EFTofLSS - Some results

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3 June 2024 |Theoretical Modeling of the LSS of the Universe | Higgs Center, Edinburgh

— Plan —

I - A comment about the EFTofLSS

Why push & How to push?

II - One aspect of EFT analyses

Self-consistent scale-cut determination

III - EFT pipelines

Validations

IV- BOSS 2+3pt

1. ΛCDM
2. f_{NL}
3. $wCDM$

V - DES 3×2pt

I - A comment about the EFTofLSS

Why push?

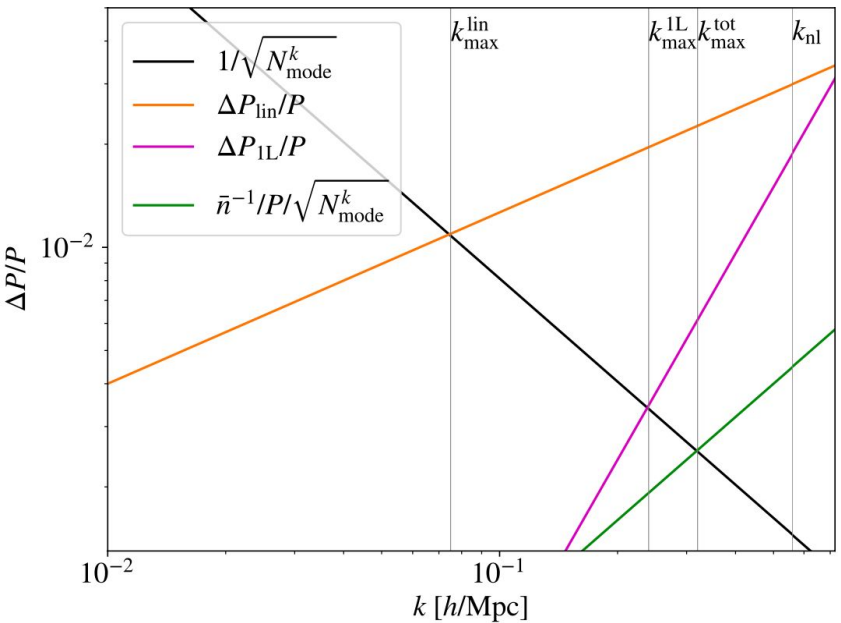
— The EFTofLSS program —

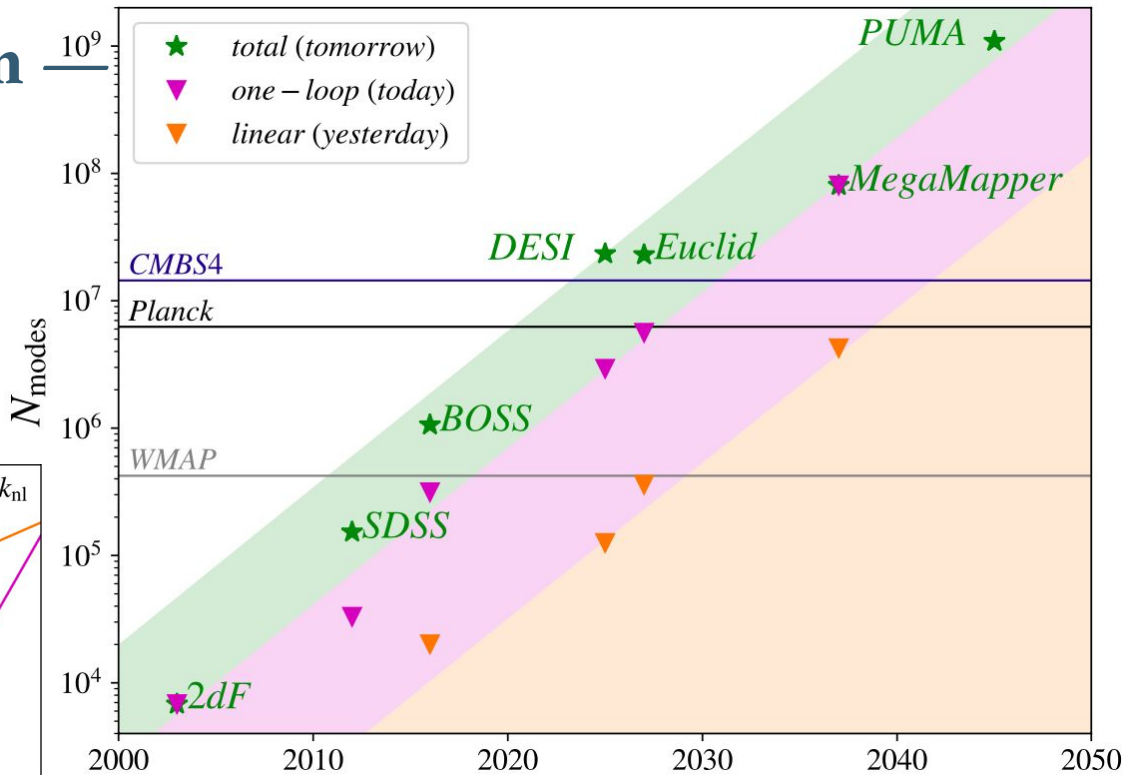
Why push?

$$N_{\rm modes}({\rm CMB}) \sim (\ell_{\rm max})^2$$

$$N^{\diamond}_{\rm modes}({\rm LSS}) \sim V_{\rm survey}(k^{\diamond}_{\rm max})^3/(6\pi^2)$$

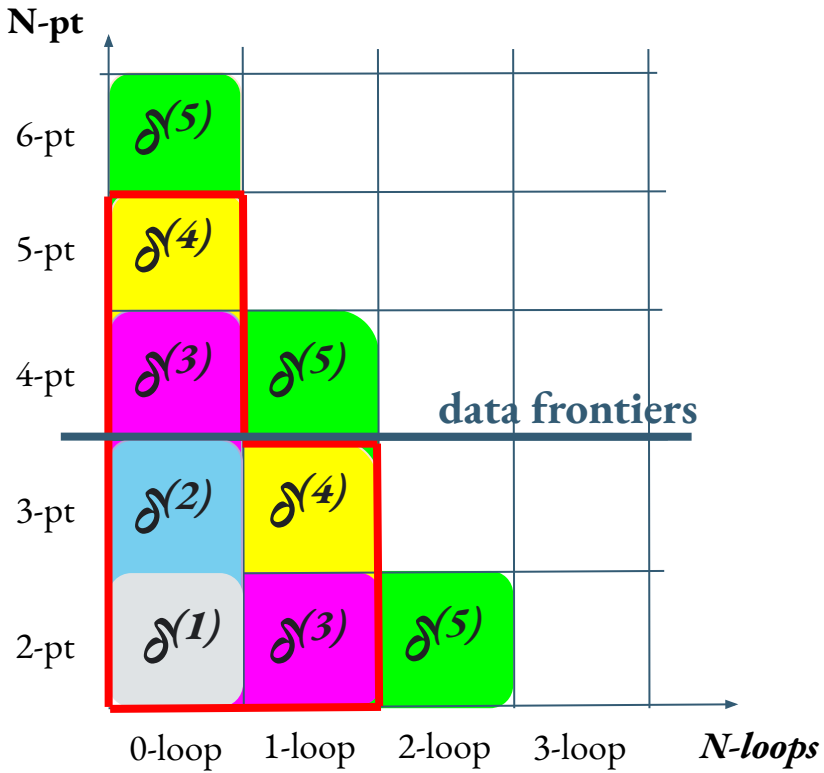
$$\diamond = {\rm total, 1loop, linear}$$





— The EFTofLSS program —

Where are we?



	DM[a]	Gal	RSD
$P^{(3)}$	✔	✔ b	✔ cde
$P^{(4)}$	✔	✔ efg	✔ gh
$P^{(5)}$	✔	✔ ij	✘

a Baumann, Carrasco, Hertzberg, Nicolis, Pajer, Senatore, Zaldarriaga, ... 10-13

b McDonald 06-09, Angulo, Assassi, Baumann, Fasiello, Fujita, Green, Mirbabayi, Schmidt, Senatore, Vlah, Zaldarriaga, ... 14-16

+ Large IR-displacements / LPT: Matsubara 07, Aviles, Baldauf, Blah, Garny, Ivanov, Lewandowski, Mirbabayi, Porto, Senatore, Seljak, Sibiryakov, Simonovic, Vlah, White, Zaldarriaga, ... 13-16

c Matsubara 08, Senatore & Zaldarriaga 14
d Perko, Senatore, Jennings, Wechsler 16
e Desjacques, Jeong, Schmidt 16

f Eggemeier, Scoccimarro, Smith 18
g D'Amico, Donath, Lewandowski, Senatore, **PZ** 22
h Philcox, Ivanov, Cabass, Simonovic, Zaldarriaga, Nishimichi 22

i Schmidt 21
j Donath, Lewandowski, Senatore 23

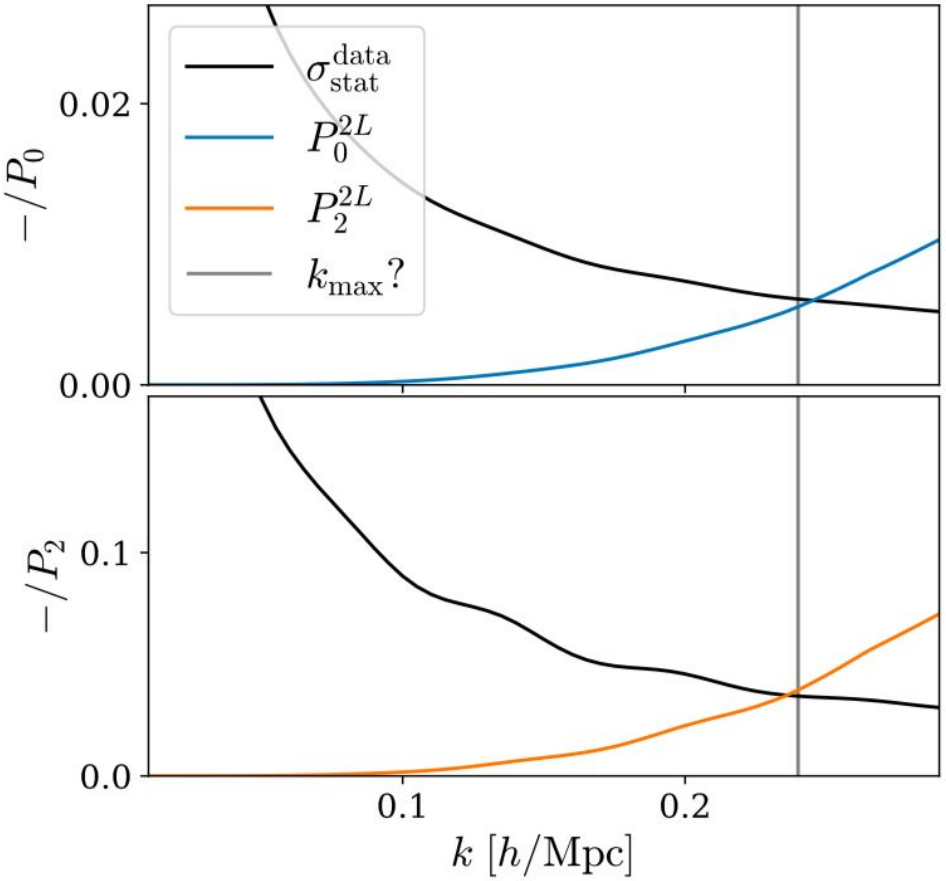
II - One aspect of EFT analyses

The Scale cut

— EFT scale cut —

w/ D'Amico, Senatore, Nishimichi 21
w/ D'Amico Senatore, Zhao, Cai 21
w/ Simon & Poulin 22

- What error we make when truncating the EFT expansion?



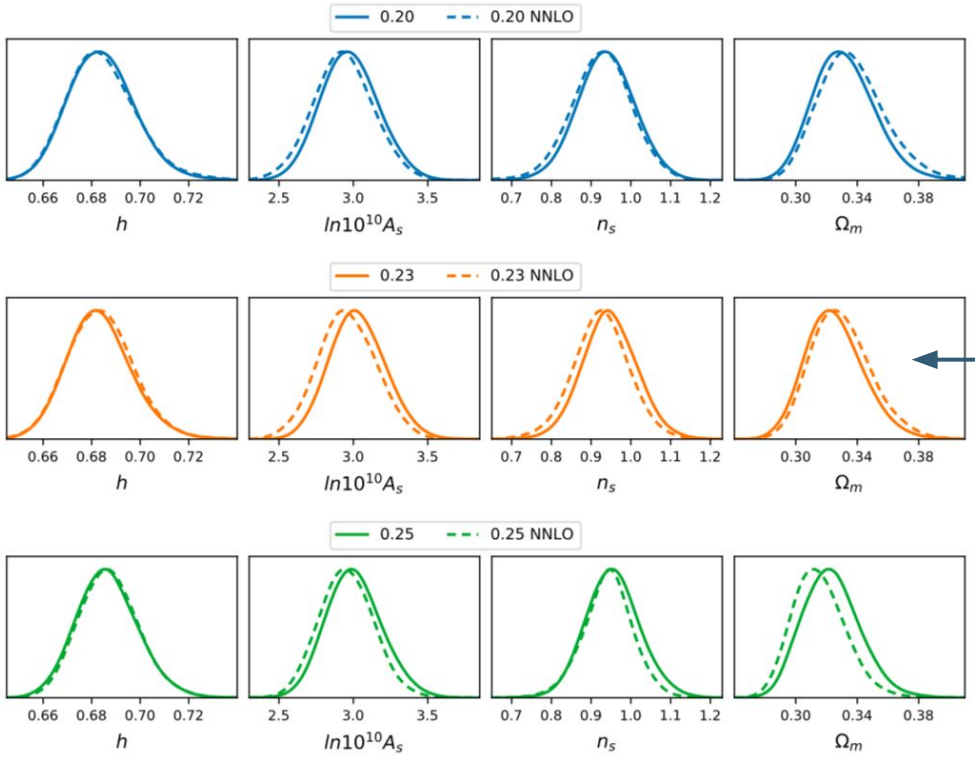
Theory error at 1-loop (NLO) = 2-loop (NNLO)

$$P_{2L}^{\mu=0}(k) \sim c_e \frac{k^2}{k_{\rm M}^2} P_{1L}^{\mu=0}(k)$$

$$P_{2L}(k) \sim \frac{1}{4} b_1 (c_{r,4} b_1 + c_{r,6}\mu^2)\mu^4 \frac{k^4}{k_{\rm R}^4} P_{11}(k)$$

— EFT scale cut —

w/ D'Amico, Senatore, Nishimichi 21
w/ D'Amico Senatore, Zhao, Cai 21
w/ Simon & Poulin 22



1. Self-determination of scale cut

from measuring shift upon adding NNLO

$$\sigma_{\rm sys} < \frac{1}{3}\sigma_{\rm stat}^{\rm data}$$

2. Automatic calibration of governing scales

such that $|c_{NLO}| \sim |c_{NNLO}| \sim O(1)$

$$k_{\rm M}^{\rm BOSS} = 0.7h\,{\rm Mpc}^{-1}, \qquad k_{\rm R}^{\rm BOSS} = 0.35h\,{\rm Mpc}^{-1},$$
$$k_{\rm M}^{\rm eBOSS} = 0.7h\,{\rm Mpc}^{-1}, \qquad k_{\rm R}^{\rm eBOSS} = 0.25h\,{\rm Mpc}^{-1}.$$

Disclaimer: Most analyses in this talk are setting w_b to BBN preferred value

III - EFT pipelines

Some validations

- PyBird: *https://github.com/pierrexyz/pybird*
  w/ D'Amico & Senatore 20

Also: Velocileptors, CLASS-PT, PBJ, FOLPS, CLASS-OneLoop, ...

— Tests against simulations —

For BOSS 2pt @1-loop

— Lettered challenge —

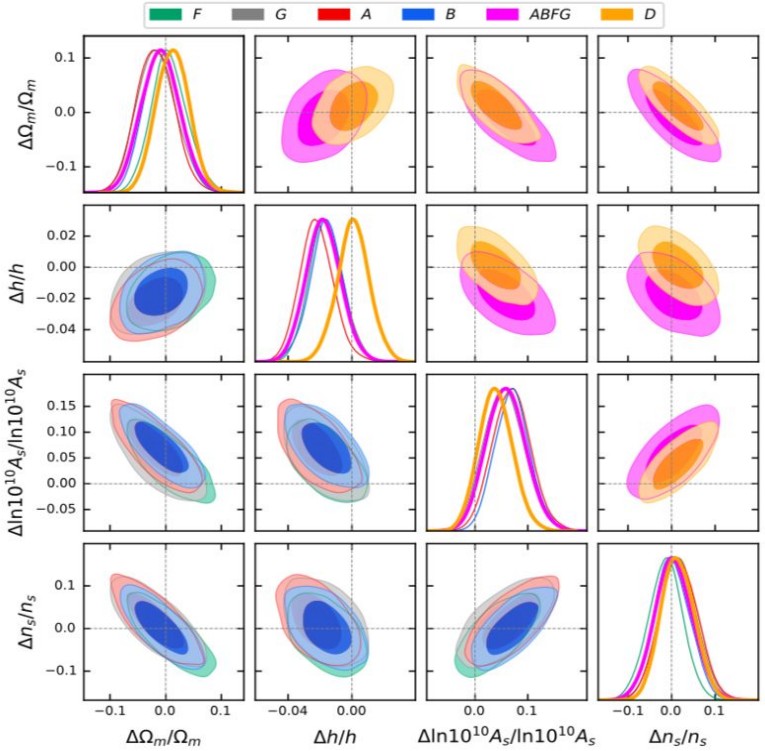
$L_{box} \sim (2.5\ Gpc/h)^3$

$V_{tot} \sim 6\ V_{BOSS}$

w/ D'Amico, Gleyzes, Kokron, Markovic, Senatore, Beutler, Gil-Marin 19

w/ Colas, D'Amico, Senatore, Beutler 19

In real space w/ D'Amico, Senatore, Zhao, Cai 21



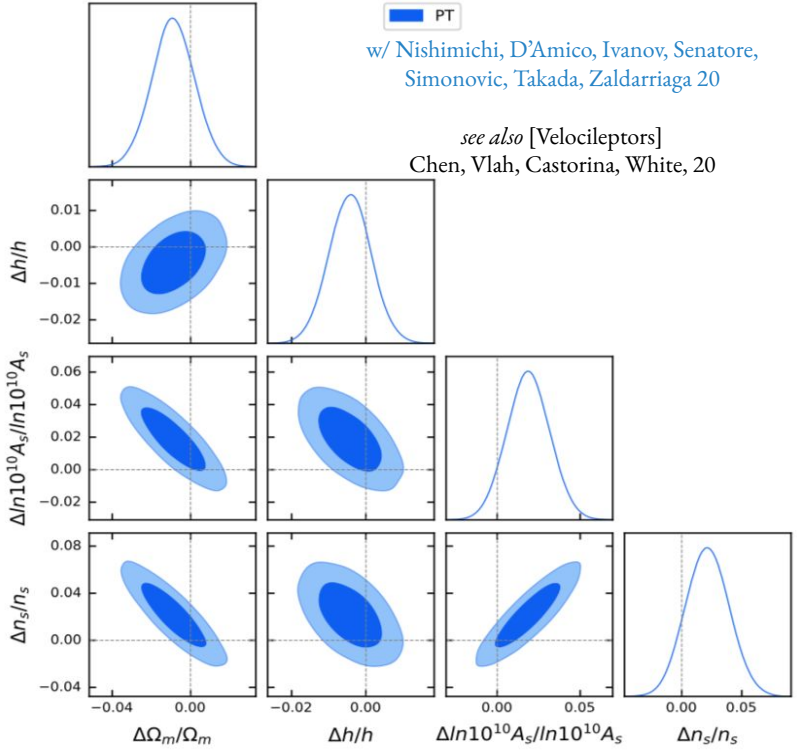
— [blind] PT challenge —

$V_{box} \sim 566\ (Gpc/h)^3$

$V_{tot} \sim 100\ V_{BOSS}$

w/ Nishimichi, D'Amico, Ivanov, Senatore, Simonovic, Takada, Zaldarriaga 20

see also [Velocileptors] Chen, Vlah, Castorina, White, 20

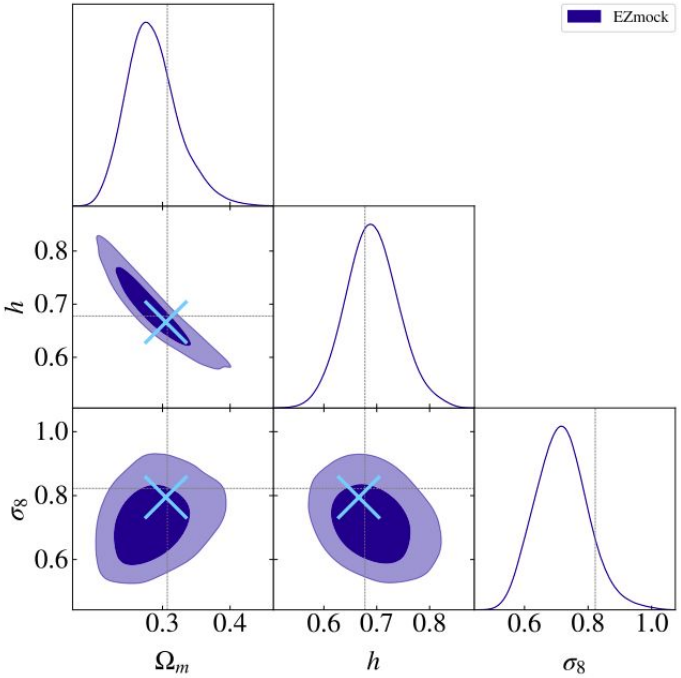


— Tests against simulations —

For eBOSS 2pt @1-loop

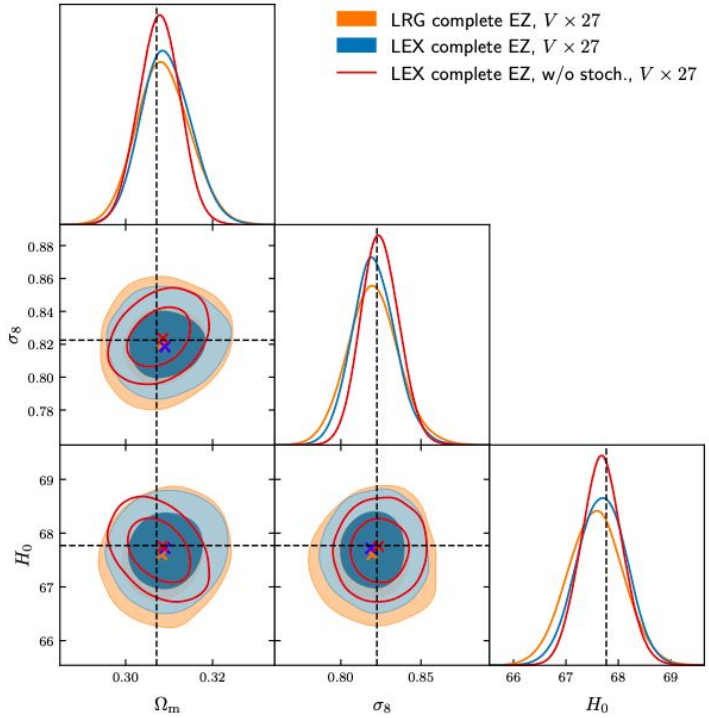
— QSO —

w/ Simon & Poulin 22
Ivanov & Chudaykin 22



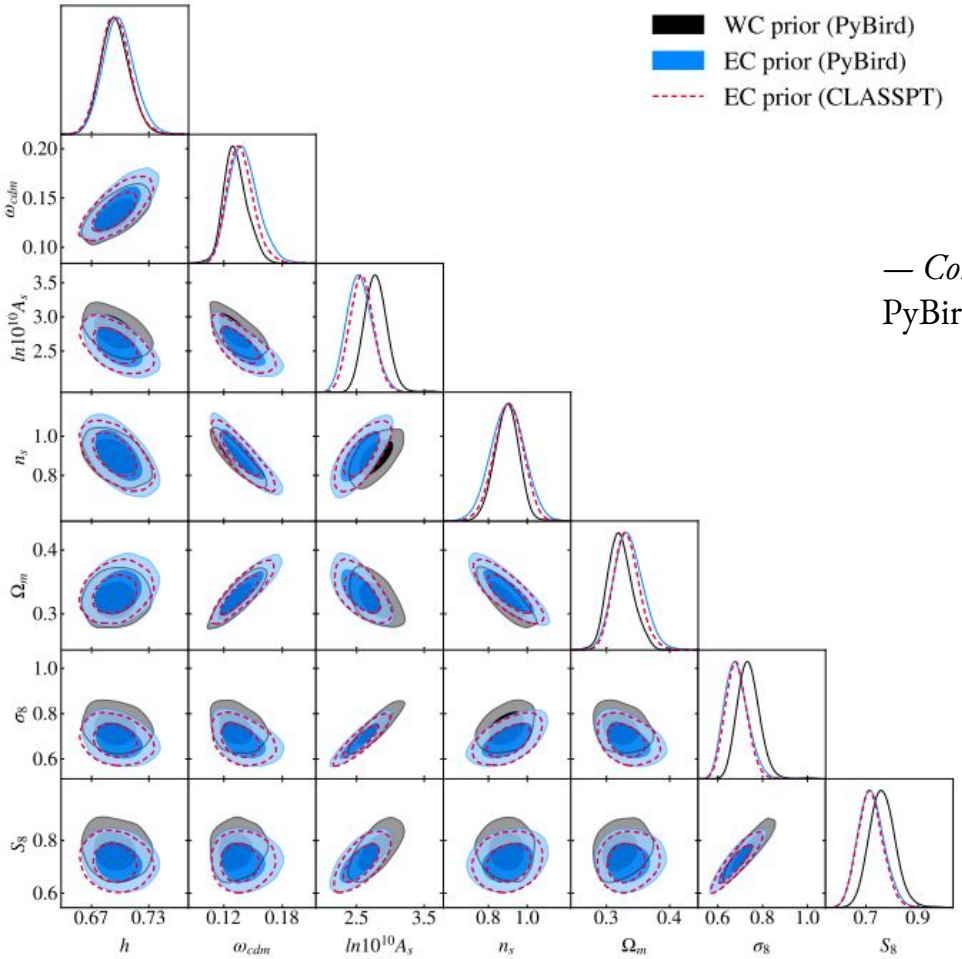
— LRG + ELG —

[multi-tracers] Zhao *et al.* 23
Ivanov 21



— Pipeline comparison —

For BOSS 2pt @1-loop



— Consistency of BOSS EFT analyses —

PyBird vs. CLASS-PT

w/ Simon, Poulin, Smith 22

For other comparisons, see also

[PBJ] Carrilho, Morettia, Pourtsidou 22

[CLASS-OneLoop] Linde, Moradinezhad Dizgah, Radermacher, Casas, Lesgourgues 24

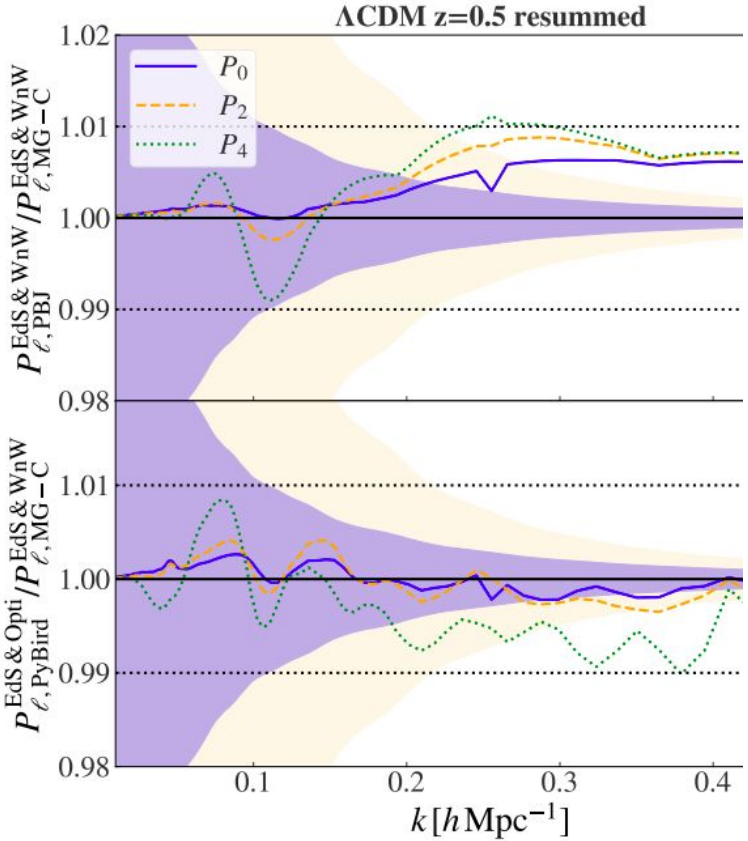
cf. talks Denis & Julien

— Pipeline comparison —

For LSS-S4 2pt @1-loop

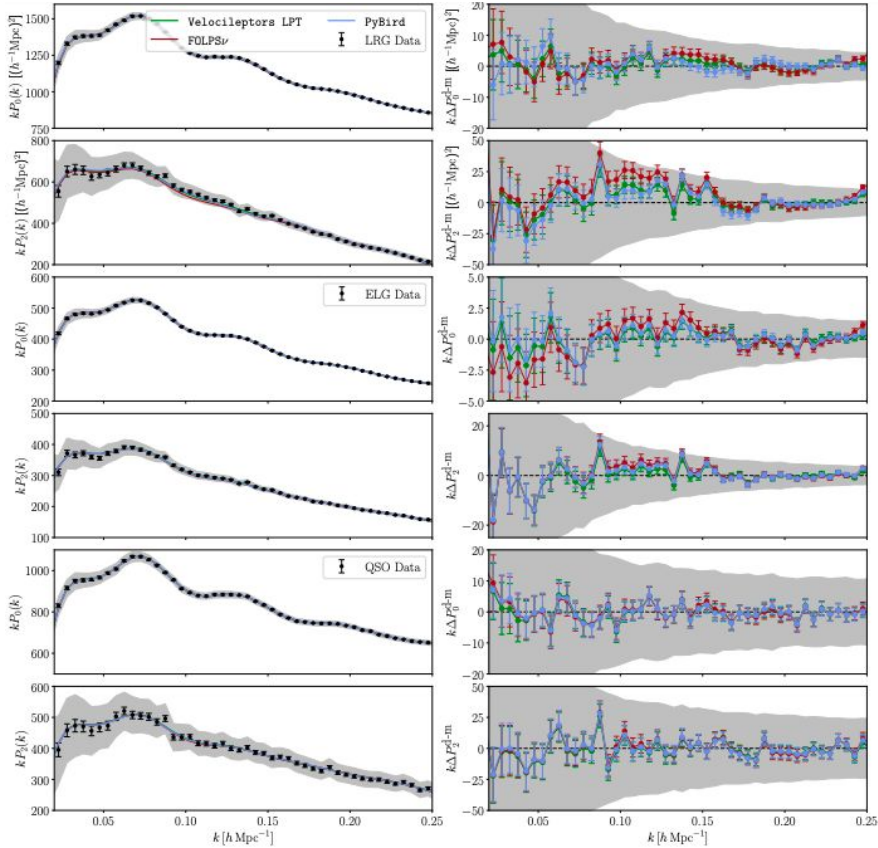
— Euclid collaboration — Bose *et al.* 24

PyBird vs. PBJ vs. MG-Copter (vs. simulations)



— DESI collaboration — Maus *et al.* 24

PyBird vs. Velocileptors vs. FOLPS (vs. Abacus simulations.)



— Retrospective summary —

- *Many independent* EFT implementations, *passing many checks*, & *agreeing*, up to:

  1. Treatment of long-wavelength modes (IR-resummation, LPT)
     ✔ but diff. at the expected level on one-loop scales

  2. Parametrization (EFT basis)
     ✔ small diff. for DESI/Euclid volume

- ***Looks like we have done a good job?!***

IV- BOSS 2+3pt @ 1-loop

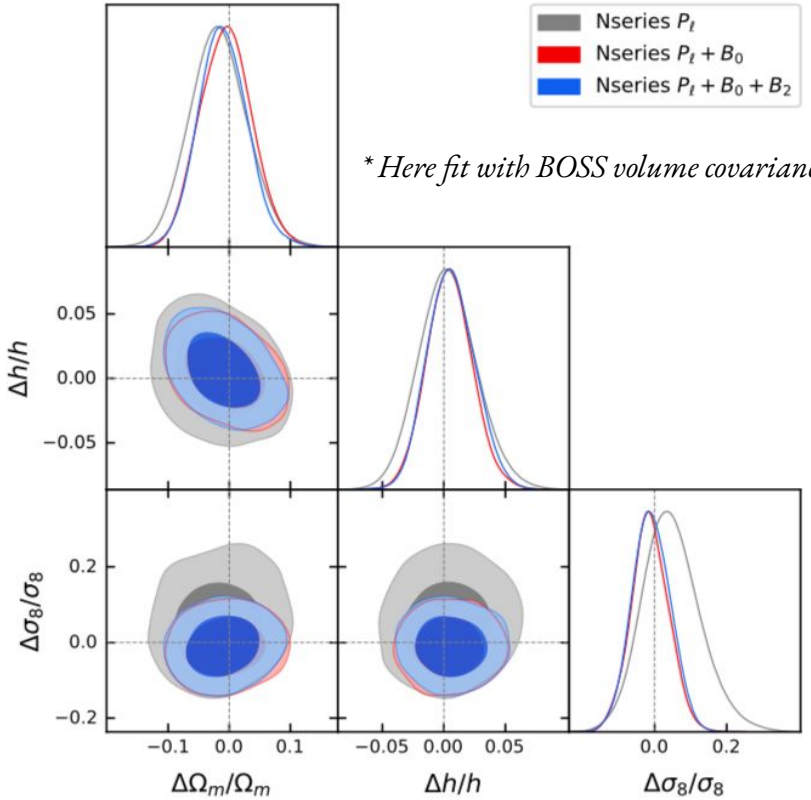
[analysis] w/ D'Amico, Donath, Lewandowski, Senatore 22a
[theory] w/ D'Amico, Donath, Lewandowski, Senatore 22b
[code] Anastasiou, Bragança, Senatore, Zheng 22

— Tests against simulations —

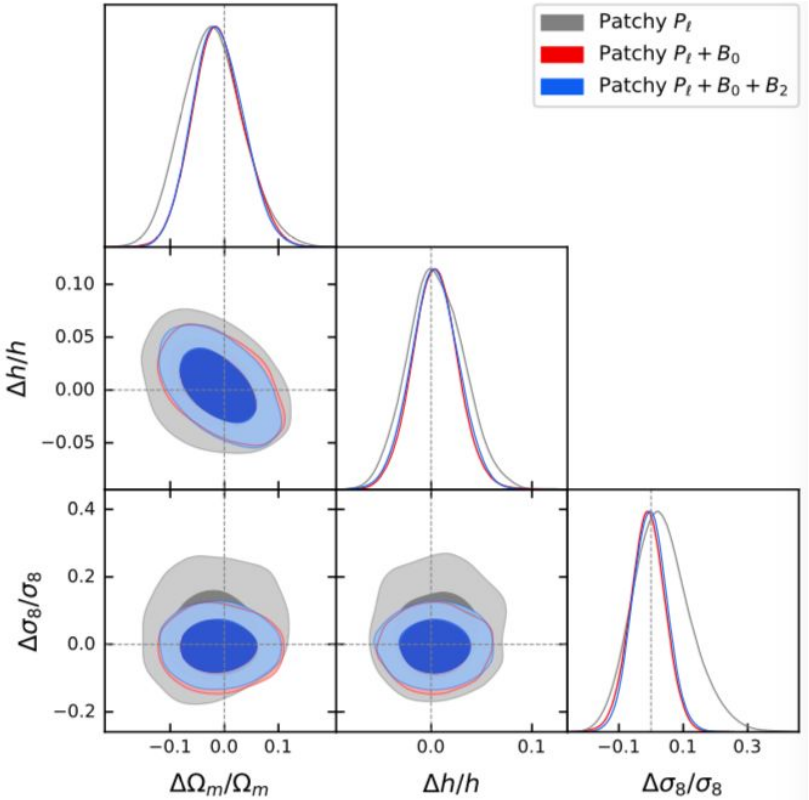
BOSS 2+3pt @1-loop

w/ D'Amico, Donath, Lewandowski, Senatore 22a

see also Philcox, Ivanov, Cabass, Simonovic, Zaldarriaga, Nishimichi 22



* *Here fit with BOSS volume covariance*

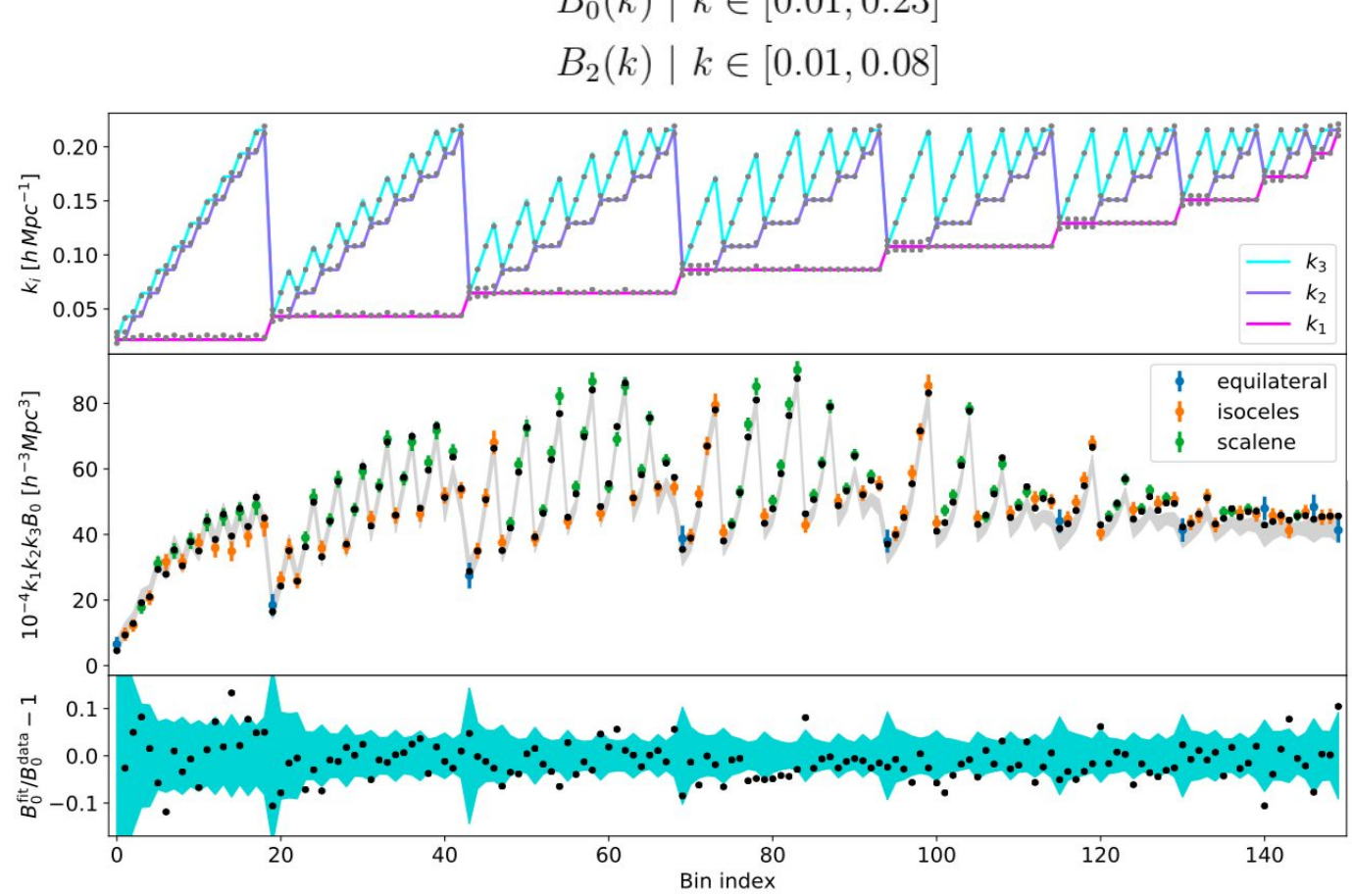


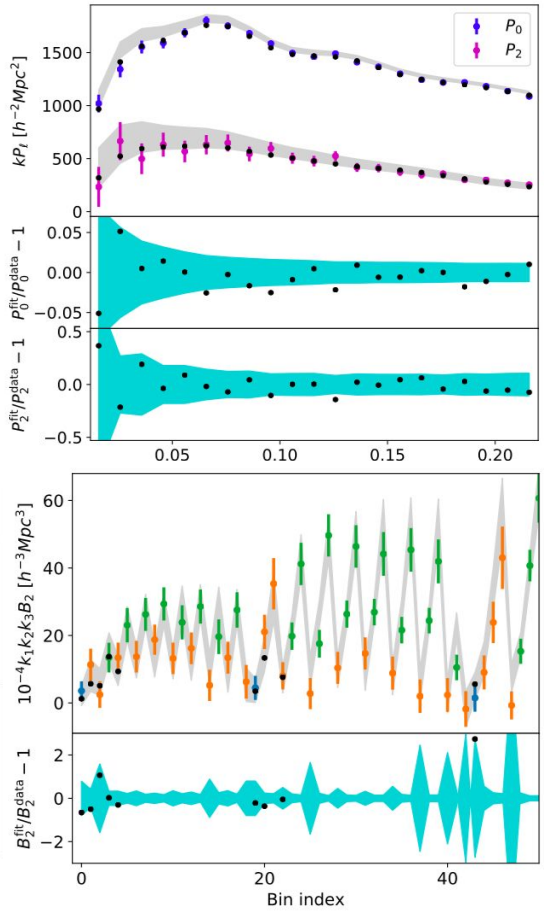
— Best-fit —

$$P_\ell(k) \mid k \in [0.01, 0.23]$$
$$B_0(k) \mid k \in [0.01, 0.23]$$
$$B_2(k) \mid k \in [0.01, 0.08]$$

BOSS 2+3pt @1-loop

w/ D'Amico, Donath, Lewandowski, Senatore 22a

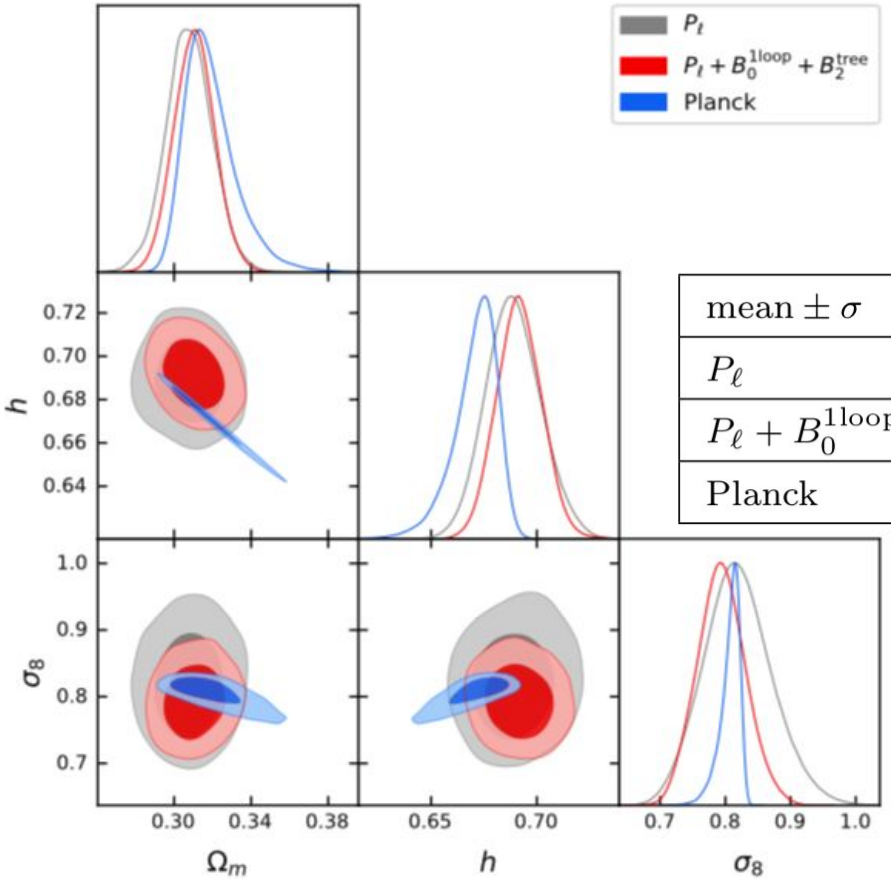




— ΛCDM —

BOSS 2+3pt @1-loop

w/ D'Amico, Donath, Lewandowski, Senatore 22a



➢ *error reduction* from *P* to *P*+*B*:

13% on Ω_m *18%* on h *30%* on σ_8

mean $\pm\,\sigma$	Ω_m	h	σ_8
P_ℓ	0.308 ± 0.012	$0.689^{+0.012}_{-0.014}$	$0.819^{+0.049}_{-0.055}$
$P_\ell + B_0^{1\text{loop}} + B_2^{\text{tree}}$	0.311 ± 0.010	0.692 ± 0.011	0.794 ± 0.037
Planck	$0.3191^{+0.0085}_{-0.016}$	$0.671^{+0.012}_{-0.0067}$	$0.807^{+0.018}_{-0.0079}$

See also [tree-level 3pt] Ivanov, Philcox, Cabass, Nishimichi, Simonovic,Zaldarriaga 23

$-f_{NL}-$

BOSS 2+3pt @1-loop

w/ D'Amico, Lewandowski, Senatore 22

	$\sigma(f_{\rm NL}^{\rm or})$	$\sigma(f_{\rm NL}^{\rm eq})$
Tree-level	136	437
*Tree-level, b_2 fixed	120	300
One-loop	72	293
One-loop, b_2 fixed	53	209

~ 15-30%

~ 30-50%

~ 30%

c.f. Misha & Oliver's talks

See also [tree-level 3pt]
* [eq / or] Cabass, Ivanov, Philcox, Simonovic,Zaldarriaga 22
[local] Cabass, Ivanov, Philcox, Simonovic,Zaldarriaga 23
[skew-spectra] Chen, Chakraborty, Dvorkin 24

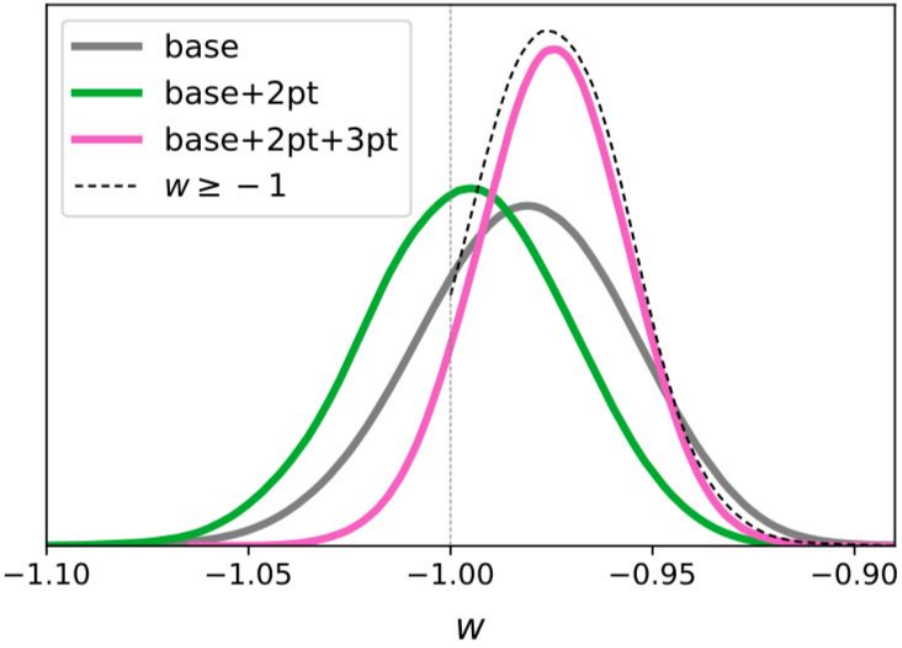
— *w*CDM —

BOSS 2+3pt @1-loop

w/ Spaar 23

base = Planck + ext-BAO + PanPlus

wCDM					
	base	base+BAO	base+2pt	base+2pt+3pt (tree)	base+2pt+3pt (1loop)
w	-0.982 ± 0.027	-0.987 ± 0.026	-0.996 ± 0.026	-1.010 ± 0.025	-0.975 ± 0.019



***~ 30%** improvement in combined probes!*

- First combined analysis w/ BOSS 2+3pt @1-loop
- … with actual improvements over Planck + BAO!

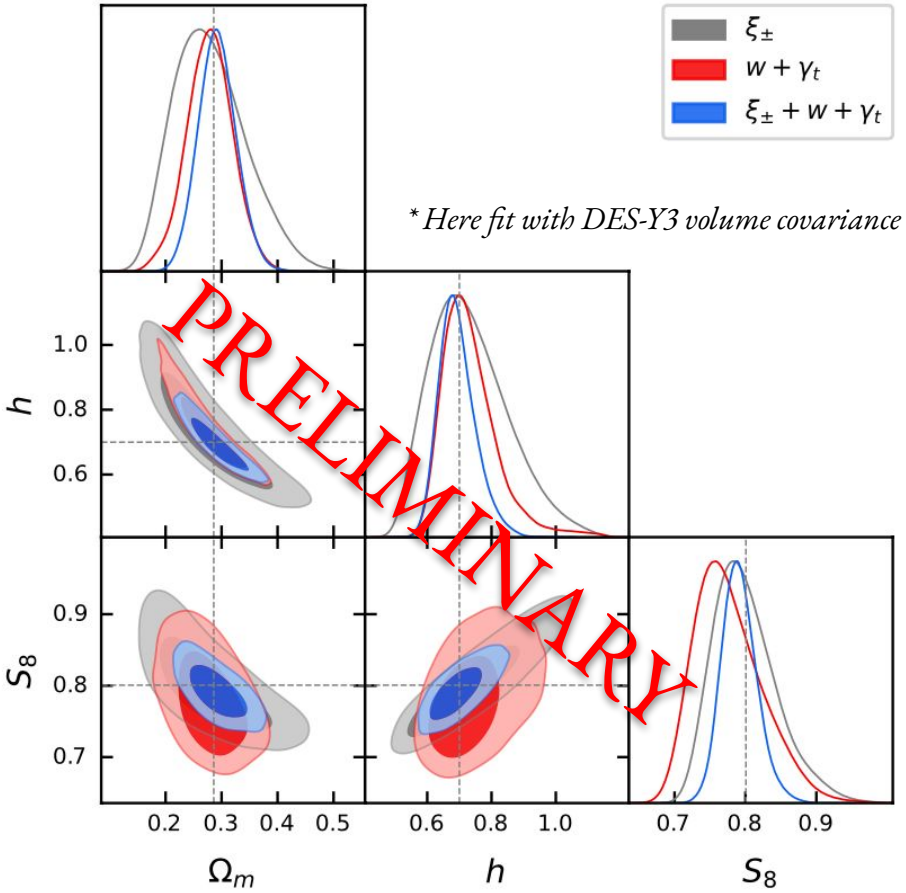
V- DES 3×2pt @ 1-loop

w/ D'Amico, Refregier, Senatore, *in prep.*

— Tests against simulations —

DES 3×2pt @1-loop

w/ D'Amico, Refregier,, Senatore, *in prep.*



** Here fit with DES-Y3 volume covariance*

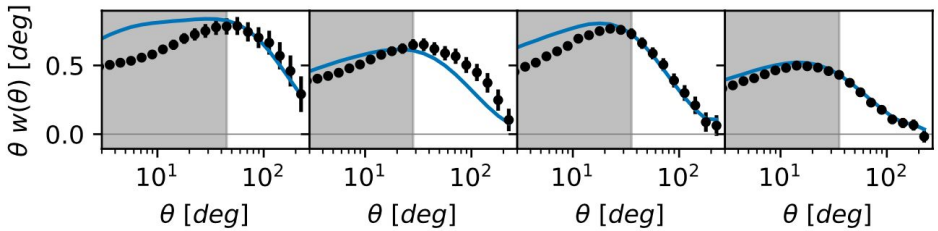
— Buzzard v2.0 —
De Rose et al. 21

$V_{tot} \sim 18\, V_{DES\text{-}Y3}$

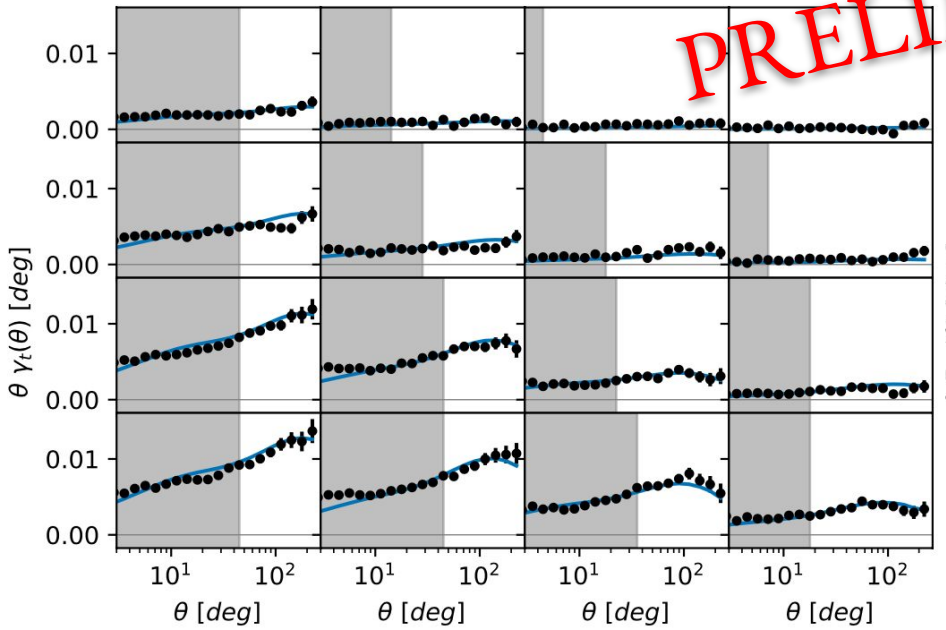
— Best-fit —

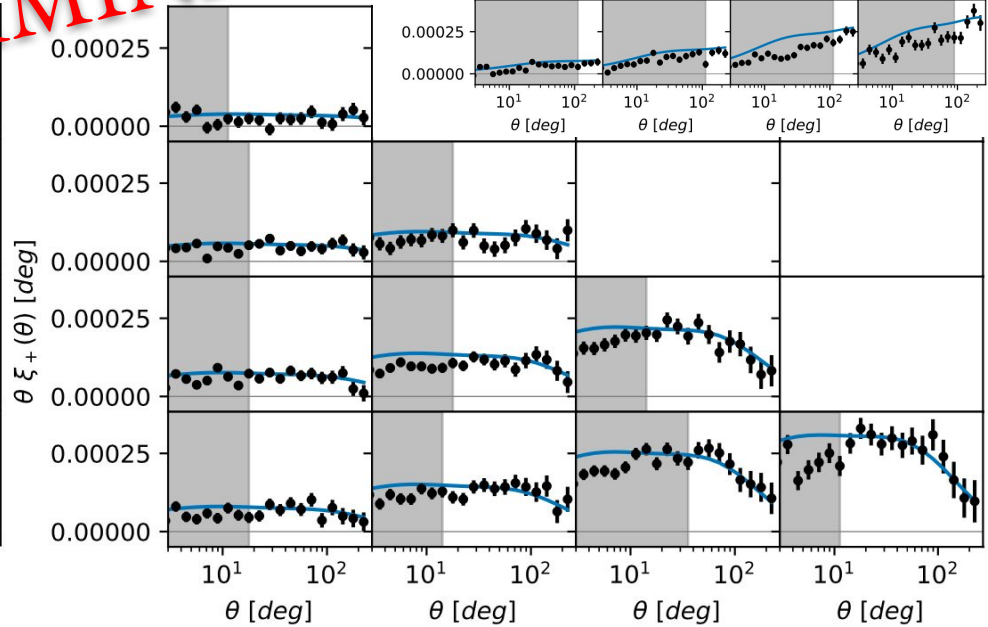
DES 3×2pt @1-loop

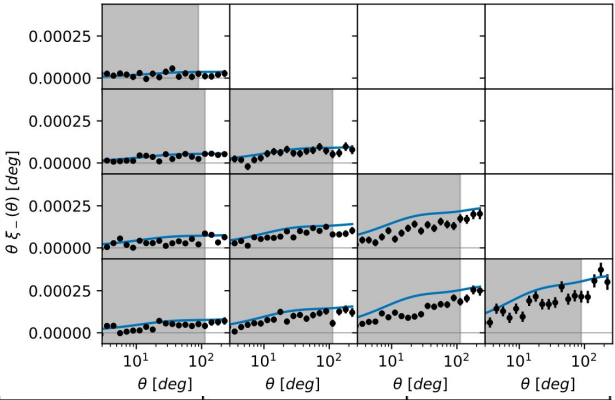
w/ D'Amico, Refregier,, Senatore, *in prep.*



min χ^2 ✔





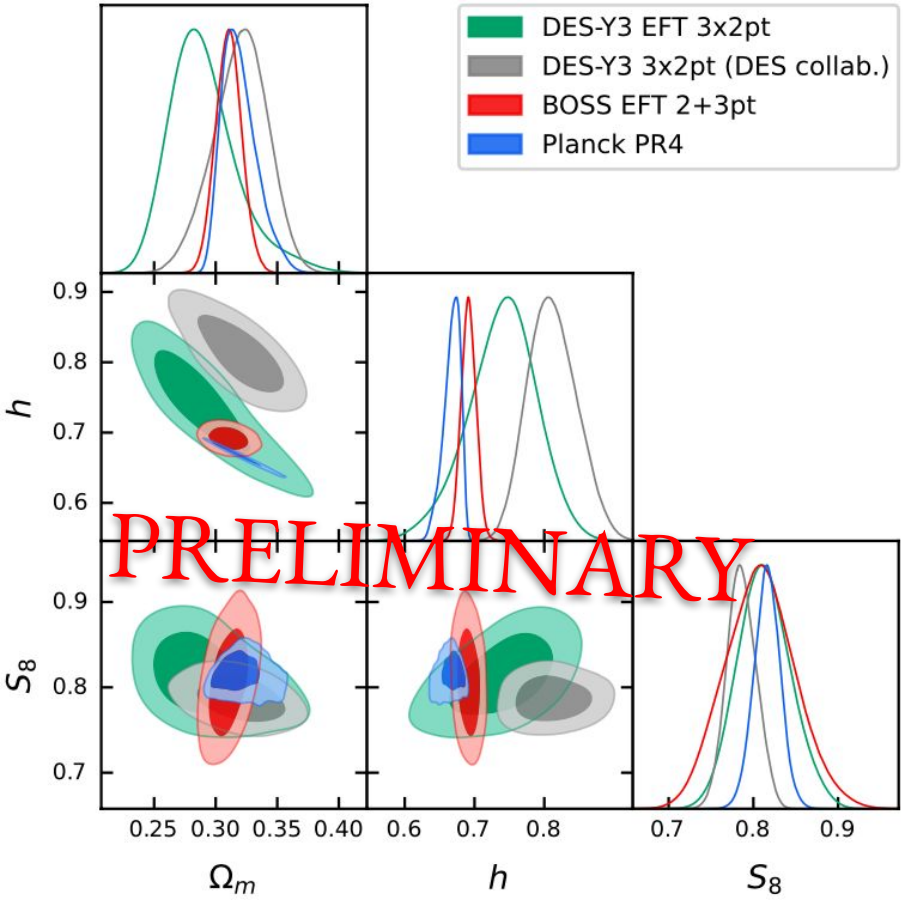


PRELIMINARY

— ΛCDM —

DES 3×2pt @1-loop

w/ D'Amico, Refregier,, Senatore, *in prep.*



- Larger error bars than DES collab. Price to pay for:
  - including only scales under EFT control
  - marginalizing over nonlinearities, baryons, etc. (*~O(100)* nuisance parameters!)
- & Significant shifts!
  - better consistency with BOSS / Planck

— Summary & Outlook —

Drawing lessons, we are making progress in the EFTofLSS …

- Increasing SNR by capturing information residing in higher N-point
  - ➢ New estimators, field-level?
  - ➢ Observational systematics modeling (beyond 2pt)?
  - ➢ Covariance?

- Increasing range of accessible scales (more loops)
  - ➢ Push PT calculations
  - ➢ Design efficient algorithm for loop integration

- Leveraging synergy of cosmological observables
  - ➢ Diversify our predictions

— Summary & Outlook —

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