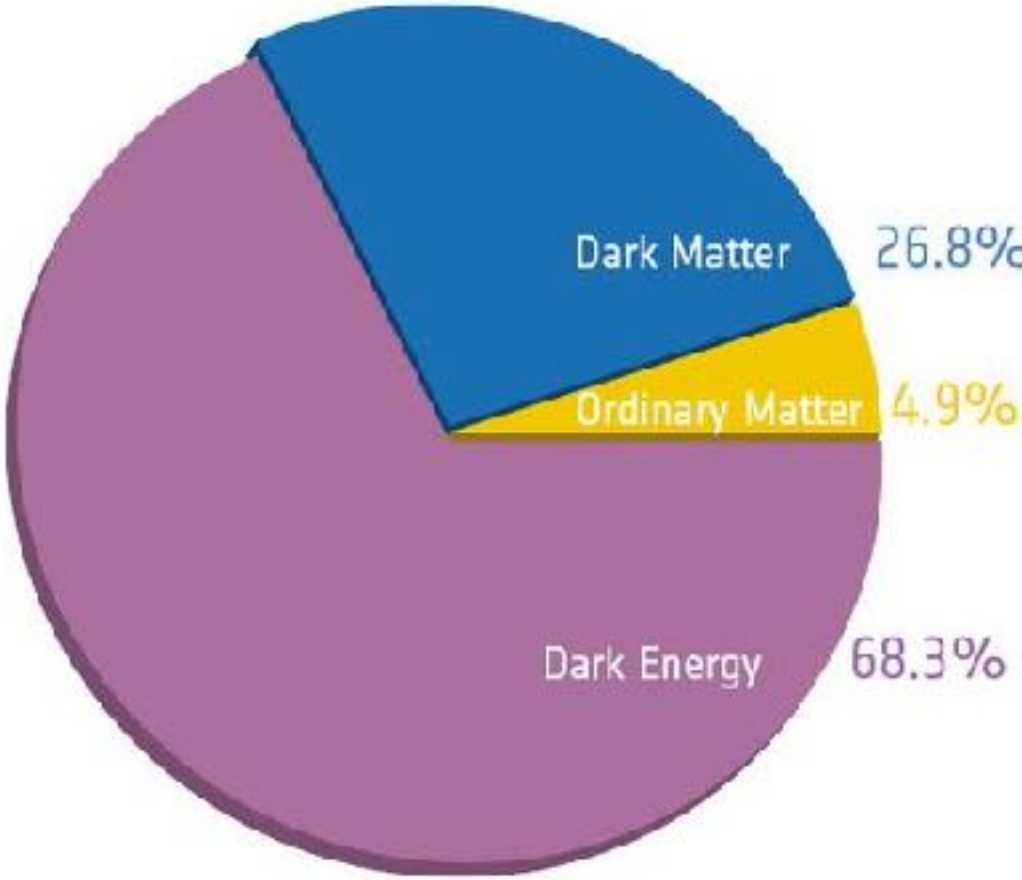
Simulating the Dark Energy Survey: Catalogs to Cosmology

Joe DeRose
with
Niall MacCrann, Eli Rykoff, Risa Wechlser
and the Dark Energy Survey

The “Standard” Model of Cosmology

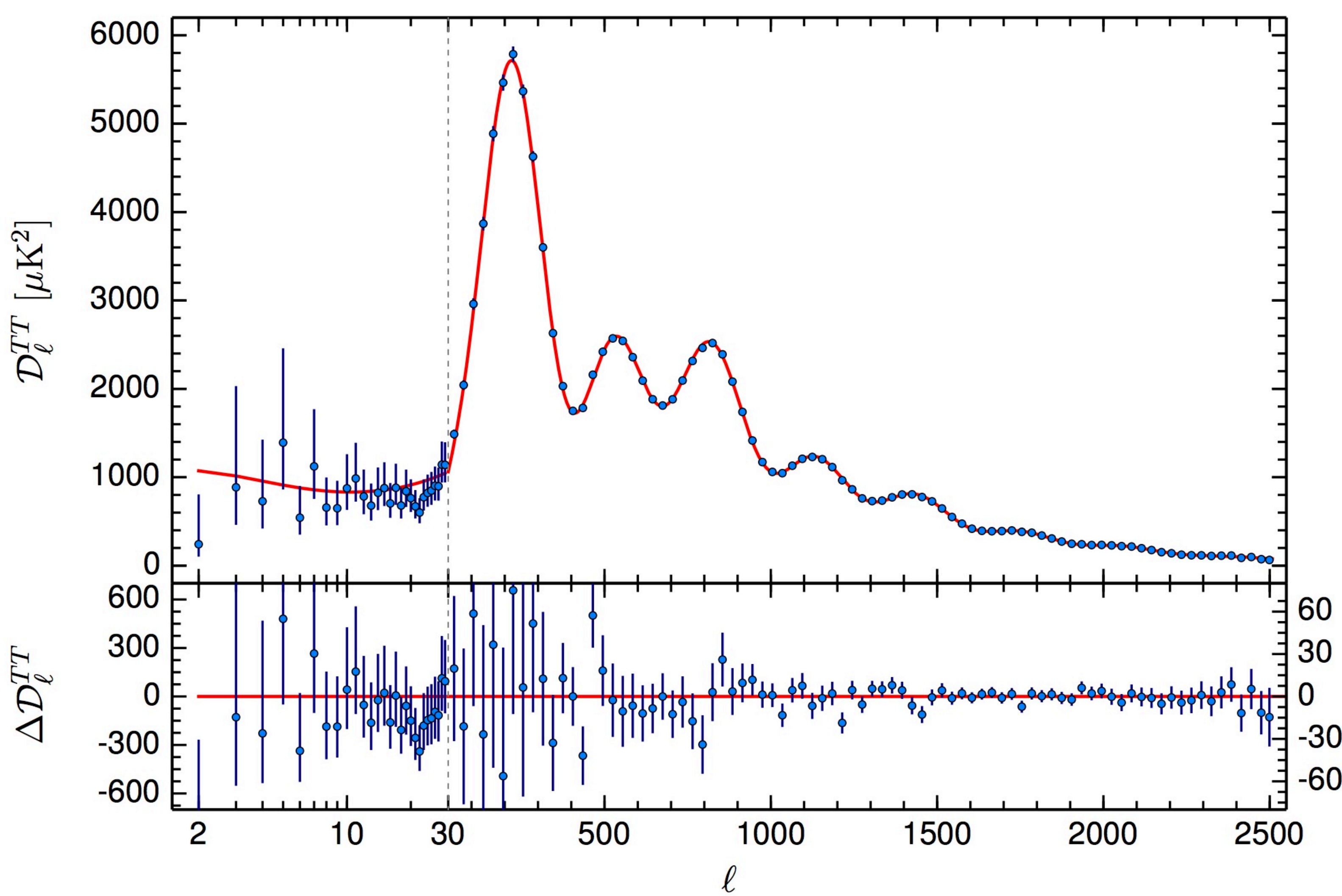
- **Inflation seeded the initial density fluctuations**
- **Gravity is described by general relativity**
- **The mass in the universe is dominated by dark matter**
- **The expansion rate of the universe is accelerating due to a cosmological constant**
- **All of this is described by a 7 parameter model**



Planck

The Planck satellite has provided exquisite confirmation of this model at high redshift.

But this still doesn't provide us any information on the puzzling aspects of the standard model!

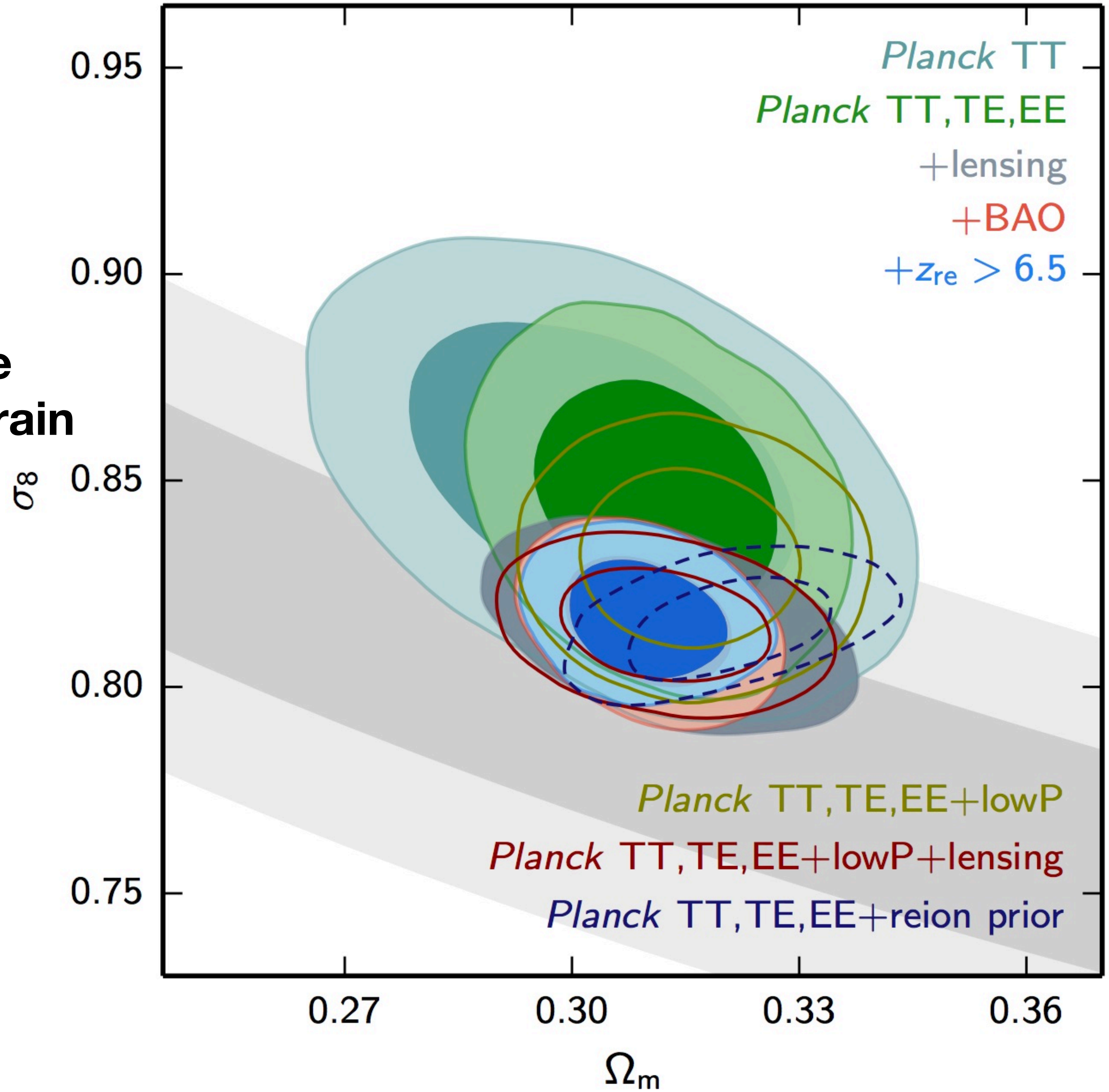


Planck 2015

Growth of Structure

Using our wonderful but poorly understood LCDM, we can use the measurements of Planck to constrain low redshift observables!

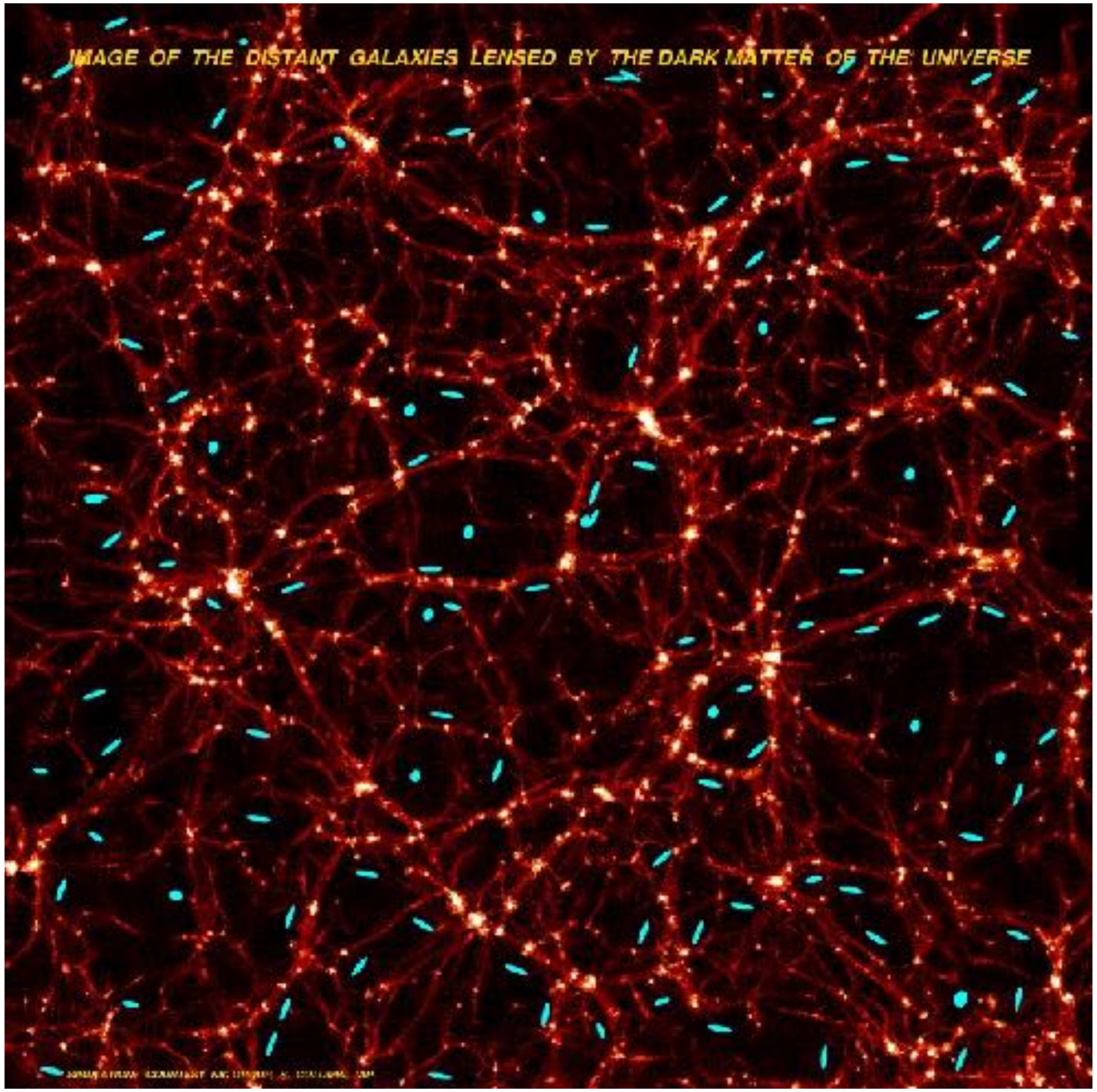
Just measure with galaxies to see if LCDM is right!



Planck 2015

Cosmic Shear

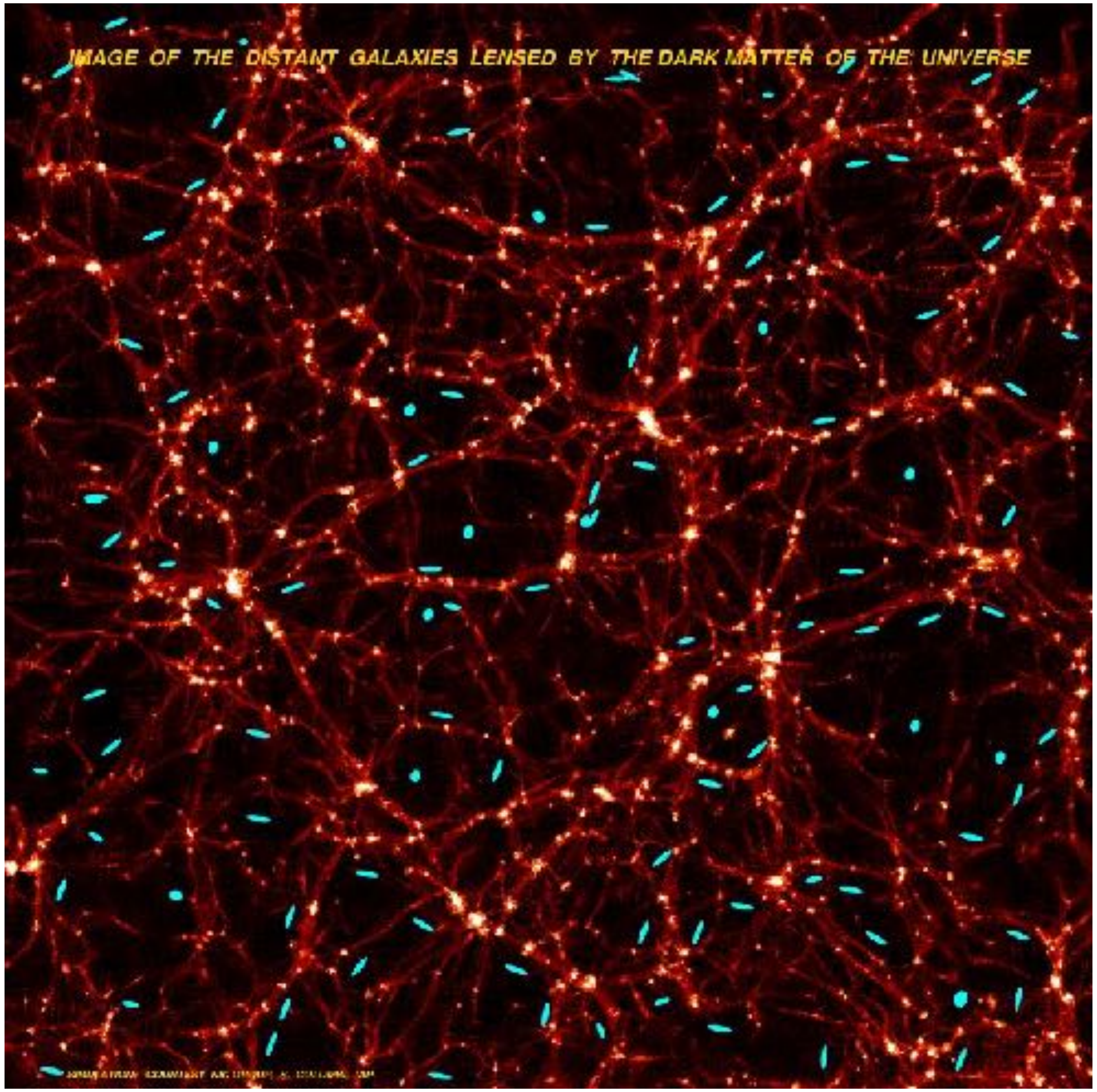
$$\xi_{\pm}^{ij}(\theta) = (1+m_i)(1+m_j)$$
$$\times \int \frac{dl\,l}{2\pi}\, J_{0,4}(l\theta) \int d\chi\,(1+z(\chi))^2$$
$$\times g^i(\chi) g^j(\chi;) P(l/\chi; z(\chi))$$



Cosmic Shear

$$\xi_{\pm}^{ij}(\theta) = (1+m_i)(1+m_j) \times \int \frac{dl\, l}{2\pi} J_{0,4}(l\theta) \int d\chi\, (1+z(\chi))^2 \times g^i(\chi) g^j(\chi;) P(l/\chi; z(\chi)$$

“Direct” probe of matter power spectrum



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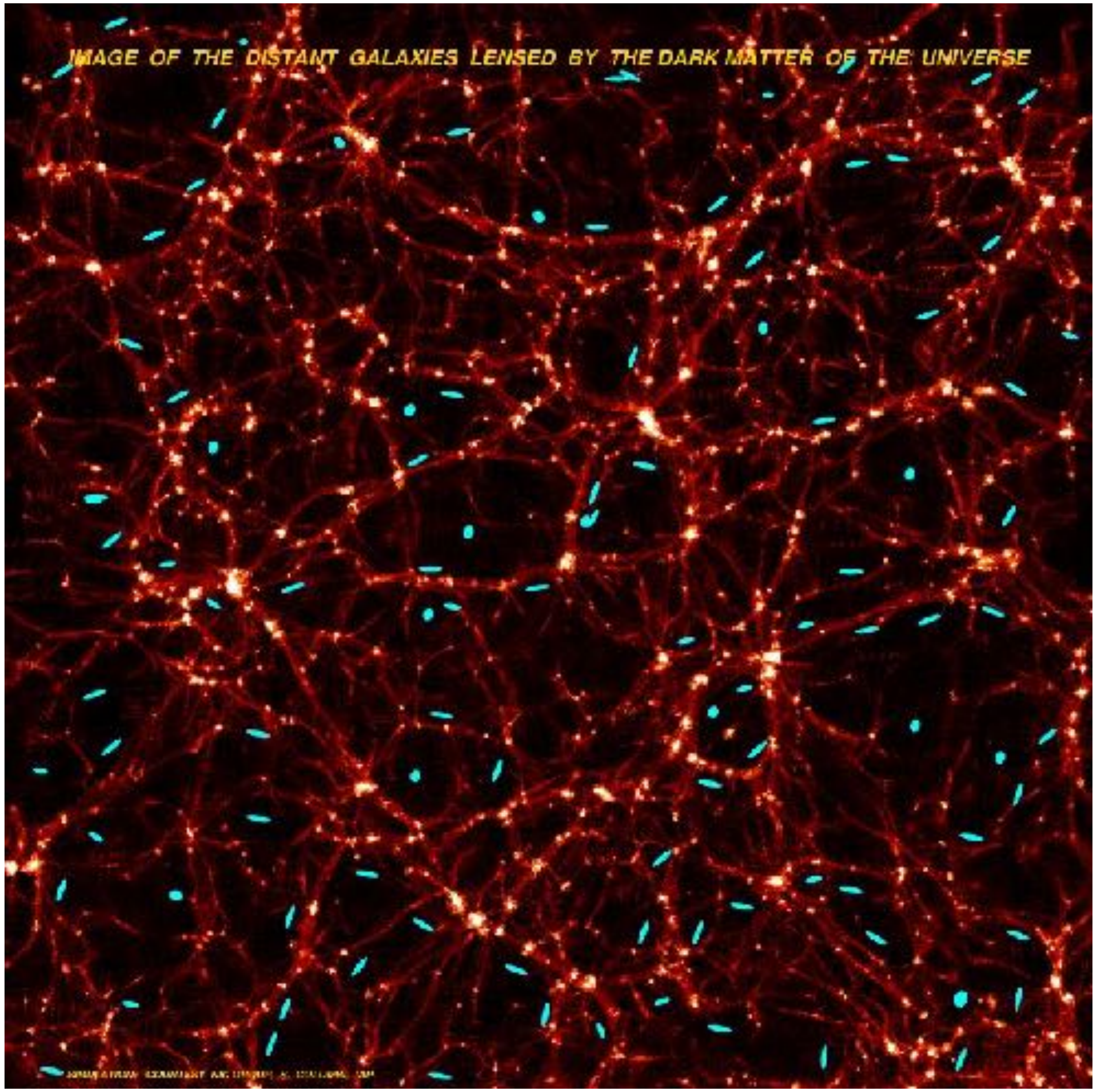
In particular we want to measure cosmic shear tomographically.

A major possible nuisance to this goal are intrinsic alignments of galaxy shapes.



Cosmic Shear

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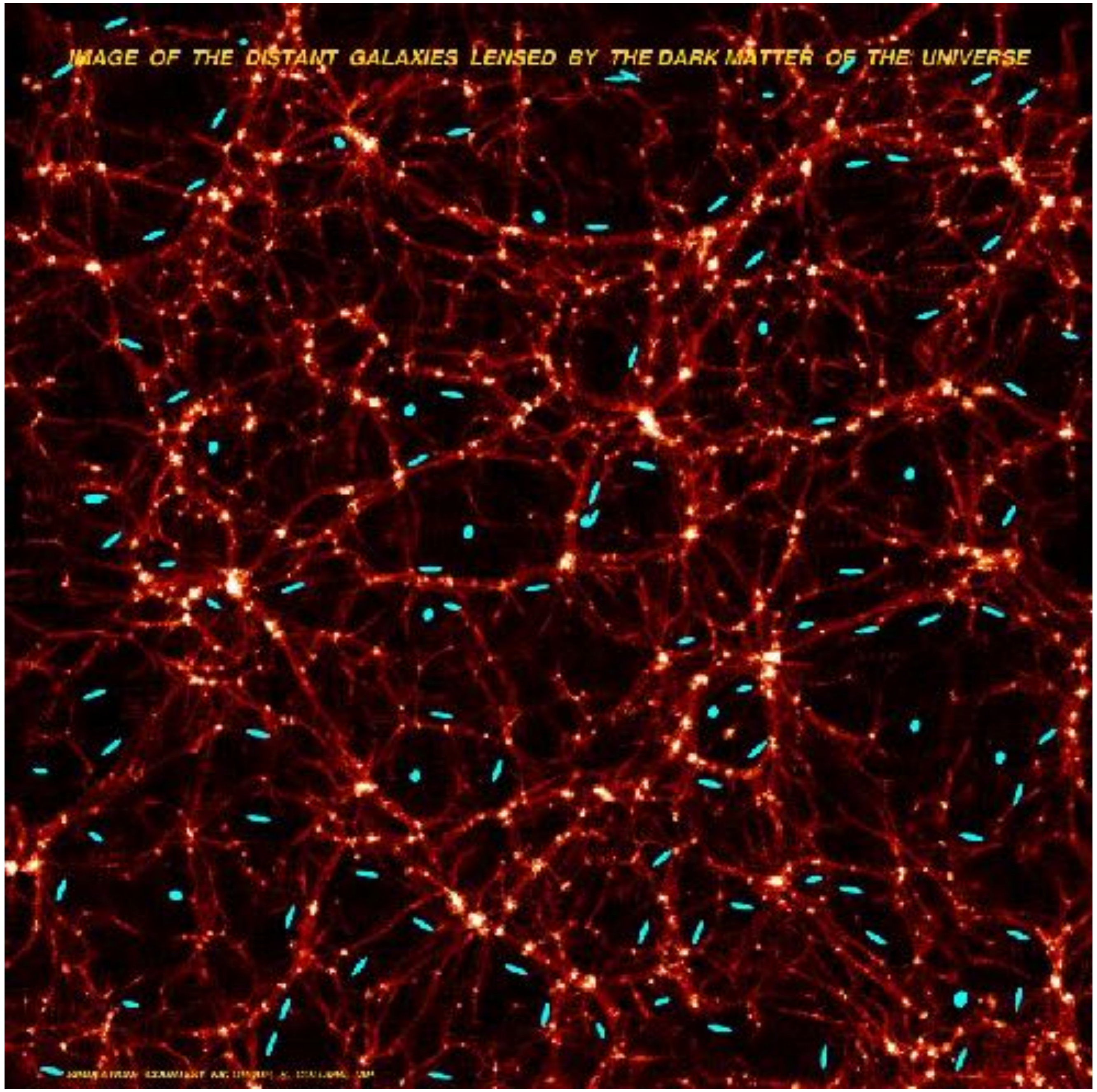
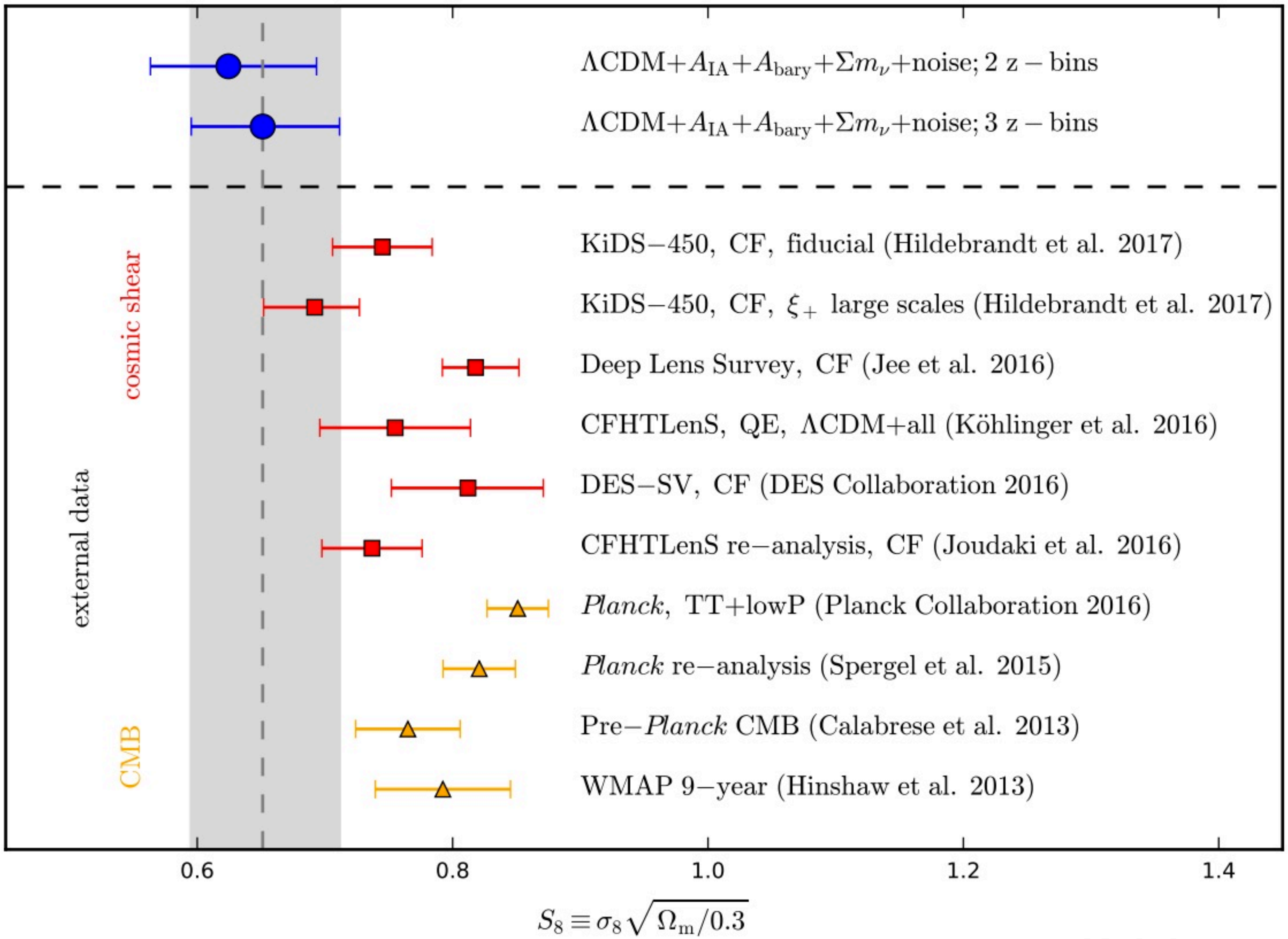
Shapes of galaxies must be measured in an unbiased manner!



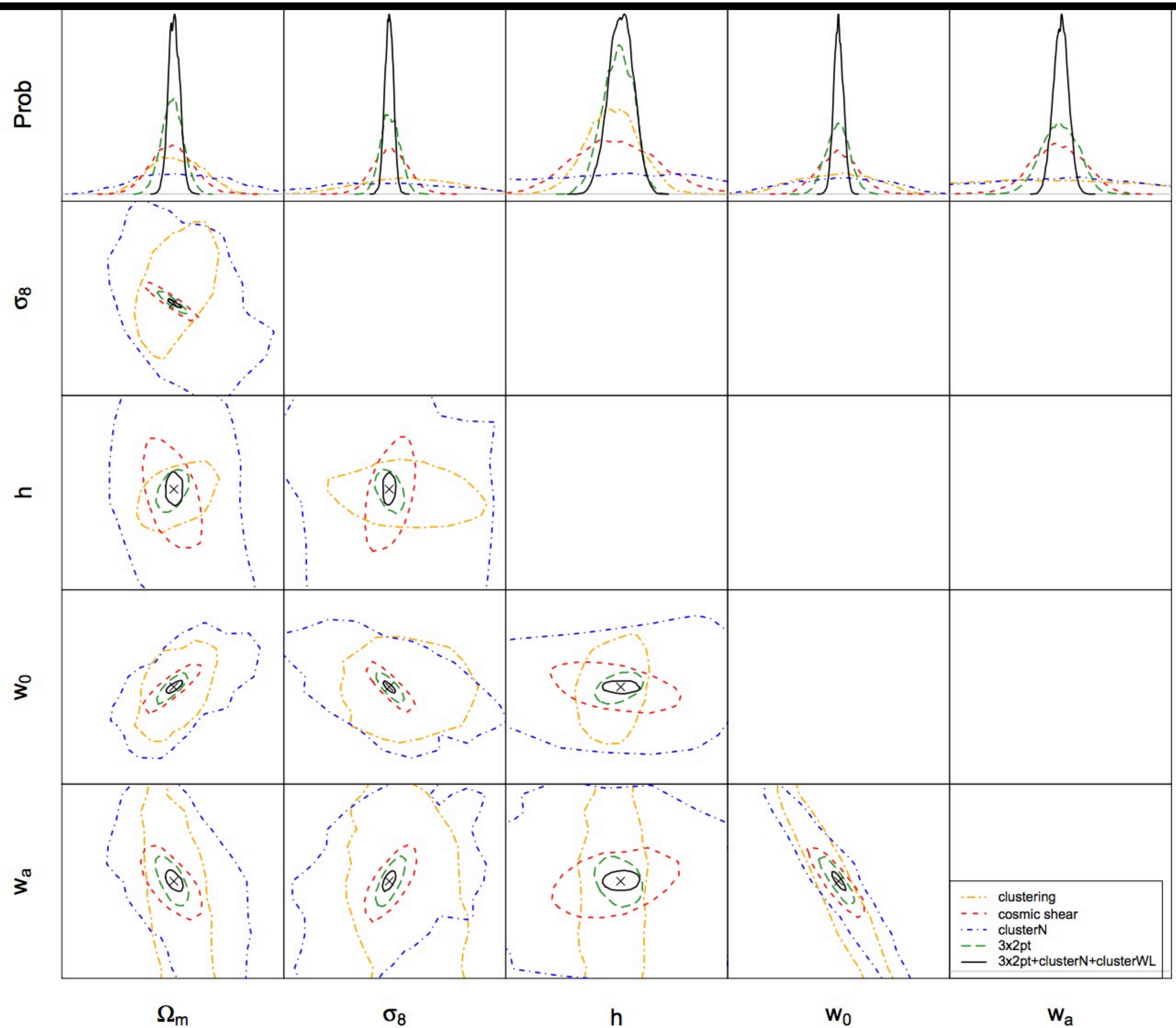
Tension?



Kohlinger et al. 2017

Combined Probes

- Self-calibration of systematics
- Different information content
- Need to know covariance!



Krause & Eifler 2016

The Dark Energy Survey

- Imaging survey
  - 2013-2018
  - 4m Blanco Telescope
  - grizY bands
- 4 years of data taken
- Currently analyzing Y1
  - ~1300 deg^2
  - 35 million galaxies to r~23

Galaxy (Cross) Correlations

Galaxy-Galaxy Lensing:

$$\gamma_t^{ij}(\theta) = b_i(1 + m_j) \int \frac{dl\, l}{2\pi} J_2(l\theta) \int dz\, n_{\rm lens}^i(z) g^j(z) \times (1 + z(\chi)) \frac{H(z)}{\chi^2(z)} P(k = l/\chi(z); z)\,.$$

Galaxy Clustering:

$$w^i(\theta) = b_i^2 \int \frac{dl\, l}{2\pi} J_0(l\theta) \int dz\, \left[n_{\rm lens}^i(z)\right]^2 \times \frac{H(z)}{\chi^2(z)} P(l/\chi(z); z)$$

We must add lens galaxy bias and redshifts as a third type of nuisance parameter on top of redshifts and shapes of source galaxies!

An Overview of the 3x2pt Analysis

- **Combination of correlations between galaxies and shear**
  - **galaxy-galaxy auto-correlation**
  - **galaxy-shear cross-correlation (galaxy-galaxy lensing)**
  - **shear-shear cross-correlation (cosmic shear)**
- **(Fiducial) Galaxy catalogs**
  - **Metacalibration source galaxy catalog**
  - **redMaGiC photometric LRG lens galaxy catalog**
- **Emphasis on redundancy**
  - **Two shape catalogs**
  - **Two methods for calibrating redshift distributions**
  - **Two parameter estimation frameworks**
- **Analysis methodologies tested extensively on realistic simulations**

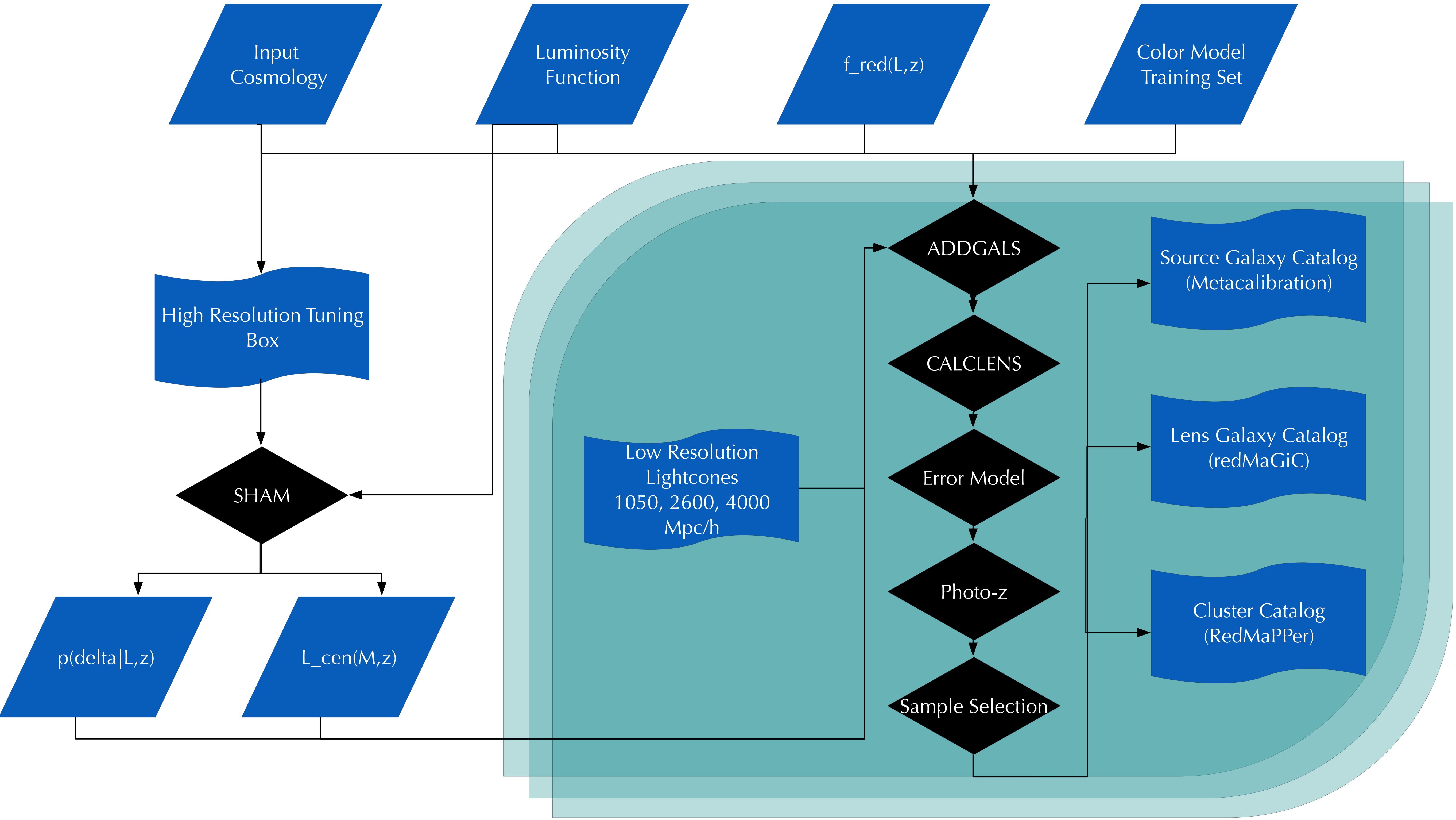
Requirements

- **Accurate modeling of mean signal**
- **Large number of simulations to constrain systematic errors on analysis pipelines and estimate data covariance matrices**
- **Incorporates galaxy observables allowing for realistic analysis of systematics**

Constraints

- **Inexpensive → No hydro / SAM / SHAM**
- **Models all desired probes → No P.T. / P.M.**
- **Magnitude (halo mass) limit → No HODs**
- **Realistic photometric properties**

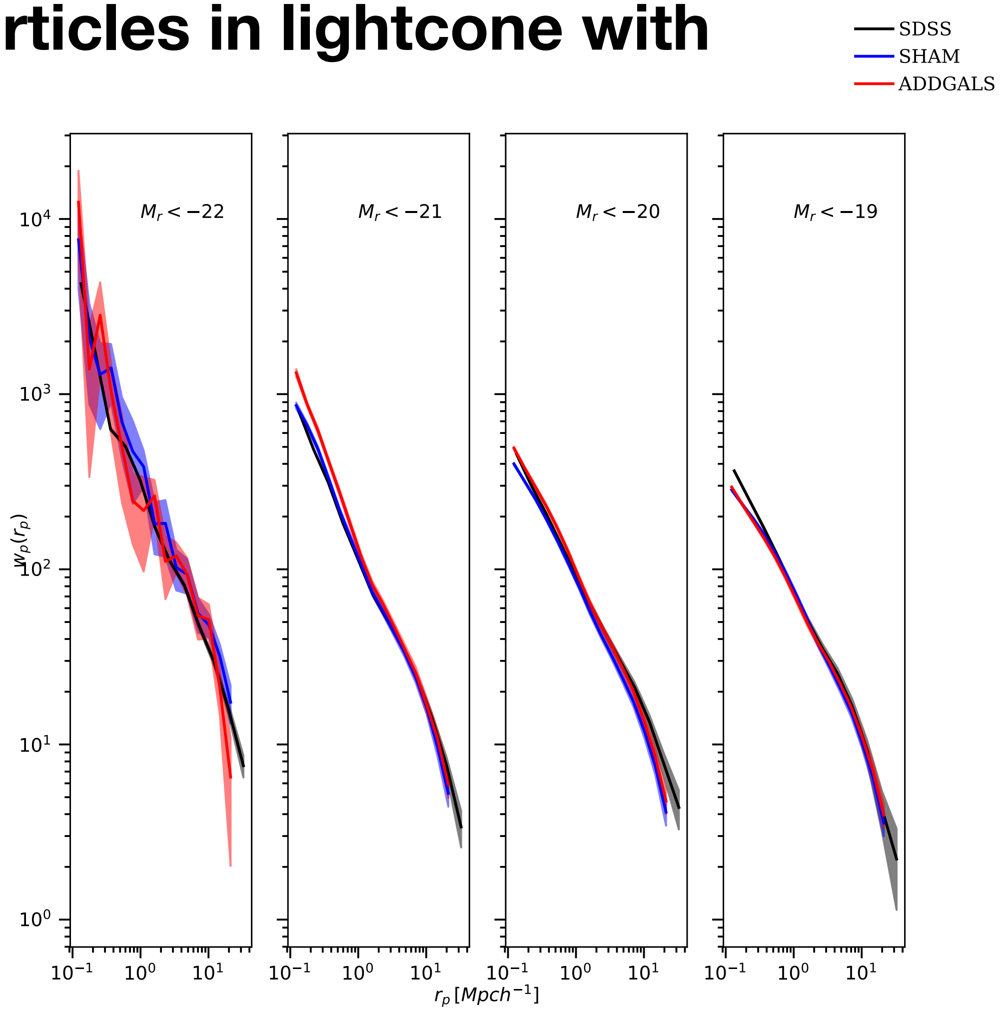
Simulation Pipeline

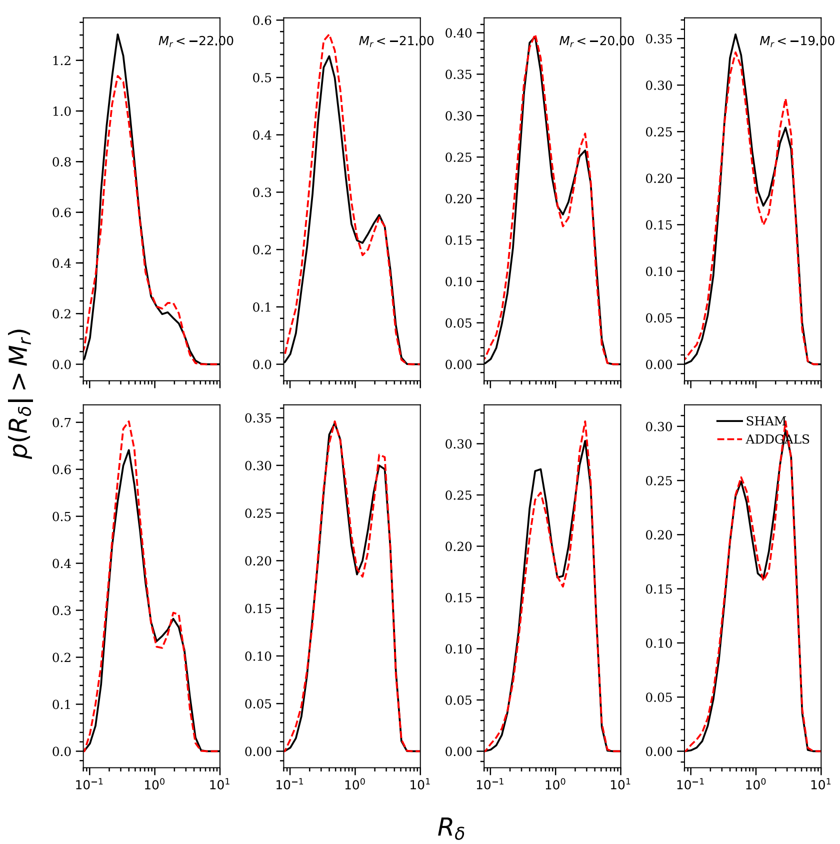


ADDGALS

Adding Density Determined Galaxies to Lightcone Simulations

- **Measure p(delta|L,z) from a subhalo abundance matching model in a high resolution simulation**
- **Integrate LF to obtain galaxies**
- **Assign galaxies to particles in lightcone with correct delta**

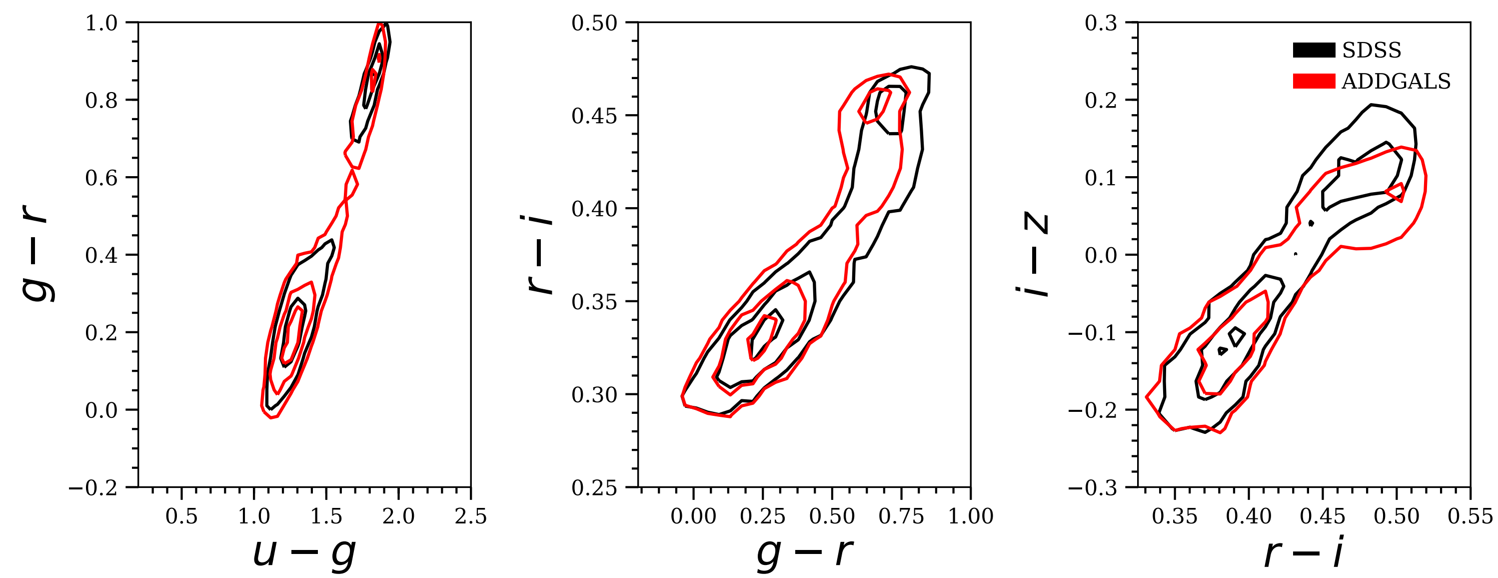


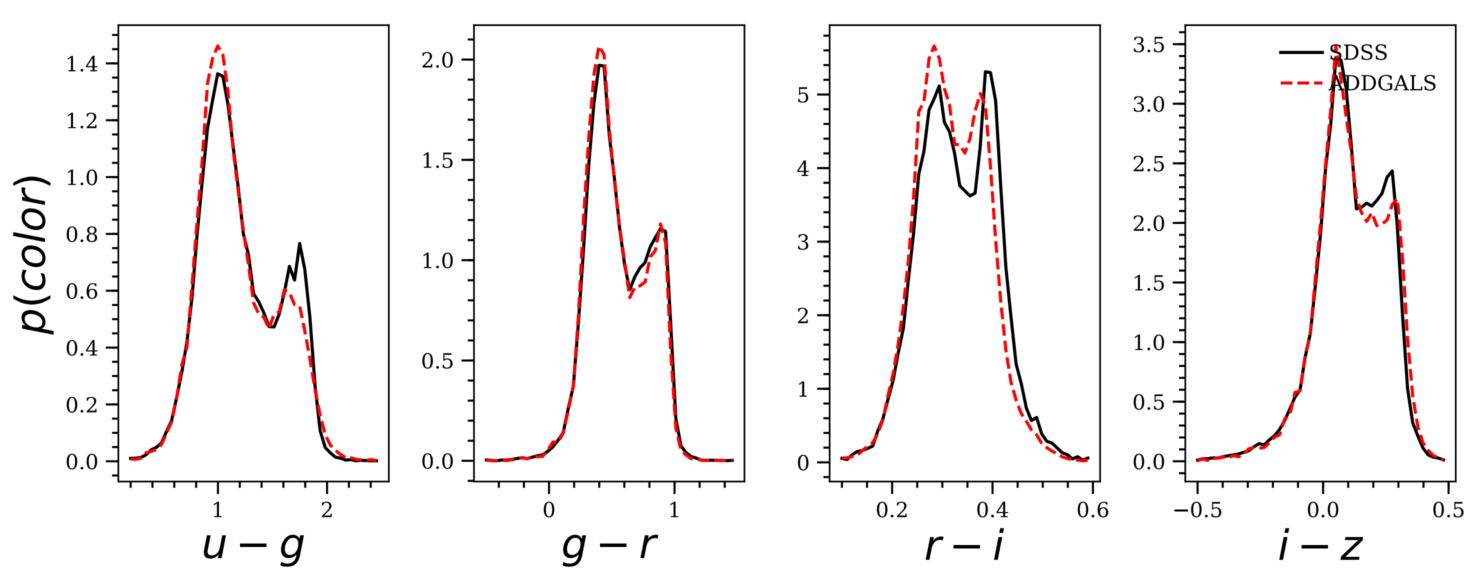


ADDSEDS

for each simulated galaxy **do**
- Measure projected distance to 5th nearest neighbor galaxy, Σ_5;
- Assign galaxy red label with probability f_Q;
- Find nearest neighbor SDSS galaxy in Σ_5-M_r space;
- Assign SDSS `kcorrect` coefficients to simulated galaxy;
- Redshift SED to z_{galaxy};
- Observe in desired bands;
- Apply noise;

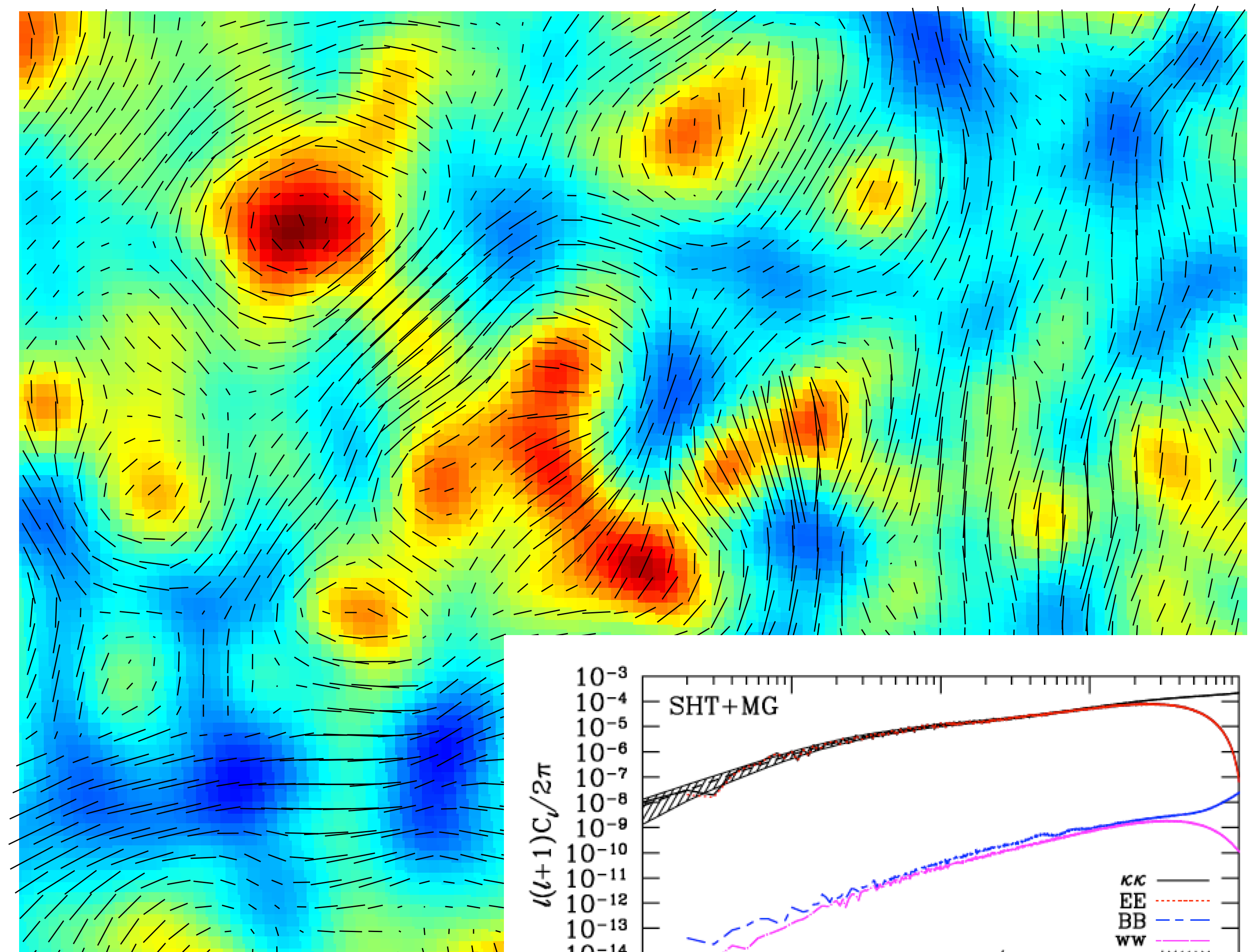
end for

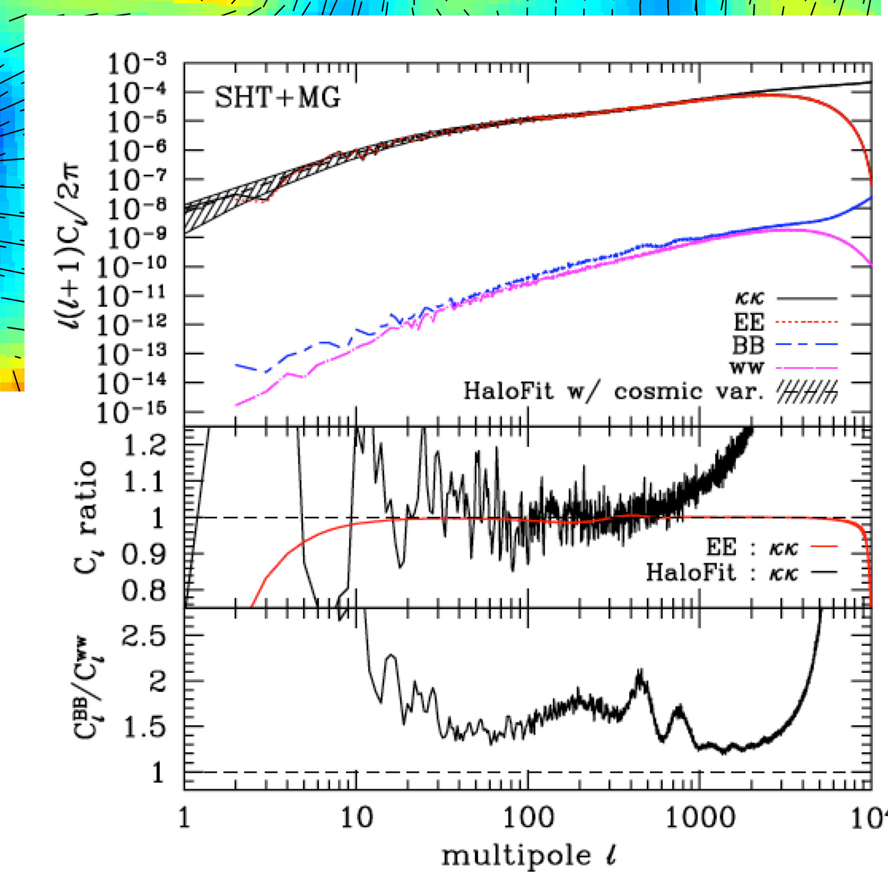




CALCLENS

- Ray-tracing on nside=8192 healpix grid
- Spherical harmonic transform Poisson solver
- Allows for calculation of weak lensing shear and magnification

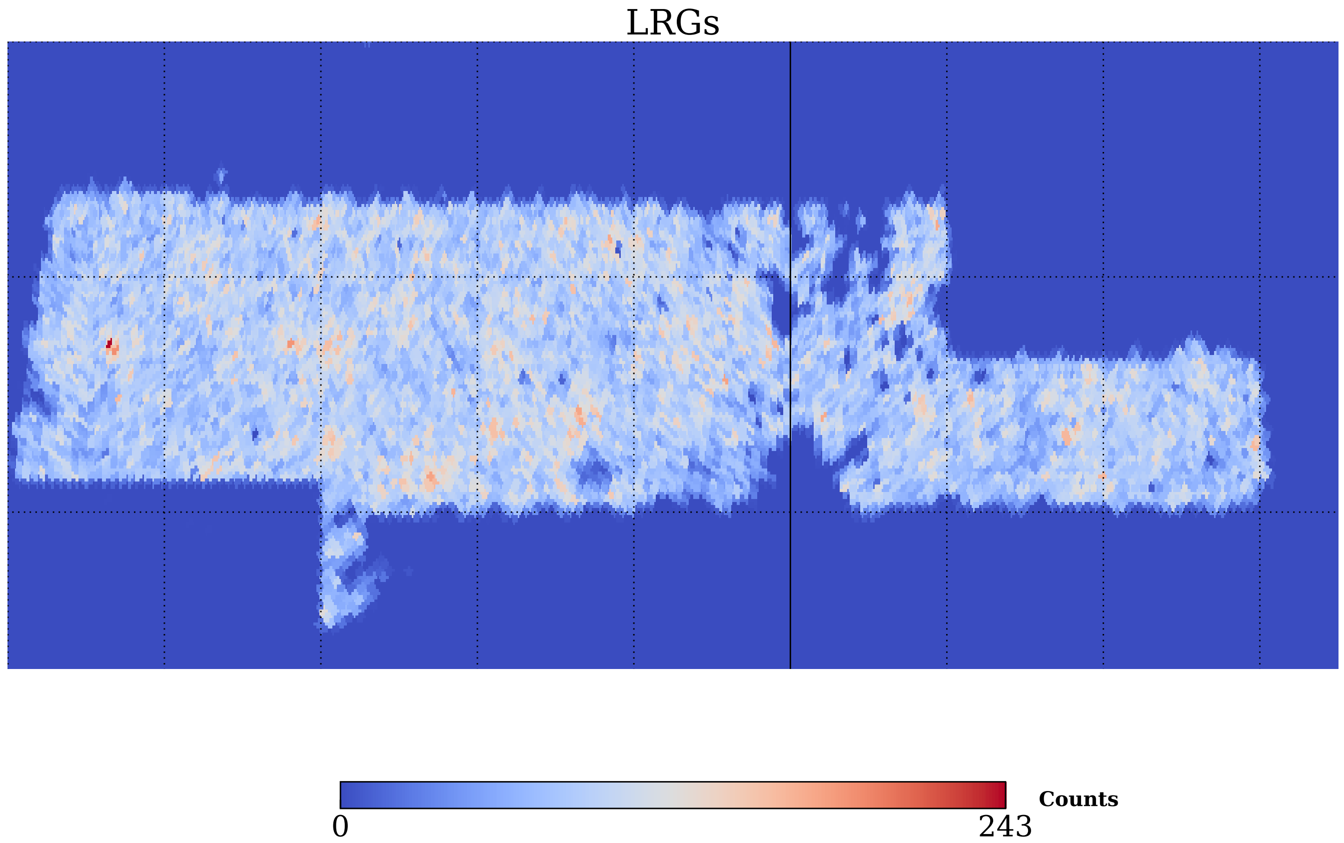


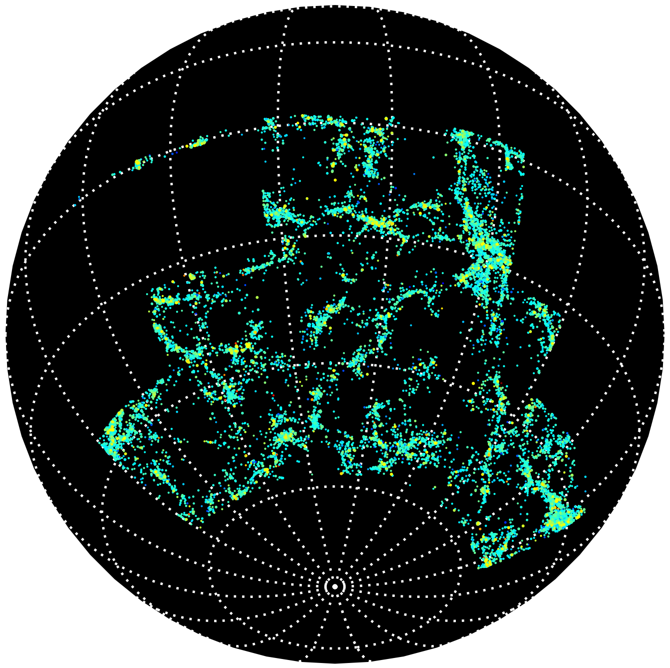


Becker 2013

Sample Selection

- **Source galaxy sample selection**
  - **Mimics Metacalibration sample**
- **Lens galaxy sample selection**
  - **Same redMaGiC photometric selection as used in data**





Back to 3x2pt

Recall the nuisances outlined before:

- **Redshift distributions (lens and source)**
- **Shape measurement**
- **Galaxy bias**
- **Galaxy intrinsic alignments**
- **Modeling the nonlinear matter power spectrum**
- **Covariance matrix**

Back to 3x2pt

Recall the nuisances outlined before:

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Redshift Uncertainty

- **Don't fully trust photo-z codes (BPZ, DNF)**
- **Philosophy:**
  - **Parameterize uncertainty**
  - **Quantify!**

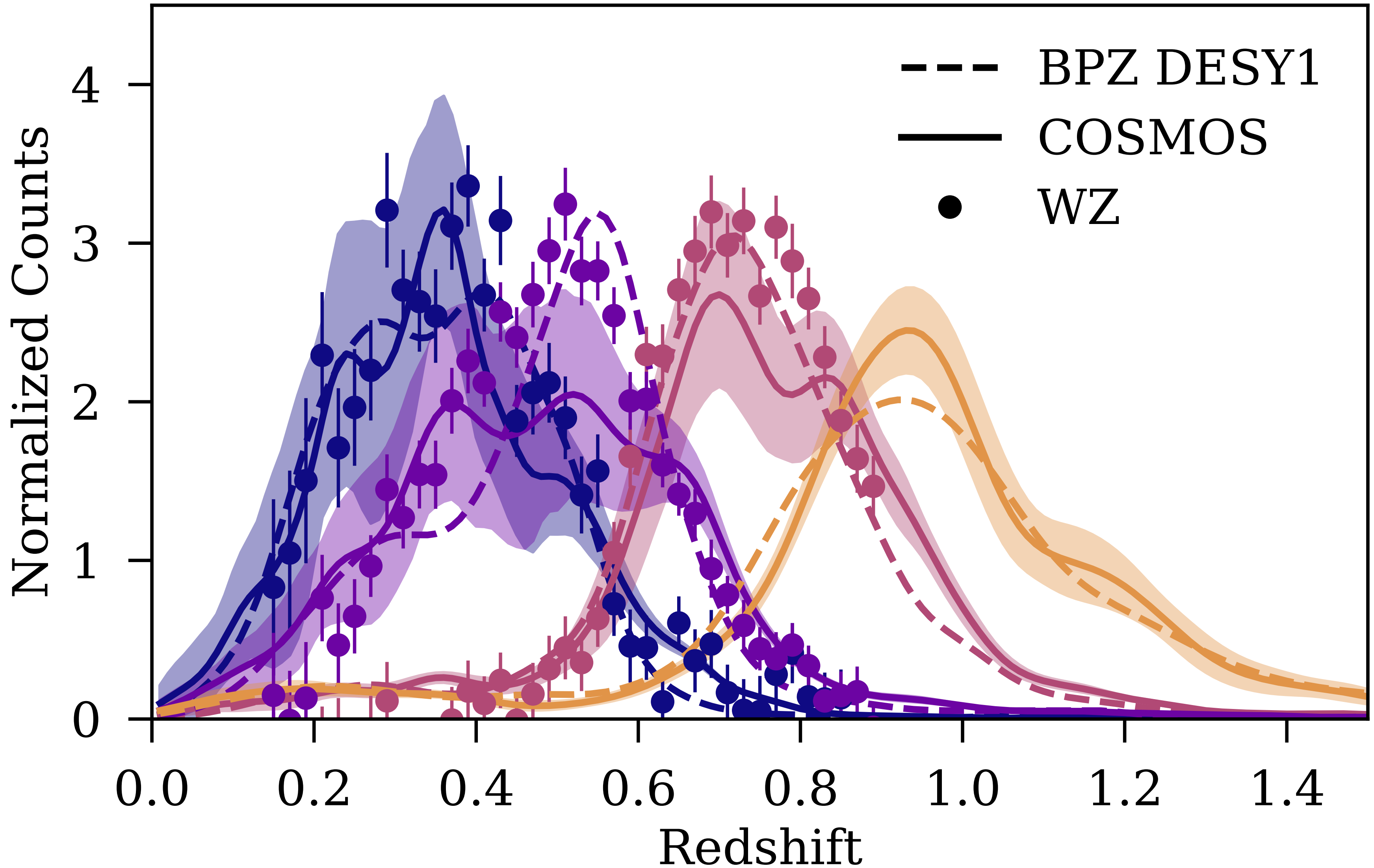
$$n^i(z) = n_i^{\mathrm{PZ}}(z - \Delta z^i)$$

Direct Photo-z Validation

Estimating \Delta(z) from reliable photometric redshifts:

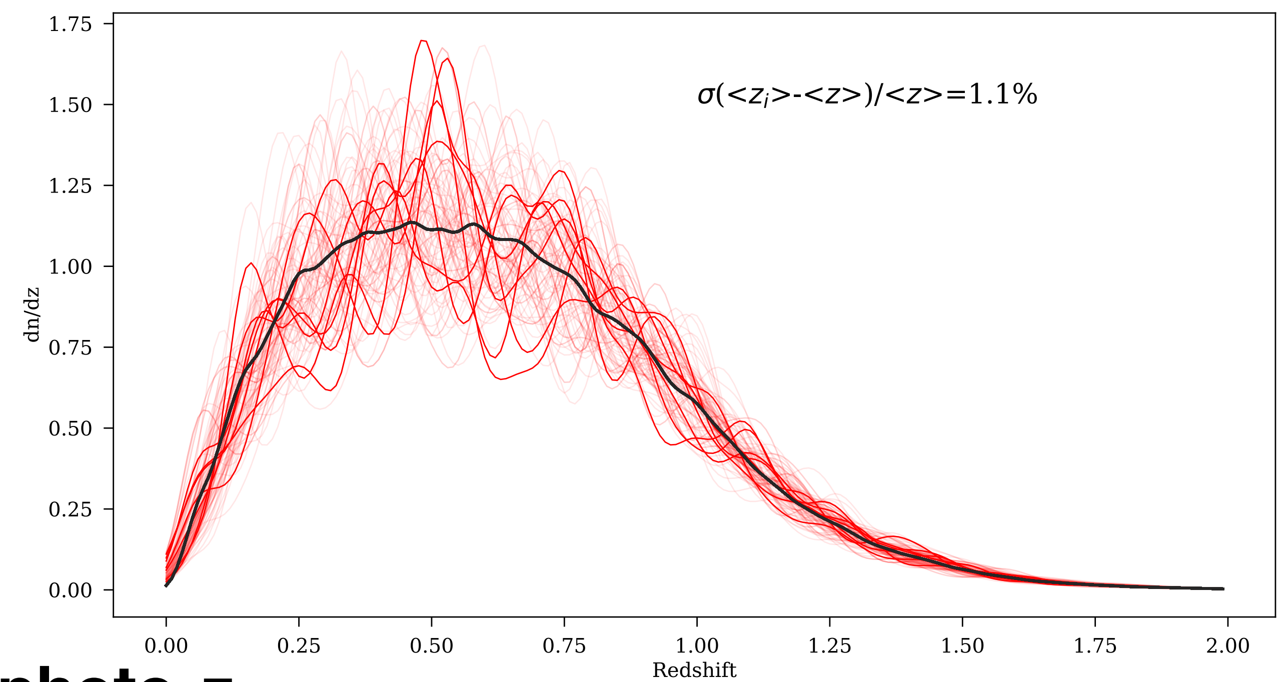
- **Match wide field galaxies to COSMOS galaxies**
- **Estimate \Delta(z) as z_30band - z_bpz**

PRELIMINARY



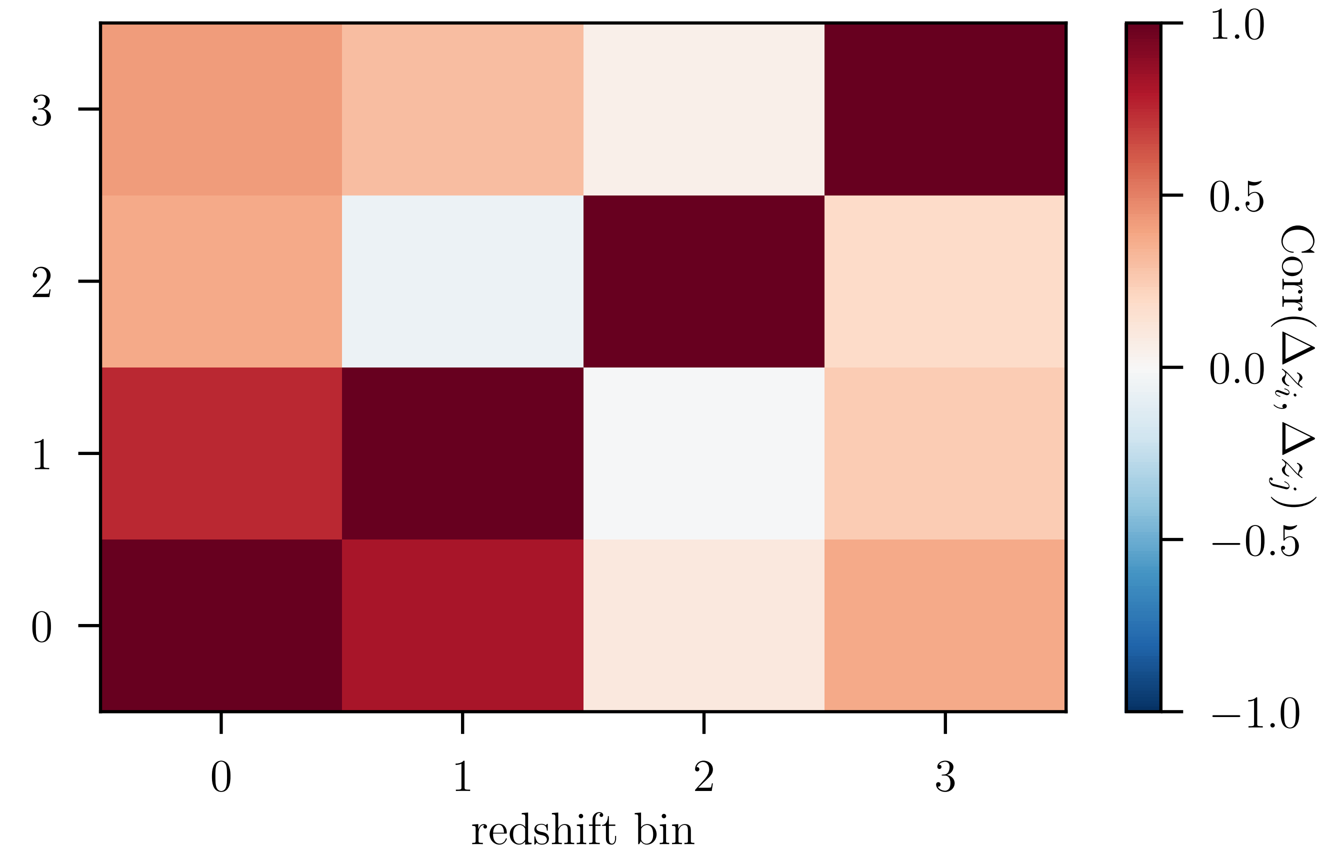
Hoyle et al. in prep
Davis et al. in prep
Gatti et al. in prep
Cawthon et al. in prep

Direct Photo-z Validation



Two sources of error:

- **30-band photo-z not exactly true**
  - **Sample from p(z) assuming unbiased photo-z**
- **Sample variance in COSMOS**
  - **Can address this with sims!**

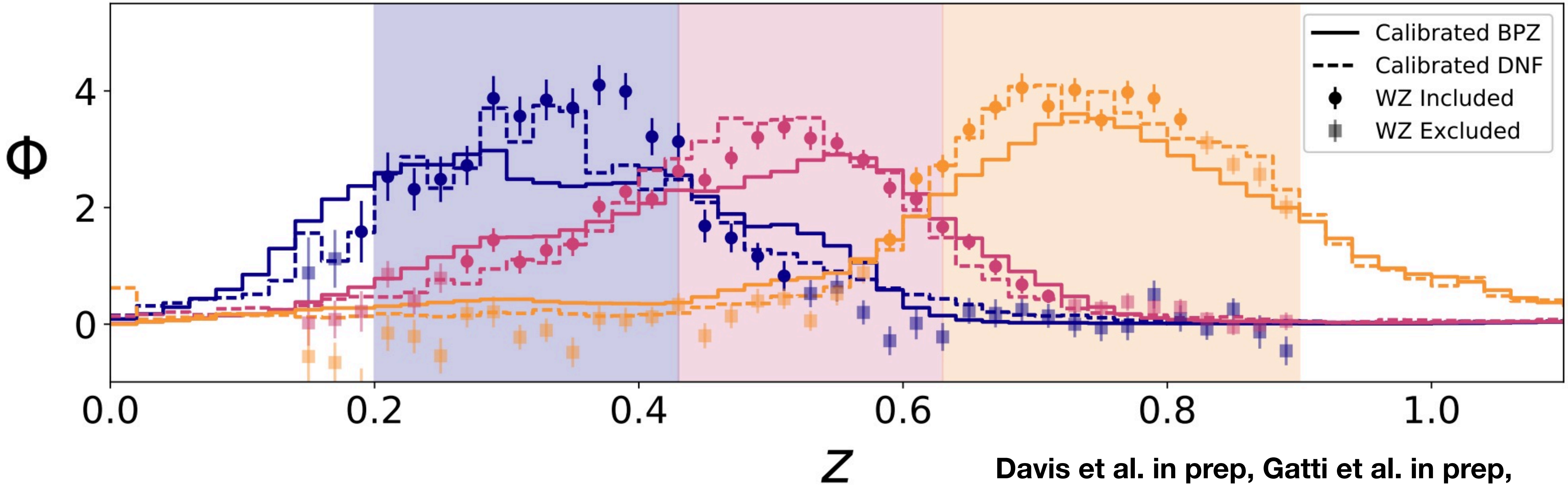


PRELIMINARY

WZ Validation

$$\overline{w}_{ur}(z) \propto \frac{\mathrm{d}N_u}{\mathrm{d}z}(z)\bar{b}_u(z)\bar{b}_r(z)\overline{w}_{\mathrm{DM}}(z)$$

PRELIMINARY



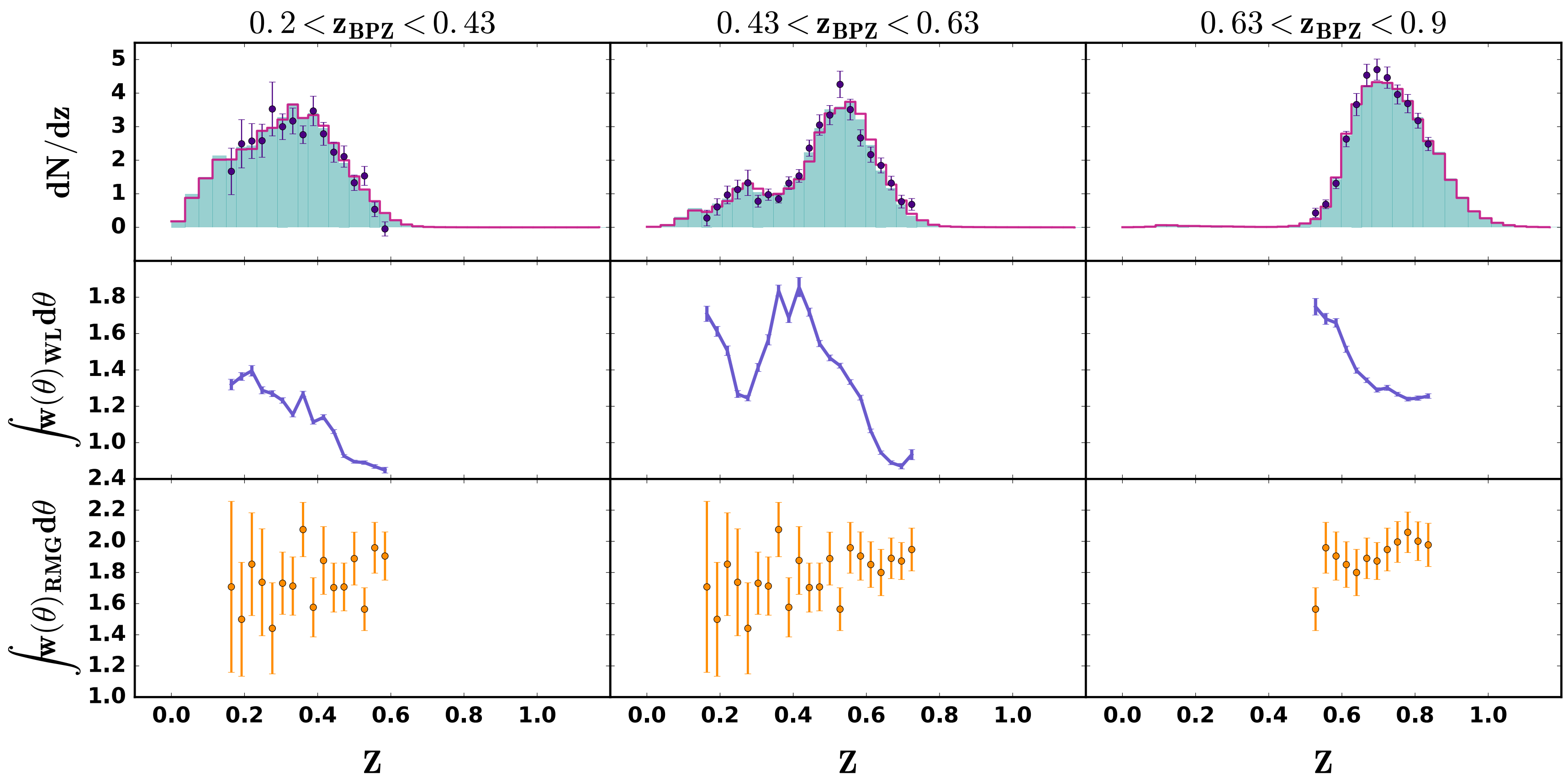
Davis et al. in prep, Gatti et al. in prep, Cawthon et al. in prep

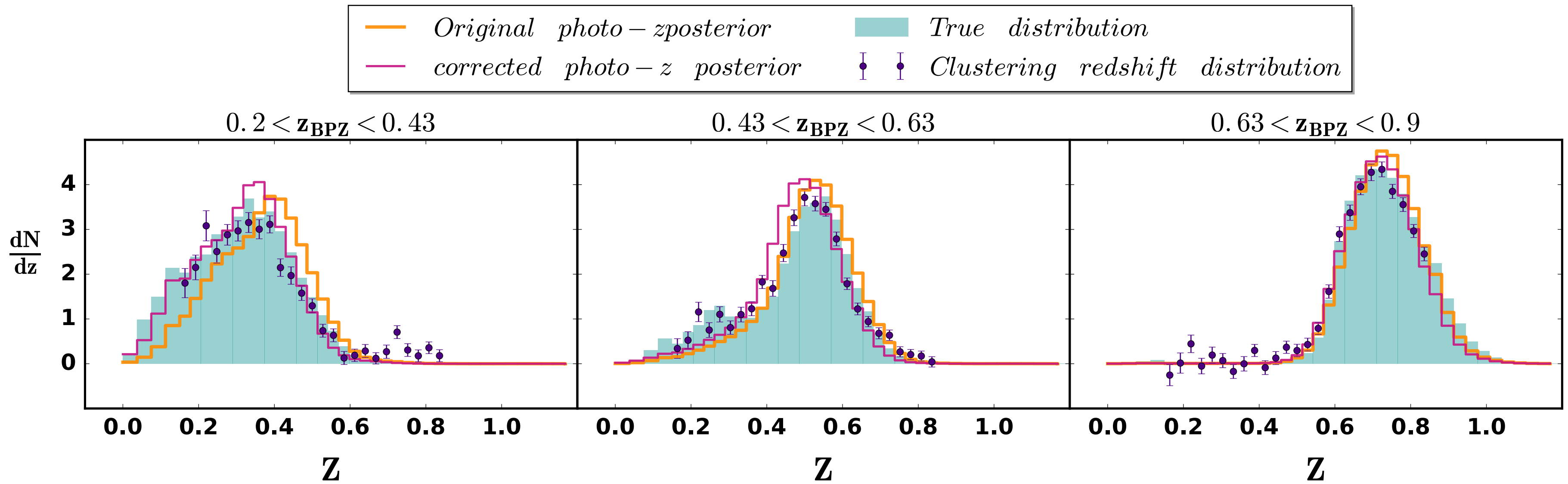
WZ Validation

Main uncertainty in method is bias evolution.

- Have perfect knowledge in simulation, can correct
- Also use to quantify systematic uncertainty

Gatti et al. in prep

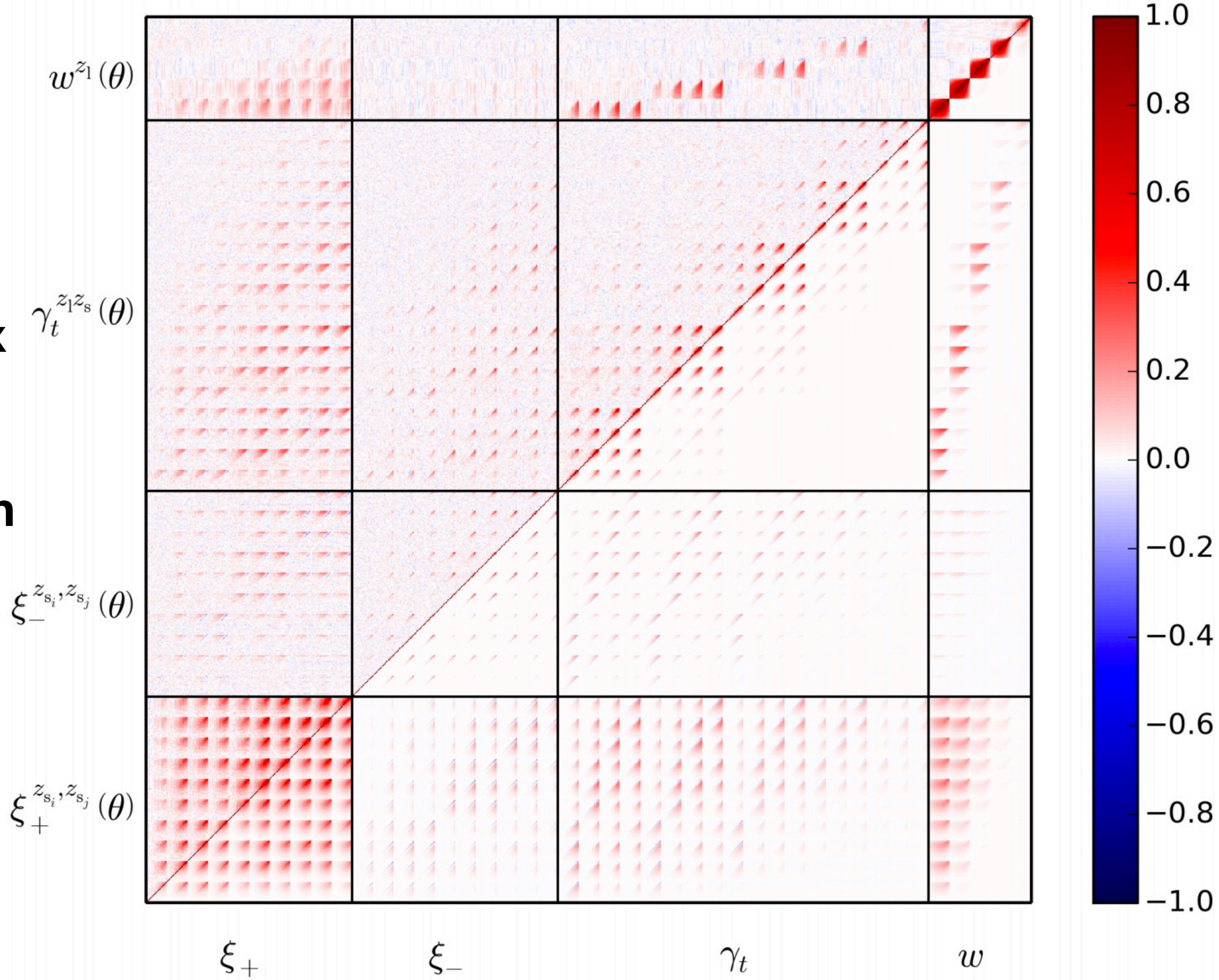




PRELIMINARY

Covariance Matrix

- Not enough area to estimate covariance matrix from data itself
- Not enough simulations to estimate it with low enough noise
- Instead we turn to the halo model!

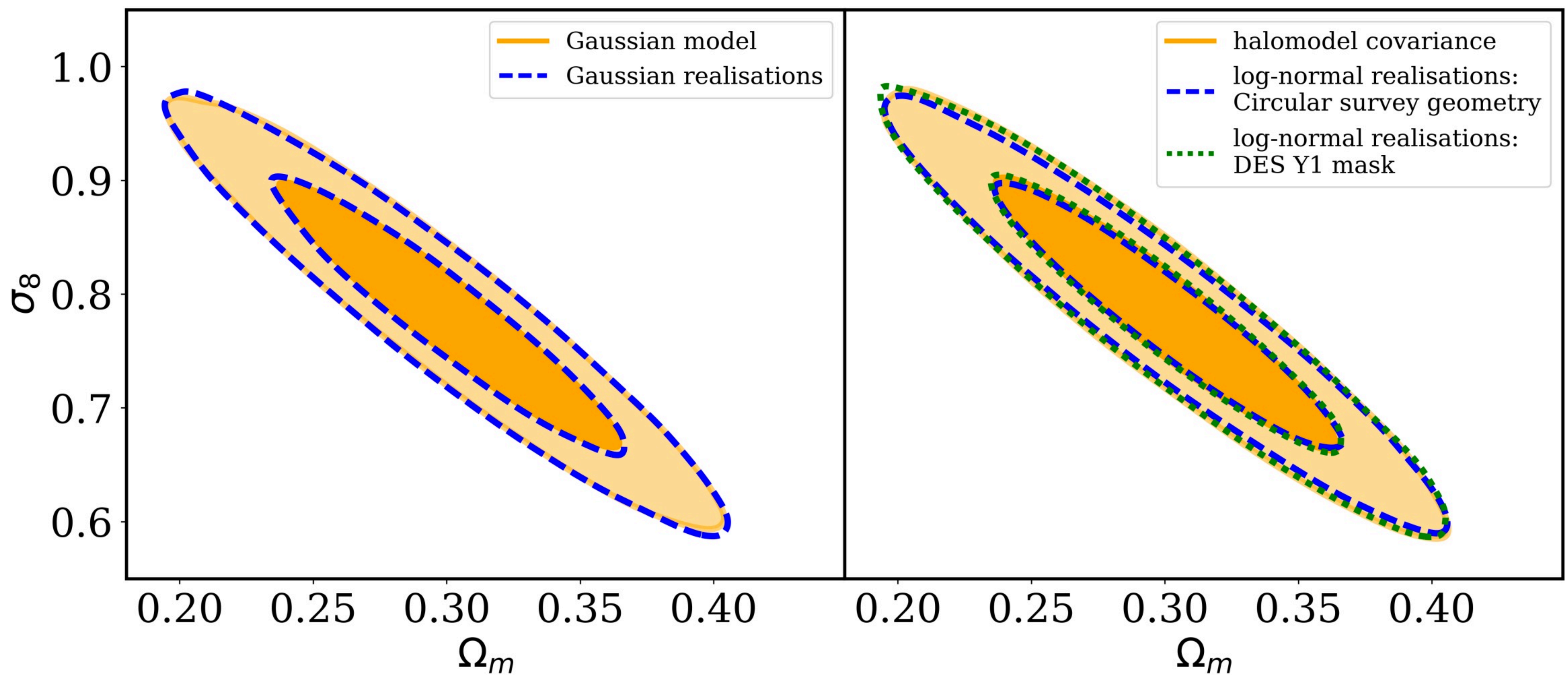


Krause et al. 2017

Covariance Matrix

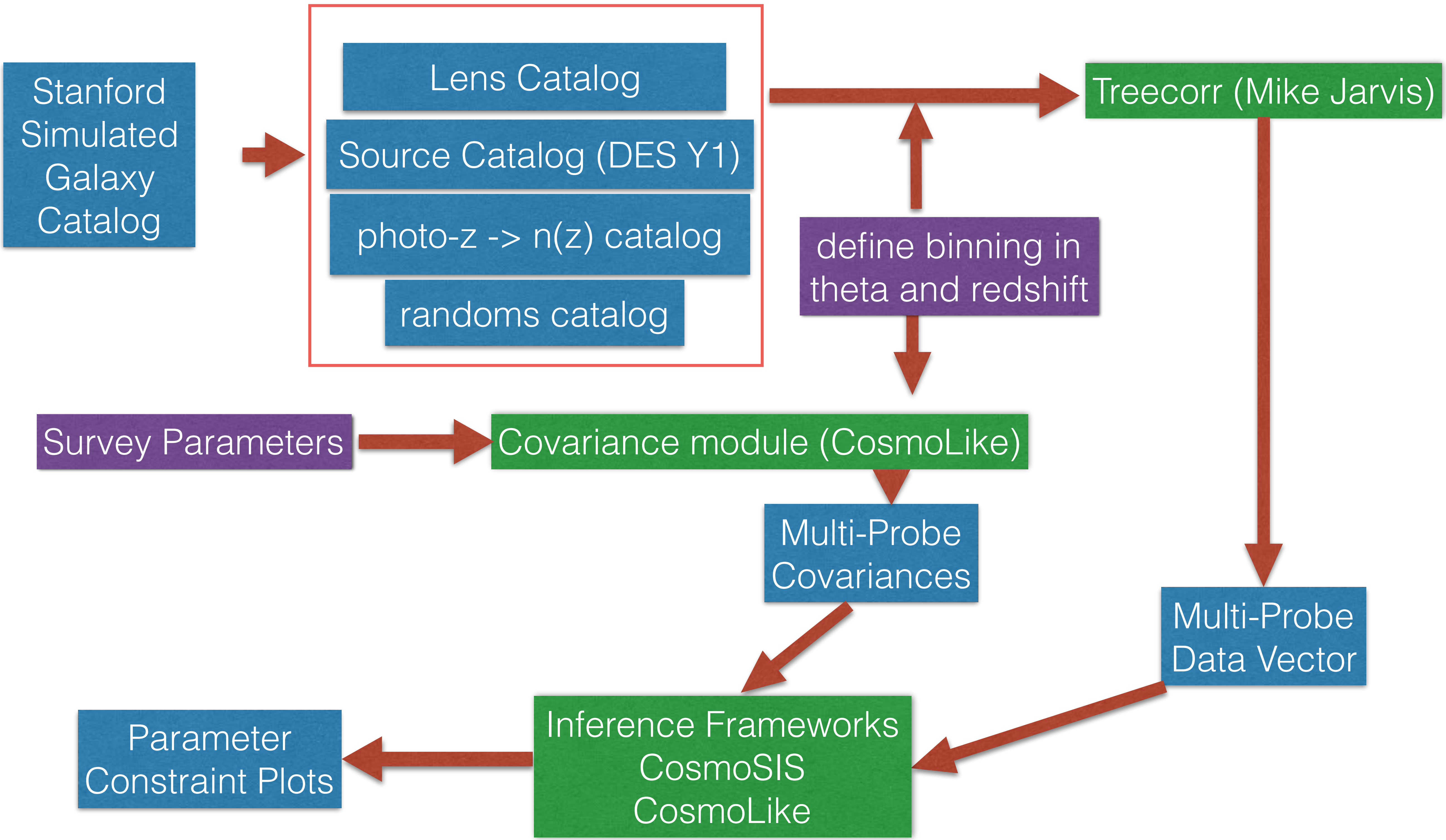
Validation using simulations

- **Gaussian field realizations for testing of gaussian portion of covariance model**
- **Log-normal field (FLASK) realizations for testing of full halo model**



Krause et al. 2017

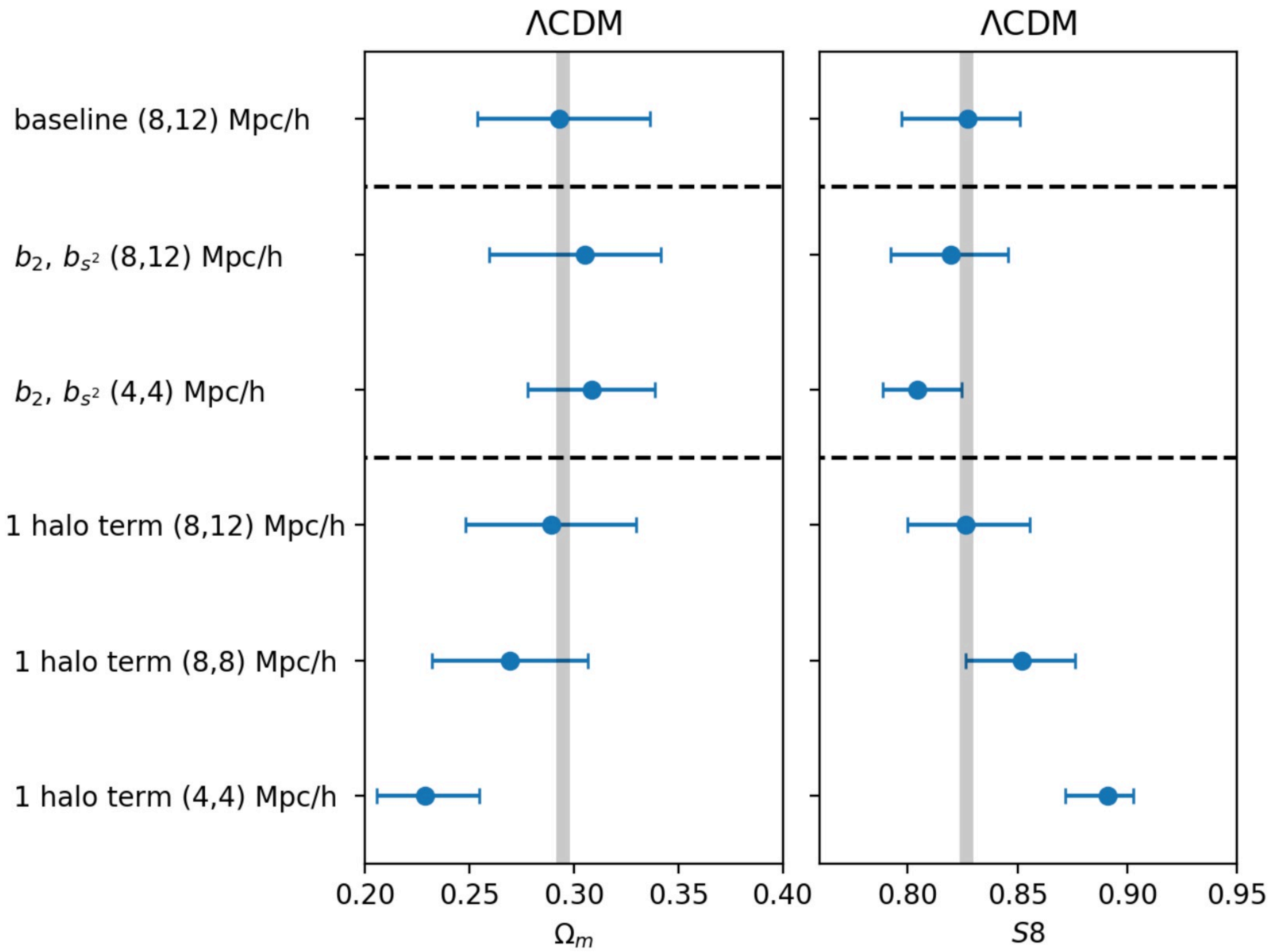
Putting it all together



with Eifler, Krause, MacCrann, Troxel, Zuntz (DES)

Bias Modeling

Scale cuts chosen so as to remove sensitivity to non-linear biasing.

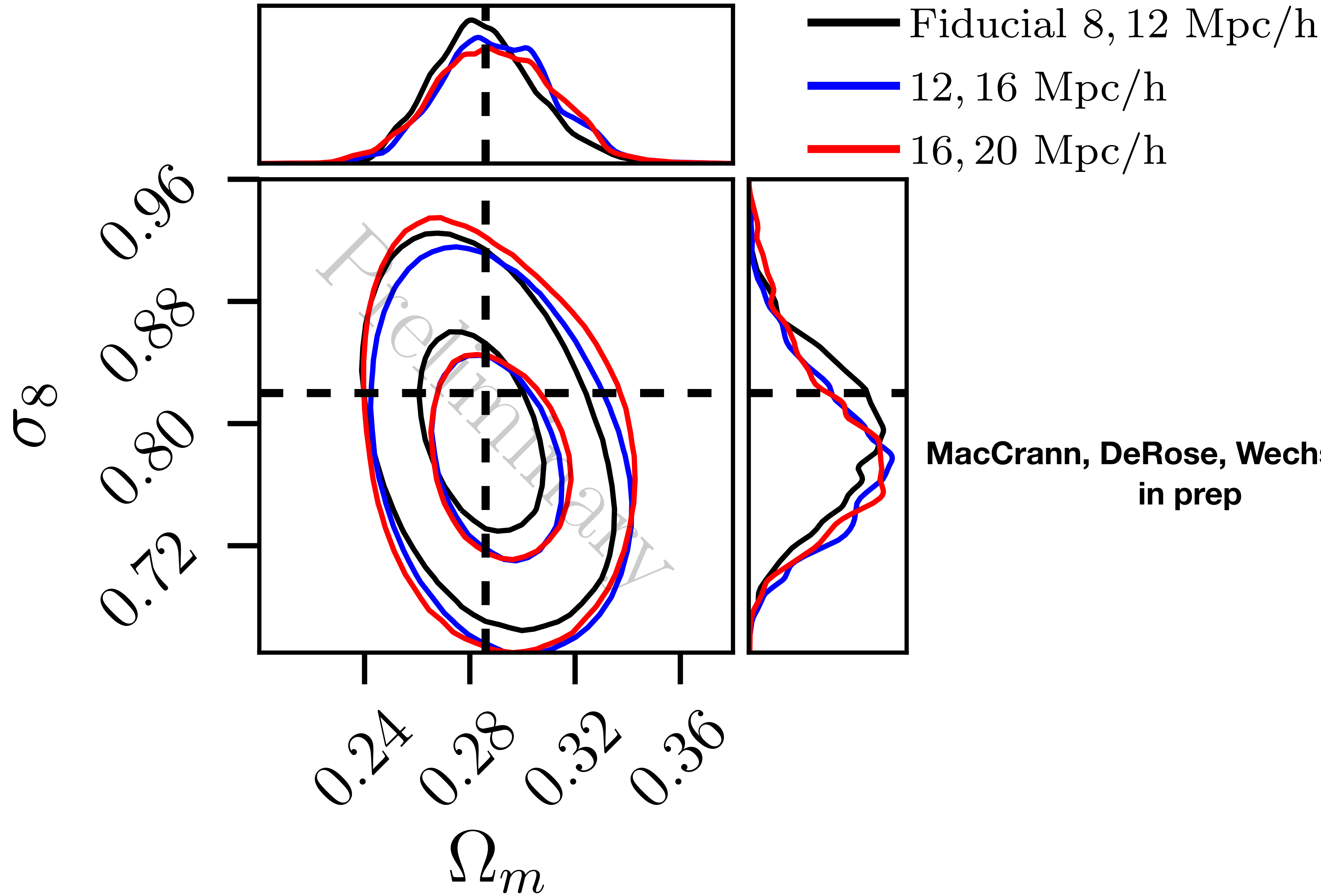


Krause et al. 2017

Bias Modeling

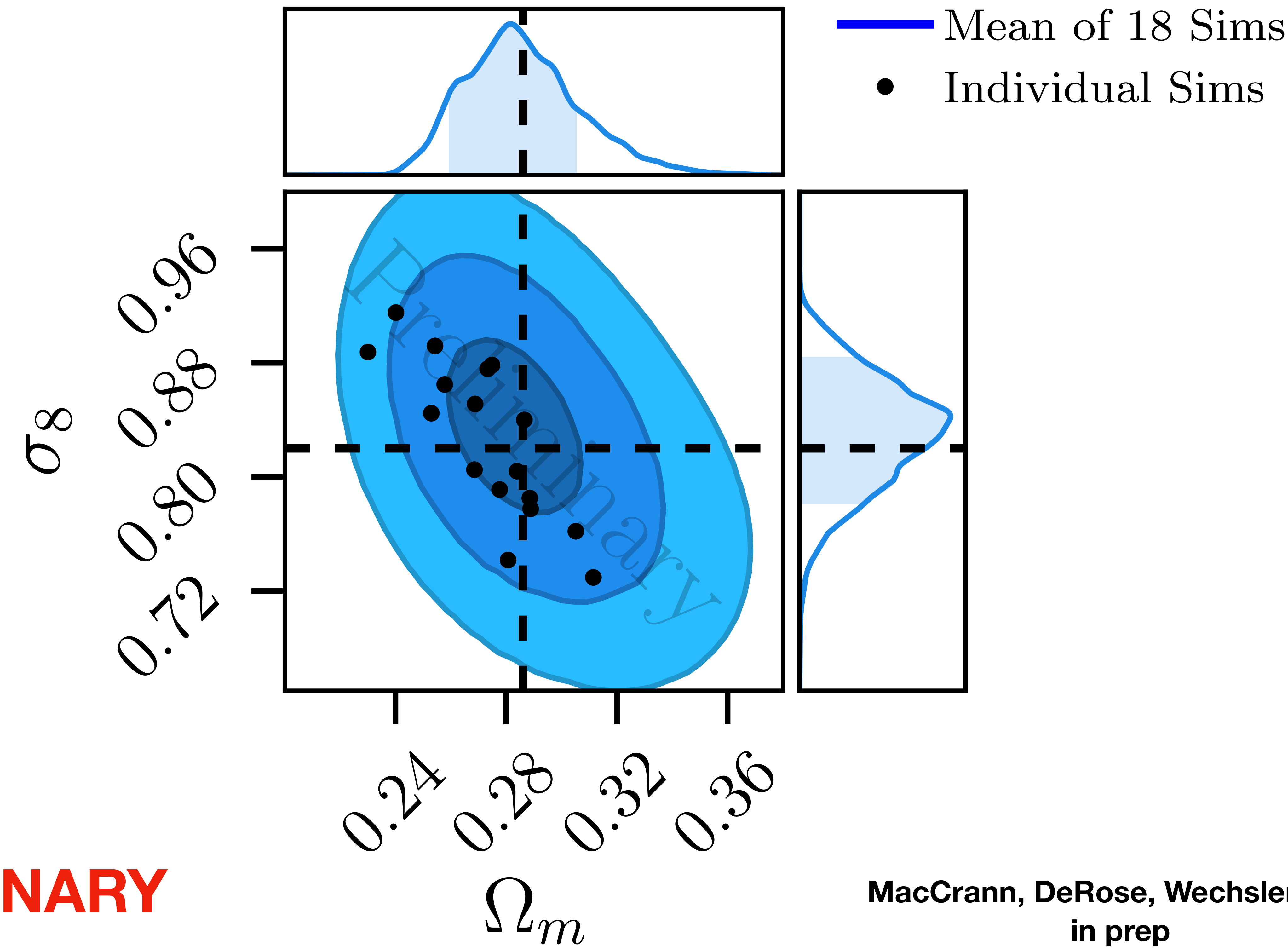
Tests on simulations corroborate simulated likelihood analyses

PRELIMINARY



MacCrann, DeRose, Wechsler et al. in prep

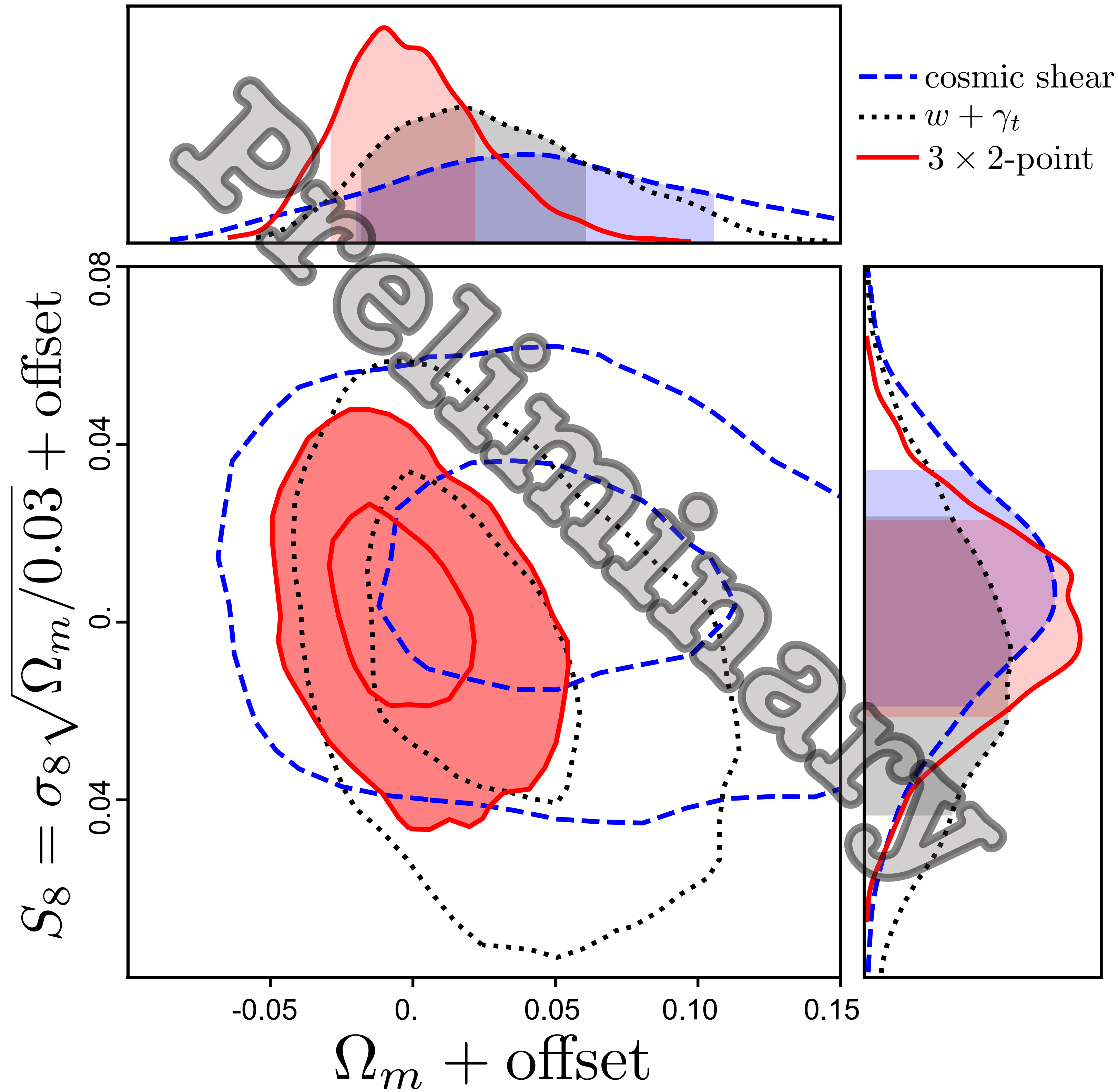
Putting it all together



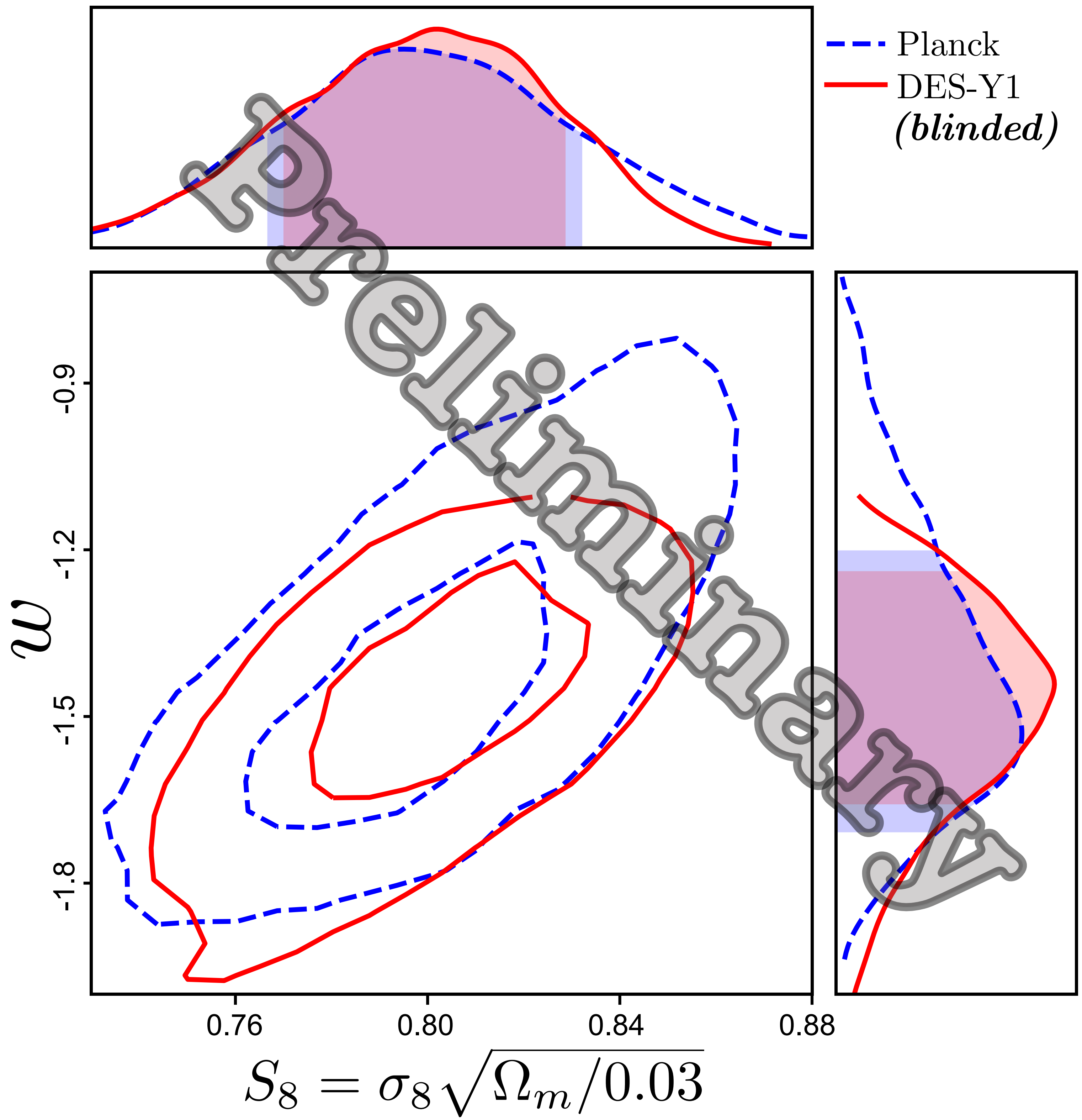
PRELIMINARY

MacCrann, DeRose, Wechsler et al. in prep

And the (Blinded) Real Data!



As Constraining as Planck!!



Future Prospects and Areas of Research

Recall the nuisances I crossed off before:

- **Redshift distributions (lens and source)**
- **~~Shape measurement~~**
- **Galaxy bias**
- **~~Galaxy intrinsic alignments~~**
- **~~Matter power spectrum~~**
- **Covariance matrix**

Conclusions

- **Combined probe analyses have the promise to deliver extremely tight constraints on cosmology from galaxy surveys**
- **The systematics associated with these analyses are complicated but tractable**
- **One of the best ways we have for controlling these systematics is through the use of state of the art simulations!**