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Nonlinear modelling of massive neutrino cosmologies in LSS

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UPPER LIMIT from COSMOLOGY

$$\sum m_\nu < 0.160\,\mathrm{eV\ at\ 95\ \%\ CL}$$

(M. Ivanov, M. Simonović, M. Zaldarriaga, Phys.Rev.D 101 (2020))

from **BOSS (Full shape)** + **Planck**

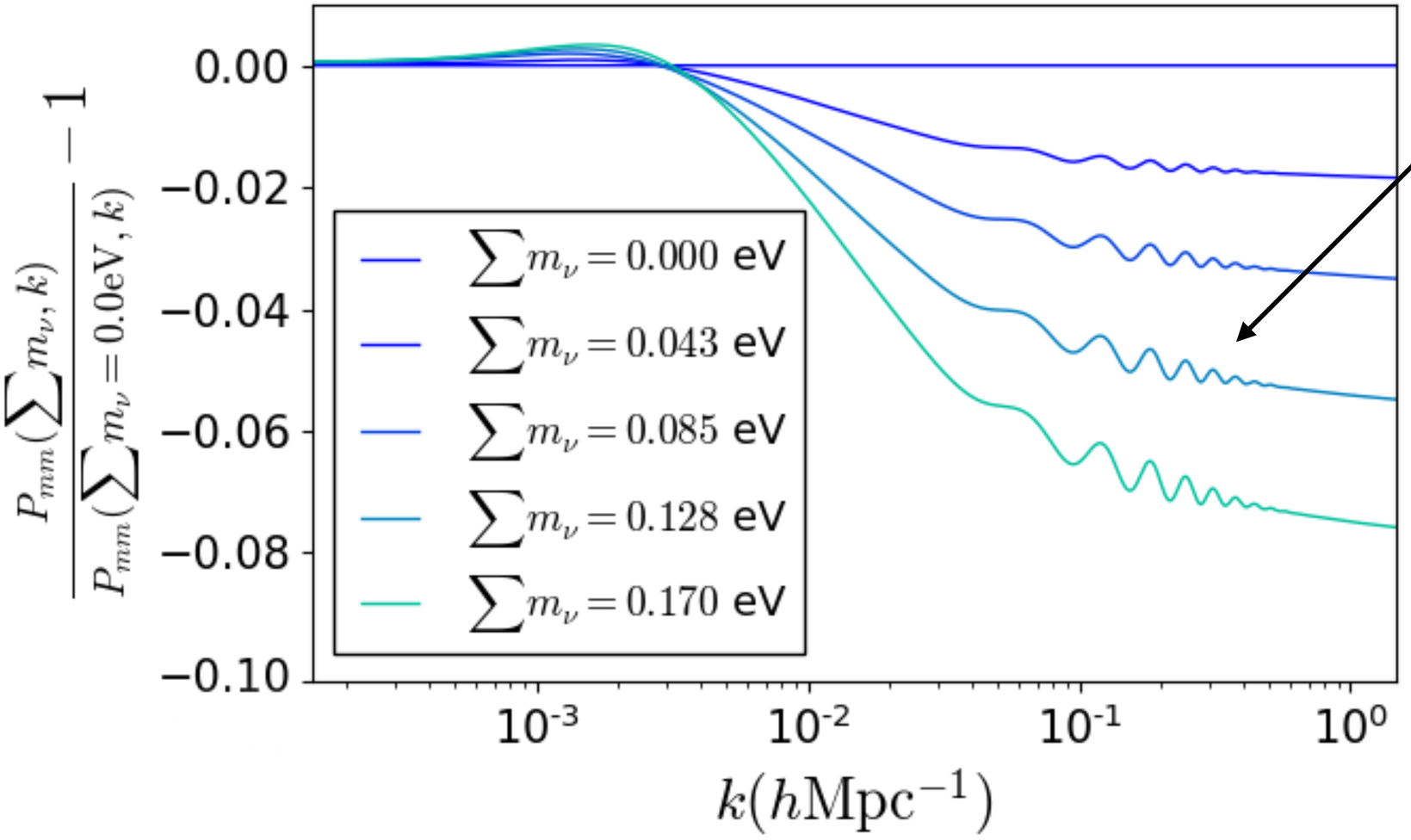
Galaxy Clustering

CMB

How is this obtained?

(with focus on galaxy clustering full shape analysis)

The linear matter power spectrum with neutrinos



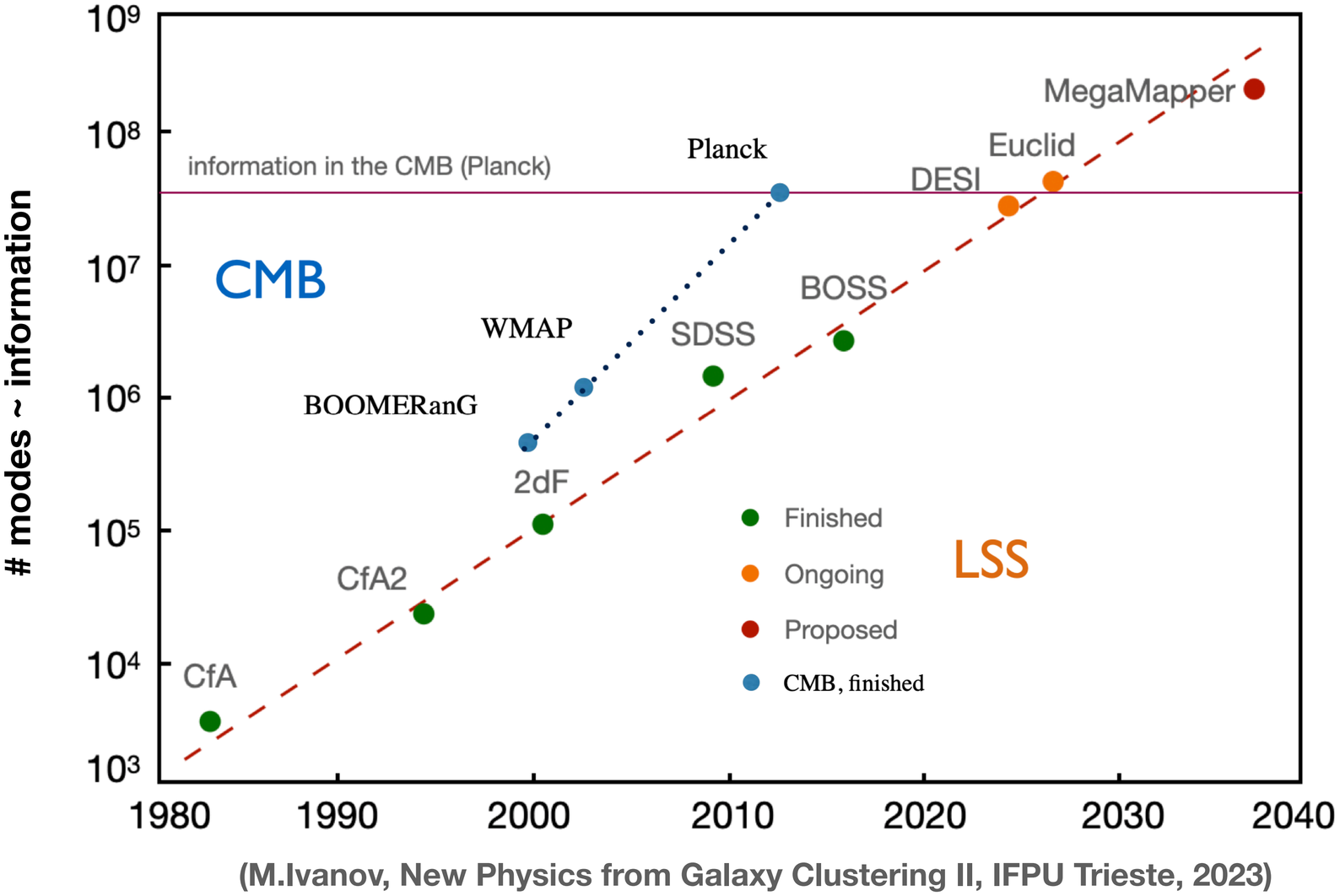
$$\frac{P_{\rm m}(k)}{P_{\rm m}(k, f_\nu = 0)} \sim 1 - 8 f_\nu$$

$$f_\nu = \frac{\sum_i m_{\nu,i}}{93.14\,\text{eV}\Omega_{\rm matt}}$$

Cosmology sensitive (realistically only) to

$$M_\nu = \Sigma \equiv \sum_i m_{\nu,i}$$

Quantify M_ν by measuring the suppression?



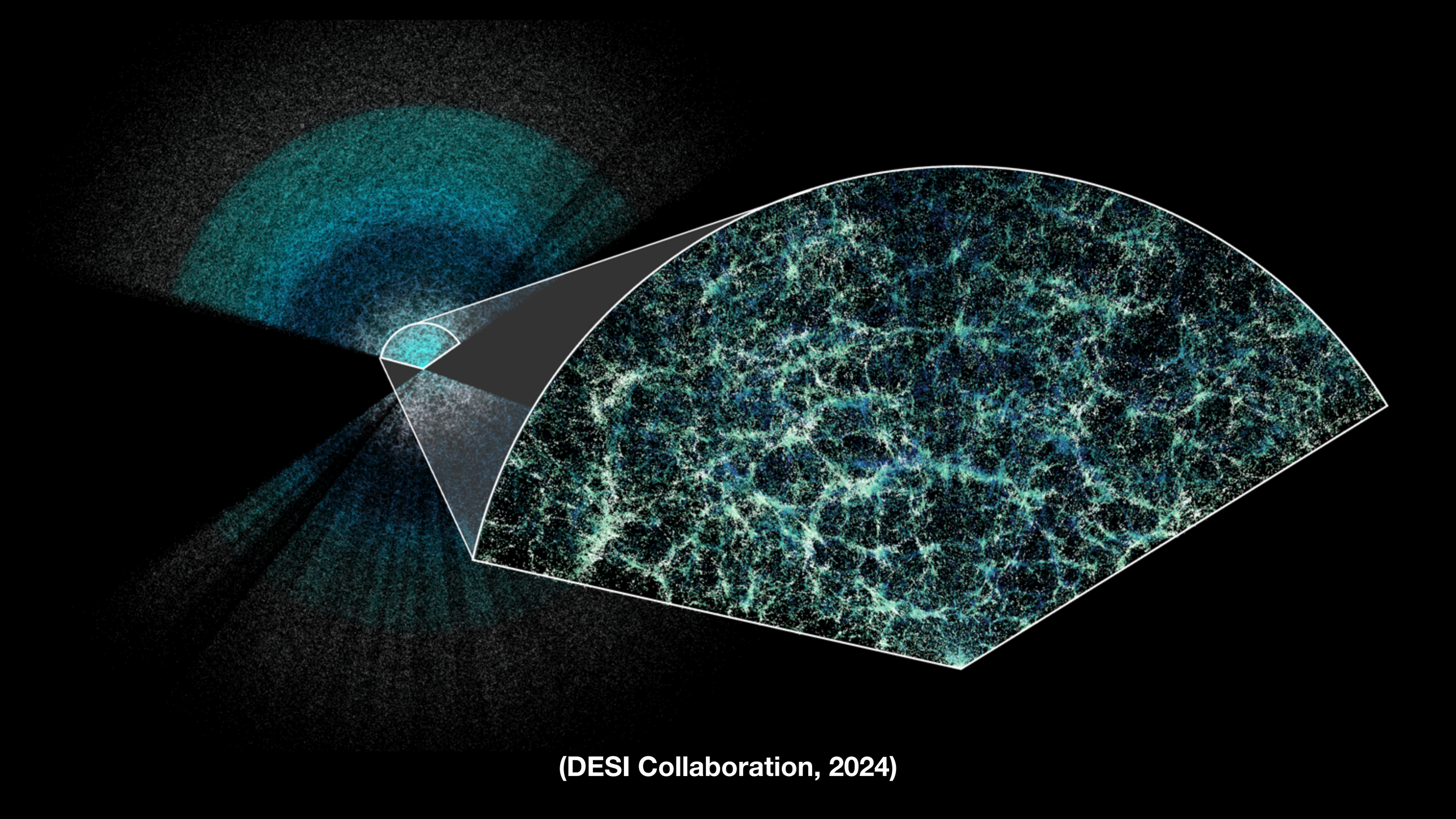
(M.Ivanov, New Physics from Galaxy Clustering II, IFPU Trieste, 2023)

Galaxy surveys

We can probe the matter power spectrum by looking at the clustering of galaxies

Opportunity: will be able to be sensitive to $\mathcal{O}(1\%)$ effects, hence M_ν

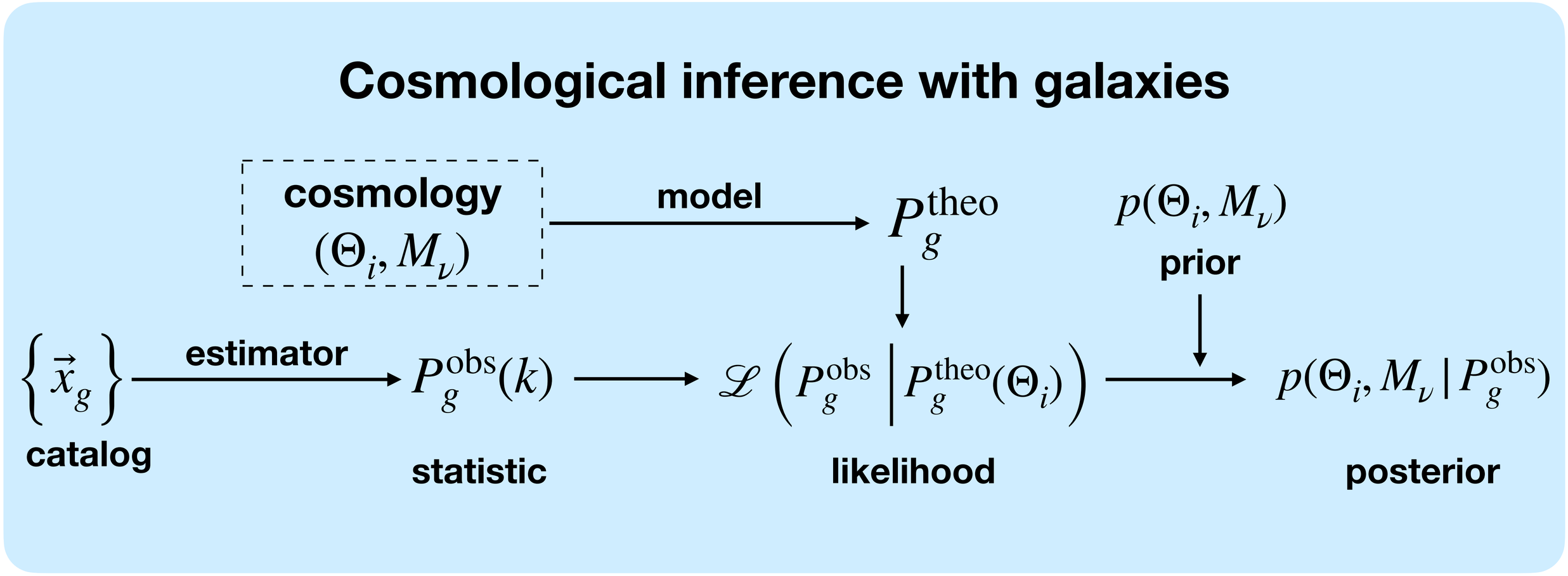
Challenge: need to accurately interpret this data.



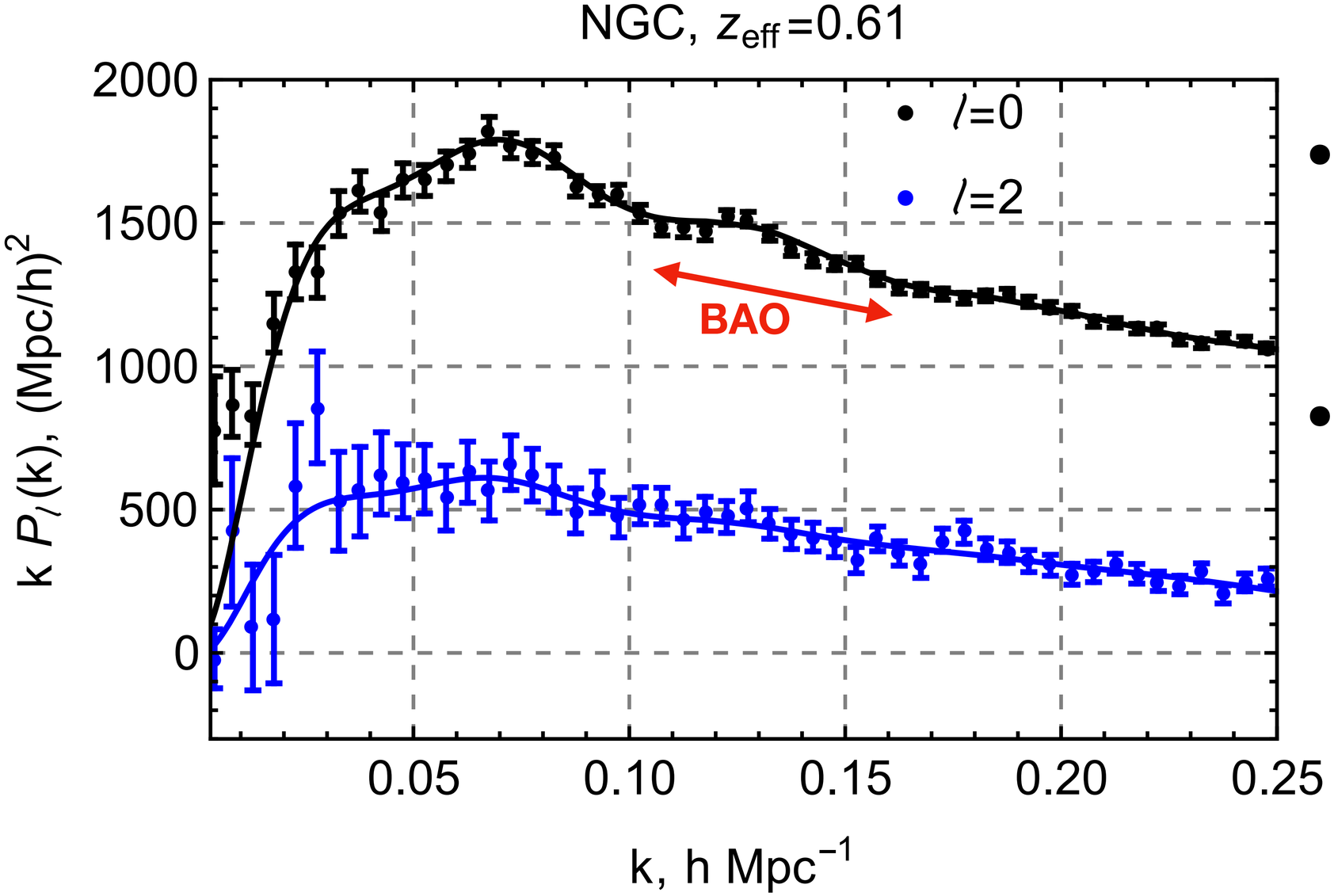
(DESI Collaboration, 2024)

Probing the matter power spectrum

Then with galaxy catalogues one can get M_ν?



BAO only vs Full Shape



(M.Ivanov et al., 1909.05277. BOSS survey data)

- *Canonical analysis*: **BAO** distance only
- *State of the art*: **full shape analysis** (all points and anisotropy)

The full shape model

Why is it difficult? two main complications:

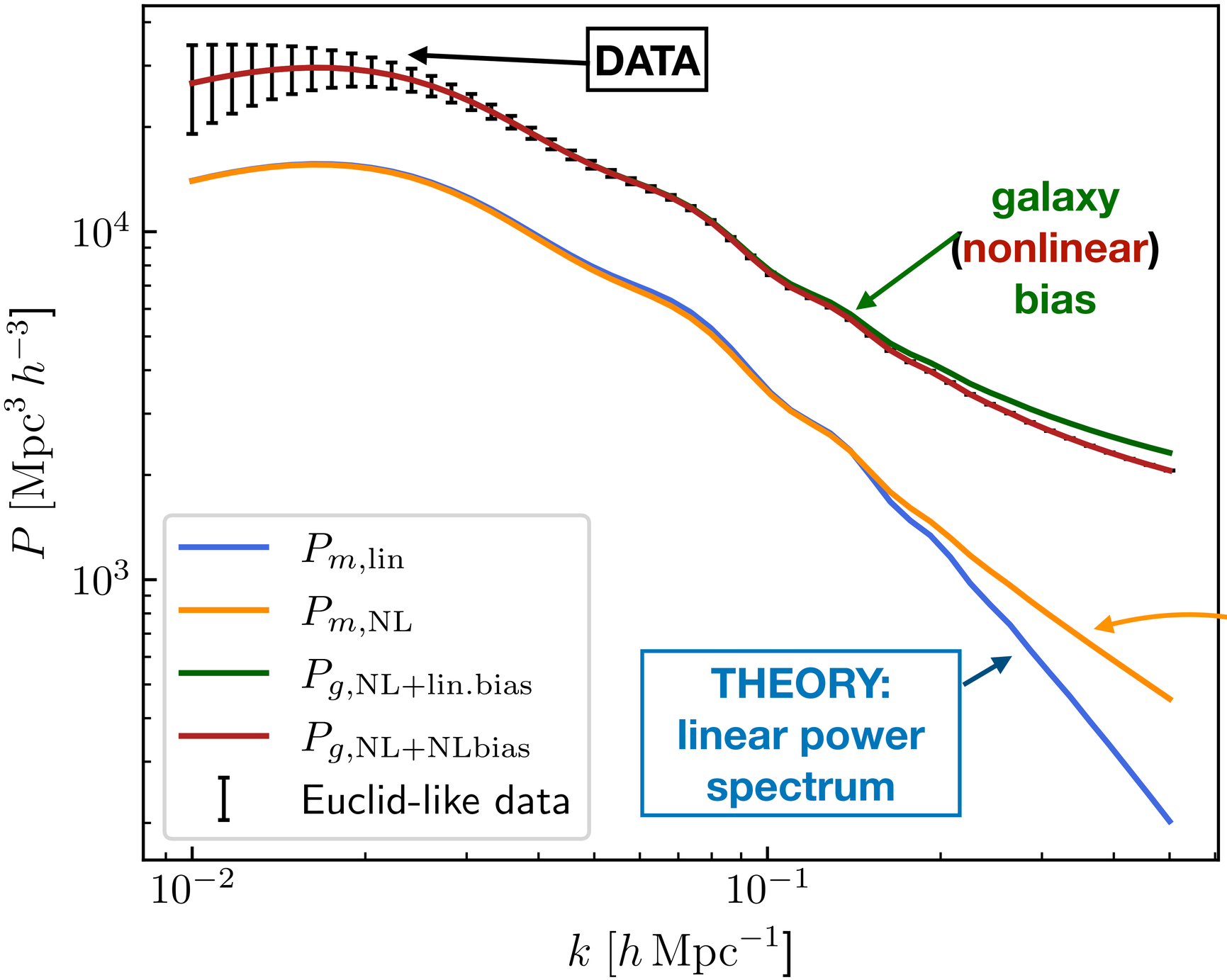
1. We don’t observe the matter power spectrum, but biased tracers
2. At late times the perturbations are non-linear

State of the art of galaxy clustering analysis:

the **Effective Field Theory of LSS**

*(**2010s-today**, Baumann, Carrasco, Senatore, Zaldarriaga, Pajer, Schmidt, Castorina, Sefusatti, Scoccimarro, Porciani, Garny, White, Chen, Vlah, Schmidt, Mirbabayi, Lewandowski, ++)*

- tackle nonlinearity with perturbation theory in an EFT framework
- bias accounted for with a controlled expansion



breakdown of galaxy power spectrum

Does this EFT model work? With massive neutrinos?

Luckily we have a cross check/validation for the model: **N-Body** simulations. However:

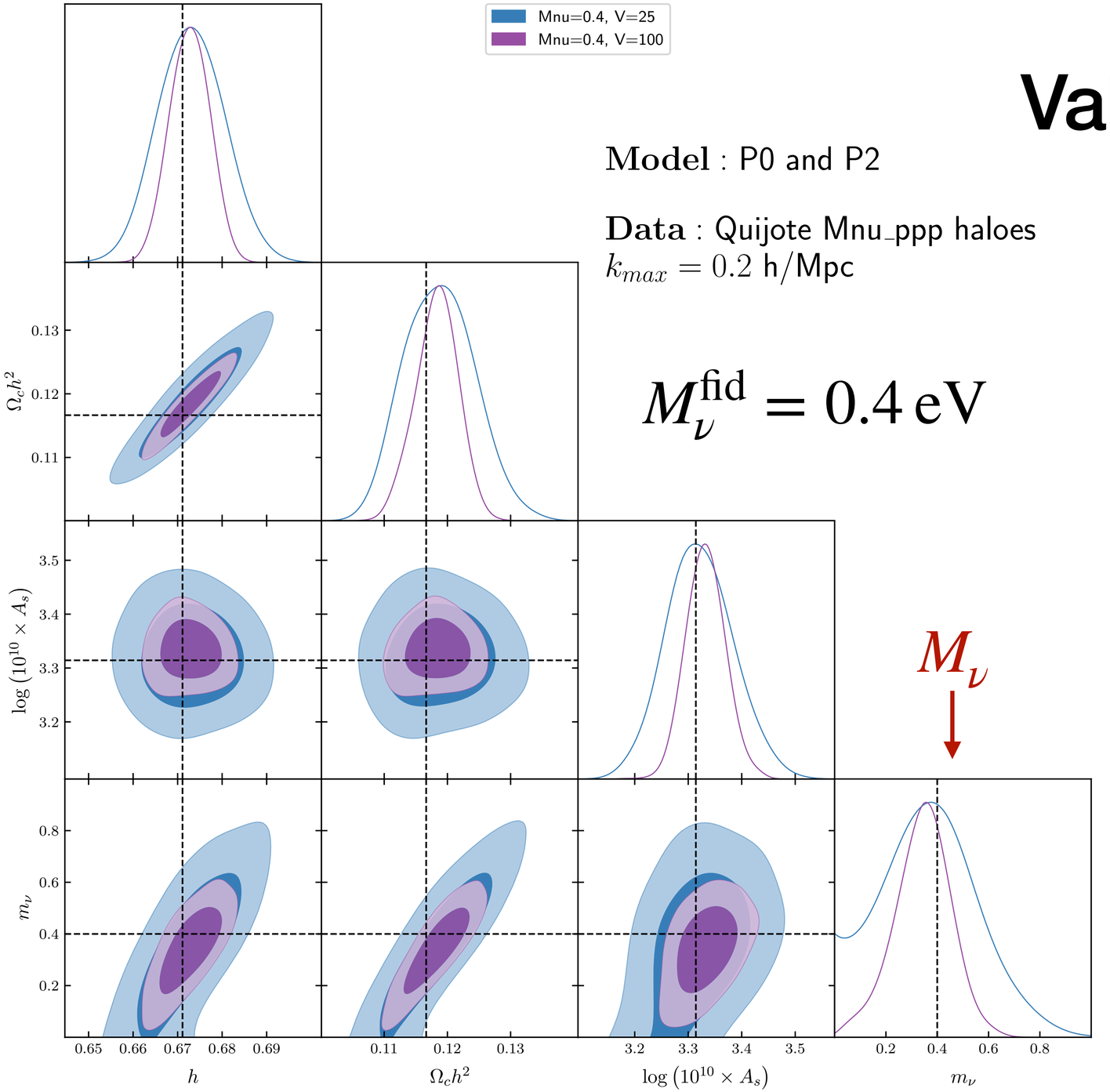
A. So far, the EFT model thoroughly validated on CDM only simulations.

B. In principle there are further (still under study) modifications to the theory (*E. Noriega et al., JCAP 11 (2022)*) due to M_ν. Are they negligible or not?

Goal: perform a realistic validation on mock galaxy catalogs

(*with E. Bellini, E. Sefusatti, M. Biagetti, C. Moretti…*)

Validation on simulations

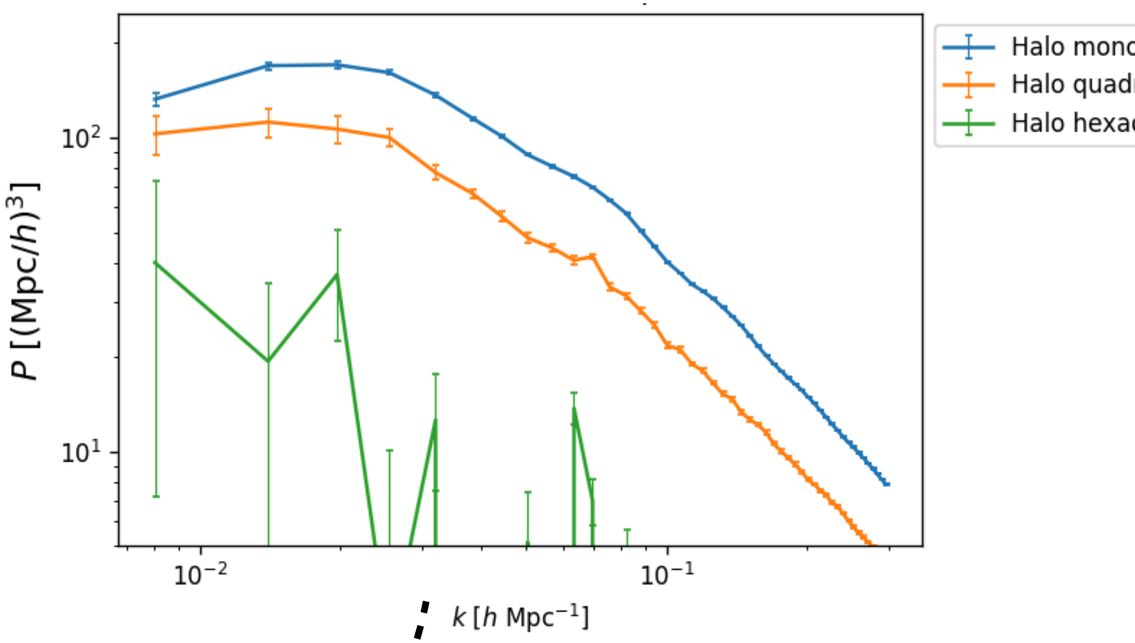


Model : P0 and P2

Data : Quijote Mnu_ppp haloes
$k_{max} = 0.2$ h/Mpc

$$M_\nu^{\rm fid} = 0.4\,{\rm eV}$$

M_ν

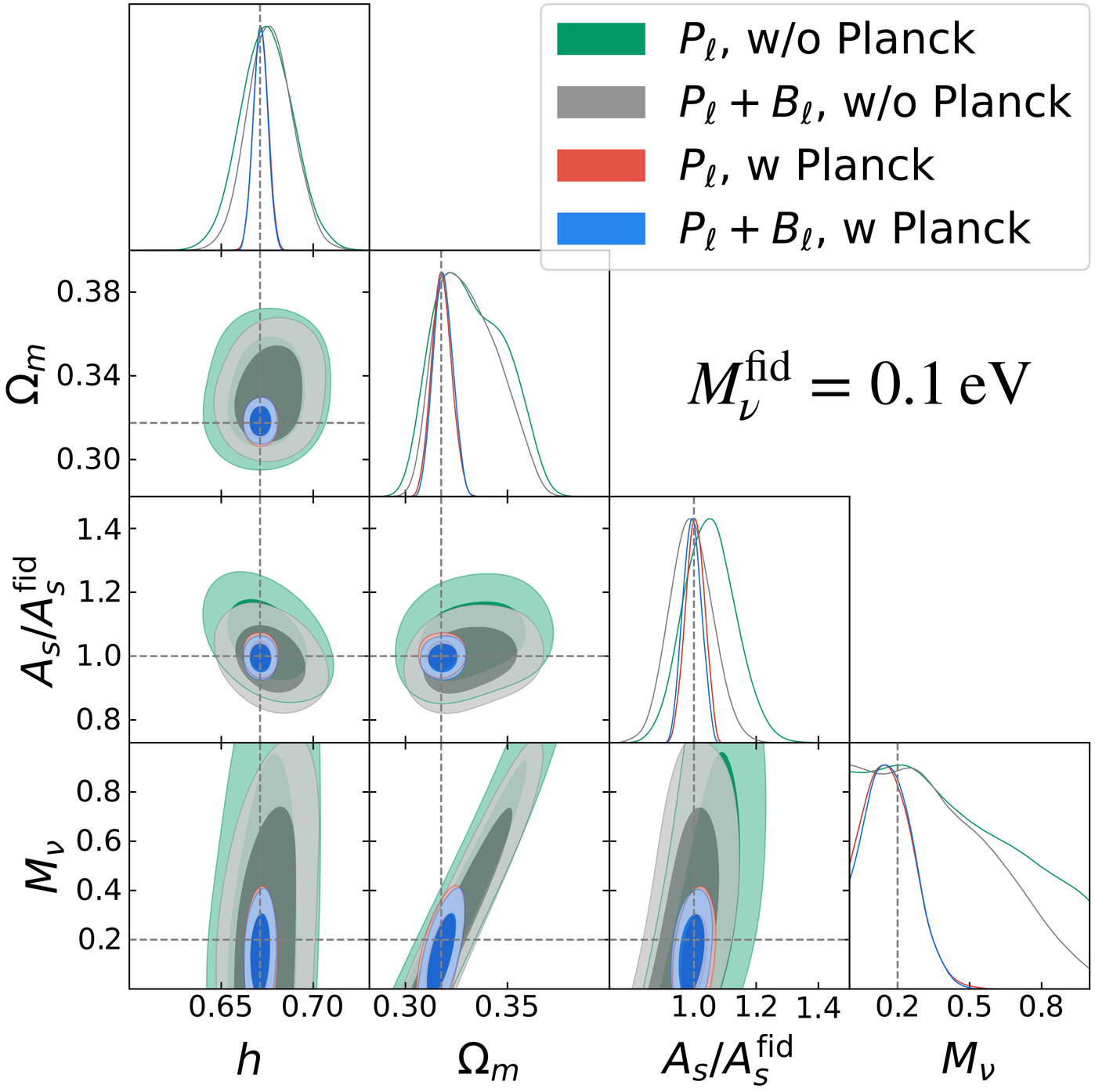


from P_g

to M_ν

using PBJ code

(*A. Oddo, C.Moretti, ++*)



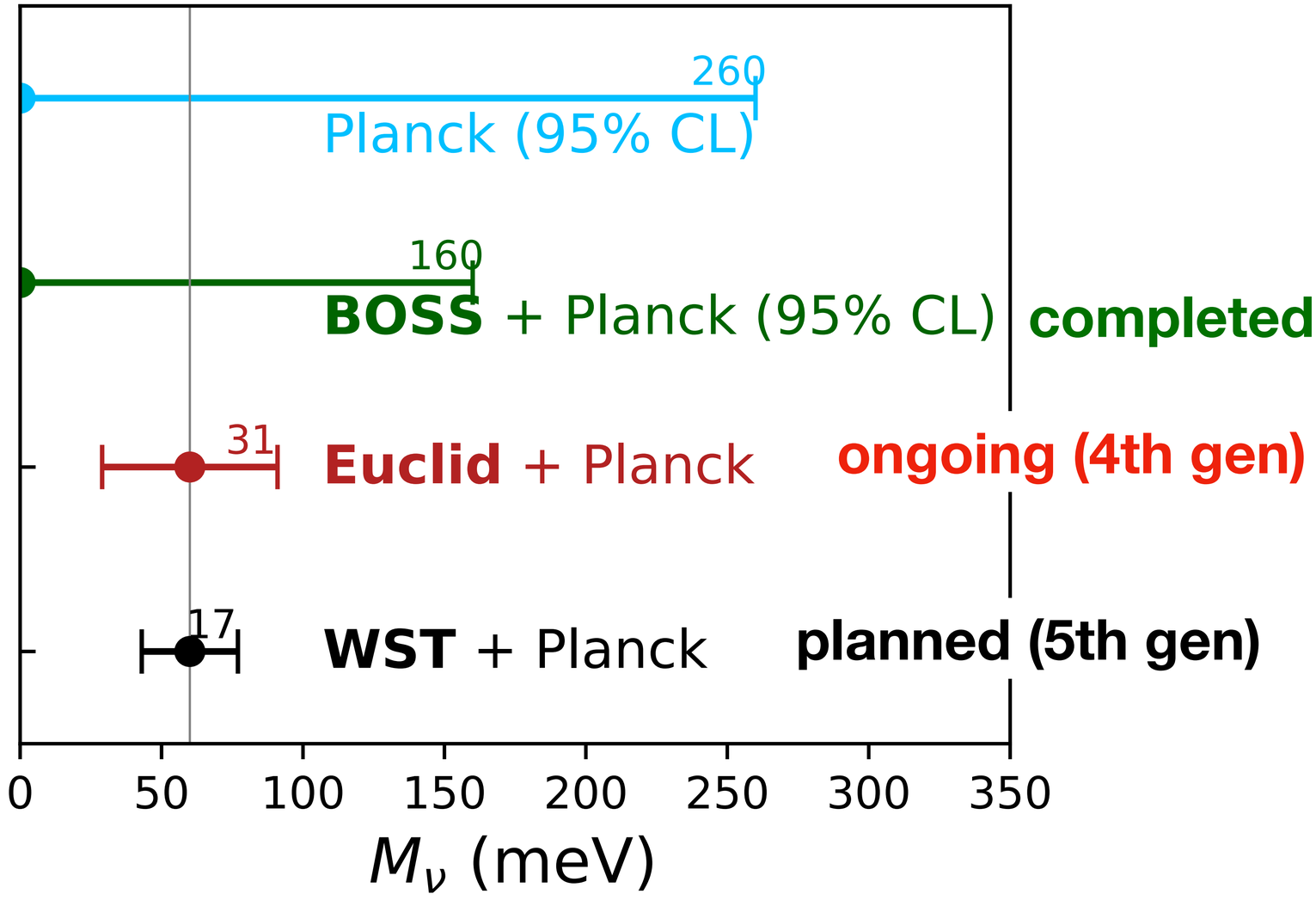
More realistic:

- Value of the masses
- Peculiar velocities of galaxies

Outcome: random velocities of galaxies (Finger of God effect) complicate the model at small scales.

Need the CMB information to have a detection.

Forecasts for full shape analyses (EFT)



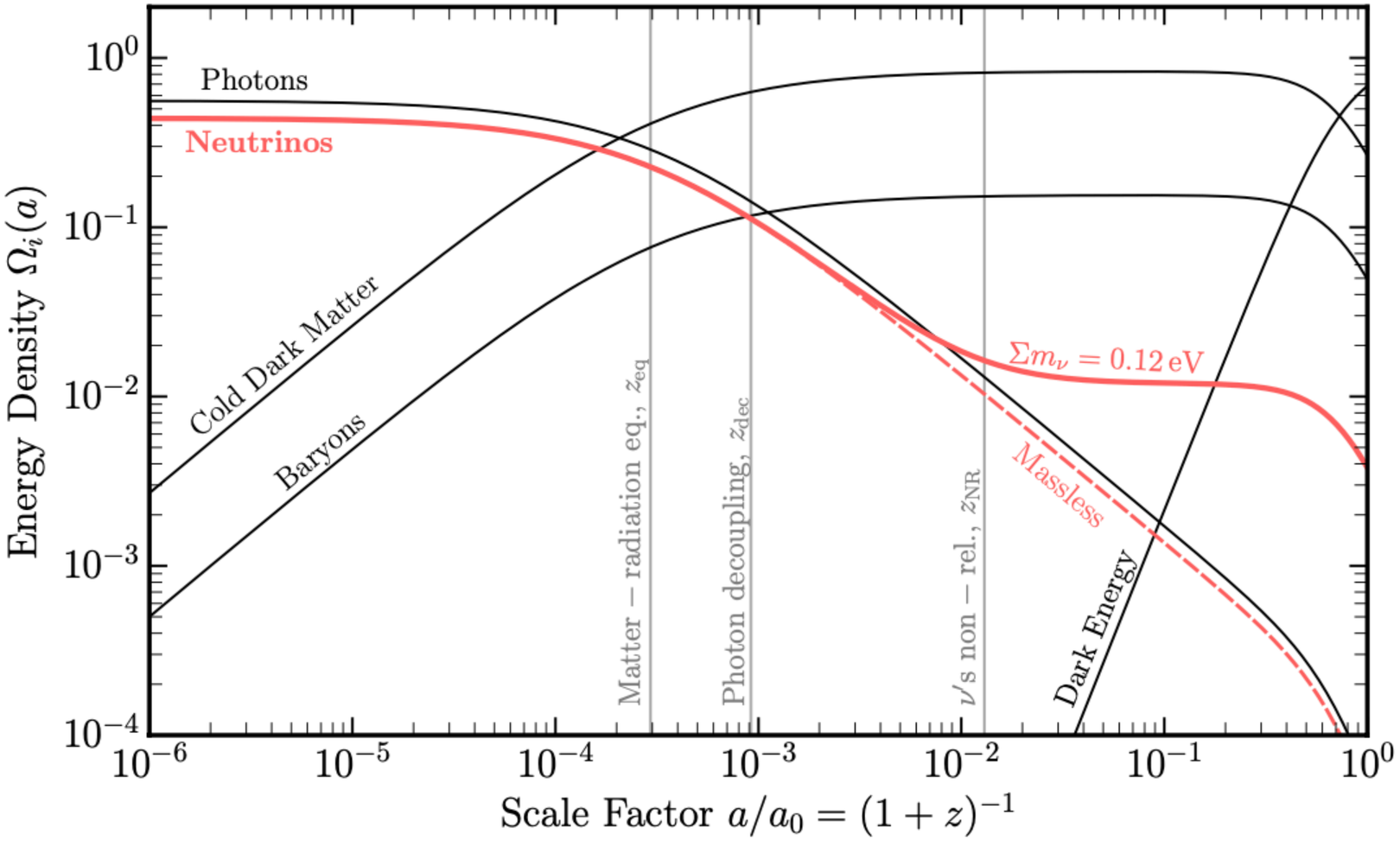
With Euclid data foreseen a detection of at least $\sim 2\sigma$.

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

(The Wide-field Spectroscopic Telescope (WST) Science White Paper, V. Manieri et al (2024))

Thanks

Massive neutrinos background cosmology



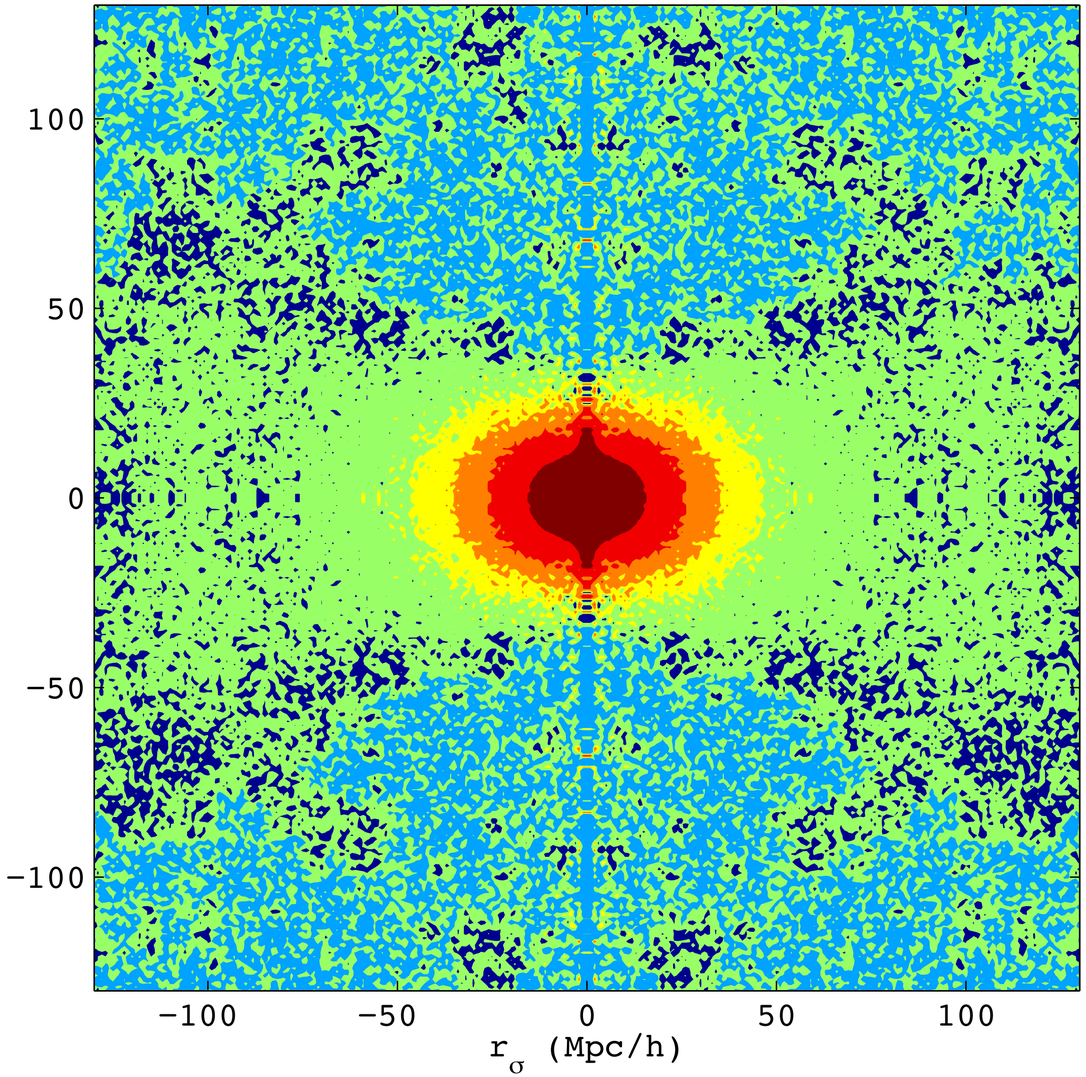
$$\Omega_\nu = \frac{\sum_i m_{\nu,i}}{93.14 h^2\,{\rm eV}} \equiv f_\nu\,\Omega_{\rm matt}$$

The Effective Field Theory of LSS

- State of the art of galaxy clustering analysis.
- Founding idea: restrict explicit the theory to $k < k_\Lambda < k_{\rm NL}$
- It's a framework:
  - A controlled Taylor series in k/k_Λ
  - Nonlinearity tackled, consistently, via perturbation theory (~fast)
  - By construction agnostic to UV (i.e. $\lambda < \Lambda$) physics.
- Resulting template:

$$P_g(k) = P_g^{\rm tree}(k) + P_g^{1-{\rm loop}}(k) + P_g^{\rm ctr}(k) + P_g^{\rm noise}(k)$$

Fluctuations in redshift space



(BOSS, Reid et al. 2012)

Redshift surveys measure the density field of galaxies in **redshift space**

Redshift space position is set by the velocity.

$$v_z = \mathscr{H} x_z + v_{\mathrm{pec},z}$$

Hence

$$\boldsymbol{s} = \boldsymbol{x} + \frac{v_{\mathrm{pec,z}}}{\mathscr{H}} \hat{z}$$

(isotropy is broken by l.o.s direction)