Cosmology with galaxy clustering

A joint analysis of the power spectrum and bispectrum

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euclid
consortium

From galaxy surveys to cosmology

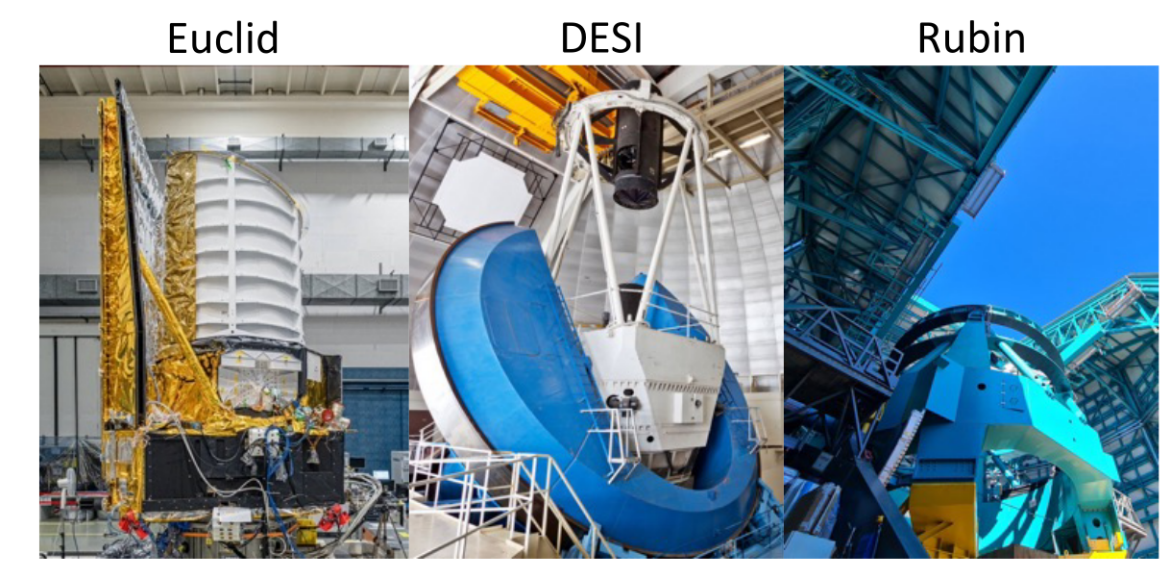
Stage IV galaxy redshift surveys

→ unprecedented volume, high precision measurements

Neutrino mass? Modified gravity? Tensions?

Full data exploitation:

- Nonlinear regime
- Higher order statistics



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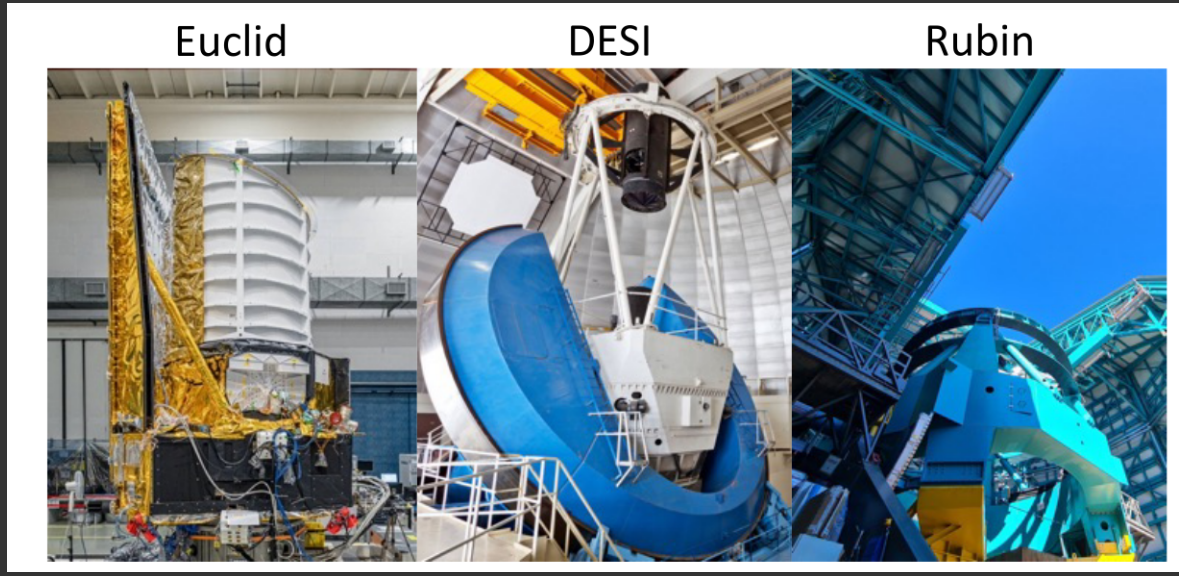

Accurate & fast theoretical model → Likelihood analysis

PBJ: Power spectrum and Bispectrum Joint analysis

POWER SPECTRUM:

- 1-loop model (EFTofLSS)
- FastPT → model evaluation (28 loop integrals!) in ~30 ms
- Wiggle-nowiggle decomposition for IR-resummation
- 11 nuisance parameters

BISPECTRUM:

- Tree-level
- Higher order multipoles
- Model evaluation in ~0.1 ms
- 6 nuisance parameters

+ samplers: emcee (affine invariant & Metropolis-Hastings), Multinest (nested sampling), pocomc (pre-conditioned MonteCarlo), different likelihood functions for noise in the covariance matrix

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CM, F. Rizzo, K. Pardede, A. Oddo, E. Sefusatti, A. Eggemeier, C. Porciani
[1908.01774] [2108.03204] [2204.13628]

Theoretical model

- Power spectrum: bias expansion + loop corrections + EFT counterterms + noise

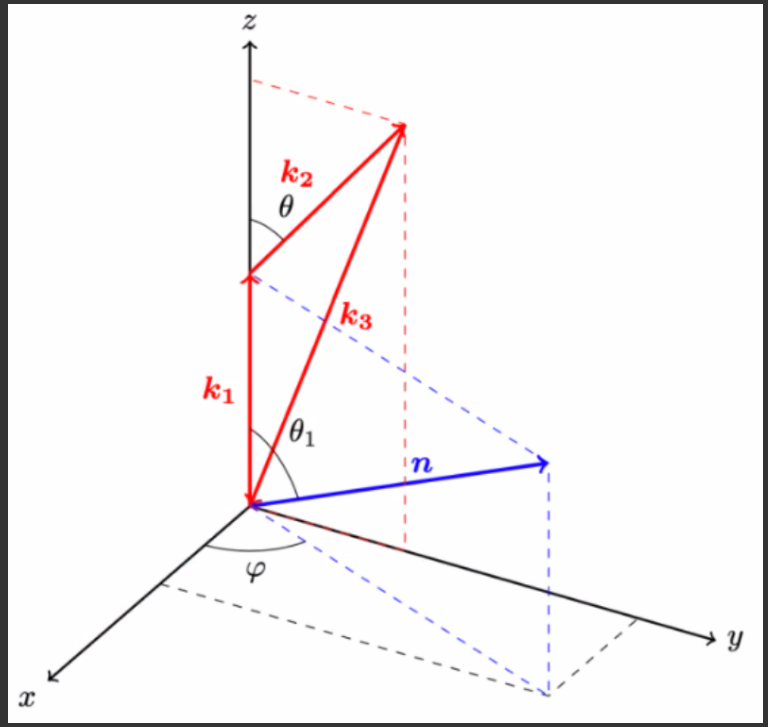
$$P_{gg}(\mathbf{k}) = Z_1^2(\mathbf{k})P_L(k) + 2\int \mathrm{d}^3\mathbf{q}\ \left[Z_2(\mathbf{q},\mathbf{k}-\mathbf{q})\right]^2 P_L(q)P_L(|\mathbf{k}-\mathbf{q}|) + 6Z_1(\mathbf{k})P_L(k)\int \mathrm{d}^3\mathbf{q}\ Z_3(\mathbf{k},\mathbf{q},-\mathbf{q})P_L(q) + P_{\rm ctr}(\mathbf{k}) + P_{\rm noise}(\mathbf{k})$$

Theoretical model

- Power spectrum: bias expansion + loop corrections + EFT counterterms + noise
- Bispectrum: bias expansion + noise

  dependence on (many) triangular configurations

⚠️



Validation dataset

- 300 DM-only N-body simulations (Minerva), ΛCDM cosmology
- L=1500 Mpc/h → $V_{tot} \approx 1000$ Gpc³/h³

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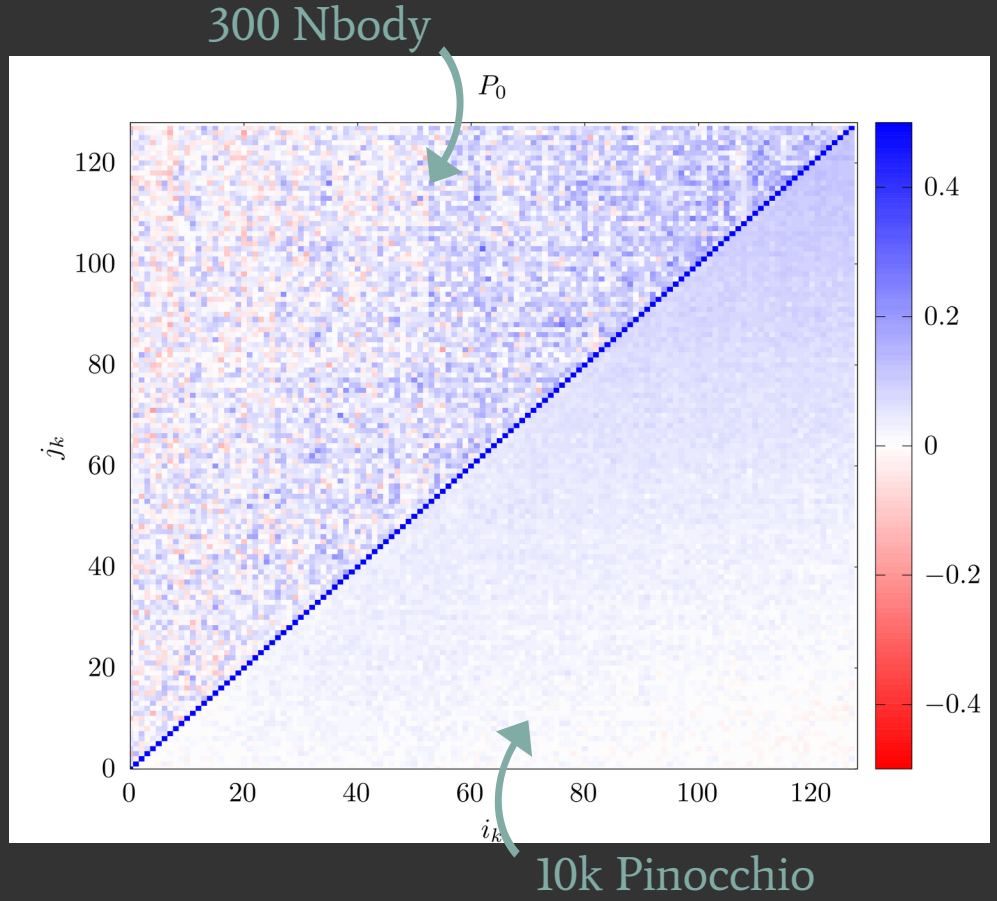
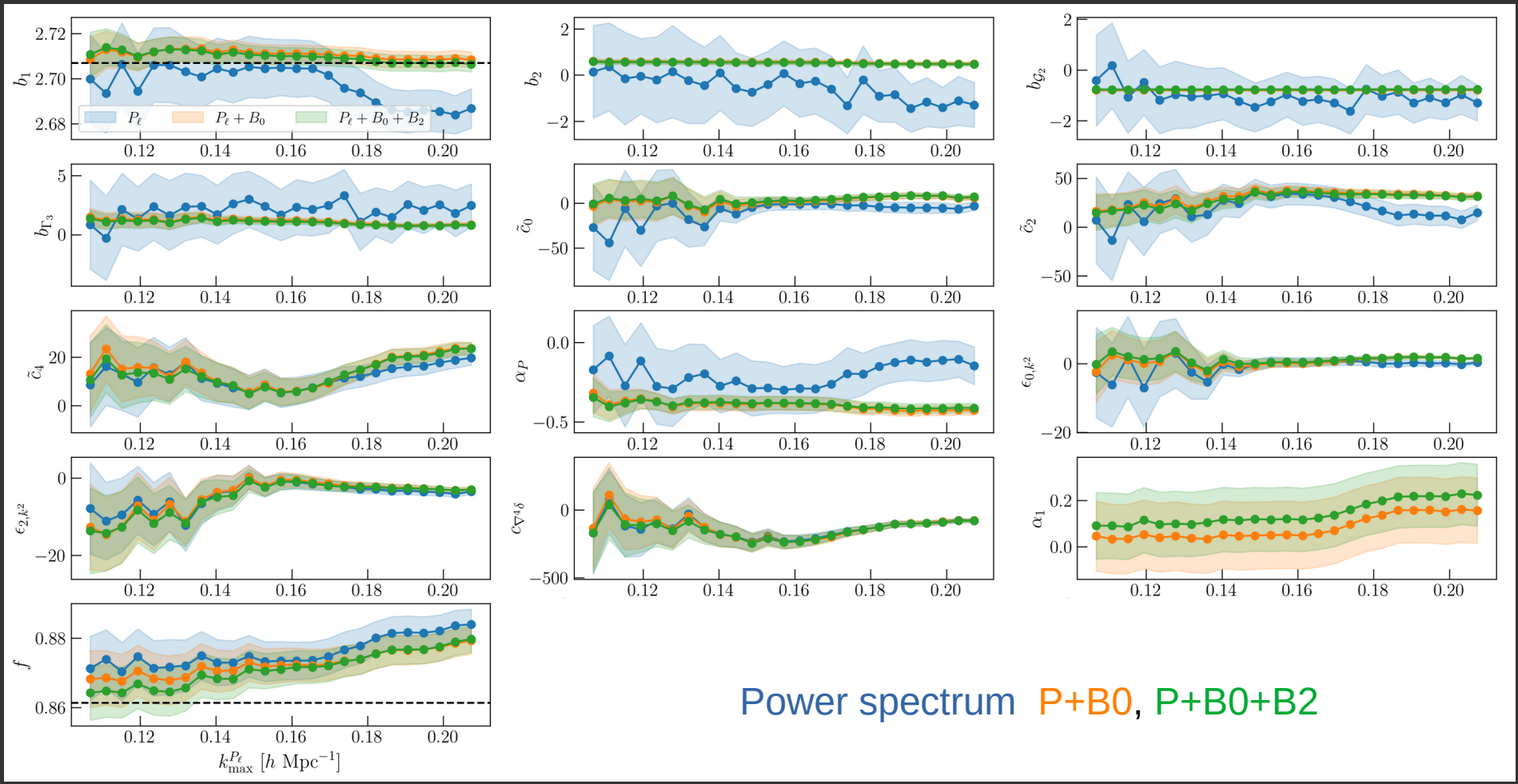
- Covariance from 10k Pinocchio mocks



P+B in redshift space

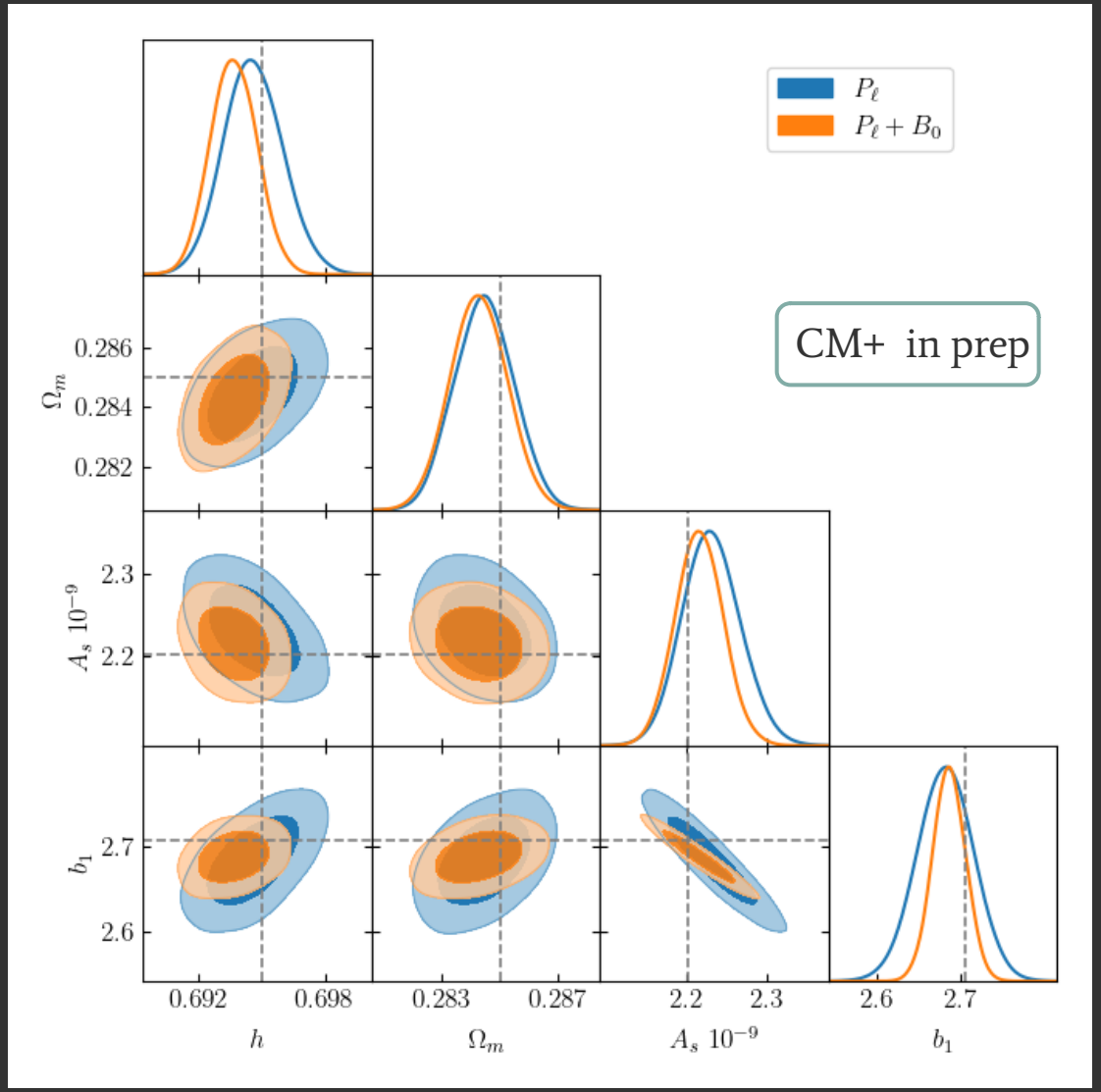
CM+ in prep



Power spectrum P+B0, P+B0+B2

P+B in redshift space

- Model selection / reducing the parameter space (bias relations)
- Fits of cosmological parameters → forecast on improved constraining power
- Public release of the code



Beyond LCDM

With P. Carrilho, M. Tsedrik, A. Pourtsidou
2207.14784, 2207.13011, 2306.09275

- Dark Scattering model: elastic scattering with DM-DE momentum transfer [Simpson+10]
- 2 additional parameters:
  w, $A = (1+w)\,\xi$

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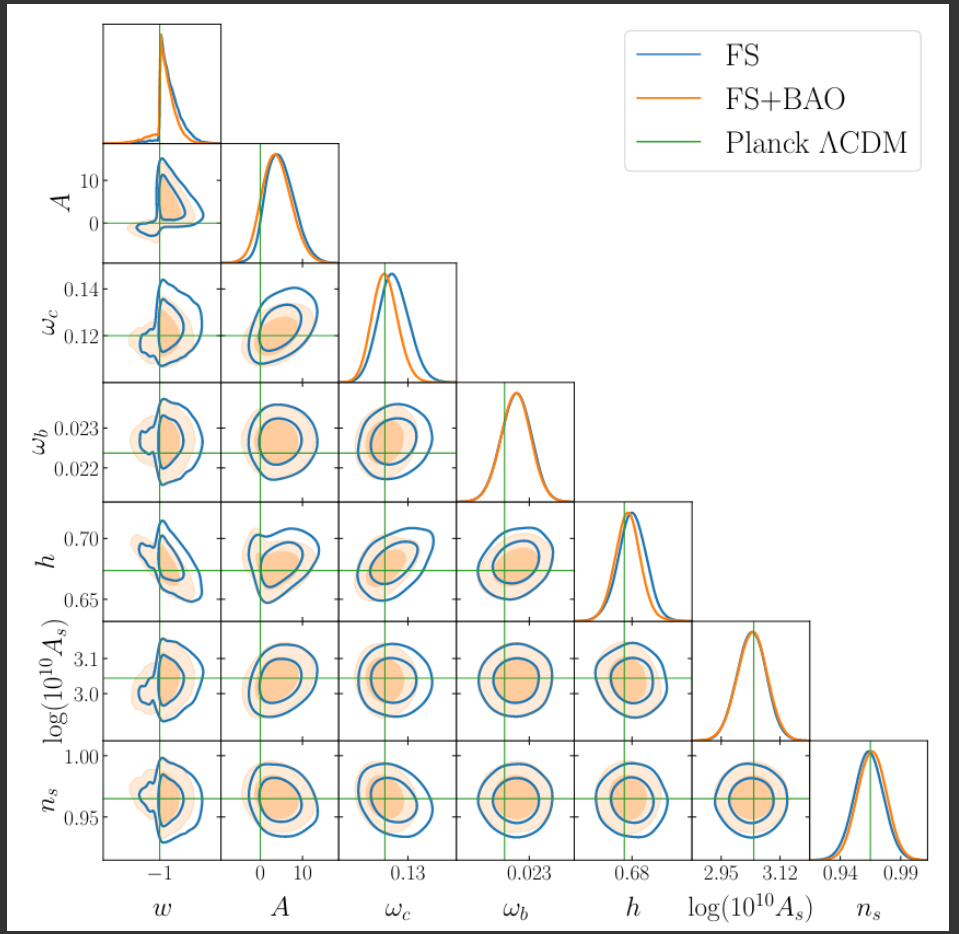
BOSS DR12 power spectrum

- Windowless estimator [Philcox+21]
- Prior dependence!
- Strong degeneracy between amplitude parameters
  → bispectrum can help



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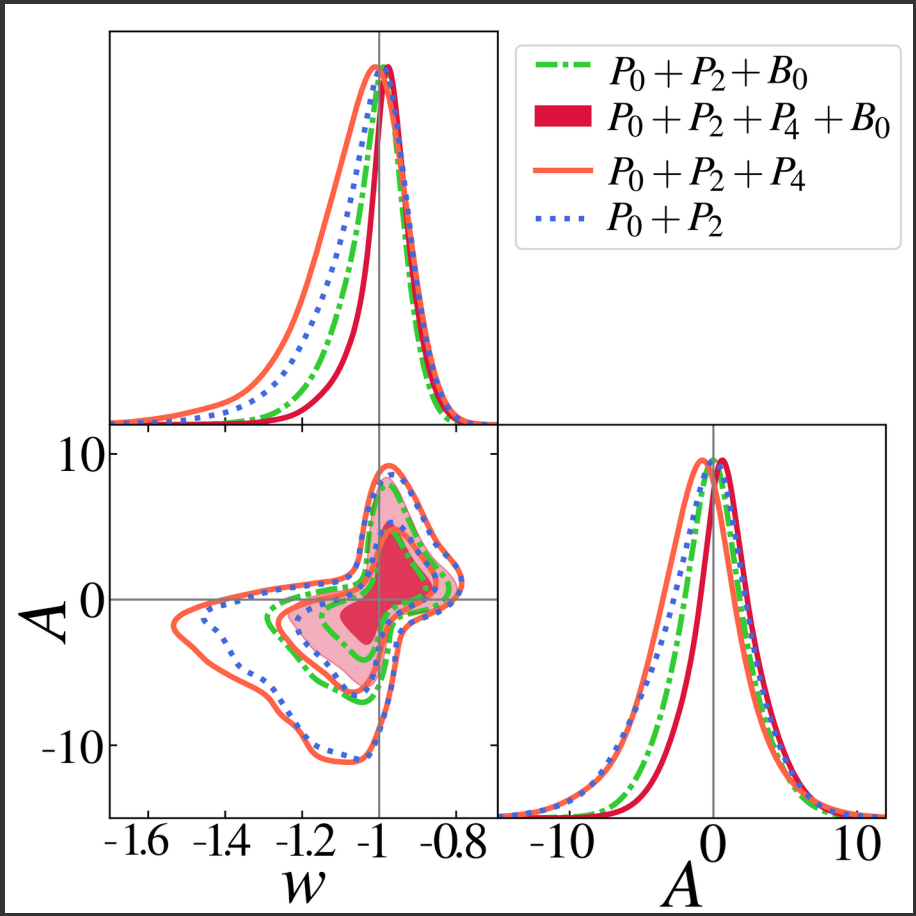


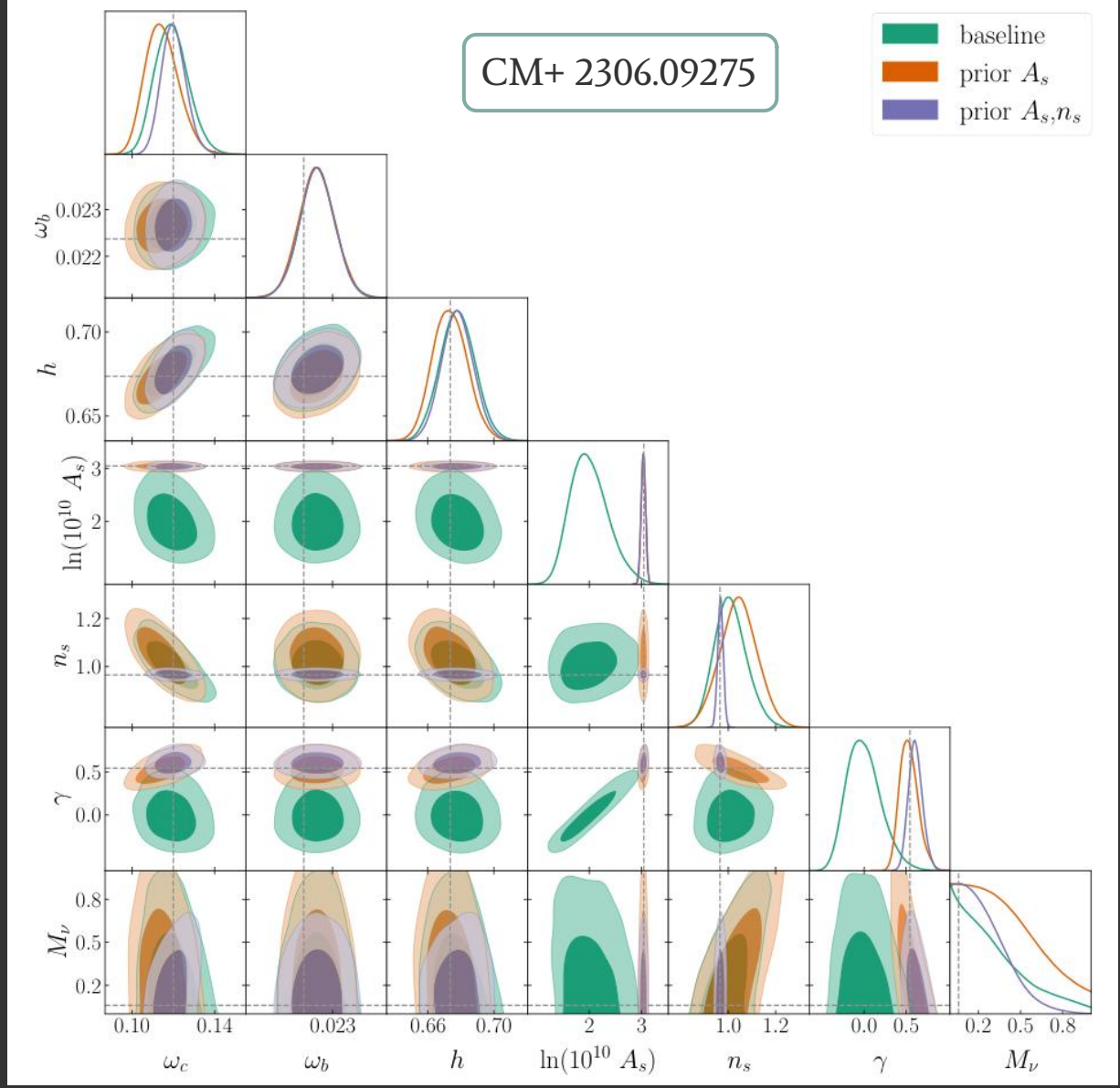
- Forecasts for P+B analysis of DS model with Euclid errorbars
- Bispectrum breaks degeneracy between amplitude params → 30% improvement on the DS parameters
- BOSS analysis ongoing, stay tuned!

Beyond LCDM

- γ parameterisation for growth [Linder 05] + massive neutrinos
- BOSS analysis (power spectrum)

  → consistent with ΛCDM

  → impact of priors: strong projection / prior volume effects



Beyond LCDM

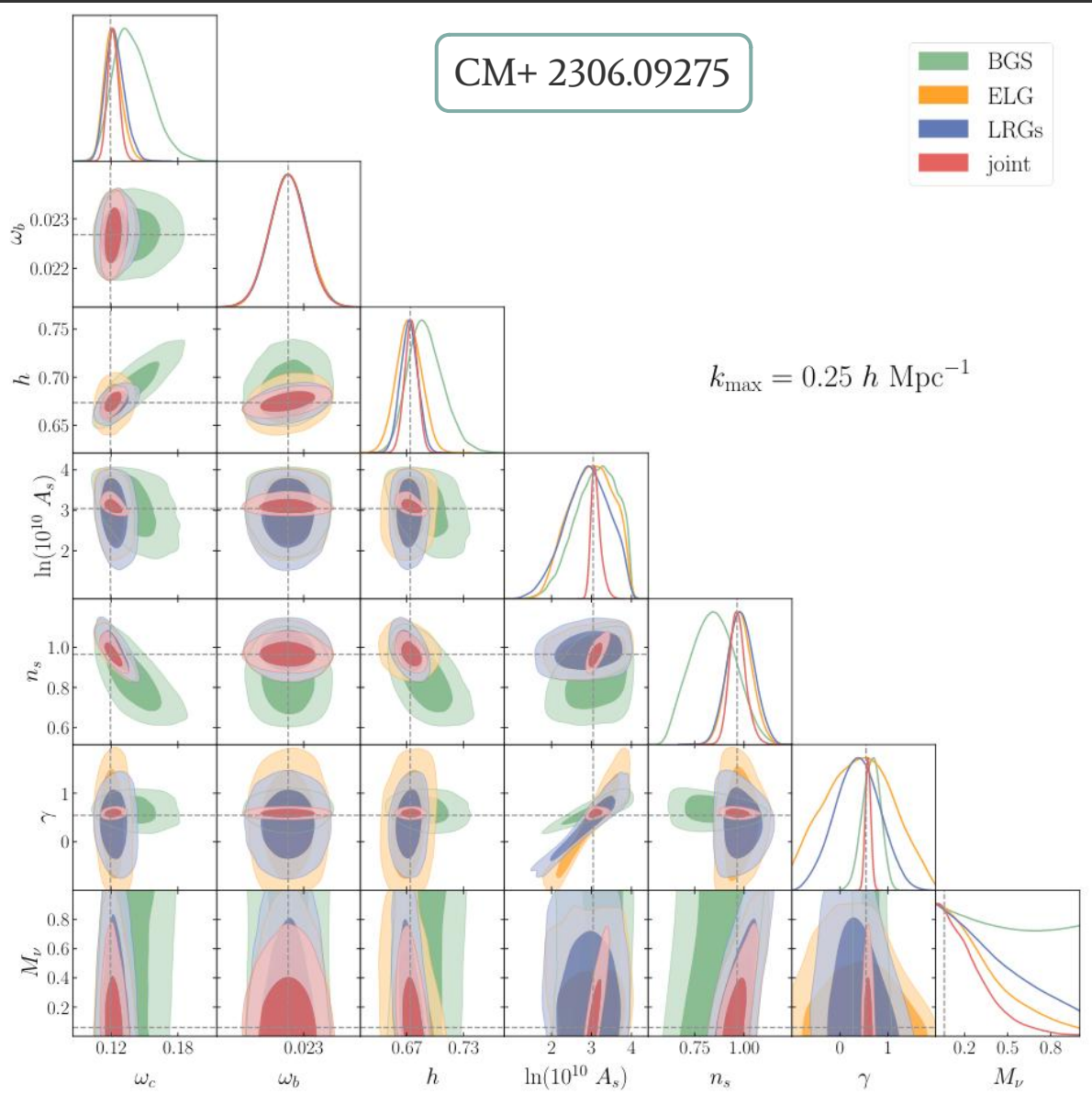
- γ parameterisation for growth [Linder 05] + massive neutrinos
- BOSS analysis (power spectrum)
- Forecast for DESI-like survey

  → joint galaxy samples:

  $\sigma(\gamma) = 0.058$

  $M_\nu < 0.27$ eV

  → projection effects mitigated



Euclid

Theoretical modelling + likelihood analysis of spectroscopic sample

Euclid

Theoretical modelling + likelihood analysis of spectroscopic sample

Bayesian analysis of Flagship simulation (power spectrum + bispectrum)

Beyond-ΛCDM: massive neutrinos, evolving DE, modified gravity

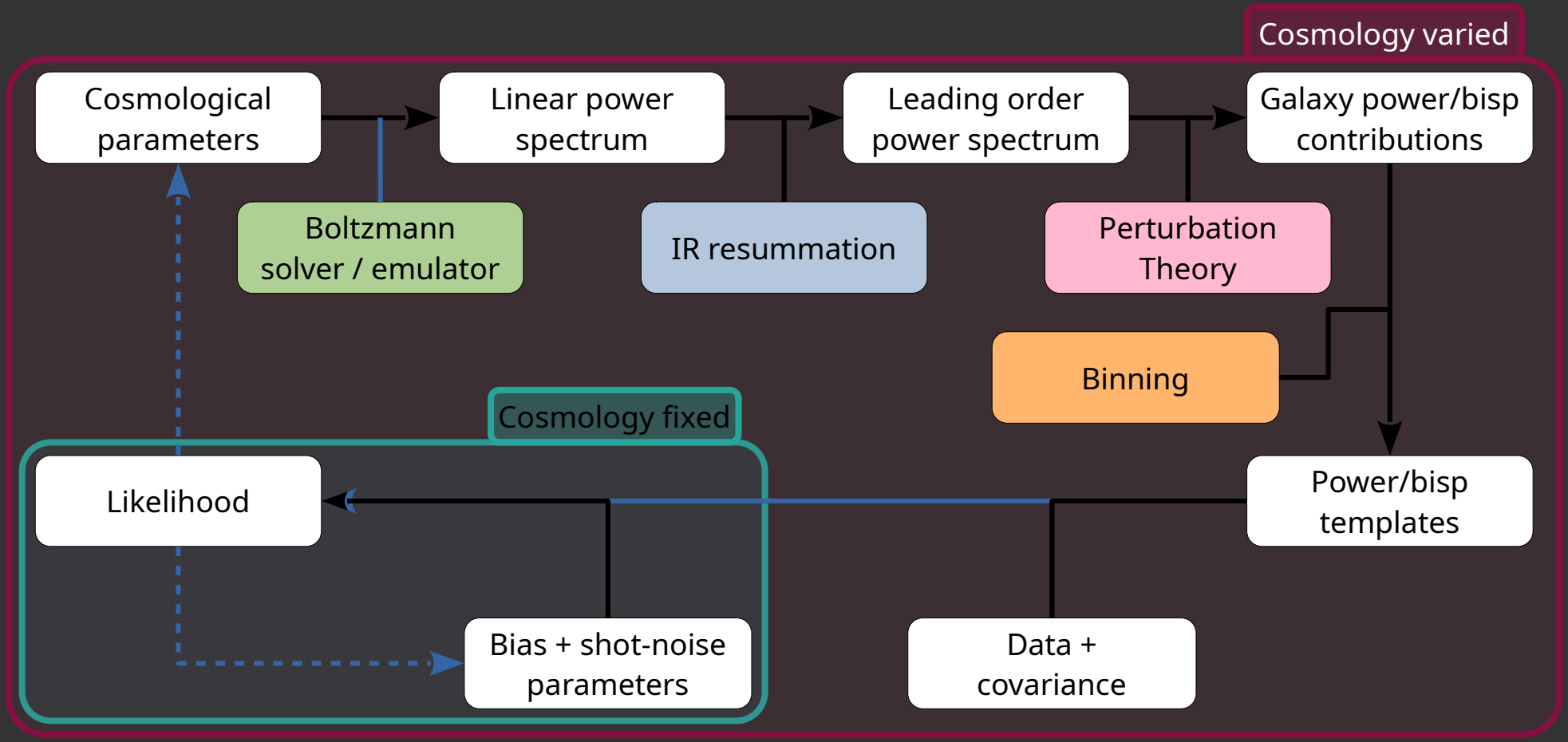
- Optimise theoretical models
- Likelihood analysis

Implement non-linear models in CLOE (power spectrum model from pbj for spectro sample)

Summary & conclusion

- Pipeline for the power spectrum + bispectrum joint analysis of biased tracers (1-loop power spectrum + tree-level bispectrum) → soon to be public
- Validation on large set of sim → robust test of theoretical model [Oddo+20,21; Pardede+22; Rizzo,CM+ 2204.13628; CM+ in prep]
- Validation and forecasts for Euclid + ported to official likelihood code
- Beyond-ΛCDM: Dark Scattering constraints from BOSS [Carrilho,CM+ 2207.14784], inclusion of bispectrum [Tsedrik,CM+ 2207.13011], growth index + massive neutrinos [CM+2306.09275] + Euclid preparation ongoing

PBJ: Power spectrum & Bispectrum Joint analysis



Theoretical model – bispectrum

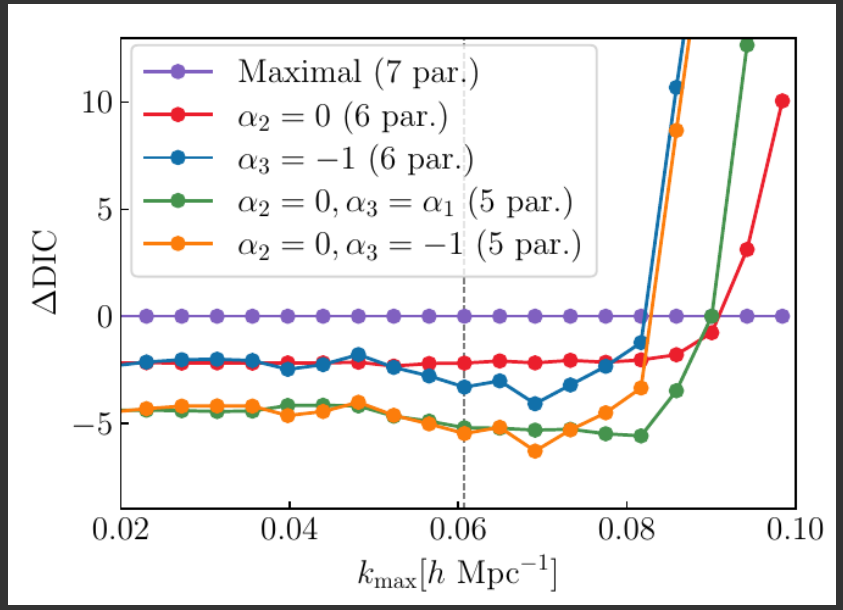
Alcock-Paczynski: expansion around $\alpha_\parallel = 1$ and $\alpha_\perp = 1$:

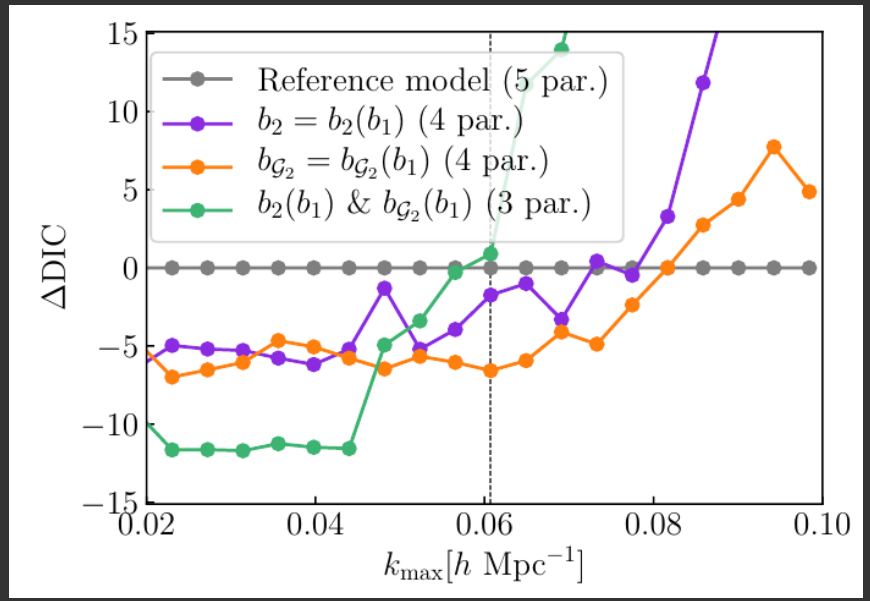
$$B_\ell(k_1,k_2,k_3) = \frac{2\ell+1}{\alpha_\perp^4\alpha_\parallel^2}\sum_{n_1,n_2}\int_{-1}^{1}\frac{\mathrm{d}\mu_1}{2}\int_0^{2\pi}\frac{\mathrm{d}\varphi}{2\pi}\mathcal{L}_\ell(\mu_1)\mu_1^{n_1}\mu_2^{n_2}B_{n_1,n_2}(k_1,k_2,k_3)\times$$
$$\Big\{1+\big[n_1(\mu_1^2-1)+n_2(\mu_2^2-1)\big](F-1)+$$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

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

Bispectrum in redshift space [Rizzo,CM 2204.13628]

- Higher order multipoles
- Model selection





Beyond LCDM

Strong dependence on priors!