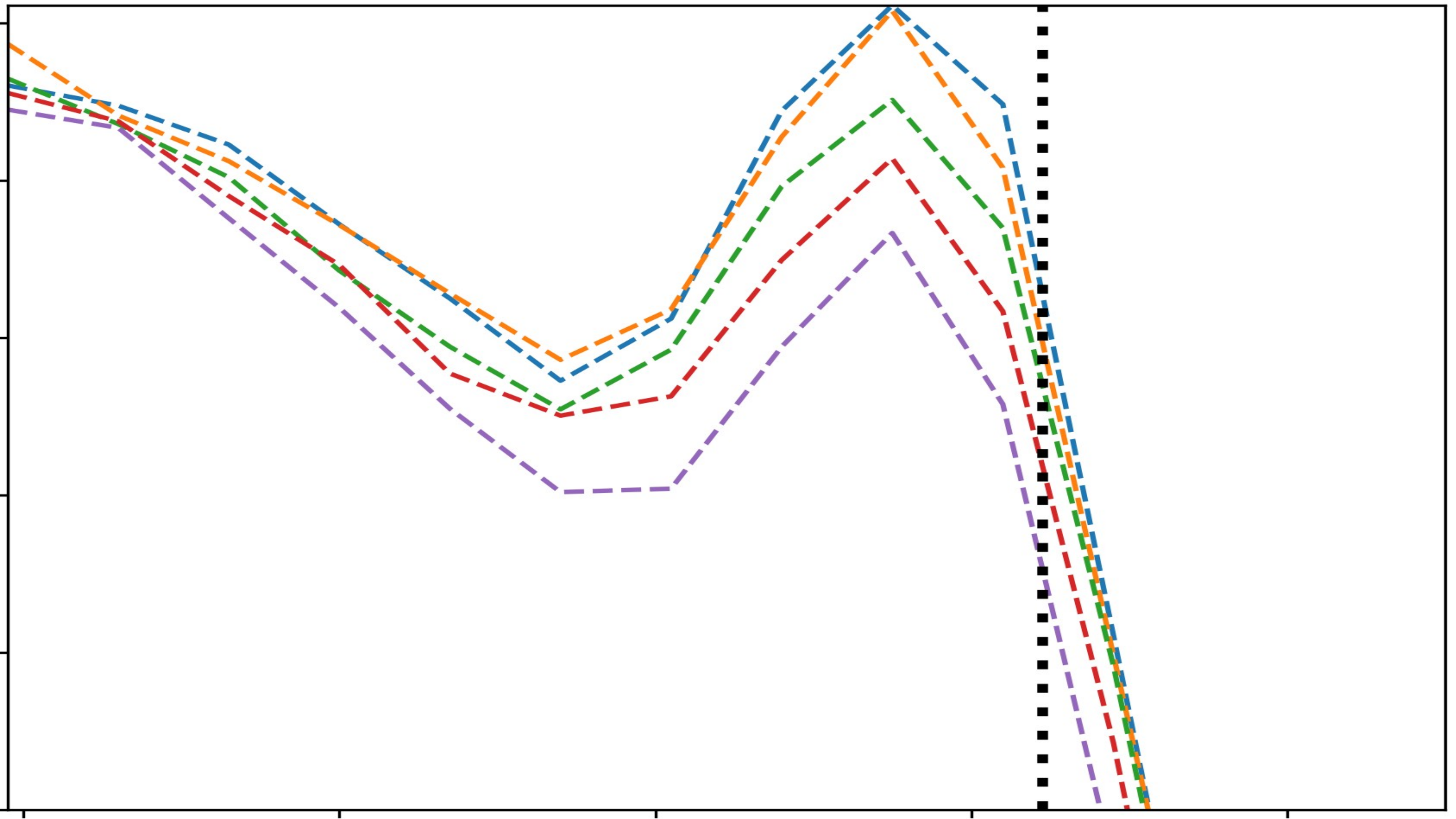
The benefits and challenges of using photometric data for BAO peak measurments

by

Christoph Saulder

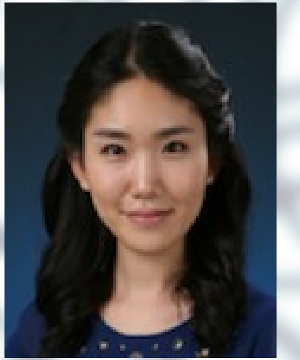
한국천문연구원
Korea Astronomy & Space Science Institute

DARK ENERGY SPECTROSCOPIC INSTRUMENT

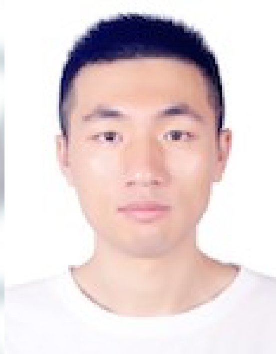


Collaborators

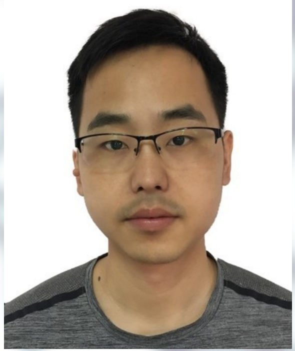
Yong-seon Song
(KASI)



Minji Oh
(Chosun University)



Yi Zheng
(SYSU)



Feng Shi
(Xidian University)

Srivatsan Sridhar
(formerly KASI)

Zhijie Ding
(SJTU)

Rongpu Zhou
(University of Pittsburgh)

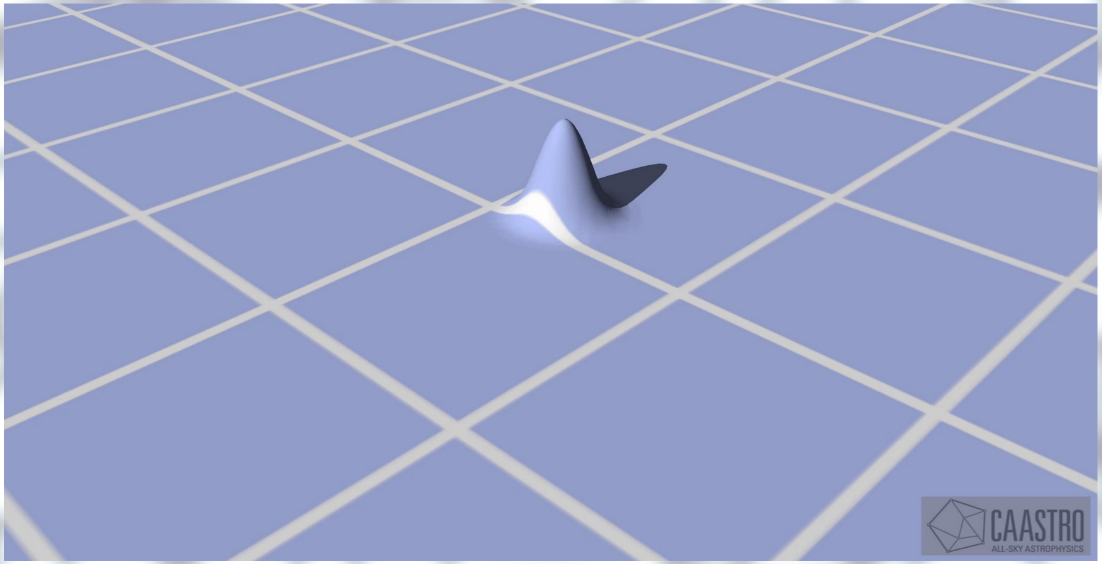
Ashley Ross
(Ohio State University)

Jeffrey Newman
(University of Pittsburgh)

Chia-Hsun Chuang
(Stanford University)

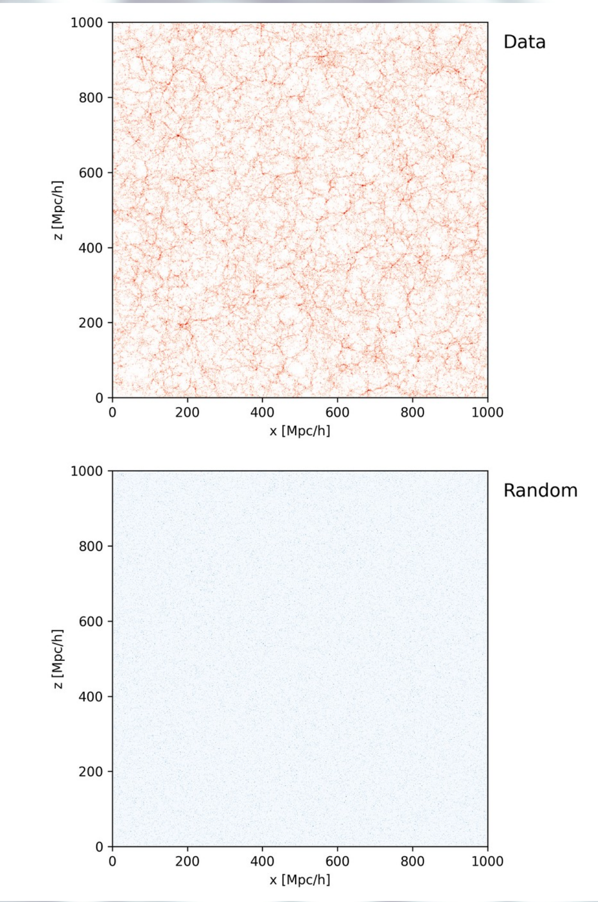
What is the BAO (peak)?

- Baryonic Acoustic Oscillations



Measuring the BAO in configuration space

- Fast codes like corrfunc
- $\rightarrow$ number counts DD, DR, RR as a function of separation



- Estimator for correlation function:

ξ_{LS} = (DD - 2*DR + RR)/RR

(Landy-Szalay estimator)

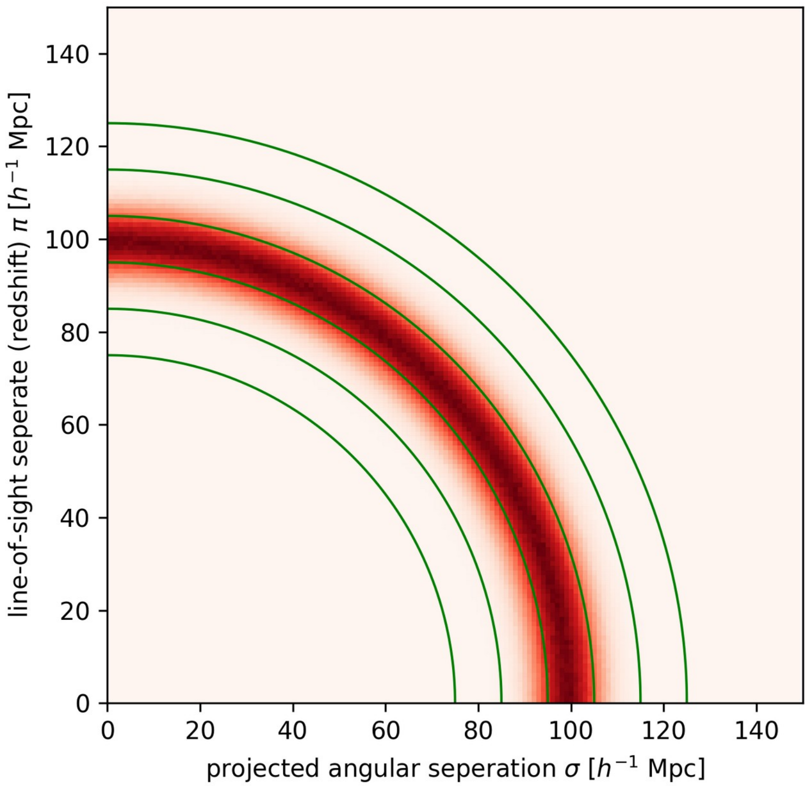
Anisotropic correlation function

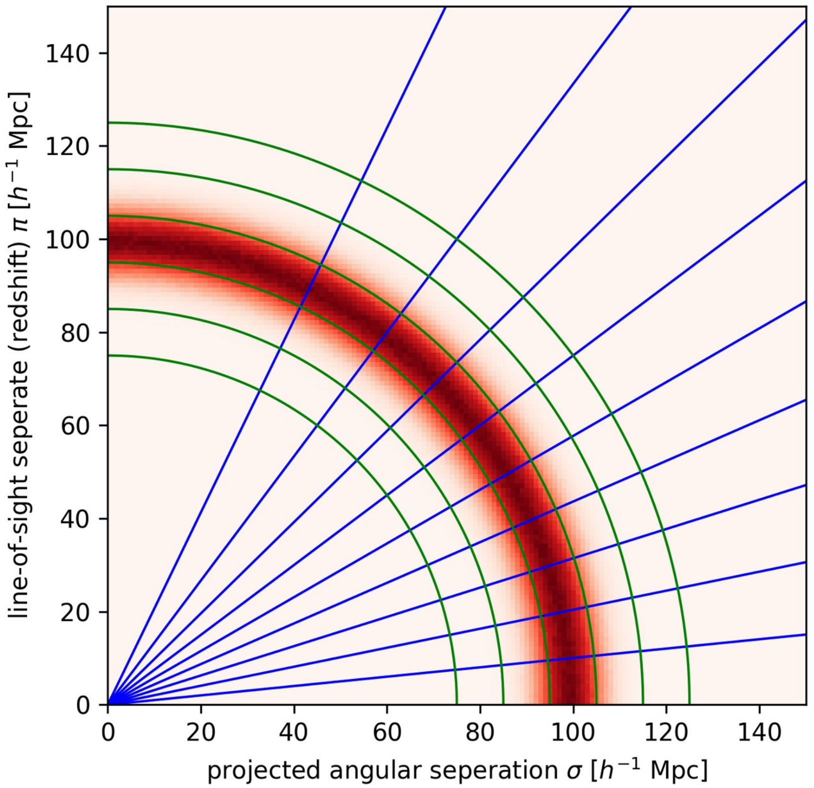
isotropic ξ(s)

$s^2=\pi^2+\sigma^2$

$\mu=\pi/s$

anisotropic ξ(s,μ)

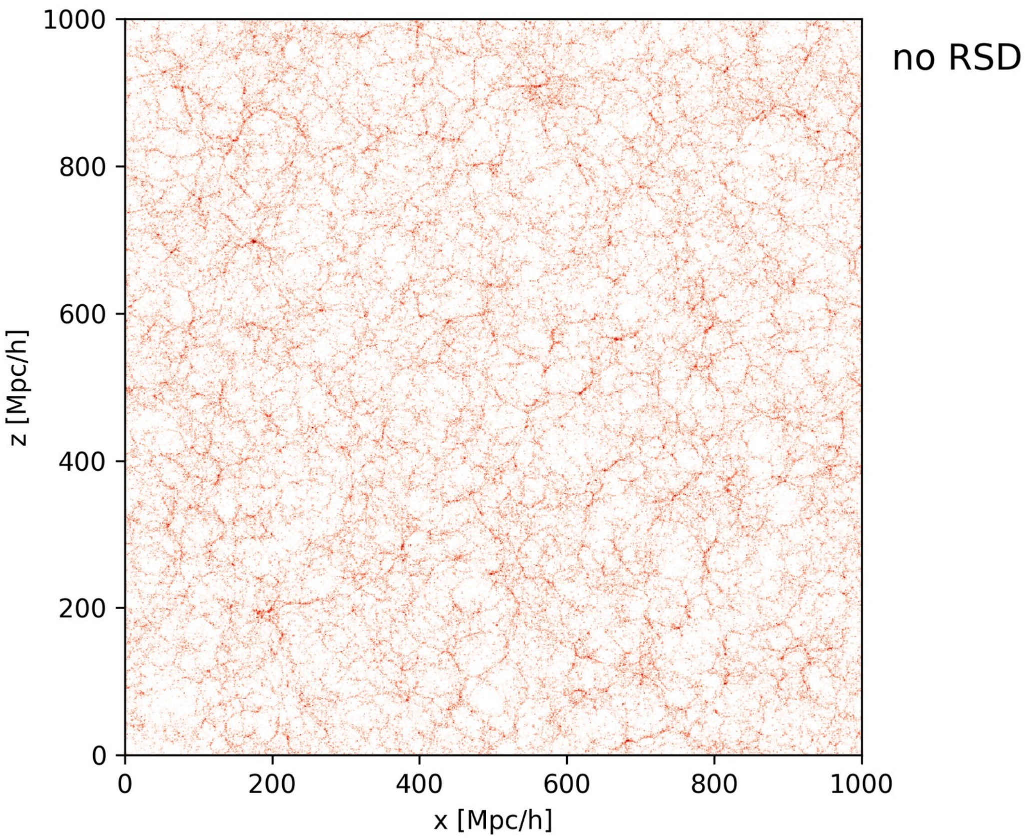




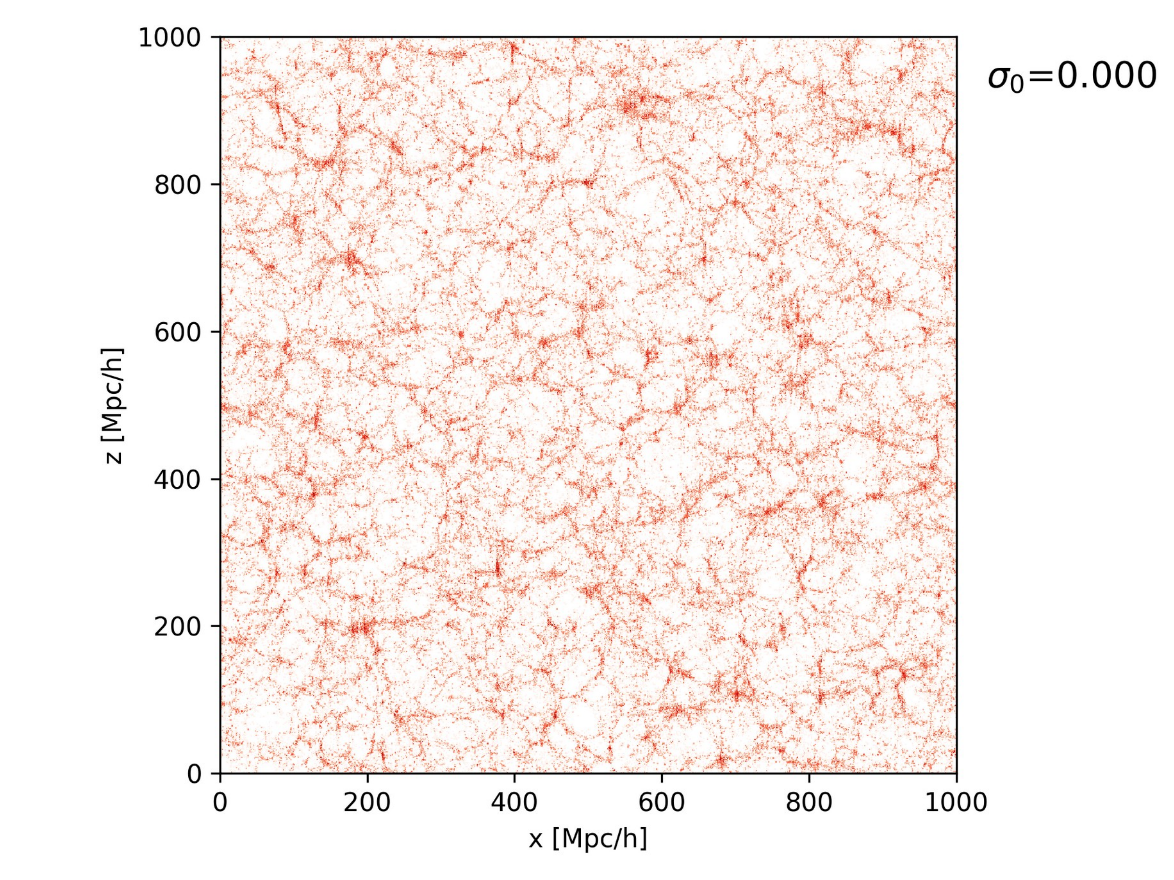
Redshift distance relation

- Ideally: perfect correlation between redshift and distance
- In practice:
  - Redshift space distortions due to peculiar motions
  - Uncertainty of redshift measurements
    - Relatively small for spectroscopic redshifts
    - **But huge for photometric redshifts (!)**

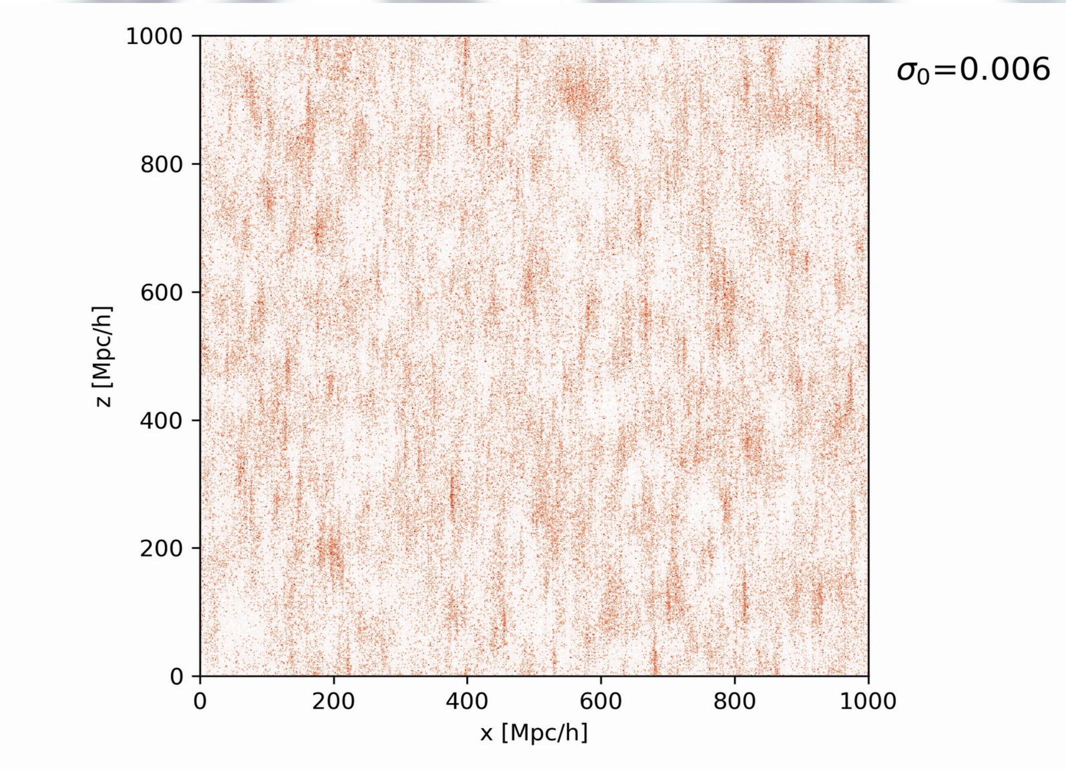
Photometric redshifts washes out clustering features



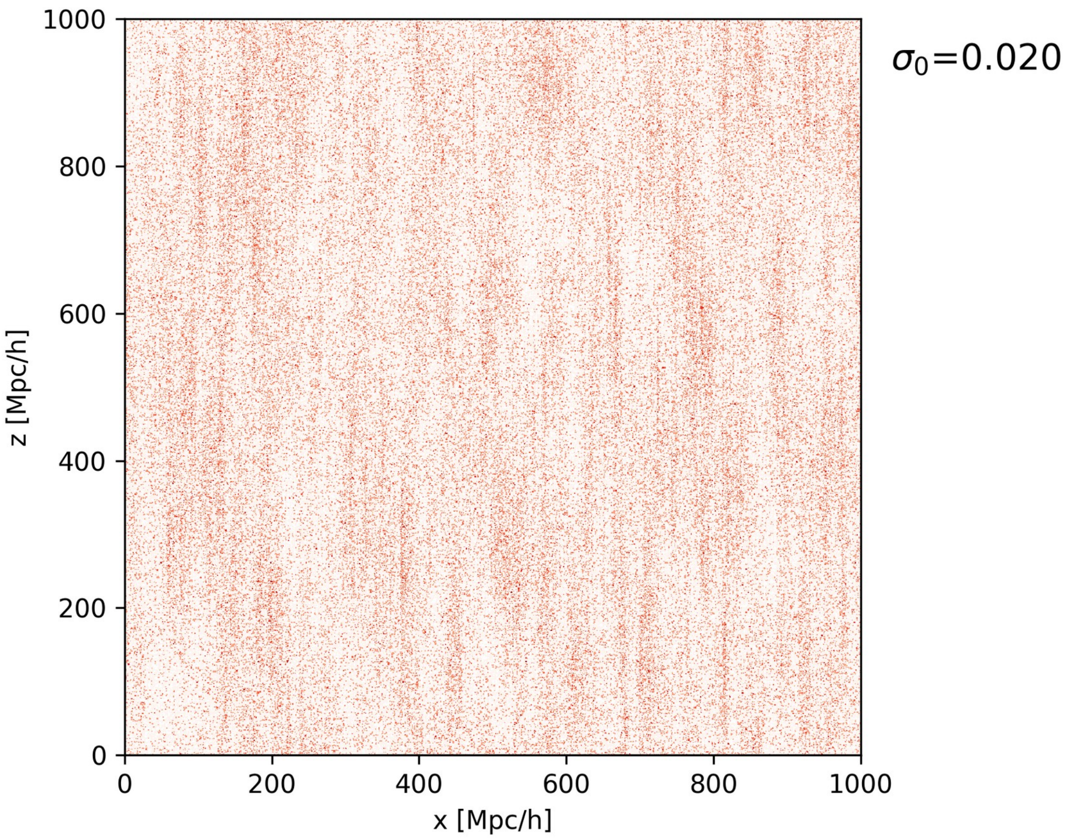
Photometric redshifts washes out clustering features



Photometric redshifts washes out clustering features



Photometric redshifts washes out clustering features



Simulations

- 100 Cubic box dark matter only simulation with 1890 Mpc/h and a mass resolution of 5.5 10^{11} $M_{\odot}$
- Populated using an HOD model corresponding to the DESI LRG at z=0.7
- Used for basic tests of our methods
- Additionally, cut-sky easy-mocks matching the DESI footprint for the covariance matrix of the observational data

Observational data

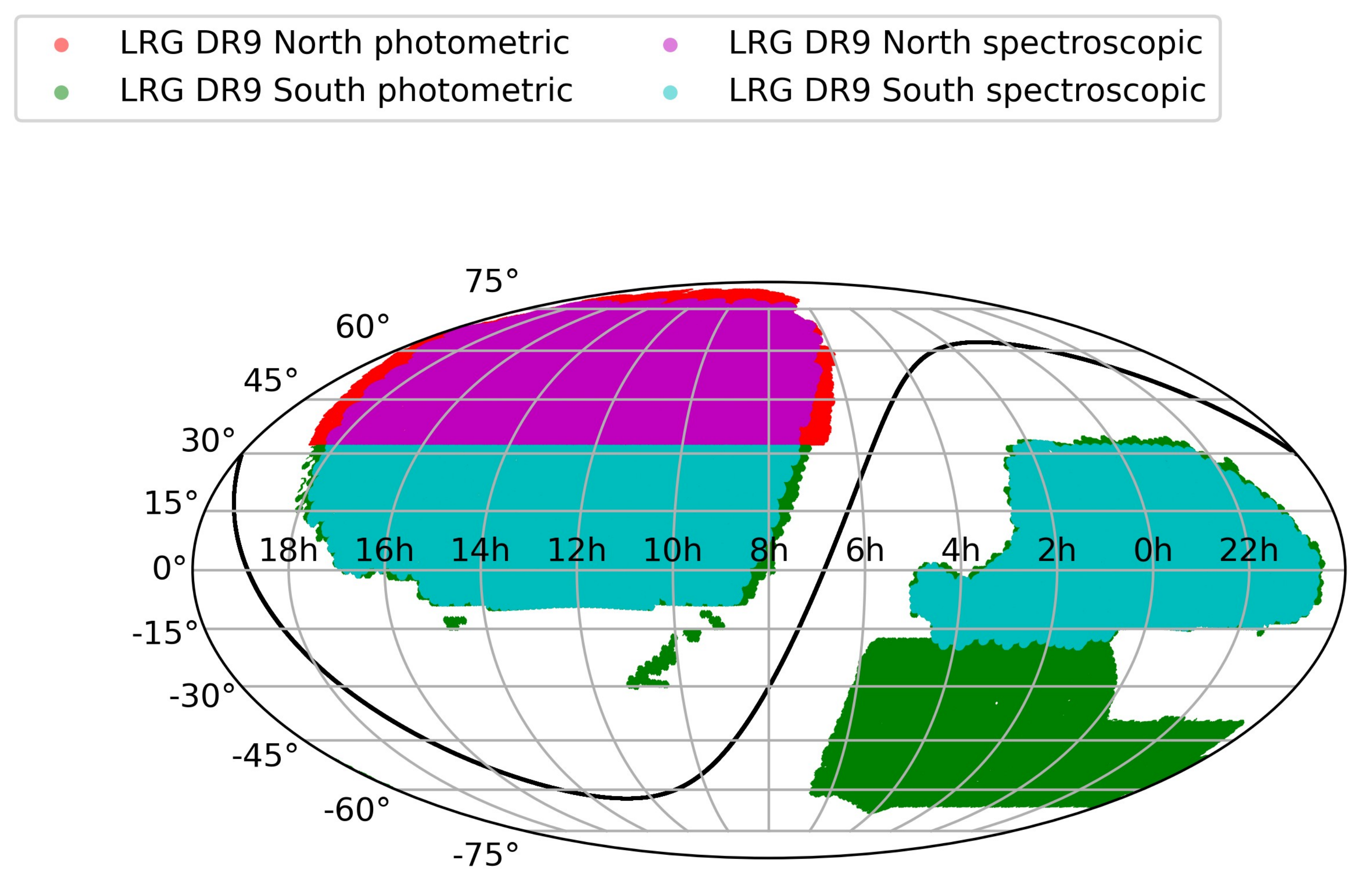
- Dark Energy Spectroscopic Instrument survey
- Ongoing spectroscopic survey
- Data from from the first few month is already internally available
- Photometric survey for target selection: DESI Legacy survey DR9

Target classes

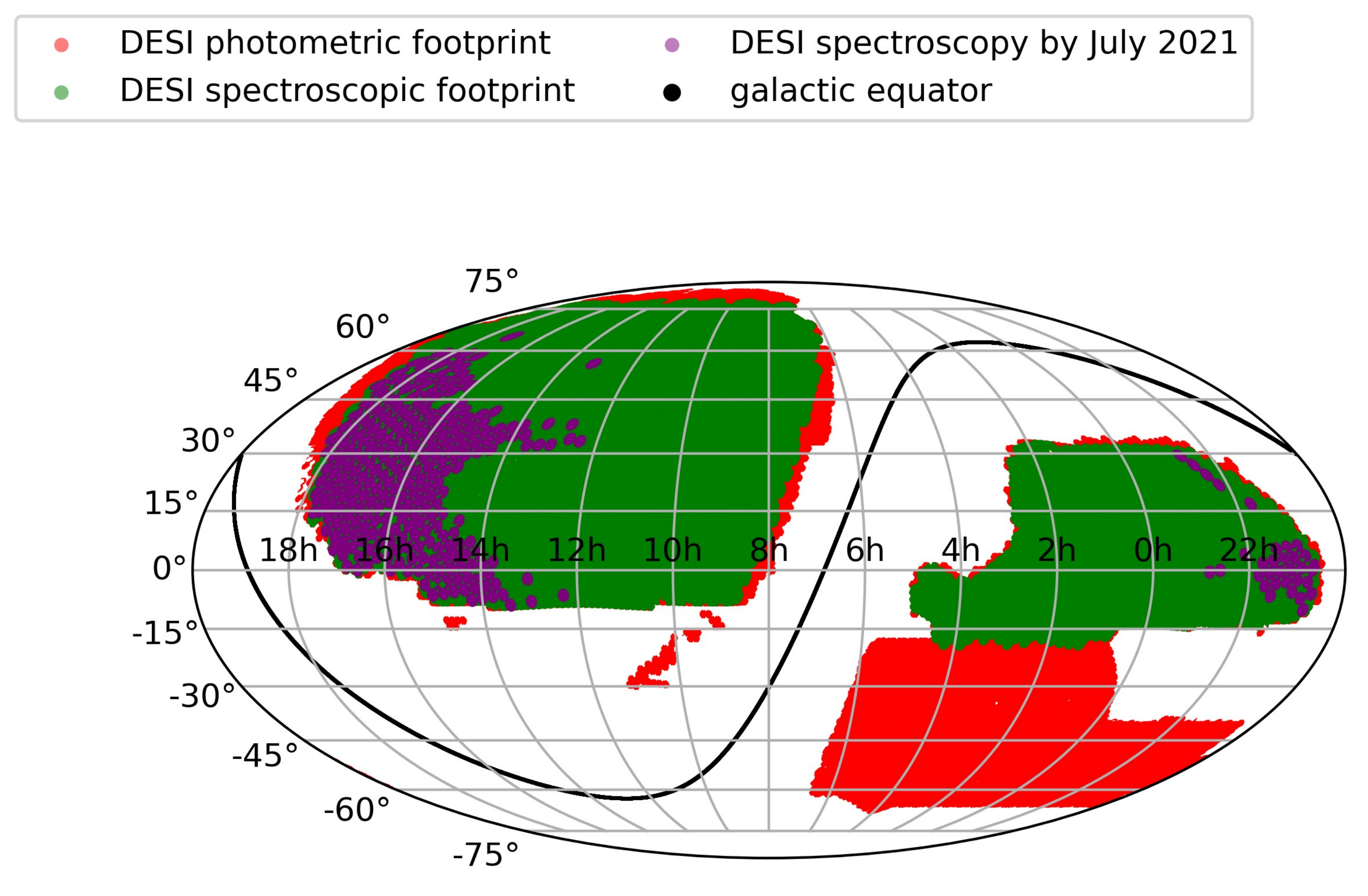
- MWS: not for cosmology
- BGS: $z < 0.5$
- **LRG: $0.4 < z < 1.1$**
- ELG: $0.6 < z < 1.5$
- QSO: $0.8 < z\ 3.5$

- Focus on LRG: balance between photometric redshift uncertainty and sample size

Footprint


LRG DR9 North photometric
LRG DR9 North spectroscopic
LRG DR9 South photometric
LRG DR9 South spectroscopic
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
18h
16h
14h
12h
10h
8h
6h
4h
2h
0h
22h

Processed spectroscopic data



Our possibilities right now:

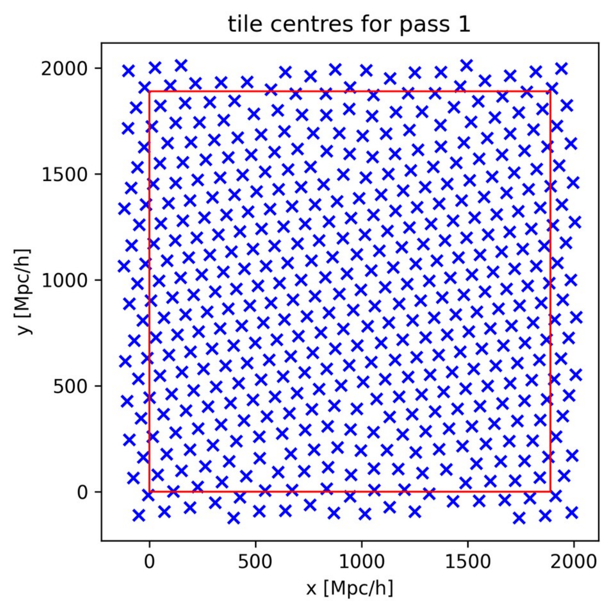
- Just use the photometric data collected by the DESI Legacy Imaging Survey DR9
- Use the already available spectroscopic data and use cross-correlation with the photometric data to account for the incompleteness of the current spectroscopic survey footprint

Cross-correlations

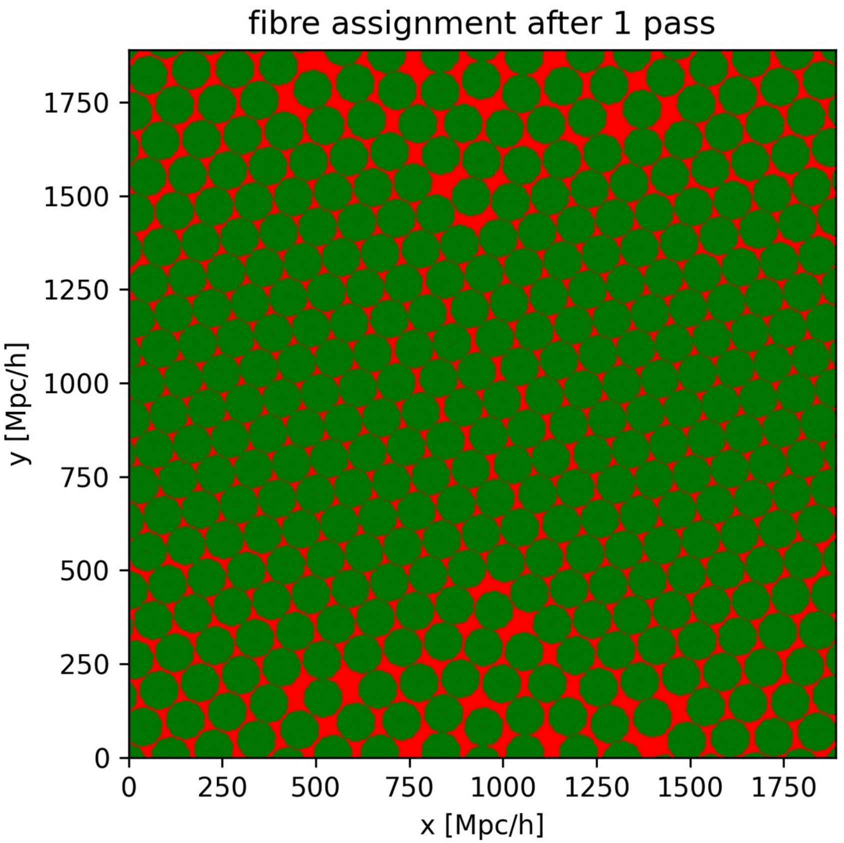
- Cross-correlations between the spectroscopic data of DESI (after about one pass) and the photometric data of the same area (and surroundings)
- Tests on simulations
- First tests with observations using the internal DESI DA0.2 data release

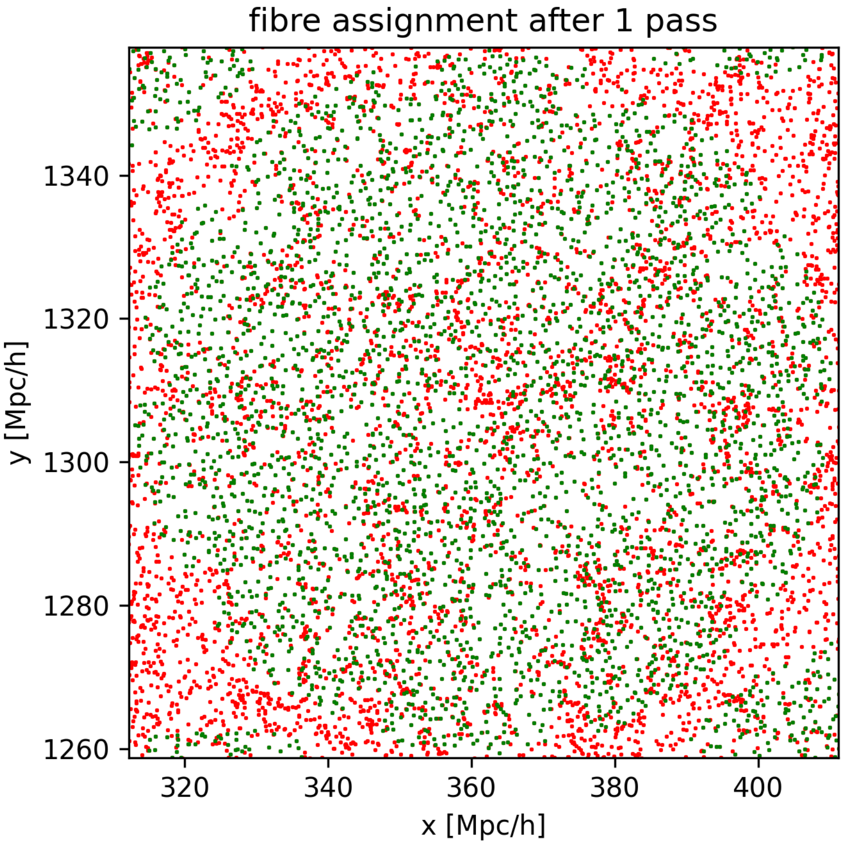
Fibre assignment

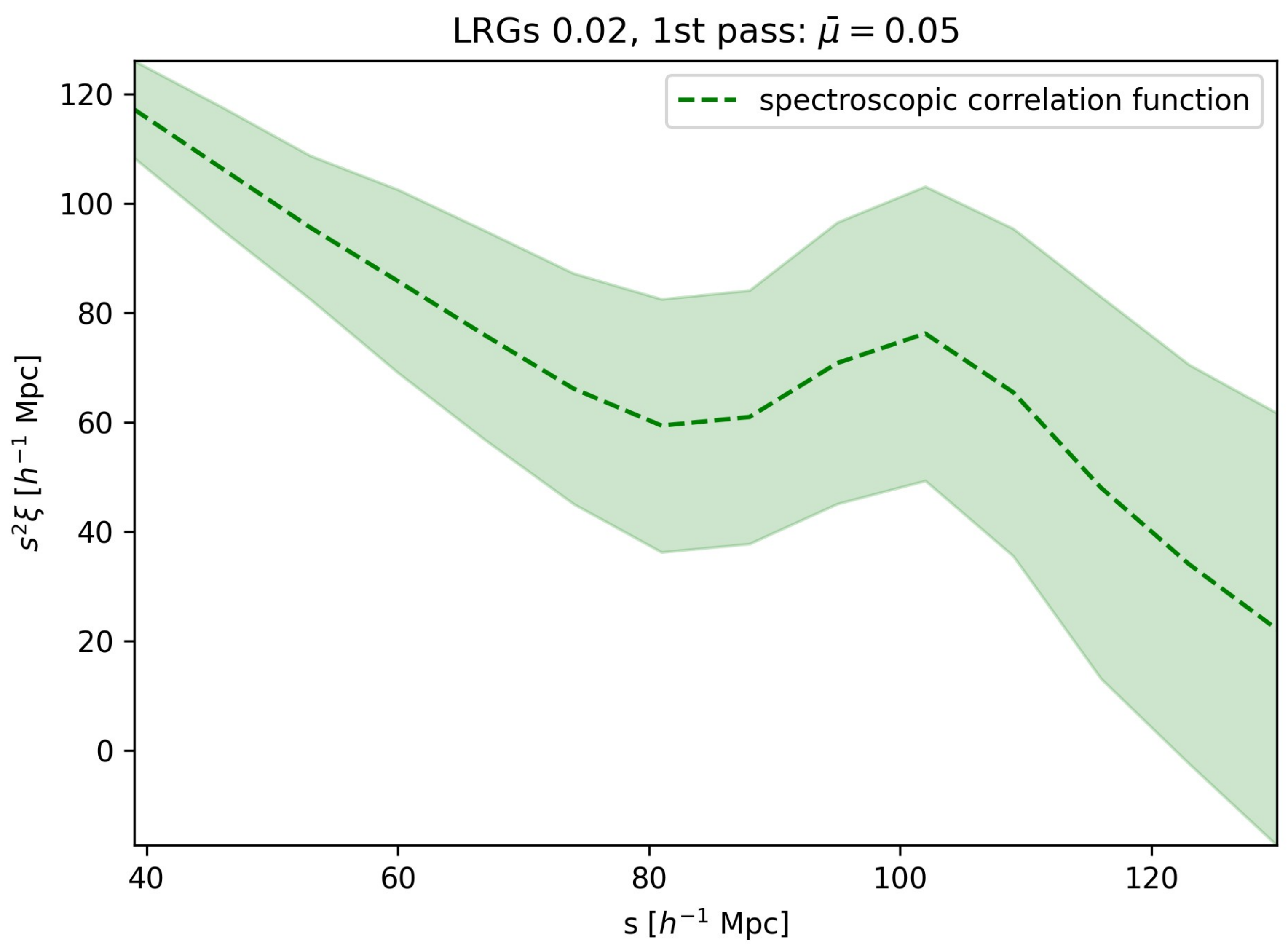
- Tiling strategy of DESI
- Comparing 1-pass with many passes
- Impact of fibre placements and completeness of the spectroscopic data



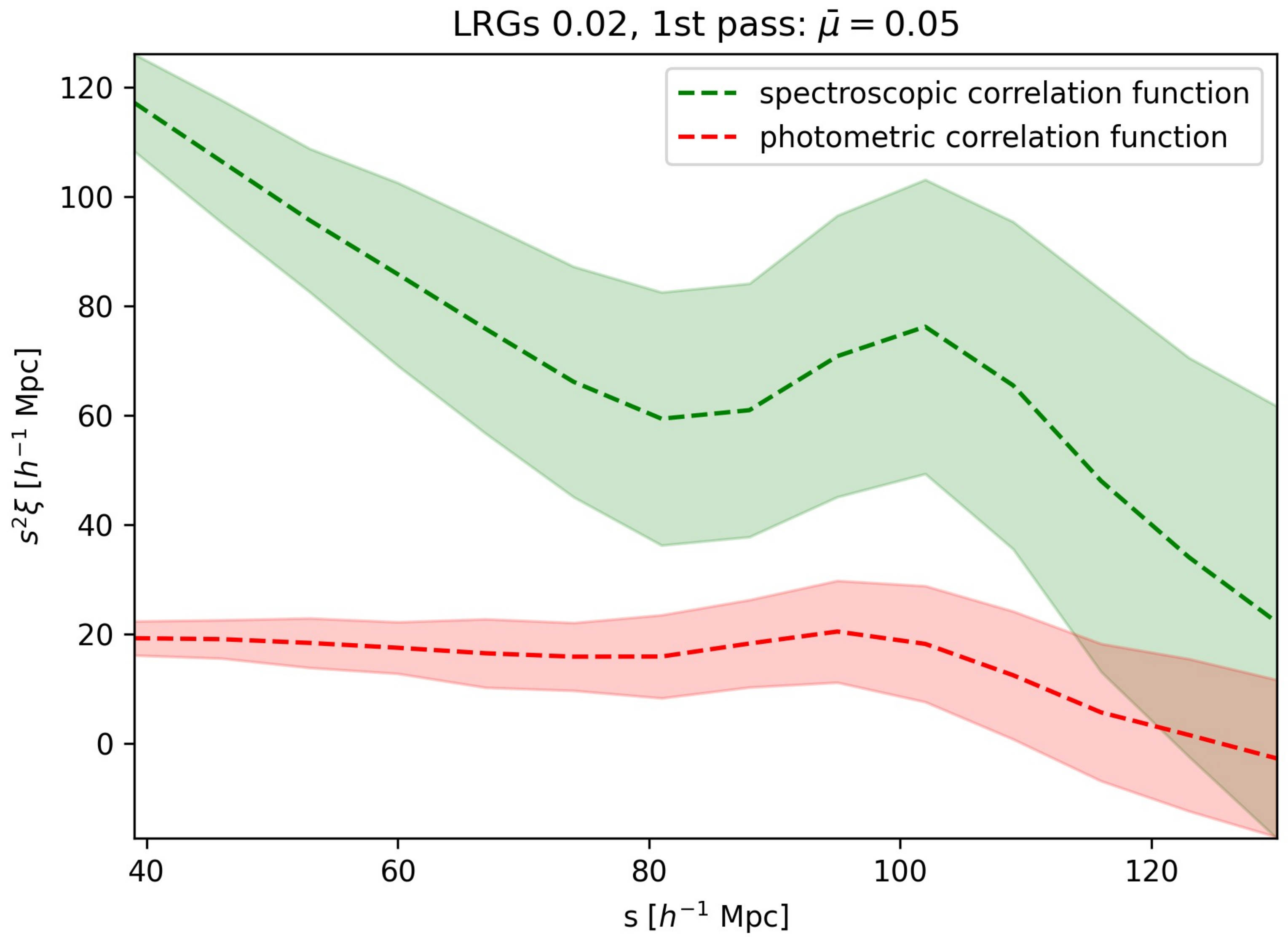
First pass


fibre assignment after 1 pass
y [Mpc/h]
x [Mpc/h]
0
250
500
750
1000
1250
1500
1750

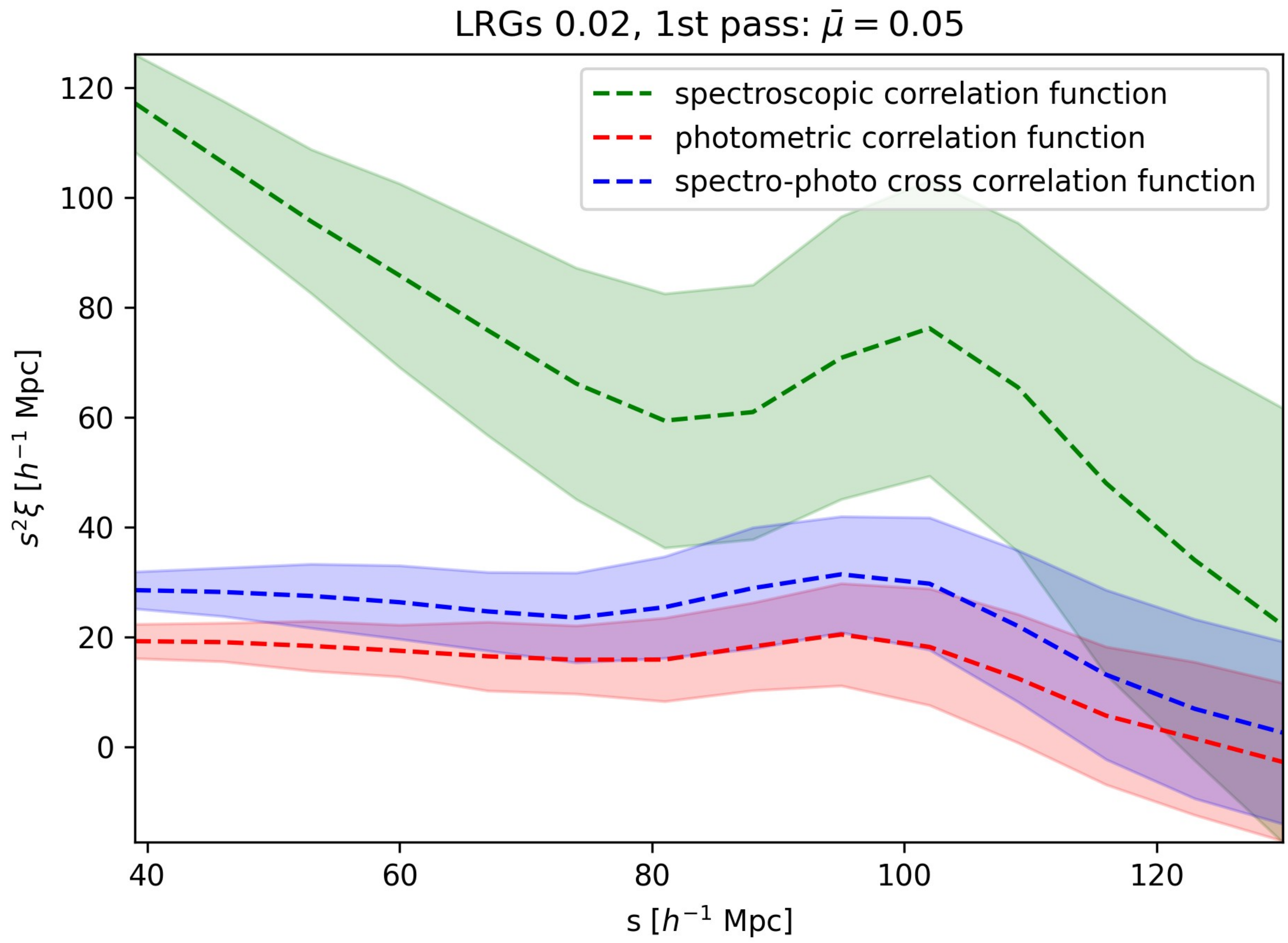

fibre assignment after 1 pass
y [Mpc/h]
x [Mpc/h]
1260
1280
1300
1320
1340
320
340
360
380
400



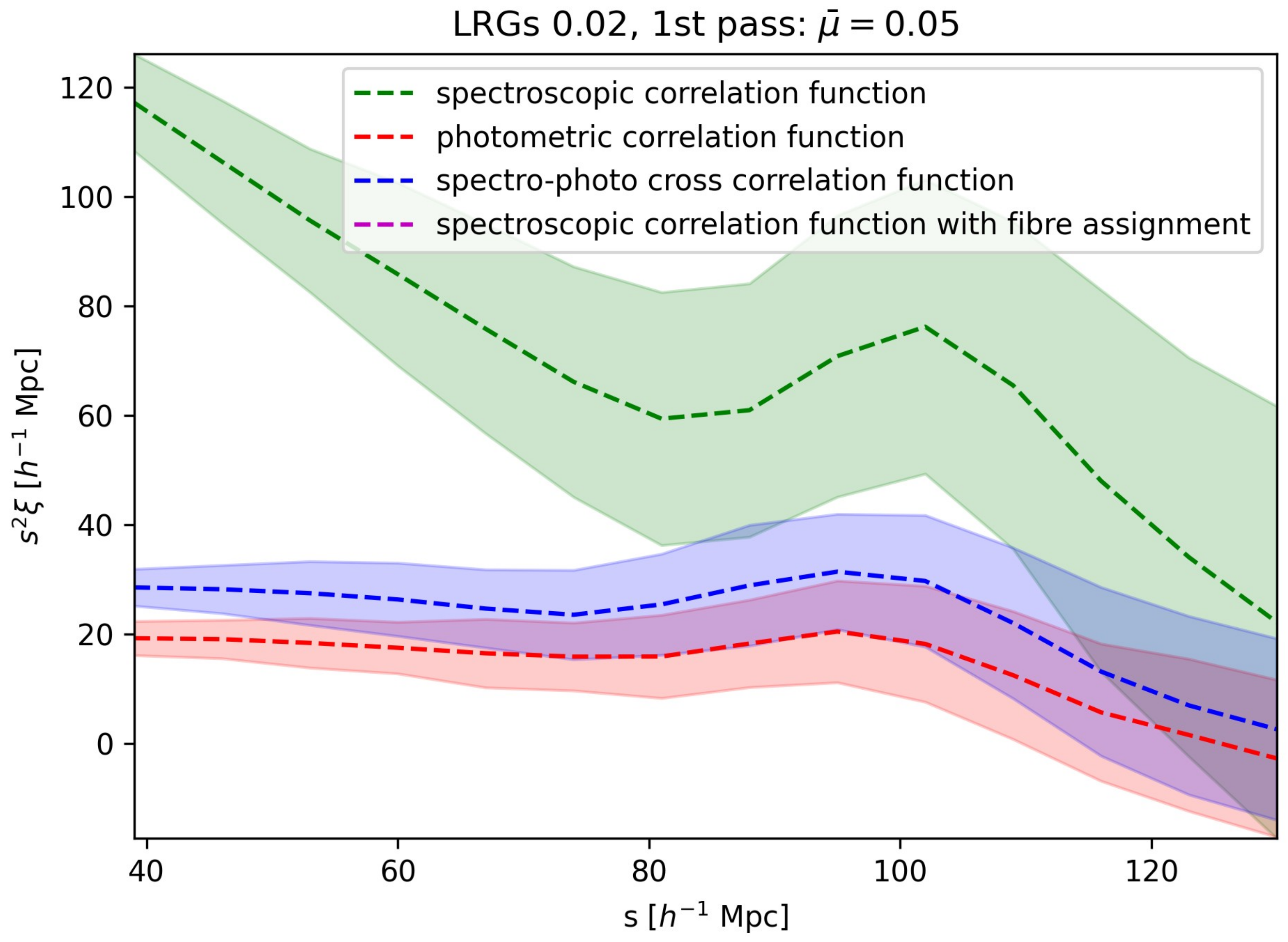
LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
120
100
80
60
40
20
0
40
60
80
100
120



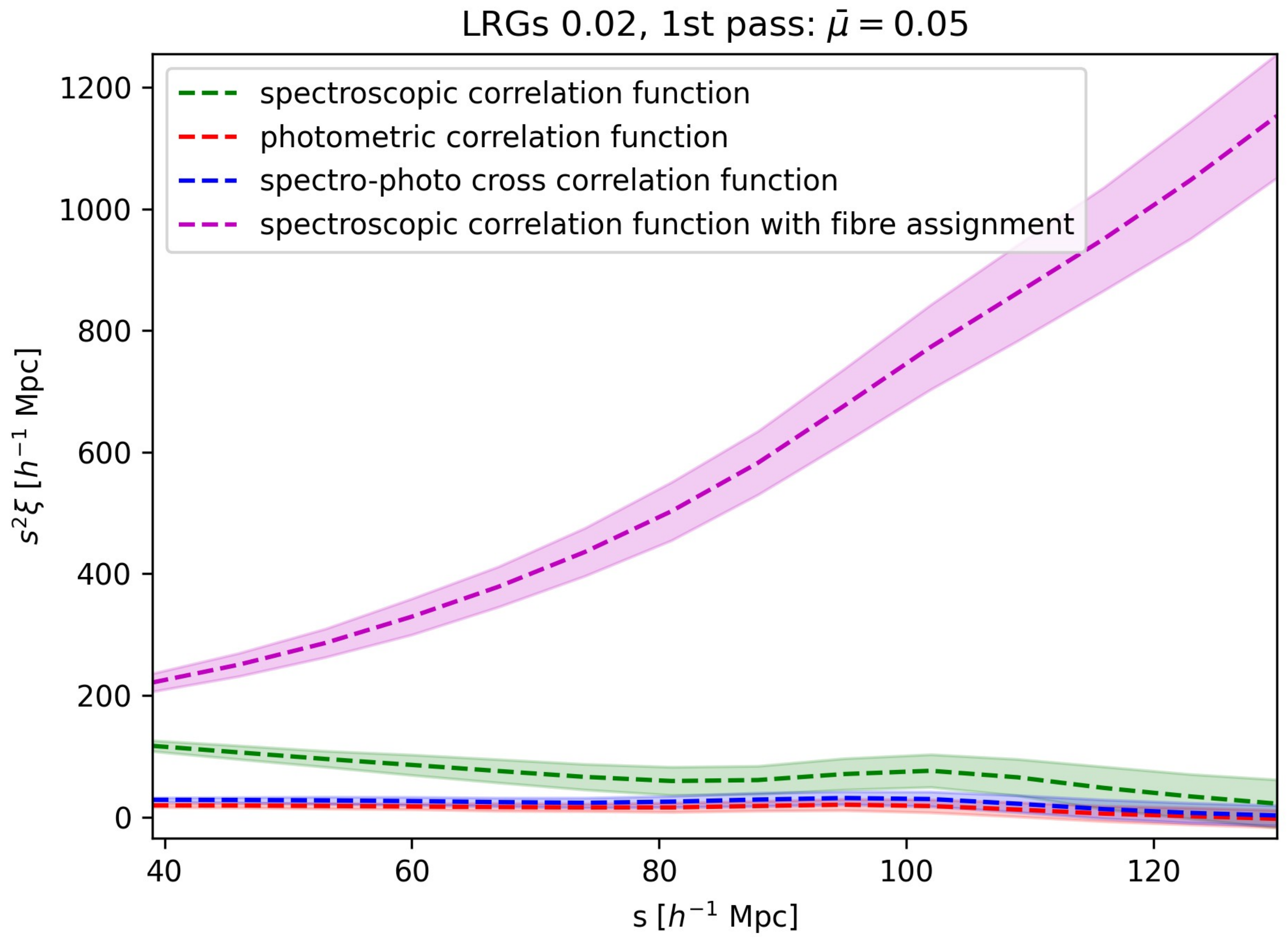
LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
120
100
80
60
40
20
0
40
60
80
100
120



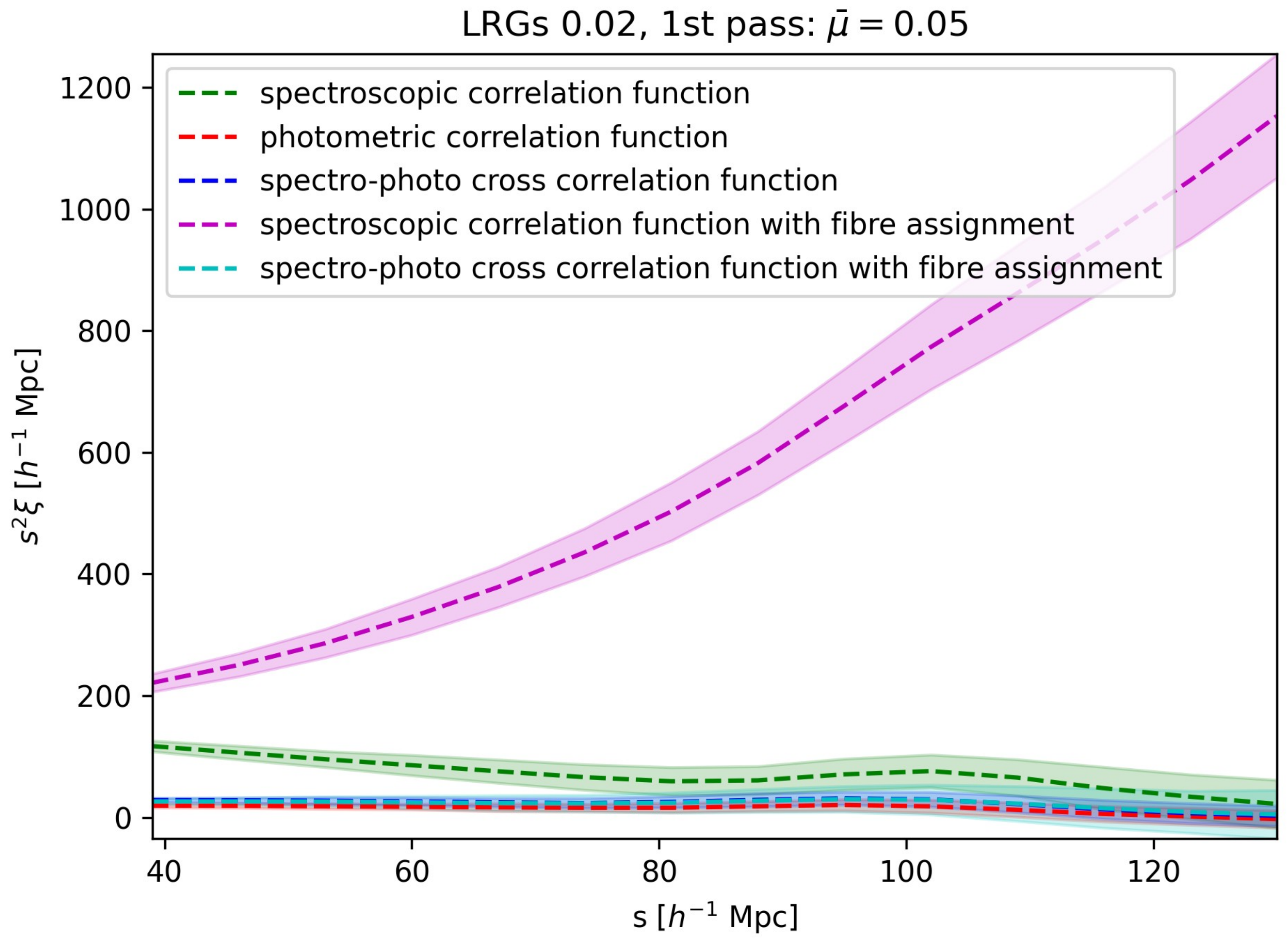
LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
spectro-photo cross correlation function
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
120
100
80
60
40
20
0
40
60
80
100
120



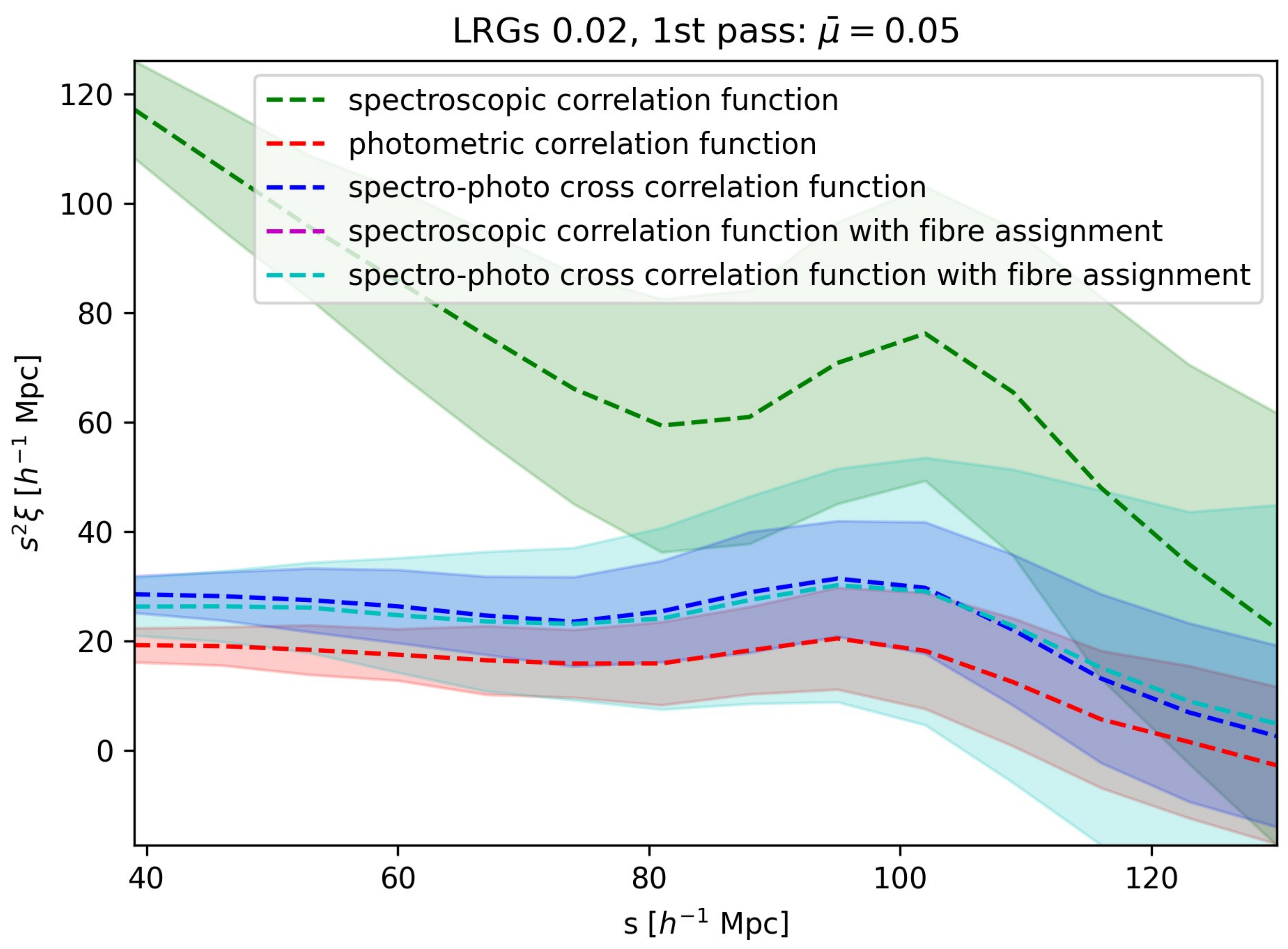
LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
spectro-photo cross correlation function
spectroscopic correlation function with fibre assignment
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
120
100
80
60
40
20
0
40
60
80
100
120

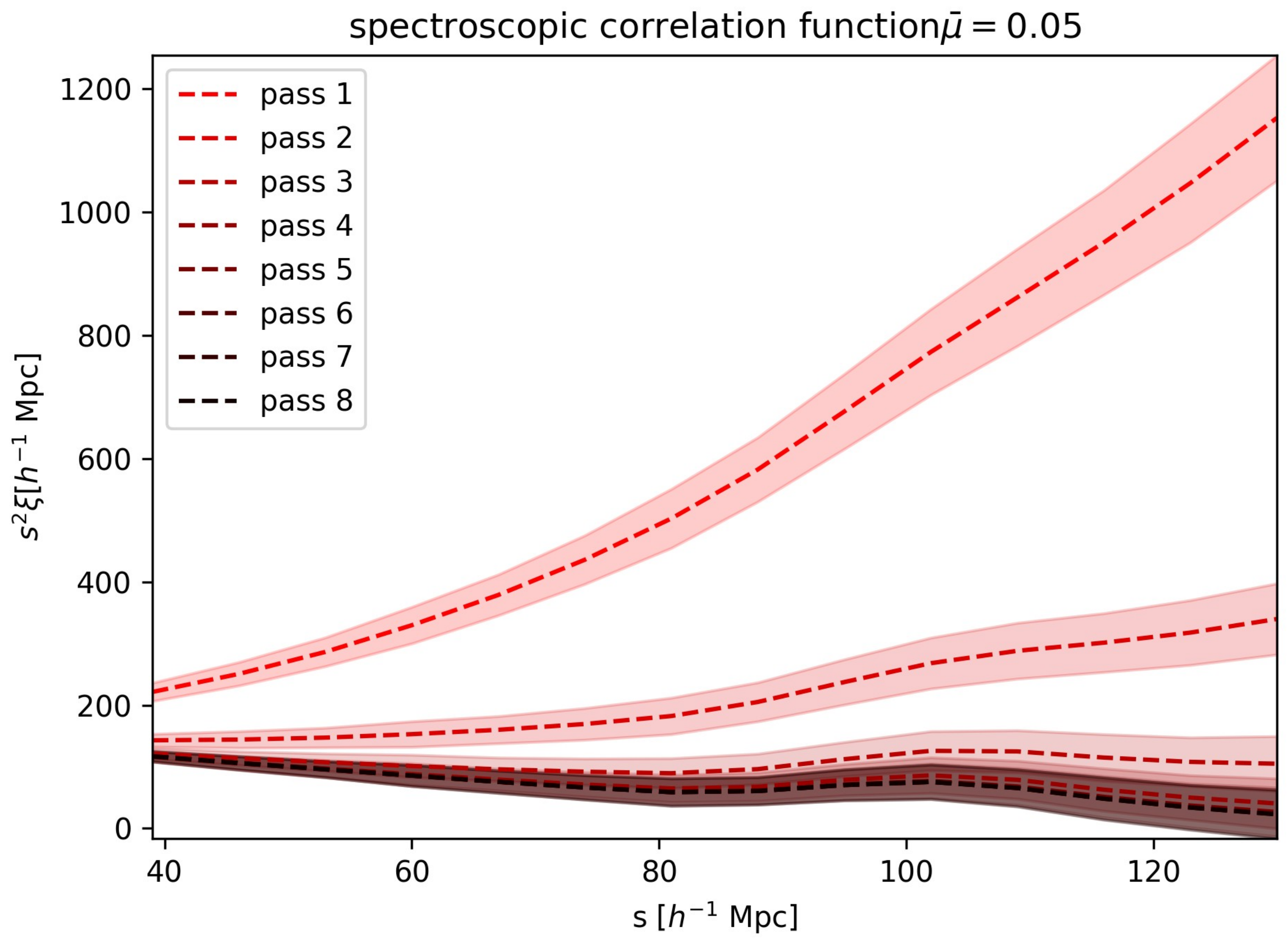


LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
spectro-photo cross correlation function
spectroscopic correlation function with fibre assignment
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
0
200
400
600
800
1000
1200
40
60
80
100
120

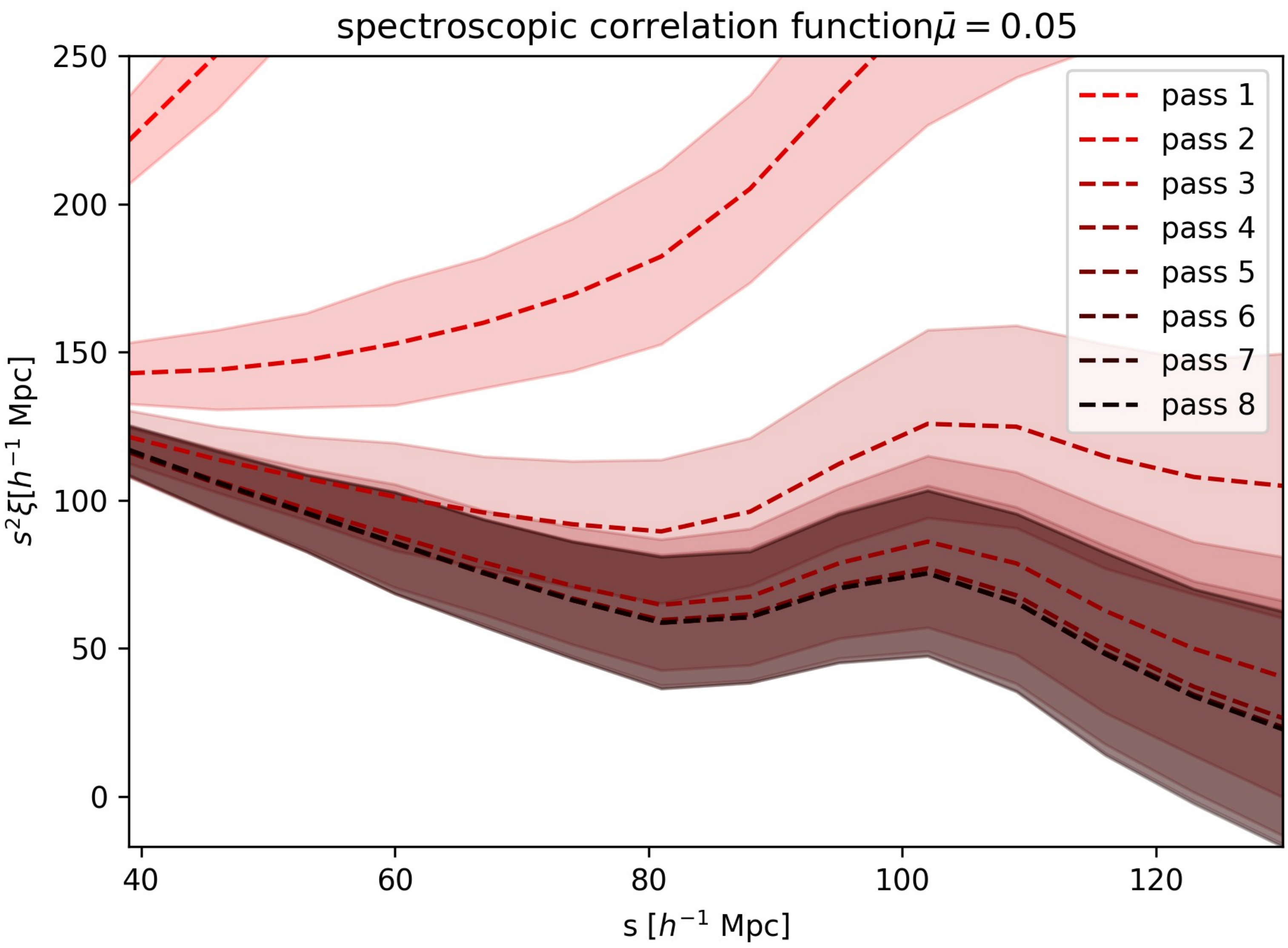


LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
spectro-photo cross correlation function
spectroscopic correlation function with fibre assignment
spectro-photo cross correlation function with fibre assignment
$s^2\xi\ [h^{-1}\ \mathrm{Mpc}]$
s $[h^{-1}$ Mpc$]$
1200
1000
800
600
400
200
0
40
60
80
100
120

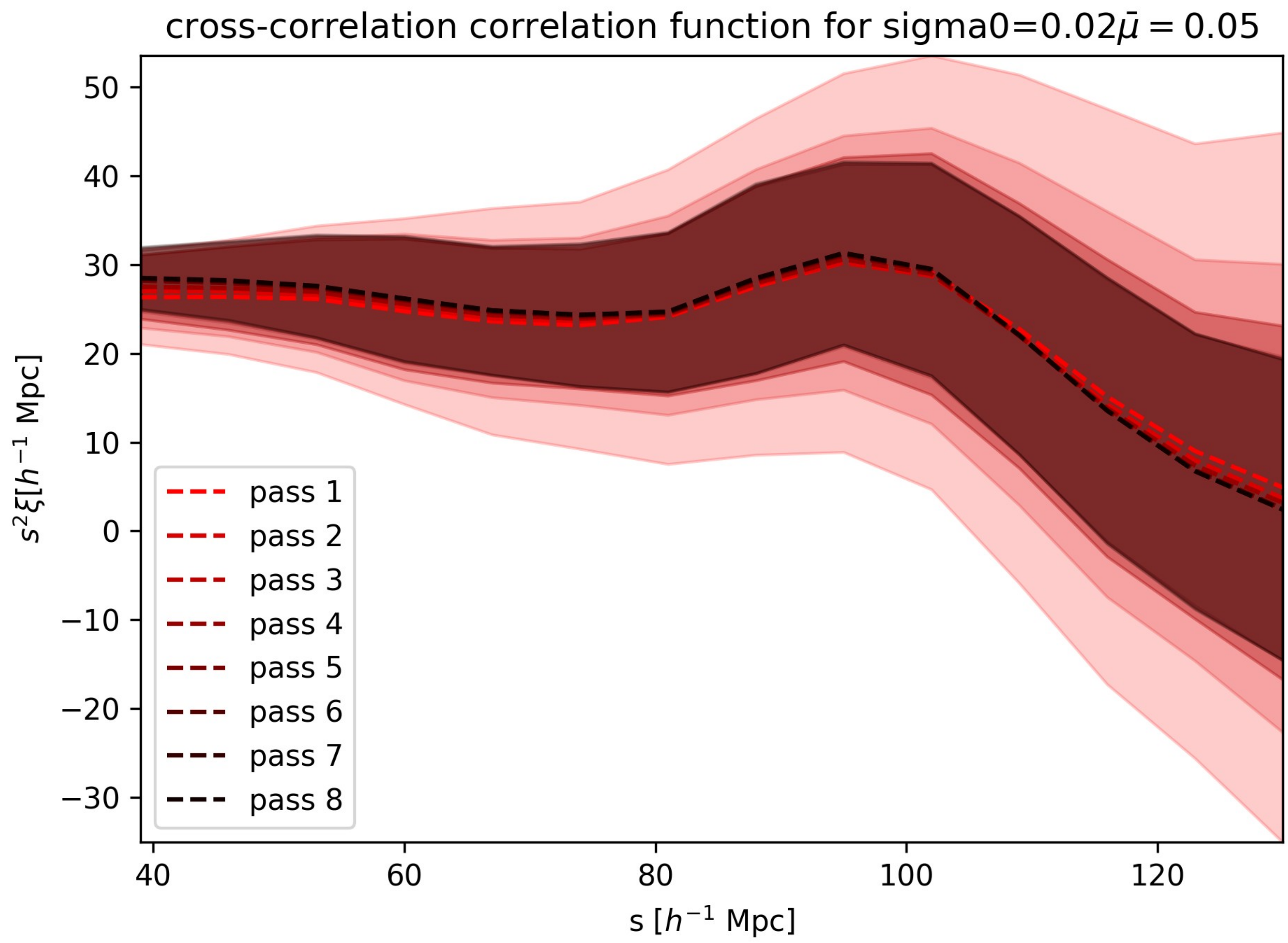

LRGs 0.02, 1st pass: $\bar{\mu} = 0.05$
spectroscopic correlation function
photometric correlation function
spectro-photo cross correlation function
spectroscopic correlation function with fibre assignment
spectro-photo cross correlation function with fibre assignment
$s^2\xi$ [h^{-1} Mpc]
s [h^{-1} Mpc]
0
20
40
60
80
100
120
40
60
80
100
120



spectroscopic correlation function$\bar{\mu} = 0.05$
pass 1
pass 2
pass 3
pass 4
pass 5
pass 6
pass 7
pass 8
$s^2\xi[h^{-1}$ Mpc]
s [h^{-1} Mpc]
0
200
400
600
800
1000
1200
40
60
80
100
120

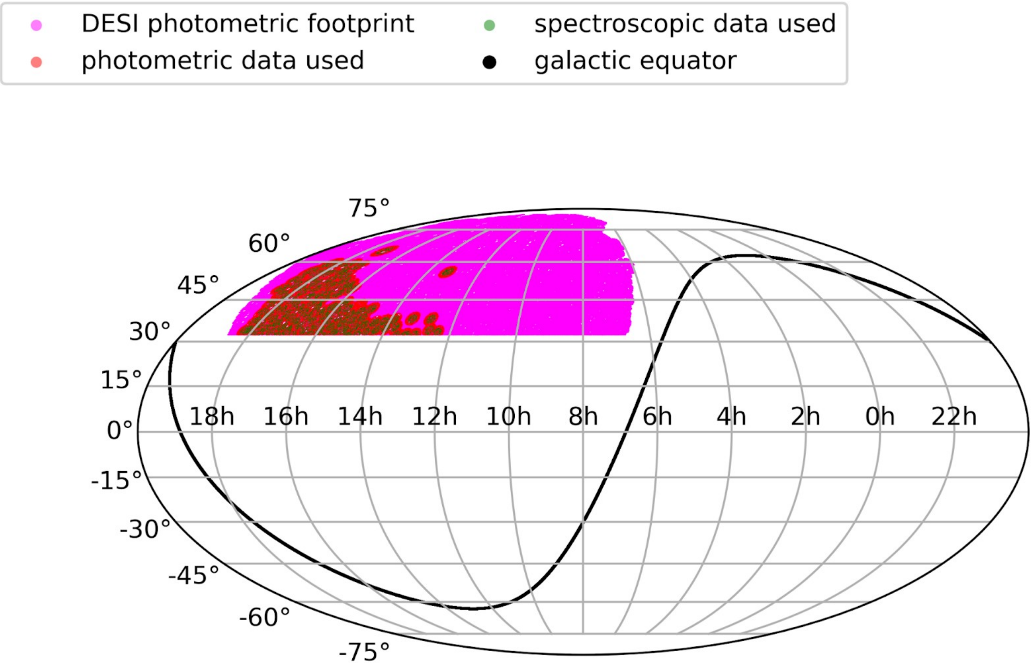


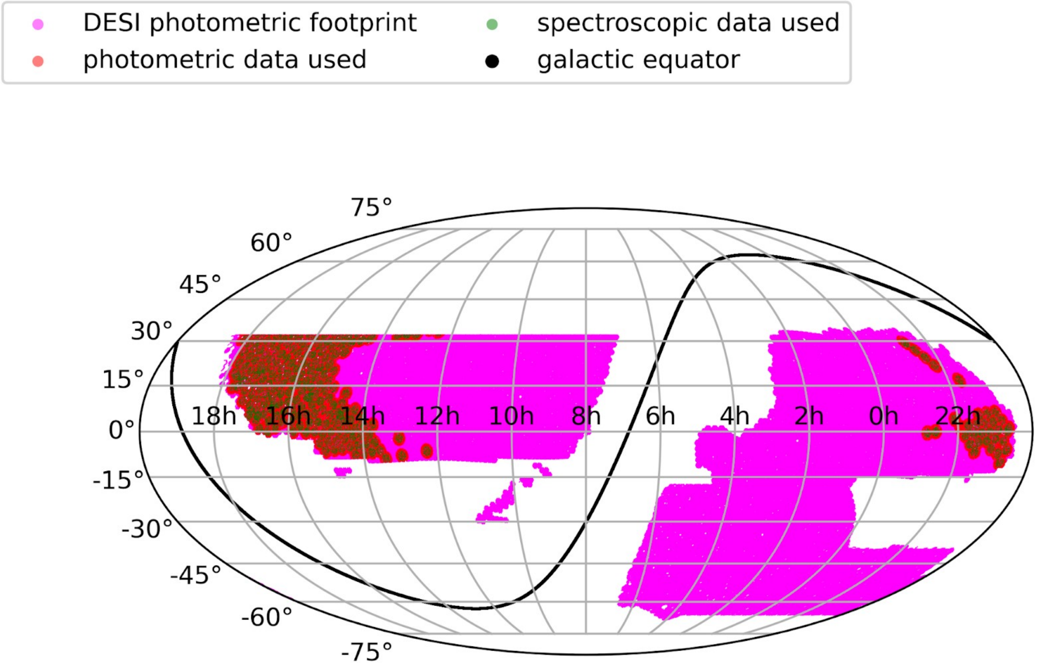
spectroscopic correlation function$\bar{\mu} = 0.05$
pass 1
pass 2
pass 3
pass 4
pass 5
pass 6
pass 7
pass 8
$s^2\xi[h^{-1}$ Mpc]
s [h^{-1} Mpc]
250
200
150
100
50
0
40
60
80
100
120



cross-correlation correlation function for sigma0=0.02$\bar{\mu} = 0.05$
$s^2\xi[h^{-1}$ Mpc]
s [h^{-1} Mpc]
50
40
30
20
10
0
−10
−20
−30
40
60
80
100
120
pass 1
pass 2
pass 3
pass 4
pass 5
pass 6
pass 7
pass 8

DESI DA0.2 data



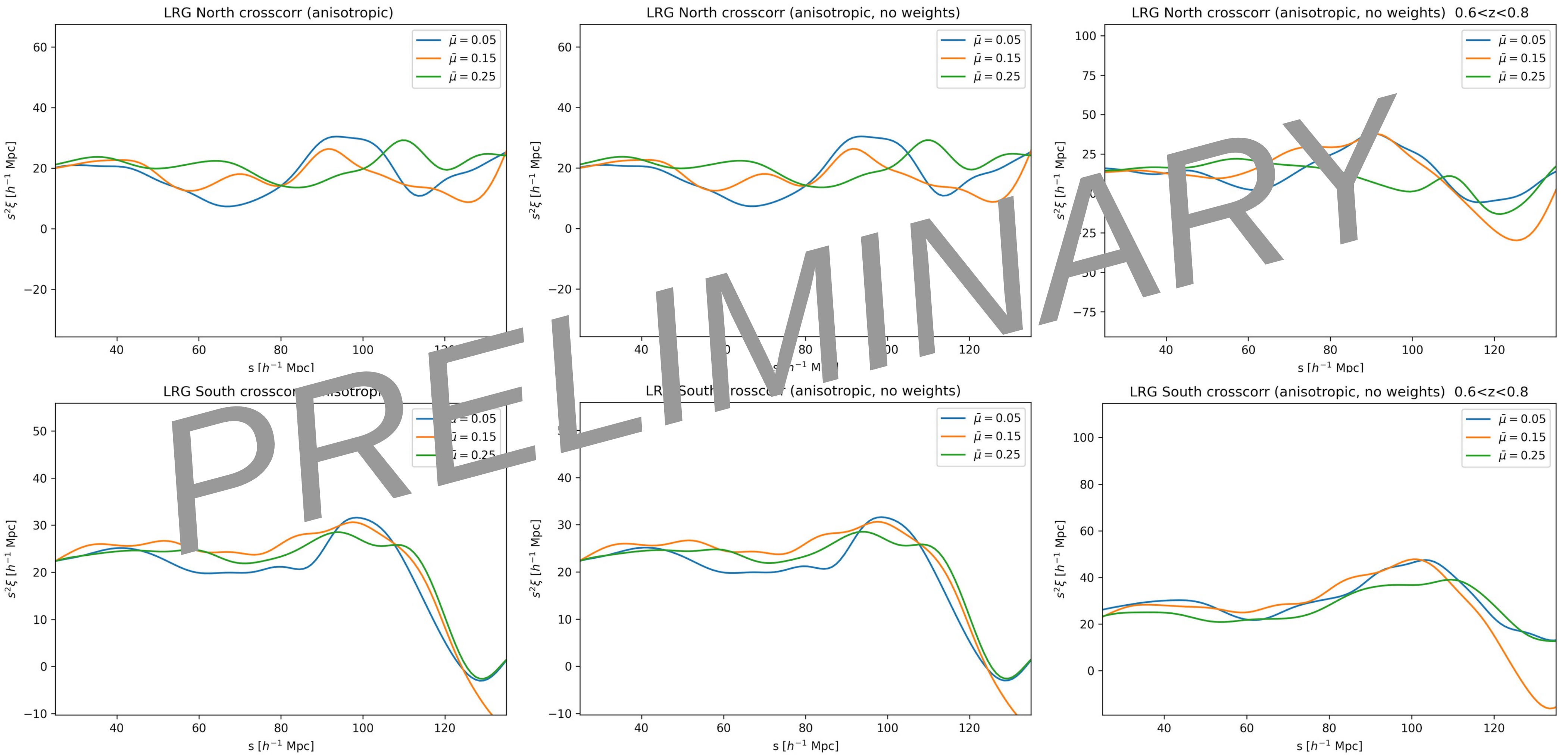


Differences in the photometric selection

→ North and South are treated separately

Photometric data used in a 2° radius around spectroscopic tile centres

DESI DA0.2 data



Advantages of cross-correlations

- Cross-correlation naturally recovers features, even if the spectroscopic data set is incomplete and biased due to fibre assignment
- Complimentary to the other methods such as PIP weights (combining both doesn't improve the data)
- Perfectly suited for early DESI data (single pass or few passes) such as DA0.2 and the year 1 data.

Disadvantages of cross-correlations

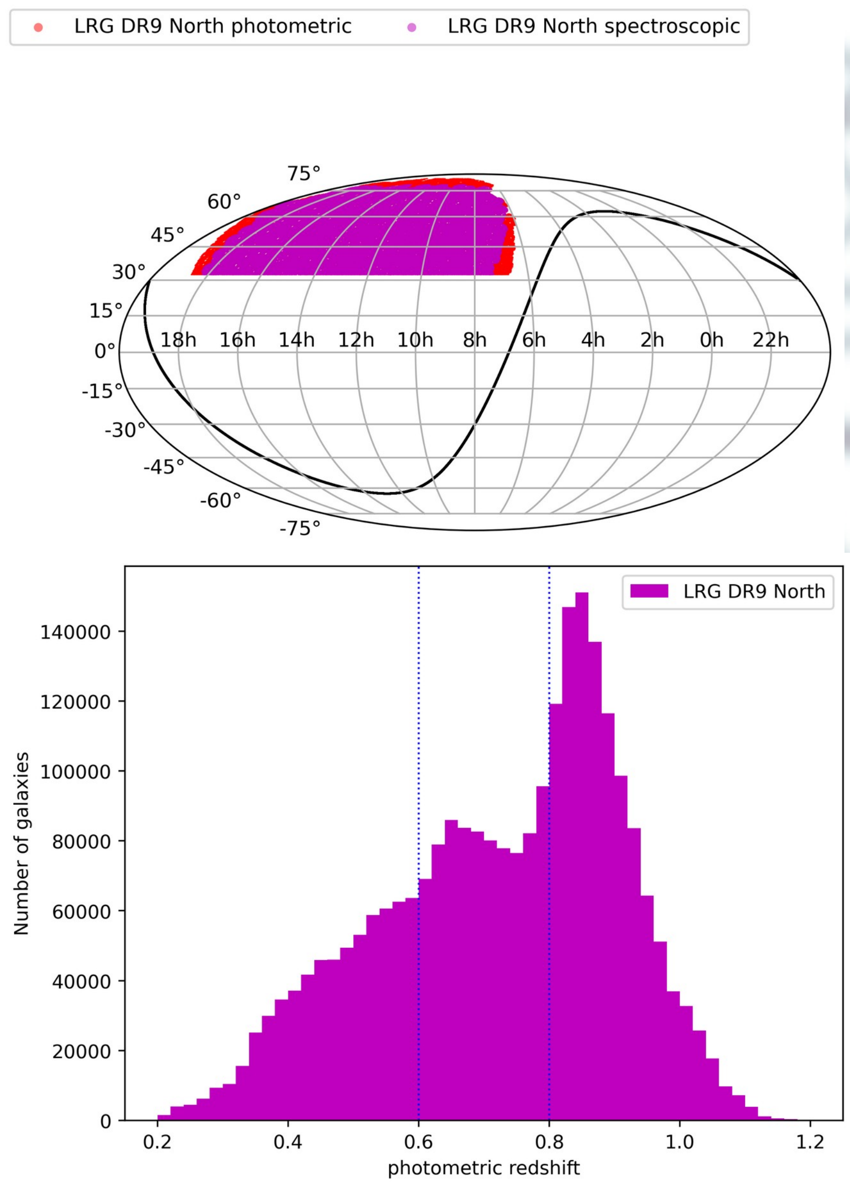
- Only the lower μ-bins of the anisotropic correlation function can be used.
- Any improvements over the photometric correlation function alone with be ultimately outdone by the spectroscopic correlation once the survey is more complete.
- Dominated by the photometric correlation function
  - **Suffers from the same systematic biases as it!**

Photometric data only

- Observational data from the DESI Legacy Imaging survey DR9
- Sridhar+ 2020 already did the Southern photometric footprint with DR8
- Original plan: update with DR9 and also include the Northern photometric footprint
- Improved LRG target selection

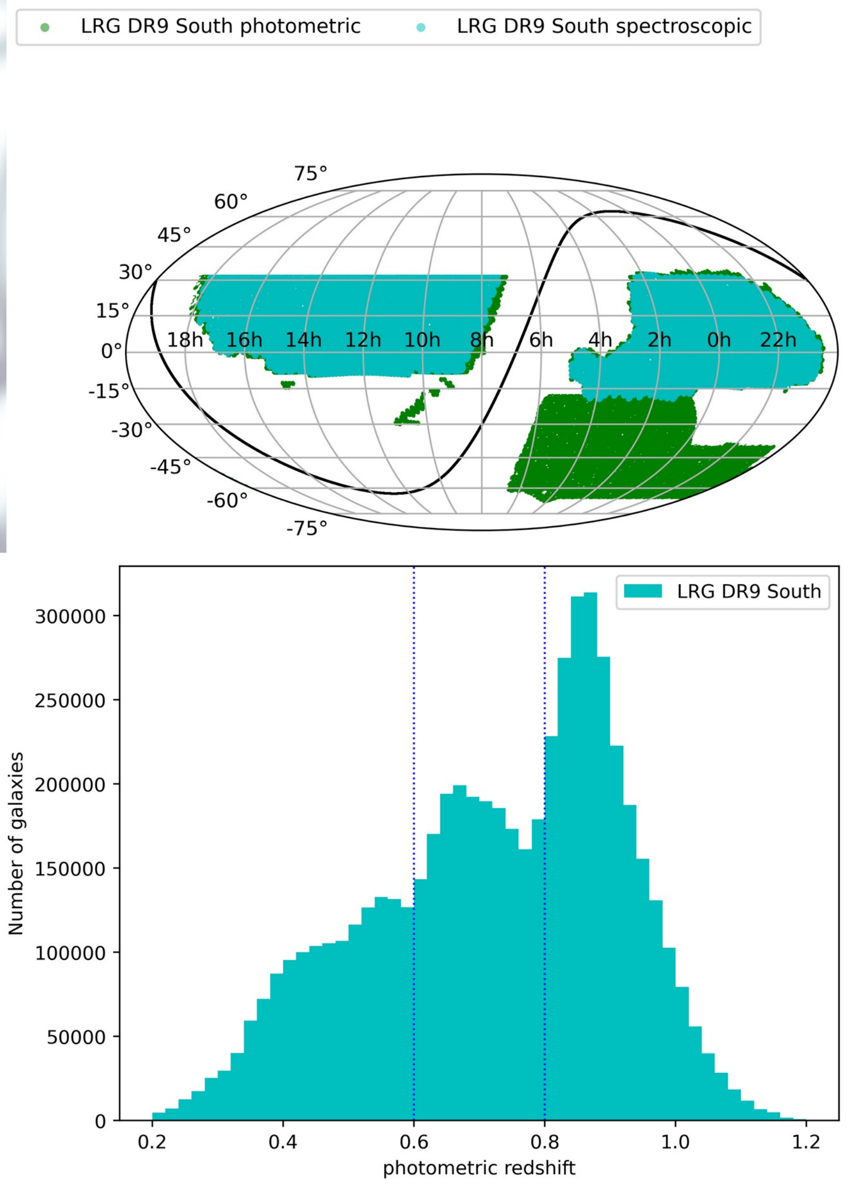
Photometric data only

- Observational data from the DESI Legacy Imaging survey DR9
- Sridhar+ 2020 already did the Southern photometric footprint with DR8
- Original plan: update with DR9 and also include the Northern photometric footprint
- Improved LRG target selection

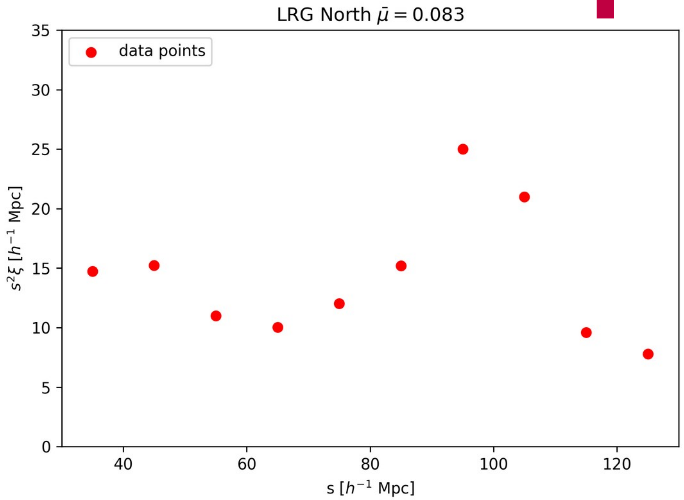

LRG DR9 North photometric
LRG DR9 North spectroscopic
LRG DR9 North
Number of galaxies
photometric redshift

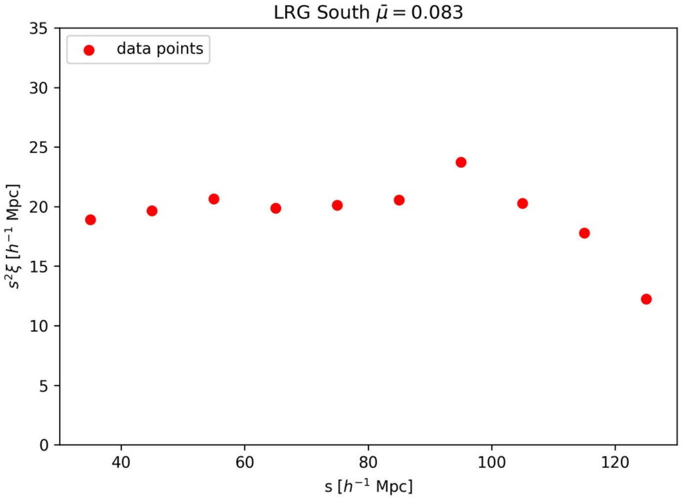
LRGs

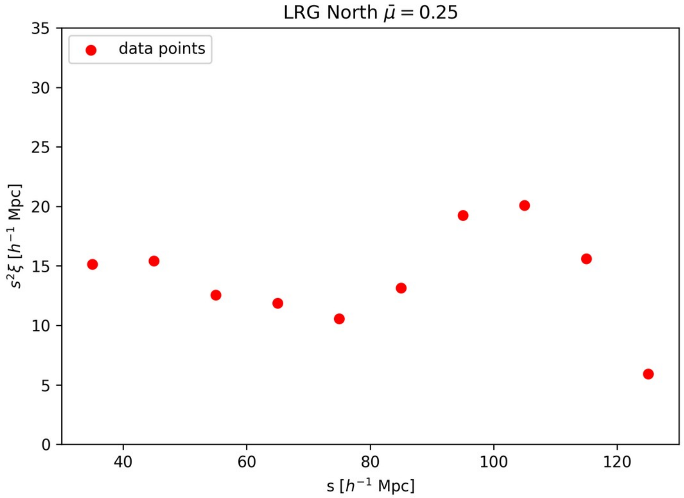
0.6<z<0.8

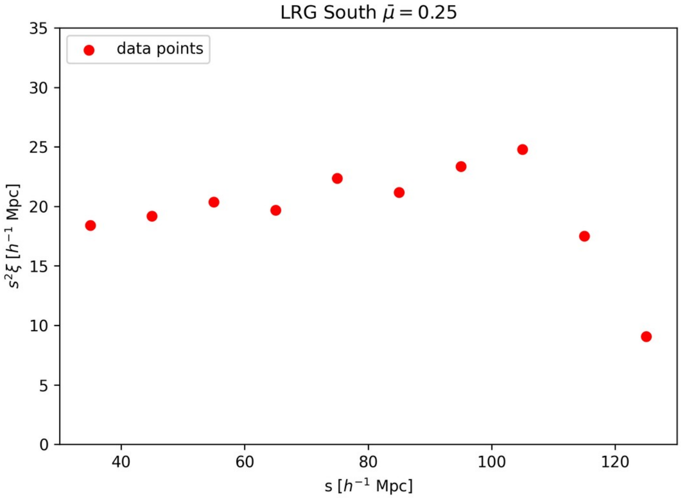

LRG DR9 South photometric
LRG DR9 South spectroscopic
LRG DR9 South
Number of galaxies
photometric redshift

BAO peak measurements

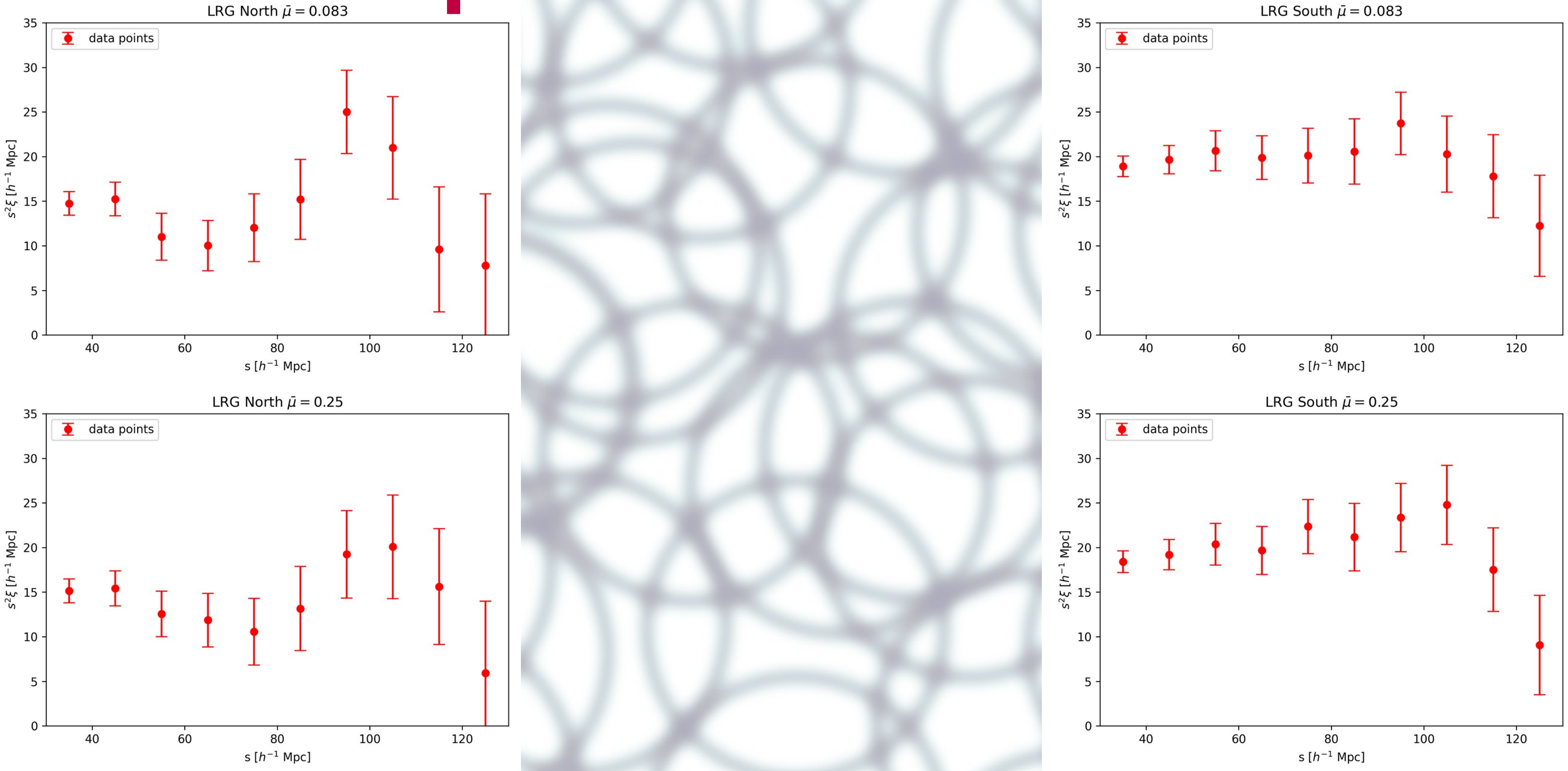




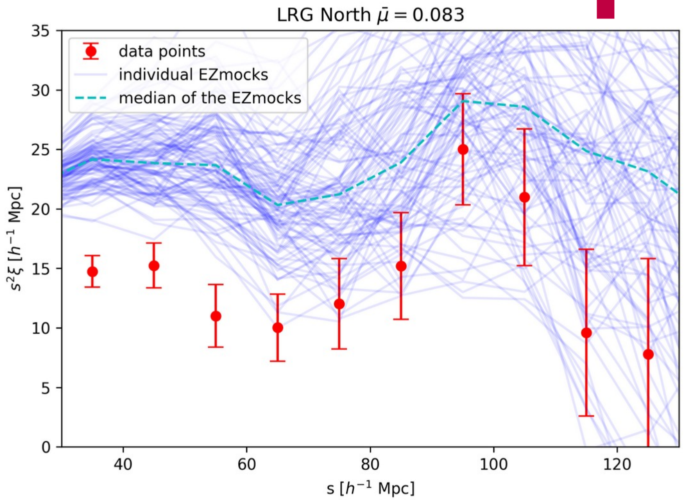


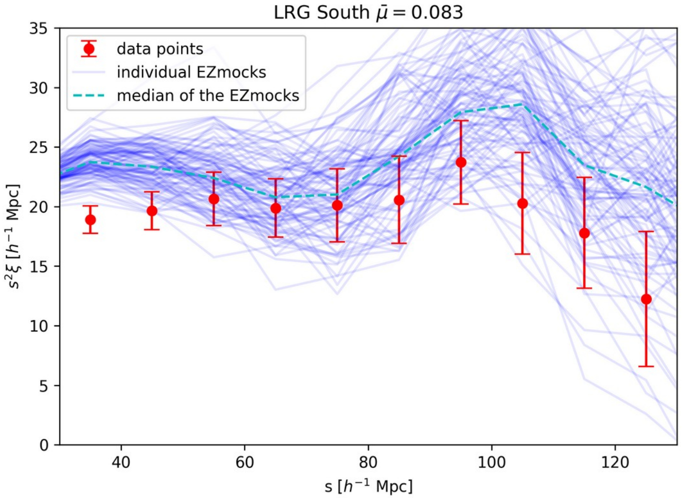


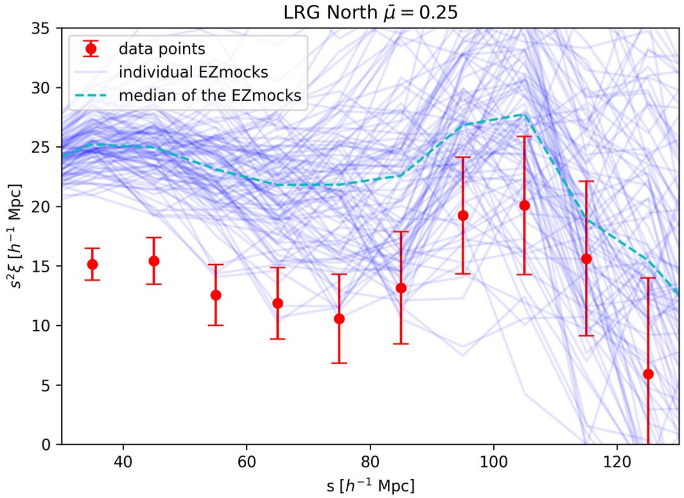
BAO peak measurements

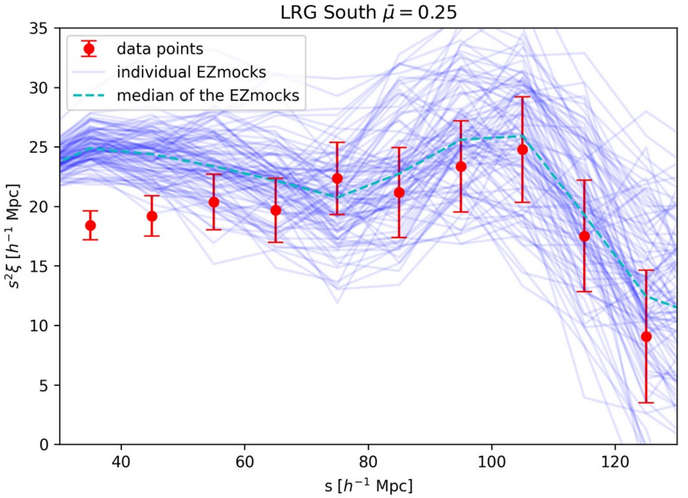


BAO peak measurements

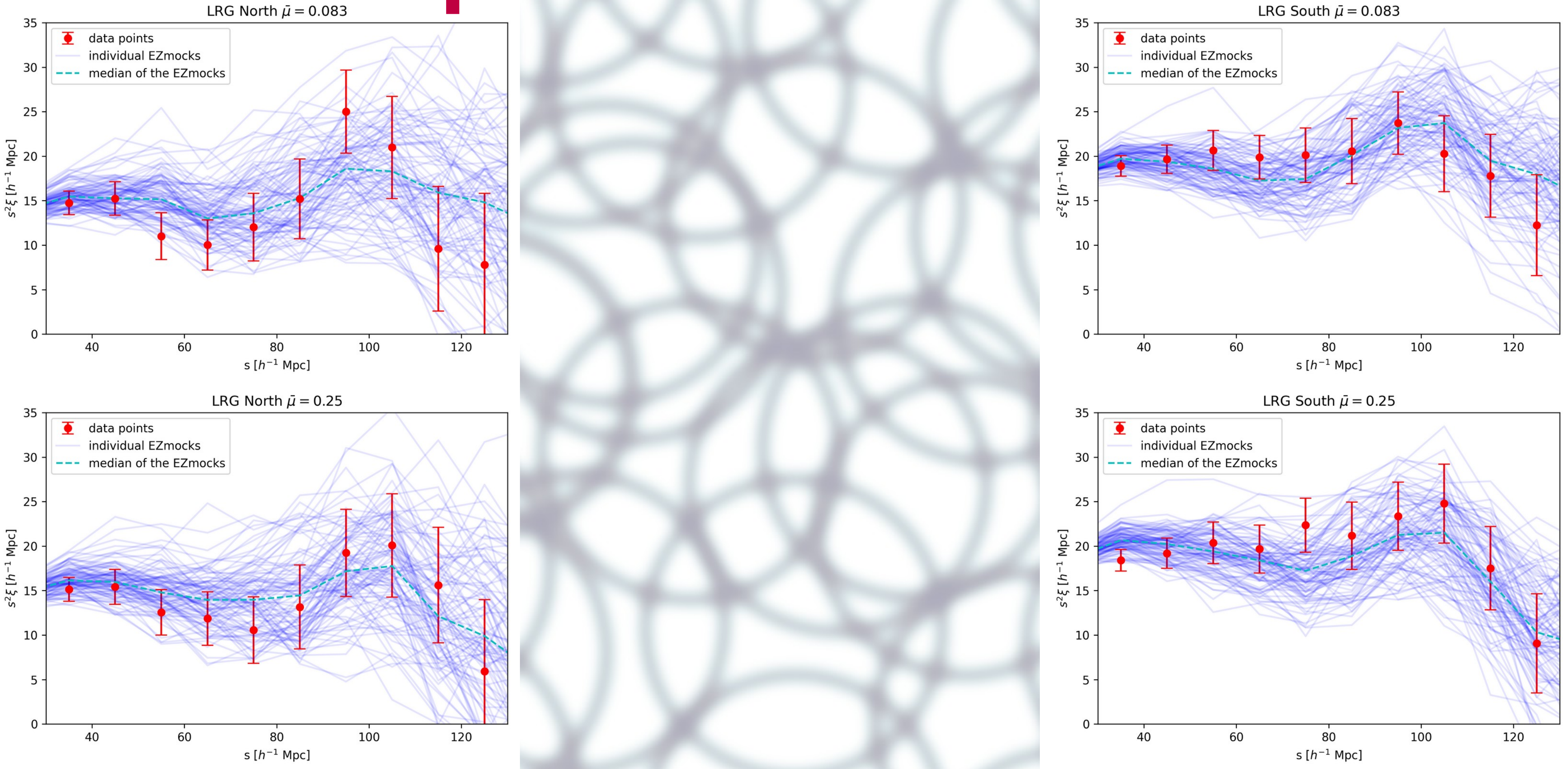




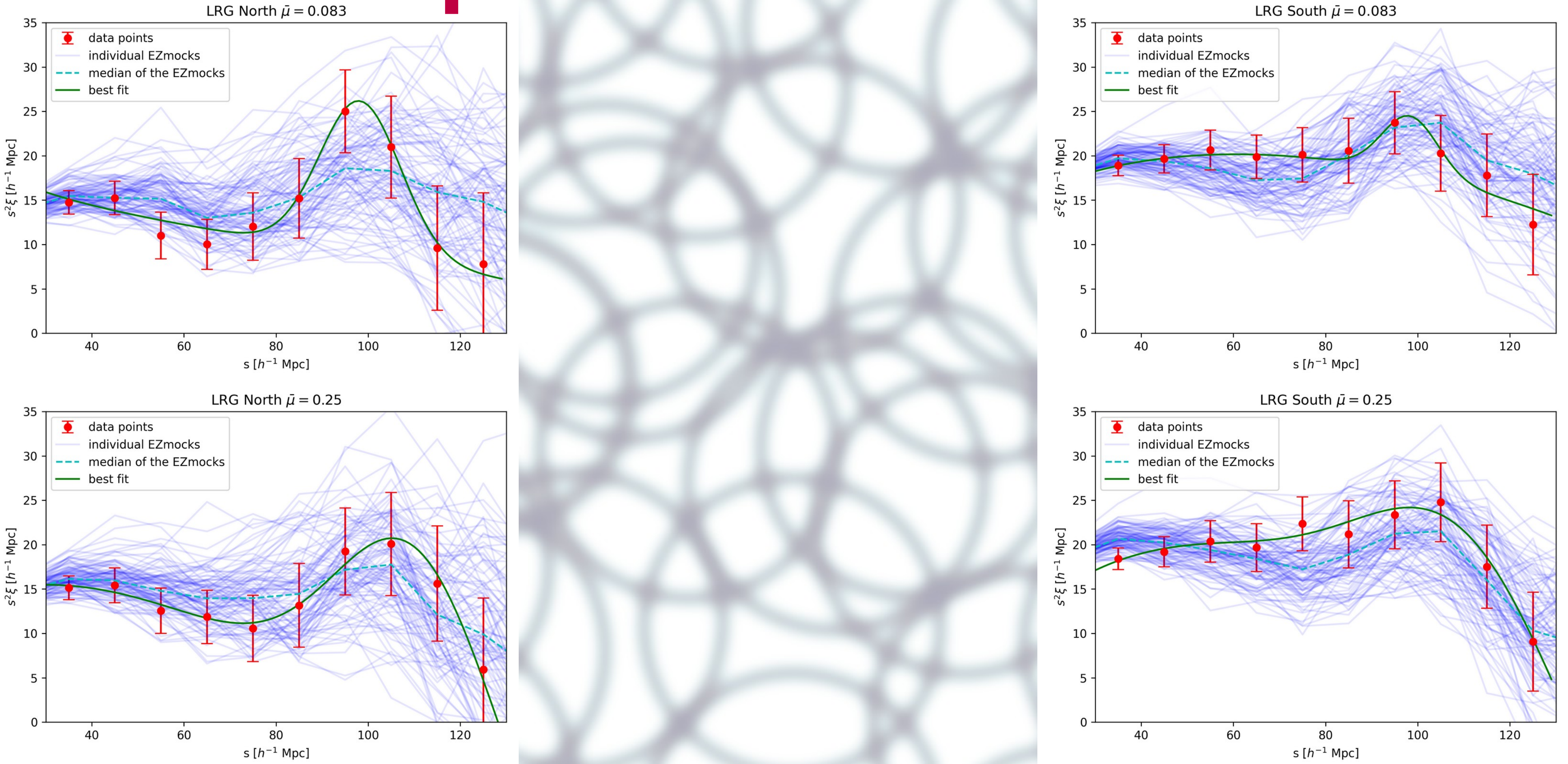




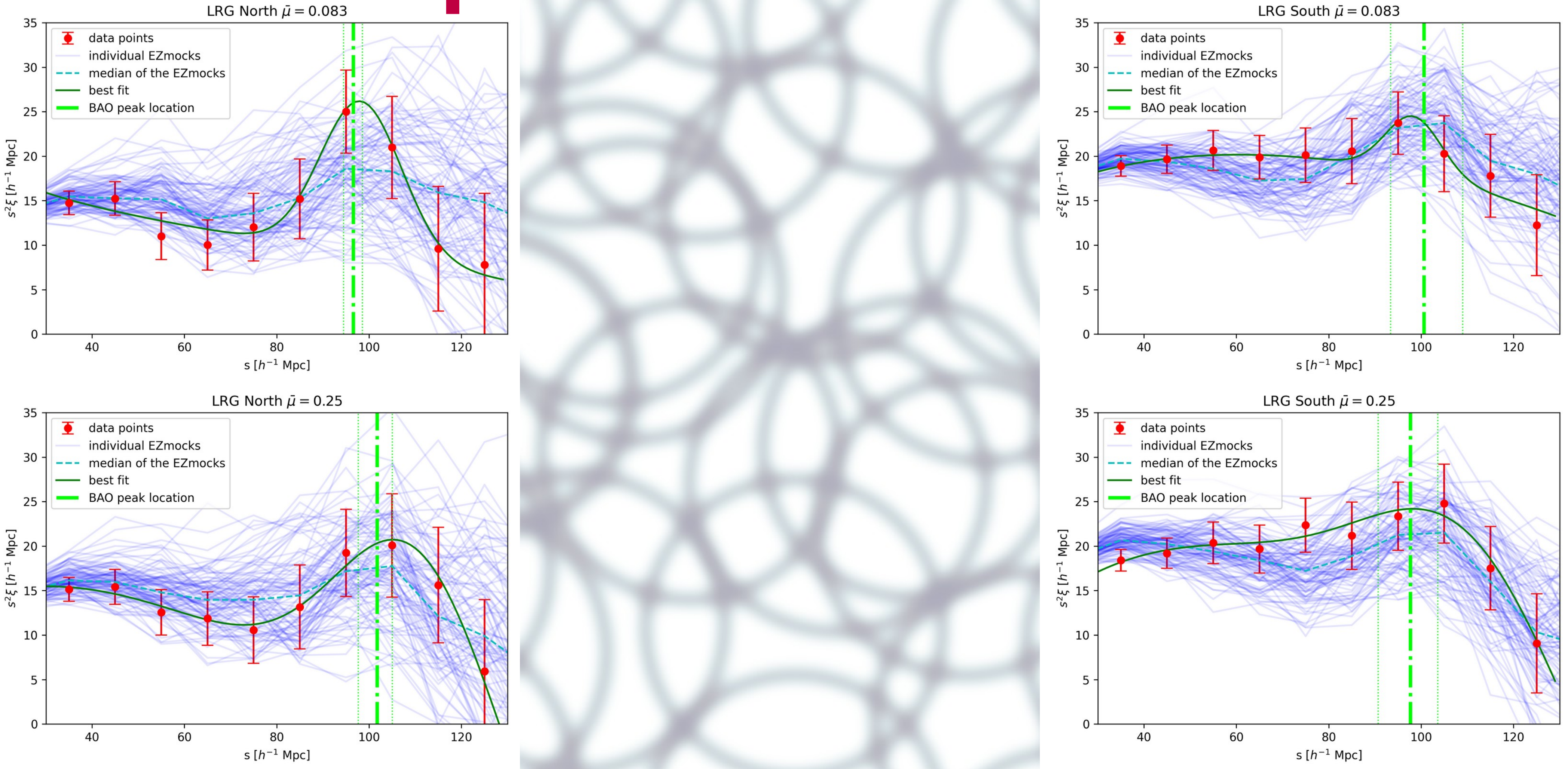
BAO peak measurements



BAO peak measurements

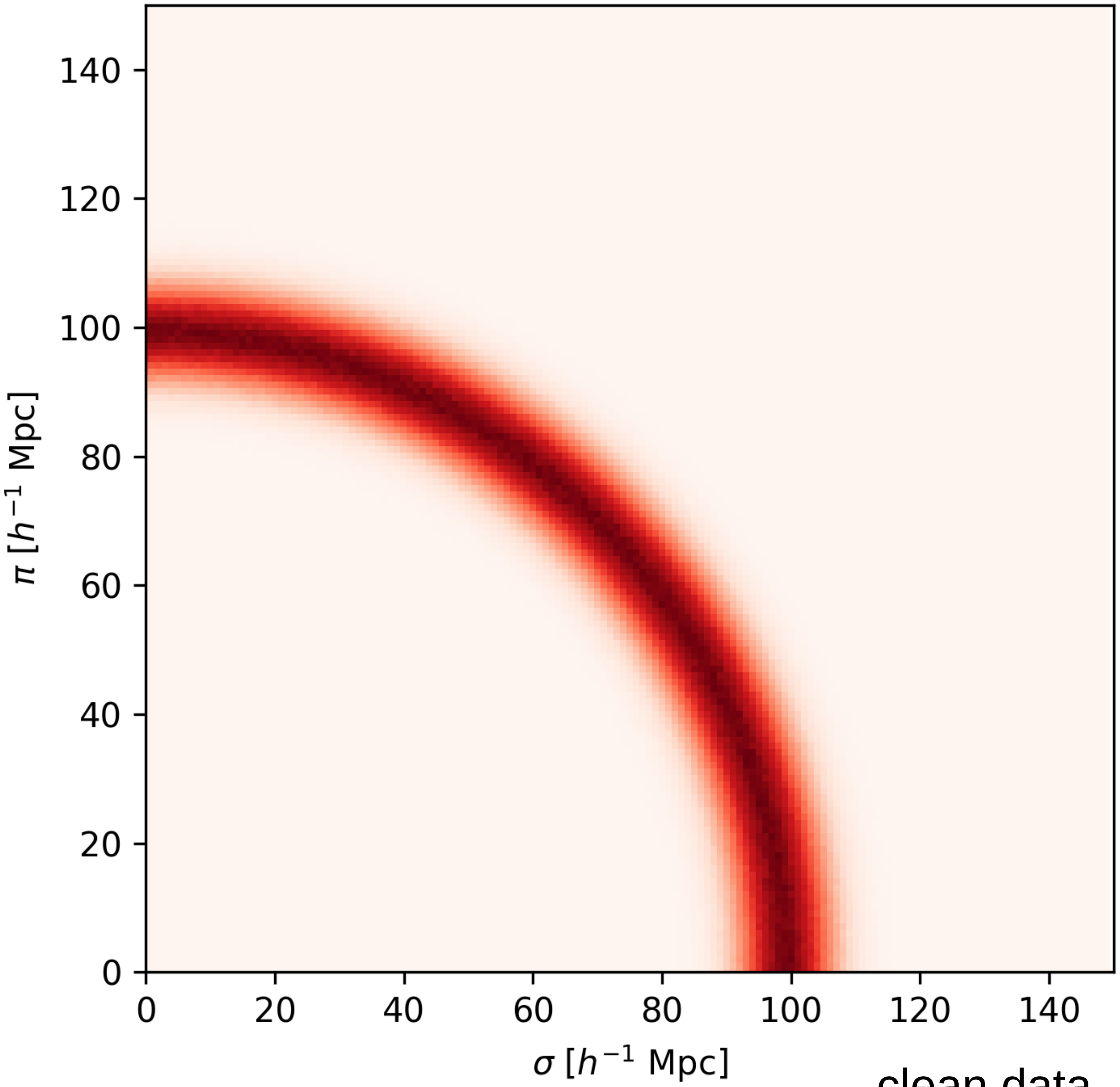


BAO peak measurements



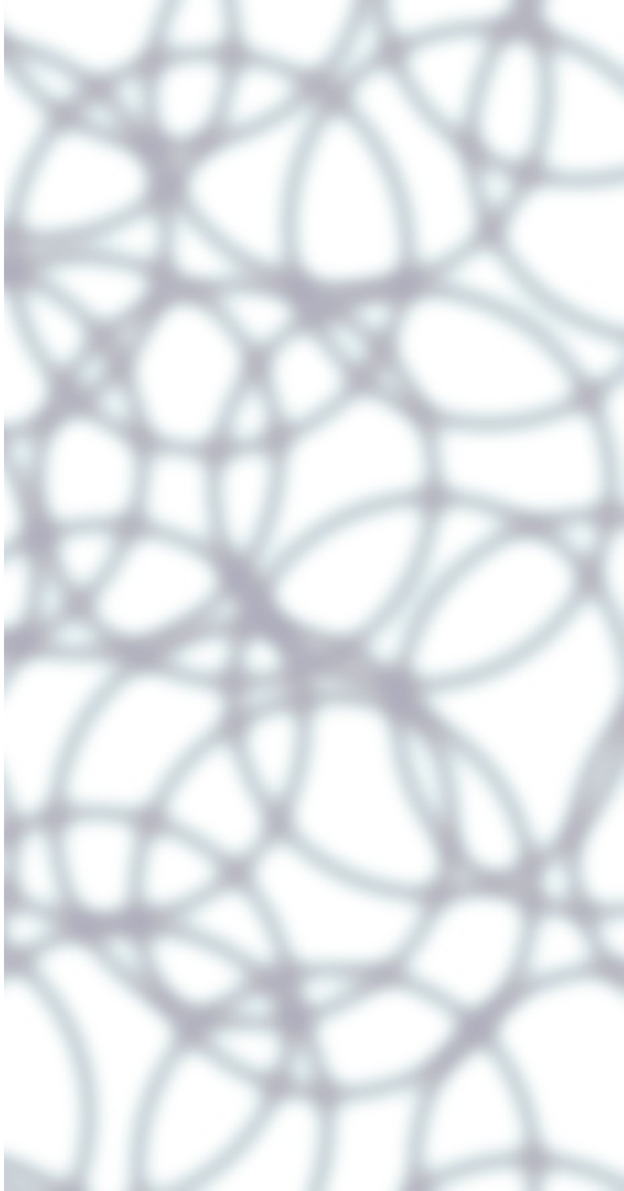
So, what is the problem?

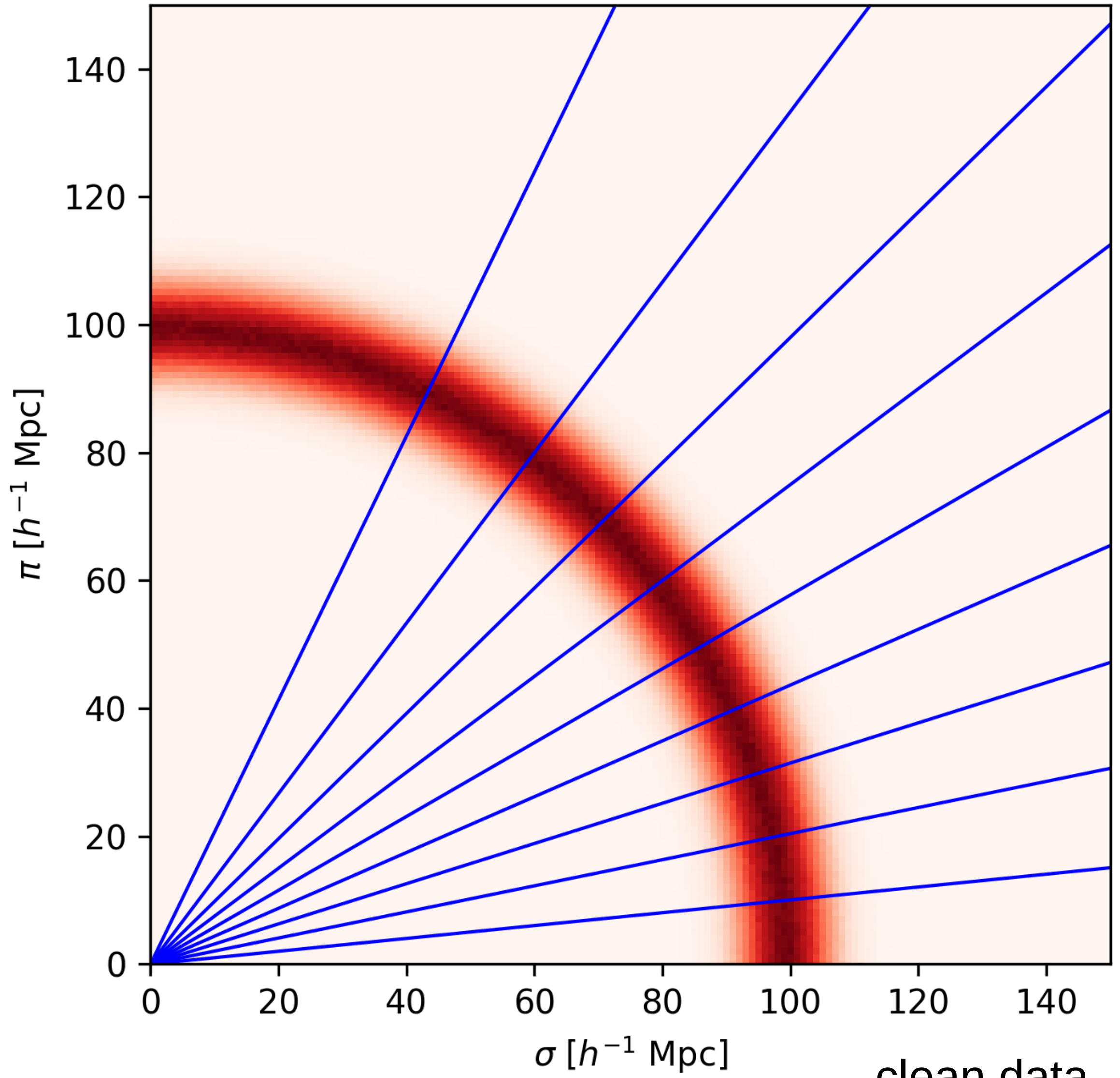
- Surprisingly well constraint value for the peak location in the North, but also relatively small value (tension with Planck).
- Additional tests: systematic shift of the photometric BAO as a function of μ.
- Chan+2021 found a similar effect and also a possible solution, but there is more to it.



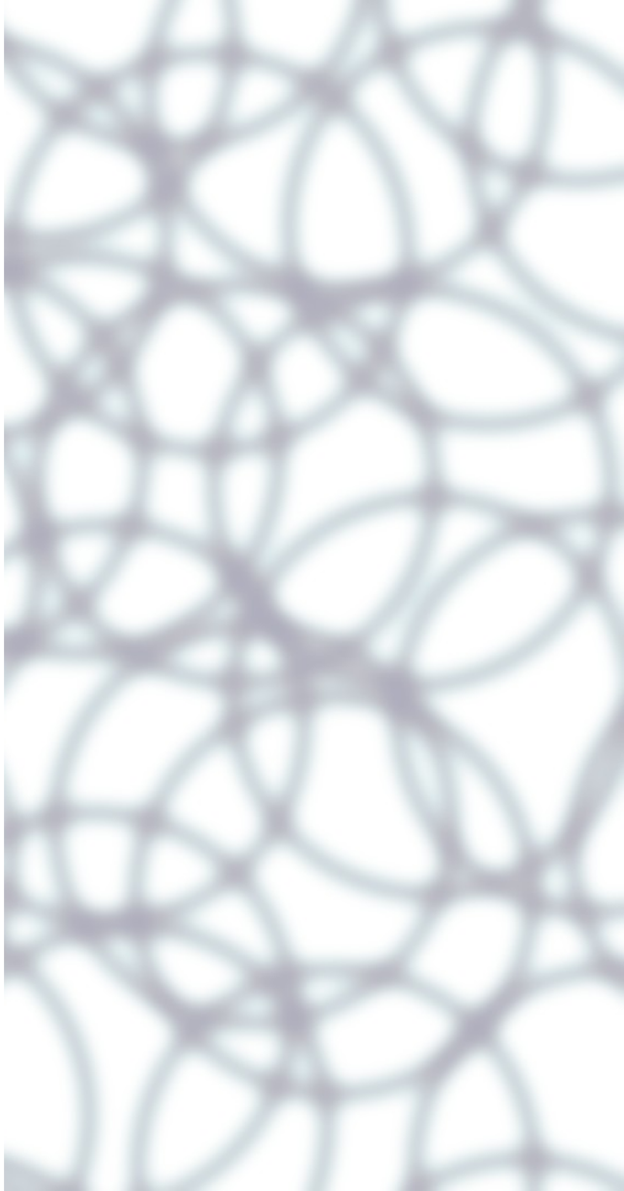
140
120
100
80
60
40
20
0
$\pi\ [h^{-1}$ Mpc]
0
20
40
60
80
100
120
140
$\sigma\ [h^{-1}$ Mpc]

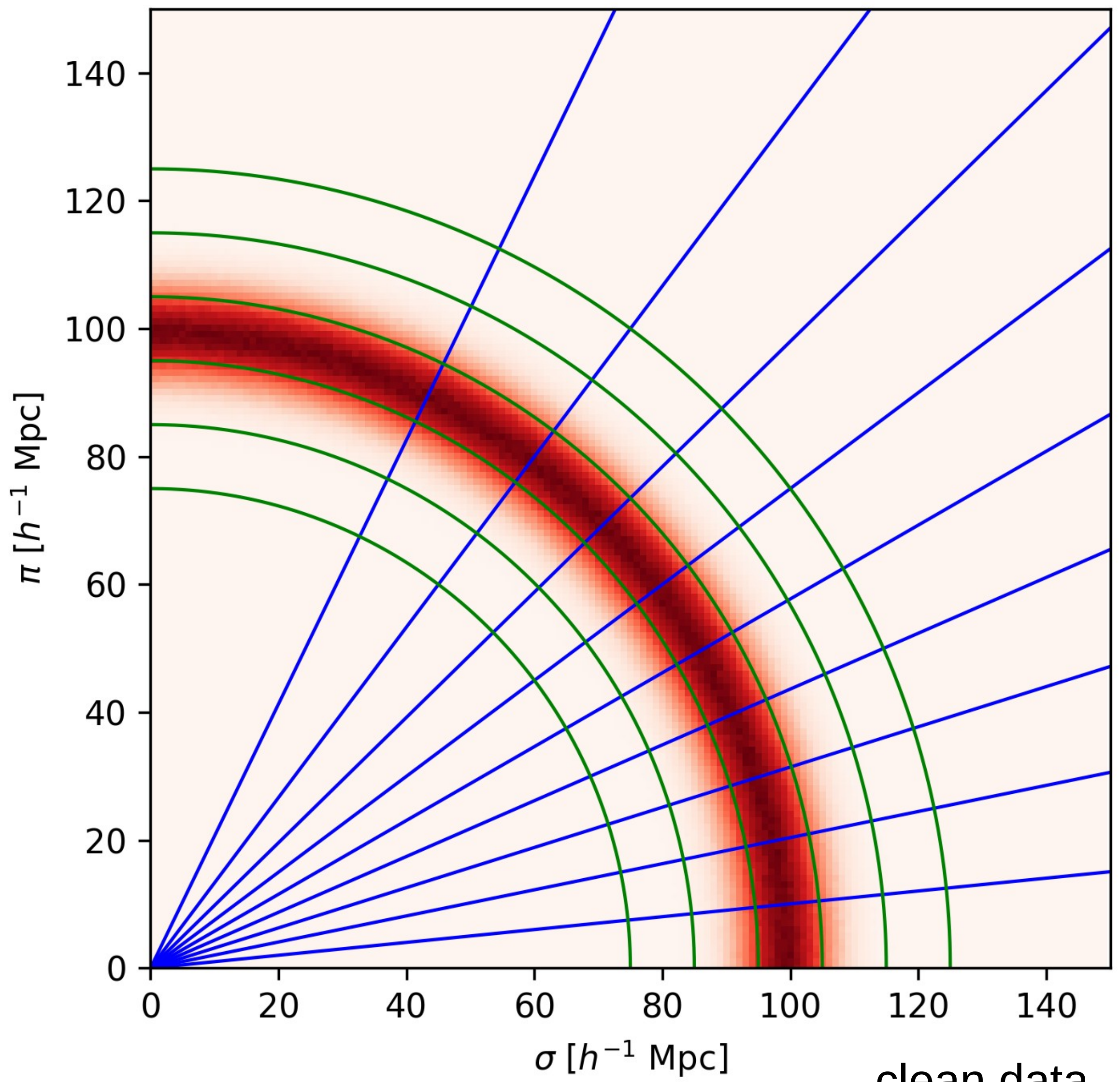
clean data

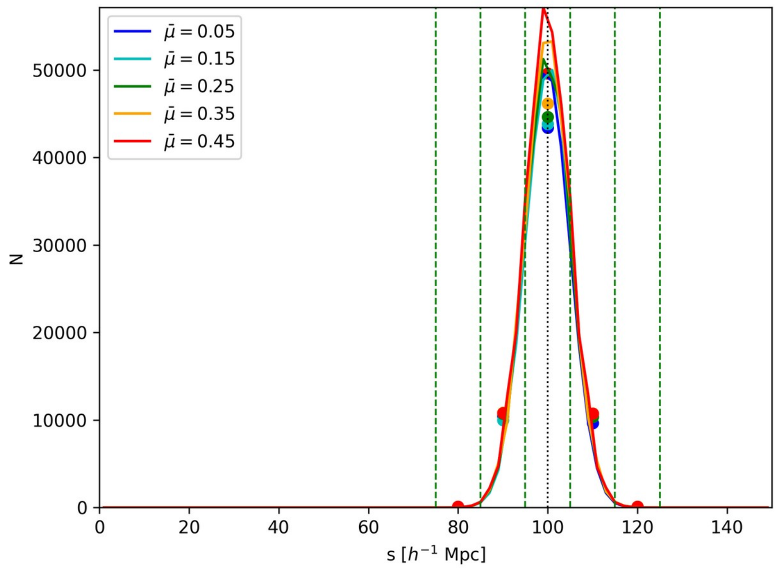




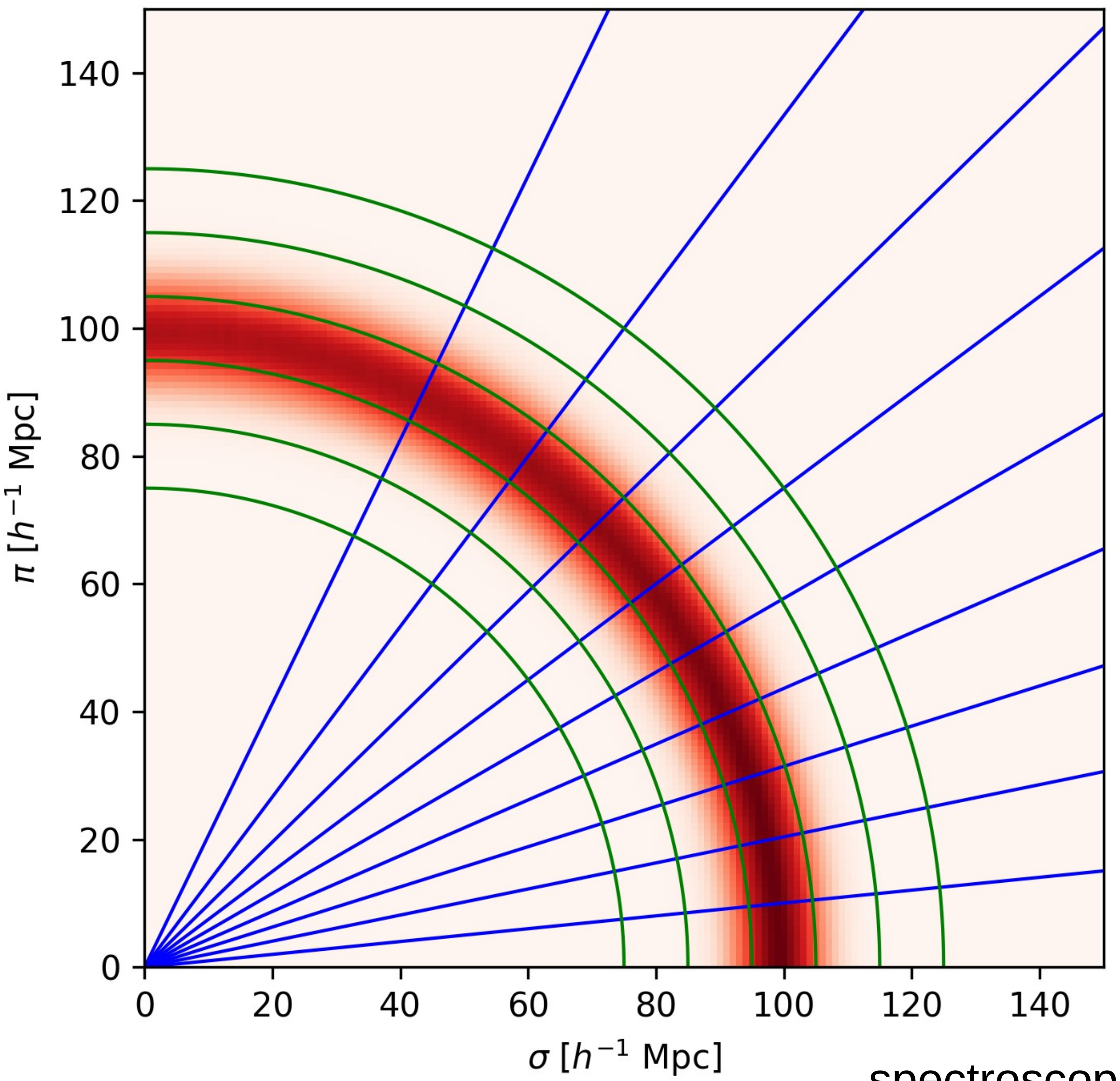
clean data

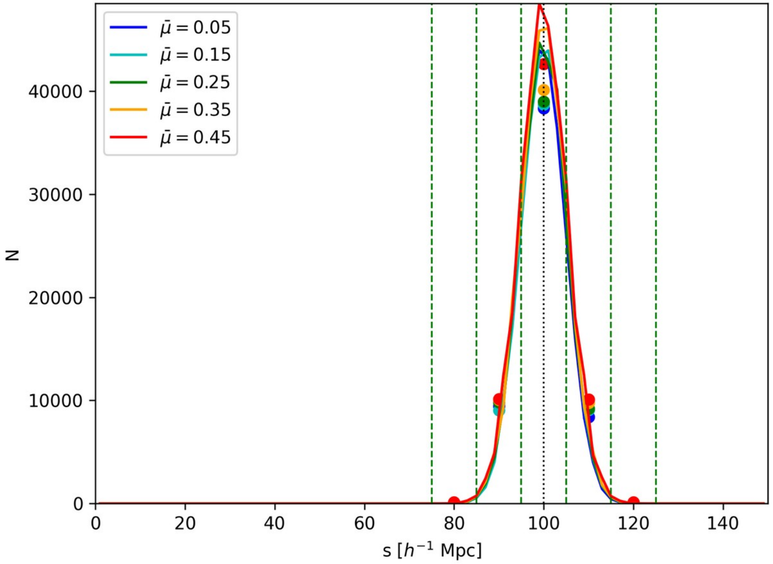



$\pi\ [h^{-1}\ \mathrm{Mpc}]$
$\sigma\ [h^{-1}\ \mathrm{Mpc}]$
0
20
40
60
80
100
120
140

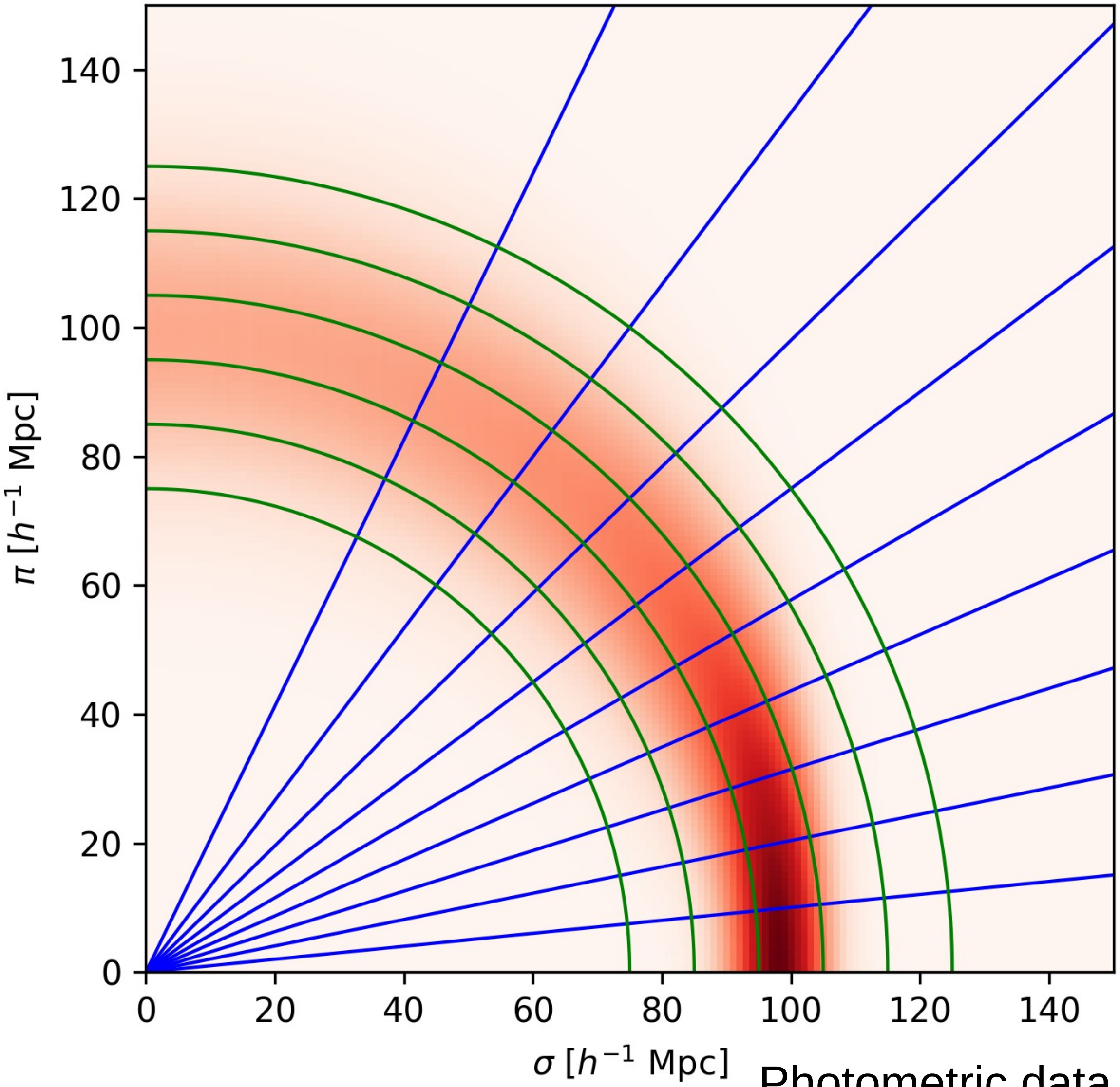

$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
N
s $[h^{-1}\ \mathrm{Mpc}]$
0
10000
20000
30000
40000
50000
0
20
40
60
80
100
120
140

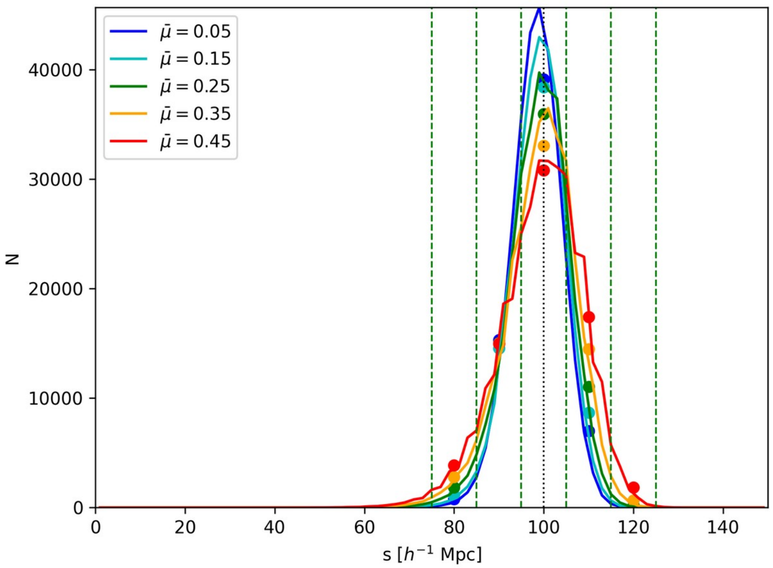
clean data



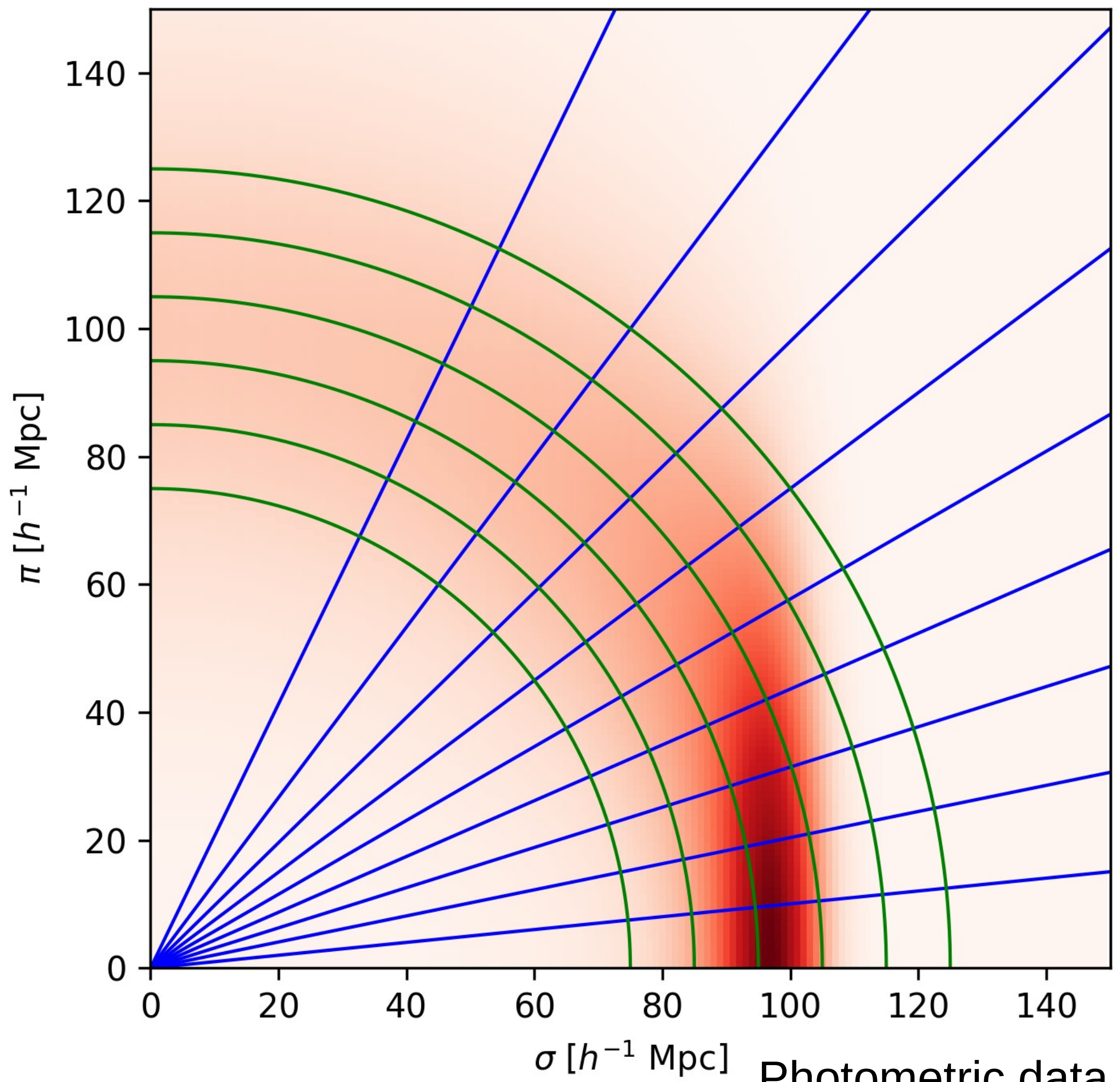


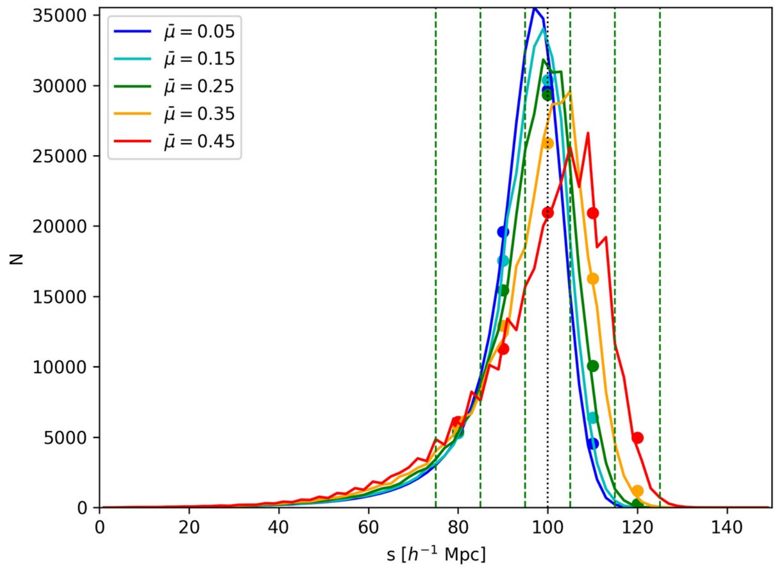
spectroscopic data



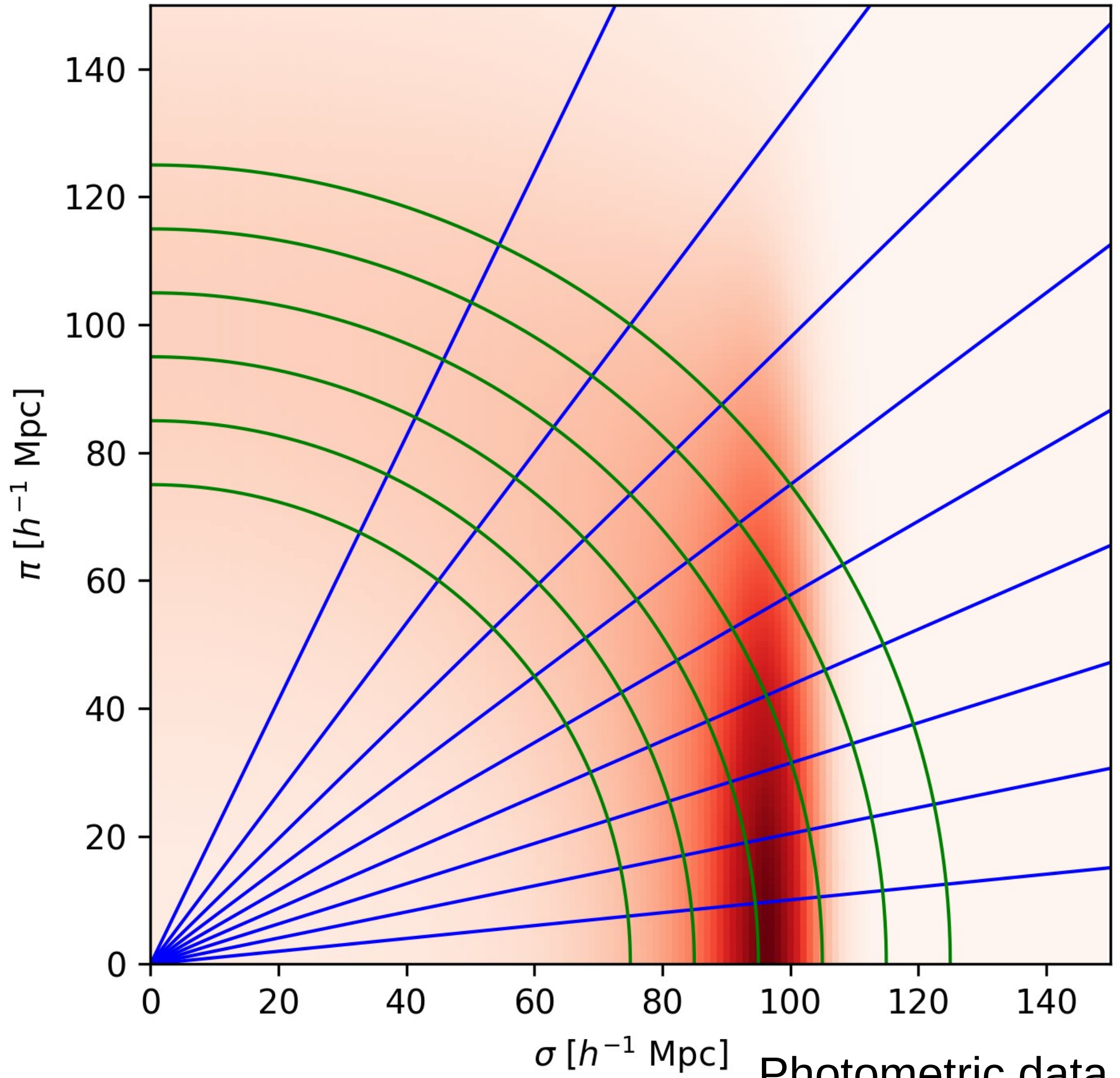


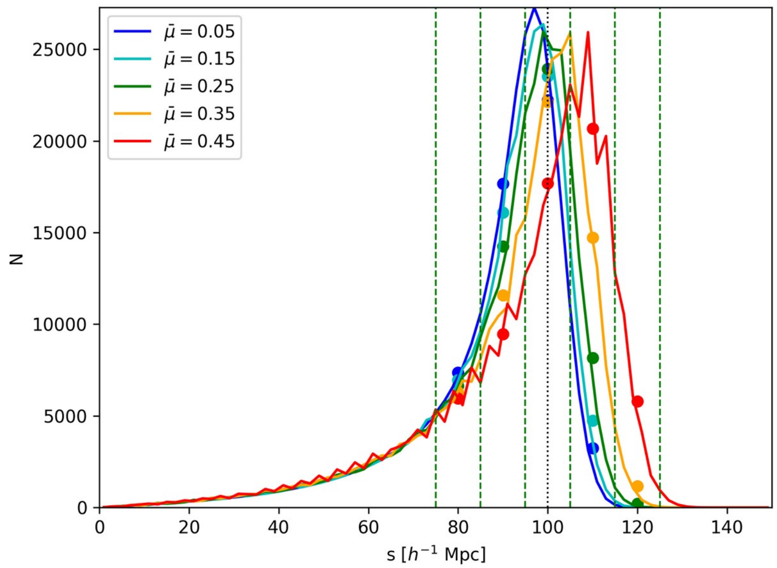
Photometric data σ_0=0.005



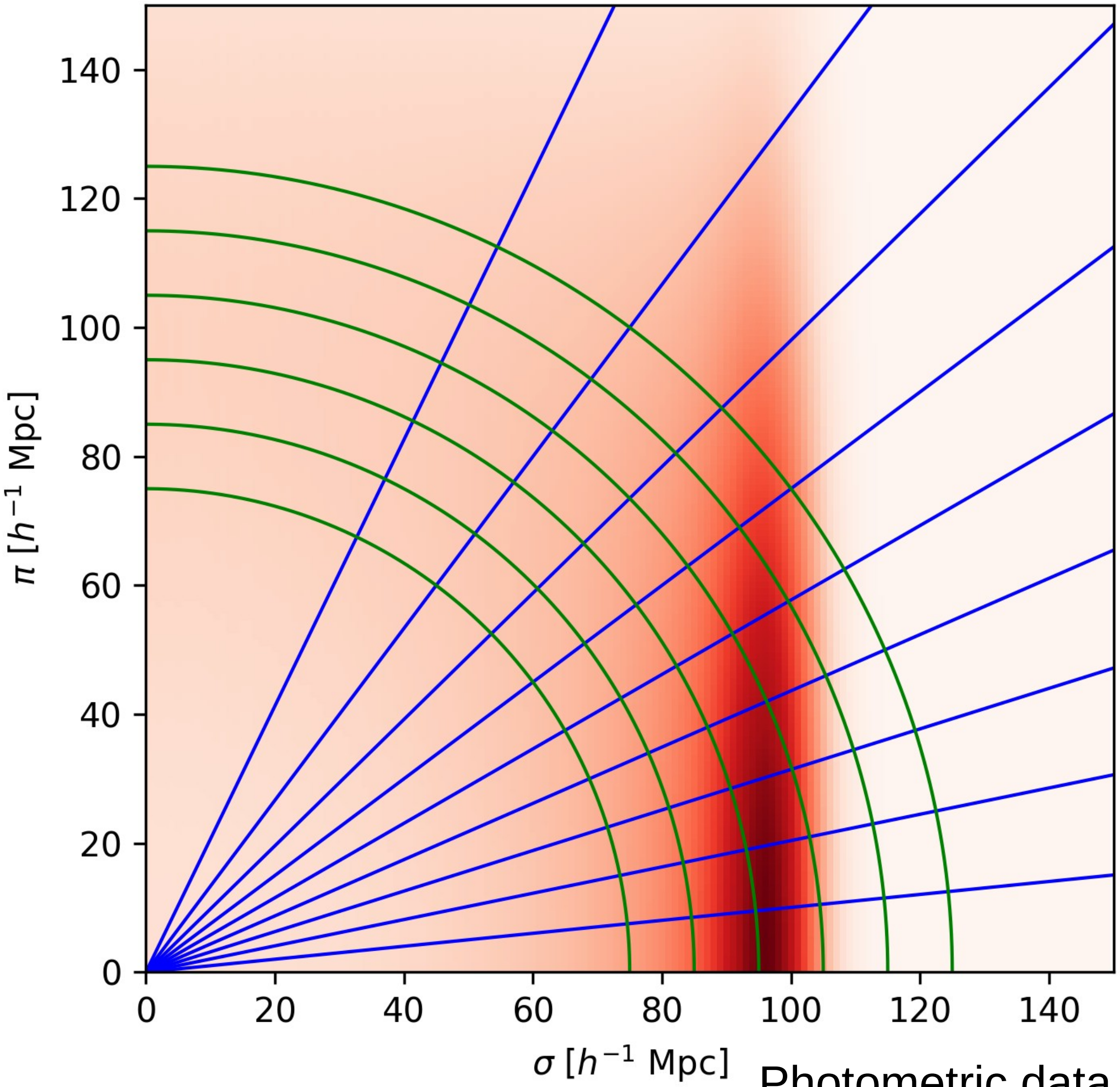


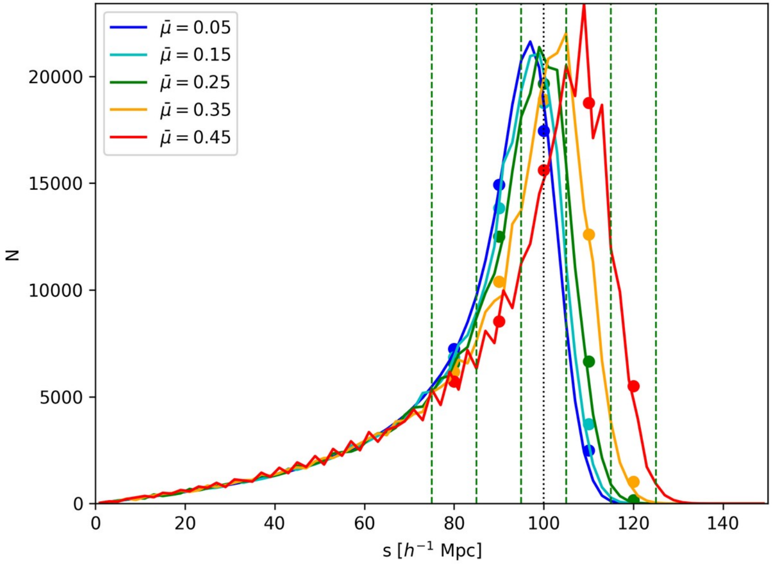
Photometric data σ_0=0.010



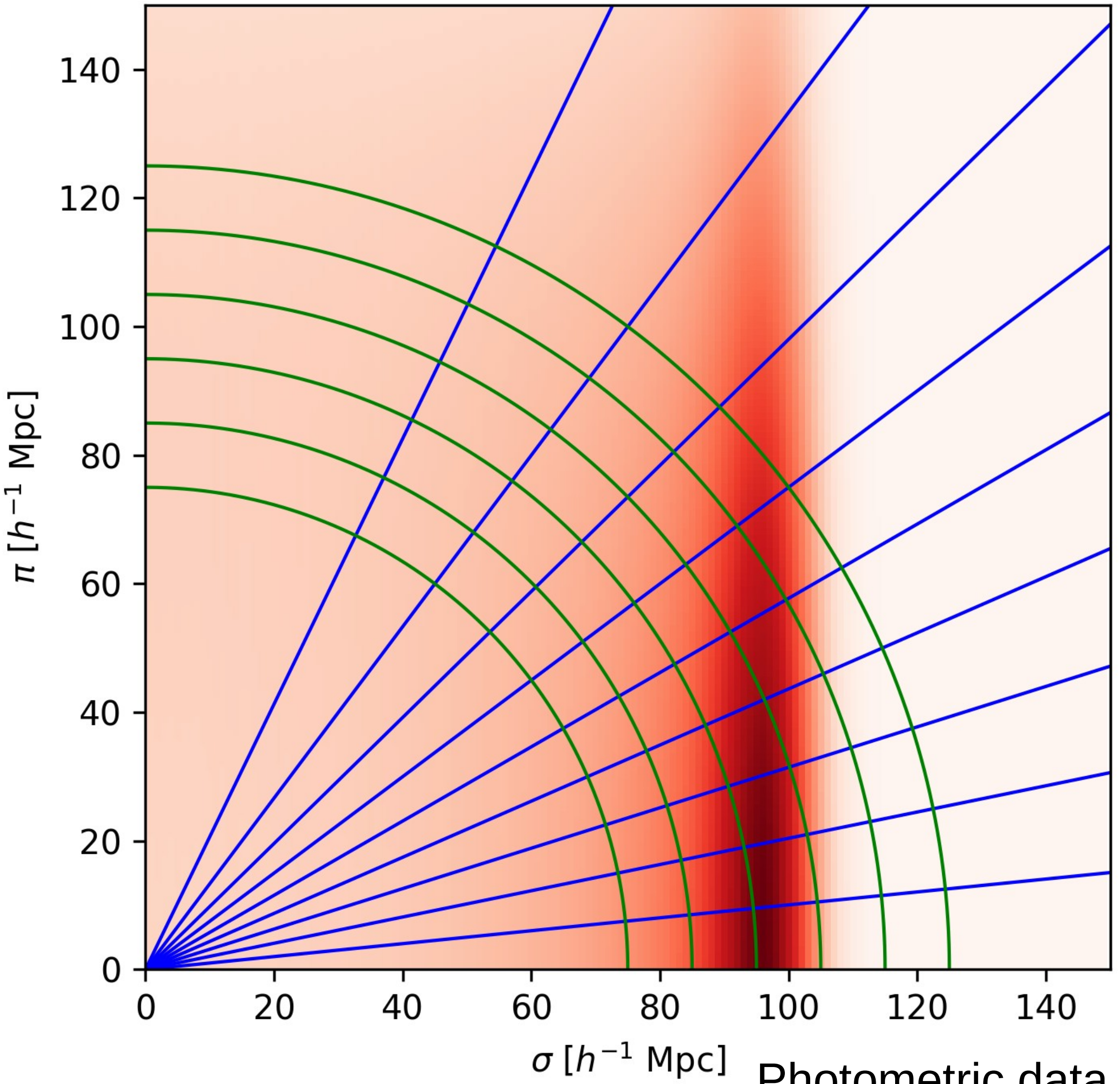


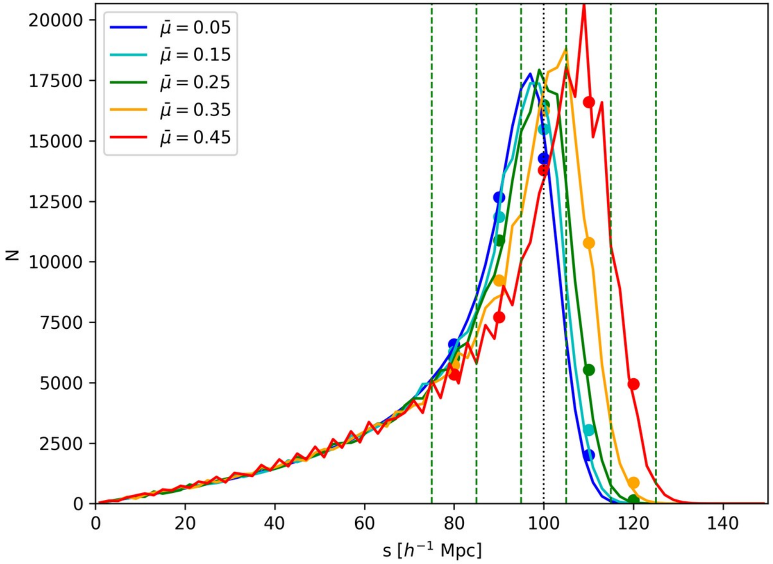
Photometric data σ_0=0.015



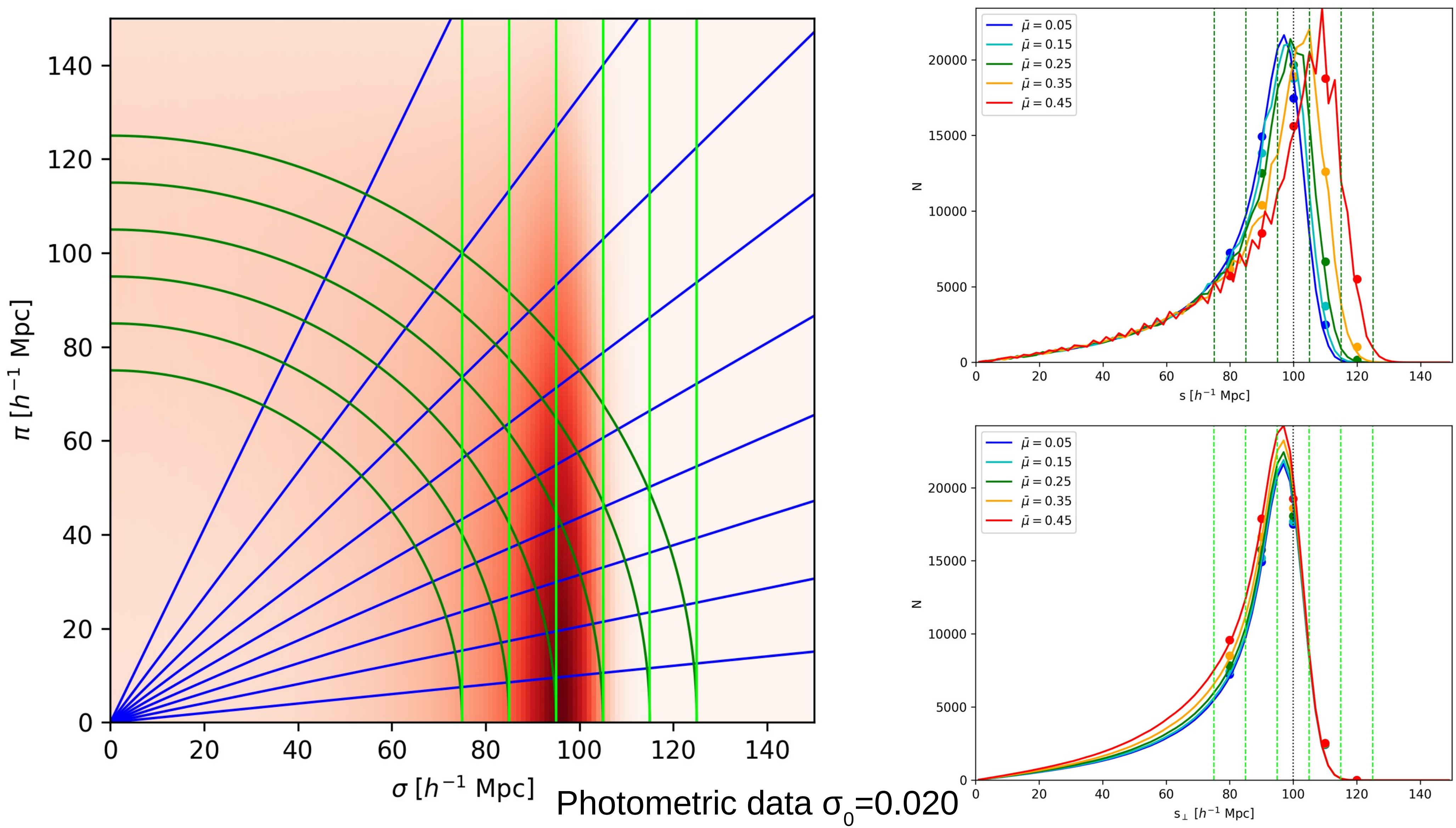


Photometric data σ_0=0.020

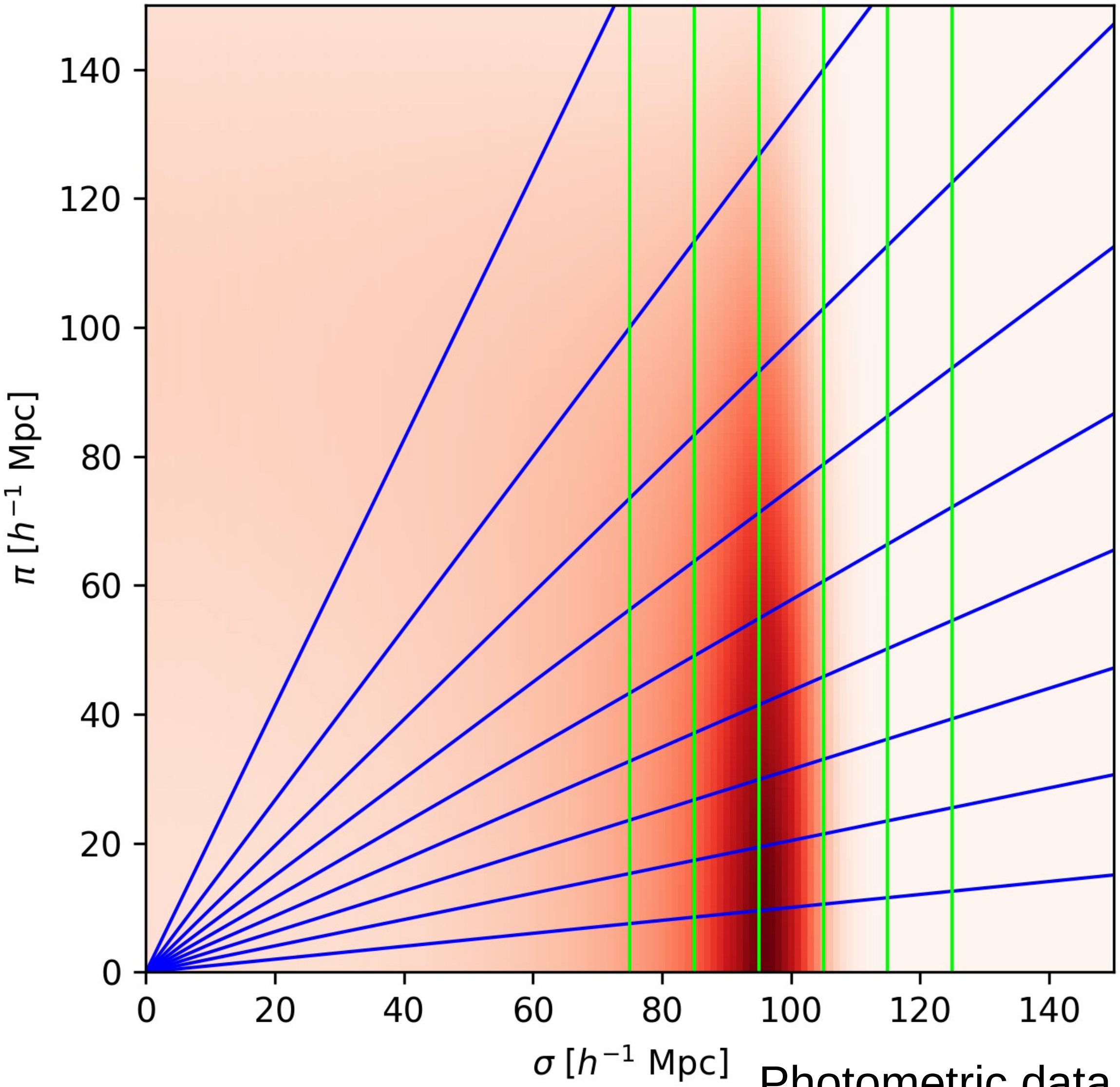


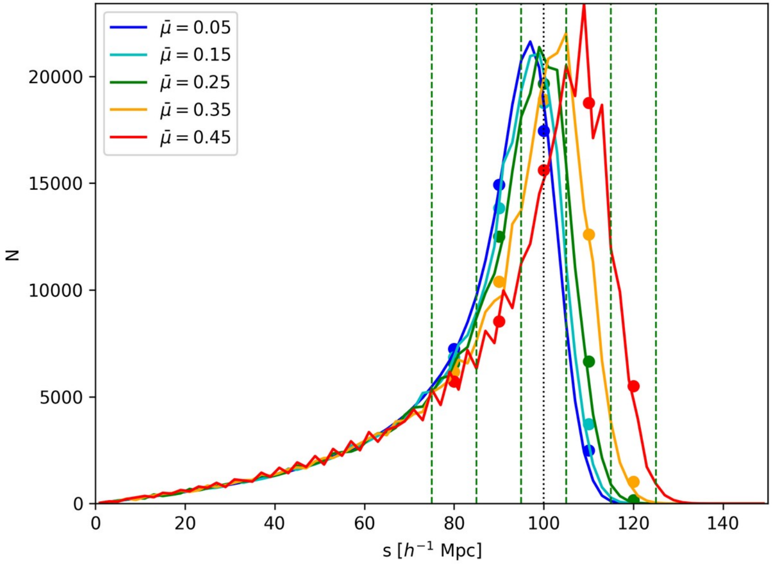


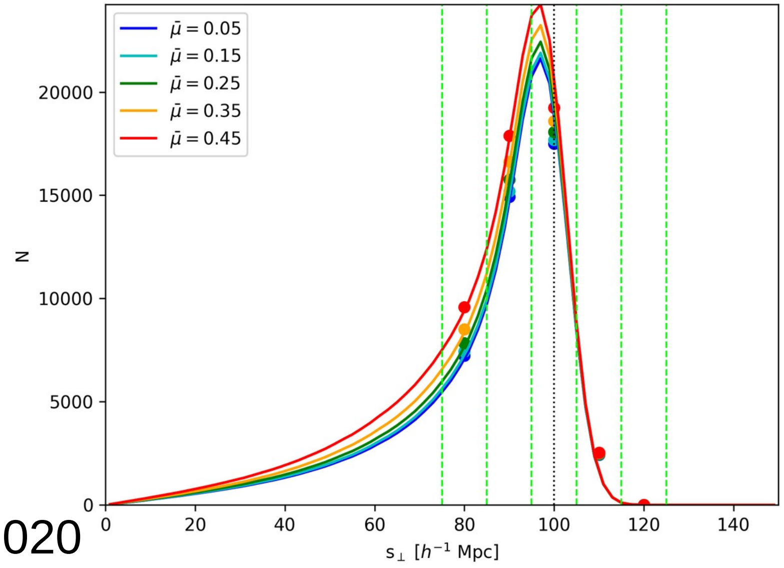
Photometric data σ_0=0.025



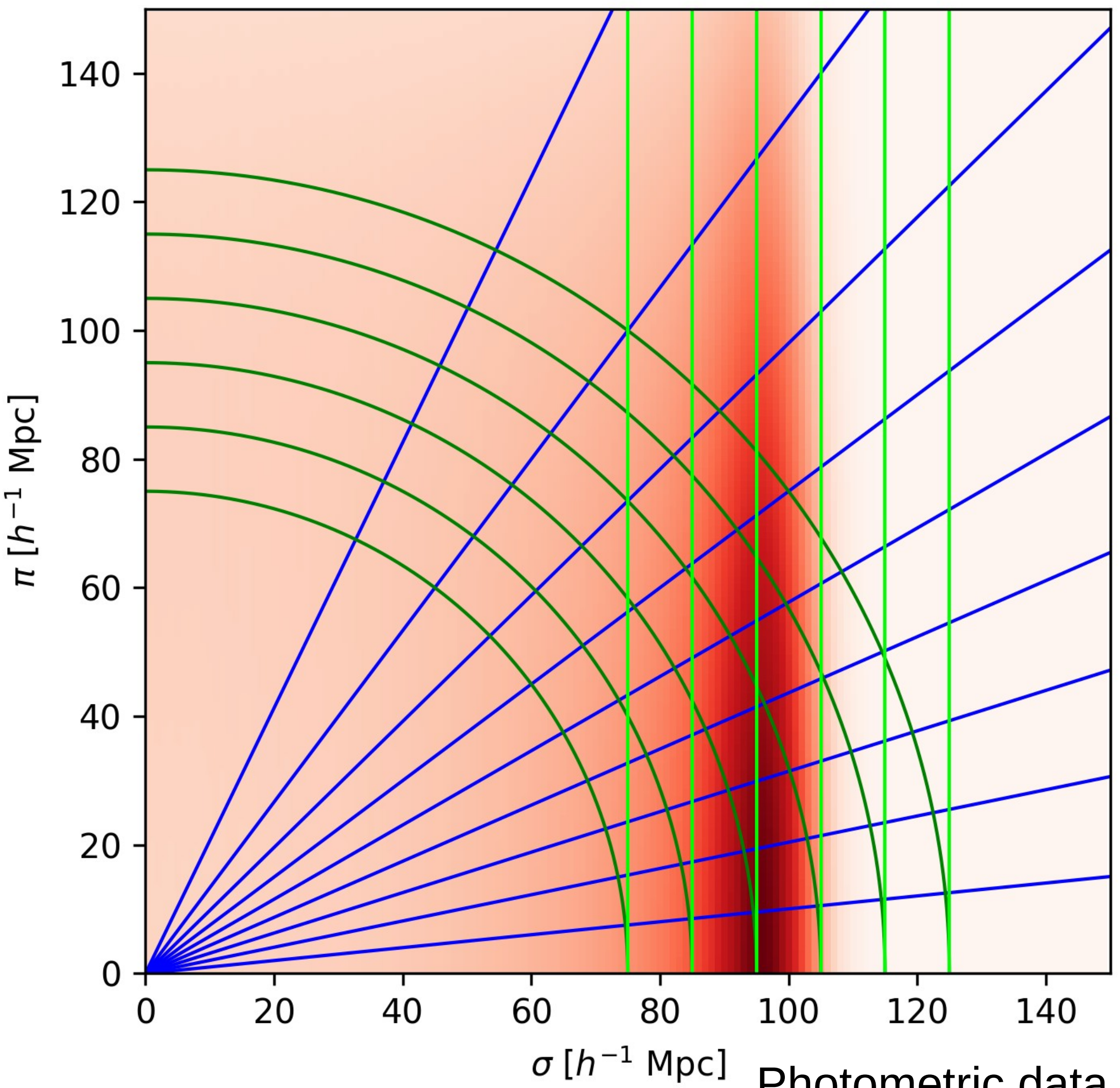
Photometric data σ_0=0.020

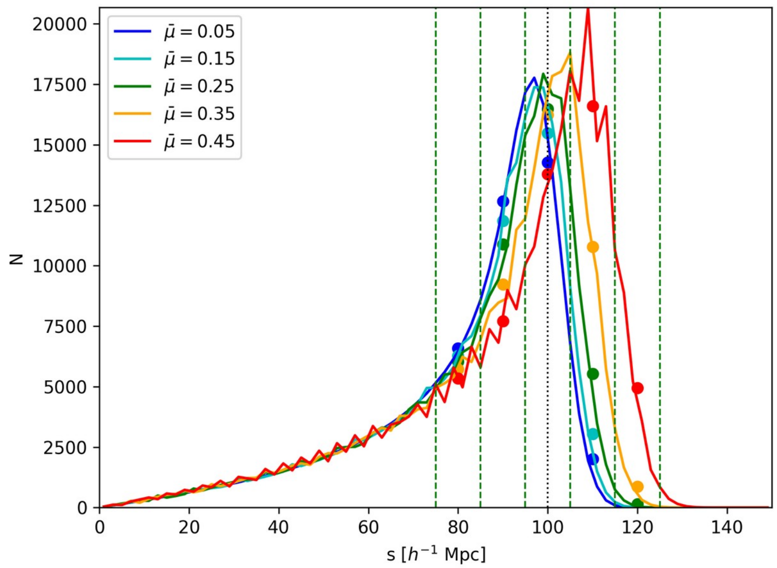


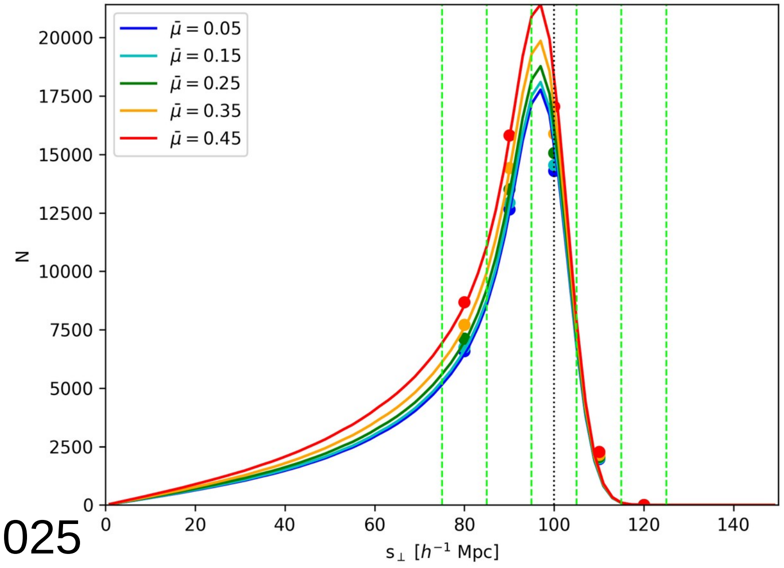




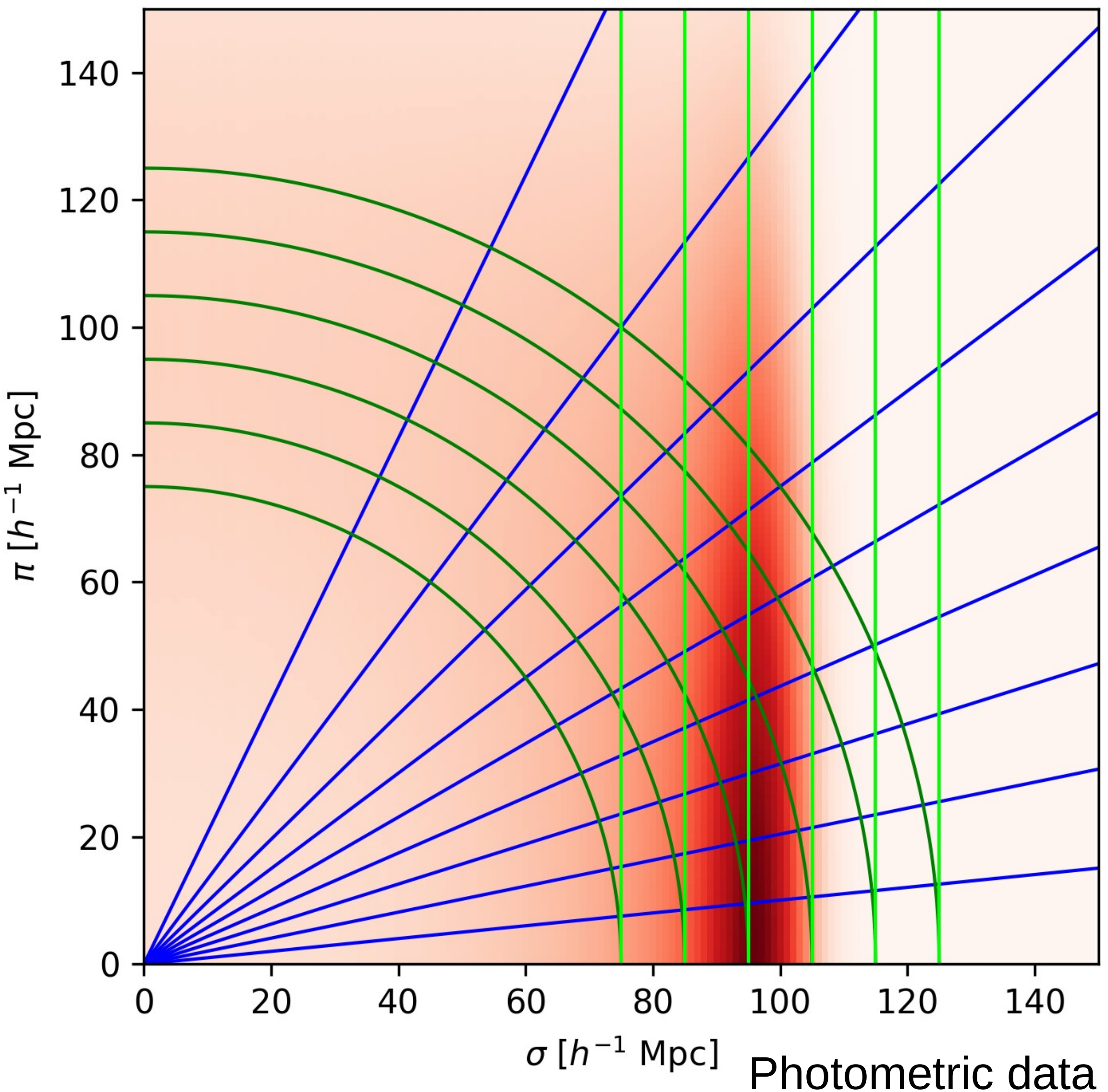
Photometric data σ_0=0.020



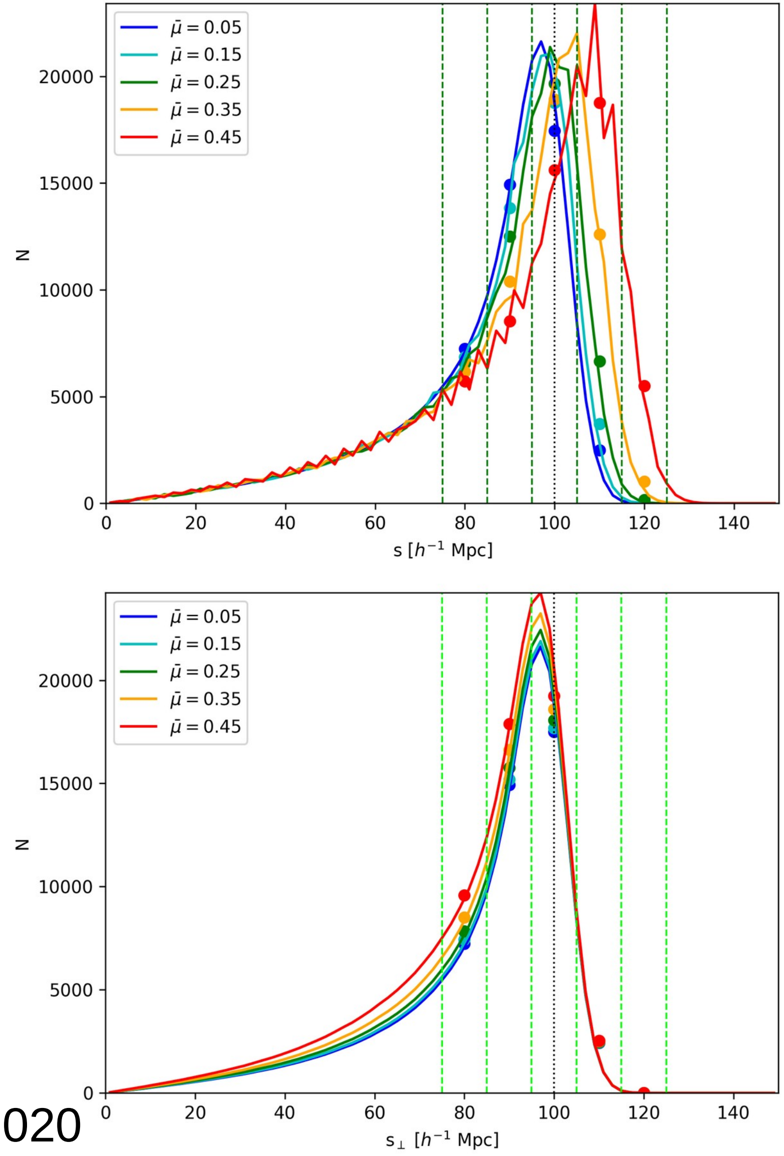


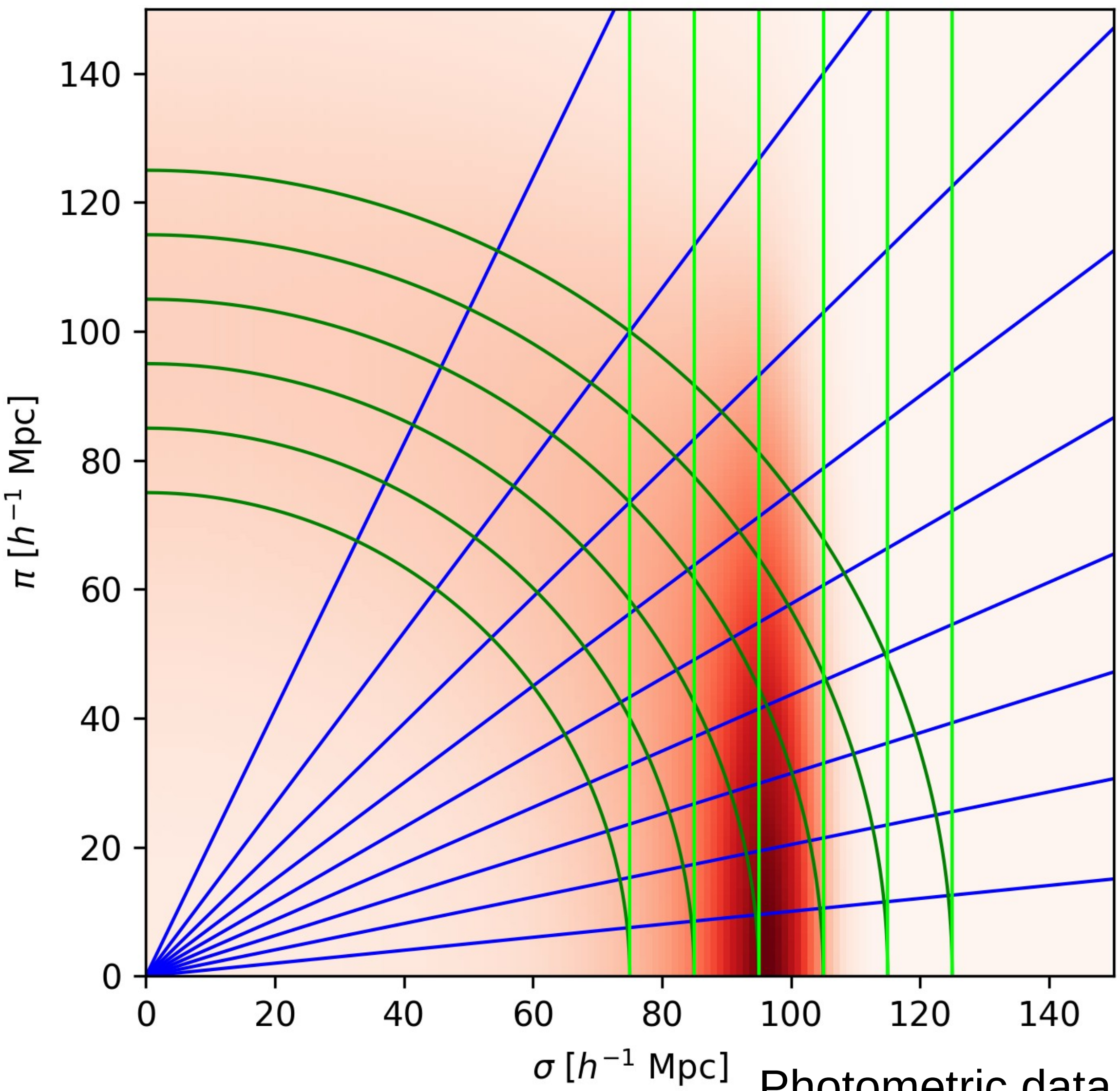


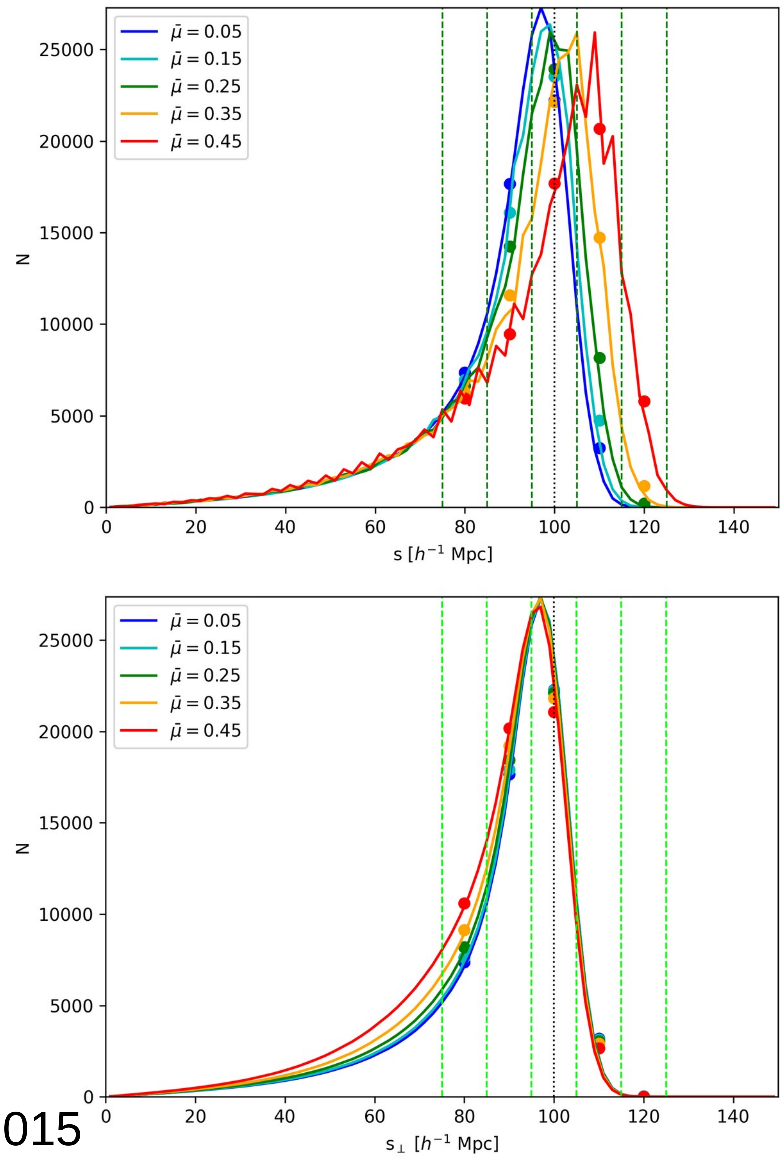
Photometric data σ_0=0.025



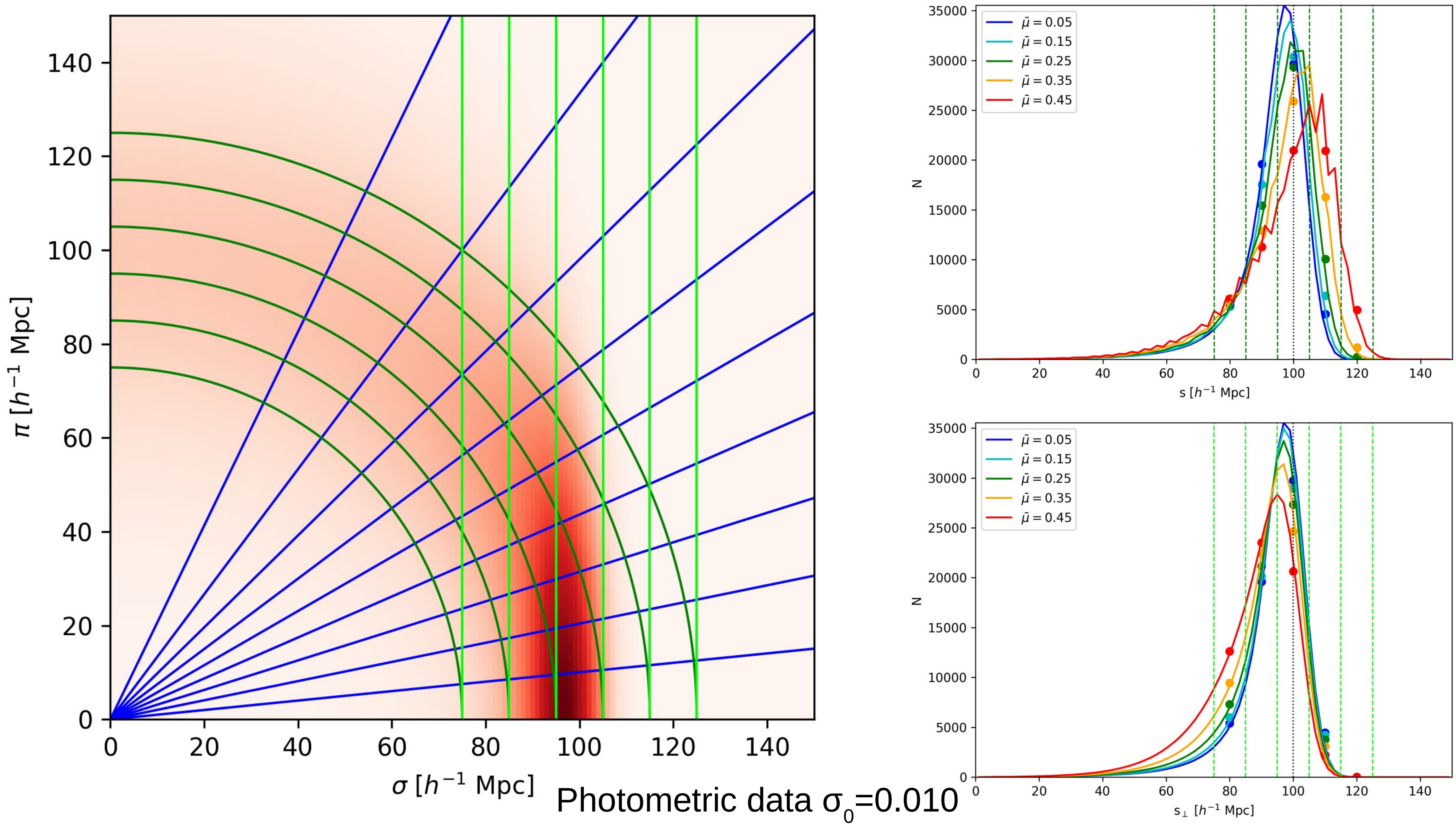
Photometric data σ_0=0.020



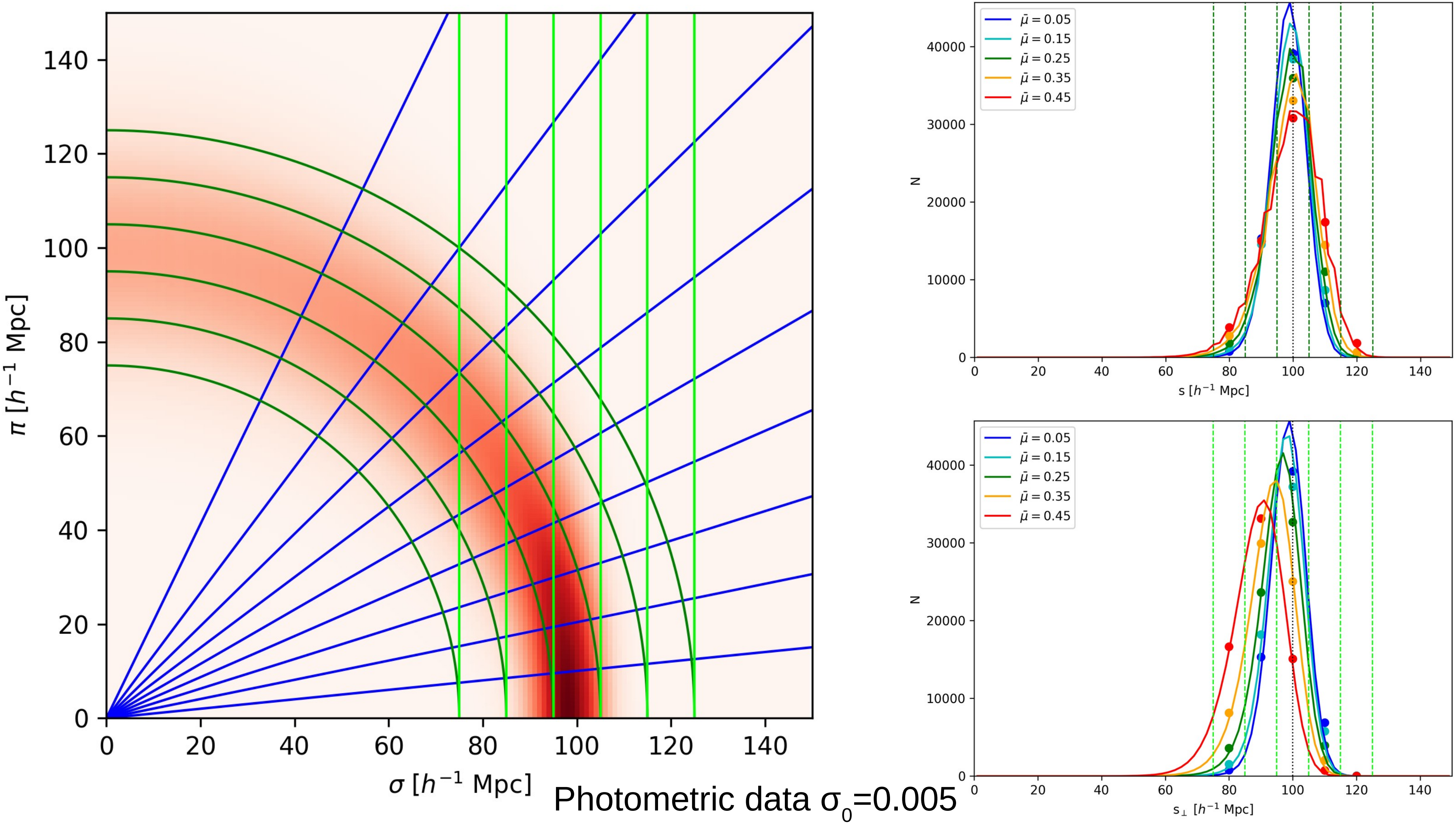




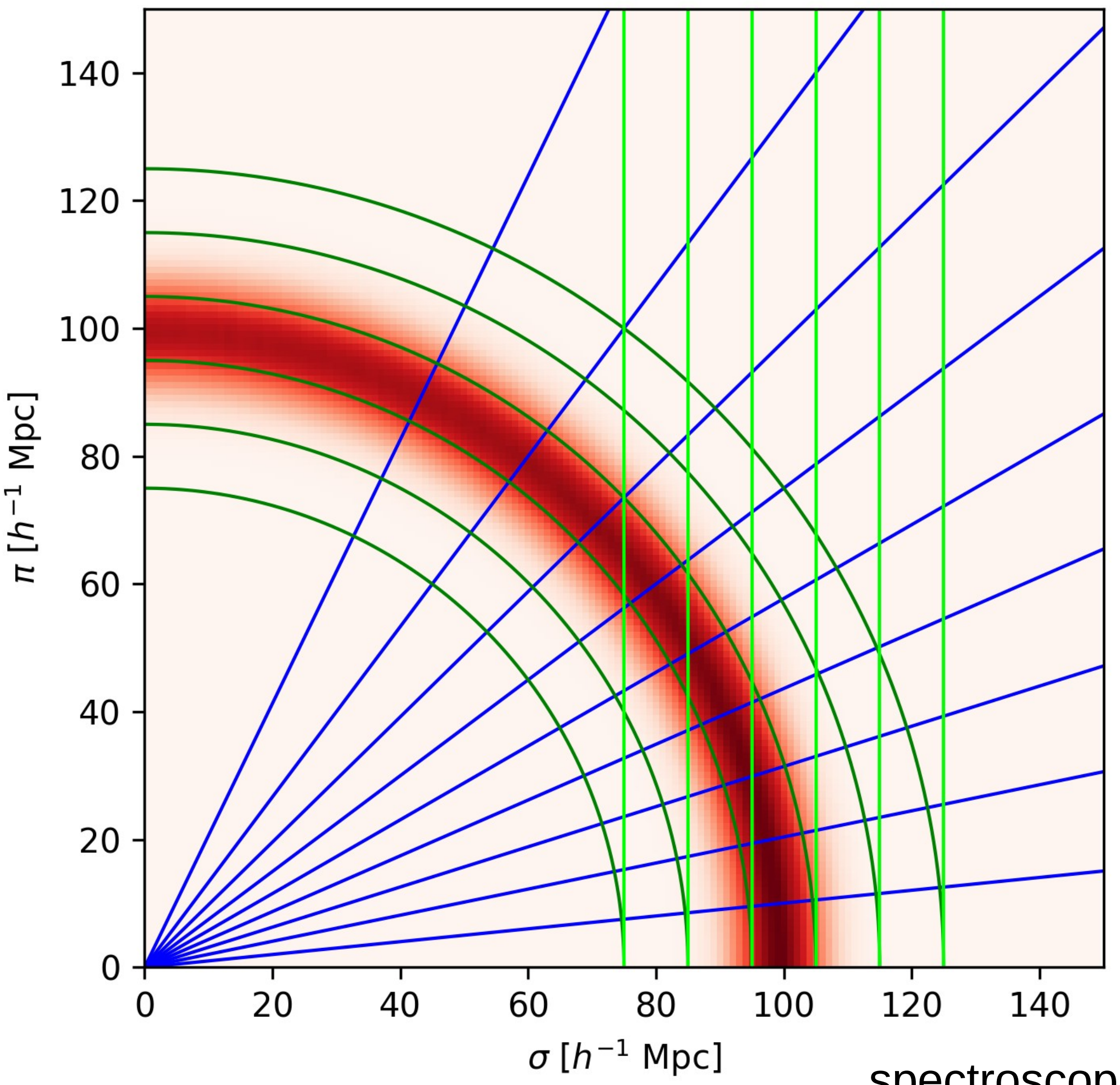
Photometric data σ_0=0.015

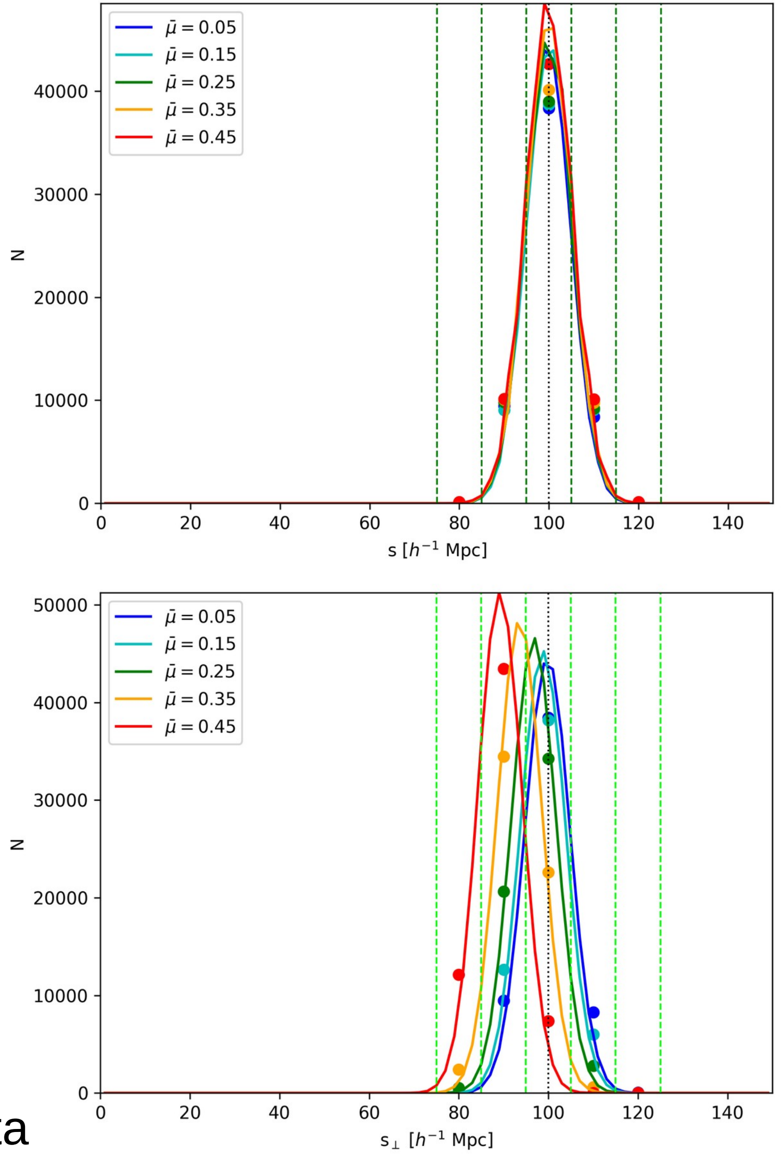


Photometric data σ_0=0.010

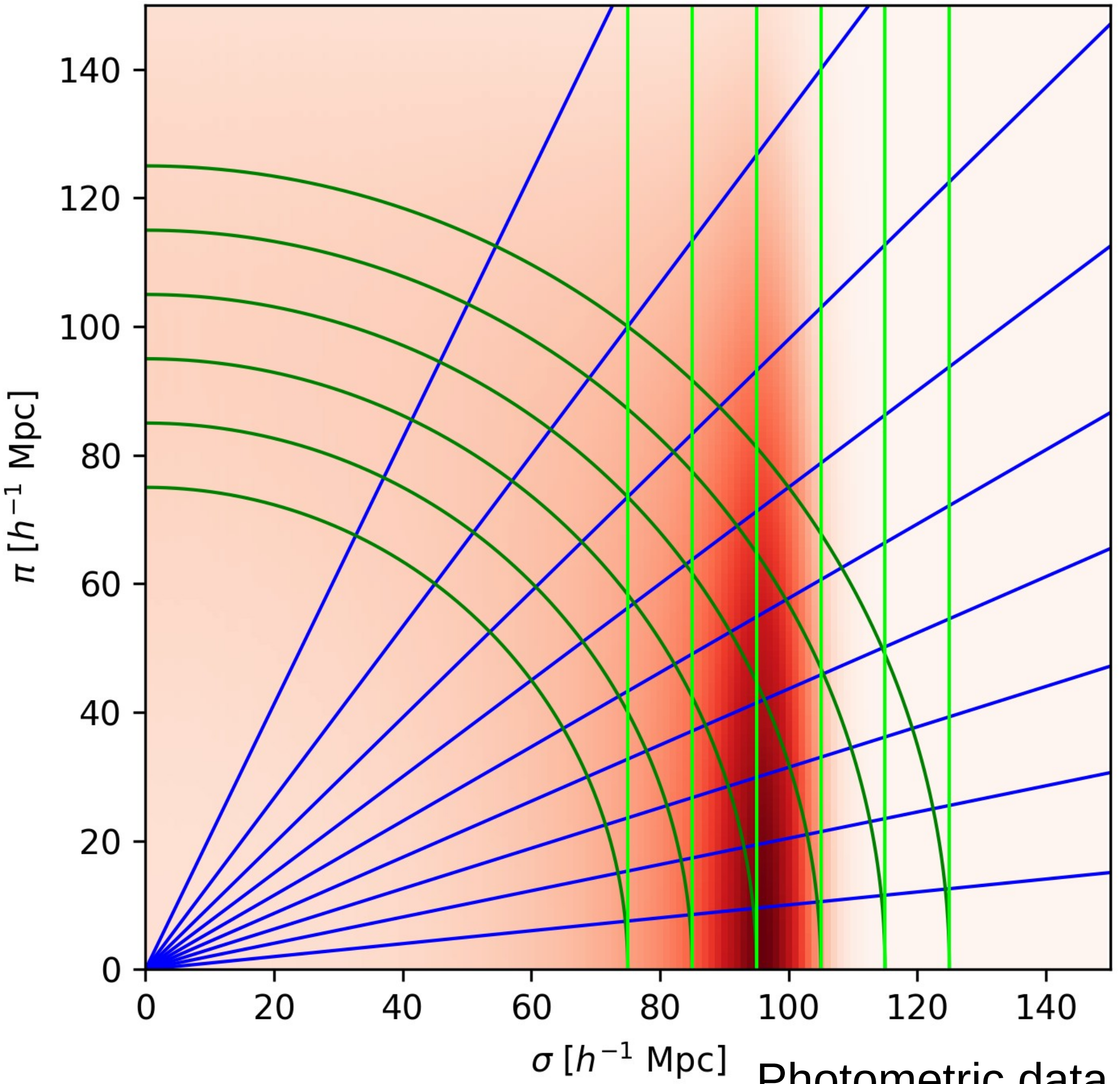


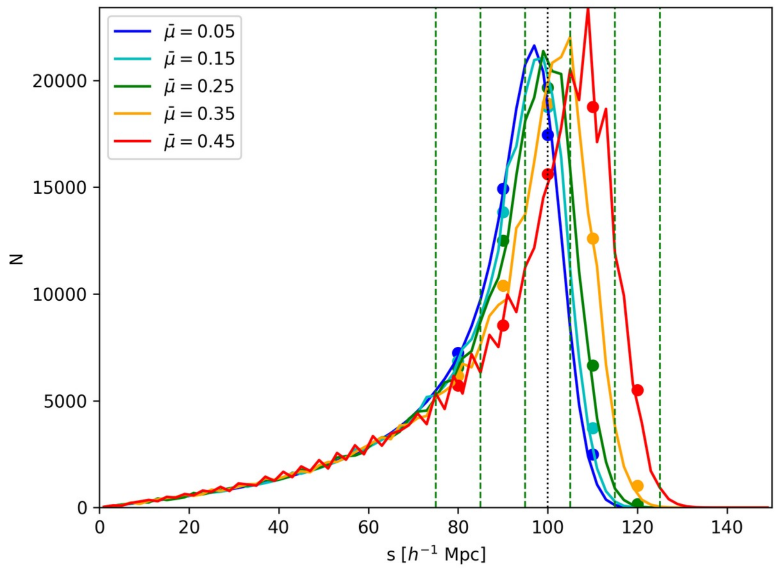
Photometric data σ_0=0.005

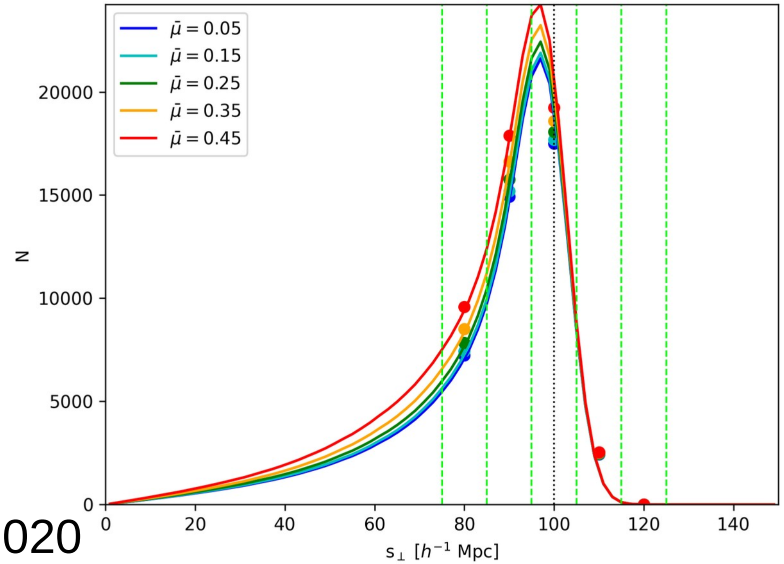




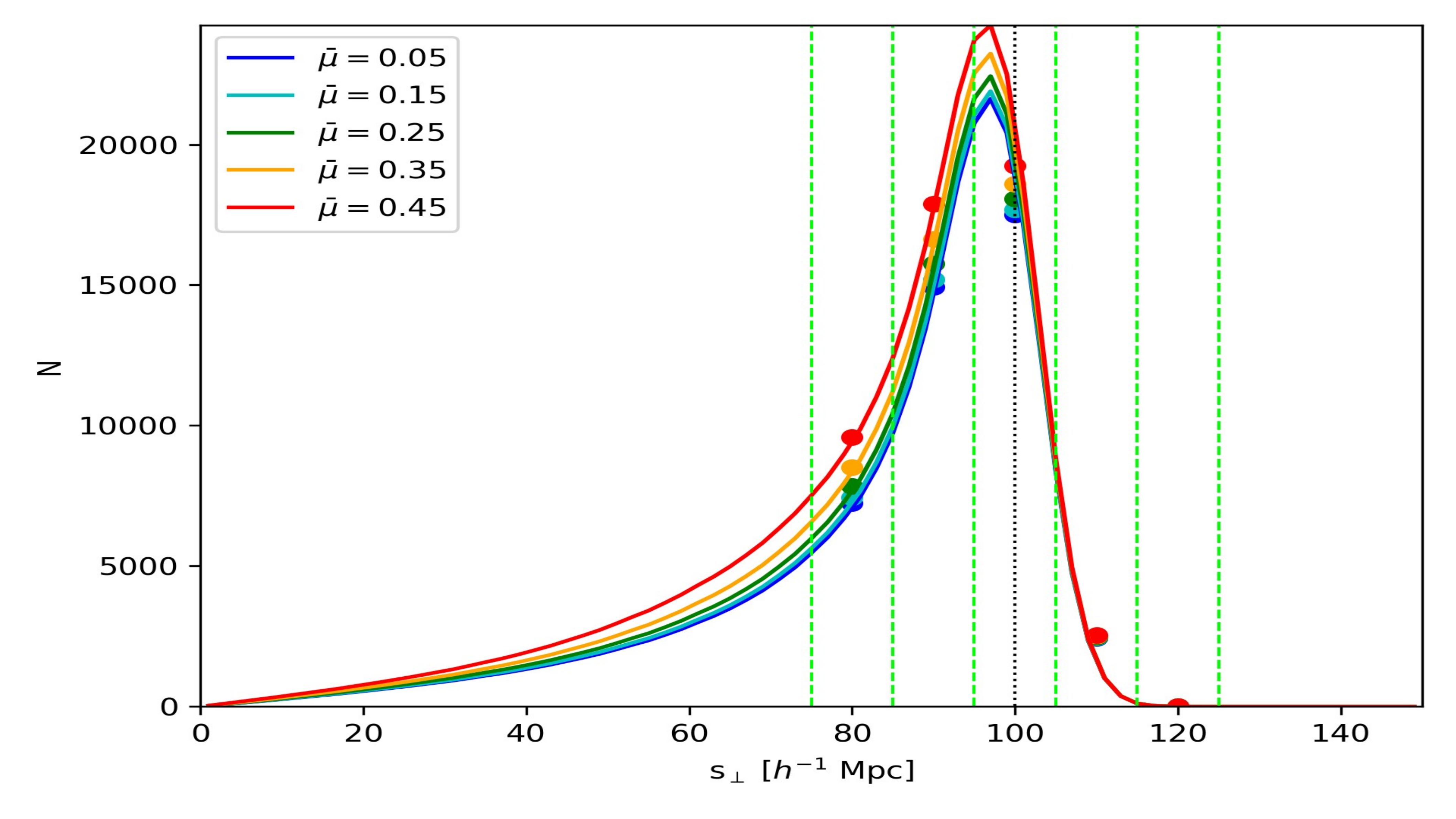
spectroscopic data





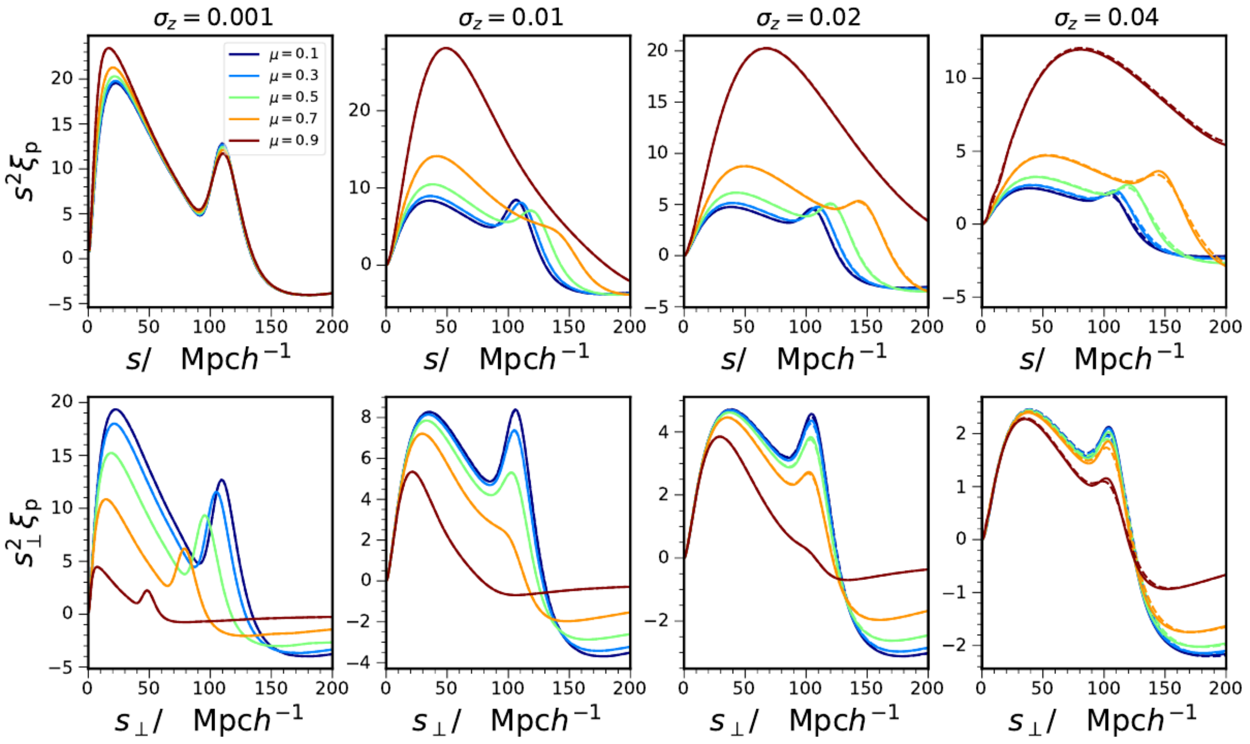


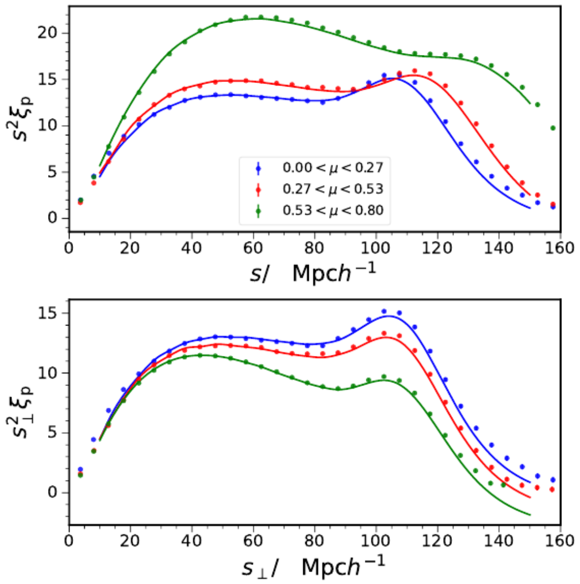
Photometric data σ_0=0.020

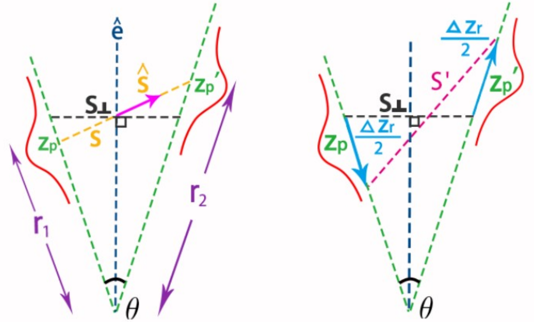


$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
N
0
5000
10000
15000
20000
0
20
40
60
80
100
120
140
$s_\perp$ [h^{-1} Mpc]

Old news: shifting BAO peak

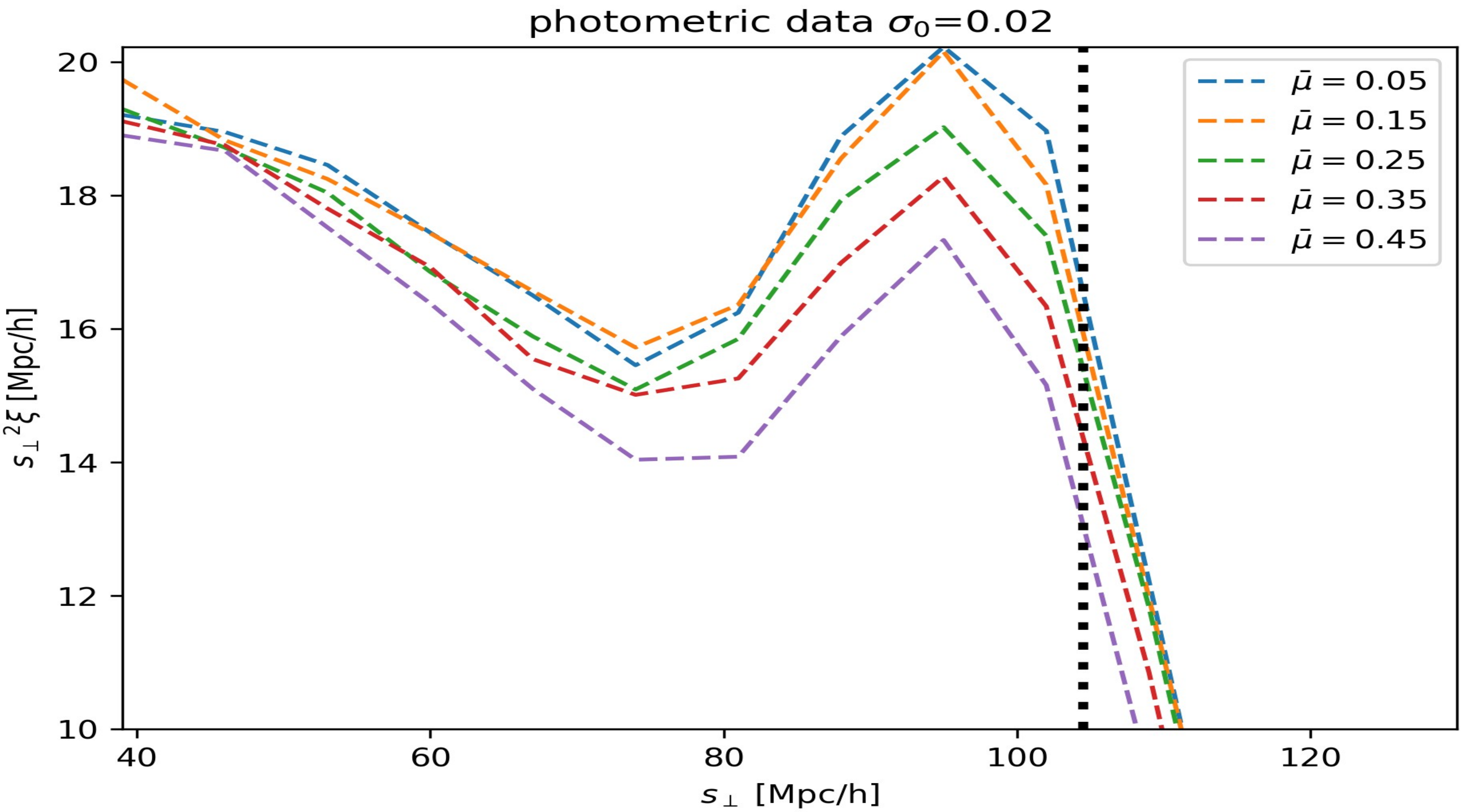






All figures on this slide are from Chan+2021 (arXiv:2110.13332)

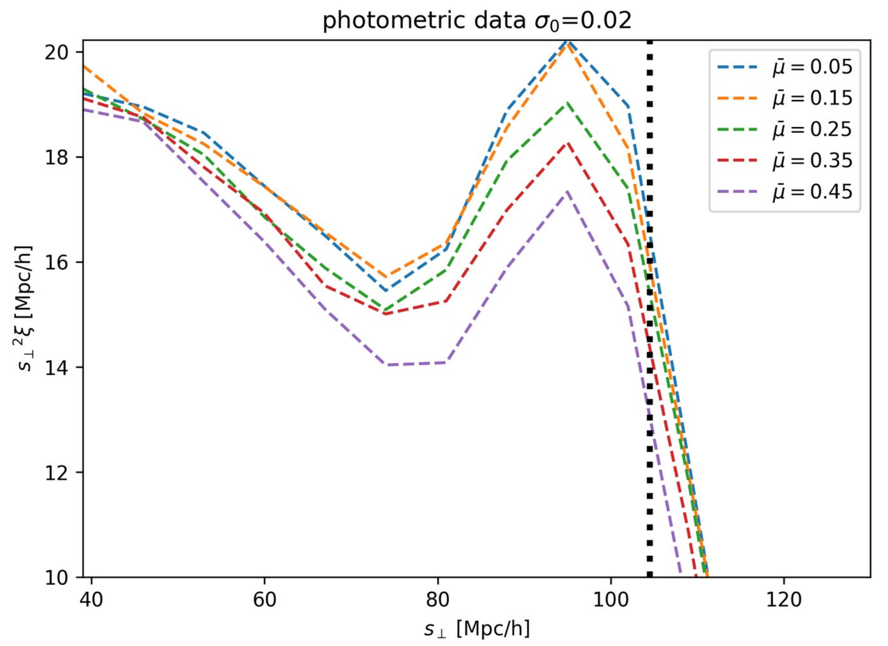
Solution: $S \rightarrow S_\perp$

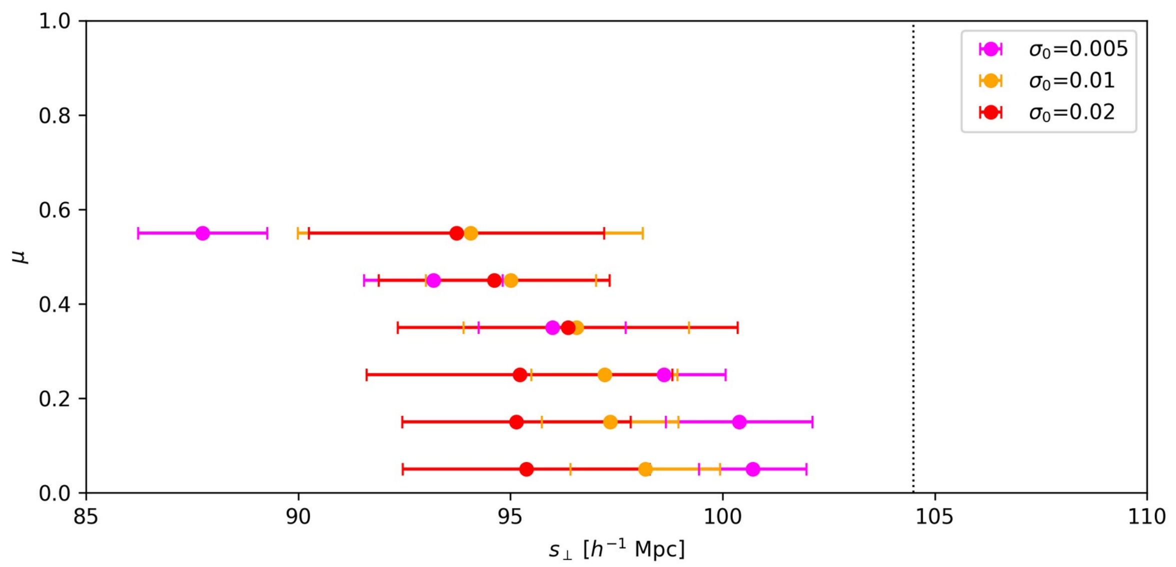


photometric data σ_0=0.02
$\bar{\mu} = 0.05$
$\bar{\mu} = 0.15$
$\bar{\mu} = 0.25$
$\bar{\mu} = 0.35$
$\bar{\mu} = 0.45$
$s_\perp{}^2\xi$ [Mpc/h]
$s_\perp$ [Mpc/h]
10
12
14
16
18
20
40
60
80
100
120

Fresh news: BAO peak offset

- One detail missed: the location of the **photometric BAO is systematically offset** from the spectroscopic BAO peak





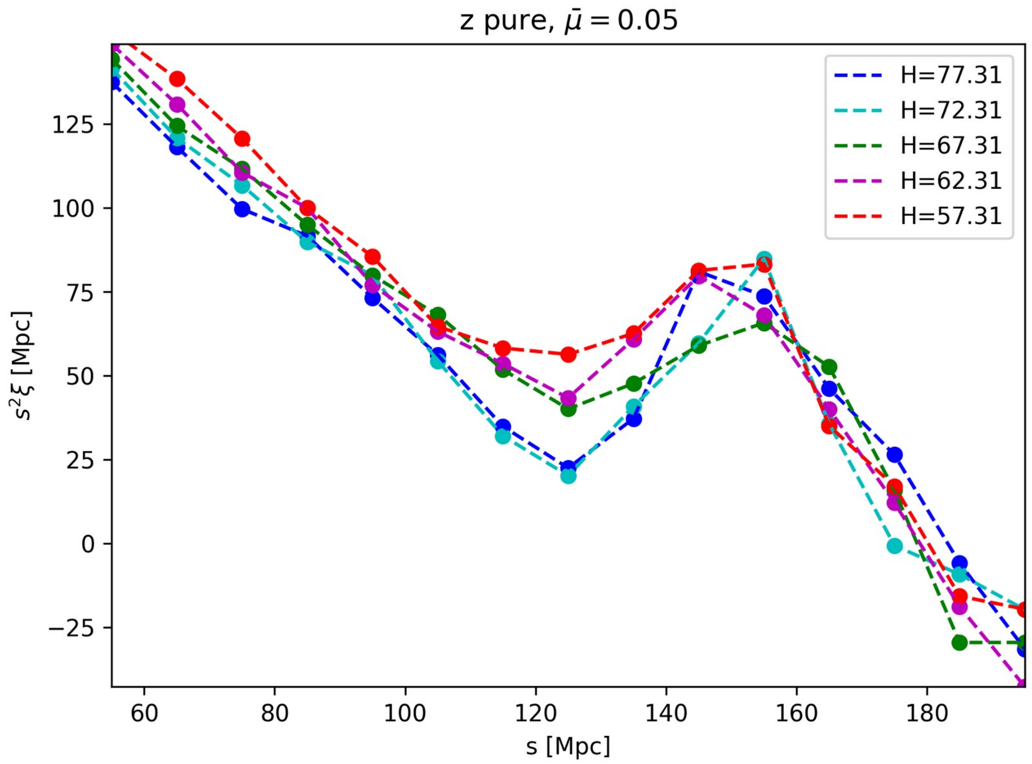
New findings, new problems

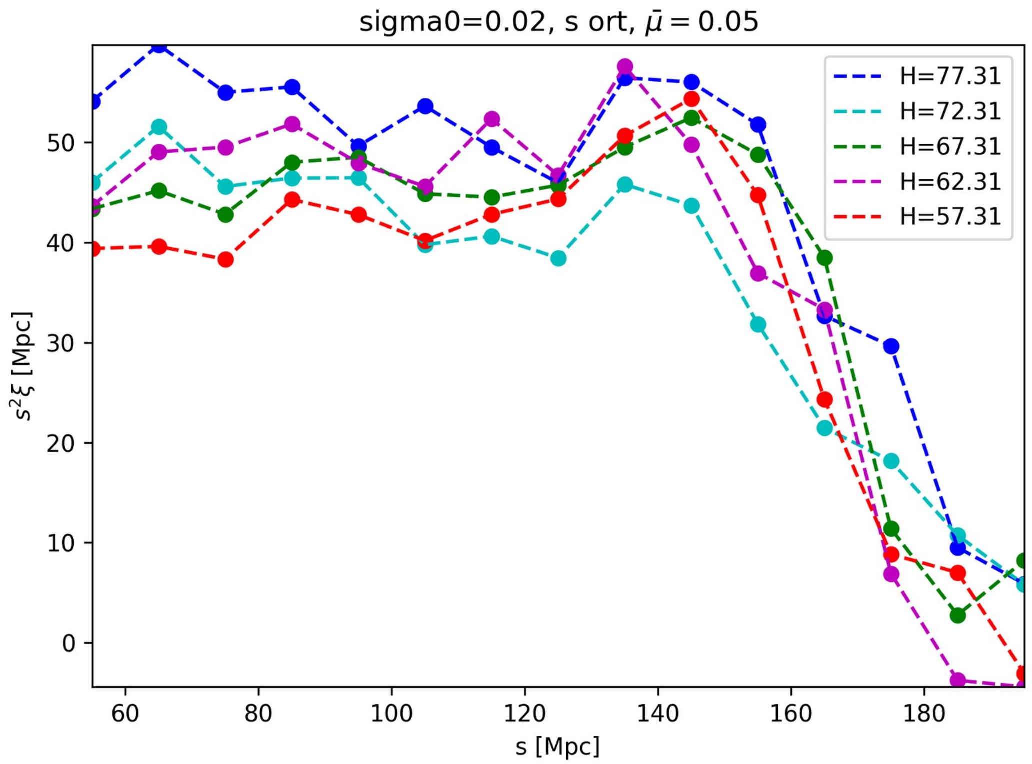
- Quantifying the offset
- Re-evaluating older papers (eg. Sridhar+ 2020)
- Also affects the photometric-spectroscopic cross-correlations

  → similar offset, but not exactly the same
- Cosmology dependence of the offset? →

  What can we still learn from the BAO peak?

Testing for cosmological dependency of the offset





Challenge: cosmic variance → more simulations

Next steps

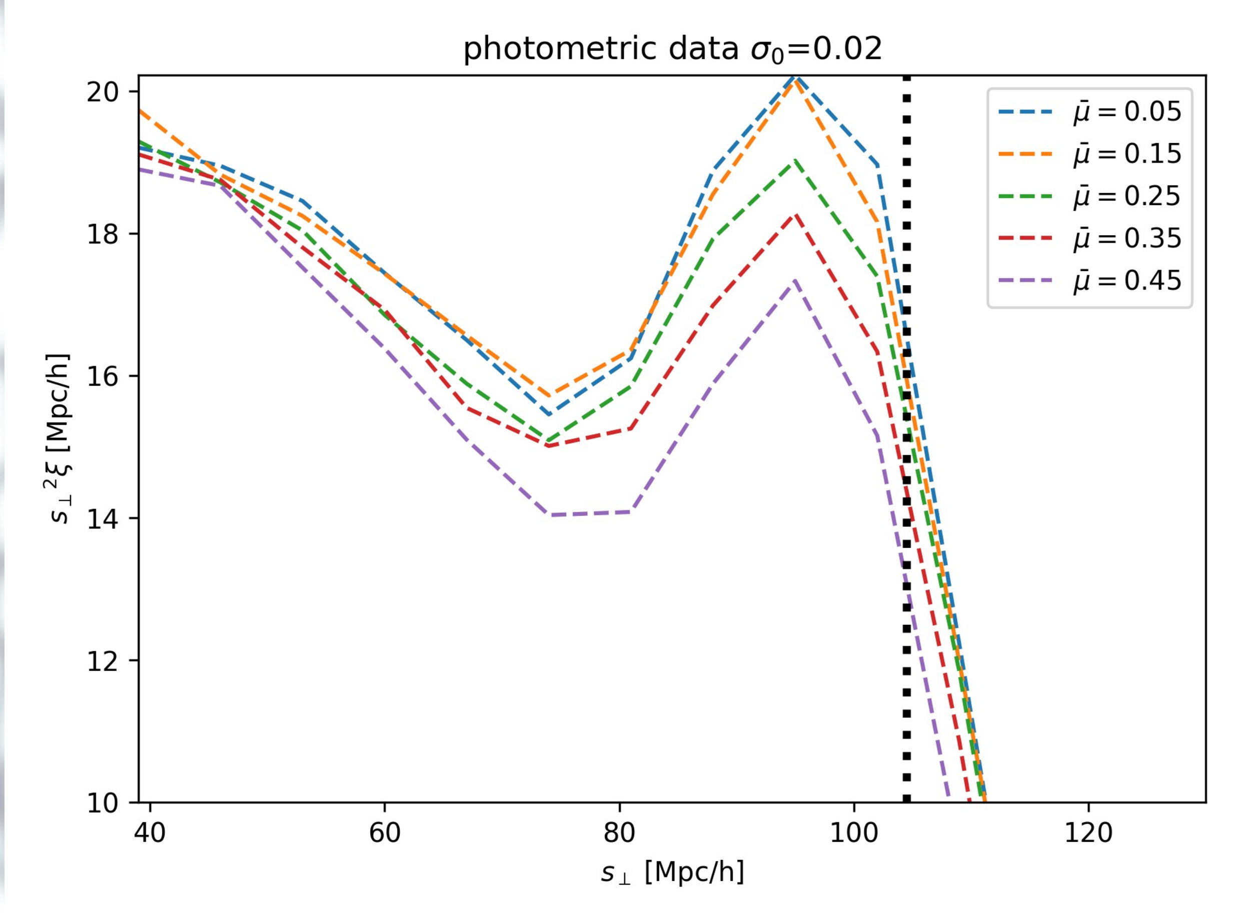
- Quantify shift of the photometric BAO peak
- Redo the photometric DR9 measurements in terms of $\xi(s_\perp,\mu)$

  → publish the much delayed paper on them
- Adjust the method for the cross-correlations
- Apply cross-correlations to DESI DA0.2 and in the future to the DESI Y1 data

Summary and Conclusion

- Photometric BAO peak is shifting between different μ-bins as a function of s
- Location of the photometric BAO peak is stable between different μ-bins as a function of $s_{\perp}$
- Location of the photometric BAO peak is systematically offset from the spectroscopic (true) location
- A challenge for all future BAO peak studies using photometric data (including the cross-correlations)

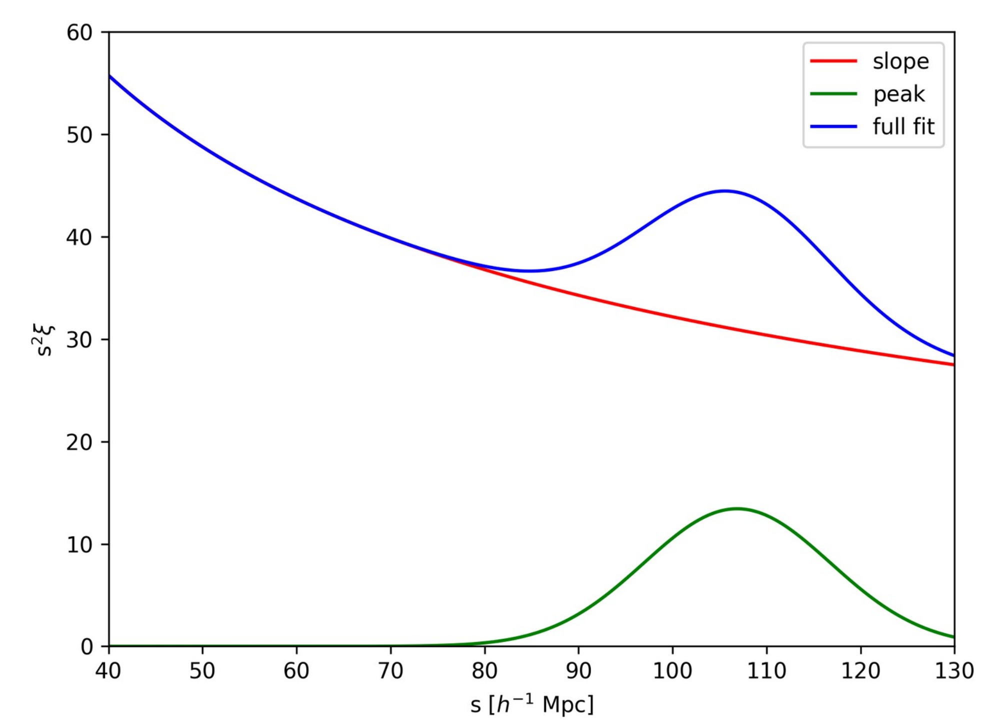
ANY QUESTIONS?



Backup Slides

The fitting function

$$\xi_{\rm mod}(s) = B + \left(\frac{s}{s_0}\right)^{-\gamma} + \frac{N}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(s-s_m)^2}{2\sigma^2}\right)$$



Other BAO peak measurements