Precision neutrino experiments versus the Littlest Seesaw

Nick Prouse
based on arXiv:1611.01999 with Steve King (Southampton), Silvia Pascoli (Durham), Peter Ballett (Durham), Tse-Chun Wang (Durham)

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- There are at least three generations
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- Two mass-squared differences have been measured
- Three oscillation angles have been measured

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- Do neutrino oscillations violate CP? ($\delta_{CP} \neq 0, \pi$)
- What is the ordering of the neutrino masses? (sign of Δm^2_{31})
- What is the octant of the atmospheric mixing angle? ($\theta_{23} > 45°$ or $\theta_{23} < 45°$)

Neutrino oscillation measurements

Experiments measure oscillation probabilities: $P_{\nu_\alpha \to \nu_\beta} = \left| \sum_{i=1}^{3} U^*_{\alpha i} U_{\beta i} e^{-i \frac{L m_i^2}{2E_\nu}} \right|^2$

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Atmospheric and accelerator experiments

$\nu_\mu \to \nu_\mu$

$\sin^2 \theta_{23} = 0.440^{+0.023}_{-0.019}$ or $0.584^{+0.018}_{-0.022}$

$|\Delta m^2_{32}| = 2.451^{+0.039}_{-0.038} \times 10^{-3}$eV^2

Solar and reactor experiments

$\nu_e \to \nu_e$

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Majorana phases not measurable with oscillation experiments

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- (Type I) Seesaw mechanism
  - Right handed neutrino for each left-handed neutrino mass
  - Dirac mass terms m_D at electroweak scale
  - Majorana mass term M_R at grand unification scale
  - $\begin{pmatrix} \bar{\nu}_L & \bar{\nu}^c_R \end{pmatrix} \begin{pmatrix} 0 & m_D \\ m_D^T & M_R \end{pmatrix} \begin{pmatrix} \nu^c_L \\ \nu_R \end{pmatrix}$
  - Diagonalising gives very small left handed neutrino mass $m^\nu_L \approx -m_D M_R^{-1} m_D^T$

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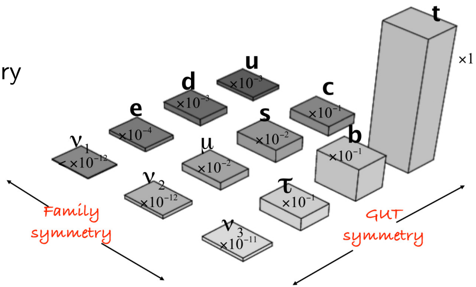
    $m_L^\nu \approx -m_D M_R^{-1} m_D^T$
- Discrete non-abelian family symmetry
  - Provides explanation of flavour structure of SM
  - Unifies fermions within each family
  - Places constraints on mixing parameters



Littlest Seesaw model

The Littlest Seesaw (LS) model provides a physically viable seesaw model with the fewest free parameters [arXiv:1512.07531]

- Based on sequential dominance with 2 right handed neutrinos
  - Dominant RH neutrino gives atmospheric neutrino mass
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- Constrained sequential dominance
  - Family symmetry provides constraints on LH neutrino mass matrix
  - LSA mass matrix from S_4 or A_4 [arXiv:1304.6264, arXiv:1512.07531]

$$m^{\nu}_{\mathsf{LSA}} = m_a \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{pmatrix} + m_b e^{i\eta} \begin{pmatrix} 1 & 3 & 1 \\ 3 & 9 & 3 \\ 1 & 3 & 1 \end{pmatrix}$$

  - LSB mass matrix from $S_4 \times U(1)$ [arXiv:1607.05276]

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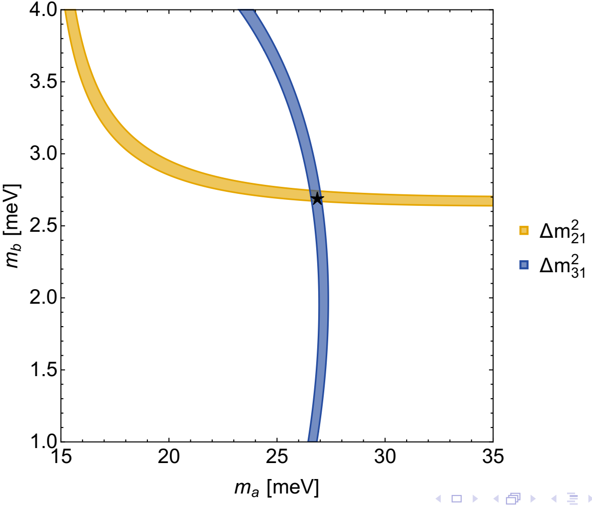
- $e^{i\eta}$ can also be fixed to a cube root of unity with Z_3 symmetries
- Diagonalising mass matrix gives LH neutrino masses and mixing matrix

Testing the LS models with existing data

Fixing η to $\eta = 2\pi/3$ successfully reproduces mixing angles and masses
Allowed regions in $m_a - m_b$ plane correspond to experimental measurements



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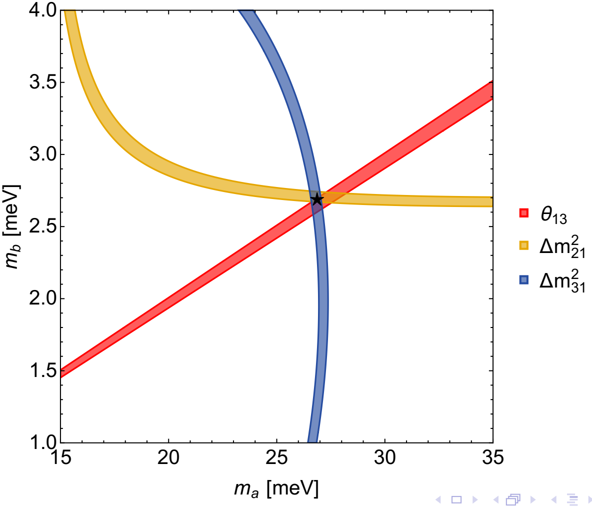

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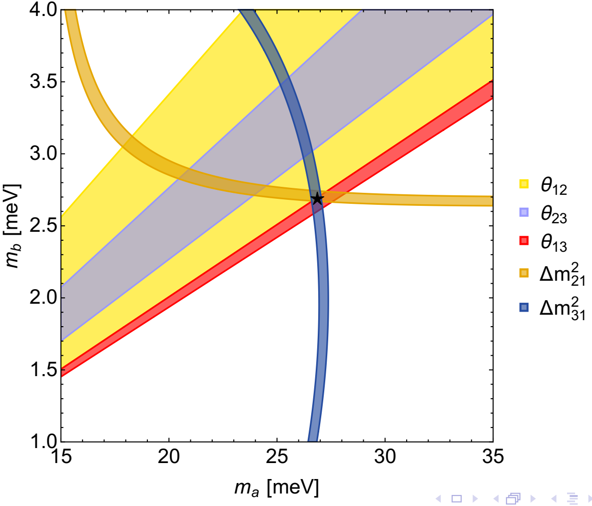
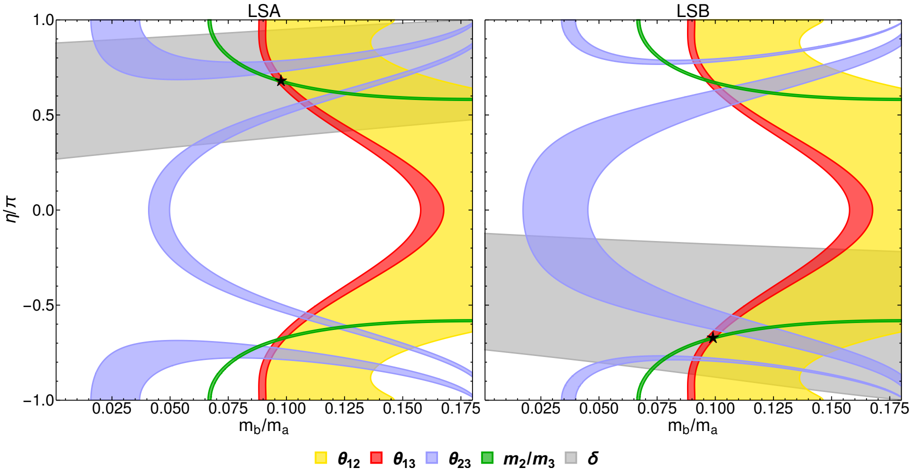


Testing the LS model with existing data

With η free, dimensionless parameters depend only on m_b/m_a and η



Fitting LS models to global data

Fit LSA and LSB models to global oscillation data

	LSA		LSB		NuFIT 2.2
	η free	η fixed	η free	η fixed	global fit
m_a [meV]	27.22	26.78	27.14	26.77	
m_b [meV]	2.653	2.678	2.658	2.681	—
η [rad]	0.680π	$2\pi/3$	-0.678π	$-2\pi/3$	
θ_{12} [°]	34.37	34.34	34.36	34.33	$33.72^{+0.79}_{-0.76}$
θ_{13} [°]	8.45	8.58	8.48	8.59	$8.46^{+0.14}_{-0.15}$
θ_{23} [°]	45.01	45.69	44.87	44.30	$41.5^{+1.3}_{-1.1}$
δ [°]	-89.9	-87.0	-90.6	-93.1	-71^{+38}_{-51}
Δm^2_{21} $[10^{-5}\text{eV}^2]$	7.499	7.362	7.482	7.379	$7.49^{+0.19}_{-0.17}$
Δm^2_{31} $[10^{-3}\text{eV}^2]$	2.505	2.515	2.505	2.515	$2.526^{+0.039}_{-0.037}$
$\Delta\chi^2$ / d.o.f	4.7 / 3	6.4 / 4	4.5 / 3	5.1 / 4	—

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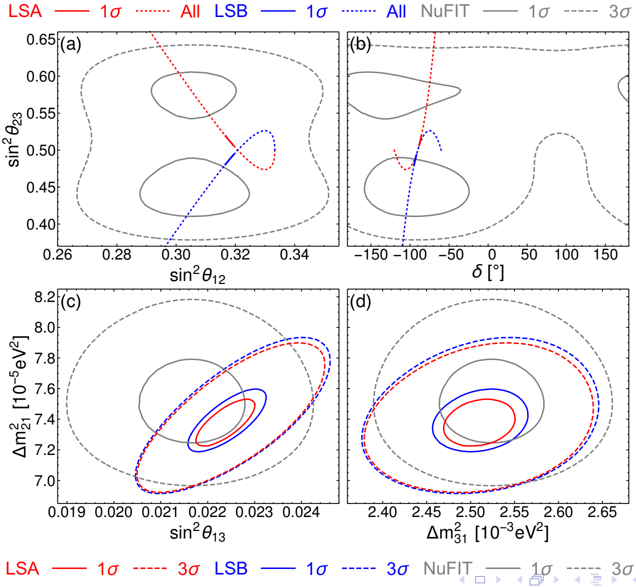


Future oscillation experiments

Use GLoBES package to simulate future experiments

DUNE

- Long baseline accelerator experiment
- δ_{CP} precision of 10° to 20°
- $\sin^2\theta_{23}$ at 1 to 3%
- Δm^2_{32} at 0.4%

Hyper-Kamiokande

- Long baseline accelerator experiment
- δ_{CP} precision of 7° to 18°
- $\sin^2\theta_{23}$ at 1 to 3%
- $|\Delta m^2_{32}|$ at 0.6%

Daya Bay

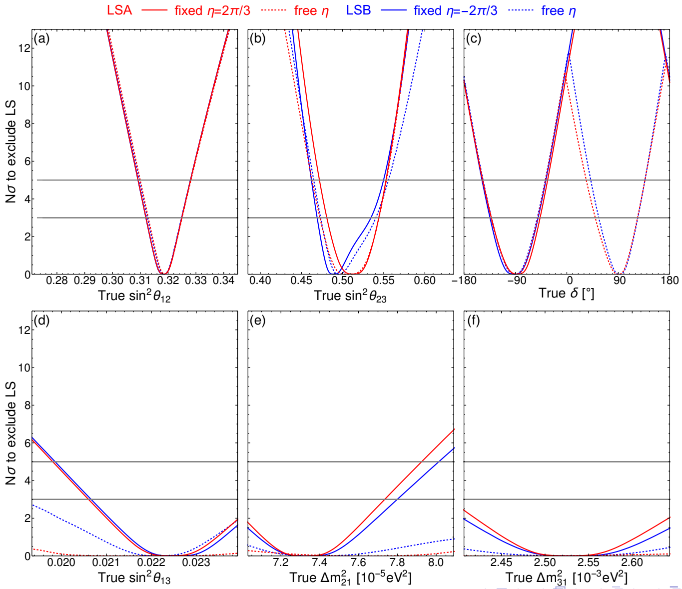
- Short baseline reactor experiment
- $\sin^2\theta_{13}$ at 3%

JUNO & RENO-50

- Medium baseline reactor experiments
- $\sin^2\theta_{12}$ at 0.5%
- Δm^2_{21} at 0.5%

Fit 10 years' simulated data to standard mixing and to LS models to get sensitivity

Excluding the LS model



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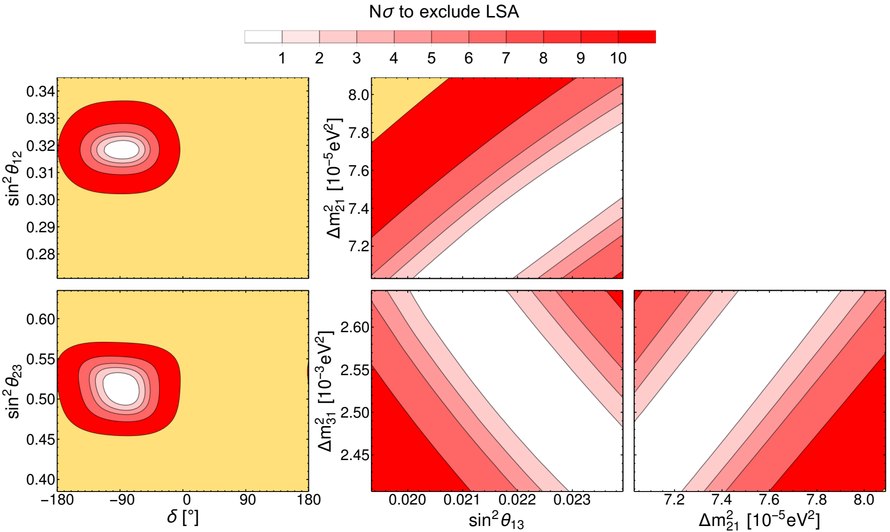

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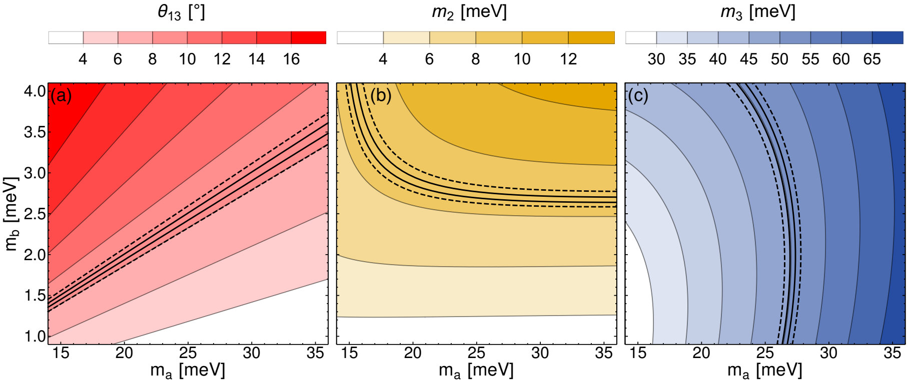
Thank you for your attention!

Backup Slides

Predictions of LS model



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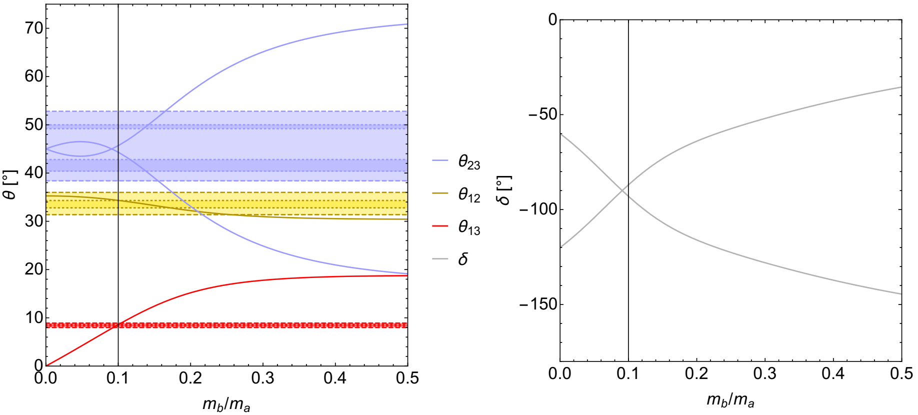

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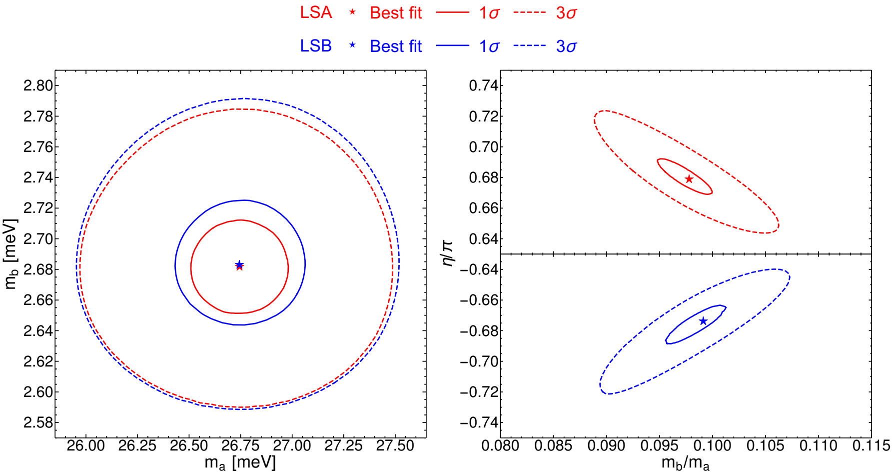

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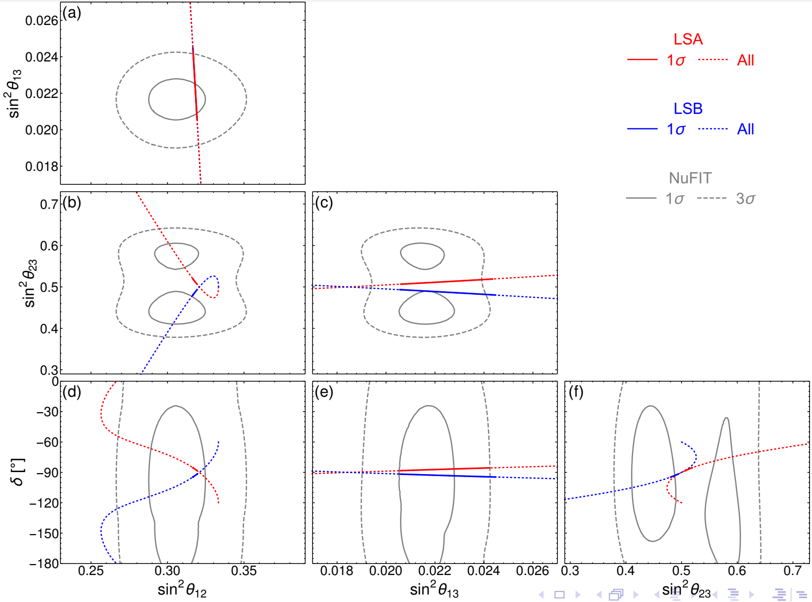

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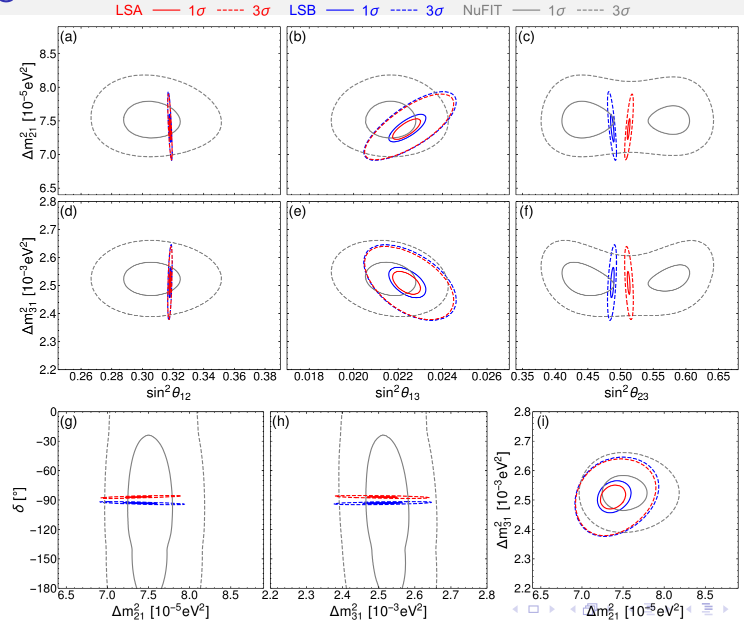

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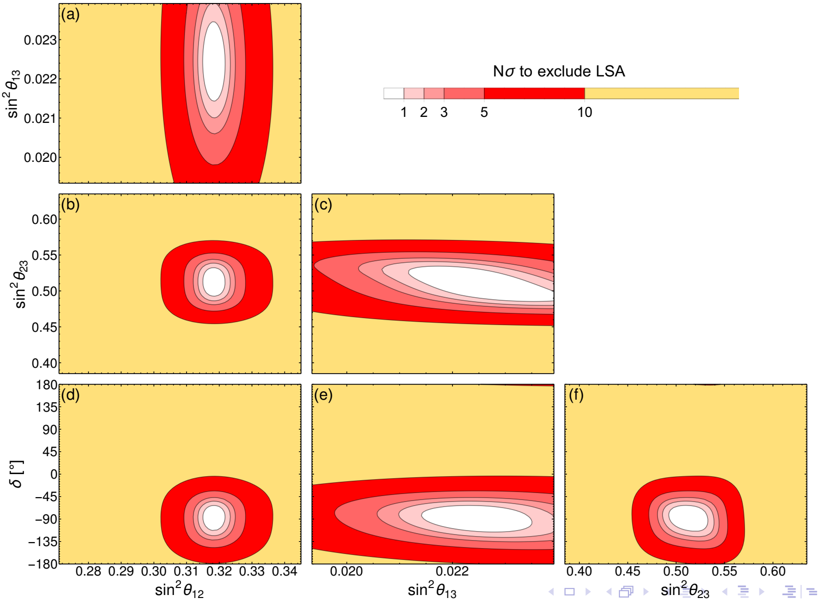

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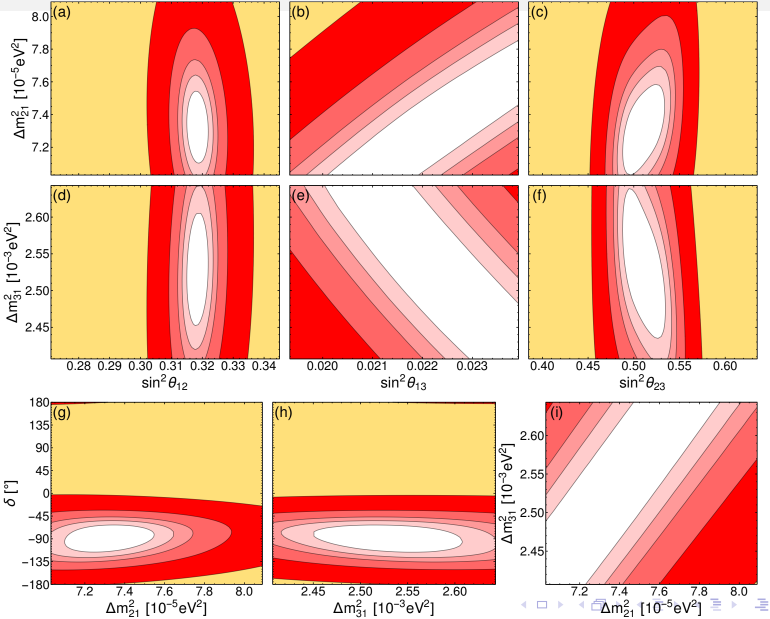

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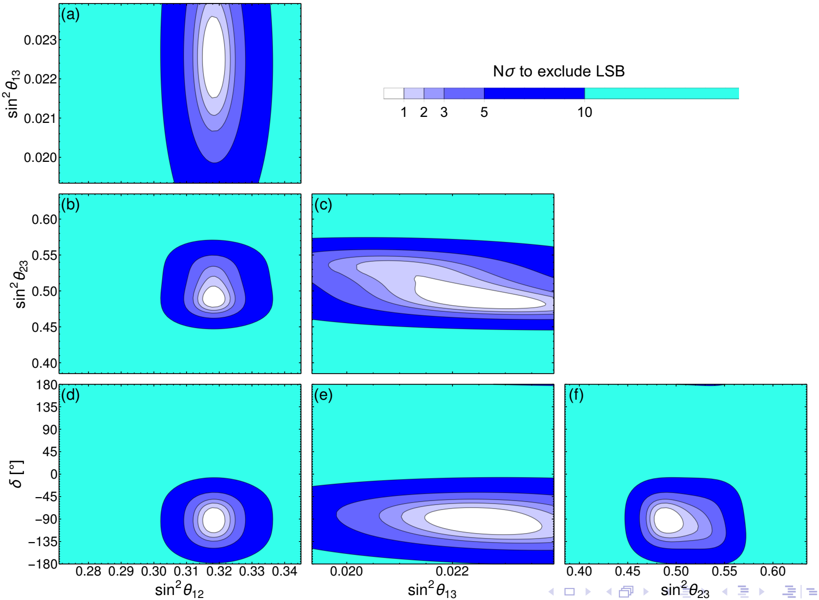

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