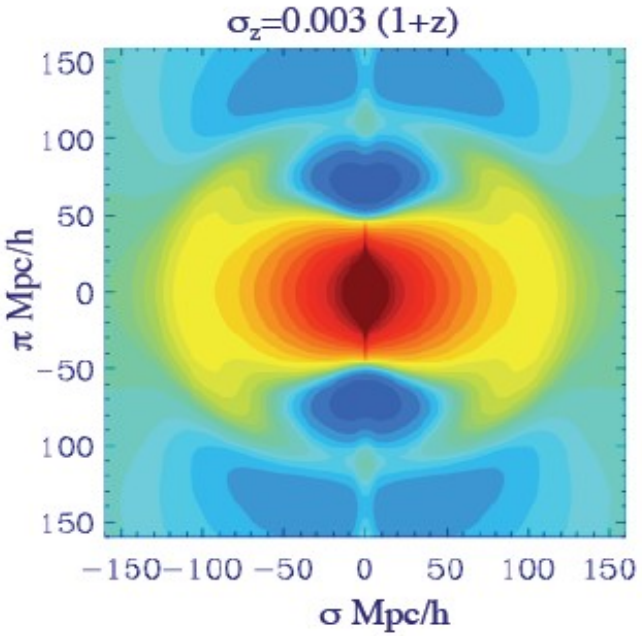
DES & DESpec:
Cross-correlation of WGL & RSDs



Donnacha Kirk
Imperial College London
Ofer Lahav, Sarah Bridle, Filipe Abdalla, Stephanie Jouvel

DES & DESpec:
Cross-correlation of WGL & RSDs

- Combination of DES (WL) & DESpec (LSS).

- Unified projected Cls framework including cross-correlations.

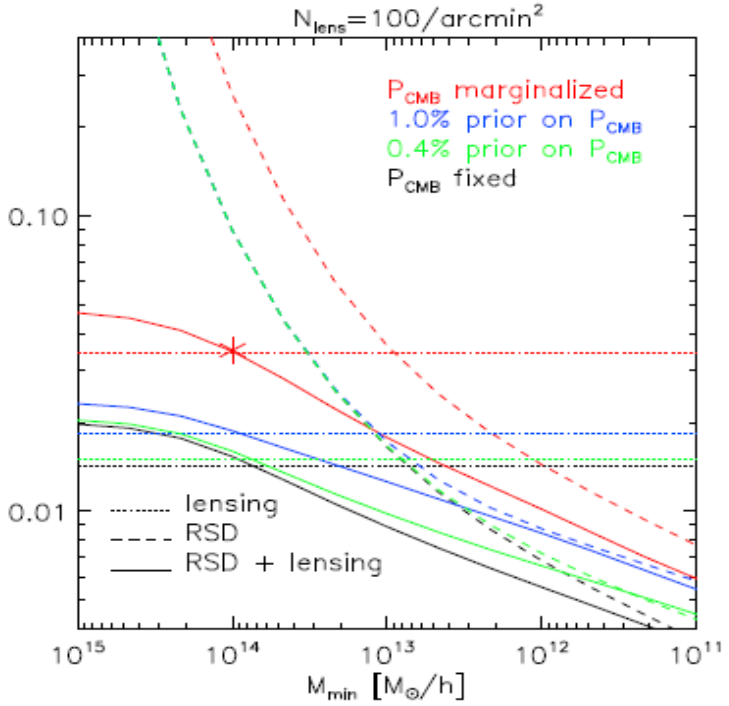
- Different Sky vs. Same Sky.

- Impact of assumptions on Galaxy Biasing, Correlation Coefficient.

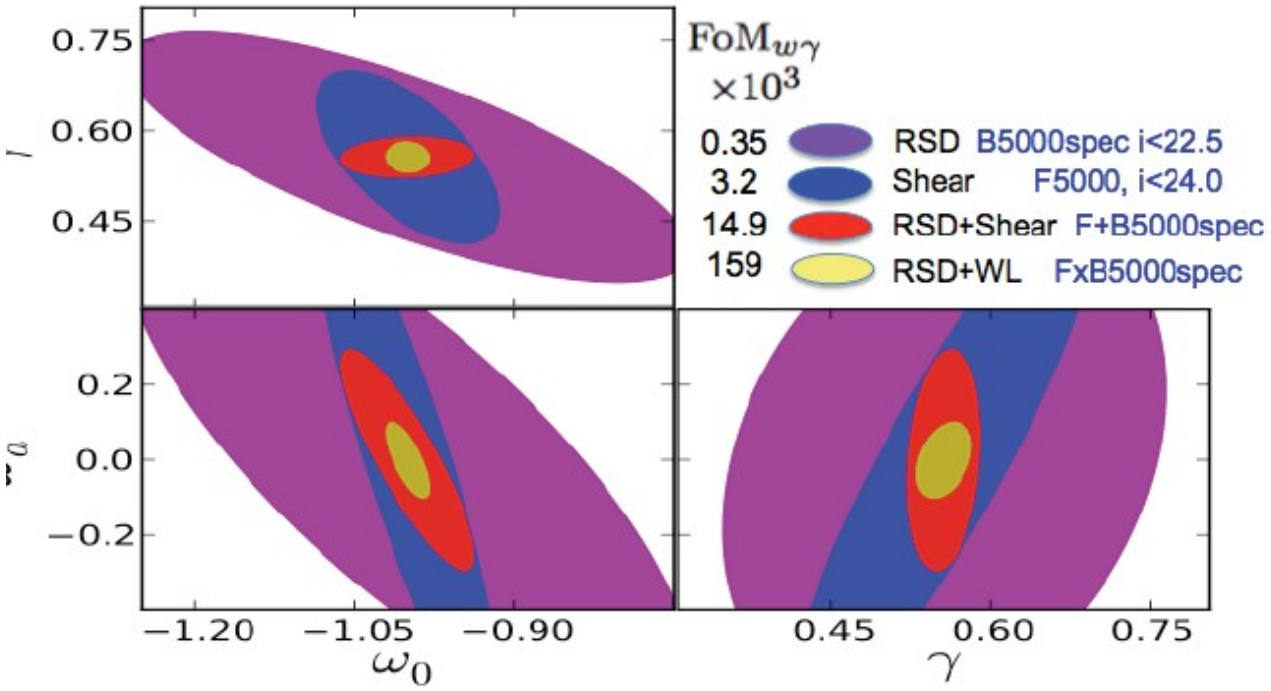
- Impact of Target Selection- initial results.

- Future work.

Exciting Work on Photo-z + Spec-z



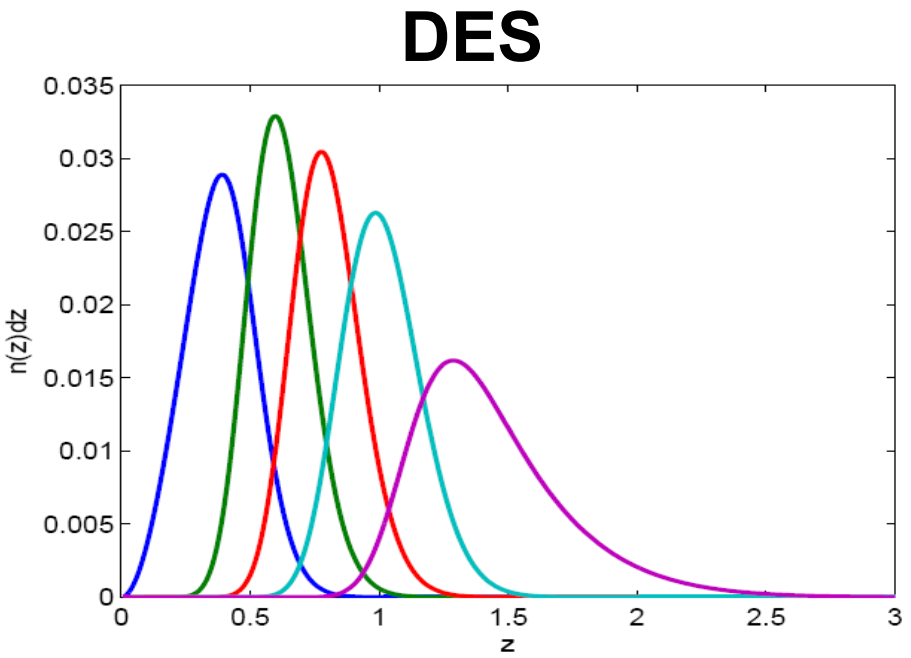
Cai & Bernstein 2011 1112.4478
Bernstein & Cai 2011 1104.3862

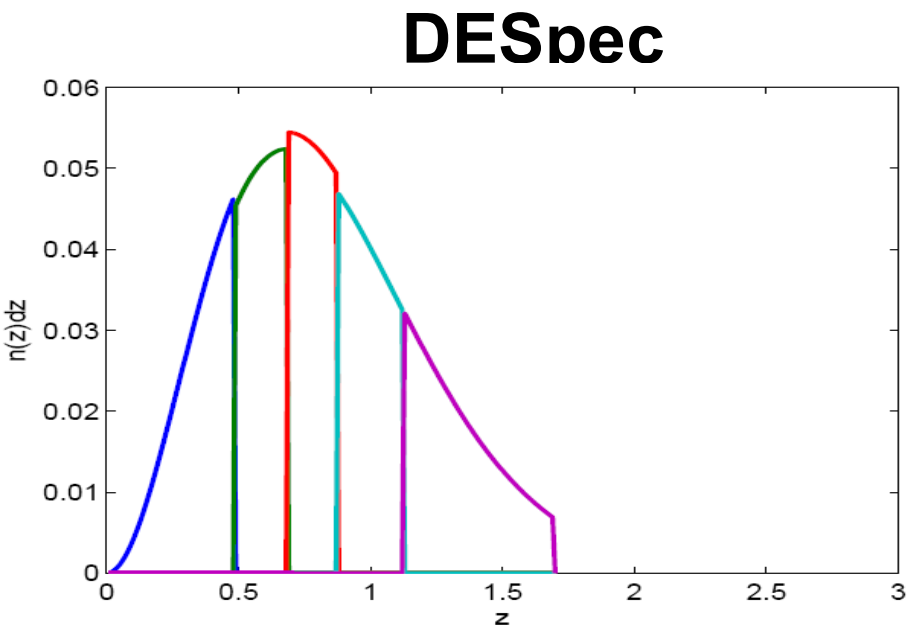


Gaztanaga et al. 2011 1109.4852

- Shear-shear, galaxy-galaxy, galaxy-shear for transverse modes.
- P(k) RSD for non-transverse modes added independently.
- Combining the probes is very useful.
- Same sky aids the control of bias etc → improves x 1.5 → 9+

A Unified Cls Approach





- Shear-shear from a DES-type photometric survey.

- Galaxy-galaxy from a DESpec-type spectroscopic survey including RSDs (Fisher et al. 1993, Padmanabhan et al 2006).

- Galaxy-shear cross-correlations.

$$C_l^{nn} = \int \frac{2}{\pi} k^2 P(k) dk \int d\chi n(\chi) D(\chi) b_g(\chi) j_l(k\chi) \int d\chi' n(\chi') D(\chi') b_g(\chi') j_l(k\chi')$$

A Unified Cls Approach

- Different Sky: 2 observables.

$$C_l^{\gamma\gamma} \quad C_l^{nn}$$

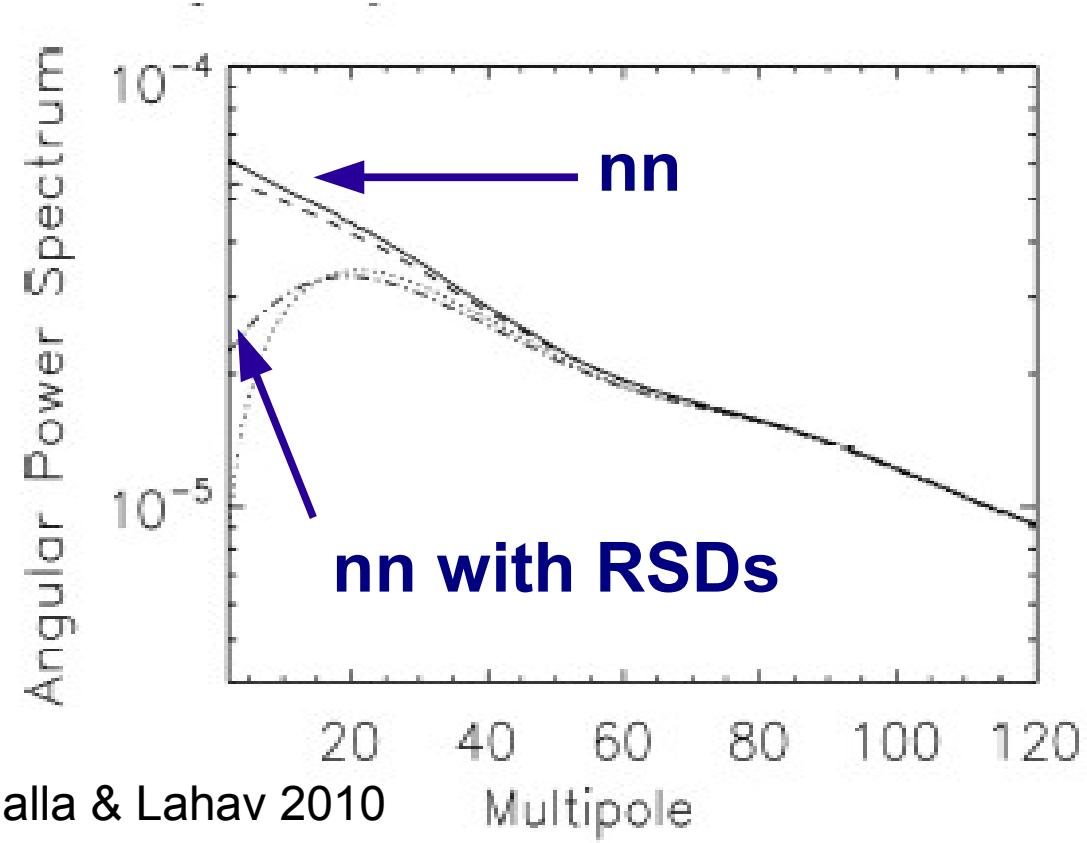
- Same Sky: 3 observables & their correlations.

$$C_l^{\gamma\gamma} \quad C_l^{nn} \quad C_l^{n\gamma}$$

- Beyond Limber
- One, unified formalism.
- Includes cross-correlations naturally.
- Beyond Limber.

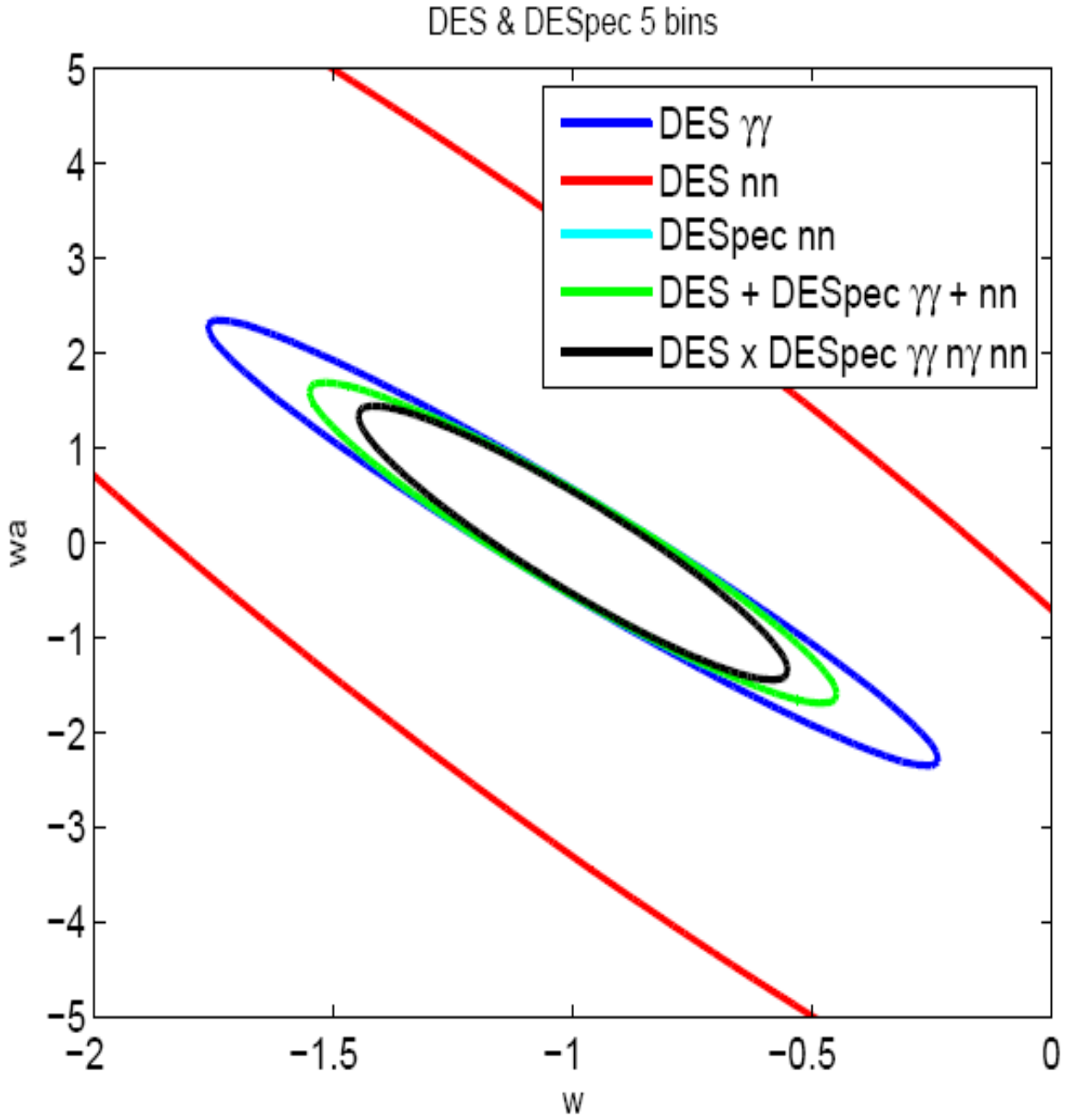
- Projection loses info, z-bins crucial, many z-bins is computationally expensive.

$$\mathrm{Cov}(\ell) = \left(\begin{array}{c|c|c} \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon n\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon nn}(\ell) \\ \hline \mathrm{Cov}^{(ijkl)}_{n\epsilon\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{n\epsilon n\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{n\epsilon nn}(\ell) \\ \hline \mathrm{Cov}^{(ijkl)}_{nn\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{nn n\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{nnnn}(\ell) \end{array}\right)$$



Thomas, Abdalla & Lahav 2010

Weak Priors on b_g, r_g



- Marginalising over cosmology and >20 nuisance parameters.
- DESpec alone is weak.
- DES + DESpec: 50% improvement on DES shear-shear for different sky.
- DES x DESpec: **25% improvement** on top for same sky.

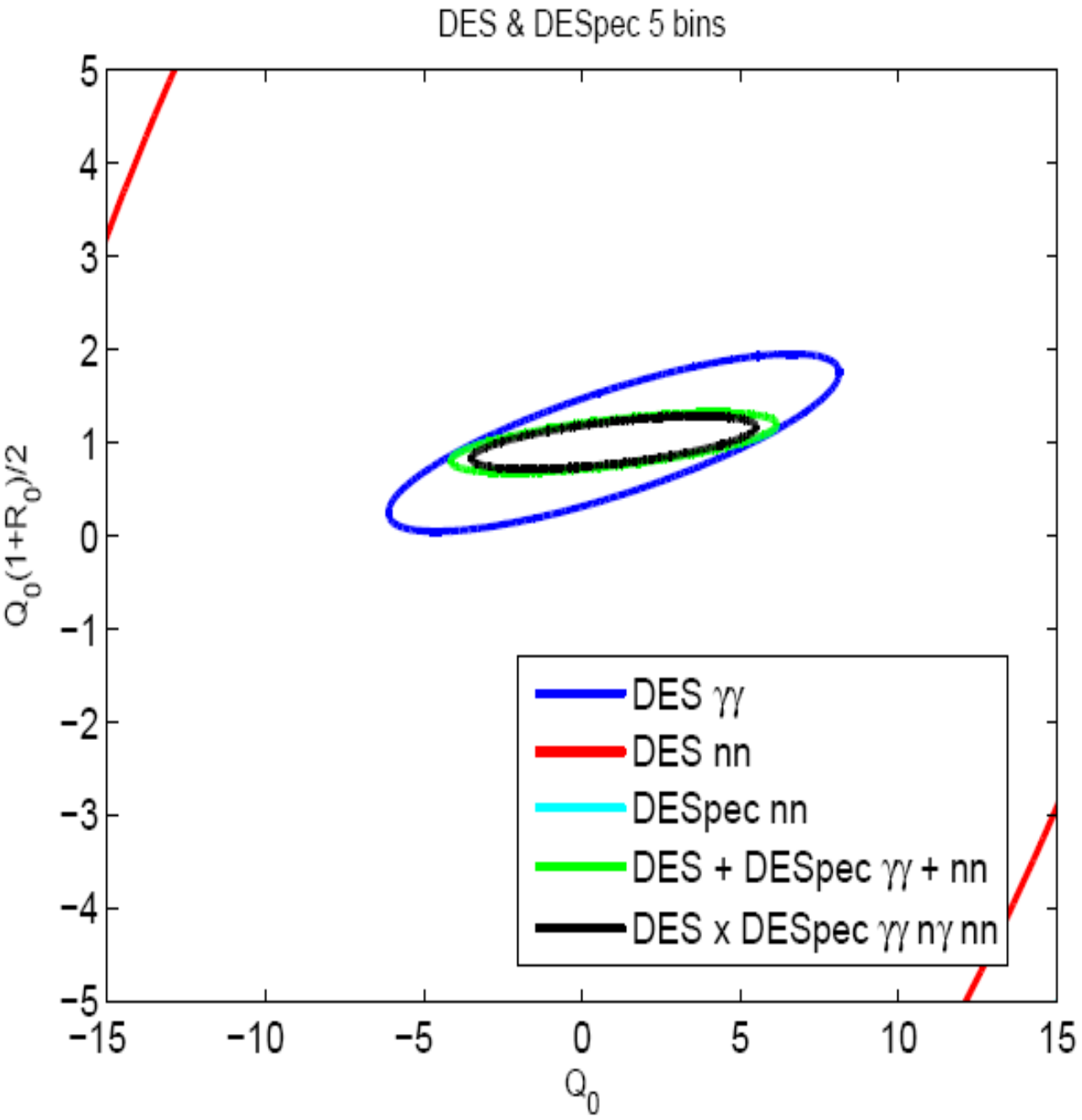
Weak Priors on b_g, r_g

$$k^2\Phi = -4\pi Q a^2 \rho\delta$$

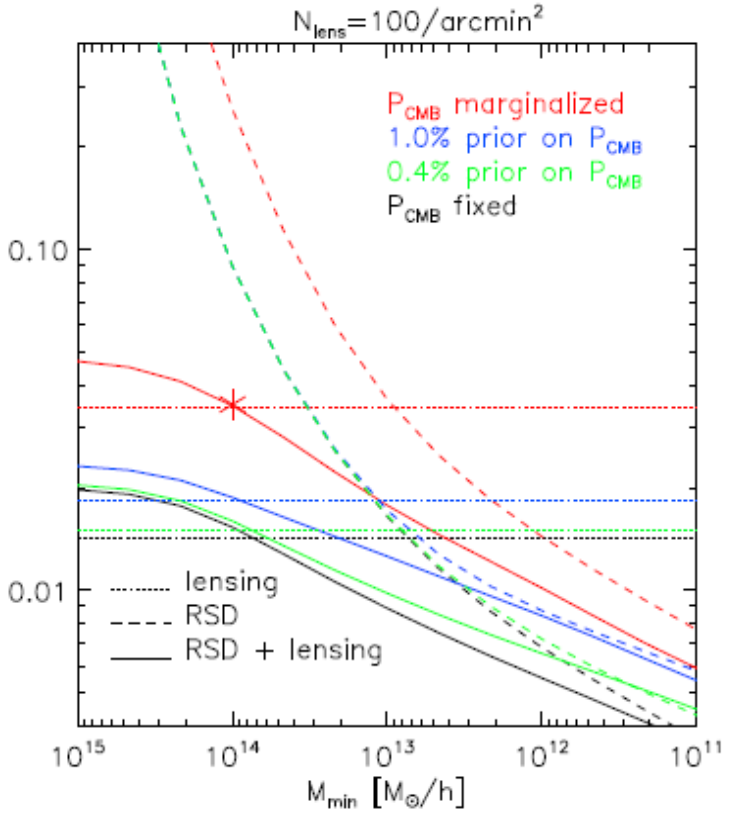
$$\Psi = R\Phi$$

- DES + DESpec:
  x 3+ improvement for different sky-**degeneracy breaking**.

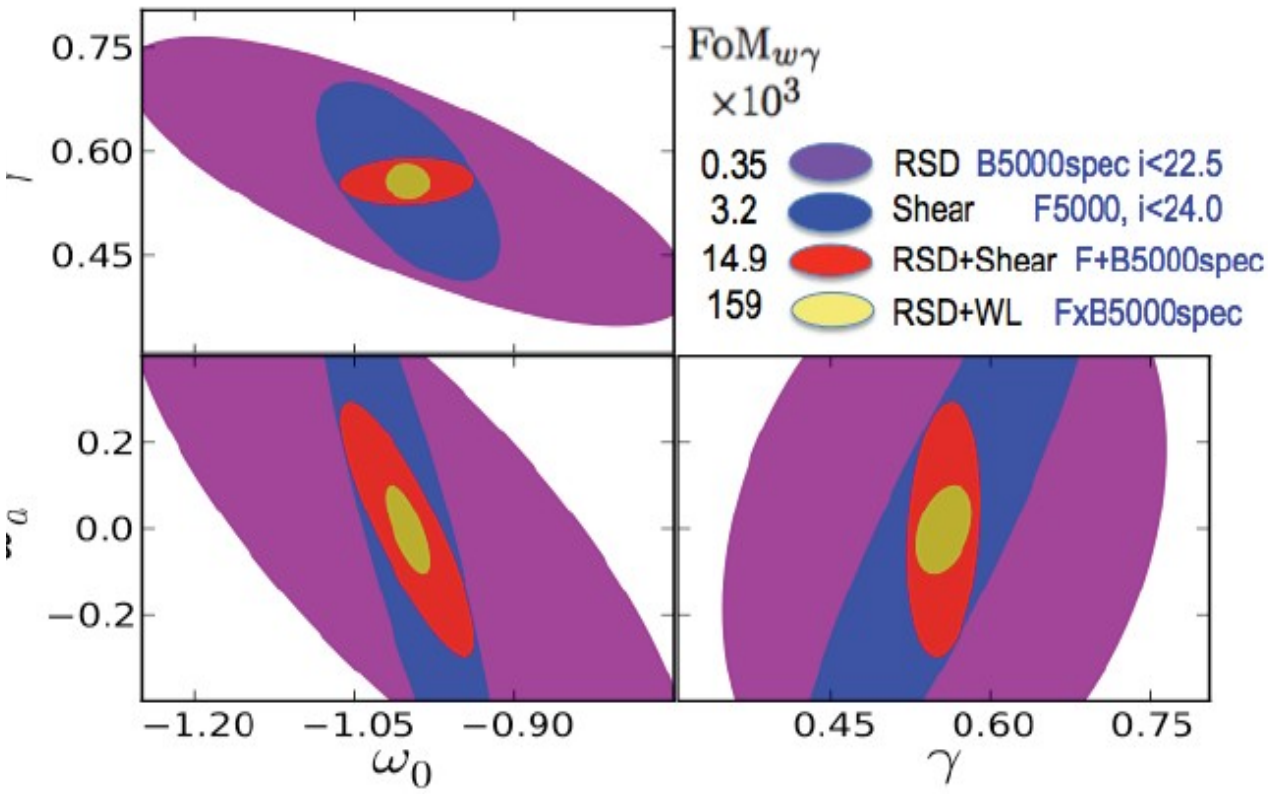
- DES x DESpec:
  25% improvement on top for same sky.



Reminder of Other Results



Cai & Bernstein 2011 1112.4478
Bernstein & Cai 2011 1104.3862



Gaztanaga et al. 2011 1109.4852

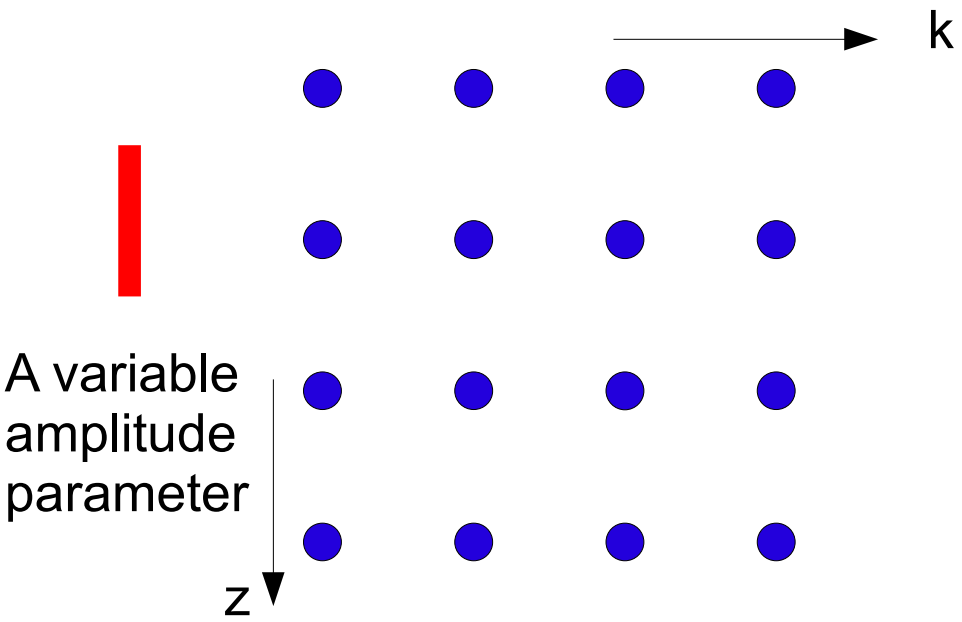
- Some disagreement, particularly on the impact of same-sky.
- My basic results are on the low-improvement side.
- Exploration of prior assumptions is crucial.

Treatment of bias, cross-correlation

$$C_l^{\gamma\gamma}$$

$$C_l^{nn}\ b_g = A_{b_g} Q_{b_g}(k,z)$$

$$C_l^{n\gamma}\ r_g = A_{r_g} Q_{r_g}(k,z)$$



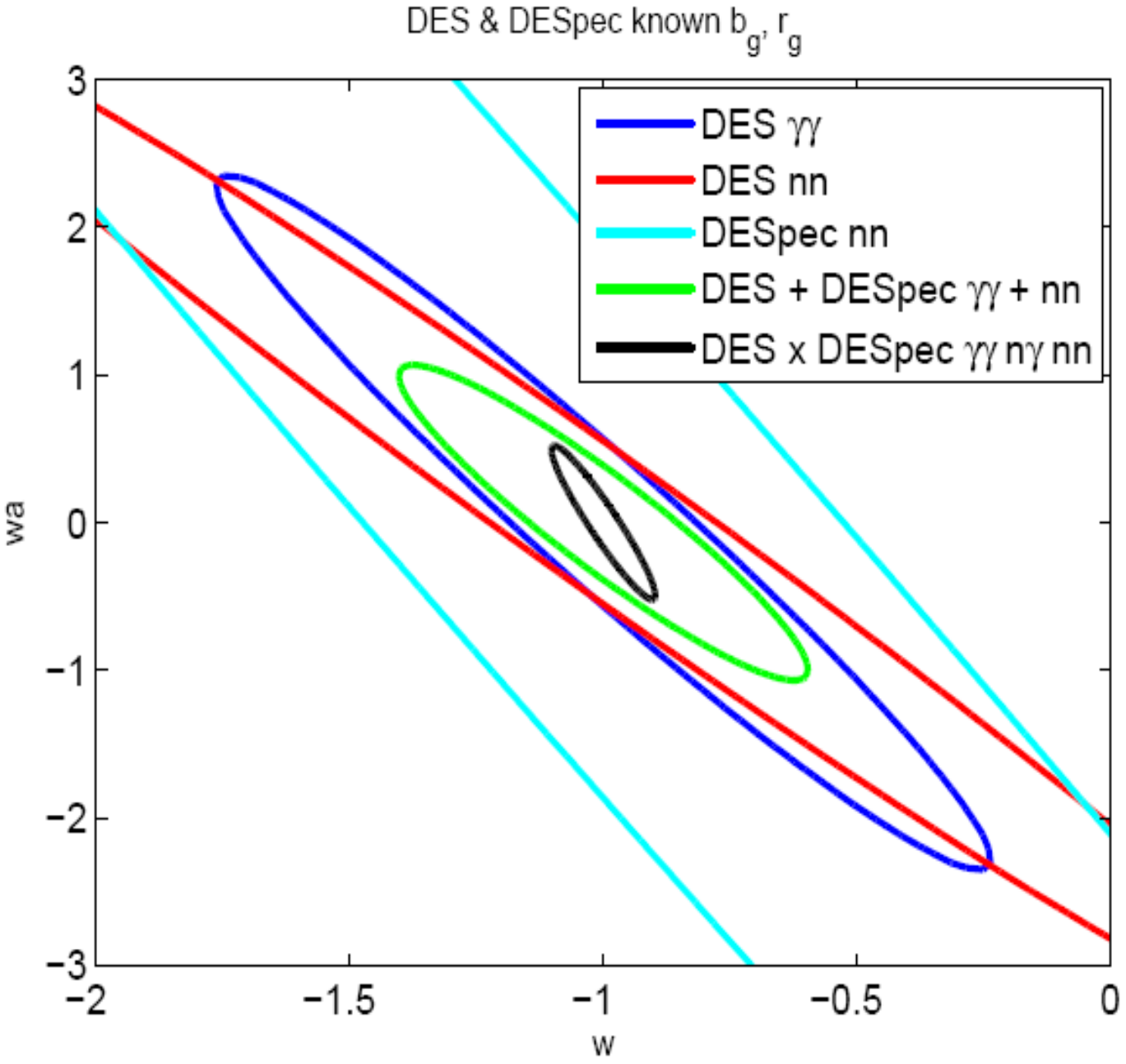
- Allow galaxy bias (bg) and cross-correlation coefficient (rg) to vary independently.

- Each has an amplitude & a grid of nuisance parameters in k/z-space.

- >20 nuisance parameters, weak priors → Robust, conservative, not necessarily realistic.

- Details of this can throw light on the literature.

Strong Priors on b_g, r_g



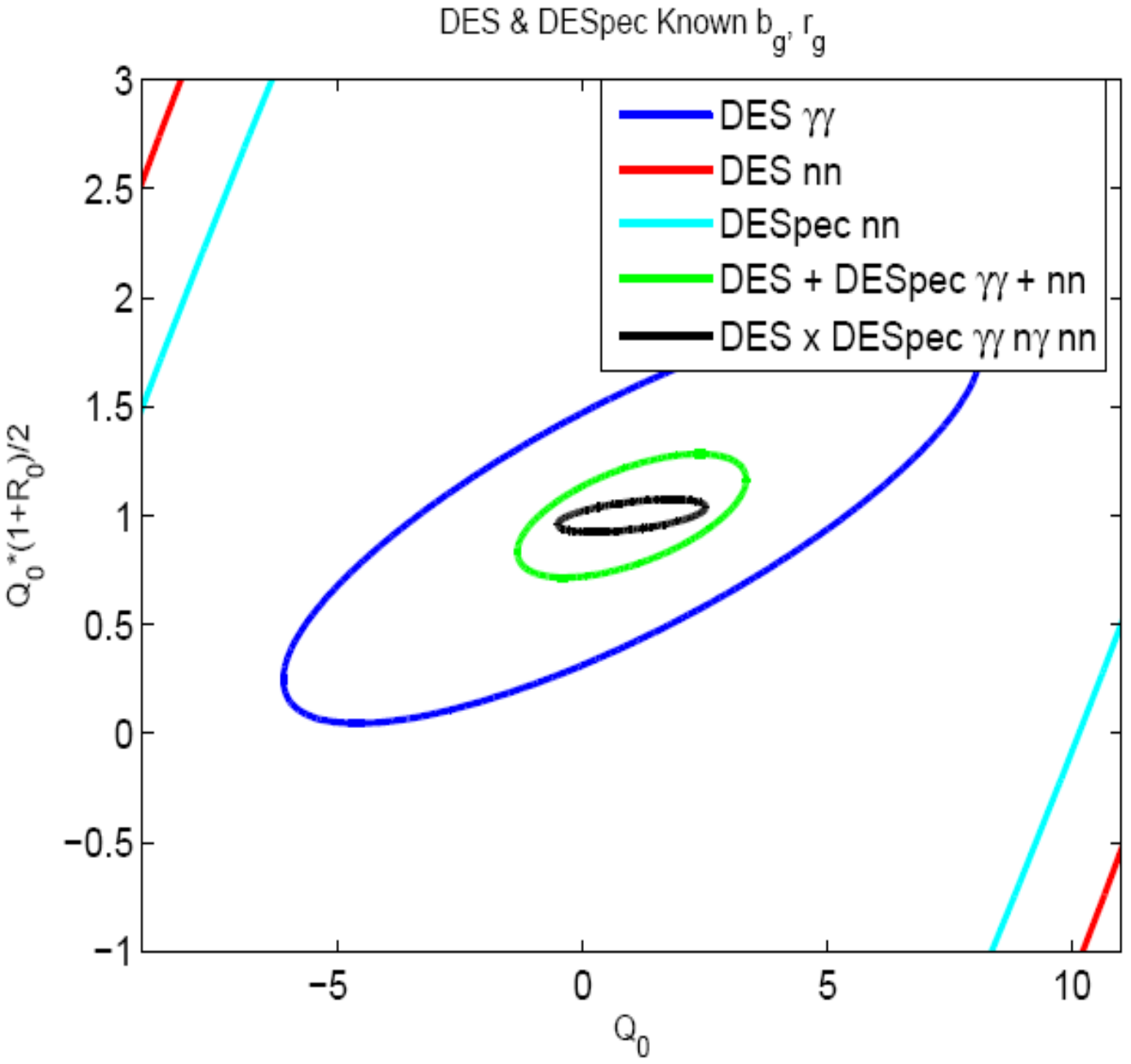
- DES + DESpec: x 3 improvement for different sky.
- DES x DESpec:
  - **x 9 improvement** on going to same sky.
- Still much to explore- treatment of magnification, LSS from photo-z survey etc.

What happens if we know bias exactly

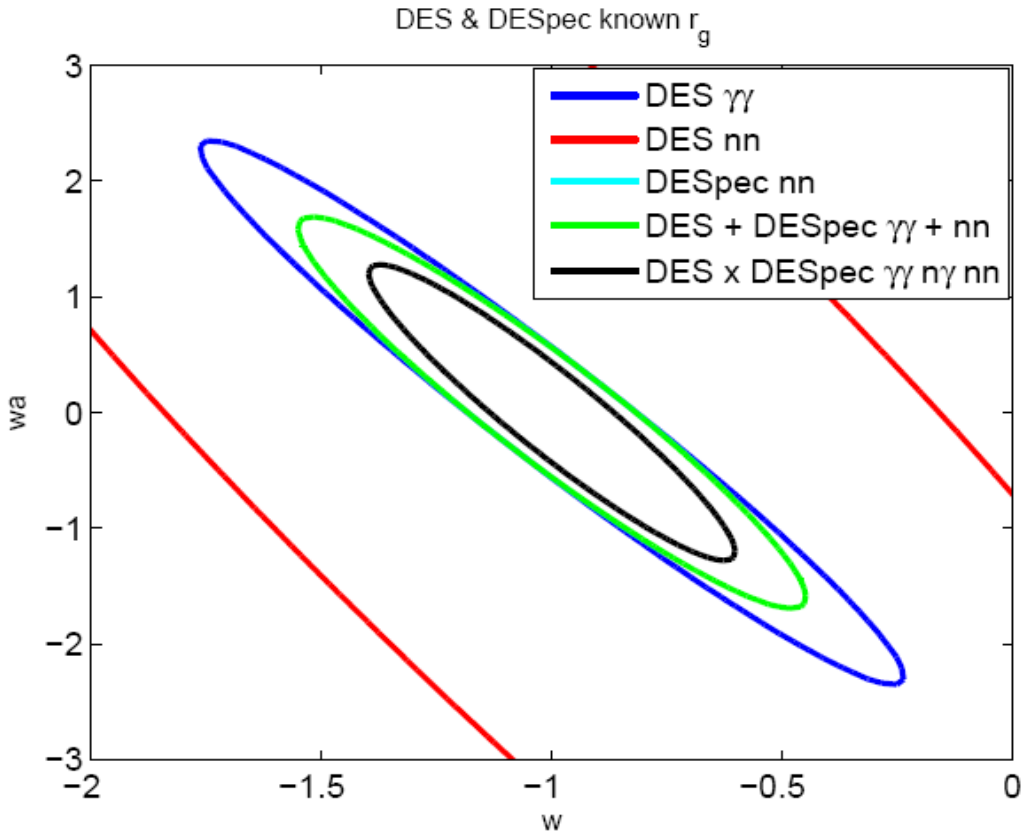
- Modified gravity sees huge benefit from combining probes.

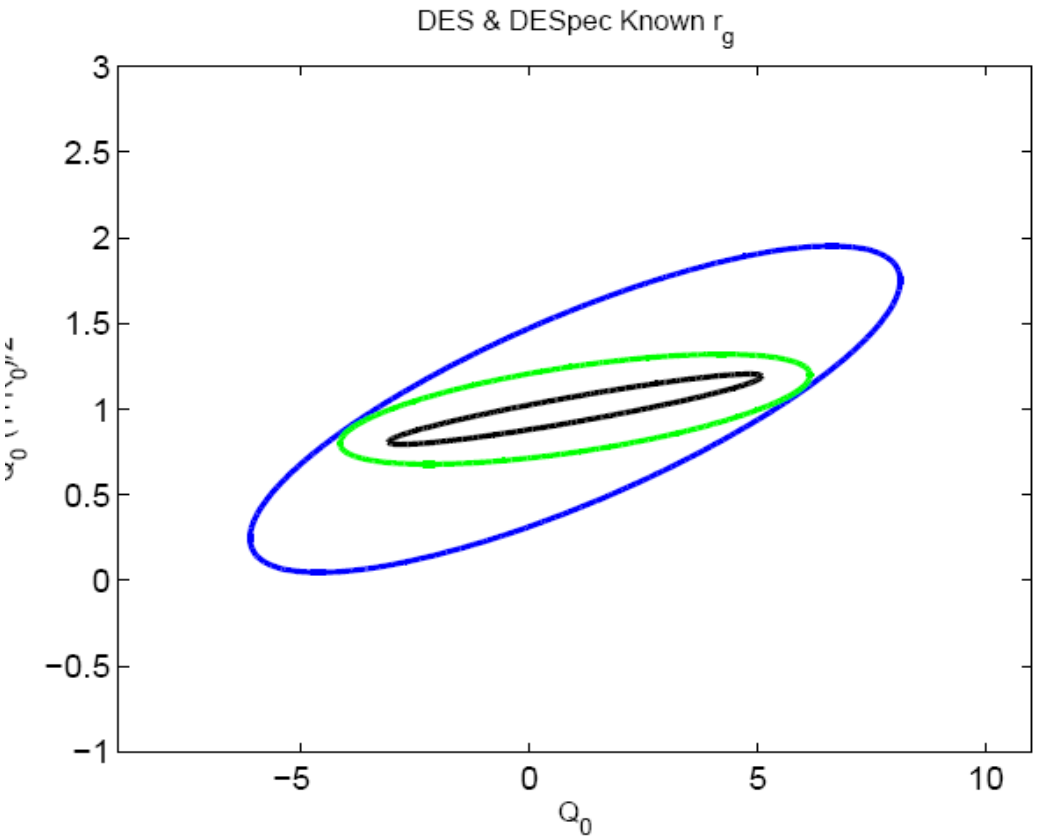
- DES + DESpec: **x 8 improvement** on DES shear-shear alone.

- DES x DESpec: **x 6 improvement** from going to same sky.



Strong Prior on r_g



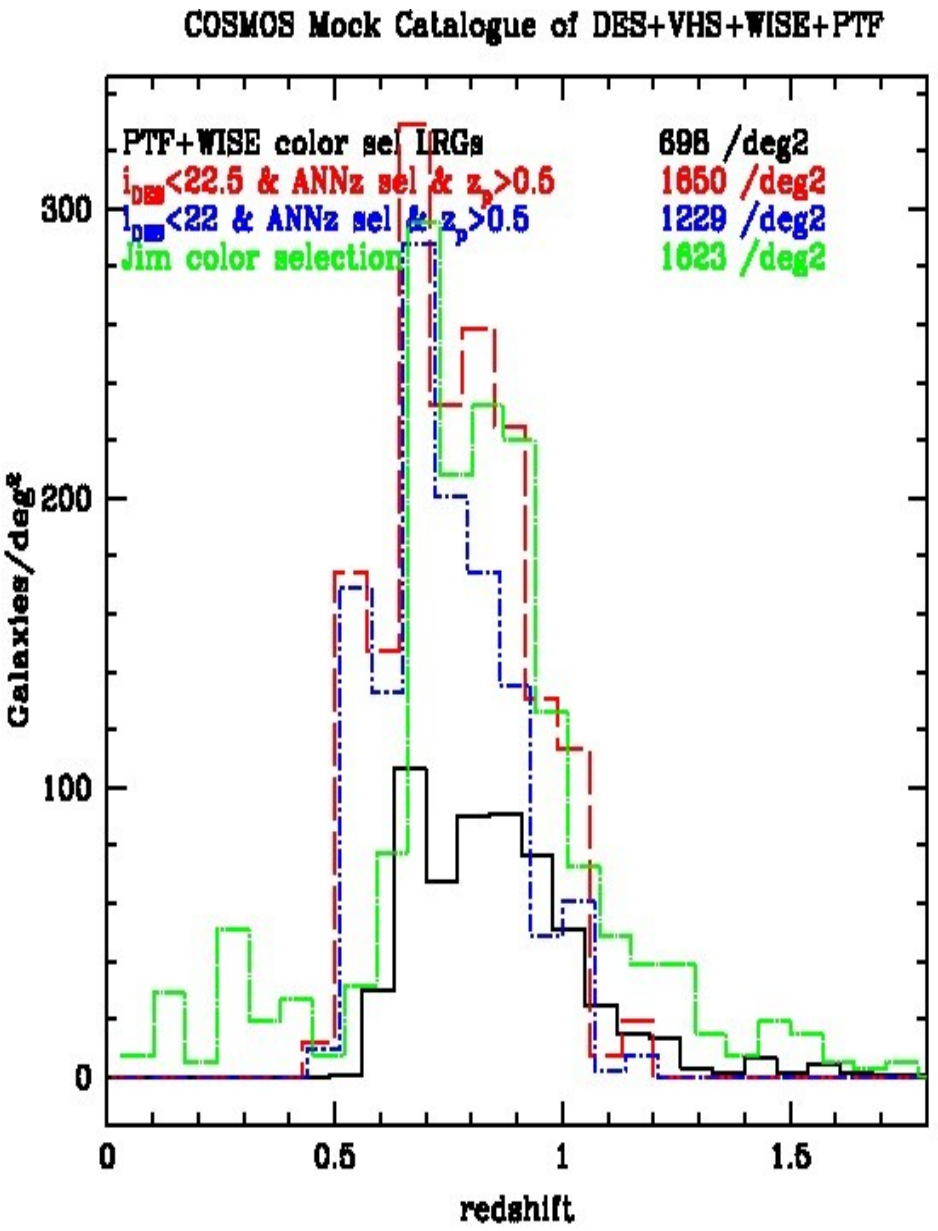


- Knowing r_g well retains a lot of the same-sky improvement, especially for MG, even when marginalising over robust bias model.

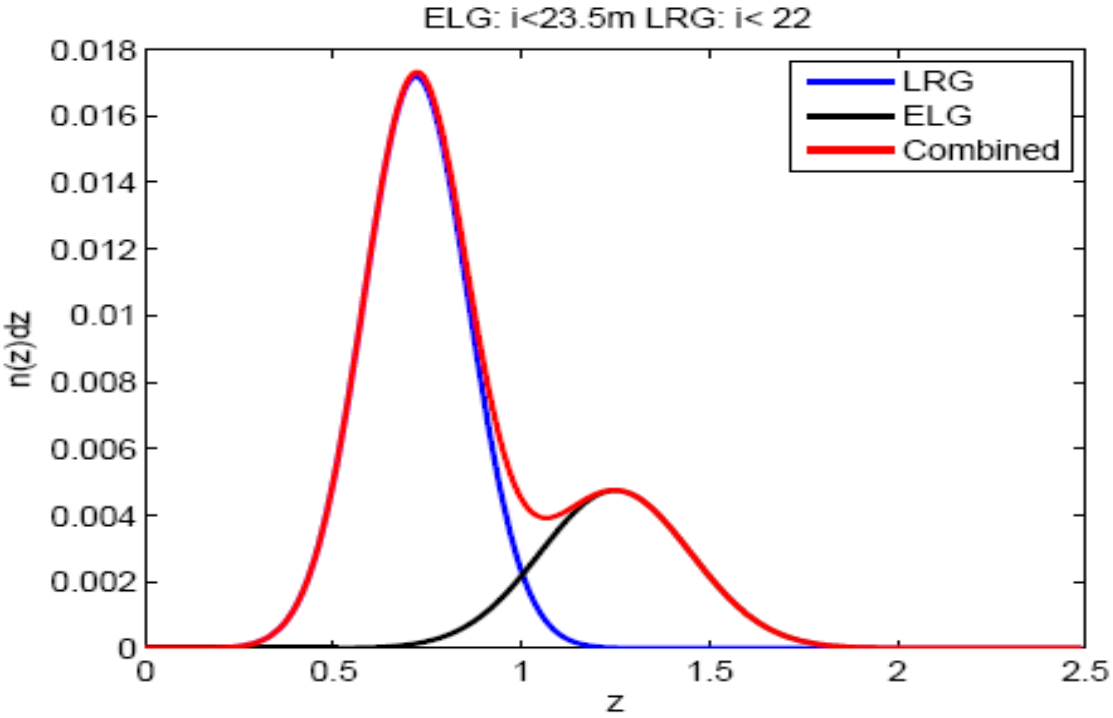
- Can we motivate this from linear bias on scales of interest?

- Lots more detail to do on bias modelling, nonlinear scales etc.

Models



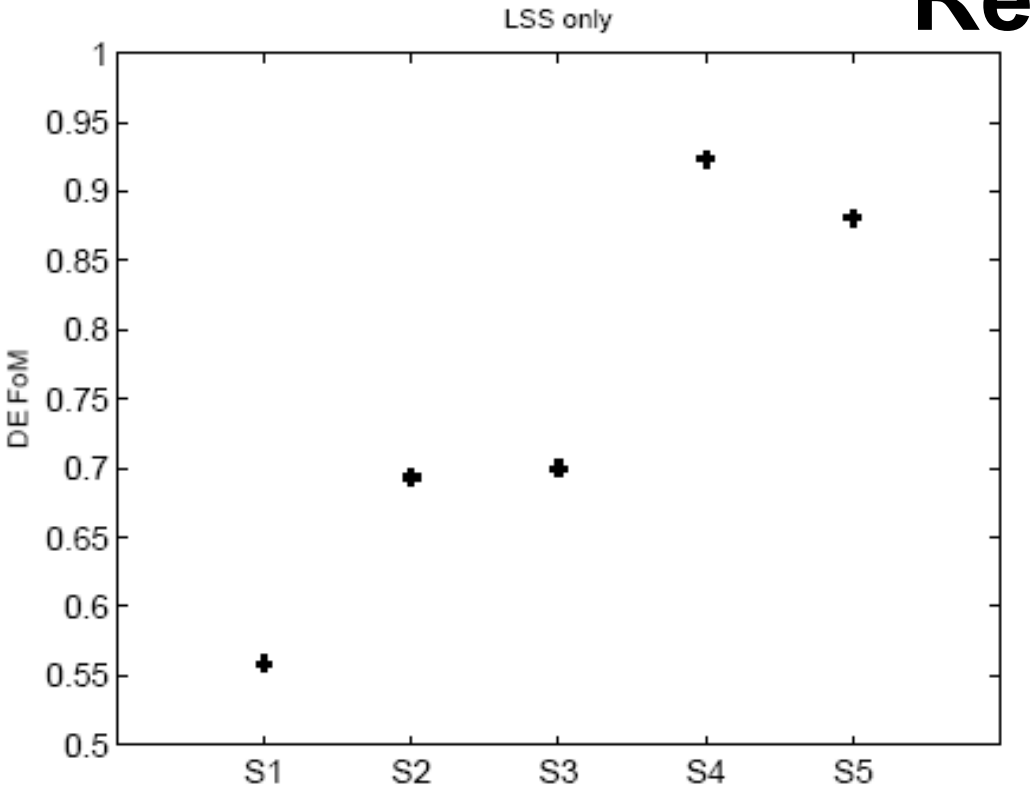
- Some realistic target selection scenarios.
- ELGs, LRGs treated separately.
- Produce aggregate n(z) distributions.
- Trade off depth/area.
- Trade off ELG/LRG.

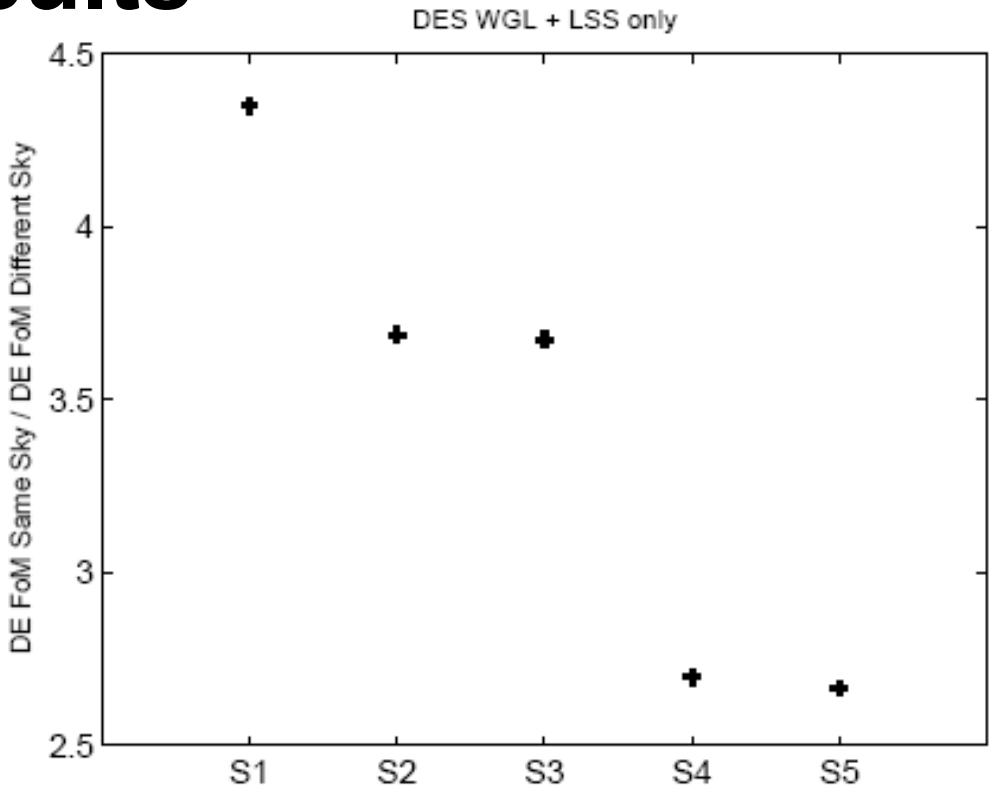


Models

- Assume ~300 nights, 4000 fibres over 3deg^2
  - Scenario 1: 5000 deg^2, 33% LRG 67%ELG
  - Scenario 2: 7500 deg^2, 25% LRG 75%ELG
  - Scenario 3: 7500 deg^2, 50% LRG 50%ELG
  - Scenario 4: 15000 deg^2, 67% LRG 33%ELG
  - Scenario 5: 15000 deg^2, 33% LRG 67%ELG
- Trade off area/depth.
- These scenarios are a simple proof of concept- we can be much more ambitious- include different selection functions, power as a function of redshift, target selection as a function of redshift etc.
- See talk by Stephanie Jouvel tomorrow for more info.

Results





- Our (simple) family of DESpec scenarios can produce factor of 2 differences in FoM.

- What a scenario can achieve on its own vs. with e.g. DES shear-shear are different questions.

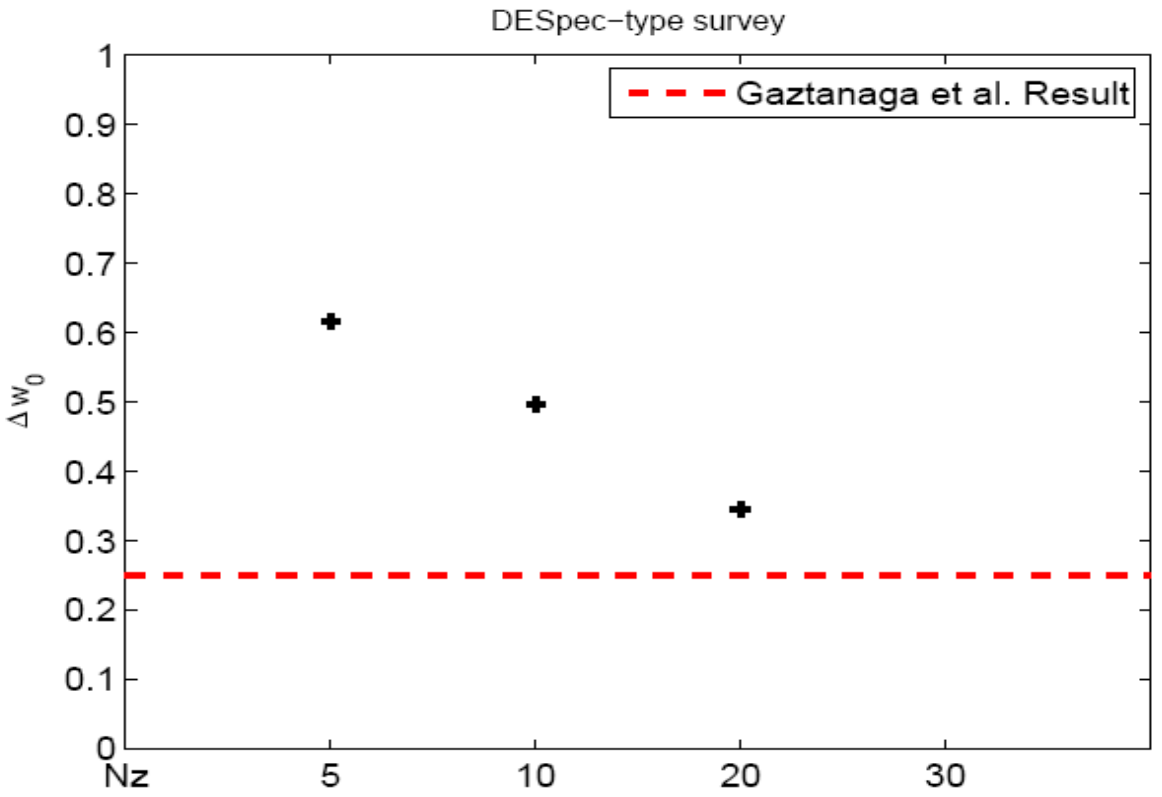
- See talk by Stephanie Jouvel tomorrow for more info.

Future Work

• Continue understanding "all in Cls" method for spec-z surveys.

• Increase Nz, compare with 3D P(k) results.

• More sophisticated target selection- different combinations, overlap, results as a fn. of z, λ etc.



• What are we going to know about bg, rg? Where are we going to know it from? Magnification, LSS with photo-z, 3pt etc. What's important to know?

• Different tracer populations of the underlying density field, McDonald & Seljak etc.

CONCLUSIONS

• We have the tools to study WGL + LSS in a Cls framework, naturally including cross-correlations. Analysis of tomographic binning etc continues.

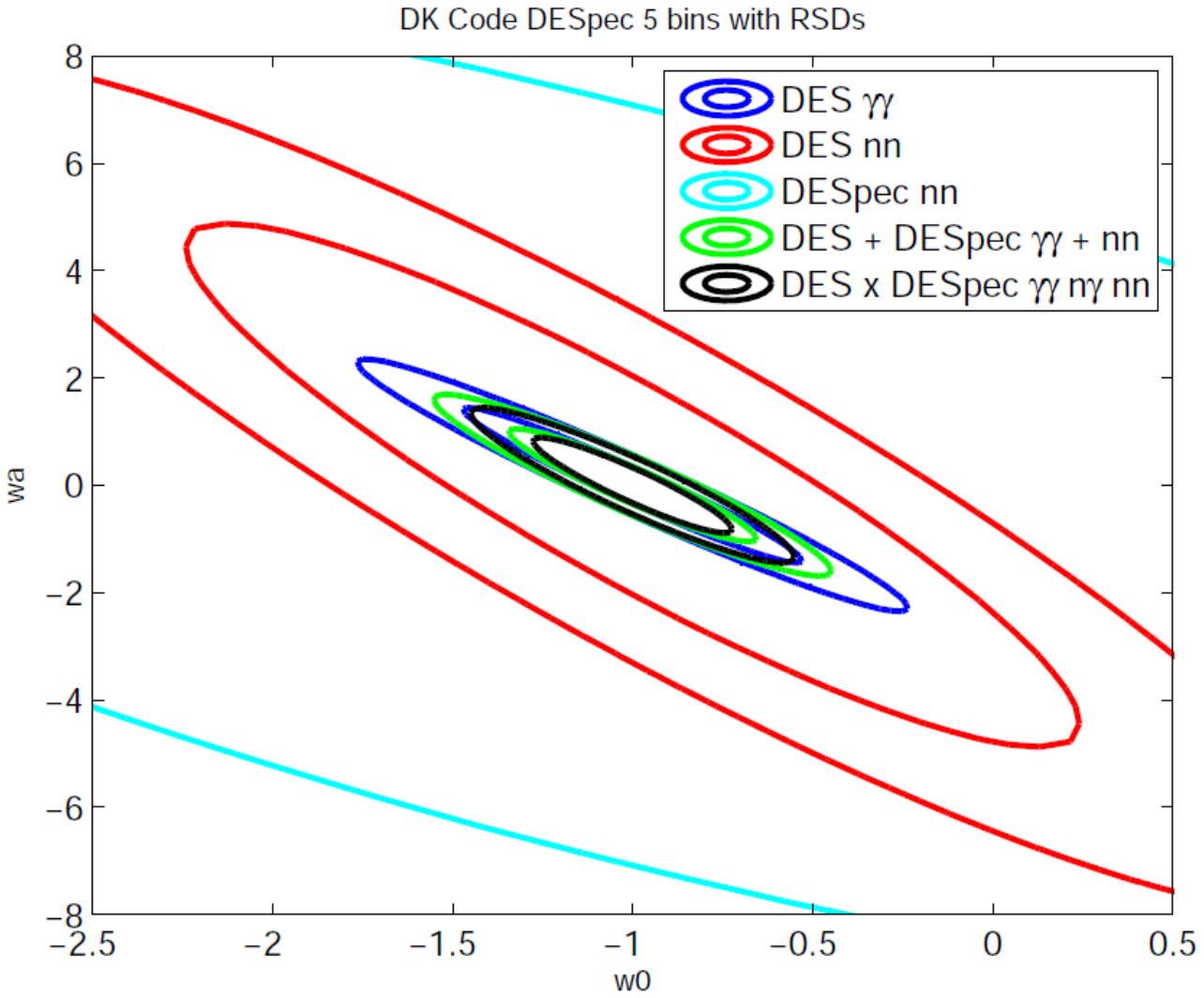
• There is some disagreement in the literature on the benefits of same-sky. Prior knowledge of bg, rg crucial.

• Altering priors on bg, and especially rg, can improve efficacy of same sky- what are we going to know & from where?

• Target selection/survey strategy have important impacts- lots of exciting work to do here.

EXTRA SLIDES

Weak Priors on b_g, r_g



- Marginalising over cosmology & >20 nuisance parameters.
-
- DESpec alone is weak.
-
- DES + DESpec:
  x 50% improvement for different sky.
- DES x DESpec:
  x 25% improvement on top for same sky.

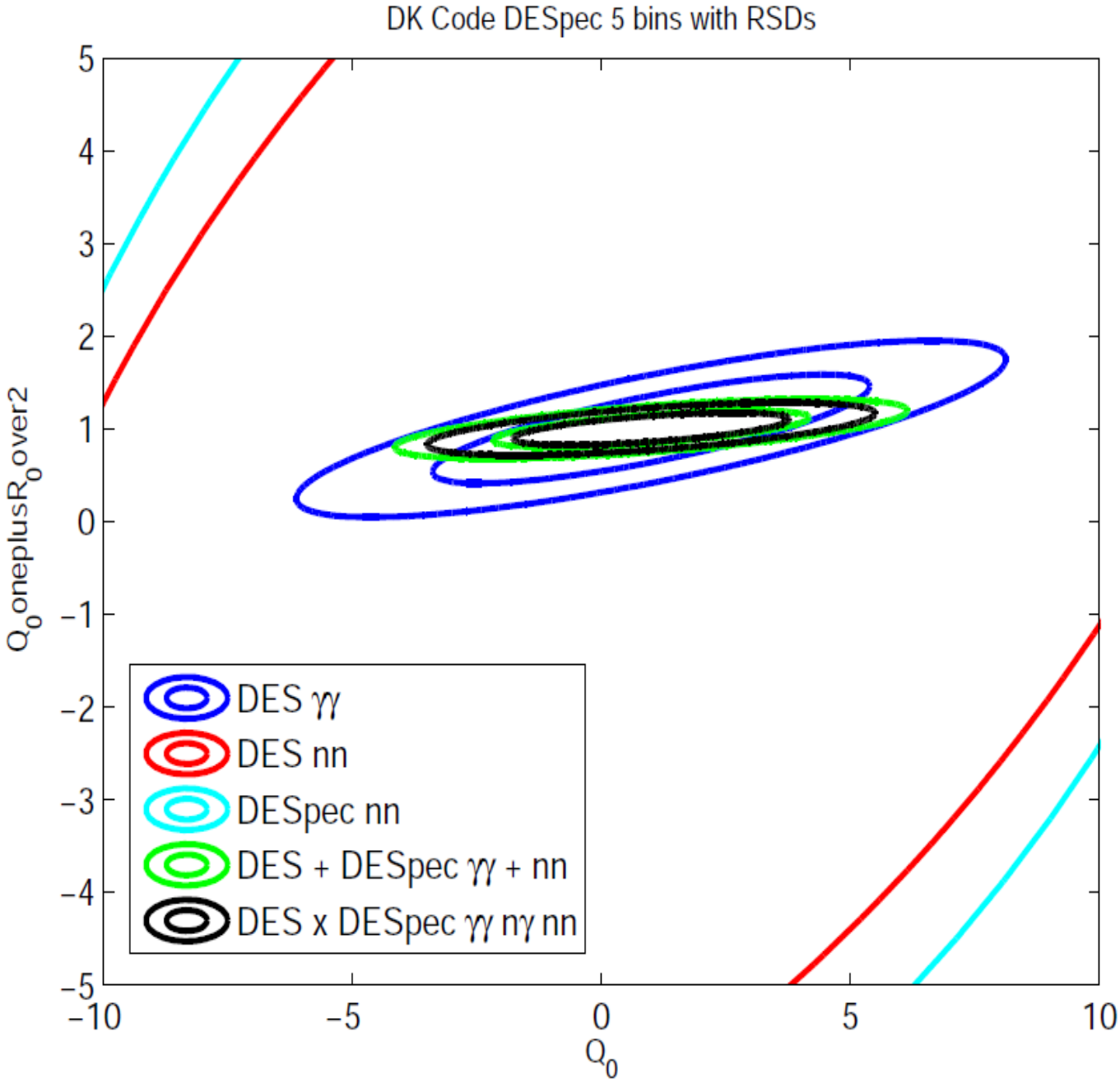
FoM: DES GG: 3.44, DES nn: 0.22, DESpec nn: 0.019 (no RSD 0.0069), DES+DESpec: 4.84 (no RSD 4.99), DESxDESpec: 6.18 (no RSD 6.19)

Weak Priors on b_g, r_g

$$k^2\Phi = -4\pi Q a^2 \rho\delta$$

$$\Psi = R\Phi$$

- MG Model
- FoMs
- Degeneracy-breaking.
- Improvement factor.



MGFoM: DES GG: 0.36, DES nn: 0.0057, DESpec nn: 0.0048 (no RSD 0.0041), DES+DESpec: 1.16 (no RSD 1.17), DESxDESpec: 1.46 (no RSD 1.47)

DESpec Fiducial Survey

- Bias
- Correlation
- K-range etc.
- Despec model
- Percival model etc.

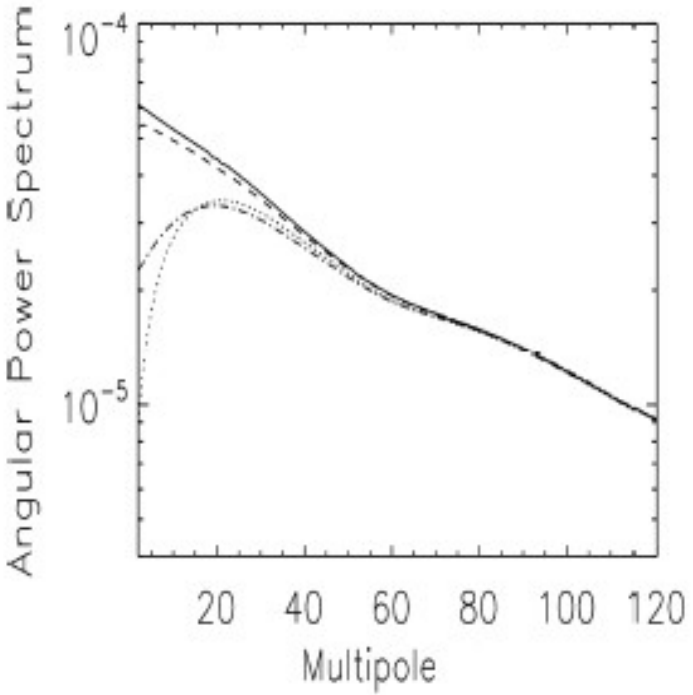
$N_K \times N_Z$	$\epsilon\epsilon$	nn	all
2×2	11	21	31
2×4	19	29	47
10×2	43	53	95
10×4	83	93	175
3×3	21	31	51
5×5	53	63	115
7×7	101	111	211

$$C_l^{\epsilon\epsilon} :$$

$$C_l^{n\epsilon} \quad b_g = A_{b_g} Q_{b_g}(k, z)$$

$$C_l^{nn} \quad r_g = A_{r_g} Q_{r_g}(k, z)$$

Why & How do we treat RSDs as Cls



- Treat DESpec as Cls, projected angular power spectra, including RSDs as per Padmanabhan.
- Observables:
  separate sky: ee, nn
  same sky: ee, ne, nn
- Unified framework including full cross-correlation between DES & DESpec.
- Treatment of galaxy bias & cross-correlation coefficient proves crucial..

$C_l^{\epsilon\epsilon}$:

$C_l^{n\epsilon}$

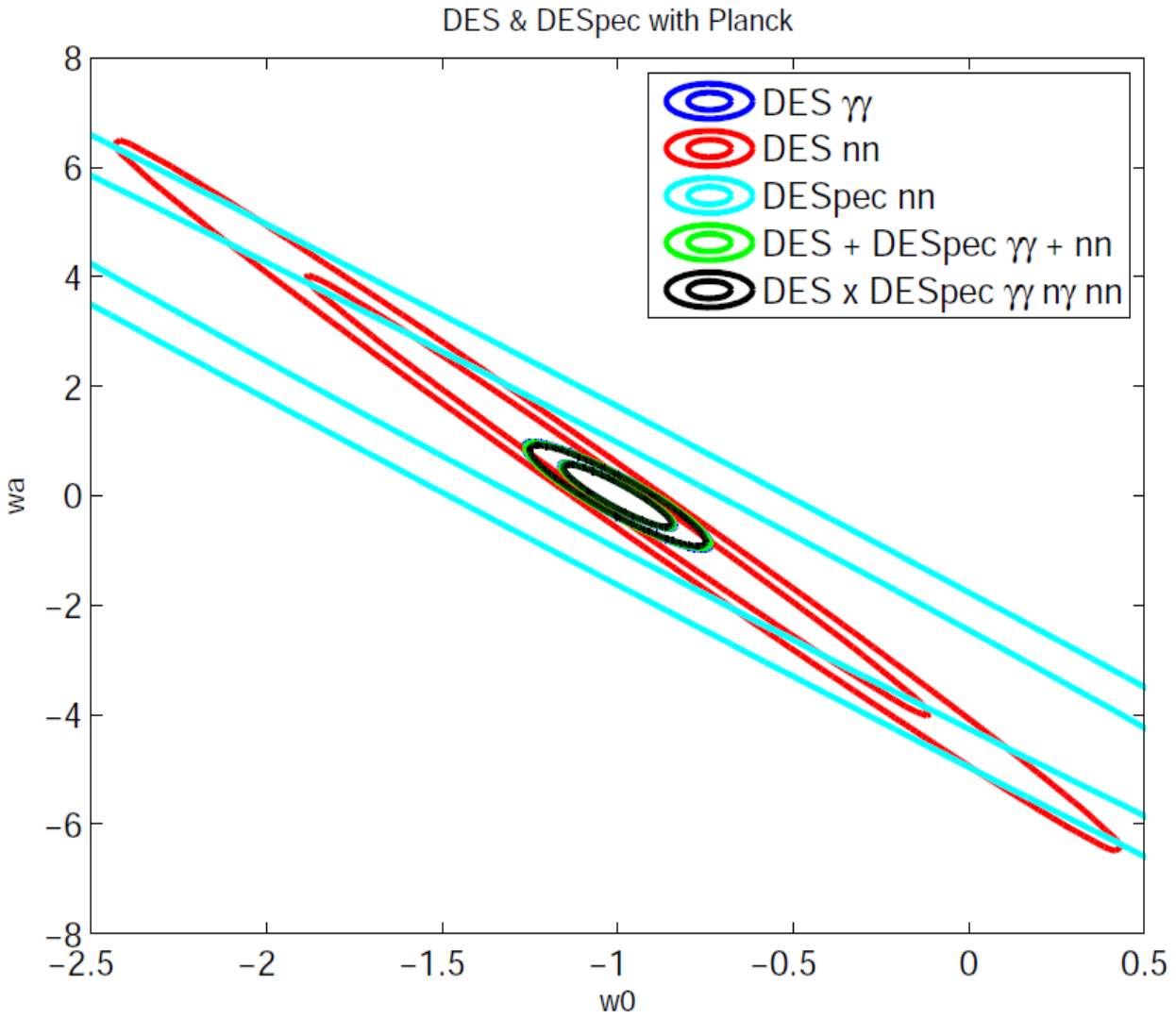
C_l^{nn}

$$W_l(k) = \int f(z) j_l(kz)\,\mathrm{d}z.$$

$$W_l^R(k) = \beta \int f(y)\Big[\frac{(2l^2+2l-1)}{(2l+3)(2l-1)} j_l(ky) + - \frac{l(l-1)}{(2l-1)(2l+1)} j_{l-2}(ky) - \frac{(l+1)(l+2)}{(2l+1)(2l+3)} j_{l+2}(ky)\Big]\,\mathrm{d}y.$$

$$\mathrm{Cov}(\ell) = \left(\begin{array}{c|c|c} \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon n\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{\epsilon\epsilon nn}(\ell) \\ \hline \mathrm{Cov}^{(ijkl)}_{n\epsilon\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{n\epsilon n\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{n\epsilon nn}(\ell) \\ \hline \mathrm{Cov}^{(ijkl)}_{nn\epsilon\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{nnn\epsilon}(\ell) & \mathrm{Cov}^{(ijkl)}_{nnnn}(\ell) \end{array}\right)$$

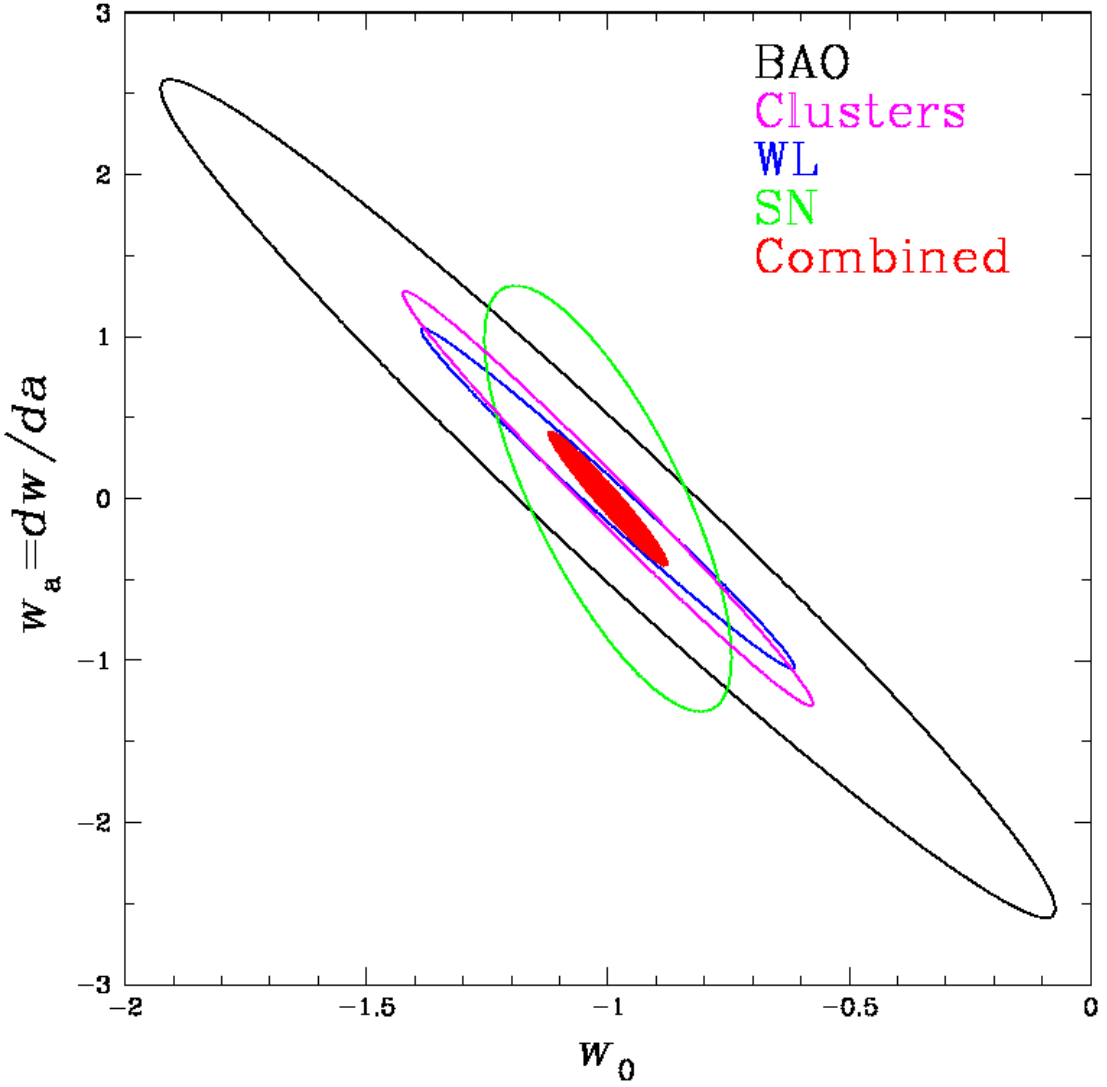
Basic Results with Planck



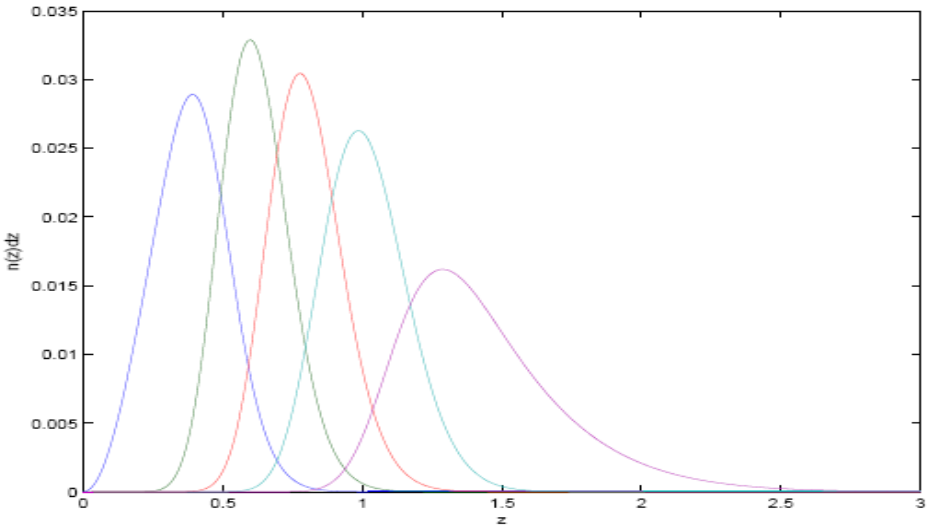
- FoMs
- DES alone.
- DESpec alone-inc. ell cuts
- Combination independent & same sky.
- Improvement factor.

FoM: DES GG: 3.44, DES nn: 0.22, DESpec nn: 0.21 (no RSD 0.19), DES+DESpec: 14.3 (no RSD 14.3), DESxDESpec: 15.67 (no RSD 15.64)

DES Survey Assumptions

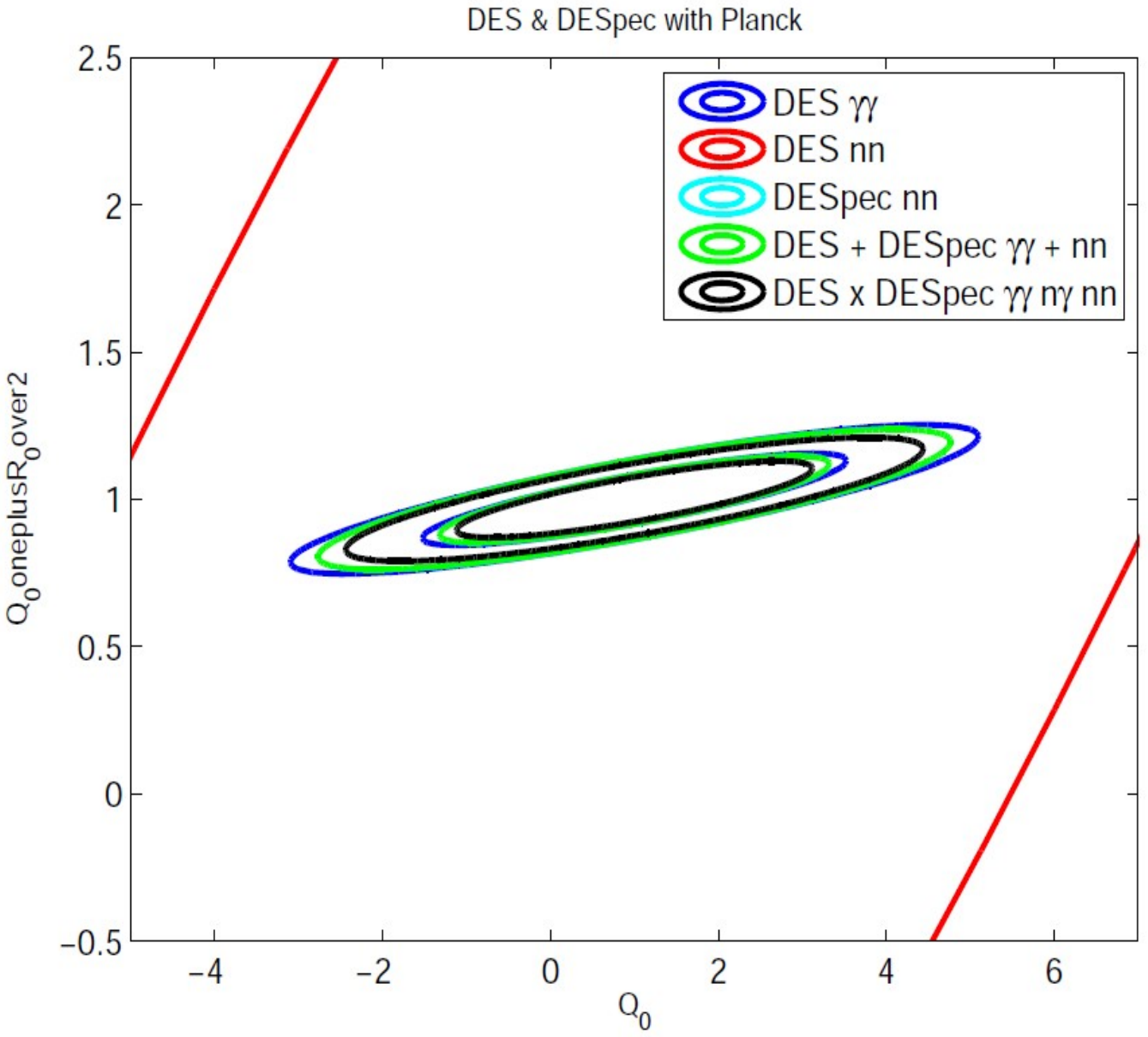


- Of the 4 probes we use WGL only for clarity.
- 300 million galaxies
- 5000deg^2
- 5 tomographic bins
- Photometric redshifts
- delta_z = 0.07(1+z), f_cat = 0.



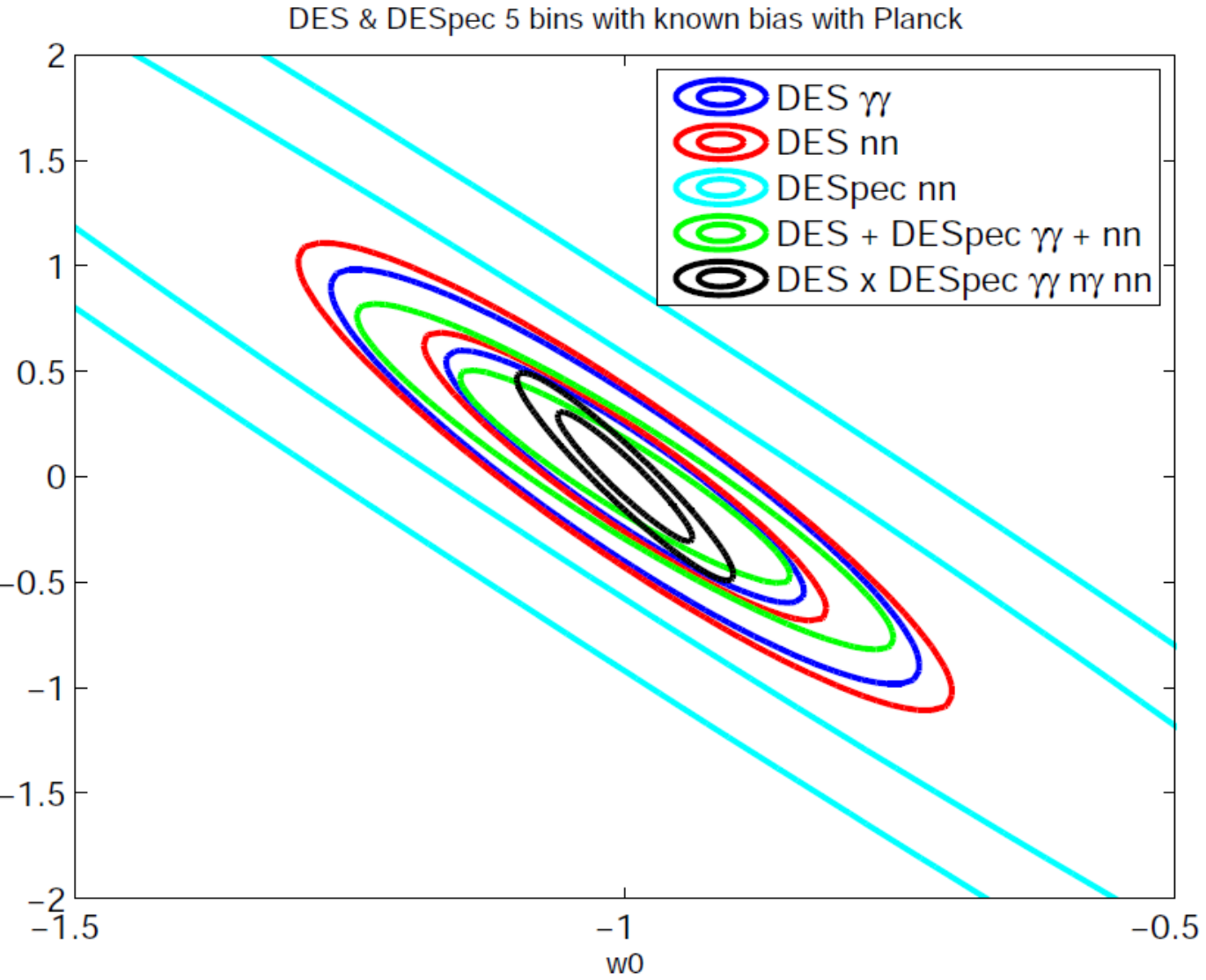
MG Results with Planck

- MG Model
- FoMs
- Degeneracy-breaking.
- Improvement factor.



MGFoM: DES GG: 2.69, DES nn: 0.013, DESpec nn: 0.0077 (no RSD 0.0059), DES+DESpec: 2.94 (no RSD 2.97), DESxDESpec: 3.54 (no RSD 3.55)

What happens if we know bias exactly with Planck



- Huge increase from cross-correlation.
- Improvement factor.

FoM: DES GG: 13.8, DES nn: 11.6, DESpec nn: 1.07 (no RSD 1.03), DES+DESpec: 20.7 (no RSD 20.8), DESxDESpec: 95 (no RSD 97)

Introduction to RSDs

Galaxies have peculiar velocities as well as being embedded in the cosmic expansion.

$$cz \approx H_0 r + \delta\vec{v} \cdot \hat{r}$$

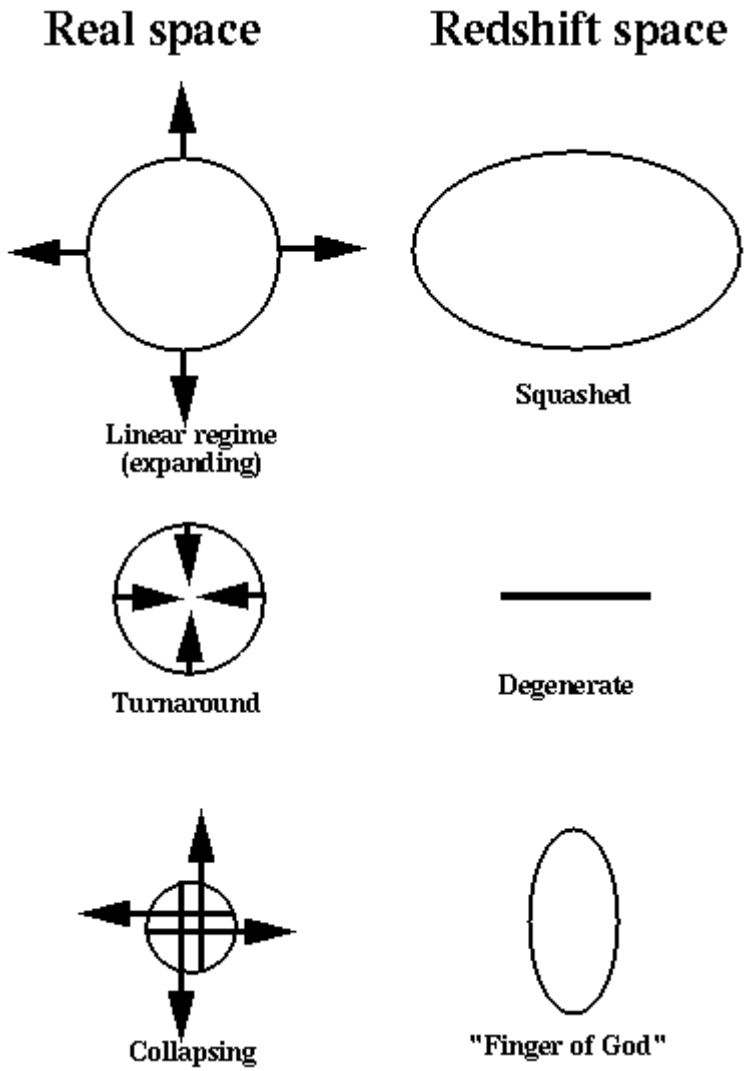
This causes distortions when viewed in redshift space.

We can decompose the redshift space galaxy power spectrum into three isotropic power spectra:

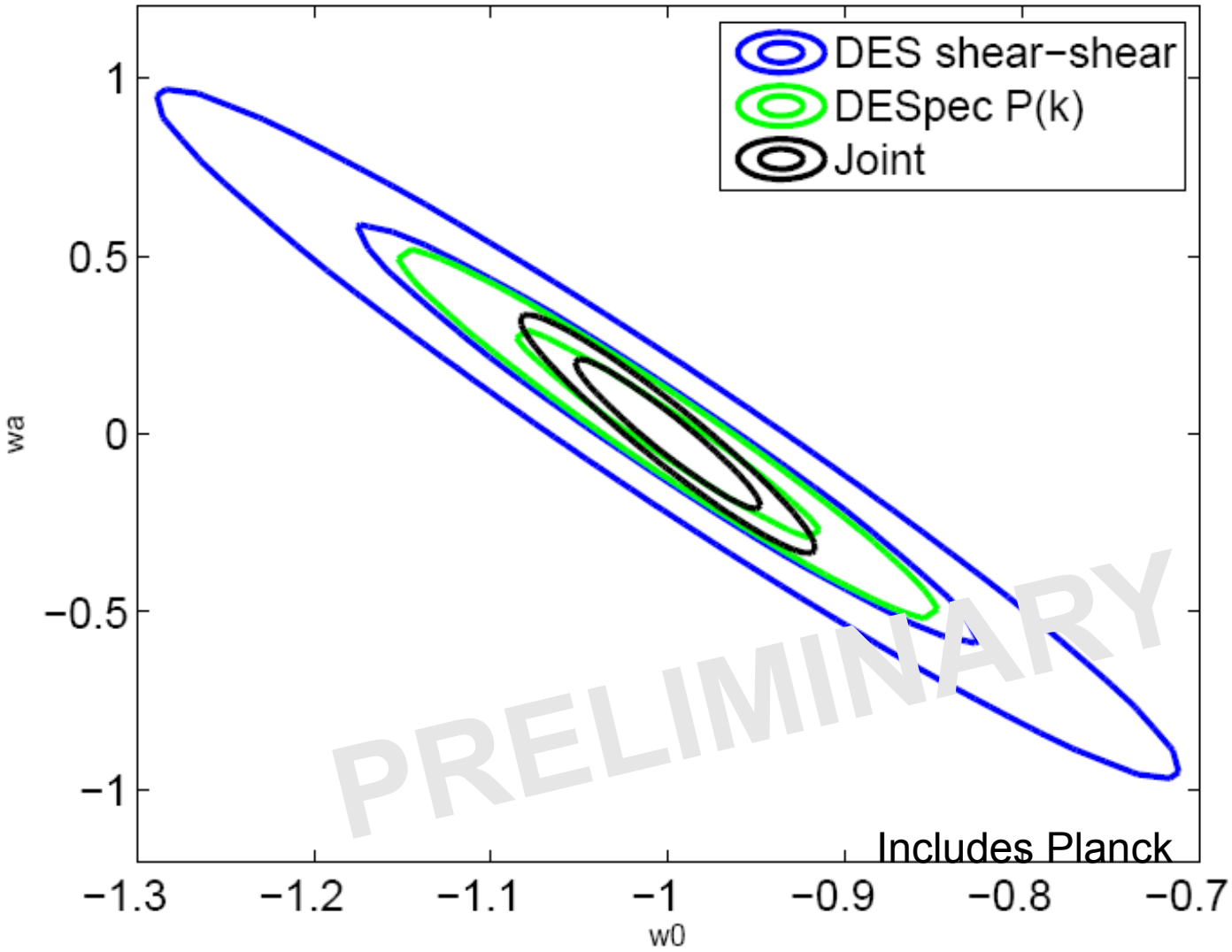
$$P_{gg}^{(s)}(k,\mu_k) = \left[P_{gg}(k) + 2\mu_k^2 P_{gv}(k) + \mu_k^4 P_{vv}(k)\right] F(k^2\mu_k^2\sigma_v^2),$$

Guzik et al. 2009

15-k band powers spaced logarithmically over the range 0.015 – 0.15 hMpc^-1. Assuming DESpec acquires 1e7 galaxies over a z-range: 0.2-1.7 with constant galaxy number density. Constant bias allowed to vary in 5 z-bins.



Improvement with RSDs



The combination of DES-WL and DESpec RSD yields a very considerable improevement.

This work is preliminary while we check the use of priors and comparison of degeneracy directions/constraints with previous studies.

DETF FoM:
DES 23
DESpec 84
DES+DESpec 180

Modified Gravity

Multiple cosmological probes provide an excellent opportunity to test General Relativity-may be possible to explain cosmic acceleration without recourse to Dark Energy.

1. A Modification of Poisson's equation: $k^2\Phi = -4\pi Q a^2 \rho\delta$

2. An inequality in Newton's potentials: $\Psi = R\Phi$

Sometimes known as “Trigger Parameters”, simple versions of Q & R should indicate deviations from GR.

$$Q = (Q_0 - 1)a^s$$

s = 3

$$R = (R_0 - 1)a^s$$

In the future it would be desirable to include k-variation.

Multiple Probes

Multiple probes have the potential to break parameter degeneracies as they respond to our MG model in different ways.

WGL & RSD very complimentary. Transverse/access to line of sight modes, biased/direct access to potential fluctuations,... See talks on docDB by Gary Bernstein, Enrique Gaztanaga etc.

The combination of WGL and RSD is particularly interesting.

$$ds^2 = -a(\tau)^2 \left[1 + 2\Psi(\mathbf{x}, t)\right] d\tau^2 + a(\tau)^2 \left[1 - 2\phi(\mathbf{x}, t)\right] d\mathbf{x}^2$$

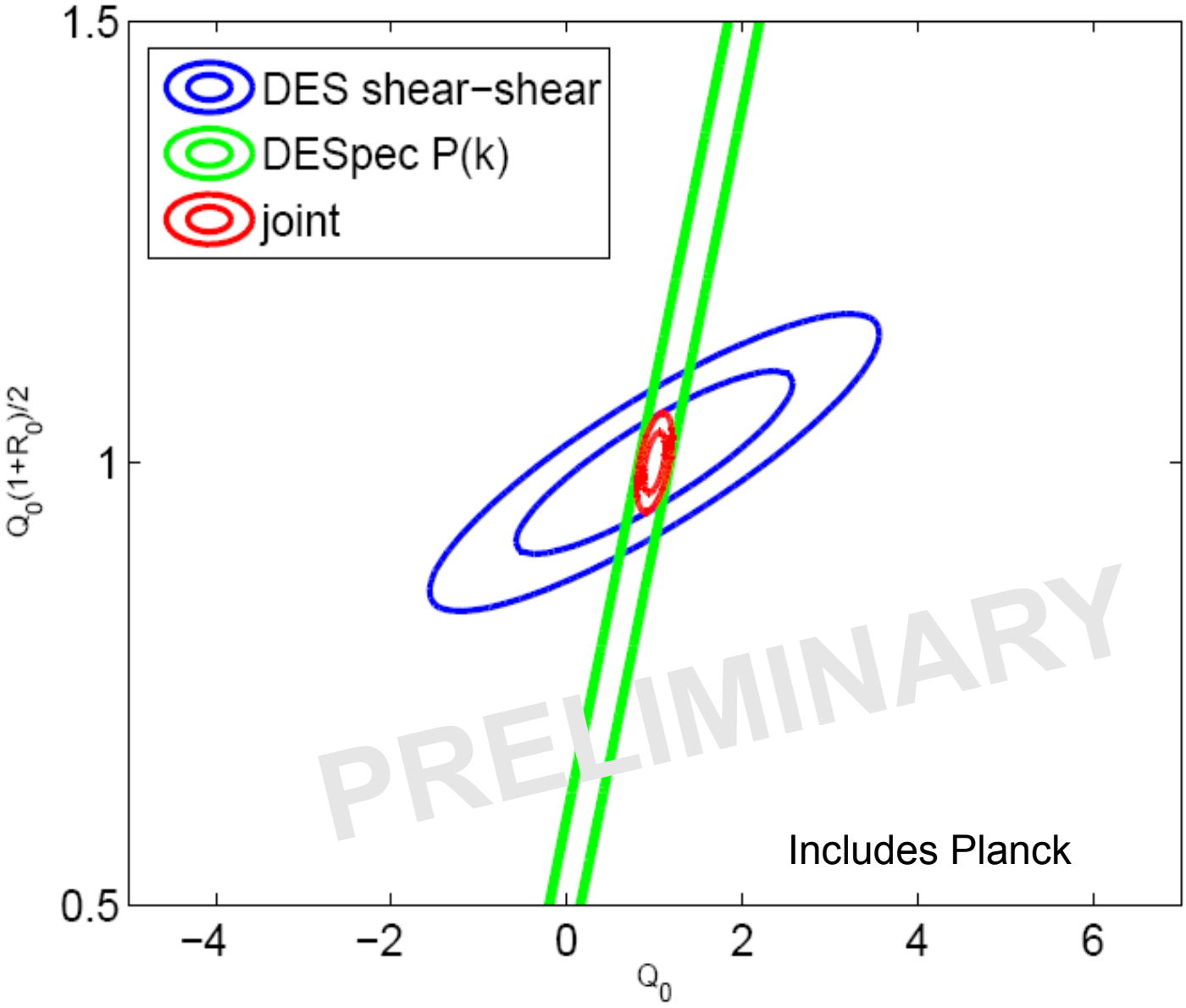
Cosmic shear is sensitive to:

$$\Phi + \Psi$$

Galaxy Position and Peculiar Velocities are sensitive to:

$$\Psi$$

MG- combined probes



Combination of DES-WGL and DESpec RSD.

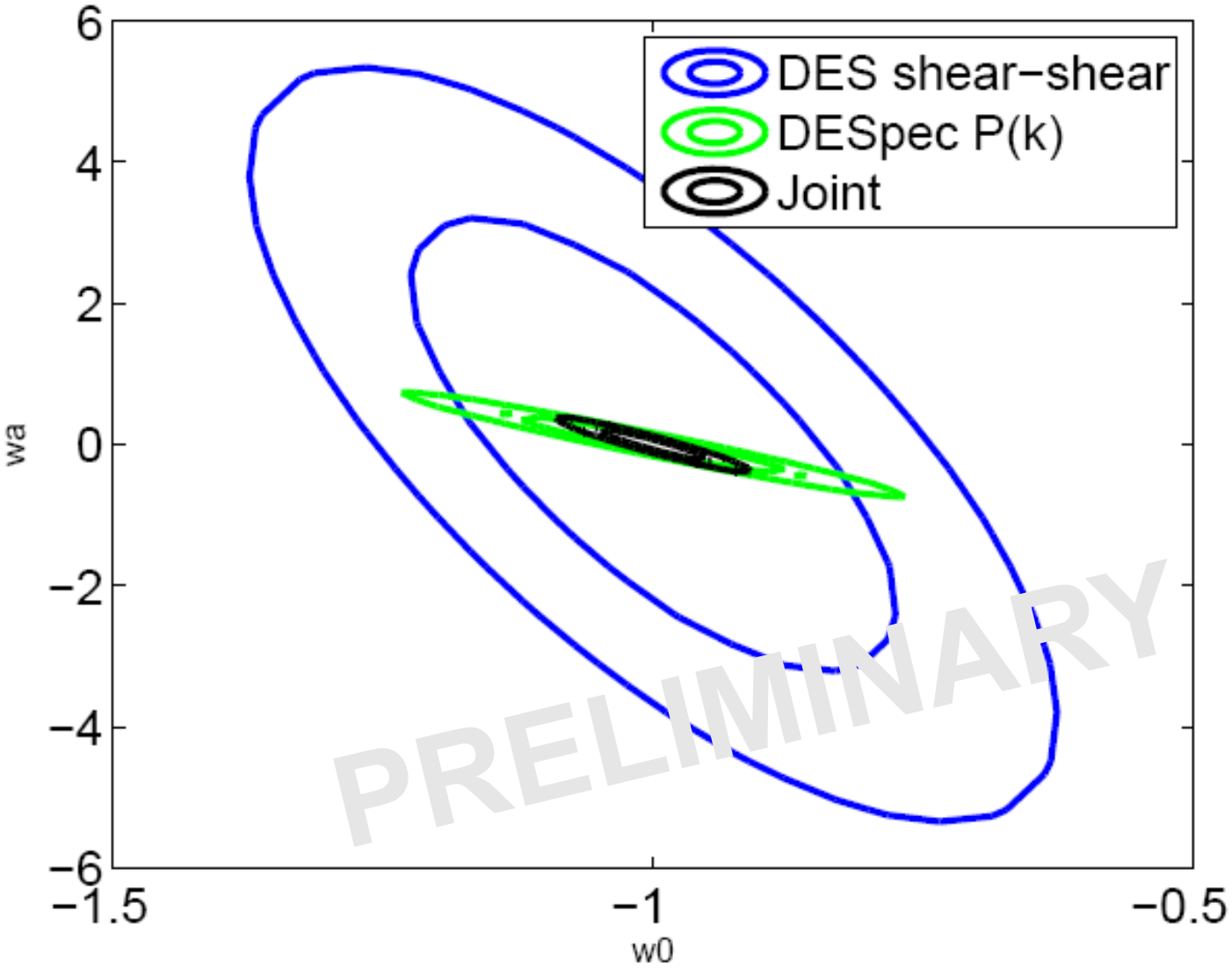
P(k) from DESpec is not very constraining but it has a very different degeneracy direction to WGL.

Joint constraints show a marked improvement

MG FoM:
DES 7
DESpec 2
DES+DESpec 153

Kirk, Lahav & Bridle 2011. in prep.

Improvement with RSDs

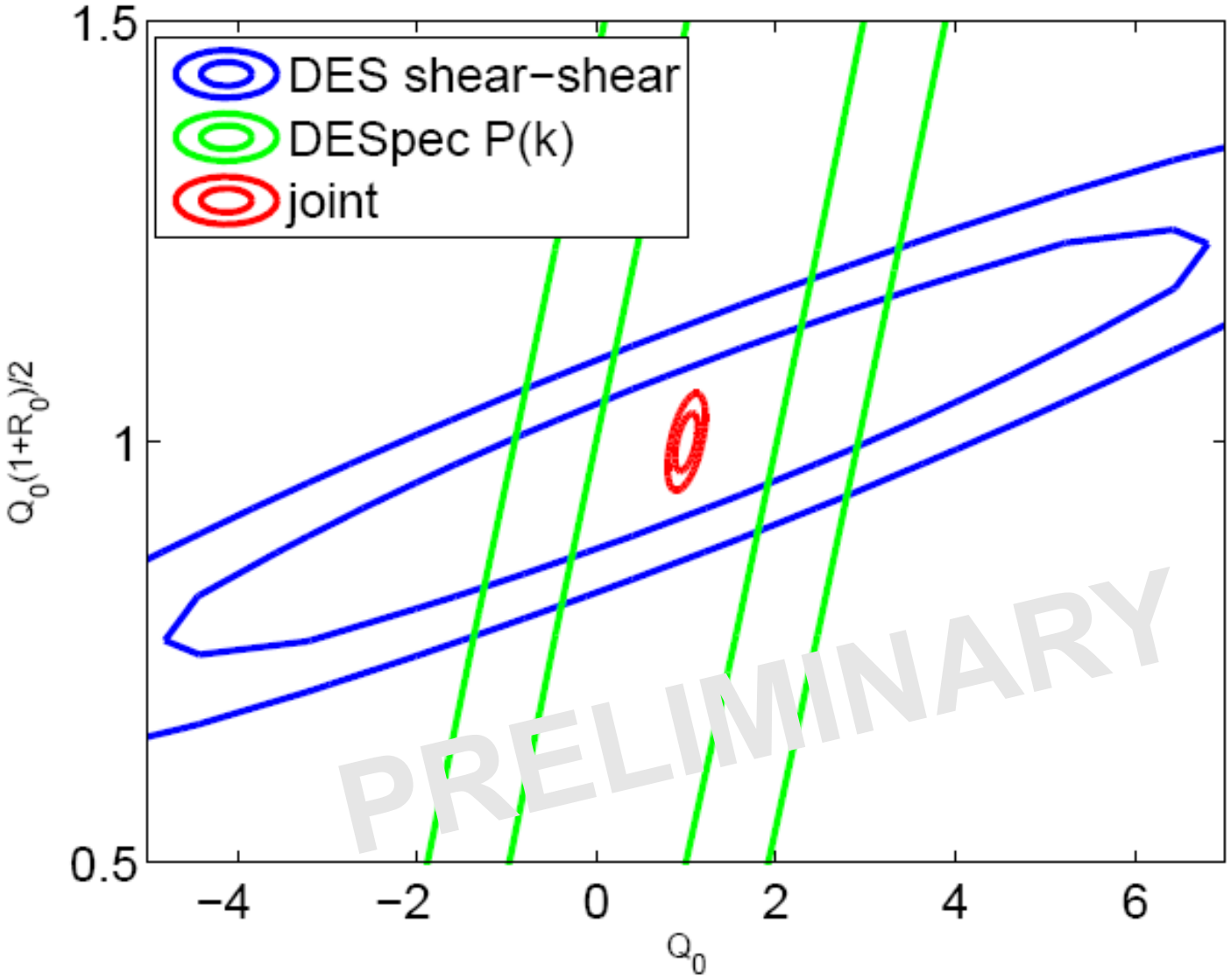


The combination of DES-WL and DESpec RSD yields a very considerable improevement.

This work is preliminary while we check the use of priors and comparison of degeneracy directions/constraints with previous studies.

DETF FoM:
DES 1.08
DESpec 36.7
DES+DESpec 133

MG- combined probes



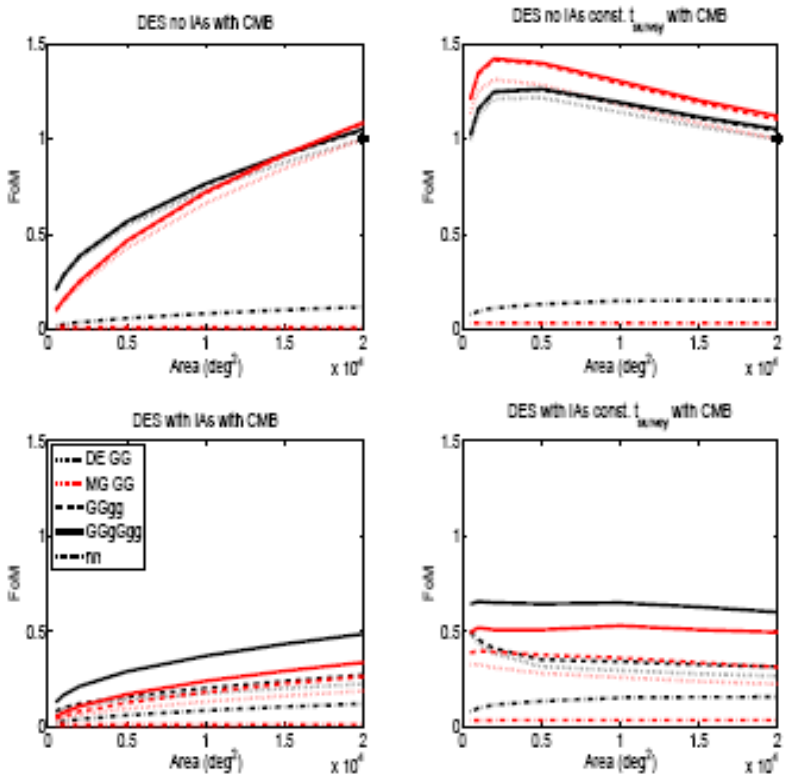
Combination of DES-WGL and DESpec RSD.

P(k) from DESpec is not very constraining but it has a very different degeneracy direction to WGL.

Joint constraints show a marked improvement

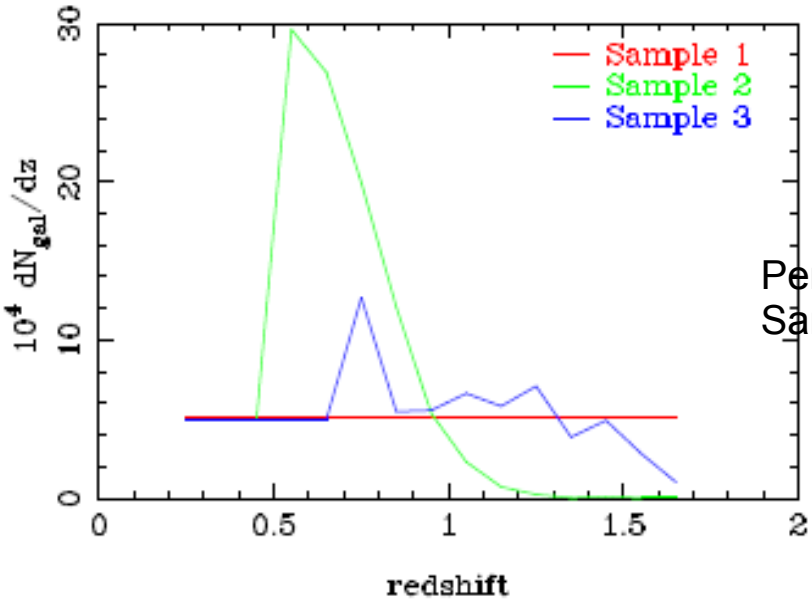
MG FoM:
DES 1.13
DESpec 0.23
DES+DESpec 145

Conclusions & Future directions

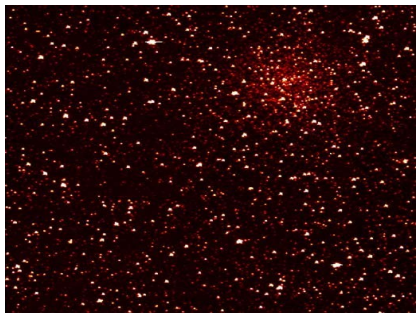


Kirk, Lazslo, Bridle, Bean 2011 in prep.

Survey Strategy- some results presented. The impact of survey strategy depends on the probe combination being used.



Percival & Samushia



DES+DESpec sees significant benefits, especially for MG but...
Cross Correlations- we have so far ignored the fact that DES and DESpec are two surveys on the same patch of the sky. This can induce cross-correlations between our measurements, perhaps providing additional information.