NEUTRINO 2018 Heidelberg 4–9 June

GDR Neutrino, June 2018

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Highlights

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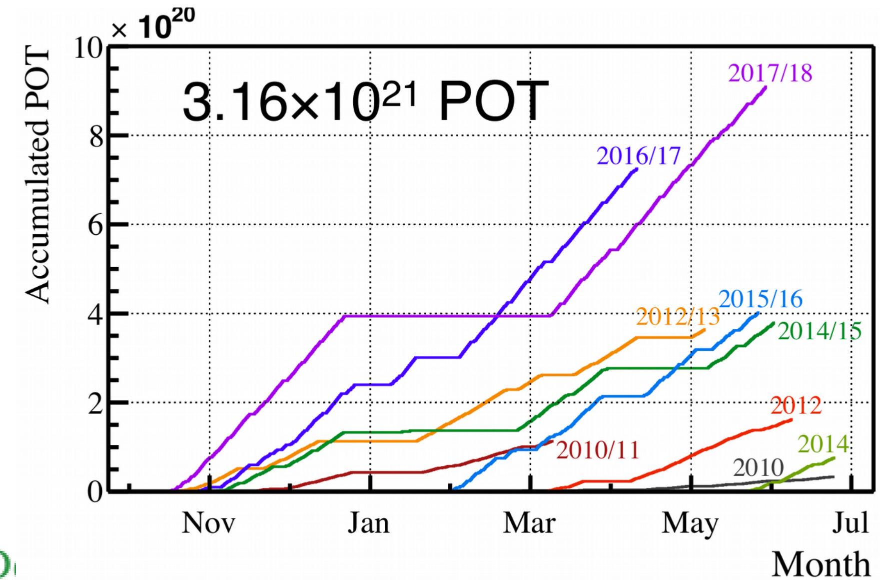
Outline

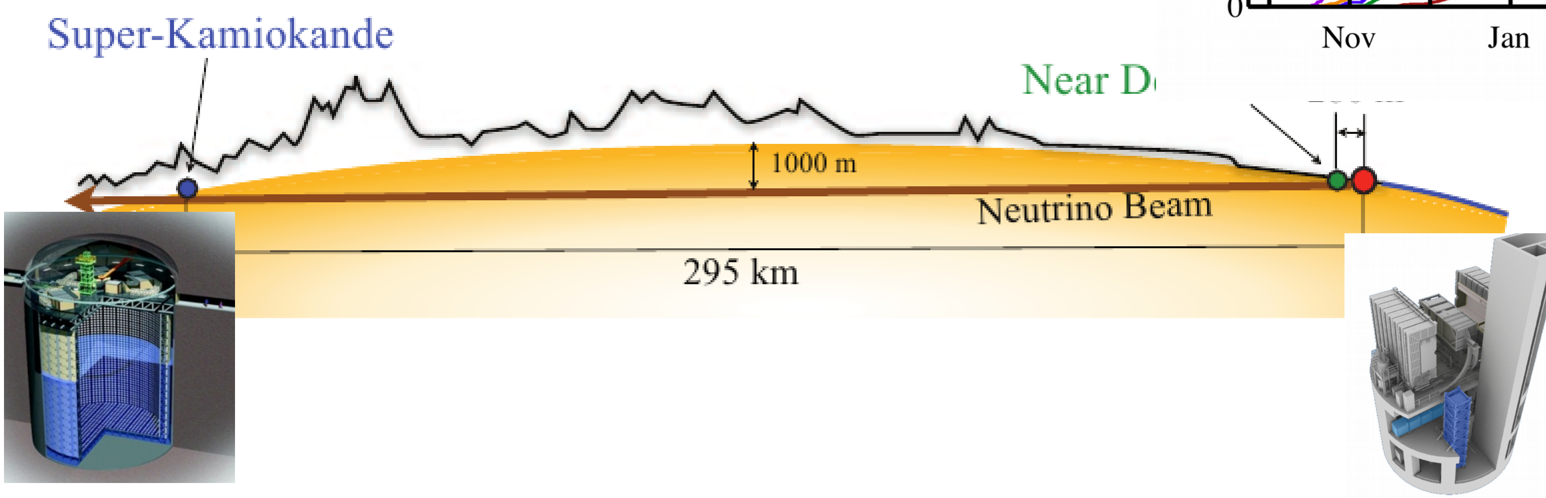
- The 3 ν paradigm
  - Accelerator neutrinos
  - Solar Neutrinos
  - Reactor/atmospheric neutrinos
- Sterile neutrinos
- Double beta decay
- Neutrino astronomy
- Coherent neutrino scattering
- Neutrino mass determination

Disclaimer: Probably biased (~3 σ) and certainly incomplete (>5 σ)

- ***Accelerator neutrinos***

- Milestones this year:
  - Exceeded 3×10^{21} POT
  - Achieved 500 kW beam power!
  - **More than double the data set shown at Neutrino2016!**





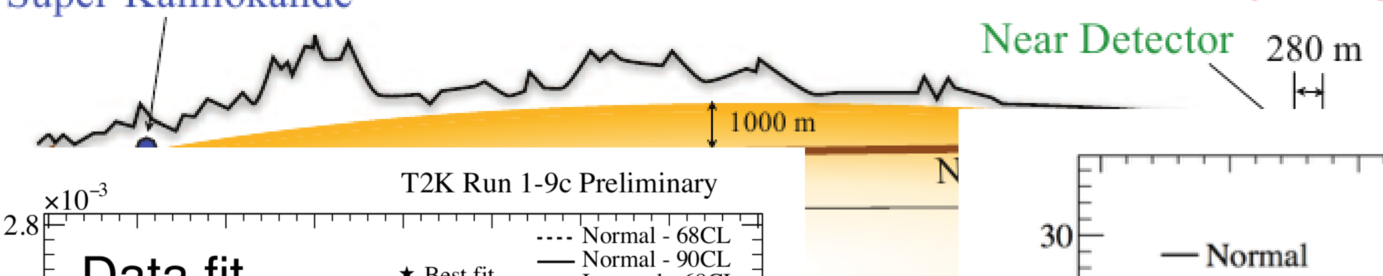
What is the value of δ ?
What is the mass hierarchy?

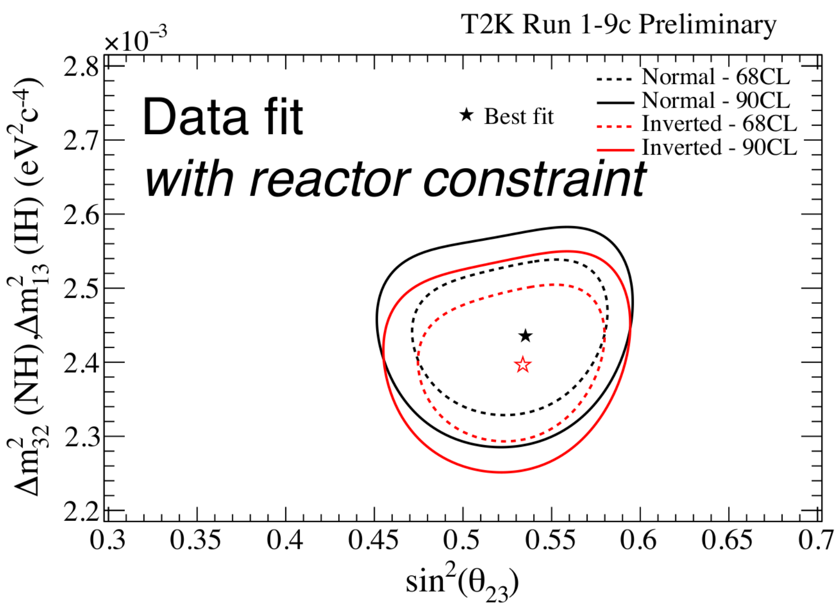
T2K

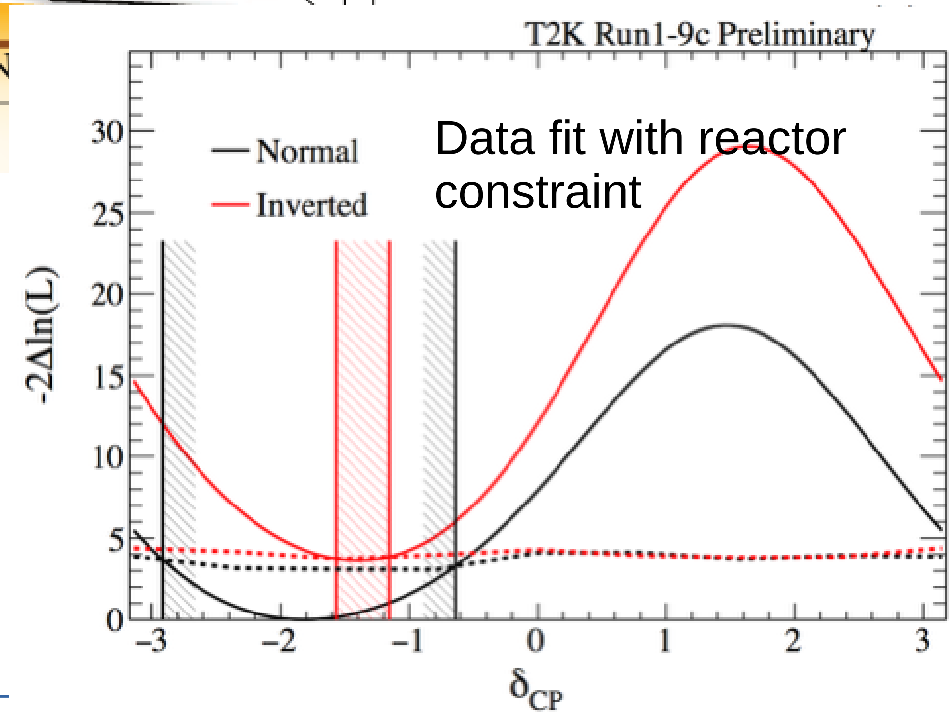
Morgan Wascko

- Analysed 1.49×10 21 POT in FHC and 1.12×10 21 POT in RHC:
  - CP conserving values of δ CP lie outside 2σ region.
  - Data show **preference** for **Normal Hierarchy**,
  - Bayes factor for NH/IH is 7.9.
- Analysis of full data set to be released late summer 2018.
- Upgrades to beam, near and far detectors progressing well

	$\sin^2\theta_{23}\leq 0.5$	$\sin^2\theta_{23}>0.5$	SUM
NH ($\Delta m^2_{32}>0$)	0.204	0.684	0.888
IH ($\Delta m^2_{31}<0$)	0.023	0.089	0.112
SUM	0.227	0.773	1







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More details tomorrow in Stephen Dolan talk

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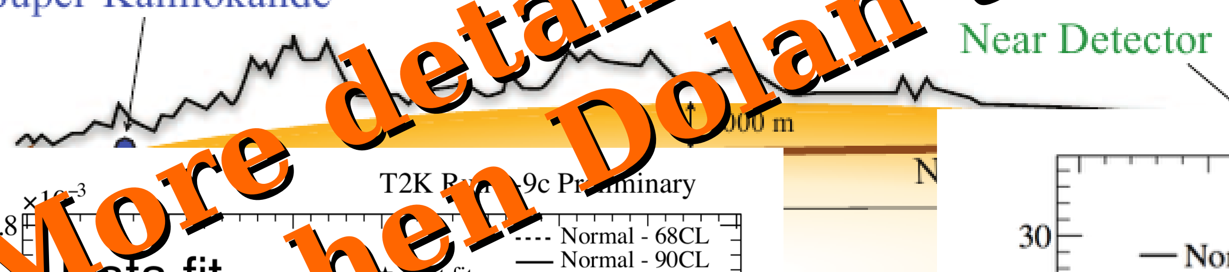
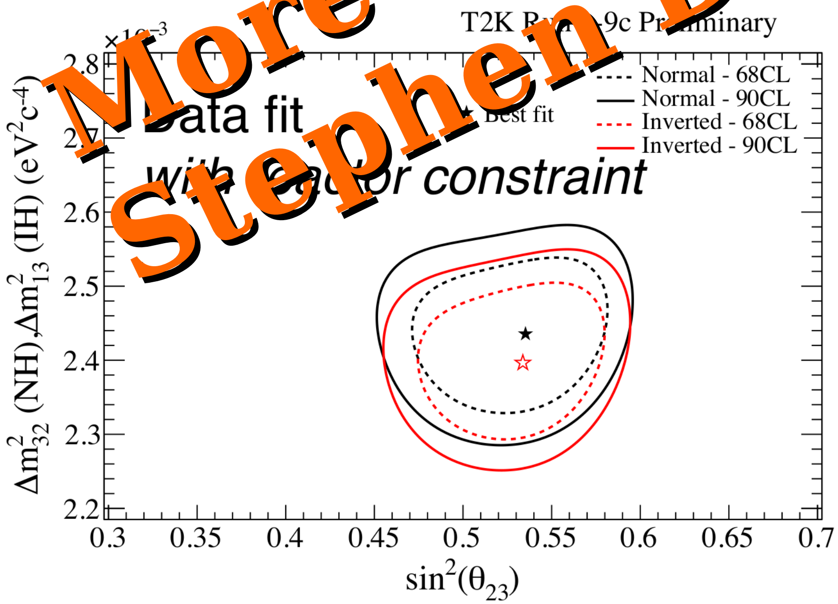
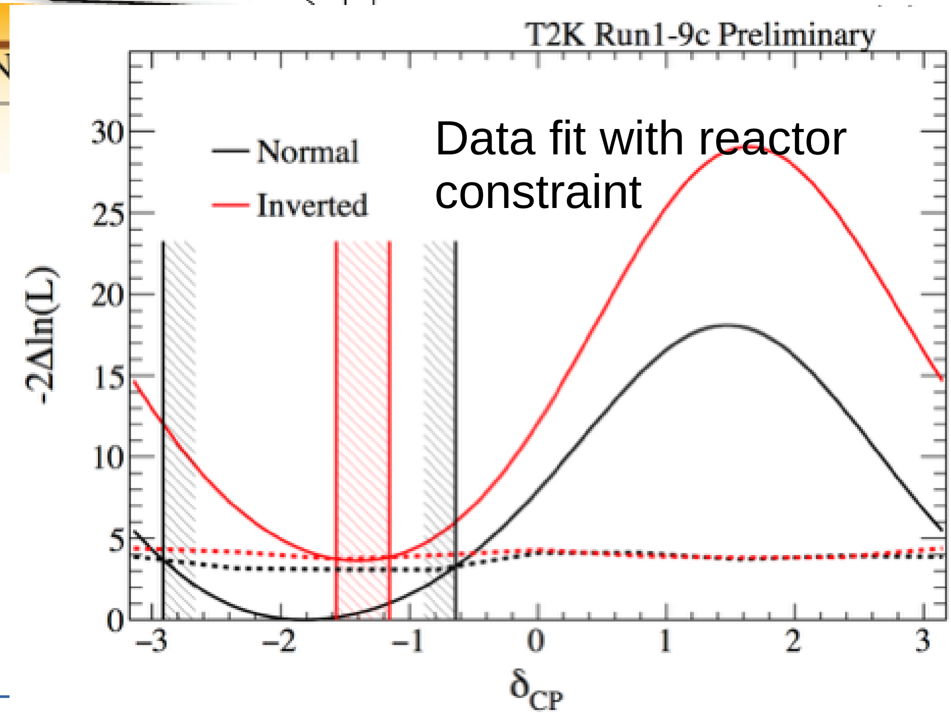


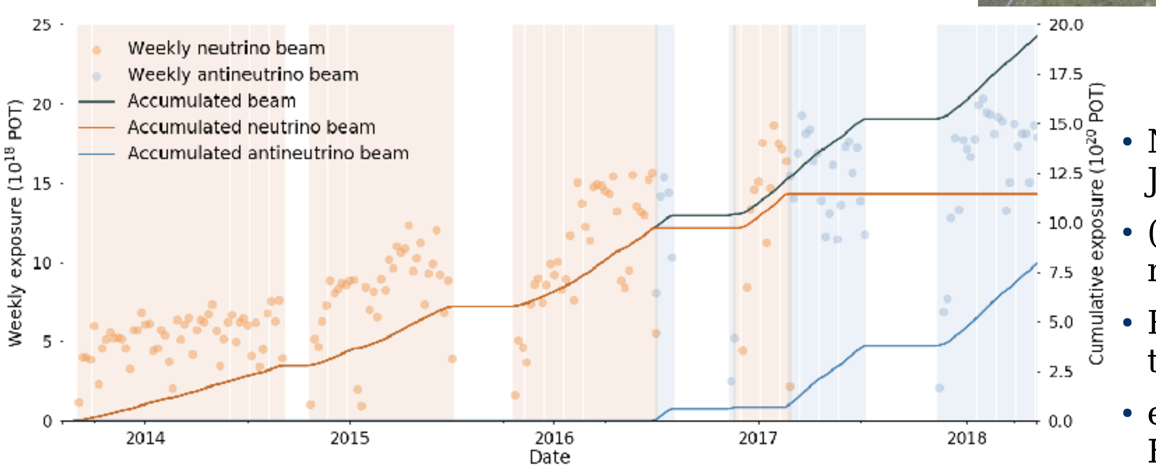




Nova

Mayly Sanchez

- What is the mass ordering for atmospheric neutrinos?
- Is there a ν_μ - ν_τ symmetry (is the
- large mixing angle 2 maximal; if not, what is the octant)?
- Is CP violated in the lepton sector?
- Are there other neutrinos beyond of the three known active flavors?

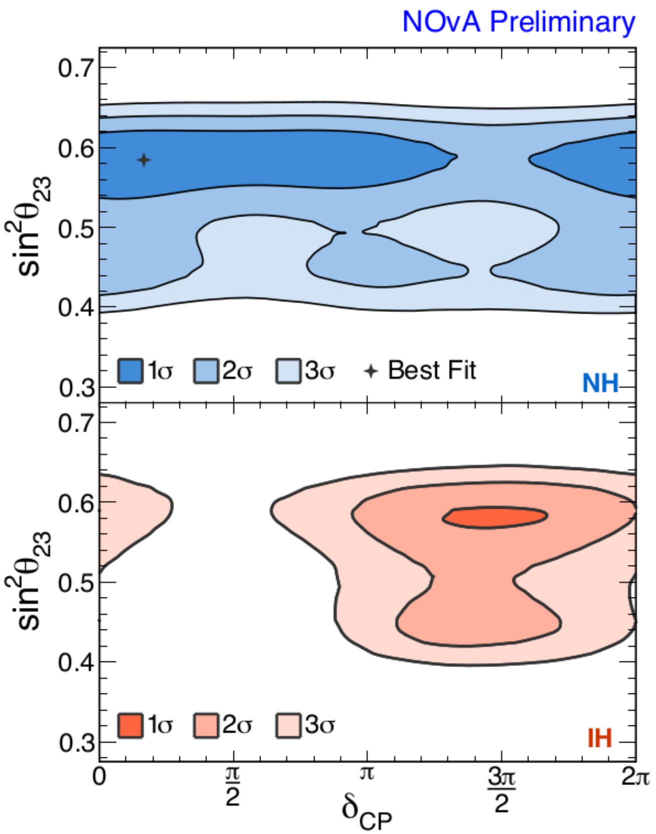


- NuMI beam running at 700 kW design power since January 2017.
- (> 18 x 10 18 protons per week). Highest power neutrino beam in the World!
- Recorded neutrino-mode running 8.85 x 10^{20} protons on target (POT) in 14 kton
- equivalent detector taken from February 2014 to February 2017.
- First antineutrino-mode running recorded between February 2017 to April 2018 resulting in 6.9 x 10^{20} POT.

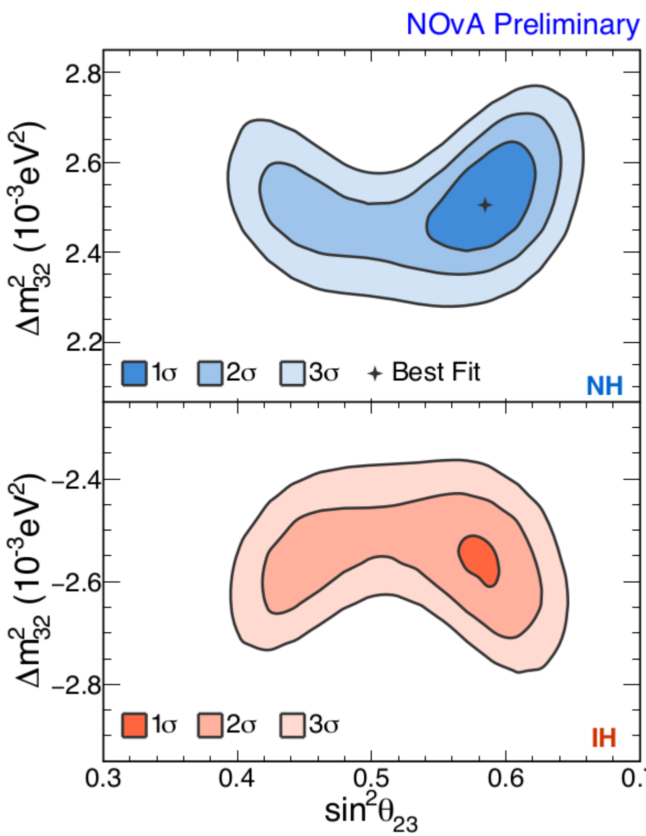
Nova results

Mayly Sanchez

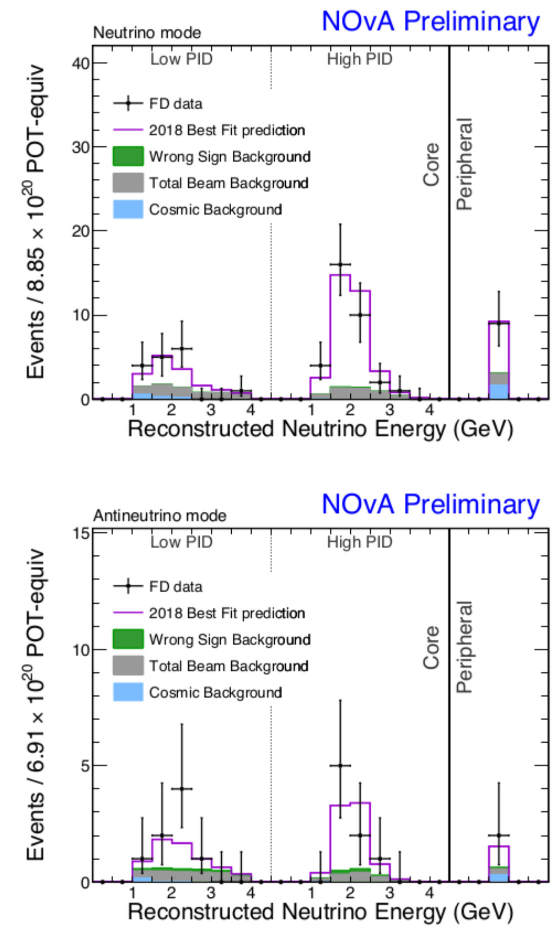
- Prefer NH by 1.8 σ
- Exclude δ = π /2 in the IH at > 3 σ



- Prefer non-maximal at 1.8 σ
- Exclude LO at similar level



- > 4 σ evidence of electron antineutrino appearance

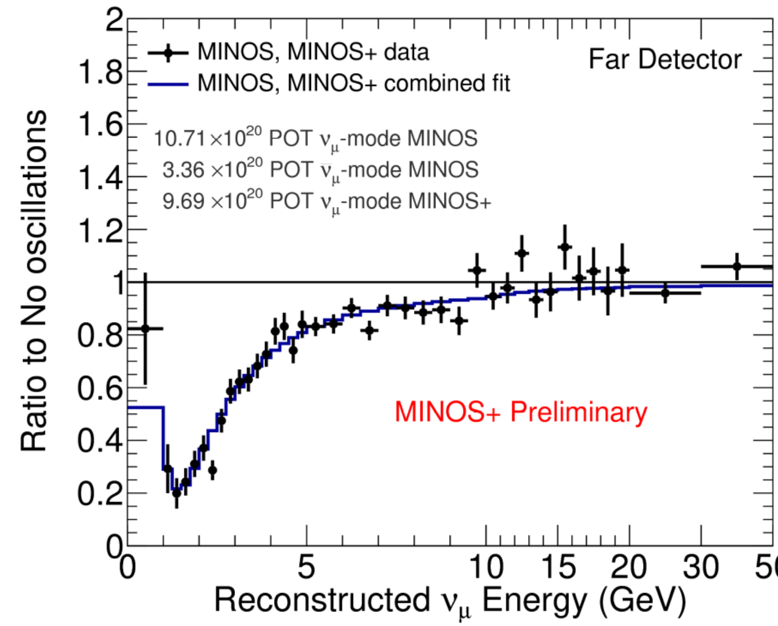


Future NOvA running can **reach 3 σ sensitivity for the mass hierarchy by 2020** and covers significant CP range by 2024

Minos+

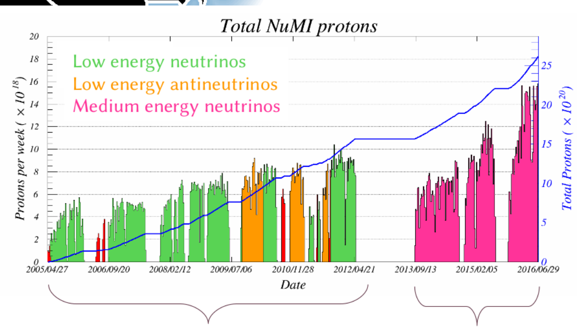
Adam Aurisano

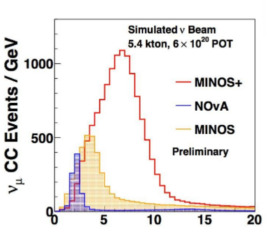
- Improved its standard oscillation measurement using the full sample of beam and atmospheric neutrinos
  - – Results are competitive with running experiments
  - – Measured Δm^2_{32} to 3.5%



MINOS:
- ~3 GeV peak energy
- Study oscillations at atmospheric frequency

MINOS+:
- ~7 GeV peak energy
- Constrain deviations from 3 flavor paradigm

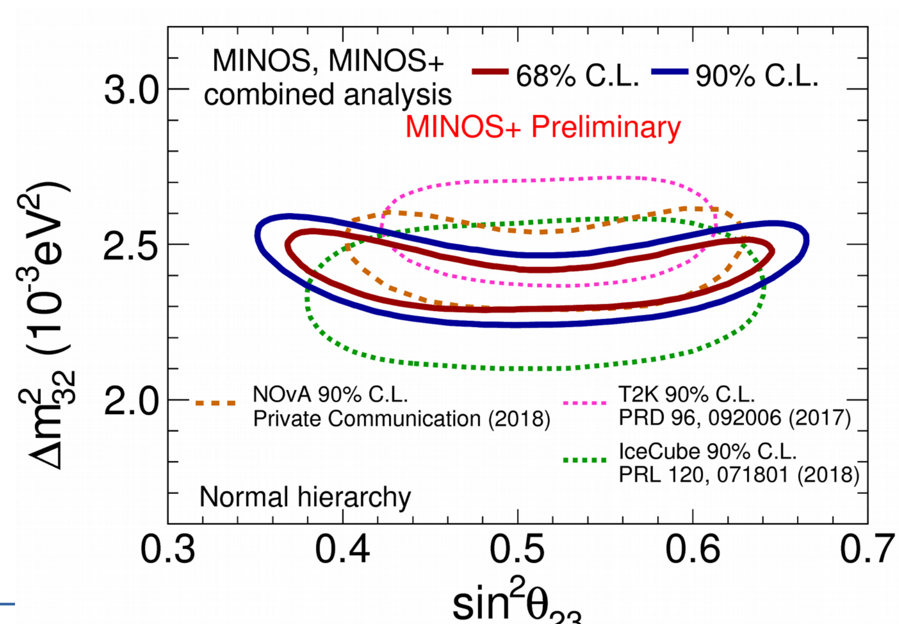




MINOS era:
- 10.56×10^{20} POT (neutrino-mode)
- 3.36×10^{20} POT (antineutrino-mode)

MINOS+ era:
- 9.69×10^{20} POT

Total:
- $\sim25\times10^{20}$ POT in 11 years of running



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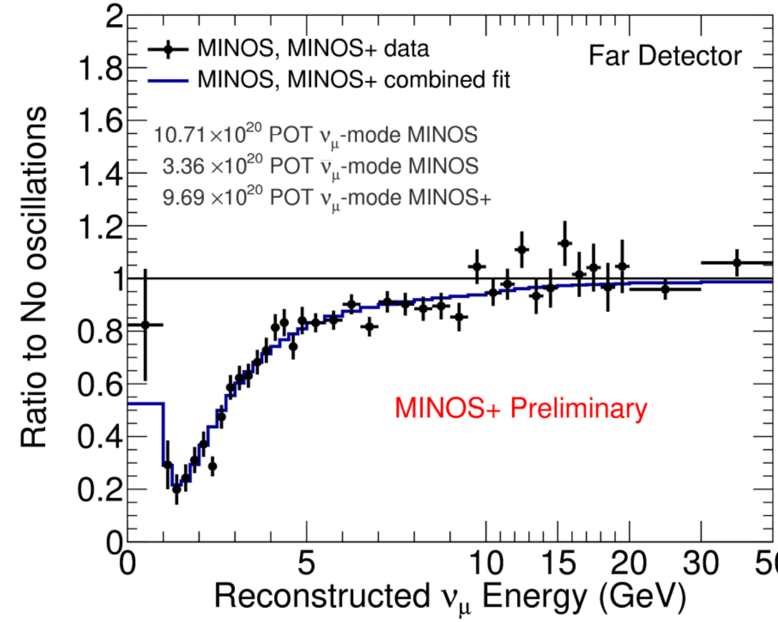
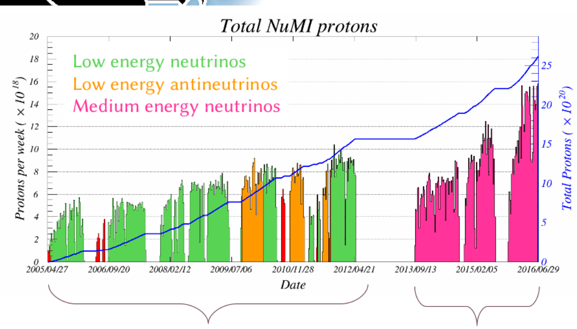
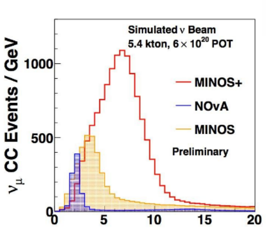


- Sterile neutrino search

MINOS:
- ~3 GeV peak energy
- Study oscillations at atmospheric frequency

MINOS+:
- ~7 GeV peak energy
- Constrain deviations from 3 flavor paradigm





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Total:
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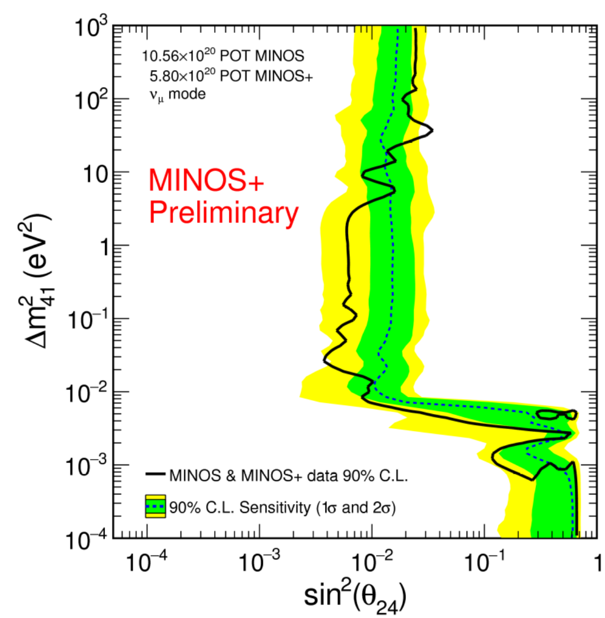
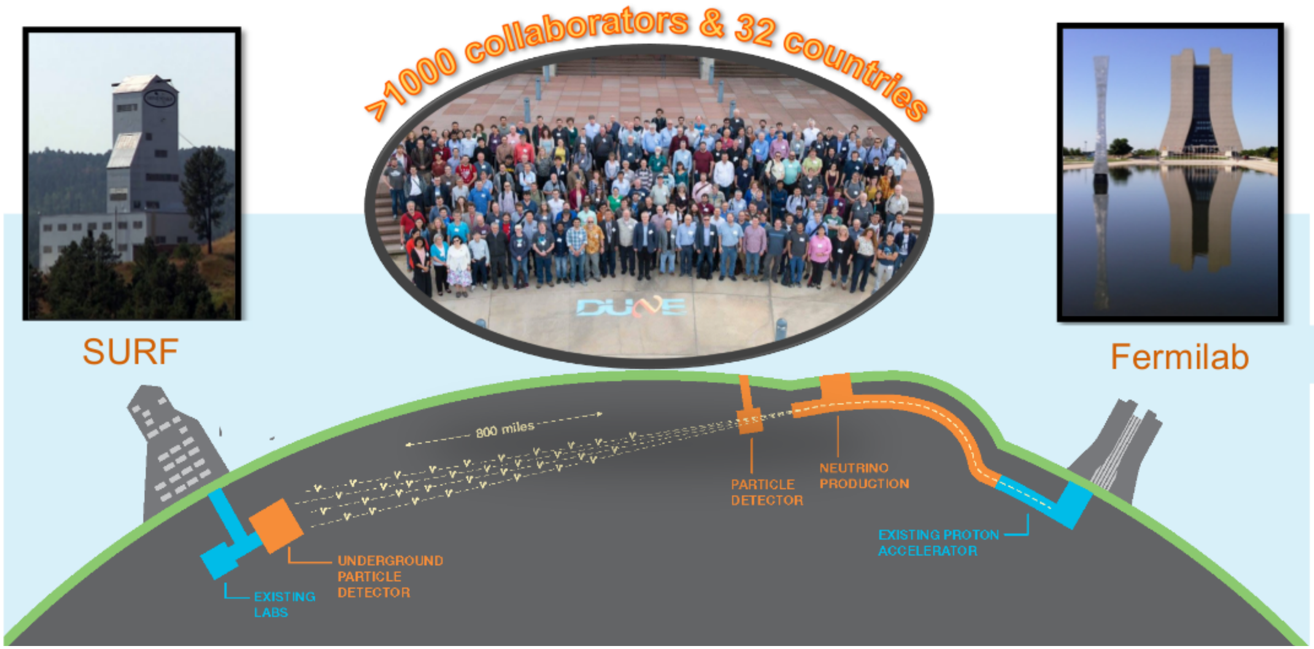
- MINOS+ sets strong limits on sterile neutrino in the critical 1 – 10 eV^2 region
- For some people it looks too good
  - → Possible problem with systematic uncertainties (~3%) which seems to be underestimated



- ***The future is bigger***

DUNE

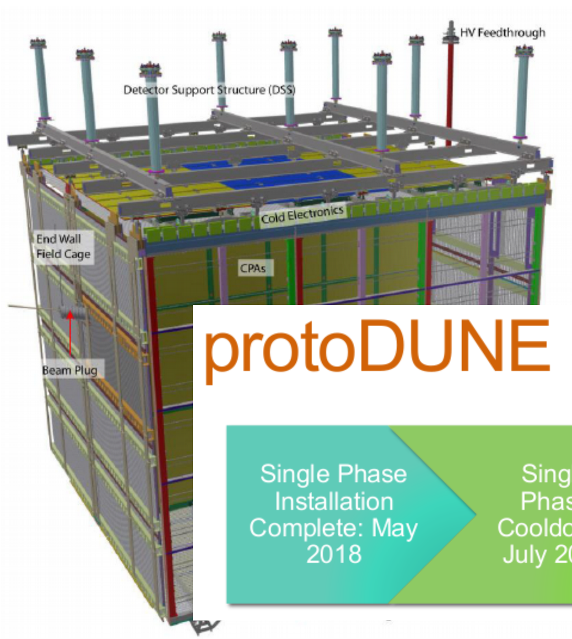
- Observe ν e appearance and ν μ disappearance at long baseline in wideband beam to measure MH, CPV, and neutrino mixing parameters in a single experiment.
- Deep underground location reduces cosmogenic background and enables sensitivity to low-energy physics.



DUNE prototypes

Single phase

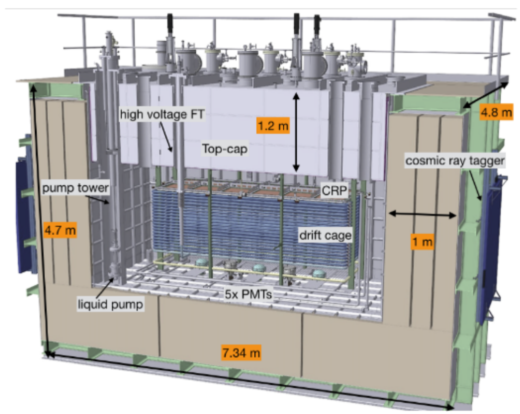
- Allows testing of assembled APA and electronics immediately before installation into protoDUNE cryostat
- Incorporates feed-thru, cabling, and readout system identical to protoDUNE
- Filled with cold nitrogen gas for testing at “cool” temperature (~160 K)
- Successful demonstration of required noise levels at cryogenic temperature



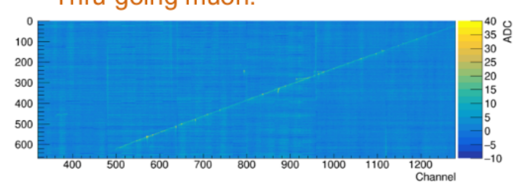
Dual phase

- **Ran from June to November 2017**
- **Successful demonstration** of dual phase LArTPC concept
- Led to improved designs for protoDUNE dual phase

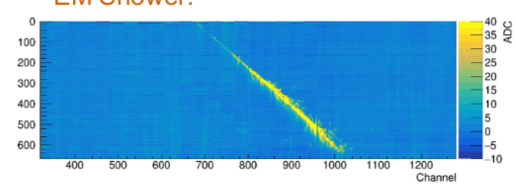
3x1x1 m^3 prototype:

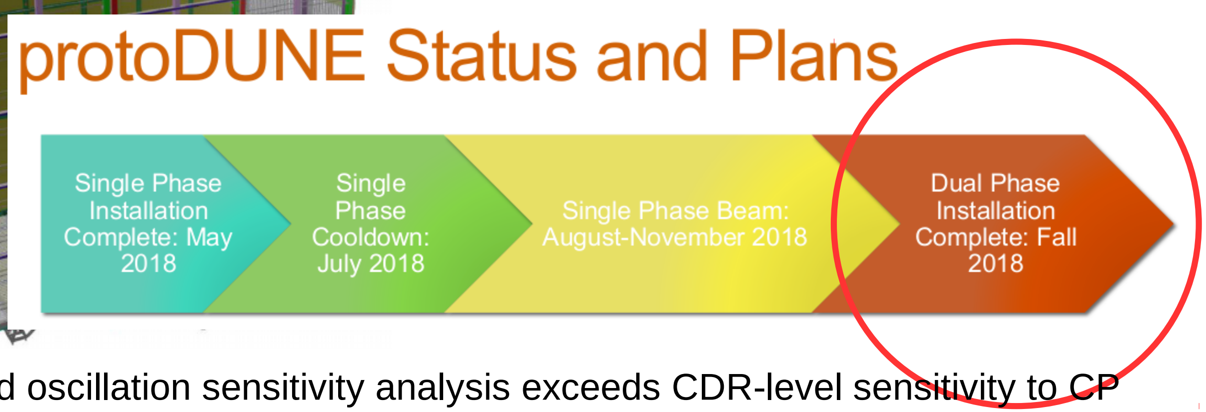


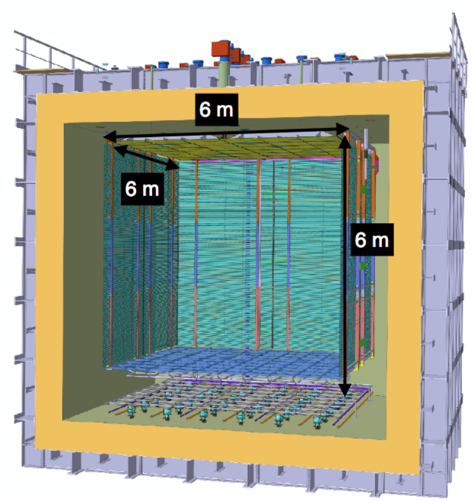
Thru-going muon:



EM Shower:







New MC-based oscillation sensitivity analysis exceeds CDR-level sensitivity to CP violation!
Expect first DUNE FD data in ~2024

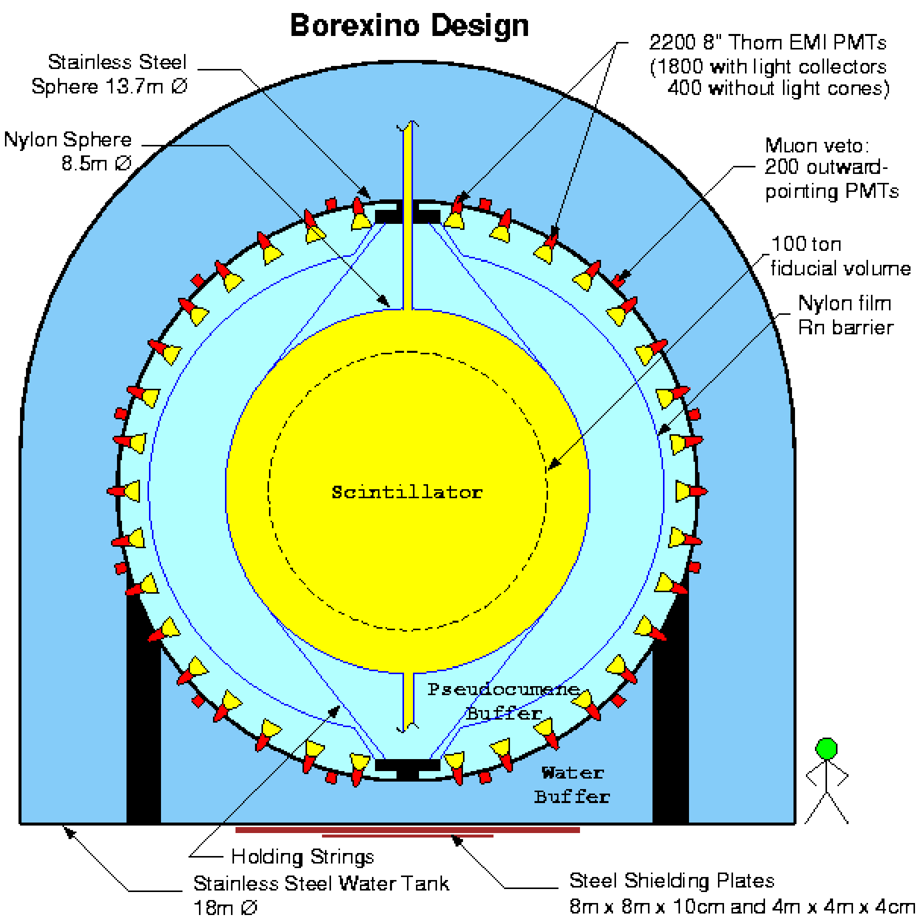
Hyper-Kamiokande

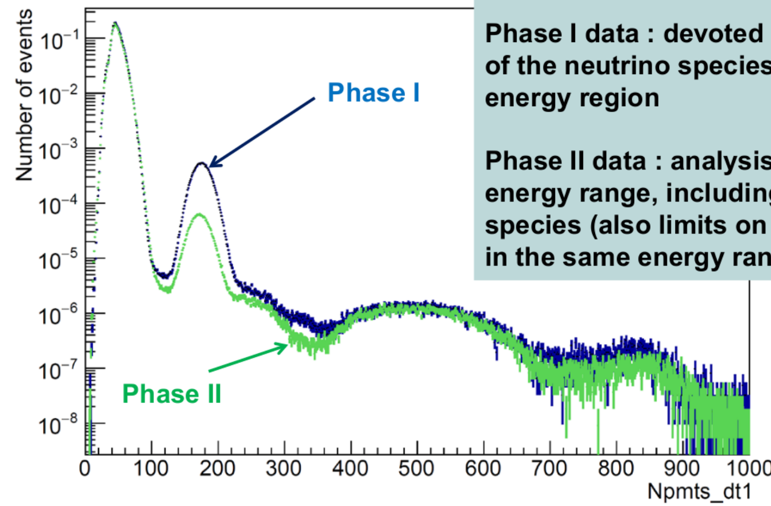
- Gigantic neutrino and nucleon decay detector ~186 kton fiducial mass : ~10 × Super-K
  - ~× 2 higher photon sensitivity than Super-K
  - ~2nd oscillation maximum by 2nd tank in Korea under study
- ~MW-class world-leading ν-beam by upgraded J-PARC
- **Project now is a priority project by MEXT's Roadmap**
  - Aiming to start construction in FY2019, operation in FY2026
- Design Report has been released (1805.04163)

- ***Solar neutrinos***

Borexino

Oleg Smirnov



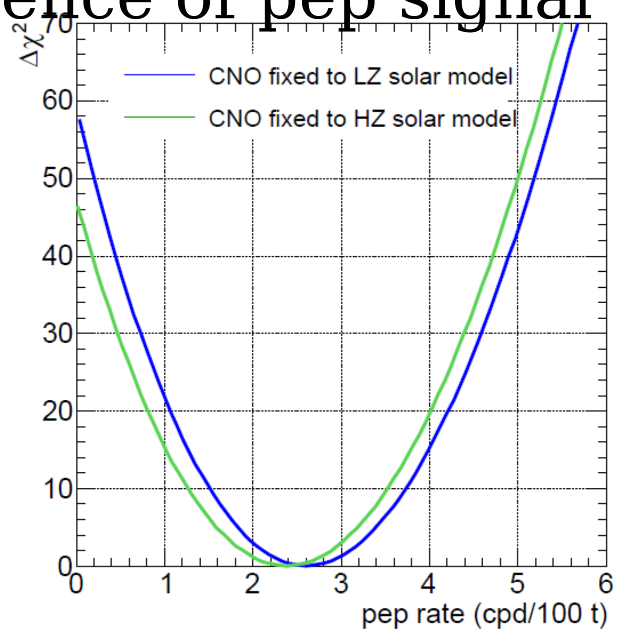


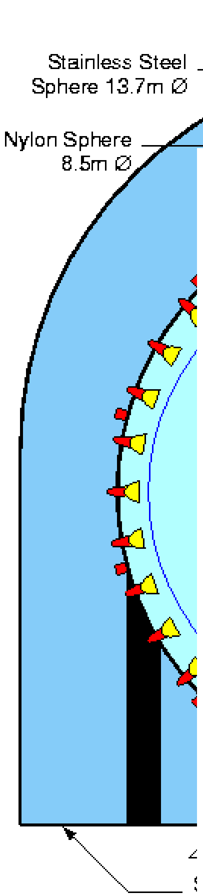
Phase II: lower ^{85}Kr and ^{210}Bi, reduced ^{210}Po

Phase I data : devoted analysis for each of the neutrino species with restricted energy region

Phase II data : analysis in the extended energy range, including pp, ^{7}Be and pep species (also limits on CNO are obtained in the same energy range)

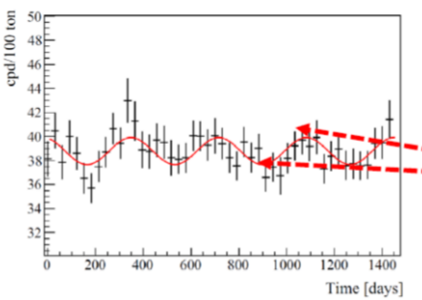
>5σ evidence of pep signal

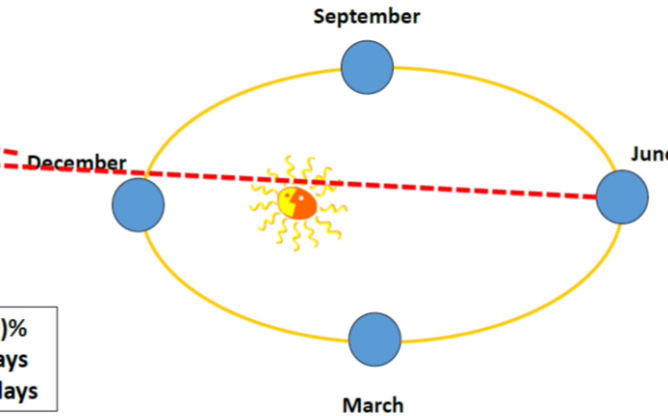




Seasonal modulations of ^{7}Be neutrino flux

M. Agostini et al. / Astroparticle Physics 92 (2017) 21–29



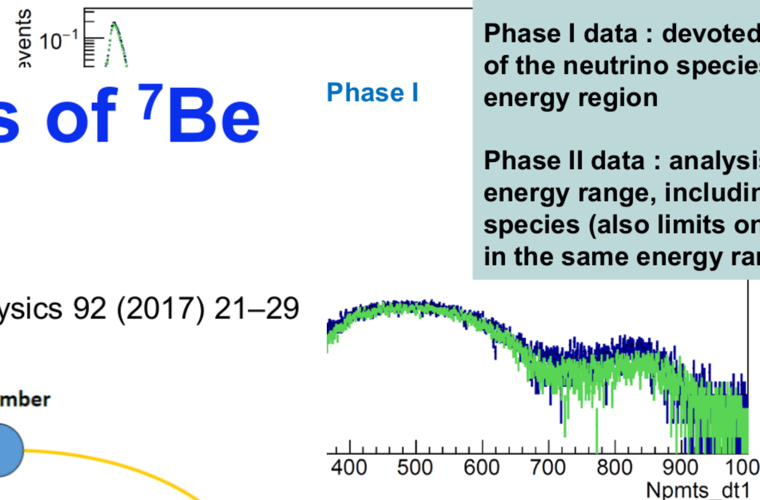


Fit to the evolution of the rate in time (bin of 30 days)

ε = (1.74 ± 0.45)%
T = (367 ± 10)days
Φ = (-18 ± 24) days

The duration of the astronomical year is measured from underground using neutrino!

Phase I



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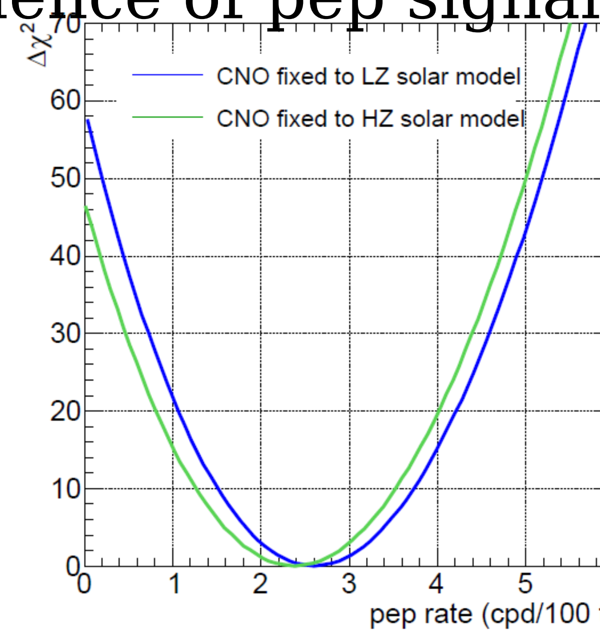
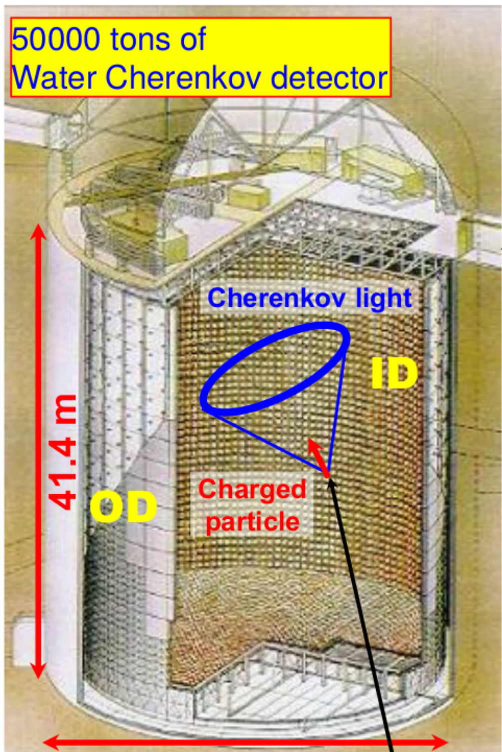


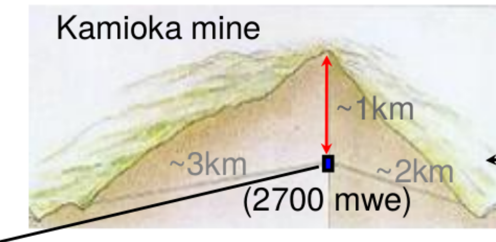
On the record

T Kisrten: “This old Borexino cow still gives good milk”

Super-Kamiokande

M. Ikeda

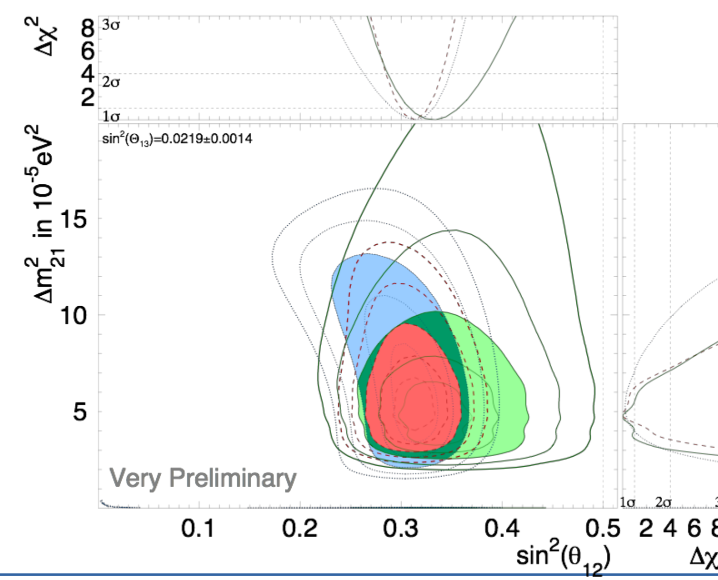


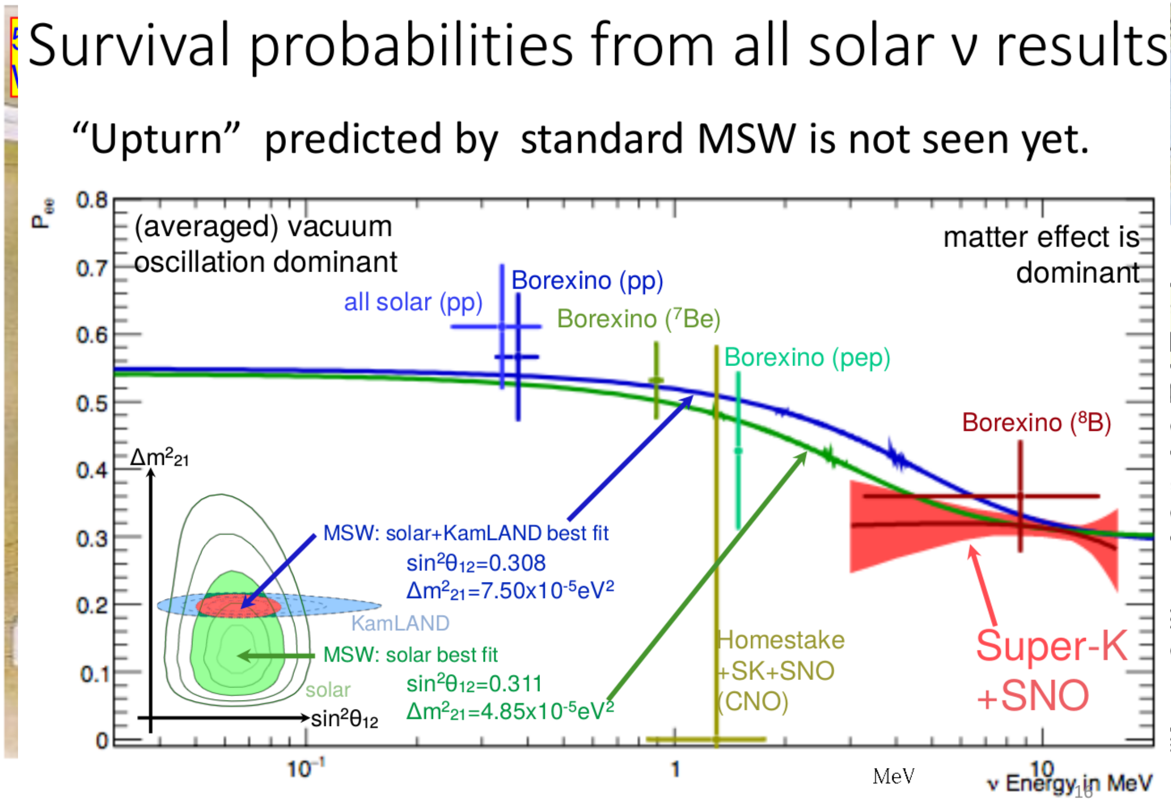


For Solar neutrino analysis

Phase	Period	Livetime (days)	Fiducial vol. (kton)	# of PMTs	Energy thr.(MeV)
SK-I	1996.4 ~ 2001.7	1496	22.5	11146 (40%)	4.5
SK-II	2002.10 ~ 2005.10	791		5182 (20%)	6.5
SK-III	2006.7 ~ 2008.8	548	22.5 (>5.5MeV) 13.3 (<5.5MeV)	11129 (40%)	4.5
SK-IV	2008.9 ~	2860	22.5 (>5.5MeV) 13.3 (4.5<E<5.5) 8.8 (<4.5MeV)		3.5
	total 5695 days			(coverage)	(Kinetic energy)

- finalizing SK-IV analysis using all data up to May 2018
- Super-K data best constrains Δm^2_{21}
- SNO data best constrains $\sin^2 \theta_{12}$
- complementarity makes combined fit beneficial
- correlation via ^{8}B flux further tightens constraints





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Thank open status

SK-Gd

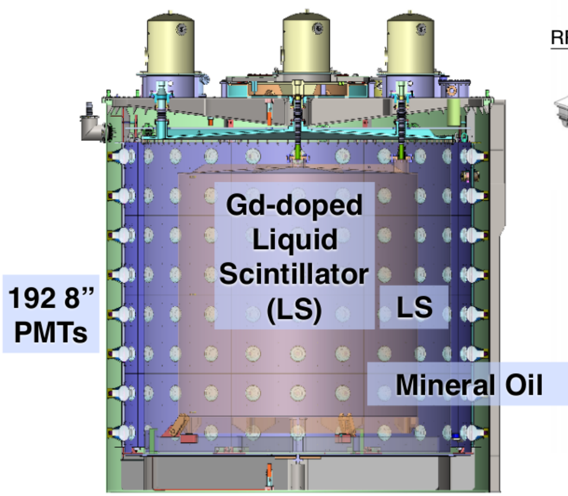
- Gd has large cross section for thermal neutron (48.89kb)
- Neutron captured Gd emits 3-4 g ray in total 8 MeV
- Can tag $\bar{\nu}_e$ by using the delayed coincidence technique
- Earliest possible Gd in Super-K would be in late 2019

- ***Reactor neutrinos***

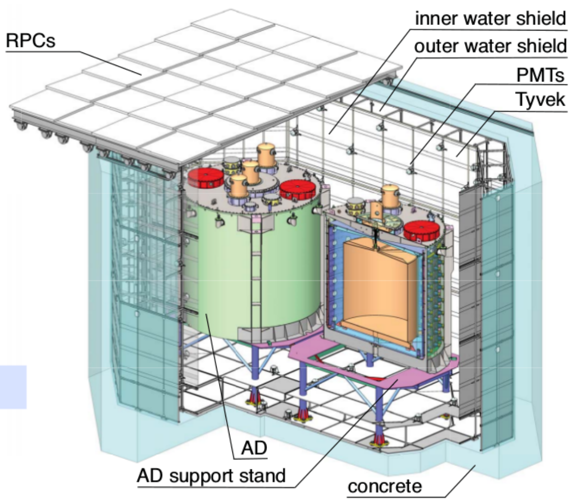
Daya Bay

Pedro Ochoa-Ricoux

- The antineutrino detectors (ADs) are "three-zone" cylindrical modules immersed in water pools:



Energy resolution: $\sigma_E/E \cong 8.5\%/\sqrt{E[\text{MeV}]}$

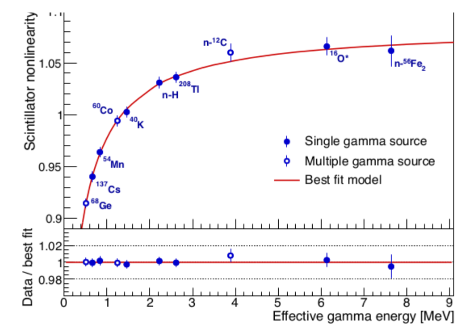


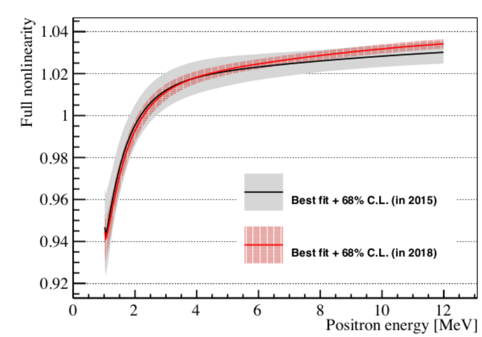
Double purpose: shield the ADs and veto cosmic ray muons

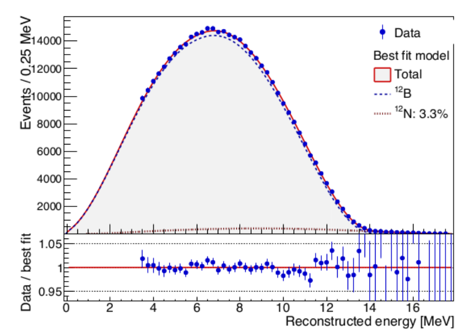
- New oscillation results with 1958 days of data
- Select unambiguous prompt-delayed pairs with right energies and time separation, not in coincidence with a muon
- < 2% background in all halls
- Roughly 60% increase in statistics with respect to previous result

- Improved energy response model
- Improved ^{9}Li/ ^{8}He and SNF Estimations
  - uncertainty in near ADs reduced from 50% to 30%
- More than 3.9 million antineutrino interactions (0.5 million at far site)

- The model is built based on various gamma peaks and the continuous ^{12}B spectrum
  - Validated with low energy $\beta+\gamma$ spectra from ^{212}Bi and ^{214}Bi
  - Halved uncertainty of absolute energy scale to **~0.5%**





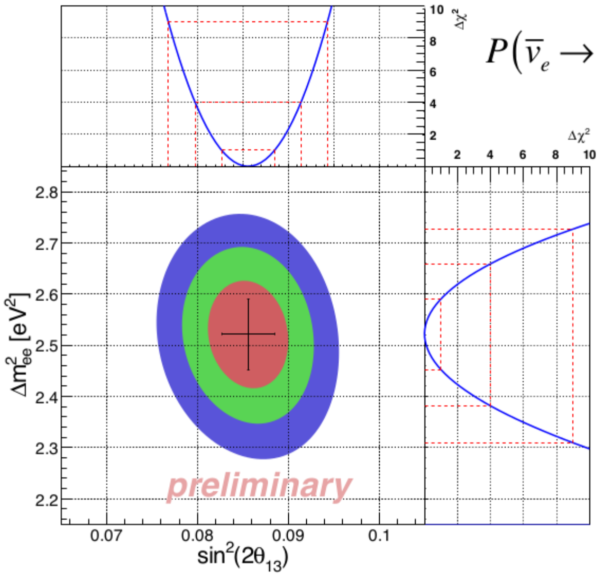


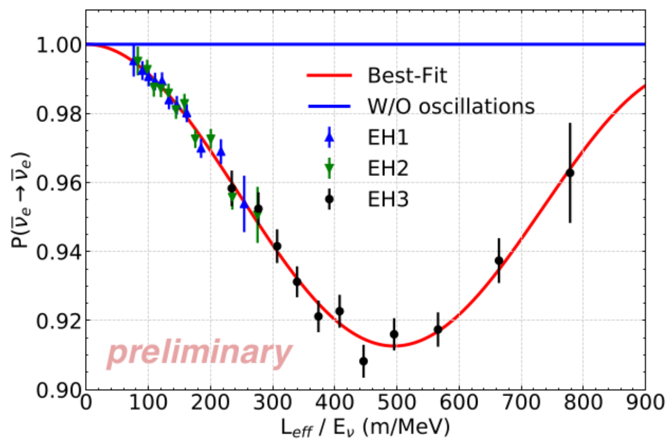
- New results
- Less new

- Measure $\sin^2 2\theta_{13}$ and $|\Delta m^2_{ee}|$ to **3.4%** and **2.8%** respectively

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{1.267 \Delta m^2_{ee} L}{E} - \text{solar term}$$

effective mass splitting



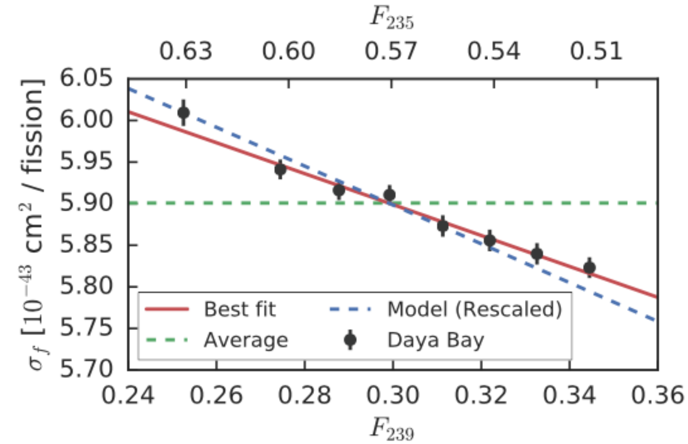


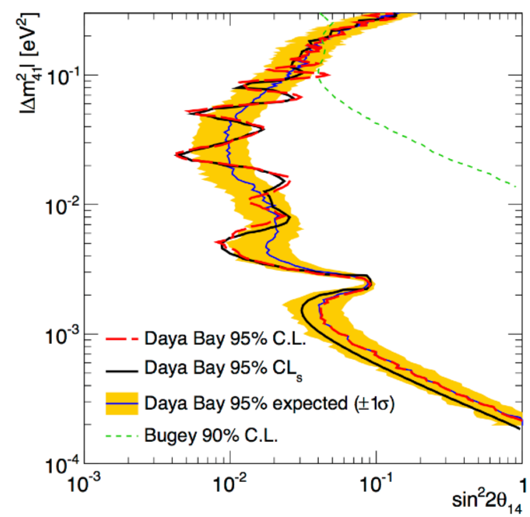
results with 1958 days →

$$\sin^2 2\theta_{13} = 0.0856 \pm 0.0029$$
$$|\Delta m^2_{ee}| = (2.52 \pm 0.07) \times 10^{-3}\ \text{eV}^2$$

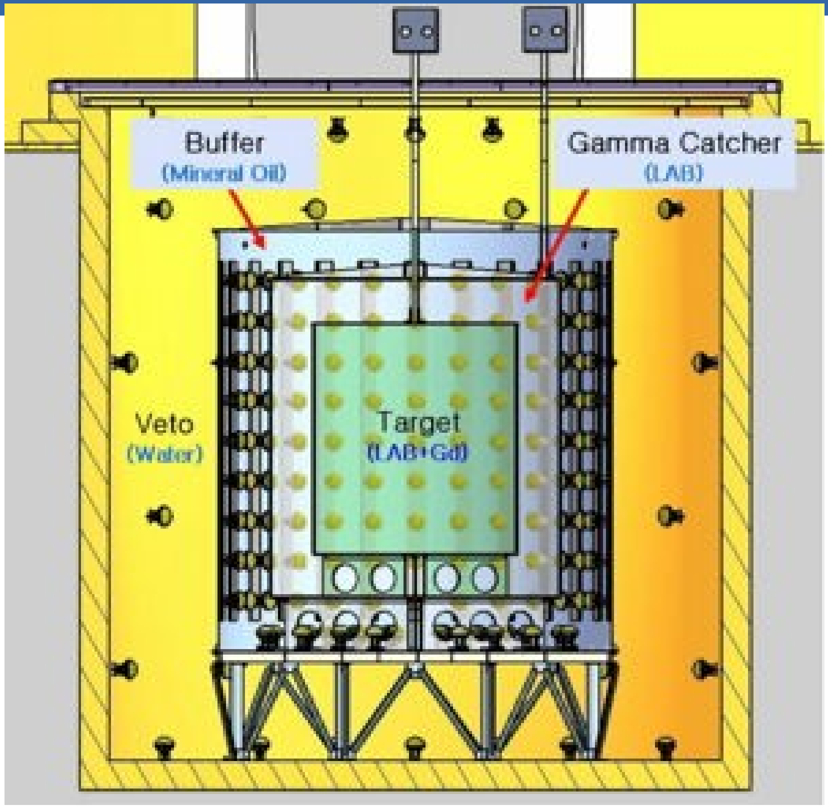
The statistical uncertainty contributes about 60% (50%) of the total θ_{13} (Δm^2_{ee}) uncertainty.

$$R_{\text{data/pred}} = 0.952 \pm 0.014(\text{exp.}) \pm 0.023(\text{model})$$
$$\sigma_f = (5.91 \pm 0.09) \times 10^{-43}\ \text{cm}^2/\text{fission}$$



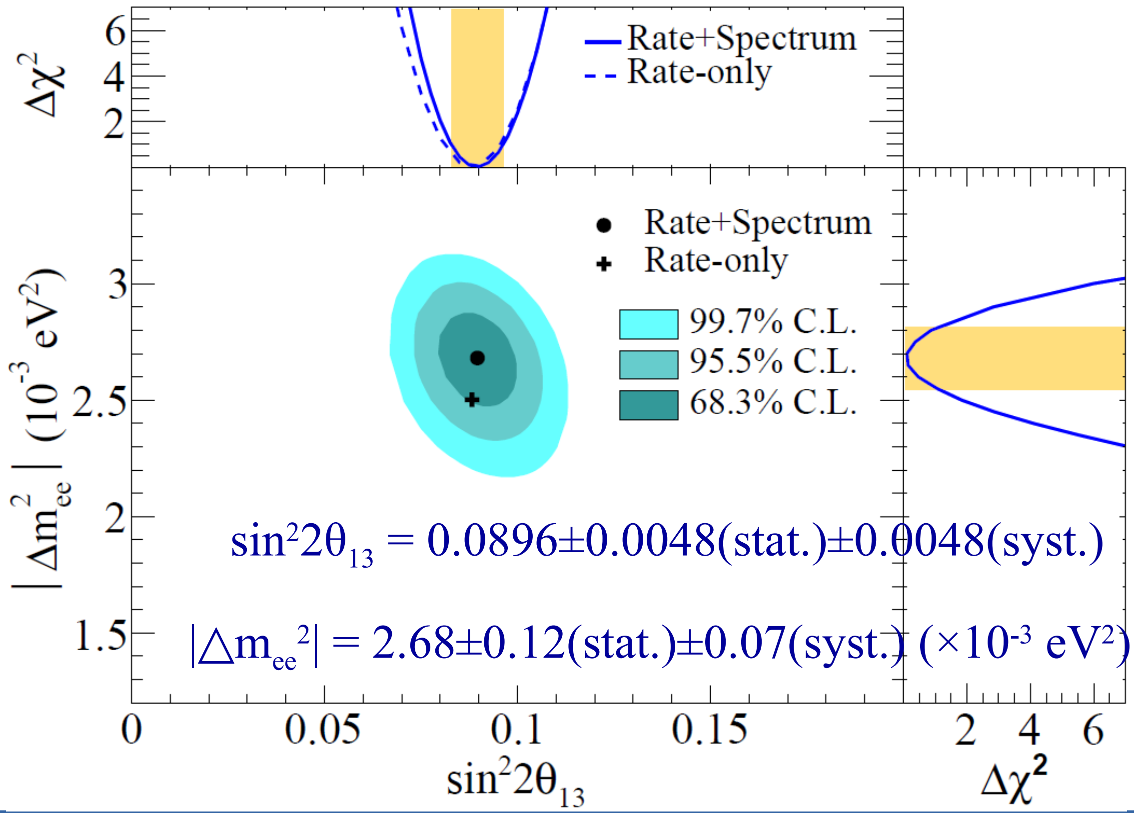


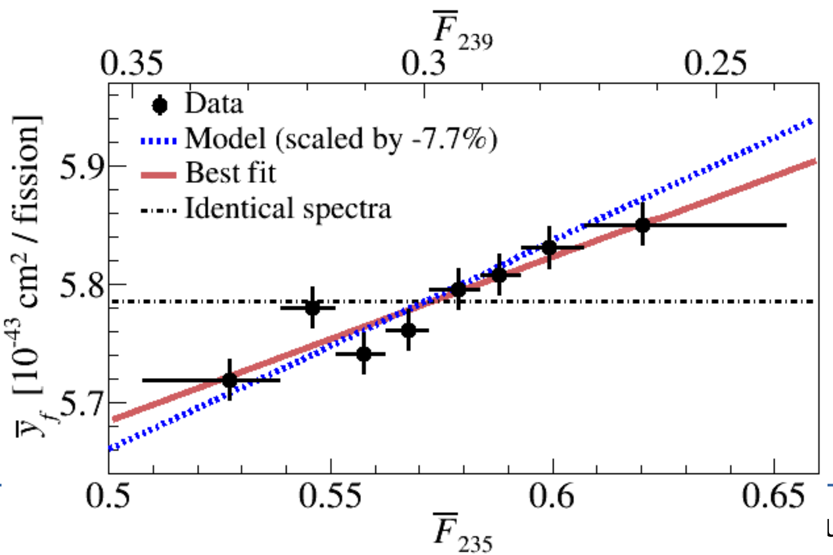
EH1-AD1 was taken down permanently and its Gd-LS replaced with JUNO LS

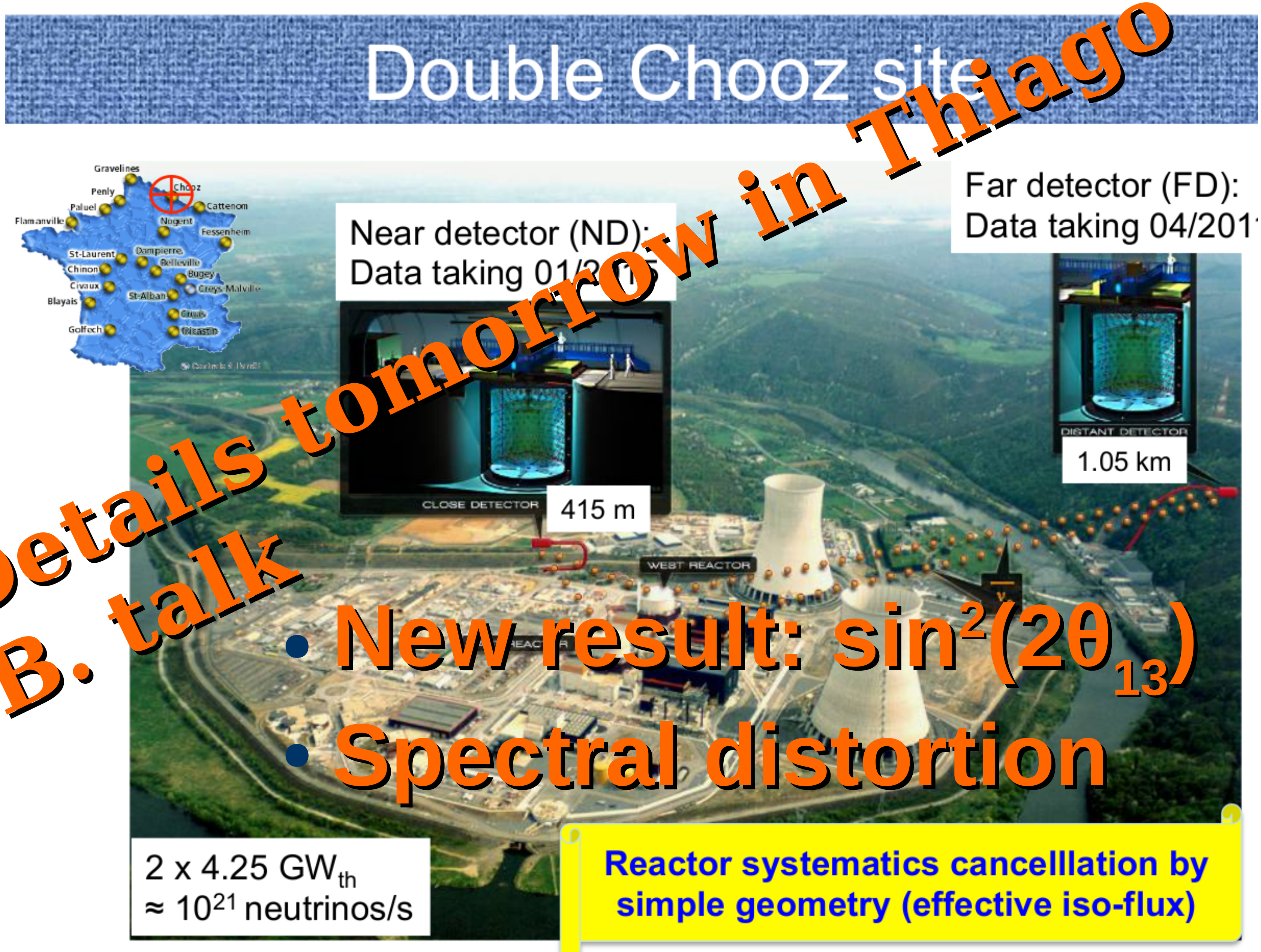


Precise measurement of $|\Delta m^2_{ee}|$ and θ_{13} using ~2200 days of data (Aug. 2011 – Feb 2018)

Fuel-composition dependent reactor antineutrino yield



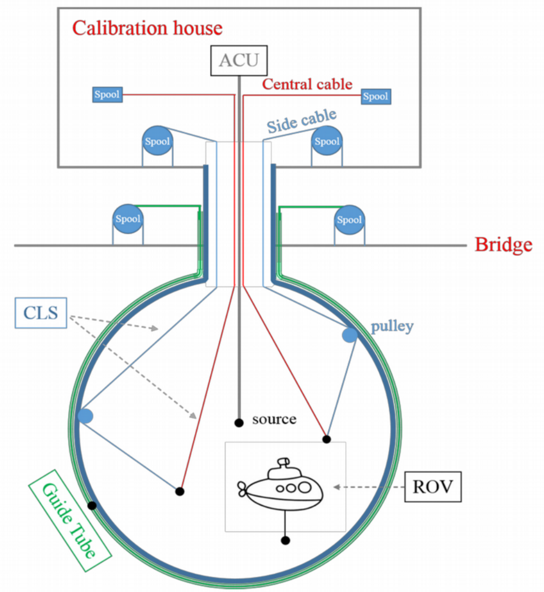


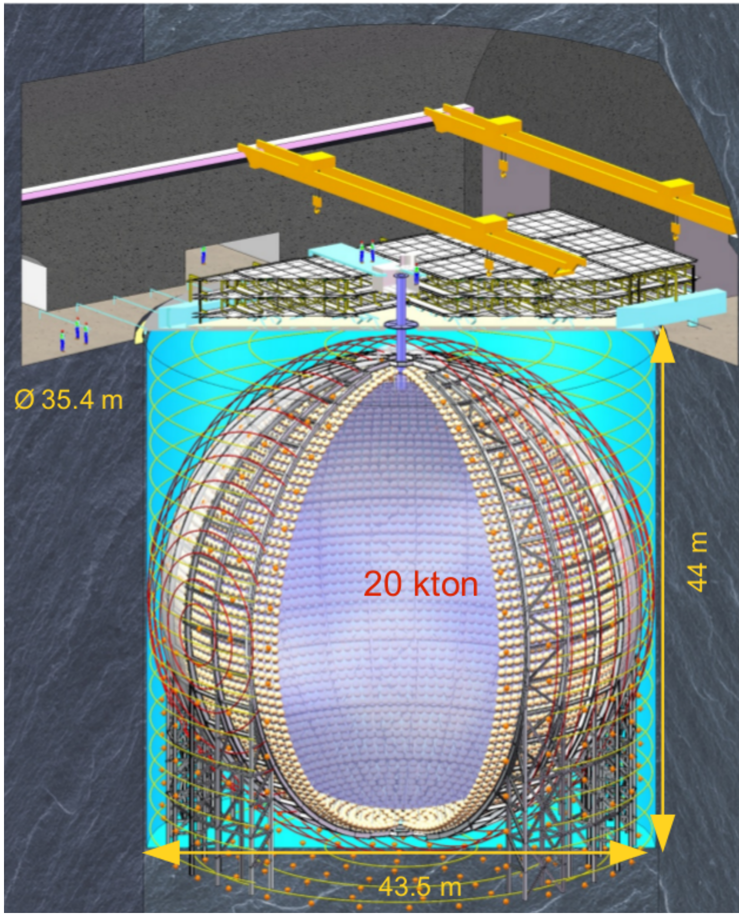


Details tomorrow in Thiago B. talk

- **New result: $\sin^2(2\theta_{13})$**
- **Spectral distortion**

- **Main goal:** Mass Hierarchy (MH)
- Additional physics program:
  - Supernova υ, diffuse supernova υ
  - Geo-neutrinos
  - Solar neutrinos
  - Proton decay
  - Atmospheric υ
  - Sterile neutrinos
- **Requirements:**
  - Reactor baseline variation: < 0.5 km
  - Energy resolution: ~ 3%/√E
  - Energy scale uncertainty: < 1%
  - Energy scale uncertainty: < 1%

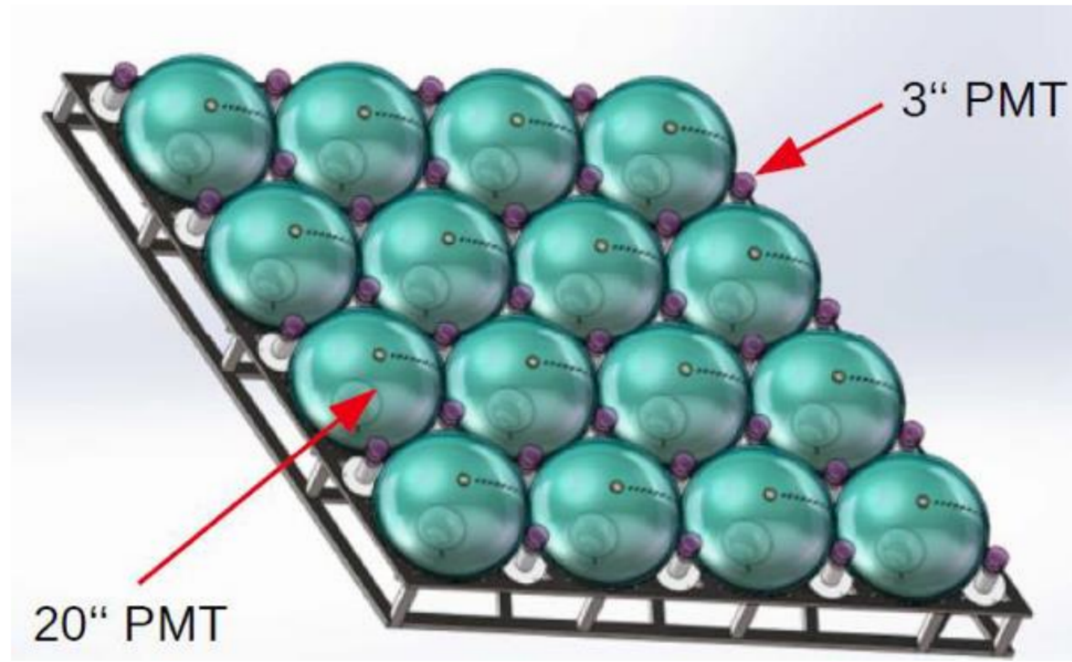




JUNO

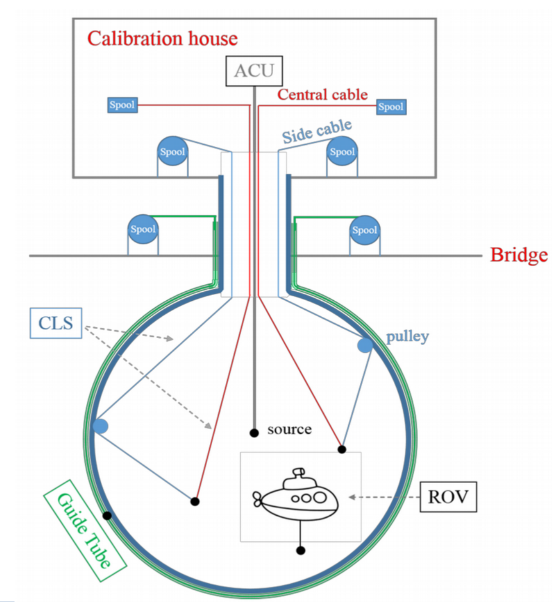
Björn Wonsak

- Double calorimetry
- Big PMTs:
  - In production since 2016
  - Already >9000 delivered
  - More than 5000 tested
- Small PMTs
  - Always photon counting
  - 25000 PMTs contracted to HZC
  - 4000 produced, 3000 tested at HZC

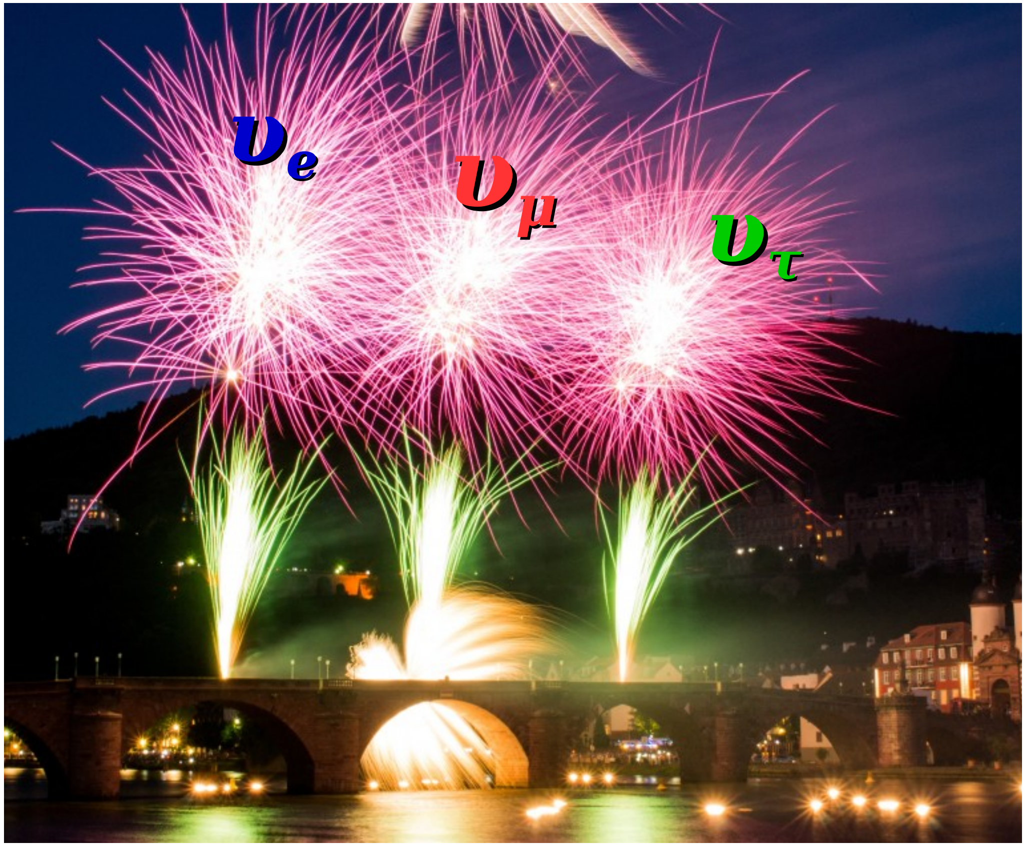


Need reactor spectrum with energy resolution similar to JUNO

- **Started near detector R&D**
- SiPM → need -50°C → **1.7% energy resolution**
- Serve as benchmark to test nuclear databases



- ***The global three-neutrino picture before Neutrino 2018***



Global 3 υ picture

Mariam Tórtola

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

- **Current status:**
  - Very precise and robust determinations for most of them (1.3-10%)
  - Slight preference for θ_{23} at the 2nd octant, with $\Delta\chi^2$ (45°) = 1.6 for NO
  - Preference for π < δ < 2π, with CP conservation allowed at 2σ
  - 3σ hint for NO from atmospheric, LBL and reactor data
  - ⇒ **new T2K and NOvA data may affect δ and θ_{23} octant results**
- By 2025/2026:
  - **2-3σ sensitivity to CP violation at NOvA and T2K-II**
- For sensitivities above 3σ from a single experiment
  - DUNE, Hyper-Kamiokande

parameter	best fit ± 1σ	3σ range
Δm^2_{21} $[10^{-5}\text{eV}^2]$	$7.55^{+0.20}_{-0.16}$	7.05–8.14
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$ (NO)	2.50±0.03	2.41–2.60
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$ (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
$\sin^2\theta_{23}/10^{-1}$ (NO)	$5.47^{+0.20}_{-0.30}$	4.45–5.99
$\sin^2\theta_{23}/10^{-1}$ (IO)	$5.51^{+0.18}_{-0.30}$	4.53–5.98
$\sin^2\theta_{13}/10^{-2}$ (NO)	$2.160^{+0.083}_{-0.069}$	1.96–2.41
$\sin^2\theta_{13}/10^{-2}$ (IO)	$2.220^{+0.074}_{-0.076}$	1.99–2.44
δ/π (NO)	$1.32^{+0.21}_{-0.15}$	0.87–1.94
δ/π (IO)	$1.56^{+0.13}_{-0.15}$	1.12–1.94

- ***BSM***

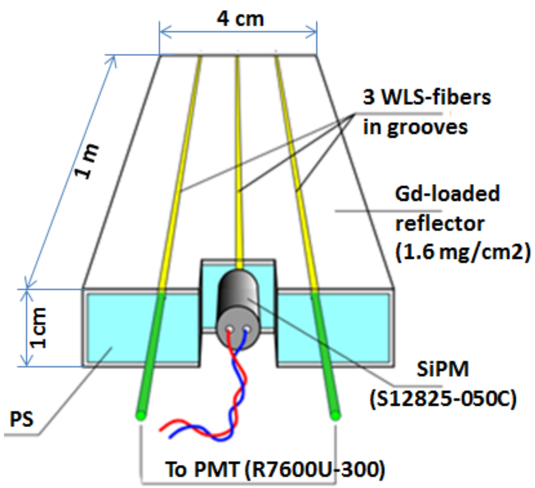
Sterile neutrinos with reactors

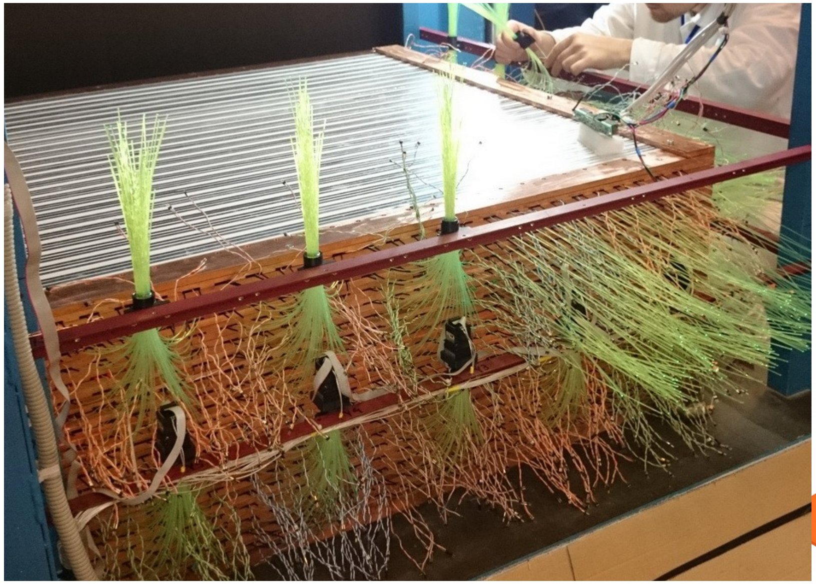
DANSS

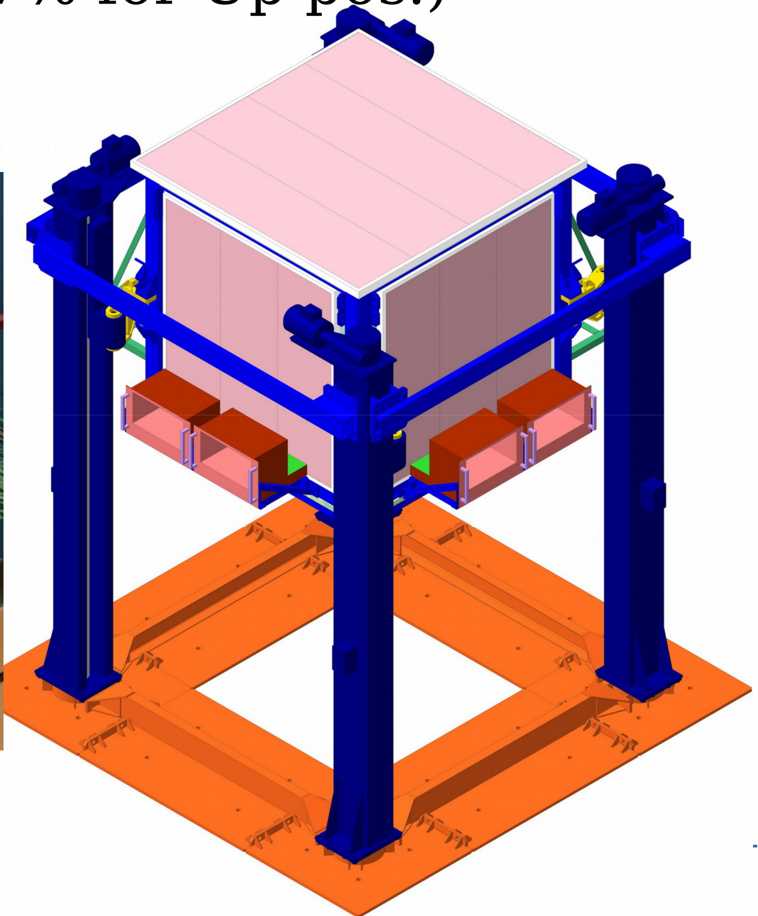
V. Egorov

- Observe evolution of the neutrino flux with distance
  - Detector placed in an elevator
- Taking data since Apr 2016 (data available for analysis since Oct 2016)
- 4910 IBD events/day are detected in the closest position
- Background: 133 μ-induced events/day (2.7% for Up pos.)

Basic element: polystyrene based scintillator strip



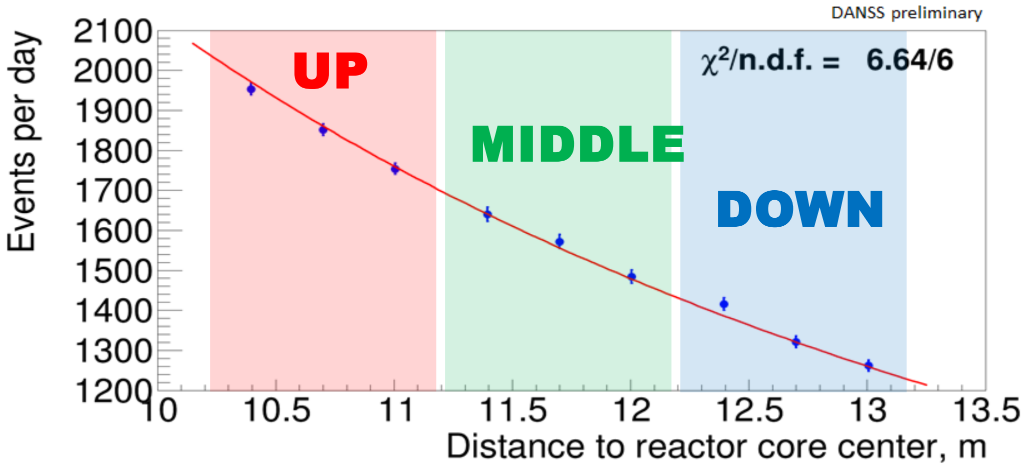


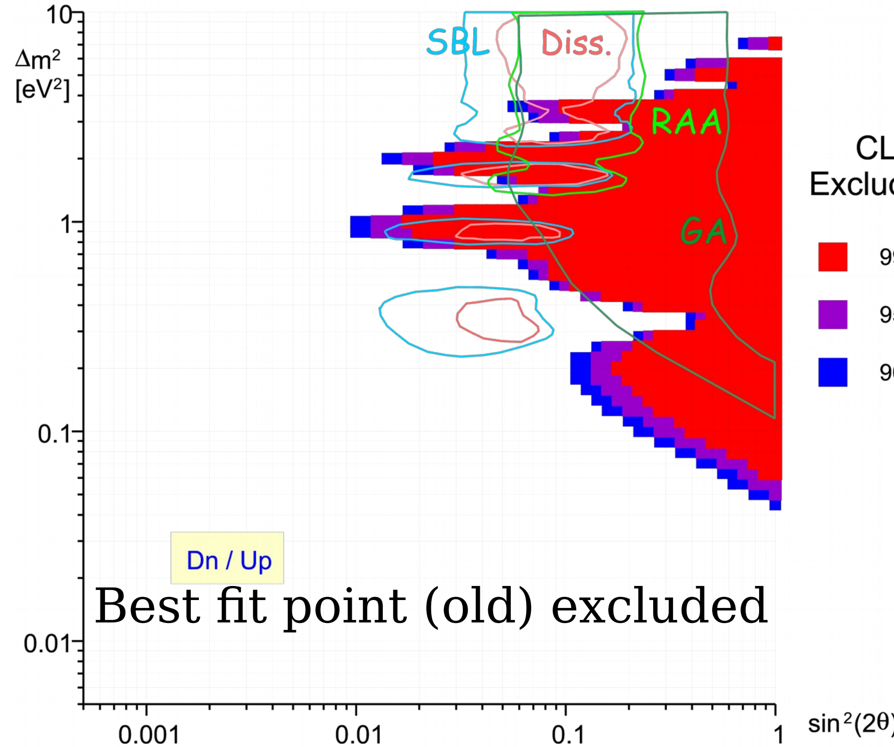


DANSS

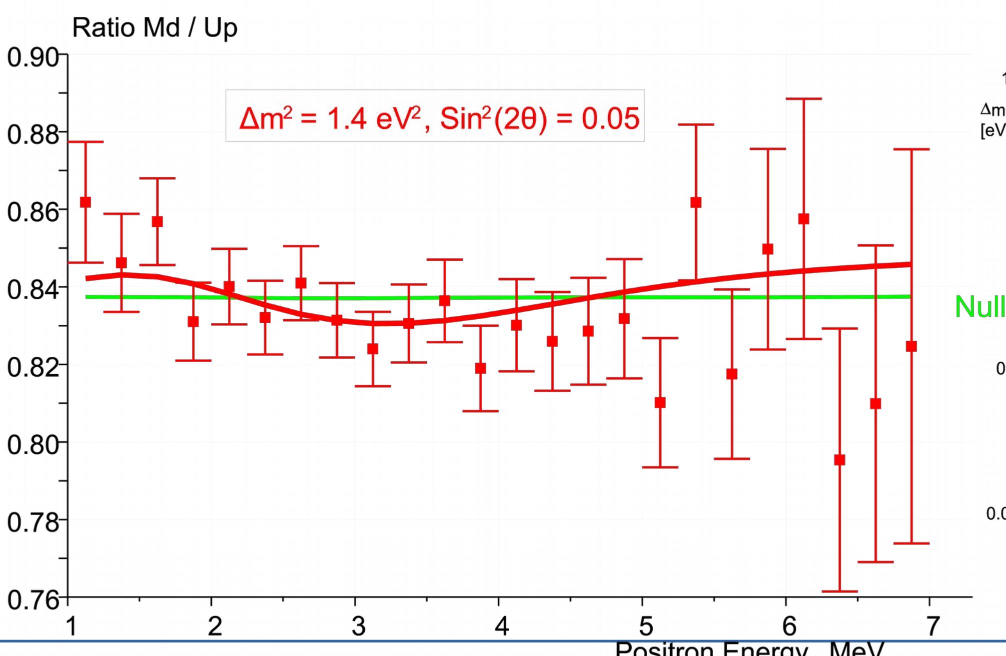
V. Egorov

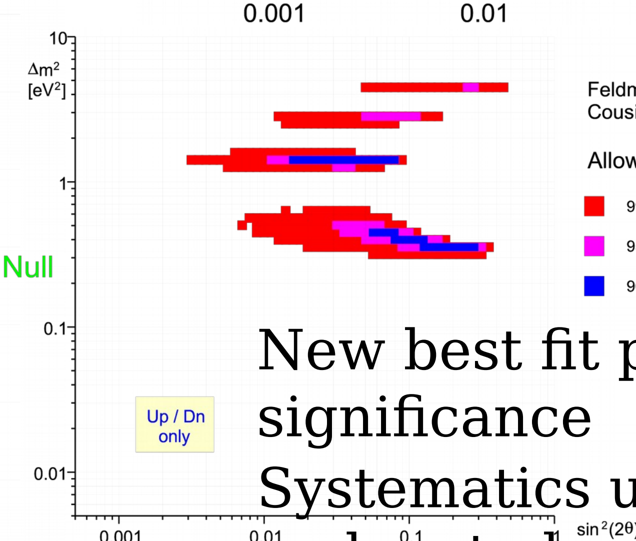
IBD intensity follows reasonably the 1 / L^2 dependence





Best fit point (old) excluded





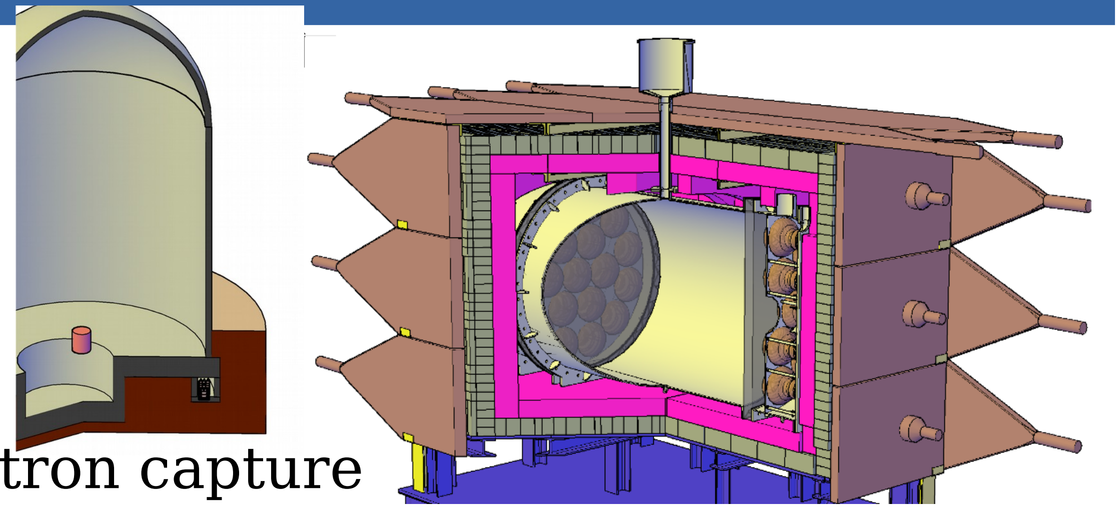
New best fit point has 2.8σ significance

Systematics uncertainties under study

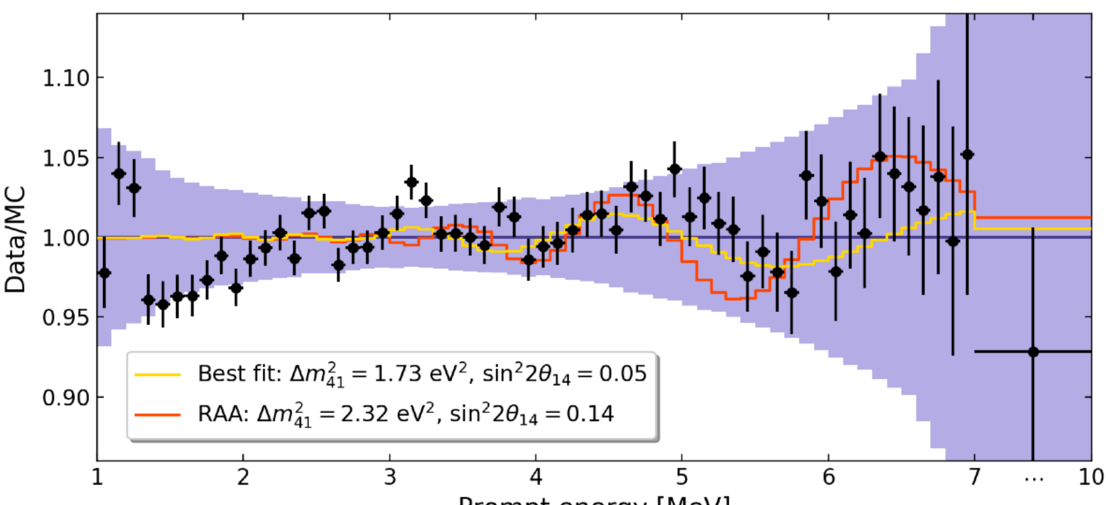
NEOS

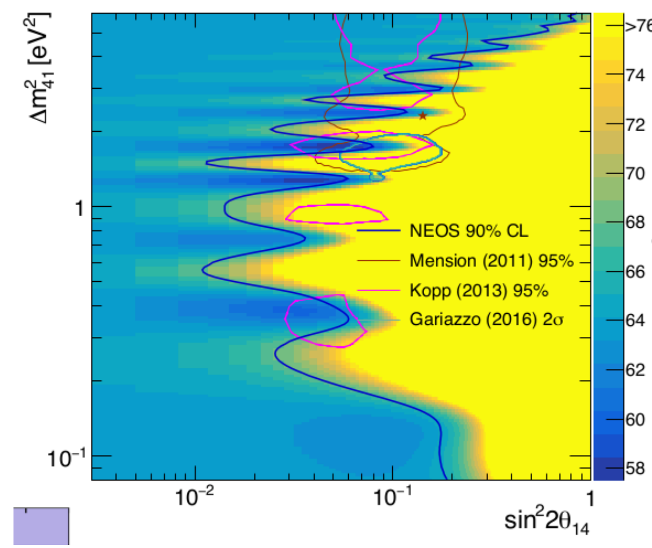
Yoomin Oh

- Homogeneous LS target
  - — 1008 L volume
  - (R 51.5, L 121) cm
  - LAB+UG-F (9:1)
  - 0.5% Gd loaded for high neutron capture efficiency
  - 38 8″ PMT in mineral oil buffer



Normalized with the Daya Bay shape
Model dependent → **Fine structures in reactor ν spectrum or oscillation?**



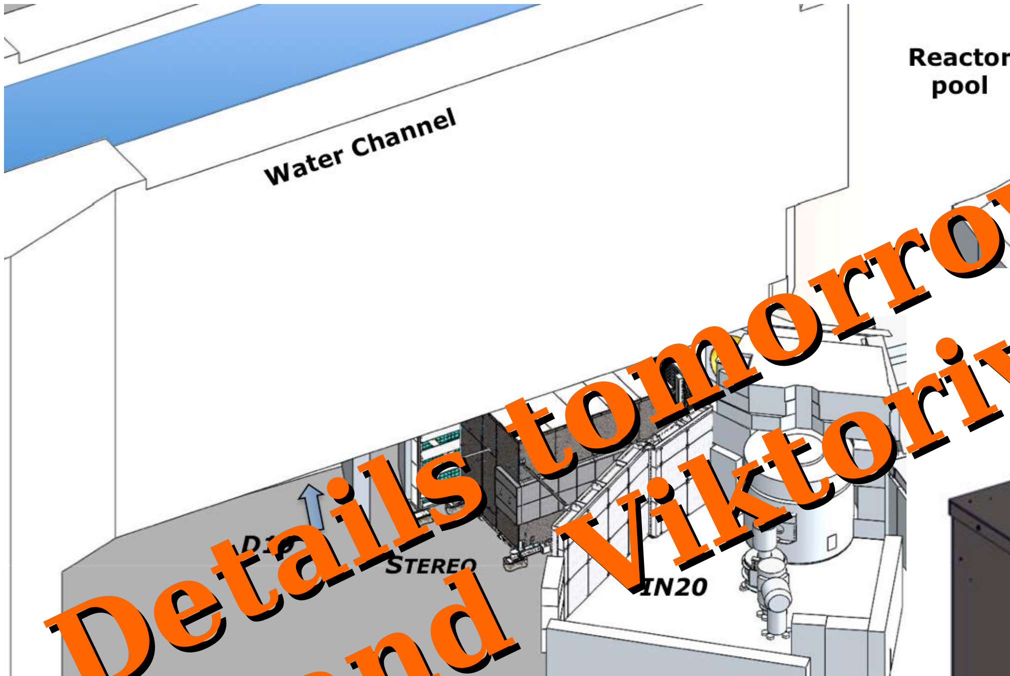


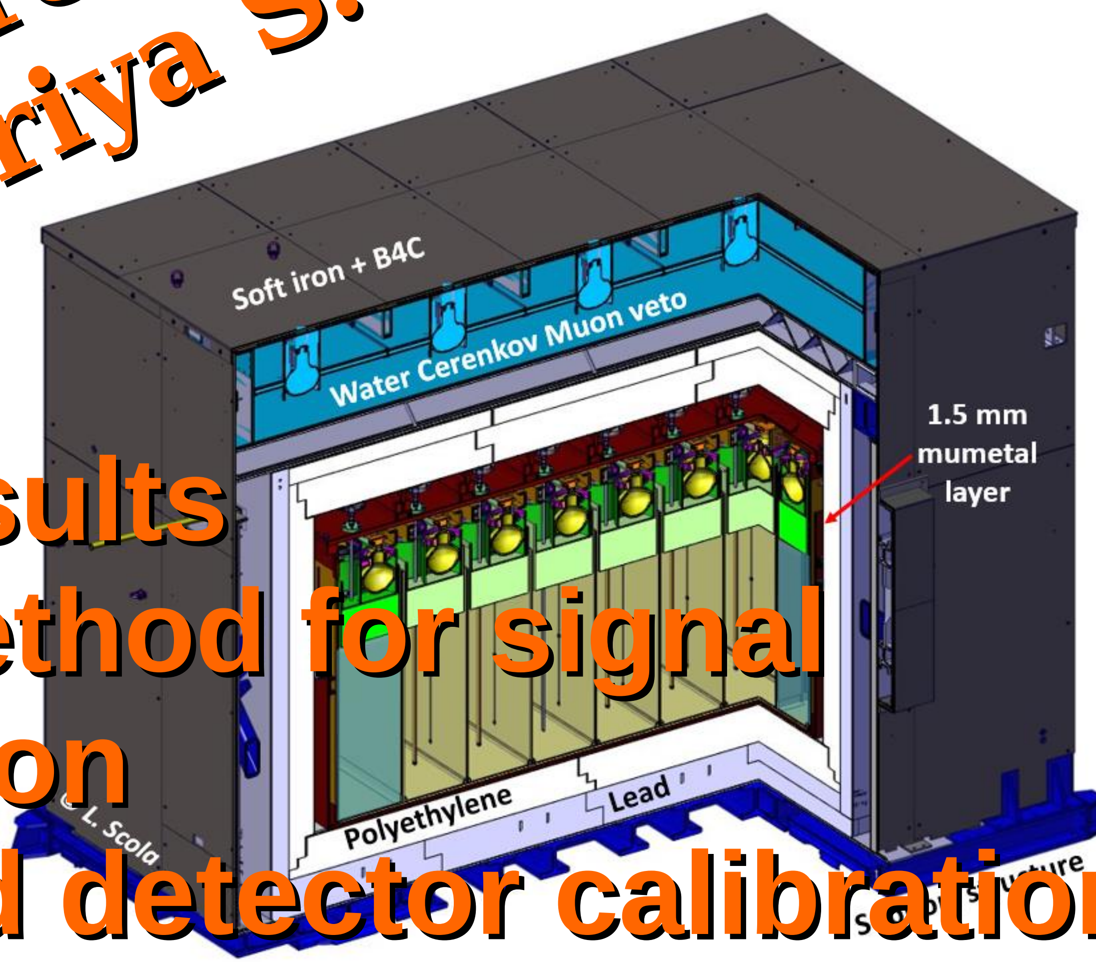
NEOS phase-II measurement from September 2018

STEREO

Jacob Lamblin

Details tomorrow in Aurelie B. and Viktoriya S. talks



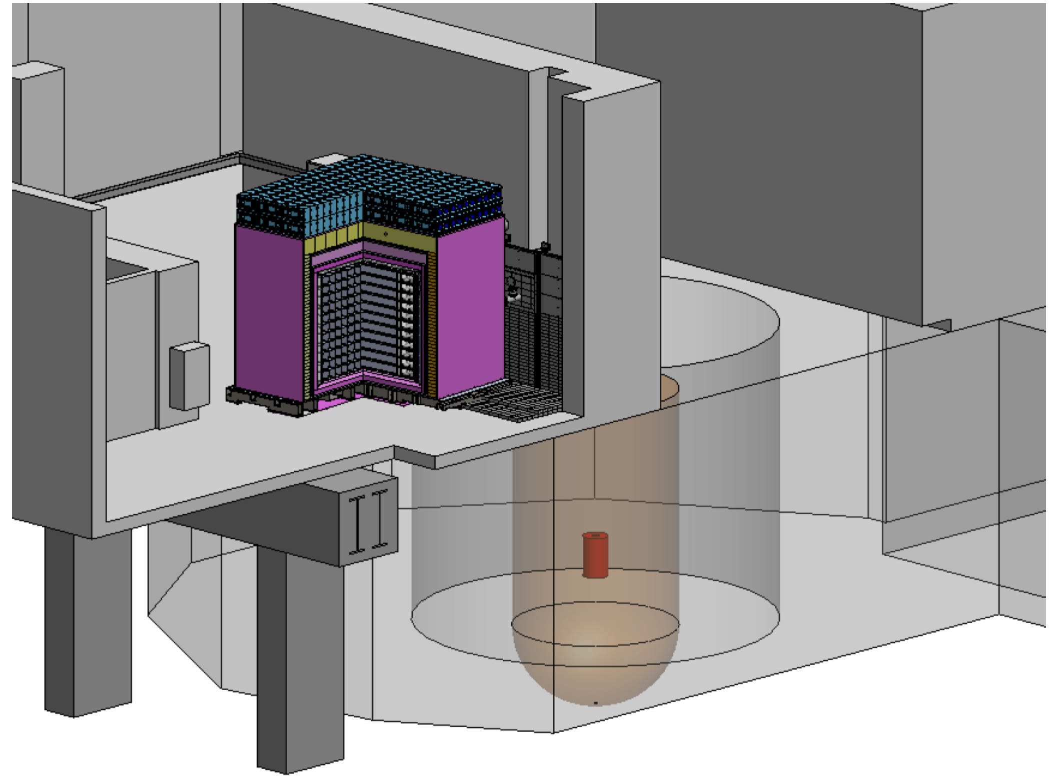


- New results
- New method for signal extraction
- Detailed detector calibration

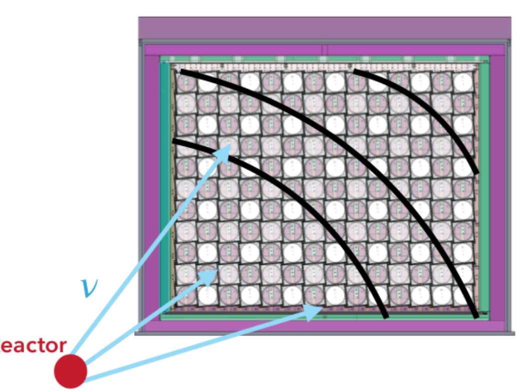
Prospect

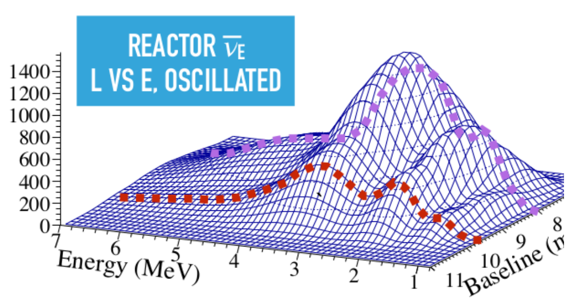
Thomas Langford

- SEARCH FOR SHORT-BASELINE OSCILLATIONS FROM STERILE NEUTRINOS INDEPENDENT FROM REACTOR MODEL INPUTS
- MEASURE ^{235}U ENERGY SPECTRUM TO RESOLVE THE SPECTRAL ANOMALY
- Experimental Strategy:
  - 154 segments, 119cm x 15cm x 15cm filled with Li loaded LS
  - Measure spectrum at a range of baselines (7-9m in current position)
  - Reactor-model independent search for oscillations throughout the detector
  - High-statistics, high-resolution ^{235}U neutrino energy spectrum

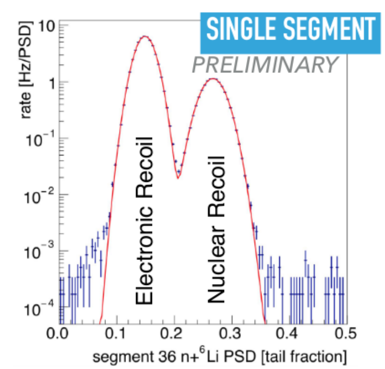


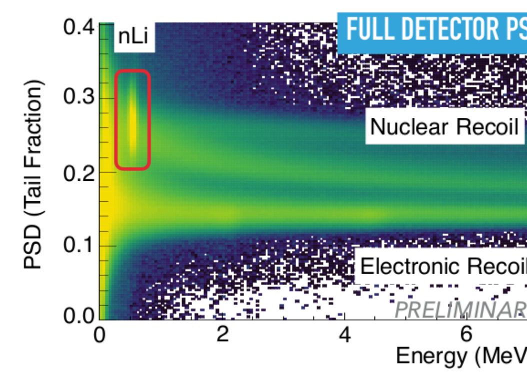
OSCILLATIONS AT PROSPECT





PULSE SHAPE DISCRIMINATION PERFORMANCE

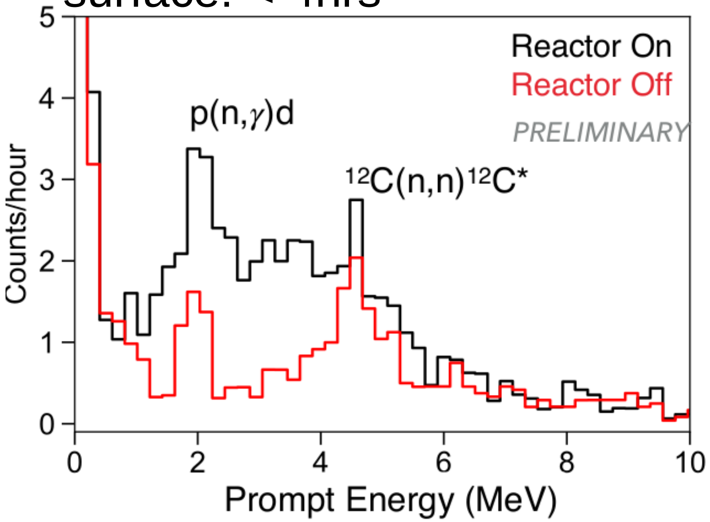




Prospect

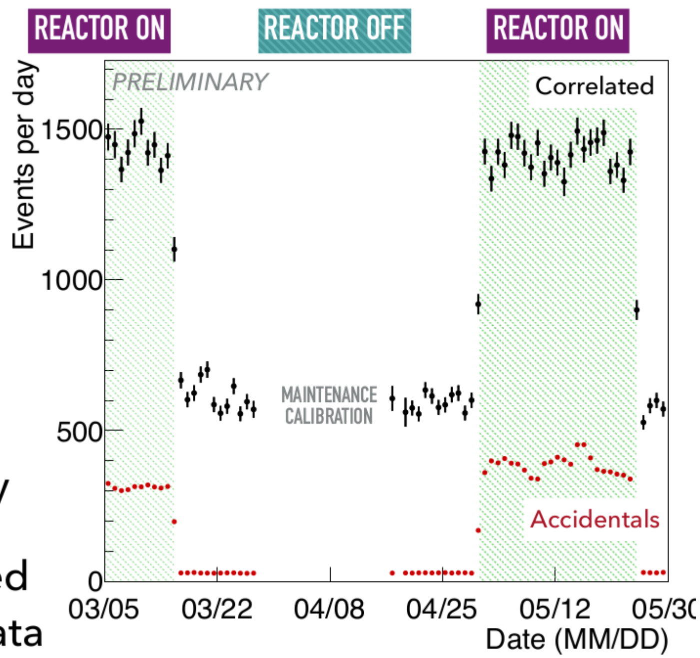
Thomas Langford

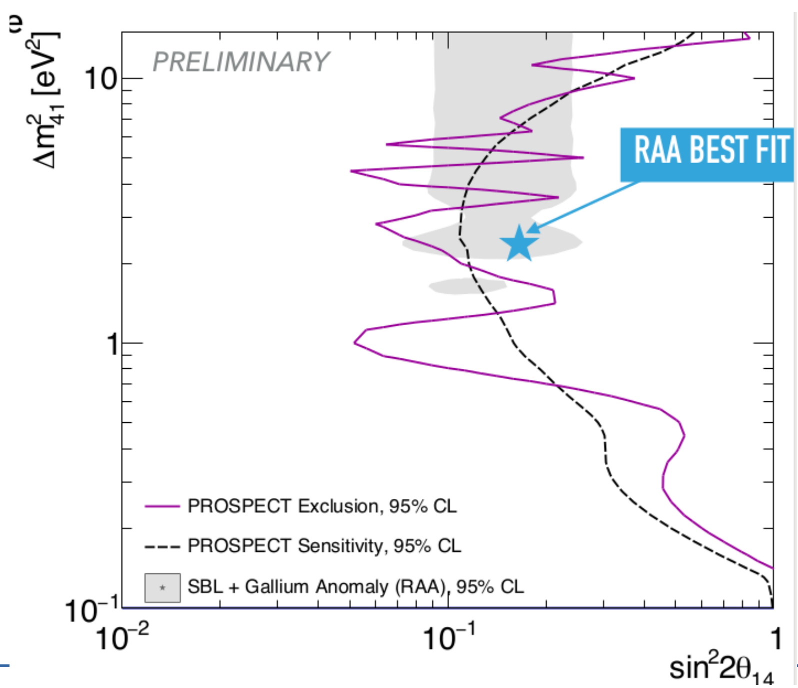
Time to 5σ detection at earth's surface: < 4hrs

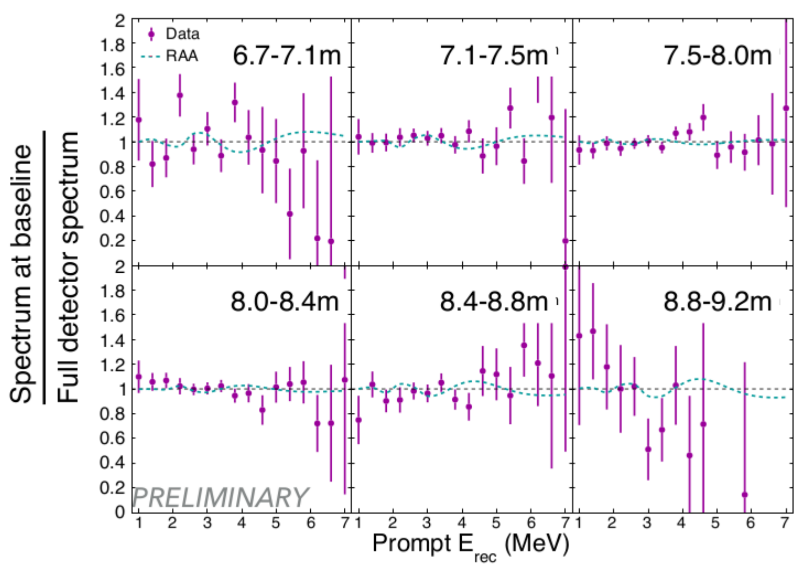


FIRST ANALYSIS DATA SET (ARXIV: 1806.02784)

- 33 days of Reactor On
- 28 days of Reactor Off
- Correlated S/B = 1.36
- Accidental S/B = 2.25
- **24,608 IBDs detected**
- Average of ~750 IBDs/day
- IBD event selection defined and frozen on 3 days of data

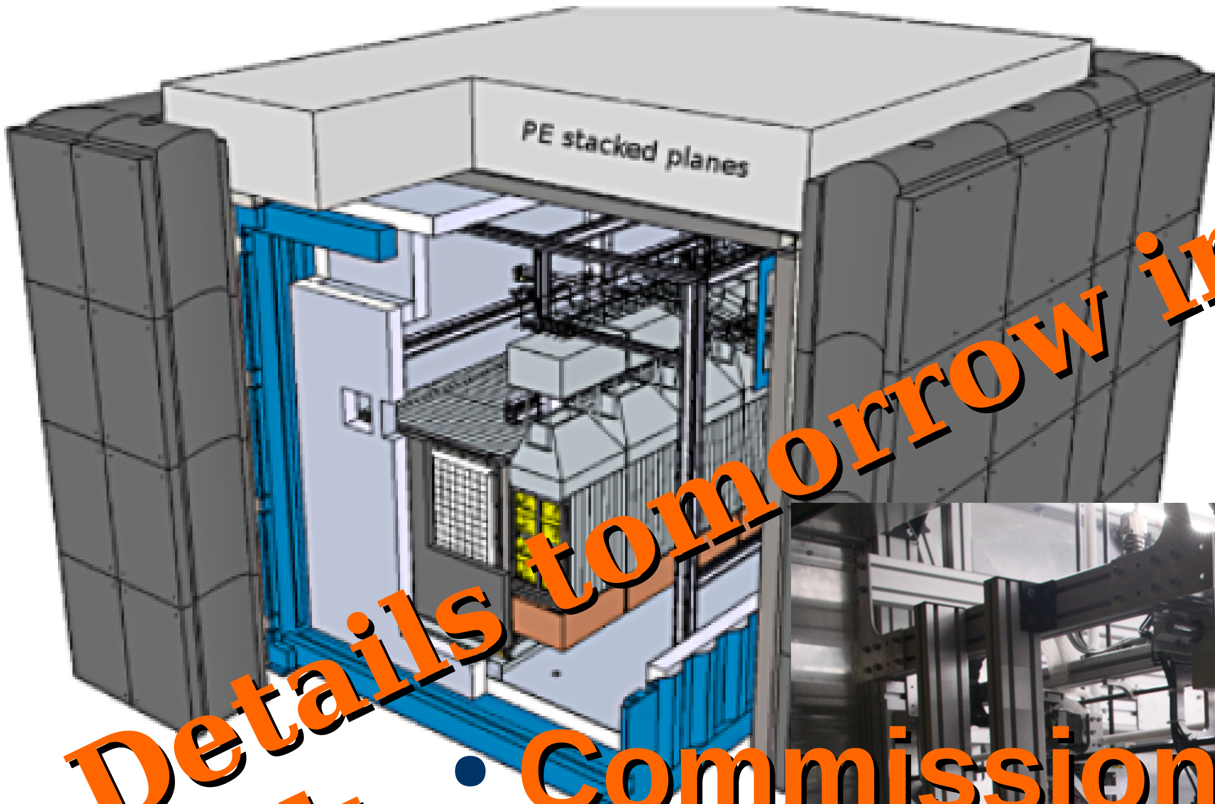






SoLid

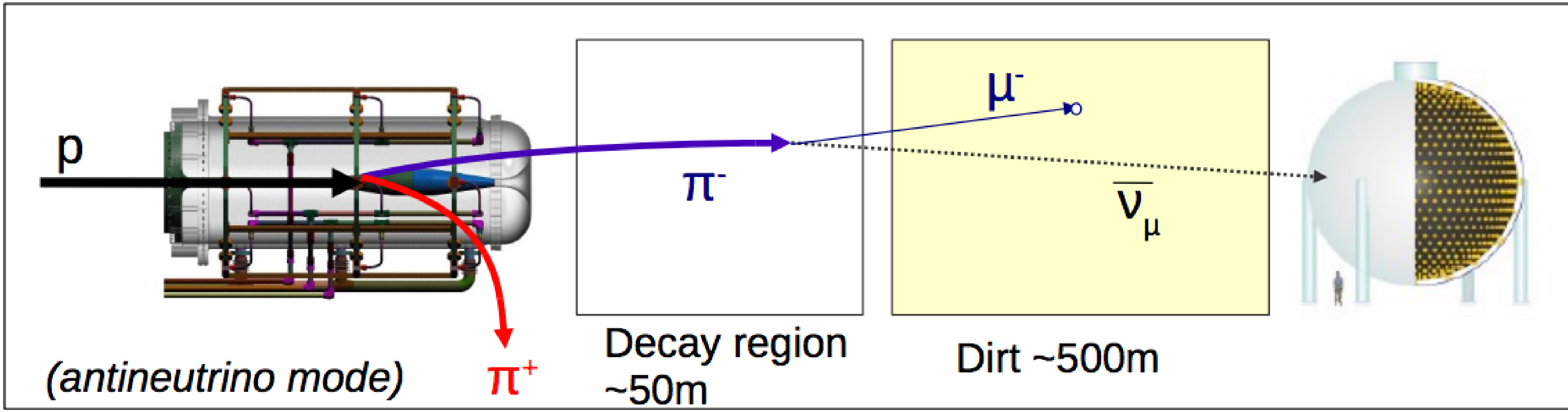
Nick V. R.



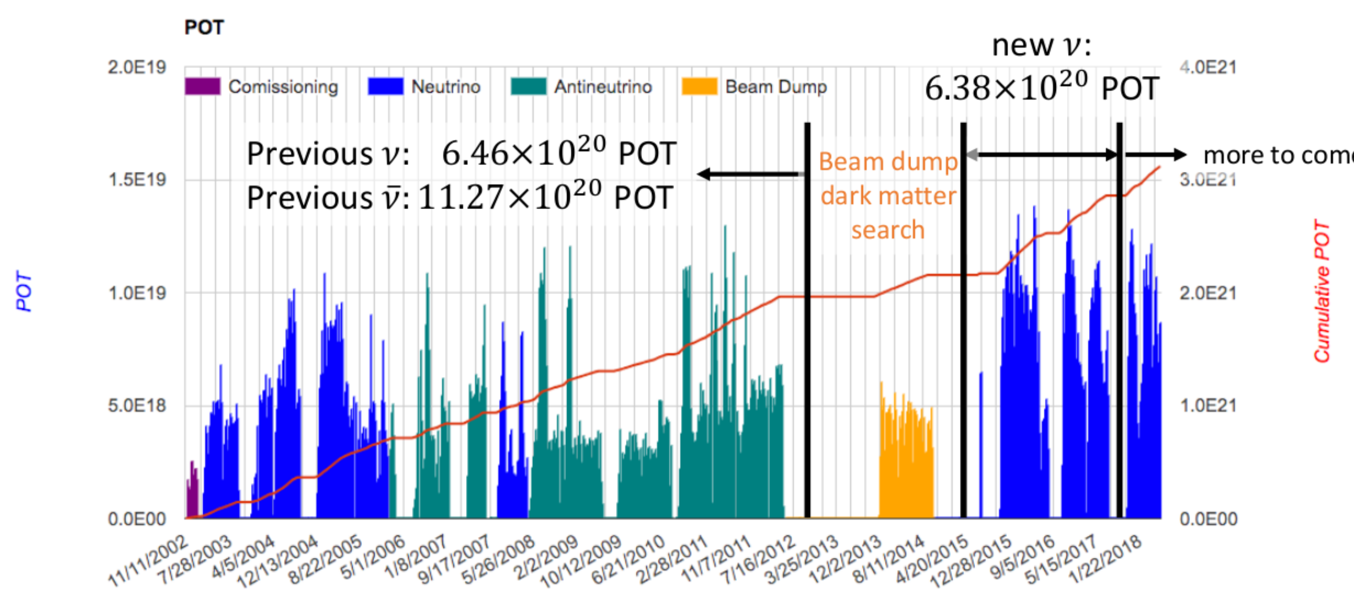
Details tomorrow in Luis M. talk

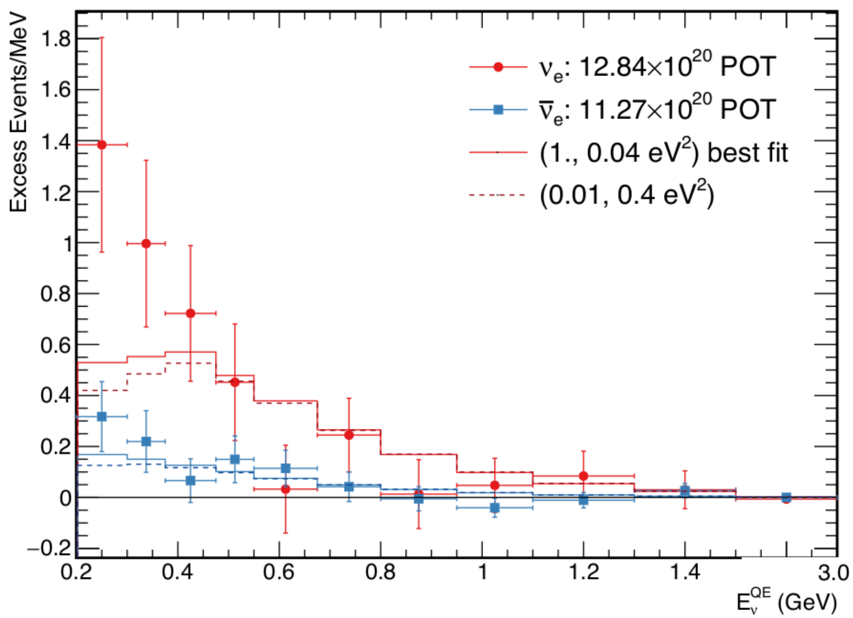
- Commissioning
- Calibration
- First IBD like events

- ***Sterile neutrinos with accelerators***



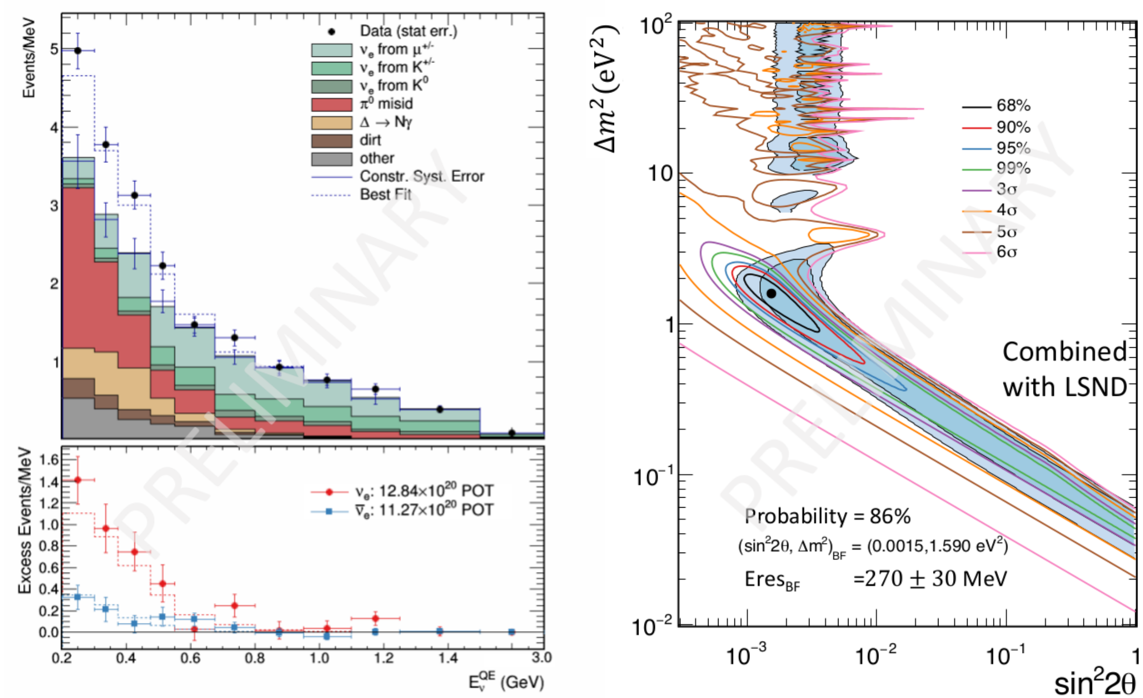
- 15+ years of running in neutrino, antineutrino, and beam dump mode. More than 30×10^20 POT to date.
- Result of a combined 12.84×10^20 POT in ν mode + 11.27×10^20 POT in $\bar{\nu}$ mode





Excess in neutrino and antineutrino mode is qualitatively consistent

An MSW-Like Resonance Model



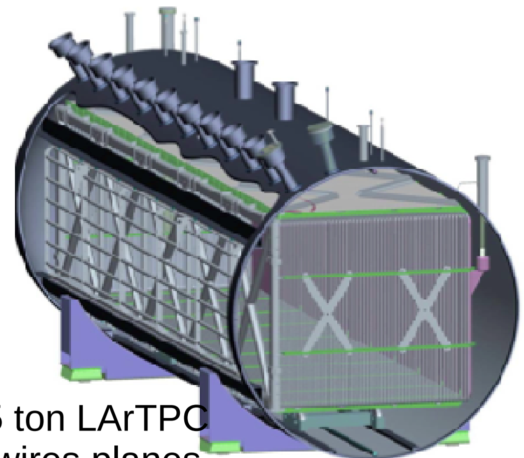
A more exotic model could provide a better fit to the MiniBooNE/LSND data

20

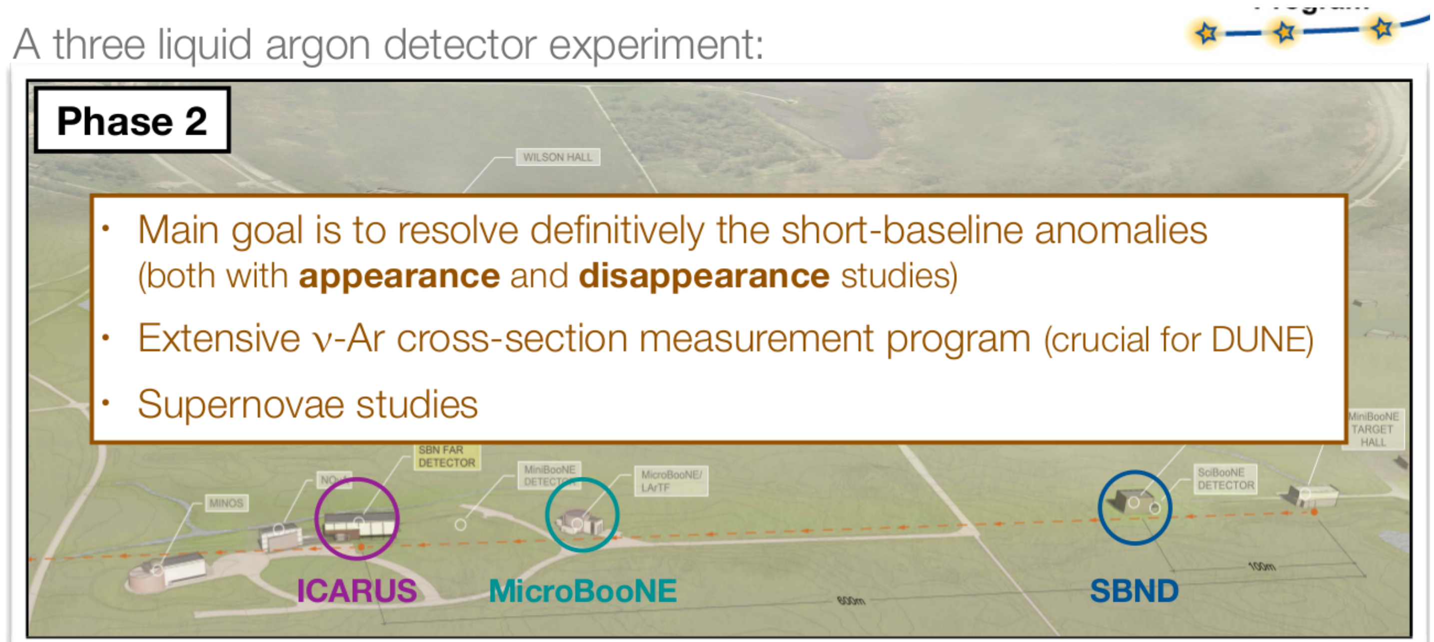
- **MiniBooNE confirms (this time) LSND excess at 4.8σ, with a combined significance at 6.1σ**
  - Gamma bkg or electrons?
  - MicroBooNE will confirm whether excess is due to electrons or photons
  - SBNP will confirm if excess is due to neutrino oscillations

MicroBoone

- DUNE long-baseline program will strongly rely on the resolution of these SB anomalies
- Need to resolve the anomalies ➡ Short Baseline Neutrino program at Fermilab



- 85 ton LArTPC
- 3 wires planes
- 32 PMTs
- Neutrino data taking since October 2015



MicroBoone

Roxanne Guenette

- DUNE long-baseline program will strongly rely on the resolution of these SB anomalies
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- 85 ton LArTPC
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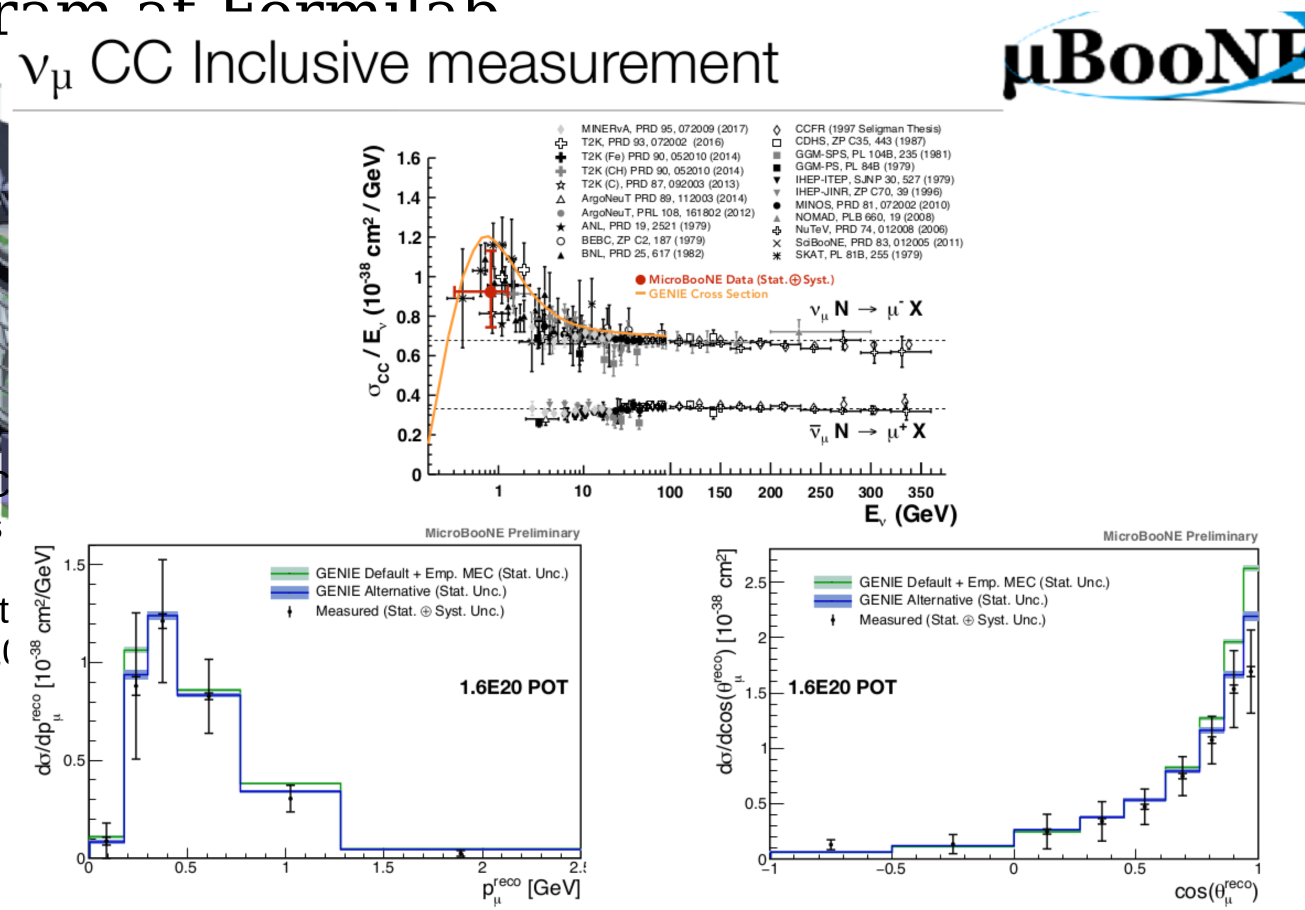
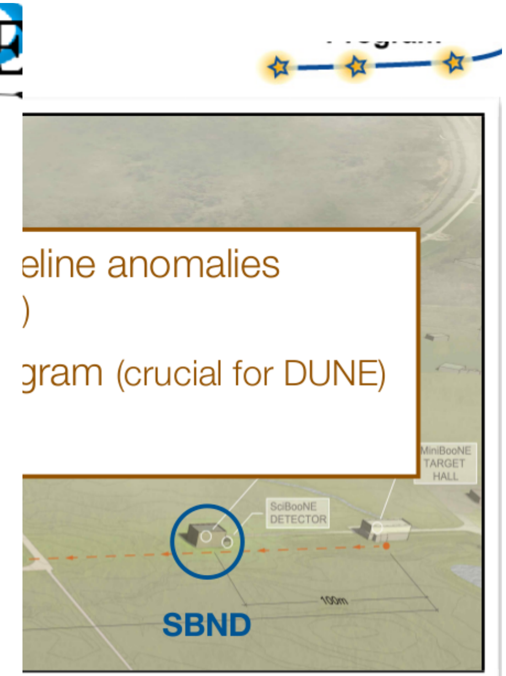
since October 2(





SBN is a definitive program to address LSND/MiniBooNE anomalies in the immediate future (~5 years)

- ***The global picture***

Global picture

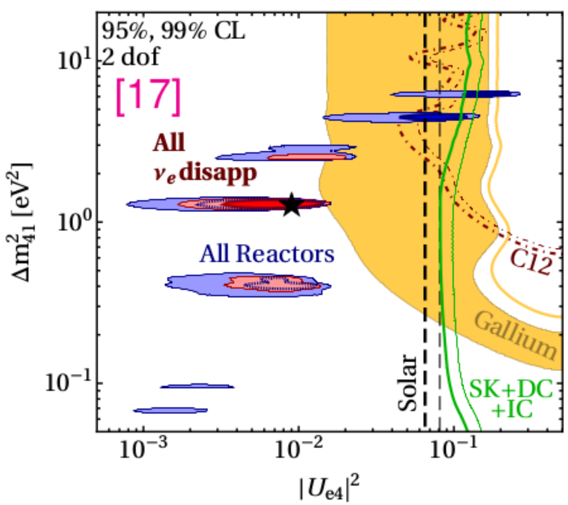
Michele Maltoni

II. Oscillation anomalies: $\nu_\mu \to \nu_e$ appearance

16

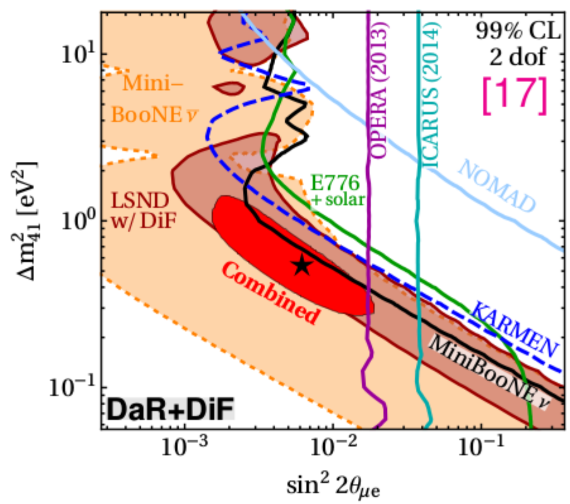
ν_e disappearance

- Relevant experiments:
  - SBL reactors $(\bar{\nu})$
  - LBL reactors $(\bar{\nu})$
  - KamLAND $(\bar{\nu})$
  - Gallium (ν)
  - Atmos $(\nu, \bar{\nu})$
  - Solar (ν)
  - ^{12}C (ν)



$\nu_\mu \to \nu_e$ appearance

- Relevant experiments:
  - MiniBooNE $(\nu, \bar{\nu})$
  - E776 $(\nu, \bar{\nu})$
  - ICARUS (ν)
  - LSND $(\bar{\nu})$
  - KARMEN $(\bar{\nu})$
  - NOMAD (ν)
  - OPERA (ν)



- Note: $\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ probe the same Δm^2 but a different mixing angle $\Rightarrow$ mutual comparison requires embedding them into a **general oscillation model**.

[17] Dentler, Hernández-Cabezudo, Kopp, Machado, MM, Martinez-Soler, Schwetz, arXiv:1803.10661.

Michele Maltoni <michele.maltoni@csic.es>

Neutrino 2018, 8/06/2018

Summary

25

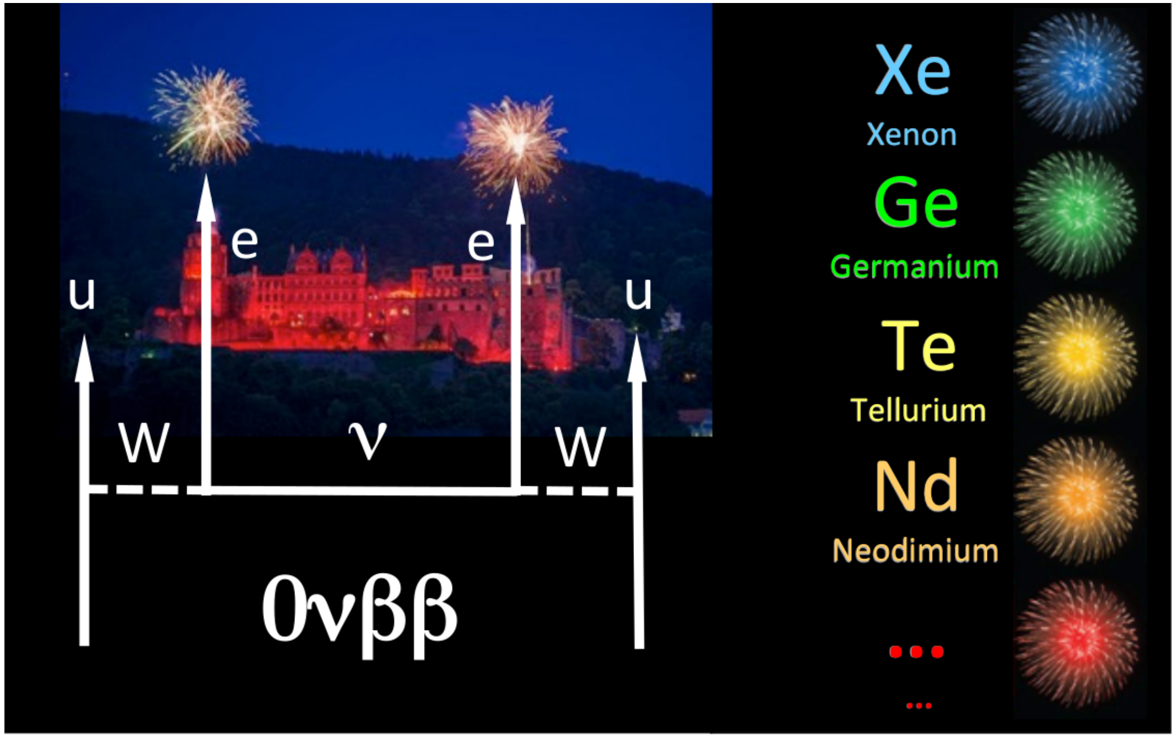
- Anomalies in $\nu_e \to \nu_e$ disappearance and $\nu_\mu \to \nu_e$ appearance experiments point towards conversion mechanisms beyond the well-established 3ν oscillation paradigm;
- each of these anomalies can be **individually** explained by sterile neutrinos;
- sterile neutrinos still succeed in simultaneously explaining groups of anomalies **sharing the same oscillation channel**. However some problem arises:
  - $\nu_e \to \nu_e$ disappearance data face issues with flux normalization and the 5 MeV bump, as well as small tensions in reactor vs gallium and "rates" vs DANSS/NEOS;
  - $\nu_\mu \to \nu_e$ appearance data show an excess in low-E neutrino data, which is not so manifest in antineutrino data.
- in contrast, no anomaly is found in any $\nu_\mu \to \nu_\mu$ disappearance data set;

$\Rightarrow$ sterile neutrino models **fail to simultaneously account** for **all** the $\nu_e \to \nu_e$ data, the $\nu_\mu \to \nu_e$ data and the $\nu_\mu \to \nu_\mu$ data. This conclusion is robust;

- if the $\nu_e \to \nu_e$ and $\nu_\mu \to \nu_e$ anomalies are confirmed, and the $\nu_\mu \to \nu_\mu$ bounds are not refuted, new physics will be needed. Such new physics may well involve extra sterile neutrinos, but together with something else (or some "unusual" neutrino property).

Michele Maltoni <michele.maltoni@csic.es> **NEUTRINO 2018, 8/06/2018**

•*Double beta decay*

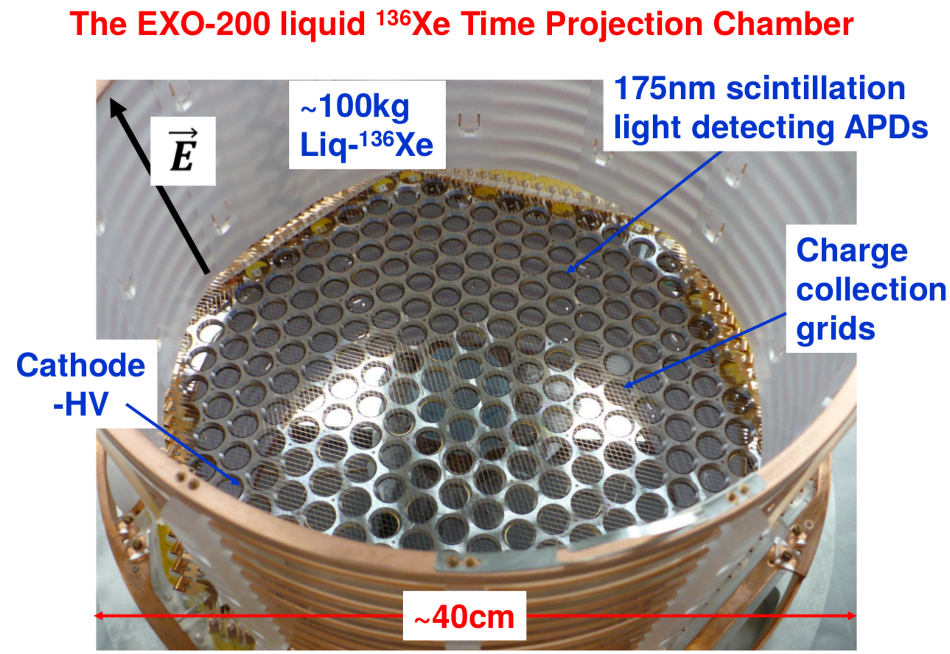


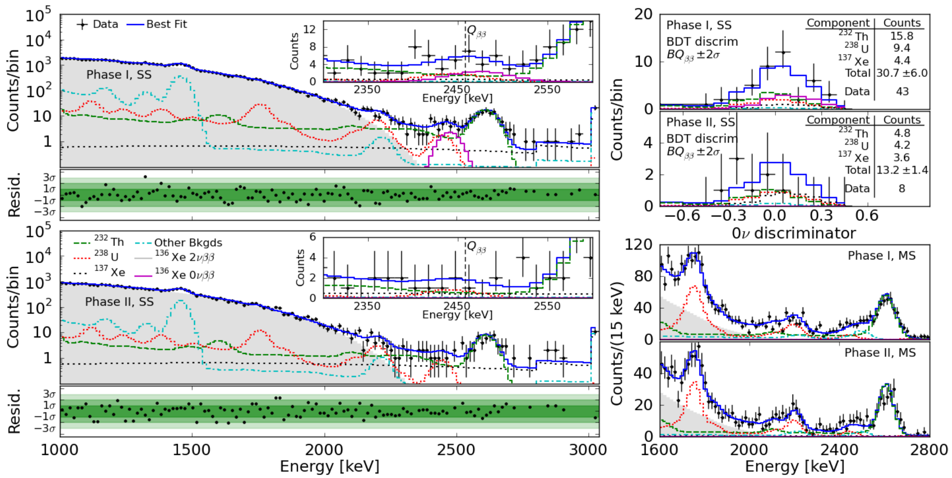
No "golden" isotope, search in a variety!

EXO-200 and nEXO

Giorgio Gratta

- Use ^{136}Xe in liquid phase
- Build EXO-200, first 100kg-class experiment to produce results. Phase II in progress, will end in Dec 2018
- Build the 5-tonne nEXO, reaching $T_{1/2}$ ~10^{28} yr and entirely covering the Inverted Hierarchy



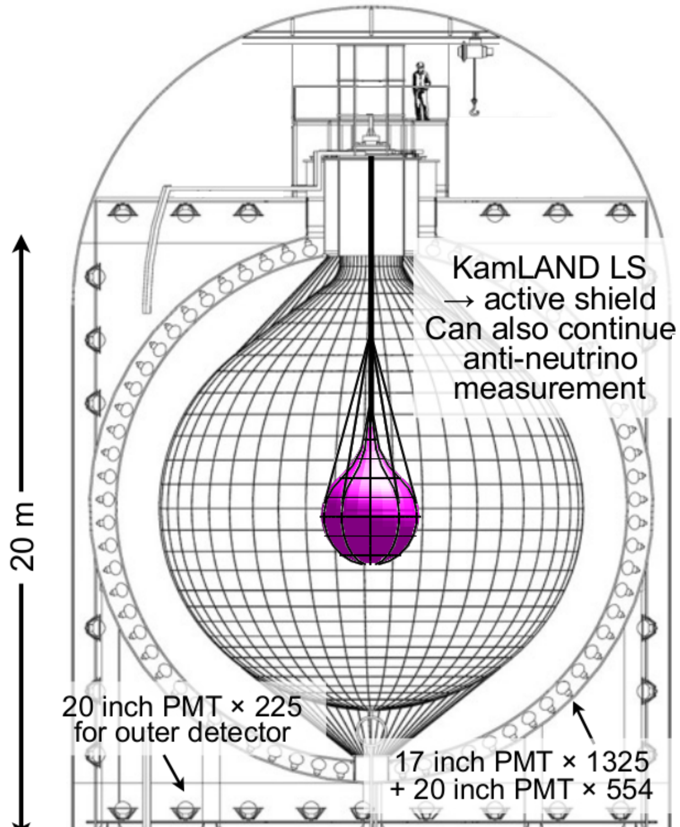


No statistically significant excess: combined p-value ~1.5σ

- A final 0νββ result will follow the end of Phase II (Dec 2018)
- **R&D in progress to finalize the design of nEXO**
- EXO-200 was the first 100kg-class experiment to run and demonstrated the power of a large and homogeneous LXe TPC
- **"nEXO pCDR" arXiv:1805.11142**

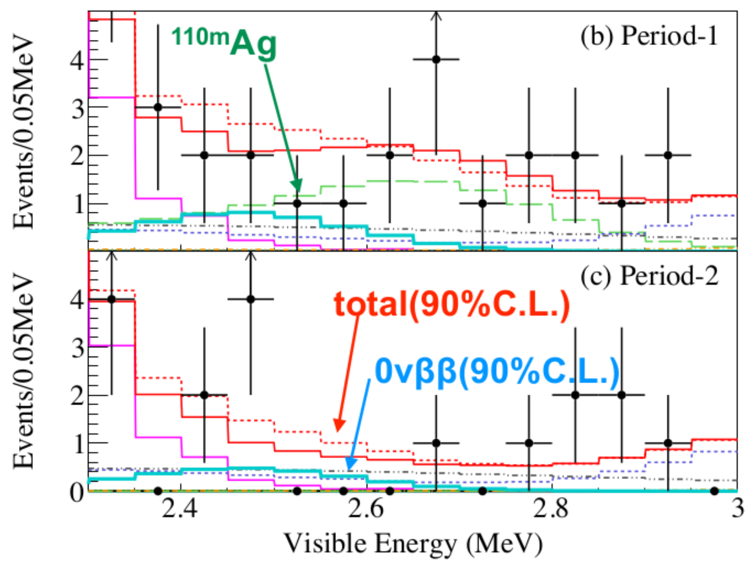
KamLAND-Zen

Azusa Gando



- ^{136}Xe loaded LS → into KamLAND center with inner balloon
- Double beta decay isotope:
  - ^{136}Xe
  - Q-value 2.458 MeV
  - Enrichment ~90%

Energy spectrum
2.3 < E < 3.0 MeV, R < 1.0 m



Found no significant 0νββ signal

Limit of Phase-II (90% C.L.)

Period-1: < 3.4 events/day/kton-LS
Period-2: < 5.5 events/day/kton-LS
→ combined: < 2.4 events/day/kton-LS

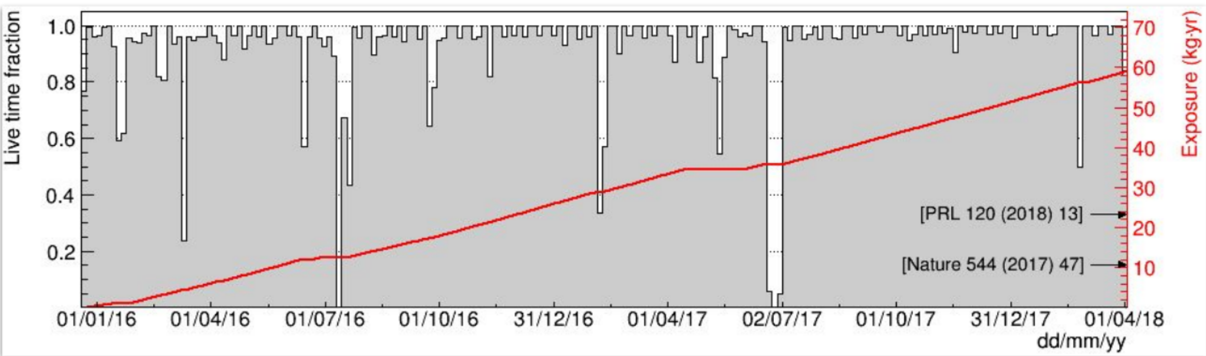
$T^{1/2} > 9.2\times10^{25}$ yr

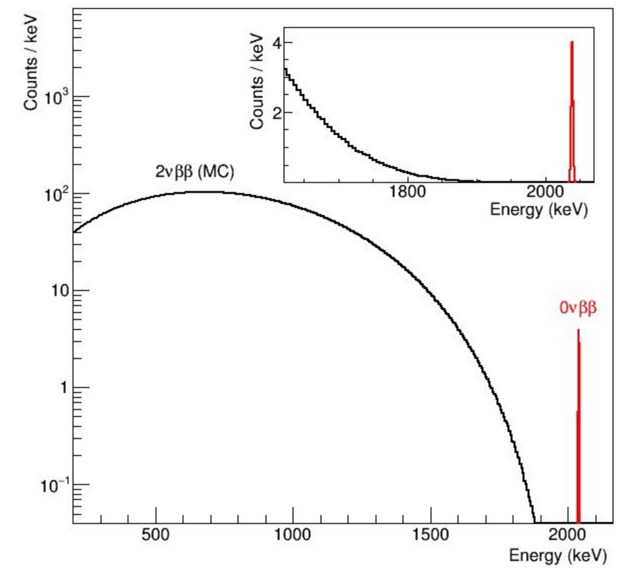
- KamLAND-Zen 800 will start this year with target 〈m ββ〉 of ~ 40 meV
- KamLAND2-Zen (~1ton of enriched Xenon) is planned to search deeper into inverted hierarchy region of 〈m ββ〉

Gerda

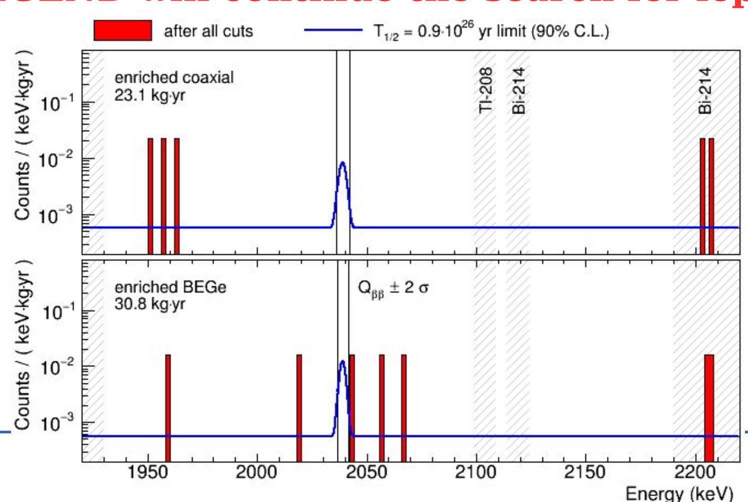
Anna Julia Zsigmond

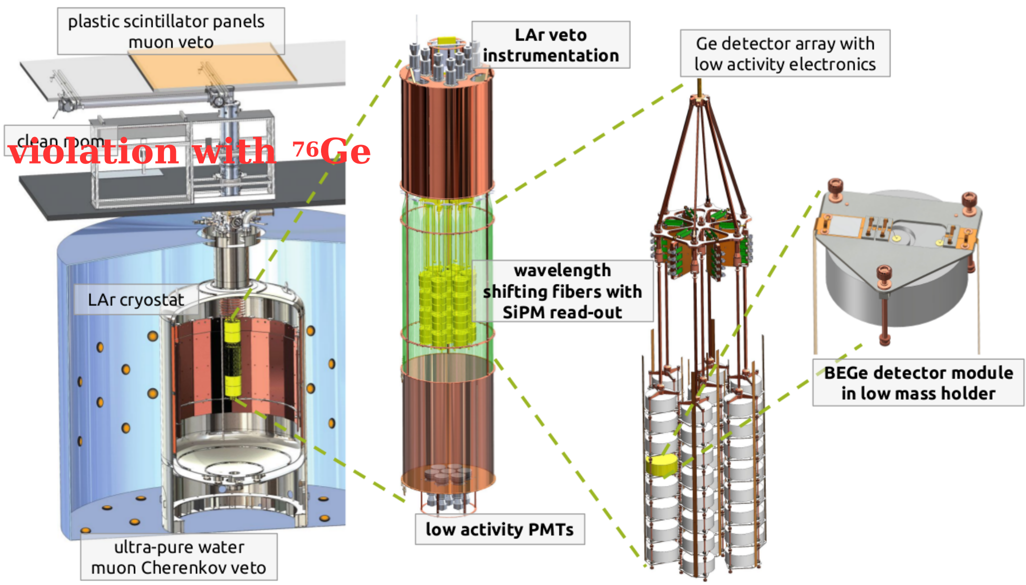
- $^{76}Ge \rightarrow {}^{76}Se + 2e^-$ with $Q_{\beta\beta} = 2039$ keV
- Source and detector are the same
- Isotope enrichment up to 88% for detector material





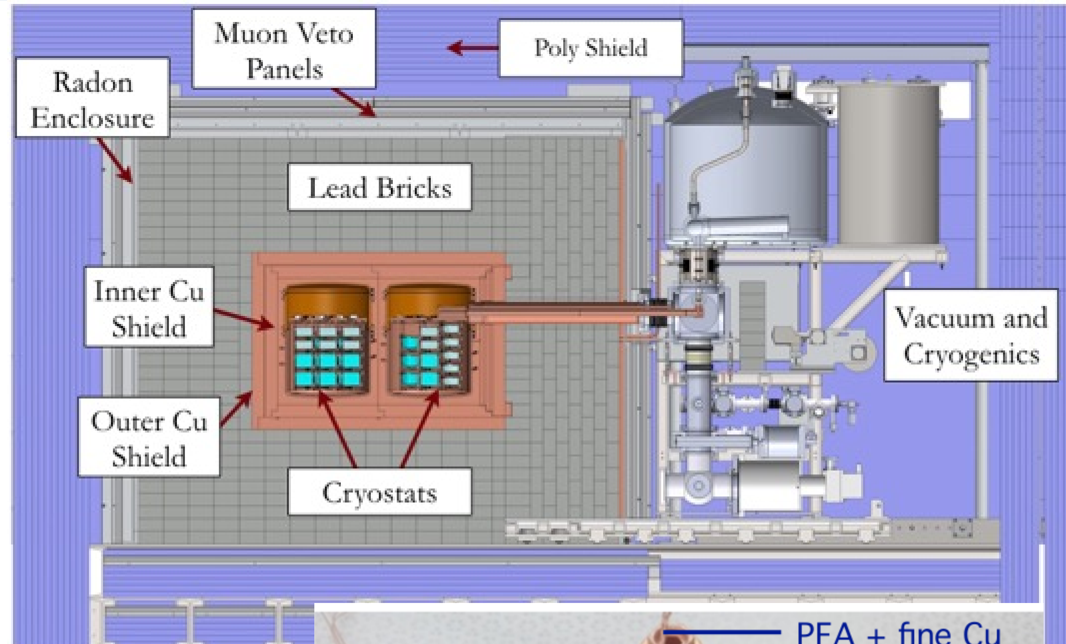
- Blinded analysis: events with energy Q ββ ± 25 keV not processed until all analysis cuts finalized
- > 10^{26} yr sensitivity for limit setting
- GERDA upgrade 2018
  - New inverted coaxial type detectors → more enriched mass
  - Improved LAr veto → more LAr light yield
- **LEGEND will continue the search for lepton number violation with ^{76}Ge**





Majorana

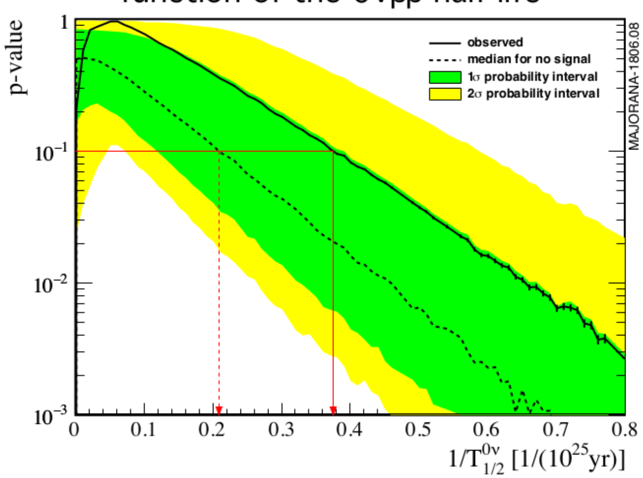
- 44.1-kg of Ge detectors
  - 29.7 kg of 88% enriched ^{76}Ge crystals
  - 14.4 kg of nat Ge
- Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - Ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - Naturally scalable



- Background index:

$$15.4 \pm 2.0\ \mathrm{cts/(FWHM\ t\ yr)}$$

Frequentist profile likelihood method, as a function of the 0νββ half life



PRELIMINARY

Method	Exclusion Limit
Nominal Profile Likelihood	2.7 x 10^{25} yr
Feldman-Cousins	2.5 x 10^{25} yr
Modified Profile Likelihood (CLS)	2.5 x 10^{25} yr
Bayesian flat decay rate prior	2.5 x 10^{25} yr

Limit implies:

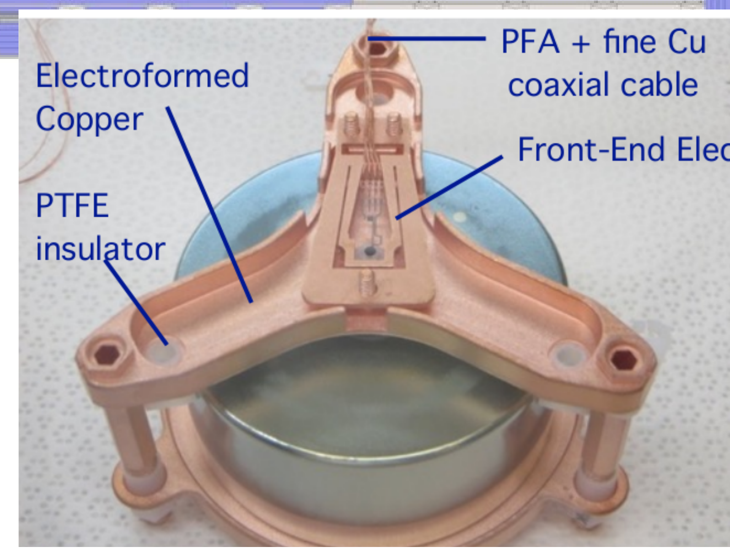
$$\langle m_{\beta\beta} \rangle < (200 - 433)\ \mathrm{meV}$$

using:

$M_{0\nu} = 2.81 - 6.13$

$G_{0\nu} = (2.36 - 2.37) \times 10^{-15}\ \mathrm{yr}^{-}$

$g_A = 1.27$

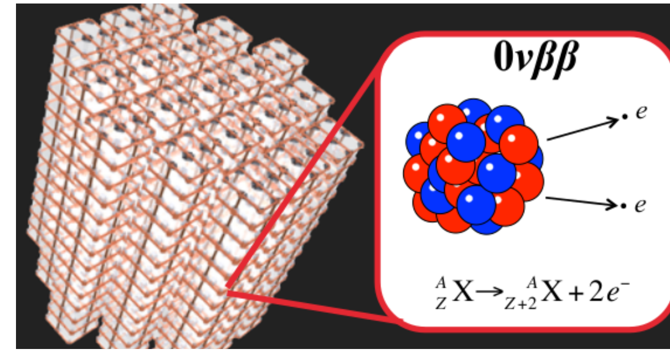


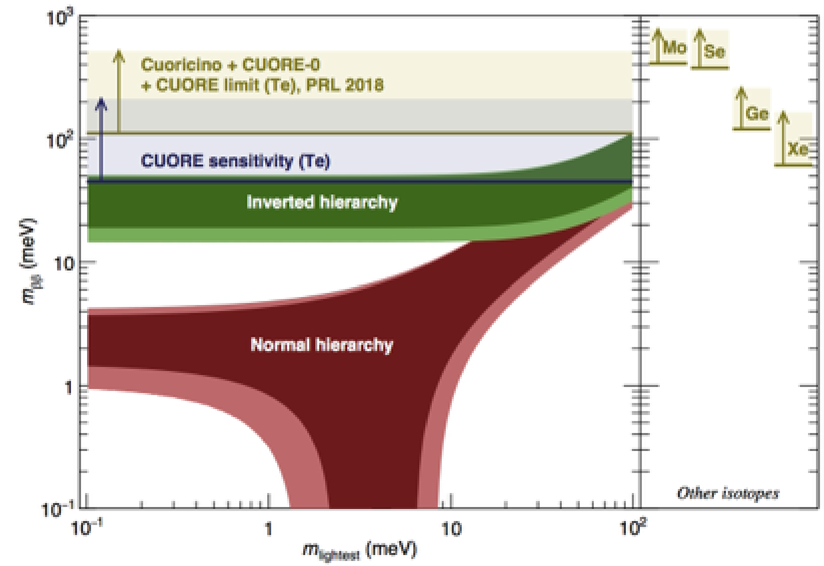
Optimization of analysis cuts underway to improve background rejection, to be tested on ongoing blind data later this year

CUORE

Jonathan Ouellet

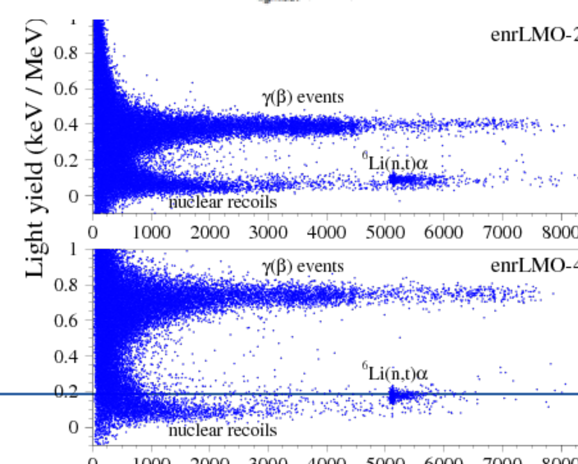
- Primary physics goal is the search for 0νββ decay of ^{130}Te
- Array of 988 TeO_2 bolometers
  - Solid state detectors operating at lo temperatures: ~10mK
  - 1 MeV energy deposition causes ~ 100 μK increase in temperature
  - Detector is made out of Te and contains the candidate isotope inside
- **With 7 weeks of data, set the most stringent limit on the 0νββ half-life of ^{130}Te to date**





CUORE Upgrade with Particle ID (CUPID) R&D

- Goal of reducing the background in the ROI by rejecting all α events with particle ID
- CUORE will execute its scientific program to completion. CUORE's success motivates a next-generation bolometric experiment



CUPID will adopt the scintillating-bolometer lithium molybdate technology

Will use present CUORE infrastucture at LNGS.

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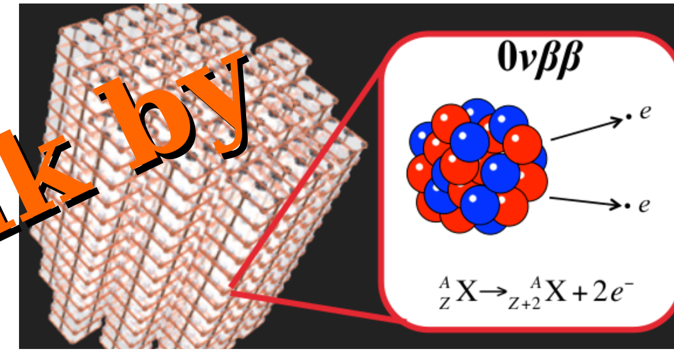

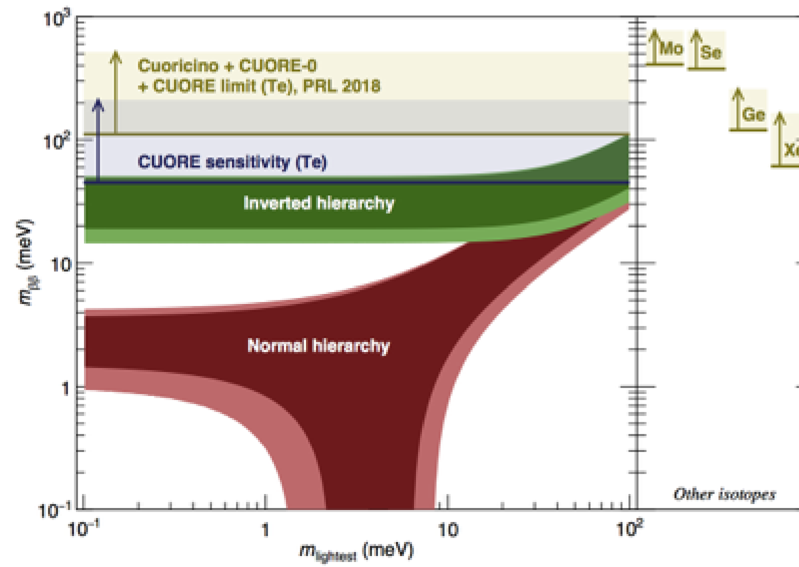

Tomorrow Cupid-0 talk by Luca Pattavina

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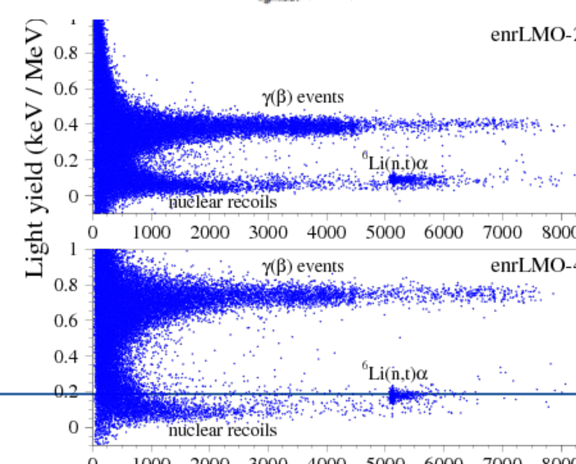

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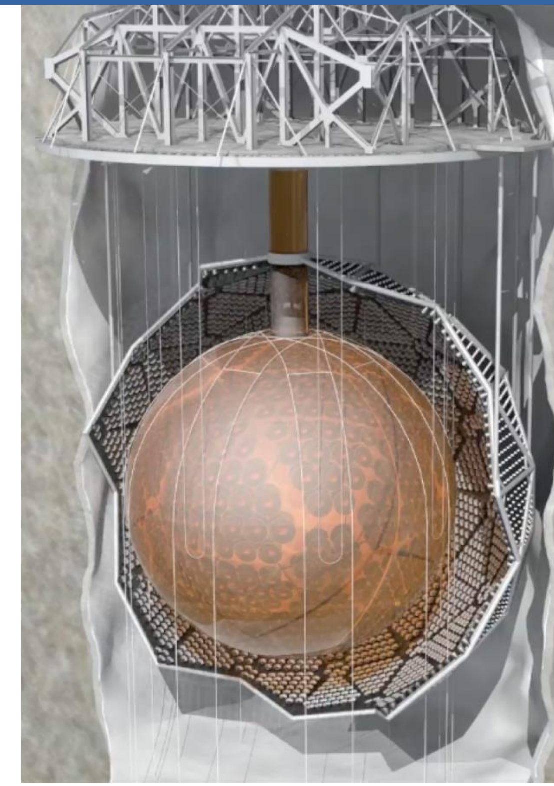
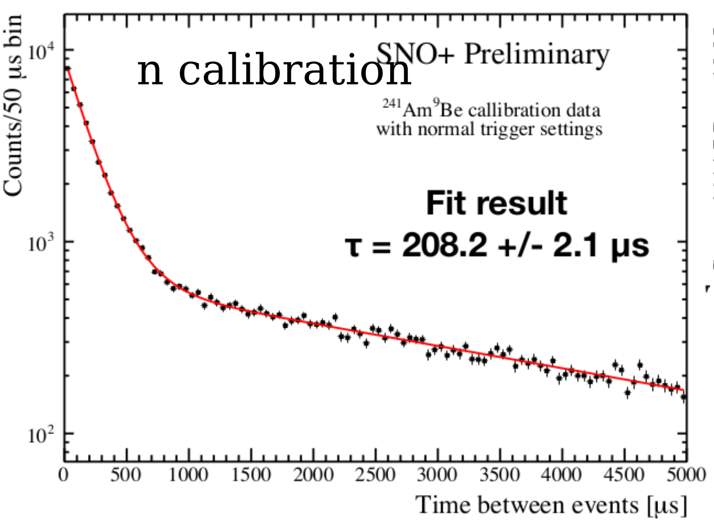
Will use present CUORE infrastucture at LNGS.

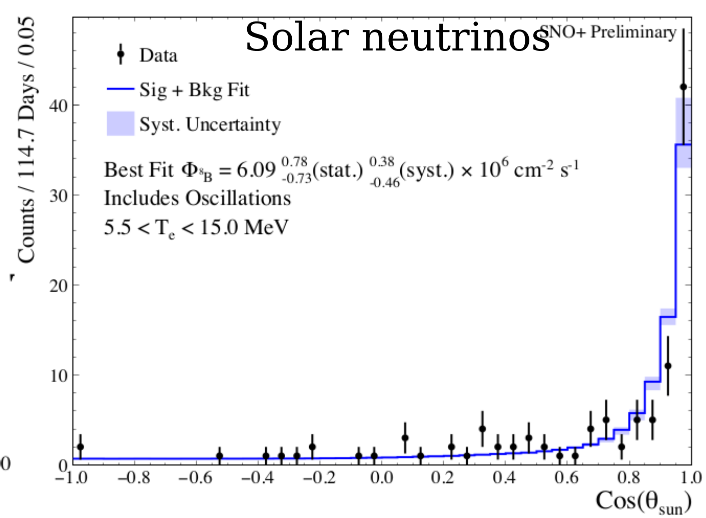
SNO+

Gabriel D. Orebi Gann

- 780 ton LAB/PPO (2g/L) in 6m radius acrylic vessel (AV)
- ~9400 PMTs at 8.5m
- **Method: Load LAB/PPO with 0.5% nat Te**
- SNO+ will operate in 3 phases:
  - Water filling complete (Feb 2017) → Data taking ongoing
  - LS fill in July 2018
  - Te loading in spring 2019





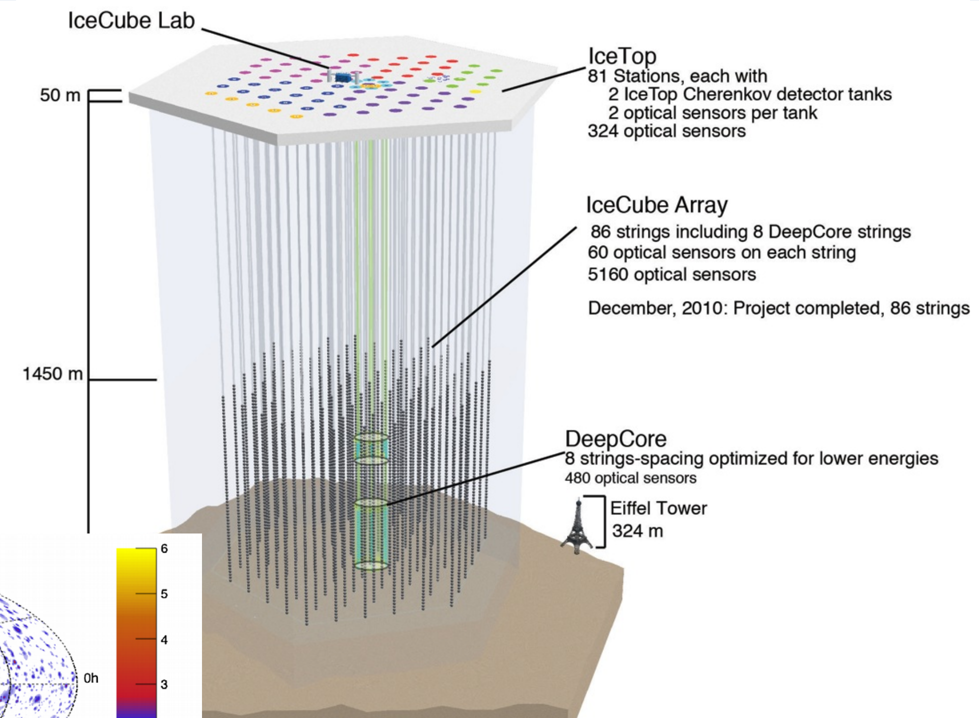


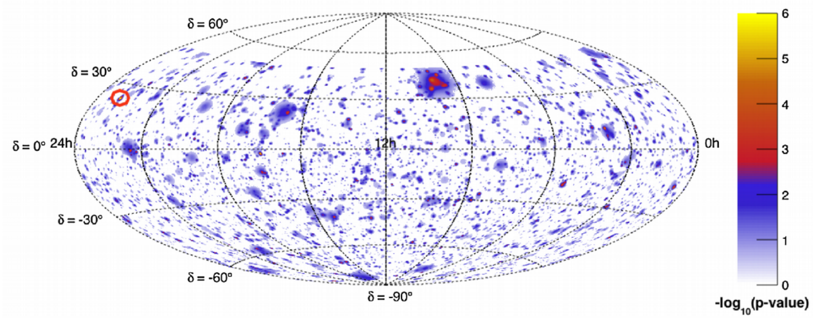
- ^8B solar ν flux measurement at low threshold and with ultra-low background
- potential for a search for antineutrinos in "unloaded" water
- **Scintillator fill (July 2018)**

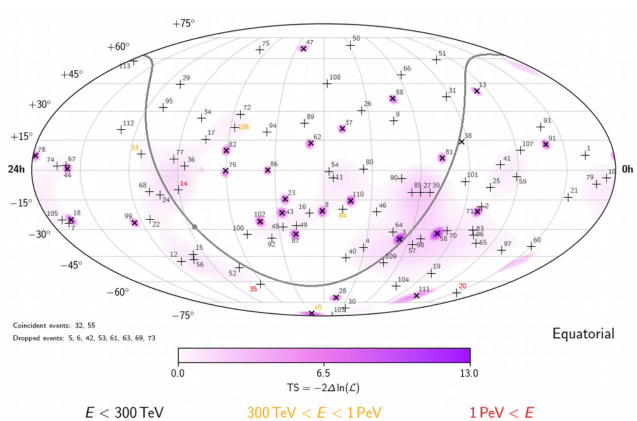
- ***Neutrino astronomy***

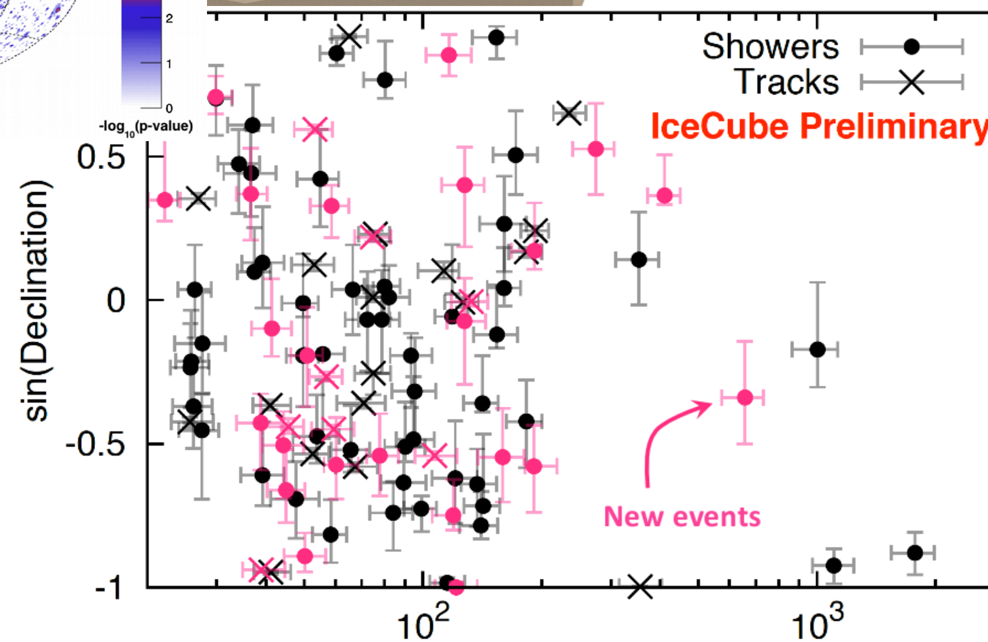
Ice cube and Antares

- No evidence for point sources, nor a correlation with the galactic plane
- Two double cascades have been identified (Ice Cube)
  - Double cascades can arise from ν_τ or mis-identified bckg (astro ν/ atm)
  - Separate study of tauness of the double cascade events ongoing









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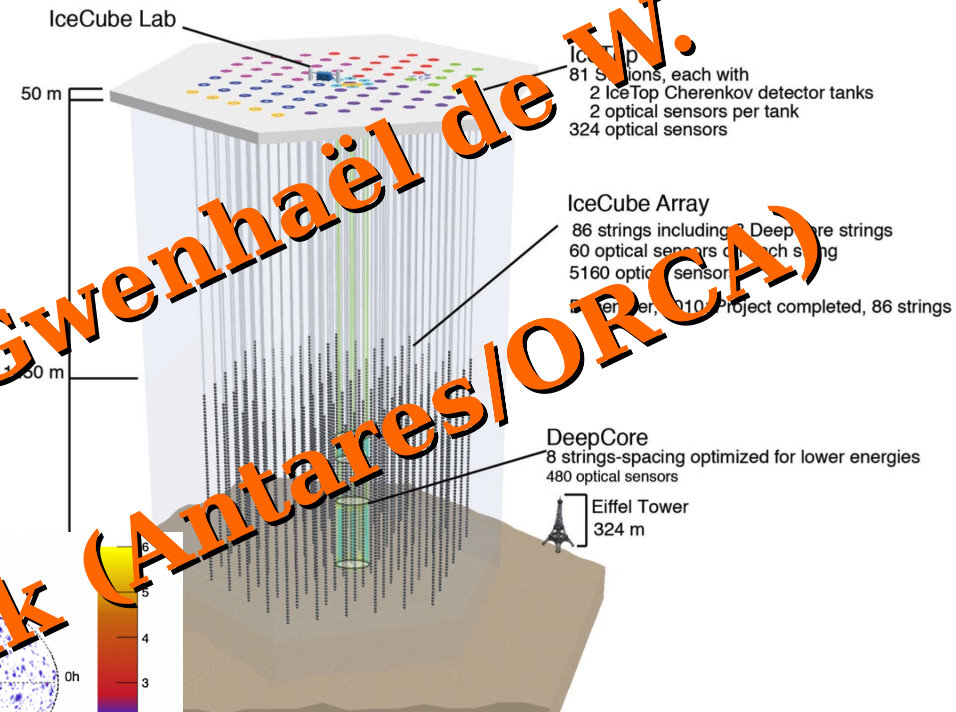
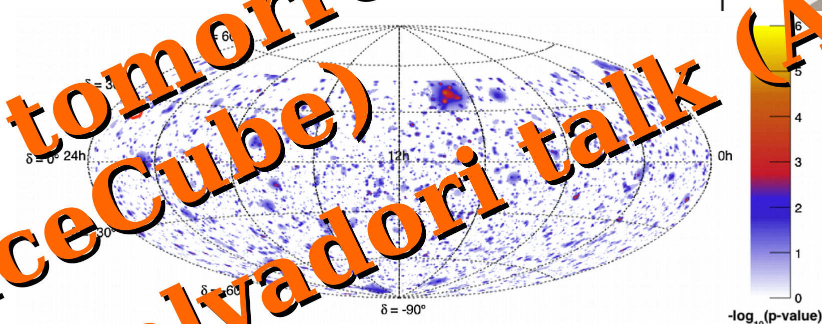
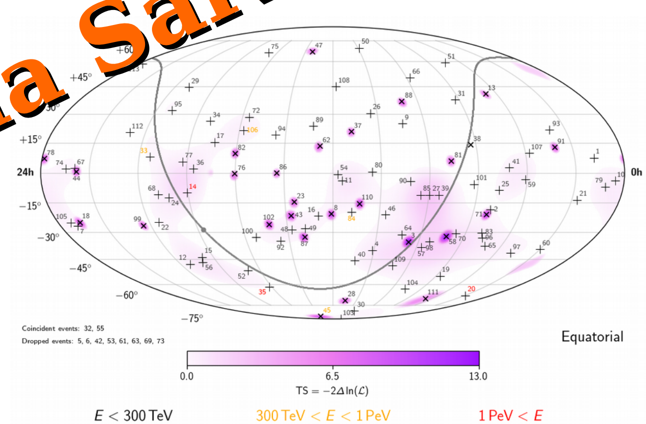
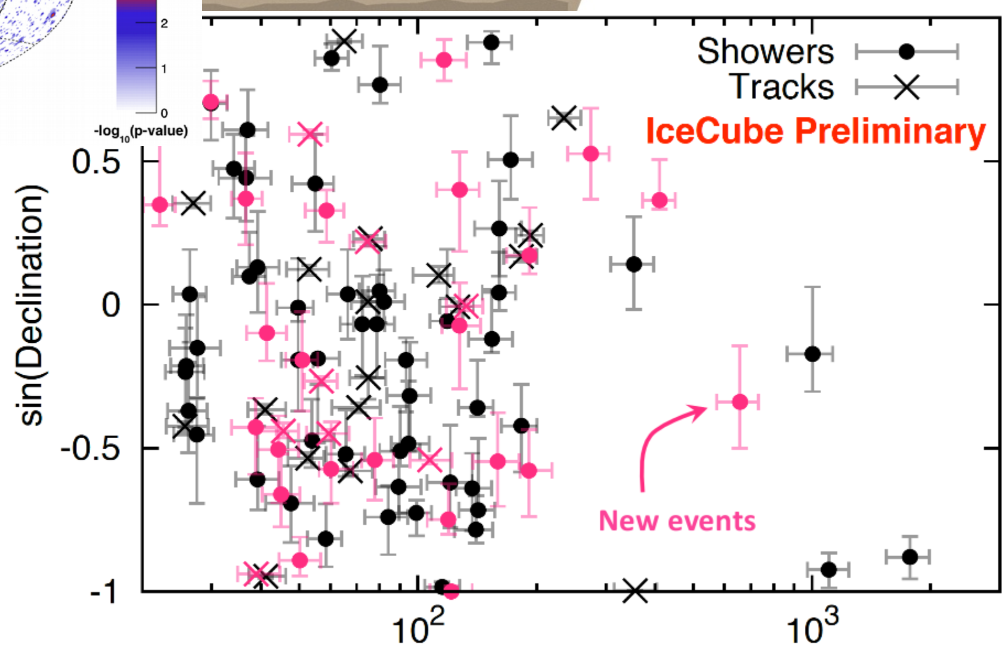
Details tomorrow in Gwenhaël de W. talk (IceCube)

Ilenia Salvadori talk (Antares/ORCA)



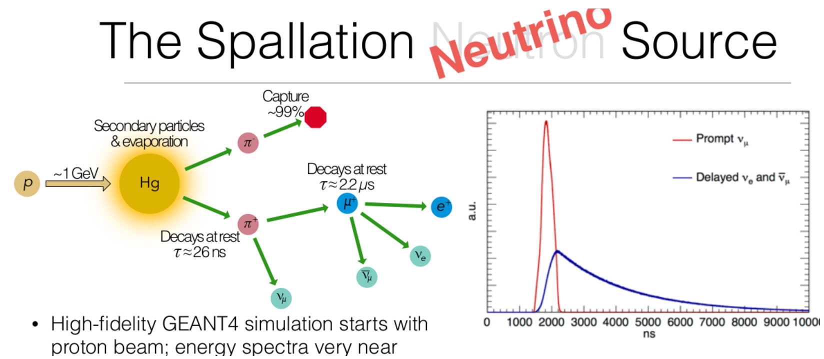


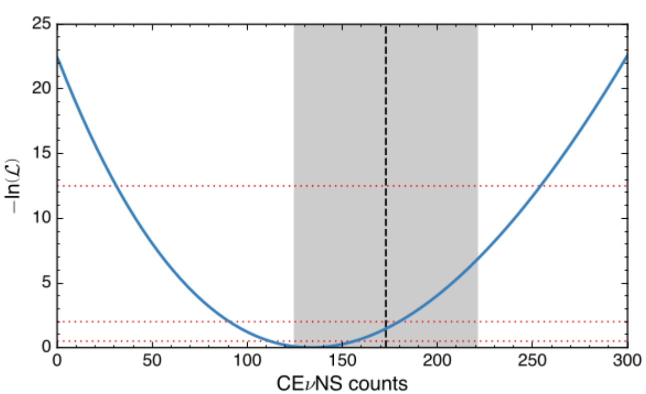




- ***Coherent neutrino scattering***

- Coherent elastic neutrino-nucleus scattering (CEνNS)
- Goal: unambiguous observation of CEνNS using multiple nuclear targets / detector technologies
  - Utilize intense, pulsed neutrino source provided by Spallation Neutron Source (SNS)
- Pioneering CEνNS detector: CsI[Na]
- Results:
  - Beam exposure: ~6 GWhr, or ~1.4 × 10^{23} protons on target (0.22 grams of protons)
  - Analyzed as a simple counting experiment: 136 ± 31 counts
  - 2-D profile likelihood analysis
    - 134 ± 22 counts, within 1-σ of SM prediction of 173 ± 48
    - **Null hypothesis disfavored at 6.7-σ level relative to best-fit number of counts**





Dominant systematic uncertainties on predicted rates

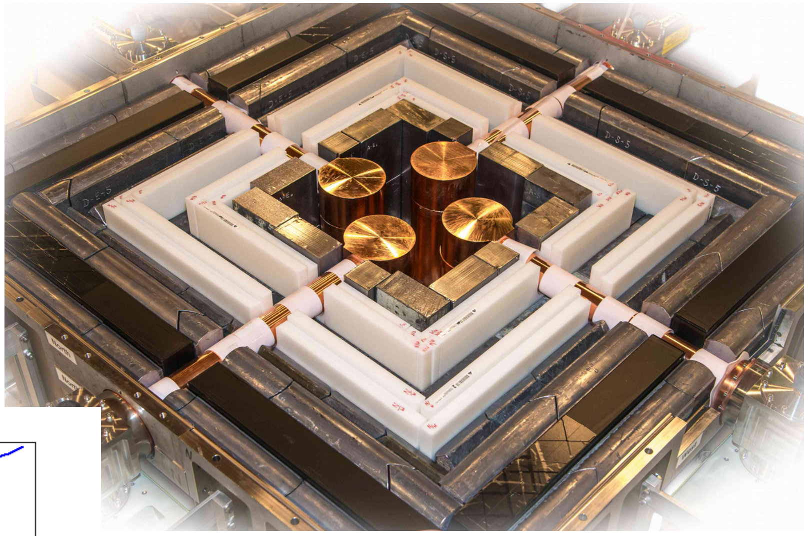
Quenching factor	25%
ν flux	10%
Nuc. form factor	5%
Analysis acceptance	5%

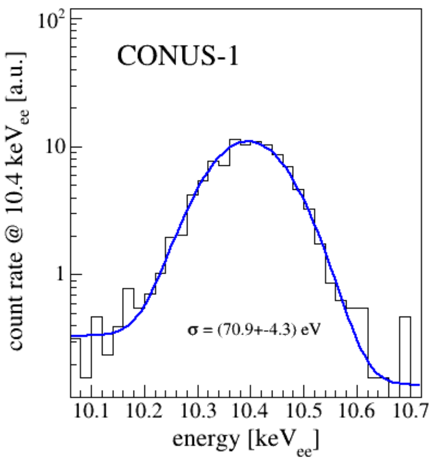
CEνNS predicted in 1974 but unobserved until 2017
→ Observed at 6.7-σ level using 14.6-kg CsI[Na] scintillator deployed at pulsed, stopped-pion ν source (SNS)
COHERENT continues to search for CEνNS with numerous detectors (LAr, NaI[Tl], Ge PPCs)

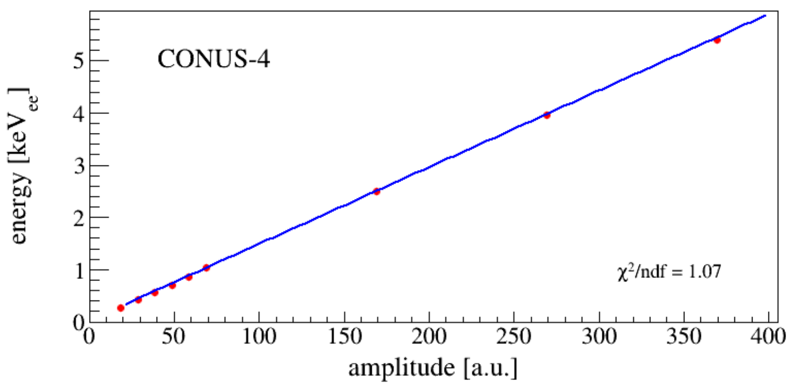
CONUS

Werner Maneschg

- CEνNS detection with reactor neutrinos
- Ge-detector approach
- Operational since April 1, 2018
- After the first 2 months, 114 kg*d / 112 kg*d of reactor OFF/ON data were collected

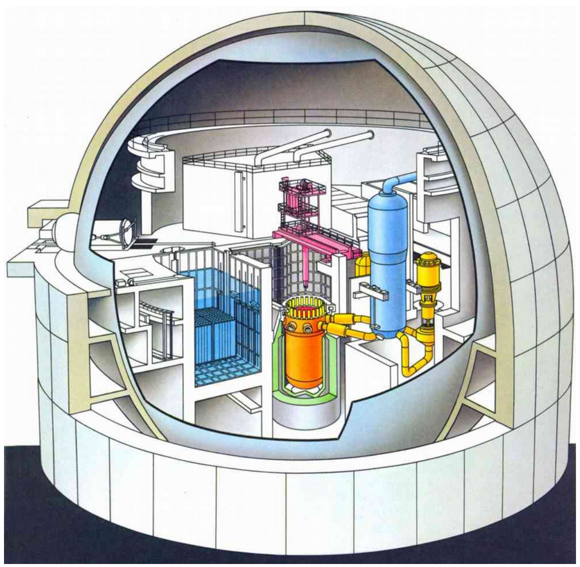






	counts	counts/(d·kg) (*)
reactor OFF (114 kg*d)	582	
reactor ON (112 kg*d)	653	
ON-OFF (exposure corr.)	84	0.94
Significance	**2.4 σ**	2.3 σ

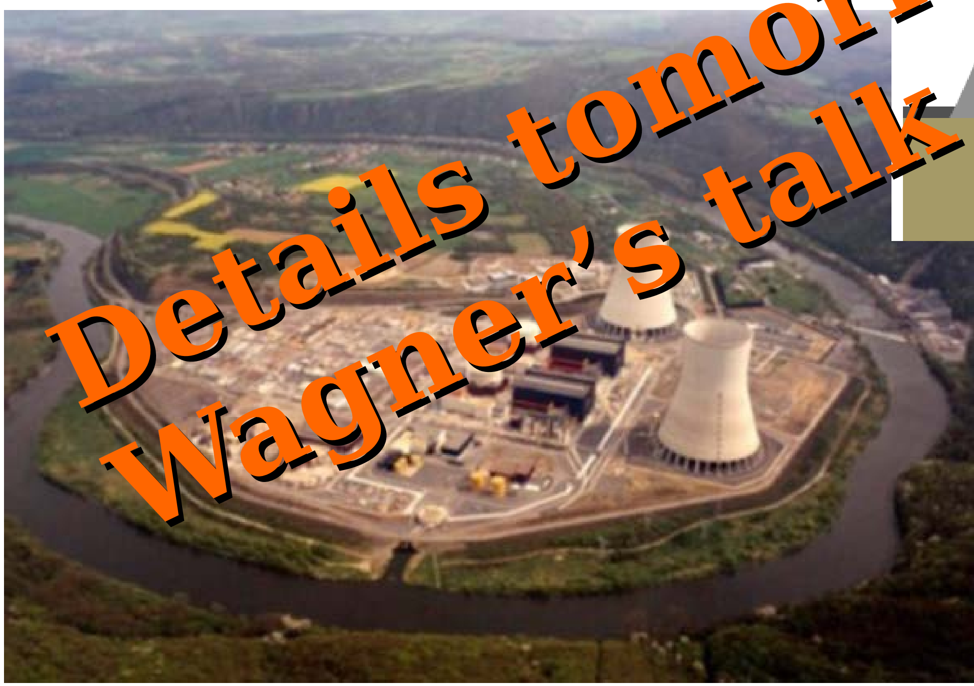
(*) Including stat. uncertainty and above efficiencies

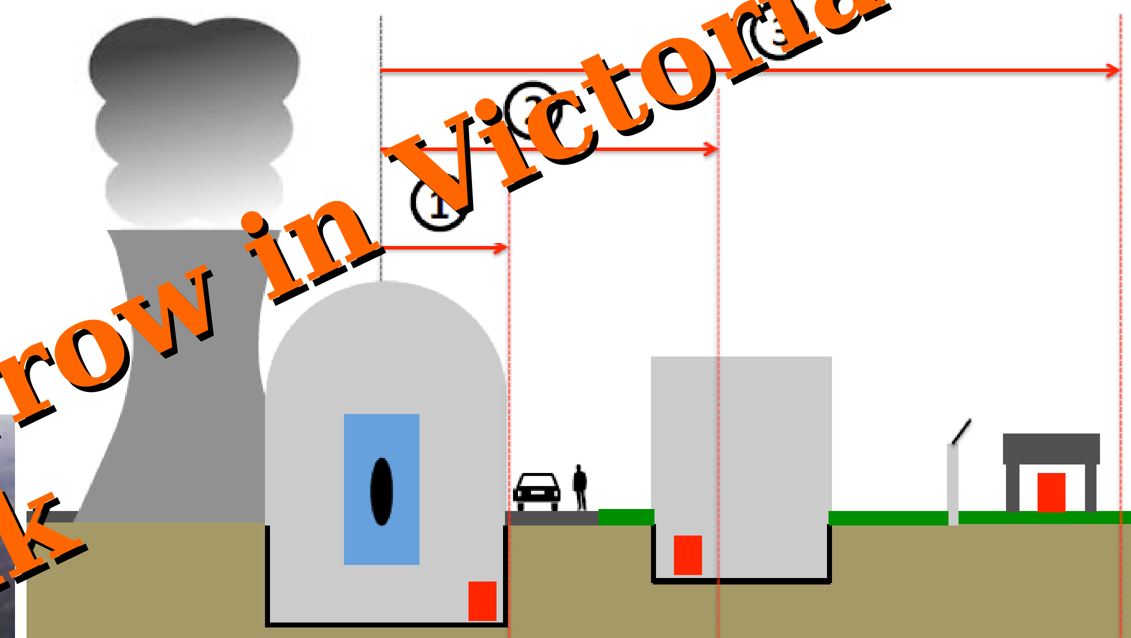


→ Observed excess of events is consistent with expected CEνNS signal range

CEνNS at Chooz

Details tomorrow in Victoria Wagner's talk





	Strategy	Detector mass and E_{th} *
①	Short range (< 10 m)	O(10-100 g) E_{th} < 300 eV
②	Mid range (< 100 m)	O(0.1-1 kg) E_{th} < 100 eV
③	Long range (< 0.5-1 km)	O(1-10 kg) E_{th} < 50 eV

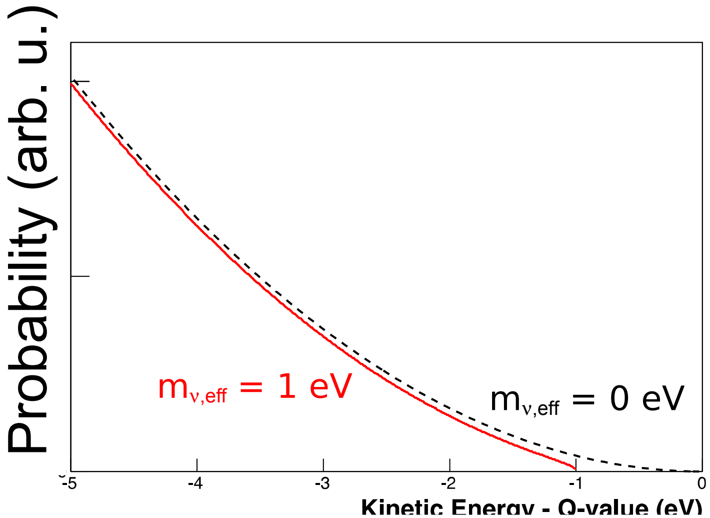
* to get $O(1\ d^{-1})$

- ***Neutrino mass determination***

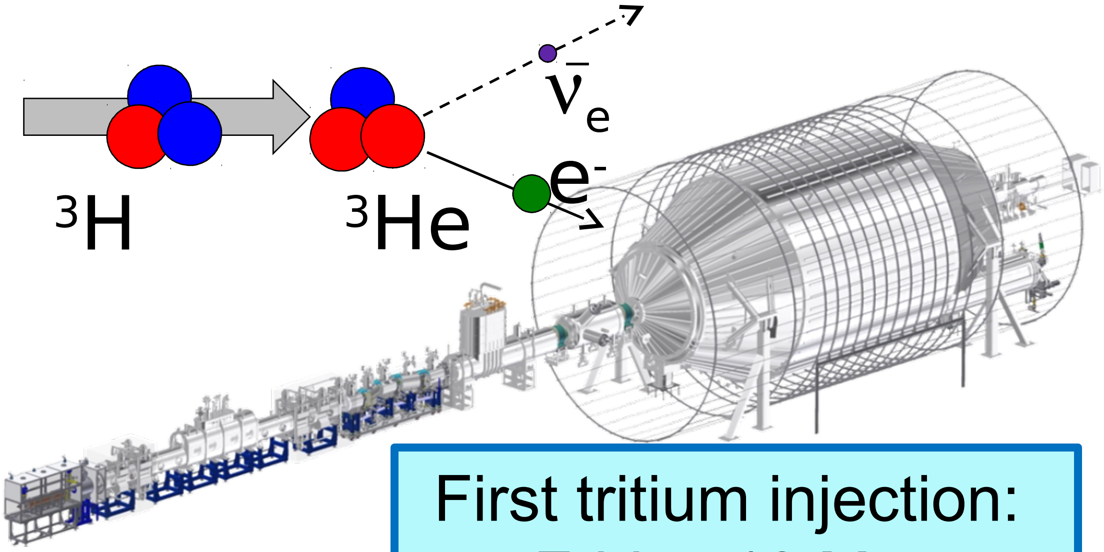
KATRIN

Diana Parno

- High-Precision Neutrino-Mass determination with Tritium
- Full sensitivity ($\sigma_{syst} = \sigma_{stat}$) after 3 beam years (~5 calendar years)



β kinetic energy - Q (eV)



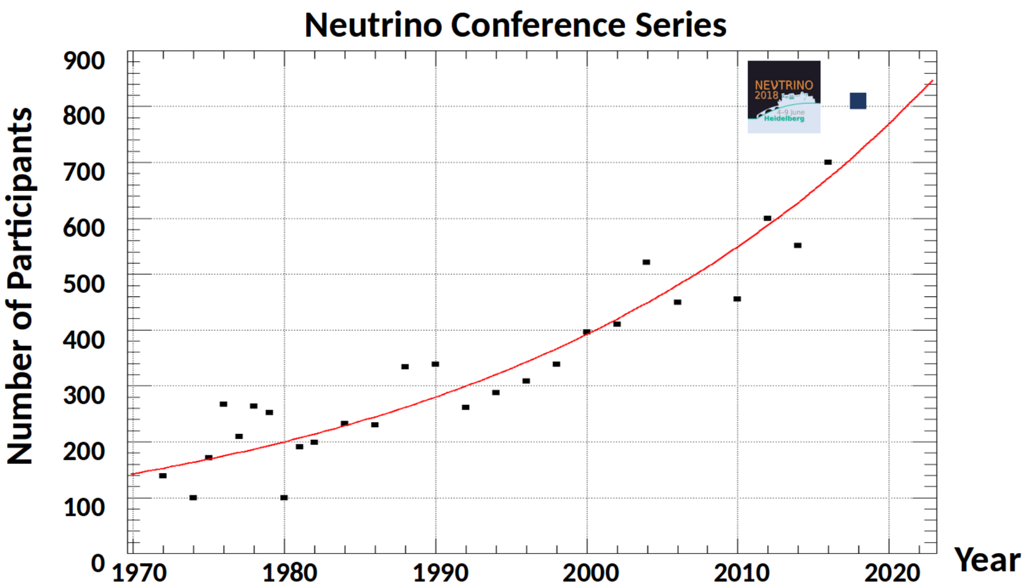
First tritium injection:
Friday 18 May
7:48 am UTC

KATRIN is a working experiment

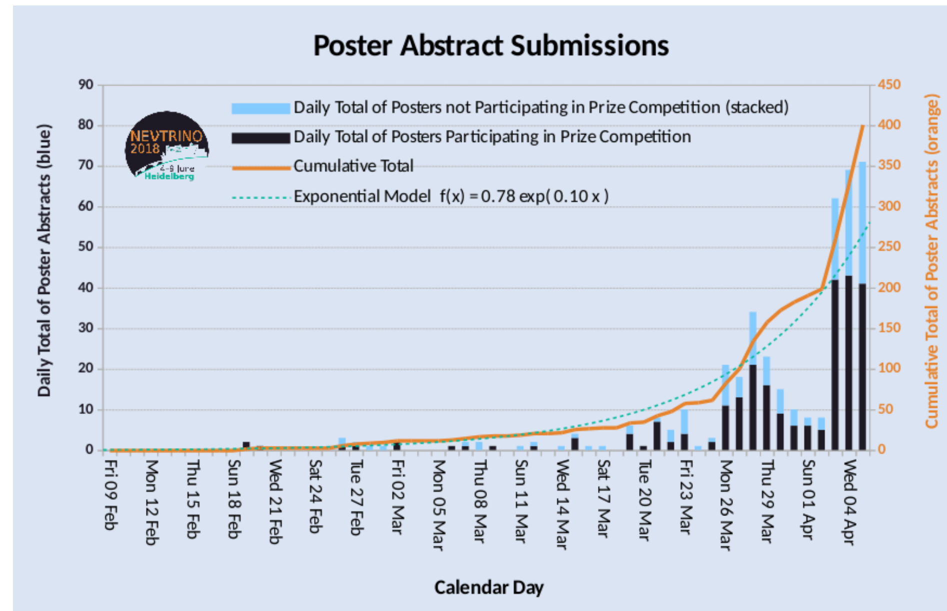
- ***Neutrino 2018***

The people

Record of participants



Record of posters



Goodbye, Heidelberg 2018
Hello, Chicago 2020!
2022 Seoul
2024 Milano

Conclusions

- A lot of new results from different experiments
- T2K/Nova can reach the 3 σ level for δ CP by 2020
  - Next generation DUNE/HK progressing quickly
- Precision measurement of θ_{13} from reactor experiments
  - JUNO development ongoing
- Light sterile neutrino hypothesis could be confirmed or rejected in the short period
- New limits from double beta decay experiments
  - Next generation coming soon

Thanks for your attention

Stay tuned! All these people are working hard to provide new results!