Cosmology with galaxy clustering

A pipeline for the joint analysis of the power spectrum and bispectrum

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PER SEGUIR VIRTUTE E CANOSCENZA
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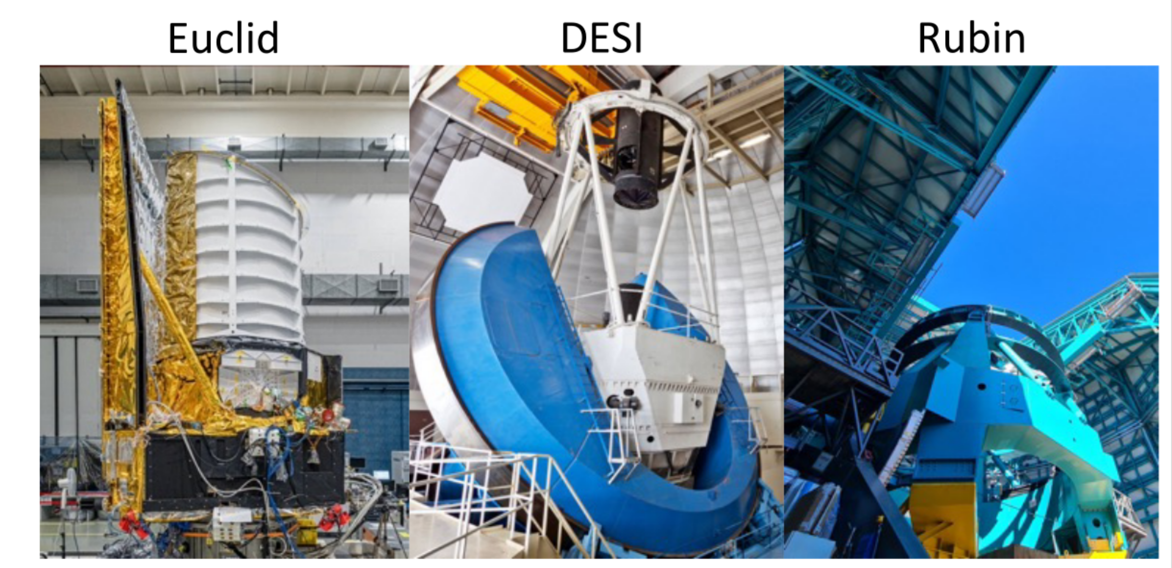
Motivation

Stage IV galaxy redshift surveys

→ unprecedented volume, high precision measurements

Neutrino mass? Modified gravity? Tensions?



Full data exploitation:

- Nonlinear regime
- Higher order statistics

Accurate and fast theoretical model + likelihood pipeline

Galaxy clustering

Homogeneous distribution of overdensities

↓

gravity

↓

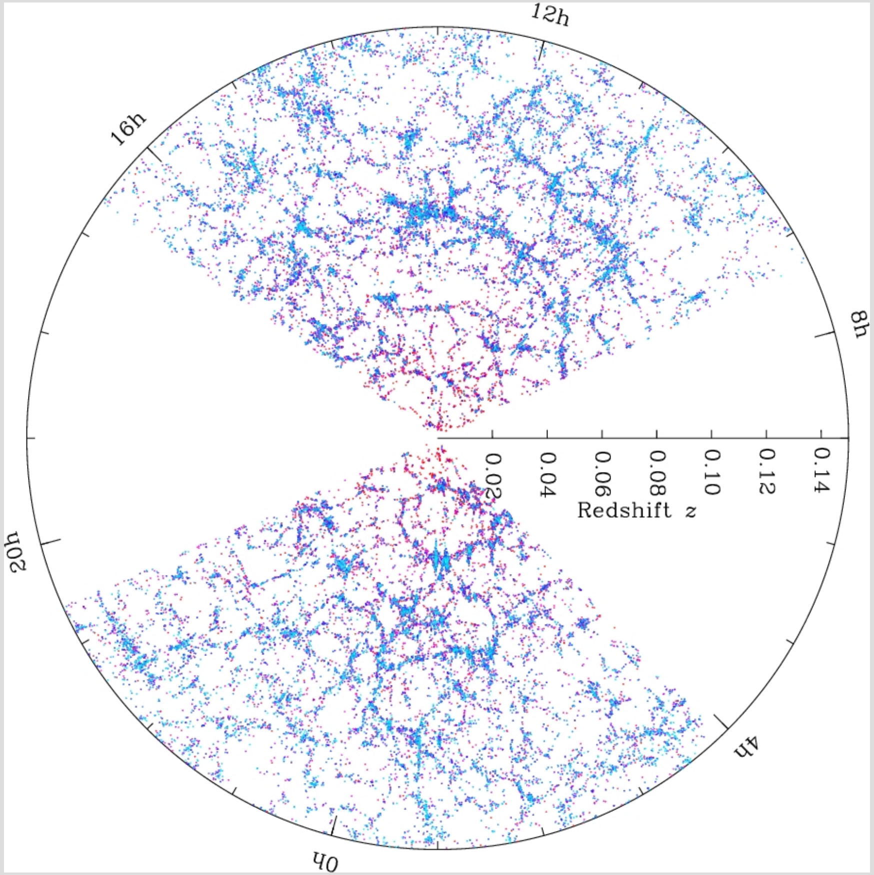
clustered distribution of galaxies

Galaxy distribution ↔ cosmological model

Correlate overdensity δ in different cells

$$\xi(r) = \langle \delta_R(\mathbf{x}) \delta_R(\mathbf{x} + \mathbf{r}) \rangle$$

$$P(k_1)\delta_D(\mathbf{k_1} + \mathbf{k_2}) = \langle \delta_{\mathbf{k_1}} \delta_{\mathbf{k_2}} \rangle$$



SDSS survey

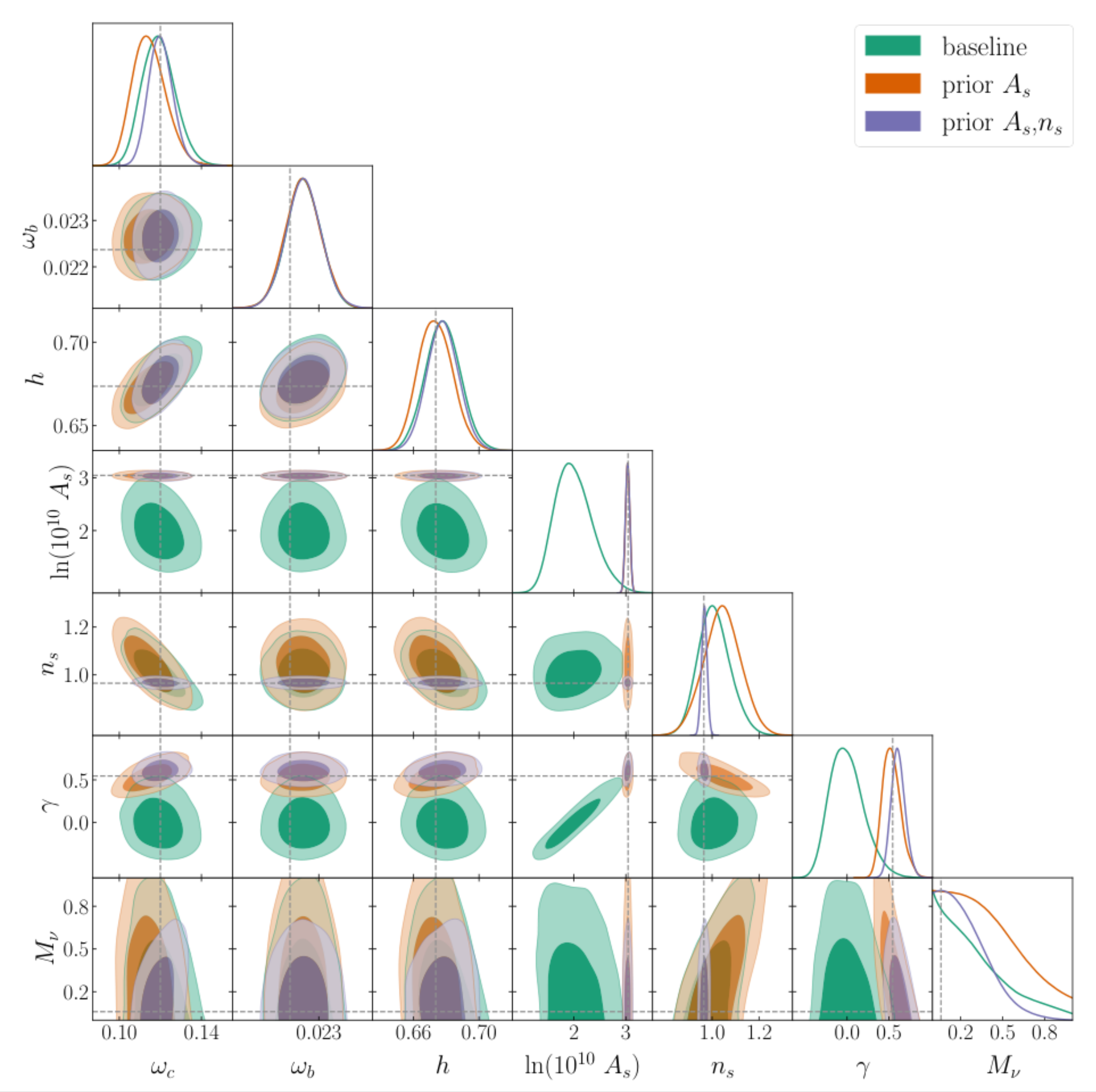
The code: PBJ Power spectrum & Bispectrum Joint analysis

- Linear P(k) with CAMB or Bacco/Cosmopower emulator
- EFTofLSS P(k) (with Fast-PT for fast evaluation – 30 ms)
- Tree-level bispectrum (0.1 s)
- 1-loop galaxy bias
- Customized IR-resummation routine (w-nw split)
- samplers: emcee (affine invariant & Metropolis-Hastings), Multinest (nested sampling), pocomc (preconditioned Monte Carlo)
- Likelihood: Gaussian + corrections for noise in the covariance

[1908.01774]
[2108.03204]
[2204.13628]
[2207.14784]
[2207.13011]

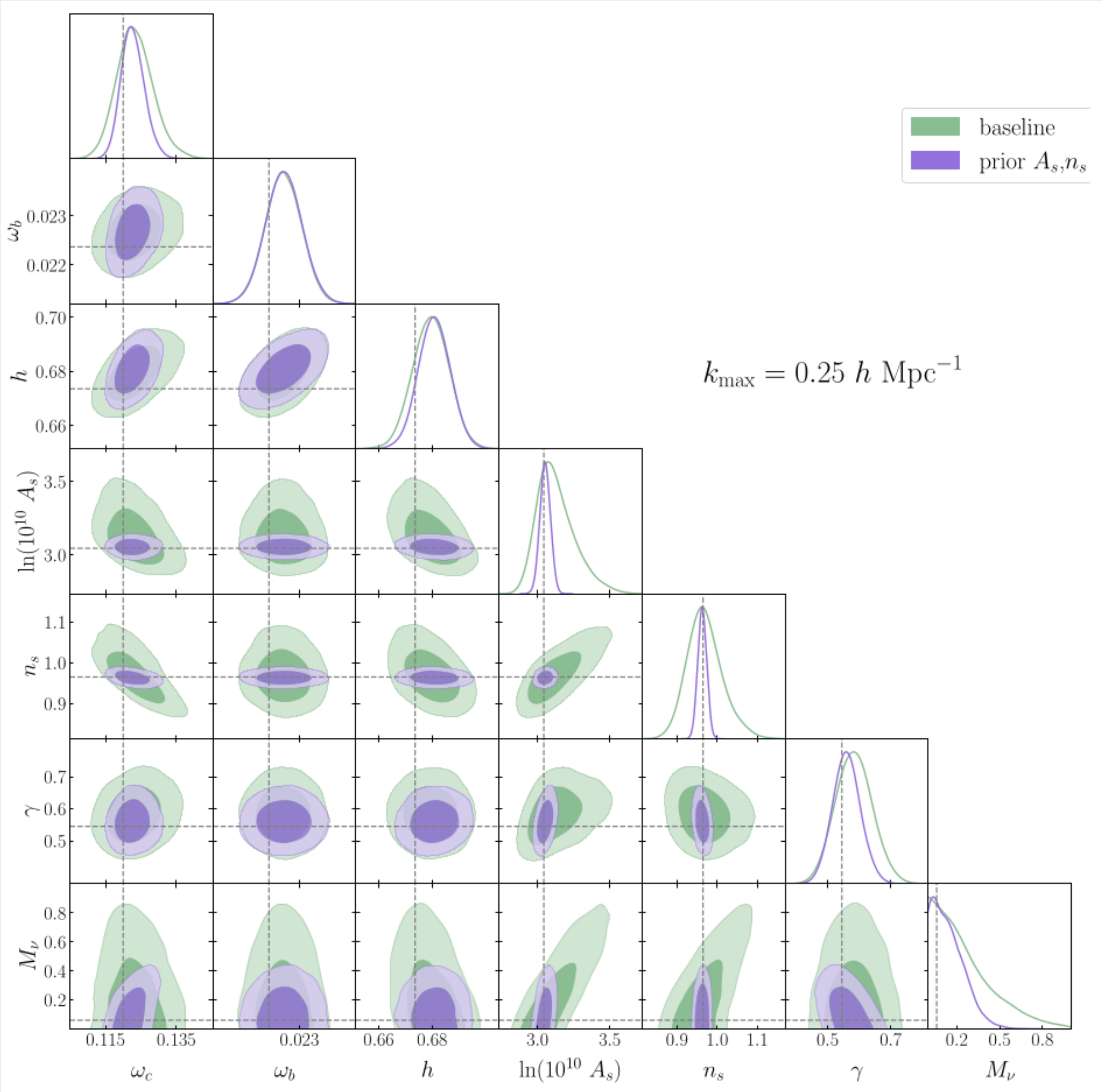
BOSS analysis

- BOSS DR12 – power spectrum multipoles
- Full shape analysis with EFTofLSS + BAO data
- γ+massive neutrinos



Stage IV forecasts

- Synthetic data, different galaxy samples → forecast future constraints
- Optimistic / pessimistic settings
- Optimal choice of priors



Euclid

Modelling challenge:
fit large, high-res Euclid-like simulation;
Comparison with several independent codes

Model from PBJ ported in official likelihood pipeline

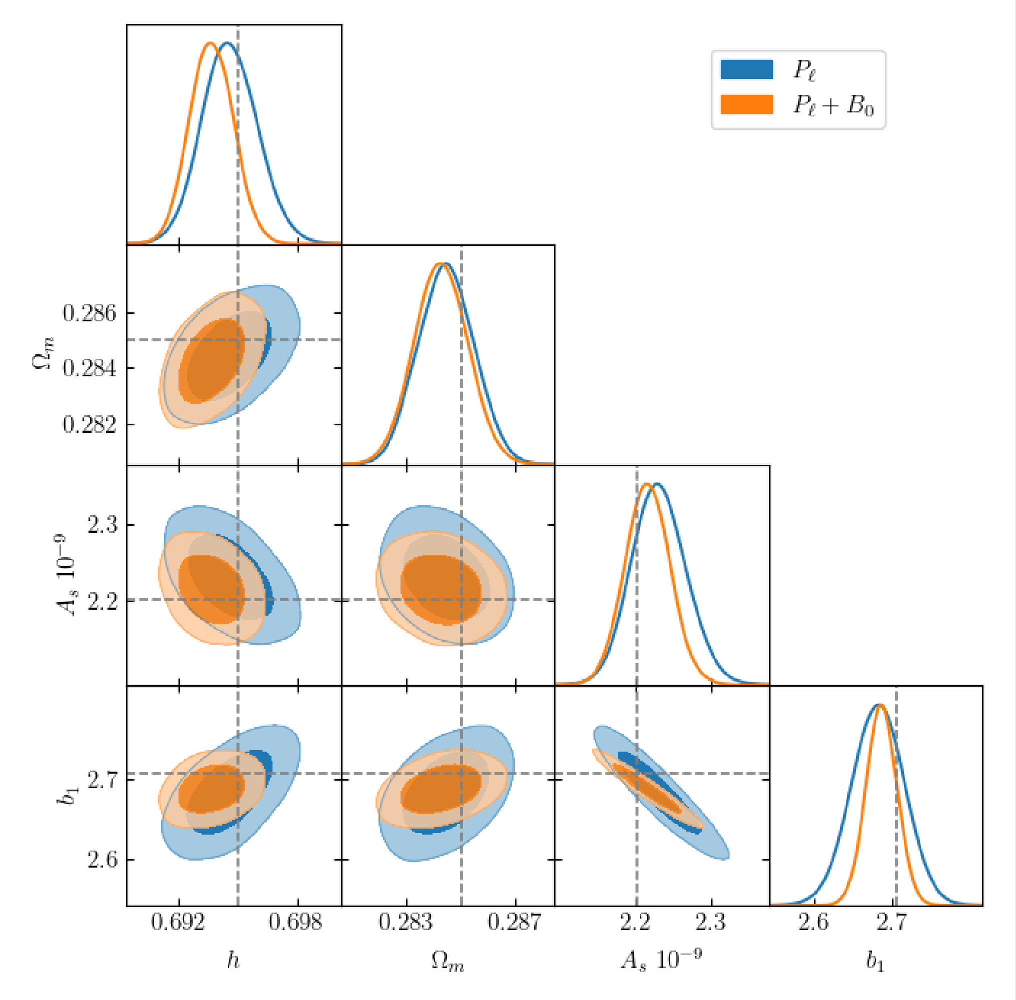
Beyond-ΛCDM:
Testing nonlinear models for massive neutrinos, evolving DE, modified gravity...

Summary

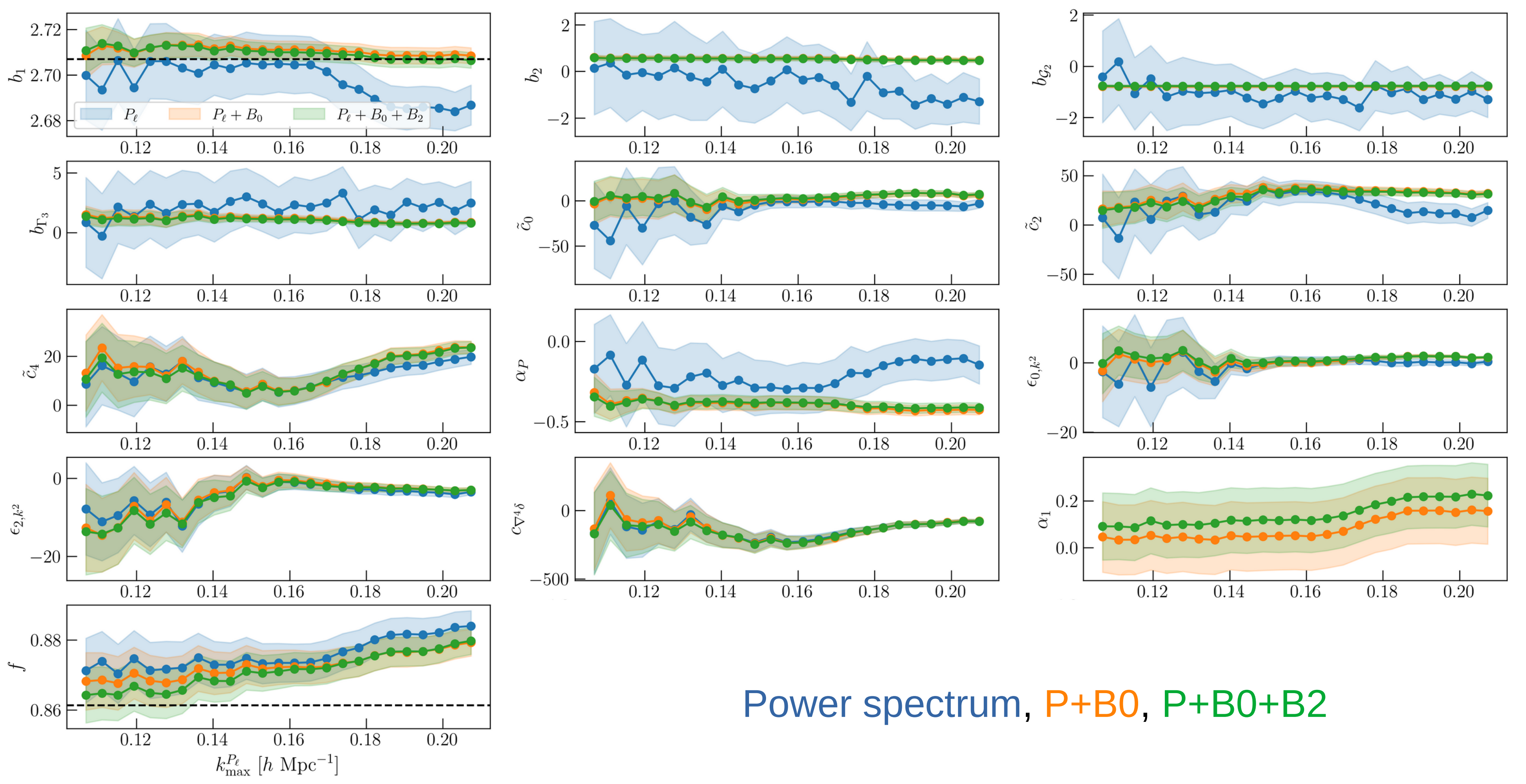
- Stage IV surveys can constrain the cosmological model to % precision
  - Extract all information with nonlinear scales, higher order statistics
  - Validity of the model to avoid “fake tensions”
- **PBJ**: a joint likelihood pipeline for power spectrum + bispectrum
  - Highly efficient, validated with large simulation set
- Applied to BOSS data for beyond-ΛCDM models
  - Priors on nuisance parameters matter
  - Strong degeneracies → bispectrum can help
- **Euclid**:
  - PBJ ported to official likelihood CLOE
  - Currently used to assess validity of the model (ΛCDM and beyond)

Cosmological parameters

- Small errorbars → stress-test the model
- Reduce the parameter space
- Find k_{max}
- Improved constraining power when including bispectrum



Finding k_{max}



Power spectrum, P+B0, P+B0+B2

Bispectrum – AP effect

Alcock-Paczynski: expansion around $\alpha_{\parallel} \simeq 1$ and $\alpha_{\perp} \simeq 1$:

$$B_\ell(k_1,k_2,k_3) = \frac{2\ell+1}{\alpha_\perp^4 \alpha_\parallel^2} \sum_{n_1,n_2} \int_{-1}^{1} \frac{\mathrm{d}\mu_1}{2} \int_0^{2\pi} \frac{\mathrm{d}\varphi}{2\pi} \mathcal{L}_\ell(\mu_1) \mu_1^{n_1} \mu_2^{n_2} B_{n_1,n_2}(k_1,k_2,k_3) \times$$
$$\left\{ 1 + \left[n_1(\mu_1^2 - 1) + n_2(\mu_2^2 - 1) \right] (F-1) + \sum_{i=1}^{3} \left[1 - \alpha_\perp + (\alpha_\perp - \alpha_\parallel)\mu_i^2 \right] \frac{\partial \ln B_{n_1,n_2}}{\partial \ln k_i}(k_1,k_2,k_3) \right\}$$

→ we can factor out the dependence on $\alpha_{\parallel}, \alpha_{\perp}$ and treat them as bias parameters

Perturbation theory -- EFT

- Basics of EFTofLSS: [Baumann et al. 2010, Carrasco et al. 2012, de la Bella et al. 2017]
- Split density into long and short modes at some scale $\Lambda < k_{\mathrm{NL}}$: $\delta = \delta_\Lambda + \delta_{\mathrm{NL}}$
- Renormalise the fields δ_Λ to take into account dependence on δ_{NL} in a general way:

$$\delta^R = \delta_\Lambda + c_{2|\delta}(a)\frac{\partial^2\delta_\Lambda}{k_{\mathrm{NL}}^2} + \mathcal{O}\left(\frac{\partial^4}{k_{\mathrm{NL}}^4}\right)$$

- Get n-point functions with counter-terms:

$$P^{EFT}(k,\mu,z) = P^{1-loop}(k,\mu,z) - 2c_{ctr}(z)\ k^2\ P_L(k,z) + \mathcal{O}(k^4\ P_L)$$

- Need unknown functions of time, $c_{\mathrm{ctr}}(z)$, but known scale-dependence