Cosmology from Non Gaussian Map-Based Statistics with DES Y3 Data

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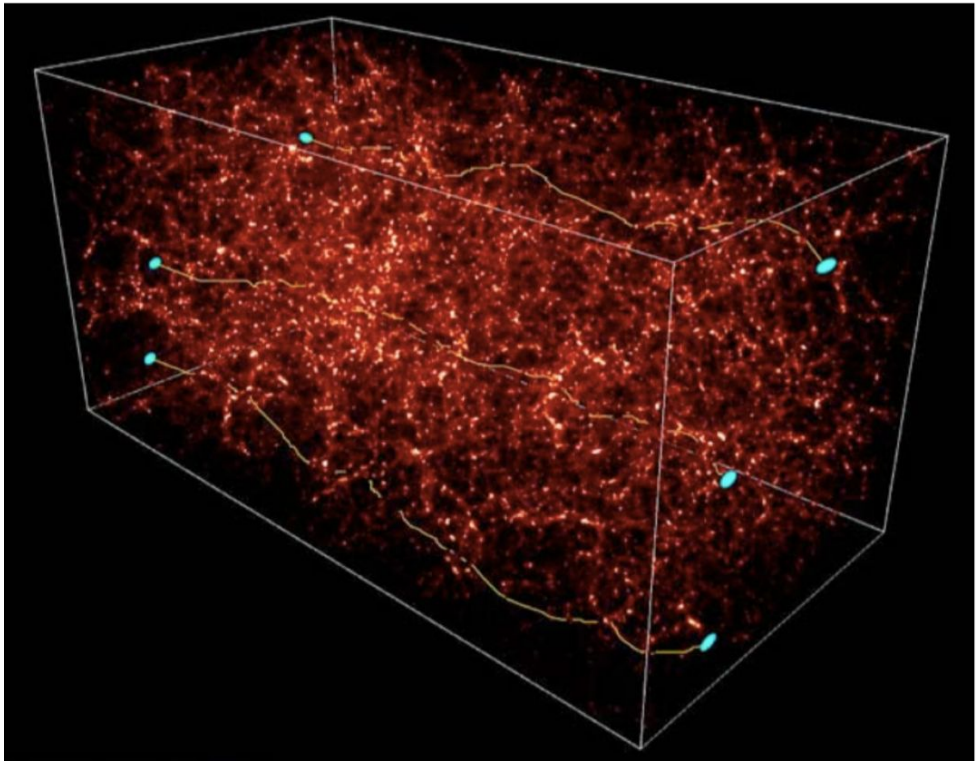
(UPenn)

Cosmology from home, July 4th-15th 2022

(Weak) Gravitational Lensing

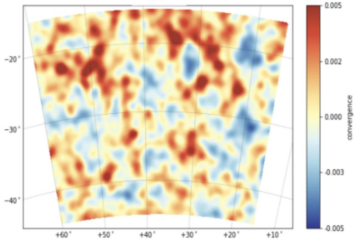


Due to the **Large Scale Structure** of the Universe,
the path followed by the light emitted by distant galaxies will appear distorted

Gravitational lensing allows to probe the matter distribution (mostly dark)

(projected) WL mass map (or convergence)

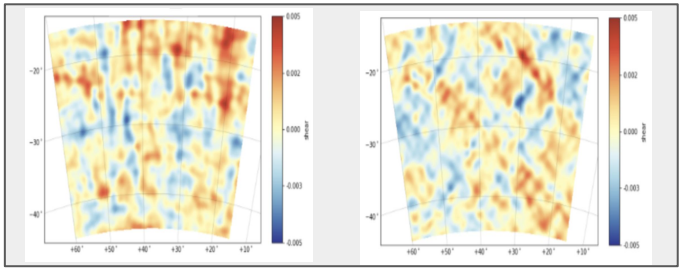
Not observable directly

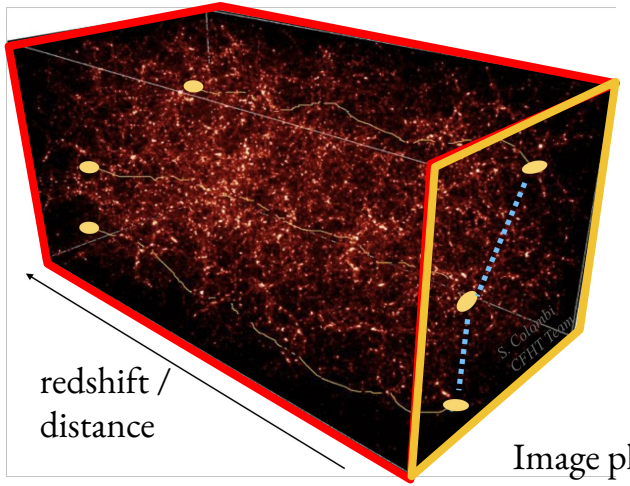


Mass Map reconstruction (e.g., Kaiser-Squires)

observable!

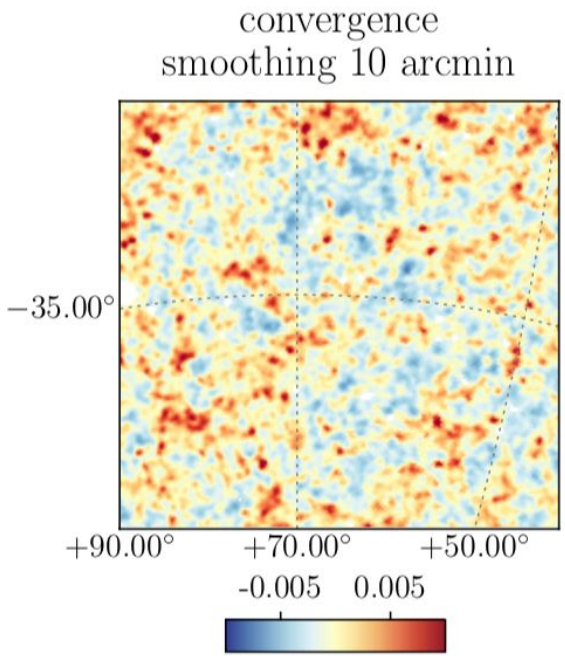
Using measured galaxies ellipticity, we can estimate the shear field (2 components)





2D weak lensing mass maps & high order statistics

(WL mass map)



Map of the mass distribution of the Universe
(integrated along the line-of-sight).

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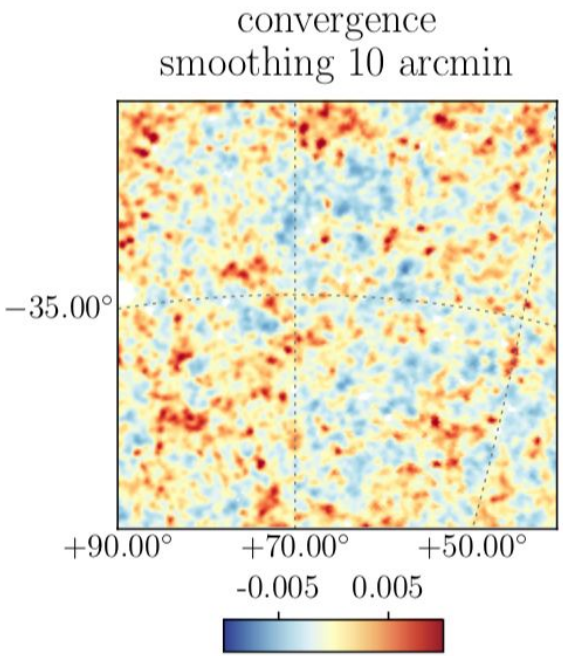

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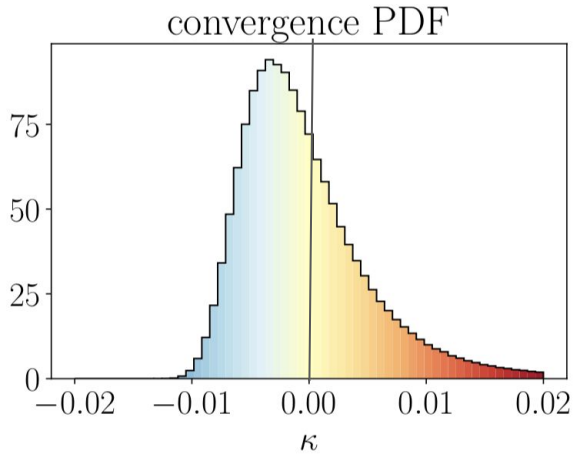

The convergence field **is not Gaussian**; high order stats can probe additional cosmological information

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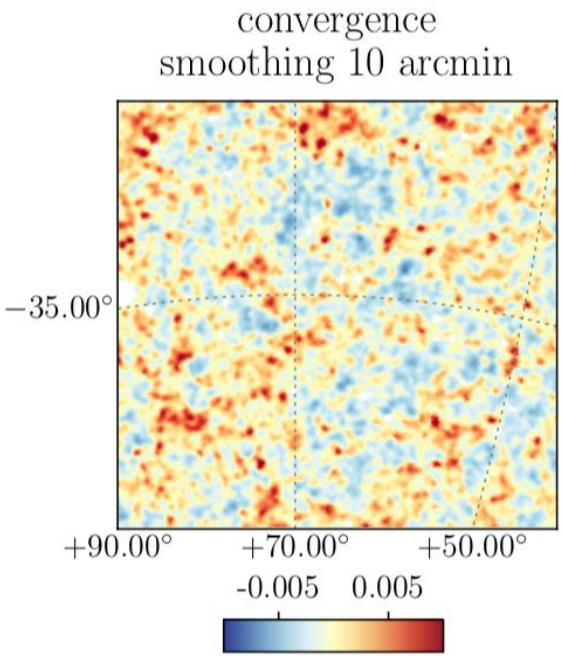

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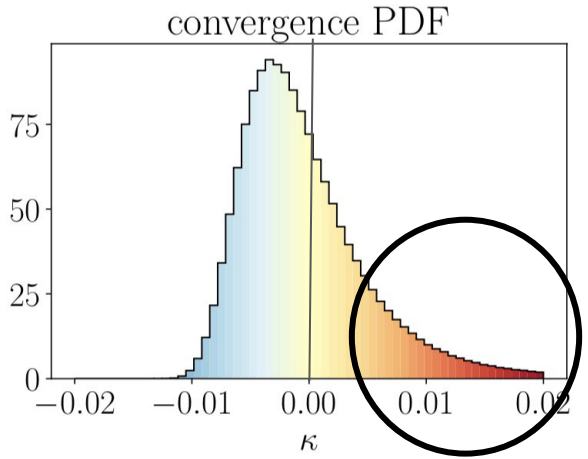

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DES Y3 moments analysis, Gatti+21, [2110.10141]

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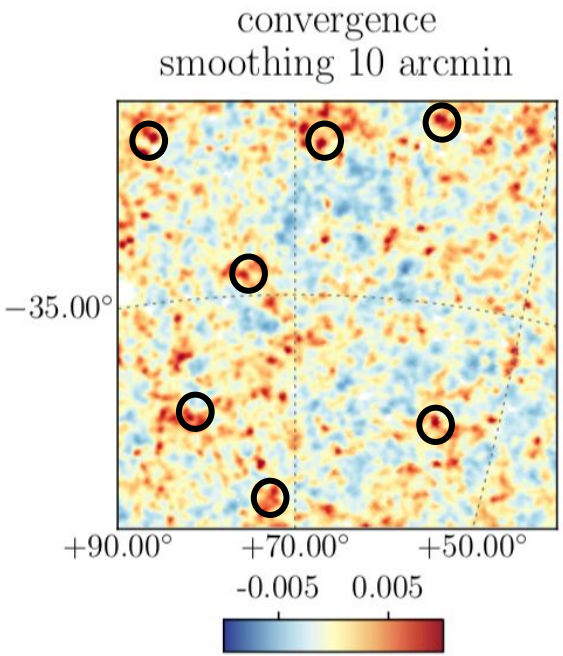

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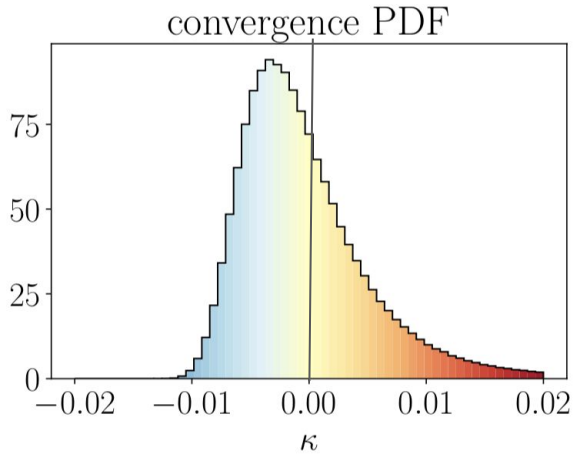

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DES Y3 moments analysis, Gatti+21, [2110.10141]
DES Y3 peaks analysis, Zuercher+22, [2110.10135]
DES Y3 peaks analysis (Jeffrey+ in prep.)

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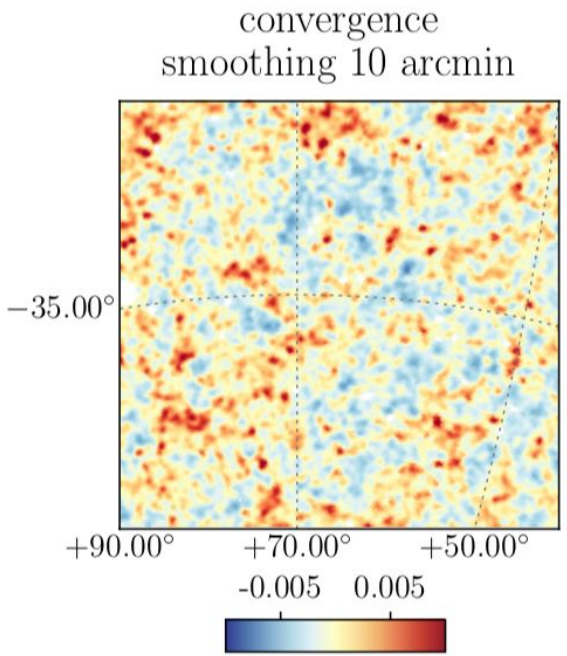

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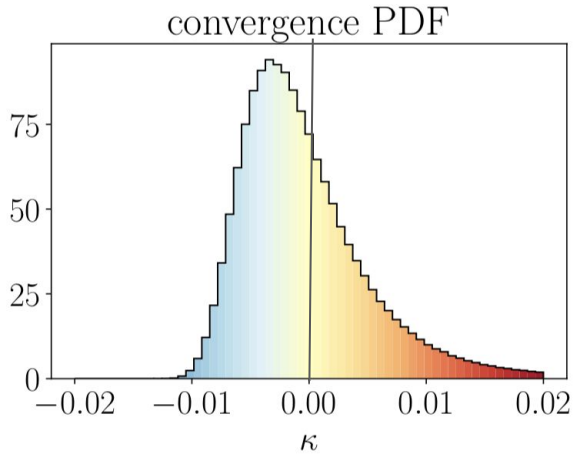
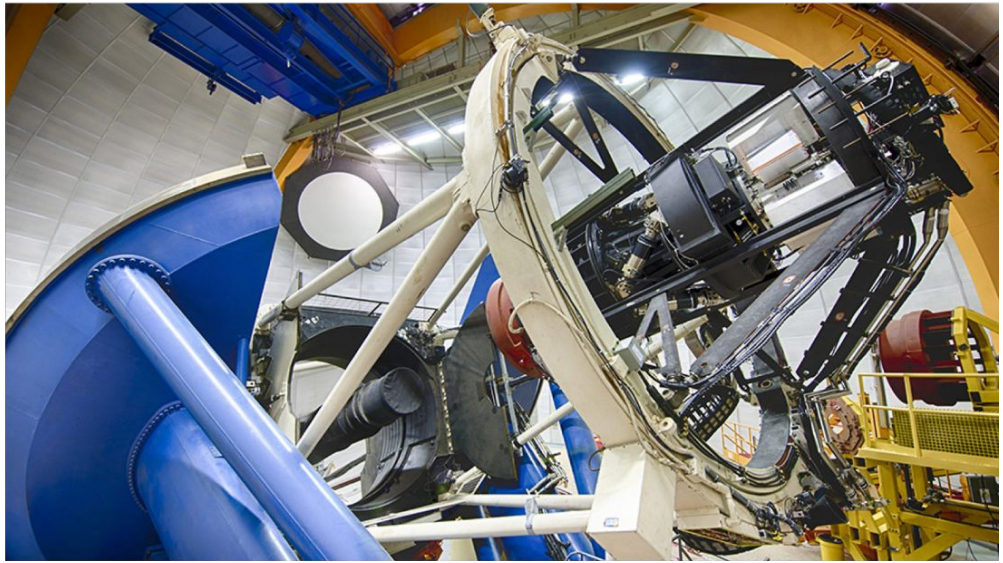


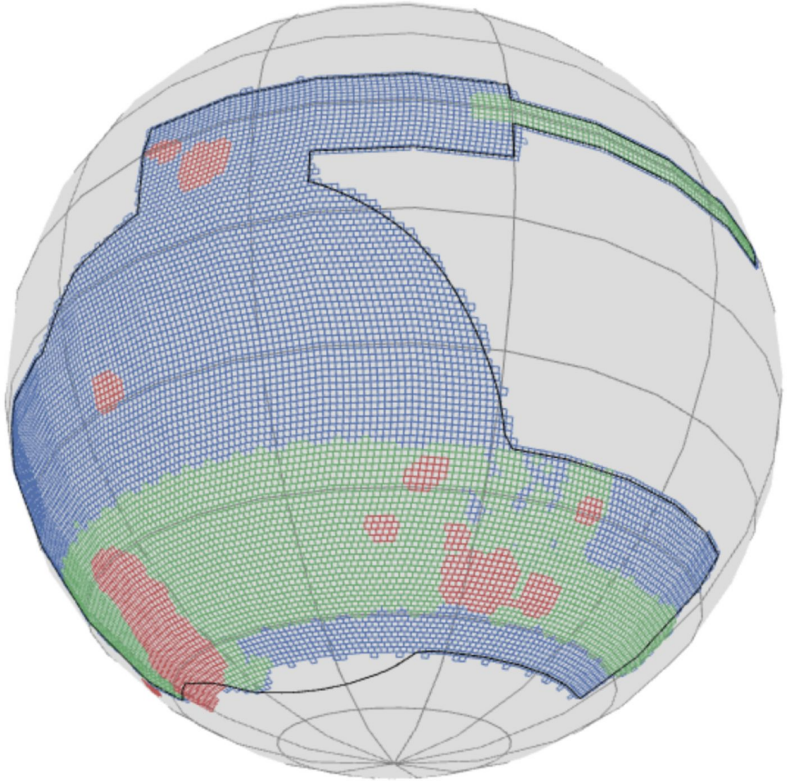
The convergence field **is not Gaussian**; high order stats can probe additional cosmological information

- Complementary & additional information wrt 2pt statistics
- Different dependence on systematics

The Dark Energy Survey

- Imaging galaxy survey.
- ~5000 sq. deg. after 6 years (2013-2019)
- Shapes, photometric redshifts and positions for 300 million galaxies.





Red : Science verification data
Green: DES Y1
Blue: DES Y3

- The DES Y3 data spans the full footprint (4134 sq deg). 100 million galaxy shapes, 10 million galaxy positions

- In 2021 we released the so called '**3x2pt**' DES Y3 cosmological analysis which featured the analysis of 3 different 2pt correlation functions (shear-shear, galaxy-shear, galaxy-galaxy). In January 2022, we released our DES Y3 catalogs.

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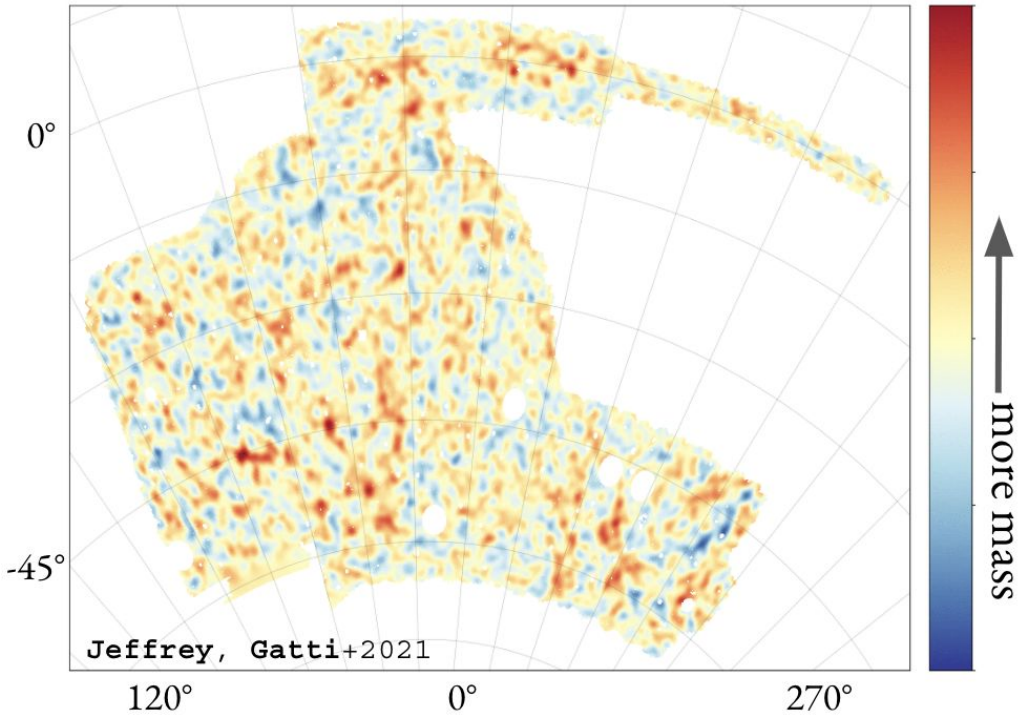
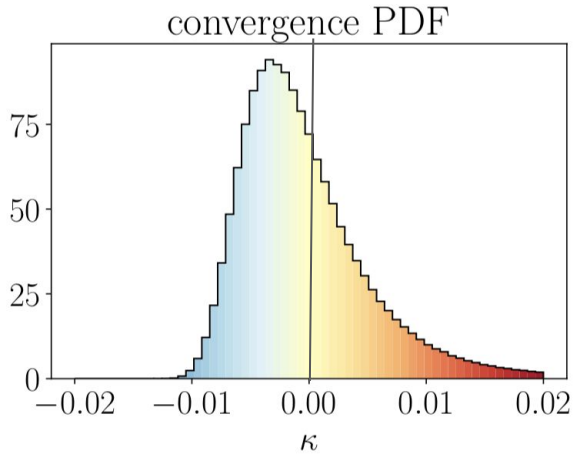
Dark Energy Survey Y3 Mass Map



5000 sq. degrees, 100 milion galaxy shapes



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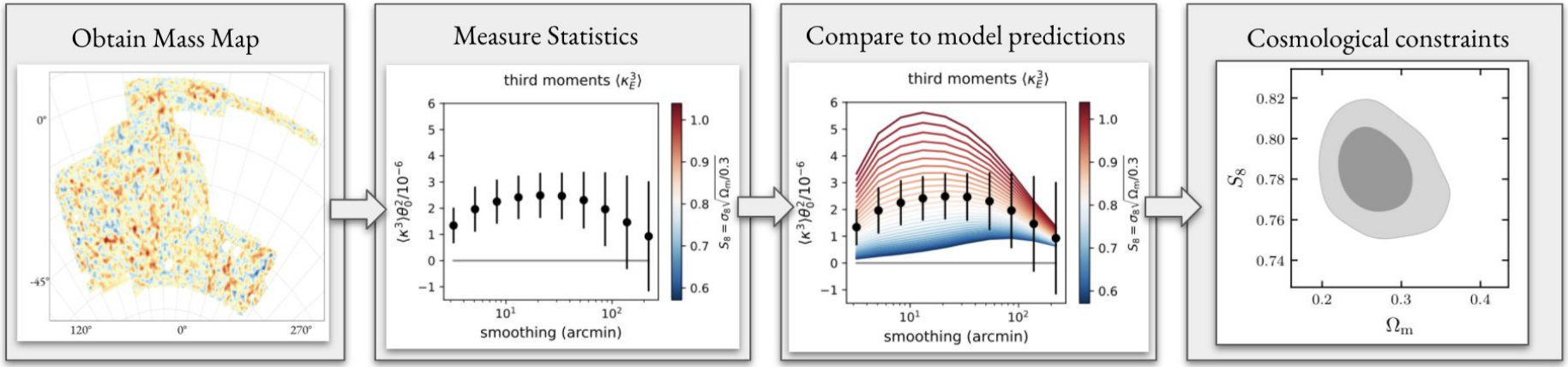
From maps to cosmology



Analytical modelling

☹ complex to develop; not always feasible

🙂 not computationally expensive

adopted in the moments analysis [Gatti+21]

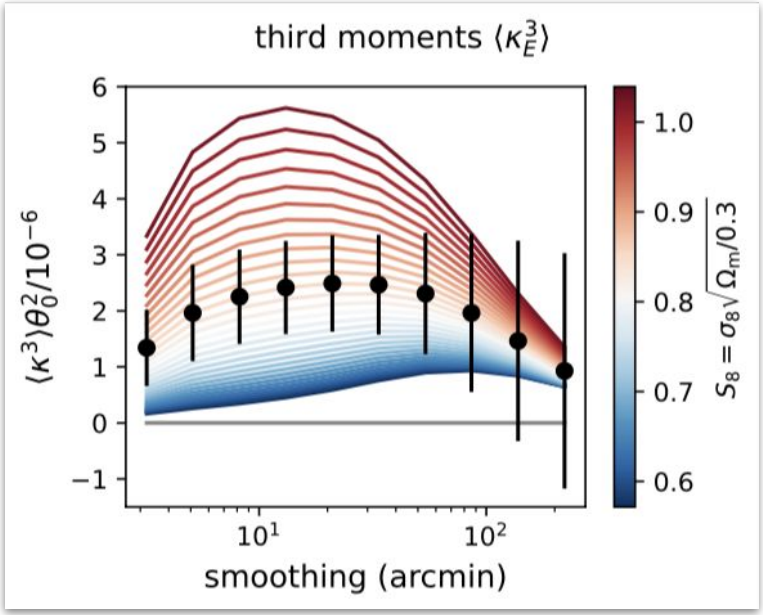
Simulation-based forward modelling

🙂 possible for any statistic

☹ computationally expensive

adopted in the DES peaks analyses [Zuercher+21, Jeffrey+22 in prep.]

Analytical predictions: complex to develop, but computationally cheap to evaluate.



$$\langle\delta^3_{\theta_0,\mathrm{lin}}\rangle(\tau) = \frac{6}{(2\pi)^3}\int \mathrm{d}^2k_1\mathrm{d}^2k_2 W(\mathbf{k}_1,\theta_0)W(\mathbf{k}_2,\theta_0)W(\mathbf{k}_1+\mathbf{k}_2,\theta_0) \times P_{\mathrm{lin}}(\mathbf{k}_1,\tau), P_{\mathrm{lin}}(\mathbf{k}_2,\tau)F_2(\mathbf{k}_1,\mathbf{k}_2,\tau), \quad \text{(A11)}$$

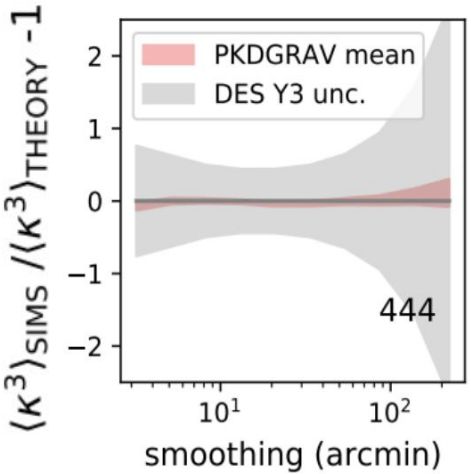
The kernels F_2, predicted by PT, can be 'extended'. Two common extensions are the SC01 and GM12, based on N-body simulations

$$F_2(\mathbf{k}_1,\mathbf{k}_2,\tau) = \frac{1}{2}[(1+\frac{k_1}{k_2}\cos\phi)+(1+\frac{k_2}{k_1}\cos\phi)] + [1-\mu(\tau)](\cos^2\phi - 1),$$

$$F_2(\mathbf{k}_1,\mathbf{k}_2,\tau) = \frac{1}{2}b_1b_2[(1+\frac{k_1}{k_2}\cos\phi)+(1+\frac{k_2}{k_1}\cos\phi)] + [1-\mu(\tau)]c_1c_2(\cos^2\phi-1) + [a_1a_2\mu(\tau) - b_1b_2 + [1-\mu(\tau)]c_1c_2].$$

Validation & systematics control

Theoretical predictions vs simulations

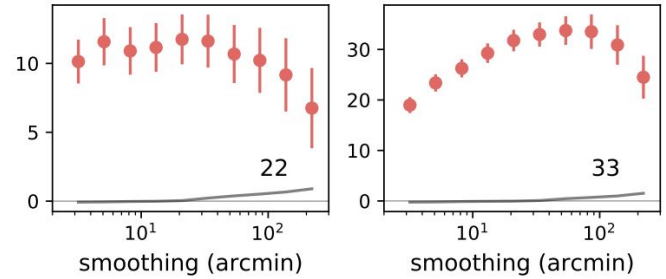


moments methods paper: 1911.05568

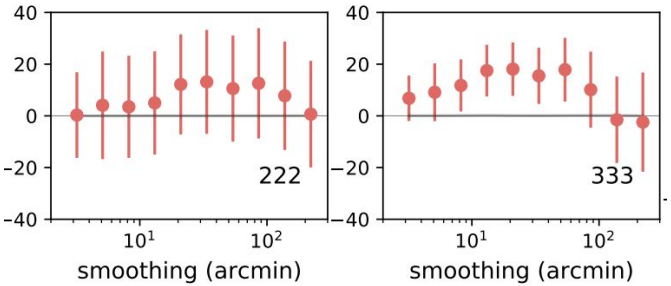
Cosmological analysis:

- ΛCDM, 5 cosmological parameters
- Intrinsic Alignment (NLA)
- Calibration systematics (redshift & shear)

PSF systematics



Second moments



Third moments

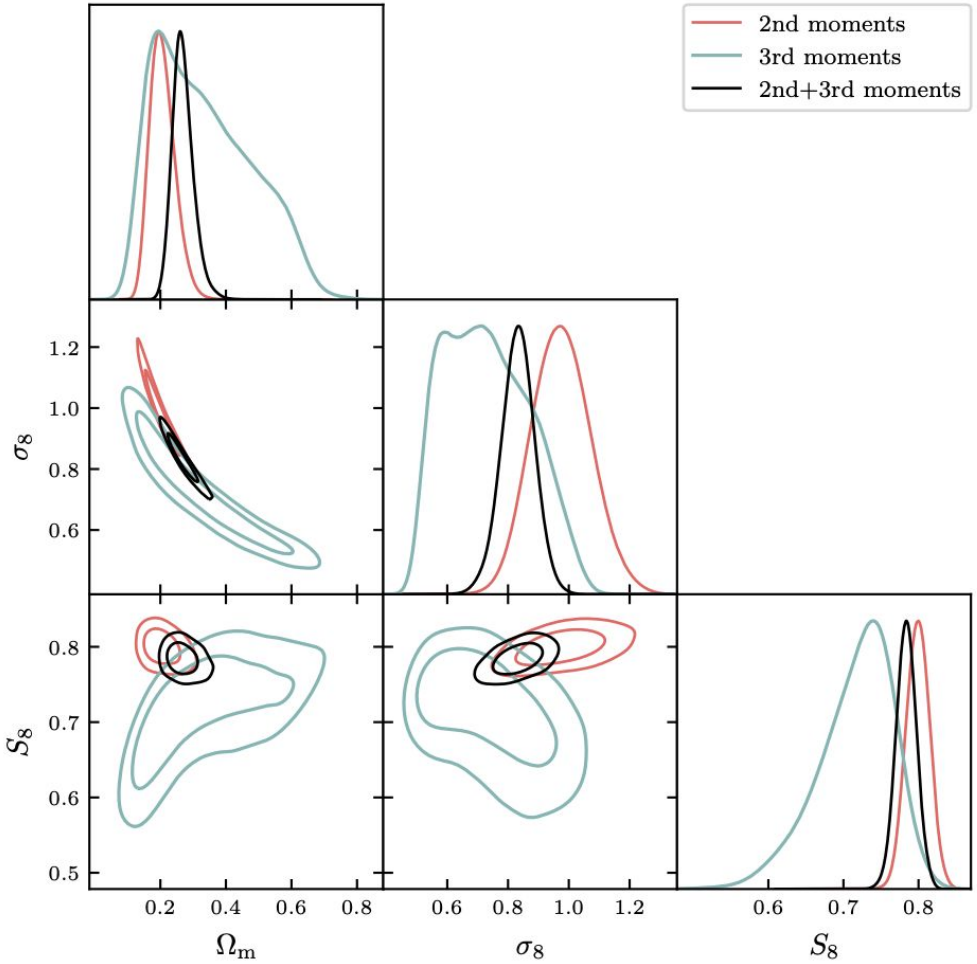
Cosmology from DES Y3 2nd+3rd moments

3rd moments probe additional non Gaussian information & break σ_8 -Ω_m degeneracy

3rd+2nd moments improve constraints by 30% over 2nd moments only

$$\Omega_m = 0.27 \pm 0.03$$
$$\sigma_8 = 0.83 \pm 0.05$$
$$S_8 = 0.784 \pm 0.013$$

Most stringent constraints on S_8 from a WL analysis to date!



Gatti+ 2021, arxiv:2110.10141

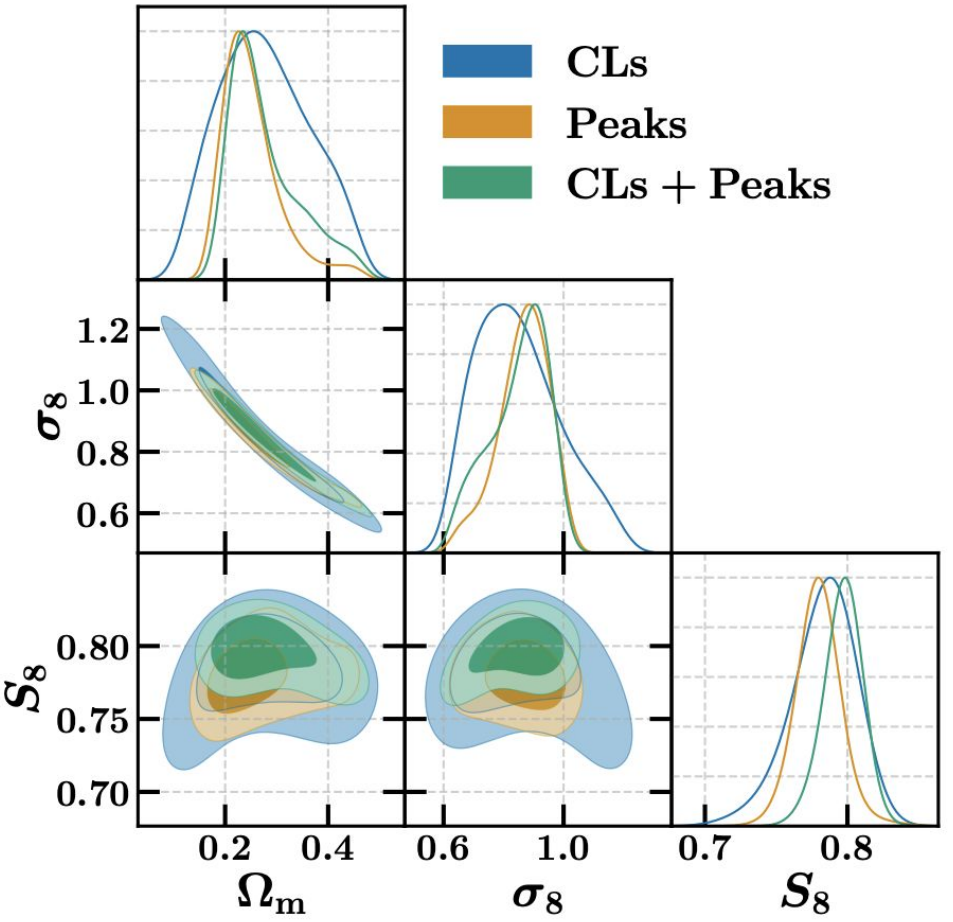
Cosmology from DES Y3 Power Spectra+ Peaks

Peaks probe additional non Gaussian information & break σ_8 -Ω_m degeneracy

Peaks+Power Spectra(CL) improve constraints by 40% over Power Spectra only

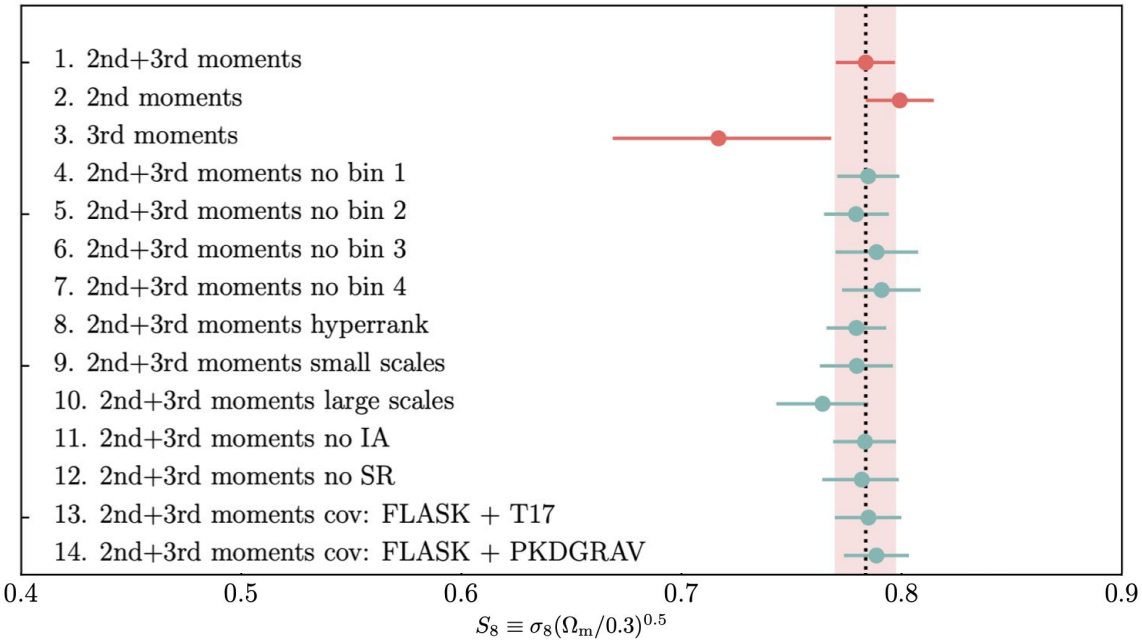
$$\Omega_m = 0.276^{+0.034}_{-0.086}$$
$$\sigma_8 = 0.850^{+0.13}_{-0.068}$$
$$S_8 = 0.797^{+0.015}_{-0.013}$$

Similar constraining power on S8 of the moments analysis

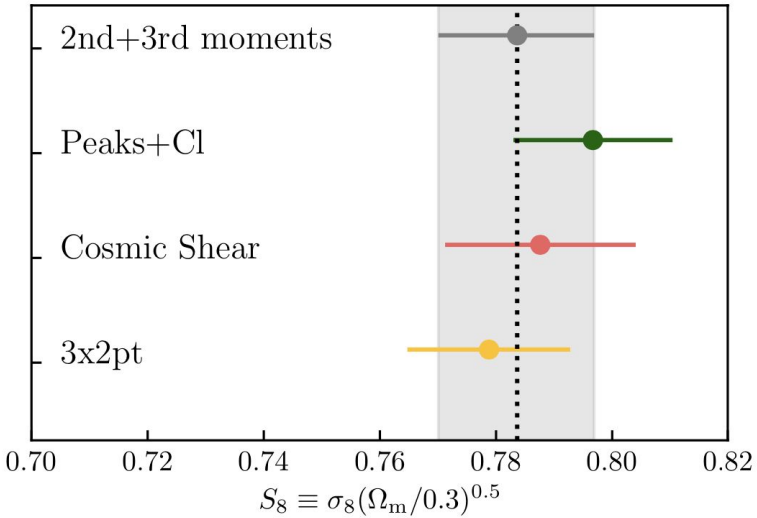


Zuercher+2021, arxiv:2110.10135

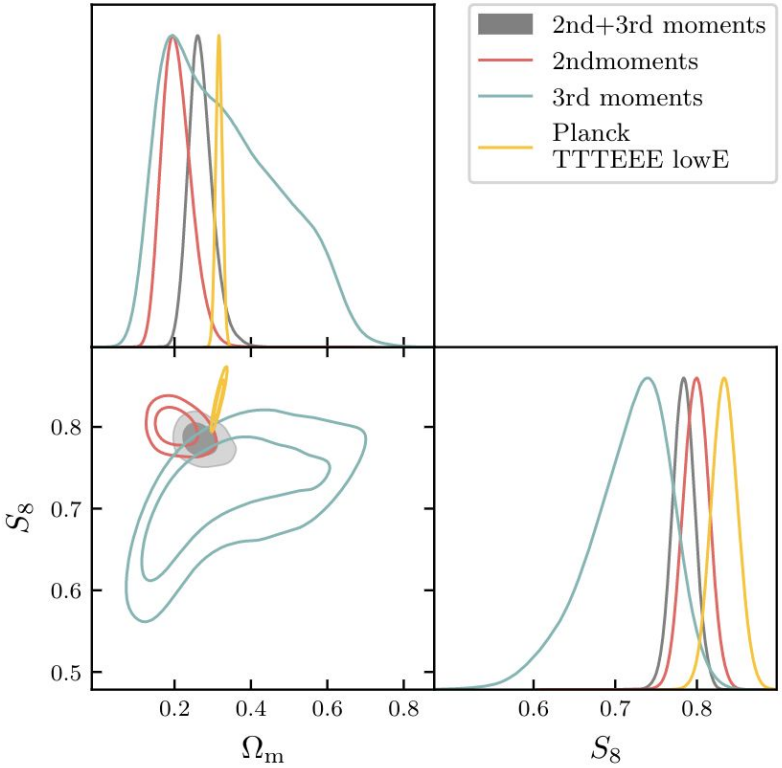
Analysis robust against different analysis choices



Consistency with other DES analyses



Consistency with Planck



2nd moments ~2.7sigma tension
3rd moments ~2.8sigma tension
2nd+3rd moments ~ 2.2sigma tension

Summary

- We presented cosmological results from 2 independent analyses using high order statistics and DES Y3 data: the moments and peaks analyses.

- Due to the additional non Gaussian information probed, these analyses provide the tightest constraints on S8 from any WL analysis to date, improving over ‘standard’ 2pt correlation analyses, and provide and independent consistency check to the fiducial DES 3x2 analysis

- Coming soon:
  >> LFI peaks / Deep Learning / phase wavelet moments cosmology with WL DES Y3 data

  >> Joint non Gaussian statistics analysis of weak lensing & galaxies

  >> DES Y6 (LSST, Euclid,...)