Tensions related to the lensing of CMB power spectra

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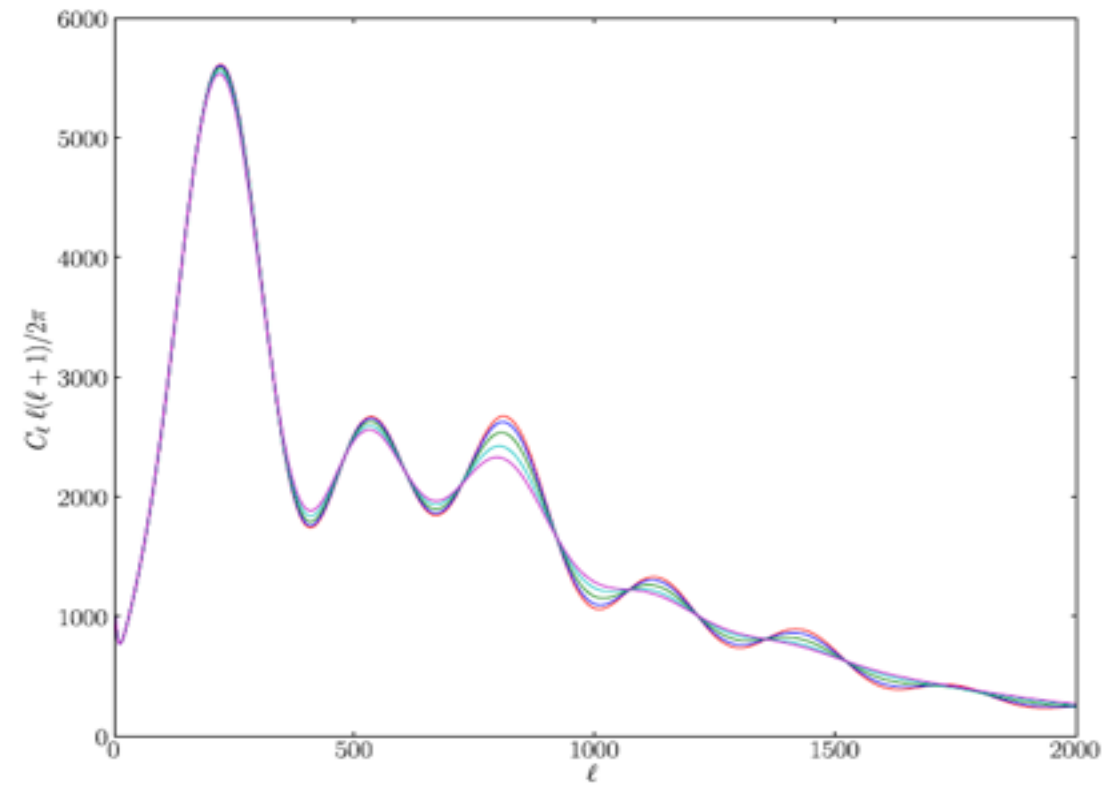
- *Relieving tensions related to the lensing of the CMB temperature power-spectra*
  [Couchot et al., A&A 597 A126 (2017), arXiv:1510.07600]
- *Cosmology with the CMB temperature-polarization correlation*
  [Couchot et al., A&A 602 A41 (2017), arXiv:1609.09730]
- *Cosmological constraints on the neutrino mass including systematic uncertainties*
  [Couchot et al., A&A forthcoming, arXiv:1703.10829]

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

The A_L parameter

- **weak lensing enters the prediction of the CMB spectrum through a convolution of the unlensed spectrum with the lensing potential power spectrum** C_ℓ^Ψ
  - ➡ smooth out the acoustic peaks



- **The A_L parameter is a fudge factor defined as:**
  - $A_L = 0$: weak lensing ignored
  - $A_L = 1$: standard ΛCDM

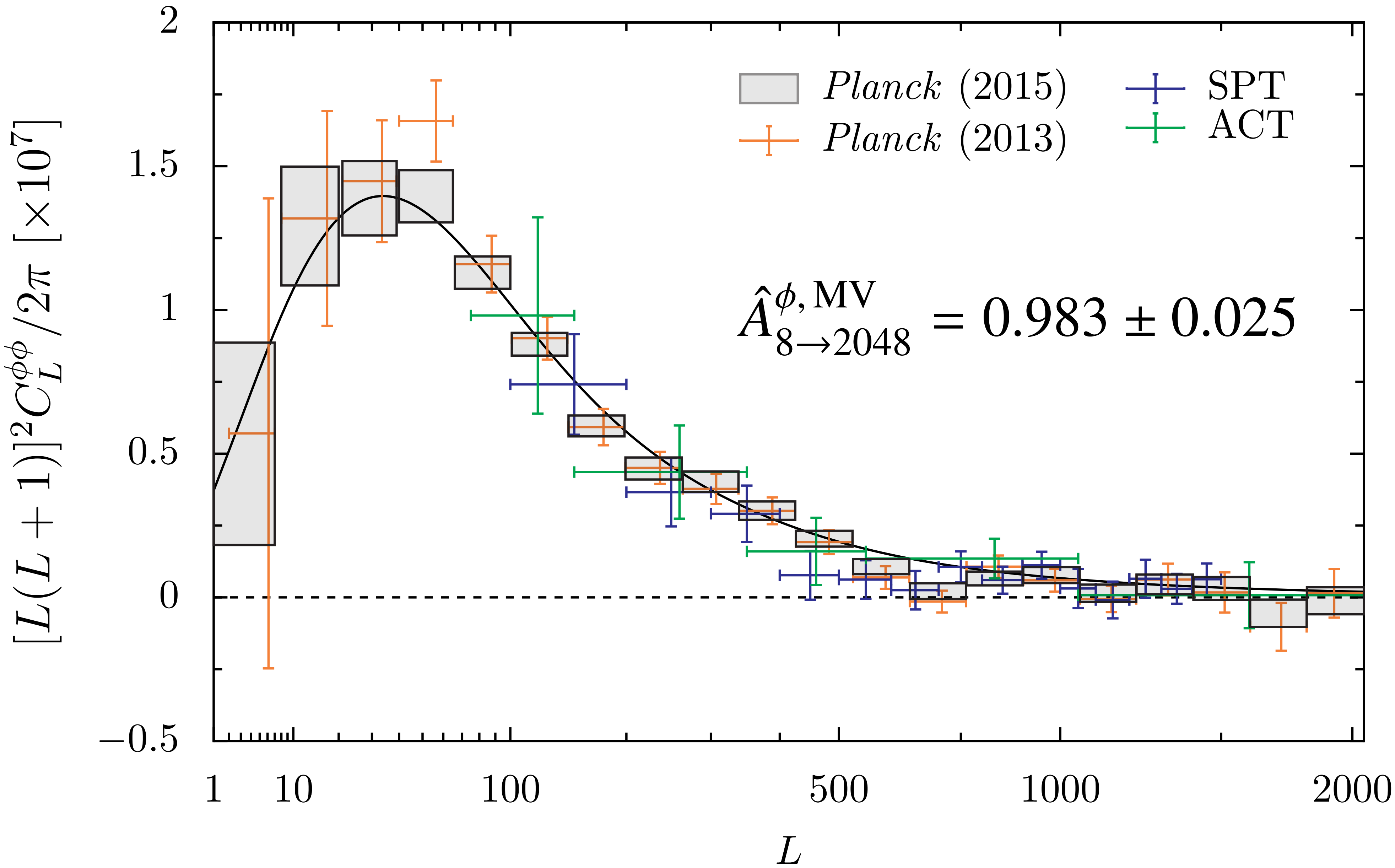
$$C_\ell^\Psi \rightarrow A_L C_\ell^\Psi$$

- **Measuring $A_L \neq 1$ indicates either a problem in the model (e.g. modification of the gravity) or remaining systematics in the data**

[Lewis&Challinor, Phys. Rept. 429 1 (2006)]
[Calabrese et al, PRD 77 123531 (2008)]

CMB lensing

- **From Planck** **gravitational lensing** **measurements, overall lensing amplitude estimate is consistent with our fiducial LCDM model**



[Planck 2015 results. XV. A&A, 594, A15 (2016)]

A_L from Planck

- But from Planck CMB anisotropies spectra, LCDM+A_L gives

$$A_{\mathrm{L}} = 1.22 \pm 0.10$$

[Planck 2015 results. XIII, A&A 594, A13 (2016)]

Where does this tension come from ?
What can we do to relieve it ?

Setting the stage

Planck constraints from CMB anisotropies are derived from

- **theoretical model (Boltzmann solver)**
  - **CAMB,** Lewis&Challinor (camb.info)
  - **CLASS,** J. Lesgourgues (class-code.net) [arXiv:1104.2932]

- **CMB data (two-component likelihoods)**
  - **low-ℓ** (lowTEB)
    temperature and polarisation map based likelihood
  - **high-ℓ** (Plik but also Hillipop, CamSpec, Mspec)
    gaussian likelihood (temperature & TE/EE polarisation)

- **Statistical analysis (parameter estimation)**
  - **Bayesian inference using Monte Carlo Markov Chains** to explore the likelihood function (usual in cosmology)
  - **Profile likelihoods** (more common in particle physics)

camel.in2p3.fr

A_L from Plik+lowTEB

- **Results from Planck:**
  [Planck 2015 results. XIII, A&A 594, A13 (2016)]

$$A_{\rm L} = 1.22 \pm 0.10 \quad (\texttt{Plik}{+}\mathrm{lowTEB},\ \texttt{camb}/\mathrm{MCMC})$$

- **Theoretical impact from the Boltzmann solver:**

$$A_{\rm L} = 1.24 \pm 0.10 \quad (\texttt{Plik}{+}\mathrm{lowTEB},\ \texttt{class}/\mathrm{MCMC})$$

- **Systematic impact from the statistical analysis:**

$$A_{\rm L} = 1.26^{+0.11}_{-0.10} \quad (\texttt{Plik}{+}\mathrm{lowTEB},\ \texttt{class}/\mathrm{profile})$$

✓ **theoretical uncertainties (but low level)**
✓ **small volume effect**
(difference between best-fit and posterior maximum)

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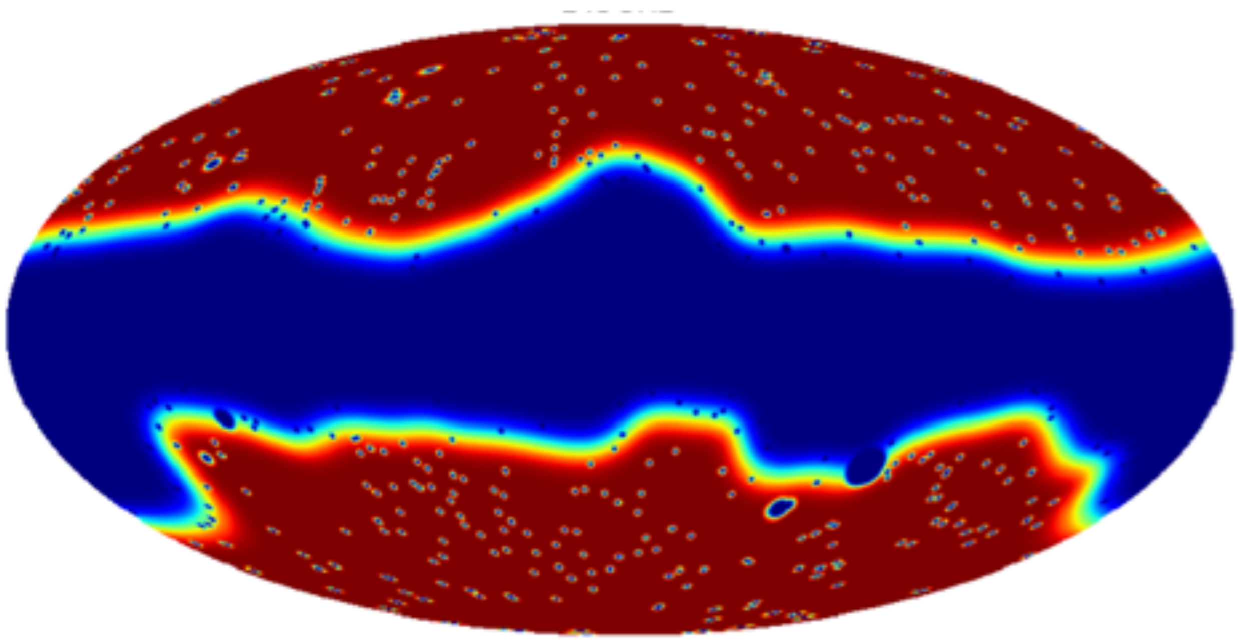
The Hillipop high-ℓ likelihood

One of the high-ℓ Planck likelihood (ℓ>50) in **temperature and polarisation** based on cross-spectra of the 100, 143 and 217GHz maps of the 2015 Planck release

$$C_\ell^{XY} = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} a_{\ell m}^{X} a_{\ell m}^{*Y}$$

- regions with high level of **foregrounds contamination** are **masked** before computing spectra



- **foregrounds residuals** are modeled in **Hillipop** as power spectra templates from Planck measurements
  - Galactic emission (dust)
  - Galaxy clustering (CIB)
  - SZ (thermal, kinetic and SZxCIB)
  - Point sources

[Planck 2015 results. XI, A&A 594, A11 (2016)]
[Couchot et al., A&A 602 A41 (2017), arXiv:1609.09730]

The high-ℓ likelihoods

- **The main differences with Plik* ?**

1. we use all 15 cross-spectra** from 6 maps
   v.s. only 7 selected cross-spectra in **Plik**
2. intercalibration coefficients are defined at the map level
   v.s. spectra level in **Plik**
3. Point sources are identified and separated from high latitude cirrus dust clouds before masking
   v.s. mixed in **Plik** masks
4. residual foregrounds are modeled using Planck measurements for SED and spectral shape
   v.s. analytical models for **Plik** with additional constraint in the SZ sector derived from ACT data: $A^{\rm SZ} = A^{\rm kSZ} + 1.6\,A^{\rm tSZ} = 9.5\,\mu{\rm K}^2$ and a dispersion $3\mu{\rm K}^2$

(*) [Planck 2015 results. XI, A&A 594 A11 (2016)]
(**) [Tristram et al., MNRAS 358 833 (2005)]

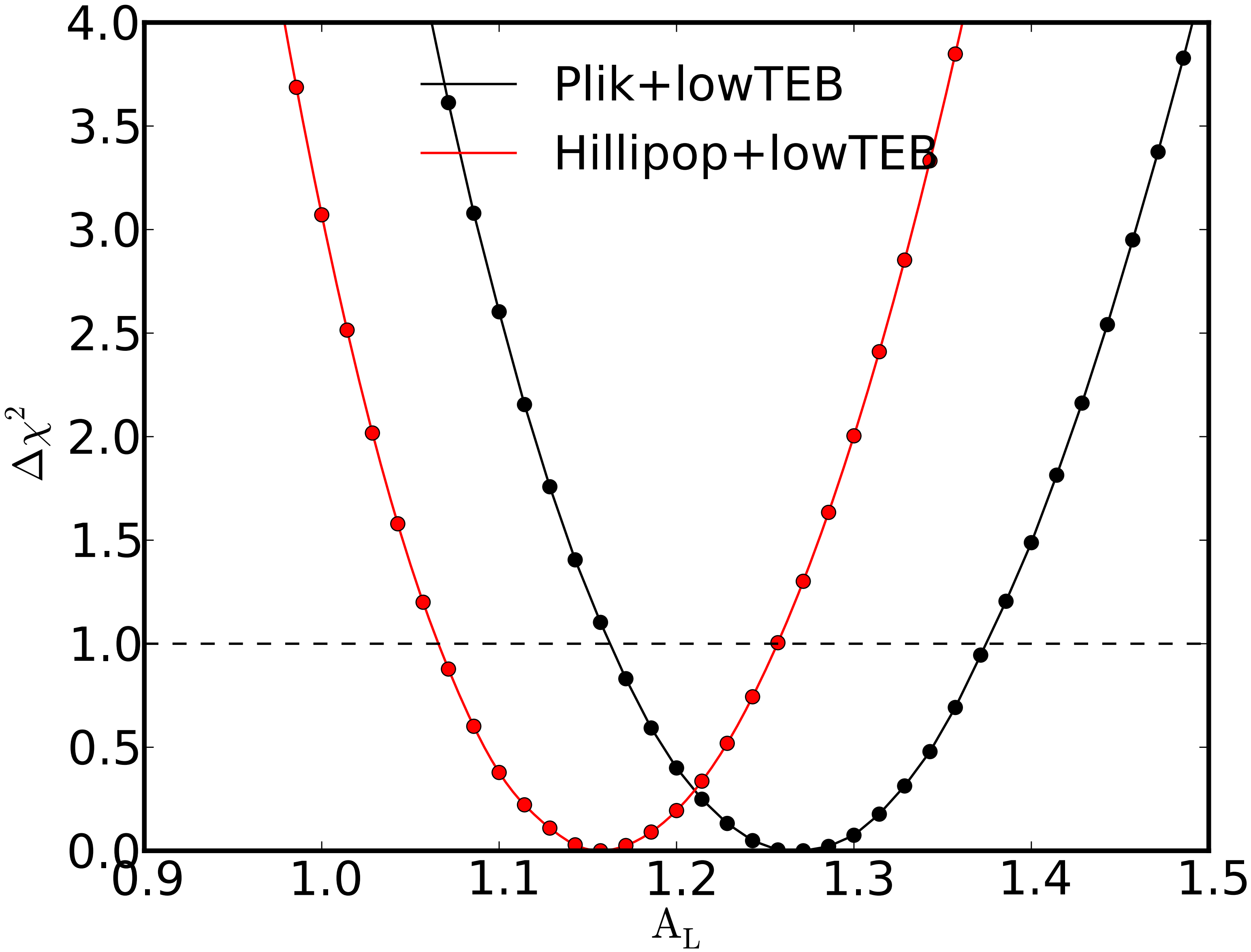
ΛCDM results

- **Comparison between** Hillipop **and** Plik

Parameters	Plik + lowTEB	Hillipop T + lowTEB
$\Omega_b h^2$	0.02225 ± 0.00023	0.02220 ± 0.00022
$\Omega_c h^2$	0.1197 ± 0.0022	0.1196 ± 0.0022
$100\theta_s$	1.04188 ± 0.00044	1.04178 ± 0.00044
τ	0.078 ± 0.019	0.070 ± 0.018
$log(10^{10} A_s)$	3.089 ± 0.036	3.071 ± 0.035
$\mathrm{n_s}$	0.9655 ± 0.0062	0.9659 ± 0.0060

[Planck 2015 results. XI, A&A 594, A11 (2016)]

A_L profile likelihood



$$A_{\rm L} = 1.26^{+0.11}_{-0.10} \quad (\texttt{Plik}{+}\text{lowTEB})$$

$$A_{\rm L} = 1.16^{+0.10}_{-0.09} \quad (\text{Hillipop} + \text{lowTEB})$$

[Couchot et al., A&A 597 A126 (2017), arXiv:1510.07600]

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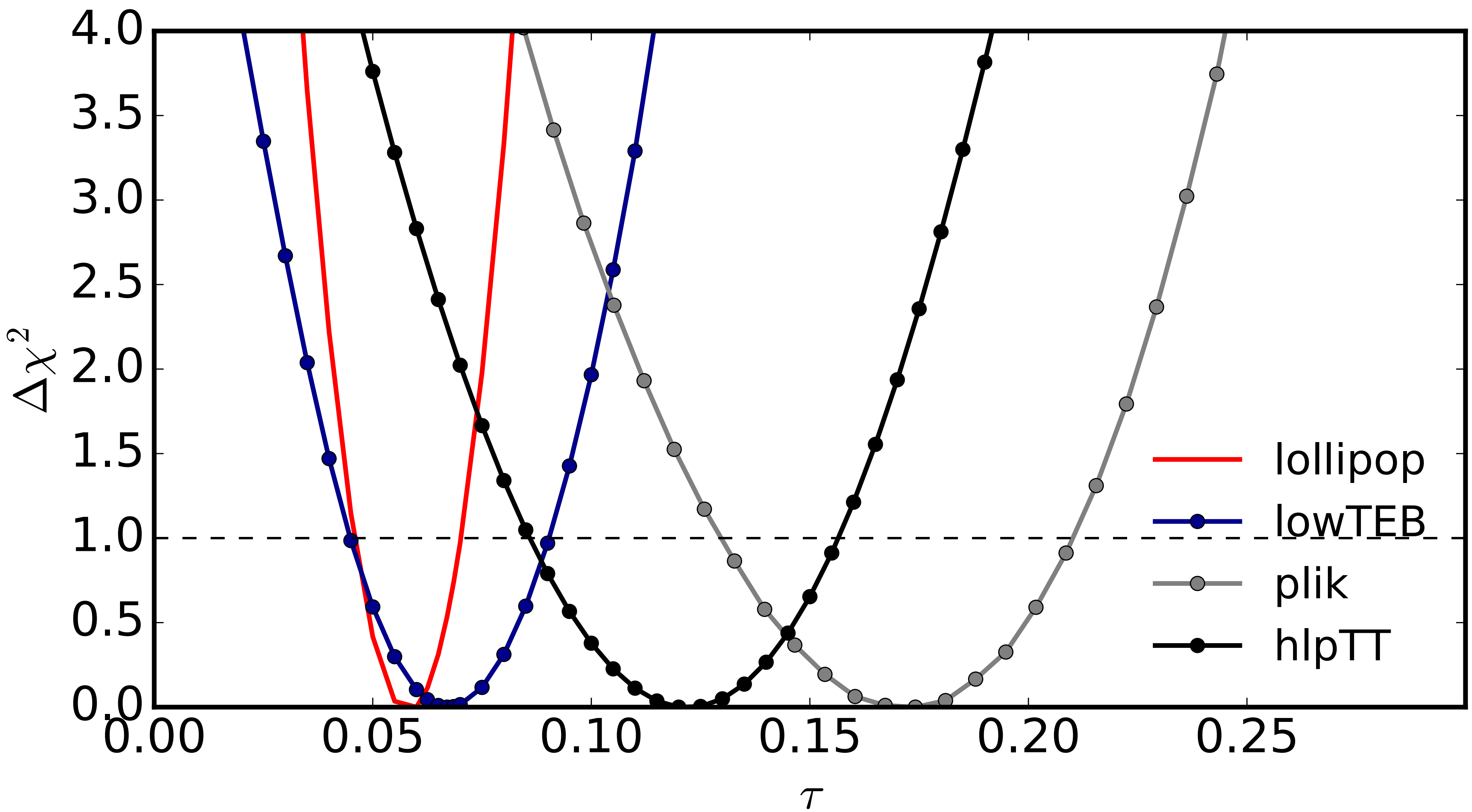
- τ mainly driven by the low-ℓ data
- τ and A_s are correlated through the amplitude of spectra $C_\ell \propto A_s e^{-2\tau}$

why different ?

tension between low-ℓ and high-ℓ data ?

optical depth profile likelihoods



low-ℓ

$$\tau = 0.067^{+0.023}_{-0.021} \quad (\mathrm{lowTEB})$$

$$\tau = 0.058^{+0.012}_{-0.012} \quad (\mathrm{lollipop})$$

high-ℓ

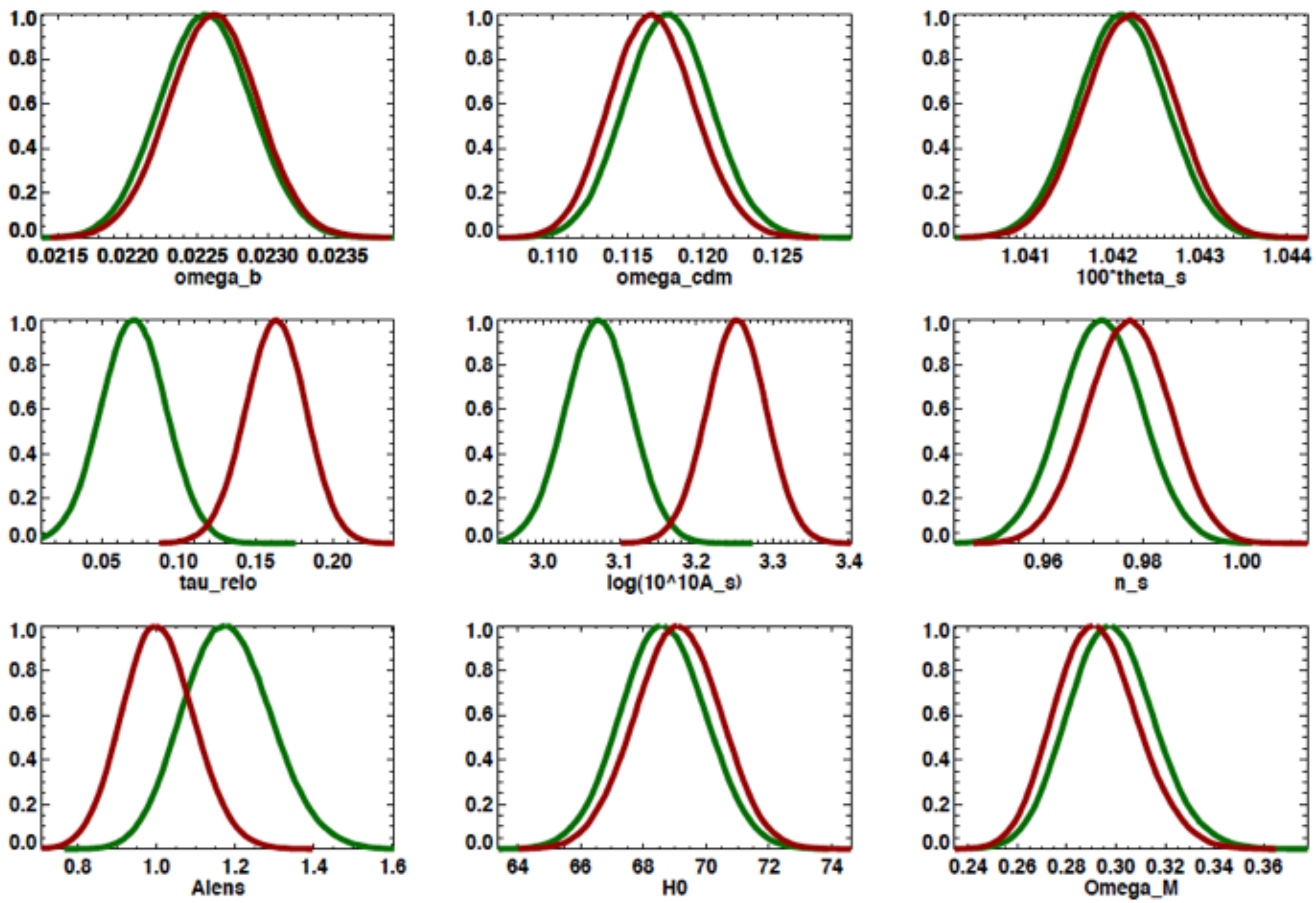
$$\tau = 0.172^{+0.038}_{-0.042} \quad (\texttt{Plik})$$

$$\tau = 0.122^{+0.034}_{-0.036} \quad (\mathrm{Hillipop})$$

"Constraints on reionization history"
[Planck intermediate results. XLVII. A&A, 596, A108 (2016)]

optical depth and A_L

low-ℓ: pulls $\tau \searrow$
high-ℓ: amplitude $C_\ell \propto A_s e^{-2\tau} \rightarrow A_s \searrow$
high-ℓ: to preserve lensing information $(C_\ell^\Phi \propto A_s A_L)$: $A_L \nearrow$



Planck
+
τ prior =0.07
τ prior =0.17

additional data

- **combination with CMB lensing likelihood**

$$A_L = 1.05 \pm 0.06 \quad \text{(Plik+lowTEB+lensing)}$$
$$A_L = 1.06 \pm 0.06 \quad \text{(Hillipop+lowTEB+lensing)}$$

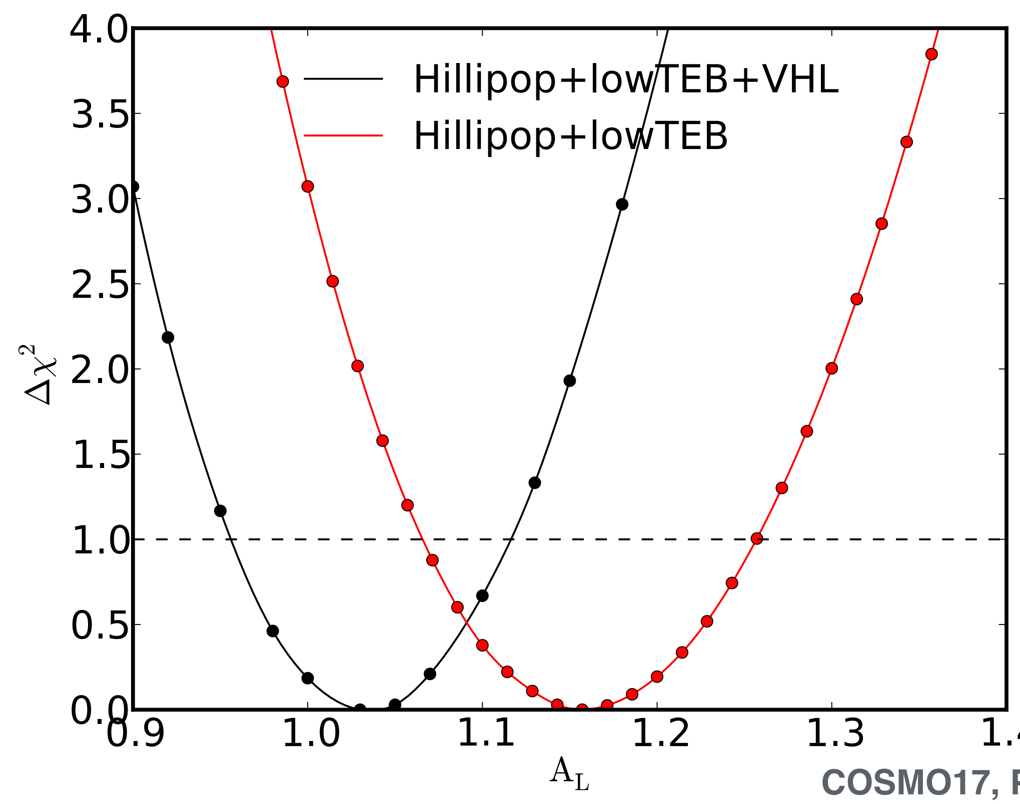
  - with **lower optical depth** (τ = 0.066 ± 0.016)

- **combination with Very-High-ℓ CMB data (ACT+SPT)**

$$A_L = 1.03 \pm 0.08 \quad \text{(Hillipop+lowTEB+VHL)}$$

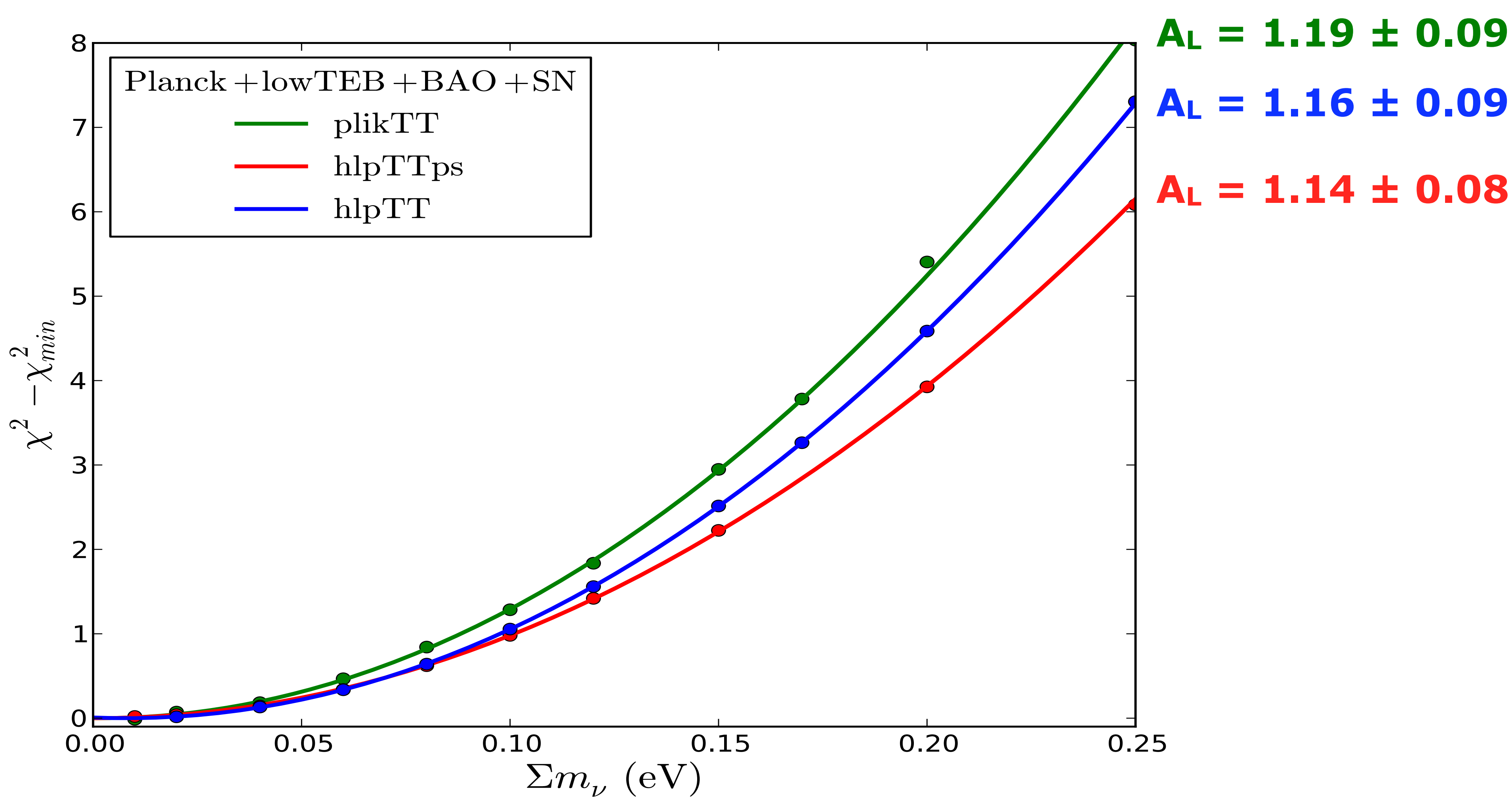
  - foregrounds better constrained
  - **optical depth** closer to low-ℓ likelihoods (τ = 0.059 ± 0.017)

Parameter	Hillipop+lowTEB +VHL
$\Omega_b h^2$	0.02200 ± 0.00019
$\Omega_c h^2$	0.1200 ± 0.0020
$100\theta_s$	1.04200 ± 0.00040
τ	0.059 ± 0.017
n_s	0.9630 ± 0.0054
$\ln(10^{10}A_s)$ . . .	3.045 ± 0.032
Ω_m	0.315 ± 0.012
H_0	67.19 ± 0.88
σ_8	0.811 ± 0.013



neutrinos

- **tension on A_L shows up on the neutrino sector**
  - high value for A_L → **artificially tighter constraints** on Σm_ν



	ΛCDM+	ΛCDM+
PlanckTT+lowTEB BAO+SNIa	Σm_ν limit (eV)	A_L
hlpTT	0.18	1.16±0.09
hlpTTps	0.20	1.14±0.08
PlikTT	0.17	1.19±0.09

[Couchot et al., A&A forthcoming, arXiv:1703.10829]

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PlanckTT+lowTEB BAO+SNIa+lensing	Σm_ν limits (eV)	A_L
`hlpTT`	0.21	1.06 ± 0.05
`hlpTTps`	0.21	1.06 ± 0.06
`PlikTT`	0.23	1.05 ± 0.06

- **only when adding to Planck data:**
  - new version of BAO data (DR12)
  - optical depth from [Planck Collaboration Int. XLVII 2016] $\tau_{\rm reio} = 0.058 \pm 0.012$

we can obtain

Σm_ν < 0.17 [incl. 0.01 (foreground syst.)] eV at 95% CL

[Couchot et al., A&A forthcoming, arXiv:1703.10829]

Conclusions

- **We investigated the tension on A_L using Planck CMB anisotropie data**
- **This can be explained neither by theoretical uncertainties nor by volume effects in the likelihood sampling (difference between bestfit and posterior maximum)**
- **Comparing with the alternative Planck high-ℓ likelihood** Hillipop **(including different foreground models and slight changes in the data treatment), we found a lower A_L indicating an effect from systematic residuals (2.6σ with** Plik+lowTEB**, 1.6σ with** Hillipop+lowTEB**)**
- **We showed that this tension is directly related to a tension on τ between low-ℓ and high-ℓ likelihoods (2.2σ with** Plik**, 1.3σ with** Hillipop**)**
- **Impact on cosmological parameters**
  - ΛCDM: a significant effect on the reionization optical depth
  - extensions: upper limit on neutrino masses is affected (artificially tighter)

end