Preparations for the analysis of the Dark Energy Survey Year 3 data of cosmic shear, clustering and CMB lensing

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WEBINAIRE ACTION DARK ENERGY

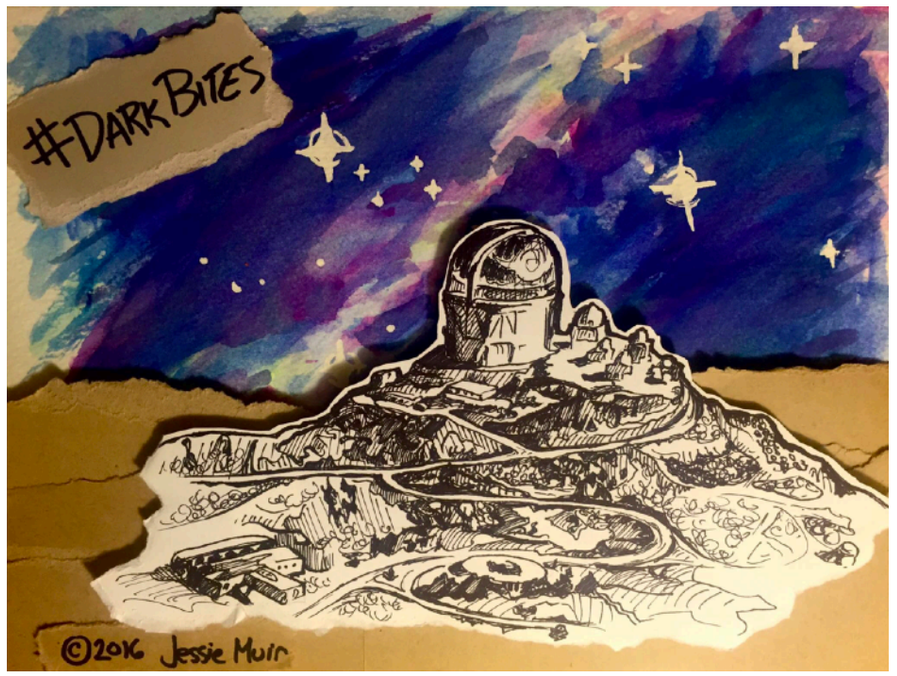
FEBRUARY 9TH 2021

THE DARK ENERGY SURVEY

Penn
UNIVERSITY *of* PENNSYLVANIA

Humans of DES Y3

- **Dark Energy Survey Year 3 Key Project**
  - @TheDESurvey : ~400 scientists from 25 institutions in 7 countries (USA, UK, Spain, Brazil, Switzerland, Germany, Australia)
  - DES Y3 shear+clustering KP : >100 people over 3 years from DES (+SPT)
- **Schedule**
  - First batch of papers released in Nov-Dec (15/29 papers), check out #darkbites!
  - See https://www.darkenergysurvey.org/des-year-3-cosmology-results-papers/

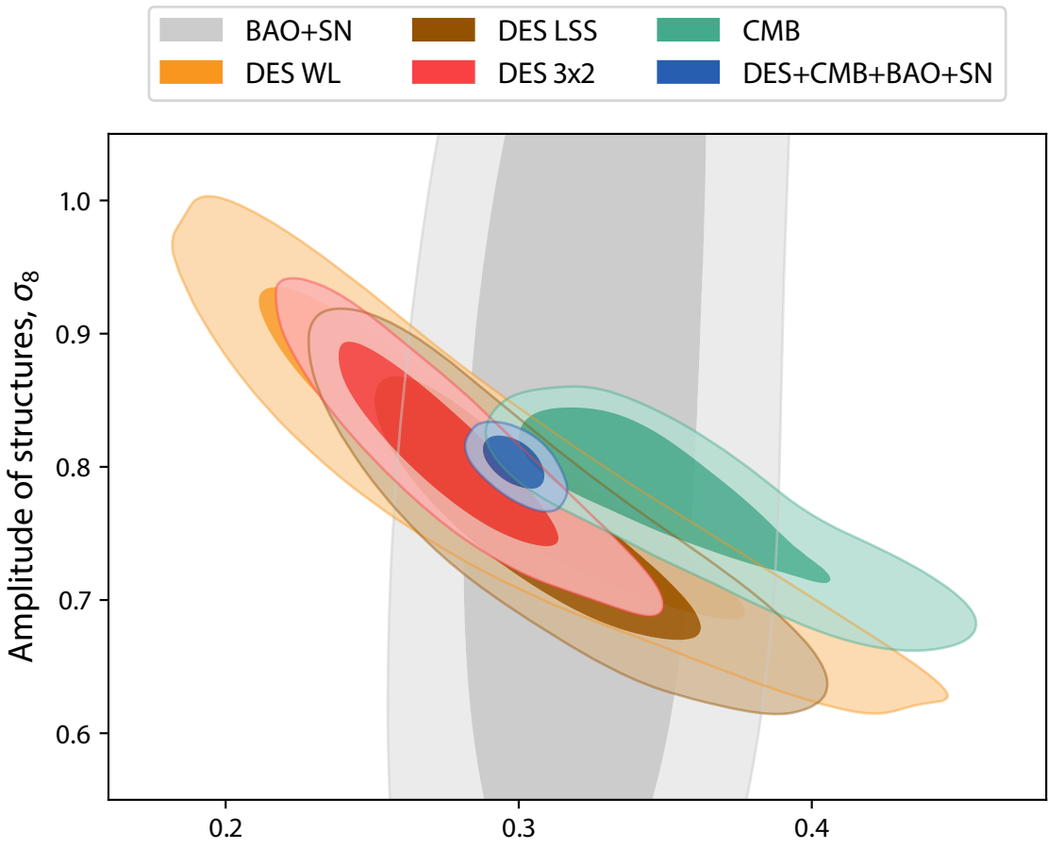


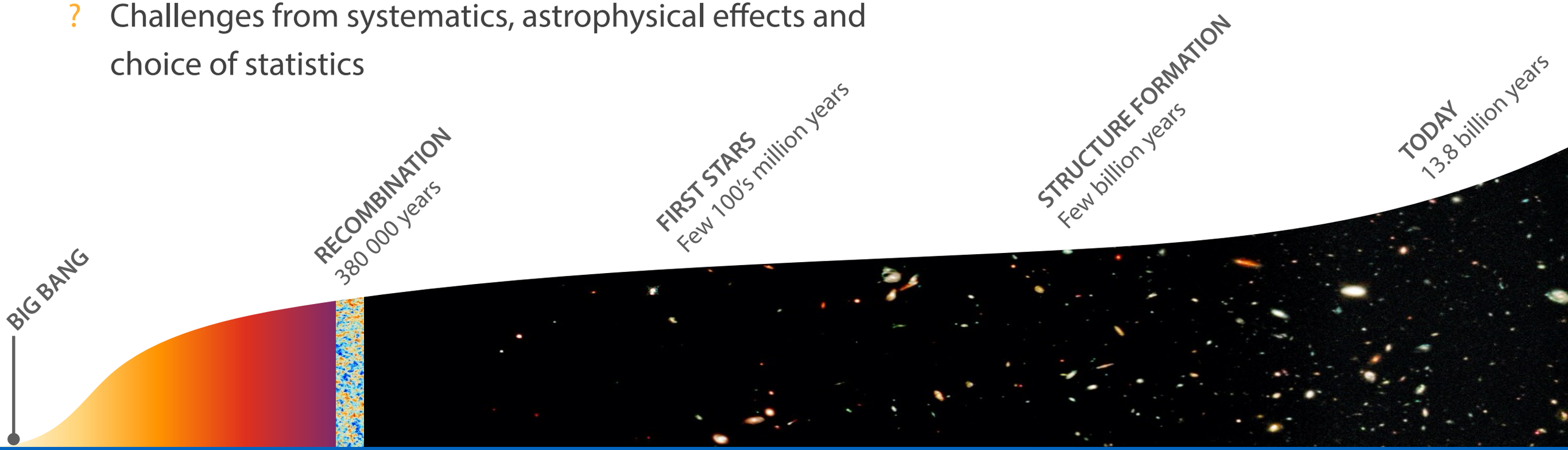
ΛCDM and cosmic shear

- **Tensions in current ΛCDM paradigm on H_0, σ_8**
  1. Early (CMB) *vs* late Universe (BAO, SNIa, LSS+WL)
  2. Geometry *vs* growth, aka background *vs* structure
  - » Combinations of probes to break degeneracies
- **Weak lensing of galaxies by large-scale structure**
  - Ongoing optical+NIR precursor surveys : DES, HSC, KiDS
  - Next-generation surveys : Rubin/LSST, Euclid

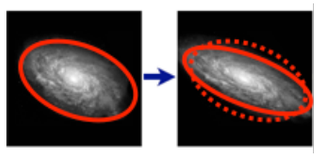
+ Probes growth *and* geometry → structure and DE $w(z)$

? Challenges from systematics, astrophysical effects and choice of statistics



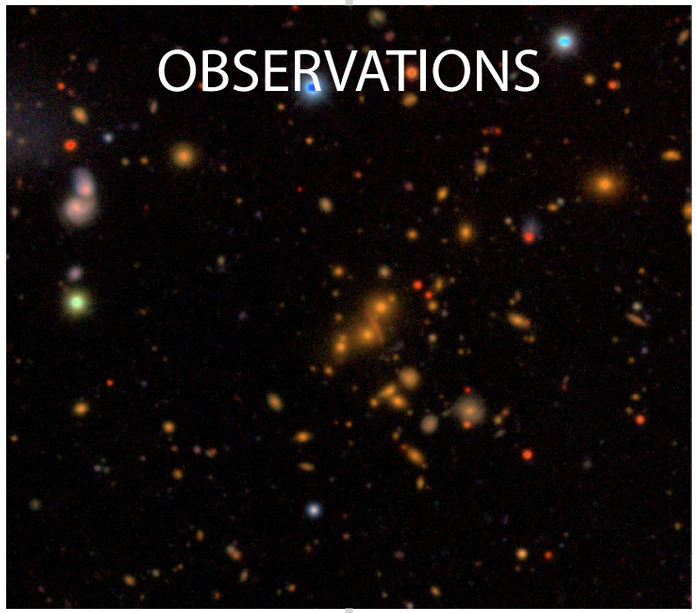


Cosmic shear pipeline



ELLIPTICITIES

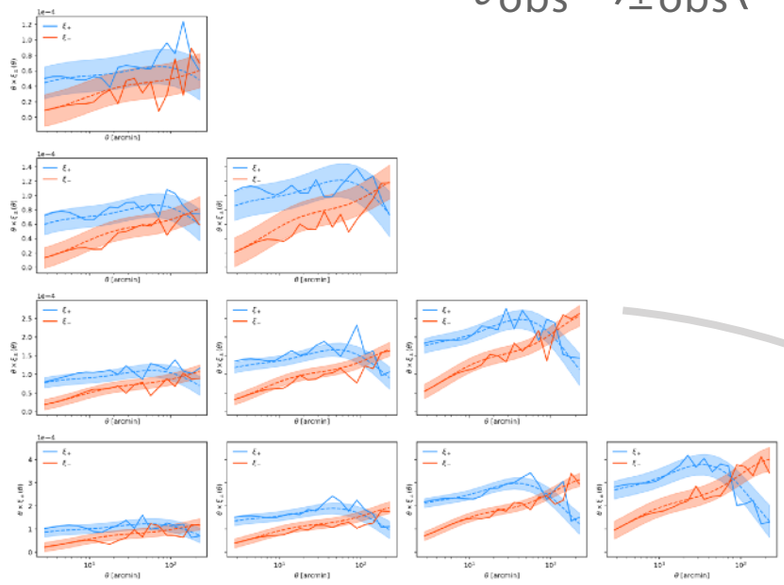
e_1/e_2



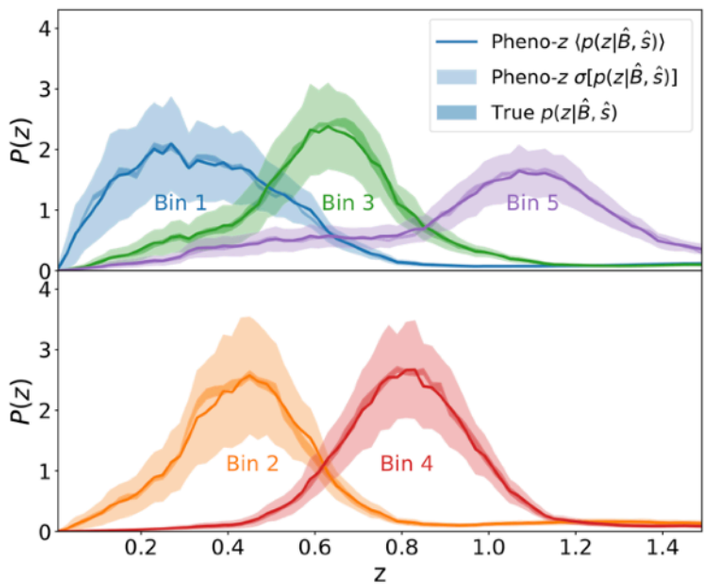
FLUXES

griz

2PT STATISTICS $\widehat{C}_{\ell\,\mathrm{obs}}^{ij}$ / $\widehat{\xi}_{\pm\,\mathrm{obs}}^{ij}(\theta)$



REDSHIFT DISTRIBUTIONS

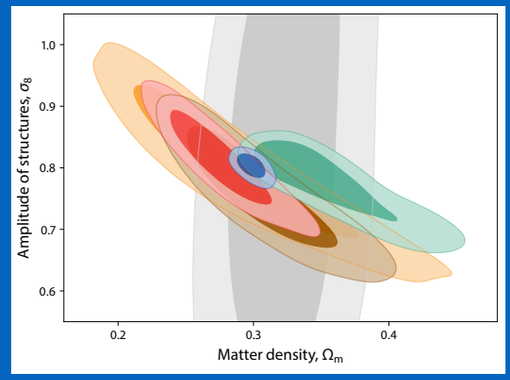


COSMOLOGICAL SIGNAL

- Matter power spectrum P_{NL}
- Lensing window functions q^i

$$C_\ell^{ij} = \int_0^{\chi_H} \mathrm{d}\chi \, \frac{q^i(\chi) q^j(\chi)}{\chi^2} P_{\mathrm{NL}}\left(k = \frac{\ell + 1/2}{\chi}, \chi\right)$$

COSMOLOGICAL PARAMETERS

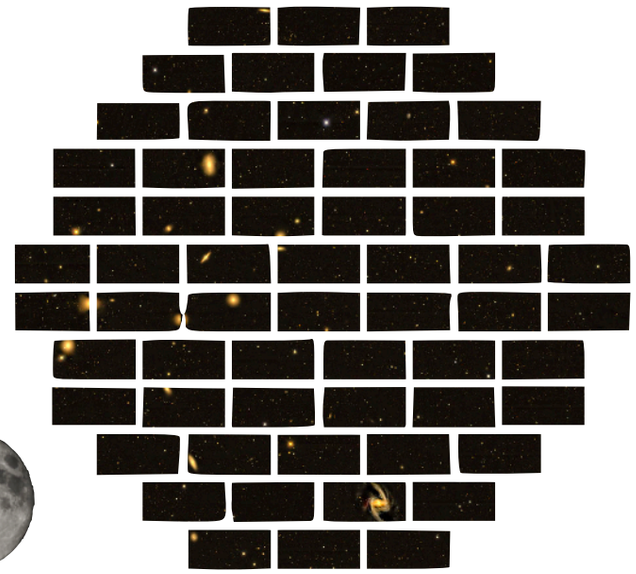


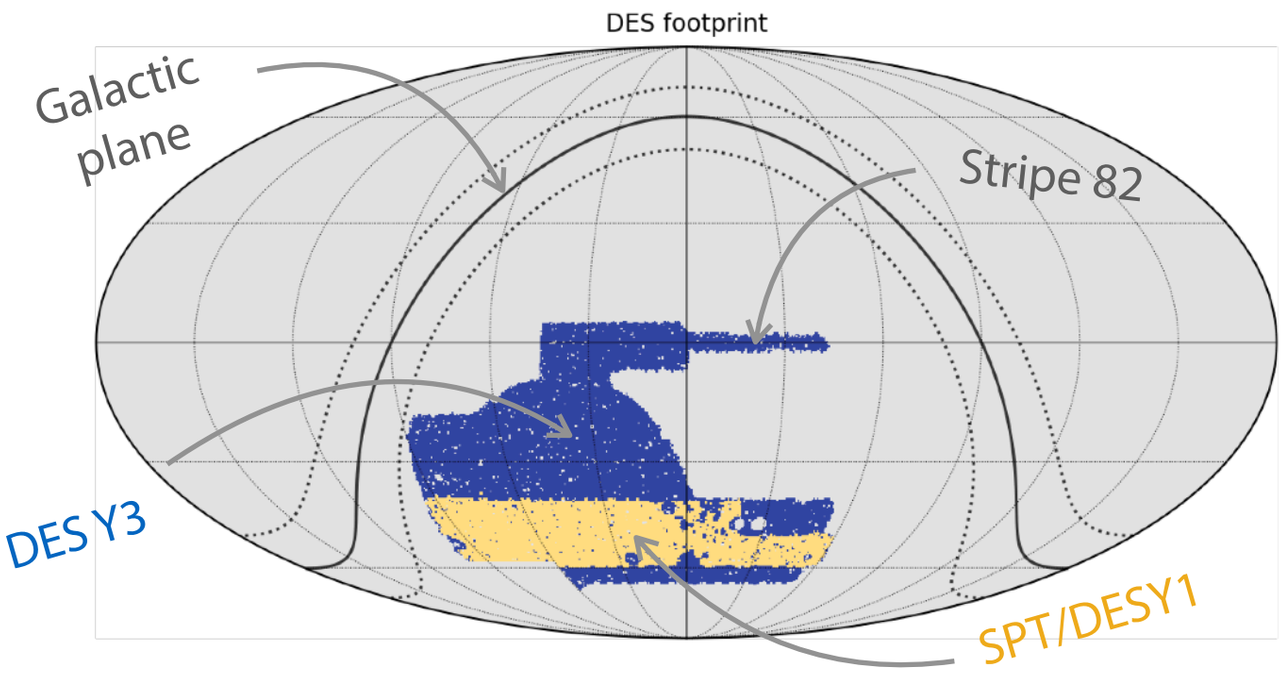
SYSTEMATIC UNCERTAINTIES

- Shear calibration m_i
- Redshift uncertainties Δz_i
- Intrinsic alignements model

The Dark Energy Survey

- **Blanco 4-meter telescope** at Cerro Tololo (CTIO) in Chile
- **Dark Energy Camera** (DECam)
  - 3.0 deg² field-of-view, 70 CCD chips, 570 Mpix, *griz(Y)* filters
  - Seeing ~0.9′ in *r*-band, magnitude i_{AB}<23.0, *r*<23.5
- **Survey(s)**
  - 5000 deg² footprint + deep fields, observed 2013-2019
  - Overlaps with SPT, BOSS and COSMOS
  - DR2 (6 years) of 543M galaxies + 145M stars to *i*~23.8





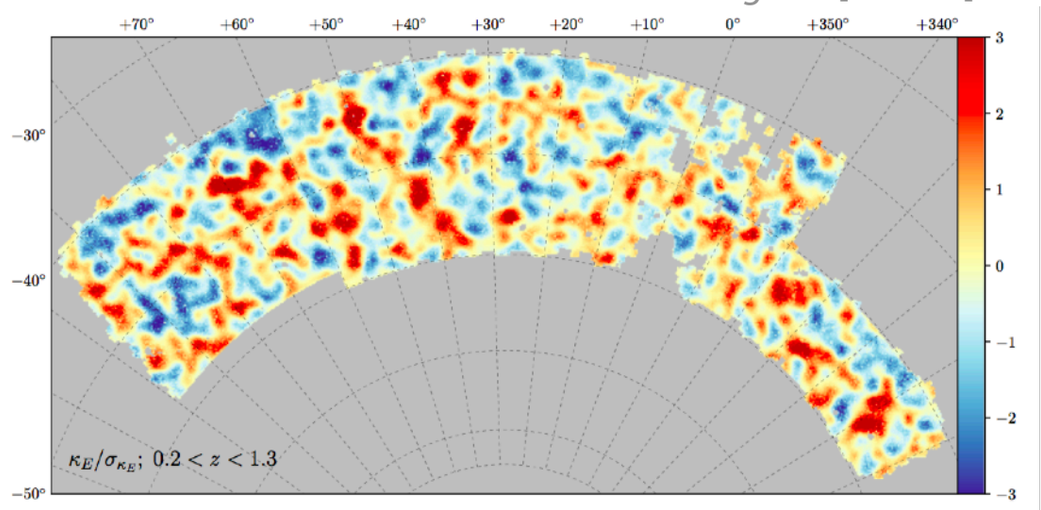
	DES	HSC	KiDS +VIKING
FoV [deg²]	**3.0**	1.8	1.0
Area [deg²]	**5000**	1400	1350
Filters	griz(Y)	grizY	**ugriz +ZYJHKS**
Seeing [arcsec]	0.9	**0.6**	0.7
Source density [gal/arcmin²]	~7	**~22**	~9
Depth	r~23.5	**i~24.5**	r~23.5

Hildebrandt

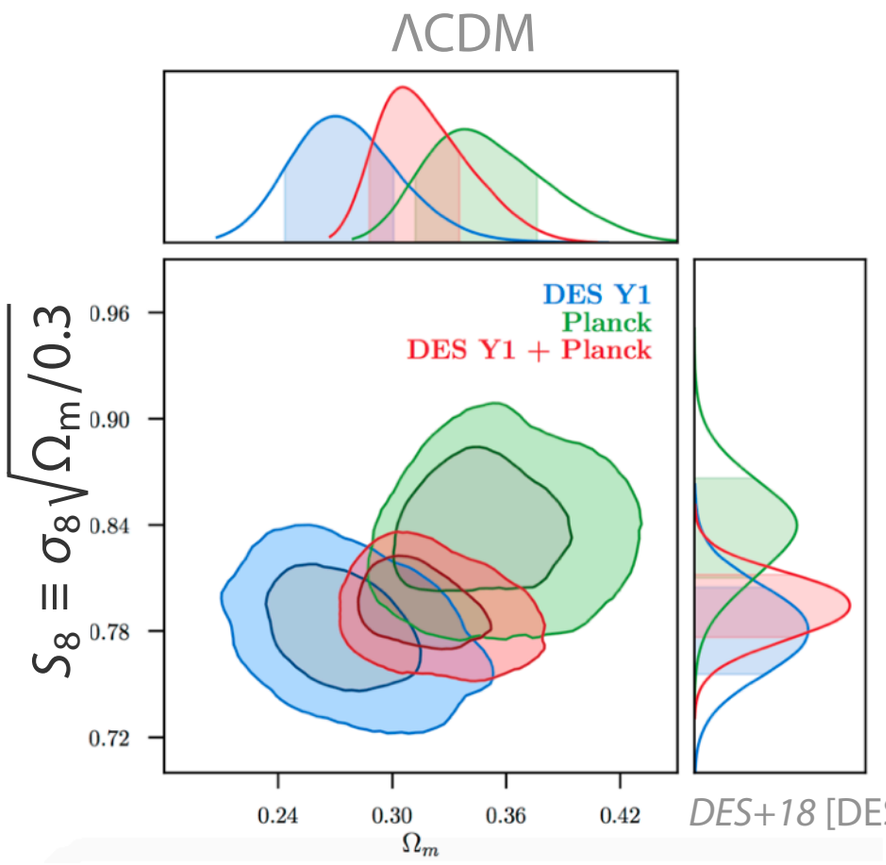
DES Y1 highlights

- **DES Y1 weak lensing**
  - Shape catalogs
    - 26M "source" galaxies (Zuntz+18), 1321 deg^2
    - IM3SHAPE + METACALIBRATION
  - Convergence maps (mass map)
- **Cosmological constraints from shear + clustering**
  - 3x2pt analysis with REDMAGIC "lens" galaxies

Chang+18 [DES Y1]

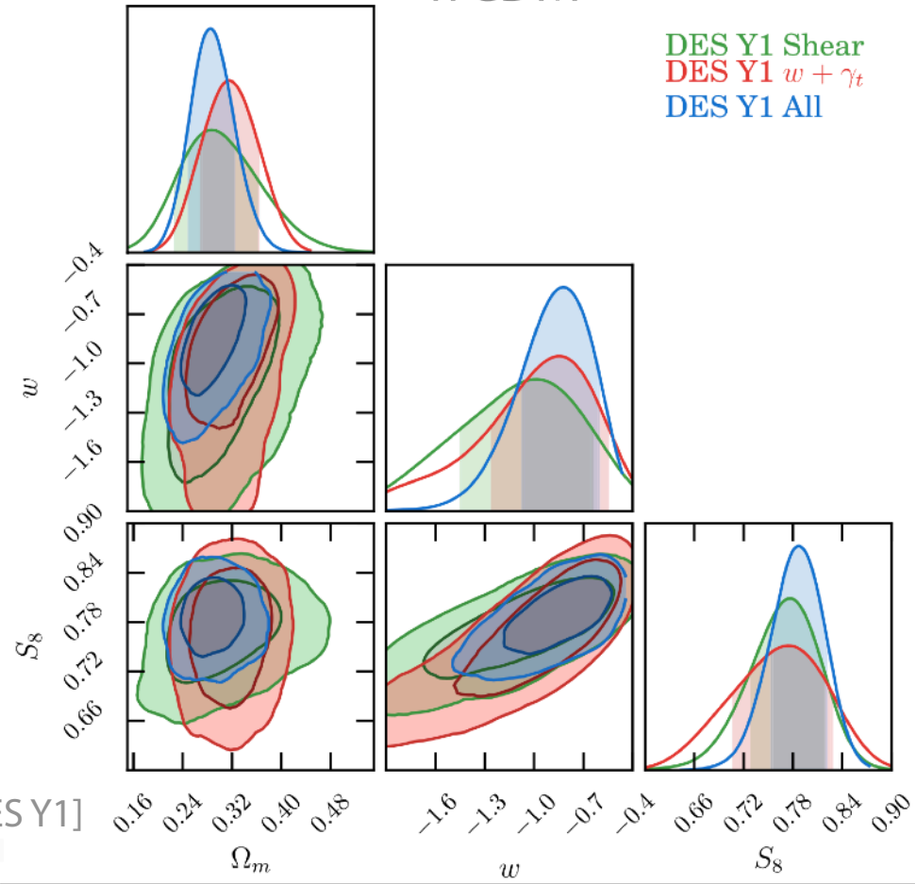


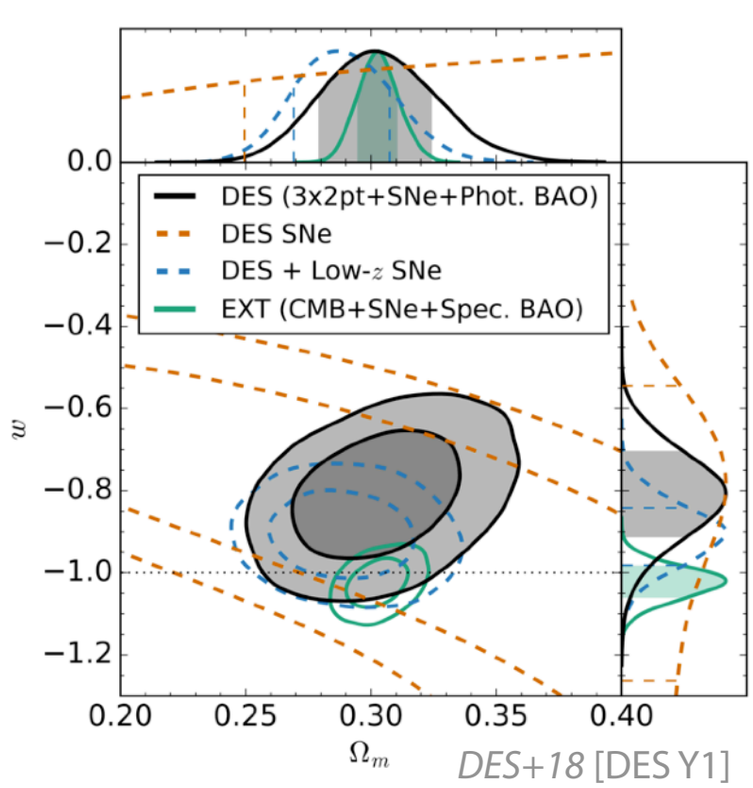
ΛCDM



DES+18 [DES Y1]

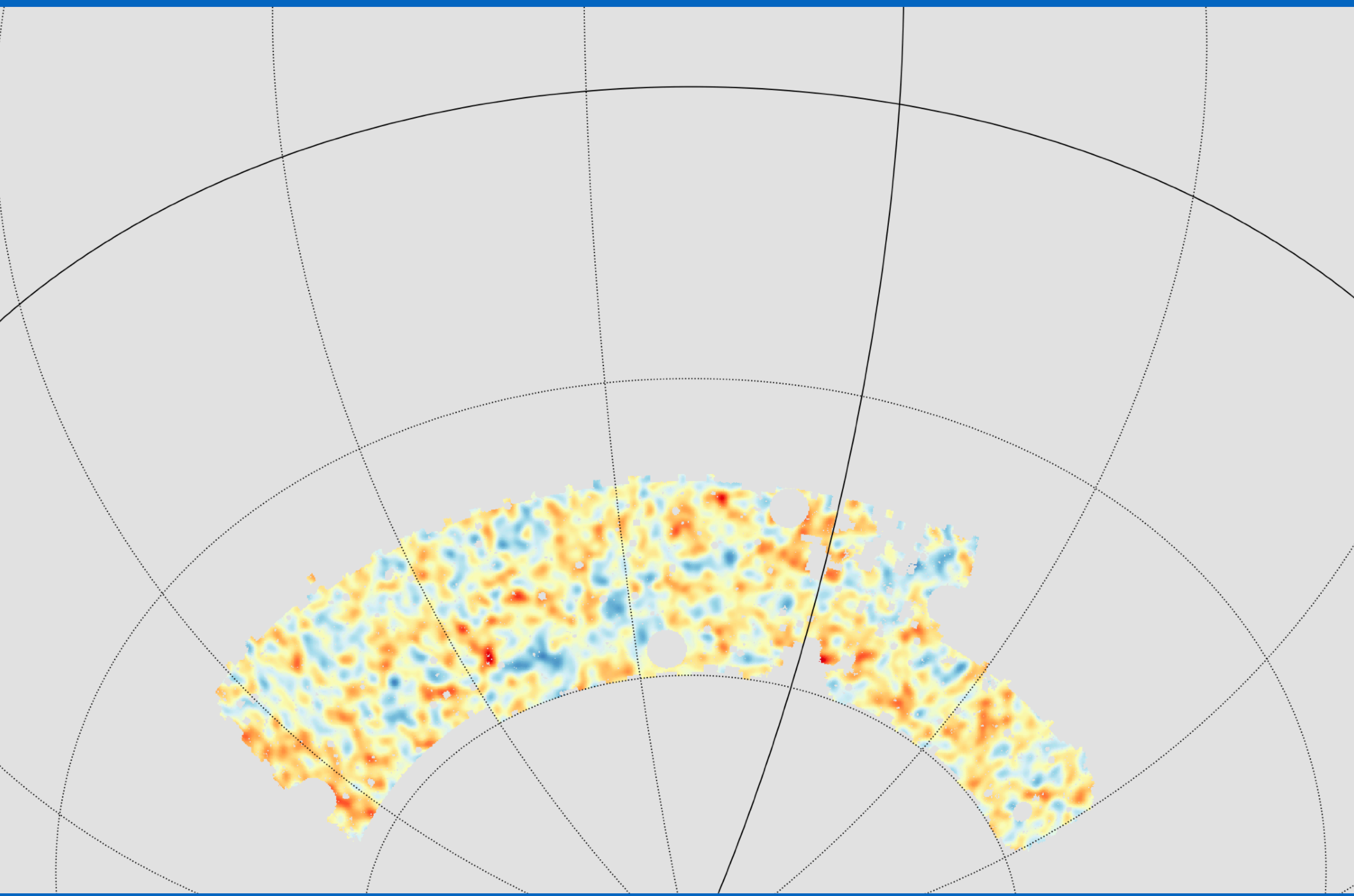
wCDM



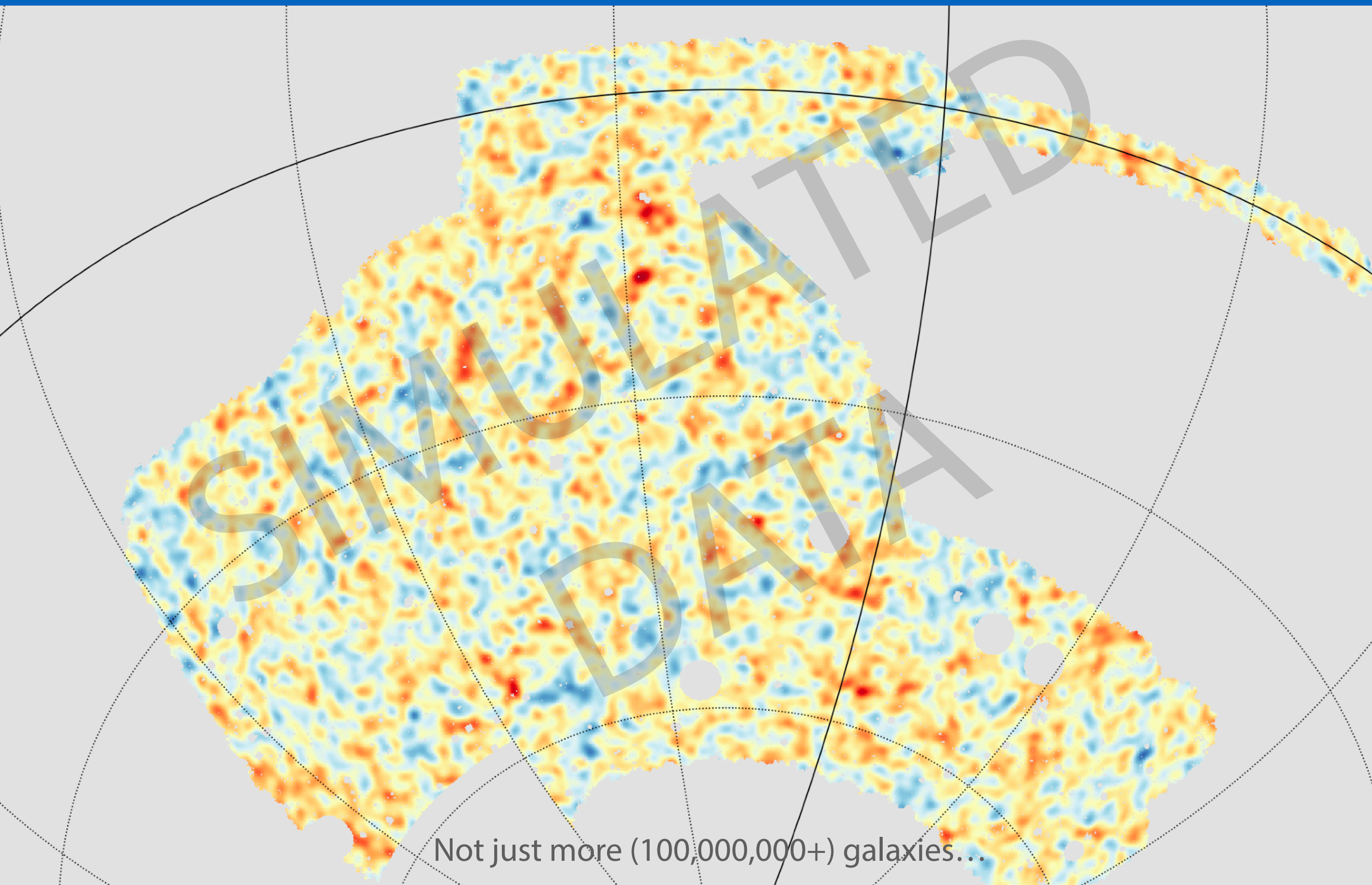


DES+18 [DES Y1]

DES Y1 to Y3



DES Y1 to Y3

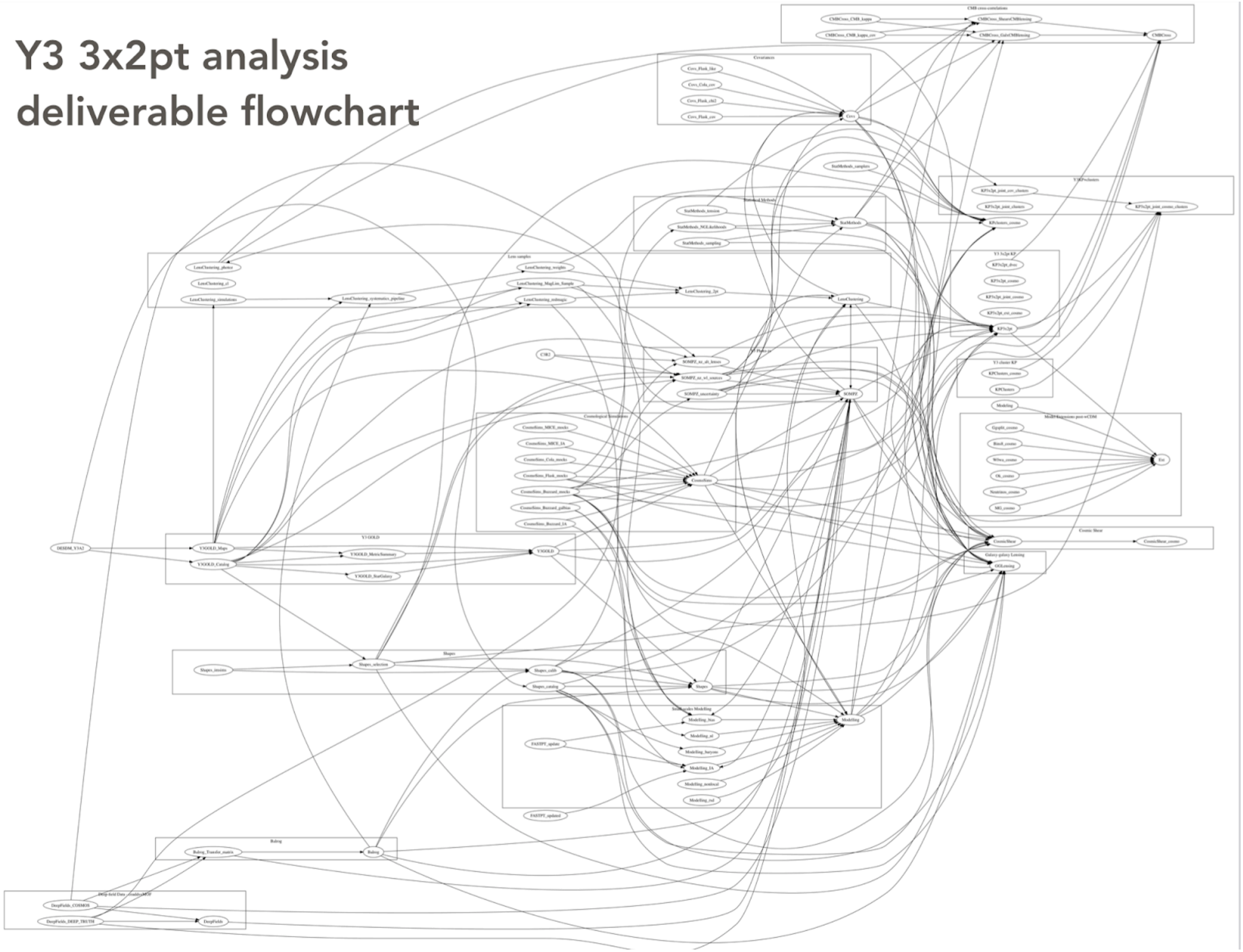


Not just more (100,000,000+) galaxies…

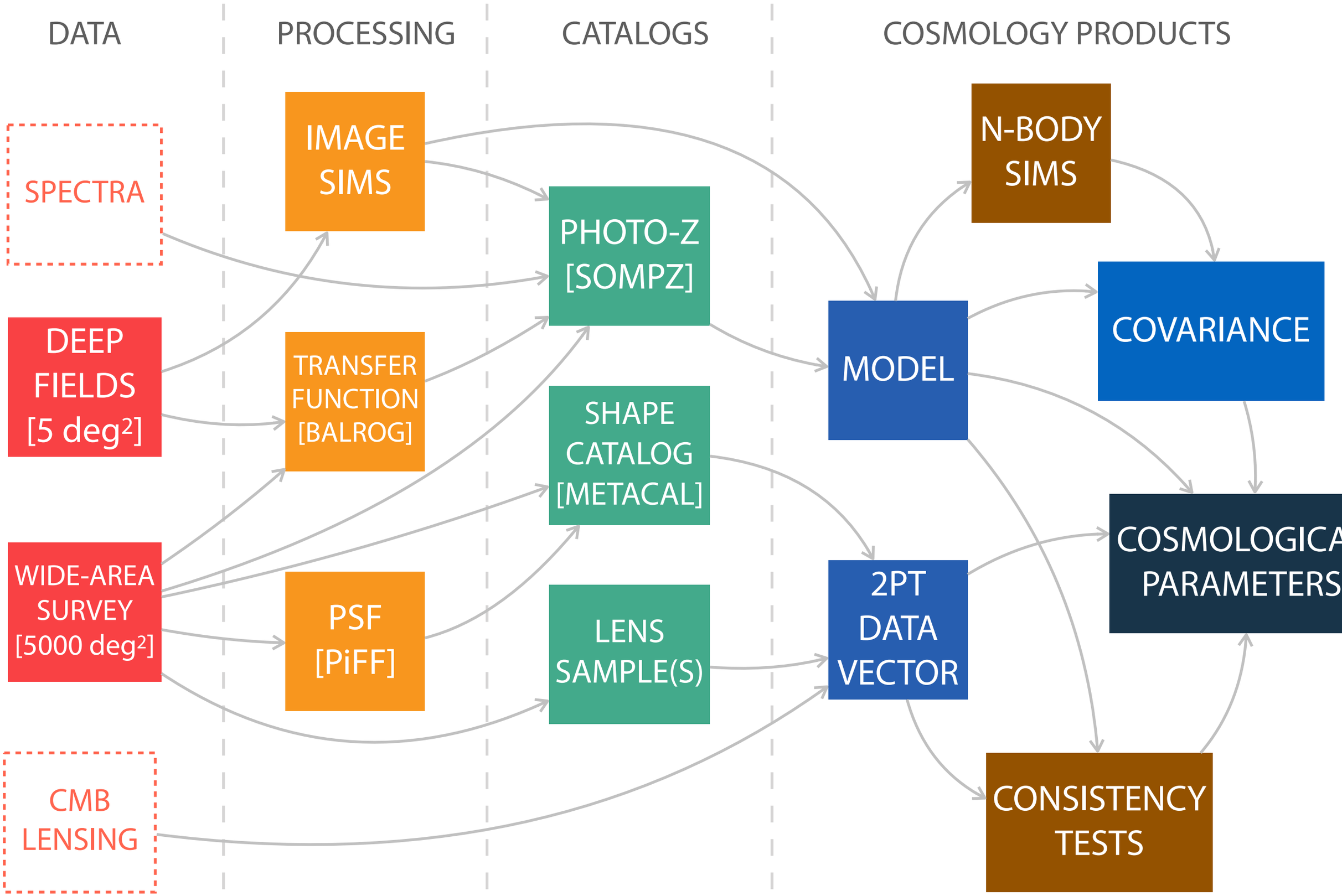
but also many innovations throughout the analysis!

DES Y3 Key Project

Y3 3x2pt analysis deliverable flowchart



DES Y3 Key Project



Outline

- DES Y3 cosmic shear : from images to cosmological parameters
  - METACALIBRATION catalog
  - Shape catalog testing
  - Redshift distributions
  - Modelling
- DES Y3 multiprobe analyses : 3×2pt and 5×2pt
  - Forecasts for multiprobe analysis
  - Internal and external consistency tests
  - Beyond ΛCDM

DES Y3 cosmic shear : from images to cosmological parameters

DES Y3 data

- **From DR1 to "GOLD" to METACAL**
  - Nearly 5000 deg^2 of *grizY* imaging, ~389 million GOLD objects, classification star/galaxy 99% i_{AB}<22.5
  - GOLD depth *S/N*~10 for extended objects up to *i*~23.0 (50% depth wrt Y6)
  - Effective area of 4143 deg^2, median seeing *i*=0.89"

DR1

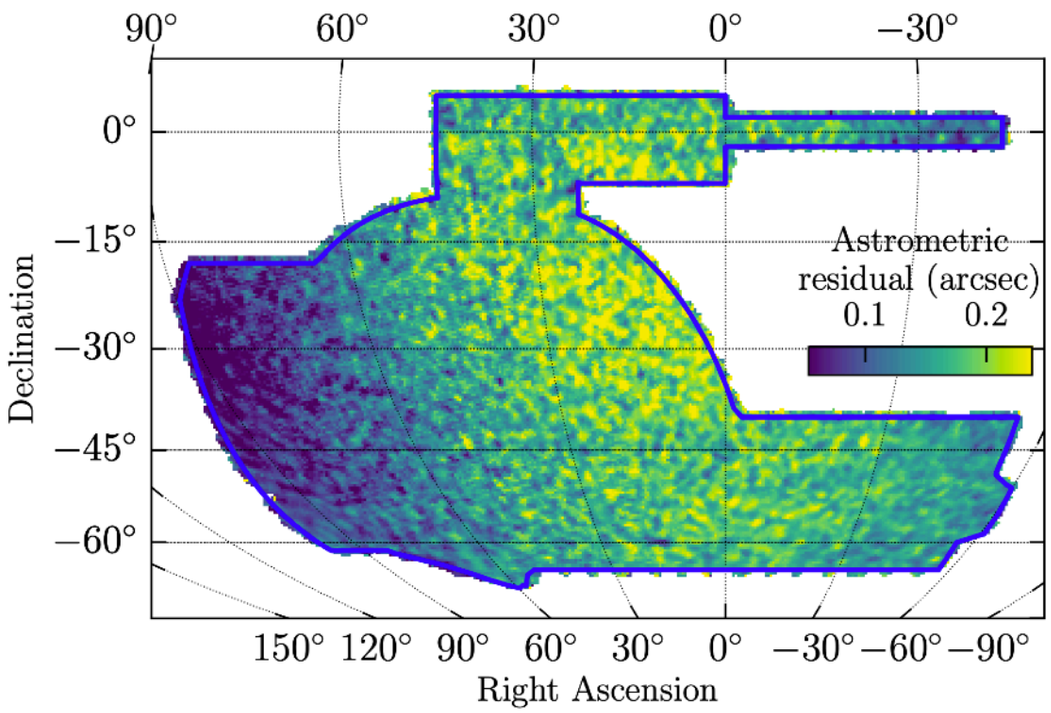
- SEXTRACTOR detection on coadds in *grizY*

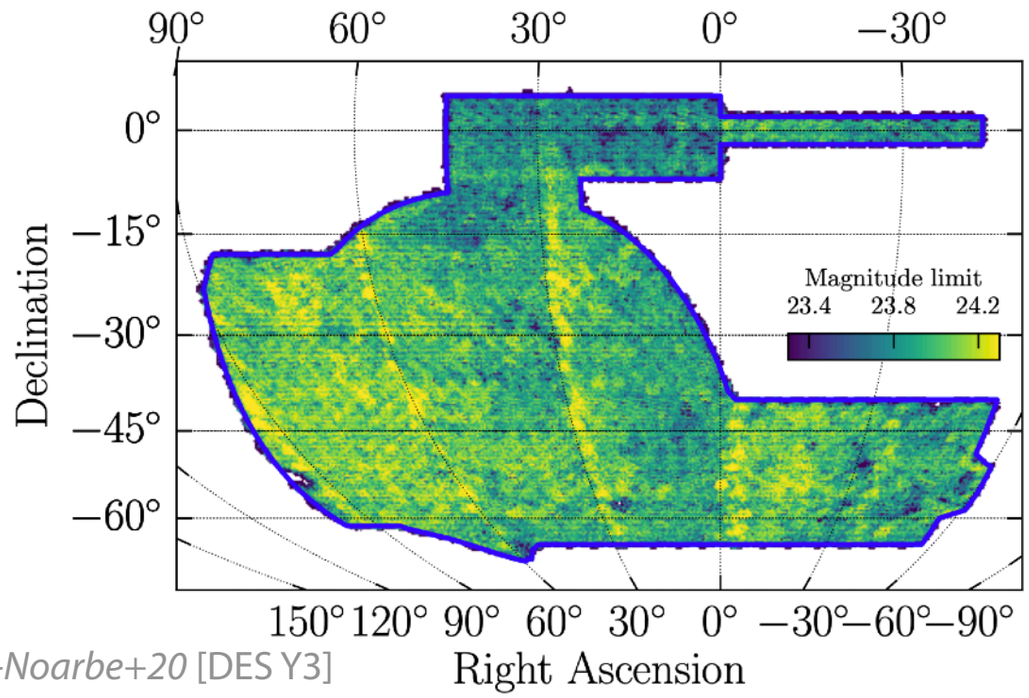
GOLD

- NGMIX-based multi/single object photometry in *griz*
- Survey depth, bad regions and clustering weights

METACAL

- Shapes from gaussian fit to PSF-deconvolved (un)sheared images
- Shear responses $\mathbf{R}_\gamma$

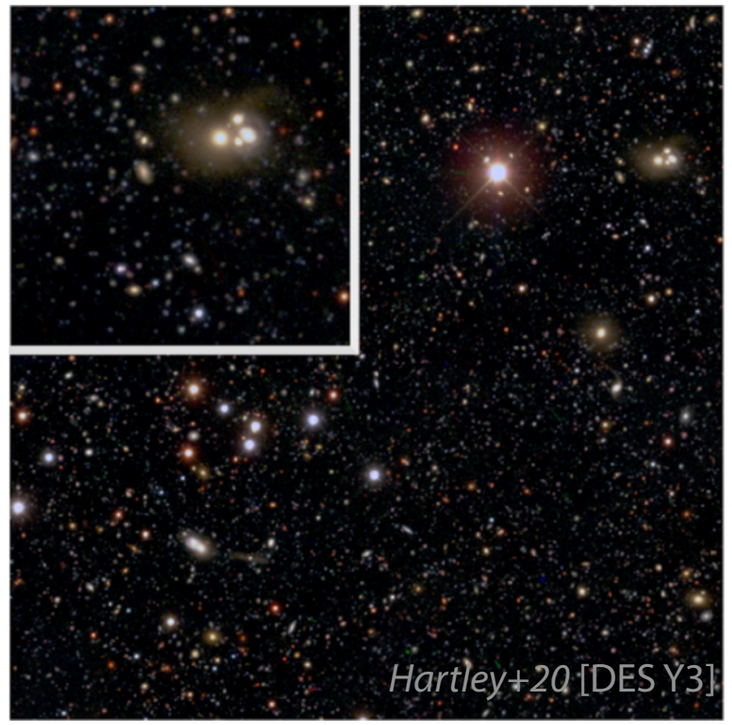




Sevilla-Noarbe+20 [DES Y3]

Deep fields and survey transfer function

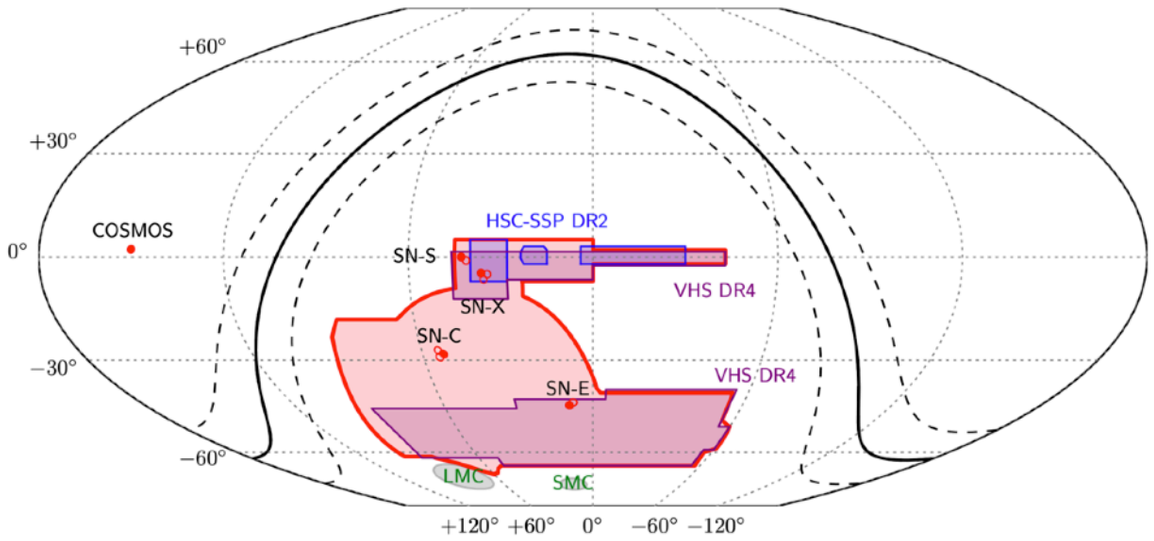
- **Deep fields**
  - DES+VISTA filters *ugrizJHKs*, 5.88 deg², 1.6 million objects with *i*<25
  - $(S/N)_{deep} \sim \sqrt{10} \times (S/N)_{wide}$ with photometry compared to COSMOS/PAUS
  - Used for Balrog, image simulations and photo-z

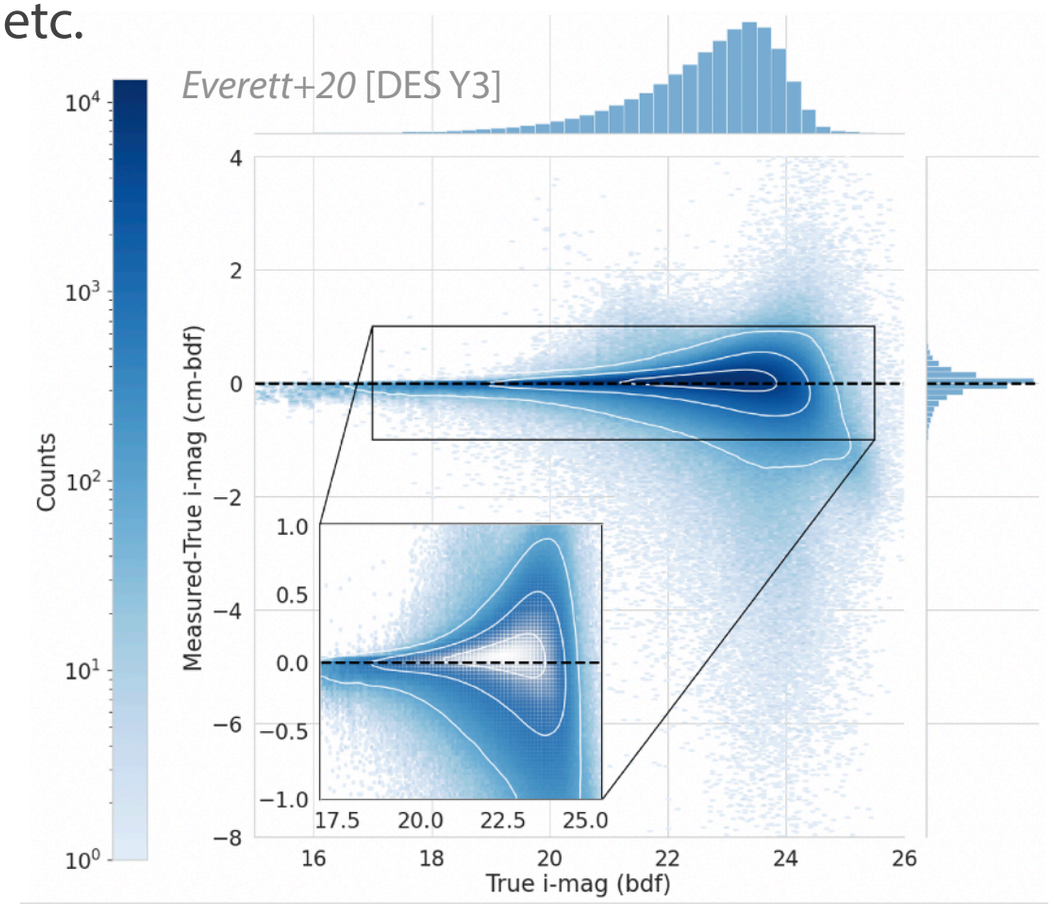


- **Balrog (survey transfer function)**

1. Injection of DF galaxies into 20% of wide-field images processed with Y3 pipeline, incl. coadds, detection, SOF/MOF photometry, etc.
2. Matching with input to measure transfer function

- Used in photo-z calibration and lens magnification bias

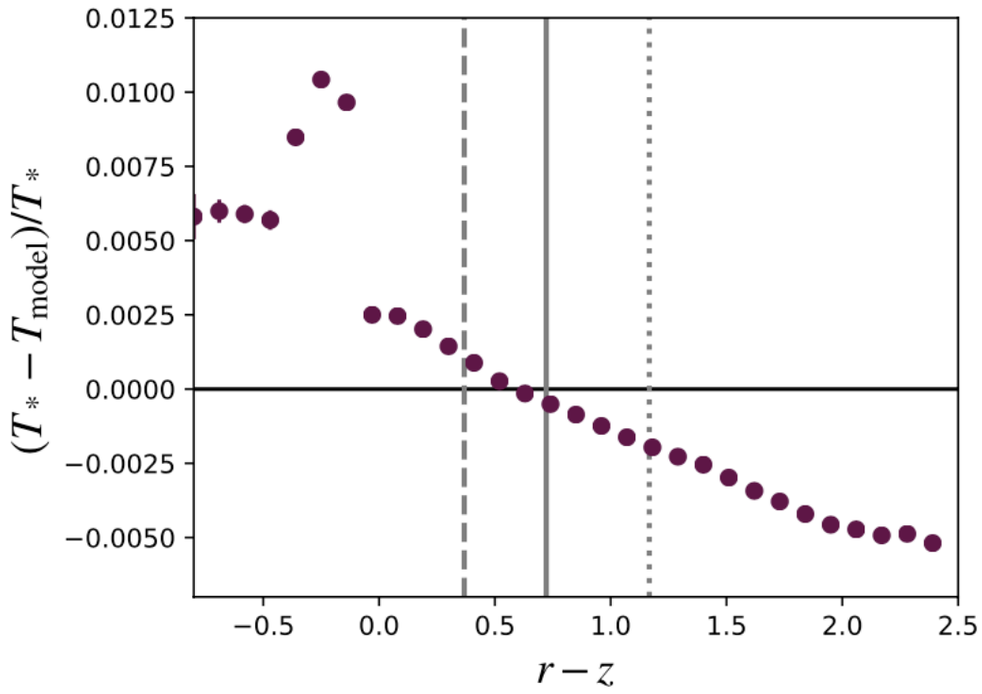


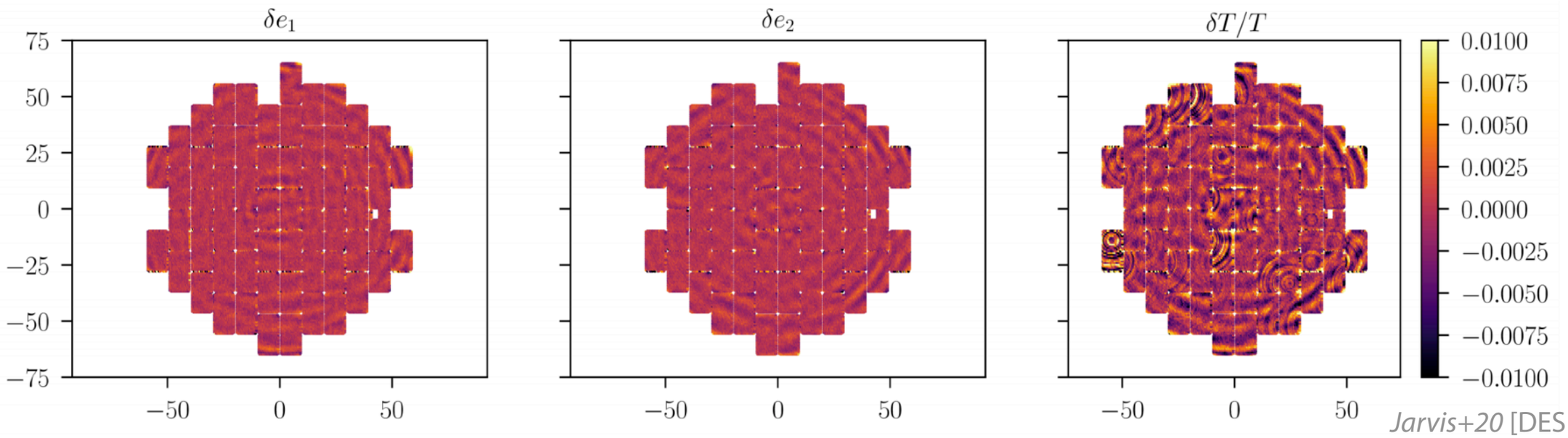


Point spread function

- **PiFF**
  - PIXELGRID model in sky coordinates to account for astrometric distorsions, with full FoV modelling
  - Polynomial interpolation with delayed solution coeff (helps with missing data, eg cosmic rays)
- **DES Y3 PSF tests**
  - Brighter-fatter effect corrected in image processing, shows low residuals
  - Color dependence due to atmosphere (differential chromatic refraction) sufficiently low for Y3, ie ~cosmic variance

Jarvis+20 [DES Y3]





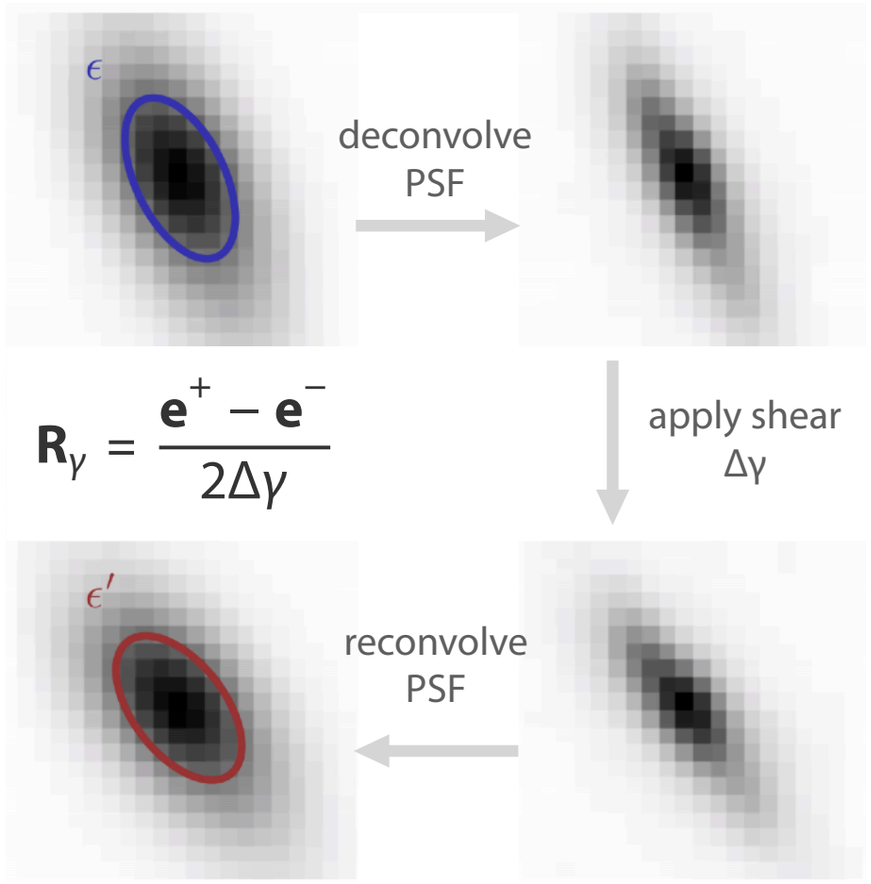
Jarvis+20 [DES Y3]

METACALIBRATION shape catalogue

- **METACALIBRATION in a nutshell** *Huff & Mandelbaum 17*
  - For any *biased* shear estimator **e**,

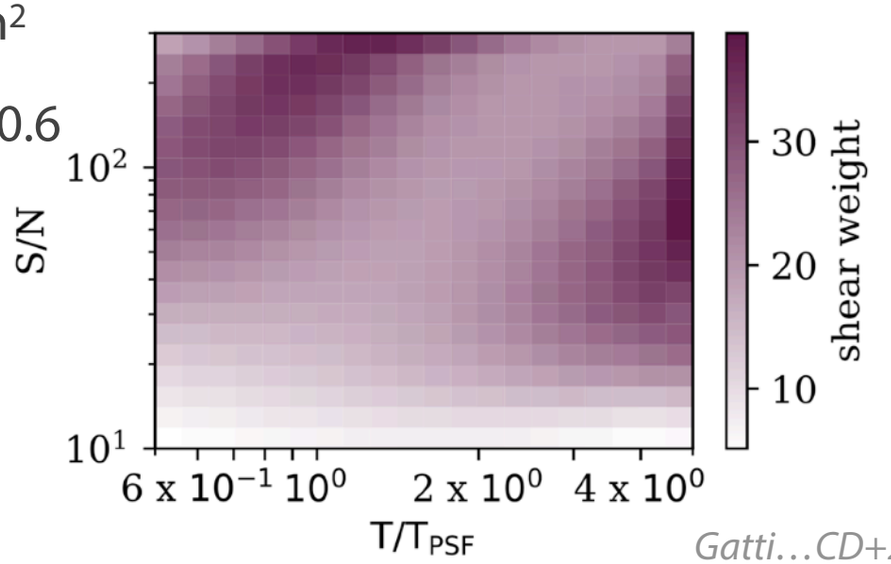
$$\mathbf{e} = \mathbf{e}|_{\gamma=0} + \gamma \cdot \underbrace{\left.\frac{\partial \mathbf{e}}{\partial \gamma}\right|_{\gamma=0}}_{\mathbf{R}_\gamma} + \mathcal{O}\left(\gamma^3\right), \text{ such that } \langle\hat{\gamma}\rangle \approx \langle \mathbf{R}_\gamma \rangle^{-1} \langle \mathbf{e} \rangle \text{ is unbiased}$$

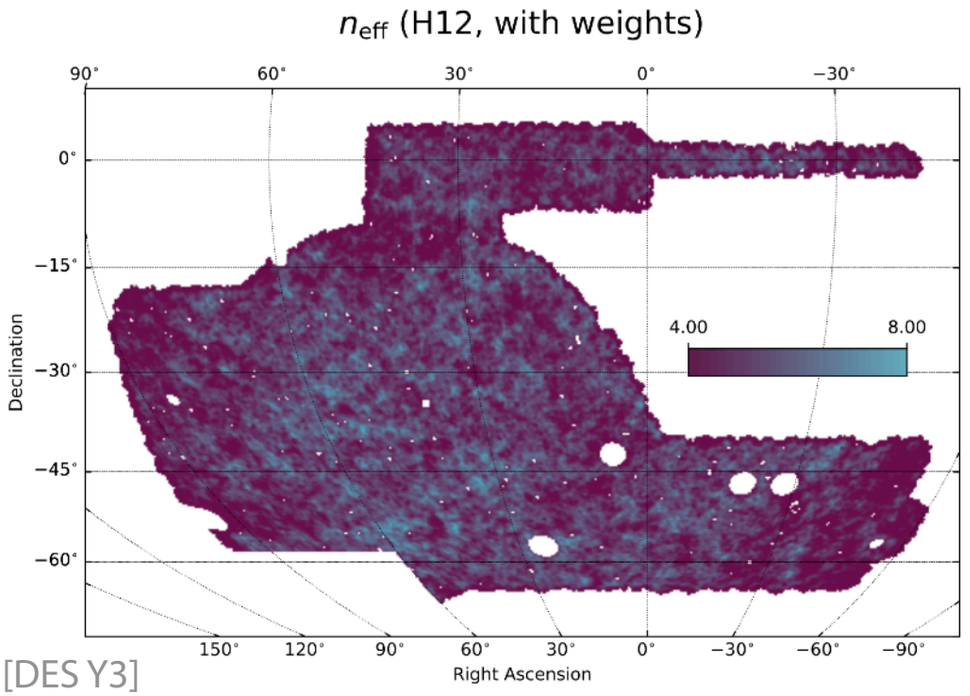
  - Mitigates model+noise biases (not blending though) and shear-dependent selection with $\langle \mathbf{R} \rangle = \langle \mathbf{R}_\gamma \rangle + \langle \mathbf{R}_s \rangle$



N. MacCrann

- **DES Y3 METACALIBRATION catalogue**
  - 100,204,026 galaxies from Y3 GOLD in *riz*
  - $10<S/N<1000$, $T/T_{\rm PSF}>0.5$ + color cuts
  - $\sigma_e = 0.261$ with inverse-variance weights(S/N,$T/T_{\rm PSF}$)
  - $n_{\rm eff} = 5.59$ gal/arcmin^2
  - Mean response $\langle \mathbf{R} \rangle \approx 0.6$





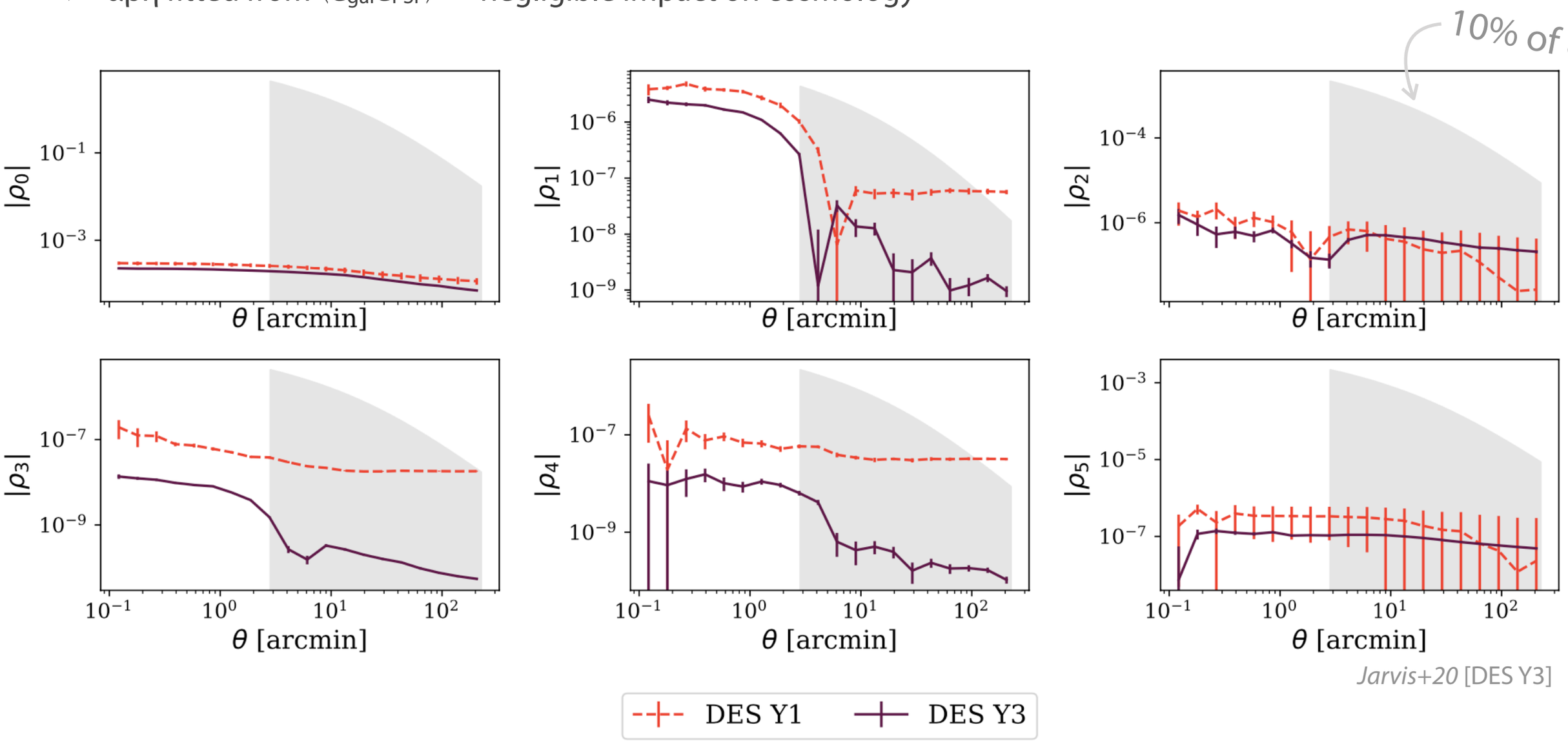
Gatti…CD+20 [DES Y3]

Shear catalogue testing : PSF

- **ρ statistics**
  - PSF contamination estimated from 20% of reserved stars with

$$\delta\mathbf{e}_{\rm PSF} = \alpha\mathbf{e}^\star + \beta\left(\mathbf{e}^\star - \mathbf{e}^\star_{\rm model}\right) + \eta\mathbf{e}\left(1 - T^\star_{\rm model}/T^\star\right)$$

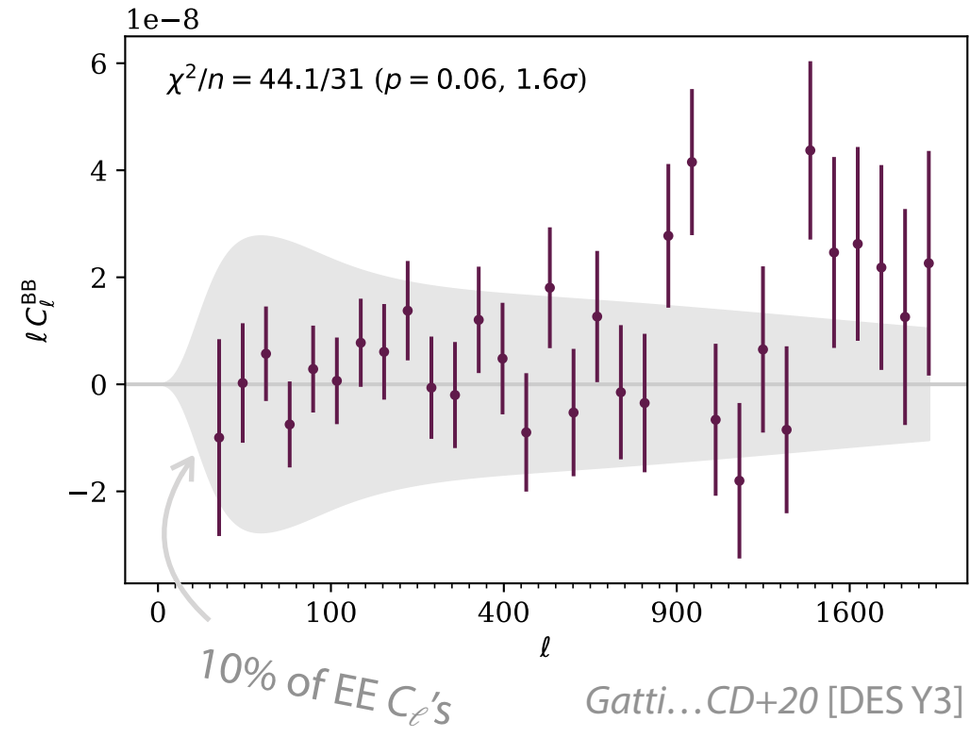
  - ρ statistics are auto/cross correlations of ⤴
  - αβη fitted from $\langle \mathbf{e}_{\rm gal}\mathbf{e}_{\rm PSF}\rangle \Rightarrow$ negligible impact on cosmology



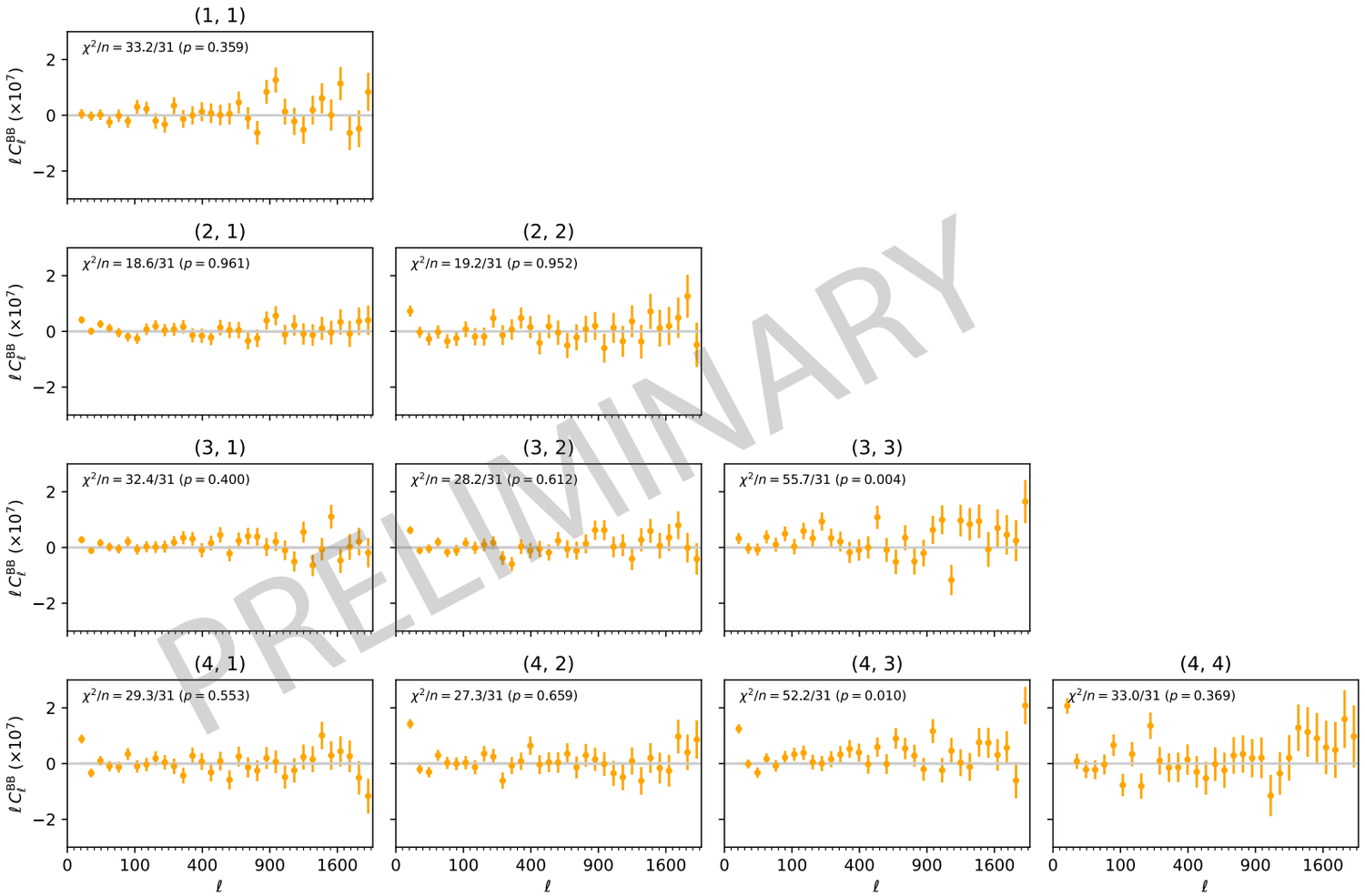
Jarvis+20 [DES Y3]

Shear catalogue testing : B-modes

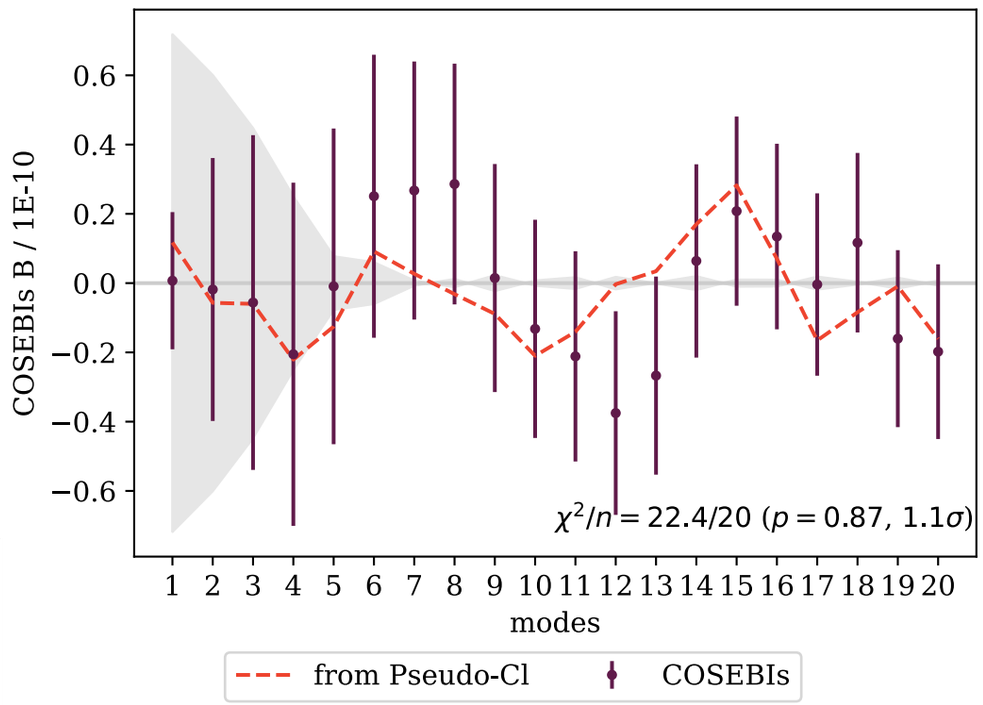
- **Non-tomographic B-mode tests**
  - Test for contamination by systematics (eg PSF additive bias) and negligible cosmological signal (higher-order or IAs)
  - Two complementary methods: pseudo-C_ℓ's for small scales, COSEBIs have better separation
  - No sign of contamination + consistency of estimators



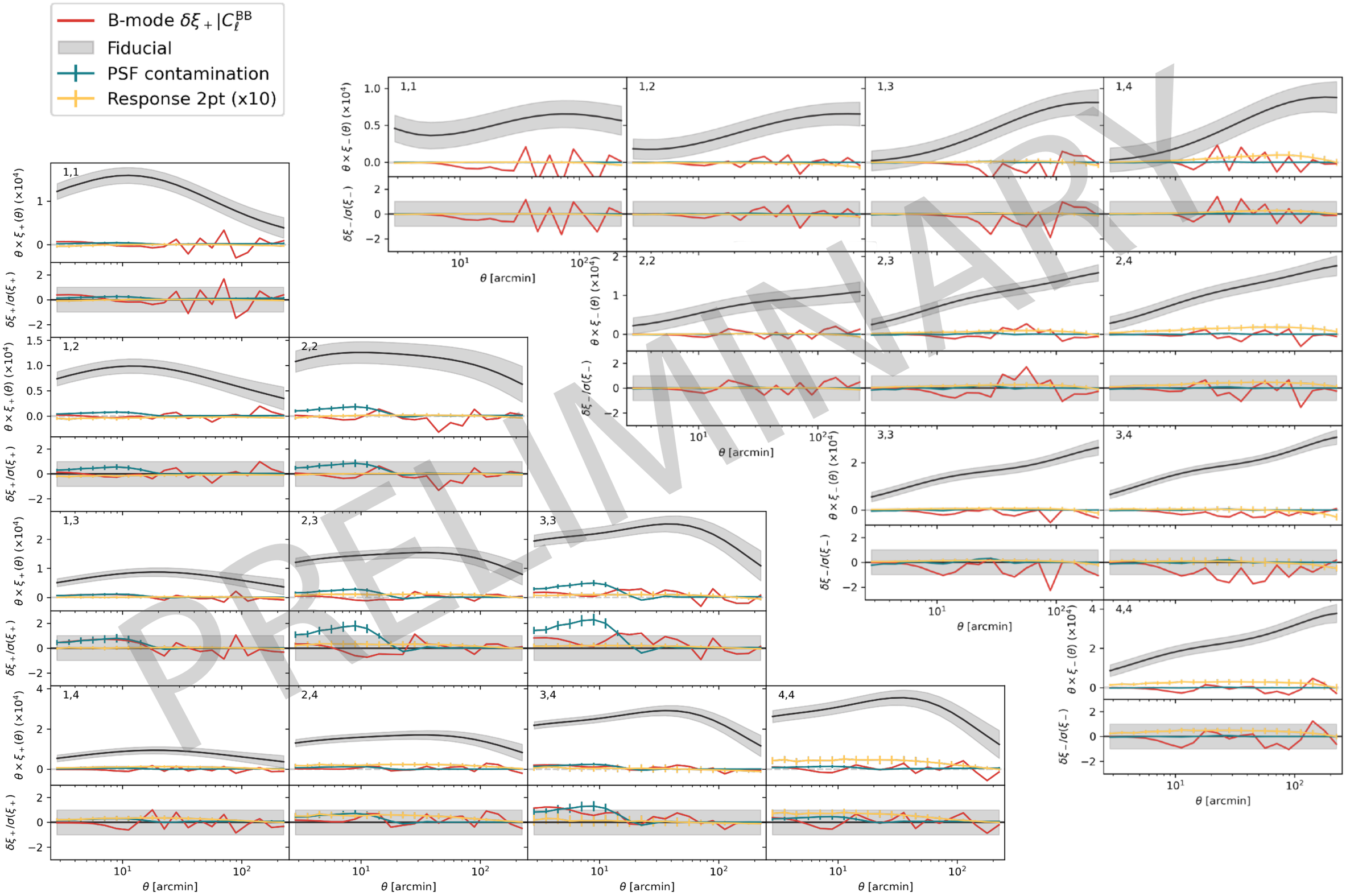
Gatti…CD+20 [DES Y3]



PRELIMINARY

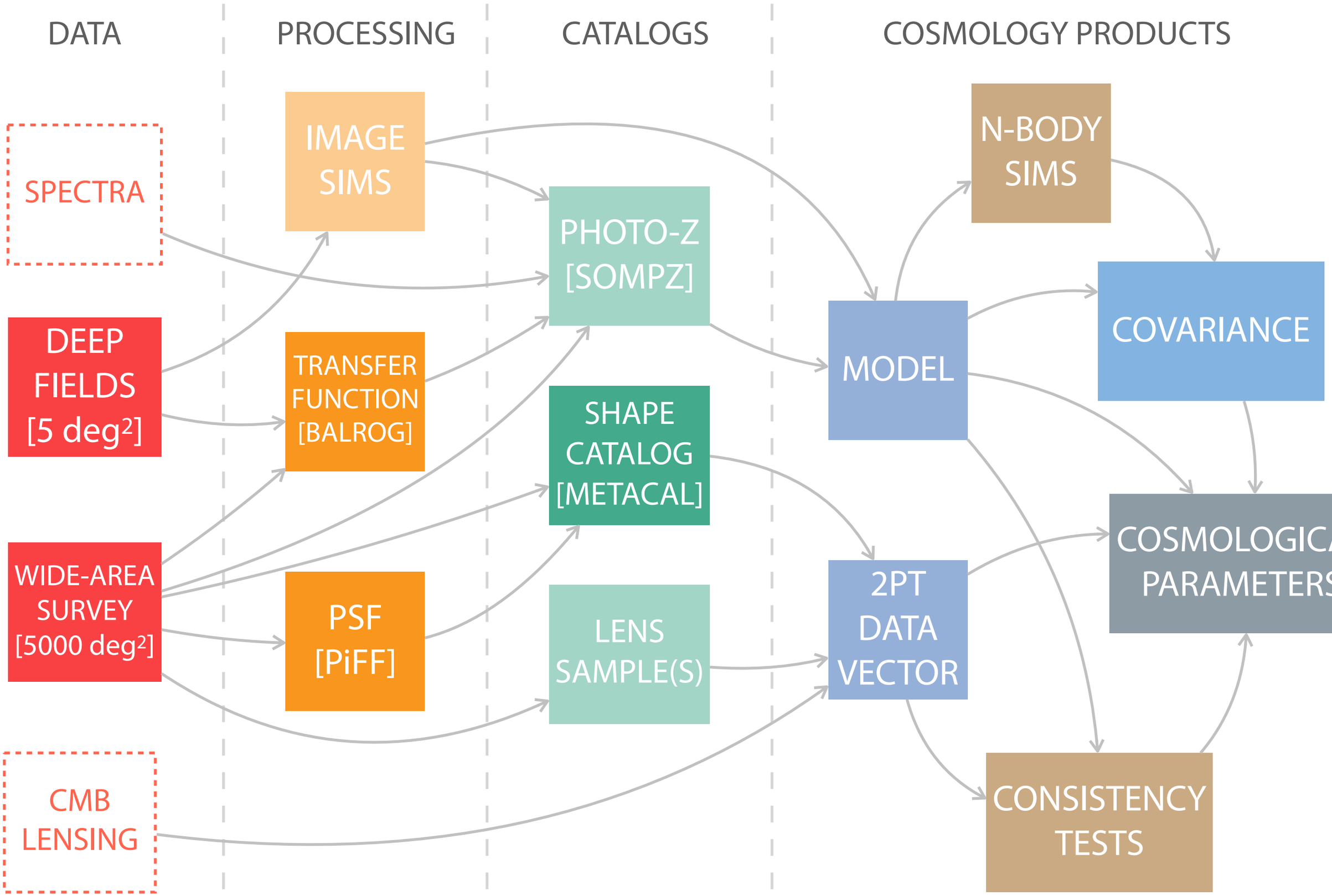


Shear catalogue testing : tomographic tests



PRELIMINARY

DES Y3 Key Project

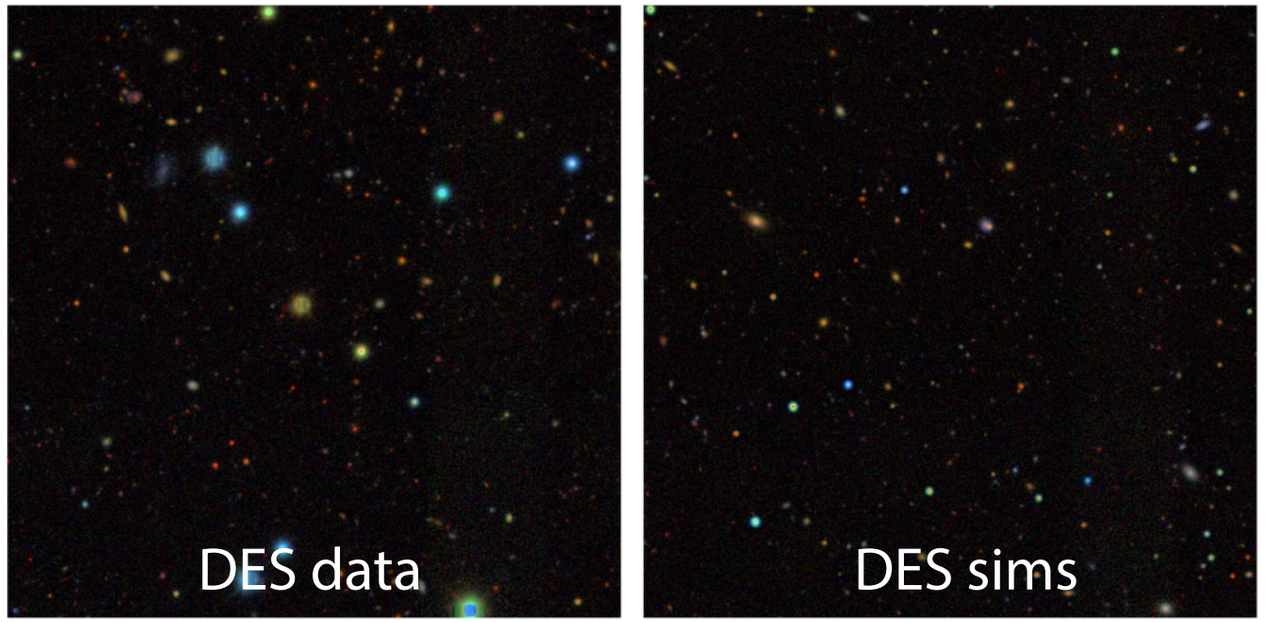


Shear calibration with image simulations

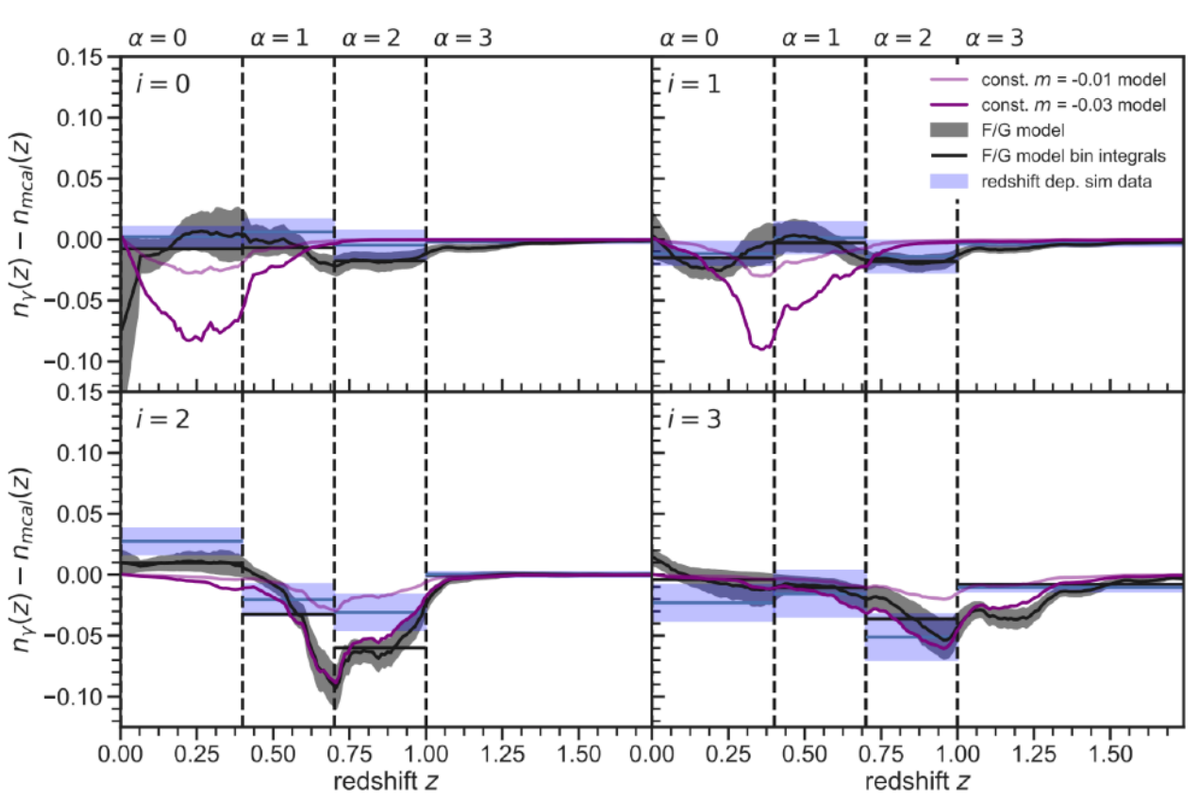
- **Simultaneous shear and photo-*z* calibration**
  - Consider $n(z)$ as response of ensemble to a shear at redshift z (≠ METACAL response $\mathbf{R}_\gamma$)

$$\langle \mathbf{e}_{\rm obs} \rangle = \int n_\gamma(z)\, \gamma_{\rm true}(z)\, {\rm d}z + c + \text{noise}$$

  - Impact of cross-redshift blending modelled by $n(z) \rightarrow n_\gamma(z)$ measured by sims
  - Normalization of $n_\gamma(z) = 1+m$
- **Results**
  - Realistic simulations using DF to match colors, morphologies, blending
  - Shear bias m=−2% dominated by blending, increasing with redshift (−1.2 to −3.6%) + priors
  - Modified redshift distributions $n_\gamma(z)$

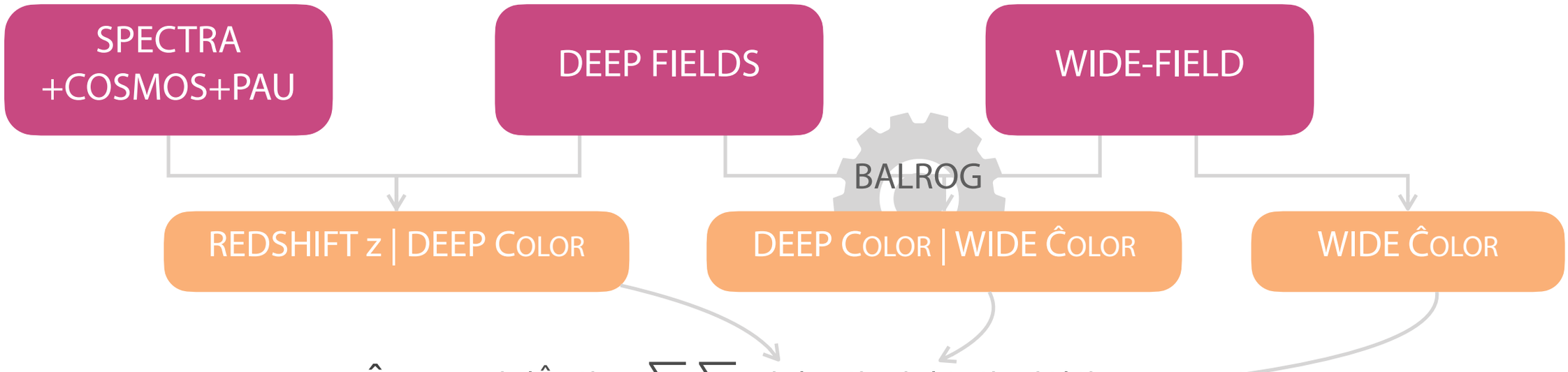


MacCrann+20 [DES Y3]



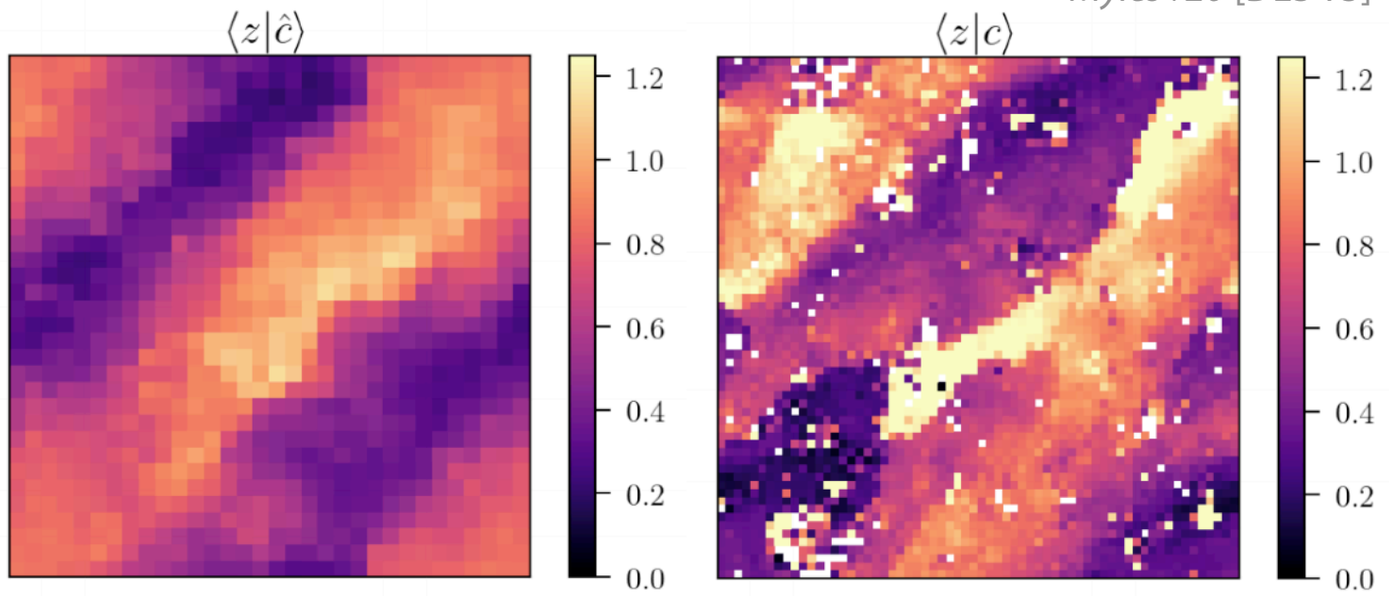
Redshift distributions : SOMPZ

- **DES Y3 SOMPZ pipeline**
  - Self-organizing maps based method (no template, no ML) from Buchs+19
  - SOMPZ uses deep fields obs to break degeneracies in color-redshift relation and produce $n(z)$



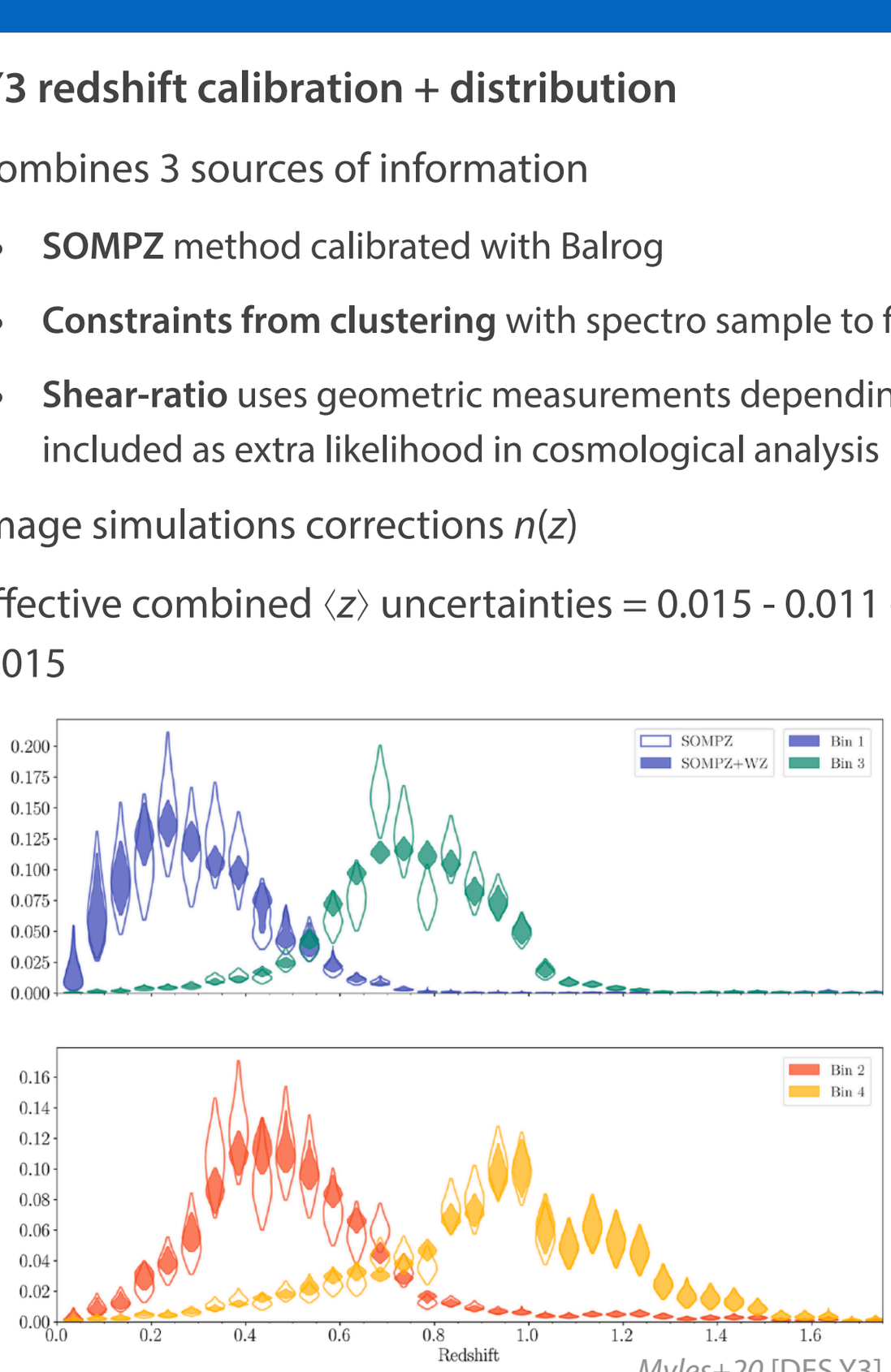
- Marginal photo-z for bin $\hat{b}$ is $p(z|\hat{b},\hat{s}) \approx \sum_{\hat{c}\in\hat{b}} \sum_{c} p(z|c,\hat{s})\, p(c|\hat{c},\hat{s})\, p(\hat{c}|\hat{s})$
- Full quantification of uncertainty sources
  - Redshift sample (sampling)
  - SOMPZ + BALROG (PIT)
  - Photometric calibration of DF (PIT)
  - Sample variance (3sDIR)
- Dominated by photo-calibration at low redshift and sample variance at higher z

Myles+20 [DES Y3]

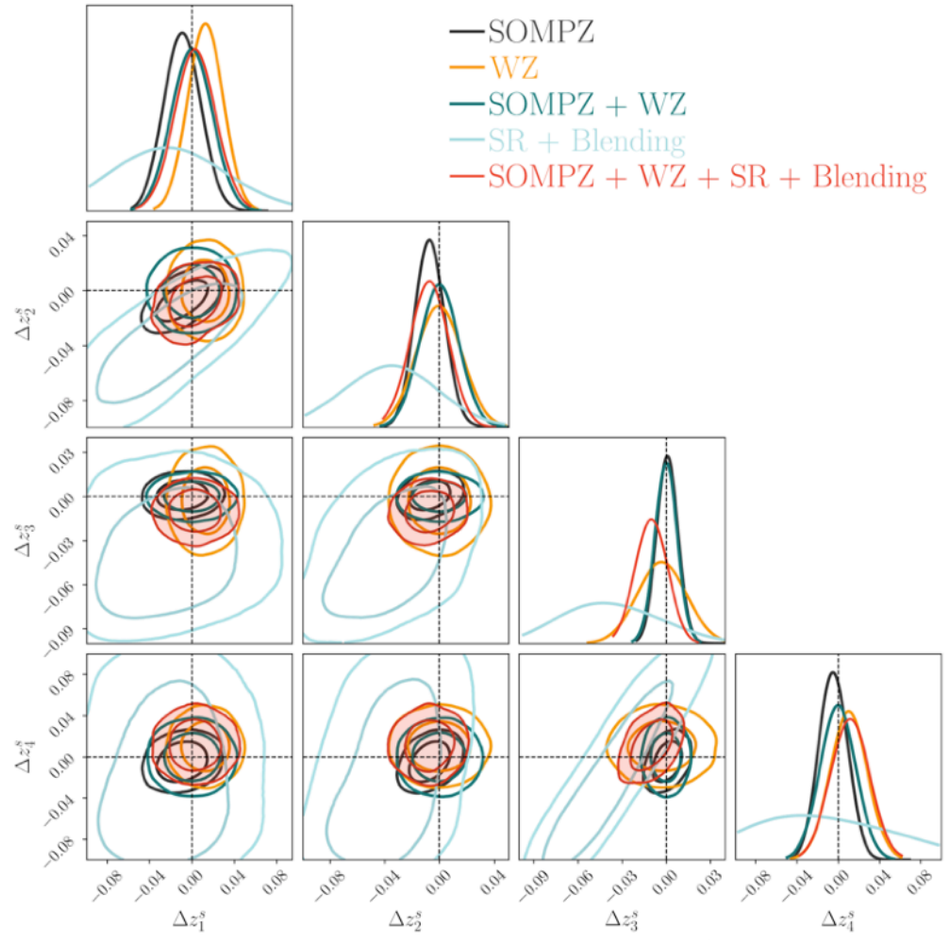


Redshift distributions

- **DES Y3 redshift calibration + distribution**
  - Combines 3 sources of information
    - **SOMPZ** method calibrated with Balrog
    - **Constraints from clustering** with spectro sample to filter out n(z)'s
    - **Shear-ratio** uses geometric measurements depending on n(z), included as extra likelihood in cosmological analysis
  - Image simulations corrections $n(z)$
  - Effective combined $\langle z \rangle$ uncertainties = 0.015 - 0.011 - 0.008 - 0.015



Myles+20 [DES Y3]



Myles+20 [DES Y3]

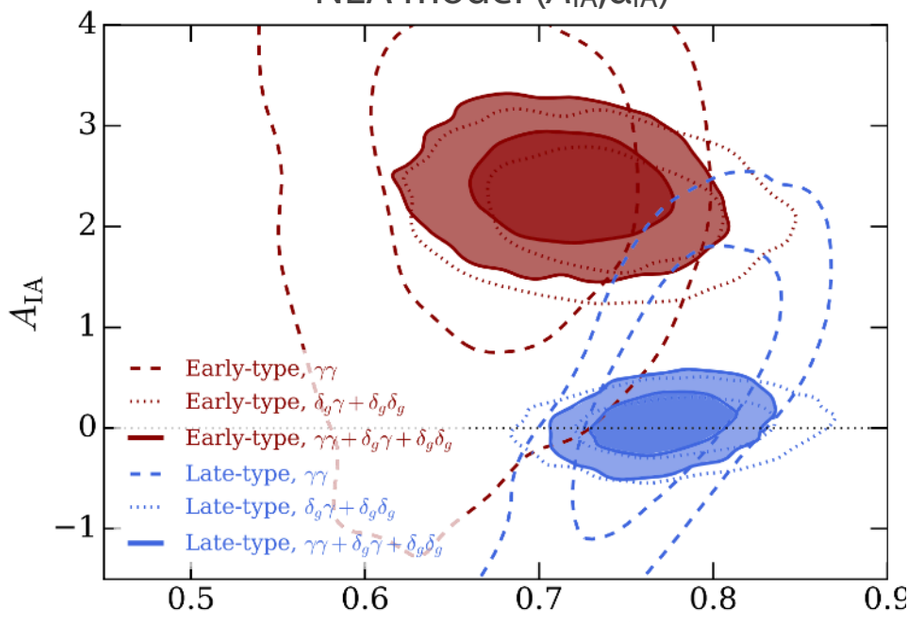
- **Samples of n(z)'s with HYPERRANK**
  - All uncertainties combined to produce *samples* of $n(z)$*'s* marginalized over with HYPERRANK (instead of n'(z) = n(z+Δz))
  - Allows marginalization over $\langle z \rangle$ *and* $n(z)$ shape

Cordero+ (in prep) [DES Y3]

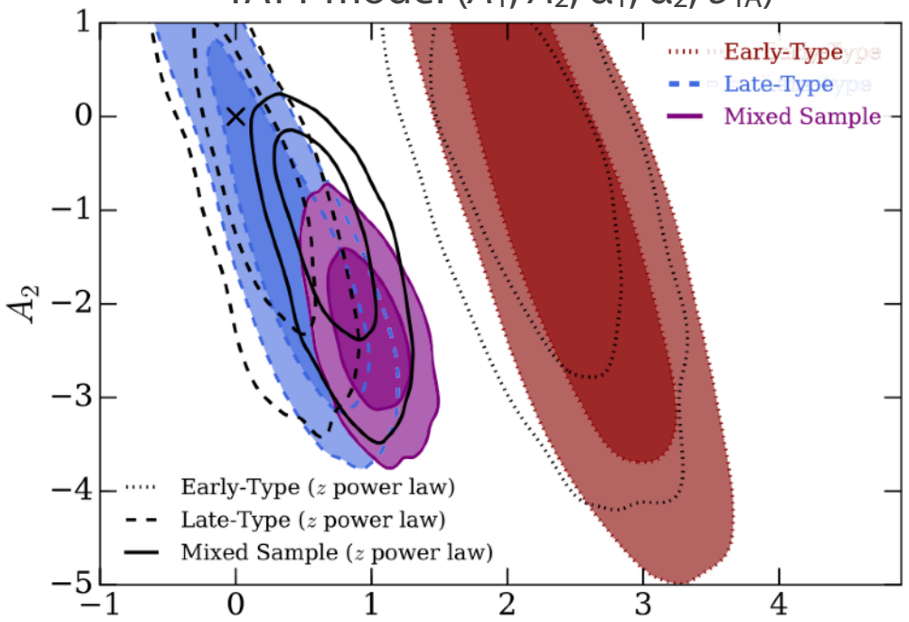
Modelling uncertainties

- **Intrinsic alignments**

NLA model (A_{IA},α_{IA})



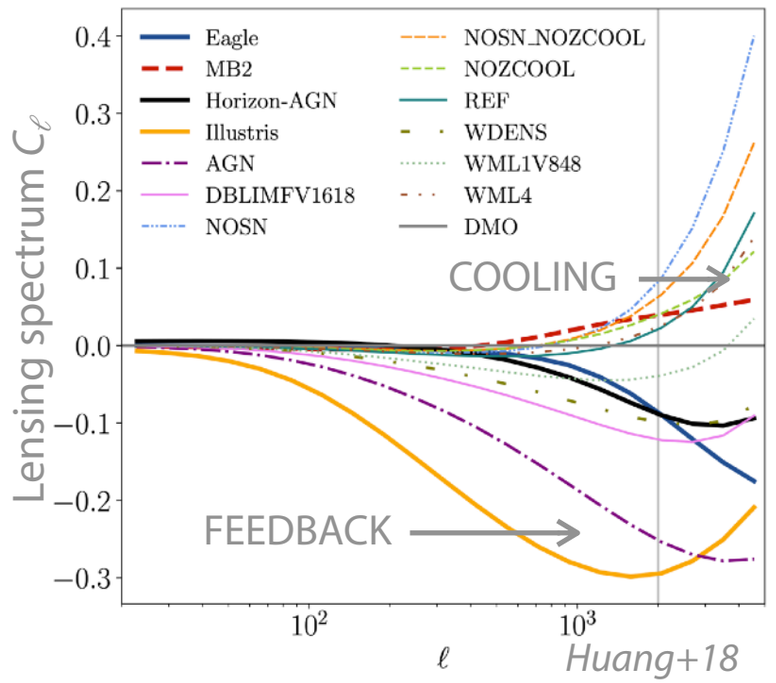
TATT model (A_1, A_2, α_1, α_2, b_{TA})



$S_8 \equiv \sigma_8(\Omega_m/0.3)^{\frac{1}{2}}$ A_1 *Samuroff+19* [DES Y1]

- DES Y3 uses TATT model (Blazek+18) *ie*
  IA = A_1·(tidal alignment) + A_1·(tidal torquing) with z-dependence
- Extension of NLA with 5 params A_1,A_2,α_1,α_2,b_{TA} (NLA is A_2=b_{TA}=0)

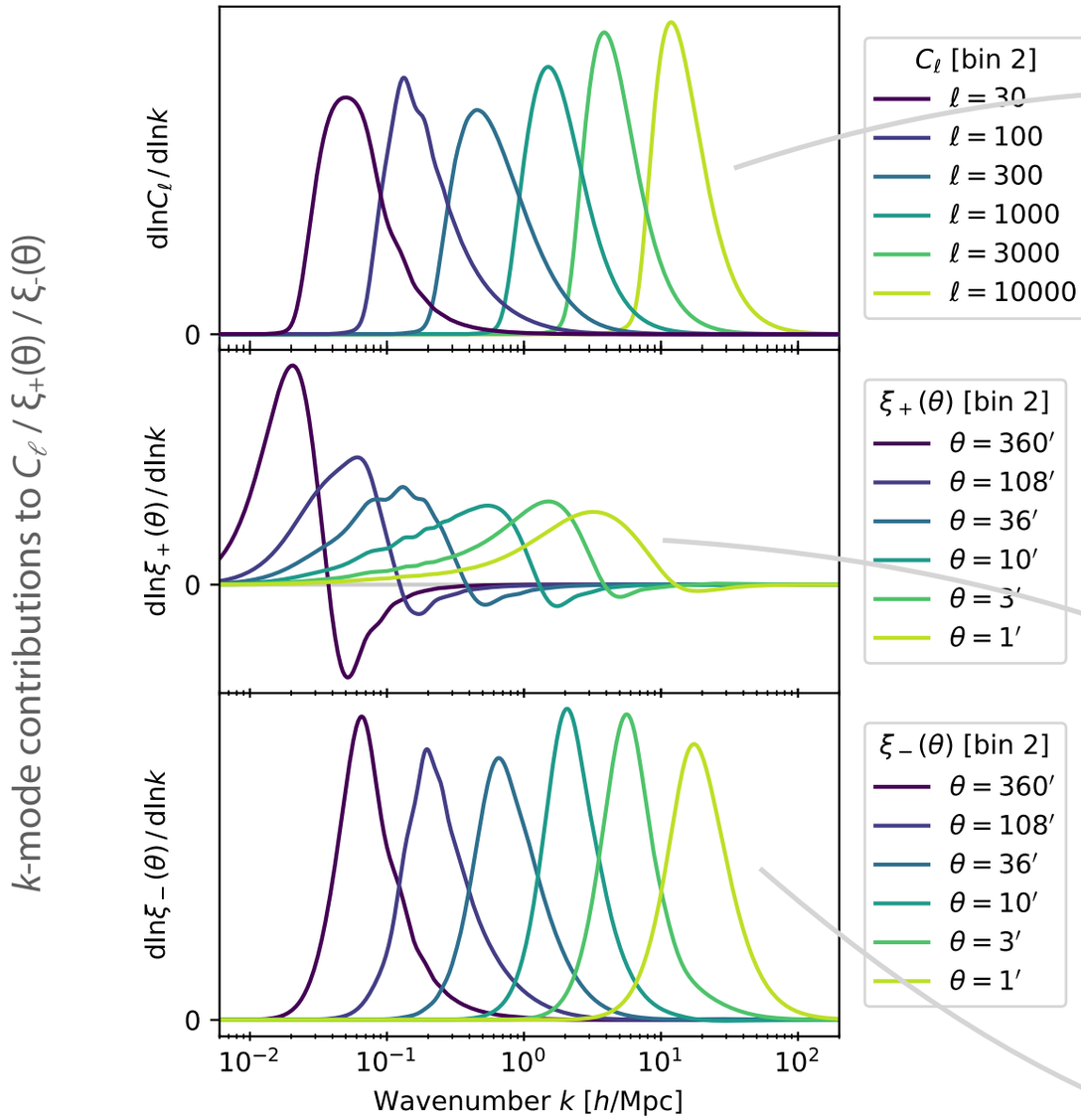
- **Baryons**
  - Suppression of power up to 30% at ℓ=3000
  - Broad variations across hydro sims
  - DES Y3 (fiducial) discards these scales



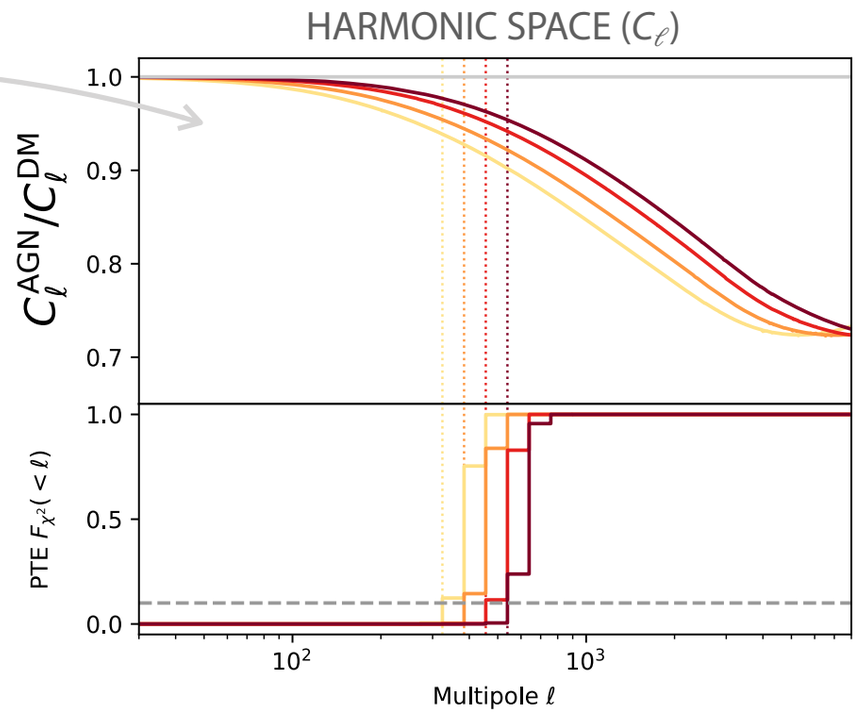
Huang+18

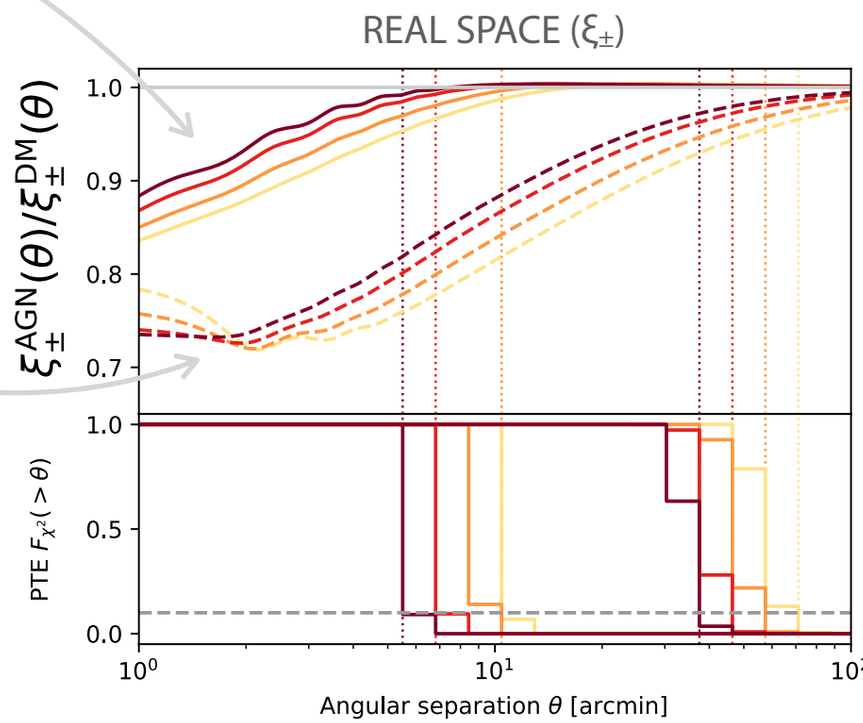
Cosmic shear in real *vs* harmonic space

- **Information from cosmic shear**



EFFECT OF BARYONS





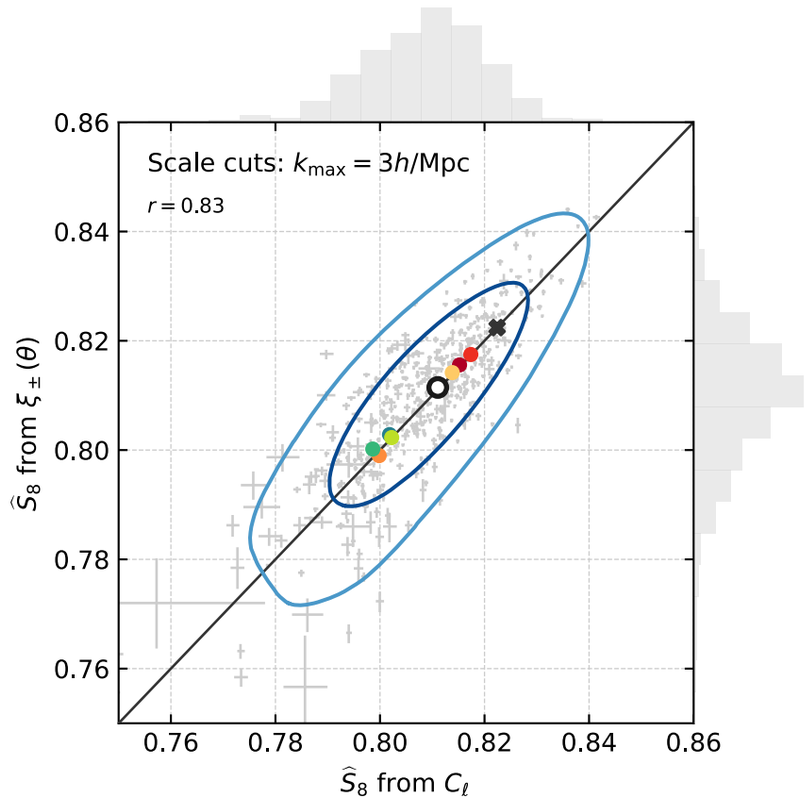
- Shear is integrated along the l.o.s → wide *k*-mode support
- 2pt functions ($\xi_\pm/C_\ell$) related by Bessel integral

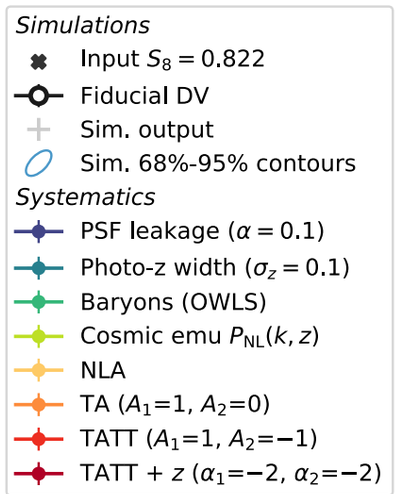
  ⇒ scale cuts select different information! consistency?

Doux+20 [DES Y3]

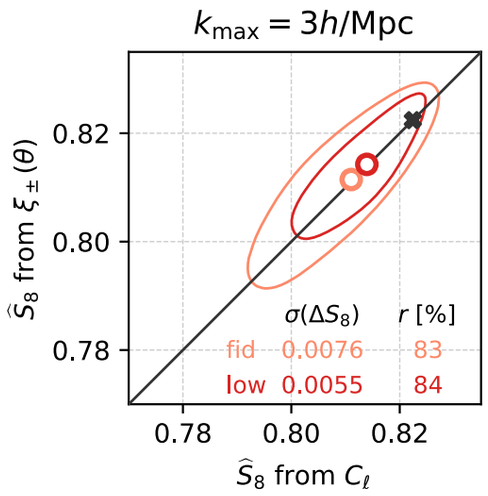
Scale cuts *vs* systematics

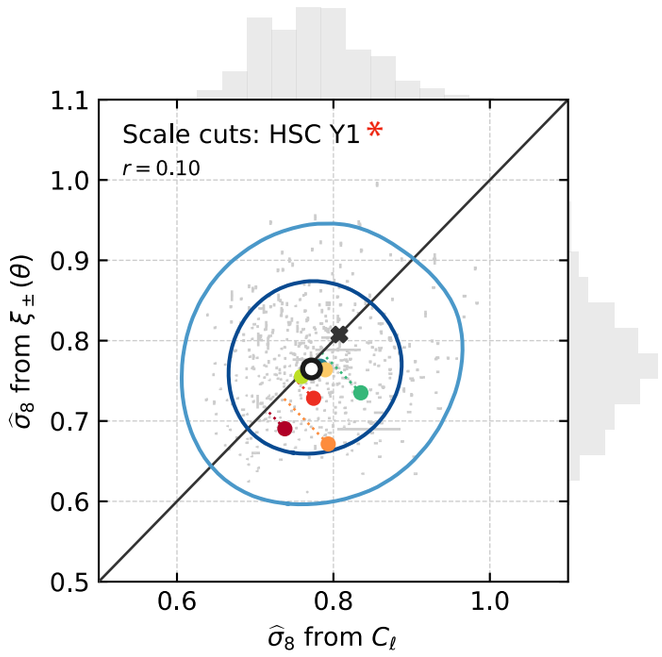
- **Simulated cosmic shear analyses**
  - 500 mock DES Y3 cosmic shear analyzed both in real ($\xi_{\pm}$) and harmonic (C_ℓ) space
  - Statistical *vs* systematic shifts on $S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$
- **Parameter shifts**
  - DES Y3 setup+ proposed cuts yield $\sigma(\Delta S_8)\sim0.01$ with correlation tied to scale cut choices
  - Projection+decorrelation effects and systematic trends with HSC Y1/KiDS-450 cuts (on DES Y3 sims!)
  - Extrapolation to $\sigma(\Delta S_8)\sim0.002$ (stat) for LSST…
  - … so $\sigma(\Delta S_8)$ (syst) needs to go down!

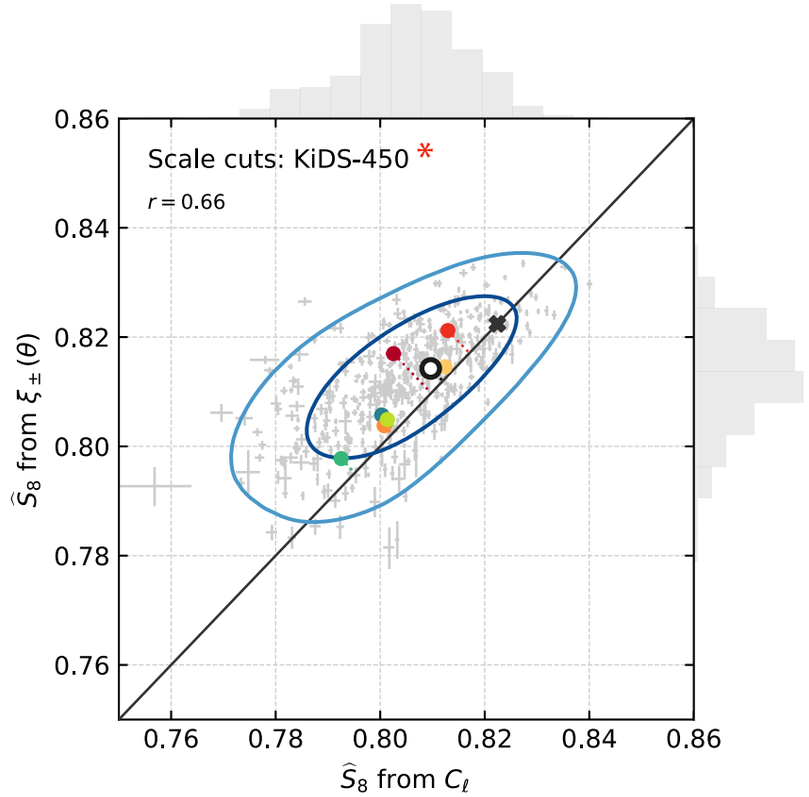




Doux+20 [DES Y3]



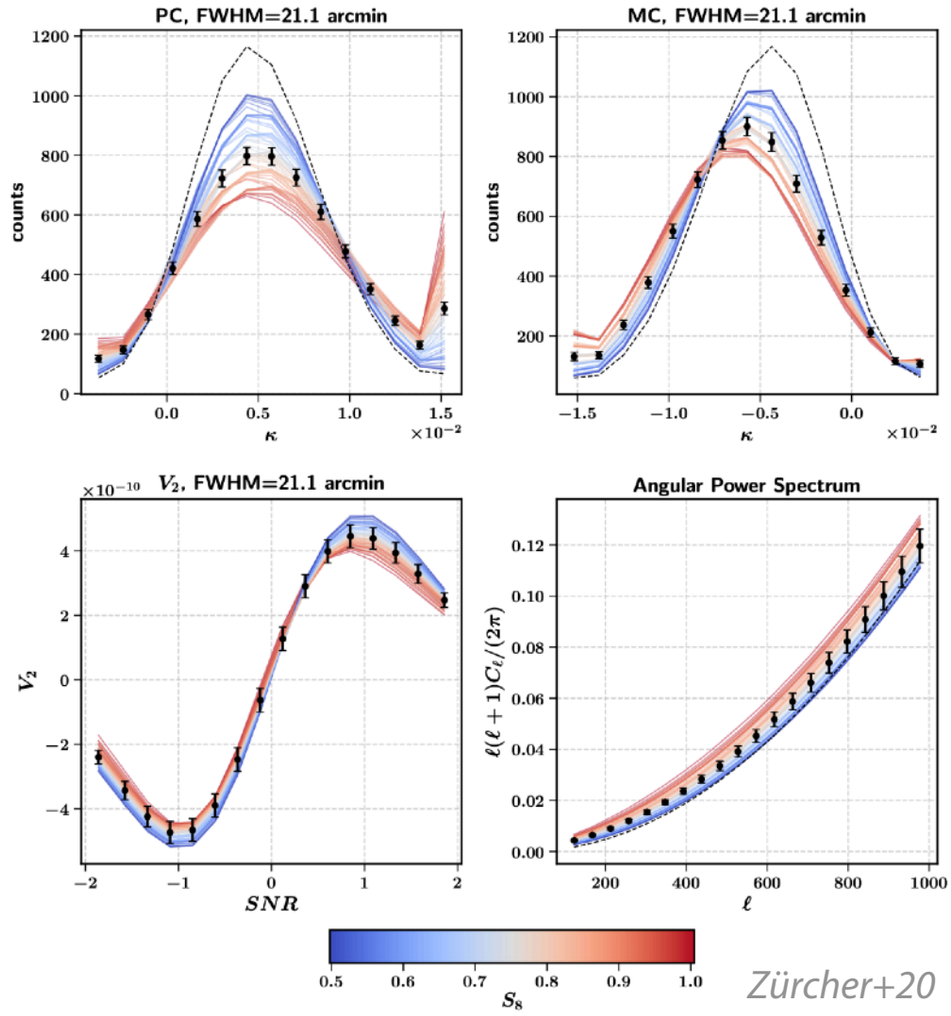




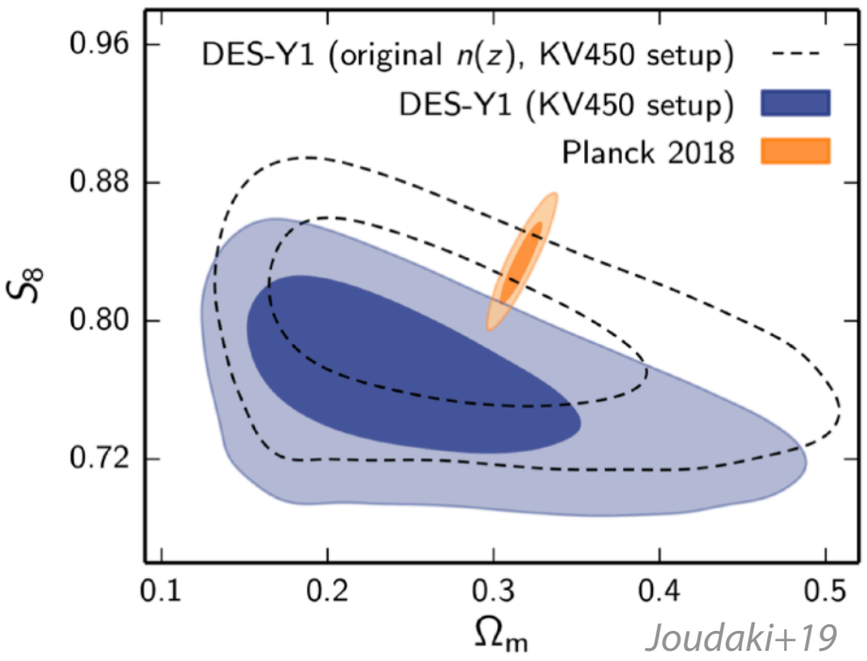
*HSC/KiDS-450 cuts on DES Y3 sims

Outstanding challenges in cosmic shear

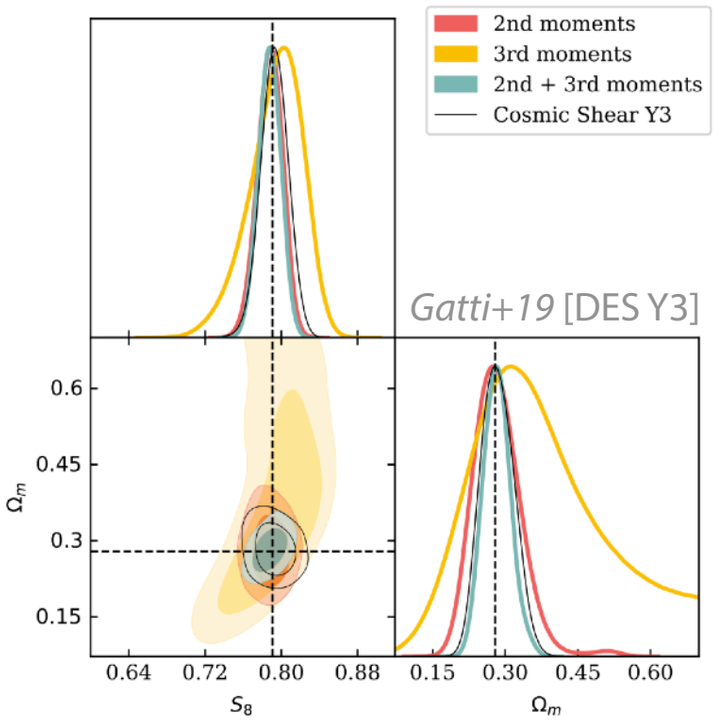
- **Redshift calibration**
  - Cross survey re-analyses are helpful!
- **Blending**
  - Becoming the major contribution to *m* and *n*(*z*)
  - Machine-learning can help! *See Arcelin, Doux et al. 2020*
- **Beyond 2pt analysis / quasi-linear regime**
  - Extra information to be captured
  - Modelling is hard… especially including all systematics!
  - Likelihood-free analyses in progress *eg Jeffrey+20 [DES SV]*



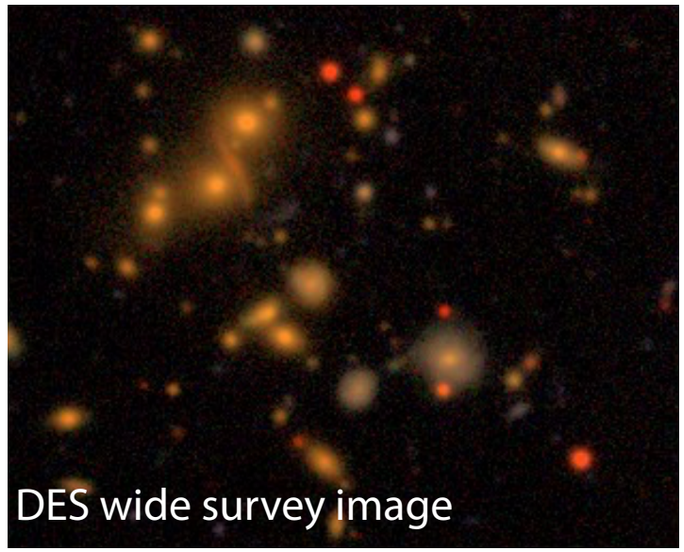
Zürcher+20



Joudaki+19

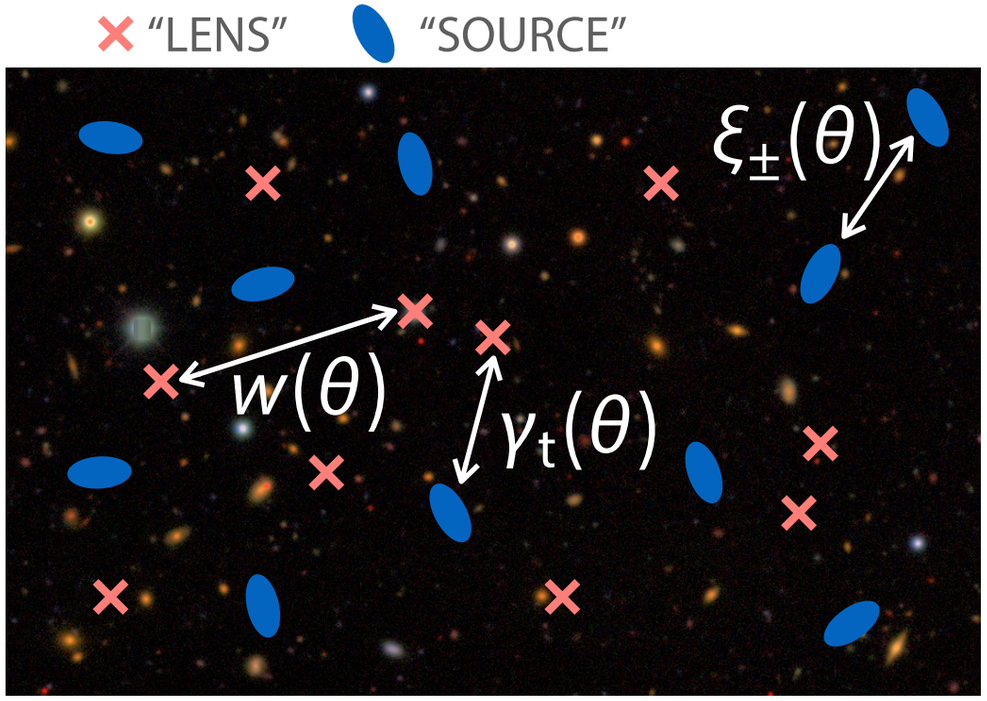


Gatti+19 [DES Y3]



- **DES Y3 multiprobe analyses : 3×2pt and 5×2pt**

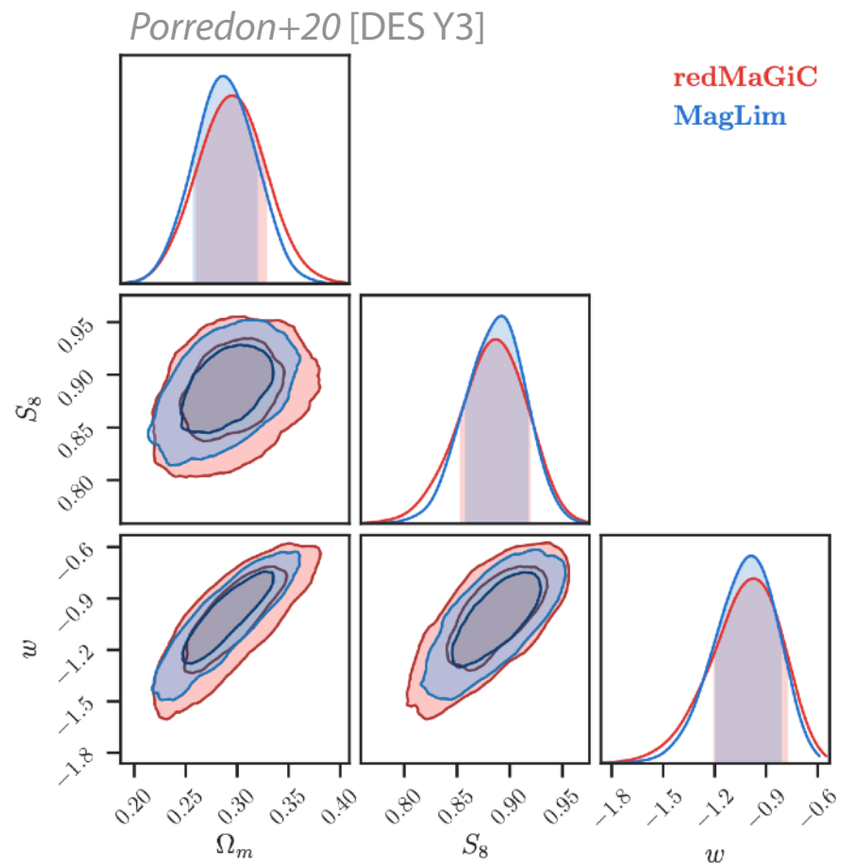
DES Y3 3×2pt



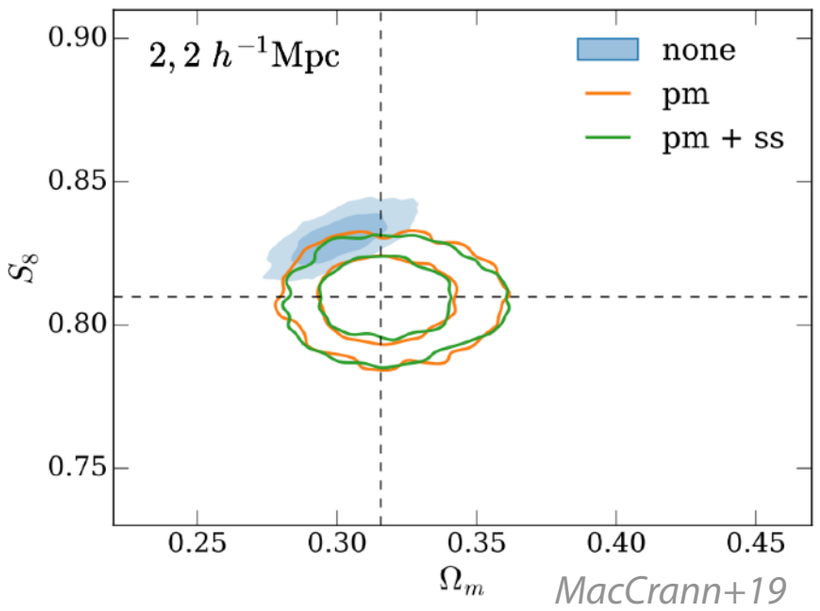
$\xi_\pm(\theta)$ = COSMIC SHEAR

$\gamma_t(\theta)$ = GALAXY-GALAXY LENSING

$w(\theta)$ = CLUSTERING



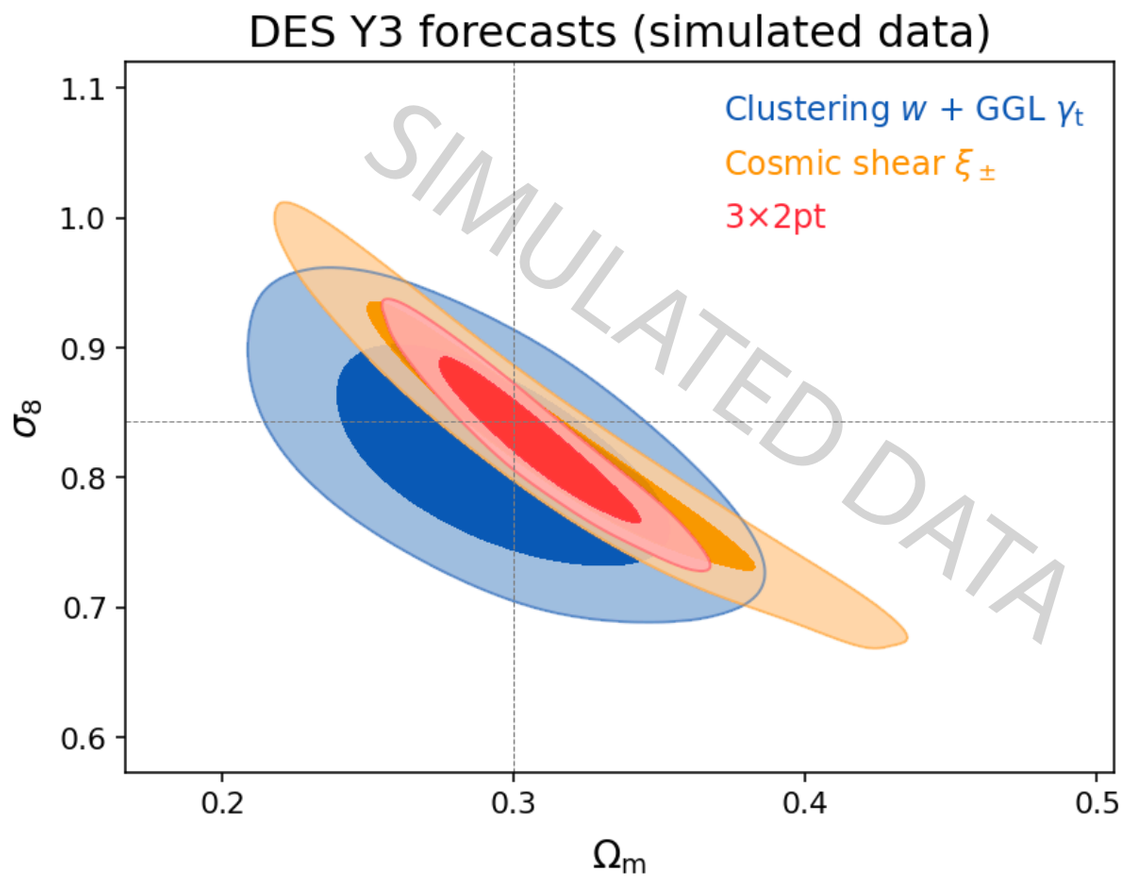
- **Photometric lens samples**
  - REDMAGIC : red sequence finder, ~2.9M galaxies
  - MAGLIM : magnitude cut $i < 4\, z_{phot} + 18$
    - 3.5× more galaxies, ~30% wider photo-z, 20-30% tighter constraints on Ω_m and σ_8
- **Modelling**
  - Non-Limber in C_ℓ's at large scales
  - Point-mass marginalization (unknown mass within θ in $\gamma_t(\theta)$)
  - Magnification, non-linear bias, etc

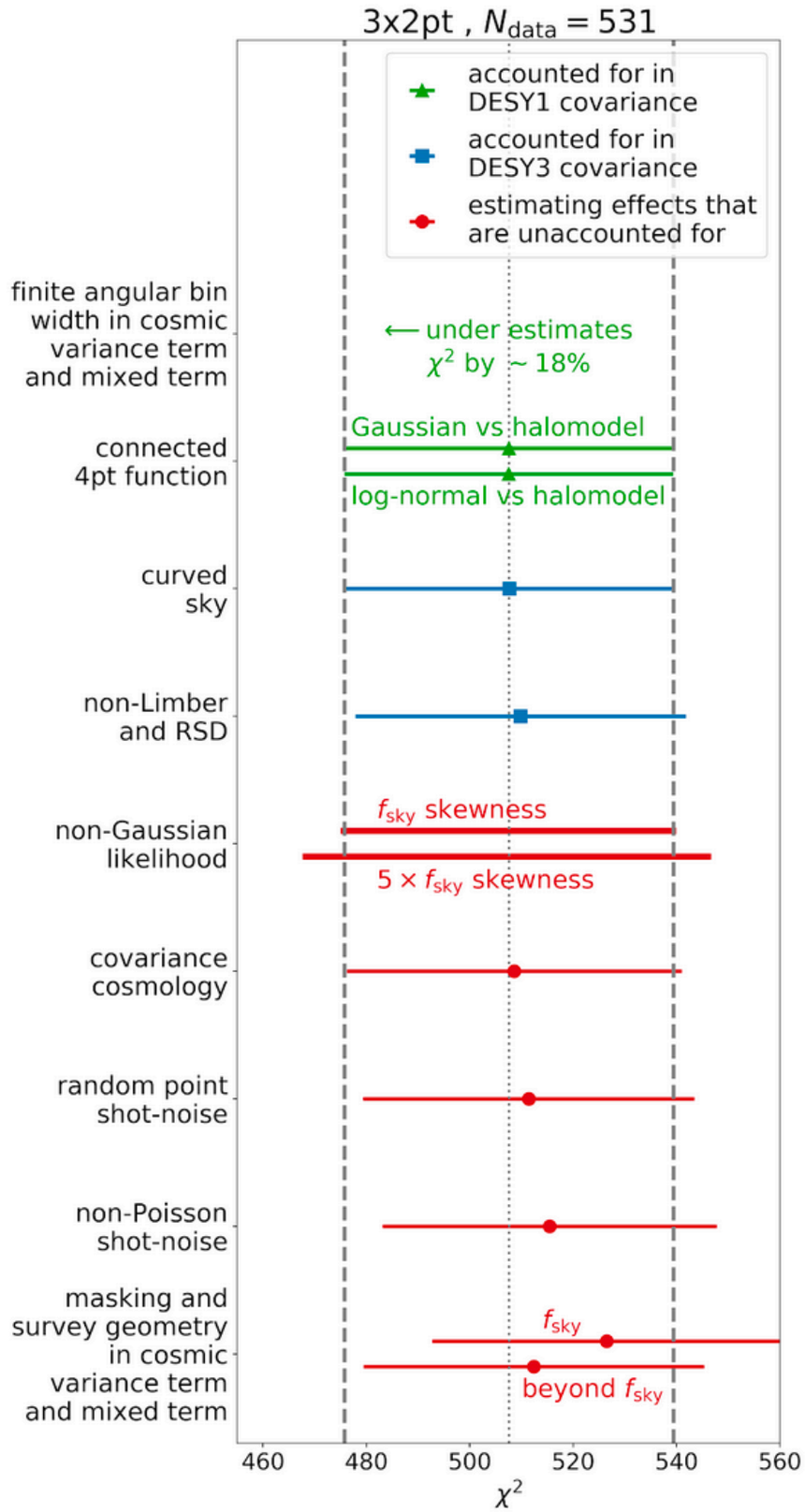


MacCrann+19

Covariance and forecasts

- **DES Y3 covariance**
  - Finite θ-bin size in cosmic variance+shot/shape-noise
  - Mask geometry (f_{sky}): 4% effect on χ^2 , negligible on params
  - Non-gaussian terms negligible for DES Y3 (probably not for Rubin/Euclid!)
- **DES Y3 forecasts**





Friedrich…CD+20 [DES Y3]

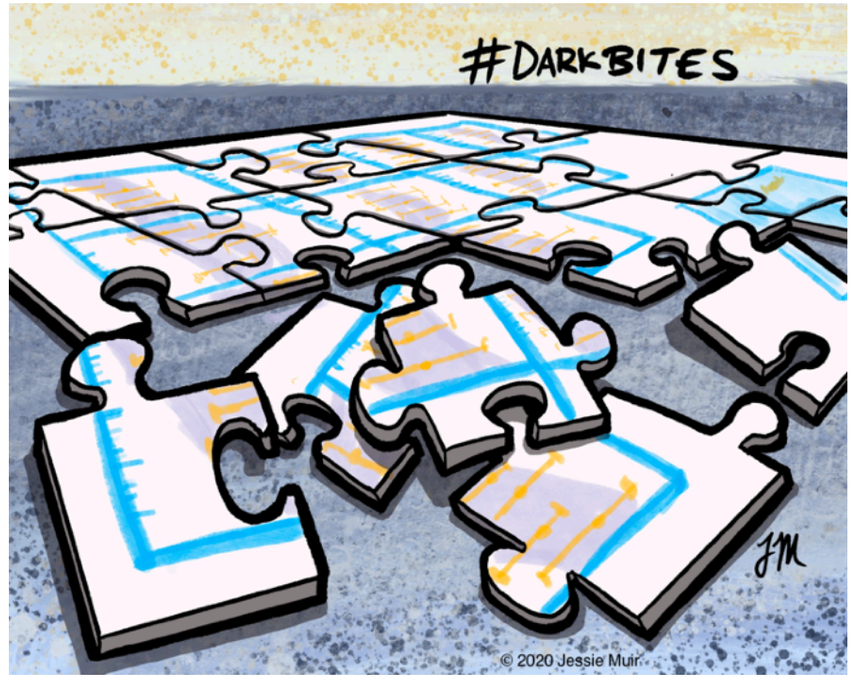
Tensions and consistency

- **Motivations**
  - Tensions between early *vs* late Universe on H_0 and σ_8
  - Systematic modelling complexity increasing
  - Multiprobe analysis offers consistency checks

3x2pt 5x2pt

- Galaxy density
- Galaxy shear
- CMB lensing

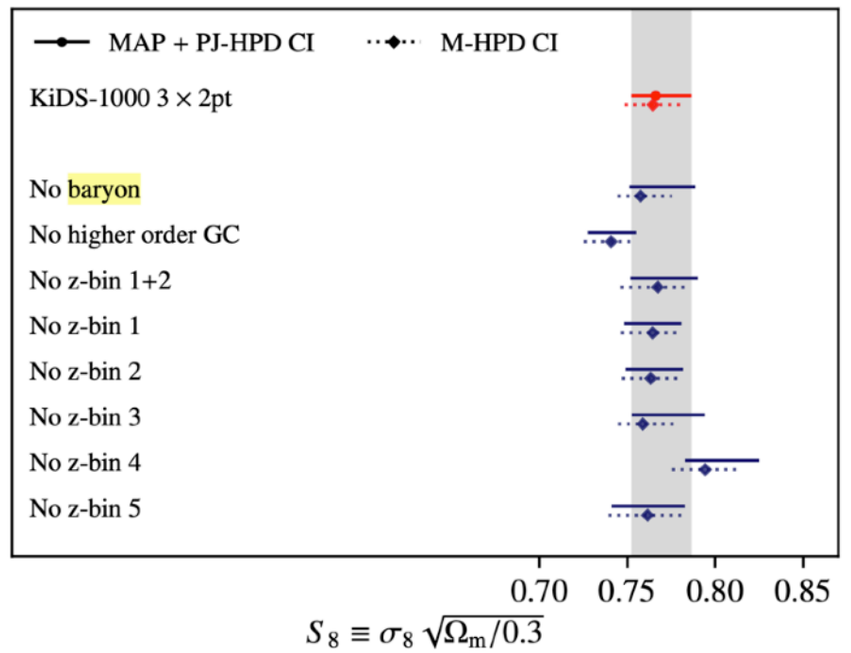
$$\begin{pmatrix} \delta_g\delta_g & \delta_g\kappa_g & \delta_g\kappa_{\rm CMB} \\ & \gamma_g\kappa_g & \kappa_g\kappa_{\rm CMB} \\ & & \kappa_{\rm CMB}\kappa_{\rm CMB} \end{pmatrix}$$



Jessie Muir | #darkbites

- **Internal *vs* external tension**
  - Internal tension within DES data — *DATA SPACE*
    1. G*oodness of fit* of ΛCDM + systematics model (with model+data uncertainties)
    2. *Consistency* across probes, redshift bins, scales by splitting data
  - External tension between DES and Planck — *PARAMETER SPACE*

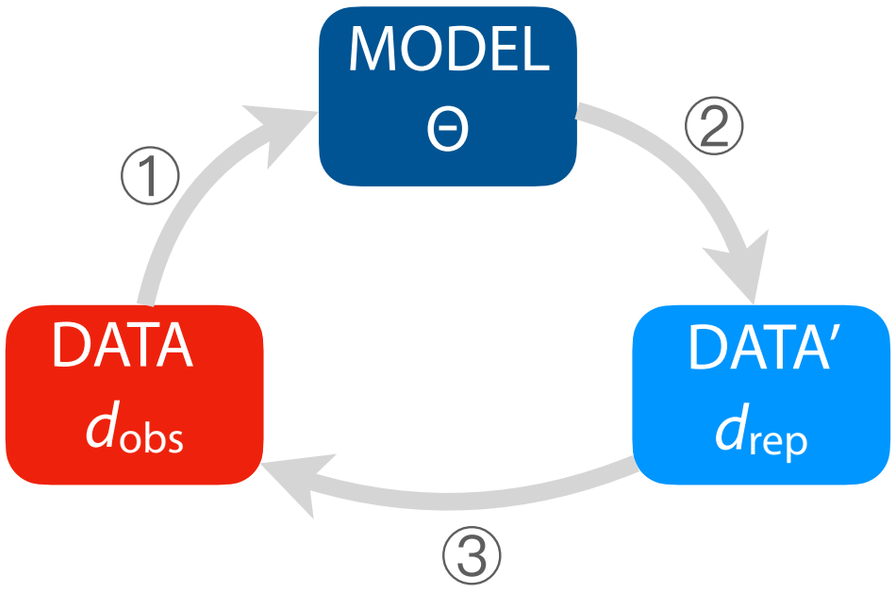
Heymans+20 [KiDS-100]

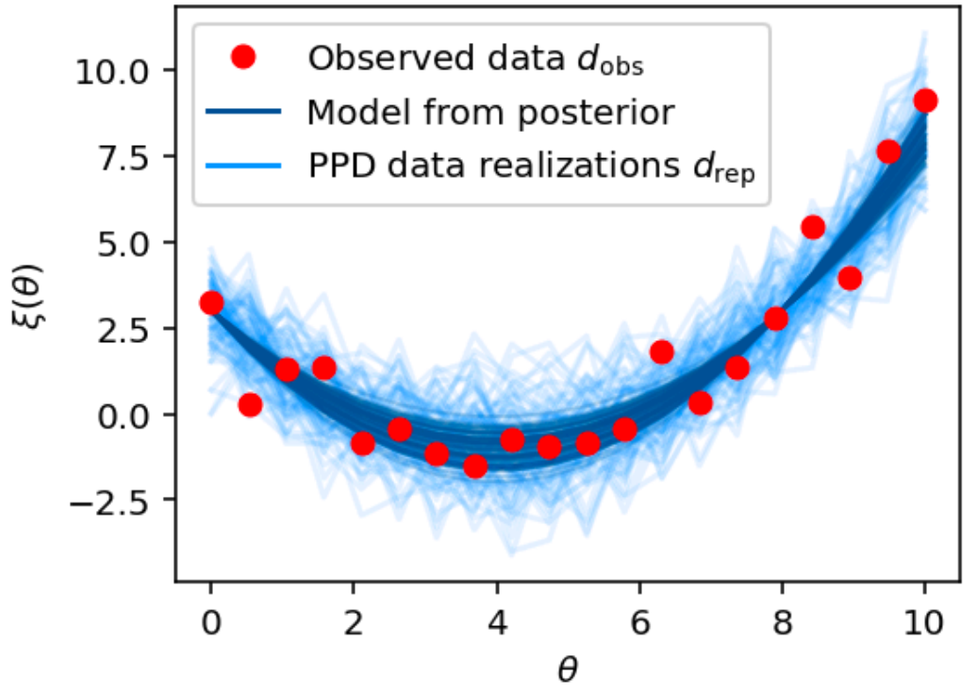


Internal consistency with PPD

- **Definition (Posterior Predictive Distribution):** given prior information I (incl. model + likelihood + prior) and observed data $d_{\rm obs}$, the PPD is the distribution of future data $d_{\rm rep}$ conditioned on $d_{\rm obs}$ and I

$$P(d_{\rm rep}|d_{\rm obs}, I) = \int \mathrm{d}\Theta \underbrace{P(d_{\rm rep}|d_{\rm obs}, \Theta, I)}_{\text{(cond'l) likelihood}} \underbrace{P(\Theta|d_{\rm obs}, I)}_{\text{posterior}}$$





- **Test statistic in data space**
  - $p = P\left(T(d_{\rm rep}, \Theta) > T(d_{\rm obs}, \Theta)\middle|d_{\rm obs}\right)$ with $T(d, \Theta) = \chi^2(d, \mu(\Theta))$, low p indicates tension*
  - Like a χ^2 GOF test, but includes parameter+data uncertainties
  - Consistency test include conditioning, eg

Cosmic shear $\xi\pm(\theta)$ ← $d_{\rm rep}$

vs

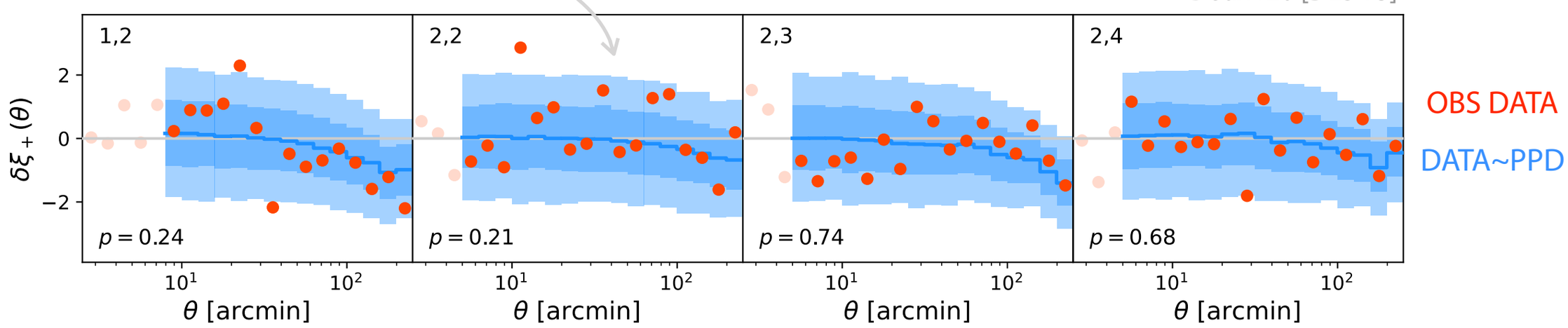
GGL $\gamma_t(\theta)$+clustering $w(\theta)$ ← $d_{\rm obs}$

*though p-values need calibration, see paper Doux+20 [DES Y3]

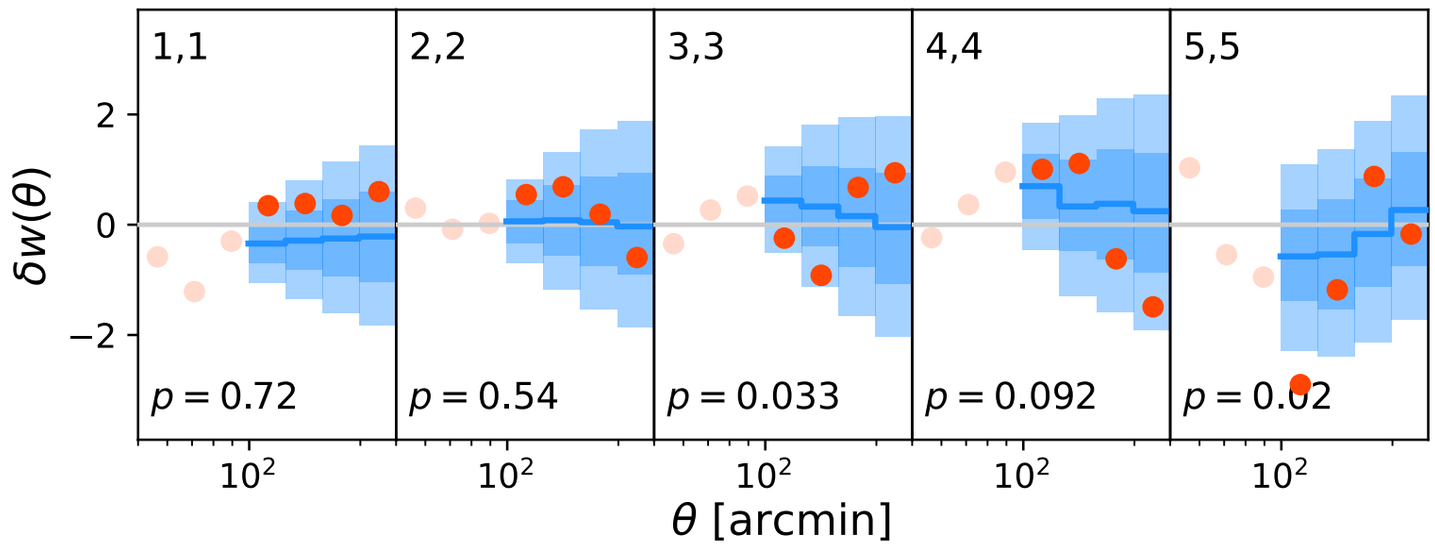
Internal consistency : DES Y1

- **Goodness of fit tests**: cosmic shear ✔ clustering+GGL ✔ 3x2 ✔ (overall p=0.046, slightly low)
- **Consistency tests**:
  - Split across probes ✔ and redshift bins ✔ → no sign of redshift biases

Doux+20 [DES Y3]

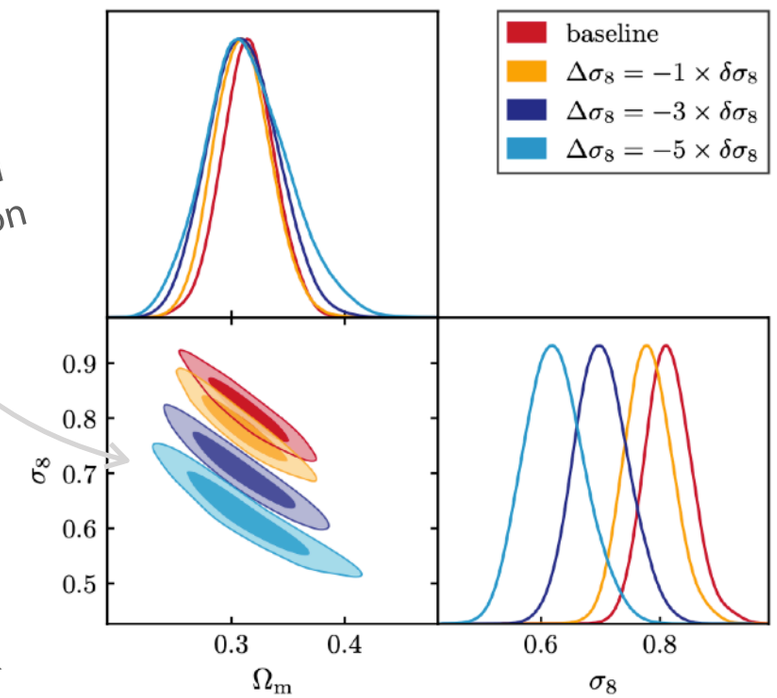


- Split across scales (θ>100′): large-scale vs small-scale predictions ✔ (p=0.016)

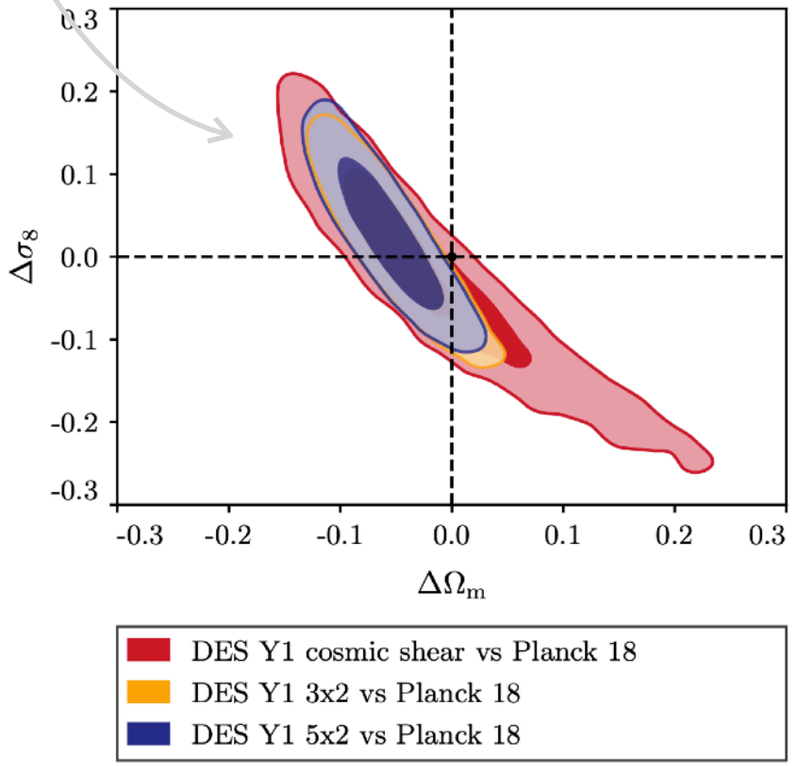


External consistency : DES Y1 *vs* Planck

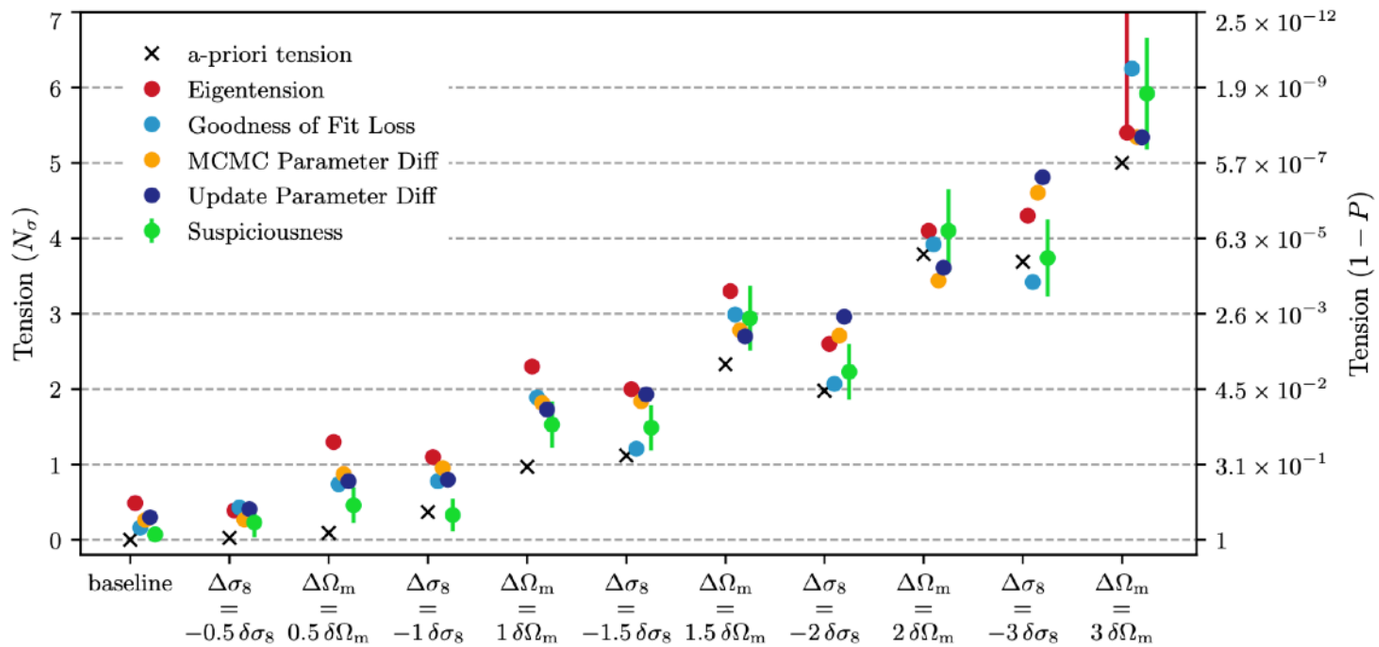
Simulated DES Y1 with input tension



DES Y1 *vs* Planck
$\Delta\theta_{cosmo}$



Lemos…CD+20 [DES Y3]



- **Benchmarking external consistency metrics**
  - Assessment of estimators (mostly Gaussian)
  - Bayes factors are unreliable (depend on prior)
  - Parameter difference distribution can avoid Gaussian approx
    - Full parameter-space tension method in prep (~3σ between DES Y1 and Planck)

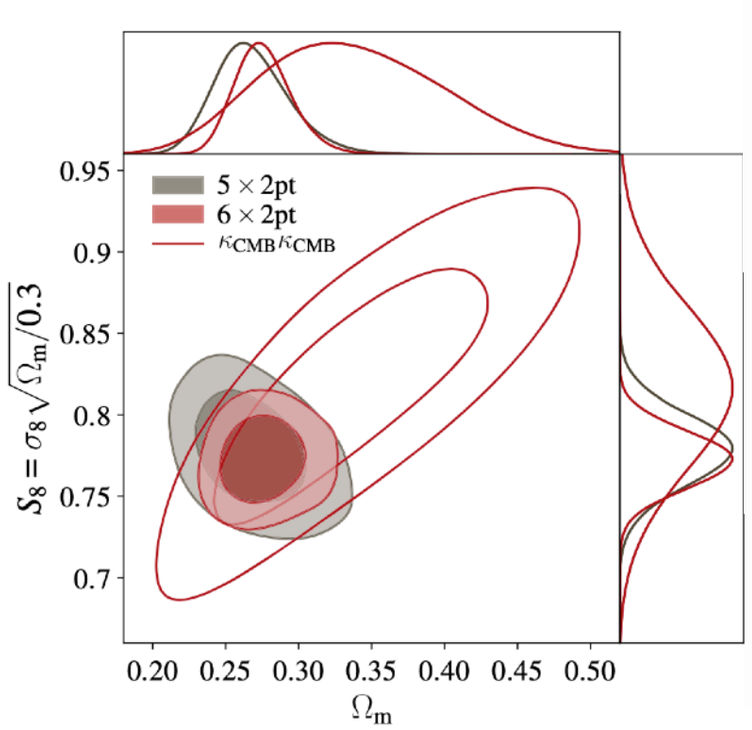
Raveri & Doux (in prep)

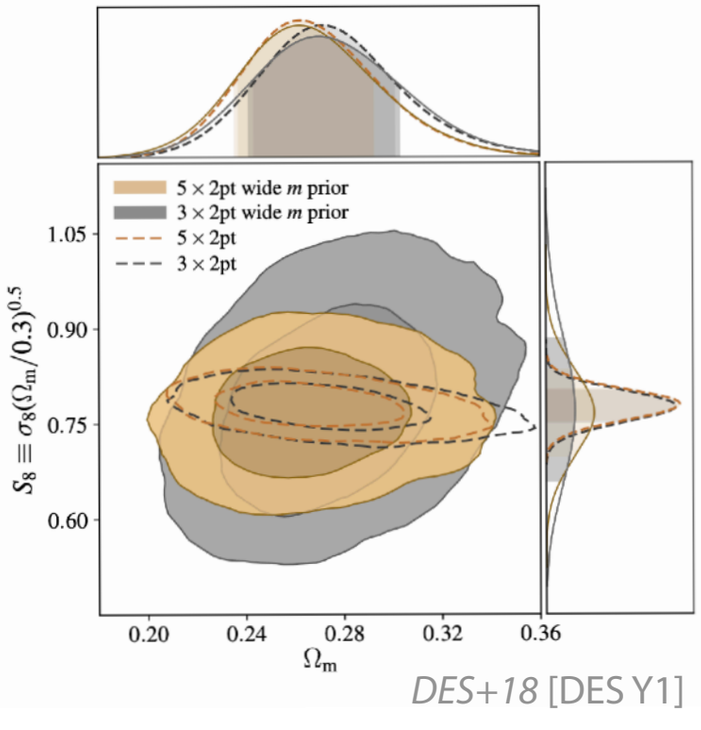
DES Y3 + SPT/Planck 5×2pt

- **Multiprobe analysis**
  - Galaxy density
  - Galaxy shear
  - CMB lensing

$$\begin{pmatrix} \overbrace{\delta_g\delta_g}^{\text{3x2pt}} & \delta_g\kappa_g & \overbrace{\delta_g\kappa_{\rm CMB}}^{\text{5x2pt}} \\ & \gamma_g\kappa_g & \kappa_g\kappa_{\rm CMB} \\ & & \kappa_{\rm CMB}\kappa_{\rm CMB} \end{pmatrix}$$

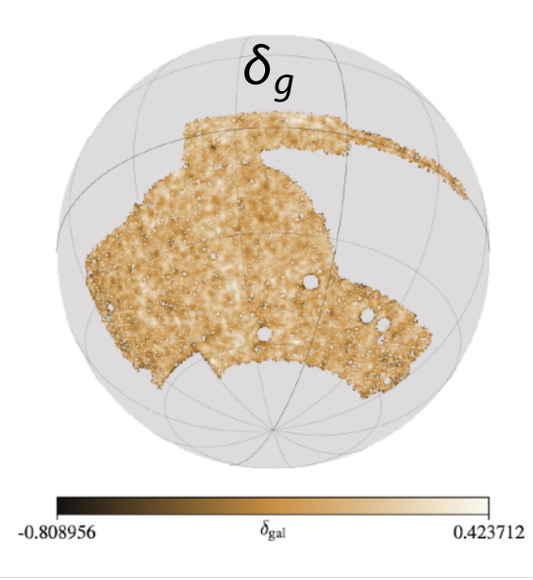
  - Tighter constraints
  - Towards self-calibration of shear *m*

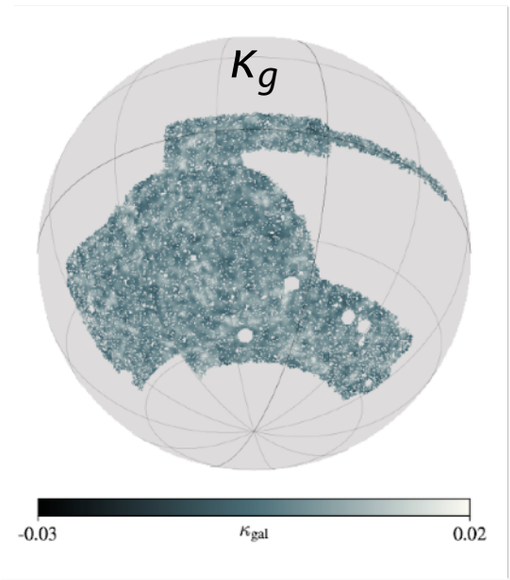


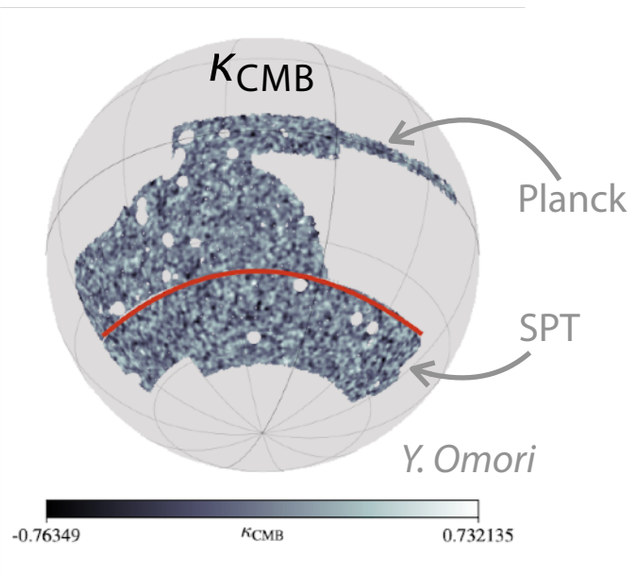


DES+18 [DES Y1]

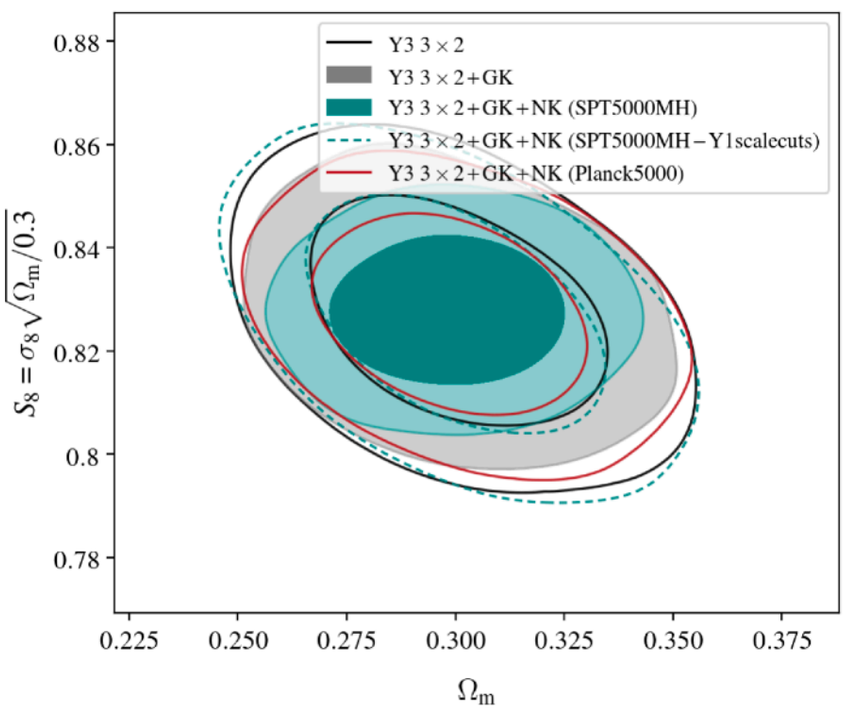
- **Forecasts for DES Y3 5x2pt**
  - SPT +Planck tSZ free lensing map (gradient cleaning, Madhavecheril & Hill 2018)
  - SPT 3G on its way + new overlap with ACTPol/AdvACT (full for Y6)





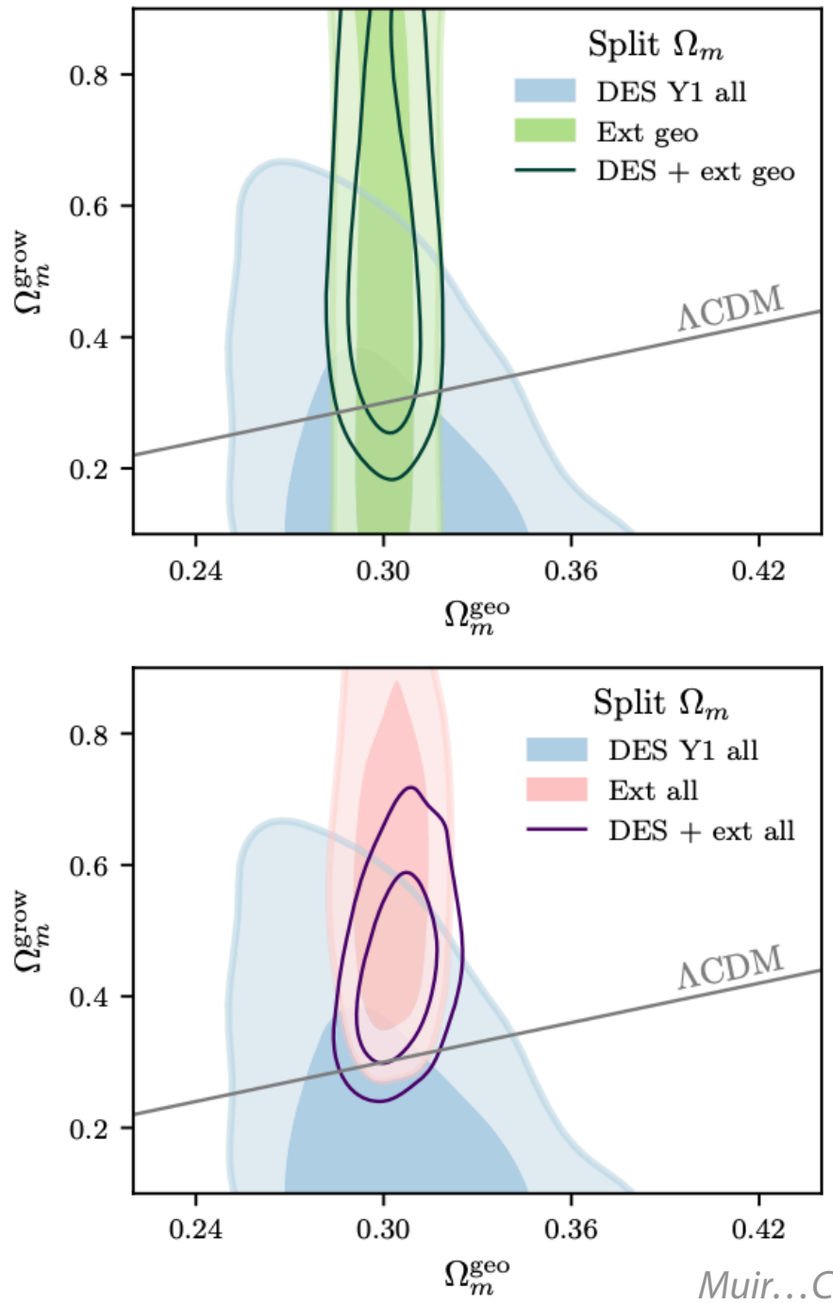


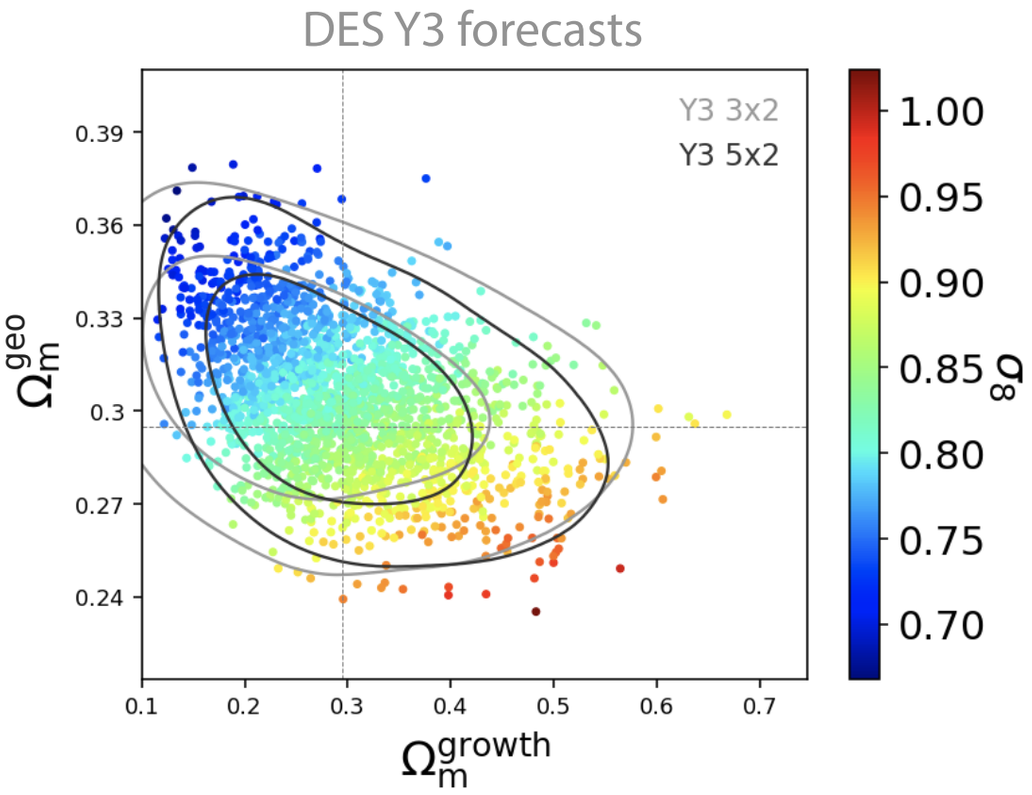
ΛCDM



DES Y3 + SPT/Planck 5×2pt : beyond ΛCDM

- **Constraining growth and geometry**
  - Splitting growth and geometry to test ΛCDM (split parameters Ω_m,w)
  - Variations of growth through $\sigma_8(z)$ for redshifts z~[0,1]

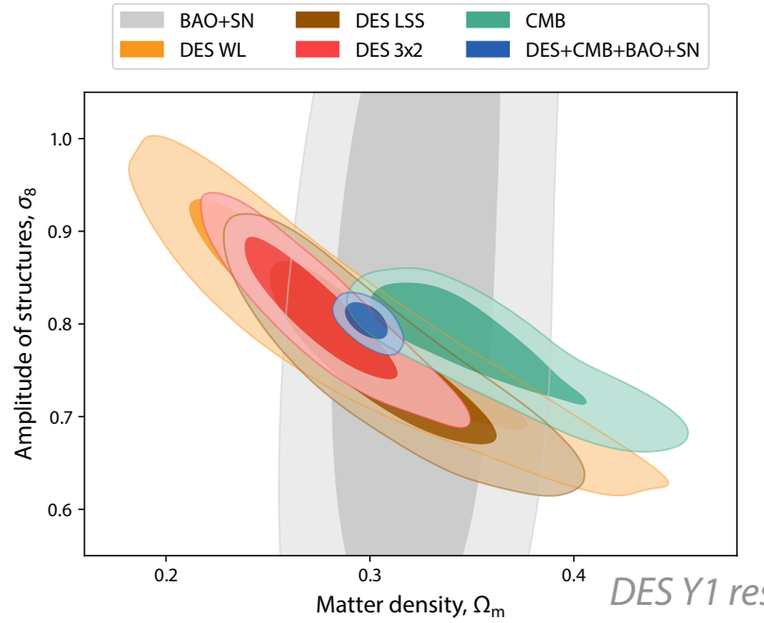




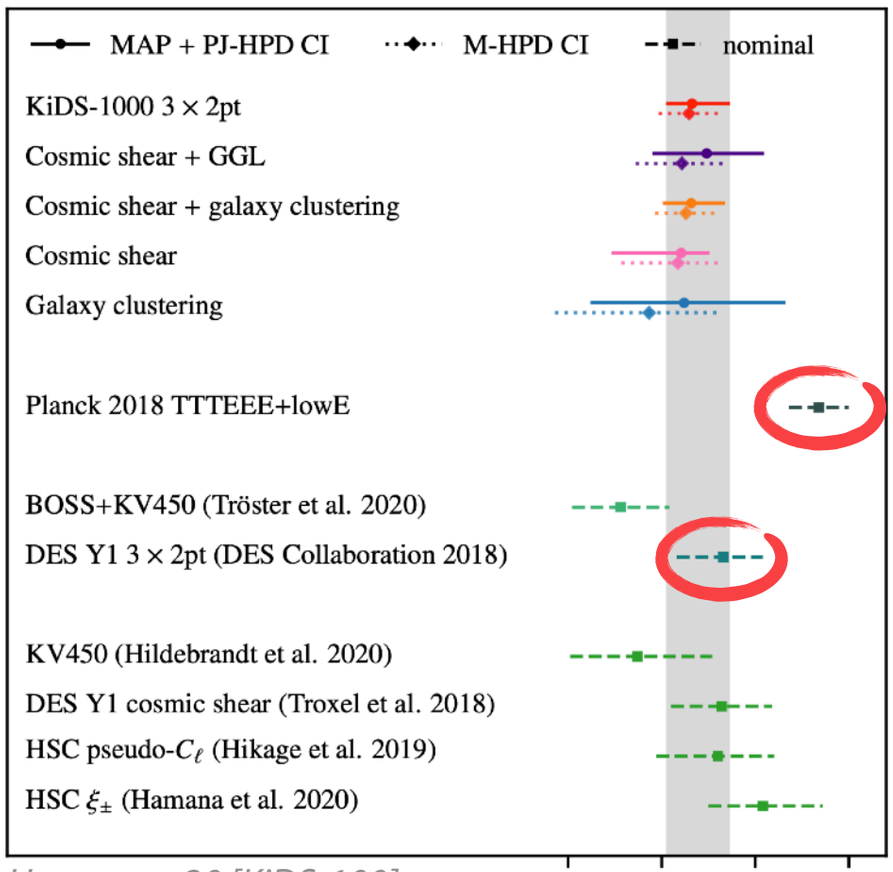
Muir…CD+20 [DES Y1]

Next steps

- **S_8/σ_8 tension?**
  - DES Y1, HSC Y1 and KiDS-1000 consistently low wrt Planck 2018 by 1-2σ
  - Stay tuned for Y3's say in it :)
- **DES Y6 is down the road…**
  - DES Y6 data over 5000 deg² at 100% depth (Y3 ~50%) collected in January 2019 (DR2~700M objects)
  - New methods!
    - *Bayesian Fourier Domain* (BFD, Bernstein+15)
    - *Metadetection* (Sheldon+19)
  - A unique data set to prepare for the next generation with Rubin/LSST and Euclid!



DES Y1 results



Heymans+20 [KiDS-100]

TAKE-AWAY MESSAGES

- DES Y3 shear catalogue of 100,204,026 galaxies over 4143 deg^2 extensively tested
- Conceptual+methodological advances in many directions — from photo-z to simulations to IA modelling to consistency tests — model complexity is increasing!
- DES Y3 3/5x2pt analysis of cosmic shear, galaxy-galaxy lensing and clustering (+CMB lensing) coming very soon — stay tuned!
- DES Y6 will likely be the largest photometric data set for a few years

References

Catalogs

1. Everett S, Yanny B, Kuropatkin N, et al. Dark Energy Survey Year 3 Results: Measuring the Survey Transfer Function with Balrog. *arXiv*. 2020;2012:arXiv:2012.12825.
2. Gatti M, Sheldon E, Amon A, et al. Dark Energy Survey Year 3 Results: Weak Lensing Shape Catalogue. *arXiv*. 2020;2011:arXiv:2011.03408.
3. Hartley WG, Choi A, Amon A, et al. Dark Energy Survey Year 3 Results: Deep Field Optical + Near-Infrared Images and Catalogue. *arXiv*. 2020;2012:arXiv:2012.12824.
4. Jarvis M, Bernstein GM, Amon A, et al. Dark Energy Survey Year 3 Results: Point-Spread Function Modeling. *Mon Not R Astron Soc*. 2020;501(1):1282-1299. doi:10.1093/mnras/staa3679.
5. Sevilla-Noarbe I, Bechtol K, Carrasco-Kind M, et al. Dark Energy Survey Year 3 Results: Photometric Data Set for Cosmology. *arXiv*. 2020;2011:arXiv:2011.03407.

Calibration

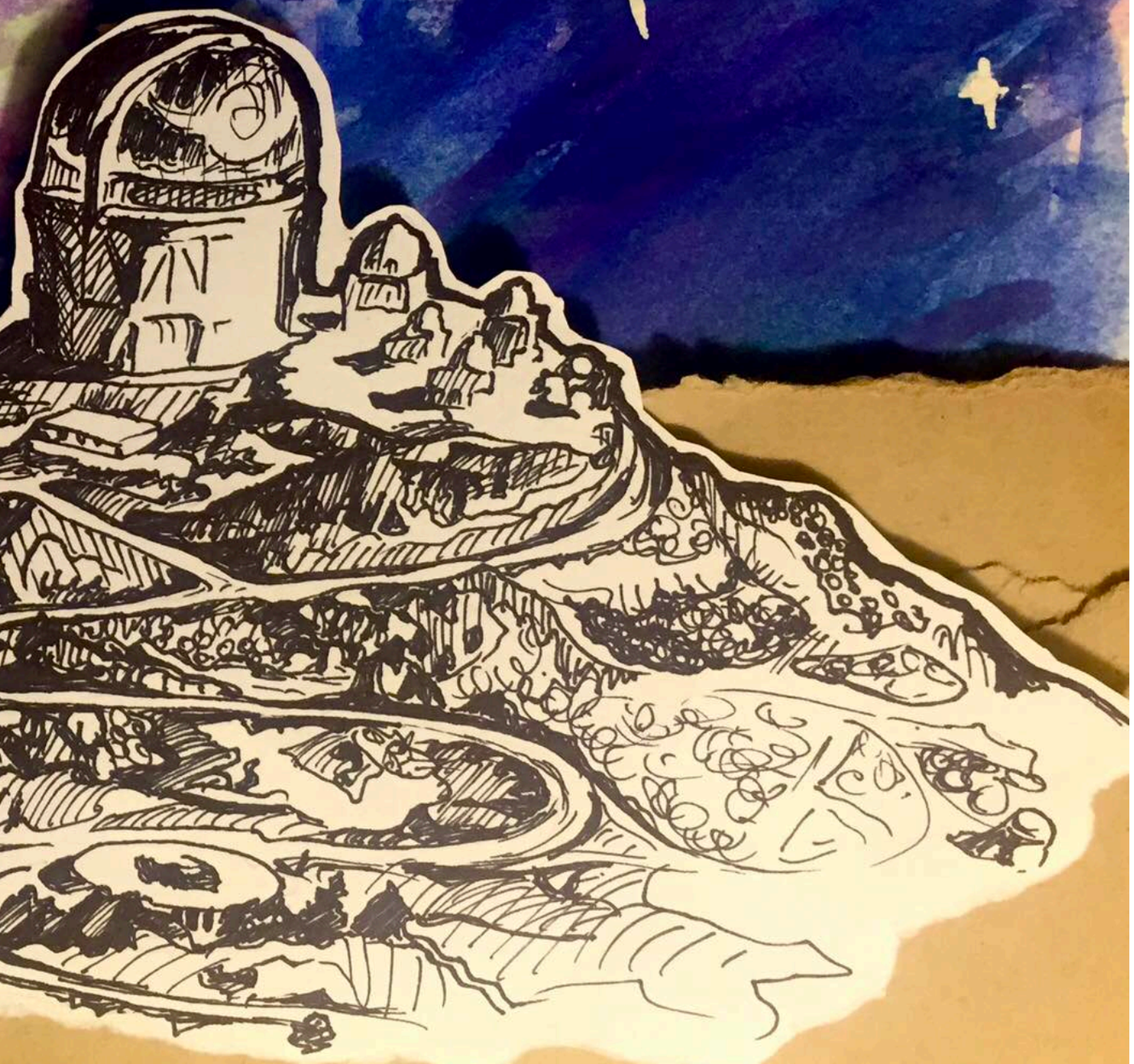
6. Buchs R, Davis C, Gruen D, et al. Phenotypic redshifts with self-organizing maps: A novel method to characterize redshift distributions of source galaxies for weak lensing. *Mon Not R Astron Soc*. 2019;489(1):820-841. doi:10.1093/mnras/stz2162.
7. Cawthon R, Elvin-Poole J, Porredon A, et al. Dark Energy Survey Year 3 Results: Calibration of Lens Sample Redshift Distributions using Clustering Redshifts with BOSS/eBOSS. *arXiv*. 2020;2012:arXiv:2012.12826.
8. Gatti M, Giannini G, Bernstein GM, et al. Dark Energy Survey Year 3 Results: Clustering Redshifts -- Calibration of the Weak Lensing Source Redshift Distributions with redMaGiC and BOSS/eBOSS. *arXiv*. 2020;2012:arXiv:2012.08569.
9. MacCrann N, Becker MR, McCullough J, et al. DES Y3 results: Blending shear and redshift biases in image simulations. *arXiv*. 2020;2012:arXiv:2012.08567.
10. Myles J, Alarcon A, Amon A, et al. Dark Energy Survey Year 3 Results: Redshift Calibration of the Weak Lensing Source Galaxies. *arXiv*. 2020;2012:arXiv:2012.08566.

Theory

11. Doux C, Baxter E, Lemos P, et al. Dark Energy Survey internal consistency tests of the joint cosmological probes analysis with posterior predictive distributions. *arXiv*. 2020;2011:arXiv:2011.03410.
12. Doux C, Chang C, Jain B, et al. Consistency of cosmic shear analyses in harmonic and real space. *arXiv*. 2020;2011:arXiv:2011.06469.
13. Friedrich O, Andrade-Oliveira F, Camacho H, et al. Dark Energy Survey Year 3 Results: Covariance Modelling and its Impact on Parameter Estimation and Quality of Fit. *arXiv*. 2020;2012:arXiv:2012.08568.
14. Lemos P, Raveri M, Campos A, et al. Assessing tension metrics with Dark Energy Survey and Planck data. *arXiv*. 2020;2012:arXiv:2012.09554.
15. Muir J, Bernstein GM, Huterer D, et al. Blinding multiprobe cosmological experiments. *Mon Not R Astron Soc*. 2020;494(3):4454-4470. doi:10.1093/mnras/staa965.
16. Porredon A, Crocce M, Fosalba P, et al. Dark Energy Survey Year 3 Results: Optimizing the Lens Sample in Combined Galaxy Clustering and Galaxy-Galaxy Lensing Analysis. *Phys Rev D*. 2020;103(4):043503. doi:10.1103/PhysRevD.103.043503.


THANKS FOR LISTENING! :^)

#DarkBites



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