Controlling weak lensing systematic uncertainties with three-point statistics

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I will discuss:

Motivation for considering 3-point statistics in the context of next-generation surveys

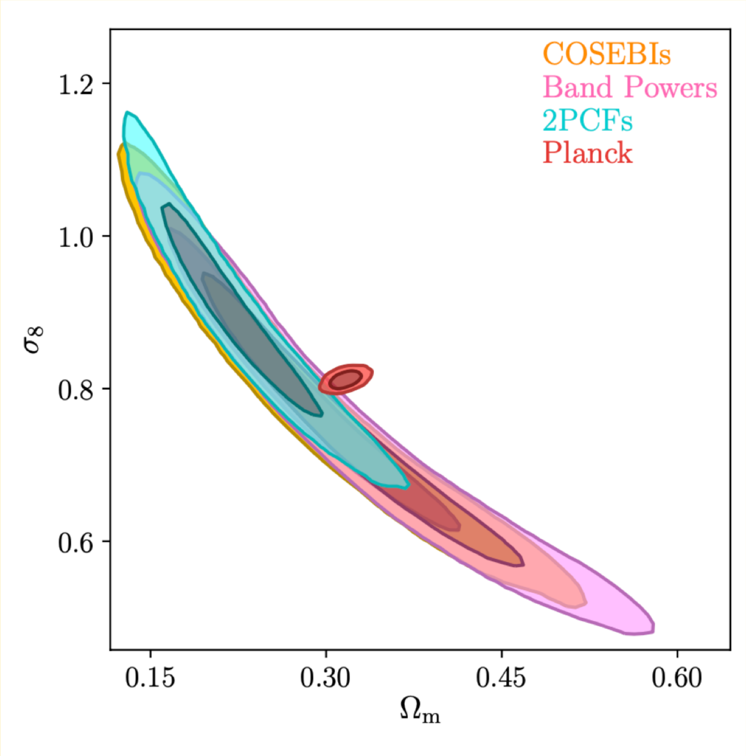
Background to the systematic uncertainties we looked at

Modelling and results, based on Fisher matrix analysis and figures of merit

Our conclusion that 3-point statistics could be a promising alternative method of mitigating systematics

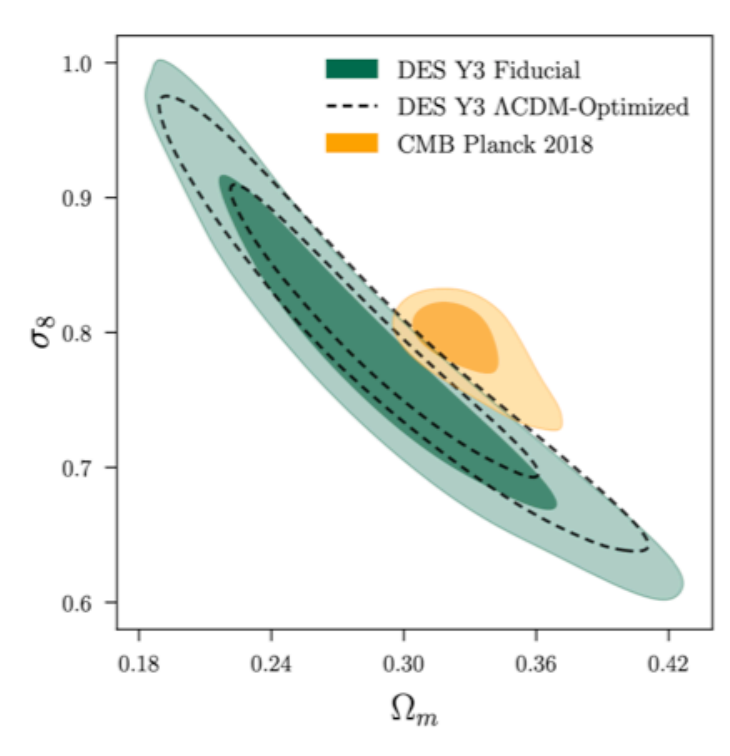
Weak lensing can already produce tight constraints on cosmological parameters – so why use three-point statistics?

Results using two-point statistics



KiDS-1000

Asgari et al 2020

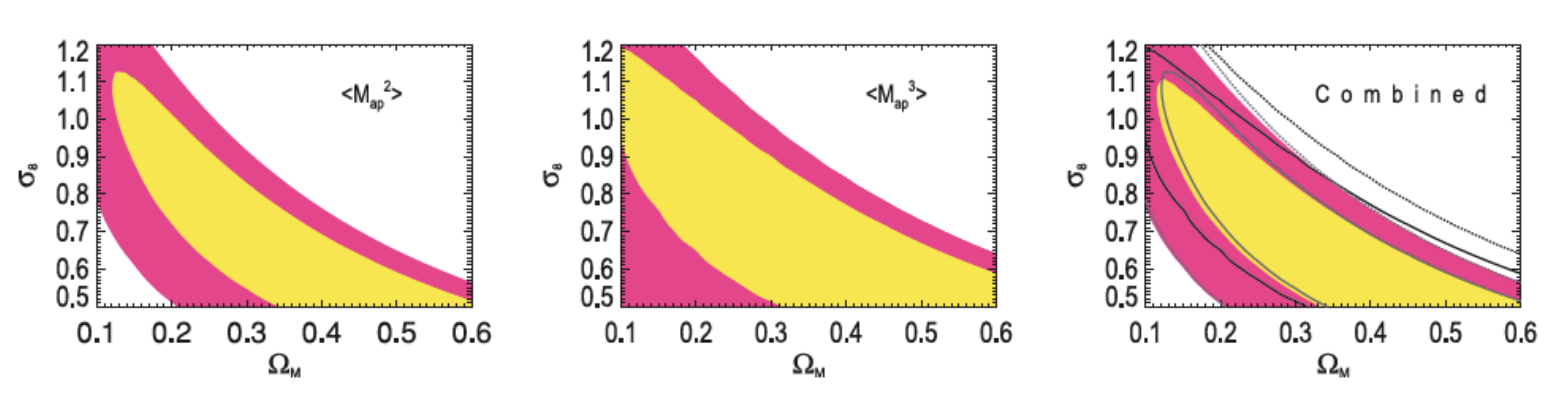


DES Y3

Amon et al 2021, Secco et al 2021

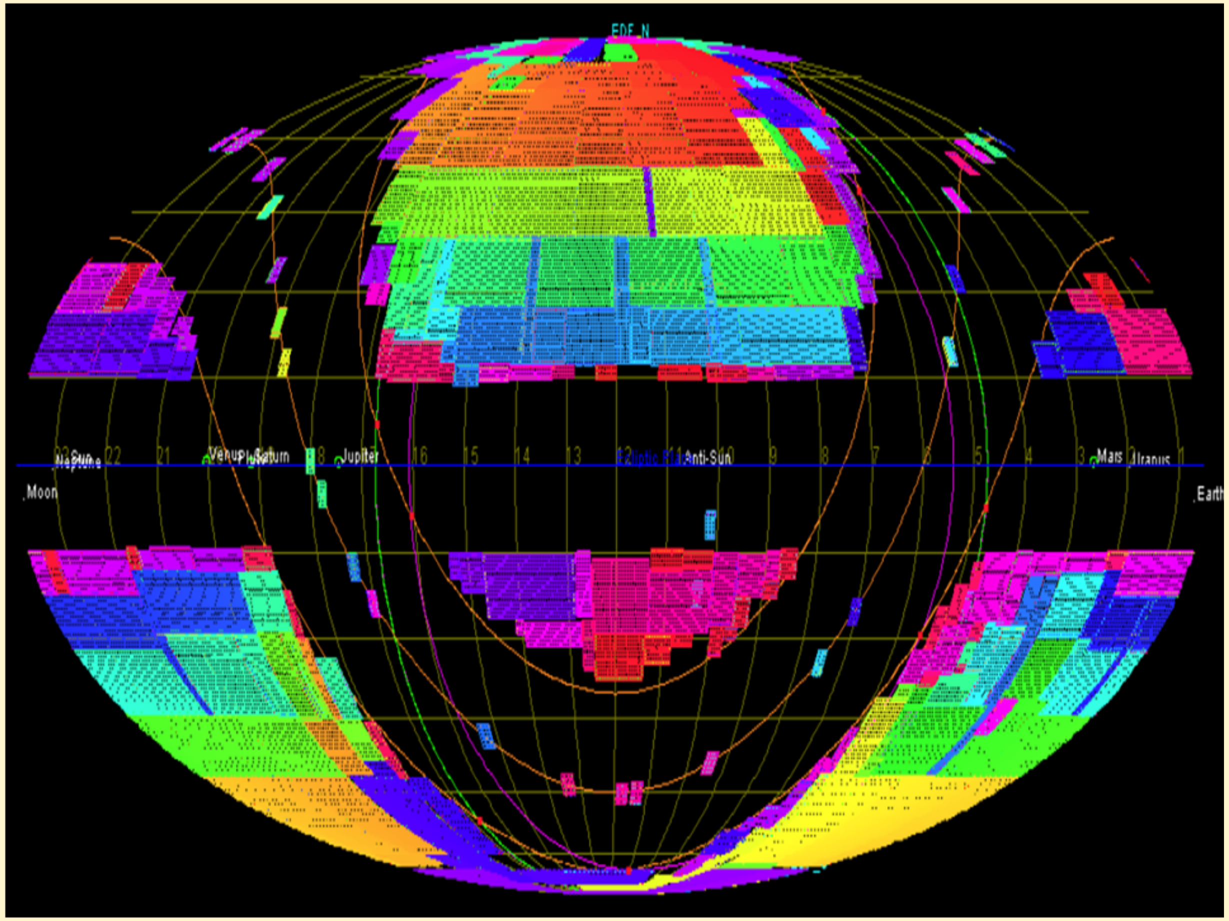
Three-point weak lensing statistics have been measured and shown to reduce statistical errors

2-point only	3-point only	2-point + 3-point



Semboloni et al. 2011
Also Fu et al 2014

Future surveys like Euclid will greatly reduce statistical errors …



15,000 deg^2

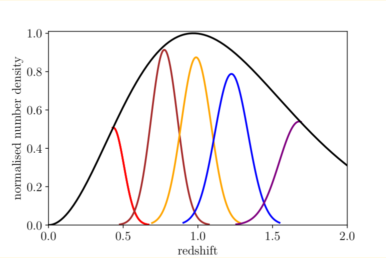
(current surveys eg KiDS 1,000 deg^2)

Shapes of > 1 billion galaxies for weak lensing

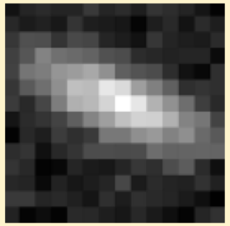
$0 < z < 2$

… but systematic errors will remain a major issue. Can three-point statistics help with these?

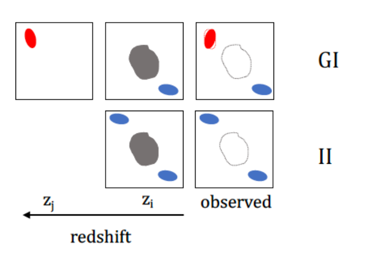
Redshift uncertainties



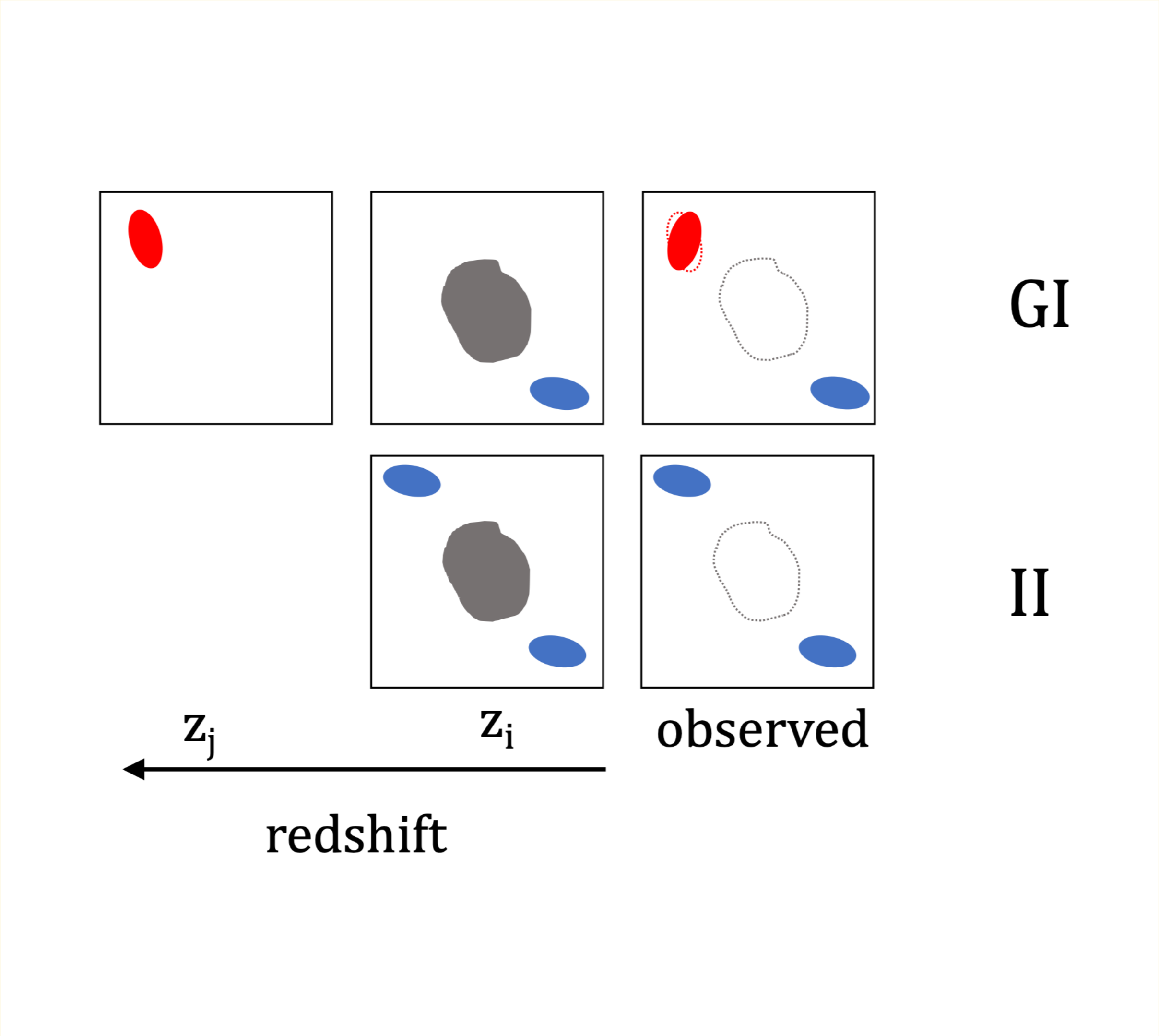
Multiplicative bias

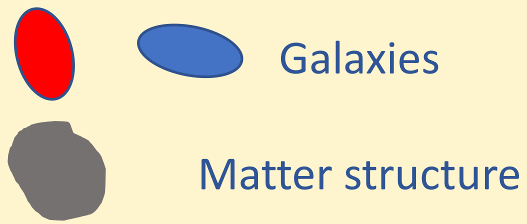


Intrinsic alignment of galaxies



Intrinsic alignment arises when galaxies are aligned with the matter field which also causes lensing



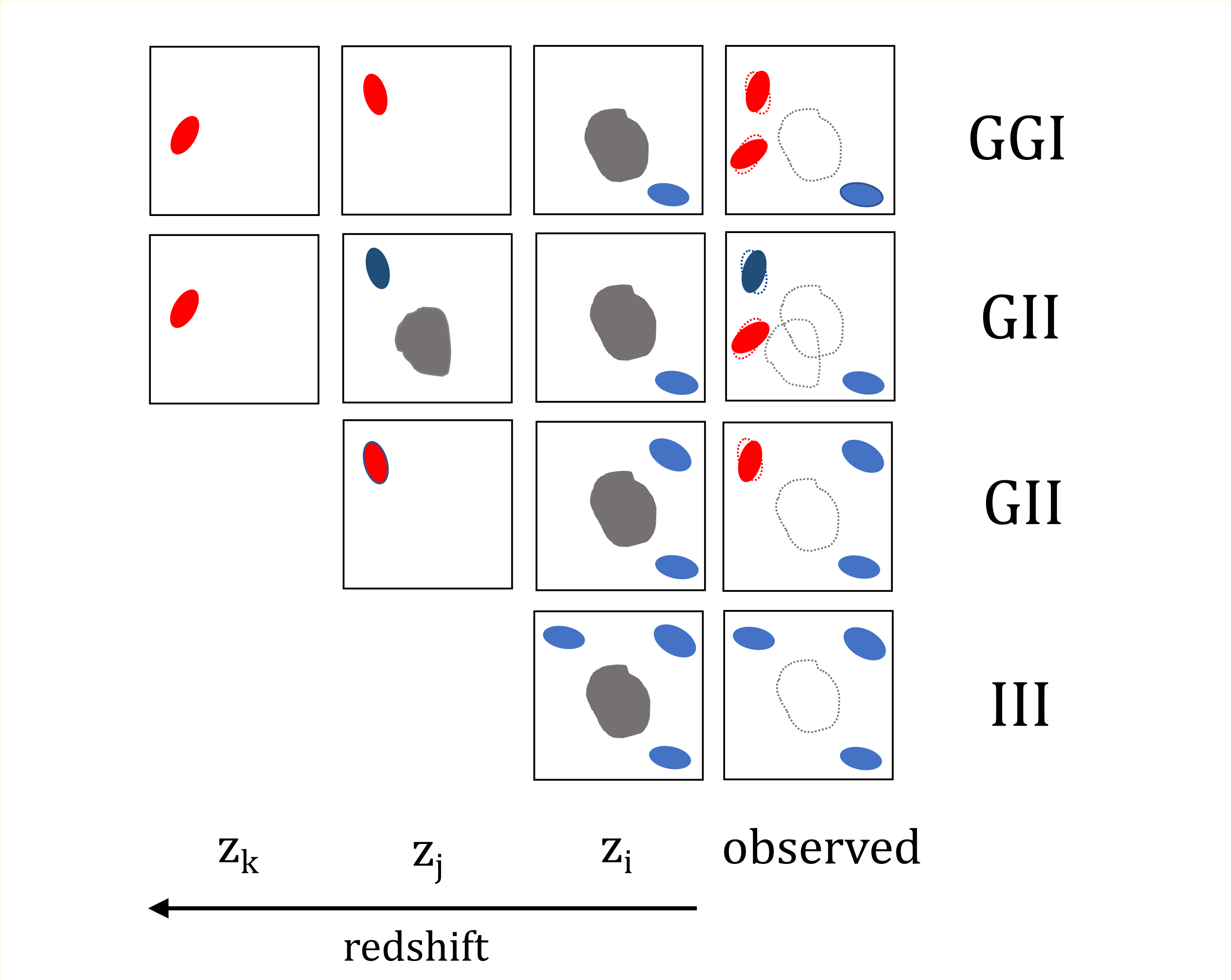


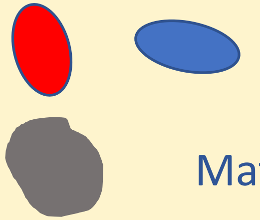
PS = GG+GI+II

lensing signal

Based on Troxel & Ishak 2015

Intrinsic alignment bispectra are more complex than power spectra





$$\boxed{\text{BS} = \text{GGG}+\text{GGI}+\text{GII}+\text{III}}$$

lensing signal

Based on Troxel & Ishak 2015

We made some simplifying modelling choices:

- *Euclid*-like survey but used only 5 tomographic bins (over whole redshift range)
- Bispectrum based only on equilateral triangles
- Only Gaussian and supersample terms of covariance
  (In-survey non-Gaussian terms are sub-dominant)
- Focus on $\Omega_{\rm m} - \sigma_8$ and $w_0 - w_a$ planes

We used standard Fisher matrix methods and figures of merit to quantify information content

Fisher matrix

$$F_{\alpha\beta} = \frac{\partial \mathbf{D}^{\mathrm{T}}}{\partial p_\alpha} \mathrm{Cov}_{\mathrm{D}}^{-1} \frac{\partial \mathbf{D}}{\partial p_\beta}$$

data vector – power spectrum only or power spectrum + bispectrum

Figure of merit

$$\mathrm{FoM}_{\alpha\beta} = \frac{1}{\sqrt{\det(\mathbf{F}^{-1})_{\alpha\beta}}}$$

cosmological parameters

We parameterise the systematic effects

Redshift uncertainties

$$p^{(i)}(z) = p^{(i)}_{\rm obs}(z - \Delta z_i)$$

5 free parameters Δz_i - one for each tomographic bin

eg Hikage et al 2019, Hildebrandt et al 2020

Multiplicative bias

$$\hat{\gamma}^{(i)} = (1 + m_i)\,\gamma^{(i)}_{\rm true}$$

Huterer et al 2006, Massey et al 2012

5 free parameters m_i

For intrinsic alignments we use the nonlinear alignment model

Fourier transform of field which produces IA

$$\tilde{\delta}_{\mathrm{I}} = f_{\mathrm{IA}} \tilde{\delta}_{\mathrm{G}}$$

matter density contrast

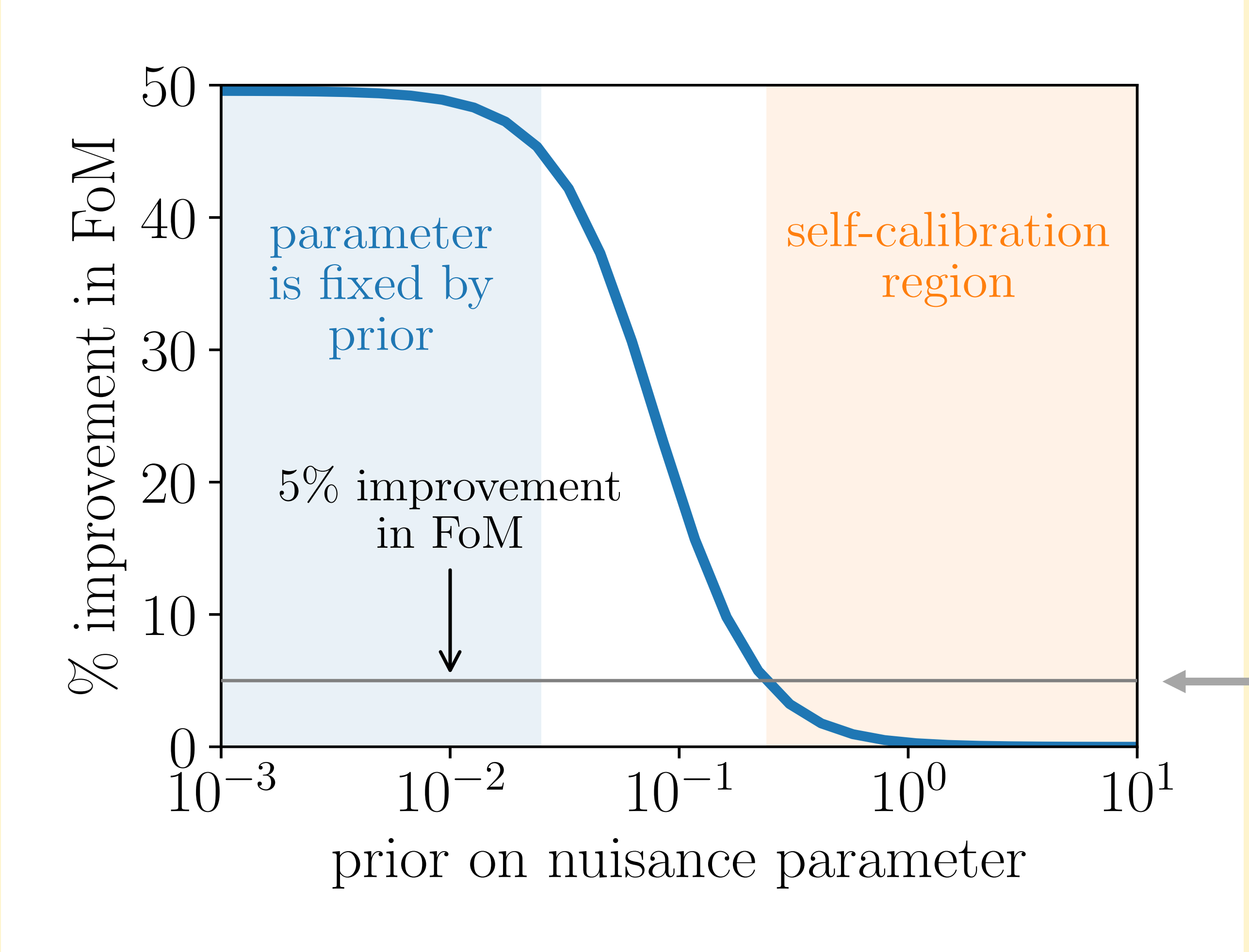
$$f_{\mathrm{IA}} = -A_{\mathrm{IA}} \frac{C_1 \bar{\rho}}{(1+z)D(z)} \left(\frac{1+z}{1+z_0} \right)^{\eta_{\mathrm{IA}}}$$

2 free parameters – amplitude A_{IA} and redshift dependence η_{IA}

Hirata & Seljak 2004, Bridle & King 2007

Then consider how the FoM varies as the prior on a nuisance parameter changes

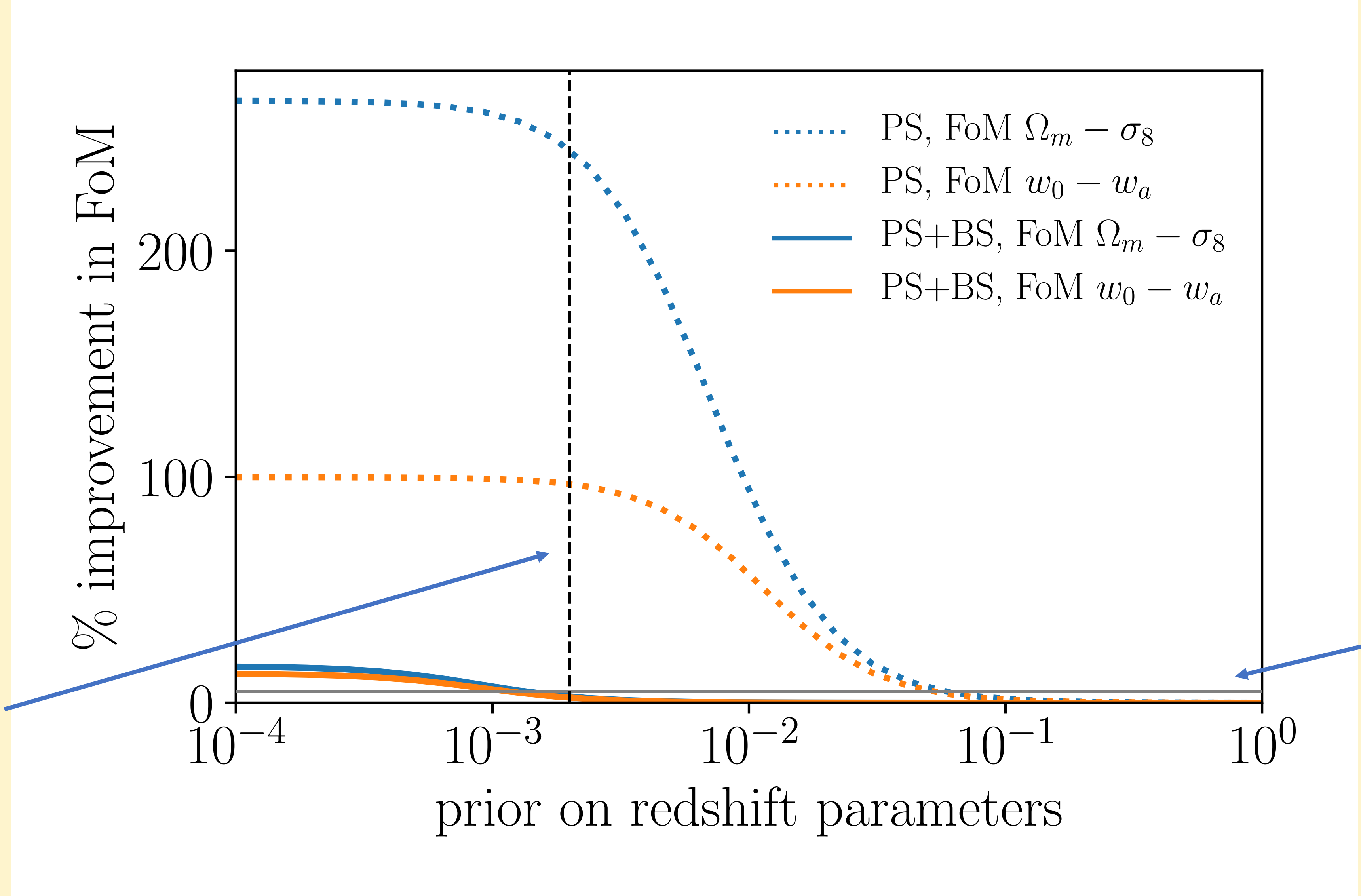
small step is good



chosen definition of self-calibration

low self-calibration point is good

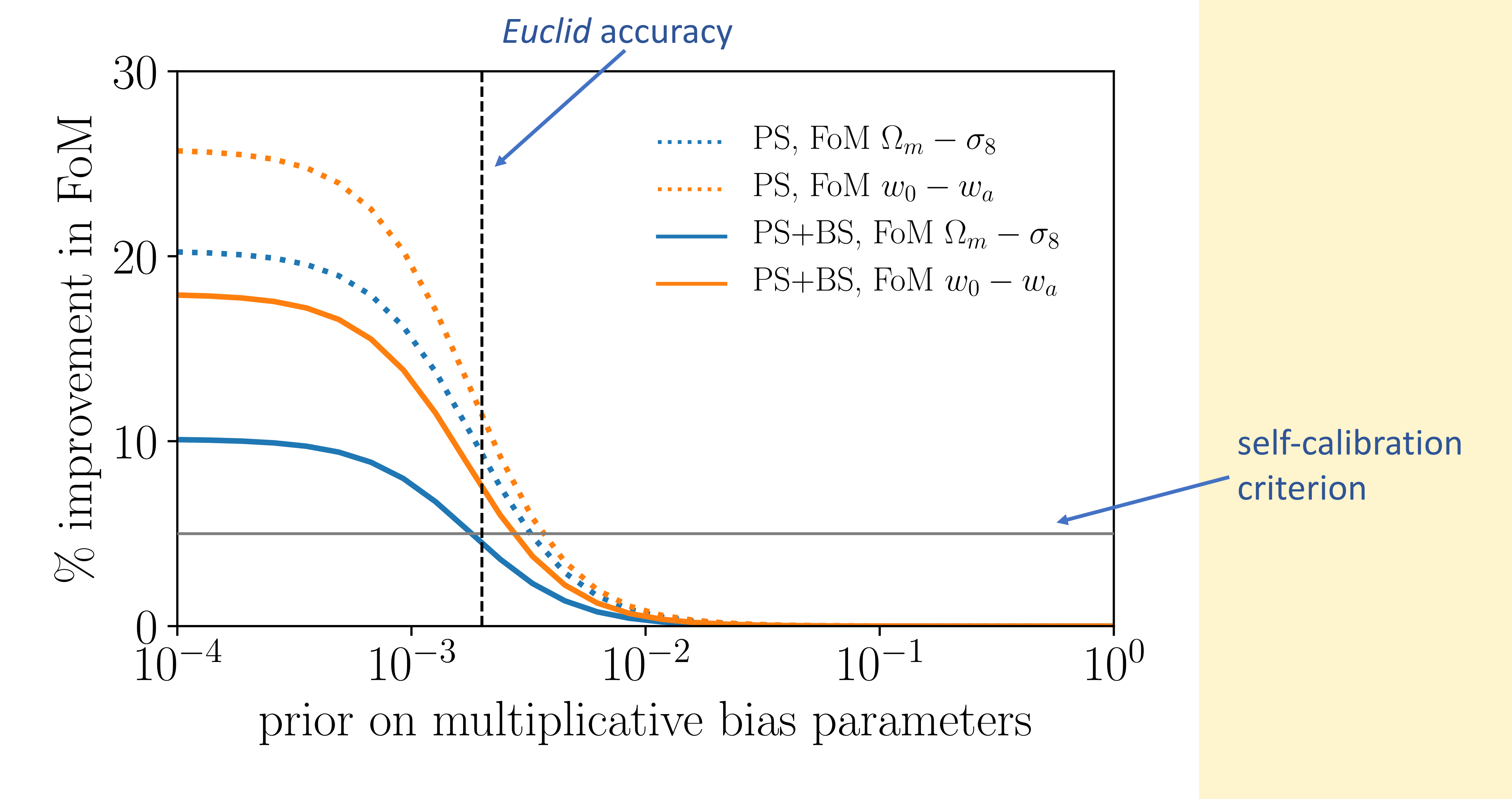
Results – redshift uncertainty



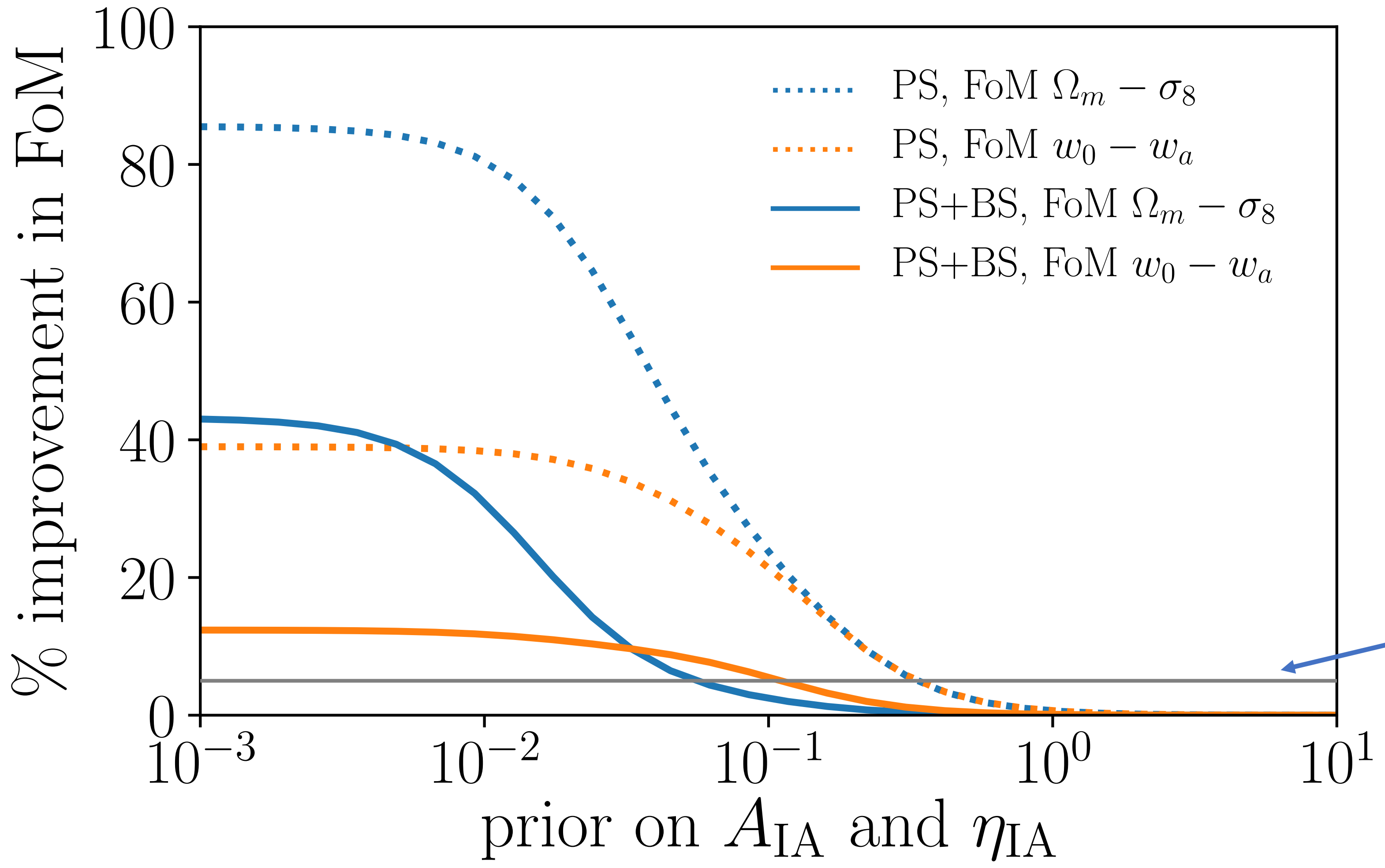
Euclid accuracy

self-calibration criterion

Results - multiplicative bias

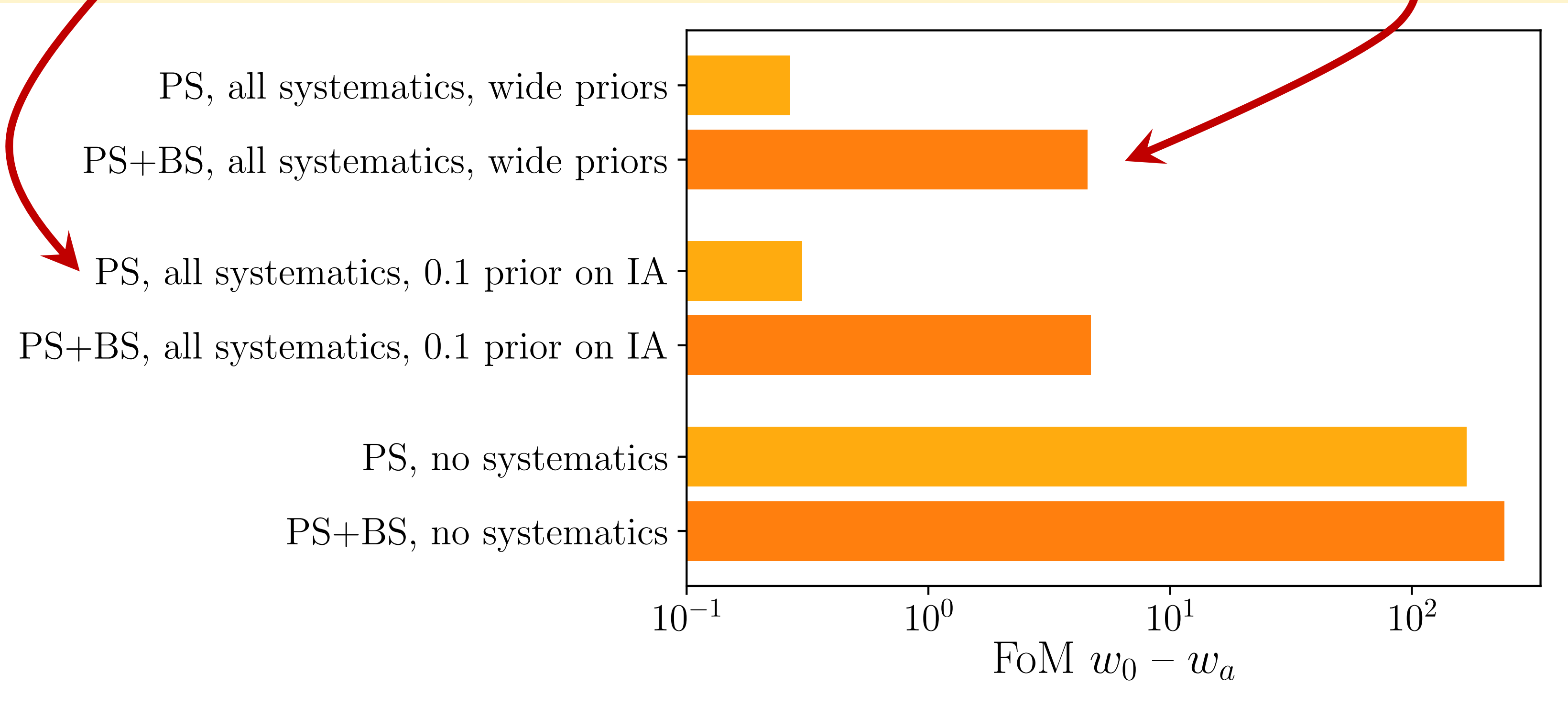


Results – intrinsic alignments



self-calibration criterion

Another way to look at this: compare PS with tight prior with self-calibration using PS+BS



Example: $w_0 - w_a$ FoM and intrinsic alignments

The results are promising, but need further work

- Verify the intrinsic alignment model, especially for three-point statistics
- Consider more practical estimators, for example aperture mass statistics
- Go to smaller scales, consider baryonic effects

Summary

- Systematics are a key challenge for next-generation weak lensing surveys

- Systematics affect the power spectrum and bispectrum differently

- Results suggest that using the bispectrum can allow self-calibration to mitigate systematics

- Hopefully this will lead to a practical alternative method for future surveys – but more work needed first!