
  - **Geoneutrinos**
  - **Diffuse Supernovae ν's**
  - **Atmos&sol neutrinos**
  - **Nucleon Decay**
  - **Exotic searches**

	Δm^2_{21}	$\sin^2\theta_{12}$	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Dominant experiment	KamLAND	SNO	T2K & NOvA /Daya Bay	Daya Bay	T2K
Individual 1σ	2.4%	6.7%	3.2%/3.5%	4.0%	9.8%
Global 1σ *	2.2%	3.9%	1.2%	3.4%	5%
JUNO expected 1σ	0.6%	0.7%	0.4%	~15%	-

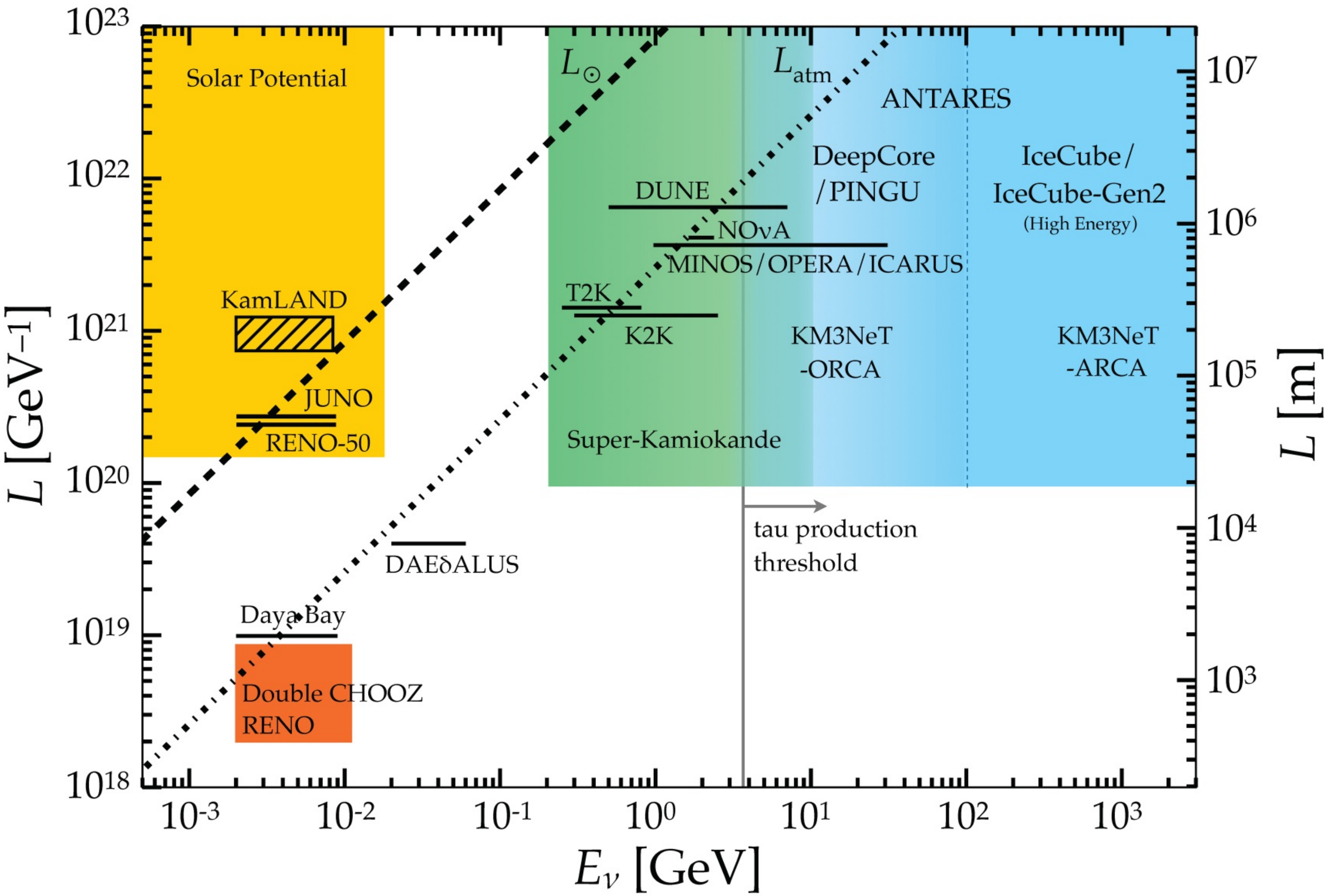
Complementarity

"There are two possible outcomes: if the result confirms the hypothesis then you've made a ***measurement****. If the result is contrary to the hypothesis then you've made a* ***discovery****",* ***Enrico Fermi****.*

- Without complementarity and redundancy HK and Dune risk to produce "boring" yet powerful measurements.
- With, they increase their discovery potential
- HK and Dune nicely complement their physics reach in neutrino oscillations (see f.i. arXiv:1501.03918)
- Juno can improve their sensitivity in precisely measuring solar parameters while HK and Dune can measure Δm_{ee}^2 for Juno
- The three liquids really complement each other in detecting SN neutrinos, proton decays, solar neutrinos, indirect DM searches, …

Complementarity: same L/E but different E

Any subleading non-oscillatory effect would violate L/E scaling

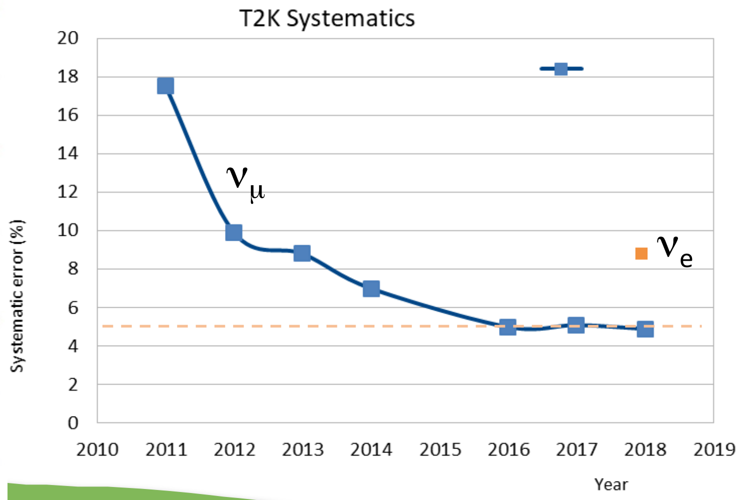


What Next

At full statistics Dune and HK, will be dominated by systematic errors. Detectors can't be improved very much and any significant progress of sensitivities can only be achieved through neutrino beams

Experiment	$\nu_e + \bar{\nu}_e$	$1/\sqrt{N}$	Ref.
T2K (current)	74 + 7	12% + 40%	2.2×10²¹ POT
NOvA (current)	33	17%	FERMILAB-PUB-17-065-ND
NOvA (projected)	110 + 50	10% + 14%	arXiv:1409.7469 [hep-ex]
T2K-I (projected)	150 + 50	8% + 14%	7.8×10²¹ POT, arXiv:1409.7469 [hep-ex]
T2K-II	470 + 130	5% + 9%	20×10²¹ POT, arXiv1607.08004 [hep-ex]
Hyper-K	2900 + 2700	2% + 2%	10 yrs 2-tank staged KEK Preprint 2016-21
DUNE	1200 + 350	3% + 5%	3.5+3.5 yrs x 40kt @ 1.07 MW arXiv:1512.06148 [physics.ins-det]

D. Hadley, Nufact '17



The focus of next to next generation of Long Baseline experiments are new concepts in neutrino beams.

Neutrino beams for precision physics: the ERC ENUBET Project

The next generation of **short baseline** experiments for **cross-section** measurements and for **precision ν physics** (e.g. sterile ν and NSI) should rely on:

- ✓ **a direct measurement of the fluxes**
- ✓ a narrow band beam: **energy known a priori** from the beam width
- ✓ a beam covering the region of interest **from sub- to multi-GeV**

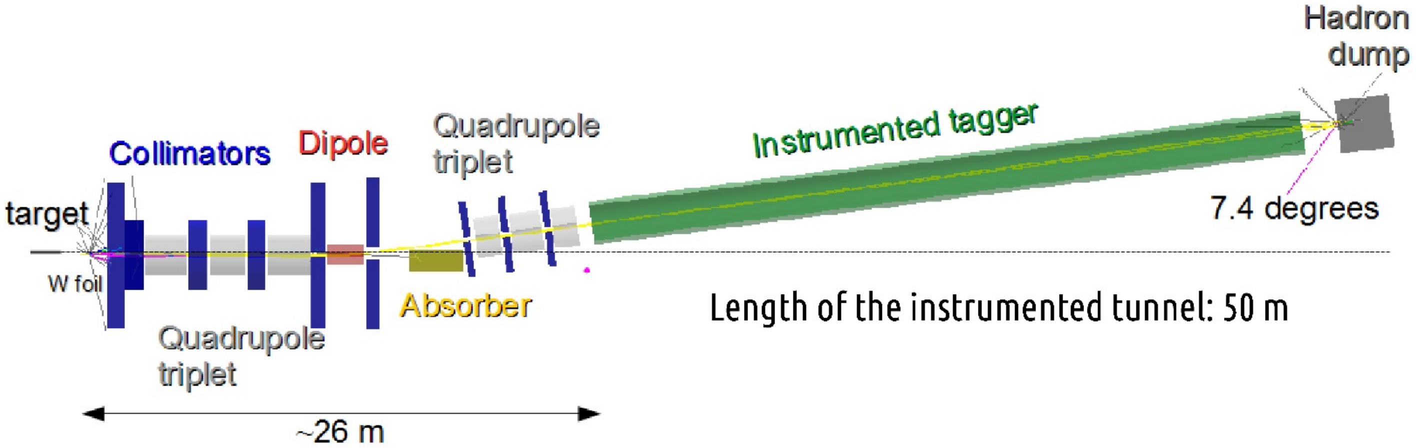
Enhanced NeUtrino BEams from kaon Tagging

ERC-CoG-2015, G.A. 681647 (2016-21)
A. Longhin, **Padova University, INFN**

CERN-EoI: 41 physicists, 10 inst:
CERN, IN2P3 (Bordeaux), INR, INFN (Bari, Bologna, Insubria, Milano-Bicocca, Napoli, Padova, Roma-I)

+ NUTECH funding from the Italian Min. of Research (MIUR)

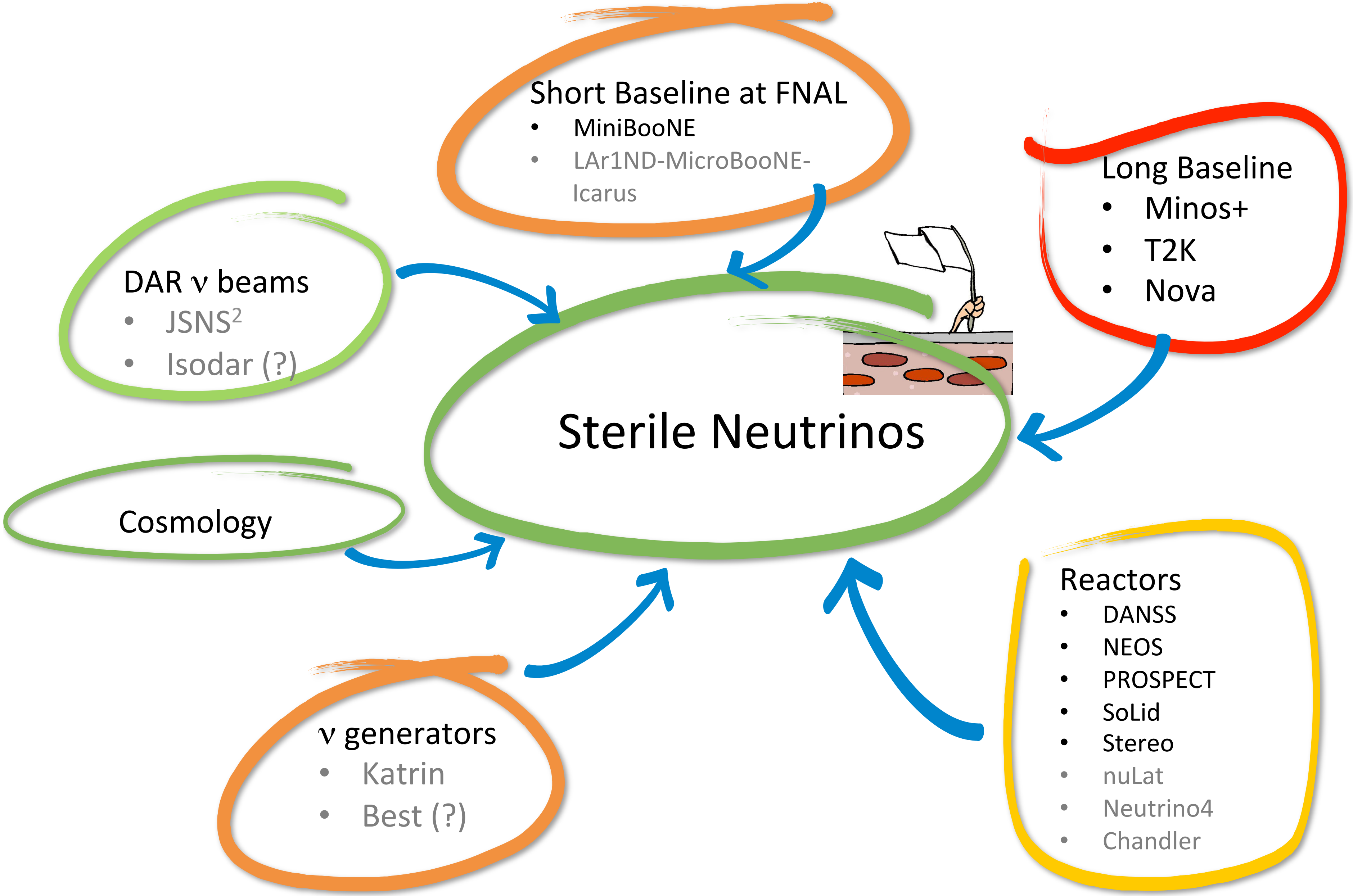
The ENUBET facility fulfills simultaneously all these requirements



~ 500 t neutrino detector @ 100 m from the target

e.g.ICARUS@FNAL or ProtoDUNE-SP/DP@CERN

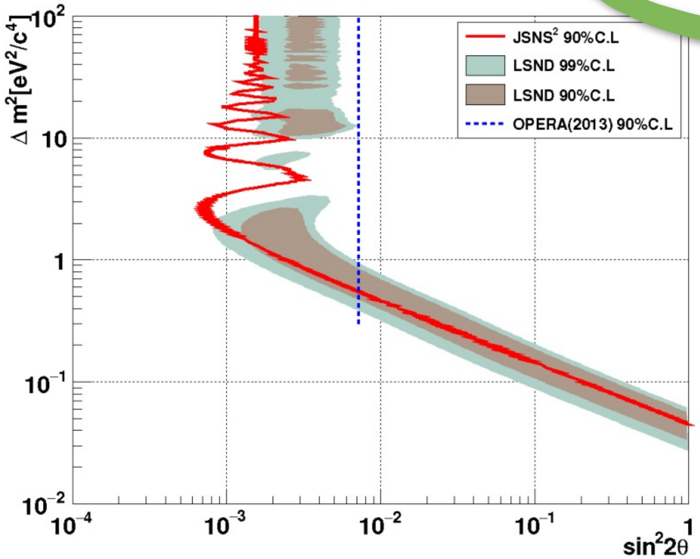
eV Sterile Neutrinos



Check of LSND

π DAR
- JSNS^2

Excess of $\overline{\nu}_e$-like events in a ν beam from π decays at rest

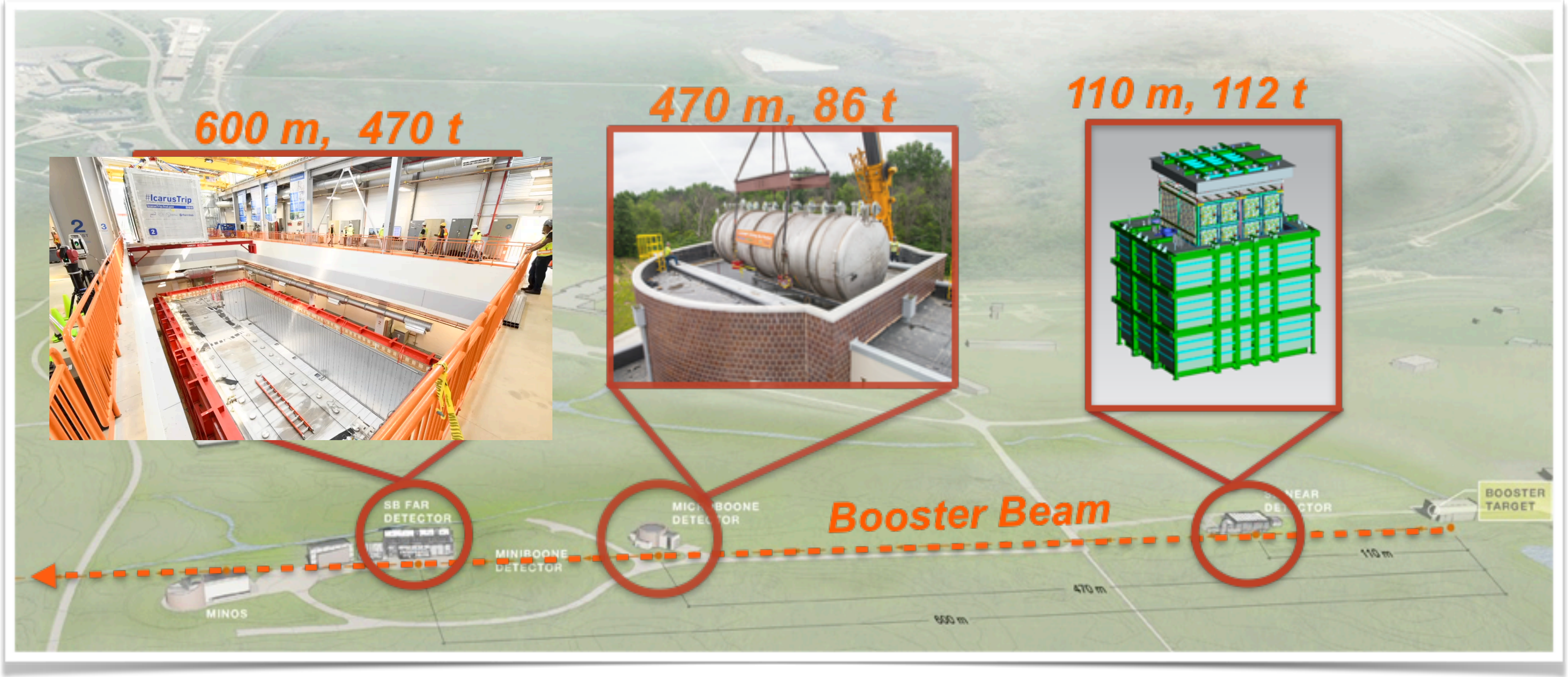


JSNS^2 TDR: arXiv:1705.08629
90%CL sensitivity for 1MW x 3 years x 1 detector

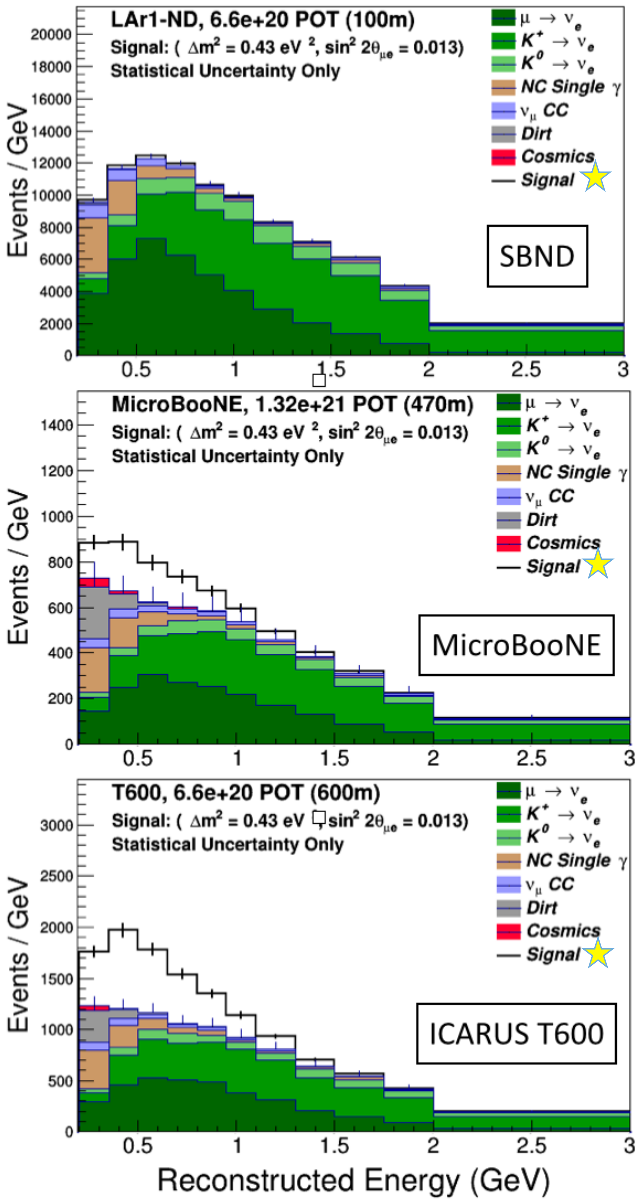
Short Baseline Neutrino Program at Fermilab

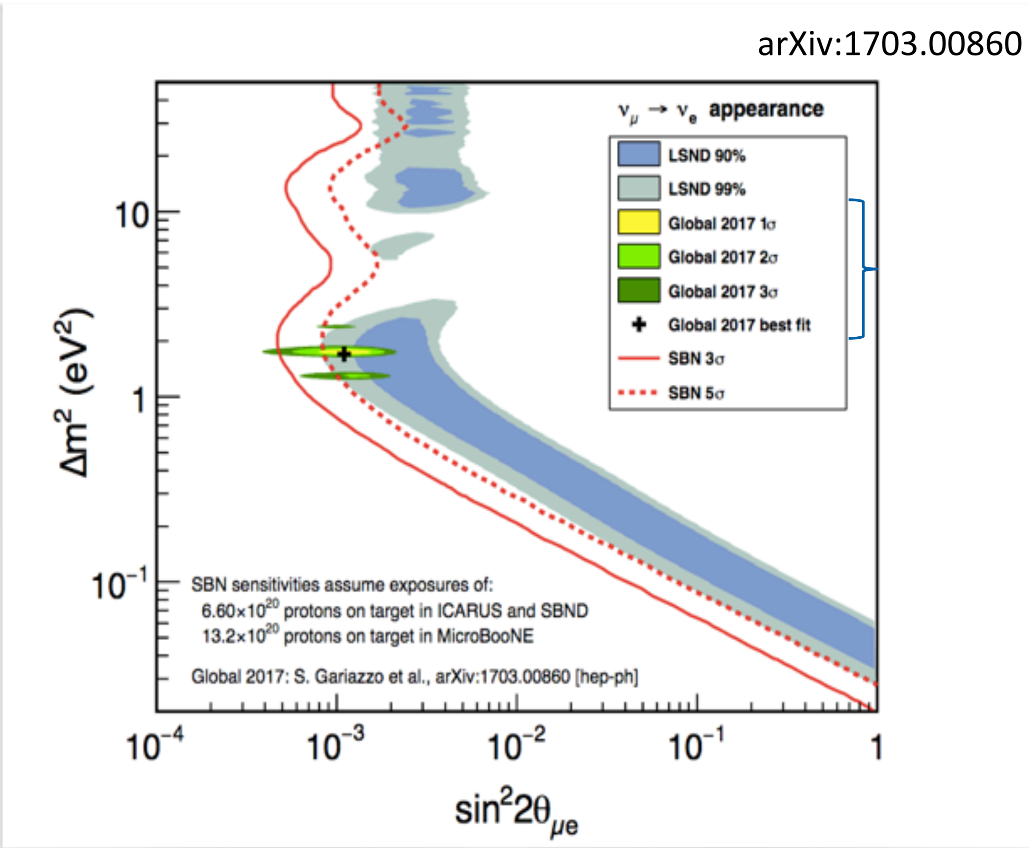
Program aimed at definitely solving the “sterile neutrino puzzle” by exploiting:

- the well characterized FNAL Booster ν beamline;
- three detectors based on the same liquid argon TPC technique.



Sensitivity of SBN program in appearance channel





The LSND 99% C.L. region will be covered at ~ 5 σ level in 3 years of data taking with positive focusing of the BNB (~ 6.6 x 10^{20} pot).

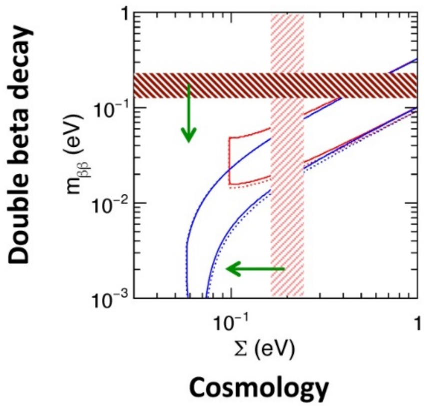
Neutrinoless double beta decay experiments

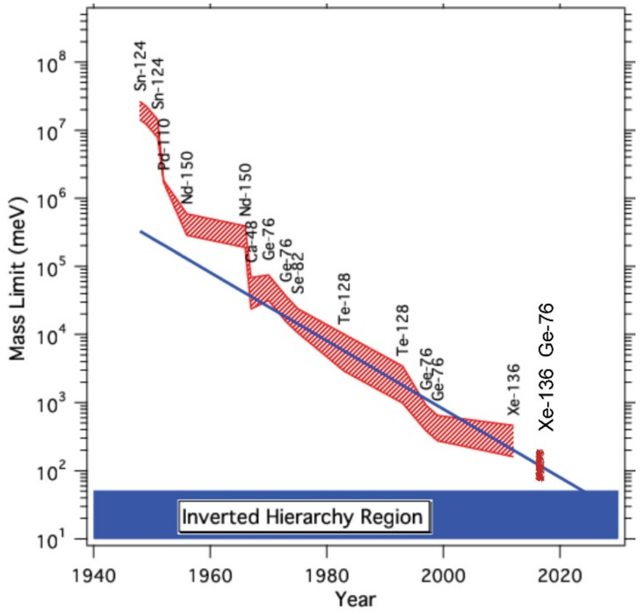
Several important new results by new generation experiments

Experiment	Isotope	Mass (isotope/tot) (kg)	$T_{1/2}$ (10^{26} yr)	$m_{\beta\beta}$ (meV)	Zero bck exposure (kg.yr)
Kamland-Zen	Xe^{136}	380/3900	1.07	45 - 160	45
Exo	Xe^{136}	100	0.18	150-400	10
Gerda	Ge^{76}	35	0.90	110-260	500
Cuore	Te^{130}	206/741	0.15	140-400	20

- Sensitivity scales as $(Mt)^{1/2}$ with null backgrounds, $(Mt)^{1/4}$ otherwise
- Critical parameter: backgrounds in the "region of interest"
- Here expressed as its inverse: expected exposure (kg yr) with zero backgrounds (kg are computed for the mass of the active isotope)
- **Goal for a next gen experiment**: zero bacgkround exposure of order of **5000 kg x yr** (1 ton x 5 years → $T_{1/2} > 10^{27}$ yr →IH region covered)

0ββν perspectives

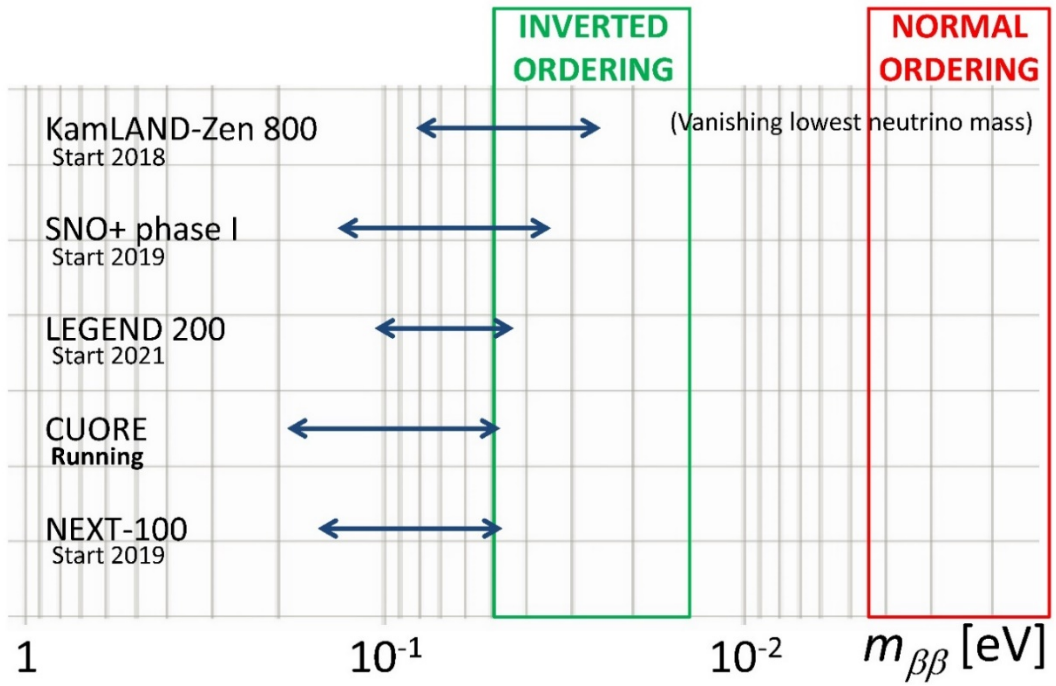




From the summary talk of A. Giuliani at Neutrino 2018

Possible scenario in 2024

Considering running or well advanced projects (for results, funding and infrastructures)



- 90%CL and not 5σ sensitivities
- Computed for the most favorable value of the quenching parameter g_A

APPEC strongly supports the present range of direct neutrino-mass measurements and searches for neutrinoless double-beta decay. Guided by the results of experiments currently in operation and in consultation with its global partners, APPEC intends to converge on a roadmap for the next generation of experiments into neutrino mass and nature by 2020.

LEGEND

^{76}Ge

LEGEND-200:

LNGS – Italy

- Initial Phase
- **~200 kg** in upgraded existing GERDA infrastructure
- **Improvements**:
  - LAr optical purity (light yield, attenuation)
  - Light detection (add readout between detector strings)
  - Cleaner materials and smaller parts near detectors
  - Larger detectors (fewer cables, readout channels)
  - Surface betas (^{42}Ar progeny): Reduce LAr volume and improve pulseshape
  - Discrimination (better electronics)
  - **New inverted-coaxial larger detectors (1.5 – 2 kg)**
- **Background goal**: 0.6 counts/FWHM t yr (**3x lower than GERDA**)
- Data-taking could start as early as 2021
- **Sensitivity: > 10^{27} y for 1 tonne × y** **$m_{\beta\beta}$ < 35 – 75 meV**

LEGEND-1000:

- Ultimate goal
- **1000 kg (phased)** required to cover neutrino-mass IO
- Timeline connected to US DOE down-select process
- Background goal: 0.1 counts/FWHM-t-yr
- Location TBD
- Required depth under investigation

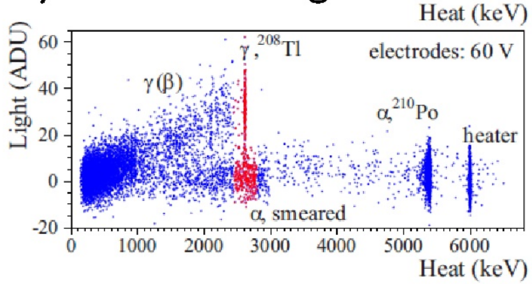
CUPID R&D and demonstrators

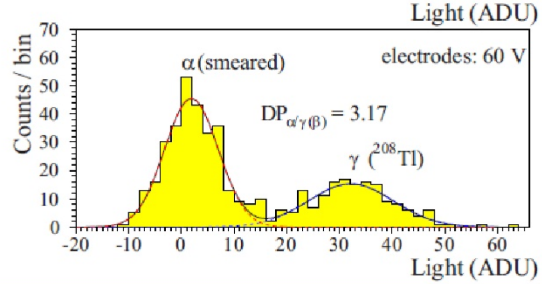
^{130}Te, ^{82}Se, ^{100}Mo

$^{130}TeO_2$ + Cherenkov light

Vibrant R&D activities (several technologies: NTDs, MKIDs, TESs)

Full α/β separation already achieved with a CUORE-size crystal and a Neganov-Luke assisted light detector – LSM





LSM – France **Q=2527 keV**

CUPID-0 – Zn^{82}Se Q=2998 keV

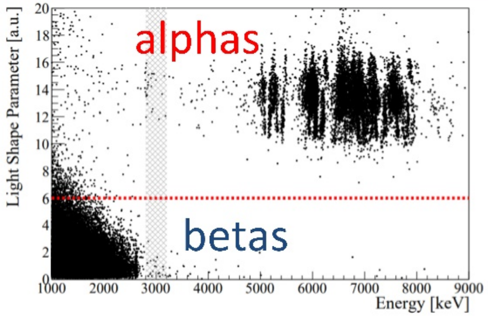
First running demonstrator - LNGS

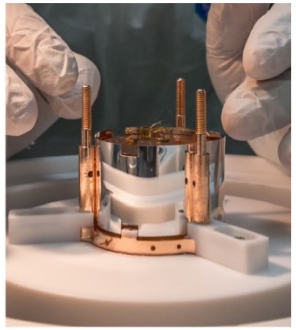
24 crystals – 5.28 kg ^{82}Se

Best limit on ^{82}Se: $T_{1/2}$ **> 2.4×10^{24} y**

Energy resolution: **~23 keV FWHM**

Required improvements in crystal quality and radiopurity





LNGS – Italy

CUPID-Mo – Li$_2$^{100}MoO$_4$ Q=3034 keV

LSM – France

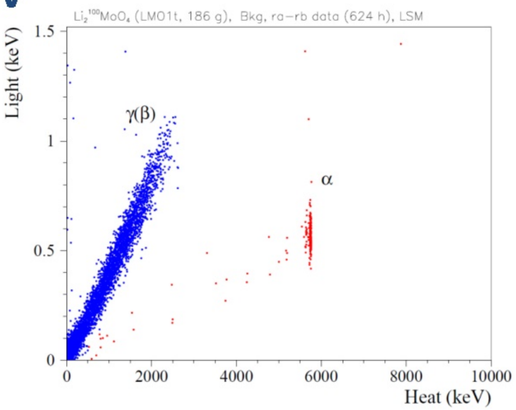
Phase-I 20 crystals – 2.34 kg ^{100}Mo
currently in commissioning

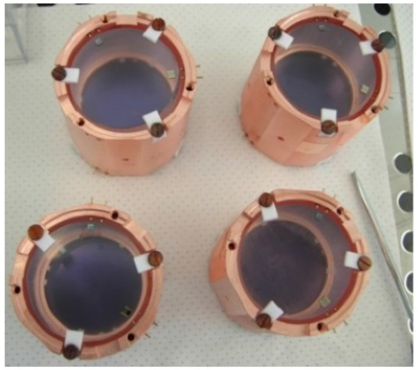
Phase-II
additional 26 crystals – 3.94 kg ^{100}Mo
data taking from 2019 – LNGS

Energy resolution: **~5 keV FWHM**

Radiopure high-quality crystals

Negligible ^{100}Mo losses in crystal growth

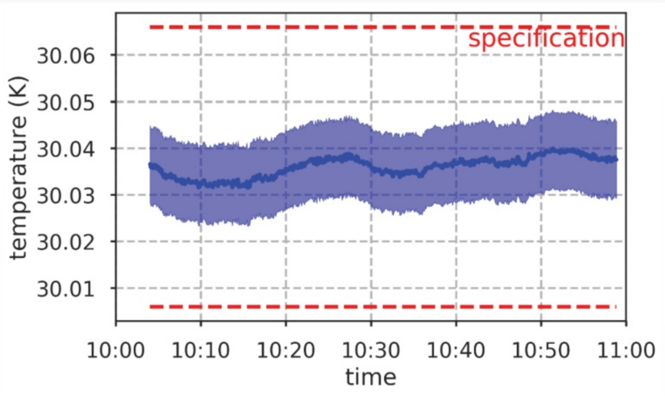


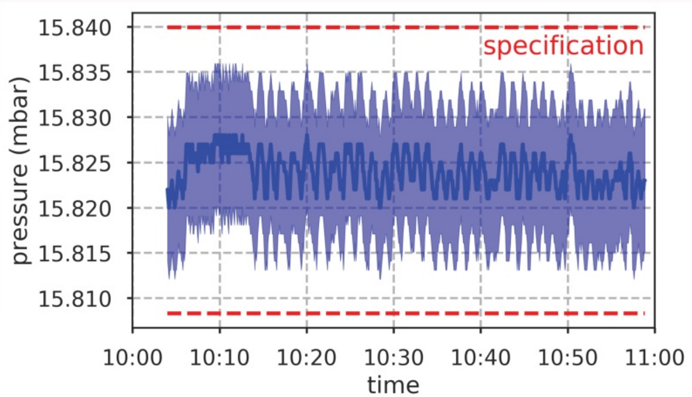


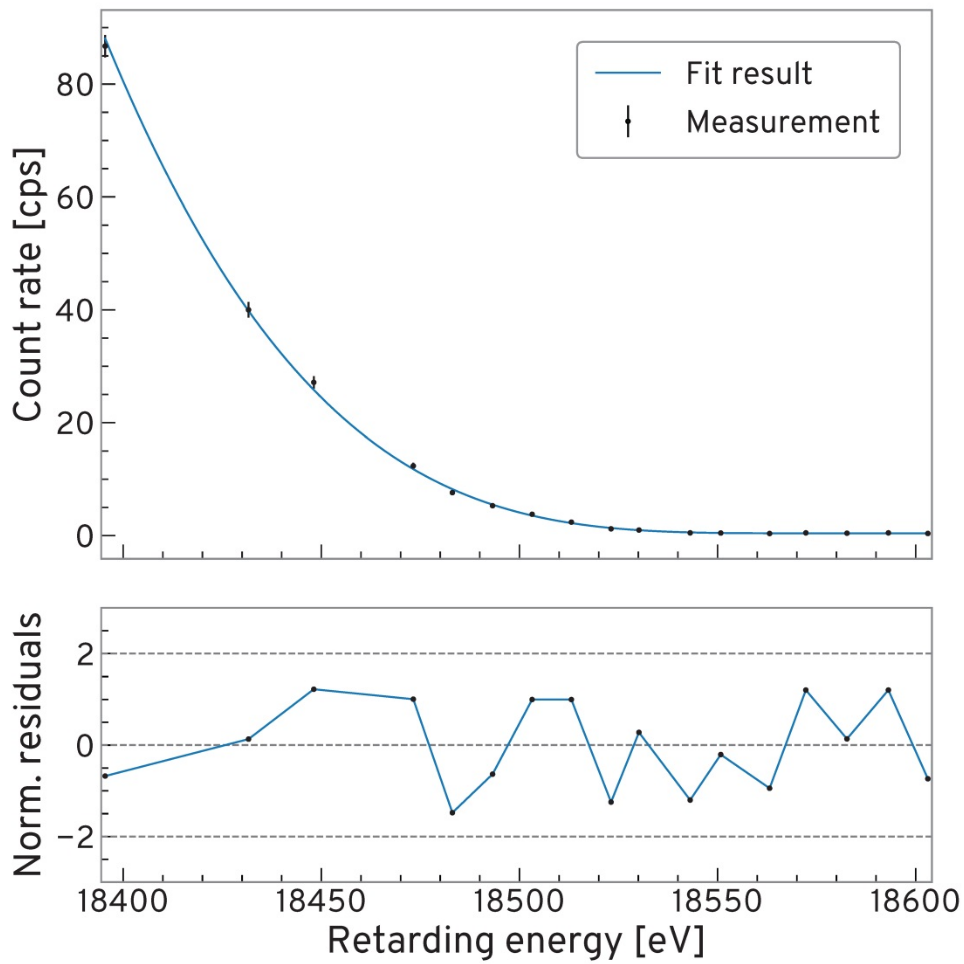
Direct neutrino mass measurement: Katrin

Commissioning started 4 months ago

- 1% of nominal tritium activity
- Tritium loop operation from 5 June - 18 June (no interruption)
- Source parameters are stable and within specifications







Goal of the experiment: 0.25 eV sensitivity on m_β

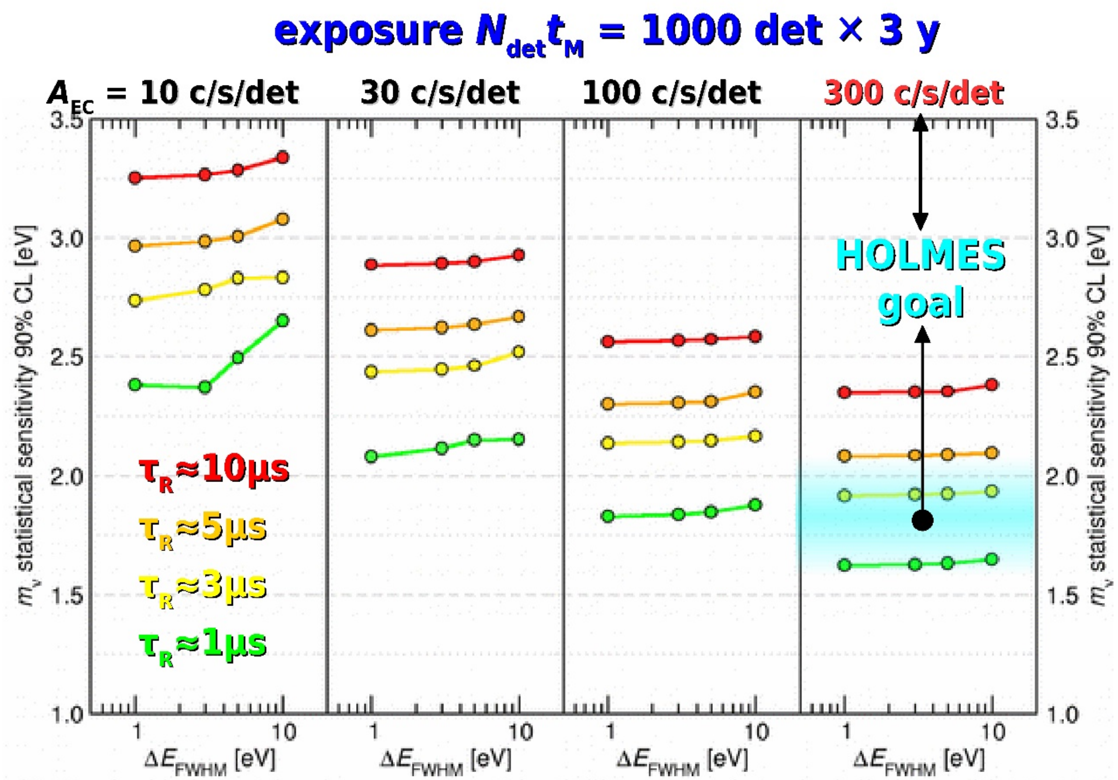
HOLMES *(ERC-Advanced Grant n. 340321)*

goal

- direct neutrino mass measurement: m_ν **statistical sensitivity around 1 eV**
- prove potential and scalability:
  - assess EC spectral shape
  - assess systematic errors

baseline

- **low *T* microcalorimeters** with **implanted ^{163}Ho**
  - 6.5×10^{13} atom/det → A_{EC}**=300 c/s/det**
  - $\Delta E \approx 1$ **eV** and $\tau_R \approx 1$ **μs**
- **1000 channel** array
  - 6.5×10^{16} ^{163}Ho nuclei → ≈18 μg
  - 3×10^{13} events in **3 years**



5 years project started on February 1st 2014 (now extended by 1 year)

B. Alpert et al., Eur. Phys. J. C, (2015) 75:112

Conclusions

- In the previous strategy neutrino physics was the 4th of the 4 main goals: "Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. *CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.*"
- … but oscillations had been delocalized in USA and Asia
- In the meantime progress in the field had been faster than "rapid" convincing a growing community of physicists and the funding agencies to invest in future experiments
- For this reason neutrino physics should jump some position in the ranking.
- CERN should secure the support of the CERN Neutrino platform and improve the support by accelerator experts
- The role of "non-accelerator" neutrino physics is becoming more and more important
- Complementarity and redundancy are necessary to strengthen the foreseen measurements and allow unexpected discoveries.
- As a "byproduct" new experiments will provide powerful BSM searches like proton decays ($\tau_p > 10^{35}$ yr) and neutron-antineutron oscillations.
- In the long term new technologies will be needed, particularly to develop neutrino beams of new concept