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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

INSTITUT D'ESTUDIS ESPACIALS DE CATALUNYA
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Angular Correlation Function in the Dark Energy Survey

DARK ENERGY SURVEY

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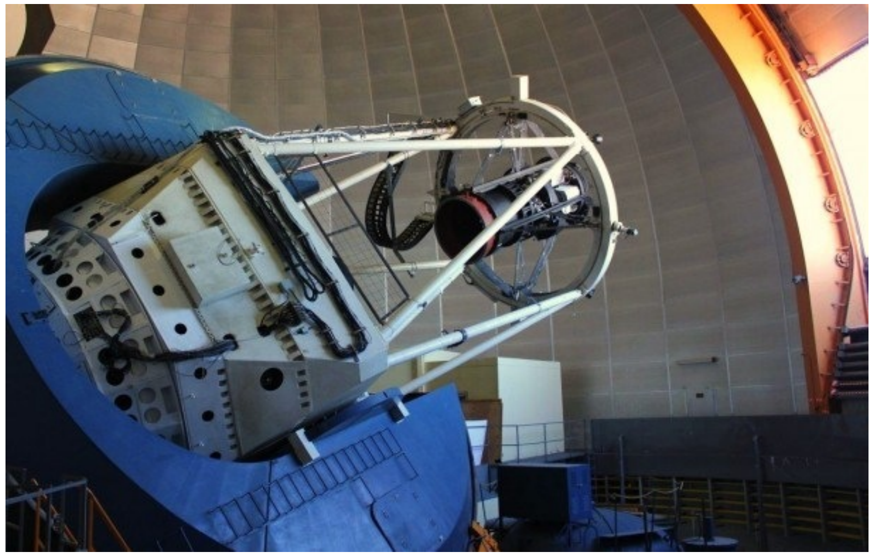
Outline

Measuring angular correlation functions in an imaging survey : how do we treat and mitigate systematics.

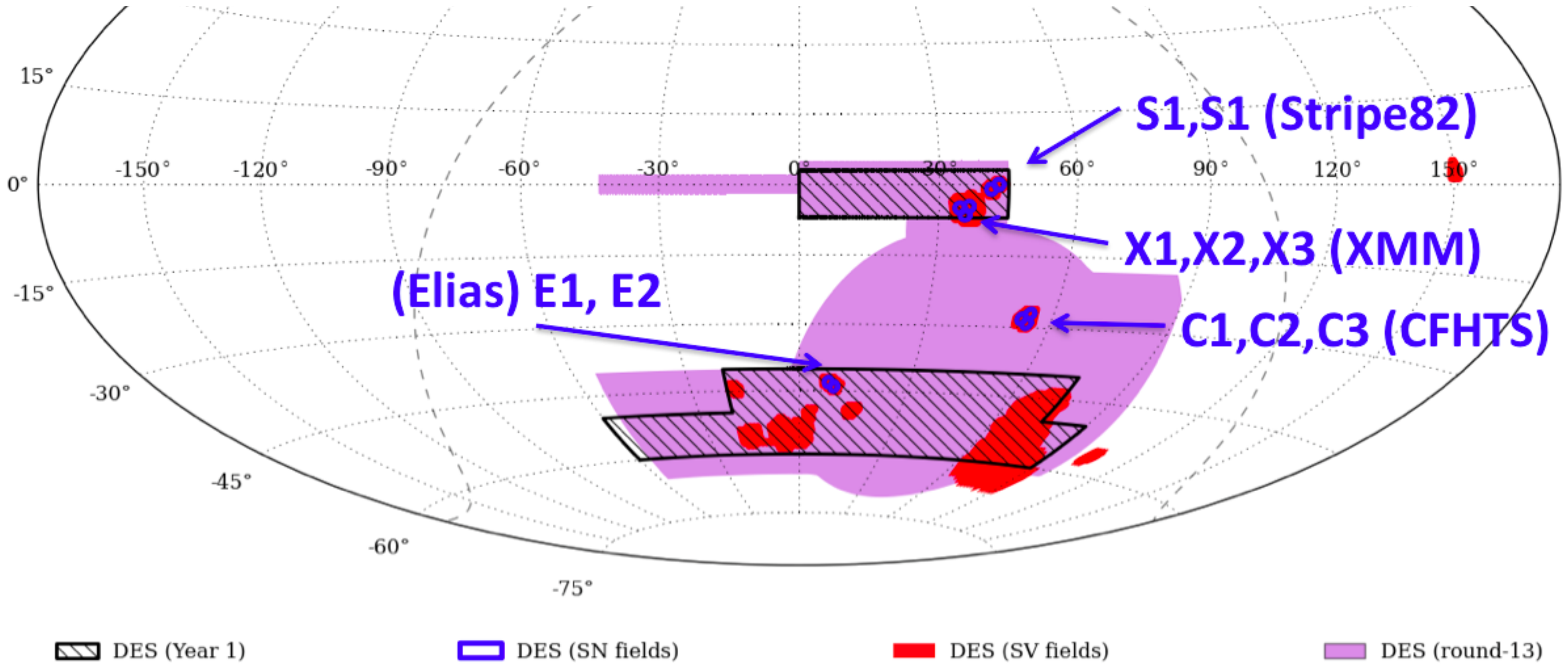
Dark Energy Survey

overview



- Wide Optical and near IR survey (grizY bands)
- 525 nights over 5 seasons in 5 imaging bands
- 300 M galaxies over 5000 deg^2 (2500 deg^2 overlap with South Pole Telescope)
- i-band magnitud limit ~24 at S/N=10, largest survey at this sensitivity
- 30 deg^2 in time domain, SN fields visited at least once per week (3000 SNIa)

Just finished 4th year of observations.



Dark Energy Survey

Weak lensing (distance, structure growth)
shapes of 200 millions galaxies

Baryonic acoustic oscillations (distance)
300 millions galaxies to z=1 and beyond

Galaxy clusters (distance, structure growth)
hundred of thousands of clusters up to z~1
synergies with SPT, VHS

robust combination of probes

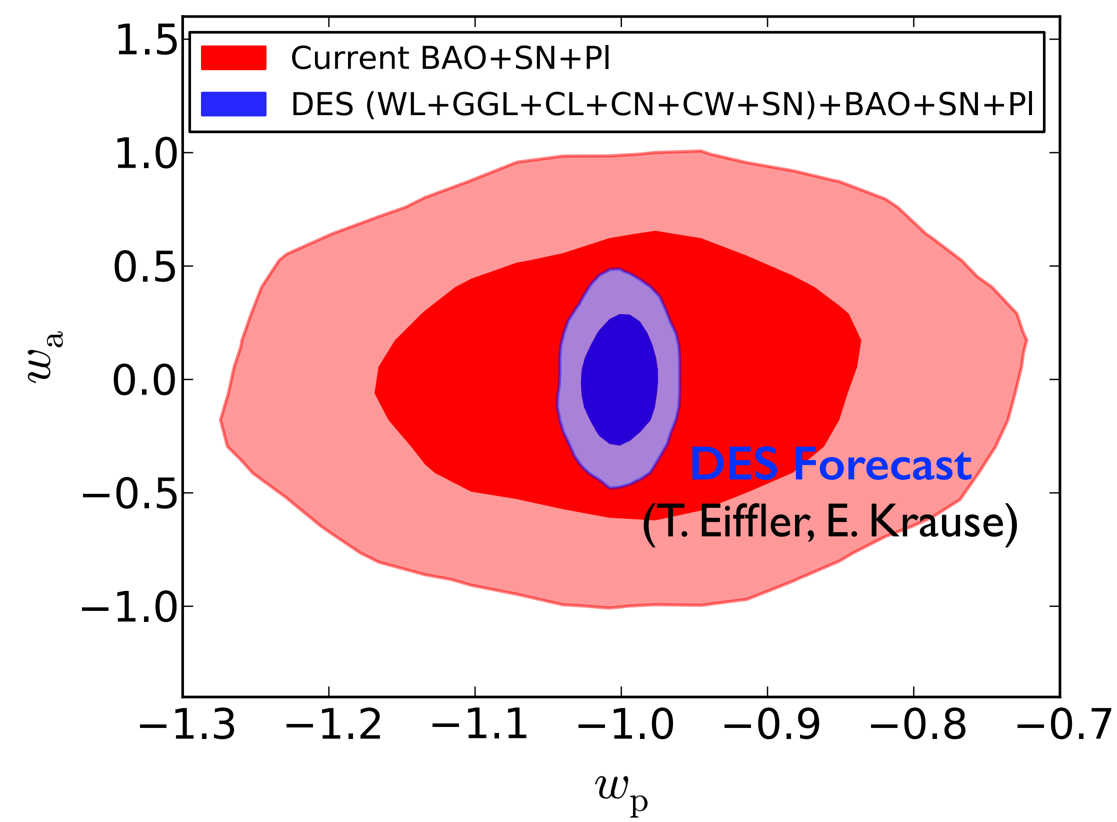
- → shared photometry/footprint
- → shared analysis of systematics
- → shared galaxy redshift estimates

Type Ia supernovae (distance)
30 sq. deg. SN fields
3000 SNIa to z~1

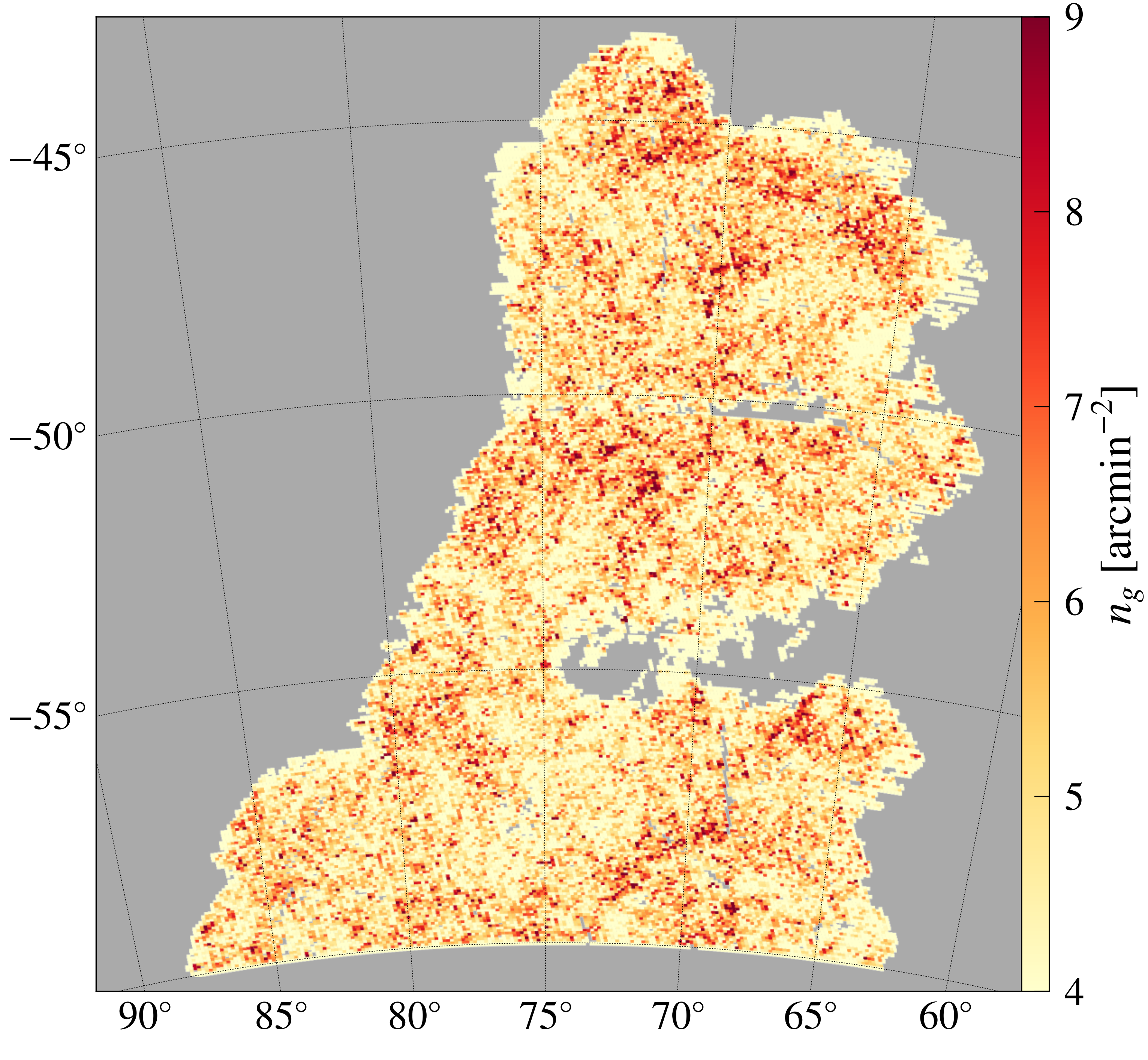
Strong Lensing (distance)
30 QSO lens time delays
Arcs with multiple source redshifts

Cross-correlations
Galaxies and WL x CMB lensing

DE equation of state $w \equiv p/\rho$
$w(a) = w_0 + (1-a)w_a$

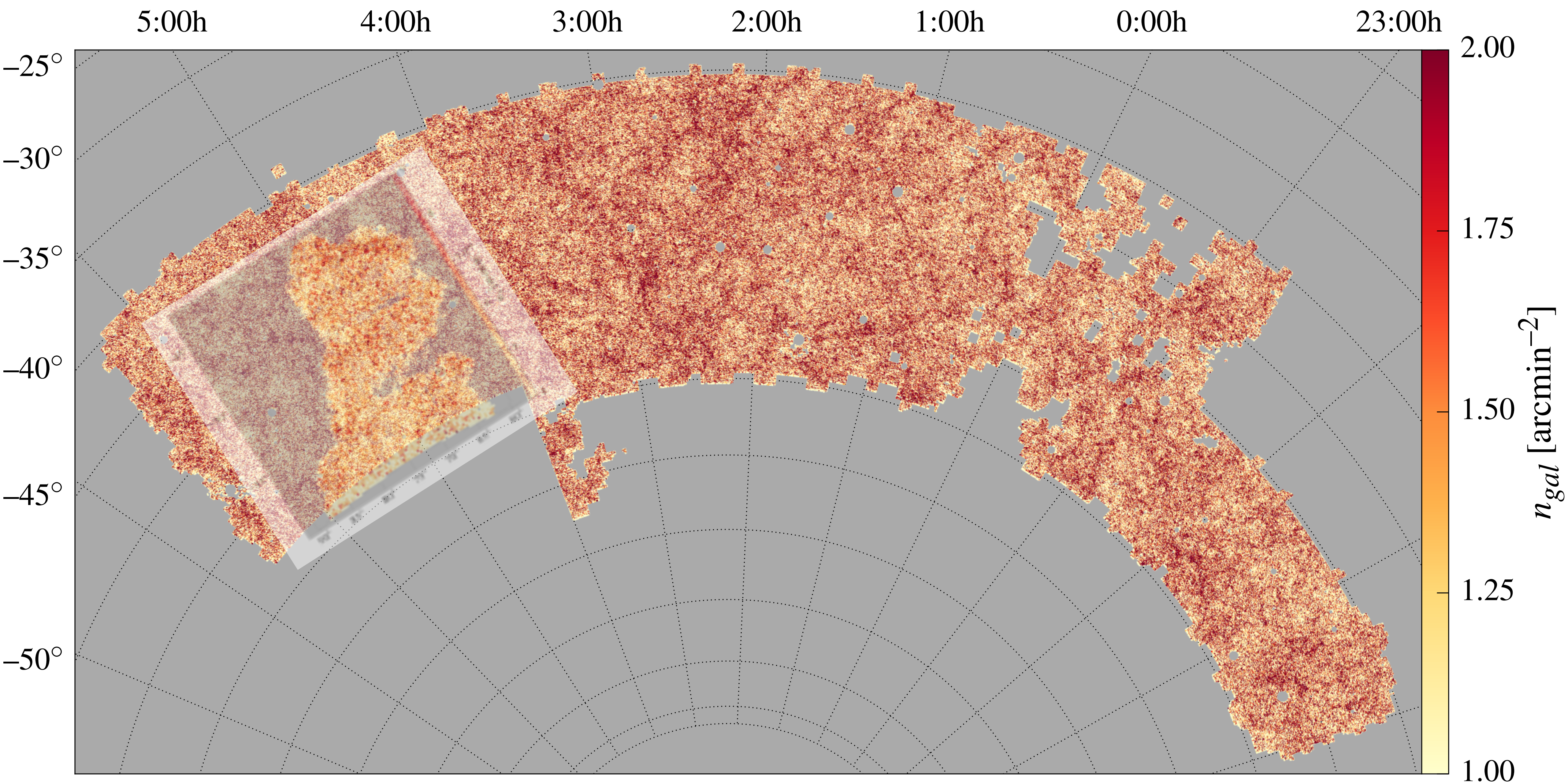


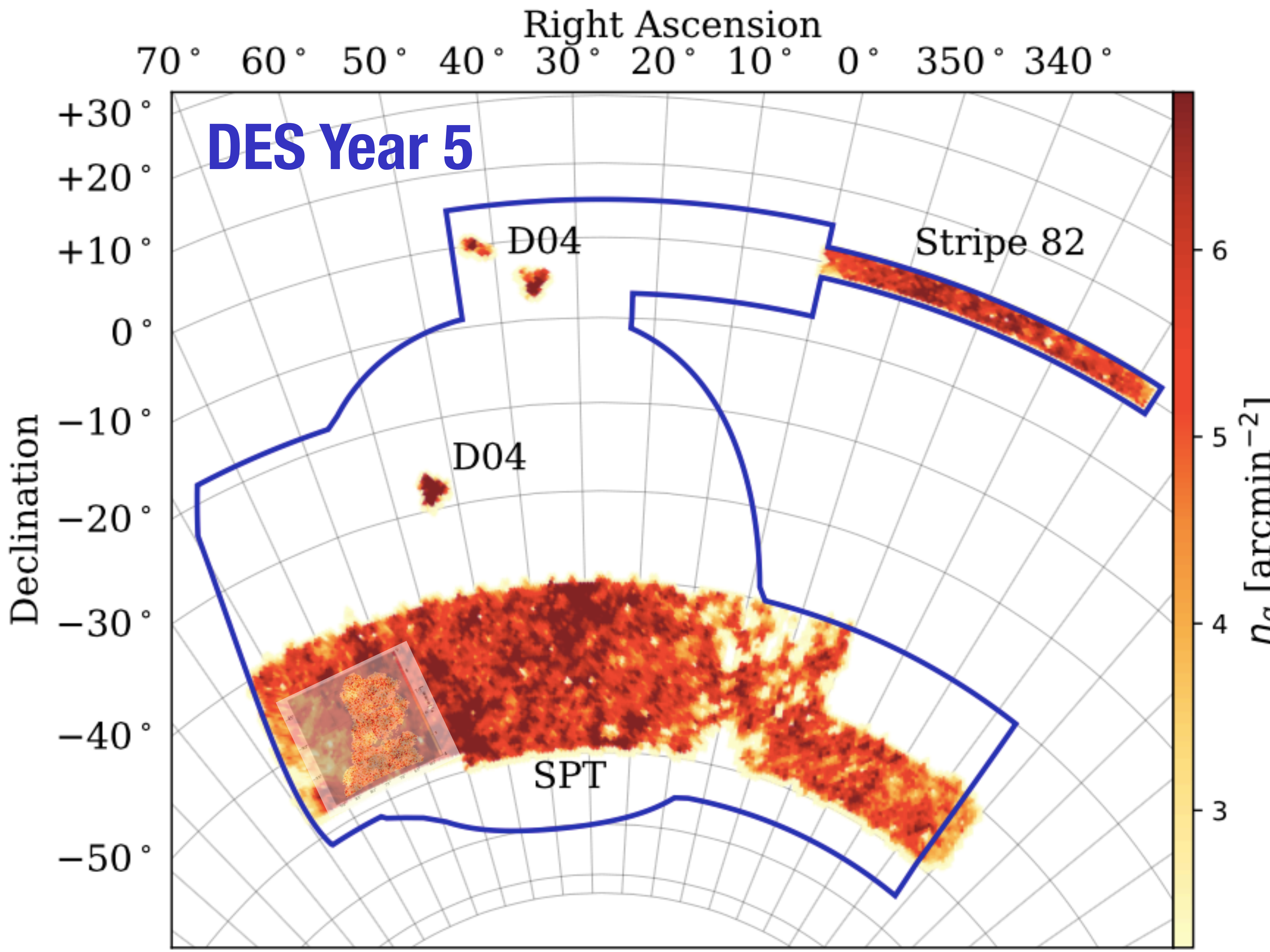
DES Science Verification Galaxy Distribution



2.3 million galaxies used in LSS (i < 22.5) in 0.2 < z < 1.2

DES Year 1 Galaxy Distribution





DES Year 5
Right Ascension
70° 60° 50° 40° 30° 20° 10° 0° 350° 340°
Declination
+30° +20° +10° 0° −10° −20° −30° −40° −50°
D04
D04
Stripe 82
SPT
n_g [arcmin^{-2}]
6 5 4 3

Clustering of red magic galaxies for Weak Lensing combination

Elvin-Pole J., Crocce M., Ross A. et al arxiv 1708.01536

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LSS $\delta_{gal} \sim b \times \delta_m$

WL $\delta_{gal\,shapes} \sim \delta_m$

$$w_{gal-gal} \sim b^2 \times D^2(z)$$

$$w_{gal-shear} \sim b \times D^2(z)$$

$$w_{shear-shear} \sim D^2(z)$$

→ Measures growth of structure as function of redshift

redMaGic luminous red galaxies

Rozo et al. 2016: 1507.05460

Uses (redMaPPer) clusters to calibrate the red sequence of galaxies as a function of redshift and use this as a photometric template for red galaxy selection.

Key features:

designed for accurate and precise redshifts.

approximately constant co-moving density

approximately constant clustering bias

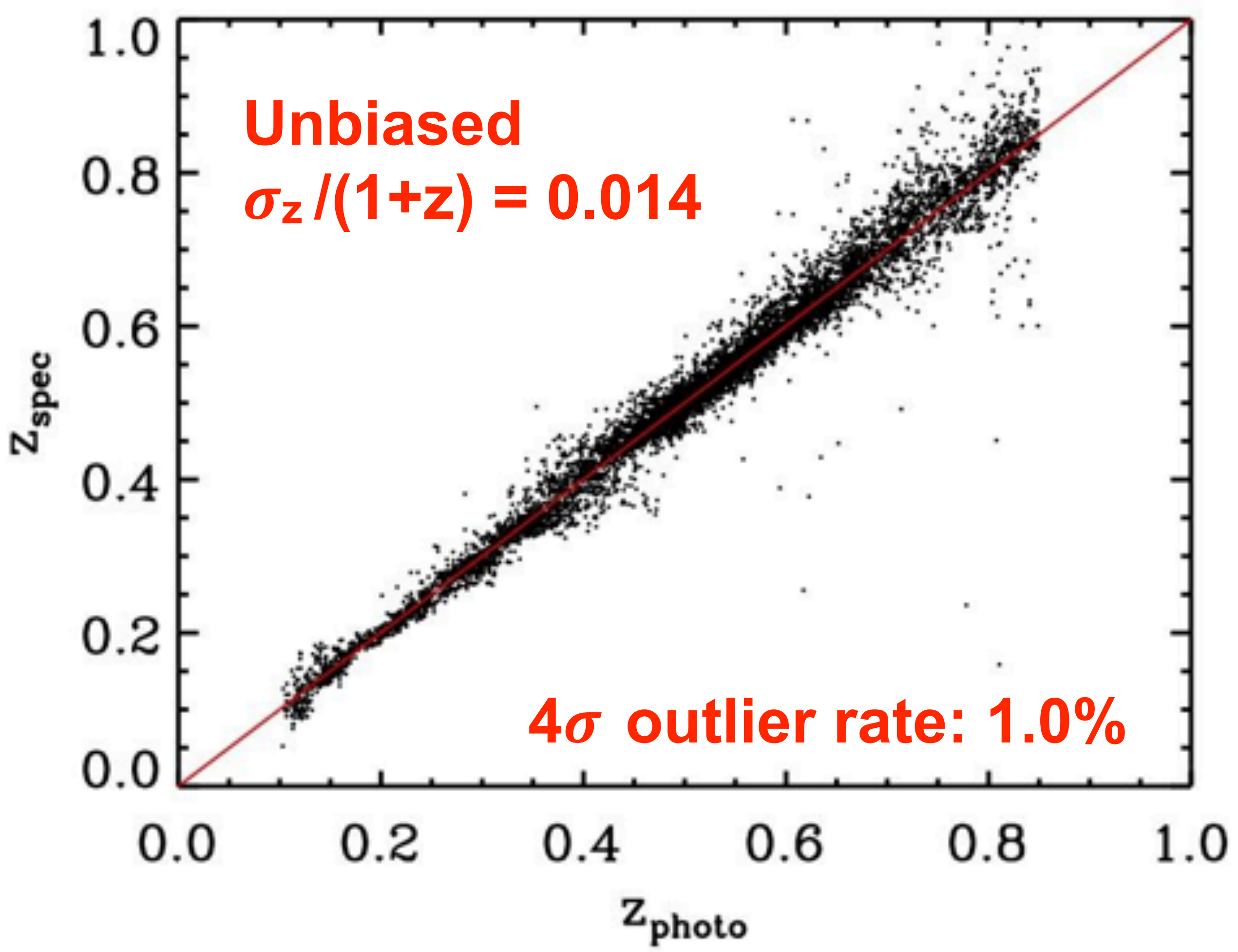
selection has only two free parameters:

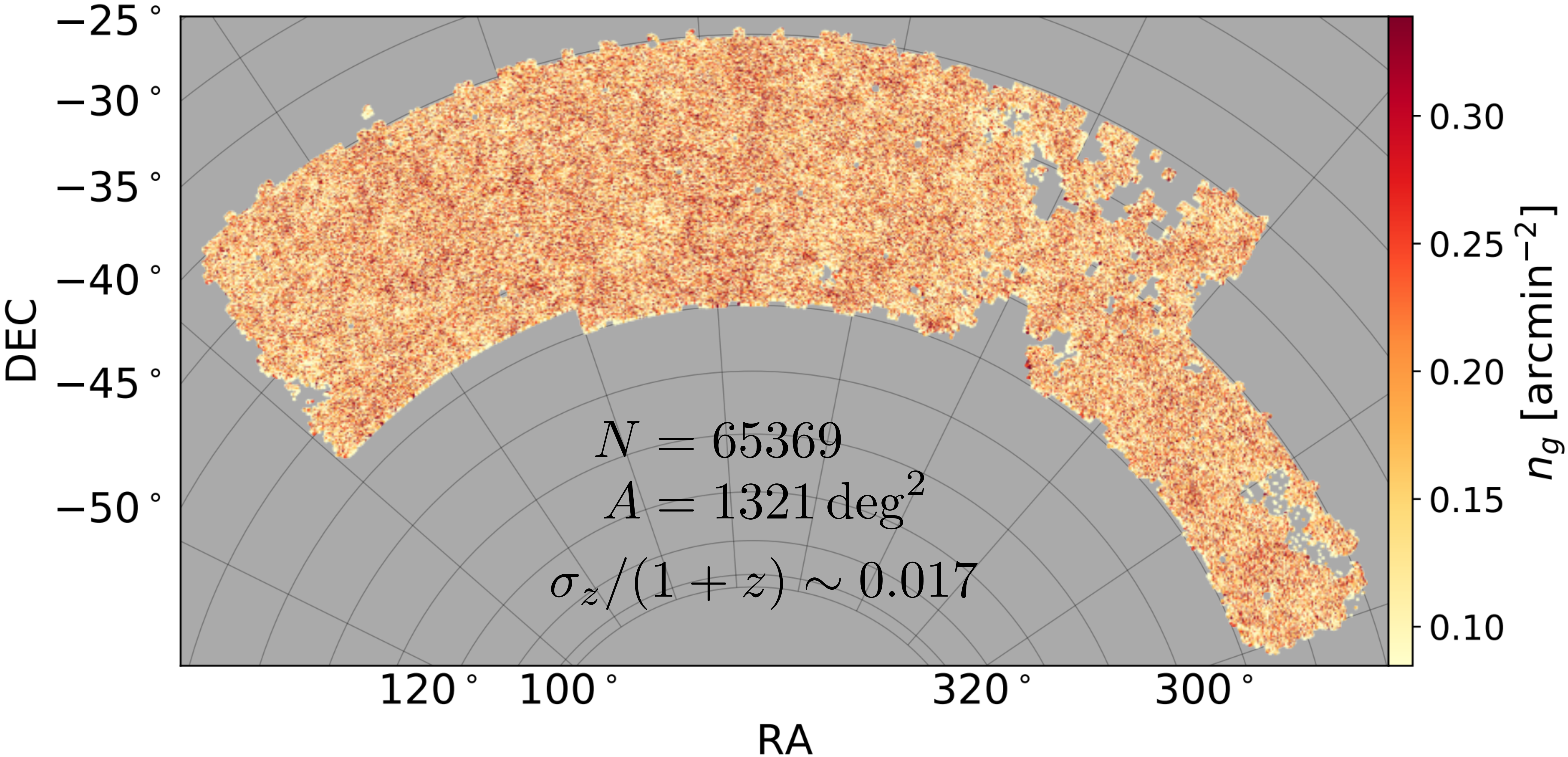
- desired co-moving density
- luminosity threshold of the galaxies

High photo-z precision was key several pour-poses:

calibration of **intrinsic alignments** from gg-lensing signal.

photoz calibration of source distribution via cross-correlations.





−25°
−30°
−35°
−40°
−45°
−50°
DEC
120°
100°
320°
300°
RA
$N = 65369$
$A = 1321\,\mathrm{deg}^2$
$\sigma_z/(1+z) \sim 0.017$
0.30
0.25
0.20
0.15
0.10
n_g [arcmin^{-2}]

We split the sample in 5 redshift bins

z range	$L_{\min}/L_*$	$n_{\rm gal}$ (deg^{-2})	$N_{\rm gal}$
$0.15 < z < 0.3$	0.5	0.0134	63719
$0.3 < z < 0.45$	0.5	0.0344	163446
$0.45 < z < 0.6$	0.5	0.0511	240727
$0.6 < z < 0.75$	1.0	0.0303	143524
$0.75 < z < 0.9$	1.5	0.0089	42275

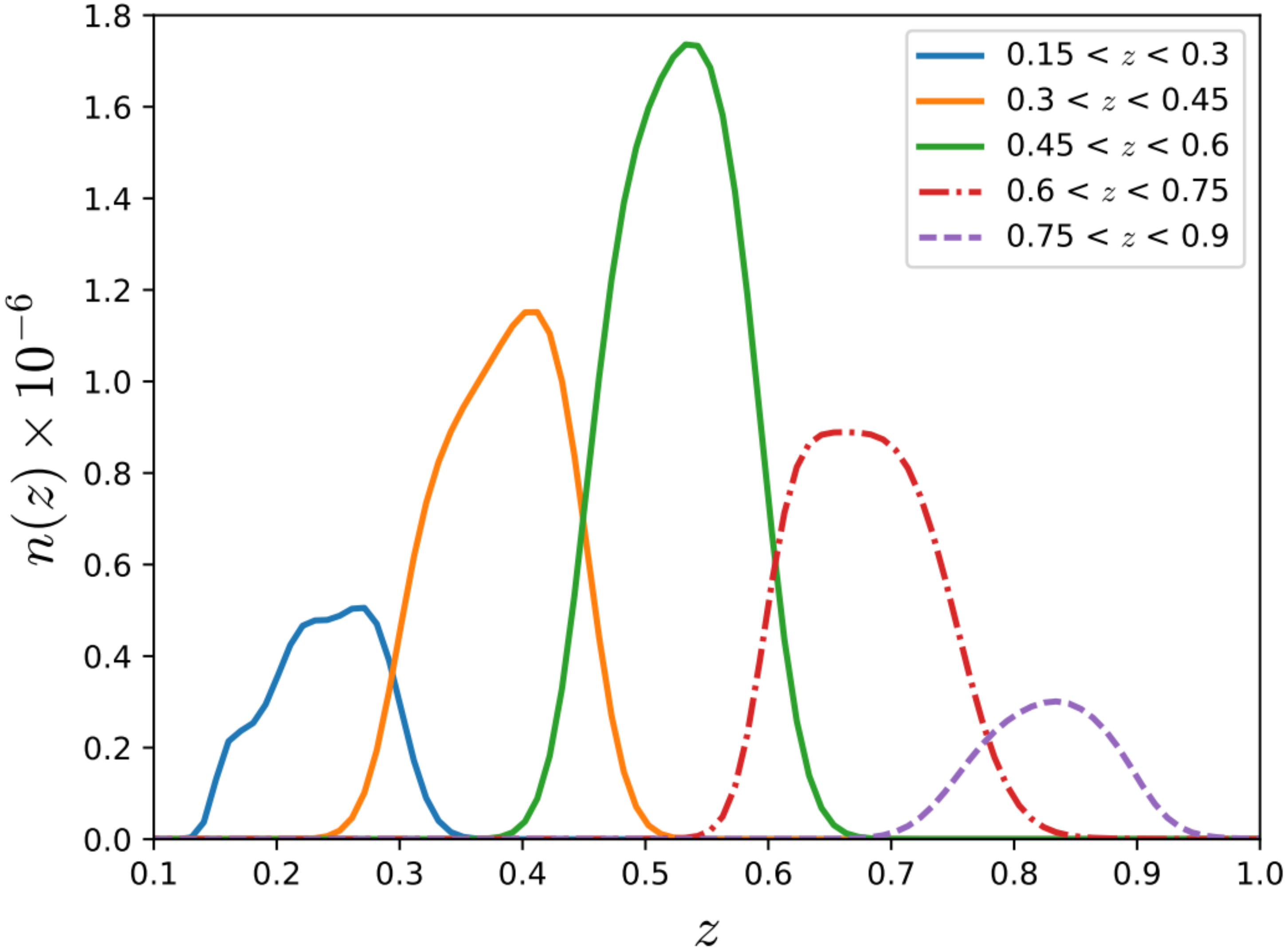
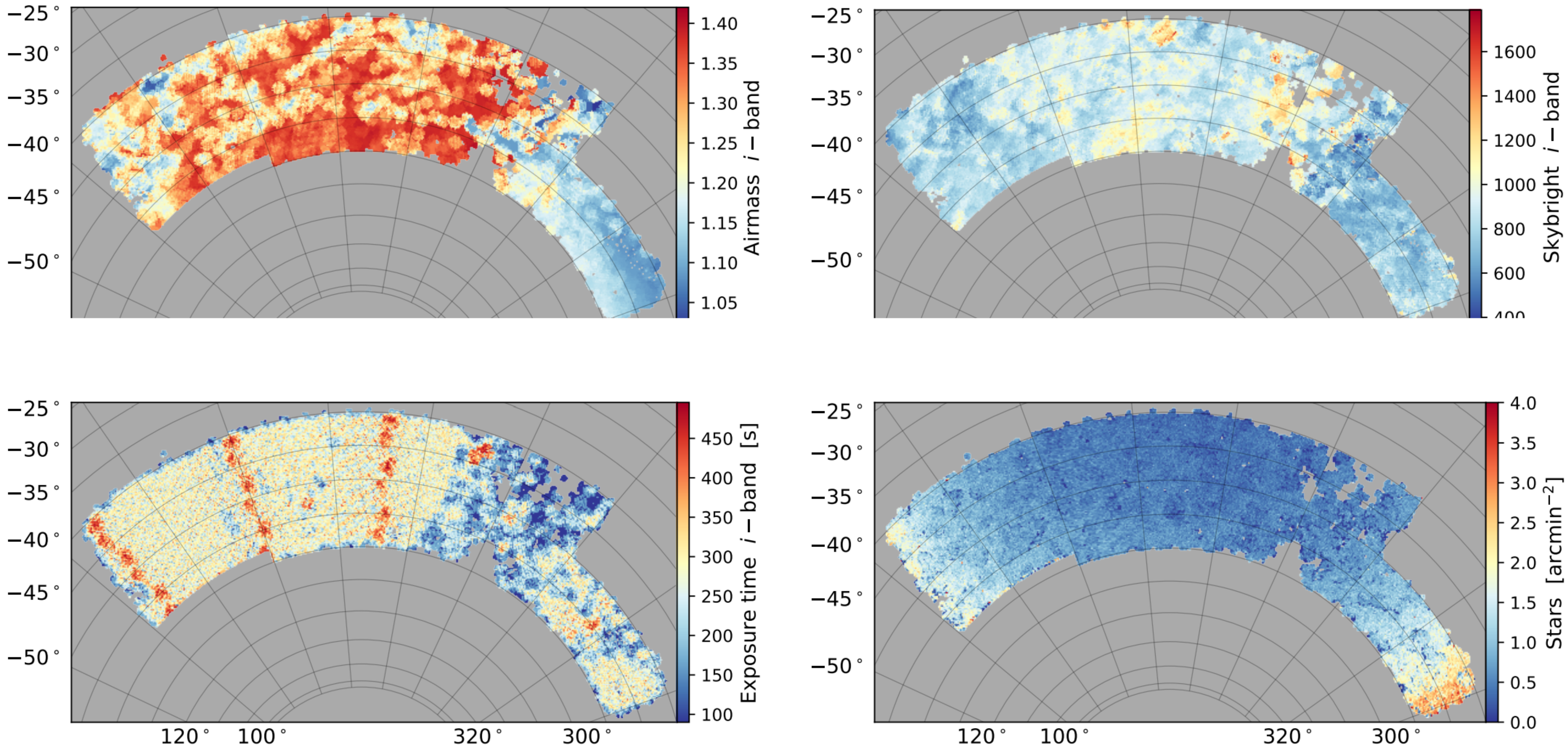


photo-z nearly gaussians for red-magic

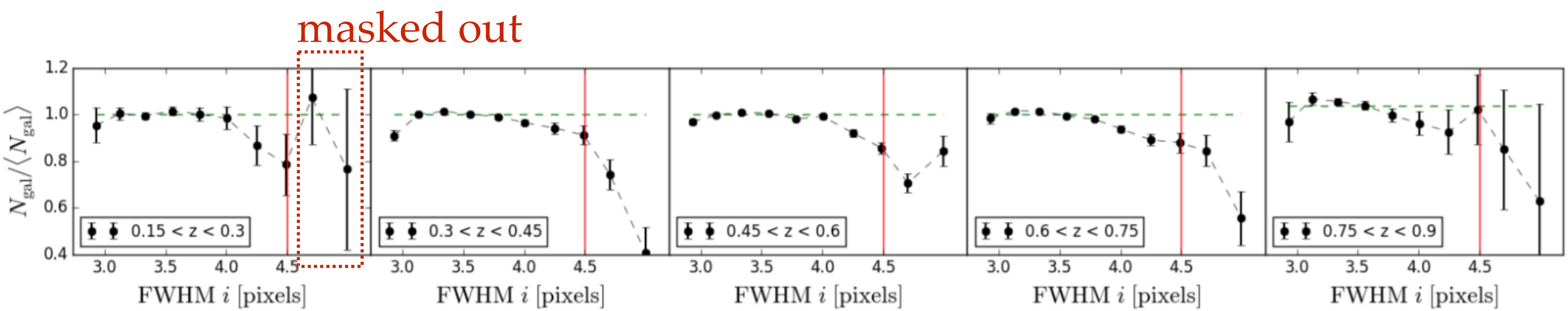
Maps of observing conditions across the sky averaged over the different exposures (that happened at different times in each band)



- For the most part these fluctuations are removed when the depth and mask is built
- Residuals imprints can induce fake fluctuations !!

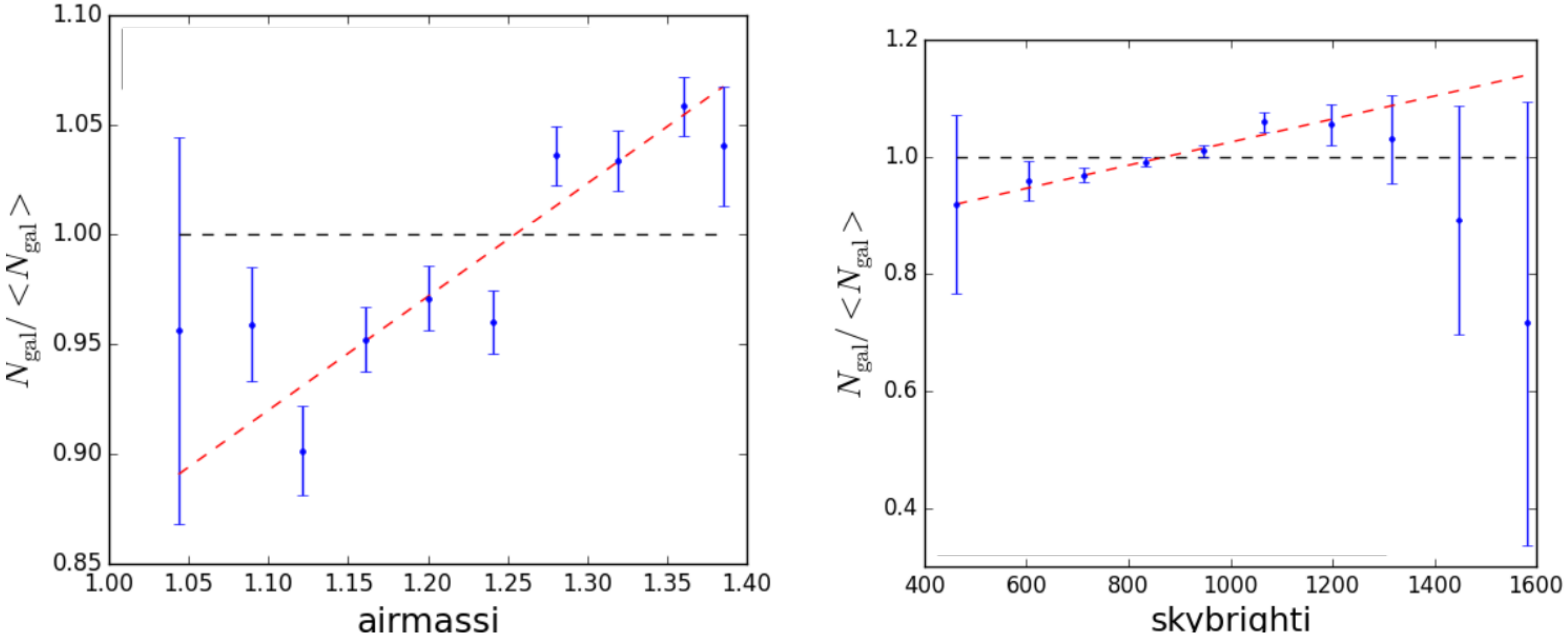
- Survey properties can contaminate the galaxy sample, biasing clustering measurements.

- We measure the mean galaxy density variations with survey properties.



- We test against 20 survey property maps in four bands (griz): depth, exposure time, PSF FWHM, airmass, sky brightness

Correlation found with multiple that in turn are correlated ! We can't correct for all of them.

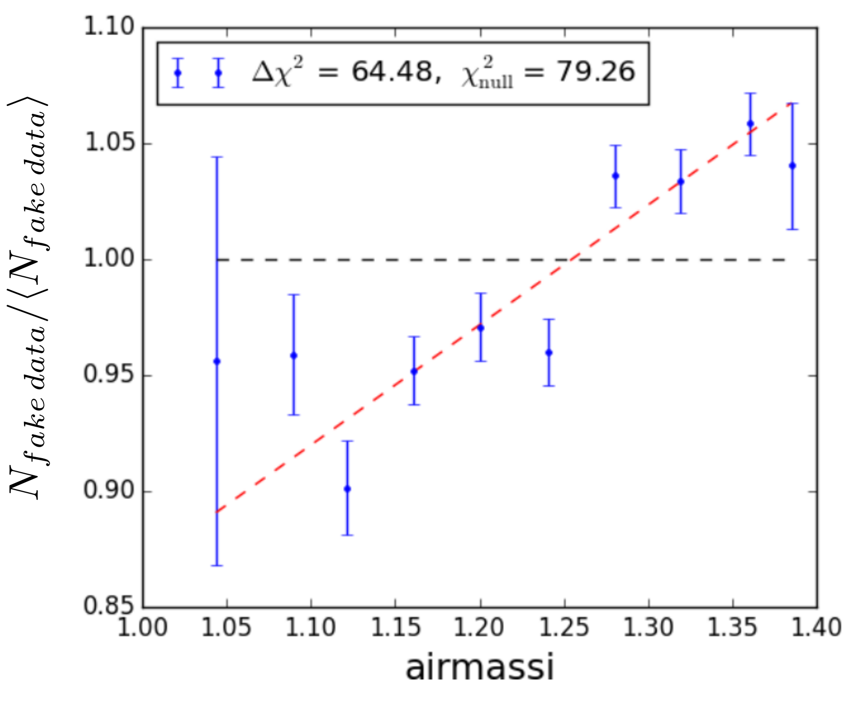


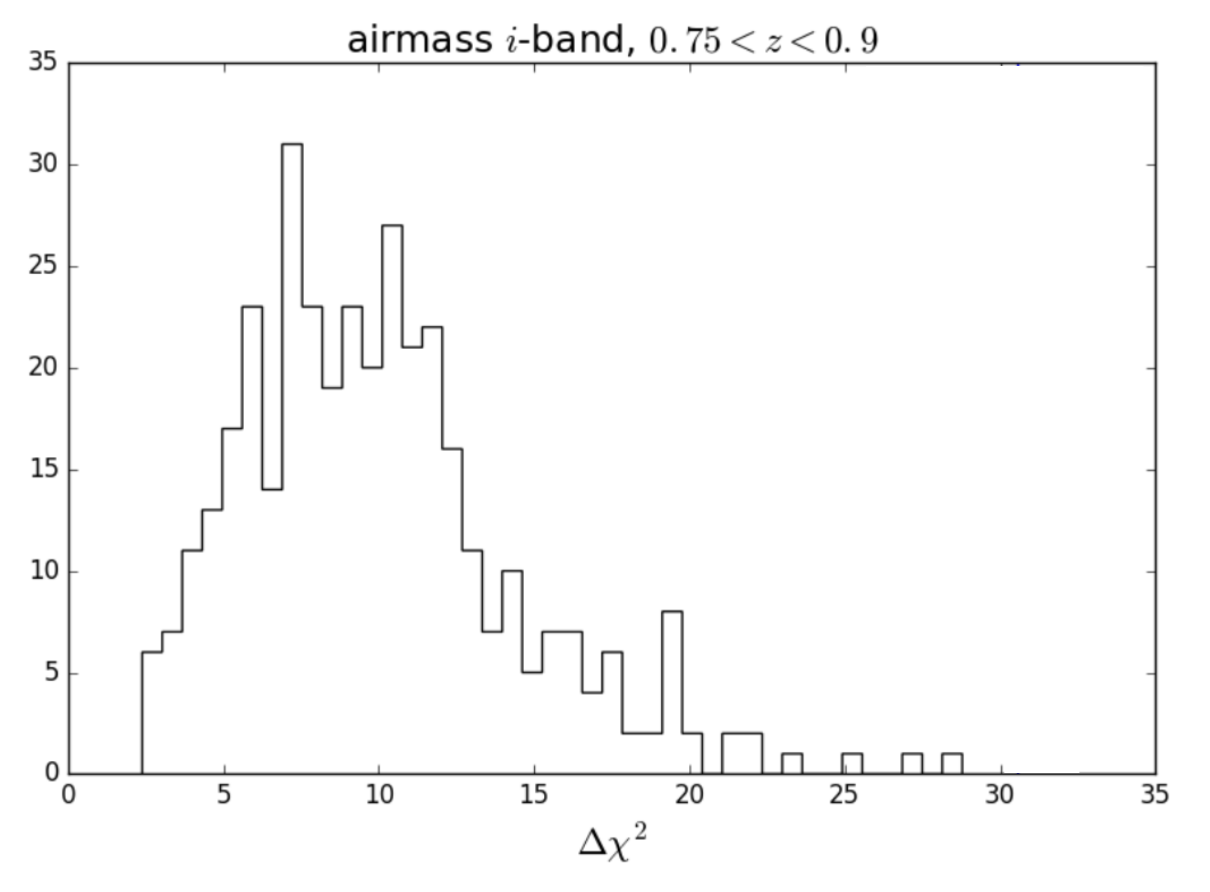
Solution: Weight catalog by the correlation with a few maps. Choose maps such that this fixes other correlations

How do we choose the most important maps?
How to distinguish noise from systematics ?

We produce a very large set of Gaussian (or log-normal) realisations of the galaxy distribution in the given bin

$$\Delta\chi^2 = \chi^2_{\rm null} - \chi^2_{\rm linear}$$

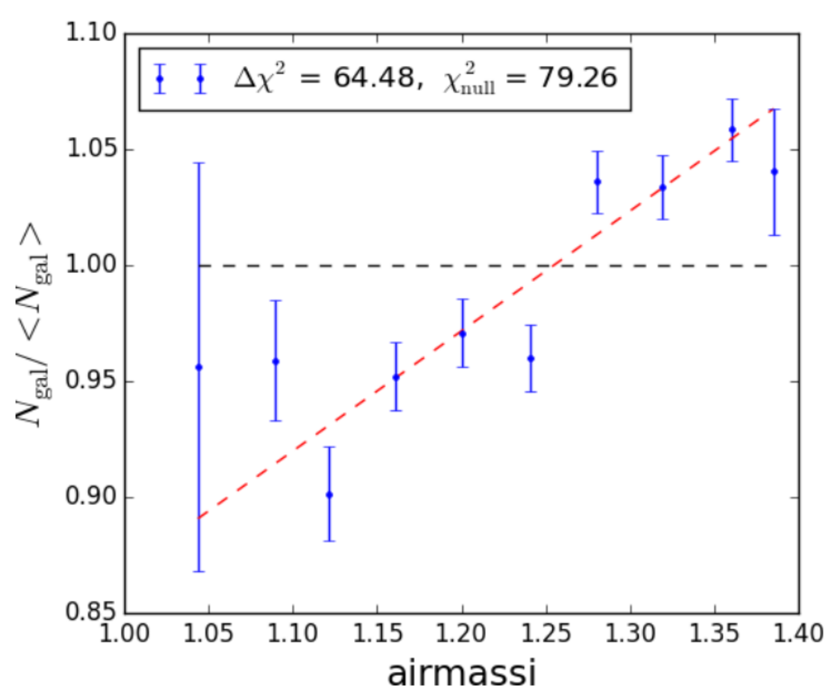


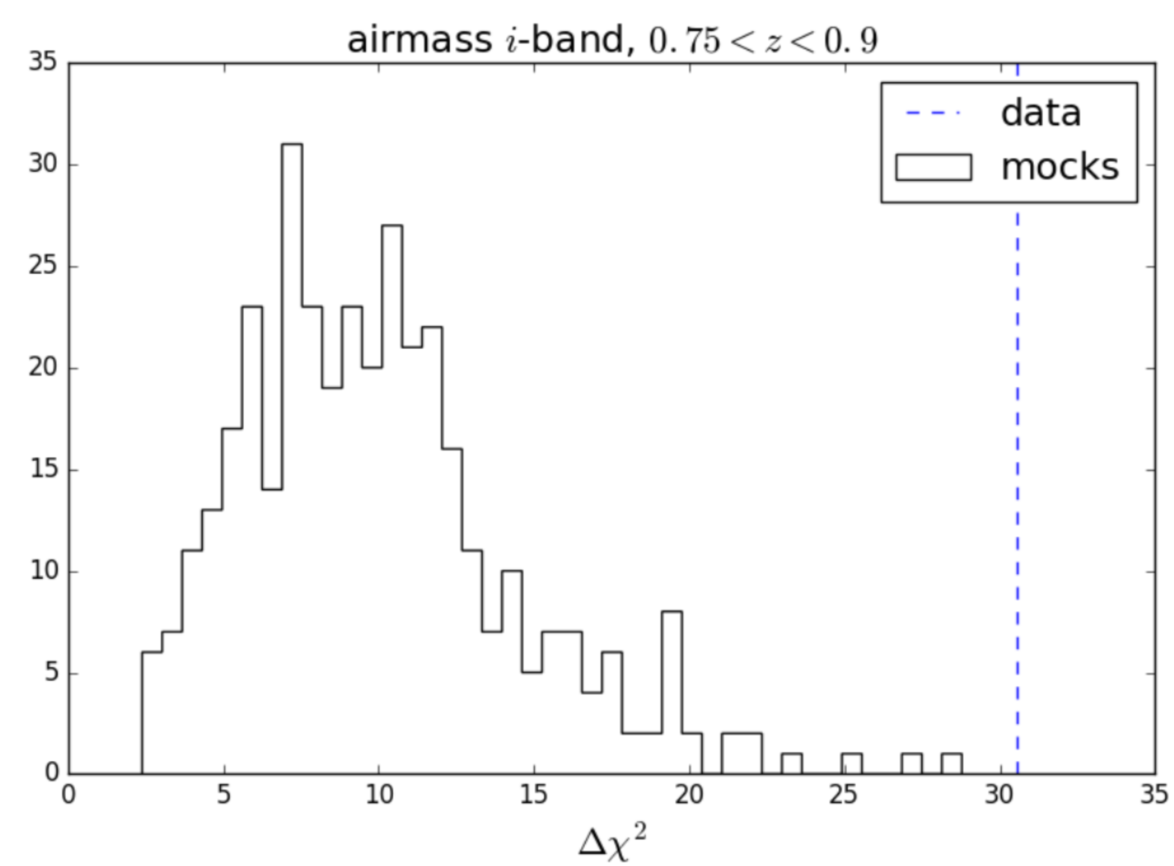


How do we choose the most important maps?
How to distinguish noise from systematics ?

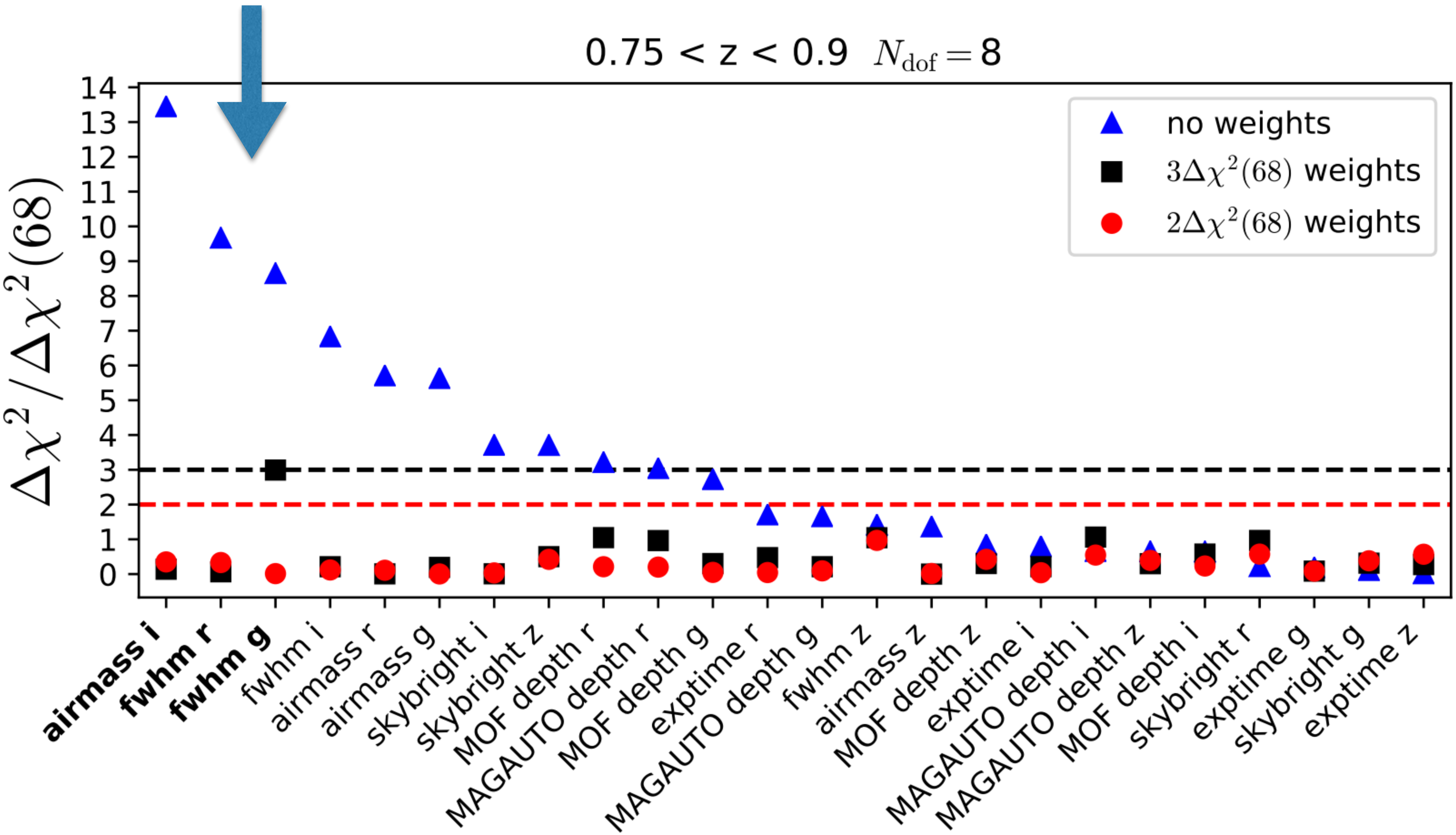
Repeat the same for the data

$$\Delta\chi^2 = \chi^2_{\rm null} - \chi^2_{\rm linear}$$

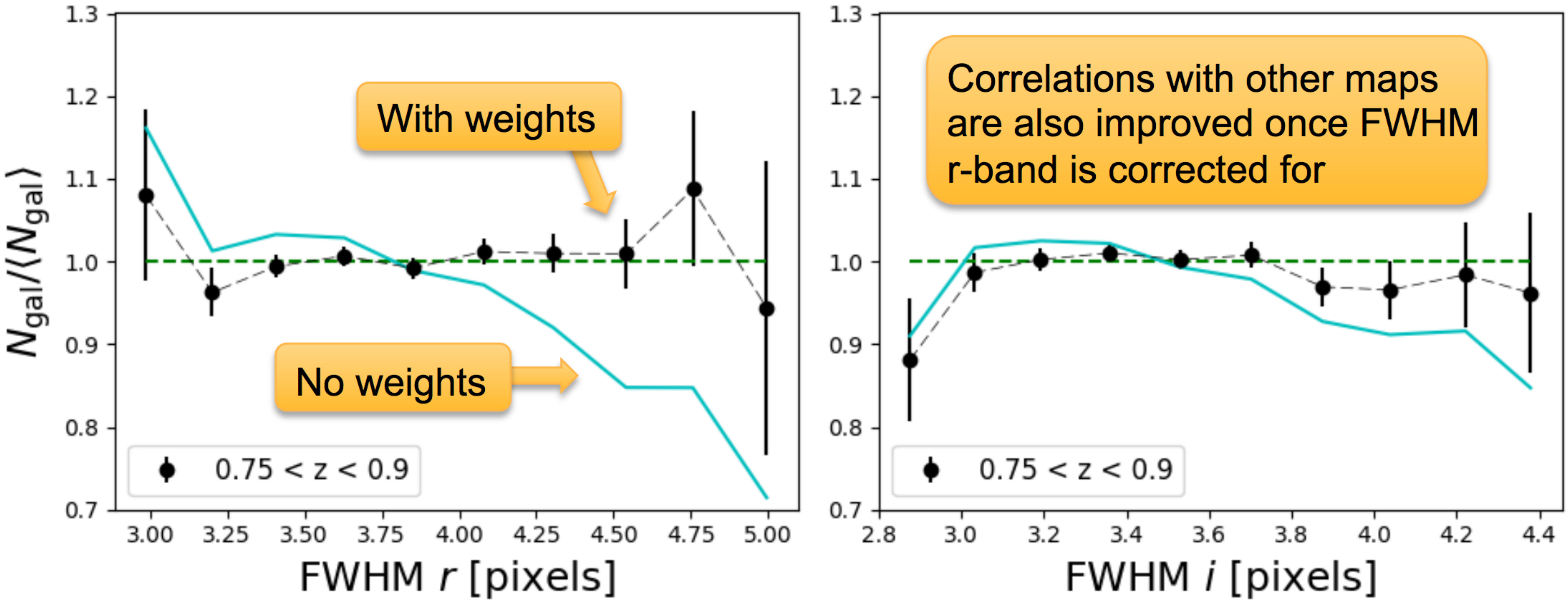




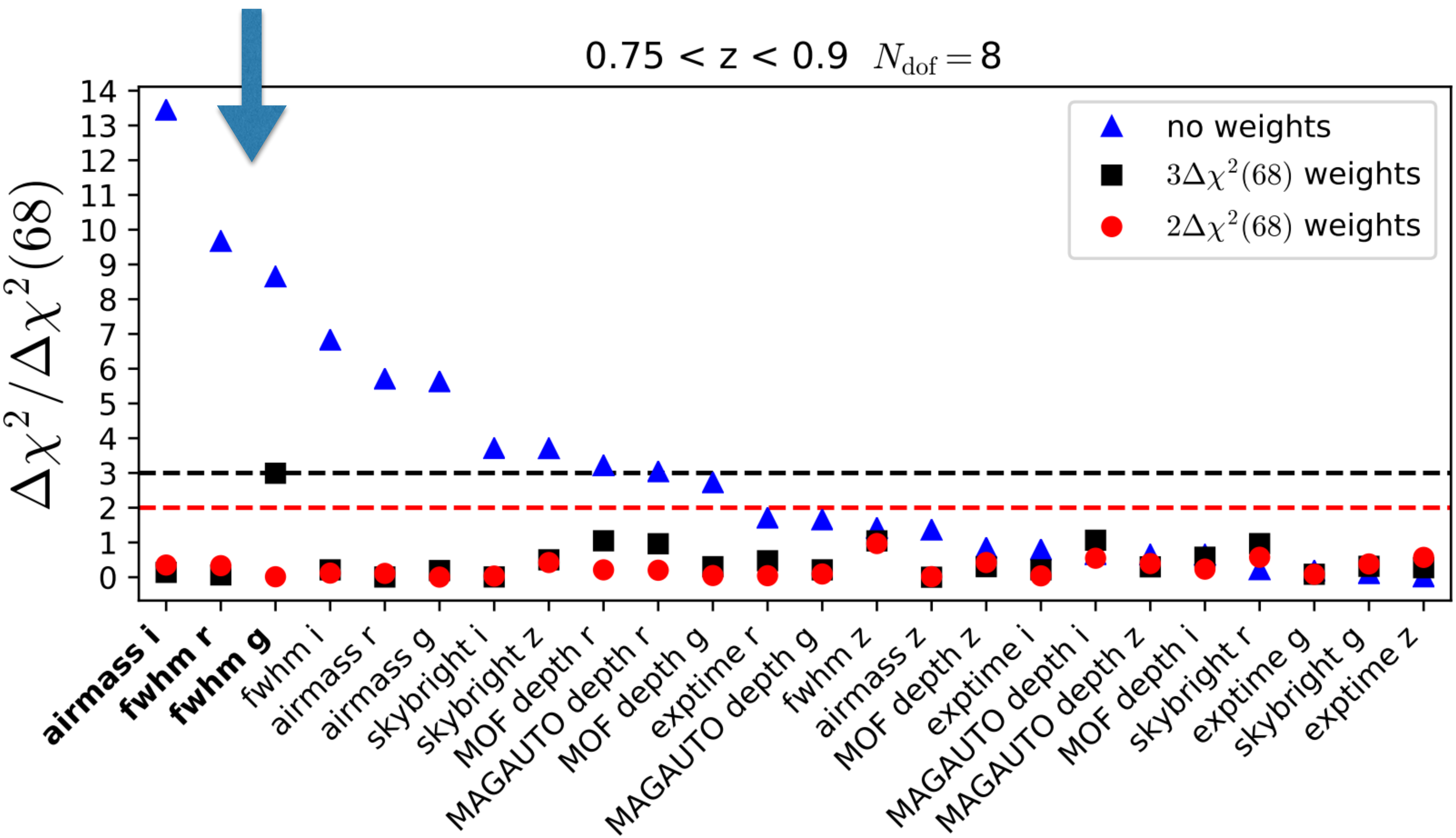
Look at the blue points



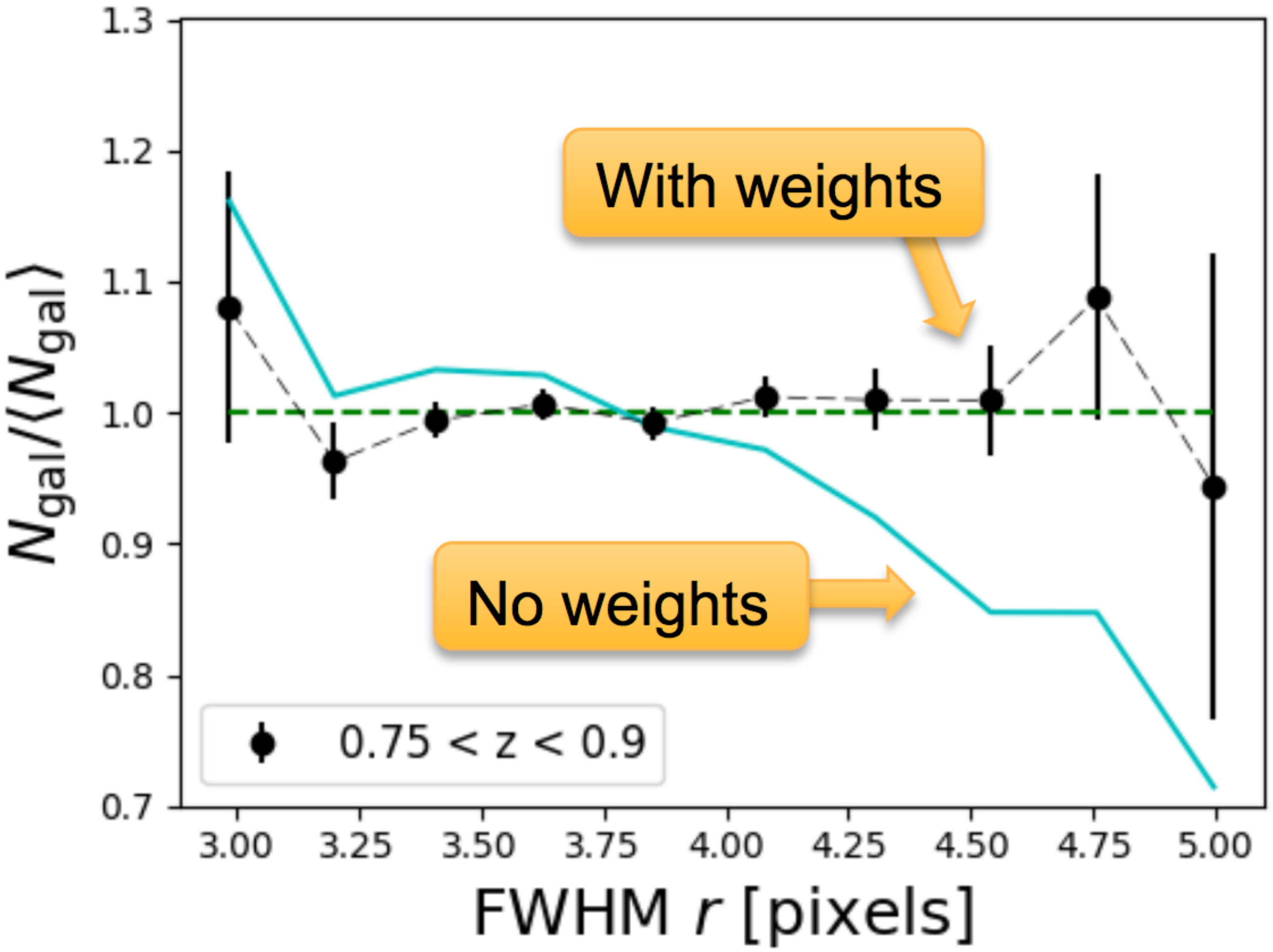
Apply weights for correlation with the most relevant first



Look at the blue points

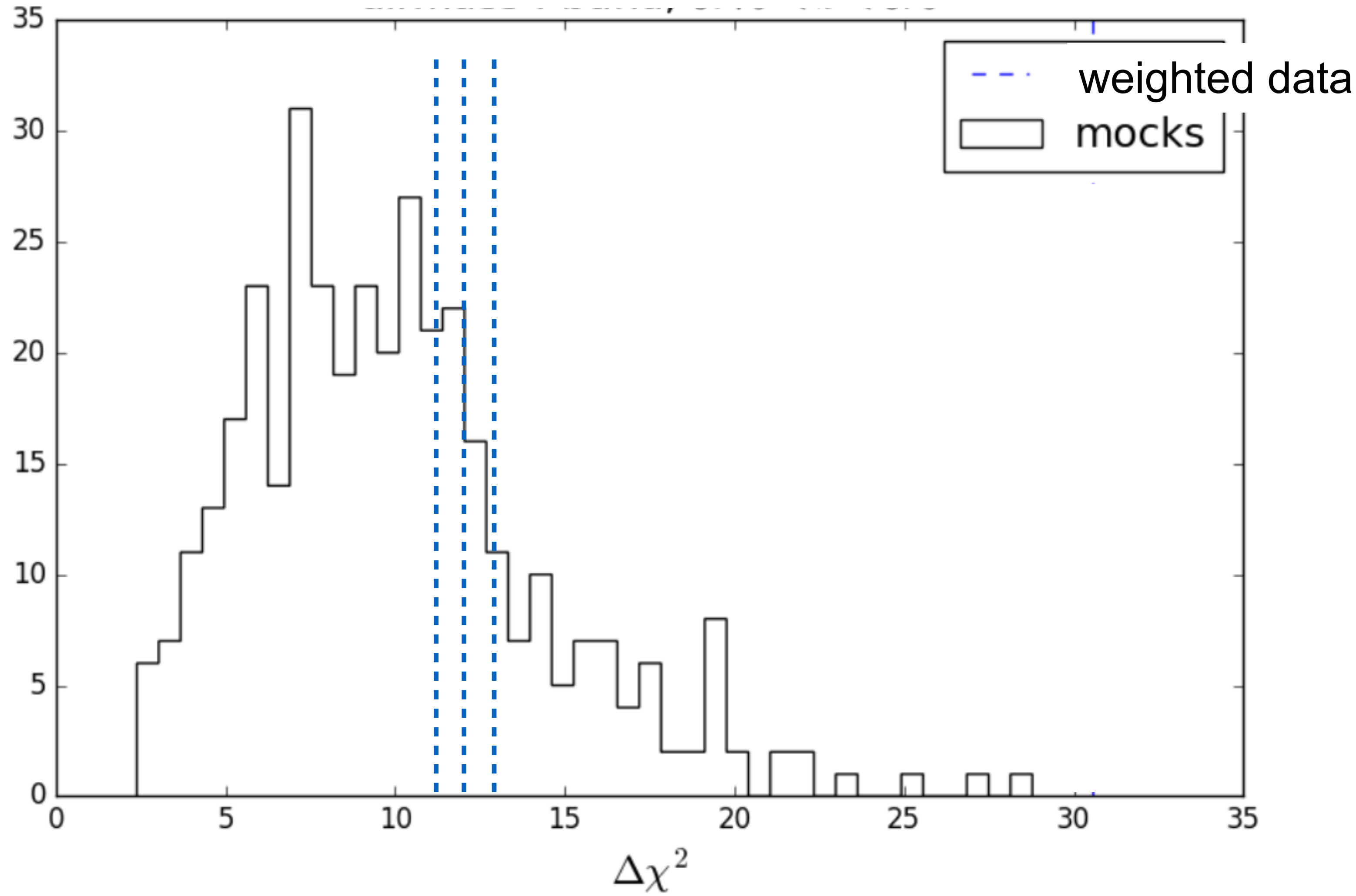


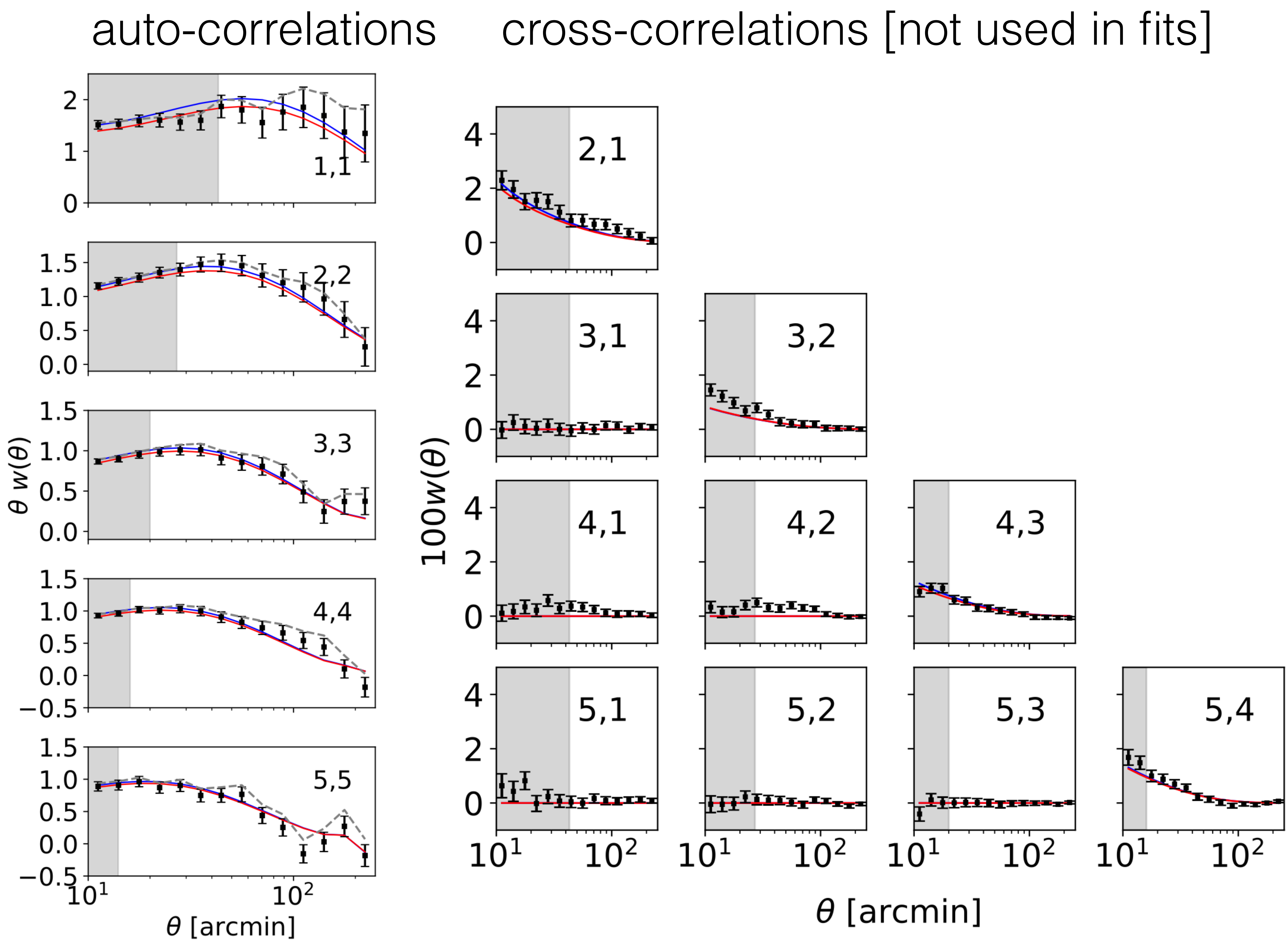
Apply weights for correlation with the next relevant



Repeat until you reach no correlations at a given significance (e.g. 2 or 3 sigmas)

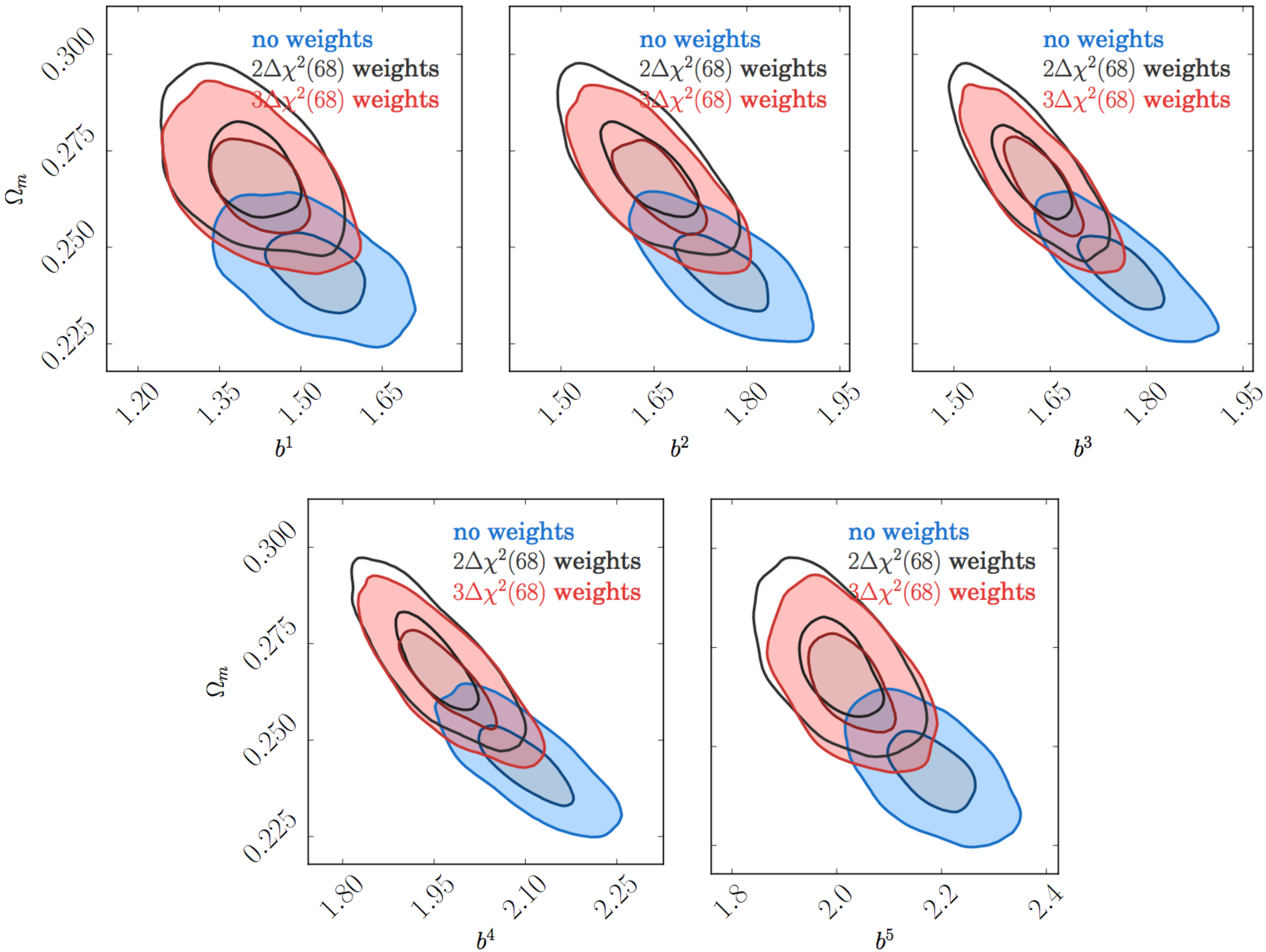
For all observational maps and z-bins



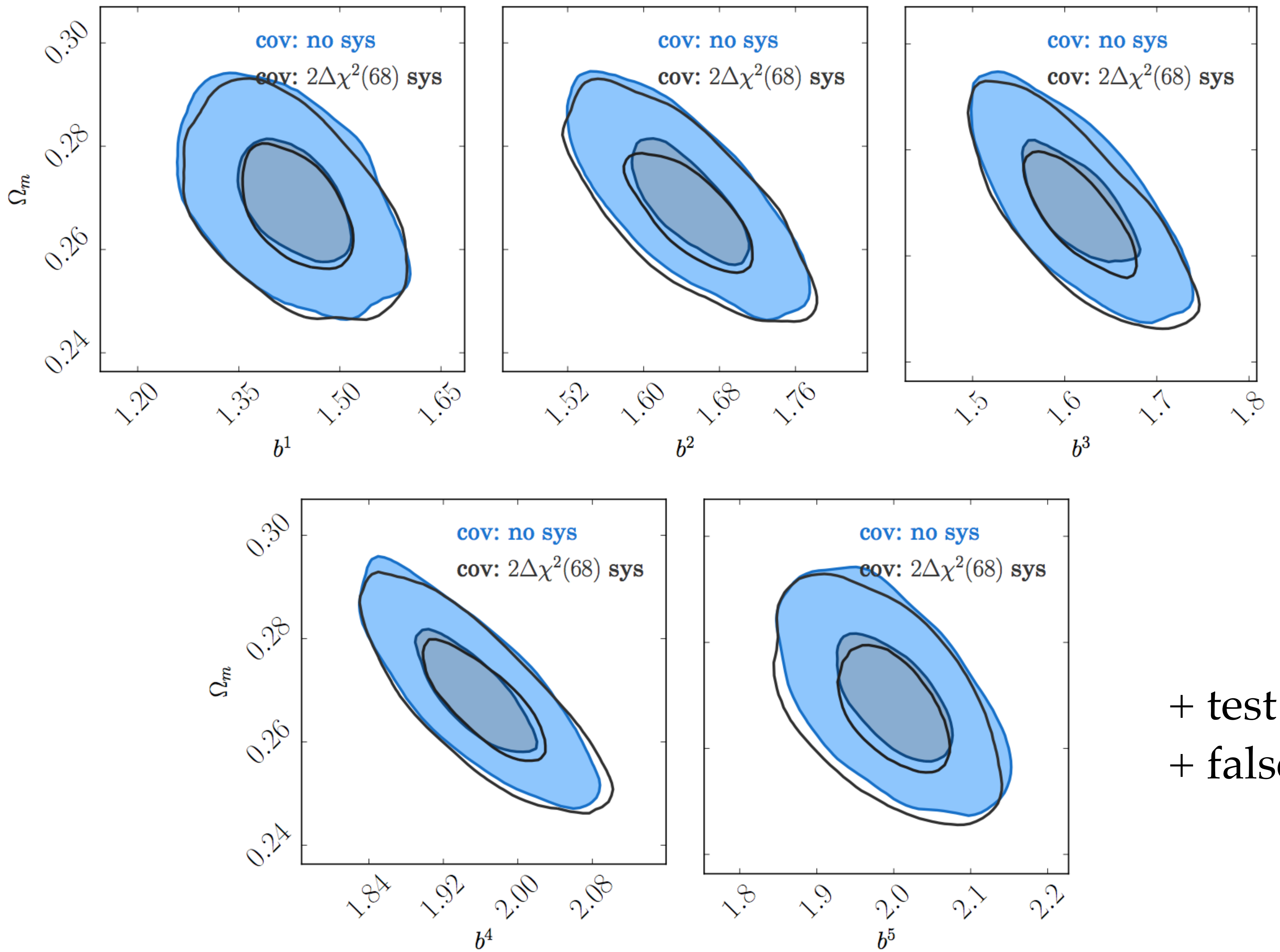


auto-correlations
cross-correlations [not used in fits]
θ w(θ)
100w(θ)
θ [arcmin]
θ [arcmin]
1,1
2,2
3,3
4,4
5,5
2,1
3,1
3,2
4,1
4,2
4,3
5,1
5,2
5,3
5,4

The impact of systematics on parameter constrains



Testing for potential removal of modes



\+ test estimator bias
\+ false correlations

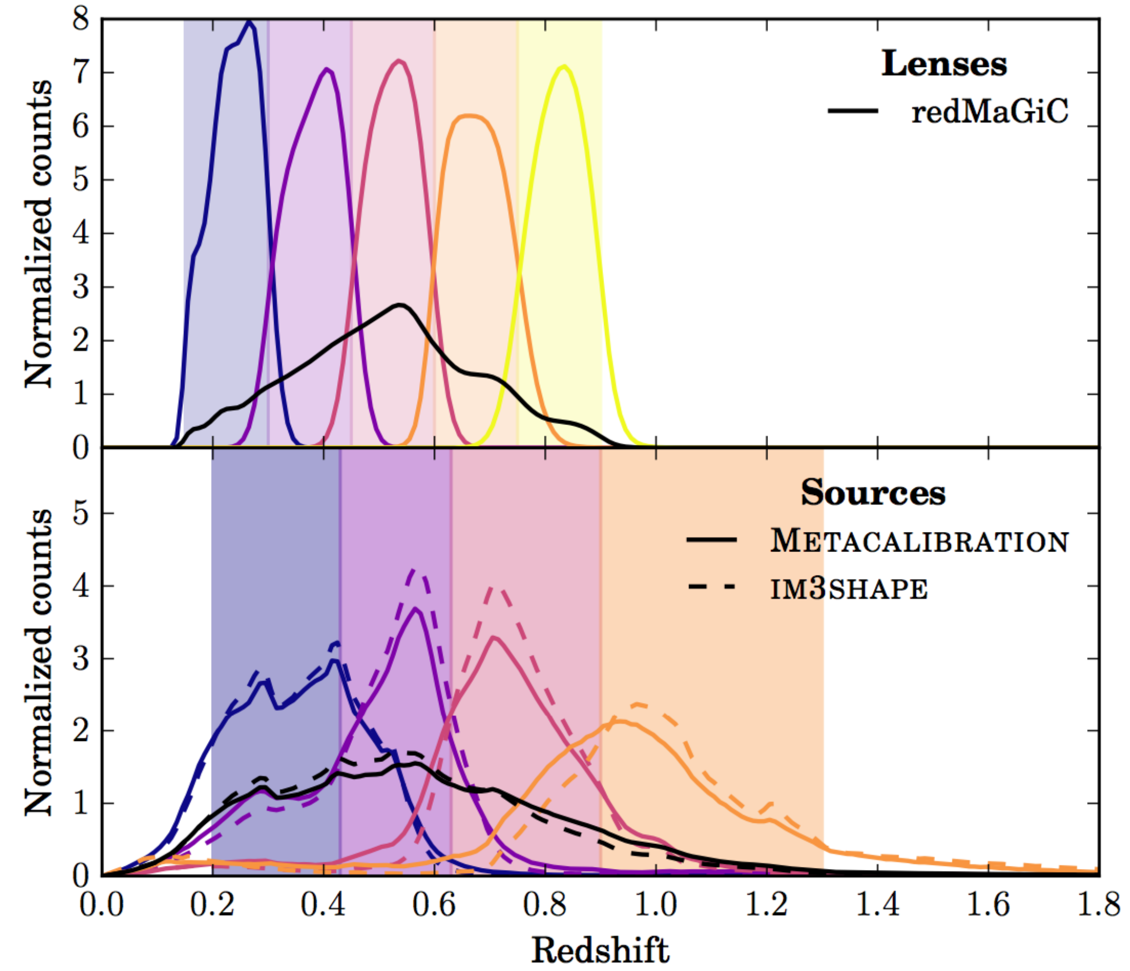
Combination with Weak Lensing

Compare & consistently combine three 2-point correlation functions

Redmagic (in 4 bins):
660000 galaxies

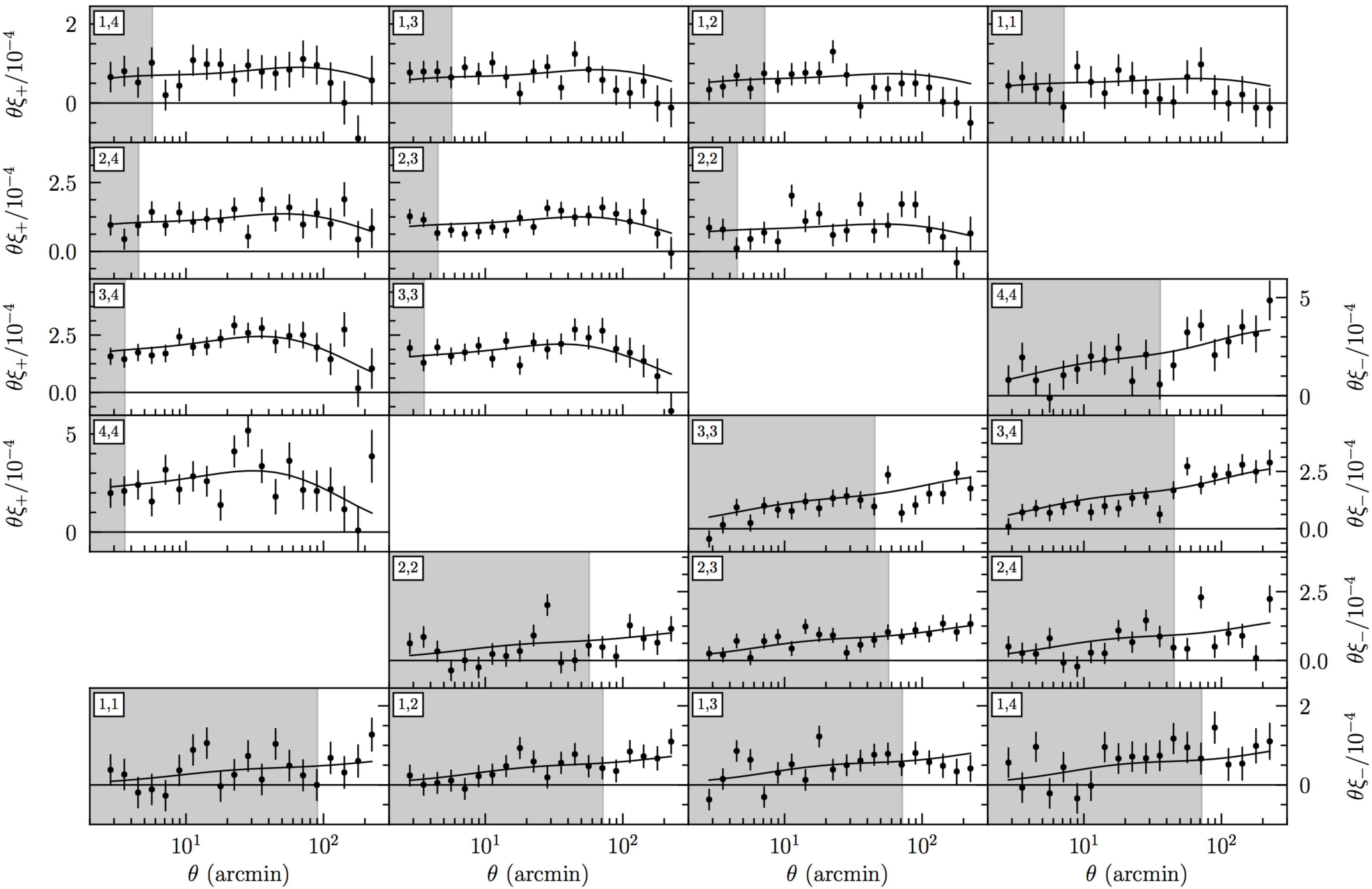
Metacalibration (in 4 bins):
26 M galaxies

Im3shape:
18 M galaxies

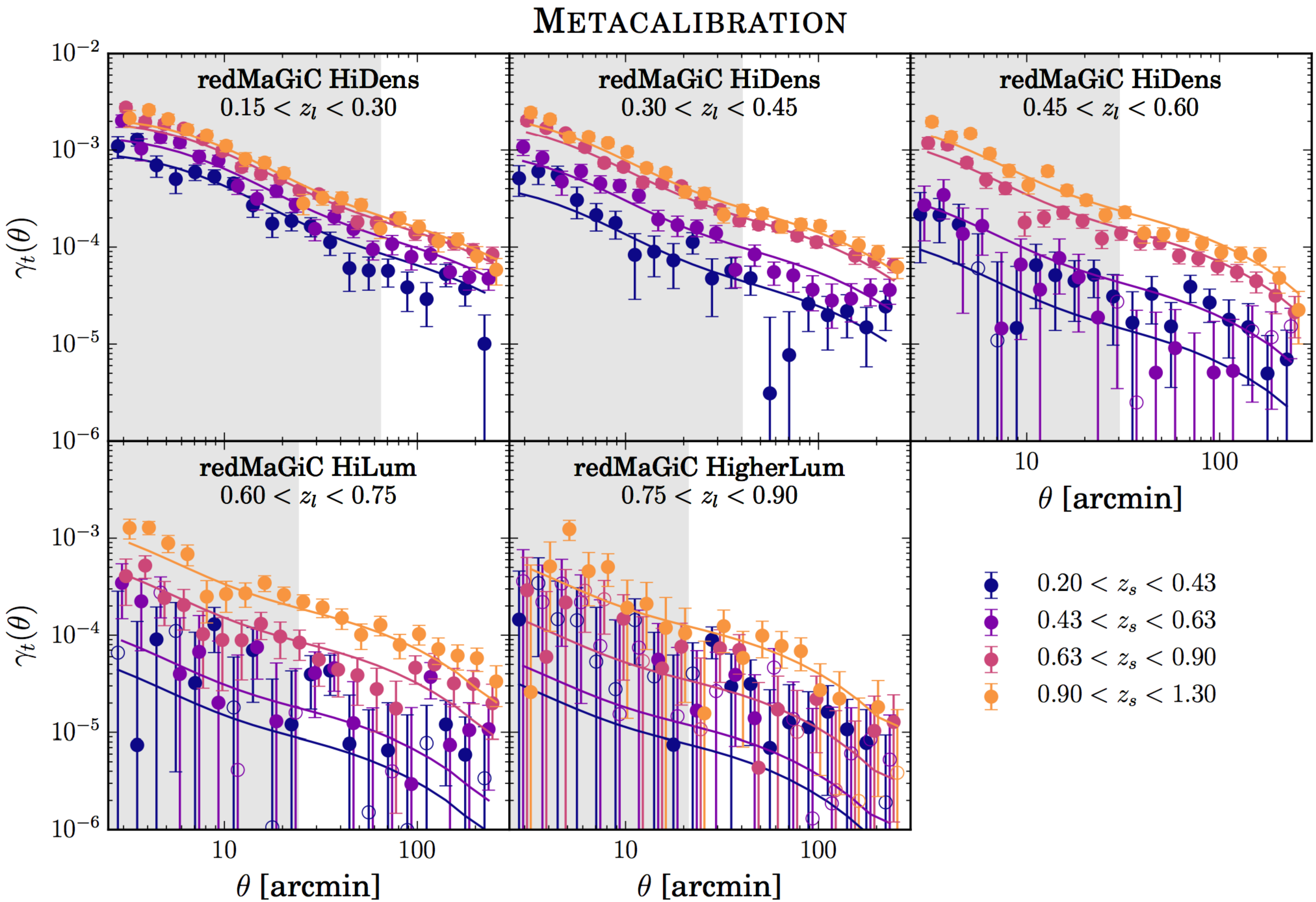


baseline systematics marginalization (20 parameters)

linear bias of lens galaxies, per lens z-bin
lens galaxy photo-zs, per lens z-bin
source galaxy photo-zs, per source z-bin
multiplicative shear calibration, per source z-bin
intrinsic alignments, power-law/free amplitude per per source z-bin



1,4
1,3
1,2
1,1
2,4
2,3
2,2
3,4
3,3
4,4
4,4
3,3
3,4
2,2
2,3
2,4
1,1
1,2
1,3
1,4
$\theta\xi_+/10^{-4}$
$\theta\xi_-/10^{-4}$
θ (arcmin)

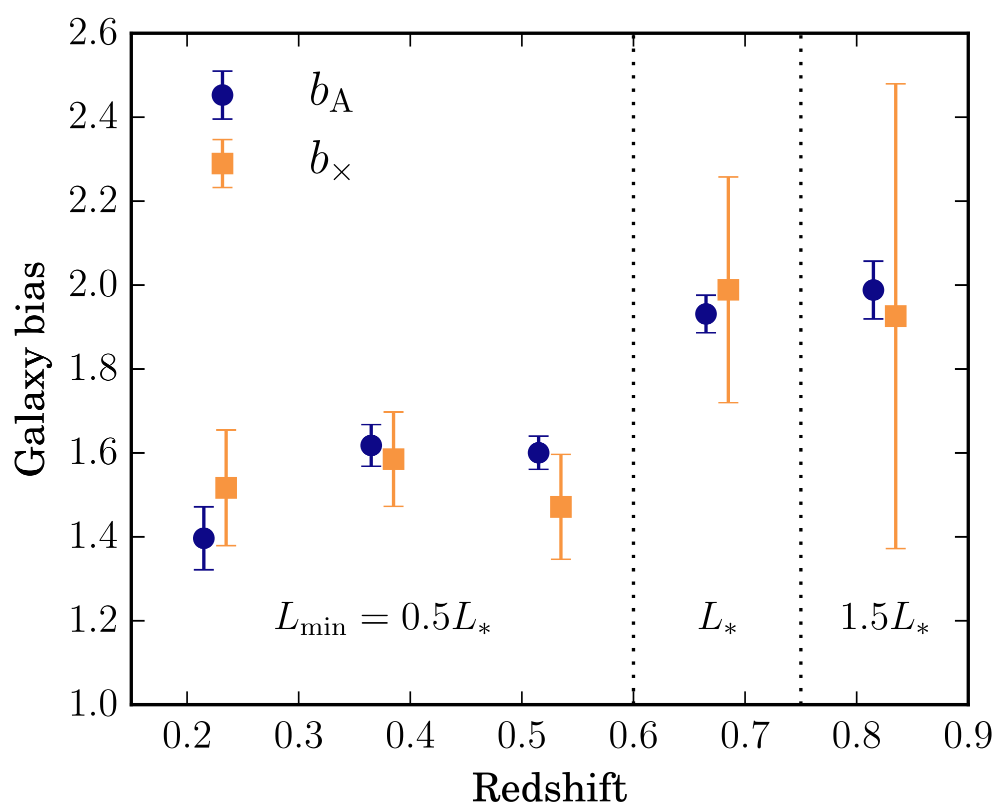


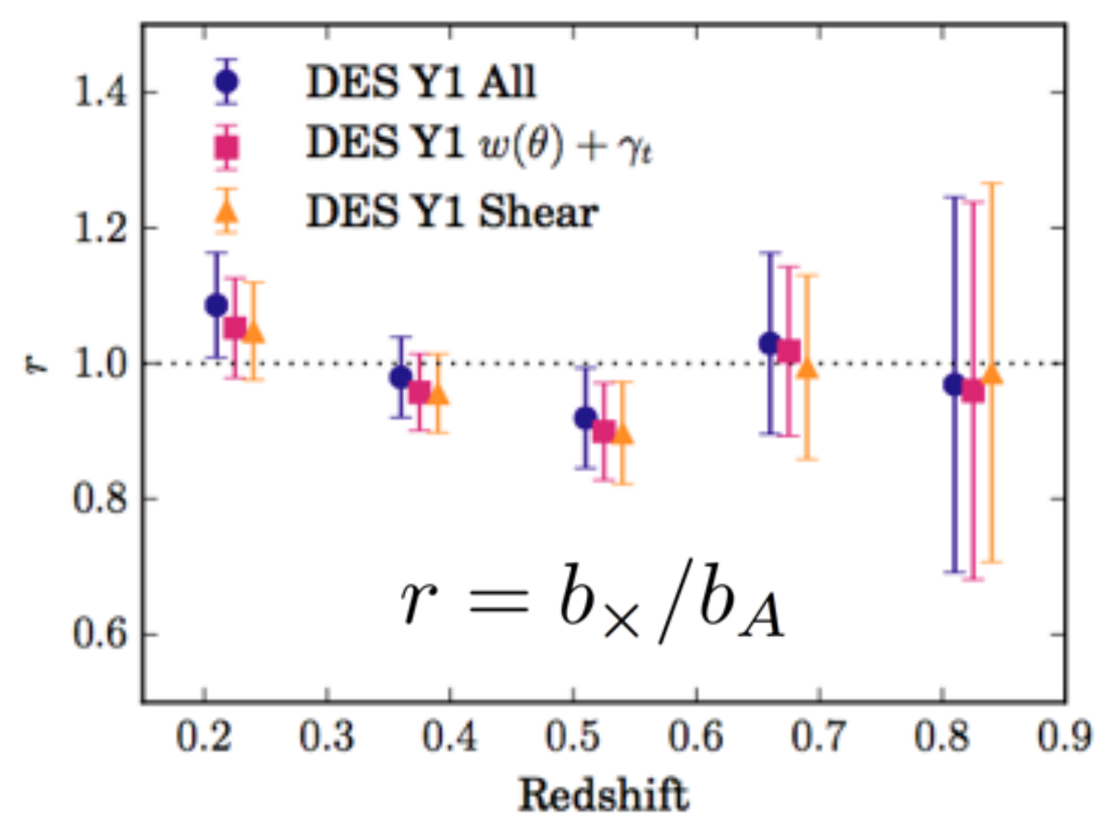
METACALIBRATION
redMaGiC HiDens
$0.15 < z_l < 0.30$
redMaGiC HiDens
$0.30 < z_l < 0.45$
redMaGiC HiDens
$0.45 < z_l < 0.60$
redMaGiC HiLum
$0.60 < z_l < 0.75$
redMaGiC HigherLum
$0.75 < z_l < 0.90$
$\gamma_t(\theta)$
θ [arcmin]
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10
100
$0.20 < z_s < 0.43$
$0.43 < z_s < 0.63$
$0.63 < z_s < 0.90$
$0.90 < z_s < 1.30$

Combination with Weak Lensing

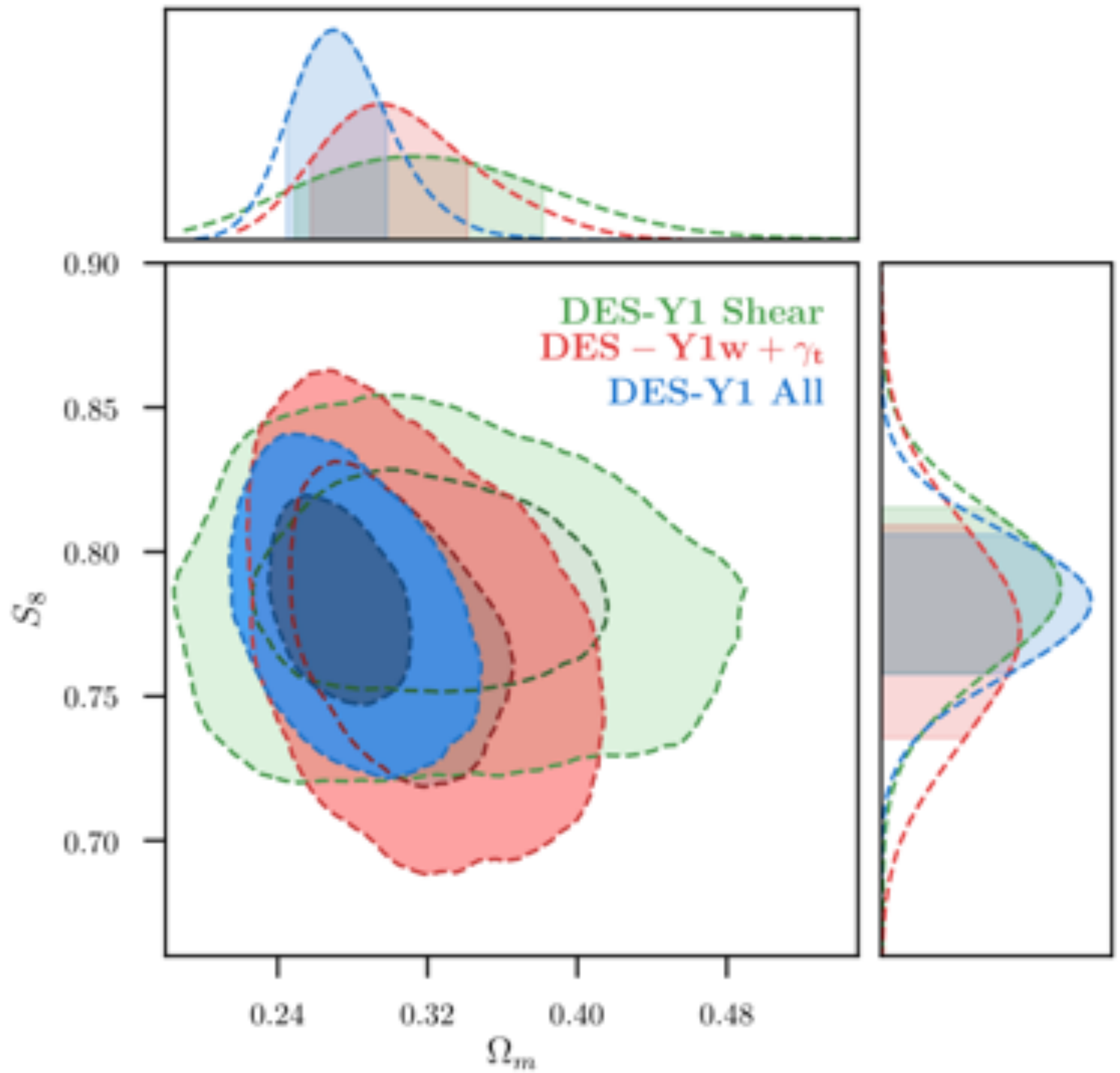
DES Y1 cosmology analysis assumes the identical linear bias for galaxy clustering and galaxy-galaxy lens in (inaccurate at small scales)

At fixed cosmology, measure galaxy bias separately for both probes.





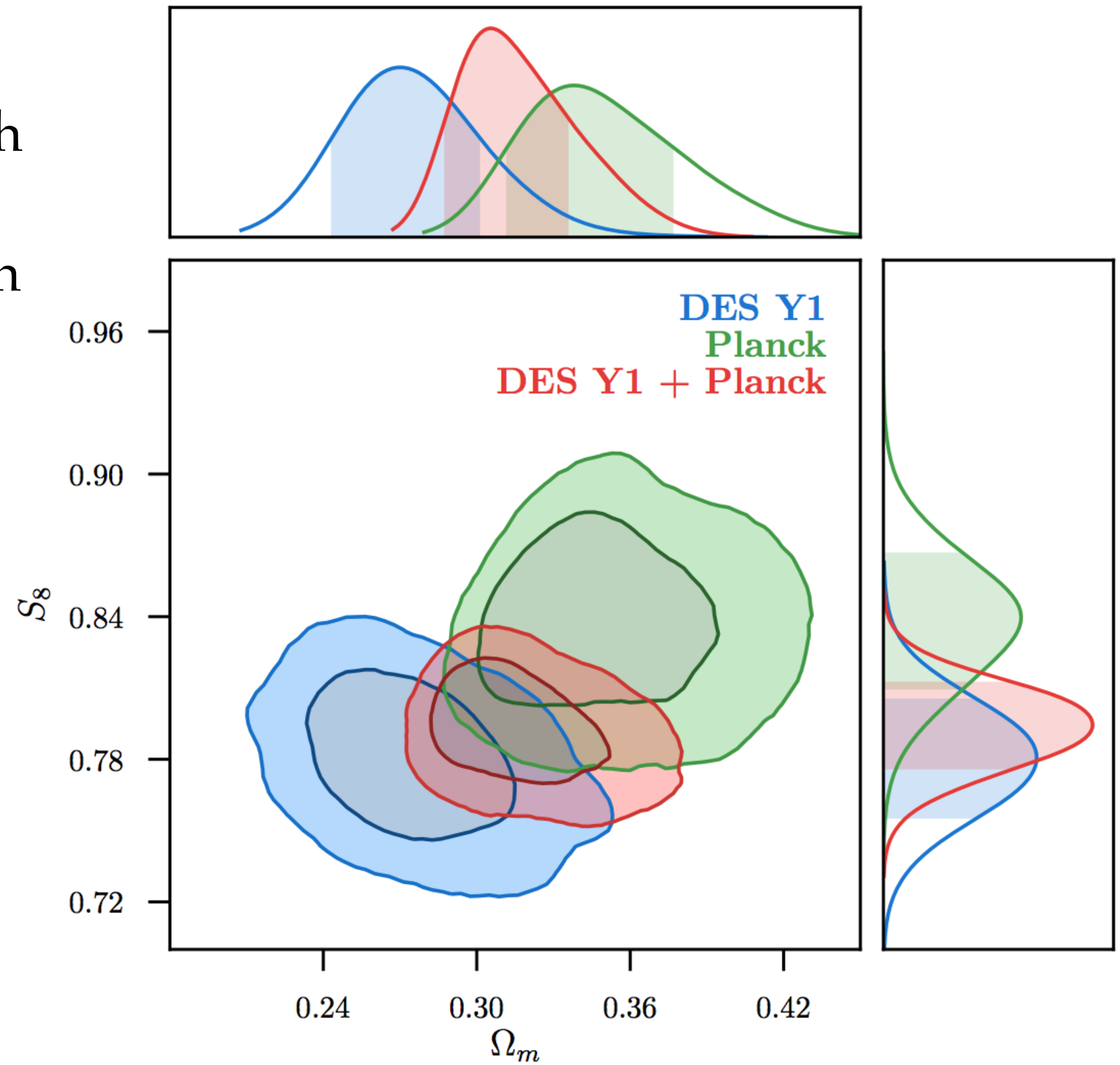
We gains by combining



- DES-Y1 weak lensing: factor ~2 increase in constraining power
- Marginalized 6 cosmological parameters, 10 clustering nuisance parameters, and 10 lensing nuisance parameters
- Consistent cosmology constraints from weak lensing and clustering in configuration space
- Joint analysis constrains IA

DES alone is competitive with Planck (in some parameters) ! and compatible

- DES and Planck constrain matter density and S8 with equal strength
- Difference in central values 1-2σ in the same direction as earlier lensing results
- Bayes Factor 4.2 – no evidence for inconsistency



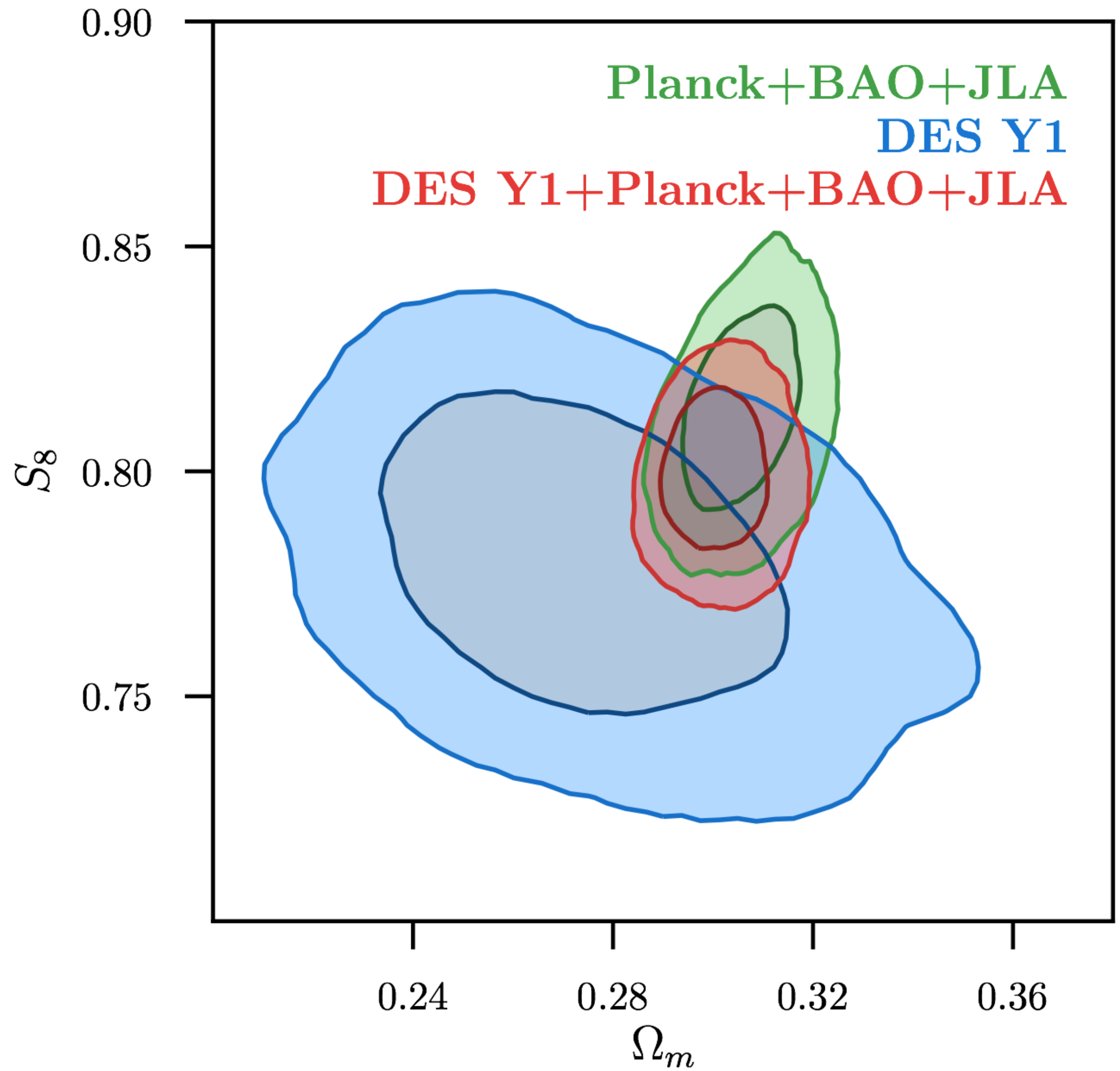
Strongest constrains when fully combined

- DES and Planck constrain matter density and S8 with equal strength
- Difference in central values 1-2σ in the same direction as earlier lensing results
- Consistency is even stronger when combined with other low-z probes
- Strongest constrains in LCDM:

$\sigma_8 = 0.801 \pm 0.014$ $\quad h = 0.682^{+0.006}_{-0.006}$

$S_8 = 0.799^{+0.014}_{-0.009}.$ $\quad \Omega_m = 0.301^{+0.006}_{-0.008}.$

DES Y1 + CMB + BAO + JLA



wCDM against LCDM

- no evidence for w different from -1 in any combination
- wCDM does not improve any of the evidence rations. Is not favoured over LCDM

$$w = -1.00^{+0.04}_{-0.05}.$$