Constraining neutrino masses with clustering in harmonic space via multi-tracing [based on arXiv: 2009.05584]

Central European Institute for Cosmology and Fundamental Physics, Prague

Università degli studi di Torino

FZU
Institute of Physics of the Czech Academy of Sciences

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Multi-tracer Technique

- **MT proposed to overcome cosmic variance**

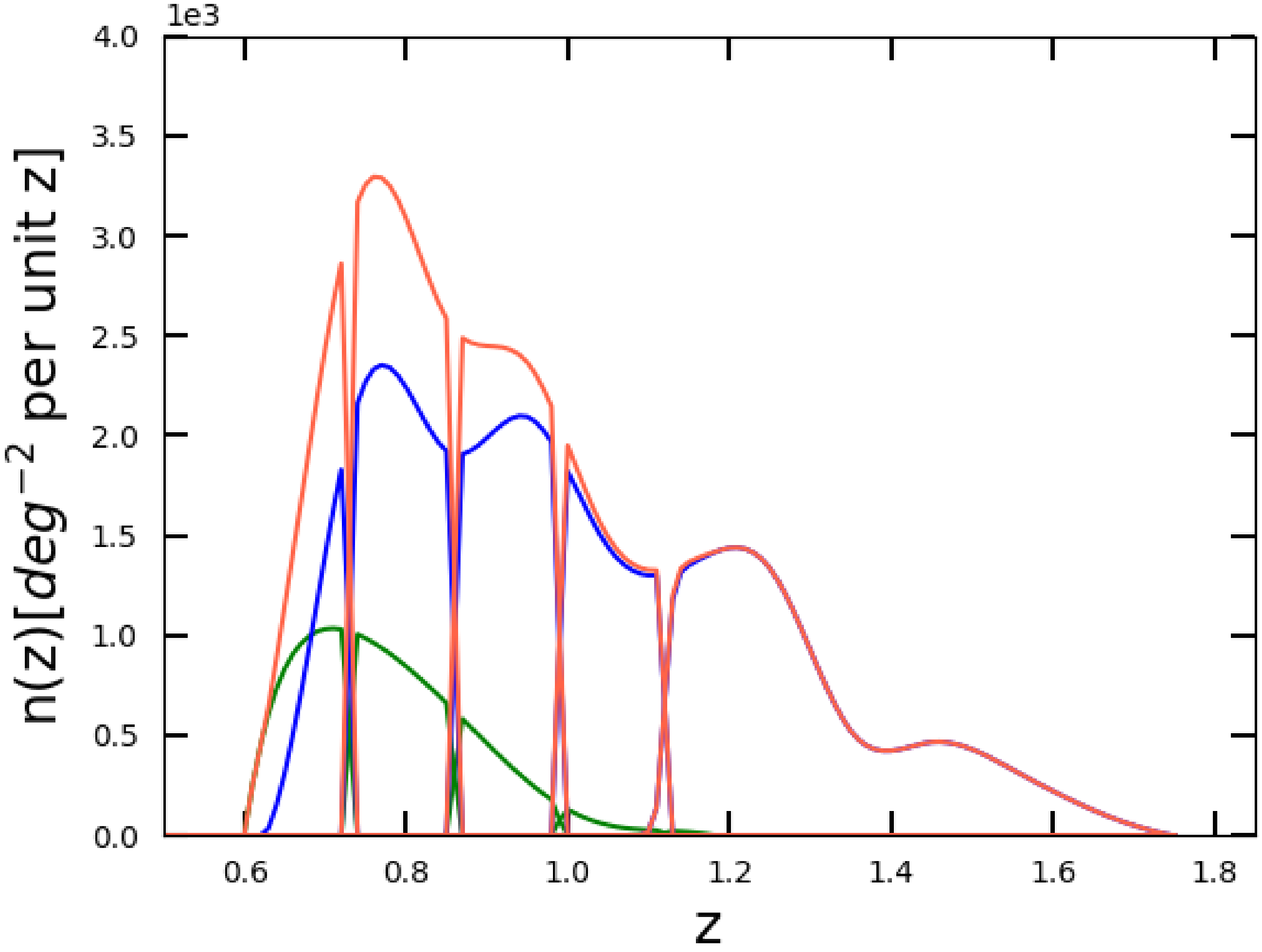
- **Galaxy bias and growth rate are deterministic quantities not affected by cosmic variance (at large scales)**

- **By MT-ing, we get the ratio of the biases net of the stochasticity of the density fluctuations**

$$\frac{\delta_{g1}}{\delta_{g2}} = \frac{b_{g1}\,\delta_m}{b_{g2}\delta_m}$$

Forecast with DESI

- **Dark Energy Spectroscopic Instrument (DESI) in optical.**
- **Sky coverage:** $\mathbf{14000}\ \boldsymbol{deg^2}$
- **Scale independent galaxy bias for Luminous Red Galaxies and Emission Line Galaxies** $\boldsymbol{b_{LRG}(z) = 1.70/D(z),\ b_{ELG}(z) = 0.84/D(z)}$



$$b_{TOT}(z) = \frac{n_{ELG}(z)b_{ELG}(z) + n_{LRG}(z)b_{LRG}(z)}{n_{ELG}(z) + n_{LRG}(z)}$$

Limber approximated angular power spectra: Galaxy clustering with RSD in linear theory and massive neutrinos : $\theta_{\{\Lambda\mathrm{CDM}+\sum m_v\}} = \{\Omega_m, h, \sigma_8\} \cup \{\sum m_v\}$

$$C^g_{\ell\gg 1}(z_i, z_j) = \int \frac{d\chi}{\chi^2} W^i(k_\ell,\chi) W^j(k_\ell,\chi) P_{lin}\left(k_\ell = \frac{\ell + 1/2}{\chi}, z = 0\right)$$

Density fluctuations →

$$W^i_{g,den}(k_\ell,\chi) = n^i(\chi) b^i(k_\ell,\chi) D(k_\ell,\chi)$$

$$D(k_\ell, z) = \sqrt{P_{lin}(k_\ell, z)/P_{lin}(k_\ell, z=0)}$$

$$b^m = \sqrt{P^g_{lin}/P_{lin}}$$

Or

$$b^{b+CDM} = \sqrt{P^g_{lin}/P^{b+CDM}_{lin}}$$

With the latter one being the more precise since for $k_\ell > k_\ell^{fs}$ where we have the galaxy formation, neutrinos do not cluster. Thus galaxies trace the b+CDM field and not the total matter field which includes neutrinos

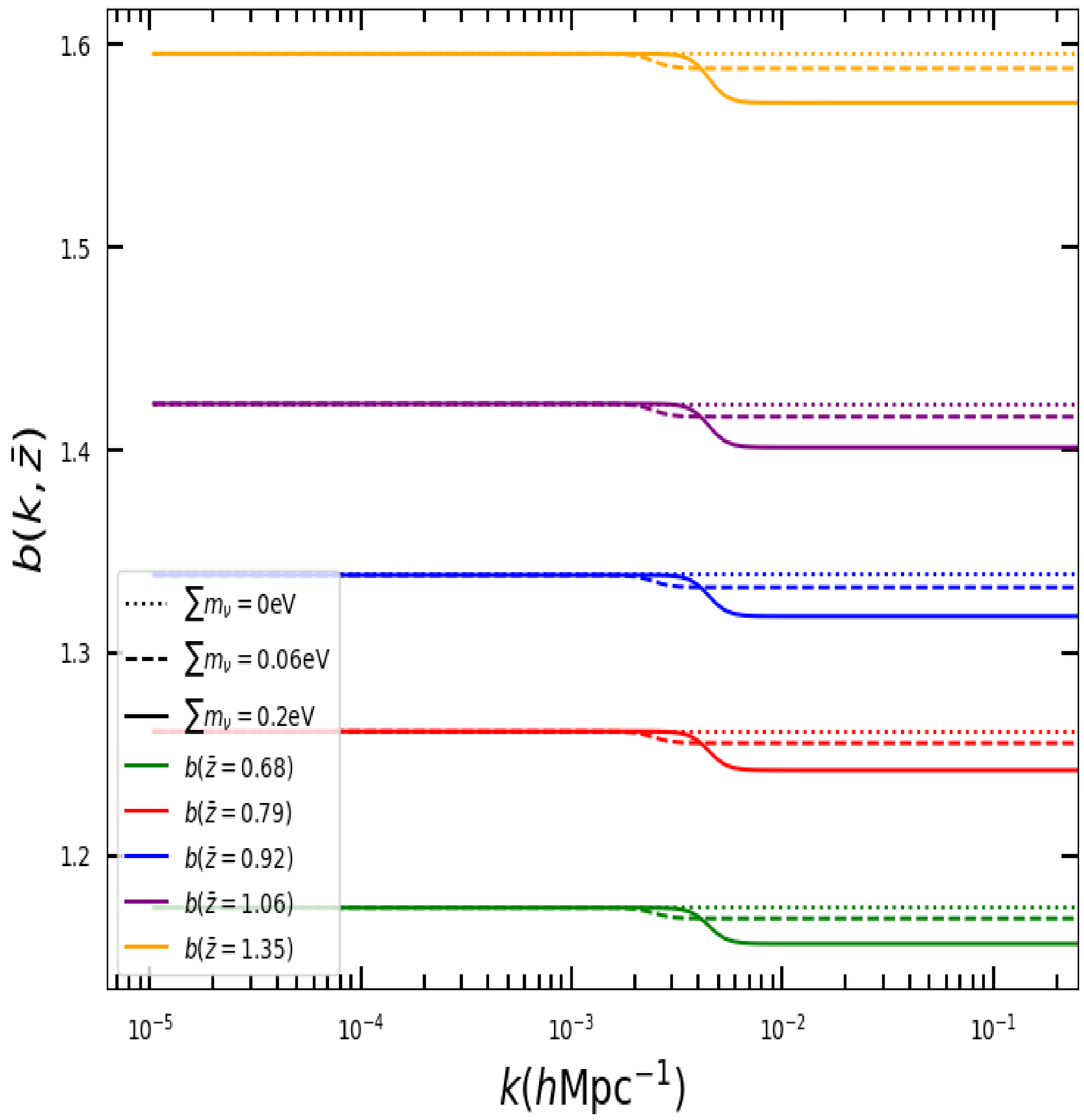
RSD ↓

$$f(k_\ell, z) = -(1+z)\, d\ lnT(k_\ell, z)/dz$$

$$W^i_{g,RSD}(k_\ell,\chi) = \frac{2\ell^2 + 2\ell + 1}{(2\ell-1)(2\ell+3)} n^i(\chi)[fD](k_\ell,\chi)$$

$$- \frac{\ell(\ell-1)}{(2\ell-1)\sqrt{(2\ell+1)(2\ell-3)}} n^i\left(\frac{2\ell-3}{2\ell+1}\chi\right)[fD]\left(k_\ell, \frac{2\ell-3}{2\ell+1}\chi\right)$$

$$- \frac{(\ell+1)(\ell+2)}{(2\ell+3)\sqrt{(2\ell+1)(2\ell+5)}} n^i\left(\frac{2\ell+5}{2\ell+1}\chi\right)[fD]\left(k_\ell, \frac{2\ell+5}{2\ell+1}\chi\right)$$



- **Minimum wavenumber at the transition in the non-relativistic regime**

$$k_{nr} \approx 0.018 \left(\frac{m_v}{1eV}\right)^{\frac{1}{2}} \sqrt{\Omega_m} h/\text{Mpc}$$

- **For $k \ll k_{nr}$, b^m and b^{b+CDM} converge, since the total matter PS and the b+CDM PS are the same**

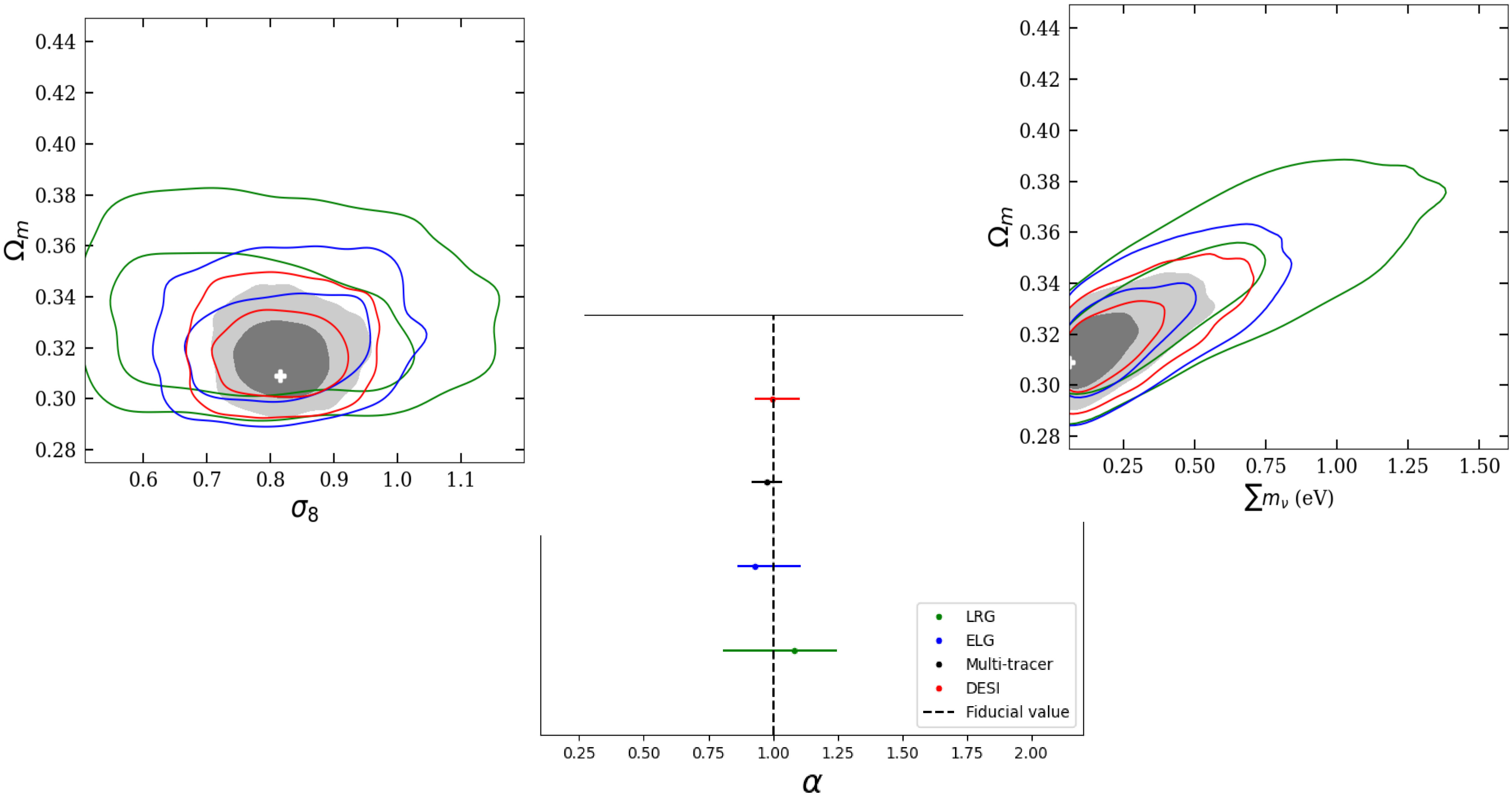
- **For $k \gg k_{nr}$,**

$$b^m \rightarrow b^{b+CDM}(1 - f_v)$$

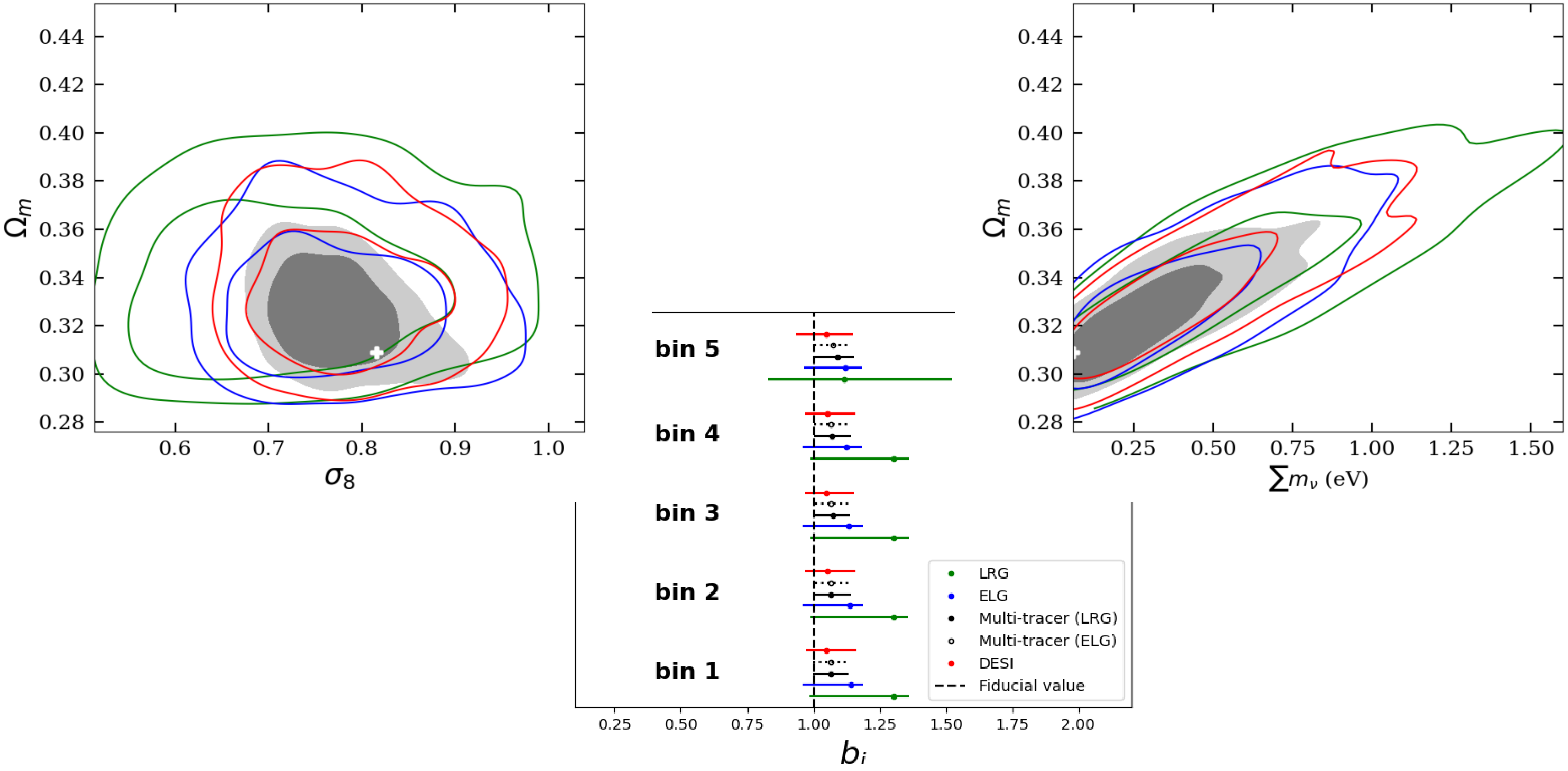
With $f_v = \Omega_v / \Omega_m$ and $\Omega_v = \sum m_v / (93.14h^2)$

Formula by Castorina et.al 2014

Pessimistic: An overall amplitude bias parameter for the whole redshift range



Conservative: An amplitude bias parameter per bin and tracer



Thank you for your attention!