Who needs BAO?! Cosmological constraints from small scale clustering of galaxies

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Cosmological Quests for the Next Decade - April 17 - 2017

Outline

* Background
  - What the problem is?
  - Statistics
  - Theory and Systematics

* Future Predictions

* Higher Order Clustering

Background: What's wrong?

* What causes cosmic acceleration?
  - Vacuum energy or Scalar field(s)?
  - Or something more strange*?!
    * (if that's not strange enough)

* What is Dark Matter?
  - Is it Self-interacting?
  - Is it Decaying?

Each of the above possibilities could effect
How the universe expands
  * therefore precise and unbiased measurements of the expansion history are crucial for cosmology

Outline

Clustering of galaxies tells us a lot about cosmology
How do we do it practically…(ok slightly simplified)…

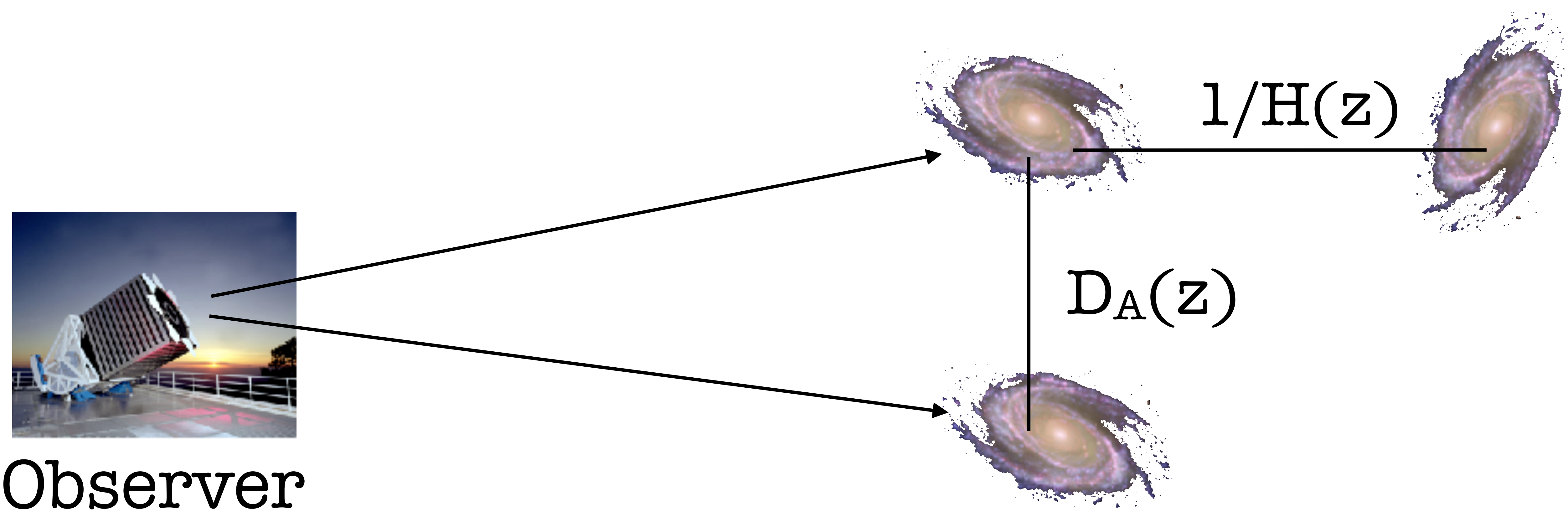
??

1) Observer many galaxies (ra, dec, z)
2) Assume a cosmological model then convert positions to (x,y,z) comoving cartesian coords
3) Visit each galaxy and count the number of neighbour galaxies in shells of different radii
<u>OR</u> download my super-duper correlation function code ;) KSTAT - https://bitbucket.org/csabiu/kstat
4) Fit a theoretical model to the result and constrain cosmological parameters

Alcock-Paczynski Effect

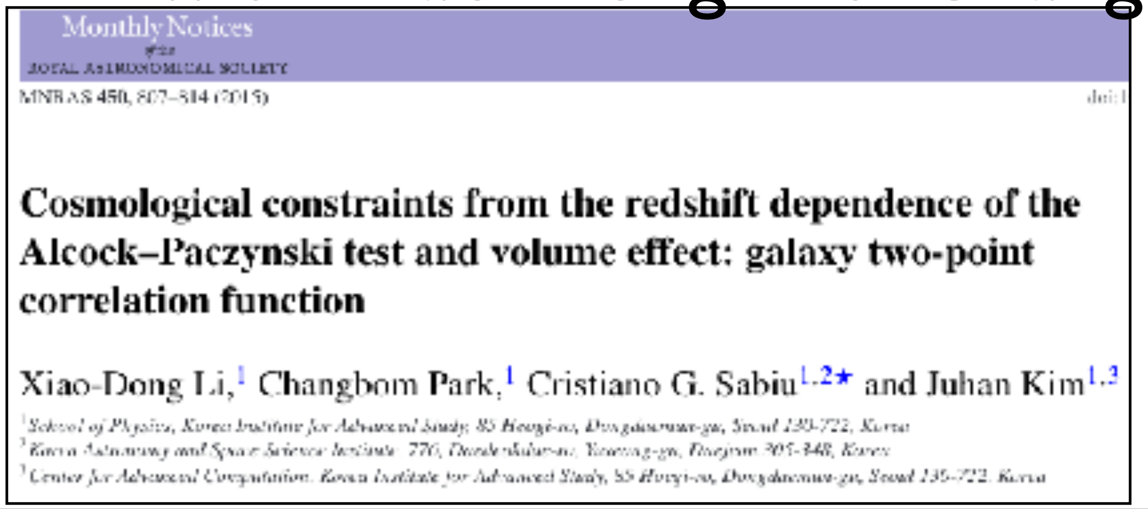
We measure RA, Dec and Redshift for each galaxy. However we must choose a cosmological model to convert these positions into a cartesian comoving coordinate system.

Even without a standard ruler, we can measure the clustering along and perpendicular to the line of sight and thus constrain the combination of $D_A * H$



Anisotropic Clustering Shells

with Xiao-Dong Li & Changbom Park (KIAS) et al


Monthly Notices of the Royal Astronomical Society

MNRAS 450, 807–814 (2015) doi:

Cosmological constraints from the redshift dependence of the Alcock–Paczynski test and volume effect: galaxy two-point correlation function

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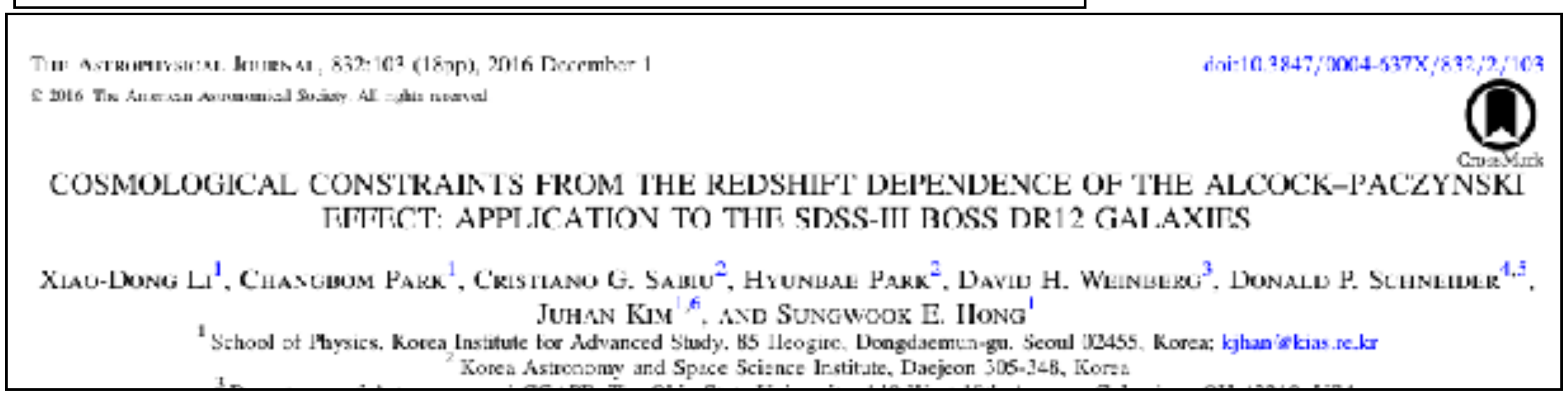
The Astrophysical Journal, 832:103 (18pp), 2016 December 1 doi:10.3847/0004-637X/832/2/103
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COSMOLOGICAL CONSTRAINTS FROM THE REDSHIFT DEPENDENCE OF THE ALCOCK–PACZYNSKI EFFECT: APPLICATION TO THE SDSS-III BOSS DR12 GALAXIES

Xiao-Dong Li[1], Changbom Park[1], Cristiano G. Sabiu[2], Hyunbae Park[2], David H. Weinberg[3], Donald P. Schneider[4,5], Juhan Kim[1,6], and Sungwook E. Hong[1]

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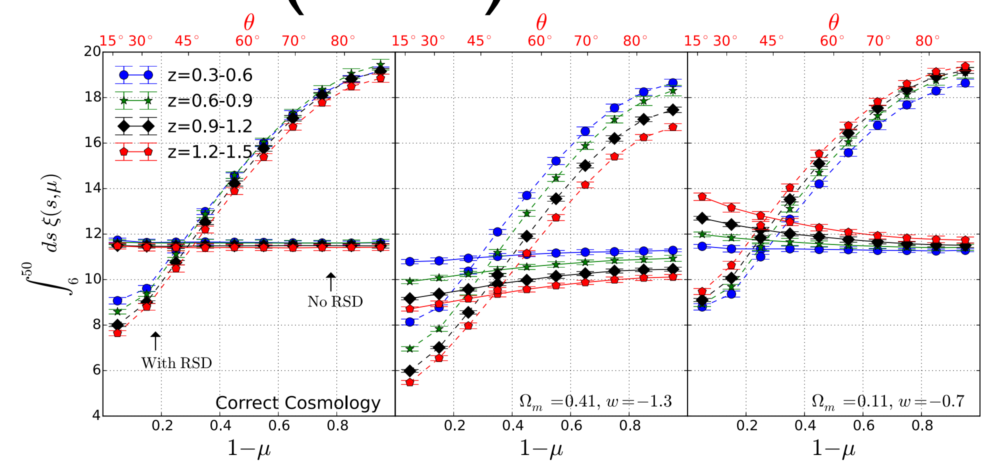
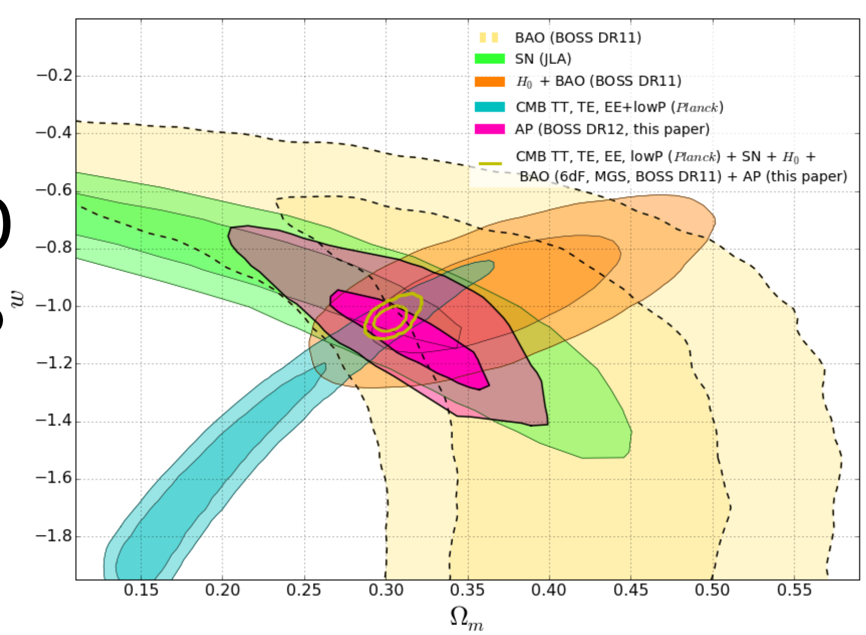


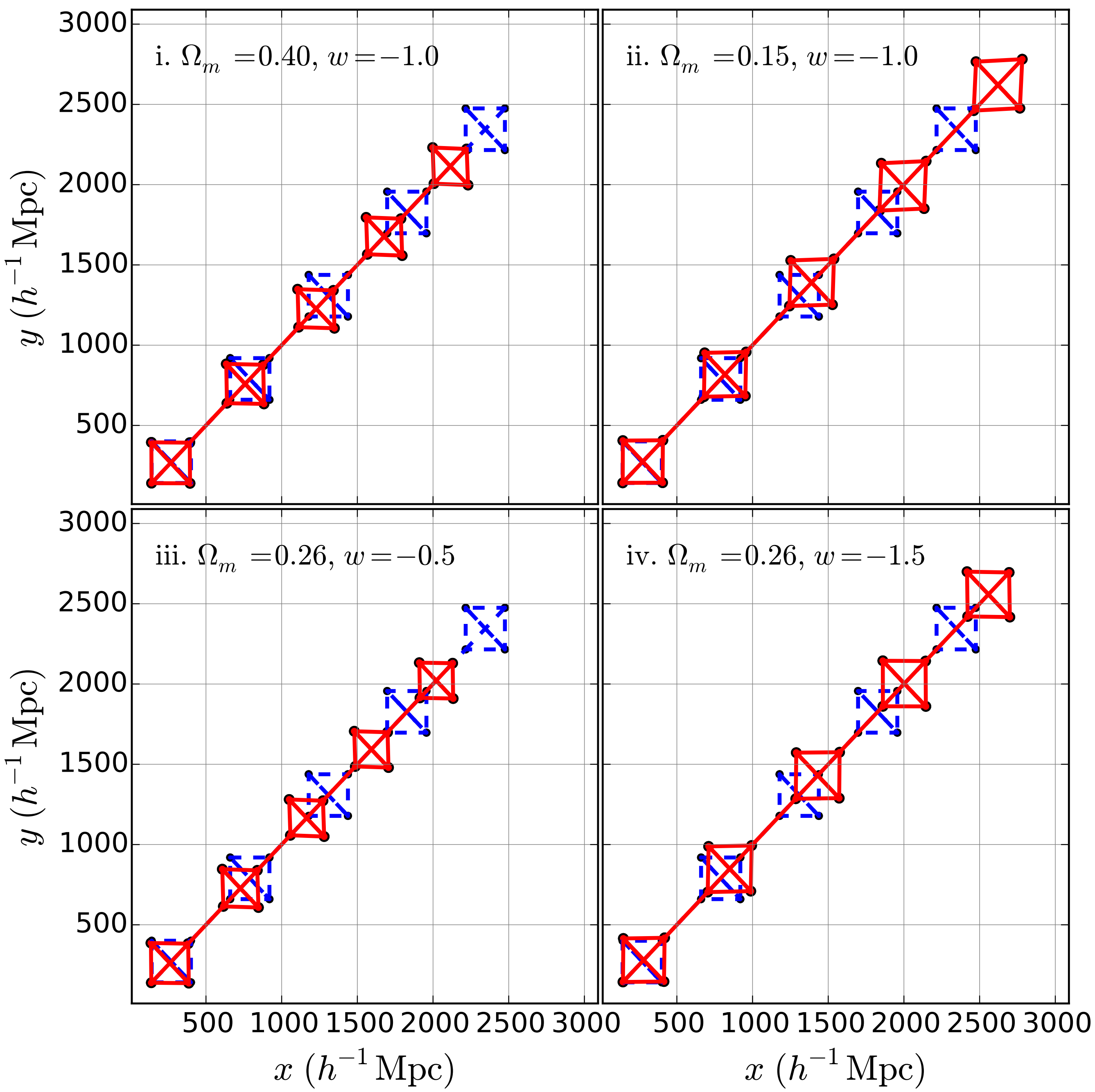


Xiao-Dong Li, Changbom Park, Cristiano G. Sabiu, +++
Mon.Not.Roy.Astron.Soc. 450 (2015) 807 arXiv:1504.00740
Astrophysical Journal (2016) 832 103 arXiv:1609.05476

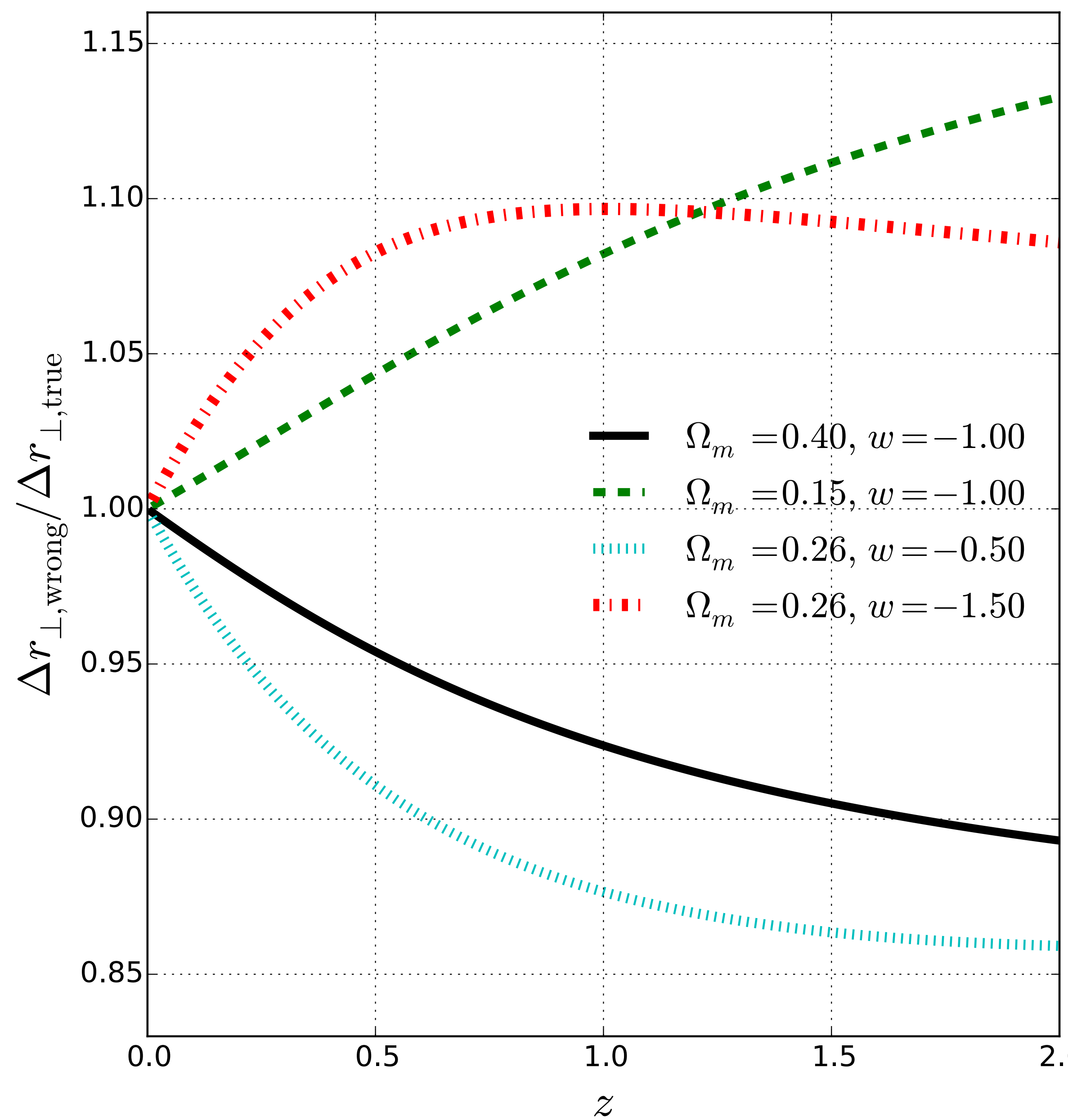
Using volume effect - Li, Sabiu, Park, etal - submitted
Using 3PCF - Li, Sabiu, Park, etal - in prep

Alcock-Paczynski - Volume Effect

Toy model picture



Projecting the position of points in an incorrect cosmological model



Da*H in various cosmological model (normalized by a 'true' fiducial model)

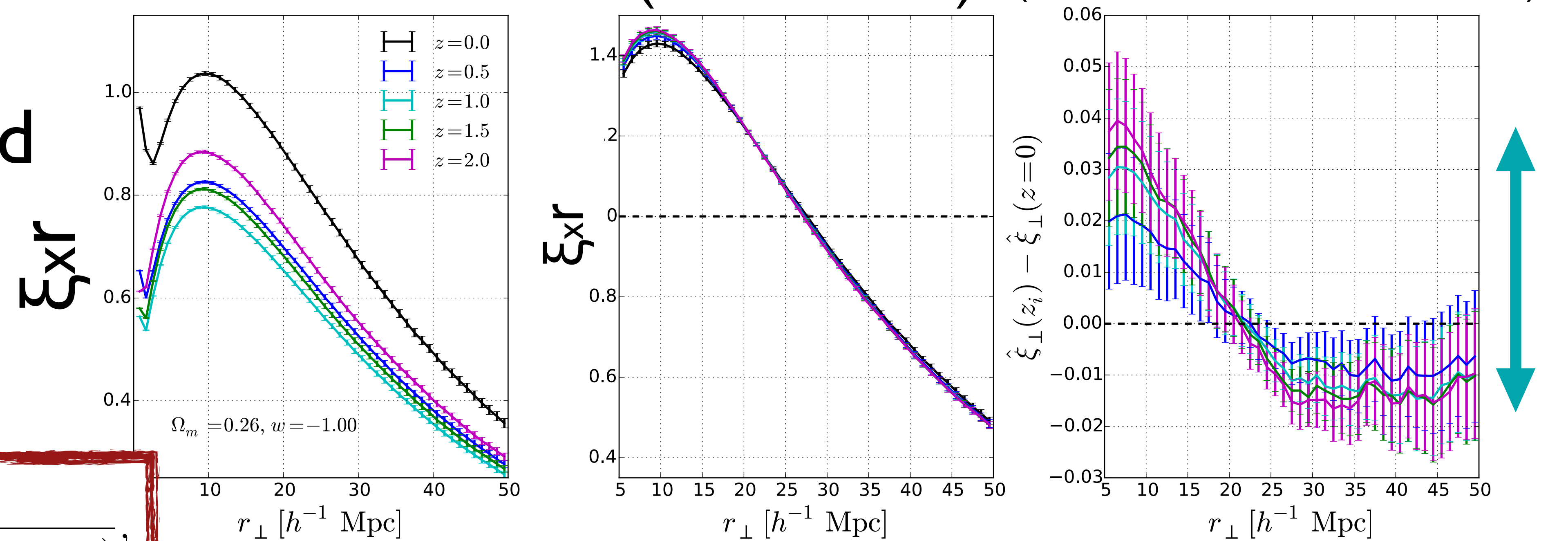
Redshift Dependent Volume Effect

search for redshift invariant quantity that captures the volume change

using 1.75 Billion mock galaxies from the Horizon Run4 simulation (Kim etal 2015)

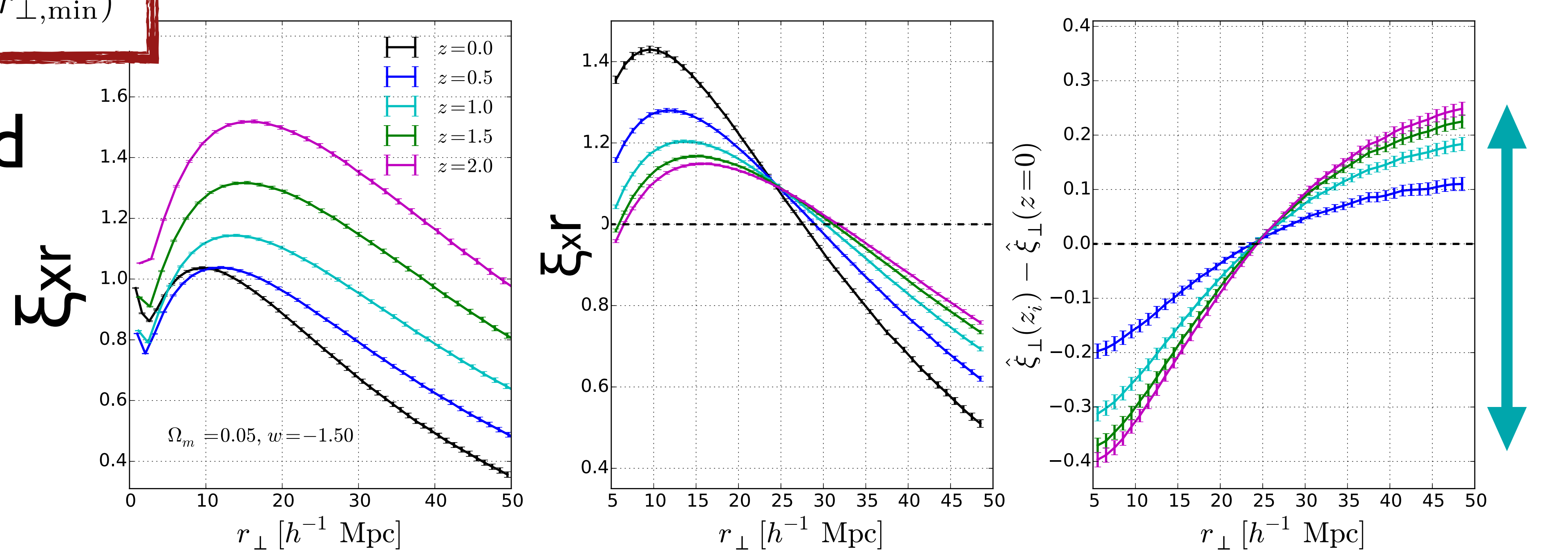
Angular 2PCF | Angular 2PCF (normalised) | Angular 2PCF (normalised & differenced)

coords transformed using correct cosmology



$$\hat{\xi}_{r_\perp} \equiv \frac{r_\perp \xi(r_\perp)}{\int_{r_{\perp,\min}}^{r_{\perp,\max}} r_\perp \xi(r_\perp) dr_\perp / (r_{\perp,\max} - r_{\perp,\min})},$$

coords transformed using incorrect cosmology

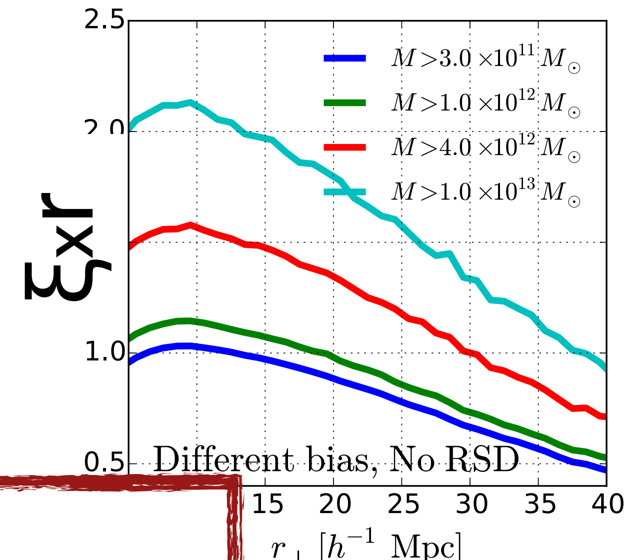


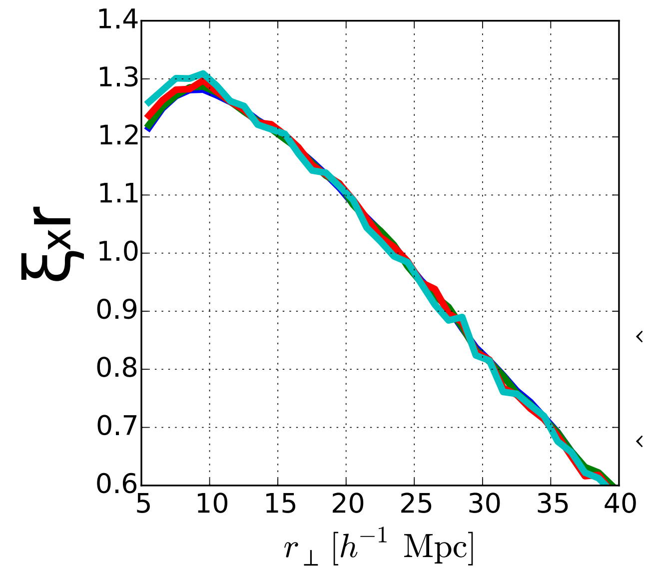
Redshift Dependent Volume Effect

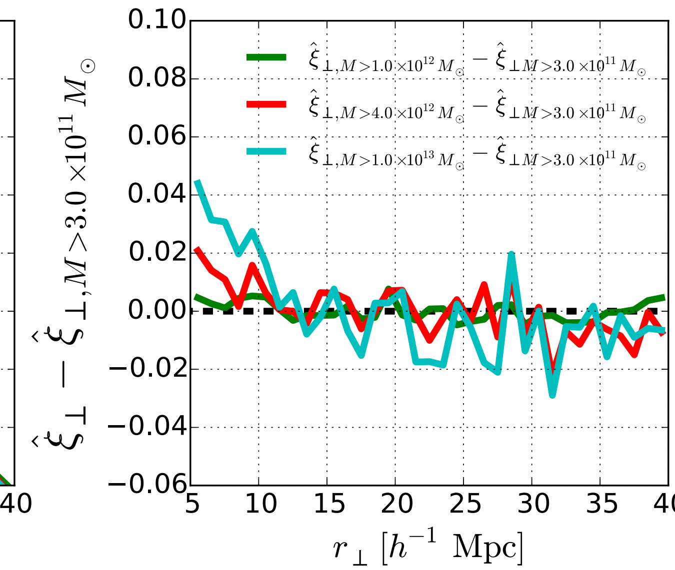
Bias & RSD systematic check

Angular 2PCF | Angular 2PCF (normalised) | Angular 2PCF (normalised & differenced)

Different mass cut, bias, no RSD

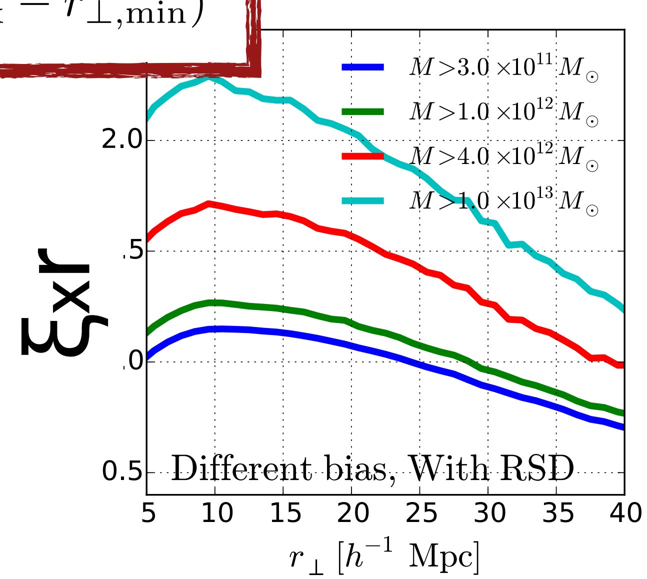


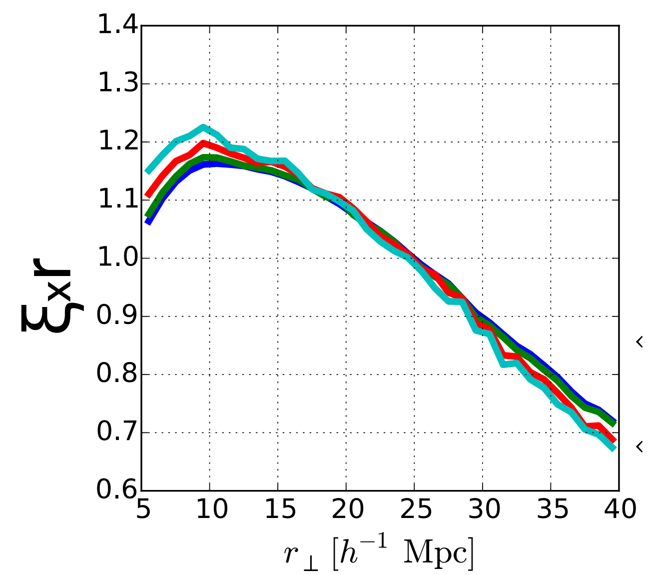


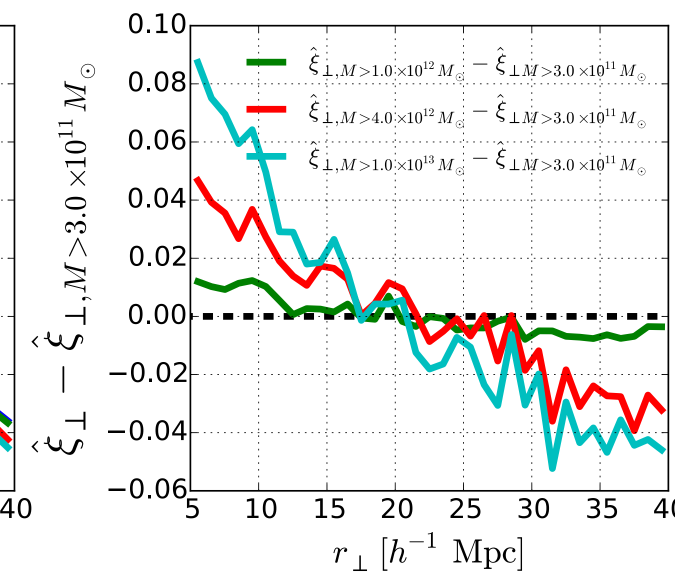


$$\hat{\xi}_{r_\perp} \equiv \frac{r_\perp \xi(r_\perp)}{\int_{r_{\perp,\mathrm{min}}}^{r_{\perp,\mathrm{max}}} r_\perp \xi(r_\perp) dr_\perp/(r_{\perp,\mathrm{max}} - r_{\perp,\mathrm{min}})},$$

Different mass cut bias, with RSD







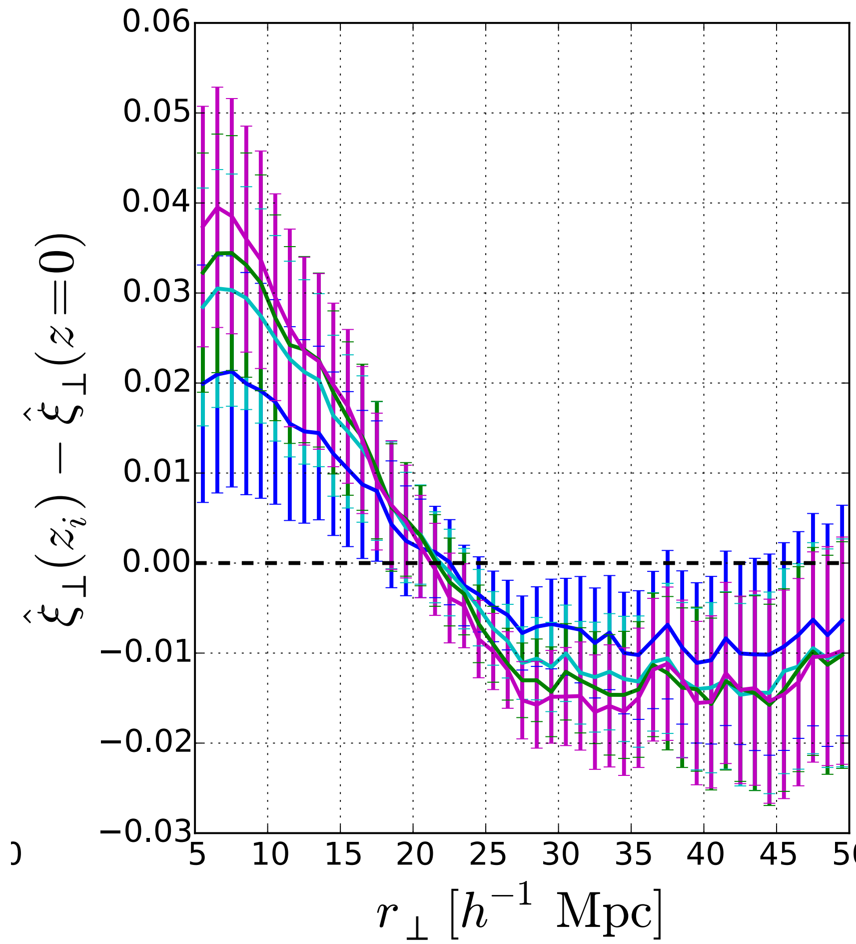
z-dept vol effect: likelihood

$$\chi^2 \equiv \sum_{i=2}^{n_z} \sum_{j_1=1}^{n_r} \sum_{j_2=1}^{n_r} \mathbf{p}(z_i, r_{j_1}) (\mathbf{Cov}_i^{-1})_{j_1,j_2} \mathbf{p}(z_i, r_{j_2}),$$

$$\mathbf{p}(z_i, r_j) \equiv \delta\hat{\xi}_{\perp}(z_i, z_1, r_j) - \delta\hat{\xi}_{r_\perp,\mathrm{sys}}(z_i, z_1, r_j)$$

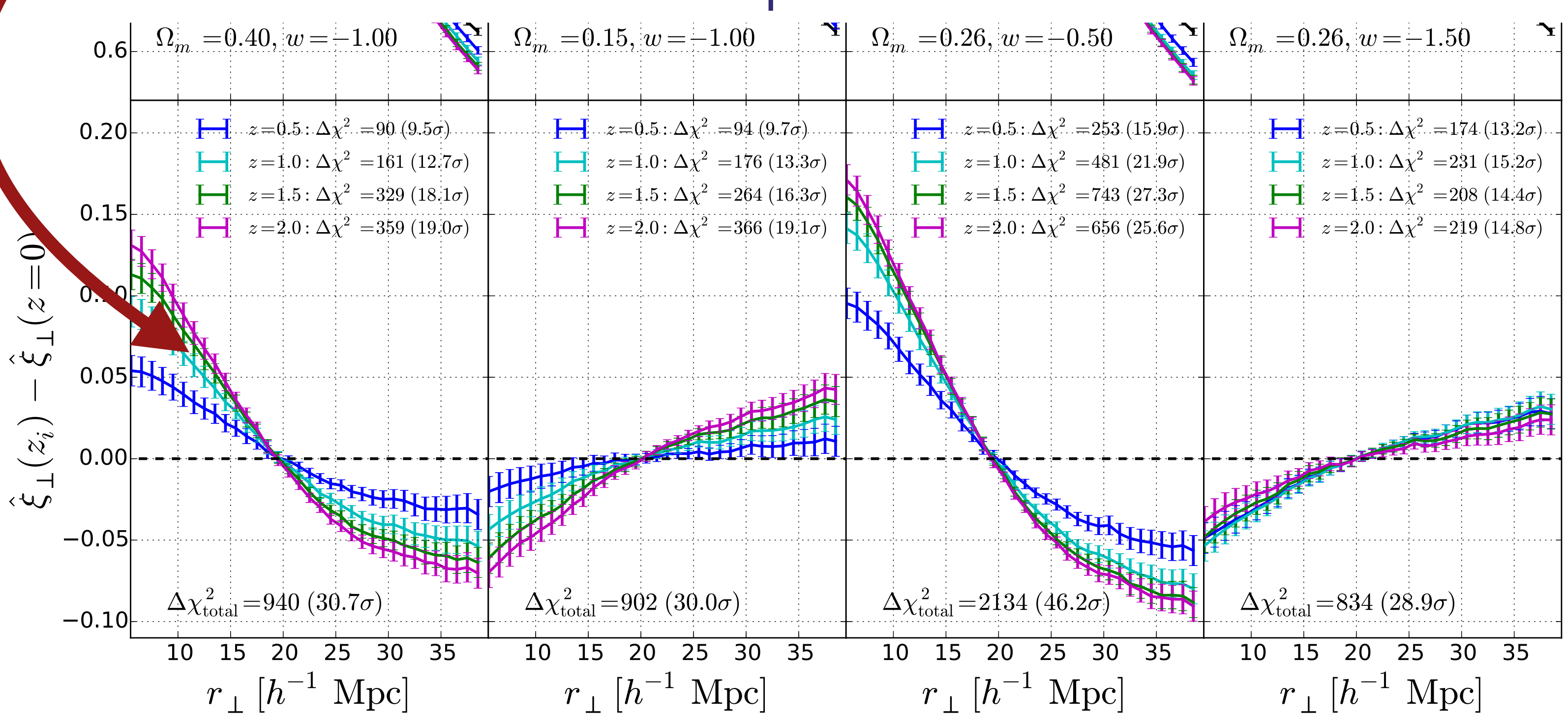
Minimise the difference

$$\delta\hat{\xi}_{r_\perp}(z_i, z_1) \equiv \hat{\xi}_{r_\perp}(z_i) - \hat{\xi}_{r_\perp}(z_1),$$



xi measured from a fiducial simulation has been used to correct our systematic, ie small scale growth of structure, RSD

Fiducial cosmology mocks coord transformed under various incorrect parameter combinations



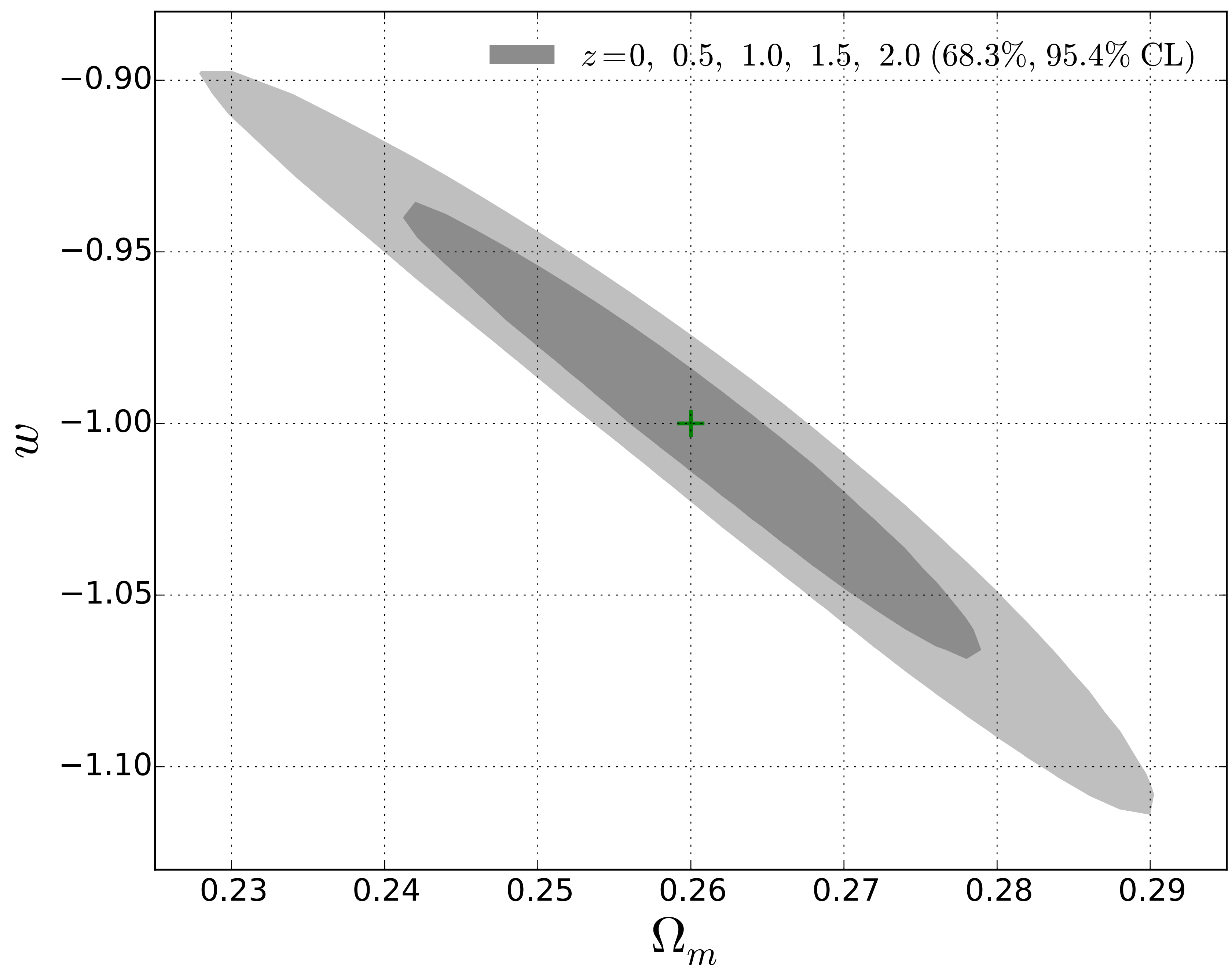
Results

Projections

using 1.75 Billion mock galaxies from the Horizon Run4 simulation

from z=0 -> 2

Potential for use with LSST

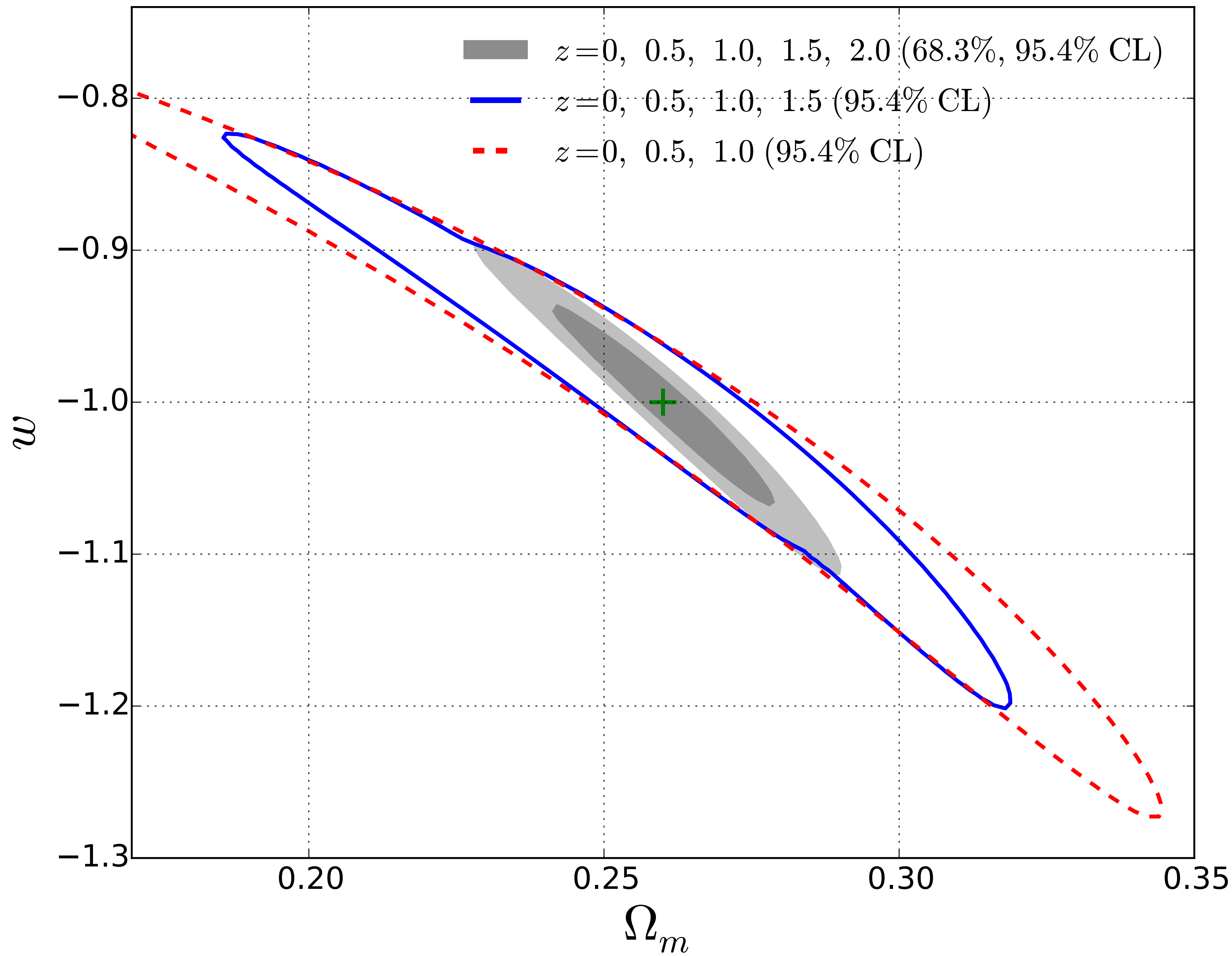


Results

Projections

using 1.75 Billion mock galaxies from the Horizon Run4 simulation

from z=0 -> 1, 1.5, 2



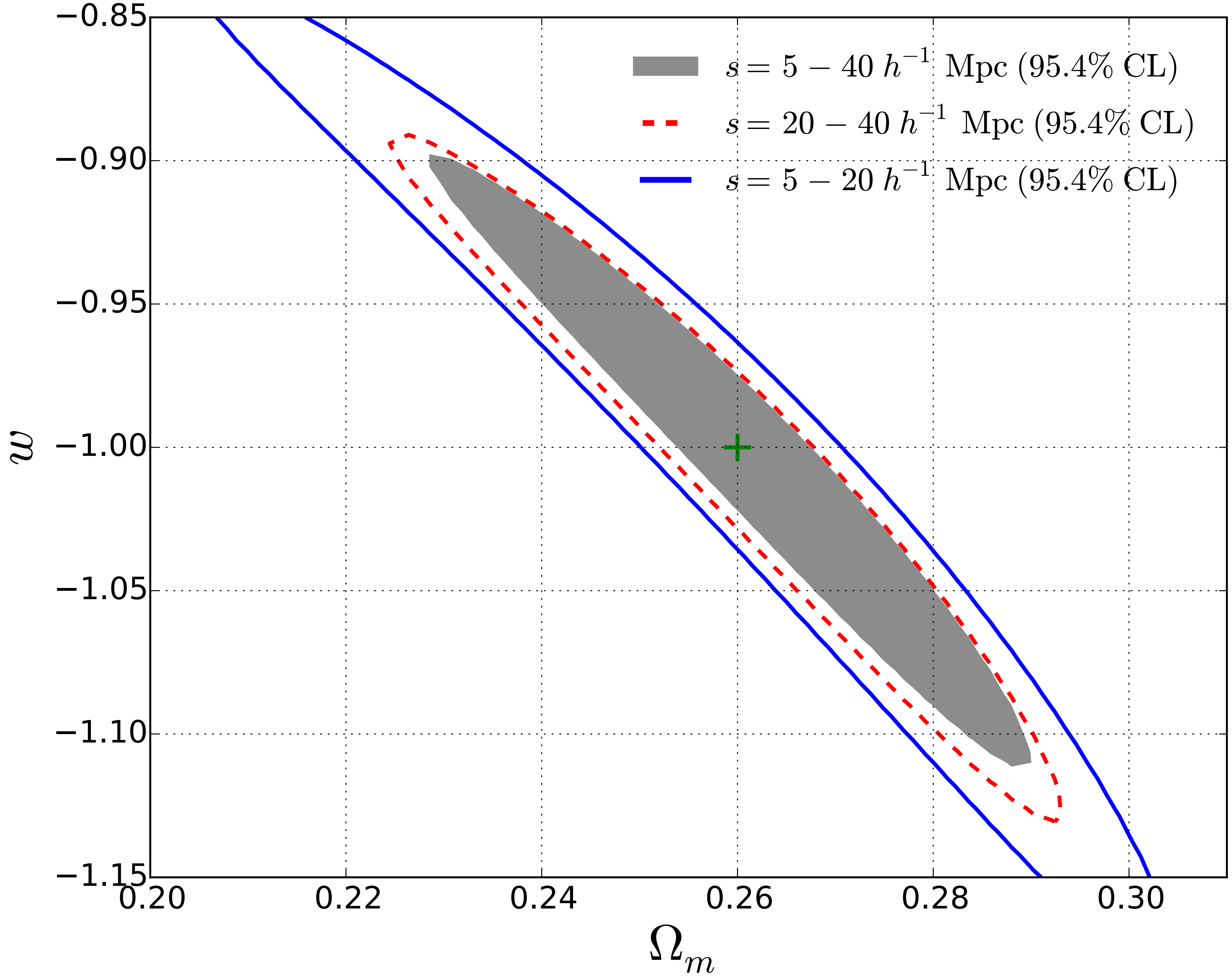
Results

Projections

using 1.75 Billion mock galaxies from the Horizon Run4 simulation

from z=0 -> 2

If you are worried about the lower distance cut, we find that even at 20Mpc are constraints are strong.



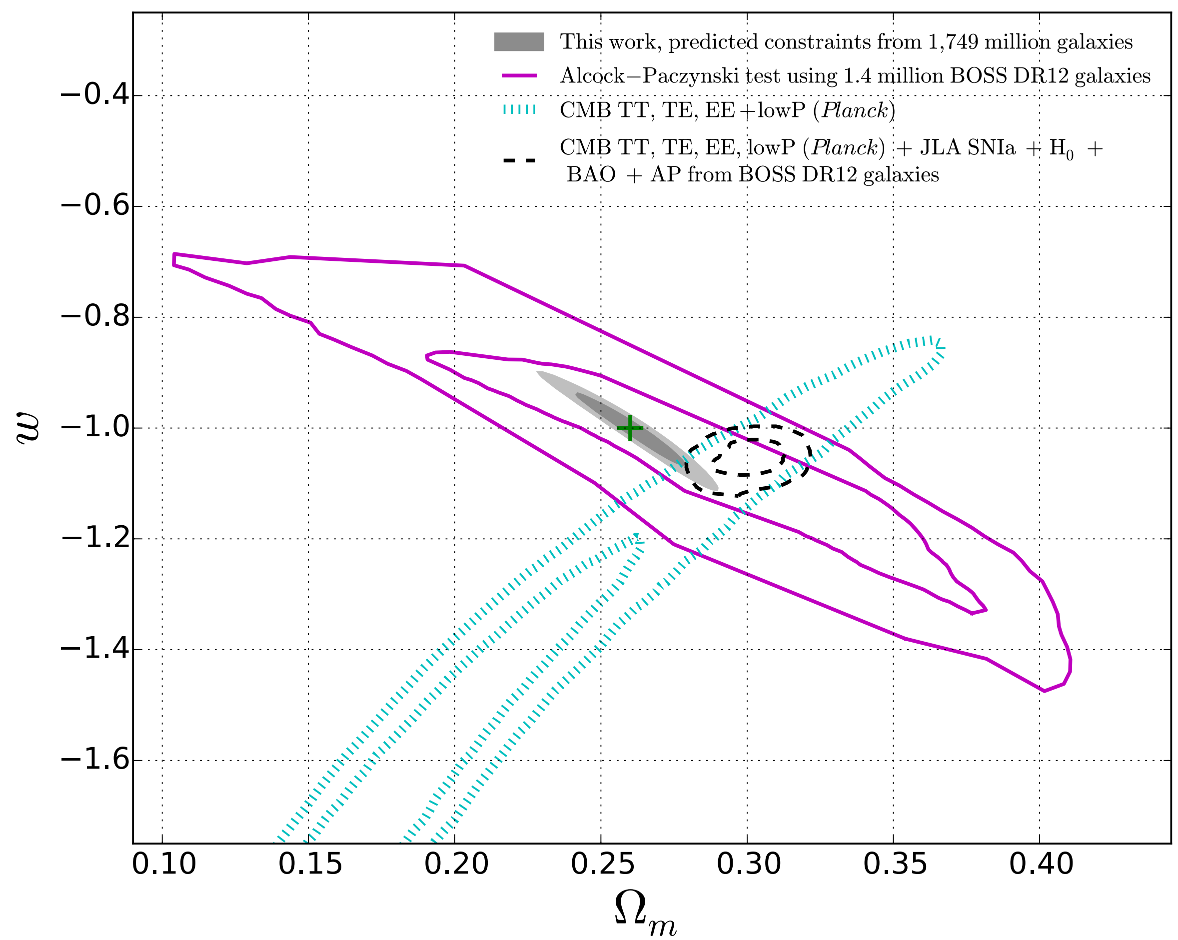
Results

Projections

The development of this methodology is still very preliminary.

This work is currently under review, however when we come to apply this to real data there will be more systematics to check.

But at this point, it seems to be a worthy avenue of investigation!



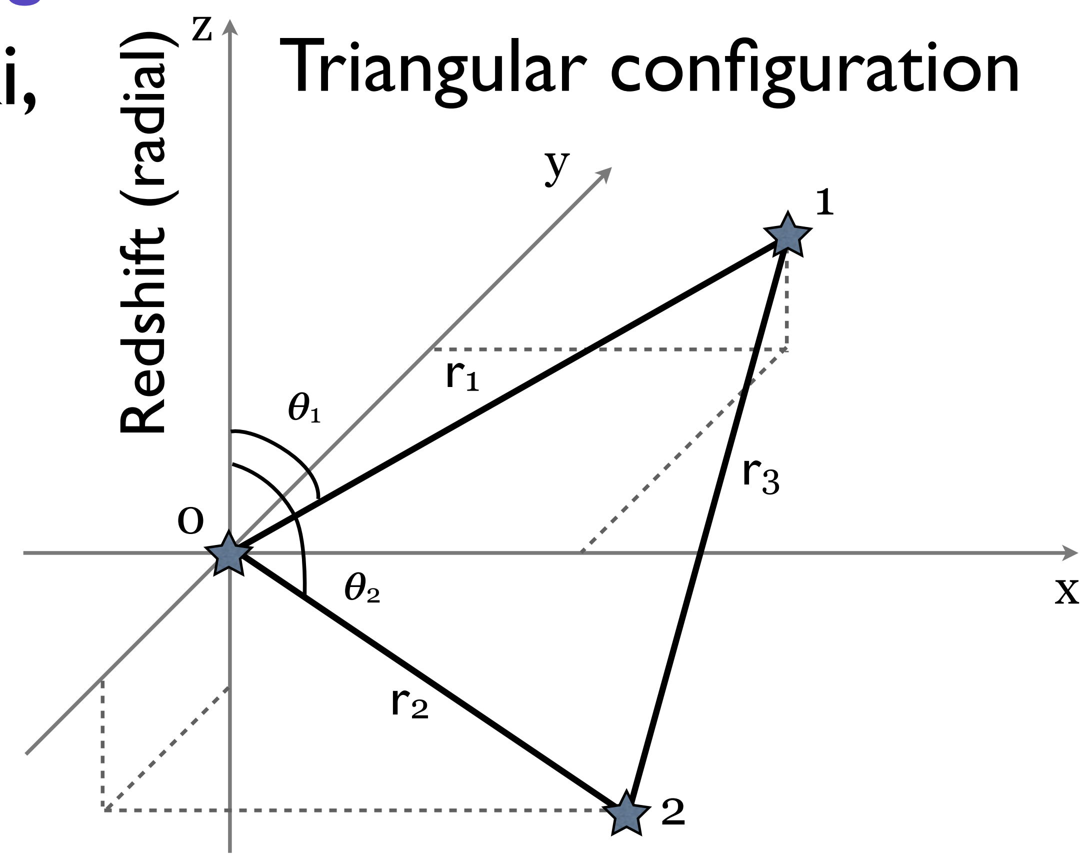
this constraint is orthogonal to CMB constraints -> GOOD!

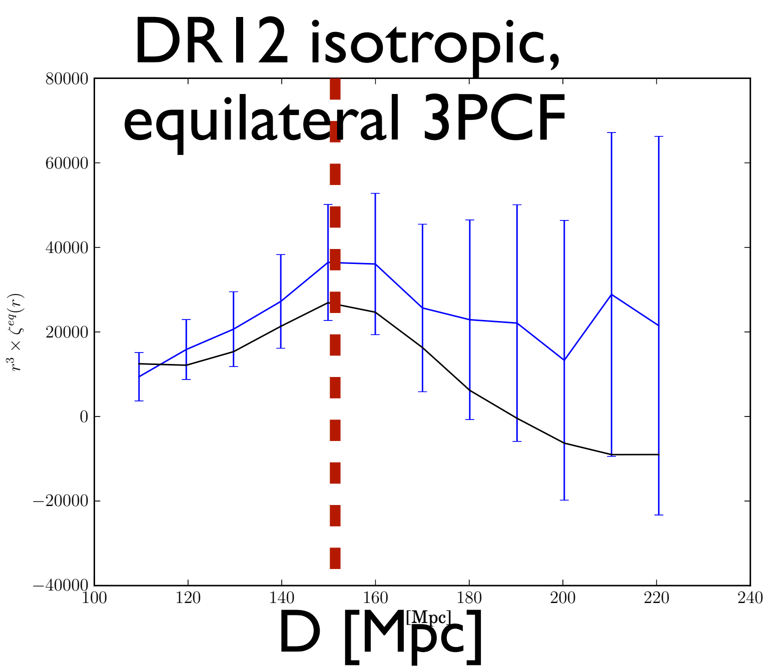
Ok, I still love BAO....

Higher Order Clustering Statistics: Towards the generalised BAO membrane

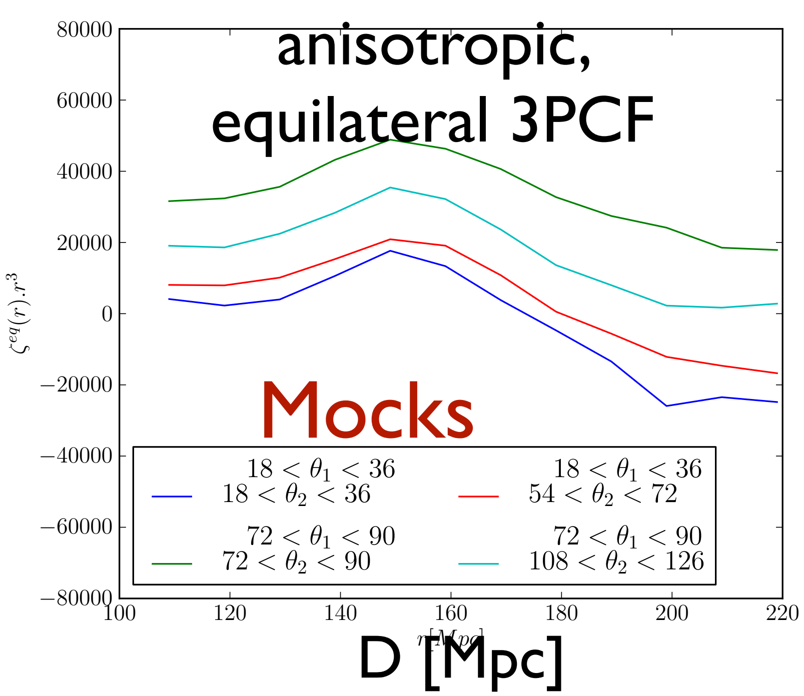
D_A, H^{-1} from higher order Alcock-Paczynski, i.e.

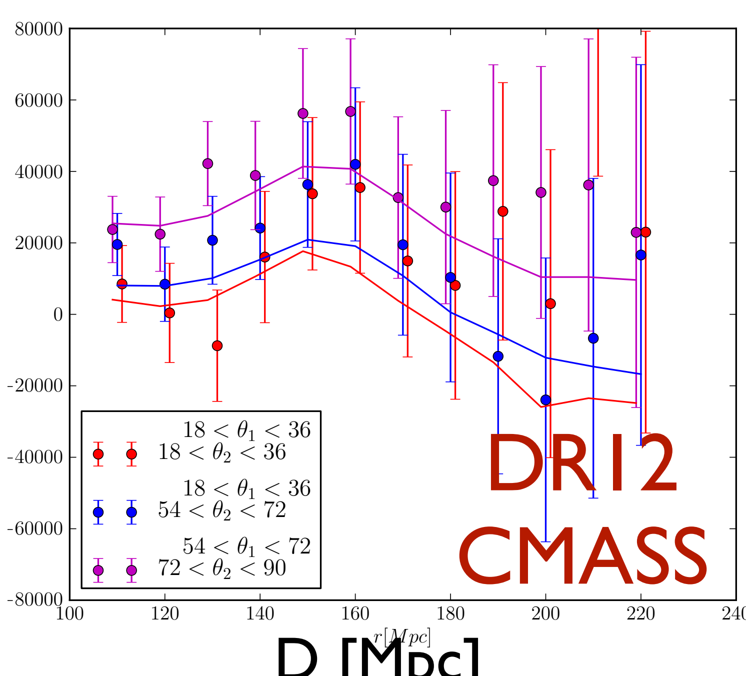
$$\tilde{B}^{\rm obs}(k_1,k_2,k_3,\mu_1,\mu_2) = \left(\frac{H^{\rm true}}{H^{\rm fid}}\right)^2 \left(\frac{D_A^{\rm fid}}{D_A^{\rm true}}\right)^4 \times \tilde{B}(q_1,q_2,q_3,\nu_1,\nu_2)\,.$$

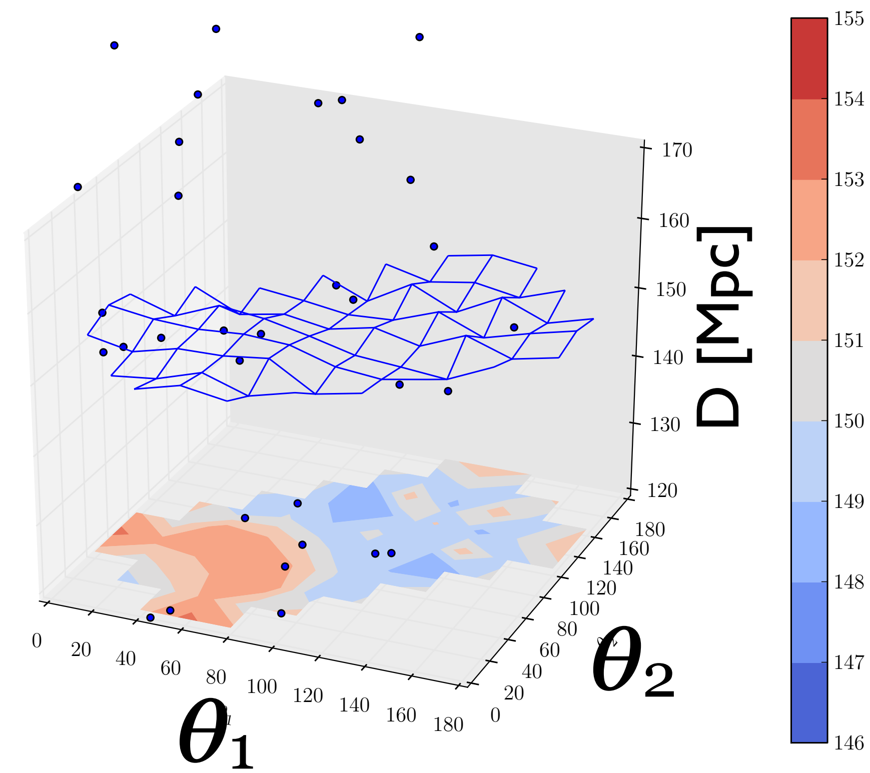




From isotropic to anisotropic to the generalised BAO membrane







Conclusions

* We look for a redshift invariant quantity that captures the volume change of the more general Alcock-Paczynski geometrical distortion.

* After modelling the residual / systematic terms we can recover tight unbiased constraints on the matter content and EoS of Dark Energy

* The systematic correction is not cosmology dept, within small shifts, but we need to test this further.

* Rather than using simulations for modelling the nonlinear small scale clustering and RSD effects, we want to develop a theoretical approach using eg perturbation theory.

* Higher Order Statistics like the 3-point correlation function may give us more information on the BAO scale

Additional slides……

Background: Observables

Key observables in spectroscopic galaxy surveys:

(1) Angular diameter distance $\mathbf{D_A}$
- Exploiting BAO as standard rulers which measure the angular diameter distance and expansion rate as a function of redshift.

(2) Radial distance $\mathbf{H^{-1}}$
- Exploiting redshift distortions as intrinsic anisotropy to decompose the radial distance represented by the inverse of Hubble rate as a function of redshift.

$$H(z) = H_0 \sqrt{\Omega_m a^{-3} + (1 - \Omega_m) a^{-3(1+w)}},$$

$$D_A(z) = \frac{1}{1+z} r(z) = \frac{1}{1+z} \int_0^z \frac{dz'}{H(z')},$$

(3) Growth Rate, f **(dδ/d ln a)**
- The coherent motion, or flow, of galaxies can be statistically estimated from their effect on the clustering measurements of large redshift surveys, or through the measurement of redshift space distortions.

Statistics: Correlation Functions

We want to evaluate the 2-point statistics of the over-density field, **δ**

$$\langle \delta(x)\delta(x+r) \rangle_x$$

We call this the two-point correlation function

$$\xi(r) = \sum_i \frac{n_i(r)}{\bar{n}dV} - 1$$

Algorithmically calculate pair counts according to Landy-Szalay estimator

$$\xi(r) = \frac{DD - 2DR + RR}{RR}$$

The probability of finding a galaxy in 2 volume elements separated by r

$$dP = n^2 \left[1 + \xi(r)\right] dV_1 dV_2$$

Statistics: Correlation Functions

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We call this

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The probab

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