Hybrid model of RSD: theory and practice

PTchat@Kyoto

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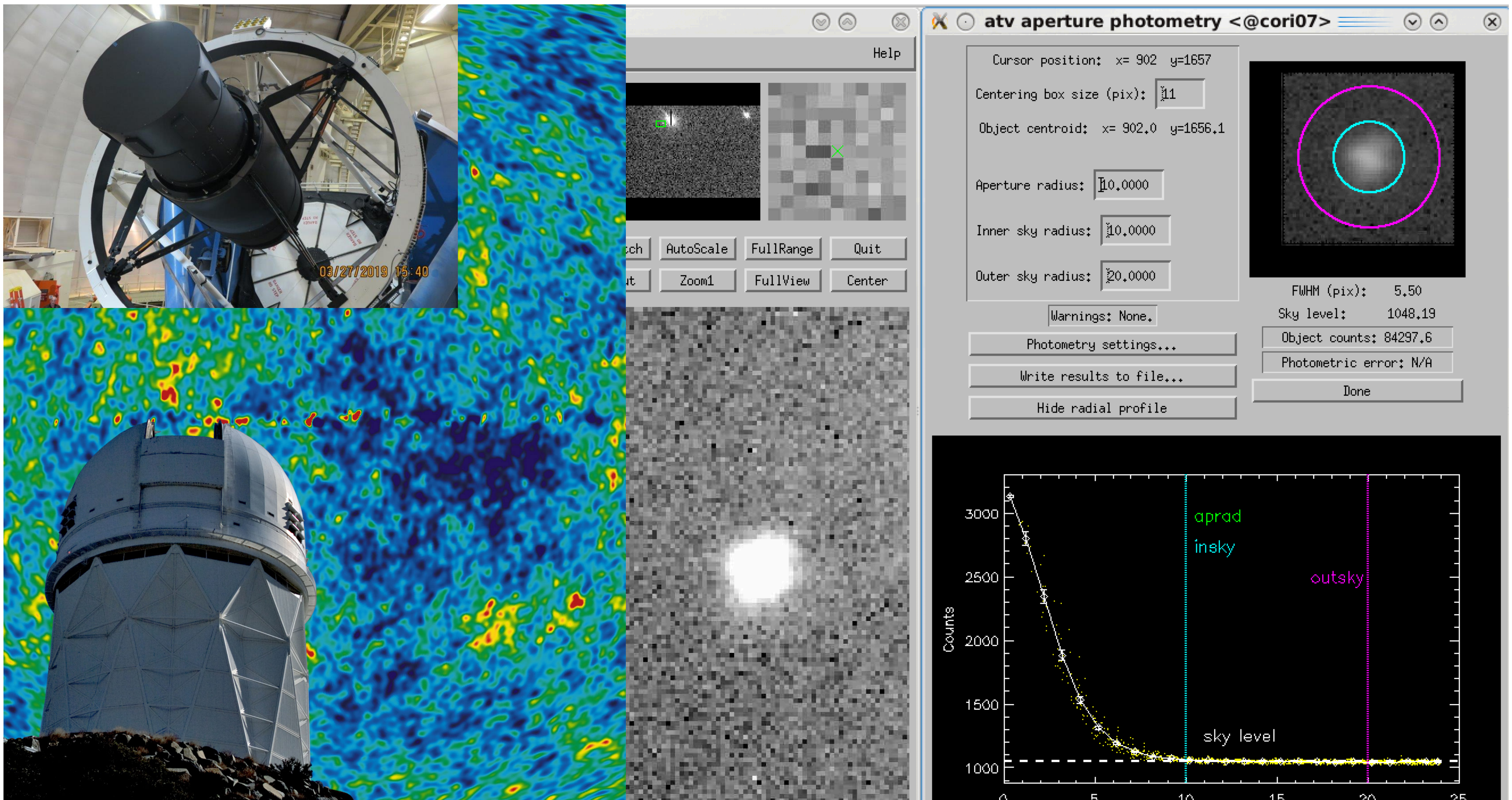
First light from DESI corrector lens

On Apr 2, DESI obtained sub-arcsecond images with the DESI Corrector and Commissioning Instrument. The attached image shows the profile of a star with FWHM of about 0.73".



Opportunities

- Breaking down our knowledge of particle physics: we have limited knowledge of particle physics bounded by testable high energy, and our efforts to explain the cosmic acceleration turn out in vain:

  Alternative mechanism to generate fine tuned vacuum energy

  New unknown energy component

  Unification or coupling between dark sectors

- Breaking down our knowledge of gravitational physics: gravitational physics has been tested in solar system scales, and it is yet confirmed at horizon size:

  Presence of extra dimension

  Non-linear interaction to Einstein equation

- Failure of standard cosmology model: our understanding of the universe is still standing on assumption:

  Inhomogeneous models: LTB, back reaction

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Dynamical Dark Energy: modifying matter

  Alternative mechanism to generate fine tuned vacuum energy

  New unknown energy component

$$G_{\mu\nu} = 4\pi G_N T_{\mu\nu} + \Delta T_{\mu\nu}$$

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Geometrical Dark Energy: modifying gravity

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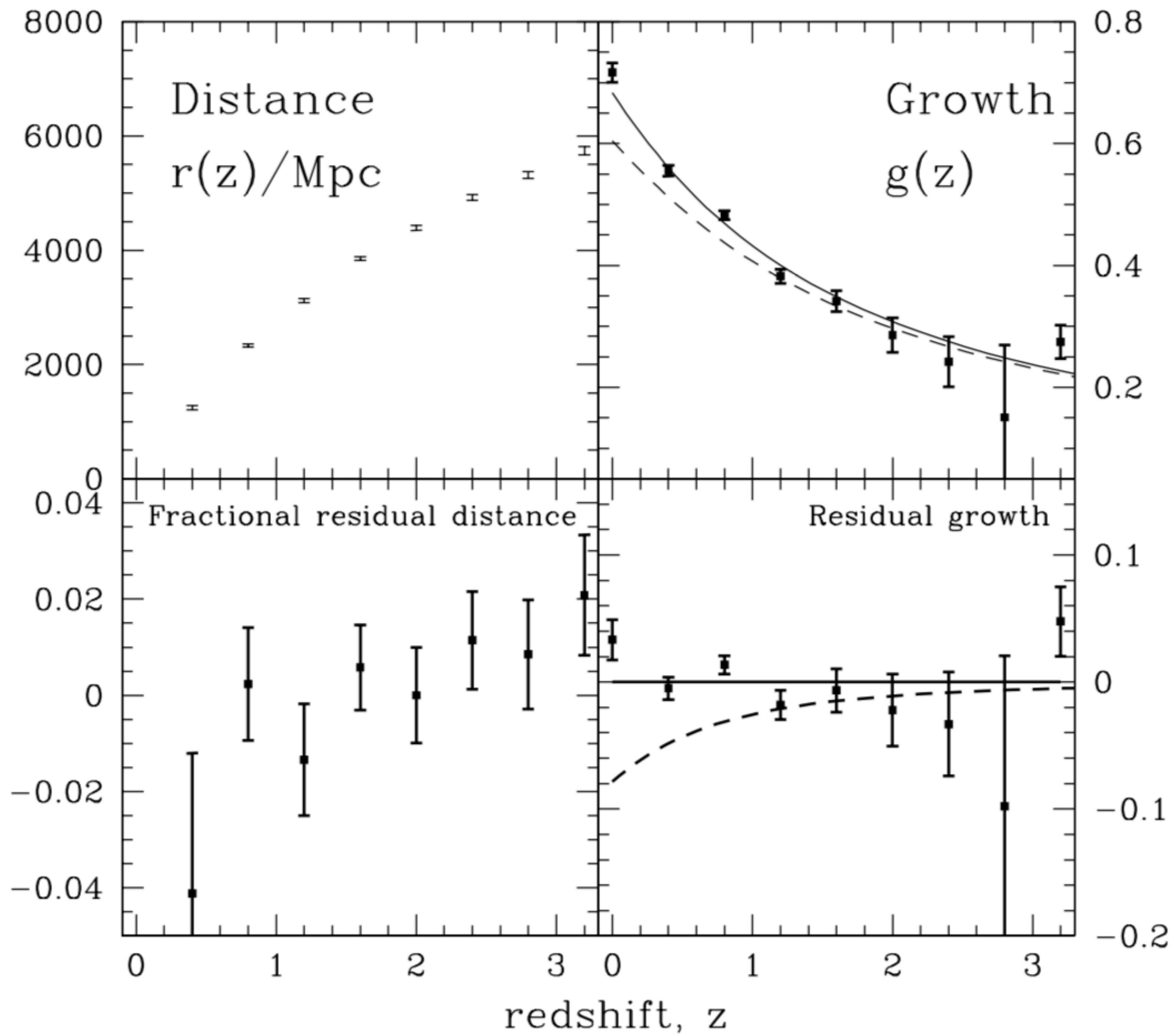
  Inhomogeneous models: LTB, back reaction

Two windows to test GR cosmologically

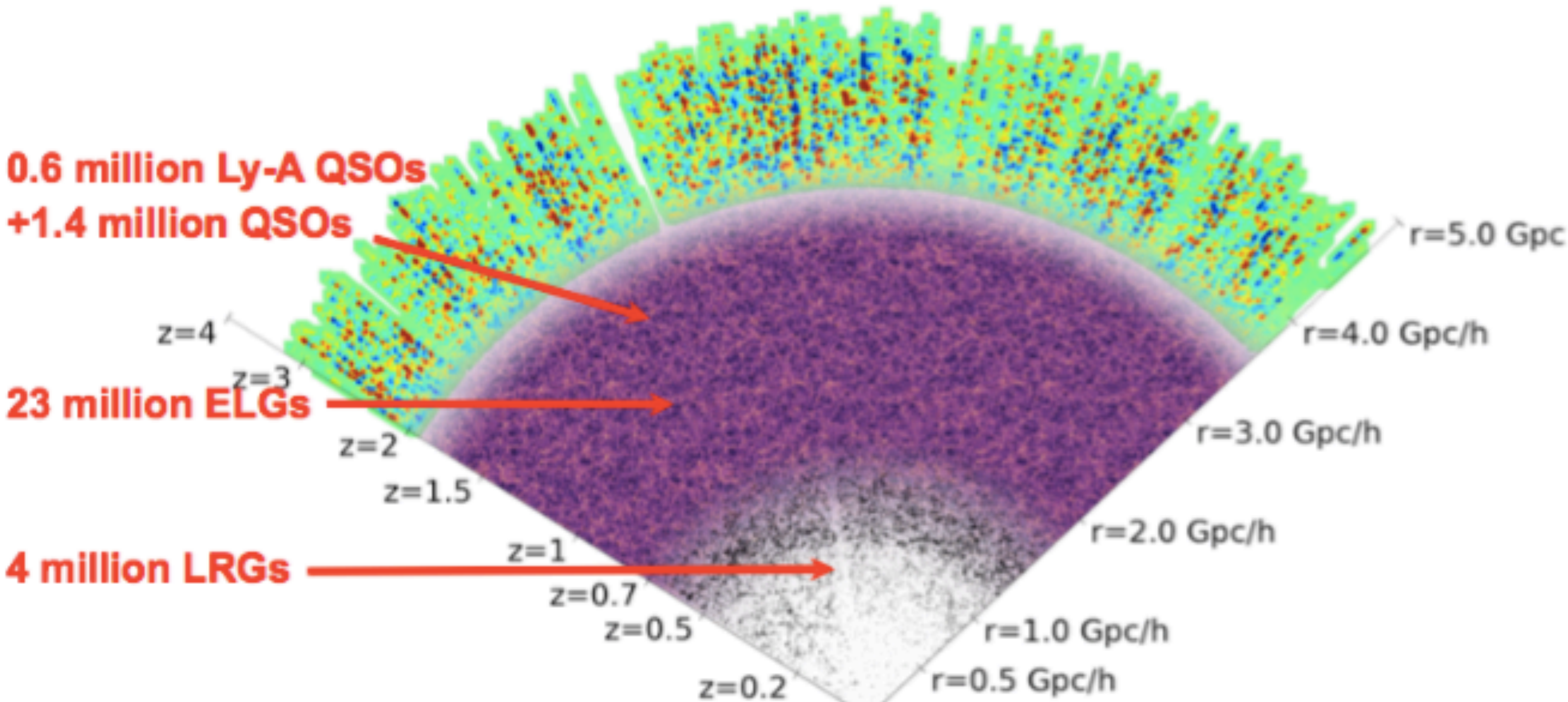
We test GR using the consistency relation in GR using simultaneously distance and structure



Target scale

z	$n_g\ [h^3 \mathrm{Mpc}^{-3}]$	$V_{\mathrm{survey}}\ [h^{-3}\ \mathrm{Gpc}^3]$
0.6–0.8	1.2×10^{-3}	5.3
0.8–1.0	1.1×10^{-3}	7.0
1.0–1.2	5.4×10^{-4}	8.3
1.2–1.4	3.3×10^{-4}	9.4
1.4–1.6	1.5×10^{-4}	10.1
1.6–1.8	5.0×10^{-5}	10.6

The access to the small scale is limited by the spectroscopic number density sample. Although the number of modes increases, the shot noise becomes bigger. The threshold scale is set to be $k < 0.2$ h/Mpc.



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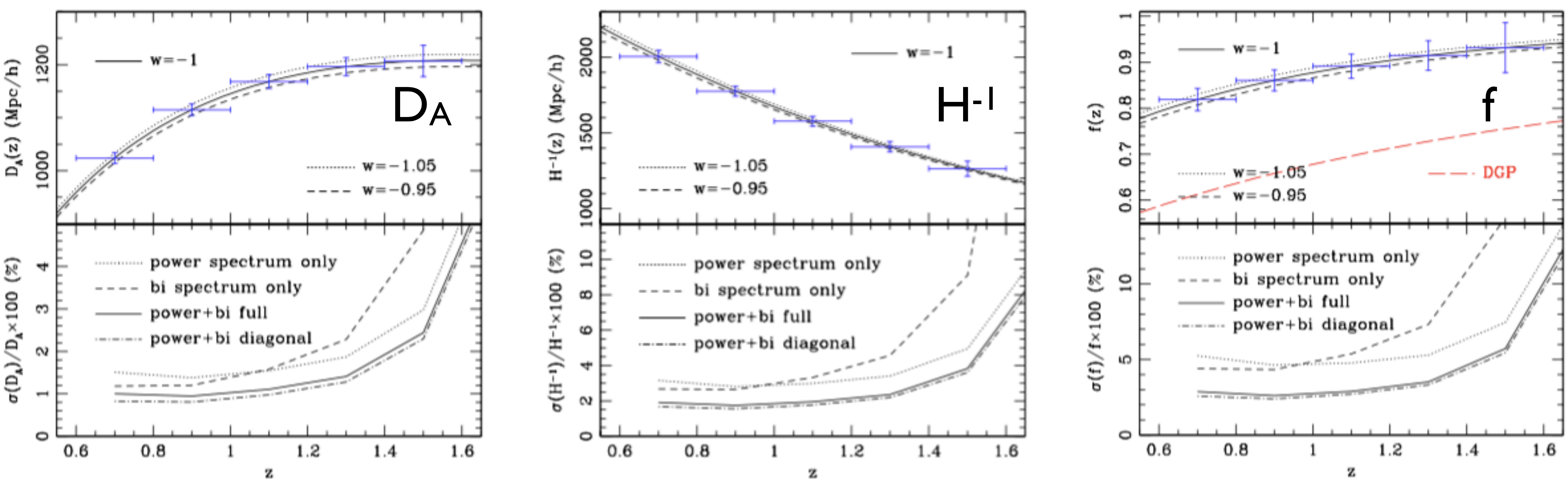
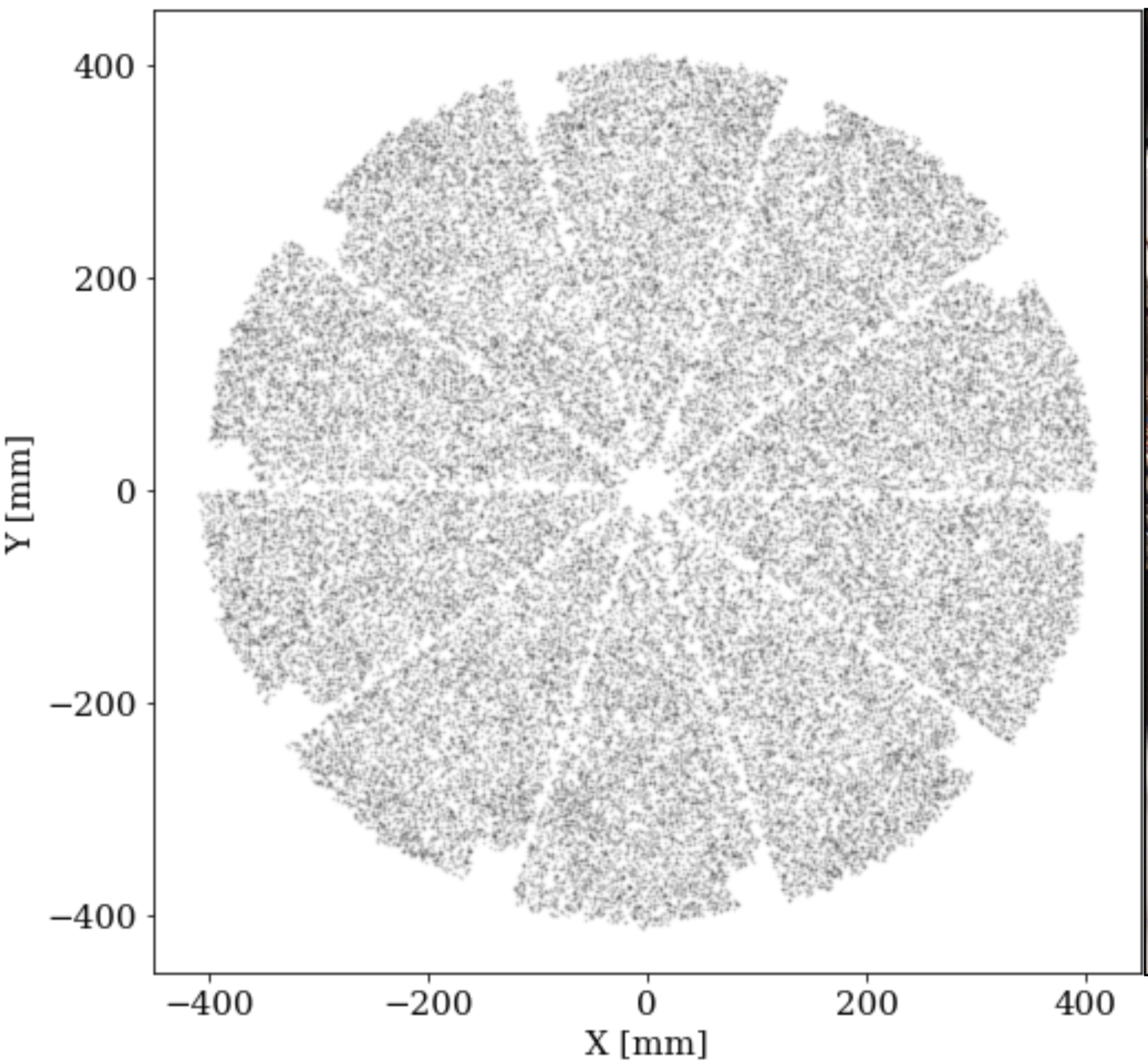
The access to the small scale is limited by the spectroscopic number density sample. Although the number of modes increases, the shot noise becomes bigger. The threshold scale is set to be $k < 0.2$ h/Mpc.

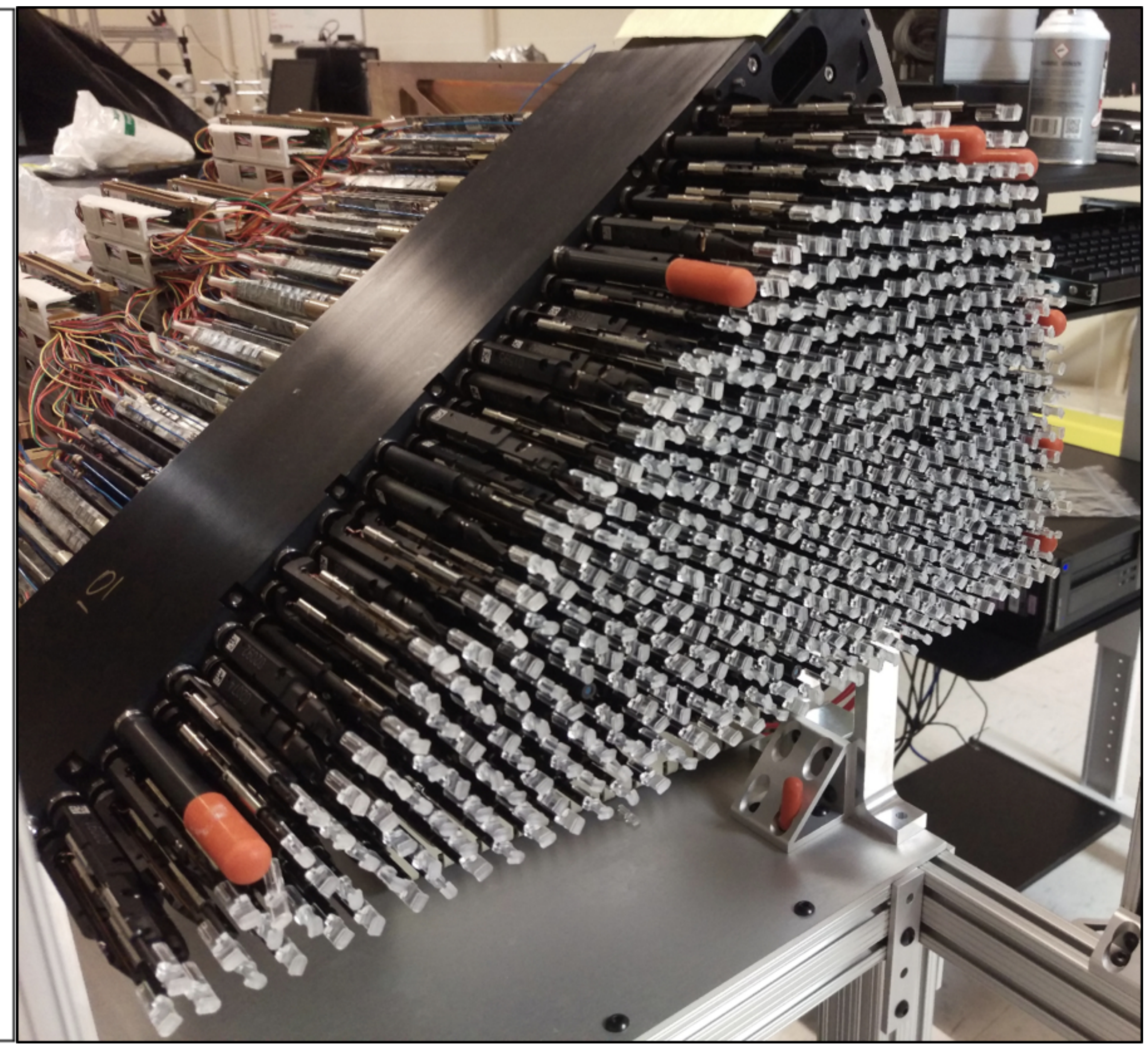
The estimated constraints on cosmic distances and structure formation is presented below. We are able to approach a couple of percentage precision at scale of $k < 0.2$ h/Mpc.



Systematic uncertainty caused by scanning strategy

DESI adapted the petal style spectroscopy instrument design in which eight fibre bundle petals complete one exposure. It caused the edge effect at boundaries, and demands the five visit scanning strategy to smooth out the distribution of targets. However, there will be a difficulty in collecting ELG samples.





Challenges

- Perturbative description of LSS in real space
  - Consistency between the observational limit and breakdown of perturbative expression
  - Cosmological independence of renormalized parameter or EFT nuisance parameters
- Understanding mapping from real to redshift spaces
  - Non-regularizable expansion of cross-correlation between velocity and density fluctuation
  - Theoretical description of non-linear random velocity effect is not known
- Non-trivial galaxy bias even at target scale in a percentage precision level
  - The theoretical description on local and non-local biases are available for detailed test
  - Request for the verification to isolate the galaxy bias test from perturbative modeling
- Systematic uncertainty caused by experimental environment
  - Concern on the correlation along the line of sight to be contaminated by fibre collision
  - Priority issue for the selection of LRG, ELG and QSO in appropriate order
- Geometrical effect on the uncertainty

Stepwise simulation test

Particle SNAP Shot

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Halo SNAP Shot

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Galaxy time streaming

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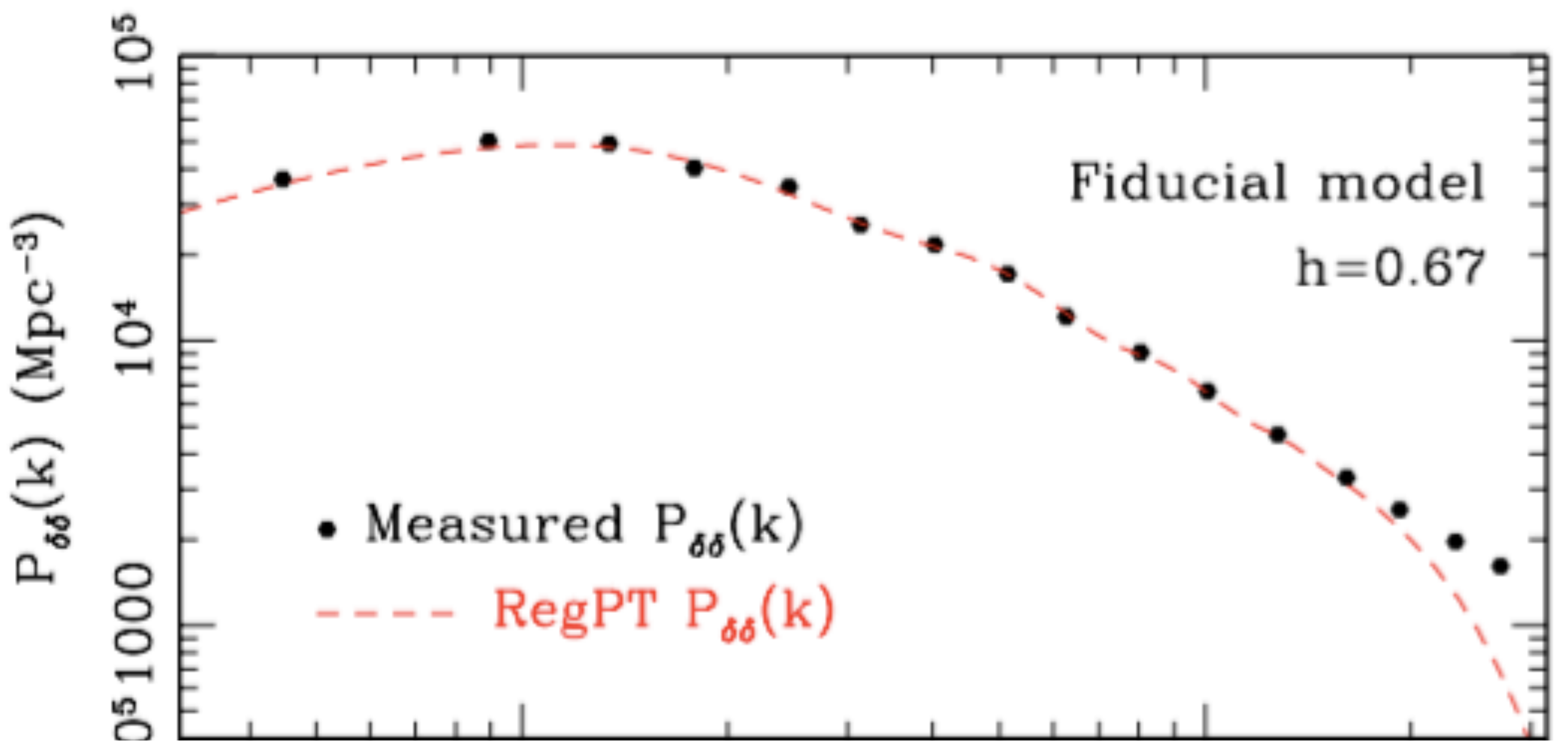
Theoretical perturbative model



- We compare the theoretical predictions from RegPT and the measured spectrum of density fluctuations. Both are consistent up to quasi linear scale.

- As this correction is not relevant to RSD mapping, we will discuss it at later part of this talk when we need to explain the growth function projection

Hybrid approach

- Non-linear spectrum: we use the perturbative theory and the simulation measurement, in order to classify the different growth function dependences

$$\bar{P}_{XY}(k,z) = \bar{P}^{\rm th}_{XY}(k,z) + \bar{P}^{\rm res}_{XY}(k,z),$$

$$\begin{aligned}\bar{P}_{XY}(k,z) &= \bar{\Gamma}^{(1)}_X(k,z)\bar{\Gamma}^{(1)}_Y(k,z)\bar{P}^i(k)\\ &+2\int \frac{d^3\vec{q}}{(2\pi)^3}\bar{\Gamma}^{(2)}_X(\vec{q},\vec{k}-\vec{q},z)\bar{\Gamma}^{(2)}_Y(\vec{q},\vec{k}-\vec{q},z)\bar{P}^i(q)\bar{P}^i(|\vec{k}-\vec{q}|)\\ &+6\int \frac{d^3\vec{p}d^3\vec{q}}{(2\pi)^6}\bar{\Gamma}^{(3)}_X(\vec{p},\vec{q},\vec{k}-\vec{p}-\vec{q},z)\bar{\Gamma}^{(3)}_Y(\vec{p},\vec{q},\vec{k}-\vec{p}-\vec{q},z)\bar{P}^i(p)\bar{P}^i(q)\bar{P}^i(|\vec{k}-\vec{p}-\vec{q}|),\end{aligned}$$

$$\begin{aligned}\bar{P}^{\rm res}_{XY} = \bar{G}_X\bar{G}_Y\bar{G}^4_\delta \Big\{ &\left[\bar{\mathcal{O}}^{(1)}_{Y,5} + \text{higher}\right]\bar{P}^i + \left[\bar{\mathcal{O}}^{(1)}_{X,5} + \text{higher}\right]\bar{P}^i,\\ &+\int\left[\bar{\mathcal{O}}^{(2)}_{Y,4}\bar{F}^{(2)}_Y + \text{higher}\right]\bar{P}^i\bar{P}^i + \int\left[\bar{\mathcal{O}}^{(2)}_{X,4}\bar{F}^{(2)}_X + \text{higher}\right]\bar{P}^i\bar{P}^i,\\ &+\int\int\left[\bar{\mathcal{O}}^{(3)}_{Y,3}\bar{F}^{(3)}_Y + \text{higher}\right]\bar{P}^i\bar{P}^i\bar{P}^i + \int\int\left[\bar{\mathcal{O}}^{(3)}_{X,3}\bar{F}^{(3)}_X + \text{higher}\right]\bar{P}^i\bar{P}^i\bar{P}^i\Big\}.\end{aligned}$$

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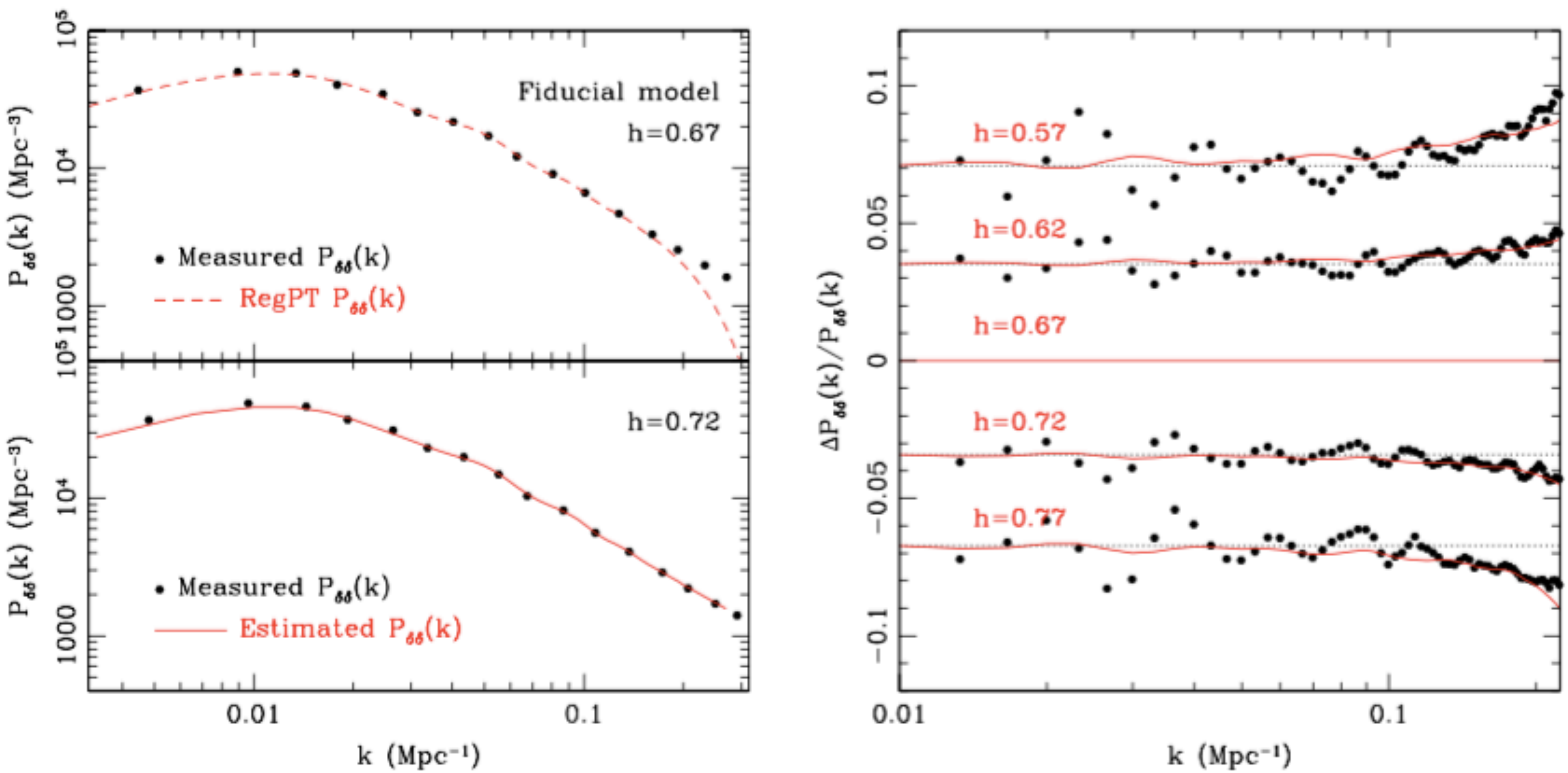

YSS, Zheng, Taruya, Oh 2017

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Mapping from real to redshift space

$$P_s(k,\mu) = \int d^3x\, e^{ikx} \langle \boldsymbol{\delta\delta} \rangle$$

$$\downarrow$$

$$P_s(k,\mu) = \int d^3x\, e^{ikx} \langle e^{jv} (\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta) \rangle$$

$$= \int d^3x\, e^{ikx} \exp\{\langle e^{jv} \rangle_c\} \left[\langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta) \rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta) \rangle_c \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta) \rangle_c \right]$$

- We understand RSD as a mapping from real to redshift space including stochastic quantity of peculiar velocity
- The mapping contains the contribution from two point correlation functions depending on separation distance, such as the cross correlation of density and velocity and the velocity auto correlation.
- The mapping also contains the contribution from one point correlation function of peculiar velocity which can be given by a functional form in terms of velocity dispersion σ_p.

Mapping from real to redshift space

$$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} \left[\langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c\right]$$

- The contribution from the cross correlation between density and velocity fields

$$\langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$= j^0 \langle(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$+ j^1 \langle v(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$+ j^2 \langle v(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c \langle v(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$+ j^2 \langle vv(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$+ j^2 \langle vv\rangle_c \langle(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$+ O(> j^3)$$

Mapping from real to redshift space

$$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} \left[\langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c \langle e^{jv}(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c\right]$$

- We truncate the infinite polynomials above j^2 order, then the following terms are defined as;

$$A(k,\mu) = j^1 \int d^3x\, e^{ikx} \langle v(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

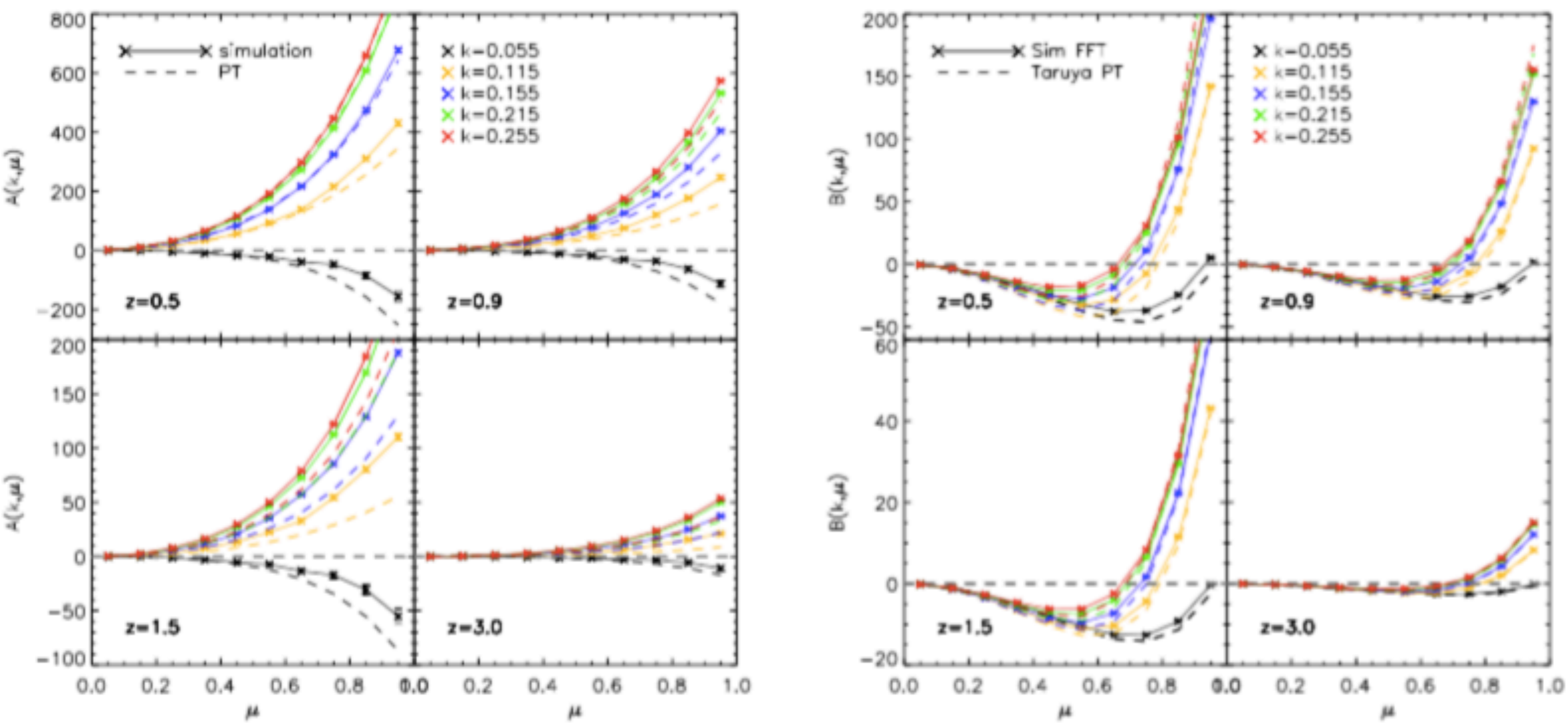
$$B(k,\mu) = j^2 \int d^3x\, e^{ikx} \langle v(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c \langle v(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

$$T(k,\mu) = j^2 \int d^3x\, e^{ikx} \langle vv(\boldsymbol{\delta}+\mu^2\Theta)(\boldsymbol{\delta}+\mu^2\Theta)\rangle_c$$

Hybrid approach for mapping

$$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} \left[\langle e^{jv}(\delta+\mu^2\Theta)(\delta+\mu^2\Theta)\rangle_c + \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c\right]$$

- The theoretical predictions of A and B are acceptable, while the measured A and B are better to be exploited;

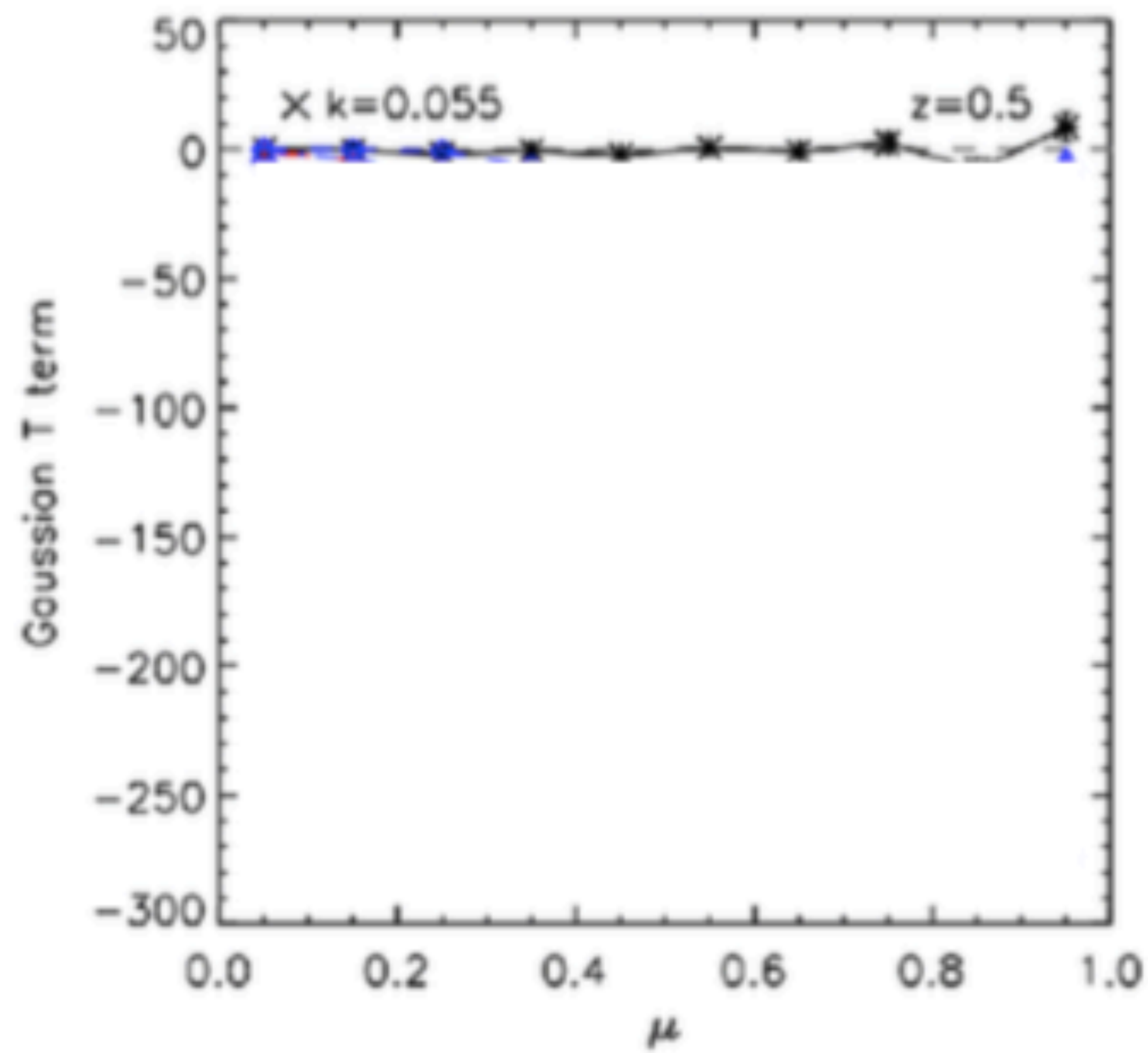


Yi Zheng, YSS 2016

Hybrid approach for mapping

$$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} \left[\langle e^{jv}(\delta+\mu^2\Theta)(\delta+\mu^2\Theta)\rangle_c + \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c\right]$$

- We are not able to predict the full theoretical T expression at this moment



Hybrid approach for mapping

$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\}\, [\langle e^{jv}(\delta+\mu^2\Theta)(\delta+\mu^2\Theta)\rangle_c + \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c \langle e^{jv}(\delta+\mu^2\Theta)\rangle_c]$

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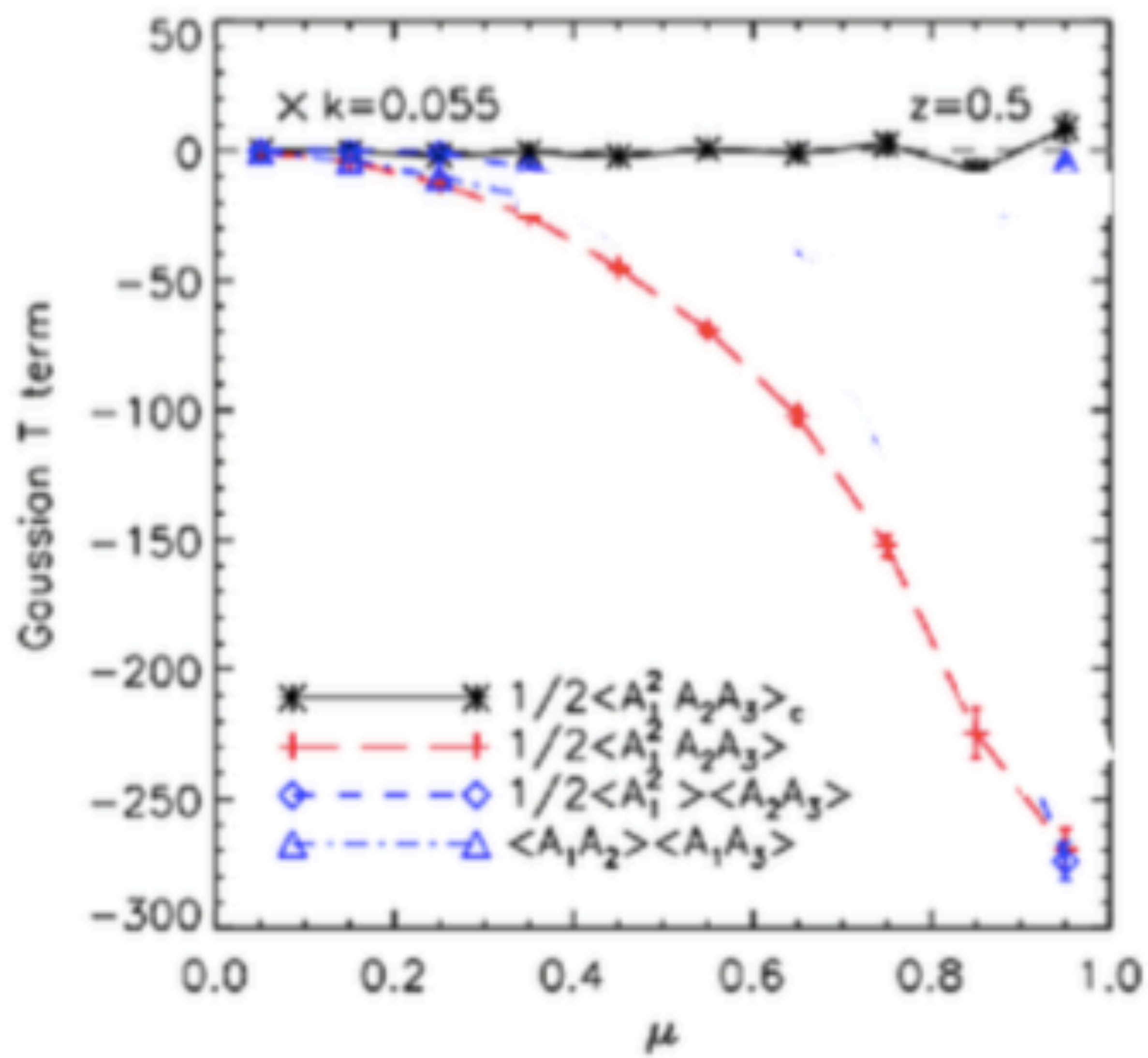


Yi Zheng, YSS 2016

Verification of hybrid mapping formulation

$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} [\langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c]$

- The term contains both one and two point correlation contributions, and we are going to separate those

$$\begin{aligned}
\exp\left\{\langle e^{j_1 A_1}\rangle_c\right\} &= \exp\left\{\sum_{n=1}^{\infty} j_1^n \frac{\langle A_1^n\rangle_c}{n!}\right\} = \exp\left\{\sum_{n=1}^{\infty} j_1^{2n} \frac{\langle (u_z(\boldsymbol{r}) - u_z(\boldsymbol{r}'))^{2n}\rangle_c}{(2n)!}\right\} \\
&= \exp\left\{\sum_{n=1}^{\infty} j_1^{2n} \frac{2\langle u_z(\boldsymbol{r})^{2n}\rangle_c}{(2n)!}\right\} \times \exp\left\{\sum_{n=1}^{\infty} j_1^{2n} \frac{\langle (u_z(\boldsymbol{r}) - u_z(\boldsymbol{r}'))^{2n}\rangle_c - \langle u_z(\boldsymbol{r})^{2n}\rangle_c - \langle u_z(\boldsymbol{r}')^{2n}\rangle_c}{(2n)!}\right\} \\
&= D_{\rm 1pt}^{\rm FoG}(k\mu) \times D_{\rm corr}^{\rm FoG}(k\mu, \boldsymbol{x}).
\end{aligned}$$

$$\begin{aligned}
D_{\rm corr}^{\rm FoG}(k\mu, \boldsymbol{x}) &= \exp\left\{\sum_{n=1}^{\infty} j_1^{2n} \frac{\langle (u_z(\boldsymbol{r}) - u_z(\boldsymbol{r}'))^{2n}\rangle_c - \langle u_z(\boldsymbol{r})^{2n}\rangle_c - \langle u_z(\boldsymbol{r}')^{2n}\rangle_c}{(2n)!}\right\} \\
&= \exp\left\{-j_1^2 \langle u_z(\boldsymbol{r}) u_z(\boldsymbol{r}')\rangle_c + \sum_{n=2}^{\infty} j_1^{2n} \frac{\langle (u_z(\boldsymbol{r}) - u_z(\boldsymbol{r}'))^{2n}\rangle_c - \langle u_z(\boldsymbol{r})^{2n}\rangle_c - \langle u_z(\boldsymbol{r}')^{2n}\rangle_c}{(2n)!}\right\}.
\end{aligned}$$

$F(k,\boldsymbol{\mu}) = j^2 \int d^3x\, e^{ikx} \langle vv\rangle_c \langle(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c$

Verification of hybrid mapping formulation

$$P_s = \int d^3x\, e^{ikx} \exp\{\langle e^{jv}\rangle_c\} [\langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c + \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c \langle e^{jv}(\boldsymbol{\delta}+\boldsymbol{\mu}^2\Theta)\rangle_c]$$

$$\downarrow$$

$$P_s = D_{1pt}(k\mu\sigma_p) \int d^3x\, e^{ikx}[P_{\delta\delta}(k) + 2\mu^2 P_{\delta\Theta}(k) + \mu^4 P_{\Theta\Theta}(k) + A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)]$$

- We would like to test whether higher order contributions of j^n $(n>2)$ is no longer contaminating mapping above threshold scale or not, by using the following residual test;

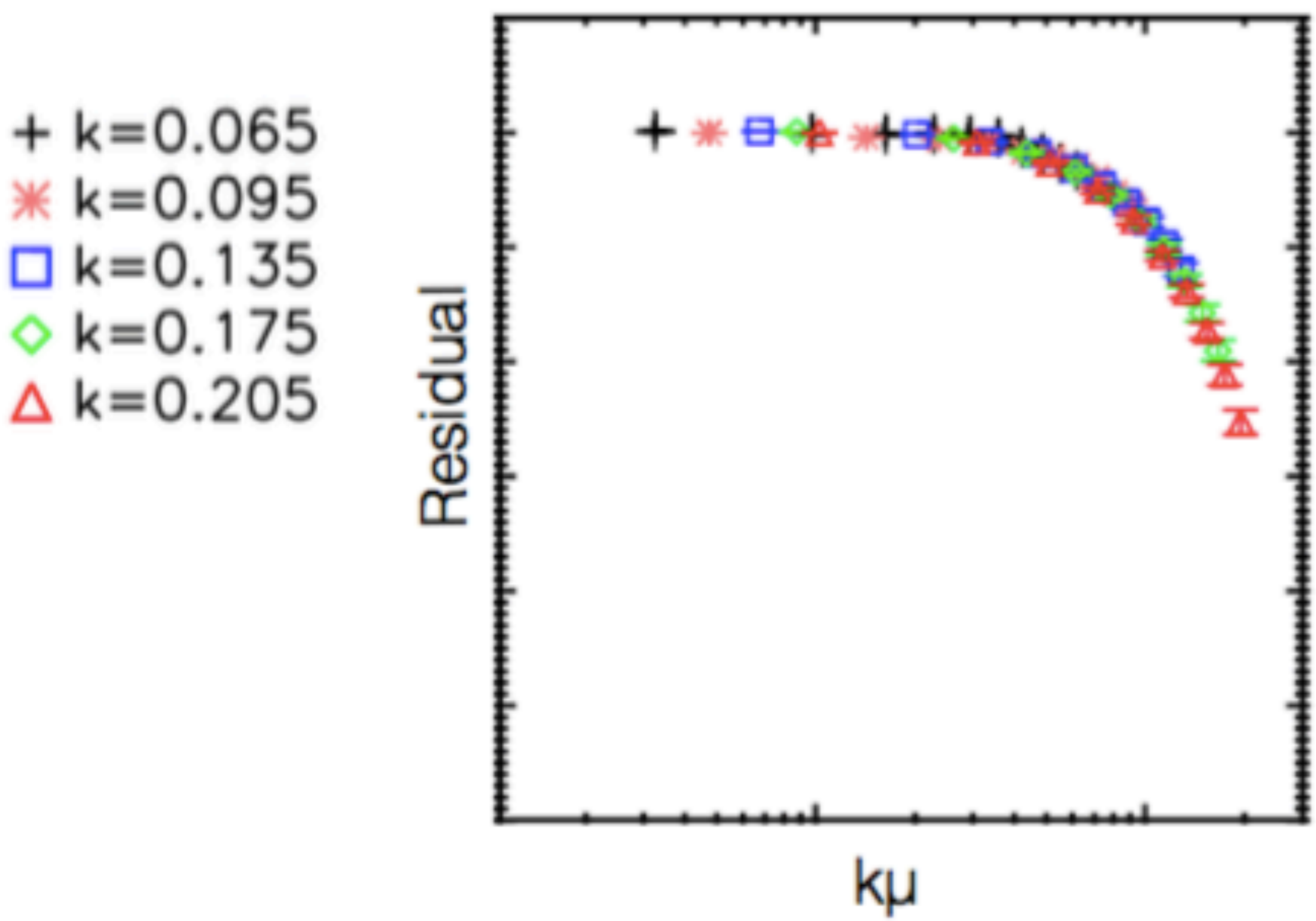
$$D_{1pt}(k\mu\sigma_p) = P_s / \int d^3x\, e^{ikx}[P_{\delta\delta}(k) + 2\mu^2 P_{\delta\Theta}(k) + \mu^4 P_{\Theta\Theta}(k) + A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)]$$

- If the truncation of correlated parts of perturbations is complete, then the measured residual would not show the explicit k dependence, but it will depend on kμ

Verification of hybrid mapping formulation

$$D_{1pt} = P_s(k,\mu)/[P_{\delta\delta}(k) + 2\mu^2 P_{\delta\Theta}(k) + \mu^4 P_{\Theta\Theta}(k) + A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)]$$

- The residual term which is the subtraction of the measured spectrum by the perturbed terms including halo density fluctuations is well fitting to Gaussian FoG function as well



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$D_{1pt} = P_s(k,\mu)/[P_{\delta\delta}(k) + 2\mu^2 P_{\delta\Theta}(k) + \mu^4 P_{\Theta\Theta}(k) + A(k,\mu) + B(k,\mu) + T(k,\mu) + F(k,\mu)]$

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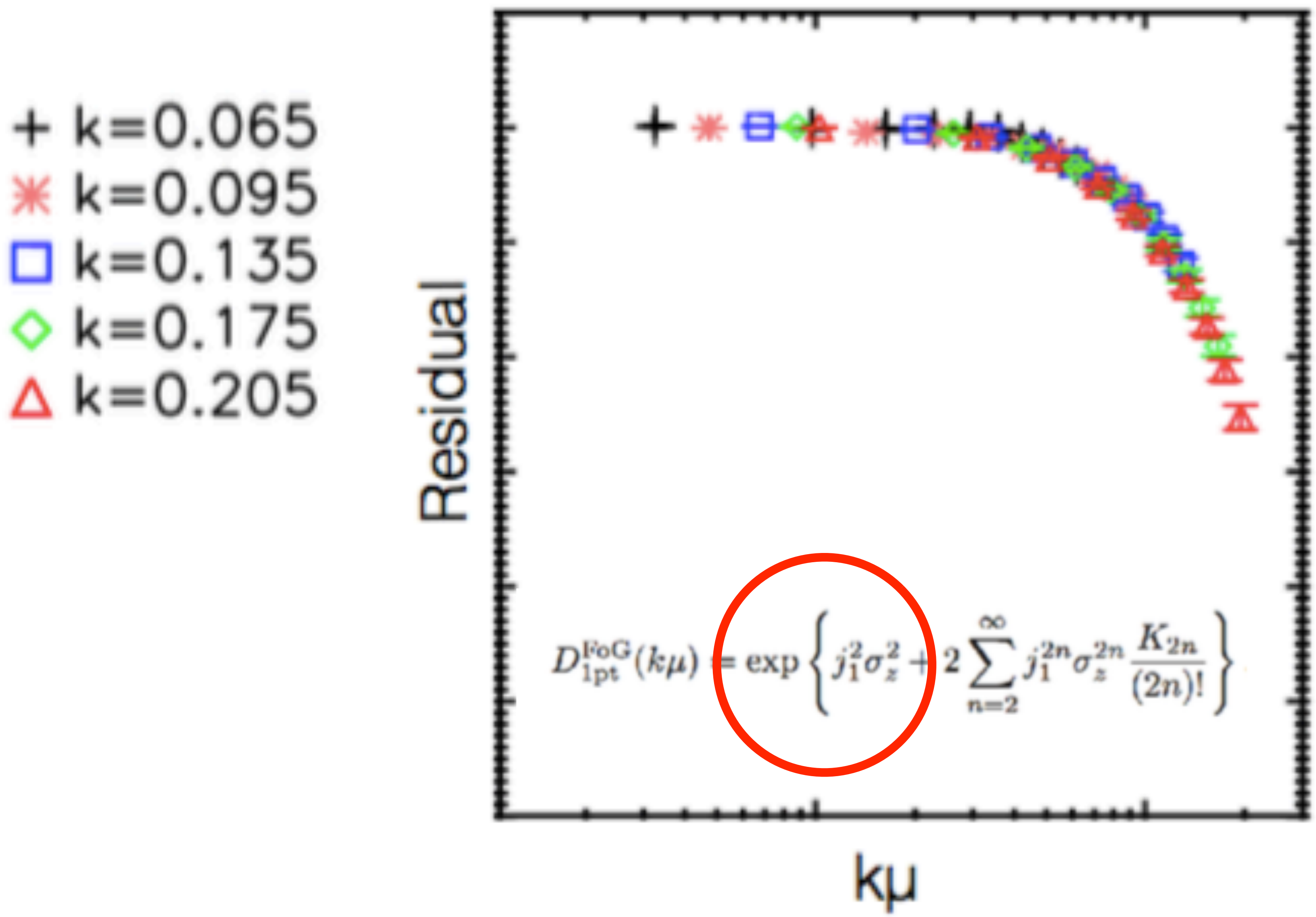

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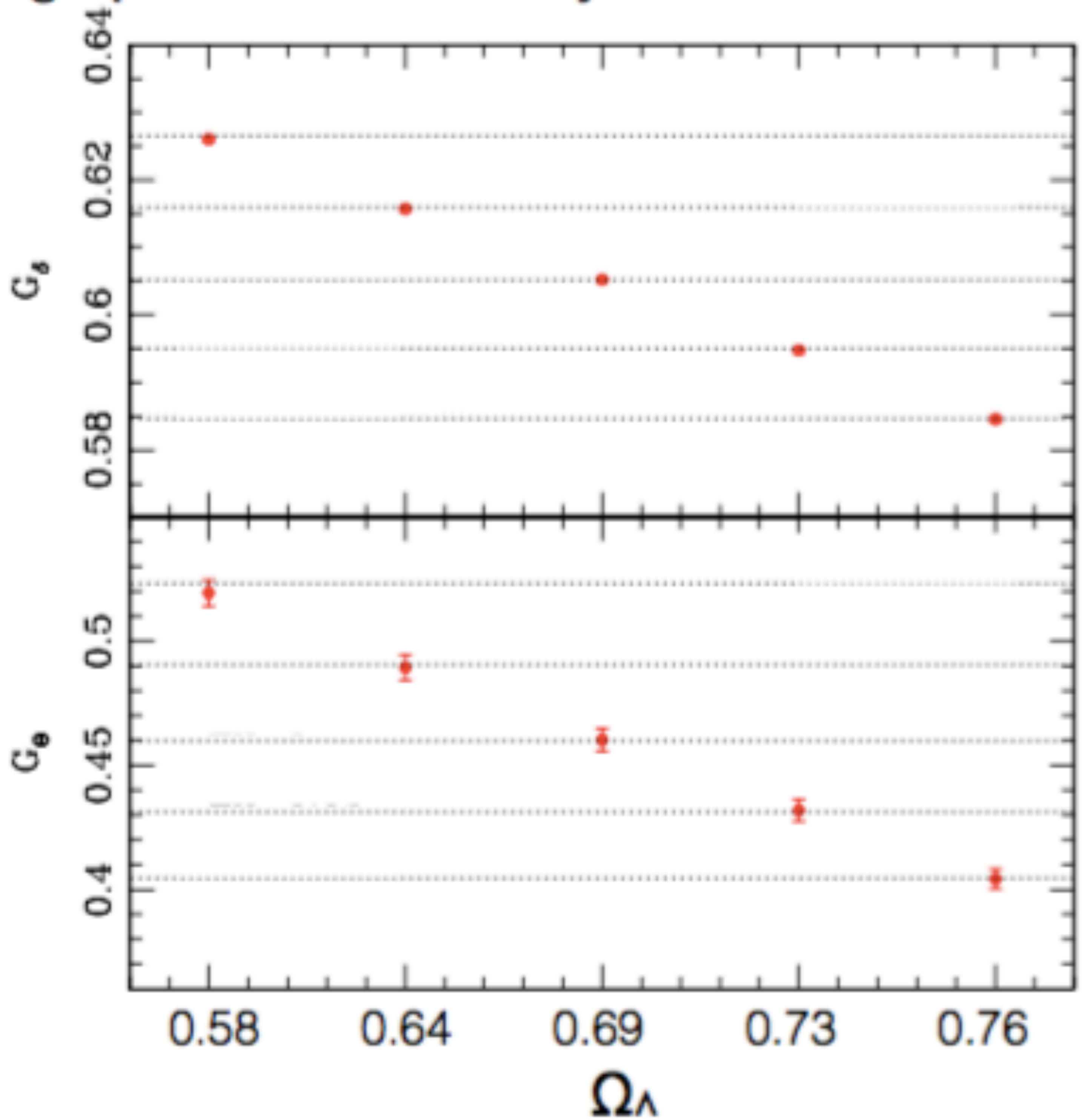
Verification of hybrid mapping formulation

We achieve the 1% accuracy measurement after a long journey through perturbation theory and simulation template



Yi Zheng, YSS 2016

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Emulator approach

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As theoretical model only description does not work even for particle distribution, we make an emulator approach for hybrid modeling of RSD. It is only dependent on the cosmological models not any clustering objects, which reduces the uncertainty.

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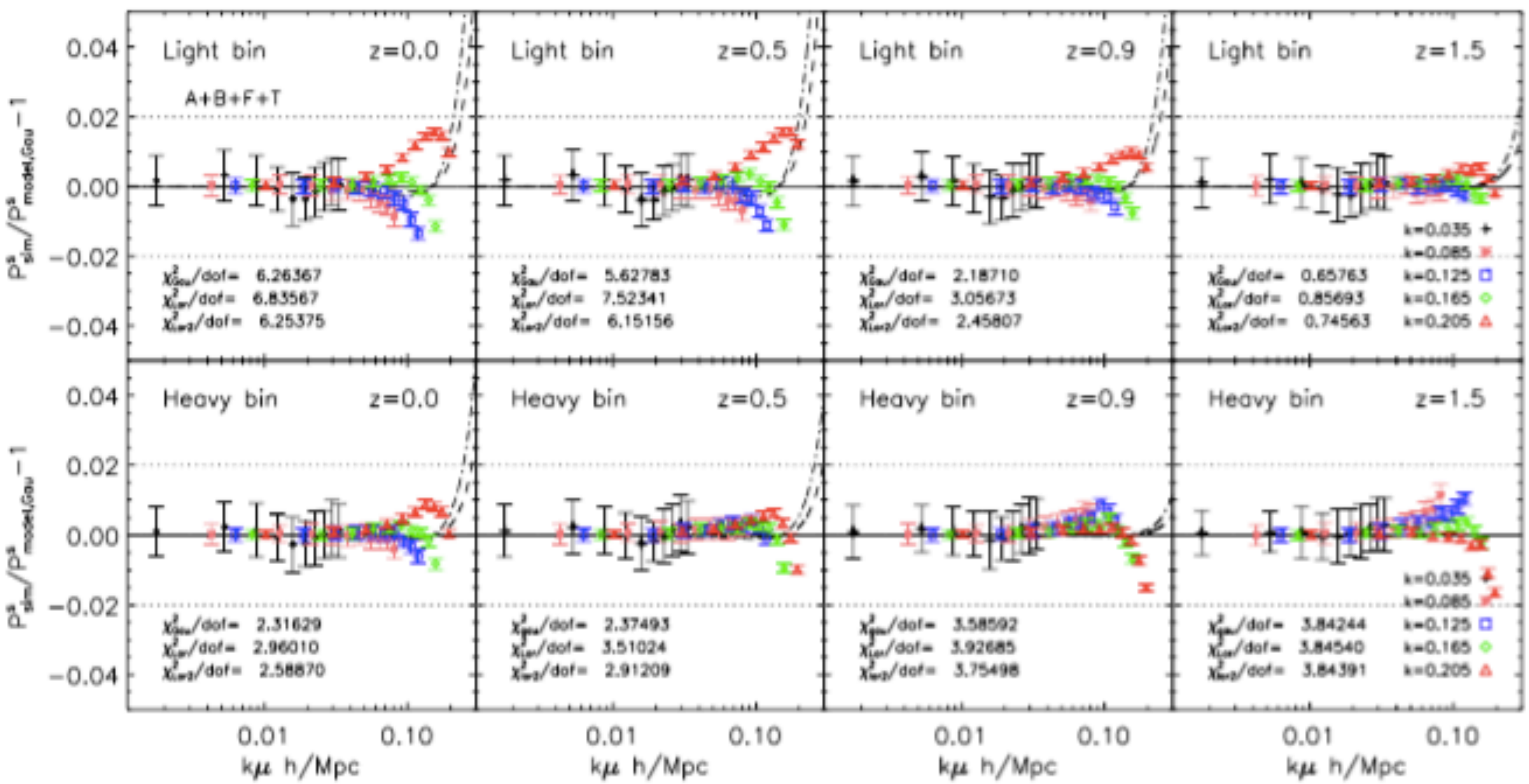
Test on halo RSD model

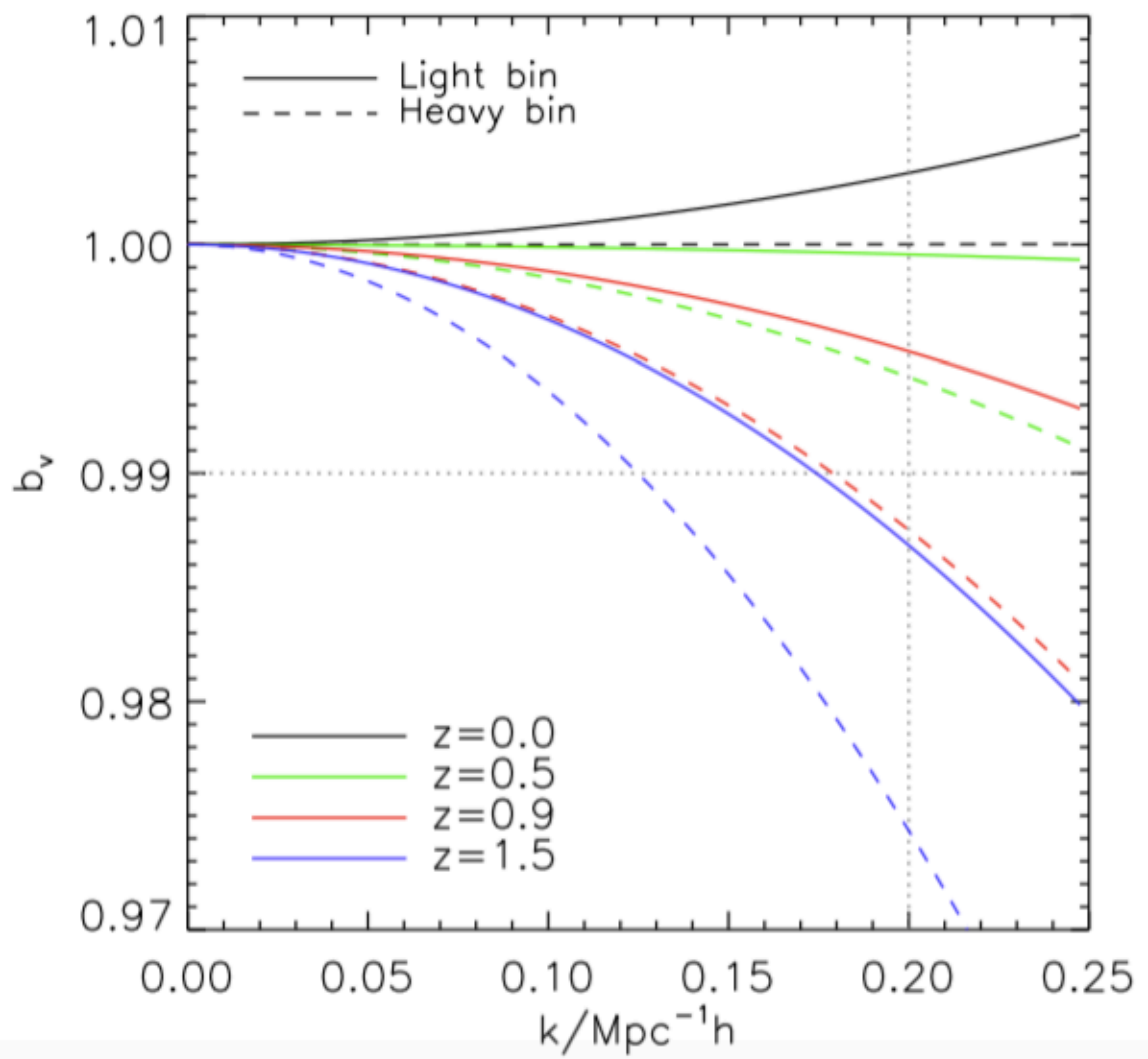
Before we apply for RSD modeling, we test the RSD modeling which is tested using dark matter is applicable for halo case;

$$
\begin{aligned}
P_h^{(\mathrm{S})}(k,\mu) &= D^{\mathrm{FoG}}(k\mu\sigma_{z,h})P_{\mathrm{perturbed},h}(k,\mu) \\
&= D^{\mathrm{FoG}}(k\mu\sigma_{z,h})[P_{\delta_h\delta_h} + 2\mu^2 P_{\delta_h\theta_h} + \mu^4 P_{\theta_h\theta_h} \\
&\qquad + A_h(k,\mu) + B_h(k,\mu) + F_h(k,\mu) + T_h(k,\mu)]\,.
\end{aligned}
$$



Velocity bias

To begin with, we investigate the halo/galaxy velocity bias. We learn that the level of biasing can be ignorable in the range of interesting scale here. It is known by the directly measured velocities of dark matter and halo.

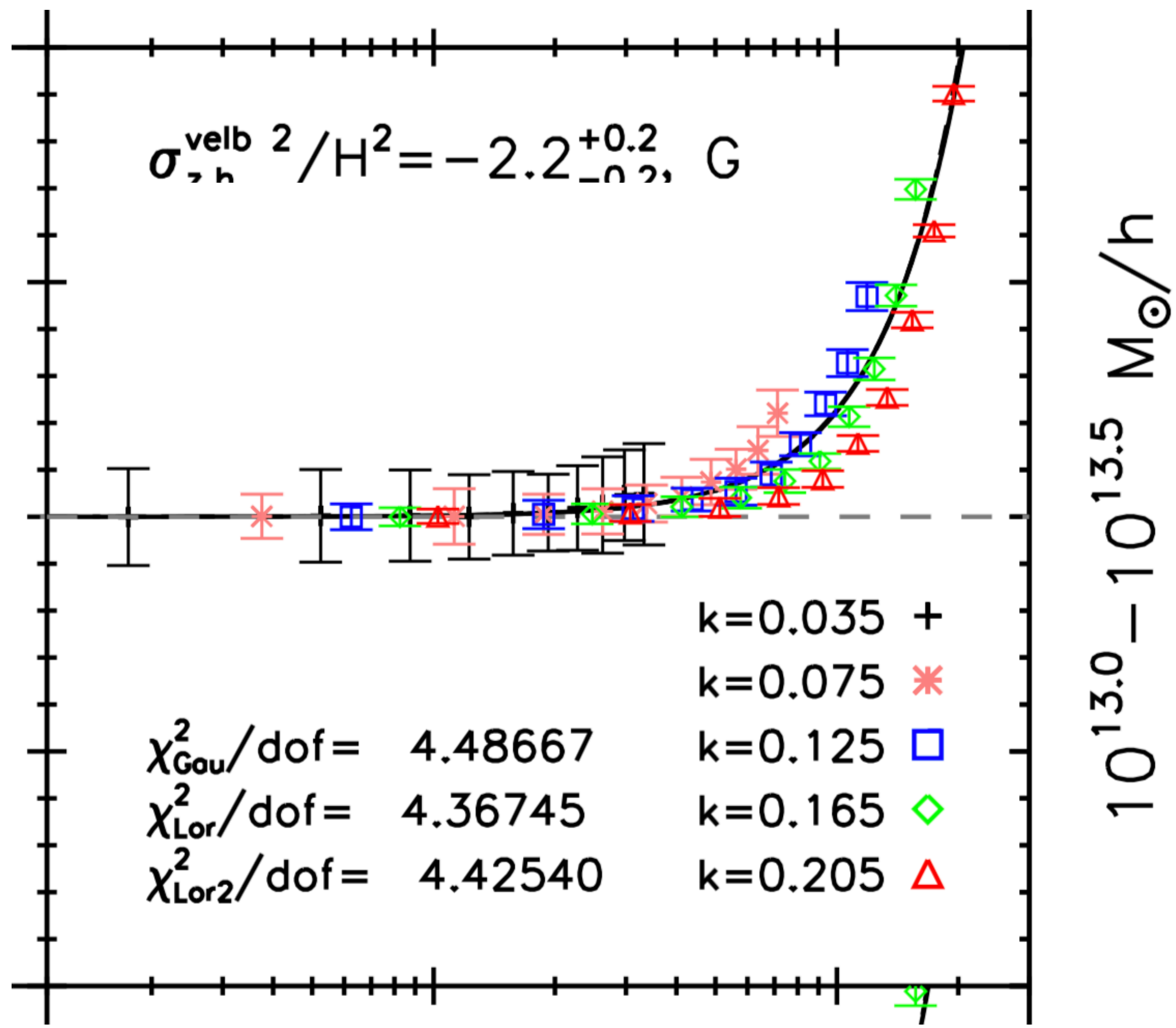


Velocity bias

But the effect of possible velocity bias on RSD formulation will be different story. We try to test the effect using the following comparison;

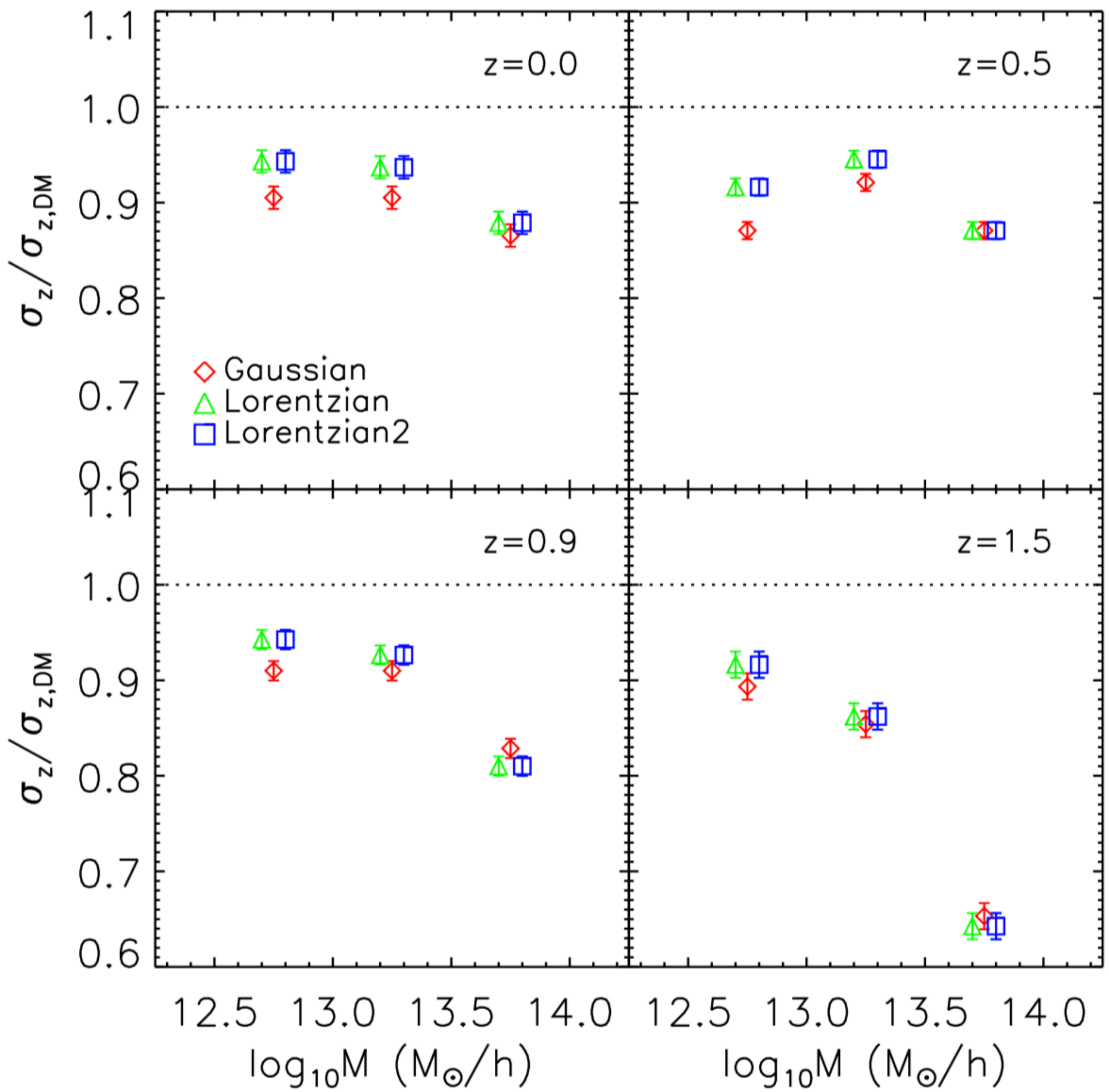
$$P^{(\mathrm{S})}_{h,v_{DM}}(k,\mu) \equiv \int d^3\boldsymbol{x}\, e^{i\boldsymbol{k}\cdot\boldsymbol{x}} \left\langle e^{j_1(u_z(\boldsymbol{r})-u_z(\boldsymbol{r}'))}(\delta_h(\boldsymbol{r}) + \nabla_z u_z(\boldsymbol{r}))(\delta_h(\boldsymbol{r}') + \nabla_z u_z(\boldsymbol{r}'))\right\rangle .$$

$$A_{b_v} \equiv \frac{P^{(\mathrm{S})}_{h}(k,\mu)}{P^{(\mathrm{S})}_{h,v_{DM}}(k,\mu)} ,$$



Velocity bias

The estimated effect of velocity bias on RSD formulation is bigger than the direct measurement, which is expected caused by ignoring the higher order FoG terms. However, the measured $f\sigma_8$ is insensitive to that much difference in FoG effect.

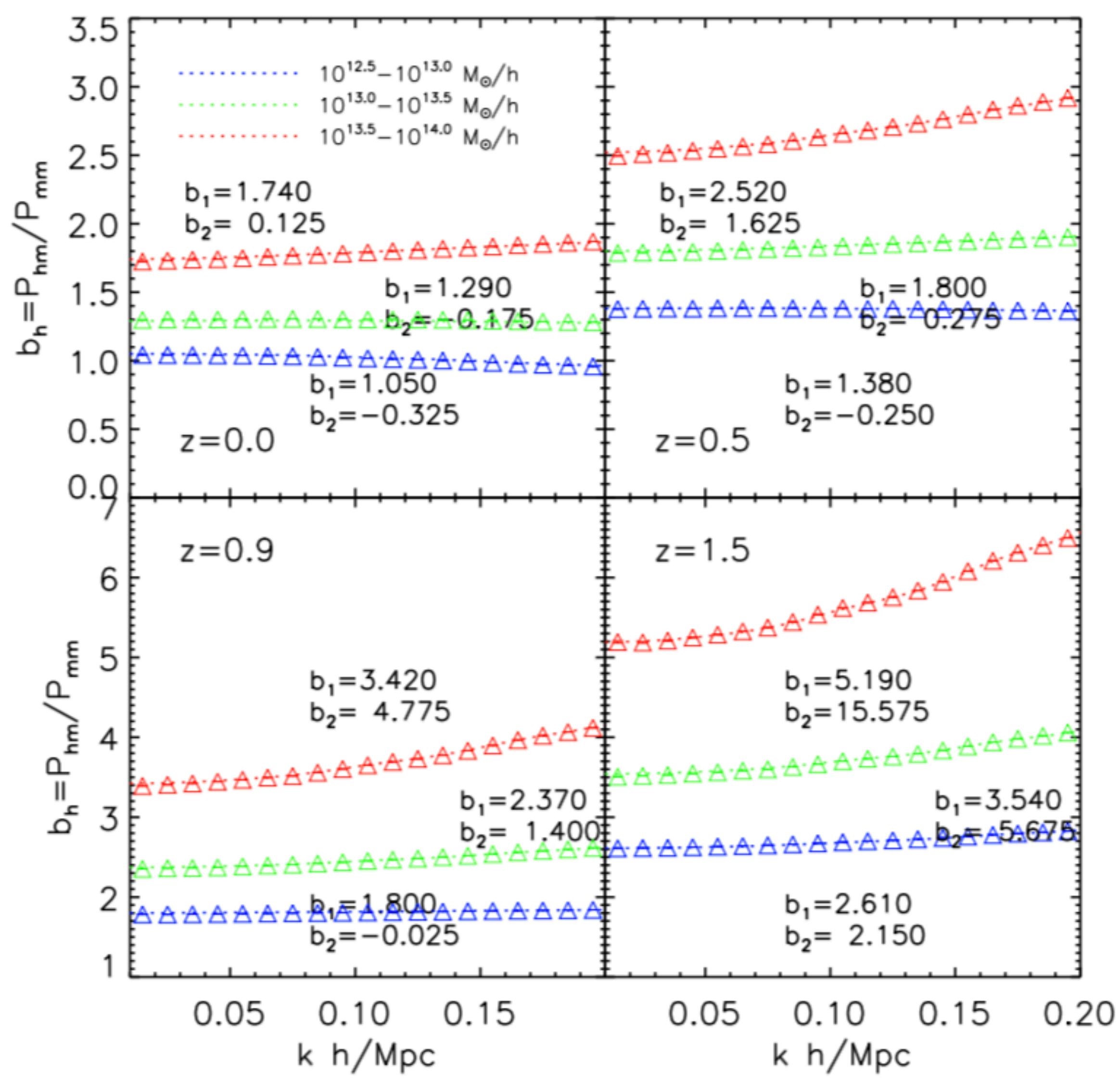


Galaxy bias for power spectrum

We test the galaxy bias model using the directly measured b(k) and the theoretical b(k)

$$b(k) = P_{\tilde{\delta}_h\delta}(k)/P_{\delta\delta}(k)\,.$$

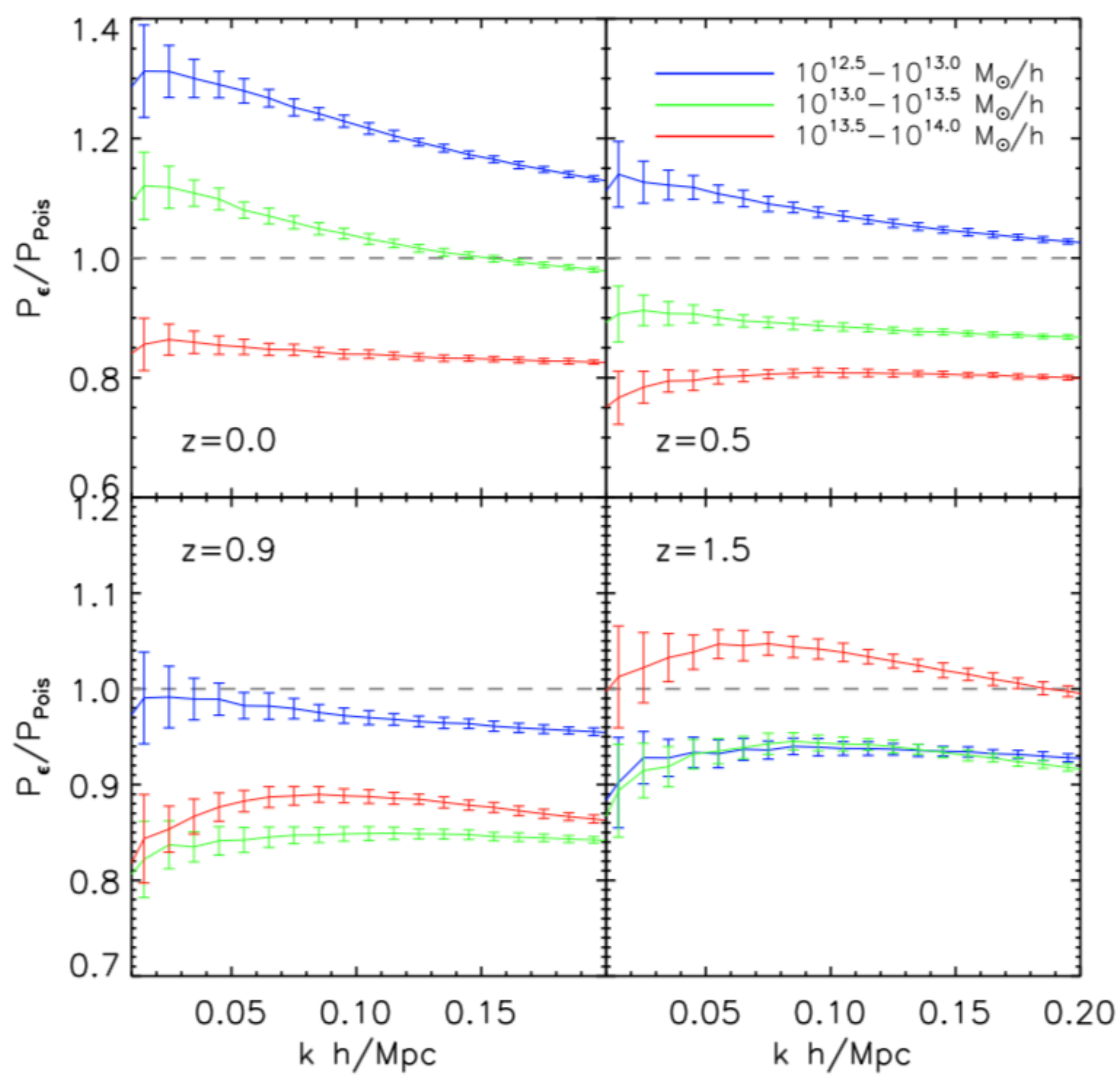
$$\delta_h(\boldsymbol{k}) = b_1\delta(\boldsymbol{k}) + \frac{1}{2}b_2\int\frac{d\boldsymbol{q}}{(2\pi)^3}\delta(\boldsymbol{q})\delta(\boldsymbol{k}-\boldsymbol{q}) + \frac{1}{2}b_{s2}\int\frac{d\boldsymbol{q}}{(2\pi)^3}\delta(\boldsymbol{q})\delta(\boldsymbol{k}-\boldsymbol{q})S_2(\boldsymbol{q},\boldsymbol{k}-\boldsymbol{q})$$



Galaxy bias for power spectrum

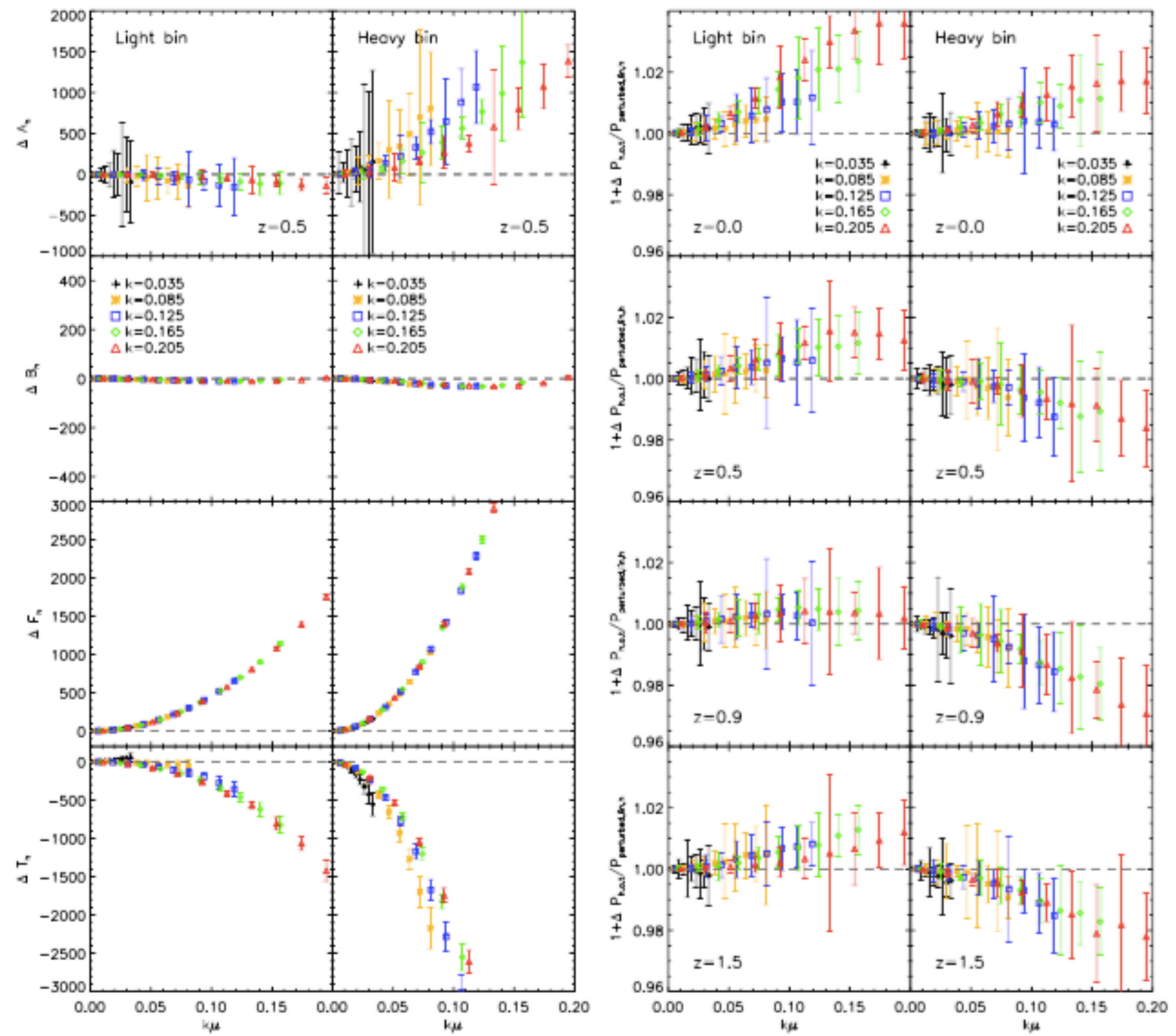
The calculated stochastic terms divided by the corresponding Poisson noise term. The error bars are standard errors of the measurements. The scale dependent sub- and super-Poissonian property of the halo density stochastic terms are clearly visible.

$$P_{\epsilon\epsilon} = P_{\tilde{\delta}_h\tilde{\delta}_h} - P_{\delta_h\delta_h} = P_{\tilde{\delta}_h\tilde{\delta}_h} - b^2(k)P_{\delta\delta}\,.$$



Galaxy bias for higher order polynomials

$$A_h(k,\mu) = b_1^3 A(k,\mu,f/b_1)\,,$$
$$B_h(k,\mu) = b_1^4 B(k,\mu,f/b_1)\,,$$
$$F_h(k,\mu) = b_1^4 F(k,\mu,f/b_1)\,,$$
$$T_h(k,\mu) = b_1^4 T(k,\mu,f/b_1)\,.$$



Effective FoG function

- While we are working on the detailed projection rule of galaxy bias, there is an alternative treatment to get over the discrepancy by apply the effective FoG function.

$$
\begin{aligned}
P_h^{(\mathrm{S})}(k,\mu) &= D^{\mathrm{FoG}}(k\mu\sigma_{z,h})P_{\mathrm{perturbed},h}(k,\mu) \\
&= D^{\mathrm{FoG}}(k\mu\sigma_{z,h})\left(P_{\mathrm{perturbed,lin},h}(k,\mu)+\Delta P_{\mathrm{h.o.t}}\right) \\
&= D^{\mathrm{FoG}}(k\mu\sigma_{z,h})P_{\mathrm{perturbed,lin},h}(k,\mu)\left(1+\frac{\Delta P_{\mathrm{h.o.t}}}{P_{\mathrm{perturbed,lin},h}}\right) \\
&= D^{\mathrm{FoG}}(k\mu\sigma_{z,h}^{\mathrm{eff}})P_{\mathrm{perturbed,lin},h}(k,\mu)\,,
\end{aligned}
$$

Effective FoG function

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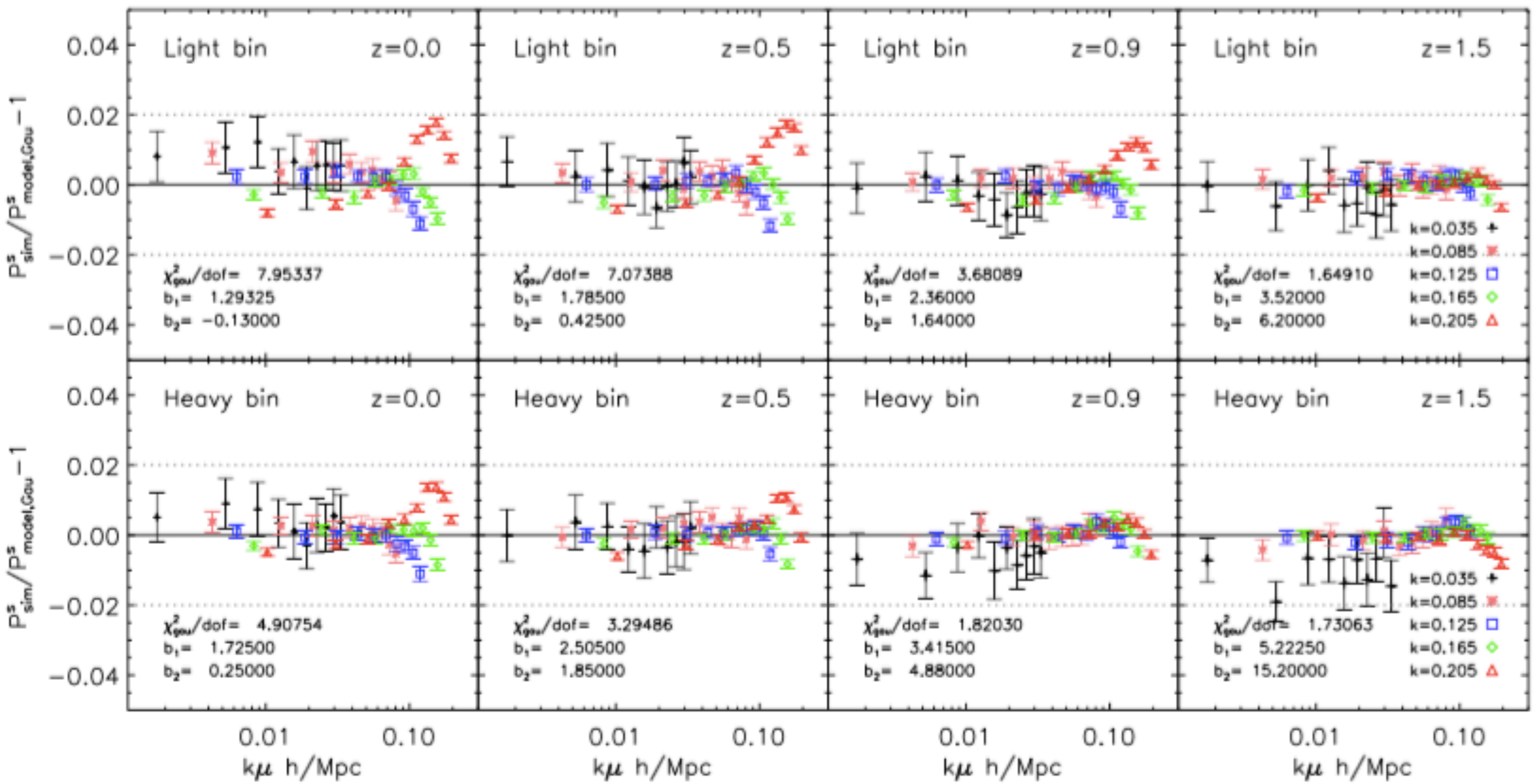


Emulator approach - can we parameterize all biases?

- Perturbative description of LSS in real space
  - Consistency between the observational limit and breakdown of perturbative expression
  - Cosmological independence of renormalized parameter or EFT nuisance parameters
- Understanding mapping from real to redshift spaces
  - Non-regularizable expansion of cross-correlation between velocity and density fluctuation
  - Theoretical description of non-linear random velocity effect is not known

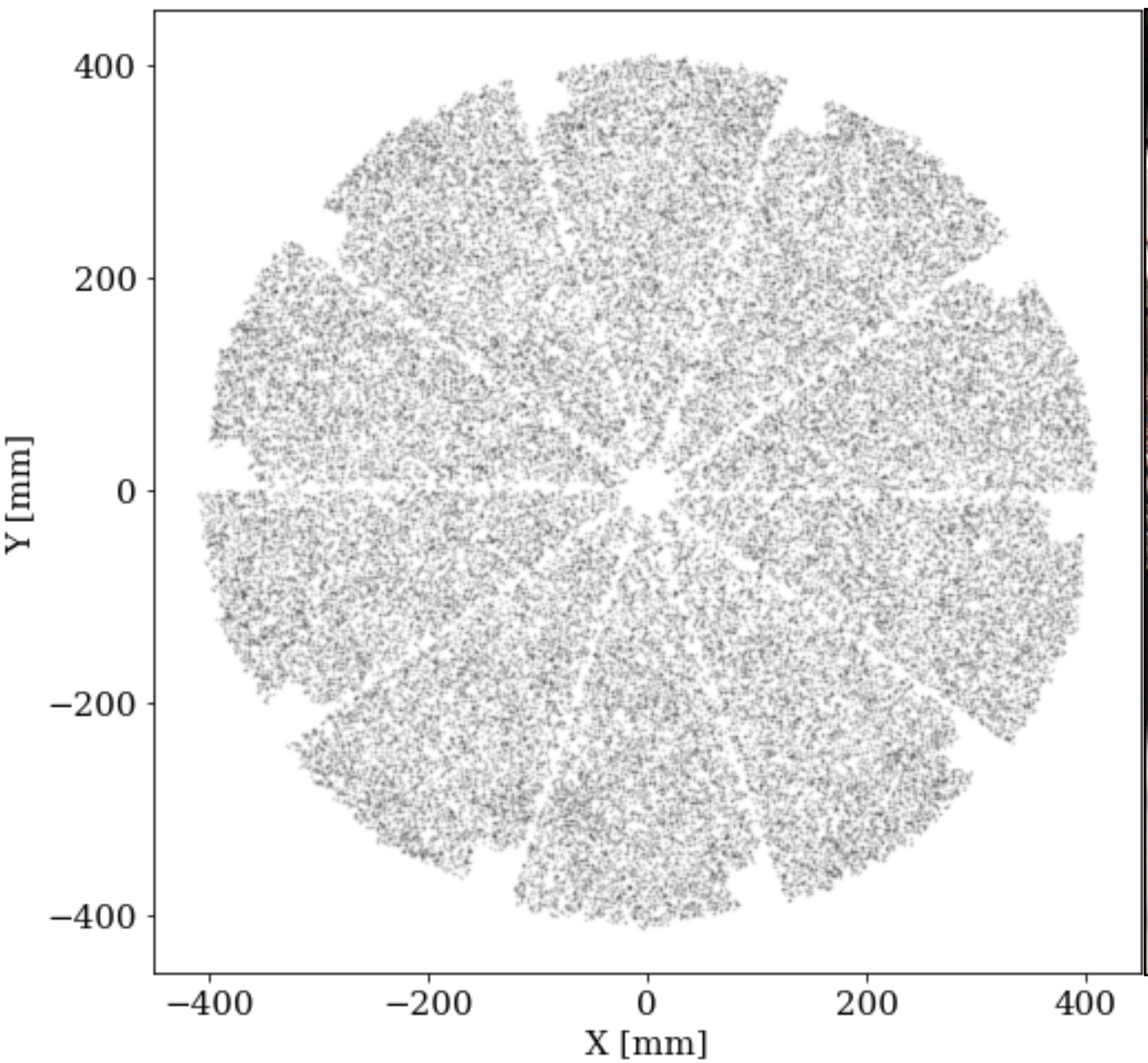
As theoretical model only description does not work even for particle distribution, we make an emulator approach for hybrid modeling of RSD. It is only dependent on the cosmological models not any clustering objects, which reduces the uncertainty.

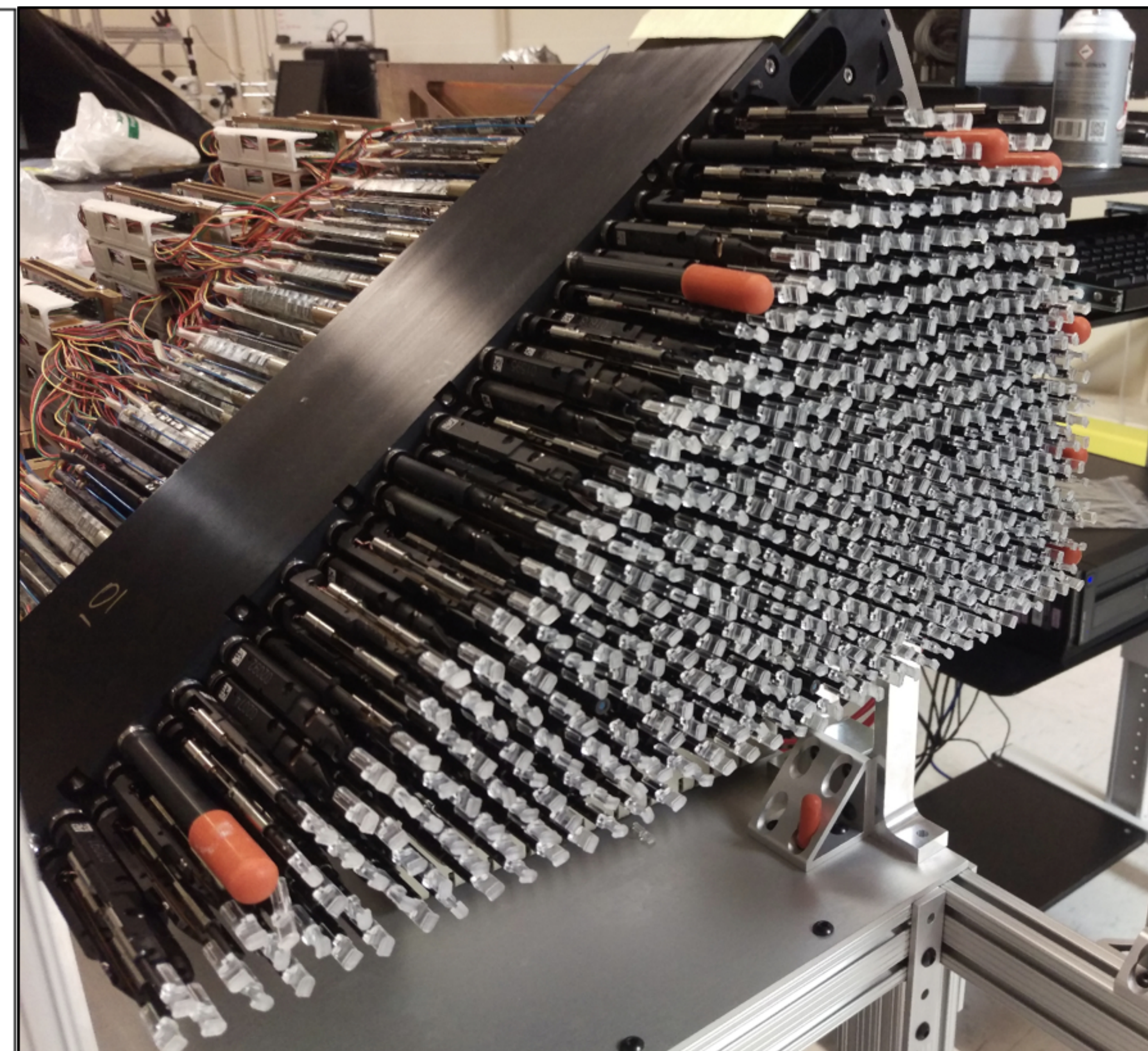
Challenges

- Perturbative description of LSS in real space
  - Consistency between the observational limit and breakdown of perturbative expression
  - Cosmological independence of renormalized parameter or EFT nuisance parameters
- Understanding mapping from real to redshift spaces
  - Non-regularizable expansion of cross-correlation between velocity and density fluctuation
  - Theoretical description of non-linear random velocity effect is not known
- Non-trivial galaxy bias even at target scale in a percentage precision level
  - The theoretical description on local and non-local biases are available for detailed test
  - Request for the verification to isolate the galaxy bias test from perturbative modeling
- Systematic uncertainty caused by experimental environment
  - Concern on the correlation along the line of sight to be contaminated by fibre collision
  - Priority issue for the selection of LRG, ELG and QSO in appropriate order
- Geometrical effect on the uncertainty

Systematic uncertainty

DESI adapted the petal style spectroscopy instrument design in which eight fibre bundle petals complete one exposure. It caused the edge effect at boundaries, and demands the five visit scanning strategy to smooth out the distribution of targets. However, there will be a difficulty in collecting ELG samples.





Challenges

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