# 3×2-pt mock challenge paper

Currently in working group circulation period – please see e-mail/Slack message with link to the paper and section-by-section comments document

THE DESI-LENSING MOCK CHALLENGE:
LARGE-SCALE COSMOLOGICAL ANALYSIS OF 3 × 2-PT STATISTICS

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ABSTRACT

The current generation of large galaxy surveys will test the cosmological model by combining multiple types of observational probes. Realising the statistical promise of these new datasets requires rigorous attention to all aspects of analysis including cosmological measurements, modelling, covariance and parameter likelihood. In this paper we present the results of an end-to-end simulation study designed to test the analysis pipeline for the combination of the Dark Energy Spectroscopic Instrument (DESI) Year 1 galaxy redshift dataset and weak gravitational lensing information from the Kilo-Degree Survey, Dark Energy Survey and Hyper-Suprime-Cam Survey. Our analysis employs the 3 × 2-pt correlation functions including cosmic shear $\xi_\pm(\theta)$ and galaxy-galaxy lensing $\gamma_t(\theta)$, together with the projected correlation function of the spectroscopic DESI lenses, $w_p(R)$. We build realistic simulations of these datasets including galaxy halo occupation distributions, photometric redshift errors, weights, multiplicative shear calibration biases and magnification. We calculate the analytical covariance of these correlation functions including the Gaussian, noise and super-sample contributions, and show that our covariance determination agrees with estimates based on the ensemble of simulations. We use a Bayesian inference platform to demonstrate that we can recover the fiducial cosmological parameters of the simulation within the statistical error margin of the experiment, investigating the sensitivity to scale cuts. This study is the first in a sequence of papers in which we present and validate the large-scale 3 × 2-pt cosmological analysis of DESI-Y1.

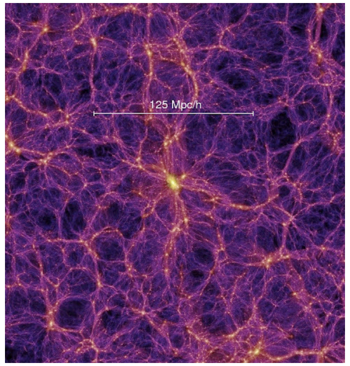
*The paper presents:*

*New statistic used in this context*

- Construction of Buzzard DESI-Lensing mocks and measurement of 3×2-pt correlations $(\xi_\pm, \gamma_t, w_p)$
- Analytical covariance matrix for these correlations, and tests using simulations and code comparison
- Model parameter fits using CosmoMC, and comparison with fiducial expectations

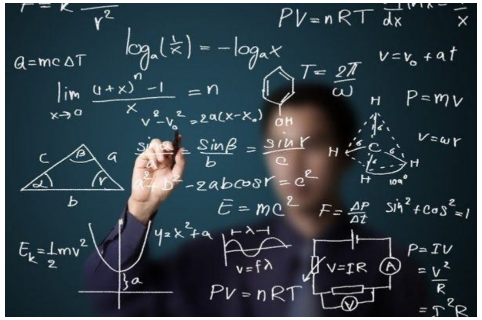
# Validation of 3×2-pt methodology

Simulation-based tests




Test covariance or parameter recovery with realistic complexity, but may not fully capture all astrophysical or observational effects

“Analytical” tests



Propagate model variations to changes in fitted parameters; choosing scale cuts to minimize the impact of modeling assumptions

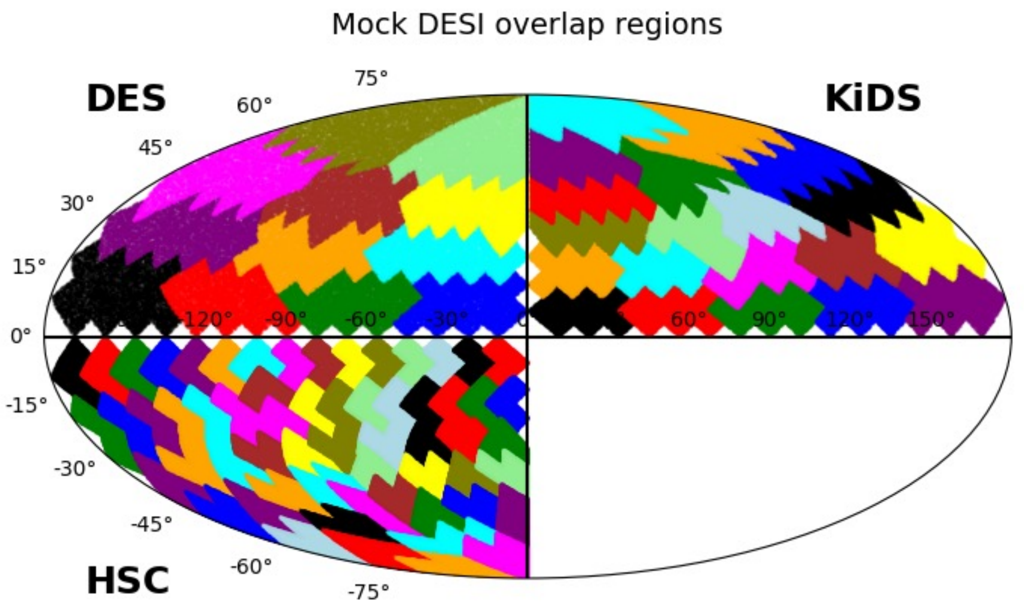
Tests on the data itself

Consider analysis variations in fits to real data vectors, but severely limited by blinding data to avoid confirmation bias

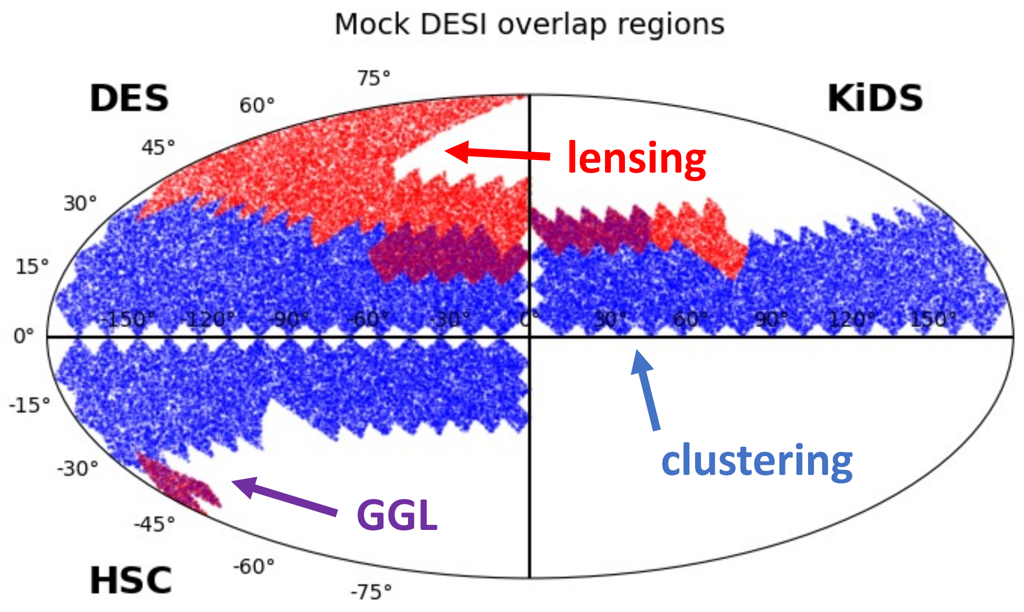
# Buzzard simulations

*We've constructed DESI + (KiDS-1000, DES-Y3, HSC-Y1) mocks from the Buzzard simulations*

- Lensing catalogues match redshift distributions, shape noise, weights, shear calibration
- DESI catalogues match clustering and number density of EDR samples
- We use 5 lens samples: BGS (0.1-0.2, 0.2-0.3, 0.3-0.4) and LRG (0.4-0.6, 0.6-0.8)
- We divide the catalogues into regions for covariance testing and cosmology testing

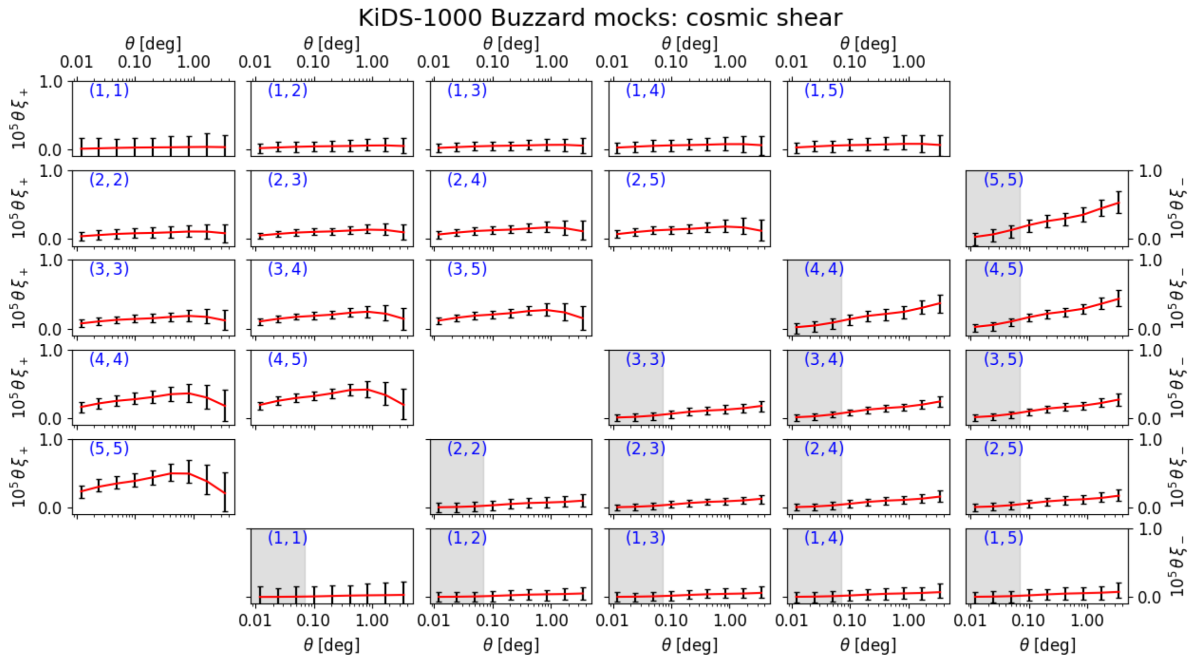


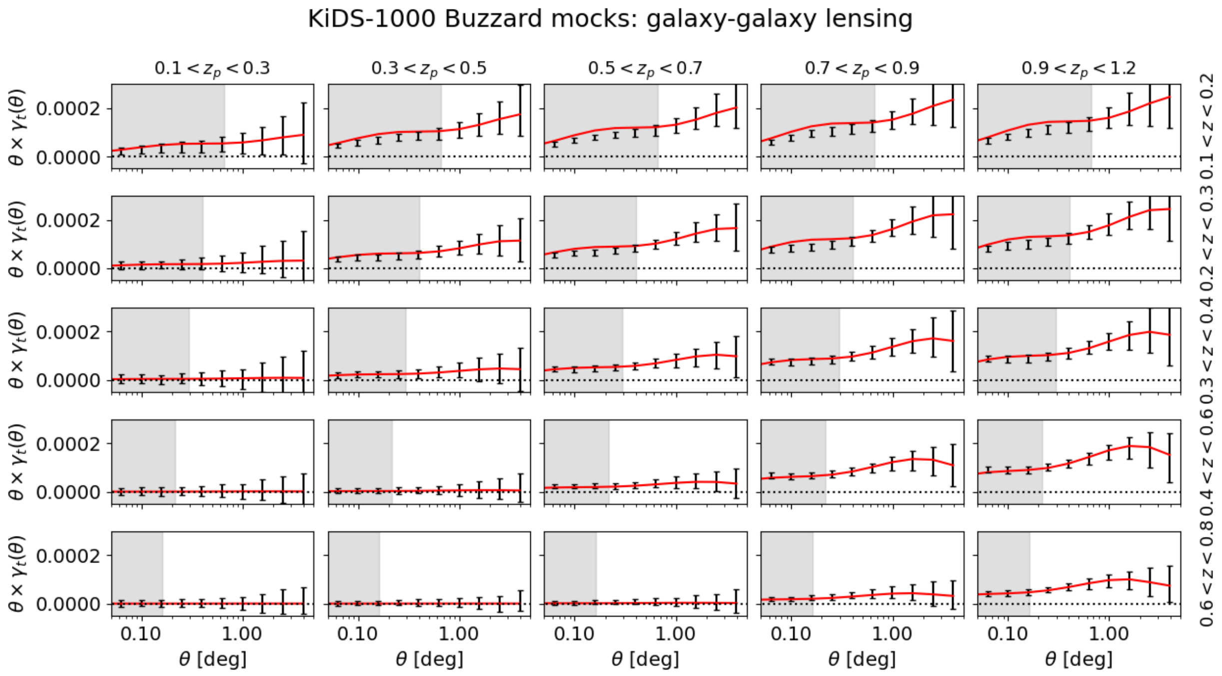

*These regions, with size approximating the overlaps with DESI, are used for covariance testing*

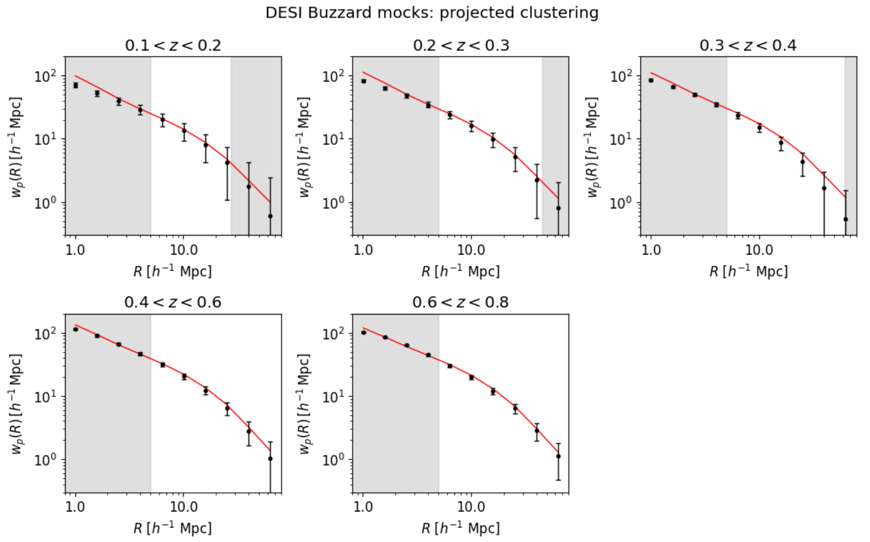



*The regions are combined into representative DESI, lensing and overlapping areas for cosmology testing*

# Correlation function measurements




- We measure **cosmic shear** source correlations $\xi_\pm(\theta)$ using treecorr with the same binning as used by each lensing collaboration
- We measure **average tangential shear** source-lens correlations $\gamma_t(\theta)$ using treecorr with our fiducial binning in the range $\theta < 5°$
- We measure the lens **projected correlation function** $w_p(R)$ using corrfunc in the range $R < 80\ h^{-1}$ Mpc with $\Pi_{\max} = 100\ h^{-1}$ Mpc

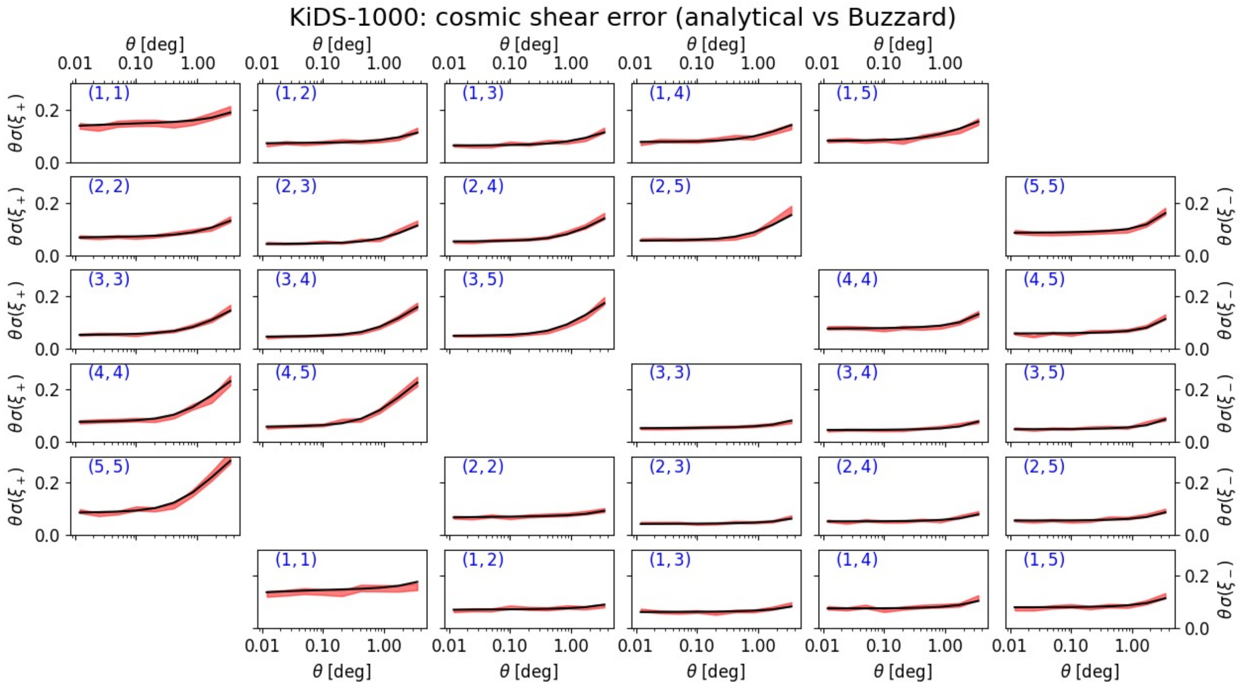
# Analytical covariance

*We determine an analytical covariance for these correlations:*

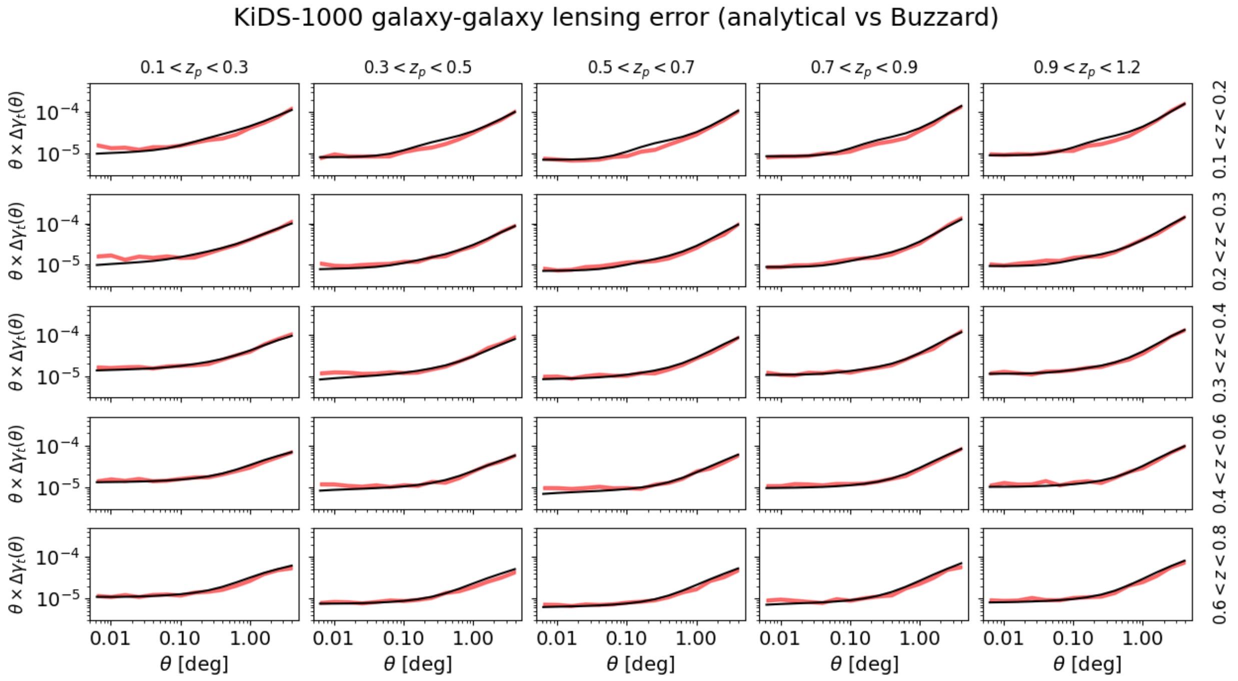
- Including sample variance, noise, mixed and super-sample contributions
- Excluding non-Gaussian contribution (currently negligible on the scales we're using)
- Note: cross-covariances using $w_p(R)$ are new to this project

We test the analytical covariance using the Buzzard mock regions → **5% error-in-error**

*Analytical vs mock covariance tests for $\xi_{\pm}(\theta)$*

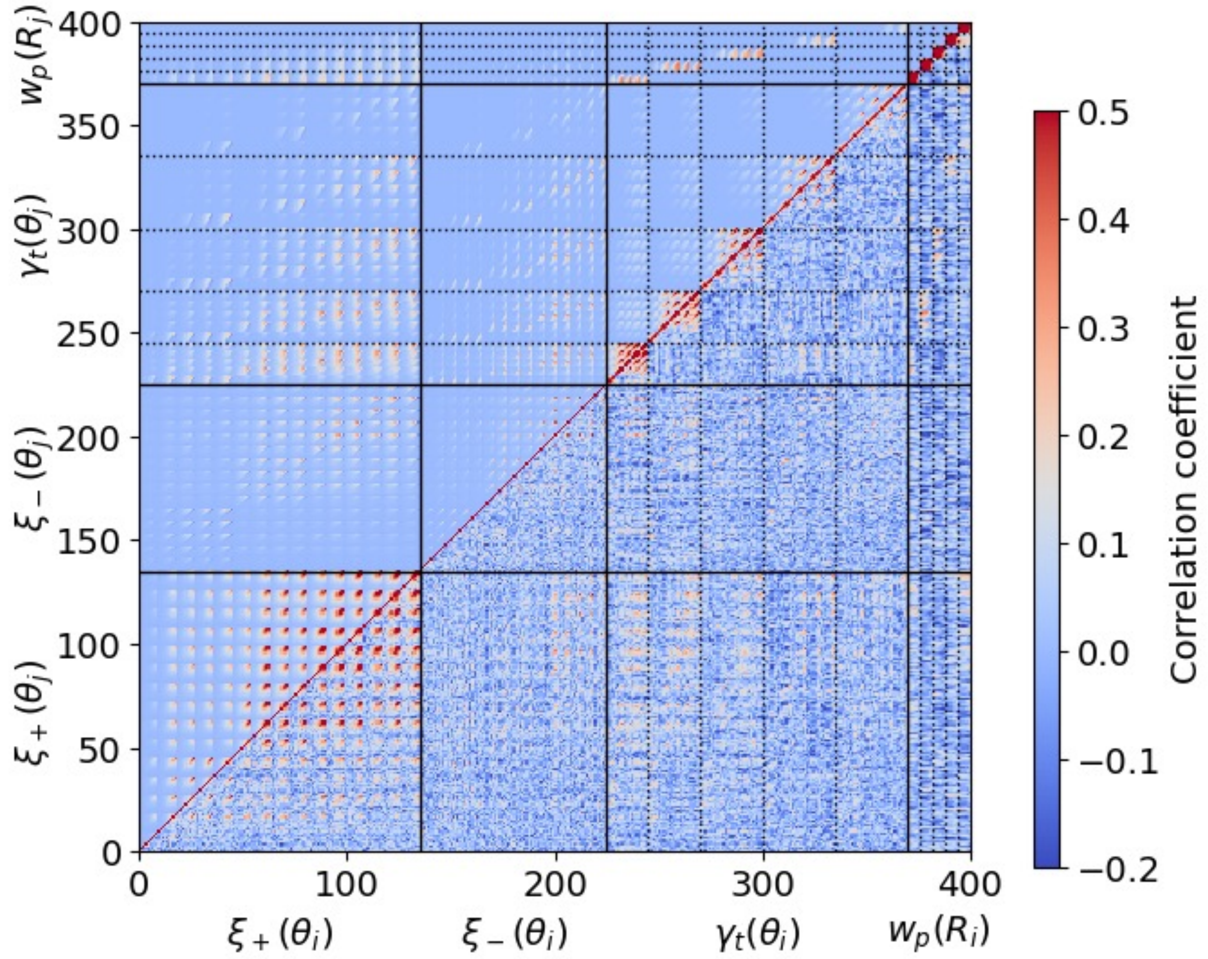



*Analytical vs mock covariance tests for $\gamma_t(\theta)$*

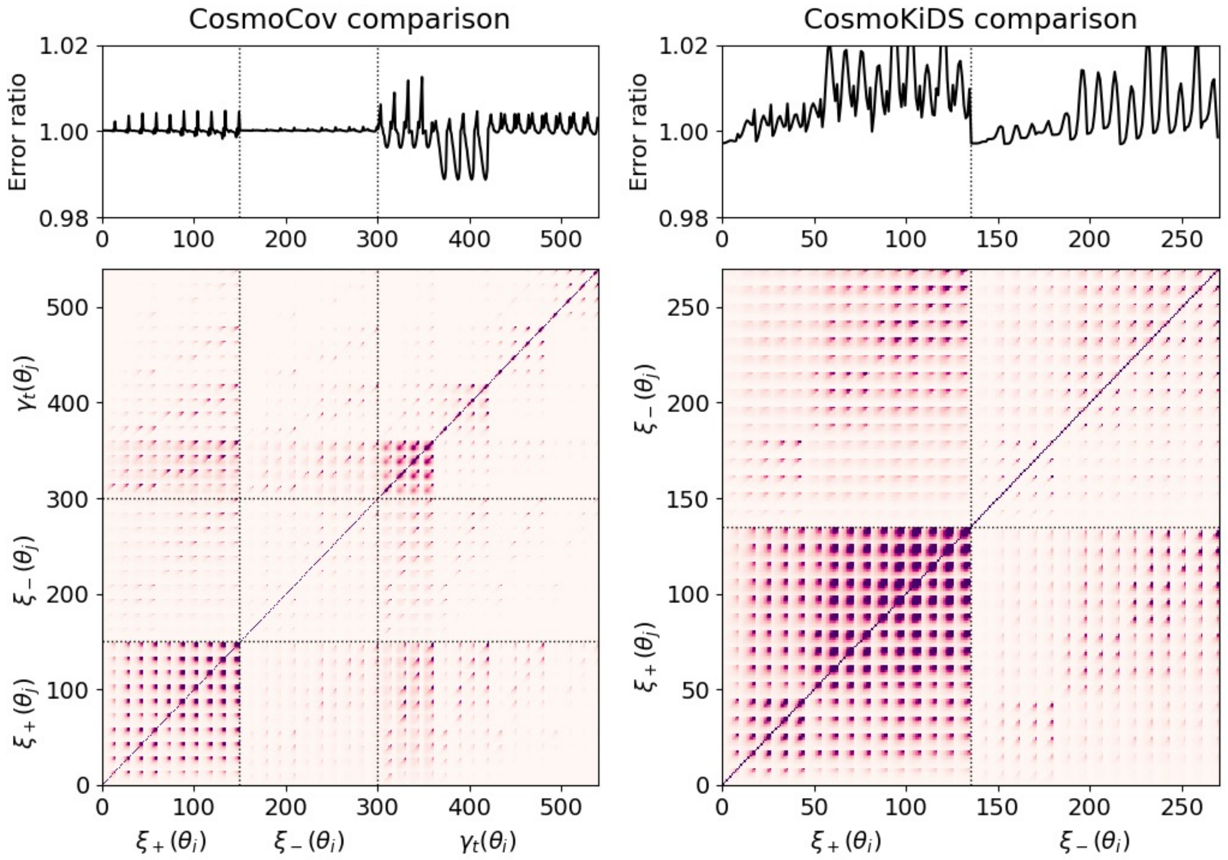


# Analytical covariance

Not enough mock realizations for accurate off-diagonal tests, but “qualitative comparison” looks reasonable




We also compared the covariance with the DES and KiDS codes – agreement is ~1% for equivalent cases



# Model fitting

*We used a CosmoMC platform to test cosmological parameter recovery on the "combined region" data:*

- Standard cosmological parameters $(\Omega_m, \Omega_b, H_0, A_s, n_s)$
- Linear galaxy bias parameters $b_i$
- Fixed magnification parameters $\alpha_i$
- Redshift distribution uncertainties $\Delta z_i$
- Multiplicative shear bias $m_i$

*We fit to 8 Buzzard realisations, the mock mean and a fiducial model vector, using the single-realization covariance*

*We considered:*

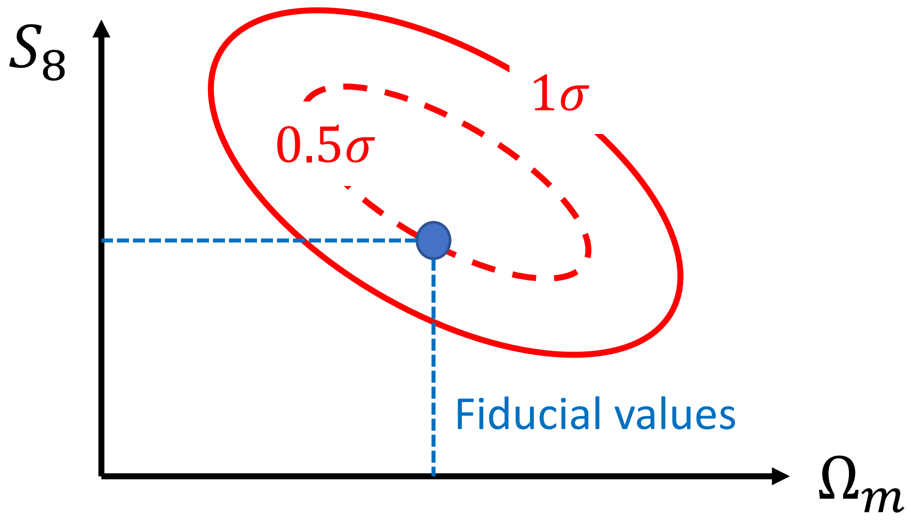
- Goodness-of-fit of best-fitting model ($\chi^2$ statistic)
- Parameter bias for $(\Omega_m, S_8)$ recovery
- "Probability-to-Exceed" statistic for $(\Omega_m, S_8)$ recovery

for different observables, and GGL and clustering scale cuts

| Common parameters for all lensing surveys | | | |
|---|---|---|---|
| **Cosmological parameters:** | | | |
| $\Omega_m$ | flat (0.1,0.9) | | |
| $\Omega_b$ | flat (0.03,0.07) | | |
| $H_0$ | flat (55,91) km s$^{-1}$ Mpc$^{-1}$ | | |
| $A_s$ | flat (0.5,5.0) $\times 10^{-9}$ | | |
| $n_s$ | flat (0.87,1.07) | | |
| **Galaxy bias:** | | | |
| $b_l^i$ | flat (0.8,3.0) | | $i = 1, 2, ..., 5$ |
| **Lens magnification:** | | | |
| $\alpha_l^1$ | Fixed to 0.91 | | |
| $\alpha_l^2$ | Fixed to 1.58 | | |
| $\alpha_l^3$ | Fixed to 2.02 | | |
| $\alpha_l^4$ | Fixed to 2.58 | | |
| $\alpha_l^5$ | Fixed to 2.26 | | |
| | **DES** | **KiDS** | **HSC** |
| **Photometric redshift uncertainties:** | | | |
| $\Delta z_s^1 \times 100$ | $\mathcal{N}(0, 1.8)$ | $\mathcal{N}(0, 1.1)$ | $\mathcal{N}(0, 10.0)$ |
| $\Delta z_s^2 \times 100$ | $\mathcal{N}(0, 1.5)$ | $\mathcal{N}(0, 1.1)$ | $\mathcal{N}(0, 10.0)$ |
| $\Delta z_s^3 \times 100$ | $\mathcal{N}(0, 1.1)$ | $\mathcal{N}(0, 1.2)$ | $\mathcal{N}(0, 10.0)$ |
| $\Delta z_s^4 \times 100$ | $\mathcal{N}(0, 1.7)$ | $\mathcal{N}(0, 0.9)$ | $\mathcal{N}(0, 10.0)$ |
| $\Delta z_s^5 \times 100$ | | $\mathcal{N}(0.0, 1.0)$ | |
| **Multiplicative shear bias:** | | | |
| $m_1 \times 100$ | $\mathcal{N}(0, 0.9)$ | $\mathcal{N}(0.0, 1.9)$ | $\mathcal{N}(0.0, 1.0)$ |
| $m_2 \times 100$ | $\mathcal{N}(0, 0.8)$ | $\mathcal{N}(0.0, 2.0)$ | $\mathcal{N}(0.0, 1.0)$ |
| $m_3 \times 100$ | $\mathcal{N}(0, 0.8)$ | $\mathcal{N}(0.0, 1.7)$ | $\mathcal{N}(0.0, 1.0)$ |
| $m_4 \times 100$ | $\mathcal{N}(0, 0.8)$ | $\mathcal{N}(0.0, 1.2)$ | $\mathcal{N}(0.0, 1.0)$ |
| $m_5 \times 100$ | | $\mathcal{N}(0.0, 1.0)$ | |

# Metrics for cosmological parameter recovery

The parameter bias is the confidence interval of the $(\Omega_m, S_8)$ fit to the mock mean (using a single-realization covariance) that intersects the fiducial point

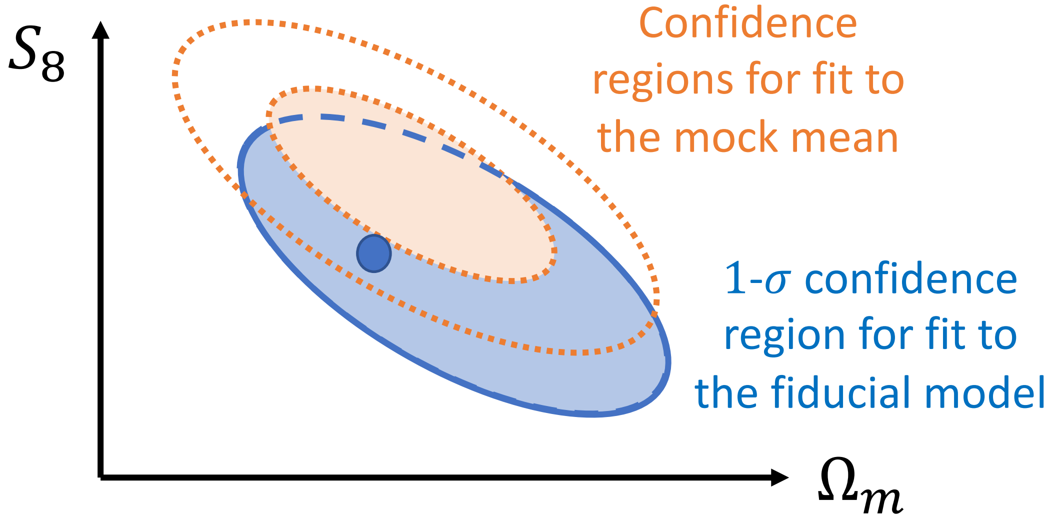



Issues: the parameter bias neglects parameter projection effects and contains noise (i.e. in the absence of systematics, it won't be equal to $0$-$\sigma$!)

To fix this, we also perform a fit to a fiducial model data vector and use this as the "baseline"

The probability-to-exceed (PTE) is the chance the fit to the mock mean lies outside the $N$-$\sigma$ confidence region of the fit to the fiducial model

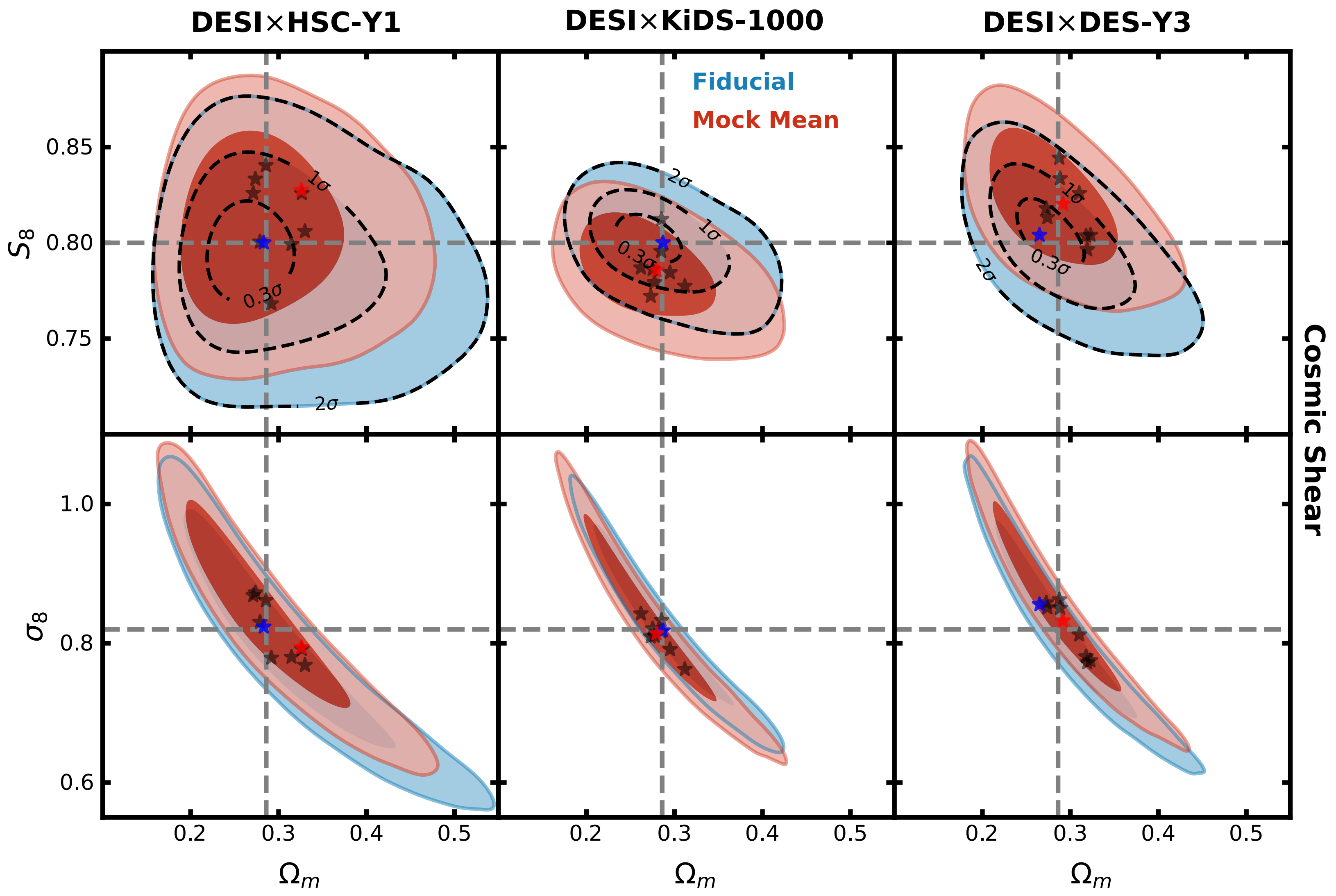
*PTE is the integrated orange probability outside the blue region*



# Parameter fits to cosmic shear only

Here are the fits to **cosmic shear only** for the 3 mock lensing surveys:

- The average reduced $\chi^2$ for the fits across the realisations is $\approx 1$
- The parameter bias is $\leq 0.5\sigma$ (consistent with noise fluctuations)
- The PTE is less than (9%, 4%) for a $(0.3\sigma, 1\sigma)$ bias

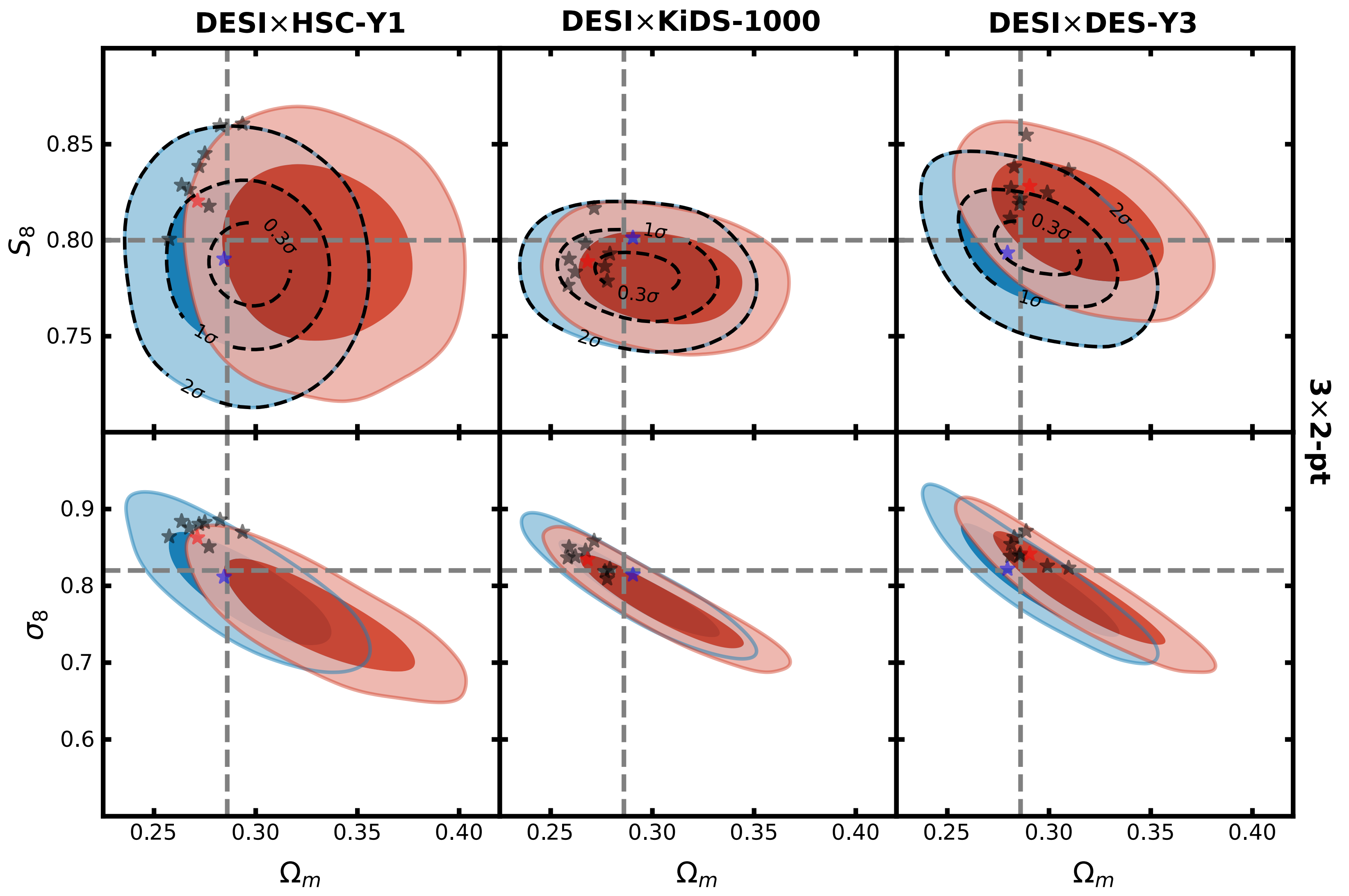



*Note: PTE calculation uses re-scaled covariance for mock mean*

# Parameter fits to full 3×2-pt correlations

Here are the fits to the **3×2-pt data vectors** with scale cuts $R_{GGL} > 10$, $R_{clus} > 7\ h^{-1}\mathrm{Mpc}$:

- The average reduced $\chi^2$ for the fits across the realisations is $\approx 1$
- The parameter errors are significantly reduced
- The parameter bias is $< 1\sigma$ but exceeds noise
- The PTE is less than (12%, 5%) for a ($0.3\sigma$, $1\sigma$) bias




*Note: PTE calculation uses re-scaled covariance for mock mean*

# Conclusions

- We have an operational end-to-end pipeline for 3×2-pt cosmology, including $w_p(R)$!
- Analytical covariance is established for $(\xi_\pm, \gamma_t, w_p)$ at $\sim 10\%$ level
- Buzzard simulation fits recover fiducial cosmology with $< 1\sigma$ systematics using scale cuts $R > 5 - 10\ h^{-1}\mathrm{Mpc}$
- We should be cautious that simulations are not the same as real data! – full scale cuts validation also requires analytical tests

Great thanks/praise due to: