PNG sensitivity in galaxy correlations of order n > 2

Zachery Brown
Advisor: Regina Demina
University of Rochester
On behalf of the DESI Collaboration

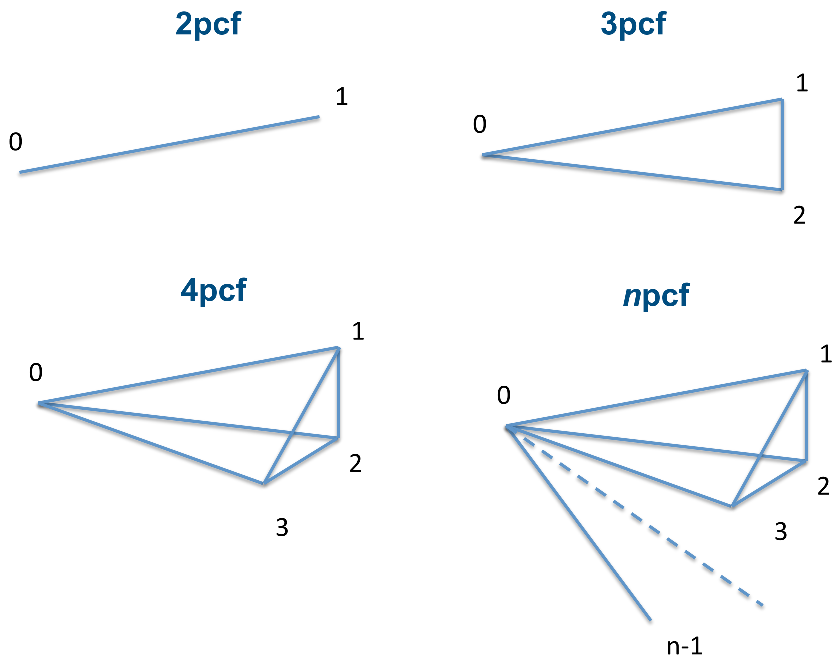
A Cosmic Window to Fundamental Physics:
Primordial Non-Gaussianity (PNG) and Beyond
Instituto de Física Teórica, Madrid
September 2022

PNG simulations and clustering statistics

Questions:

Are galaxy *n*-pt functions sensitive to primordial non-gaussianity? Which orders?

How do we appropriately model bias when constraining f_{NL}?



- 3 ensembles of mocks* from Santiago Avila
  - Cubic boxes with L = 1 Gpc/h
  - 512^3 particles at z = 32 evolved to z = 1
  - Halos with >10 particles identified
- Mocks with f_{NL} = 0, 10, 100
- Measure equidistant *n*pcf ($s_1 = s_2 = \ldots = s_{n-1}$) with the `ConKer` algorithm** (convolves spherical kernels with the matter distribution)

*https://arxiv.org/abs/2007.14962 Wang et al. (2020): Mock details

**https://arxiv.org/abs/2108.00015 Brown et al. (2022) preprint: ConKer algorithm

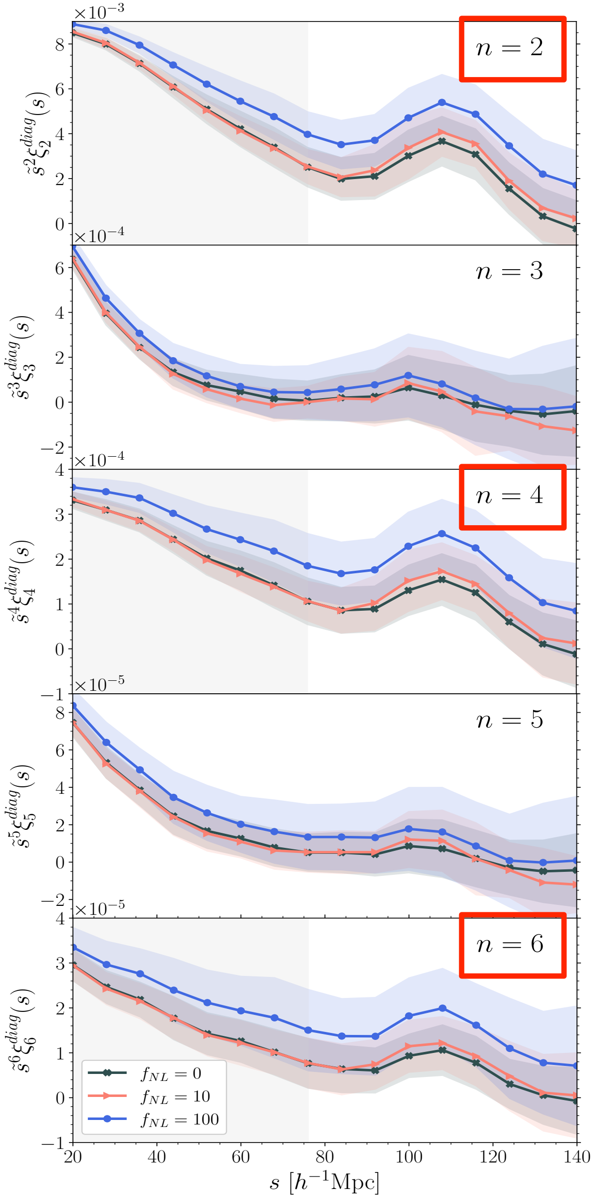
PNG simulations *n*pcf

- Measure ξ_n (equidistant/diagonal case) monopole in bins of Δs = 8 Mpc/*h* from 20—140 Mpc/*h*
- f_{NL} sensitivity observed especially in even *n*pcf
- Choose the *n* = 2, 4, 6 cases and a window from *s* = 20—76 Mpc/*h* to construct our model (grey box)
- Characterize the PNG sensitivity of each model bin with $\delta\xi_n(f_{NL},s)$

PNG clustering signal

$$\delta\xi_n(f_{NL},s) = \frac{\xi_n(f_{NL},s) - \xi_n(0,s)}{\xi_n(0,s)}$$

No PNG case



Derivation of PNG sensitivity

PNG bias

$$b = b_g\left(1 + \frac{b_\phi}{b_g}\alpha^{-1} f_{NL}\right)$$

Linear galaxy bias

Primary *s*-dependence

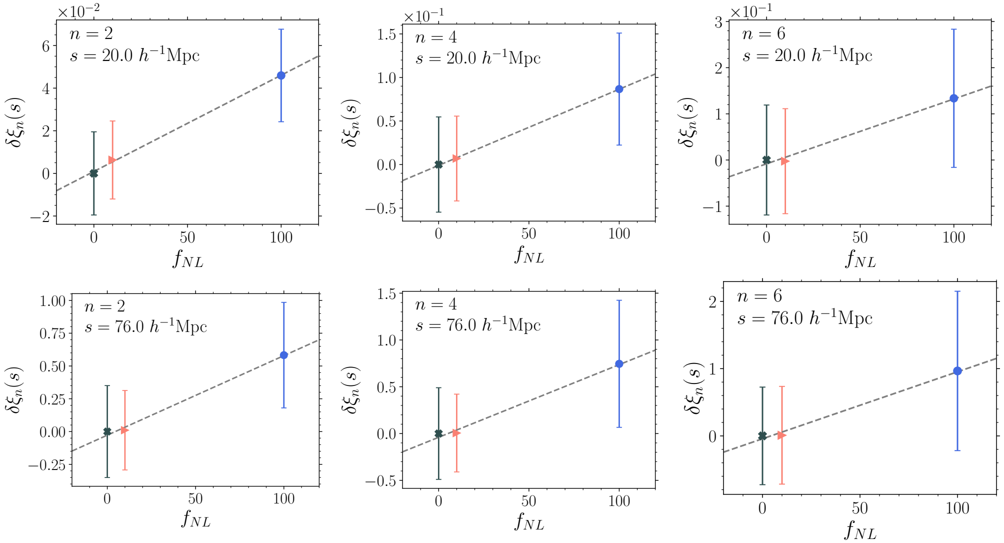
$$\alpha^{-1}(s,z) = \frac{3\Omega_m(z)}{2D(z)}\frac{g(z_{rad})}{g(0)}T^*(s)^{-1}\frac{s^2}{4\pi^2 d_H^2}$$

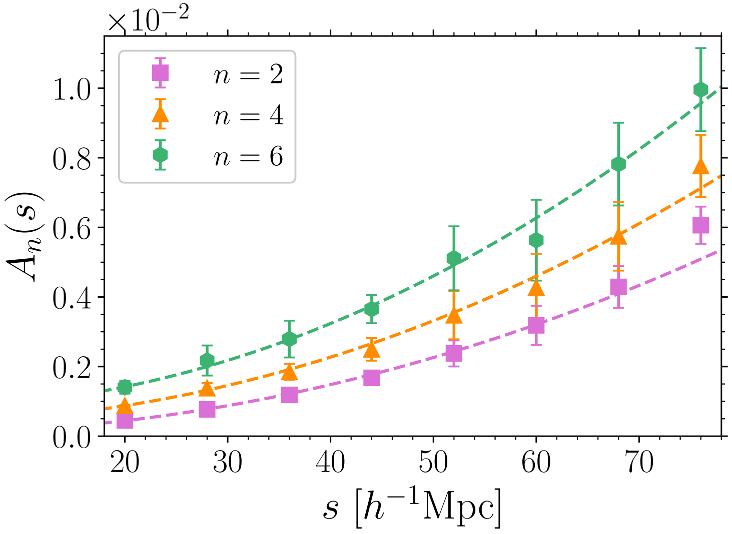
- Expand in α^{-1} when $s << d_H$
- Predicted and observed sensitivity (A_n) is quadratic in s

$$\xi_n(b_g, f_{NL}) = b^n \xi_n(1{,}0) = b_g^n\left(1 + n\alpha^{-1}\frac{b_\phi}{b_g} f_{NL}\right)\xi_n(1{,}0)$$

- ξ_n scales as b_g^n , linear in f_{NL}
- Fit $\delta\xi$ vs f_{NL} to 1st order polynomial with slope $A_n(s)$

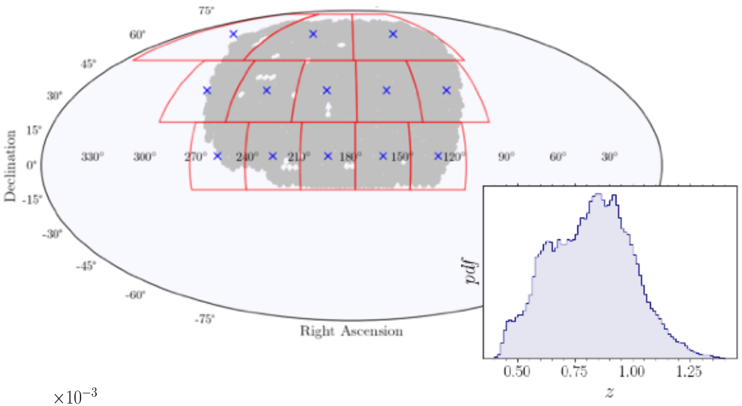
$$\delta\xi_n = n\alpha^{-1}\frac{b_\phi}{b_g} f_{NL}$$





Toy models with DESI LRG covariance

- Using DESI north luminous red galaxy (LRG) **mocks** (f_{NL} = 0), evaluate average npcf, $\xi_n^{DESI}(s)$ with covariance, *C*



1.8M mock galaxies in DESI Y3 footprint

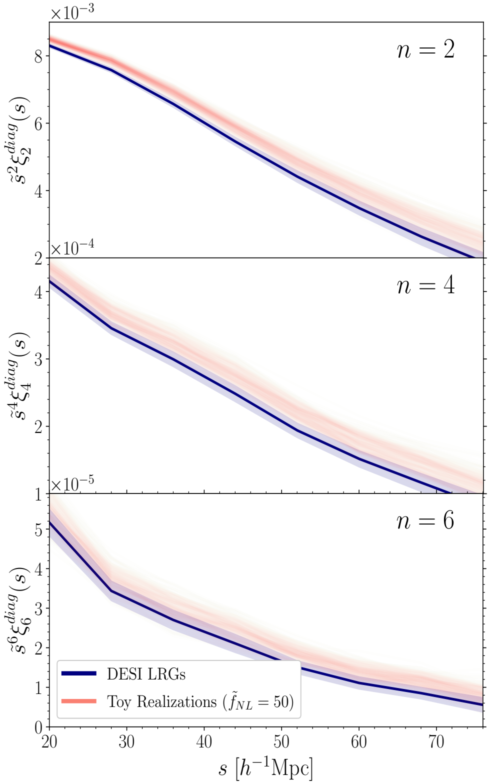
z-distribution from SV3 (survey validation)

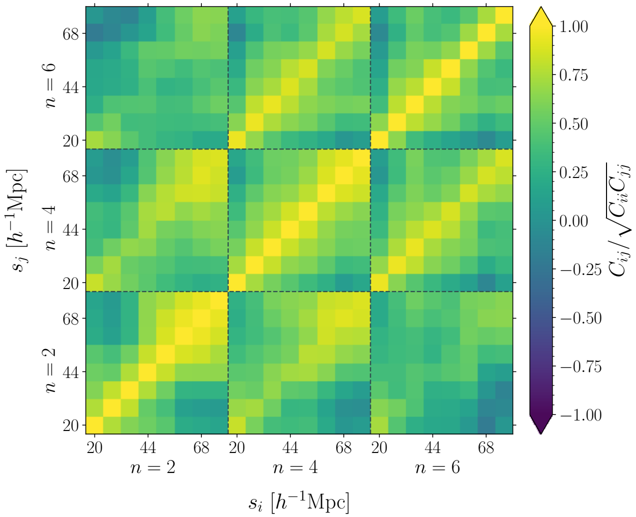
- Using $\delta\xi$ from PNG mock model calculate the expected value, $\mu_i(f_{NL})$ for a given f_{NL}

$$\mu_i(f_{NL}) = \underset{\substack{\uparrow\\ \text{From DESI}\\ \text{LRG mocks}}}{\xi_n^{DESI}}(s_i)\left[1 + \underset{\substack{\nwarrow\\ \text{From PNG}\\ \text{mocks}}}{\delta\xi_n^{model}}(f_{NL}, s_i)\right]$$

- Generate "toy" model data $\xi_n^{toy}(s)$ distributed about $\mu_i(f_{NL})$ according to covariance, *C*

- Concatenate ξ_2, ξ_4, ξ_6, to form an observable, $\tilde{O}$





Simple 1 parameter model

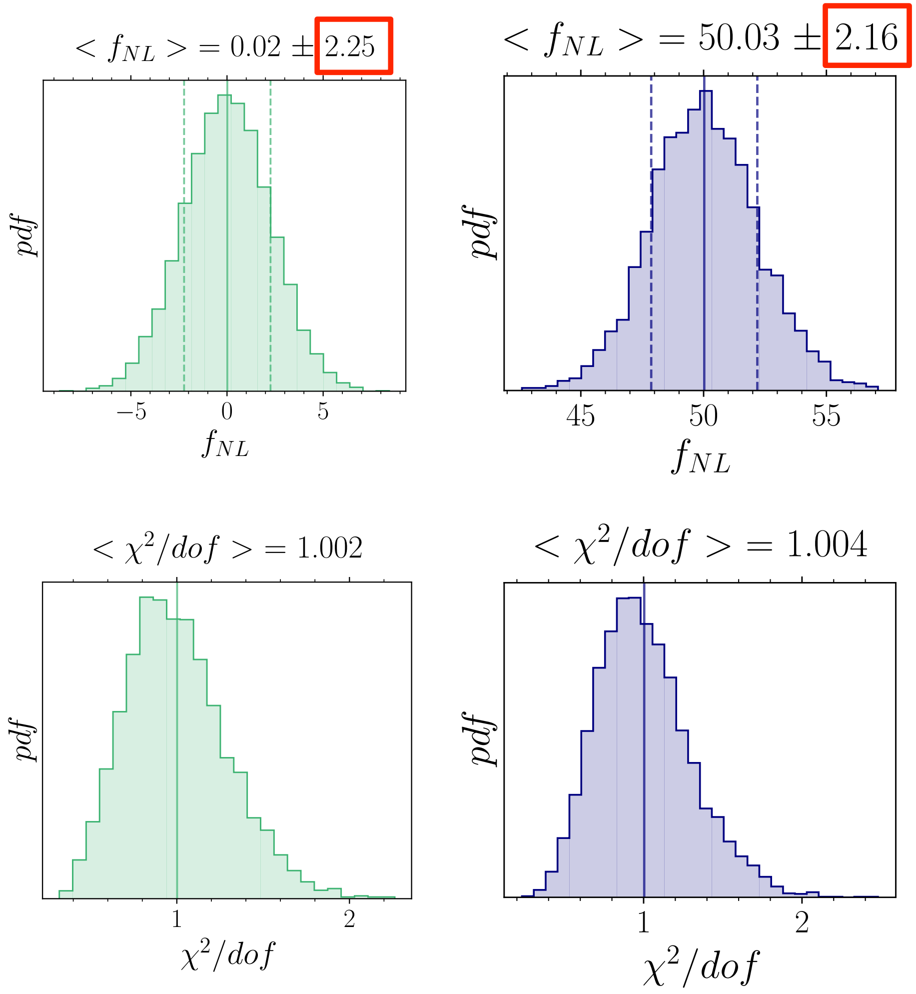
- To extract an observed value of f_{NL}, minimize χ^2 for each of 5000 toy realization $\tilde{O}$ ($\tilde{f}_{NL} = 0$, $\tilde{f}_{NL} = 50$)

$$\chi^2(f_{NL}) = \sum_{ij} (\tilde{O}_i - \mu_i(f_{NL}))^T C_{ij}^{-1} (\tilde{O}_j - \mu_j(f_{NL}))$$

Toy observable

Interpolated model

DESI LRG covariance



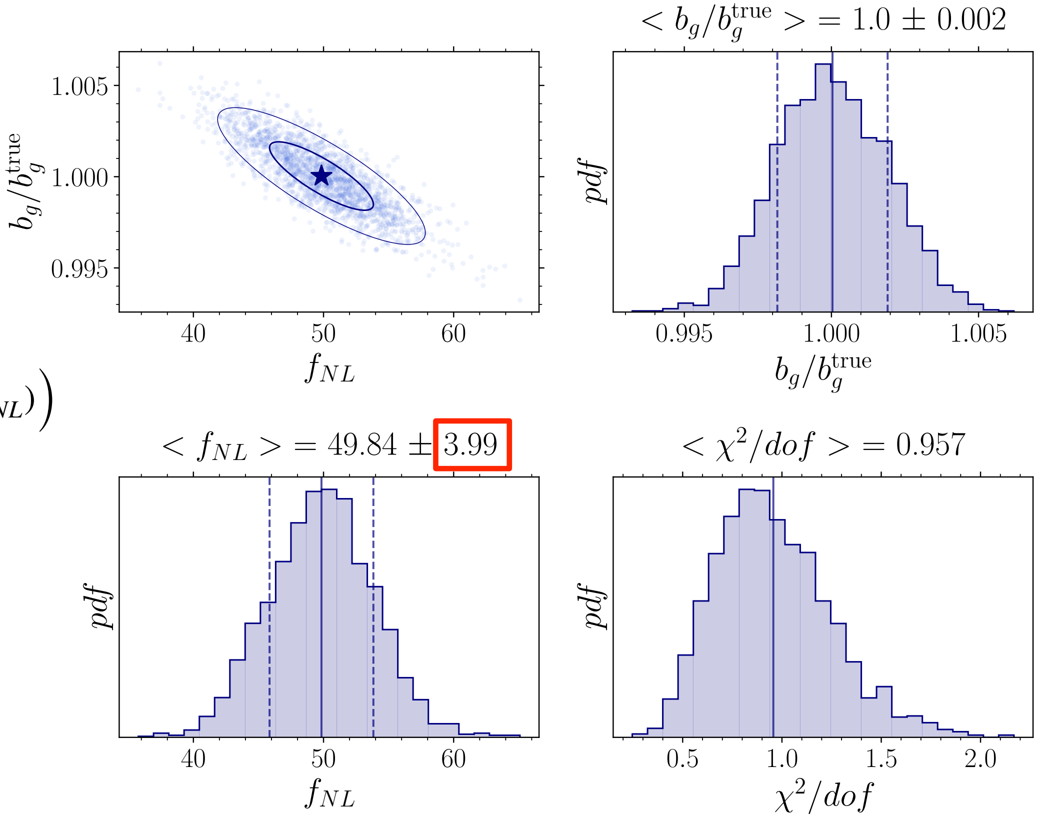
2 parameter model with strict bias priors

- Redefine χ^2 for each toy realization, including a factor for the linear galaxy bias, b_g

$$\chi^2(f_{NL}, b_g) = \sum_{ij} \left(\underset{\substack{\uparrow\\\text{Toy}\\\text{observable}}}{\tilde{O}_i} - \overset{\substack{\text{Linear}\\\text{galaxy bias}\\\downarrow}}{b_g^n} \underset{\substack{\uparrow\\\text{Interpolated}\\\text{model}}}{\mu_i(f_{NL})}\right)^T \underset{\substack{\uparrow\\\text{DESI LRG}\\\text{covariance}}}{C_{ij}^{-1}} \left(\tilde{O}_j - b_g^n \mu_j(f_{NL})\right)$$

- b_g is galaxy bias relative to the DESI mocks ($b_g^{true} = b_g^{DESI}$)

- We assume b_φ / b_g is equal to value assumed in the PNG mocks

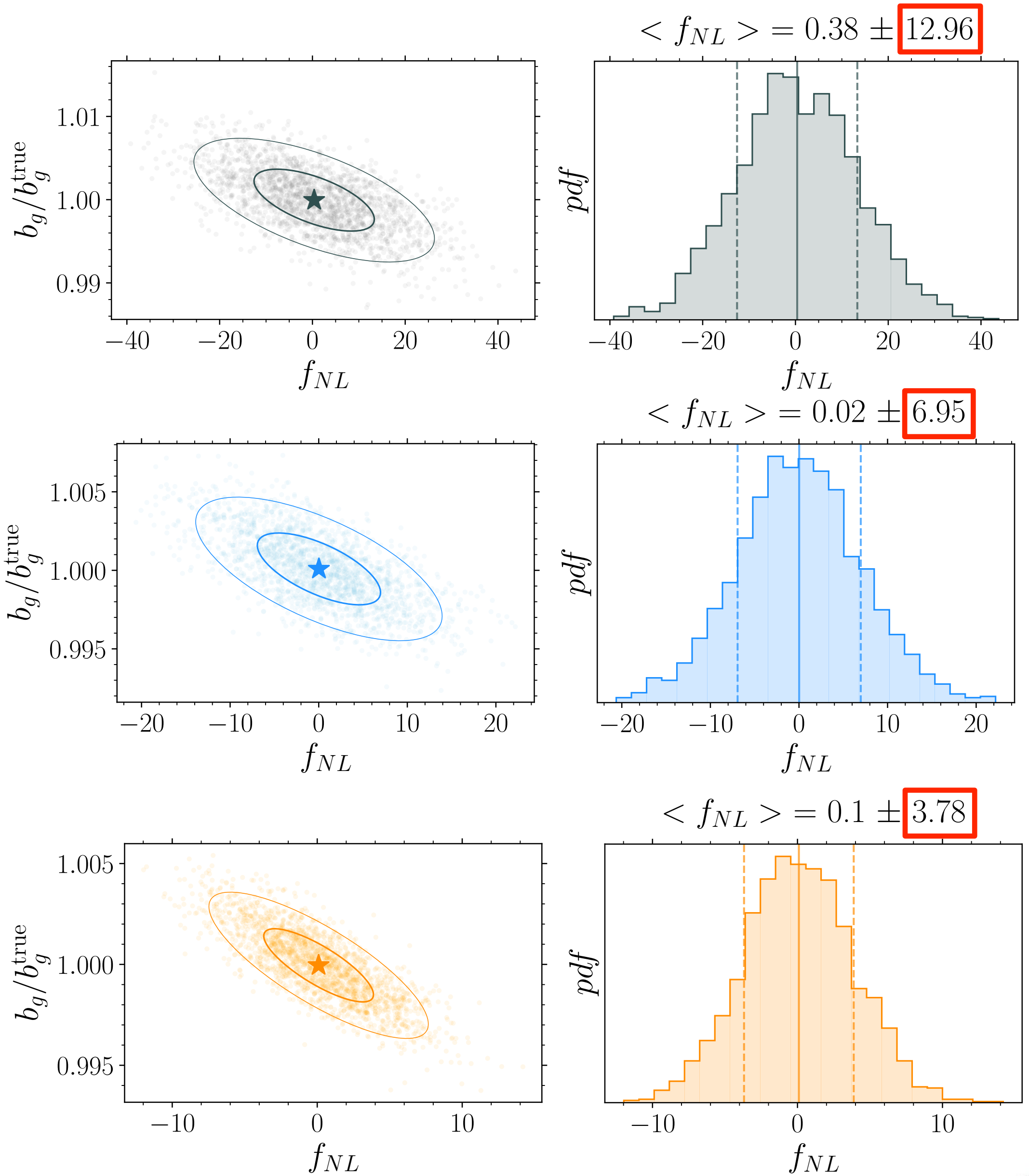


Z. Brown (zbrown5@ur.rochester.edu)

Benefit of higher order correlations

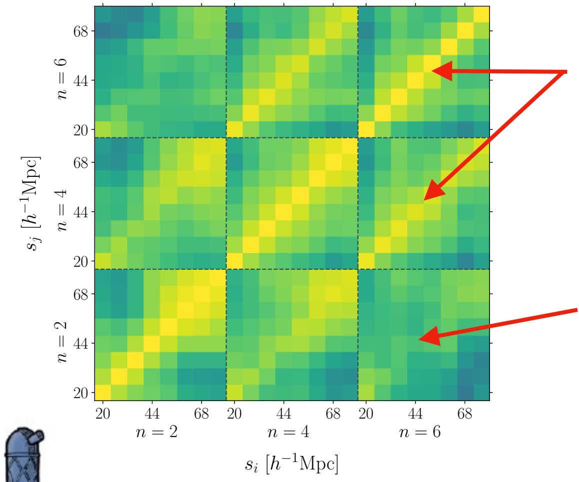
- Repeat procedure for toy models with $\tilde{f}_{NL} = 0$ that include only ***n* = 2**, ***n* = 2, 4**, and ***n* = 2, 4, 6**

- Significant gain in sensitivity when including higher orders


$< f_{NL} > = 0.38 \pm \boxed{12.96}$

$< f_{NL} > = 0.02 \pm \boxed{6.95}$

$< f_{NL} > = 0.1 \pm \boxed{3.78}$



More correlated

Less correlated

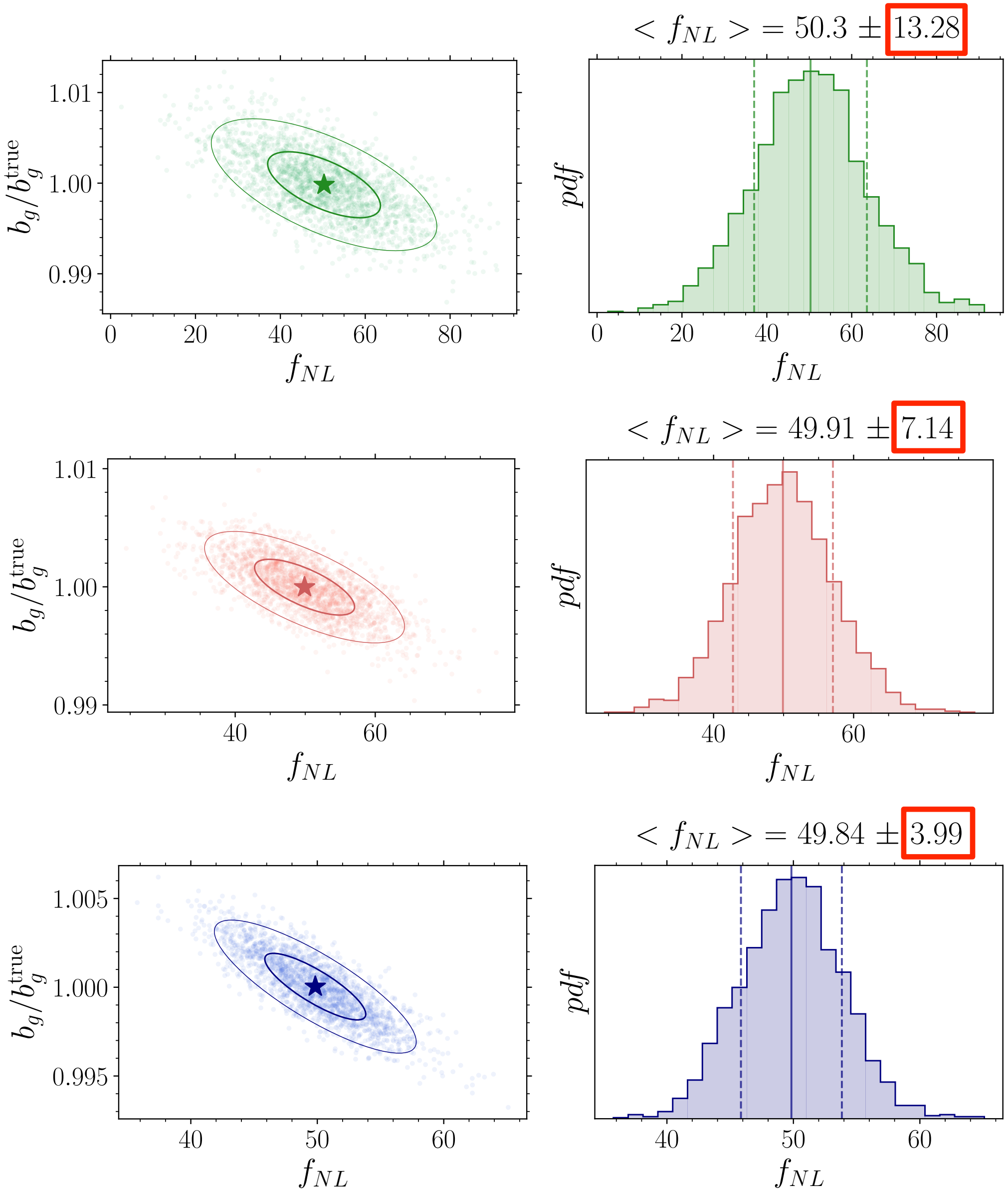
Z. Brown (zbrown5@ur.rochester.edu)

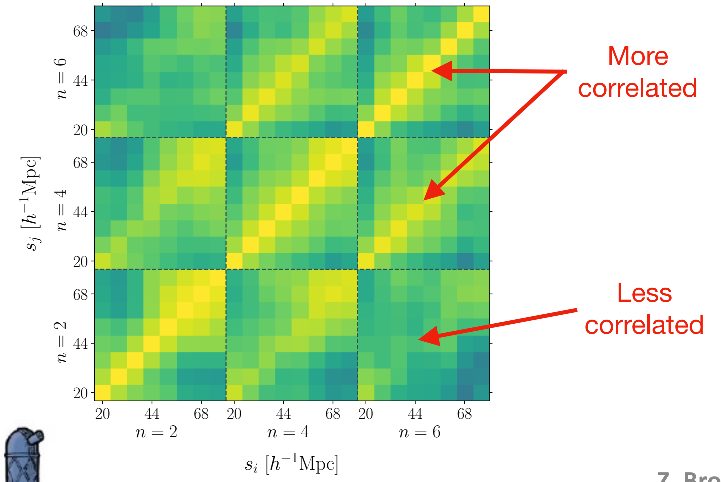
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Benefit of higher order correlations

- Repeat procedure for toy models with $\tilde{f}_{NL}$ = 50 that include only ***n* = 2**, ***n* = 2, 4**, and ***n* = 2, 4, 6**

- Significant gain in sensitivity when including higher orders





More correlated

Less correlated

Z. Brown (zbrown5@ur.rochester.edu)

Summary and outlook

- Higher order correlations provide additional sensitivity to f_{NL}!

- Investigate window (s-range) dependence of bias constraints and use b_g, b_φ relations

- To apply this method to DESI data…

  1. Simulations with known priors on p/b_g
  2. Understand the effects of HOD choices at small scales
  3. Study systematics due to fiber collisions
  4. Optimal galaxy weighting scheme* for constraining f_{NL}

*https://arxiv.org/pdf/1702.05088 Mueller et al. (2018): Optimized PNG weights

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

NSF

NERSC

FROM RESEARCH TO INDUSTRY
cea

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD

CONACYT

HEISING-SIMONS FOUNDATION

GORDON AND BETTY MOORE FOUNDATION

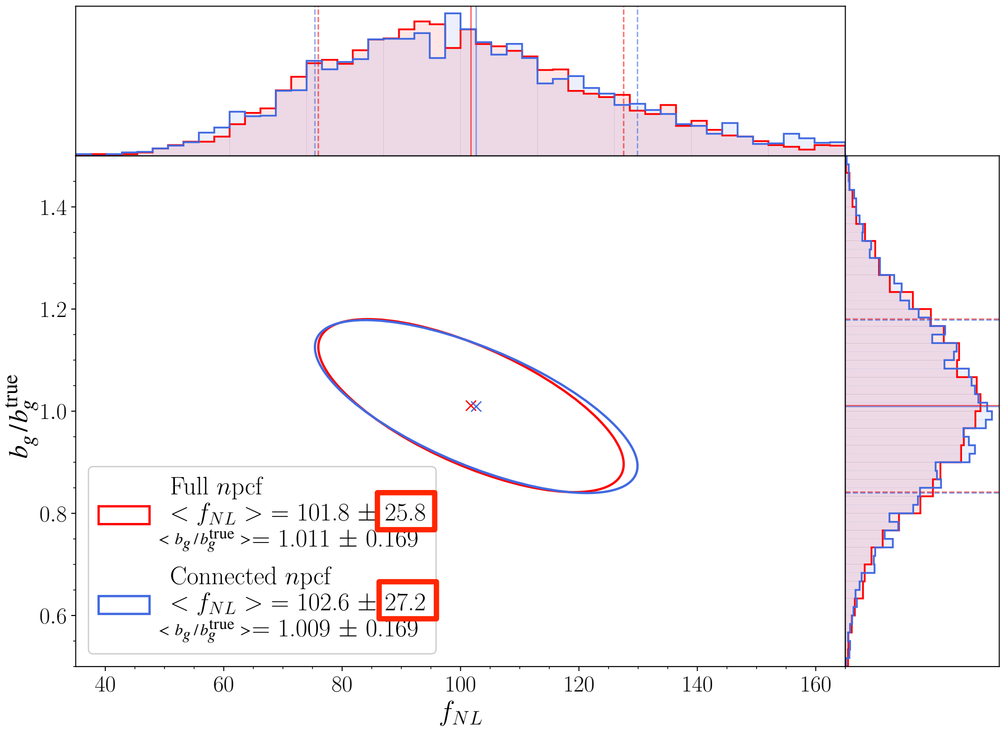
Science & Technology Facilities Council

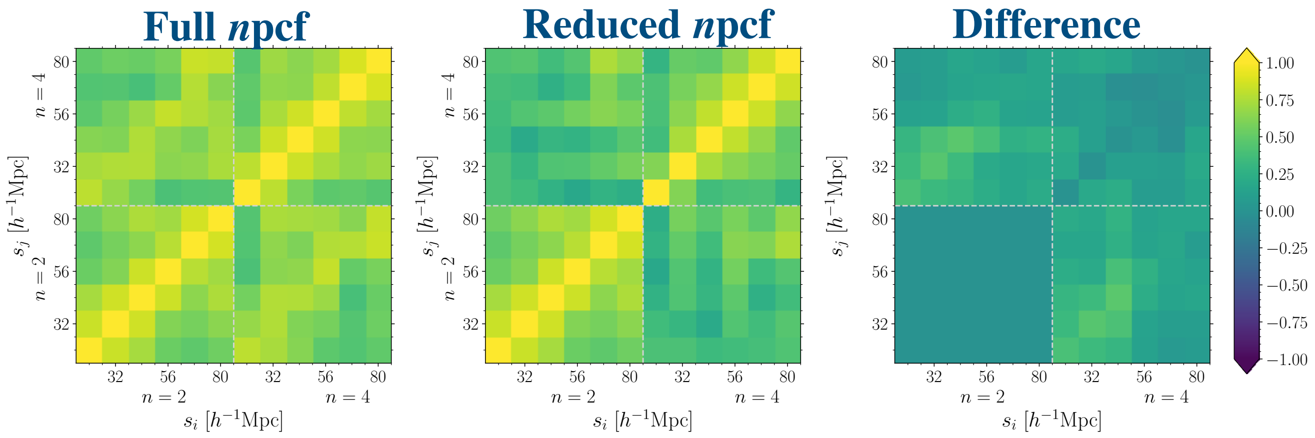
Thanks to our sponsors and
69 Participating Institutions!

Disconnected term removal

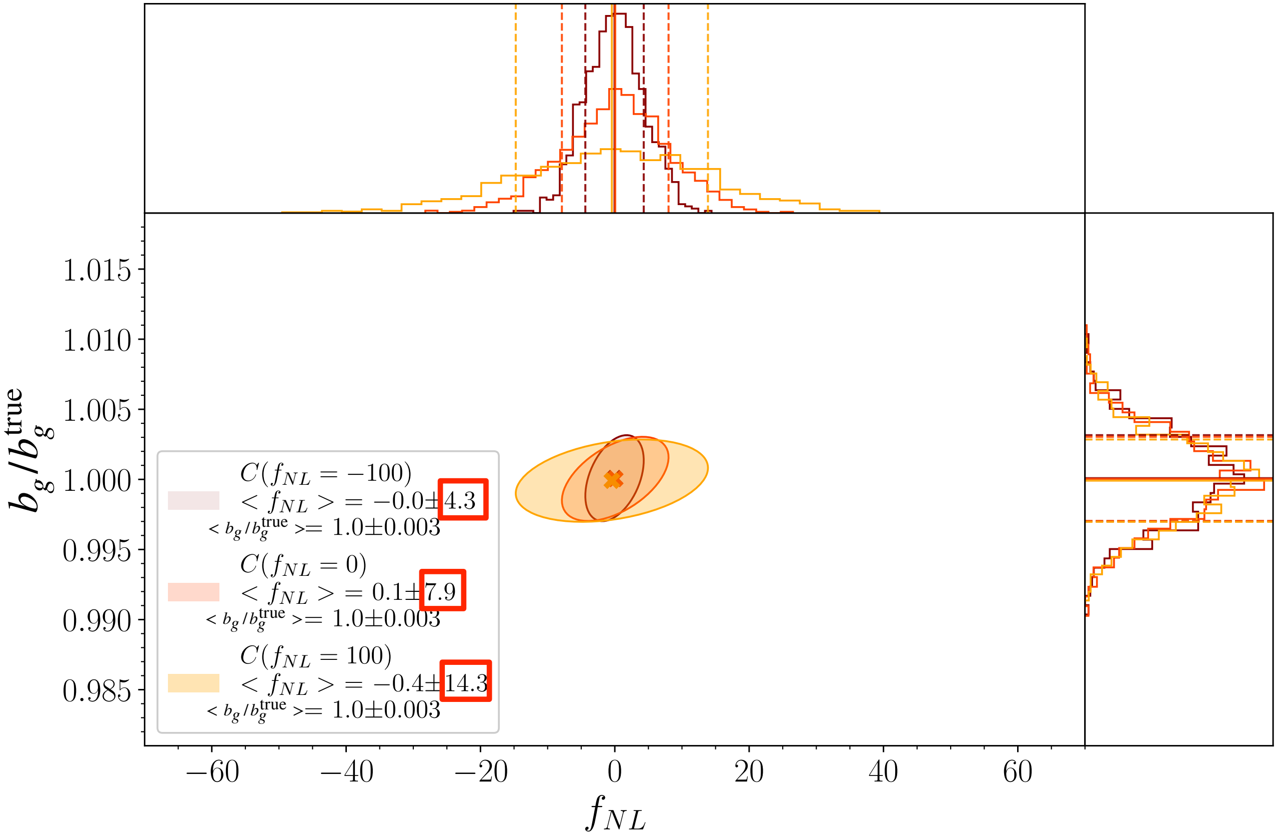
- Measured (full) *npcf* is the sum of reduced and disconnected terms
- Repeat the procedure using *n* = 2, 4 for the **full** and **reduced** case (PNG mocks only)
- Removing the disconnected terms does little to overall constraints

$$\xi^{diag}_{4,full}(s) = \xi^{diag}_{4,red}(s) + 3\xi^{diag}_{2}(s)$$





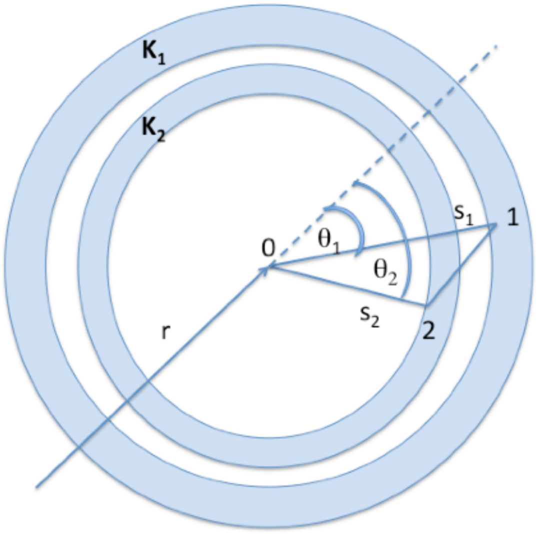
Choice of covariance matrix



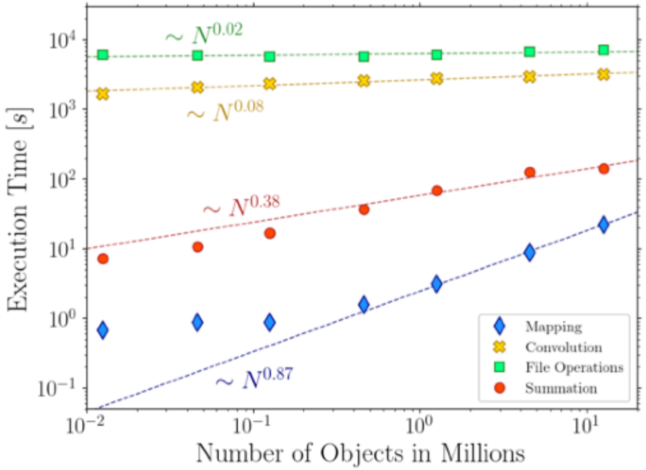
- Some change in f_{NL} sensitivity when using covariance NOT corresponding to f_{NL} = 0 (using PNG mocks only)

Fast *n*pcf calculations with `ConKer`

- Matter tracers are mapped onto a 3D grid
- Spherical kernels are constructed and populated by Legendre polynomials (wrt LOS)
- Kernels are convolved with the matter map at desired scales using an FFT convolution
- Fast *n*pcf estimates with manageable complexity



Includes 2pcf (*l=0,2,4*), 3pcf, diag. *n*pcf 2<*n*<5



arXiv: 2108.00015
Upcoming A&A article!