I. INTRODUCTION

The standard paradigm of structure formation relies on the inflationary scenario. As shown in several inflationary models involving the existence of a primordial non-Gaussianity. A detection or exclusion of non-Gaussianities would hence be of fundamental interest for the understanding the physics of the primordial Universe. Several cosmological observables and methods can be used to constrain non-Gaussianities.

Cosmic Microwave Background (CMB) anisotropies provide the most direct method for the detection of primordial non-Gaussianity, through measurements of the three-point correlation function (or equivalently the bispectrum) which is non-zero in presence of non-Gaussianities. The large scale structure of the Universe is also affected by non-Gaussianities that may be detected by looking at the bispectrum or the trispectrum of galaxy distribution. The abundance of galaxy clusters, that depends on the tails of the density probability distribution, is also sensitive to any deviation from gaussianity. Non-Gaussianity has a direct impact on the clustering of dark matter halos by changing their mass and correlation function. A common way to parameterize primordial non-Gaussianities is to introduce a quadratic correction to the potential:

\[ \Phi = \phi + f_{NL}(\phi^2 - \langle \phi^2 \rangle) \] (1)

where \( \Phi \) is the primordial potential and \( \phi \) is a gaussian random field. In this case the non-Gaussianity is a local type correction whose amplitude is given by \( f_{NL} \). The most recent constraint on \( f_{NL} \) from CMB gives \( -10 < f_{NL} < +74 \) at 95\% C.L. from bispectrum analysis of WMAP-7 years data, improving the WMAP5 constrain \( -9 < f_{NL} < +111 \). The authors of used a different estimator applied to WMAP5 data, finding \( f_{NL} = -13 \pm 62 \) at 68\% C.L., while using the needlet bispectrum applied to the same data, found \( f_{NL} = +84 \pm 40 \) at 68\% C.L.. In it has been shown that a quadratic correction to the potential like that of equation (1) produces a scale dependence in the bias of the galaxy clustering with respect to matter distribution. In particular, a scale dependent term \( \Delta g(k) \) arises in the halo bias on larger scales (smaller \( k \)) and is proportional to \( f_{NL} (\Delta g(k) \propto f_{NL}/k^2) \) hence with galaxies being more (less) clustered for positive (negative) values of \( f_{NL} \). The authors of analyzed the galaxy power spectrum of luminous red galaxies (LRG) of the Sloan Digital Sky Survey (SDSS) to constrain this scale dependence of the bias, putting the constraint \( -21 < f_{NL} < +209 \) at 95\% C.L.. In the same work other large scale datasets have been used to constrain non-gaussianity (Quasars, integrated Sachs-Wolfe effect data and photometric LRG sample) finding \(-29 < f_{NL} < +70 \) at 95\% C.L. from the combination of all datasets. Recently, the authors of obtained \( +25 < f_{NL} < +117 \) at 95\% C.L. from the combination of WMAP-7 years data, Baryonic Oscillations data from SDSS and Two-degree Field Galaxy Redshift Survey (2dFGRS) and Supernovae distance moduli measurements, with auto correlation function measurements of radio sources from NRAO VLA Sky Survey, claiming a detection of non gaussianity at \( \sim 3\sigma \).

In this paper we follow the methodology and constrain \( f_{NL} \) by looking at the scale dependence of the bias in current galaxy surveys data. We implement the calculation of galaxy and halo power spec-
trum using the halo-model (see [39] and section [H]) and we include in it the non-Gaussian scale-dependent correction to the bias. We then place constraints on $f_{NL}$ by comparing this model to the Sloan Digital Sky Survey (SDSS) [40] galaxy power spectrum data [41] and to the halo power spectrum data obtained from the luminous red galaxies (LRG) sample [42]. We include in the analysis the WMAP-7 years cosmic microwave background anisotropy data [27]. We also fit the LRG galaxy power spectrum data to the same model, including Hubble constant measurements from Hubble Space Telescope (HST, [43]) and Supernovae distance moduli measurements for the Union dataset [37]. Results are shown in section [III]. We finally forecast the power of future Galaxy surveys in constraining non-gaussianity by generating mock data for galaxy power spectrum using specifications of EUCLID [44] survey combined with mock data from Planck [45] satellite and showing in section [IV] that the combination of data from these experiments could reach the precision required to detect even small non-Gaussianities.

II. HALO-MODEL

In the halo model scenario (see [39] for a detailed review) all matter is contained in halos and, as a consequence, the abundance of halos, their spatial distribution and their internal density profiles are closely connected to the initial dark matter fluctuation field. Under the assumption that galaxies are formed in these halos of dark matter [46] it is then possible to use the halo model to calculate the statistical properties of distribution of galaxies. To this aim, the basic quantity is the halo occupation distribution (HOD, see [37]) that encodes the information on how galaxies populate dark matter halos as a function of halo mass. The statistical information is contained in the two-point correlation function of galaxies or equivalently its Fourier transform, the galaxy power spectrum. It is hence important to assess the number of pairs of galaxies in an individual halo and the number of pairs of galaxies in separate halos. The former can be shown to be related to the variance of the HOD, $\sigma^2(M, z) = \langle N_g(N_g - 1) \rangle$ while the latter is the square of the mean halo occupation number $N(M, z) = \langle N_g \rangle$. The galaxy power spectrum is then the sum of the 1-halo term describing pairs of objects in the same halo and of 2-halo term for objects in different halos: $P(k, z) = P_{1h}(k, z) + P_{2h}(k, z)$. The two terms can be written as:

$$P_{1h}(k, z) = \frac{1}{n_{gal}^2(z)} \times$$

$$\int dM n_{halo}(M, z) u_{DM}(k, M, z) \sigma^2(M, z),$$

$$P_{2h}(k, z) = \frac{P_0(k, z)}{n_{gal}^2(z)} \times$$

$$\left[ \int dM n_{halo}(M, z) N(M, z) b(M, z) u_{DM}(k, M, z) \right]^2$$

where $n_{halo}$ is the halo mass function [48], $u_{DM}(k, M, z)$ is the normalized dark matter halo density profile in Fourier space, $P_0(k, z)$ is the linear dark matter power spectrum, $b(M, z)$ the linear bias parameter and $n_{gal}$ is the mean galaxy number per unit of comoving volume:

$$n_{gal}(z) = \int dM n_{halo}(M, z) N(M, z).$$

For low occupied halos ($N(M, z) < 1$) the exponent $\rho$ of the density profile in the (2) is equal to 1 while it is equal to 2 otherwise [39]. To calculate the two terms (2) and (3) it is necessary to assume a form for the HOD. We choose the parameterization described in [19], [50] where the HOD consists of two separated contributions for central and for satellite galaxies:

$$\langle N_{cen}(M) \rangle = \frac{1}{2} \text{Erfc} \left[ \frac{\ln(M_{min}/M)}{\sqrt{2}\sigma_{cen}} \right]$$

$$\langle N_{sat}(M) \rangle = \left[ \frac{M - \gamma M_{min}}{M_1} \right] \alpha$$

where $M_{min}$, $M_1$, $\sigma_{cen}$, $\gamma$ and $\alpha$ are free parameters of the model. In this description the mean occupation number of central galaxies is modeled as a smoothed step function above the minimum mass $M_{min}$ while satellite galaxies follow a Poisson distribution with a mean given by a power low and a cut-off at multiple $\gamma$ of the minimum mass. This 5-parameters model showed a good agreement with hydrodynamical and N-body simulations and semi-analytic models [51], [52], [53].

For the halo density profile $u_{DM}(k, M, z)$ we choose the shape of the Navarro, Frenk & White profile (NFW) [48]. The variance of the HOD can be calculated as in [55]:

$$\sigma^2(M, z) = N(M, z), \quad N(M, z) > 1 \quad \text{and} \quad \sigma^2(M, z) = \beta(M)^2 N(M, z), \quad N(M, z) < 1 \quad (6)$$

with $\beta(M, z) = \log_{10}(M/M_{min})/\log_{10}(M_0/M_{min})$ and $M_0$ is the mass at which the mean occupation number is equal to 1. This parameterization of $\sigma^2(M, z)$ has been shown to have a good agreement with both semi-analytic models and hydrodynamical simulations [50], [57].

The halo mass function is given by the Press & Schechter relation [58]:

$$\frac{M^2 n_{halo}(M, z) dM}{\rho} = \nu f(\nu) \frac{d\nu}{\nu} \quad (8)$$
where $\bar{\rho}$ is the background comoving density and $\nu$ is defined as the ratio between the critical density required for spherical collapse at redshift $z$ ($\delta_{sc}(z)$) and the variance of the initial density fluctuation field $\sigma_0(M)$: $\nu = \delta_{sc}(z)/\sigma_0^2(M)$. Here we choose the Sheth-Tormen model\cite{59} for the shape of $\nu f(\nu)$:

$$\nu f(\nu) = A(p)(1 + (q\nu)^p) \left(\frac{q\nu}{2\pi}\right)^{1/2} \exp\left(-\frac{q\nu}{2}\right)$$

(9)

with $p \sim 0.3$, $A(p) \sim 0.3222$ and $q \sim 0.75$. The linear bias $b(M, z)$ is then given by\cite{59,60}:

$$b(M, z) = 1 + \frac{q\nu - 1}{\delta_{sc}(z)} + \frac{2p/\delta_{sc}(z)}{1 + (q\nu)^p}$$

(10)

### A. Non-Gaussian corrections

The halo model described so far allows the calculation of the galaxy power spectrum starting from the assumption of Gaussian primordial fluctuations. The existence of deviations from gaussianity determines a correlation between small-scale and large scale perturbations because of the quadratic correction $f_{NL}\delta^2$ (in the case of local non-gaussianities we are considering here) that appear in the potential\cite{61,22}. As shown in\cite{31,33,34} the effect of non-Gaussian fluctuations on the galaxy power spectrum appears on large scales through a scale dependent correction of the halo bias. Following\cite{34} we write this correction as:

$$\Delta b(M, z, k) = \frac{3\Omega_m H_0^2}{c^2 k^2 T(k) G(z)} f_{NL} \frac{\partial \ln n_{halo}}{\partial \ln \sigma_8}$$

(11)

that reduces to:

$$\Delta b(M, z, k) = \frac{3\Omega_m H_0^2}{c^2 k^2 T(k) G(z)} f_{NL} (b - r) \delta_{sc}$$

(12)

| $WMAP7 + LRG$ | $WMAP7 + LRG + HST + SNe$ |
|-----------------|-----------------------------|
| $10^2\Omega_b h^2$ | $2.241^{+0.065}_{-0.063}$ | $2.263^{+0.055}_{-0.054}$ |
| $\Omega_c h^2$ | $0.1103^{+0.0047}_{-0.0047}$ | $0.1123^{+0.0036}_{-0.0035}$ |
| $\theta$ | $0.010395^{+0.000032}_{-0.000030}$ | $0.010396^{+0.000028}_{-0.000027}$ |
| $\tau$ | $0.088^{+0.00075}_{-0.00072}$ | $0.087^{+0.00065}_{-0.00062}$ |
| $n_s$ | $0.964^{+0.014}_{-0.012}$ | $0.965^{+0.013}_{-0.012}$ |
| $ln(10^{10} A_s)$ | $3.08^{+0.04}_{-0.04}$ | $3.08^{+0.03}_{-0.04}$ |
| $h$ | $0.715^{+0.021}_{-0.021}$ | $0.705^{+0.016}_{-0.015}$ |
| $\sigma_8$ | $0.800^{+0.028}_{-0.029}$ | $0.812^{+0.025}_{-0.025}$ |
| $\log(M_{min})$ | $13.90^{+0.16}_{-0.16}$ | $14.19^{+0.12}_{-0.12}$ |
| $\alpha$ | $0.85^{+0.20}_{-0.18}$ | $0.83^{+0.17}_{-0.18}$ |
| $\gamma$ | $9.97^{+0.53}_{-5.6}$ | $10.7^{+0.51}_{-5.1}$ |
| $\sigma_{cen}$ | $1.00^{+0.57}_{-0.57}$ | $1.09^{+0.56}_{-0.56}$ |
| $\log(M_1)$ | $12.0^{+2.7}_{-2.4}$ | $12.3^{+2.7}_{-2.6}$ |
| $f_{NL}$ | $171^{+140}_{-130}$ | $202^{+129}_{-140}$ |

TABLE I: Best fit values and 68% C.L. errors on the parameters of our model for $WMAP7 + LRG$ and $WMAP7 + LRG + SNe + HST$ data. The combination with SNe ans HST data improves only slightly the constraints.
FIG. 3: 68% and 95% C.L. contour plots and likelihoods for $f_{NL}$ and other parameters of the model for the fit to SDSS DR4 galaxy power spectrum combined with WMAP7, SNe and HST data. The plot shows the degeneracies of $f_{NL}$ with cosmological and halo model parameters. As expected $f_{NL}$ results to be correlated with matter density and Hubble parameter. Strong degeneracies involve also $M_{\text{min}}$, $\Omega_m$, $\sigma_8$ and $H_0$ weakening the constraints on these parameters.

$k > 0.01h\text{Mpc}^{-1}$ (see Fig. 1). The amplitude of the correction is proportional to $f_{NL}$ but also to $H_0$ and $\Omega_m$. One should expect hence important degeneracies among these parameters that will affect the strength of constraints on $f_{NL}$.

III. ANALYSIS AND RESULTS

A. Constraints from Red Luminous Galaxies power spectra

We implemented the calculation of the theoretical galaxy power spectrum through the halo model described above and performed a Monte Carlo Markov Chain analysis using Cosmic Microwave Background data from WMAP-7 years of observations [27] and the most recent LRG galaxy power spectrum data available from Sloan digital Sky Survey at a mean redshift $z \simeq 0.35$. We fitted these data assuming flatness of the Universe over a 13 parameters model that consists of 7 standard cosmological parameters (the physical baryon and cold dark matter densities, the ratio of sound horizon to the angular diameter distance at decoupling, , the optical depth to reionization, the scalar spectral index, the overall normalization of the spectrum at $k = 0.002h\text{Mpc}^{-1}$ and the amplitude of Sunyaev-Zel’dovich spectrum: $\Omega_b h^2$, $\Omega_c h^2$, $\theta$, $\tau$, $n_s$, $\log_{10} 10^{10} A_s$, $A_{SZ}$ ) and of the 5 parameters of the halo-model plus the non-gaussianity parameter ($\log_{10} M_{\text{min}}$, $\alpha$, $\gamma$, $\sigma_{\text{cen}}$, $\log_{10} M_1$, $f_{NL}$). In what follows we will express the masses in units of solar masses. The Markov Chain analysis has been performed using the publicly available cosmological code cosmoMC [62] suitably modified to include the calculation of the halo model and to fit over the parameters of the halo model and $f_{NL}$. The convergence diagnostic of this code is based on the Gelman and Rubin statistic [63] (also known as $R - 1$ statistic, where $R$ is defined as the ratio between the variance of chain means and the mean of variances). The results of our fit are shown in table 1 and Fig. 4.
For this model we found weak constraints on the non-gaussianity, $f_{NL} = 171^{+140}_{-139}$ at 68% C.L. and a range $-69 < f_{NL} < +492$ at 95% C.L. from the combination WMAP7 and LRG galaxy power spectrum. The best fit power spectrum computed for the values of table II is shown in Fig. 2 as one can see there is a slight preference for a non-zero value of $f_{NL}$ at 1σ but is largely consistent with gaussian initial conditions when we consider 2σ constraints. These limits are weaker than those obtained with a similar dataset in [34] where small scale non linearities are modeled with a two parameter $k$ dependent correction. The difference is that in our case the uncertainty on $f_{NL}$ is heavily affected by degeneracies with $\Omega_m$, $H_0$ and $\sigma_8$, parameters which are themselves degenerate with the parameters of the halo model. We are in fact requiring the information on $f_{NL}$ to come only from SDSS data since we are using WMAP data only to constrain cosmological parameters. The LRG data range only for scales between $0.01 < k < 0.2 h Mpc^{-1}$ and, as shown in Figure 2, on these scales the effect of an even large non-gaussianity is small and can be easily confused with the effect of cosmological or halo-model parameters. We repeated this fit including both the Hubble Space Telescope prior on $H_0$ from [43] and Supernovae distance moduli measurements for the Union dataset [37] obtaining only a slightly improved constraint on $f_{NL}$, i.e. $-35 < f_{NL} < +479$ at 95%, and other pa-
parameters. In Fig 3 we plot constraints on \( f_{NL} \) and on the parameters most involved in degeneracies with \( f_{NL} \) for the fit to WMAP7 + LRG + SNe + HST data. As for the model parameters, we found generally higher values for \( \log_{10} M_{\text{min}} \), \( \gamma \), and \( \sigma_{\text{cen}} \) than \( [49] \), but with greater uncertainty, while \( \alpha \) results to be in good agreement and \( \log_{10} M_{1} \) has a very large uncertainty. These differences may arise because of the different dataset and modeling (in \( [49] \) they fit the parameter space). The same figure confirms the expected degeneracy between \( \Omega_{m} \) and \( \log_{10} M_{\text{min}} \), as found also in \( [49] \), due to the correlation between halo masses and number of galaxies in massive halos \( [64, 65] \). The consequence of this degeneracy is that our constraint on the matter density is \( \Omega_{m} = 0.264 \pm 0.022 \) from WMAP7 + LRG and hence only slightly better than the constrain from WMAP7 alone \( \Omega_{m} = 0.266 \pm 0.029 \).

B. Constraints from halo power spectra

In this section we constrain \( f_{NL} \) using recent data of power spectrum for the reconstructed halo density field derived from a sample of LRGs \( [42] \) in the seventh data release of the SDSS (DR7). The halo power spectrum is more directly connected to dark matter density field for a wider \( k \) range and this allows to use data points in the power spectrum up to \( k \sim 0.2h\,\text{Mpc}^{-1} \). The main difference with respect to the analysis of the previous subsection is that to model the halo power spectrum it is not necessary to model the halo occupation distribution of galaxies. The halo power spectrum in \( [42] \) is modeled as:

\[
P_{\text{halo}}(k) = P_{\text{damp}}(k) r_{DM,damp}(k) r_{\text{halo}}(k) F_{n}(k)
\]

(13)

where \( P_{\text{damp}} \) is a power spectrum that account for damping of Baryonic Acoustic Oscillations and is calculated as:

\[
P_{\text{damp}}(k) = P_{0}(k) e^{-\frac{k^{2} \sigma_{\text{eff}}^{2}}{2}} + P_{nw}(k) \left( 1 - e^{-\frac{k^{2} \sigma_{\text{eff}}^{2}}{2}} \right)
\]

(14)

with \( P_{0} \) being the linear matter power spectrum and \( P_{nw} \) is the matter power spectrum with baryon oscillations removed calculated as in \( [60] \). The value of \( \sigma \) is chosen fitting the reconstructed halo density field in the mock LRG catalogues \( [42, 67] \). The factor \( F_{n}(k) \) is a nuisance term defined as:

\[
F_{n}(k) = b_{0}^{2} \left( 1 + a_{1} \left( \frac{k}{k_{s}} \right) + a_{2} \left( \frac{k}{k_{s}} \right)^{2} \right)
\]

(15)

where \( b_{0} \) is the effective bias of the LRG at the effective redshift \( z_{\text{eff}} = 0.313 \) and \( k_{s} = 0.2h\,\text{Mpc}^{-1} \). The likelihood code for halo power spectra free SDSS-DR7 is implemented in cosmoMC and performs a marginalization over the nuisance parameters \( b_{0}, a_{1} \) and \( a_{2} \). The terms \( r_{DM,damp}(k) \) and \( r_{\text{halo}}(k) \) in \( [13] \) model the connection between the non-linear matter power spectrum and the damped linear power spectrum and between halo and matter power spectrum and they are calibrated against numerical simulations (see section 3 in \( [42] \) for more details). Here we use a modified version of the modeling described so far introducing the \( k \)-dependent bias correction \( [12] \) averaged over masses:

\[
b(k,z) = \frac{\int [b(M,z) + \Delta b(M,z,k)] n_{\text{halo}}(M,z) M dM}{\int n_{\text{halo}}(M,z) M dM}
\]

(16)

We then fitted the data varying \( f_{NL} \) together with the seven cosmological parameters (\( \Omega_{b} h^{2}, \Omega_{c} h^{2}, \theta, \tau, n_{s}, \log_{10} 10^{10} A_{s}, A_{SZ} \)) and minimizing the chi-square by
varying nuisance parameters \( a_1 \) and \( a_2 \). Our results are shown in table [II] and in Figure [3]. We also show our best fit halo power spectra in Figure [3]. Our fit for this dataset shows a preference for a negative value \( f_{NL} = -93 \pm 128 \) at 68% C.L. that allows to have a better fit to five point in the observed power spectra in the range \((0.03 < k < 0.05) \, h \, \text{Mpc}^{-1}\). The uncertainty on this value remains anyway quite large and the 95% C.L. range for \( f_{NL} \) is \(-327 < f_{NL} < 177\), hence with a very slight improvement with respect to the constraints from previous dataset. For the other cosmological parameters we find a good agreement with results from [27] for WMAP7 combined with halo power spectra of LRG sample. We note that, according to degeneracies showed in Figure [3], allowing for a possible non-Gaussianity implies an increase of uncertainty on some cosmological parameters, namely \( h \) and \( \sigma_8 \) with an increase of a \( \sim 10\% \) on the 1σ error with respect to \( \Lambda \text{CDM} \) case for WMAP7+LRG and an increase of a \( \sim 14\% \) on the error for \( \Omega_c h^2 \).

### IV. FORECAST FOR FUTURE SURVEYS

In this section we consider constraints on \( f_{NL} \) from future data generating mock datasets for both CMB anisotropy and galaxy power spectra. For a galaxy surveys the error on the matter power spectrum can be calculated as [63, 60]:

\[
\left( \frac{\sigma_P}{P} \right)^2 = \frac{2\pi^2}{4k^2\Delta k V_{eff}}
\]

where the effective volume of the survey is given by:

\[
V_{eff} = V \left( \frac{nP}{nP+1} \right)^2
\]

and \( \Delta k \) is the width of \( k \)-bins. Here we use specification for a typical future galaxy survey like EUCLID [14] with galaxy number density \( n \simeq 1.6 \cdot 10^{-3} \) redshift range \( 0 < z < 2 \) and \( f_{sky} \simeq 0.5 \). The minimum \( k \) of the mock dataset is choose to be greater than \( 2\pi/V^{1/3} \), while the maximum \( k \) we use is \( 0.02h \text{Mpc}^{-1} \). For CMB anisotropy power spectrum we use specification for Planck experiment [13] assuming the noise of the 143 GHz channel. We explore a \( \Lambda \text{CDM}+f_{NL} \) model and we choose as fiducial model the WMAP-7 years best fit for \( \Lambda \text{CDM} \) parameters [27]. For the non-Gaussianity parameter we choose three fiducial models, \( f_{NL} = +1, +5, +10 \). Remember that in our approach we are using only the information of large scale galaxy clustering to constrain non-gaussianity, while we use CMB measurements only to constrain other cosmological parameters and hence to break degeneracies.

Results for our forecast on \( f_{NL} \) are shown in table [III] as one can see the combination of accurate galaxy power spectrum measurements, attainable with a survey like EUCLID and Planck CMB measurements could reach the sensitivity required to detect an even small non-Gaussianity, such as \( f_{NL} = +5 \) or \( f_{NL} = +10 \), with a confidence level of at least 95%. We note that this results is in agreement with other forecast for future galaxy surveys (see [70] for example). Very small non-Gaussianities \( (f_{NL} = +1) \) seem instead rather difficult to detect, mainly due to degeneracies with other parameters. Nevertheless in [71] it has also been shown that in more complicated models (allowing variation of neutrino mass, running of spectral index, dark energy equation of state and relativistic degrees of freedom) constraints on \( f_{NL} \) may deteriorate up to \( \sim 80\% \).

### V. SYSTEMATICS

Before concluding we discuss the possible systematics introduced by the assumptions we made or, more generally, by the theoretical uncertainties of the model.

First, we have seen that the value of \( r \) that appear in the [12] may have a value in the range \( 1 - 1.6 \). We have assumed \( r = 1 \) since we are using Luminous Red Galaxies that are old galaxies at the center of halos. This is a common assumption for this kind of analysis (see also [34]). Anyway we find that even assuming \( r = 1.6 \) the differences in the power spectrum with respect to the case \( r = 1 \) are very small. Using \( r = 1.6 \) we find only a slight variation in the \( \chi^2 \) with respect to \( r = 1 \) for the best fit model: \( \Delta \chi^2 \sim 0.3 \). The reason for this is that actual data constrain scales \( k > 0.02h \text{Mpc}^{-1} \) where the exact value of \( r \) is less relevant. Nevertheless for future low-\( k \) data it may be necessary a more precise modeling of the [12].

A second assumption we made is that the density profile of the halos is described by the NFW profile. Although the exact shape of the profiles in the halos is still uncertain, this profile has been tested against several numerical simulations and it turned out to be a good approximation [52]. Moreover, again, the information on \( f_{NL} \) is coming from \( k < 0.1h \text{Mpc}^{-1} \) where the density profile is constant in Fourier space. An important point is the comparison between the results from the LRG power spectrum of [11] and the

### Table III: 1σ errors (68% C.L.) from the combination of mock datasets generated for the specifications of Planck experiment and EUCLID survey and for three different fiducial values of \( f_{NL} \).

| Fiducial value | \( f_{NL} \) | 1σ error |
|---------------|-------------|-----------|
| \( +1 \)     | 2.23        |
| \( +5 \)     | 2.29        |
| \( +10 \)    | 2.39        |
halo power spectrum from \cite{42}. The first dataset provides a galaxy power spectrum while the second a halo density field that doesn’t require any assumption about the halo occupation number. In \cite{12} there is a large discussion on the differences between these two dataset and we refer the reader to this work for a complete discussion. Here we remark that the main differences are due to the heavy Finger of Gods compression algorithm used in \cite{11} to obtain the matter power spectrum. This process may cause transfer of power from a scale to another, causing consistent deviations (up to $\sim 40\%$ on $k = 0.2 h Mpc^{-1}$) between the reconstructed halo density field and the matter power spectrum \cite{12}. For the DR7 halo power spectrum instead, the halo density field is reconstructed before the computation of the power spectrum (see section 2.2 in \cite{12}) and the deviations between the two are smaller than 4\%. Also the modeling of the theoretical halo power spectrum and of the galaxy power spectrum is different. The model of \cite{12} is calibrated on N-body simulations and mock data-sets made especially for this LRG sample. Moreover the authors of \cite{12} imposed priors on the nuisance parameters of the model based on N-body simulations. For the galaxy power spectrum of \cite{11} it was used the Q-model \cite{72} for the non linear part of the power spectrum, marginalizing over $Q$ with weak priors. All these differences necessarily reflects on the cosmological parameters estimation, including $f_{NL}$. The comparison between results of the two datasets is made in section 6.1 of \cite{42}. Significant differences are found on some cosmological parameters from the two LRG datasets only (i.e. not including CMB) of the two releases: in particular the $\Omega_m h$ values (that enters also in the \cite{12}) differ of almost 2$\sigma$ between the two surveys.

In our work, to fit the DR7 data we are only introducing the bias scale dependent correction to the model of \cite{12}, in order to be as much as possible consistent with the data compression algorithm of this LRG catalogue. We ascribe the differences between the results of section \ref{sec:results} to the significant differences of the data compression process, as noted also in \cite{42}. A last issue concern the modeling of power spectra on non-linear scales. For DR7 data, the authors of \cite{12} normalize the final halo power spectrum using mock catalogues to account for the small offset between the N-body and HALOFIT results. Concerning the galaxy power spectrum we used to fit data from \cite{11}, the $P(k)$ we are using in relation \ref{eq:Pk} is the linear matter power spectrum, which is well known. The galaxy power spectrum is calculated through the halo-model itself. The 5-parameters model we are using showed a good agreement with hydrodynamical and N-body simulations and semi-analytic models \cite{51,52,53,56,57}. Moreover, we are marginalizing over the 5 free parameters that account for the uncertainties of the model, so that our analysis is rather conservative.

In the forecast section we model the galaxy power spectrum relying on the same assumption made above ($r = 1$ for galaxies and NFW profiles) and using the same HOD modeling. Our results show the potential of a survey like Euclid to detect even small non gaussianities and are in good agreement with forecast done for the same survey and for a similar modeling of the scale dependent bias $\delta_{NL}$. It is clear, however that the analysis of real data from these future surveys will probably require a more accurate modeling of the galaxy power spectrum and of the scale dependent correction in order to not bias the estimated value of the cosmological parameters.

\section{Conclusions}

We place new constraints on the local type non-gaussianity parameter $f_{NL}$ by looking at the scale dependence of the halo bias (at small wave vectors) in the recent galaxy and halo power spectra measurements from LRG sample of the Sloan Digital Sky Survey. We fit 2006 SDSS power spectra data with an halo model consisting of 5 parameters plus 7 cosmological parameters and $f_{NL}$. Our large parameter space and the the restriction of the dataset to relatively small scales ($k > 0.01 h Mpc^{-1}$) leads to a weak constraint: $-69 < f_{NL} < +492$ at 95\% C.L.. We show and discuss degeneracies with halo model parameters. When including both Type Ia Supernovae and HST data the 1$\sigma$ error on $f_{NL}$ is reduced of about $\sim 10\%$. We use also 2009 halo power spectra data obtained from SDSS LRG sample finding a slightly better constraint $-327 < f_{NL} < +177$ at 95\% C.L., again limited by the fact that the dataset does not extend below $k \sim 0.02 h Mpc^{-1}$. We also forecast the constraints obtainable from datasets of a survey like Euclid when combined with Planck CMB data, finding that these surveys could reach the accuracy required to detect even small non-gaussianities as $f_{NL} = +5$, thus confirming the power of this method. Finally we discuss the possible systematics and theoretical uncertainties that may affect the results.

\textit{Acknowledgements}

FDB thanks UCI Center for Cosmology for support and hospitality while this research was conducted. This work was supported by NSF CAREER AST-0645427 and NASA NNX10AD42G at UCI. This research has been partially supported by the ASI/INAF agreement I/072/09/0 for the Planck LFI Activity of Phase E2.
[58] Press, W.H., Schechter, P. 1974, ApJ, 187, 425
[59] R. K. Sheth and G. Tormen, Mon. Not. Roy. Astron. Soc. 308 (1999) 119 [arXiv:astro-ph/9901122].
[60] H. J. Mo, Y. P. Jing and S. D. M. White, Mon. Not. Roy. Astron. Soc. 282 (1996) 1096 (1996MNRAS.282.1096M)
[61] E. Komatsu and D. N. Spergel, Phys. Rev. D 63 (2001) 063002 [arXiv:astro-ph/0005036].
[62] A. Lewis and S. Bridle, Phys. Rev. D 66 (2002) 103511 [arXiv:astro-ph/0205436].
[63] A. Gelman and D. B. Rubin., Statist. Sci. Vol. 7, Number 4 (1992), 457-472
[64] Z. Zheng, J. L. Tinker, D. H. Weinberg and A. A. Berlind, Astrophys. J. 575 (2002) 617 [arXiv:astro-ph/0202358].
[65] E. Rozo, S. Dodelson and J. A.Frieman, Phys. Rev. D 70 (2004) 083008 [arXiv:astro-ph/0401578].
[66] D. J. Eisenstein and W. Hu, Astrophys. J. 496 (1998) 605 [arXiv:astro-ph/9709112].
[67] B. A. Reid, D. N. Spergel and P. Bode, Astrophys. J. 702 (2009) 249 [arXiv:0811.1025 [astro-ph]].
[68] Feldman, H. A., Kaiser, N., Peacock, J. A. 1994, ApJ, 426, 23
[69] M. Tegmark, Phys. Rev. Lett. 79 (1997) 3806 [arXiv:astro-ph/9706198].
[70] C. Carbone, L. Verde and S. Matarrese, Astrophys. J. 684 (2008) L1 [arXiv:0806.1950 [astro-ph]].
[71] C. Carbone, O. Mena and L. Verde, [arXiv:1003.0456 [astro-ph.CO]].
[72] S. Cole et al. [The 2dFGRS Collaboration], Mon. Not. Roy. Astron. Soc. 362 (2005) 505 [arXiv:astro-ph/0501174].