

# Angular Clustering in Photometric Surveys

a window for red-shift space distortions

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# Photo-Z surveys

Benitez et al. (2008)



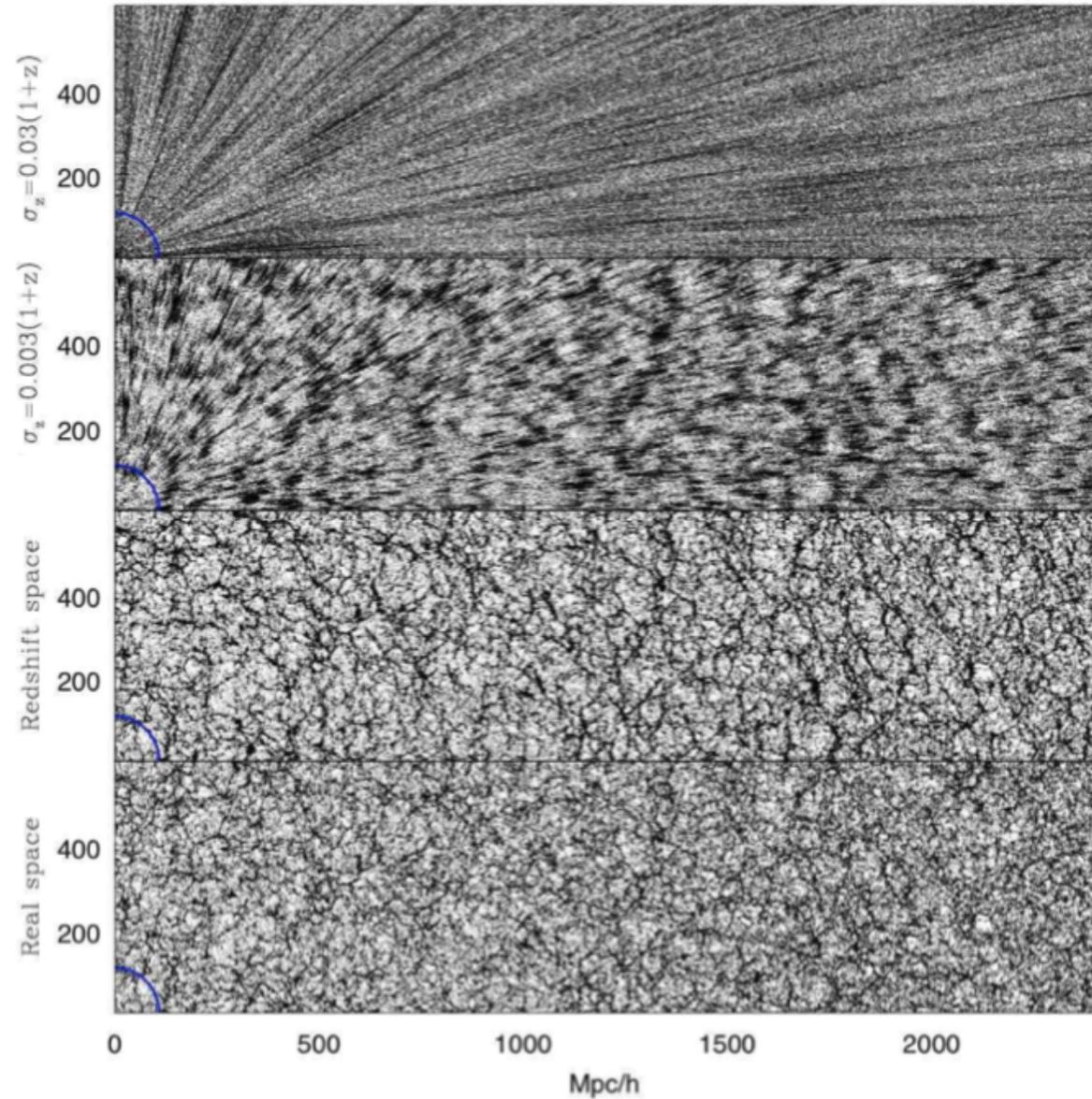
DARK ENERGY SURVEY



More in the future :

Euclid-imaging

LSST



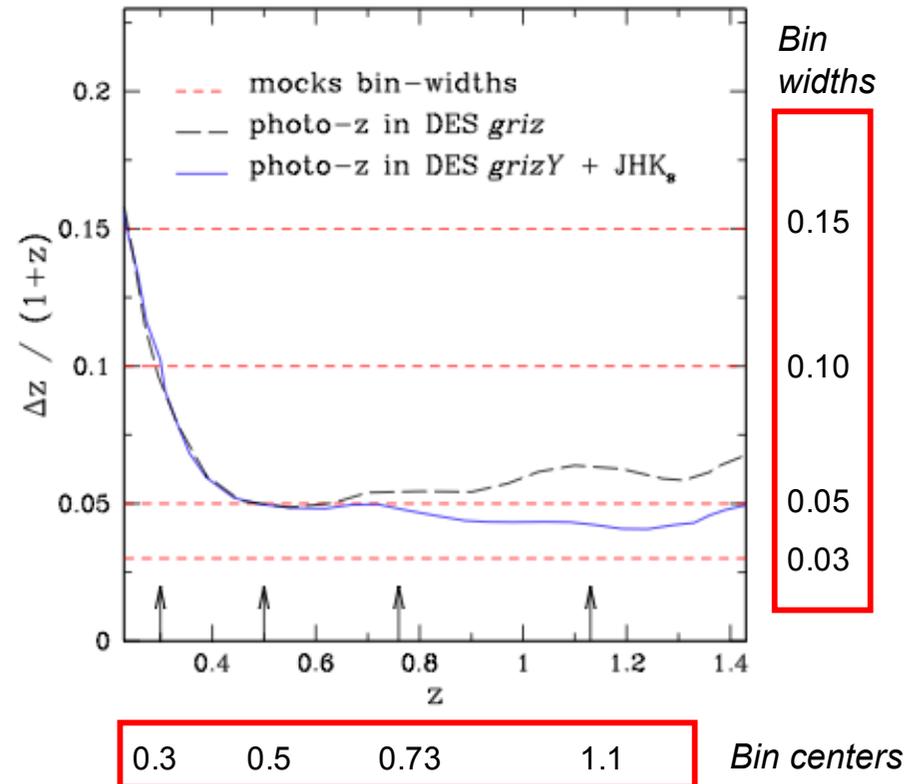
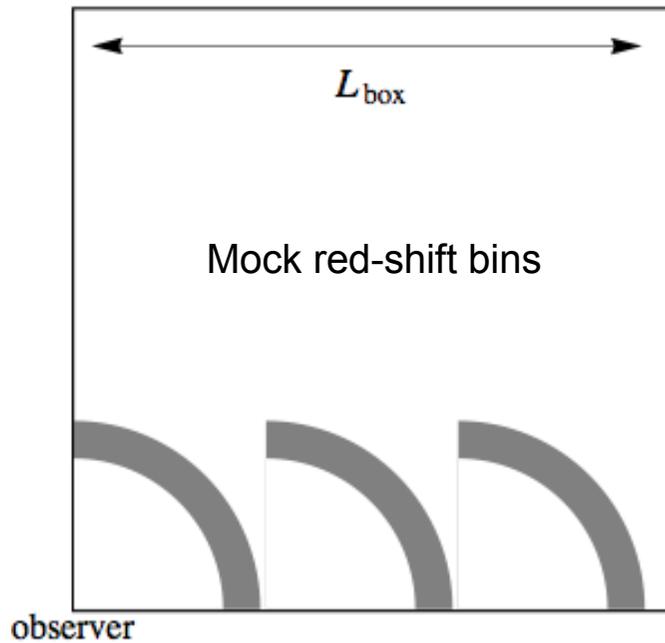
Will probe  $z > 1$  in near future. But radial positions of the galaxies will be known with large uncertainties ( $\sim 100$  Mpc/h), erasing the 3D-clustering information

Brief outline,

- How well can we model the clustering signal, identify most important effects. How well can we model the errors
- Theory vs. Simulated Survey Catalogs
- Forecast. What can we learn with these tools
- Proof-of-concept. Testing the tools with actual data.

# Simulations and survey mock catalogs

- Use co-moving outputs of a very large N-body simulation - MICE7680 (~ 450 cubic Gpc/h)
- **Ensemble of mock red-shift bins**, assuming 1/8 of sky and  $0.2 < z < 1.4$  (DES-like survey)
- Impose underlying red-shift distribution :  $dN/dz \propto (z/0.5)^2 \exp [-(z/0.5)^{1.5}]$
- Include **bin projection, NL clustering, bias , red-shift distortions and/or photometric errors.**



# Modeling the angular correlation :

$$w(\theta) = \int dz_1 \Phi(z_1) \int dz_2 \Phi(z_2) \xi(r_{12}(\theta), \bar{z})$$

Assuming linearly biased tracers and growth with respect to the mean red-shift of the bin

$$\Phi(z) = D(z, \bar{z}) \phi(z)$$

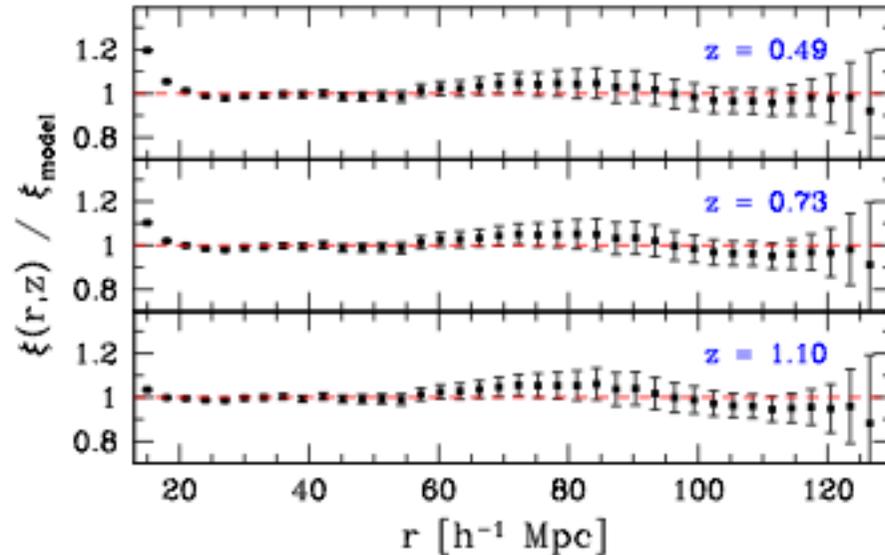
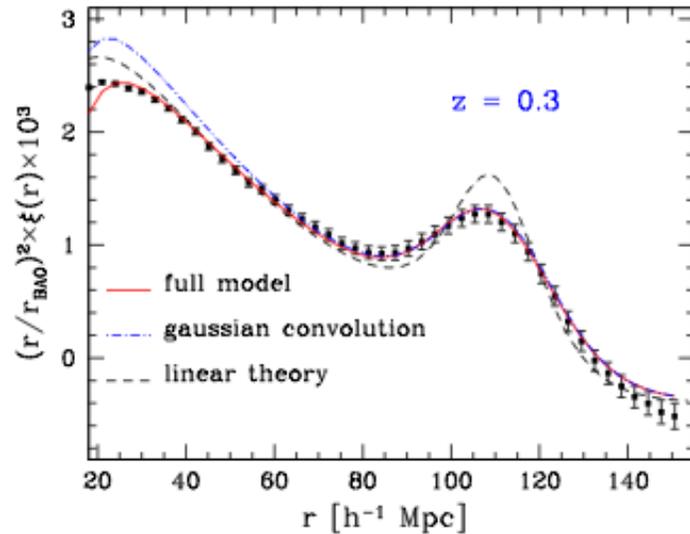
$$r_{12}(\theta) = \{r(z_1)^2 + r(z_2)^2 - 2r(z_1)r(z_2)\cos(\theta)\}^{1/2}$$

## Nonlinear Gravity and evolution

$$\xi(r, z) = D(z) [\xi_{\text{Lin},0}(r) \otimes e^{-(r/D(z)s_{\text{bao}})^2}] (r) + A_{mc} D^4(z) \xi_{\text{Lin},0}^{(1)}(r) \xi'_{\text{Lin},0}(r)$$

Use theoretical estimates for  $s_{\text{bao}}$  and  $A_{mc}$  or a fit in a single redshift b/c they scale with the growth

3D



## Modeling the angular correlation :

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### Red-shift Distortions :

$$\xi(r_1, r_2) = \xi(\sigma, \pi)$$

$$\xi(\sigma, \pi) = \xi_0(r_{12})P_0(\mu) + \xi_2(r_{12})P_2(\mu) + \xi_4(r_{12})P_4(\mu)$$

$$\pi = r_2 - r_1 \quad \text{and} \quad \mu = \pi/r_{12}$$

Where  $\xi_0, \xi_2, \xi_4$  are multi-poles of  $\xi$  that depend on bias and growth rate  $f \equiv \frac{d \ln D(a)}{d \ln a}$

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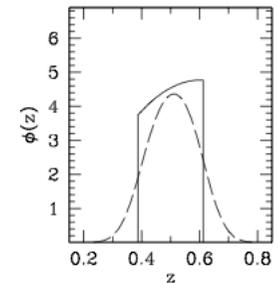
$$\Phi(z) = D(z, \bar{z}) \phi(z)$$

Use theoretical estimates for  $s_{\text{bao}}$  and  $A_{\text{mc}}$  or a fit in a single redshift b/c they scale with the growth

### Photo-z :

$$\phi(z) = \frac{dN_g}{dz} W(z).$$

$$\phi(z) = \frac{dN_g}{dz} \int dz_p P(z|z_p) W(z_p),$$

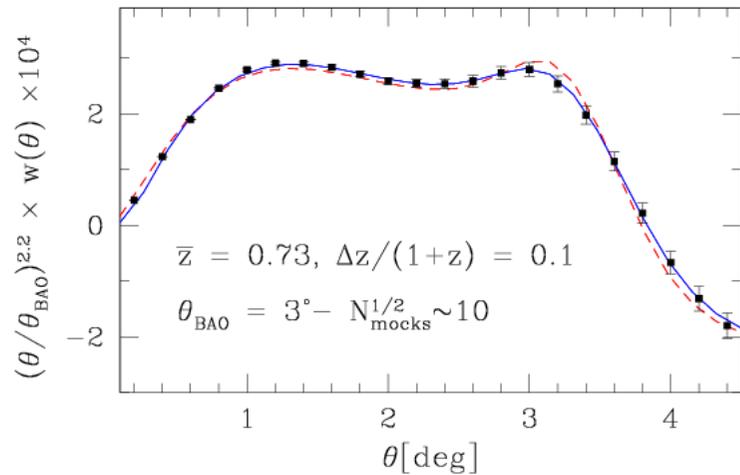
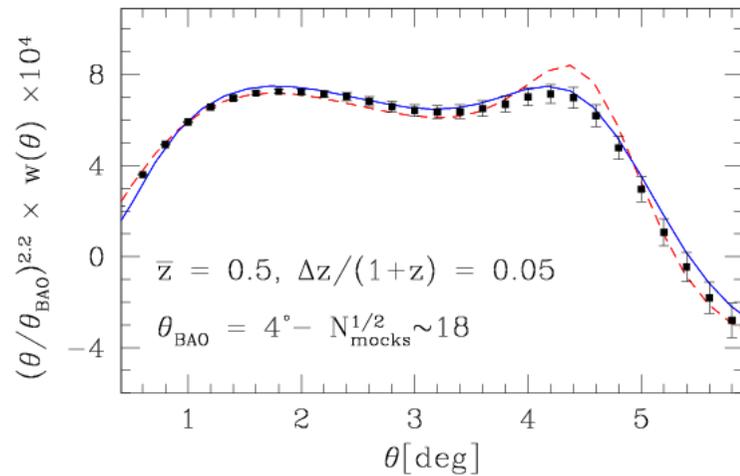


(distribution of galaxies in true red-shifts)

# Angular Correlation Function : Theory vs. Mocks

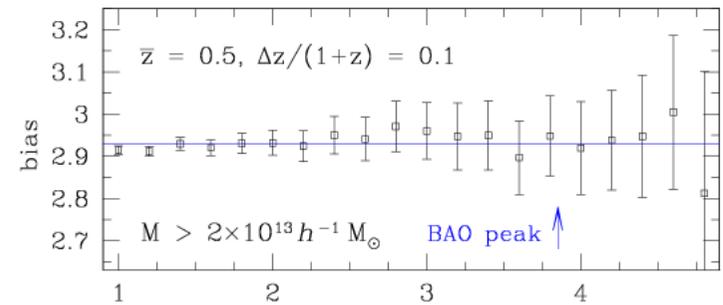
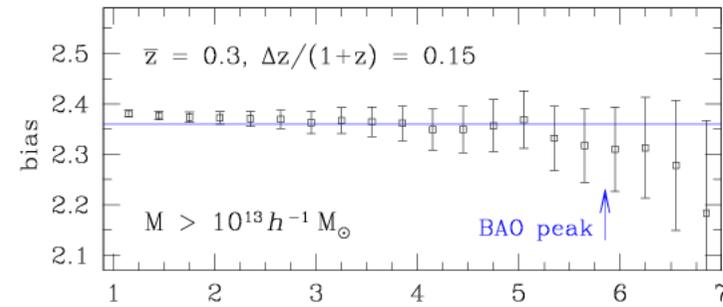
Real space

Nonlinear gravity and evolution

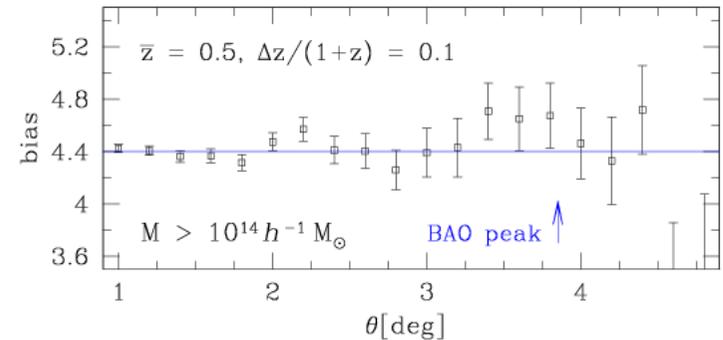


Halo Bias

Roughly galactic halo mass scale



Cluster mass scale



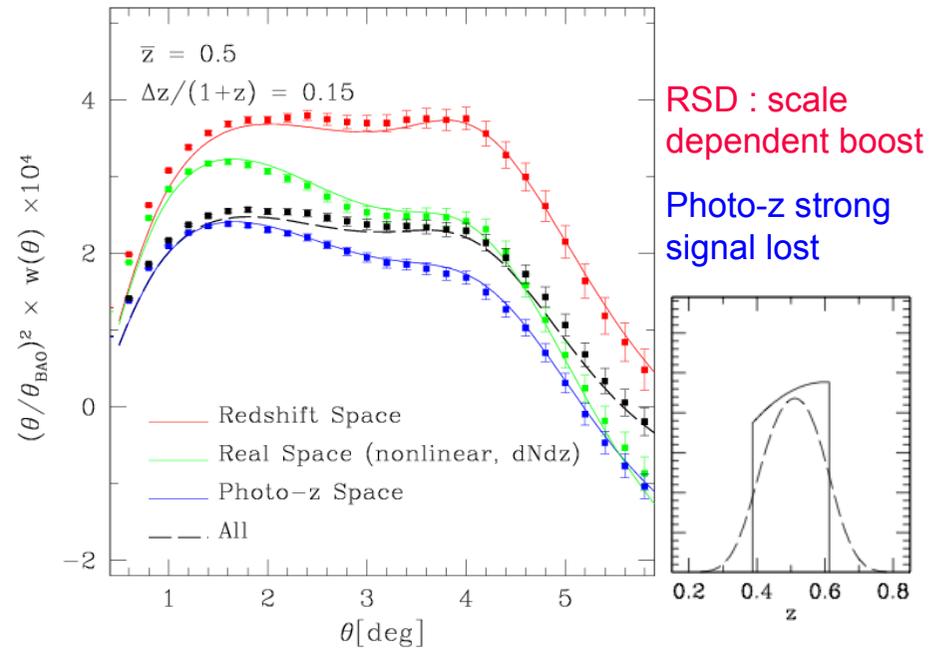
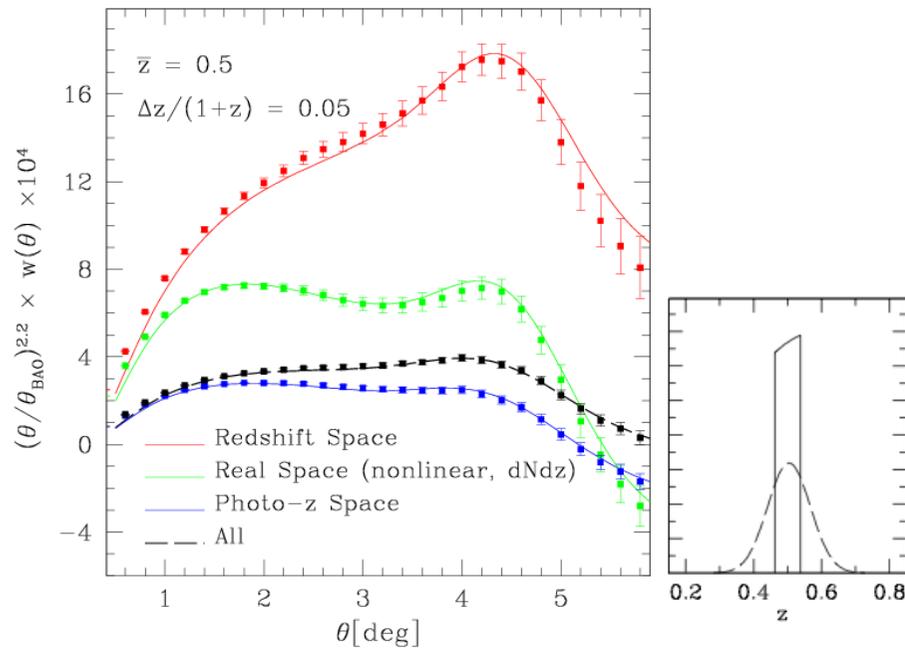
# Angular Correlation Function : Theory vs. Mocks

## Red-shift Space Distortions and Photo-z effects

$$\sigma_z = 0.06 \quad \beta = f/b = 0.7047$$

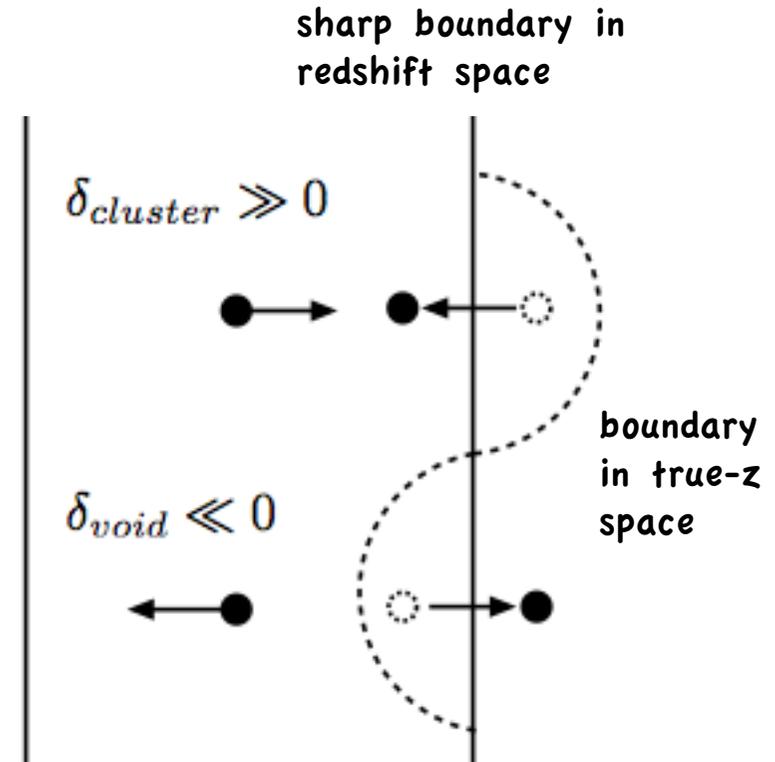
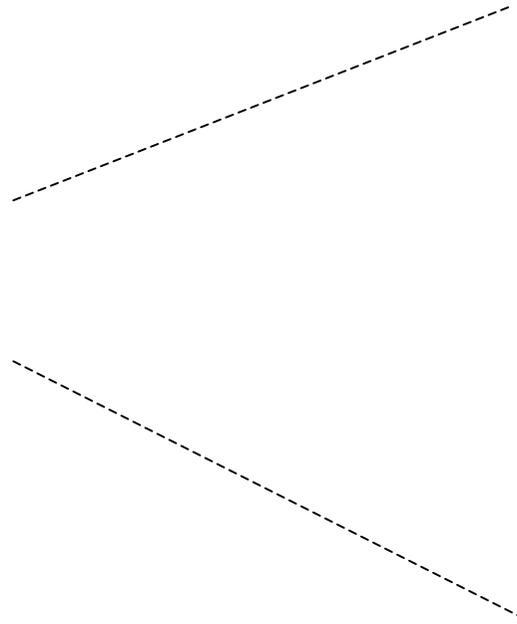
Narrow bin (width  $\sim 178$  Mpc/h  $\sim$  photo-z)

Wide bin (width  $\sim 500$  Mpc/h  $\sim 4$  photo-z)



- The effect of RSD is very important even for bins as broad as 500 Mpc/h (where it “counter-acts” the photo-z smearing)
- The theoretical modeling works very nicely in all cases

Why ?



**Red-shift distortions** move particles in and out of the red-shift bin coherently with density perturbations at the edge.

This makes over-densities larger and under-density emptier, increasing the amplitude of fluctuations.

Instead **photo-z** does this but fully randomly, smoothing out fluctuations

# Measuring growth of structure

$$f \equiv \frac{d \ln D(a)}{d \ln a}$$

$$\xi^s(s, \mu) = \xi_0(s)P_0(\mu) + \xi_2(s)P_2(\mu) + \xi_4(s)P_4(\mu)$$



$$\xi_0(r) = (b^2 + 2bf/3 + f^2/5) [\xi(r)]$$

$$\xi_2(r) = (4bf/3 + 4f^2/7) [\xi(r) - \xi'(r)]$$

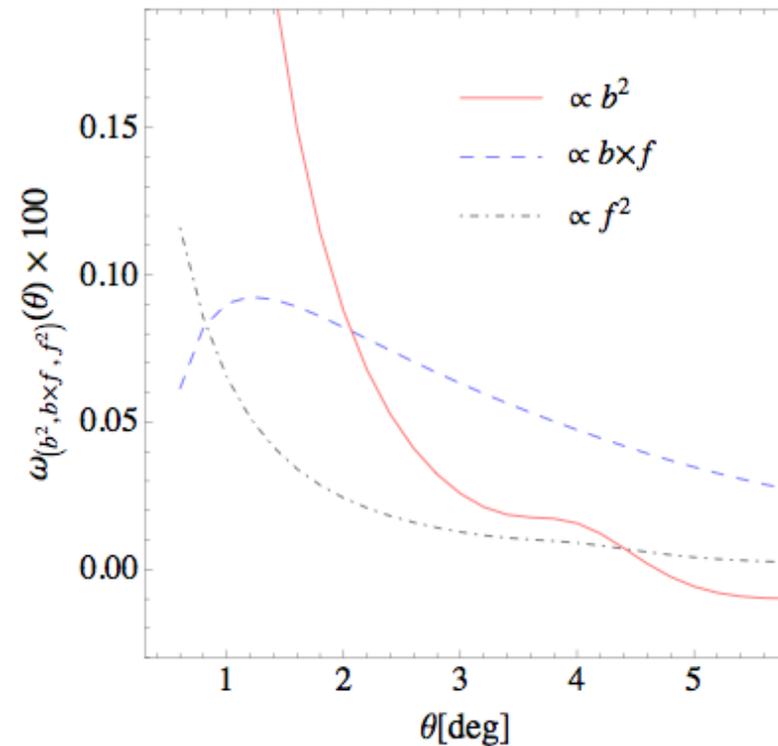
$$\xi_4(r) = (8f^2/35) [\xi(r) + 5/2 \xi'(r) - 7/2 \xi''(r)]$$



$$w(\theta) = p_0(b, f)w_0(\theta) + p_2(b, f)w_2(\theta) + p_4(b, f)w_4(\theta)$$

Collect terms in  $b^2$ ,  $f^2$  and  $bf$

(degenerate with  $\sigma_8(z)$ )



Modeling the error and covariance :

$$w(\theta) = \sum_{\ell \geq 0} \left( \frac{2\ell + 1}{4\pi} \right) P_{\ell}(\cos\theta) C_{\ell} \quad \langle a_{\ell m} a_{\ell' m'} \rangle \equiv \delta_{\ell\ell'} \delta_{mm'} C_{\ell}$$

$$\text{Cov}_{\theta\theta'} = \sum_{\ell, \ell' \geq 0} \left( \frac{2\ell + 1}{4\pi} \right)^2 P_{\ell}(\cos\theta) P_{\ell'}(\cos\theta') \text{Cov}_{\ell\ell'}$$

Assume that  $\text{Cov} \sim 1 / f_{\text{sky}}$  and use that in “full sky”  $\text{Var}(C_{\ell}) = 2 C_{\ell}^2 / (2\ell + 1)$ .

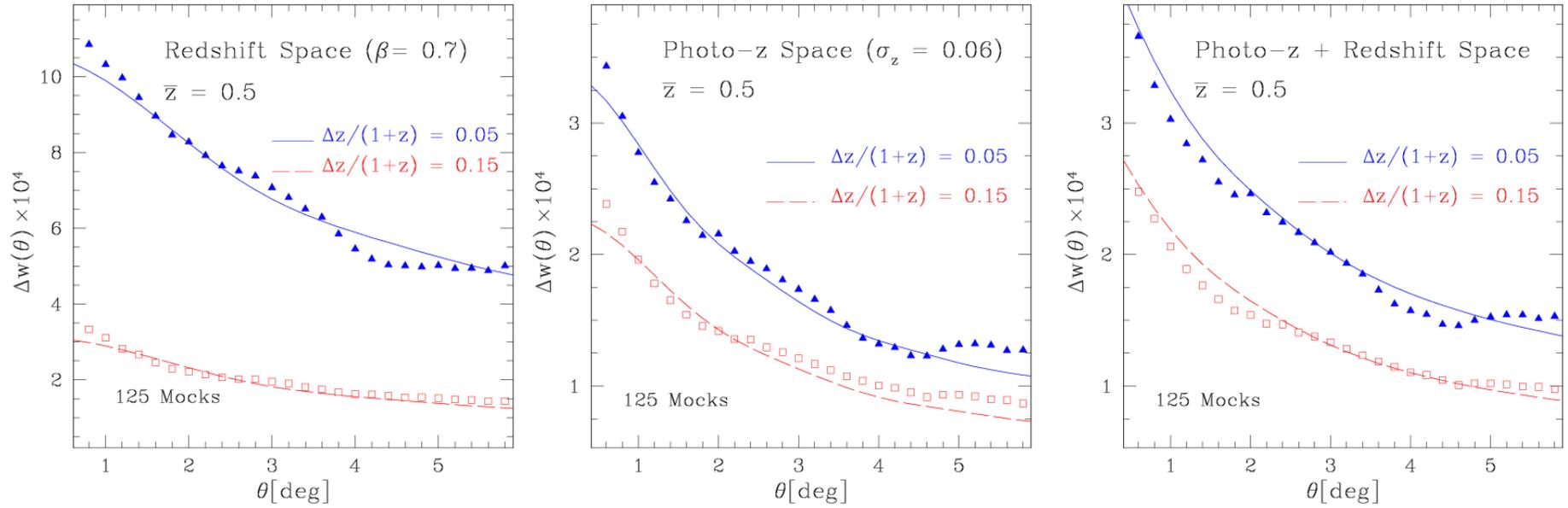
$$\text{Cov}_{\theta\theta'} = \frac{2}{f_{\text{sky}}} \sum_{\ell \geq 0} \frac{2\ell + 1}{(4\pi)^2} P_{\ell}(\cos\theta) P_{\ell}(\cos\theta') (C_{\ell} + 1/\bar{n})^2$$

$$C_{\ell, \text{Exact}} = \frac{1}{2\pi^2} \int 4\pi k^2 dk P(k) \Psi_{\ell}^2(k) \quad \Psi_{\ell}(k) = \int dz \phi(z) D(z) j_{\ell}(kr(z))$$

And a similar expression for red-shift space involving also  $j_{\ell-2}(kr) j_{\ell+2}(kr)$

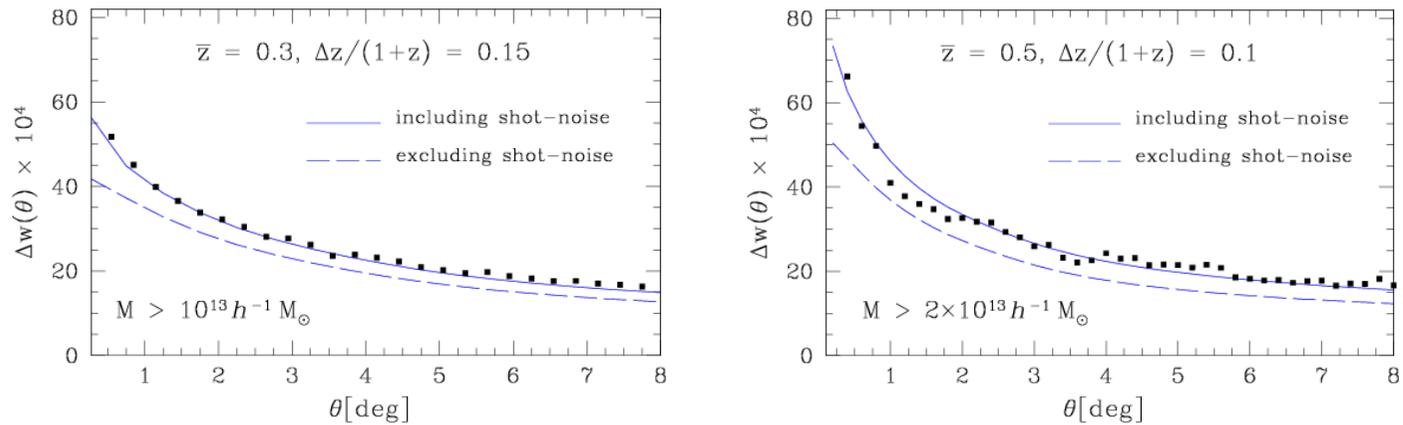
# Errors : Theory vs. Mocks

## Red-shift and/or Photo-z space



## The impact of shot-noise :

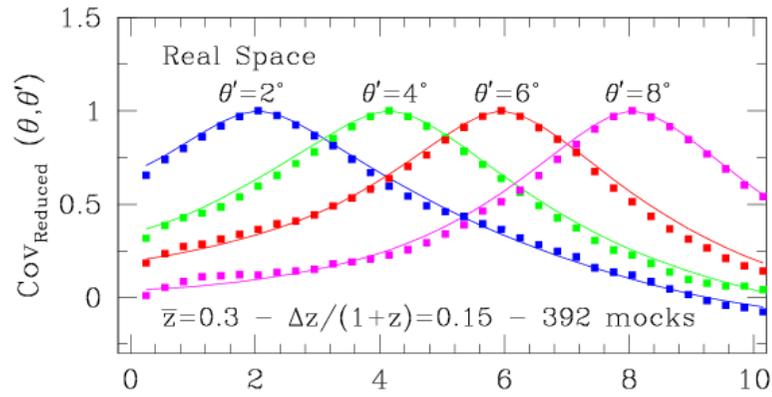
Including a Poisson term  $1/n$  into  $C_l$



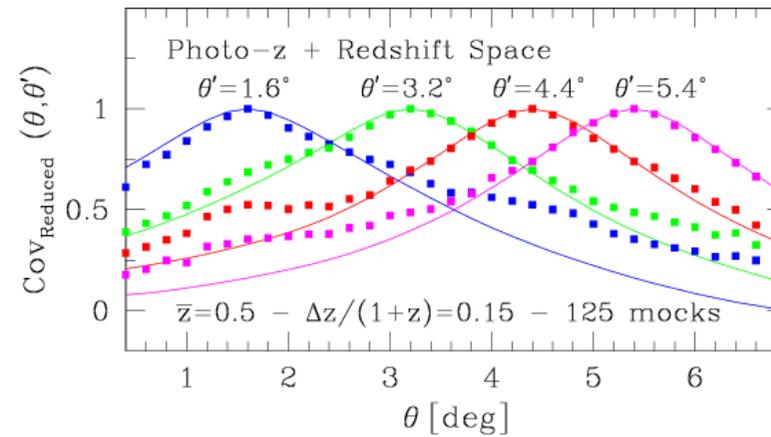
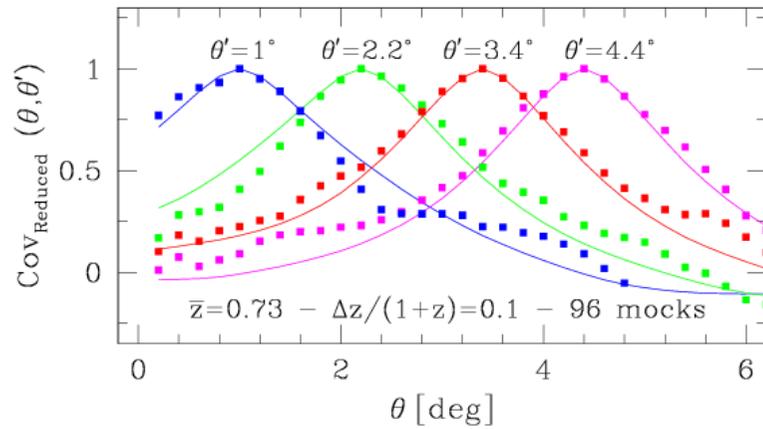
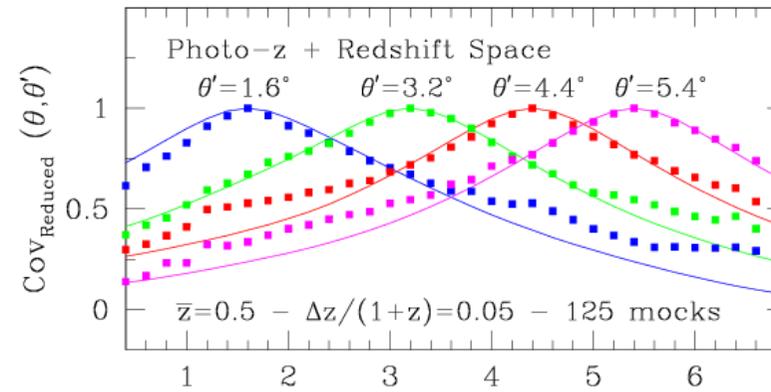
# Reduced Covariance : Theory vs. Mocks

## Rows of the reduced covariance

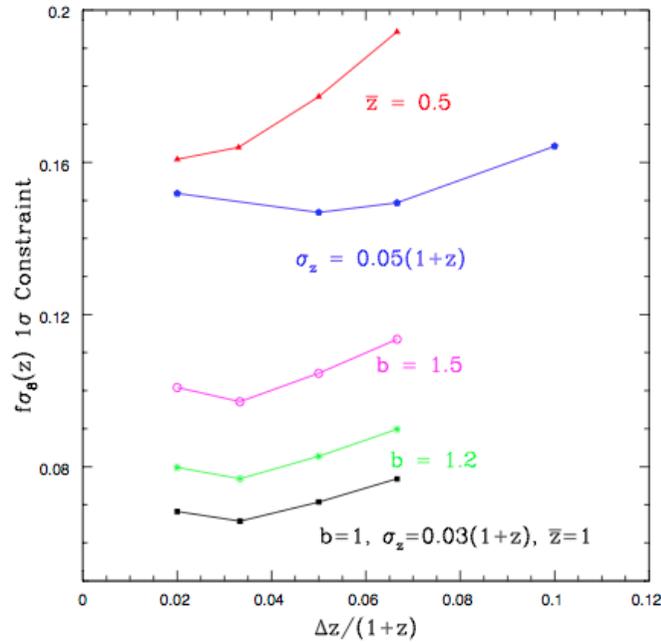
### Real Space



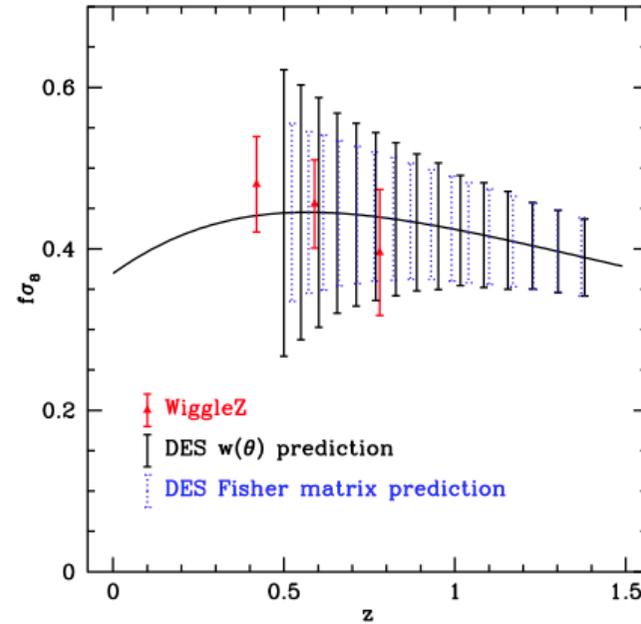
### Redshift + Photo-z Space



# Forecast - DES like survey



**Figure 8.** The black points show the expected error on  $f(z)\sigma_8(z)$  versus the width of the photometric redshift bin, for unbiased tracers with average photometric redshift error  $\sigma_z = 0.03(1+z)$ , selected from redshift bins centred on  $z = 1.065$ . The other lines display the same information, for samples changed as labeled.



**Figure 7.** The solid line displays the model  $f(z)\sigma_8(z)$  for our default  $\Lambda$ CDM model.  $1\sigma$  errors (black) were calculated for the expected measurements made via successive top-hat photometric redshift bins for DES galaxies between  $0.475 < z < 1.42$  and the blue error-bars display Fisher matrix predictions for similar redshift bins. The red points with  $1\sigma$  errors are the measurements made with the WiggleZ survey (Blake et al. 2010).

# Angular clustering in the Sloan Digital Sky Survey II

Imaging catalog of the (final) data release (DR7)

From M. Crocce, E. Gaztagaña, A. Cabre, A. Carnero and E. Sanchez, 2011, arXiv: 1104.5236  
(see also Carnero et al 2011, arXiv 1104.5426)

- Use **luminous red galaxies (LRG) sample** in the imaging catalog of the final Data Release (DR7) of SDSS II
- Angular clustering analysis at the ***largest angular scales*** and  $0.45 < z < 0.6$ , ***including a detailed study of systematic effects***
- Probe to what extent **red-shift space distortions and BAO** can be extracted from a photometric sample
- Do we match expectations? Are we dominated by systematic effects ? Is the clustering signal compatible with LCDM or anomalous?

- Selection of the galaxy sample

- color-color cuts to select high-z LRGs (Eisenstein et al 2001) :

$$(r - i) > \frac{(g - r)}{4} + 0.36,$$

$$(g - r) > -0.72 (r - i) + 1.7,$$

- flux limit :

$$17 < petror < 21,$$

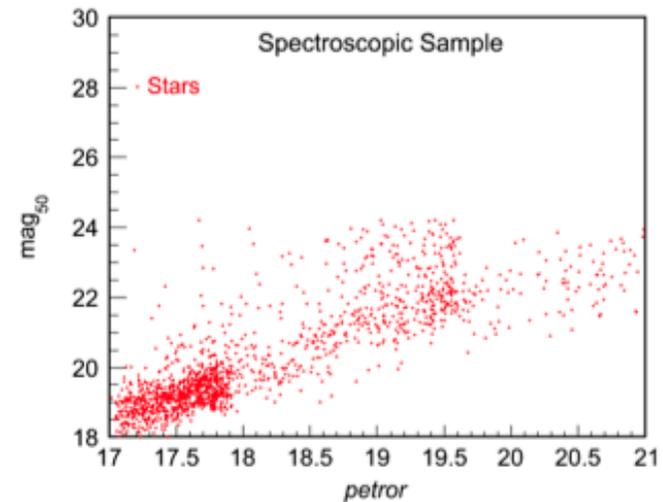
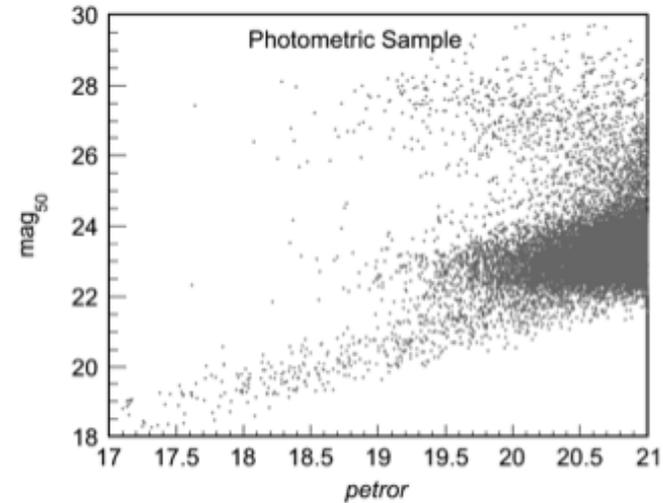
$$0 < \sigma_{petror} < 0.5,$$

- additional cuts to minimize star contamination :

$$0 < r - i < 2,$$

$$0 < g - r < 3,$$

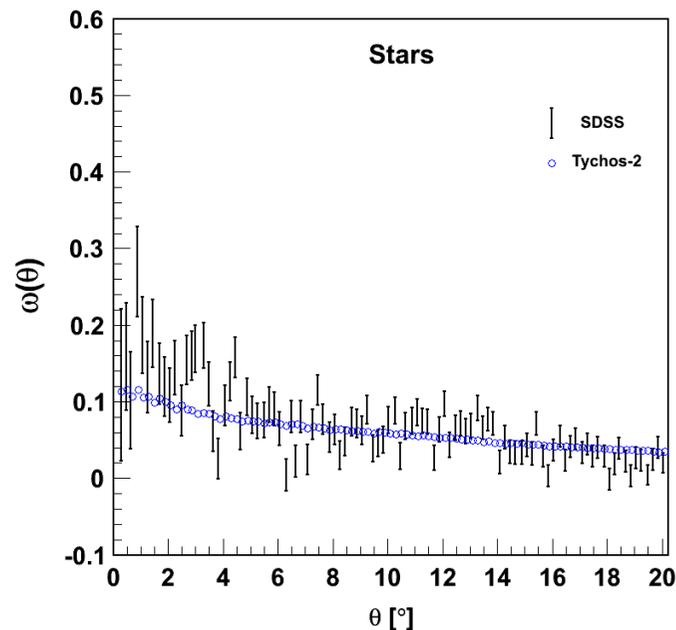
$$22 < mag_{50} < 24.5,$$



- Residual Star Contamination

- From the corresponding SDSS DR7 spectroscopic sub-sample we identify  $\sim 4\%$  residual star contamination

- Using those objects identified as stars in the SDSS spec sub-sample as well as the Tycho2 star catalog we measure the angular correlation of stars,



Both estimates coincide and are well fit by,  
 $w_{stars,fit}(\theta) = 0.0904 - 0.00313 \theta$ .

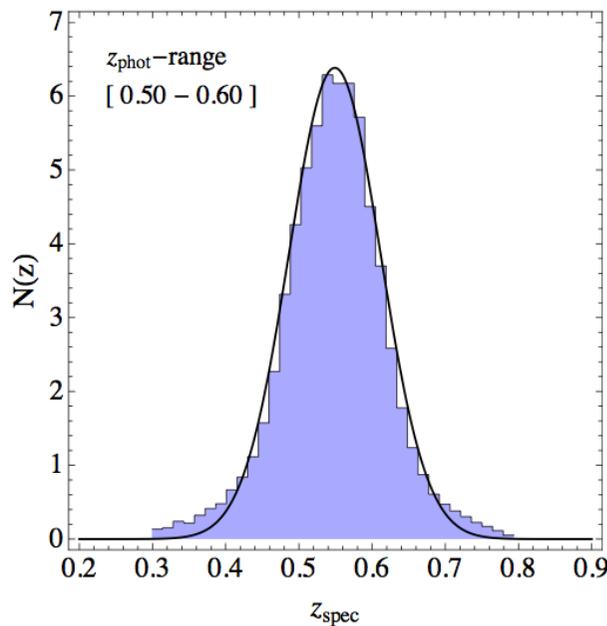
$$w_{obs,model}(\theta, z) = (1 - f_{stars})^2 w_{gal,model}(\theta, z) + f_{stars}^2 w_{stars,fit}(\theta)$$

- Photo-z and red-shift distribution

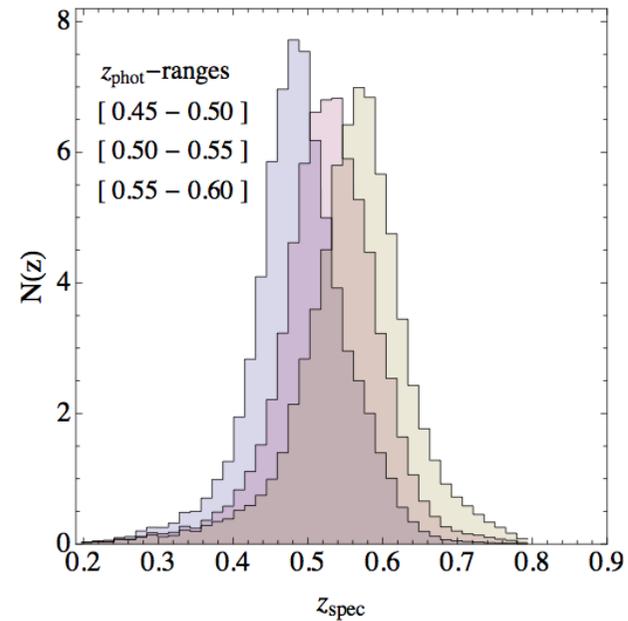
- We used the value added catalog of Cunha et al 2009 (also Lima et al 2008) available at [http://www.sdss.org/dr7/products/value\\_added](http://www.sdss.org/dr7/products/value_added)

- It provides accurate red-shift probability distributions  $p(z)$  for each galaxy

- The true distribution of galaxies is then estimated as : 
$$N(z) = \sum_{i=1}^{N_{gal,bin}} p_i(z).$$



**Figure 7.** True (spectroscopic) redshift distribution for the bin 0.5 – 0.6 resulting from sum of the individual redshift probability distributions. A fit to a Gaussian function (shown in solid black) yields a media of  $\mu = 0.549$  and standard deviation  $\sigma = 0.062$ .

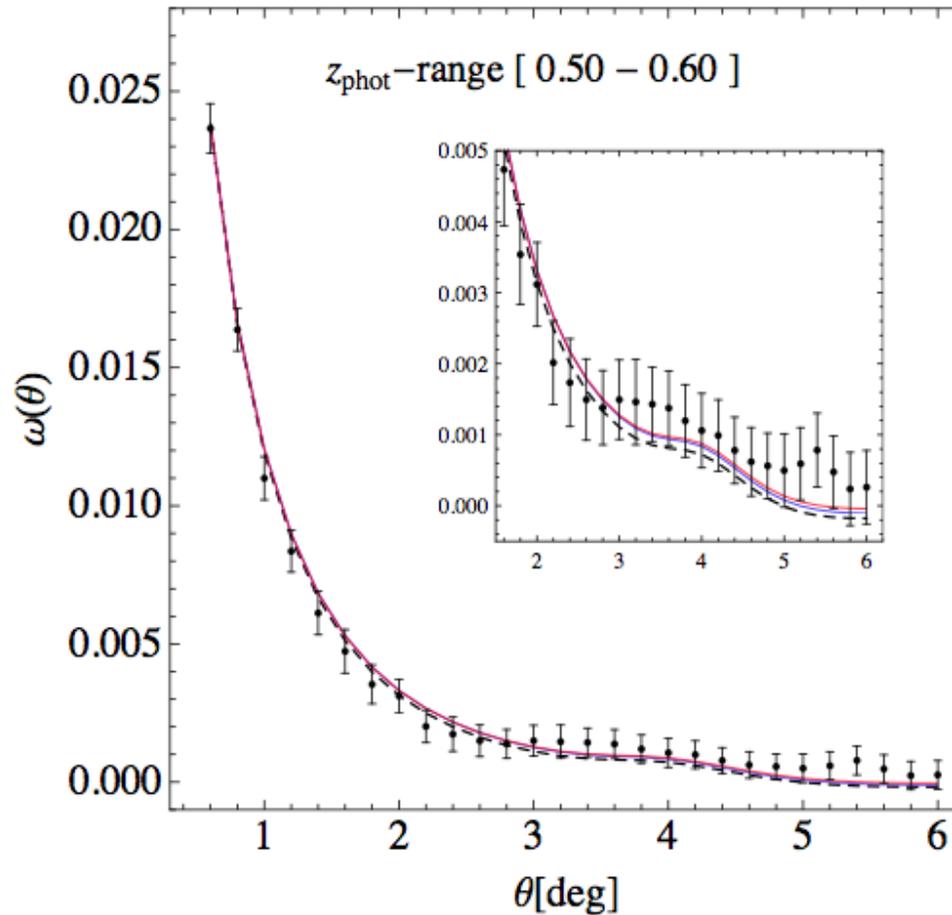


**Figure 8.** True redshift distribution for a set of “narrow” bins of width similar to the typical photometric error ( $\Delta z = 0.05$ ).

- Data vs. Model I :

## Red-shift Space Distortions

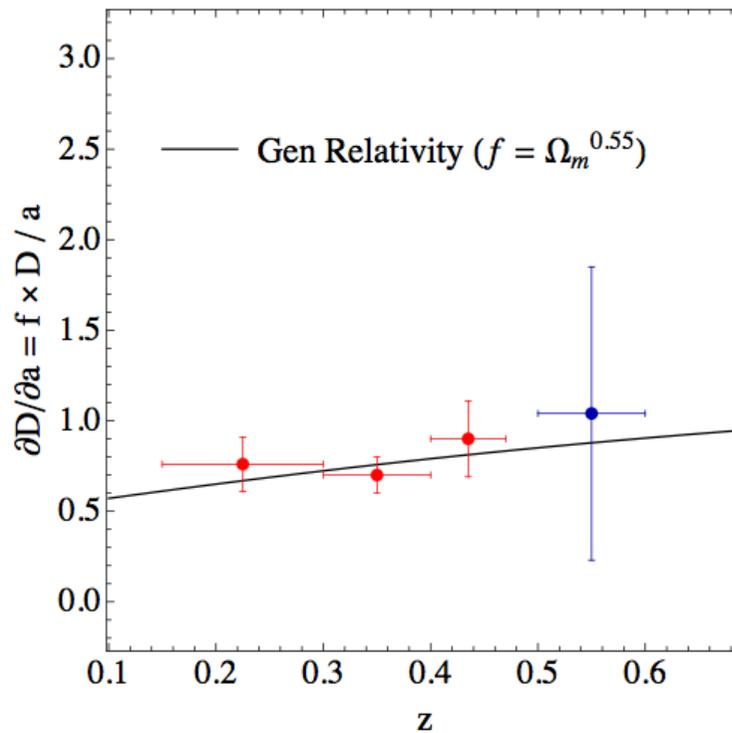
redshift bin	$b(z)\sigma_8(z)$	$f(z)\sigma_8(z)$
0.50 – 0.60	$1.12 \pm 0.02$	$0.53 \pm 0.42$



**Figure 15.** Angular correlation function in our central bin of width 0.1 centered at  $z = 0.55$ . Solid red line is our best-fit model including the effect of star contamination ( $f_{\text{star}} = 4\%$ ). Solid blue line is the corresponding best-fit model if  $f_{\text{star}} = 0$ . The values for  $f$  and  $b$  are given in Table 1. For reference we include with a dashed black line a WMAP7  $\Lambda$ CDM model assuming General Relativity, that is with  $f$  set to  $\Omega_m^{0.55}$  ( $f_{\text{star}} = 0$  in this case). The inset panel zooms in the region where the baryon acoustic peak is located (see Fig. 18 for the BAO significance). Notably the different models match the data very well in all the range of scales.

- Data vs. Model I :

## Red-shift Space Distortions - Constraint in Growth



$$\frac{\partial D}{\partial a} = \frac{D(z)}{a} f(z) = \frac{1+z}{\sigma_8(0)} f(z) \sigma_8(z),$$

These data leads to

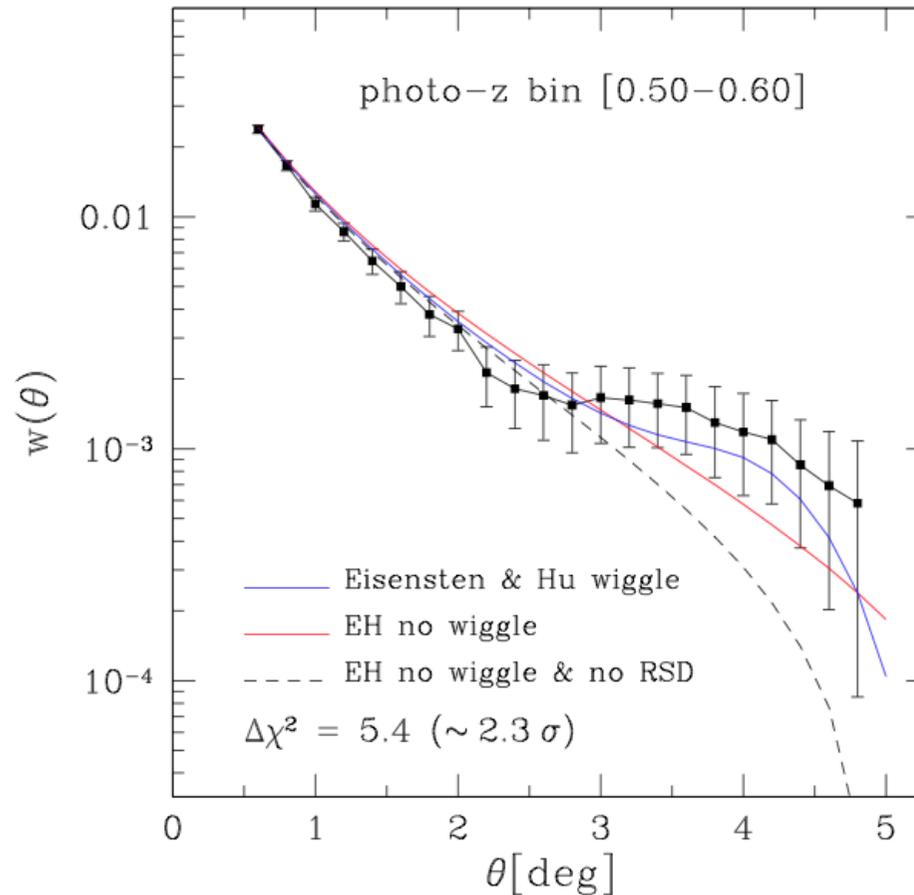
$$\gamma = 0.54 \pm 0.17 \text{ in a model}$$

where  $f = \Omega_m(z)^\gamma$ .

- Data vs. Model II :  
Baryon Acoustic Feature

Comparing a BAO vs. no BAO model (Eisenstein and Hu 1998) we find a detection with 98% confidence level

RSD also impacts the detectability of BAO !



# Conclusions

- Accurate and well tested model for the angular correlation function and its full covariance matrix. Good for data analysis but also for forecasts.
- Publicly available ensembles of mock catalogs from photometric surveys
- Nonlinear gravity and bias seems minor issue. Red-shift distortions is very important even for wide bins, might compete with photo-z smearing.
- A single bin at  $z \sim 1$  in a DES-like survey should measure  $f(z)\sigma_8(z)$  to  $(17 \times b)\%$ , comparable to current constraints from Wiggle-Z at  $z = 0.78$ .  
Combining bins in  $0.5 < z < 1.4$  and  $f(z) = \Omega_m(z)^\gamma$  gives  $\gamma = 0.557^{+0.25}_{-0.22}$ . (DES alone)
- Angular correlation function of LRGs in the imaging catalog of DR7 in good agreement with LCDM :
  - ✓ Red-shift distortions is robustly measured matching expectations.
  - ✓ It shows 2.3 sigma's evidence for the Baryon Acoustic Feature
- Future should look for the complementariness of photometric and spectroscopic data.