The Correlation Function of Galaxy Clusters
Measuring the equation of state w and the scatter in the mass richness relation

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Abstract

Cluster of galaxies are becoming a powerful tool for constraining the cosmological parameters. The measurement of cosmological parameters by counting the numbers of clusters as a function of redshift is a key project of the Dark Energy Survey. The use of clusters as a cosmological probe depends on our understanding of the mass of the clusters. We present a method to constrain the equation of state w and the scatter in the mass richness relation by making use of the bias measured in the cluster correlation function. First, we use this method to constrain only the scatter for the maxBCG sample of optically selected clusters in the SDSS data. Finally, we also present the potential to measure both parameters with this method using the dark matter halos in cosmological simulation with the DES volume.

The Method

The cluster bias can be measured in a cluster catalog or simulation by measuring the spatial correlation function $\xi_{cl}(r)$ and comparing it to the correlation function of dark matter halos using the relation :

$$\xi_{cl}(r) = b^2 \xi_{dm}(r)$$

We compare the measured bias with the predicted linear bias using the Halo Model and the Mass Richness relation. The average bias expected for a richness value N_200 is

$$b(N_{200}, z) = \frac{\int dlnM \frac{dn}{dlnM} P(ln(M)|N_{200}) b(M,z)}{\int dlnM \frac{dn}{dlnM} P(ln(M)|N_{200})} \quad (1)$$

- For a given z and N_{200} bin (N_1,N_2) the bias is $b(N_1,N_2) = \frac{\sum_{N_1}^{N_2} b(N_{200},z) n_{meas}(N_{200},z)}{\sum_{N_1}^{N_2} n_{meas}(N_{200},z)}$ **(2)**
- The linear bias predictions is calculated with the Sheth Thormen 1999 mass function

The Method

- Assuming a lognormal scatter around the mean scaling relation (Gaussian scatter in lnM) distribution, the probability P(ln(M)|N) of having the true mass M given the observed richness N_{200} is :

$$P(ln(M)|N) = \frac{1}{\sigma_{lnM}(2\pi)^{1/2}} exp \frac{-(ln(M)-\mu)^2}{2\sigma^2_{lnM}}$$

The mean cluster mass for a given N_{200} using weak lensing measurements (*See Rozo et al,:arxiv: 0809.2794*)

$$<\mu> = <M|N_{200}> = 10^{14} M_{sun} exp(B) (\frac{N_{200}}{40})^{\alpha}$$

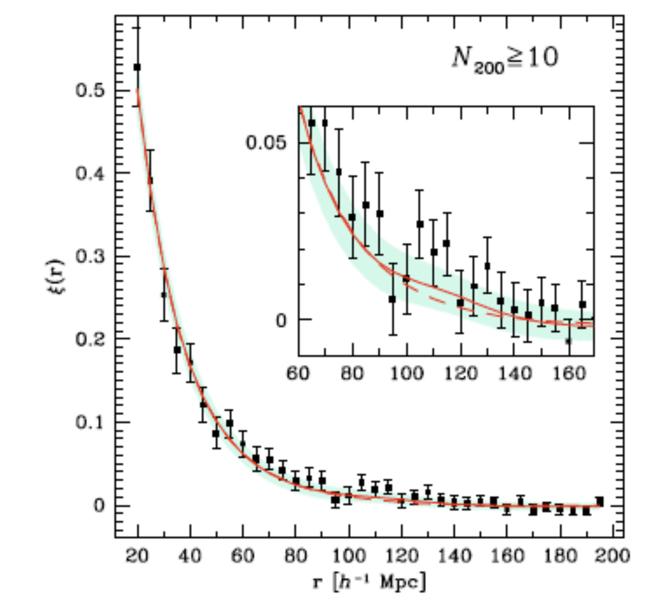
We perform a likelihood comparing the measurements with the predictions

$$P(\sigma, B, \alpha, \Lambda) \propto exp \sum_i [\frac{1}{2} \frac{b_i(\sigma, B, \alpha, \Lambda) - b_{meas}}{\sigma_{b_{meas}}}]^2$$

where Λ represents the dependence in cosmological parameters.
Combining with priors from other measurements and marginalizing we can obtain P(w) and P(scatter).

MaxBCG results

- The cluster samples analized are derived from the SDSS MaxBCG catalog for the SDSS DR5 in an area of ~7500 deg^2 in the redshift range 0.1 <= z <=0.3
- The public catalog contains 13823 clusters with N_{200} >= 10
- For the analysis, the catalog is divided in four samples using thresholds in cluster richness and the correlation function is measured



Estrada et al, Astrophysics J, 692.265-282. (2009)

- Bias results:

N_{th}	measured $b(N_{th})$
10	2.80 ± 0.13
11	2.91 ± 0.15
13	3.26 ± 0.20
16	3.76 ± 0.24

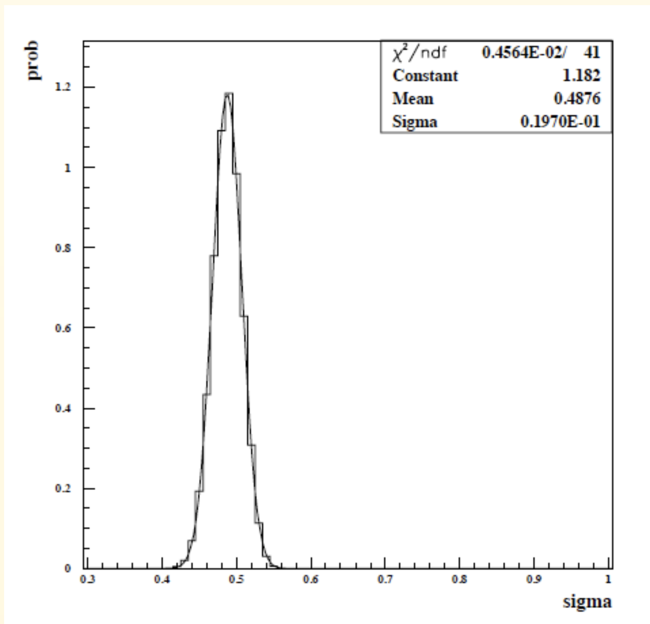
MaxBCG results

Marginalized likelihood for the scatter determinated from the bias results.

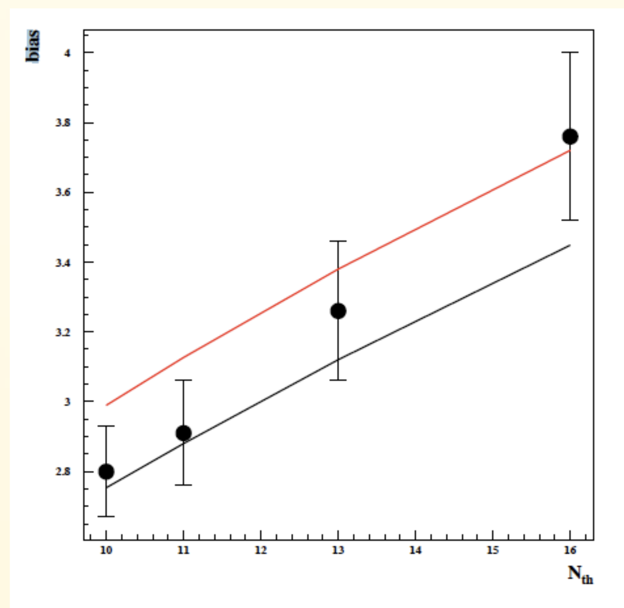
A likelihood calculation compare the bias measured with the predictions from the equations (1) and (3) and marginalized over the priors for B and α.

The predictions are made at the median redshift z=0.2.

$$b(N_{threshold}) = \frac{\sum_{N_{th}}^{\infty} b(N_{200}) n_{meas}(N_{200})}{\sum_{N_{th}}^{\infty} n_{meas}(N_{200})} \quad (3)$$

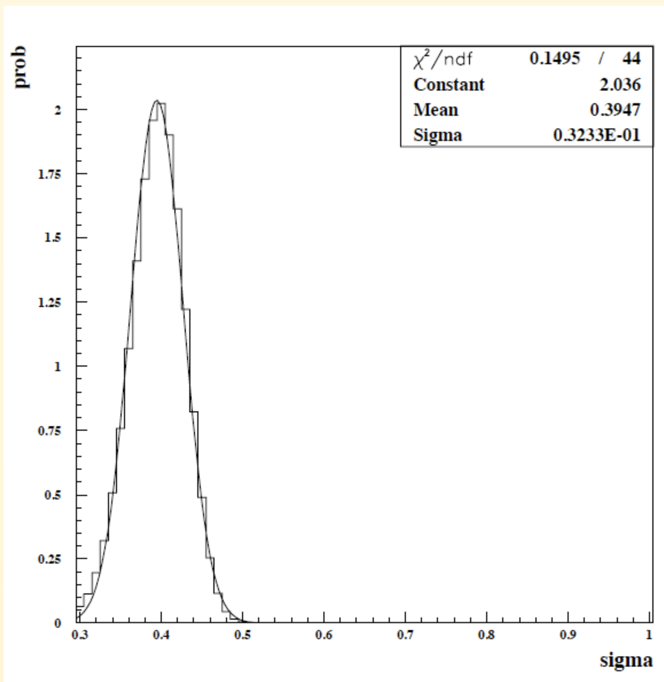


Bias measurements compared with model



black line model with peak likelihood and 1 sigma away (red line). Black dots are the data

Potential of the method to measure the scatter measurements on DES



Likelihood results

On DES dark matter halo simulation based on Hubble Volumen PO Lightcone with 5000 deg^2, flat ΛCDM cosmology, redshift range **0.1<=z<=1.4** and 247000 halos **a N_{200} richness catalog is created with a gaussian scatter in the mass observable relation (lognormal in M) (scatter $\sigma = 0.4$).**

The catalog is divided in **richness bins** with enough halos to measure the correlation function.

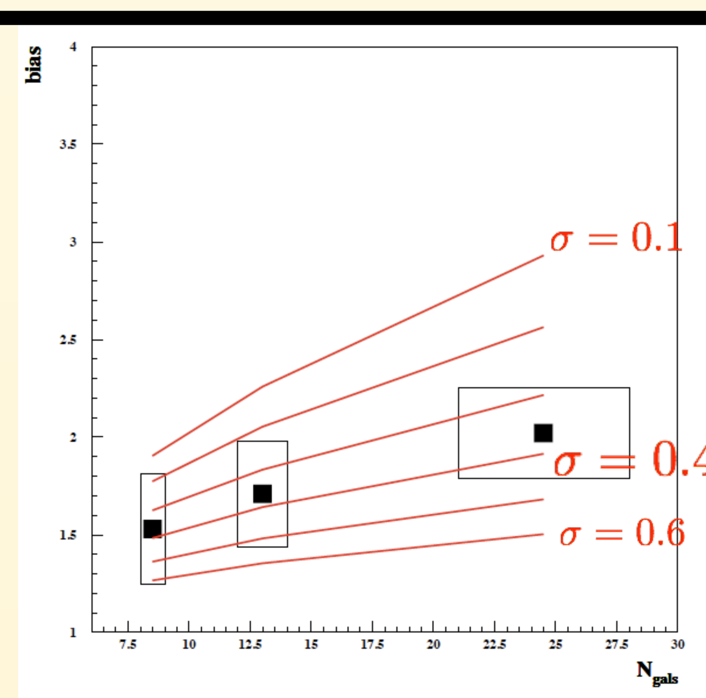
A likelihood is performed for a fixed cosmology and knowing B and α.

The bias model for the scatter $\sigma = 0.4$ is taken as a measurement and the number of halos per N_{200} from DES simulation $n_{meas}(N_{200})$ is used in equation (2).

No divided in redshift bins

Next step: The richness catalog is divided in redshift and N_{200} bins * with enough number of halos $n_{meas}(N_{200}, z)$ to calculate the correlation function

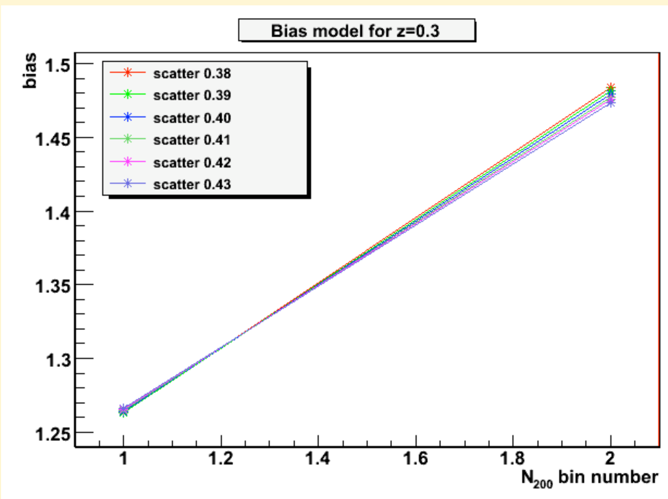
*Note:
Redshift bin width of 0.2
#N_{200} bin = 1 is [7,16]
#N_{200} bin = 1 is [17,43]

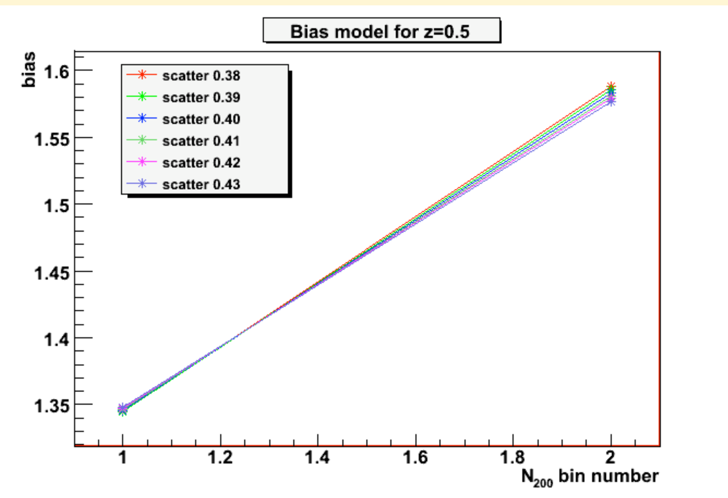


Black dots are the data with the bin with and error. Red lines are the predictions for different scatter values

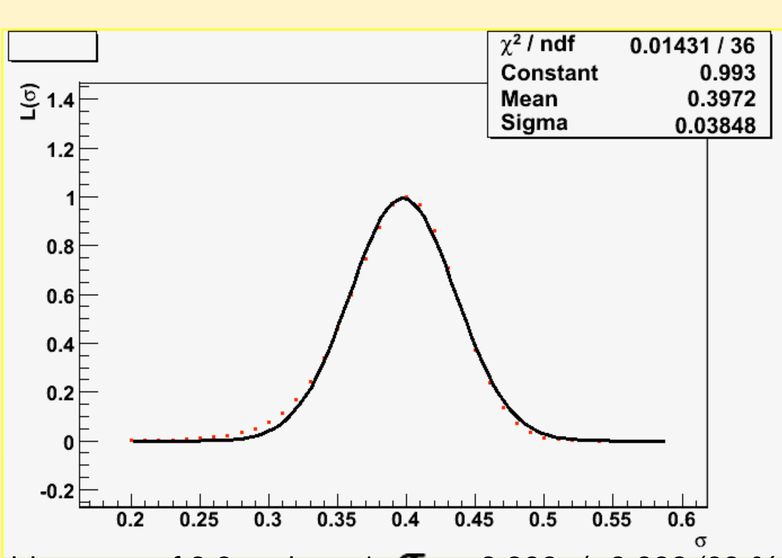
On DES volume:Potential of the method to measure the scatter

The predictions for the bias for different scatter and redshift values are calculated with equations (1) and (2) for a fixed cosmology and knowing the mass richness relation parameters.

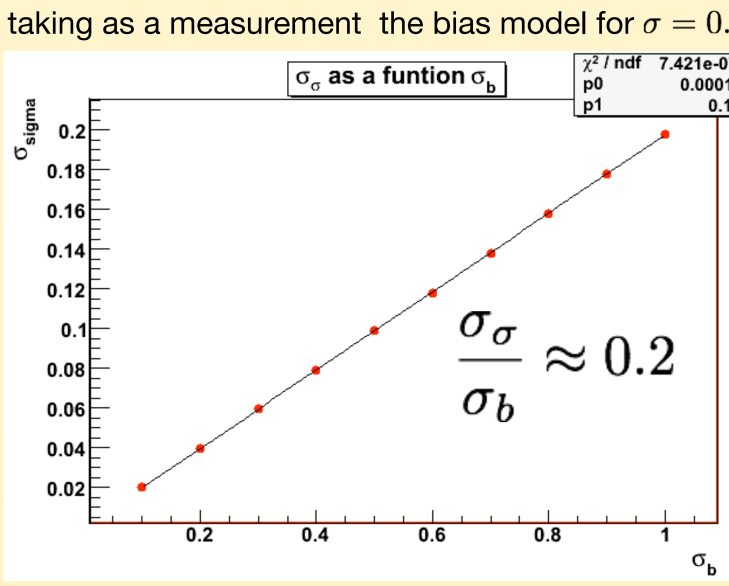




1D likelihood for scatter: A likelihood is performed taking as a measurement the bias model for $\sigma = 0.4$.



For a bias error of 0.2 and w=-1, σ = 0.399+/- 0.038 (68 % CL)

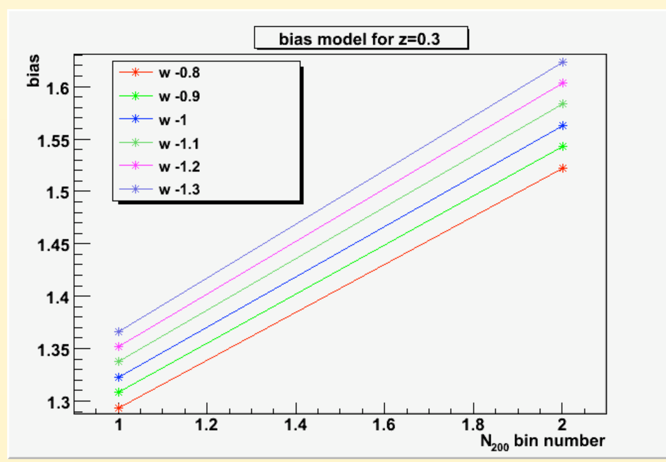


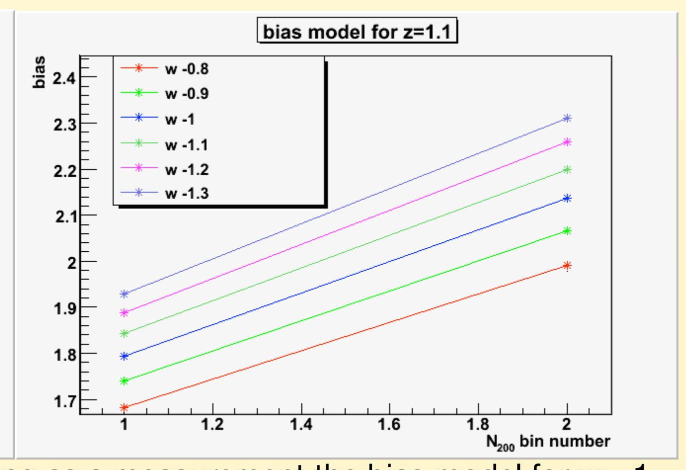
The variation of σ_σ as a function of bias error

On DES Volume: Potential of method to measure w

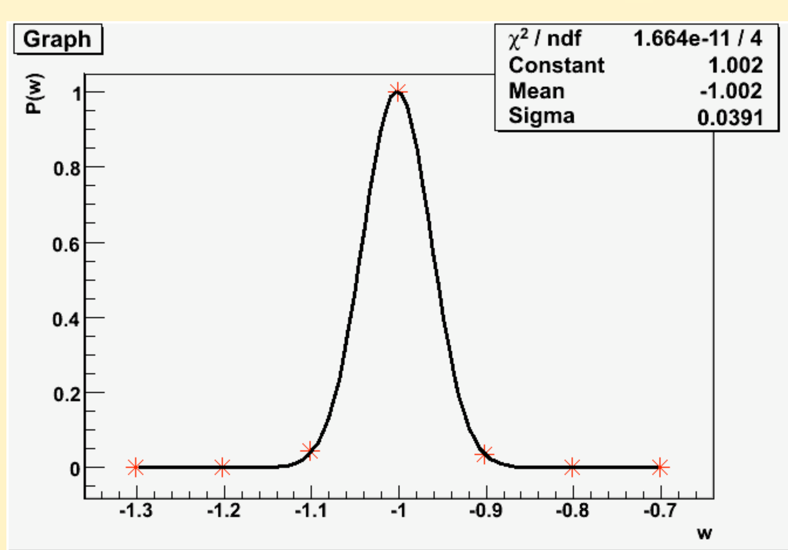
The value of w is also constrained with this method because the bias is sensitive to the variation of the cosmological parameters

The predictions for the bias for different w and redshift values are calculated knowing the mass richness relation parameters and the scatter 0.4.

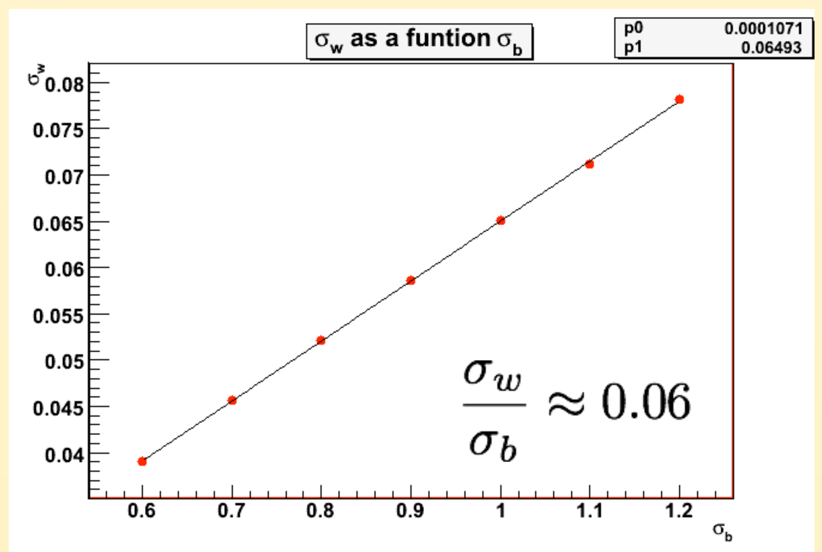




1D likelihood for w: A likelihood is performed taking as a measurement the bias model for w=-1.



For a bias error of 0.6 and $\sigma = 0.4$, w = -1.002+/- 0.039 (68 % CL)



The variation of σ_w as a function of bias error

Conclusions

The results show the high potential to constrain the scatter and the w with this method. We have taken the number of halos from dark matter simulation to simulate the DES data. We want to continue this work comparing the model with data from simulations dividing in redshift and richness bins and marginalizing over the priors. The next steps are combine the likelihood with the likelihood for the number of clusters as a function of richness and redshift also predicted from the Halo Model. With this combined likelihood the cosmological parameters could be fitted and at the same time the mass observable relation is calibrated.

References: Cluster bias: Manera & Gaztañaga, Arxiv:0912.0446
Halo Model of large scale structure: A. Cooray & R. Sheth, astro-ph: 0206508
Self Calibration of dark energy studies: Lima & Hu 2005, 2007
www.darkenergysurvey.org