

# Neutrino Physics in 2020

*Maury Goodman  
Argonne National Lab  
High Energy Physics Division*

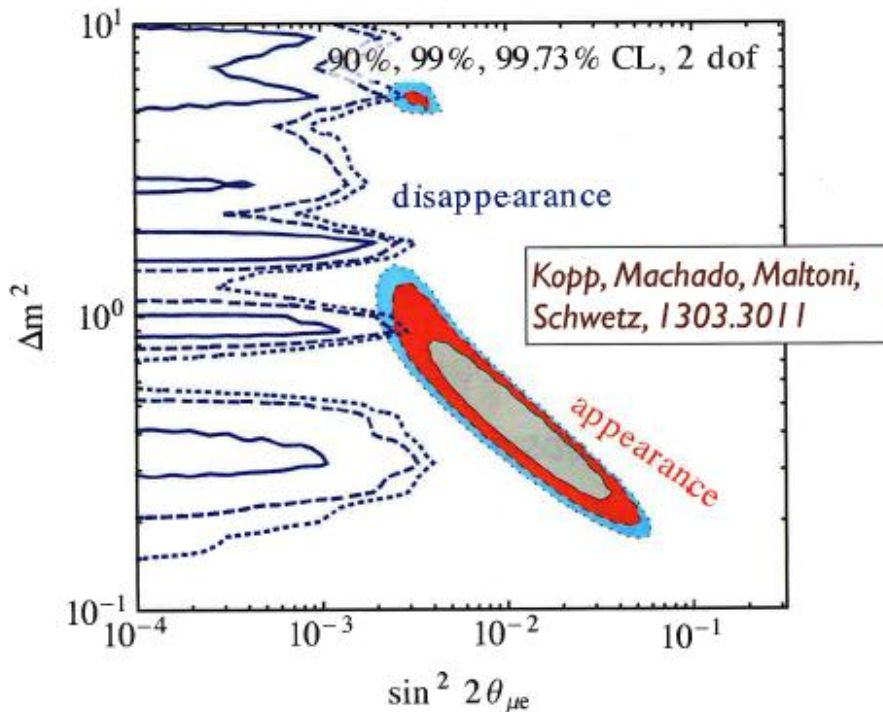
**KITP**

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# Sterile Neutrinos?

## *Strong tension in global data*

- consistency of appearance and disappearance data with  $p$ -value  $10^{-4}$



expect somewhat increased tension due to recent data from MINOS, SK-atm, ICARUS, OPERA

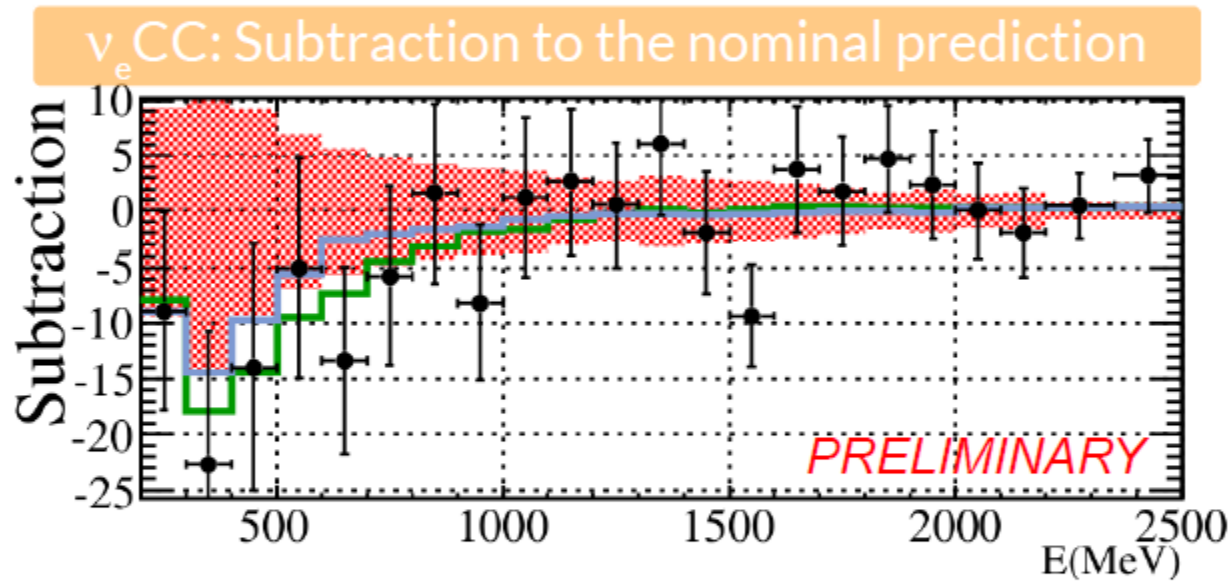
C. Giunti et al find somewhat better fit:  $p$ -value  $10^{-3}$  1308.5288

T. Schwetz

# Binned log-likelihood ratio analysis

$$\chi^2 = \chi^2_{\nu_e} + \chi^2_{\nu_\gamma} + \text{penalty term}(\vec{f})$$

Nuisance parameters to model the systematics



- Systematics
- Best Fit
- Best Fit w/o oscillation
- Data

Important to calculate the significance

Best fit parameters  
 $\Delta m_{41bf}^2 = 2.14 \text{ eV}^2$   
 $\sin^2(2\theta_{ee})_{bf} = 1.00$

3 Dec 2014

# The <sup>remaining</sup> World Neutrino Experimental Program

## ➤ Parameter Measurement

- $\theta_{23}$  Octant ( $>$ ,  $<$   $45^\circ$ )
- Mass hierarchy
- Mass scale
- CP violation  $\delta$
- Dirac or Majorana?
- More accuracy for  $\theta_{12}$ ,  $\theta_{23}$ ,  $\theta_{13}$ ,  $\Delta m^2_{32}$ ,  $\Delta m^2_{21}$

## ➤ Paradigm testing

- Sterile neutrinos?
- Non standard Interactions?
- Lorentz violation?
- CPT violation?
- Non-Unitarity of MNS matrix?
- velocity

Questions with answers

Questions which might or might not have answers

# My guess by 2020

- Parameter Measurement
  - $\theta_{23}$  Octant ( $>$ ,  $<$   $45^\circ$ ) ✓
  - Mass hierarchy ✓
  - Mass scale ✓
  - CP violation  $\delta$   $\pm 60^\circ$
  - Dirac or Majorana? not yet
  - More accuracy for  $\theta_{12}$ ,  $\theta_{23}$ ,  
 $\theta_{13}$ ,  $\Delta m^2_{32}$ ,  $\Delta m^2_{21}$  ✓

Questions with answers

## ➤ Paradigm testing

- Sterile neutrinos?
- Non standard Interactions?
- Lorentz violation?
- CPT violation?
- Non-Unitarity of MNS matrix?
- velocity

Questions which might or might not have answers

# The program in 2020

## ↪ Parameter Measurement



- CP violation  $\delta$   $\pm\sim 60^\circ \rightarrow \pm\sim 20^\circ$  in LBNE/LBNO/HyperK
- Dirac or Majorana? will be determinable if inverted hierarchy
- More accuracy for  $\theta_{12}$ ,  $\theta_{23}$ ,  
 $\theta_{13}$ ,  $\Delta m^2_{32}$ ,  $\Delta m^2_{21}$  **even better**

Questions with answers

## In 2020, Maybe

- ★ We'll know these parameters with no paradigm shifts, but theoretically we'll be where we are now; **then**
  - ⇒ I see no strong argument for a new or continued \$B scale program.
- ★ Or there will be strong theoretical progress and we'll want to know parameters even better, **then**
  - ⇒ We'll press on with better larger long-baseline experiments.
- ★ Or something outside the 3ν paradigm shows up, **then**
  - ⇒ We'll need new experiments, but don't know what those might be.

# Intelligent Design of Neutrino Parameters?

(from S. Wojcicki)

- The optimum choice for  $\Delta m_{21}^2$ ?

Such as to give resonant transition (MSW effect) in the middle of solar energy spectrum -,  $\Delta m_{21}^2 = 8.2 \times 10^{-5} \text{ eV}^2$

- The optimum choice for  $\sin\theta_{12}$ ?

Big enough for oscillations to be seen in KamLAND -  $\sim 0.8$

- The optimum choice for  $\Delta m_{32}^2$ ?

Such as to give full oscillation in the middle of the range of possible distances that atmospheric  $\nu$ 's travel to get to the detector -

$$\Delta m_{32}^2 = 2.3 \times 10^{-3} \text{ eV}^2$$

- The optimum choice for  $\sin\theta_{23}$ ?

Big enough so that oscillations could be seen easily -  $\theta_{23} \sim \pi/4$

- The optimum choice for  $\sin\theta_{13}$ ?

Small enough so as not to confuse interpretation of the above -  $\theta_{13} < 10^\circ$

- **But the acid test - will  $\theta_{13}$  be big enough to see CP violation and determine mass hierarchy?**

December 2014



In 2020

? Suppose parameters are such that the “Intelligent Design” arguments can get longer?

↪  $\delta \sim \pi/2$

⊕ to most quickly determines the hierarchy

⊕ to get large CP violation & answer the CP violation question

↪ The inverted hierarchy, so we can tell Dirac/Majorana & maybe beta decay endpoint

↪ Majorana, which seems to be more interesting so that some of our theorists will be happy (seesaw, etc.)