MANCHESTER
1824

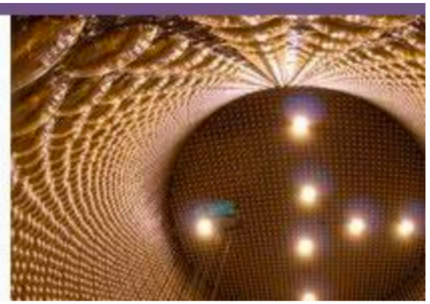
Closing Remarks

IOP Institute of Physics

International Workshop on Next Generation Nucleon Decay and Neutrino Detectors (NNN17)

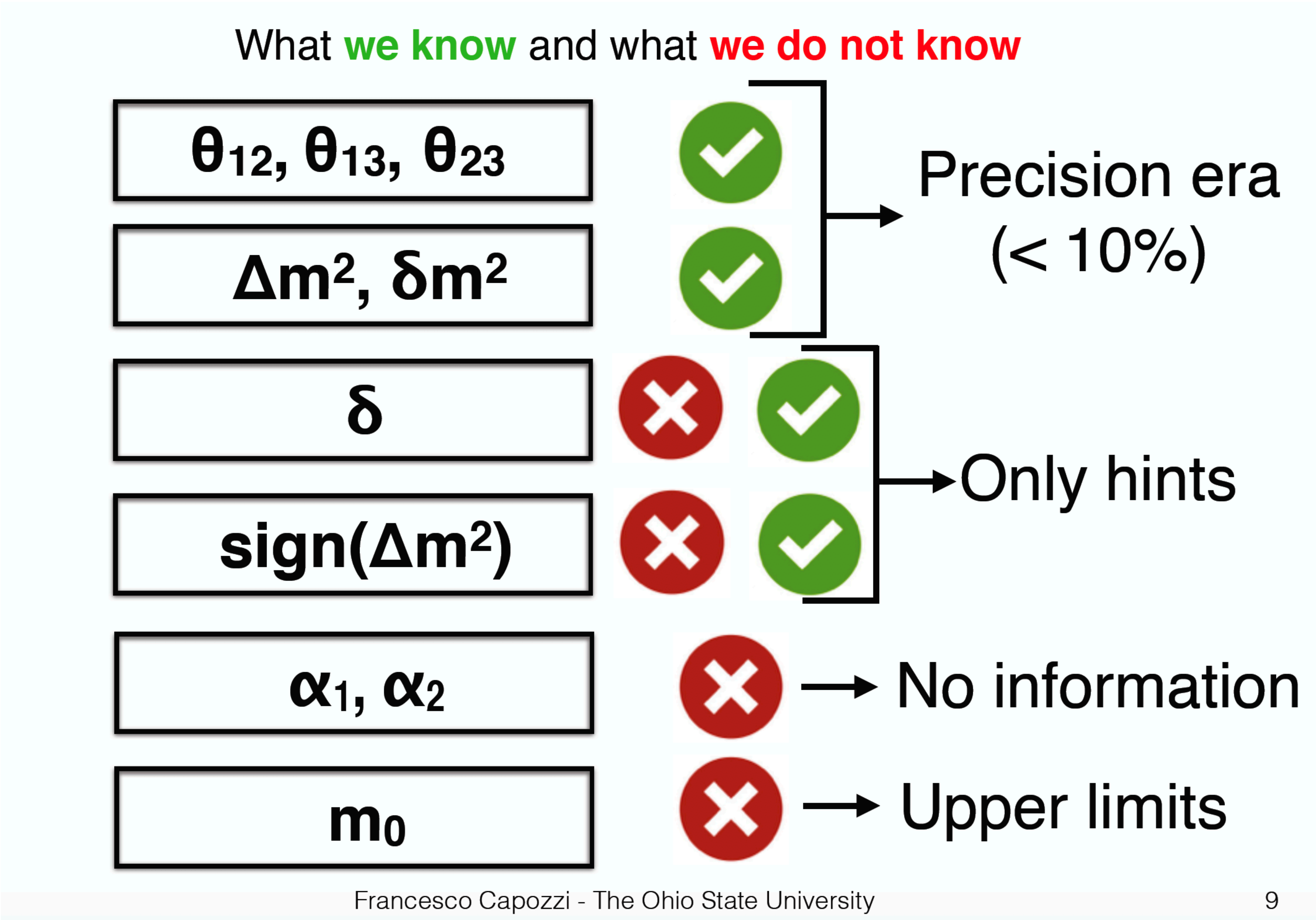
26–28 October 2017, University of Warwick, UK

WARWICK



Stefan Söldner-Rembold
University of Manchester

28 October 2017


What we know and what we do not know
θ12, θ13, θ23
Δm², δm²
Precision era
(< 10%)
δ
sign(Δm²)
Only hints
α1, α2
No information
m0
Upper limits
Francesco Capozzi - The Ohio State University
9

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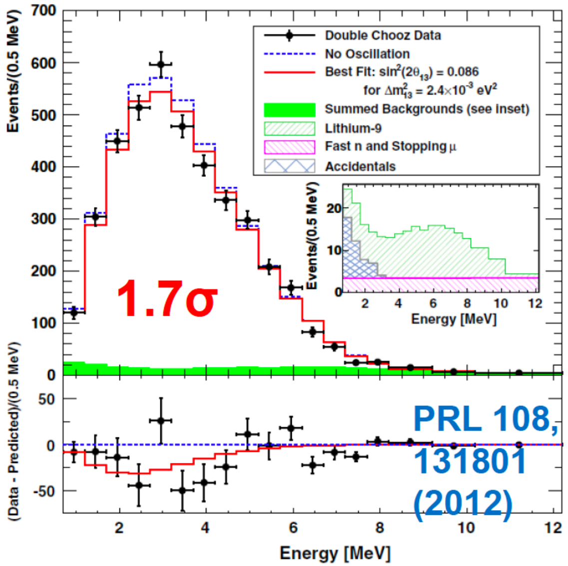
The θ_{13} Miracle

Miao He
Jamie Dawson

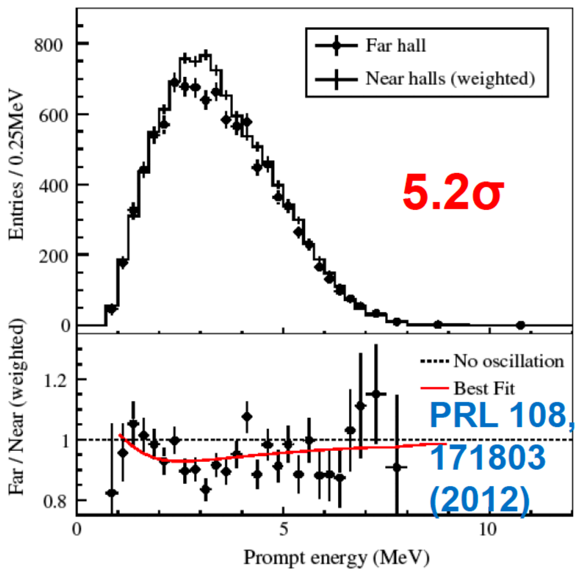
Double Chooz with only a far detector (Nov. 2011)



Rate+shape

$$\sin^2 2\theta_{13} = 0.086 \pm 0.041(\text{stat}) \pm 0.030(\text{syst})$$

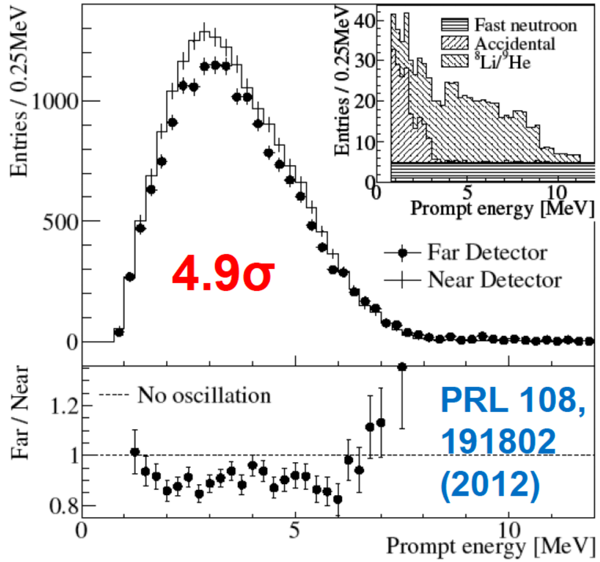
Daya Bay (March 2012)



Rate only

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat.}) \pm 0.005(\text{syst.})$$

RENO (April 2012)



Rate only

$$\sin^2 2\theta_{13} = 0.103 \pm 0.013(\text{stat.}) \pm 0.011(\text{syst.})$$

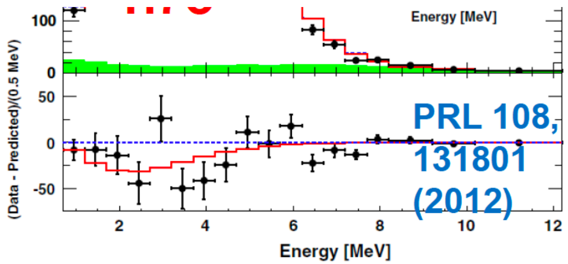
M.He: Overview of reactor neutrinos 11

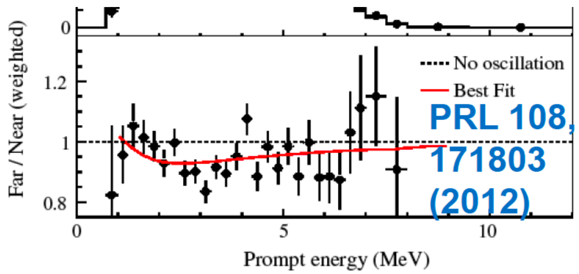
The θ_{13} Miracle

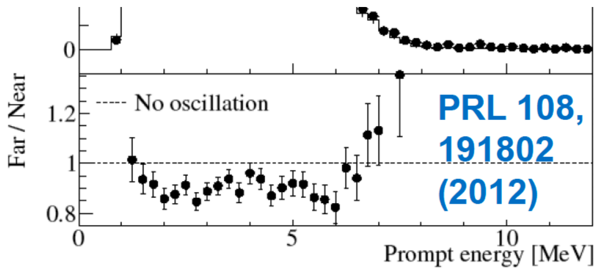
Dorota Stefan

$$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2$$
$$+\sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31}\frac{\sin(aL)}{(aL)}\Delta_{21}\cos(\Delta_{31}+\delta_{CP})$$
$$+\cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2$$

$$a = G_F N_e/\sqrt{2}$$
$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E}$$







Rate+shape

$$\sin^2 2\theta_{13} = 0.086 \pm 0.041(\text{stat}) \pm 0.030(\text{syst})$$

Rate only

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat.}) \pm 0.005(\text{syst.})$$

Rate only

$$\sin^2 2\theta_{13} = 0.103 \pm 0.013(\text{stat.}) \pm 0.011(\text{syst.})$$

M.He: Overview of reactor neutrinos 11

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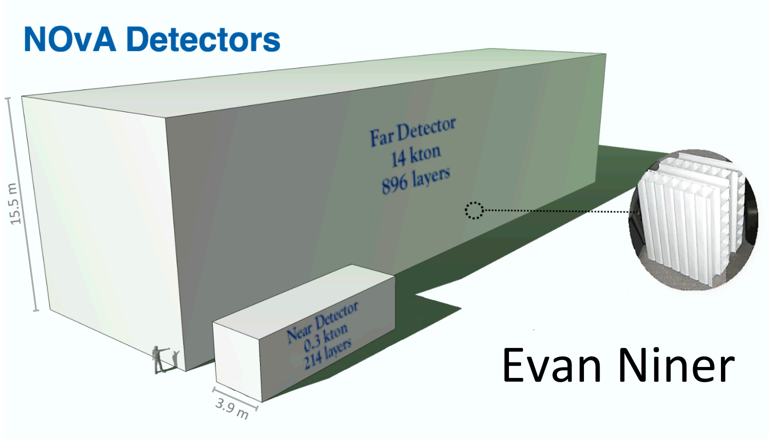
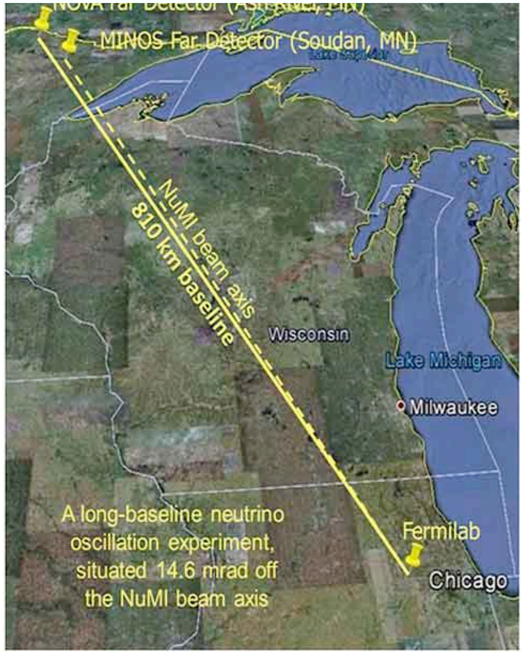
Operating Long-baseline Experiments

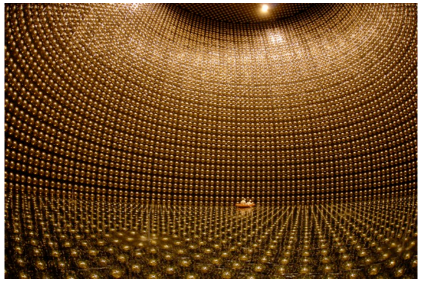


Evan Niner

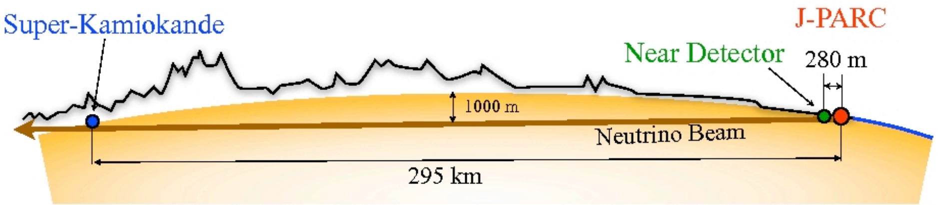
NOvA
810 km

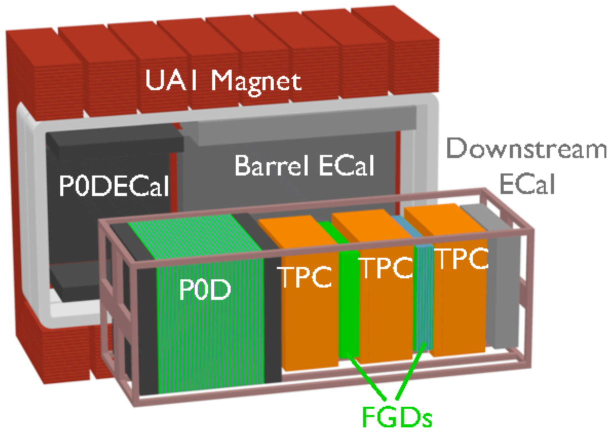


Helen O'Keeffe

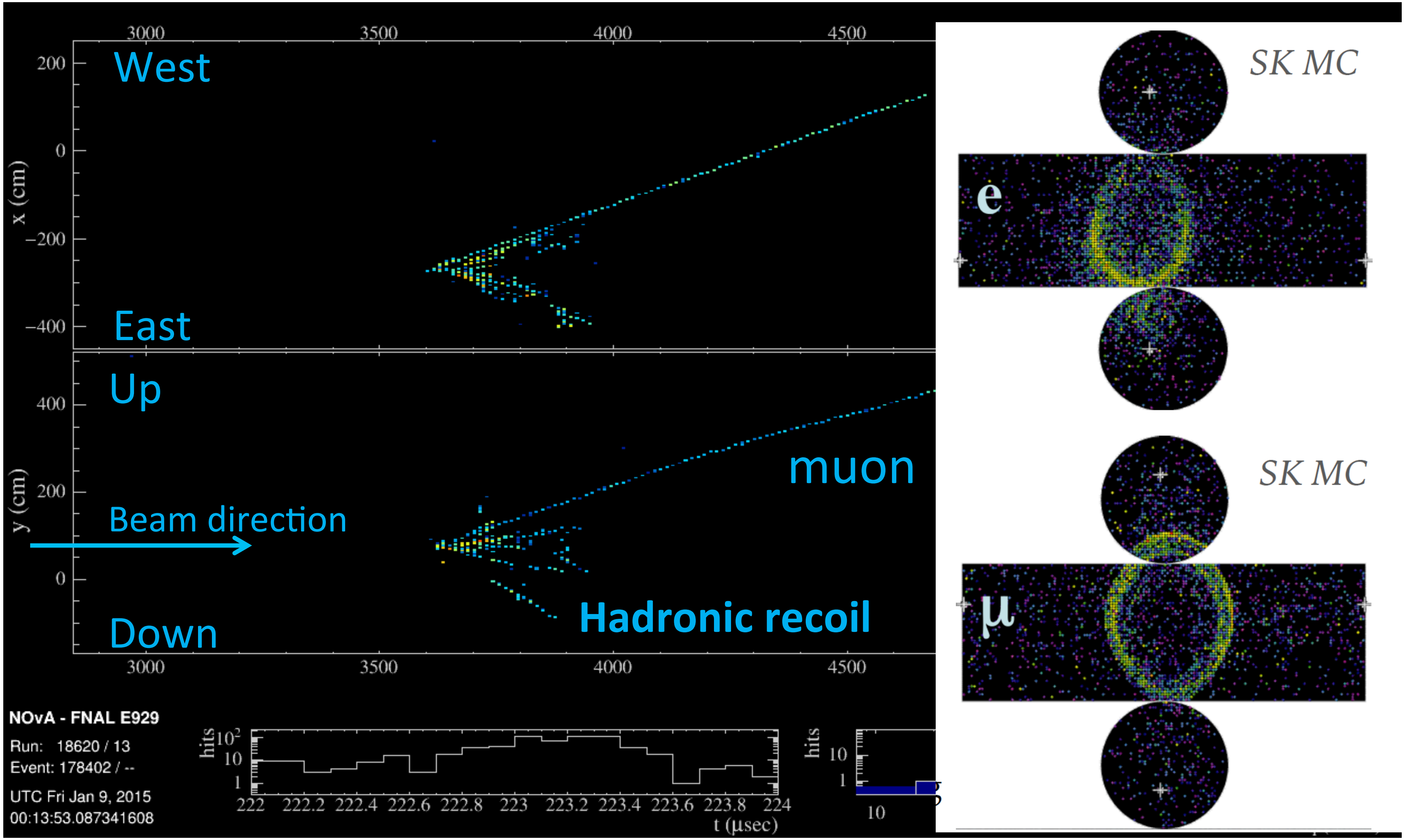


T2K
295 km



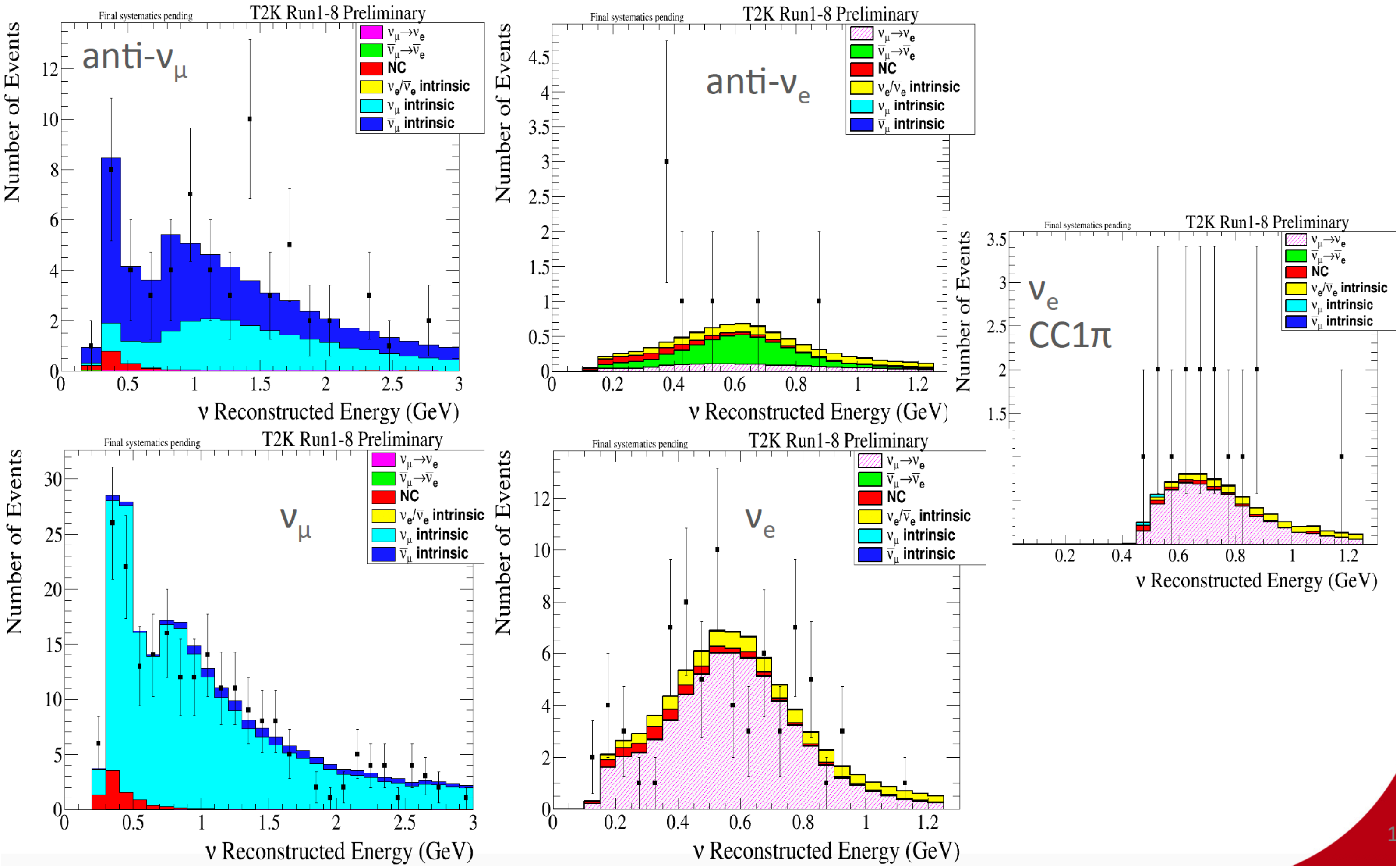


NOvA and T2K Events

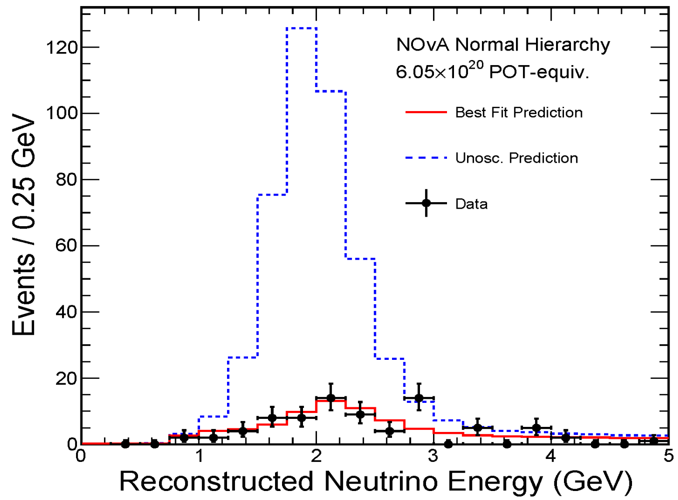


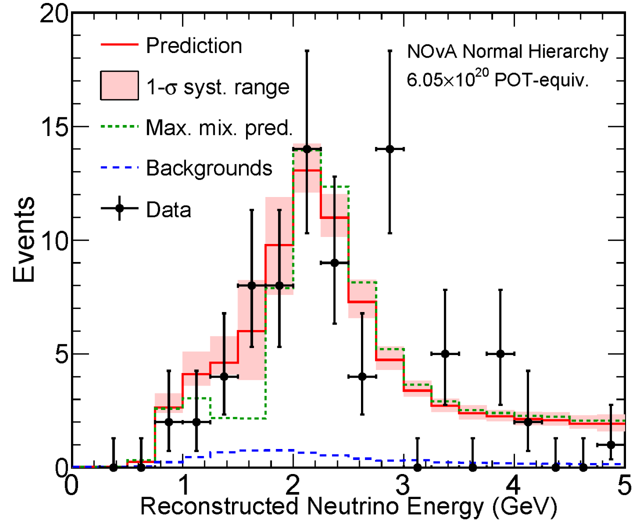
T2K Far Detector Rates

Observed spectra at Super-K



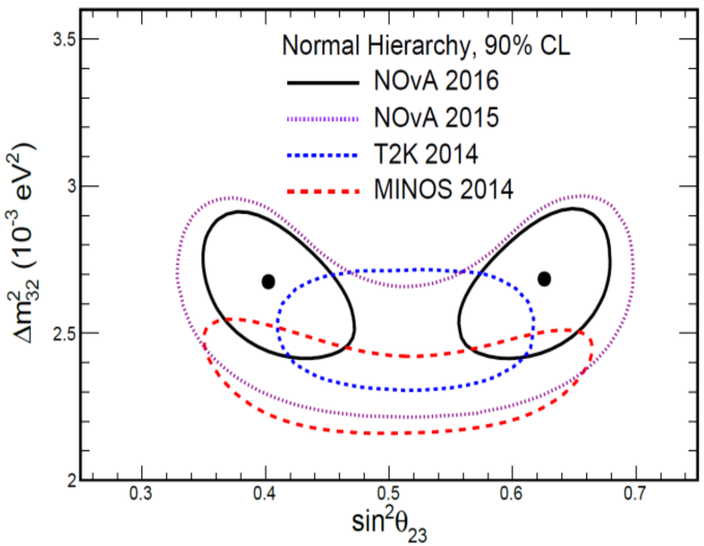
NOvA – ν_μ Disappearance





78 events observed

Evan Niner



Exclude maximal mixing at 2.6 σ

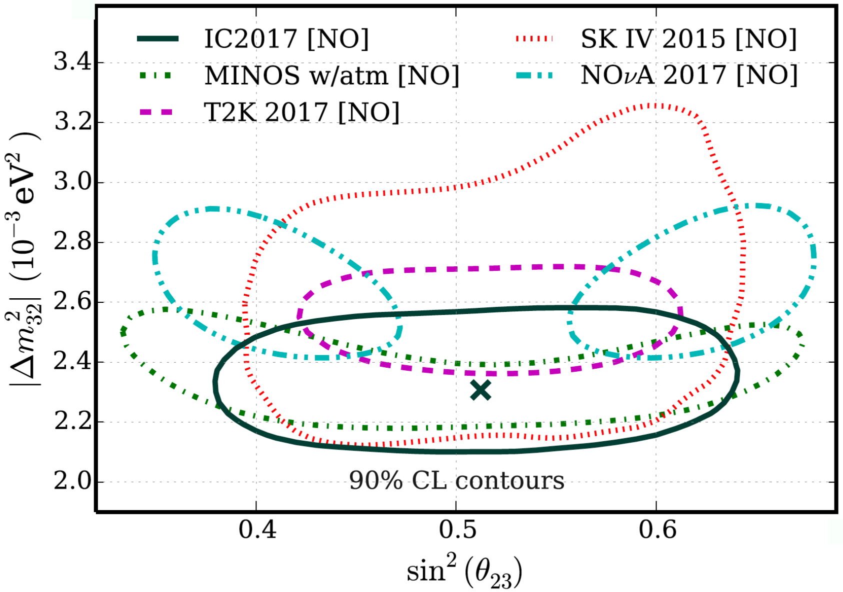
NOvA vs T2K vs IceCube

NOvA excludes maximal mixing at 2.6 σ

T2K result:

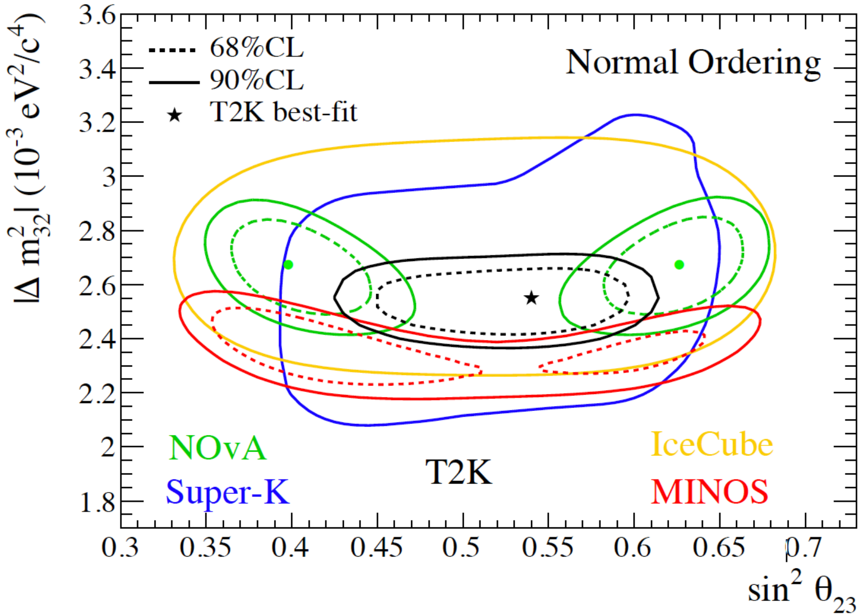
$$\sin^2\theta_{23} = 0.55$$
$$\Delta m^2_{23} = (2.54 \pm 0.08) \times 10^{-3}\ \text{eV}^2/\text{c}^4$$

*arXiv:1707.07081



Best Fit: $\Delta m^2_{32} = 2.31^{+0.11}_{-0.13} \cdot 10^{-3}\text{eV}^2$ & $\sin^2\theta_{23} = 0.51^{+0.07}_{-0.09}$

41,599 total events from 2012-2014

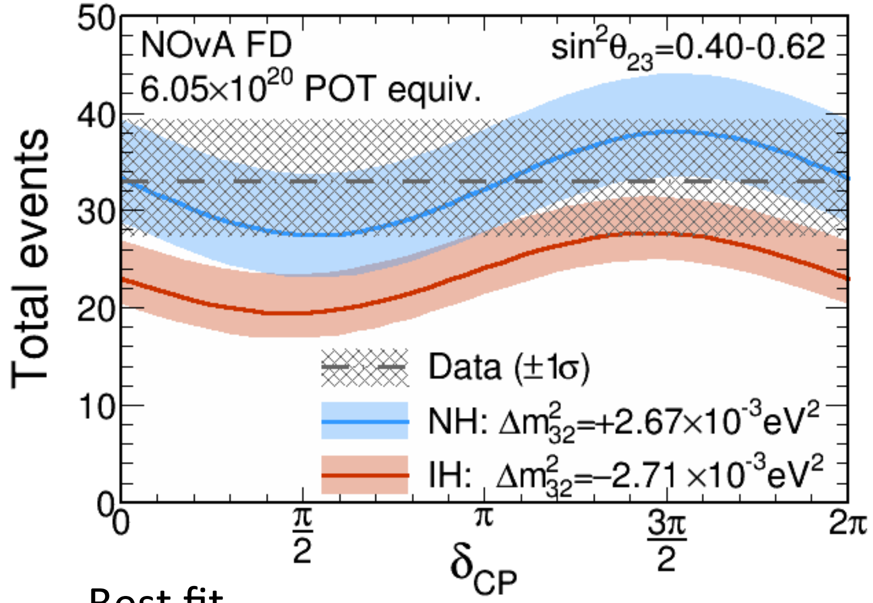


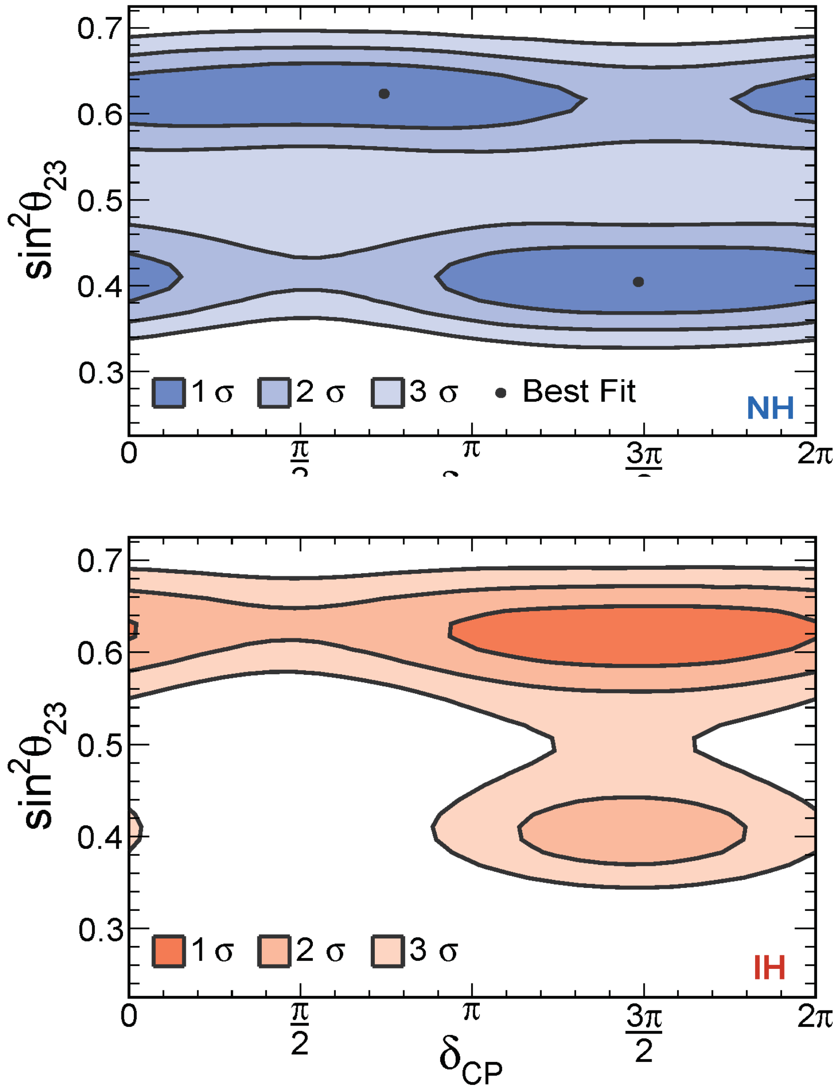
Not statistically significant, but still interesting..

IceCube, Jason Koskinen

NOvA – ν_e Appearance

Evan Niner



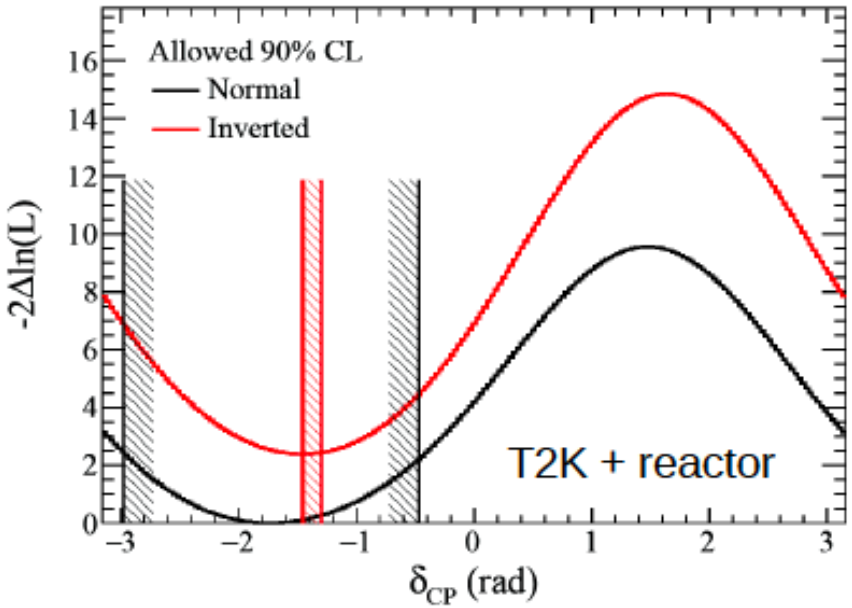


Best fit

$$\delta_{cp} = 1.48\pi, \sin^2(\theta_{23}) = 0.404$$
$$\delta_{cp} = 0.74\pi, \sin^2(\theta_{23}) = 0.623$$

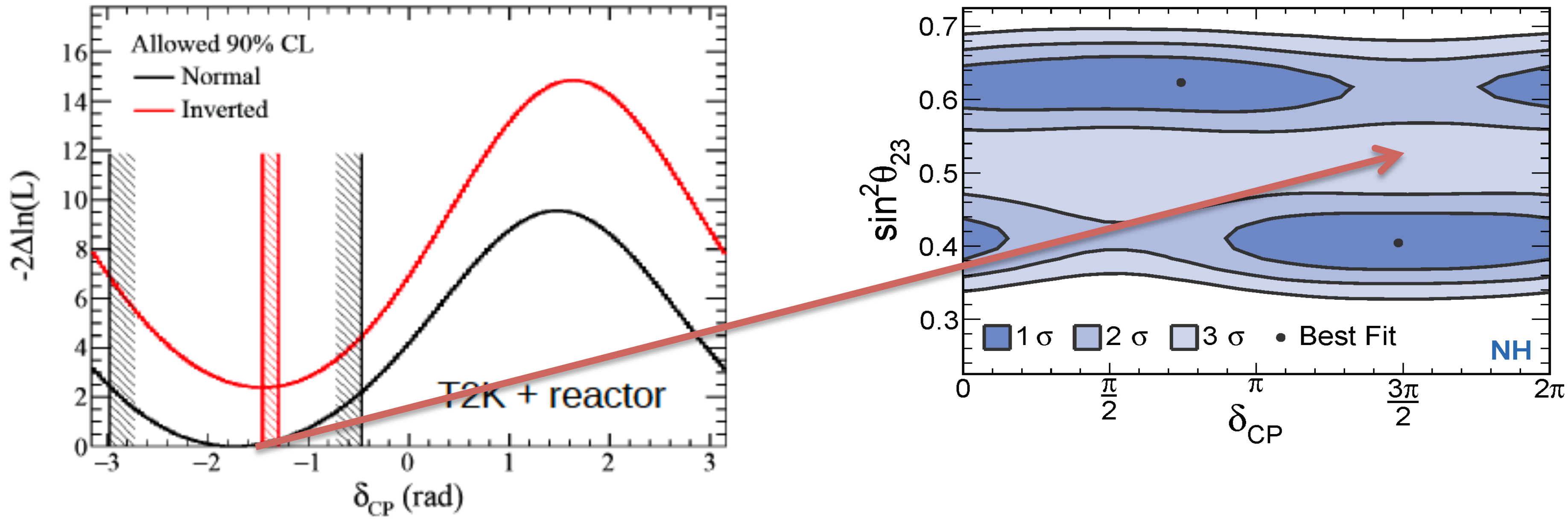
- Need anti-neutrino data to resolve degeneracies.
- Lower left octant in inverted hierarchy excluded at 3σ for all δ

CP Phase



- T2K: CP conservation hypothesis outside 2σ interval.
- Sensitivity driven by electron-like excess of events

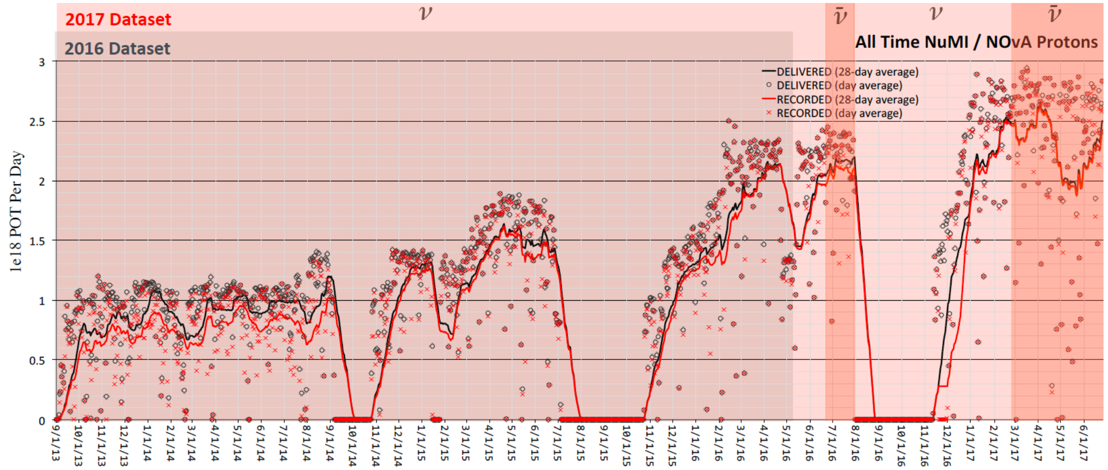
CP Phase

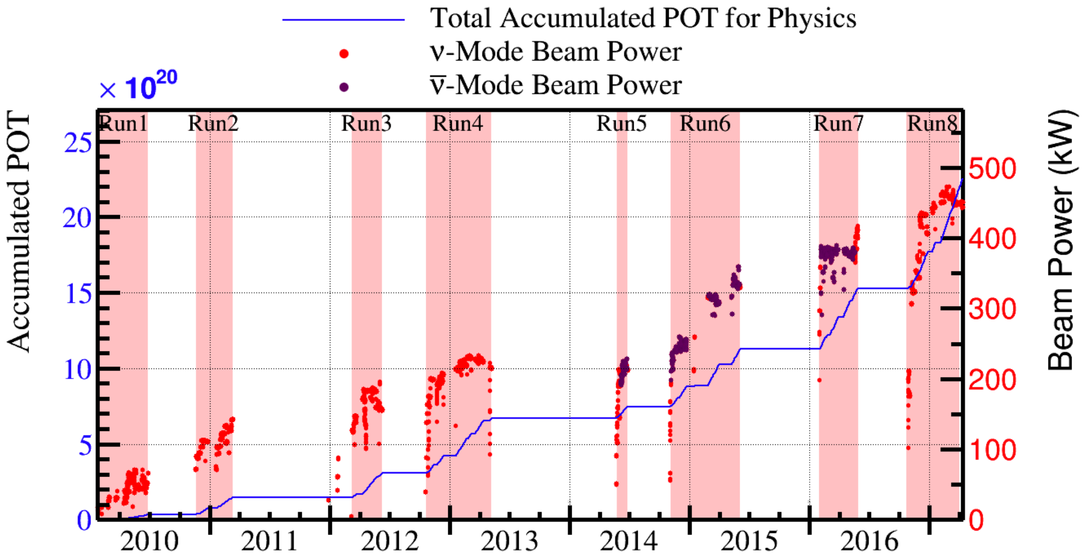


- T2K: CP conservation hypothesis outside 2σ interval.
- Sensitivity driven by electron-like excess of events
- Both experiments prefer normal hierarchy
- Different preference for maximal vs. non-maximal mixing

Off-axis neutrino beams

NOvA: 17% of approved POTs



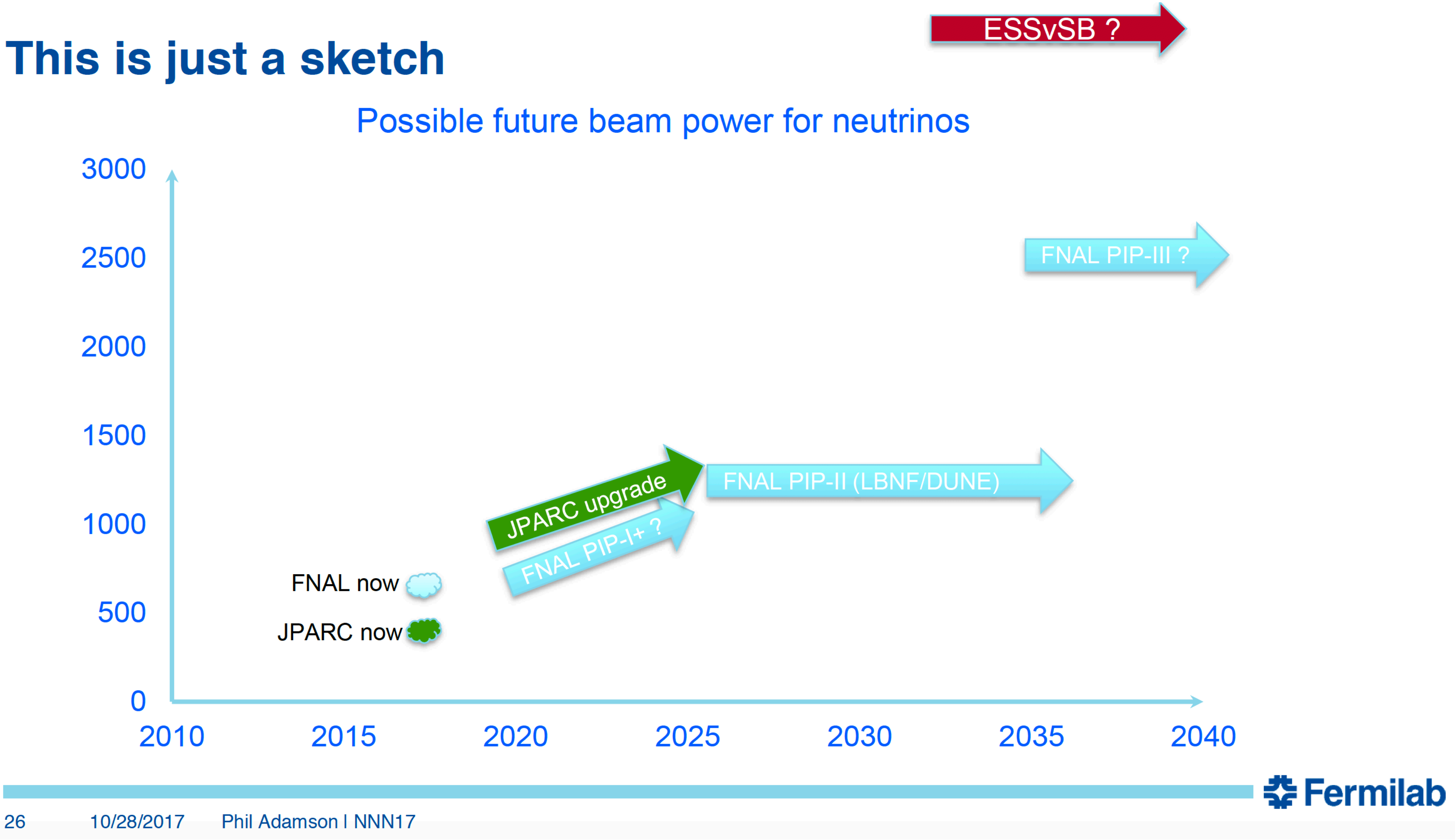


T2K: 30% of approved POTs

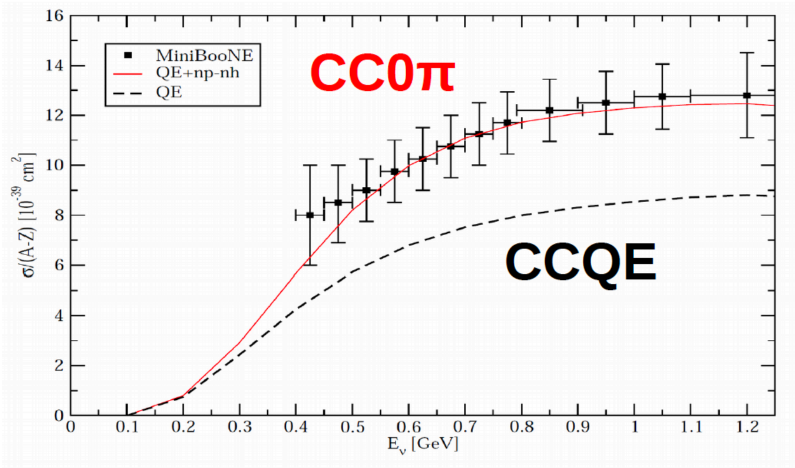
Talks on neutrino beams by Chris Densham and Phil Adamson this morning.

The future is bright?

This is just a sketch



Reducing Systematics

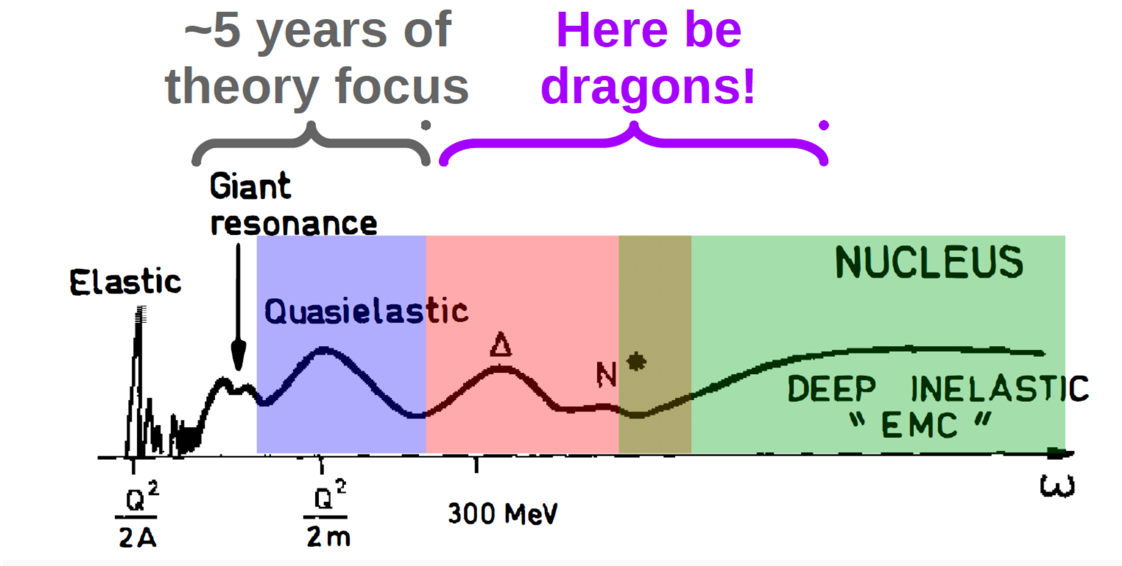


PRC 80 065501 (2009)

Callum Wilkinson

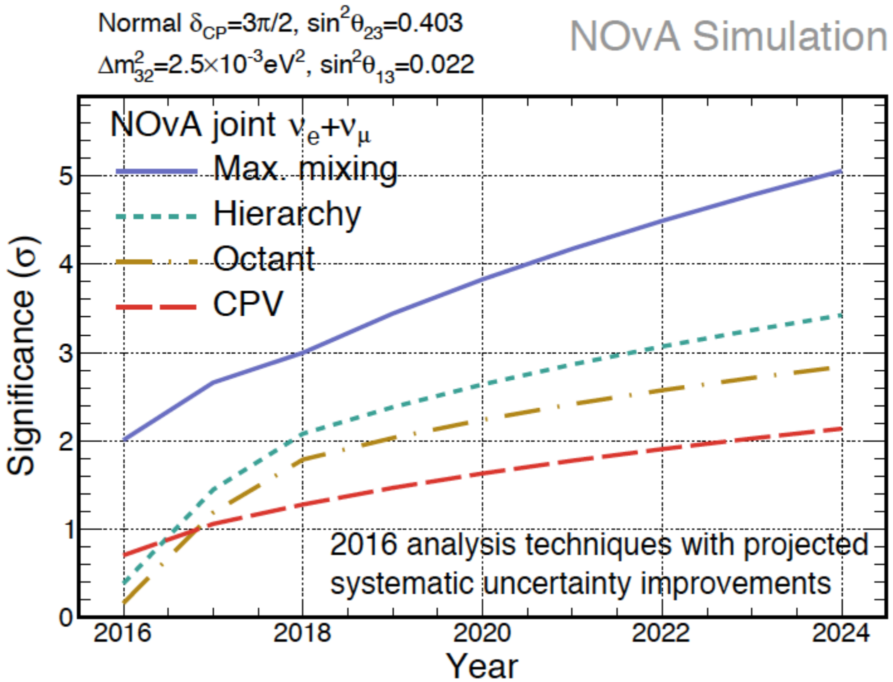
Jacobo Lopez Pavon

Ingredients:
- improved theory and modelling
- comprehensive measurement programme

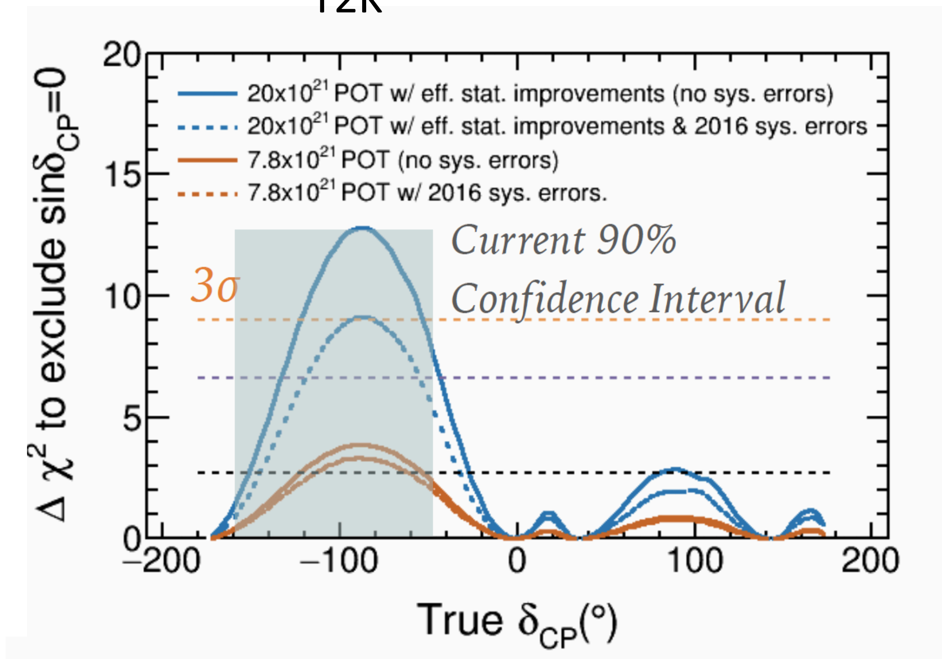


T2K and NOvA Projections

Assumes 6 x 10^{20} POT/year



T2K



Expect ≈ 2-3σ on CPV by the time DUNE and HK turn on

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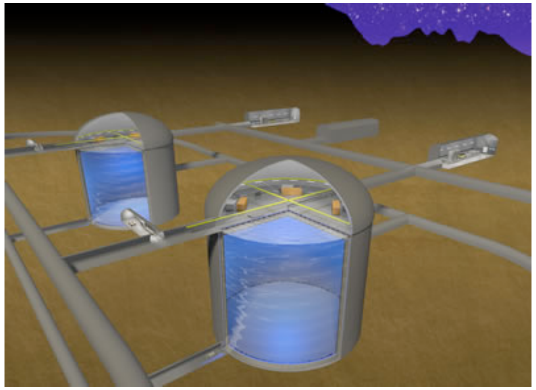
Future: DUNE and HK

Itaru Shimizu
Shoei Nakayma

L ≈ 200 km

$$\frac{\Delta m^2_{31} L}{4E} \sim \frac{\pi}{2} \Rightarrow E_\nu < 1\,\mathrm{GeV}$$

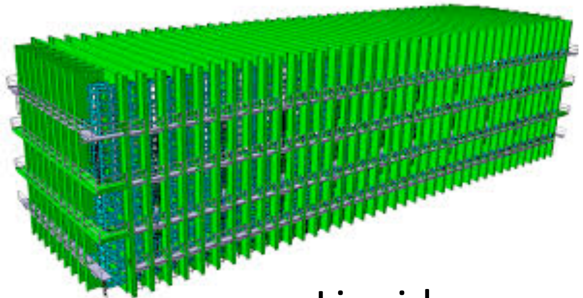
- no matter effects; first oscillation maximum.
- use narrow width beam (off axis).



Water Cherenkov

L > 1000 km

$$\frac{\Delta m^2_{31} L}{4E} \sim \frac{\pi}{2} \Rightarrow E_\nu > 2\,\mathrm{GeV}$$



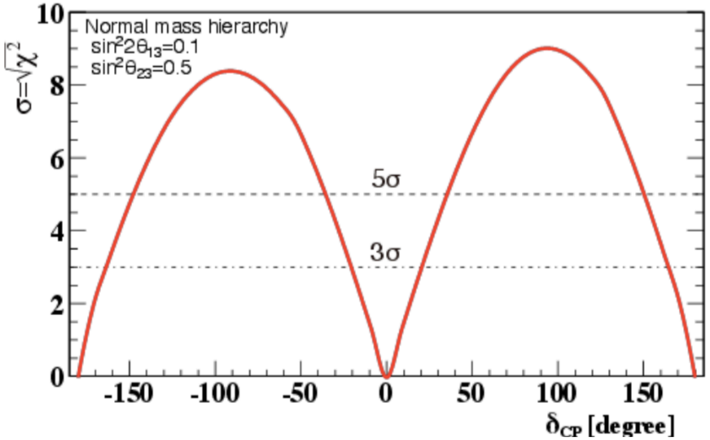
Liquid argon

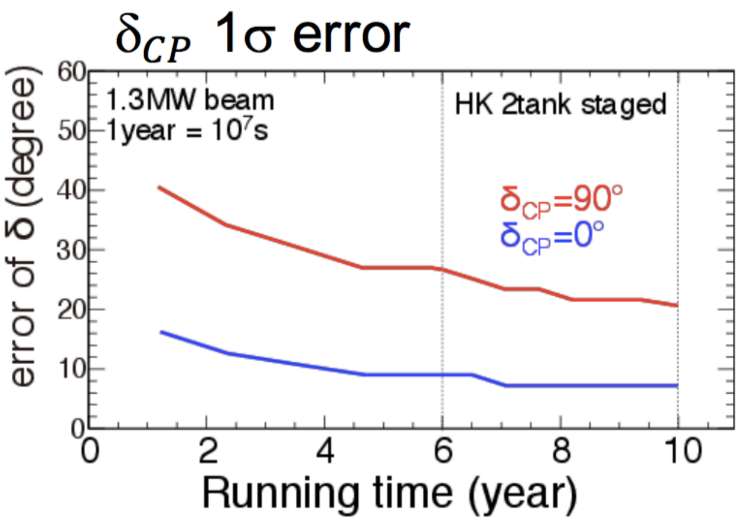
- matter effects; first and second oscillation maximum.
- use broad-band beam (on axis).
- unfold CP and MH effects through energy dependence.

Dorota Stefan
Jonathan Asaadi

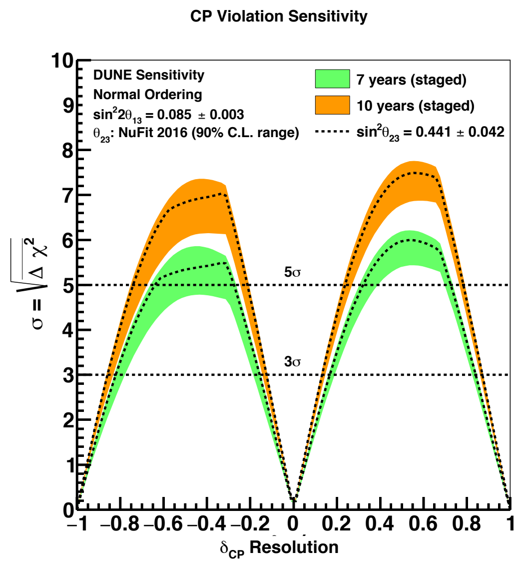
Sensitivity CP Phase

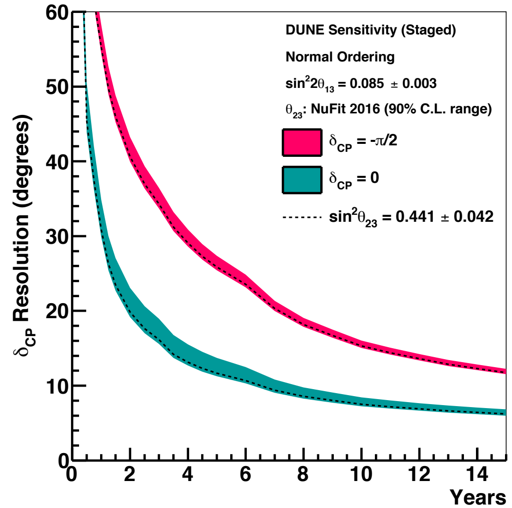
Hyper-K



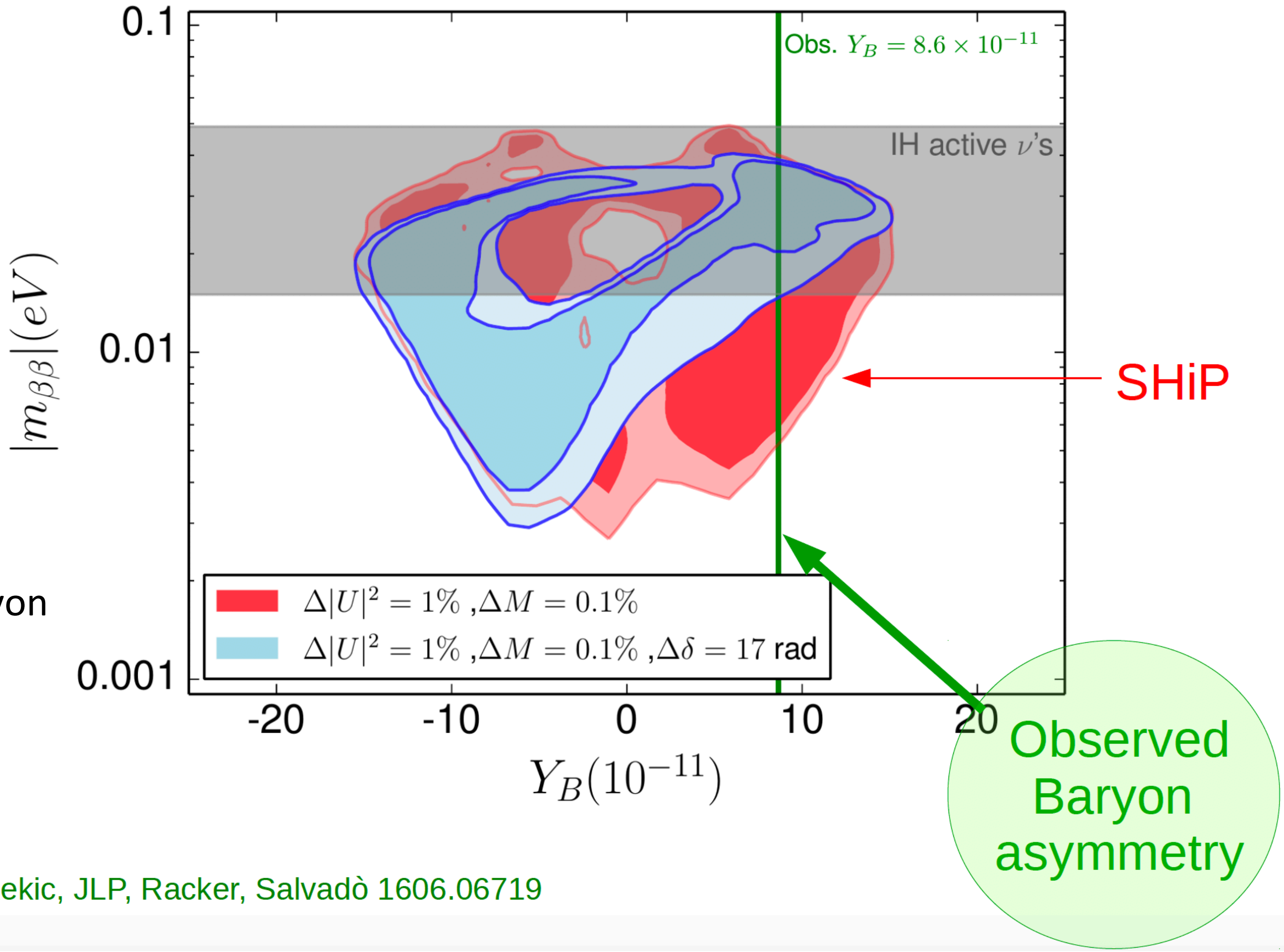


DUNE





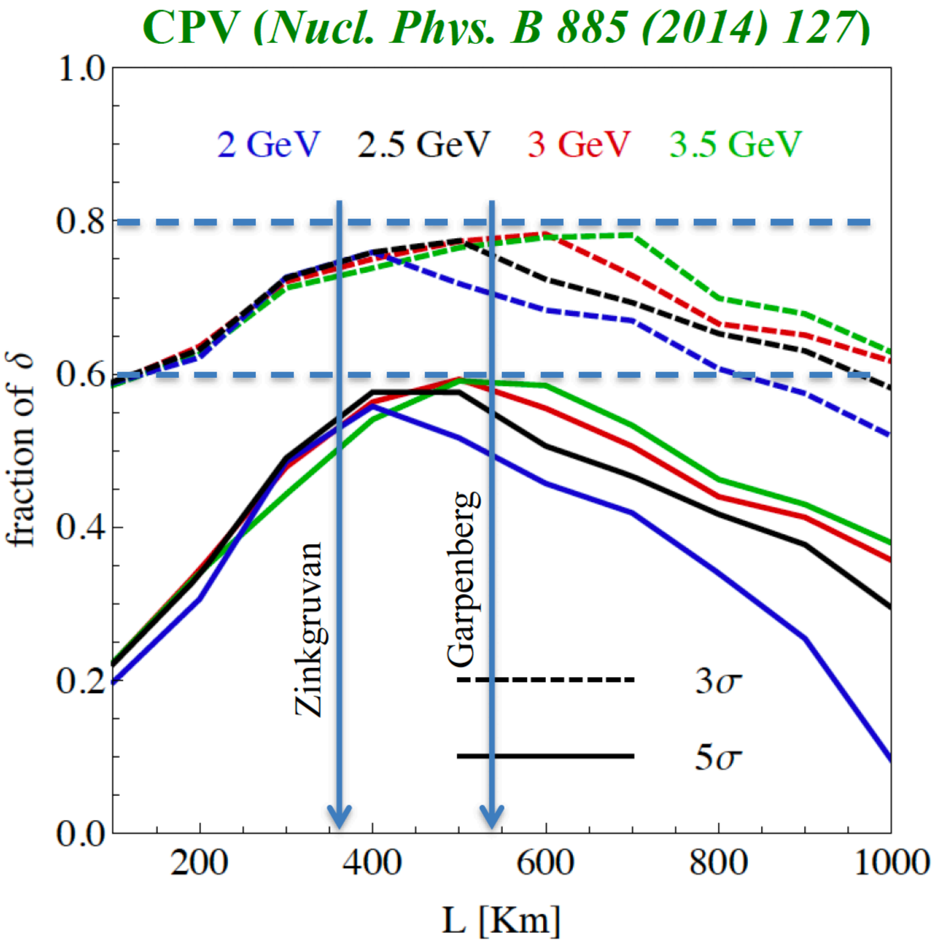
Relevance of Dirac CP phase δ



Jacobo Lopez Pavon

Hernandez, Kekic, JLP, Racker, Salvadò 1606.06719

Another option: ESS

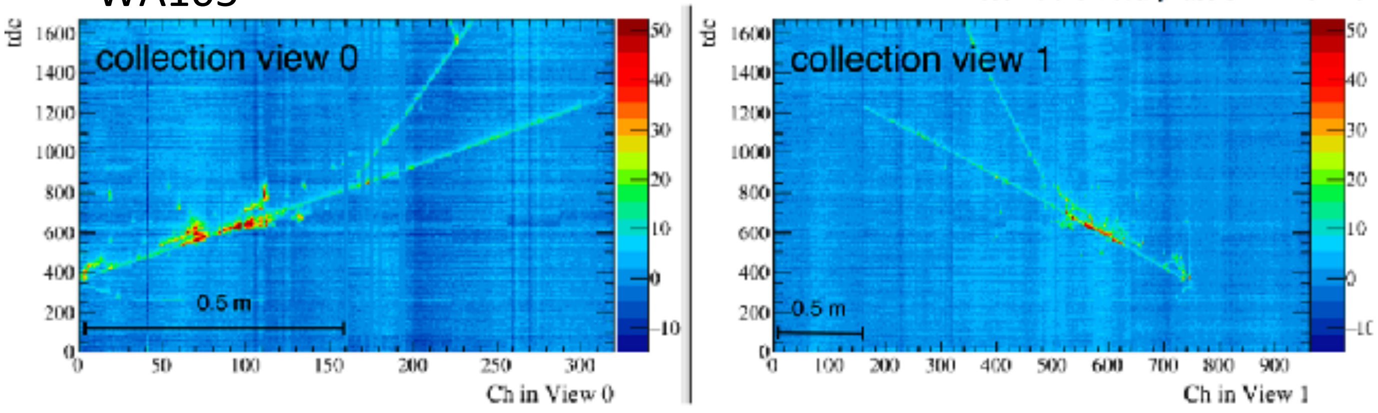


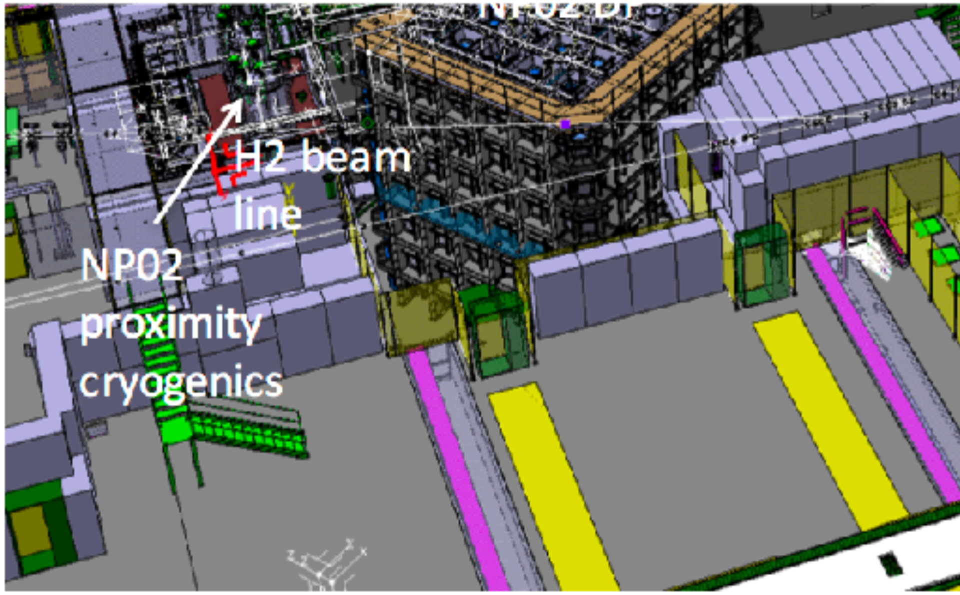
Marco Dracos

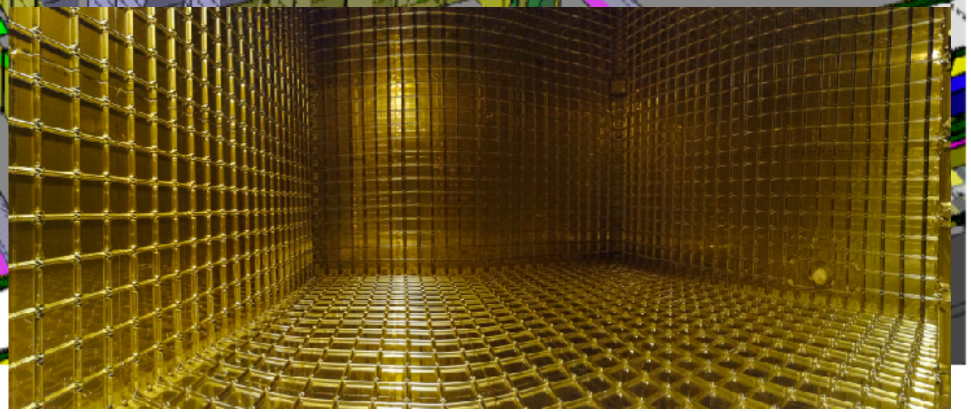
ProtoDUNE-SP/DP@CERN

Laura Molina Bueno

WA105





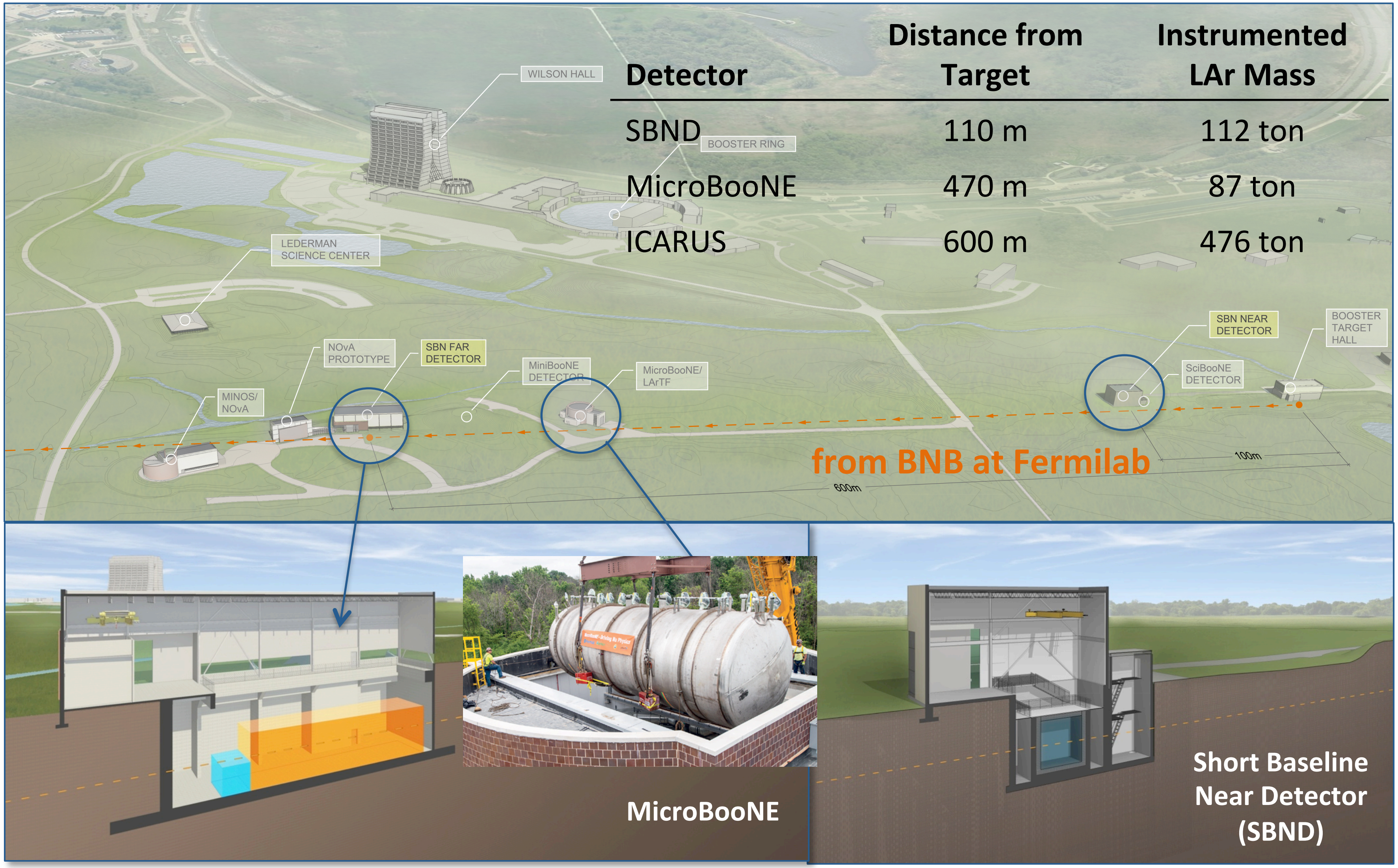


Commissioning in 2018 –ready for LS2

Short-baseline experiments

Jo Pater, Joseph Zennamo

Detector	Distance from Target	Instrumented LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton



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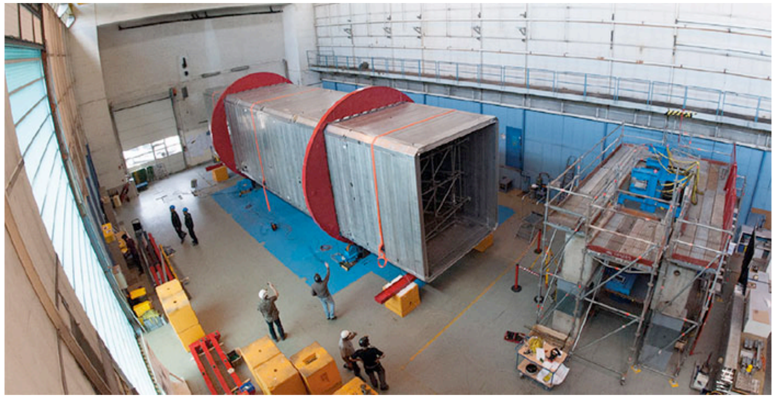
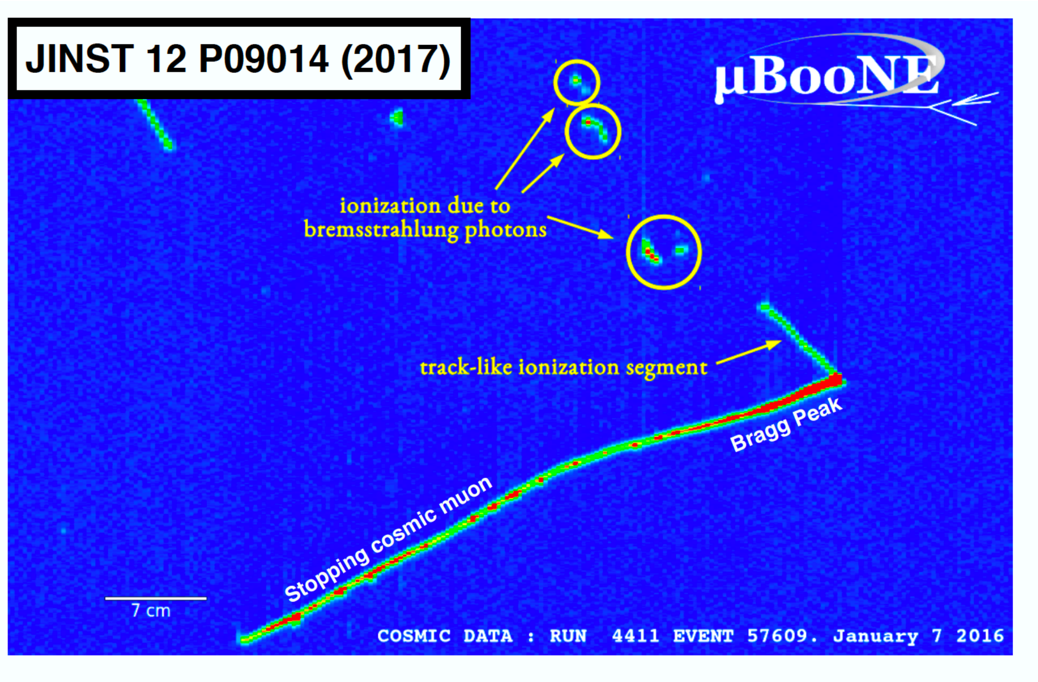
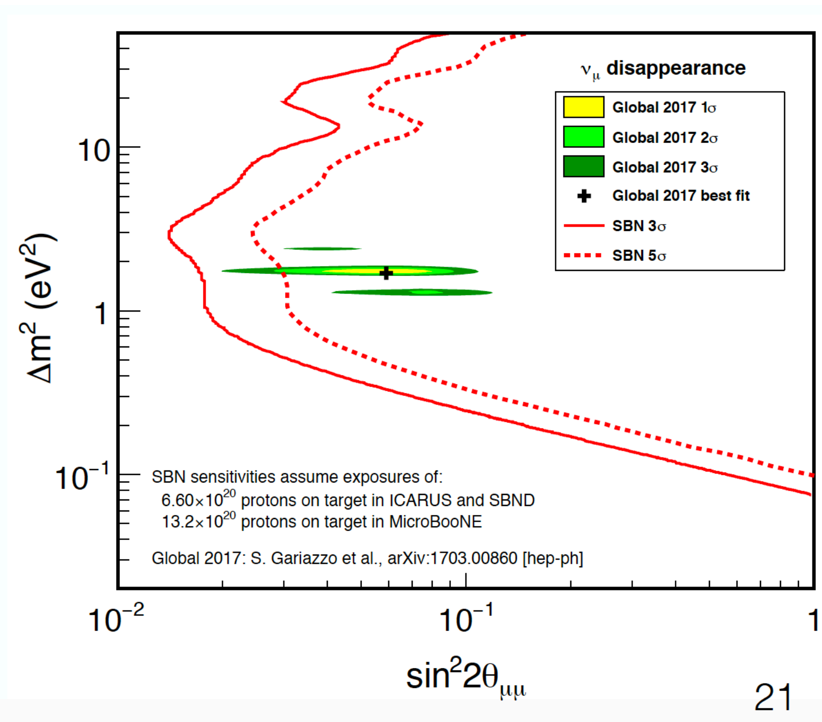
SBND and ICARUS



MicroBooNE

Joseph Zennamo





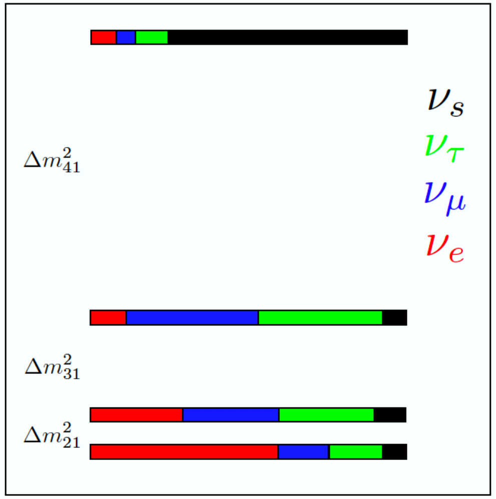
Michel electrons: demonstration of ‘text book’ measurements using LAr

SBN programme will probe MiniBooNE anomaly and search for sterile neutrinos.

Thomas Schwetz

Sterile neutrinos at the eV scale?

- Reactor anomaly ($\bar{\nu}_e$ disappearance)
- Gallium anomaly (ν_e disappearance)
- LSND ($\bar{\nu}_\mu \to \bar{\nu}_e$ appearance)
- MiniBooNE ($\nu_\mu \to \nu_e, \bar{\nu}_\mu \to \bar{\nu}_e$ appearance)



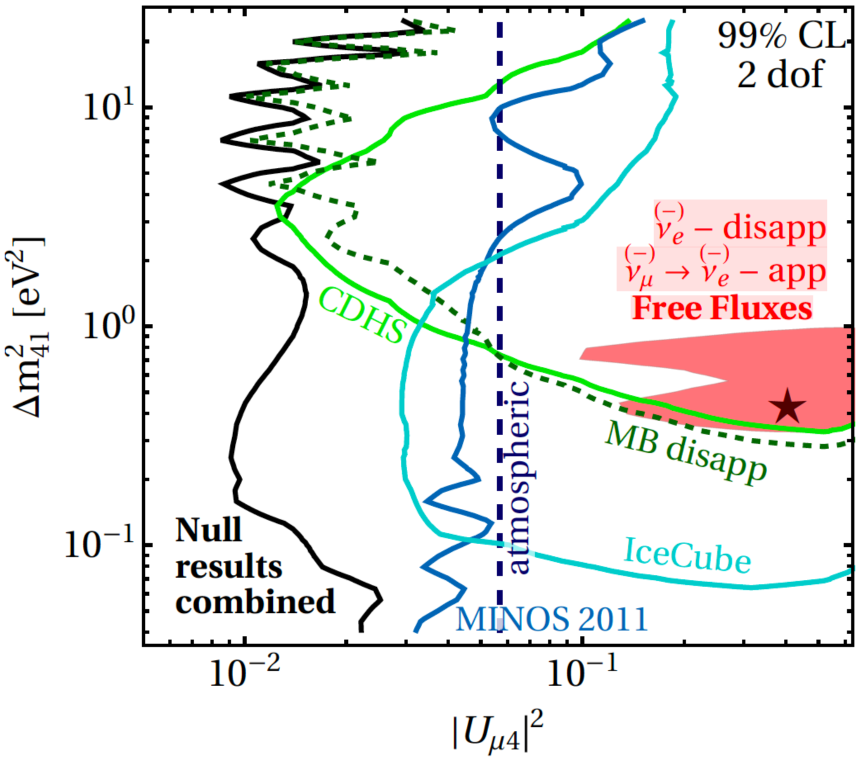
- "phenomenological model": eV scale state is not related to seesaw or the mechanism of neutrino mass generation
- eV scale seesaw e.g.: Blennow, Fernandez-Martinez, 11; Fan, Langacker, 12; Donini, Hernandez, Lopez-Pavon, Maltoni, TS, 12

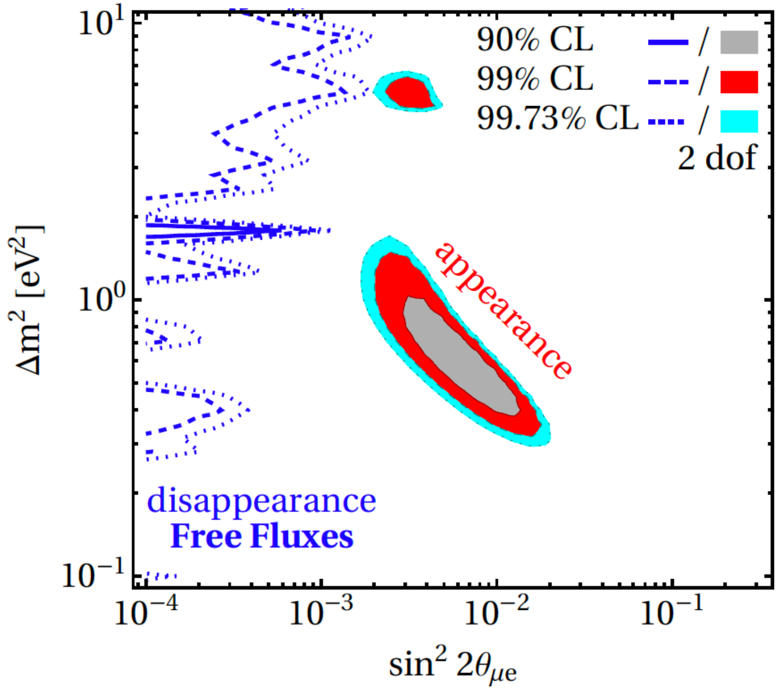
Sterile neutrino searches are tests of the three-flavour paradigm

Sterile Neutrinos

Thomas Schwetz

ν_μ disappearance



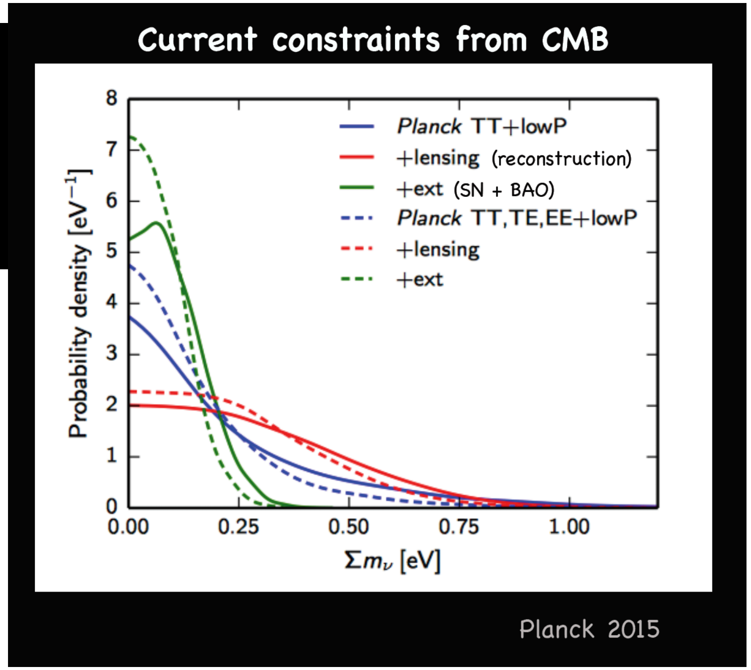


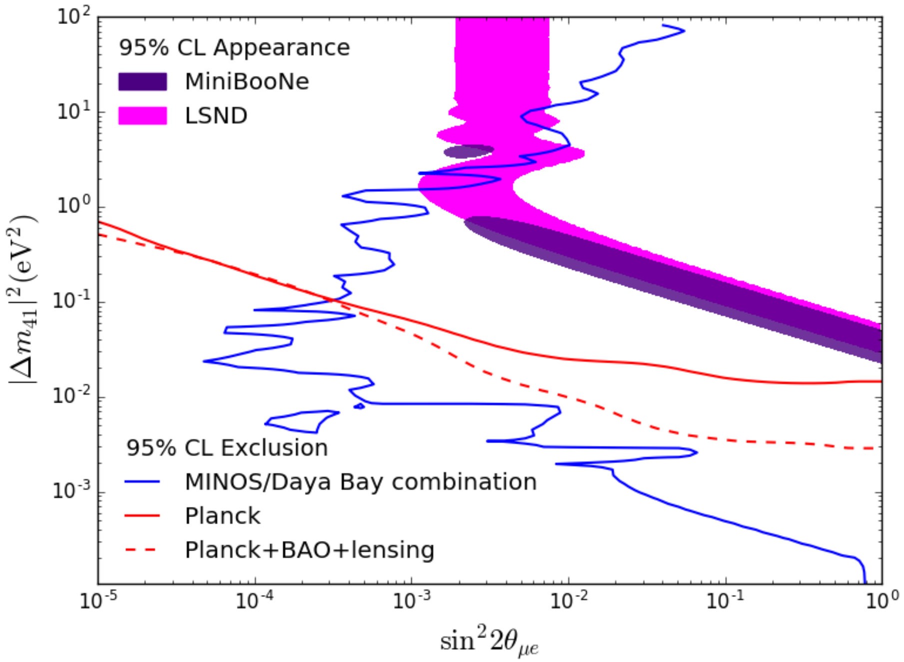
Strong tension between disappearance and appearance

Neutrinos and Cosmology

Marilena LoVerde

$$\rho_{radiation} = \frac{\pi^2}{15} T_\gamma^4 + \frac{7\pi^2}{240} (N_{eff} \times 2)\, T_\nu^4$$





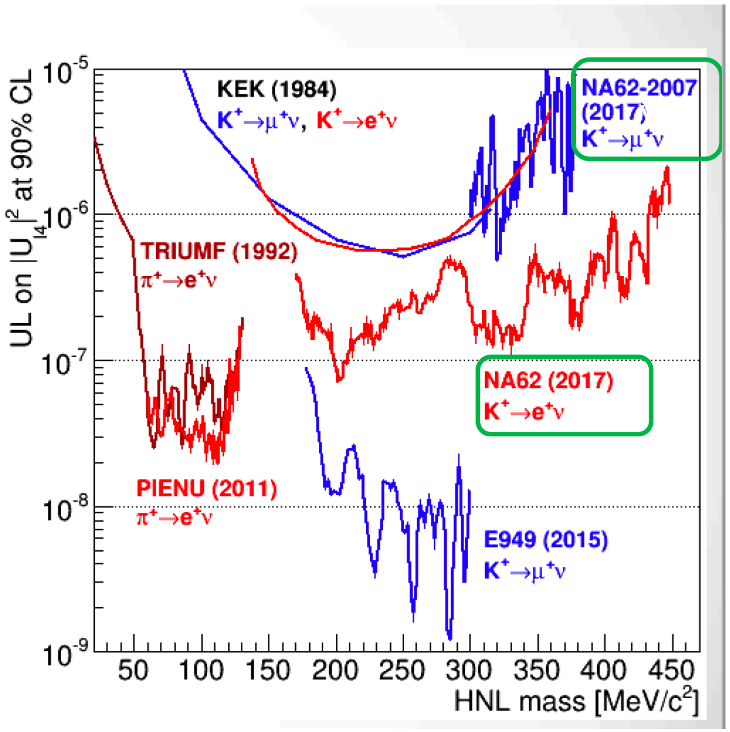
Planck

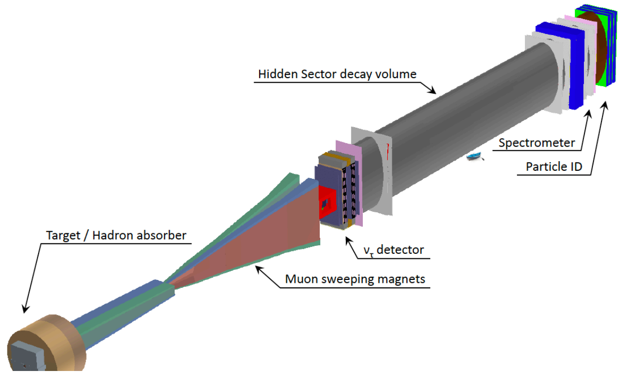
Planck+Lensing+ BAO

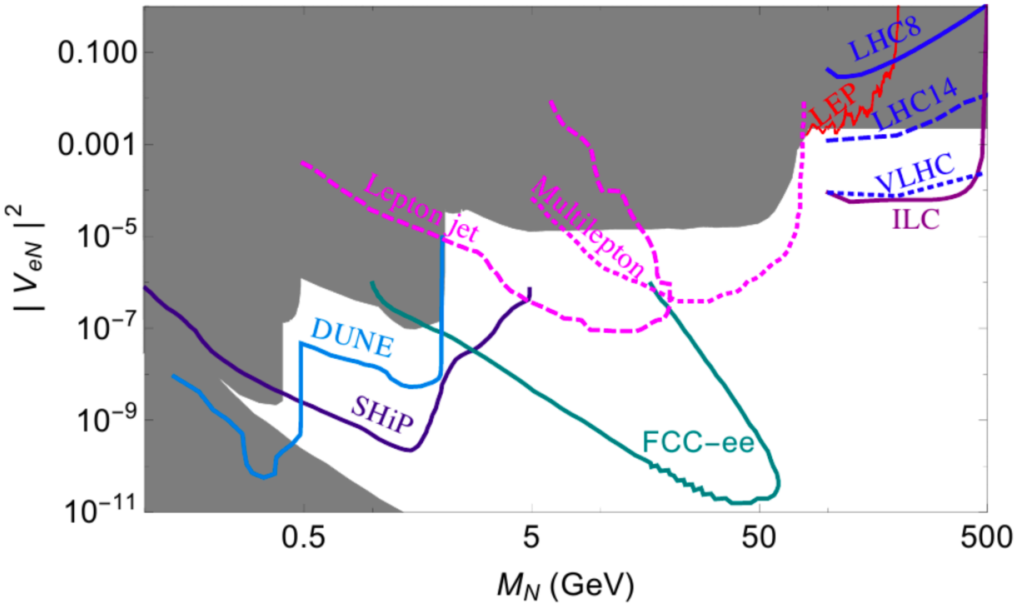
HNL Searches: NA62 and SHIP

Viacheslav Duk

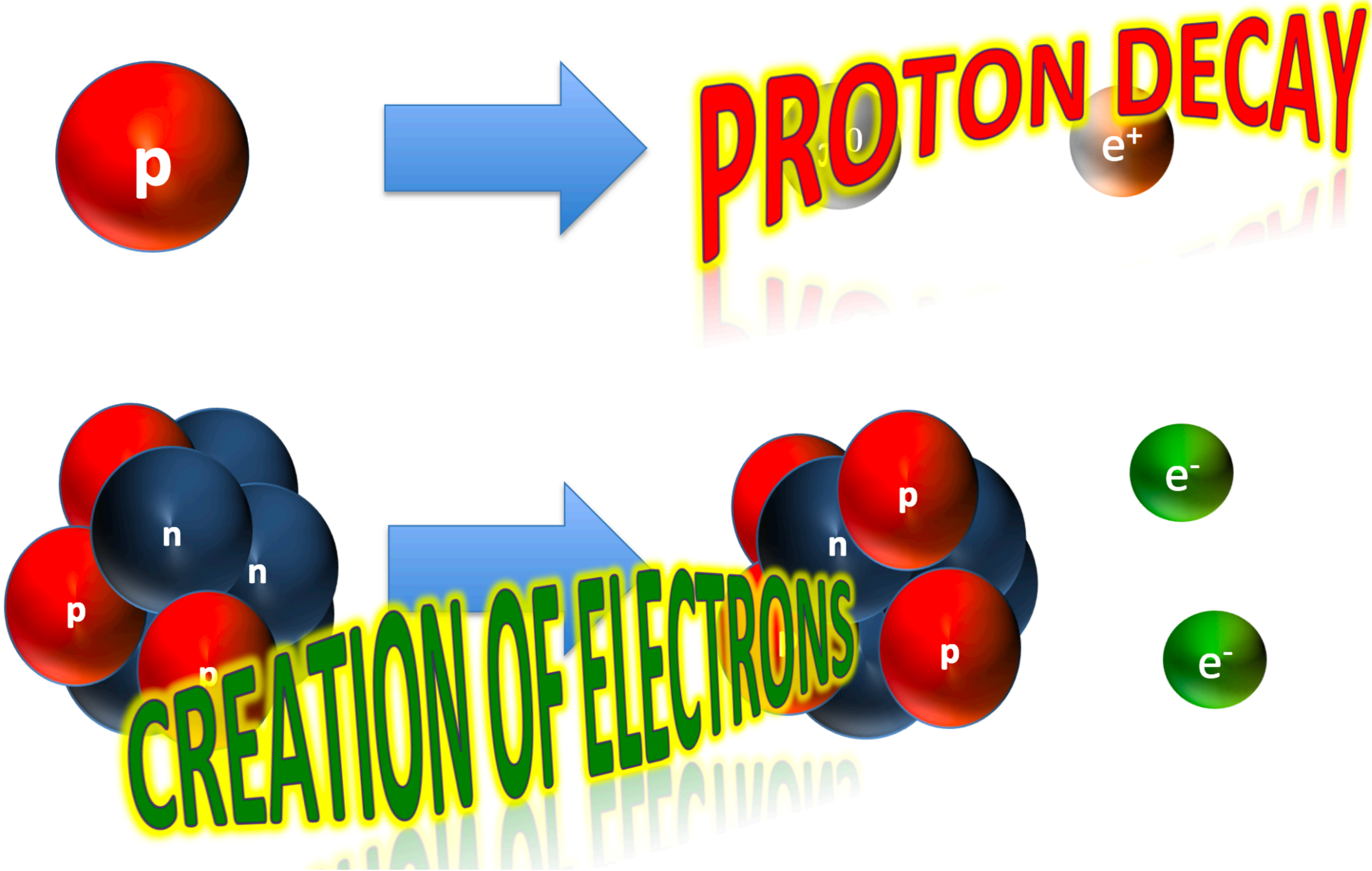
Anne-Marie Magnan





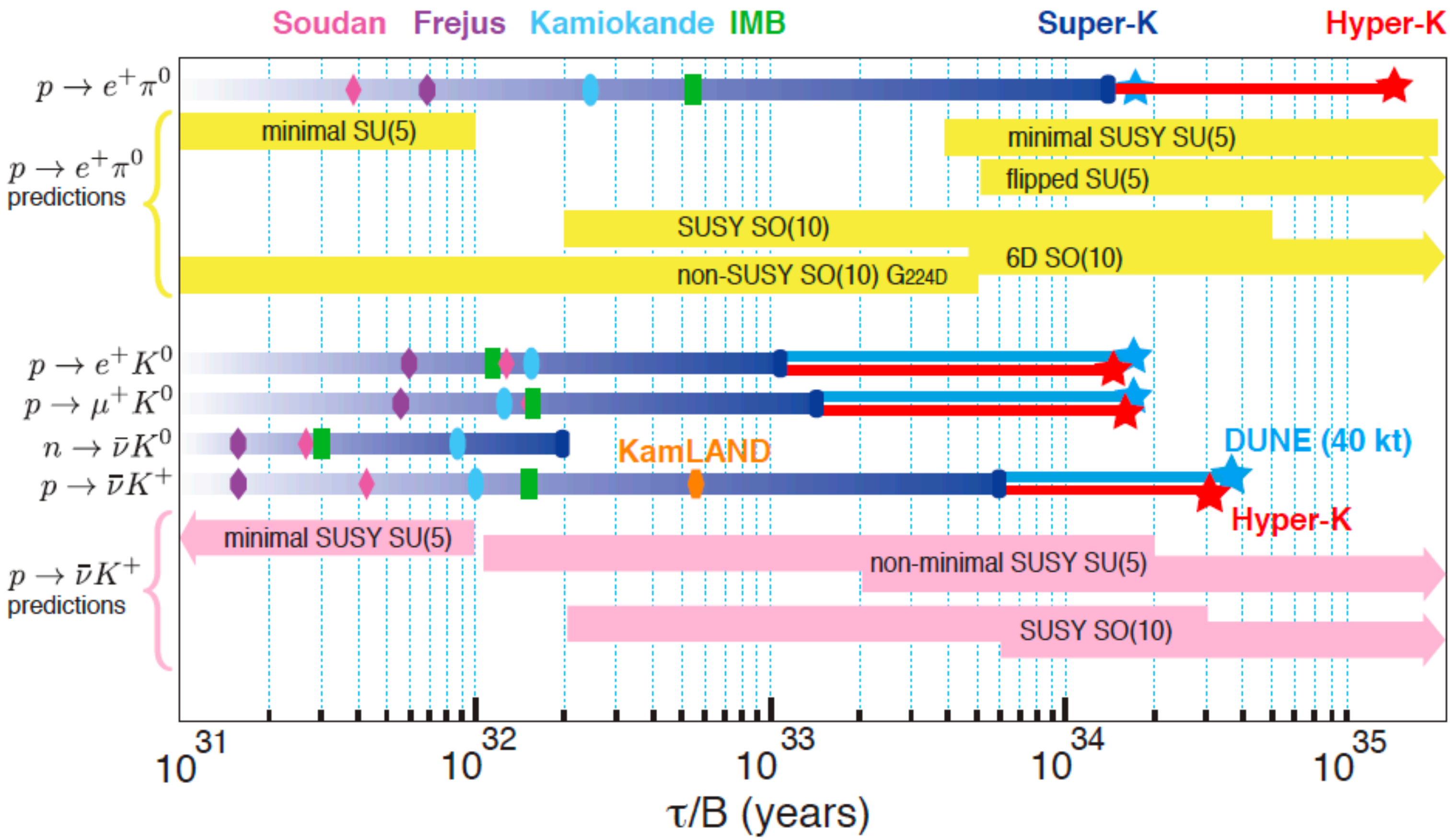


MAYBE MATTER IS NOT FOREVER



Proton Decay

Junji Hisano



Proton decay may be enhanced in

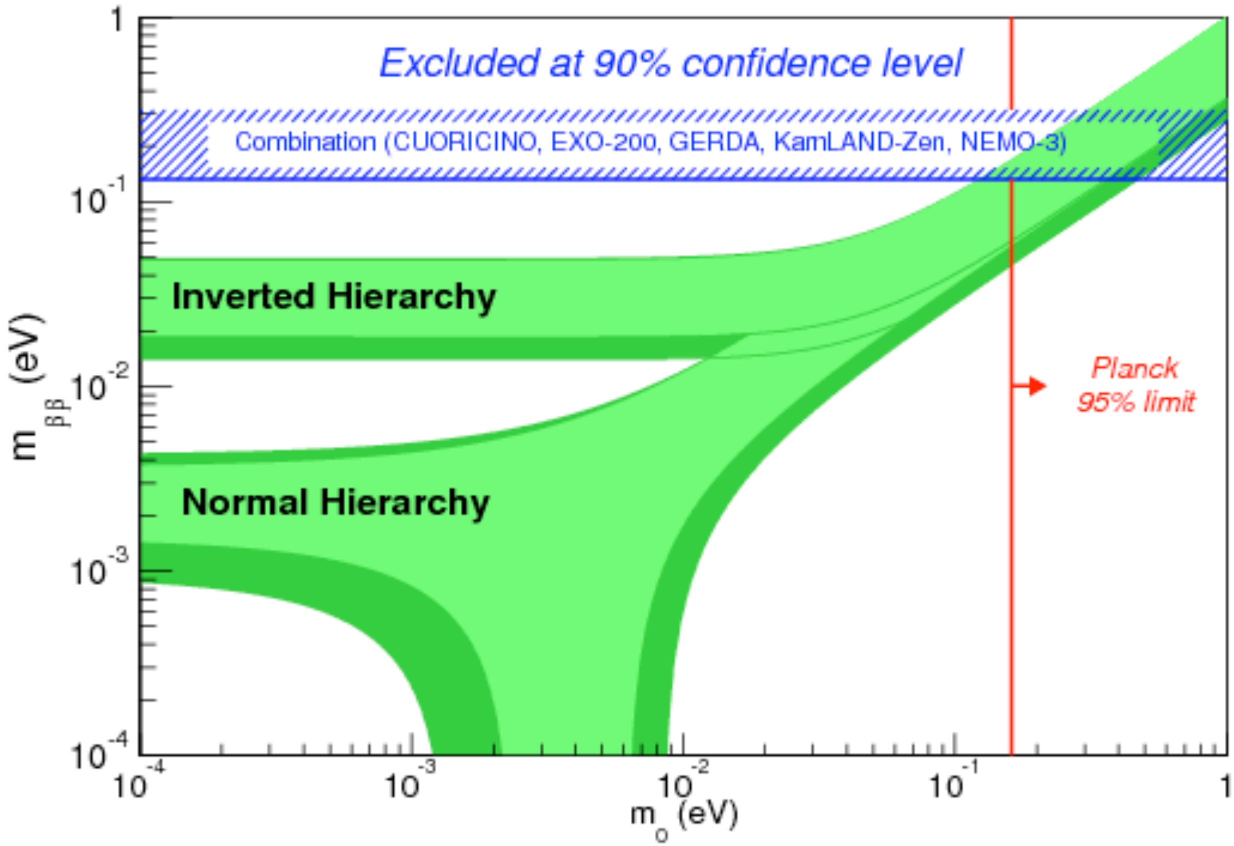
- models with extra matter at intermediate scale
- high-scale supersymmetry

0νββ Status 2015

Stefano Dell'Oro

Full combination using correlations

Phys.Rev. D92 (2015) no.1, 012002

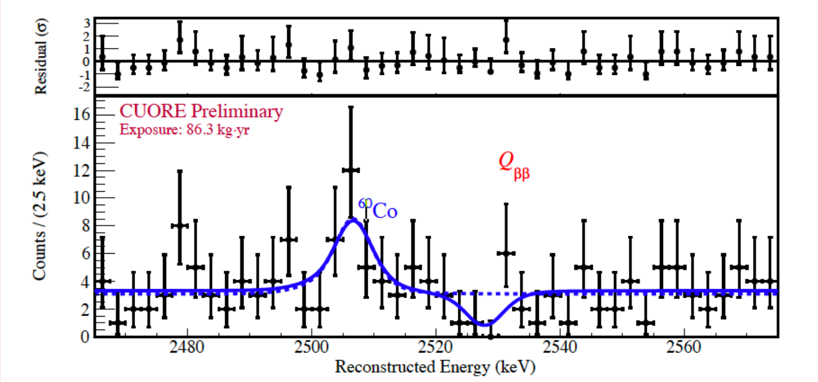


- Goal of current and near-future experiments: cover inverted hierarchy.
- Width of bands depend on mixing parameters (within 3 flavour model).
- Oscillation experiments provide input regarding hierarchy.

CUORE/CUPID and Gerda/Legend

CUORE first results (Oct 2017)

arXiv:1710.07988 [nucl-ex]



$t_{1/2}^{0\nu}(^{130}Te) > 1.5 \cdot 10^{25}$ yr @ 90% C. L.

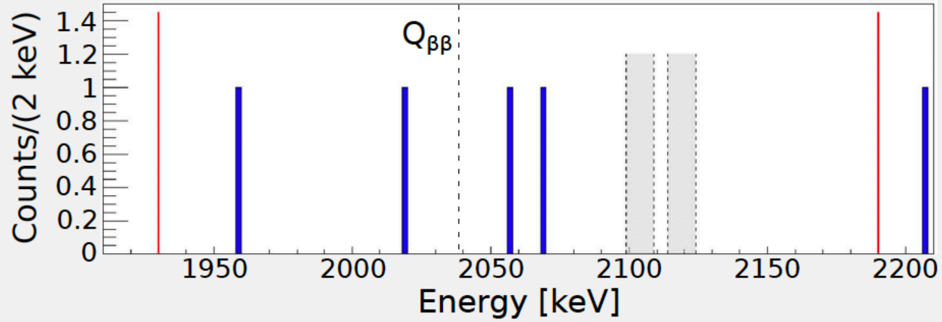
$T_{1/2} > 1.5 \times 10^{25}$ years

Low background experiments with excellent energy resolution.

Stefano Dell'Oro

GERDA-II new results (Jul 2017)

L. Pandola, *talk @ TAUP 2017*

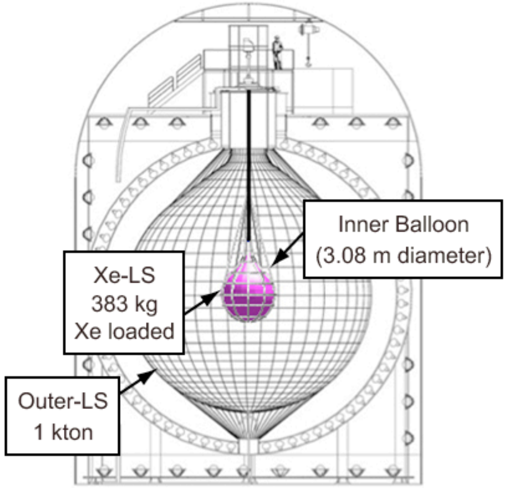


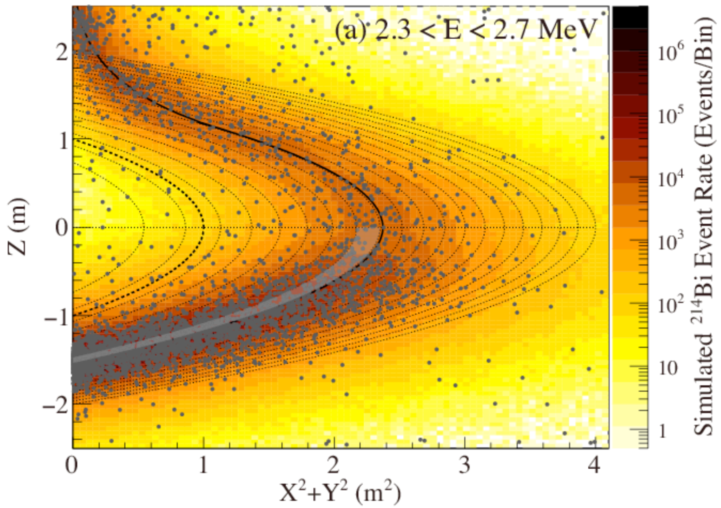
$t_{1/2}^{0\nu} > 8.0 \cdot 10^{25}$ yr @ 90% C. L.

$T_{1/2} > 8.0 \times 10^{25}$ years

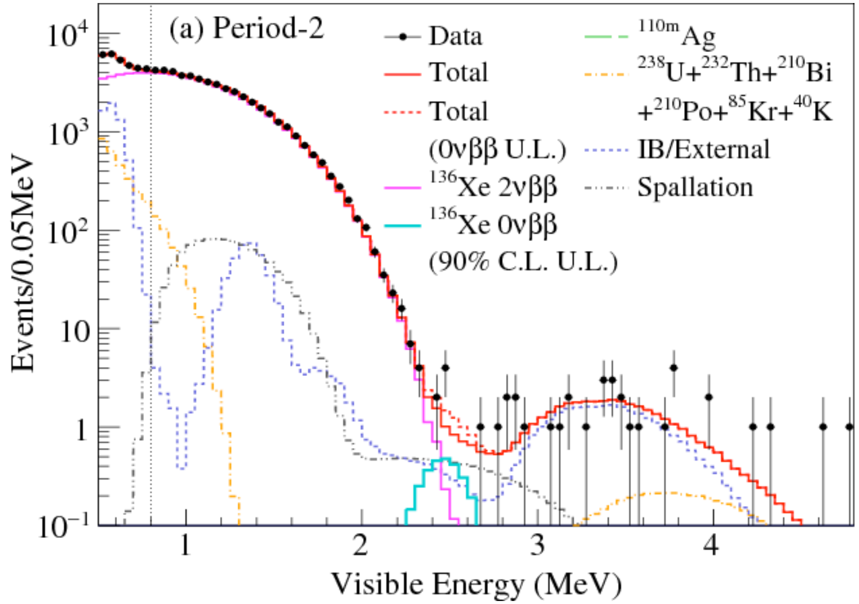
Current best limit: KamLAND-Zen

13 tons of Xe-loaded scintillator
- lower energy resolution





Full data set not shown in publication

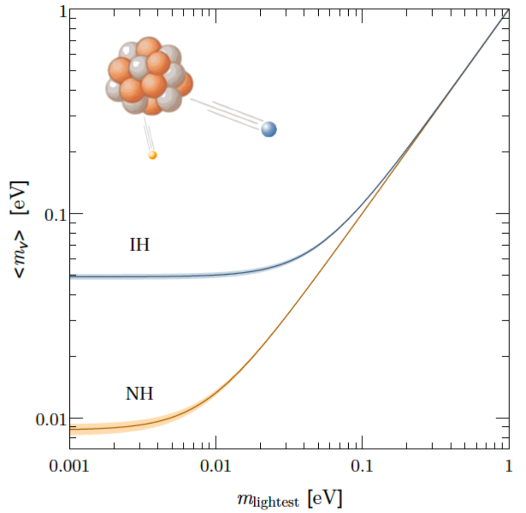


$T_{1/2} > 1.07 \times 10^{26}$ years

$m_{\beta\beta} < 61 - 165$ meV

Assessing the neutrino masses

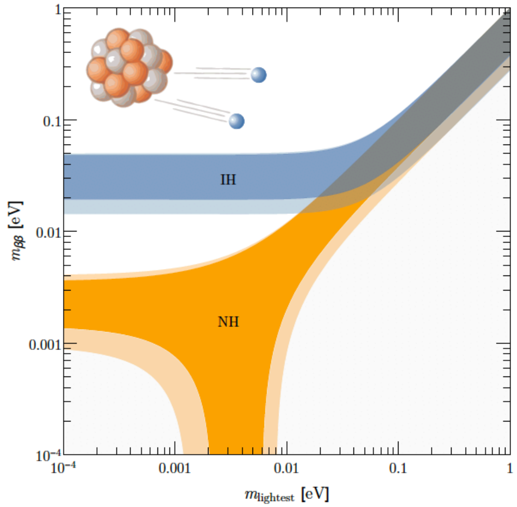
Direct measurement



- effect of electron neutrino mass in β decay
- model independent: relies on pure kinematic considerations
- sensitive to effective electron neutrino mass:

$$\langle m_\nu \rangle = \sqrt{\sum_{i=1}^{3} \left| U_{ei}^2 \right| m_i^2}$$

Search for 0νββ

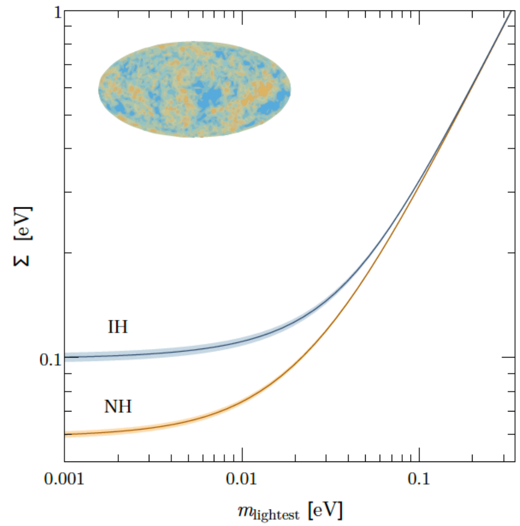


- *requires* Majorana neutrinos
- large theoretical uncertainties
- sensitive to Majorana mass:

$$m_{\beta\beta} = \left| \sum_{i=1}^{3} U_{ei}^2 \, m_i \right|$$

- bands due to Majorana phases

Cosmology



- strong model dependence
- very stringent bounds
- sensitive to sum of neutrino masses:

$$\Sigma \equiv \sum_{i=1}^{3} m_i$$

The low-energy frontier

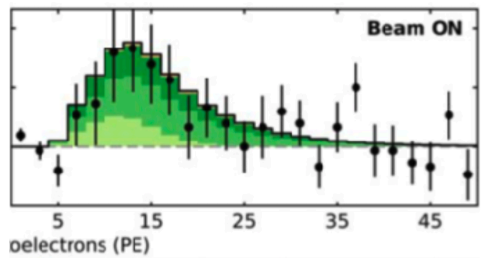
Alfredo Cocco

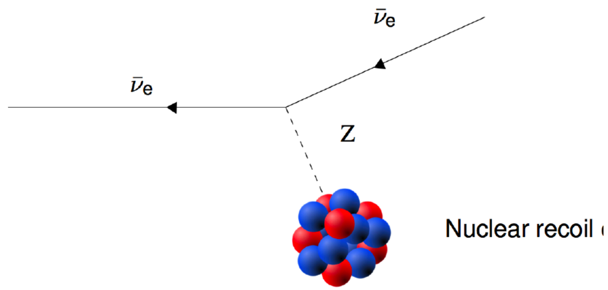
Tritiated graphene

Neutrinos decouple
(CνB)

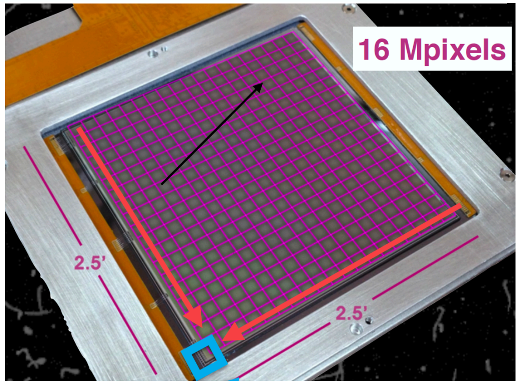
P rinceton
T ritium
O bservatory for
L ight,
E arly-universe,
M assive-neutrino
Y ield

COHERENT



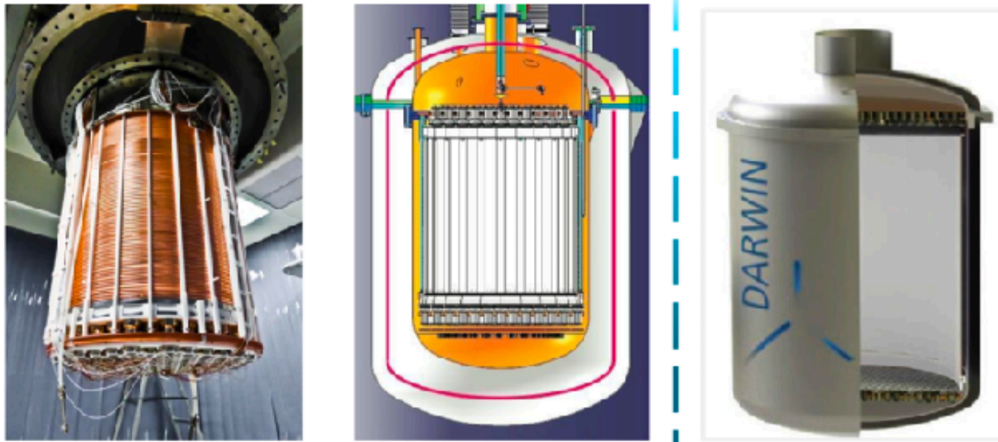


CONNIE



Ben Kilminster

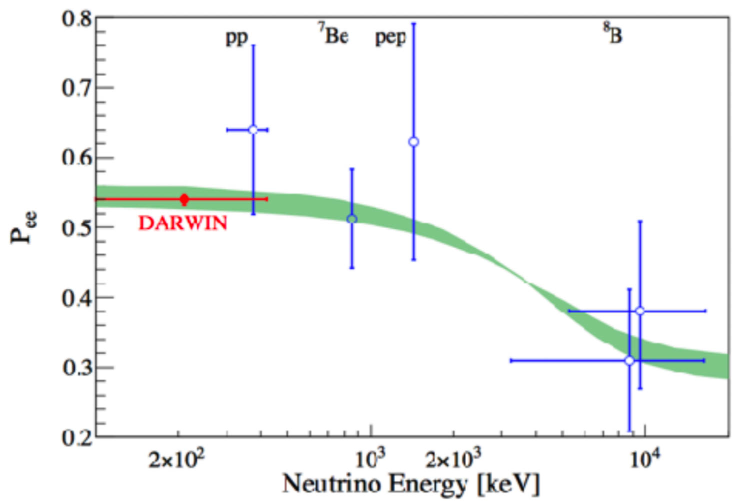
The low-energy frontier



XENON1T	XENONnT	DARWIN
2012 - 2018	2019 - 2023	2020+
3200 kg	7500 kg	~ 50 000 kg
~10^{-47} cm²	~10^{-48} cm²	~10^{-49} cm²

Marco Selvi

JCAP 1611 (2016) no.11, 017

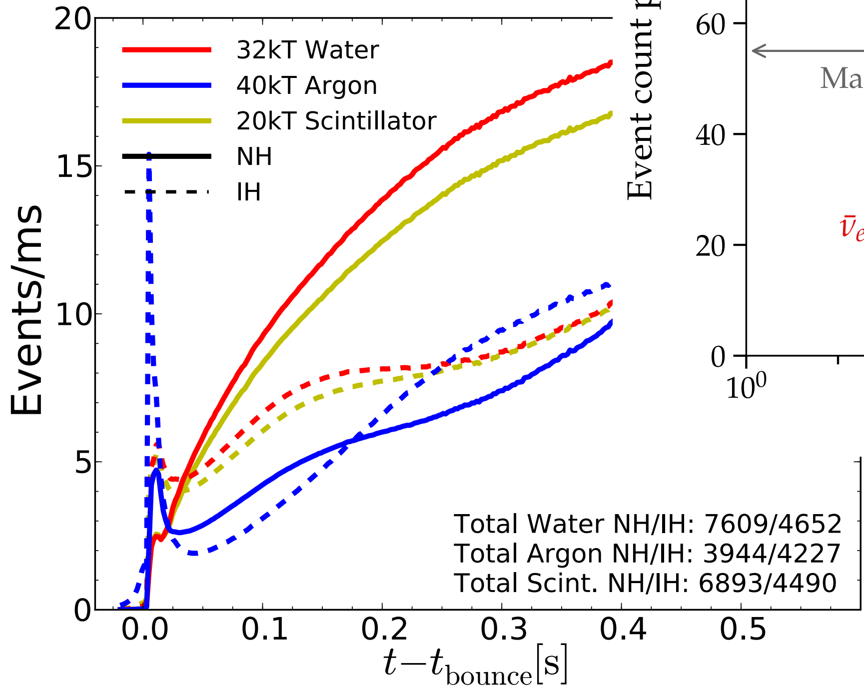


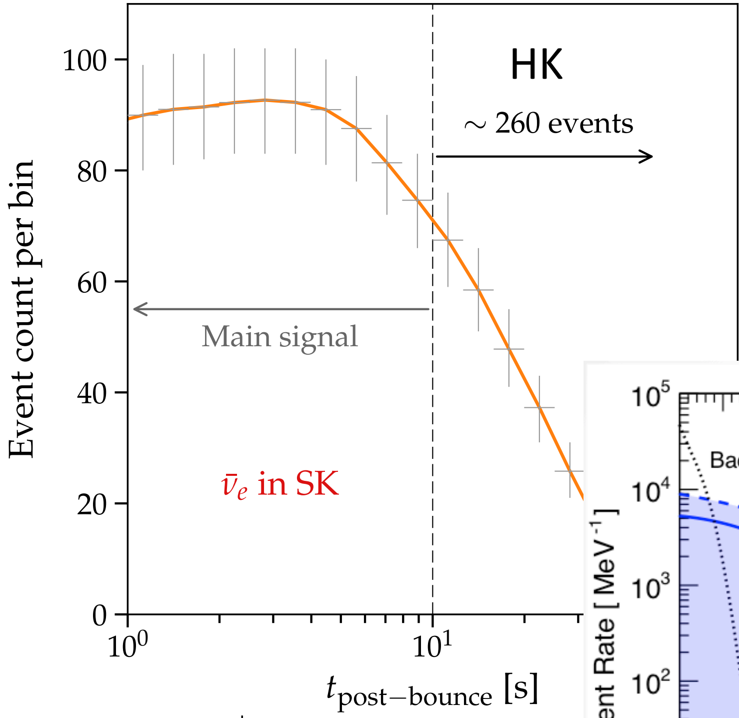
Neutrinos as background to DM searches but also as possible future signal (e.g., solar, SN..)

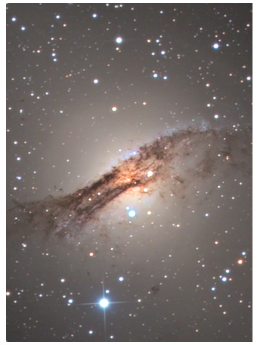
Supernova and Solar Neutrinos

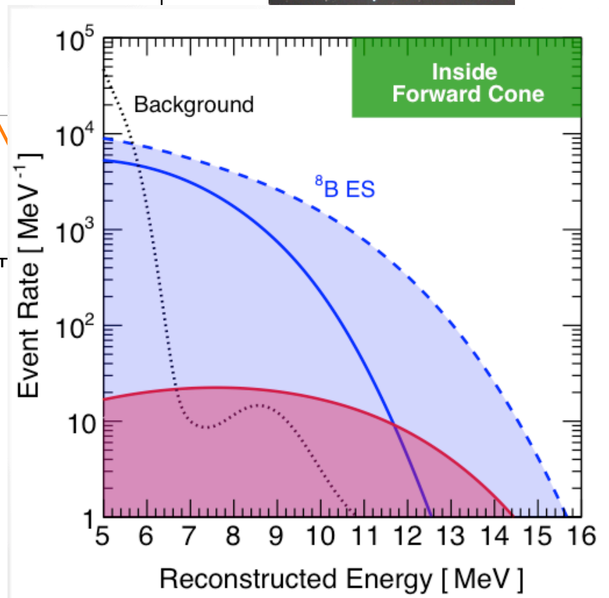
Evan O'Connor
Shirley Li

@10kpc





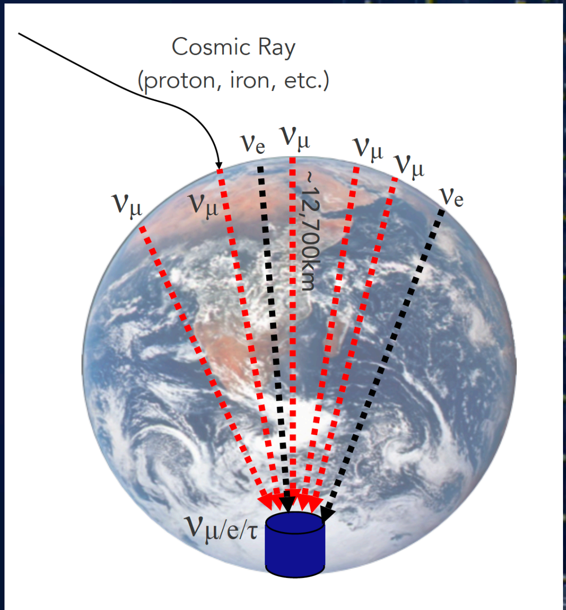


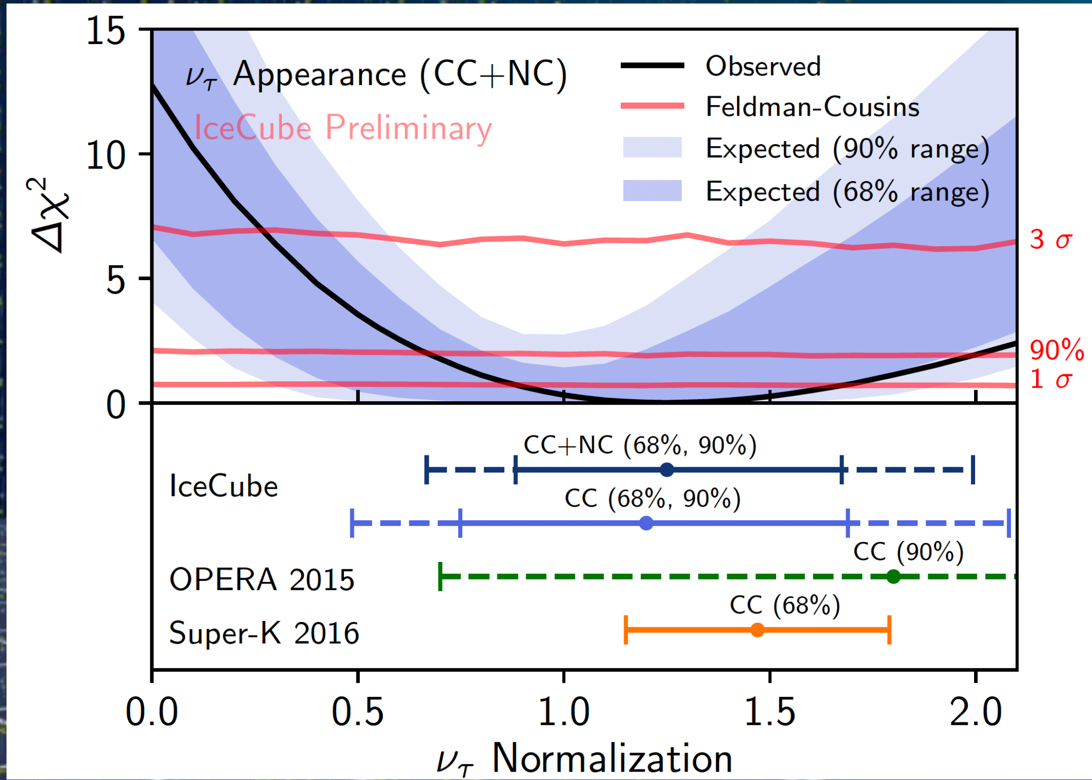


- Supernova neutrinos will teach us about SN evolution, as well as neutrino physics (MH).
- Low-energy reconstruction very challenging, especially for liquid-argon detectors.

IceCube and KM3NET

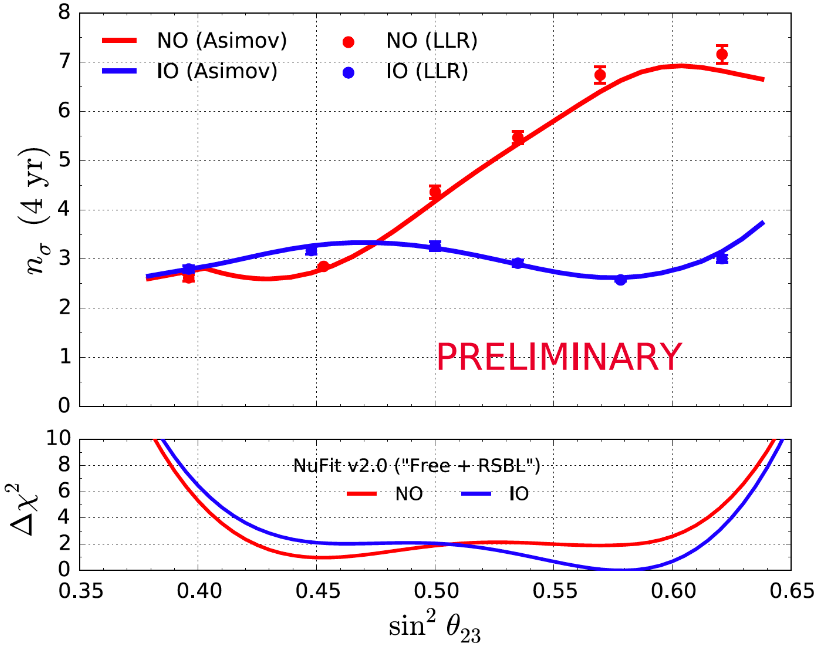
J. Koskinen
P. Coyle

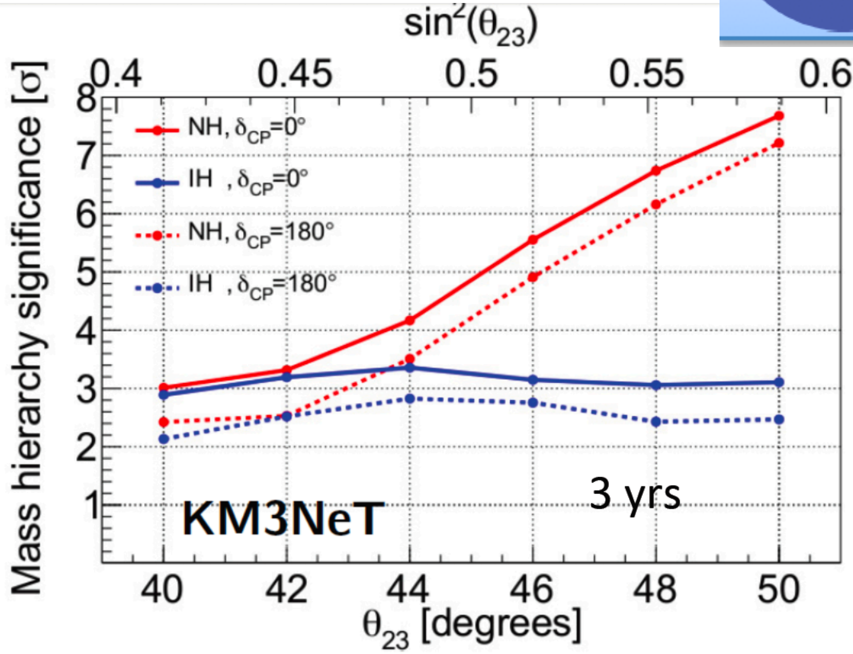


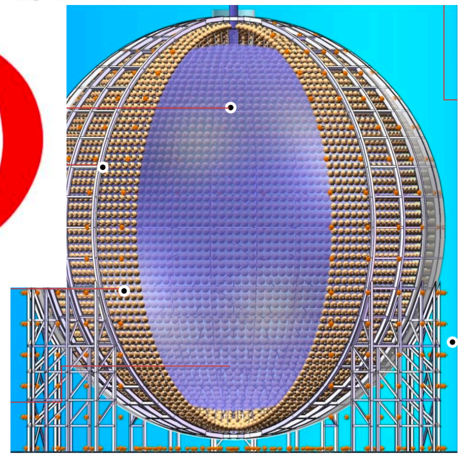


Mass Hierarchy

PINGU



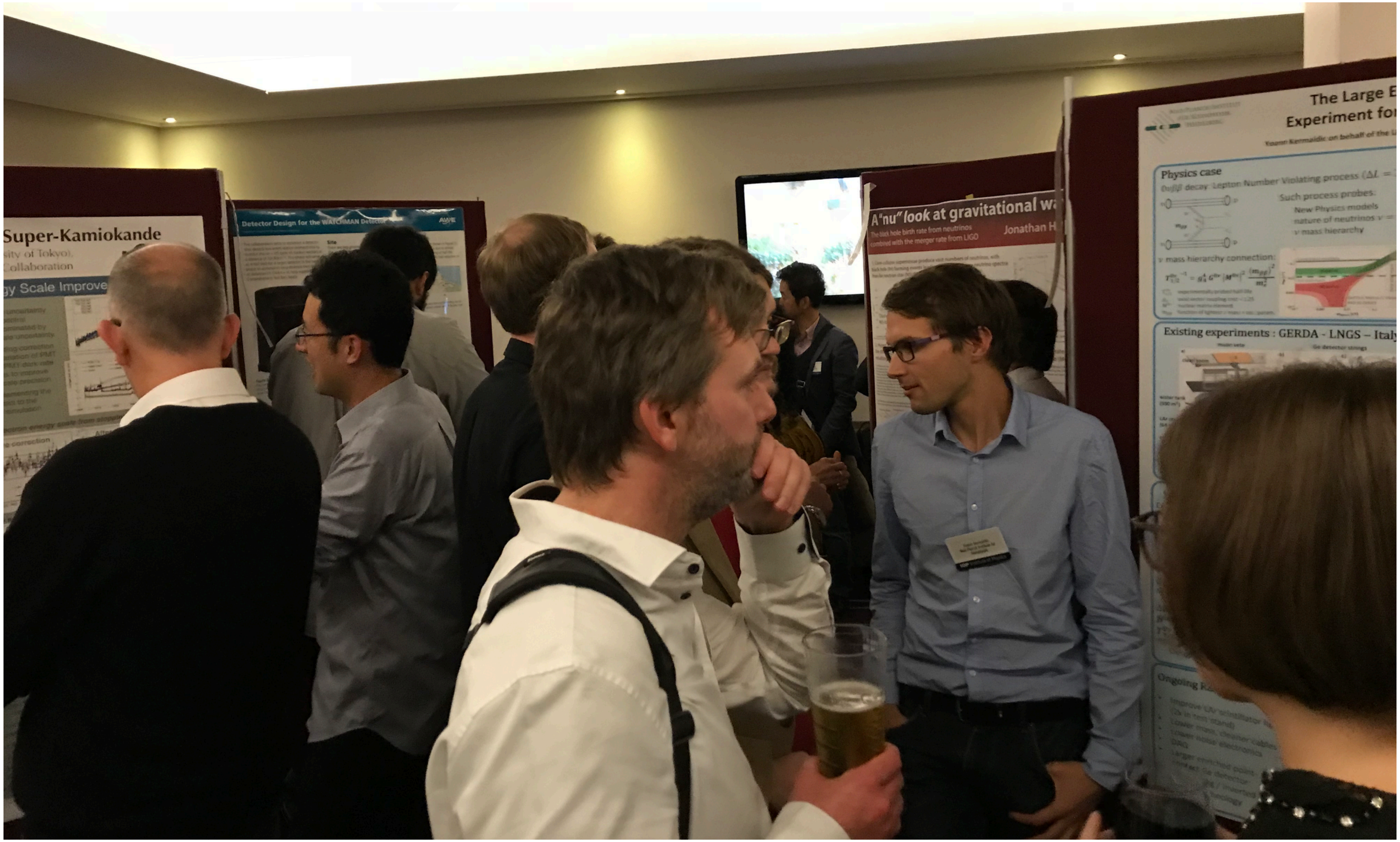




Good chance to resolve MH before next-generation LBL experiments turn on.

MANCHESTER
1824

Poster Session



Thanks for a great Workshop!

Local organising committee

- Gary Barker (chair)
- Steve Boyd
- Paul Harrison
- Ben Morgan
- Yorck Ramachers

NNN workshop-series steering committee

- C K Jung (Stony Brook University)
- T Kajita (ICRR/Tokyo University)
- S Katsanevas (APC)