# Updates on forecasts including CMB cross-correlation

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# Introduction

- Objective: to quantify the importance of the CMB-LSS cross-correlation on constraining the cosmological parameters in a joint analysis of CMB+LSS+Xc, using temperature, polarization and lensing for the CMB and future galaxy surveys for galaxy clustering

- Methodology: standard Fisher approach

- Model: ΛCDM + 6 extra parameters (12 in total)
  - 2 dark energy parameters ($w_0$, $w_a$)
  - 2 neutrino physics parameters ($\Sigma m_\nu$, $N_{\mathrm{eff}}$)
  - 2 primordial universe parameters ($dn_s/d\ln k$, $f_{\mathrm{NL}}$)

# Data: CMB

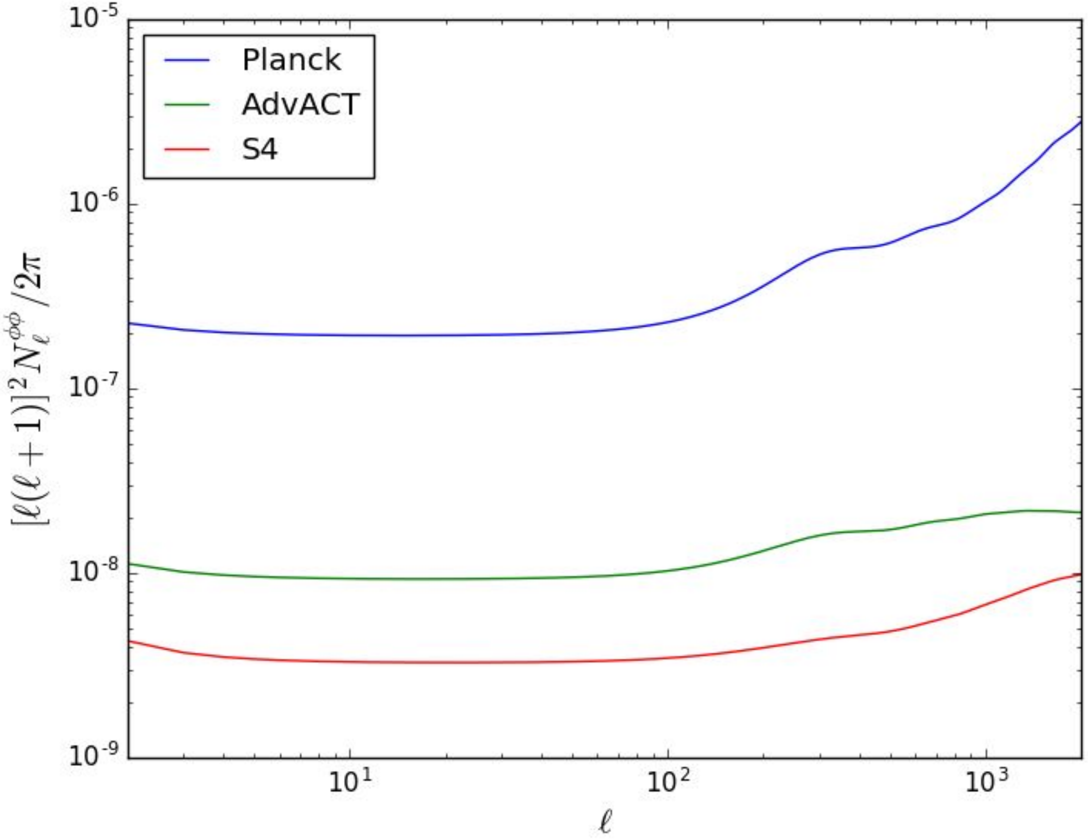
We consider the following surveys:

- Planck-like: we readapt the specifications of the 143 GHz channel in order to mimic the Planck 2018 TT+TE+EE constraints for the ΛCDM model. We inflate the noise in EE by a factor 8. We use $\ell_{max} = 1500$ for T,E and $8 < \ell < 400$ for $\phi\phi$
- Advanced ACTpol, following the specifications by Henderson et al. (2015)
- CMB Stage-4 (S4), following the specifications by Henderson et al. (2015)

For both AdvACT and S4 we use $\ell_{min} = 30$, $\ell_{max} = 3000$ ($\ell_{max} = 1000$ for $\phi\phi$) and we consider the Planck specifications for $\ell < 30$

# Data: CMB lensing noise

We obtain the CMB lensing noise using the recipe by Okamoto & Hu (2003) and the public code *quicklens* by D. Hanson



# Data: future galaxy surveys

We consider the following surveys:

- Euclid: photometric and spectroscopic surveys
- LSST
- EMU
- SKA

We use and modify CAMB_sources to obtain the power spectra

Relativistic corrections are considered

Non-linear correction recipe: Takahashi halofit

We limit the analysis to quasi-linear scales: we consider the $GG$ spectra up to $\ell_{\rm max} = 500$ and the cross-correlation with CMB lensing ($\phi G$) up to $\ell_{\rm max} = 1000$

# Example of LSS data: Euclid photometric survey

We consider the following number density:

$$\frac{\mathrm{d}N}{\mathrm{d}z} = \frac{1}{\Gamma\left(\frac{\alpha+1}{\beta}\right)}\beta\frac{z^{\alpha}}{z_0^{\alpha+1}}\exp\left[-\left(\frac{z}{z_0}\right)^{\beta}\right] \qquad \alpha = 2,\ \beta = 1.5,\ z_0 = 0.64$$

The bias redshift evolution follows: $b_g(z) = b_0\,(1+z)^a$ and we account for a scale-dependent bias to introduce $f_{\mathrm{NL}}$

$$b(z,k) = \bar{b}(z) + \Delta b(z,k) = \bar{b}(z) + [\bar{b}(z) - 1]f_{\mathrm{NL}}\delta_{\mathrm{ec}}\frac{3\Omega_m H_0^2}{c^2k^2T(k)D(z,k)}$$

Tomography: we convolve the dNdz with a gaussian photo-z distribution of dispersion $\boldsymbol{\sigma}_z$ to model the redshift uncertainties:

$$p(z_m|z) = \frac{1}{\sqrt{2\pi}\sigma_z}e^{-\frac{1}{2}(z_m-z)^2/\sigma_z^2} \qquad \frac{\mathrm{d}n_i}{\mathrm{d}z} = \frac{\mathrm{d}N}{\mathrm{d}z}\int_{z_{\min}}^{z_{\max}}\mathrm{d}z_m p(z_m|z)$$

We include as nuisance parameters: $z_0$, $\boldsymbol{\sigma}_z$ and two bias parameters per bin ($b_0$,a)

# Forecast methodology: Fisher approach

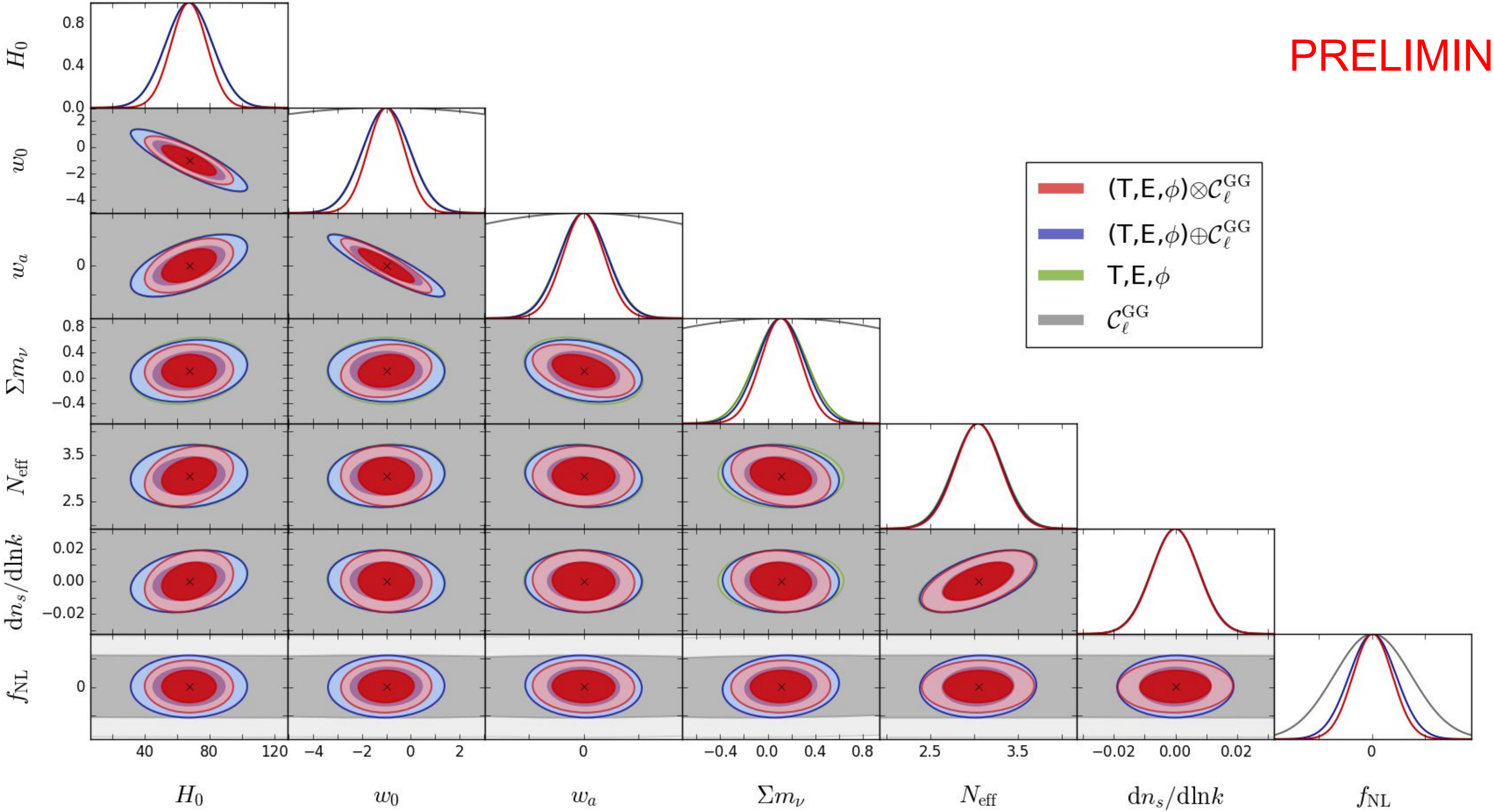
Standard Fisher approach

$$\mathcal{F}_{\alpha\beta} = \frac{\partial^2 \mathcal{L}}{\partial\theta_\alpha \partial\theta_\beta} = \frac{1}{2}\mathrm{Tr}\left[\frac{\partial \mathcal{C}}{\partial\theta_\alpha}\mathcal{C}^{-1}\frac{\partial \mathcal{C}}{\partial\theta_\beta}\mathcal{C}^{-1}\right] \qquad \sigma_i \geq \sqrt{(\mathcal{F}^{-1})_{ii}},$$

Theoretical covariance matrix for the CMB x G case for *N* galaxy bins

$$\mathcal{C} = \begin{bmatrix} \bar{C}_\ell^{TT} & C_\ell^{TE} & C_\ell^{T\phi} & C_\ell^{TG_1} & \dots & C_\ell^{TG_N} \\ C_\ell^{TE} & \bar{C}_\ell^{EE} & C_\ell^{E\phi} & C_\ell^{EG_1} & \dots & C_\ell^{EG_N} \\ C_\ell^{T\phi} & C_\ell^{E\phi} & \bar{C}_\ell^{\phi\phi} & C_\ell^{\phi G_1} & \dots & C_\ell^{\phi G_N} \\ C_\ell^{TG_1} & C_\ell^{EG_1} & C_\ell^{\phi G_1} & \bar{C}_\ell^{G_1G_1} & \dots & C_\ell^{G_1G_N} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ C_\ell^{TG_N} & C_\ell^{EG_N} & C_\ell^{\phi G_N} & C_\ell^{G_1G_N} & \dots & \bar{C}_\ell^{G_NG_N} \end{bmatrix}$$

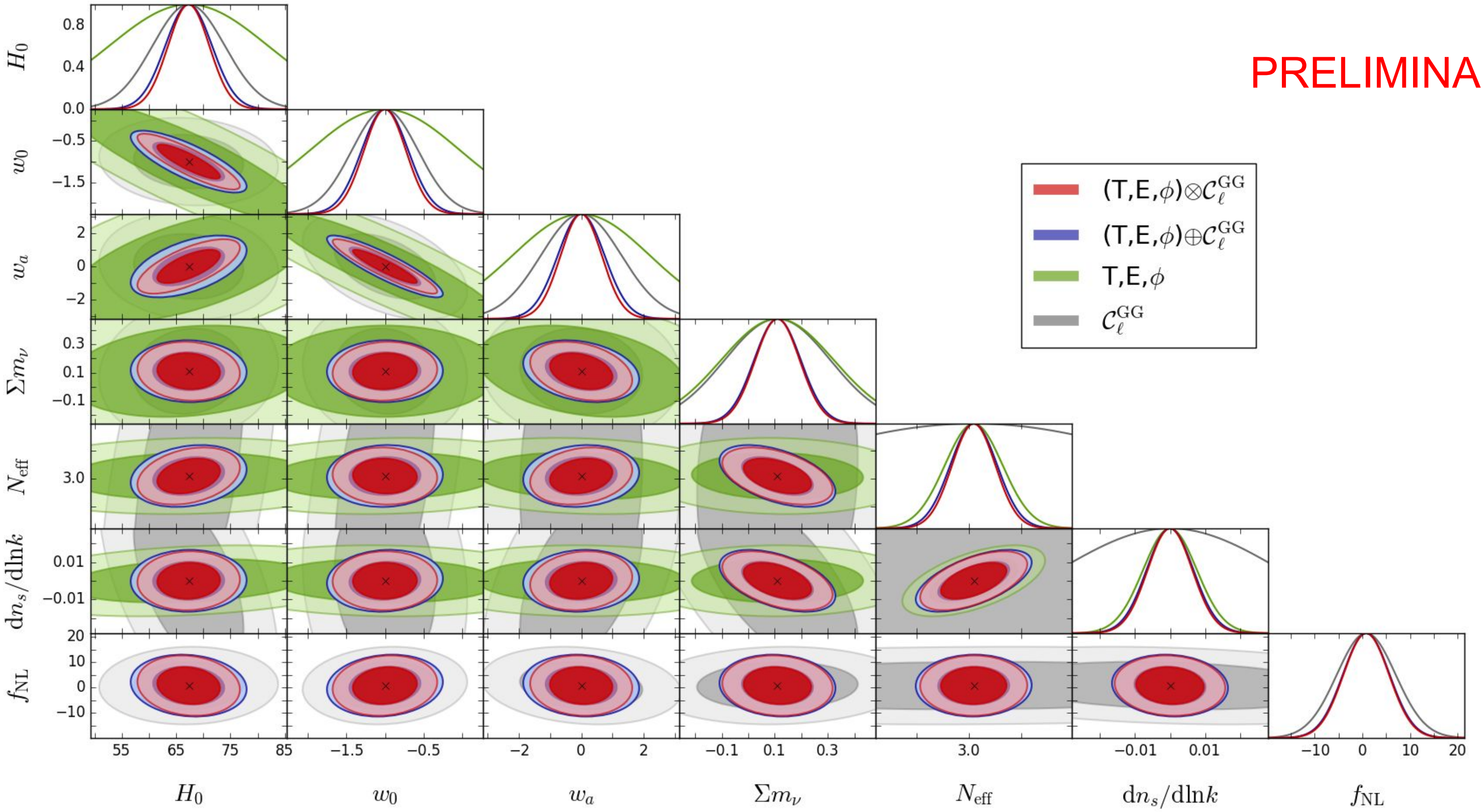
# Forecast results: Planck + Euclid_ph (1 bin)



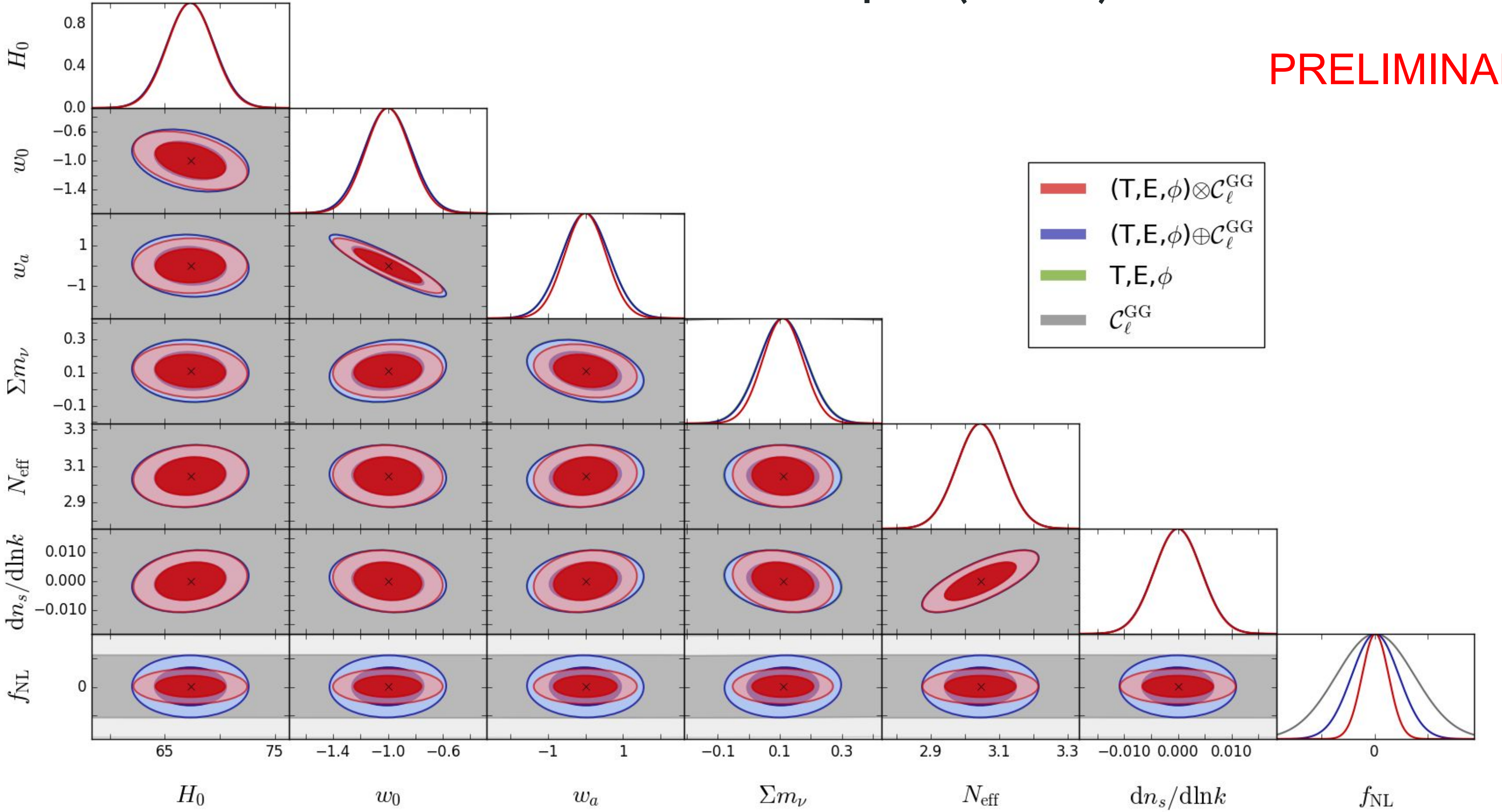
PRELIMINARY

# Forecast results: Planck + Euclid_ph (6 bins)

PRELIMINARY

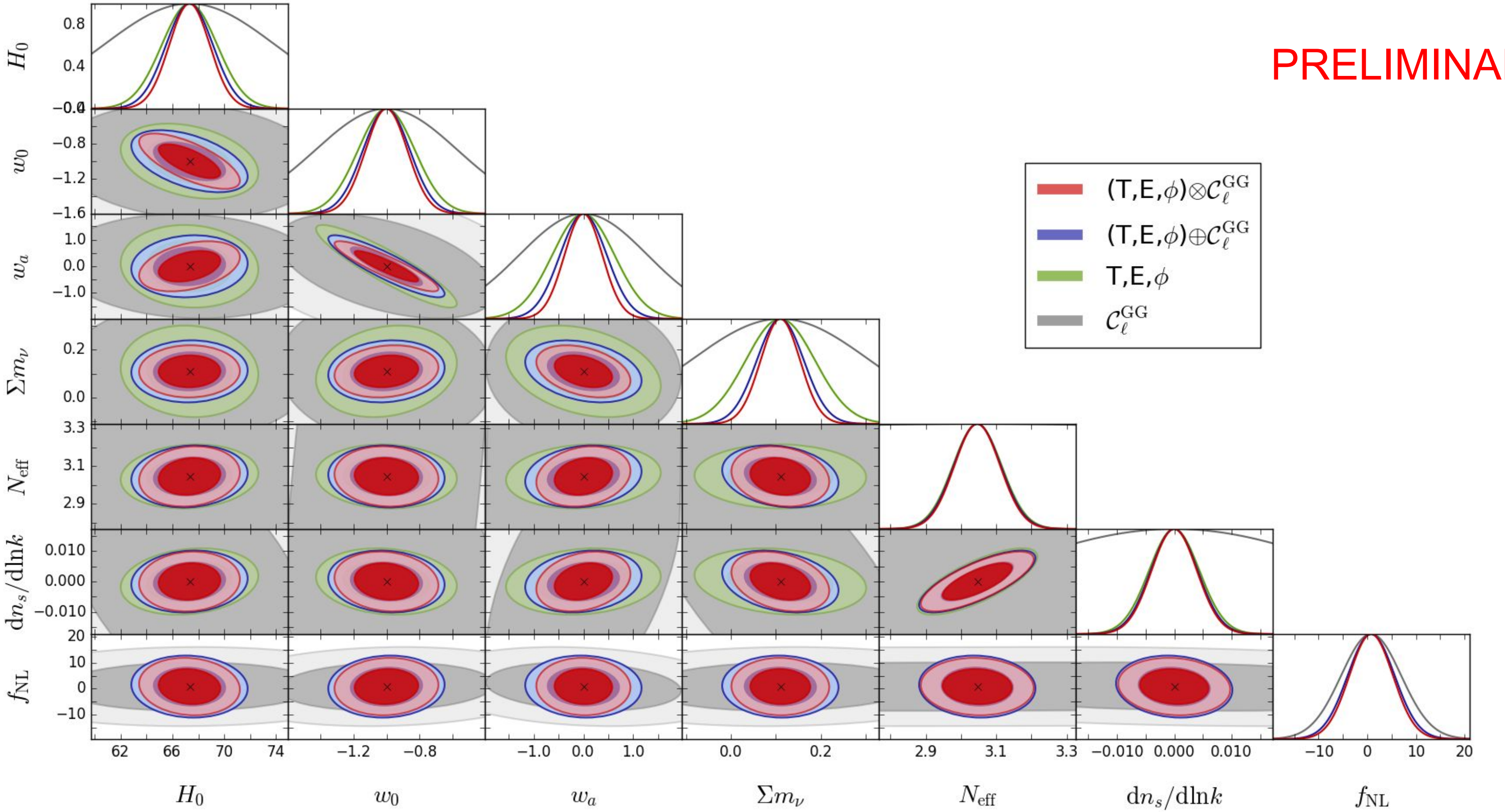


# Forecast results: S4 + Euclid_ph (1 bin)



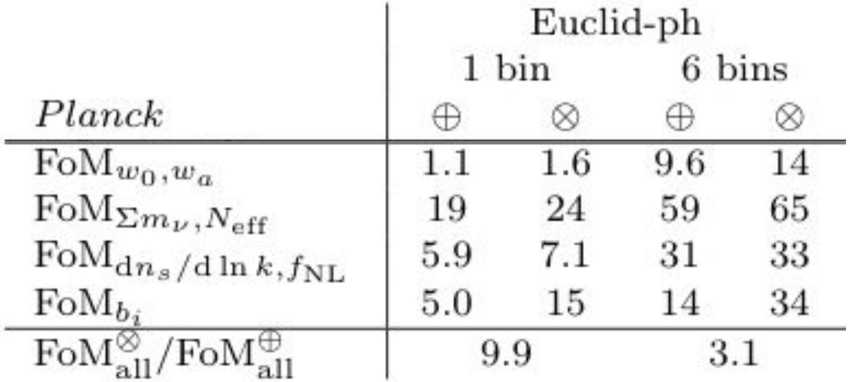
# Forecast results: S4 + Euclid_ph (6 bins)

PRELIMINARY

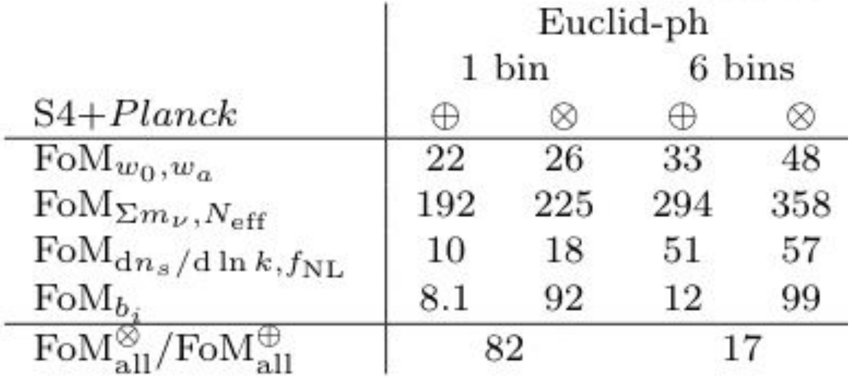


# Forecast results: Figures of Merit

PRELIMINARY



| | Euclid-ph | | | |
|---|---|---|---|---|
| | 1 bin | | 6 bins | |
| *Planck* | $\oplus$ | $\otimes$ | $\oplus$ | $\otimes$ |
| $\mathrm{FoM}_{w_0,w_a}$ | 1.1 | 1.6 | 9.6 | 14 |
| $\mathrm{FoM}_{\Sigma m_\nu,N_\mathrm{eff}}$ | 19 | 24 | 59 | 65 |
| $\mathrm{FoM}_{\mathrm{d}n_s/\mathrm{d}\ln k,f_\mathrm{NL}}$ | 5.9 | 7.1 | 31 | 33 |
| $\mathrm{FoM}_{b_i}$ | 5.0 | 15 | 14 | 34 |
| $\mathrm{FoM}^{\otimes}_\mathrm{all}/\mathrm{FoM}^{\oplus}_\mathrm{all}$ | 9.9 | | 3.1 | |



| | Euclid-ph | | | |
|---|---|---|---|---|
| | 1 bin | | 6 bins | |
| S4+*Planck* | $\oplus$ | $\otimes$ | $\oplus$ | $\otimes$ |
| $\mathrm{FoM}_{w_0,w_a}$ | 22 | 26 | 33 | 48 |
| $\mathrm{FoM}_{\Sigma m_\nu,N_\mathrm{eff}}$ | 192 | 225 | 294 | 358 |
| $\mathrm{FoM}_{\mathrm{d}n_s/\mathrm{d}\ln k,f_\mathrm{NL}}$ | 10 | 18 | 51 | 57 |
| $\mathrm{FoM}_{b_i}$ | 8.1 | 92 | 12 | 99 |
| $\mathrm{FoM}^{\otimes}_\mathrm{all}/\mathrm{FoM}^{\oplus}_\mathrm{all}$ | 82 | | 17 | |