Precise measurement of the radial BAO scale in galaxy redshift surveys

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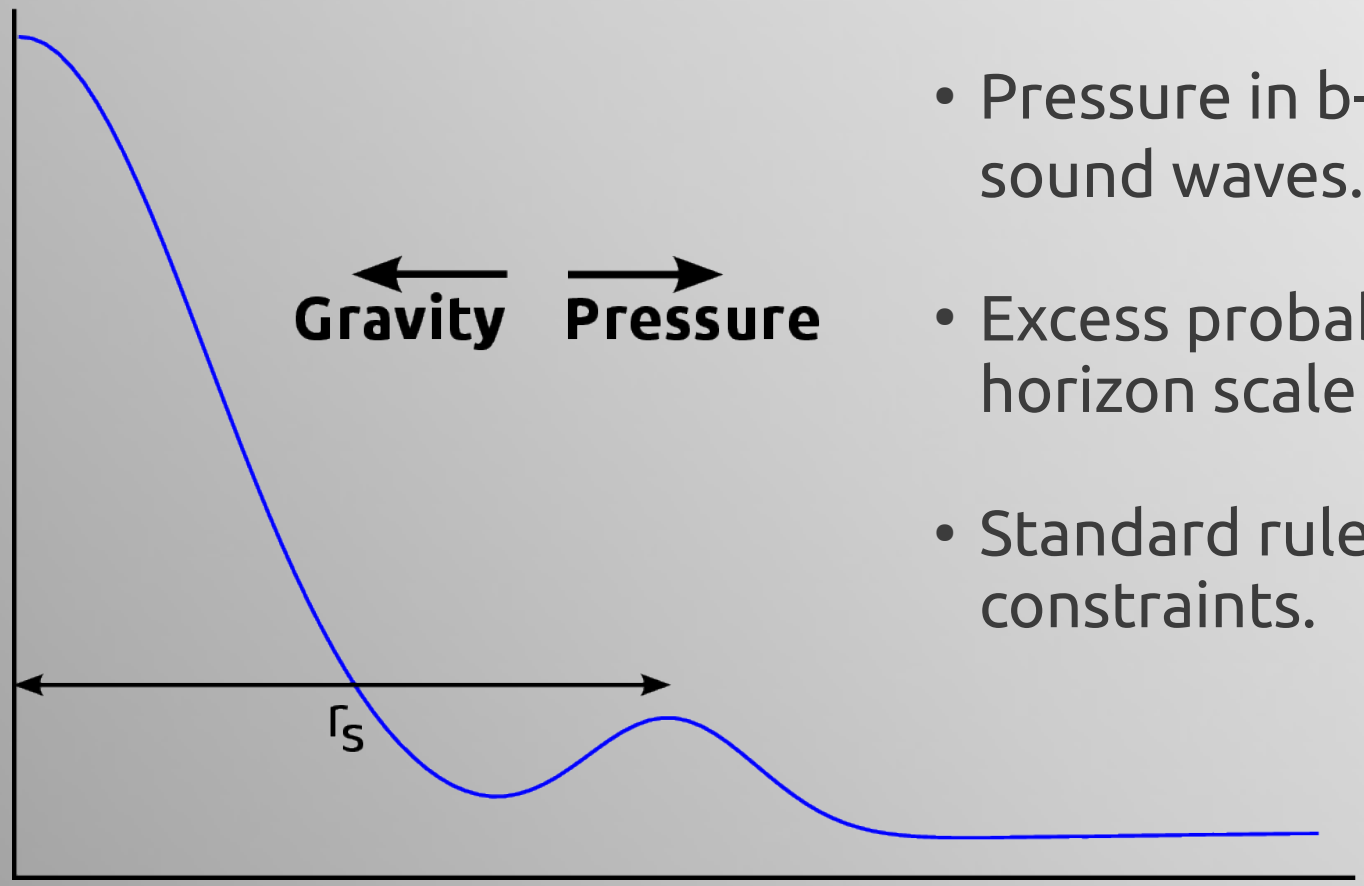
Based on the work arXiv:1210.6446
In collaboration with: E. Sánchez, F. J. Sánchez,
J. García-Bellido and I. Sevilla

Baryon Acoustic Oscillations



- Pressure in b-γ fluid creates sound waves.
- Excess probability at the sound horizon scale ($r_s \sim 110$ Mpc/h).
- Standard ruler for cosmological constraints.

Radial and angular BAO

- Usual approach to BAO: measure position in the angular-averaged 3-D correlation function $\xi(r)$.
- Alternative: separate measurements in the radial and angular correlation functions.

$$\xi(r) \neq \xi_{||}(\Delta z) + w(\theta)$$

Radial and angular BAO

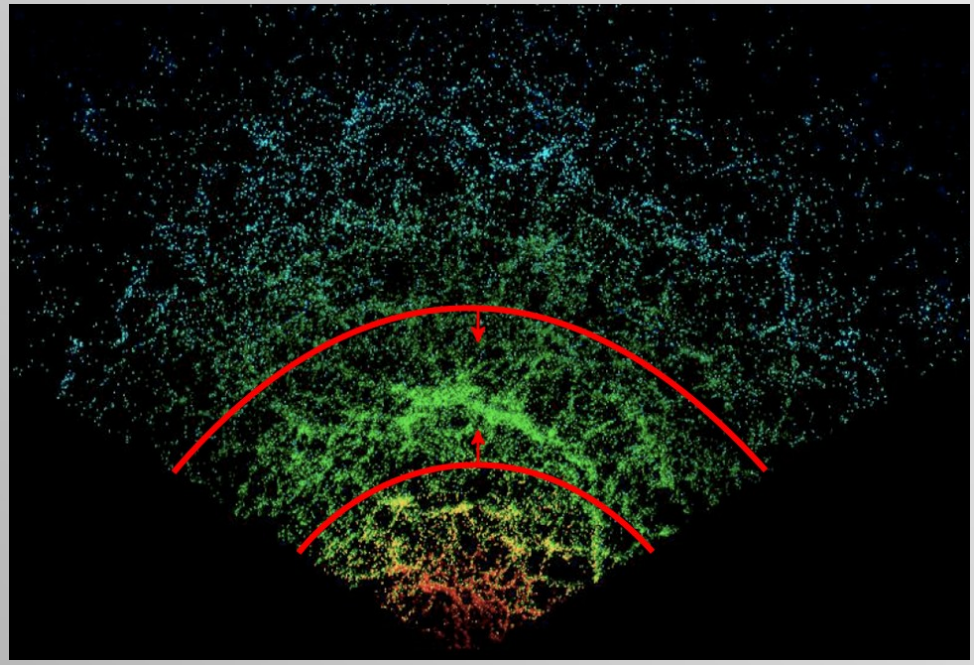
Advantages:

- Only direct observables (Δz, θ) are involved. No fiducial model needed.
- θ_{BAO} and Δz_{BAO} are complementary cosmological probes.

$$\Delta z_{\rm BAO} = \frac{H(z)}{c\, r_s} \qquad \theta_{\rm BAO} = \frac{r_s}{(1+z)\, d_A(z)}$$

Extracting the angular BAO

- Project a redshift bin on the sphere and calculate angular correlation.



Sánchez E. et al. (2011) MNRAS 411:277, arXiv:1006.3226

Extracting the angular BAO

- Project a redshift bin on the sphere and calculate angular correlation.
- Fit data to the model:

$$w(\theta) = A + B\theta^{\gamma} + C\, e^{-(\theta-\theta_{\rm FIT})^2/2\,\sigma^2}$$

- Correct $\theta_{\rm FIT}$ for projection effects to obtain $\theta_{\rm BAO}$

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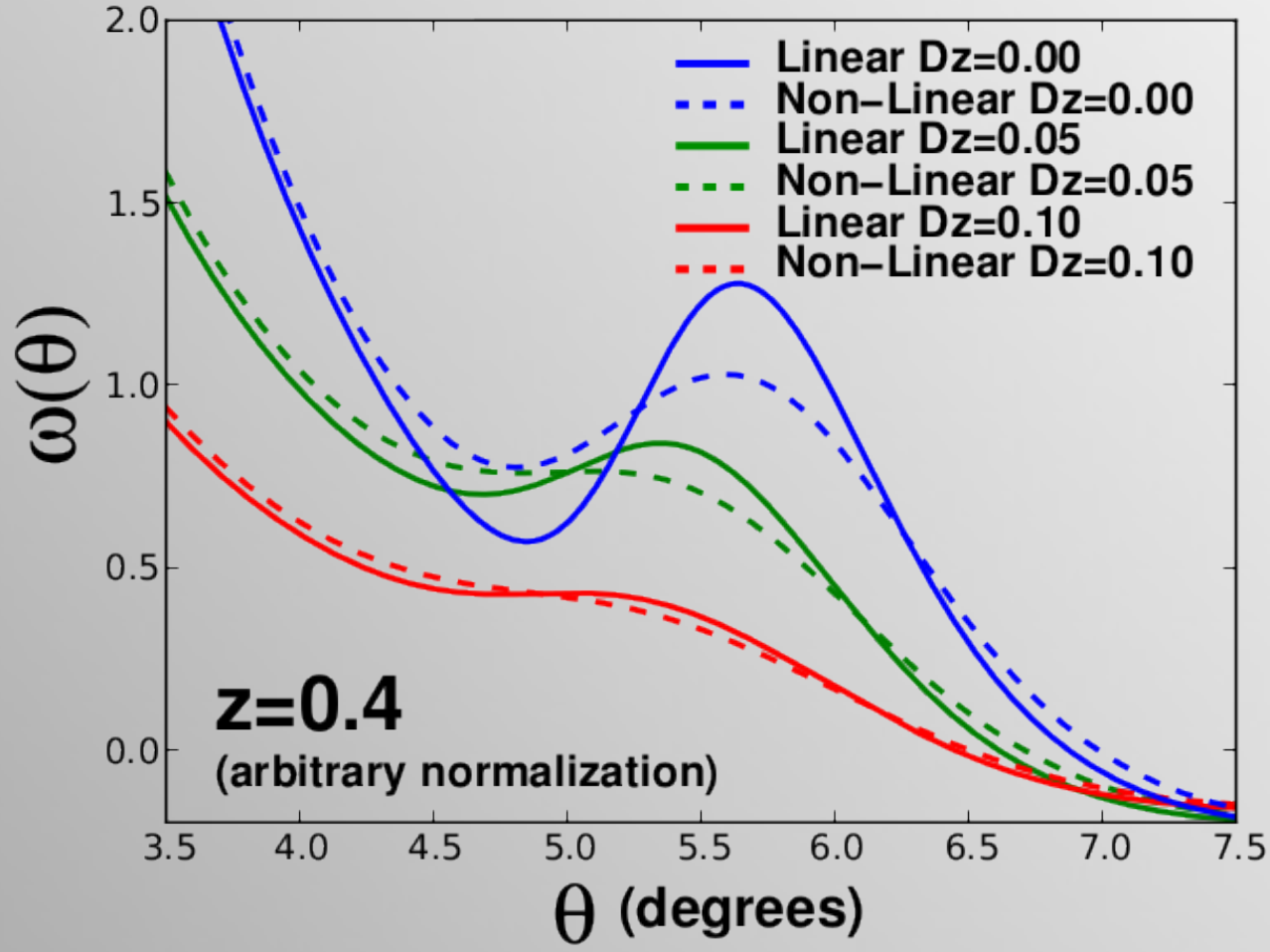
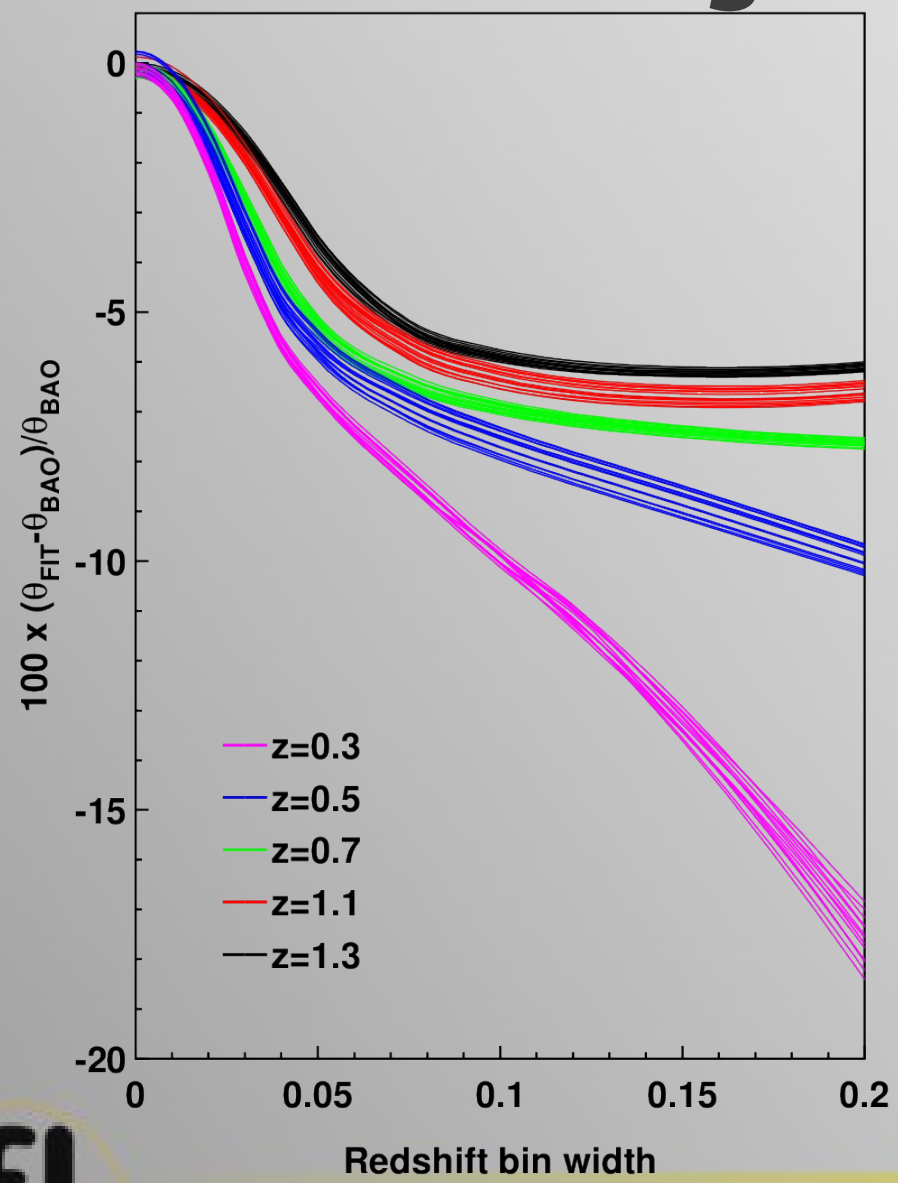
Extracting the angular BAO

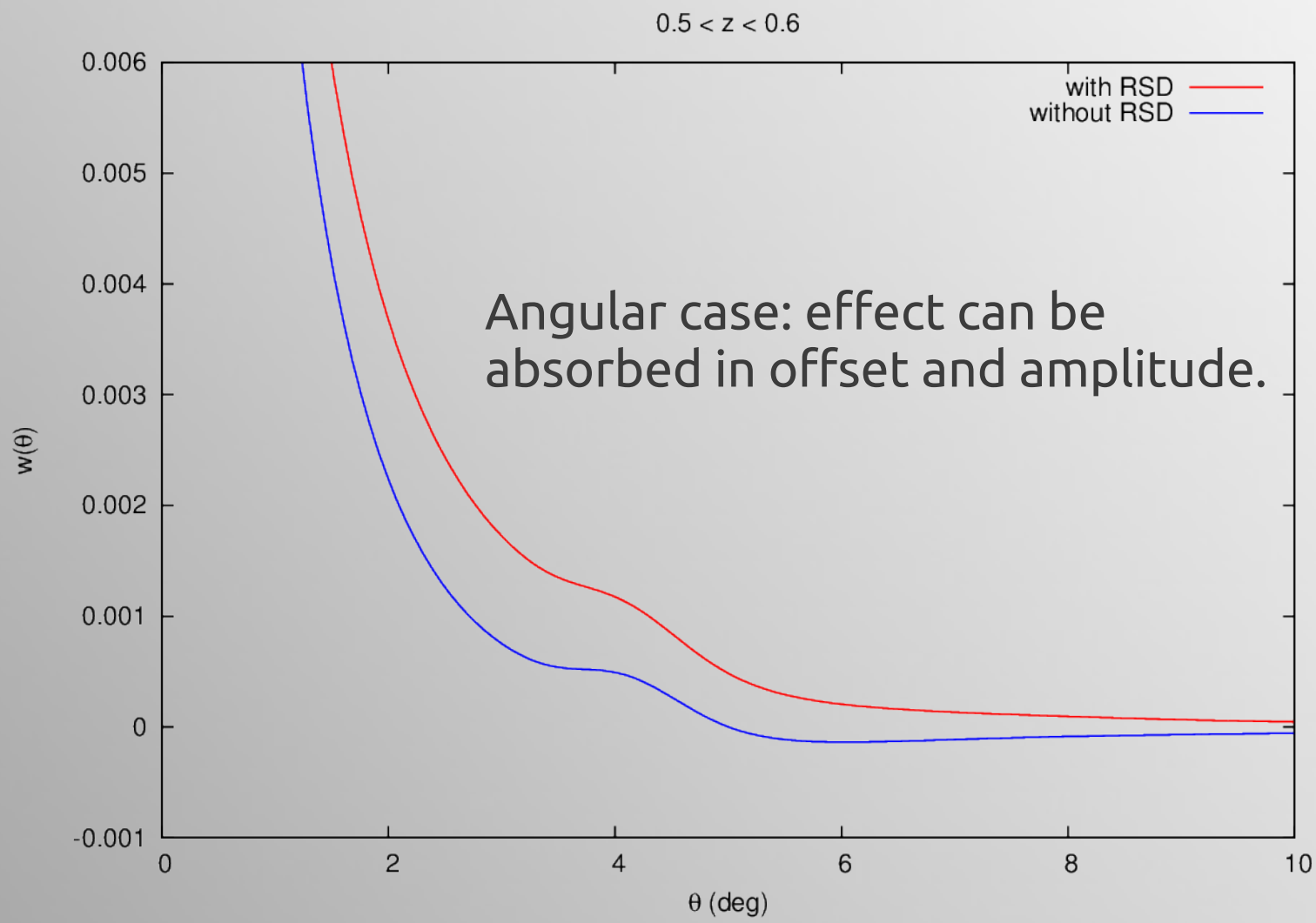


Extracting the angular BAO



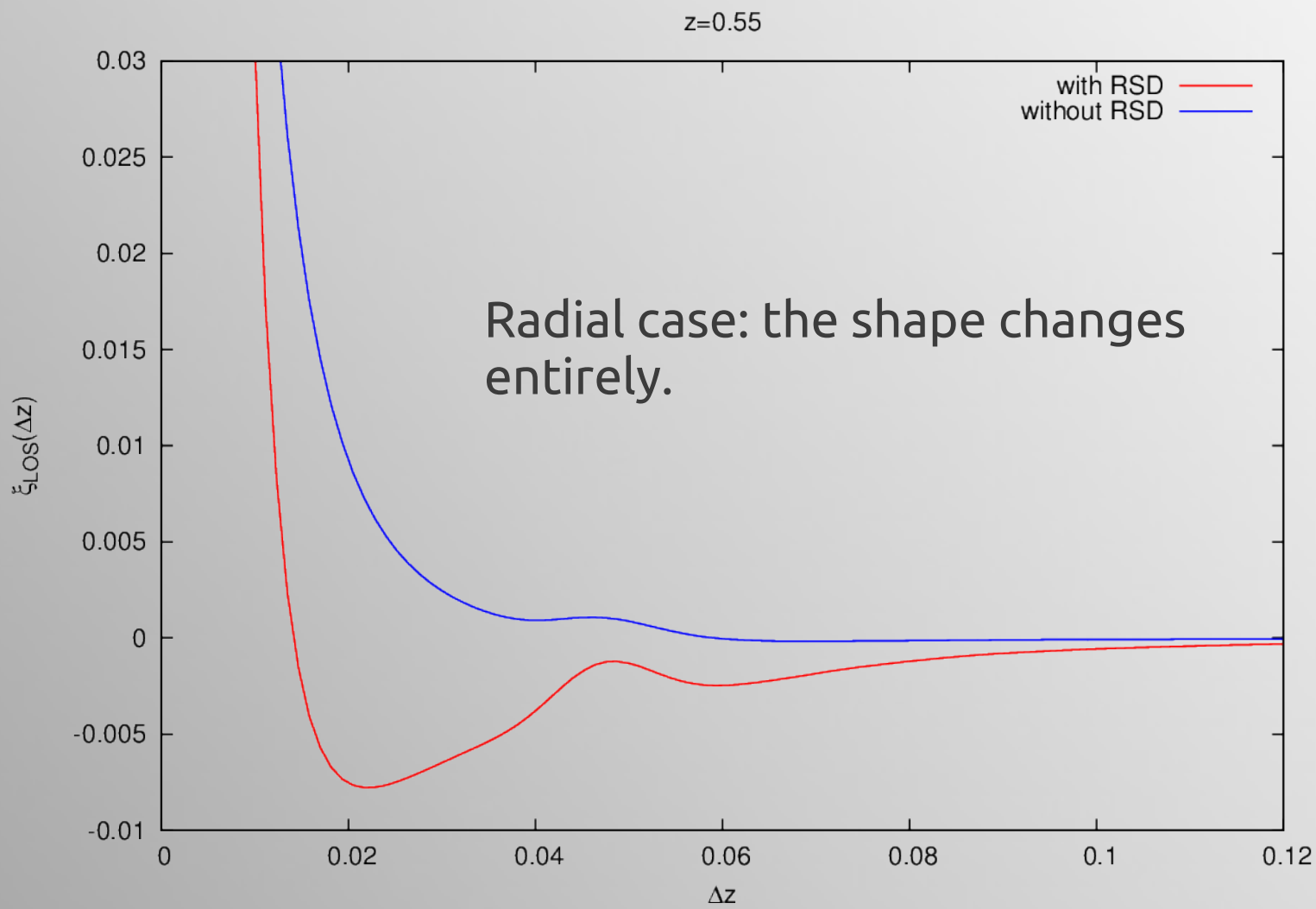
- Estimator must be corrected for projection effects.
- The estimator coincides with actual value (to 0.75%) for infinitesimal redshift bins.
- The correction is largely model-independend.

Effect of RSDs



Angular case: effect can be absorbed in offset and amplitude.

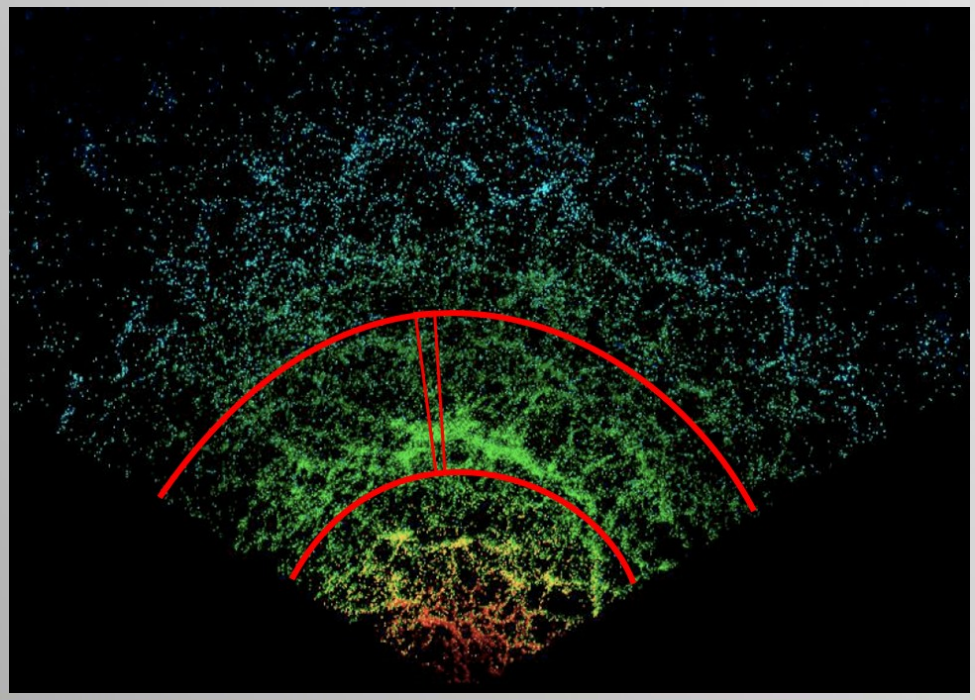
Effect of RSDs



Radial case: the shape changes entirely.

Extracting the radial BAO

- Divide your survey into appropriate redshift bins.
- Divide each bin into small angular pixels.
- Correlate galaxy pairs belonging to the same angular pixel.



Extracting the radial BAO

- Fit model

$$\xi_{\parallel}(\Delta z) = A + B\,e^{-C\Delta z} - D\,e^{-E\Delta z} + F\exp\left(-\frac{(\Delta z - \Delta z_{\rm BAO})^2}{2\sigma^2}\right)$$

- The BAO scale is given directly by $\Delta z_{\rm BAO}$.
- Limited interpretation of the other parameters.
- Now, let's see the results...

Pause for commercials: CUTE

- Have loads of objects to correlate? Beware! 2PCF is $O(N^2)$

Catalog	**#objects**	**Time for 2PCF**
SDSS DR7	80 K	~ 60 s
DES	~ 20 M (per bin)	~ 40 days
Simulation	1024^3	~ 340 years

Pause for commercials: CUTE

- Have loads (>1 M) of objects to correlate?
- Tired of waiting for ages for a trivial calculation?
- Don't have the dough for a big computer?

GPUs may be that miracle you were praying for...

Try CUTE*!!!

*Correlation Utilities and Two-point Estimation

Pause for commercials: CUTE

GPUs

LOTS of slow(er) nodes for fast graphics rendering.

Ups

- Very fast simple computations.
- Cheap.

Downs

- No support for complicated operations.
- More difficult to code.

CPUs

Few(er) fast(er) nodes

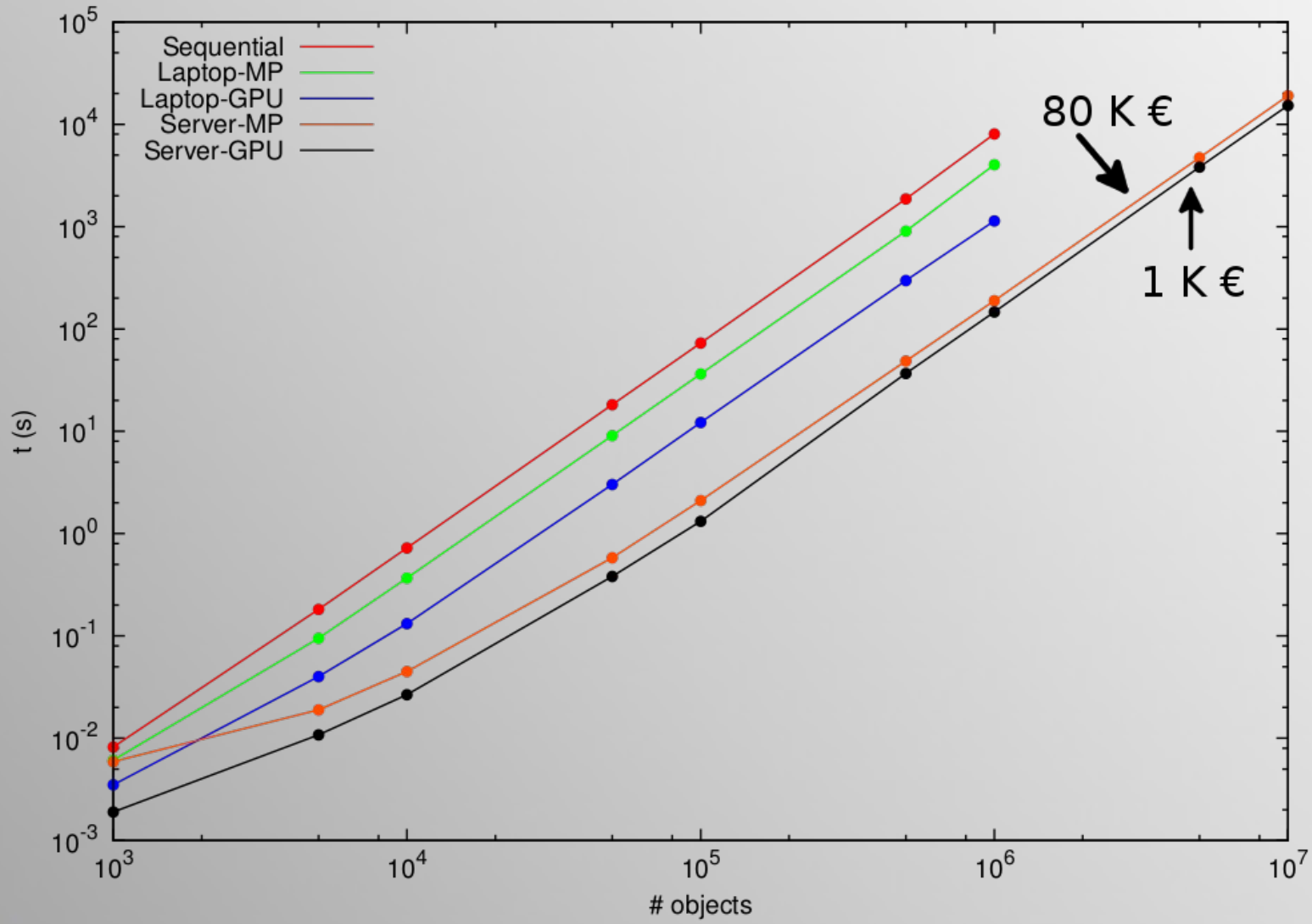
Ups

- Complicated operations supported.
- Easy to code.
- Easy to parallelize.

Downs

- Expensive.

Pause for commercials: CUTE



Pause for commercials: CUTE

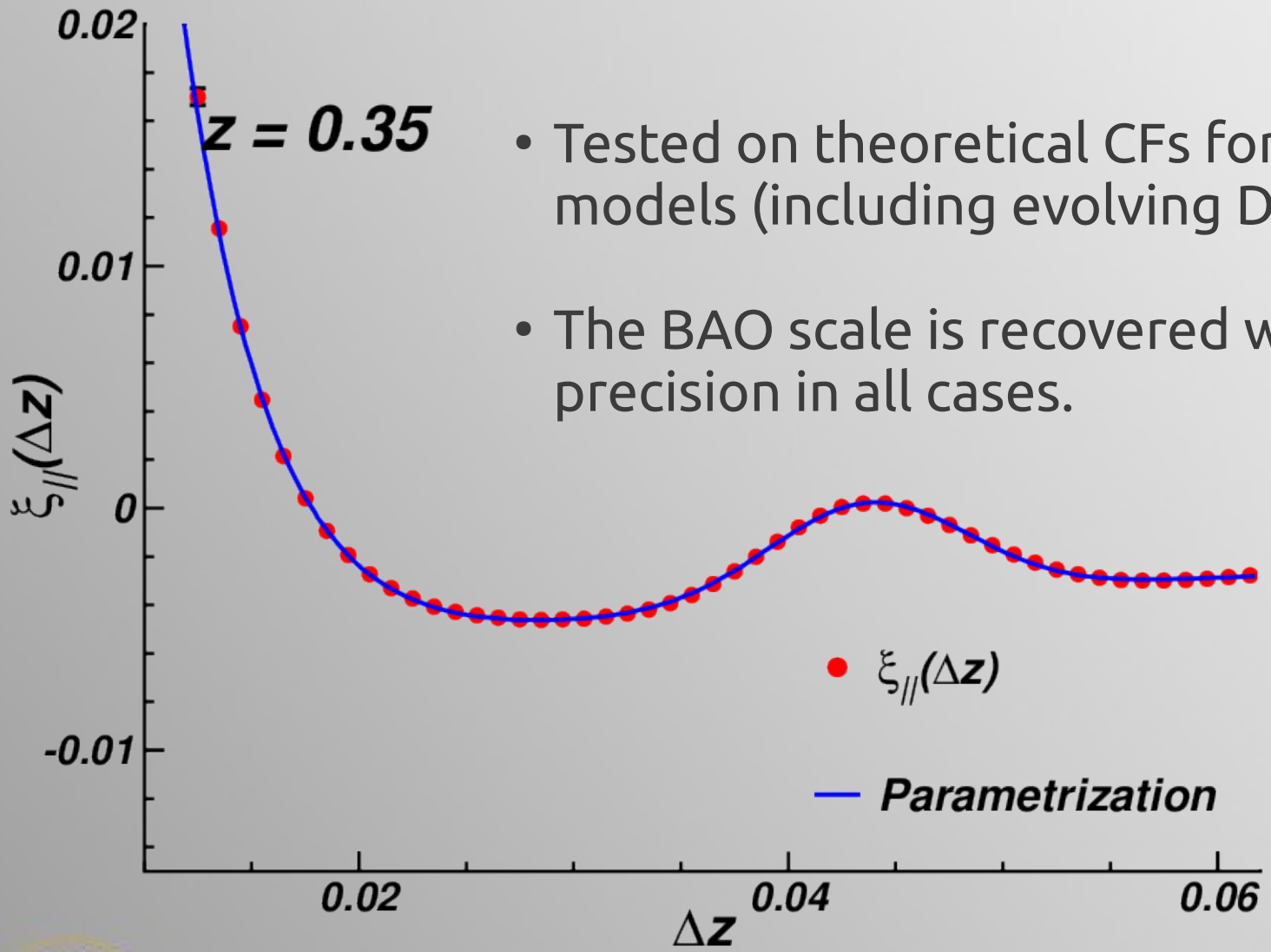
- x100 faster than sequential code with a high-end GPU.
- x10 faster than sequential code with a gaming GPU.
- Supports: radial, angular, monopole and 3D anisotropic 2PCFs.
- Brute-force, pixels and hybrid algorithms for even faster computation.
- Also parallelized for CPUs (OpenMP).
- Working on optimized P^3M algorithm to reduce the $O(N^2)$ scaling.

Pause for commercials: CUTE

Now in stores!!

arXiv:1210.1833 [astro-ph.IM]
http://members.ift.uam-csic.es/dmonge/CUTE.html

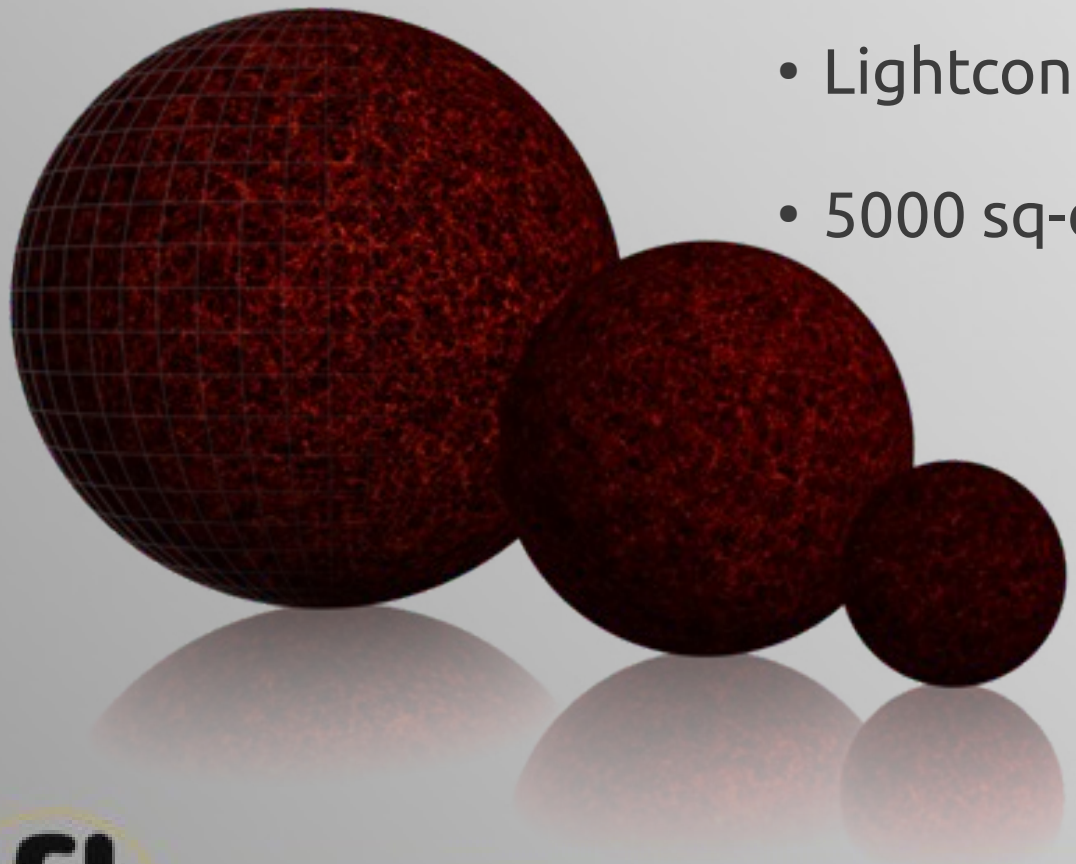
1st test: theoretical 2PCFs



- Tested on theoretical CFs for 14 different models (including evolving DE).
- The BAO scale is recovered with 0.1% precision in all cases.

2nd test: mock catalog

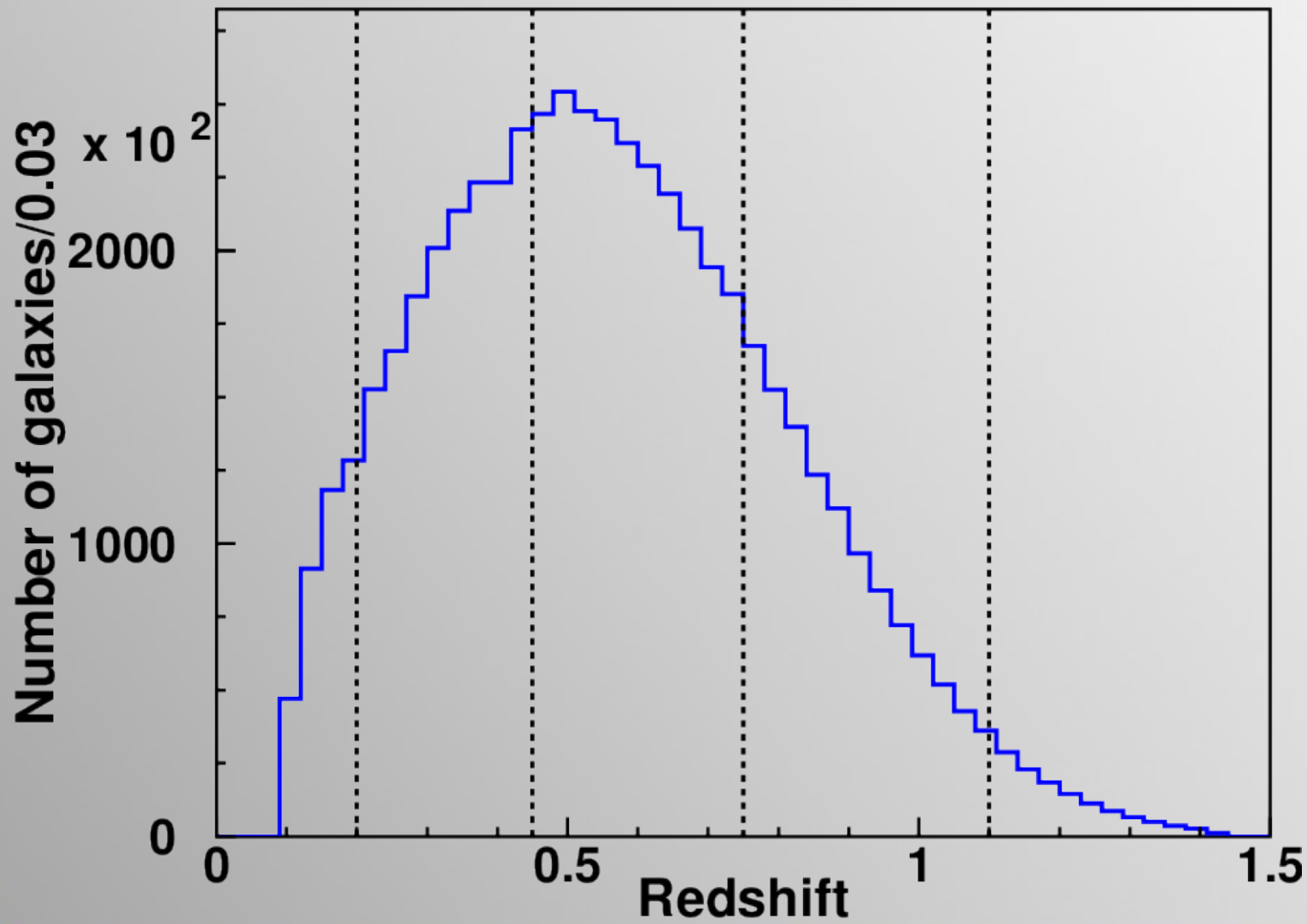
- Mock catalog from the MICE collaboration.
- Lightcone + RSD effects present.
- 5000 sq-deg, 0.1 < z < 1.5, 55 M objects.



MICE

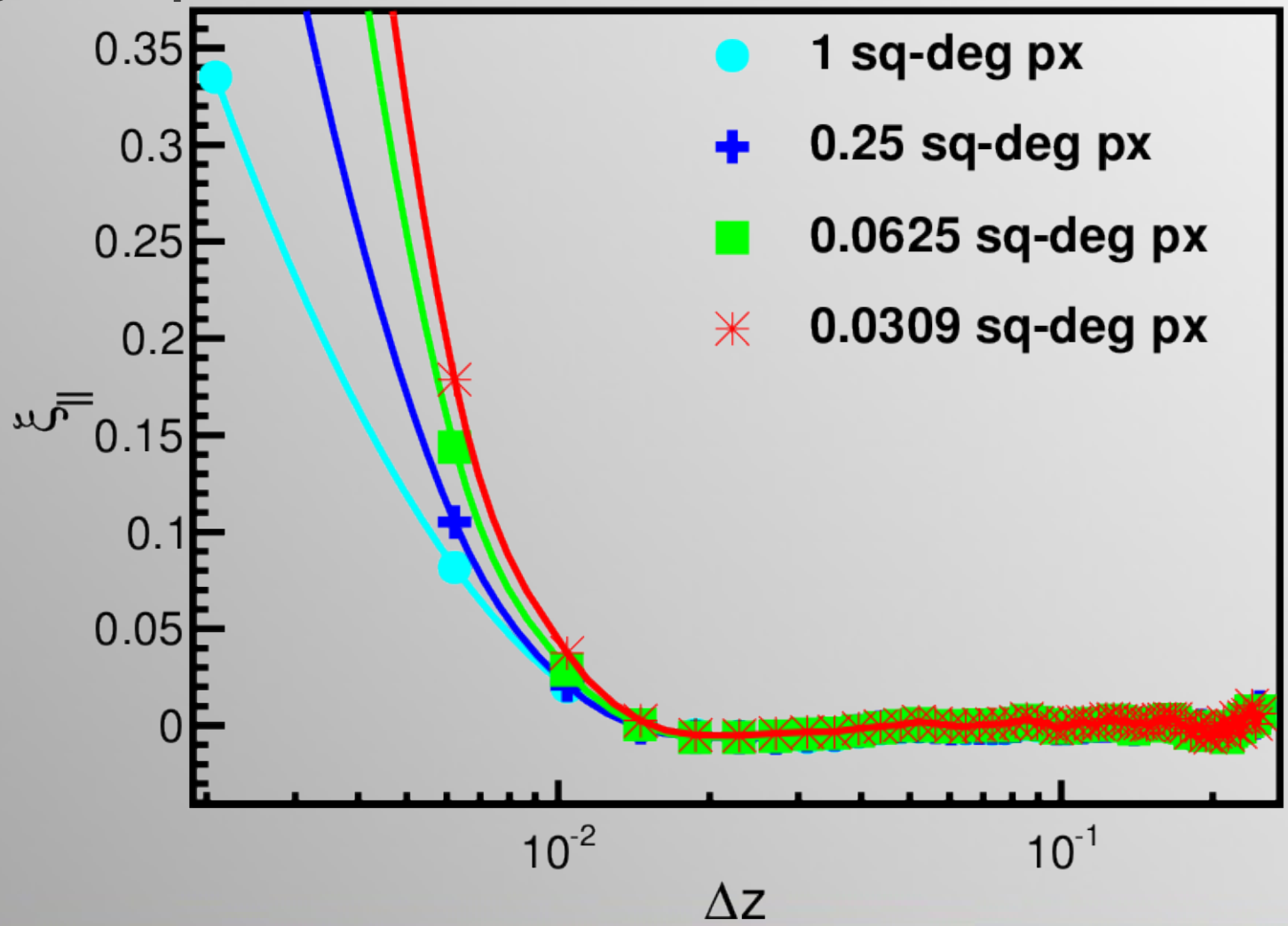
http://maia.ice.cat/mice/

2nd test: mock catalog



Systematic errors

- Angular pixel size



Systematic errors

- Angular pixel size ~ 0.20%
- Non-linearities ~ 0.10%
- Bias ~ 0.20%
- Fit limits ~ 0.10%

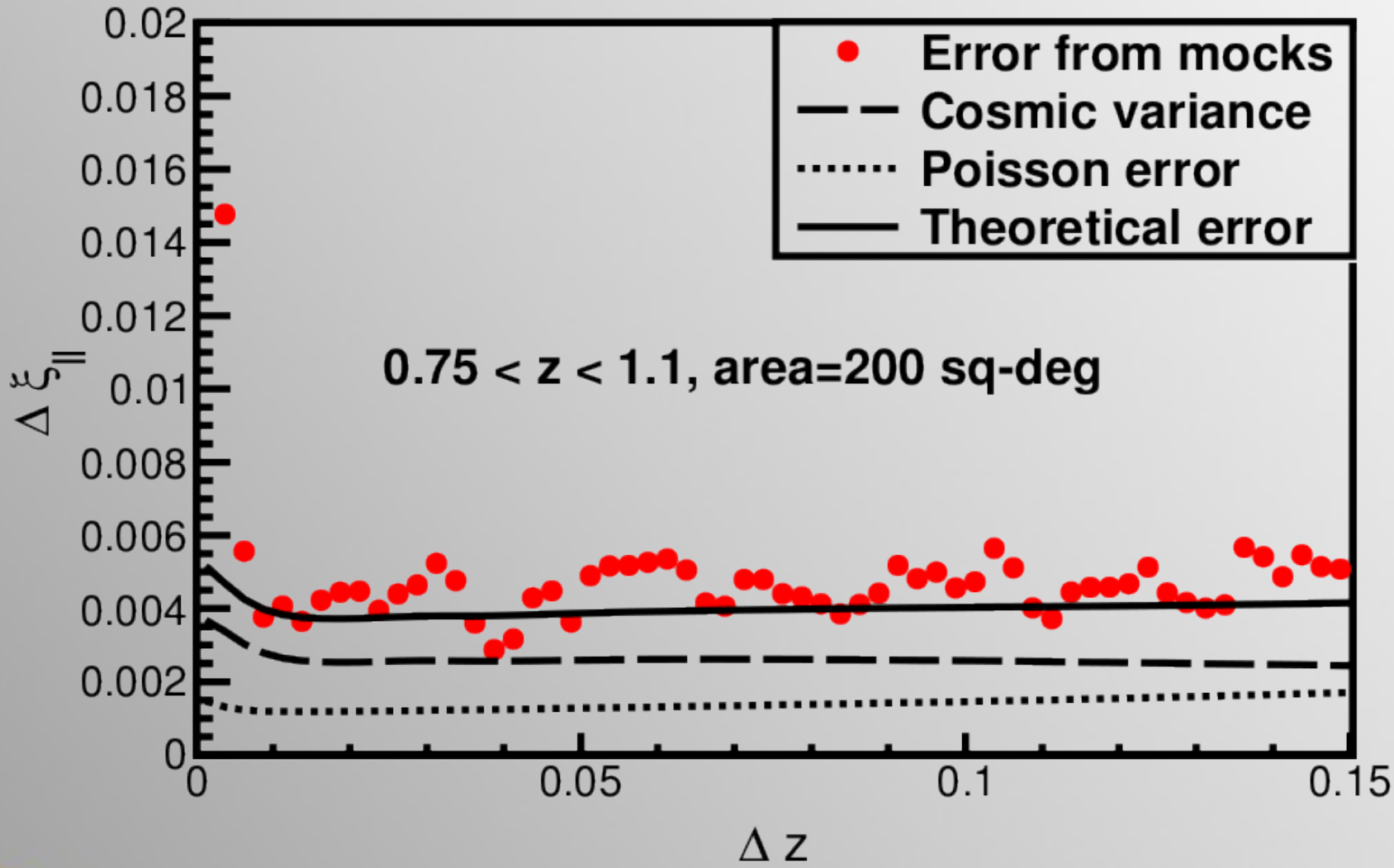
Total systematic error

$$\delta(\Delta z_{BAO}) < 0.35\%$$

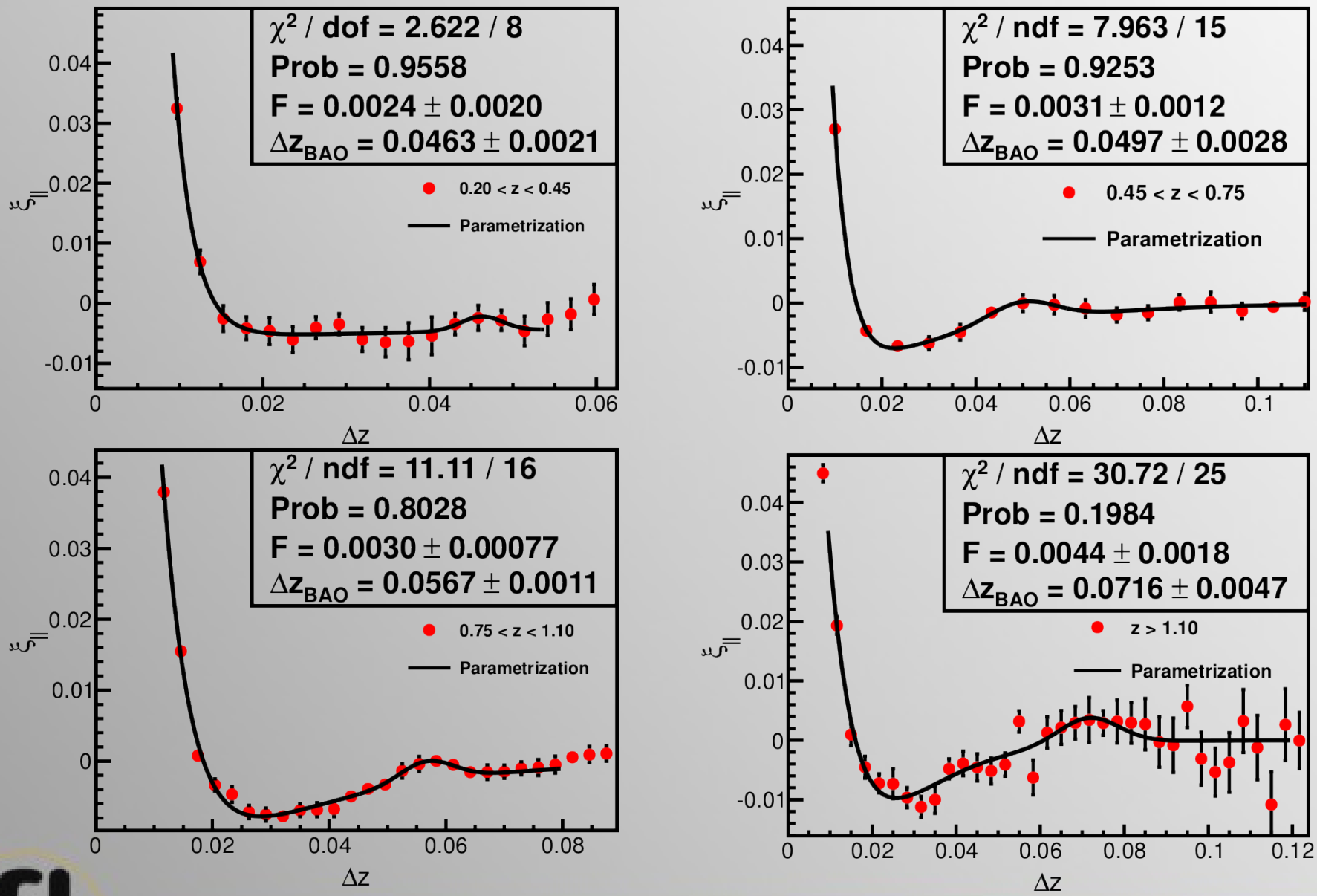
Statistical errors

- Computed theoretically and compared with jacknife.
- Very large volume is needed to suppress cosmic variance.
- Cosmic variance and Poisson errors are comparable.

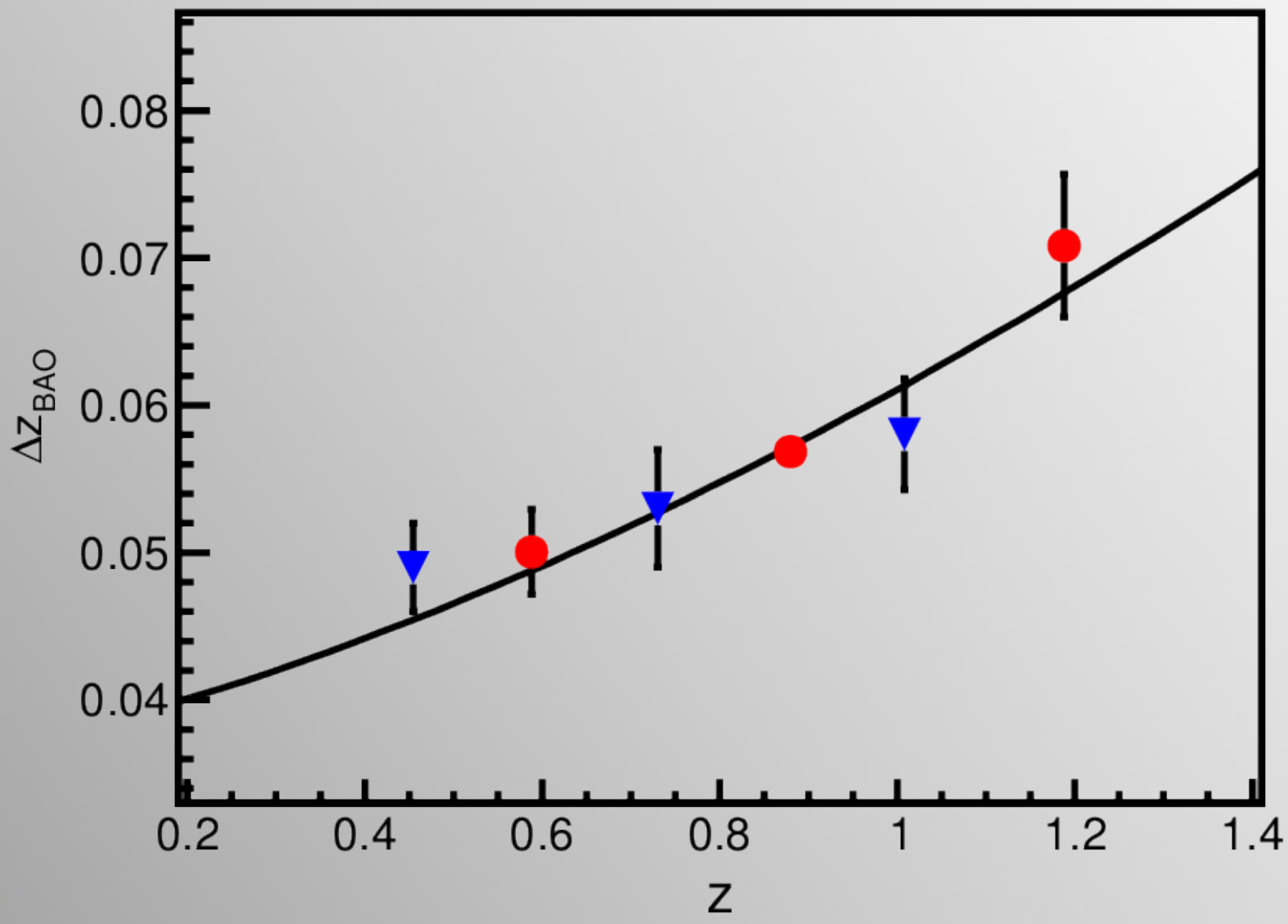
Statistical errors



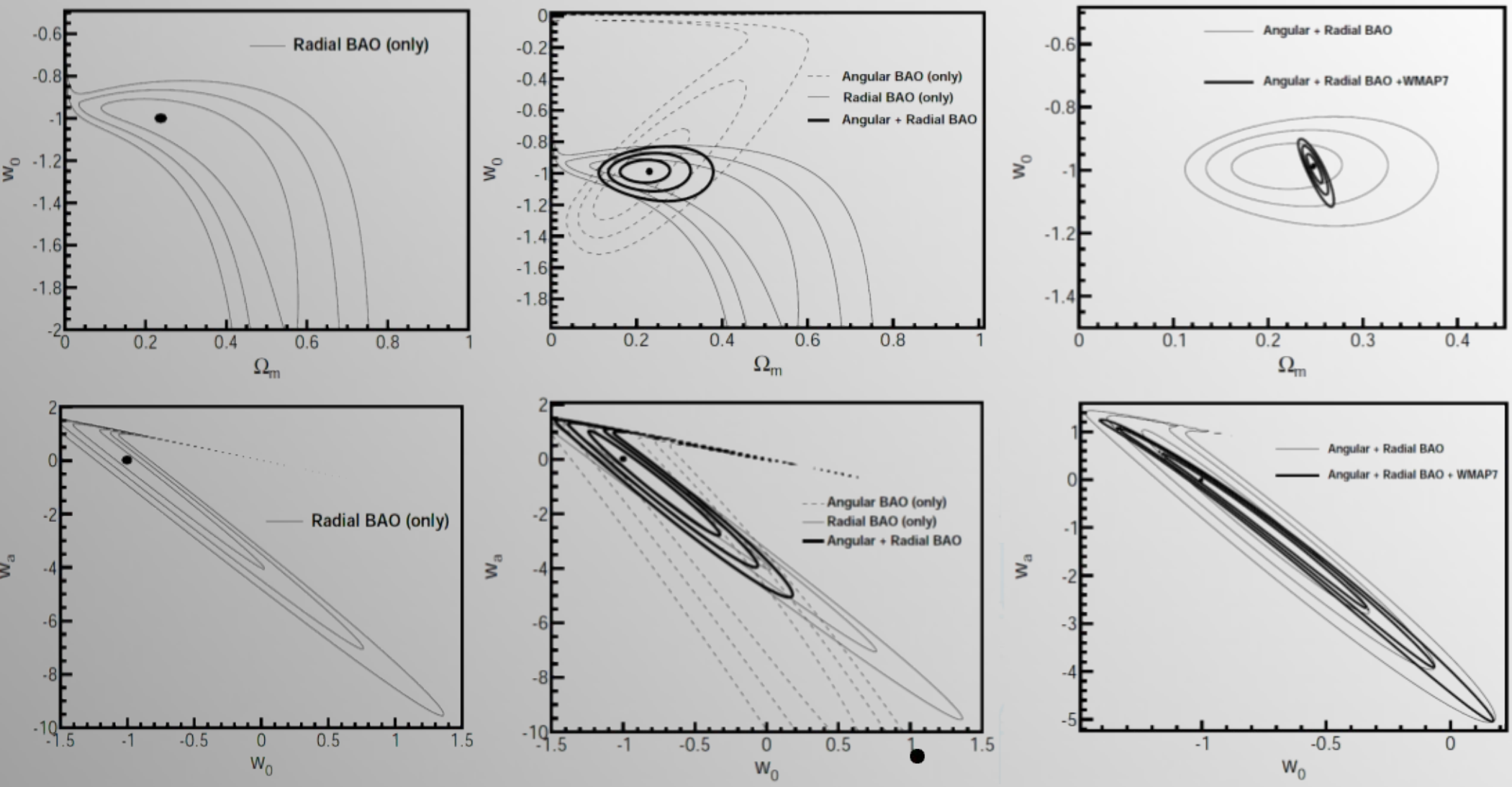
Results


χ^2 / dof = 2.622 / 8
Prob = 0.9558
F = 0.0024 ± 0.0020
Δz_{BAO} = 0.0463 ± 0.0021
0.20 < z < 0.45
Parametrization
χ^2 / ndf = 7.963 / 15
Prob = 0.9253
F = 0.0031 ± 0.0012
Δz_{BAO} = 0.0497 ± 0.0028
0.45 < z < 0.75
Parametrization
χ^2 / ndf = 11.11 / 16
Prob = 0.8028
F = 0.0030 ± 0.00077
Δz_{BAO} = 0.0567 ± 0.0011
0.75 < z < 1.10
Parametrization
χ^2 / ndf = 30.72 / 25
Prob = 0.1984
F = 0.0044 ± 0.0018
Δz_{BAO} = 0.0716 ± 0.0047
z > 1.10
Parametrization
$\xi_{\parallel}$
Δz

Results



Results


Radial BAO (only)
Angular BAO (only)
Radial BAO (only)
Angular + Radial BAO
Angular + Radial BAO
Angular + Radial BAO +WMAP7
Radial BAO (only)
Angular BAO (only)
Radial BAO (only)
Angular + Radial BAO
Angular + Radial BAO
Angular + Radial BAO + WMAP7
w_0
Ω_m
w_a

Conclusions

- New method to extract the radial BAO scale.
- The method is model-independent.
- Huge volume is needed for a precise determination.
- Robust against systematic uncertainties.
- Important constraints can be obtained from angular + radial BAO.

Coming soon...

- We want to try this method on the latest dataset (DR-9) from SDSS (BOSS).
- Analogous formalism to study RSDs in a model-independent way.
- Study the possible bias on cosmological constraints from the standard BAO analyses.

Thanks!