Target Neutrino Mass Precision for Determining the Neutrino Hierarchy

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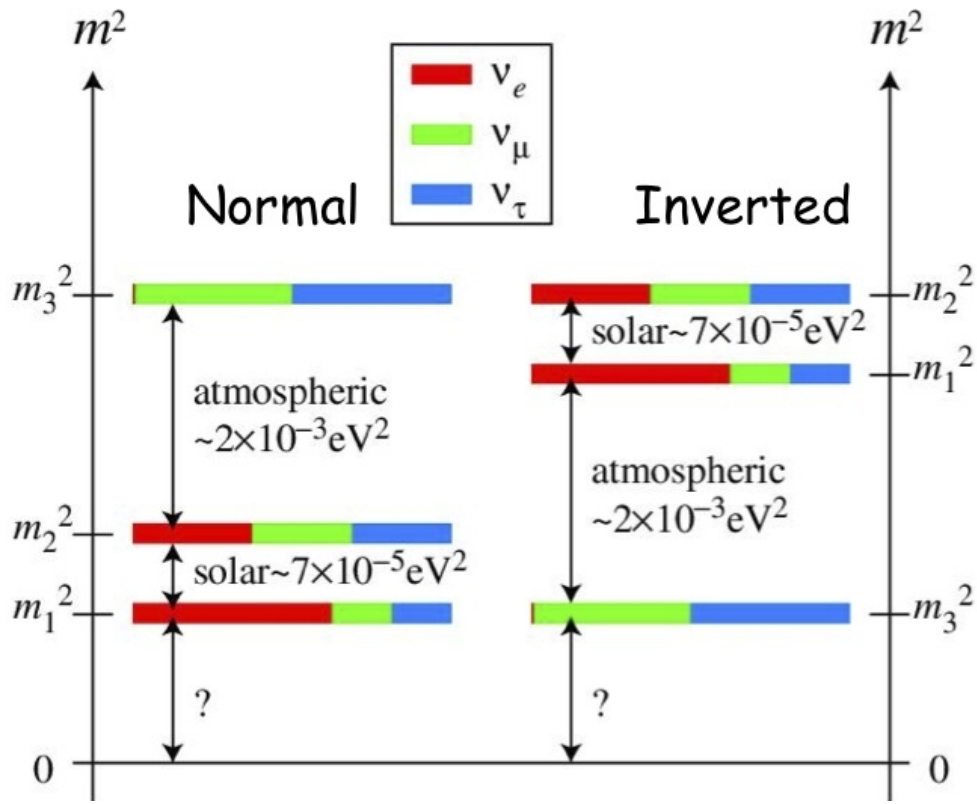
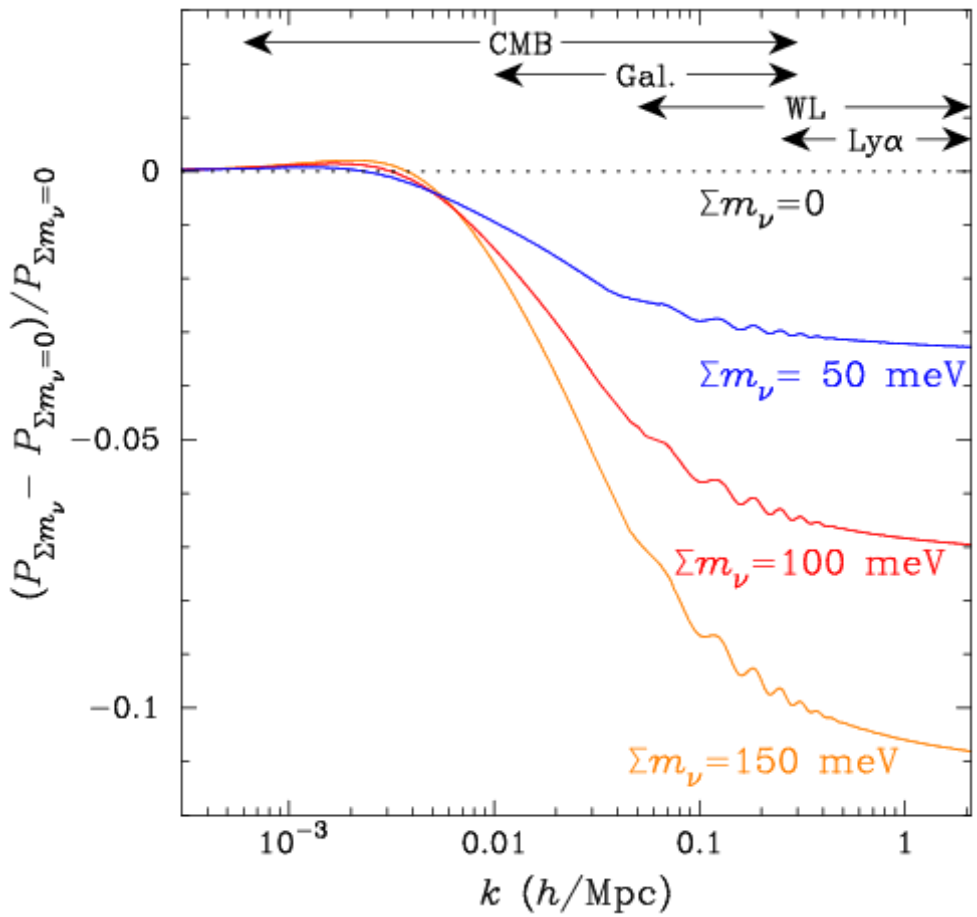


Minimum total mass allowed by oscillations

Normal $\Sigma_\nu \sim 0.06 \text{ eV}$

Inverted $\Sigma_\nu \sim 0.1 \text{ eV}$

Cosmology



large scales small scales

Planck + BAO: $\Sigma_\nu < 0.12 \text{ eV } (95\%)$

Image credit: K.N. Abazajian et al. 1309.5383

Literature

Normal : Inverted

42:1 (Simpson et al. 2017)

3:2 (Hannestad and Schwetz 2016, Gerbino et al. 2016)

1.8:1, **3.3:1** (Vagnozzi et al. 2017)

130:1, **19:1**, **470:1** (Long et al. 2017)

5:1 (Heavens and Sellentin 2018)

Data Driven Odds → Hierarchy-Agnostic Prior

Posterior Odds

$$\frac{p(\mathrm{NH}|D)}{p(\mathrm{IH}|D)} = \cancel{\frac{p(\mathrm{NH})}{p(\mathrm{IH})}} \boxed{\frac{p(D|\mathrm{NH})}{p(D|\mathrm{IH})}}$$

NH – Normal Hierarchy
IH – Inverted Hierarchy
D – current data

$$p(\mathrm{NH}) = p(\mathrm{IH})$$

Marginal Likelihoods

$$\boxed{p(D|\mathrm{H})} = \int p(D|\boldsymbol{\theta},\mathrm{H})\boxed{p(\boldsymbol{\theta}|\mathrm{H})}\,\mathrm{d}\boldsymbol{\theta}$$

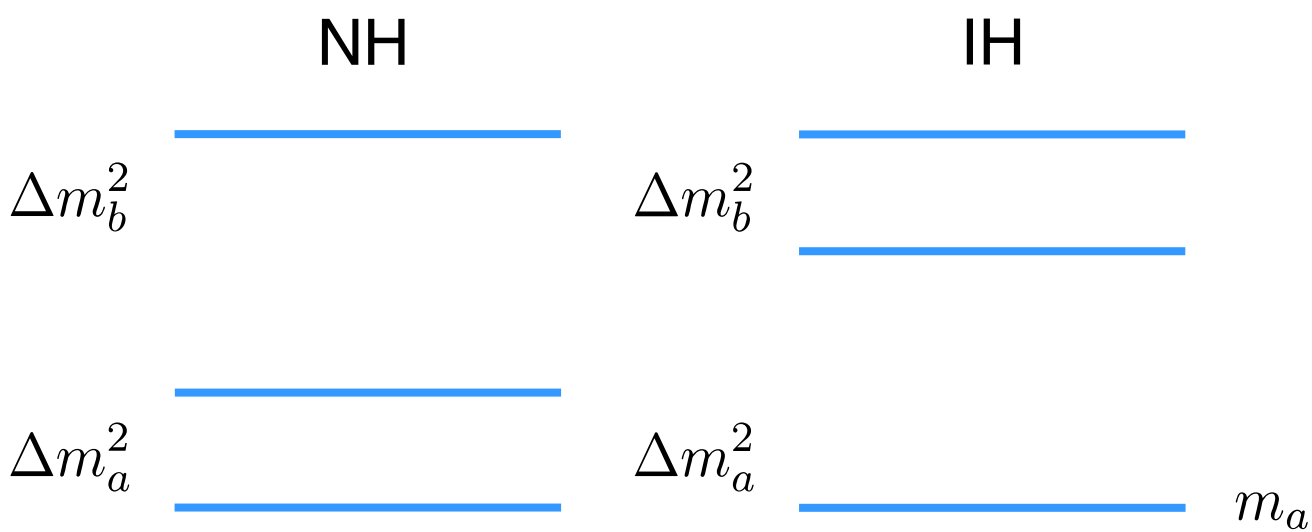
$$\approx \frac{1}{N}\sum_{i=1}^{N}\boxed{p(\Delta m_S^2|\boldsymbol{\theta}_i,\mathrm{H})\,p(\Delta m_L^2|\boldsymbol{\theta}_i,\mathrm{H})\,p(\Sigma_\nu|\boldsymbol{\theta}_i,\mathrm{H})}$$

Experiment Likelihoods

H – hierarchy
θ – model parametrization which describes the hierarchy
N – number of sets of neutrino properties drawn from prior

Hierarchy-Agnostic Prior

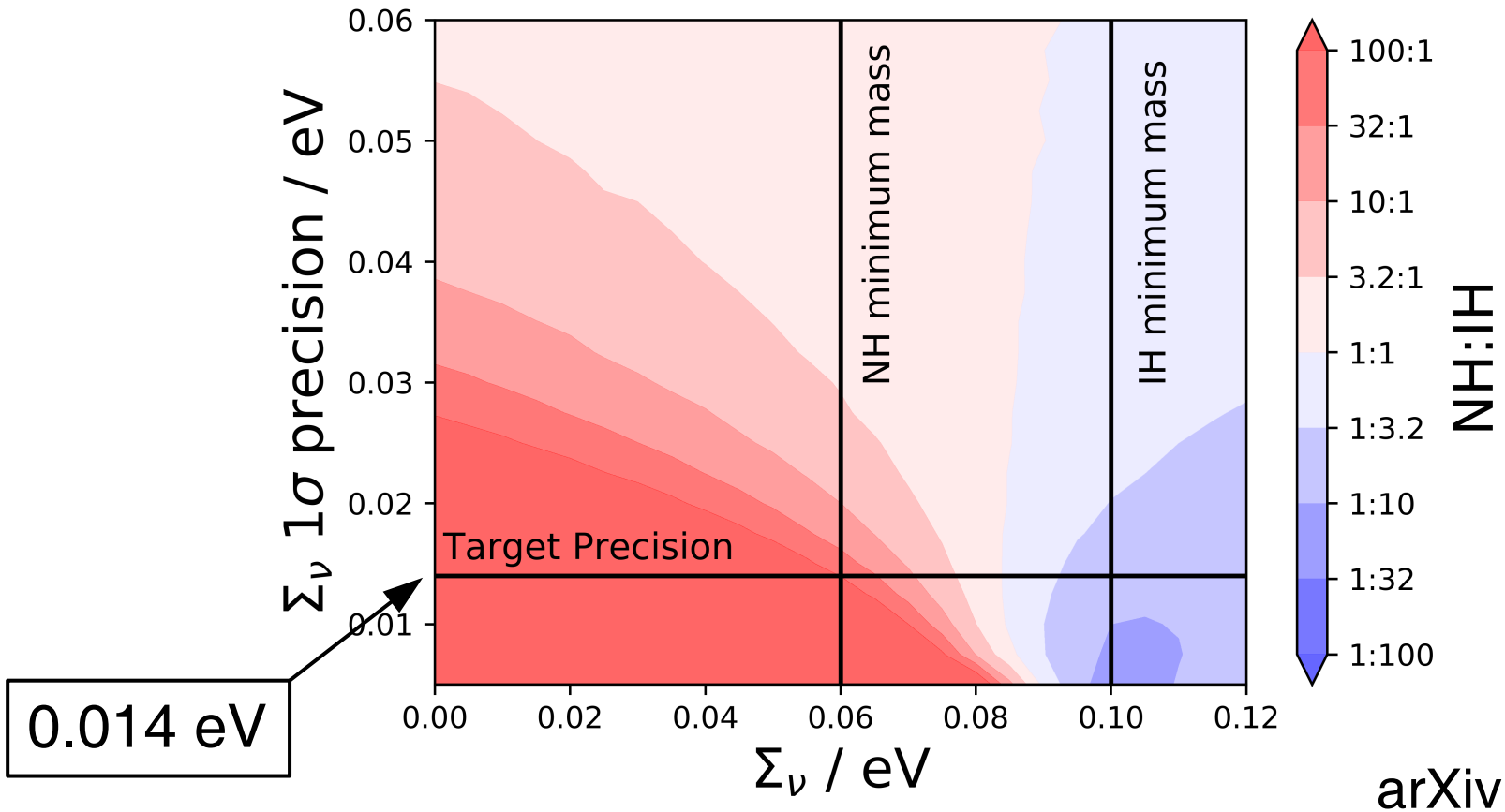
$$\boldsymbol{\theta} = \{\Delta m_a^2, \Delta m_b^2, m_a\}$$



$$\mathrm{p}(\Delta m_a^2 < \Delta m_b^2) = p(\Delta m_b^2 < \Delta m_a^2)$$

Results

$$\frac{p(\mathrm{NH}|D)}{p(\mathrm{IH}|D)} = 2.66 \pm 0.04$$



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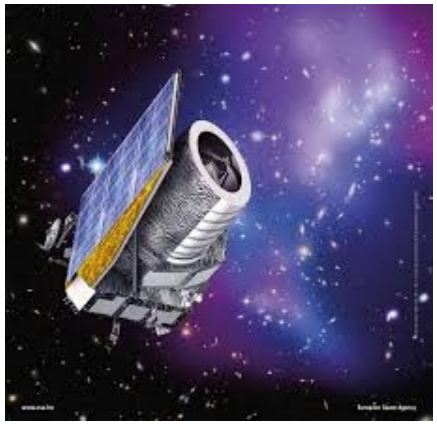
Future Experiments

Large Scale Structure



Euclid

DESI

LSST

CMB

LiteBIRD

Simons Observatory

CMB S4

Forecasts

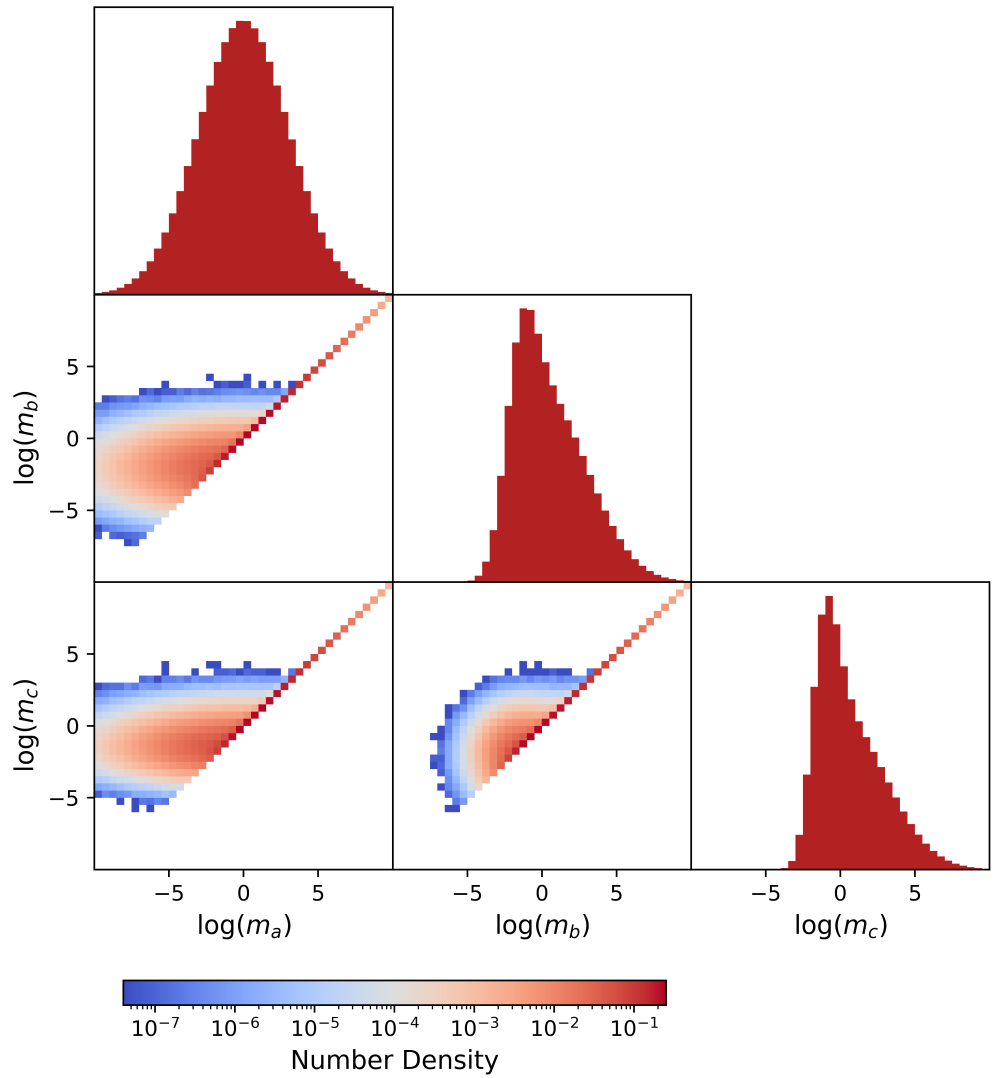
Brinckmann et al. 1808.05955:

1σ precision	Experiments
0.02 eV	Planck + Euclid (/LSST/DESI)
0.016 eV	Litebird + Euclid
0.012 eV	Litebird + Euclid + CMB S4

Summary

- Developed a hierarchy-agnostic prior for a joint analysis of neutrino data from particle physics and cosmology
- Found odds of **2.7:1** in favour of the NH for current data → inconclusive
- Set a target precision of **0.014 eV** for establishing the NH with odds of 100:1, for a measurement at the NH minimum mass 0.06 eV

Next step:
Include slight preference for the NH from T2K and NOvA

Bonus

Our hierarchy-agnostic prior translated to the log neutrino masses