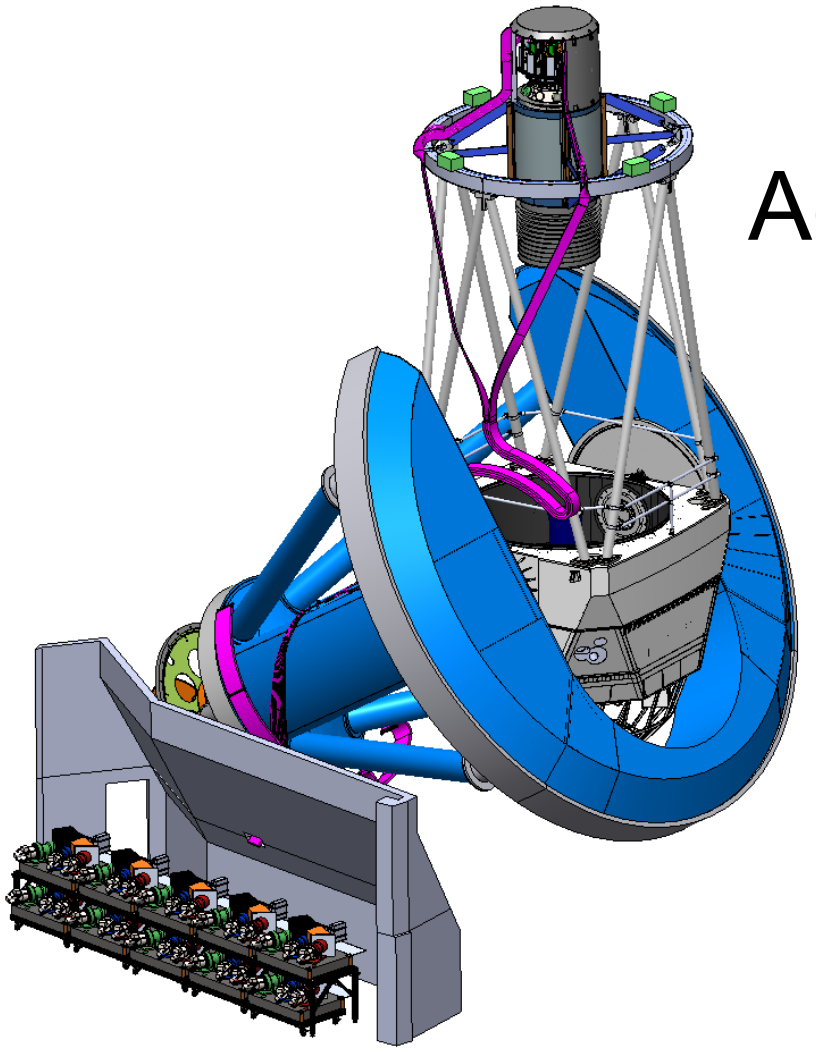

The optimal Baryon Acoustic Oscillation (BAO) reconstruction for DESI Y1-KP4

Enrique Paillas, Zhejie Ding, Xinyi Chen co-lead

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On behalf of the DESI Collaboration

Outline

- Background
- DESI First generation cutsky mocks
- Methodology of the BAO reconstruction
- BAO reconstruction and fitting on mocks
- Preliminary result of the reconstructed DESI Y1 blinded data

Backgroud and Motivation

- DESI will observe different types of tracers, i.e. BGS, LRG, ELG and QSO.

- Different tracers locate at different redshift ranges. They have different galaxy biases and number densities.

  BGS: $0.1<z<0.4$

  LRG: $0.4<z<1.1$

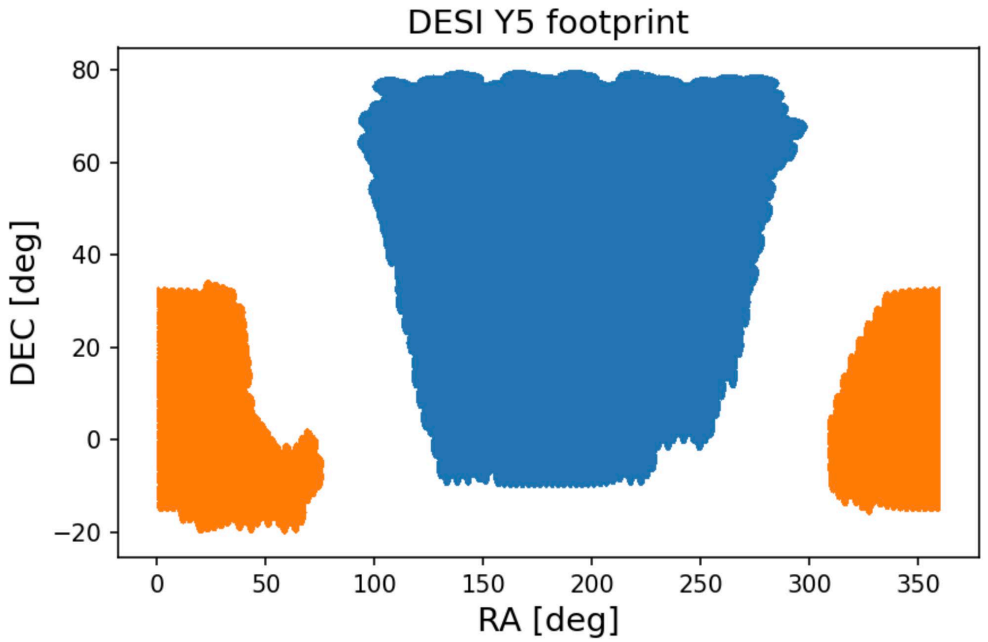
  ELG: $0.8<z<1.6$

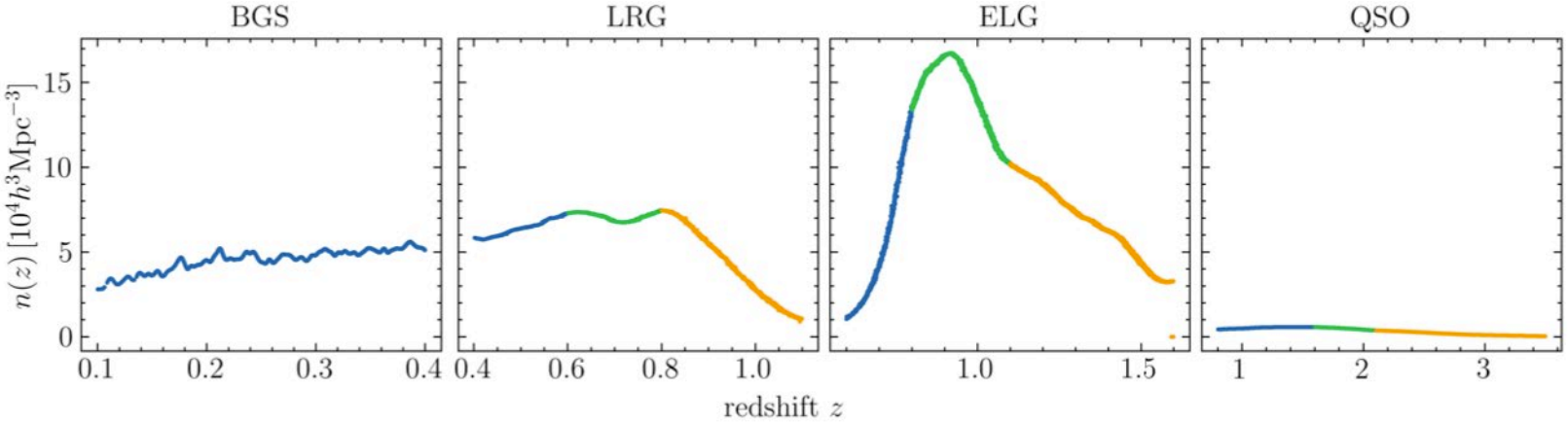
  QSO: $0.8<z<2.1$

❖ Goal: Finding some optimal BAO reconstruction settings for different tracers. Provide the theoretical systematics quantitatively. Apply the study to the DESI Year 1 BAO science.

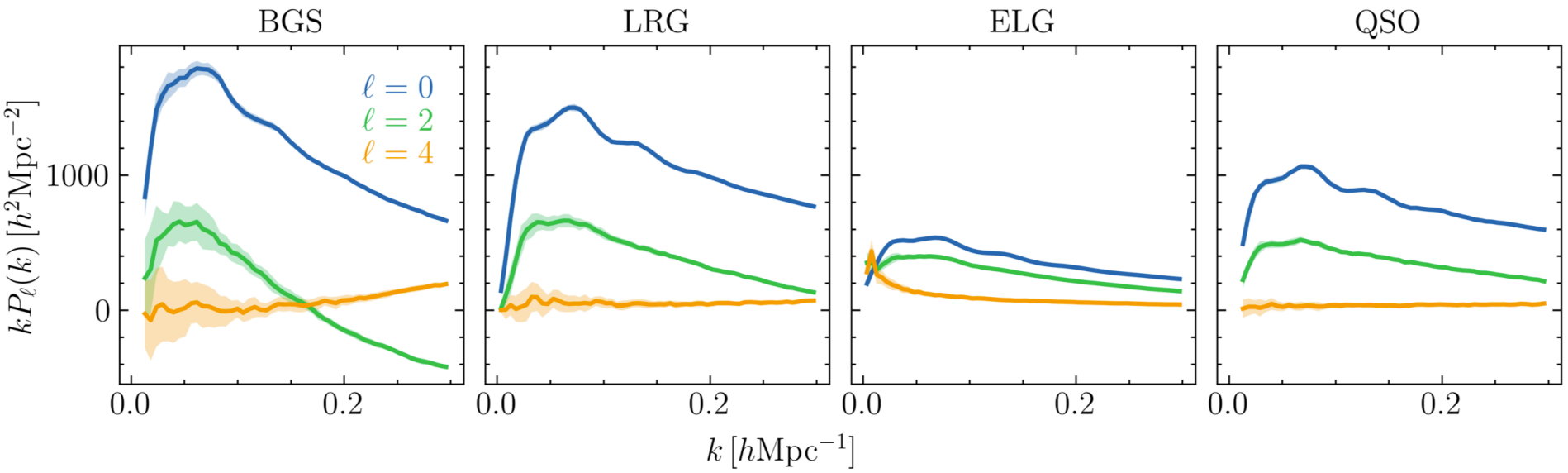
First generation DESI simulation mocks

- AbacusSummit simulation ph000 — ph025 (2Gpc/h).
- HOD applied, calibrated based on the DESI SV3 clustering at small scale.
- CutSky mocks are generated using a primary redshift (snapshot):
  - z=0.2 for BGS;
  - z=0.8 for LRG;
  - z=1.1 for ELG;
  - z=1.4 for QSO.





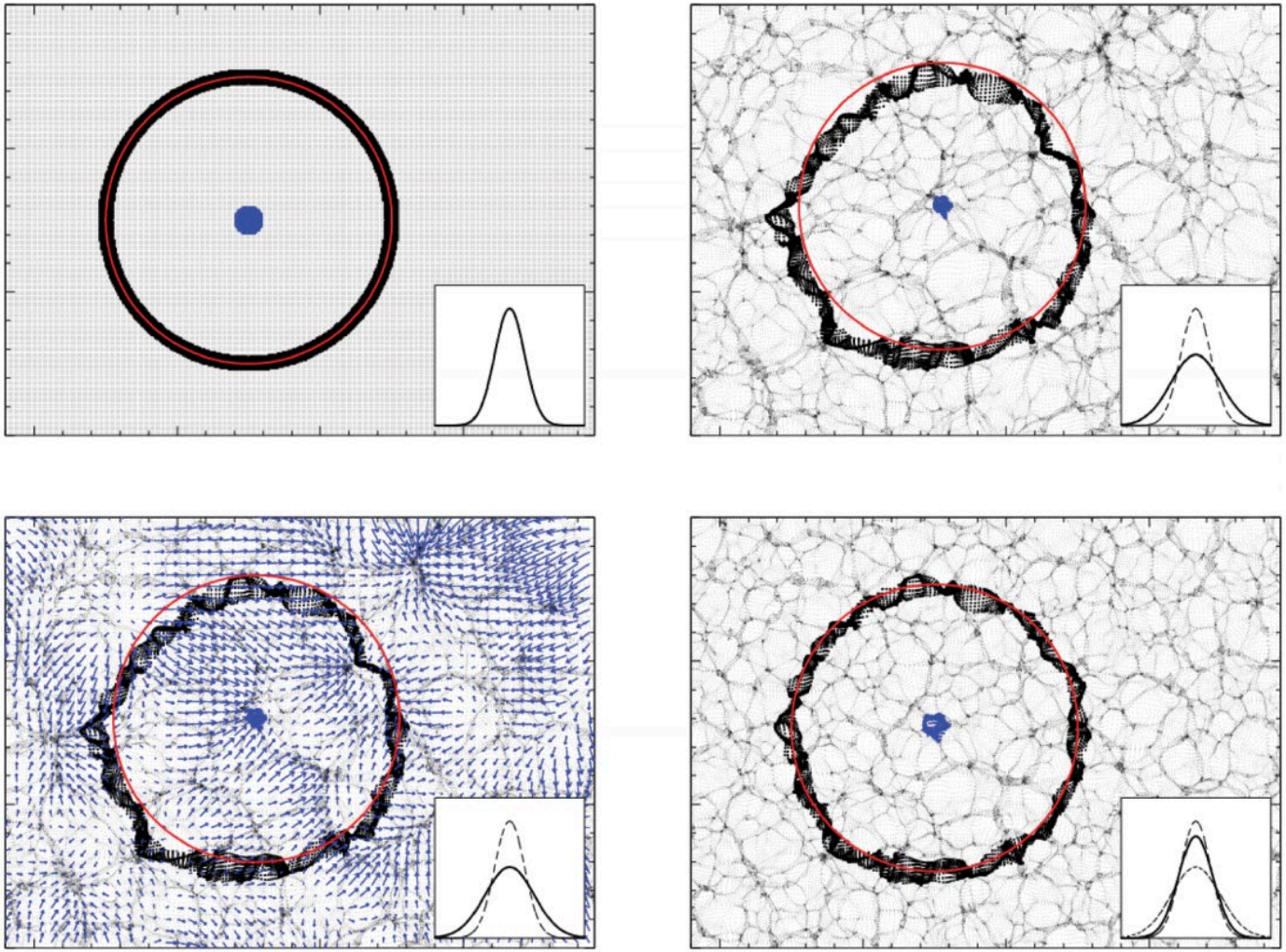
Galaxy power spectrum multipoles



$$P_\ell(k) = \frac{2\ell+1}{2}\int_{-1}^{1} P(k,\mu)L_\ell(\mu)d\mu,$$

Galaxy bias: BGS 1.5 LRG 1.99 ELG 1.2 QSO 2.07

A demo on the BAO reconstruction



Padmanabhan et al. 2012

Methodology of the BAO reconstruction

- Solving the displacement field from the linear continuity equation

$$\nabla \cdot \mathbf{\Psi} + f \nabla \cdot [(\mathbf{\Psi} \cdot \hat{\boldsymbol{r}})\hat{\boldsymbol{r}}] = -\frac{\delta_{\rm gal}}{b},$$

Zeldovich approximation

To first order $\vec{\Psi}$ is irrotational, so we can write $\vec{\Psi} = \nabla\phi$ and hence

$$\nabla^2\phi + f\vec{\nabla} \cdot \left(\left[\hat{r} \cdot \vec{\nabla}\phi \right] \hat{r} \right) = -\delta$$

MultiGrid reconstruction:

Solve the differential equation using a standard multigrid technique (V-cycle) in configuration space.

IterativeFFT reconstruction:

Solve the equation in Fourier space with FFT and iteration (arXiv: 1504.02591).

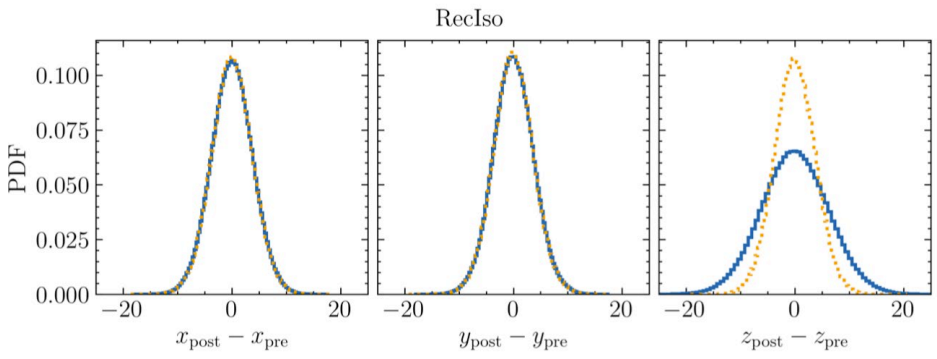
GitHub - cosmodesi/pyrecon: package for BAO reconstruction

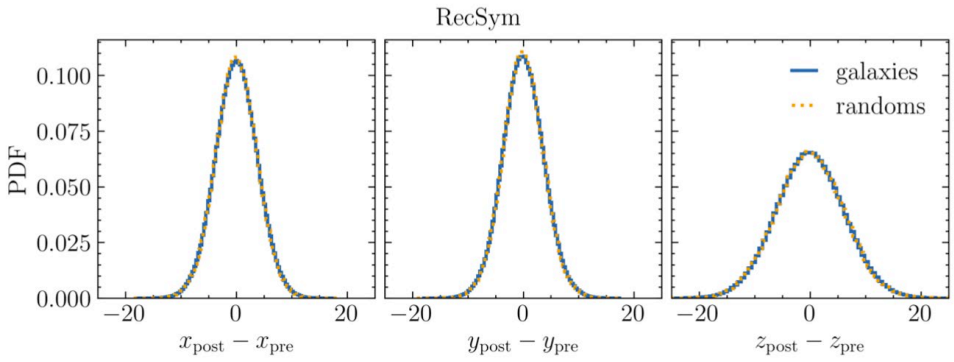
RecIso vs RecSym

After obtaining the displacement field $\boldsymbol{\Psi}$, we displace the galaxies by $-\boldsymbol{\Psi} - f(\boldsymbol{\Psi} \cdot \hat{\boldsymbol{r}})\hat{\boldsymbol{r}}$. For the displacement on the random density field, we distinguish it with two cases:

- displacing the random particles by $-\boldsymbol{\Psi}$, which is denoted as RecIso.
- displacing the random particles by $-\boldsymbol{\Psi} - f(\boldsymbol{\Psi} \cdot \hat{\boldsymbol{r}})\hat{\boldsymbol{r}}$, which is denoted as RecSym.

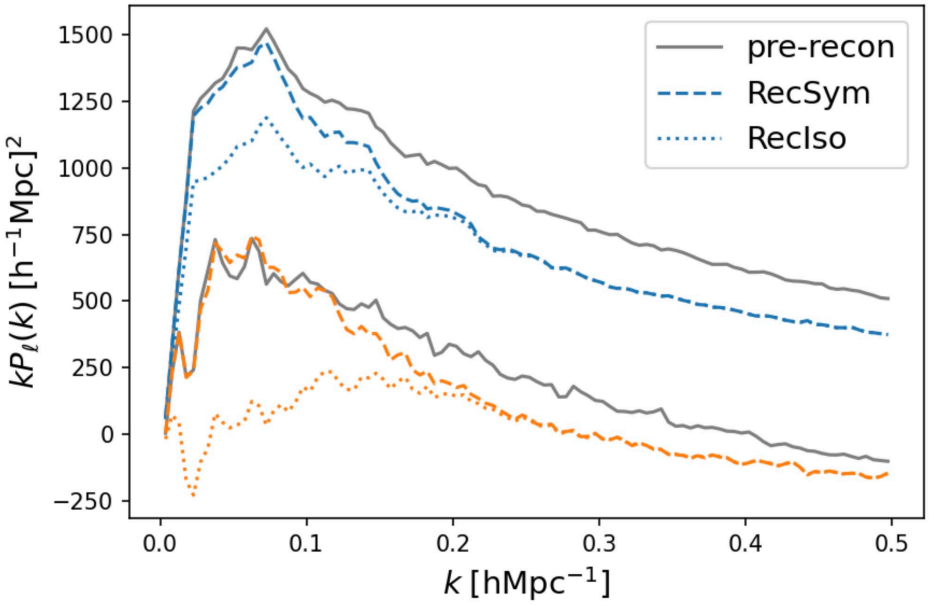
The final reconstructed field: $\delta_r \equiv \delta_d - \delta_s$.



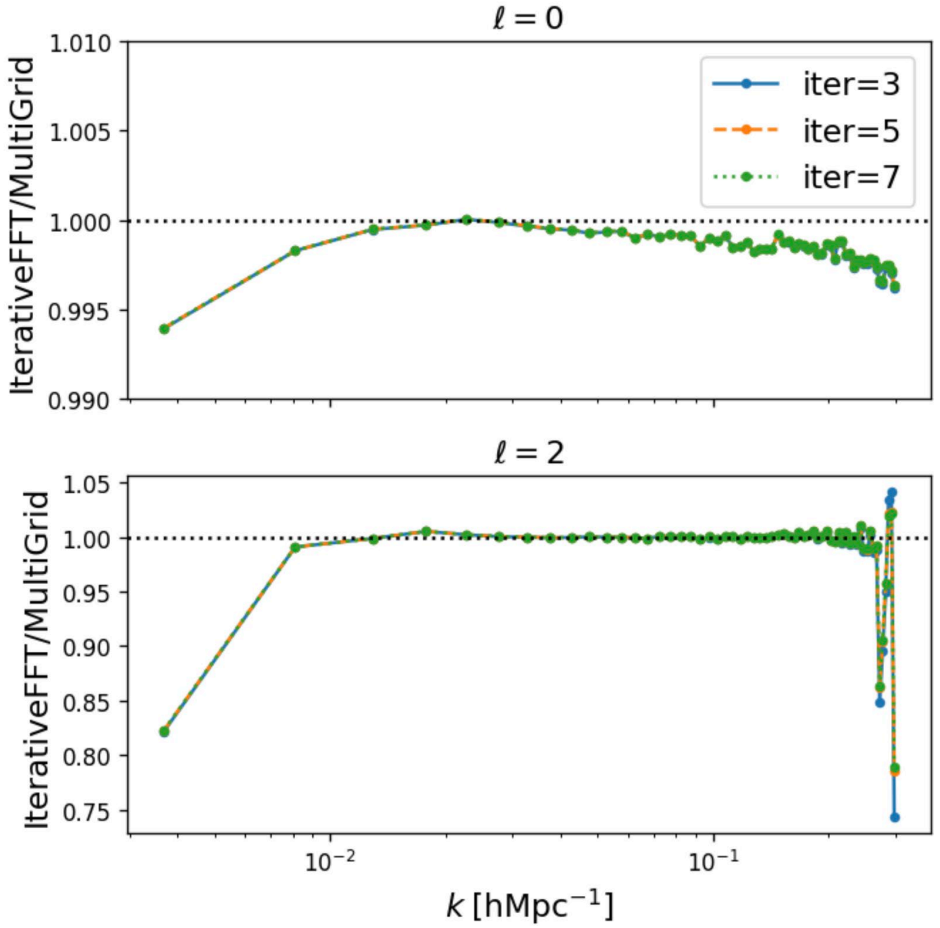


BAO reconstruction on mocks

Pre-reconstruction vs reconstruction



$$P_\ell(k) = \frac{2\ell+1}{2}\int_{-1}^{1} P(k,\mu)L_\ell(\mu)d\mu$$



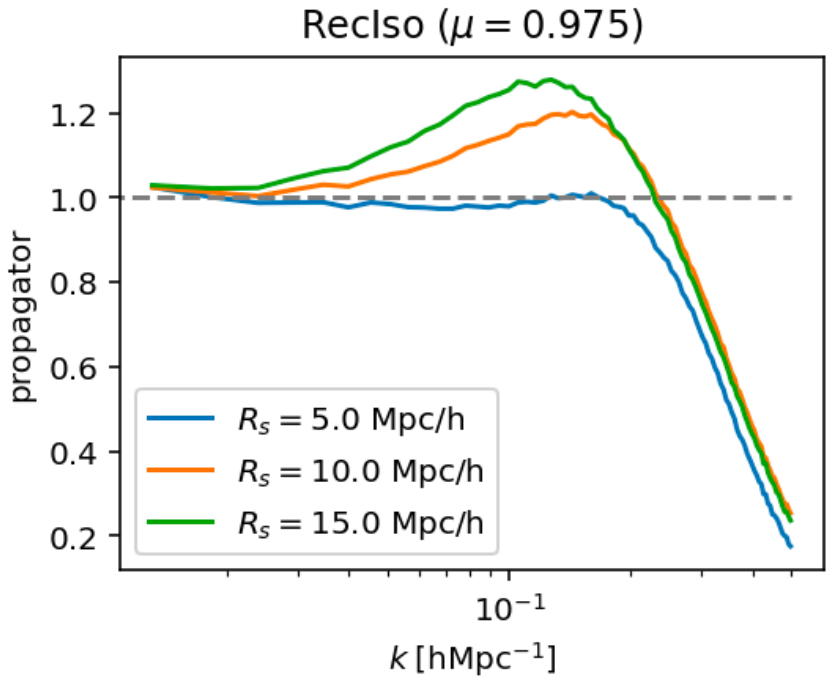
Results from the two reconstruction algorithms agree to each other.

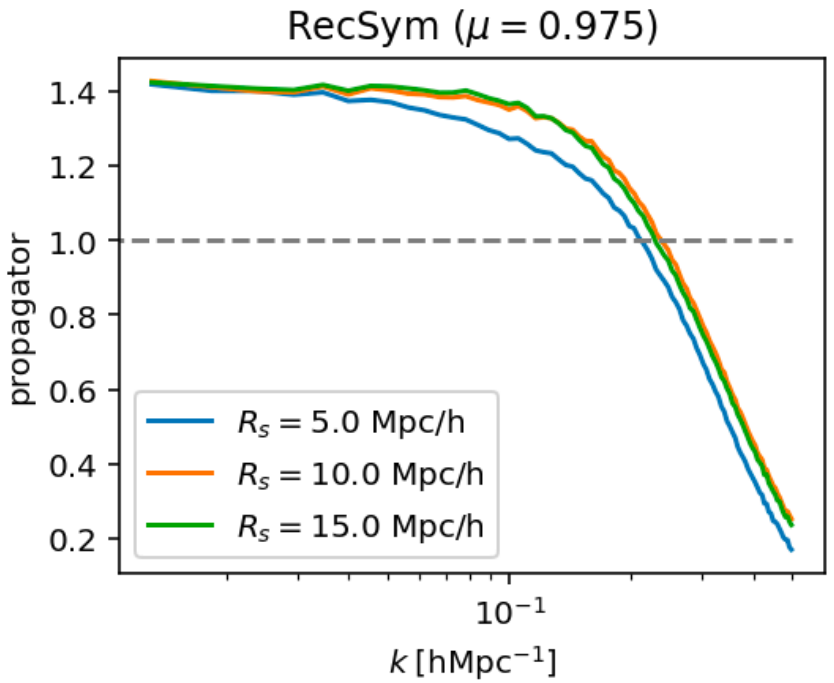
Propagator

We need to smooth the density field before reconstruction:

$$\tilde{\delta}_{\rm gal} = \delta_{\rm gal}(k)\exp\left(-k^2\Sigma_{\rm sm}^2/2\right),$$

$$C(k,\mu,z_o) = \frac{\langle\hat{\delta}_{\rm lin}(k,z_0)\hat{\delta}^*(k',z_0)\rangle}{bP_{\rm lin}(k,z_o)}$$





Results based on QSO cubic mock

BAO fitting model

same as the BOSS DR 12 BAO fitting model

$$P_g(k,\mu) = b_0^2\left(1+\beta\mu^2(1-S(k))\right)^2 F_{\rm FoG}(k,\mu,\Sigma_s)P_{\rm dw}(k,\mu),$$

$$F_{\rm FoG} = \frac{1}{(1+k^2\mu^2\Sigma_s^2)^2} \qquad P_{\rm dw}(k,\mu) = [P_{\rm lin}(k) - P_{\rm sm}(k)] \times \exp\left[-\frac{k^2\mu^2\Sigma_\parallel^2 + k^2(1-\mu^2)\Sigma_\perp^2}{2}\right] + P_{\rm sm}(k),$$

$$P_0(k) = \frac{1}{2}\int_{-1}^{1} P(k,\mu)\mathrm{d}\mu + A_0(k), \qquad A_\ell^{\text{pre-recon}}(k) = \frac{a_{\ell,1}}{k^3} + \frac{a_{\ell,2}}{k^2} + \frac{a_{\ell,3}}{k} + a_{\ell,4} + a_{\ell,5}k,$$

$$P_2(k) = \frac{5}{2}\int_{-1}^{1} P(k,\mu)\mathcal{L}_2(\mu)\mathrm{d}\mu + A_2(k), \qquad A_\ell^{\text{post-recon}}(k) = \frac{a_{\ell,1}}{k^3} + \frac{a_{\ell,2}}{k^2} + \frac{a_{\ell,3}}{k} + a_{\ell,4} + a_{\ell,5}k^2.$$

We fit the BAO scale shifting parameters $\alpha_\parallel$ and $\alpha_\perp$

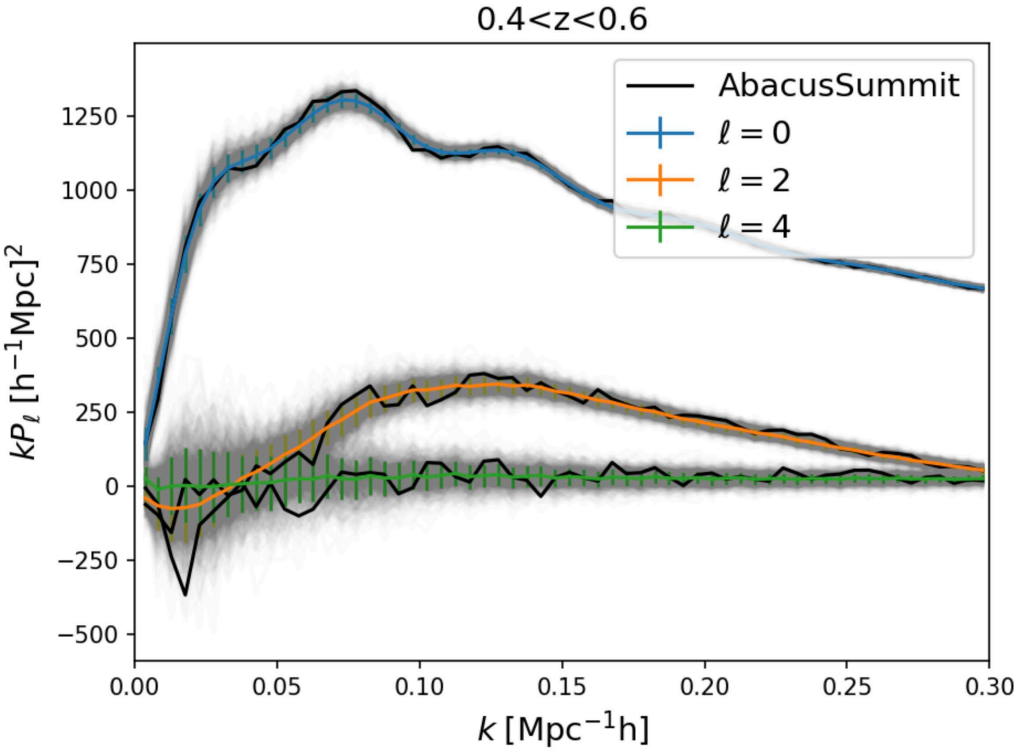
$$k'_\parallel = \frac{k_\parallel}{\alpha_\parallel}, \; k'_\perp = \frac{k_\perp}{\alpha_\perp},$$

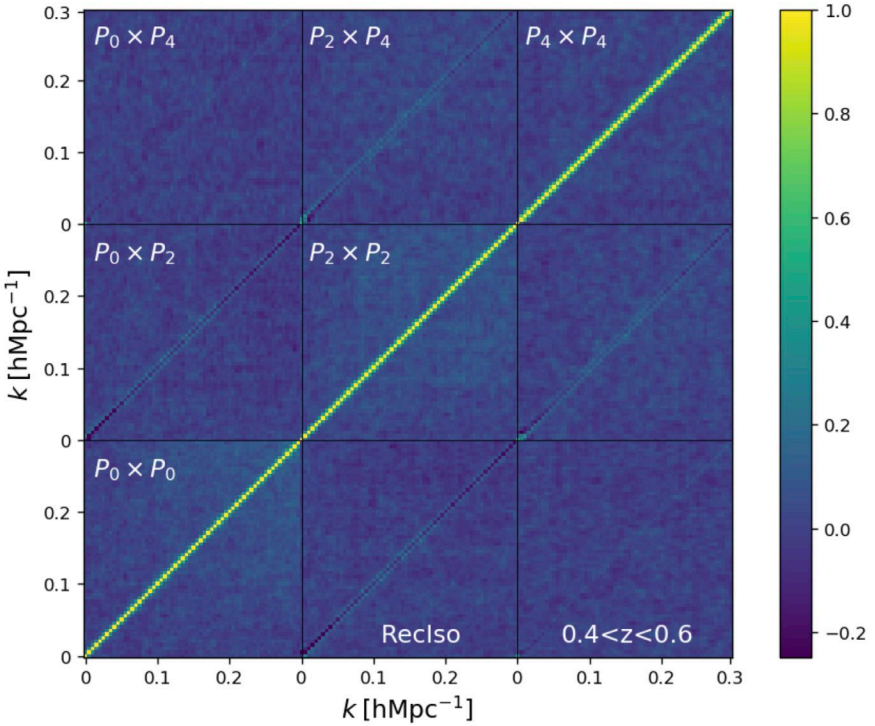
If alpha parameters deviate from 1.0, it is only due to the theoretical systematics (galaxy field nonlinear evolution, BAO reconstruction performance, BAO fitting model, etc).

BAO fitting code: https://github.com/Samreay/Barry

EZmocks for the covariance matrix

LRG cutsky mocks

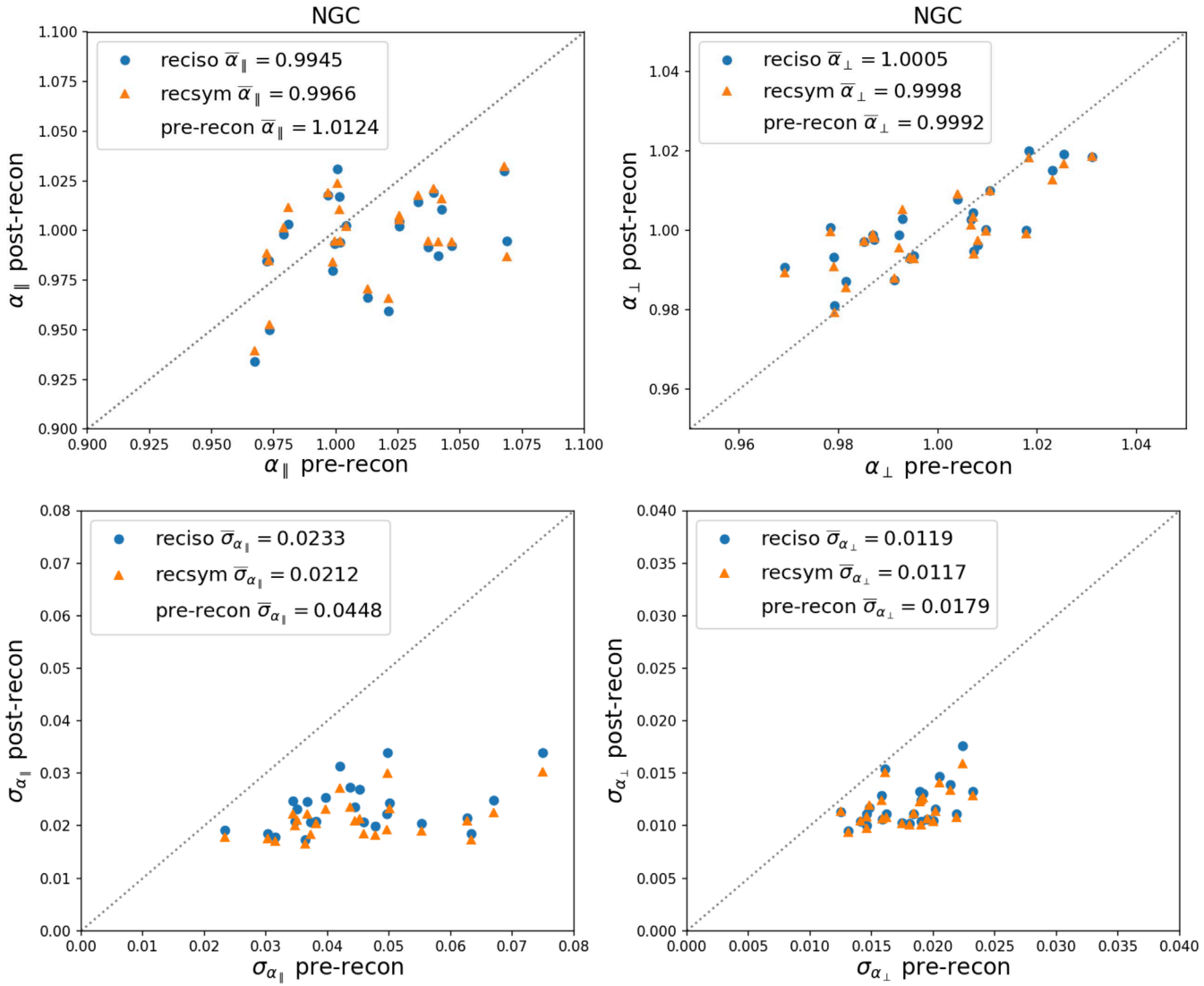




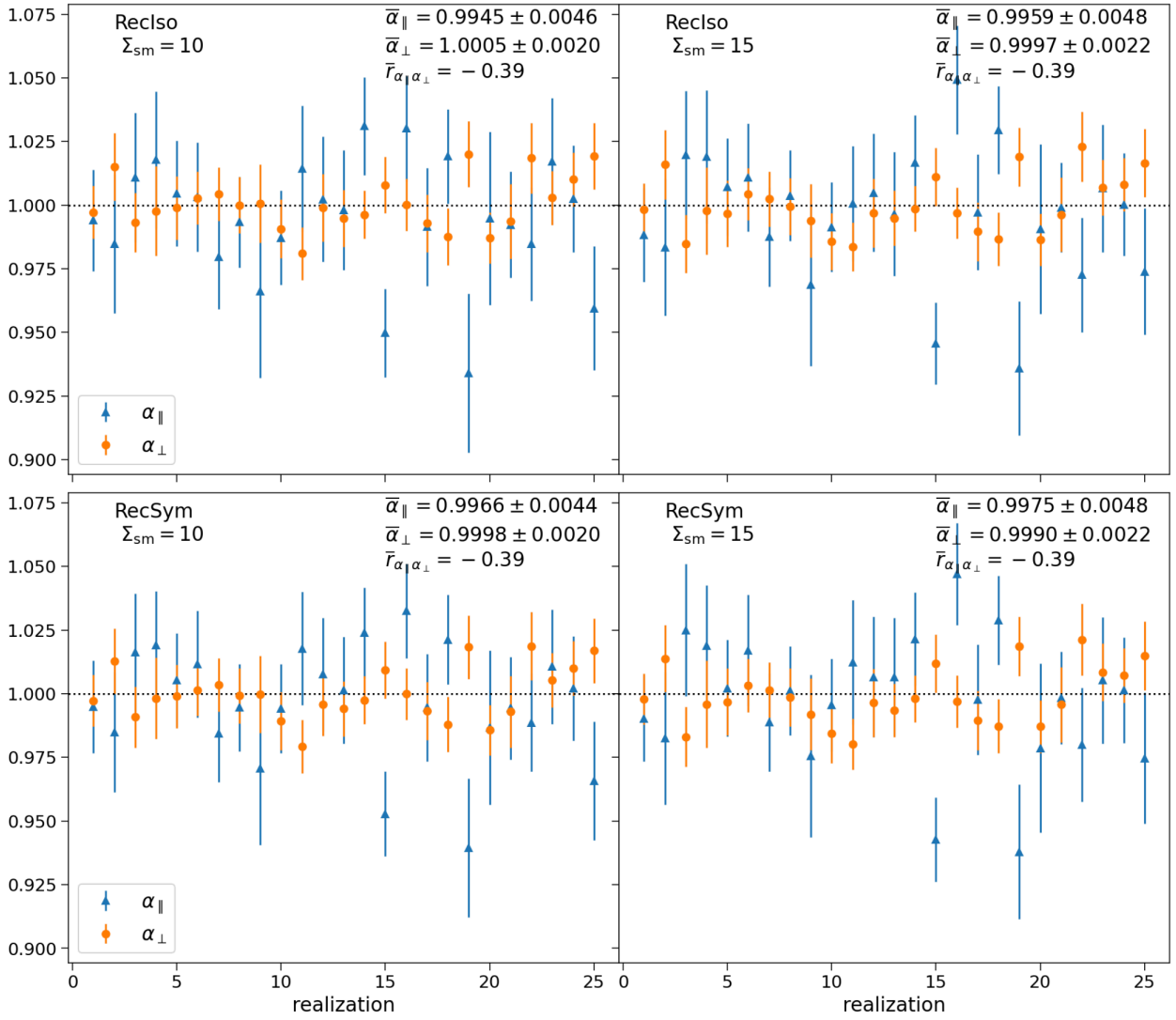
1000 EZmocks are generated and calibrated to match the galaxy clustering of AbacusSummit.

BAO fitting from power spectrum

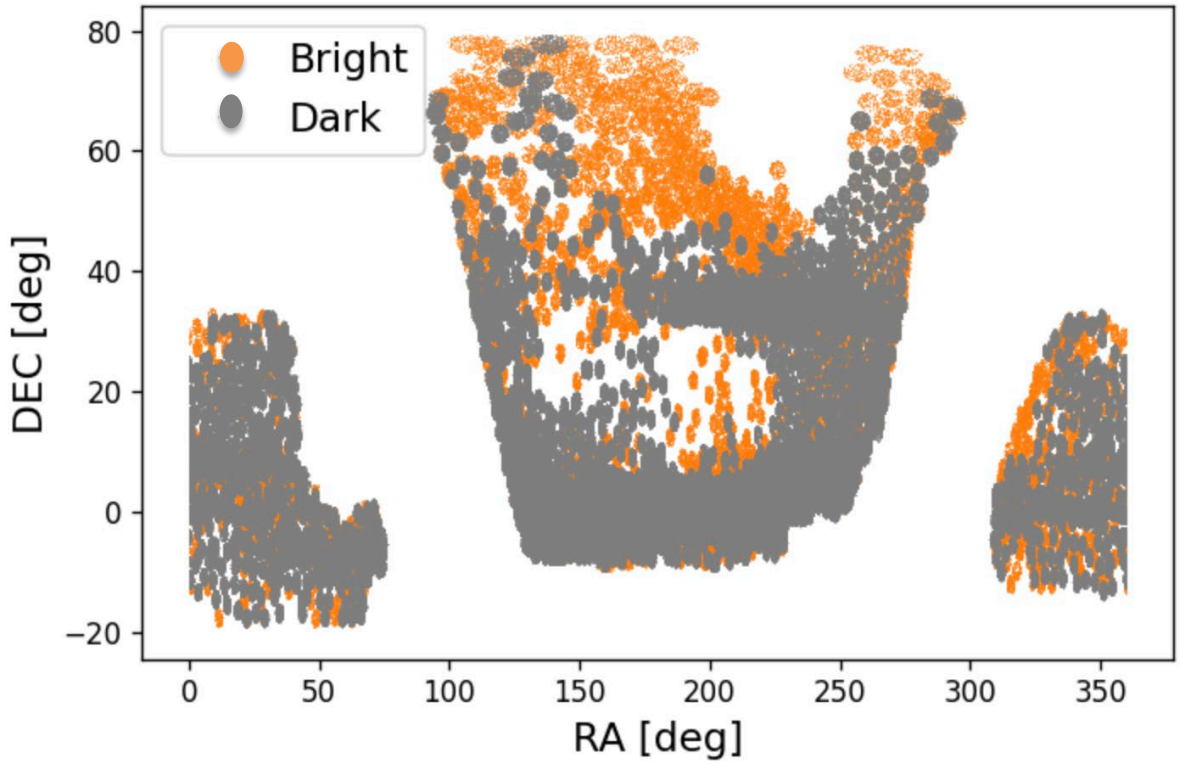
Cutsky LRG 0.4<z<0.6, MultiGrid recon, density smoothing scale 10 Mpc/h.
Fit power spectrum monopole and quadrupole.



LRG cutsky
0.4<z<0.6



BAO reconstruction on DESI Y1 blinded data

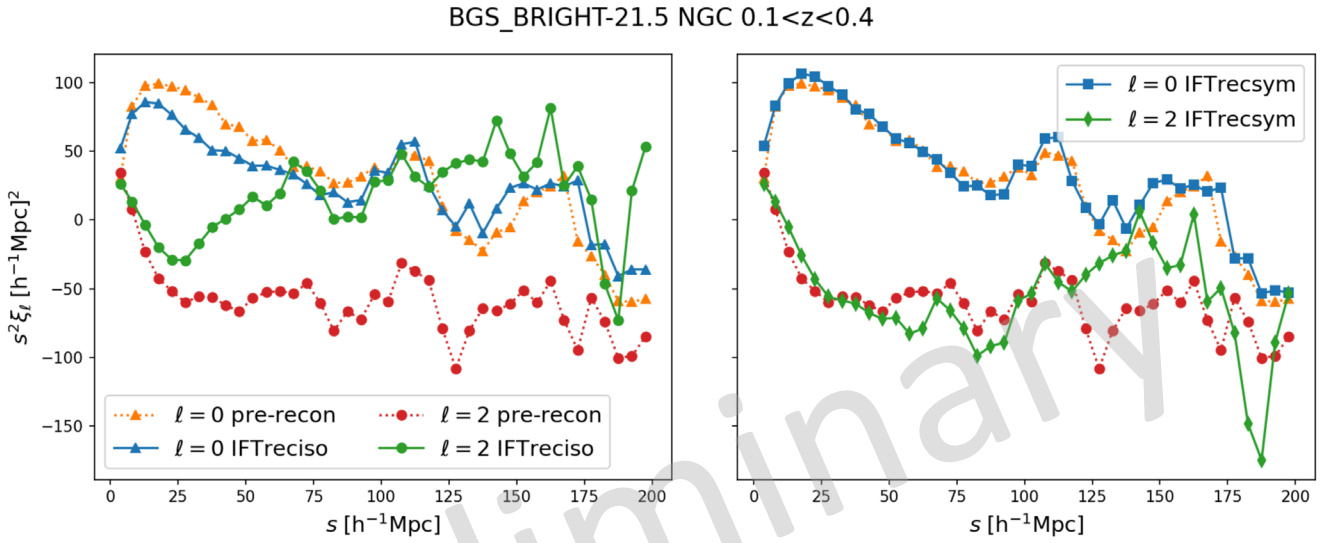


	BGS_BRIGHT_21.5	LRG	ELG_LOPnotqso	QSO
redshift range	0.1<z<0.5	0.4<z<1.1	0.8<z<1.6	0.8<z<3.5
NGC	326,657	1,510,389	1,845,724	818,936
SGC	124,270	686,636	624,018	448,120

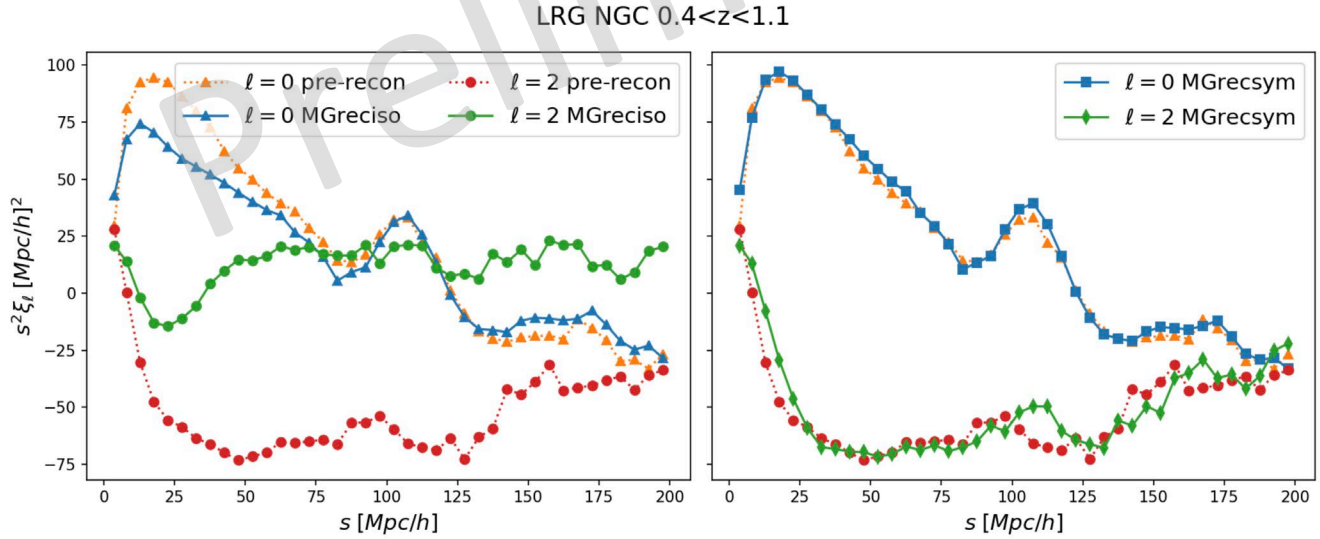
Correlation function before/after BAO reconstrction

NGC

BGS Bright

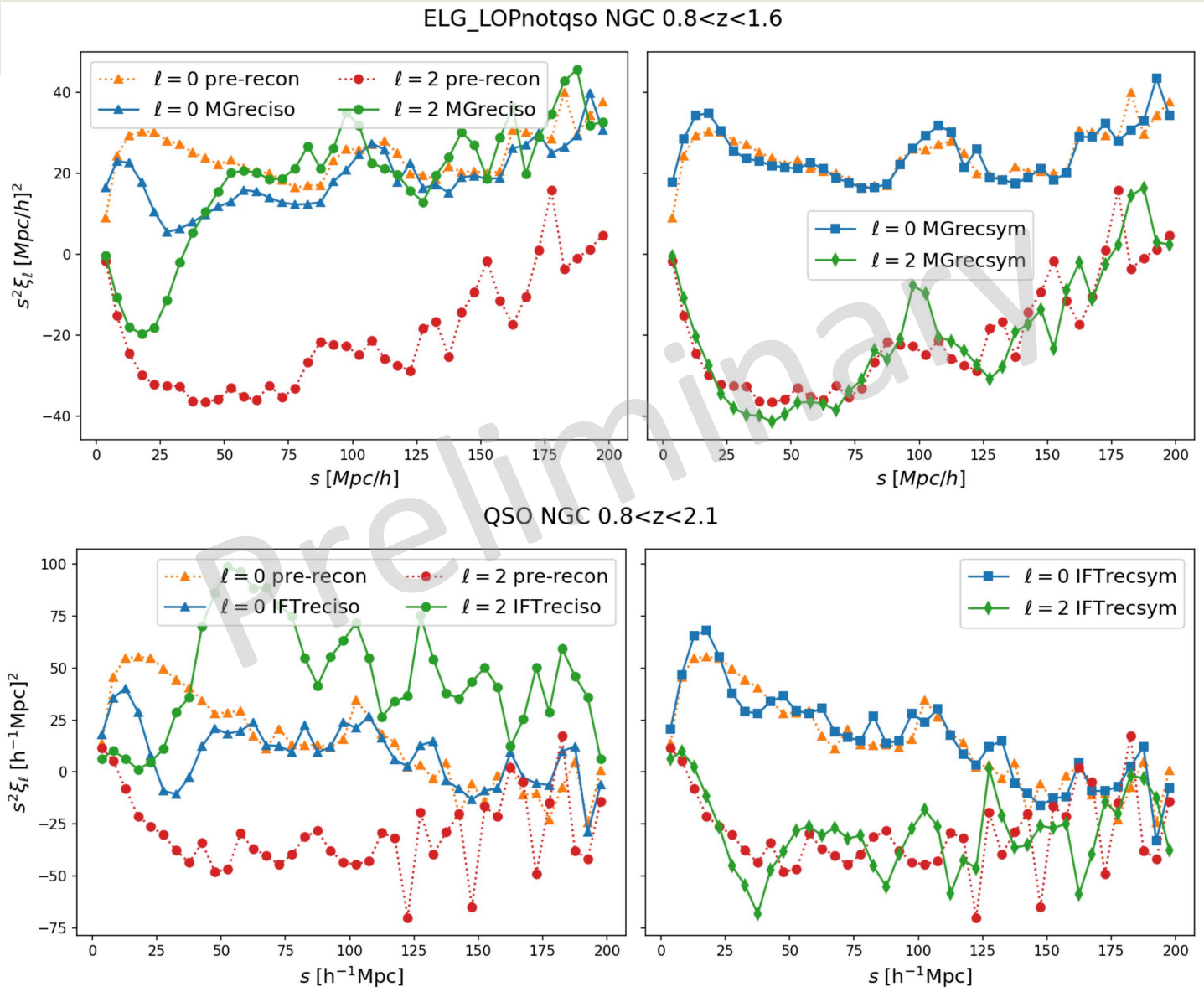


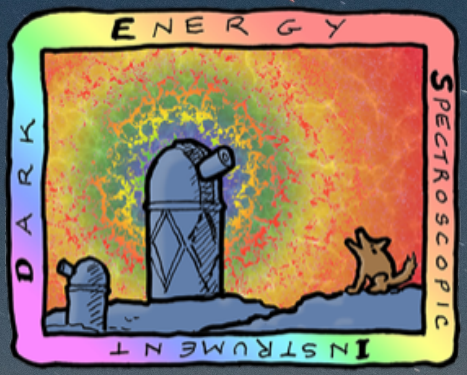
LRG



ELG

QSO


ELG_LOPnotqso NGC 0.8<z<1.6
ℓ = 0 pre-recon
ℓ = 2 pre-recon
ℓ = 0 MGreciso
ℓ = 2 MGreciso
ℓ = 0 MGrecsym
ℓ = 2 MGrecsym
$s^2\xi_\ell$ [Mpc/h]^2
s [Mpc/h]
QSO NGC 0.8<z<2.1
ℓ = 0 IFTreciso
ℓ = 2 IFTreciso
ℓ = 0 IFTrecsym
ℓ = 2 IFTrecsym
$s^2\xi_\ell$ [h^{-1}Mpc]^2
s [h^{-1}Mpc]
Preliminary



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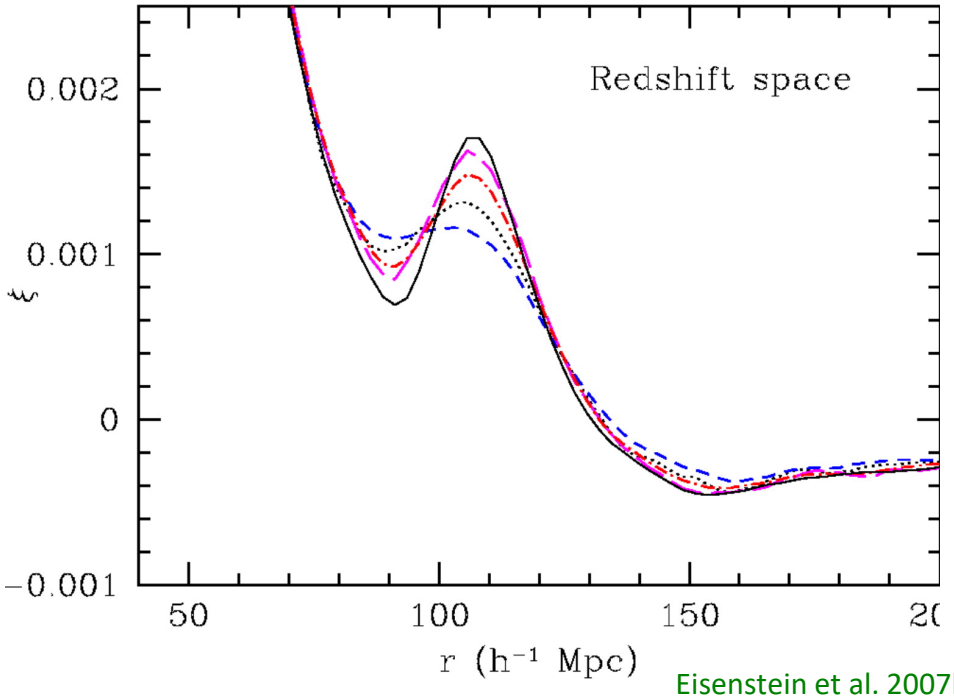
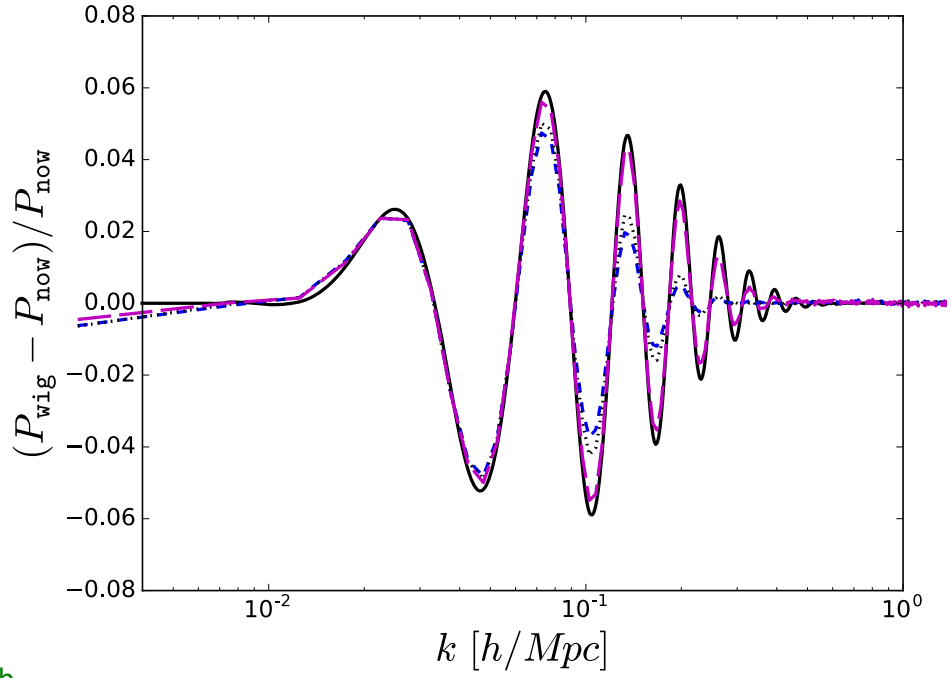
Backup slides

BAO reconstructon reduces the nonlinear systematics from structure growth





Eisenstein et al. 2007b

Black solid line: linear;

Blue: in redshift space before BAO reconstruction;

Magenta line: after density field reconstruction.