Correction of the effect of fiber collisions in DESI Y1

Action Dark Energy – Nov. 6 & 7 2023

Mathilde Pinon – CEA Saclay

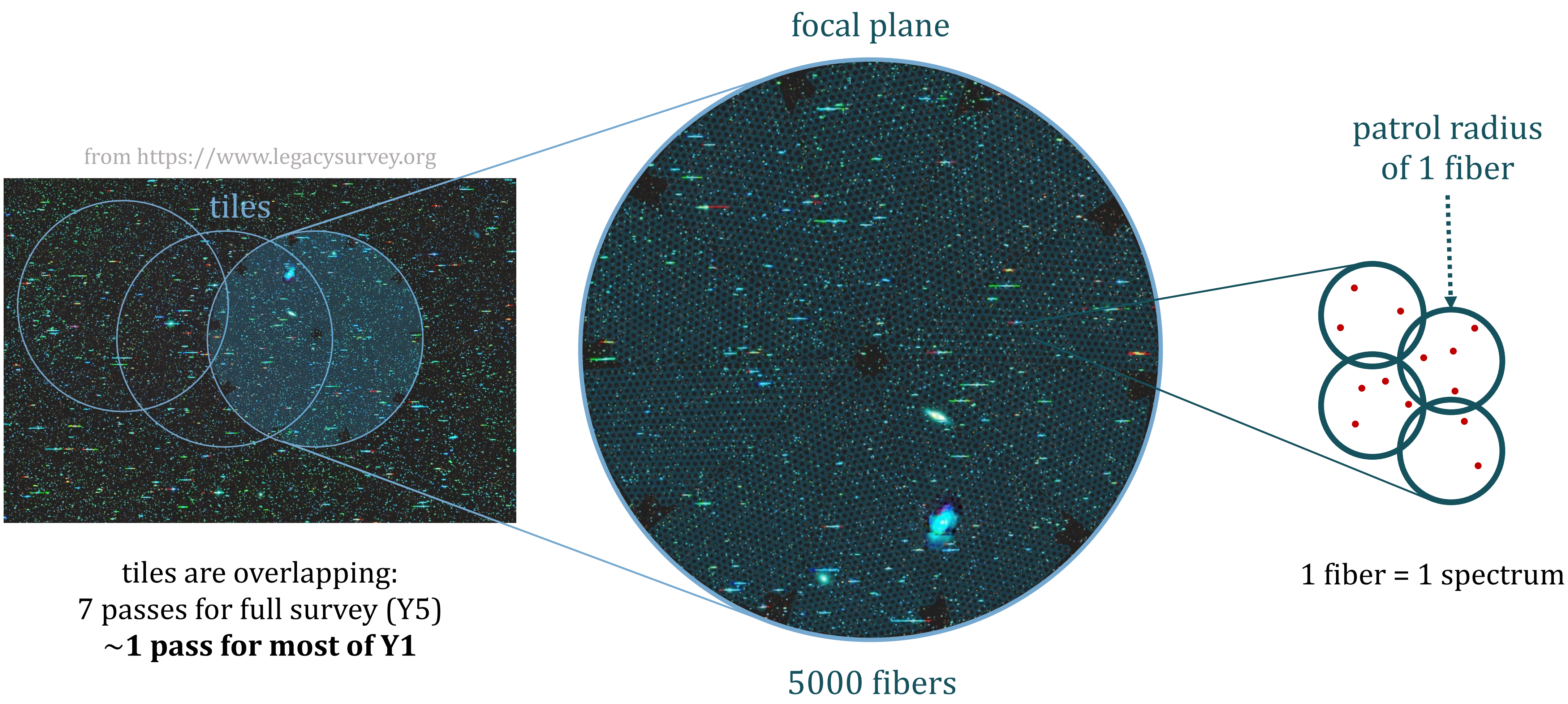
Supervised by Arnaud de Mattia, Étienne Burtin, Vanina Ruhlmann-Kleider

In collaboration with Pat McDonald

Dark Energy Spectroscopic Instrument
U.S. Department of Energy Office of Science

IRFU – CEA Saclay
Institut de recherche sur les lois fondamentales de l’univers

DESI fibers



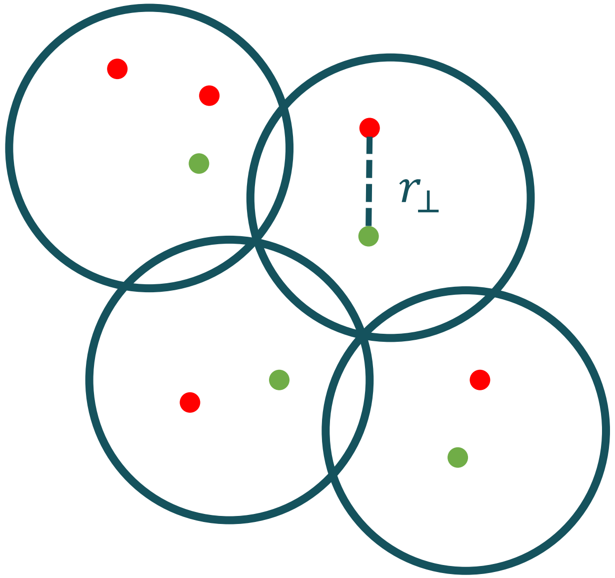
tiles are overlapping:
7 passes for full survey (Y5)
~1 pass for most of Y1

1 fiber = 1 spectrum

Fiber collisions: 2 galaxies fall within the patrol radius of the same fiber

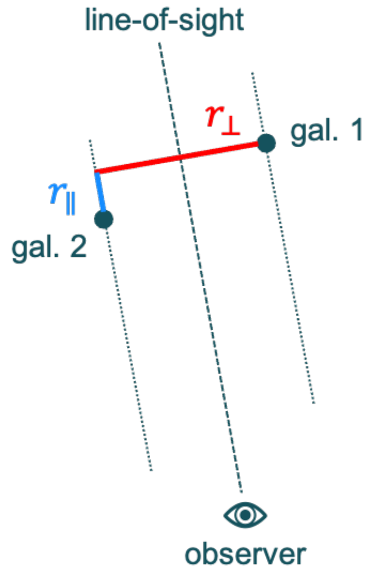
observed galaxies

missed galaxies

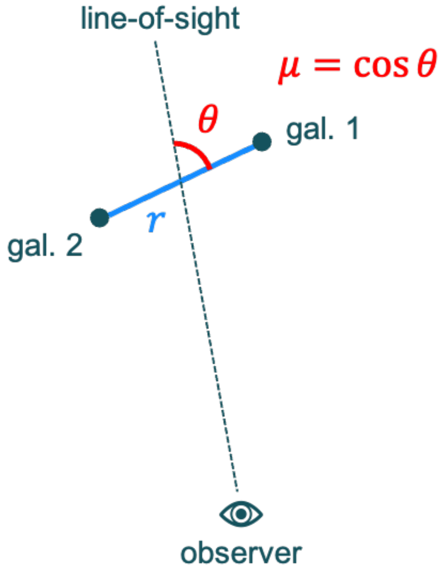


2 systems of coordinates

$(r_\parallel, r_\perp)$ coordinates

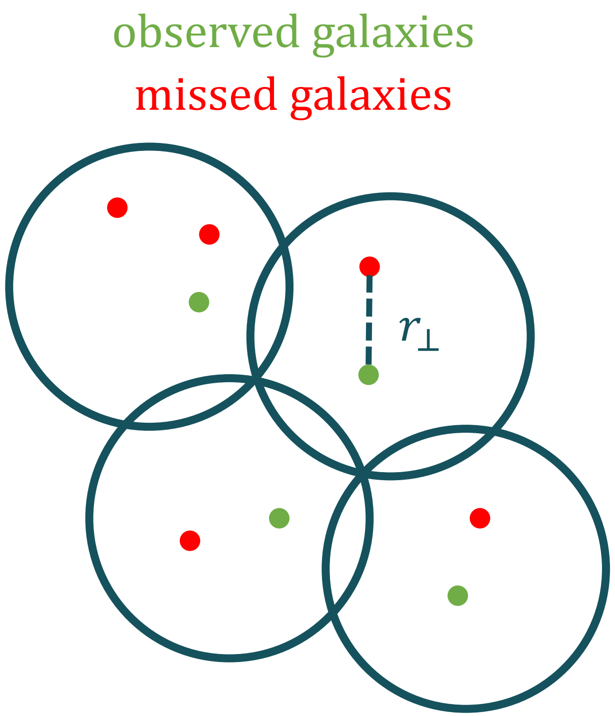


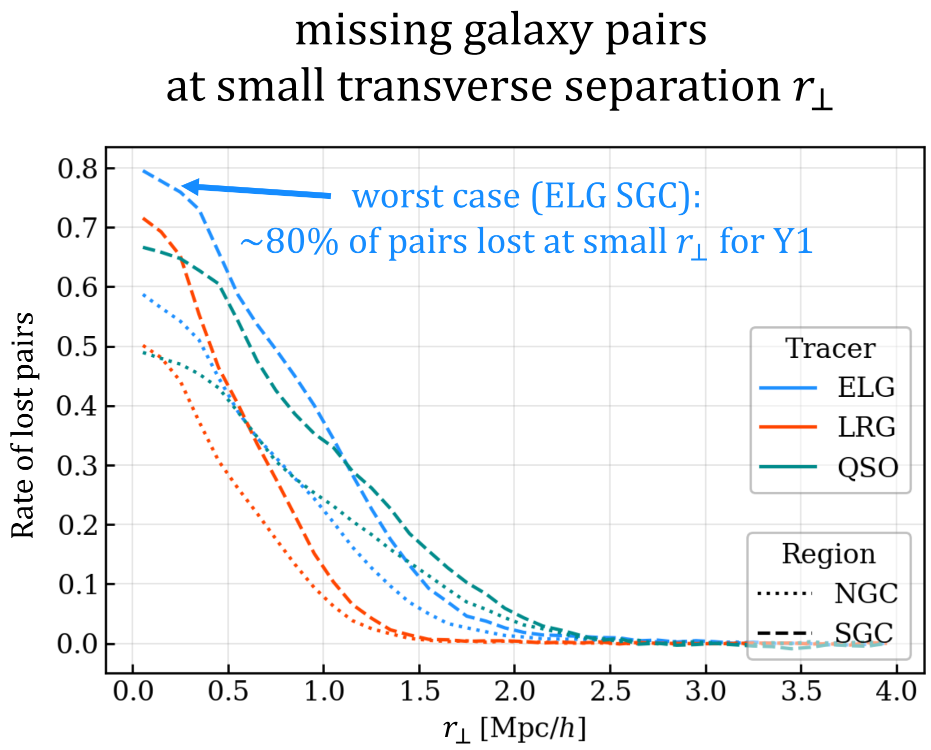
(r, μ) coordinates



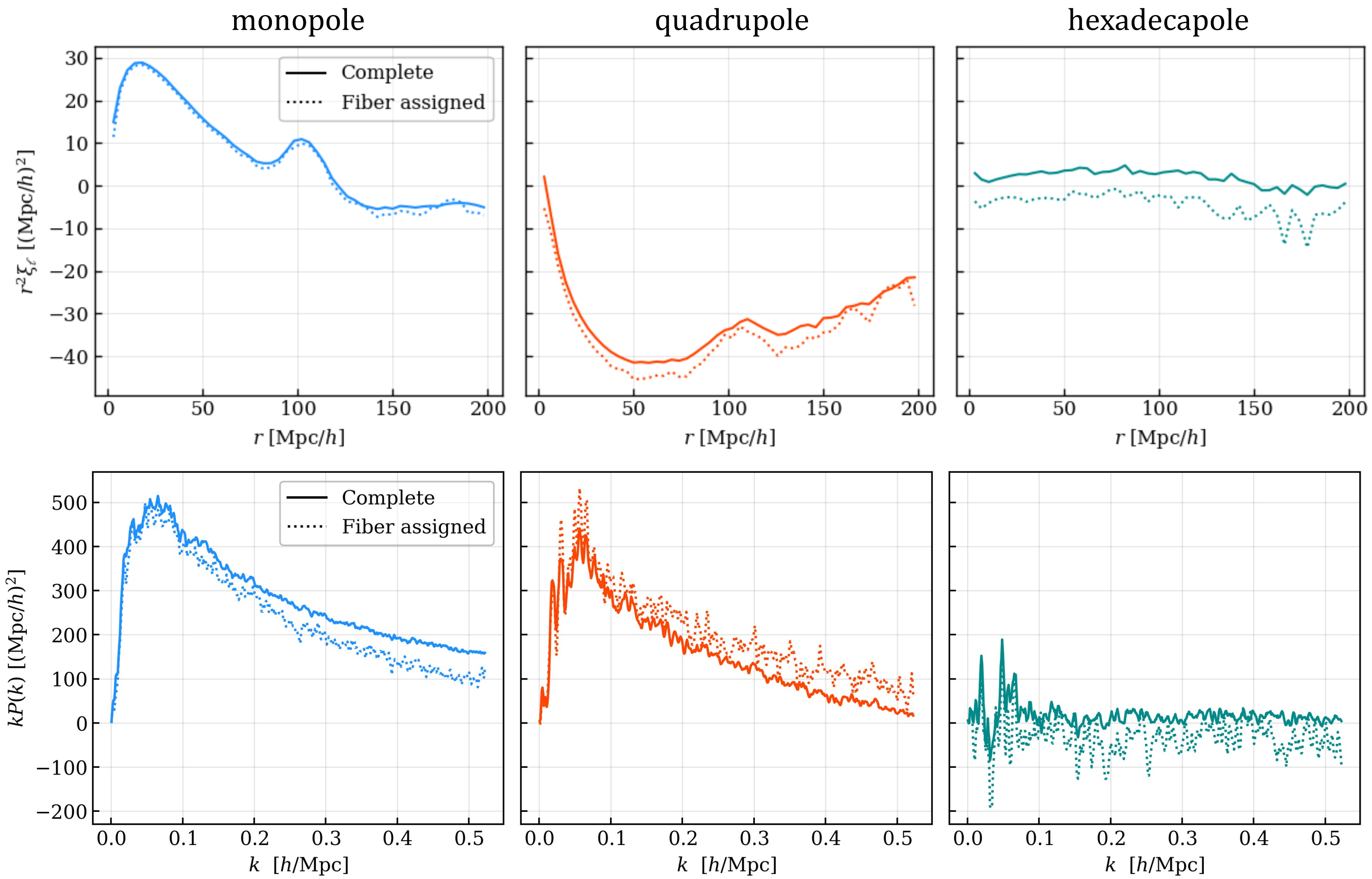
usually used
(Legendre decomposition)

Fiber collisions: 2 galaxies fall within the patrol radius of the same fiber





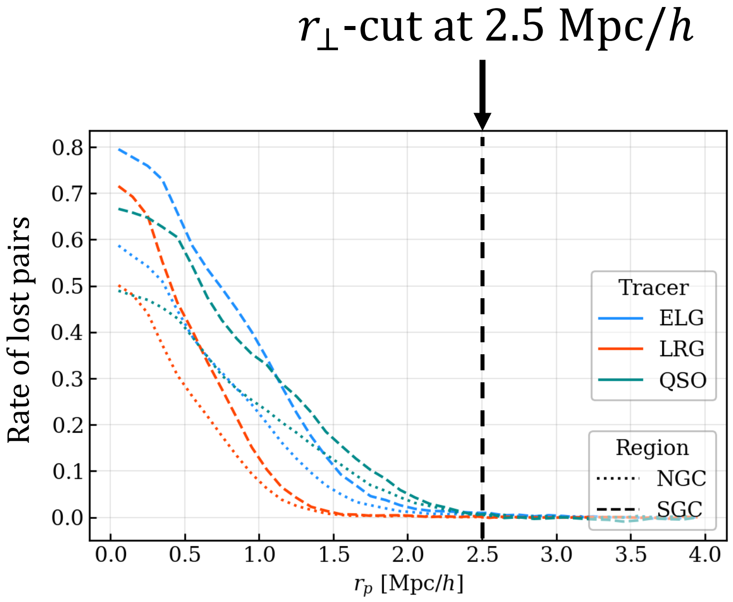
Fiber collisions bias two-point statistics



correlation function multipoles

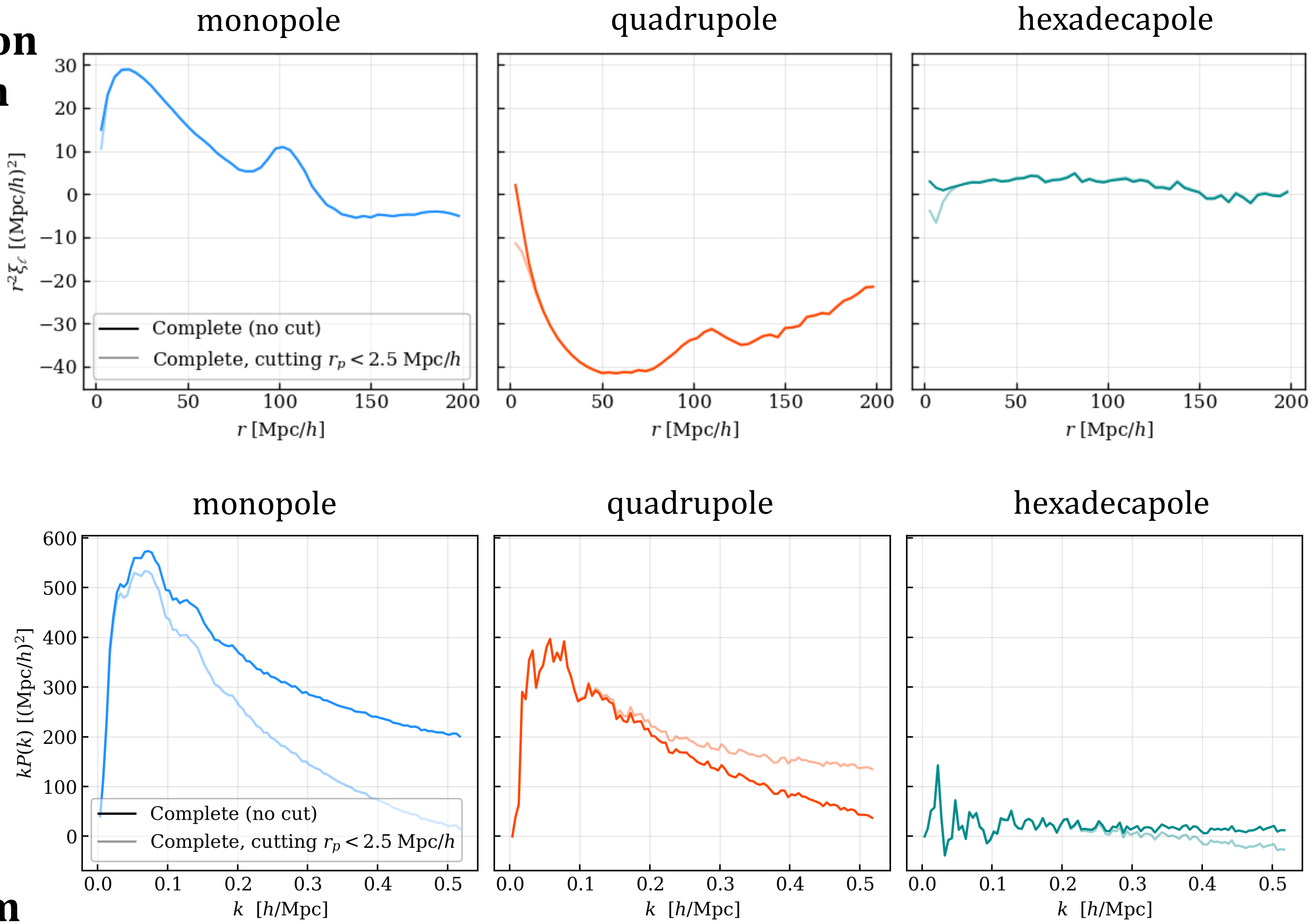
power spectrum multipoles

Idea: modify 2-pt estimators by removing all galaxy pairs at small transverse separation



correlation function

power spectrum

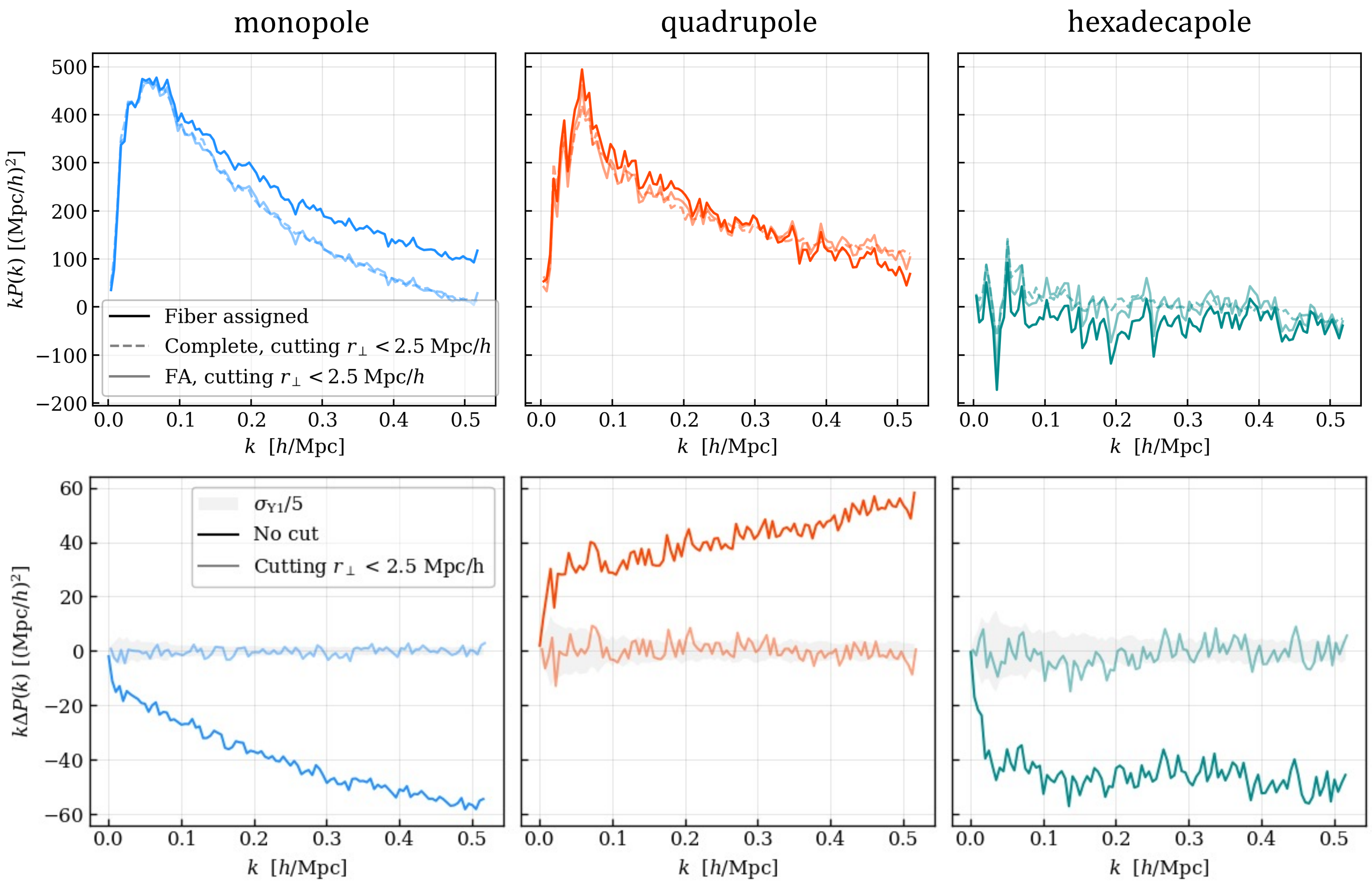


Removing pairs at $r_\perp < 2.5$ Mpc/h removes fiber collisions effect

$r_\perp$-cut $P(k)$ estimator:
(see also Bianchi & Verde 2020)

$$\widehat{P}_\ell^{r_\perp-\mathrm{cut}}(k) = \underbrace{\widehat{P}_\ell^{\mathrm{FFT}}(k)}_{\text{mesh-based standard estimator}} - \underbrace{\widehat{P}_\ell^{r_\perp<\Lambda_{r_\perp}}(k)}_{\text{direct pair counts}}$$

residuals between **fiber assigned** and **complete** mocks:



$r_\perp$-cut must be accounted for in the model

$r_\perp$-cut correlation function

$$\langle \hat{\xi}_\ell^{\text{cut}}(s)\rangle = W_{\ell\ell'}^{\text{cut}}(s)\xi_{\ell'}(s)$$

window matrix

$$W_{\ell\ell'}^{\text{cut}}(s) = \frac{2\ell+1}{|I_\mu(s)|}\int_{I_\mu(s)} d\mu \mathcal{L}'(\mu)\mathcal{L}(\mu)$$

integration over μ
such that $r_\perp > \Lambda_{r_\perp}$

$$I_\mu(s) = \{\mu, r_\perp^2 = s^2(1-\mu^2) > \Lambda_{r_p}^2\}$$

2.5 Mpc/h

$r_\perp$-cut power spectrum

$$\langle \widehat{P}_\ell(k)\rangle = 4\pi \int k'^2 dk' W_{\ell\ell'}(k,k')P_{\ell'}(k')$$

window matrix

$$W_{\ell\ell'}(k,k') = \frac{(-i)^\ell i^{\ell'}}{2\pi^2 A}\int s^2 ds \sum_p \frac{2\ell+1}{2p+1}A_{p\ell\ell'}W_p^{\text{cut}}(s)j_{\ell'}(k's)j_\ell(ks)$$

$$W_p^{\text{cut}}(s) = \frac{2p+1}{4\pi}\int d\mathbf{x}\int d\phi \int_{I_\mu(s)} d\mu \bar{n}(\mathbf{x})\bar{n}(\mathbf{x}+\mathbf{s})\mathcal{L}_p(\mu)$$

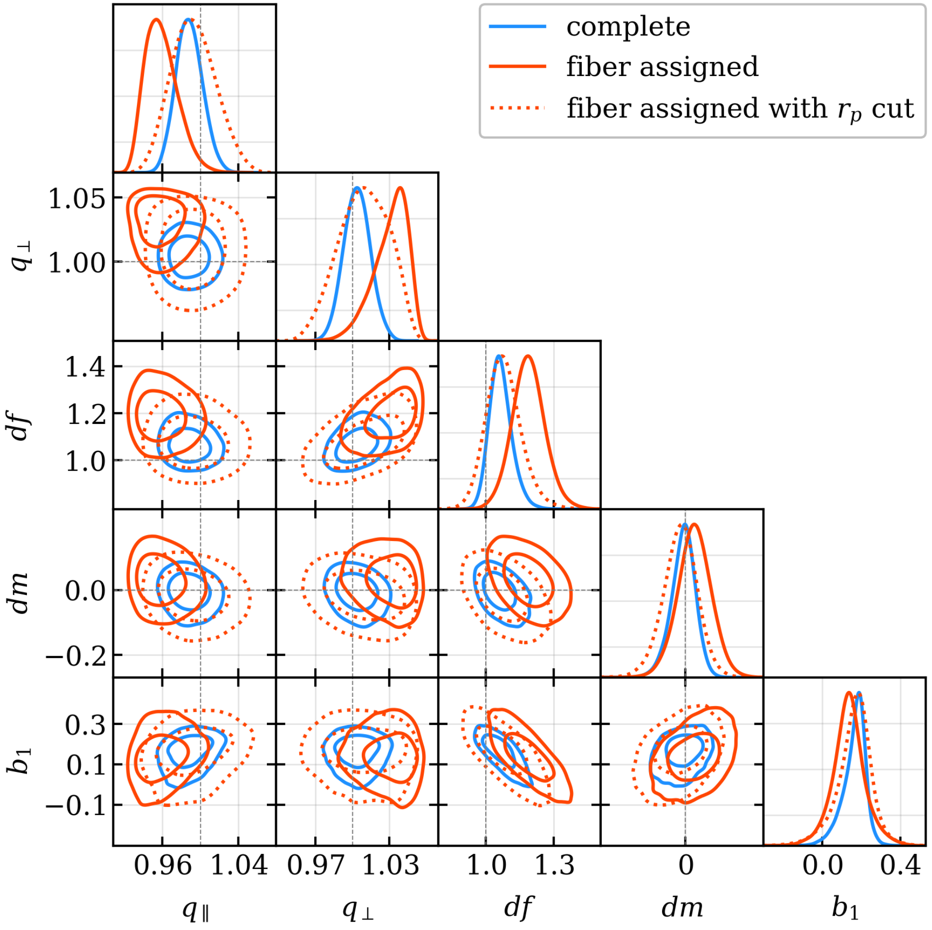
$$= W_p^{\text{FFT}}(s) - W_p^{r_\perp<\Lambda_{r_\perp}}(s)$$

standard window estimator

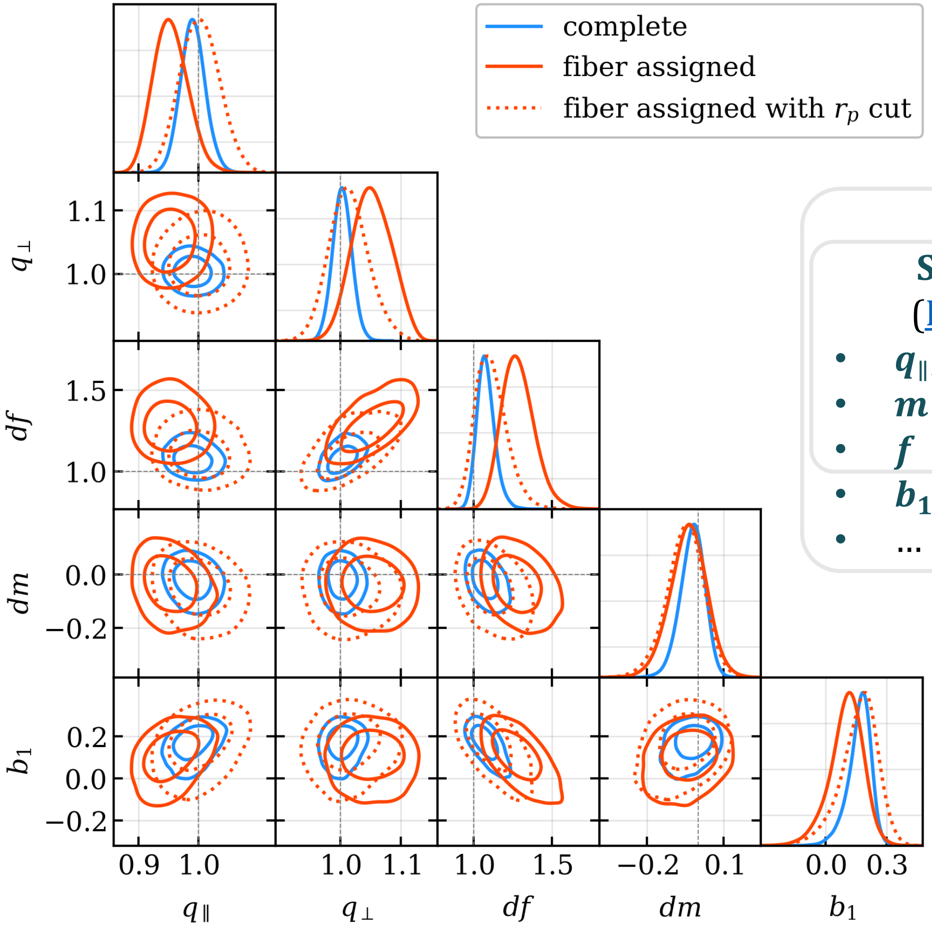
$r_\perp$-cut part direct pair counts

$r_\perp$-cut removes bias on cosmological parameters due to fiber collisions

correlation function



power spectrum



model

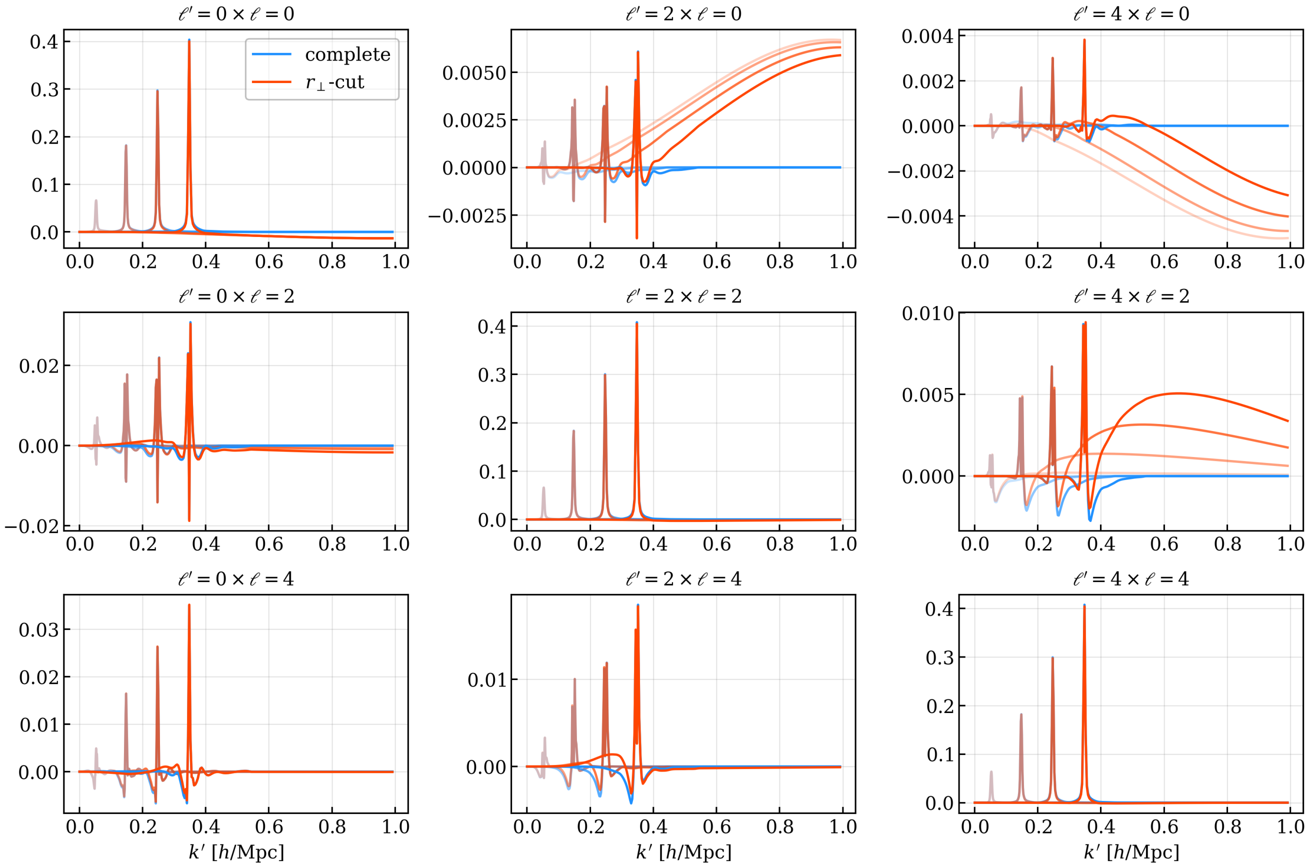
ShapeFit template

(Brieden et al 2021)

- $q_\parallel, q_\perp$ Alcock-Paczynski
- m tilt parameter
- f growth rate
- b_1 linear bias
- ... nuisance param.

Potential issue: $r_\perp$-cut power spectrum window matrix overweights theory at high k

$$P_\ell^{\mathrm{obs}}(k) = W_{\ell\ell'}(k, k') \times P_{\ell'}^{\mathrm{theory}}(k')$$



fixed $k = [0.05, 0.15, 0.25, 0.35]\ h/\mathrm{Mpc}$

We can transform the window to force it to converge to zero at high k

method by Pat McDonald (in prep)

- **change of basis** with a transformation optimized to **remove high-k** tails from the window matrix

$$\chi^2 = (d - Wt)^T C(d - Wt)$$

$$= (d' - W't)^T C'(d' - W't)$$

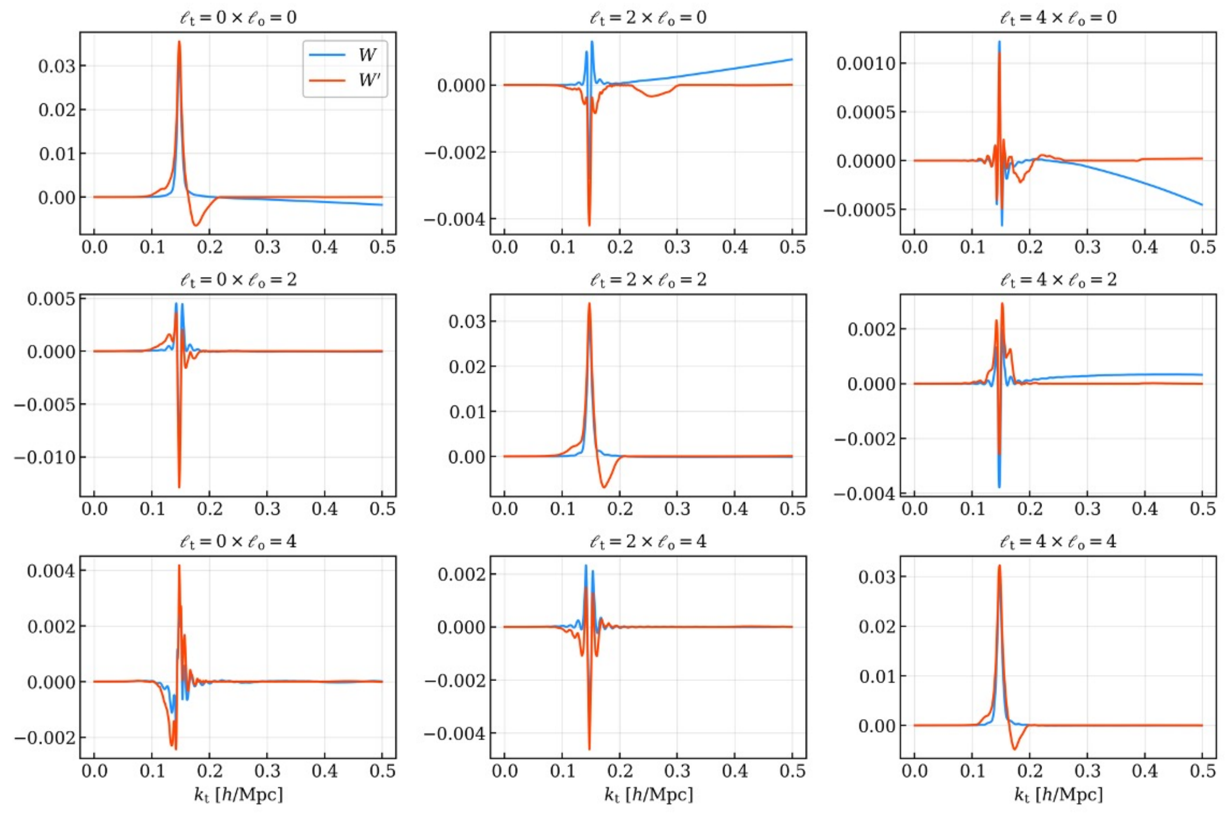
$$W' = MW$$

$$d' = Md$$

$$C' = MC$$

- **loss $L(M) = L_W(M) + L_C(M) + L_M(M)$**
  → penalizes far-off-diagonal terms in W and C
  → normalizes M

$W_{\ell\ell'}(k, k')$



fixed $k_{\text{obs}} = 0.15\ h/\text{Mpc}$

Conclusion

- Cutting out small-$r_\perp$ pairs in **2-point measurements and model**
  - ➢ **removes the effect of fiber collisions**
  - ➢ **unbiased constraints** on cosmological parameters

- We can **transform** the $r_\perp$-cut window to remove high-k tails without changing the likelihood, and thus **avoid integrating theory up to high *k***

- Default method for **DESI Y1 standard analyses**

Back up

Legendre multipoles

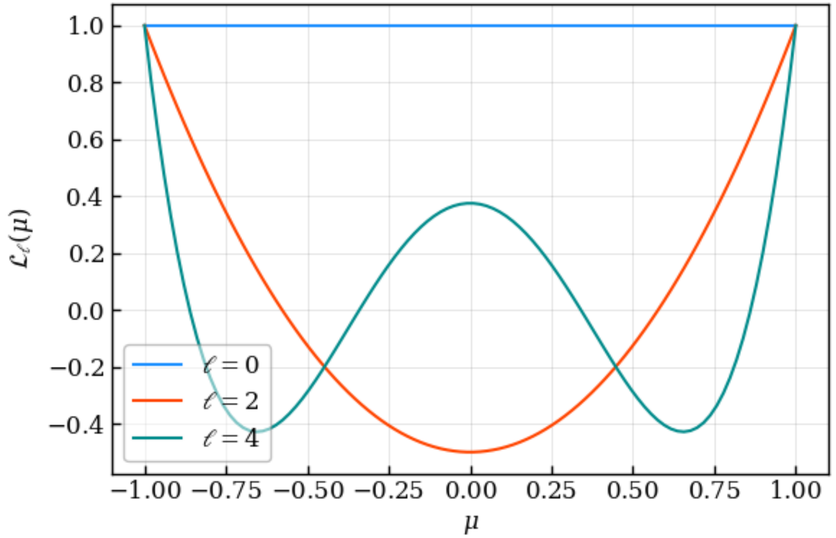
$$P(k, \mu) \quad \Rightarrow \quad P_\ell(k) = \frac{2\ell + 1}{2} \int_{-1}^{1} d\mu P(k, \mu) \mathcal{L}_\ell(\mu)$$

$$\xi(s, \mu) \quad \Rightarrow \quad \xi_\ell(s) = \frac{2\ell + 1}{2} \int_{-1}^{1} d\mu \xi(s, \mu) \mathcal{L}_\ell(\mu)$$

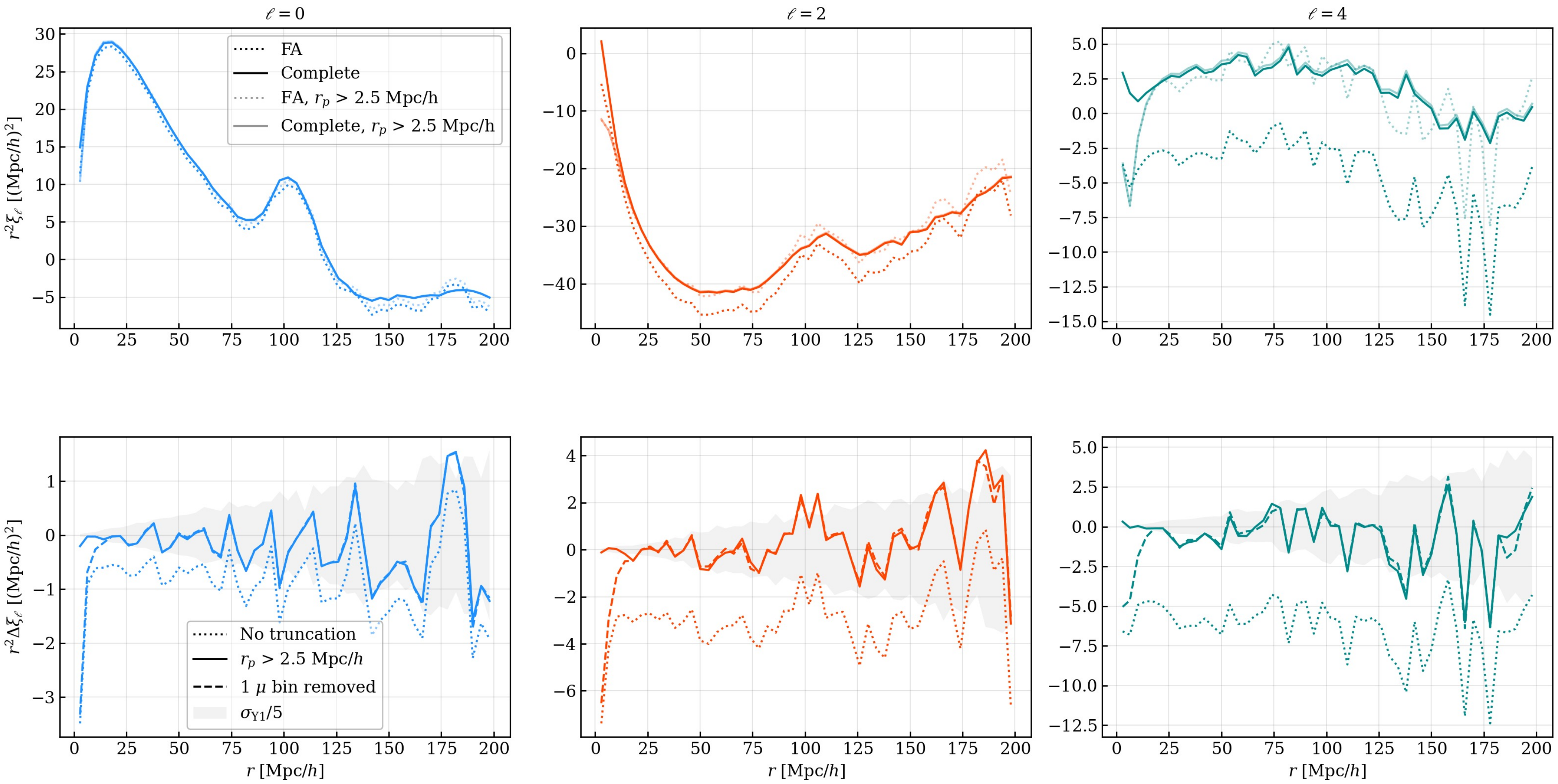
$$\mathcal{L}_0(x) = 1$$

$$\mathcal{L}_2(x) = \frac{1}{2}(3x^2 - 1)$$

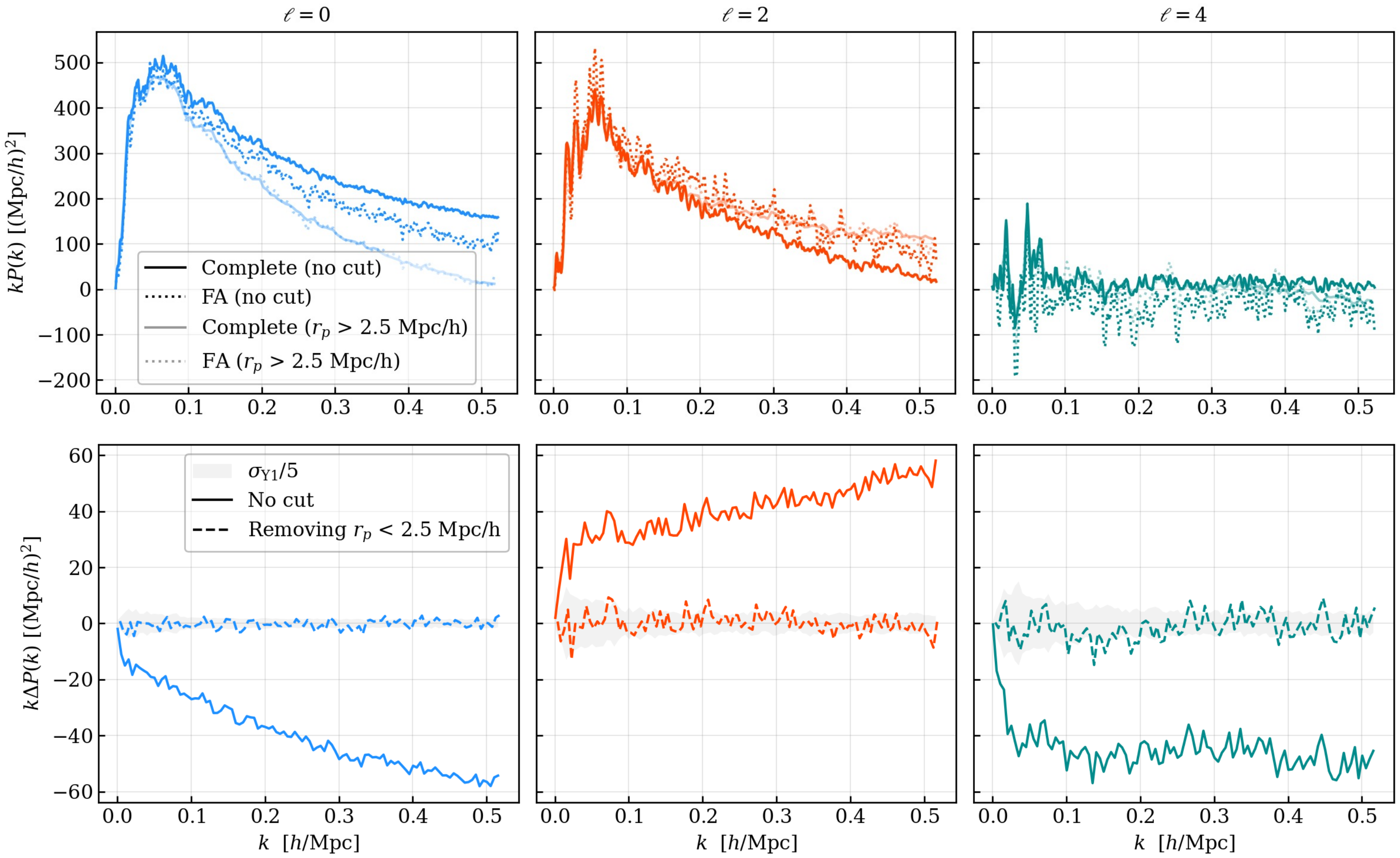
$$\mathcal{L}_4(x) = \frac{1}{8}(35x^4 - 30x^2 + 3)$$



$r_\perp$-cut correlation function

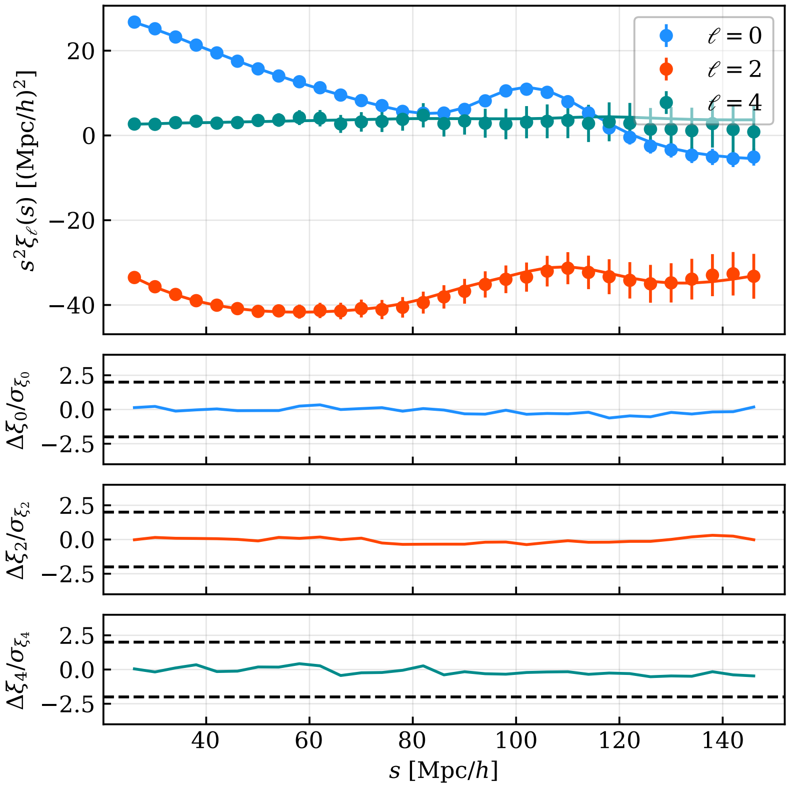


$r_\perp$-cut power spectrum

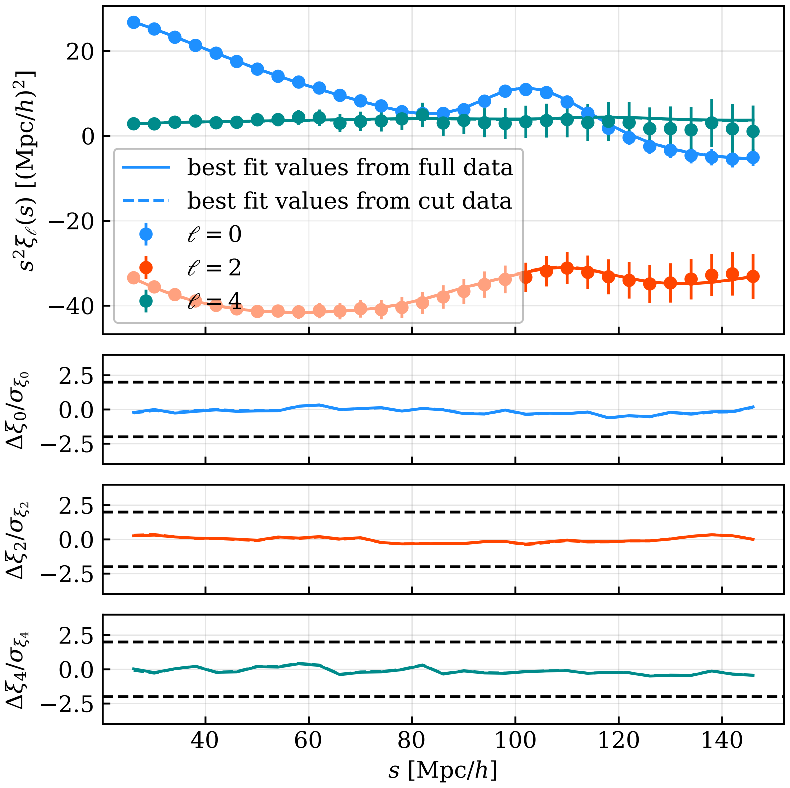


$r_\perp$-cut correlation function is well modelled by multiplying the theory with an appropriate window matrix

Complete mocks vs. best fit theory model

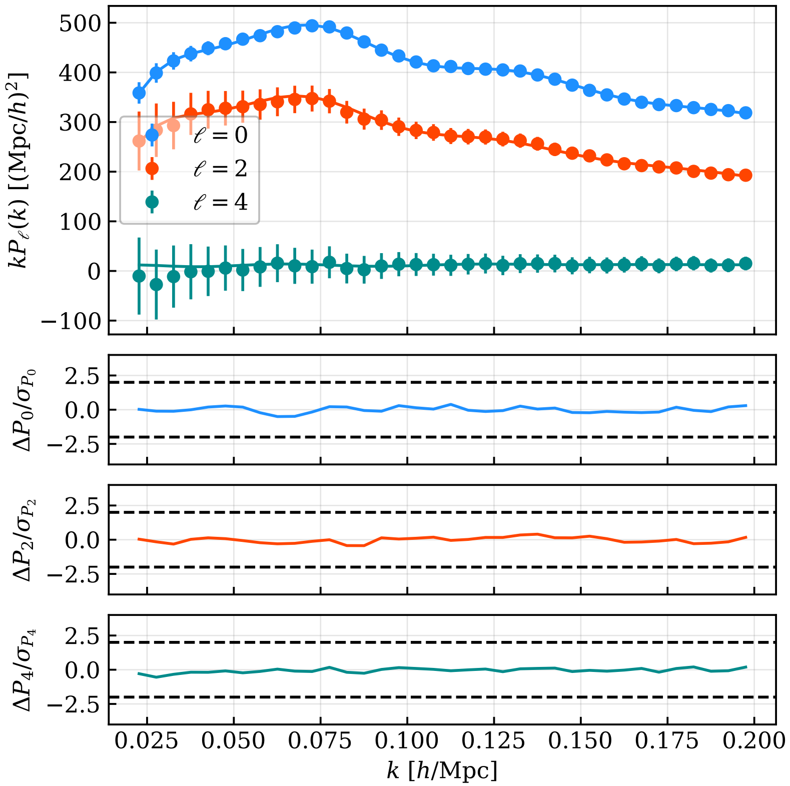


Complete mocks with r_p-cut vs. r_p-cut theory model

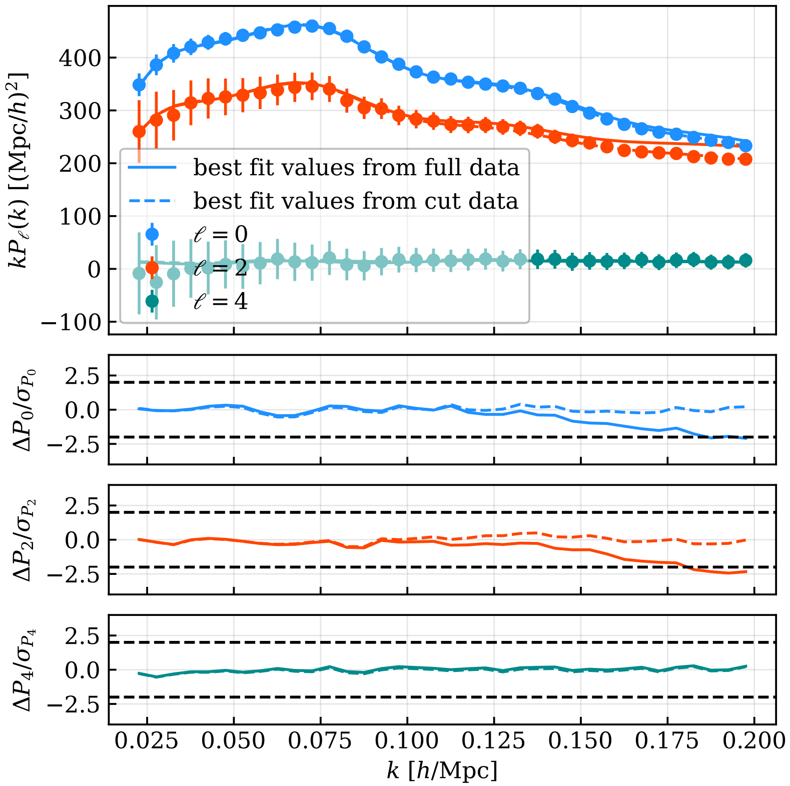


$r_\perp$-cut power spectrum model fits well to $r_\perp$-cut data (mostly stochastic parameters are changed)

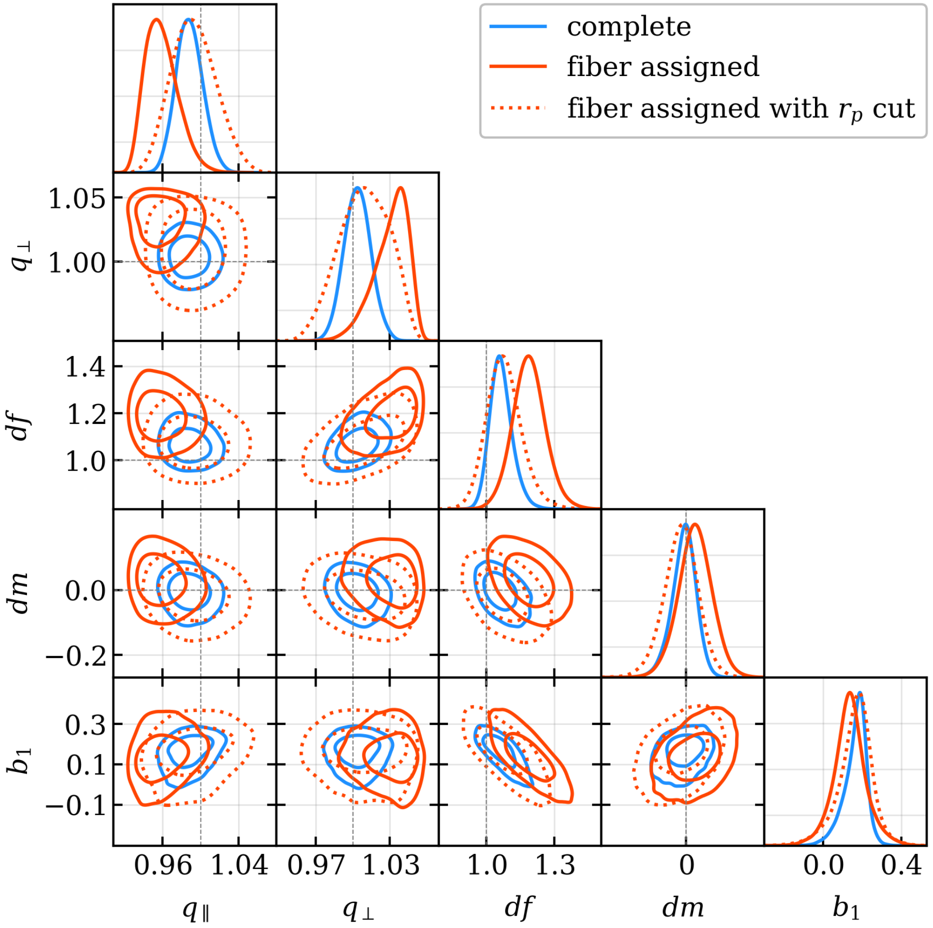
Complete mocks vs. best fit theory model



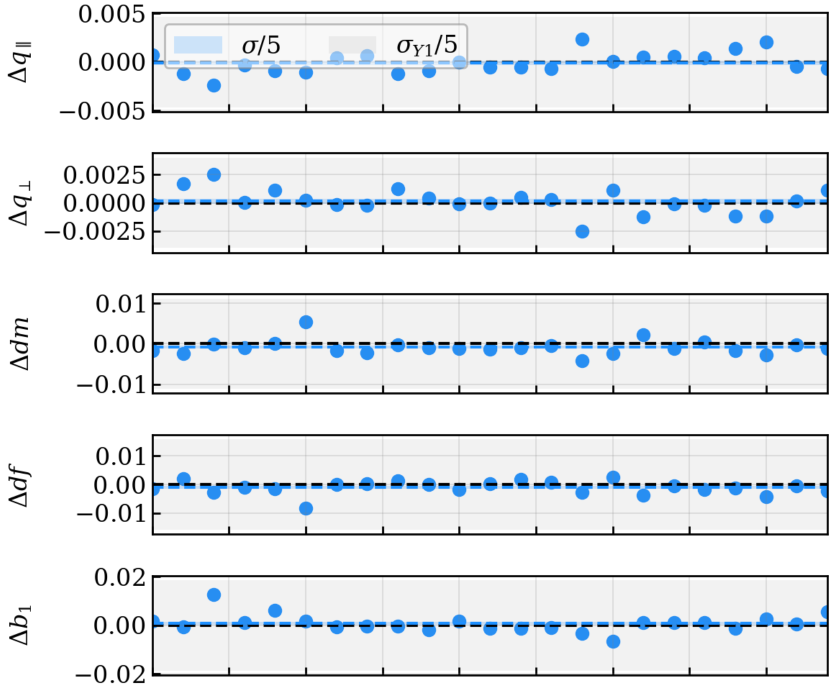
Complete mocks with r_p-cut vs. r_p-cut theory model



$r_\perp$-cut correlation function constraints

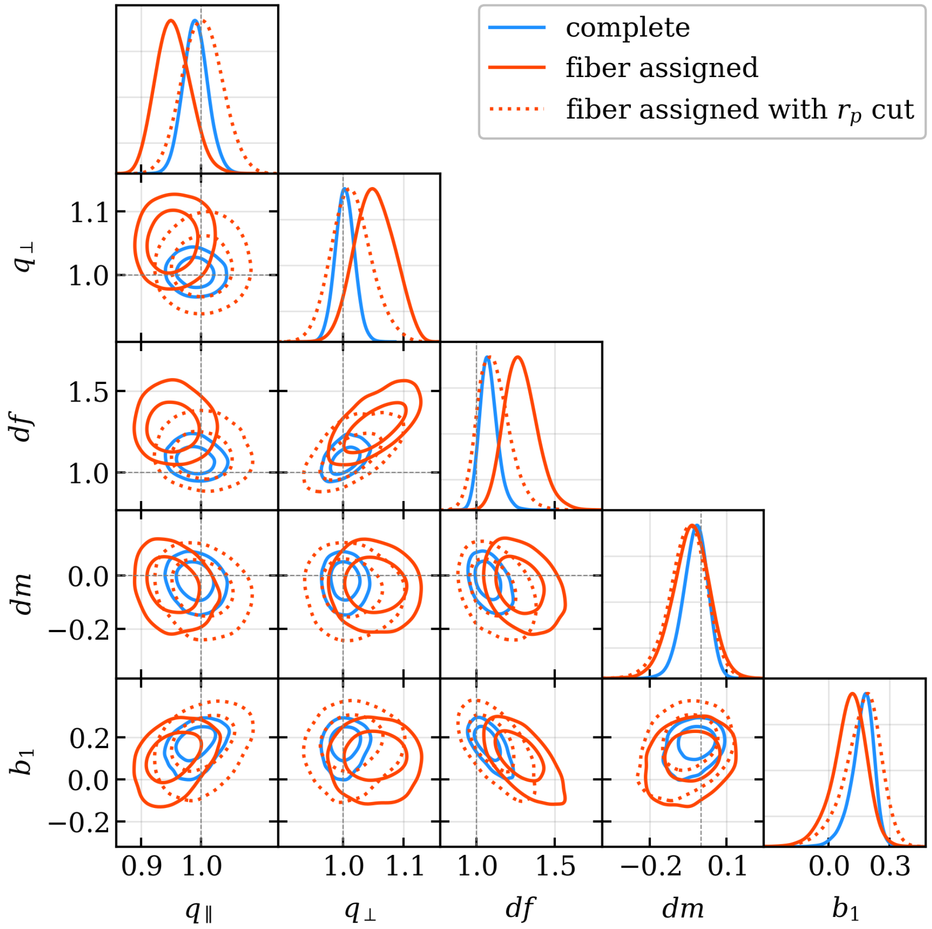


Difference of posterior mean between complete and r_p-cut mocks

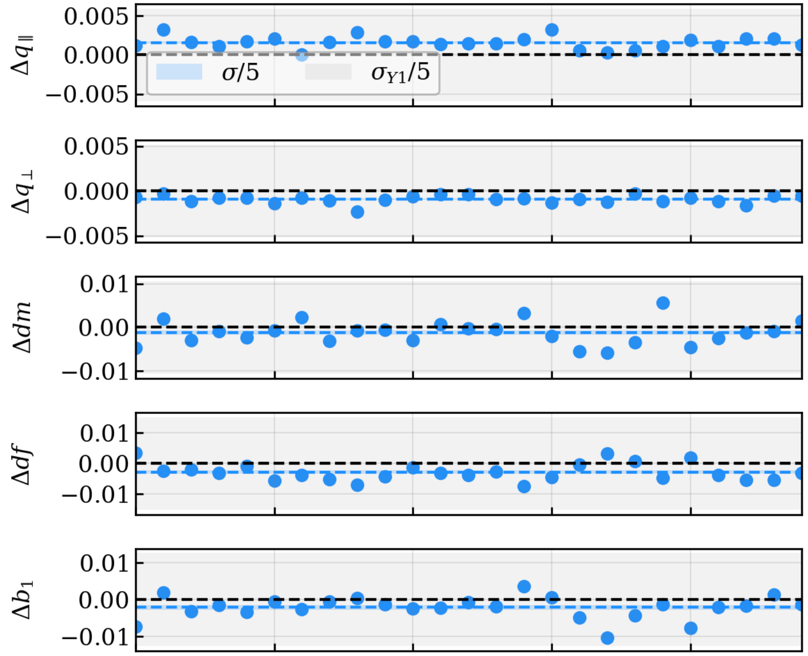


Grey area: 1/5 of Y1 uncertainty

$r_\perp$-cut power spectrum constraints

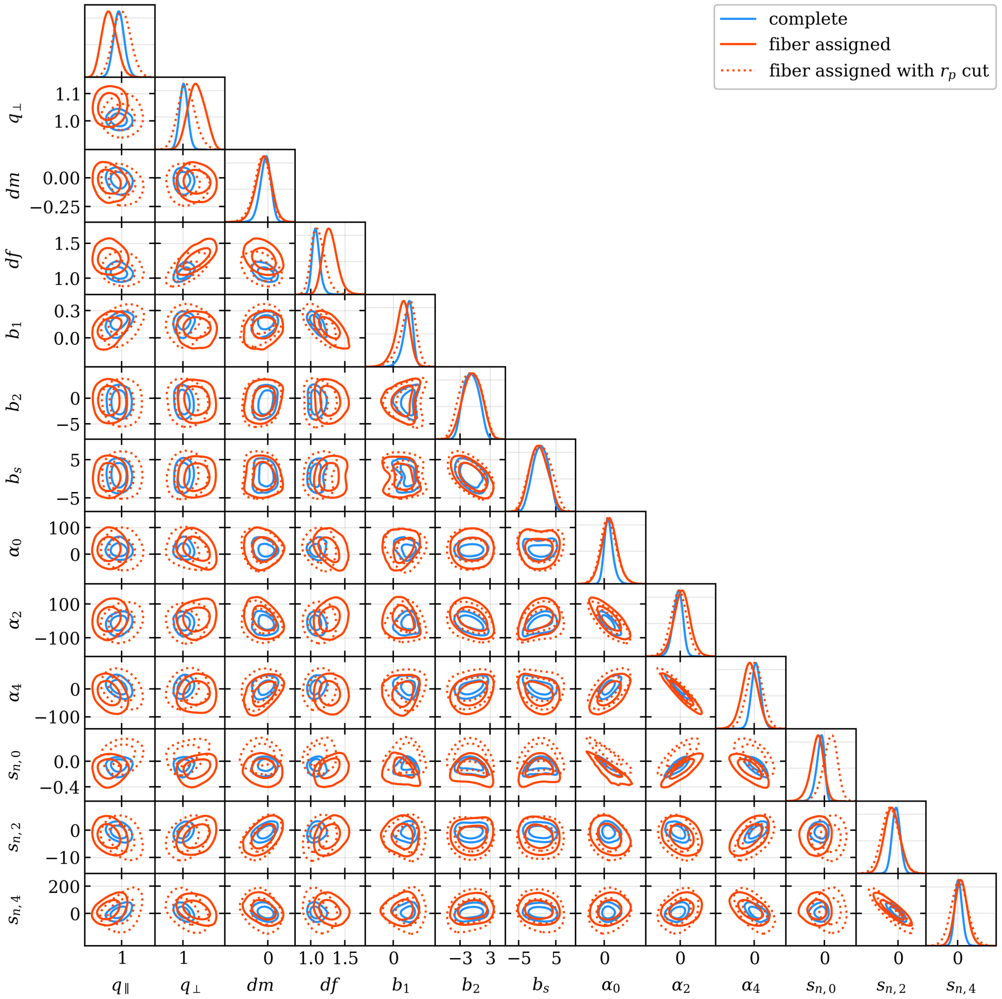


Difference of posterior mean between complete and r_p-cut mocks



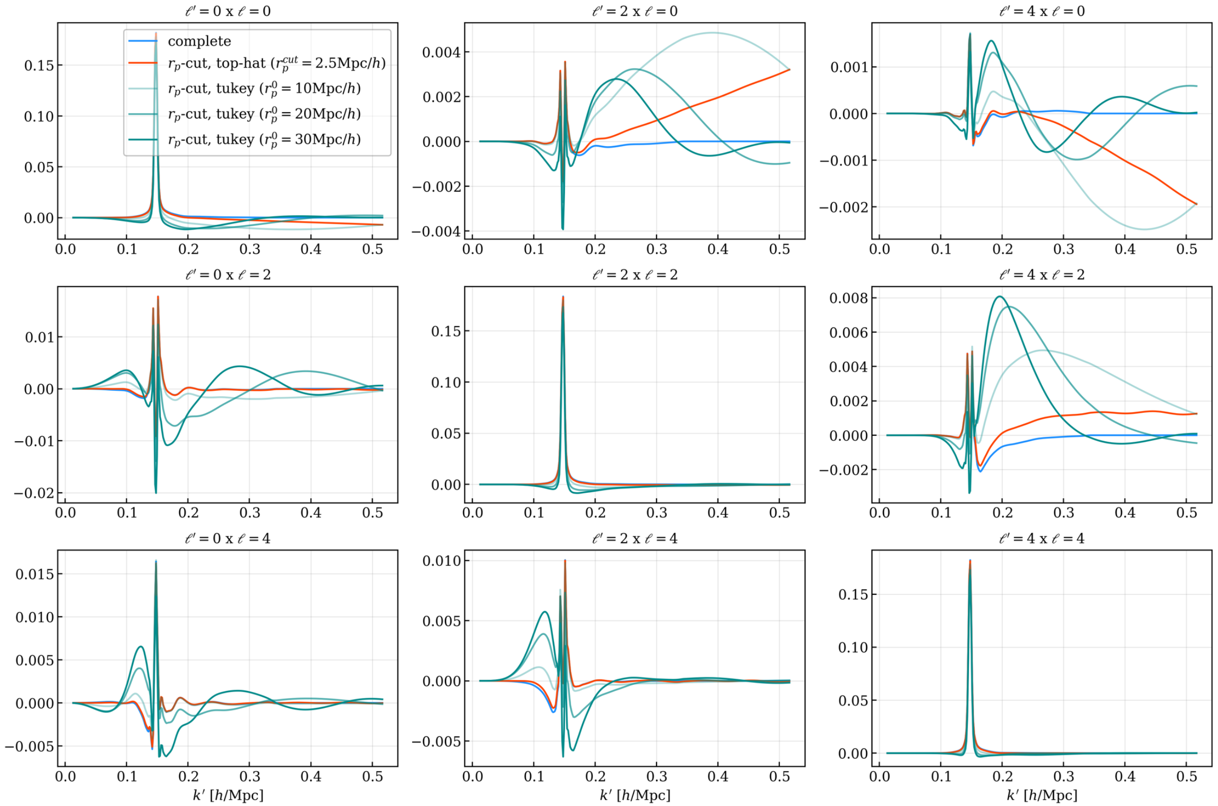
Grey area: 1/5 of Y1 uncertainty

$r_\perp$-cut power spectrum constraints (all parameters)



Apodization: using a smoother $r_\perp$-cut

Power spectrum window



Possible r_p-cut windows