Looking for neutrino suppression in power spectrum with DESI DR1 data

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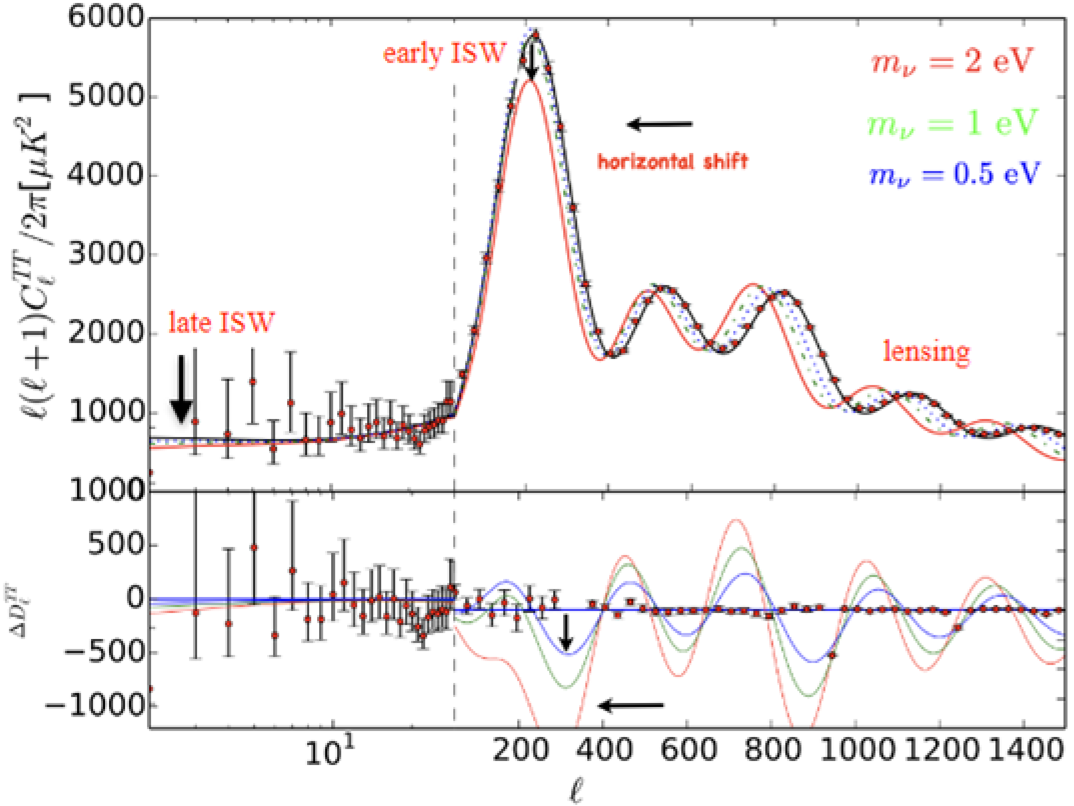
Cosmology with massive neutrinos

- Existence of massive neutrinos implied by neutrino oscillations
- Massive neutrinos affects both background expansion and on growth of fluctuations
- Neutrinos contribute both as radiation and as non-relativistic matter respectively in early universe and recent epochs
- High-velocity dispersion implies the suppression of matter power spectrum below the free streaming length

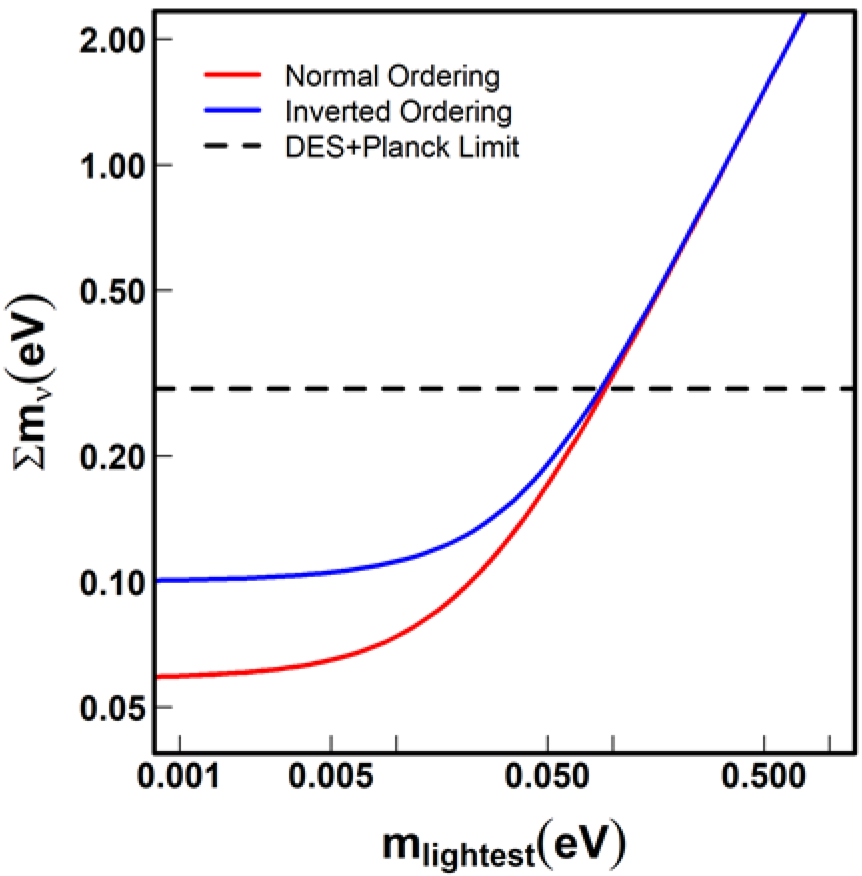


Cosmology with massive neutrinos

- At low z, neutrinos are non-relativistic, contributing to the non-relativistic matter density

  $\omega_M = \omega_b + \omega_{CDM} + \omega_\nu$ with $\omega_\nu = \sum m_\nu/(93.14 eV h^2)$

- Massive neutrinos affect background evolution, in particular the redshift of matter-Λ equality
- **Normal Ordering** (NO): the two smallest mass neutrino eigenstates have the smallest mass splitting ($\sum m_\nu \geq 0.059\ eV$)
- **Inverted Ordering** (IO): the two smallest mass neutrino eigenstates have the biggest mass splitting ($\sum m_\nu \geq 0.10\ eV$)



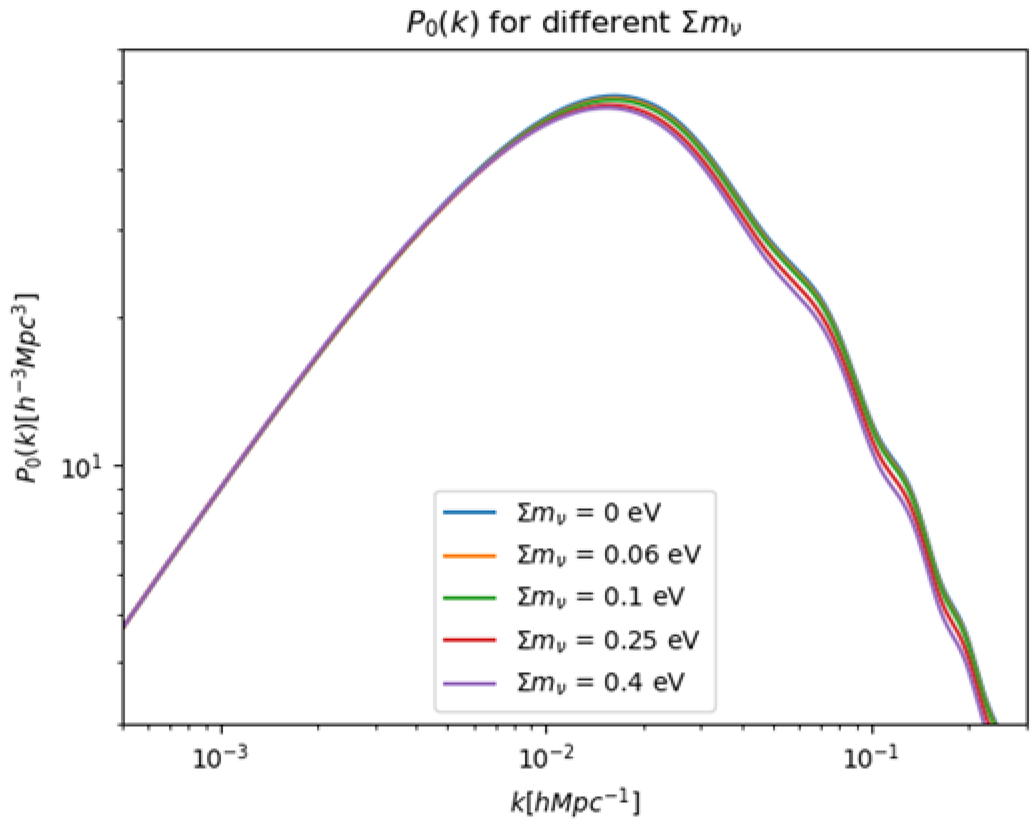
Neutrino mass effects on matter power spectrum

Effects of neutrino masses on P(k)

- Suppression in $P(k)$ on small scales (large k)
- Two main effects:
    - Neutrinos do not cluster below their free-streaming scale
    - CDM and baryon perturbations grow slower in the presence of massive neutrinos

Growth of matter perturbations:

- Above the neutrino free-streaming scale: $\delta_m \propto a$ (purely matter dominated).
- Below the free-streaming scale: $\delta_m \propto a^{1-3\,f_\nu/5}$
- $f_\nu = \Omega_\nu/\Omega_m$



Neutrino mass effects on matter power spectrum

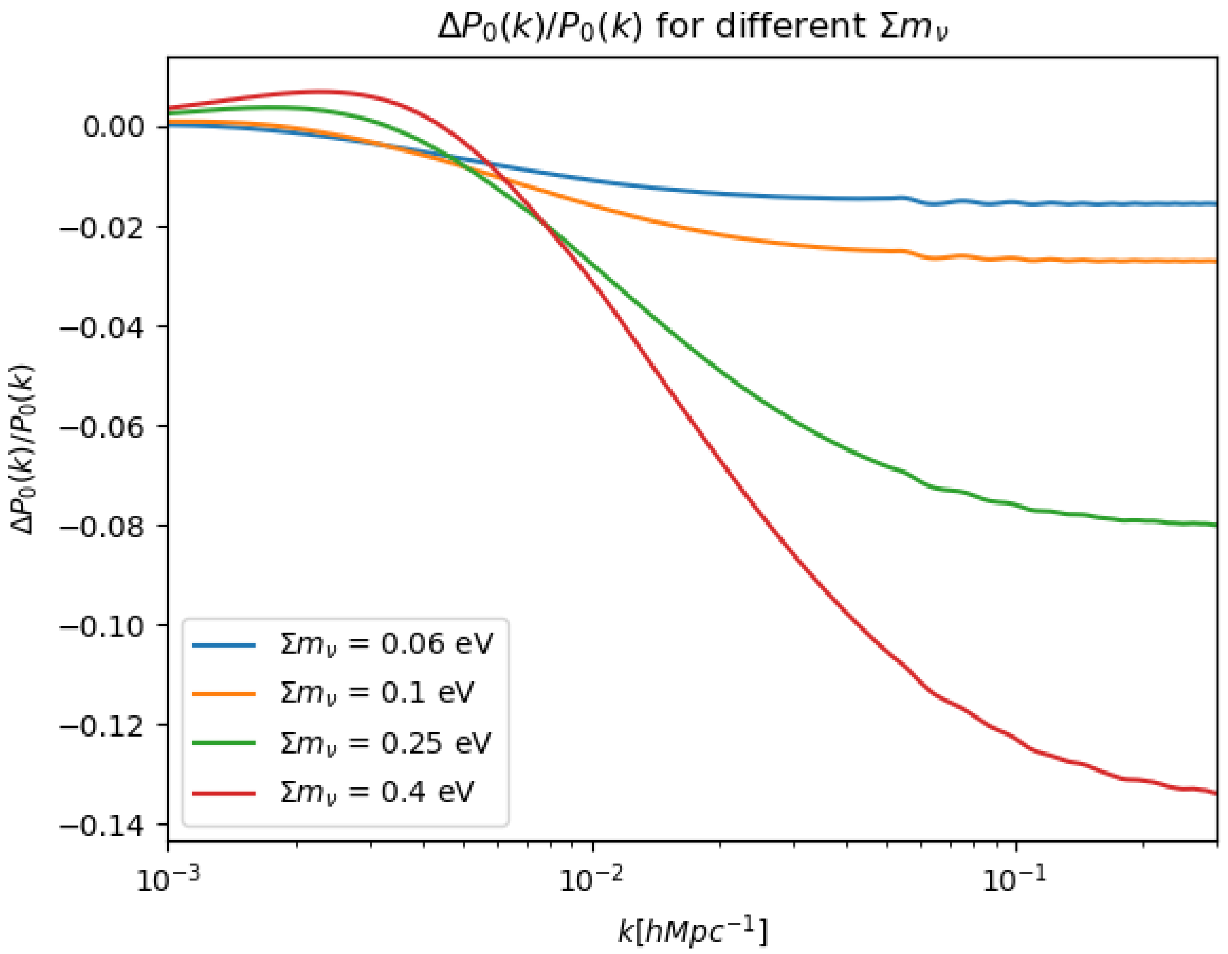
Suppression of Δ*P*(*k*)/*P*(*k*):

- $\approx -8 f_\nu$ for linear matter perturbations
- $\approx -10 f_\nu$ including non-linear effects

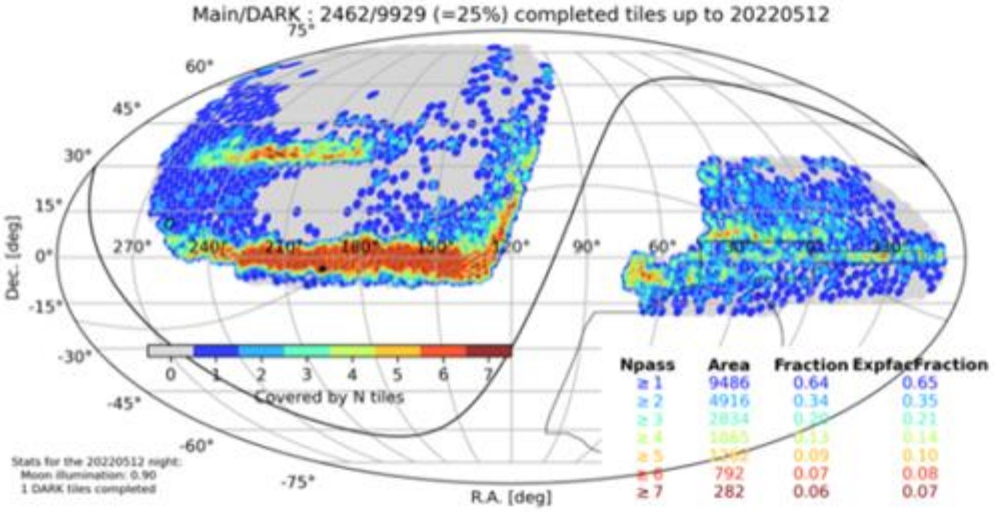
Step-like suppression:

- Since neutrinos with different masses become non-relativistic at different times, it is expected that the suppression of matter power spectrum happens in three steps, according to the free-streaming scale of each neutrino mass eigenstate

- Current cosmological data is sensitive only to the total neutrino mass $\sum m_\nu$



Dataset: Full-shape DR1



- Galaxy power spectrum analyzed for each z bin
- No scale-cuts (k_{min} = 0, k_{max} = 0.522, dk = 0.001)
- Covariances calculated with **thecov** module

Tracer	redshift range	$N_{\rm tracer}$	$z_{\rm eff}$	P_0 $[(h^{-1}{\rm Mpc})^3]$	$V_{\rm eff}$ $[{\rm Gpc}^3]$
BGS	$0.1 - 0.4$	300,017	0.295	$\sim 9.2 \times 10^3$	1.7
LRG1	$0.4 - 0.6$	506,905	0.510	$\sim 8.9 \times 10^3$	2.6
LRG2	$0.6 - 0.8$	771,875	0.706	$\sim 8.9 \times 10^3$	4.0
LRG3	$0.8 - 1.1$	859,824	0.930	$\sim 8.4 \times 10^3$	5.0
ELG2	$1.1 - 1.6$	1,415,687	1.317	$\sim 2.9 \times 10^3$	2.7
QSO	$0.8 - 2.1$	856,652	1.491	$\sim 5.0 \times 10^3$	1.5

Theoretical Power Spectra

- Theoretical power spectra calculated with **CAMB** code
- **Planck cosmology** assumed as fiducial
- A three degenerate neutrino mass eigenstates model is adopted
- m_ν set to ***0 eV*** (reference)***, 0.06 eV, 0.1 eV, 0.25 eV*** and ***0.4 eV***
- For the ratio, a theoretical PS was calculated for each bin of redshift considered
- Calculated for the same *k* range and *dk*

Approximation and simplifications

As this work is still in an embryonic state, until now some simplifications and approximations have been considered

- Effects of non-linearities at large scales not considered
- Effects of different cosmologies not considered and only tests on ΛCDM
- Biases used for scaling the PS, especially for QSO, under discussion
- Still no study on scale cuts or different binning options

Test on data samples

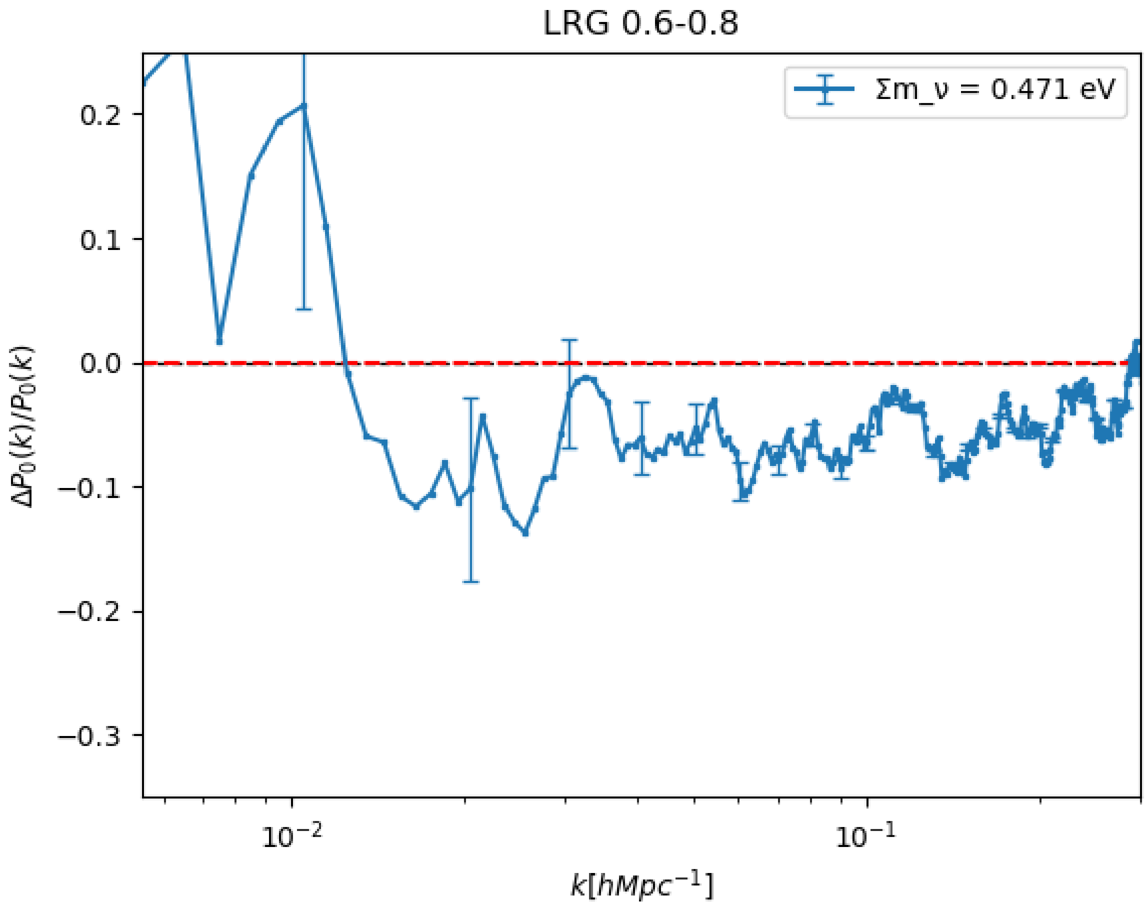
$\Delta P(k)/P(k)$ calculated between data PS and synthetic PS with $m_\nu = 0$

Bias considered for different tracers:

- 2 for LRG
- 1.5 for BGS
- 1.2 for ELG
- 2.1 for QSO
- 1.6 for combined tracer

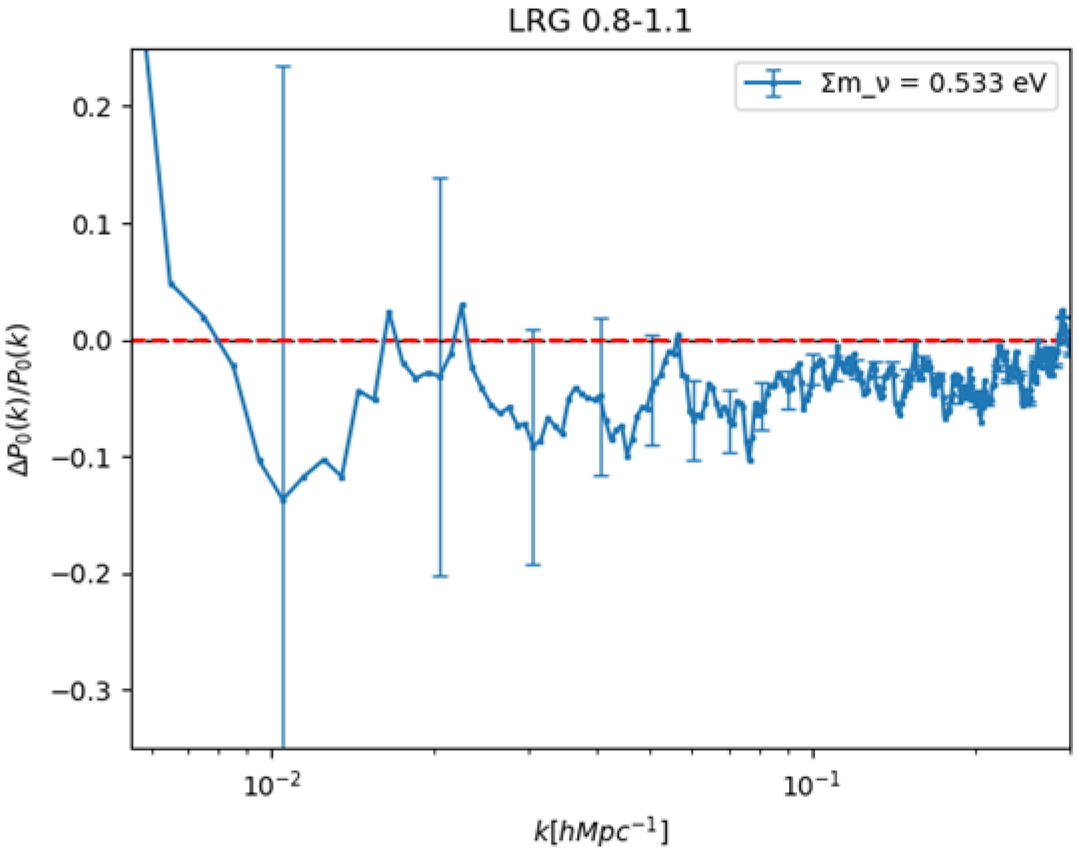
Growth factor is considered

Almost all tracers show the step!

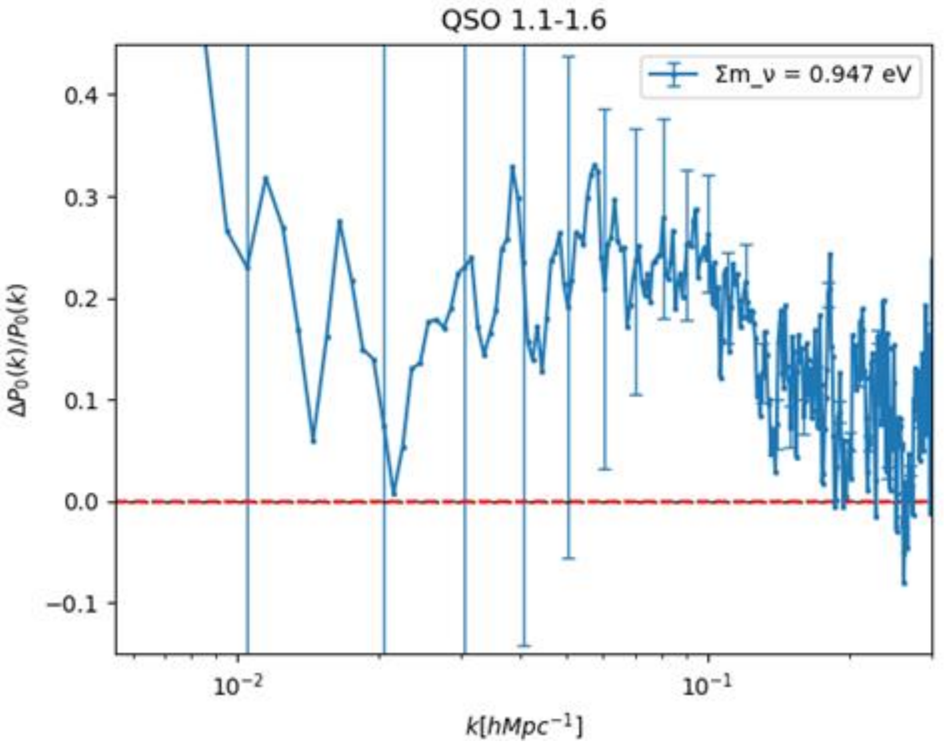


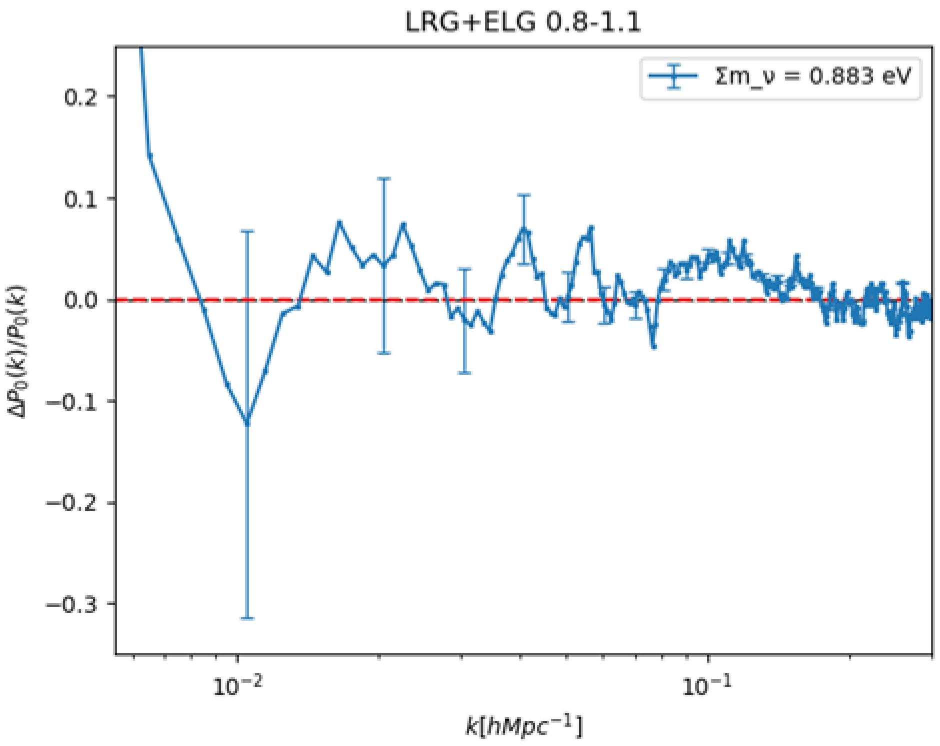
Test on data samples

- $\sum m_\nu$ information obtained fitting the fractional difference via f_ν using **curve_fit** function in python
- Very simple model added to the various approximations and simplifications: handle with care!
- Fit done in full k range, including large scales (with non-linearities)
- Not so focused on the number, but it seems already not so unreasonable



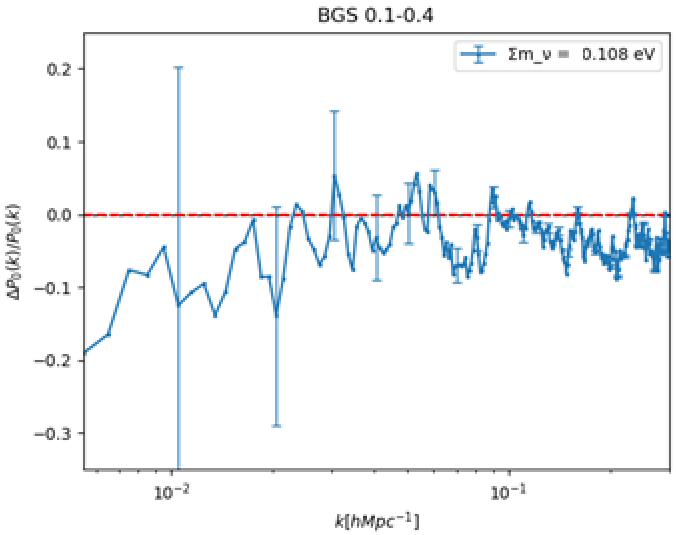
Test on data samples

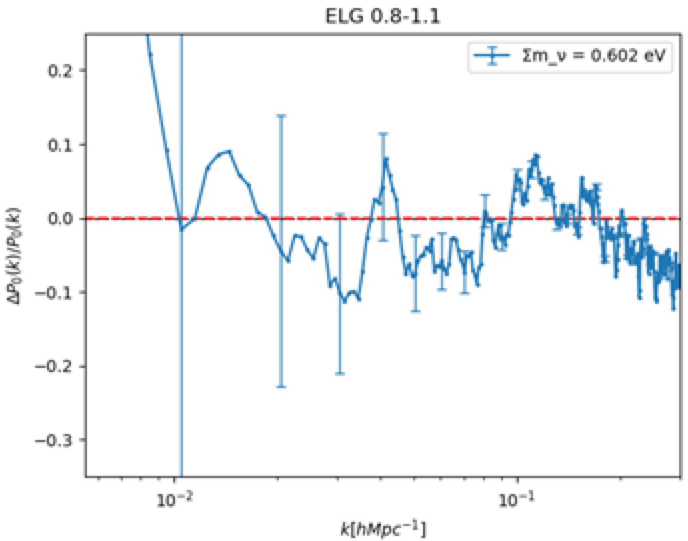


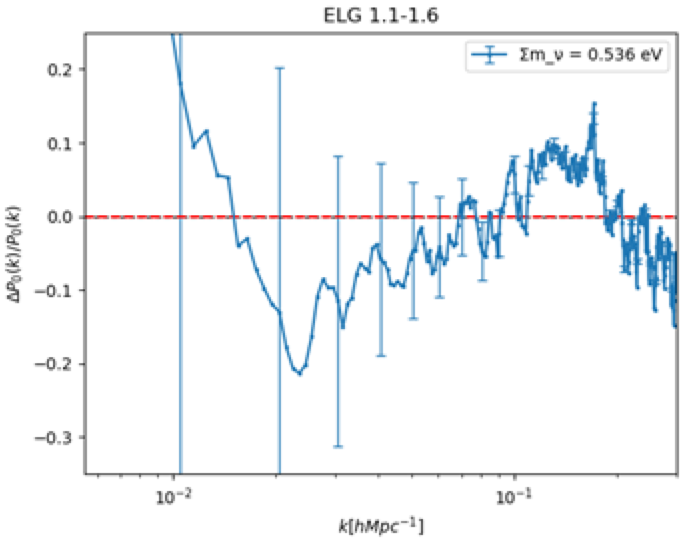


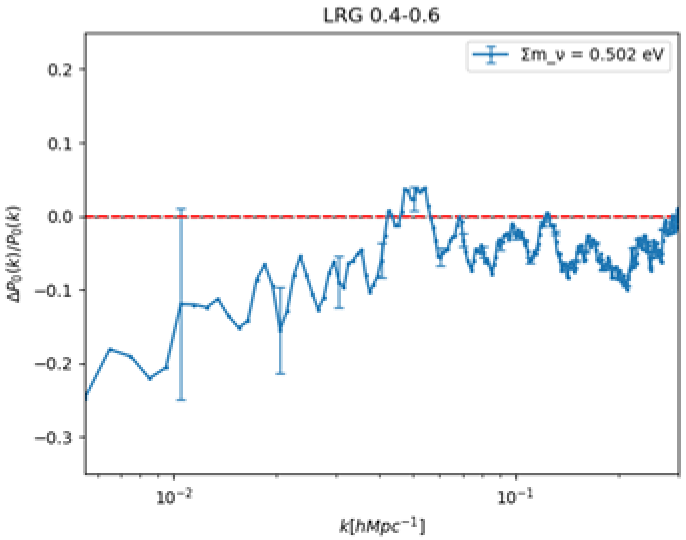
Most anomalous case: QSO. All positive values (maybe due to bias value?)

Test on data samples



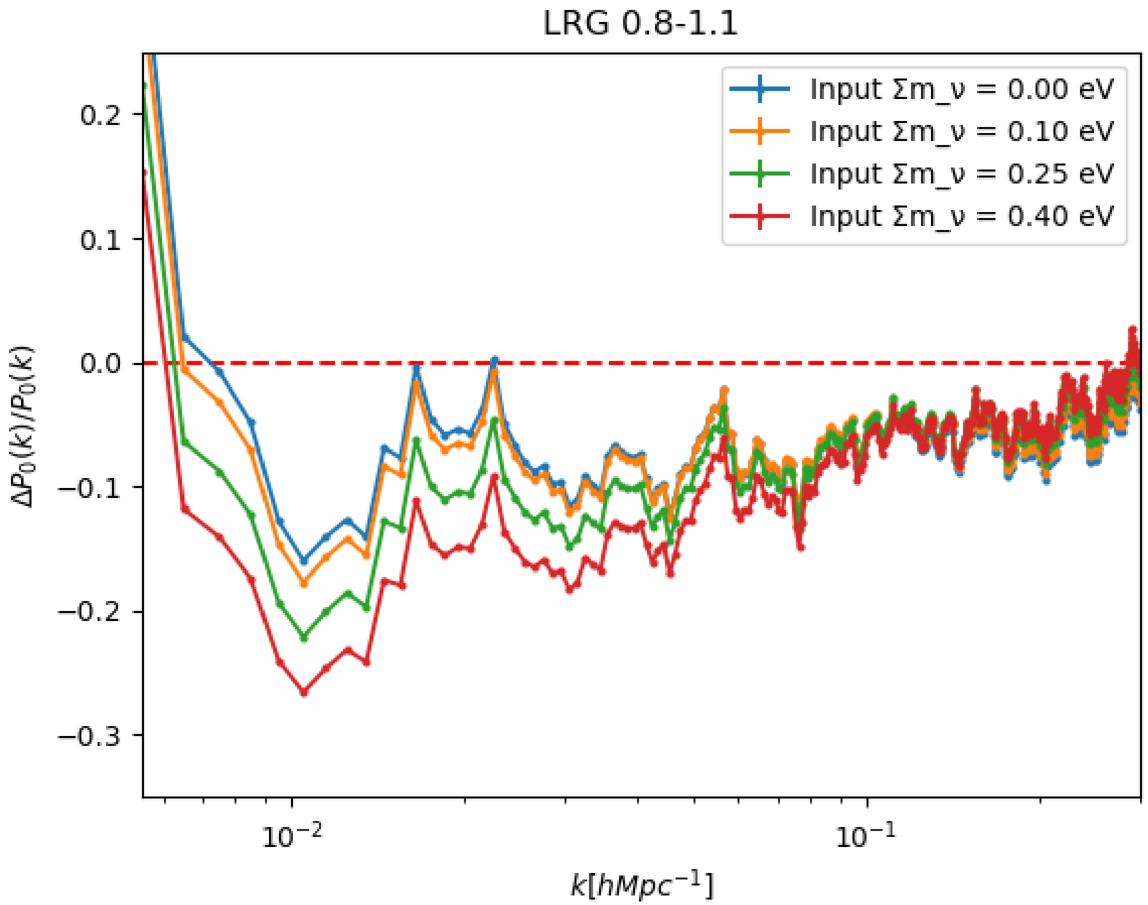






Test on data samples

- We tried to compare PS from data with different synthetic ones considering models with different neutrino masses
- Suppression entity seems to change varying neutrino masses as expected
- Small effect given by the different $\sum m_\nu$ considered in the model

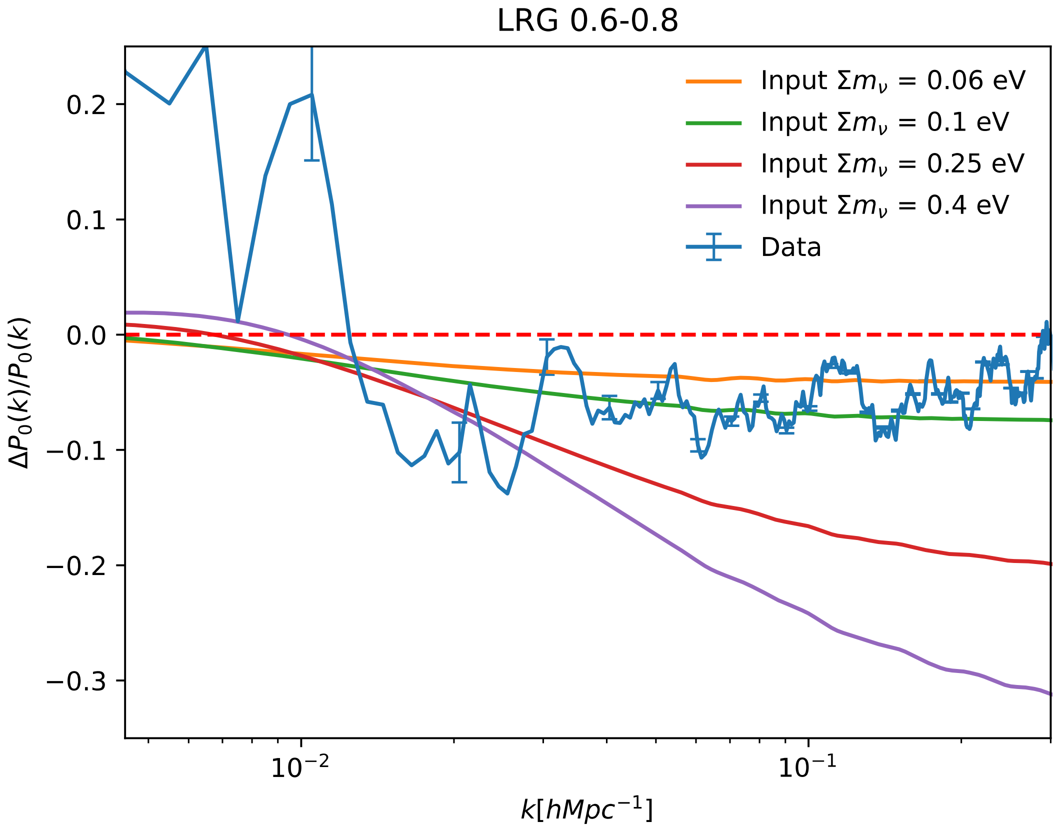


Comparison with theory

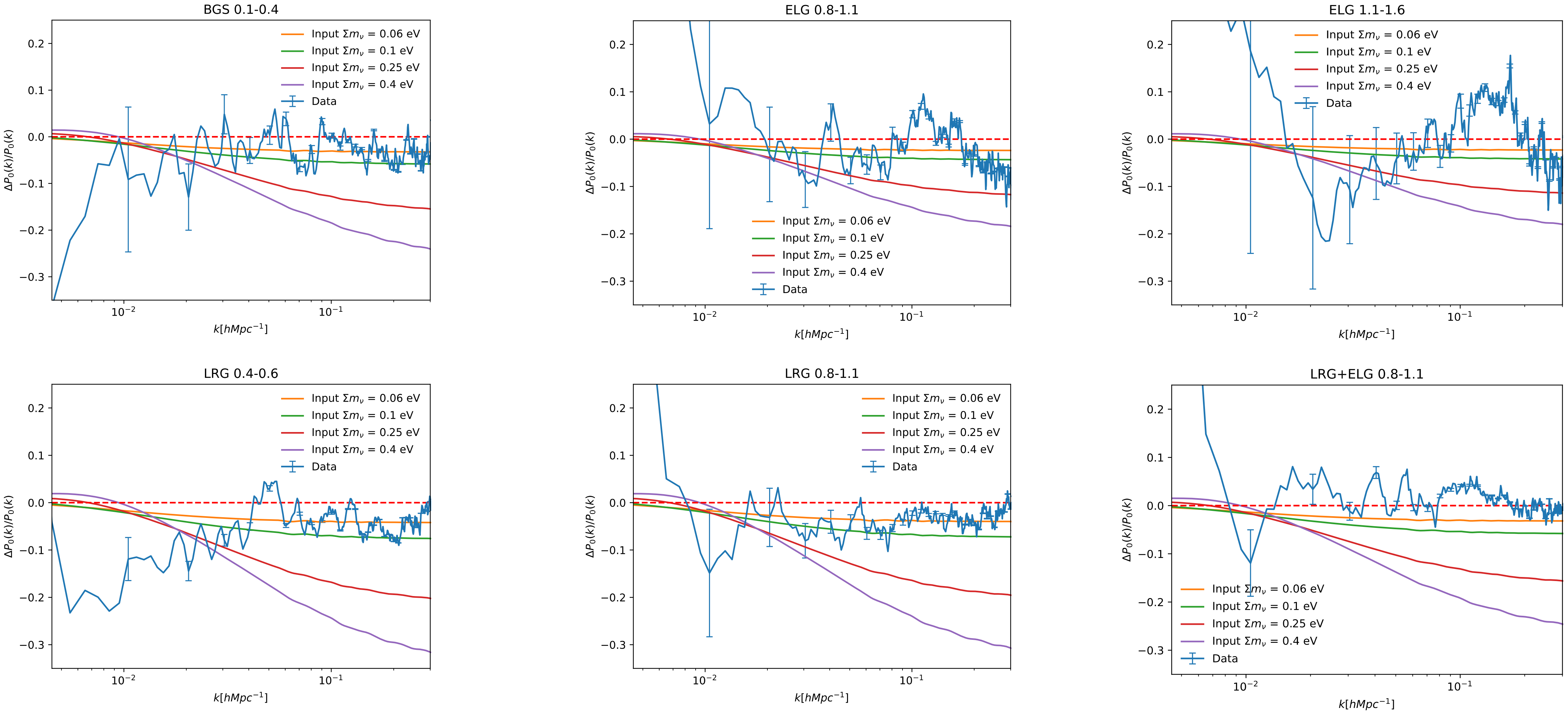
- Pretty noisy signal, given also by the small *dk* choice

- Comparison with theoretical expectations underline the presence of the signature

- Even considering all the approximations, signature seems to rule out $\sum m_\nu < 0$ and $\sum m_\nu > 0.4\ eV$ (but not excluded within the error)



Comparison with theory



Conclusions and outlook

Neutrino suppression signature in full-shape power spectrum could be a powerful instrument that could help on constrain $\sum m_\nu$ and excluding scenarios independently from combinations with external datasets

This work is still in an embryonic state, but we want to improve it:

- Better understanding of the non-linear part
- Better implementation of the bias
- Improving fitting model and considering use of scale-cuts
- Exploration of different binning and fiducial cosmologies
- Better understanding in other potential effects

These preliminary results are obtained using just DR1 Full-shape data: even better perspectives for Y3 data release and future ones!