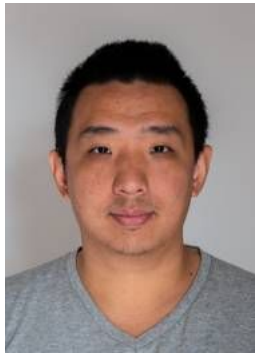
Simulation-Based Inference of KiDS-1000 Cosmic Shear

A not so “normal” beverage of choice seminar

Maximilian von Wietersheim-Kramsta

KiDS Busy Week Bochum - 26th September 2023

KiDS



Kiyam Lin

Nicolas Tessore

Benjamin Joachimi

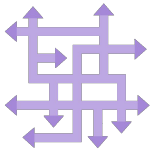
Arthur Loureiro

Robert Reischke

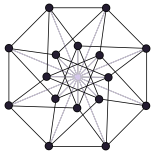
Angus Wright

Simulation-Based Inference (SBI)

a.k.a. likelihood-free inference or implicit likelihood inference



Signal and uncertainty modelling of arbitrary complexity



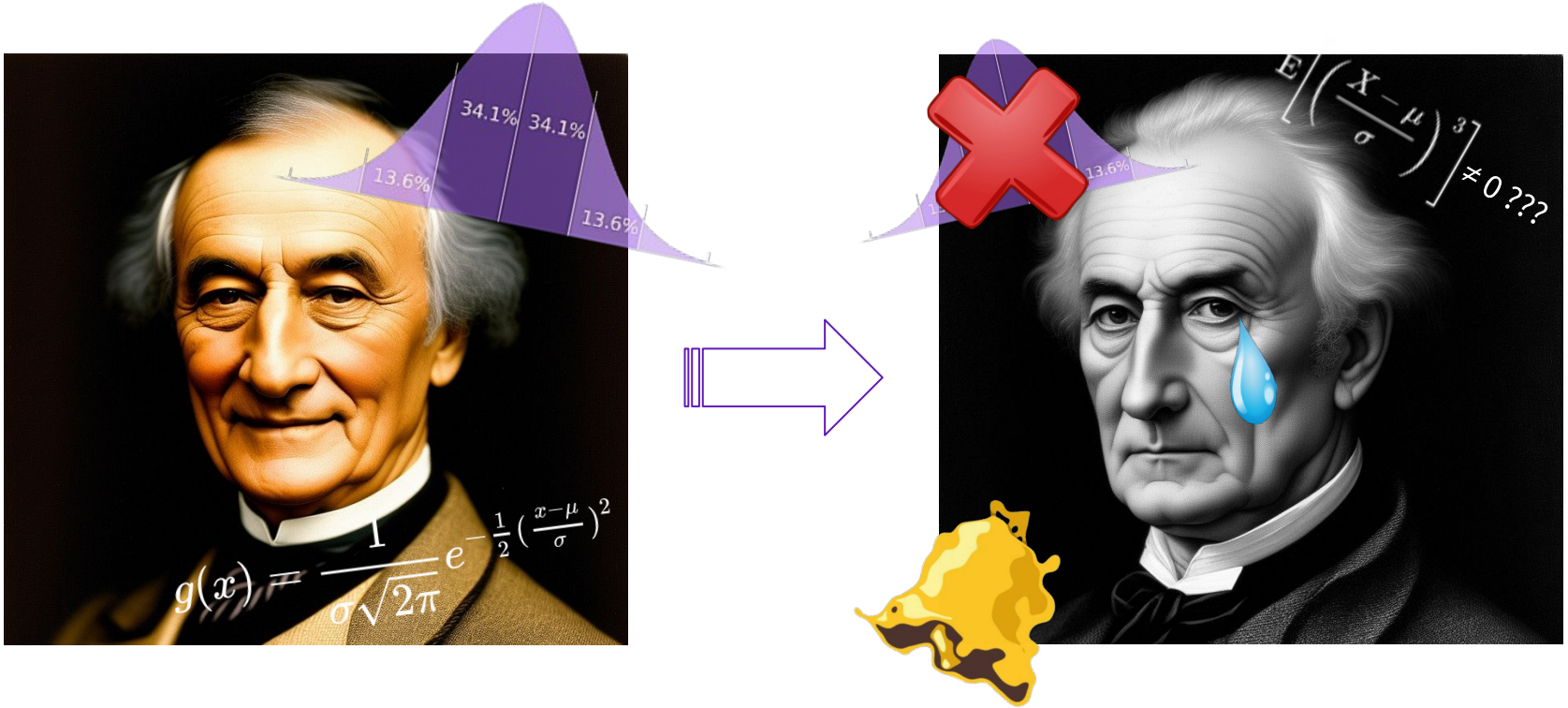
Requires a similar number of realisations as a numerical covariance

$t \rightarrow \theta$

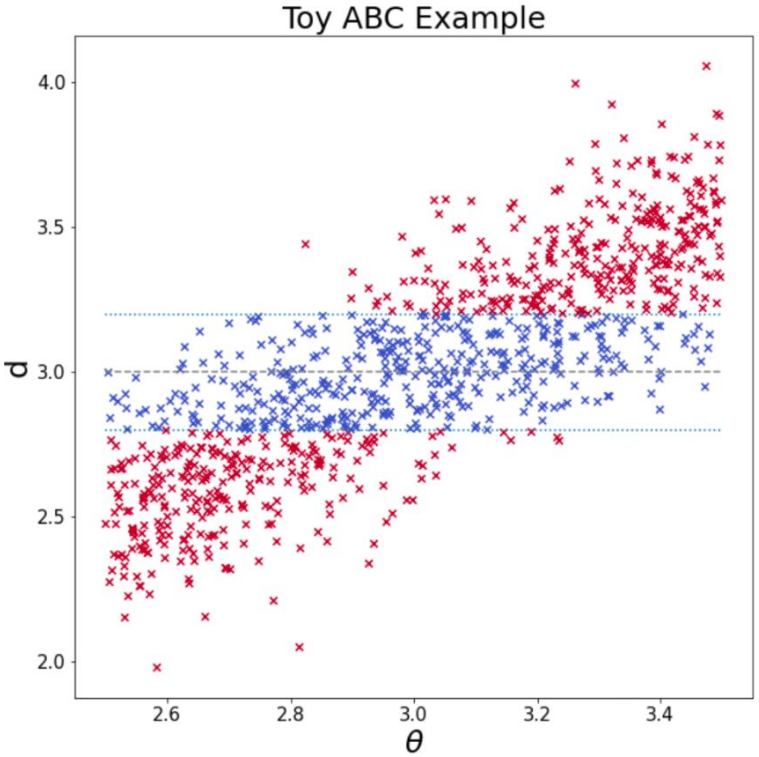
Bayesian uncertainty propagation from data to parameters

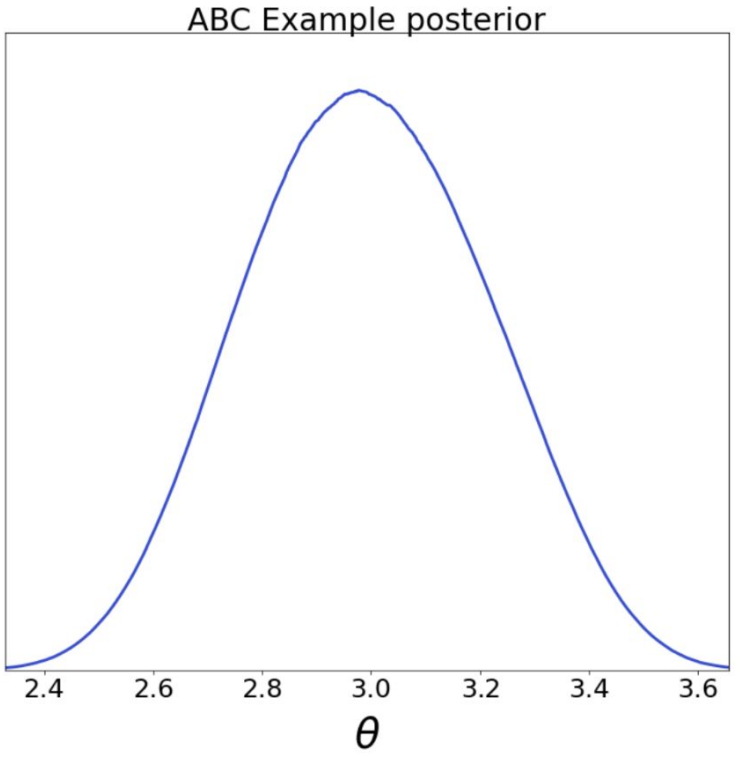
Likelihood can take an arbitrary form

Dropping the assumption of Gaussianity…

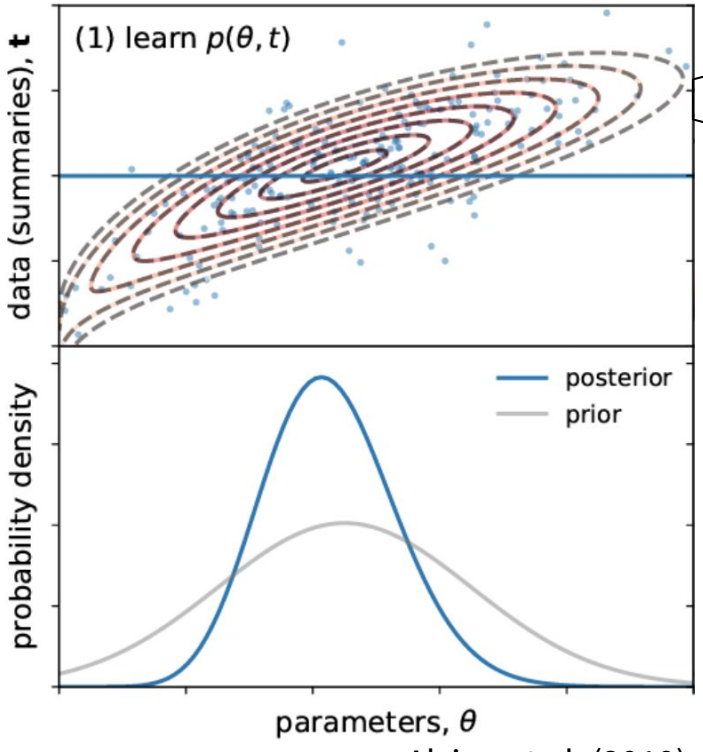


SBI: Approximate Bayesian Computation

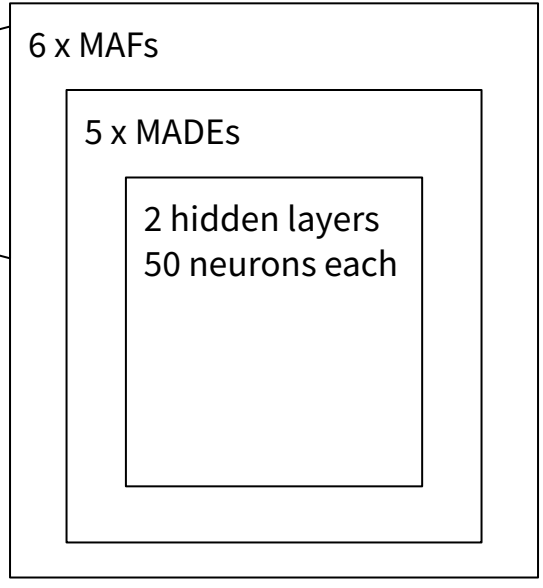




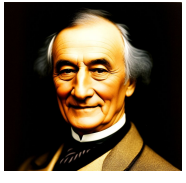
SBI: Neural Density Estimation

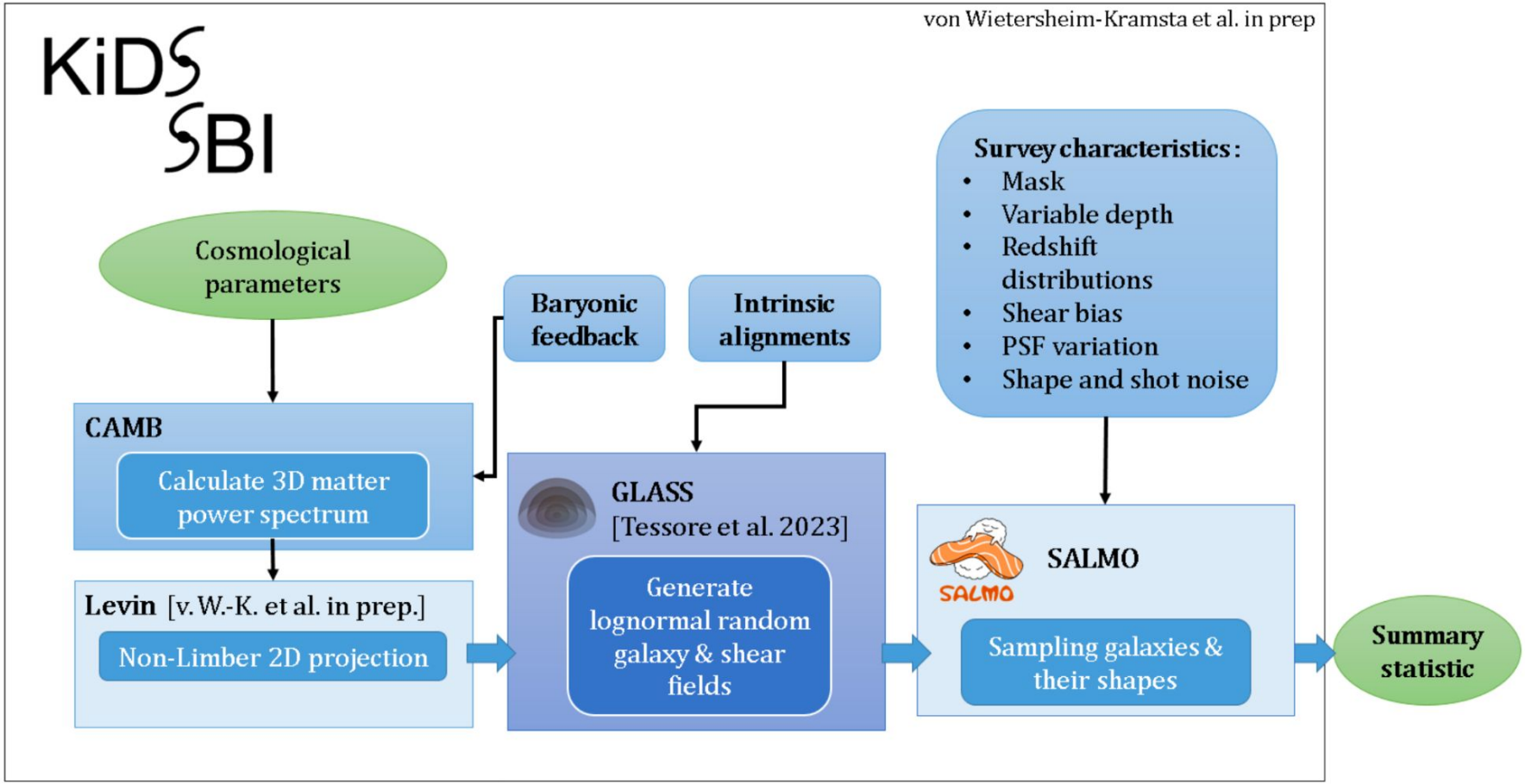


Alsing et al. (2019)

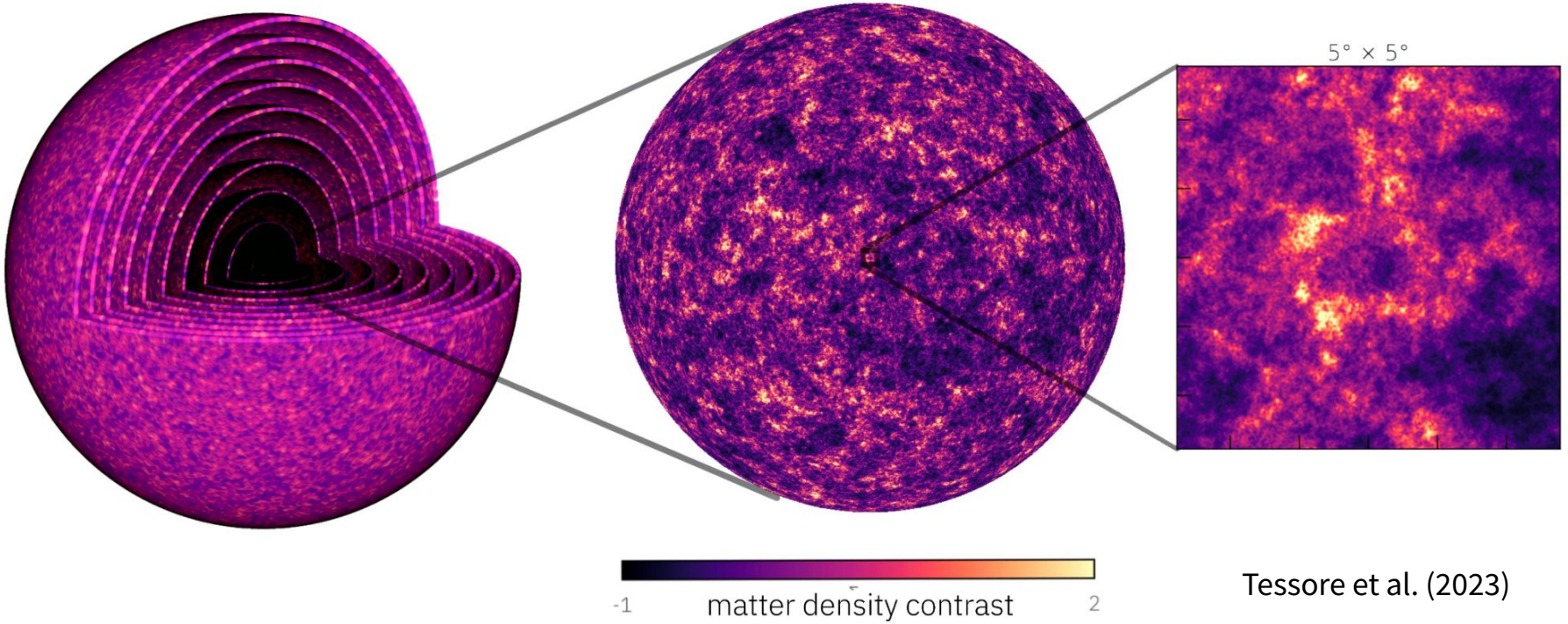


→ 6 x 5 x $|\mathbf{t}|$ multivariate Gaussians, P($\mathbf{t}|\boldsymbol{\theta}$)




KiDS
SBI
von Wietersheim-Kramsta et al. in prep
Cosmological parameters
Baryonic feedback
Intrinsic alignments
Survey characteristics:
• Mask
• Variable depth
• Redshift distributions
• Shear bias
• PSF variation
• Shape and shot noise
CAMB
Calculate 3D matter power spectrum
Levin [v.W.-K. et al. in prep.]
Non-Limber 2D projection
GLASS
[Tessore et al. 2023]
Generate lognormal random galaxy & shear fields
SALMO
SALMO
Sampling galaxies & their shapes
Summary statistic

Generator for Large Scale Structure



Tessore et al. (2023)

Galaxy sampling

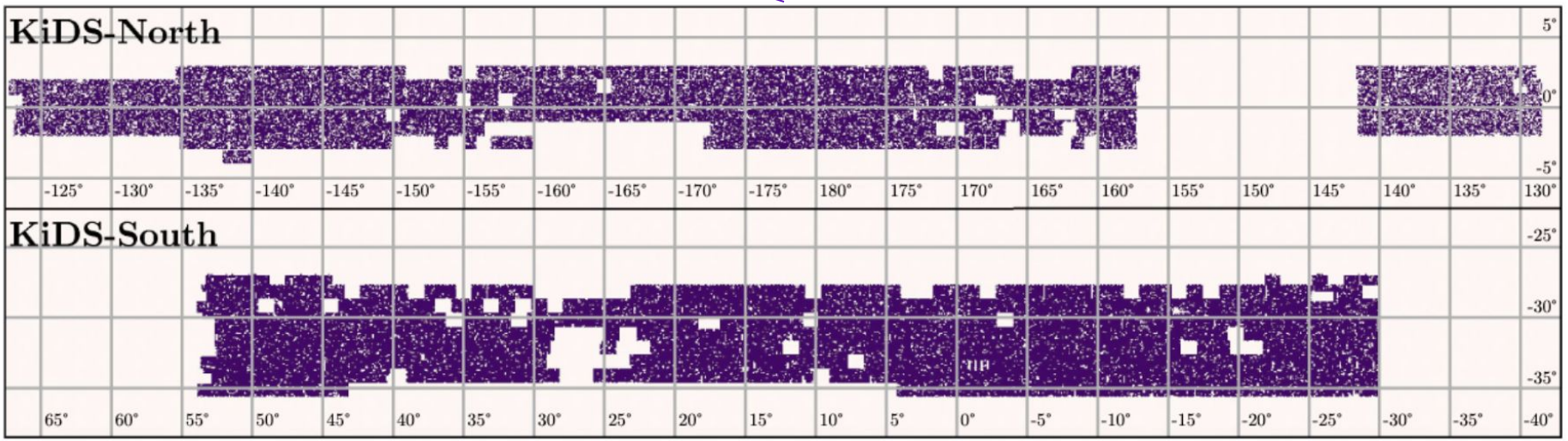
Shell

Tomographic bin

$$\langle N_m^{(i)(p)} \rangle(\Theta) = w_m(\Omega_{\rm survey}) \left[1 + b^{(i)}\delta^{(i)}(\theta_m;\Theta)\right] P_m(p|i)\, n^{(p)}_{{\rm gal},m}\, A_{{\rm pix},m}$$

Pixel

Mask



Galaxy sampling

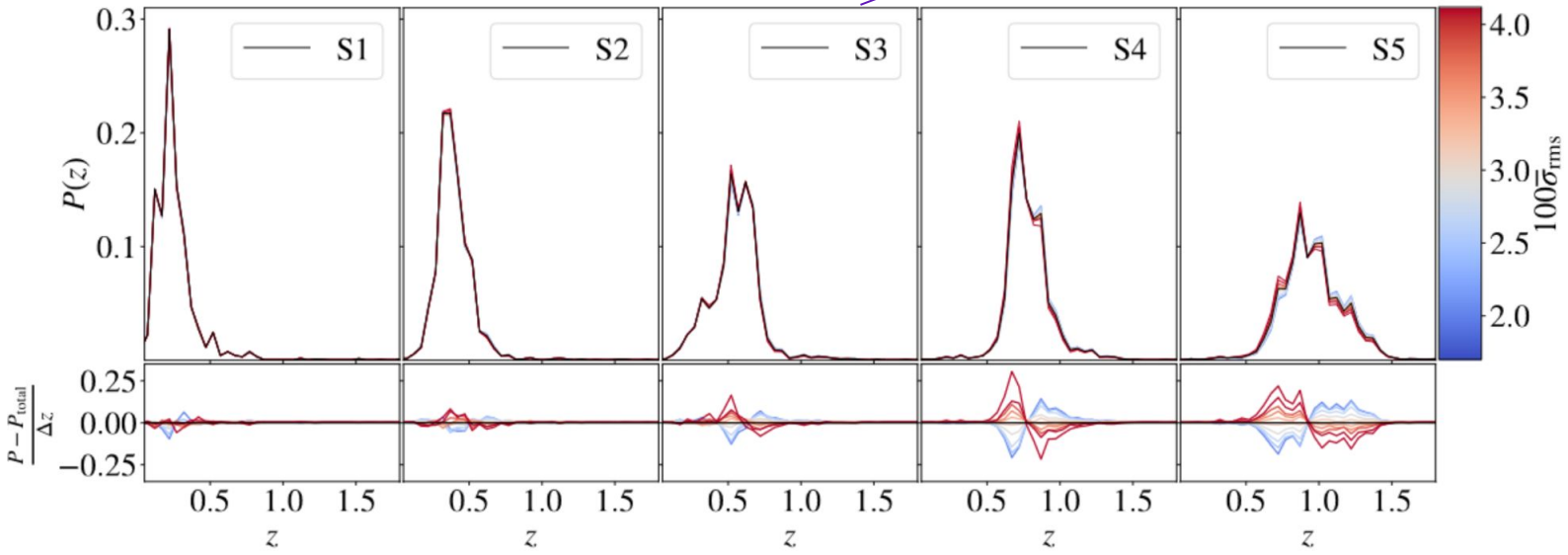
Shell

Tomographic bin

$$\langle N_m^{(i)(p)} \rangle(\Theta) = w_m(\Omega_{\rm survey}) \left[1 + b^{(i)} \delta^{(i)}(\theta_m; \Theta)\right] P_m(p|i)\, n_{{\rm gal},m}^{(p)}\, A_{{\rm pix},m}$$

Pixel

Redshift distributions



Galaxy sampling

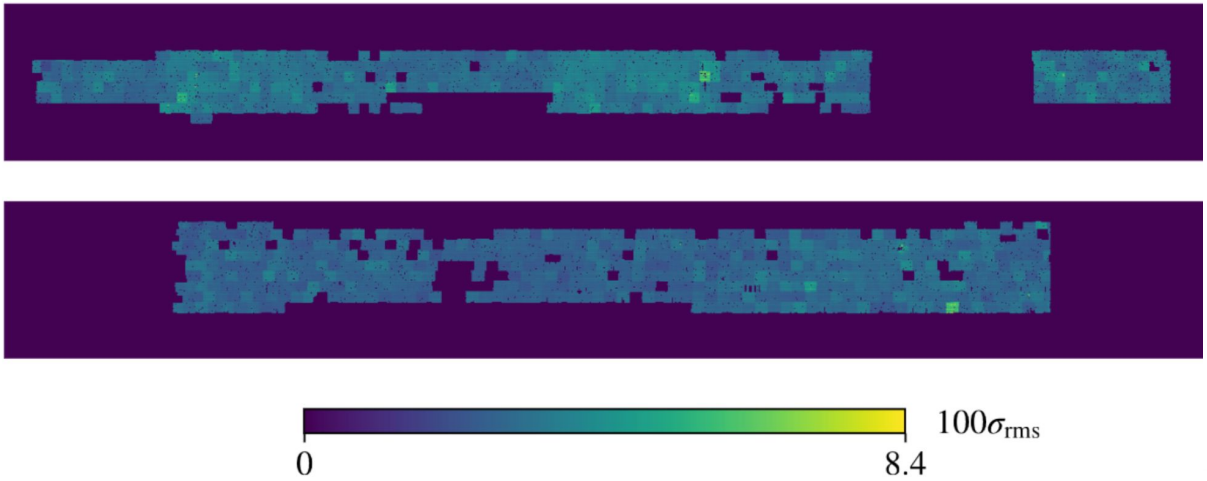
Shell

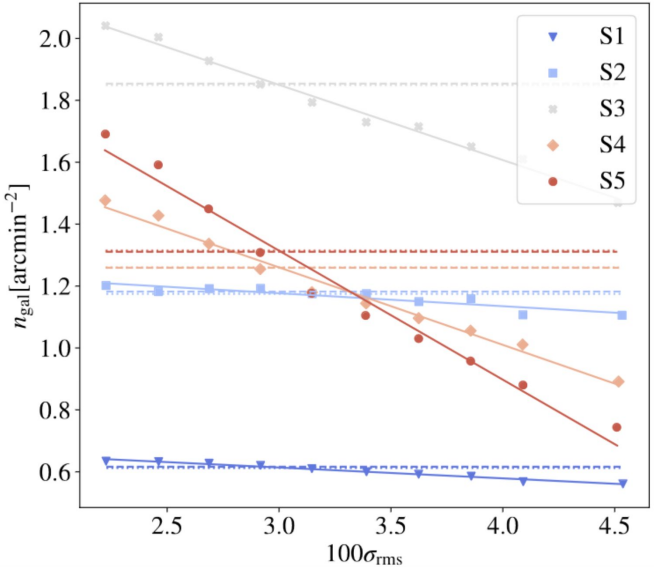
Tomographic bin

$$\langle N_m^{(i)(p)} \rangle(\Theta) = w_m(\Omega_{\rm survey}) \left[1 + b^{(i)} \delta^{(i)}(\theta_m; \Theta)\right] P_m(p|i)\, n_{{\rm gal},m}^{(p)}\, A_{{\rm pix},m}$$

Pixel

Galaxy density (variable depth)



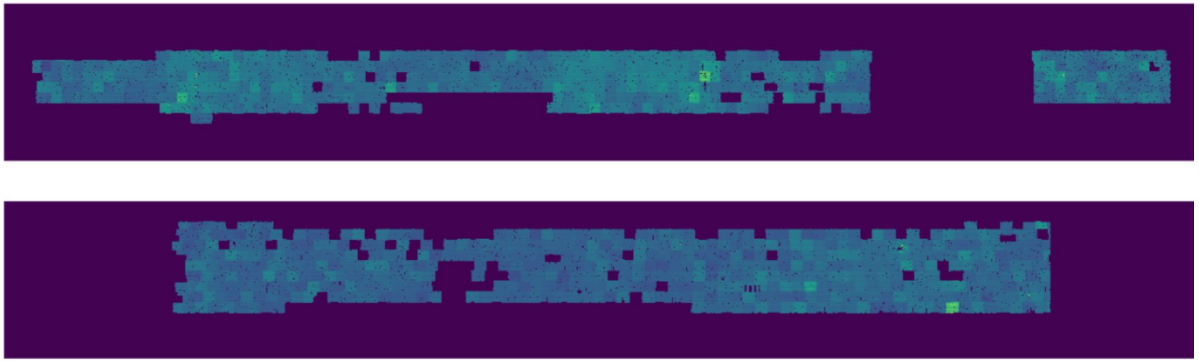


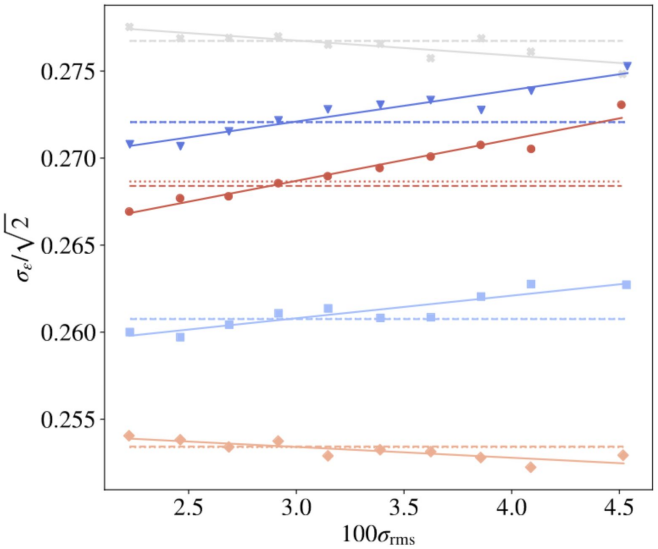
Galaxy shear

Reduced shear

$$\epsilon_{\text{lensed}}(\boldsymbol{\Theta}) = \frac{\epsilon_{\text{int}} + g(\boldsymbol{\Theta})}{1 + g^*(\boldsymbol{\Theta})\epsilon_{\text{int}}}$$

Intrinsic shapes
(variable depth)





Galaxy shear

$$\epsilon_{\rm obs}(p, m; \Theta) = \left(1 + M^{(p)}\right)\epsilon_{\rm lensed}(\Theta) + \alpha^{(p)}\epsilon_{\rm PSF}(m) + \beta^{(p)}\delta\epsilon_{\rm PSF} + c^{(p)}$$

Pixel

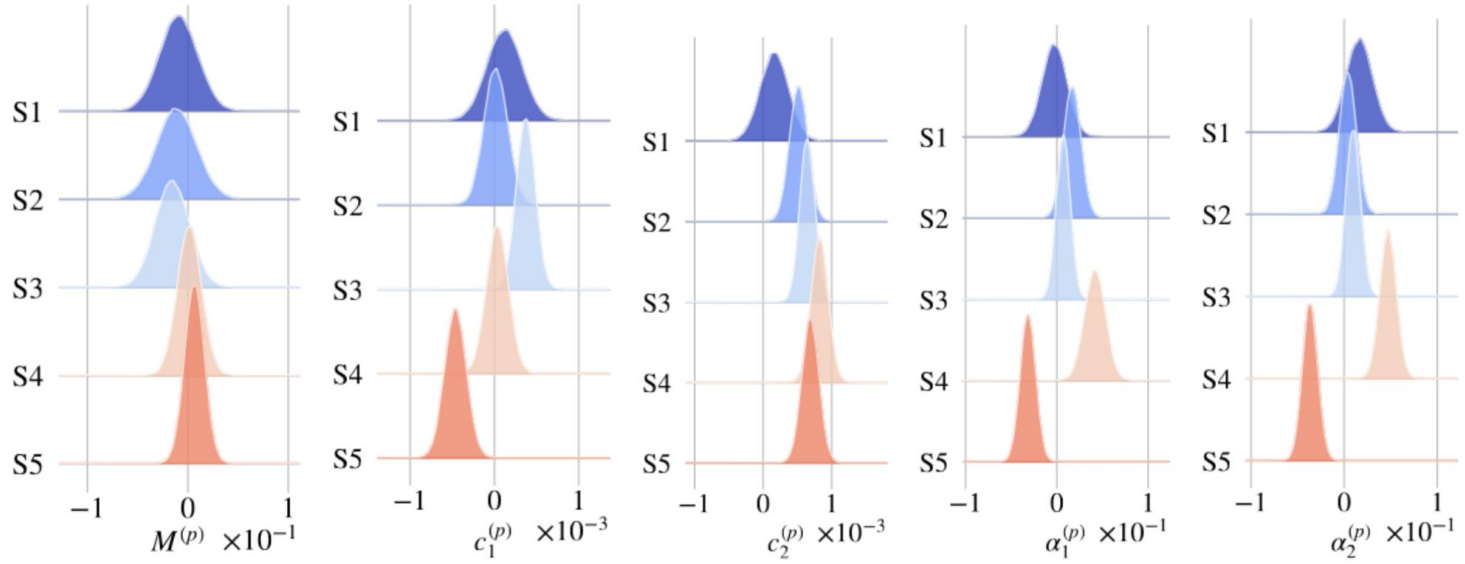
Tomographic bin

Multiplicative shear bias

PSF shear bias

0

Additive shear bias



Galaxy shear

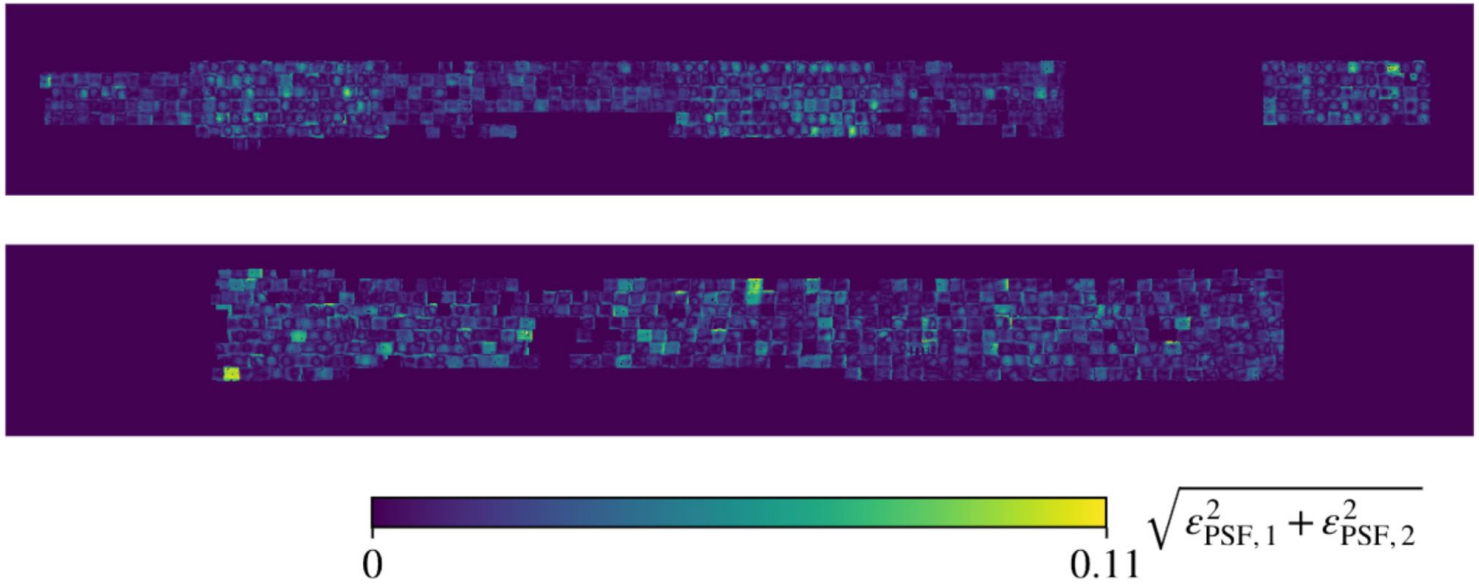
$$\epsilon_{\rm obs}(p, m; \Theta) = \left(1 + M^{(p)}\right)\epsilon_{\rm lensed}(\Theta) + \alpha^{(p)}\epsilon_{\rm PSF}(m) + \beta^{(p)}\delta\epsilon_{\rm PSF} + c^{(p)}$$

Pixel

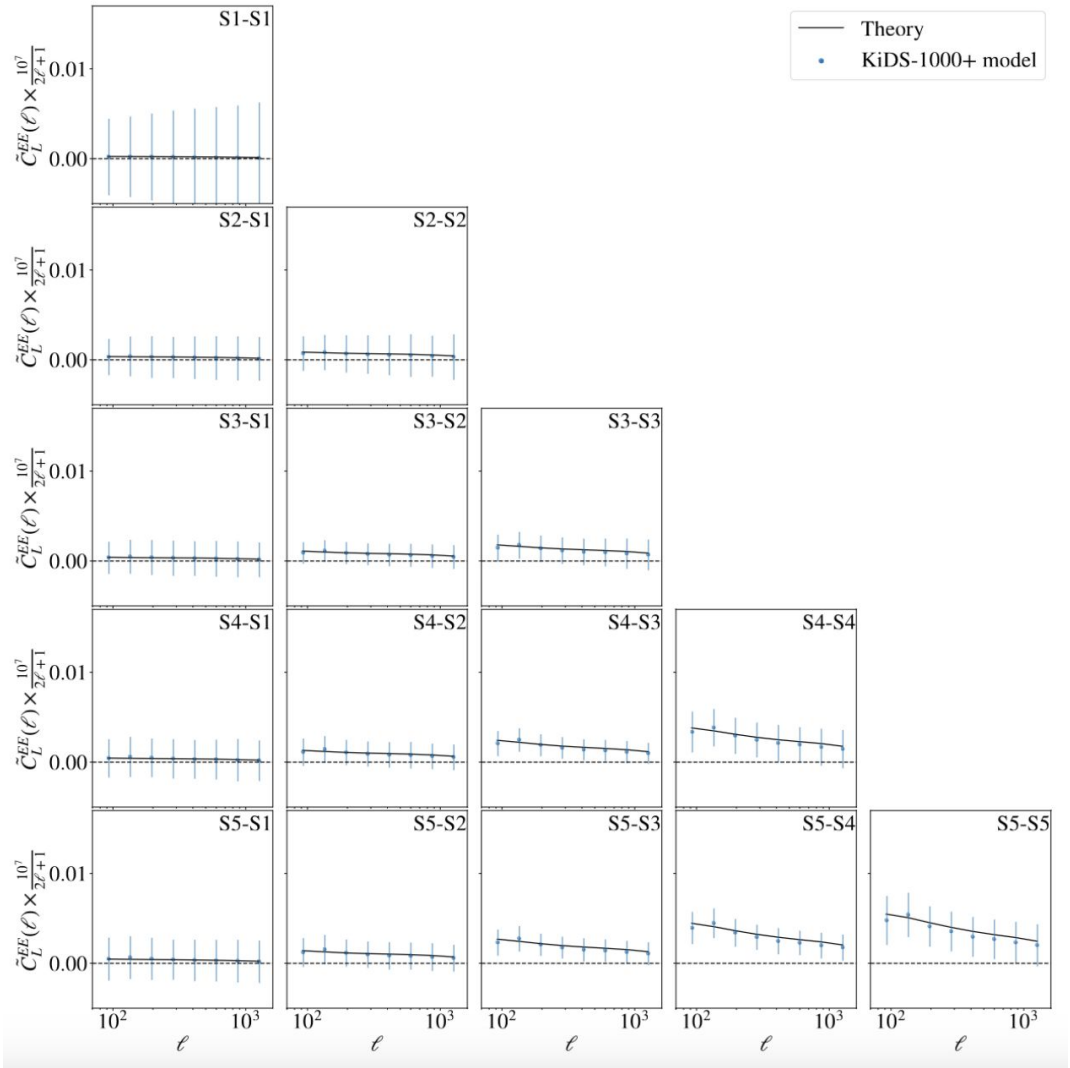
Tomographic bin

PSF shear bias

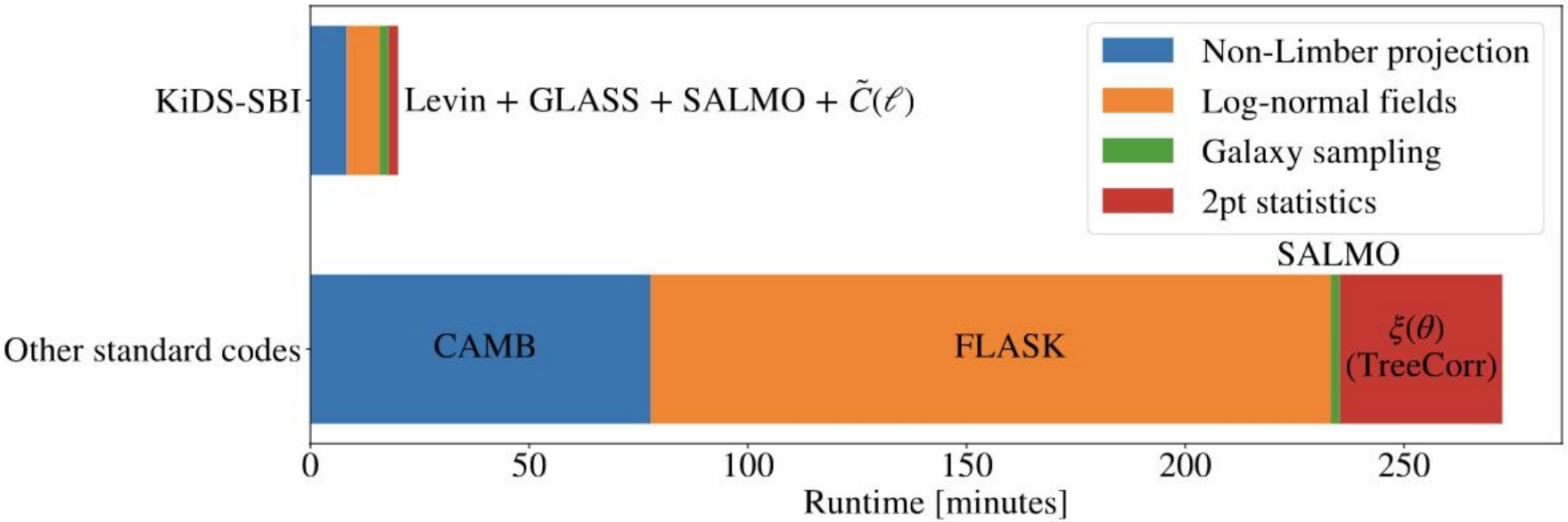
0



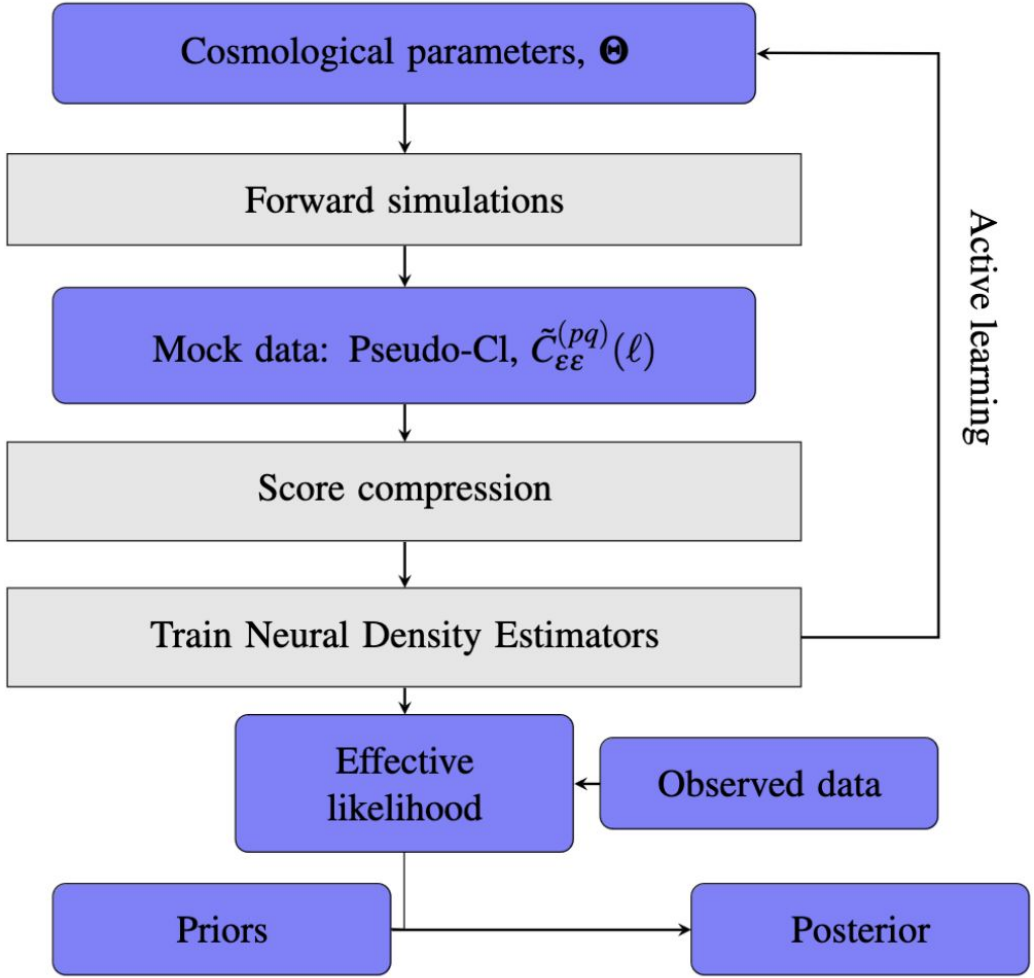
2pt statistics: pseudo-Cls



Forward simulations



SBI

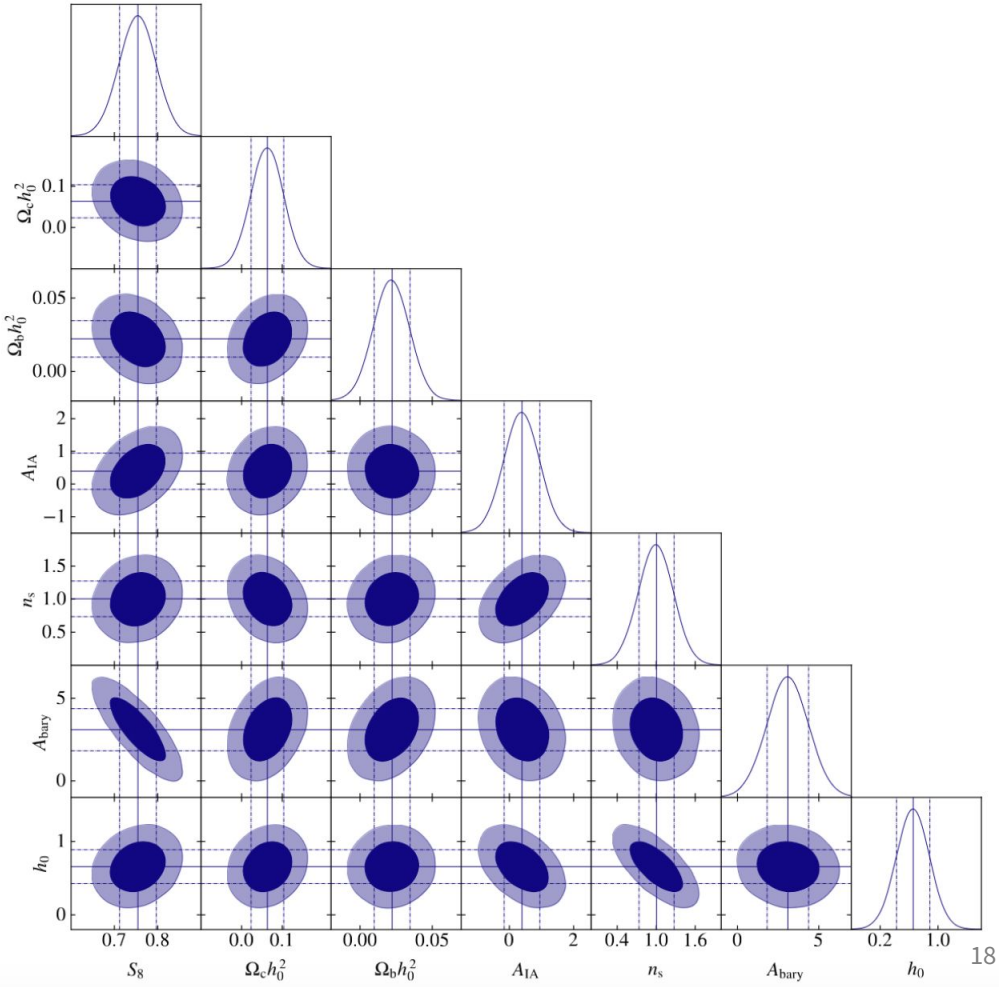

Cosmological parameters, Θ
Forward simulations
Mock data: Pseudo-Cl, $\tilde{C}_{\varepsilon\varepsilon}^{(pq)}(\ell)$
Score compression
Train Neural Density Estimators
Active learning
Effective likelihood
Observed data
Priors
Posterior

Score Compression

Compress **t** down to $|\boldsymbol{\theta}|$

$$\boldsymbol{t} \equiv \nabla \mathscr{L}_*$$

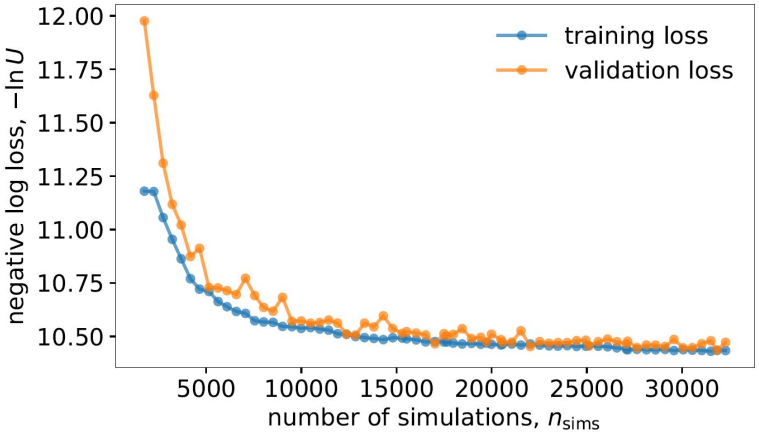
Implicitly margninalise over **δz**

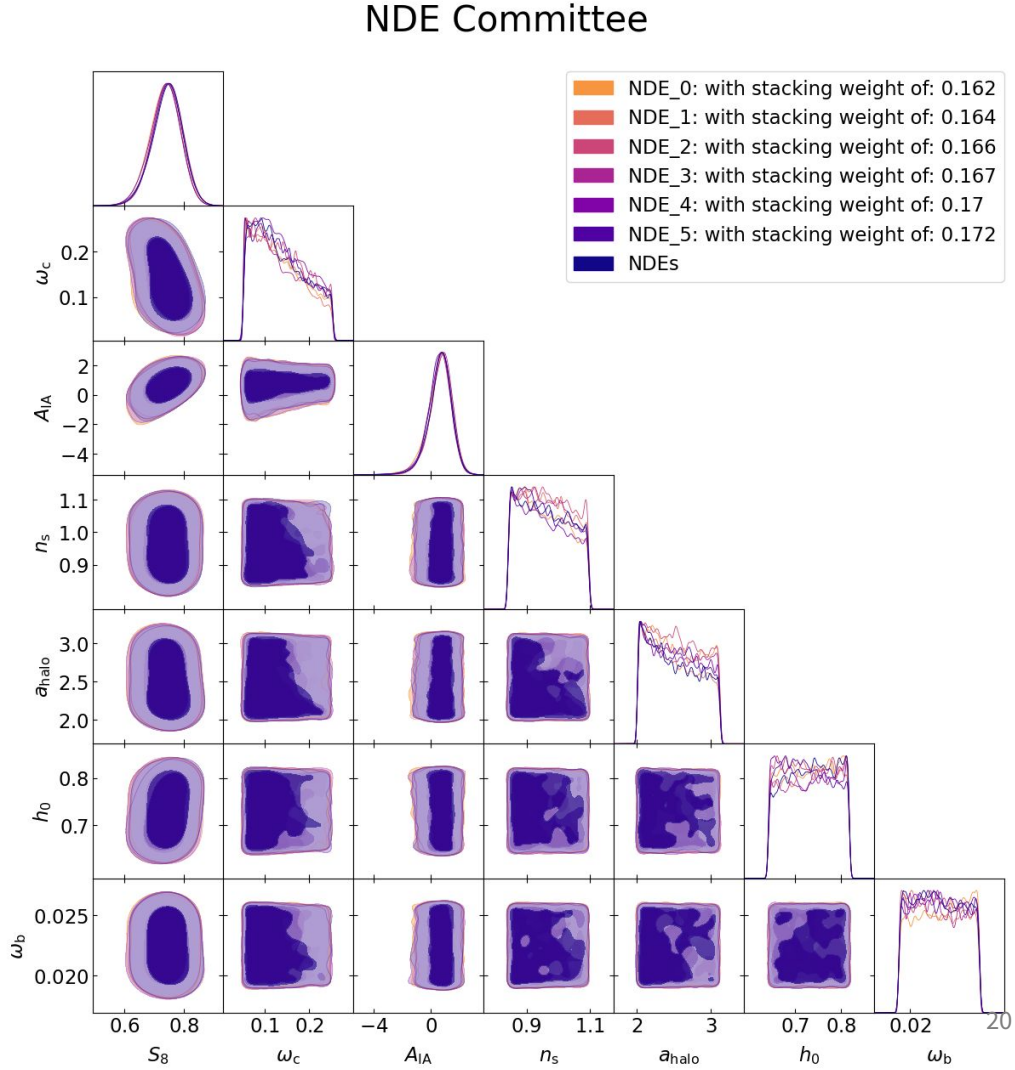


Priors

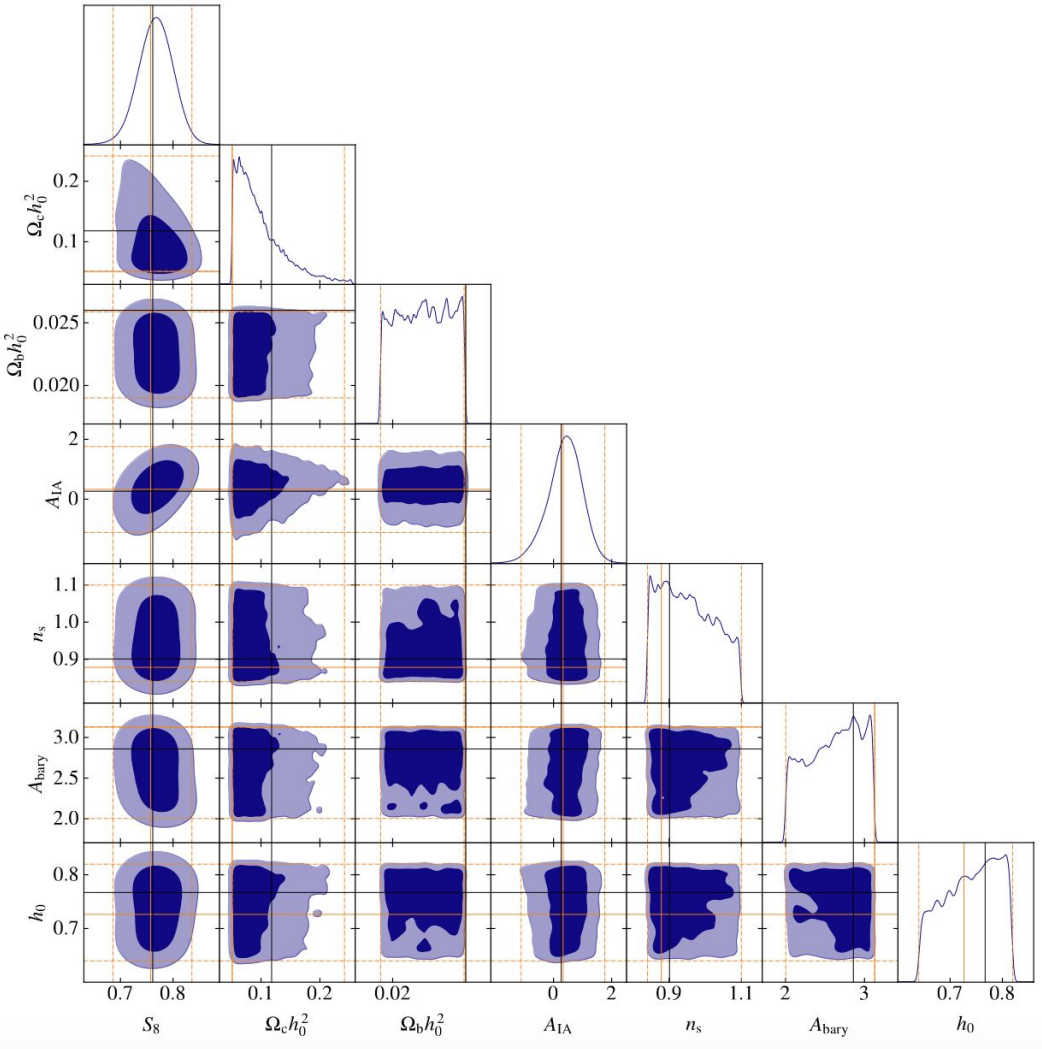
Parameter	Symbol	Prior type	Prior parameters
Density fluctuation amp.	S_8	Flat	[0.1, 1.3]
Hubble constant	h_0	Flat	[0.64, 0.82]
Cold dark matter density	ω_c	Flat	[0.051, 0.255]
Baryonic matter density	ω_b	Flat	[0.019, 0.026]
Scalar spectral index	n_s	Flat	[0.84, 1.1]
Intrinsic alignment amp.	A_{IA}	Flat	[-6, 6]
Baryon feedback amp.	A_{bary}	Flat	[2, 3.13]
Redshift displacement	$\boldsymbol{\delta}_z$	Gaussian	$\mathcal{N}(\mathbf{0}, \boldsymbol{C}_z)$

NDEs


training loss
validation loss
negative log loss, $-\ln U$
number of simulations, n_{sims}

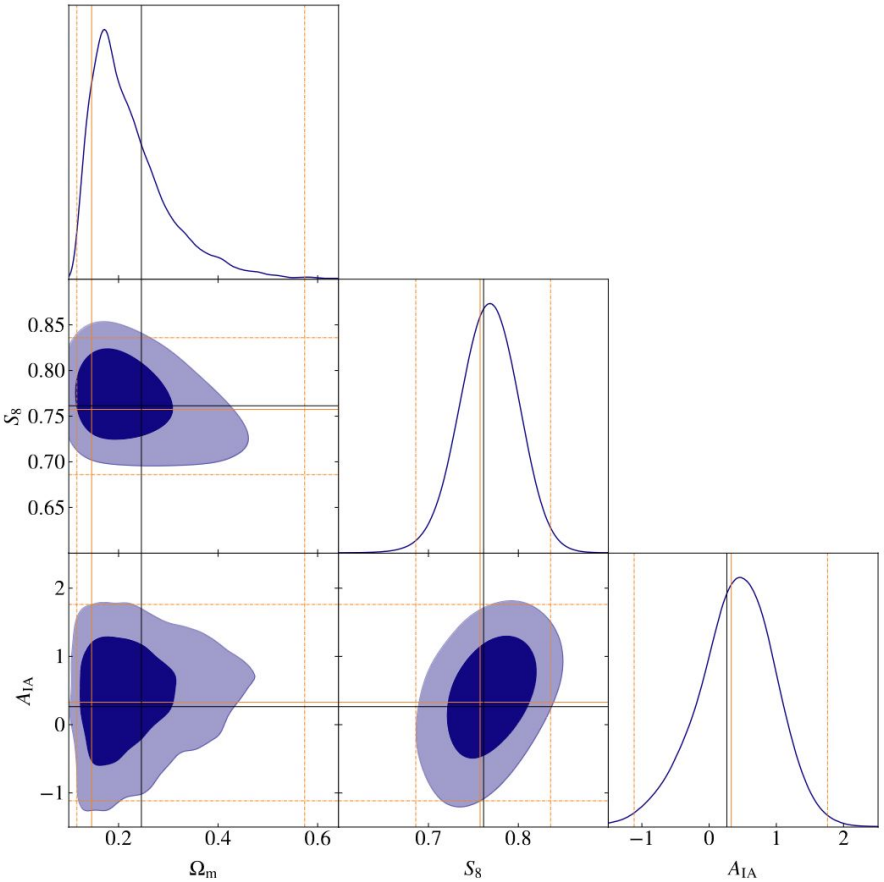

NDE Committee
NDE_0: with stacking weight of: 0.162
NDE_1: with stacking weight of: 0.164
NDE_2: with stacking weight of: 0.166
NDE_3: with stacking weight of: 0.167
NDE_4: with stacking weight of: 0.17
NDE_5: with stacking weight of: 0.172
NDEs
S_8
ω_c
A_{IA}
n_s
a_{halo}
h_0
ω_b

Posterior from mock data

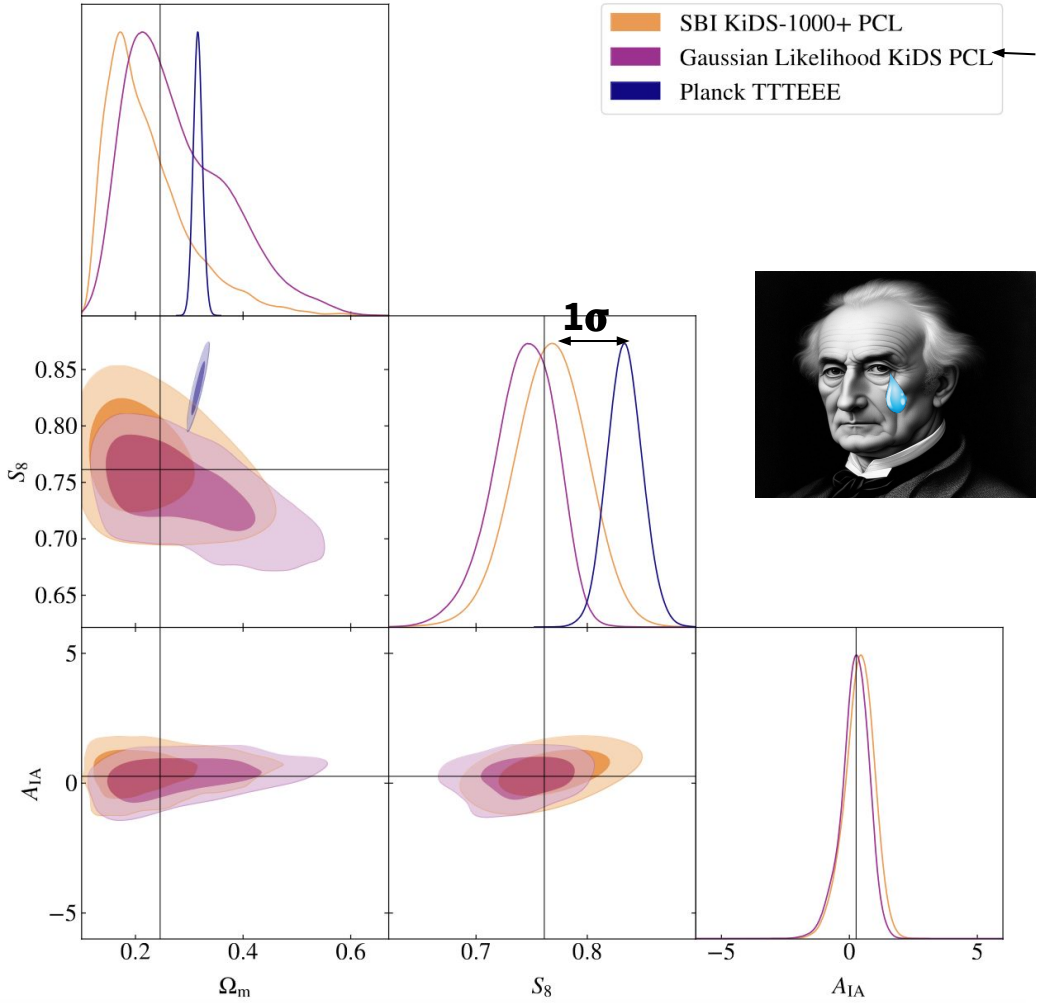


Posterior from mock data

Parameter	Mock truth	MAP ± PJ-HPD from KiDS-SBI
S_8	0.761	$0.757^{+0.078}_{-0.072}$
σ_8	0.842	$1.086^{+0.118}_{-0.544}$
Ω_m	0.245	$0.145^{+0.428}_{-0.030}$
h_0	0.767	$0.726^{+0.093}_{-0.086}$
ω_c	0.118	$0.050^{+0.191}_{-0.001}$
ω_b	0.026	$0.025^{+0.001}_{-0.007}$
n_s	0.901	$0.878^{+0.221}_{-0.038}$
A_IA	0.264	$0.329^{+1.432}_{-1.445}$
A_bary	2.859	$3.129^{+0.001}_{-1.128}$

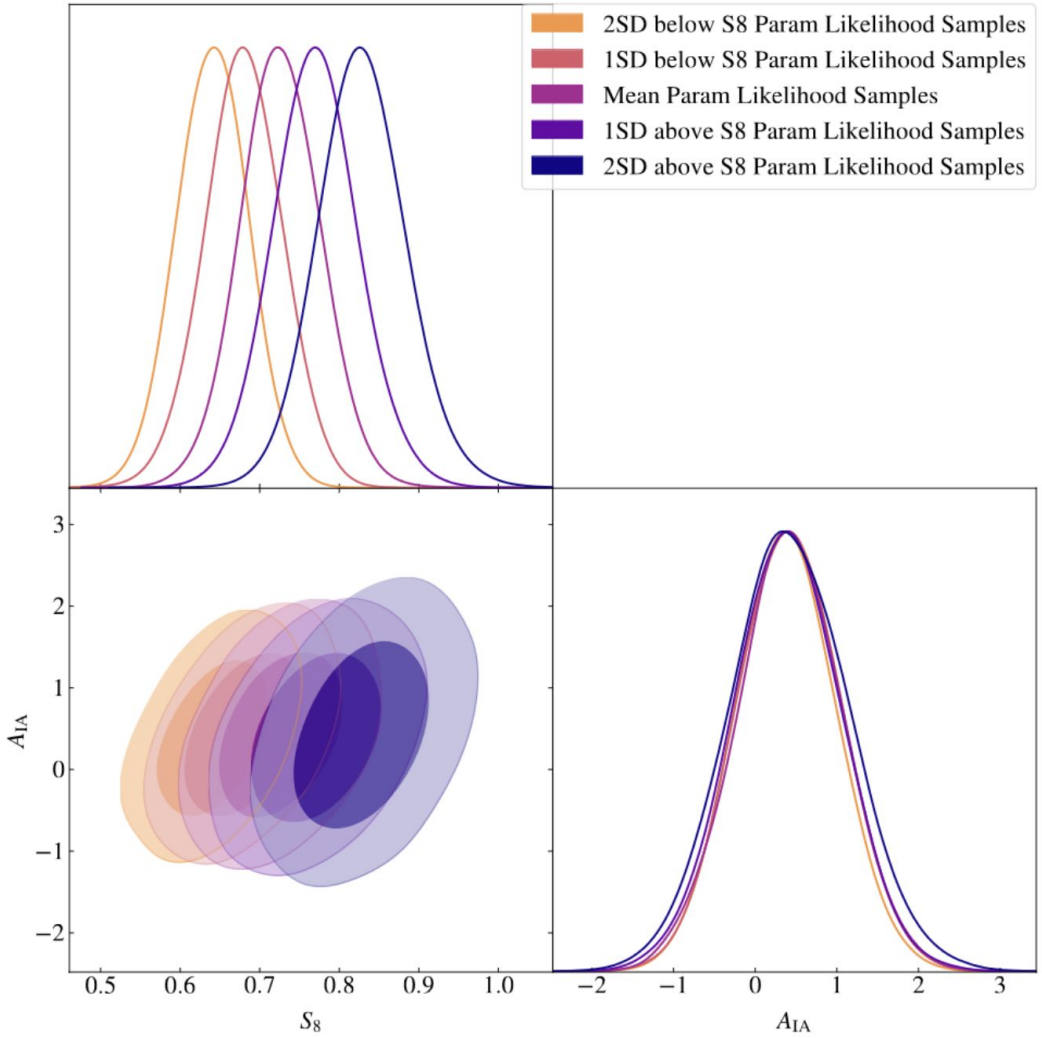


Comparison

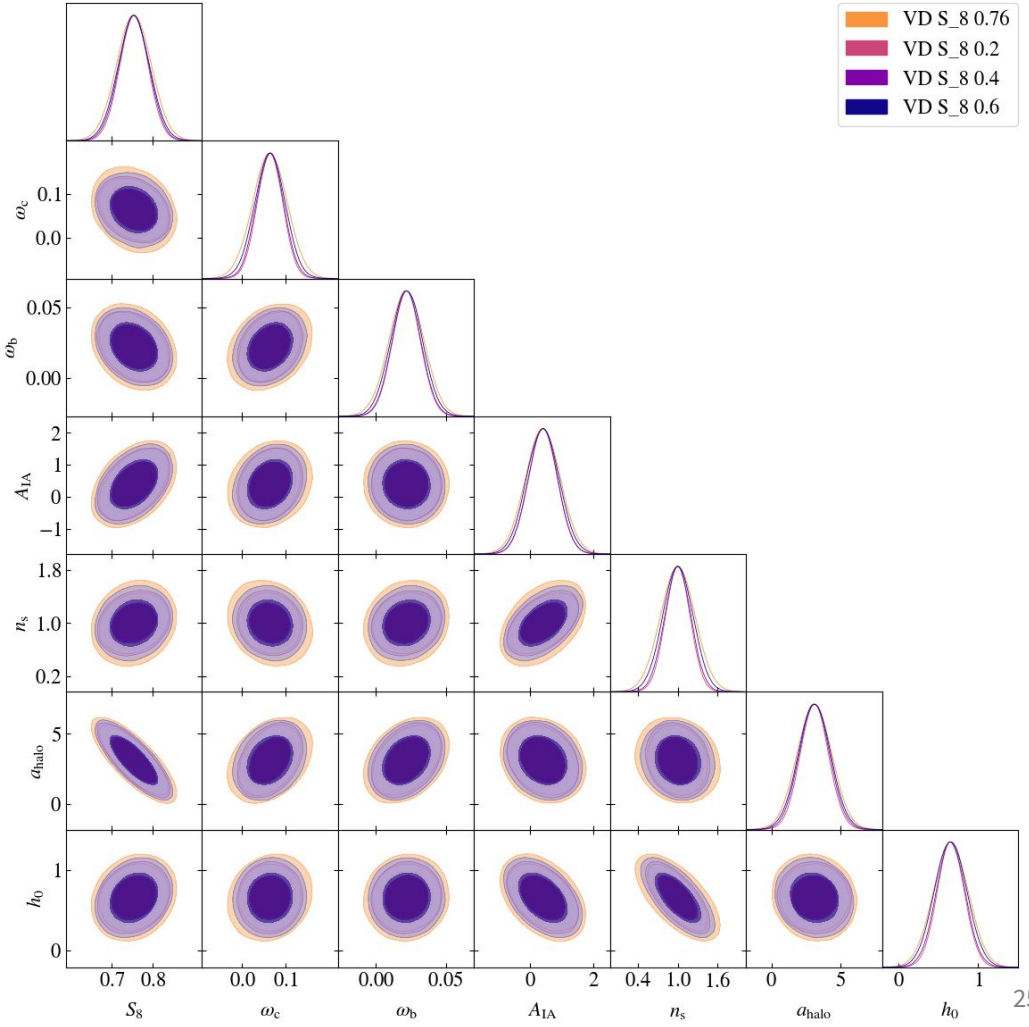

SBI KiDS-1000+ PCL
Gaussian Likelihood KiDS PCL
Planck TTTEEE
Arthur's results
1σ
S_8
Ω_m
A_{IA}
0.85
0.80
0.75
0.70
0.65
0.2
0.4
0.6
0.7
0.8
5
0
−5

Origins of non-Gaussianity

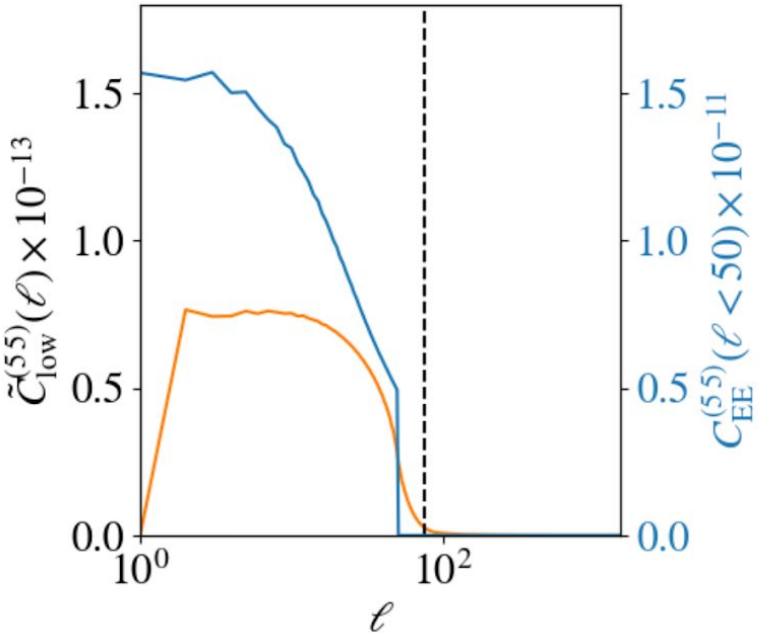
S_8	σ_{S_8}	$\sigma_{A_{\rm IA}}$
0.650	0.045	0.62
0.701	0.049	0.64
0.761	0.051	0.66
0.802	0.054	0.68
0.851	0.056	0.75

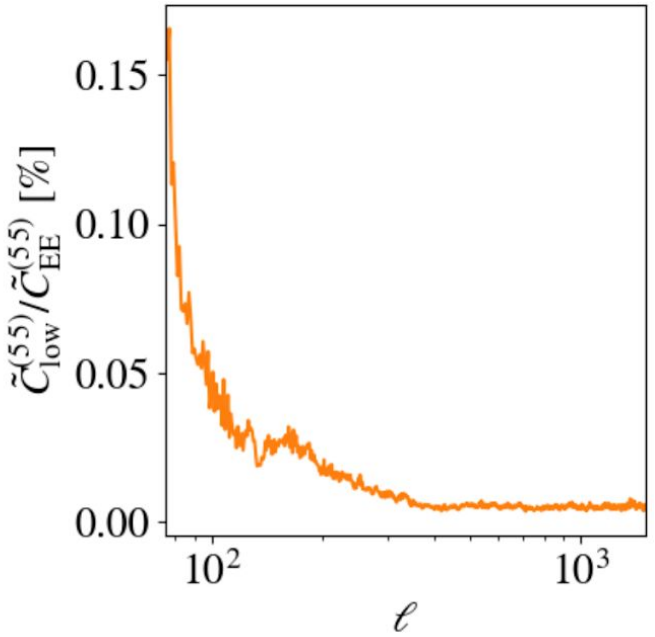


Tests:
Fisher forecasts with S_8

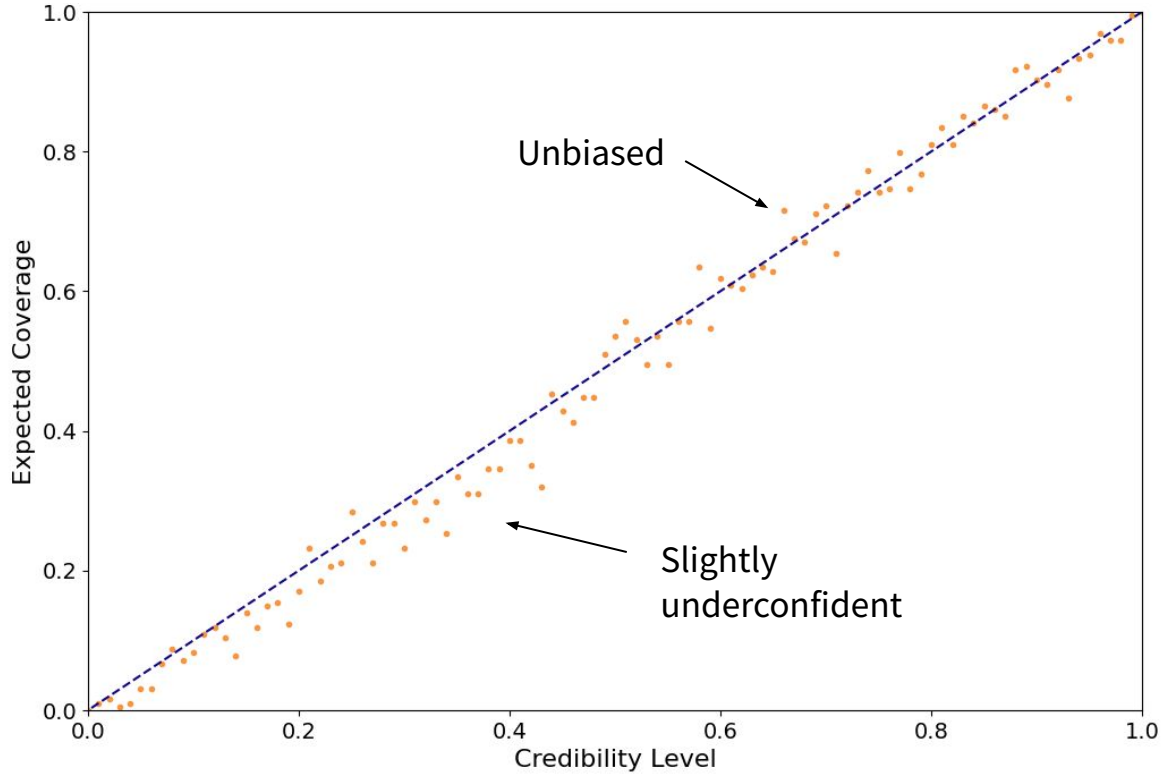


Tests: low-ell modes?





Tests: Coverage Test



Based on method from Lemos et al. (2023a)

Lin et al. (in prep.)

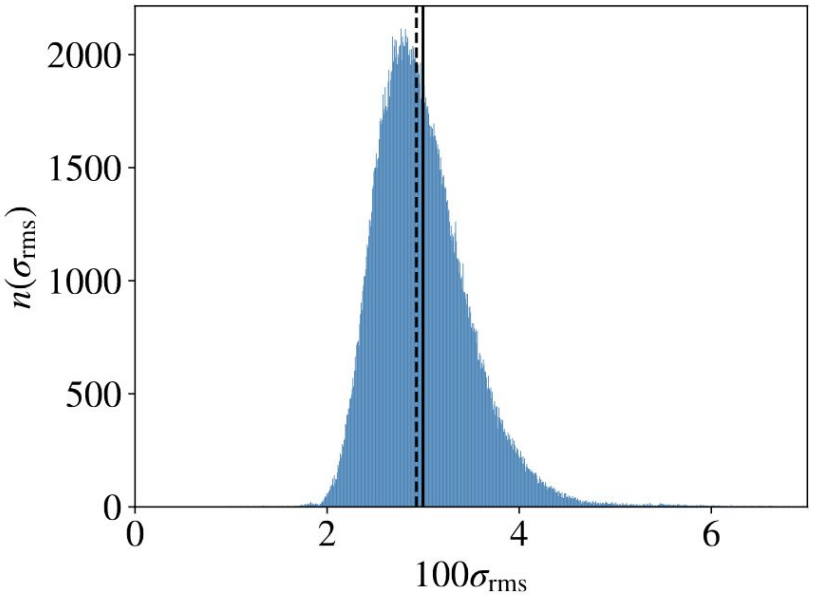
Conclusions

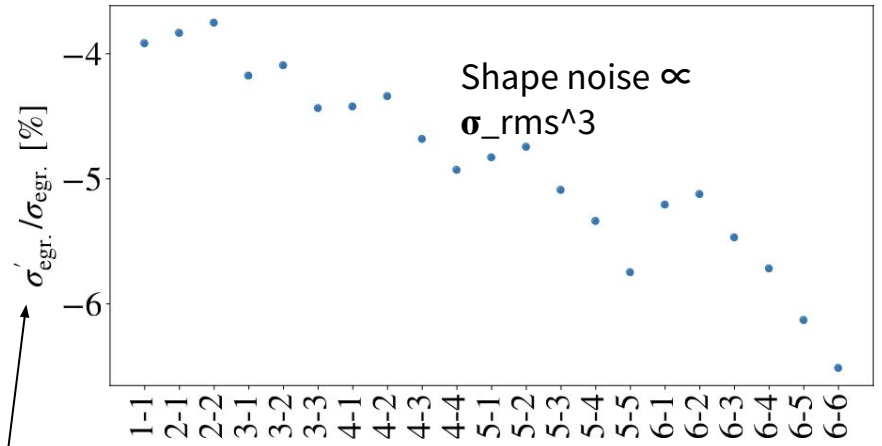
- If these results remain, it implies a 1σ tension in S_8 between KiDS-1000 and Planck 2018

- The cosmic shear 2PCF likelihood is roughly Gaussian at a given cosmology, but varies considerably with S_8, likely due to cosmic variance

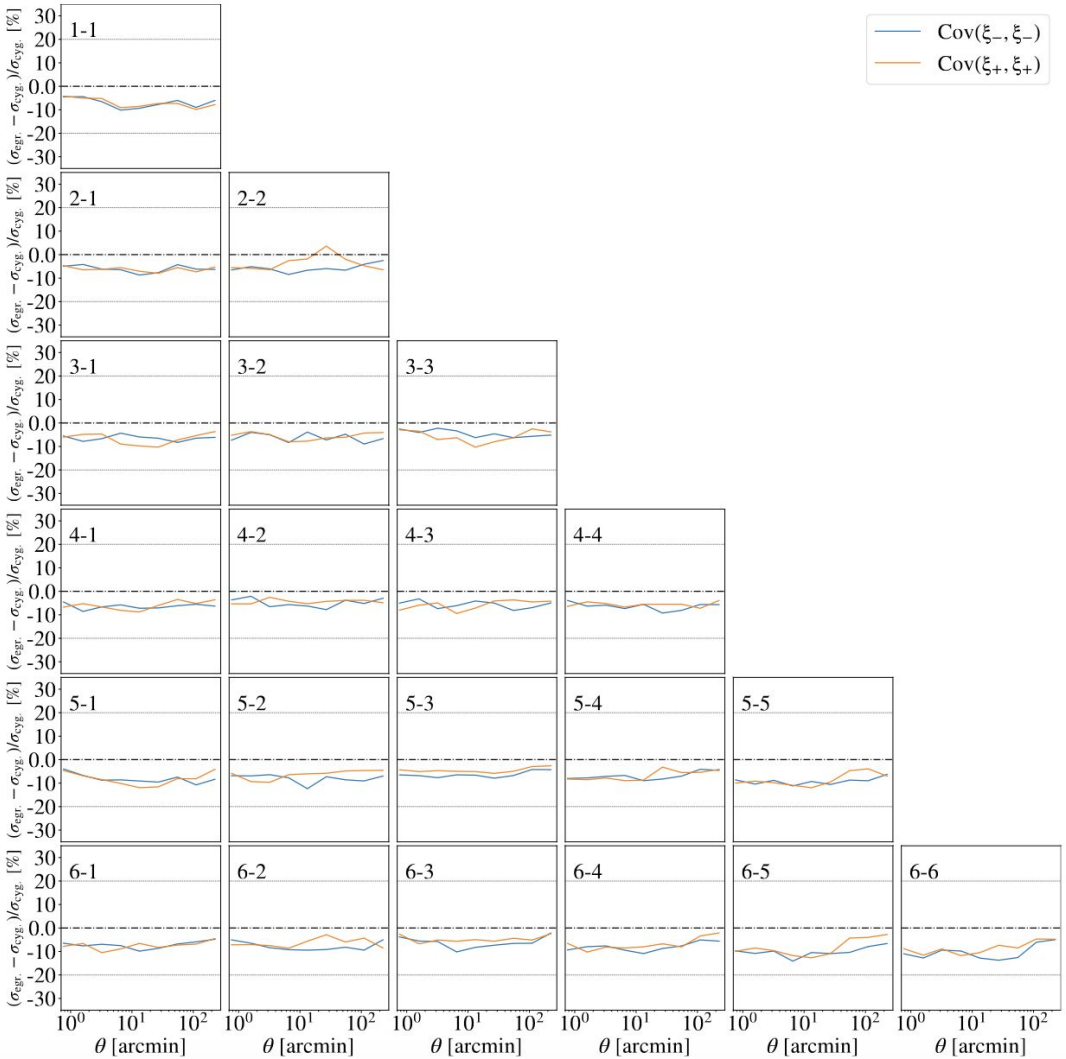
- But more tests are needed… Any ideas?

Appendix: variable depth shape noise





Δσ _rms = -7 x 10^-4


Cov(ξ−, ξ−)
Cov(ξ+, ξ+)
1-1
2-1
2-2
3-1
3-2
3-3
4-1
4-2
4-3
4-4
5-1
5-2
5-3
5-4
5-5
6-1
6-2
6-3
6-4
6-5
6-6
(σgpr. − σcyg.)/σcyg. [%]
θ [arcmin]