DARK ENERGY SPECTROSCOPIC INSTRUMENT
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# New DESI Y1 results

Astroparticle Symposium
Institut Pascal - 22/11/2024

Eric Armengaud - CEA Saclay

cea irfu

# DARK ENERGY SPECTROSCOPIC INSTRUMENT

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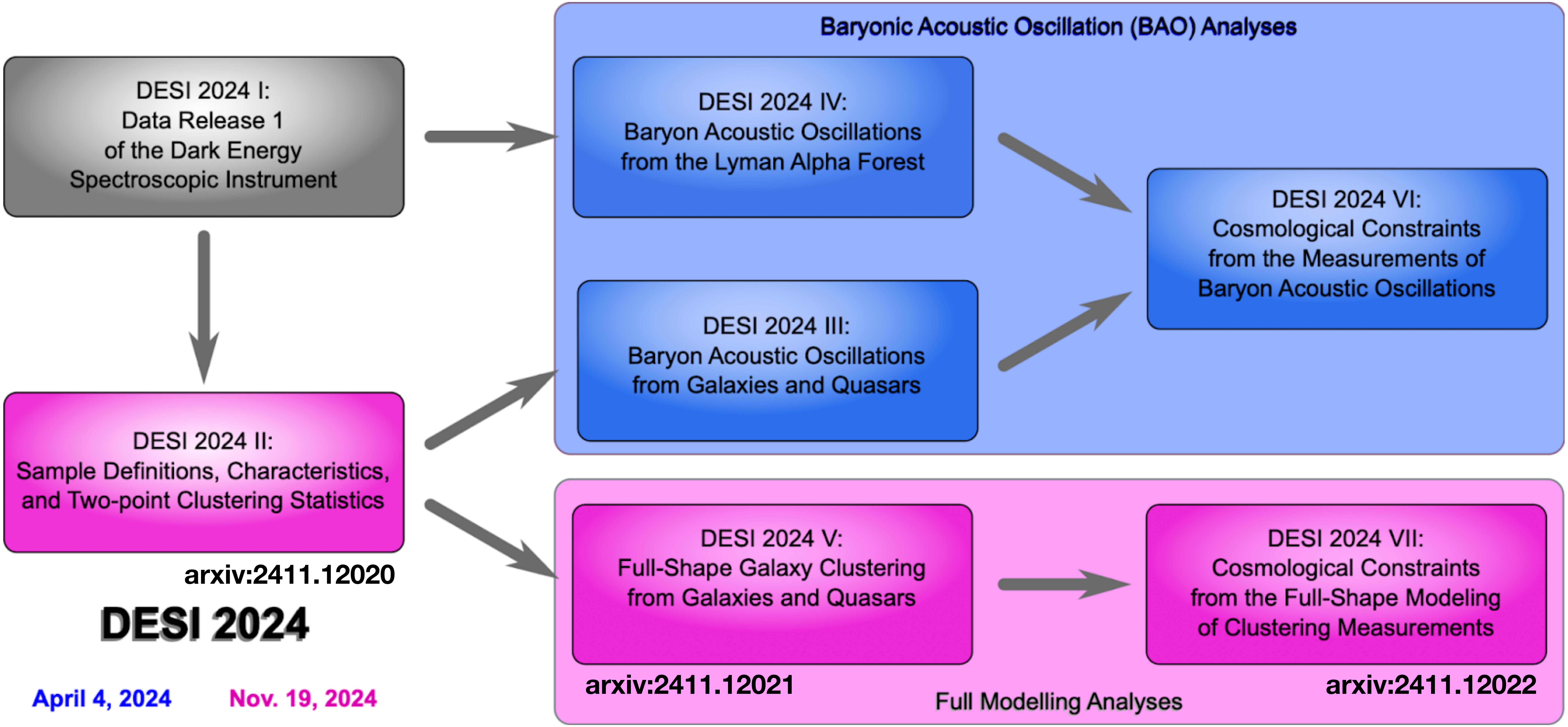

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https://www.youtube.com/watch?v=-2mlU-YzEbw


DESI 2024 - Cosmology Results from the Power Spectrum's Full...

DESI 2024 I:
Data Release 1
of the Dark Energy
Spectroscopic Instrument

DESI 2024 II:
Sample Definitions, Characteristics,
and Two-point Clustering Statistics

arxiv:2411.12020

alyses

DESI 2024 VI:
osmological Constraints
m the Measurements of
yon Acoustic Oscillations

DESI 2024 V:
Full-Shape Galaxy Clustering
from Galaxies and Quasars

arxiv:2411.12021

DESI 2024 VII:
Cosmological Constraints
from the Full-Shape Modeling
of Clustering Measurements

arxiv:2411.12022

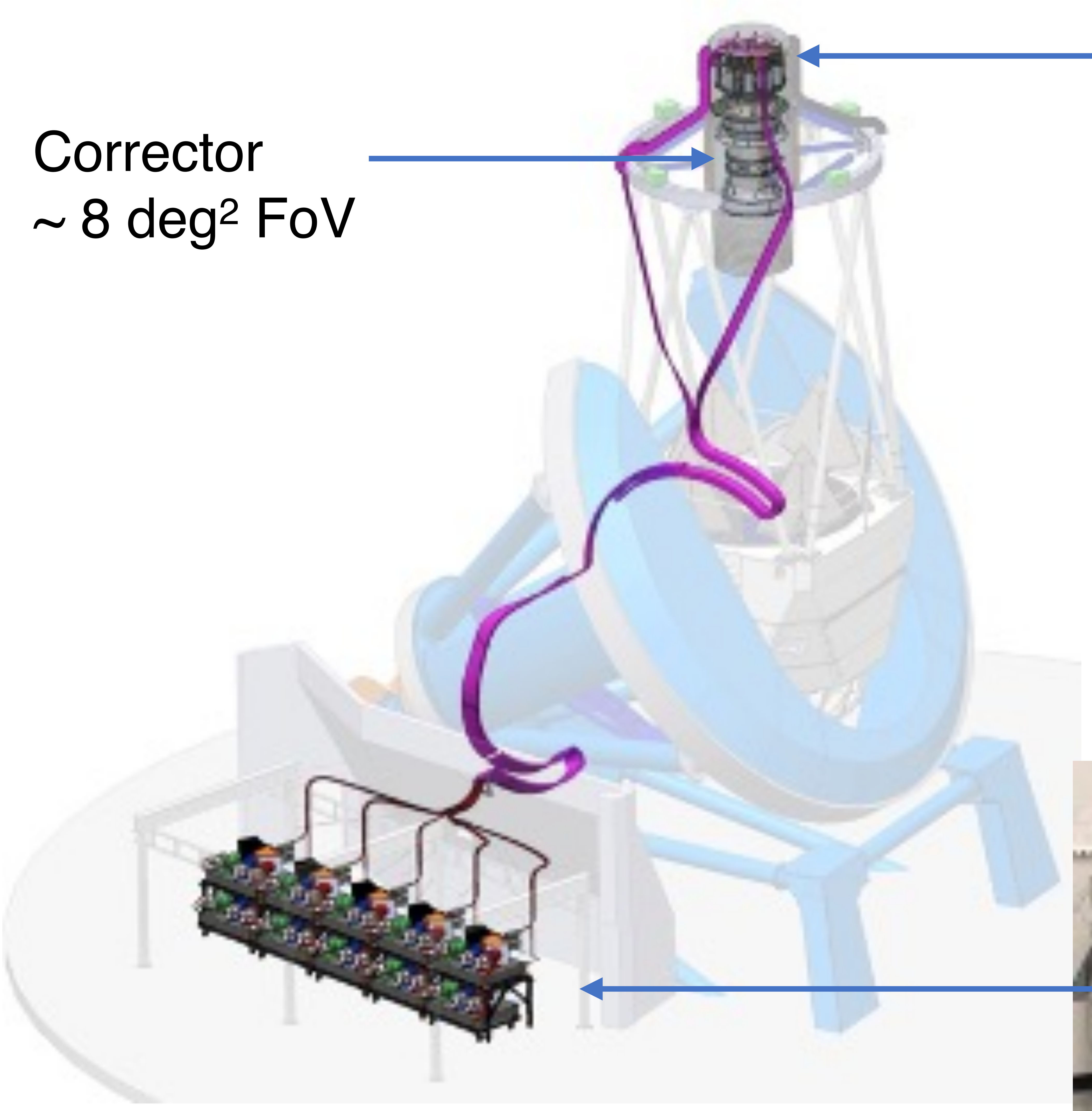
Full Modelling Analyses

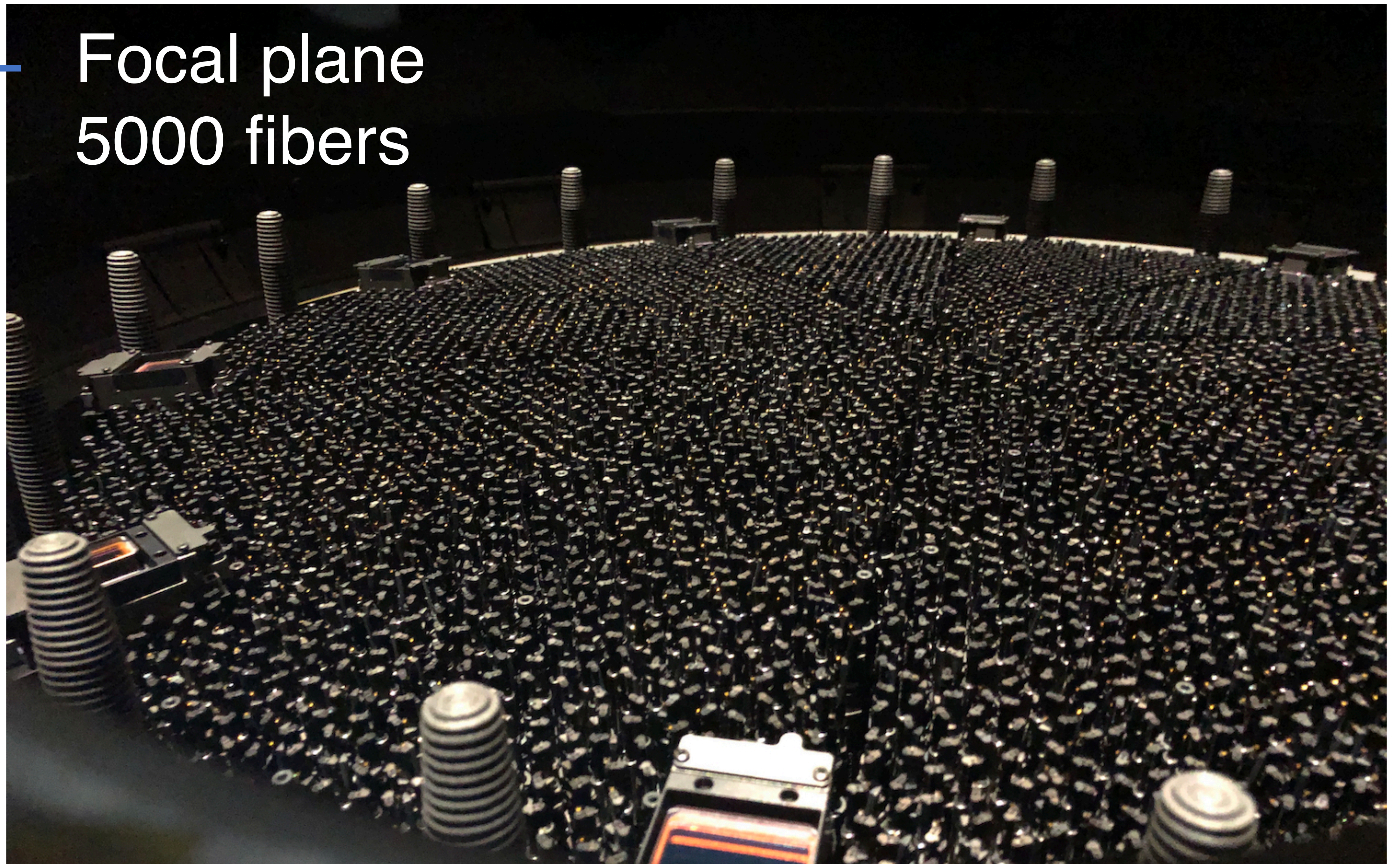
**DESI 2024**

April 4, 2024 Nov. 19, 2024

# The DESI instrument

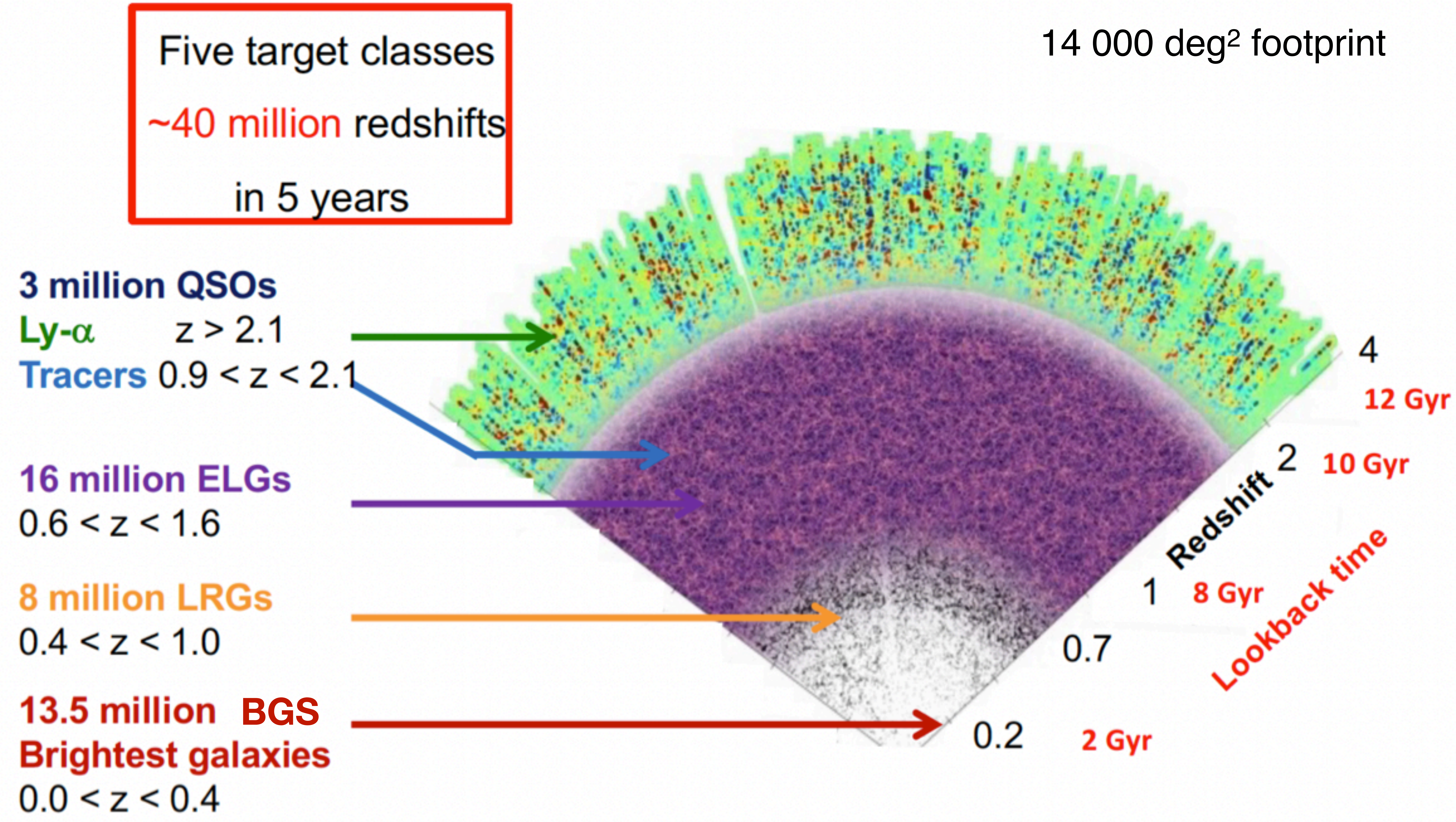
Corrector
~ 8 $deg^2$ FoV



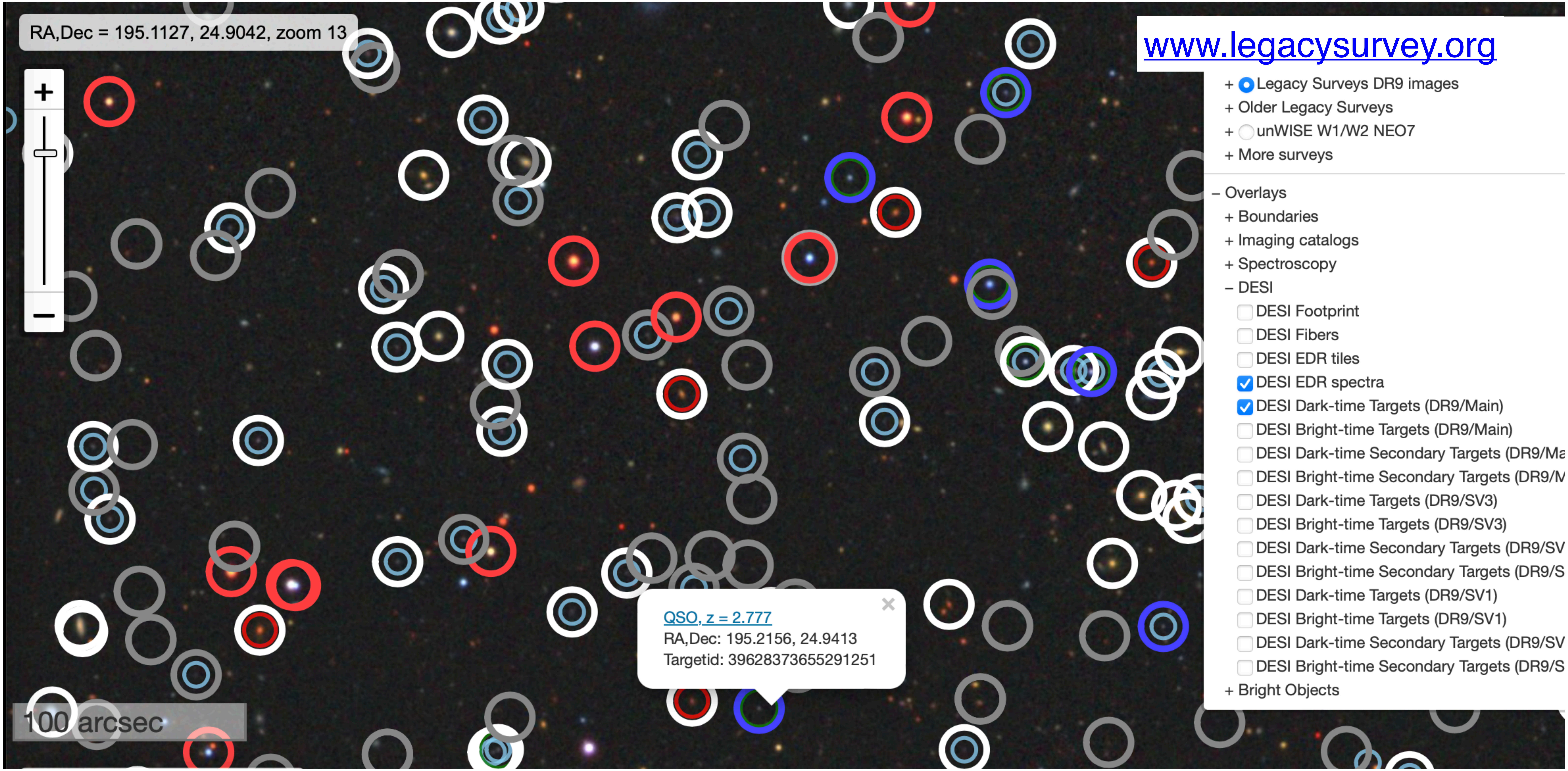



10 spectrographs

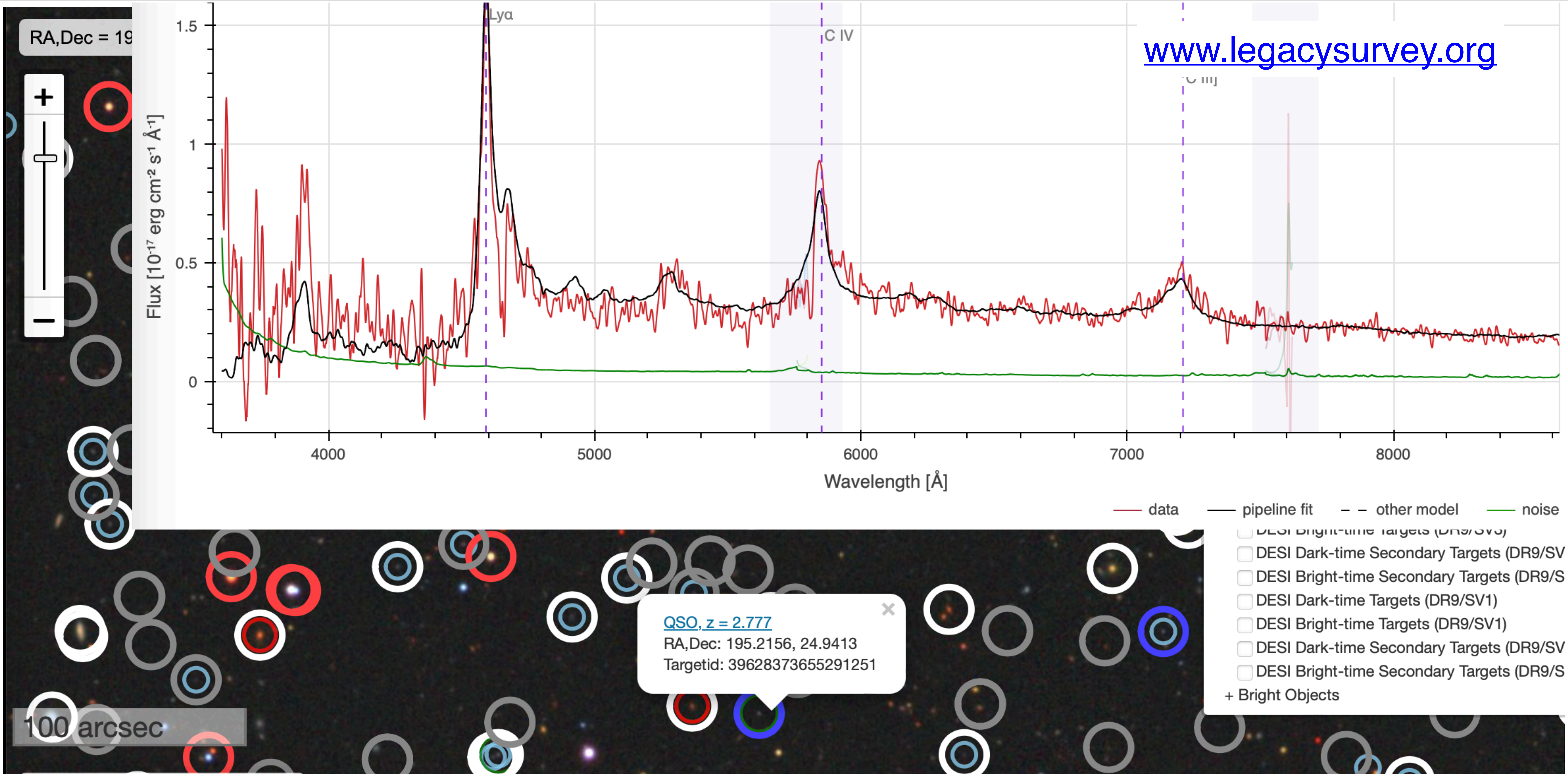
# DESI main survey



# Matching fibers to targets from imaging

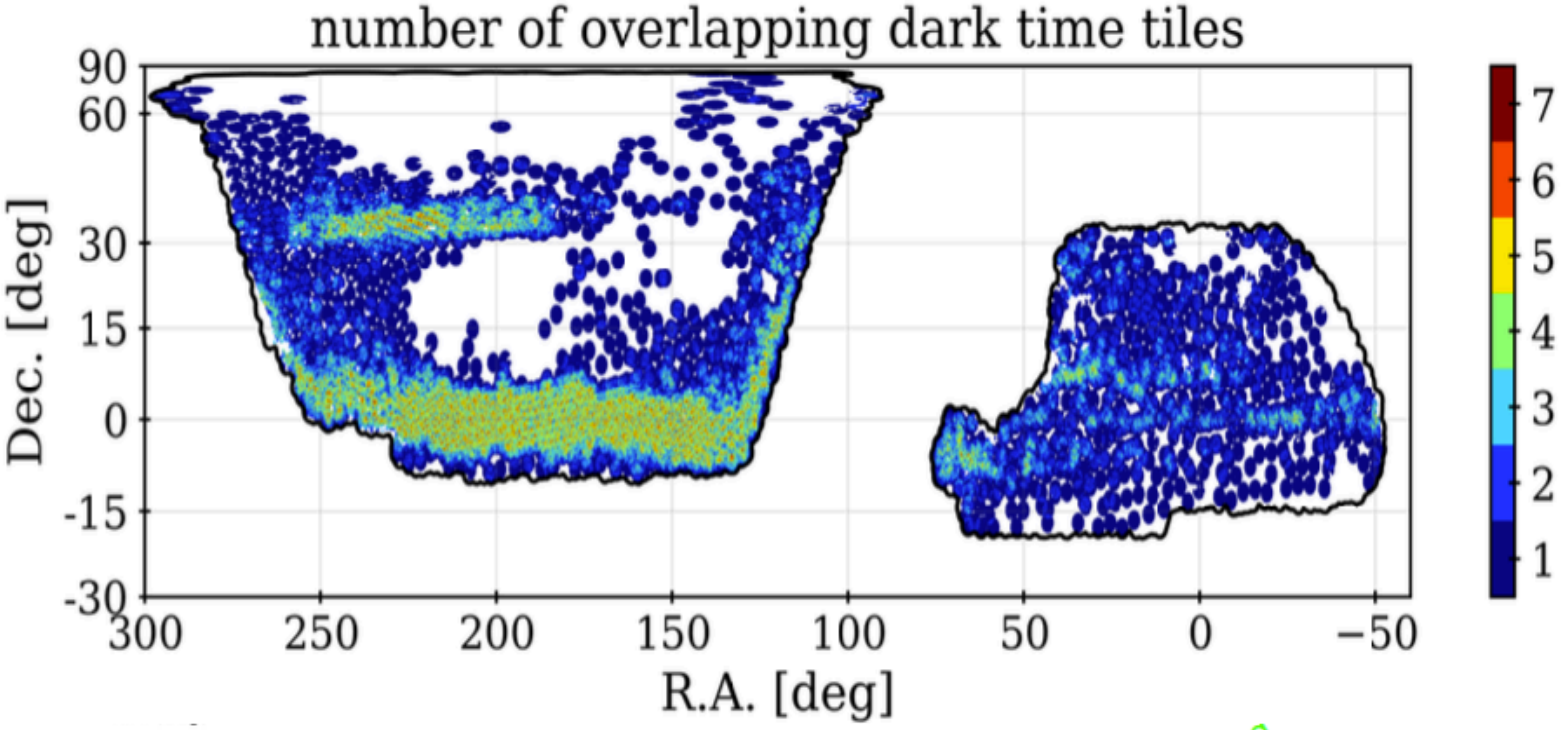


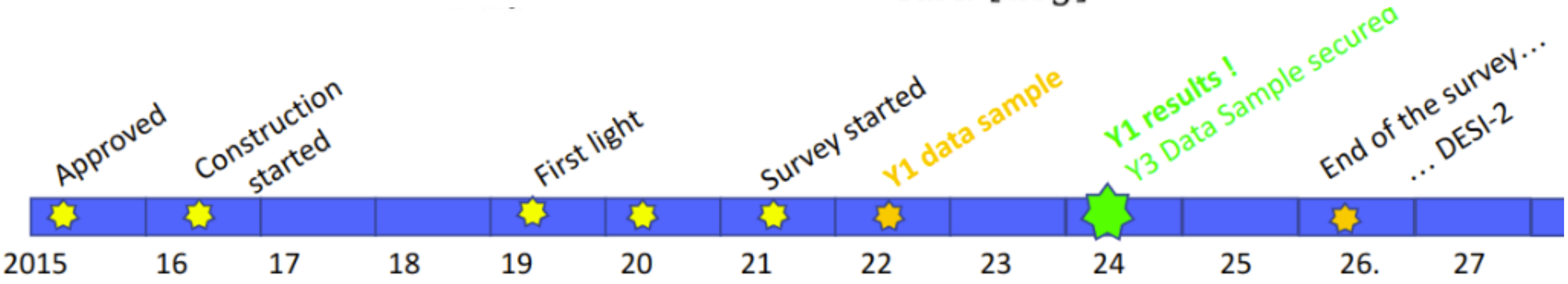
# ... and getting spectra



# DESI Y1 sample

a tile ~ a sky pointing, with associated set of targets



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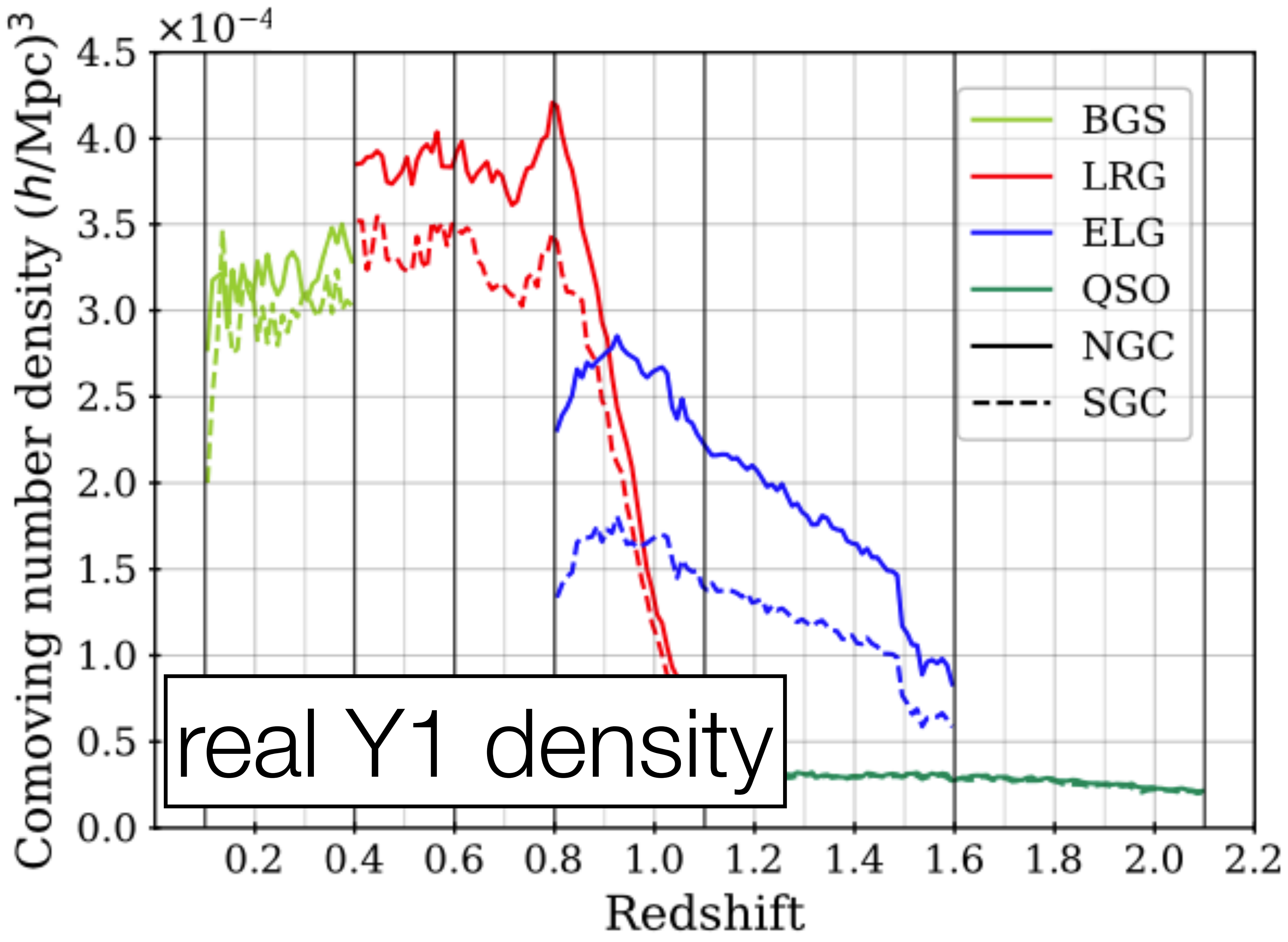


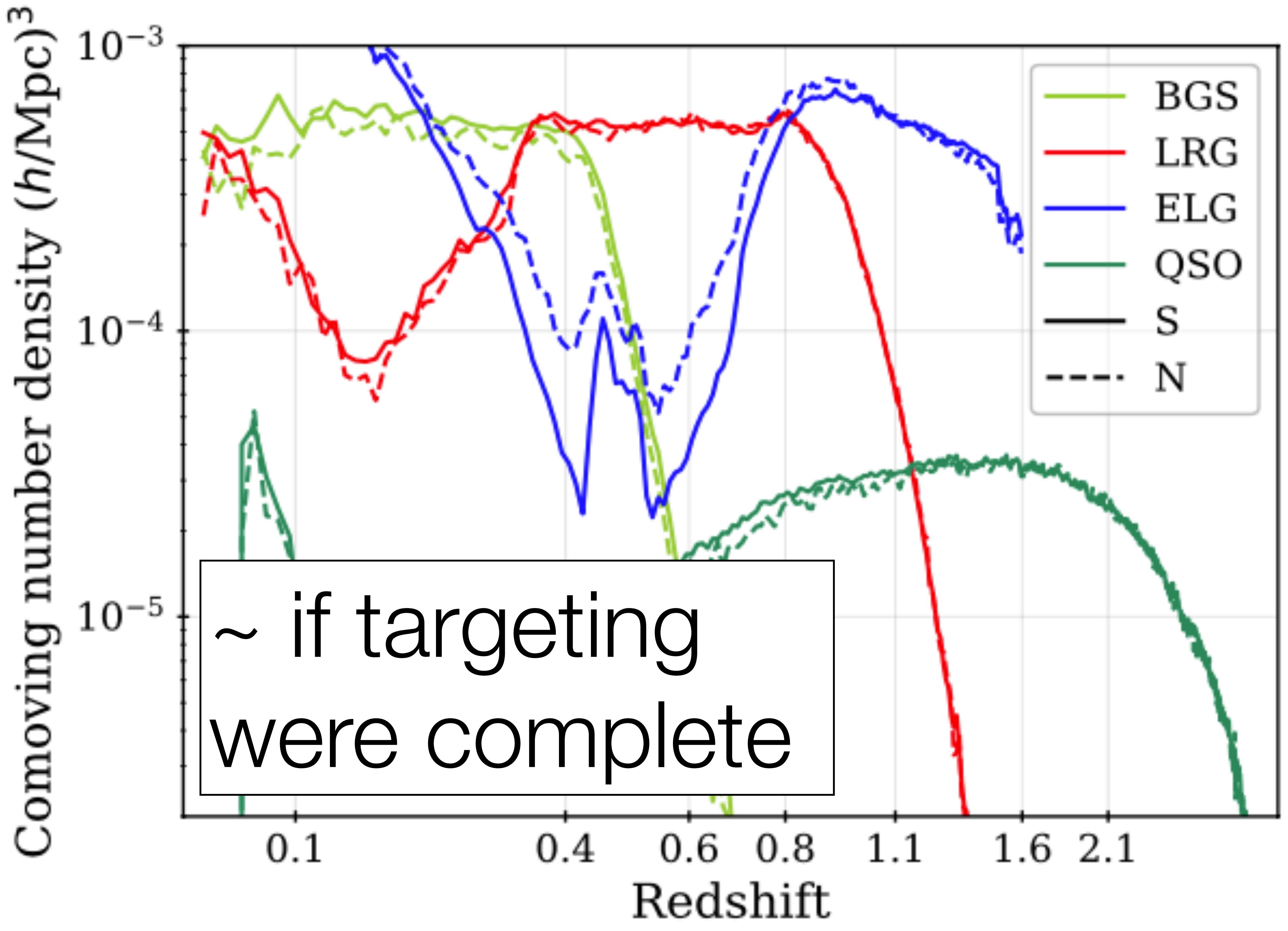


| Tracer | # of good z | z range | Area [deg²] | $C_{assign}$ | z succ. % |
|---|---|---|---|---|---|
| BGS ($M_r < -21.5$) | 300,043 | $0.1 < z < 0.4$ | 7473 | 63.6% | 98.9% |
| LRG | 2,138,627 | $0.4 < z < 1.1$ | 5740 | 69.3% | 99.1% |
| ELG | 2,432,072 | $0.8 < z < 1.6$ | 5924 | 35.2% | 72.7% |
| QSO | 1,223,391 | $0.8 < z < 3.5$ | 7249 | 87.4% | 66.8% |
| QSO | 856,831 | $0.8 < z < 2.1$ | 7249 | 87.4% | 66.8% |

ELGs will do much better in Y3+

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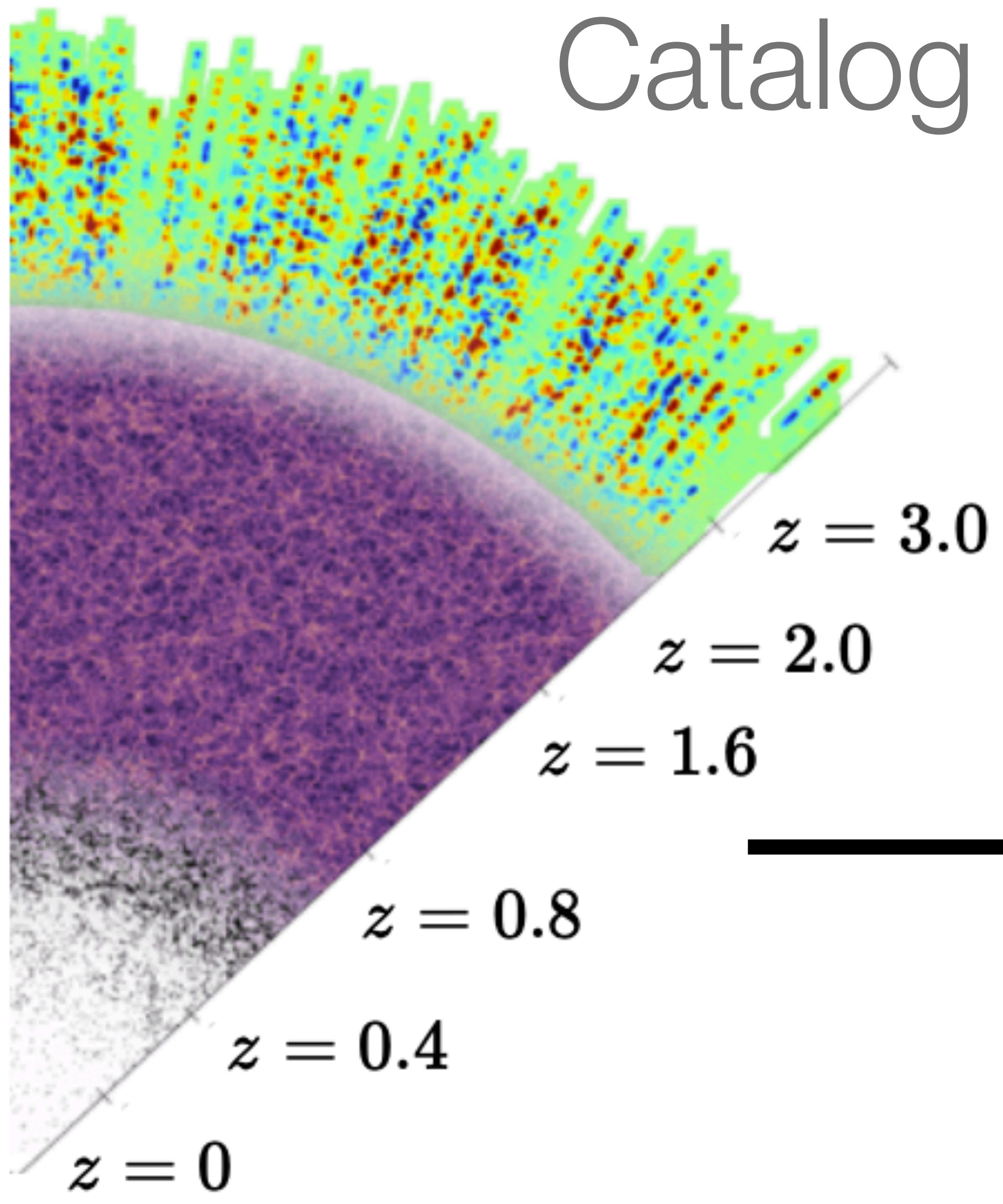
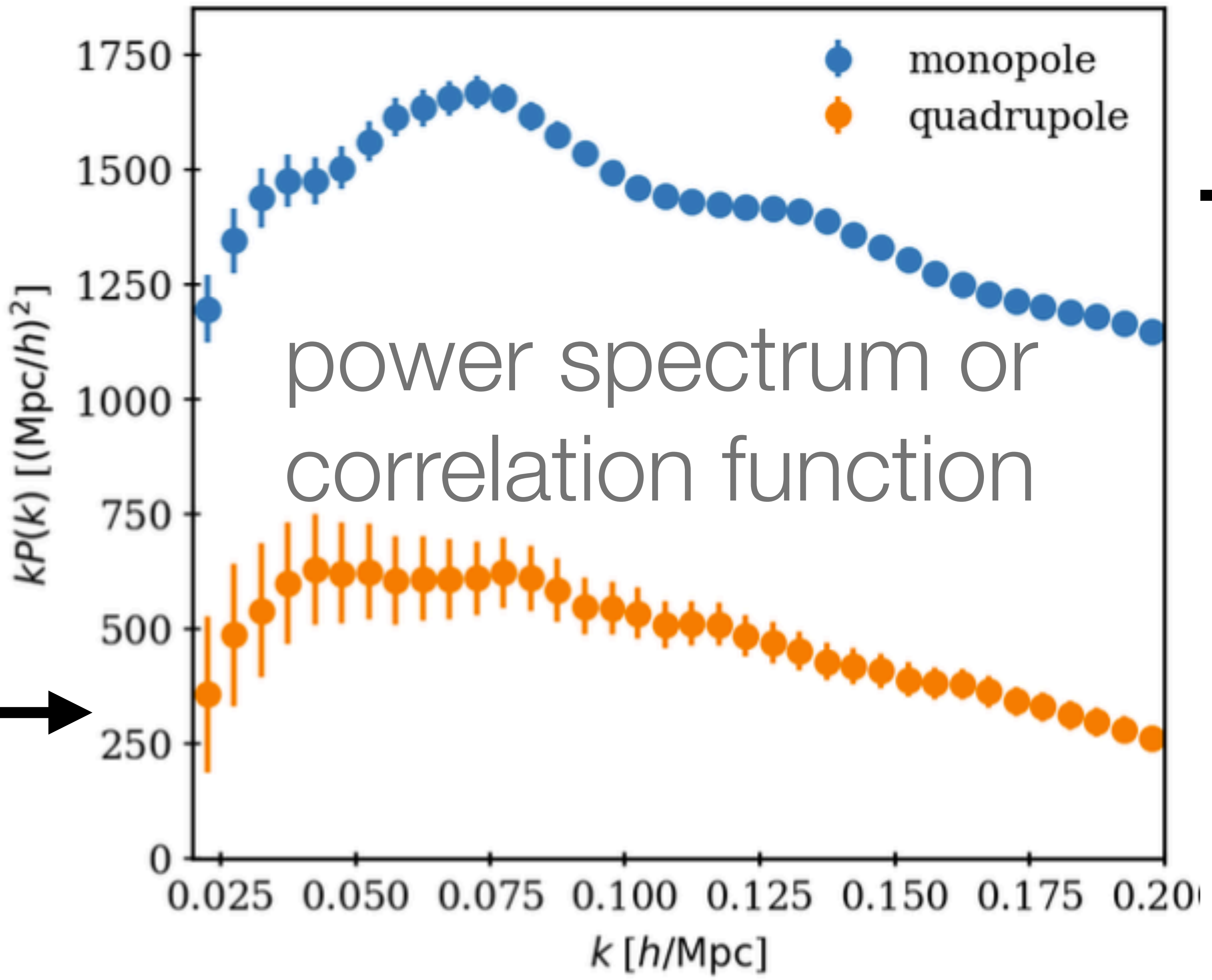
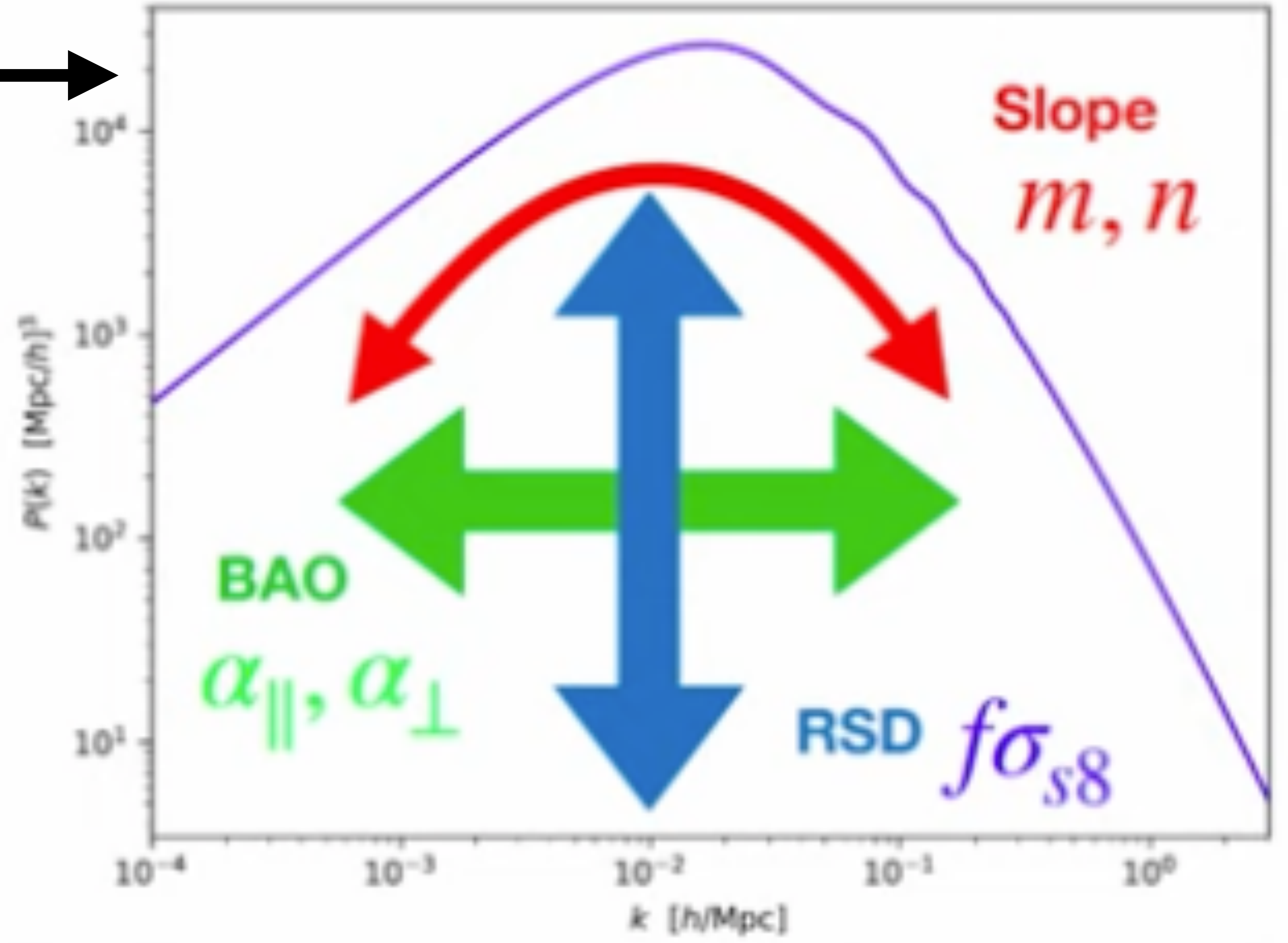
# From BAO to "Full shape"




Compressed quantities




(a) Compress correlations to BAO's $\alpha_\parallel$, $\alpha_\perp$ (+ reconstruction: BAO results) **April papers**

(b) Compress power spectra, using ShapeFit scheme

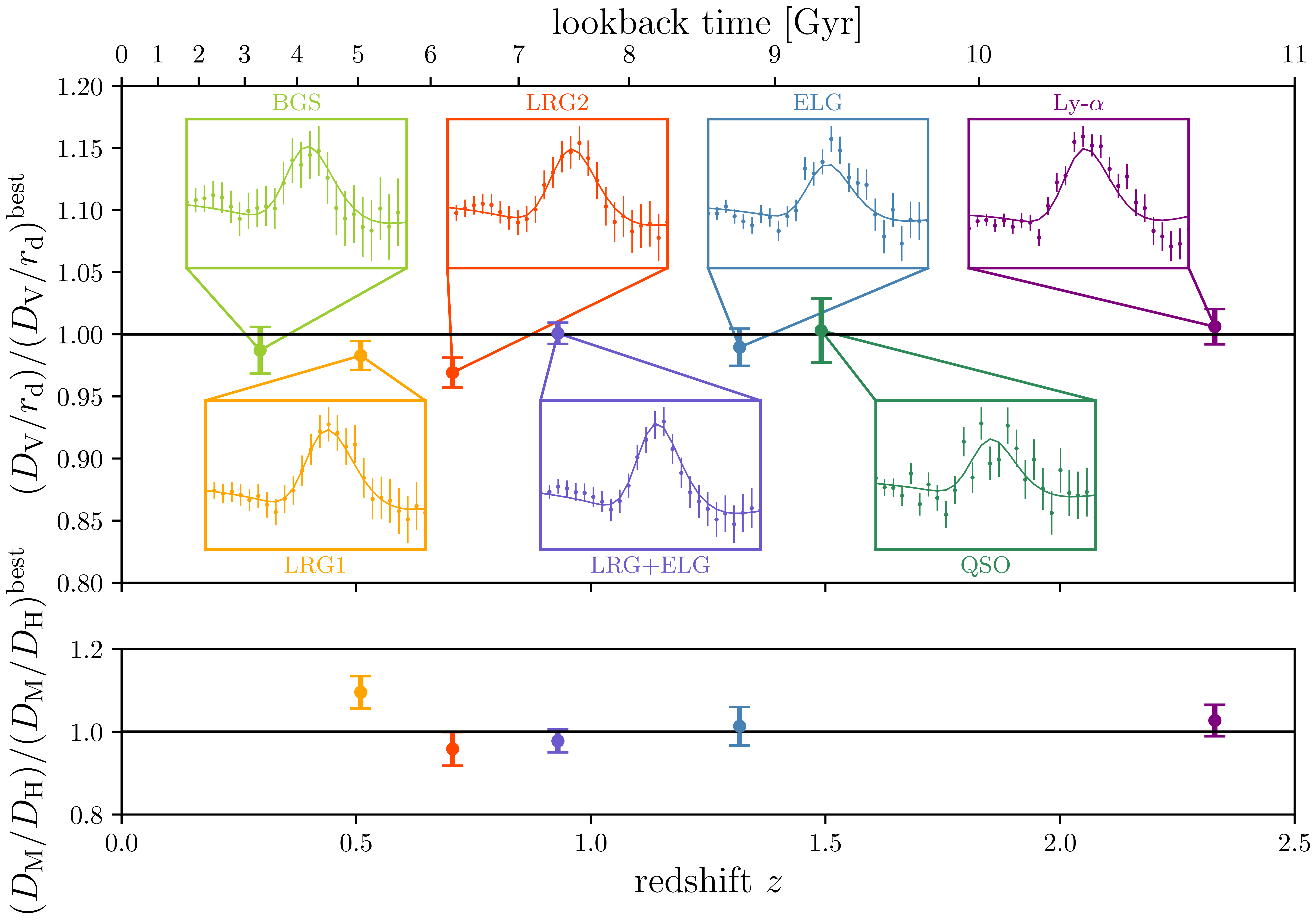
(c) Directly fit power spectra ("Full modelling") **Baseline Nov papers**

in (b) and (c) combine with $\alpha_\parallel$, $\alpha_\perp$ from reconstructed BAO

# Combined DESI Y1 BAO-only result

$\sim (\alpha_{\parallel}\, \alpha_{\perp}^2)^{1/3}$

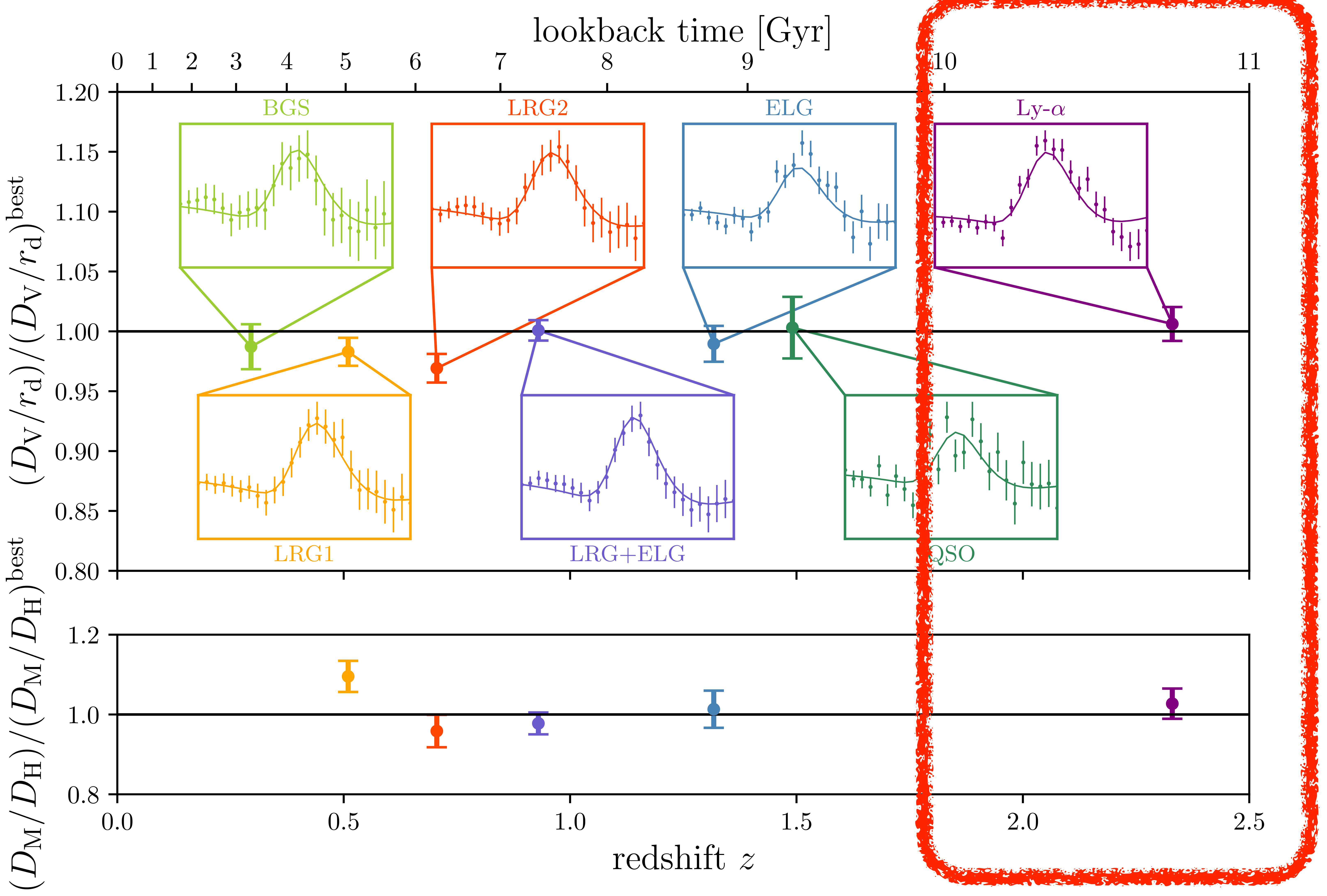
$\sim \alpha_{\perp}/\alpha_{\parallel}$



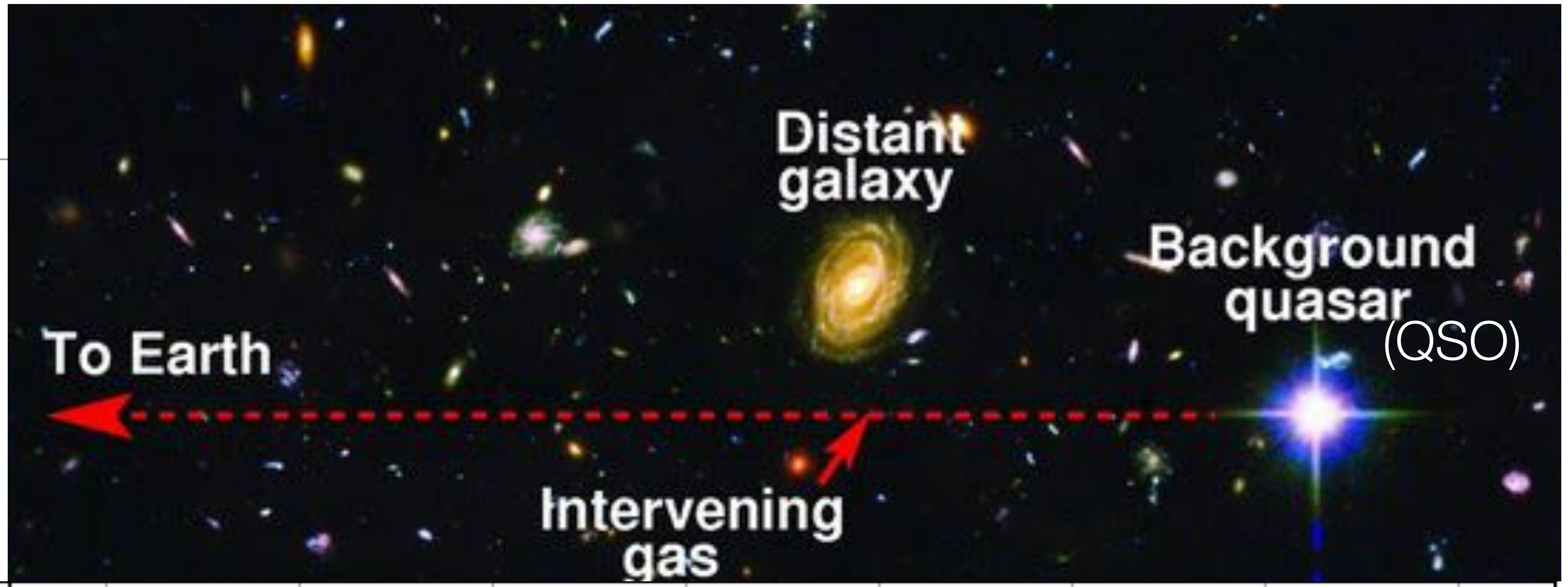
# Combined DESI Y1 BAO-only result

$\sim (\alpha_\parallel \, \alpha_\perp^2)^{1/3}$

$\sim \alpha_\perp / \alpha_\parallel$



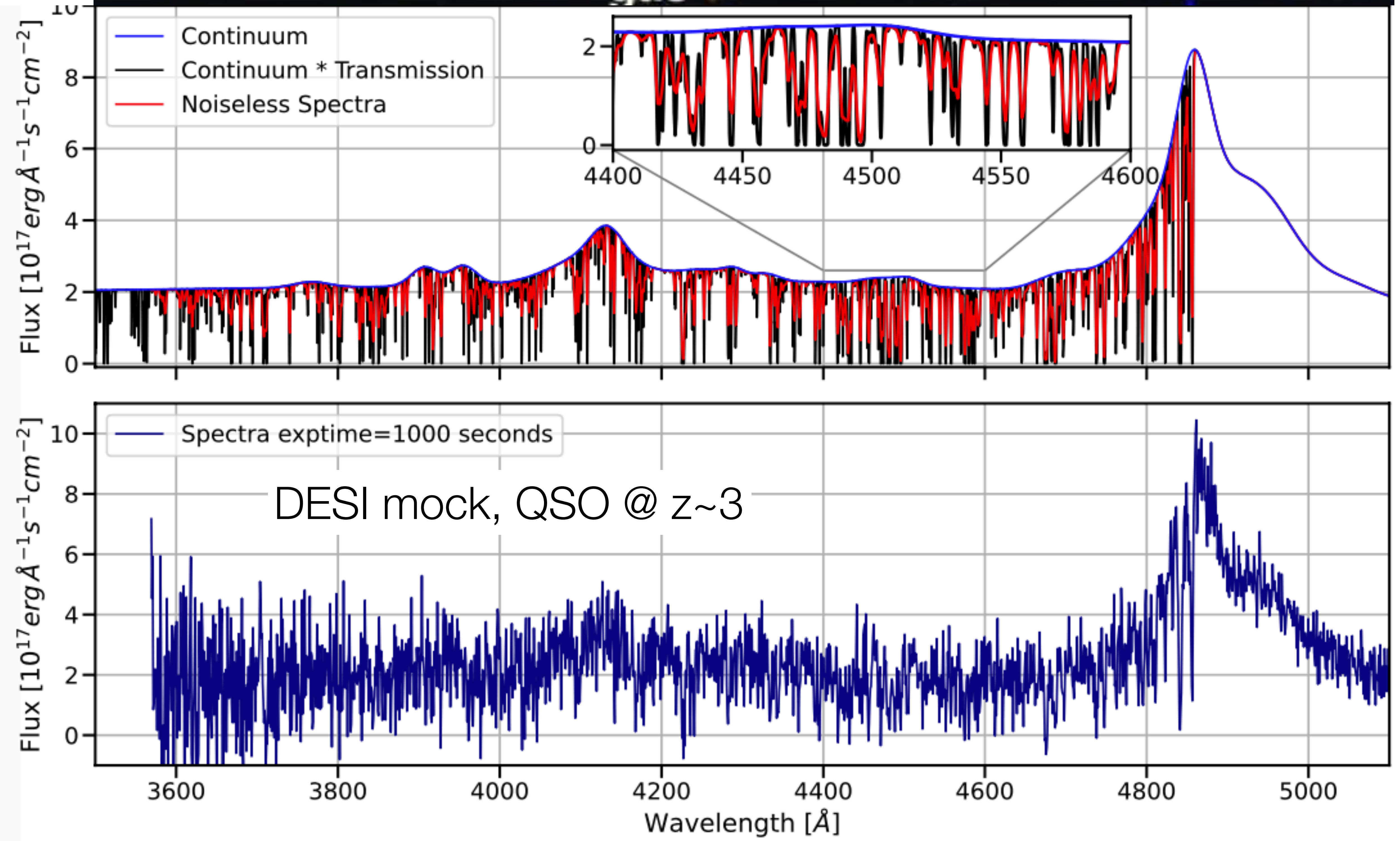
# The Lyman-$\alpha$ forest




- Resonant absorption of QSO's light by neutral hydrogen HI in the intergalactic medium

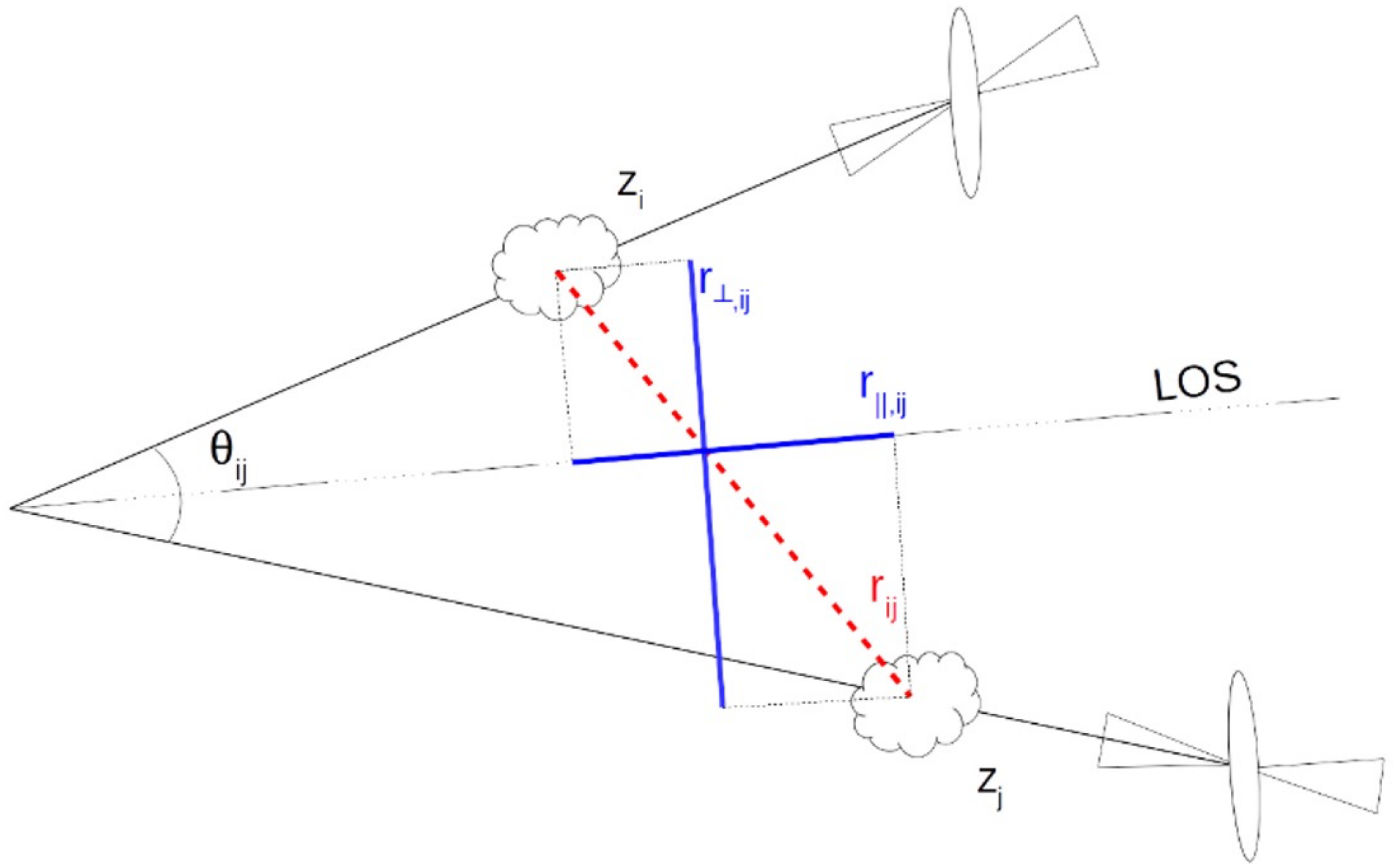
$$\lambda_{\rm abs} = 1215.17\,\text{Å} \times (1 + z_{\rm HI})$$

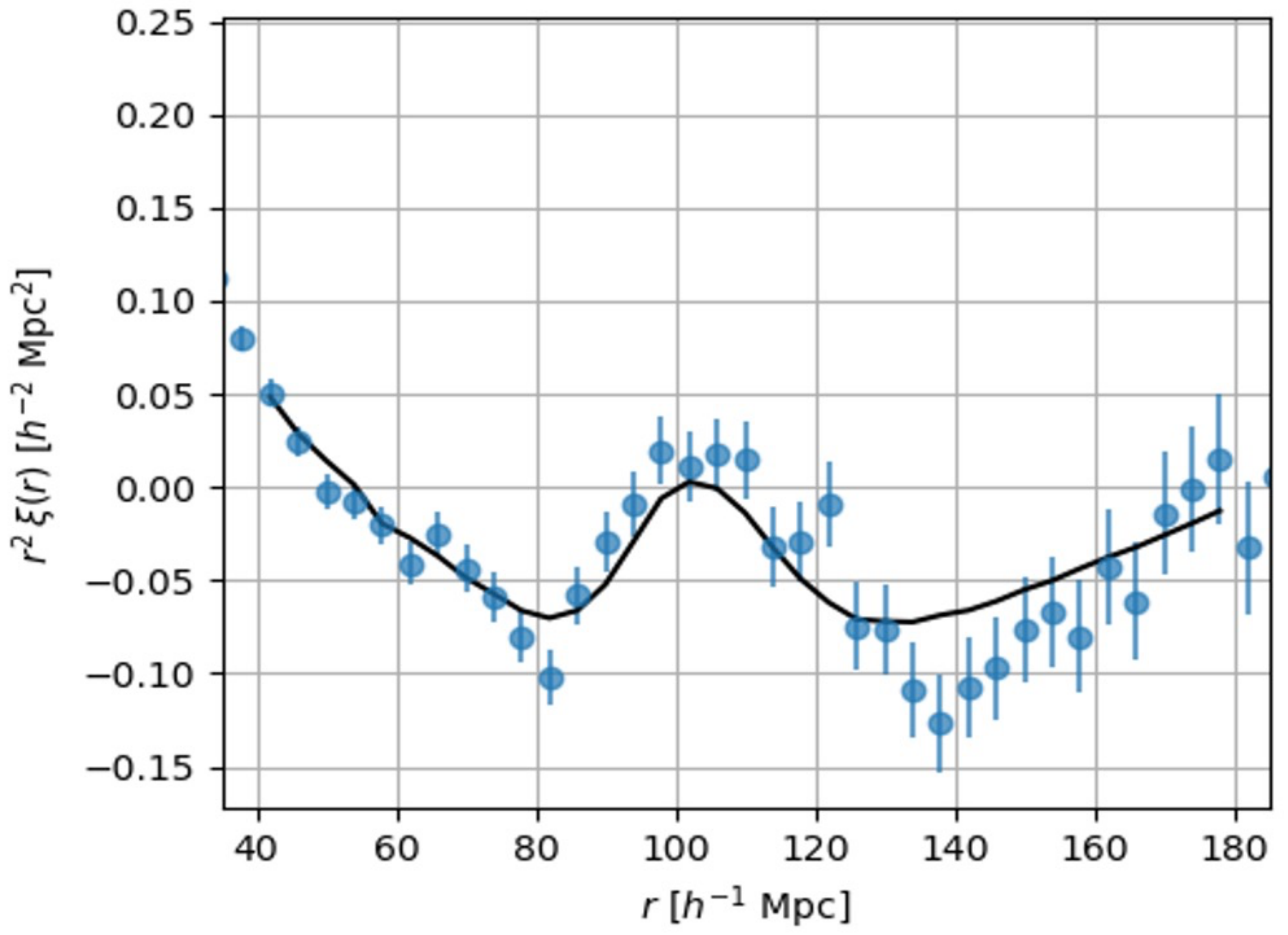
- **tracer of mild density fluctuations in the cosmic web, at z > 2**
- **DESI Y1 sample:**
  - 420,000 Lya QSO (60/deg$^2$, x2 wrt 20 years of SDSS)
  - low SNR
  - contaminations: atmospheric skylines, metals, quasar's continuum etc.




Herrera-Alcantar et al., arxiv:2401.00303

# Lyman-$\alpha$ spatial correlations



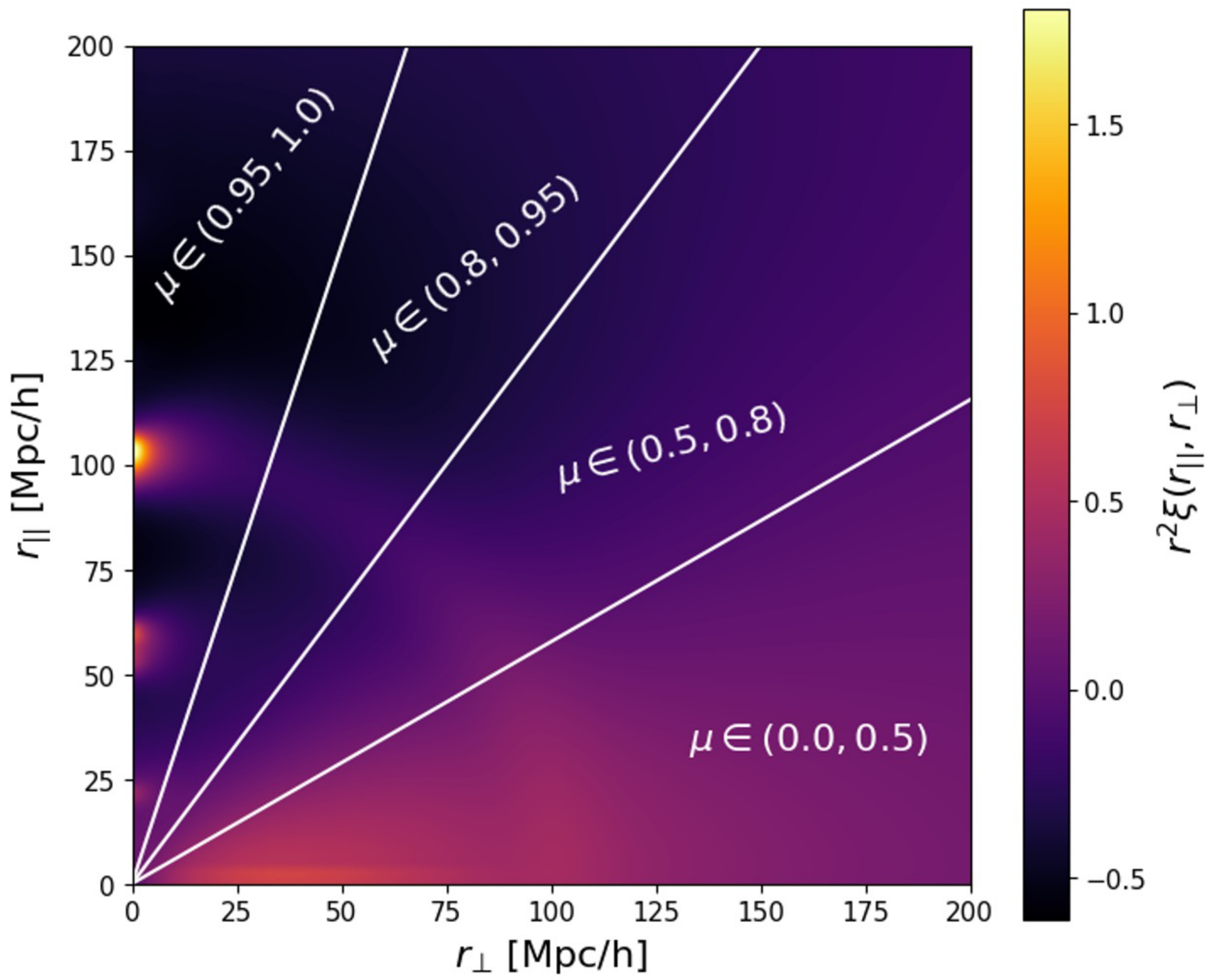




Simple weighted mean in ($r_\parallel$,$r_\perp$) separation bins "A" :

$$\xi_A = \frac{\sum_{(i,j)\in A} w_i w_j \delta_i \delta_j}{\sum_{(i,j)\in A} w_i w_j}$$

$\delta$: relative flux absorption

# Modelling the measured Lya correlations



# Modelling the measured Lya correlations

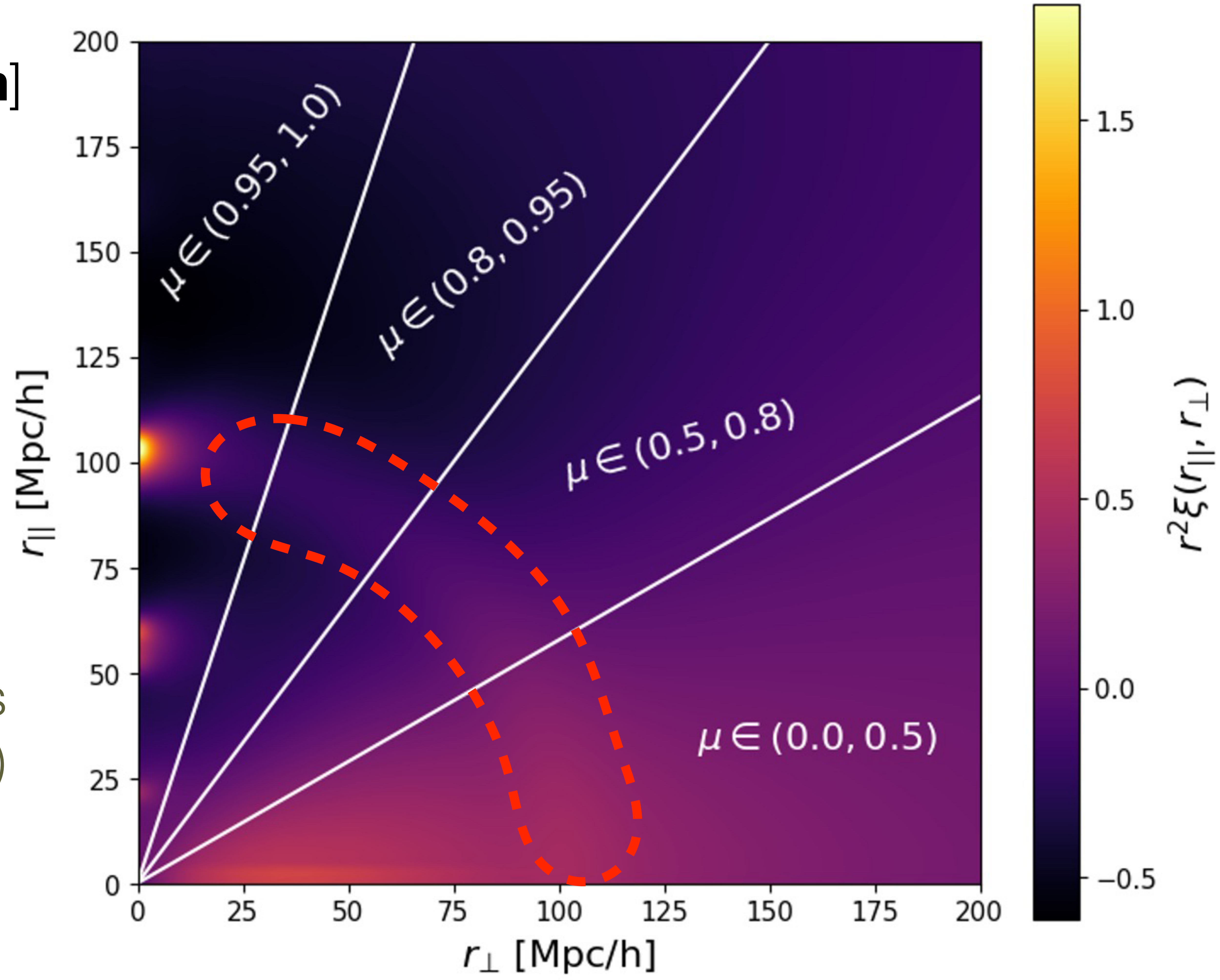
Correlation function = Fourier[**power spectrum**]

$$P(k,\mu) \sim b^2(1+\beta\mu^2)^2 P_{\rm lin}(k,\mu) F_{\rm NL}(k,\mu)$$

linear bias + RSD

includes BAO

non-linear corrections
(from hydrodynamical simulations)



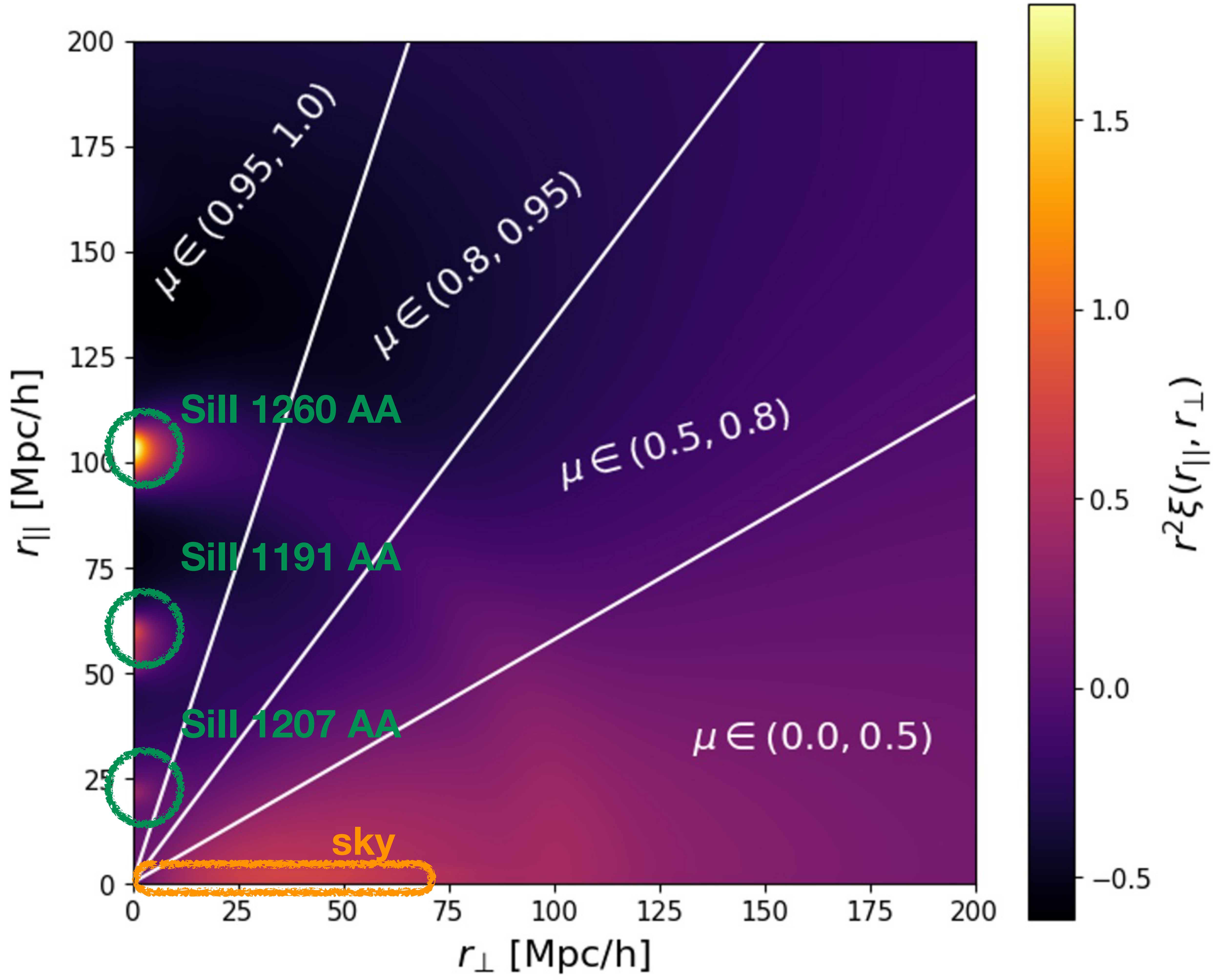
# Modelling the measured Lya correlations

**Contaminants** included in the model

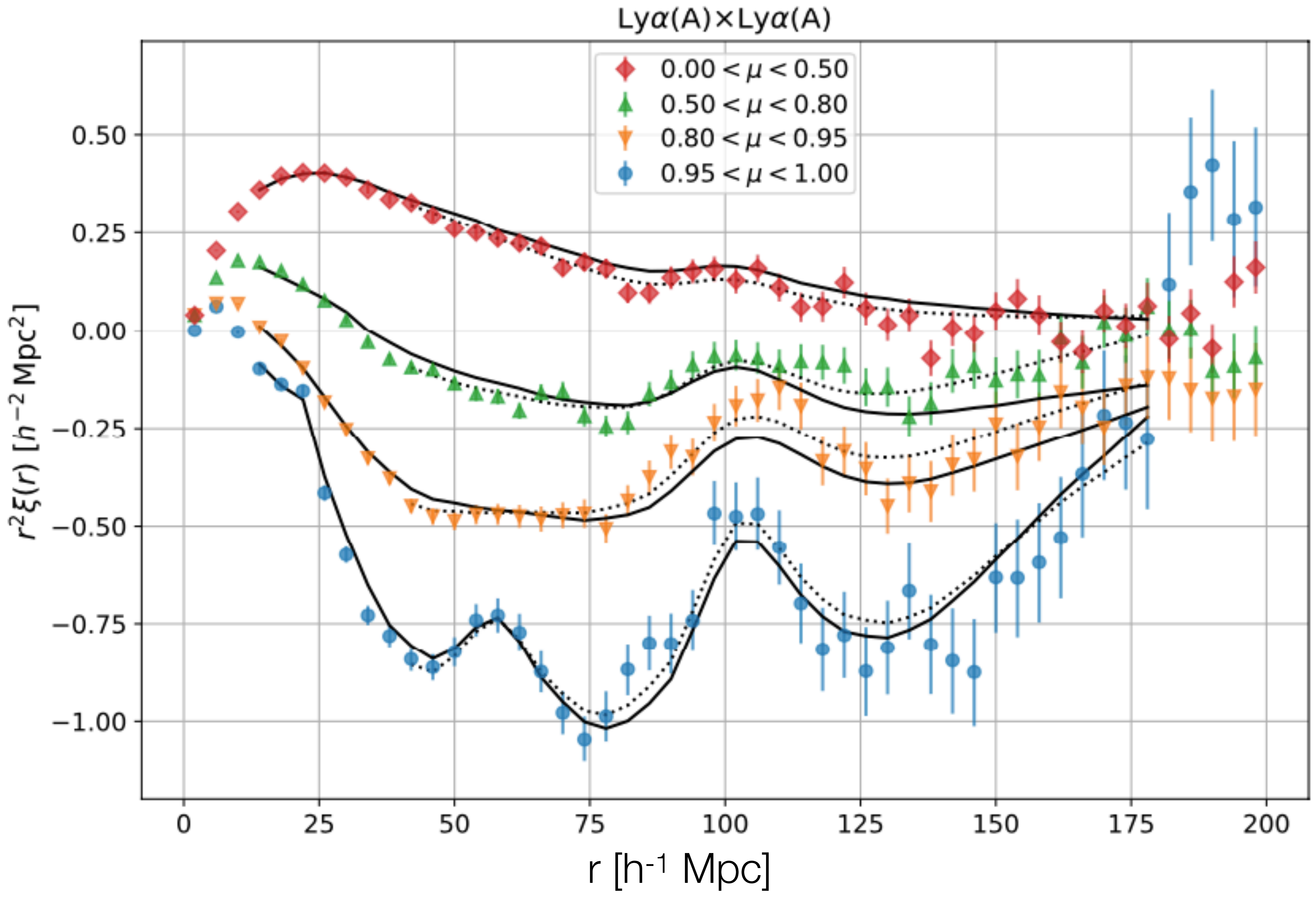
- impact of QSO continuum
- high-column density and metal absorbers:

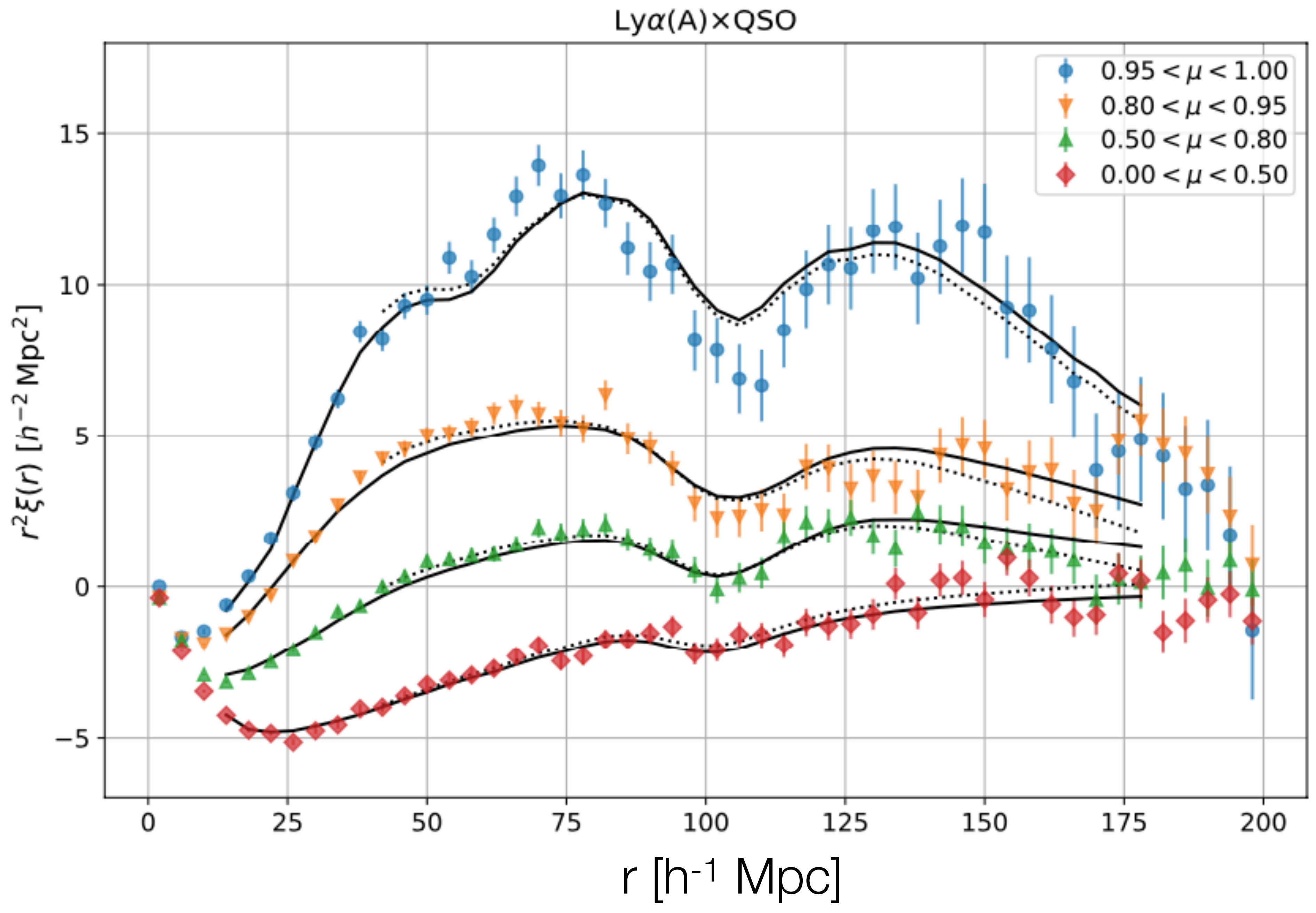
$$r_{\parallel} = \frac{c\,\lambda_{\rm obs}}{H(z)} \left| \frac{1}{\lambda_{\rm Lya}} - \frac{1}{\lambda_{\rm metal}} \right|$$

- Correlated noise from sky subtraction
  [Guy et al. arxiv:2404.03003]



# Measured correlation function




+ Correlation between Lya forest and quasar's positions

——— physical model fit

······· + broadband polynomial

# Lyman-$\alpha$ BAO : pre-unblinding validation

- **Validation with mocks (synthetic data)**: recover unbiased BAO parameters, good understanding of statistical uncertainties

- **Data splits** on the blinded data set:
  - LyaxLya vs LyaxQSO
  - Lya region A vs region B
  - North vs South
  - high/low SNR in QSO spectra
  - large/weak CIV equivalent width in QSO spectra

- **Variations in the analysis**

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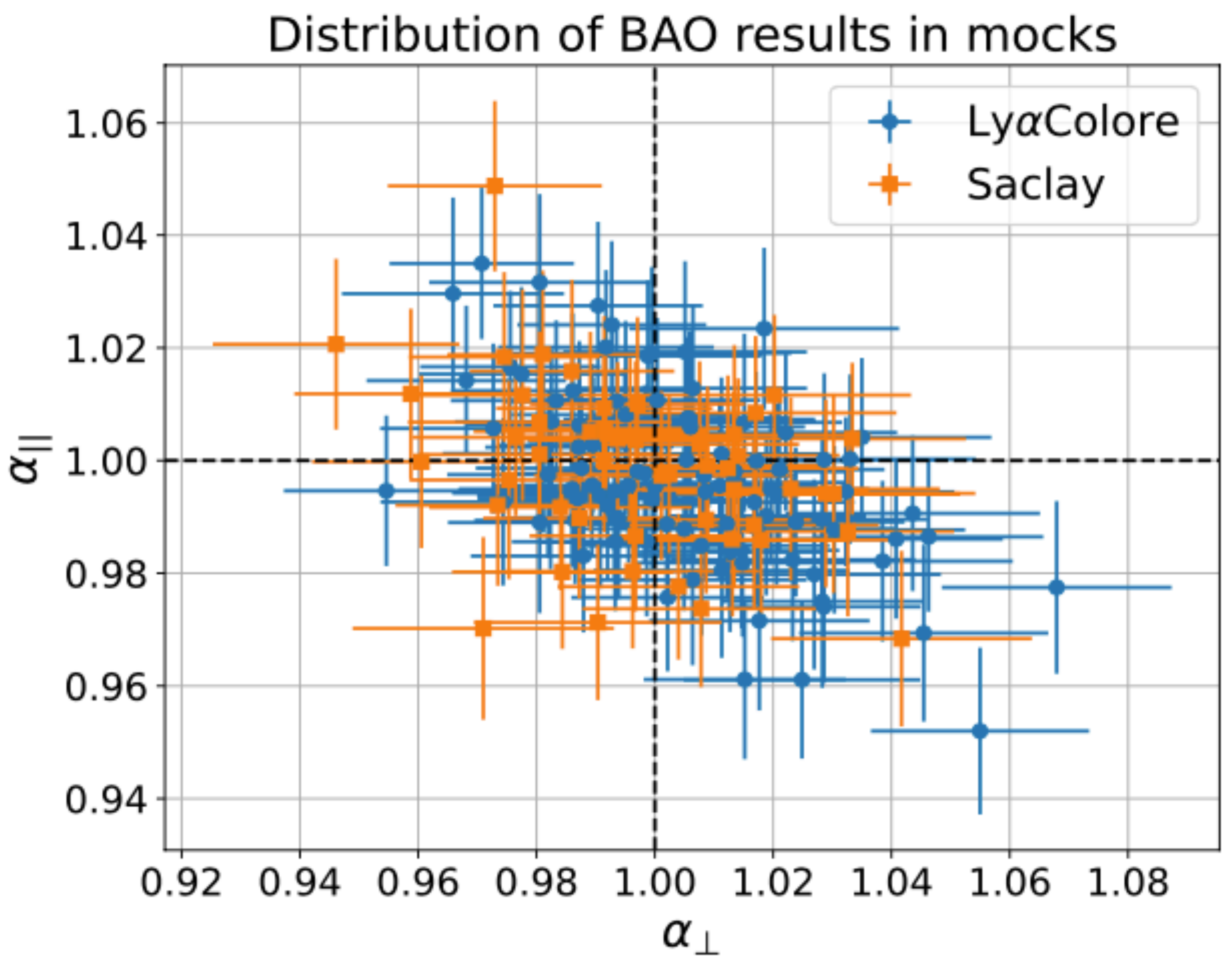


Cuceu et al., arxiv:2404.03004

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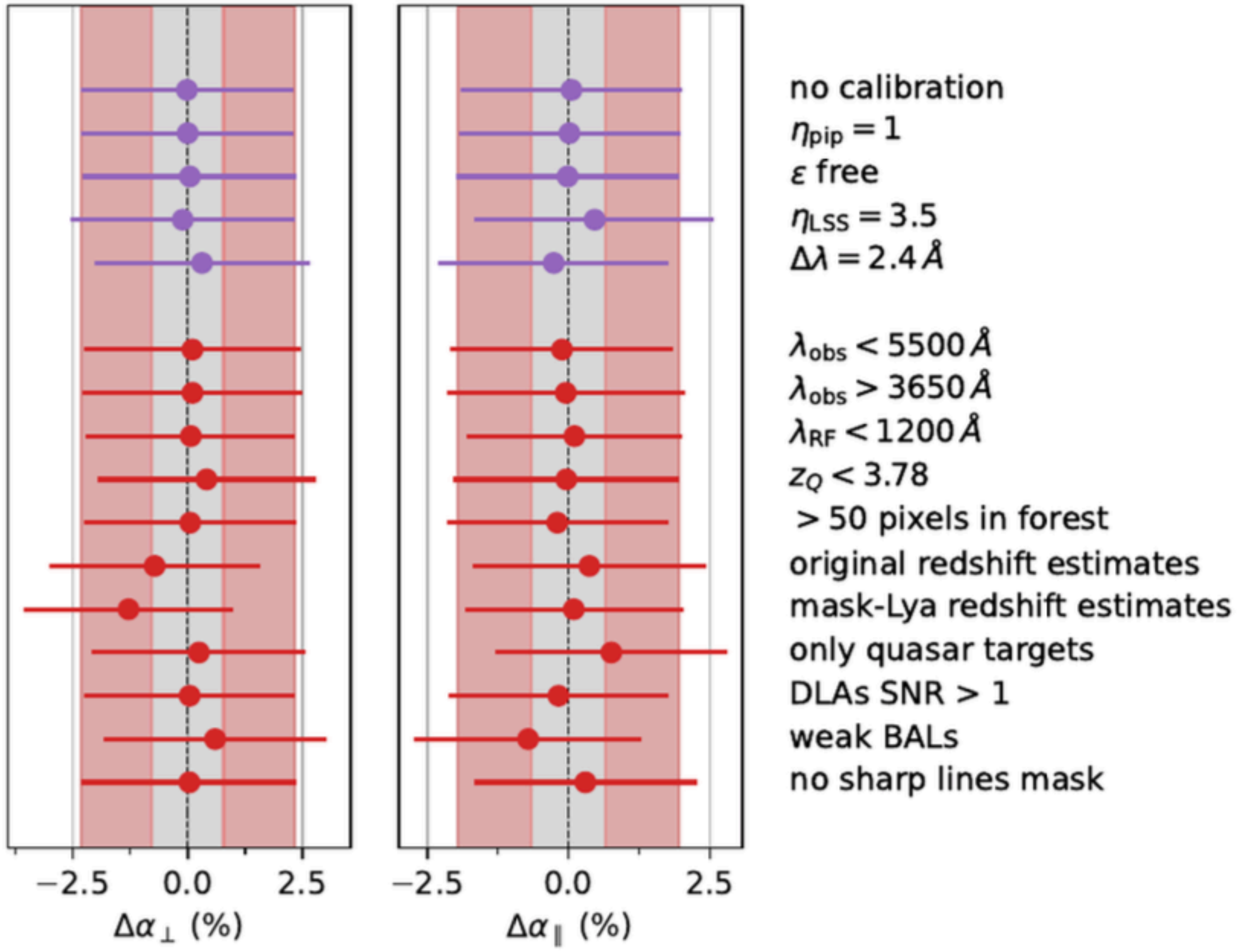
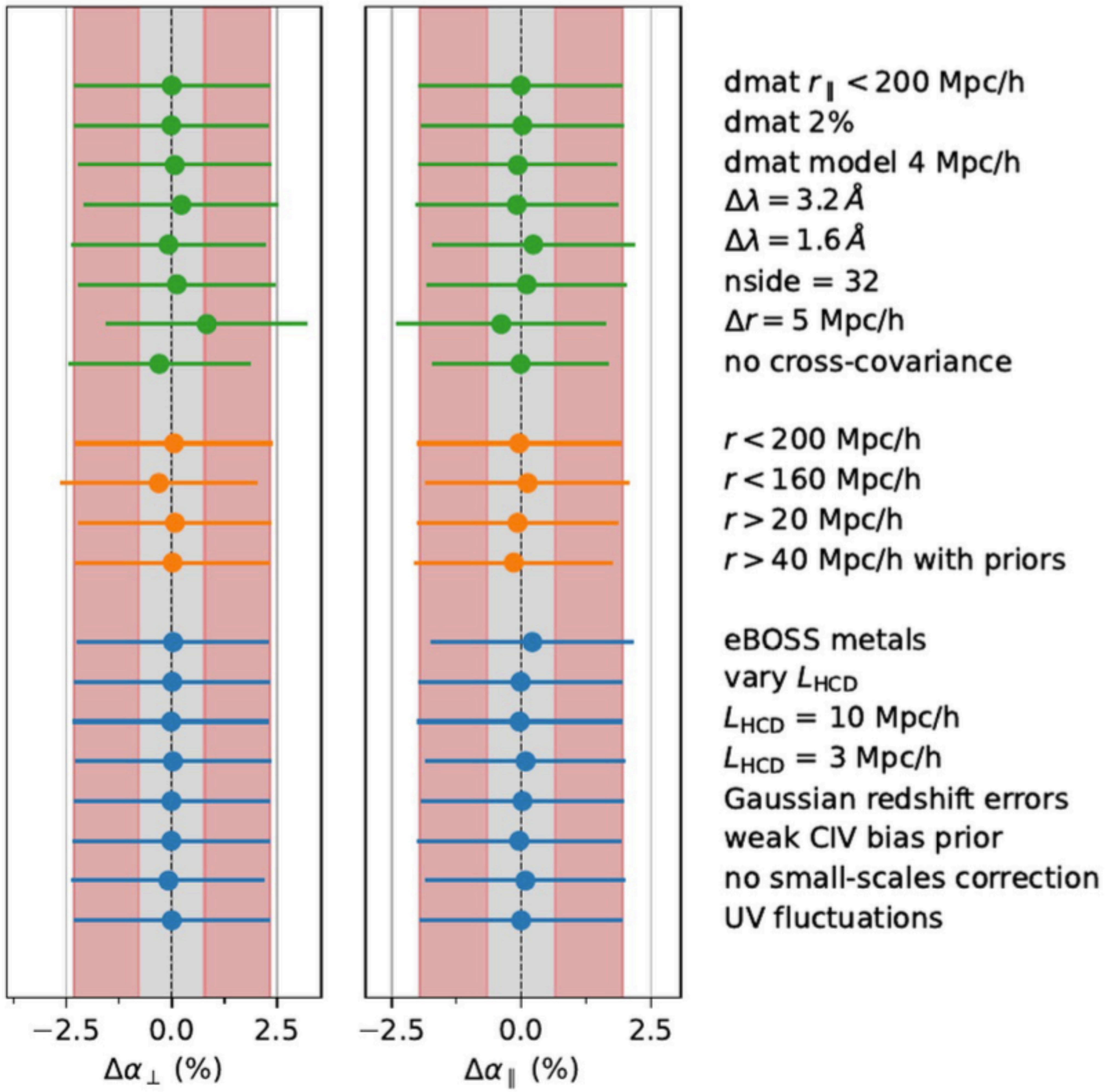
# Lyman-$\alpha$ BAO : pre-unblinding validation




- **Variations in the analysis**

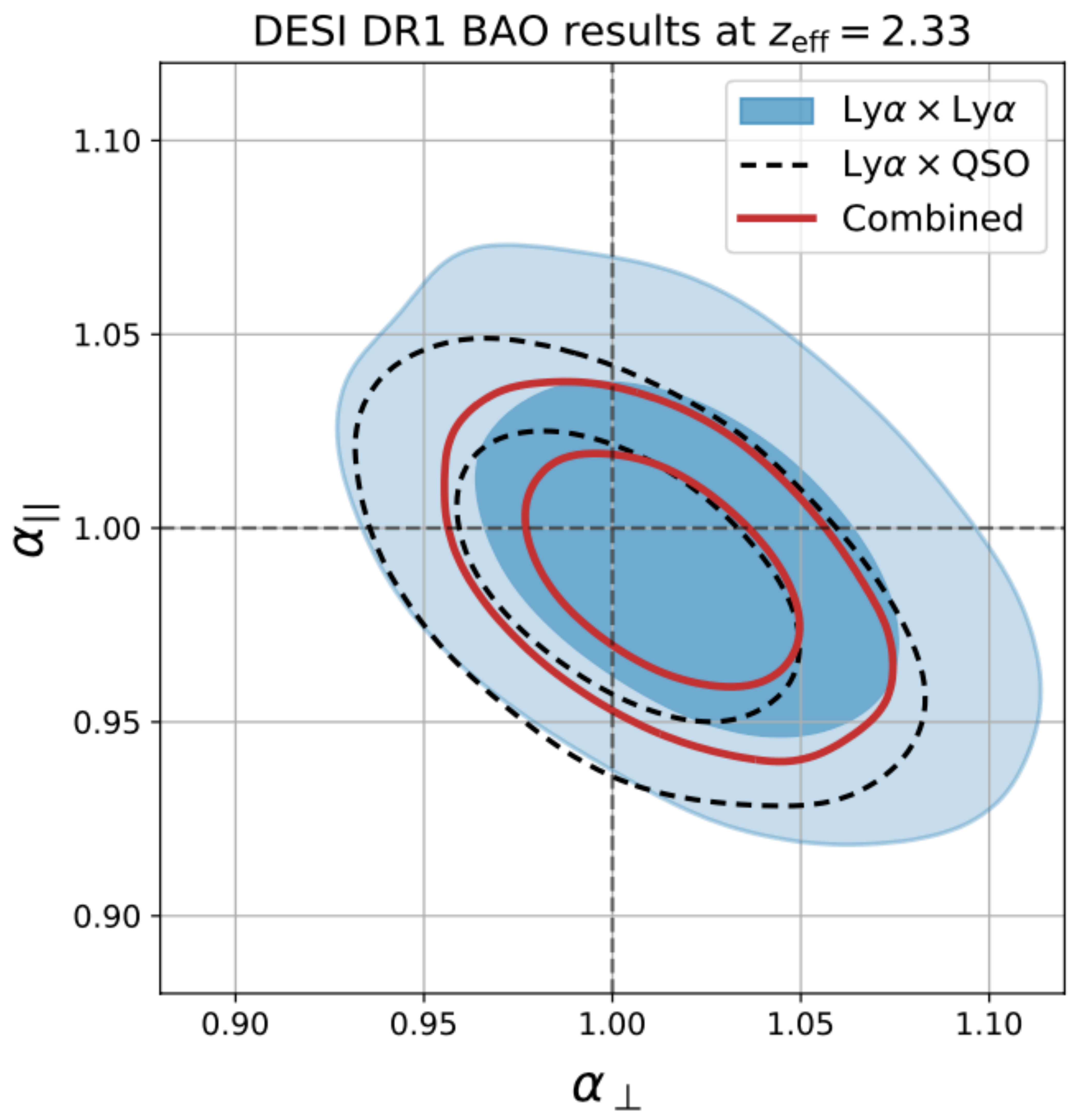
# Lyman-$\alpha$ forest: unblinded BAO result

$$\alpha_{\parallel} = \frac{D_H(z_{\rm eff})/r_d}{[D_H(z_{\rm eff})/r_d]_{\rm fid}} = 0.989 \pm 0.020$$

$$\alpha_{\perp} = \frac{D_M(z_{\rm eff})/r_d}{[D_M(z_{\rm eff})/r_d]_{\rm fid}} = 1.013 \pm 0.024$$

1.1% precision measurement of the isotropic BAO scale at z=2.33

DESI Collaboration, arxiv:2404.03001



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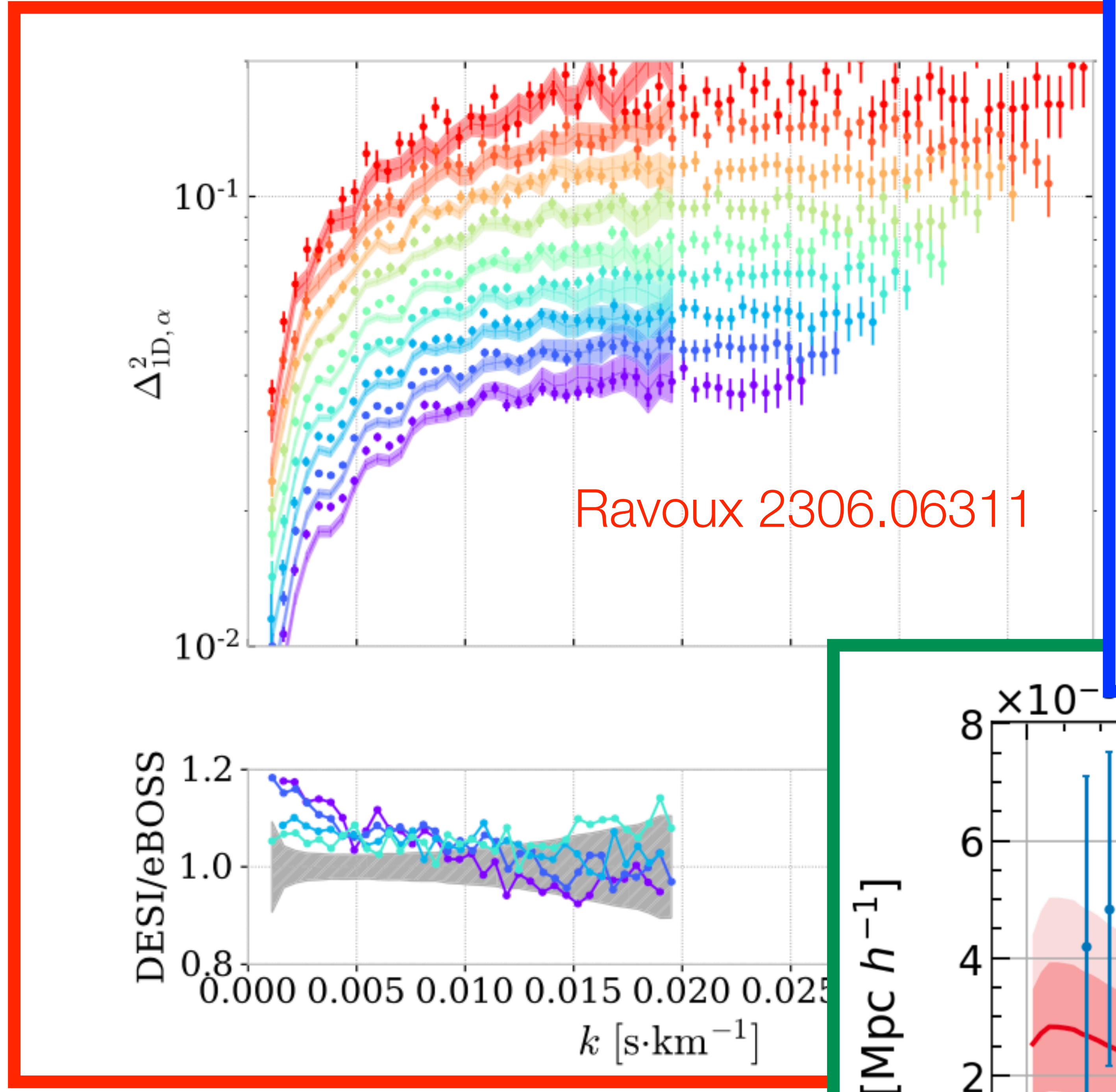
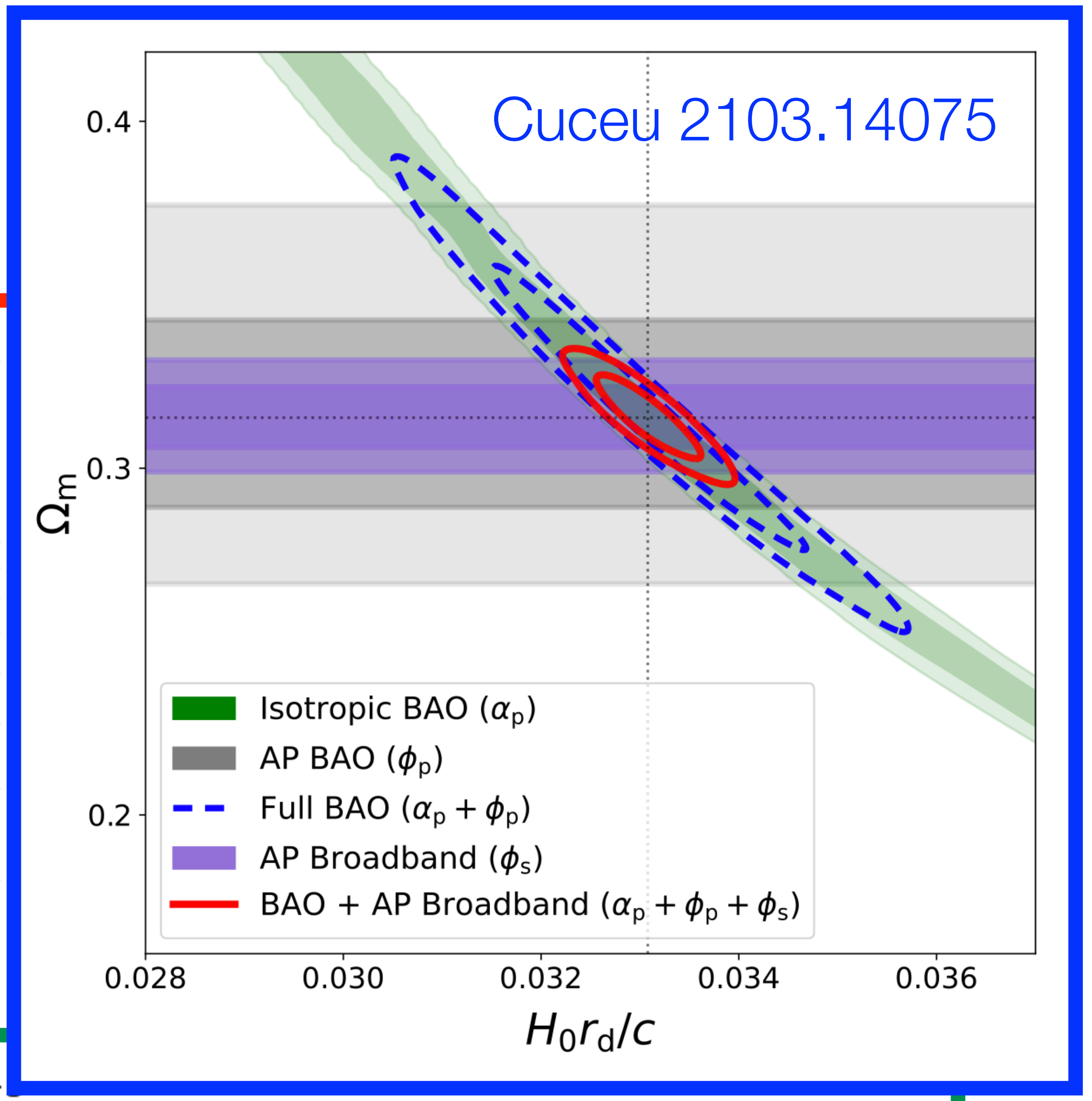
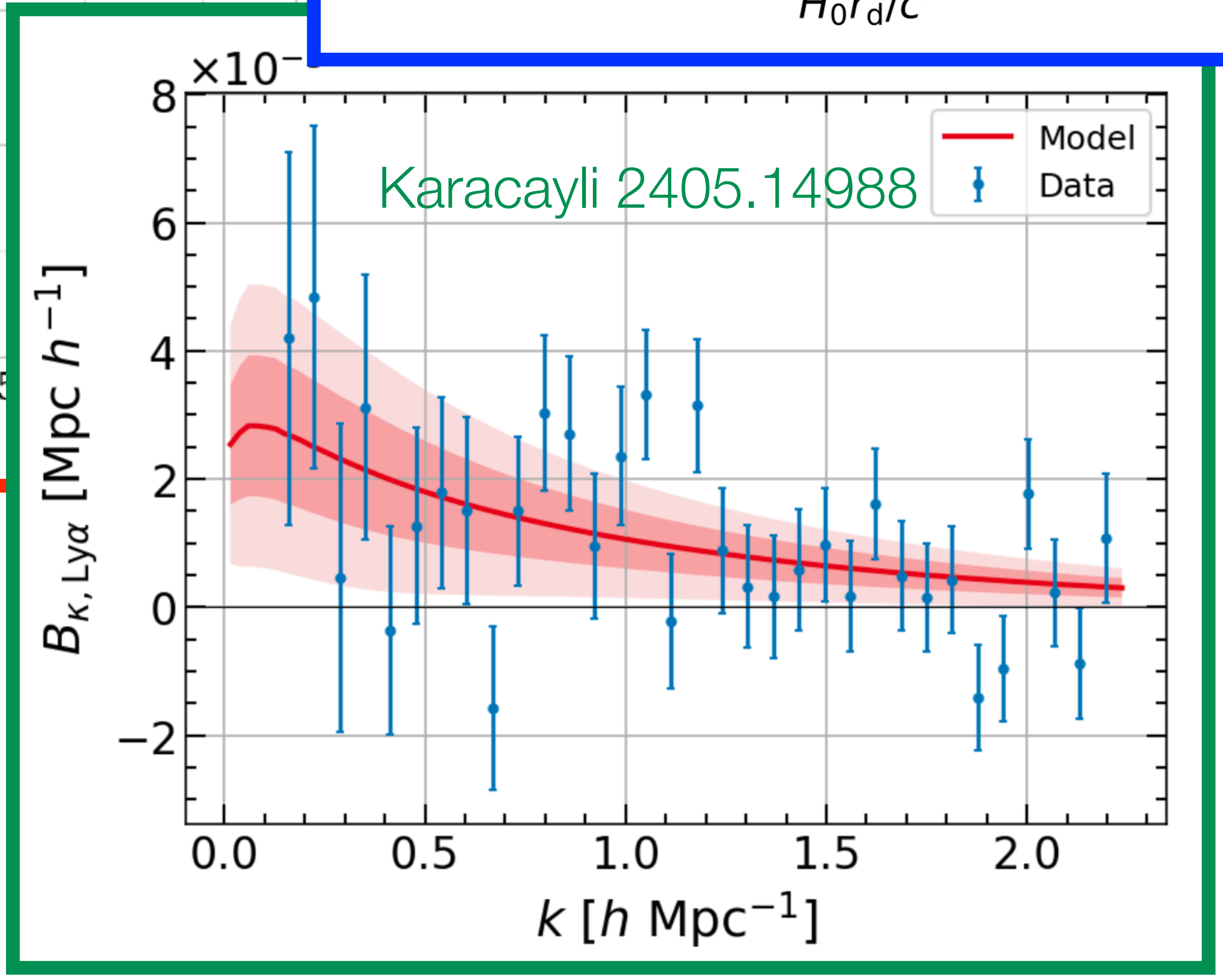
# Much more Lyman-alpha with DESI

- "Full-shape": AP and linear growth measurements at z~2.4
- 1D flux power spectrum
- Small scale 3D power spectrum (M-L. Abdul Karim, arxiv:2310.09116)
- Cross-correlation with CMB lensing
- and others... eg. protocluster searches, cross with 21cm...



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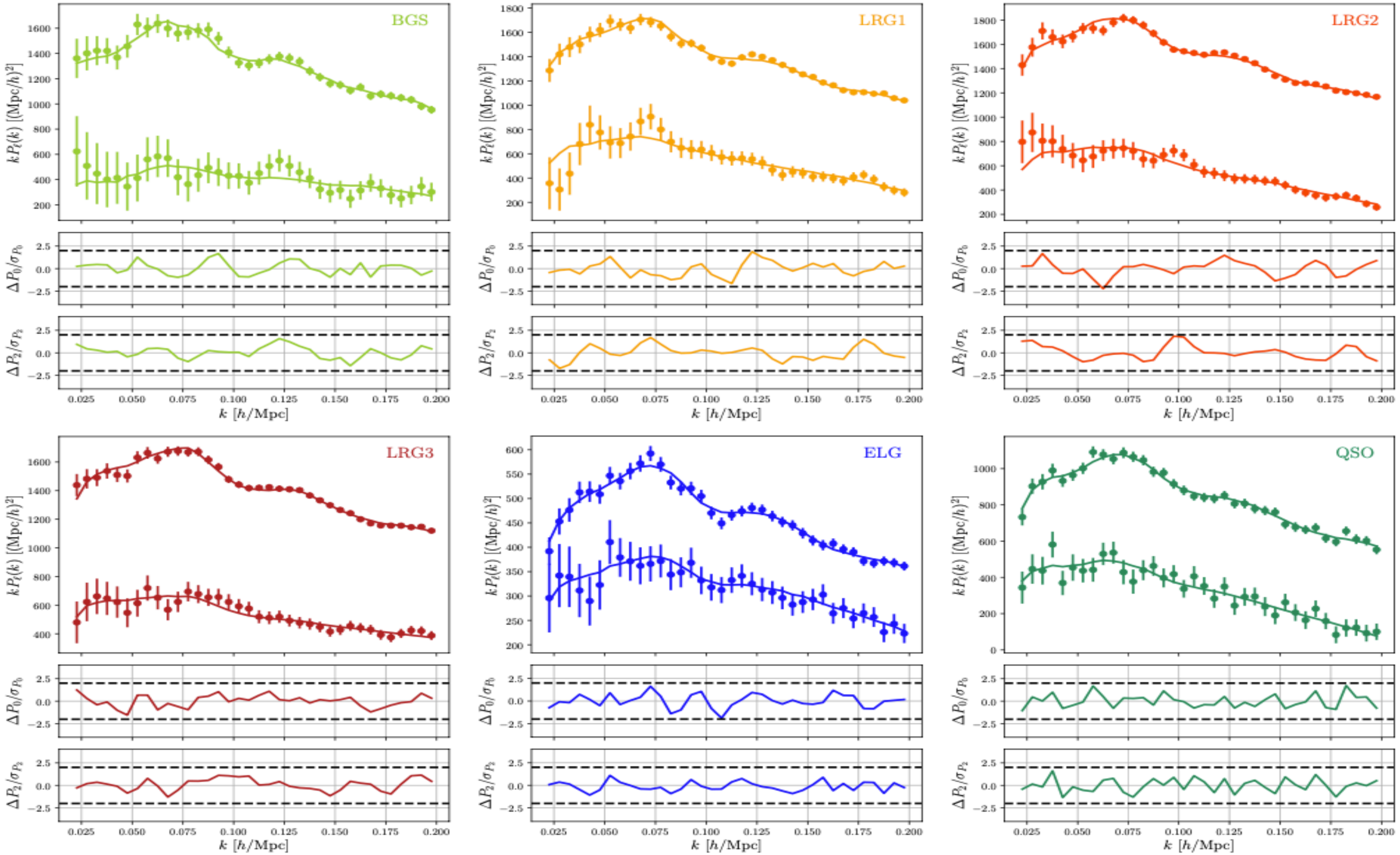
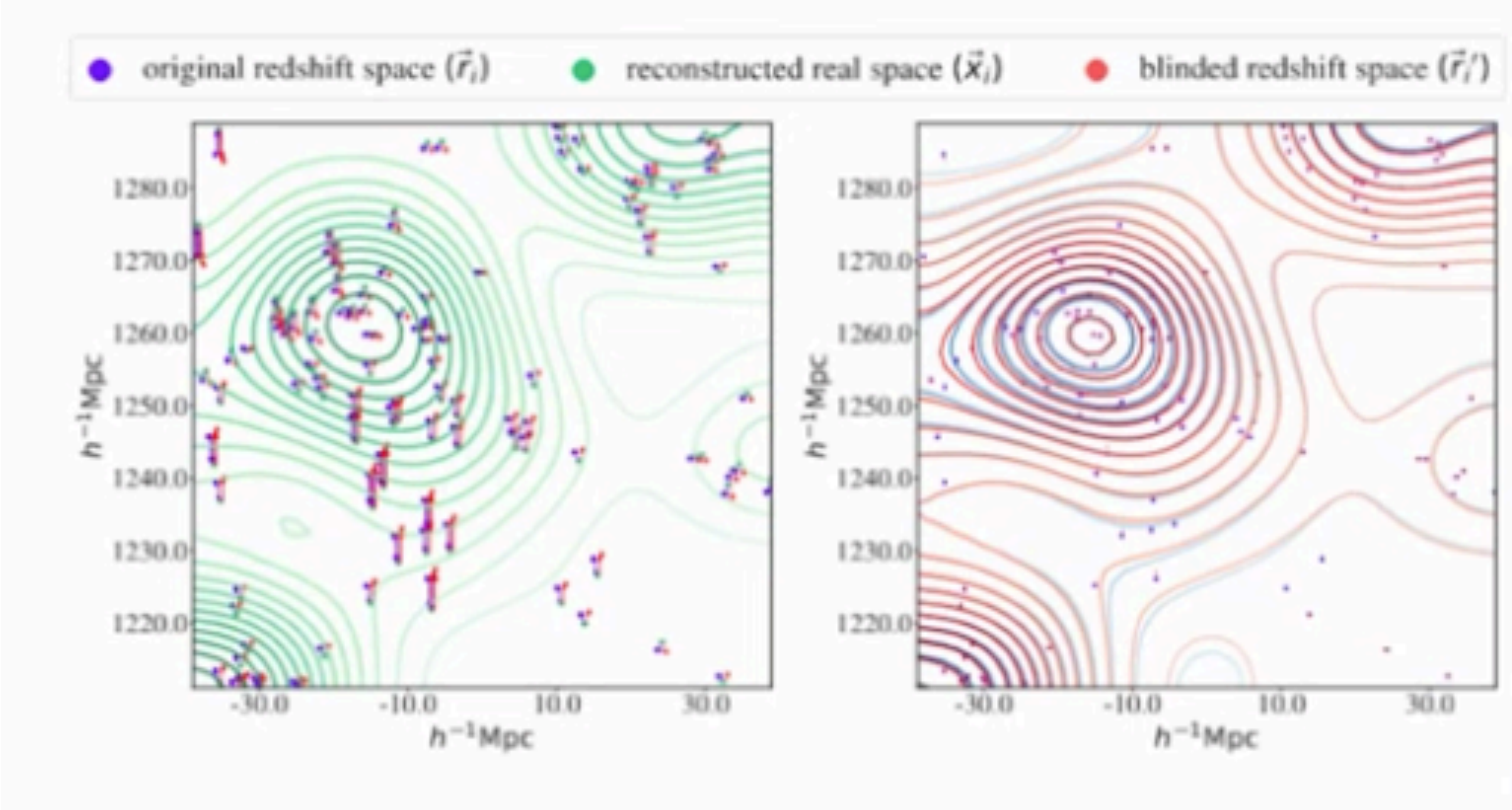
# NEW result: galaxy power spectrum measurements



# Full-shape analysis

**Blind catalogs:**

- change overall z-to-distance (same as BAO)
- change RSD using reconstruction
- Additional blinding of weights for $f_{NL}$ (Chaussidon in prep.)




**Power spectrum estimator:**

- only monopole and quadrupole
- $0.02 < k < 0.2$ h/Mpc
- window functions from randoms
- theta-cut (M. Pinon, arxiv:2406.04804)
- mock-based covariance + systematics included at the data vector level

# Full-shape analysis

## Modelling: Effective field theory

3 biases, 2+2 counter-terms/stochastic-terms

- Stochastic terms to include small-scale galaxy physics
- Implementation: velocileptors (Eulerian version)

MCMC fits

- Some "projection effects", no result shown when eg the MAP is outside the bayesian contours

| Cosmological parameters (FM) | Priors |
|---|---|
| $\omega_{\rm cdm}$ | $\mathcal{U}[0.01,0.99]$ |
| $\omega_{\rm b}$ | $\mathcal{N}[0.02218, 0.00055^2]$ |
| $h$ | $\mathcal{U}[0.2,1]$ |
| $\ln(10^{10}A_s)$ | $\mathcal{U}[1.61,3.91]$ |
| $n_s$ | $\mathcal{N}[0.9649, 0.042^2]$ |

| Non-cosmological parameters | Priors |
|---|---|
| $(1+b_1)\sigma_8$ | $\mathcal{U}[0,3]$ |
| $b_2\sigma_8^2$ | $\mathcal{N}[0, 5^2]$ |
| $b_s\sigma_8^2$ | $\mathcal{N}[0, 5^2]$ |
| $\alpha_0$ | $\mathcal{N}[0, 12.5^2]$ |
| $\alpha_2$ | $\mathcal{N}[0, 12.5^2]$ |
| $\mathrm{SN}_0$ | $\mathcal{N}[0, 2^2] \times 1/\bar{n}_g$ |
| $\mathrm{SN}_2$ | $\mathcal{N}[0, 5^2] \times f_{\rm sat}\sigma_{1\,\rm eff}^2/\bar{n}_g$ |

$$P_{s,g}(k,\mu) = P^{\rm PT}(k,\mu) + (b + f\mu^2)(b\alpha_0 + f\alpha_2\mu^2 + \cancel{f\alpha_4\mu^4})k^2 P_{s,b_1^2}(k) + \mathrm{SN}_0 + \mathrm{SN}_2 k^2\mu^2 + \cancel{\mathrm{SN}_4 k^4\mu^4}$$

perturbation theory term — counter-terms contribution — stochastic-terms contribution

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# Full-shape analysis: systematics budget

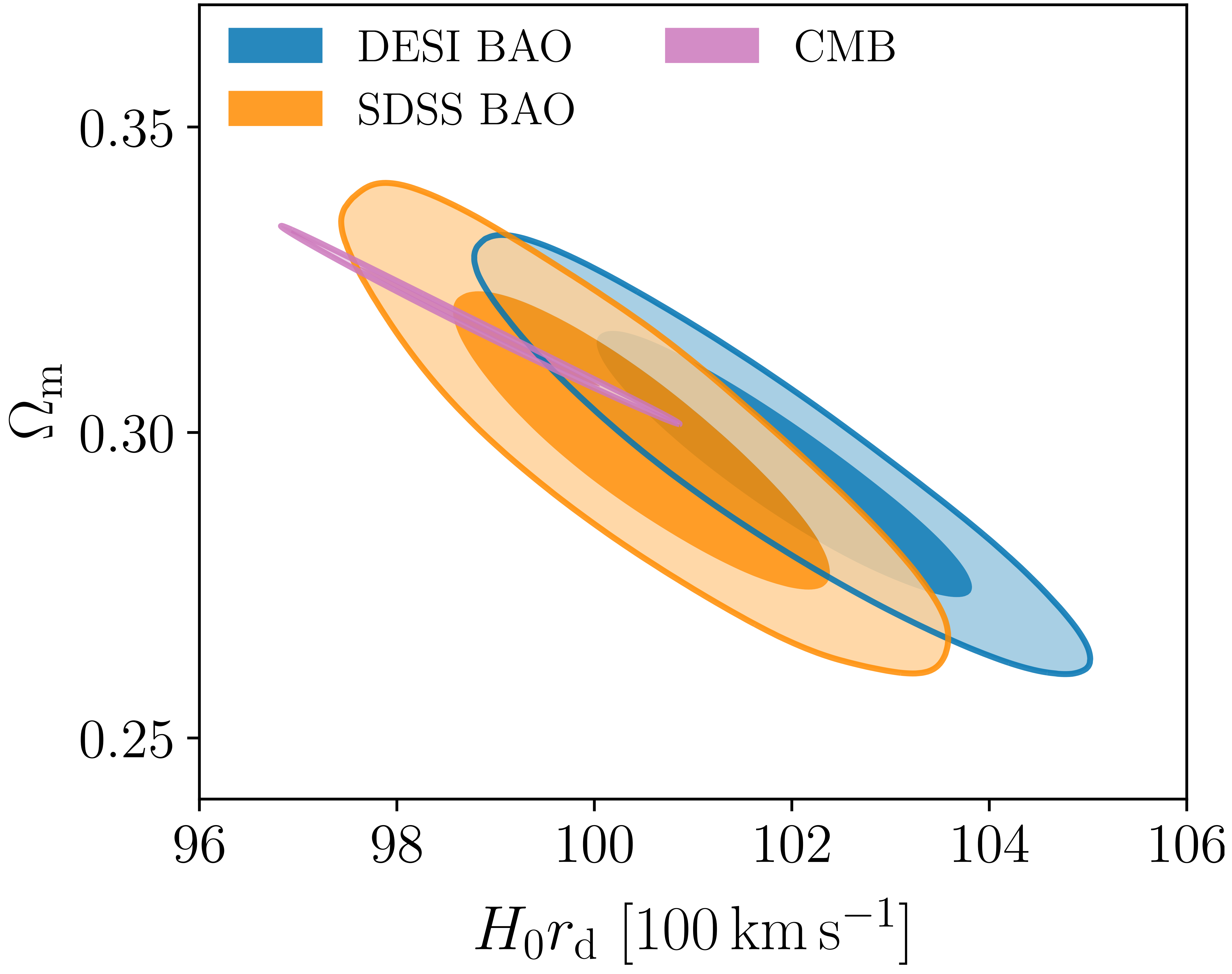
| **Systematic** | **Methodology** | **Contribution (units of $\sigma$ DR1)** |
|---|---|---|
| Theoretical | Comparison between 4 EFT models $k_{\rm max} = 0.20\, h\,{\rm Mpc}^{-1}$ | not detected for DR1 ($< 0.1$) |
| Observational | | |
| a. Imaging | Imaging weights per tracer, mode removal and polynomial correction (ELG, QSO) | $\sim 0.2$ (ELG, QSO)<br>$< 0.1$ (BGS, LRG) |
| b. Spectroscopic | Tested with mocks and repeated observations | $< 0.2$ (ELG)<br>$< 0.1$ (BGS, LRG, QSO) |
| c. Fiber assignment | $\theta$-cut method tested on mocks with and without fibre-assignment | $\sim 0.2$ |
| HOD+PWE | Varying HOD in Abacus-1 cubic and DR1-like mocks | HOD: $\sim 0.3$ (Table 2 of [101])<br>PWE: $\sim 0.2$ |
| Fiducial cosmology | Varying catalogue cosmology<br>Varying catalogue and template cosmology | $< 0.2$ (FM, SF) |
| Covariances | Based on comparisons between analytic and mock covariances, rescaling factor | $< 0.2$ |
| **Total** | All contributions above $0.2\sigma$ of DR1 error are added in quadrature | $\sim 0.46$ (FM, SF) |

# Cosmology result: BAO-only in ΛCDM

DESI Y1 BAO consistent with:

- SDSS BAO (eBOSS 2020)
- CMB (primary: Planck 2018; lensing: Planck PR4 + ACT DR6)

**DESI and CMB are consistent at 1.9σ-level**



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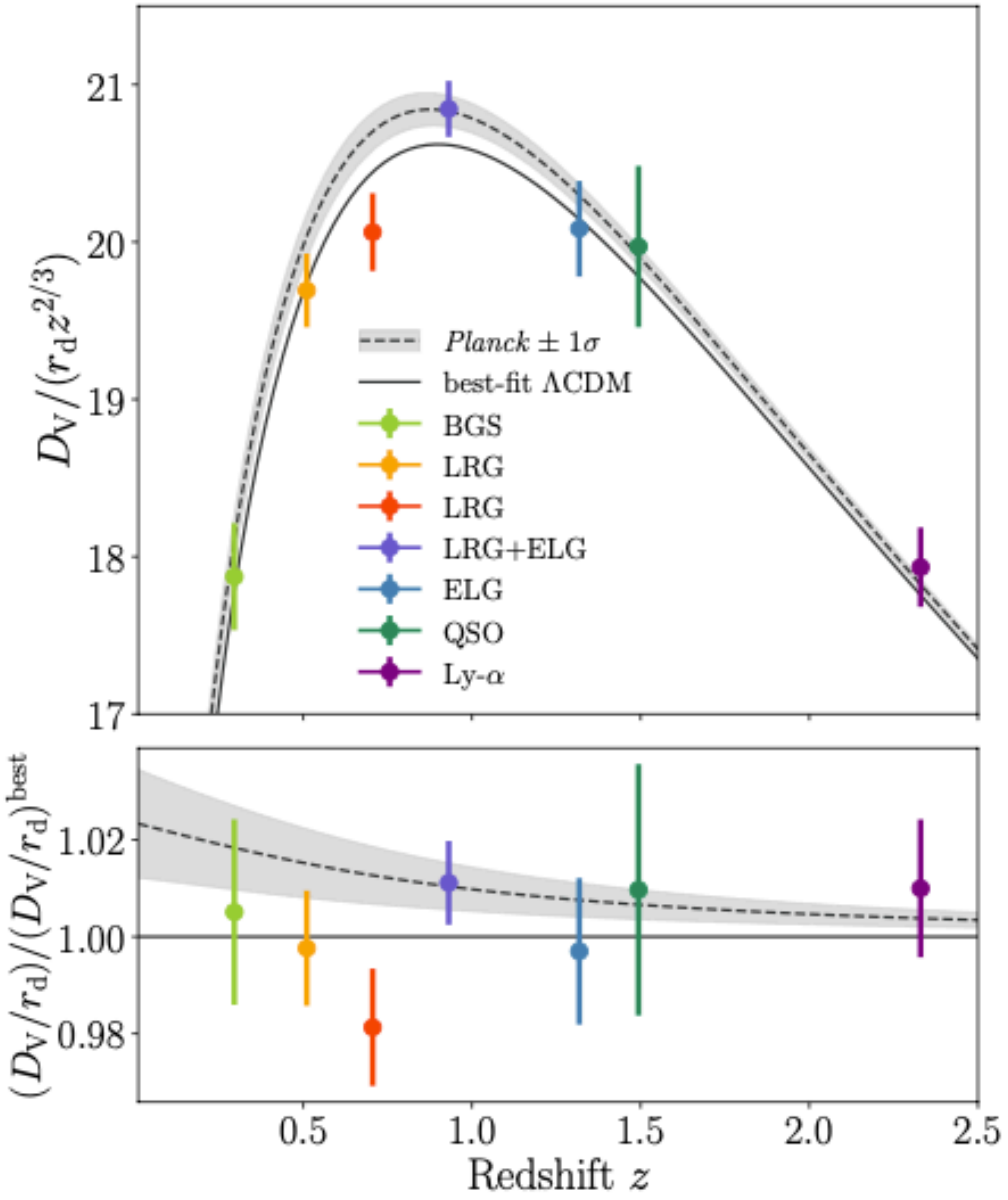
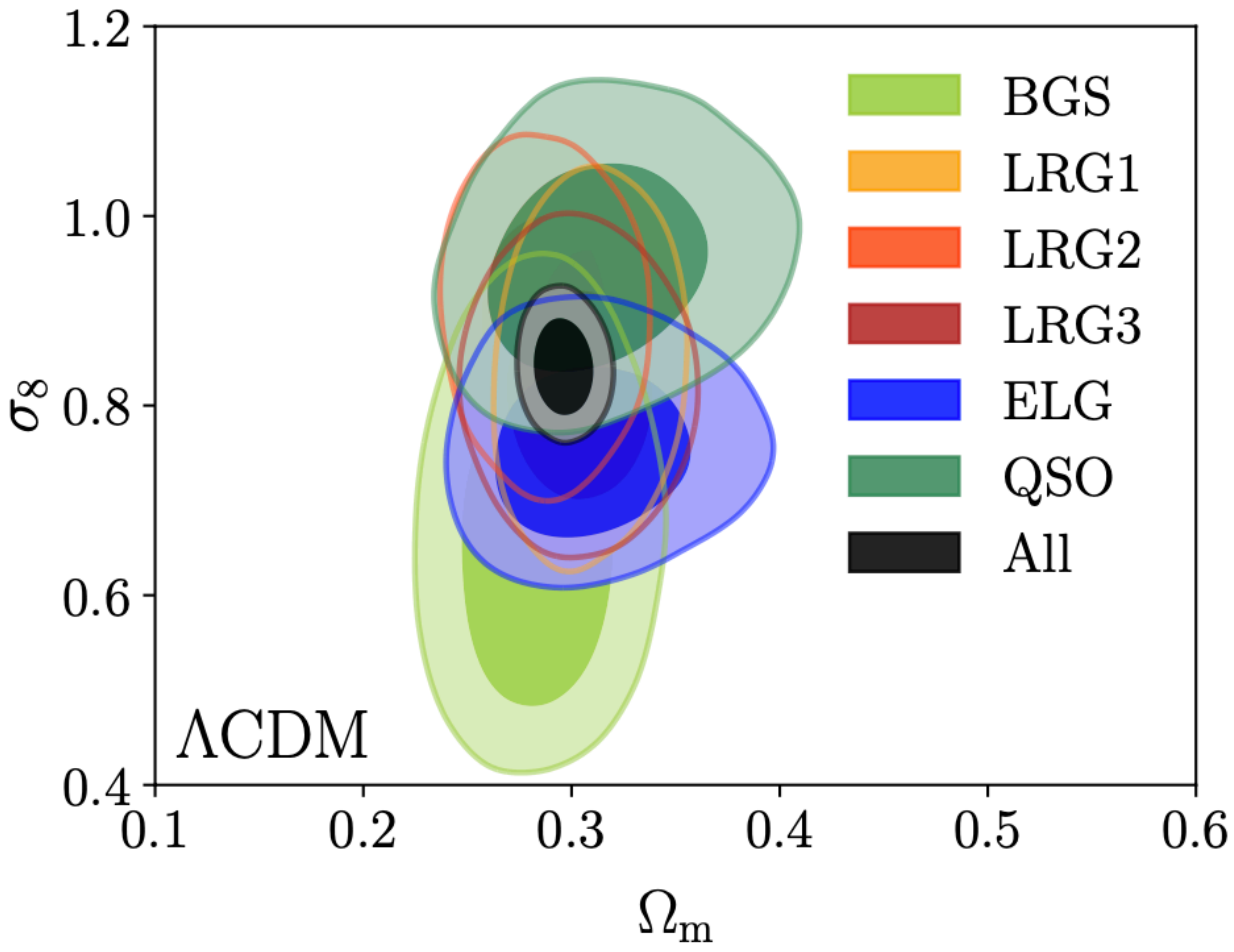
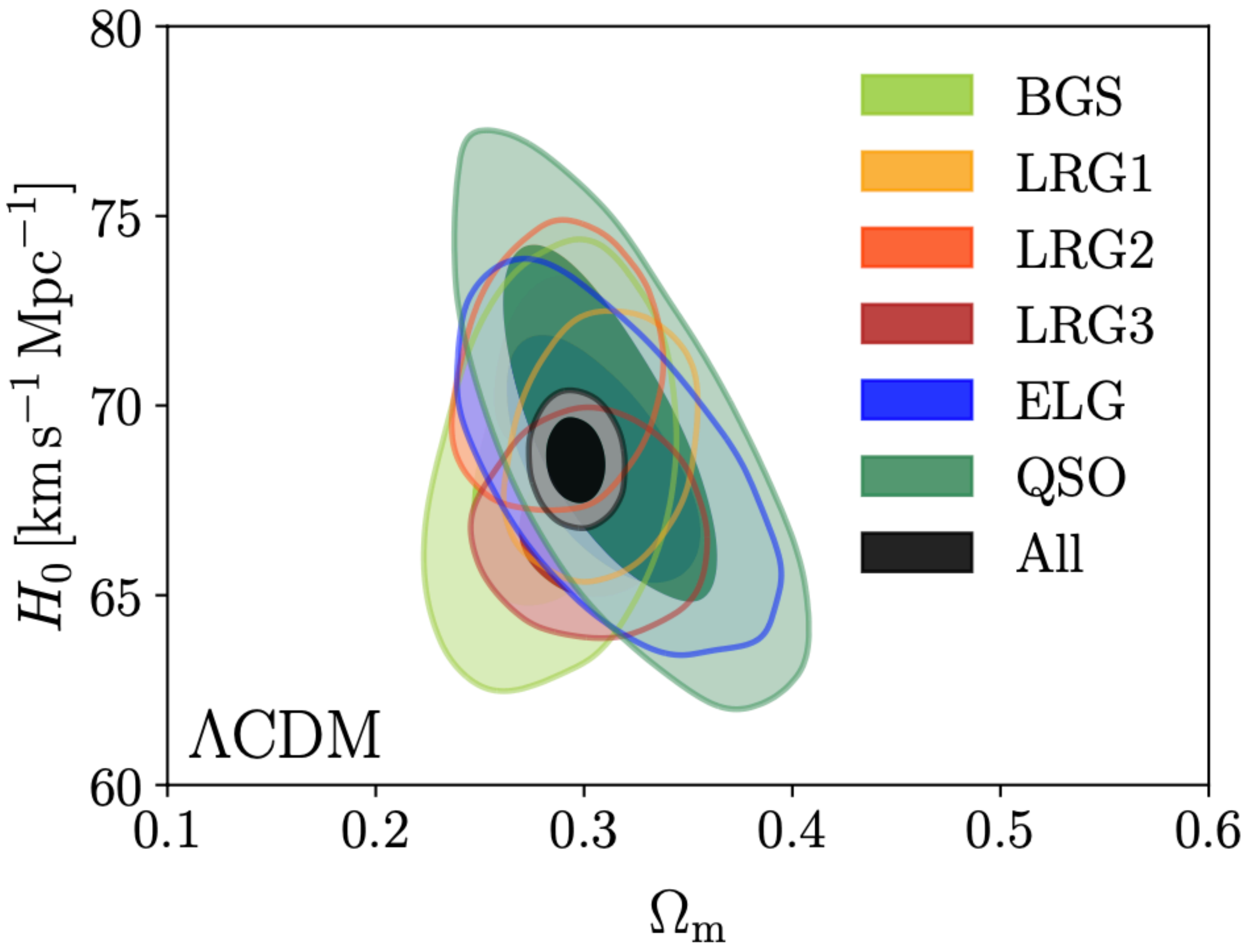


# DESI Y1 Full-shape + BAO fit in ΛCDM




Consistent results between all tracers

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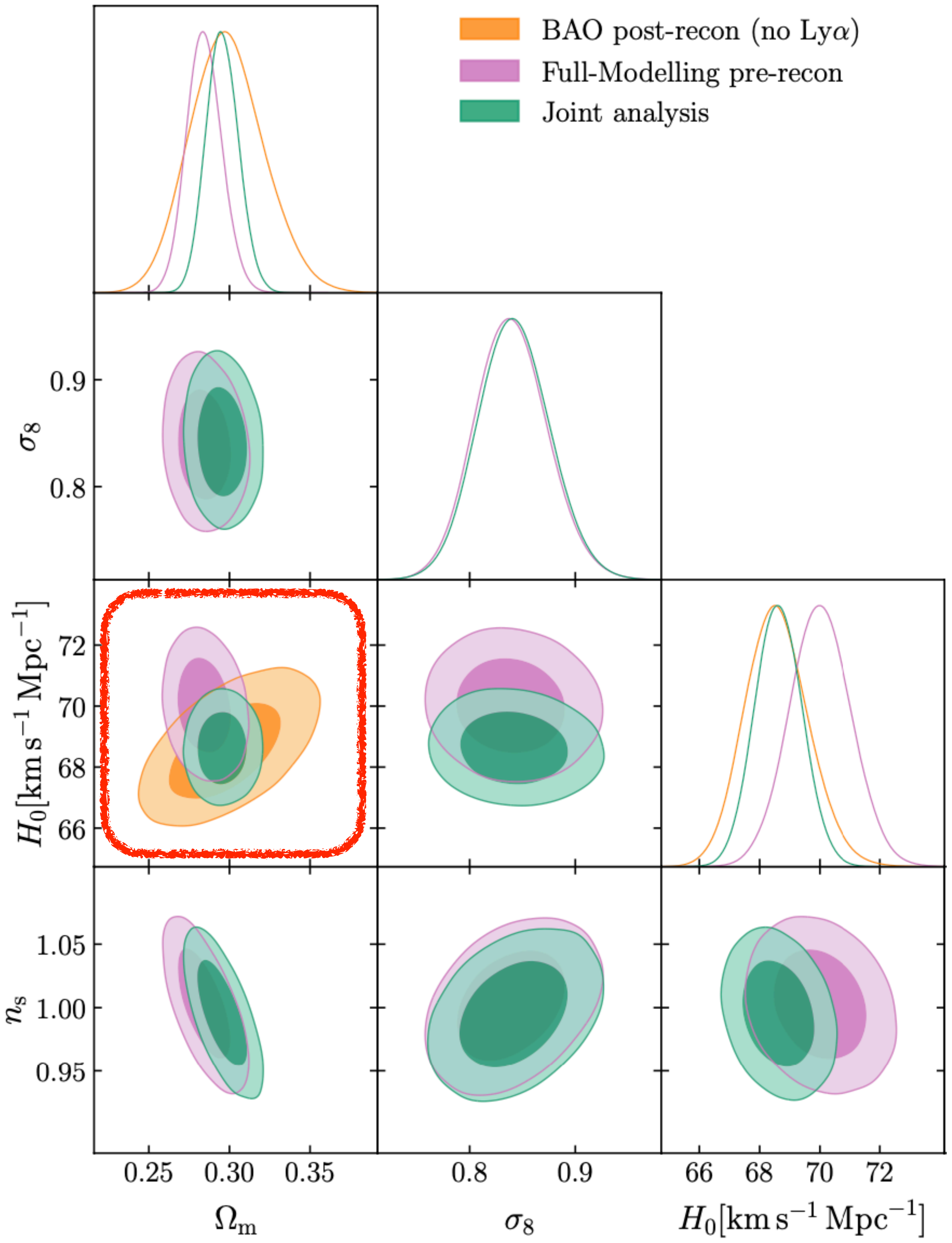



DESI FS+BAO + priors on BBN and $n_s$ :

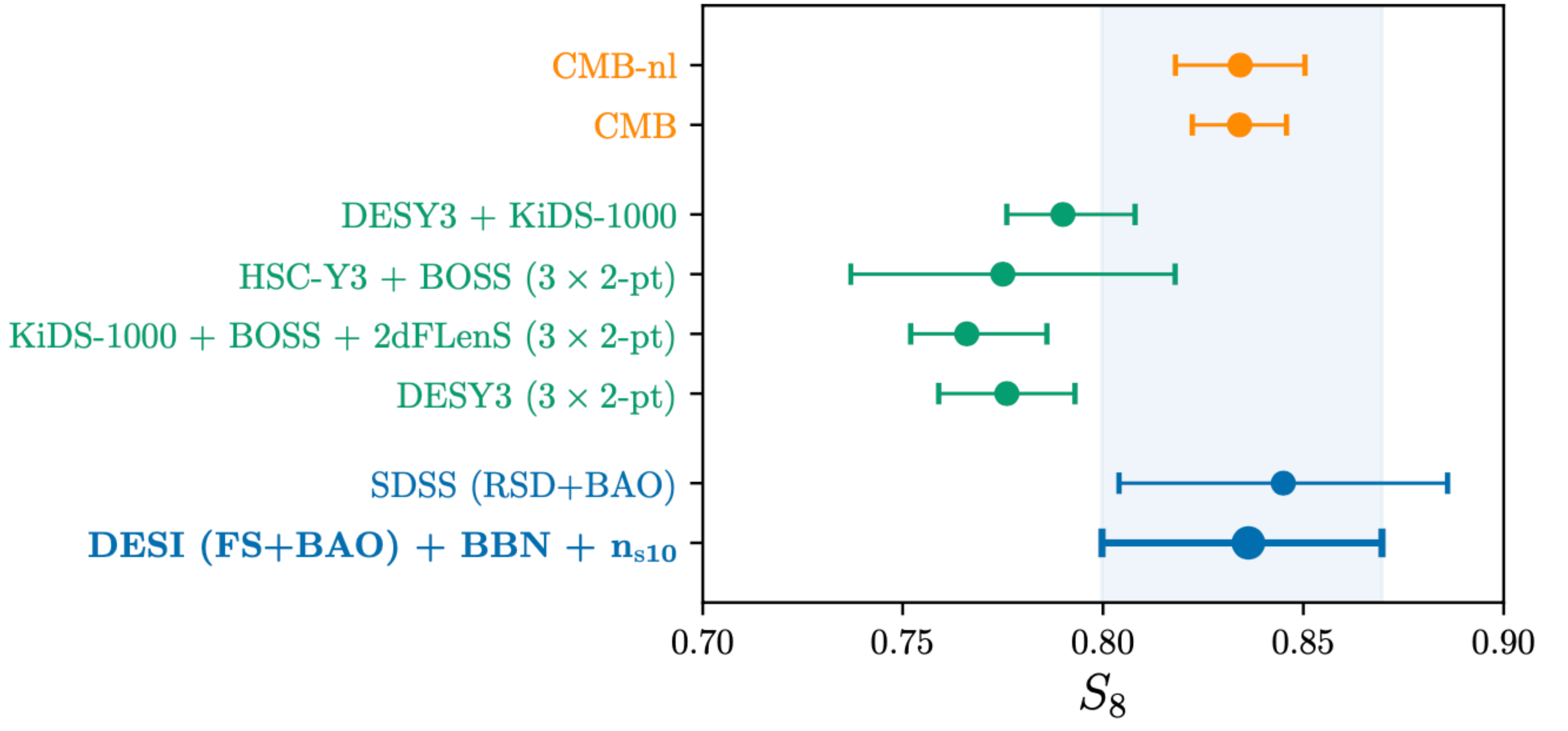
$$\Omega_\mathrm{m} = 0.2962 \pm 0.0095,$$

$$\sigma_8 = 0.842 \pm 0.034,$$

$$H_0 = (68.56 \pm 0.75)\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$$

Improve BAO-only for $\Omega_\mathrm{m}$

New $\sigma_8$ measurement based on LSS growth (k<0.2)



# Dark energy: DESI BAO + external

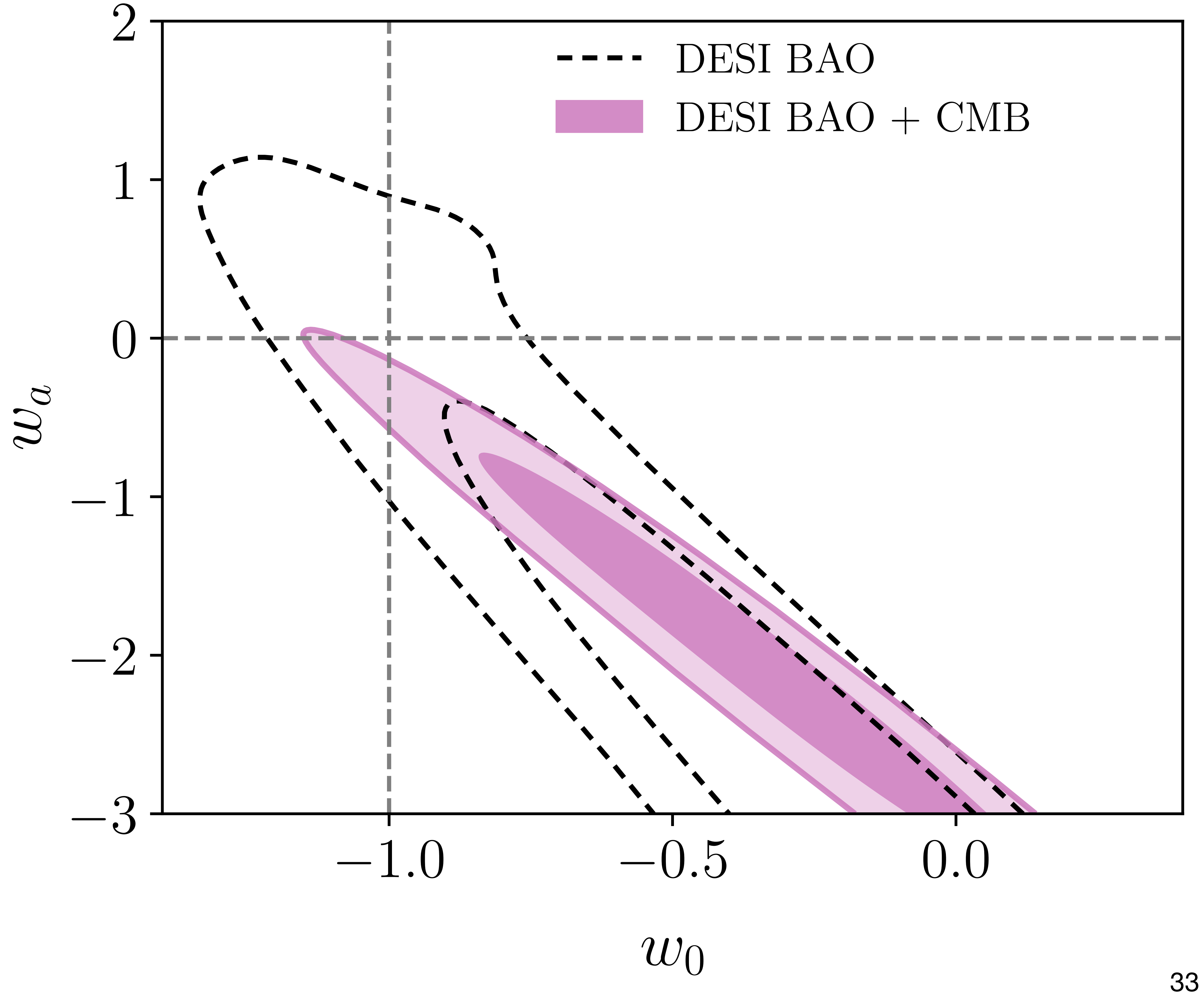
Dark energy with constant EoS: compatible with w=-1

The previous conclusion changes when considering a time-varying equation of state:

$$w(z) = w_0 + \frac{z}{1+z} w_a$$ (CPL parametrization)

- DESI BAO alone has poor constraining power
- **DESI + CMB $\Longrightarrow$ 2.6 $\sigma$**

**fit varying w(z)**



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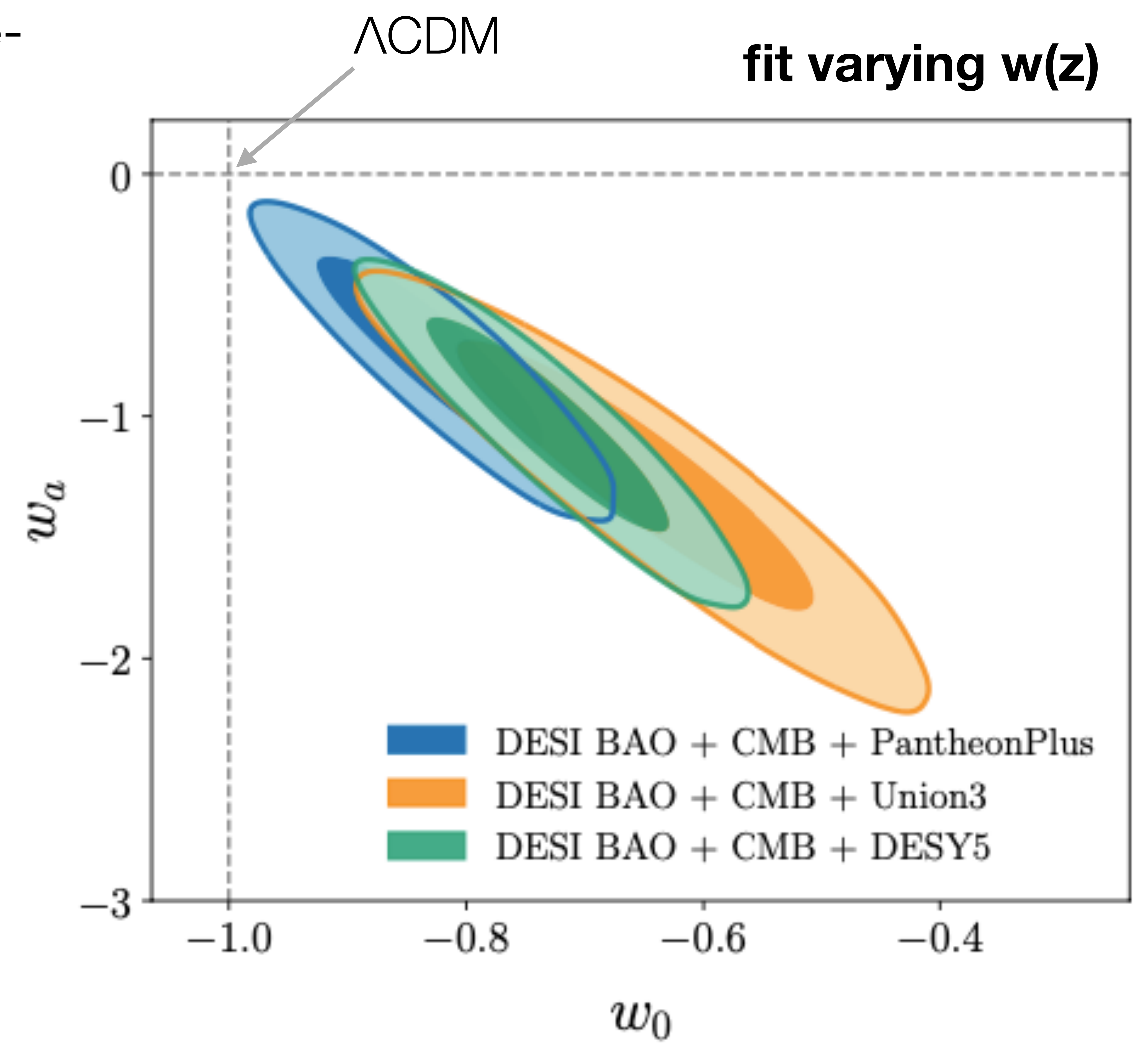
- DESI BAO alone has poor constraining power
- DESI + CMB $\Longrightarrow$ 2.6 $\sigma$
- **DESI + CMB + supernovae $\Longrightarrow$ from 2.5 $\sigma$ to 3.9$\sigma$, depending on the considered SN sample**

$w_0 > -1$, $w_a < 0$ favored



# Dark energy: DESI BAO + external

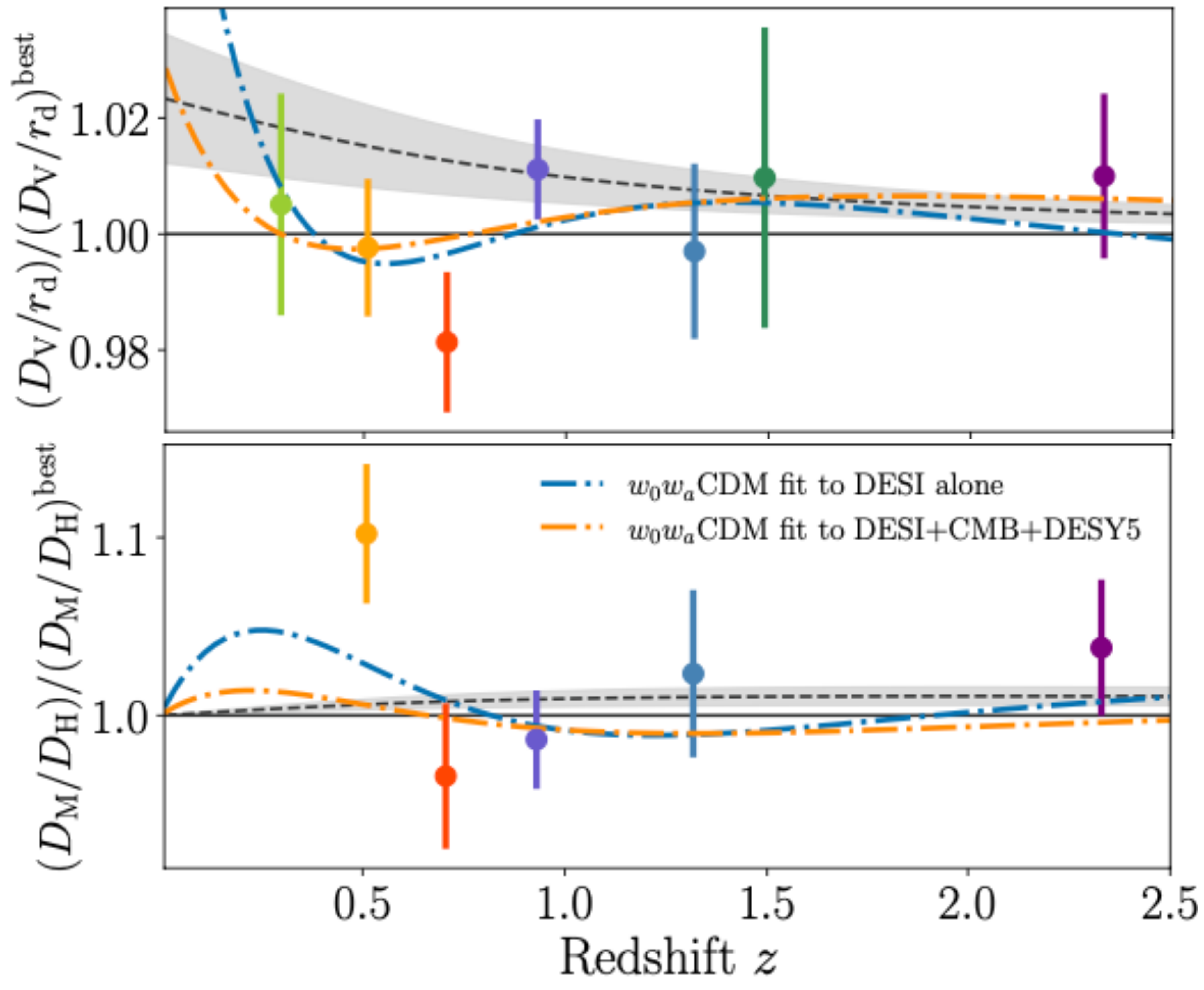
Dark energy with constant EoS: compatible with w=-1

The previous conclusion changes when considering a time-varying equation of state:

$$w(z) = w_0 + \frac{z}{1+z} w_a$$ (CPL parametrization)

- DESI BAO alone has poor constraining power
- DESI + CMB $\Longrightarrow$ 2.6 $\sigma$
- **DESI + CMB + supernovae $\Longrightarrow$ from 2.5 $\sigma$ to 3.9$\sigma$, depending on the considered SN sample**

$w_0 > -1$, $w_a < 0$ favored



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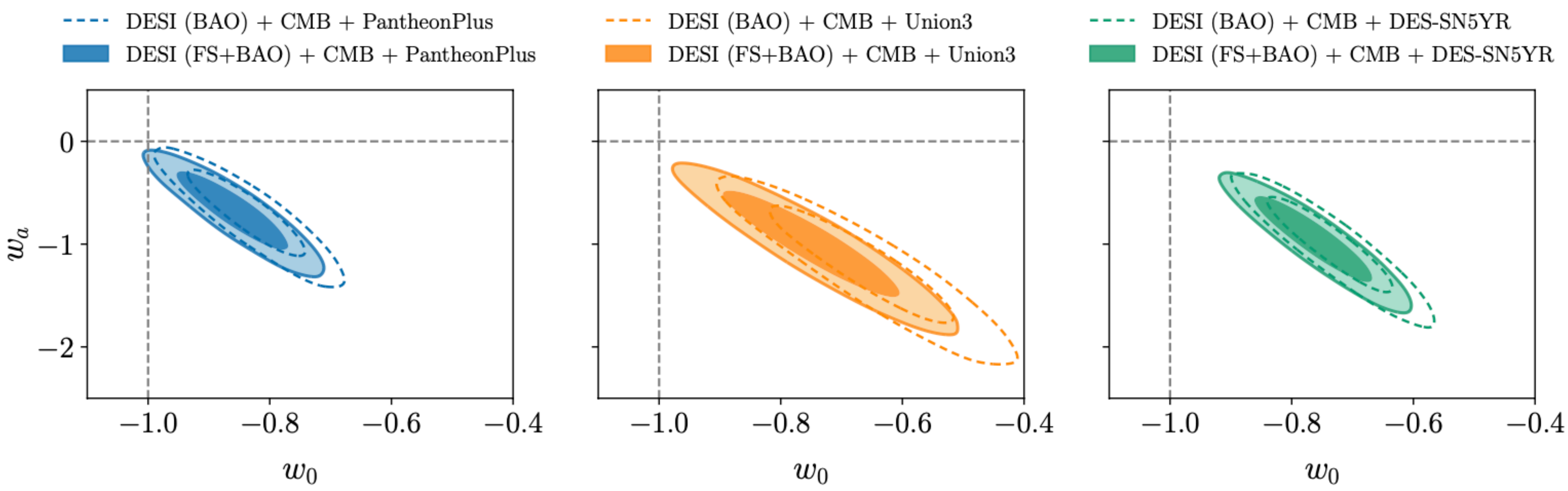
U.S. Department of Energy Office of Science

# Dark energy: adding DESI Full-shape




error bars slightly reduced

significances almost unchanged

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# The sum of neutrino masses: CMB + DESI BAO

**CMB measurements** are sensitive to $\Sigma m_\nu$

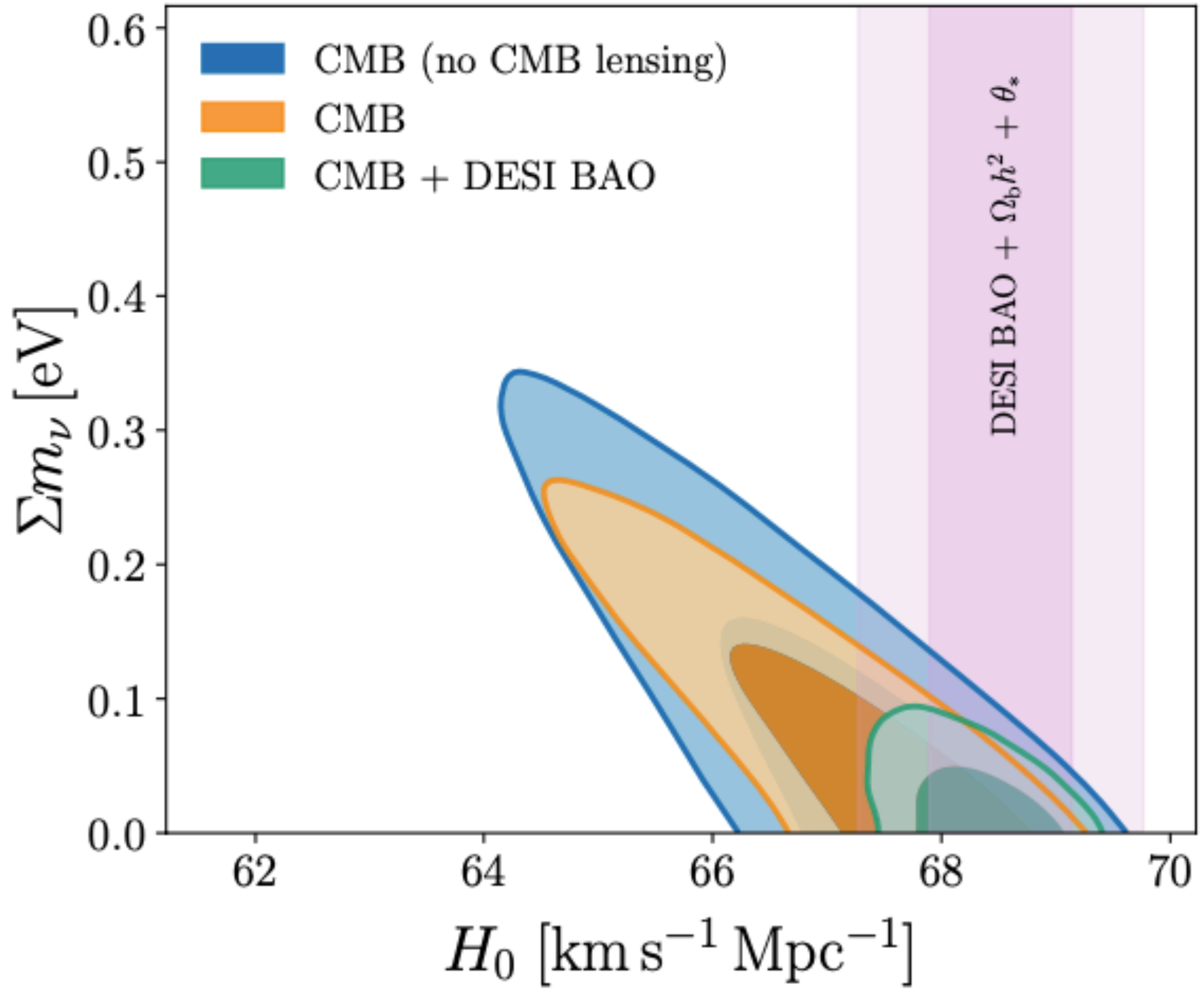
But internal degeneracies limiting its precision

BAO helps break degeneracies (through $H_0$ / $\Omega_m$)

95% CI limits:

$$\sum m_\nu < 0.21\,\mathrm{eV}$$ CMB alone, ΛCDM

**ΛCDM fit**



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# The sum of neutrino masses: CMB + DESI BAO

**CMB measurements** are sensitive to $\sum m_\nu$

But internal degeneracies limiting its precision

BAO helps break degeneracies (through $H_0$ / $\Omega_m$)

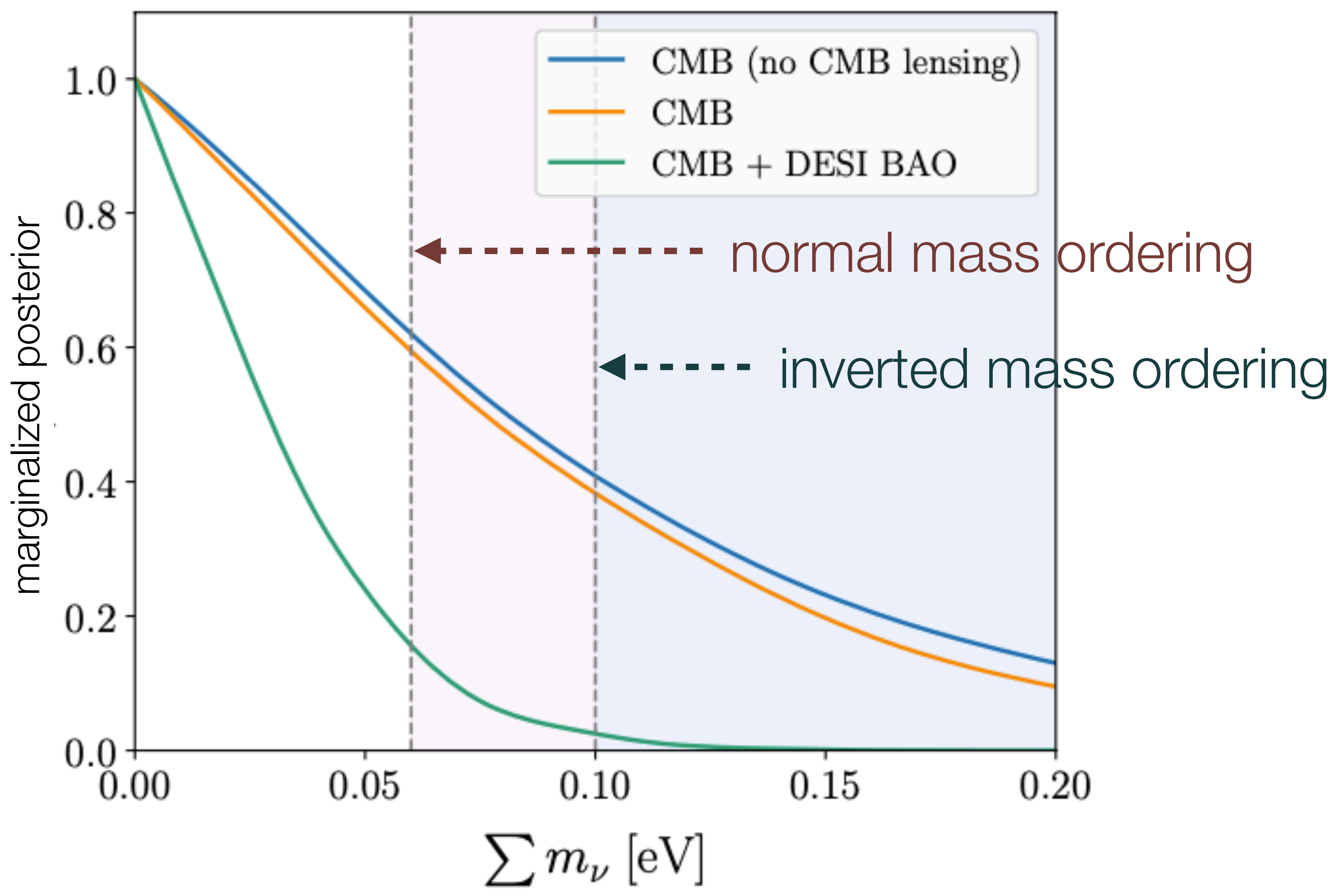
95% CI limits:

$\sum m_\nu < 0.21\,\mathrm{eV}$ CMB alone, ΛCDM

$\sum m_\nu < 72\,\mathrm{meV}$ CMB + DESI BAO, **ΛCDM**

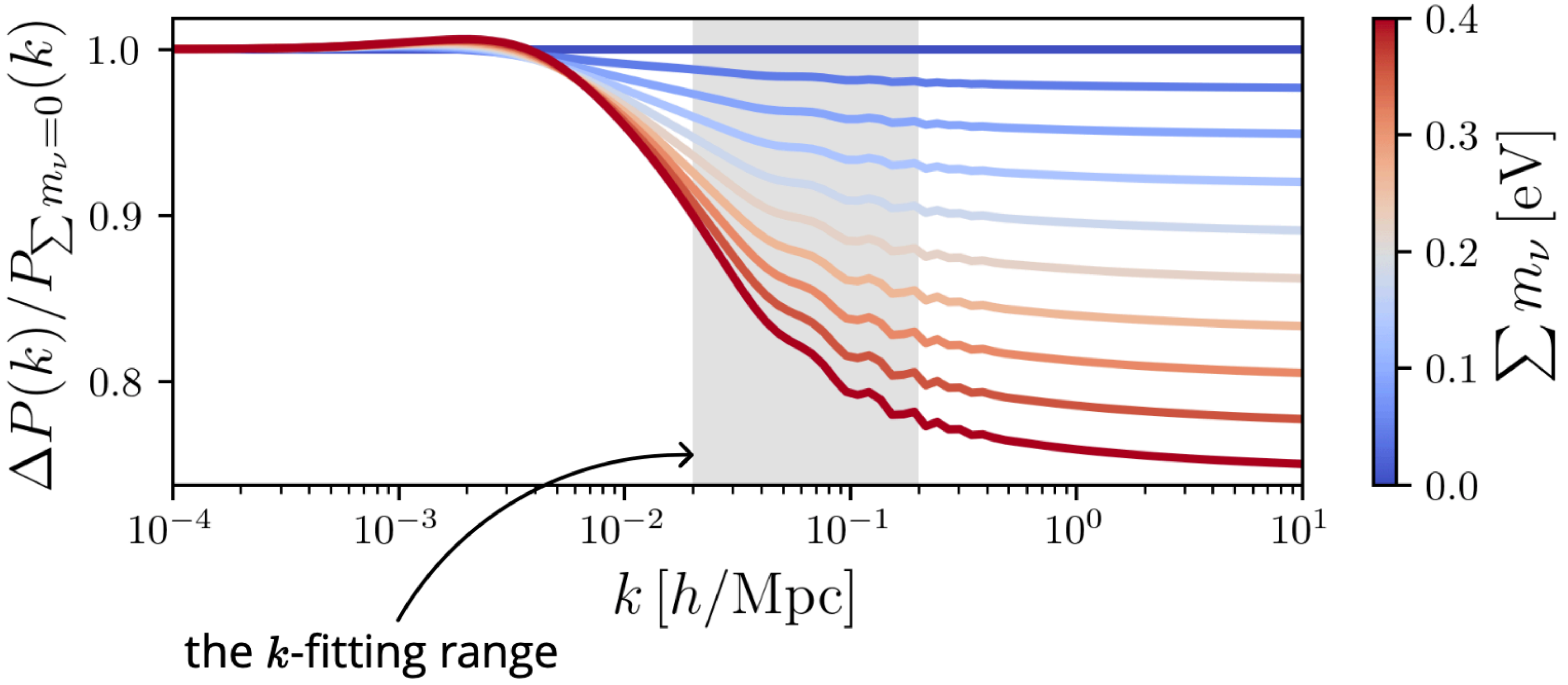
( as in DESI 2024 VI paper:
Planck 2018, ACT likelihood v1.1 )

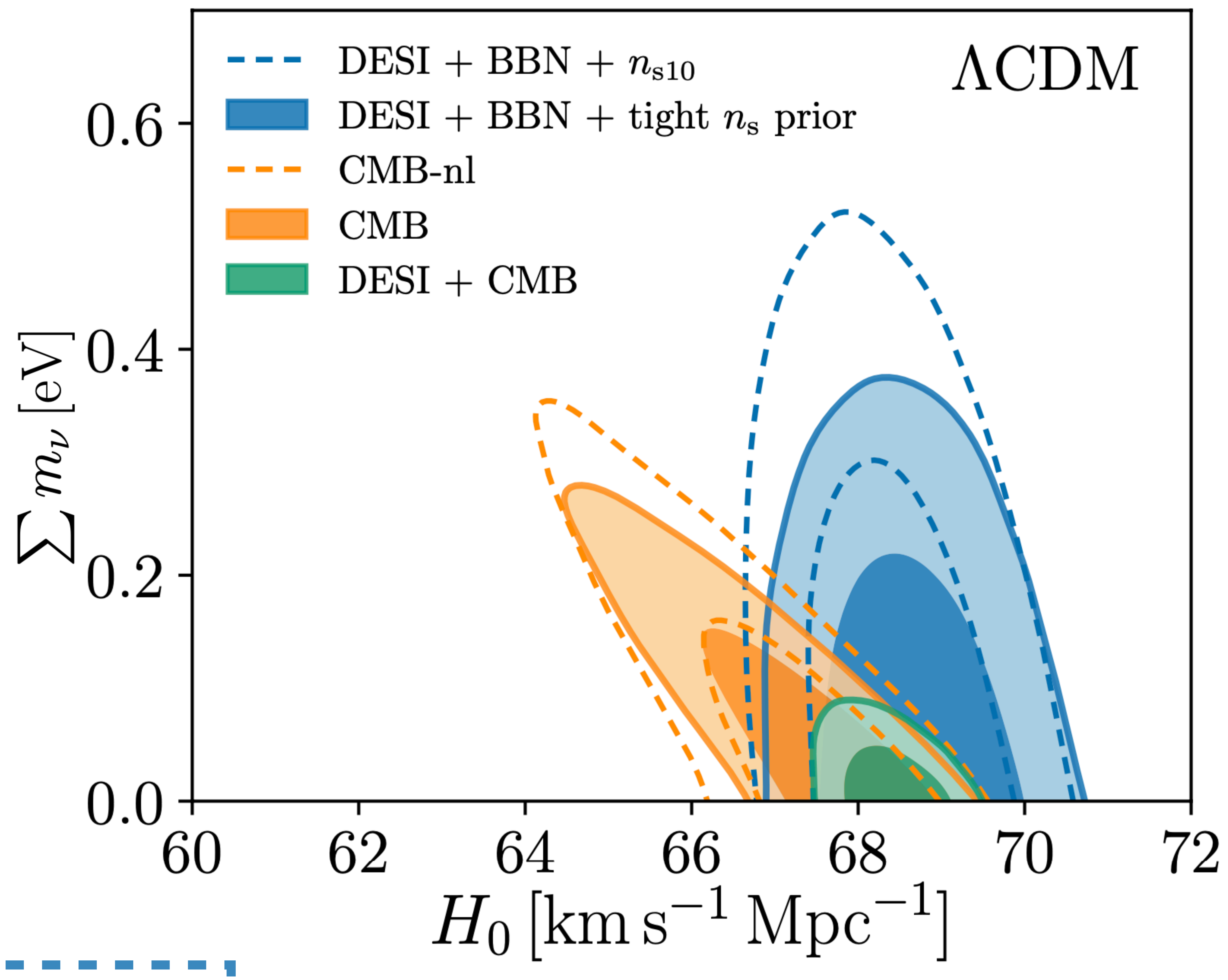
**ΛCDM fit**




driven by the "1.9 σ consistency" between DESI and CMB within ΛCDM

# Neutrino mass information from Full-shape



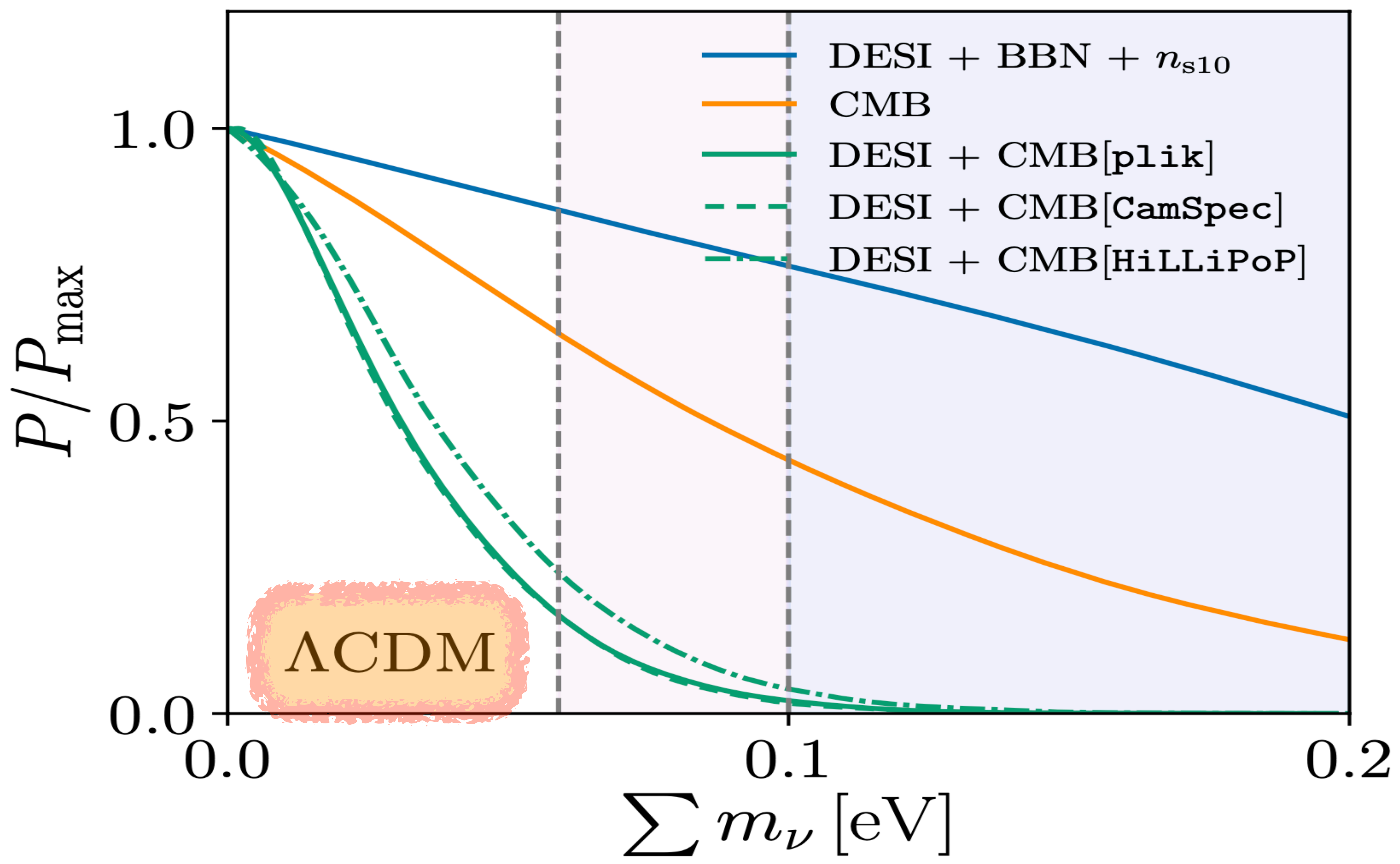



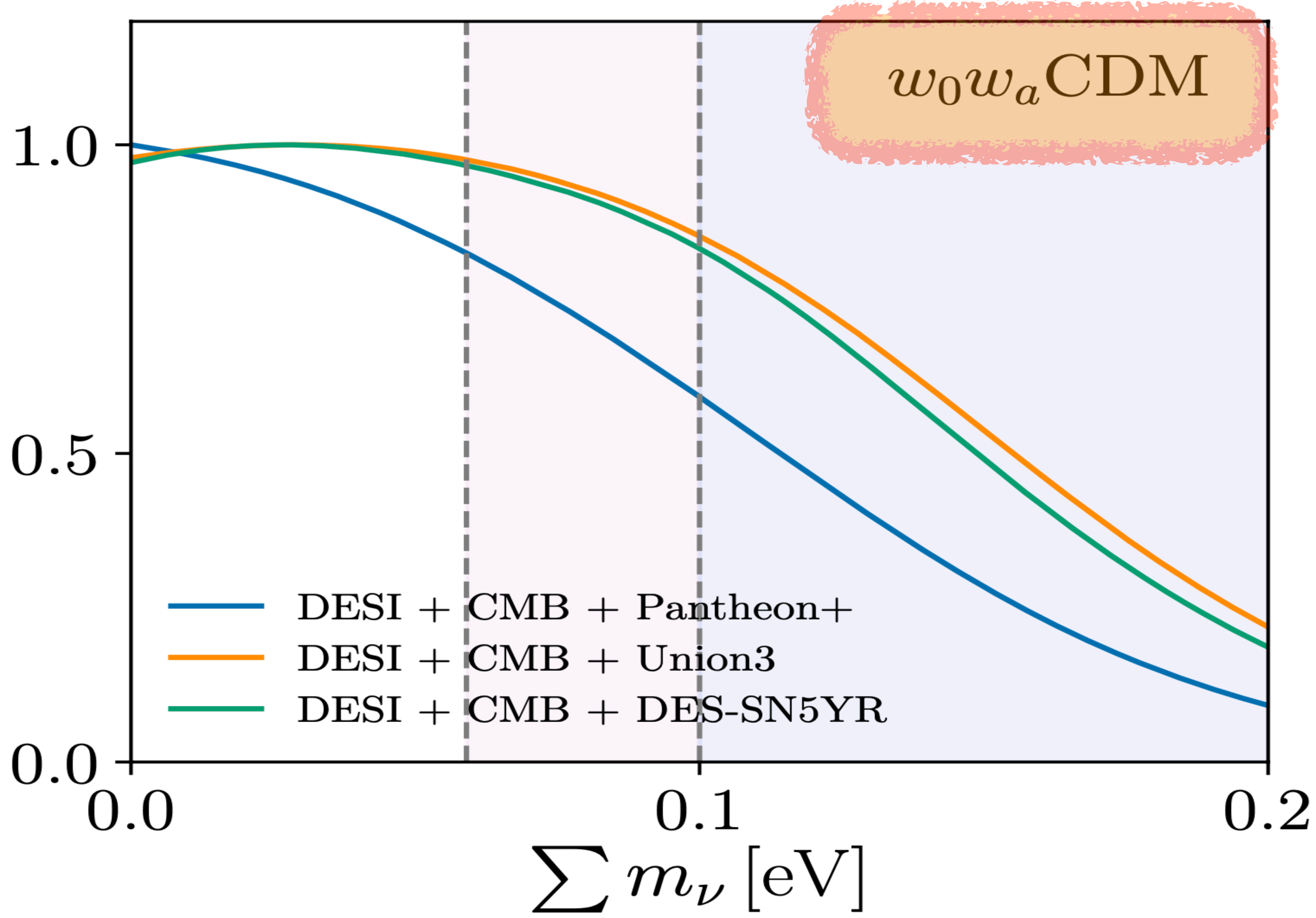

Impact of neutrino masses on the growth of structures

However, on DESI scales, broadband suppression ~ degenerate with $n_s$

$$\sum m_\nu < 0.409\,\mathrm{eV} \quad (95\,\%,\ \mathrm{DESI\ (FS{+}BAO){+}BBN{+}}n_{s10})$$

# Updated bounds on neutrino mass (CMB + DESI BAO + Full shape)




$$\sum m_\nu < 0.084\,\mathrm{eV} \quad (95\,\%,\ \mathrm{DESI\ (FS{+}BAO) + CMB[\texttt{HiLLiPoP}]})$$

wrt DESI 2024 VI paper:

DESI Full-shape + ACT likelihood v1.2
+ (LoLLiPoP+HiLLiPoP)

$$\sum m_\nu < 0.194\,\mathrm{eV} \quad (95\%)$$

with DES-SN5YR

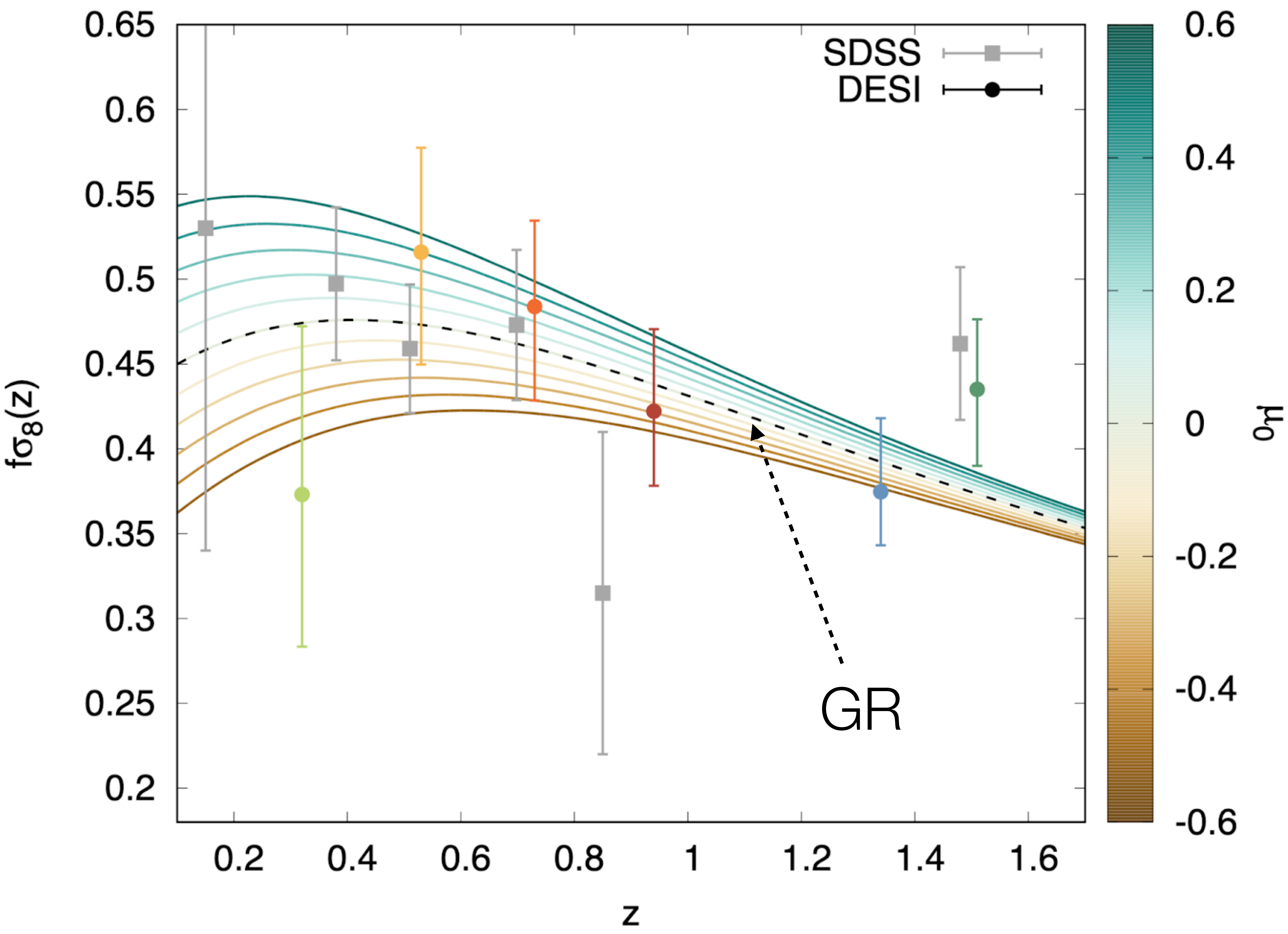
(~unchanged wrt BAO alone)

# " New DESI Results Weigh In On Gravity "

**Growth of structure measurement:**

(relative intensity of quadrupole)

using ShapeFit compression scheme



# " New DESI Results Weigh In On Gravity "

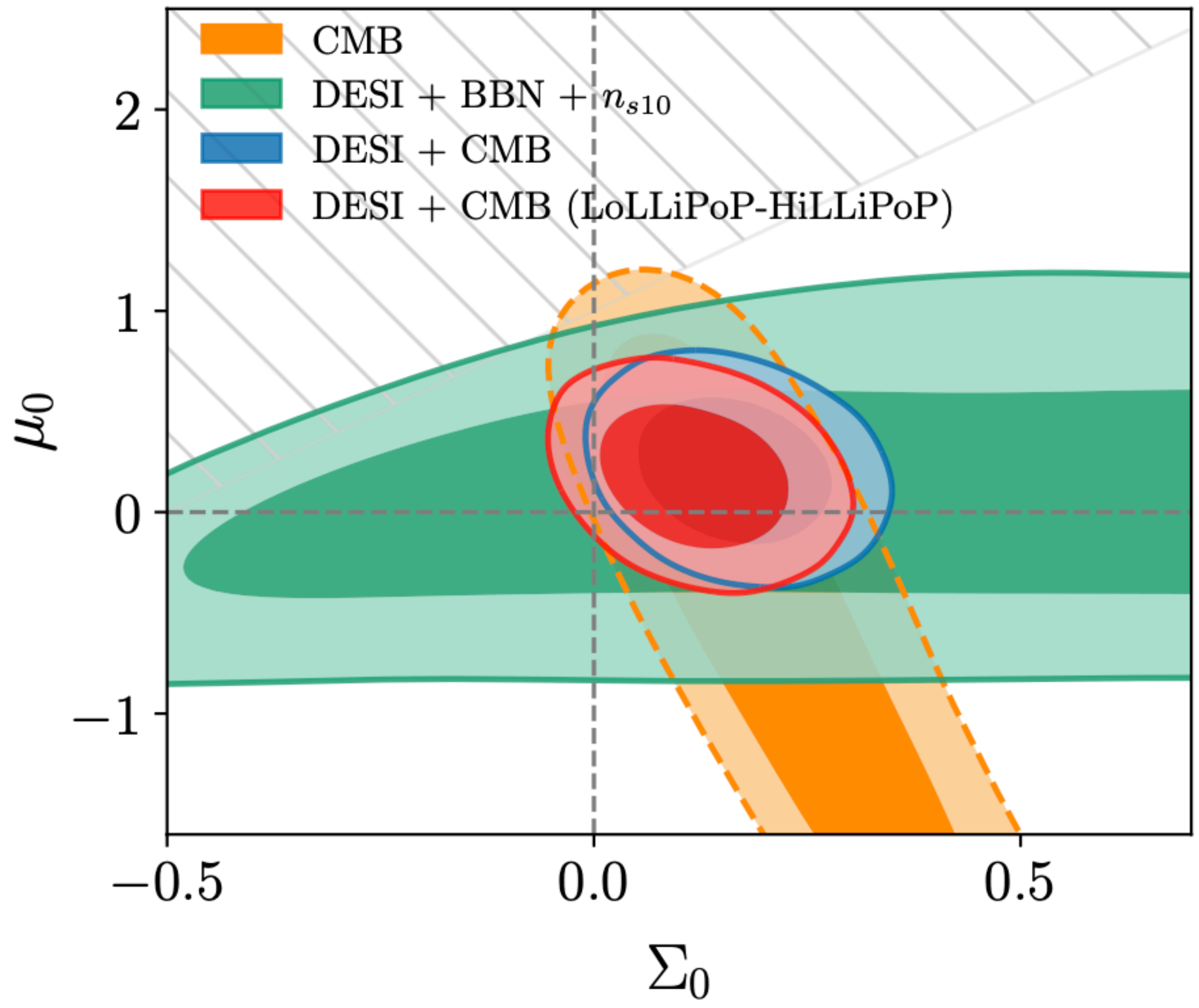
## Model of modified gravity connected to late-time cosmic acceleration:

$$k^2\Psi = -4\pi G a^2 \mu(a,k)\Sigma_i \rho_i \Delta_i$$

$$k^2(\Phi+\Psi) = -8\pi G a^2 \Sigma(a,k)\Sigma_i \rho_i \Delta_i$$

$$\mu(a) = 1 + \mu_0 \frac{\Omega_{\rm DE}(a)}{\Omega_\Lambda}, \qquad \Sigma(a) = 1 + \Sigma_0 \frac{\Omega_{\rm DE}(a)}{\Omega_\Lambda}$$

$$\mu_0 = 0.11^{+0.44}_{-0.54} \quad \text{(DESI (FS+BAO)+BBN+}n_{s10}\text{)}$$



# Summary: results from DESI Y1

- Adding Full-shape information to BAO:
  - sensitivity to growth of structures
  - **favors $\sigma_8$, $S_8$ consistent with Planck**
  - neutrino mass from structure growth
  - **modified gravity $\mu_0$ parameter consistent with GR**
- No major change / confirm earlier DESI BAO findings (dynamical dark energy, sum of neutrino masses)

**https://data.desi.lbl.gov/doc/papers/**

**What's next?**

- Many additional results on Y1 data: $f_{NL}$, Lyman-alpha small-scale power spectra, cross-correlations...
- Y1 data release next year ("DESI 2024 I")
- Year-3 data collection completed last Spring, BAO analysis ongoing