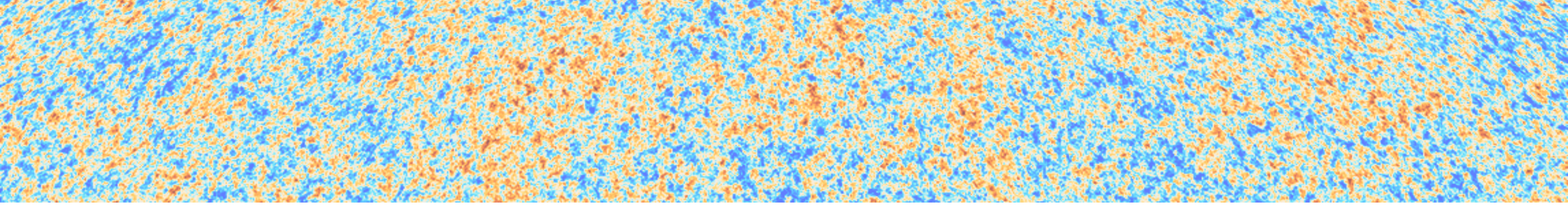

CMB polarization map self-calibration

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Preliminary results

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Motivation

1. The **third and final 2018 data** release in **Planck** was characterized by the correction of polarization **systematics**, both at large scales and small scales.
2. At small scales (l>30), there were two main systematics, beam leakage, and **uncorrected polarization efficiencies**.

$$P(t) = G\{I + \rho\,[Q\cos 2(\psi(t)) + U\sin 2(\psi(t))]\} + n(t),$$

Detector gain

Stokes parameters

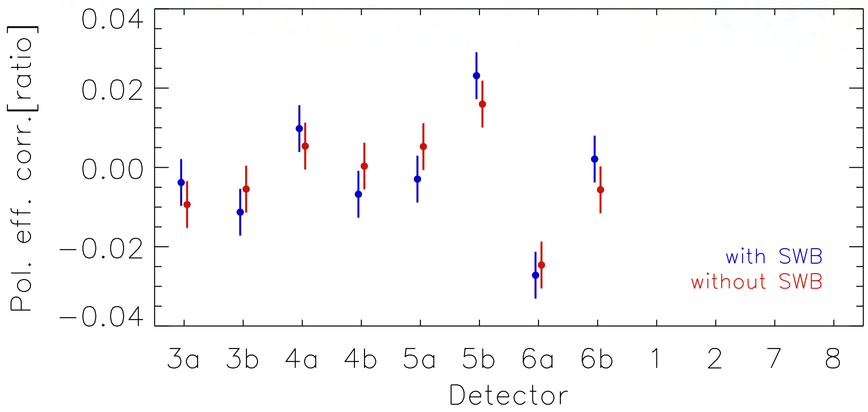
Detector polarization efficiency

In Planck, polarization efficiencies for HFI (High Frequency Instrument) where measured in the lab **and estimated to be between 80-95%** **(**92–96 % at 100 GHz, 83–93 % at 143 GHz, and 94–95 % at 217 GHz **)** with uncertainties that ranged between **0.1-0.3%.**

Motivation

1. However, in-flight observations of strong polarized galactic emission revealed differences between polarization efficiencies of detectors of the **percent-level**.

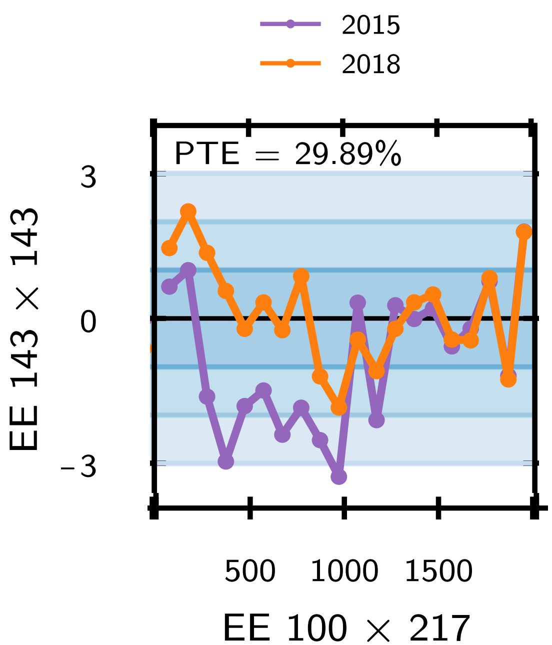
Relative polarization efficiency estimated on dust at 353 GHz.



Planck 2018 results. III

2. These were responsible for large differences between power spectra estimated from different frequencies.

3. Uncorrected polarization efficiencies impact parameters in Planck up to **0.6σ**



Planck 2018 results. V

Motivation

1. In Planck residual uncorrected polarization efficiencies were **modeled at the frequency map** level, where efficiencies from different detectors coadd into one multiplicative factor (**Pcal)**.
2. We define **Pcal** as the polarization calibration parameter adjusting theoretical power spectra at each frequency:

$TE' = TE / T_{cal}^2\ P_{cal}$ $EE' = EE / T_{cal}^2\ P_{cal}^2$

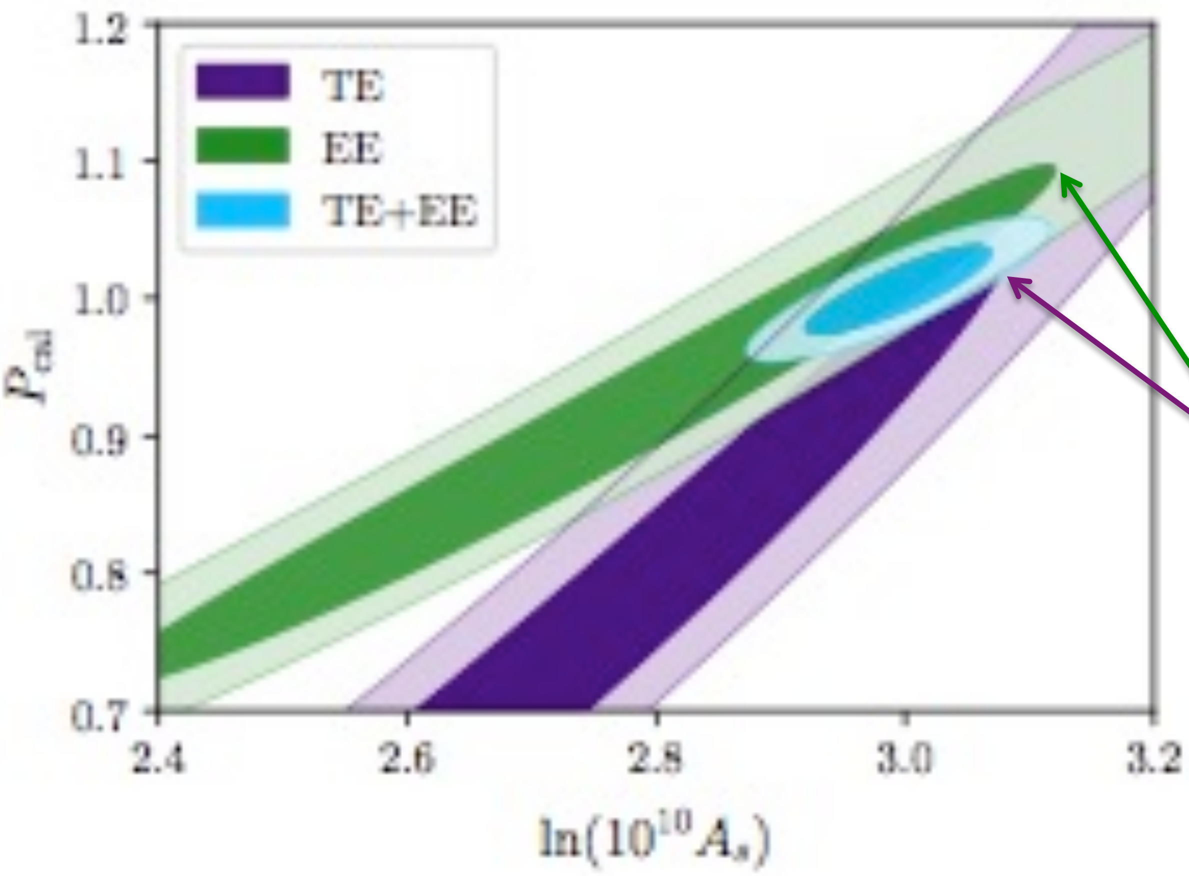
1. Planck 2018 re-measured **Pcal by recalibrating the TE and EE power spectra with respect to a fiducial** power spectrum calculated **from the best-fit TT** ΛCDM model (model dependence was shown to be small).
2. **However, in this work realized that one can constrain Pcal only just using the combination of EE and TE, without any external TT data.**
3. TE and EE depend on Pcal with different powers (linear versus quadratic). This can be used to break degeneracies with other cosmological parameters that impact the amplitude of the spectra, such logAs. **Independent from TT, which is good for ground-based experiments and cross-checks**

Data

1. **SPTpol**: **SPTpol TE,EE** from Henning 2018 at 150 GHz over 490 deg2. Multipoles l=50-8000, with polarization noise level measured in the l range 1000 < l < 3000 of this data set is 9.4 μK arcmin. We use a prior on the optical depth of reionization.

2. **Planck 2018**. We use:
   a. **Low-l EE** in polarization SimAll (l = 2 − 29 in EE only)
   b. **High-l TE, EE** Plik (l = 30−1997),
   c. **Low-l TT** Commander (l = 2 − 29 in TT)
   d. **High-l TT** Plik (l = 30−2508 in TT)

SPTpol

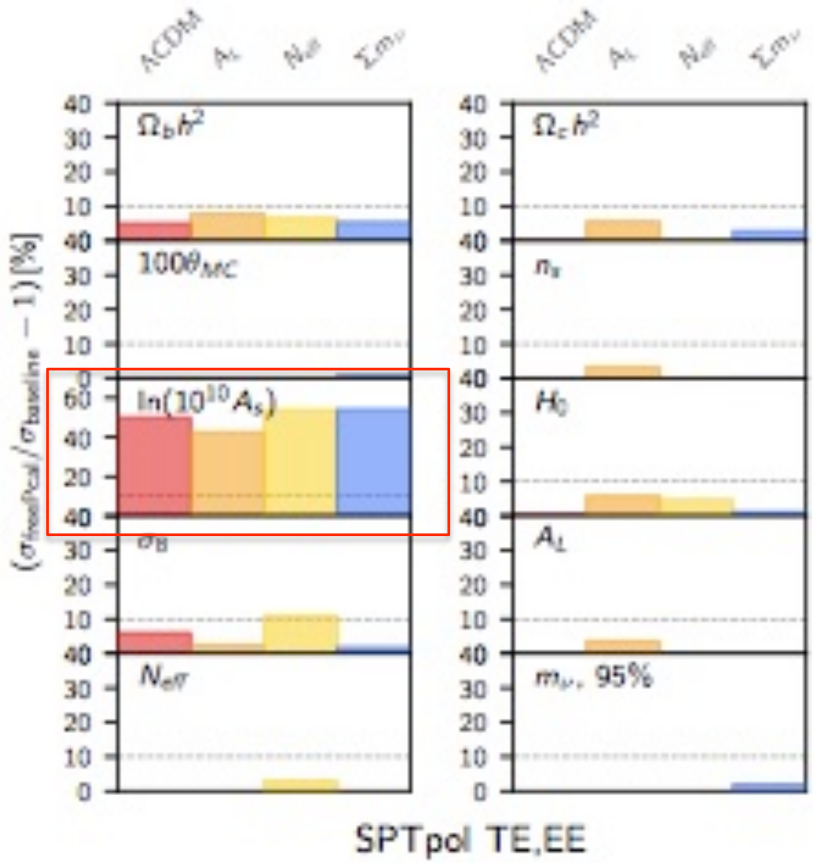


The combination of SPTpol TE and EE data allows one to constrain Pcal at the **2%** level assuming ΛCDM and other.

Even TE and EE alone can place a weak constraint on Pcal since the presence of lensing breaks the degeneracy with logA_s

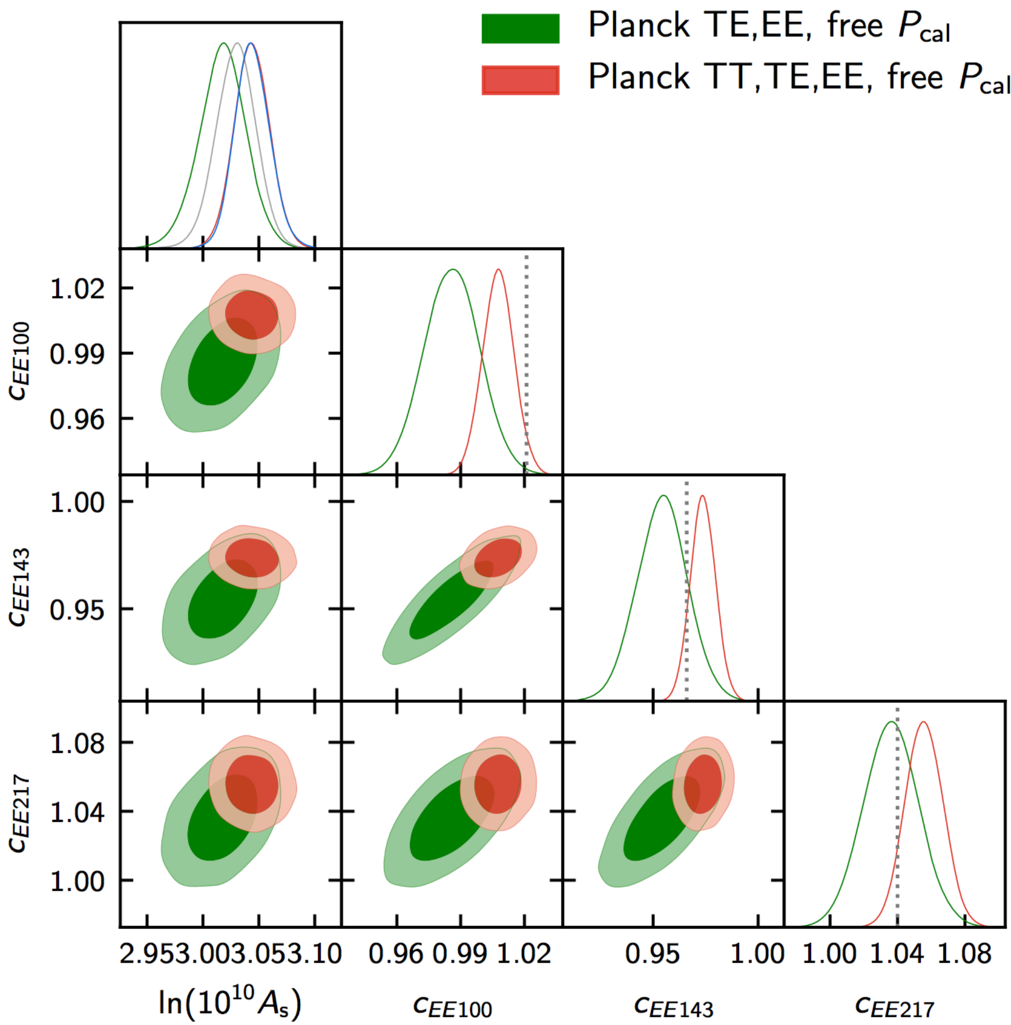
Model	SPTpol TEEE (no P_{cal} prior)
ΛCDM	1.0022 ± 0.0203
ΛCDM+A_L	0.9936 ± 0.0213
ΛCDM+N_{eff}	1.0081 ± 0.0219
ΛCDM+M_ν	0.9976 ± 0.0208

Impact on cosmological parameters



Increase in error bars due to letting Pcal free to vary.
The most affected parameter is logAs, whose error bar increase by ~50%.

Planck



The theory power spectra multiplied by g defined as:

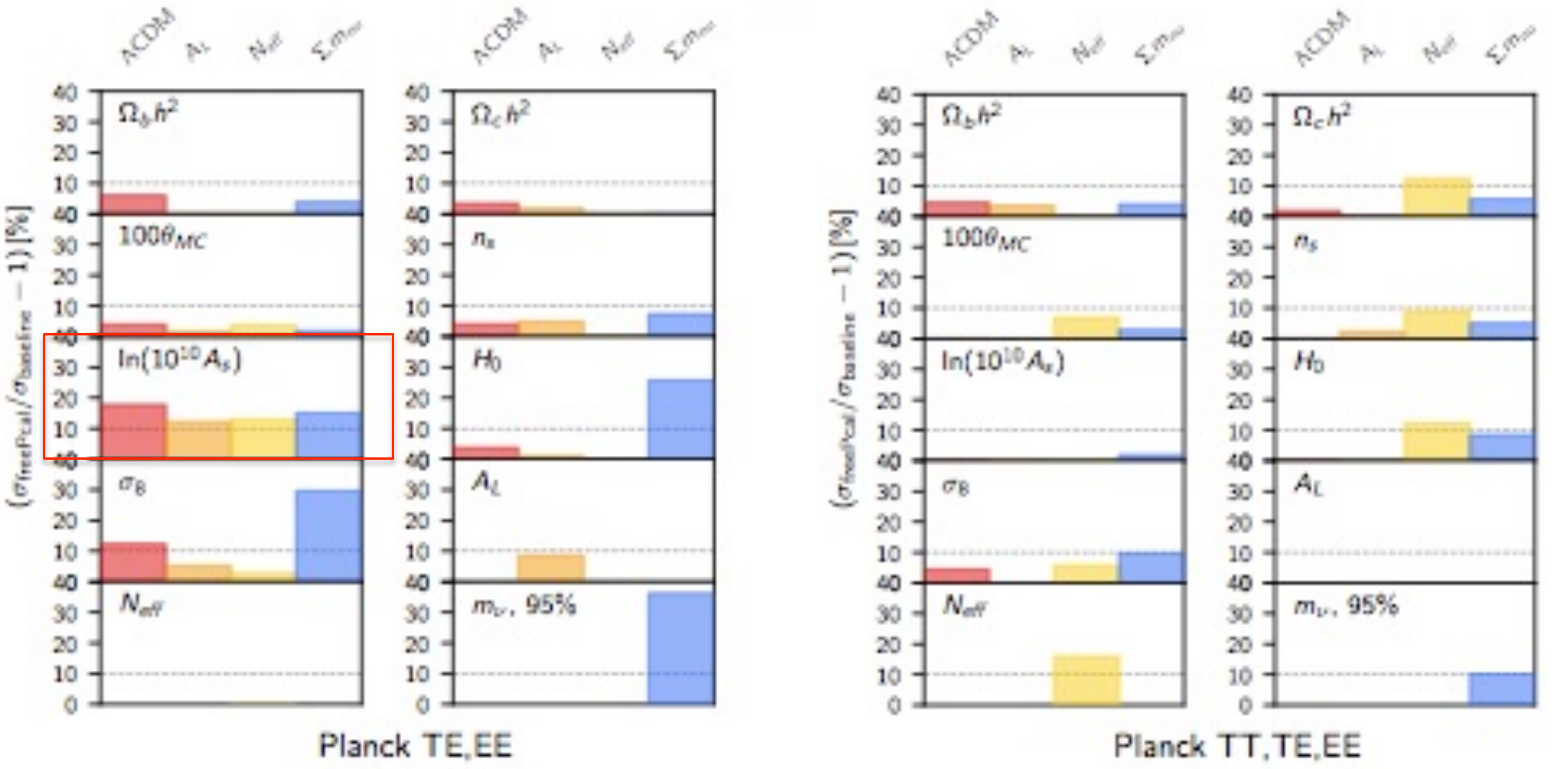
$$g^{XY}_{\nu\times\nu'} = \frac{1}{2y_{\rm P}^2}\left(\frac{1}{\sqrt{c^{XX}_{\nu} c^{YY}_{\nu'}}} + \frac{1}{\sqrt{c^{XX}_{\nu'} c^{YY}_{\nu}}}\right)$$

with $c^{EE}_{\rm freqxfreq} = {\rm Pcal}^2$

Parameter	*Planck* TE, EE+lowE	*Planck* TT,TE, EE+lowE
ΛCDM		
c_{EE100}	0.985± 0.013	1.007 ± 0.007
c_{EE143}	0.954± 0.012	0.973 ± 0.0060
c_{EE217}	1.036± 0.017	1.056 ± 0.011
$P_{\rm cal}{}^{EE100}$	0.9925 ±0.0066	1.0035± 0.0035
$P_{\rm cal}{}^{EE143}$	0.9767 ±0.0064	0.9864± 0.0031
$P_{\rm cal}{}^{EE217}$	1.0178 ±0.0081	1.0276± 0.0051

Planck **TE+EE** can determine polarization calibration parameters at **0.65%, 0.6% and 0.8%** at the map level for 100, 143, 217 GHz. Adding TT reduces this by a factor of 2.

Impact on cosmology



The uncertainty on LogAs increases by ~20%. When neutrino mass is varied, the constraint can worsen by up to ~40%

When also TT data is included, increase in the error bars is strongly reduced.

Forecasts

1. **SPT-3G**: 16000 detectors, over 1500 deg2 of the sky in 5 years (2019-2023). SPT-3G will provide maps at **90, 150 and 220GHz** with white noise levels in temperature of **3.0, 2.2, and 8.8** μK arcmin (multiplied by a factor of 2 for polarization), at resolutions of 1.7, 1.2, 1.1 arcmin respectively. We include foreground and atmosphere contributions to noise.
   We use **l = 100 – 3500** and **Gaussian prior on the optical depth to reionization of σ(τ) = 0.007.**

2. **CMB-S4:** Observe ~70% of the sky with angular resolution < 1.5 arc minutes at 150 GHz and the frequency coverage spans **20 to 270 GHz**. We include foreground and atmosphere contributions to noise.
3. We only use information between **l = 100 – 3500**.

Forecasts: SPT-3G

	$\Omega_b h^2$ [$\times10^{-4}$]	$\Omega_c h^2$ [$\times10^{-3}$]	H_0 [$\times10^{-1}$]	τ [$\times10^{-3}$]	ns [$\times10^{-3}$]	$ln[10^{10}As]$ [$\times10^{-2}$]	$P_{\rm cal}$ [$\times10^{-3}$]
ΛCDM							
SPT-3G TE+EE 150GHz	1.4	2.0	7.5	6.6	8.0	1.3	
SPT-3G TE+EE	1.3	1.9	7.1	6.6	7.7	1.3	
SPT-3G TT+TE+EE	1.4	1.7	6.5	6.4	7.4	1.2	
ΛCDM+P_{cal}							
SPT-3G TE+EE 150GHz	1.6	2.1	8.0	6.6	8.2	2.0	7.6
SPT-3G TE+EE	1.5	2.0	7.7s	6.6	7.9	1.9	7.4
SPT-3G TT+TE+EE	1.4	1.8	6.8	6.4	7.4	1.2	2.1

1. In ΛCDM and other models, SPT-3G **TE and EE** can constrain *P*cal at the level of ~ **0.8%**, either using only one frequency or coadding the information from all the three available frequencies.

2. For cosmological parameters:
   a. In ΛCDM, the largest impact is onconstraint on **log*As***, degraded by **50%**.
   b. In ΛCDM+*M*ν (ΛCDM+*N*eff), uncertainties on **log*As*** degraded by **40% (70%)** . In ΛCDM+*N*eff, $\Omega_b h^2$ and H_0 degraded by ~ **30%** in the model
   c. If one includes the information from TT, there is no degradation in cosmological parameters, and Pcal can be determined at 0.2%.

Forecasts: CMB-S4

	$\Omega_b h^2$ [$\times 10^{-4}$]	$\Omega_c h^2$ [$\times 10^{-3}$]	H_0 [$\times 10^{-1}$]	τ [$\times 10^{-3}$]	ns [$\times 10^{-3}$]	$ln[10^{10} As]$ [$\times 10^{-2}$]	$P_{\rm cal}$ [$\times 10^{-3}$]
ΛCDM							
CMB-S4 TE+EE	0.36	0.71	2.7	5.1	2.5	0.88	
CMB-S4 TT+TE+EE	0.36	0.67	2.5	4.9	2.3	0.85	
ΛCDM+P_{cal}							
CMB-S4 TE+EE	0.42	0.75	2.9	5.1	2.5	1.0	2.0
CMB-S4 TT+TE+EE	0.37	0.70	2.6	4.9	2.3	0.86	0.56

1. In ΛCDM and other models, S4 **TE and EE** can constrain *P*cal at the level of ~ **0.2%** coadding the information from all frequencies.

2. For cosmological parameters:
    a. In ΛCDM, constraints are not affected.
    b. In ΛCDM+*N*eff, uncertainties on **log*As*, $\Omega_b h^2$ and H_0** degraded by **30%**
    c. If one includes the information from TT, there is no degradation in cosmological parameters, and Pcal can be determined at <0.1%.

Conclusions

1. Uncorrected polarization efficiencies at the detector level can be modeled as **effective polarization calibrations** at the map level.
2. We point out that the different functional dependence of TE and EE on **Pcal** allows one to let Pcal free to vary at parameter estimation level.
3. We find that leaving **Pcal free** to vary mostly impacts the estimates on the **amplitude of scalar perturbations.** This information can be completely recovered once we include information from TT.
4. SPTpol can set constraints on **Pcal by 2%** at the map level, while **Planck by <1%**.
5. Future experiments such **SPT-3G and S4** will be able to constrain Pcal at **sub-percent level** just by using the combination of TE and EE.
6. Also in this case, the most affected parameter will be **logAs**.