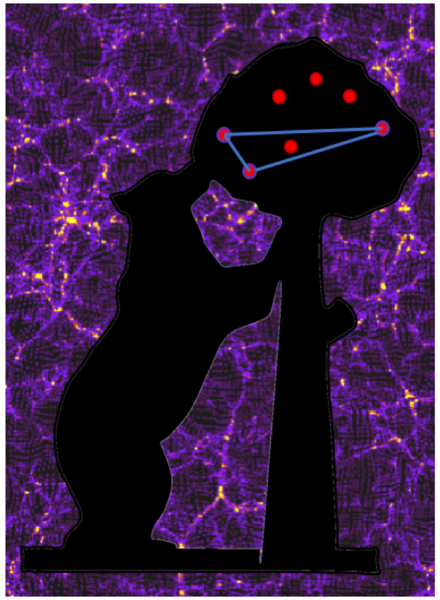
Validating galaxy clustering models with *Fixed* & *Paired* and *Matched*-ICs simulations: application to Primordial Non-Gaussianities



arXiv:[2204.11103](https://arxiv.org/abs/2204.11103)

[check also references therein]

Santiago Avila

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UAM Universidad Autónoma de Madrid

ift Instituto de Física Teórica UAM-CSIC

IFT PNG workshop
19th-Sep-2022, Madrid

EXCELENCIA SEVERO OCHOA

Primordial Non-Gaussianities (PNG)

- One of the few observables of Inflation
- Local PNG
  - Definition: $\Phi(\mathbf{x}) = \Phi_G(\mathbf{x}) + f_{\rm NL}^{\rm loc}\left(\Phi_G(\mathbf{x})^2 - \langle \Phi_G^2 \rangle\right)$
  - If detected, ($\mathcal{O}(f_{\rm NL}) = 1$), a smoking gun for Multi-field inflation

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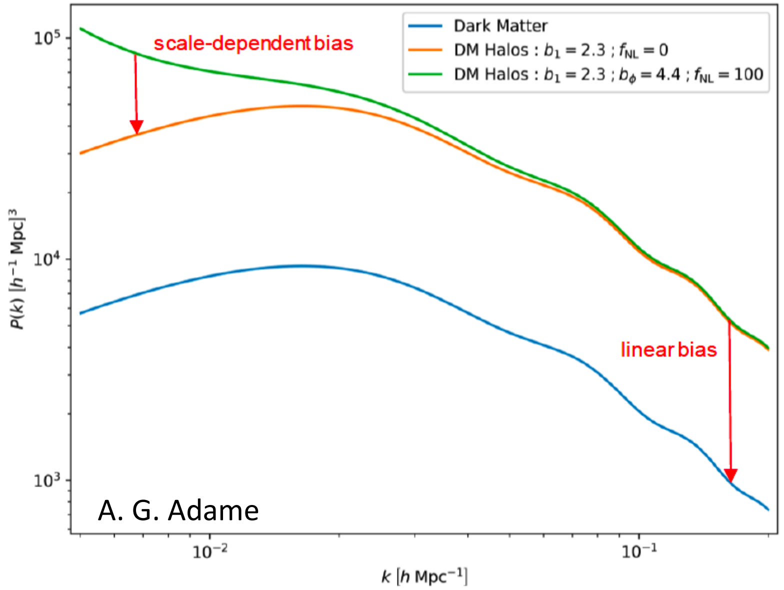
  - If detected, ($\mathcal{O}(f_{\rm NL}) = 1$), a smoking gun for Multi-field inflation

  - Creates a scale-dependent bias on halos

$$b(k) = b_g + 2\delta_c(b_g - p)\cdot f_{\rm NL}\cdot\frac{1}{\alpha(k,z)} \qquad \alpha(k,z) = \frac{2D(z)}{3\Omega_m(z)}\frac{c^2}{H_0^2}\frac{g(z_{\rm rad})}{g(0)}k^2T(k) \propto k^2$$

Dalal+08, Slosar+08, Barreira+20, PNG-UNITsim in prep.



Fix, Pair, Match and local-PNG ICs

- Normal (Gaussian) Initial Conditions ($\Phi_i(k) \curvearrowleft \mathcal{N}_{\mathbb{C}}(\Phi_i(k); \mu = 0, \sigma^2 = P(k)/\alpha^2)$)
  - Modulus (Rayleigh) $|\Phi(k)|_i \curvearrowleft \mathcal{P}_{\text{Rayleigh}}(|\Phi(k)|)$
  - Phase (flat PDF) $\varphi_i \curvearrowleft \frac{1}{2\pi}\Theta_{[0,2\pi]}(\varphi)$

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From Gravitational potential to density perturbations

$$\delta(k, z) = \alpha(k, z)\Phi(k)$$

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Then we use 2LPT to generate ICs

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- Paired

$$\varphi_{Inverted} = \varphi_{Original} + \pi$$

Angulo & Pontzen 2016

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Goliat-PNG simulations

- 41 different seeds
- For $f_{\rm NL} = 0$ & $f_{\rm NL} = 100$
- And ICs:
    - Normal
    - Normal-Inverted
    - Fixed
    - Fixed-Inverted

- Halos with 10 parts. (AHF)
- At z=1
- L=1Gpc/h

Goliat-PNG simulations: halo power spectrum

- 41 different seeds
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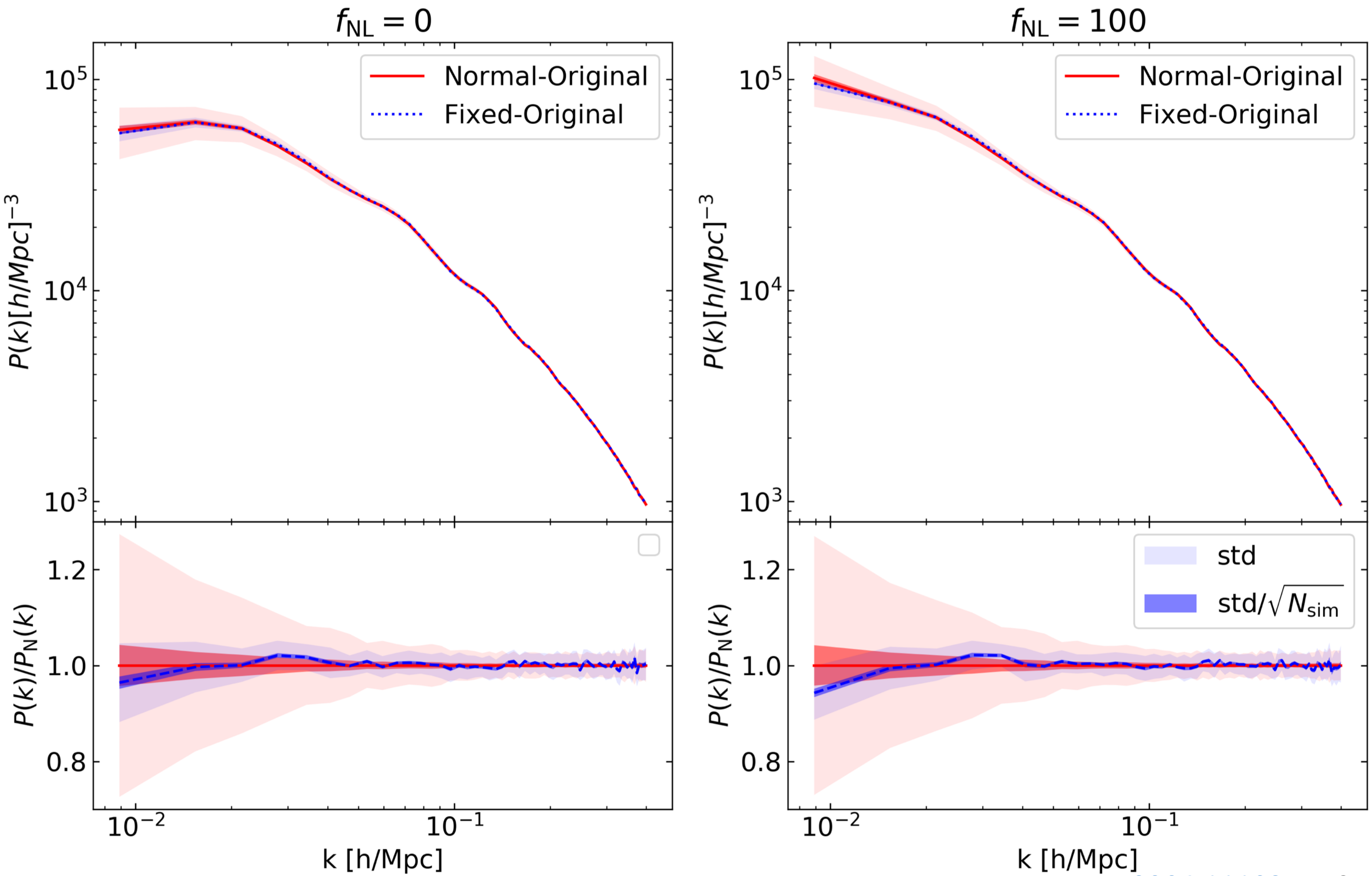
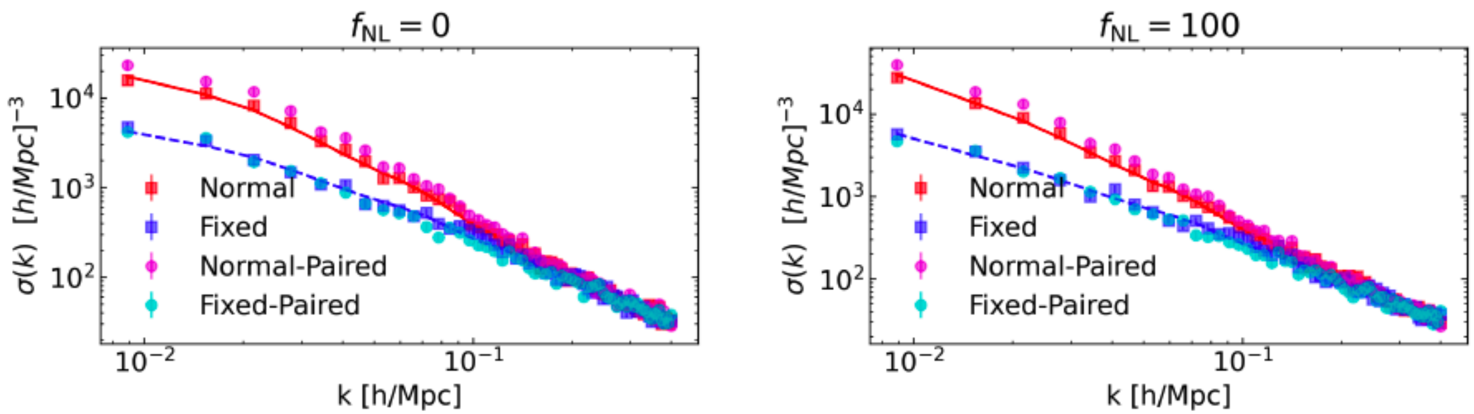


Variance of the halo power spectrum

- Similar reduction between $f_{\mathrm{NL}} = 0$ and $f_{\mathrm{NL}} = 100$



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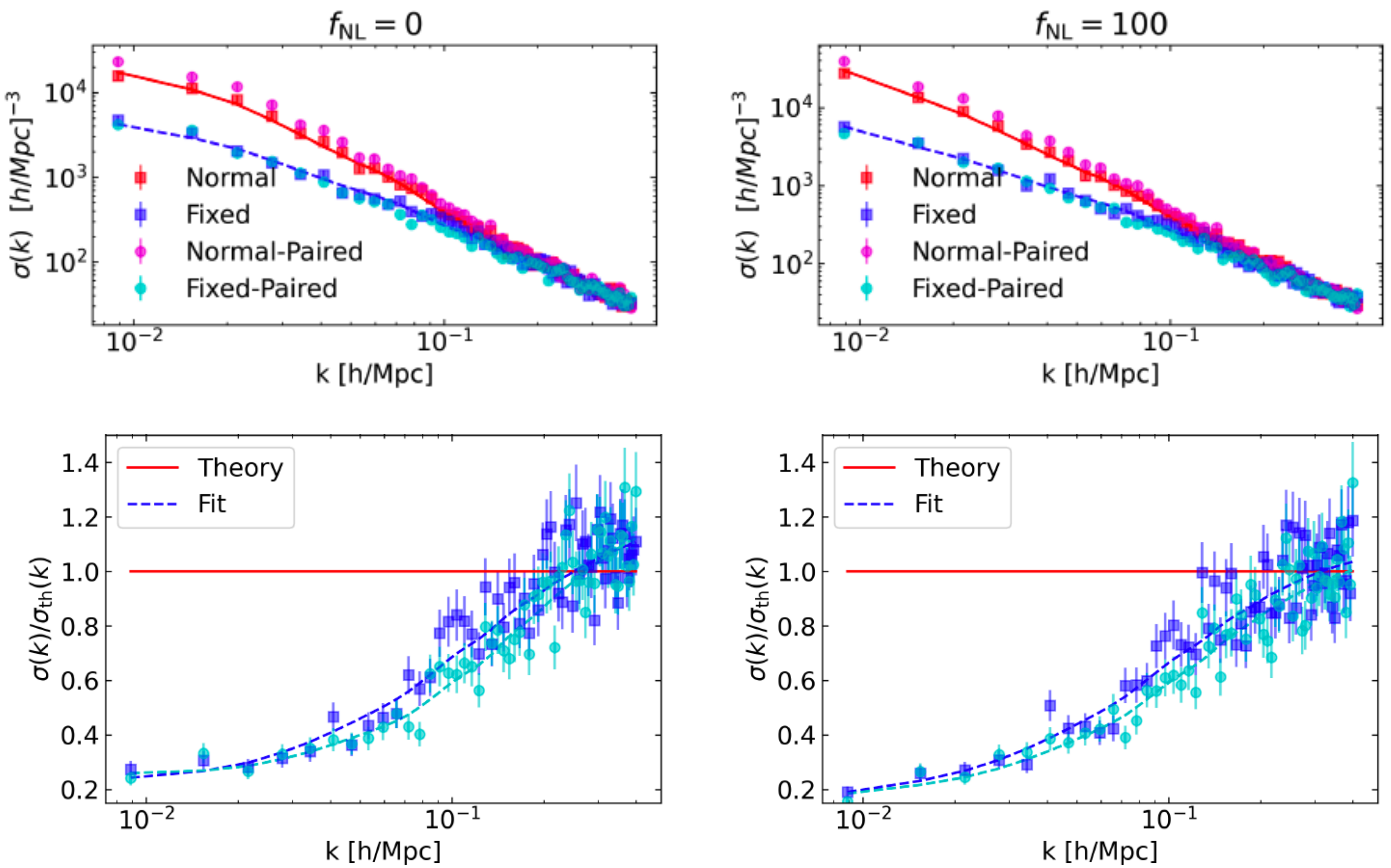
- Ratio w.r.t. Normal Gaussian error

$$\sigma_{th}(k)^2 = \frac{4\pi^2}{V\,k^2\,\Delta k}\left(P(k) + \frac{1}{n}\right)^2$$



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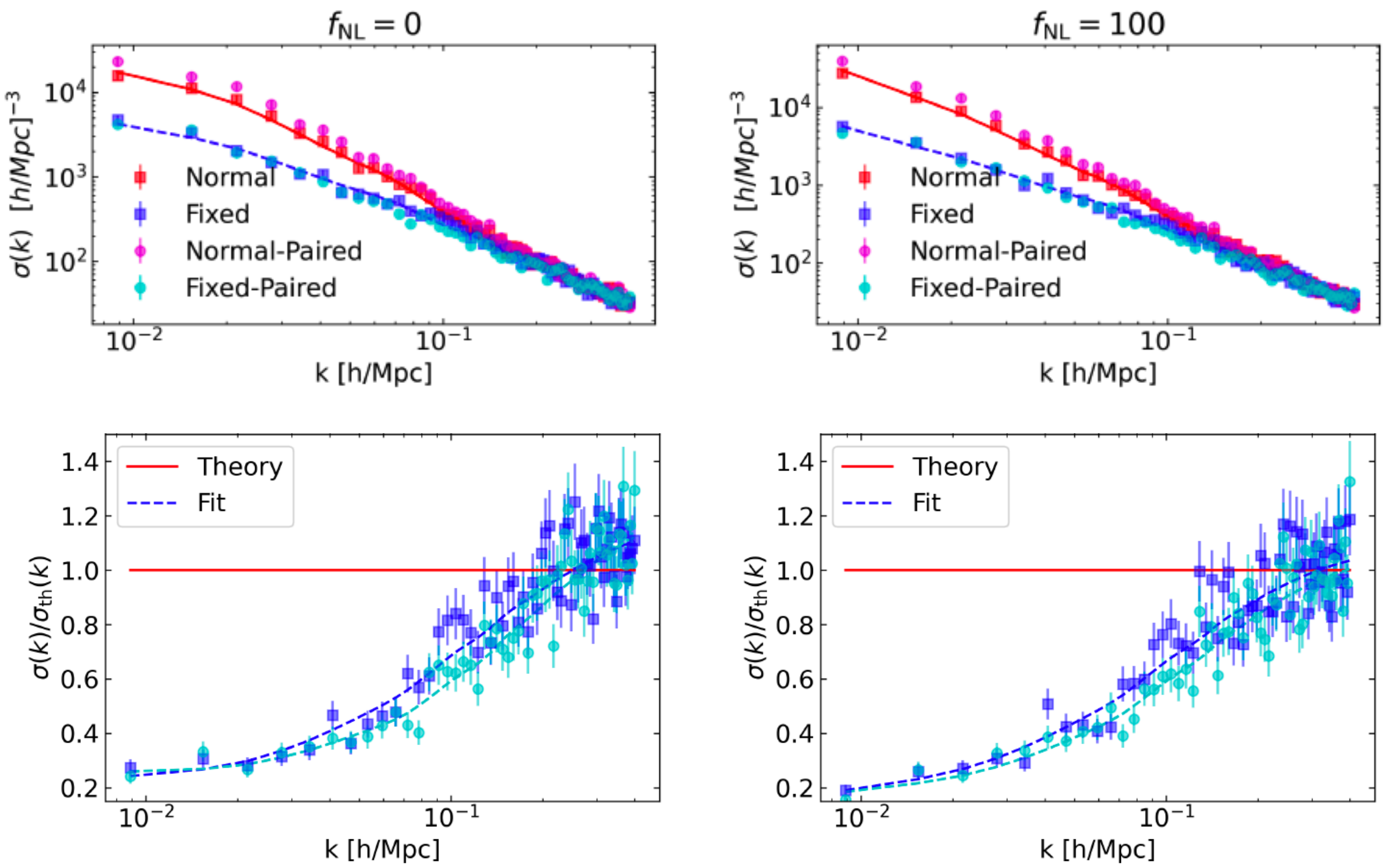
- Pairing:

$$P_{\rm Paired,i}(k) = \frac{1}{2}\left(P_{\varphi_i}(k) + P_{\varphi_i+\pi}(k)\right)$$

$$\sigma_{\rm Paired} = \sqrt{2}\cdot {\rm std}\left(\frac{1}{2}\left(P_{\varphi_i}(k) + P_{\varphi_i+\pi}(k)\right)\right)$$

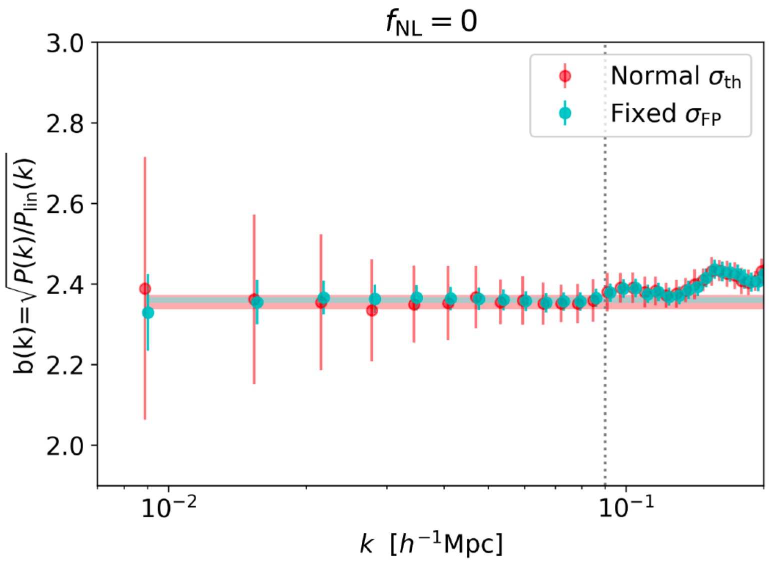


Halo bias

- Linear halo bias
  (valid at large scales)

$$\delta_{\text{halo}} = b \cdot \delta$$

$$P_{\text{halo}}(k) = b^2 \cdot P(k)$$



Error-bar: simulations
Lines/bands: theory

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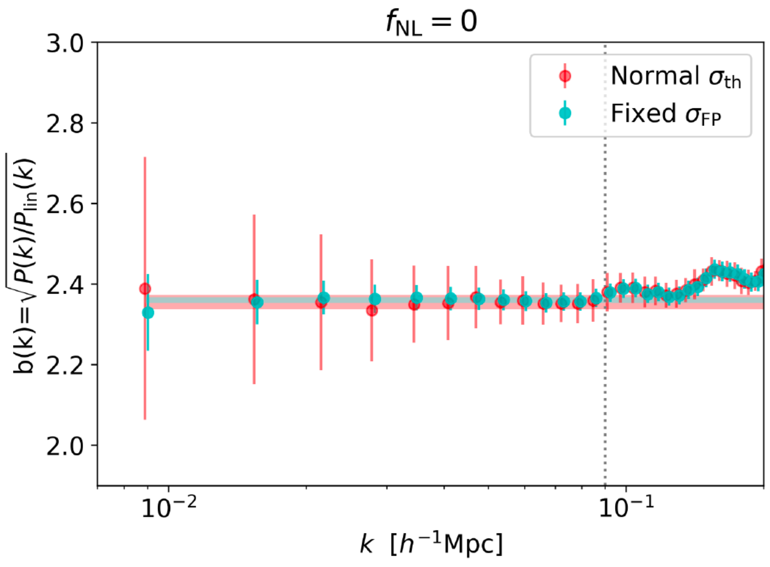

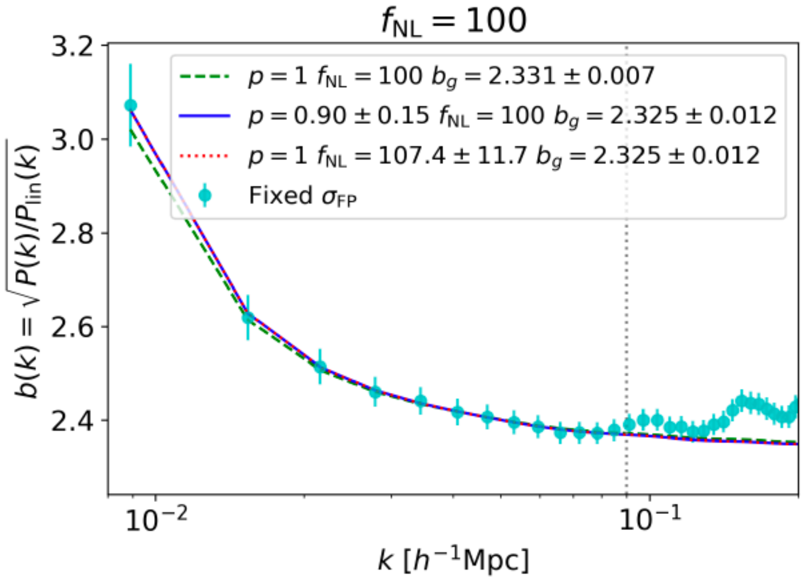

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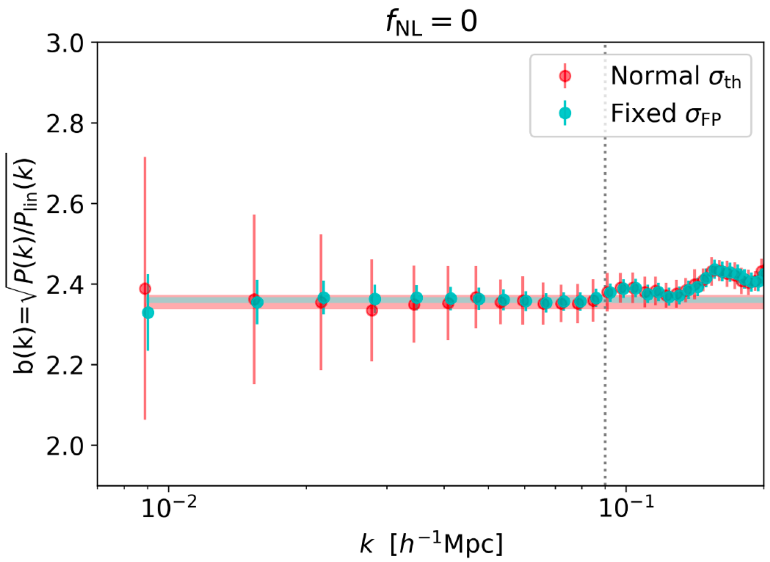
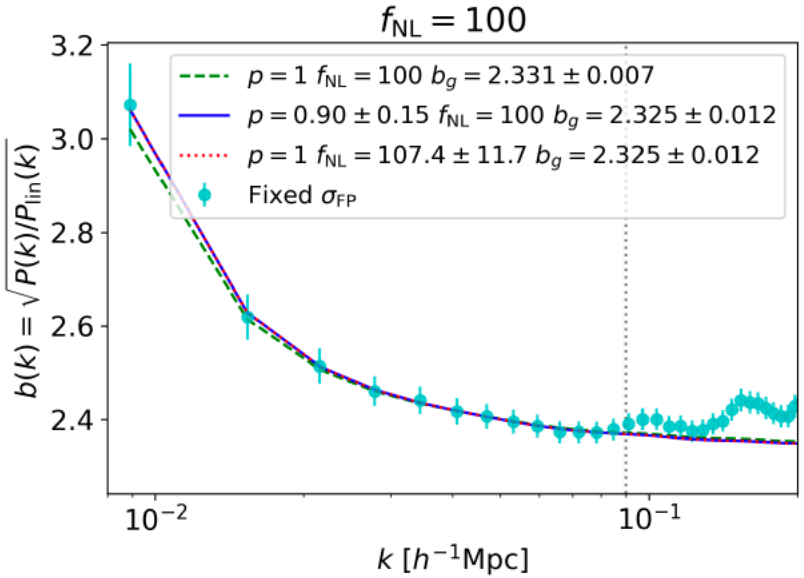
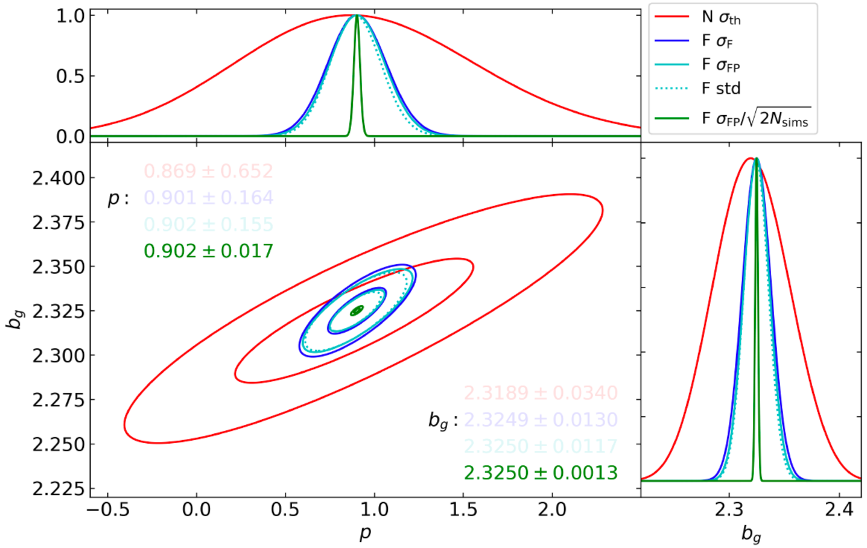




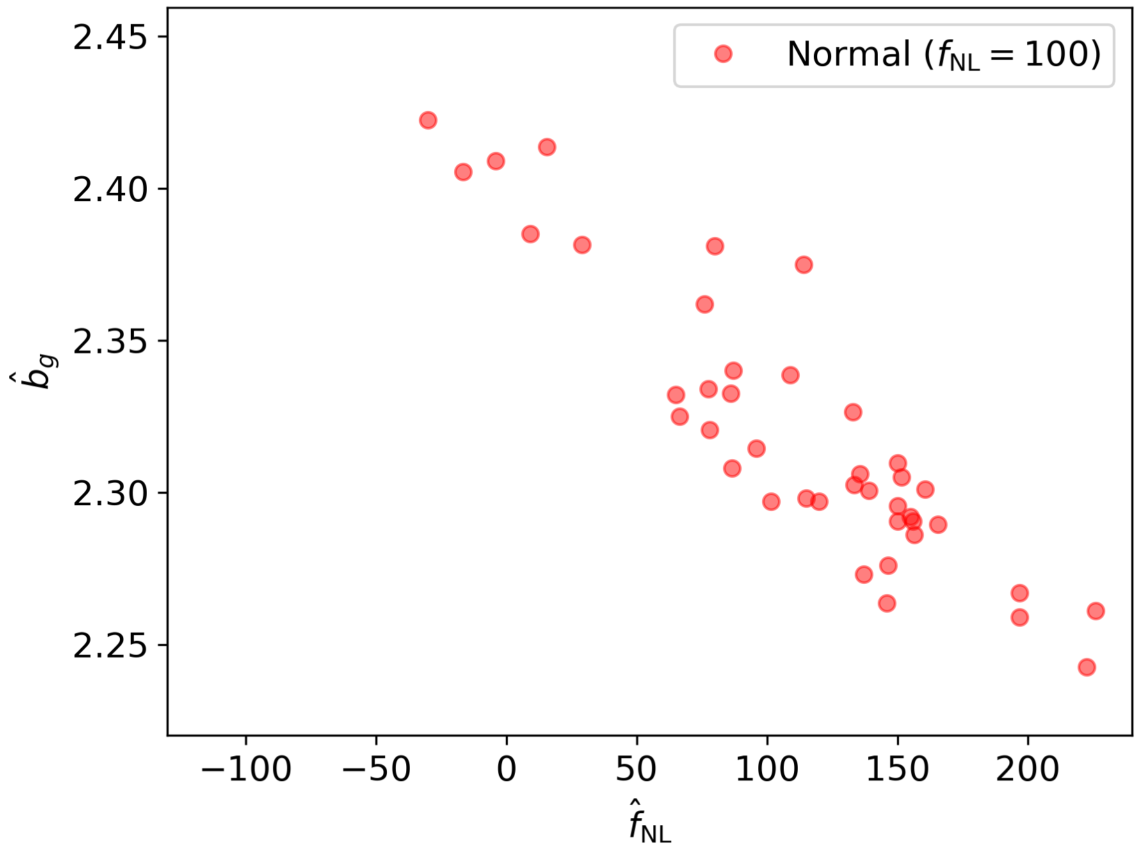


Individual fits

- Normal sims.

$$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$$

$$111.4 \pm 60.5$$



$$p = 1$$

$$P_{\rm halo}(k) = b^2 P_{\rm lin}(k)$$

$$b(k) = b_g + 2\delta_c (b_g - p) \cdot f_{\rm NL} \cdot \frac{1}{\alpha(k,z)}$$

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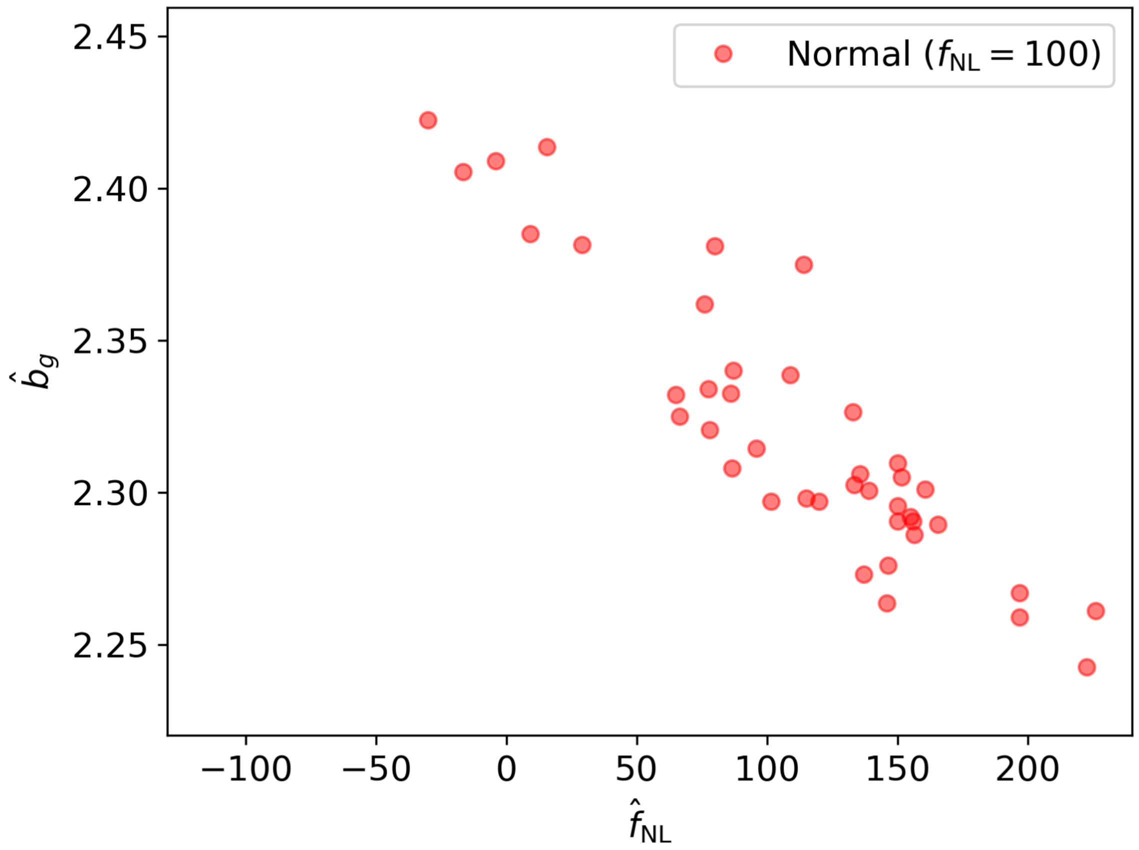

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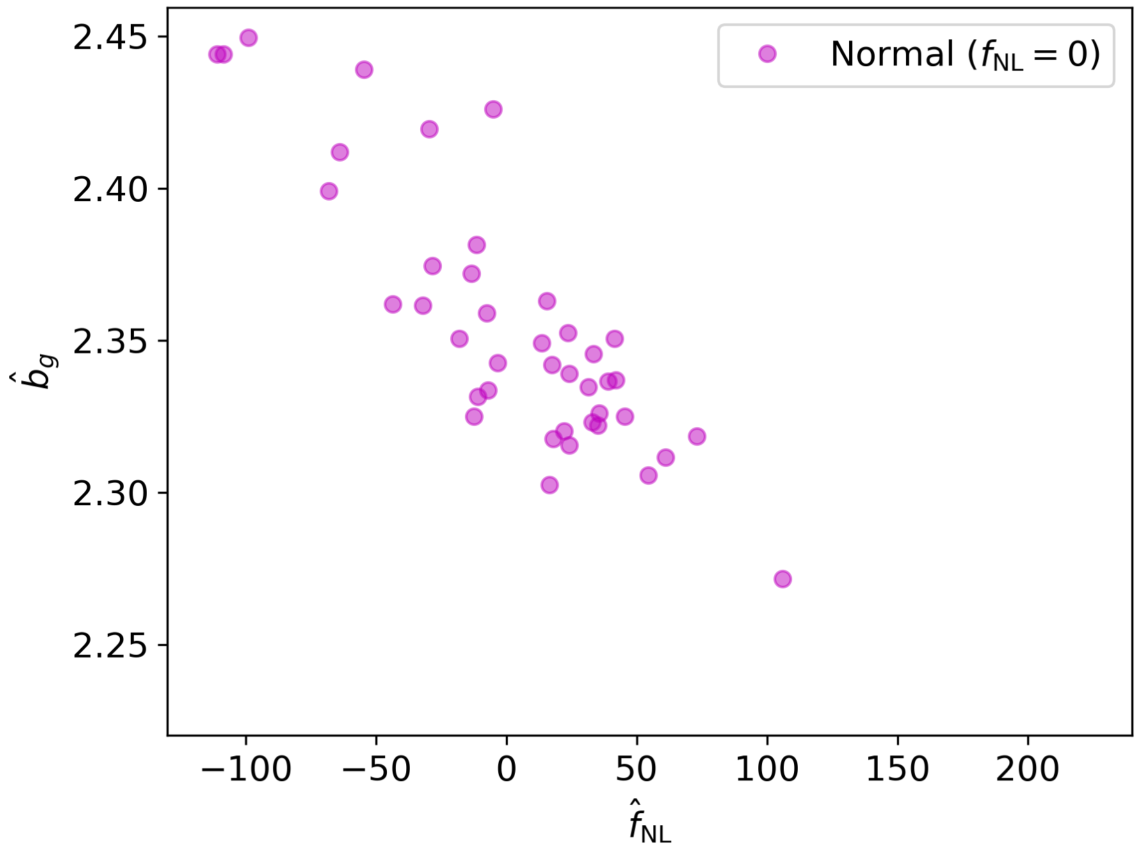
1.9 ± 47.0	111.4 ± 60.5



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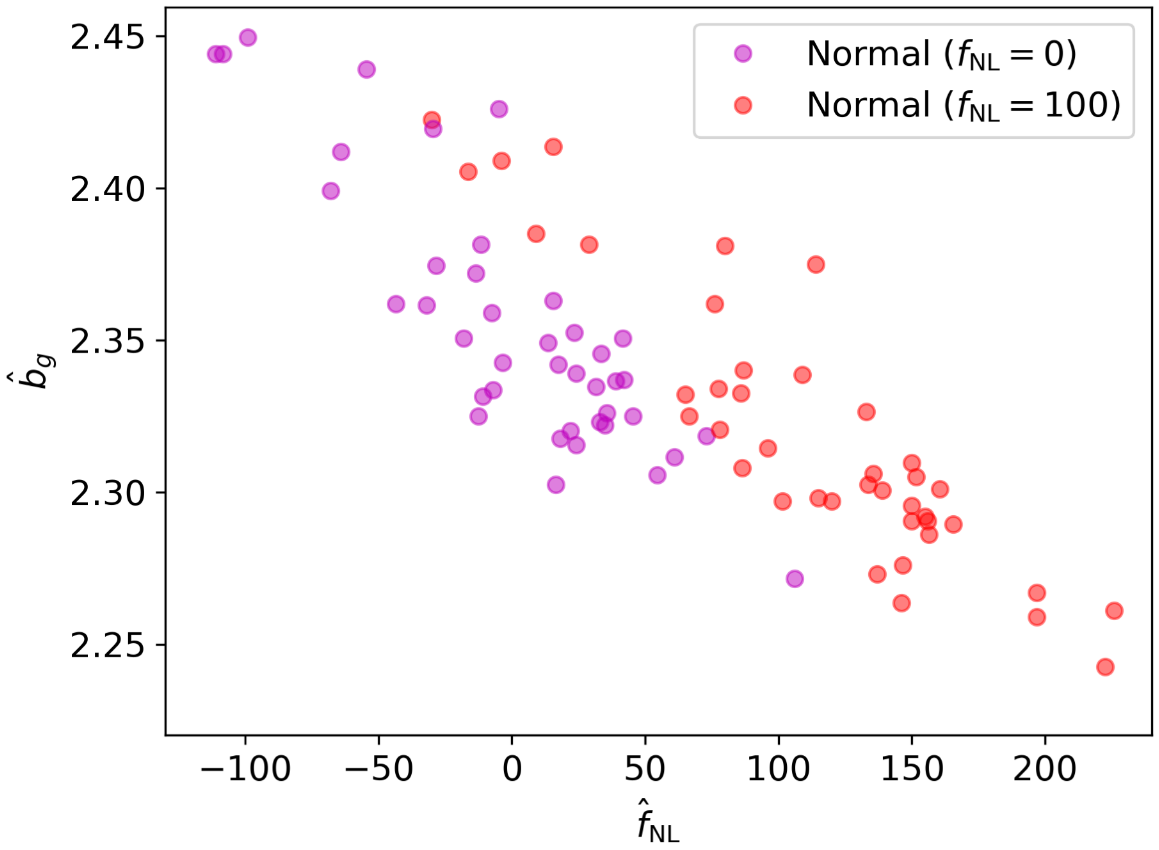

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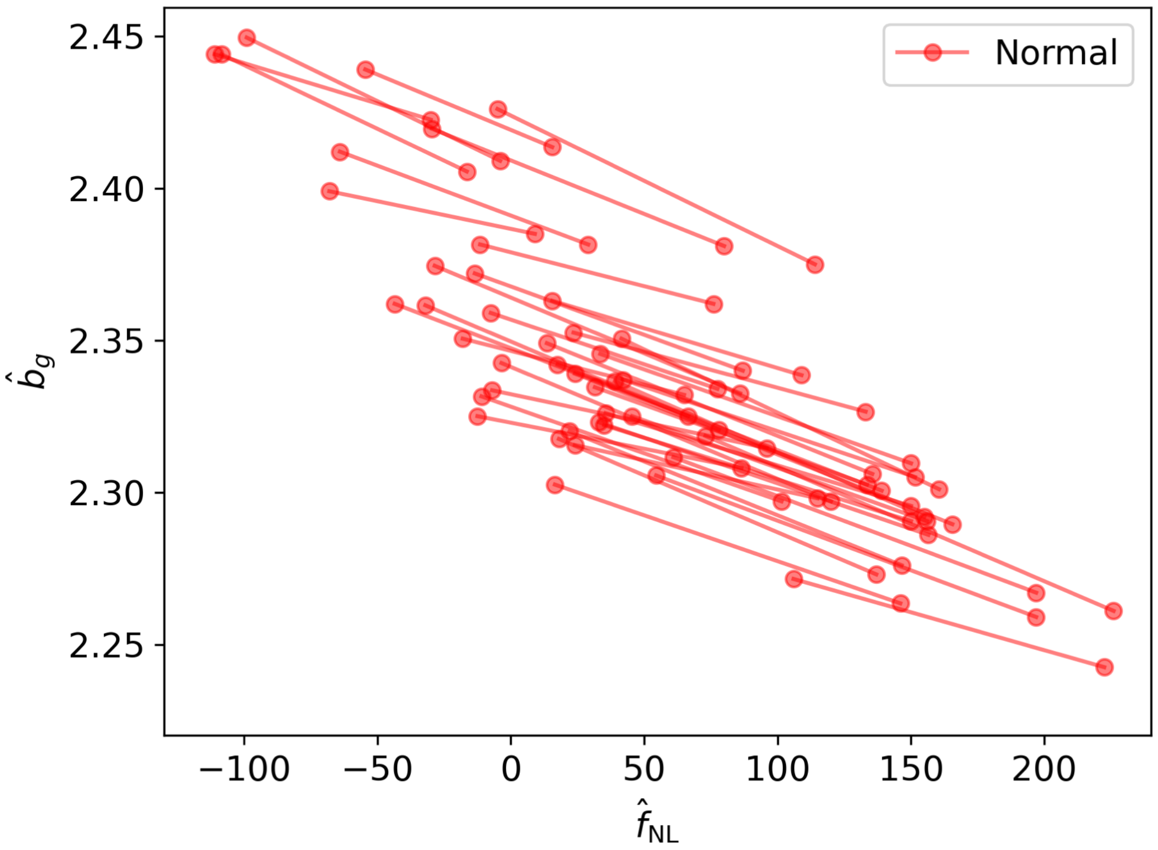

Matching: $$\Delta \hat{f}_{\rm NL} = \hat{f}_{\rm NL}^{100} - \hat{f}_{\rm NL}^{0}$$

$$\sigma(\Delta \hat{f}_{\rm NL})^2 = \sigma(\hat{f}_{\rm NL}^{100})^2 + \sigma(\hat{f}_{\rm NL}^{0})^2 - 2 \cdot \rho \cdot \sigma(\hat{f}_{\rm NL}^{100})\sigma(\hat{f}_{\rm NL}^{0})$$

Individual fits

<u>Matched</u>

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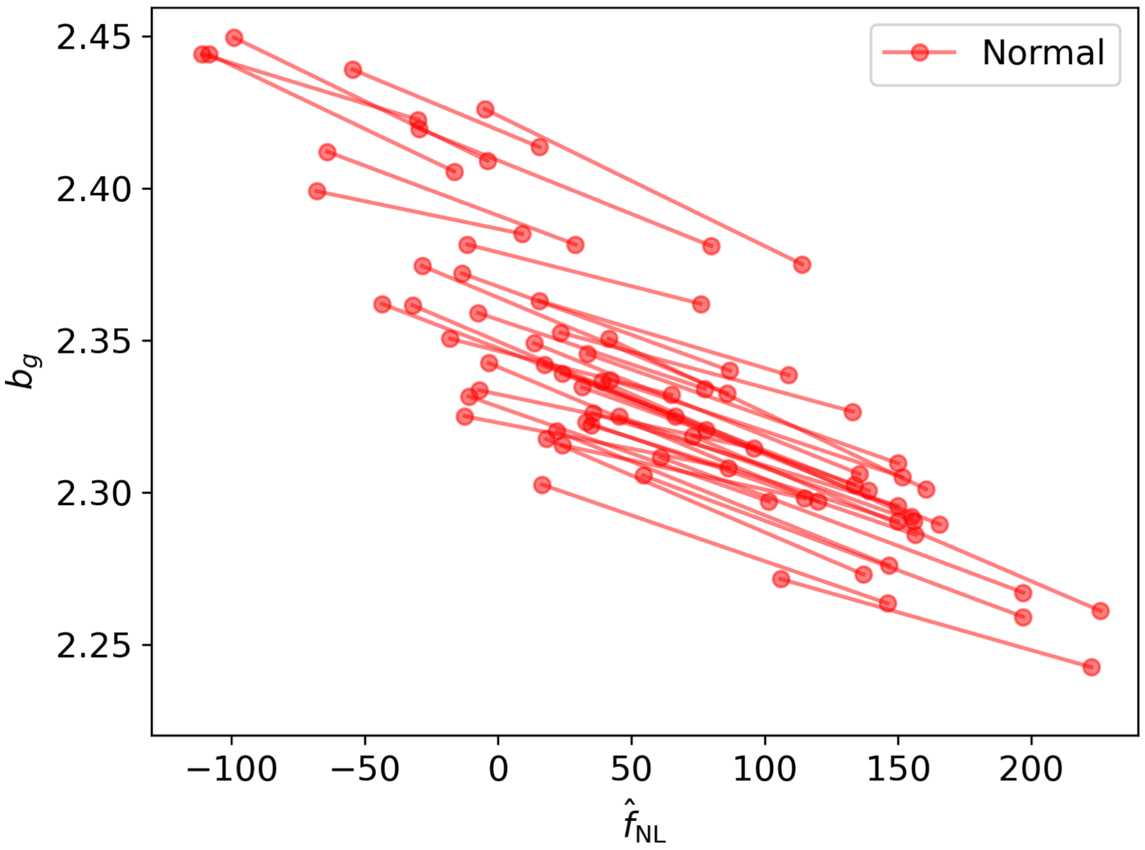
$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta\hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta\hat{f}_{\rm NL})$
1.9 ± 47.0	111.4 ± 60.5	109.5 ± 18.1



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ρ = 0.97

Individual fits

Matched

- Normal sims.

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$ 1.9 ± 47.0

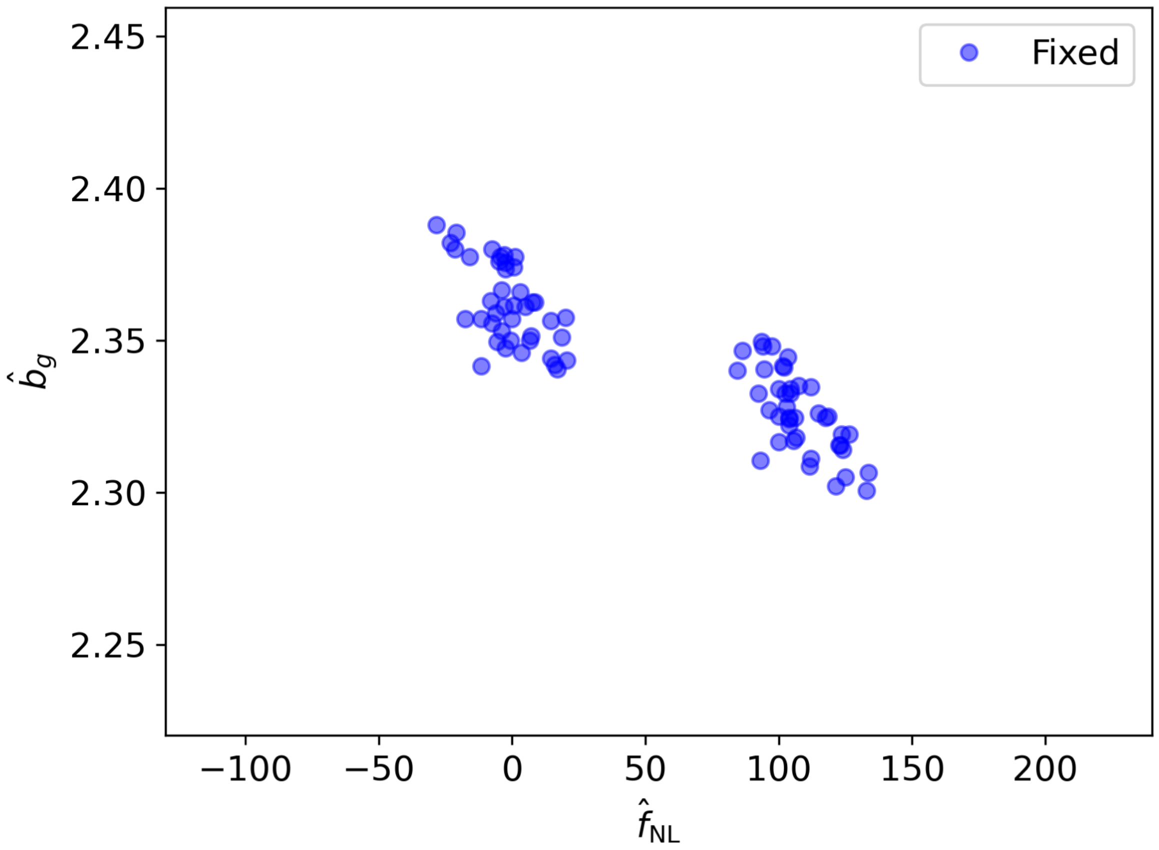
$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$ 111.4 ± 60.5

$\langle \Delta \hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta \hat{f}_{\rm NL})$ $\underline{109.5 \pm 18.1}$

- Fixed

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$ -1.3 ± 11.8

$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$ 107.6 ± 12.1



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Individual fits

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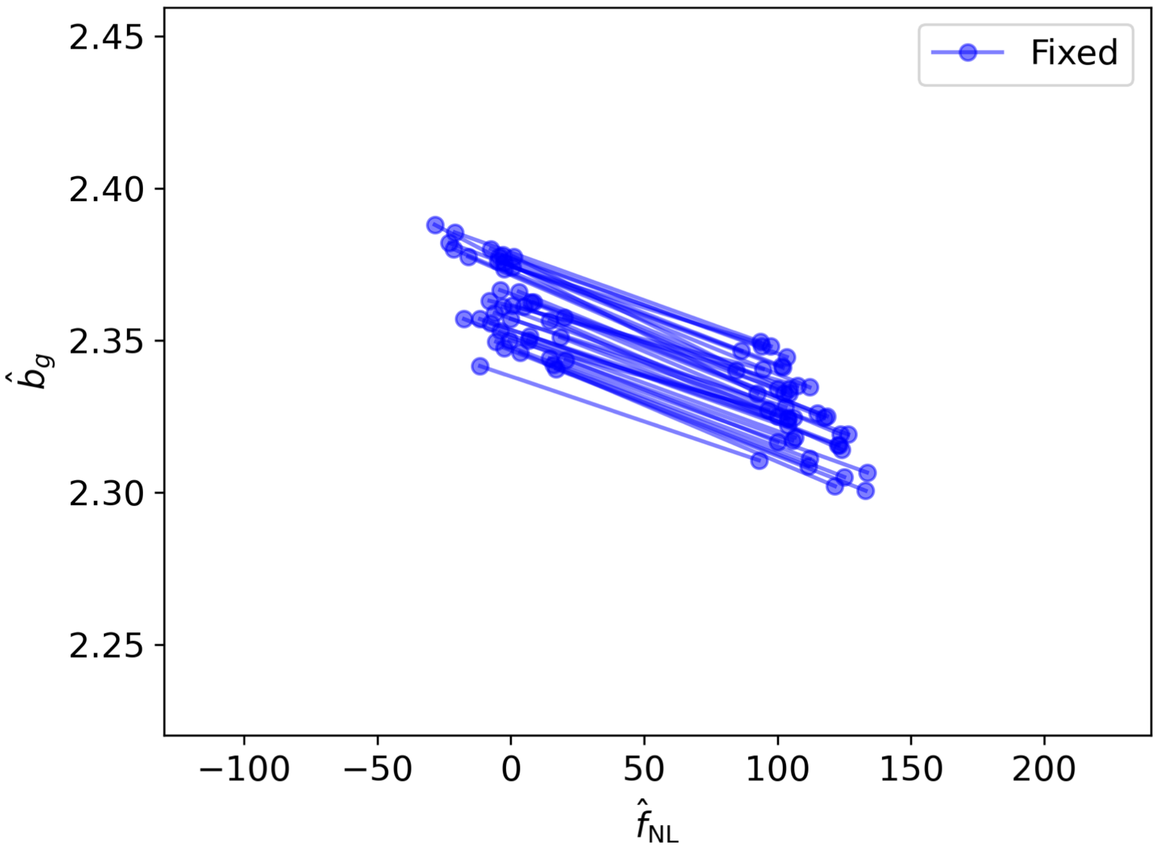
1.9 ± 47.0	111.4 ± 60.5	109.5 ± 18.1

- Fixed

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta\hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta\hat{f}_{\rm NL})$
-1.3 ± 11.8	107.6 ± 12.1	108.9 ± 8.3



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ρ = 0.97, 0.76

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$\langle \hat{f}_{\rm NL}^{\,100} \rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{\,100})$ 107.6 ± 12.1

Compensate the doubling of Volume

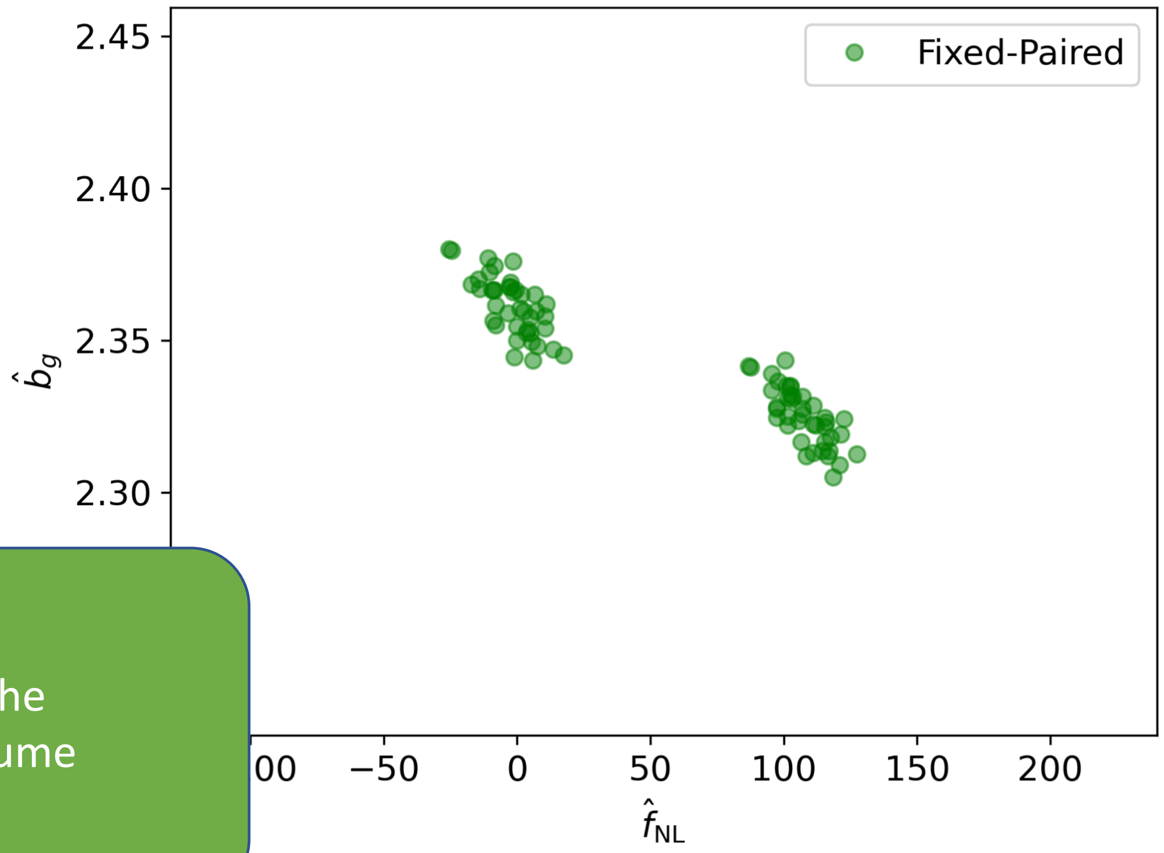
- Fixed-Paired

$\langle \hat{f}_{\rm NL}^{\,0} \rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{\,0})$ -1.8 ± 9.5

$\langle \hat{f}_{\rm NL}^{\,100} \rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{\,100})$ 107.4 ± 9.3

$\times\sqrt{2}$

± 13.5 ± 13.2



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ρ = 0.97, 0.76

Individual fits

<u>Matched</u>

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$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$ $\quad \langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$ $\quad \langle \Delta \hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta \hat{f}_{\rm NL})$

1.9 ± 47.0 $\quad 111.4 \pm 60.5$ $\quad \underline{109.5 \pm 18.1}$

- Fixed

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$ $\quad \langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$ $\quad \langle \Delta \hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta \hat{f}_{\rm NL})$

-1.3 ± 11.8 $\quad 107.6 \pm 12.1$ $\quad \underline{108.9 \pm 8.3}$

- Fixed-Paired

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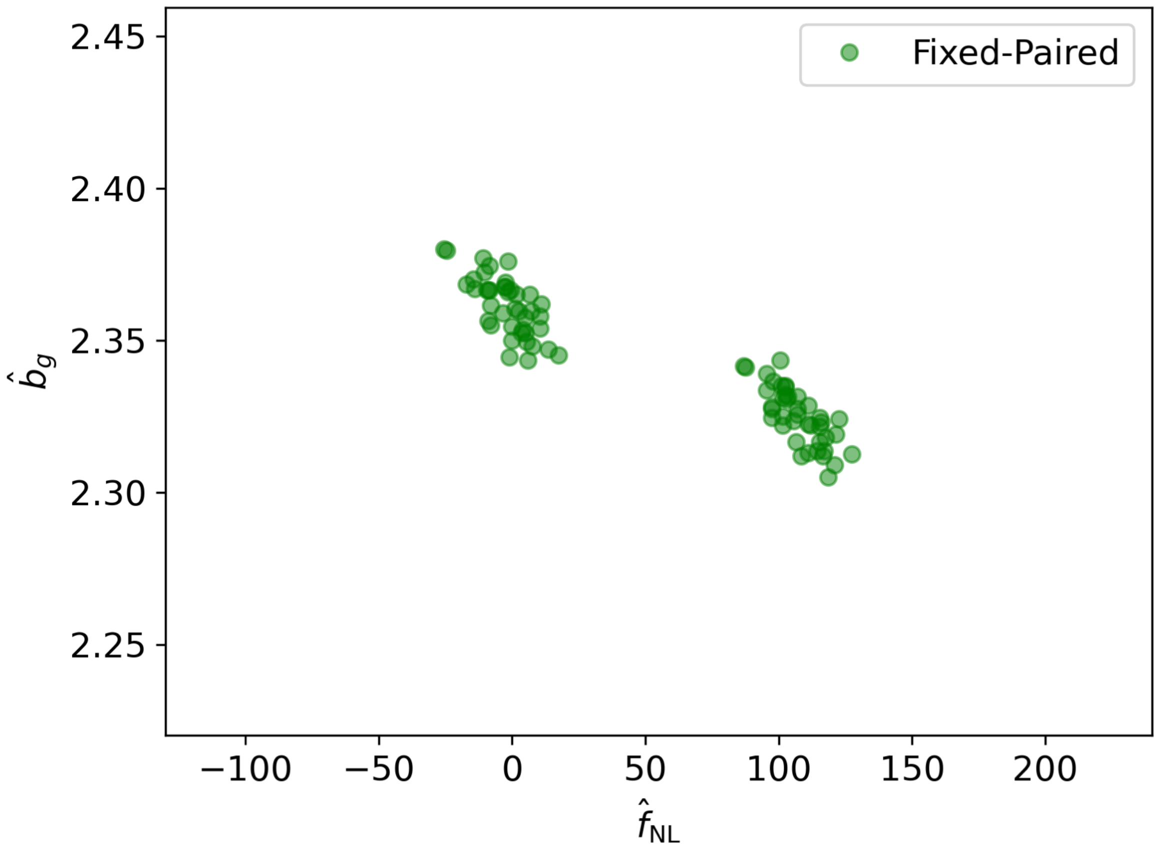
$\times\sqrt{2}$

± 13.5 $\quad \pm 13.2$

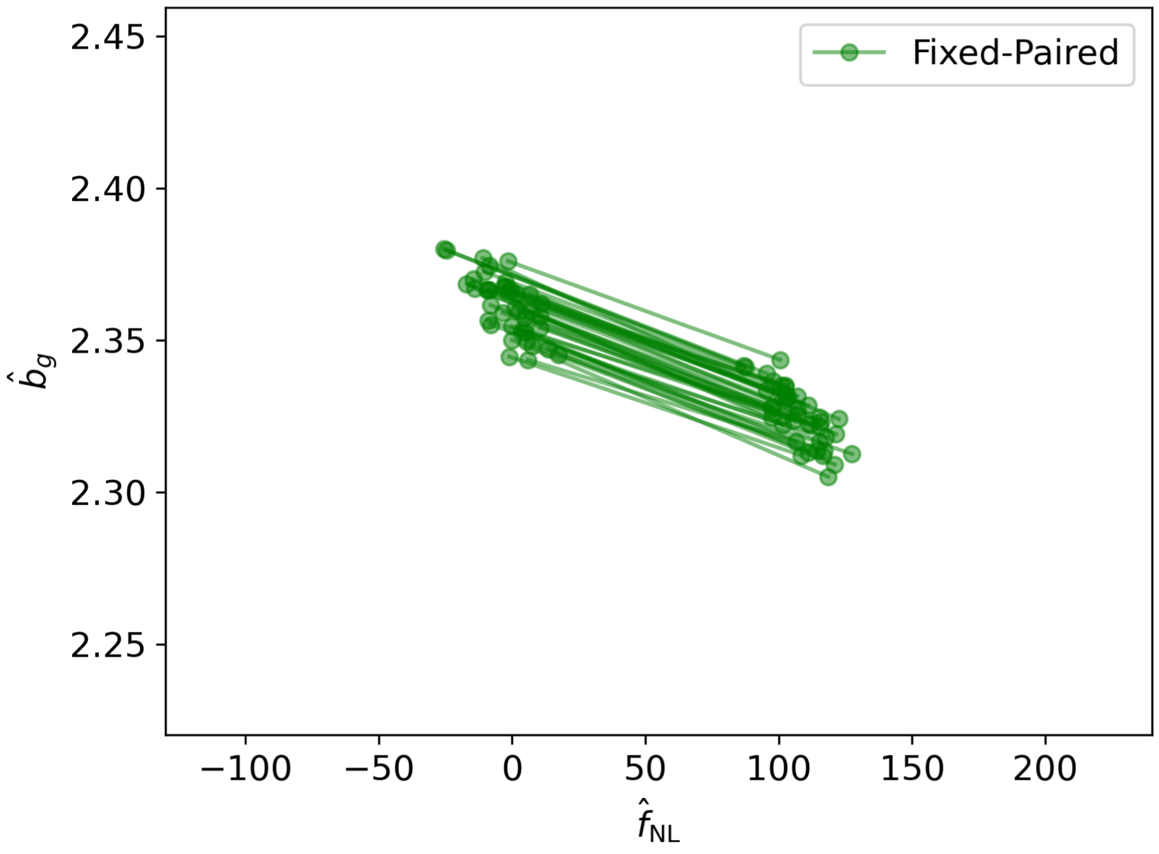


Matching: $\Delta \hat{f}_{\rm NL} = \hat{f}_{\rm NL}^{100} - \hat{f}_{\rm NL}^{0}$

$$\sigma(\Delta \hat{f}_{\rm NL})^2 = \sigma(\hat{f}_{\rm NL}^{100})^2 + \sigma(\hat{f}_{\rm NL}^{0})^2 - 2 \cdot \rho \cdot \sigma(\hat{f}_{\rm NL}^{100})\sigma(\hat{f}_{\rm NL}^{0})$$

ρ = 0.97, 0.76

Individual fits



Matched

- Normal sims.

$\langle \hat{f}^{0}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{NL})$ | $\langle \hat{f}^{100}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{NL})$ | $\langle \Delta\hat{f}_{NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{NL})$

1.9 ± 47.0 | 111.4 ± 60.5 | 109.5 ± 18.1

- Fixed

$\langle \hat{f}^{0}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{NL})$ | $\langle \hat{f}^{100}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{NL})$ | $\langle \Delta\hat{f}_{NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{NL})$

-1.3 ± 11.8 | 107.6 ± 12.1 | 108.9 ± 8.3

- Fixed-Paired

$\langle \hat{f}^{0}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{NL})$ | $\langle \hat{f}^{100}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{NL})$ | $\langle \Delta\hat{f}_{NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{NL})$

-1.8 ± 9.5 | 107.4 ± 9.3 | 109.2 ± 5.2

$\times\sqrt{2}$

± 13.5 | ± 13.2 | ± 7.3

Matching: $\Delta\hat{f}_{NL} = \hat{f}^{100}_{NL} - \hat{f}^{0}_{NL}$

$$\sigma(\Delta\hat{f}_{NL})^2 = \sigma(\hat{f}^{100}_{NL})^2 + \sigma(\hat{f}^{0}_{NL})^2 - 2\cdot\rho\cdot\sigma(\hat{f}^{100}_{NL})\sigma(\hat{f}^{0}_{NL})$$

ρ = 0.97, 0.76, 0.85

Individual fits

Matched

- Normal sims.

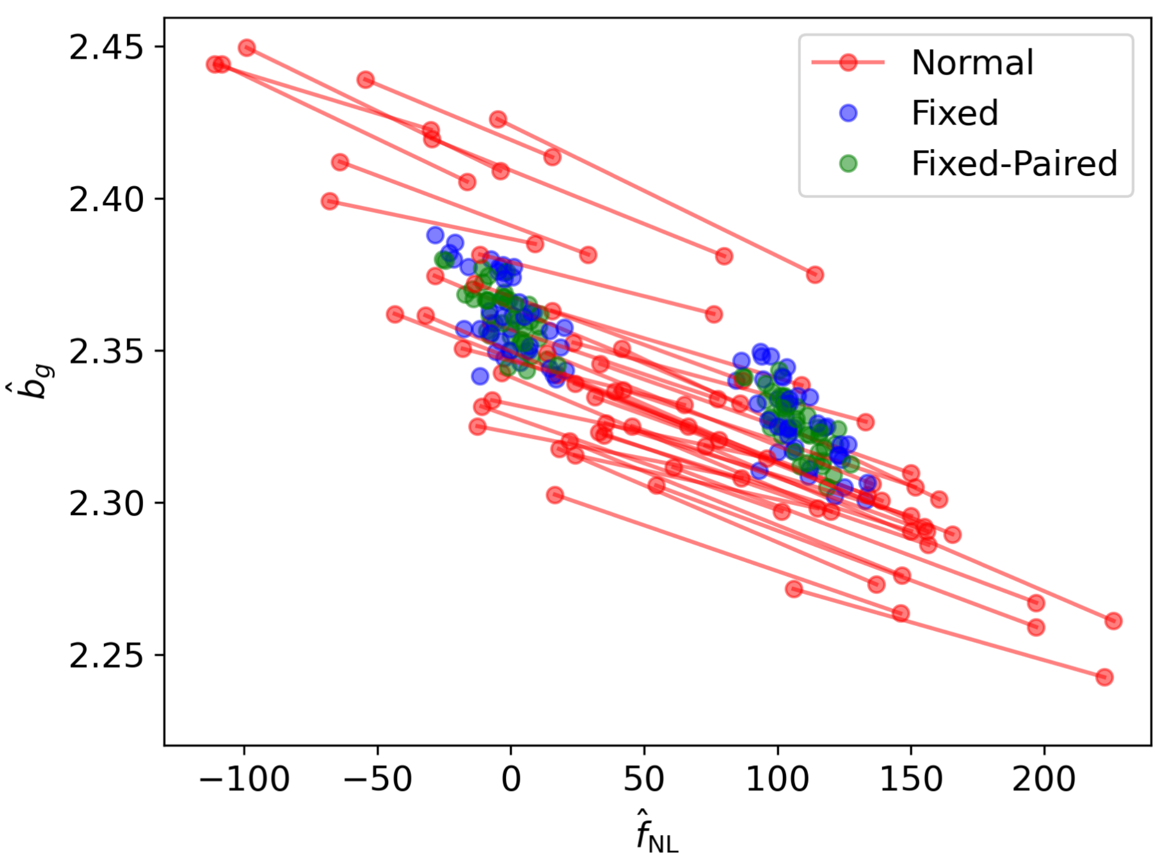
$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta\hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta\hat{f}_{\rm NL})$
1.9 ± 47.0	111.4 ± 60.5	109.5 ± 18.1

- Fixed

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta\hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta\hat{f}_{\rm NL})$
-1.3 ± 11.8	107.6 ± 12.1	108.9 ± 8.3

- Fixed-Paired

	$\langle \hat{f}_{\rm NL}^{0} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm {\rm std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta\hat{f}_{\rm NL} \rangle \pm {\rm std}(\Delta\hat{f}_{\rm NL})$
	-1.8 ± 9.5	107.4 ± 9.3	109.2 ± 5.2
$\times\sqrt{2}$	± 13.5	± 13.2	± 7.3



Matching: $$\Delta\hat{f}_{\rm NL} = \hat{f}_{\rm NL}^{100} - \hat{f}_{\rm NL}^{0}$$

$$\sigma(\Delta\hat{f}_{\rm NL})^2 = \sigma(\hat{f}_{\rm NL}^{100})^2 + \sigma(\hat{f}_{\rm NL}^{0})^2 - 2\cdot\rho\cdot\sigma(\hat{f}_{\rm NL}^{100})\sigma(\hat{f}_{\rm NL}^{0})$$

ρ = 0.97, 0.76, 0.85

Individual fits

<u>Matched</u>

- Normal sims.

$\langle \hat f_{\rm NL}^{0}\rangle \pm {\rm std}(\hat f_{\rm NL}^{0})$ $\langle \hat f_{\rm NL}^{100}\rangle \pm {\rm std}(\hat f_{\rm NL}^{100})$ $\langle \Delta \hat f_{\rm NL}\rangle \pm {\rm std}(\Delta \hat f_{\rm NL})$

1.9 ± 47.0 111.4 ± 60.5 109.5 ± 18.1

- Fixed

$\langle \hat f_{\rm NL}^{0}\rangle \pm {\rm std}(\hat f_{\rm NL}^{0})$ $\langle \hat f_{\rm NL}^{100}\rangle \pm {\rm std}(\hat f_{\rm NL}^{100})$ $\langle \Delta \hat f_{\rm NL}\rangle \pm {\rm std}(\Delta \hat f_{\rm NL})$

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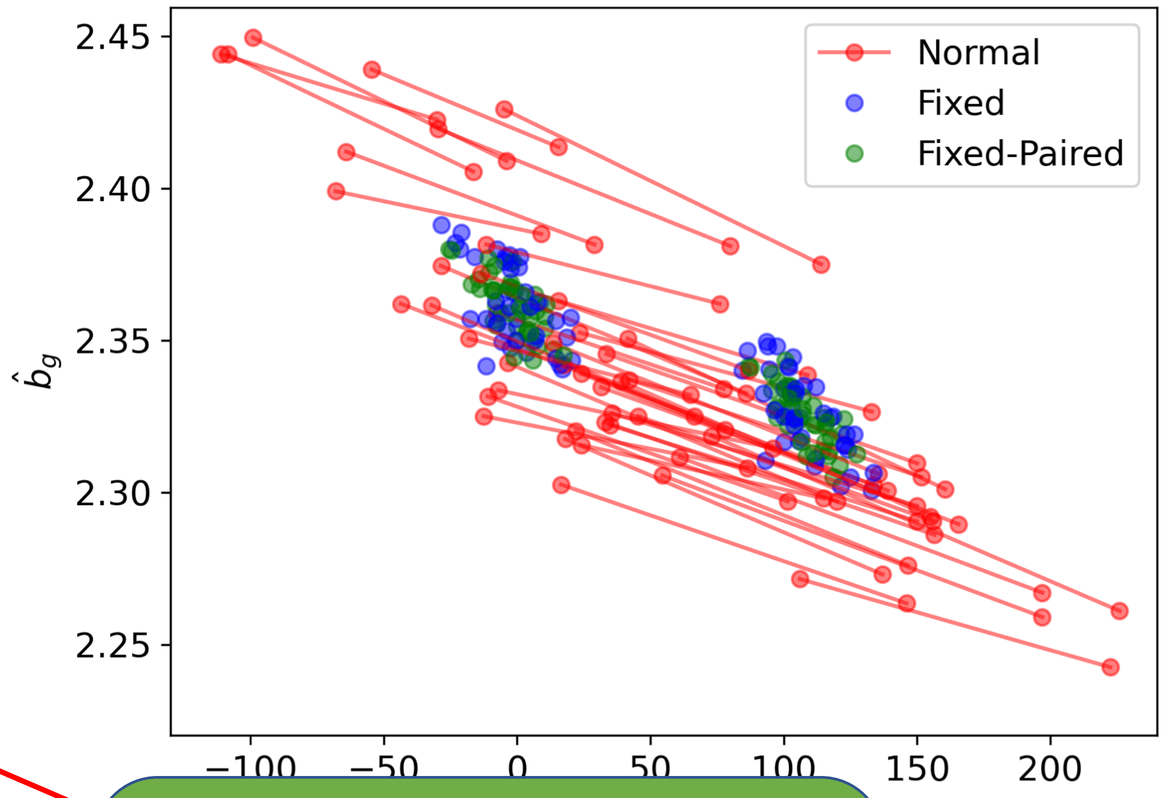
- Fixed-Paired

$\langle \hat f_{\rm NL}^{0}\rangle \pm {\rm std}(\hat f_{\rm NL}^{0})$ $\langle \hat f_{\rm NL}^{100}\rangle \pm {\rm std}(\hat f_{\rm NL}^{100})$ $\langle \Delta \hat f_{\rm NL}\rangle \pm {\rm std}(\Delta \hat f_{\rm NL})$

-1.8 ± 9.5 107.4 ± 9.3 109.2 ± 5.2

$\times\sqrt{2}$ ± 13.5 ± 13.2 ± 7.3



Equivalent to running 70 simulations
(w.r.t. normal unmatched)

$- \hat f_{\rm NL}^{0}$

$\sigma(\hat f_{\rm NL}^{100})\sigma(\hat f_{\rm NL}^{0})$

ρ = 0.97, 0.76, 0.85

Individual fits

Matched

One pair is enough to hint us a ~2σ deviation from the assumed model:
- Universality Halo Mass Function
- Dalal+2008, or
- Slosar+2008 with p=1
(deviations expected)

$\pm\ \mathrm{std}(\Delta \hat{f}_{\rm NL})$

$\pm\ 18.1$

$\pm\ \mathrm{std}(\Delta \hat{f}_{\rm NL})$

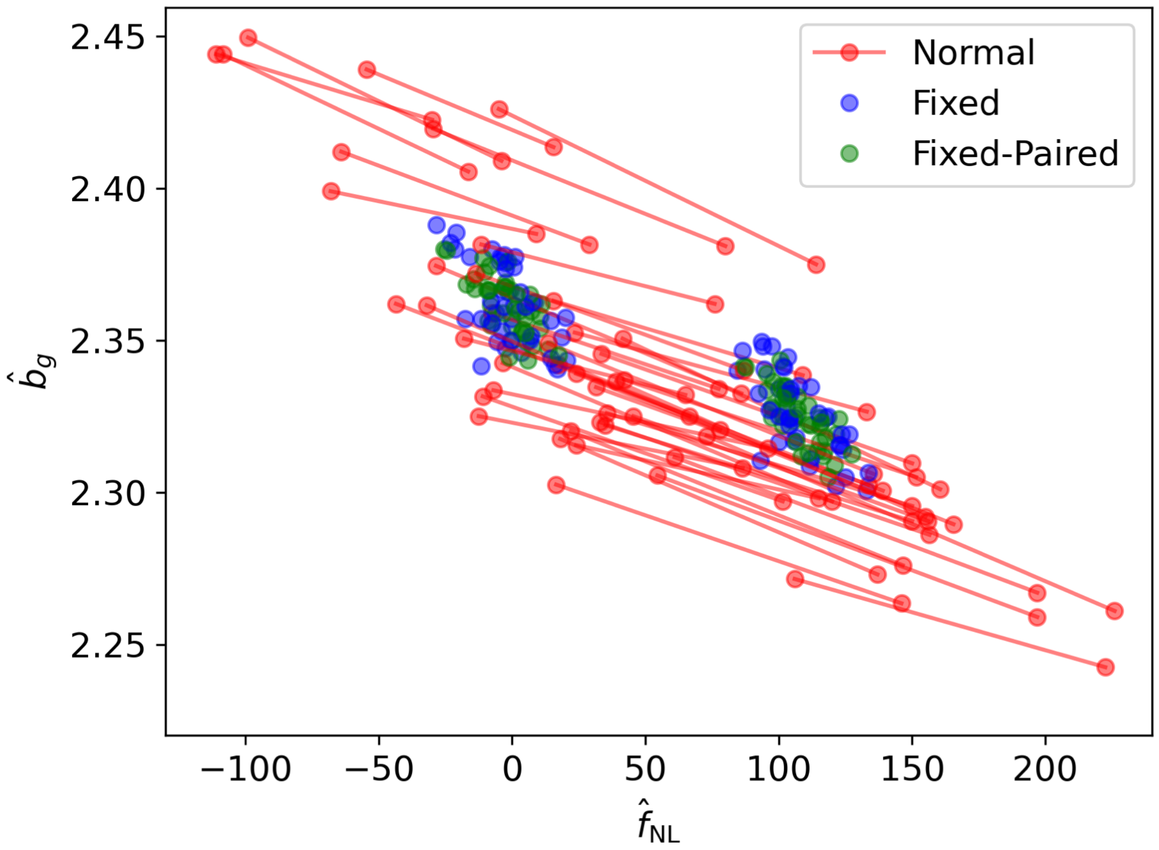
$\pm\ 8.3$

- Fixed-Paired

$\langle \hat{f}_{\rm NL}^{0} \rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{0})$	$\langle \hat{f}_{\rm NL}^{100} \rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{100})$	$\langle \Delta \hat{f}_{\rm NL} \rangle \pm \mathrm{std}(\Delta \hat{f}_{\rm NL})$
-1.8 ± 9.5	107.4 ± 9.3	$\boxed{109.2 \pm 5.2}$

$\times\sqrt{2}$

± 13.5	± 13.2	± 7.3

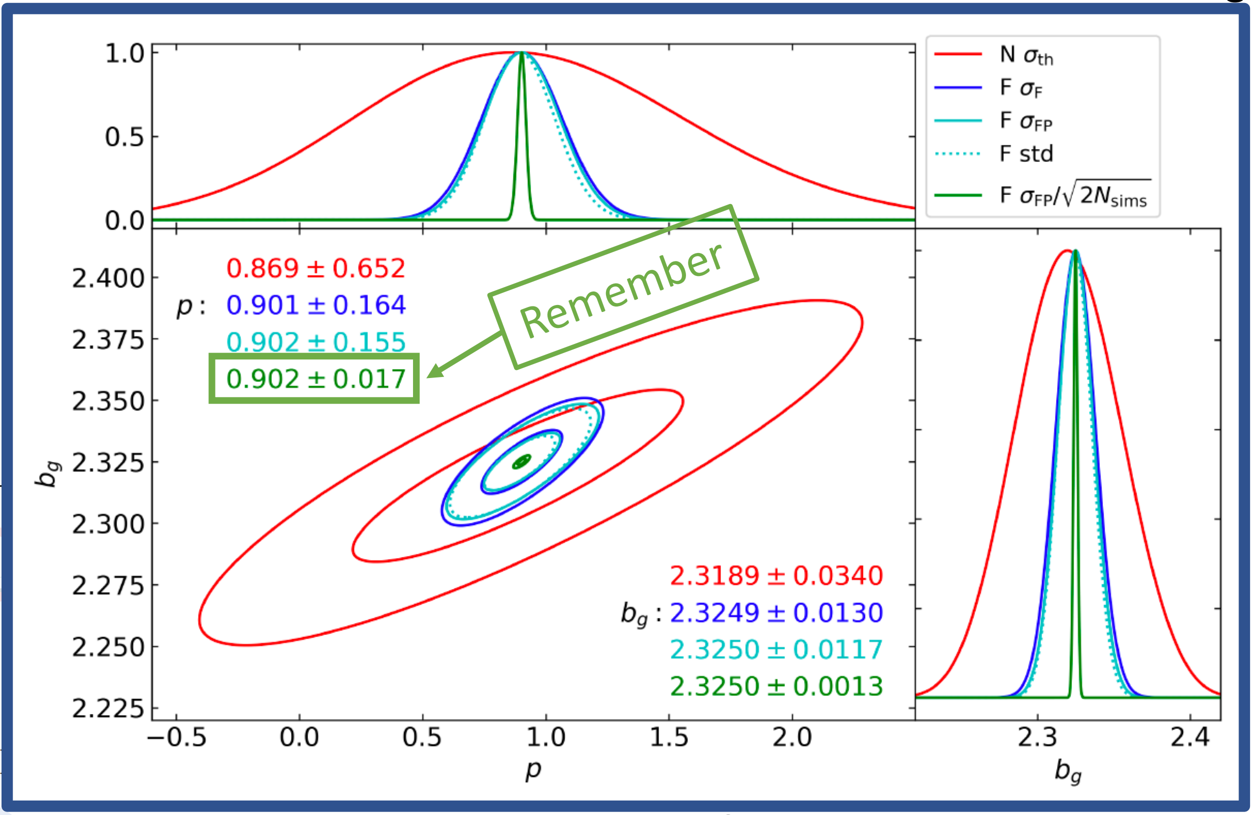


Matching: $$\Delta \hat{f}_{\rm NL} = \hat{f}_{\rm NL}^{100} - \hat{f}_{\rm NL}^{0}$$

$$\sigma(\Delta \hat{f}_{\rm NL})^2 = \sigma(\hat{f}_{\rm NL}^{100})^2 + \sigma(\hat{f}_{\rm NL}^{0})^2 - 2\cdot\rho\cdot\sigma(\hat{f}_{\rm NL}^{100})\sigma(\hat{f}_{\rm NL}^{0})$$

$\rho = 0.97,\ 0.76,\ 0.85$

Individual fits



Matched

$\pm$ std$(\Delta\hat{f}_{\rm NL}$

± 18.1

$\pm$ std$(\Delta\hat{f}_{\rm NL}$

± 8.3

$\hat{f}_{\rm NL}$

One pair is enough to hint us a ~2σ deviation from the assumed model:

- Universality Halo Mass Function
- Dalal+2008, or
- Slosar+2008 with p=1

(deviations expected)

- Fixed-Paired

Matching: $$\Delta\hat{f}_{\rm NL} = \hat{f}_{\rm NL}^{100} - \hat{f}_{\rm NL}^{0}$$

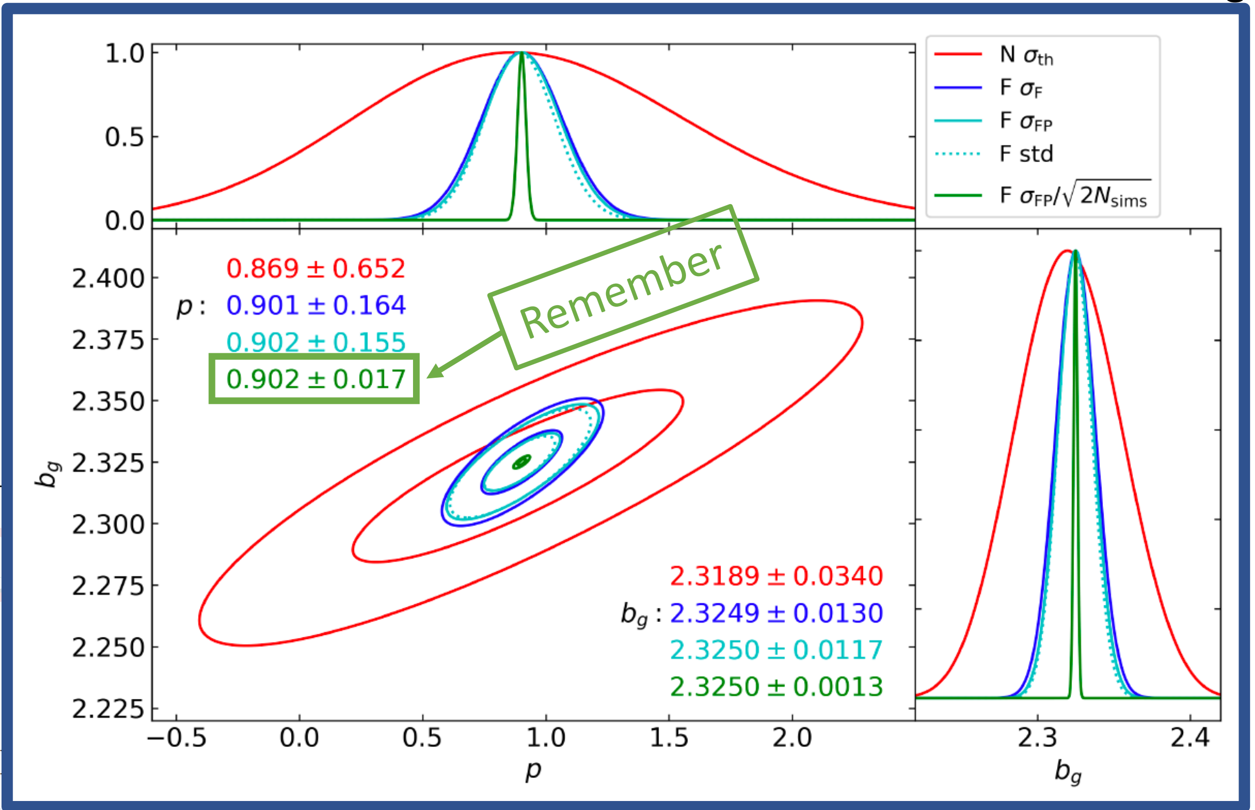
$\langle\hat{f}_{\rm NL}^{0}\rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{0})$	$\langle\hat{f}_{\rm NL}^{100}\rangle \pm \mathrm{std}(\hat{f}_{\rm NL}^{100})$	$\langle\Delta\hat{f}_{\rm NL}\rangle \pm \mathrm{std}(\Delta\hat{f}_{\rm NL})$
-1.8 ± 9.5	107.4 ± 9.3	$\boxed{109.2 \pm 5.2}$
± 13.5	± 13.2	± 7.3

$\times\sqrt{2}$

$$\sigma(\Delta\hat{f}_{\rm NL})^2 = \sigma(\hat{f}_{\rm NL}^{100})^2 + \sigma(\hat{f}_{\rm NL}^{0})^2 - 2\cdot\rho\cdot\sigma(\hat{f}_{\rm NL}^{100})\sigma(\hat{f}_{\rm NL}^{0})$$

$\rho = 0.97,\ 0.76,\ 0.85$

Individual fits



Matched

One pair is enough to hint us a ~2σ deviation from the assumed model:
- Universality Halo Mass Function
- Dalal+2008, or
- Slosar+2008 with p=1

(deviations expected)

$\pm$ std$(\Delta \hat{f}_{NL})$

± 18.1

$\pm$ std$(\Delta \hat{f}_{NL})$

± 8.3

With use p=0.902, we unbiased results $f_{NL} = 101.7 \pm 4.8$

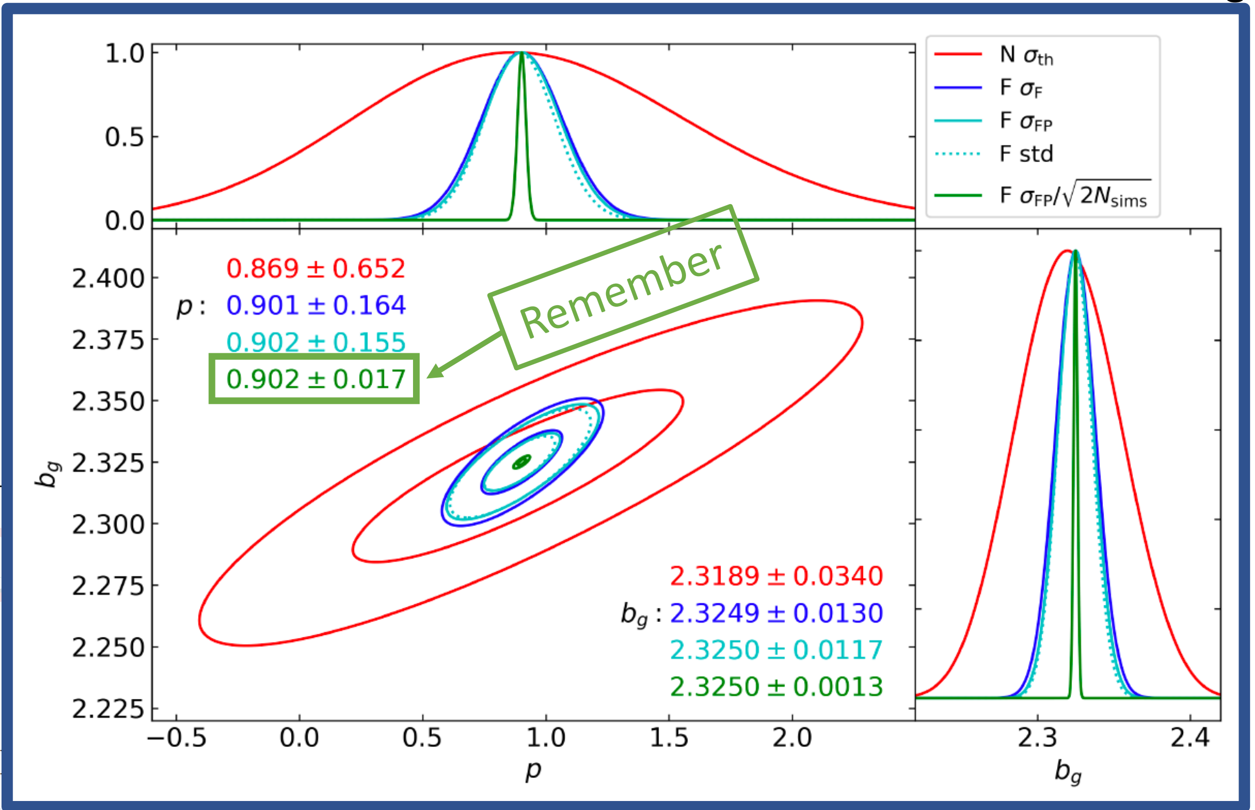
- Fixed-Paired

$\langle \hat{f}^{0}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{NL})$	$\langle \hat{f}^{100}_{NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{NL})$	$\langle \Delta \hat{f}_{NL} \rangle \pm \mathrm{std}(\Delta \hat{f}_{NL})$
-1.8 ± 9.5	107.4 ± 9.3	109.2 ± 5.2
$\times\sqrt{2}$ ± 13.5	± 13.2	± 7.3

$$\sigma(\Delta \hat{f}_{NL})^2 = \sigma(\hat{f}^{100}_{NL})^2 + \sigma(\hat{f}^{0}_{NL})^2 - 2 \cdot \rho \cdot \sigma(\hat{f}^{100}_{NL})\sigma(\hat{f}^{0}_{NL})$$

ρ = 0.97, 0.76, 0.85

Individual fits



Matched

One pair is enough to hint us a ~2σ deviation from the assumed model:

- Universality Halo Mass Function
- Dalal+2008, or
- Slosar+2008 with p=1

(deviations expected)

$\pm\,\mathrm{std}(\Delta\hat{f}_{\mathrm{NL}})$

$\pm\,18.1$

$\pm\,\mathrm{std}(\Delta\hat{f}_{\mathrm{NL}})$

$\pm\,8.3$

- Fixed-Paired

$\langle \hat{f}_{\mathrm{NL}}^{\,0}\rangle \pm \mathrm{std}(\hat{f}_{\mathrm{NL}}^{\,0})$	$\langle \hat{f}_{\mathrm{NL}}^{\,100}\rangle \pm \mathrm{std}(\hat{f}_{\mathrm{NL}}^{\,100})$	$\langle \Delta\hat{f}_{\mathrm{NL}}\rangle \pm \mathrm{std}(\Delta\hat{f}_{\mathrm{NL}})$
-1.8 ± 9.5	107.4 ± 9.3	109.2 ± 5.2
± 13.5	± 13.2	± 7.3

$\times\sqrt{2}$

With use p=0.902, we unbiased results

$$f_{\mathrm{NL}} = 101.7 \pm 4.8$$

Or we can reverse the fit, to obtain the PNG response:

$$\hat{p} = \hat{b}_g - (\hat{b}_g - 1)\frac{\hat{f}_{\mathrm{NL}}}{f_{\mathrm{NL}}^{\mathrm{true}}}$$

$$\hat{p} = 0.88 \pm 0.07$$

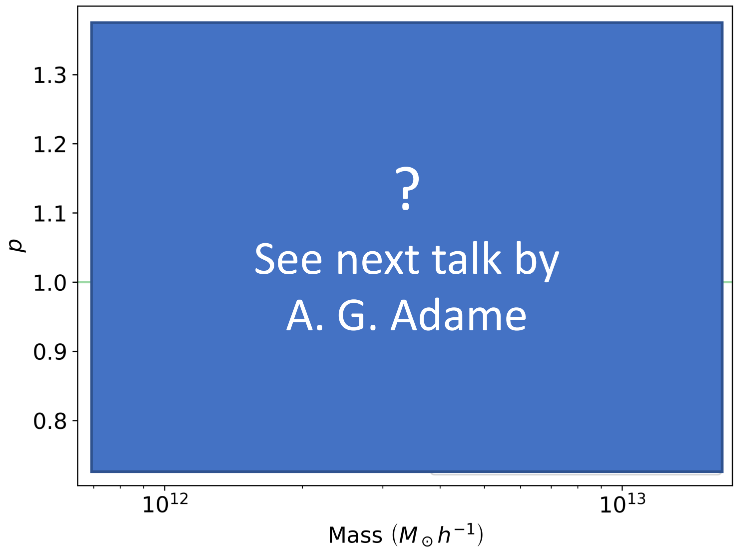
PNG-UNITsim

In collab. with A.G. Adame, G. Yepes, V. Gonzalez-Perez, M. Pellejero, J. Garcia-Bellido et al.

- Same properties as UNITsim:
  - L=1Gpc/h, N=4096^3, m_p=1.2 x10^9 M_{sun}/h
  - Fixed
  - Gadget, Rockstar, MergerTrees
- Re-run :
  - UNITsim1 **f_{NL}=100** to z=0
  - UNITsim2 f_{NL} =-20 to z=1
- Also new FastPMs:
  - N=2048^3, L=1 Gpc/h
  - f_{NL}=100 & f_{NL}=0
  - x 100 realisations
  - Fixed

Currently, under investigation

Could be made immediately available



$$b(k) = b_g + 2\delta_c(b_g - p)\cdot f_{\rm NL}\cdot\frac{1}{\alpha(k,z)}$$

We expect to put priors on *p(M)*, equivalent to an uncertainty of σ(f_{NL})~5

We also plan to run SAMs to know the *p* for different tracers

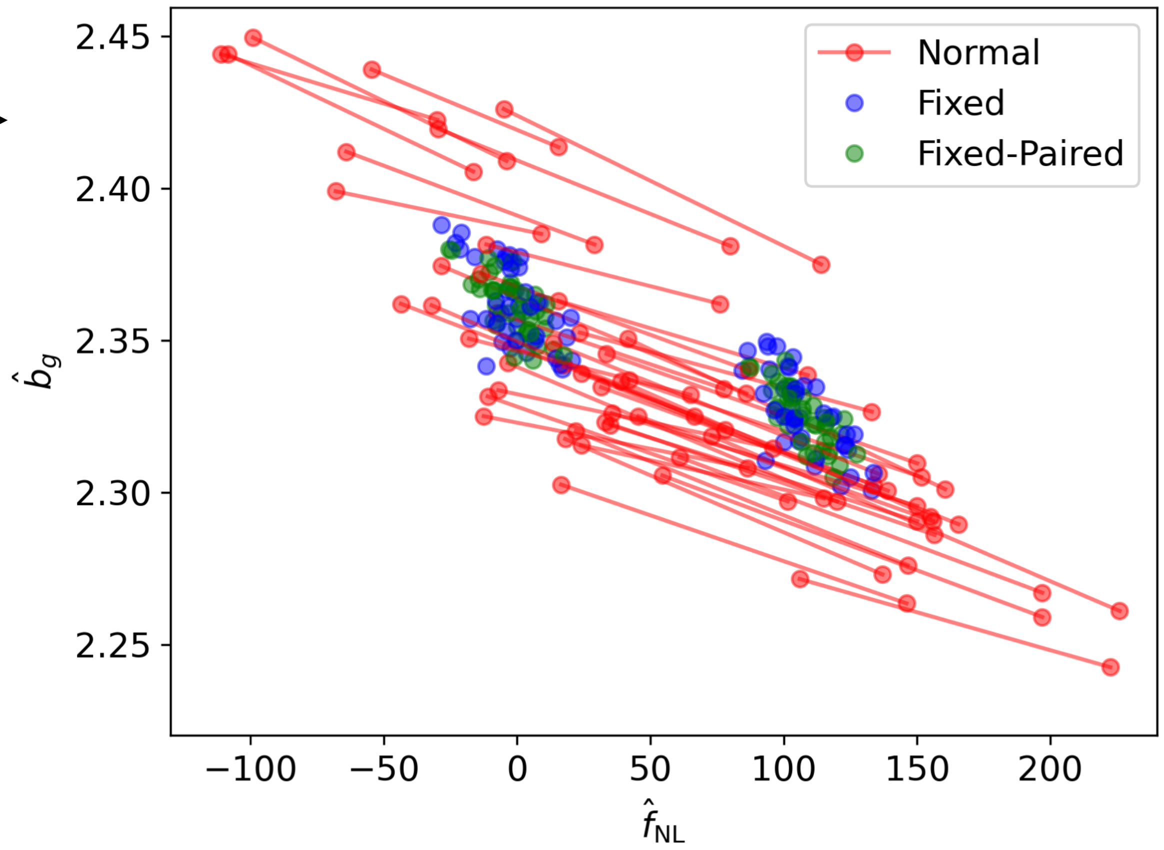
See [Knebe, Lopez-Cano, **SA** et al. 2022 MNRAS 510 5391]

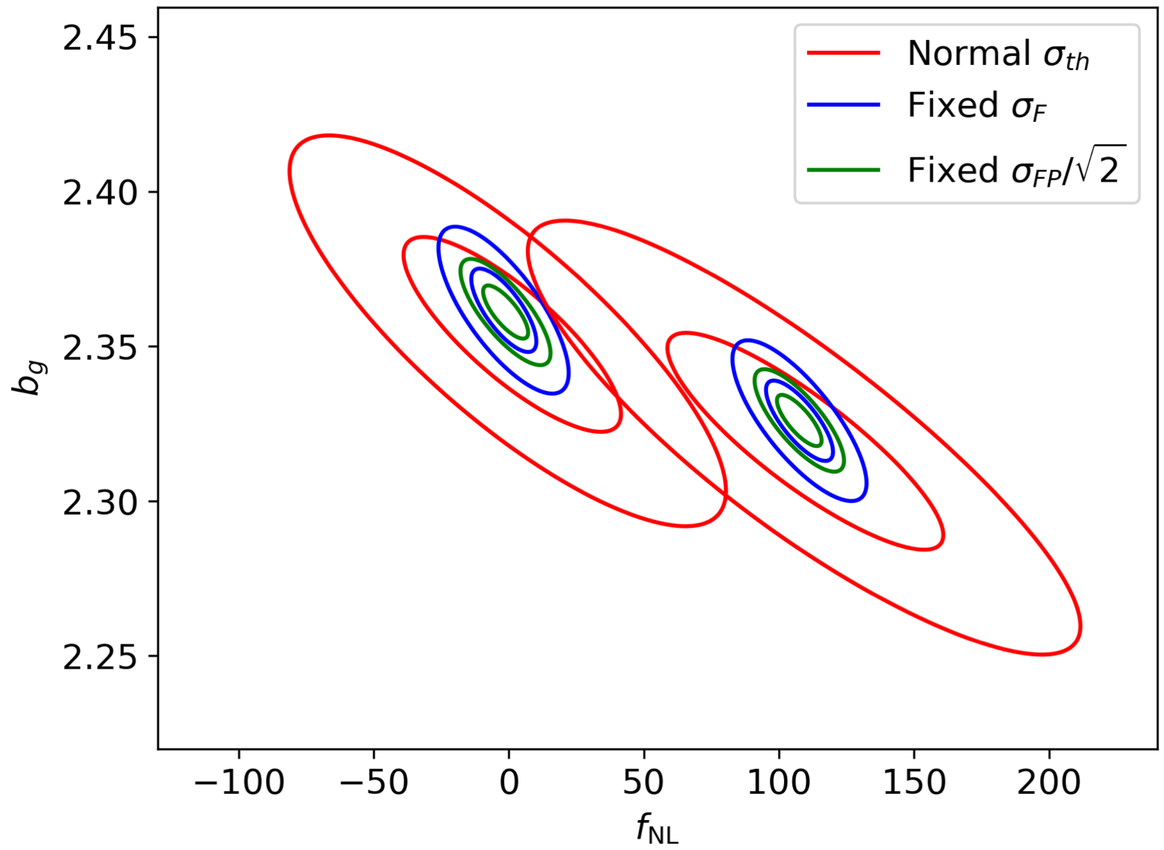
Take-home messages

- *Fixing* for local PNG:
  - Gives unbiased halo P(k)
  - Greatly reduces the σ(P(k))
- *Fixing* reduces $\sigma(f_{NL})$ by a factor ~5
- *Matching*-ICs (and explicitly using their correlation) reduces $\sigma(f_{NL})$ by a factor
  - ~ 3 For *Normal* simulations
  - ~2 for *Fixed-Paired* simulations
- One couple of *Fixed-Paired-Matched* L = 1 Gpc/h simulations can give us $\sigma(f_{NL})$ =5
  - Comparable with Euclid/DESI
  - Motivation for PNG-UNITsim (V=2 x1 $[\mathrm{Gpc}/h]^3$, V_{eff}~140 $[\mathrm{Gpc}/h]^3$)

Additional Slides

Individual fits

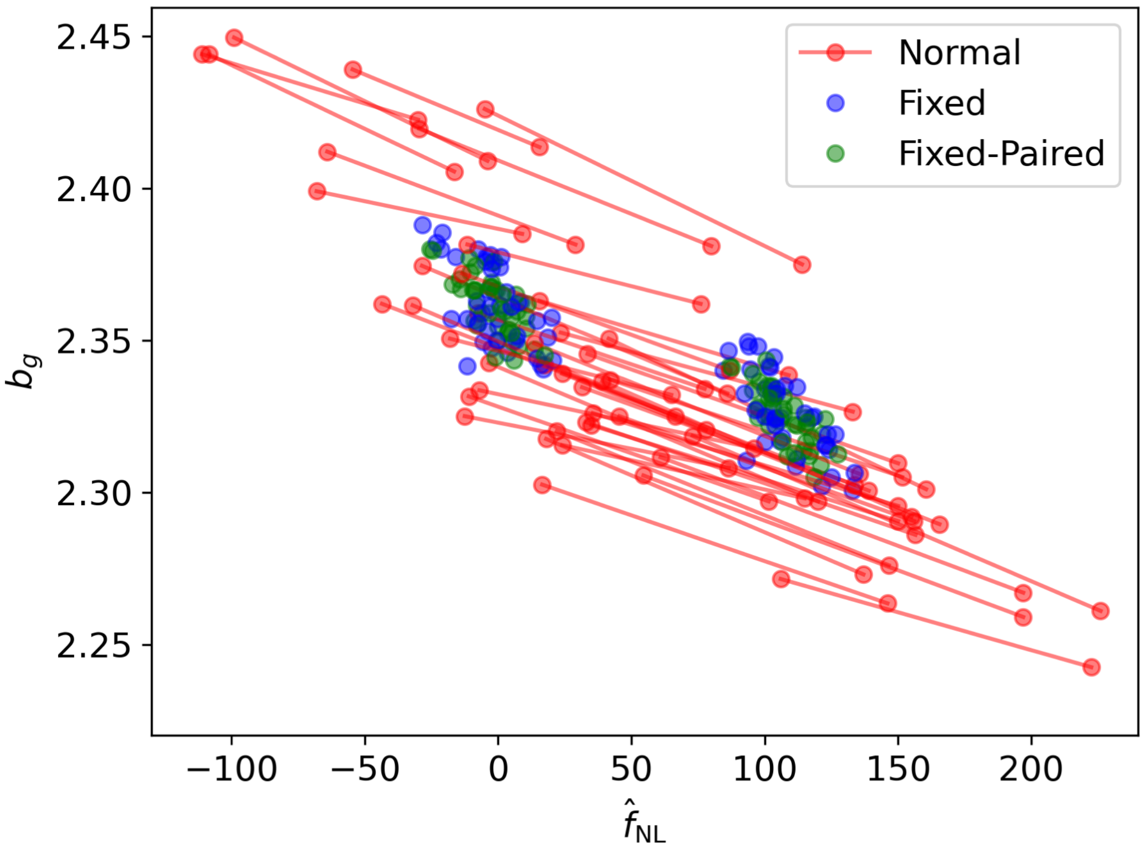




Fit on the mean

2204.11103 Avila & Adame

Individual fits



Matched

- Normal sims.

$\langle \hat{f}^{0}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{\rm NL})$ | $\langle \hat{f}^{100}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{\rm NL})$ | $\langle \Delta\hat{f}_{\rm NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{\rm NL})$

1.9 ± 47.0 | 111.4 ± 60.5 | 109.5 ± 18.1

- Fixed

$\langle \hat{f}^{0}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{\rm NL})$ | $\langle \hat{f}^{100}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{\rm NL})$ | $\langle \Delta\hat{f}_{\rm NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{\rm NL})$

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- Fixed-Paired

$\langle \hat{f}^{0}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{0}_{\rm NL})$ | $\langle \hat{f}^{100}_{\rm NL} \rangle \pm \mathrm{std}(\hat{f}^{100}_{\rm NL})$ | $\langle \Delta\hat{f}_{\rm NL} \rangle \pm \mathrm{std}(\Delta\hat{f}_{\rm NL})$

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$\times\sqrt{2}$

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Matching: $$\Delta\hat{f}_{\rm NL} = \hat{f}^{100}_{\rm NL} - \hat{f}^{0}_{\rm NL}$$

$$\sigma(\Delta\hat{f}_{\rm NL})^2 = \sigma(\hat{f}^{100}_{\rm NL})^2 + \sigma(\hat{f}^{0}_{\rm NL})^2 - 2\cdot\rho\cdot\sigma(\hat{f}^{100}_{\rm NL})\sigma(\hat{f}^{0}_{\rm NL})$$

ρ = 0.97, 0.76, 0.85

2204.11103 – S. Avila

Variance of the halo power spectrum

- Similar reduction between

  $f_{\mathrm{NL}} = 0$ and $f_{\mathrm{NL}} = 100$

- Ratio w.r.t. Normal Gaussian error

$$\sigma_{\mathrm{th}}(k)^2 = \frac{4\pi^2}{V\ k^2\ \Delta k}\left(P(k) + \frac{1}{n}\right)^2$$

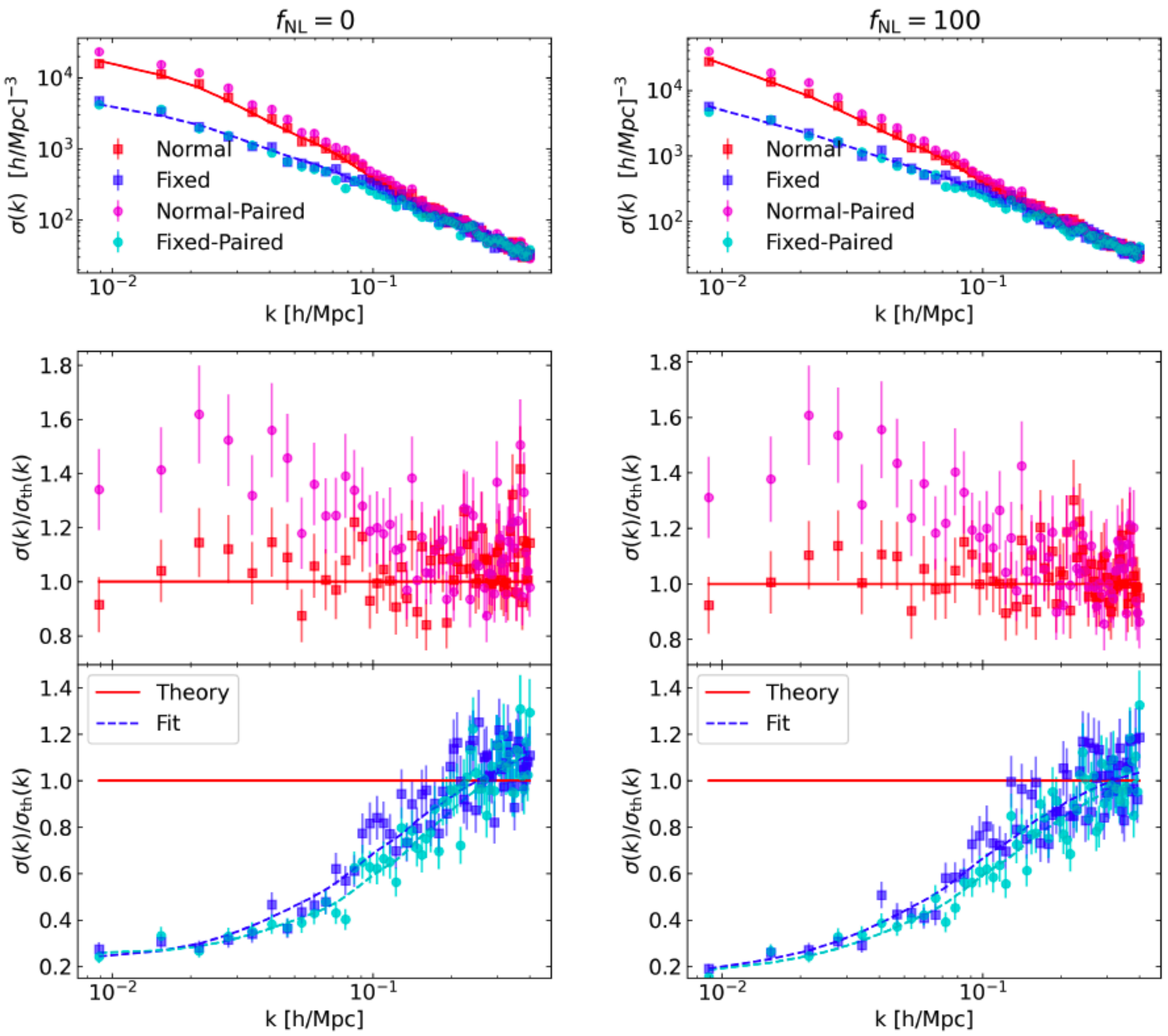
- Pairing:

$$P_{\mathrm{Paired,i}}(k) = \frac{1}{2}\left(P_{\varphi_i}(k) + P_{\varphi_i+\pi}(k)\right)$$

$$\sigma_{\mathrm{Paired}} = \sqrt{2}\cdot \mathrm{std}\left(\frac{1}{2}\left(P_{\varphi_i}(k) + P_{\varphi_i+\pi}(k)\right)\right)$$

- Fit for Fixed (& Paired)

$$\sigma_{\mathrm{r}}(k) = \sqrt{\frac{4\pi^2}{V\ k^2\ \Delta k}}\left(P(k)\cdot\left[R_{\mathrm{cv}}-(1-R_{\mathrm{cv}})\cdot\frac{2}{\pi}\arctan\left(\frac{k}{k_{\mathrm{soft}}}\right)\right]+\frac{1}{n}\cdot f_{\mathrm{sn}}\right)$$



Reference

MNRAS **000**, 1–13 (2022) Preprint 26 April 2022 Compiled using MNRAS LaTeX style file v3.0

IFT-UAM/CSIC-22-47

Validating galaxy clustering models with Fixed & Paired and Matched-ICs simulations: application to Primordial Non-Gaussianities

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[2] *Instituto de Física Teorica UAM-CSIC, c/ Nicolás Cabrera 13-15, , 28049 Madrid*

2204.11103

Check also references therein