Model-agnostic interpretation of 10 billion years of cosmic evolution traced by BOSS and eBOSS data

Based on **SB, HGM,** LV, 2204.11868

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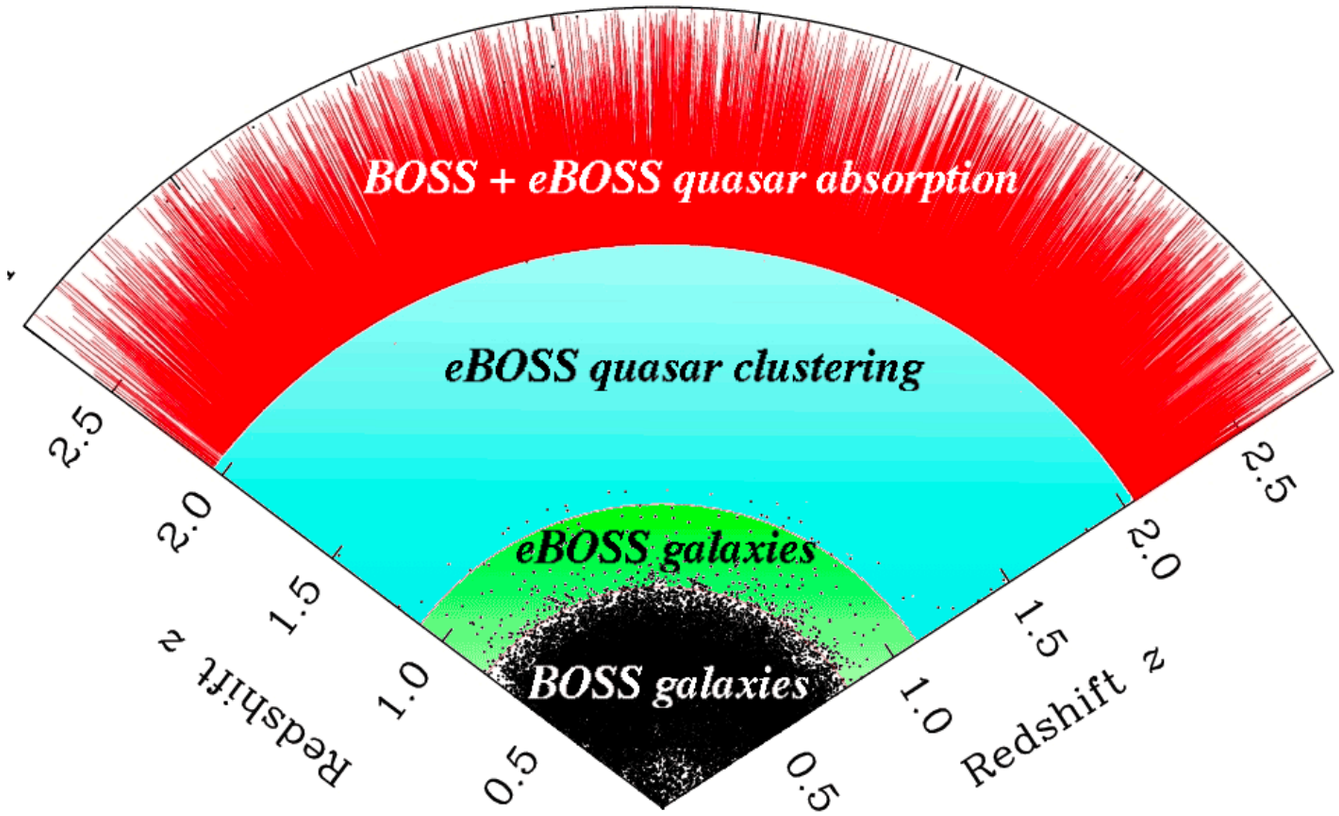
ShapeFit Saga:
BOSS+eBOSS: **SB, HGM,** LV, 2204.11868
PT challenge: **SB, HGM,** LV, 2201.08400
BOSS data: **SB, HGM,** LV, 2106.11931
ShapeFit methodology:
SB, HGM, LV, 2106.07641



Content

I. What is ShapeFit?

Two different philosophies …

Standard model

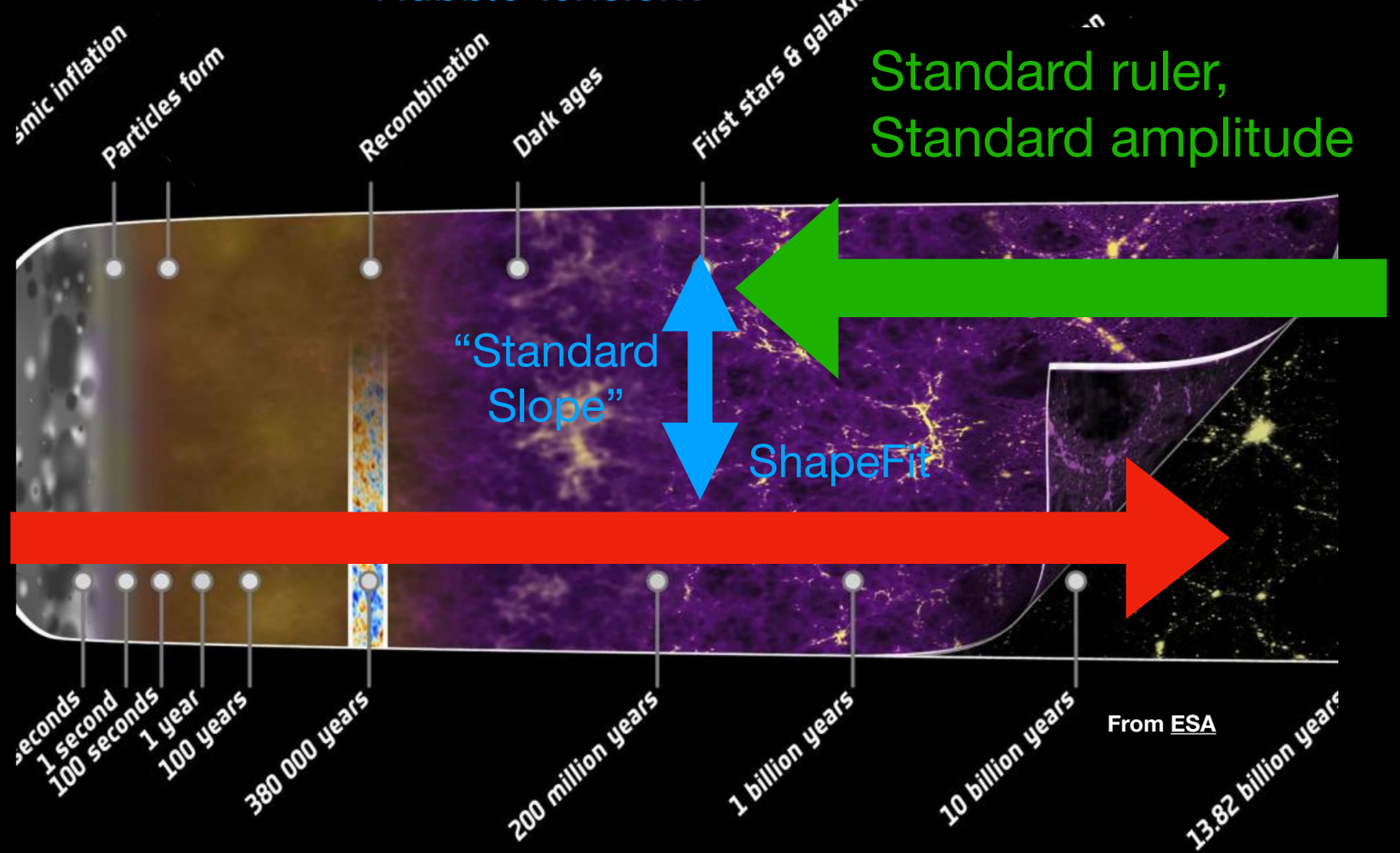
Standard candle

CMB analysis (model-dependent)

SN analysis (model-independent)

Hubble tension?

Standard ruler, Standard amplitude



Direct Fits to Galaxy power spectra (Full modeling)

"Galaxy clustering analysis (Classic BAO+RSD)"

I. What is ShapeFit?

ShapeFit methodology

Classic BAO Fit

Horizontal scaling: D_V/r_d [or $(\alpha_\parallel \alpha_\perp^2)^{1/3}$]

Anisotropy: F_{AP} [or $\alpha_\perp/\alpha_\parallel$]

Classic RSD Fit

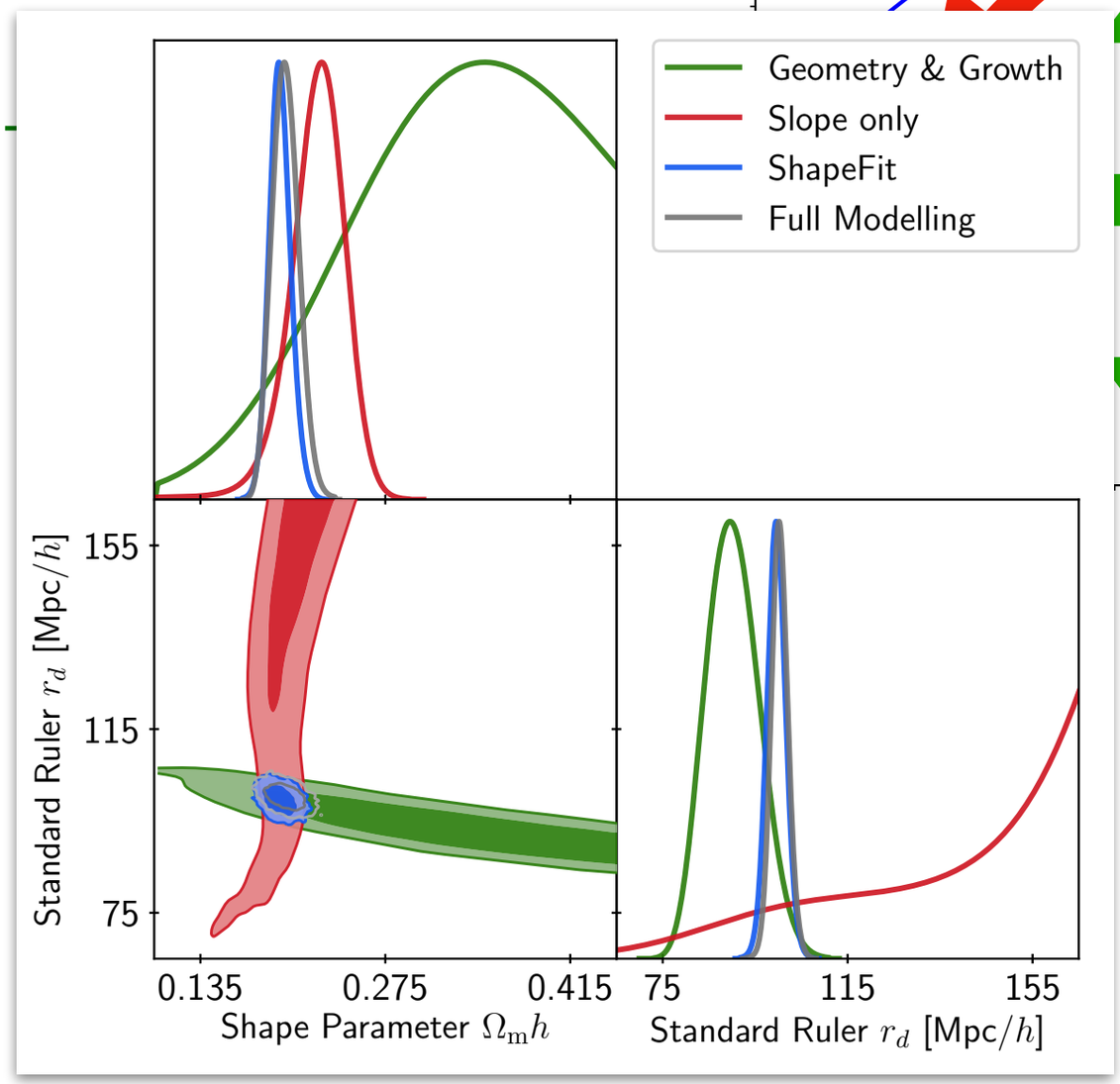
+ Vertical scaling: σ_8

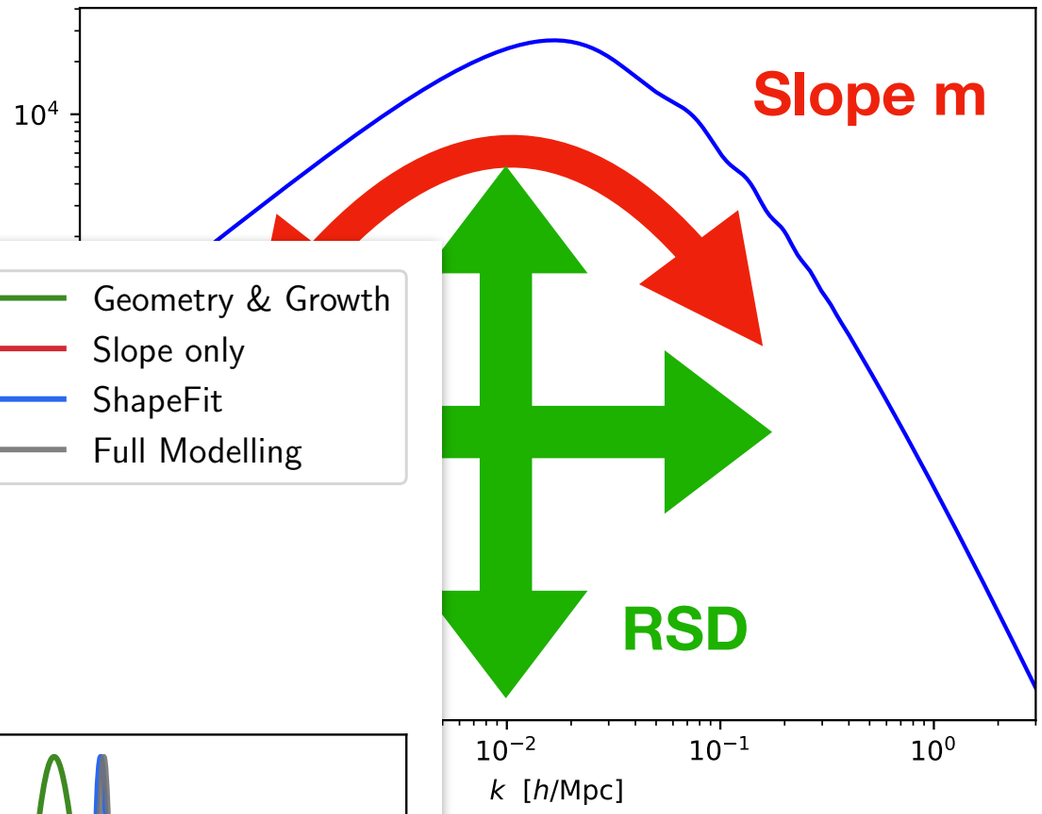
+ Anisotropy: f

ShapeFit

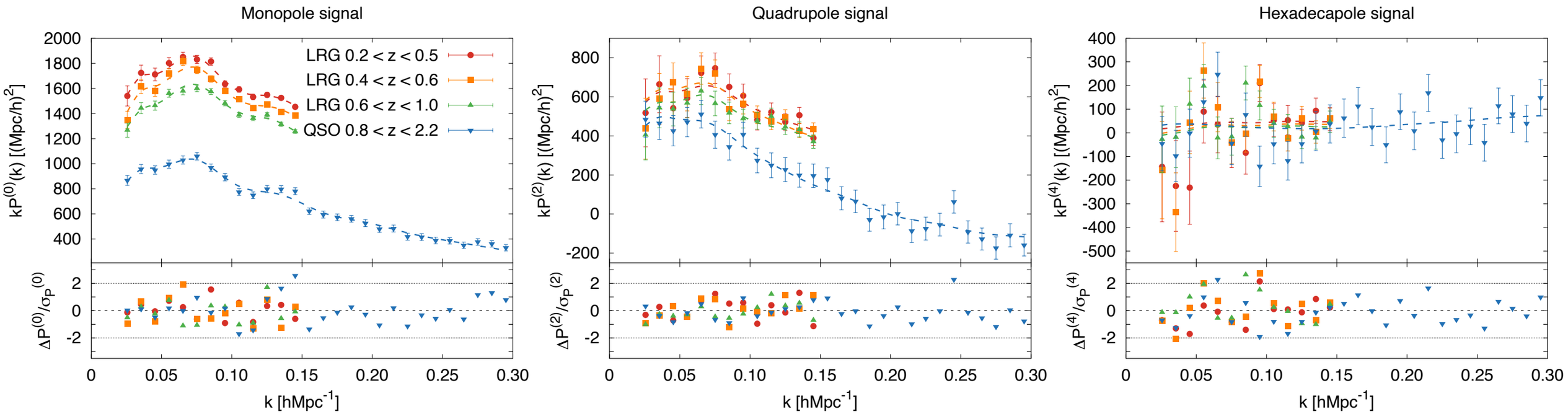
+ "Diagonal" tilt: m

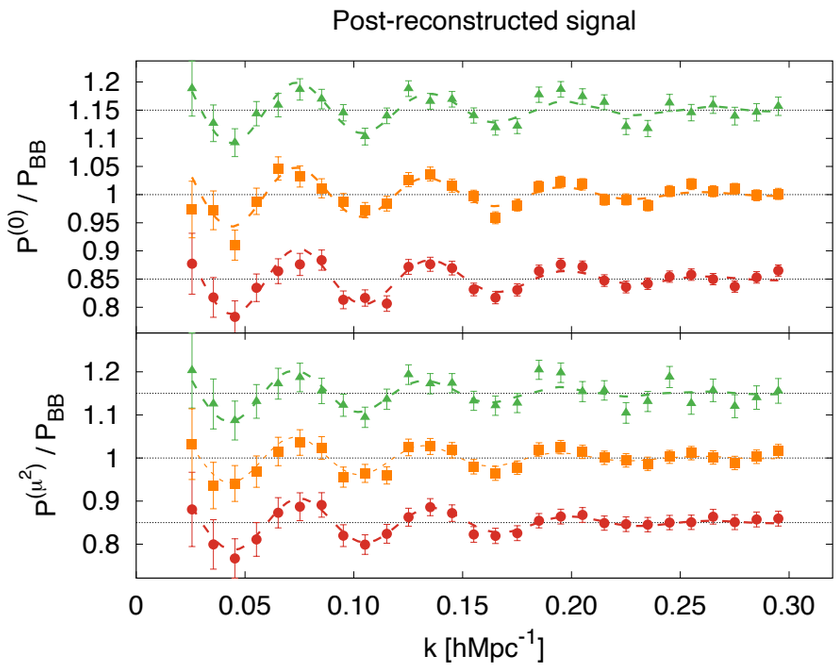
Shown to reproduce FM results in **SB, HGM,** LV, 2106.11931



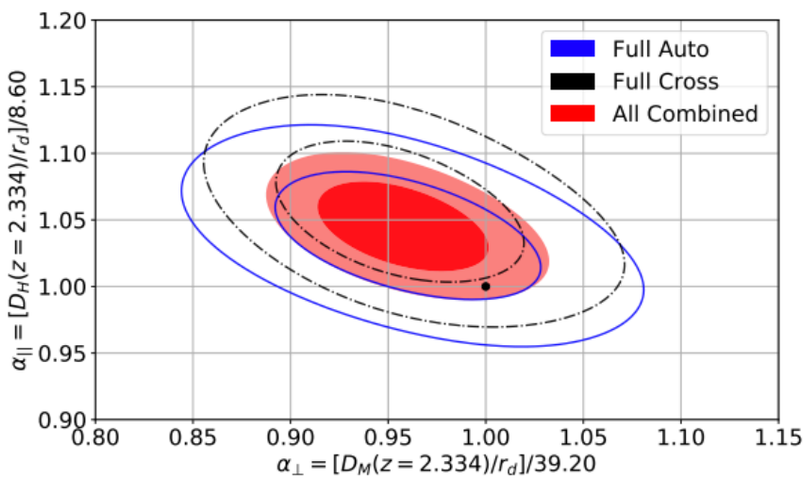


II. Overview of datasets





Lyman-α BAO from HdMdB et al 2007.08995



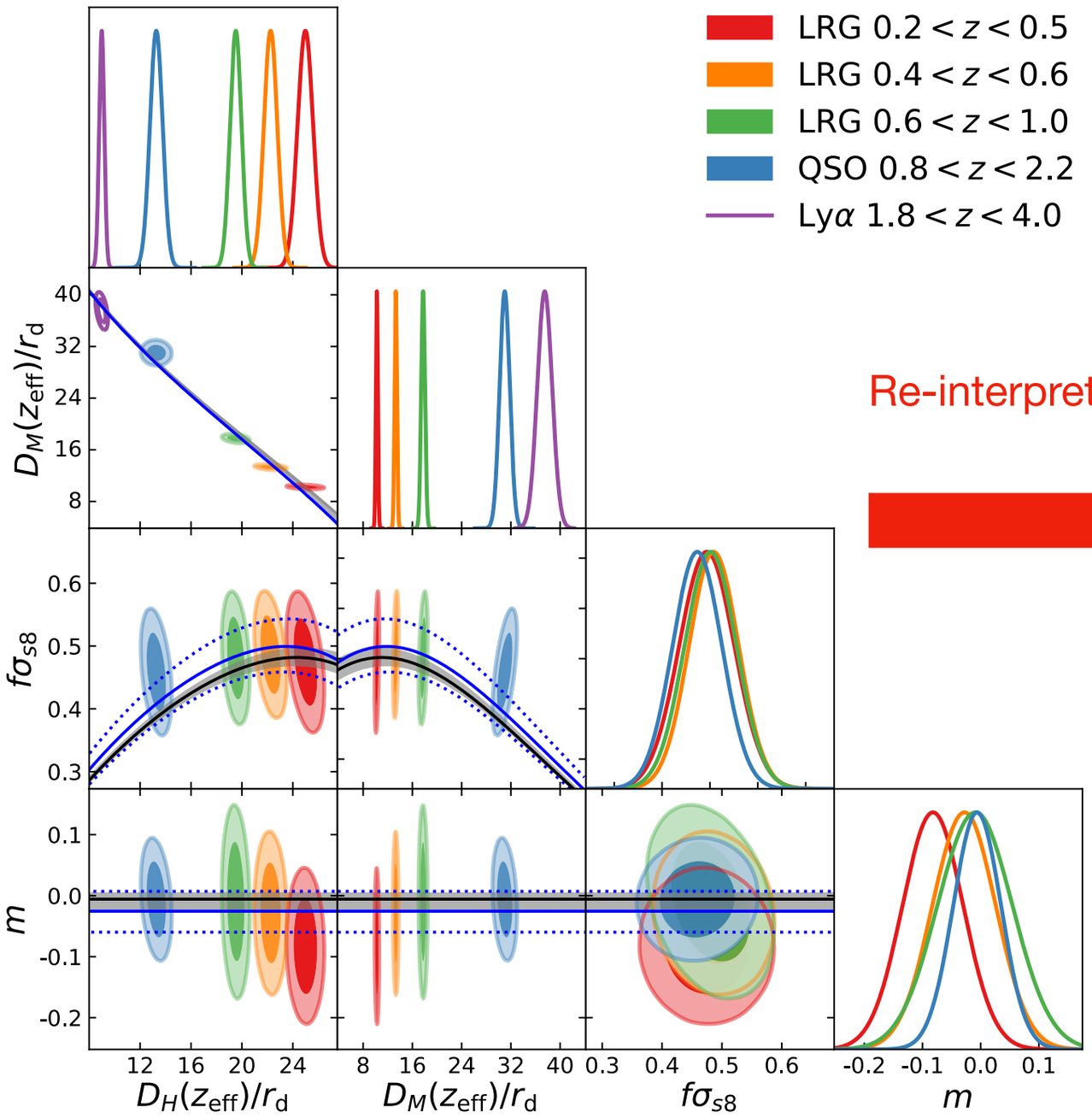
ShapeFit (Top row)
+
BAO (Bottom row)
analysis:

SB, HGM, LV,
2204.11868

III. Results

Compressed and Cosmological results

Compressed (model-independent!) parameters

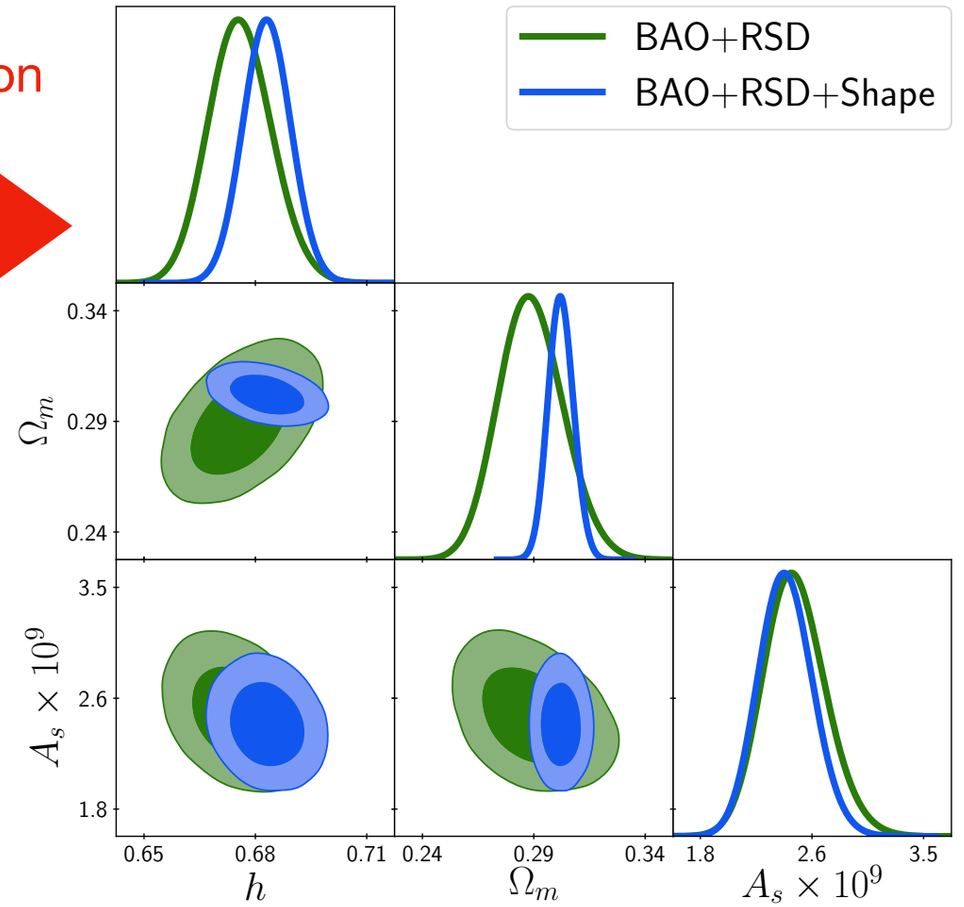


Cosmological (ΛCDM) parameters

	$\Omega_{\rm m}$	$H_0 \left[\frac{\rm km/s}{\rm Mpc}\right]$	σ_8
BBN + Classic	0.287 ± 0.014	$67.42^{+0.84}_{-0.91}$	0.822 ± 0.044
BBN + ShapeFit	0.3001 ± 0.0057	68.16 ± 0.67	0.858 ± 0.036

Exceeding Planck precision of 0.008!

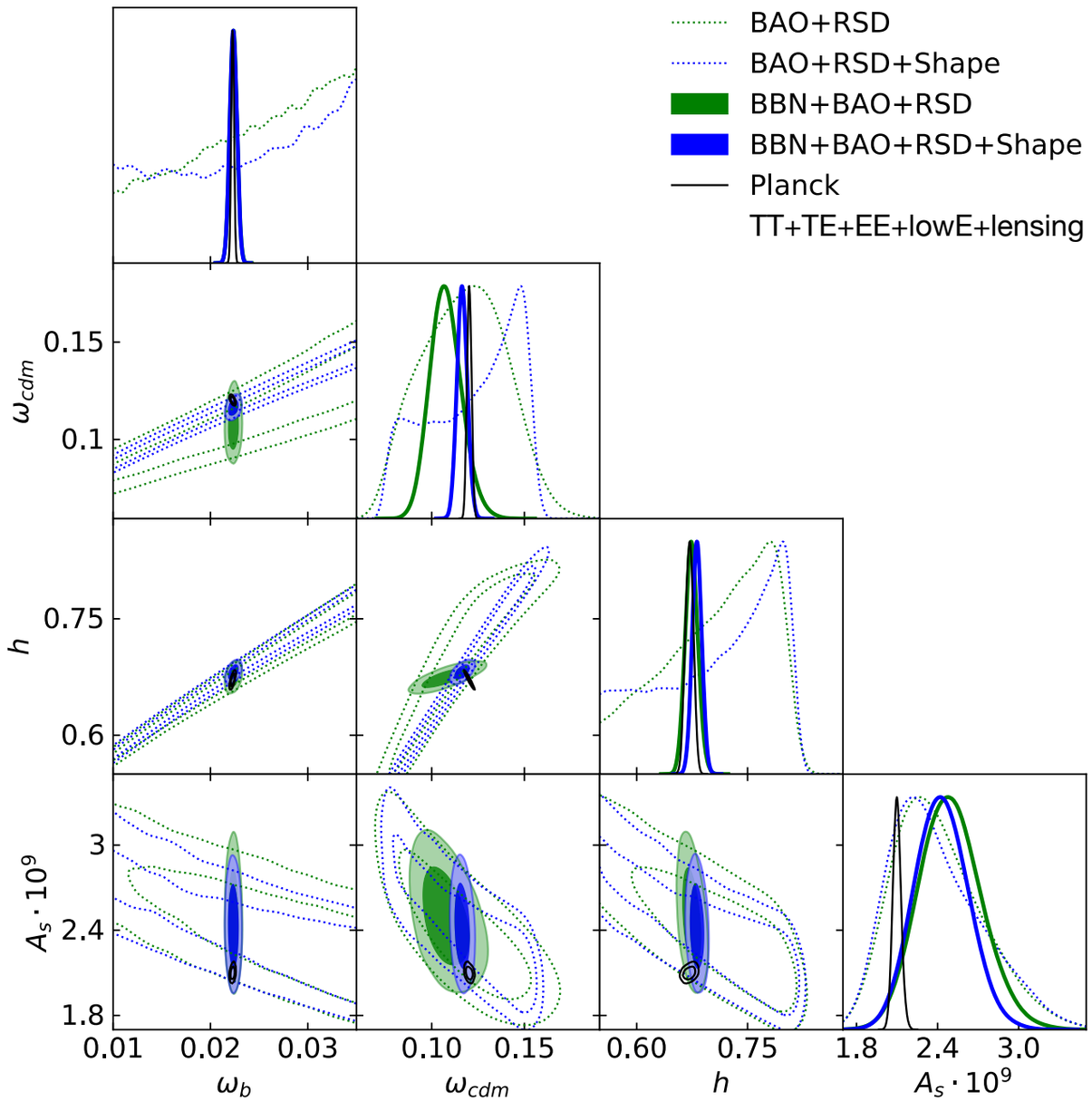
Re-interpretation



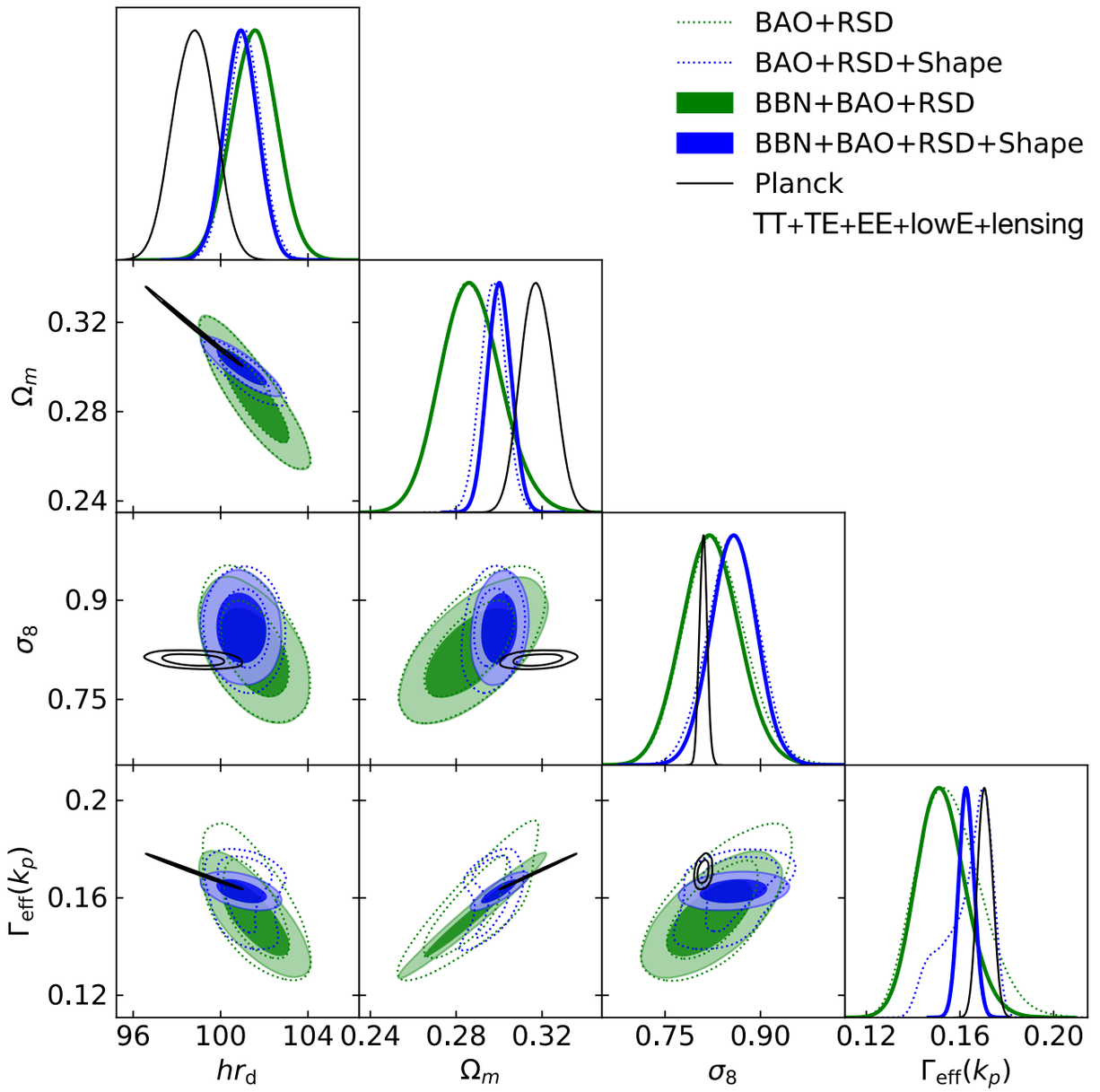
III. Results

Impact of BBN prior

Varied cosmological parameters

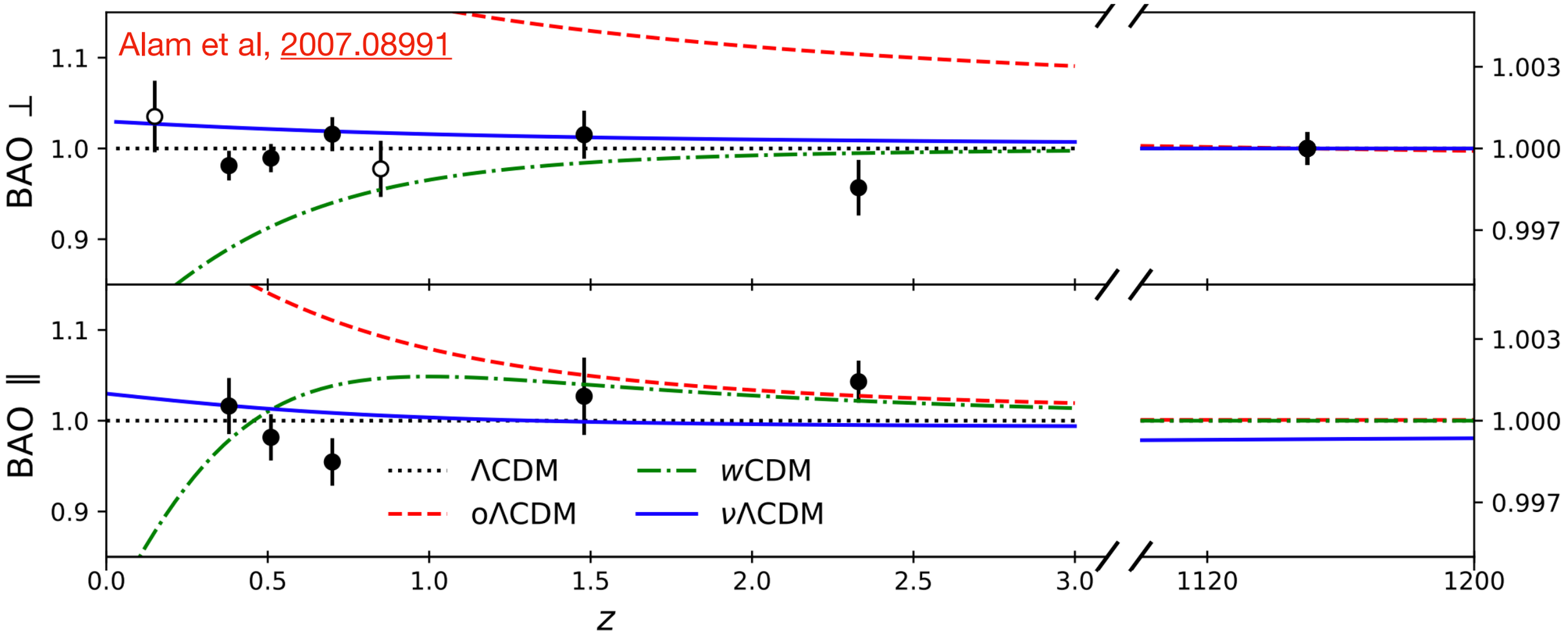


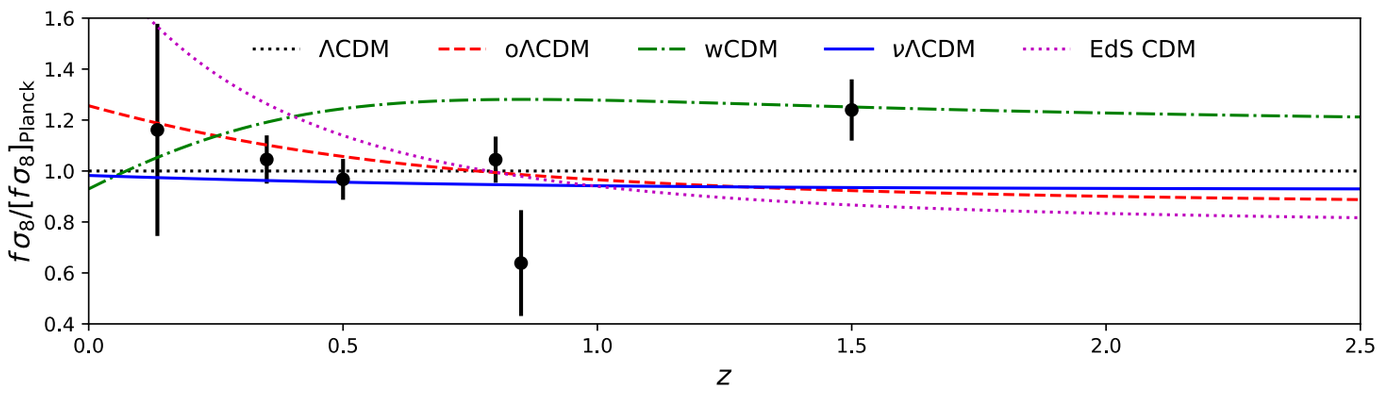
Derived cosmological parameters



III. Results

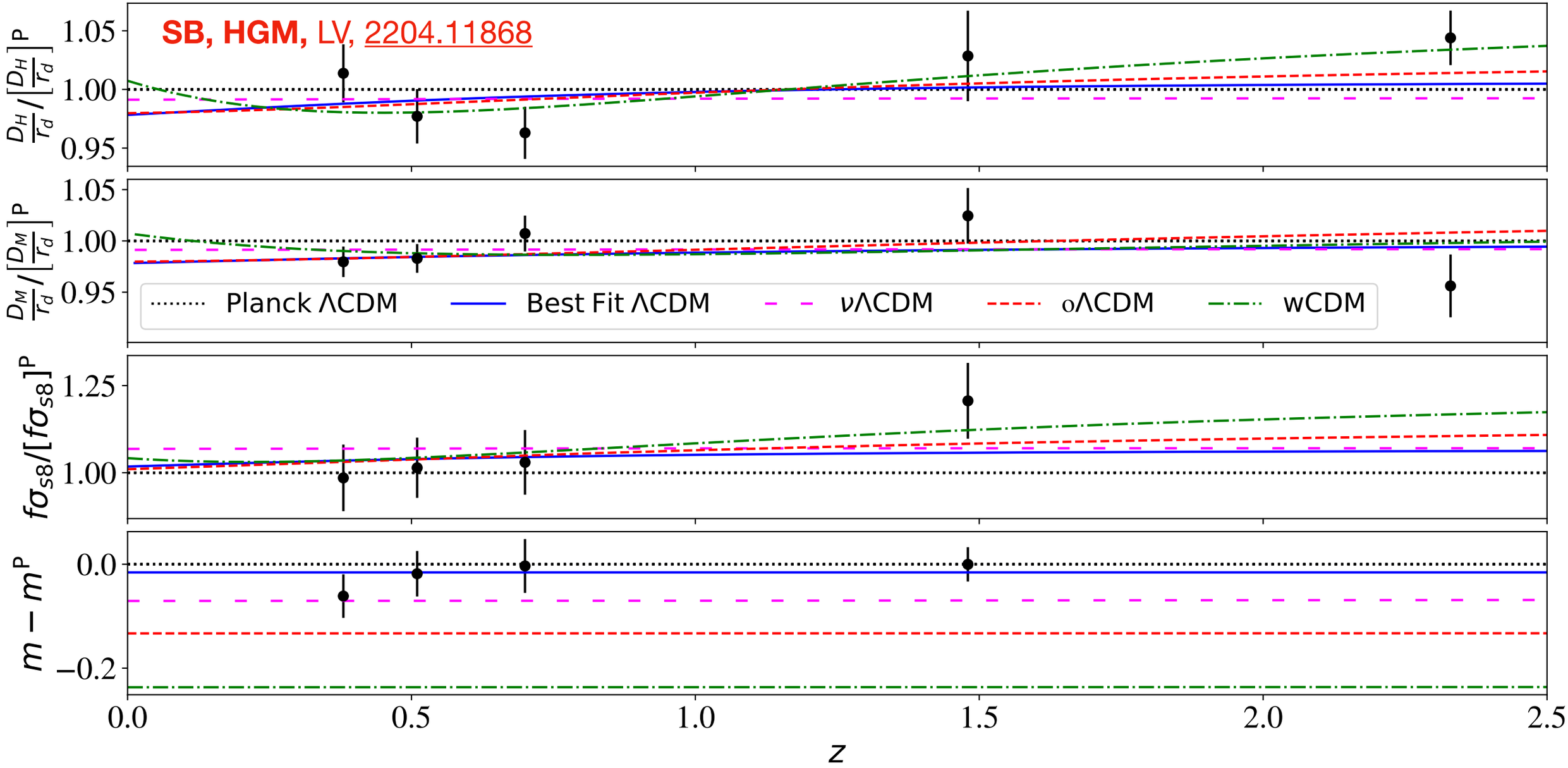
Extended cosmologies (official eBOSS results)





III. Results

Extended cosmologies (ShapeFit results)

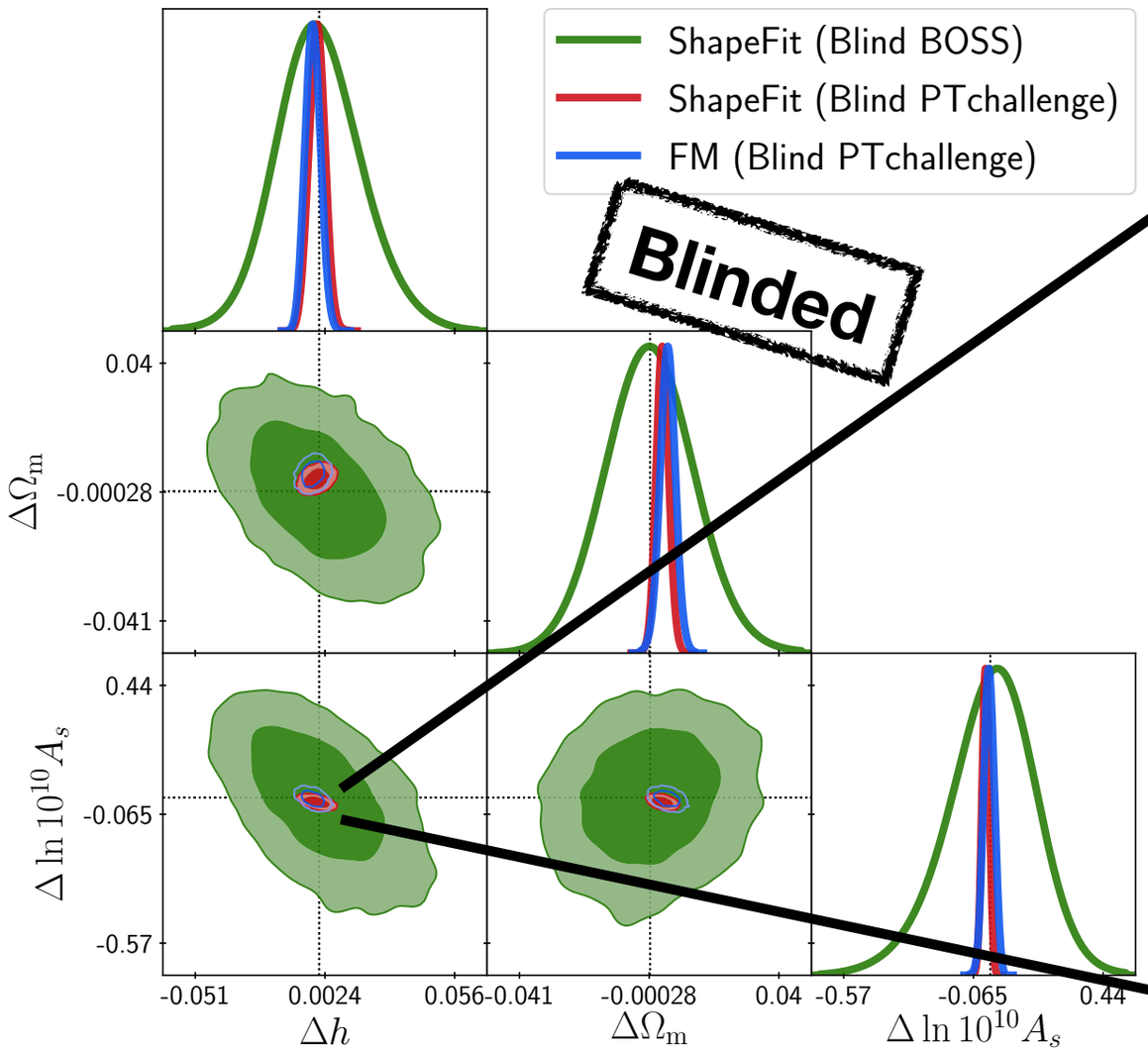


Sum of neutrino mass of $\Sigma m_\nu = 0.4\,\mathrm{eV}$ excluded by m at 95% CL

III. Results

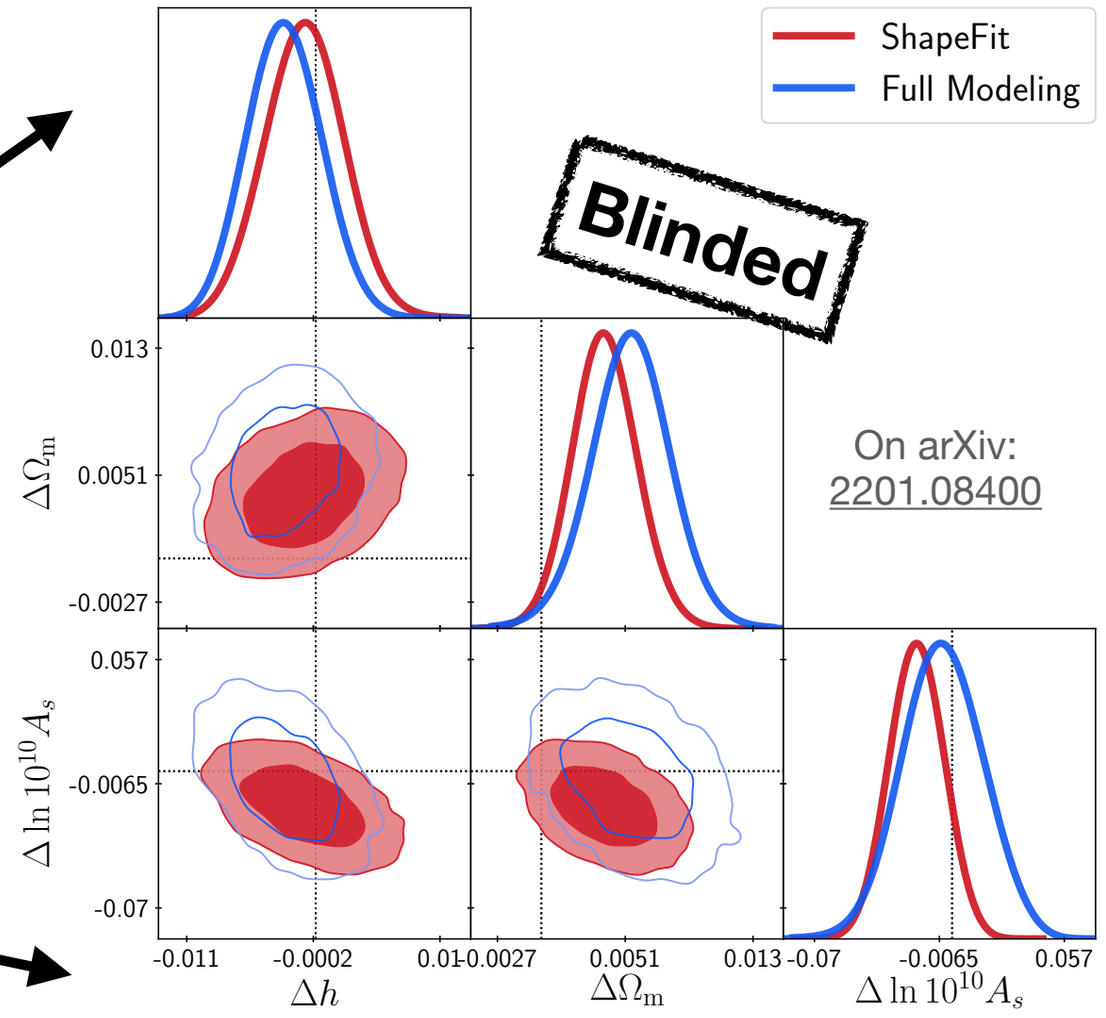
Validation on high-precision mocks

eBOSS DR16 galaxies
Effective volume: 11 (Gpc/h)^3



Blind PTchallenge
Effective volume: 566 (Gpc/h)^3

Results submitted to PTchallenge website by Takahiro Nishimichi
https://www2.yukawa.kyoto-u.ac.jp/~takahiro.nishimichi/data/PTchallenge/



On arXiv:
2201.08400

IV. Conclusions

- BAO+RSD+*Shape* analysis of BOSS+eBOSS delivers **tightest constraints on Ω_m** to date

- ShapeFit compressed variables **constrain model extensions** without need for combination with Planck

- With respect to classic BAO+RSD analysis, ShapeFit delivers
    - **2x** more constraining power **for all Samples combined**
    - **Beyond LCDM:** up to **5x** more constraining power
    - **identical** constraining power **when combining with Planck**

- Everything you need to compare your favourite model to eBOSS+BOSS data: Appendix E of 2204.11868

IV. Outlook

- For DESI: BAO+RSD remain most important observables, but measuring *Shape* in model-independent way still interesting for number of reasons:
    - Assure **template independence** of BAO+RSD measurements
    - Assess impact of **systematic effects** (both due to observation and nonlinear modeling)
    - Hint towards **new physics** (see also **SB, HGM,** LV 2106.11931)
- In prep: Use *Shape* to **measure H0 independent from standard ruler**

Can ShapeFit shed light on Hubble tension?

Standard model

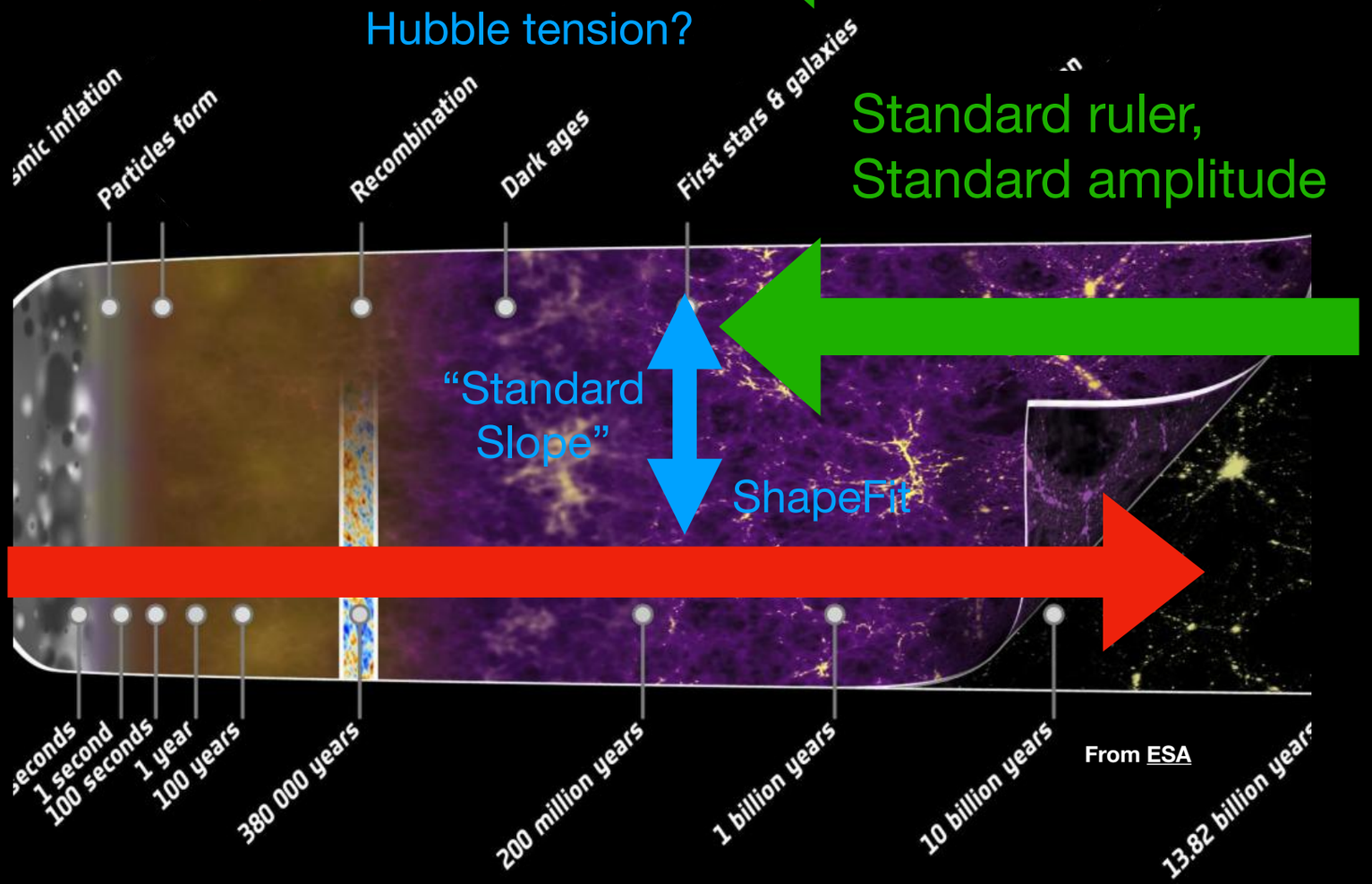
Standard candle

CMB analysis (model-dependent)

SN analysis (model-independent)

Hubble tension?

Standard ruler, Standard amplitude

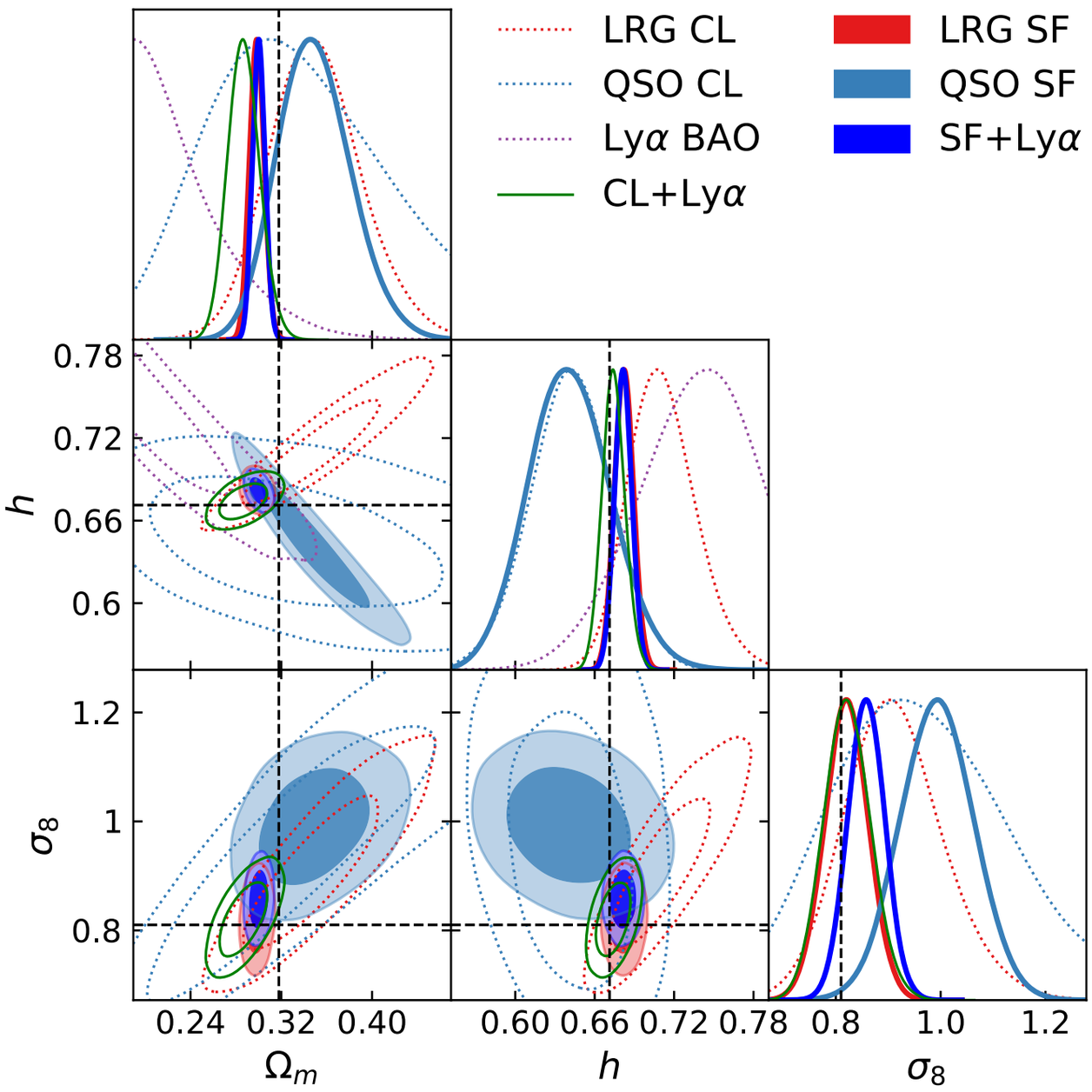


Direct Fits to Galaxy power spectra (Full modeling)

"Galaxy clustering analysis (Classic BAO+RSD)"

Backup Slides

Consistency between Samples

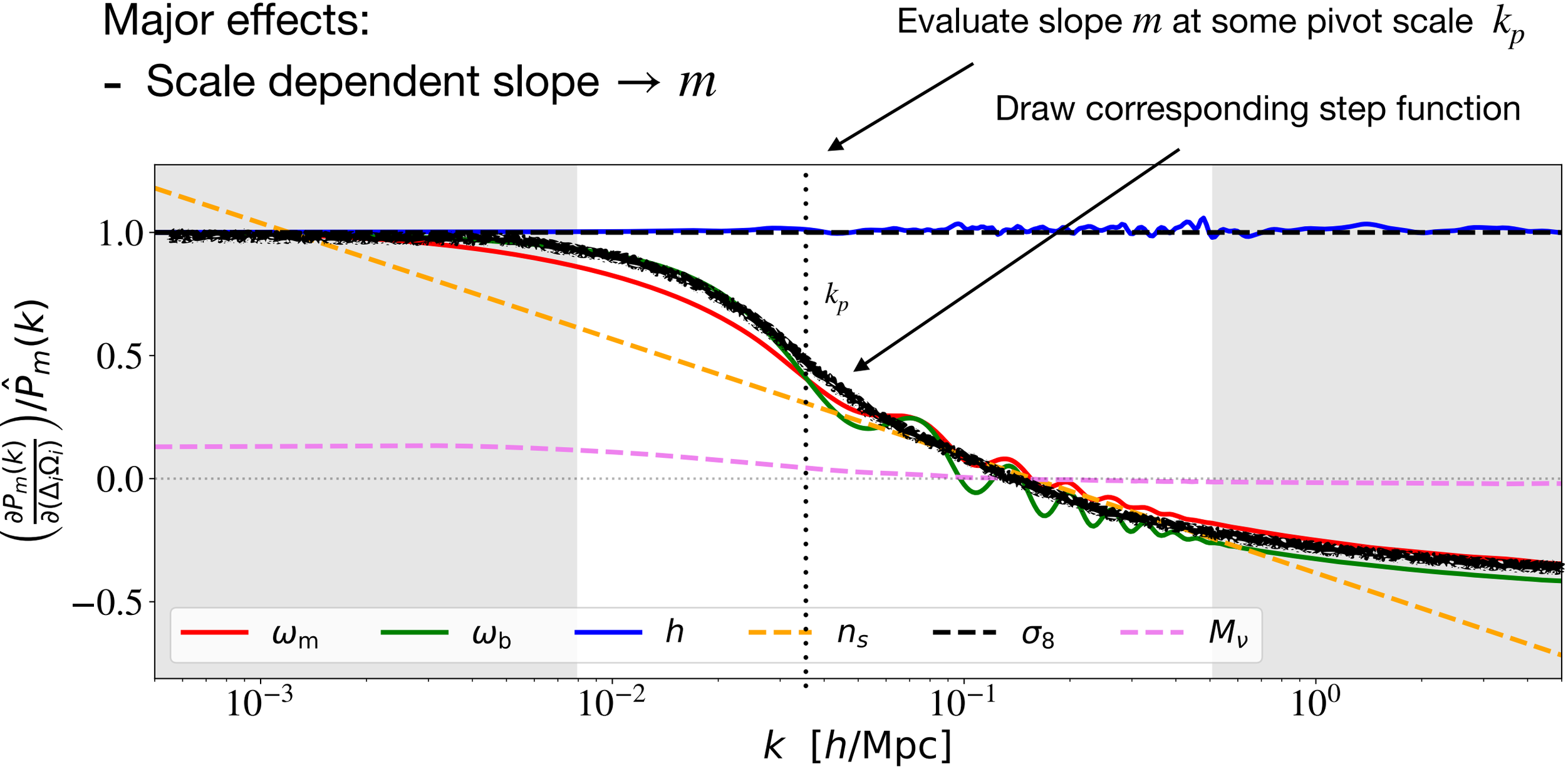


Shape

What is the residual parameter dependence of power spectrum after rescaling with $r_{\rm d}$? — Look at P(k) derivative response:

Major effects:

- Scale dependent slope $\rightarrow m$



Numbers

LCDM

Sample	Priors	Method / Ref.	Ω_m	$H_0 \left[\frac{\mathrm{km/s}}{\mathrm{Mpc}}\right]$	$A_s \cdot 10^9$	σ_8
Full	n_s	**ShapeFit**	0.2971 ± 0.0061	–	$2.39^{+0.24}_{-0.43}$	0.857 ± 0.040
	ω_b, n_s	**ShapeFit**	0.3001 ± 0.0057	68.16 ± 0.67	2.43 ± 0.20	0.858 ± 0.036
LRG DR12	$\frac{\omega_\mathrm{b}}{\omega_\mathrm{m}}, n_s$	D'Amico [16]	0.309 ± 0.010	68.5 ± 2.2	1.52 ± 0.84	–
	ω_b, n_s	Ivanov [17]	0.295 ± 0.010	67.9 ± 1.1	–	0.721 ± 0.043
	ω_b, n_s	Philcox [65]	$0.2962^{+0.0082}_{-0.0080}$	$67.81^{+0.68}_{-0.69}$	–	$0.739^{+0.040}_{-0.041}$
	ω_b	Tröster [66]	$0.317^{+0.015}_{-0.019}$	70.4 ± 2.4	–	0.71 ± 0.049
	ω_b, n_s	Chen [67]	0.3030 ± 0.0082	69.23 ± 0.77	–	0.733 ± 0.047
	n_s	ShapeFit [24]	0.295 ± 0.014	–	2.56 ± 0.51	0.806 ± 0.065
LRG DR16	ω_b, n_s	Neveux [69]	0.315 ± 0.013	66.9 ± 1.9	–	0.763 ± 0.046
	ω_b, n_s	**ShapeFit**	0.2984 ± 0.0066	68.20 ± 0.73	2.24 ± 0.24	0.820 ± 0.043
QSO DR16	ω_b, n_s	Neveux [69]	0.321 ± 0.016	65.1 ± 1.9	–	1.12 ± 0.10
	ω_b, n_s	**ShapeFit**	0.350 ± 0.033	64.1 ± 3.1	3.25 ± 0.47	0.993 ± 0.072
LRG +QSO DR16	$\omega_\mathrm{b}, \omega_\mathrm{cdm}, n_s$	Semenaite [68]	0.3037 ± 0.0081	$68.55^{+0.84}_{-0.94}$	–	0.800 ± 0.039
	ω_b, n_s	Neveux [69]	0.308 ± 0.010	66.4 ± 1.4	–	0.869 ± 0.046
	ω_b, n_s	**ShapeFit**	0.3012 ± 0.0057	68.24 ± 0.67	2.42 ± 0.20	0.860 ± 0.036

Numbers

Extended cosmologies

		Ω_m	$H_0\left[\frac{\mathrm{km/s}}{\mathrm{Mpc}}\right]$	Σm_ν [eV]	N_eff	Ω_k	w_0	w_a
$\nu\Lambda$CDM	ShapeFit [this work]	$0.300^{+0.008}_{-0.011}$	–	< 0.54	–	–	–	–
	BBN + ShapeFit	$0.302^{+0.007}_{-0.010}$	68.03 ± 0.68	< 0.40	–	–	–	–
	Planck	$0.321^{+0.009}_{-0.015}$	$66.95^{+1.1}_{-0.68}$	< 0.26	–	–	–	–
	Planck + (e)BOSS	0.3089 ± 0.0058	67.87 ± 0.45	< 0.10	–	–	–	–
	Planck + Classic	0.3052 ± 0.0052	68.14 ± 0.40	< 0.085	–	–	–	–
	Planck + ShapeFit	0.3034 ± 0.0049	68.28 ± 0.39	< 0.082	–	–	–	–
$N_\mathrm{eff}\Lambda$CDM	Planck	0.321 ± 0.011	$66.5^{+1.4}_{-1.7}$	–	$2.94^{+0.21}_{-0.24}$	–	–	–
	Planck + Classic	0.3066 ± 0.0060	68.5 ± 1.3	–	3.16 ± 0.22	–	–	–
	Planck + ShapeFit	0.3053 ± 0.0056	68.44 ± 0.12	–	3.12 ± 0.19	–	–	–
oΛCDM	(e)BOSS BAO	0.285 ± 0.023	–	–	–	$0.078^{+0.086}_{-0.099}$	–	–
	Classic [this work]	$0.276^{+0.021}_{-0.019}$	–	–	–	$0.054^{+0.079}_{-0.092}$	–	–
	ShapeFit [this work]	$0.2943^{+0.0080}_{-0.0092}$	–	–	–	$-0.022^{+0.032}_{-0.038}$	–	–
	BBN + Classic	$0.279^{+0.023}_{-0.021}$	65.9 ± 3.5	–	–	$0.047^{+0.083}_{-0.099}$	–	–
	BBN + ShapeFit	$0.2942^{+0.0078}_{-0.0085}$	68.8 ± 1.1	–	–	$-0.027^{+0.032}_{-0.037}$	–	–
	Planck	0.355 ± 0.025	$63.4^{+2.6}_{-2.1}$	–	–	-0.0104 ± 0.0067	–	–
	Planck + (e)BOSS	0.3105 ± 0.0056	67.75 ± 0.56	–	–	0.0003 ± 0.0017	–	–
	Planck + Classic	0.3077 ± 0.0052	68.10 ± 0.51	–	–	0.0014 ± 0.0017	–	–
	Planck + ShapeFit	0.3058 ± 0.0047	68.25 ± 0.49	–	–	0.0015 ± 0.0016	–	–
wCDM	(e)BOSS BAO	$0.271^{+0.038}_{-0.017}$	–	–	–	–	-0.69 ± 0.15	–
	Classic [this work]	$0.279^{+0.018}_{-0.016}$	–	–	–	–	$-0.81^{+0.13}_{-0.11}$	–
	ShapeFit [this work]	0.296 ± 0.013	–	–	–	–	$-0.998^{+0.085}_{-0.073}$	–
	BBN + ShapeFit	0.298 ± 0.013	68.23 ± 1.6	–	–	–	$-1.007^{+0.083}_{-0.073}$	–
	Planck + (e)BOSS	0.3039 ± 0.0092	68.6 ± 1.0	–	–	–	-1.037 ± 0.039	–
	Planck + Classic	0.2928 ± 0.0093	69.9 ± 1.2	–	–	–	$-1.090^{+0.050}_{-0.041}$	–
	Planck + ShapeFit	0.2906 ± 0.009	70.1 ± 1.2	–	–	–	$-1.093^{+0.048}_{-0.044}$	–
w_0w_aCDM	BBN + Classic	$0.300^{+0.041}_{-0.051}$	–	–	–	–	$-0.70^{+0.23}_{-0.31}$	$-0.58^{+1.3}_{-0.76}$
	BBN + ShapeFit	0.335 ± 0.027	–	–	–	–	$-0.55^{+0.30}_{-0.27}$	$-1.50^{+0.96}_{-0.92}$
	Planck + (e)BOSS	0.329 ± 0.017	66.1 ± 1.7	–	–	–	-0.70 ± 0.19	$-0.99^{+0.62}_{-0.52}$
	Planck + Classic	0.333 ± 0.025	$65.7^{+2.2}_{-2.6}$	–	–	–	-0.63 ± 0.26	$-1.29^{+0.79}_{-0.69}$
	Planck + ShapeFit	0.330 ± 0.023	$66.0^{+2.2}_{-2.5}$	–	–	–	-0.64 ± 0.25	$-1.27^{+0.78}_{-0.65}$

Systematic Tests

$\Delta x \pm 2\sigma$	Nseries-$\mathcal{Z}$ Sky	Nseries Box	PT challenge	1σ error of data
$\alpha_\parallel$	0.0066 ± 0.0088	0.0082 ± 0.0076	0.0077 ± 0.0036	$[0.022 - 0.038]$
$\alpha_\perp$	-0.0038 ± 0.0054	-0.0021 ± 0.0043	-0.0003 ± 0.0024	$[0.014 - 0.028]$
$f\sigma_{s8}$	-0.0056 ± 0.0115	-0.007 ± 0.010	-0.0039 ± 0.0049	$[0.041 - 0.045]$
m	-0.014 ± 0.013	-0.009 ± 0.012	-0.0012 ± 0.0068	$[0.033 - 0.052]$
Ω_m	-0.0048 ± 0.0050	-0.0026 ± 0.0043	0.0008 ± 0.0022	0.0057
H_0	-0.10 ± 0.75	-0.16 ± 0.70	-0.24 ± 0.36	0.67
$A_s \times 10^9$	0.033 ± 0.103	0.008 ± 0.093	-0.007 ± 0.053	0.20