Nonlinear galaxy clustering in massive neutrino cosmologies

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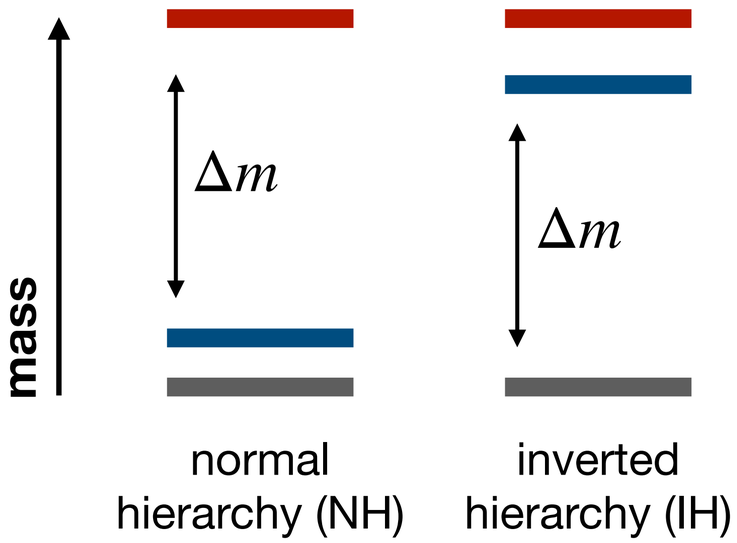
Sestri Levante, 16/09/2024

Neutrino masses

Neutrino oscillations indicate that this particles are massive: scale still unknown



CURRENT LOWER BOUNDS

$\sum m_\nu > 60\,\mathrm{meV}$ for **NH**

$\sum m_\nu > 100\,\mathrm{meV}$ for **IH**

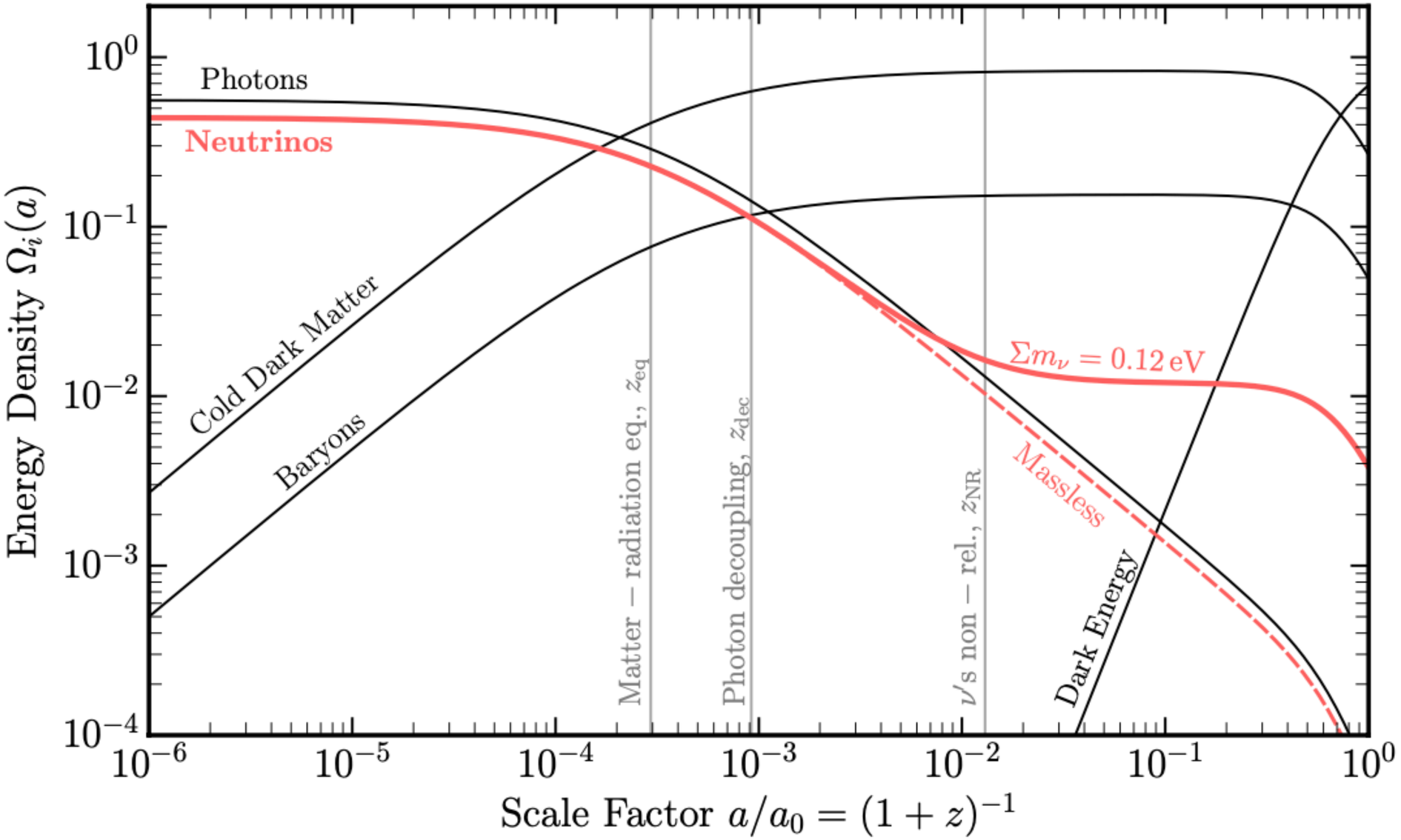
UPPER from experiments (KATRIN) $m_{\nu,e} < 1.1\,\mathrm{eV}$

COSMOLOGY:

$\sum m_\nu \equiv M_\nu < 160\,\mathrm{meV}$ at 95%CL from **BOSS (Fs) + Planck**

[*Ivanov*+19]

Massive neutrinos: background cosmology



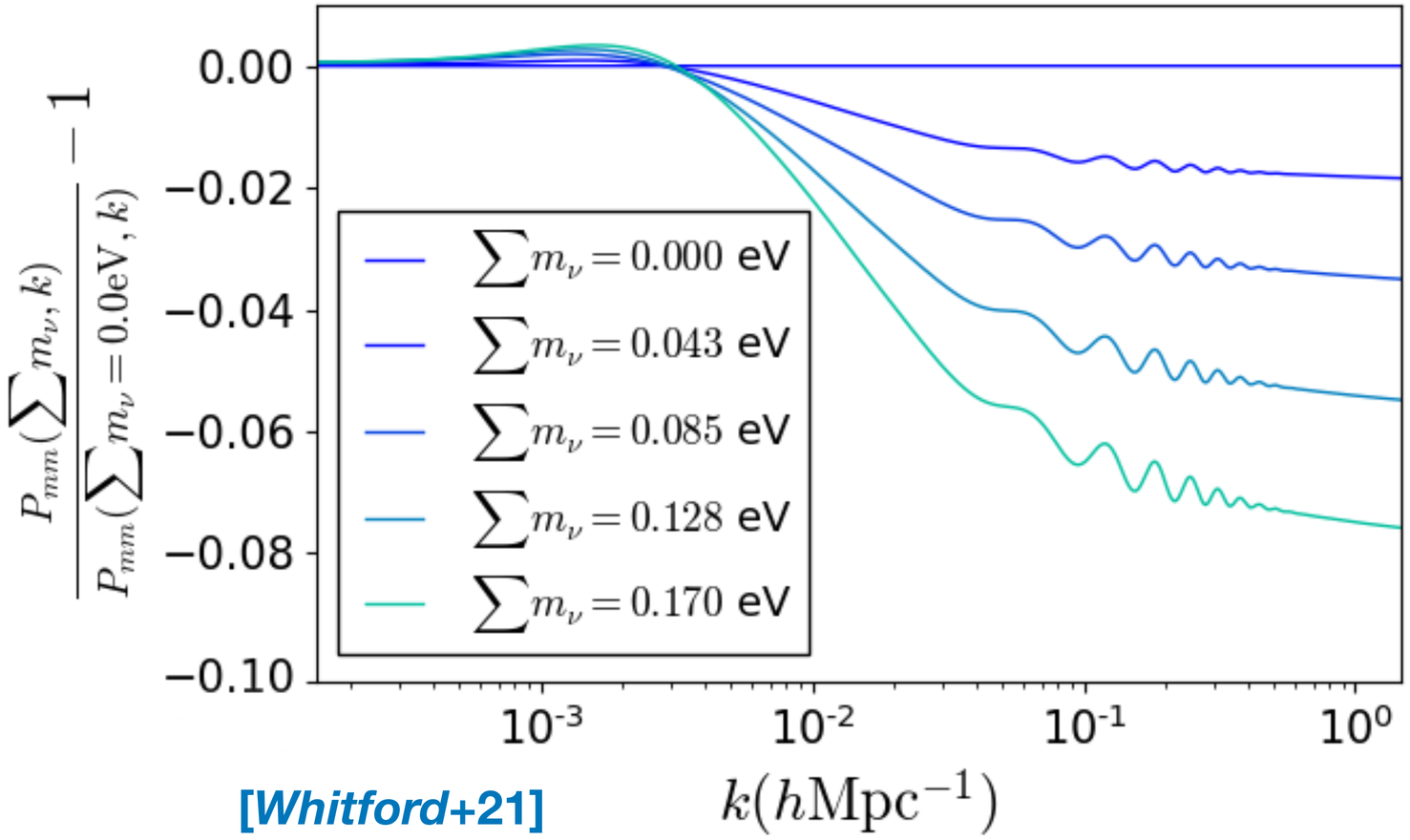
$$\Omega_\nu = \frac{\sum_i m_{\nu,i}}{93.14 h^2\,\mathrm{eV}}$$

$$f_\nu \equiv \frac{\Omega_\nu}{\Omega_{\mathrm{matt}}}$$

Massive neutrinos: matter perturbations

Yet neutrinos are matter at late time, they are free-streaming.

At the level of linear perturbations: suppression on small scales.



[*Whitford*+21]

$$\frac{P_{\rm m}(k)}{P_{\rm m}(k, f_\nu = 0)} \sim 1 - 6 f_\nu$$

For $M_\nu = 60\,\mathrm{meV}$, this is a $\sim 3\,\%$ effect!

Galaxy clustering in cosmologies with massive neutrinos

- Effects beyond linear power spectrum are tiny.
- **Motivation**: if not accounted for might introduce systematic biases
- Some potential subtleties still to be fully worked out

I present two aspects:

- Redshift-space distortions in M_ν cosmologies
- Validation of the full EFT model with massive neutrinos

Example: bias with massive neutrinos

- Halos/galaxies are biased tracers $\delta_h = b_1\delta + \ldots$
- But now there are two matter component: the total one (CDM+baryons+ν) and the cold-only (CDM+baryons)
- **Question**: is it then $\delta_h = b_1\delta_m + \ldots$ or $\delta_h = b_1\delta_c + \ldots$?
- **Method**: check it in simulations. **Outcome**: $\delta_h = b_1\delta_c + \ldots$ better reproduces data

[*Castorina*+14, Cosmology with massive neutrinos II: on the universality of the halo mass function and bias]

Halo velocity with massive neutrinos

- **Another question**: and for the velocity field?
- This is relevant, for cosmology with galaxy clustering, due to Redshift-space Distortions (RSDs)

$$\delta_{h,s} = b\delta + f\mu^2\Theta_h \qquad \text{(with only one fluid } \Theta_h = \Theta = \delta\text{)}$$

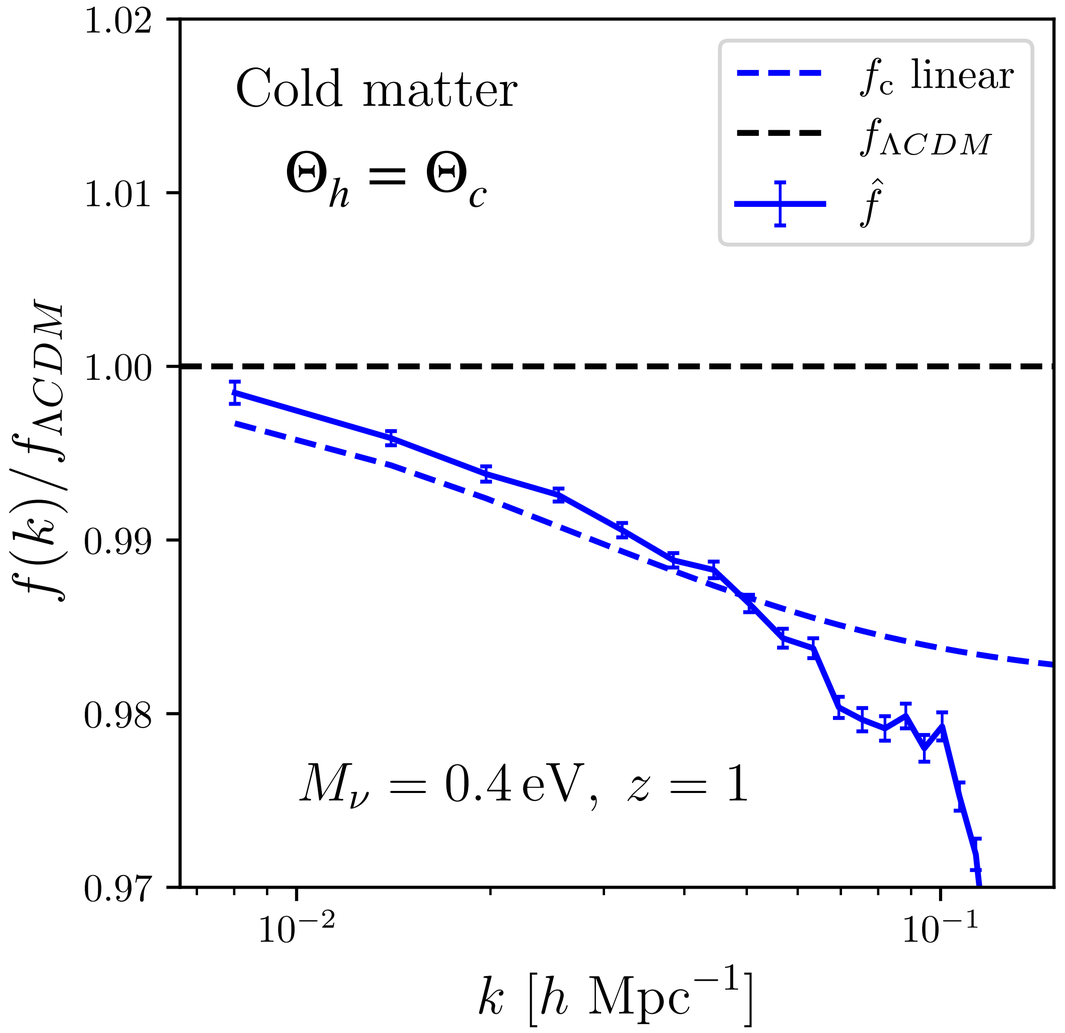
- Is it $\Theta_h = \Theta_m$ or $\Theta_h = \Theta_c$?
- Very independent question to the density bias one.

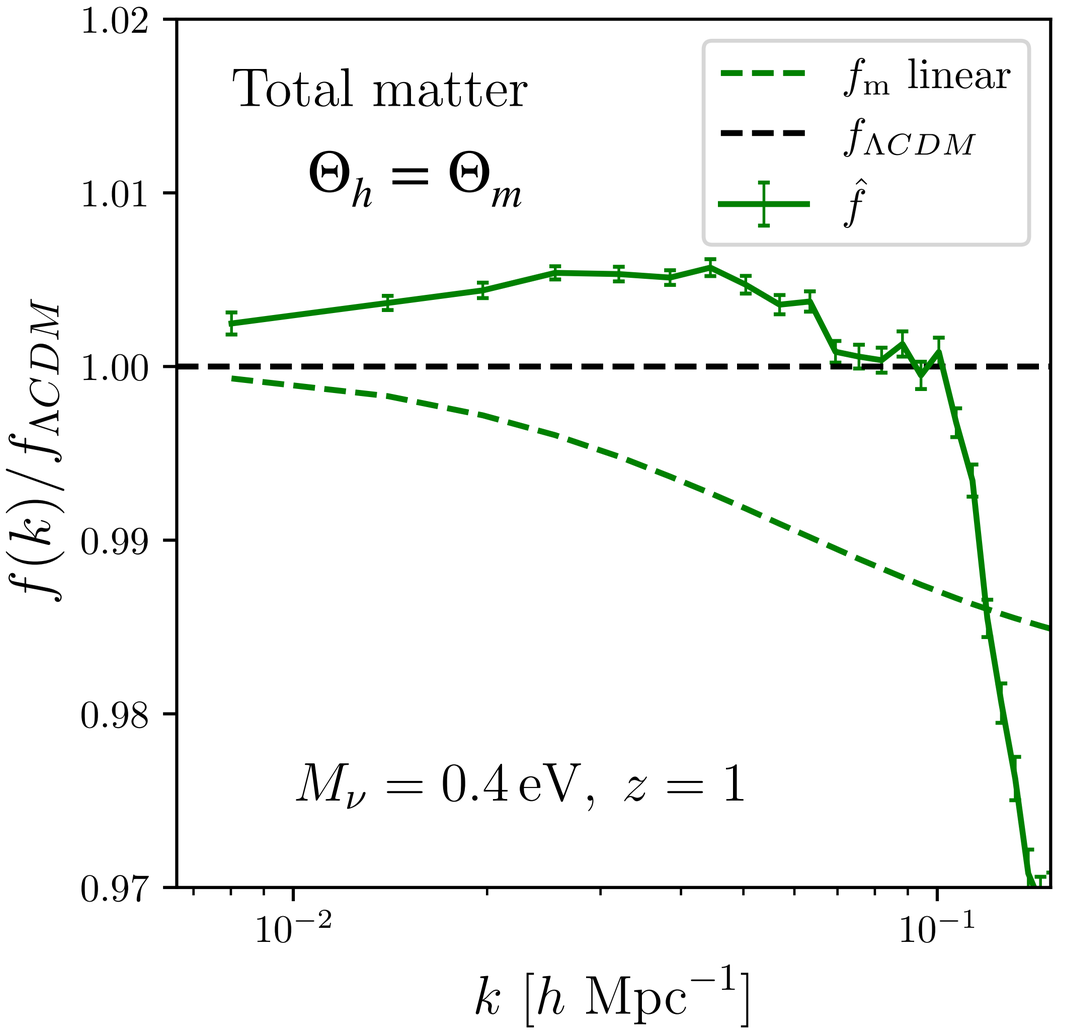
[*Castorina*+15, *Marulli*+11, *Villaescusa-Navarro*+17]

QUIJOTE & DEMNuni
[*Villaescusa-Navarro*+19, *Carbone*+17]

Halo velocity with massive neutrinos

Let's address it the same way: take simulations, and see which *ansatz* better recovers the growth rate.





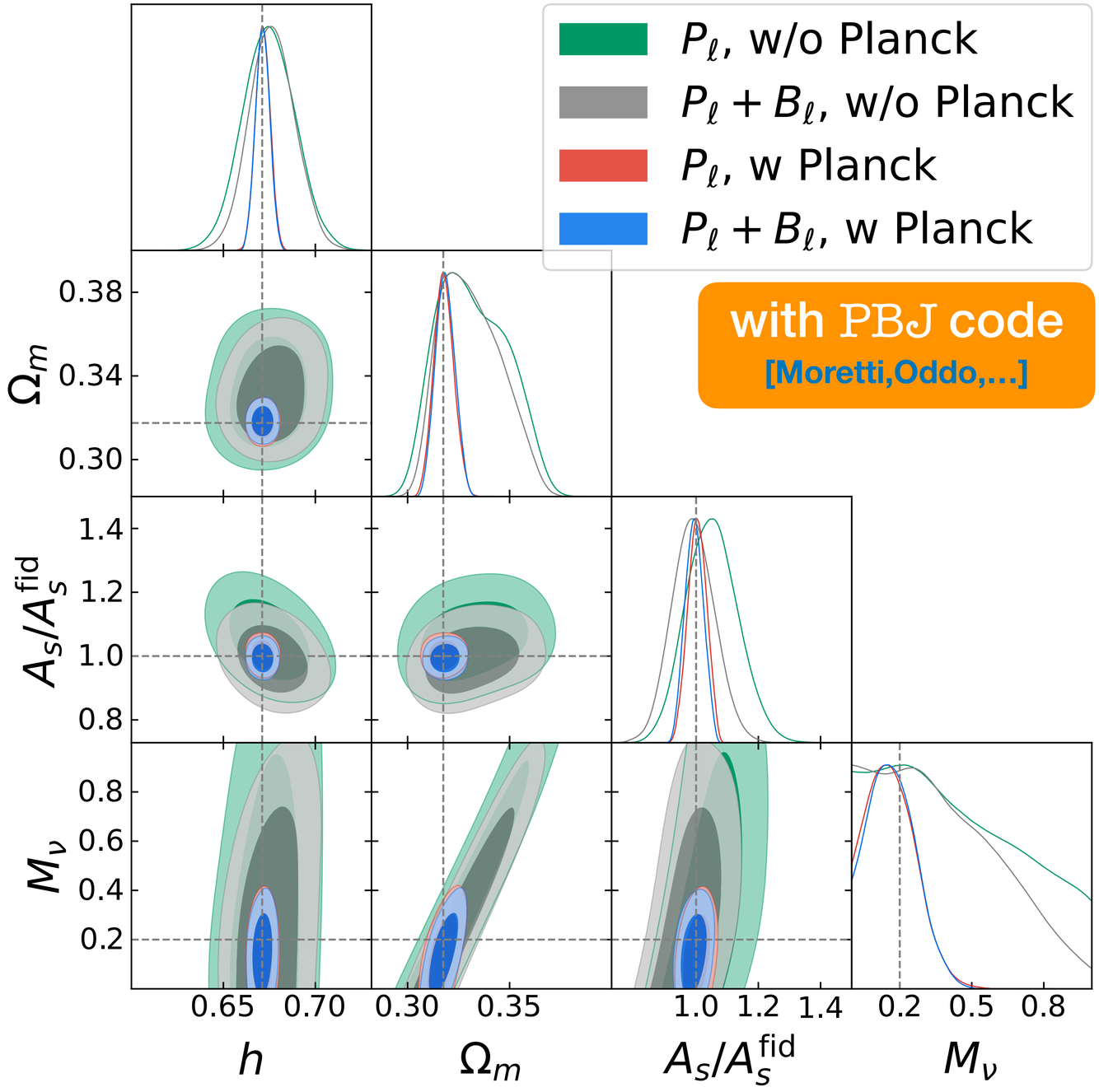
EFT model with massive neutrinos

The state of the art model for full-shape analysis of galaxy clustering.

A. So far, the EFT model thoroughly validated on CDM only simulations.
B. In principle there are **[under study with *Castorina*, *Redigolo*, *Salvioni*]** modifications to the theory due to M_ν. Are they negligible or not? **[*Noriega+22*]**

Goal: perform a realistic validation on mock galaxy catalogs, both for power spectrum and bispectrum

(E. Bellini ++, 2024)



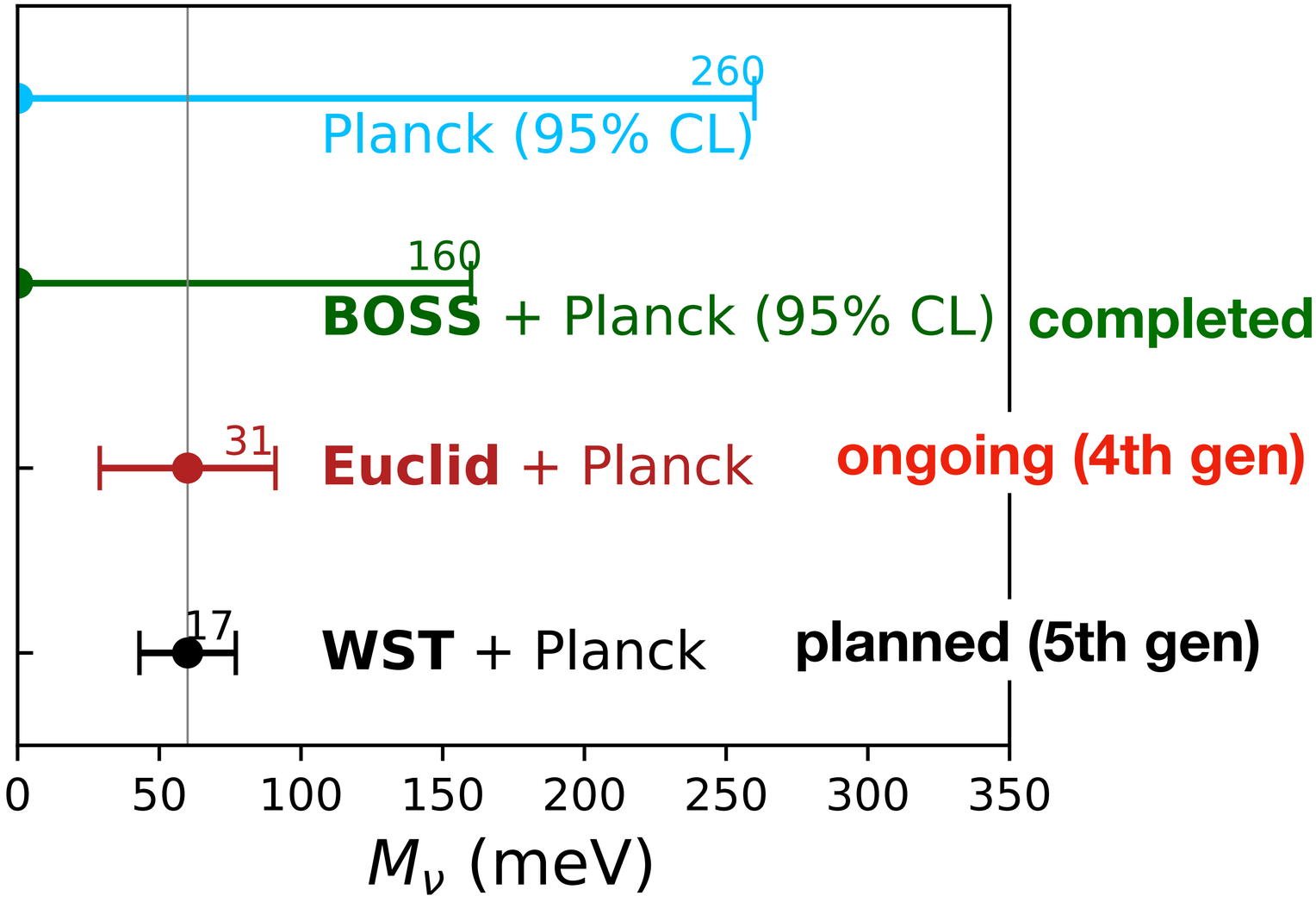
(*E. Bellini ++, 2024*)

sancho galaxy mock catalogs **[M. Biagetti++]**

Outcome:

- The EFT properly fits the galaxy mock $P + B$
- Model reaches $k_{max} = 0.18\,h/\mathrm{Mpc}$ for a cumulative volume of $25\,(\mathrm{Gpc}/h)^3$
- Need priors from the CMB to have a detection.

Forecasts for full shape analyses (EFT)



[*Manieri*+24, The Wide-field Spectroscopic Telescope (WST) Science White Paper]

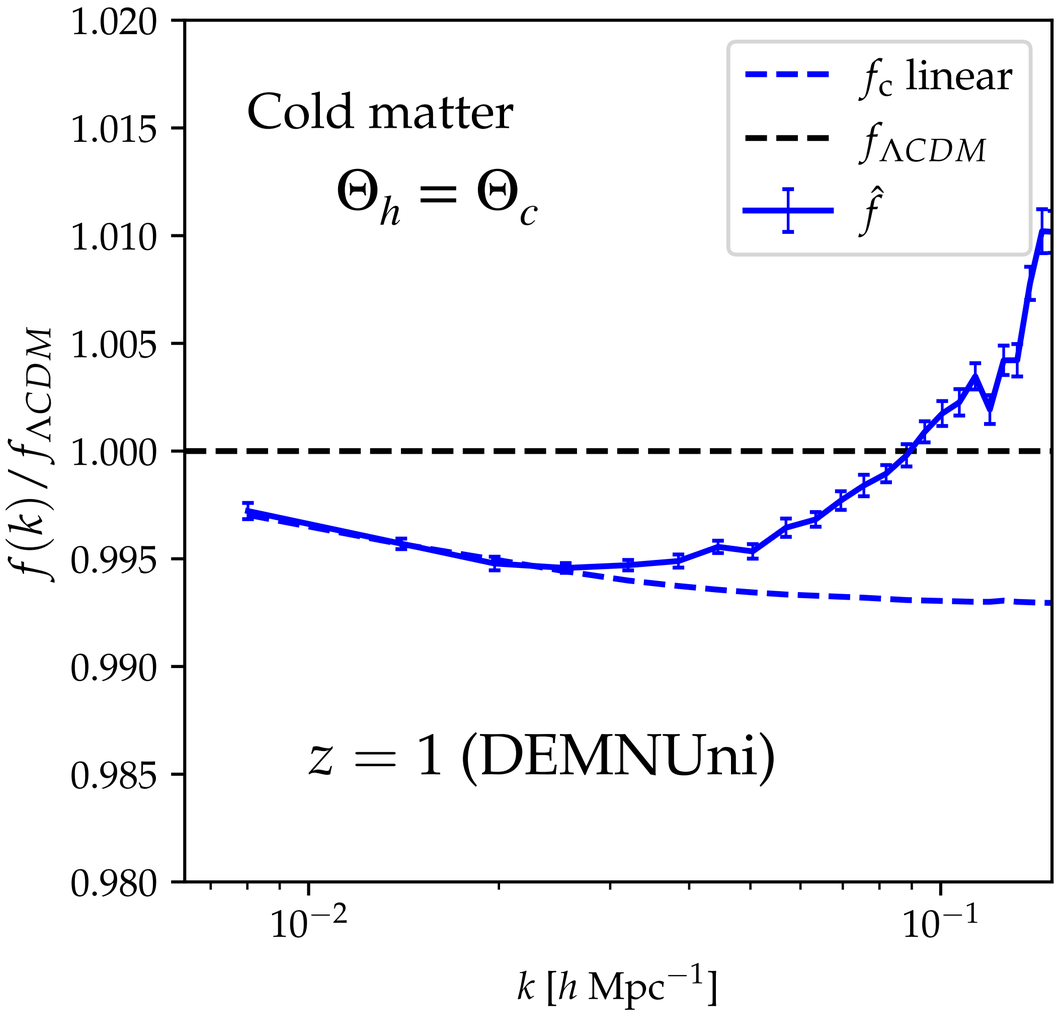
With Euclid data foreseen a detection of at least $\sim 2\sigma$.

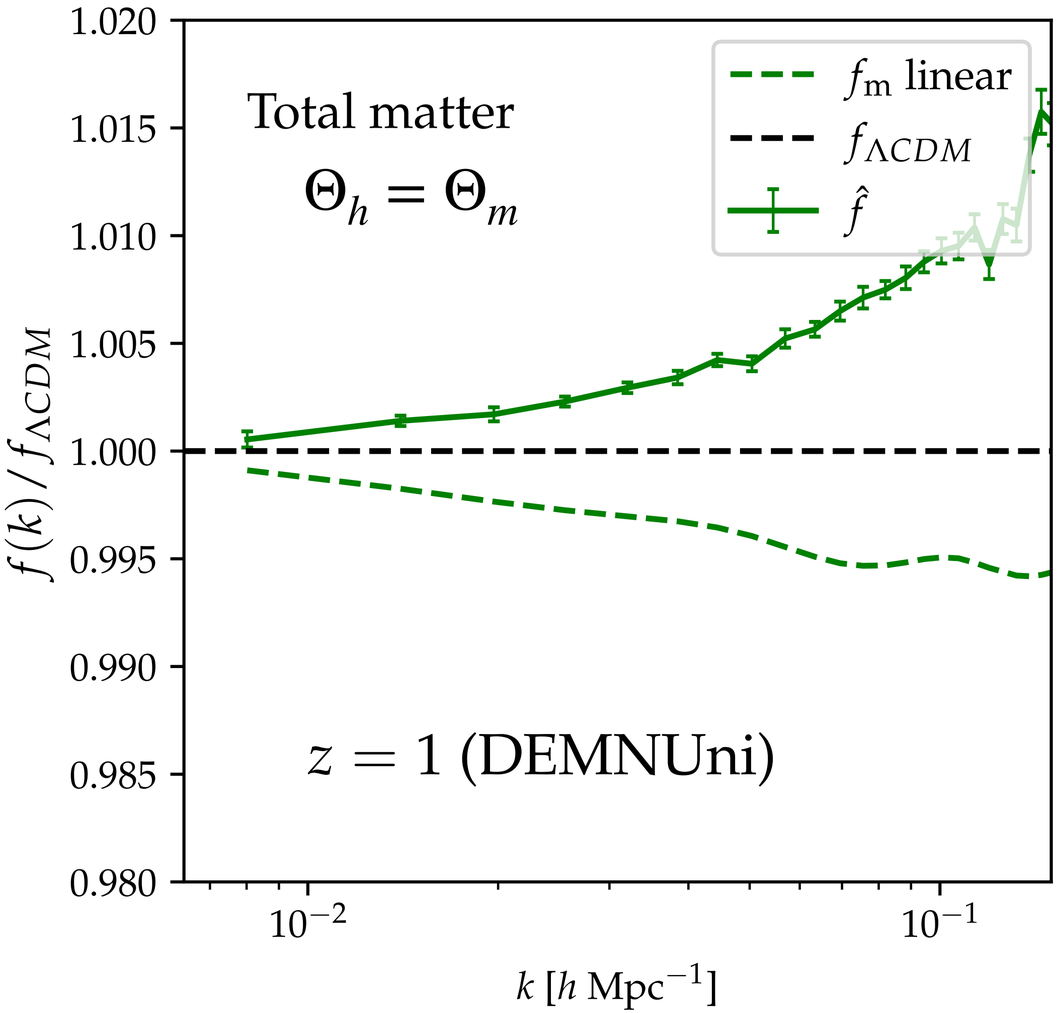
Will get to 3.5σ with next generation (like WST)!

Thanks

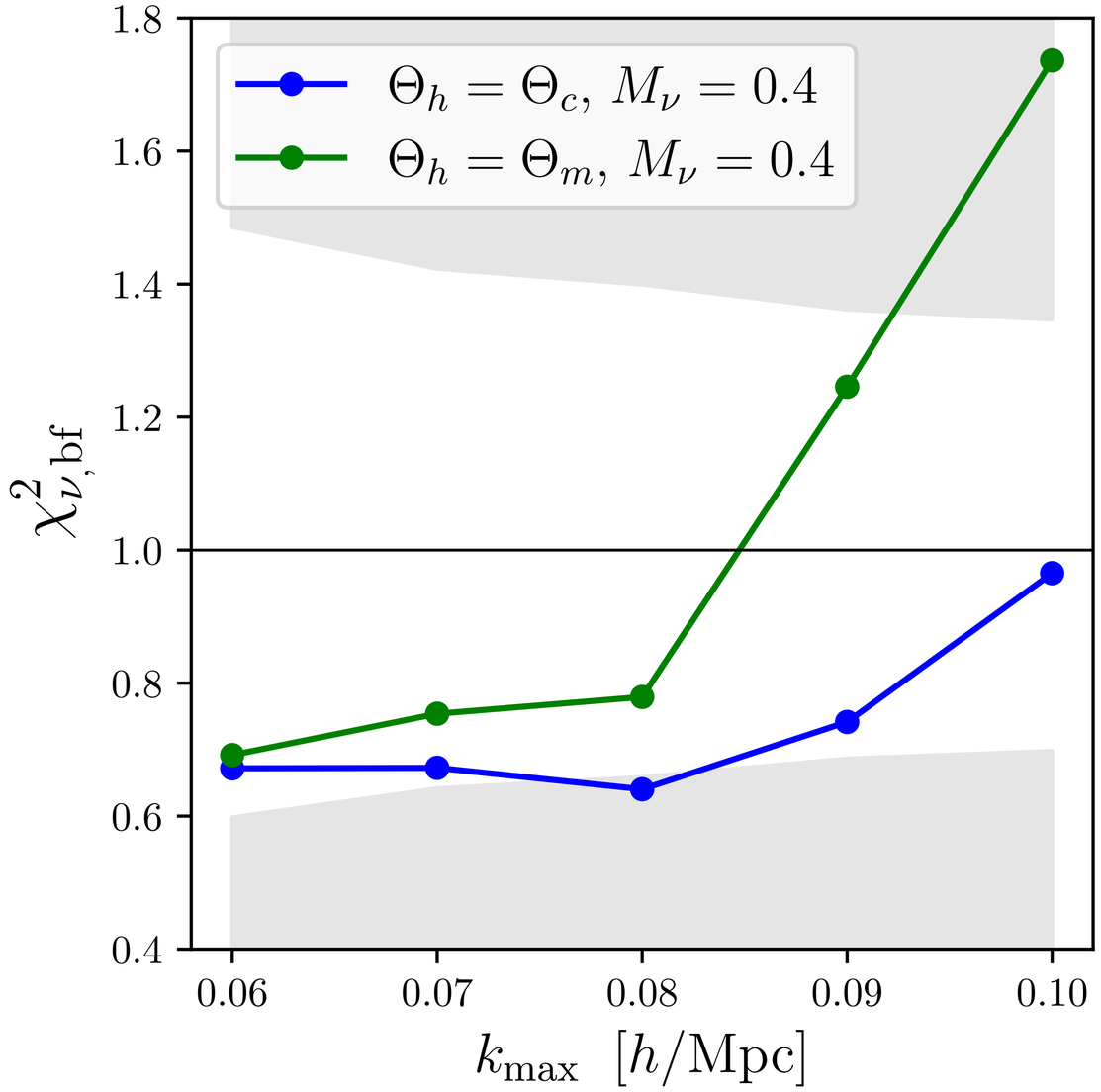
Halo velocity with massive neutrinos

Let's address it the same way: take simulations, and see which *ansatz* better recovers the growth rate.

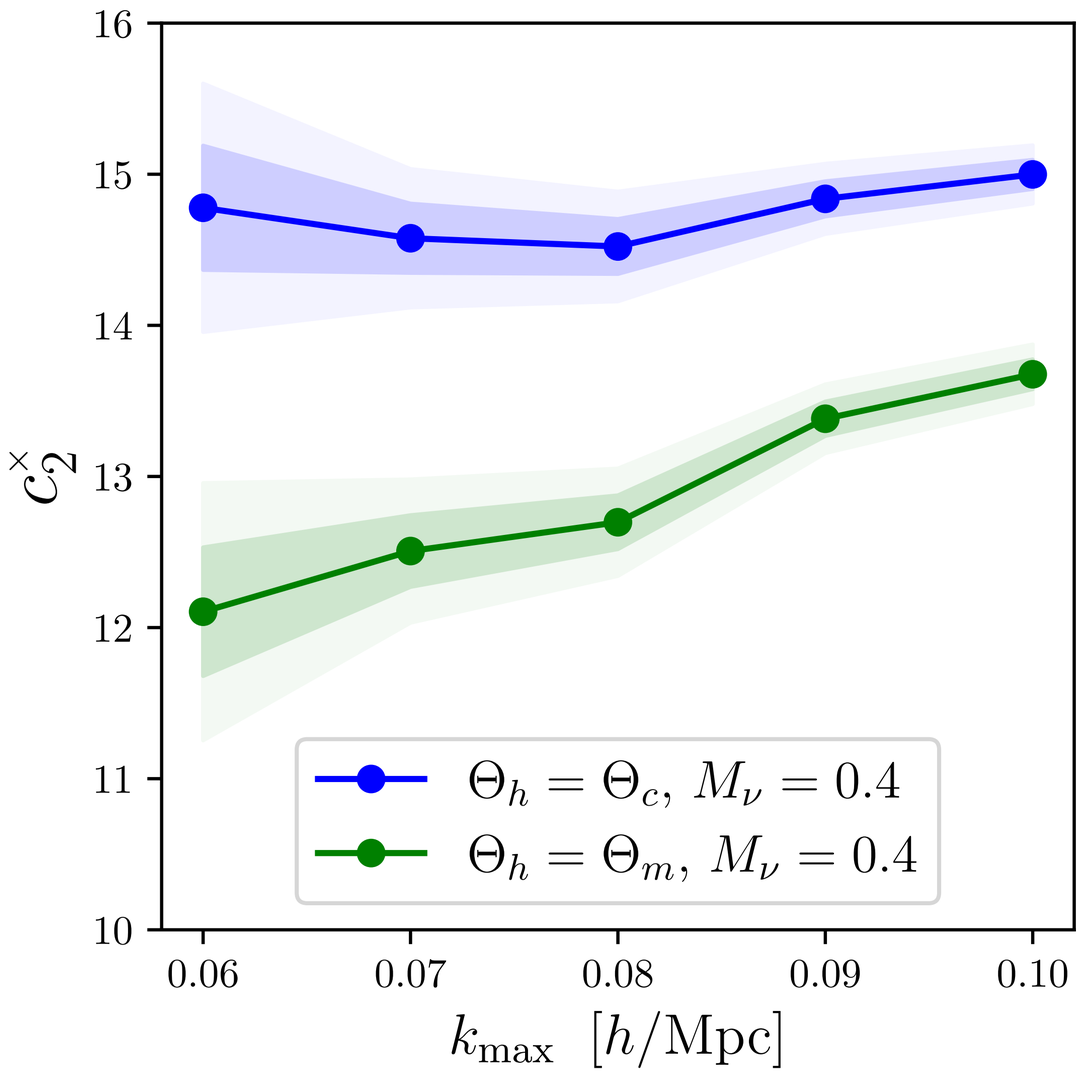


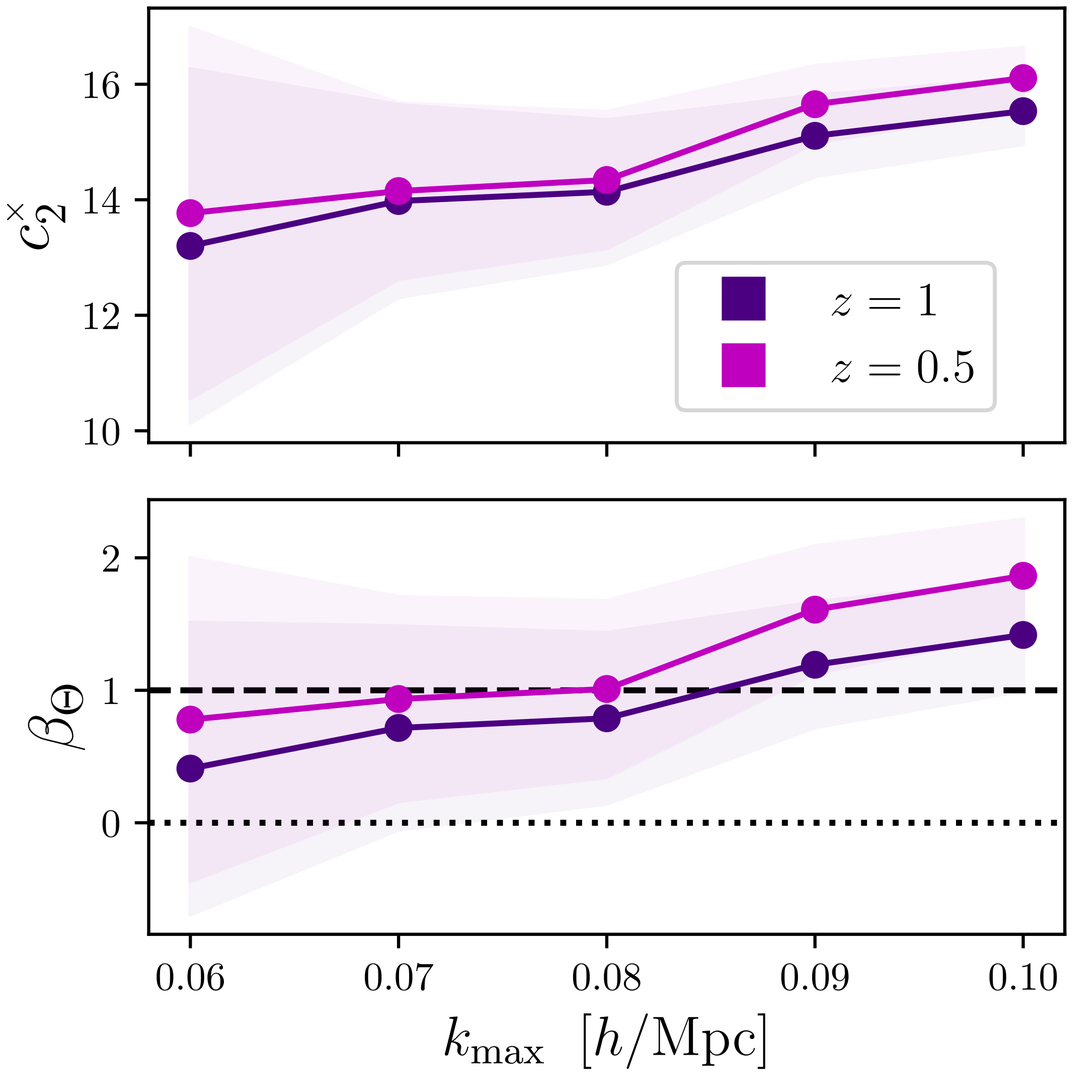


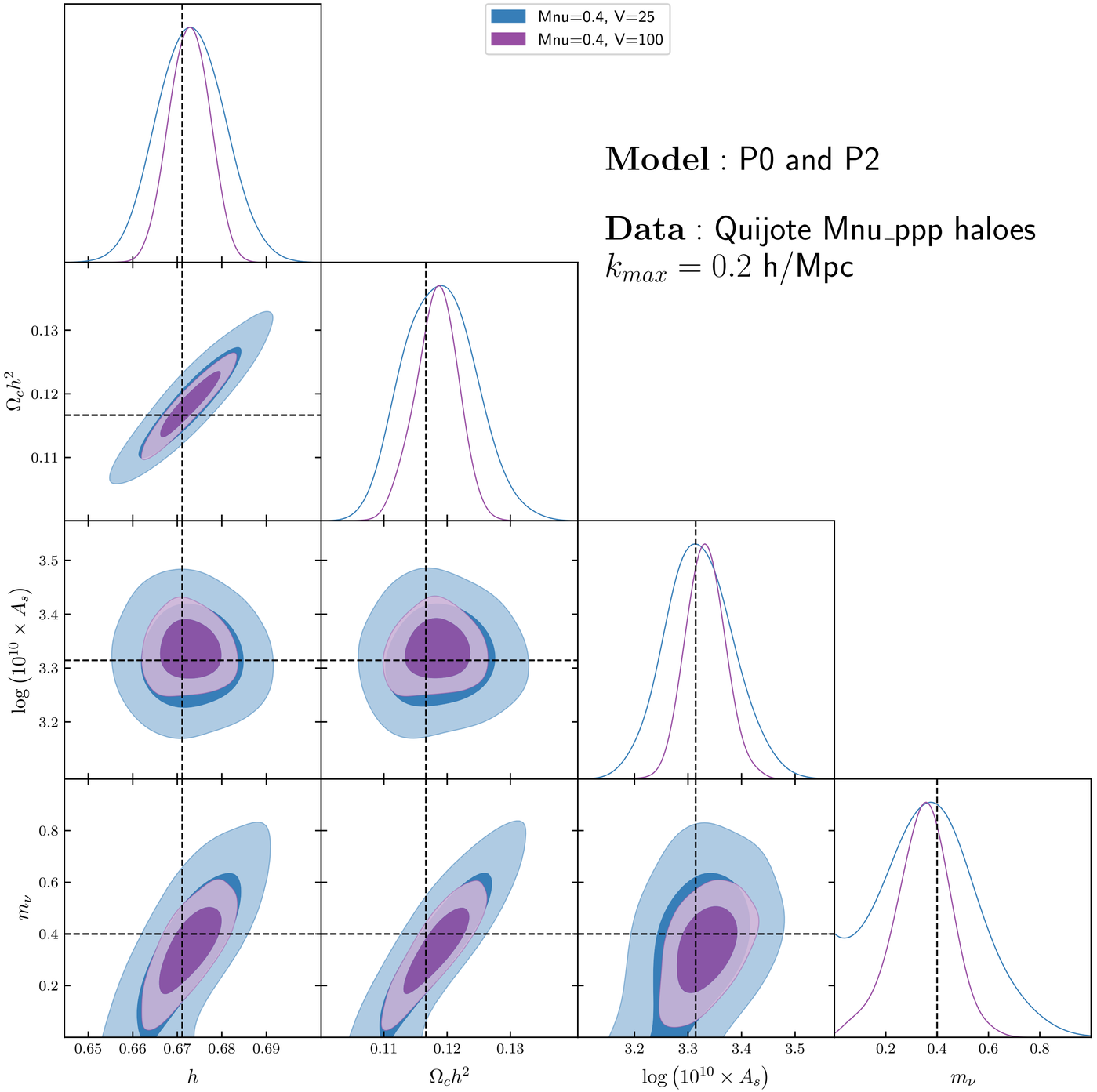
Halo velocity with massive neutrinos



$\Theta_h = \Theta_c$ also gives a better fit to the data than $\Theta_h = \Theta_m$


16
15
14
13
12
11
10
$\mathcal{C}_2^\times$
$\Theta_h = \Theta_c,\ M_\nu = 0.4$
$\Theta_h = \Theta_m,\ M_\nu = 0.4$
0.06
0.07
0.08
0.09
0.10
$k_{\rm max}$ $[h/{\rm Mpc}]$


16
14
12
10
$\mathcal{C}_2^\times$
$z = 1$
$z = 0.5$
2
1
0
β_Θ
0.06
0.07
0.08
0.09
0.10
$k_{\rm max}$ $[h/{\rm Mpc}]$



Model : P0 and P2

Data : Quijote Mnu_ppp haloes

$k_{max} = 0.2$ h/Mpc