KiDS-450: Cosmology Constraints with Weak Lensing Peak Statistics

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Collaborators: X.K. Liu, H. Hildebrandt, C.Z. Pan, N. Martinet, Z.H. Fan, P. Schneider, and KiDS collaboration

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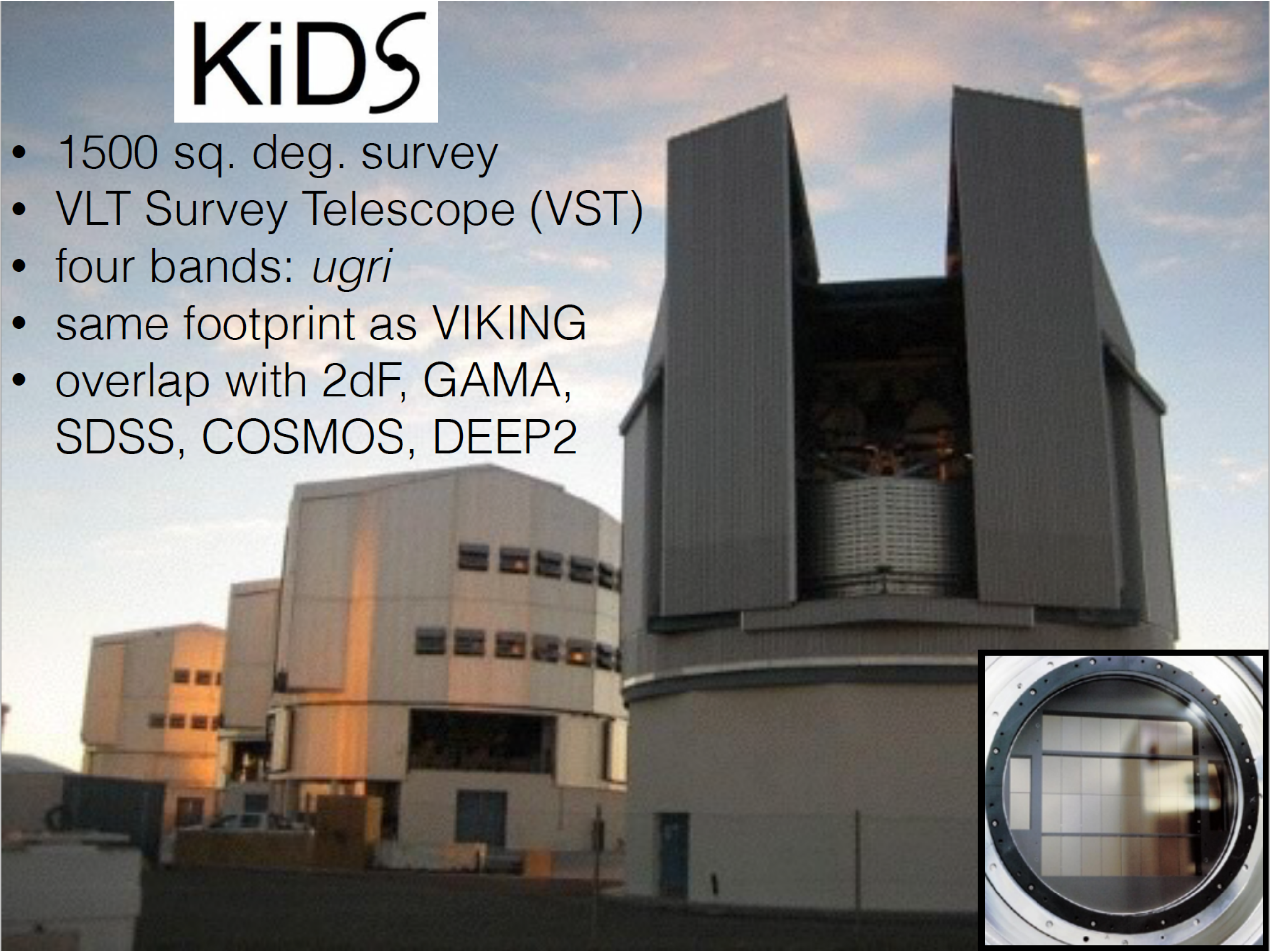
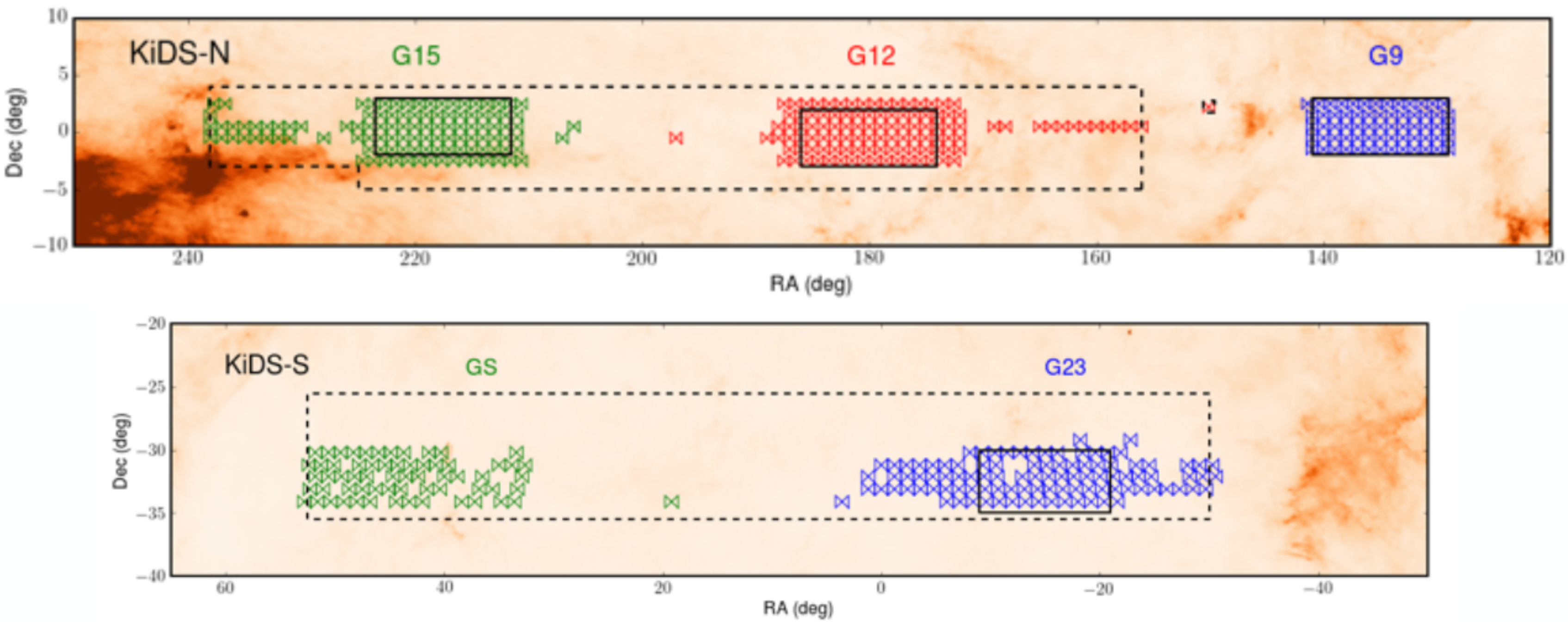
KiDS

- 1500 sq. deg. survey
- VLT Survey Telescope (VST)
- four bands: *ugri*
- same footprint as VIKING
- overlap with 2dF, GAMA, SDSS, COSMOS, DEEP2



KiDS-450 (DR3)

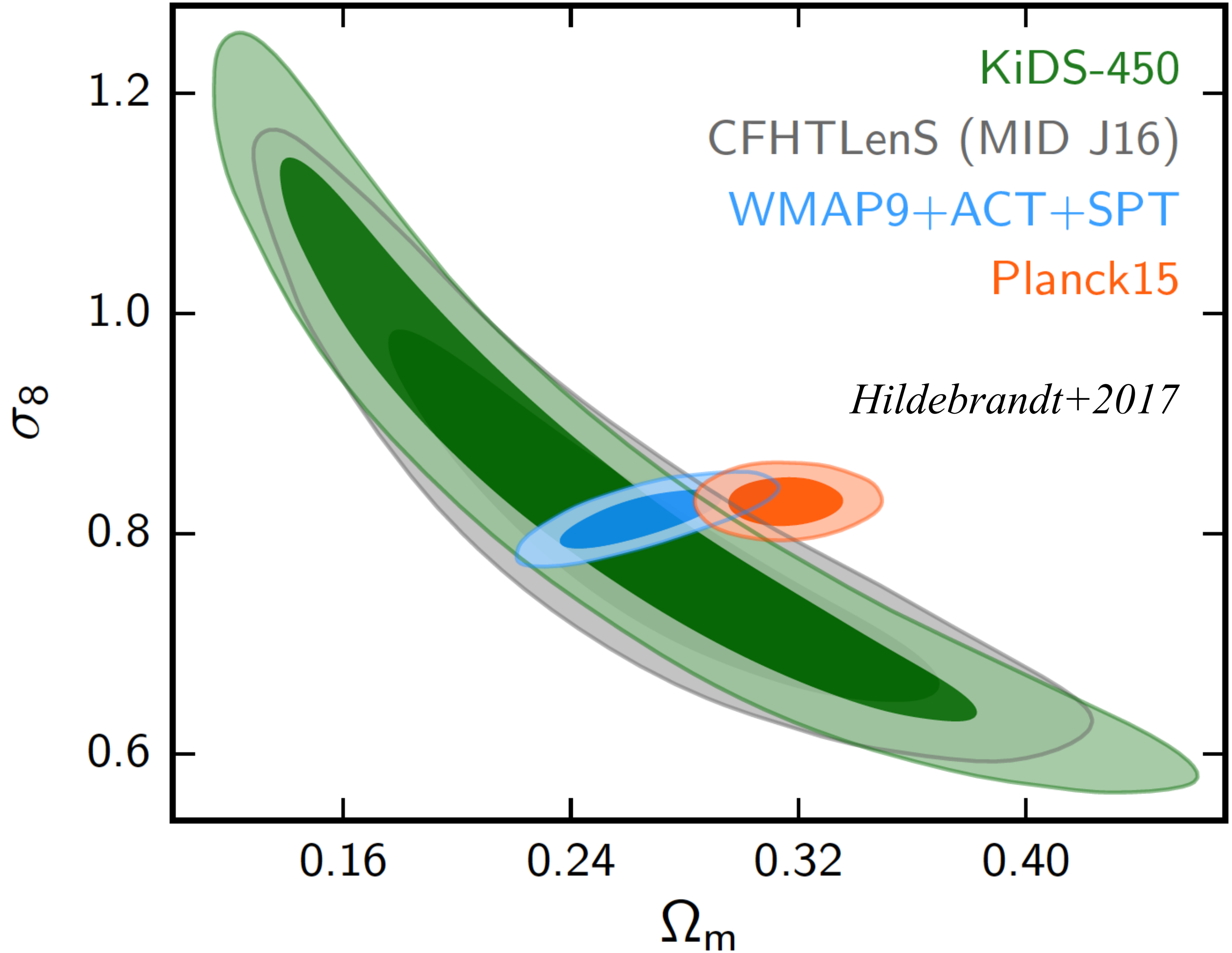


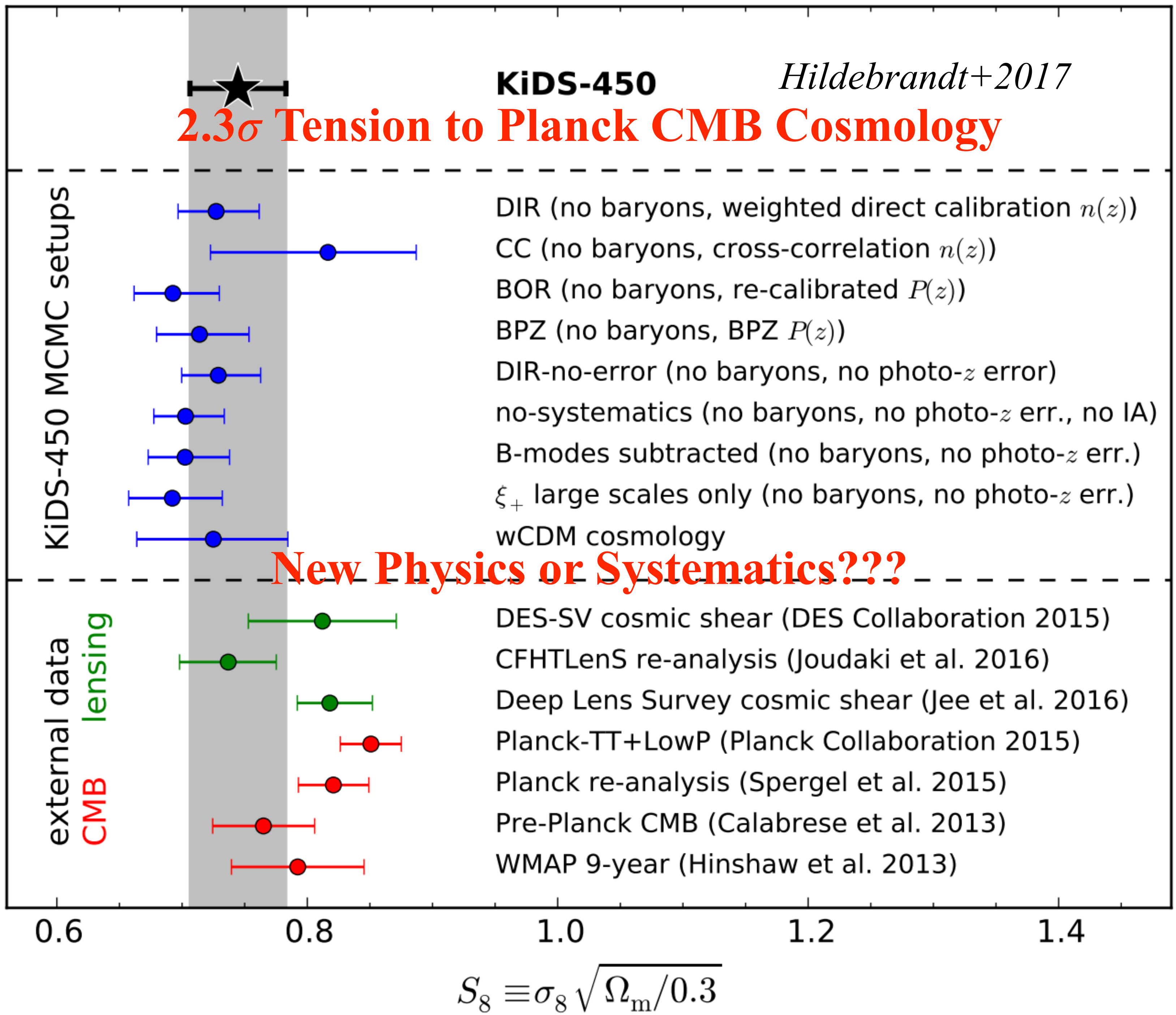
- 454 deg^2 (observations up to July 2015)

Systematic error control

- Shape measurement systematics:
  - Telescope/camera design (Cassegrain focus)
  - Observing conditions (0.7” median seeing)
- Photo-z systematics:
  - Survey design (shallow and wide)
  - VIKING overlap 5 NIR bands
- State-of-the-art analysis tools:
  - Shear calibration systematics (New low-bias lensfit/ Extensive image sims)
  - Photo-z (Direct calibration to deep spec-z fields)

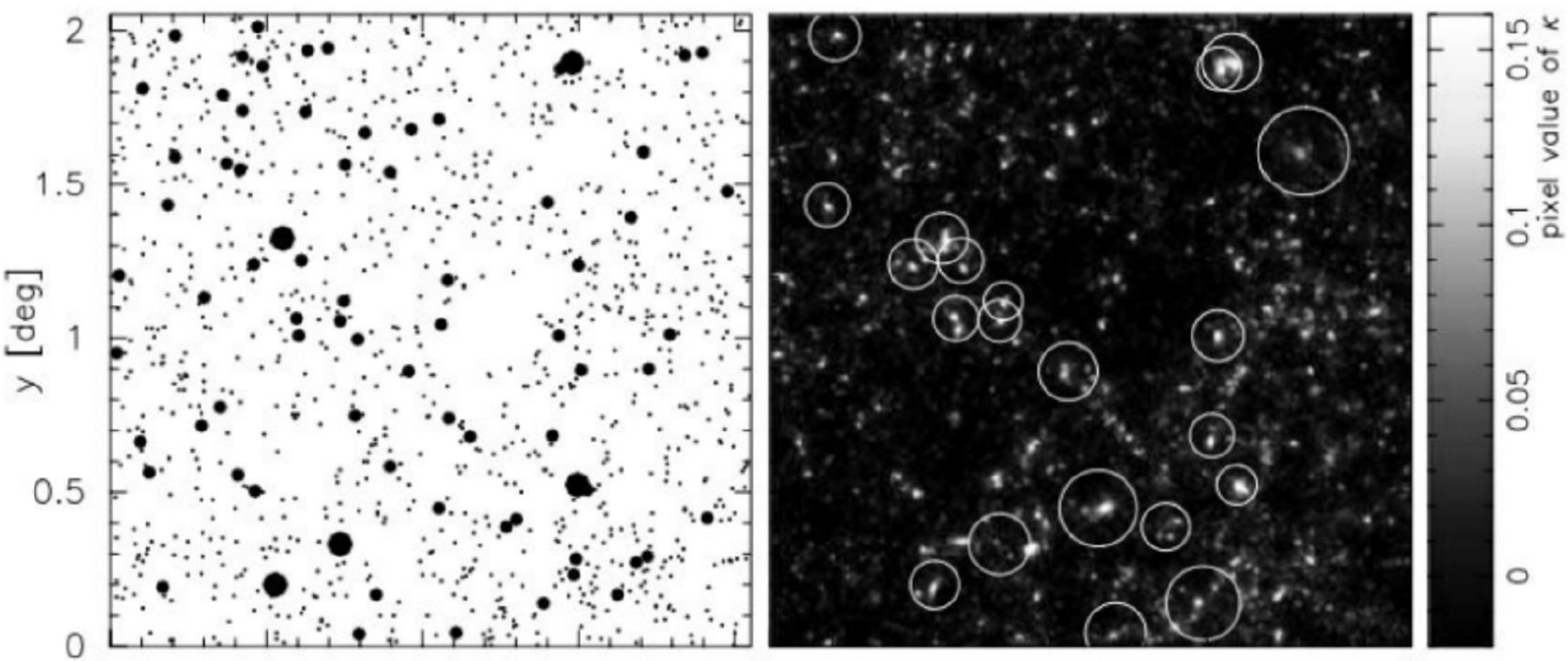
Setup	Sect.	Fig.	baryons	IA	photo-z error	$n(z)$	covariance	w	comb. w. Planck	B mode subtr.	scales ξ_+
KiDS-450	6.2	6	$\surd$	$\surd$	$\surd$	DIR	analytical	–	–	–	$0\farcm5 - 72'$




KiDS-450
Hildebrandt+2017
2.3σ Tension to Planck CMB Cosmology
KiDS-450 MCMC setups
DIR (no baryons, weighted direct calibration $n(z)$)
CC (no baryons, cross-correlation $n(z)$)
BOR (no baryons, re-calibrated $P(z)$)
BPZ (no baryons, BPZ $P(z)$)
DIR-no-error (no baryons, no photo-z error)
no-systematics (no baryons, no photo-z err., no IA)
B-modes subtracted (no baryons, no photo-z err.)
ξ_+ large scales only (no baryons, no photo-z err.)
wCDM cosmology
New Physics or Systematics???
external data
lensing
CMB
DES-SV cosmic shear (DES Collaboration 2015)
CFHTLenS re-analysis (Joudaki et al. 2016)
Deep Lens Survey cosmic shear (Jee et al. 2016)
Planck-TT+LowP (Planck Collaboration 2015)
Planck re-analysis (Spergel et al. 2015)
Pre-Planck CMB (Calabrese et al. 2013)
WMAP 9-year (Hinshaw et al. 2013)
0.6
0.8
1.0
1.2
1.4
$S_8 \equiv \sigma_8 \sqrt{\Omega_m/0.3}$

Weak Lensing Peak Statistics

- Massive clusters are expected to generate high weak lensing signals, and appear as peaks in weak lensing maps



Hamana+2004

Weak Lensing Peak Statistics

- Associate closely with massive structures along lines of sight

- Reflect the underlining halo mass function weighted by the lensing efficiency kernel

✓ Probe efficiently the nonlinear regime of the structure formation
✓ Complementary to the cosmic shear 2pt correlation analysis

➢ The feasibility of performing weak lensing peak searches observationally (e.g., *Wittman+2006; Gavazzi & Soucail 2007; Miyazaki+2007; Geller+2010; Shan+2012, 2014*)

Challenge: Modelling WL Peak Counts

Complications: "false peaks" from systematics
— **The key is to predict accurately the cosmology dependence of WL peaks**

- WL simulation templates densely sampled in cosmological parameter space (*Dietrich & Hartlap 2010;* ***CFHTLenS****: Liu+2016;* ***DES****: Kacprzak+2016*)

- Halo-based WL peak Monte Carlo method (*CAMELUS*, *Lin & Kilbinger 2015*)

- Theoretical model based on Gaussian random field theory (*Maturi+2010; Fan, Shan & Liu 2010;* ***CS82****: Liu+2016*)

WL peaks from KiDS-450

- KiDS-450 galaxy shear catalog

- Map making:

- Convergence map (Iterative K-S mass reconstruction)

$$\langle \boldsymbol{\epsilon} \rangle(\boldsymbol{\theta}) = \frac{\sum_j W_{\theta_G}(\boldsymbol{\theta}_j - \boldsymbol{\theta}) w(\boldsymbol{\theta}_j) \epsilon^c(\boldsymbol{\theta}_j)}{\sum_j W_{\theta_G}(\boldsymbol{\theta}_j - \boldsymbol{\theta}) w((\boldsymbol{\theta}_j)(1 + m_j)}, \quad W_{\theta_G}(\boldsymbol{\theta}) = \frac{1}{\pi \theta_G^2} \exp\left(- \frac{|\boldsymbol{\theta}|^2}{\theta_G^2} \right).$$

- Noise map — randomly rotate the corrected ellipticity of each galaxy

- Peak identification

The convergence value is the highest among its nearest 8 neighbouring pixels

The Signal-to-Noise ratio of the peak: $\nu = \kappa / \sigma_0$

Cosmology constraints

- Fitting method, peaks with SNR above 3

$$\chi_p^2 = \sum_{i,j=1}^{4} \Delta N_i^{(p)} (\widehat{C_{ij}^{-1}}) \Delta N_j^{(p)}, \qquad \Delta N_i^{(p)} = N_{\mathrm{peak}}^{(p)}(\nu_i) - N_{\mathrm{peak}}^{(d)}(\nu_i)$$

- Covariance matrix estimated from bootstrap sampling

$$C_{ij} = \frac{1}{R-1} \sum_{r=1}^{R} [N_{\mathrm{peak}}^{r}(\nu_i) - N_{\mathrm{peak}}^{(d)}(\nu_i)][N_{\mathrm{peak}}^{r}(\nu_j) - N_{\mathrm{peak}}^{(d)}(\nu_j)],$$

- 10000 bootstrap samples by resampling the 454 tiles from KiDS-450

- CosmoMC (*Lewis & Bridle 2002*) with the likelihood function for WL peak counts: (Ω_m, σ_8) in parameter fitting (other parameters fixed to Planck16)

Systematics

- **Boost factor**: Include in the model
- **Baryonic effects**: self-calibration (m-c relation of DM halos)
- **IA**: *Insignificant*
- **Projection effects of LSSs**: *Insignificant*
- **Shear measurement bias**: *Insignificant*
- **Photo-z errors**: *Insignificant*

Fiducial analysis: Boost factor & baryonic effects

- **Boost factor**: the dilution effects on lensing signals from cluster members Considering the cluster candidates from KiDS survey (*Radovich+17*)

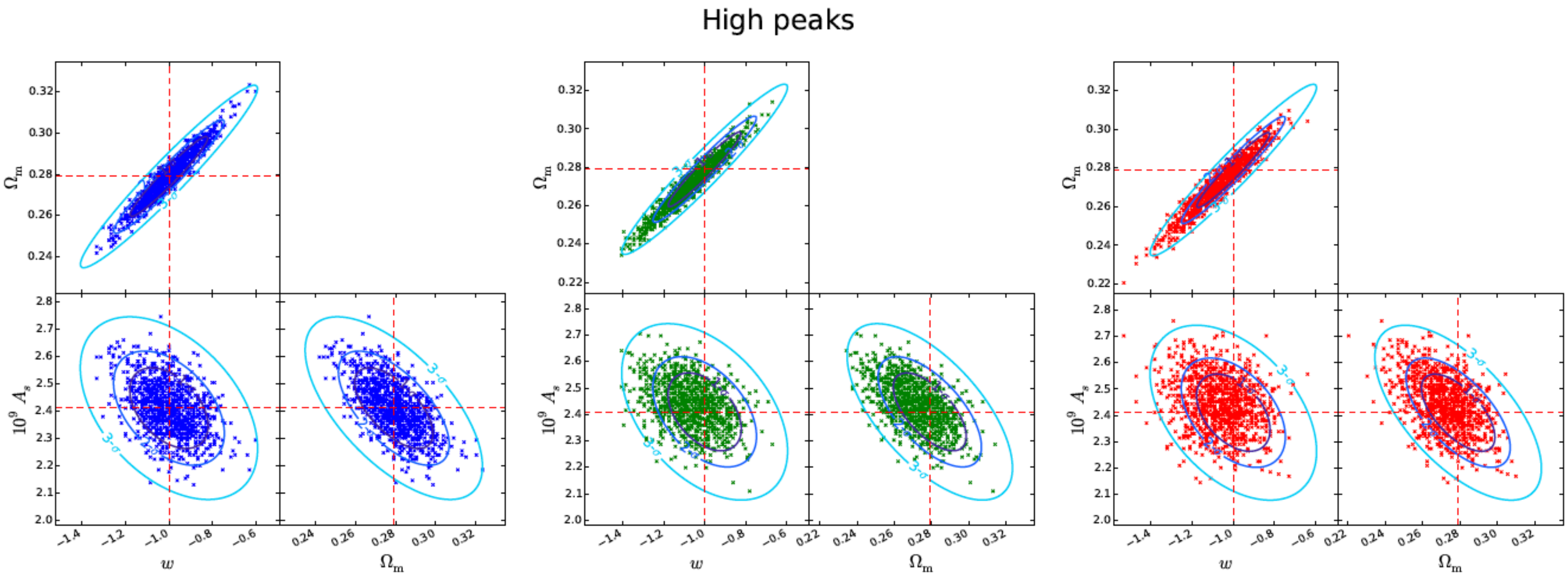
Table D1. The cluster samples in six mass and redshift bins used in the boost factor measurement.

bin	mass range	$z_{\rm B}$ range	dilution factor
bin11	$1 \leqslant M/10^{14}{\rm M}_{\odot}/h < 2$	$z_{\rm B} < 0.35$	$1/1.067$
bin12	$1 \leqslant M/10^{14}{\rm M}_{\odot}/h < 2$	$z_{\rm B} \geqslant 0.35$	$1/1.108$
bin21	$2 \leqslant M/10^{14}{\rm M}_{\odot}/h < 3$	$z_{\rm B} < 0.35$	$1/1.135$
bin22	$2 \leqslant M/10^{14}{\rm M}_{\odot}/h < 3$	$z_{\rm B} \geqslant 0.35$	$1/1.164$
bin31	$3 \leqslant M/10^{14}{\rm M}_{\odot}/h < 4$	$z_{\rm B} < 0.35$	$1/1.259$
bin32	$3 \leqslant M/10^{14}{\rm M}_{\odot}/h < 4$	$z_{\rm B} \geqslant 0.35$	$1/1.254$

- **Baryonic effects**:
  - Cooling+Stellar/SN/AGN feedback: hydro-simulations and semi-analytical

    1%−2% biases on the (Ω_m, σ_8) (*Osato+2015*)

Osato+2015



- **Baryonic effects**: we use self-calibration method instead of simulation

  - Assume baryon effects only the DM halo profile

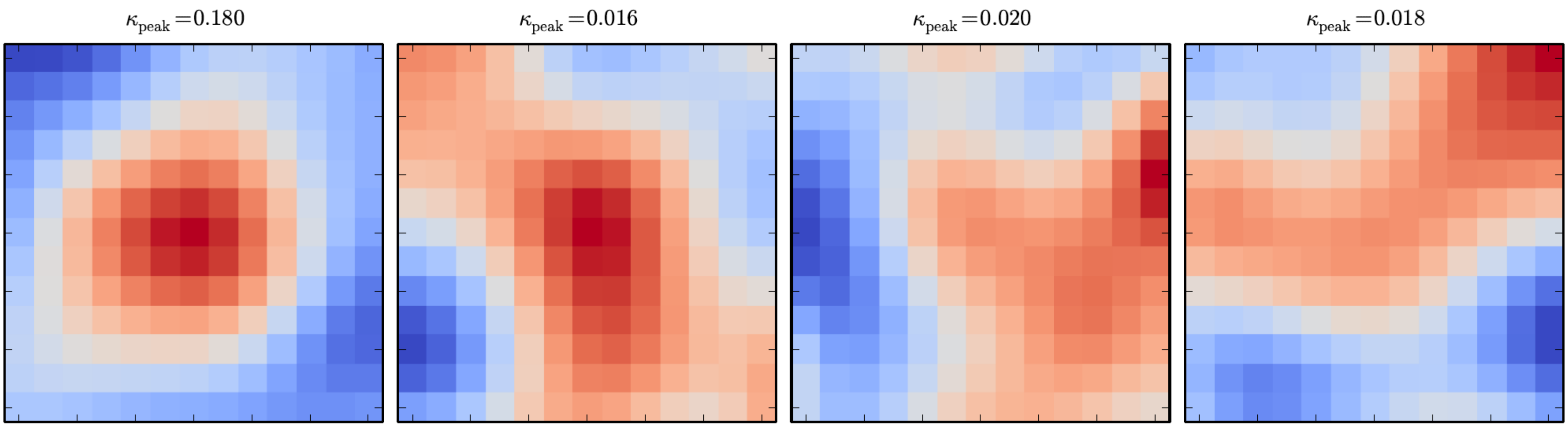
  - We set the amplitude of m-c relation as a free parameter in the fit

$$c_{\rm vir} = \frac{A}{(1+z)^{0.7}} \left(\frac{M_{\rm vir}}{10^{14} h^{-1} M_\odot} \right)^{\beta},$$

Astrophysical Systematics

- **Projection effects of LSSs**: *Insignificant*

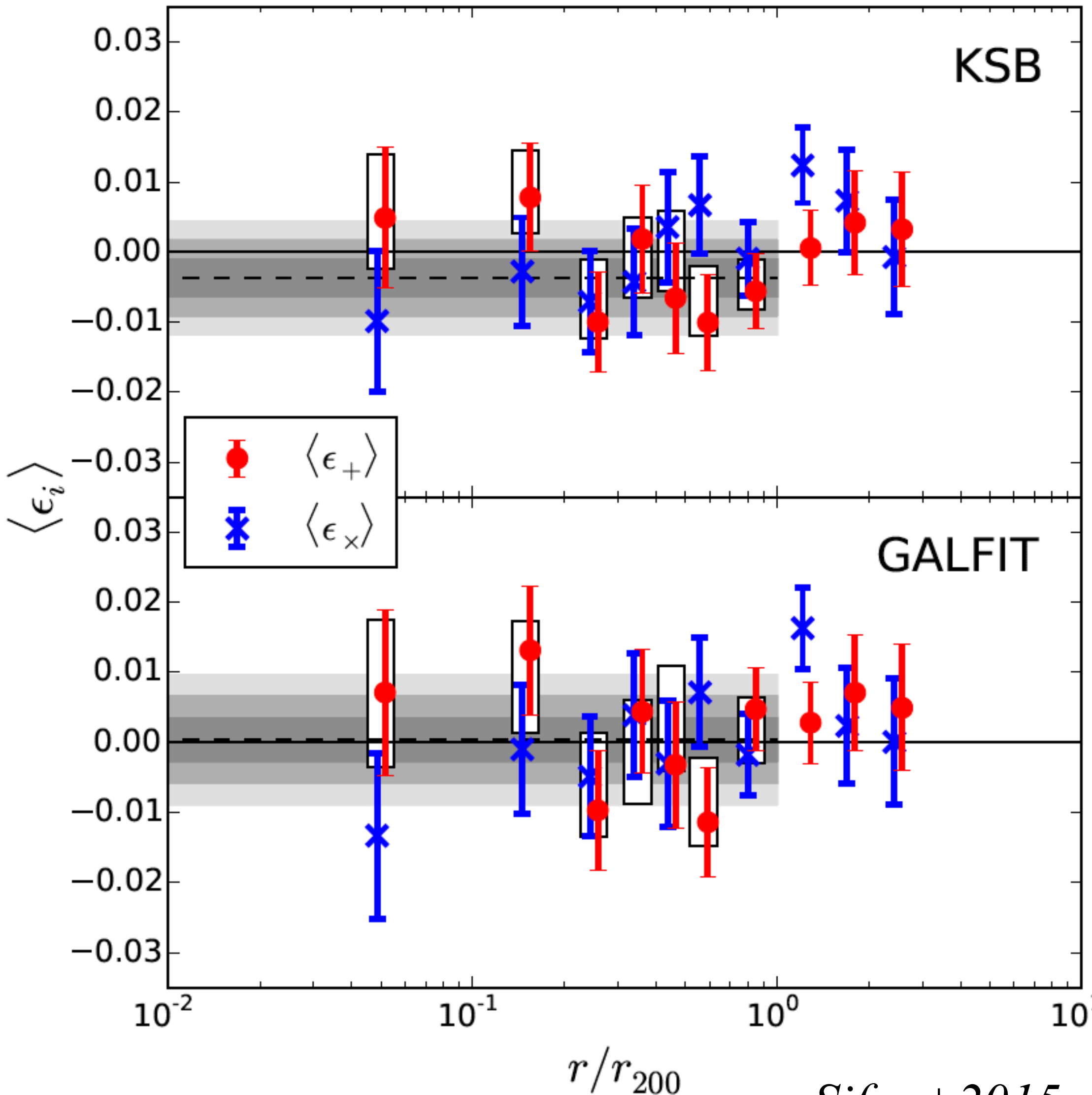
  - High SNR peaks from massive clusters (*Yang+2011; Liu & Haiman 2016*)
  - Important for Low SNR peaks & the WL survey with z_{med}>1 (*Yuan+2017*)
  - Mock results



Liu & Haiman2016

Astrophysical Systematics

- **IA**: *Insignificant*
  - noise: $\sigma_{IA}^2/\sigma_{ran}^2<0.6\%$ (*Fa*
  - IA around cluster: ~0 (*Chi*



Sifon+2015

Measurement Systematics

- **Shear measurement bias**: *Insignificant*

$$\gamma_j^{\mathrm{obs}} = (1 + m_j)\gamma_j^{\mathrm{true}} + c_j\,.$$

- m: σ~1.0% with the uncertainties of KiDS-450 => δN_{peak}~ 1-2%
- c: negligible for WL peak (with smoothing)

- **Photo-z errors**: *Insignificant*
- δN_{peak}~ (0.32%,0.57%,1.07%,1.97%) for 4 SNR bins

Mock Analysis

To test the peak analyses procedures

- Multiple-plane ray-tracing calculation to obtain the convergence and shear maps (*Hilbert+2009*)

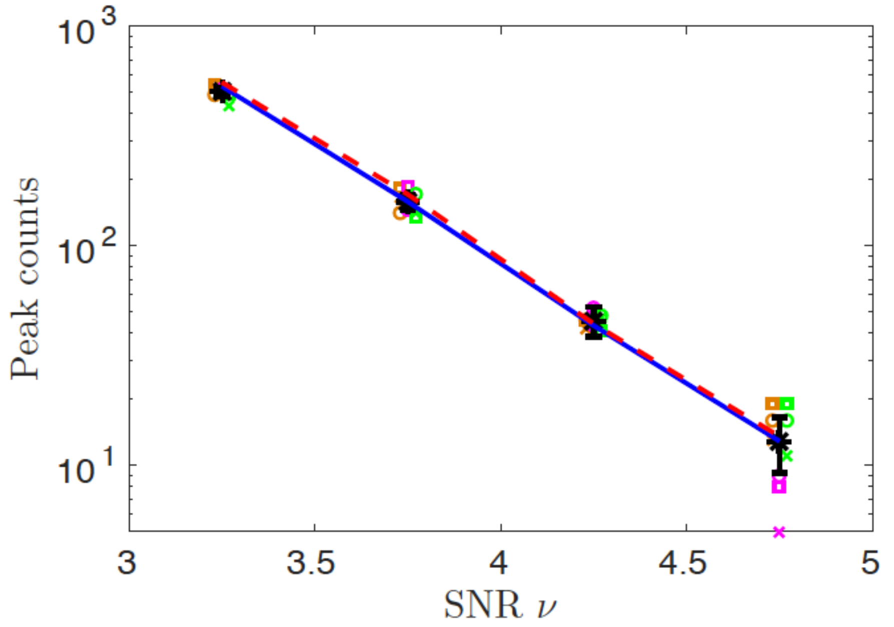
- Mocks construction:

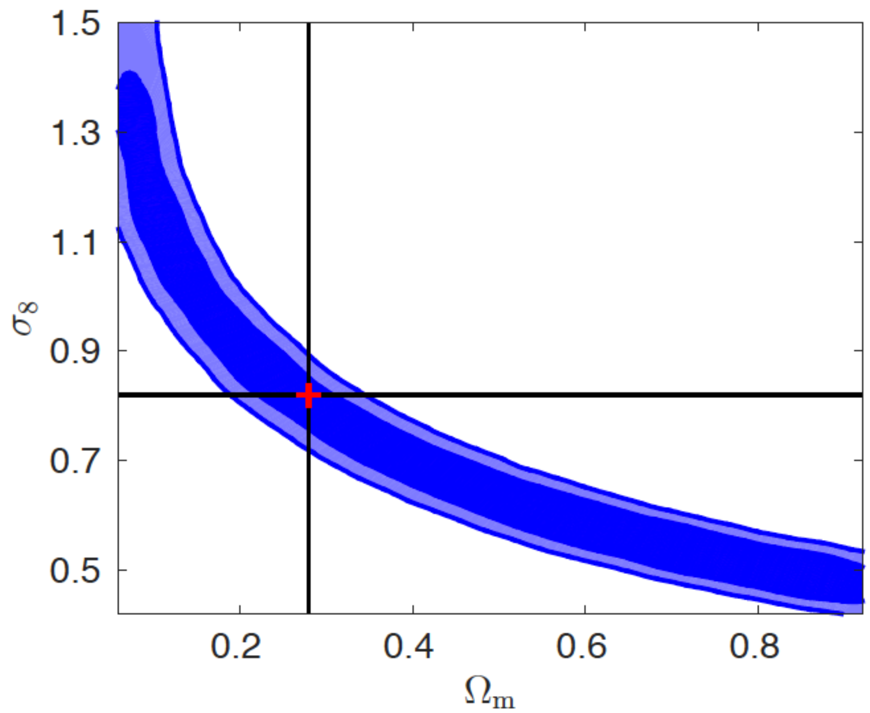
- The positions and the amplitudes of ellipticities of the galaxies are preserved, but with their orientations being randomized
- The redshift follow the redshift distribution of ***KiDS-450***
- Weights and the mask information are also preserved

Observed ellipticity=
Intrinsic (randomized)&shear (interpolating from simulated maps)

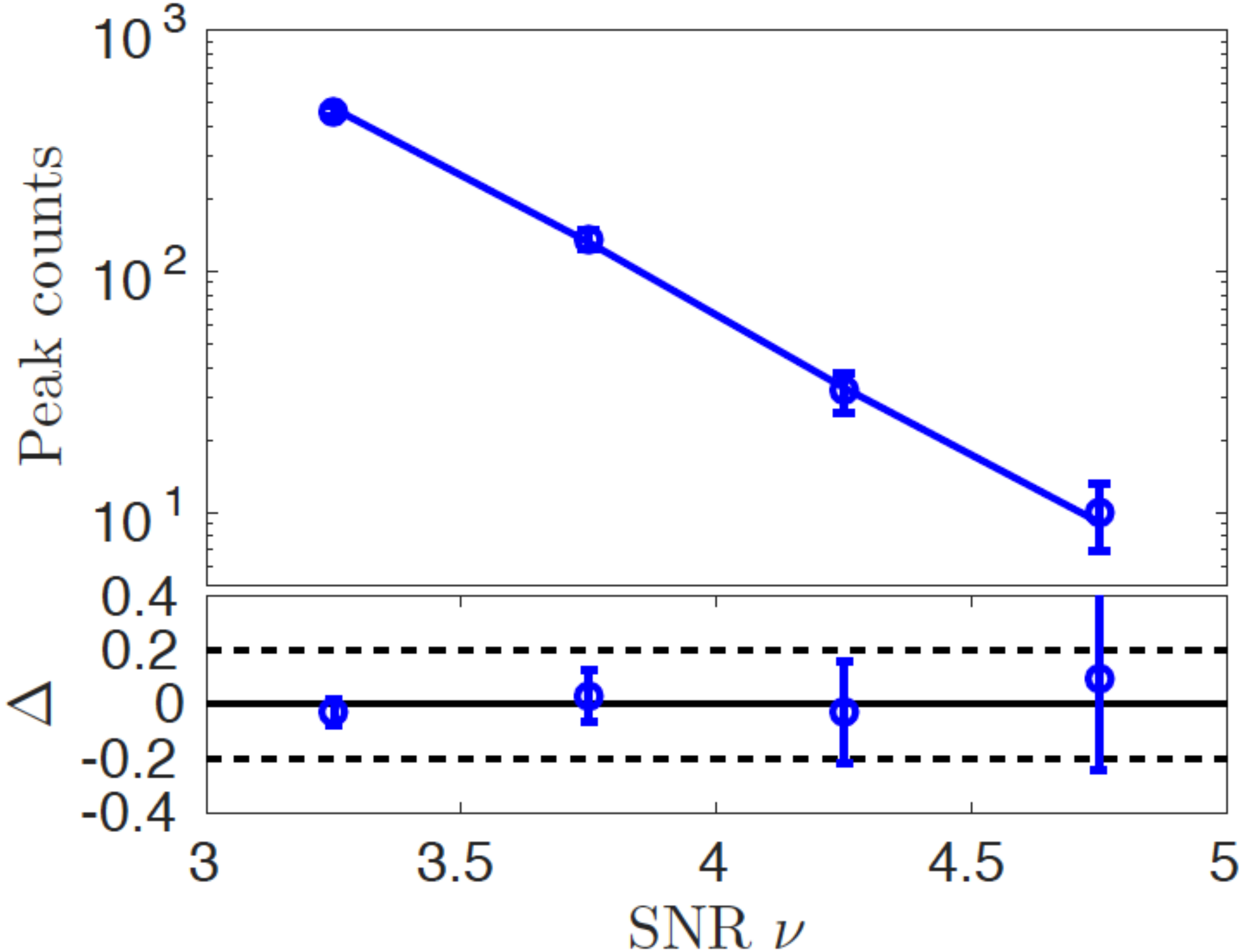
- The same convergence reconstruction & peak identification pipeline

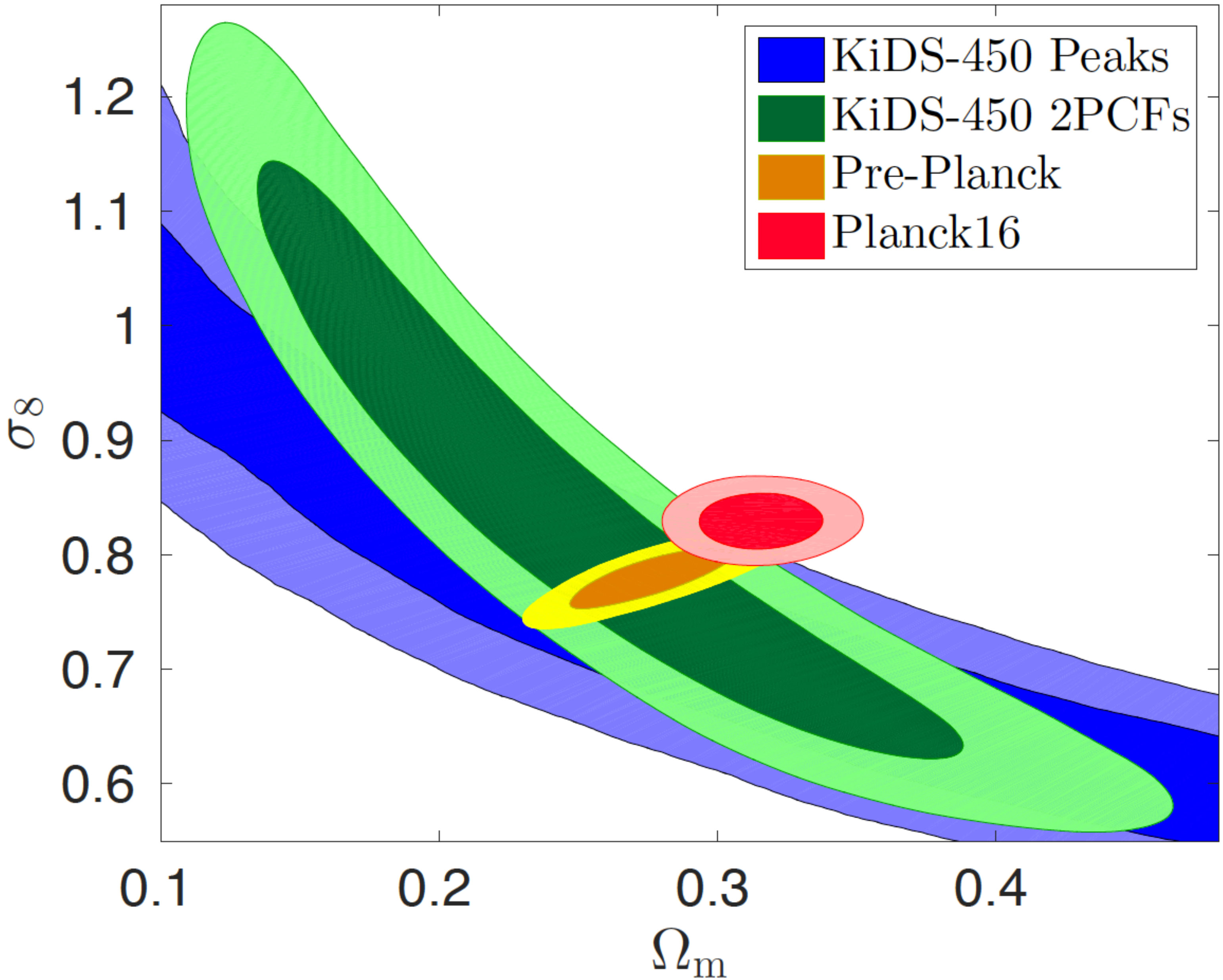
- Mock Analysis:
  verifying the analysis pipeline with Mock data (3 independent mocks)



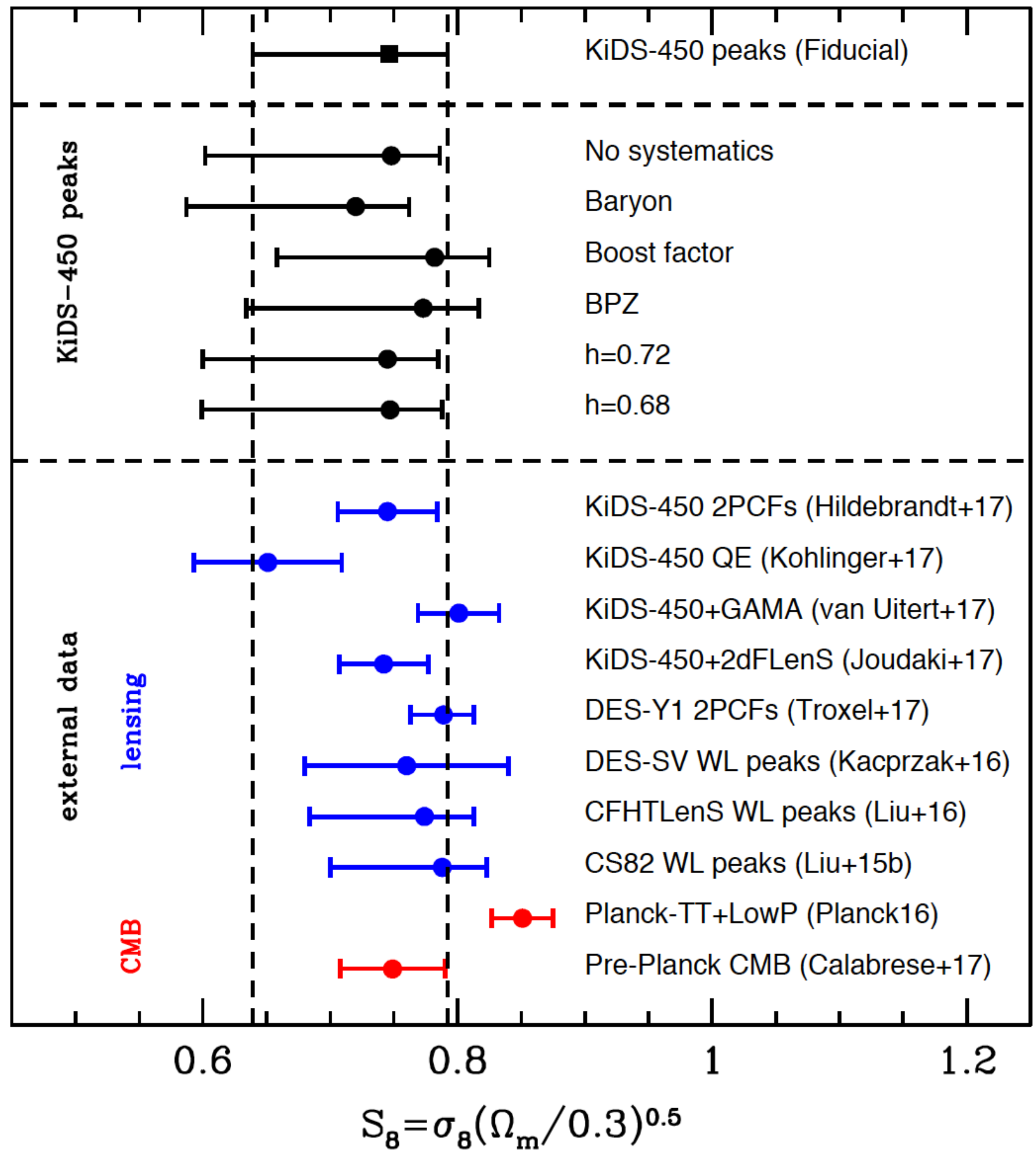


Results

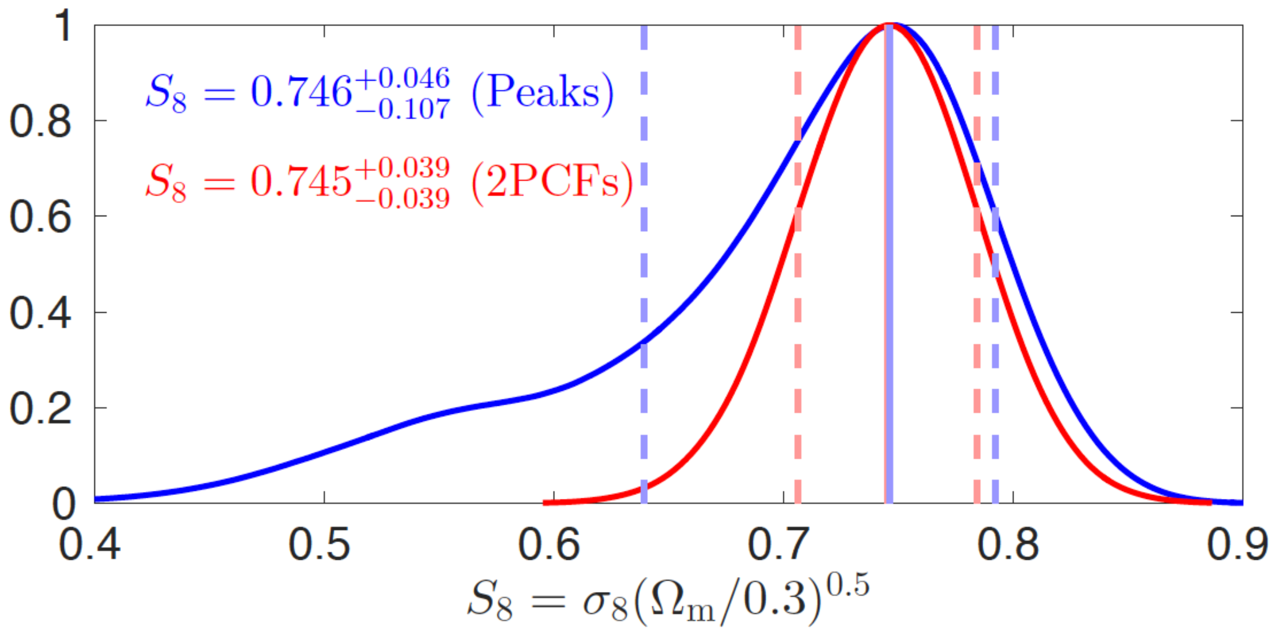




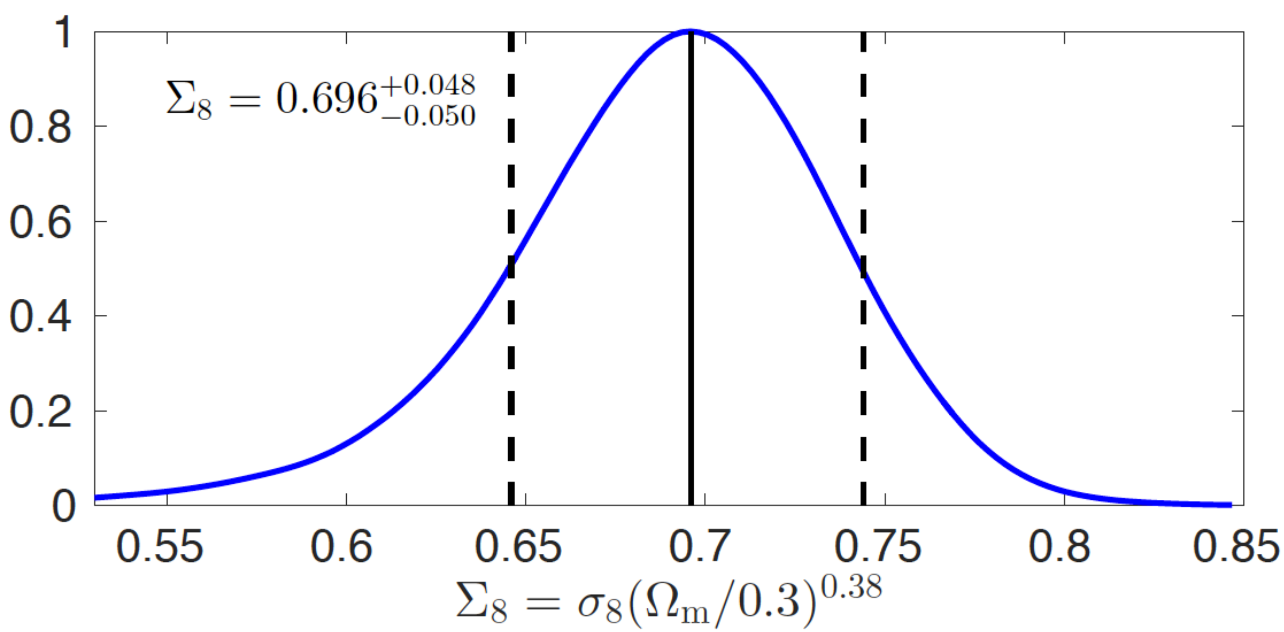
KiDS-450 Peaks
KiDS-450 2PCFs
Pre-Planck
Planck16
σ_8
1.2
1.1
1
0.9
0.8
0.7
0.6
0.1
0.2
0.3
0.4
Ω_m



KiDS-450 peaks (Fiducial)
KiDS−450 peaks
No systematics
Baryon
Boost factor
BPZ
h=0.72
h=0.68
external data
lensing
CMB
KiDS-450 2PCFs (Hildebrandt+17)
KiDS-450 QE (Kohlinger+17)
KiDS-450+GAMA (van Uitert+17)
KiDS-450+2dFLenS (Joudaki+17)
DES-Y1 2PCFs (Troxel+17)
DES-SV WL peaks (Kacprzak+16)
CFHTLenS WL peaks (Liu+16)
CS82 WL peaks (Liu+15b)
Planck-TT+LowP (Planck16)
Pre-Planck CMB (Calabrese+17)
0.6
0.8
1
1.2
$S_8=\sigma_8(\Omega_m/0.3)^{0.5}$



α=(0.47,0.41,0.3) for X-ray cluster, MaxBCG, Planck SZ clusters



Summary

- The S8 value from WL peak is consistent with the KiDS-450 cosmic shear tomography measurement. A 2σ tension to Planck cosmology is still present, although not so strong from DES-Y1.

- Systematic studies: The boost factor and baryonic effects are the major systematics for weak lensing peak statistics. The other various systematics are insignificant. The constraint results are also insensitive to the Hubble parameter.

- The degeneracy direction of the (Ω_m, σ_8) is flatter than those from the cosmic shear 2PCFs analysis, showing a promising potential to break the degeneracy of the two parameters.

Thank you!