CMB S4

Probing Particle Physics Frontiers with CMB S4: Unveiling Cosmic Secrets

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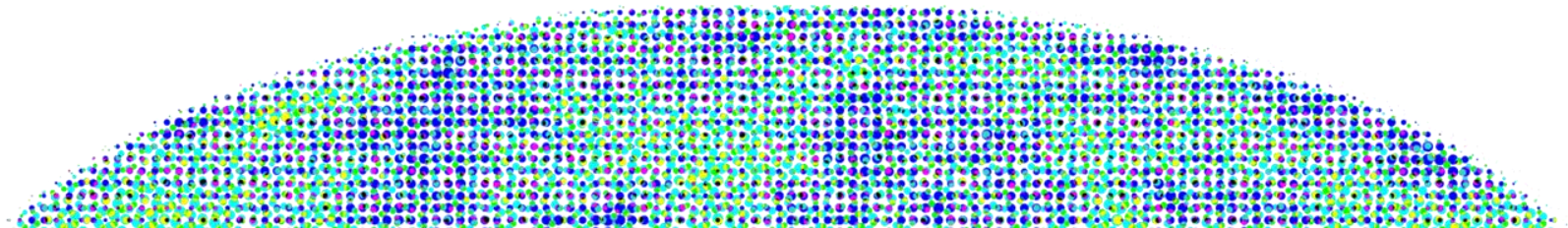
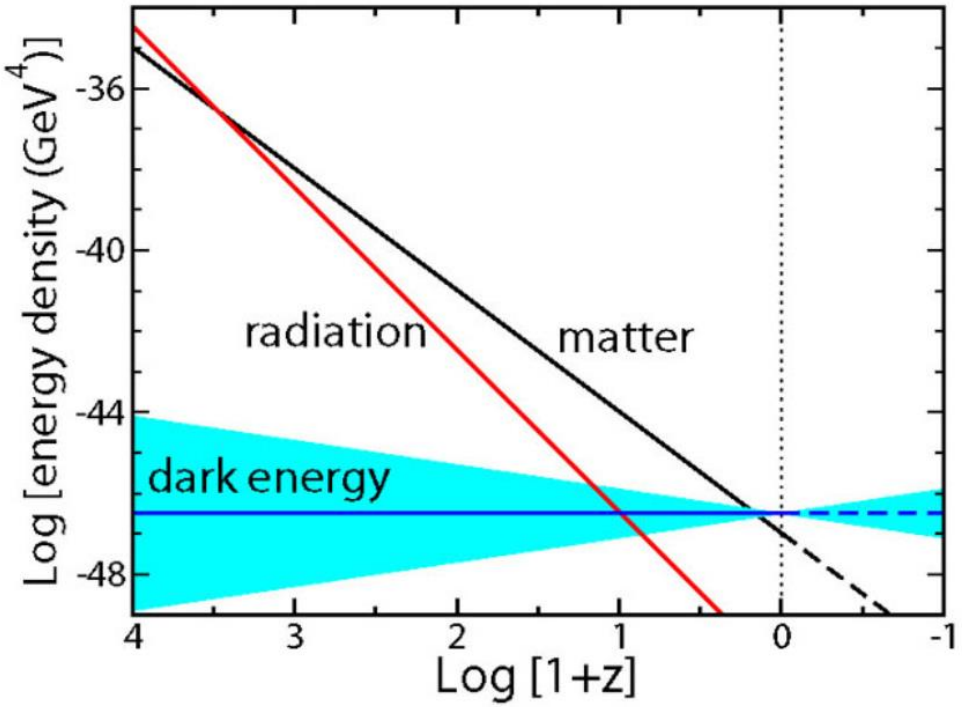


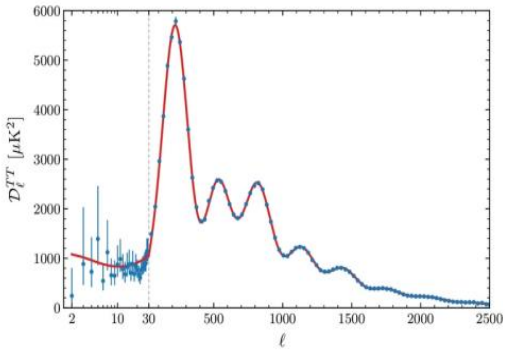
Cosmic Evolution

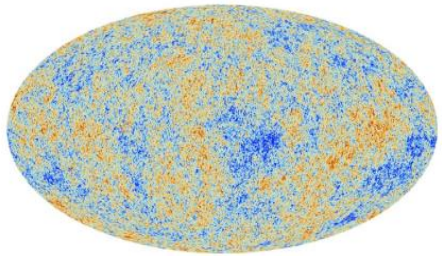


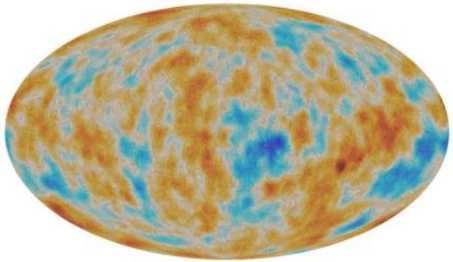
Credit: NED, CalTech

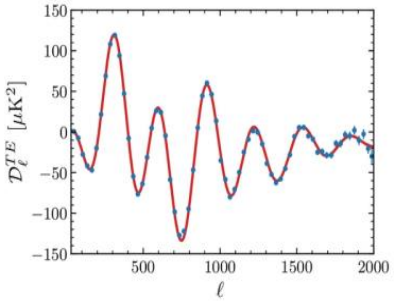
CMB Power Spectra: Planck

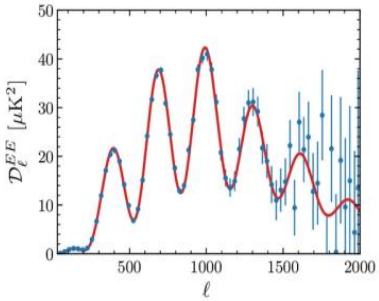
- $\Delta T/T \sim 10^{-5}$
- Angular scale, $\theta \sim 180°/\ell$







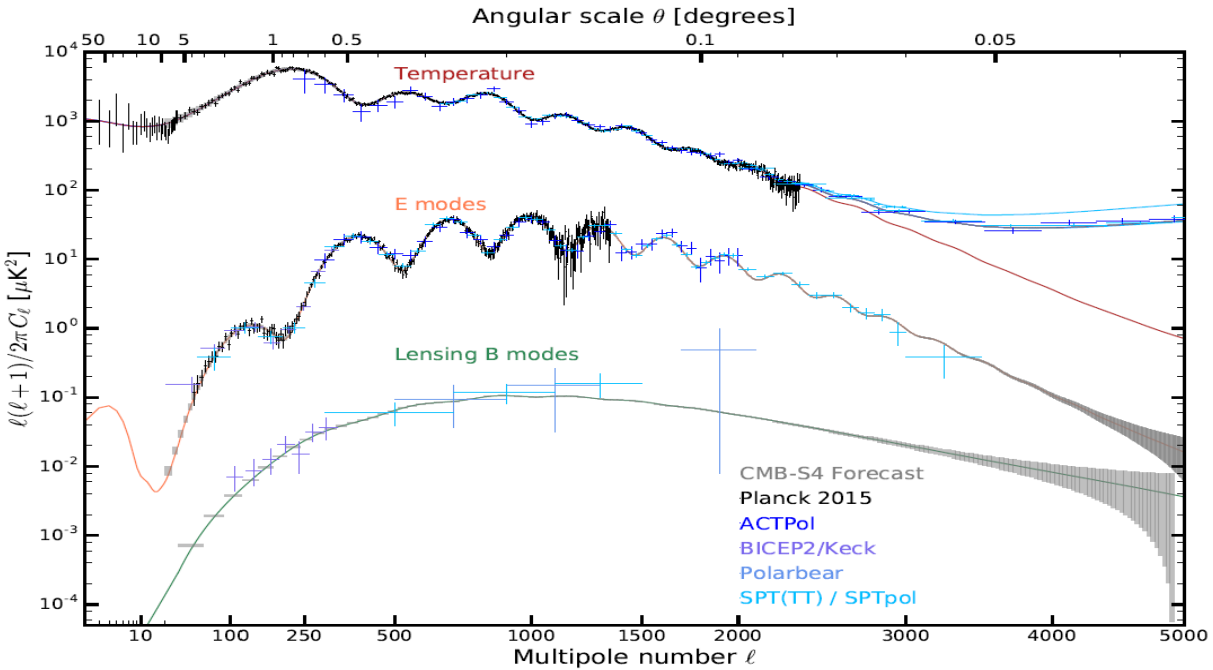




Credit: Planck Collaboration

Possible improvements with CMB-S4

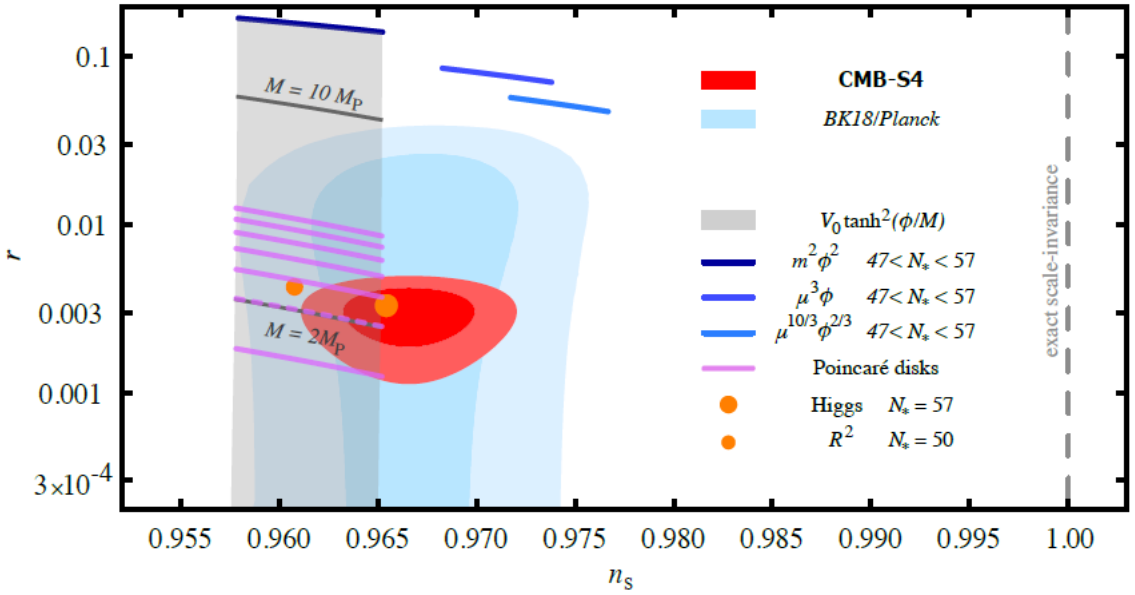
- Being a ground-based survey, CMB-S4 will not see the full sky like Planck.
- However, error bars will be smaller, along with much improved small-scale resolution.



CMB-S4 Science Book, First Edition, arXiv: 1610.02743

Inflation and the tensor-to-scalar ratio, r

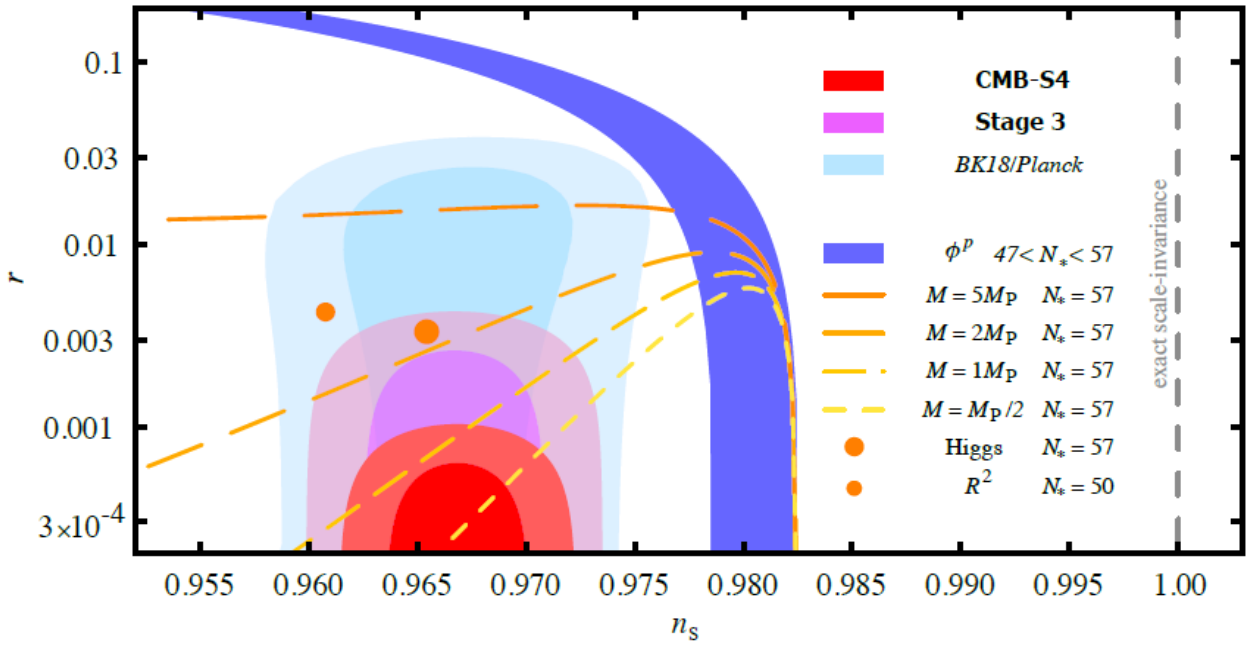
- Forecast for a fiducial model with r = 0.003.
- If true value of r>0.003, then a 5σ detection is possible.



CMB S4 Design Report

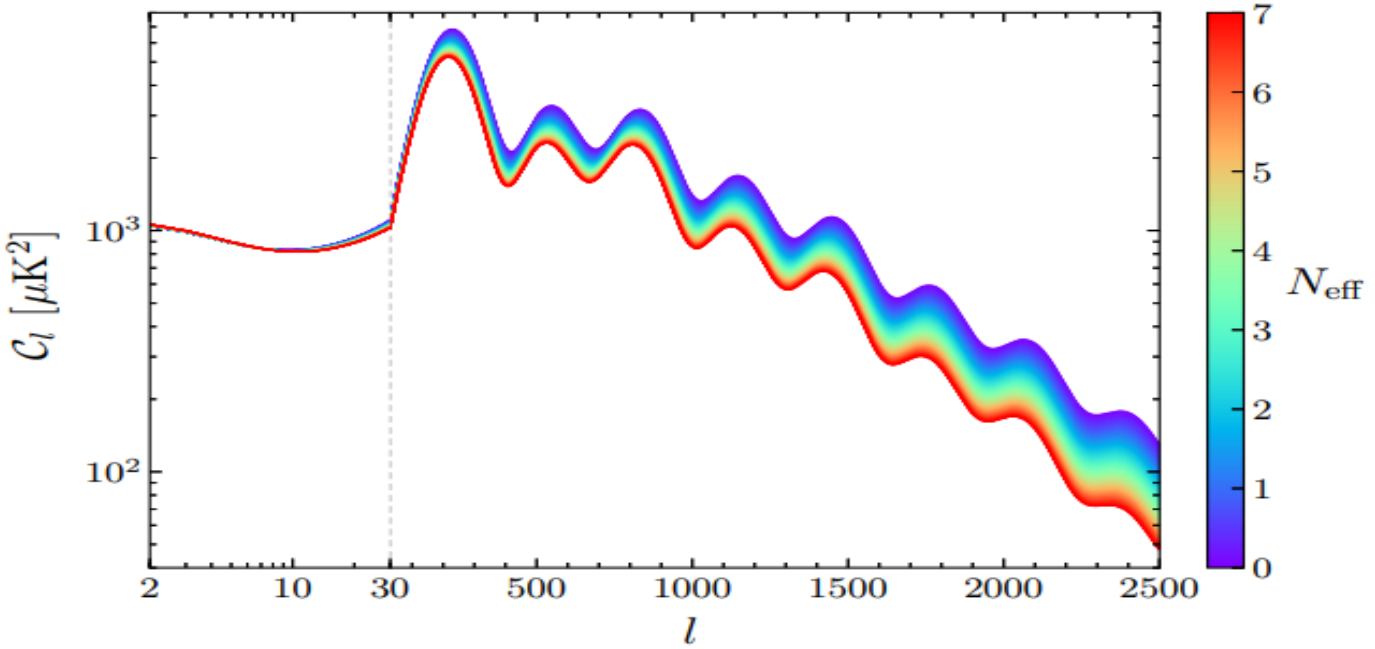
Inflation and the tensor-to-scalar ratio, r

- Forecast for a fiducial model with r = 0.
- If true value is r=0, then a constraint of r<0.001 at 2σ is possible.



CMB S4 Design Report

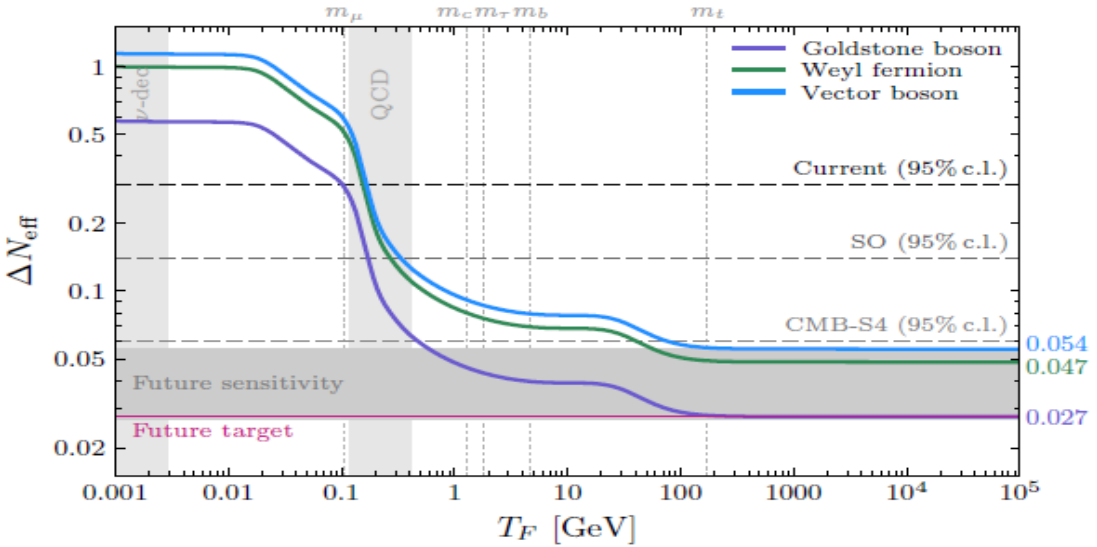
Effective number of non-photon radiation species, N_{eff}



D. Baumann, arXiv: 1807.03098

Effective number of non-photon radiation species, N_{eff}

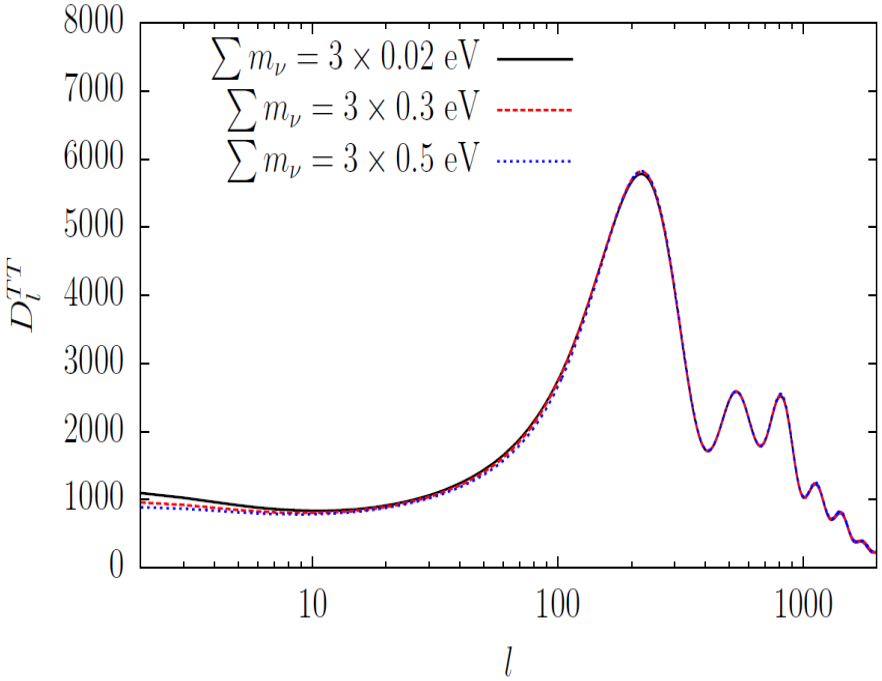
CMB-S4 shall determine N_{eff} with an uncertainty ≤ 0.06 (95% C.L.)

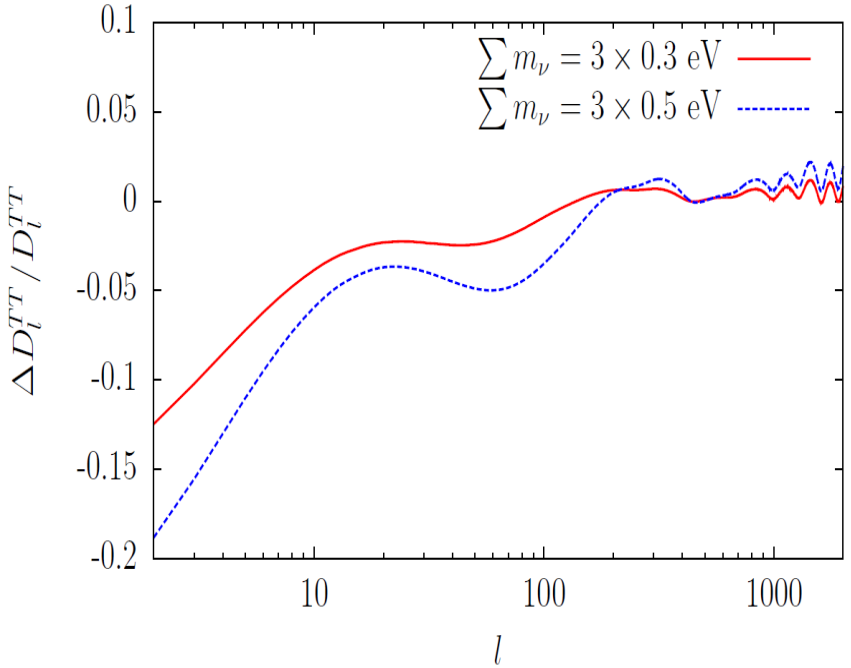


Dvorkin et al, arXiv: 2203.07943

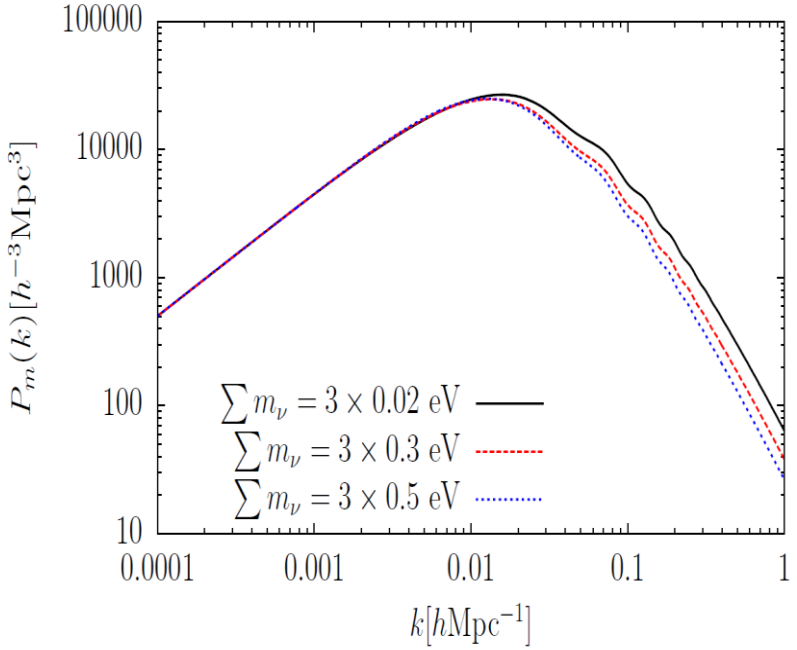
Contributions of a single massless particle, which decoupled from the Standard Model at a freeze-out temperature T_F, to the effective number of relativistic species.

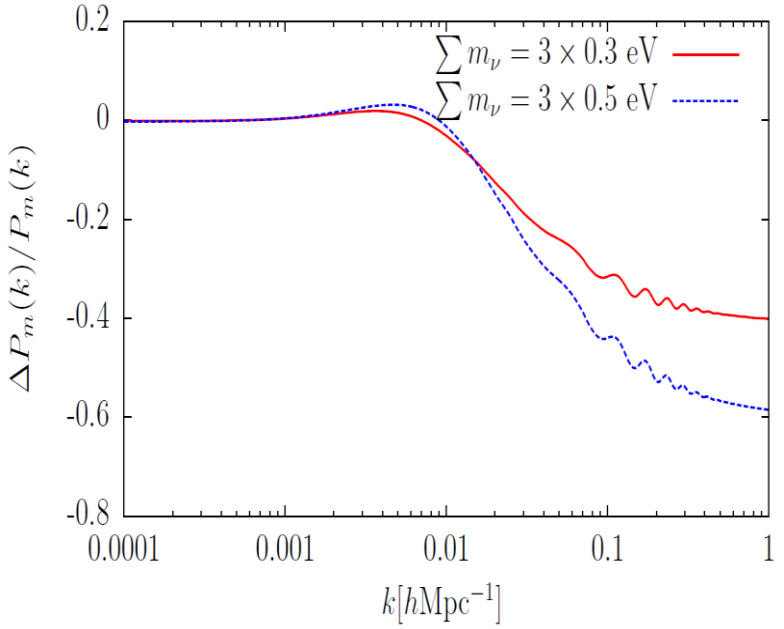
Neutrino Masses: Effect on CMB





Neutrino Masses: Effect on Matter Power Spectrum





Neutrino Masses: Oscillations

Minimum mass for normal hierarchy: 0.057 eV, for inverted hierarchy, it is 0.096 eV.

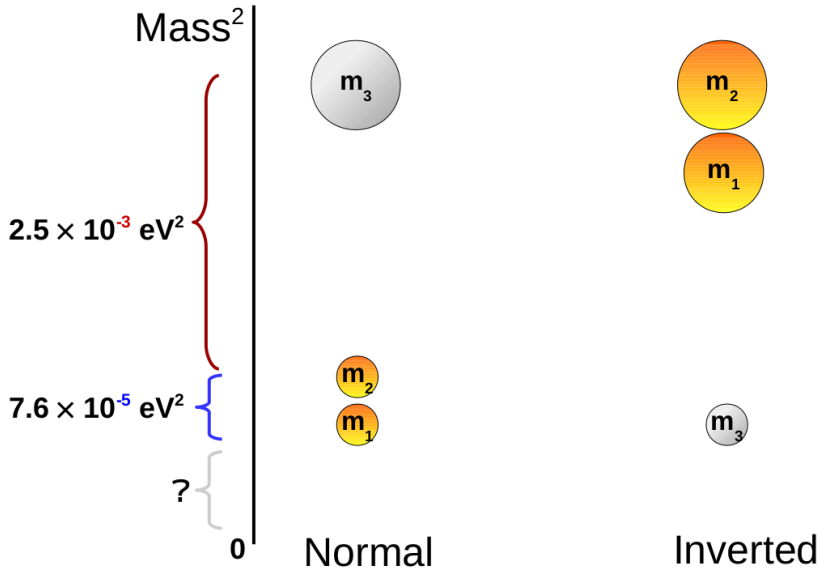
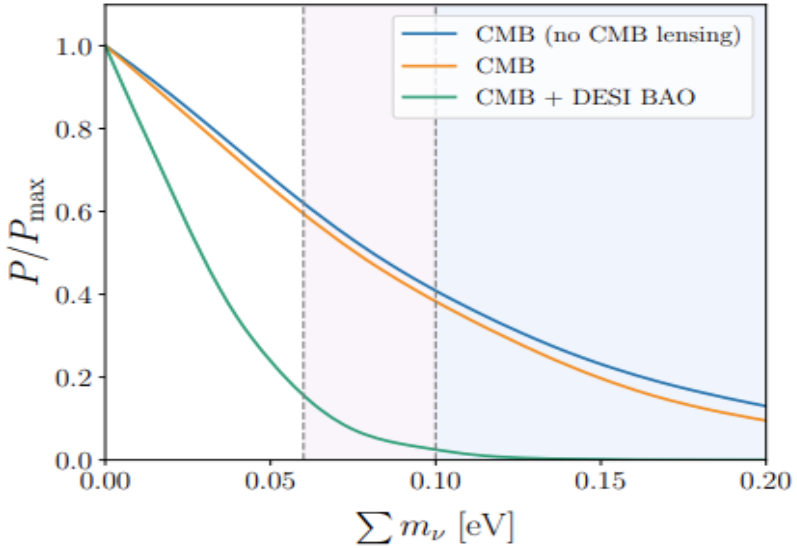
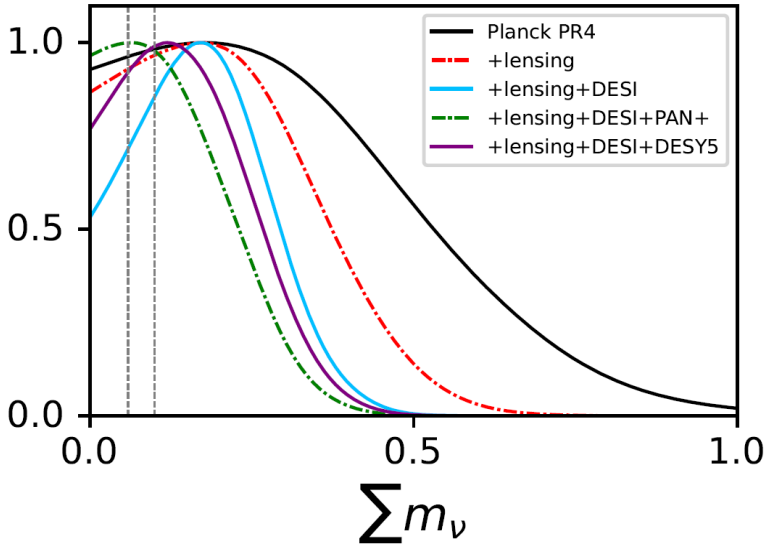


Image credit: Hyper-Kamiokande Collaboration

Neutrino Masses: Current constraints



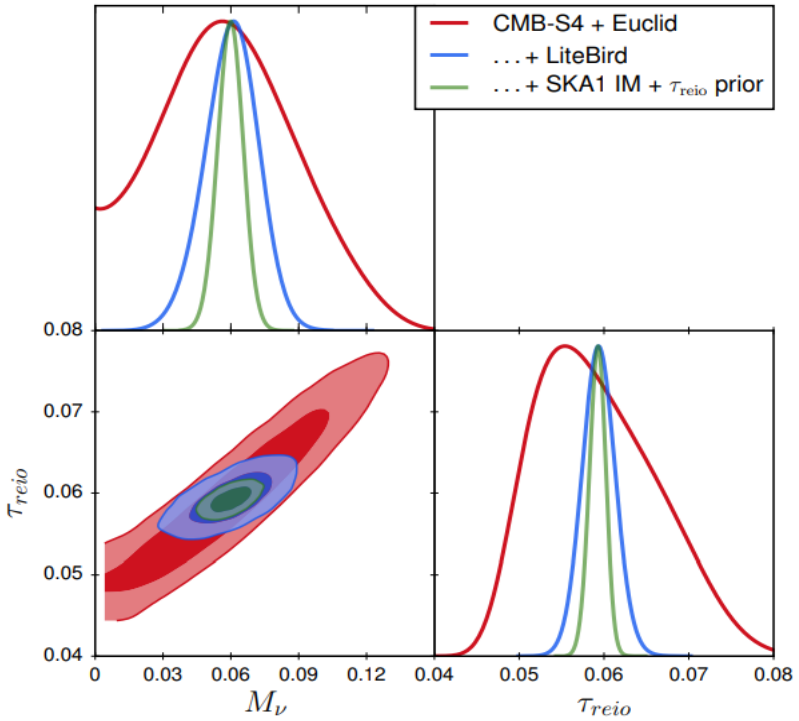
Constraints in a ΛCDM model.
DESI BAO Collaboration, arXiv: 2404.03002



Constraints in a largely extended parameter space with dynamical dark energy.
Roy Choudhury and Okumura, arXiv: 2409.13022

Neutrino Masses: Forecasts

- Strong degeneracy exists between τ_{reio} and neutrino masses.
- CMB S4 shall not constrain τ_{reio} well as low-ell (large angular scale) measurements will not be there.
- $\sigma(\tau_{reio}) = 0.001$ has been assumed in the τ_{reio} prior.



Brinckmann et al, arXiv: 1808.05955

Neutrino Masses: Forecasts

$$\sigma\left(\sum m_\nu\right) = 24 \text{ meV} \quad \text{CMB-S4} + \text{DESI BAO} + \text{Planck } \sigma(\tau)$$

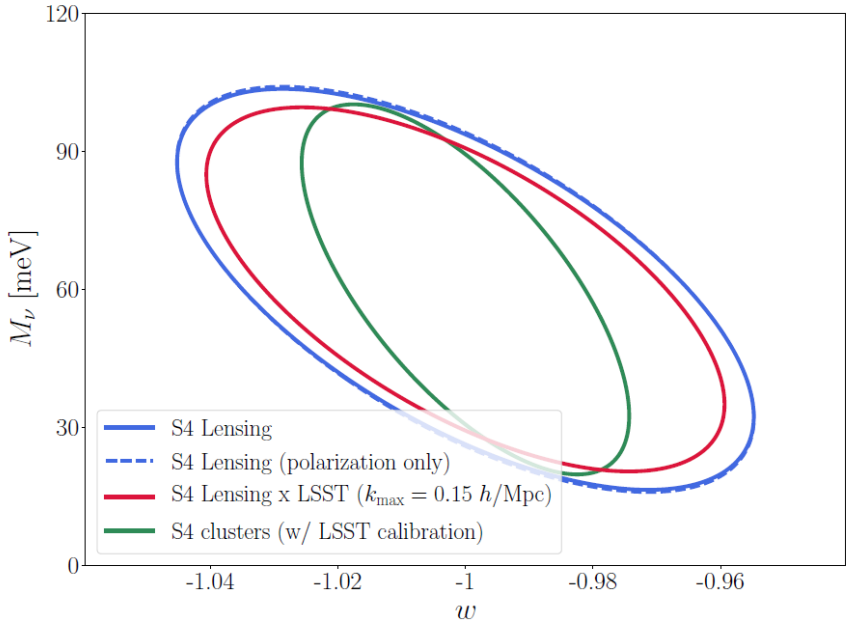
$$\sigma\left(\sum m_\nu\right) = 14 \text{ meV} \quad \text{CMB-S4} + \text{DESI BAO} + \text{Cosmic Variance } \sigma(\tau)$$

Since minimum mass sum for Normal Ordering is 0.06 eV and for Inverted Ordering is 0.1 eV, **a sensitivity of at least 20 meV is needed to rule out Inverted Ordering at 2σ** if the true value of $\Sigma m_\nu = 0.06$ eV.

Neutrino Masses: Forecasts

- Strong degeneracy also exists between the **dark energy equation of state, w,** and neutrino masses.

- These forecasts (68%) already include primary CMB S4 + DESI BAO and a prior on τ_{reio}

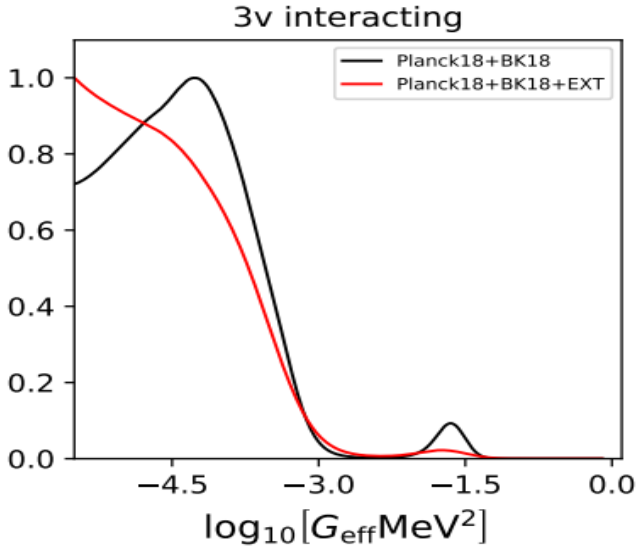


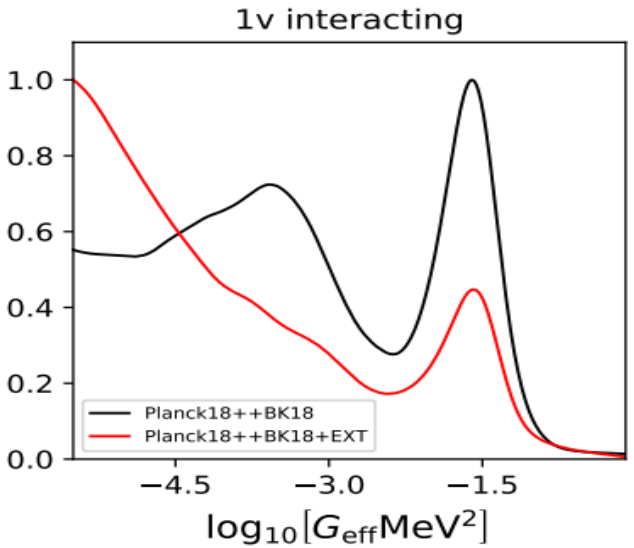
CMB S4 Reference Design Report (arXiv:1907.04473)

Neutrino Self-Interactions

- Here we consider neutrino self-interactions with scalar mediator mass of M >1 keV, in the effective 4-fermion interaction limit (CMB temperature at decoupling is 0.26 eV, which is far lower than the keV range).
- Simplified universal interaction: $\mathcal{L}_{\rm int} \sim g_{ij}\bar{\nu}_i\nu_j\Phi$, with $g_{ij} = g\delta_{ij}$
- The effective self-coupling, $\mathbf{G_{eff} = g^2/M^2}$, with $\mathbf{G_{eff} > G_F}$ (Fermi constant), so that they remain interacting with each other even after decoupling from the photons at T~1 MeV.
- They remain self-interacting until the interaction rate falls below the Hubble expansion rate.
- CMB data can put constraints on $\mathbf{G_{eff}}$.

Neutrino Self-Interactions: Current constraints on G_{eff}

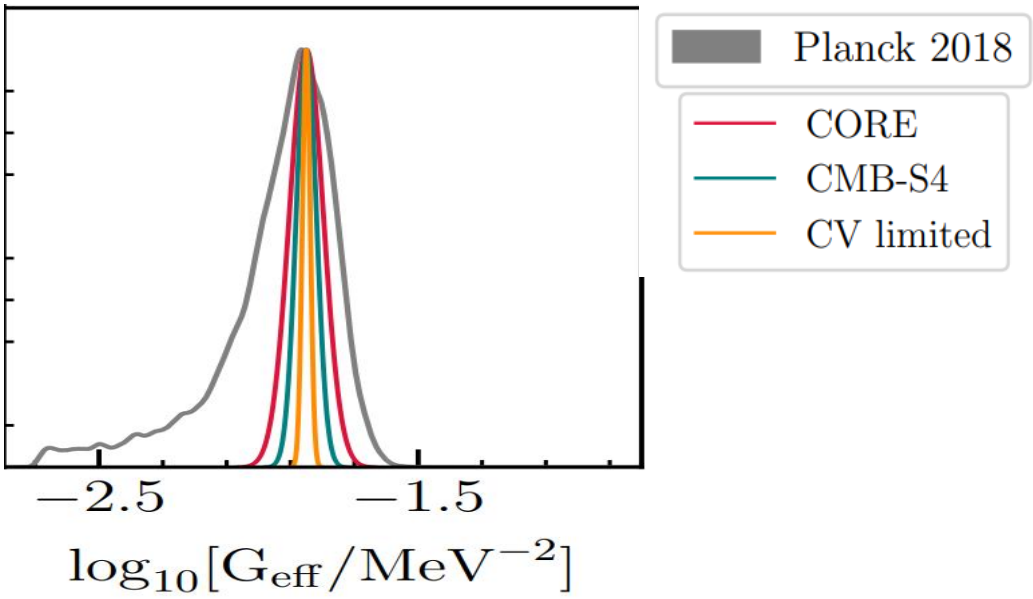




Roy Choudhury, Hannestad & Tram, JCAP 10 (2022) 018

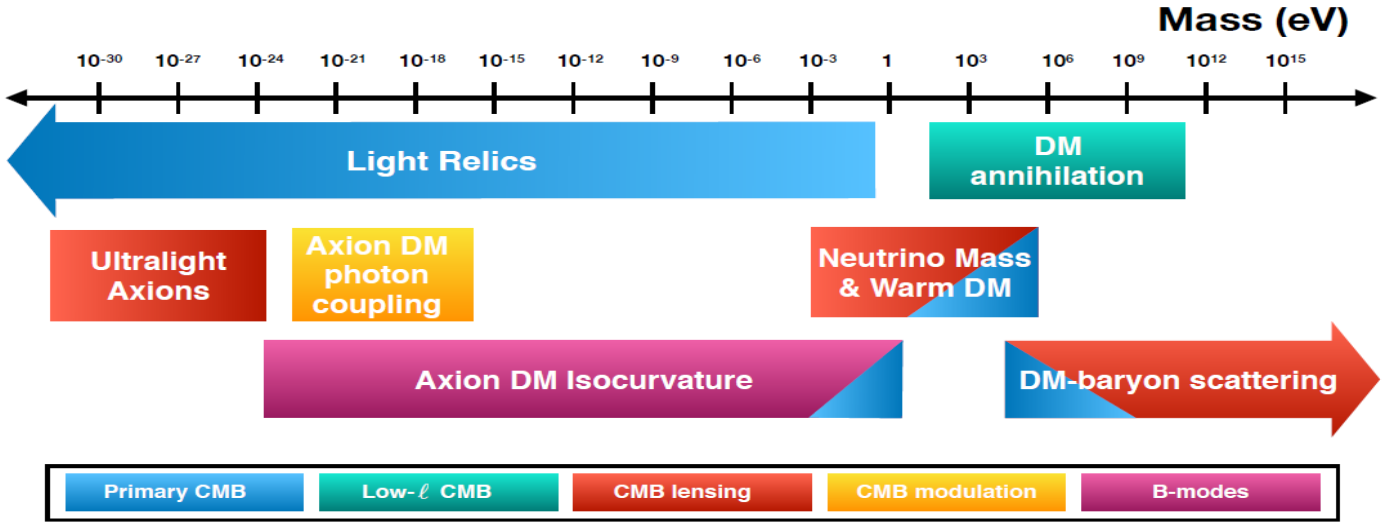
Neutrino Self-Interactions: Forecasts on the strongly interacting mode

CMB S4 can improve the bound by a factor of three compared to Planck.



Das & Ghosh, JCAP 09 (2023) 042

Other Areas



CMB S4 Reference Design Report (arXiv: 1907.04473)

CMB-S4 will be able to probe light relics, axions, warm dark matter, and different dark matter scenarios. The relevant mass to which the CMB is sensitive to is shown for each case. The observable that drives the constraint is shown in different colors.

CMB S4

Thank you for listening to our presentation.

Learn more at **https://cmb-s4.org/**