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# The anisotropic distribution of satellites around pairs of dark matter halos

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**The 2nd Shanghai Assembly on Cosmology and Structure Formation**

# Outline

1. Introduction
2. Data and methods
3. Results
4. Summary

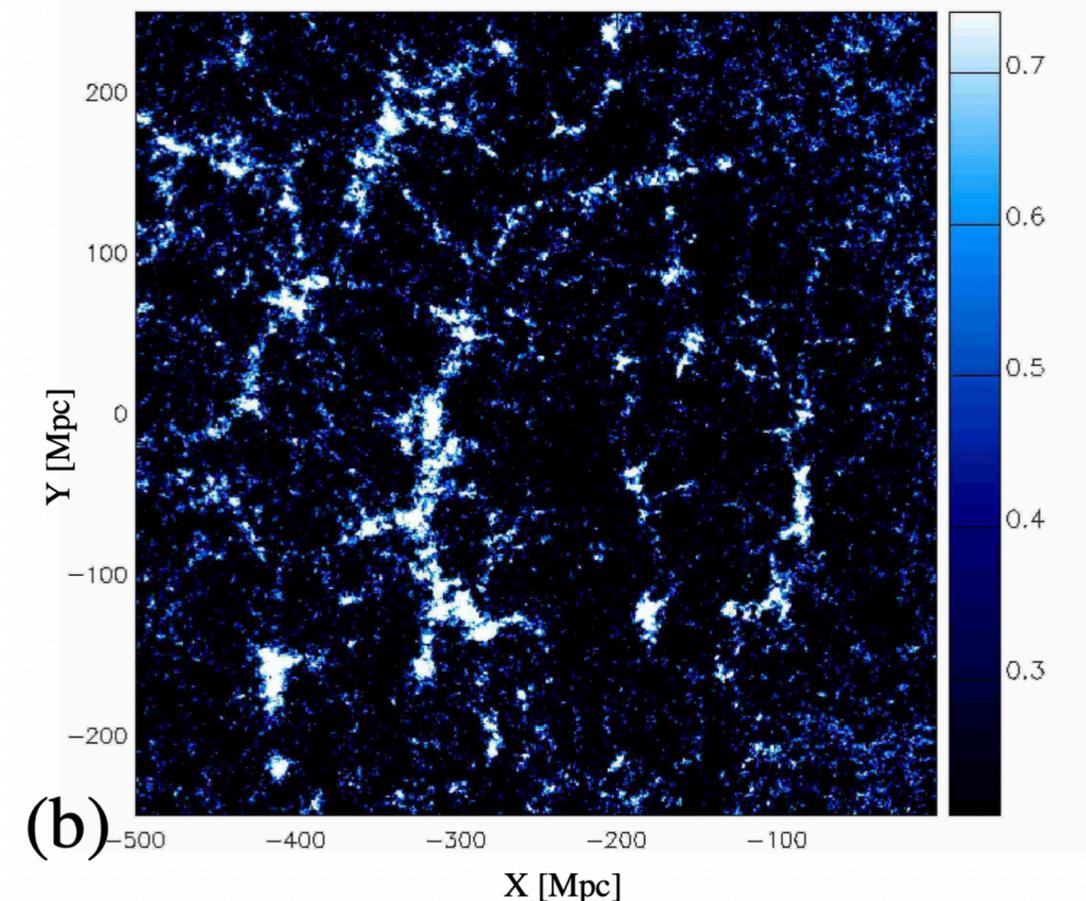
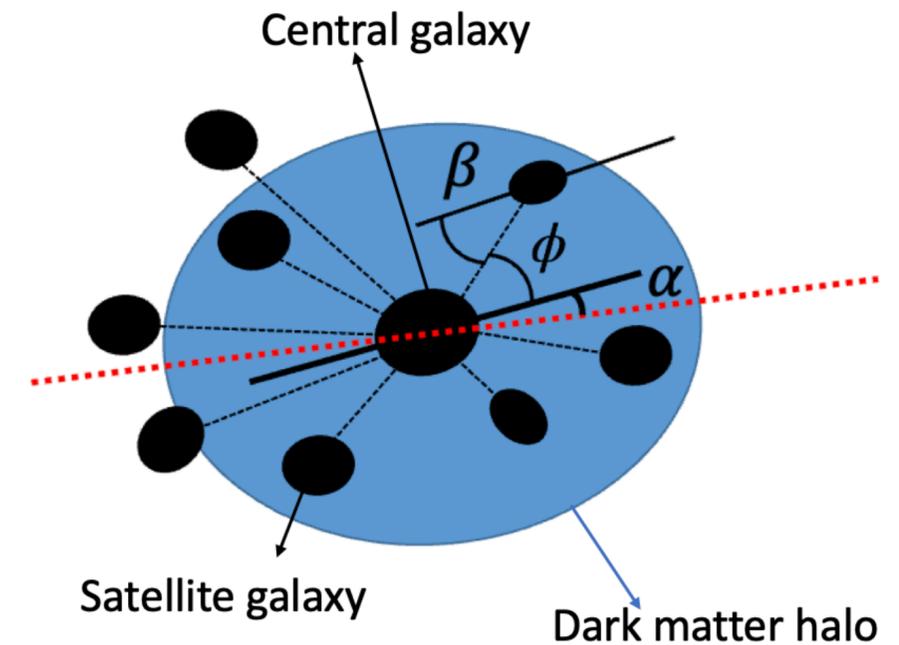
# The orientations of galaxies show various forms of alignment

## Types of alignment:

- satellite galaxies — central galaxies
- central galaxies — host halos
- dark matter halos — large-scale structure

**The alignment can be understood from preferential accretion along large-scale filaments**

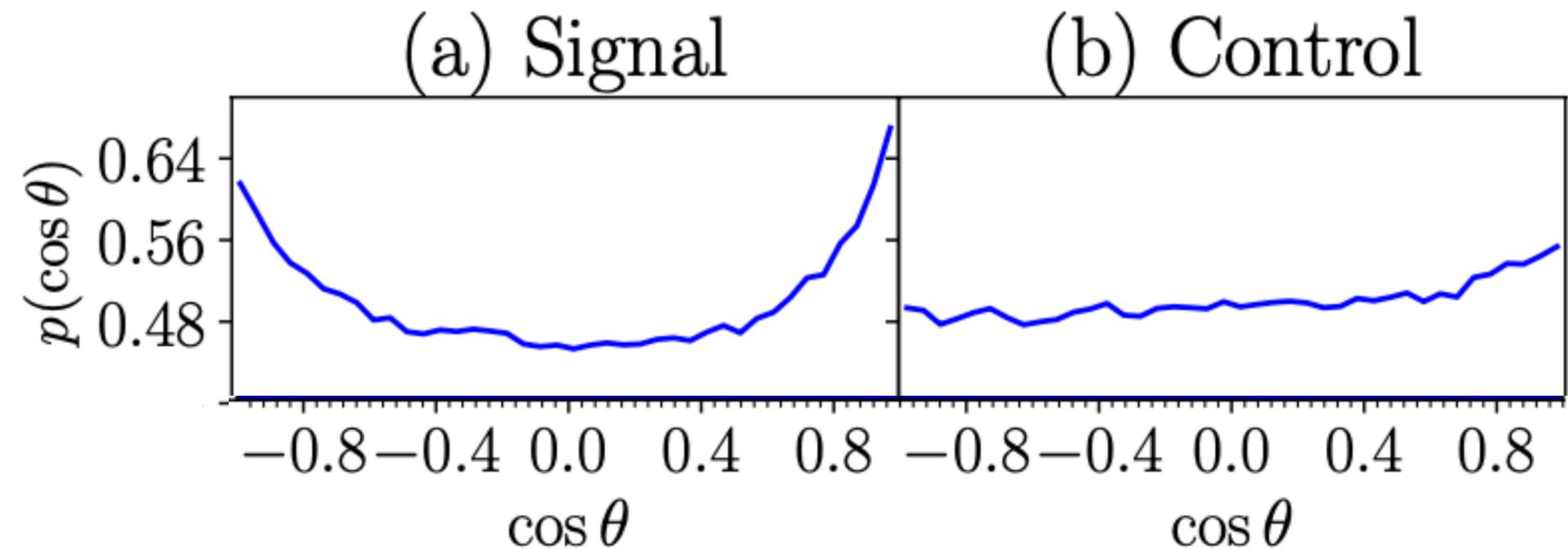
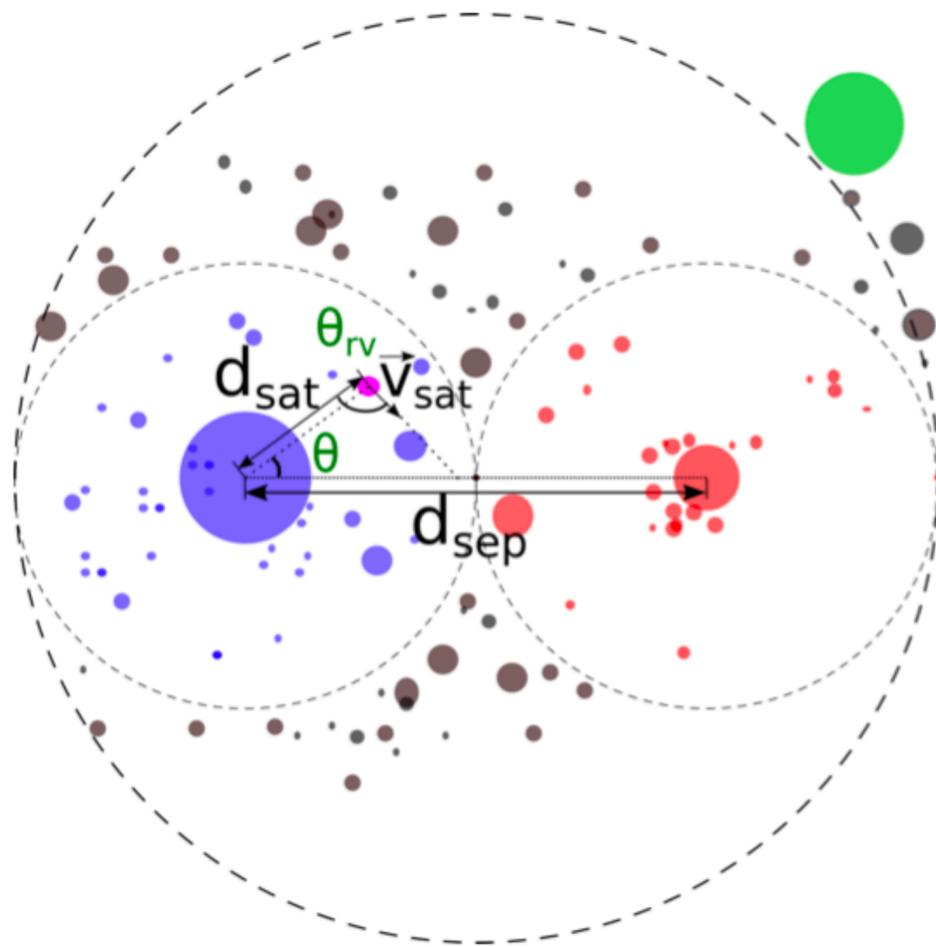
( Brainerd 2005; Agustsson & Brainerd 2006; Yang et al. 2006; Azzaro et al. 2007; Faltenbacher et al. 2007ab, 2009, 2012; Kang et al. 2007; Okumura et al. 2008; Wang et al. 2008, 2009, 2010; Hao et al. 2011; Smargon et al. 2012; Li et al. 2013; Dong et al. 2014; Wang et al. 2014 )



Kitaura et al. 2009

# Satellites around galaxy pairs show anisotropic distribution

- Satellites in Local Group preferentially occupy the space in between the Milky Way and M31. (Conn et al. 2013)
- Gong et al. 2019 showed similar anisotropic distribution in halo pairs with ESM simulation data.



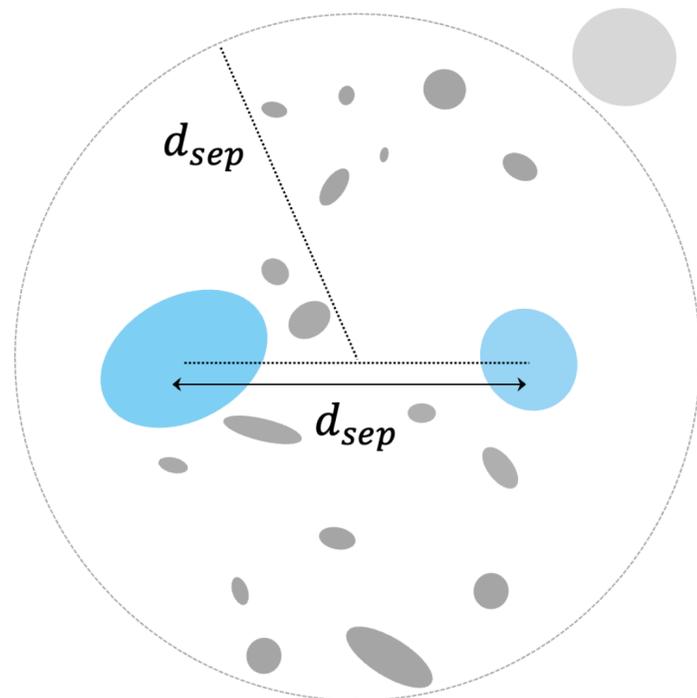
Gong et al. 2019

# Outline

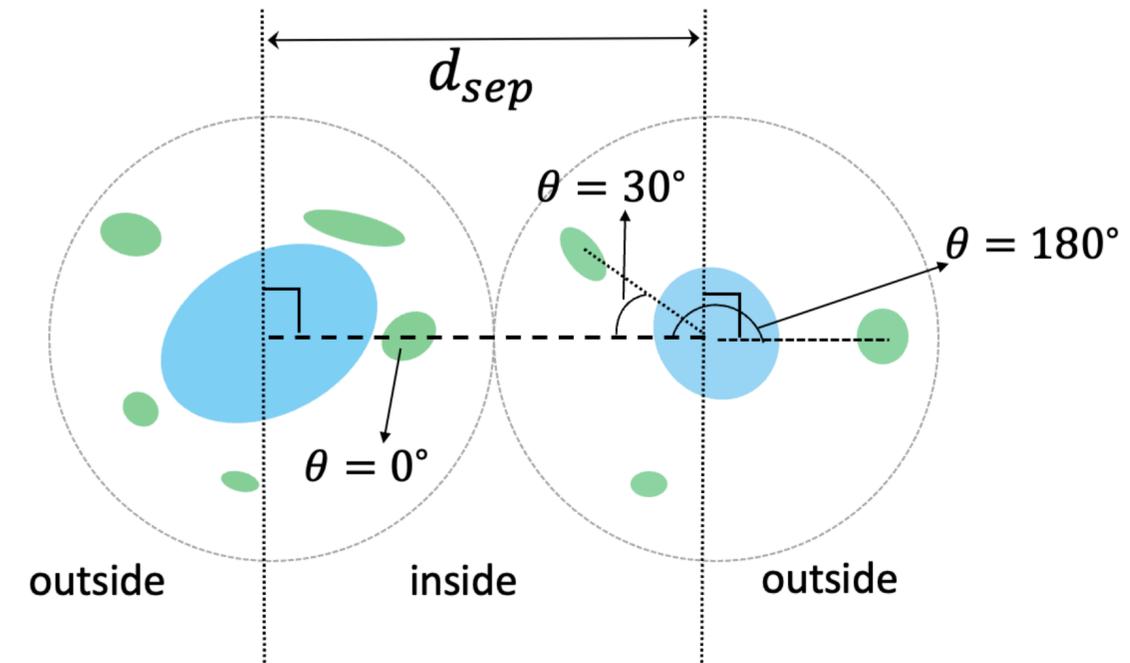
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# Data and methods

- Observational sample: SDSS DR7
- Central galaxies (most massive  $< 2.5 r_{vir}$ ) : correspond to dark matter halos
- Halo pairs: mass dominated (no third halo more massive than 1/2 of the mass of the less massive host halo) in the radius of  $d_{sep}$
- Number of pairs: 180390



halo pair selection

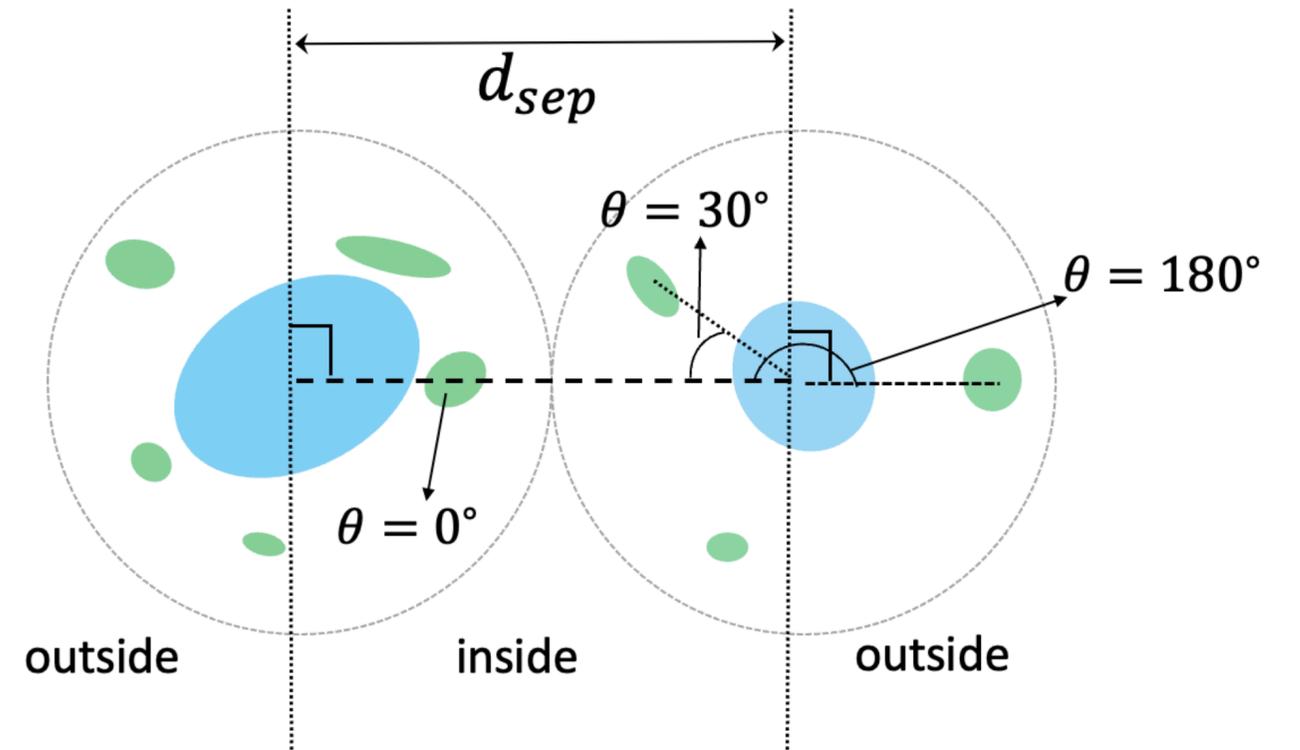
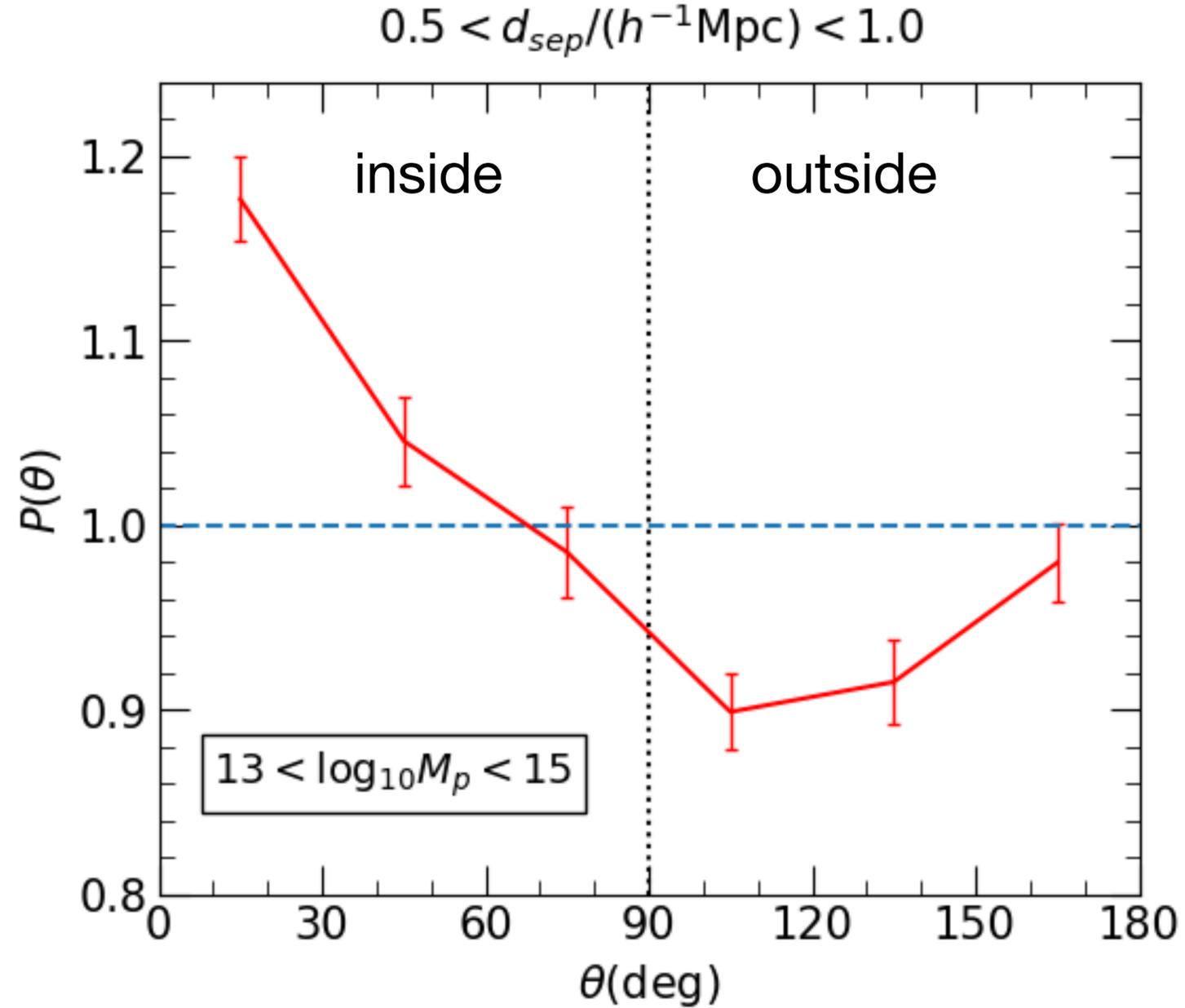


the distribution of satellites

# Outline

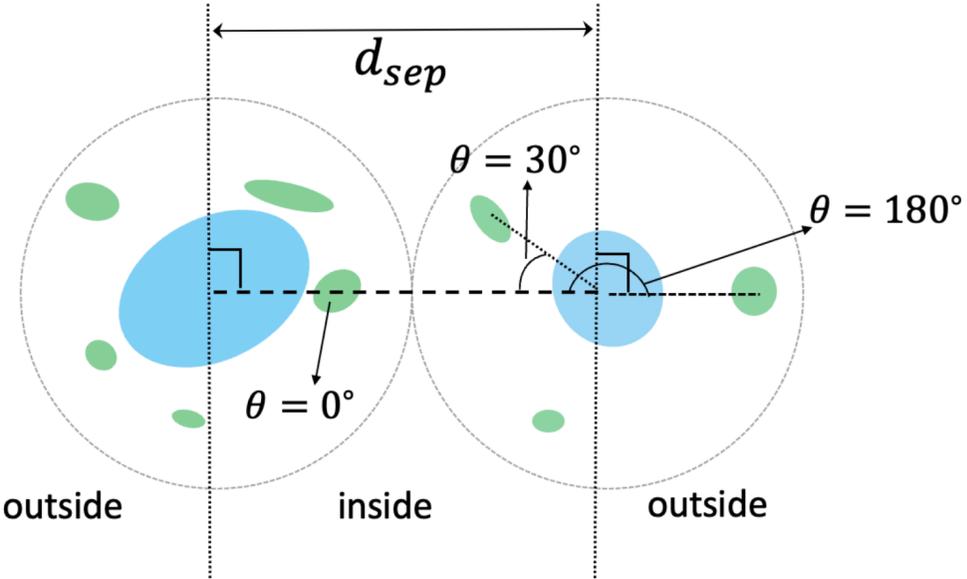
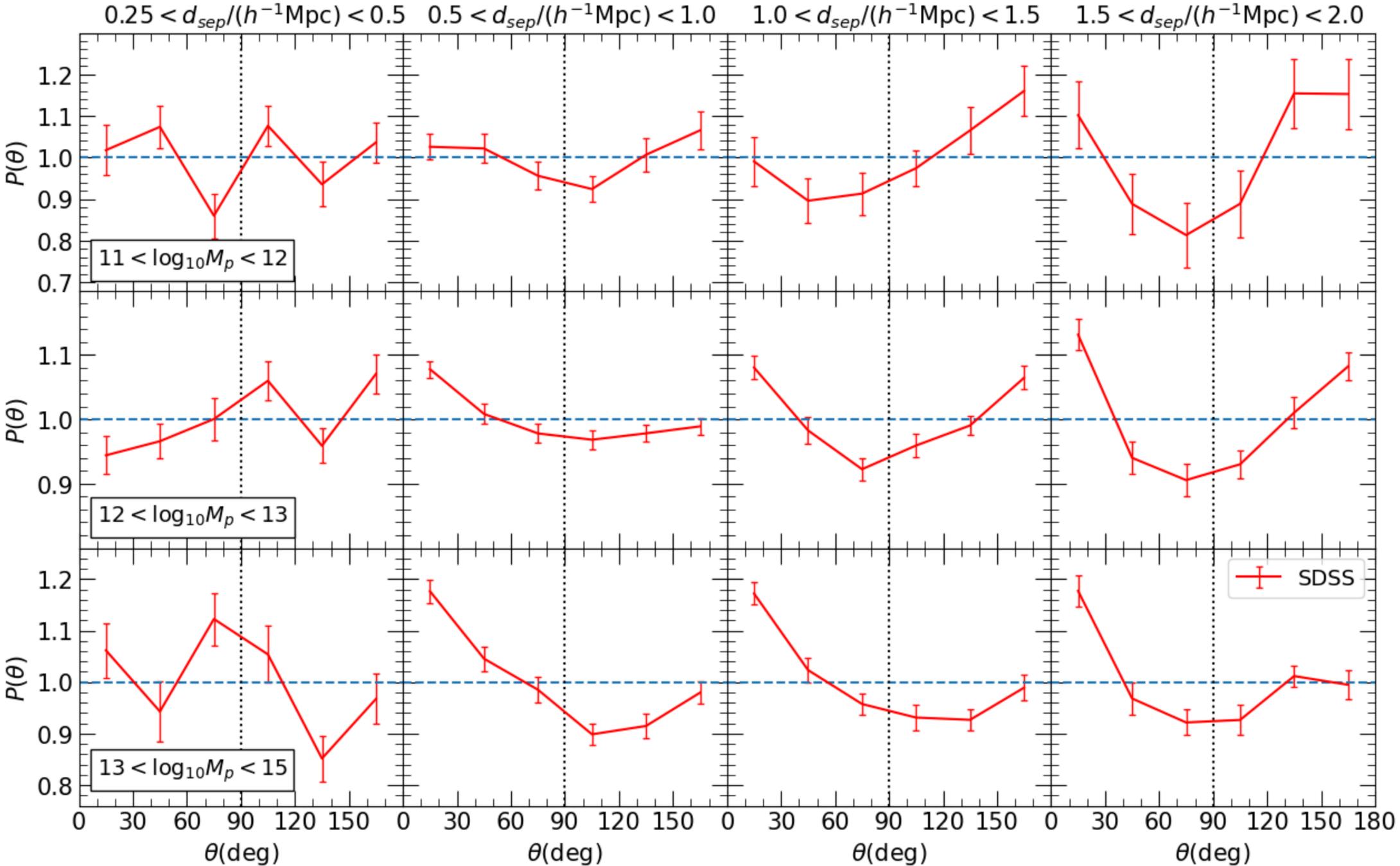
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# Anisotropic distribution of satellites around halo pairs



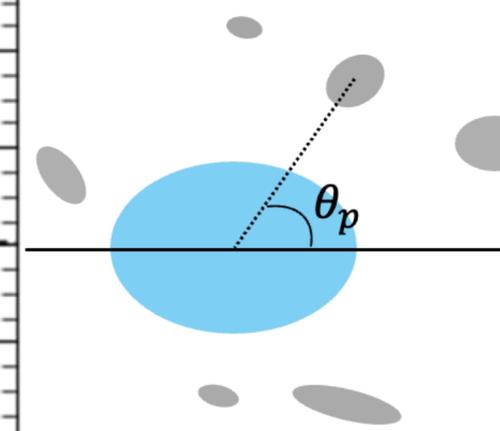
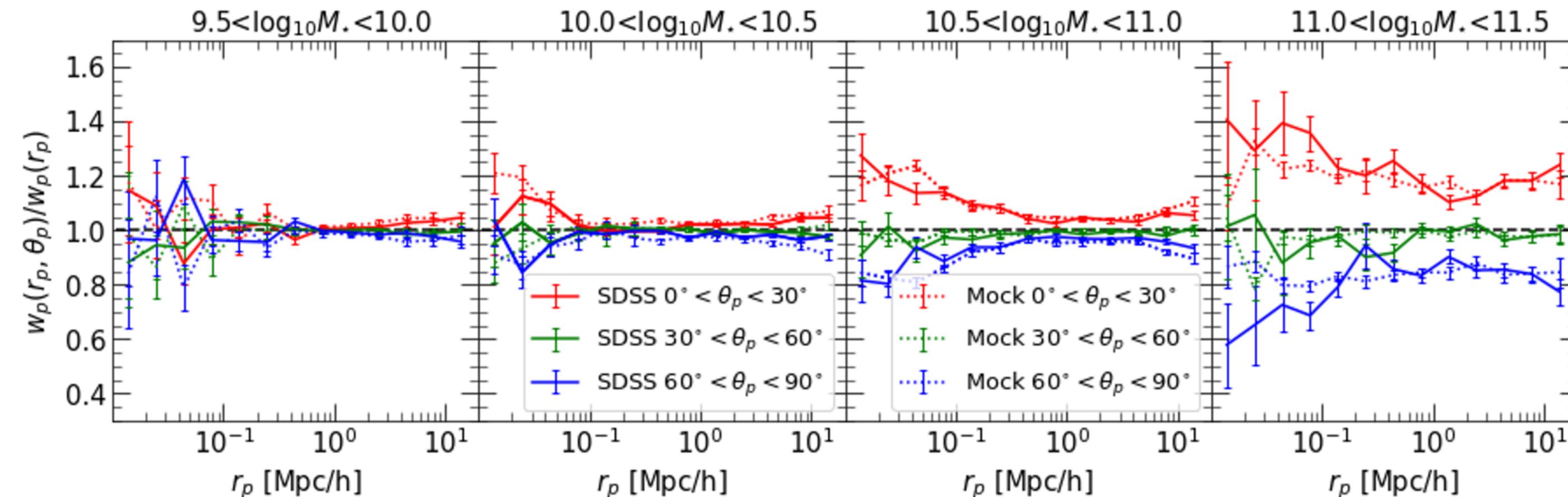
- Satellites align with the line connecting halo pair
- Satellites prefer inside halo pair

# The anisotropic signal increases with pair separation

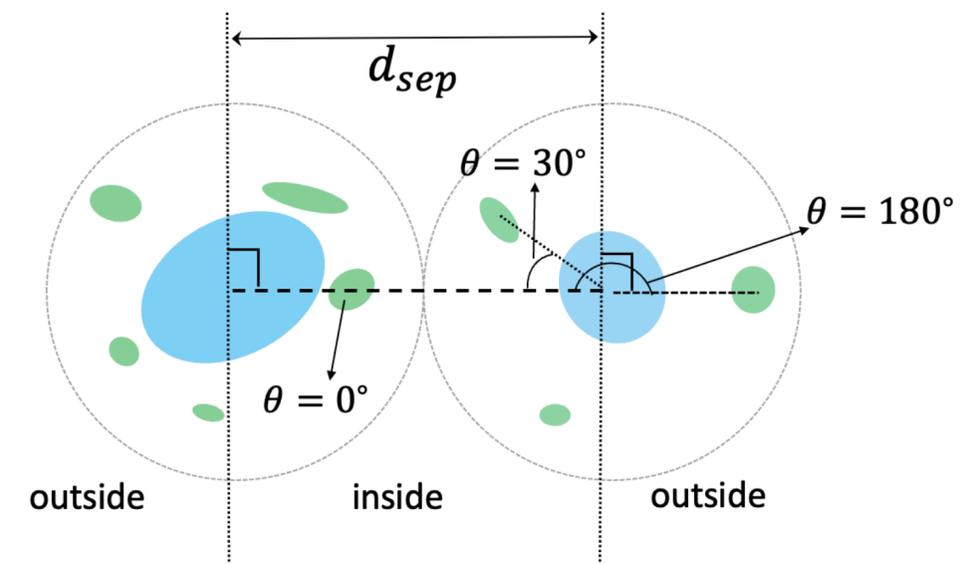
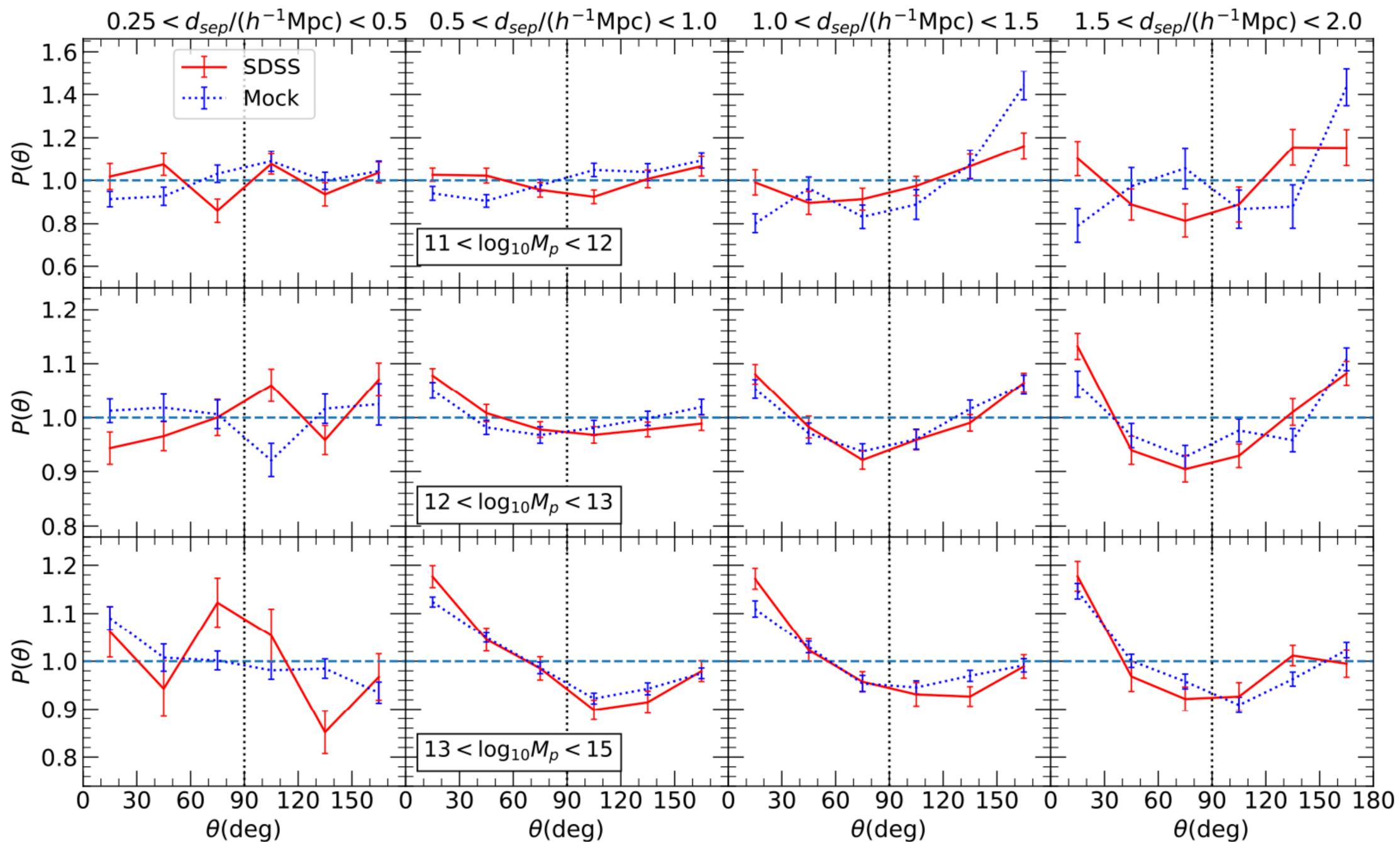


# Mock catalog: based on TNG300

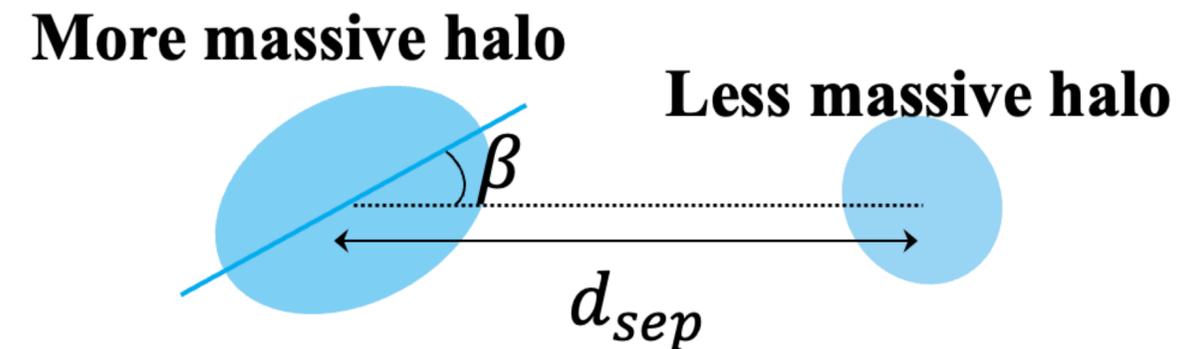
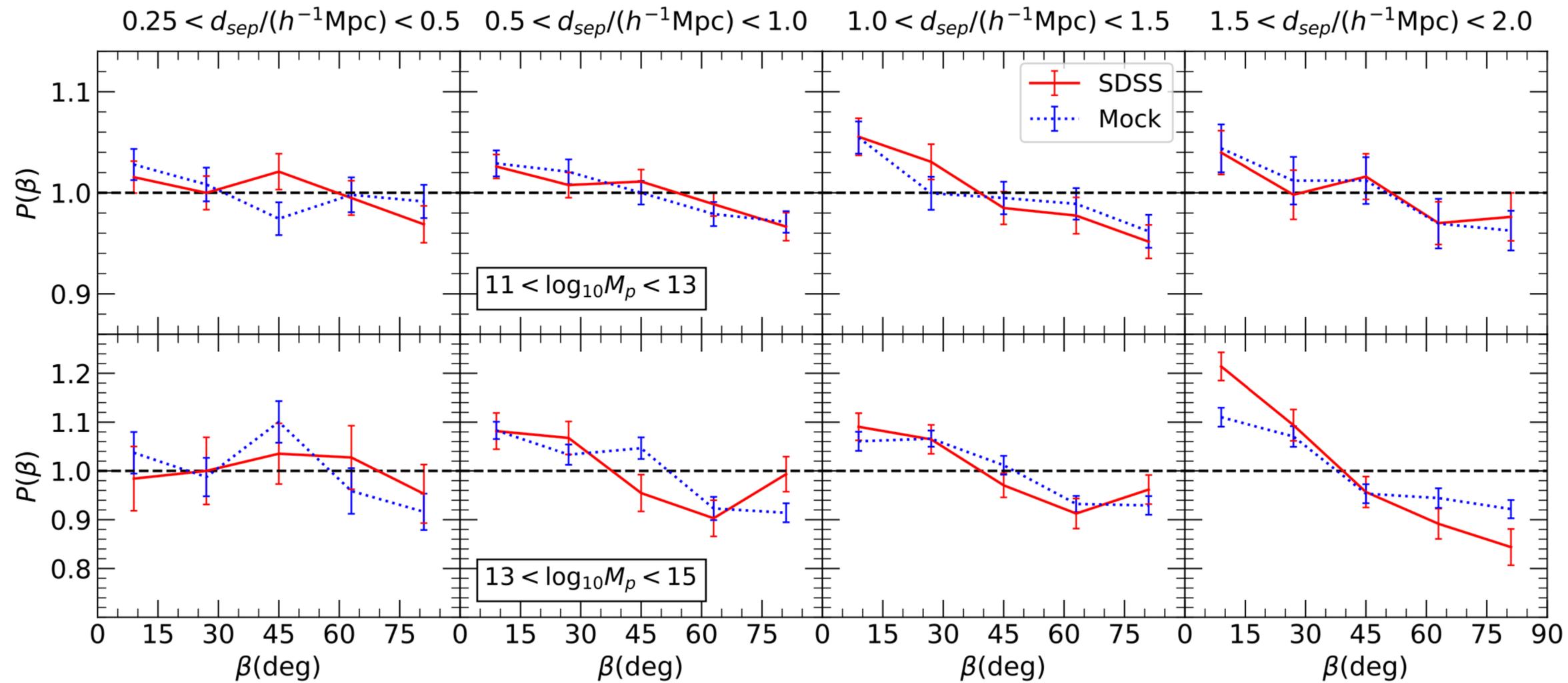
- Apply the model of subhalo abundance matching (SHAM) to assign galaxy stellar mass to halos
- Mimic observational selection effects in SDSS (i.e. apparent magnitude limits and incompleteness)
- The orientations of mock galaxies: the central part of halos, adding a misalignment angle which follows a Gaussian distribution.



# The results in mock agree quite well with SDSS



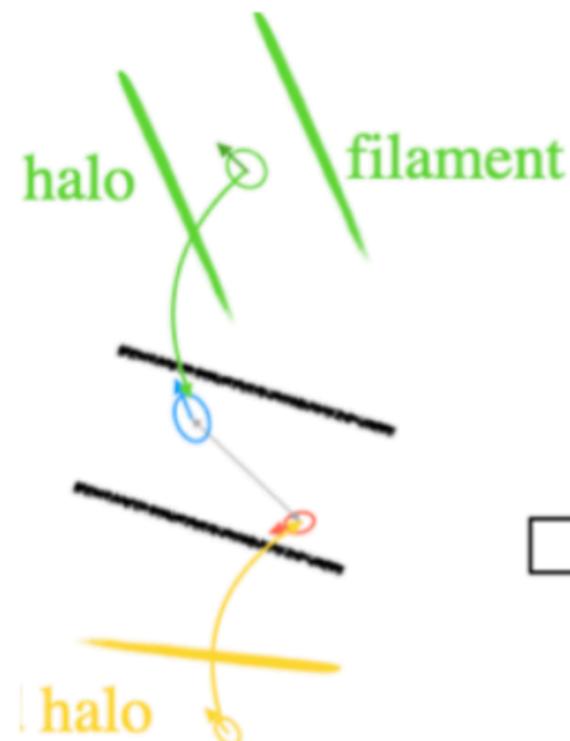
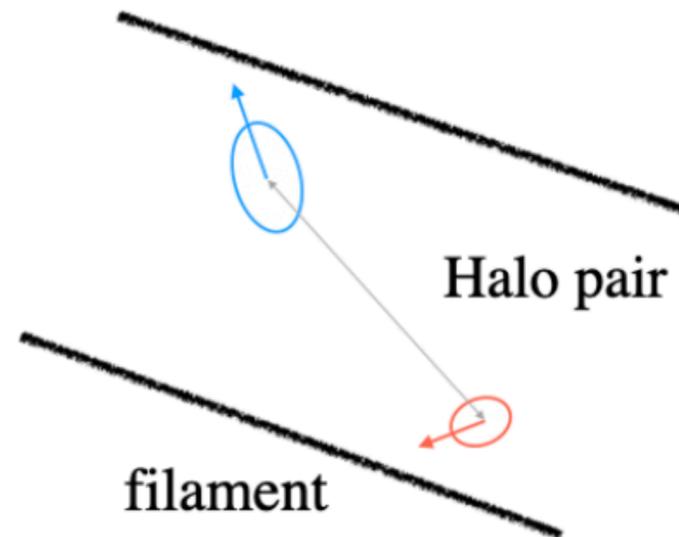
# Orientations of the more massive halos in halo pairs align with the line connecting halo pairs



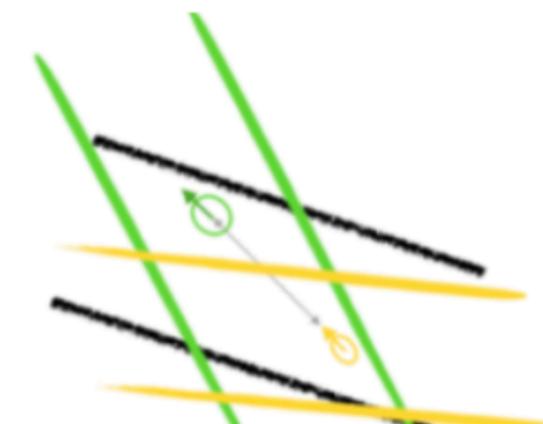
# Examine the effect of large-scale filaments – overlap sample

- randomly select halos, matching the mass distribution of real halo pairs
- artificially place the two halos with surrounding halos at the location of the real halo pair.
- align the major axes of overlap halos with the line connecting halo pairs

Spatial distribution of filament and halo pair

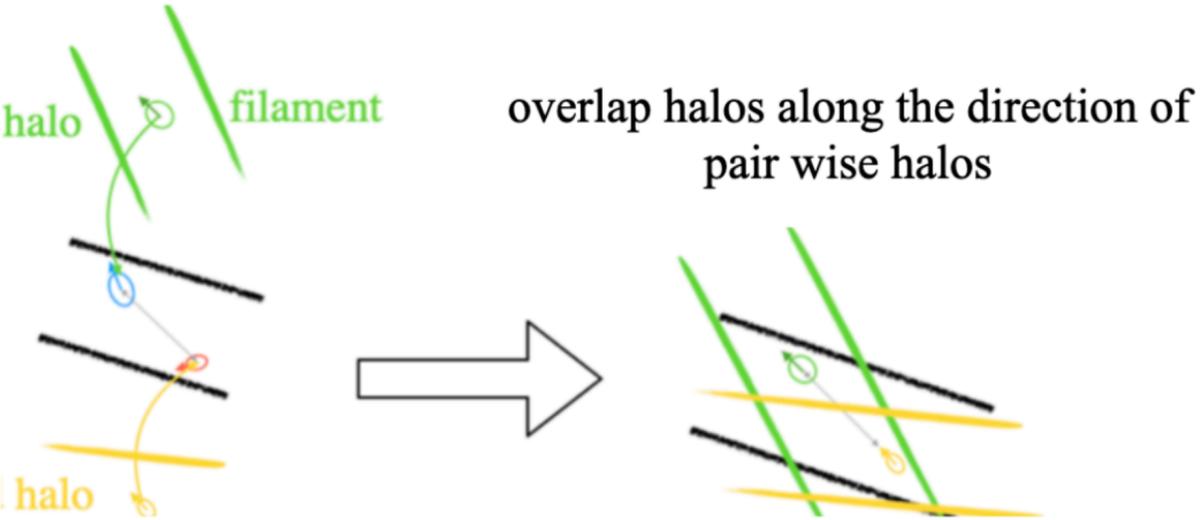
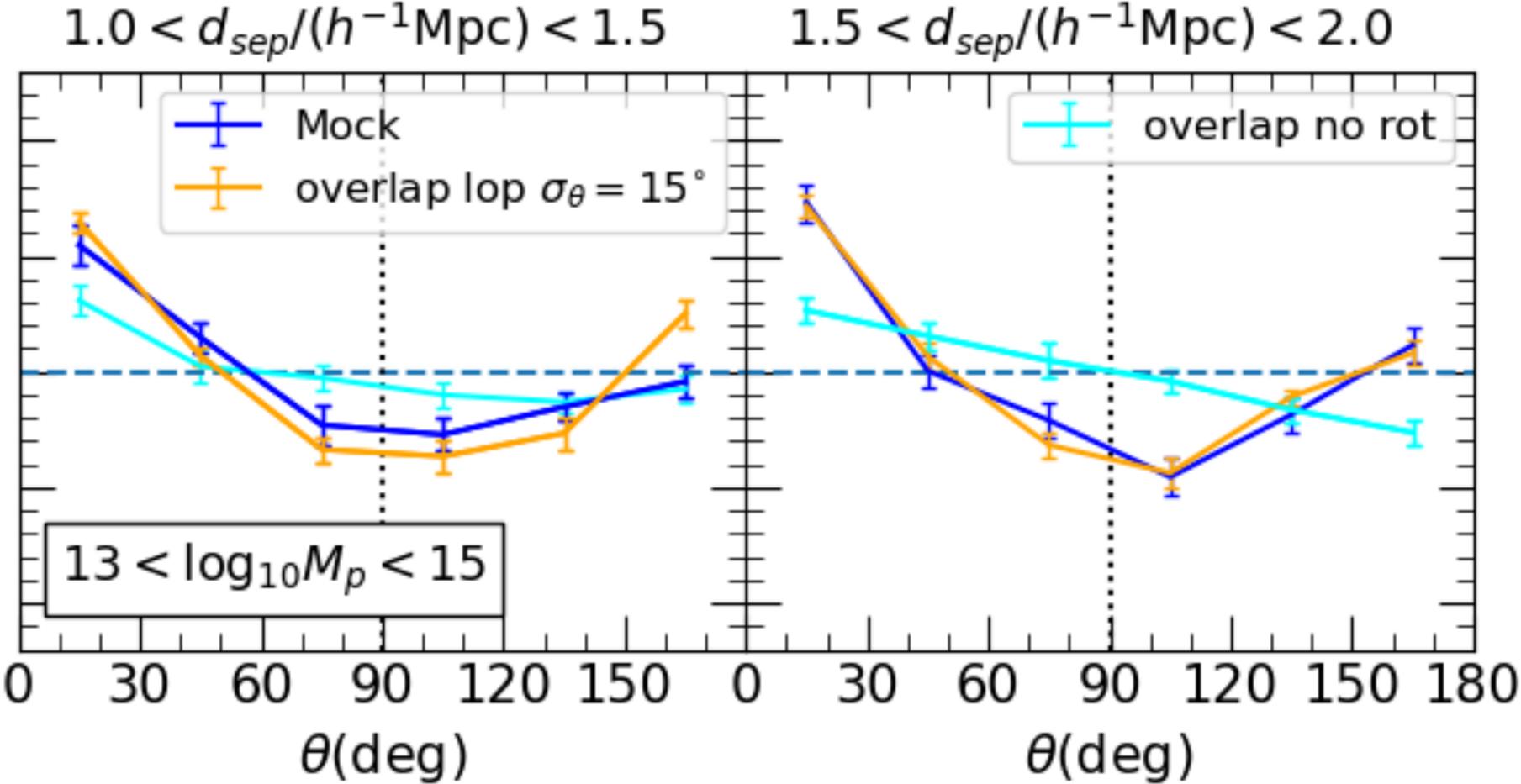


overlap halos along the direction of pair wise halos



# The anisotropic signal can be naturally explained by large-scale filamentary structures.

lop: align major axes of halos in overlap sample with the line connecting real halo pairs



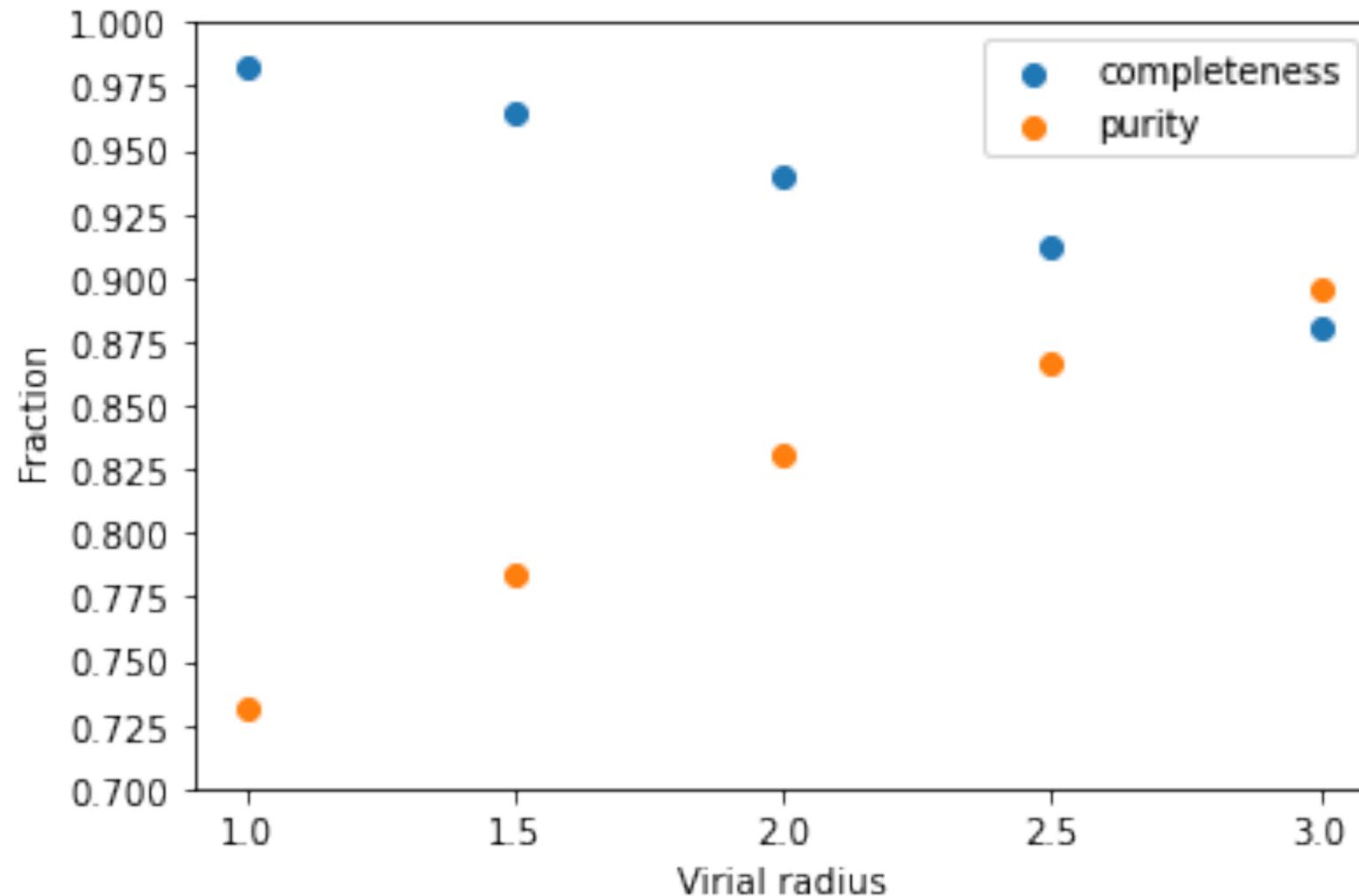
# Summary

- Anisotropic distribution of satellites around halo pairs: aligned with the line connecting halo pairs; occupy the inside region
- Mock catalog and simulation: agree quite well with SDSS.
- Origin of the signal: large-scale filamentary structures.

# Appendix

# Test in mock catalog on the method of finding central galaxies

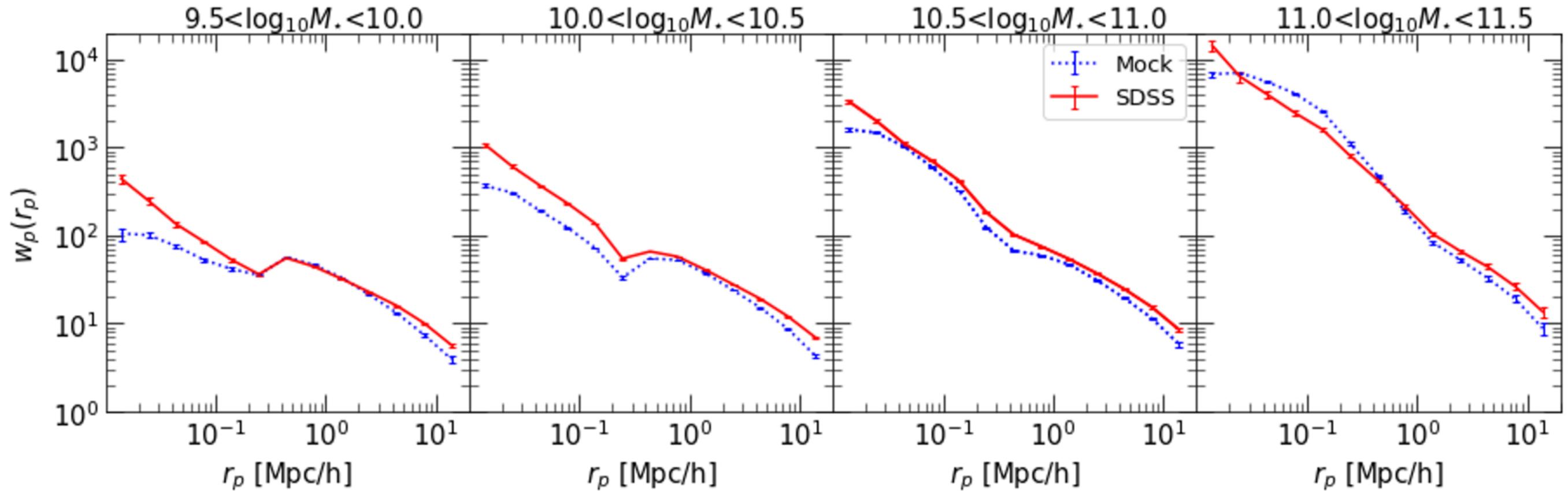
- Most massive galaxy in  $r_p < 2.5 * R_{vir}$ ,  $\Delta v < 1000 km/s$



**Completeness:** Fraction of true members  
**Purity:** Ratio between the true members and the central members

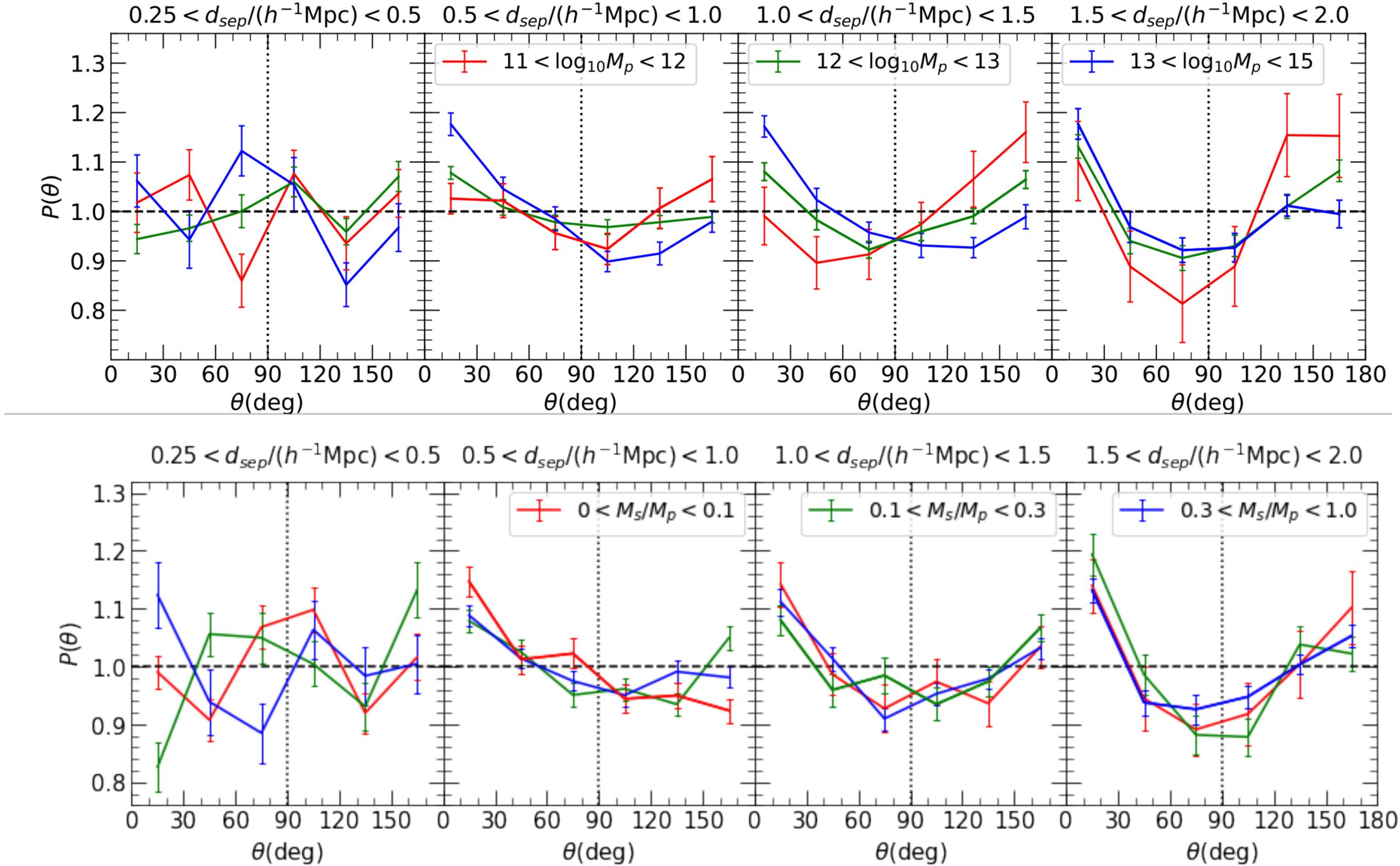
- Our method finds ~90% true central galaxies in mock, with interlopers ~10%, proved to perform well.

# Test on the galaxy clustering in mock catalog

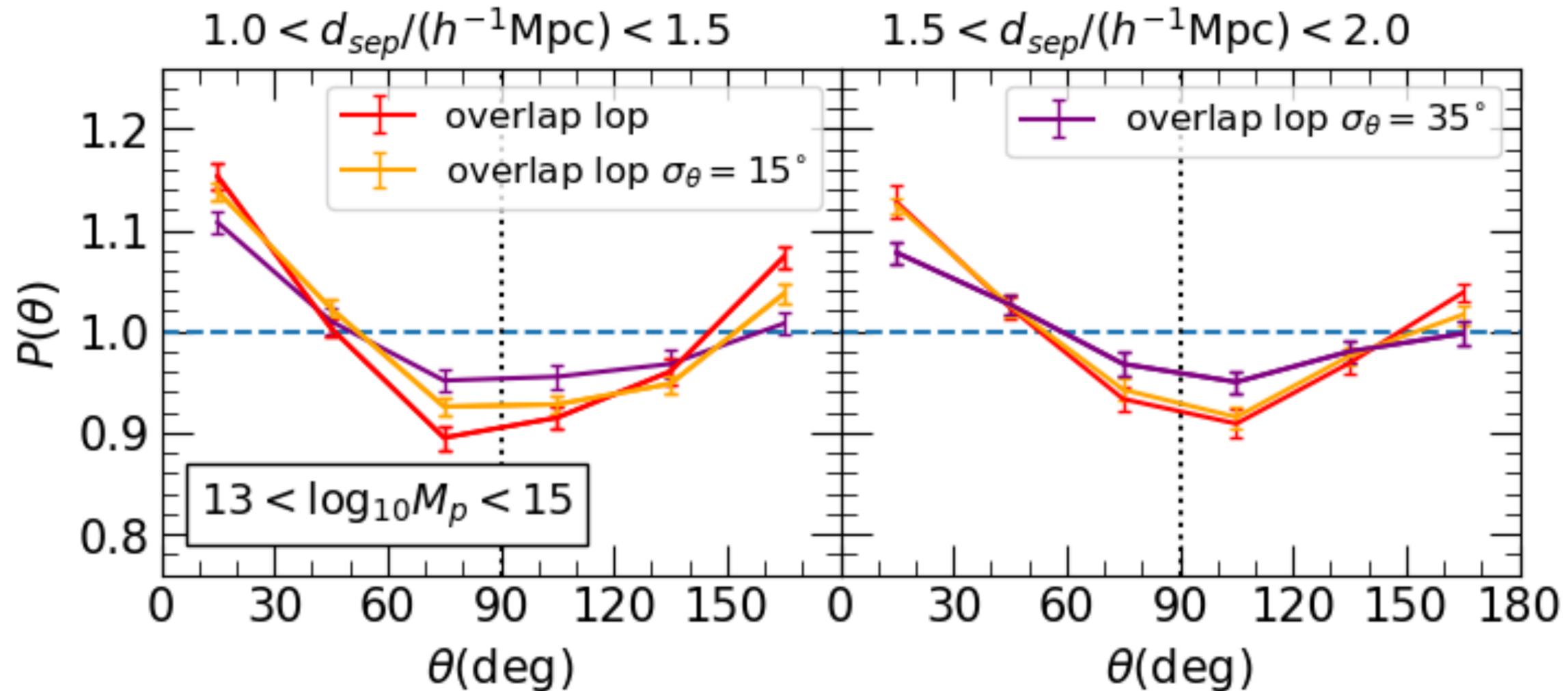


- Galaxy clustering in mock catalog are consistent with that in observational sample.

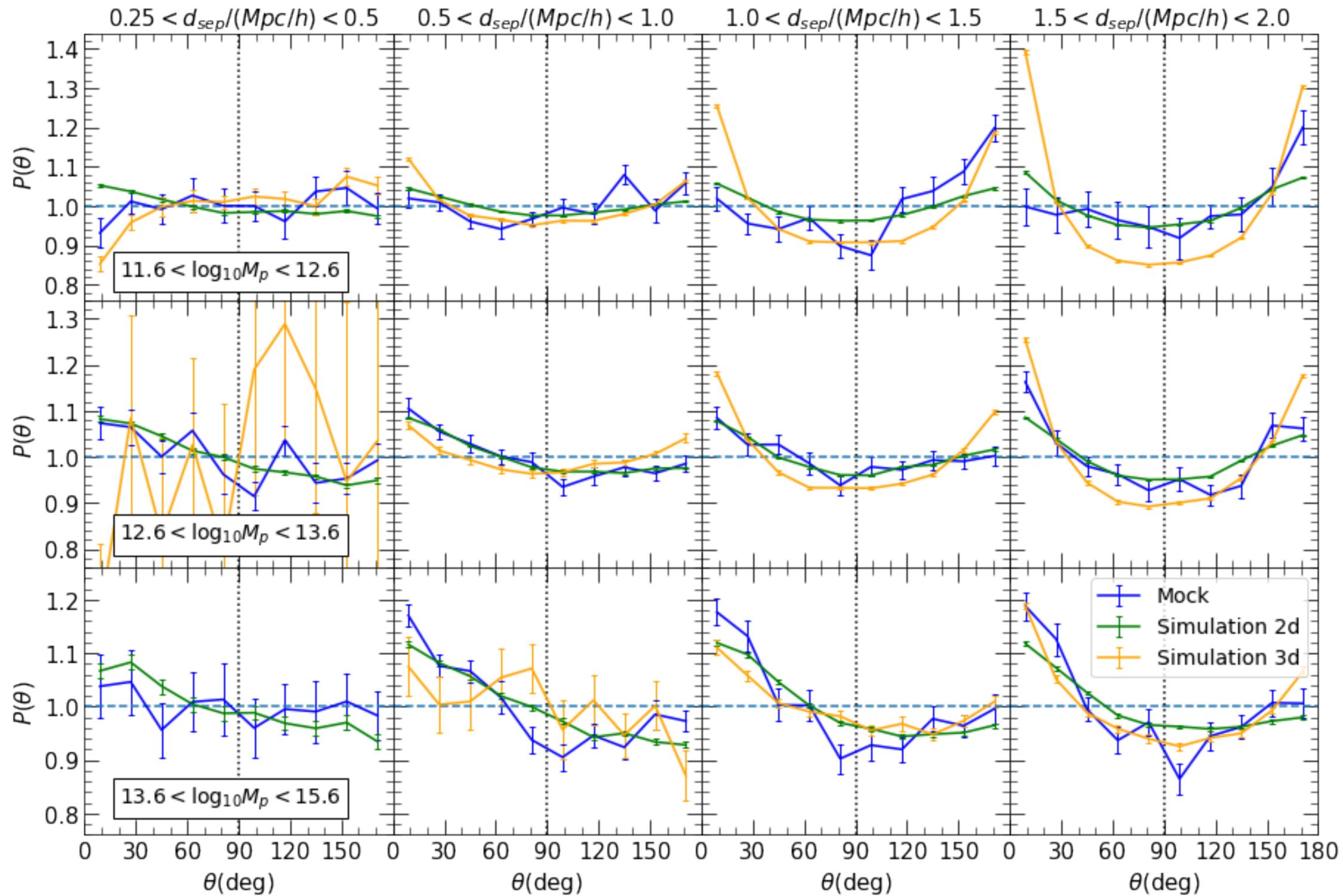
# Dependence on halo mass and mass ratio – Direct comparison



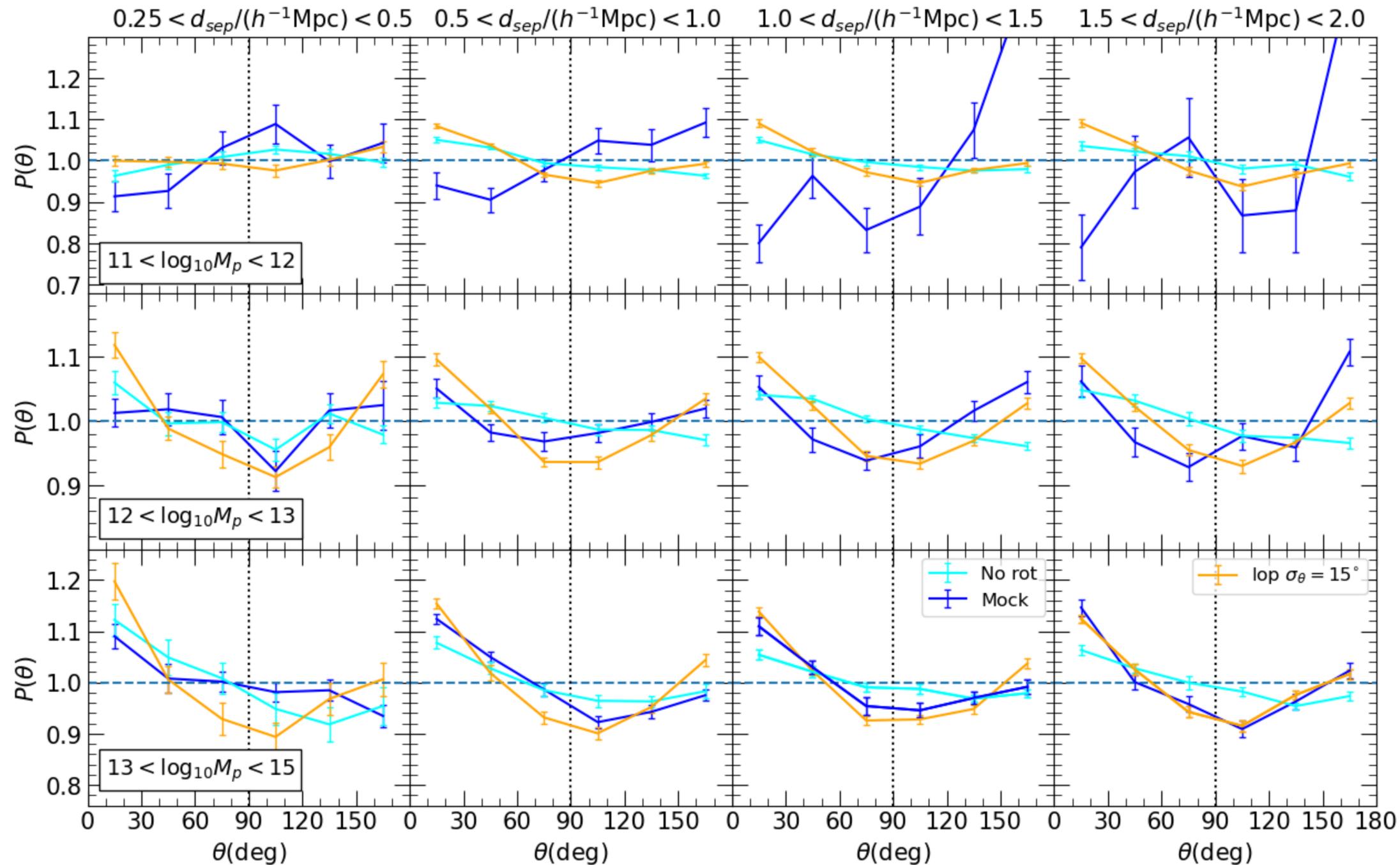
# The signal is quite sensitive to the alignment between filaments and halo orientations



# Compare mock with simulation

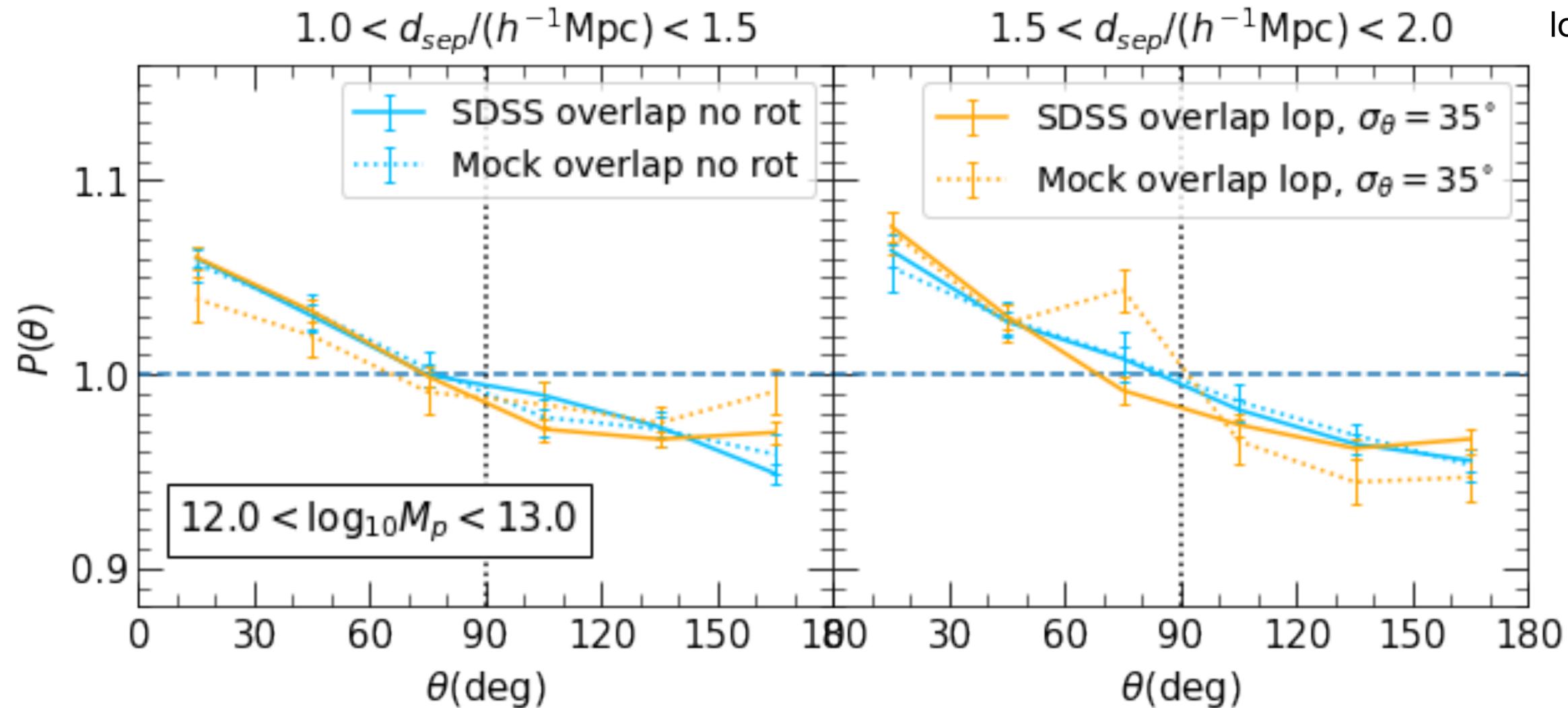


# Comparison between overlap sample and real signal



- The distribution of satellites in anisotropic overlap sample is similar to that in real pairs
- The anisotropic signal can be naturally explained by the alignment of the galaxy distribution within dark halos with large-scale filamentary structures

# Align galaxy major axes with the line connecting halo pairs



- The overlap effect show no dependence on the alignment of satellites around galaxy major axis.
- Is our anisotropic overlap sample fails to carry the information of filaments? No!