

Cosmological inference with halo clustering reconstructed from the redshift-space galaxy distribution

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Ryuichiro Hada (Postdoc Fellow, ASIAA)
with Teppei Okumura (ASIAA)



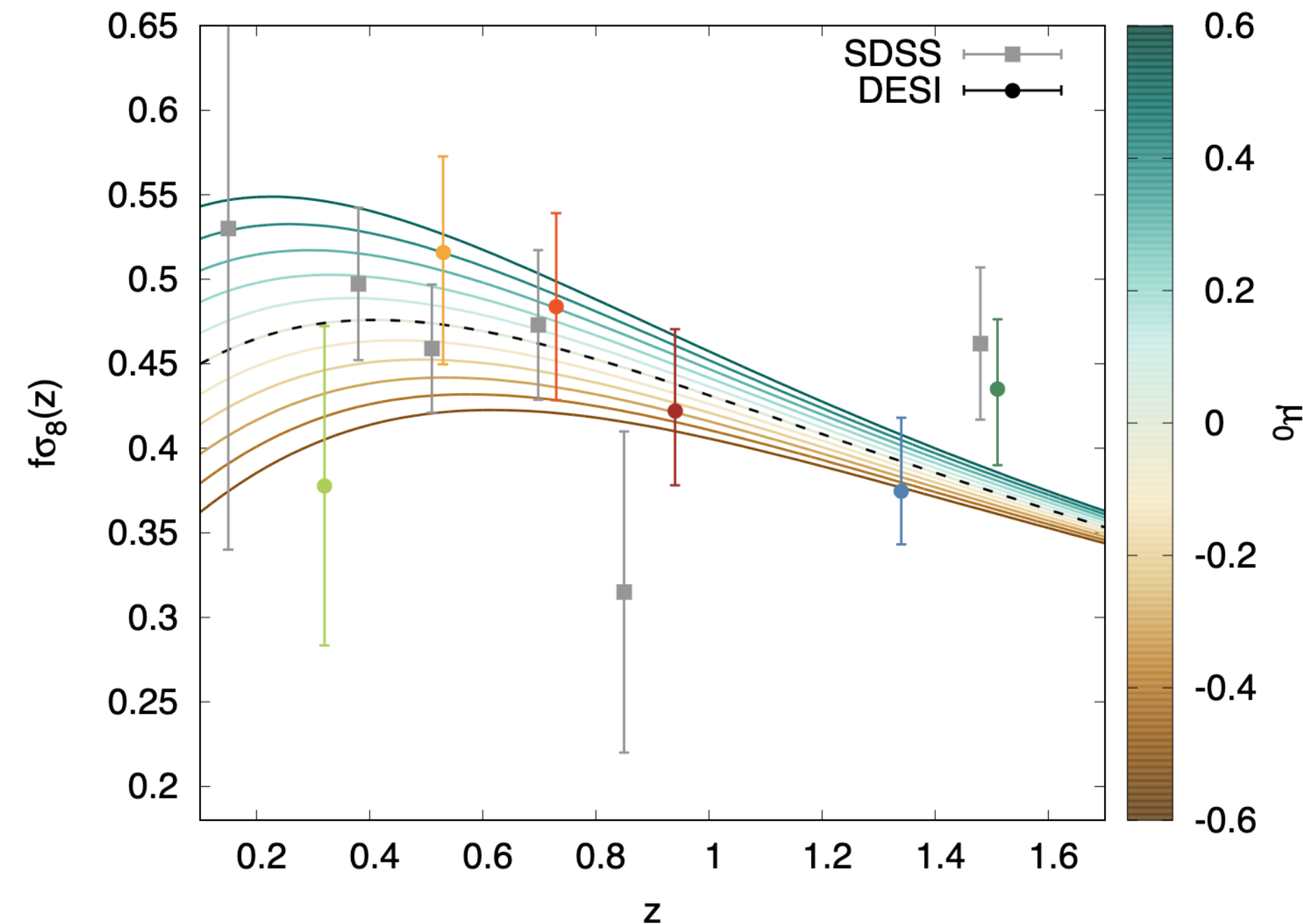
中央研究院
天文及天文物理研究所

ACADEMIA SINICA
Institute of Astronomy and Astrophysics

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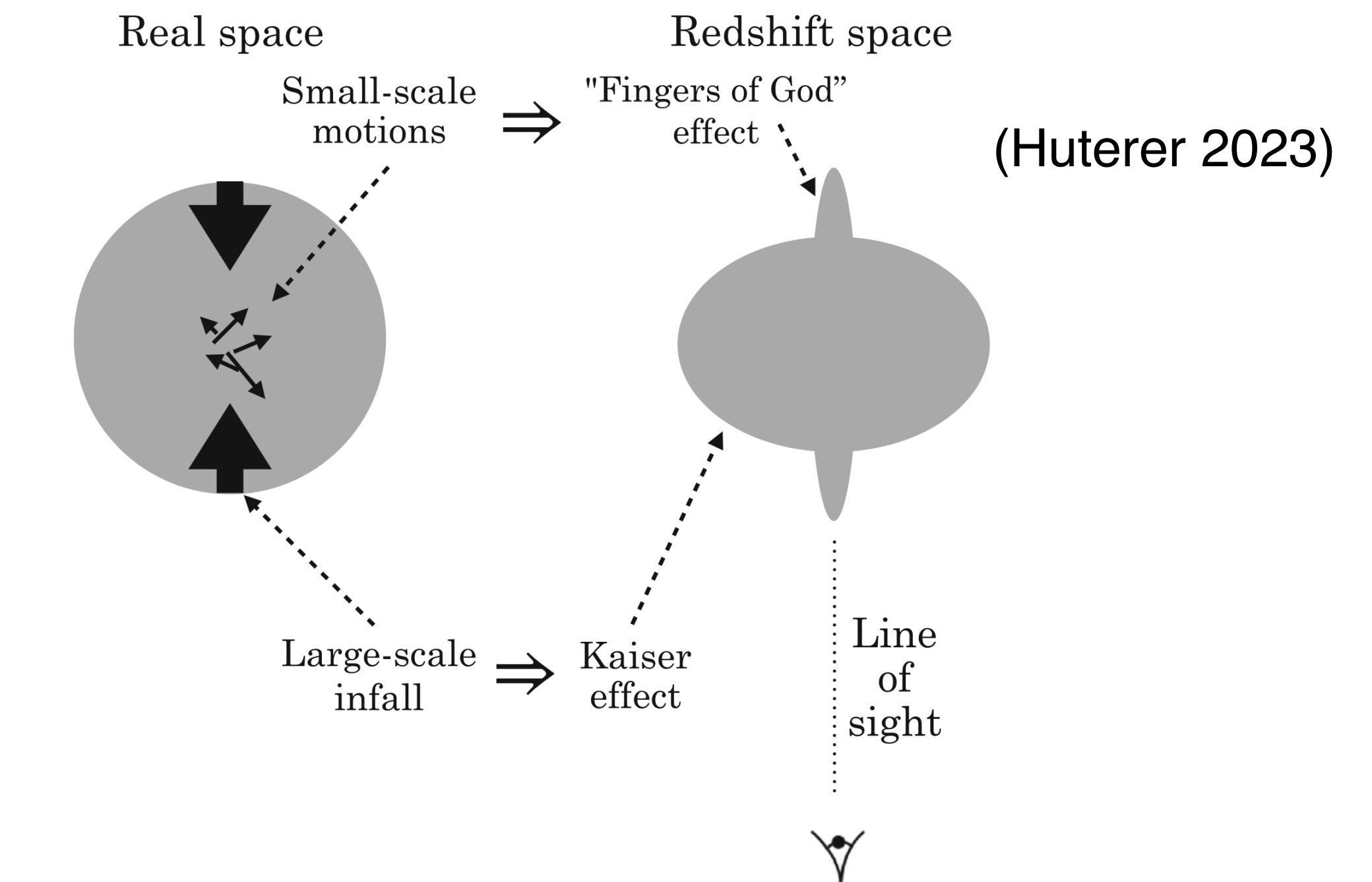
Satellite FoG limits small-scale gains in RSD precision

(DESI 2024 V)



4.7% combined RSD precision

Comparable to the precision accumulated over ~20 years

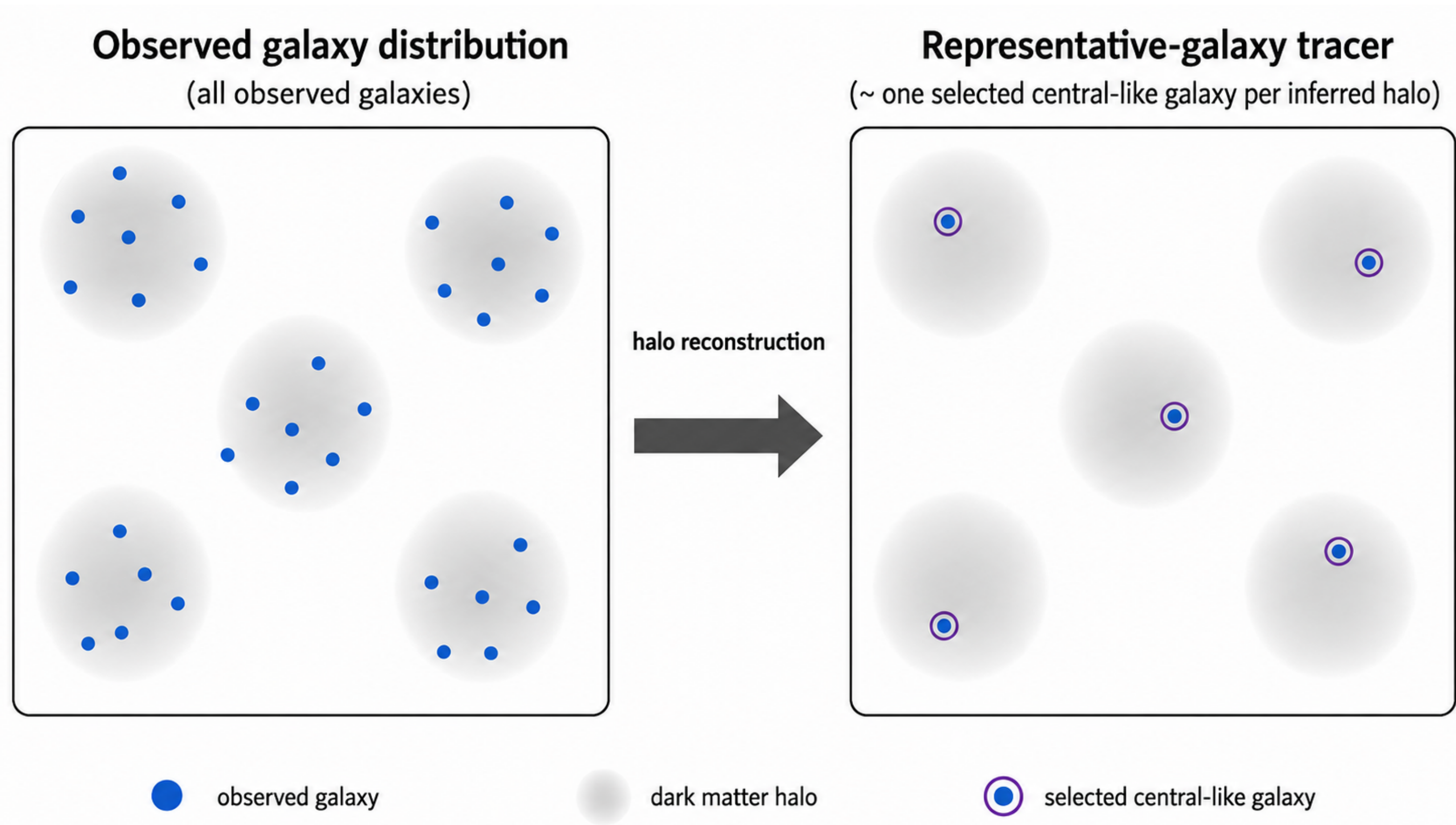


Satellite virial motions

produce nonlinear line-of-sight distortions

Can we suppress satellite FoG while preserving coherent RSD?

Key idea: select one galaxy to represent each halo



Goal:

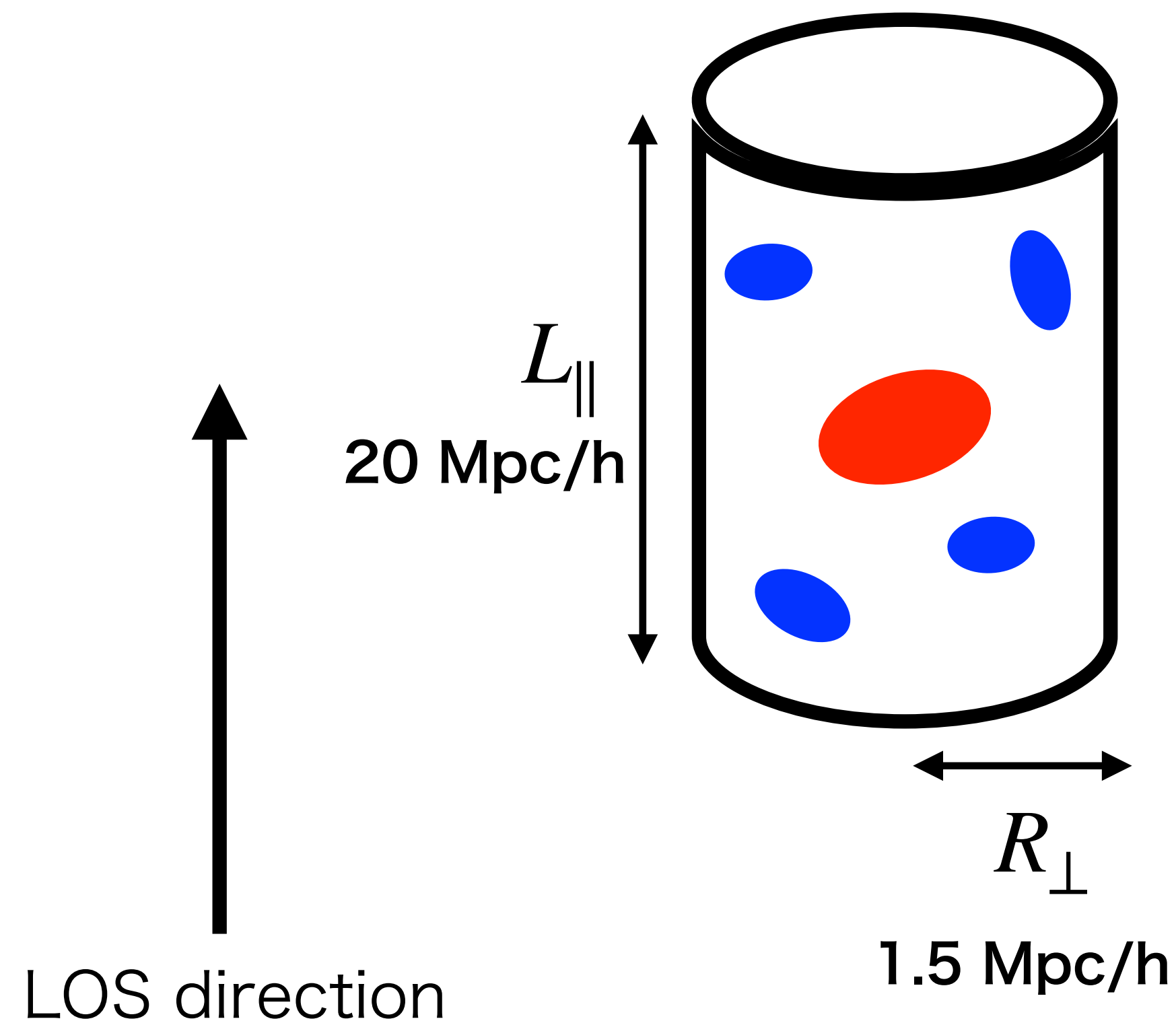
construct a cleaner, approximately one-object-per-halo tracer
(e.g., Reid+2009a,b; Okumura+2017)

Why?

- reduced satellite FoG
- suppressed 1-halo pairs
- cleaner redshift-space clustering

How can we select representative galaxies from observations?

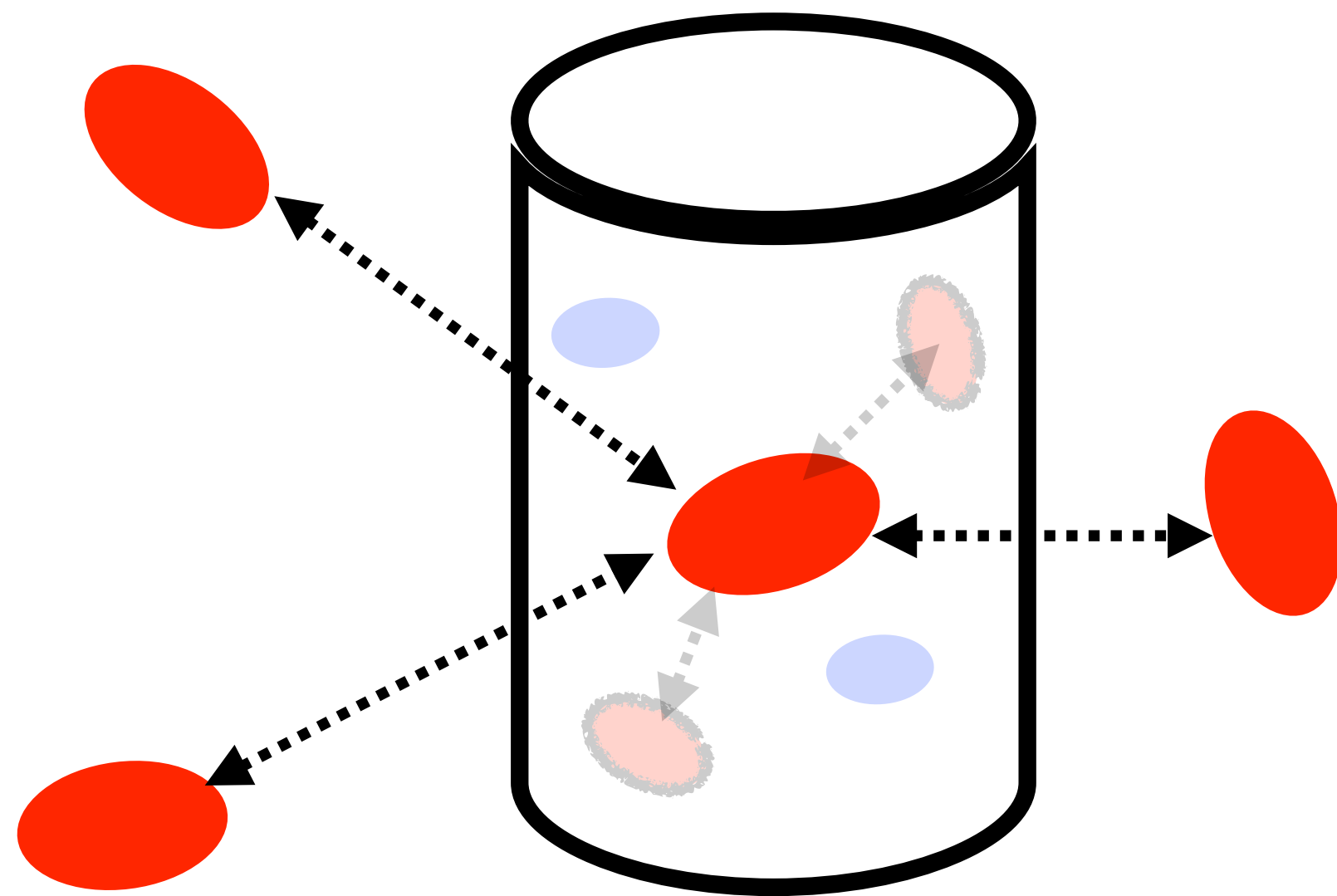
Cylinder-grouping (CG) method (based on Okumura+ 2017)



1. Rank galaxies by a halo-mass proxy (e.g., local density, luminosity)
2. Select the highest-ranked remaining galaxy as a **central representative**
3. Classify all other galaxies within a LOS-aligned cylinder as **satellite candidates**
4. Remove the central and satellites from the ranked list, and repeat until the list is exhausted

The LOS-elongated cylinder captures satellites displaced by the FoG effect

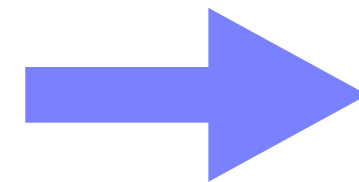
Known CG systematic 1: small-scale exclusion



Misidentification of central/satellite galaxies

>> Some pairs of true halo centers inside the cylinder are incorrectly removed

>> **Exclusion effect** (Baldauf+2013, van den Bosch+ 2013)



Can be modeled using the cylinder window function

$$P_h(\mathbf{k}) \rightarrow \underbrace{-V_{\text{excl}} W_R(\mathbf{k})}_{\text{Pure exclusion}} \underbrace{-V_{\text{excl}} [W_R * P_h](\mathbf{k})}_{\text{Clustering modified by exclusion}} + P_h(\mathbf{k})$$

Pure exclusion

Clustering modified by exclusion

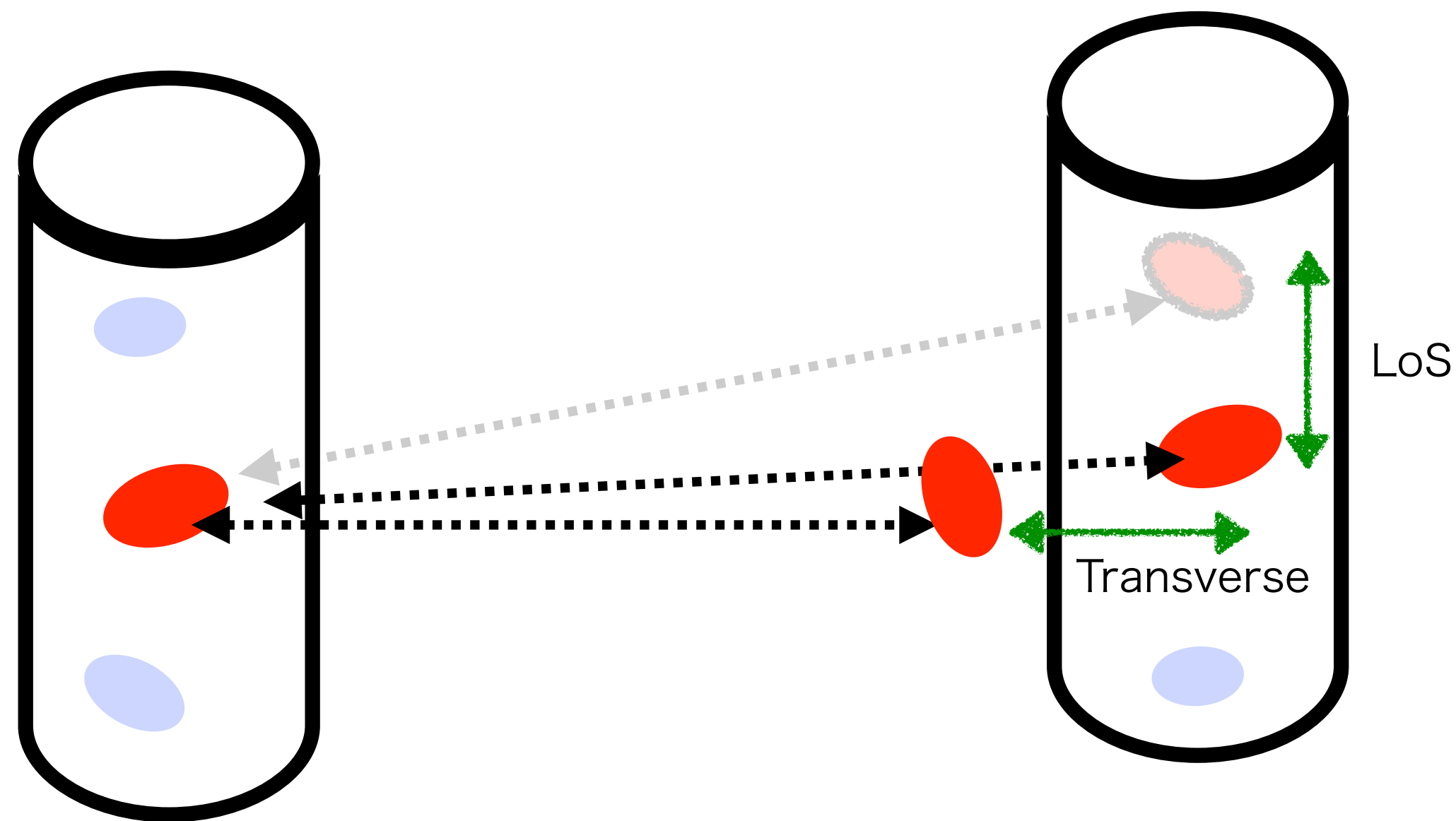
Schematically, at low k , the correction reduces to a constant plus smooth powers of k

$$V_{\text{excl}} = \pi R_{\perp}^2 L_{\parallel}$$

$$W_R(k, \mu) = \frac{2J_1(k_{\perp} R_{\perp})}{k_{\perp} R_{\perp}} \frac{\sin(k_{\parallel} L_{\parallel}/2)}{k_{\parallel} L_{\parallel}/2}$$

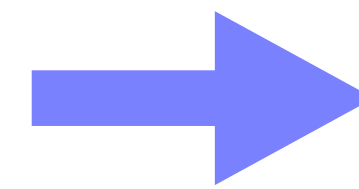
$$\Delta P_{\text{excl}}(k, \mu) = A_0 + k^2 \left[A_{\perp} (1 - \mu^2) + A_{\parallel} \mu^2 \right] + \mathcal{O}(k^4)$$

Known CG systematic 2: large-scale directional masking



Misidentification of central/satellite galaxies

- >> LOS-aligned halo pairs are preferentially merged into the same CG group
- >> Leads to apparent large-scale anisotropy (**Directional masking**)



Okumura+ (2017) proposed a minimal large-scale model:

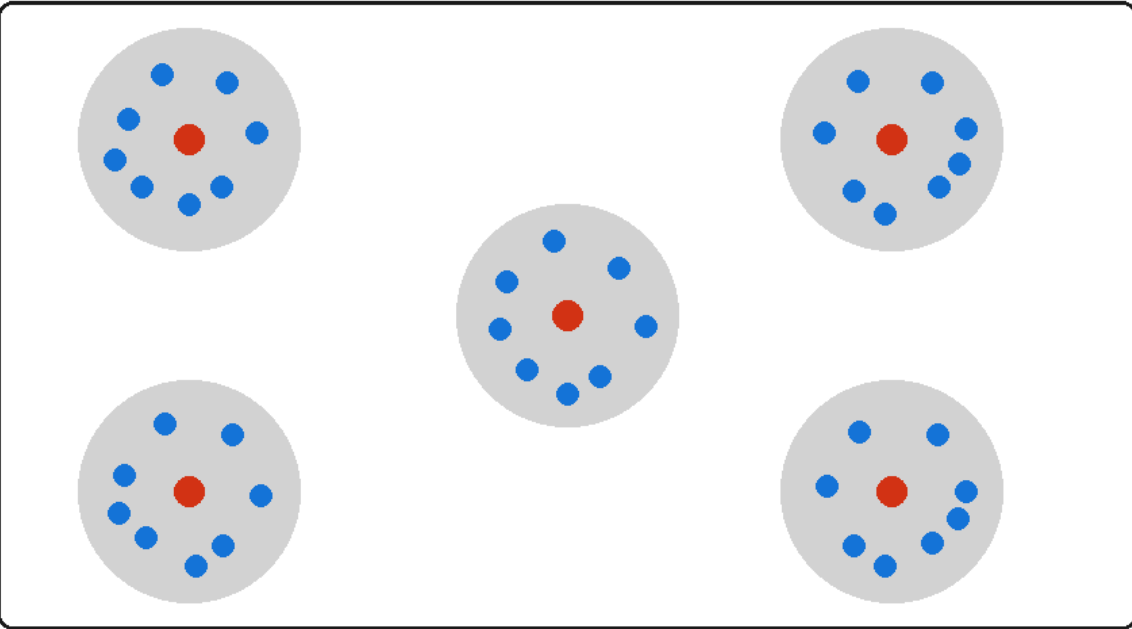
$$P_{\text{rec}}^S(k, \mu) \rightarrow P_{\text{rec}}^S(k, \mu) + \Delta P_{\text{mis}}^S(k, \mu),$$

$$\Delta P_{\text{mis}}^S(k, \mu) = \alpha(\mu) P_{\text{lin}}^R(k)$$

$$\mu \equiv \hat{\mathbf{n}}_{\text{los}} \cdot \hat{\mathbf{k}}$$

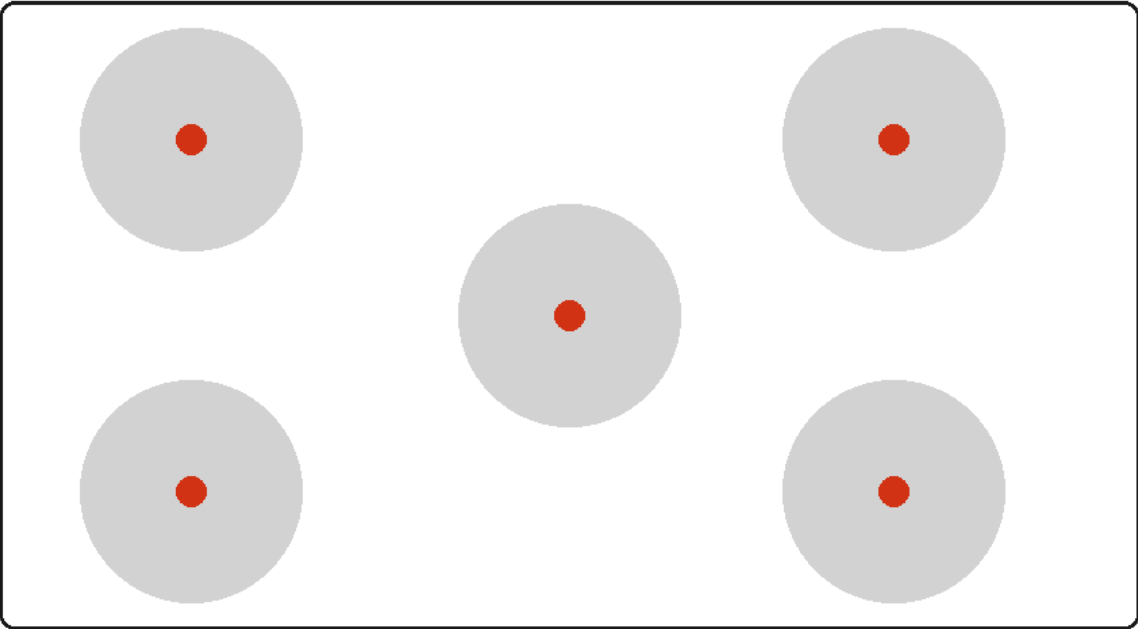
Mock test: three tracer samples (Hada & Okumura, 2026)

Galaxies (DESI-like LRG)
centrals + satellites



True host halos

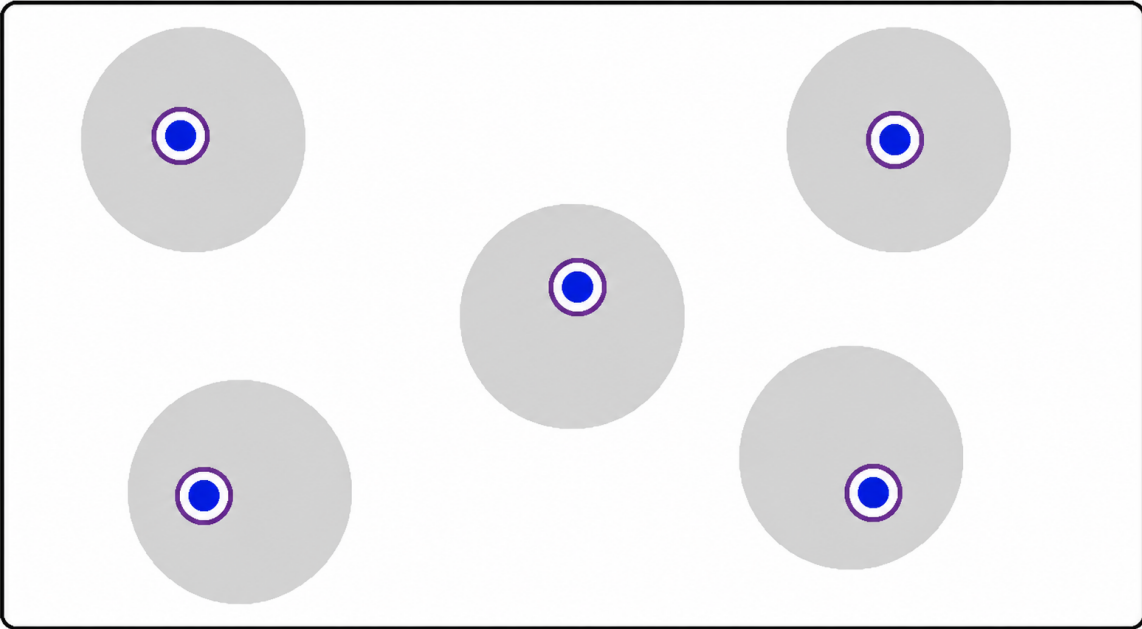
halos hosting at least one mock galaxy



populate halos



Selected central-like galaxies
observable proxy



cylinder grouping
(our reconstruction)

validation target

Controlled test:

Can the observable proxy recover true-halo clustering and cosmological information?

(Maksimova+ 2021)

AbacusSummit N-body simulations

25 realizations

$L = 2 \text{ Gpc/h}$, $z = 1.1$

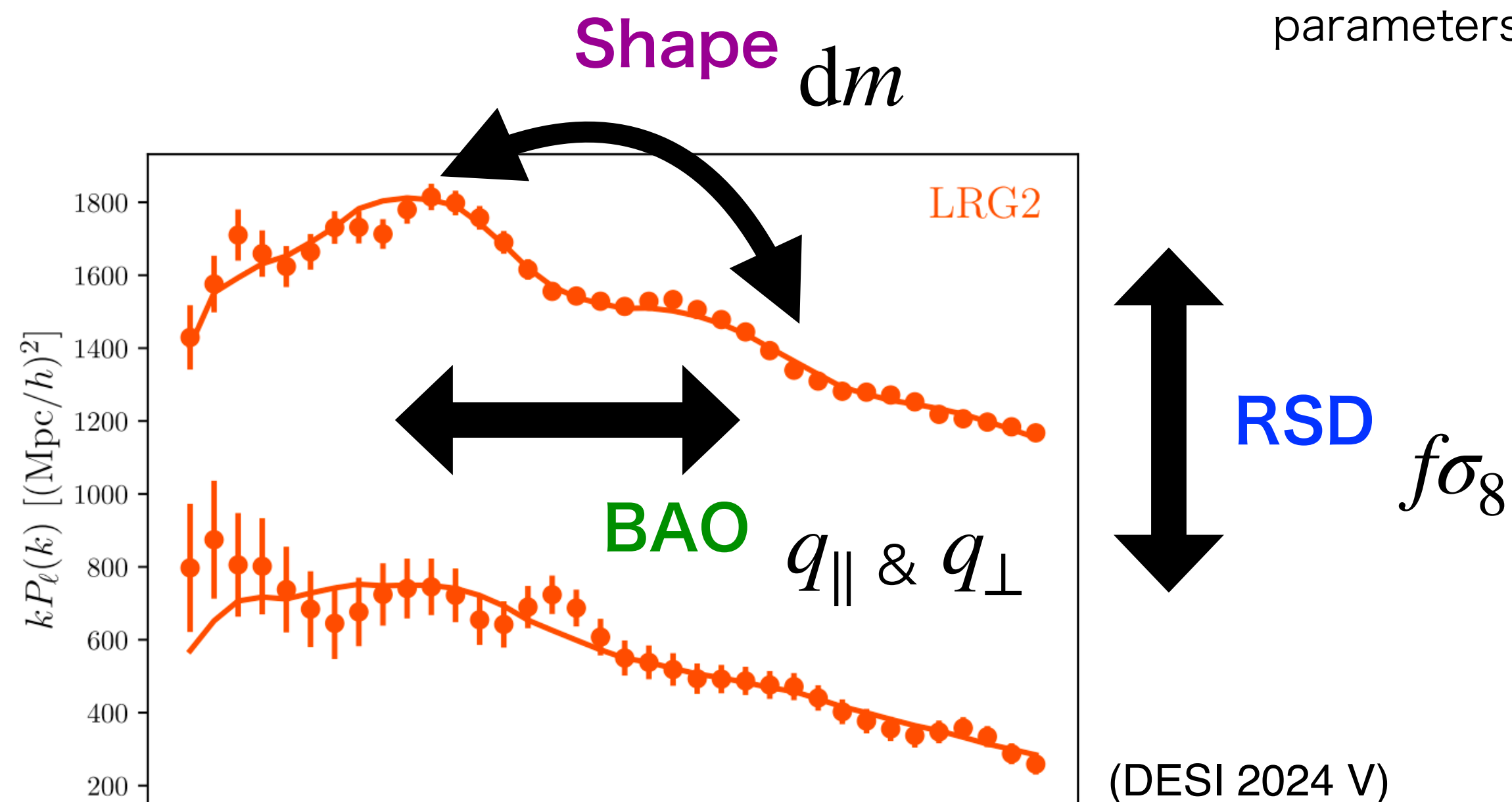
DESI-like LRG HOD

central galaxy satellite galaxy dark matter halo selected central-like galaxy

Baseline model: velocileptors + ShapeFit

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

1-loop LPT power spectrum
determined by the linear power
spectrum and bias parameters



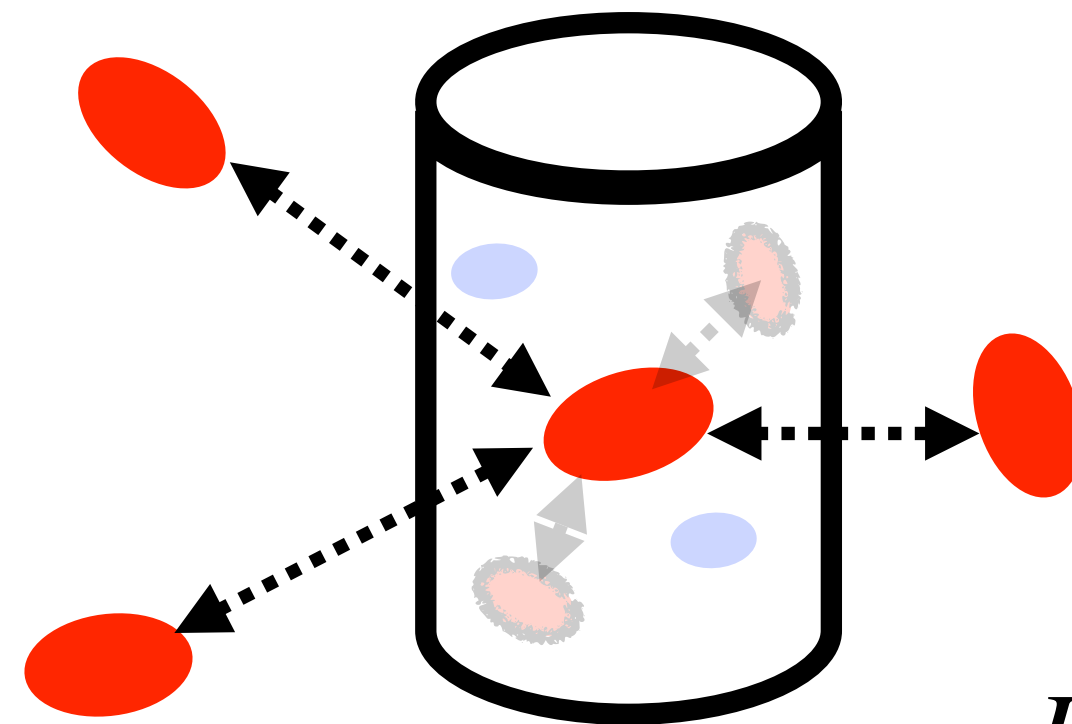
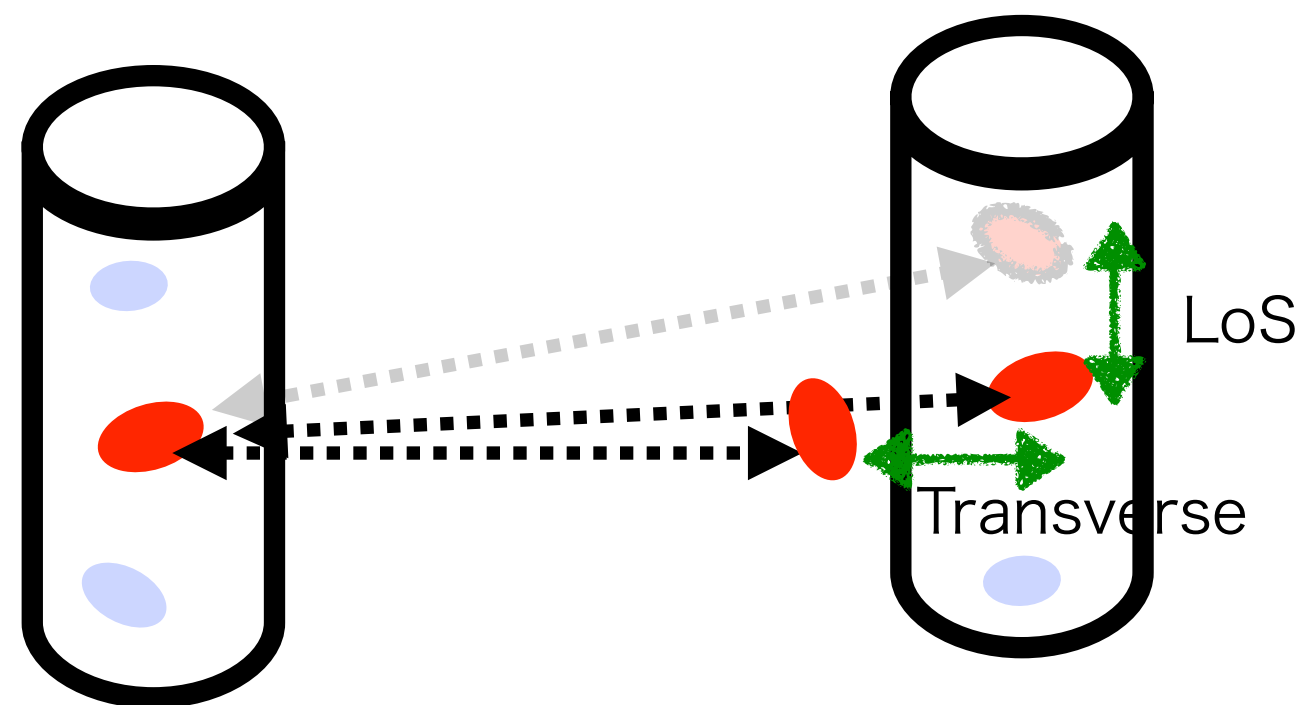
- **velocileptors** (Chen+2020, 2021)
based on the Lagrangian Perturbation Theory (LPT) approach and the Effective Field Theory (EFT) framework
- **ShapeFit** (Brieden+ 2021)
compression into shape, geometry, and growth parameters

Reconstruction systematics enter different model components

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

Deterministic contribution
(perturbative + counterterm)

Stochastic contribution



- **Directional masking:**

- rescales the deterministic contribution using the measured low-k multipole ratio

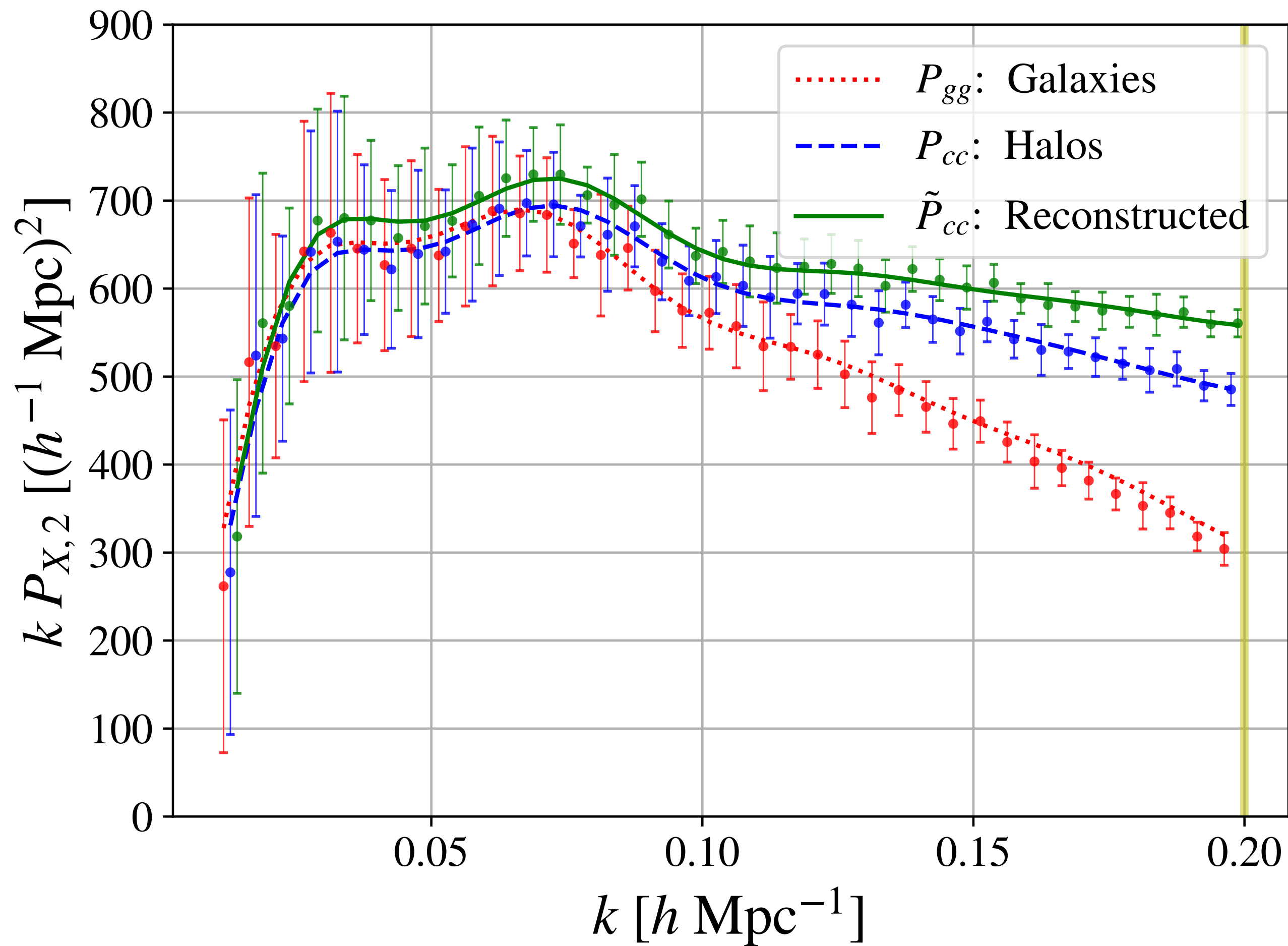
$$R_\ell \equiv \left\langle \frac{P_{\text{rec},\ell}(k)}{P_{\text{gal},\ell}(k)} \right\rangle_{k < 0.03 h \text{ Mpc}^{-1}}$$

- **Exclusion effect:**

- absorbed primarily by the stochastic terms
- residual smooth scale dependence is captured by counterterms

$$P_{\text{rec},\ell}^{\text{model}}(k) = R_\ell \left[P_\ell^{\text{PT}}(k) + P_\ell^{\text{ct}}(k) \right] + P_\ell^{\text{stoch}}(k)$$

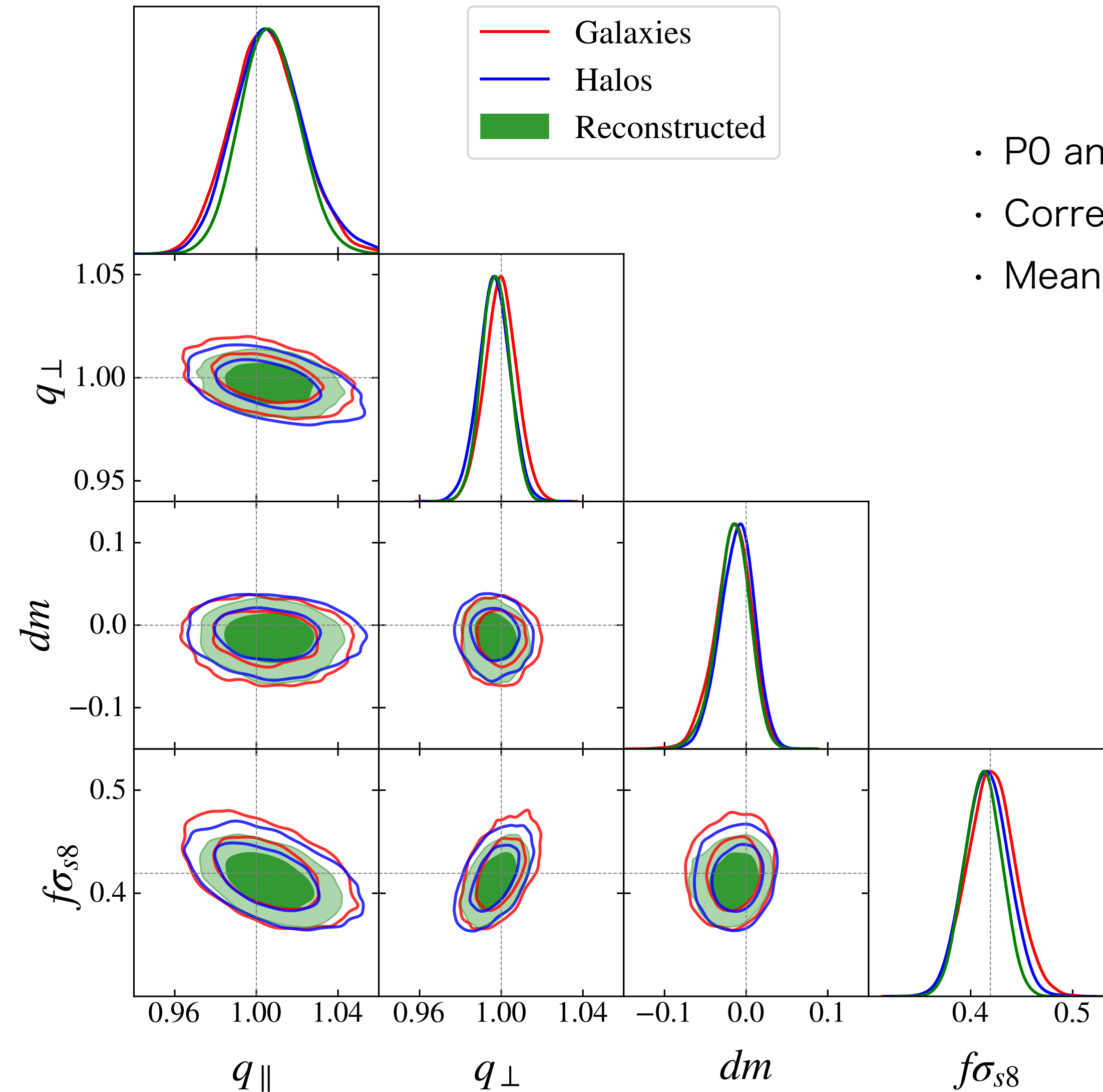
Reconstructed clustering is more halo-like



Satellite FoG is suppressed: the quadrupole moves toward the true-halo signal

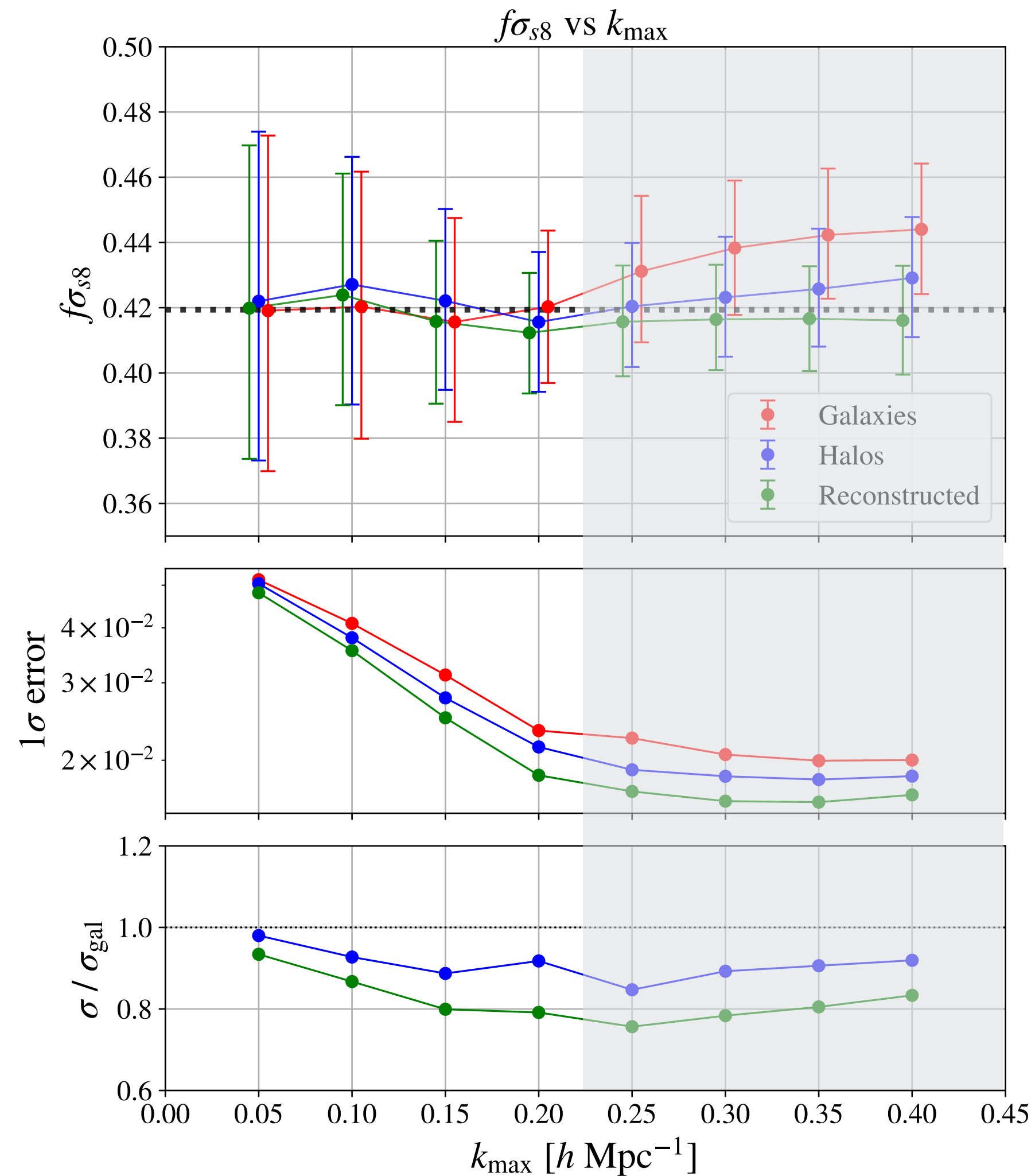
Residual reconstruction effects are captured by the EFT model up to $k_{\text{max}} = 0.2 \text{ h/Mpc}$

Cosmological parameters are recovered without bias



- P0 and P2 up to $k_{\text{max}}=0.2$ h/Mpc
 - Correlations between different k bins are neglected
 - Mean of 25 realizations; uncertainties correspond to one $L=2$ Gpc/h box
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- All four ShapeFit parameters are consistent with the fiducial values
 - Reconstructed constraints are comparable to those from true host halos

Reconstruction yields stable and tighter growth constraints

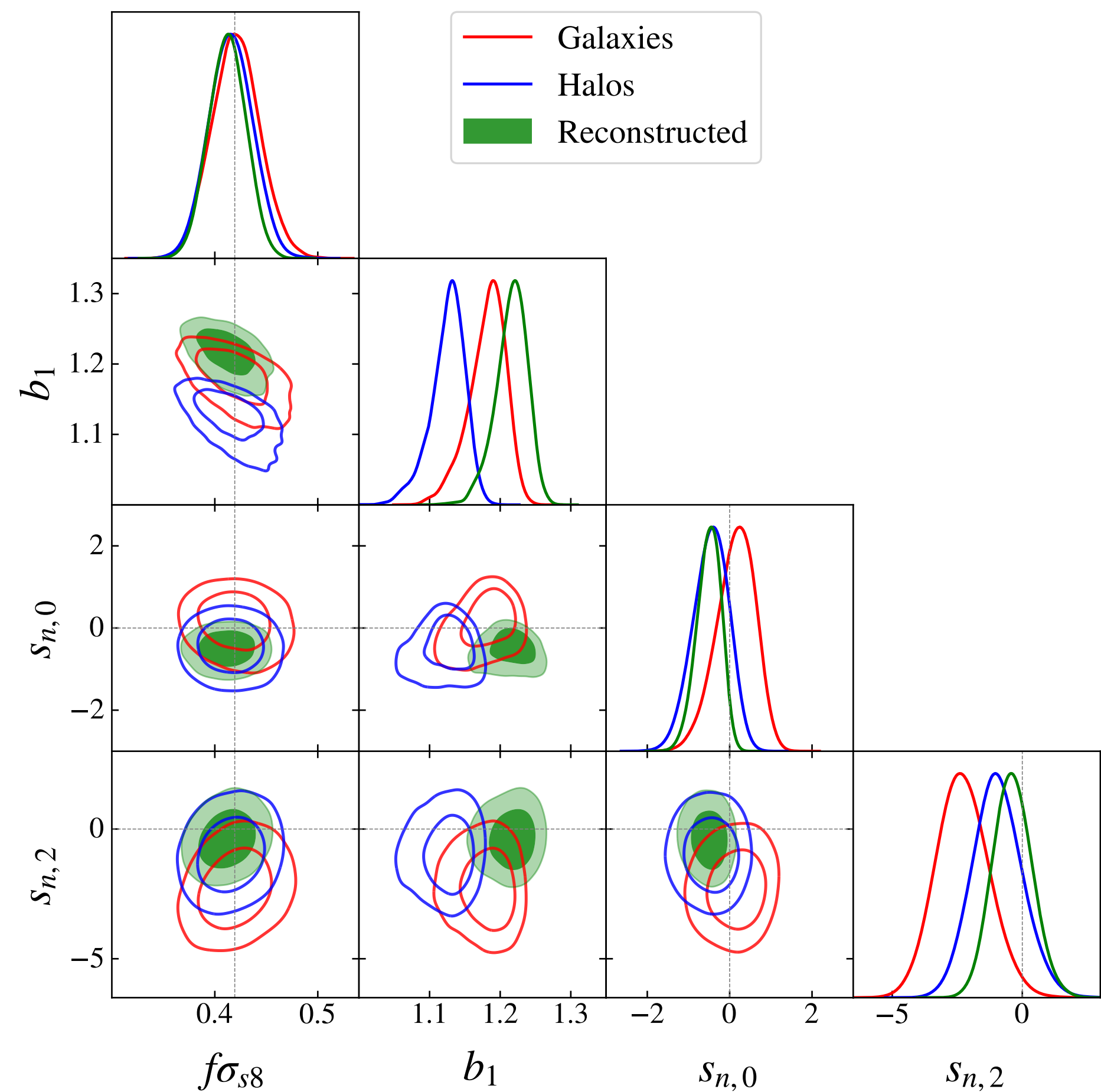


- Reconstructed $f\sigma_8$ remains stable as $k_{\max}$ increases
- Galaxy constraints begin to drift beyond the fiducial scale cut
- Results beyond $k_{\max} = 0.2 \text{ h/Mpc}$ are diagnostic only

$$\sigma(f\sigma_8) : 0.023 \text{ [galaxy]} \rightarrow 0.018 \text{ [reconstructed]} \\ (0.021 \text{ [true halo]})$$

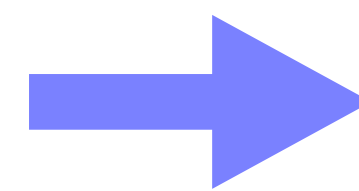
~20% tighter than galaxies at $k_{\max} = 0.2 \text{ h/Mpc}$

Breaking the stochastic-term degeneracy tightens $f\sigma_8$



Flat prior on SN2

- In the galaxy sample, SN0 and SN2 are strongly degenerate
- Reconstruction separates the isotropic and anisotropic stochastic contributions, tightening SN2
- This weakens the SN2- $f\sigma_8$ degeneracy and tightens the growth constraint



The reduced stochastic degeneracy more than offsets reconstruction-induced systematics

Summary

- Cylinder grouping retains one representative galaxy per inferred halo, suppressing satellite FoG and one-halo pairs
- Directional masking and exclusion are captured by $R \ell$ rescaling and standard EFT nuisance terms
- In DESI-like mocks, reconstruction recovers unbiased $f \sigma_8$ with ~20% smaller uncertainty than galaxies at $k_{\text{max}} = 0.2 \text{ h/Mpc}$
- **Outlook:** The reconstructed tracer may also be less sensitive to fiber-assignment incompleteness

Cleaning the tracer before modeling may offer an alternative to more detailed modeling of the original galaxy field