Towards CP Violation in ν Physics – Five Colloquia and Counting?

Praque Colloquium 2019
Oct. 25th, 2019

Dave Wark
Oxford University/RAL

Conclusions and Outlook

From Fedor's talk.

$$\frac{1}{\Lambda}\sum_i c_i^{(5)}\mathcal{O}_i^{(5)}$$

ν's, the Standard Model misfits

WE are at the beginning of the Beyond Standard Model Road…

people often overestimate what will happen in the next two years and underestimate what will happen in ten (Bill Gates)

In two years we will have been having Prague ν Colloquia for ten years

- Where have we got so far?
- What might come in the next two(?) years?
- How will we move beyond that?

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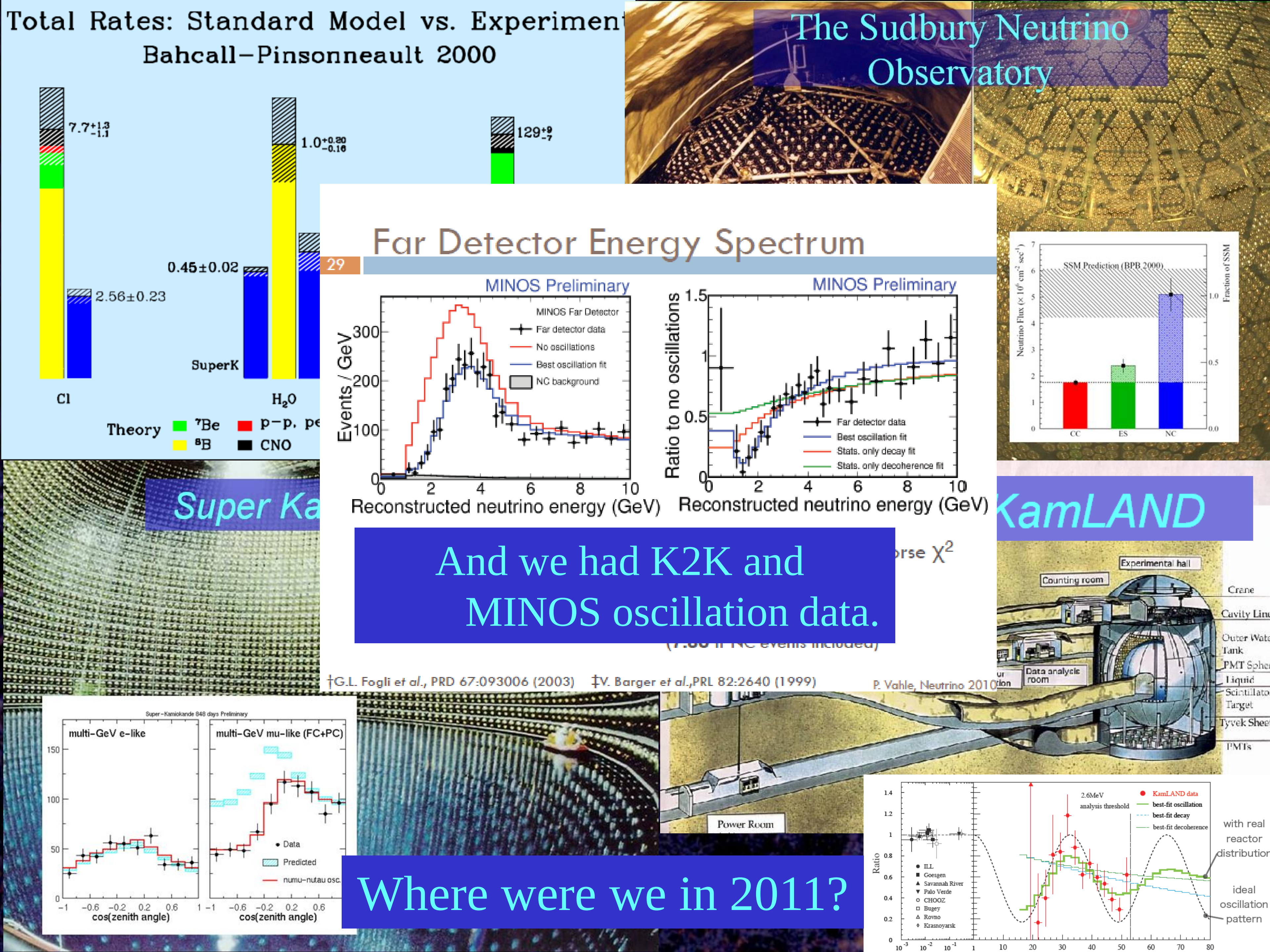
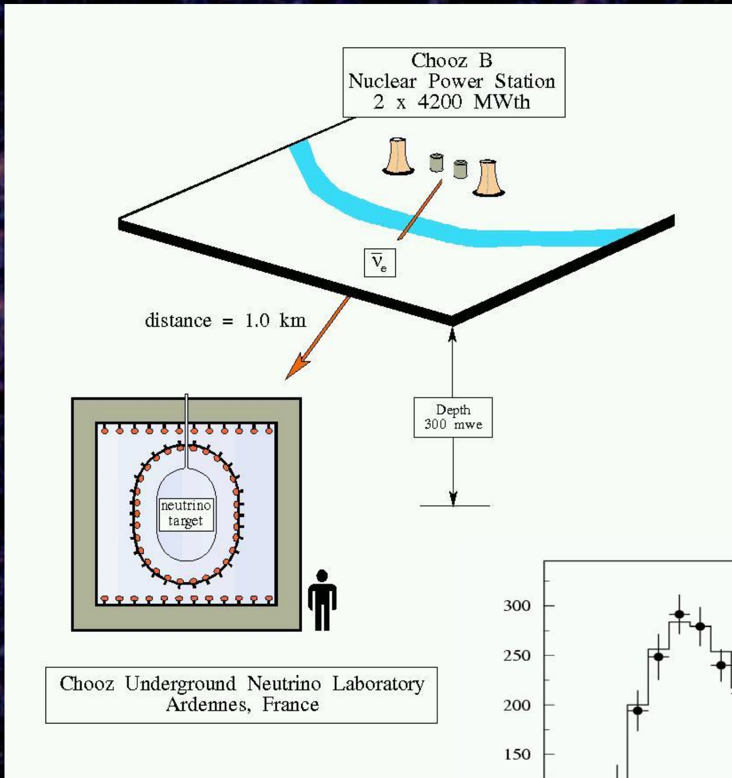
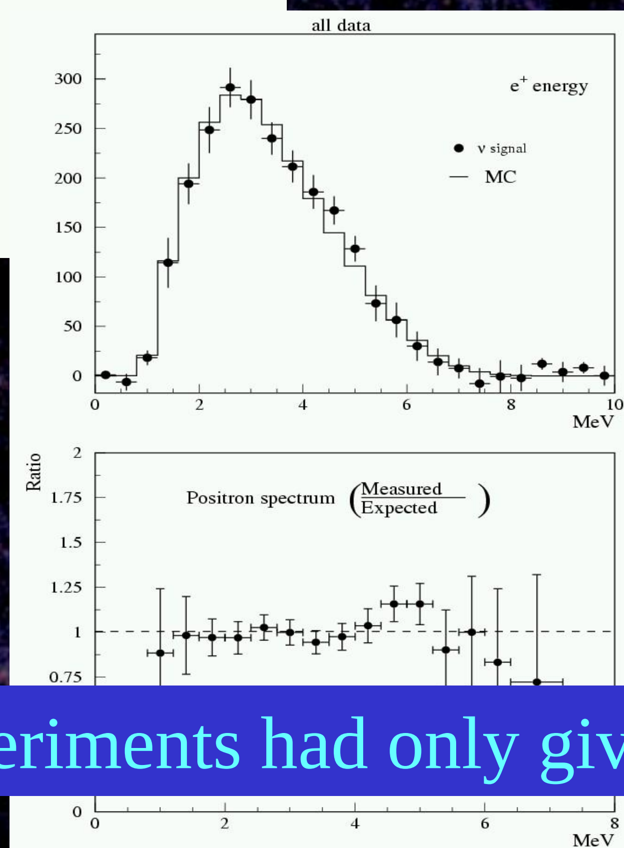
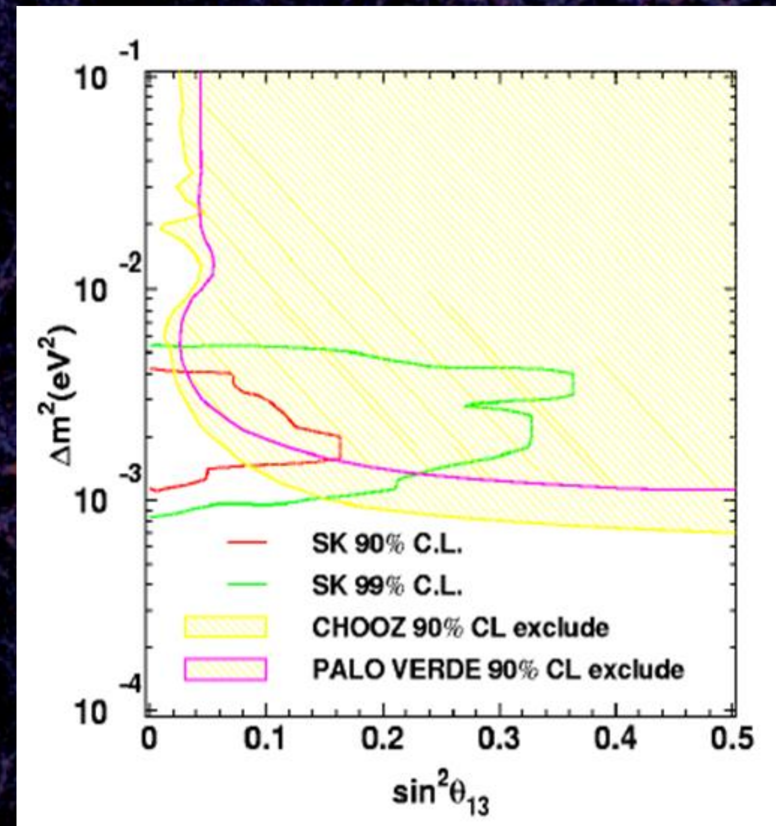

Total Rates: Standard Model vs. Experiment
Bahcall−Pinsonneault 2000
7.7+1.3−1.1
2.56±0.23
0.45±0.02
1.0+0.20−0.16
129+9−7
SuperK
Cl
H2O
Theory
7Be
8B
p−p, pe
CNO
The Sudbury Neutrino Observatory
Far Detector Energy Spectrum
29
MINOS Preliminary
MINOS Far Detector
Far detector data
No oscillations
Best oscillation fit
NC background
Events / GeV
Reconstructed neutrino energy (GeV)
Ratio to no oscillations
Far detector data
Best oscillation fit
Stats. only decay fit
Stats. only decoherence fit
SSM Prediction (BPB 2000)
Neutrino Flux (× 10^6 cm^−2 sec^−1)
Fraction of SSM
CC
ES
NC
Super Ka
KamLAND
And we had K2K and
MINOS oscillation data.
†G.L. Fogli et al., PRD 67:093006 (2003)
‡V. Barger et al., PRL 82:2640 (1999)
P. Vahle, Neutrino 2010
Experimental hall
Counting room
Crane
Data analysis room
Power Room
Super−Kamiokande 848 days Preliminary
multi−GeV e−like
multi−GeV mu−like (FC+PC)
Data
Predicted
numu−nutau osc.
cos(zenith angle)
Where were we in 2011?
2.6MeV analysis threshold
KamLAND data
best-fit oscillation
best-fit decay
best-fit decoherence
ILL
Goesgen
Savannah River
Palo Verde
CHOOZ
Bugey
Rovno
Krasnoyarsk
Ratio
with real reactor distribution
ideal oscillation pattern

Chooz and Palo Verde Limits on θ_{13}







Reactor experiments had only given limits on θ_{13}

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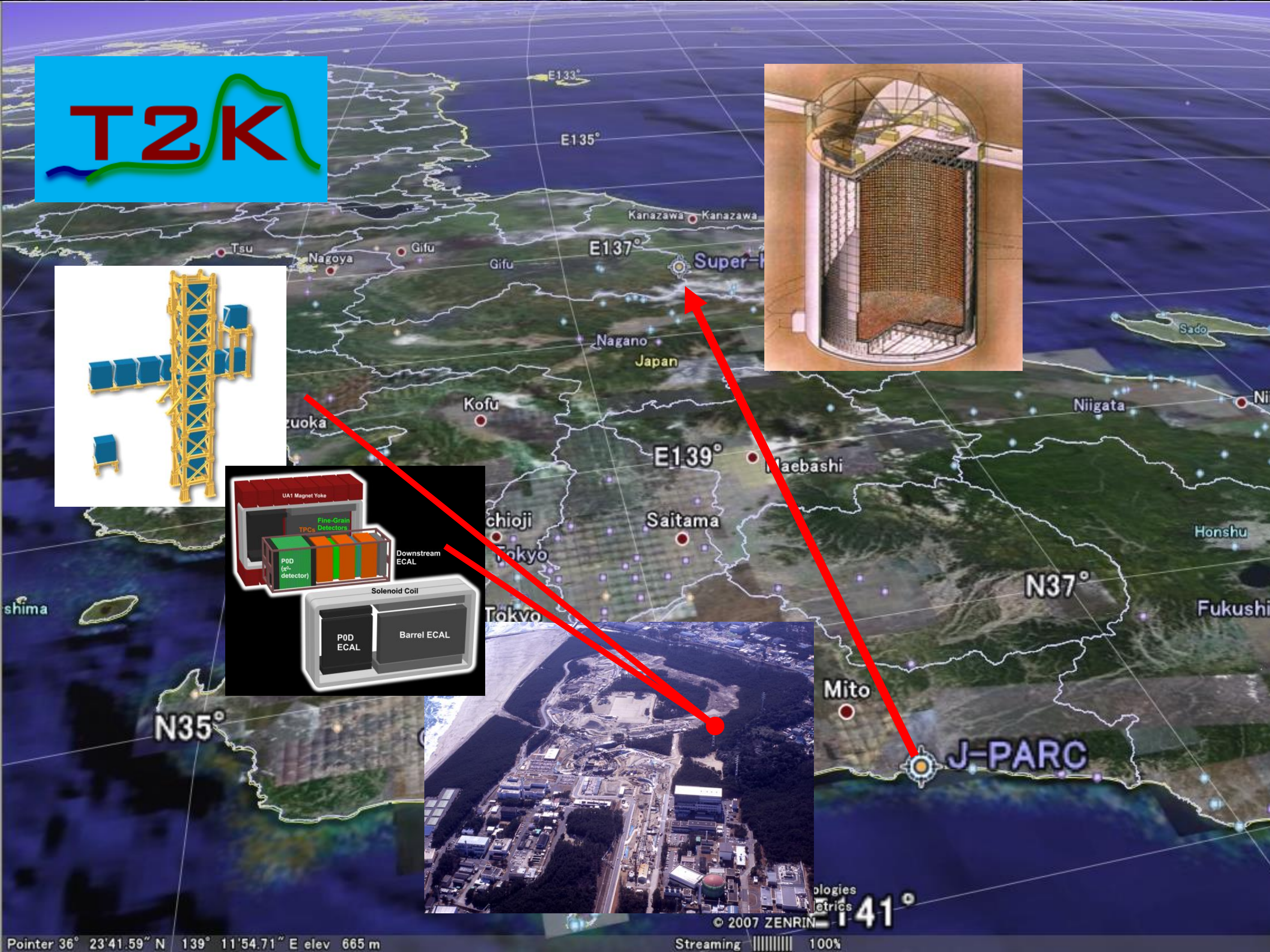
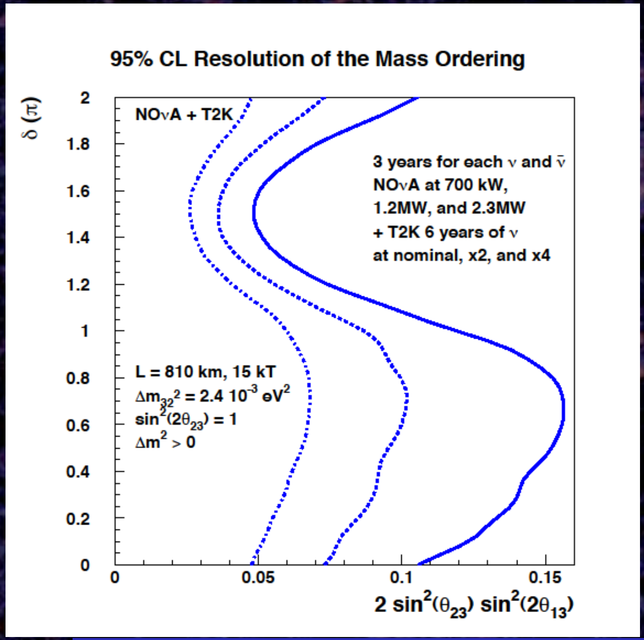
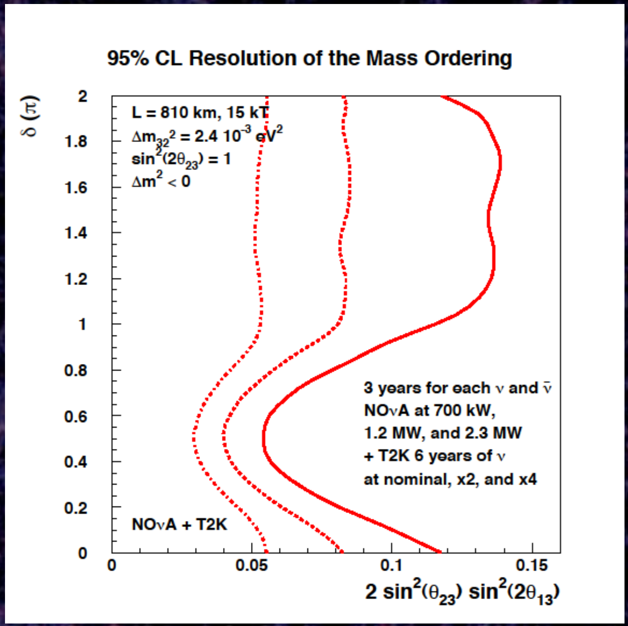


T2K
E133°
E135°
Kanazawa
Kanazawa
Tsu
Nagoya
Gifu
Gifu
E137°
Nagano
Japan
Sado
Kofu
Niigata
E139°
Saitama
Tokyo
Honshu
N37°
Tokyo
Mito
J-PARC
N35°
E141°
UA1 Magnet Yoke
Fine-Grain Detectors
TPCs
P0D (π^0-detector)
Downstream ECAL
Solenoid Coil
P0D ECAL
Barrel ECAL
© 2007 ZENRIN
Pointer 36° 23'41.59" N 139° 11'54.71" E elev 665 m
Streaming 100%

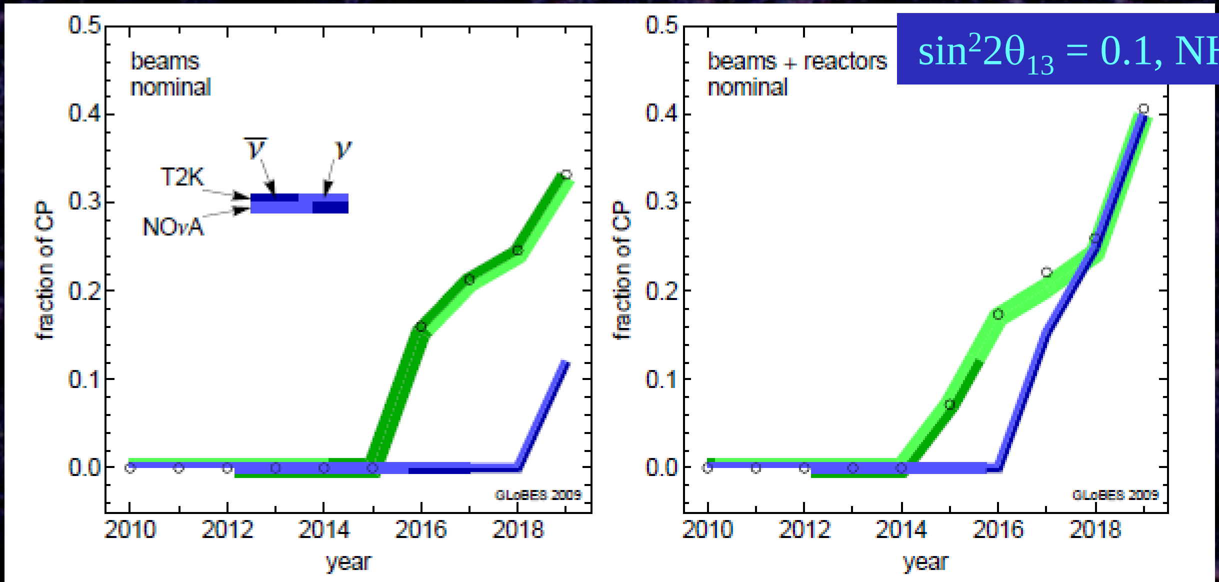
What will existing experiments yield?





Even some 90% CP violation sensitivity...

$\sin^2 2\theta_{13} = 0.1$, NH



arXiv:0907.1896v1 [hep-ph] 10 Jul 2009

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We had theorists leading us (astray?).

An incremental approach to CP ?

- **Excitement ➡ H. Murayama presented his (anarchical) prediction for mixing angles $\theta_{12}, \theta_{23}, \theta_{13}$ which hinted at a large θ_{13}**

$$P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e) = -16 s_{12} c_{12} s_{13} c_{13}^2 s_{23} c_{23} \sin\delta \sin\frac{\Delta m_{12}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{23}^2 L}{4E}$$

all parameters turned out to be favorable !!!

- **What about δ_{CP} ?**
  - ➡ the favorable values δ_{CP}=90, 270º are still allowed. Will Nature be kind again ?
  - ➡ if so, one could find evidence for CP violation in the lepton sector early on
  - ➡ if not, we can upgrade the sensitivity by increasing the far detector mass and/or beam power

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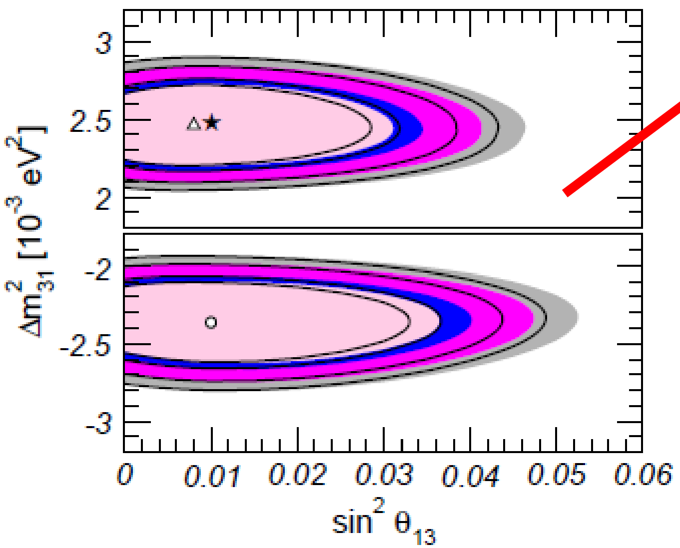
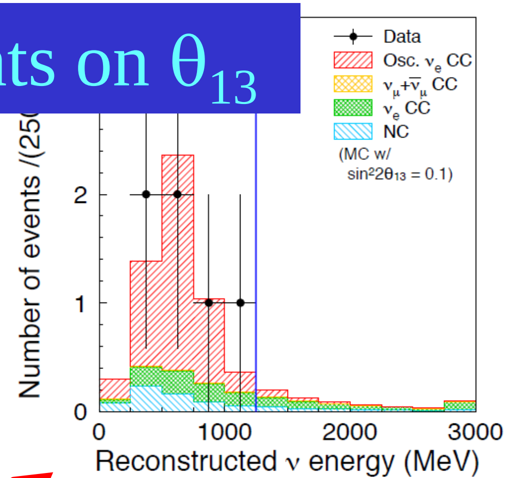
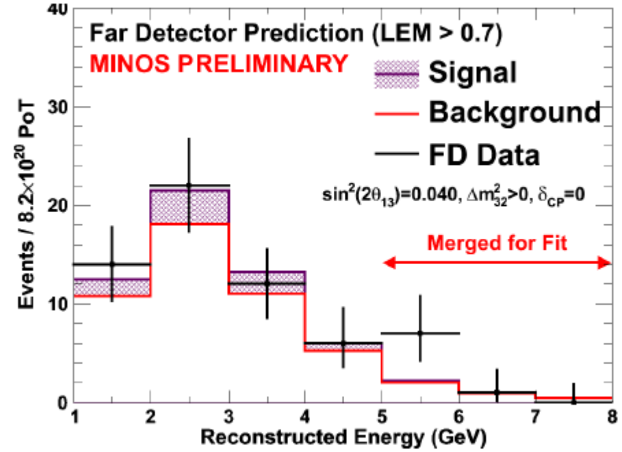
No CP info, just hints on θ_{13}

What about θ_{13}?





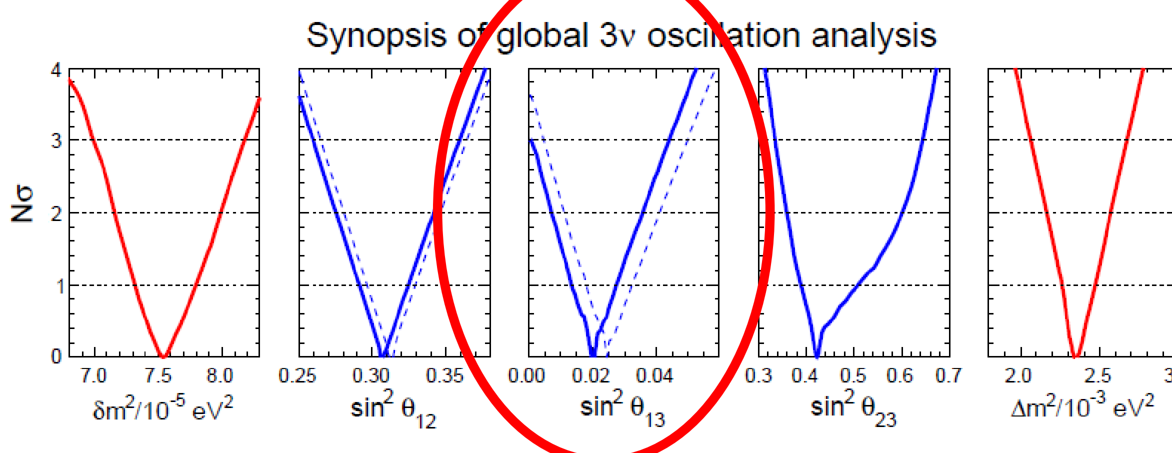


T2K (2.5σ) MINOS (1.7σ)

ν_e appearance, $\theta_{13} > 0$?

Evidence of $\theta_{13} > 0$ from global neutrino data analysis

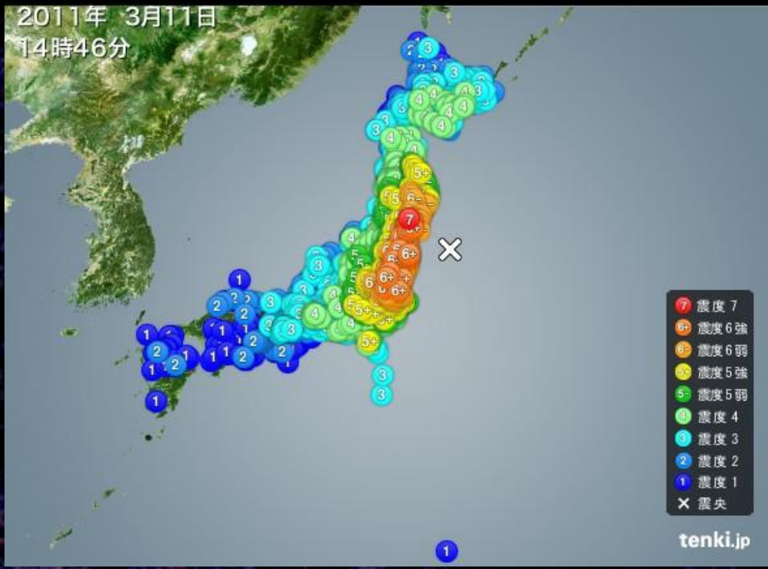
G.L. Fogli,[1,2] E. Lisi,[2] A. Marrone,[1,2] A. Palazzo,[3] and A.M. Rotunno[1]



arXiv:1106.6028v1 [hep-ph] 29 Jun 2011

Interesting hints that $\theta_{13} > 0$, but clearly more data needed.

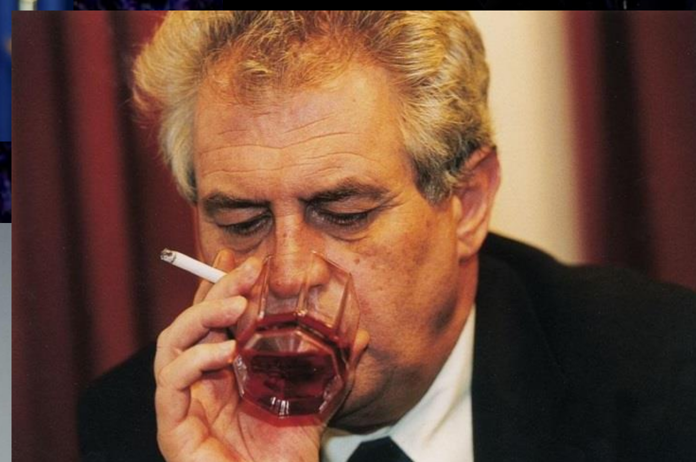
5/11, 14:46, all
Hell broke loose...



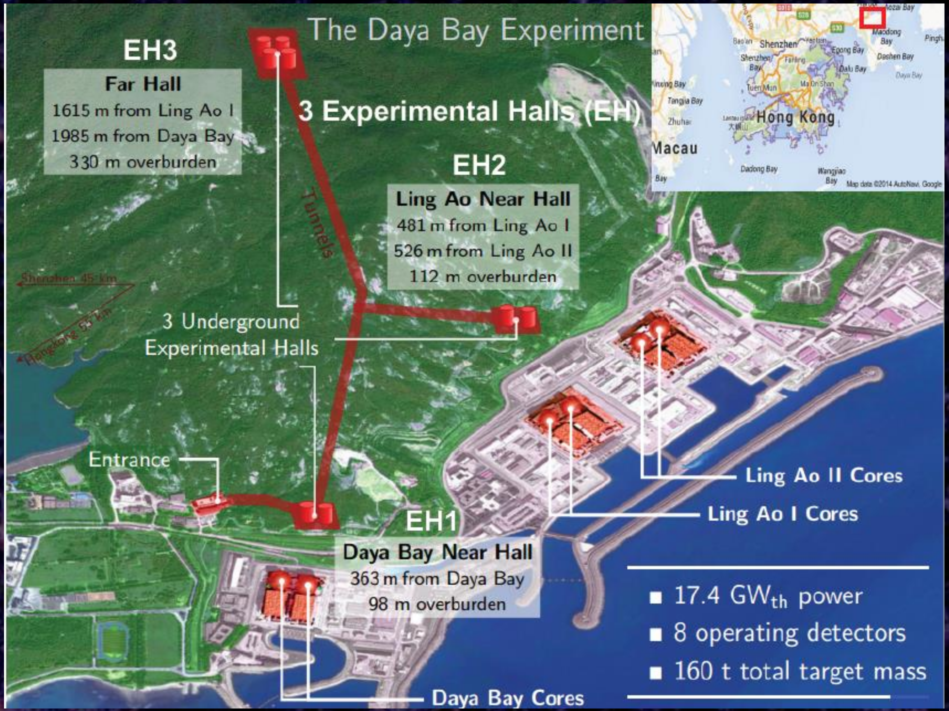
The outside world was giving us issues. . .

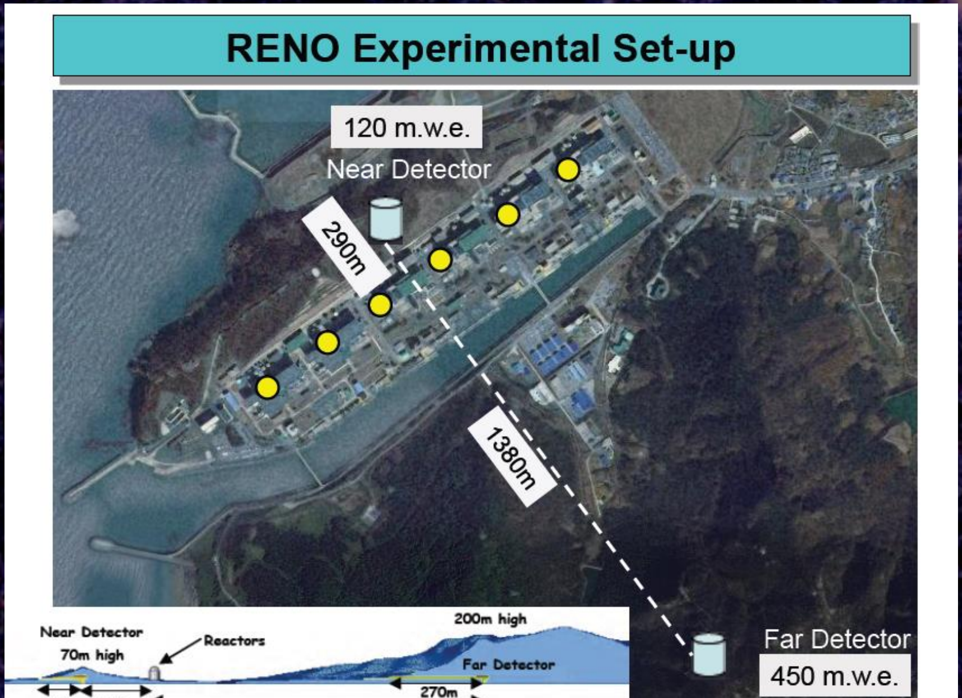
So where are we now, in October 2019 ?

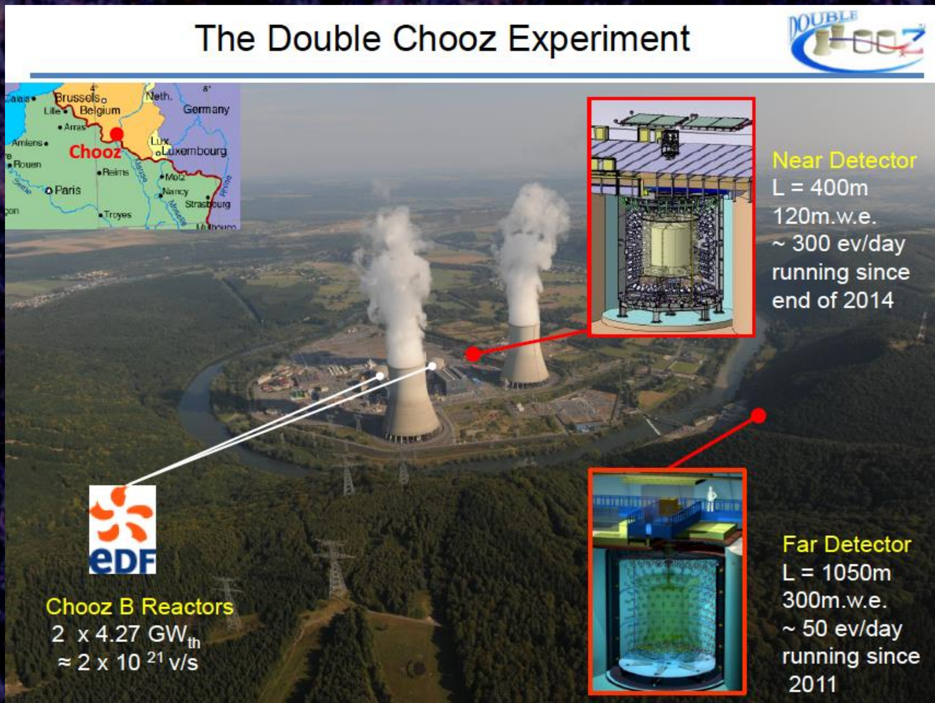
The outside world is still giving us issues. . .



Reactor Experiments







Latest Results From Daya Bay

Kam-Biu Luk
University of California, Berkeley
And
Lawrence Berkeley Nati
On Behalf of the Daya B

大亚湾反应堆中微子实验站
Daya Bay Reactor Neutrino Experiment Station

Neutrino Colloquium
24 October

Daya Bay θ13

Prompt-energy Spectrum in 2018

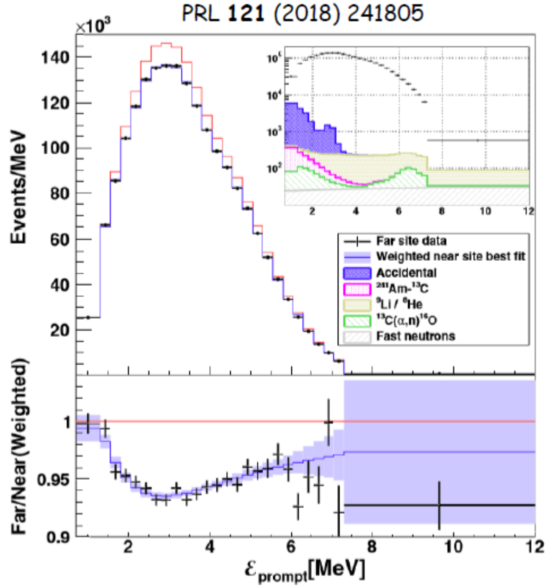
1958 days of data

- 3.5 millions inverse beta decay candidates (IBDs) were detected in the near halls, and 0.5 million IBDs in the far hall.
- B/S ≲ 2% in all halls

	EH1	EH2	EH3
Accidental/IBD	1.3%	1.0%	1.3%
^{9}Li-^{8}He/IBD	0.4%	0.3%	0.3%
Fast n/IBD	0.1%	0.1%	0.07%
Am-C/IBD	0.03%	0.02%	0.07%
^{13}C(α,n)^{16}O/IBD	0.01%	0.01%	0.04%

Background contributes <0.15% to the uncertainty in the IBD rate

PRL **121** (2018) 241805



DoubleChooz

(status 2019)

Colloquium ...

2019

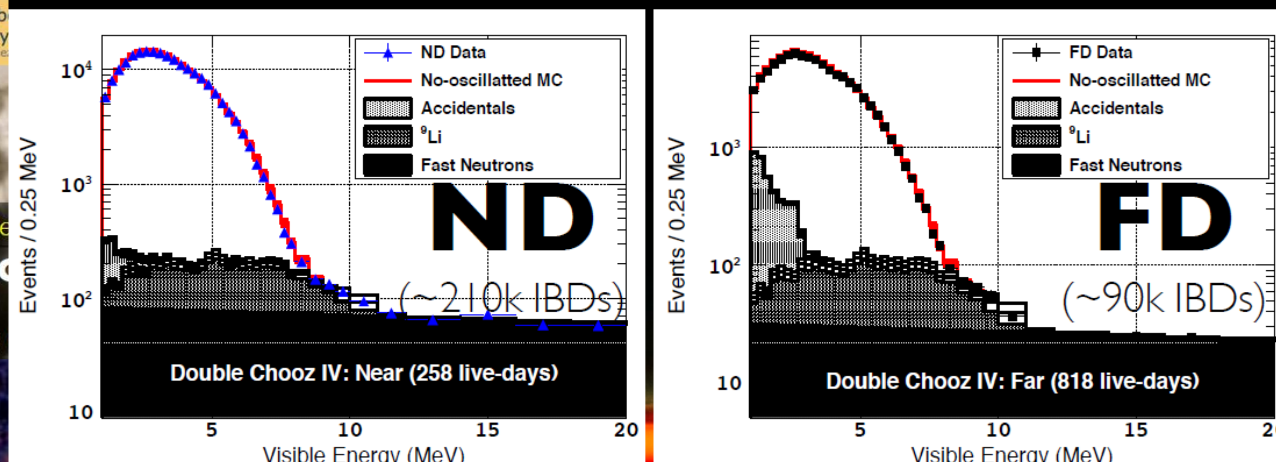
24-25 Octob...
J. Heyrovsky...
Europe/Prague time...

on behalf of the Double...

Anatael C...

CNRS / IN2P3 @ LAL/FLUO

each single-detector (SD) spectra…



well understood spectra signal & BG

(**reactor "ILL data" based model**→scrutinise)

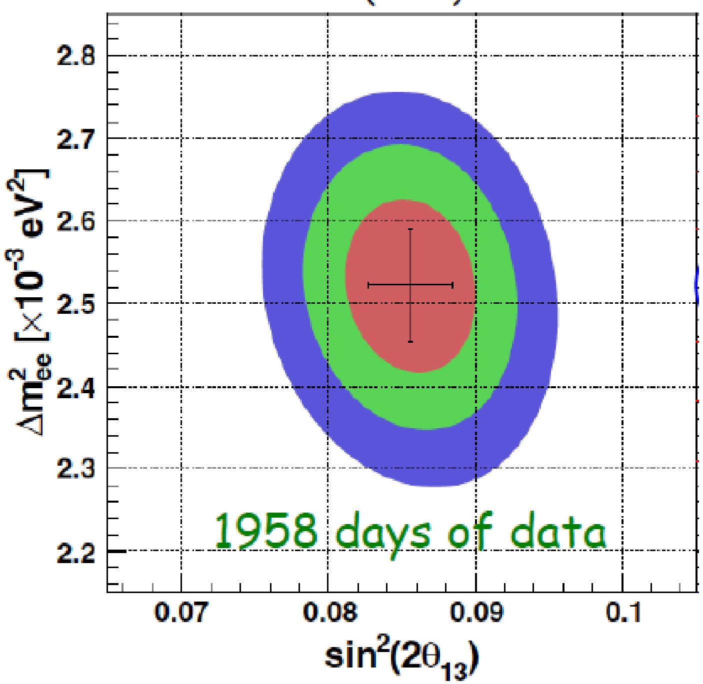
multi-detector (MD) combination

(physics extraction)

Most Precise $\sin^2 2\theta_{13}$ & Δm^2_{ee}

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right) + \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$

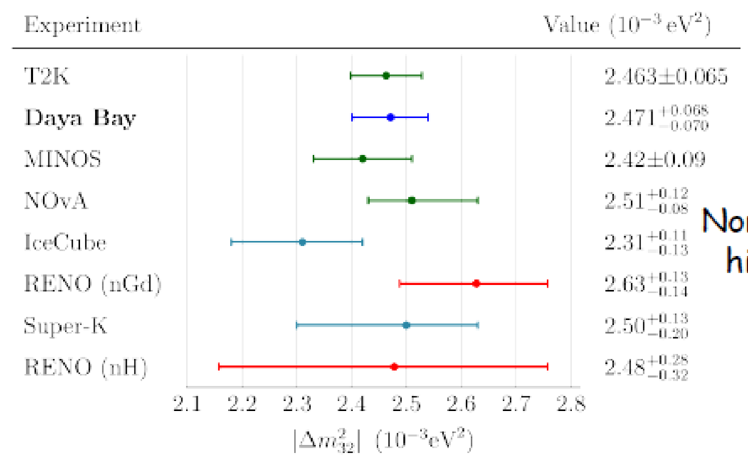
PRL **121** (2018) 241805



$$\sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right) \leftrightarrow \cos^2\theta_{12}\sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) + \sin^2\theta_{12}\sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)$$

$\Delta m^2_{32} = +(2.471^{+0.068}_{-0.070}) \times 10^{-3}$ eV^2 (NH)

$\Delta m^2_{32} = -(2.575^{+0.068}_{-0.070}) \times 10^{-3}$ eV^2 (IH)



Δm^2_{32}
Normal mass hierarchy

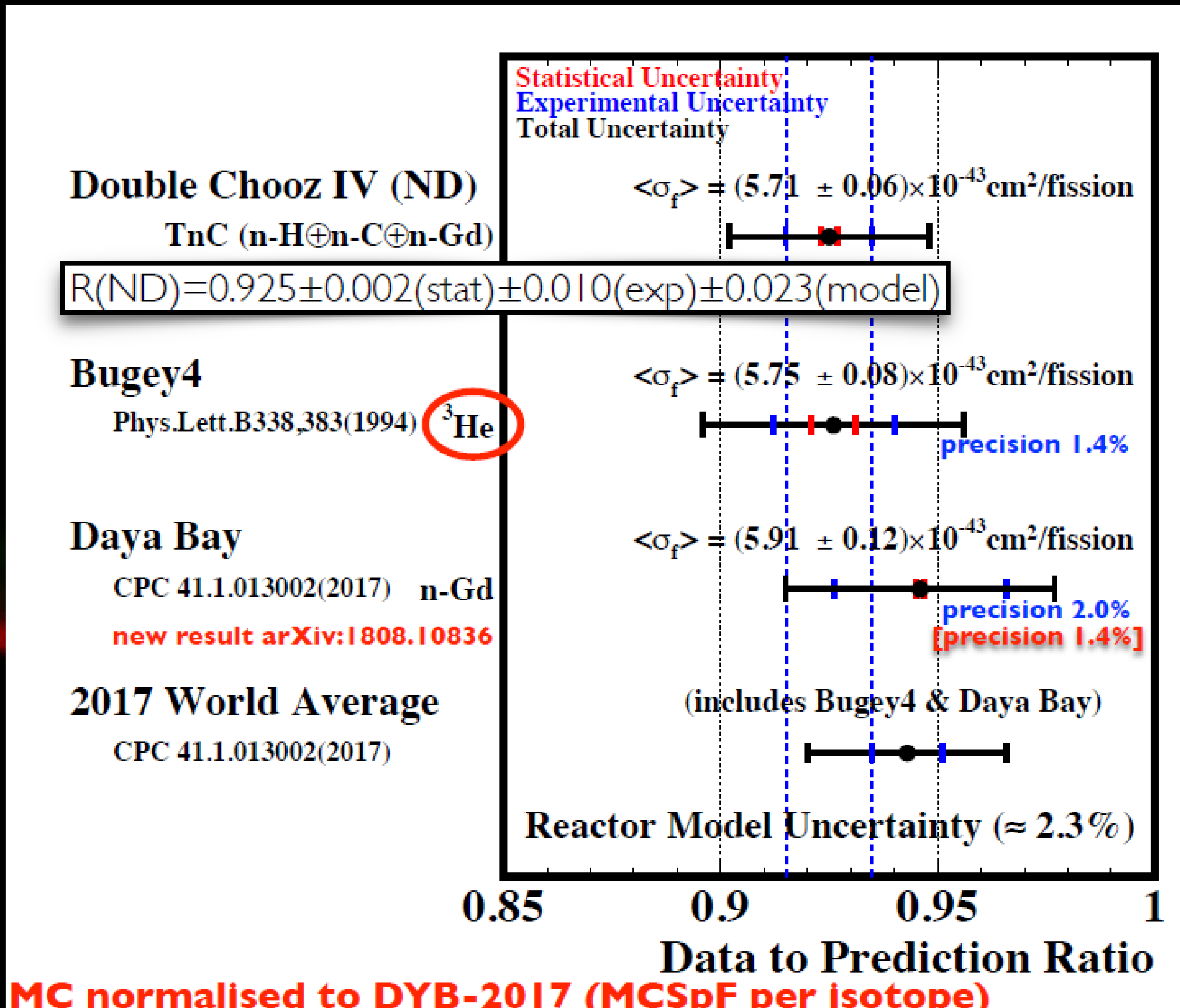
$\sin^2 2\theta_{13} = 0.0856 \pm 0.0029$

$\Delta m^2_{ee} = (2.522^{+0.068}_{-0.070}) \times 10^{-3}$ eV^2

$|\Delta m^2_{32}|$'s obtained with ν_e & ν_μ agree, supporting 3-flavor paradigm

our ND rate (normalisation) validation…

Mean Cross-Section per Fission



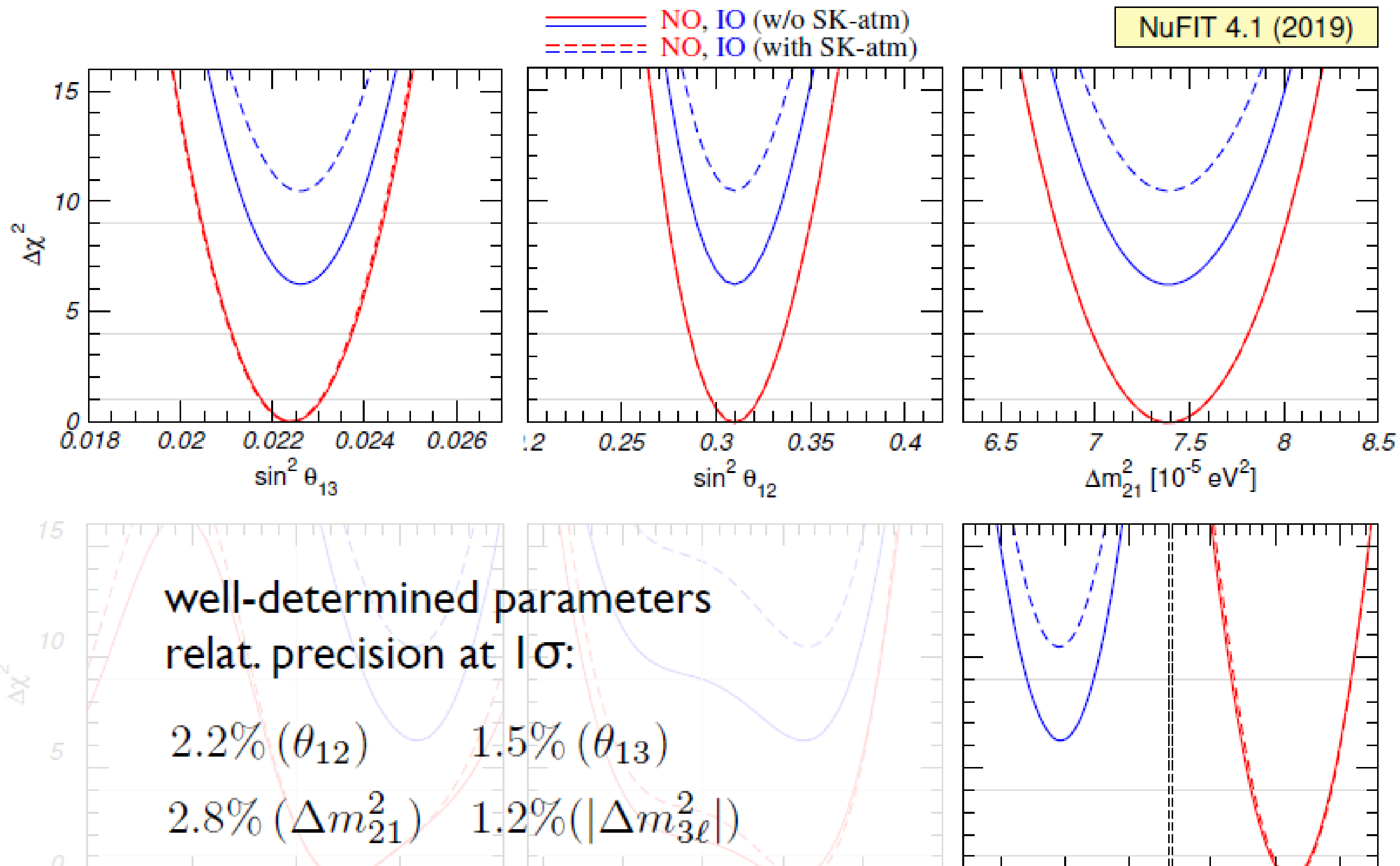
best world precision (9.7‰)

ND normalisation→ no impact to θ13!

(excellent agreement with Bugey4 et al)

NuFit 4.1 (2019)

www.nu-fit.org



well-determined parameters
relat. precision at 1σ:

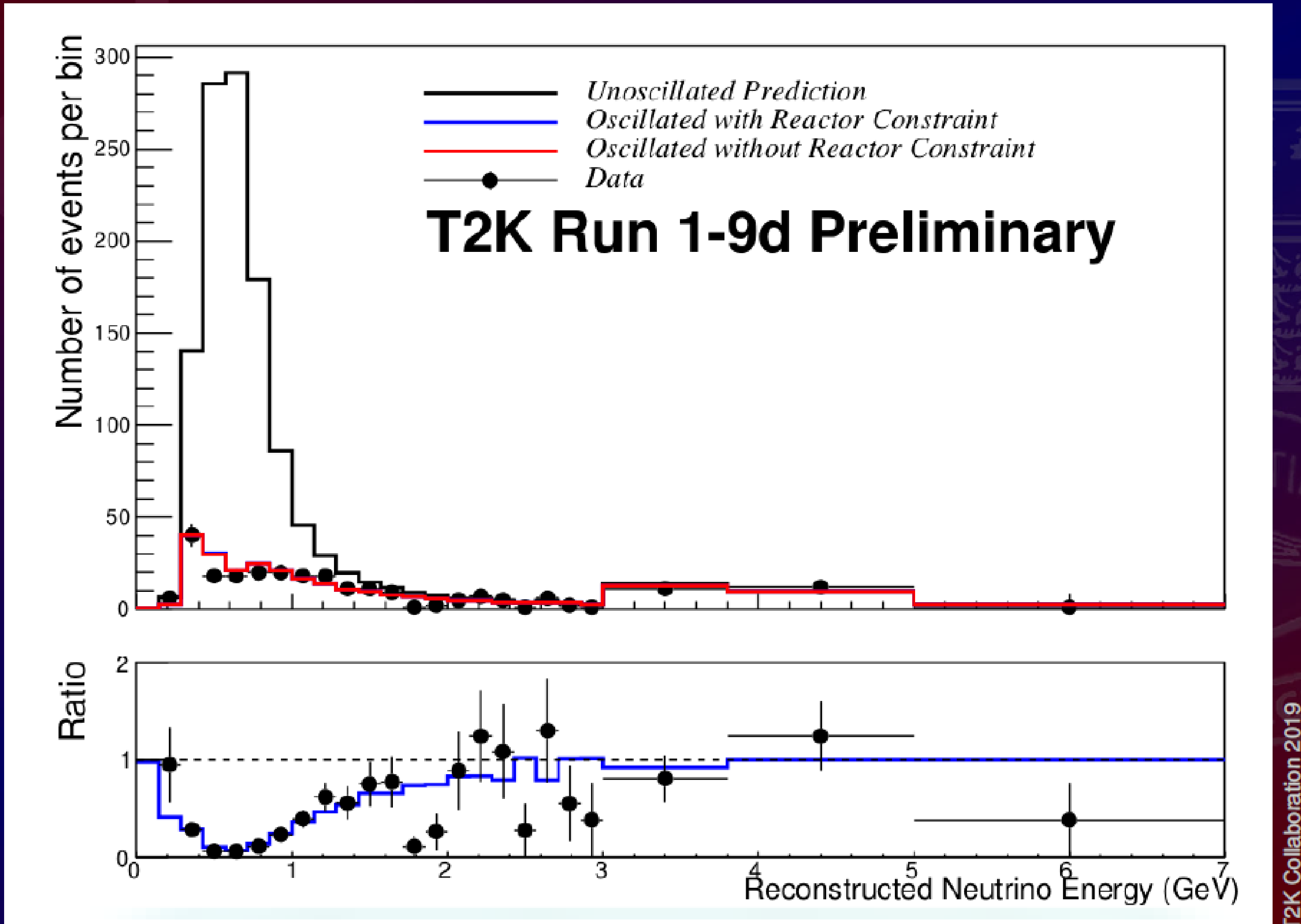
$2.2\% \, (\theta_{12})$ $\quad 1.5\% \, (\theta_{13})$

$2.8\% \, (\Delta m^2_{21})$ $\quad 1.2\% (|\Delta m^2_{3\ell}|)$

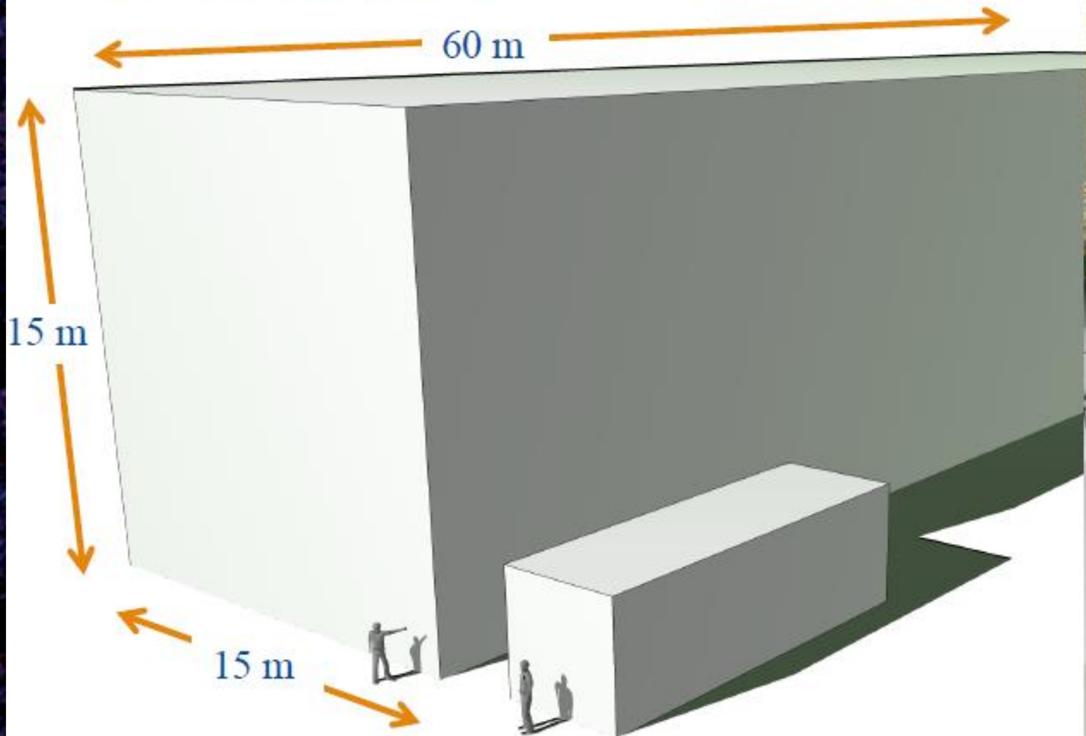
In 8 years θ_{13} has gone from unknown to the most accurately measured angle!

Latest Results from T2K

Disappearance of ν_μ from a ν_μ beam



NOvA Detectors

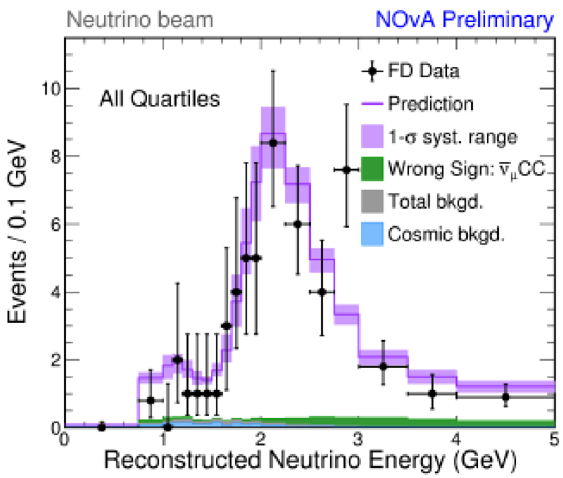


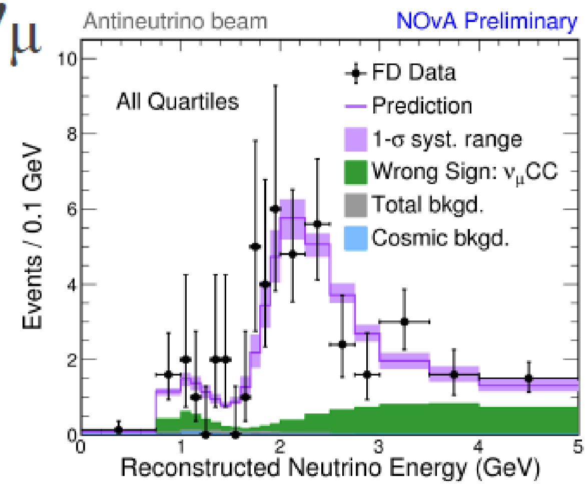
- Far Detector
  - 14 kt, 896 planes

- Near Detector at Fermilab
  - 293 tons, including muon catcher
  - used to measure neutrino beam flavor and energy spectrum before oscillations

Far Detector Data and Oscillation Fit

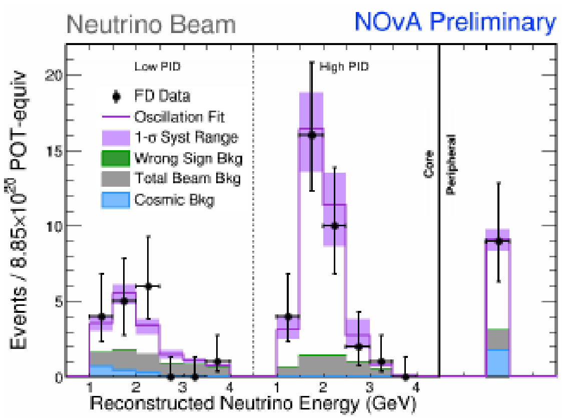
ν_μ

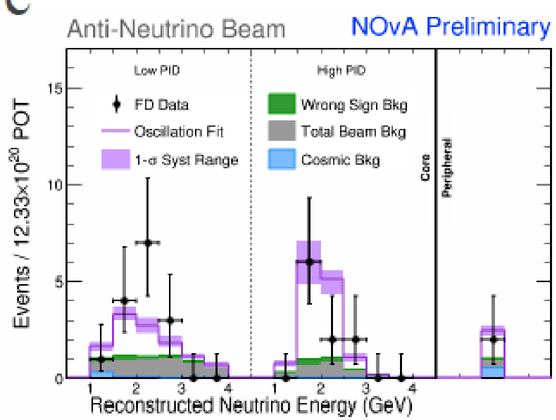




	ν	$\bar{\nu}$
Observed	*113*	*102*
Best Fit	*124*	*96*
Signal	*120(11)*	*93.9 (8)*
Background	*4.2(0.5)*	*2.2(0.4)*
No Oscillation	*730*	*476*

ν_e





	ν	$\bar{\nu}$
Observed	*58*	*27*
Best Fit	*59.3*	*26.8*
Signal	*44.3(3.8)*	*16.6(1)*
Background	*15.0(0.9)*	*10.3(0.6)*
(Wrong Sign)	*0.6*	*2.2*

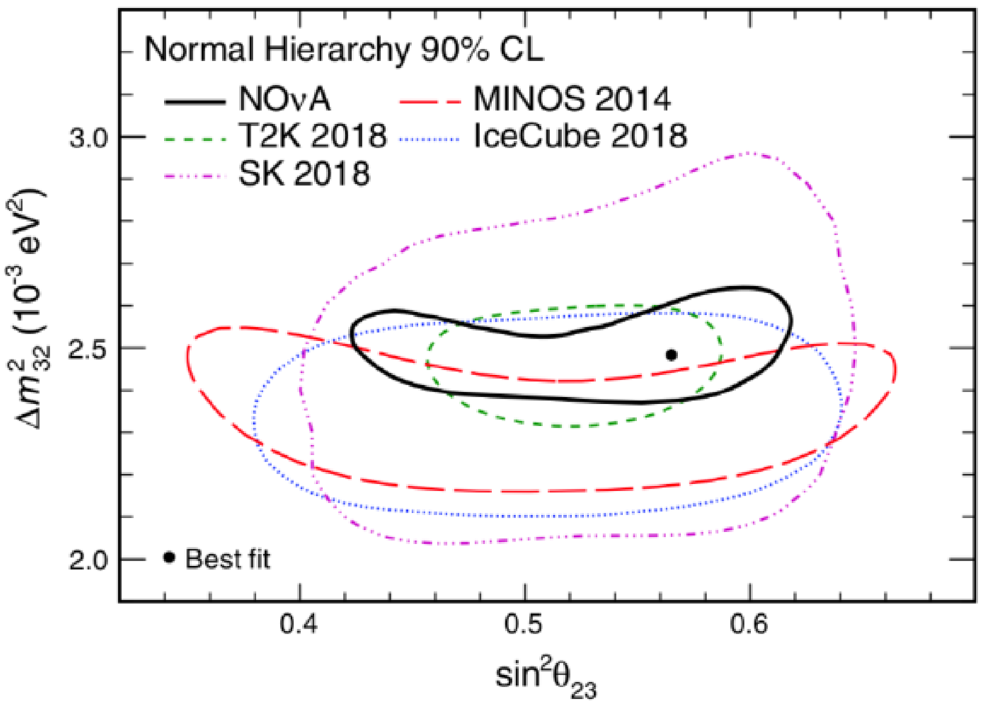
Note: uncertainties () are approximate
see arXiv:1906.04907 for full table

Oscillation Parameters from Joint fit to data

Best fit (with reactor θ_{13} constraint):

- **$\Delta m^2_{32}=(+2.48^{+0.11}_{-0.06}$ x10^{-3}) eV^2**
- **$\sin^2(\theta_{23})=0.56^{+0.04}_{-0.03}$ (upper octant)**
- **Previous slight tension (p=0.04) between disappearance fit in neutrino and antineutrino beams has resolved with more statistics**

Feldman-Cousins Contours



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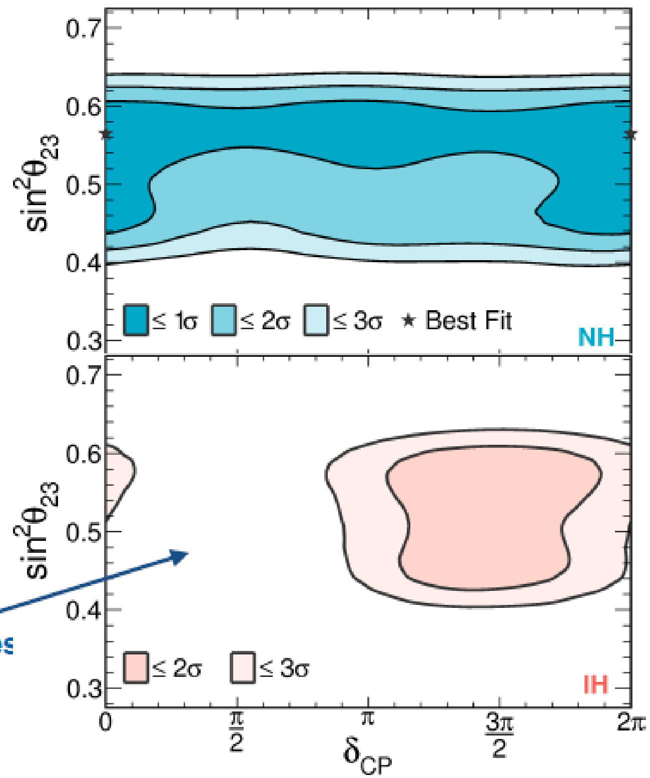
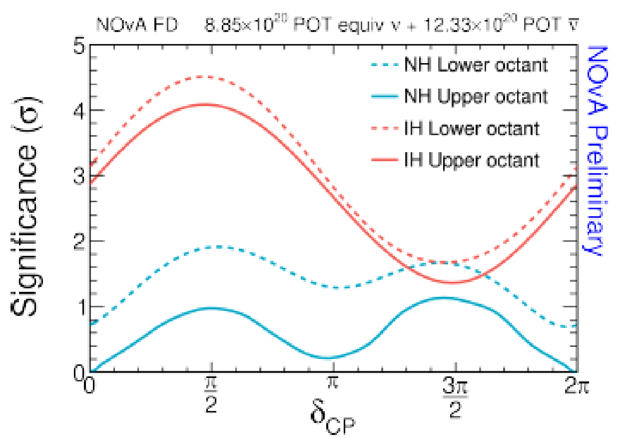


- **Normal Hierarchy**
- $\delta_{CP}/\pi=0.0^{+1.3}_{-0.4}$

Large slice of δ_{CP} values disfavored at > 3σ for all θ_{23} values in IH



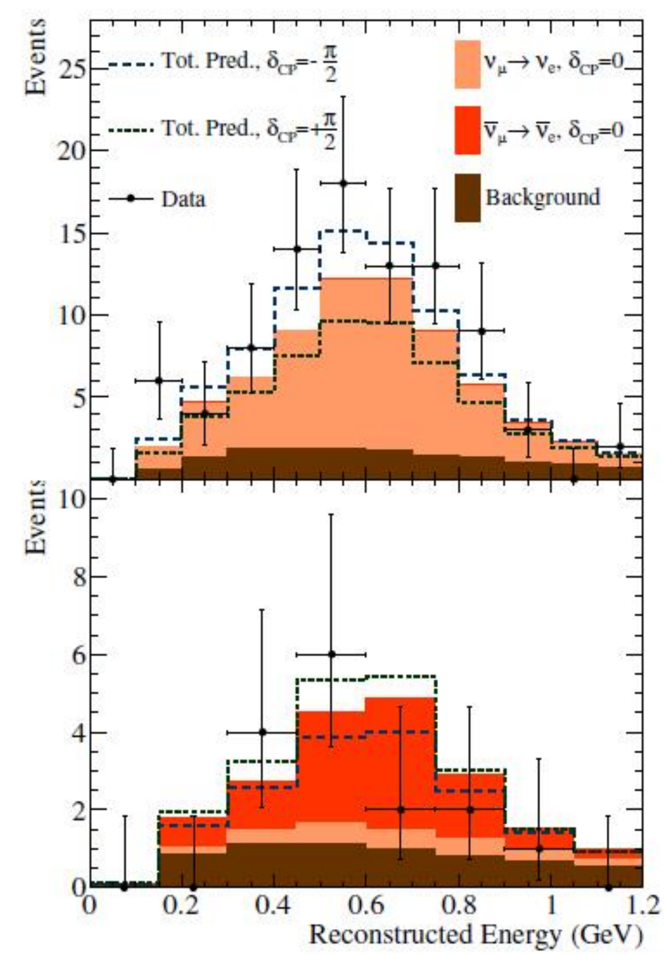
Profiling over all other parameters

- **Normal Hierarchy preferred at 1.9σ**
- **Upper θ_{23} Octant preferred at 1.6σ**
- Within Normal MH, Upper Octant, all values of δ_{CP} compatible at 1.1σ

Latest Results from T2K

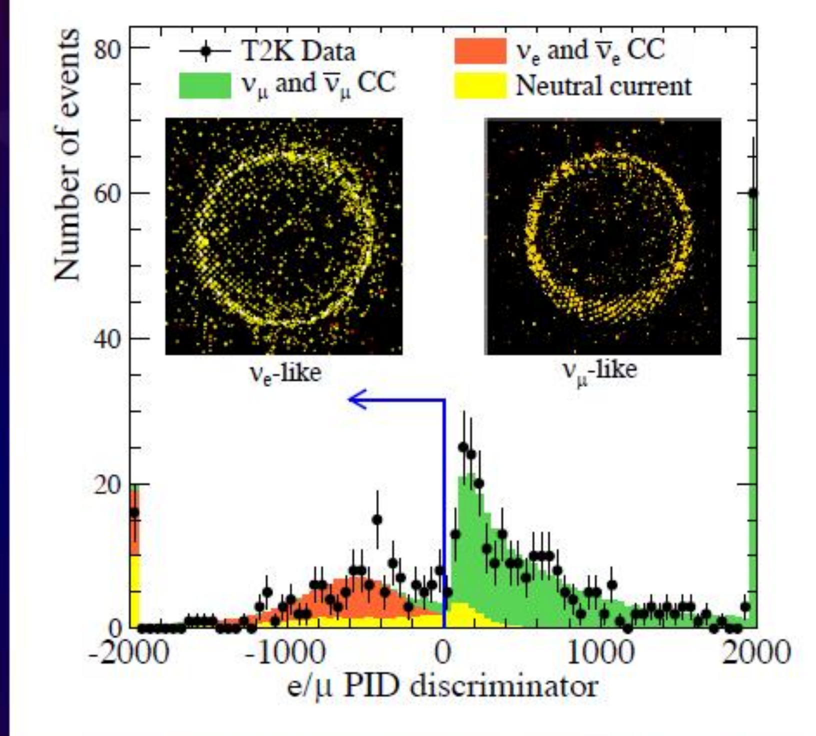
CP Violation

Current version of the 2011 plot, now for both neutrinos and antineutrinos, and how the appearance signal is affected by CP violation



Sample	ν-mode Events	$\bar{\nu}$-mode Events
Single Electron	75 (74.8)	15 (17.2)
Charged Pion	15 (7.0)	N/A

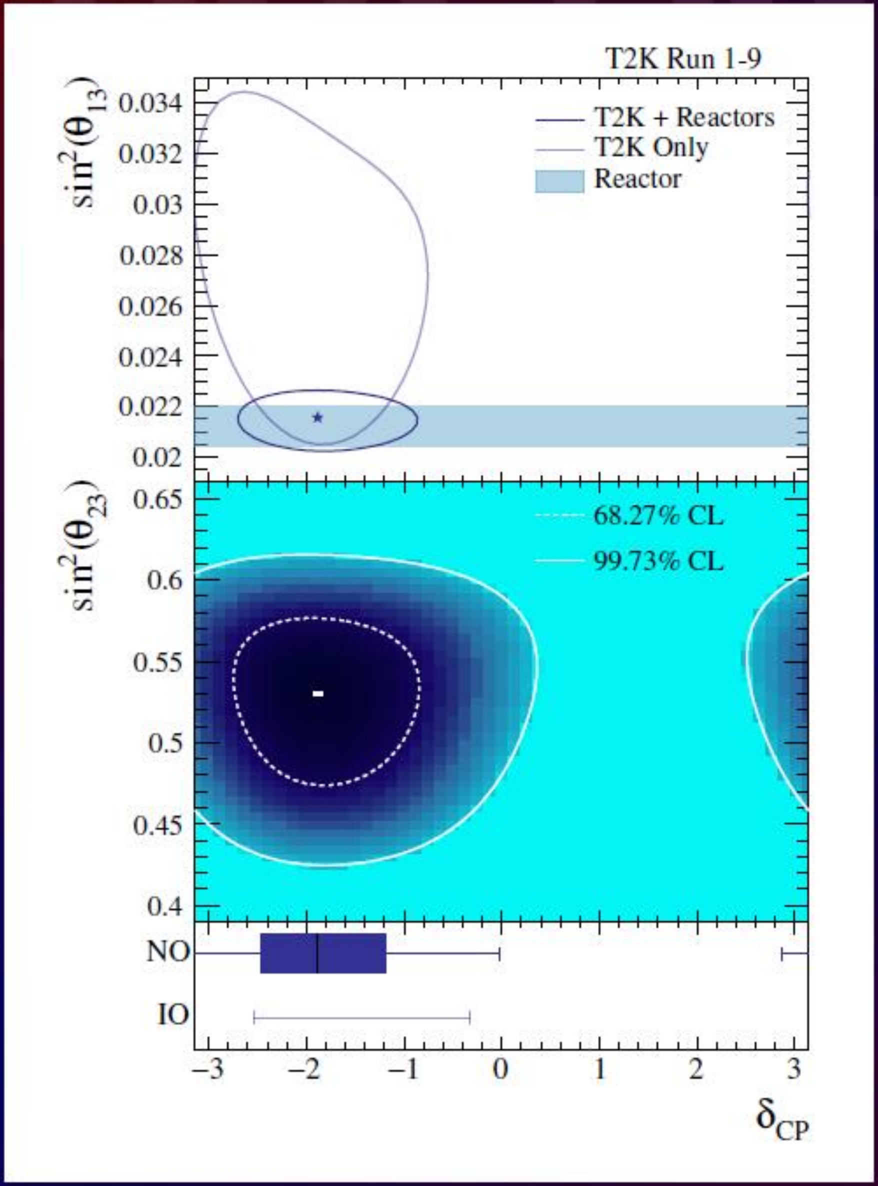
T2K Collaboration arXiv:1910.03887; paper forthcoming)



T2K Collaboration arXiv:1910.03887; paper forthcoming)

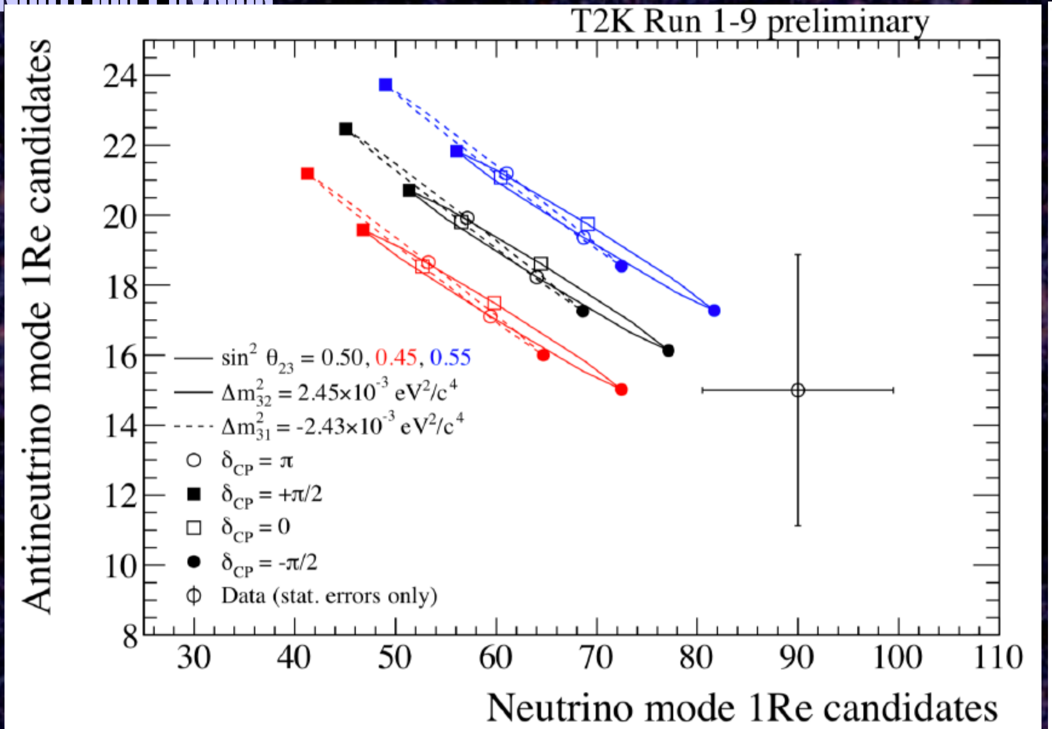
- Data taken between 2009 and 2018
- Electron-neutrino appearance in both neutrino and antineutrino mode running

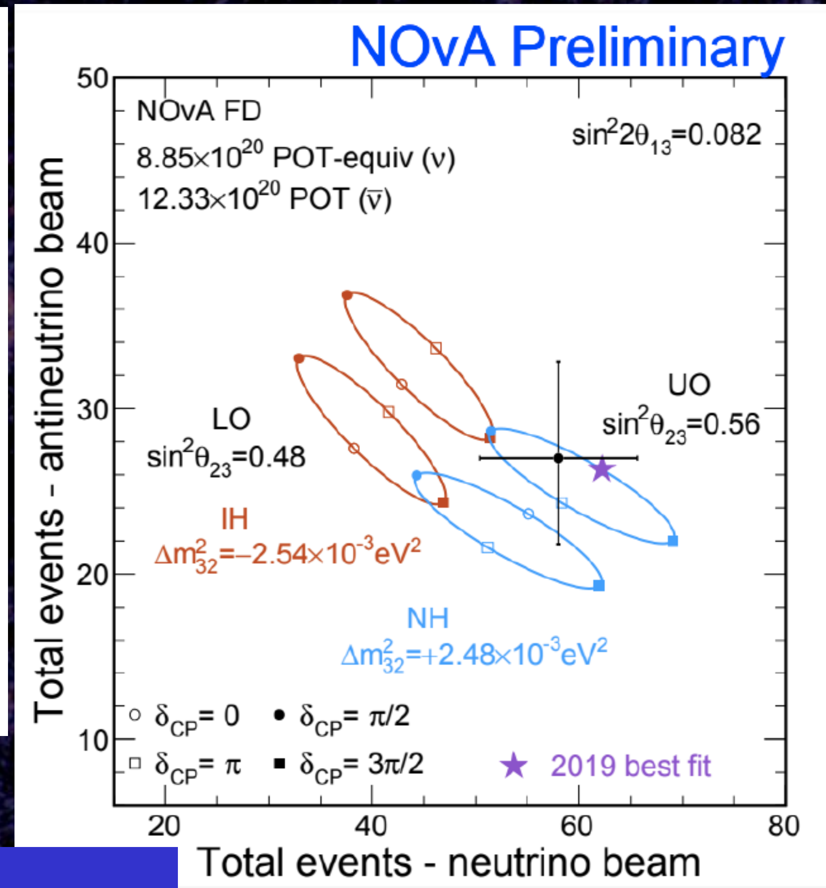
Latest Results from T2K



T2K Collaboration arXiv:1910.03887; paper forthcoming)

- Upper two plots: Normal mass ordering
- Bottom: intervals for CP-violating δ_{CP}
- **World's first exclusion of any value of δ_{CP} at the 3-σ level, for both orderings; 40% of Normal Ordering values excluded**





Time will tell if this is a fluctuation or an issue with one or both experiments!

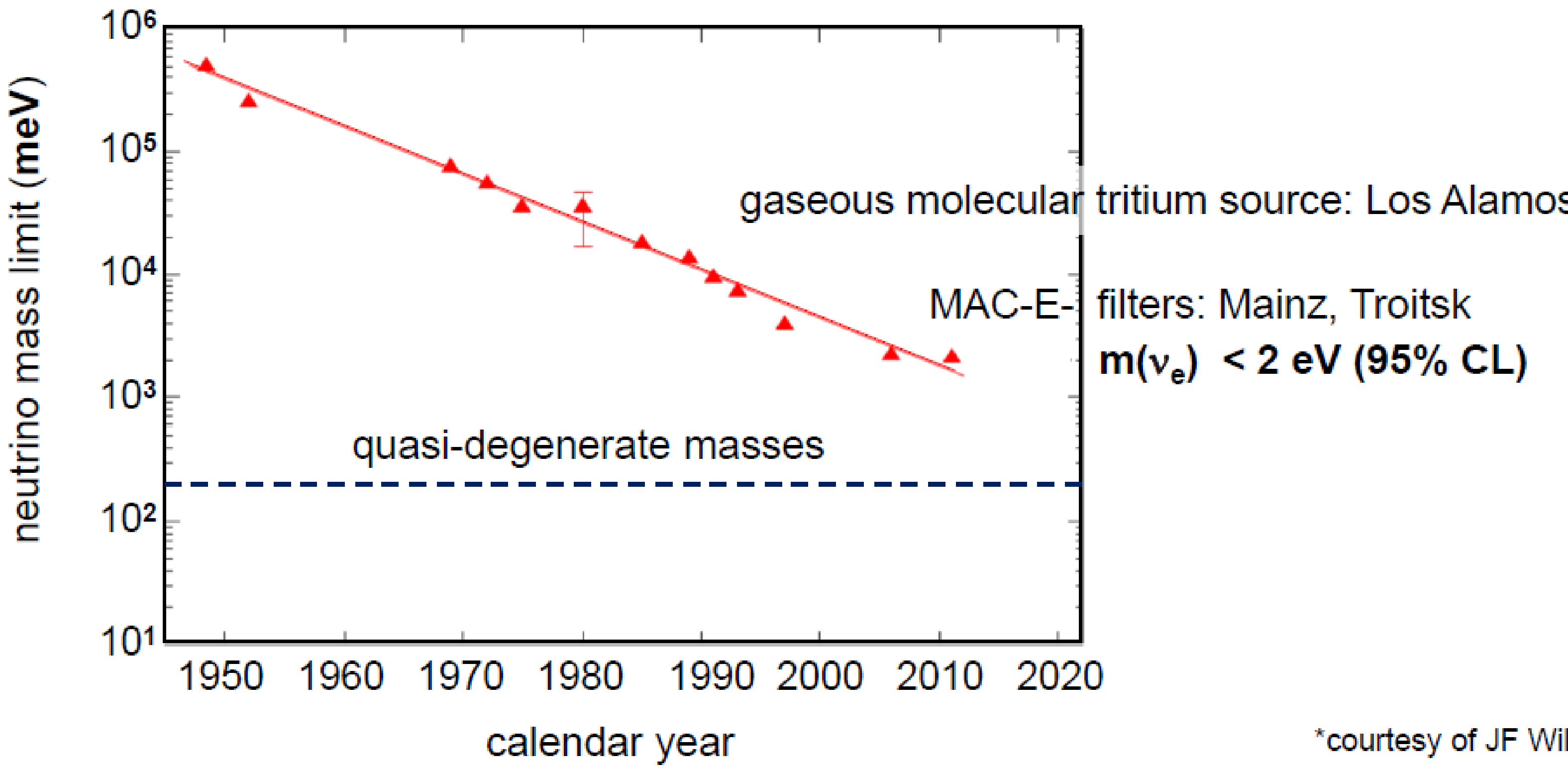
The ongoing joint analysis of T2K and NOvA data should probe assumptions and models – Prague ν 2021?

Both will continue to run, T2K with upgrades.

Moore´s law* of direct ν-mass sensitivities

Karlsruhe Institute of Technology

- **setting the stage:** experimental progress over past decades due to **new technologies**

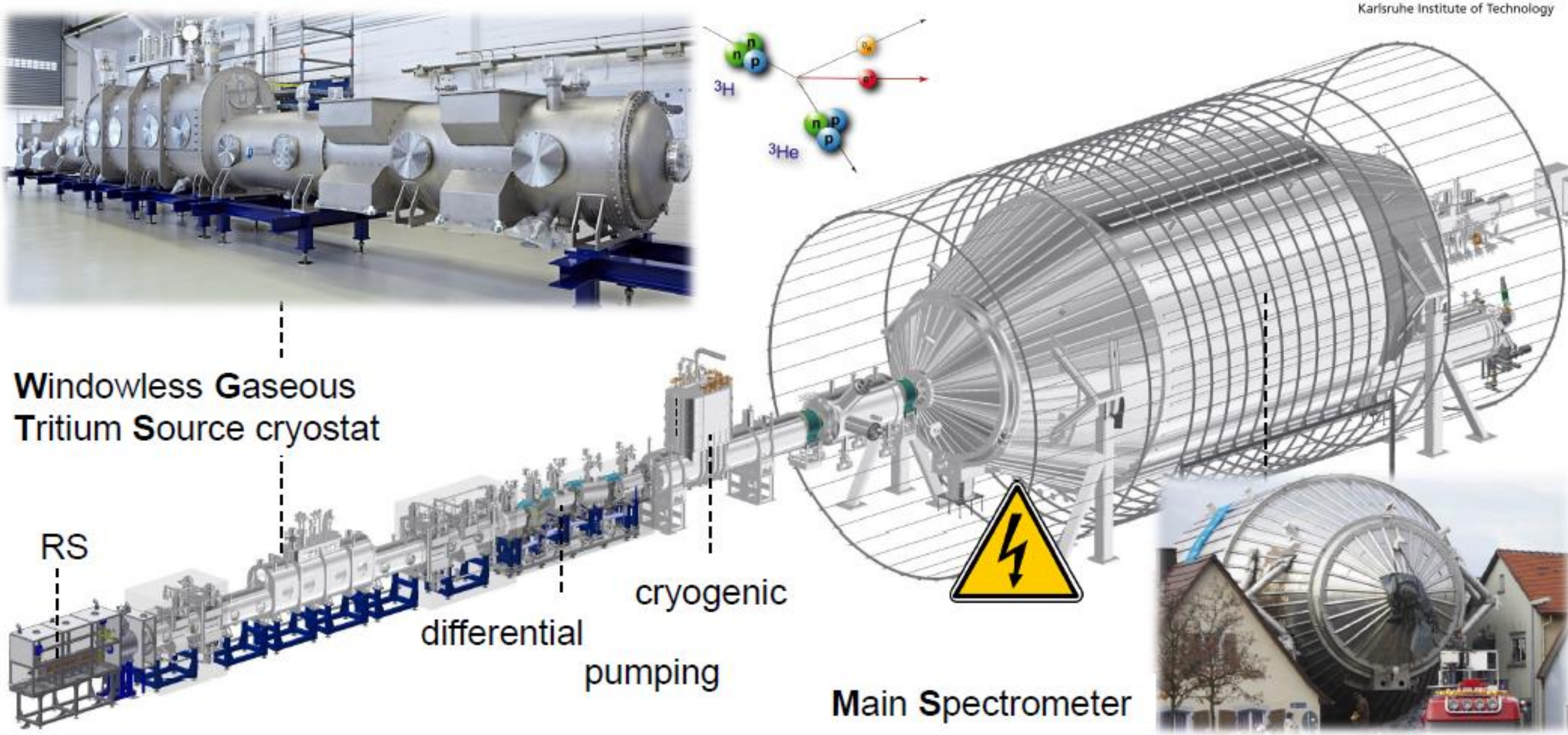


*courtesy of JF Wilkerson

Where we have been since 2011…

KATRIN overview: 70 m long beamline

Karlsruhe Institute of Technology



10 Oct. 25, 2019 G. Drexlin – KATRIN KIT-KCETA

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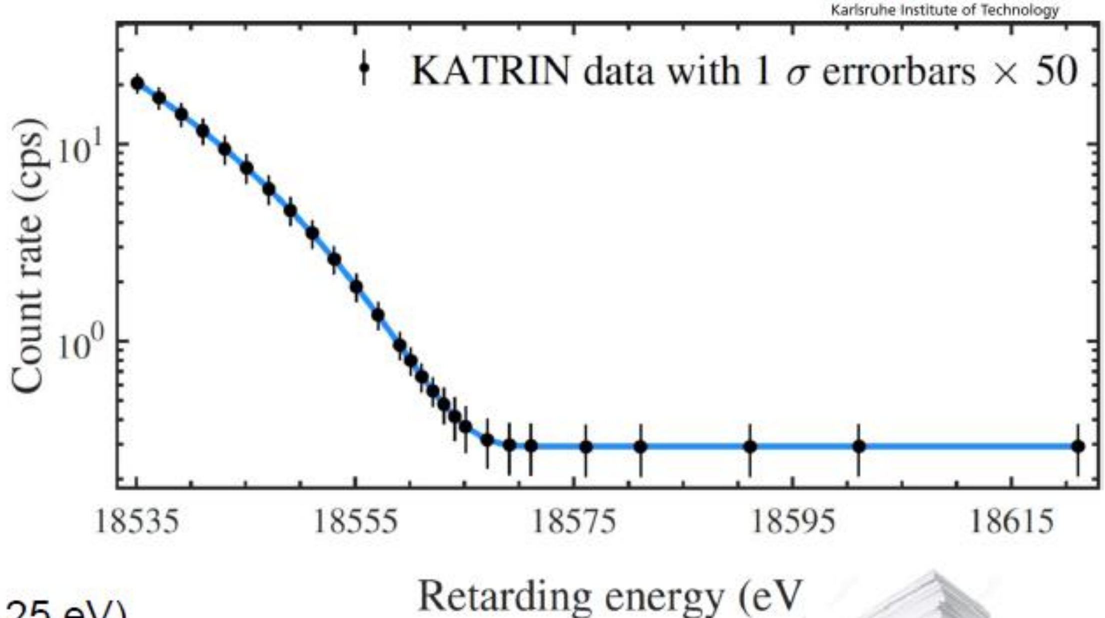
Integral tritium ß-decay spectrum - merged

- **High-statistics ß-spectrum**
  - 2 million events in in 90-eV-wide interval (522 h of scanning)



- **merged data set**
  - combine all 274 scans: excellent stability of all fitted ß-decay endpoints E_0 (σ = 0.25 eV)

  ⇨ "stacking" of events at mean HV set-point (excellent reproducability: RMS = 34 mV)

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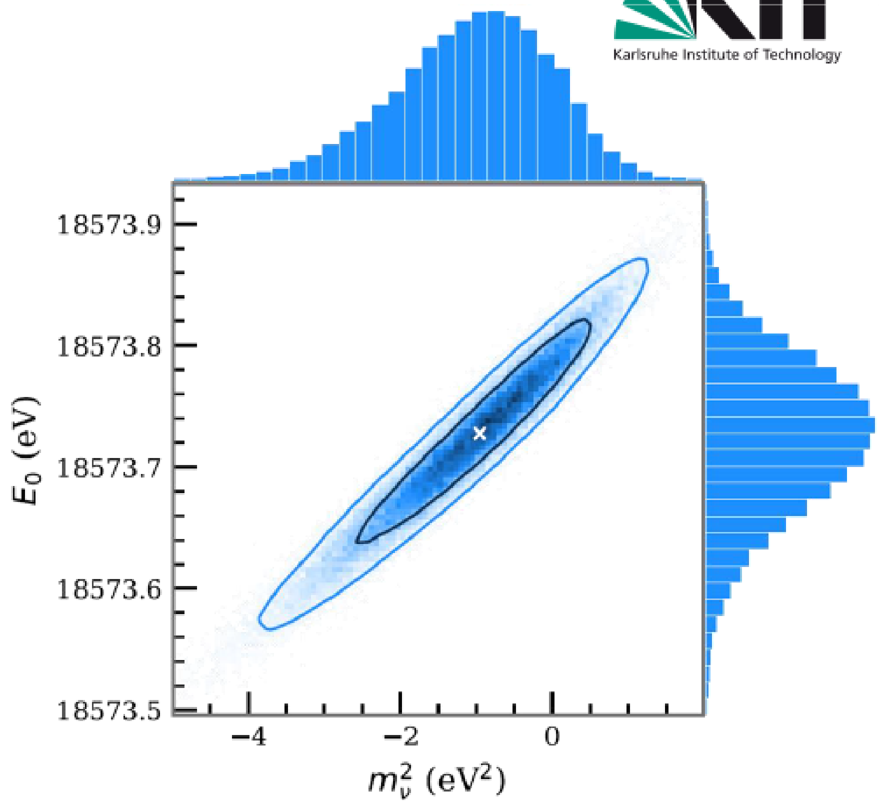
Oxford U./RAL

analysis chain & ν-mass result

- **two independent analysis methods**
  to propagate uncertainties & infer parameters
  - Covariance matrix:
    covariance matrix + χ^2-estimator
  - MC propagation:
    10^5 MC samples + likelihood ($-2 \ln \mathcal{L}$)
  - both methods agree to a few percent
- **ν-mass and E_0: best fit results**

$$m^2(\nu_e) = \left(-1.0 \begin{array}{l} +0.9 \\ -1.1 \end{array}\right) \mathrm{eV}^2 \ (90\% \ \mathrm{CL})$$

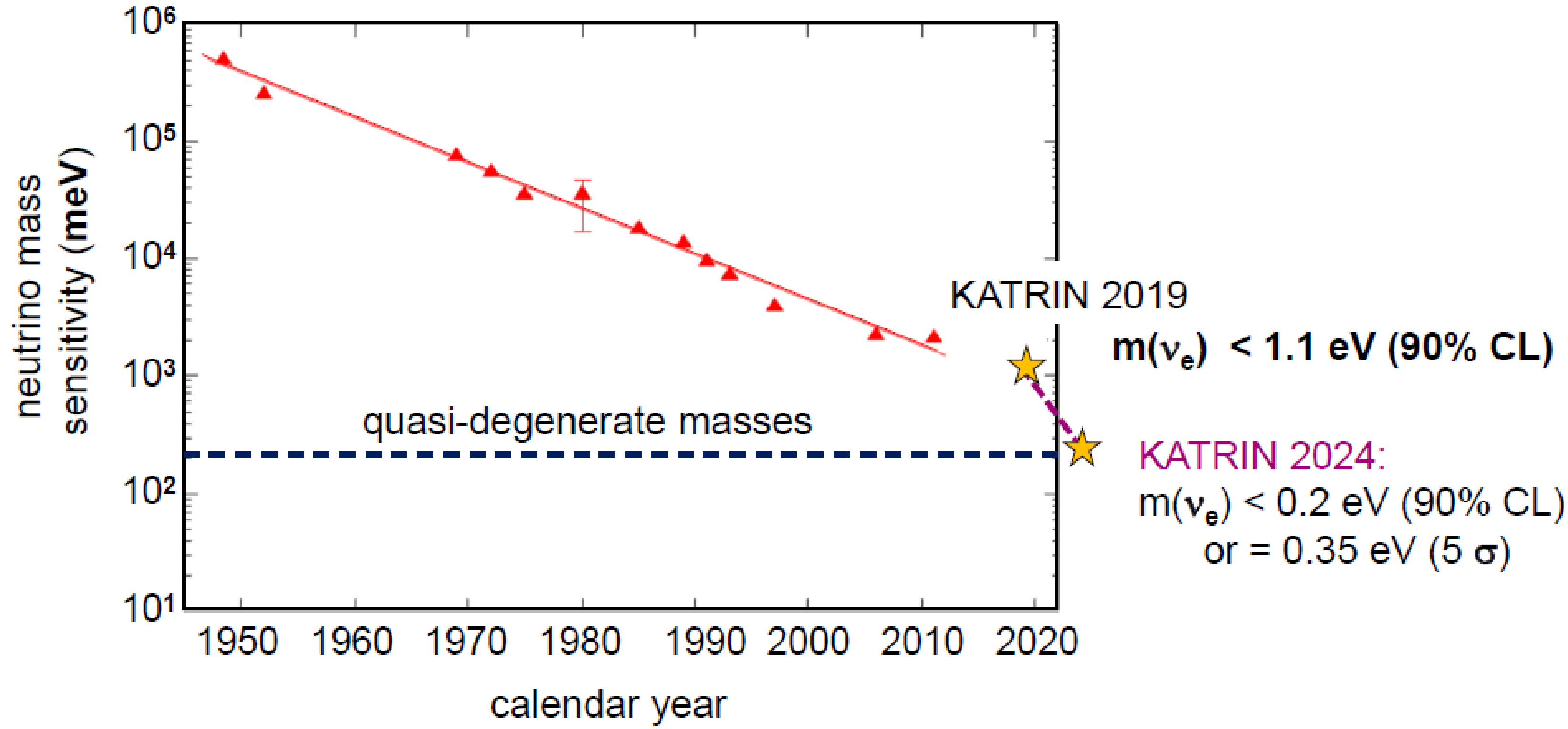


E_0 = (18573.7 ± 0.1) eV ⇨ Q-value : (18575.2 ± 0.5) eV Q-value [$\Delta M(^3H,^3He)$]: (18575.72 ± 0.07) eV

future Moore´s law of direct ν-mass sensitivities

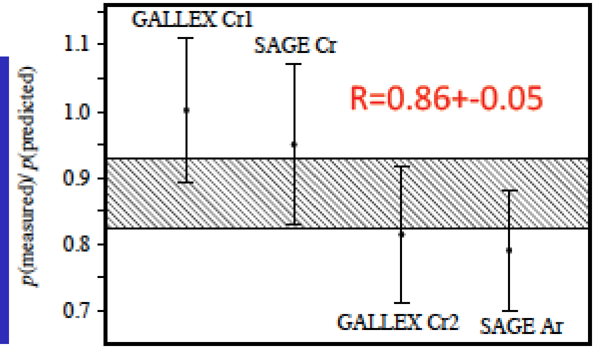
Karlsruhe Institute of Technology

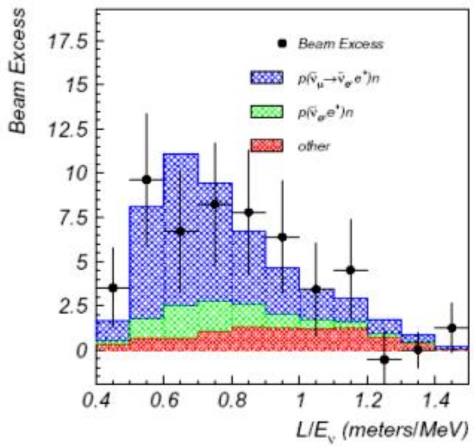
- KATRIN 2019 – 2024: **a new, much steeper slope for Moore´s law**

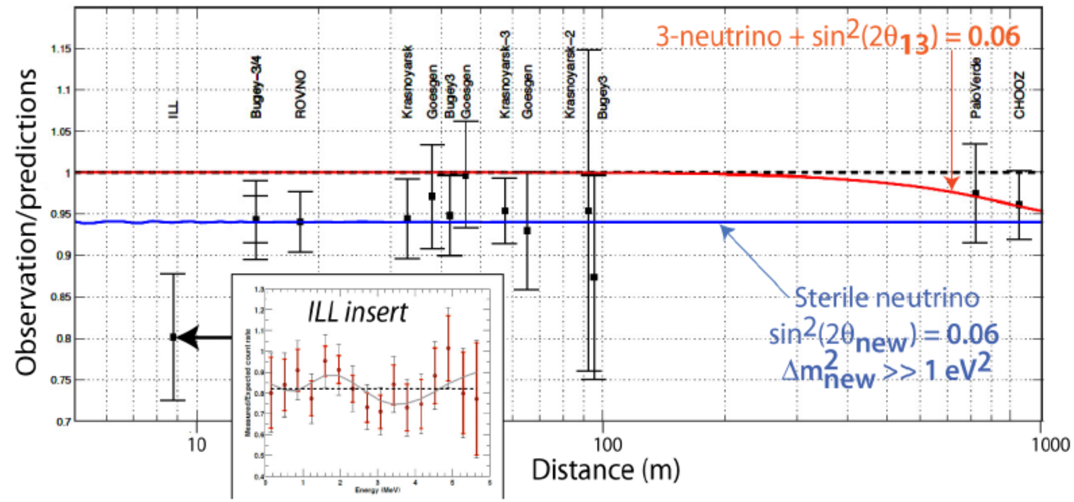


Sterile Indications…

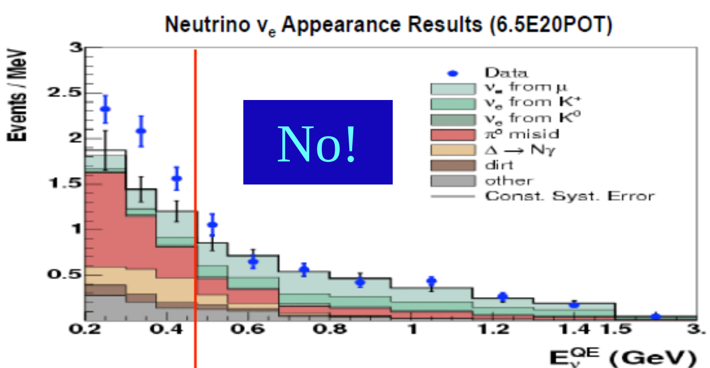
Short baselines (L/E ~ 1) and Sterile ν.

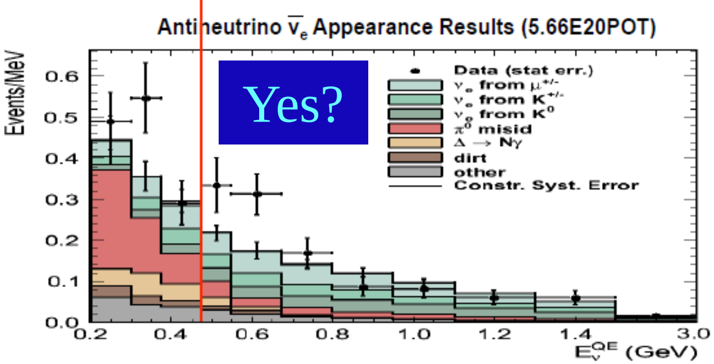




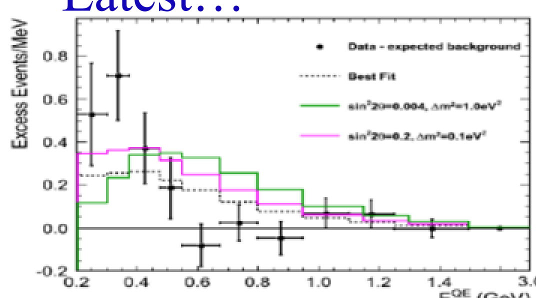


MiniBooNE says....

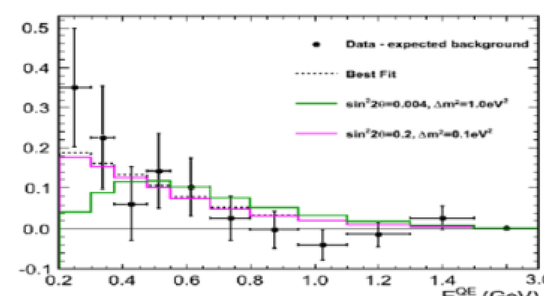




Latest…



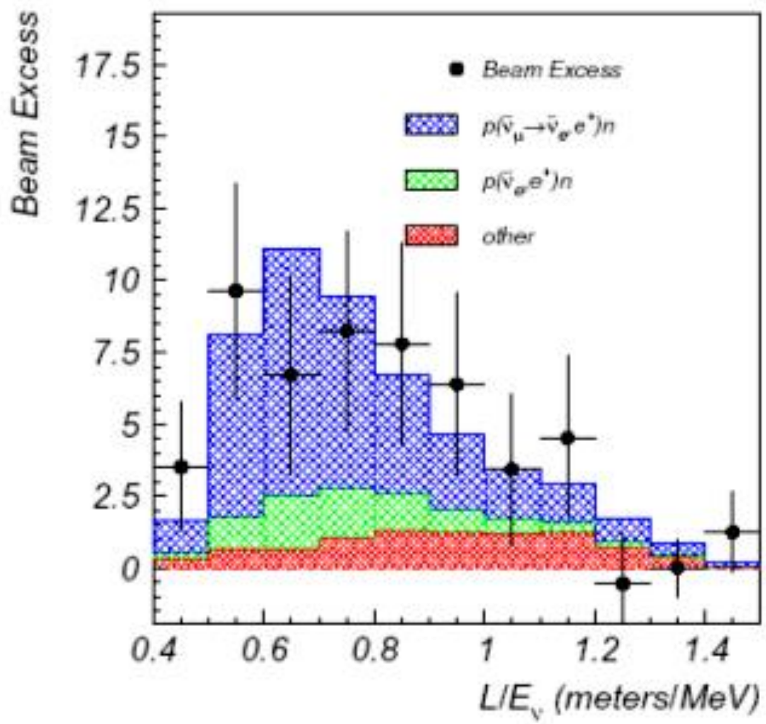
Excess: 146.3 ± 28.4 ± 40.2



Excess: 77.8 +/- 20.0 +/- 23.4

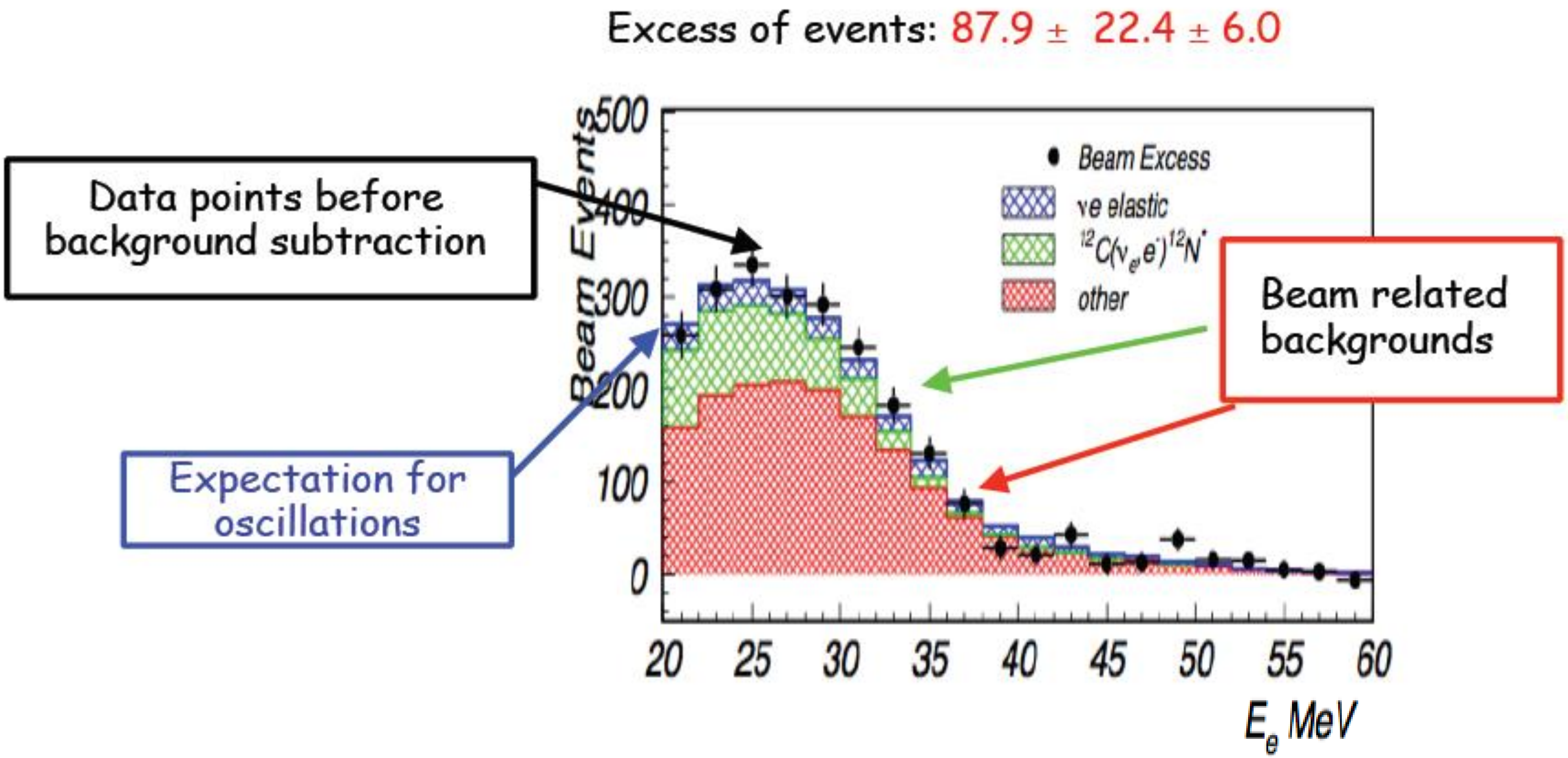
Sterile Neutrinos: LSND Starts it all...

- Backgrounds in green,red
- Fit to oscillation hypothesis in blue



Excess of electron anti-neutrinos in a “beam” from stopped pion decay…

LSND Starts it all...



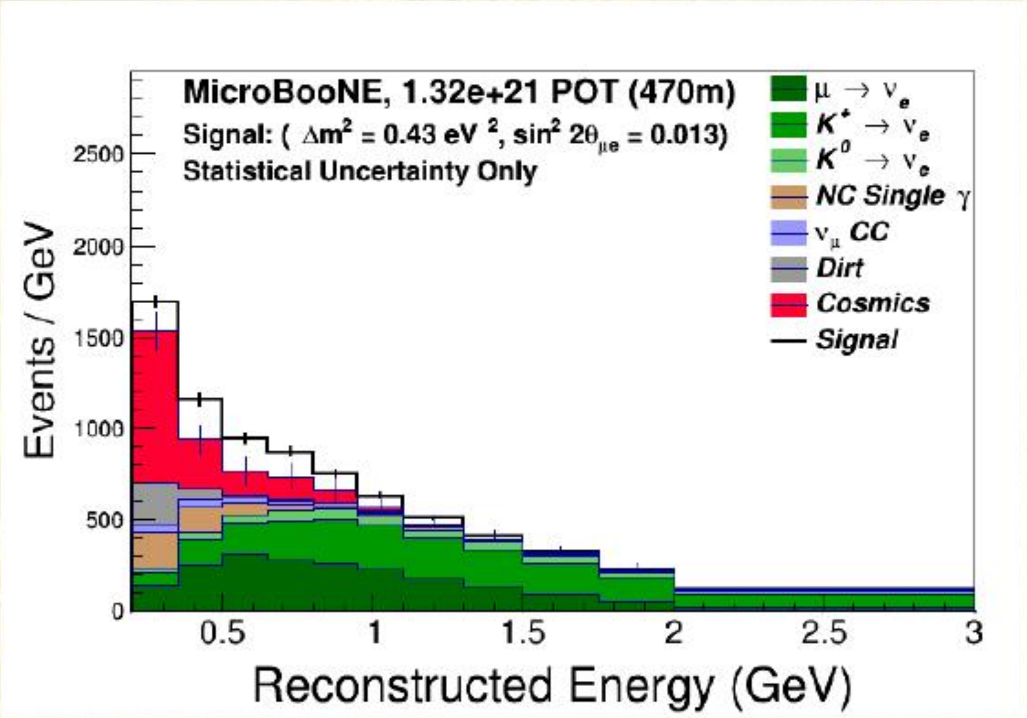
Excess not seen by

KARMEN experiment with similar sensitivity...

Coming Soon!!

MicroBooNE LEE Analysis

Simulated ν_e distributions in MicroBooNE as a function of reconstructed neutrino energy.

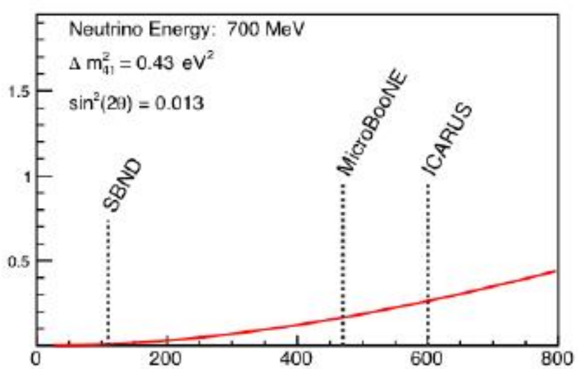


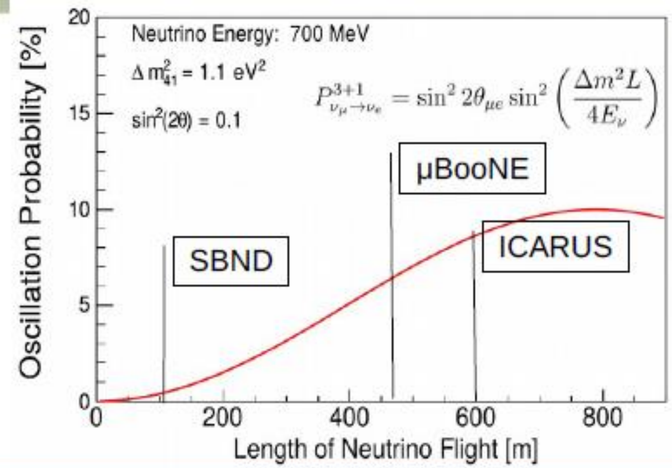
All backgrounds shown, only muon proximity and dE/dx cuts used to reject cosmogenic backgrounds.

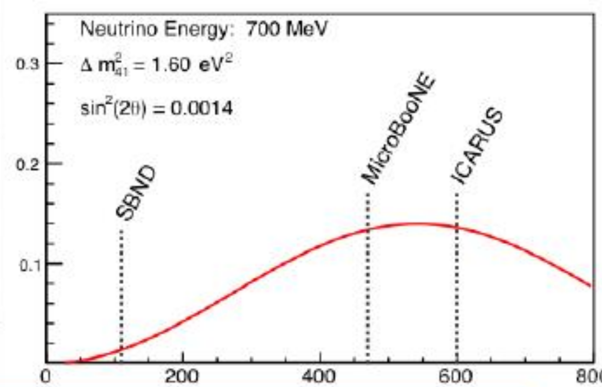
Oscillation signal events for the best-fit 3+1 oscillation parameters from Kopp et al. (arXiv:1303.3011) indicated by the white (top) histogram.

- Assumed ν_e recon efficiency of 80%, mis-id from photons of 6%, of events passing a topological cut.

The Fermilab Short Baseline Neutrino program

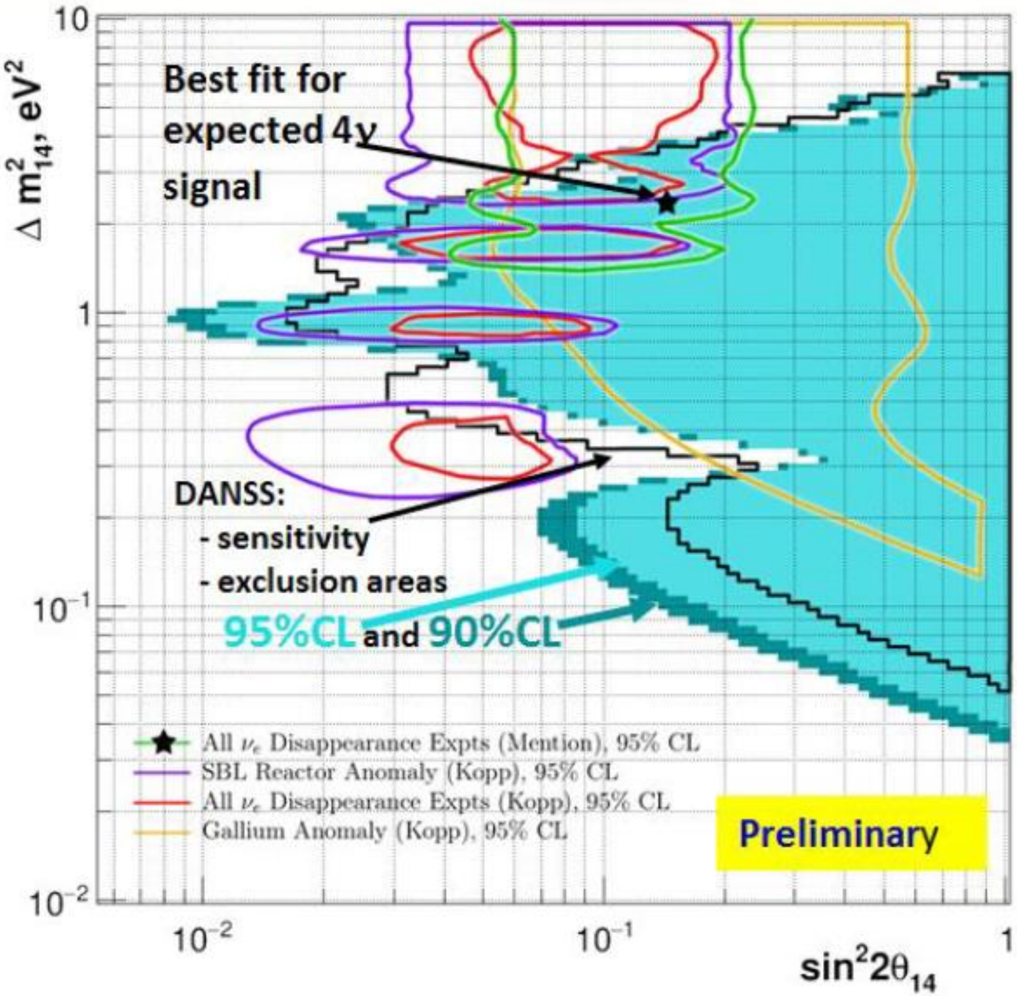






The DANSS: sensitivity plot

- Exclusion region was calculated using Gaussian CLs method (for e^+ in 1.5-6 MeV to be conservative), which is also more conservative than usual Cl method.
- Systematics included:
  - Energy resolution +/-10%
  - Energy scale +/-2%
  - Cosmic background +/-25%
  - Flat background +/-30%
- Systematics influence is small, results of our method are independent from shape of ν-spectrum and detector efficiency.
- New data allowed to extend excluded area of 4ν phase space in comparison with old results published in 2018.



Imperial College London

erc

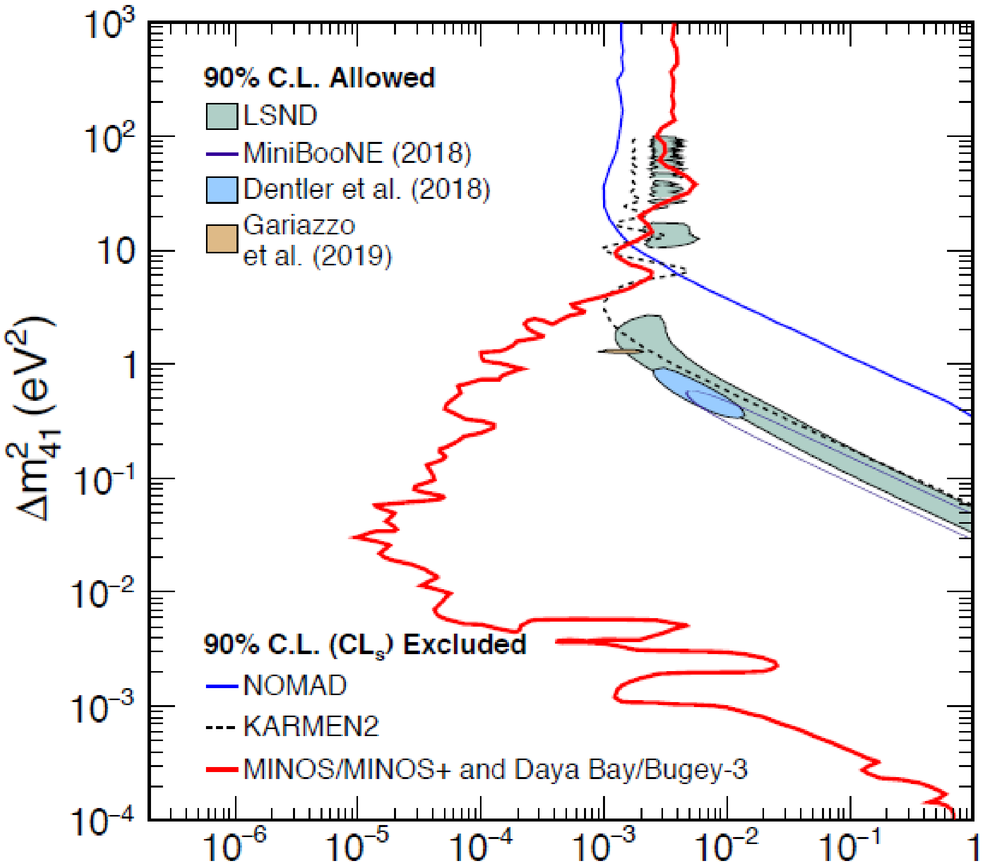
Sterile Neutrino Search at Reactors

Antonin Vacheret

Neutrino workhsop 2019
24-25 October 2019,
Prague, CR

Tease of the first data from SOLiD…

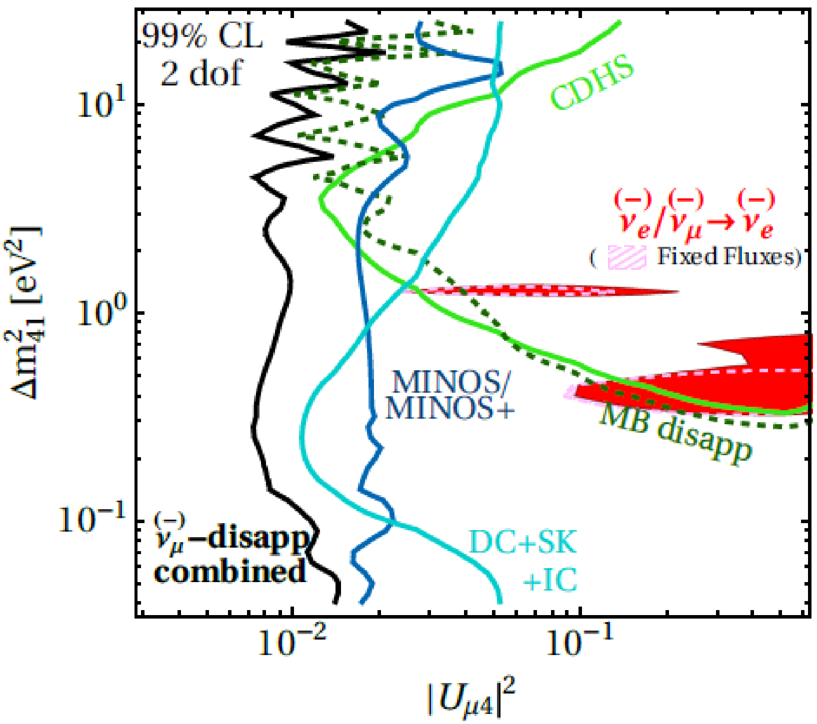
Sterile Neutrinos: MINOS+Daya Bay+Bugey-3

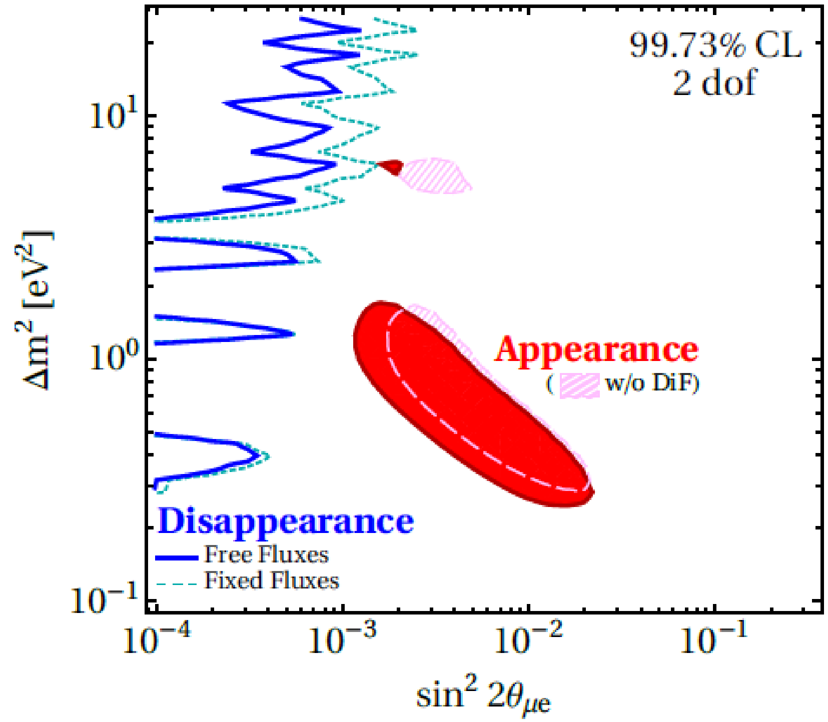


$$\sin^2 2\theta_{\mu e} = 4|U_{\mu 4}|^2 |U_{e4}|^2 = \sin^2\theta_{24}\sin^2 2\theta_{14}$$

- Excluded all the allowed region of LSND and MiniBooNE for $\Delta m^2_{41} < 10$ eV^2 (90% C.L.) and the best fits of Dentler et al. and Gariazzo et al.

Strong tension btw appearance and disappearance





non-observation of oscillations in ν_μ disappearance (CDHS, MiniB

consistency of appearance and disapp.

10^{-6}

Do we know how to interpret these results?

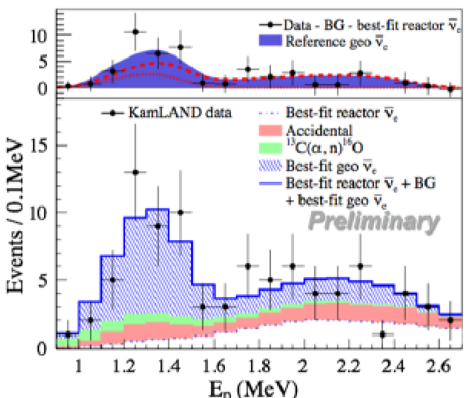
Dentler et al, 1803.10661

Do we need to expand our model base?

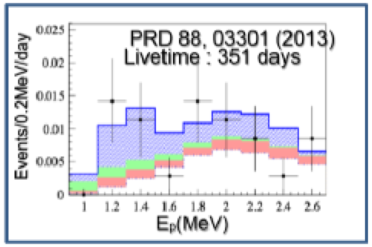
KamLAND 2016 Geoneutrino Published Result

Livetime : 1259.8 days 2016 Preliminary Result

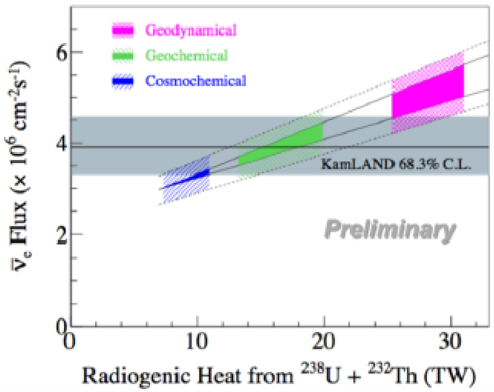
model prediction : Enomoto et al. EPSL 258, 147 (2007)



best-fit : Period 3 analysis



We measured clear distribution of geo-neutrino events!



solid line – model band varies between homogeneous mantle and sunken-layer hypothesis ;

dashed line – incorporates crustal contribution uncertainty

Rate+Shape+time analysis (ratio fixed)

	[event]	[TNU]	Flux [$\times 10^6$ cm^{-2}s^{-1}]		0 signal rejection
			best-fit	model	
U+Th	164 +28/-25 (17%)	34.9 +6.0/-5.4	3.9 +0.7/-0.6		

slide from Hiroko Watanab

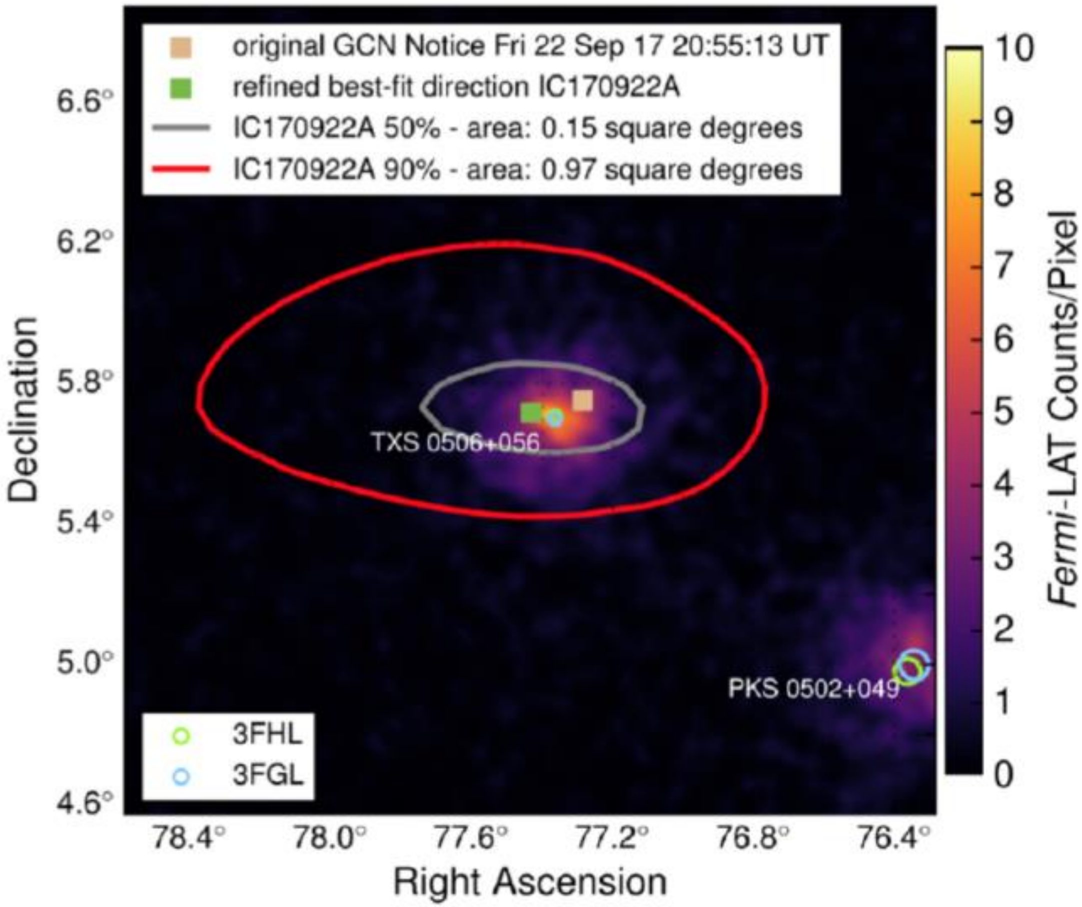
Geoneutrinos

Han Ran
BeiJing Institute of Spacecraft Environment and Engineering
2019.10.25

Colloquium Prague v19

2019
24-25 October 2019
J. Heyrovsky Institute of Physical Chemistry

TXS 0506+056: First evidence of a ν source



See Talks by:

- A. Franckowiak
- C. Finley (today)

- T. Glauch (HE 1)
- C. Raab (HE 1)

Science 361 (2018) eaat1378
Science 361 (2018) 147-151

IceCube-170922: a neutrino alert issued by IceCube

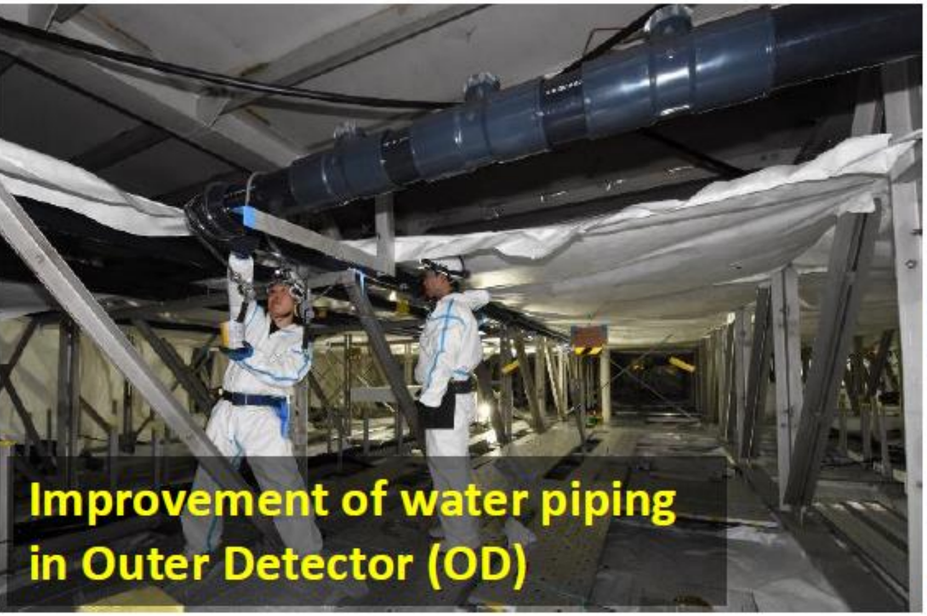
Fermi and MAGI

A ν-flare was found in archival IceCube data (10/2014 – 03/2015)

Not a complete list – Borexino, for instance.

What else might we get by 2021 ?

Refurbishment of SK de… /2


Improvement of water piping in Outer Detector (OD)

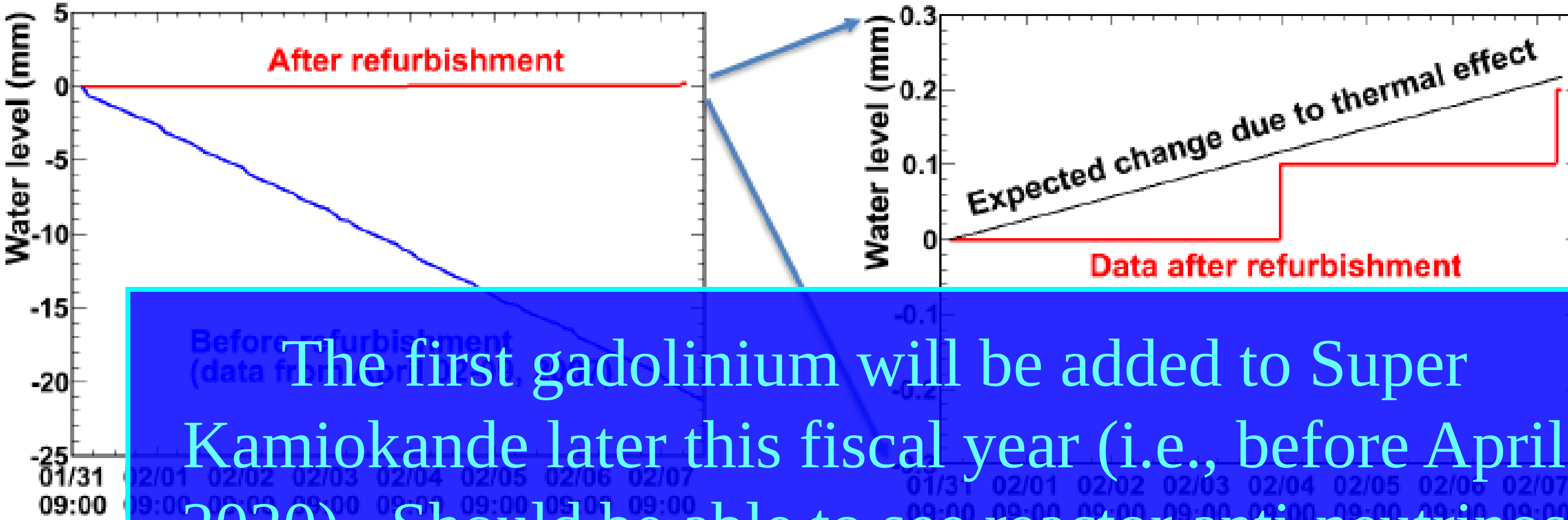

ment
of OD PMTs


Improvement of water sealing in OD


Inner Detector July 15, 2018

Water Leakage from SK tank

After filling the tank completely with water, we started the water leakage measurement from 11:30 on 31st January to 15:52 on 7th February, 2019. (7 days 4 hours 22 minutes in total)

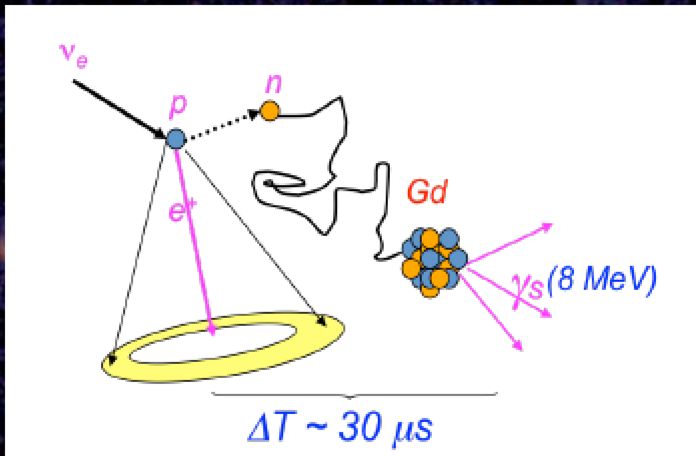


The first gadolinium will be added to Super Kamiokande later this fiscal year (i.e., before April 2020). Should be able to see reactor anti-neutrinos from individual reactors within a year.

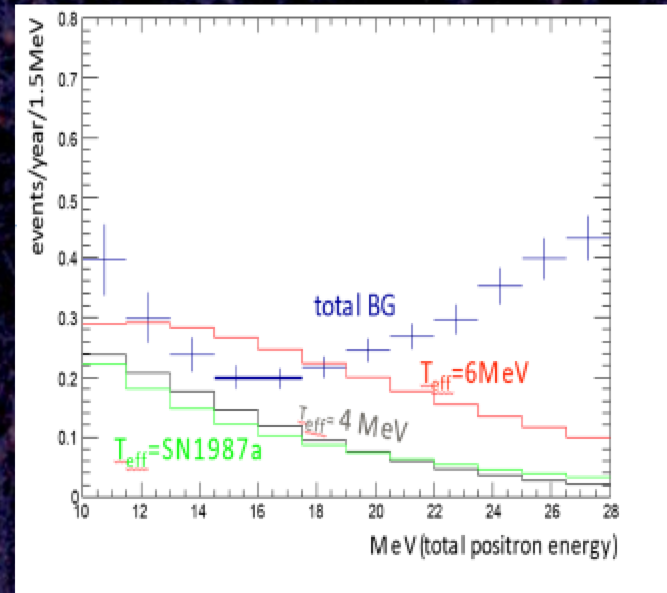
Conclusion

- Currently we do not observe any water leakage from the SK tank within the accuracy of our measurement, which is less than 0.017 tons per day.
- This is less than 1/200th of the leak rate observed before the 2018/2019 tank refurbishment.

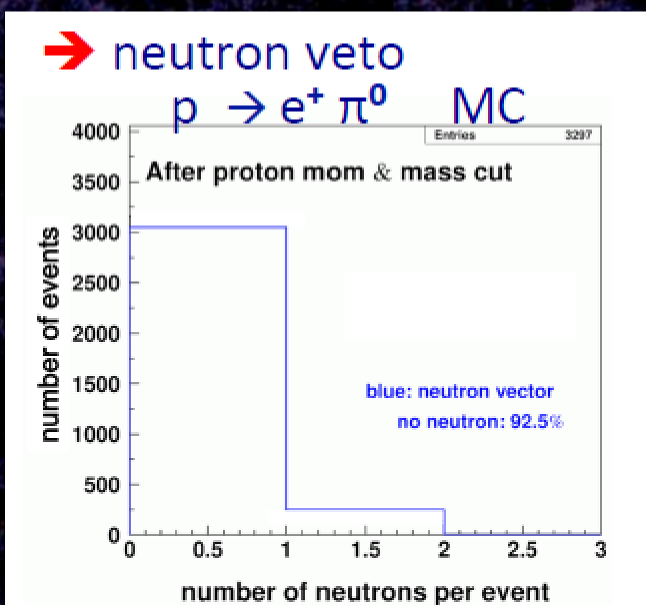
Many added capabilities…



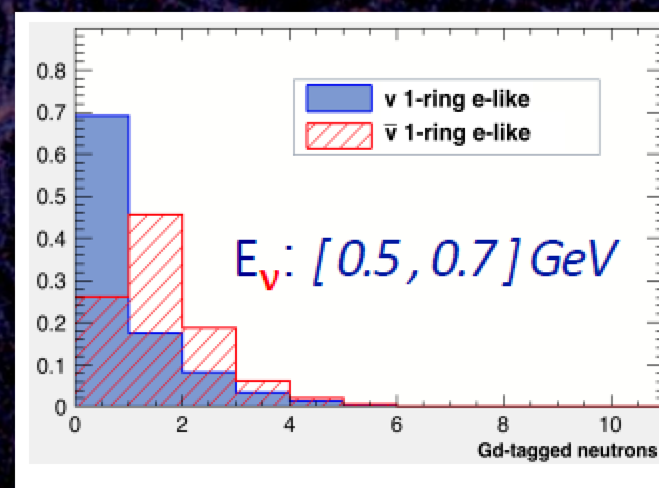
Find DSNR neutrinos. . .



Slash PDK background. . .



Tell ν from anti-ν. . .



Dave Wark
Oxford U./RAL

What is coming in the ten years beyond 2021 ?

Dave Wark
Oxford U./RAL

The tool: a large LS spherical detector

– LS large volume: ➔ for statistics
– High Light(PE) ➔ for energy resolution 1200 pe/MeV

Both crucial for the physics capabilities

Steel Truss

Holding PMTs

~20000 x 20"

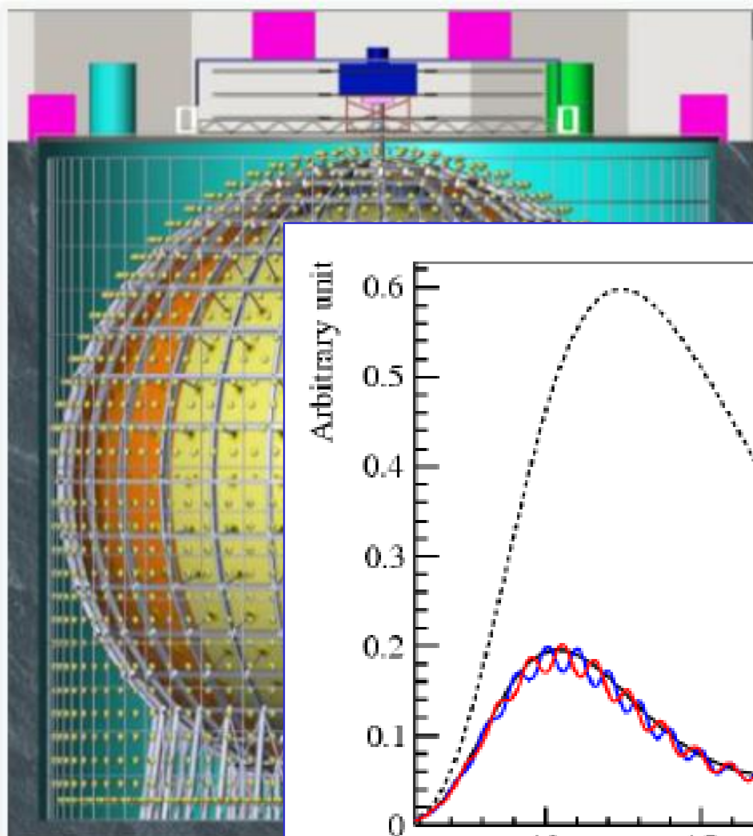
18000 Inner

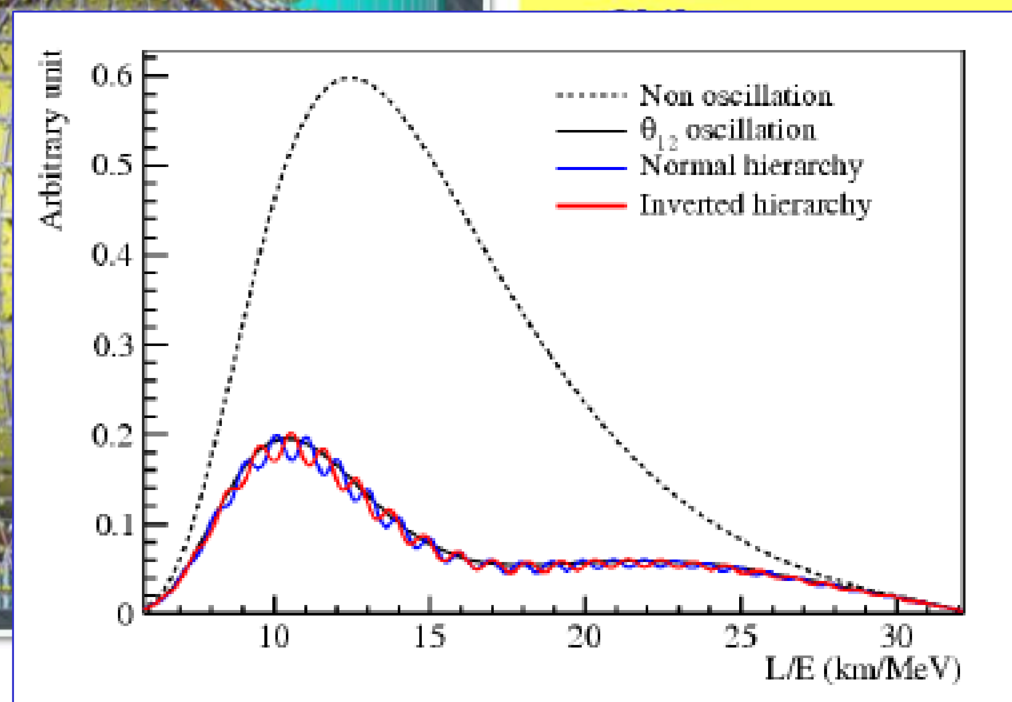
2000 veto

~25000 x 3"

Acrylic Sphere

filled with 20 kt LS





JUNO has been approved in China in Feb. 2013

Participation and contributions from several other countries:

- **Armenia**
- **Belgium**
- **Brazil**
- **USA**

Hyper-Kamiokande

The successor to Super-K

Hyper-Kamiokande Design Report, arXiv:1805.04163

- Much larger fiducial volume: **from 22.5 kt to 188 kt**
- Higher power of proton beam which produces neutrinos: **from 500 kW to 1.3 MW**
- Improved photosensor technologies
- Incorporates the neutrino beam from J-PARC
- **Increase in event rate of 20 times compared to T2K**

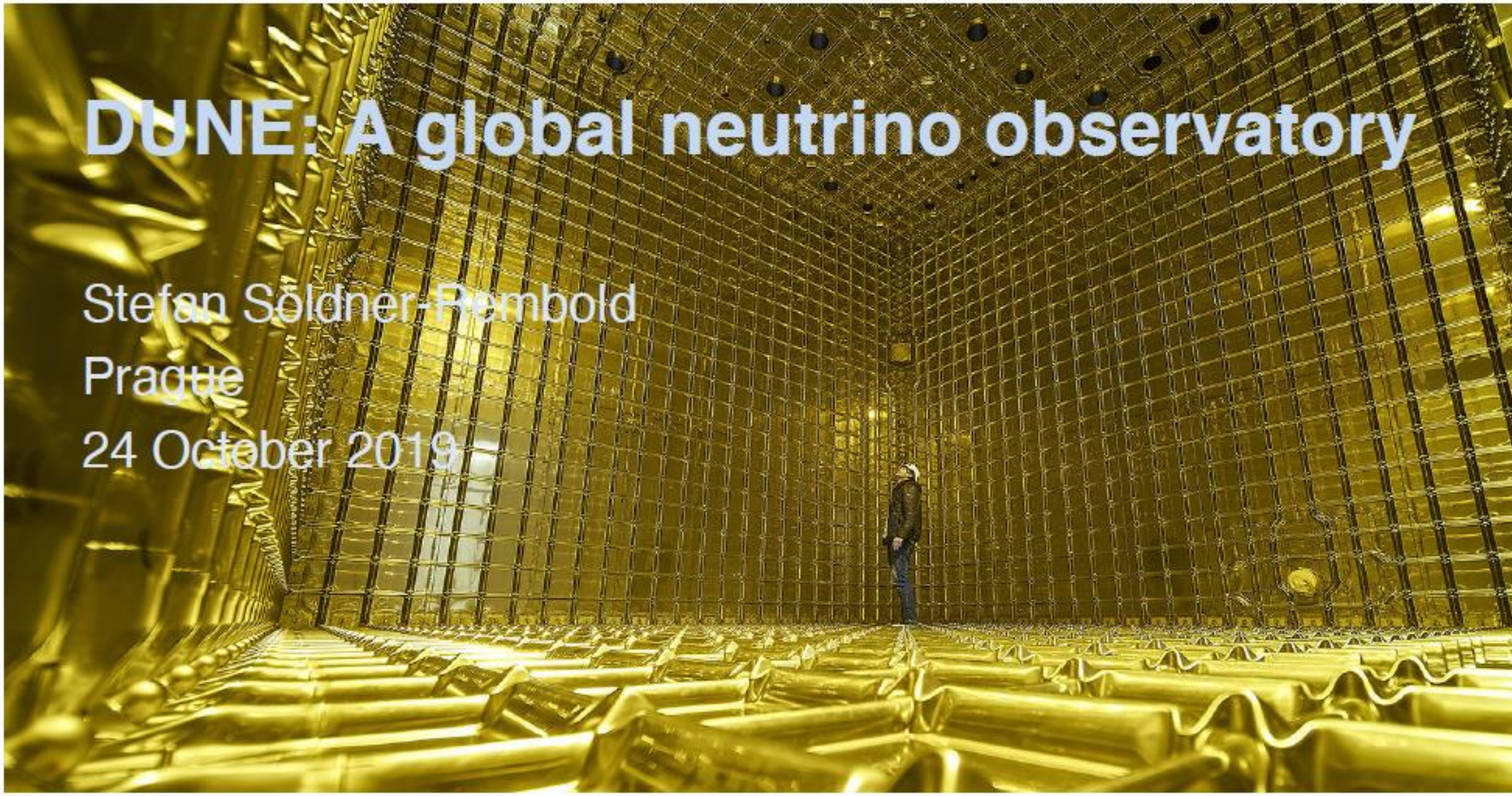
Very broad physics programme.

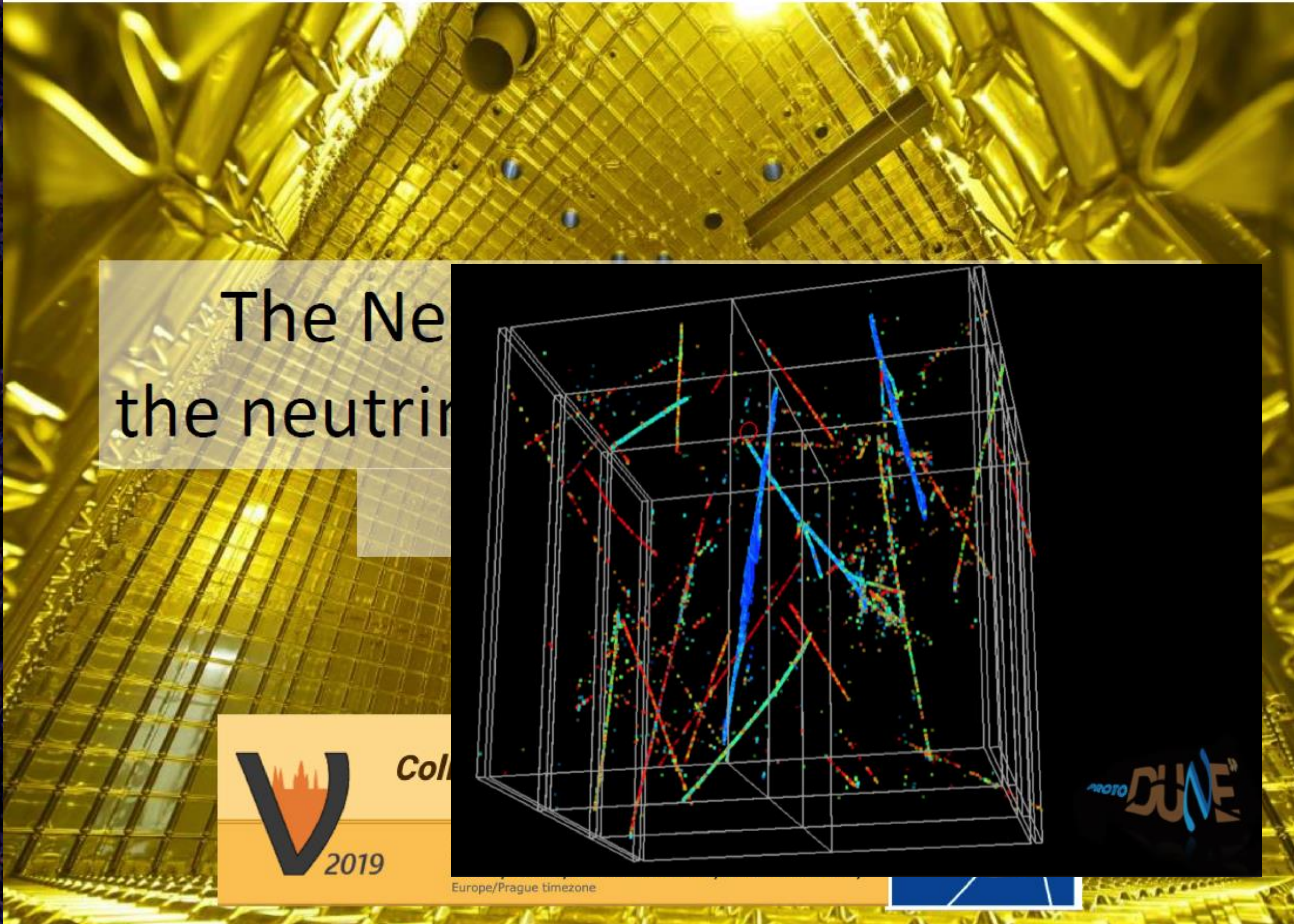
MEXT have asked MoF for construction money for next year.

Hyper-Kamiokande

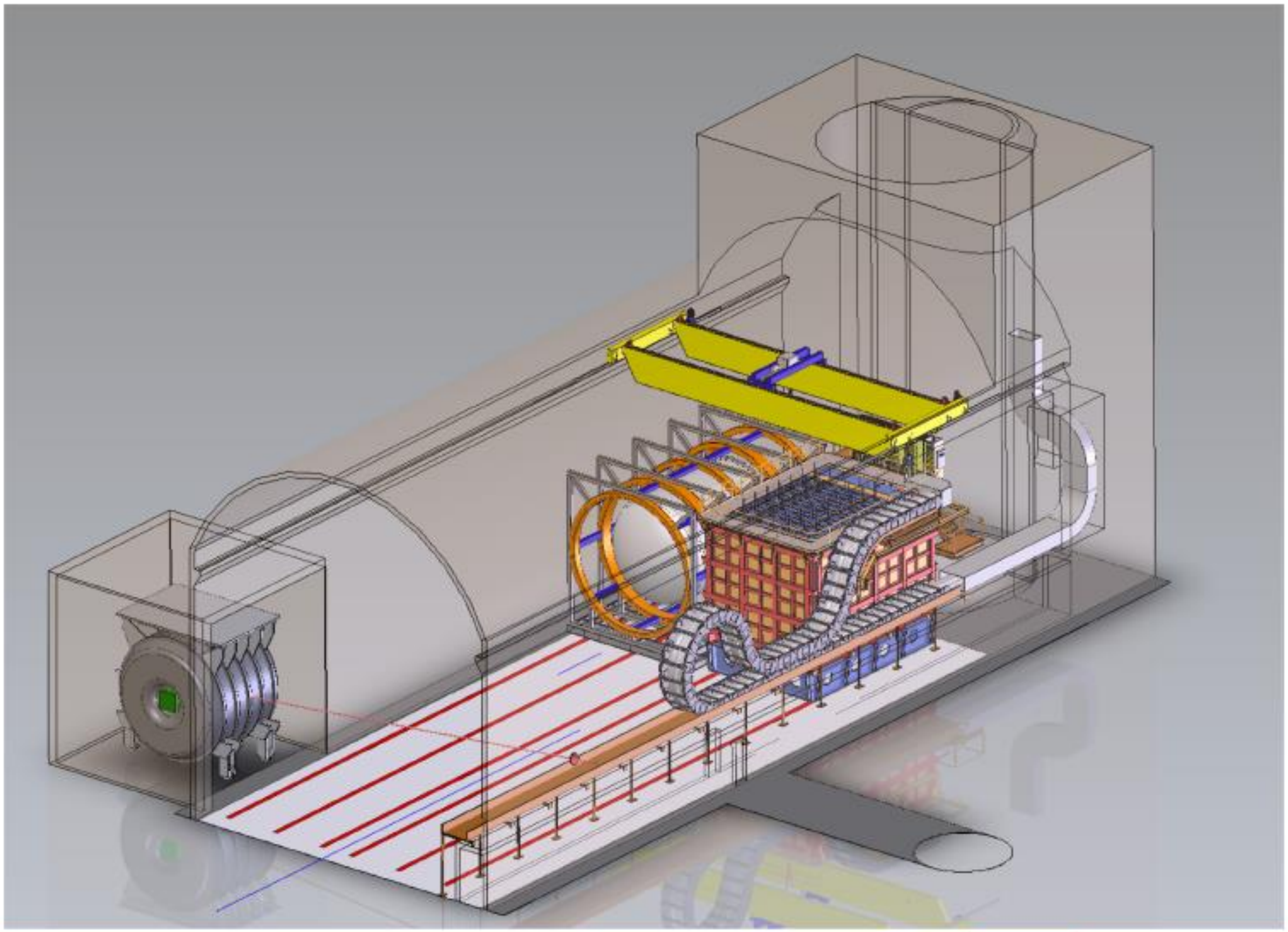
An "Intermediate" Water Cherenkov detector

- "Intermediate" since located farther than the "near" detectors
- Near detectors with different technologies to the far detector are valuable; but also detectors with similar technologies
- Water Cherenkov detectors need to be large; cannot be too close to the beam source
- Roughly a kilometre away from the beam origin
- Historical names for such detectors for Hyper-K include **TITUS**, **nu-PRISM** and **E61**, but for now we are going with:
- **IWCD**, for Intermediate Water Cherenkov Detector

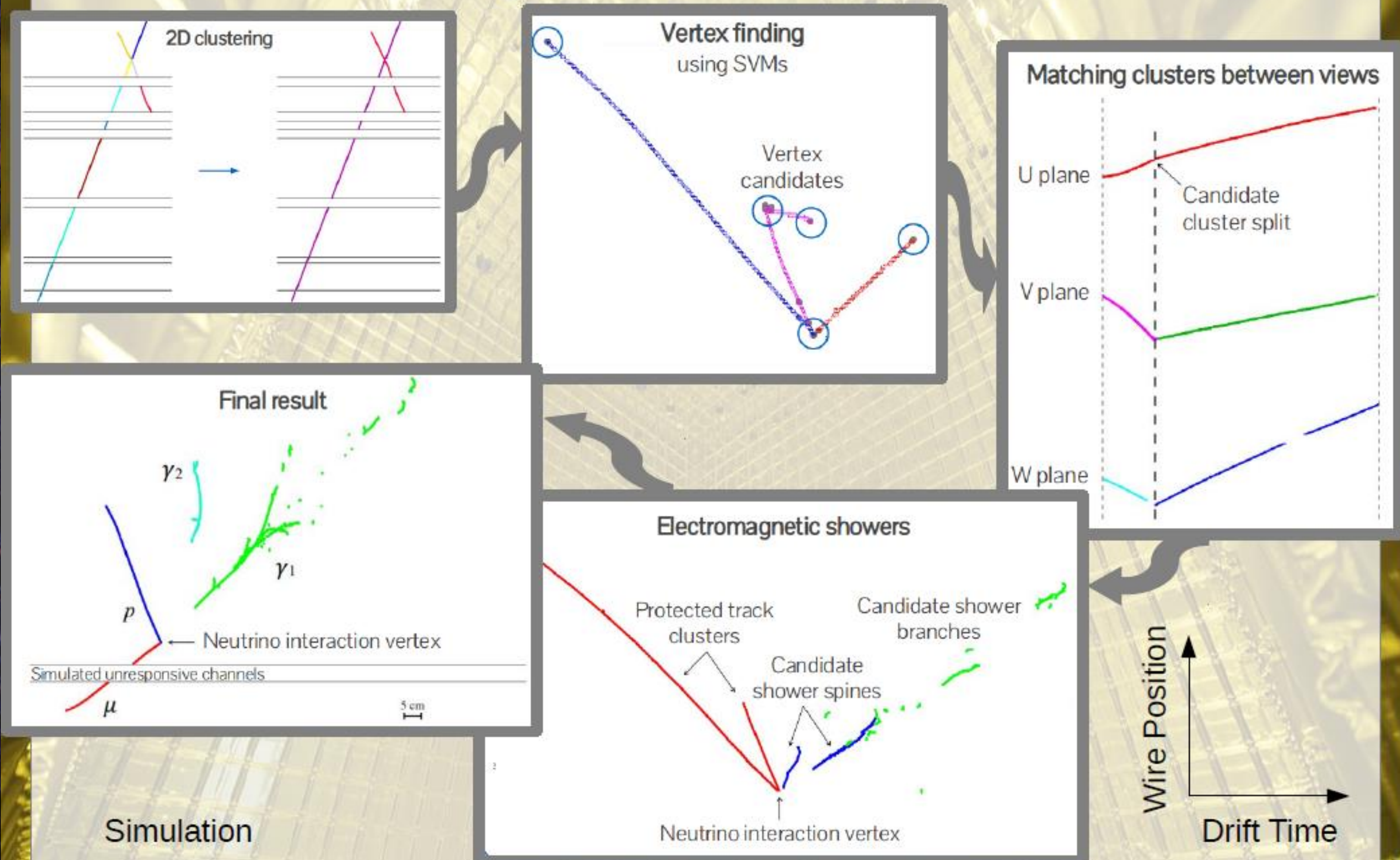

DUNE: A global neutrino observatory
Stefan Söldner-Rembold
Prague
24 October 2019


The Ne
the neutri
Col
2019
Europe/Prague timezone
PROTO DUNE

The DUNE Near Detector

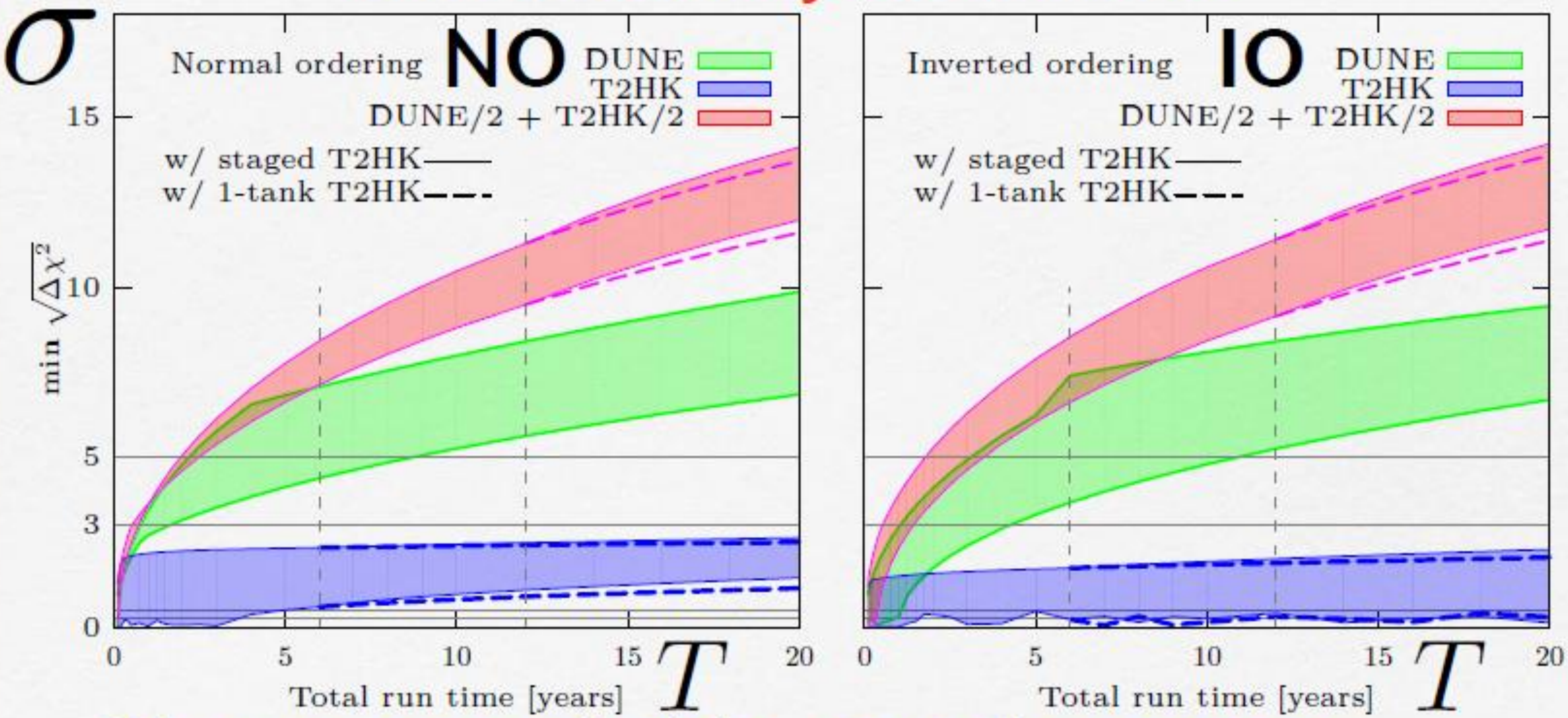


Pandora's algorithms for MicroBooNE



Sensitivity to Mass Ordering

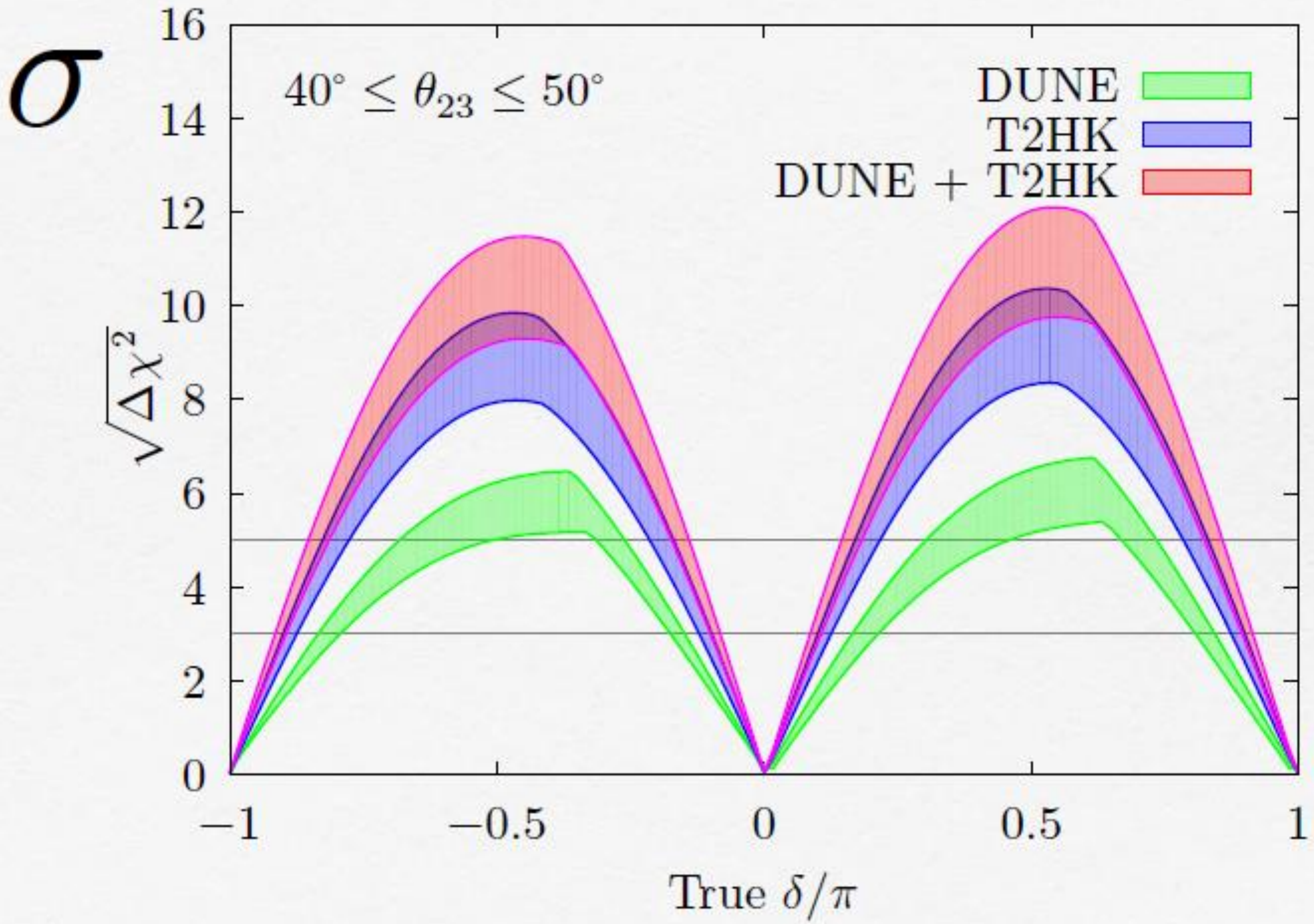
Band uncertainty due to theta23



Shows remarkable complementary
(statistics are irrelevant after T=5 years)

From Steve King's talk at NuPhys 2016.

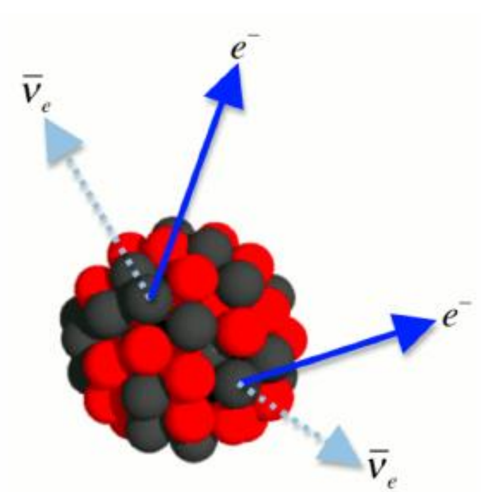
CP violation sensitivity

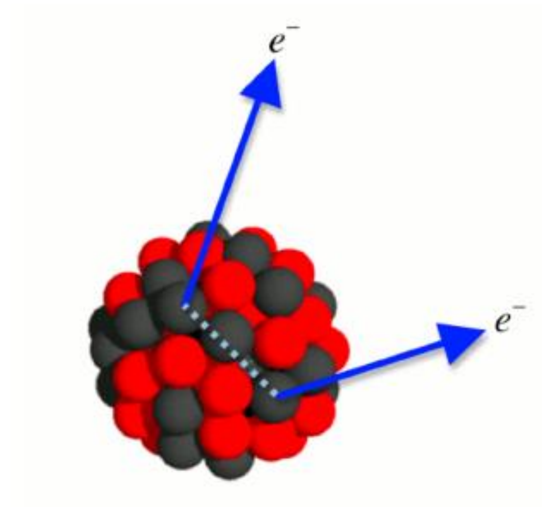


Neutrinoless Double-Beta Decay : Experimental Perspectives

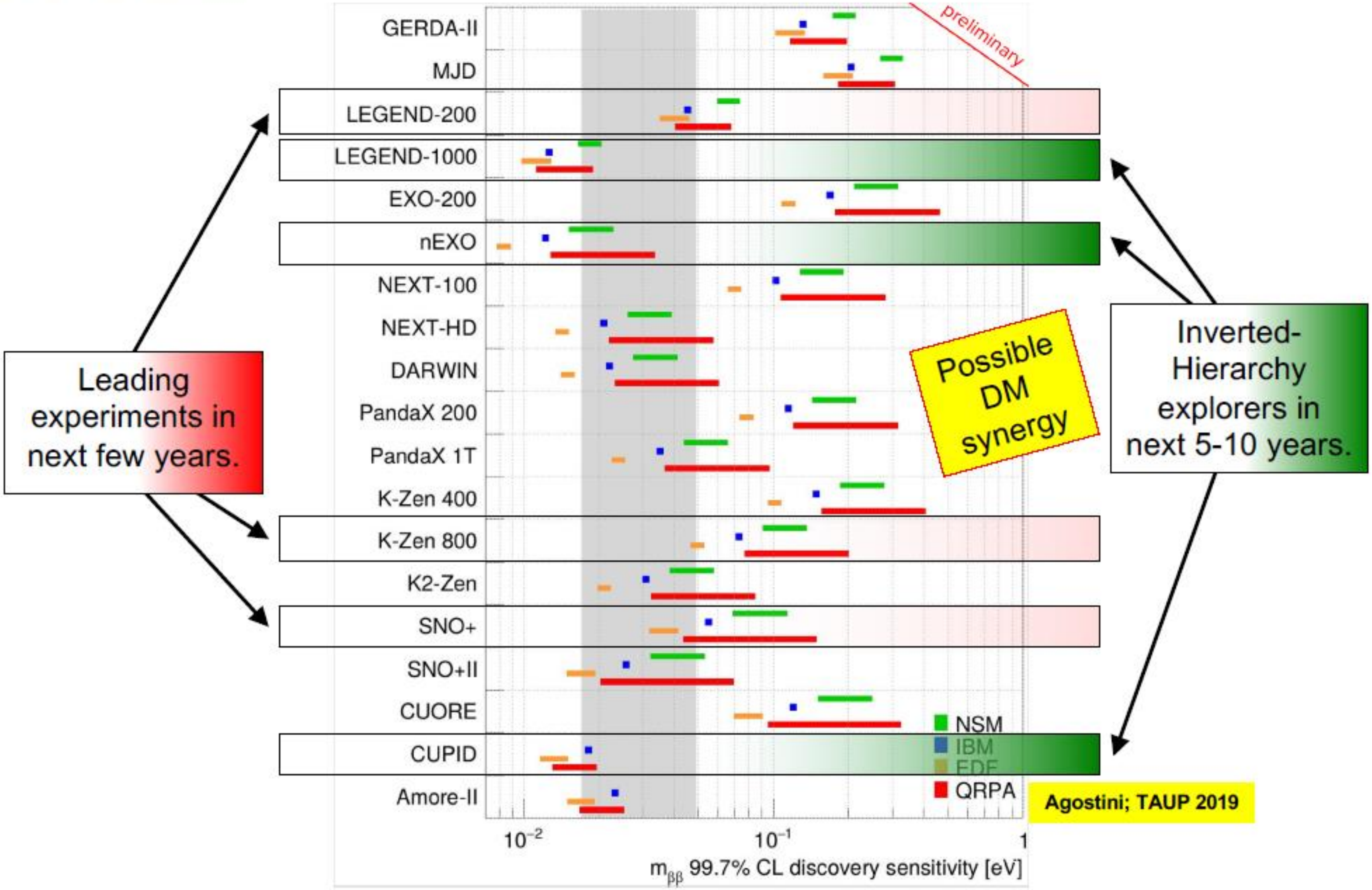
Dave Waters
University College London

Prague Colloquium, 24th October 2019

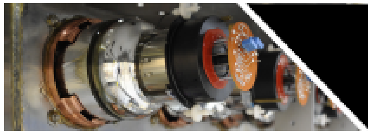




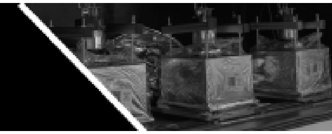
Projected Sensitivities



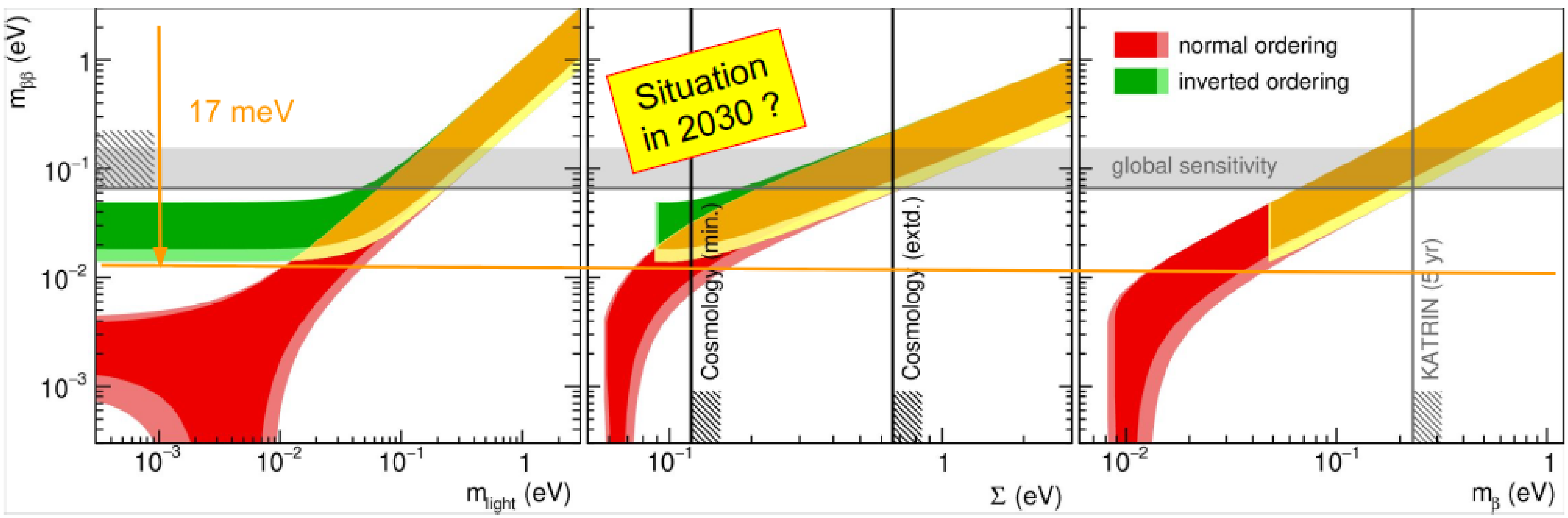
Agostini; TAUP 2019

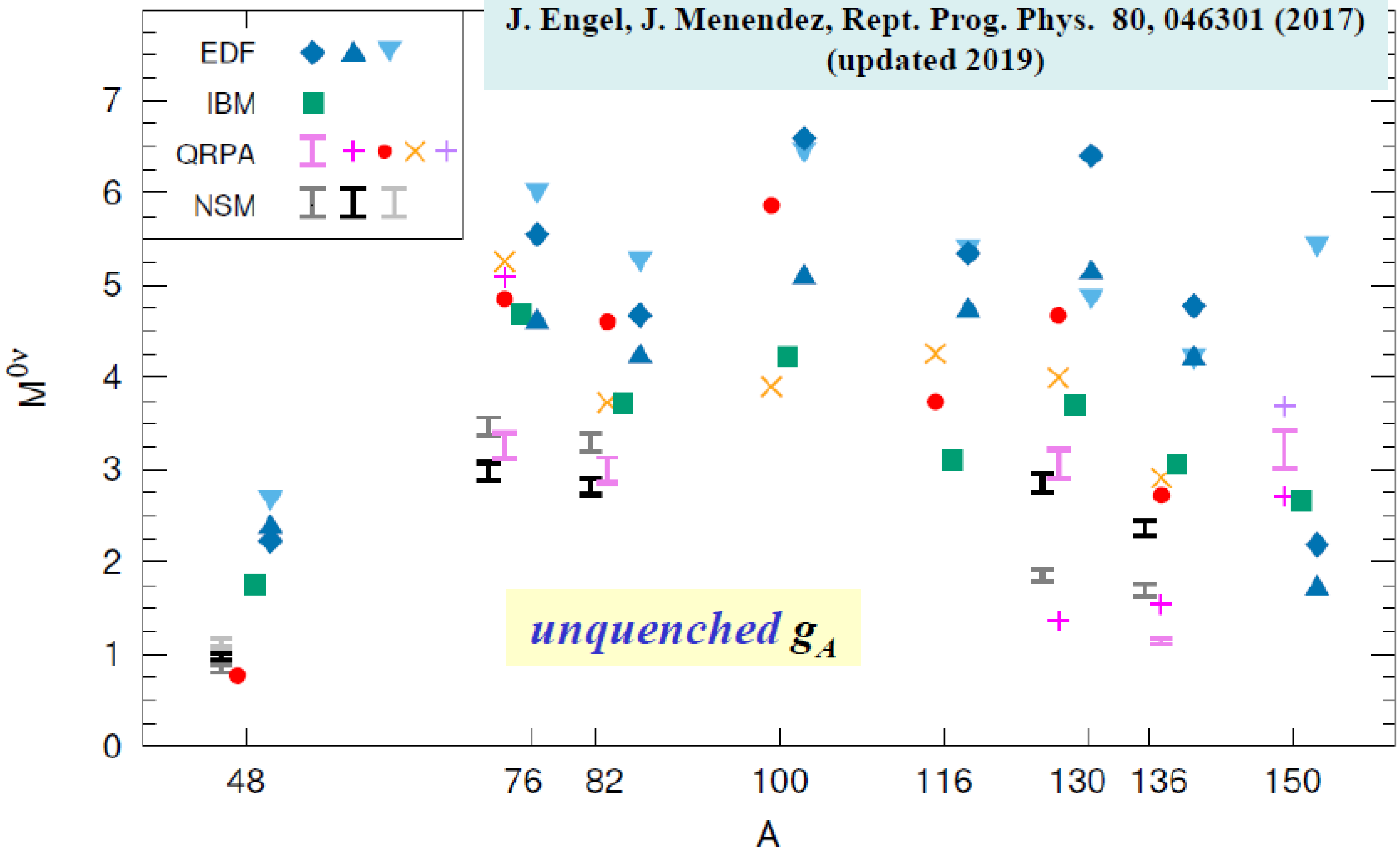


Concluding Remarks



- The scientific imperative to ~~search for~~ discover neutrinoless double-beta decay remains as compelling as ever.
- Remember that we will want to characterize and test any signal claim.
- The phase space of techniques is still wide but is narrowing → there will be 2-4 experiments that cover the IH region.
- Diving further into the NH will be challenging. What can we say now ?
  - → Probably tellurium (^{130}Te natural abundance of 34%)
  - → Perhaps massive scintillator detectors ?
- Or perhaps we will be guided to a specific mass by other experiments ?





0νββ-decay NME status 2019

All models missing essential physics

Impossible to assign rigorous uncertainties

Nuclear Shell Model (Madrid-Strasbourg, Michigan, Tokyo): Relatively small model space (1 shell), all correlations included, solved by direct diagonalization

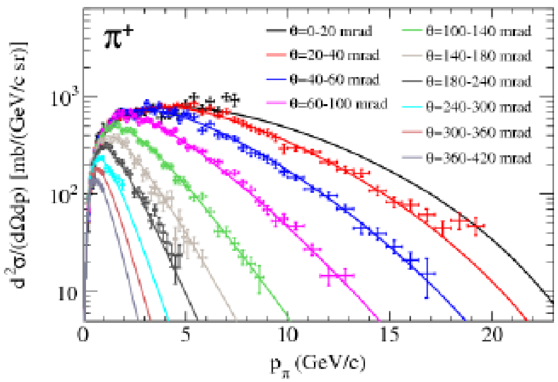
QRPA (Tuebingen-Bratislava-Calltech, Jyvaskyla, Chapel Hill, Lanzhou, Prague): Several Shells, only simple correlations included

Interacting Boson Method (Yale-Concepcion): Small space, important proton-neutron Pairing correlations missing

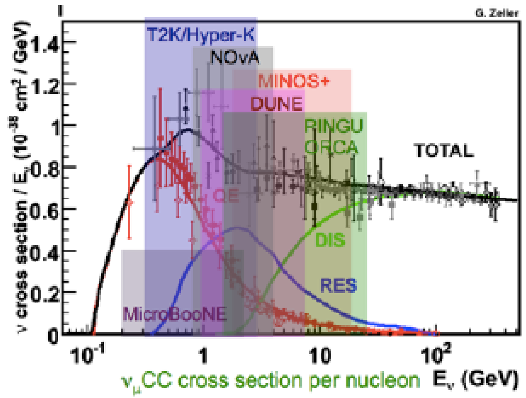
Energy Density Functional theory (Madrid, Beijing): >10 shells, important proton-neutron pairing missing

Ubiquitous role of strong interaction (theory & models) in ν physics

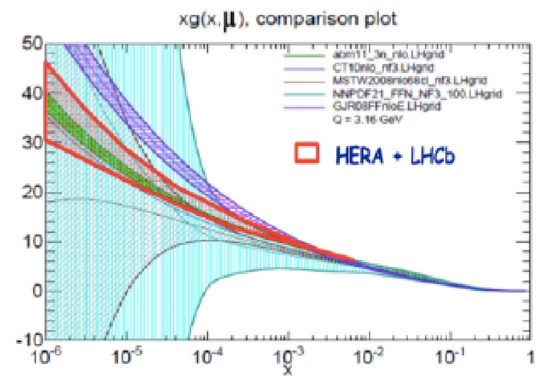
Need hadron production data, e.g. pA → πX, +theory models to improve estimates of atm. and acceler. ν fluxes and errors

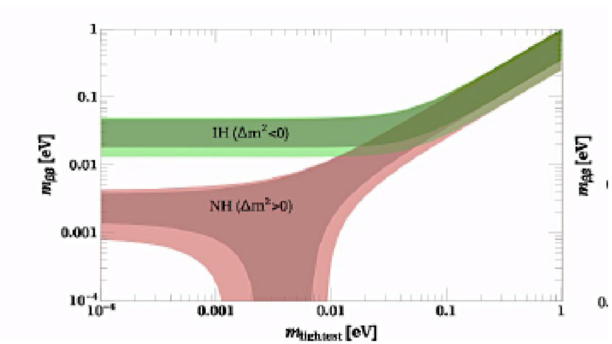


Current understanding of ν cross sections at O(GeV) does not match the needs of (next-generation) ν expts



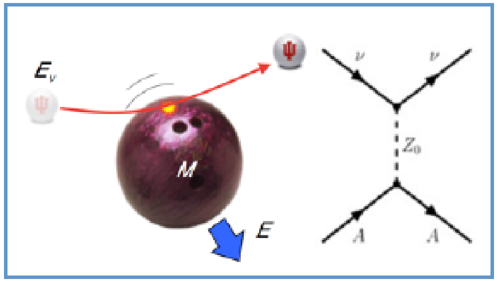
Improved PDFs at low-x via ~forward charm production at LHCb essential to constrain prompt component in UHE ν





Control of nuclear EW response (e.g., form factors) relevant to interpret many low-energy data: 2β, coherent scatt., reactor spect.

...



Emerging inter-disciplinary field of Electroweak Nuclear Physics

Talks by: Honda [Atmos.], Yuan, Wilikinson [Xsec], Ejiri [g_A], Studenikin, Sharma [Coherent], Marrone [reactor]

From Eligio Lisi's talk at TAUP 2019.

Neutrino colloquium, Prague, October 24-25 2019

What is leptonic CP violation good for?

(Is it necessary or just optional?)

Michal Malinský

IPNP, Charles University in Prague

Theoretical Prospective on Leptonic CP Violation

S. T. Petcov

SISSA/INFN, Trieste, Italy, and
Kavli IPMU, University of Tokyo, Japan

Towards CP Violation in Neutrino Physics
Colloquium, Heyrovsky Institute
Academy of Sciences of Czech Republic
Prague, October 25, 2019

Theory breakthrough could occur at any time – PLEASE.

Thanks to Rupert and Milos for inviting us all and for the wonderful organization…

Dave Wark
Oxford U./RAL