SEARCHING FOR LOCAL CUBIC-ORDER NON-GAUSSIANITY WITH GALAXY CLUSTERING

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ARE PRIMORDIAL FLUCTUATIONS (NON-)GAUSSIAN ?

- Single field slow roll inflation gives thus far the best fit to cosmic microwave background (CMB) and large scale structure (LSS) data. It predicts a negligible level of primordial non-Gaussianity (NG)
- Any evidence for or against primordial NG would strongly constrain mechanisms for the generation of primordial curvature perturbations.

cf. Leonardo Senatore's talk on Tuesday

OUTLINE

- Primordial NG of the local cubic type
- Scale-dependent bias of dark matter haloes
- Constraints on a cubic order contribution
- Optimal weighting schemes of halo/mass density fields

Desjacques V., Seljak U., 2010, PRD, 81, 3006 (arXiv:0907.2257)

Seljak U., Hamaus N., Desjacques V., 2009, PRL, 103, 1303 (arXiv:0904.2963)

Hamaus N., Seljak U., Desjacques V., in progress

PRIMORDIAL NG OF THE LOCAL CUBIC TYPE

- Local mapping: $\Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\rm NL}\phi(\mathbf{x})^2 + g_{\rm NL}\phi(\mathbf{x})^3$ (Salopek & Bond 1990;...)

  ϕ Gaussian, $|\phi| \sim 10^{-5}$, $P_\phi(k)\ k^{n_s-4}$

  $\mathcal{O}(f_{\rm NL}) \sim \mathcal{O}(g_{\rm NL})$

- In some models, $|f_{\rm NL}| \ll |g_{\rm NL}|$ so that the cubic order contribution dominates

Sasaki, Valiviita & Wands (2006); Enqvist & Takahashi (2008); Huang & Wang (2008); Chingangbam & Huang (2009); Ichikawa, Suyama, Takahashi & Yamaguchi (2008); Huang (2008,2009); Byrnes & Tasinato (2009); Lehners & Renaux-Petel (2009);...

- Leading contribution to the primordial four-point (trispectrum) function:

$$T_\Phi(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3,\mathbf{k}_4) = 6g_{\rm NL}\left[P_\phi(k_1)P_\phi(k_2)P_\phi(k_3) + ({\rm cyclic})\right]$$
$$+4f_{\rm NL}^2\left[P_\phi(k_{13}P_\phi(k_3)P_\phi(k_4) + (11\ {\rm perms})\right]$$

PROBES OF PRIMORDIAL NG: CMB AND LSS

- CMB advantage: linearity

$$a_\ell^m = 4\pi(-i)^\ell \int \frac{d^3\mathbf{k}}{(2\pi)^3} \Phi(\mathbf{k}) g_{T\ell}(k) Y_\ell^{m\star}(\hat{\mathbf{k}})$$

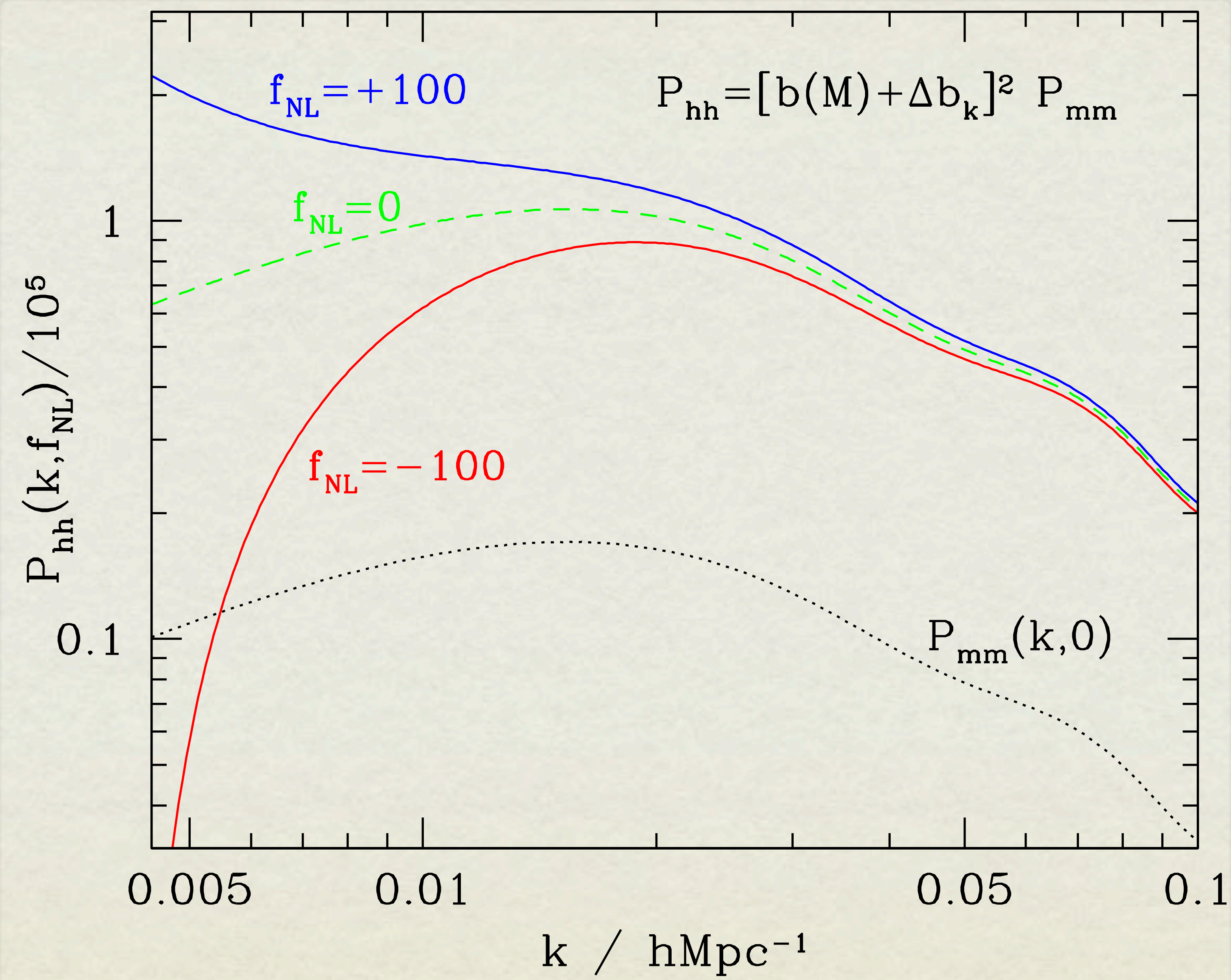
- LSS advantage: biasing

$$\delta_{\rm g} = b_1 \delta_{\rm m} + \frac{b_2^2}{2} \delta_{\rm m}^2 + \cdots$$

SCALE-DEPENDENT BIAS IN THE LOCAL f_{NL} MODEL

Dalal, Dore, Huterer & Shirokov (2008); Matarrese & Verde (2008)

$$\Delta_\kappa(k, f_{\rm NL}) = 3 f_{\rm NL}\,[b(M) - 1]\,\delta_c \frac{\Omega_m H_0^2}{k^2 T(k) D(z)}$$



TESTING THE THEORY WITH N-BODY SIMULATIONS

- 1024^3 particles in a periodic cubic box of size L=1600 Mpc/h (simulations described in Desjacques, Seljak & Iliev 2009; Desjacques & Seljak 2010)

- Several realisations of the following models

$$(f_{\rm NL}, g_{\rm NL}) = (\pm 100, 0)$$

$$(f_{\rm NL}, g_{\rm NL}) = (0, \pm 10^6)$$

$$(f_{\rm NL}, g_{\rm NL}) = (\pm 100, -3 \times 10^5)$$

- Identify dark matter haloes with a spherical overdensity (SO) finder

- Compute halo and dark matter auto- and cross-power spectrum

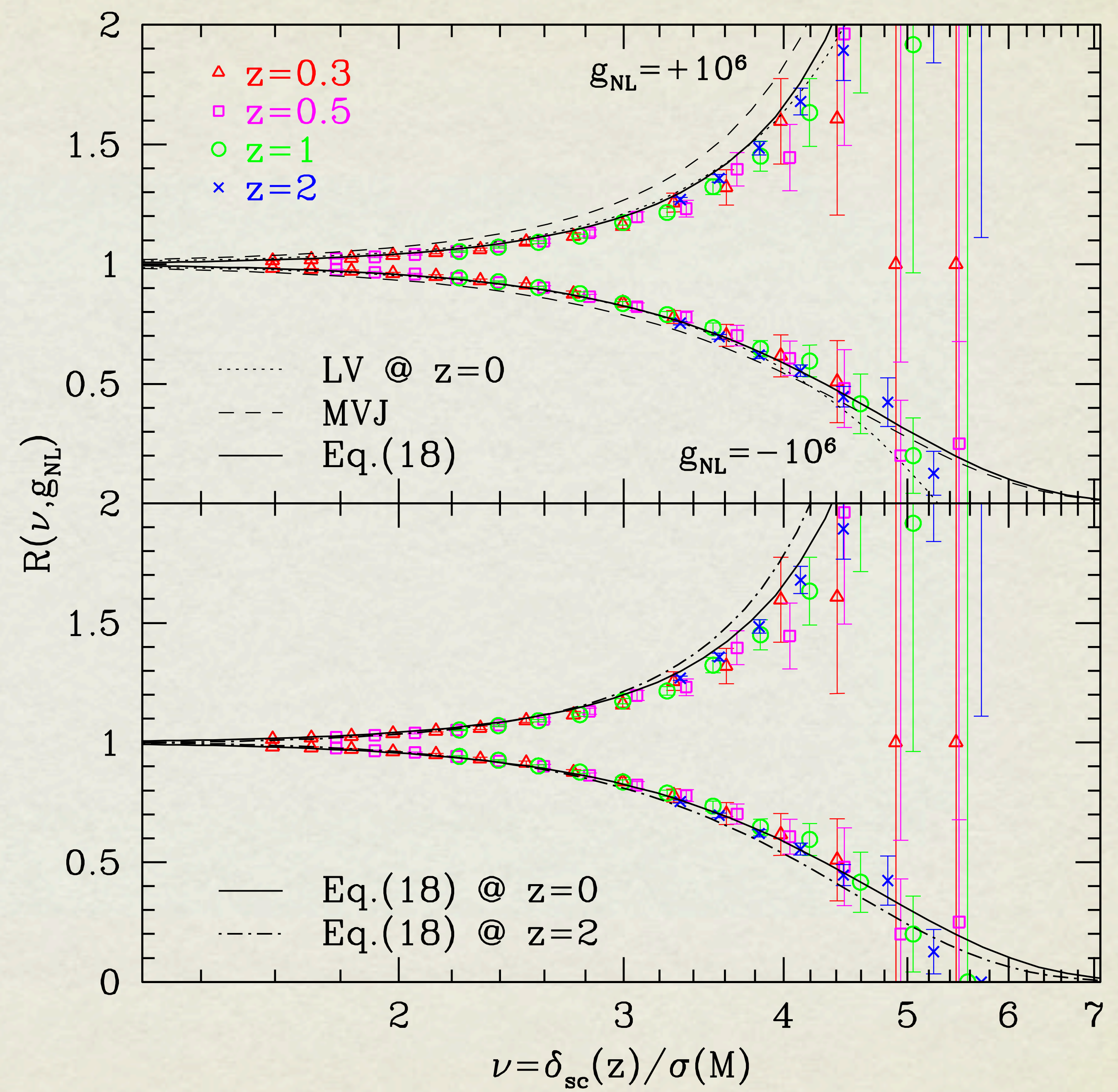
HALO MASS FUNCTION

The solid curve (Eq.18) is

$$R(\nu, g_{\rm NL}) = \exp\left[\frac{\nu^4}{4!}\sigma^2 S_4 + \nu^2 \delta\sigma_8\right]$$
$$\times \left\{1 - \frac{\nu^2}{4}\sigma S_4 - \frac{\nu^4}{4!}\frac{d(\sigma^2 S_4)}{d\ln\nu}\right\}$$

There is a first order correction to σ_8 because the simulations have identical primordial scalar amplitude

$$\delta\sigma_8 \approx 0.015$$



SCALE-DEPENDENT BIAS IN $g_{\rm NL}$ MODELS

- The scale-dependent bias contribution can be derived from the statistics of highly overdense regions

$$\xi_{\rm hh}(|\mathbf{x_1}-\mathbf{x}_2|) = -1 + \exp\left\{\sum_{n=2}^{\infty}\sum_{j=1}^{n-1}\frac{\nu^n\sigma^{-n}}{j!(n-j)!}\xi^{(n)}\left(\begin{array}{cc}\mathbf{x}_1,\cdots,\mathbf{x}_1, & \mathbf{x}_2,\cdots,\mathbf{x}_2\\ j\ \text{times} & (n-j)\ \text{times}\end{array}\right)\right\}$$

(Matarrese, Bonometto & Lucchin 1986)

- We find

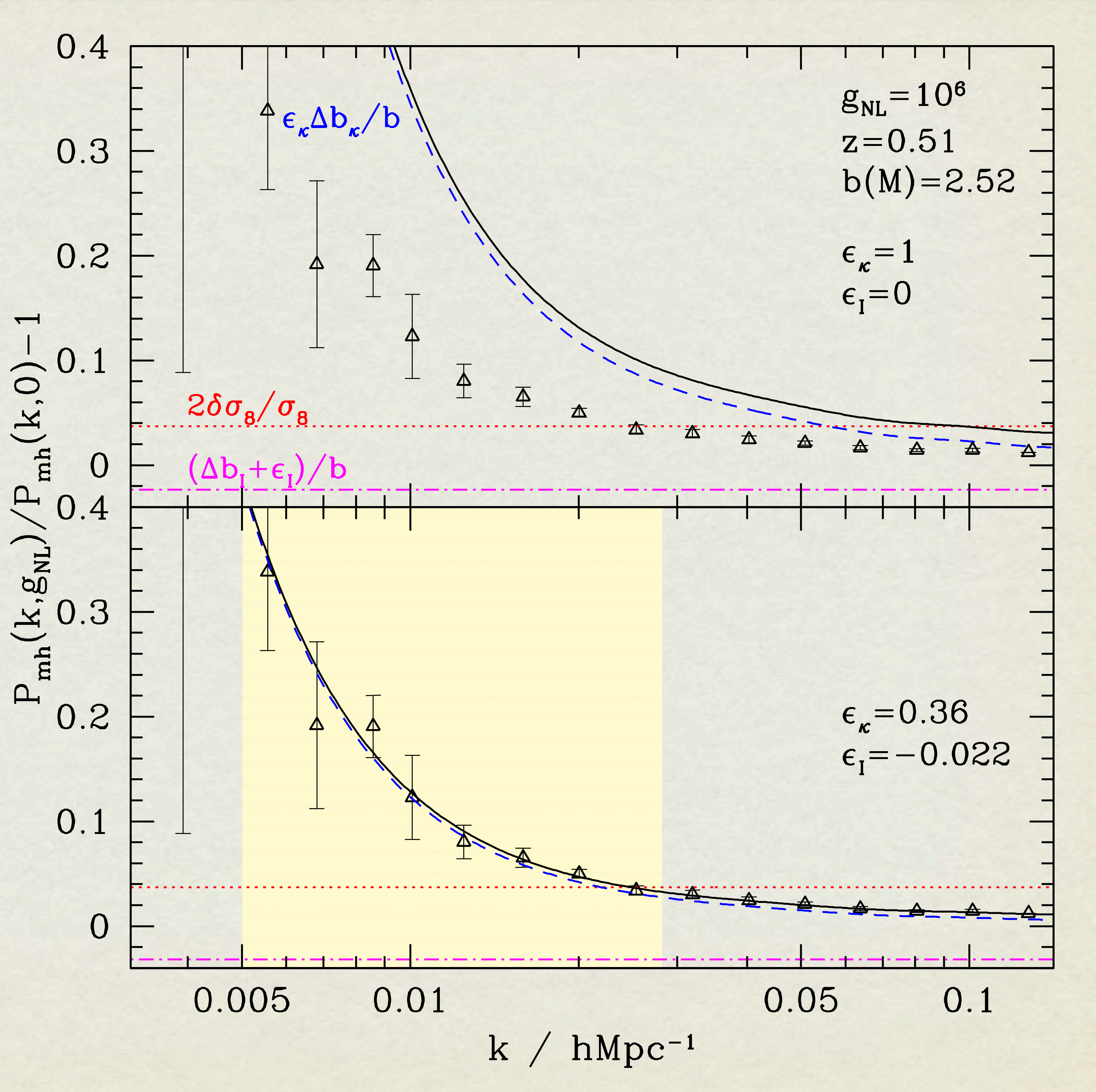
$$\Delta b(k, g_{\rm NL}) = \Delta b_\kappa(k, g_{\rm NL}) + \Delta b_{\rm I}(g_{\rm NL})$$

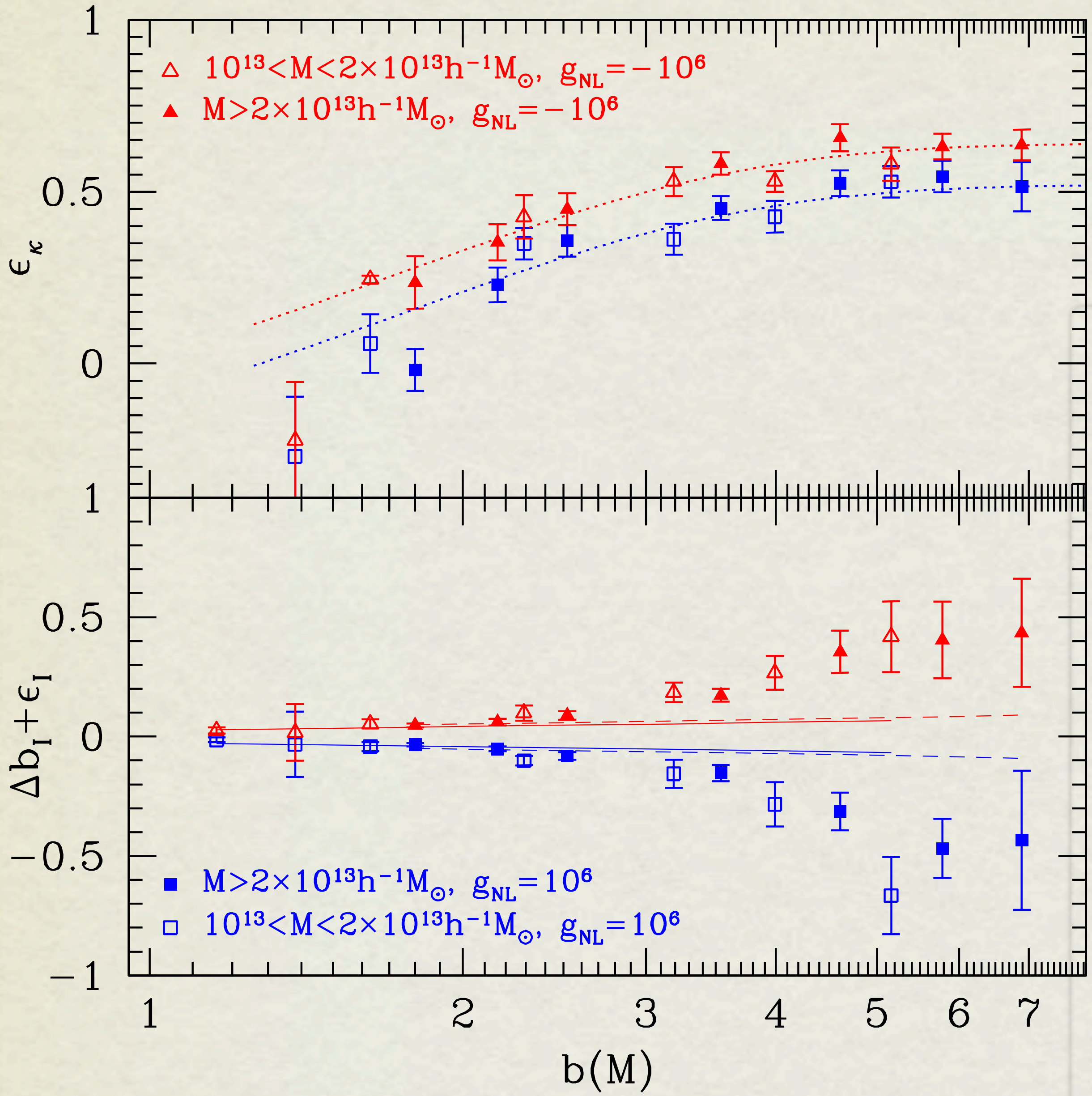
$$\Delta b_\kappa(k, g_{\rm NL}) = \frac{3}{4}\left(g_{\rm NL} S_3^{(1)}(M)\right)[b(M)-1]\,\delta_c^2\frac{D(0)}{D(z)}\frac{\Omega_m H_0^2}{k^2 T(k)}$$

$$|||$$

$$\text{skewness} \sim 10^{-4} g_{\rm NL}$$

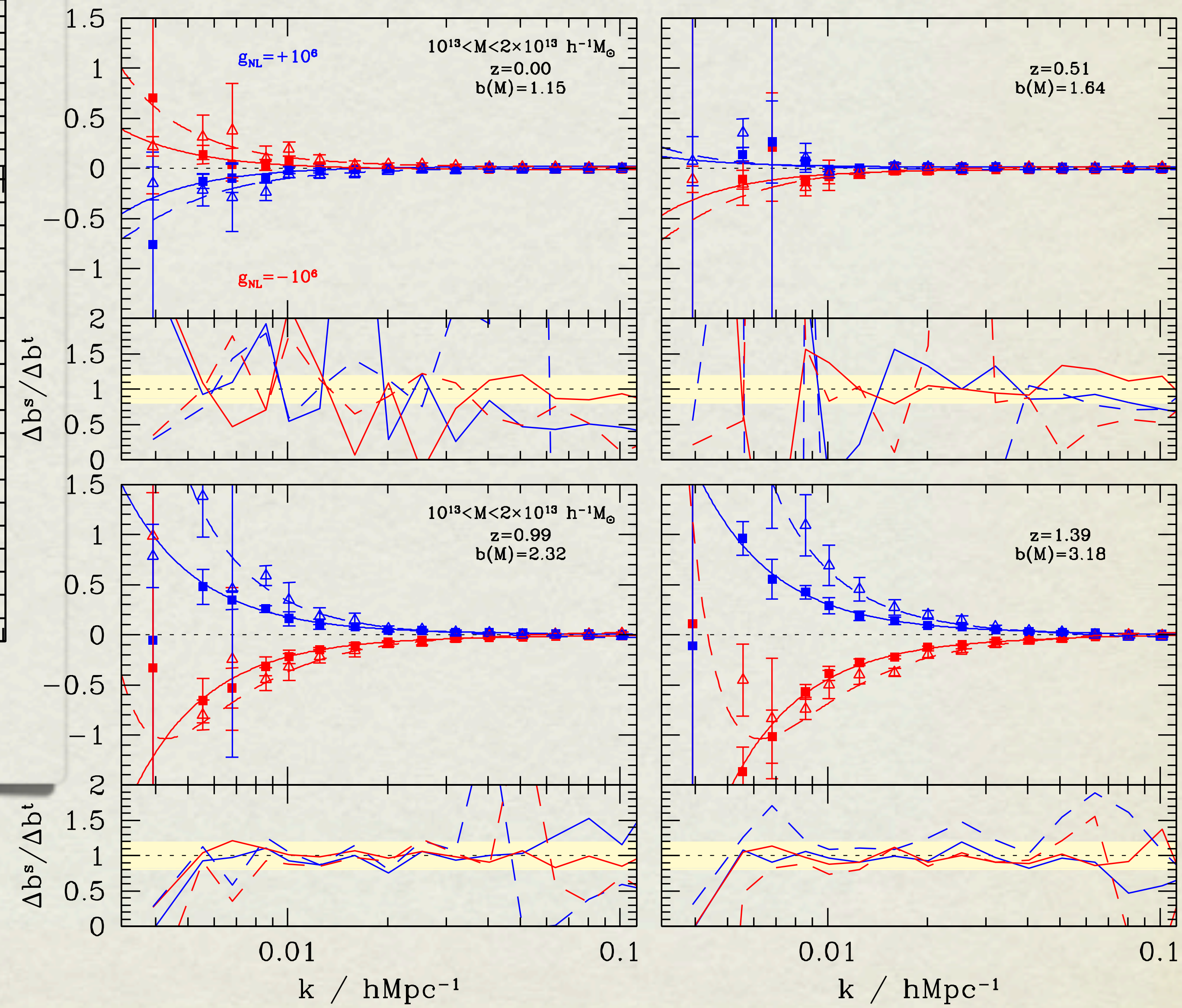
To match the simulations, we consider $\Delta b = \epsilon_\kappa \Delta b_\kappa + [\Delta b_{\rm I} + \epsilon_{\rm I}]$





Best-fit ε_κ and ε_I

Fractional non-Gaussian bias correction



$$\frac{\Delta b^s}{\Delta b^t} = \frac{\text{theory}}{\text{simulation}}$$

OBSERVATIONAL LIMITS ON g_{NL} FROM LSS

- We can translate the limits on f_{NL} obtained by Slosar et al. (2008) into limits on g_{NL} (assuming f_{NL}=0)

$$-3.5 \times 10^5 < g_{\rm NL} < 8.2 \times 10^5 \quad (95\% \text{ C.L.})$$

FORECAST FOR DETECTION OF g_{NL}

- Signal-to-noise for a survey of volume *V* centred at redshift *z*:

$$\left(\frac{S}{N}\right)^2 \approx 8.1 \times 10^{-13} g_{\rm NL}^2 \epsilon_\kappa^2 \left(1 - \frac{1}{b}\right)^2 D(z)^{-4} \left(\frac{S_3^{(1)}}{10^{-4}}\right)^2 \left(\frac{V}{h^{-3}{\rm Gpc}^3}\right)^{4/3}$$

- For a single population of tracers with bias *b(M)*=2, the miminum g_{NL} detectable is

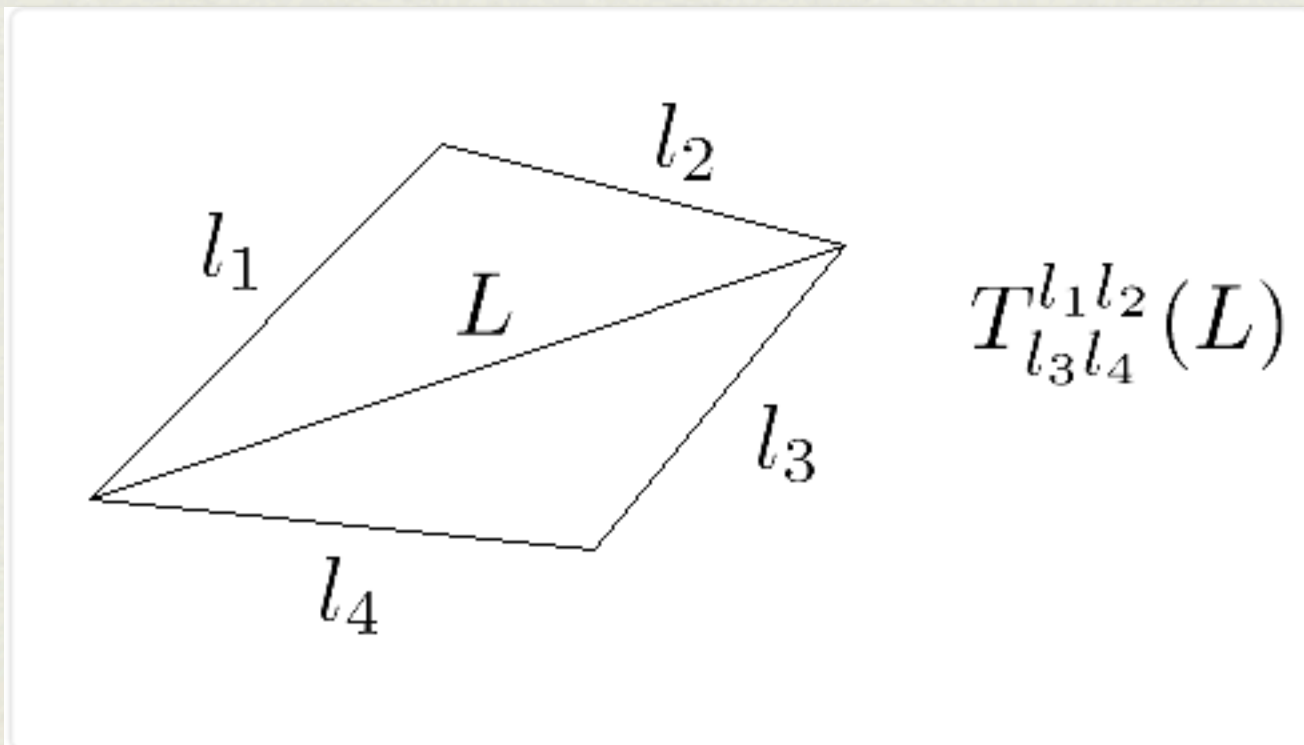
$$\sim 4 \times 10^5 \quad ({\rm BOSS})$$

$$\sim 2 \times 10^4 \quad ({\rm EUCLID})$$

g_{NL} FROM THE CMB TRISPECTRUM

- $g_{NL}\varphi^3$ generates a connected CMB trispectrum at first order

$$\langle a_{\ell_1}^{m_1} a_{\ell_2}^{m_2} a_{\ell_3}^{m_3} a_{\ell_4}^{m_4} \rangle = \sum_{L,M} (-1)^M \begin{pmatrix} \ell_1 & \ell_2 & L \\ m_1 & m_2 & -M \end{pmatrix} \begin{pmatrix} \ell_3 & \ell_4 & L \\ m_3 & m_4 & M \end{pmatrix} \left[Q_{\ell_3 \ell_4}^{\ell_1 \ell_2}(L) + T_{\ell_3 \ell_4}^{\ell_1 \ell_2}(L) \right]$$



Hu (2002)

- In the Sachs-Wolfe approximation and for cosmic variance dominated errors:

$$\left(\frac{S}{N}\right)^2 \simeq 3.15 \times 10^{-18} g_{\rm NL}^2 \left(\frac{A_s}{10^{-9}}\right)^2 \ell_{\rm max}^{2.6}$$

- No significant detection of a trispectrum would imply

$$|g_{\rm NL}| \leq 2 \times 10^5 \quad \text{(WMAP)}$$

$$|g_{\rm NL}| \leq 1.3 \times 10^4 \quad \text{(PLANCK)}$$

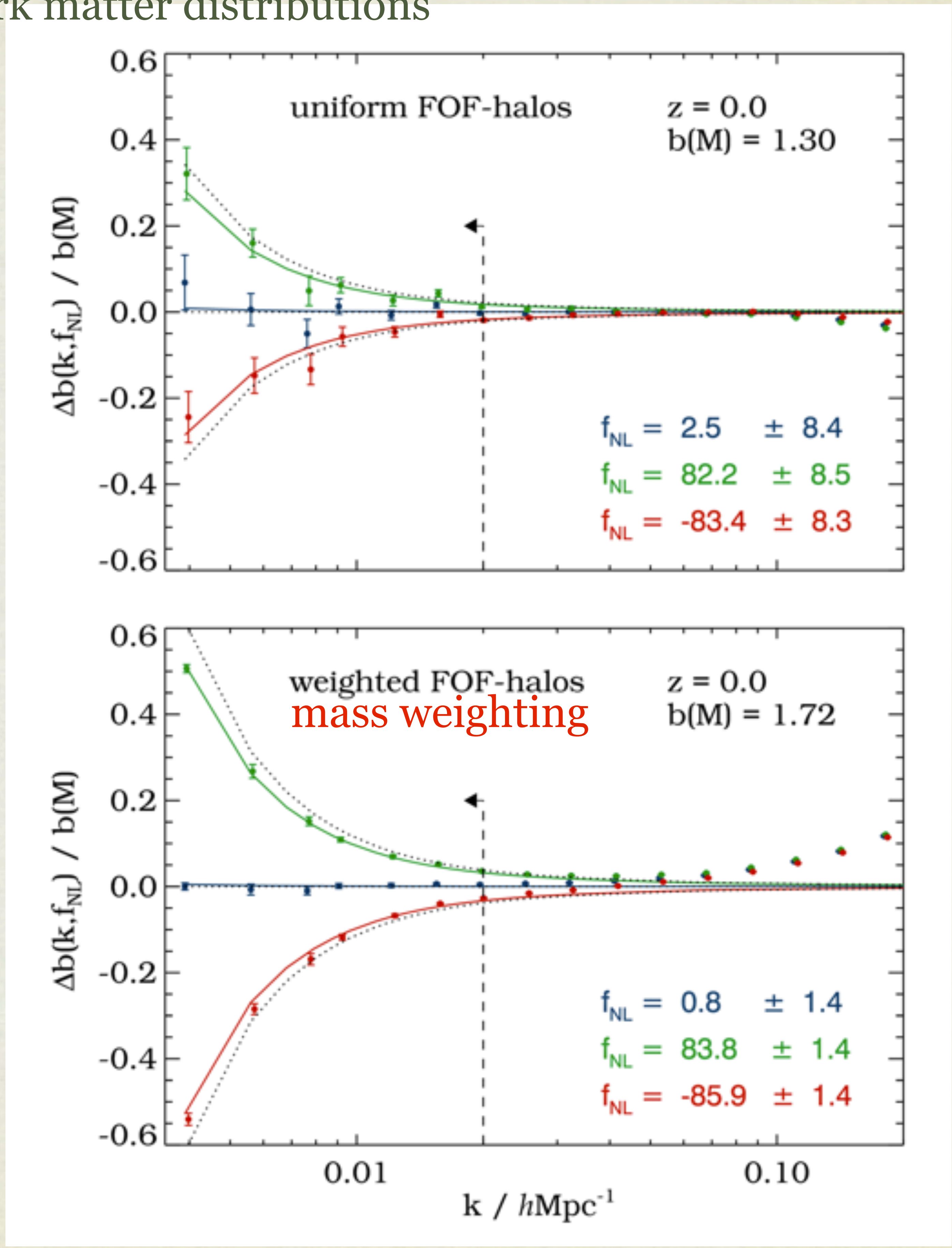
TIGHTENING CONSTRAINTS WITH OPTIMAL WEIGHTING

- A measurement of the galaxy power spectrum implies two sources of errors: cosmic variance (limited number of modes accessible) and shot noise (discreteness of the tracers)

- Taking the ratio of measurements obtained with two different tracer populations can take out most of cosmic variance (Seljak 2008), but there are residual fluctuations induced by discrete sampling

- Mass weighting can considerably reduce the shot noise level (Seljak, Hamaus & Desjacques 2009)

Idealized case: we know the halo *and* dark matter distributions



- Error bars go down by a factor of ~ 5
- Note also that central values are lower that input $f_{NL}=\pm 100$

CONCLUSION

- The statistics of thresholded regions can be used to predict the scale-dependent bias for local cubic primordial NG

- In contrast to models with the quadratic coupling $f_{NL}\varphi^2$, the theory strongly overestimates the effect for the cubic coupling $g_{NL}\varphi^3$

- The power spectrum of SDSS quasars sets limits on g_{NL},

$$-3.5 \times 10^5 < g_{\rm NL} < 8.2 \times 10^5 \quad (95\% \text{ C.L.})$$

- Future galaxy surveys will improve these limits by a factor of 10-100

- Optimal weighting of several tracers populations may further improve the constraints by a factor of a few