LSS constraints with controlled theoretical uncertainties

Marko Simonović
IAS, Princeton

with Tobias Baldauf, Mehrdad Mirbabayi and Matias Zaldarriaga

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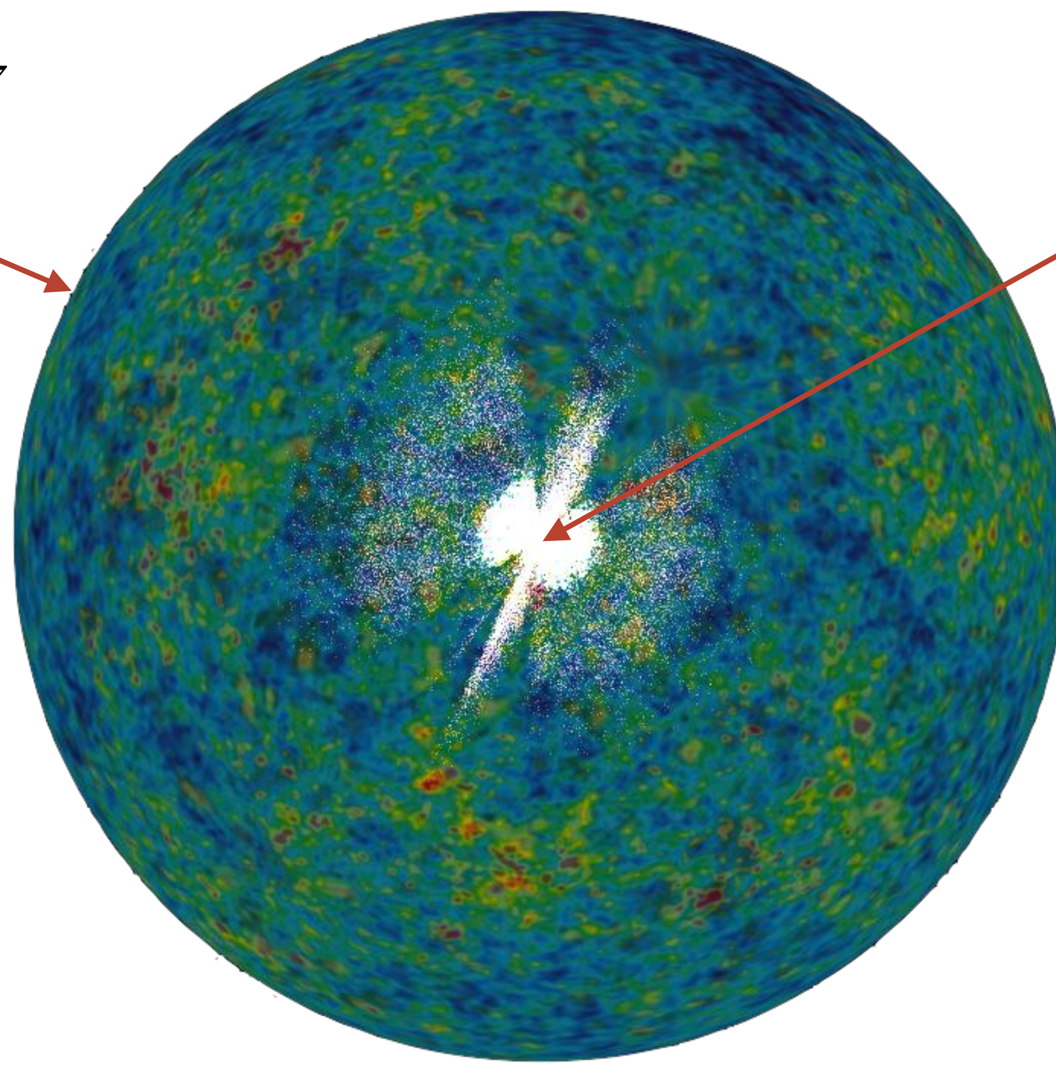
Moriond Cosmology, March 2016

"The future of precision cosmology is in LSS"

$N_{\mathrm{CMB}} \approx l_{\mathrm{max}}^2 \sim 10^7$

$N_{\mathrm{LSS}} \approx \left(\frac{k_{\mathrm{max}}}{k_{\mathrm{min}}}\right)^3$



Galaxies

Lyα

21cm

…

How much information can we get from a LSS survey? (including "theoretical errors")

— Can we reach some (theoretically interesting) thresholds?

$\sigma(M_\nu) \sim 60 \text{ meV} \;, \quad \sigma(f_{\rm NL}) \sim 1$

(many talks about neutrinos this afternoon)

(BAO peak position, weak lensing, DE equation of state, anomalies…)

— Data analysis: constraints on cosmological parameters

Fisher matrix

— Uncertainties taken into account

statistical errors

nuisance parameters such as bias parameters

— Additional systematic errors due to the theoretical uncertainties
Usually neglected!

they are largish ~1%, and can change the constraints significantly

present in PT and simulations

even with the full nonlinear DM field, usual bias models are perturbative

Theoretical errors in PT

— Increase k_{max} as much as possible

— Gravitational nonlinearities become large

$$P_{\rm NL}(k) = P(k) + P_{\rm SPT}^{1-\rm loop}(k) + P_{\rm ct}(k) + \cdots$$

$$P_{\rm ct}(k) = -2R_p^2 k^2 P(k)$$

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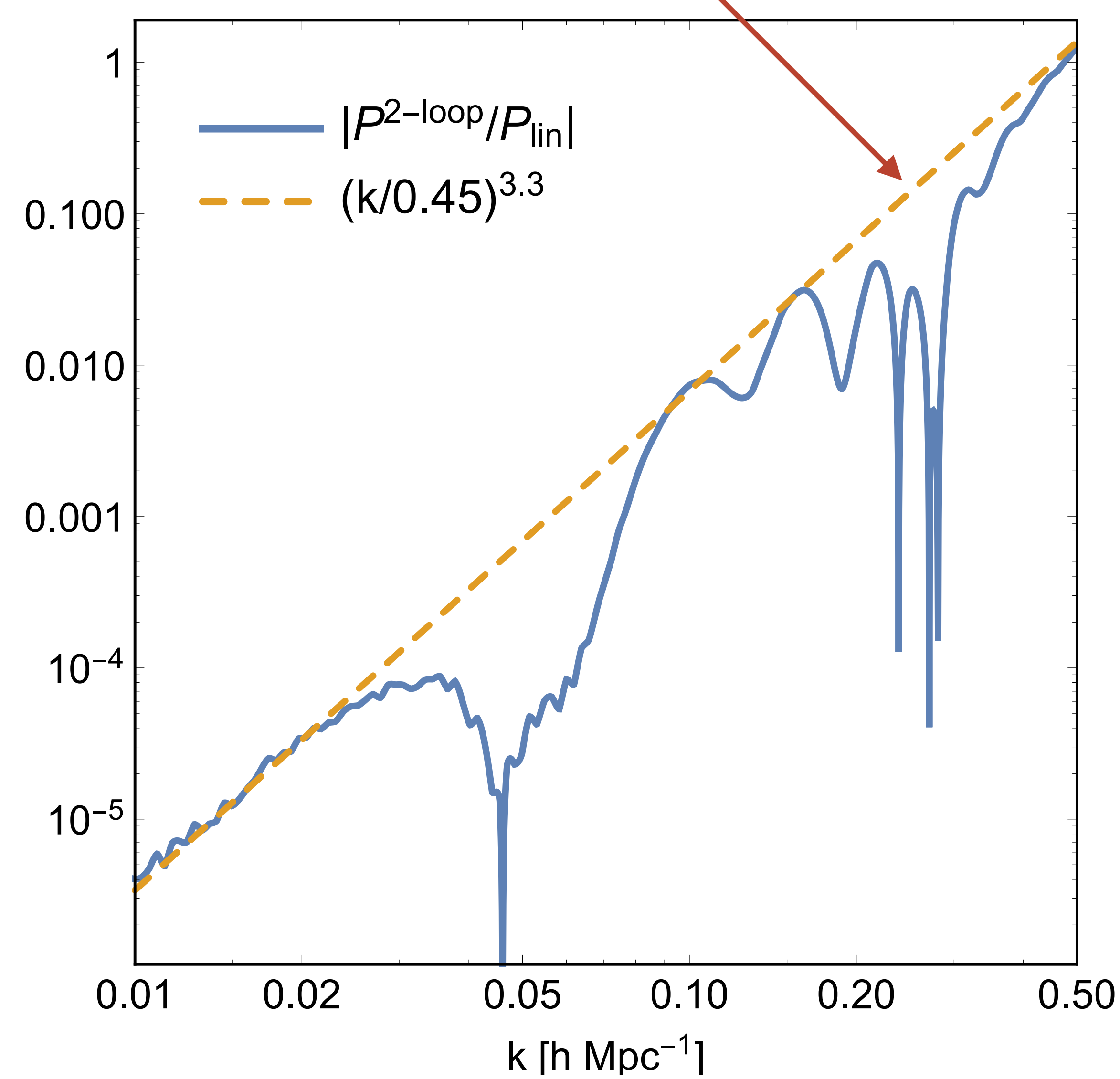
— Higher order terms are estimate of the error

$$P(k) \propto k^n$$

$$P^{1-\rm loop}(k)/P(k) \propto (k/k_{\rm NL})^{(3+n)l}$$

$$k_{\rm NL} \sim 0.3\ h{\rm Mpc}^{-1}\ , \quad n \sim -1.5$$

“error for 1-loop”



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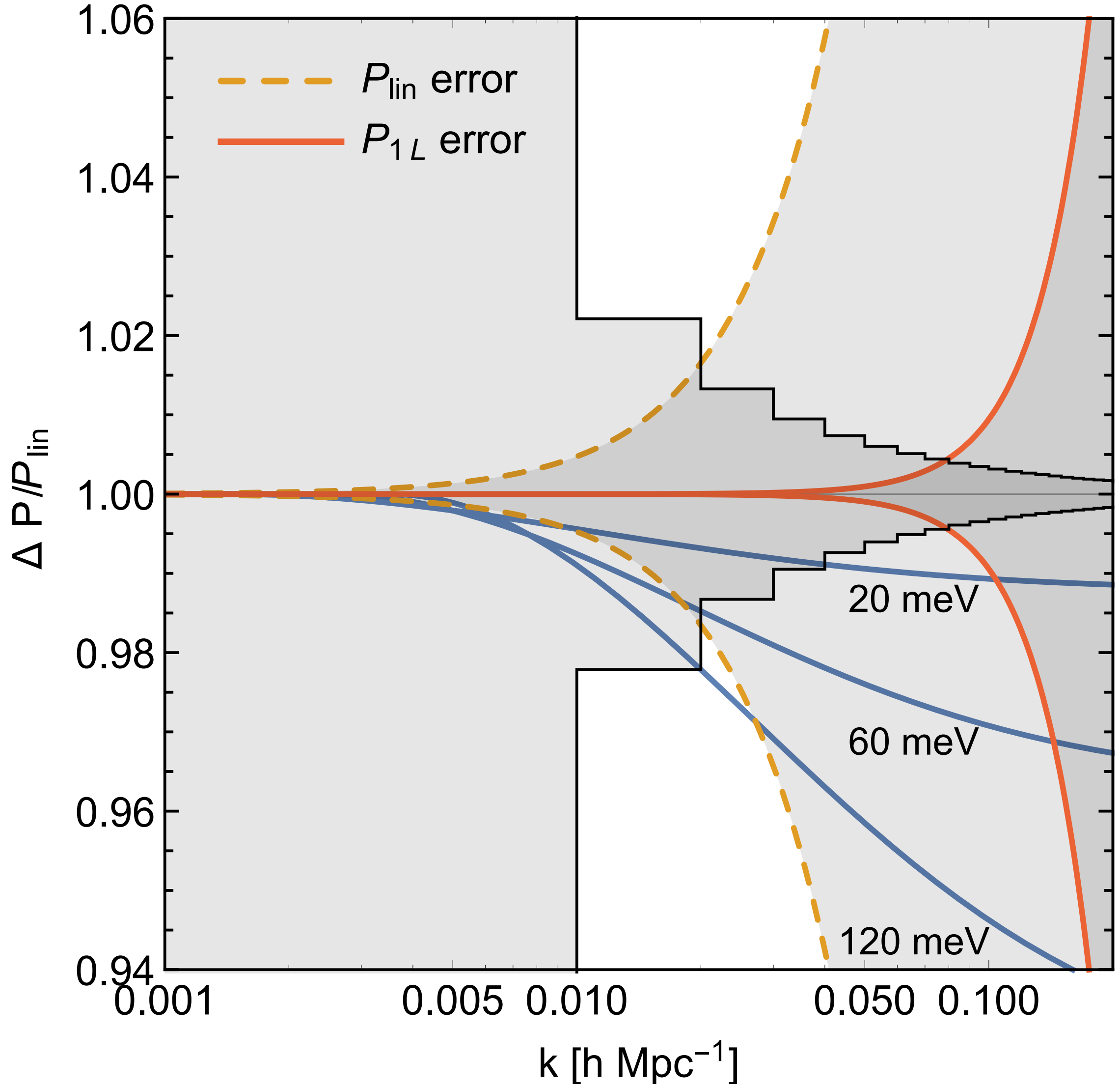


Fisher matrix with theoretical errors

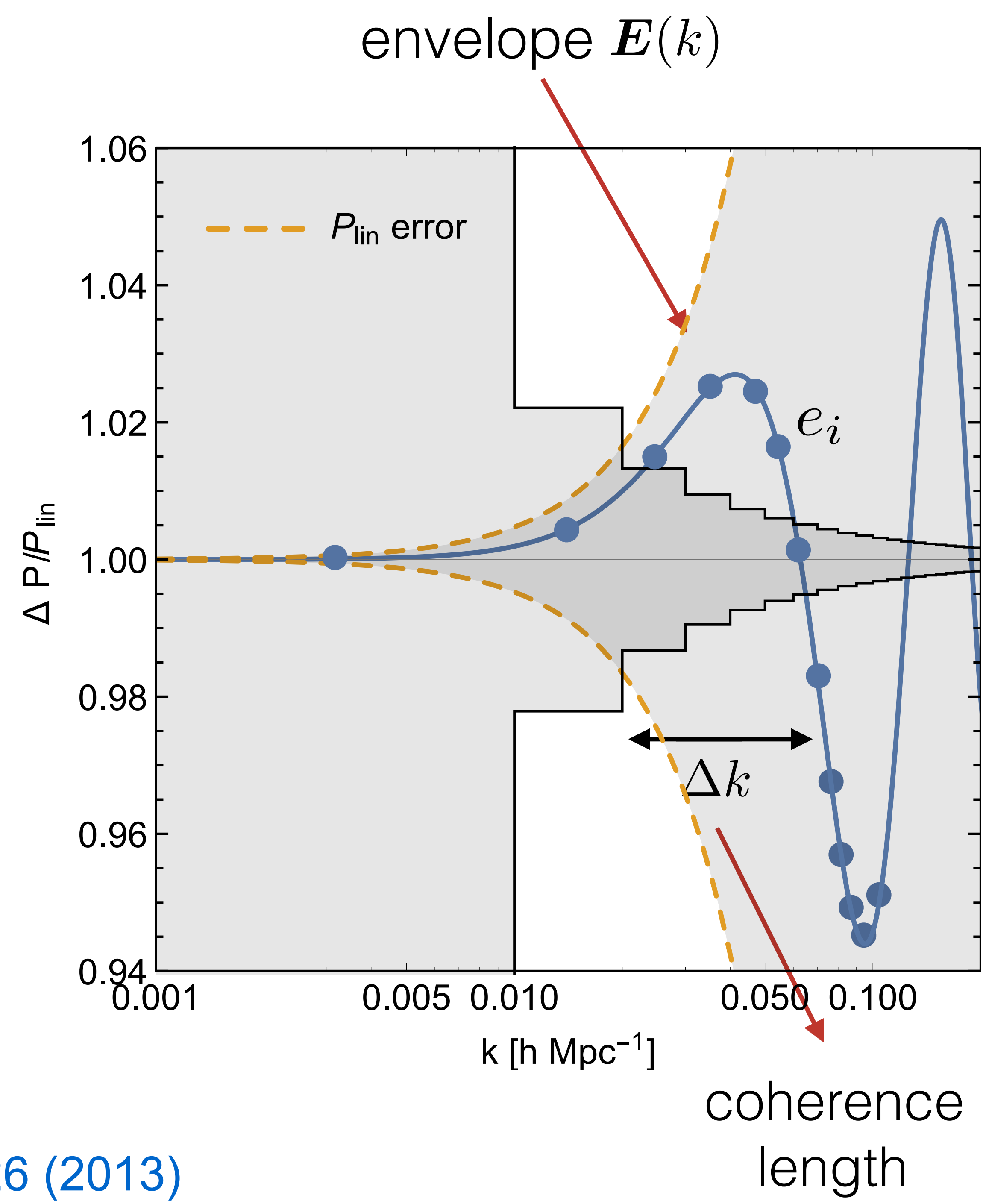
marginalize over all possible models with given $\boldsymbol{E}(k)$ and Δk

$$\mathcal{L}_e = \frac{1}{\sqrt{(2\pi)^{N_c}|C_d|}} \exp\left[-\frac{1}{2}(\boldsymbol{d}-\boldsymbol{t}_\mathrm{f}-\boldsymbol{e})C_d^{-1}(\boldsymbol{d}-\boldsymbol{t}_\mathrm{f}-\boldsymbol{e})\right] \times \frac{1}{\sqrt{(2\pi)^{N_c}|C_e|}} \exp\left[-\frac{1}{2}\boldsymbol{e}C_e^{-1}\boldsymbol{e}\right]$$

$$\mathcal{L} = \frac{1}{\sqrt{(2\pi)^{N_c}|C|}} \exp\left[-\frac{1}{2}(\boldsymbol{d}-\boldsymbol{t})C^{-1}(\boldsymbol{d}-\boldsymbol{t})\right]$$

$$C = C_d + C_e \qquad (C_e)_{ij} = E_i \rho_{ij} E_j$$

$$\rho_{ij} = \begin{cases} \exp\left[-(k_i-k_j)^2/2\Delta k^2\right] & P\,, \\ \prod_{\alpha=1}^{3} \exp\left[-(k_{i,\alpha}-k_{j,\alpha})^2/2\Delta k^2\right] & B\,. \end{cases}$$



A different proposal (without coherence length)
Audern, Lesgourgues, Bird, Haehnelt, Viel, JCAP 1301, 026 (2013)

Results

— The model is one-loop power spectrum + one-loop bispectrum

$$P(k) + P^{1-\mathrm{loop}}(k)$$

two joint analyses

$$B^{\mathrm{tree}}(k_1, k_2, k_3) + B^{1-\mathrm{loop}}(k_1, k_2, k_3)$$

— Bias model $\delta_g = b_1 \delta + \frac{b_2}{2} \delta^2 + b_{\mathcal{G}_2} \mathcal{G}_2 + \cdots$

— The set of parameters in the model

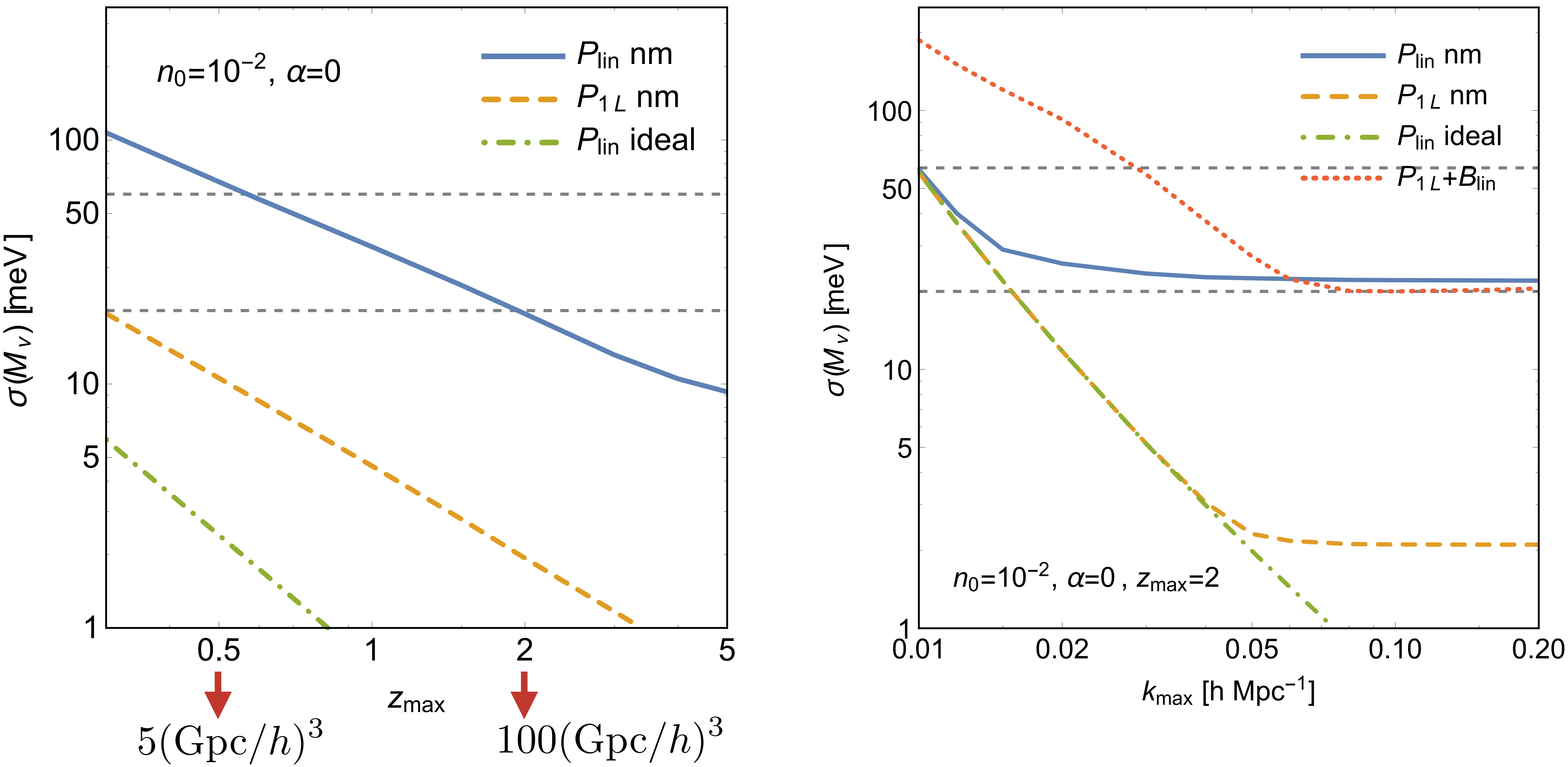
$$\boldsymbol{p} = \{f_{\mathrm{NL}}, M_\nu, A, R_p, R_b, b_1, b_2, b_{\mathcal{G}_2}, b_{\Gamma_3}\}$$

— f_{sky}=0.5, 0<z<5, constant nuisance parameters (very optimistic)

— Our choice of coherence length $\Delta k = 0.05\ h\mathrm{Mpc}^{-1}$

Results — neutrinos

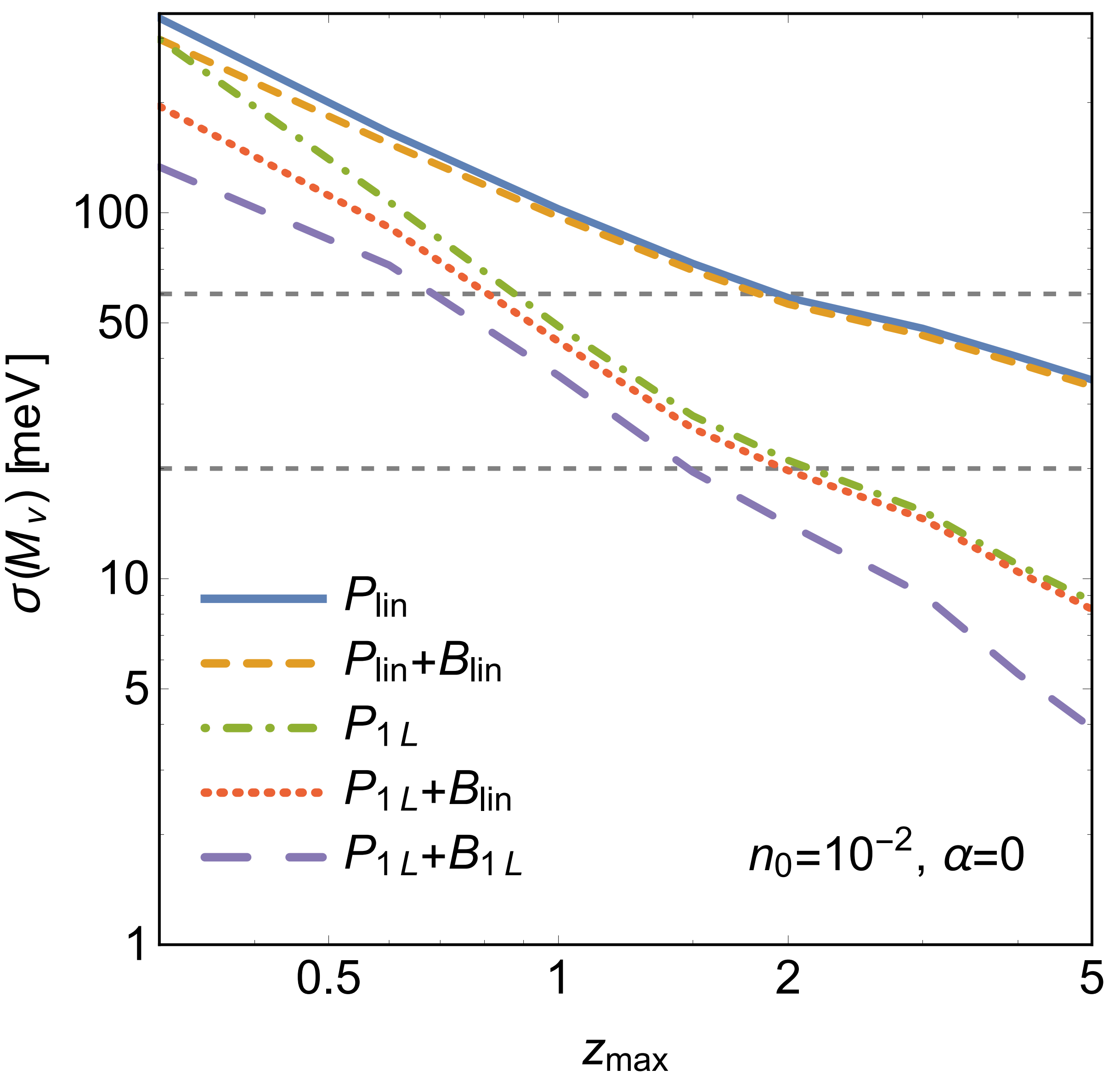
— Without marginalization over nuisance parameters



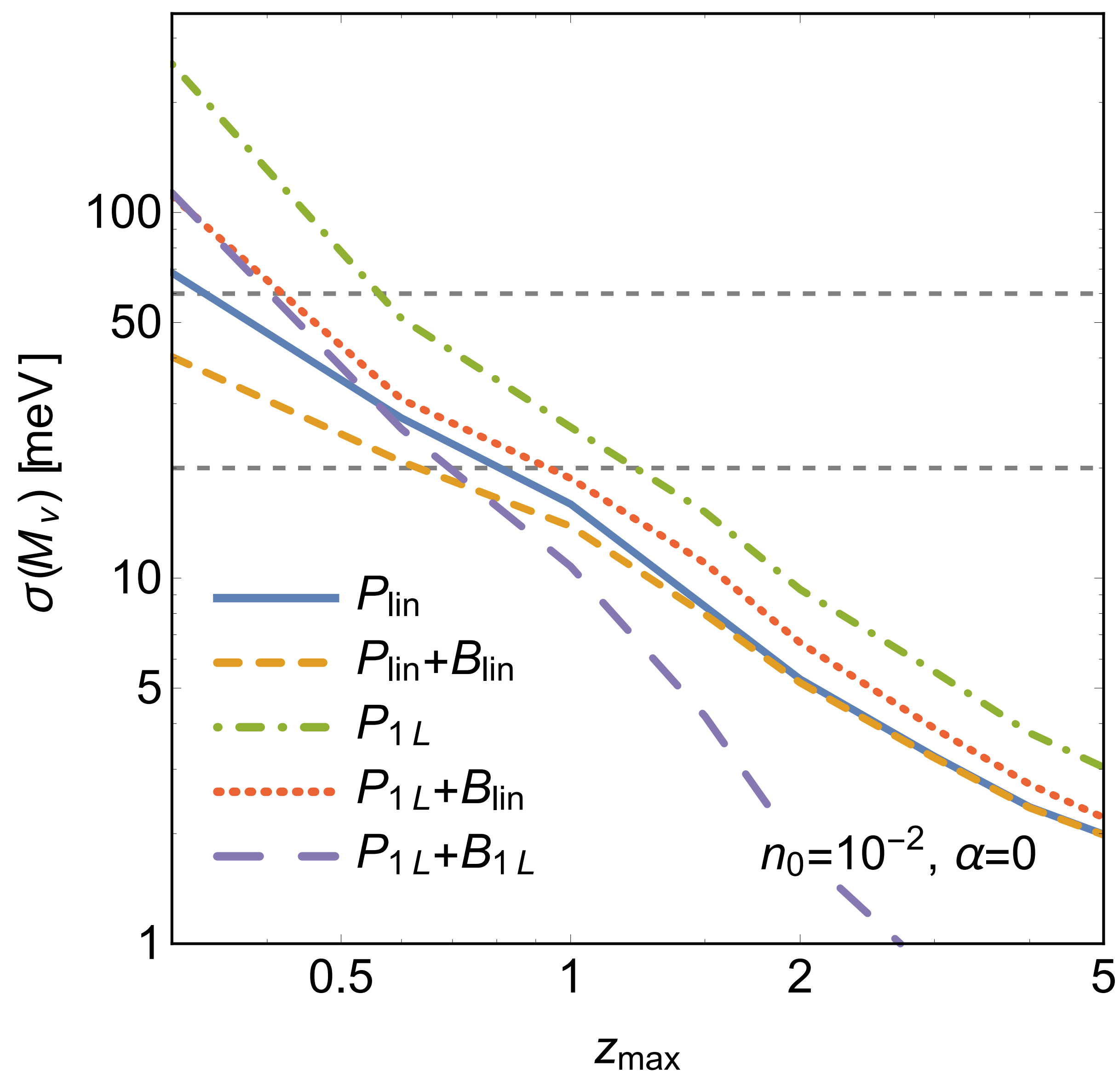
Results — neutrinos

— Marginalizing over all nuisance parameters

with theoretical error



without theoretical error



Results — neutrinos

— 1-loop enough for S3

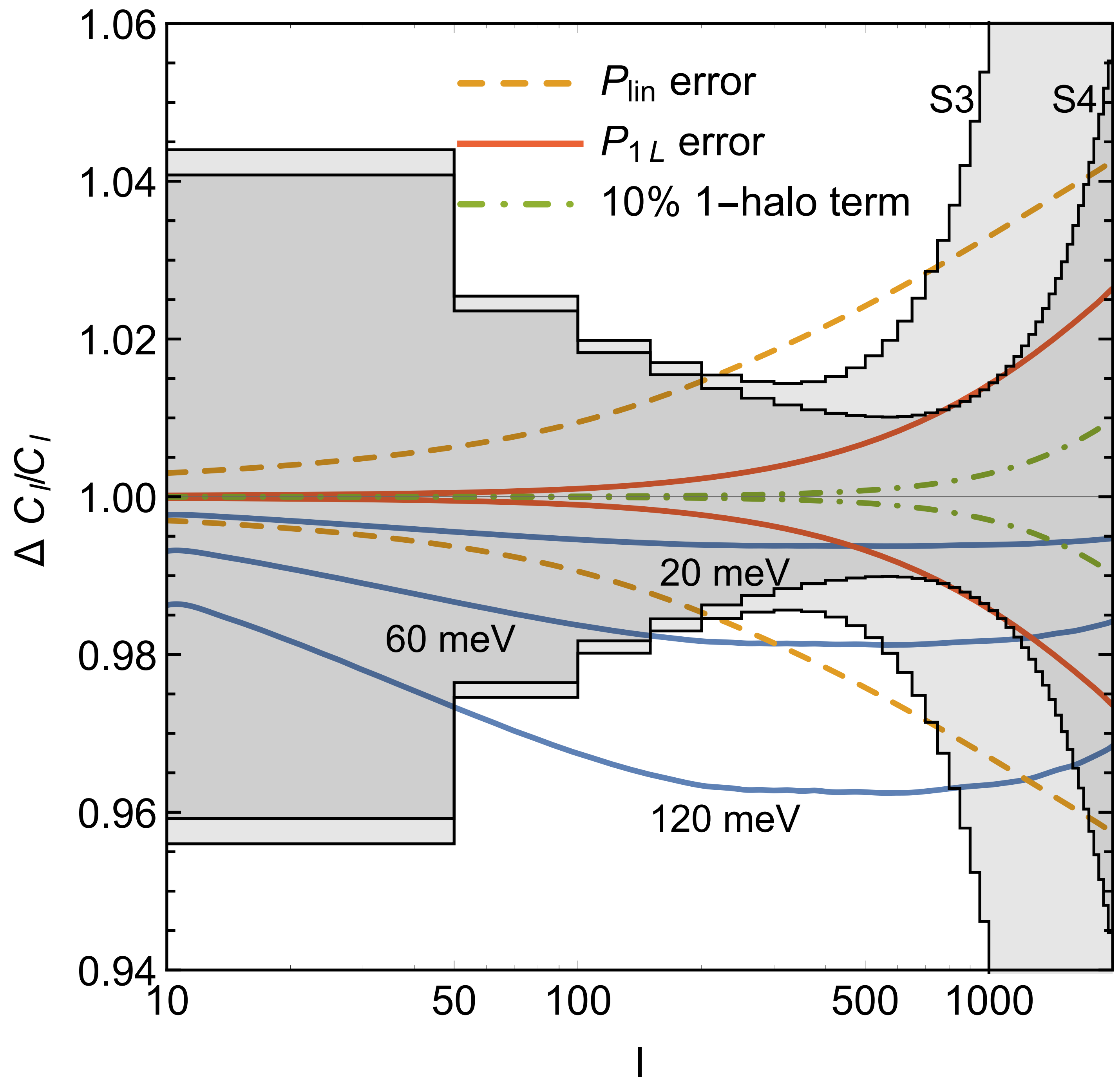
— 2-loops enough for S4

— Results strongly depend on priors for the amplitude

$$\sigma(M_\nu) \sim 30 \text{ meV}$$

with

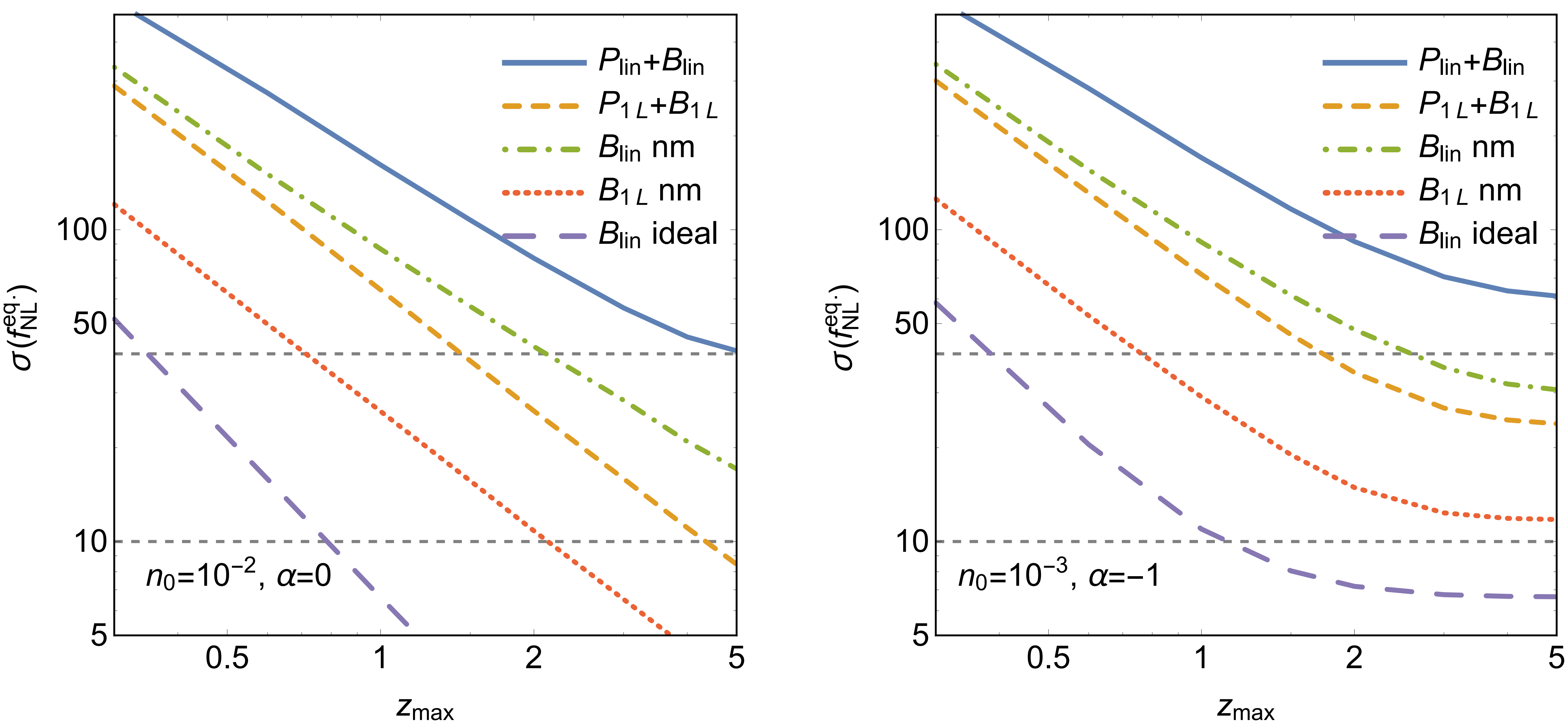
$$\sigma_A = 0.5\%$$



Results — equilateral NG

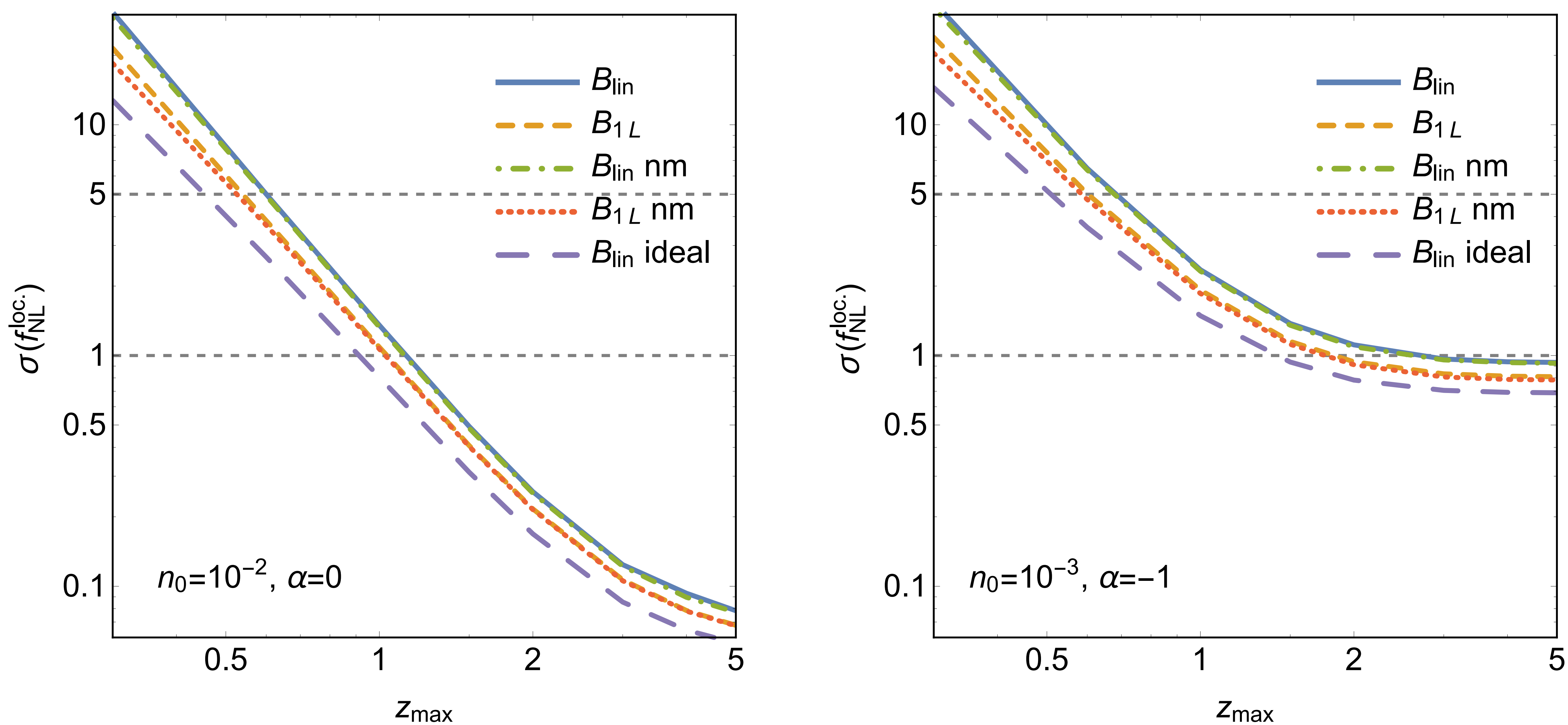
$$B^{\rm eq.}(k)/P^2(k) \sim f_{\rm NL}^{\rm eq.}\frac{9H_0^2\Omega_{\rm m}}{k^2T(k)D_+(0)} \qquad \text{vs.} \qquad B^{\rm grav.}_{l-{\rm loop}}(k)/P^2(k) \sim (k/k_{\rm NL})^{(3+n)l}$$

— Hard to improve the CMB limits! (important for future surveys, like SPHEREx)



Results — local NG

— Local NG have characteristic shape protected by the Equivalence Principle



Conclusions

— Theoretical errors present in PT and simulations, O(1%)

— They should be included in the likelihood as any other uncertainty

— Consistent way to include relevant systematics

— Consistent way to avoid biased results in data analysis

— A more detailed study needed

more realistic forecasts
the real size of errors in the bispectrum
different shapes of primordial NG
the correct coherence length
how well simulations do?