Looking through the same lens: Shear calibration with CMB lensing

arxiv:1607.01761

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CMB S4 & Future Surveys, Chicago, Sept. 2016

Collaborators

arXiv:1607.01761

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Tim Eifler

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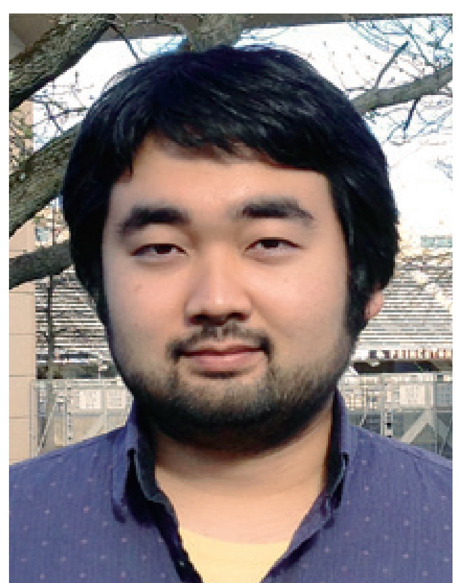


Hironao Miyatake

Jason Rhodes

David Spergel

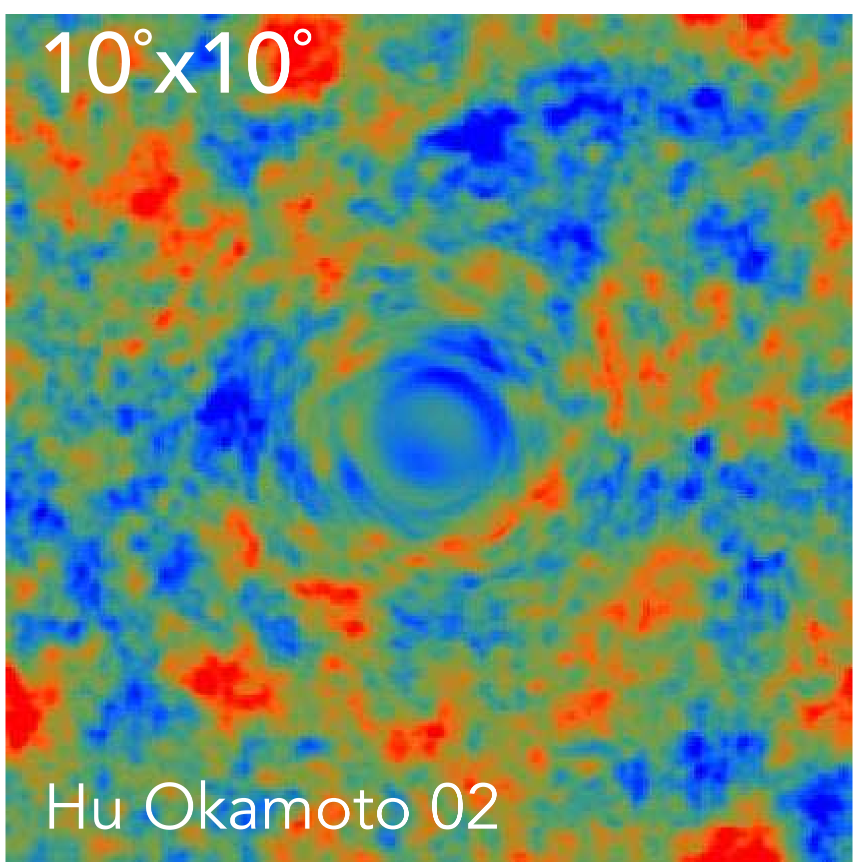
Weak gravitational lensing

SDSS J103842.59+484917.7, Hubble image

Galaxy lensing

perfect disk   shear ~1%   shape ~20%

→ SNR~5% for one galaxy,
SNR~10^3 with 10^9 galaxies



Hu Okamoto 02

CMB lensing

Arcmin deflections, coherent on degree scale
Smoothed peaks, extra power, E→B, correlates modes

Shear calibration: the case for redundancy

$$< e >= (1 + m)\,\gamma_{\rm true} + \alpha\, e_{\rm PSF} + c$$

Heymans+06
Taylor Kitching 16

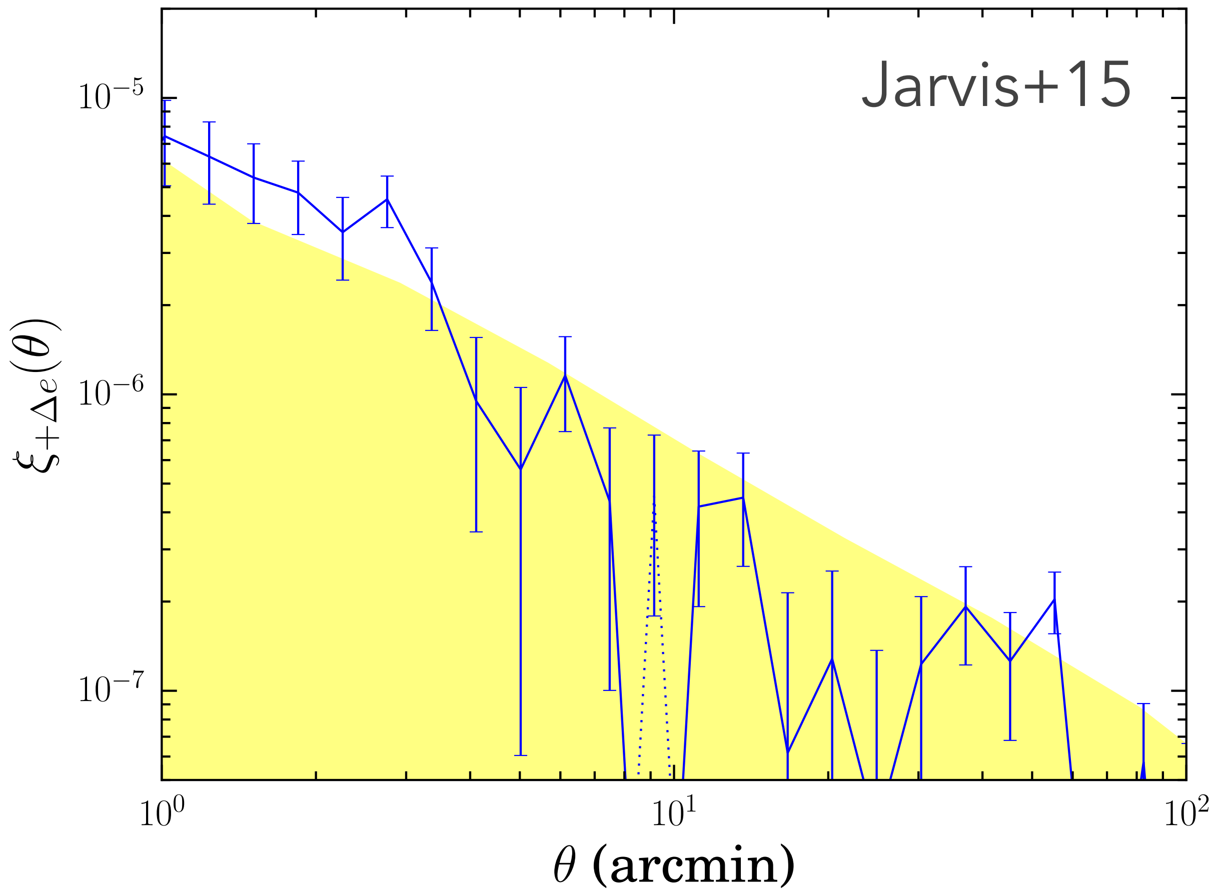
Scary: m(z) degenerate with growth, hence dark energy EOS

“Required” for LSST: < 0.5% (Huterer+06, Massey+12, ES+16)

Image simulations: 3-5% DES (Jarvis+15), 1% KiDS (Fenech-Conti+16)

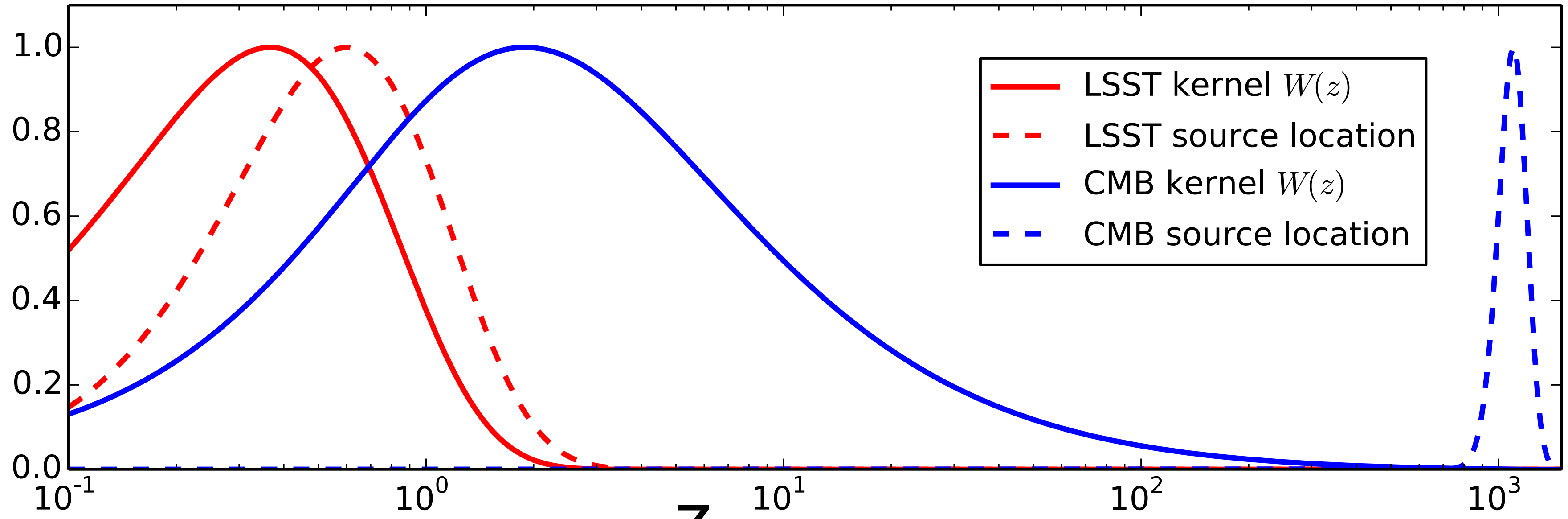
Difficult:

- Noise/Model biases
- Selection bias: simulate below the detection limit (Hoekstra+15)
- Mode coupling: simulate below the image resolution
- PSF size error



→ **Redundancy is valuable**

Shear calibration with CMB lensing



Madhavacheril, CMB S4 science book

Principle:

Vallinotto12,13, Das+13

κ_{gal} ~ (1+m) σ_8

κ_{CMB} ~ σ_8

Value:

Purely empirical, self-calibration

No assumption on galaxy population/morphologies

Just the beginning!

Liu+16, Baxter+16, Miyatake Madhavacheril+16, Singh+16

~10-20% calibration, (mostly) fixed cosmology & nuisances

Questions:

Competitive with image simulations / requirements?

Varying cosmology & nuisance?

Robustness to photo-z, IA?

What combination is best?

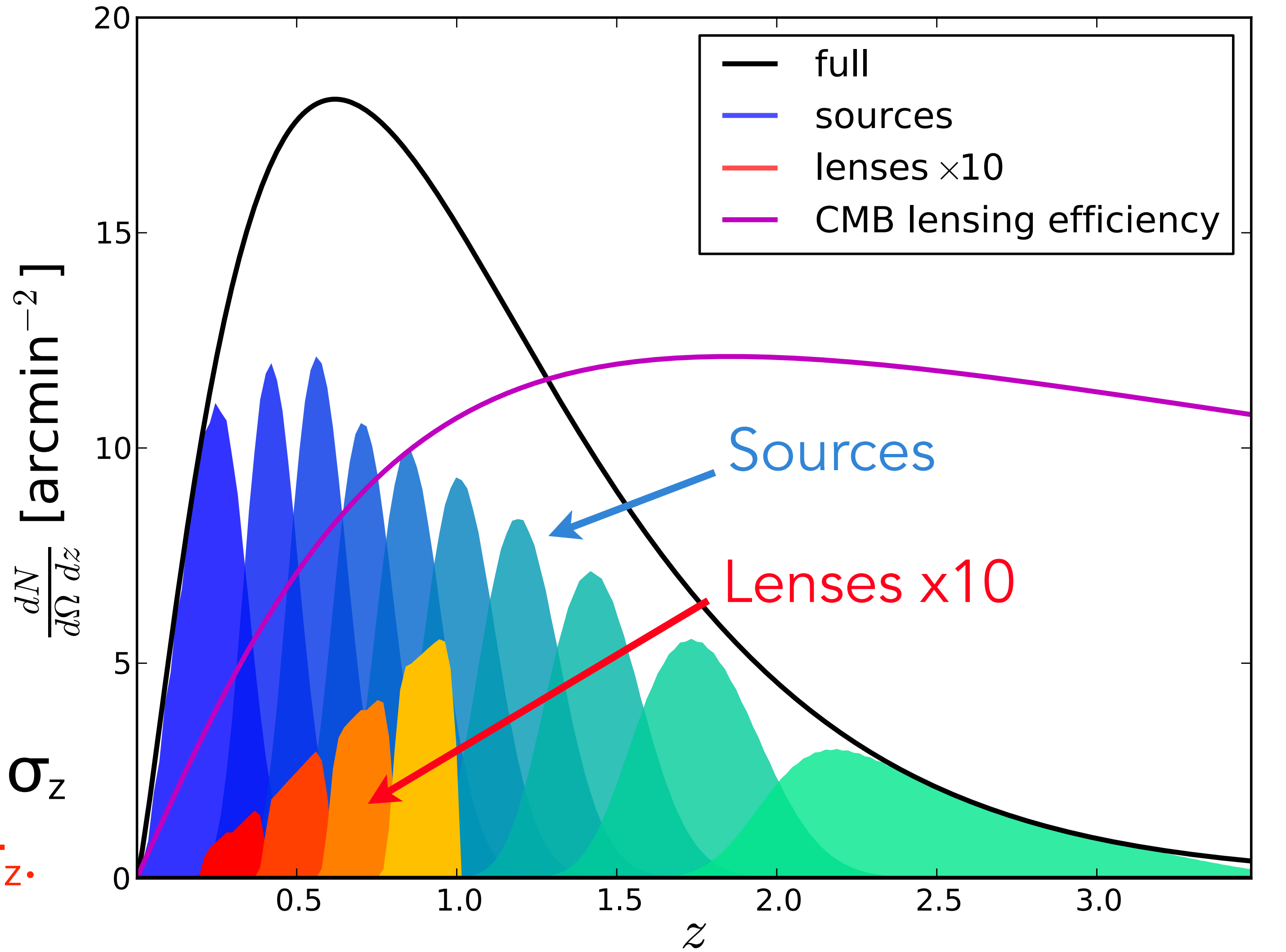
Forecast: LSST & CMB S4 lensing

- **Observables:**
  clustering
  gal - shear
  shear - shear
  gal - CMB lensing
  shear - CMB lensing
  CMB lensing auto

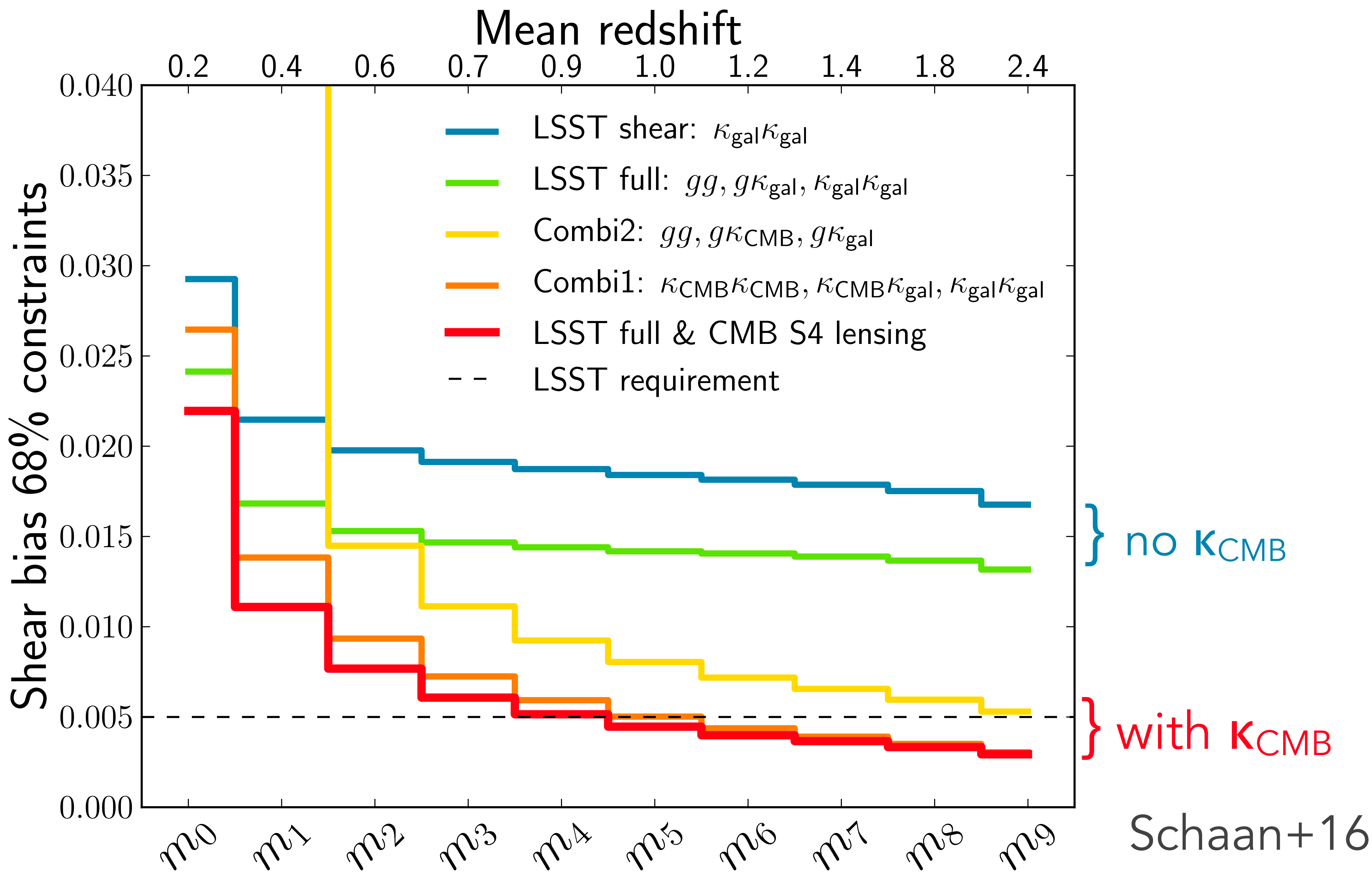
- **Constrain:** cosmology, b_i, m_i, Δ_{zi}, σ_z
  No prior on b_i, m_i. Priors on Δ_{zi}, σ_z.

- **Realistic, conservative:**
  Full non-Gaussian covariances
  Explore likelihood with MCMC

- **Built on CosmoLike (Eifler Krause+14)**
  Extended to include CMB lensing
  Soon to be public!



CMB S4 lensing can calibrate the shear ~ LSST requirements

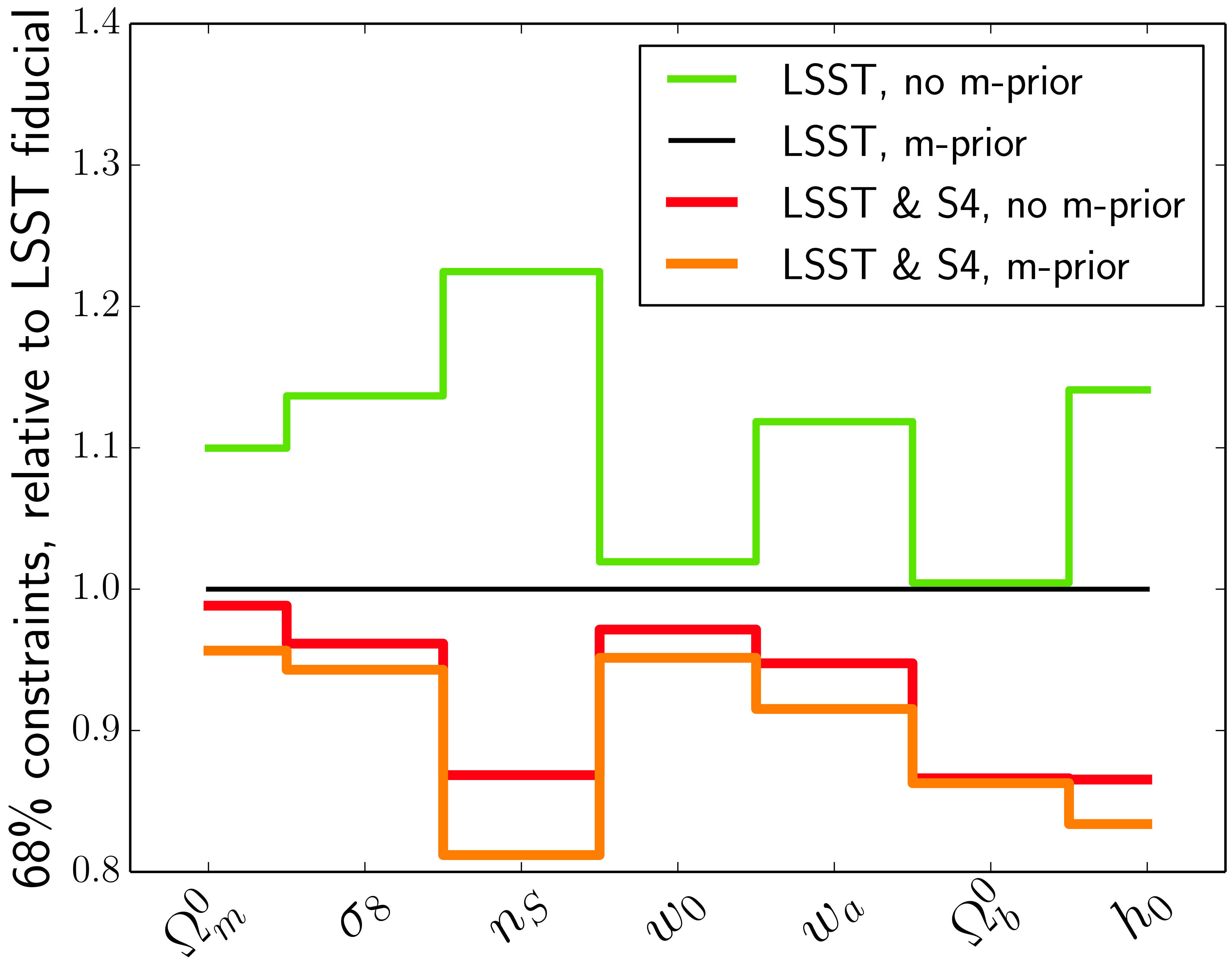


Varying cosmo & nuisance params

Better at high z where most challenging

Purely empirical, self-calibration

CMB S4 lensing replaces a prior on m



Summary: Shear calibration with CMB lensing

arXiv:1607.01761

- **CMB S4 lensing can constrain the shear bias to 0.5% ~ LSST requirements**
- **Purely empirical, self-calibration, no assumption on galaxy population/morphologies**
- **Works best at high z where most difficult**
- Robust to IA, photo-z degradation, non-linearities & baryons, CMB S4 specs
- In the works: “delensing” with CIB, iterative reconstruction, photo-z outliers, correlated mi

More shear self-calibration with CMB lensing!

Large Synoptic Survey Telescope

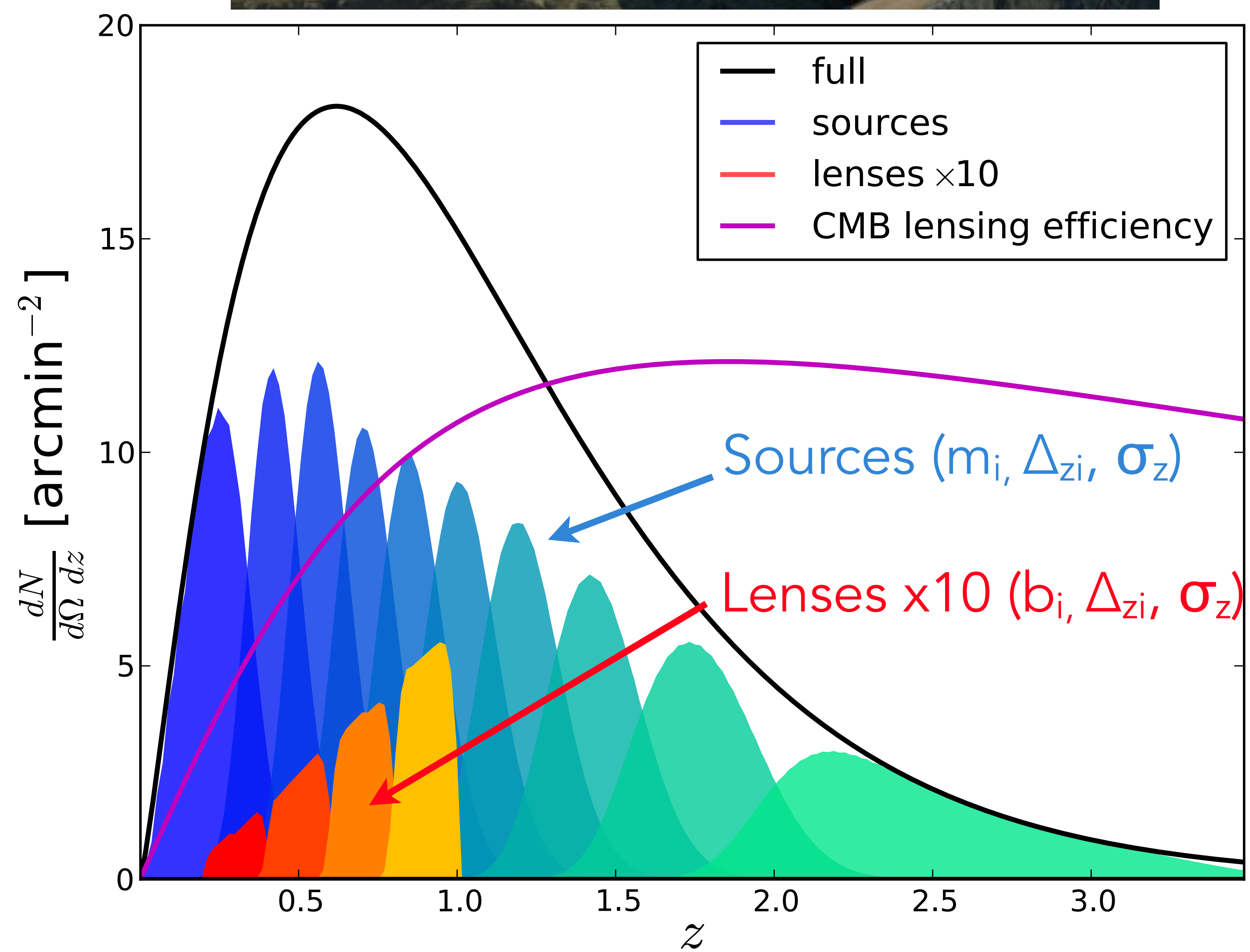
8.4m telescope in Chile

Survey starts 2022-23

~ half the sky

Sources: 26 arcmin^{-2}

Lenses: redmagic-like



18,000 deg^2, 26 sources/arcmin^2, 0.25 lenses/arcmin^2, shape noise = 0.26

$\sigma_z/(1+z)$ = 5% for sources, known to 0.2% for sources

$\sigma_z/(1+z)$ = 1% for lenses, known to 0.06% for lenses

Forecast: LSST

LSST specifications	
Ω_s	18,000 deg^2
source distribution	$dn_{\rm source}/dz \propto z^{\alpha} e^{-(z/z_0)^{\beta}}$, $\alpha = 1.27, \beta = 1.02, z_0 = 0.5$, $n_{\rm source} = 26$ arcmin^{-2} 10 bins $\sigma_\epsilon = 0.26$
lens distribution	$dn_{\rm lens}/dz \propto \chi(z)^2/H(z)$, $n_{\rm lens} = 0.25$ arcmin^{-2} 4 bins

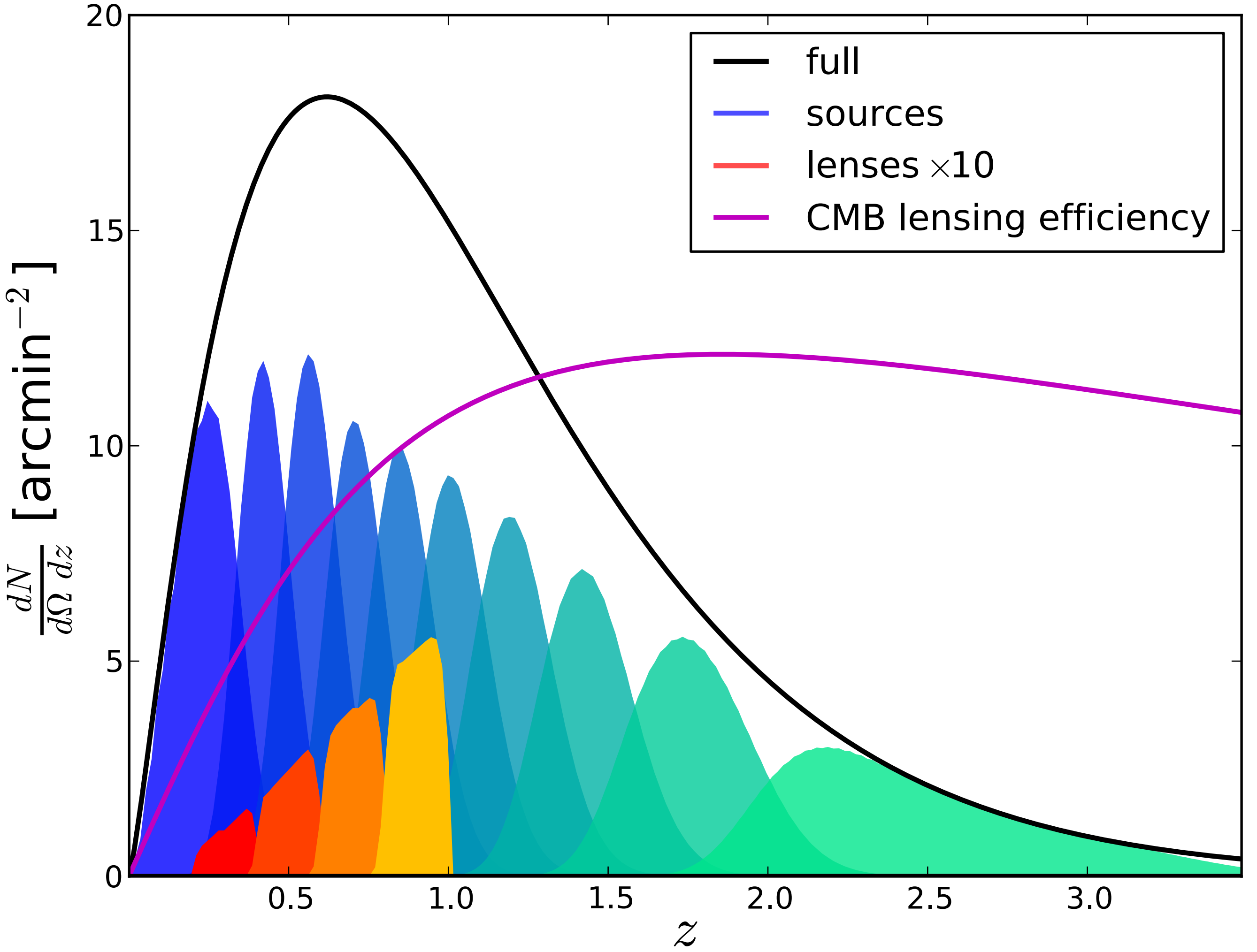


Photo-z: lens sample		
$\Delta_{z,\rm lens,i}$	0	Gauss(0, 0.0004)
$\sigma_{z,\rm lens}/(1+z)$	0.01	Gauss(0.01, 0.0006)
Photo-z: source sample		
$\Delta_{z,\rm source,i}$	0	Gauss(0, 0.002)
$\sigma_{z,\rm source}/(1+z)$	0.05	Gauss(0.05, 0.003)

CMB Stage 4

Stage 4: ~500,000 detectors

Beam: 1′

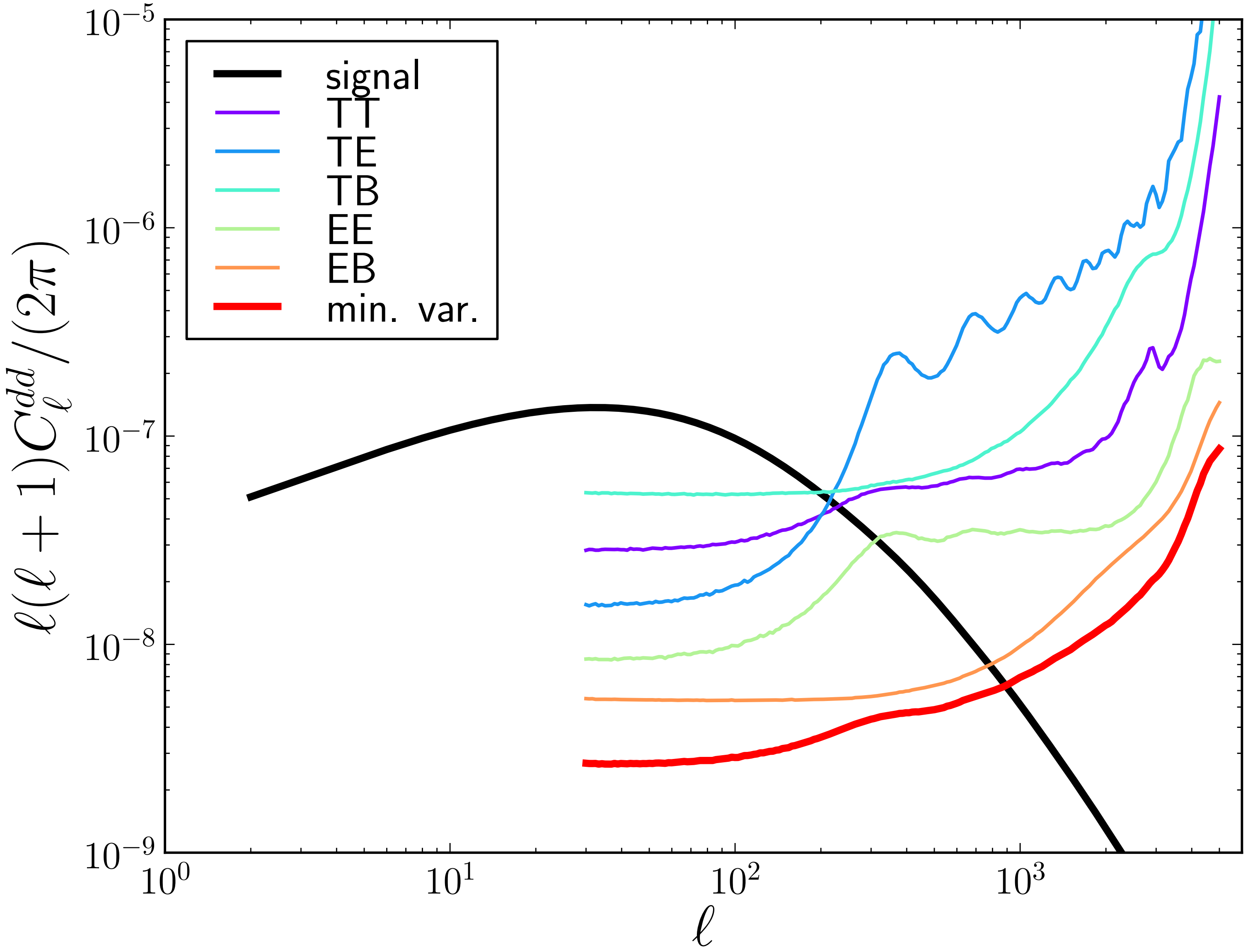
Sensitivity: 1μK′

l_{min}=30,

$l_{max,T}$=3000, $l_{max,E,B}$=5000

Foreground cleaned input map

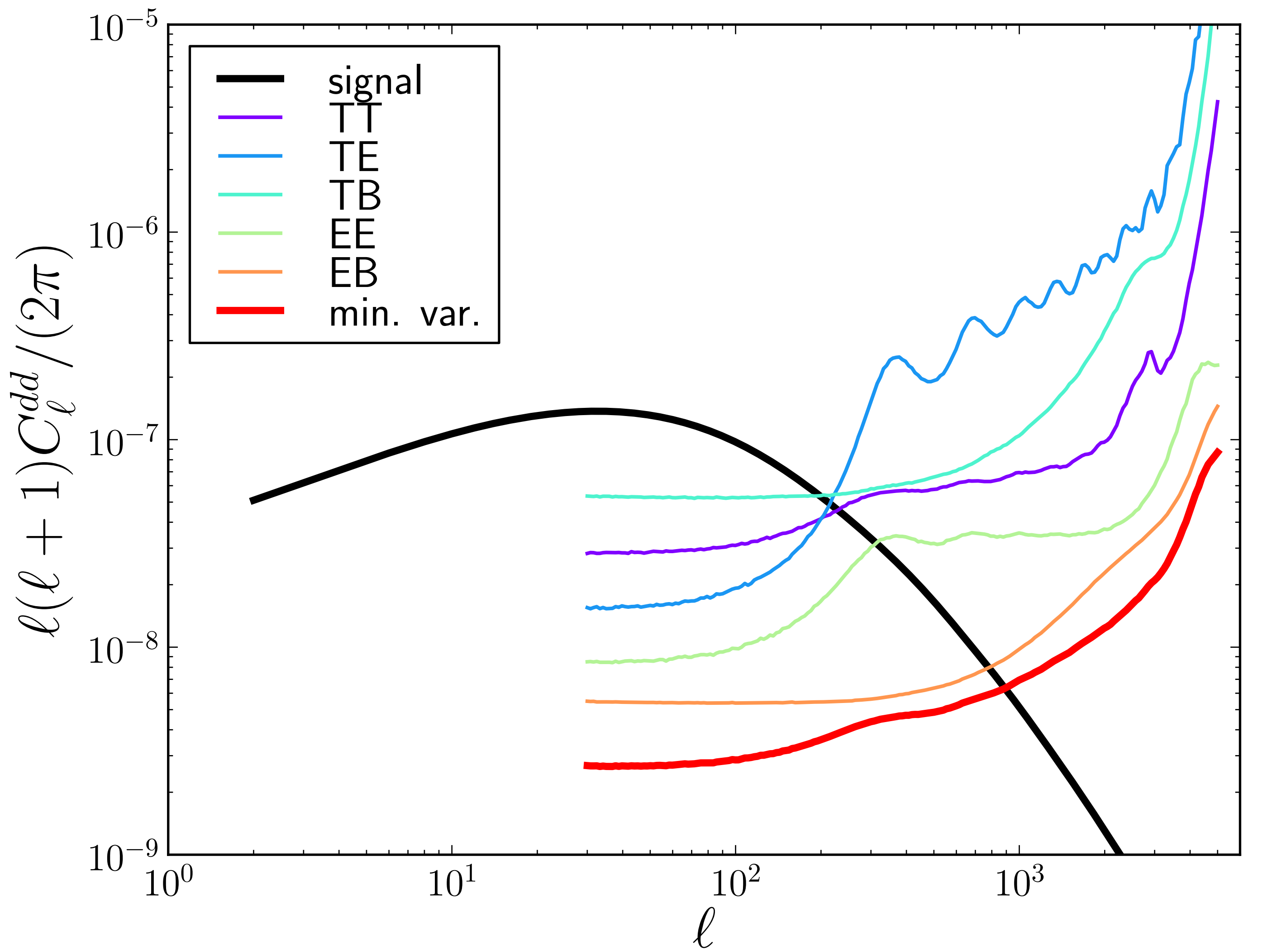
Assumed no systematics



Forecast: CMB S4

CMB S4 specifications	
Ω_s	18,000 deg^2 ($f_{sky} = 44\%$)
beam	FWHM$= 1'$
white noise	$1\mu K'$ for T; $1.4\mu K'$ for E,B
ℓ_{min}	30 for T, E, B, κ_{CMB}
ℓ_{max}	3000 for T; 5000 for E, B, κ_{CMB}

Assumed no systematics!



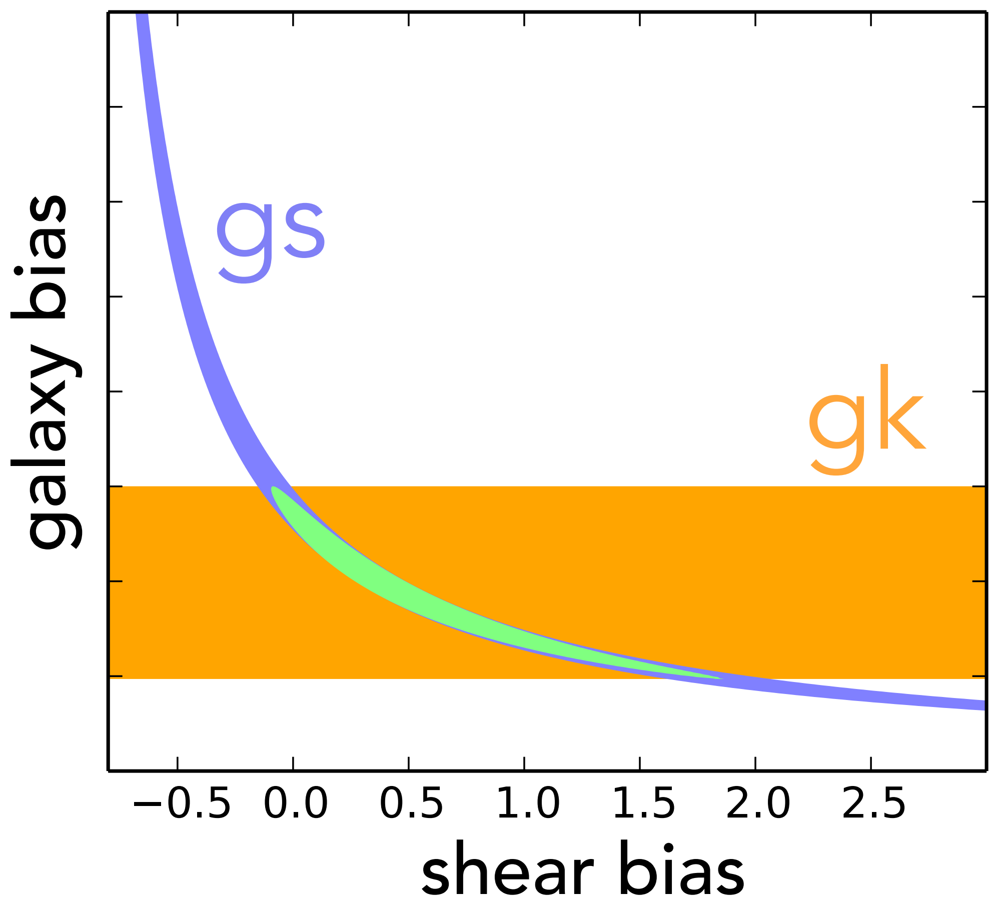
But, the SNR...

- SNR in κ_{CMB} is 75% of κ_{gal}; and marginalizing over systematics degrades constraints by factor of a few for LSST

- SNR is not all; info not only one amplitude; hard to have intuition with high-dimensional parameter space

- Calibrating the shear useful for cosmo params, but also for maps (cf Planck)

- Shear does things CMB lensing can't: small scales, lower z



Baxter+16

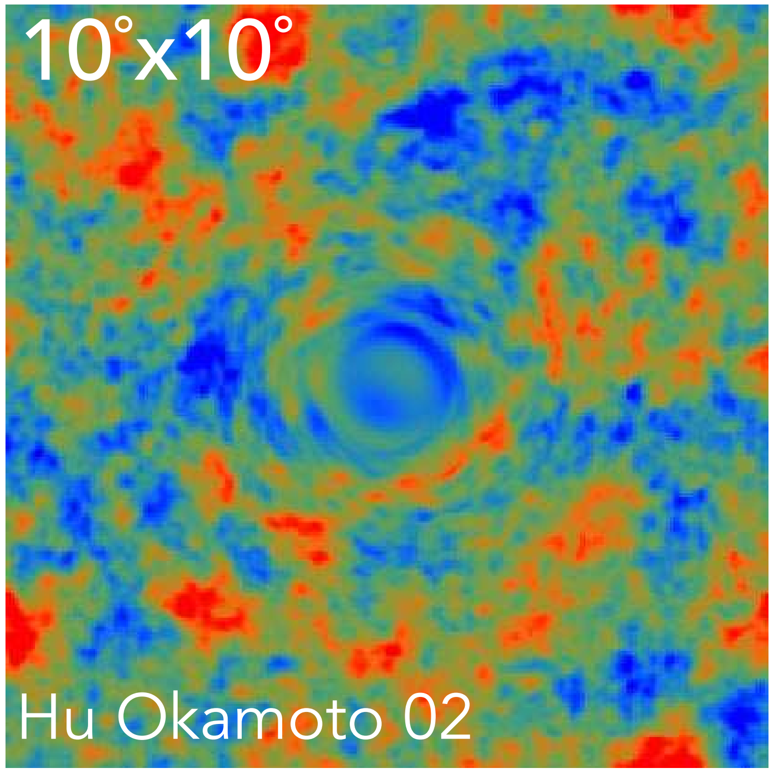
CMB lensing & reconstruction

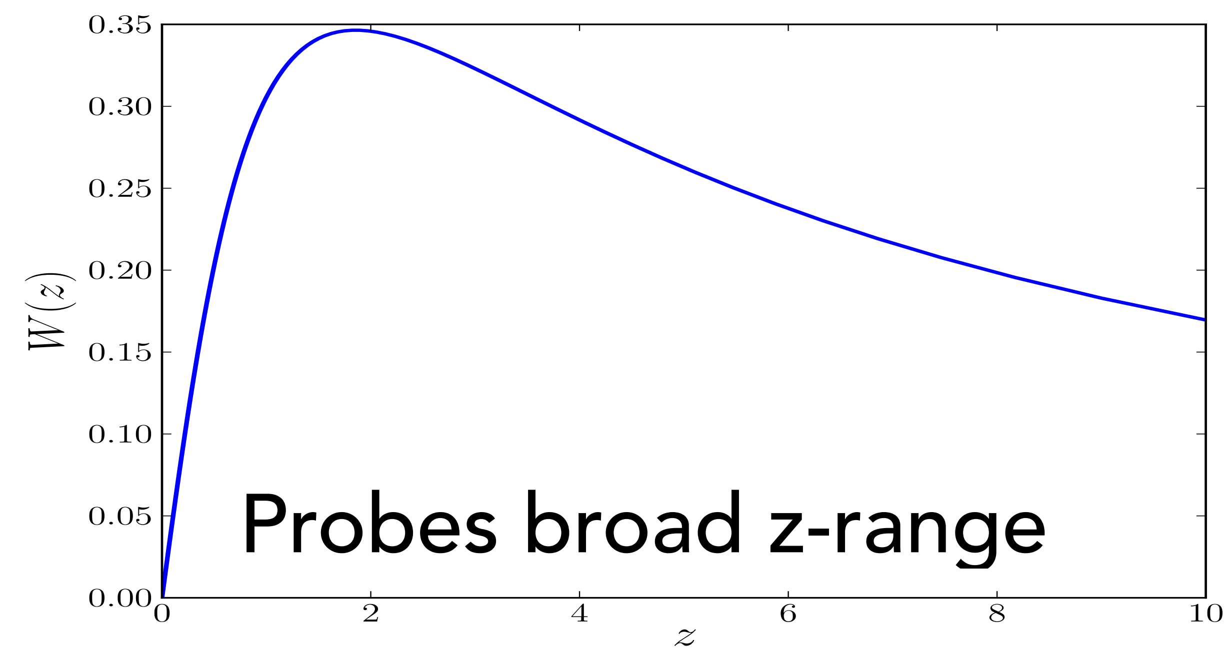
$$T(\hat{n}) = T_0(\hat{n}) + \vec{d} \cdot \vec{\nabla} T_0(\hat{n})$$

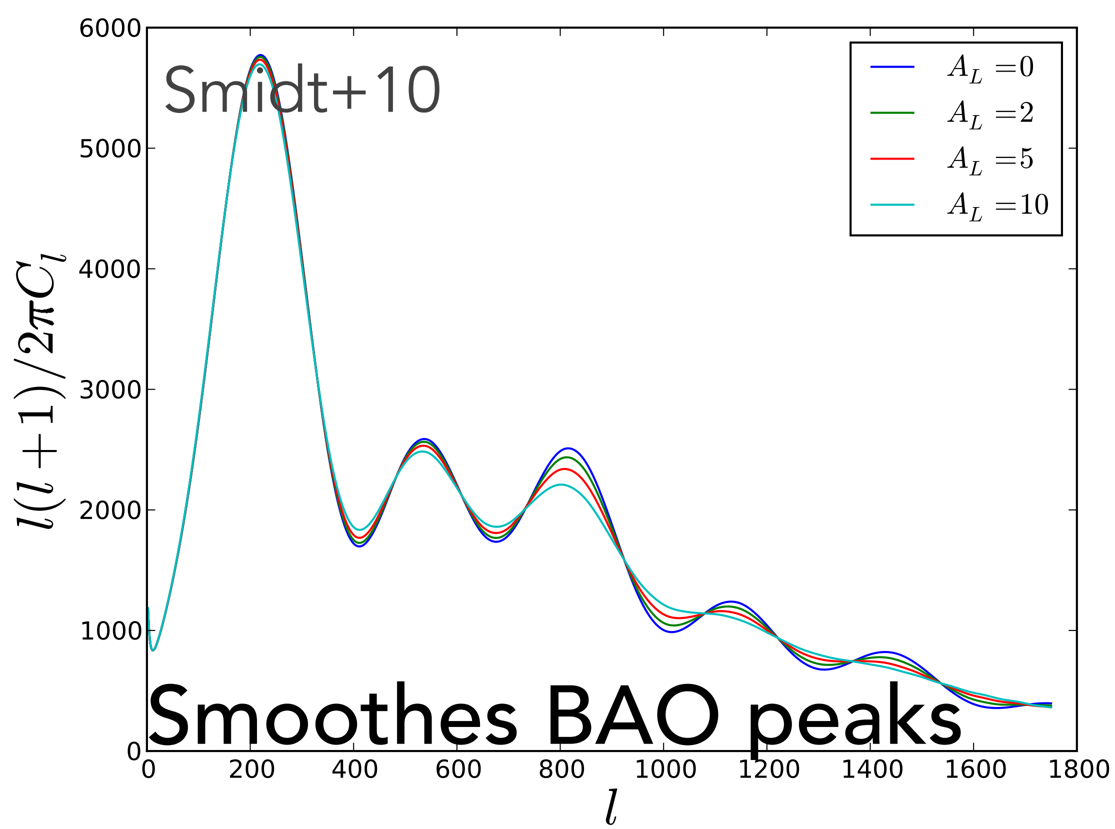
Arcmin deflections, coherent on degree scale

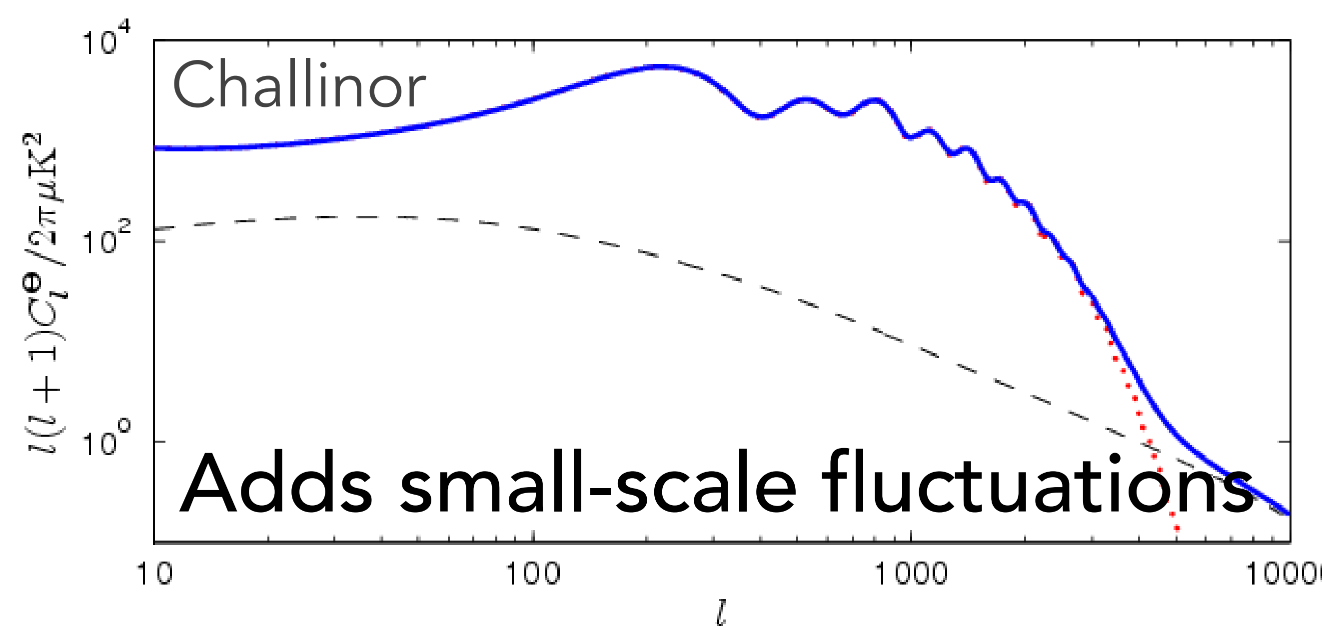
Breaks statistical isotropy → reconstruction

Different systematics (SZ, point sources)





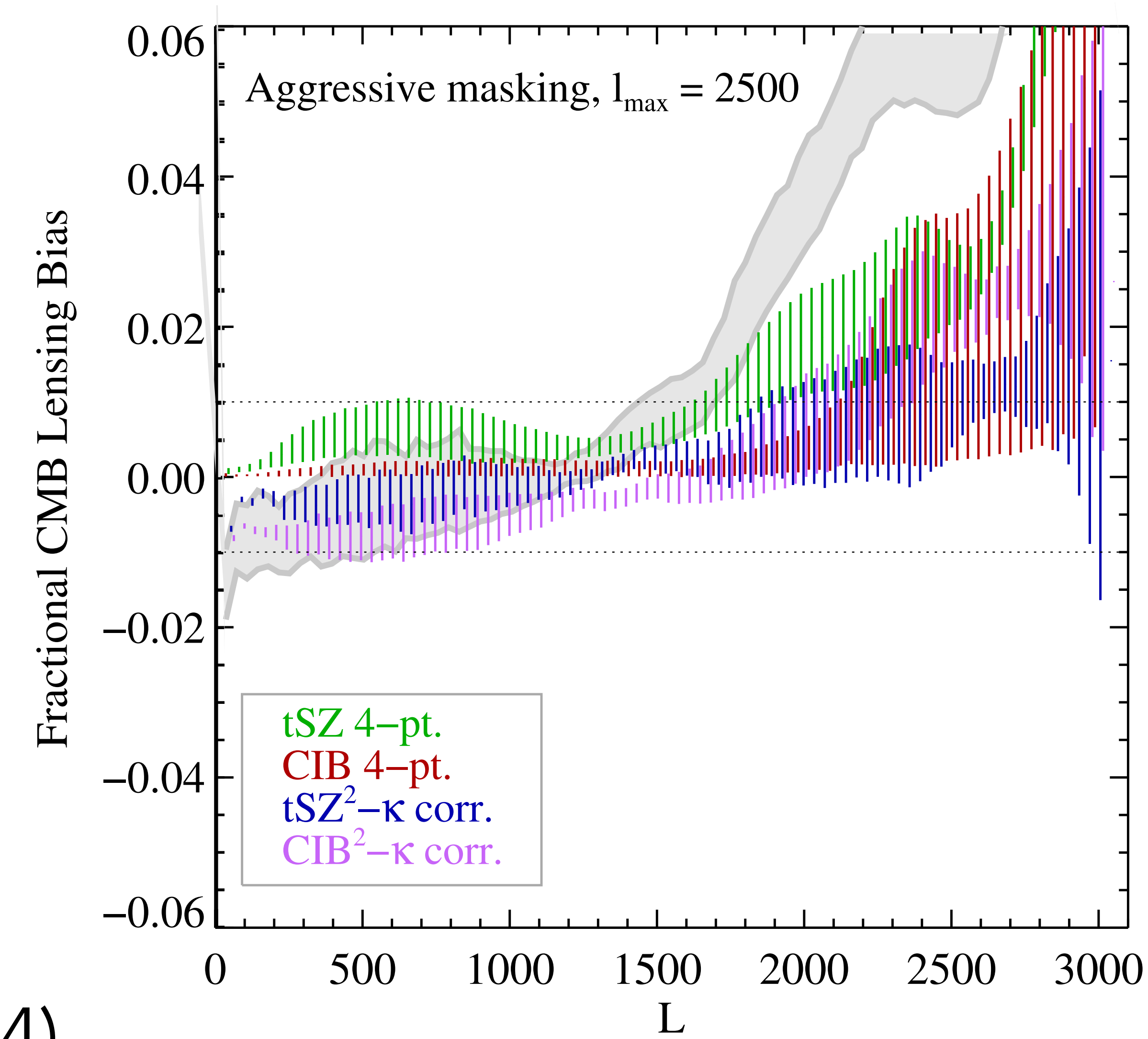




Why no "m_{CMB}" in CMB lensing?

CMB lensing systematics:

- biases in $<\kappa_{CMB}\ \kappa_{CMB}>$:
  $<S^2\ \kappa_{CMB}>$
  $< S^4>$
- biases in $<\kappa_{CMB}$ anything>:
  $<S^2$ anything>
- Remove with:
  multiple wavelength
  project out bispectrum (Osborne+14)
- (Likely) less important in polarization



van Engelen+14

Galaxy lensing: systematics/uncertain physics

- Non-linear gravity/Baryonic effects
  Rudd+08, Zentner+08, van Daalen+11,14, Vellisciq+14, Osato+15, Hellwing+16

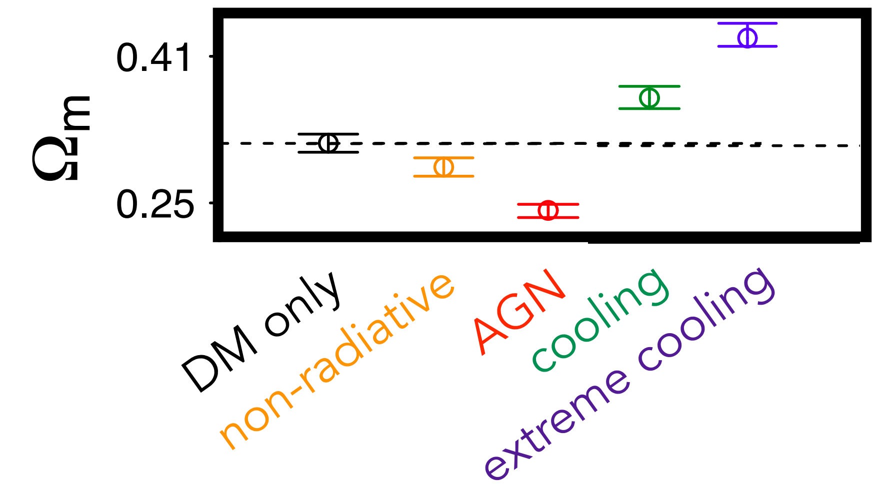
- Consistent joint analysis of probes

- Intrinsic alignments
  up to 1%-10% of cosmic shear
  II: remove auto-correlation, z-cut;
  GI: remove red galaxies?
  Kiessling et al 2015, Kirk et al 2015

- Shape measurement
  shear bias <~0.4% , Huterer+06, Massey+12

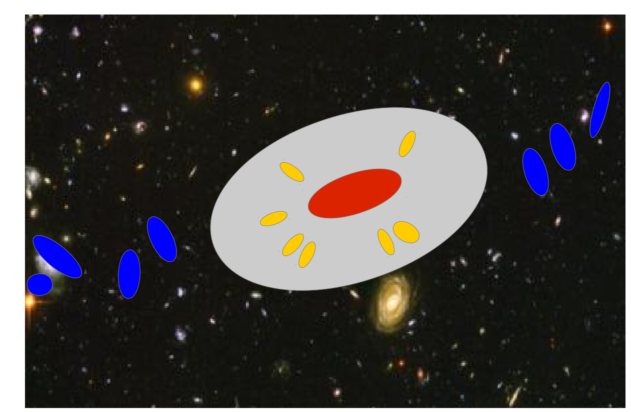
- Photo-z uncertainties
  bias and scatter known to 0.3%, Huterer+06;
  1.e5-1.e6 spectra for calibration, Ma Bernstein 08

Eifler Krause+14

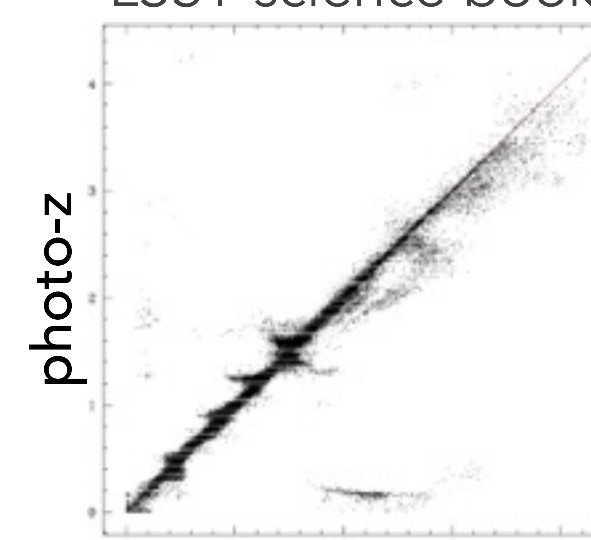


true z

Chisari



LSST science book



Statistics < Systematics

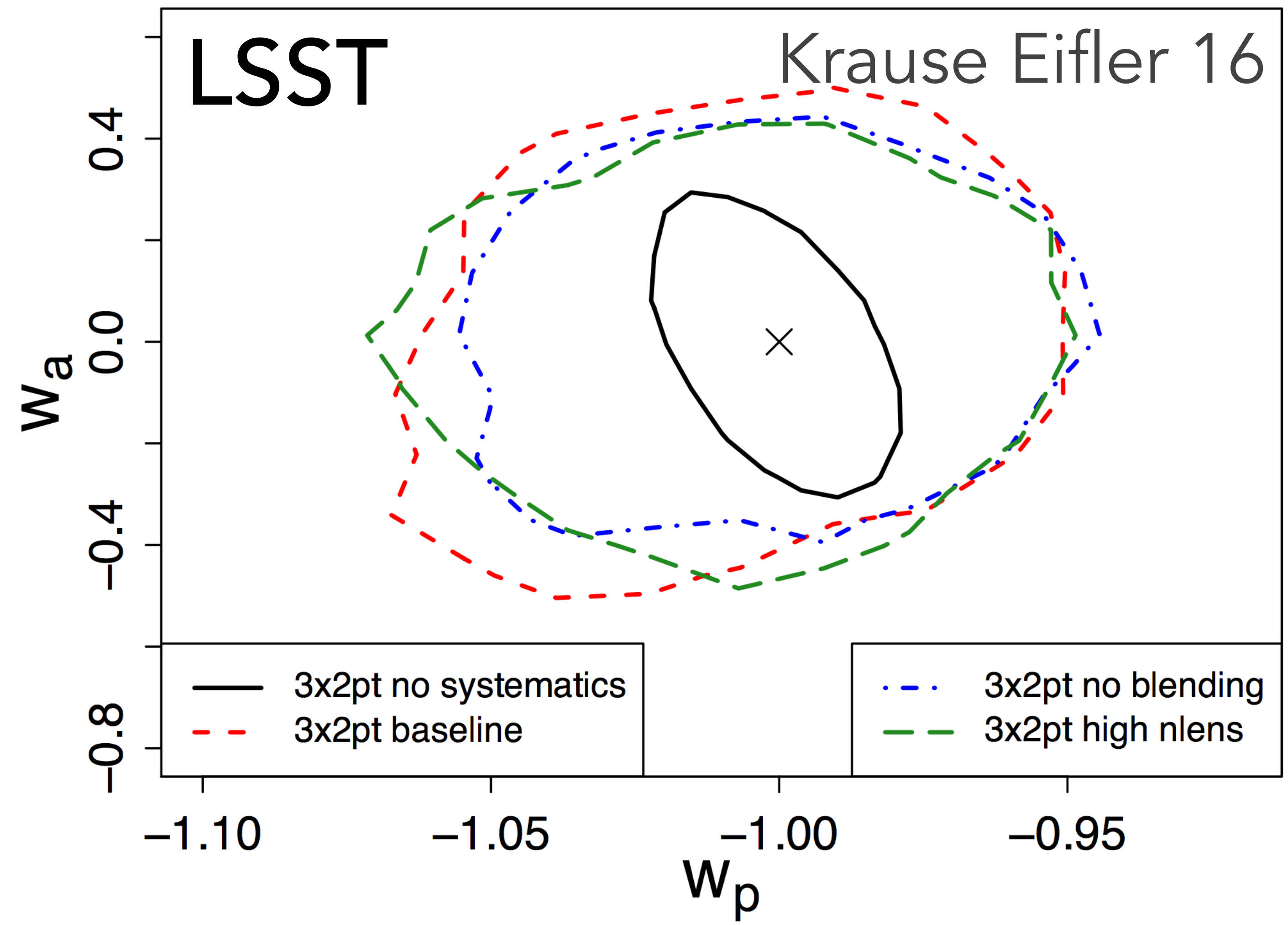
Shear calibration

Photo-z uncertainties

Intrinsic alignments

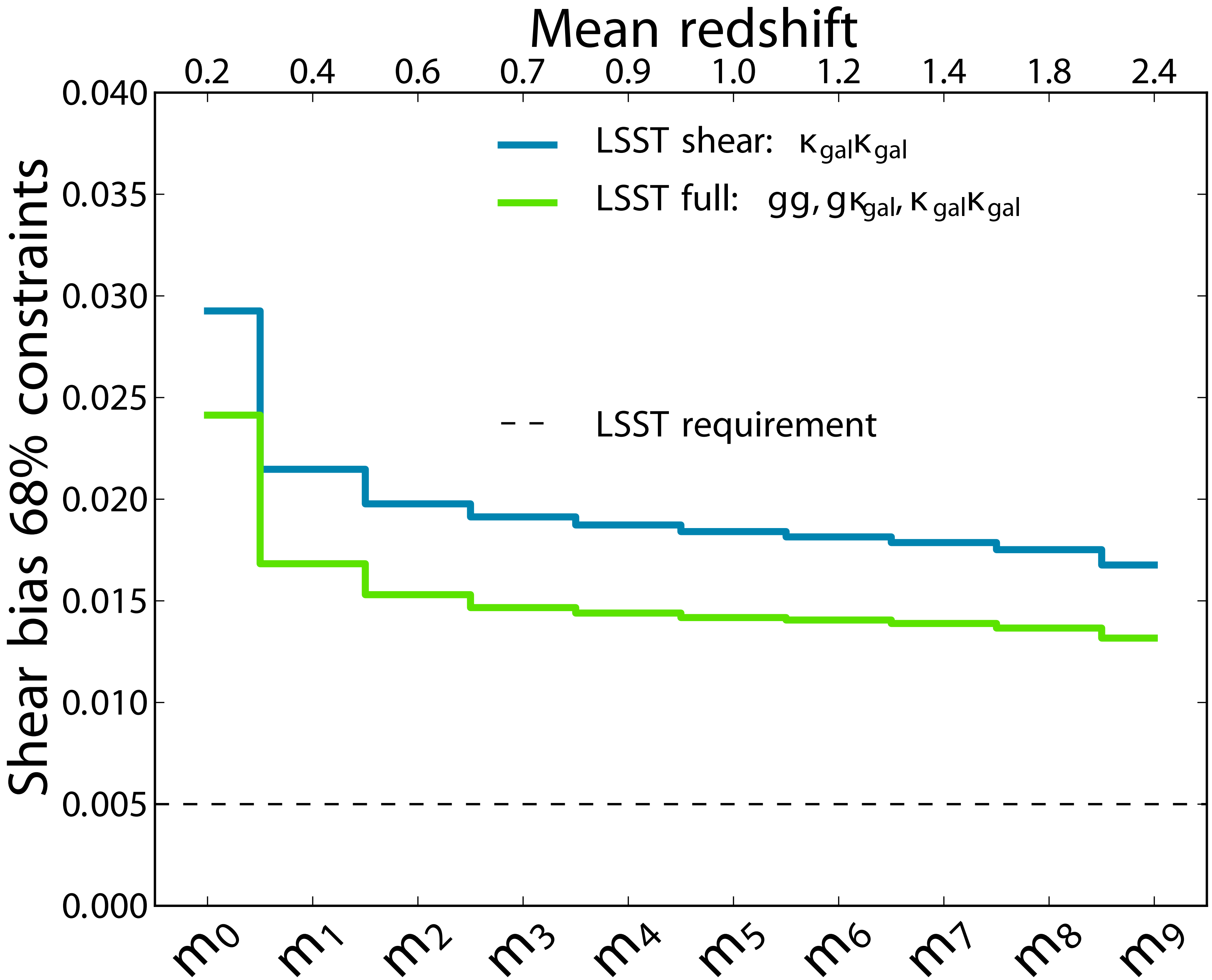
Non-linear/baryonic effects

Consistent joint analyses



→ Signal-to-noise/FoM is not all

→ Systematics are limiting

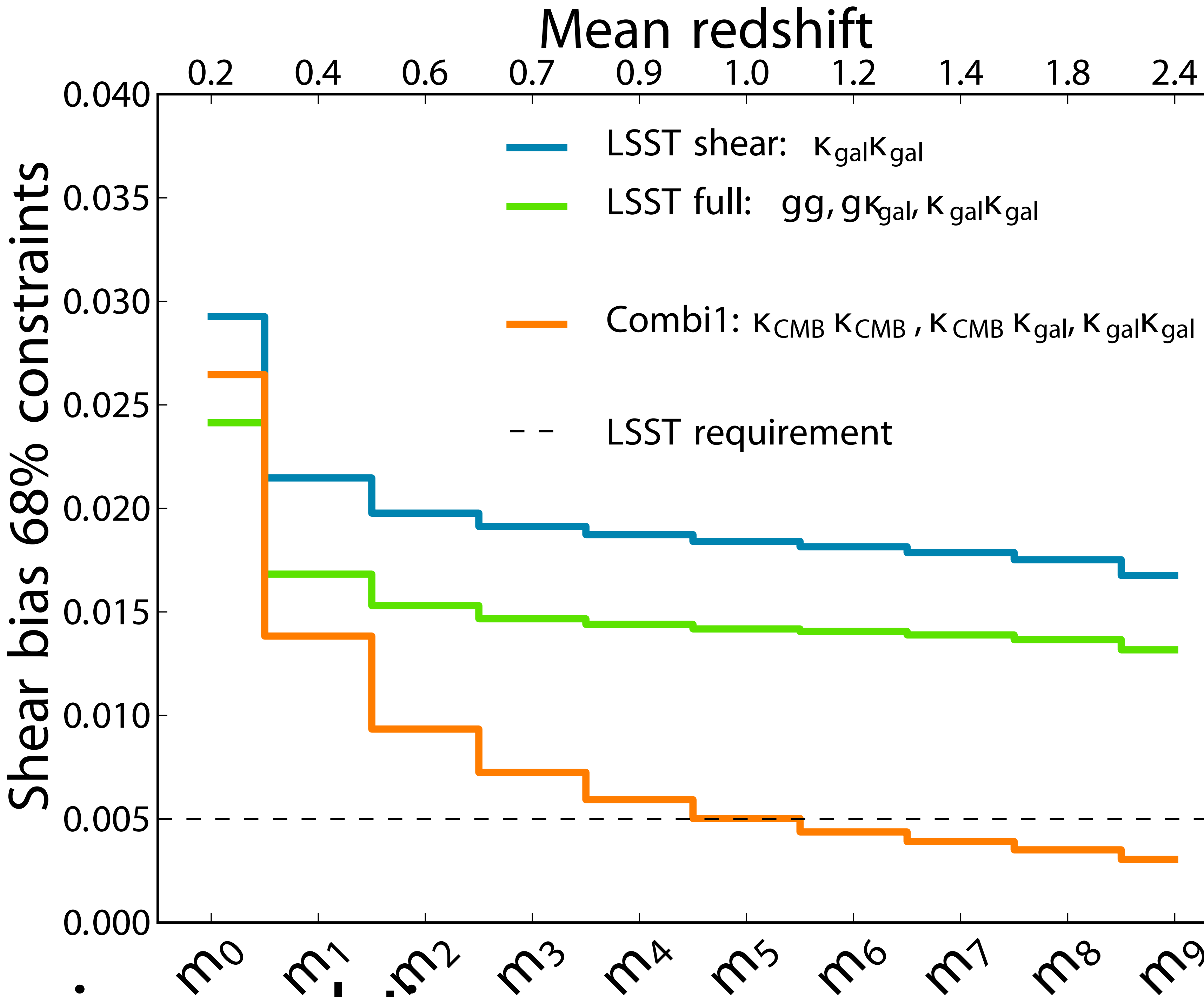


Schaan+16

Shear alone/LSST alone:

Self-calibration to ~2%

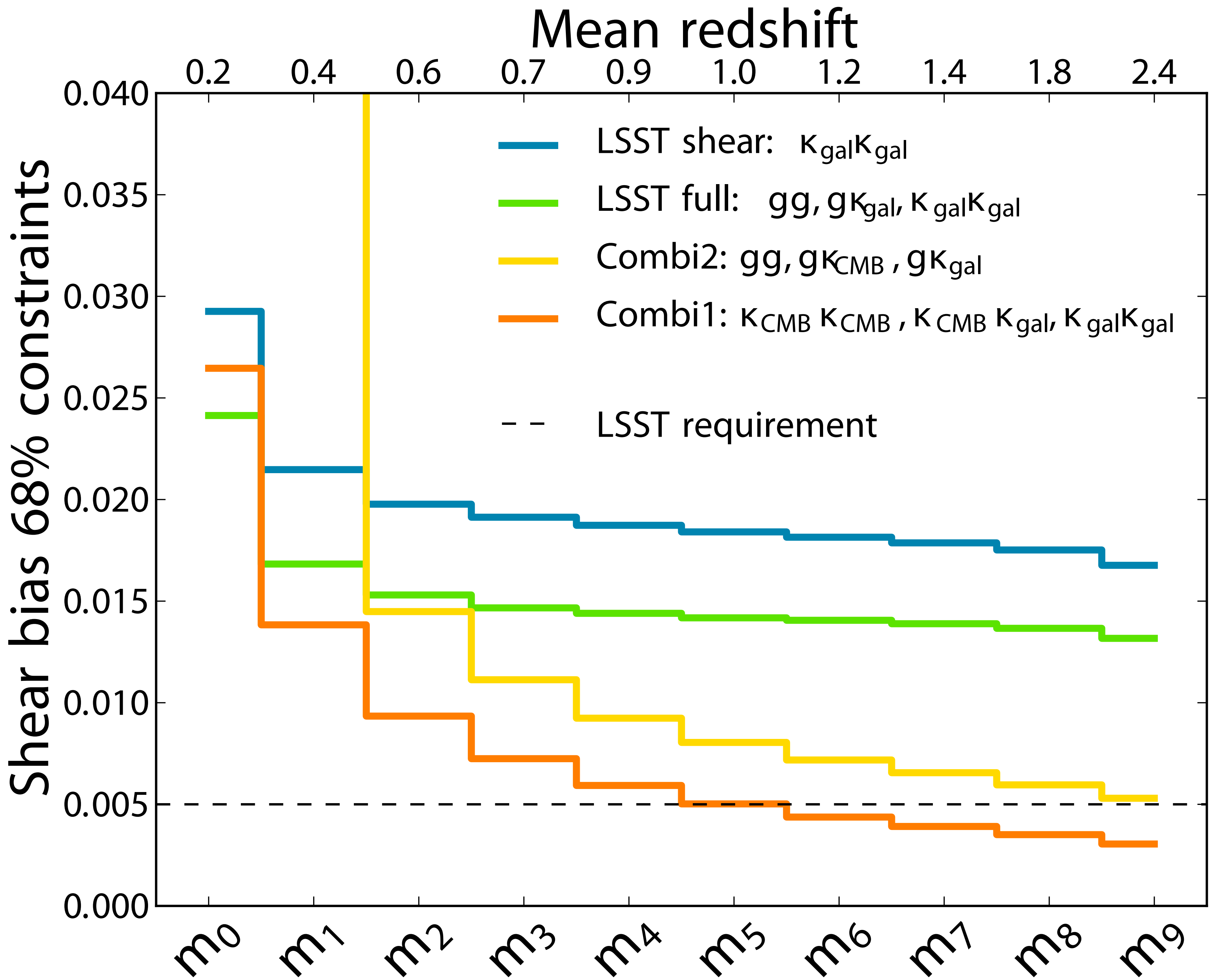
Relies on mildly non-linear scales



Schaan+16

Lensing-lensing correlations:

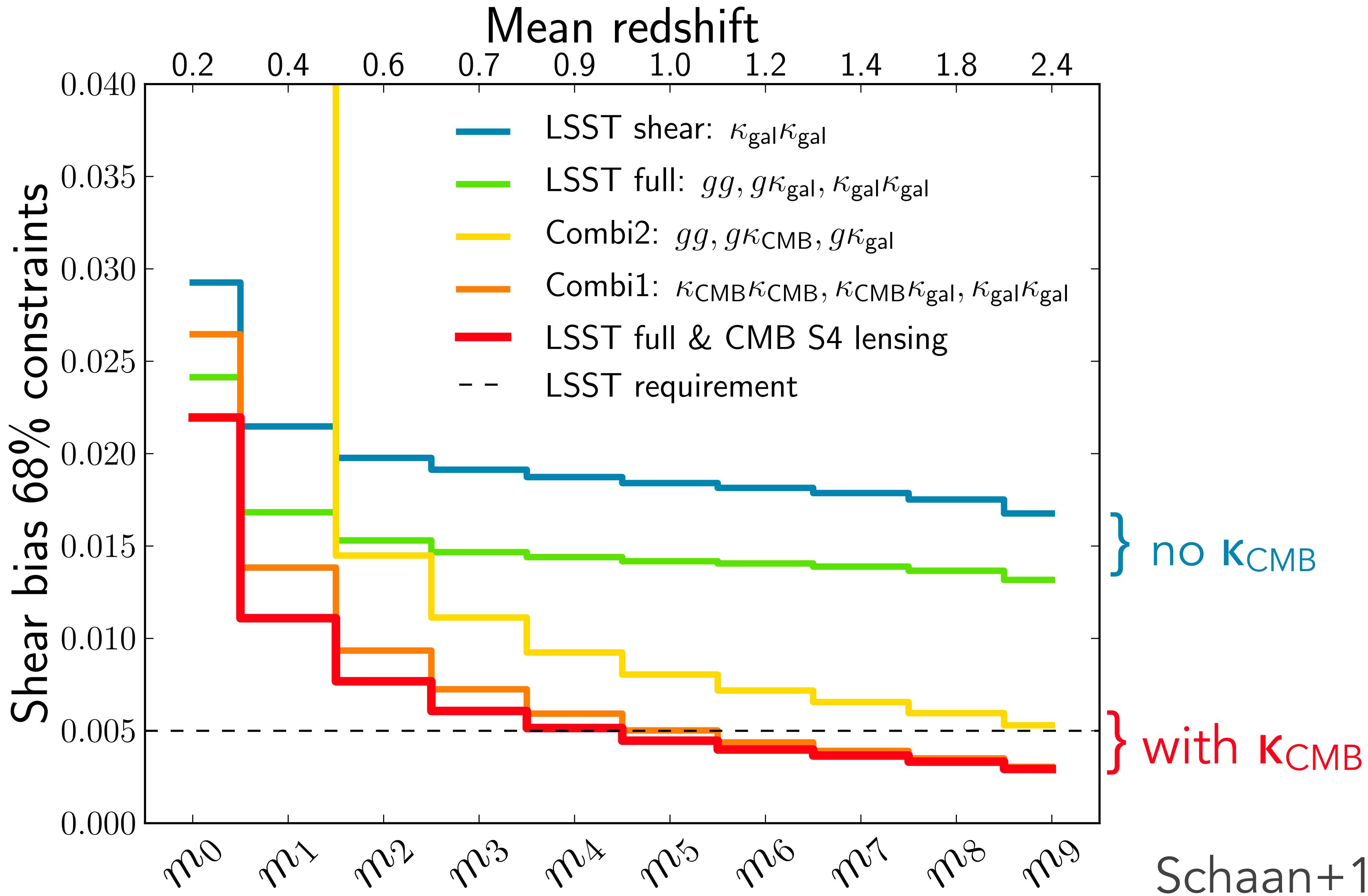
- requires auto spectra
- IA always present
- fixed angular scale ← arbitrary small physical scales



Schaan+16

Tracer-lensing correlations:

+ no lensing auto
+ fairly insensitive to cosmology (distance ratios)
+ no IA if perfect photo-z
+ fixed angular scale ← **not** arbitrary small physical scales



Schaan+16

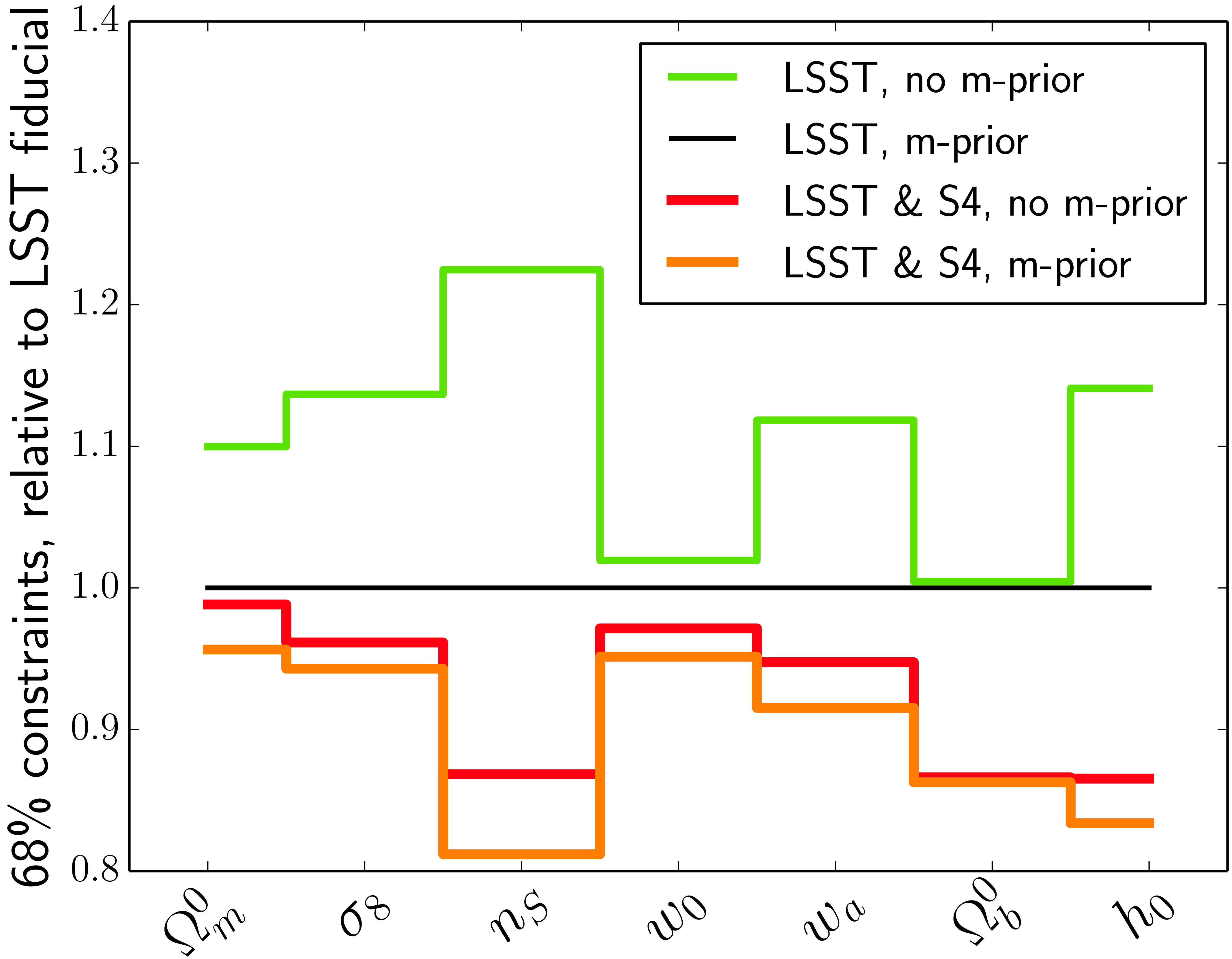
CMB S4 lensing can calibrate the shear ~ requirements

while varying cosmo & nuisance params

better at high z where most challenging

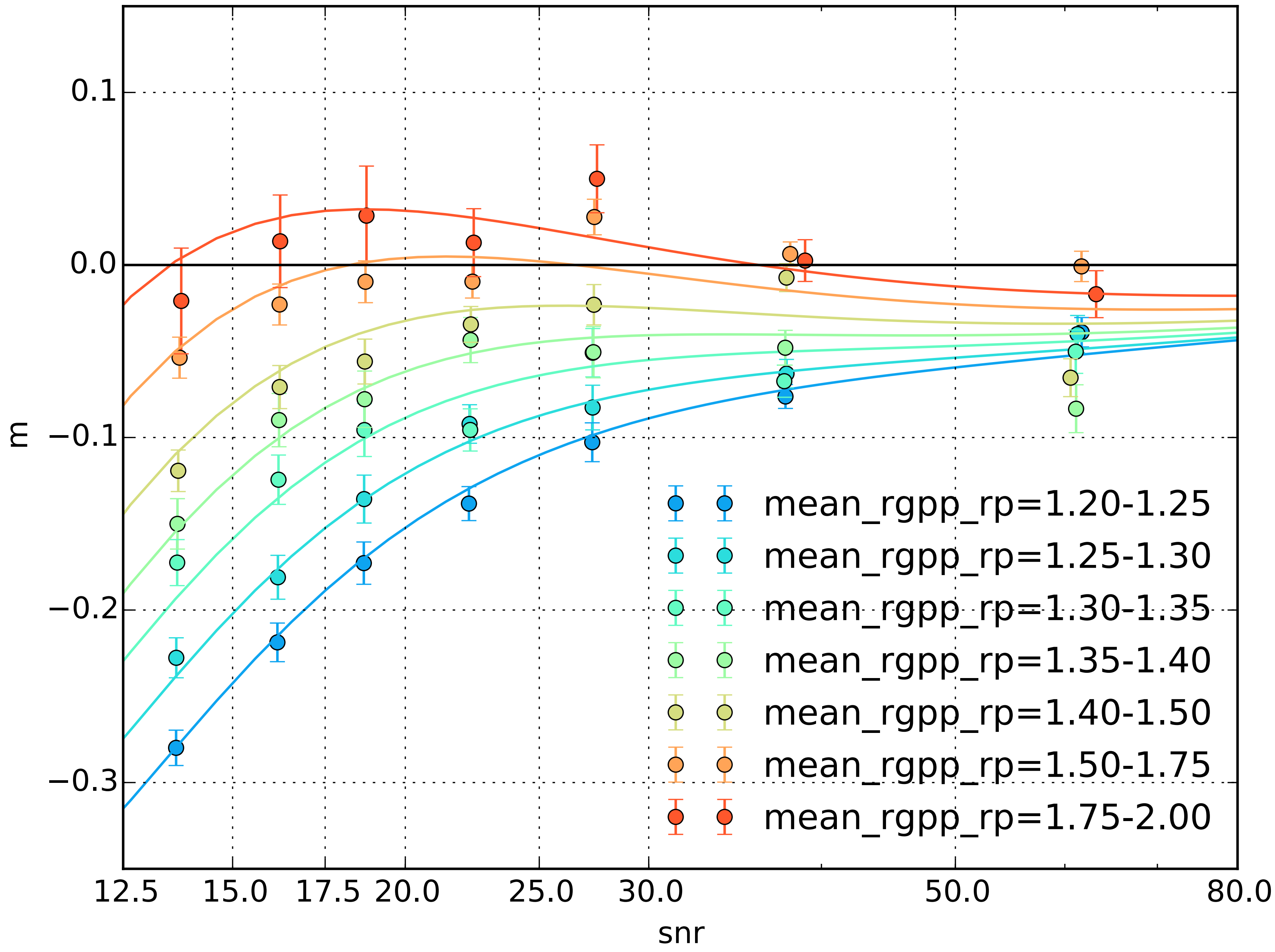
purely empirical, self-calibration

CMB lensing replaces a prior on m



Shear calibration

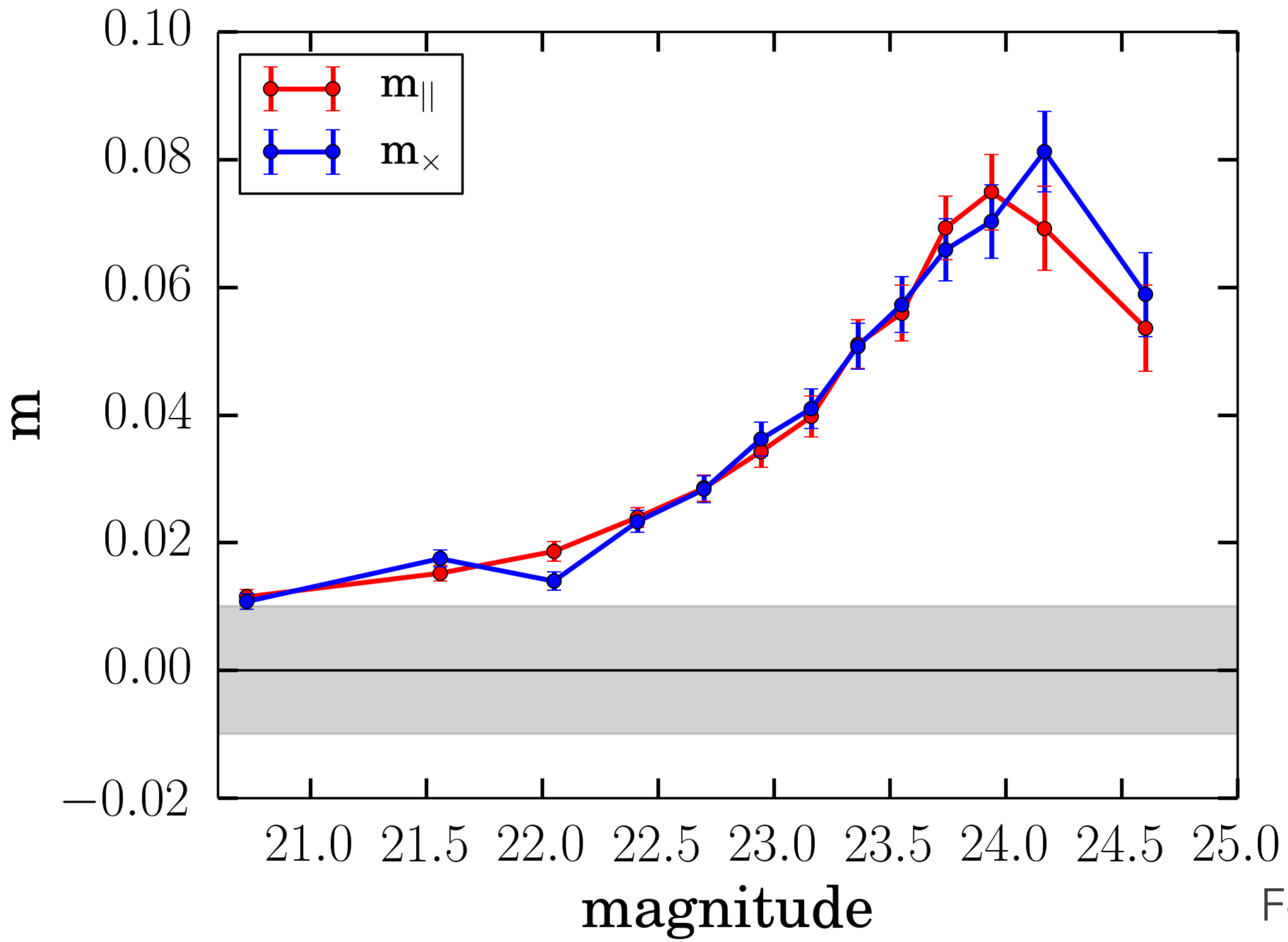
Large corrections from simulations



Jarvis+15

The calibration from simulation can be a large factor
→ needs to be precisely measured

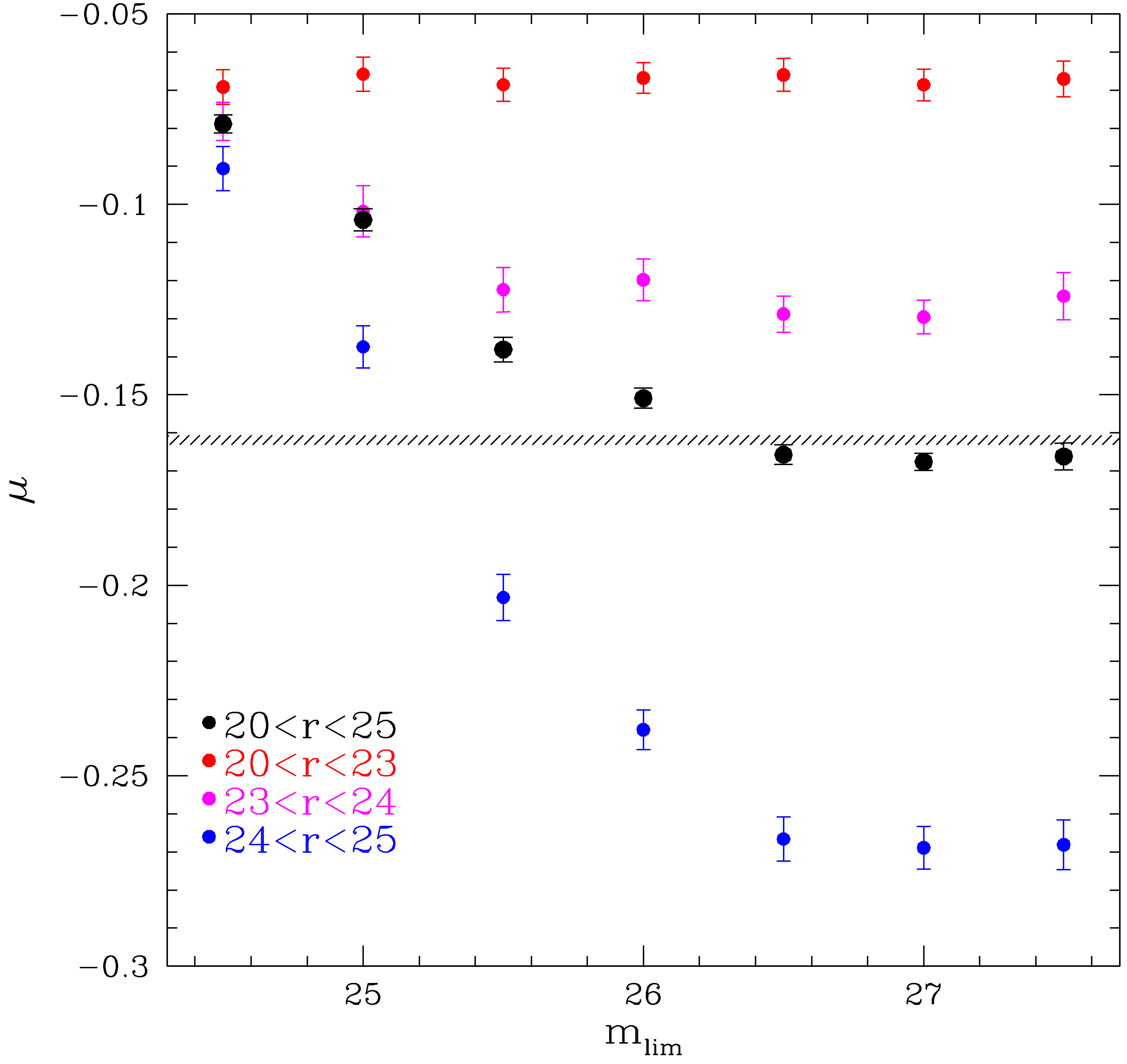
Selection bias



Fenech-Conti+16

Selection bias is large,
especially for faint galaxies

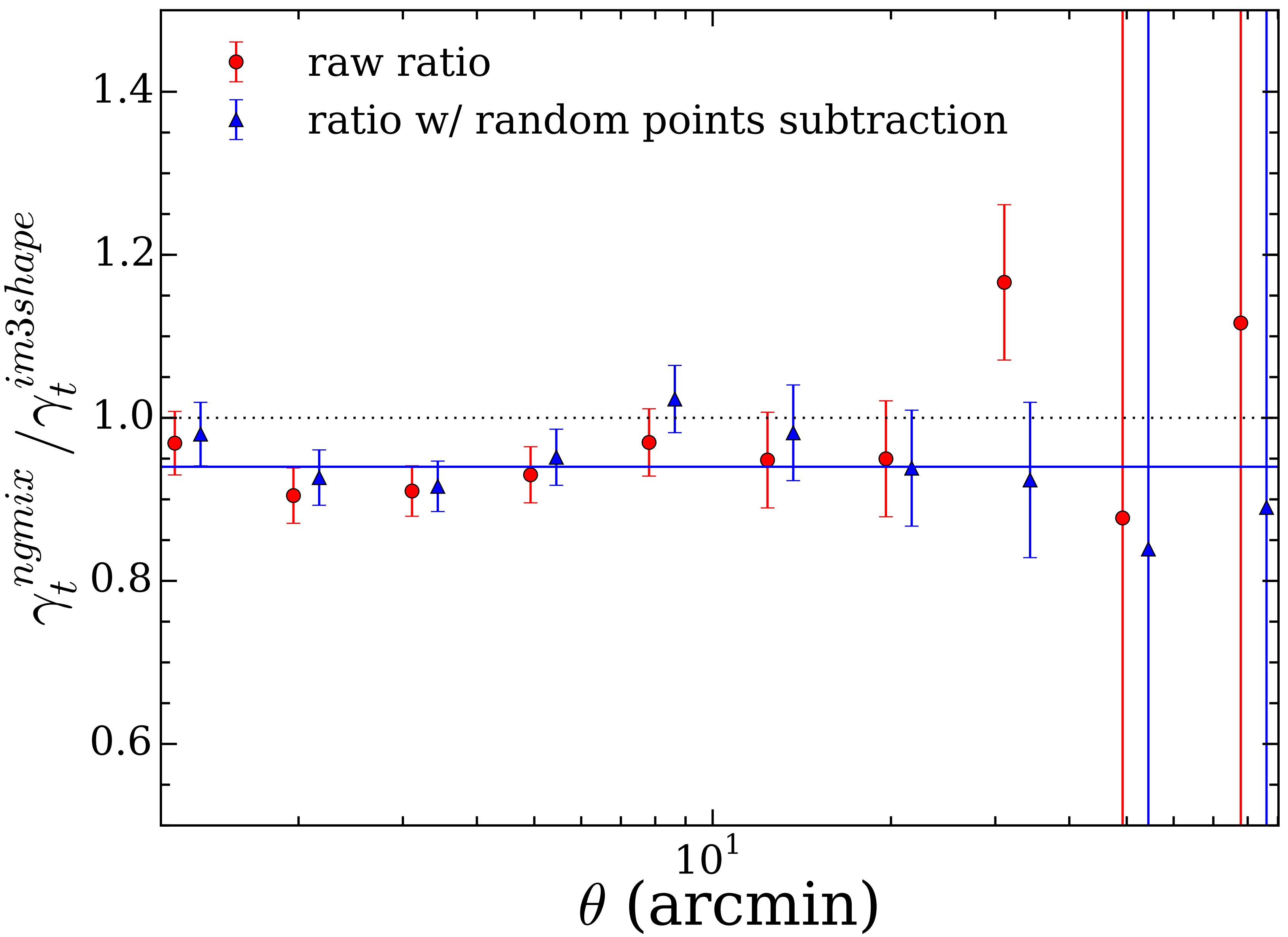
Need to go beyond detection limit



Hoekstra + 15

Go 1.5mag deeper than limit

Subtlety of selection biases



Jarvis+15

- (Does NOT imply a multiplicative bias in either algorithm)
- Implies that selection effects can bias the shear by ~5%
- These effects are subtle and can be easily missed

Robustness

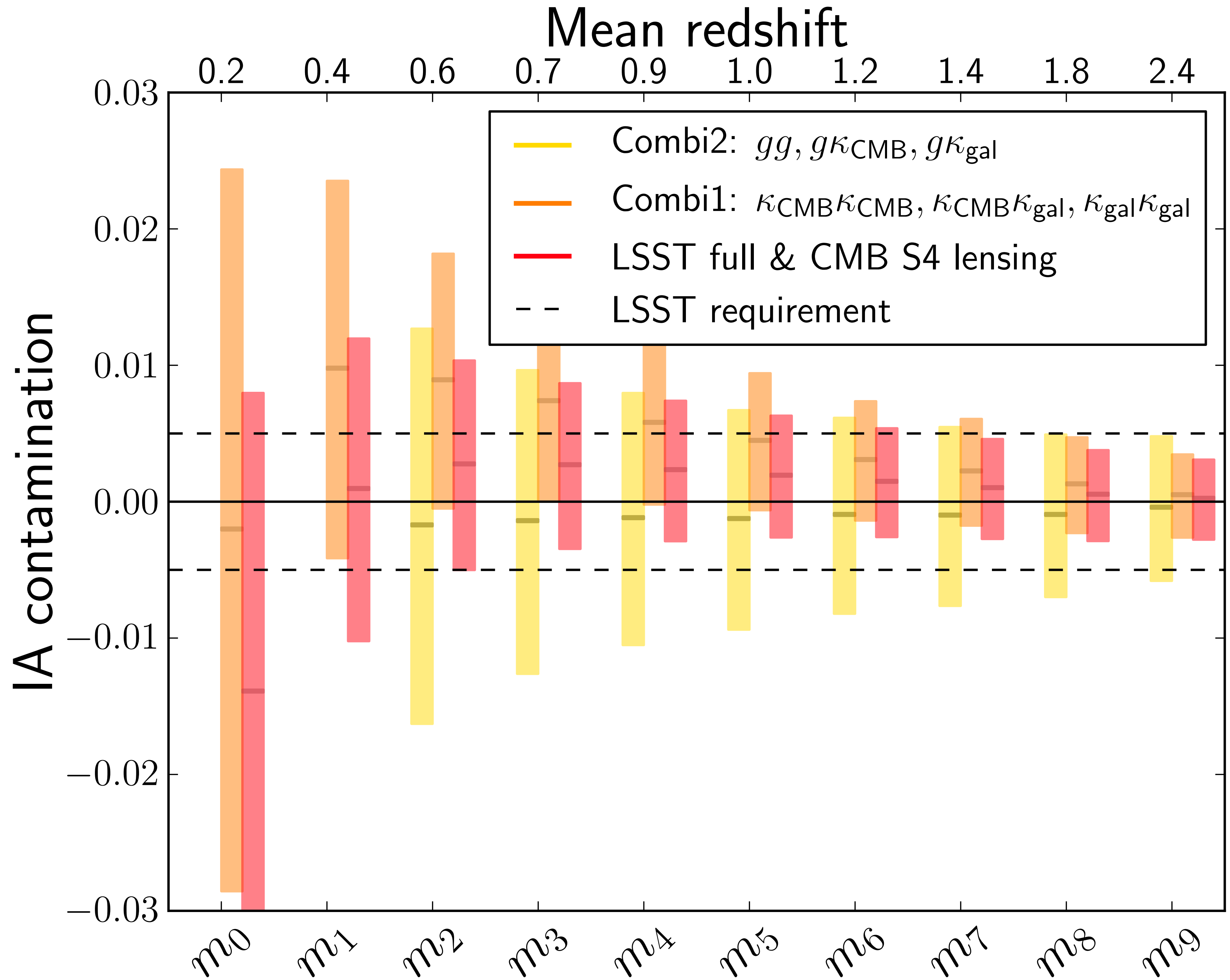
- **IA contamination:**
  Unaccounted IA in the data produce $<1\sigma$ bias in m_i, without mitigation

- **Non-linearities/baryons:**
  Varying l_{max} beyond 1000 does not affect m_i much

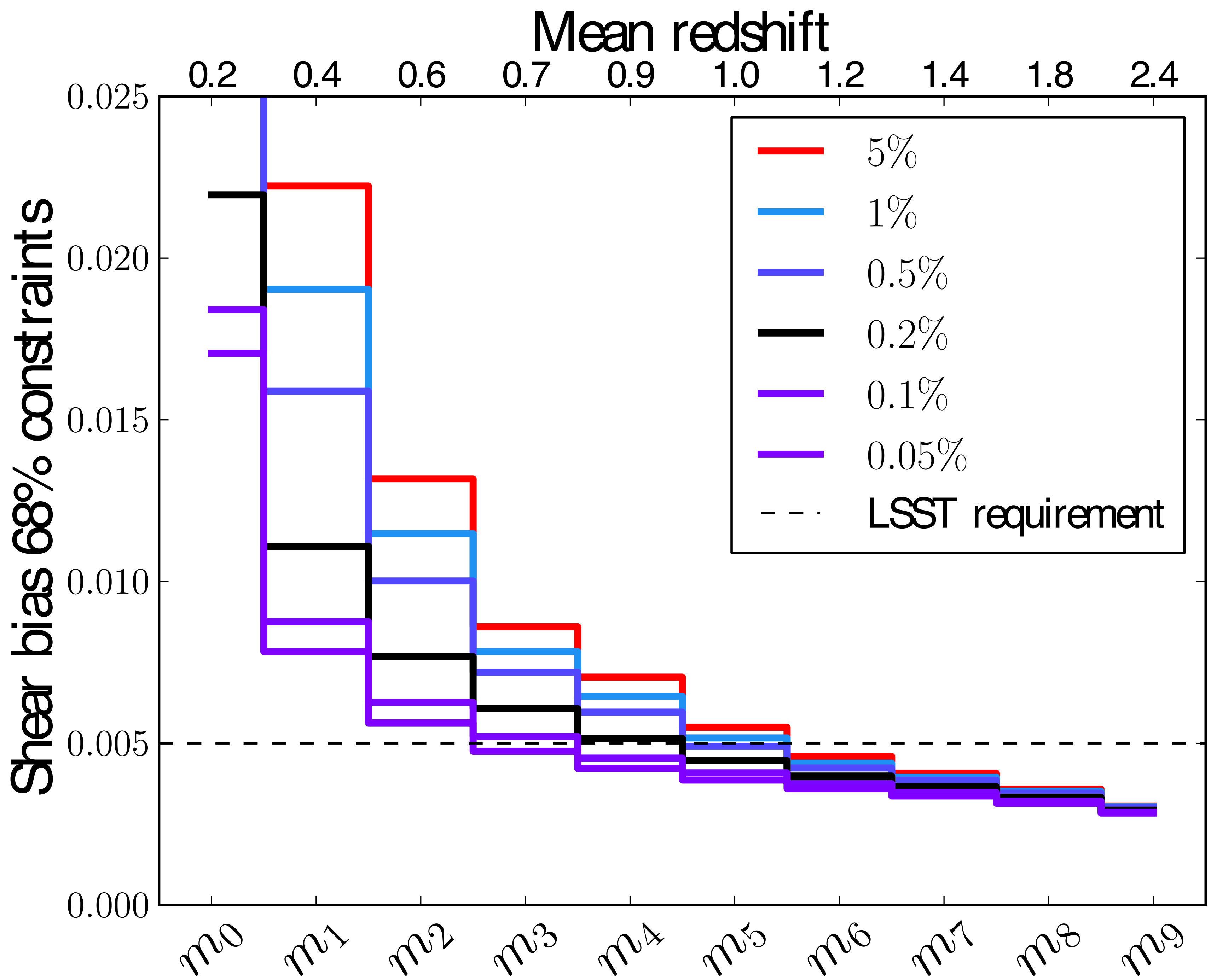
- **Wider photo-z errors:**
  Weakening prior on photo-z only weakens m_i constraints in the lower z-bins

- **CMB S4 specs:**
  m_i constraints are sensitive to noise, but not much to l_{max} or resolution

Robustness to IA

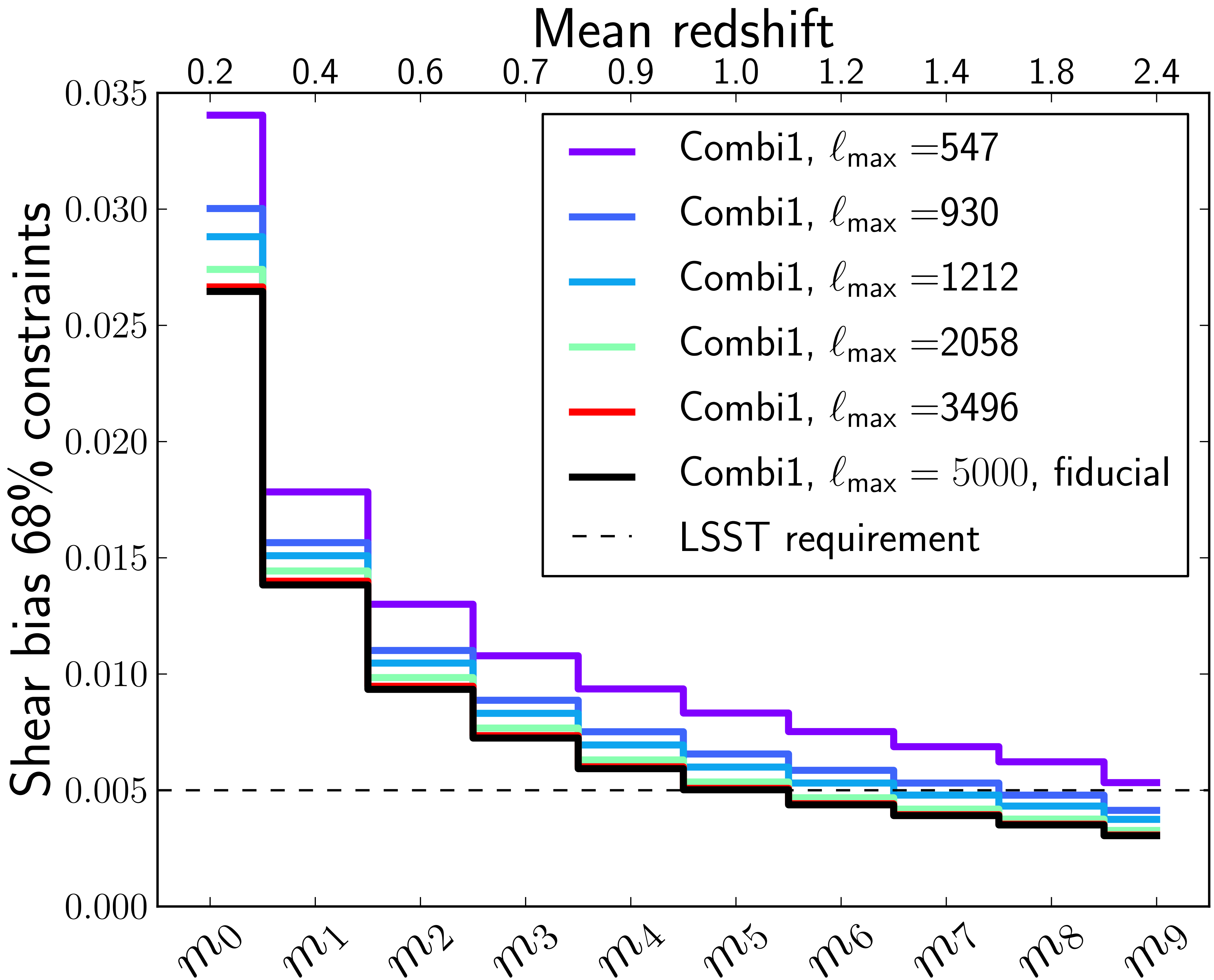


Robustness to photo-z



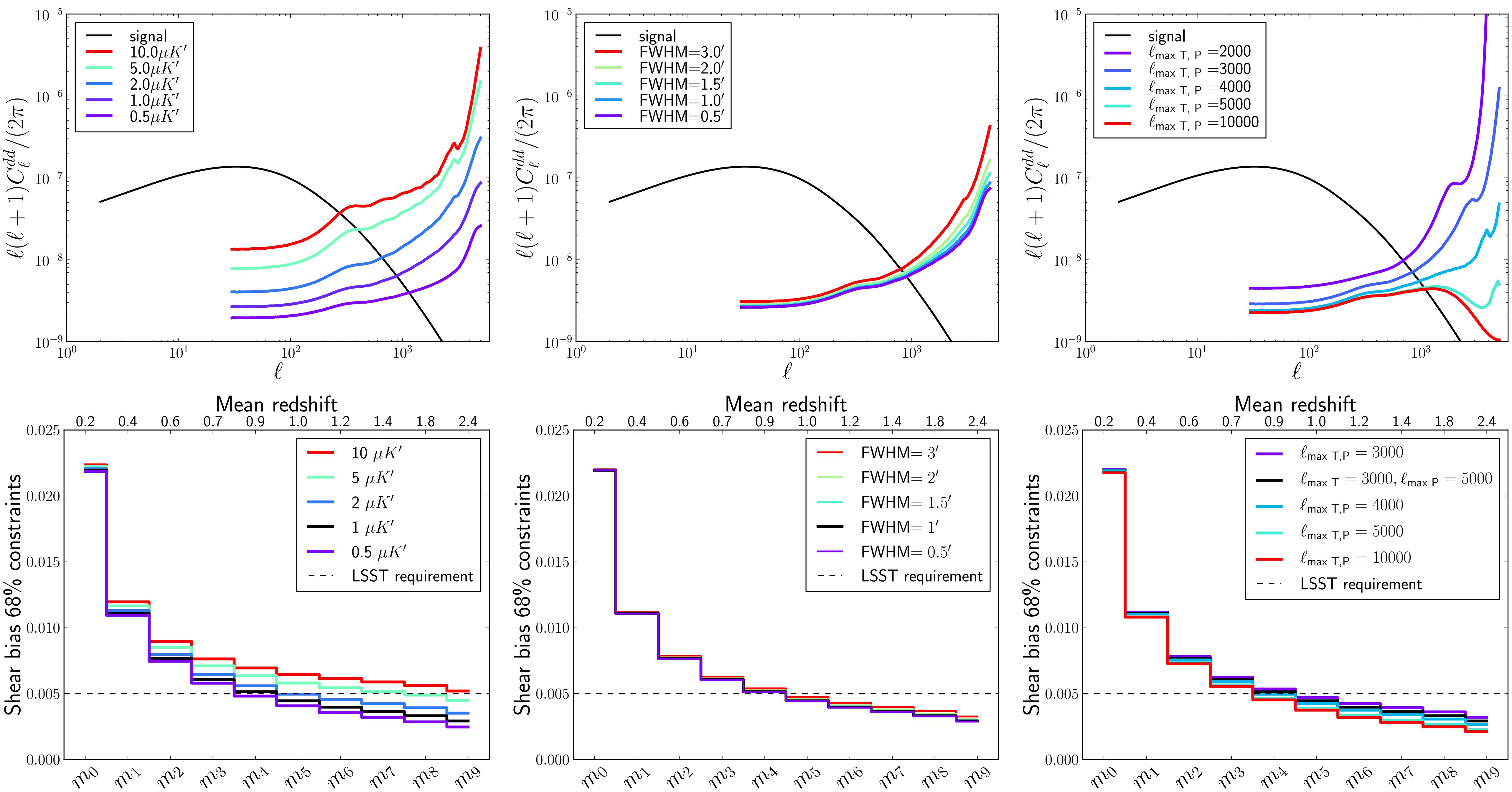
Fixing the source photo-z scatter $\sigma_z/(1+z) = 0.05$,
Varying the prior on it.

Non-linearities / Baryons

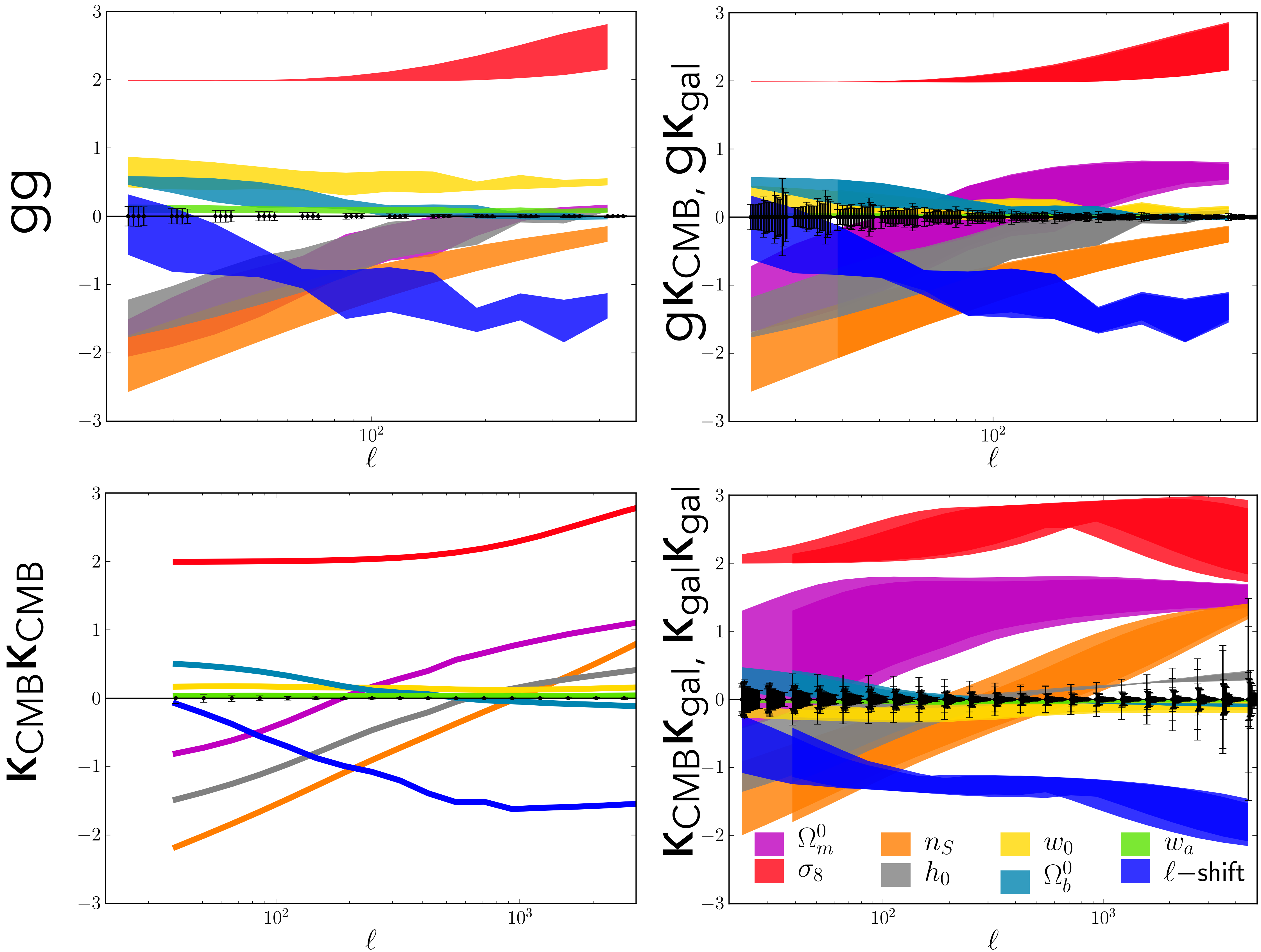


CMB S4 specs?

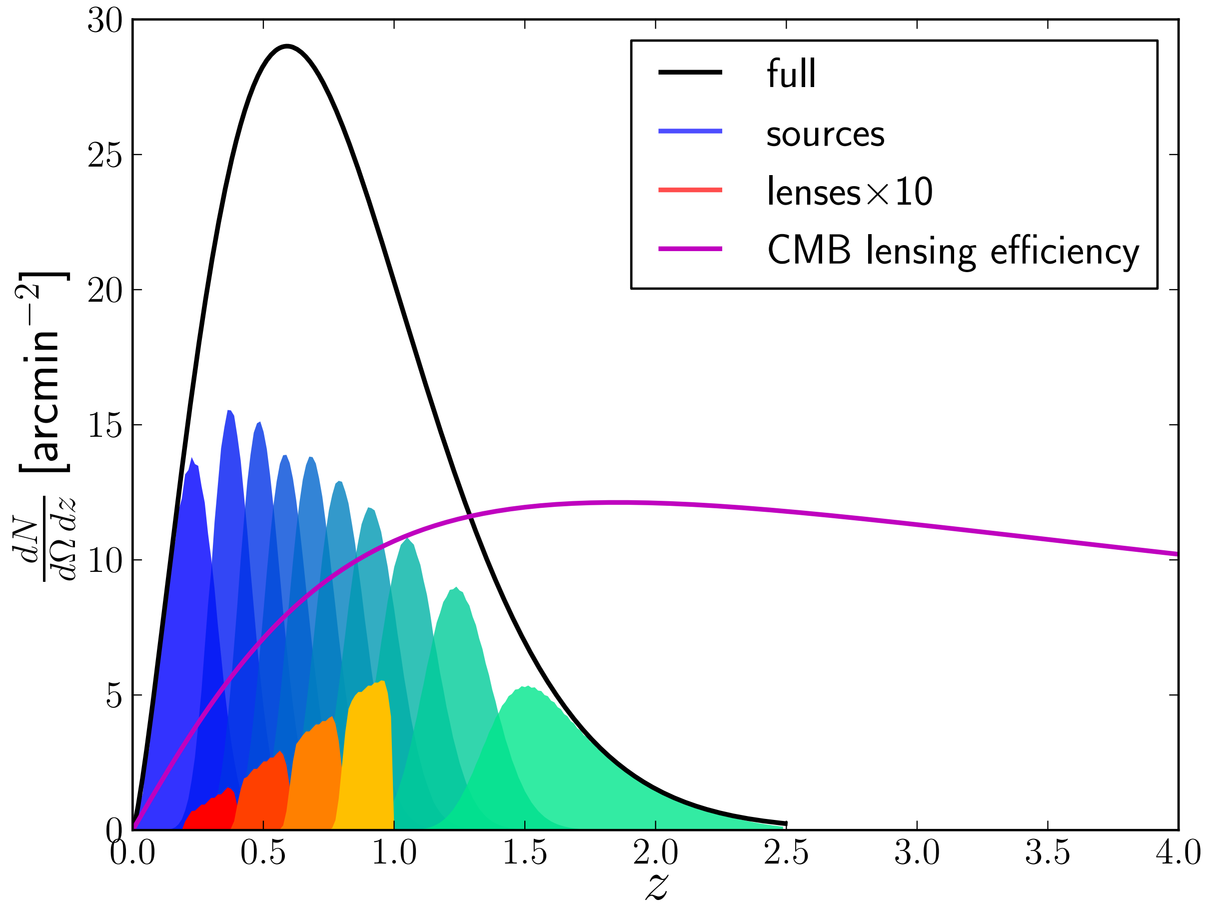
Noise | Beam | l_{max}

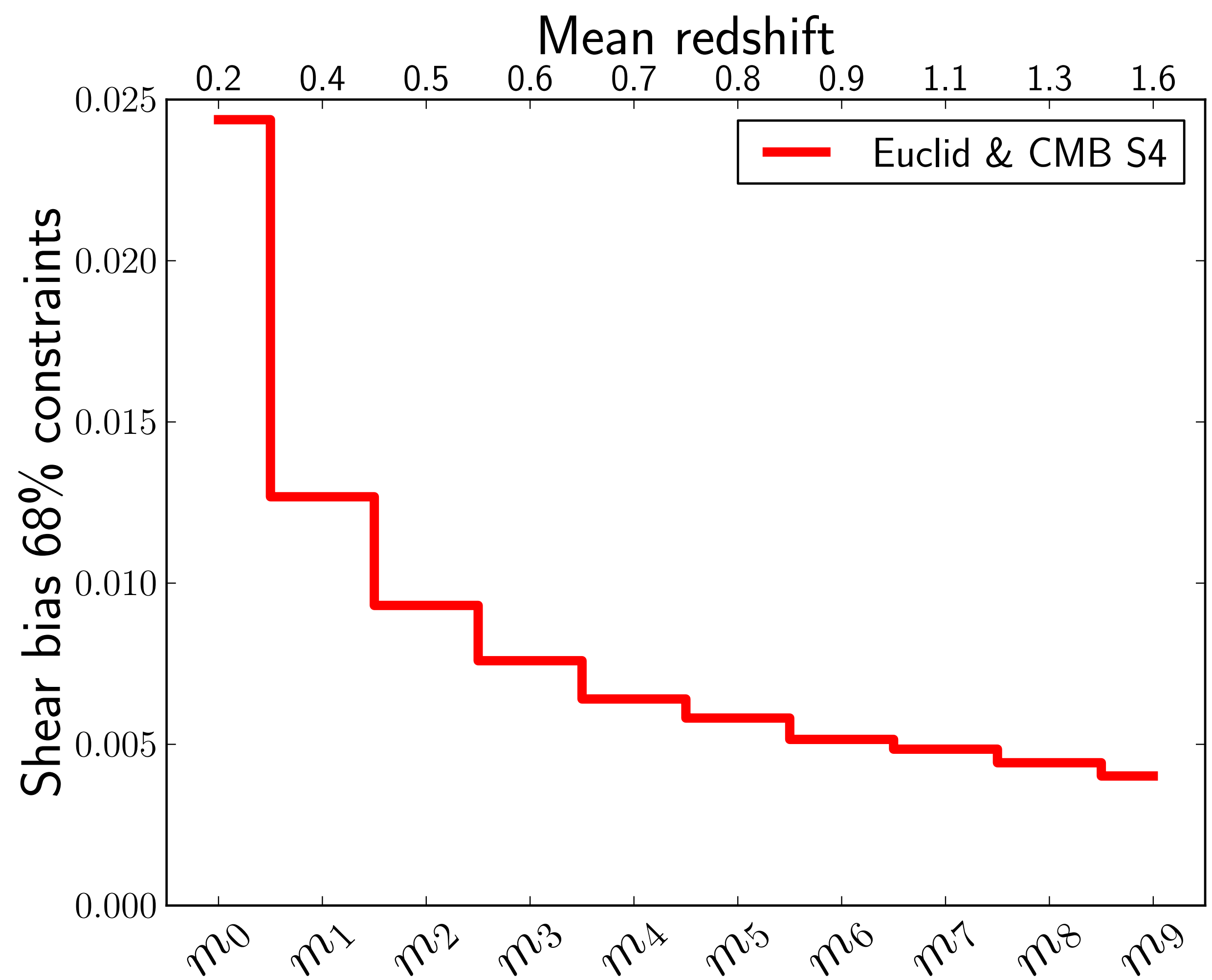


Parameter dependence



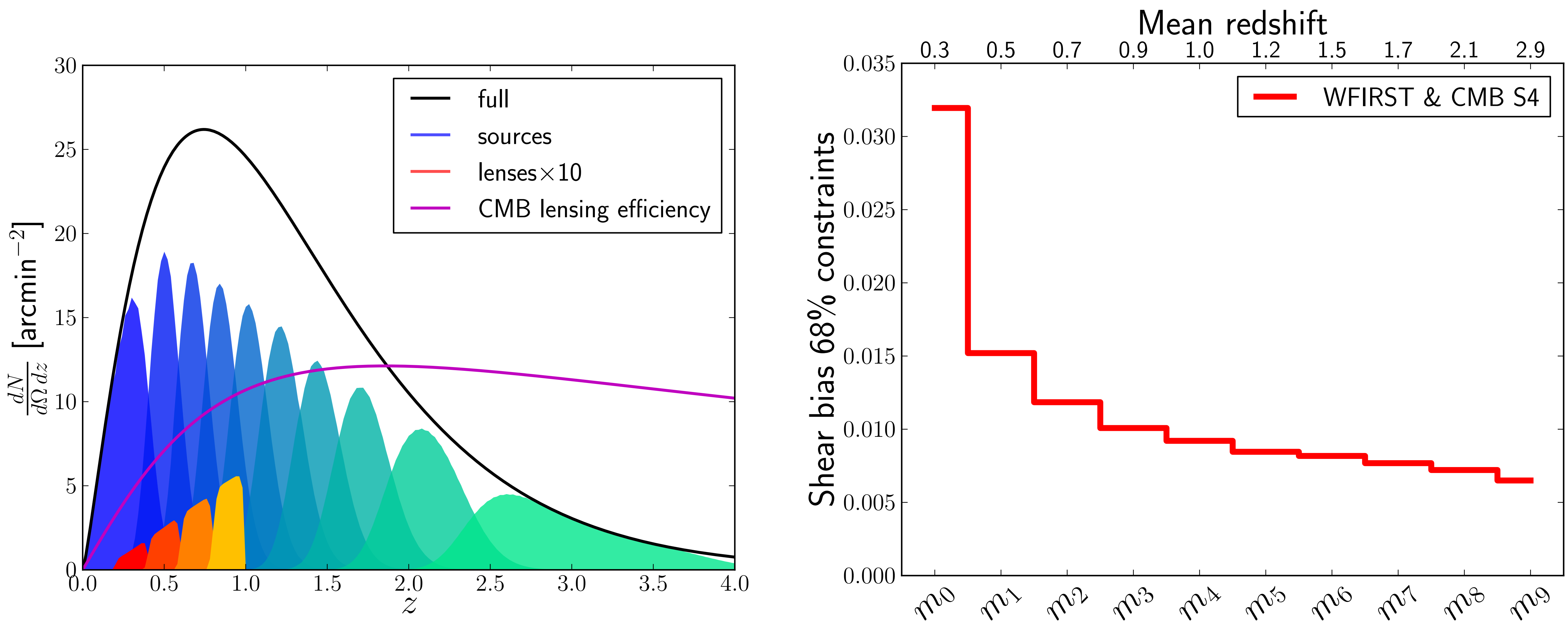
Euclid





Schaan+16

WFIRST



Schaan+16