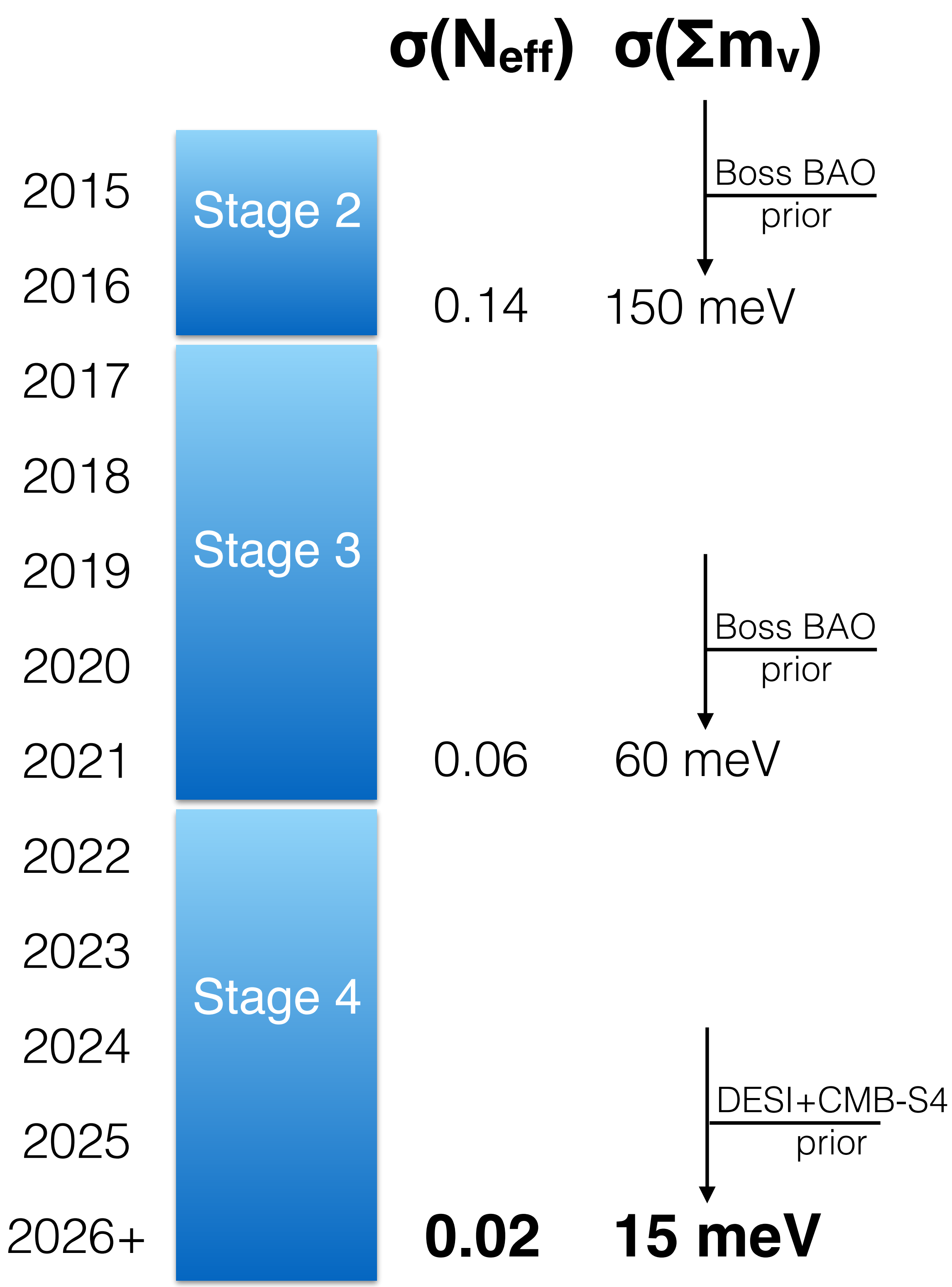
Cosmological Constraints on Neutrinos



Cosmology constrains:

- **Sum of the neutrino masses (Σm_ν)**; expected to be > 60 meV from oscillation experiments
- **Relativistic energy density:** Typically re-defined as the effective number of relativistic species (***N_{eff}***); expected to be ~3, i.e., the number of neutrino species

Future (~10 years) experiments (CMB-S4, DESI, LSST), expect factor of several improvements in constraints.

Modified from CMB-S4 Science Book (arXiv:1610.02743)

Cosmic Complementarity with HEP Neutrino Experiments

Lower limits for ββ Exp.

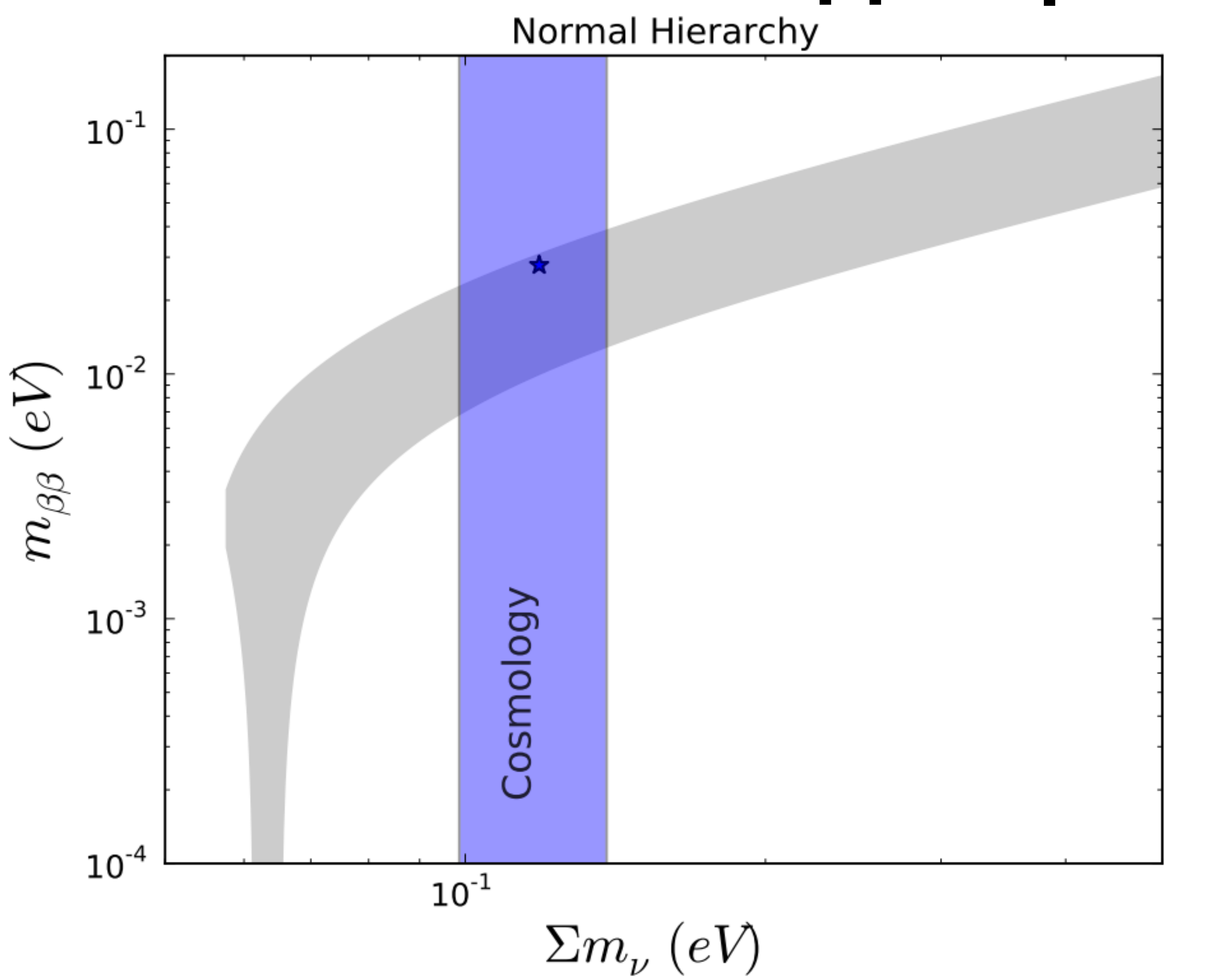
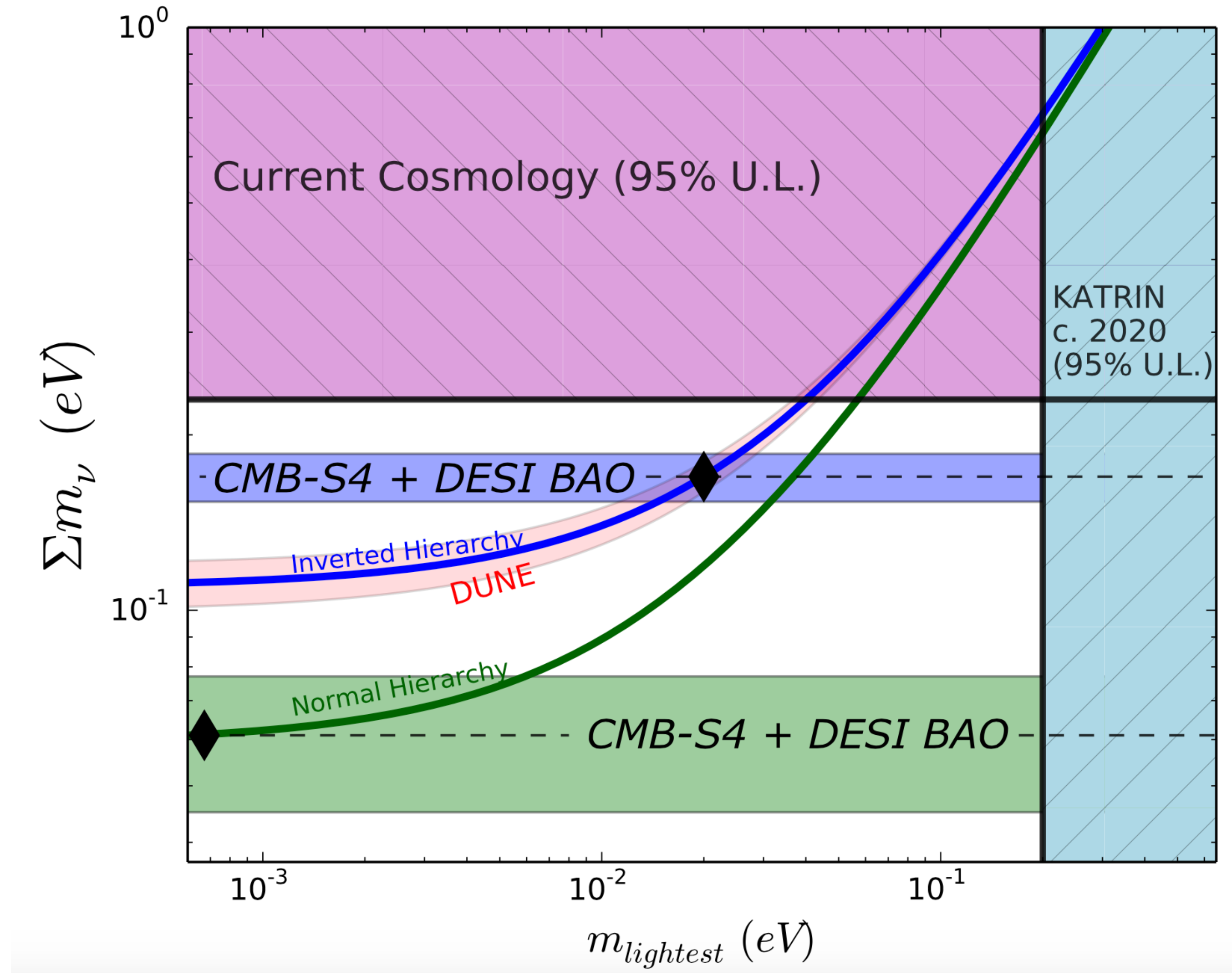


FIG. 3: If the mass hierarchy is normal but the sum of the masses is still relatively large, for example at the value indicated by the star, then there will be a lower limit on $m_{\beta\beta}$, a target for ambitious future double beta decay experiments.

Dodelson & Lykken (arXiv:1403.5173)

CMB-S4 Science Book (arXiv:1610.02743)

Synergy with DUNE



“In the case of a normal neutrino mass ordering with an example case marked as diamond on the lower curve, CMB-S4 would detect the lowest $\mathbf{\Sigma m_\nu}$ at >3σ. Also shown is the sensitivity from the long baseline neutrino experiment (DUNE) as the pink shaded band, which should be sensitive to the neutrino hierarchy. “

Cosmic Complementarity with HEP Neutrino Experiments

	ββ	β	Cosmo		
Scenario	$m_{\beta\beta}$	m_β	$\sum m_\nu$	$\Delta N_{\rm eff}$	Conclusion
Normal hierarchy	$< 2\sigma$	$< 2\sigma$	60 meV	0	Normal neutrino physics; no evidence for BSM
Dirac Neutrinos	$< 2\sigma$	$< 2\sigma$	350 meV	0	Neutrino is a Dirac particle
Sterile Neutrino	$< 2\sigma$	$< 2\sigma$	350 meV	> 0	Detection of sterile neutrino consistent with short-baseline
Diluted Neutrinos	0.25 eV	0.25 eV	< 150 meV	< 0	Modified thermal history (e.g. late decay)
Exotic Neutrinos	0.25 eV	0.25 eV	< 150 meV	0	e.g. Modified thermal history; (e.g. neutrino decay to new particle)
Excluded	0.25 eV	0.25 eV	500 meV	0	Already excluded by cosmology
Dark Radiation	$< 2\sigma$	$< 2\sigma$	60 meV	> 0	Evidence for new light particles; normal hierarchy for neutrinos
Late Decay	$< 2\sigma$	$< 2\sigma$	60 meV	< 0	Energy-injection into photons at temperature $T \lesssim 1$ MeV

Table 3-2. *Relation between neutrino experiments and cosmology. We include the measurement of the Majorona mass via NLDBD ($m_{\beta\beta}$) or a kinematic endpoint (m_β) compared to the cosmological measurement of the sum of the masses $\sum m_\nu$ and the CMB measurement of $N_{\rm eff}$. Here $< 2\sigma$ indicates an upper limit from future observations. For Section 3.4, one can use $\sigma(m_{\beta\beta}) \approx 0.075$ eV and $\sigma(m_\beta) \approx 0.1$ eV for observations on the timescale of CMB-Stage IV. For $\Delta N_{\rm eff}$ the use of $\gtrless 0$ indicates a significant deviation from the Standard Model value.*

CMB-S4 Science Book (arXiv:1610.02743)