

COSMOS
Astroparticle and Fundamental physics with the CMB
University of Ferrara

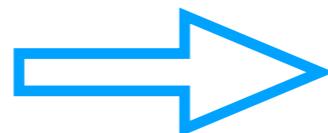
Cosmological constraints on the neutron lifetime

Laura Salvati



Introduction

Cosmic Microwave Background
+
Big Bang Nucleosynthesis



**Independent evaluation of
the neutron lifetime**

- ◆ Planck 2016 results
- ◆ direct astrophysical observations of light elements
- ◆ latest evaluation from particle physics experiments



$$Y_p = \frac{4n_{\text{He}}}{n_b}$$

BBN: theoretical predictions

Cyburt et al., Rev. Mod. Phys. 88 (2016) 015004

$$Y_p = 0.24703 \left(\frac{10^{10} \eta}{6.10} \right)^{0.039} \left(\frac{N_\nu}{3.0} \right)^{0.163} \left(\frac{G_N}{G_{N,0}} \right)^{0.35} \left(\frac{\tau_n}{880.3s} \right)^{0.73} \\ \times [p(n, \gamma)d]^{0.005} [d(d, n)^3\text{He}]^{0.006} [d(d, p)t]^{0.005}$$

$$\frac{D}{H} \propto \tau_n^{0.41}, \quad \frac{^3\text{He}}{H} \propto \tau_n^{0.15}, \quad \frac{^7\text{Li}}{H} \propto \tau_n^{0.43}$$



$$Y_p(\omega_b, \Delta N_{\text{eff}}, \tau_n) = \left(\frac{\tau_n}{880.3} \right)^{0.728} \cdot \left[0.2311 + 0.9502 \cdot \omega_b - 11.27 \cdot \omega_b^2 + \right. \\ \left. + \Delta N_{\text{eff}} \cdot (0.01356 + 0.008581 \cdot \omega_b - 0.1810 \cdot \omega_b^2) + \right. \\ \left. + \Delta N_{\text{eff}}^2 \cdot (-0.0009795 - 0.001370 \cdot \omega_b + 0.01746 \cdot \omega_b^2) \right]$$

Pisanti et al., Comput. Phys. Commun. 178 (2008) 956

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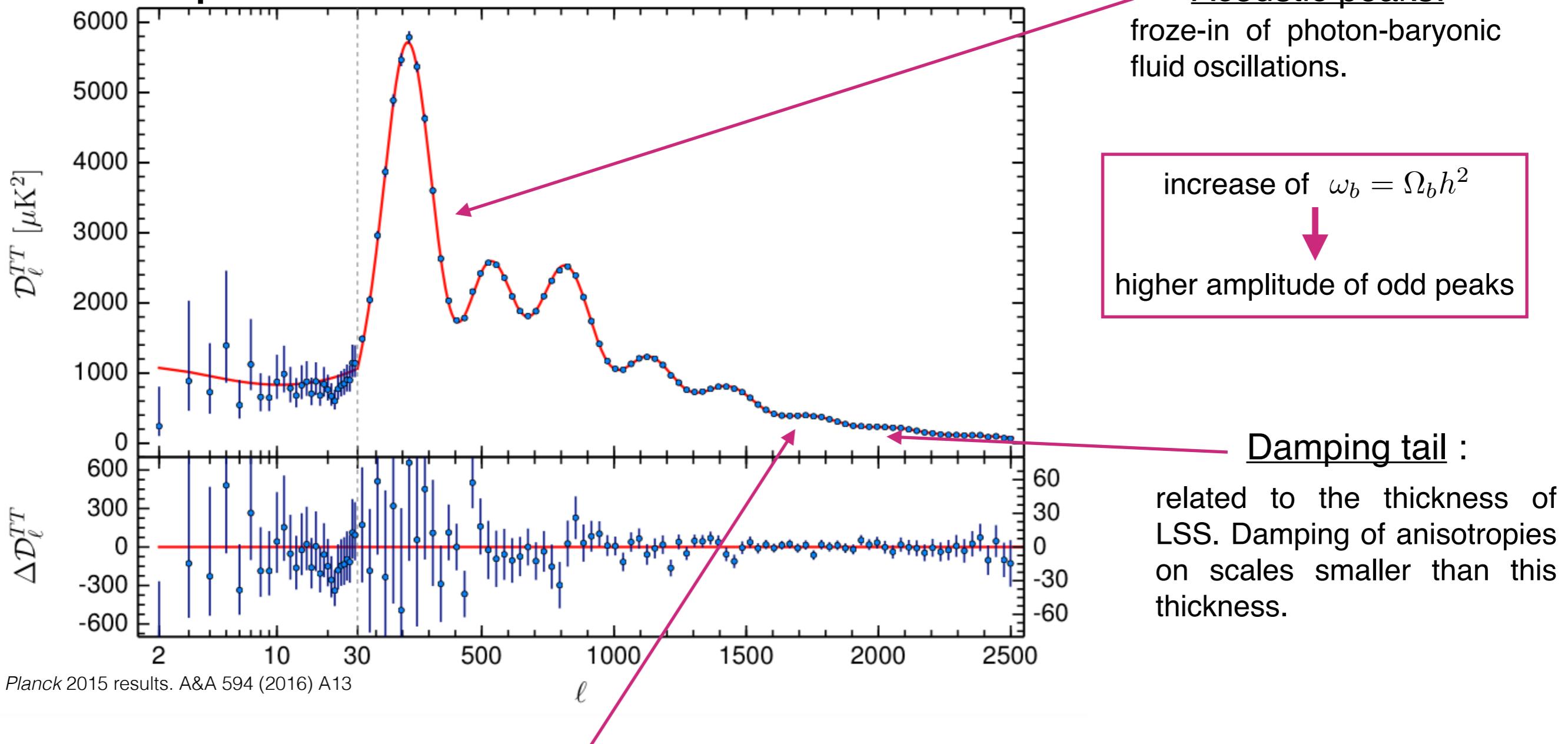
Standard BBN

- ◆ $N_{\text{eff}} = 3.046$ (LCDM)
- ◆ $\tau_n = (880.3 \pm 1.1) [\text{s}]$

K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014)

Cosmic Microwave Background

Planck TT spectrum



Planck 2015 results. A&A 594 (2016) A13

Helium recombination :

- it affects free electrons fraction.
- Effects can be seen on the damping tail: increase of the diffusion damping.

increase of Y_p

higher suppression at high ℓ

CMB and BBN: Planck

Planck Collaboration
A&A 594 (2016) A13

(95% c.l.)

Parameter	<i>Planck</i> TT,TE,EE + lowP
$\Omega_b h^2$	$0.02225^{+0.00032}_{-0.00030}$
Y_p^{BBN}	$0.24667^{+(0.00014)}_{-(0.00014)}{}^{+0.00062}_{-0.00062}$
y_{DP}	$2.614^{+(0.057)}_{-(0.060)}{}^{+0.13}_{-0.13}$

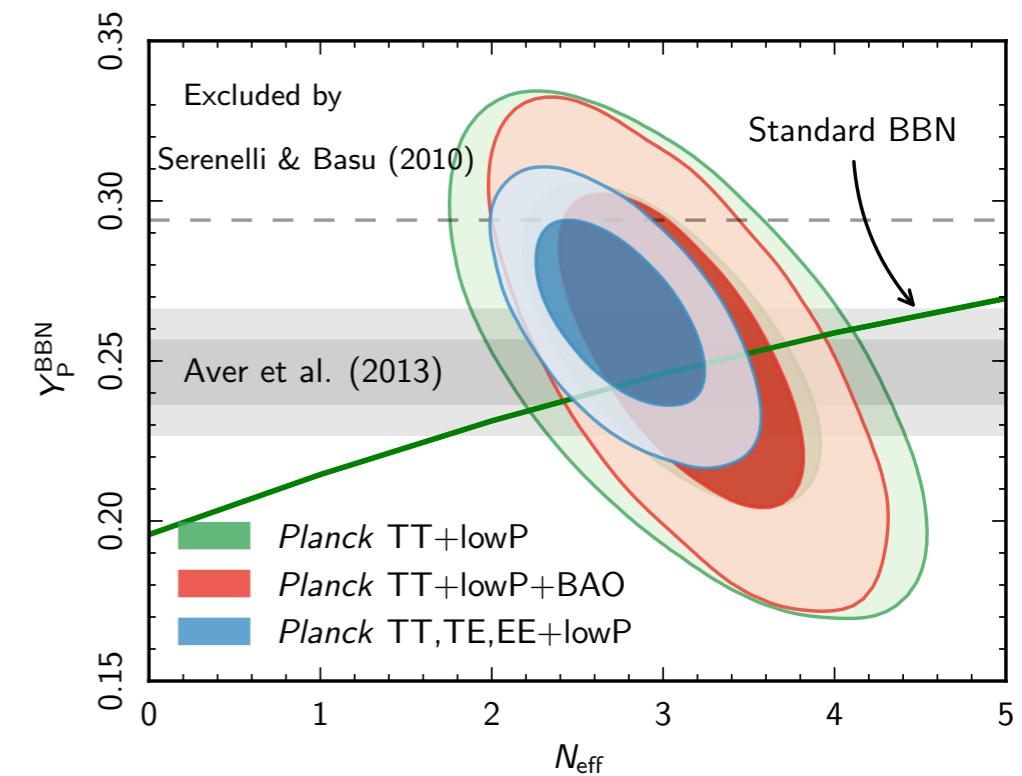
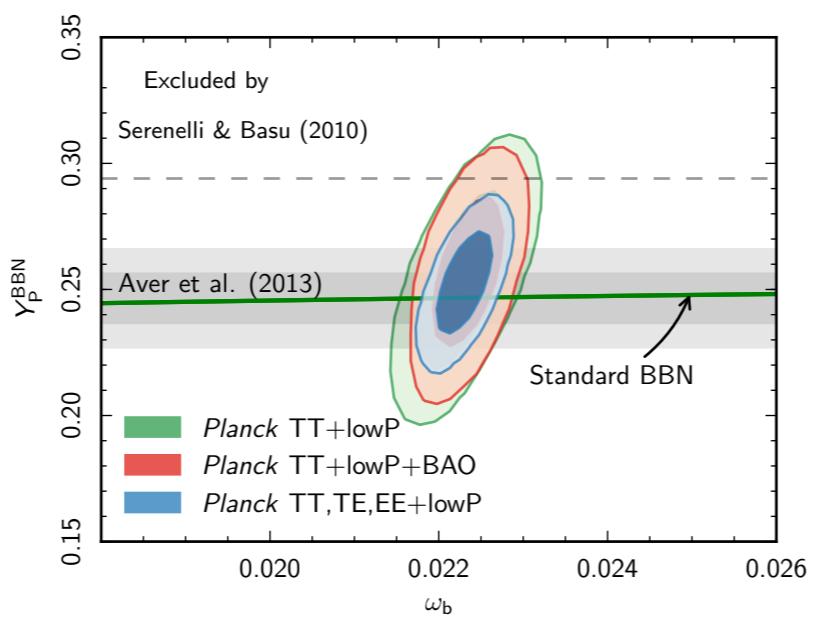
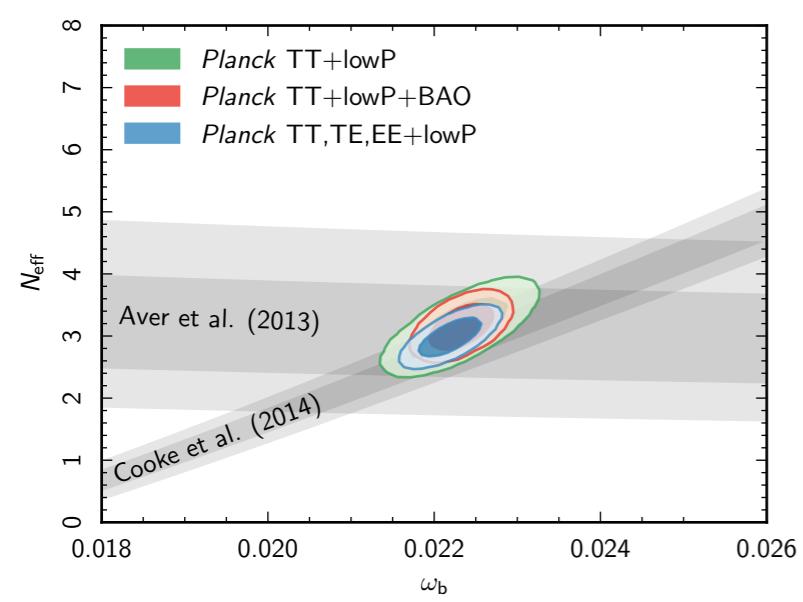
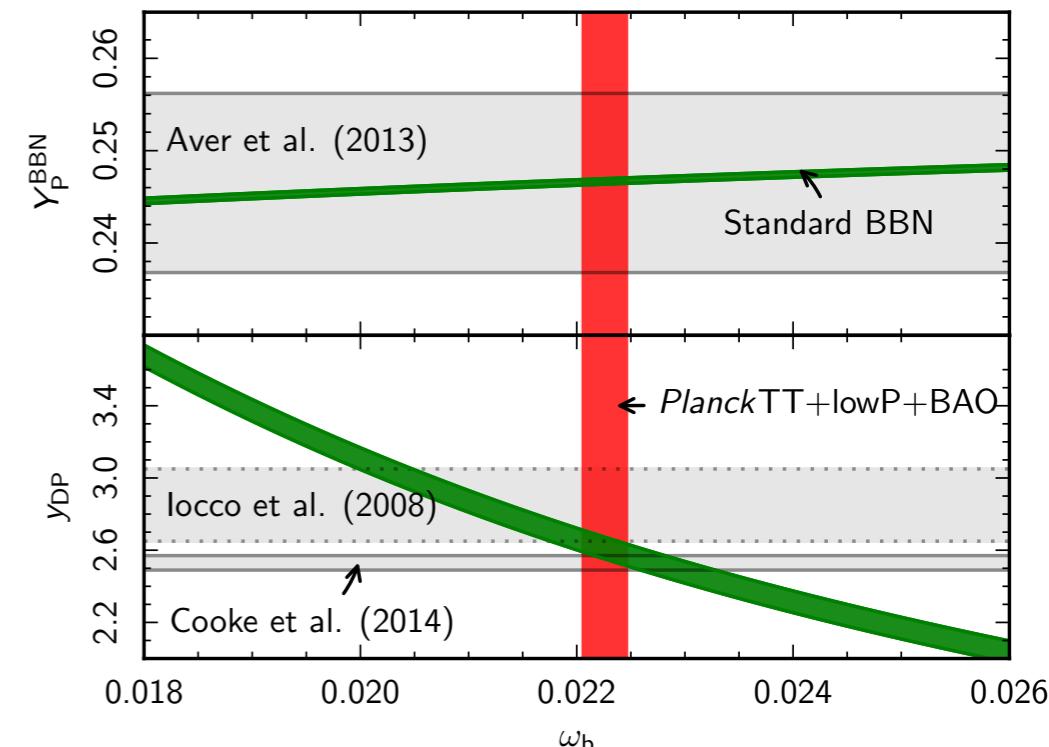
from uncertainty on neutron lifetime:
 $\sigma(Y_p^{\text{BBN}}) = 0.0003$

$$y_{\text{DP}} = 10^5 \frac{n_D}{n_b}$$

from uncertainty on $D(p, \gamma)^3\text{He}$:
 $\sigma(y_{\text{DP}}) = 0.06$

(PArthENoPe code)

Pisanti et al., Comput. Phys. Commun. 178 (2008) 956



Particle Data Group

$\tau_n = 880.3 \pm 1.1 [s]$
PDG 2014



bottle method
 $\tau_n = 879.6 \pm 0.8 [s]$

beam method
 $\tau_n = 888.0 \pm 2.0 [s]$

$\sim 4\sigma$ discrepancy

PDG 2018 <http://pdg.lbl.gov>

VALUE (s)

880.2± 1.0 OUR AVERAGE
880.2± 1.2
887.7± 1.2± 1.9
882.5± 1.4± 1.5
880.7± 1.3± 1.2
878.5± 0.7± 0.3
889.2± 3.0± 3.8
882.6± 2.7

DOCUMENT ID

Error includes scale factor of 1.9. See the ideogram below.
1 ARZUMANOV 15 ★ CNTR UCN double bottle ●
2 YUE 13 CNTR In-beam n , trapped p ○
3 STEYERL 12 CNTR UCN material bottle ●
PICHLMAIER 10 CNTR UCN material bottle ●
SEREBROV 05 CNTR UCN gravitational trap ●
BYRNE 96 CNTR Penning trap ○
4 MAMPE 93 CNTR UCN material bottle ●

TECN

COMMENT

bottle method
 $\tau_n = 879.6 \pm 0.7 [s]$

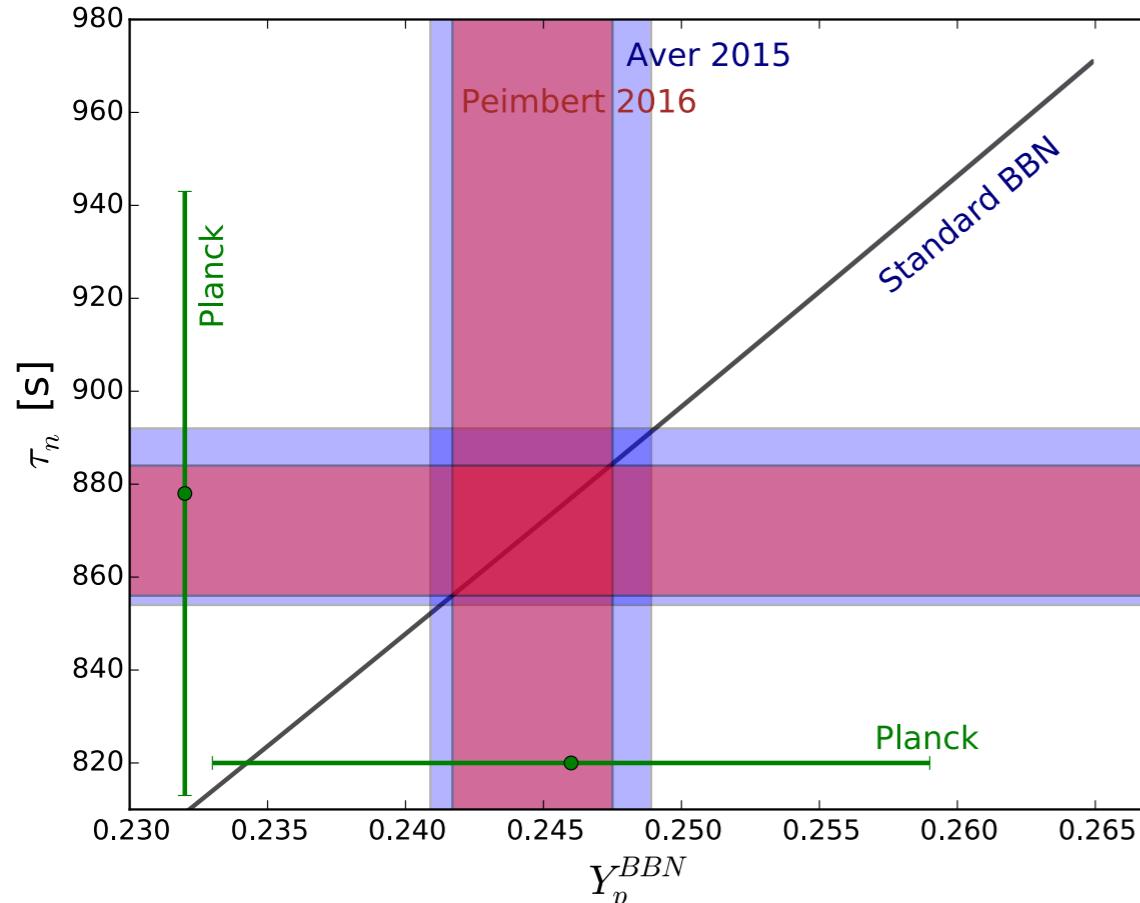
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beam method
 $\tau_n = 888.0 \pm 2.0 [s]$

Neutron lifetime

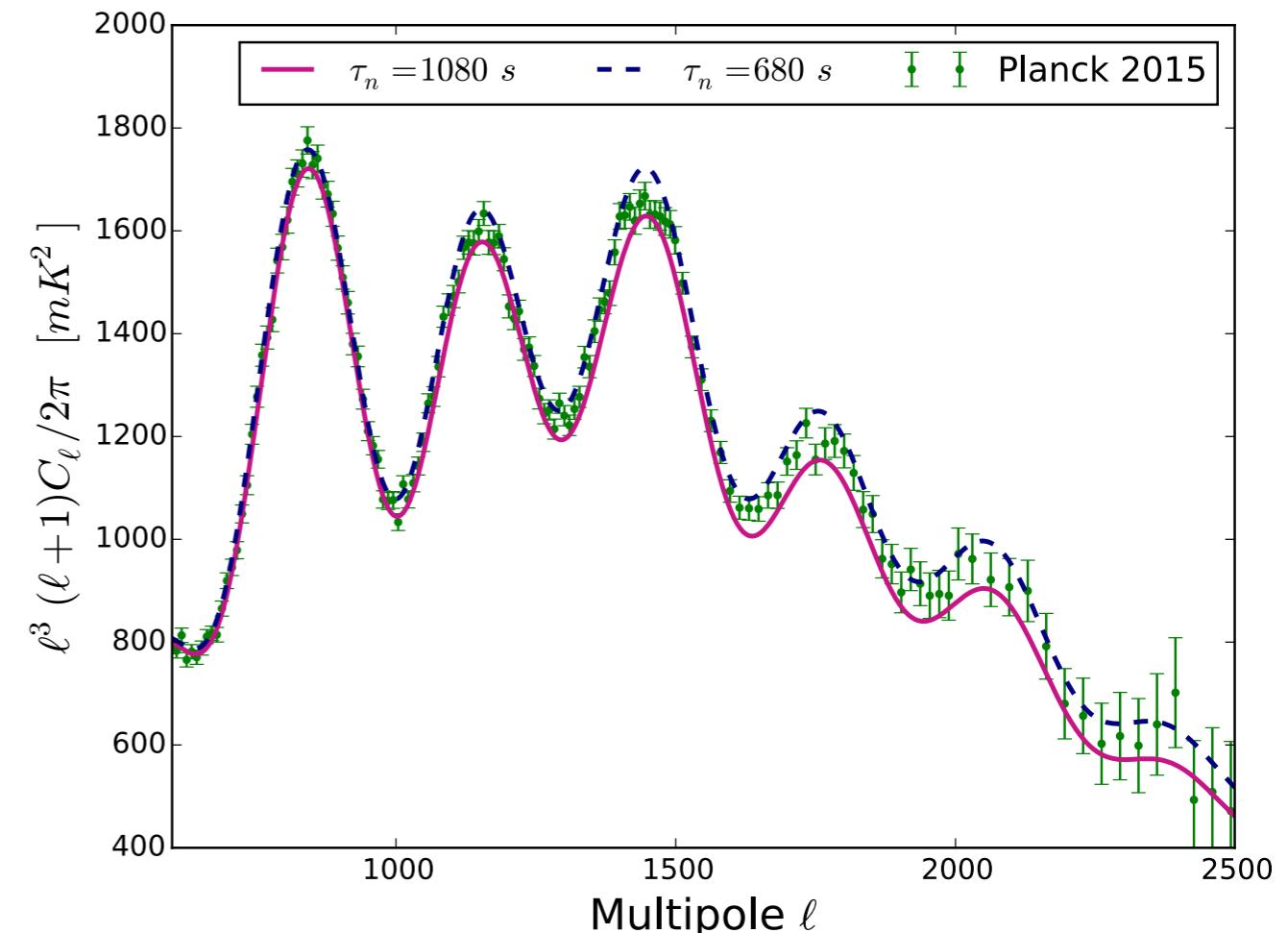
based on: **Salvati et al.**
JCAP 1603 (2016) no.03, 055

CMB: ω_b, Y_p + BBN: $Y_p(\omega_b, N_{\text{eff}}, \tau_n)$



Aver 2015
Aver et al., JCAP 1507 (2015) no.07, 011

Peimbert 2016
Peimbert et al., Rev. Mex. Astron. Astrofis. 52 (2016) 419

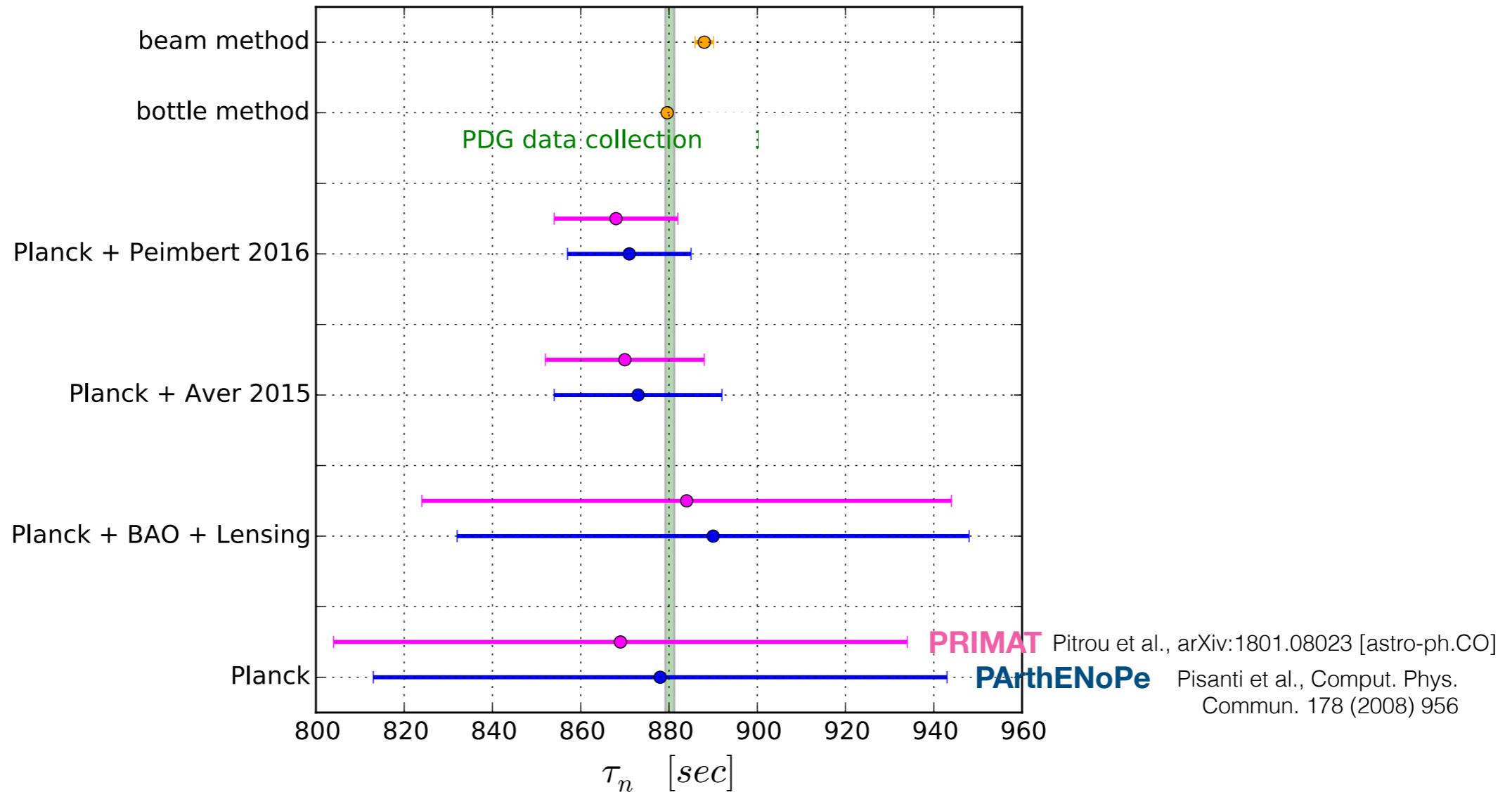


$$Y_p = 0.2449 \pm 0.0040$$

$$Y_p = 0.2446 \pm 0.0029$$

Neutron lifetime

based on: **Salvati et al.**
JCAP 1603 (2016) no.03, 055



Datasets	Y_p^{BBN}	τ_n [s]
<i>Planck</i> (PArthENoPe)	0.246 ± 0.013	878 ± 65
<i>Planck + Lensing + BAO</i> (PArthENoPe)	0.248 ± 0.012	890 ± 58
<i>Planck + Aver2015</i> (PArthENoPe)	0.2451 ± 0.0040	873 ± 19
<i>Planck + Peimbert2016</i> (PArthENoPe)	0.2447 ± 0.0029	871 ± 14

Neutron lifetime

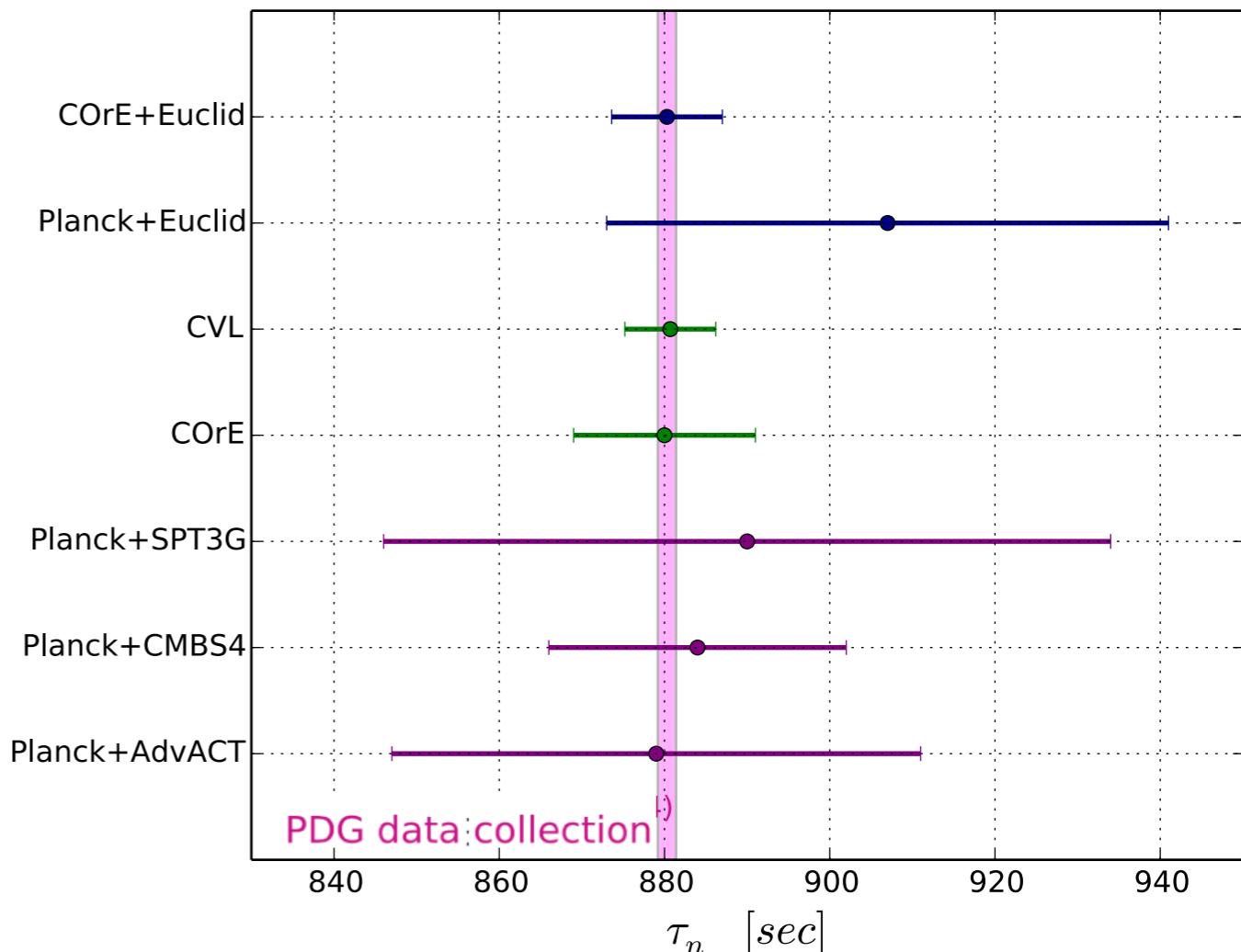
based on: **Salvati et al.**
JCAP 1603 (2016) no.03, 055

Dataset	Y_p^{BBN}	τ_n [s]
<i>Planck</i> TT,TE,EE + AdvACT	0.2464 ± 0.0065	879 ± 32
<i>Planck</i> TT,TE,EE + CMB-S4	0.2475 ± 0.0037	884 ± 18
<i>Planck</i> TT,TE,EE + SPT-3G	0.2487 ± 0.0091	890 ± 44
COrE	0.2467 ± 0.0023	880 ± 11
CVL	0.2467 ± 0.0011	880.7 ± 5.5
<i>Planck</i> TT,TE,EE + Euclid	0.2521 ± 0.0069	907 ± 34
COrE + Euclid	0.2467 ± 0.0014	880.3 ± 6.7

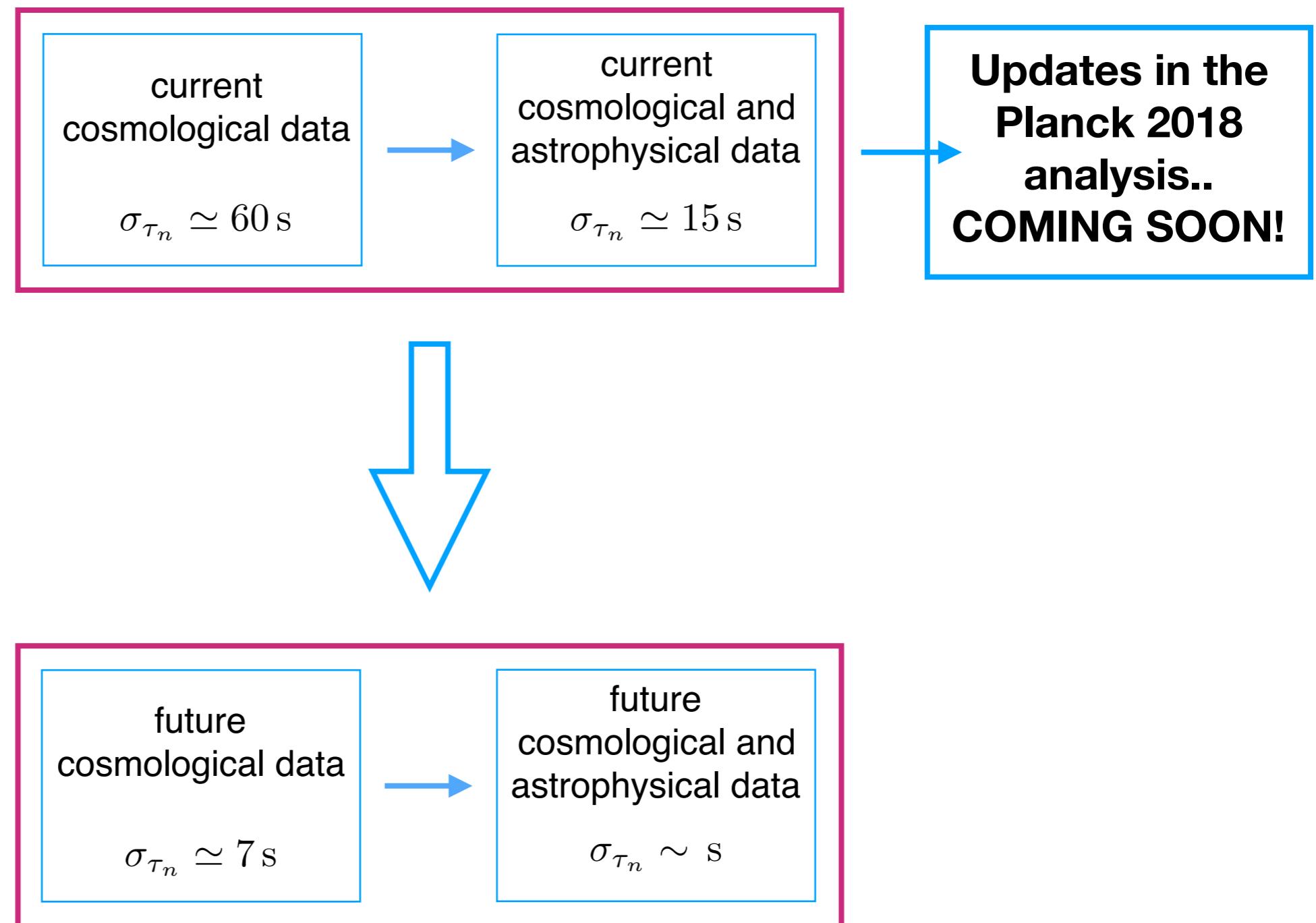
(68% c.l.)

Required precision for
astrophysical observations

$$\sigma(Y_p) = 0.0002$$

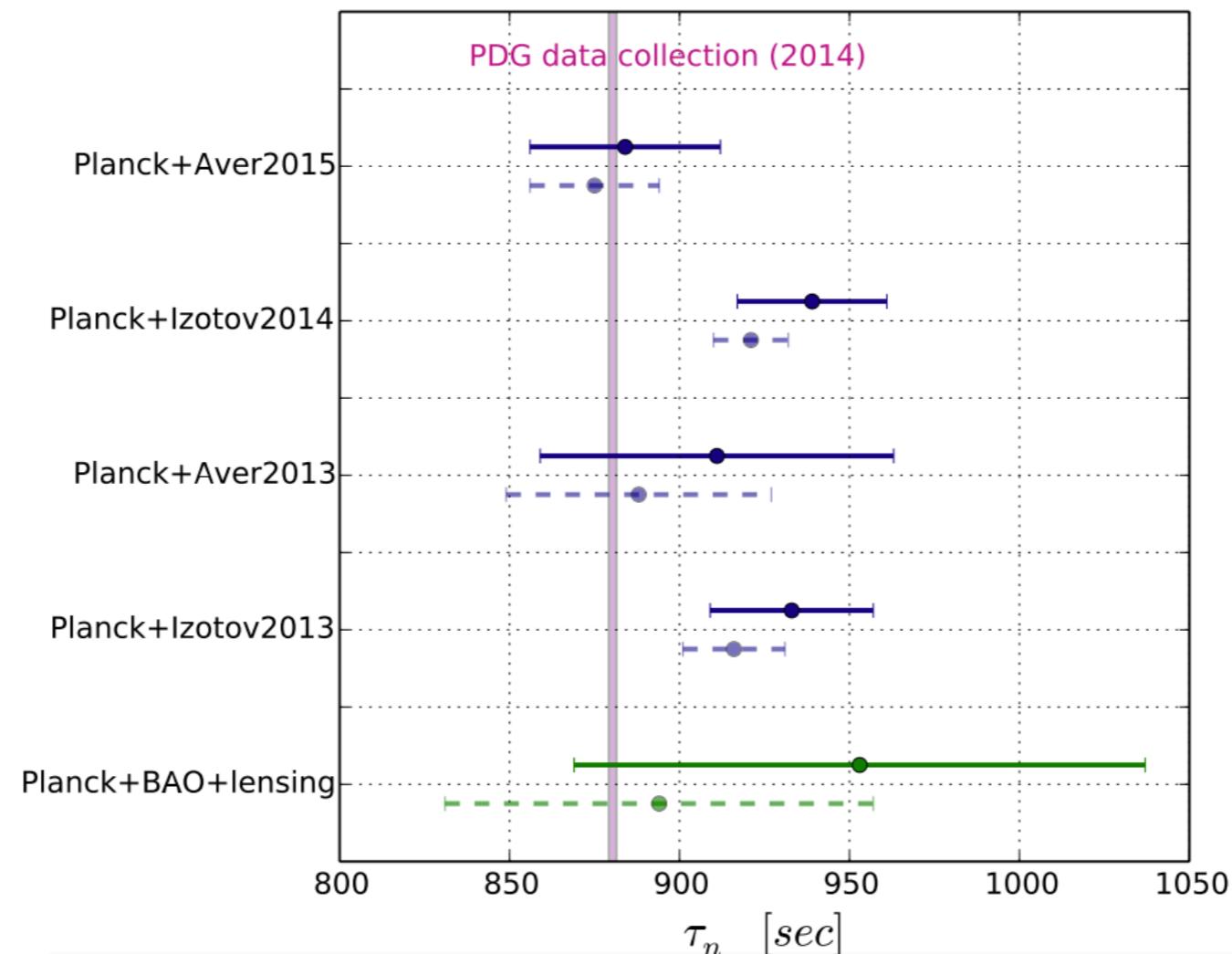


Conclusions



Back up

Varying N_{eff}



Dataset	Y_p^{BBN}	N_{eff}	τ_n [s]
Planck TT,TE,EE	0.263 ± 0.018	2.76 ± 0.30	986 ± 109
Planck TT,TE,EE + BAO + lensing	0.258 ± 0.014	2.83 ± 0.25	953 ± 84
Planck TT,TE,EE + Izotov et al. (2013)	0.2542 ± 0.0029	2.84 ± 0.23	933 ± 24
Planck TT,TE,EE + Aver et al. (2013)	0.2505 ± 0.0085	2.90 ± 0.25	911 ± 52
Planck TT,TE,EE + Izotov et al. (2014)	0.2552 ± 0.0022	2.83 ± 0.23	939 ± 22
Planck TT,TE,EE + Aver et al. (2015)	0.2458 ± 0.0040	2.95 ± 0.24	884 ± 28

^4He : primordial abundance

^4He abundance from HeI emission lines in HII extragalactic regions

Astrophysical sources of uncertainties

- Reddening
- Underlaying stellar absorption in HeI lines
- Collisional excitation of HeI lines
- Fluorescence of HeI lines
- Collisional excitation of Hb lines
- Non standard emissivity
- Temperature and ionisation structure of HII regions

total abundance

$$y = (y^+ + y^{2+}) \cdot \text{ICF}(\text{He}^+ + \text{He}^{2+})$$

single ionised ^4He

double ionised ^4He

mass fraction

$$Y = \frac{4y(1 - Z)}{1 + 4y}$$

linear regression to zero metallicity

$$Y = Y_p + \frac{dY}{d(O/H)}(O/H)$$

$$Y = Y_p + \frac{dY}{d(N/H)}(N/H)$$

^4He : primordial abundance

Aver 2015

Aver et al., JCAP 1507 (2015) no.07, 011

$$Y_p = 0.2449 \pm 0.0040$$

Peimbert 2016

Peimbert et al., Rev. Mex. Astron. Astrofis. 52 (2016) 419

$$Y_p = 0.2446 \pm 0.0029$$

- 15 HII regions
- optical lines + IR line
- 5 HII regions
- optical lines
- different evaluation of physical properties
- different extrapolation to zero metallicity