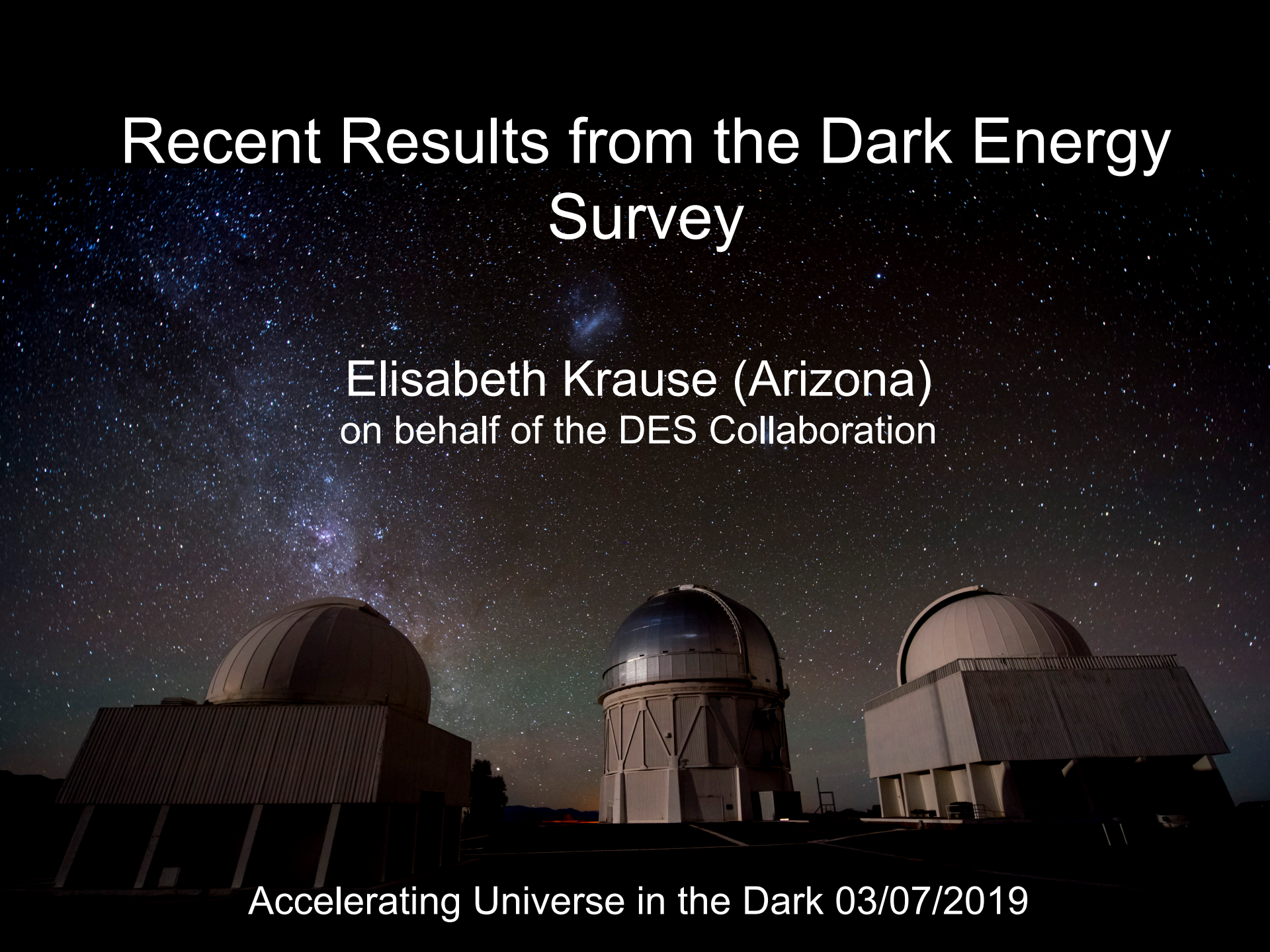
Recent Results from the Dark Energy Survey

Elisabeth Krause (Arizona)
on behalf of the DES Collaboration



Accelerating Universe in the Dark 03/07/2019


FOR
SALE

It's muddy deep down in the swamp…

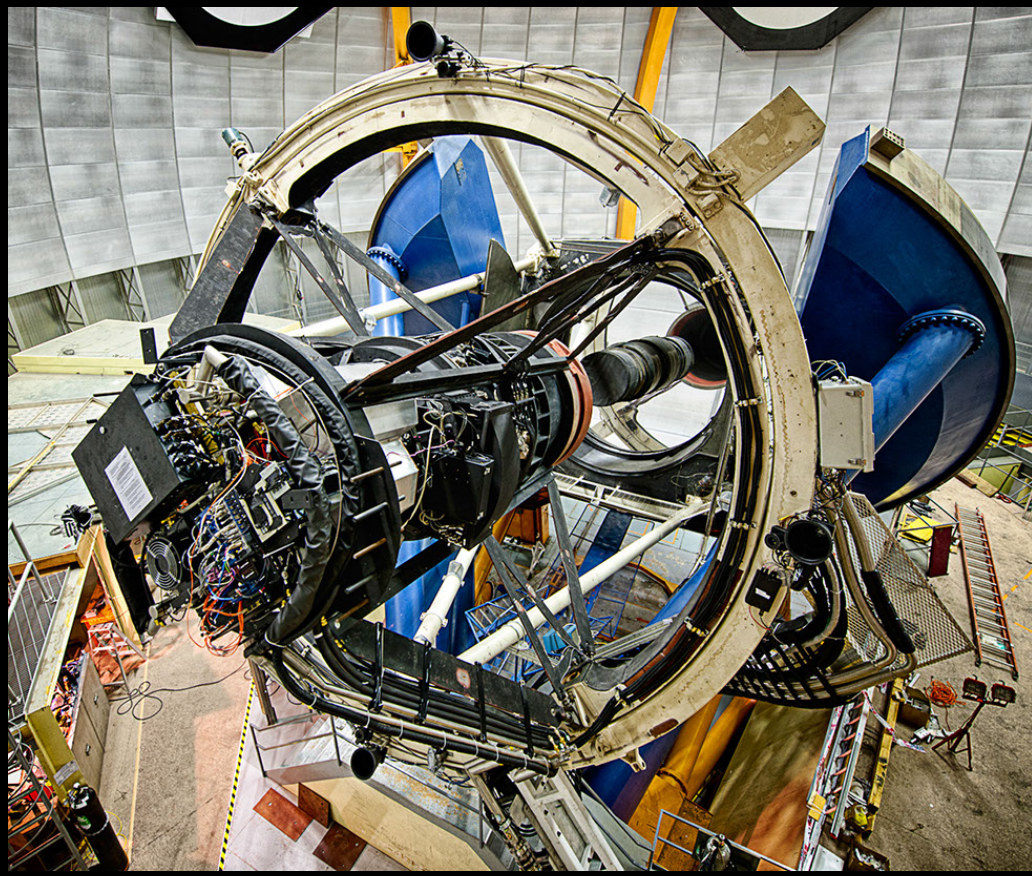
- difficult to measure colors and shapes
- obstacles can lurk in plain sight

Dark Energy Survey Collaboration

The Dark Energy Survey

- New camera for CTIO Blanco 4m telescope
  - DECam Facility instrument
- Two multicolor surveys:
  - 300 M galaxies over 5000 sq deg, grizY to 24th mag
  - 3000 supernovae (27 sq deg)
- Probe origin of Cosmic Acceleration:
  - Distance vs. redshift
  - Growth of Structure
- Survey completed after 5.5 years of observations

DECam on the CTIO Blanco 4m



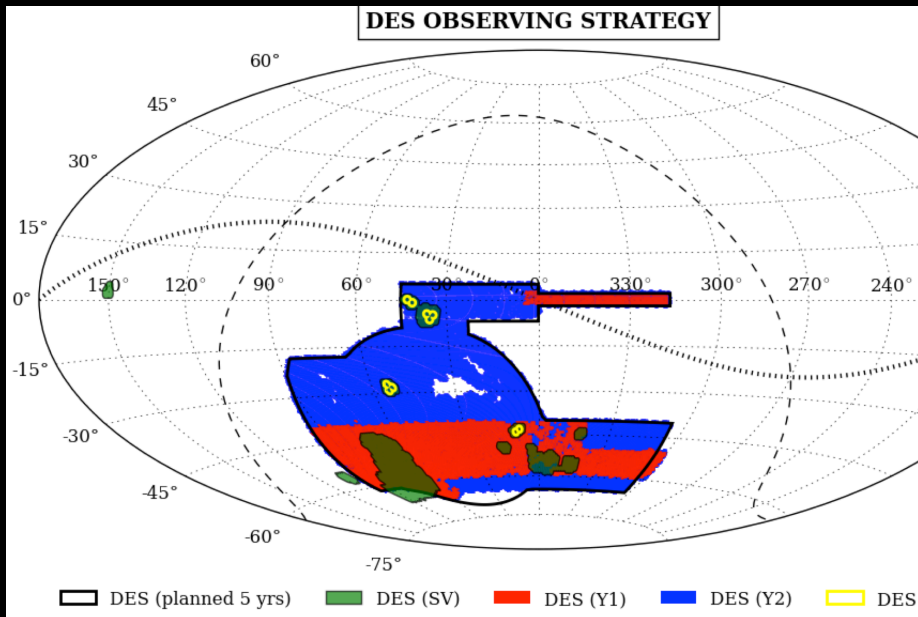
www.darkenergysurvey.org

Dark Energy Survey: Progress

SV (150 sq .deg., full depth)
science done, catalogs public

Y1 (1500 sq. deg., 40% depth)
most science done, catalogs public

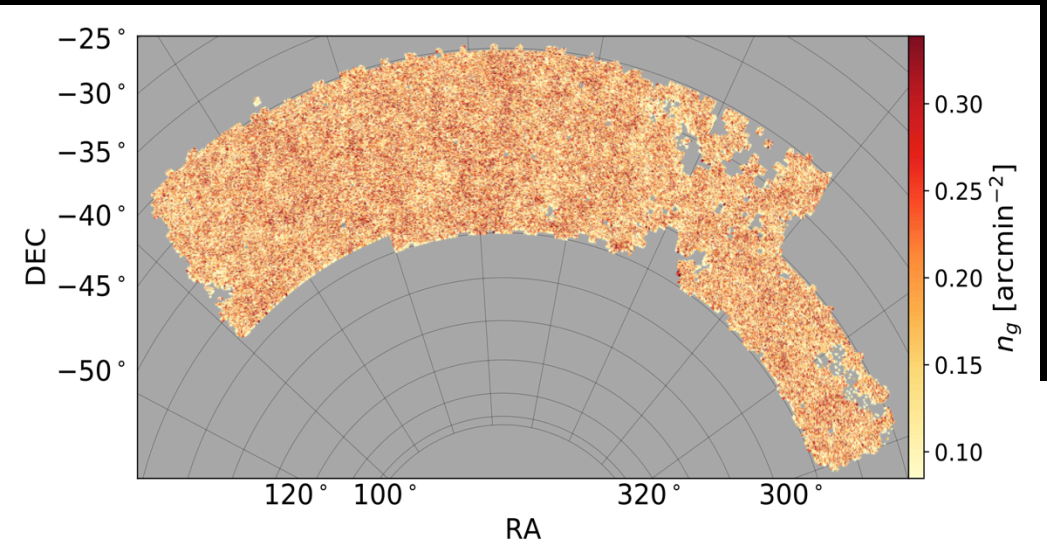
Y3 (5000 sq. deg., 50% depth)
data processed, vetting catalogs, preliminary analyses ongoing



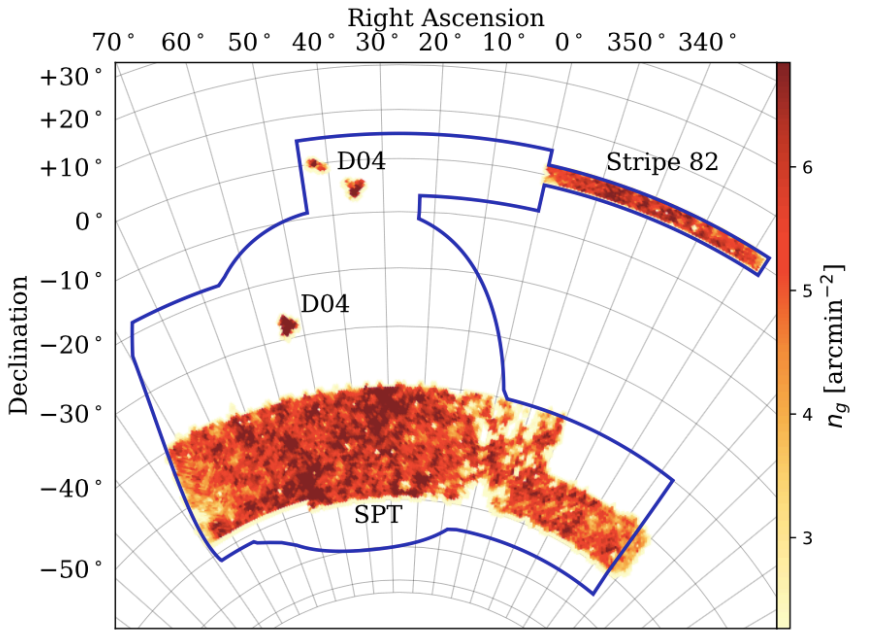
	Area	Exposure time (s) (per visit for SNe) Specified median PSF FWHM (arcsec)					Dithering	Cadence
	(deg²)	g	r	i	z	Y		
Wide	5000	10x90 - 0.9"	10x90 0.9"	10x90 0.9"	10x90 0.9"	10x45 -	10 fully interlaced tilings	10 tilings over 5 years
SN Shallow	24	1x175 -	1x150 -	1x200 -	2x200 -	-	Minimal dithers	Seeing >1.1" or 7 days since last observed
SN Deep	6	3x200 -	3x400 -	5x360 -	10x330 -			

Major El Nino affected Year 3

DES Year 1 Galaxy Samples



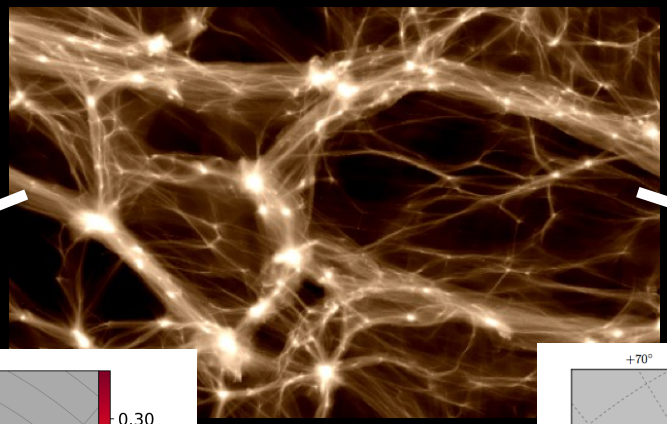
- 26 million source galaxies
- 4 redshift bins
- Sources for cosmic shear & galaxy-galaxy lensing

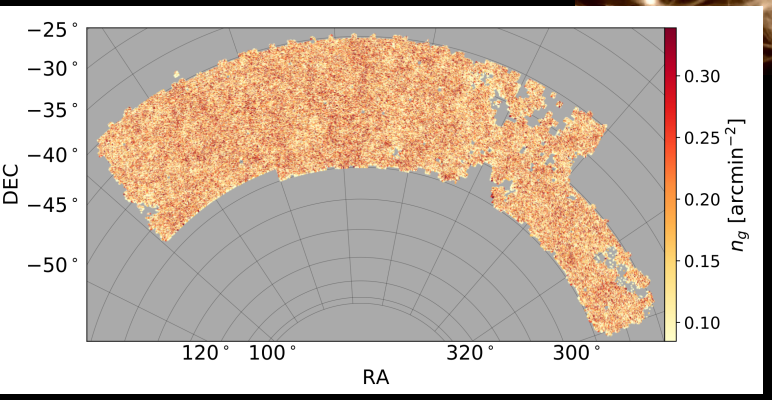


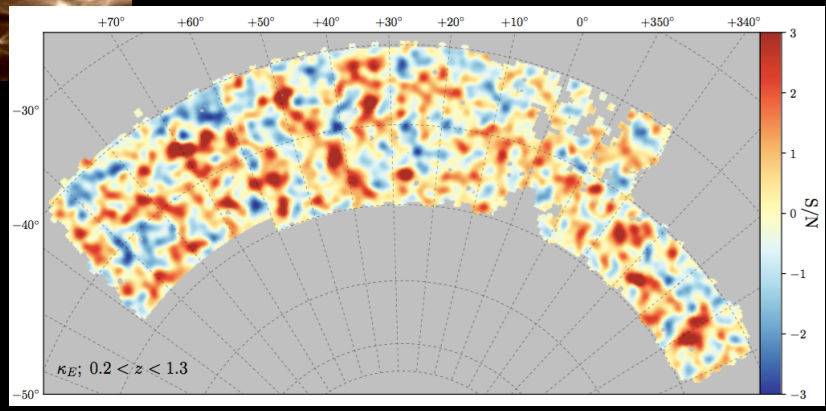
- 660,000 redMaGiC galaxies with excellent photo-z's
- Measure angular clustering in 5 redshift bins
- Use as lenses for galaxy-galaxy lensing

First Year of Data: ~1800 sq. deg. Analyzed 1321 s.d. after cuts

DES Year 1 3x2pt Analysis



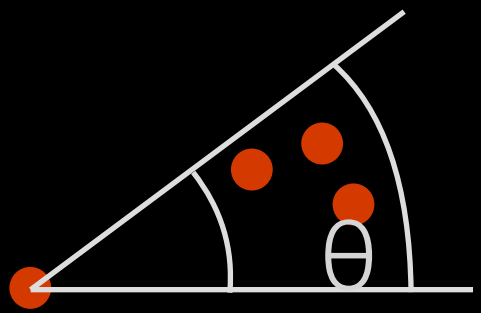


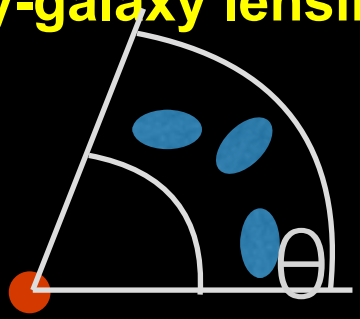


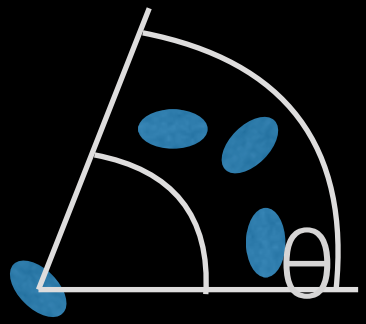
galaxies x galaxies:
angular clustering

galaxies x lensing:
galaxy-galaxy lensing

lensing x lensing:
cosmic shear

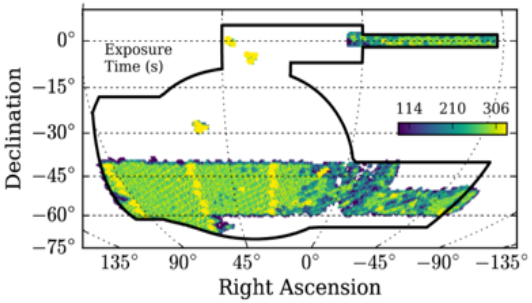






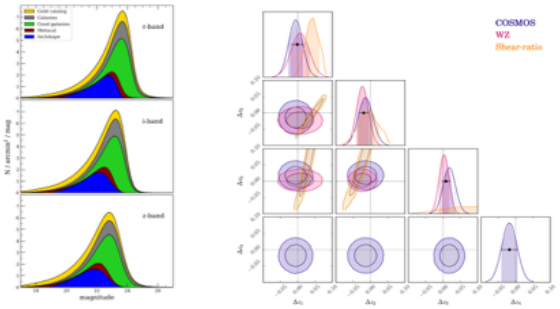
With great statistical power comes great systematic responsibility

Unprecedented size and depth of photometric data



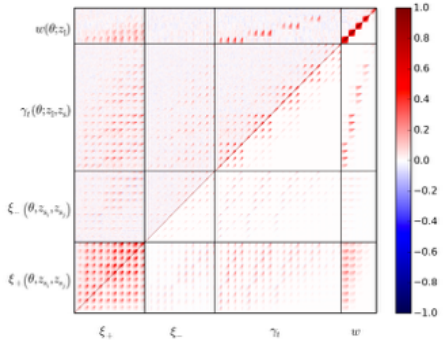
Drlica-Wagner, Rykoff, Sevilla+

Two independent shape & photo-z catalogs and calibrations

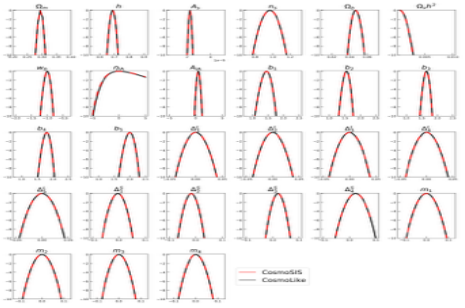


Zuntz, Sheldon+, Samuroff+
Cawthon+, Davis+, Gatti, Vielzeuf+, Hoyle, Gruen+

Full, validated treatment of covariance and nuisance parameters (including v)



Theory and simulation tested, blind, analysis with two independent codes, CosmoLike and CosmoSIS

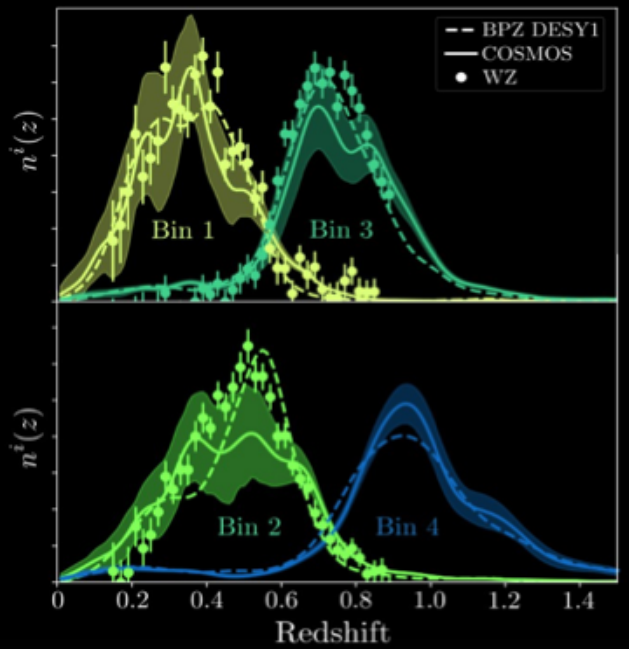


Krause, Eifler+, MacCrann, DeRose+

With great statistical power comes great systematic responsibility

- unprecedented combination of area and depth
- two independent galaxy shape measurements, including novel metacalibration algorithm
- two independent calibrations of photometric redshifts

- Matching galaxy population to COSMOS galaxies with known redshift: Hoyle, **Gruen+** (1708.01532)
- Clustering of galaxy population with galaxies with known redshift: **Davis+** (1707.08256)
- Methods agree, ~0.015 joint errors!



Measurements: shear catalogs

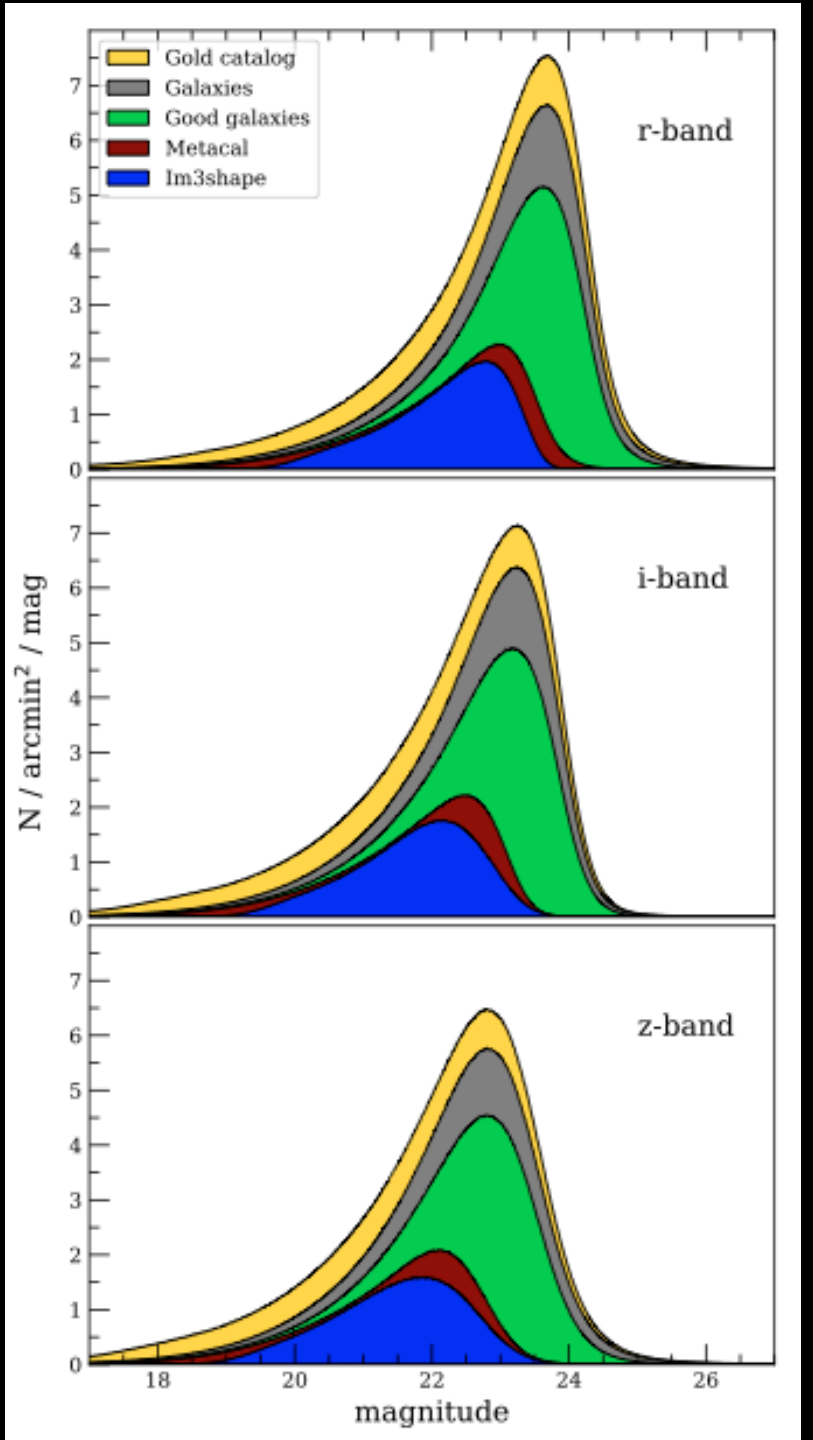
(Huff+17, Sheldon+17, Zuntz+17)

Metacalibration

- New estimator measuring shear response internally by deconvolving, shearing, deconvolving.
- Uses g, r, i bands.
- 35 M galaxies (26 M for cosmology).

im3shape

- Best-fit bulge & disc models, calibrated with simulations.
- Uses only r-band.
- 22 M galaxies (18 M for cosmology).



Systematics Modeling + Mitigation

baseline systematics marginalization (20 parameters)

- *linear bias of lens galaxies, per lens z-bin*
- *lens galaxy photo-zs, per lens z-bin*
- *source galaxy photo-zs, per source z-bin*
- *multiplicative shear calibration, per source z-bin*
- *intrinsic alignments, power-law/free amplitude per per source z-bin*

EK, Eifler+ (DES) 1706.09359

Systematics Modeling + Mitigation

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- *intrinsic alignments, power-law/free amplitude per per source z-bin*

-> this list is known to be incomplete

how much will known, unaccounted-for systematics bias Y1 results?

-> choice of parameterizations ≠ universal truth

are these parameterizations sufficiently flexible for Y1 analyses?

Angular Scale Cuts: remove known, unaccounted-for systematics

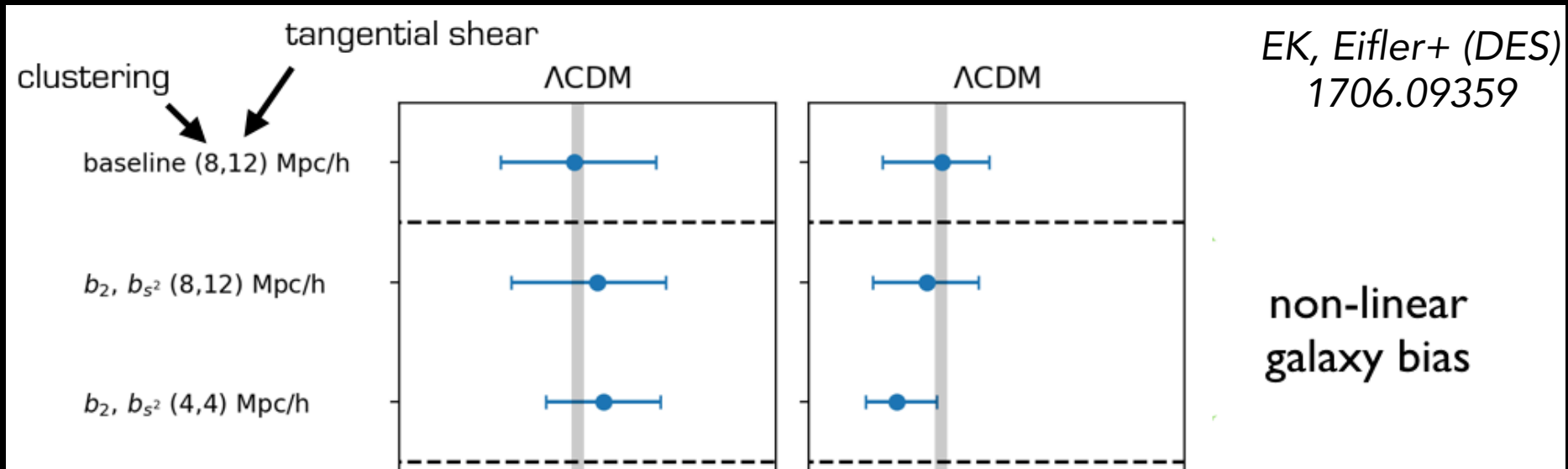
-> this list is known to be incomplete

how much will known, unaccounted-for systematics bias Y1 results?

Example: generate input 'data' incl. 2nd order galaxy bias

enhances clustering signal on small physical scales

determine scale cuts to minimize parameter biases



Systematics Modeling + Mitigation: if you asked us 3 years ago…

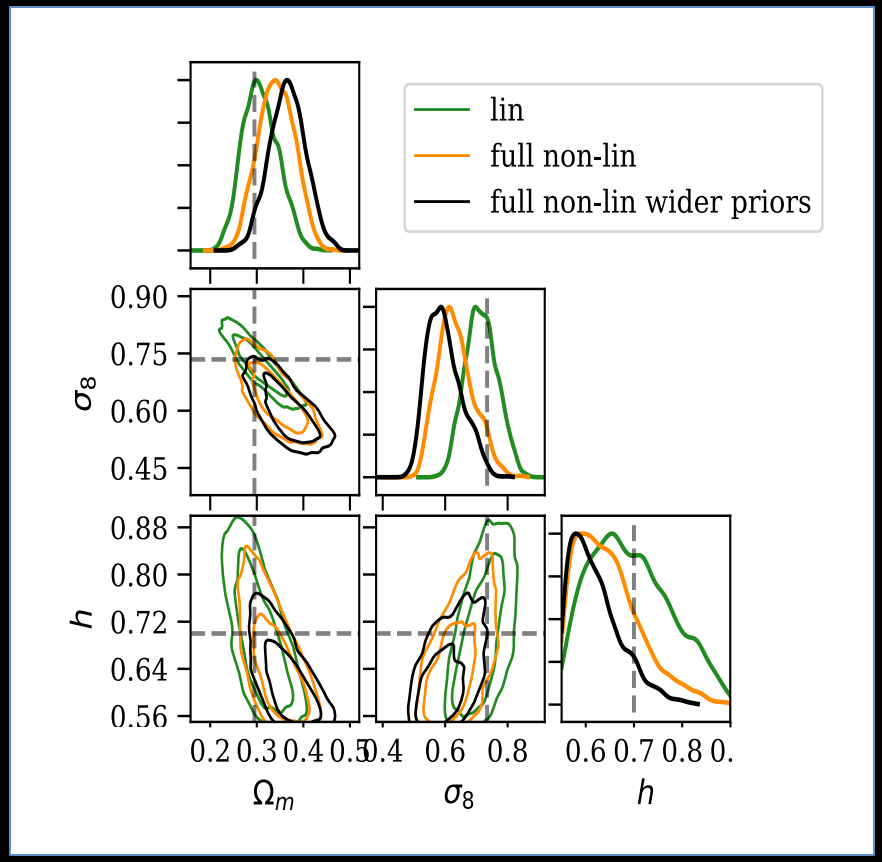
Easy to come up with large list of systematics parameters:

- LSS: LF, bias (e.g., 5 HOD parameters + b_2 per z-bin,type)
- Clusters: MOR, projection effects, triaxiality, …
- WL: shear calibration, photo-z uncertainties, intrinsic alignments,...

Σ(poll among DES working groups) ~ 500-1000 parameters

Systematics Modeling + Mitigation: why such simple models?

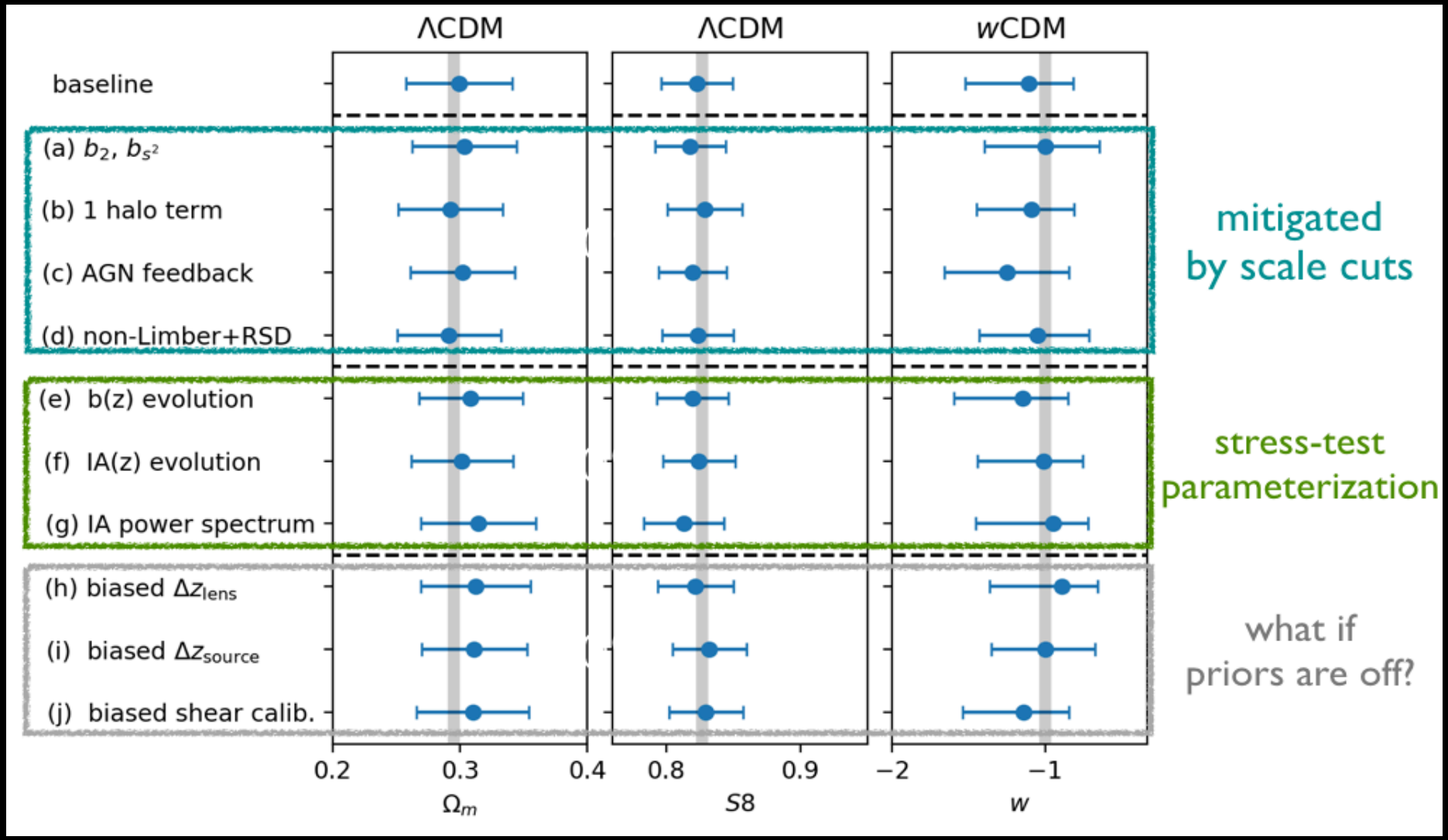
- *More accurate (+more complex) systematics models have been around for decades… why not use them?*
- *Sampling over poorly constrained model parameters may bias inferred cosmology (if model parameters are degenerate with cosmology)*
- *Model evaluation time is important when running hundreds of chains*
- *(save most accurate model for validation)*



Constraining power influences allowed model complexity

Lesson: simulate analyses early and often!

Systematics Mitigation: **imperfect parameterizations**



Analysis Validation: Mock Catalogs -> Cosmology

DeRose+ *2019:*

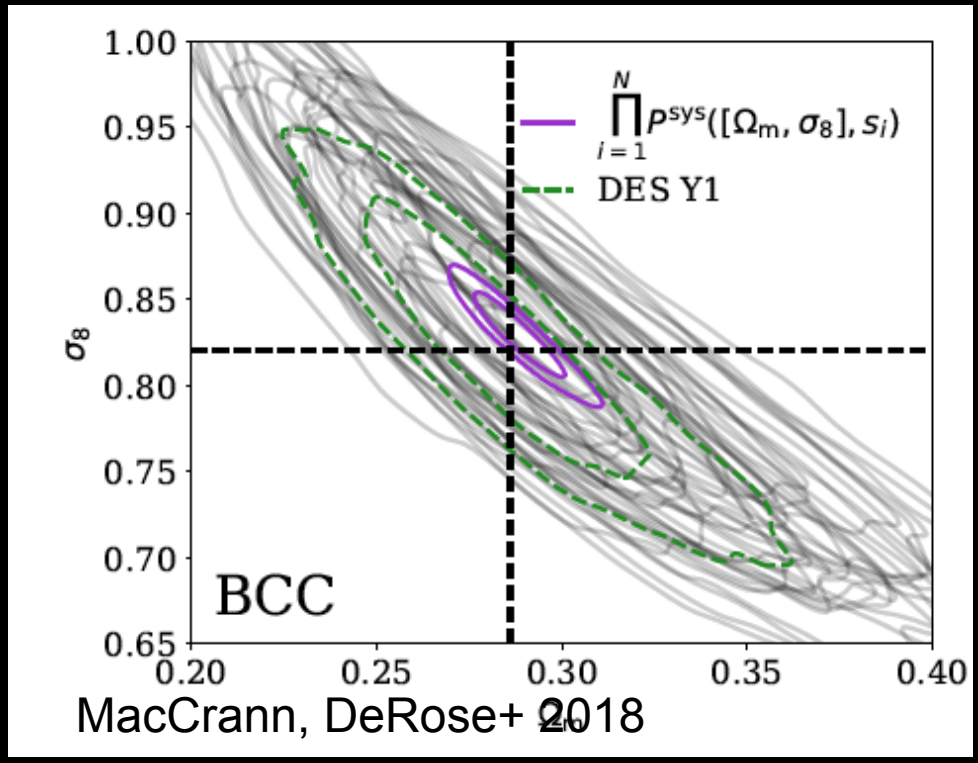
Realistic DES mock catalogs including galaxy properties and DES-specific observational effects

MacCrann, DeRose+ *2018:*

Measure 3x2pt on mock catalogs (with known cosmology)

Analyze with DES cosmology pipeline

Recover input cosmology!



MacCrann, DeRose+ 2018

Multi-Probe Blinding

Implementation: two-staged blinding process

- *shear catalogs scaled by unknown factor, until catalogs fixed*
- *cosmo params shifted by unknown vector, until full analysis fixed*
- *(do not overplot measurement + theory)*
- *(clearly state any post-unblinding changes in paper)*

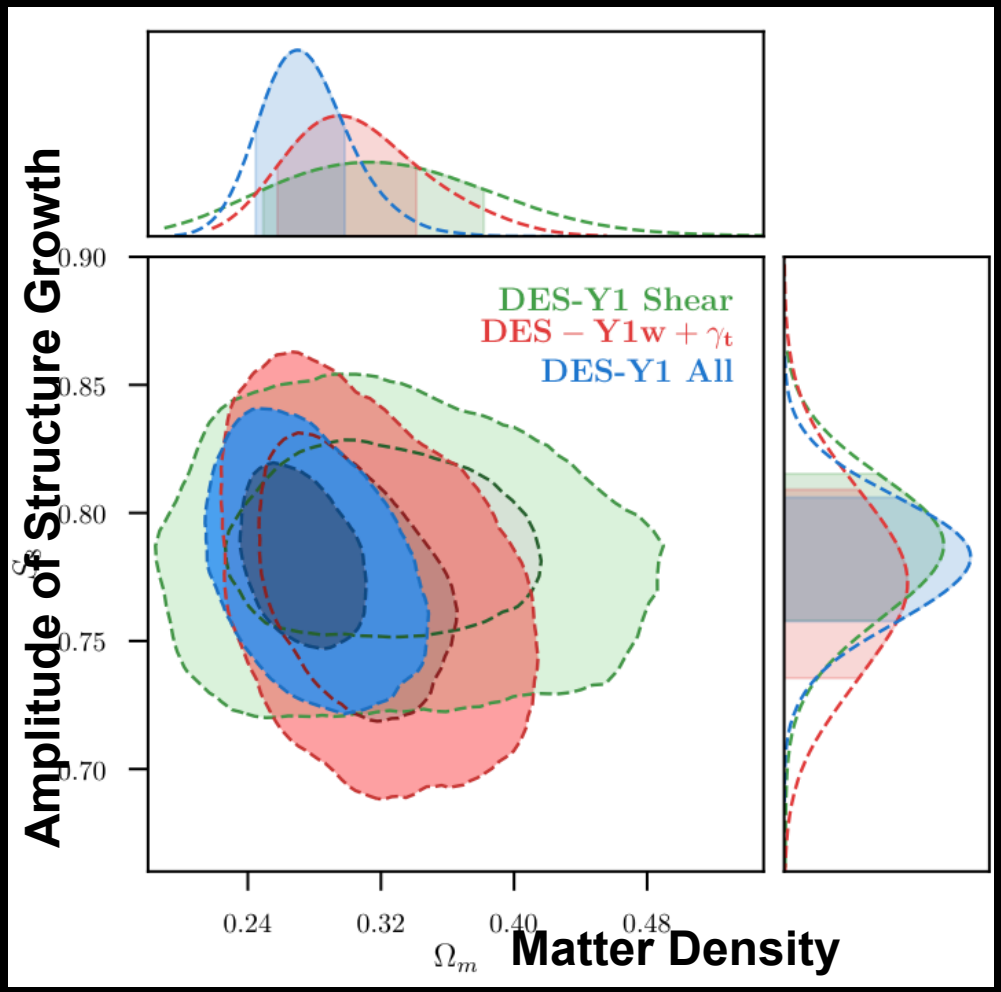
Post-Unblinding Updates

- *shear catalog blinding removed by meta-calibration*
    - *best-kept secret in DES*

- *include survey footprint in shot/shape noise model*
    - *updates to evidence ratios, χ^2*
        - *χ^2/dof =1.16*
    - *parameter values ~unaffected*

DES Collaboration 1708.01530

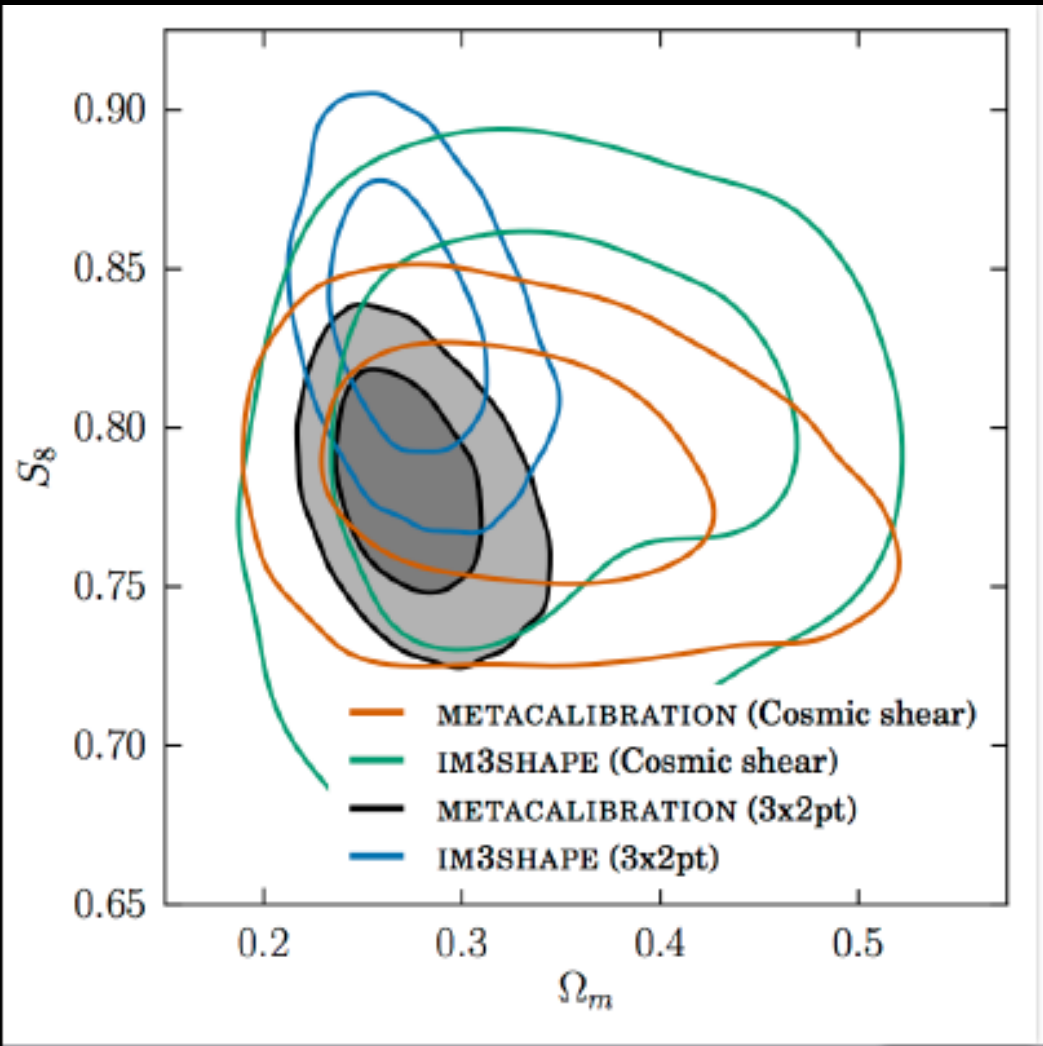
Multi-Probe Constraints: LCDM



- *DES-Y1 most stringent constraints from weak lensing*
- *marginalized 4 cosmology parameters, 10 clustering nuisance parameters, and 10 lensing nuisance parameters*
- *consistent cosmology constraints from weak lensing and clustering in configuration space*

DES Collaboration 1708.01530

Independent pipelines



Shear measurement consistency

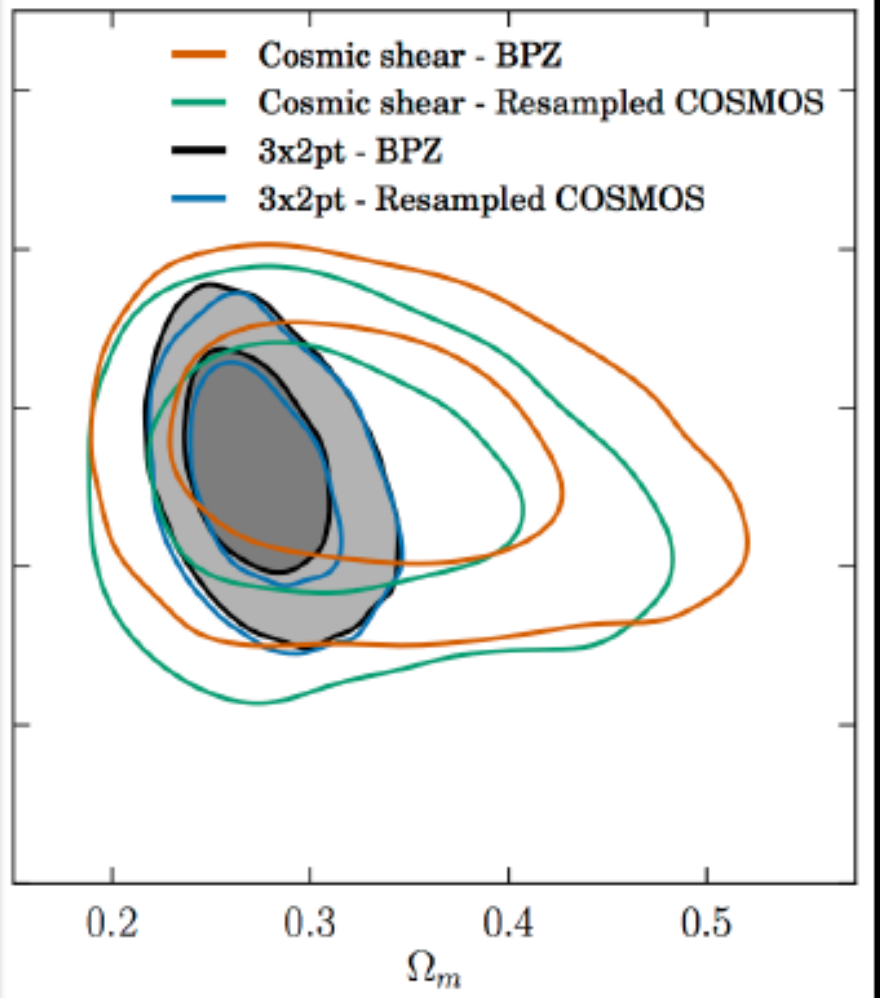
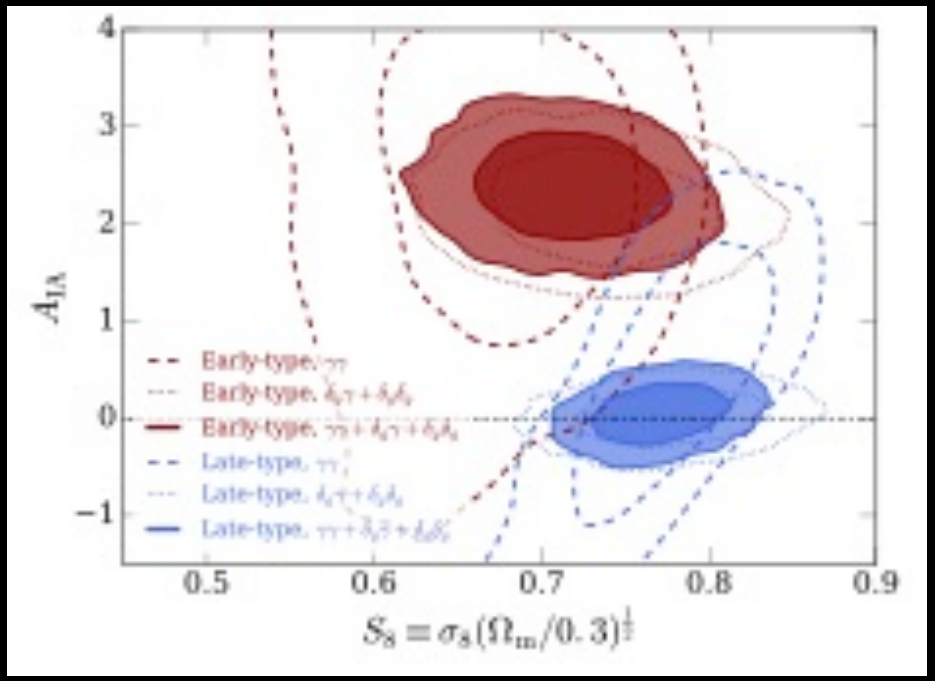
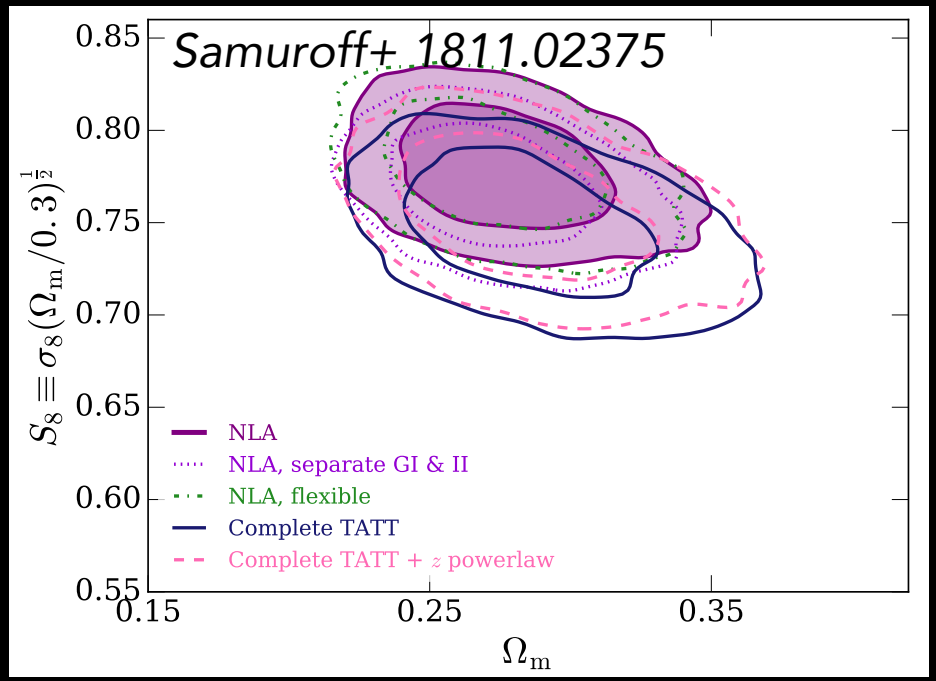


Photo-z consistency

compilation by Troxel

Extended IA Modeling

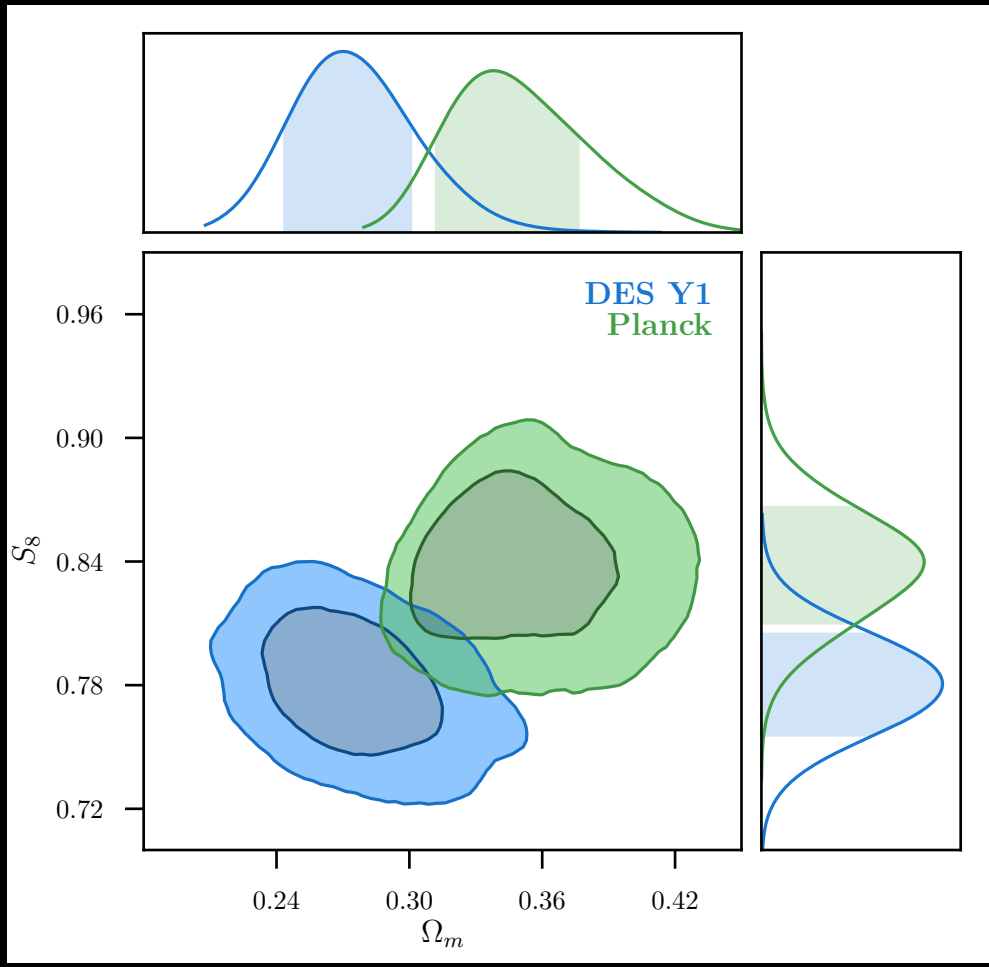




- Repeated DES-Y1 3x2pt analysis with early/late galaxy split, and using different IA models (NLA; TATT, Blazek+2017)
- DES-Y1 3x2pt baseline analysis robust to these IA modeling choices

Comparison of DES 3x2 with Planck CMB: low-z vs high-z in ΛCDM

- *note: contours marginalized over M_ν=[0.06,1]eV*
- *Central values differ by* >1σ, in same direction as KiDS
- *Bayes factor R = 6.6, "substantial" evidence for consistency in* ΛCDM



DES Collaboration 1708.01530

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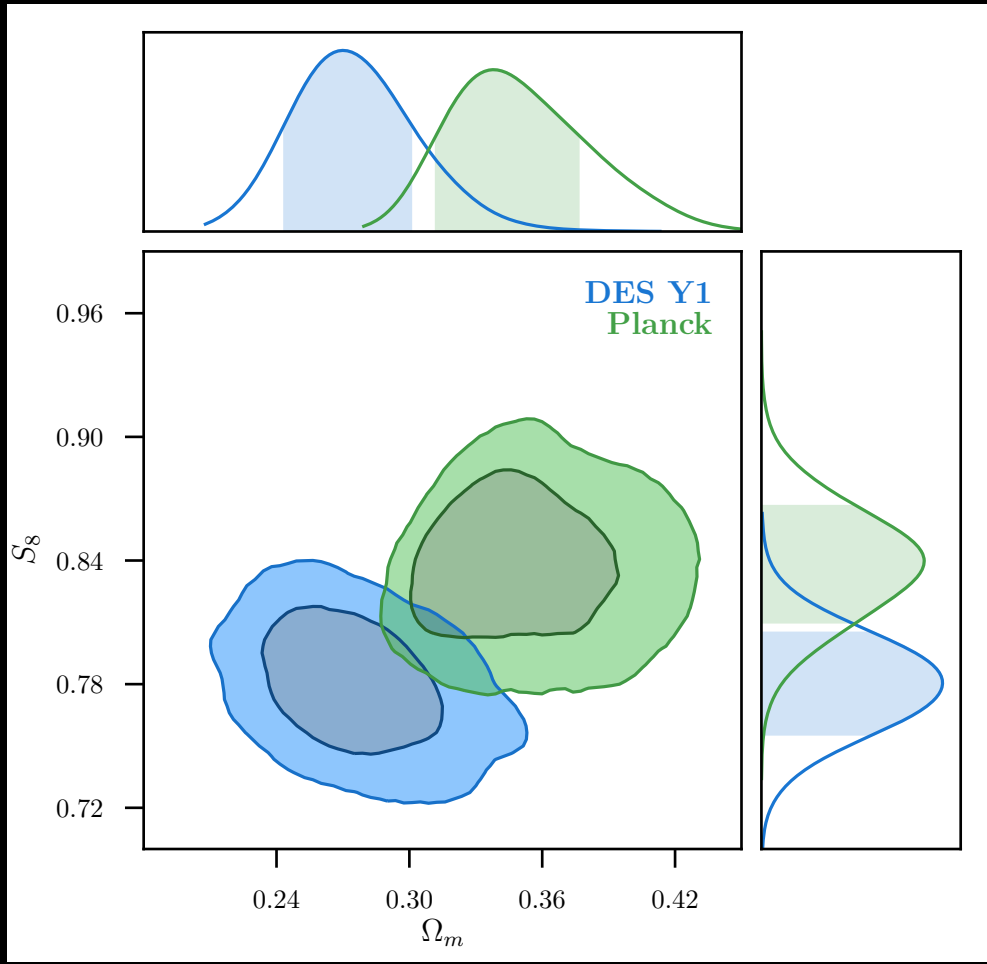
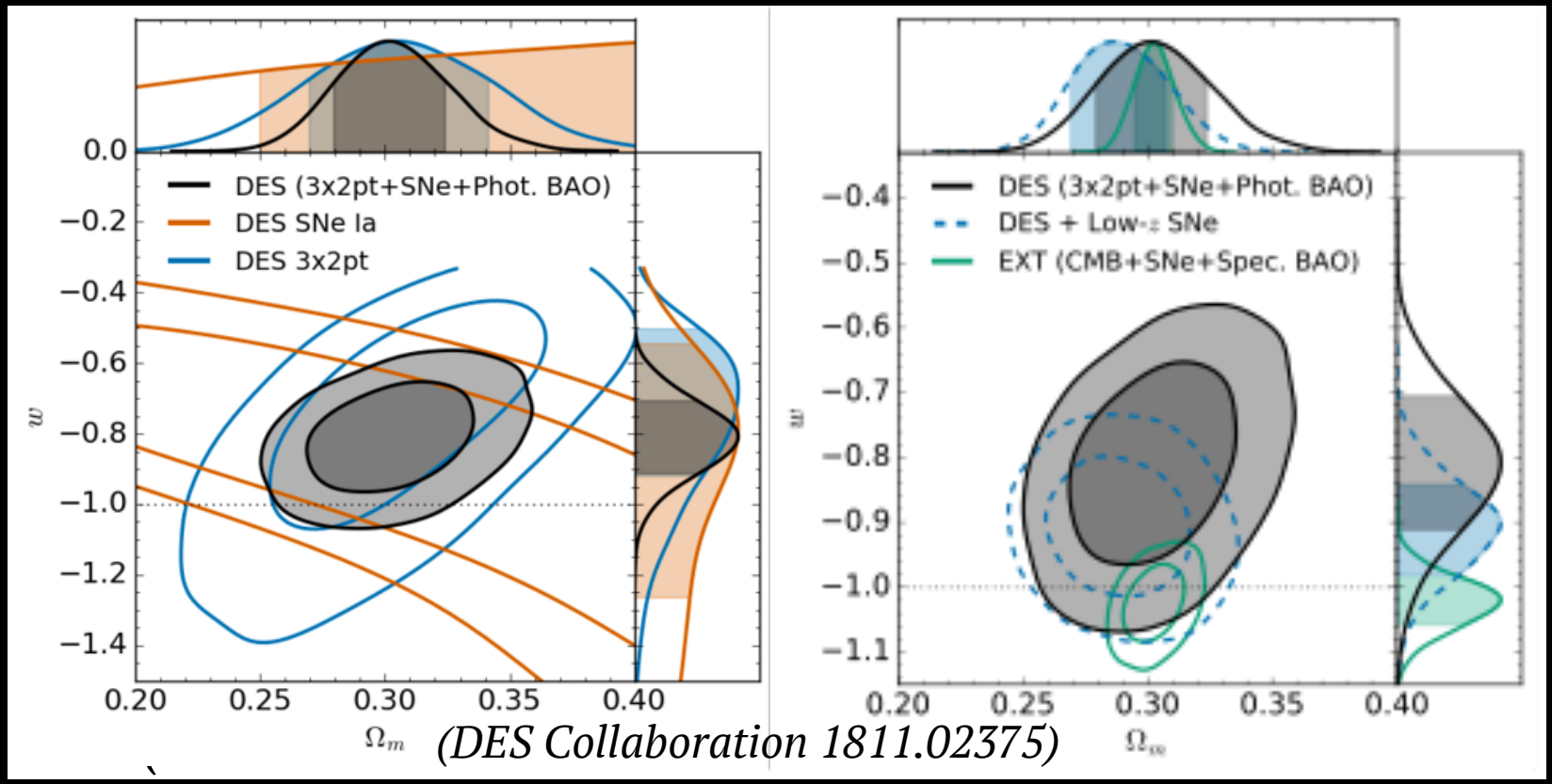
- *Bayes factor R = 6.6, "substantial" evidence for consistency in* ΛCDM
  - ***or not**, due to dependence of evidence on prior volume (Raveri & Hu 18, Handley & Lemos 19)*



DES Collaboration 1708.01530

DES Y1: 3x2pt + BAO + SN

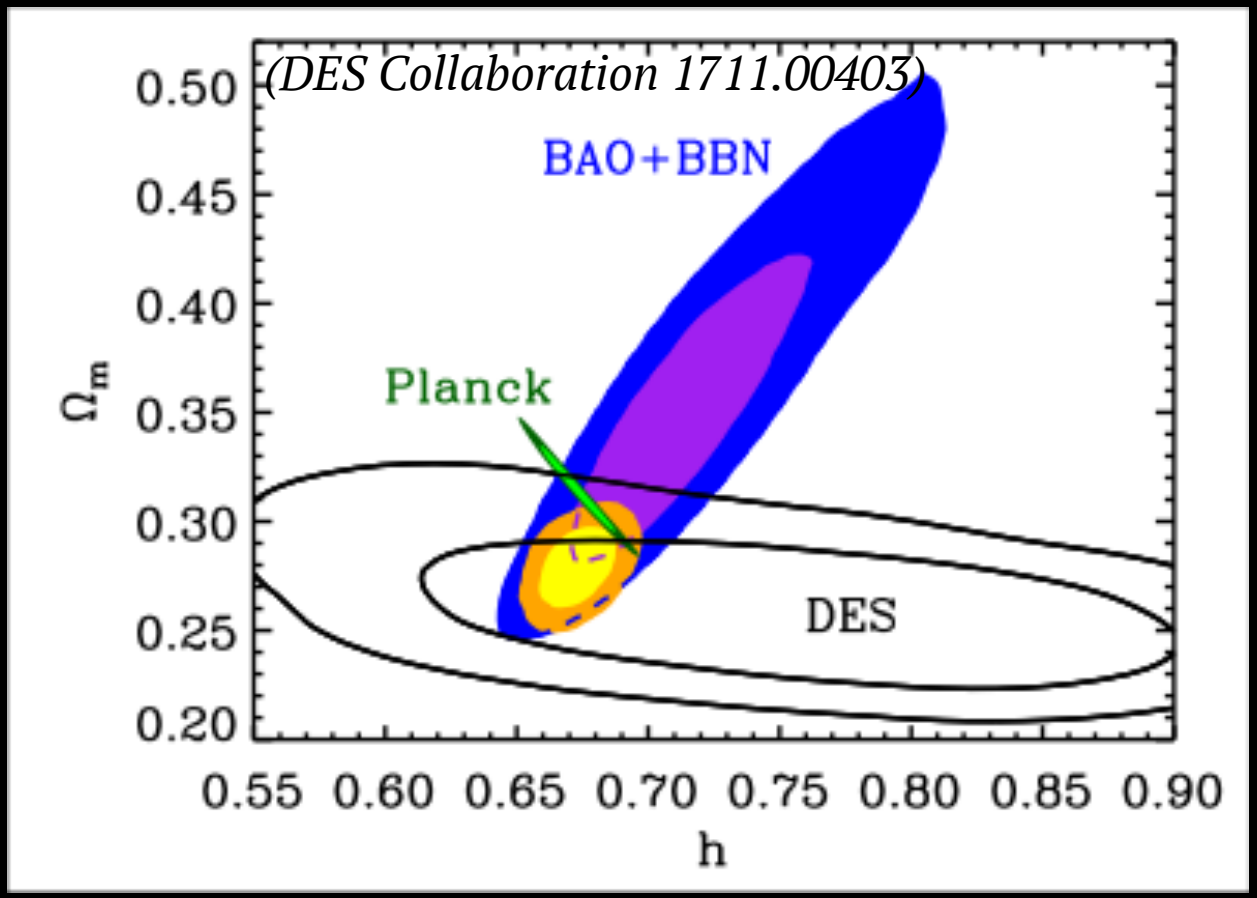


(DES Collaboration 1811.02375)

- Combined DES-Y1 results detect dark energy at 4σ
- Combined DES-Y1 results ~consistent with external probes, and LCDM

DES Y1: H_0 from combination with BBN, BAO

BAO observables depend on Ω_m, $\Omega_b h^2$, h
Combine with BBN constraint on $\Omega_b h^2$
Combine with DES 3x2pt constraint on Ω_m

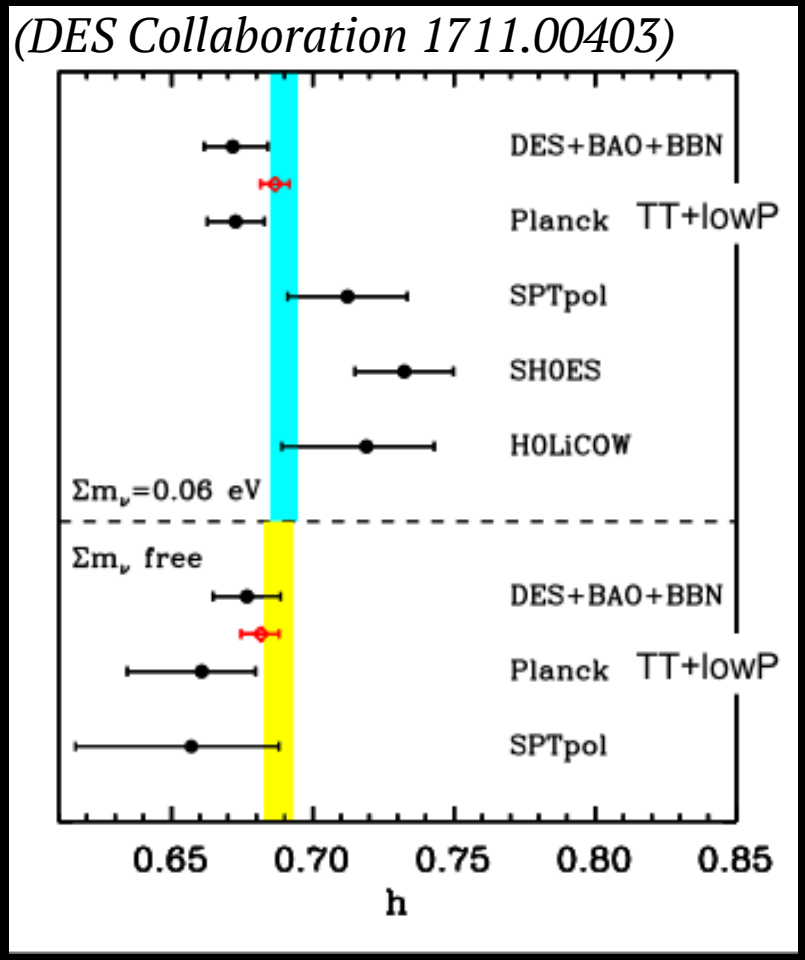


DES Y1: H_0 from combination with BBN, BAO

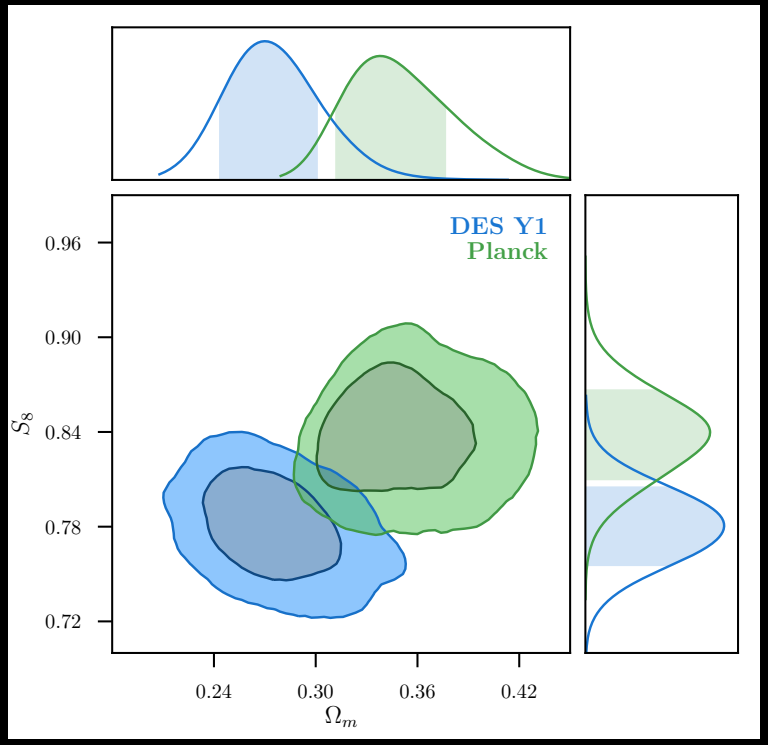
Five measurements
statistically independent
no shared systematics

Joint fit to all measurements:
2.1σ discrepancy

(DES Collaboration 1711.00403)



DES Cosmology: What's next?

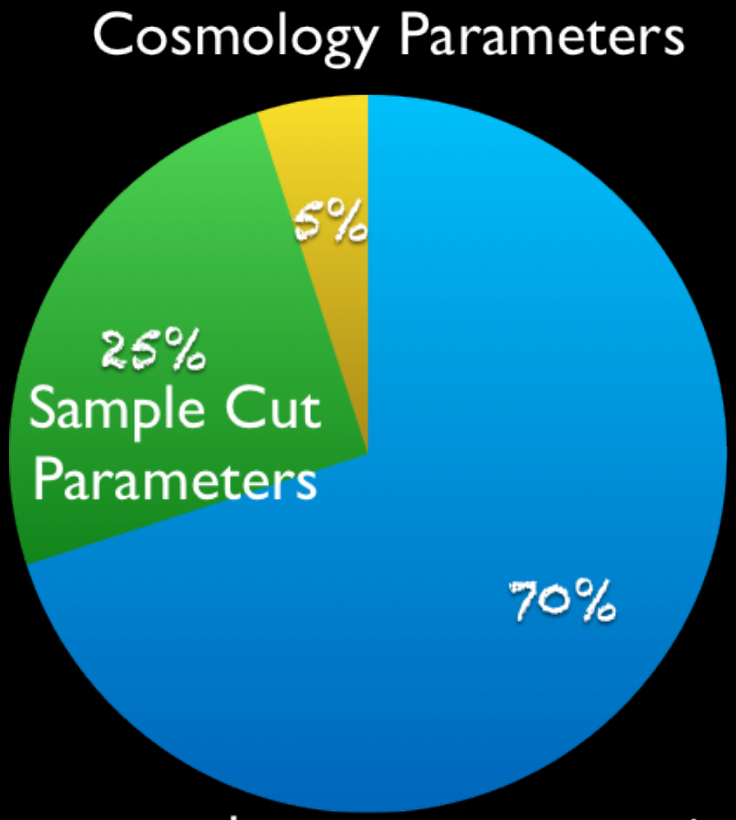


Soon: DES-Y1 cluster results!

Summer 2019

- DES-Y1->Y3 data
  - 3x increase in area
- include additional probes
  - SN, BAO
  - galaxy clusters
- include astrophysics
  - DES-Y1 small-scale cuts reduced S/N by factor 2.5

Outlook



"Systematics Parameters"

- observational systematics
  - survey specific
- astrophysical systematics
  - observable + survey specific

sample cuts + systematics highly interconnected
95% systematics…

-> multi-wavelength & multi-probe cosmology to navigate complex parameter spaces

Conclusions

- DES Y1 Cosmology results (from galaxy clustering, galaxy-galaxy lensing, and cosmic shear (3x2), SN) are now out:
  34 papers, more to follow.
- No significant tension DES Y1 <-> Planck in ΛCDM (yet?).
- Precision will increase with
  - larger data sets
  - including more probes (clusters, SN, cross-correlations…)
  - improved astrophysics modeling

  enabling tests of more complex models.