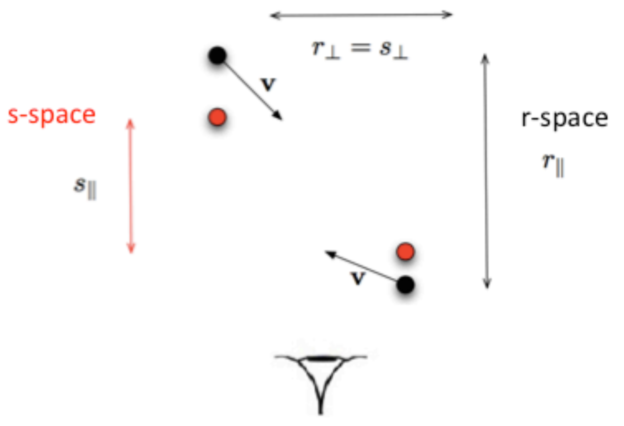
# Modeling QSO infall velocity distribution using N-body simulations for eBOSS RSD analysis


**Zarrouk Pauline[1], Burtin Etienne[1]**

[1] CEA-Saclay, F-91191 Gif-sur-Yvette Cedex, France


## Redshift space distortions

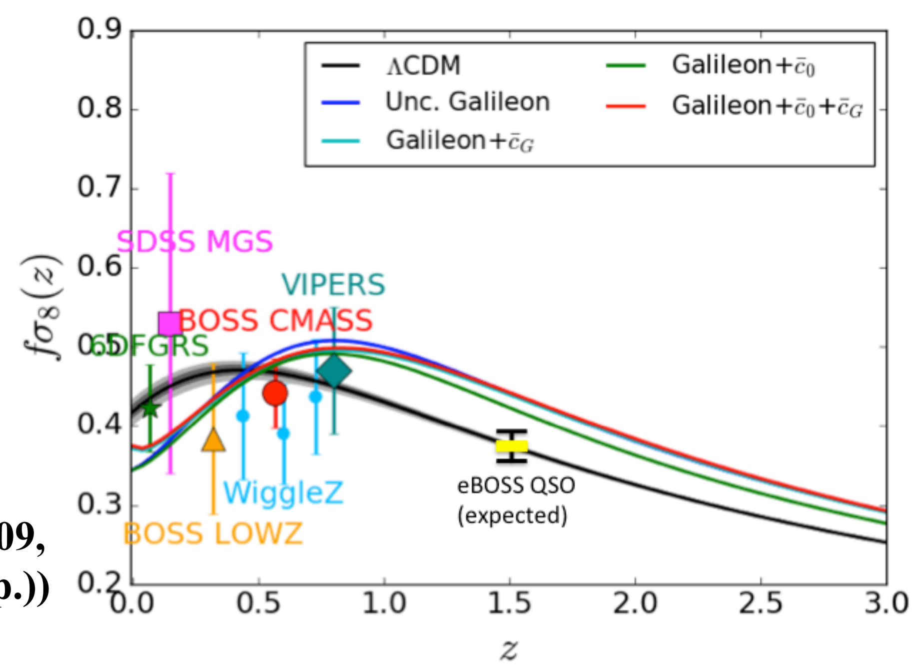
Galaxy redshift surveys like SDSS-IV eBOSS provide a three-dimensional view of the large-scale structure of the universe.
If the Universe were statistically isotropic and homogeneous on large scale, these redshifts would accurately measure radial distances from the observer, so that the mapping between real space (r-space) to redshift space (s-space) would be an identity.
It instead exhibits an anisotropy with respect to the line-of-sight (LOS) direction because galaxies recession velocities both include components from the Hubble flow and peculiar velocities.




Because of gravitational growth, galaxies tend to fall towards high-density regions and flow away from low-density regions, such that in redshift-space the clustering is enhanced in the LOS direction.

### Test of general relativity using RSD

The shape of the correlation function in redshift space can be used to constrain cosmological parameters such as the growth rate of structures f defined by: f(z) = d lnD(z) / d ln(z)
In the ΛCDM model, general relativity predicts $f(z) = \Omega_m(z)^\gamma$ with γ=0.55
Measurements can thus be compared with predictions from general relativity and modified gravity models like the Galileon (Nicolis et al. 2009, Appleby & Linder, 2012 and Neveu et al. (in prep.))



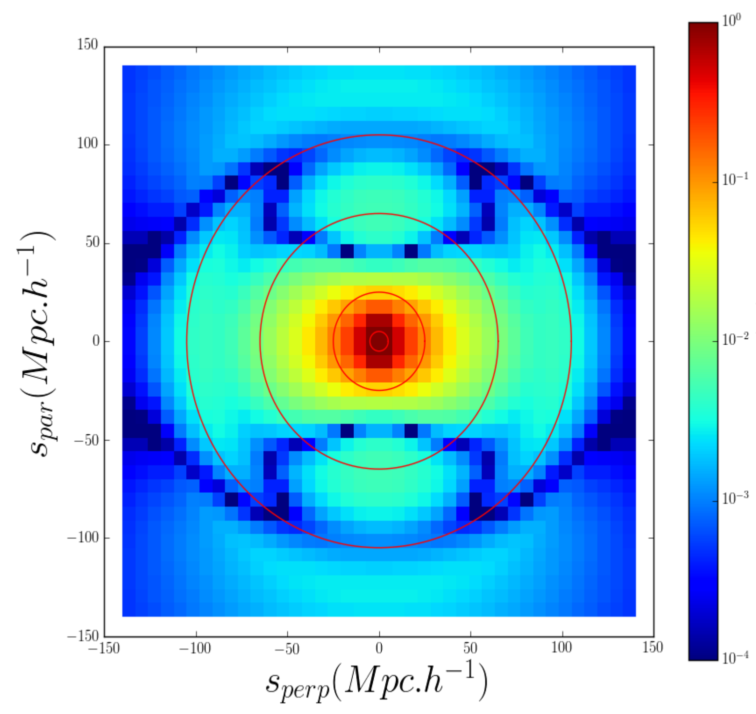

### From real-to-redshift space: Gaussian Streaming model

$$1+\xi_g(s_\parallel, s_\perp) = \int dr_\parallel \, [1+\xi_g(r)] P(s_\parallel - r_\parallel, v_{12}, \sigma_{12}^2)$$

This type of relation between the real and the redshift space correlation functions is known as the streaming model (Fisher, 1995) where P is assumed to be a Gaussian centered on $\mu v_{12}$ where μ is the cosine of the LOS angle.

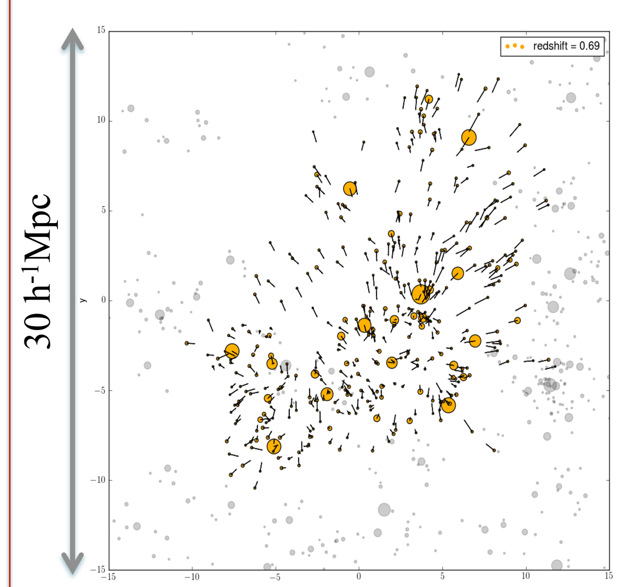
### Convolution Lagrangian Perturbation Theory (CLPT)

Wang, Reid and White (2013) extended the work of Matsubara (2008a) and Carlson et al. (2012) to enable the calculation of moments of the pairwise velocity distribution for tracers that are biased in a local Lagrangian formalism. These are the key ingredients of the Gaussian streaming model to calculate the two-point correlation function in redshift-space and then the multipoles.




## CLPT validity for velocity and clustering statistics for eBOSS QSO at z=1.55

### CLPT validity using BigMDPL simulation

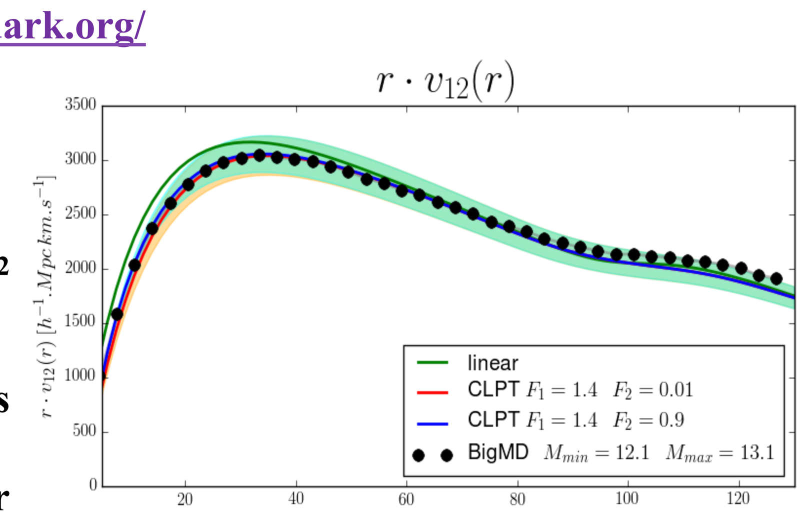


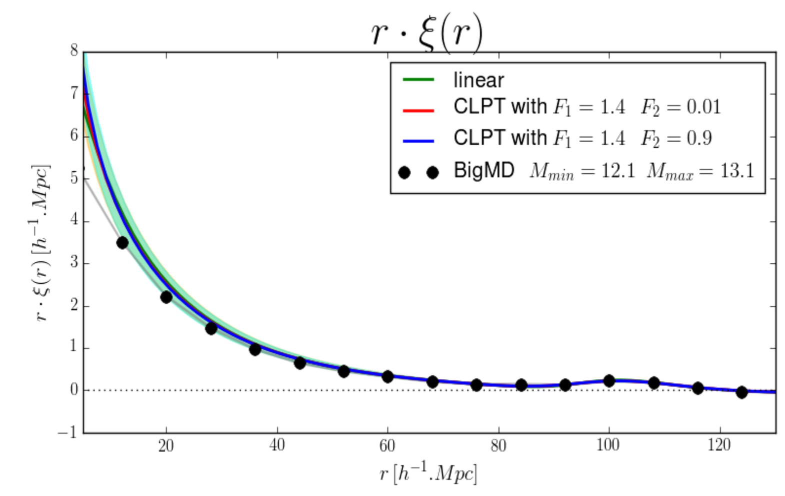

The BigMDPL is one of the MultiDark[1] *N*-body simulation described in Klypin et al. (2014). The BigMDPL was performed with GADGET-2 code (Springel 2005). This simulation was created in a box of 2.5 $h^{-1}$ Gpc on a side, with 38403 dark matter particles. The mass resolution is $2.4 \times 10^{10}\ h^{-1}\ M_\odot$. The initial conditions, based on initial Gaussian fluctuations, for the simulation are generated with Zel'dovich approximation at $z_i$=100.

[1] http://www.multidark.org/

### Infall velocity and real-space clustering

The public CLPT code[2] gives predictions for $v_{12}$, $\sigma_{12}$ and ξ(r) according to the formula:
$A = A_0 + F_1 A_{10} + F_2 A_{01} + F_1^2 A_{20} + F_1 F_2 A_{11} + F_2^2 A_{02}$
where $F_1$ and $F_2$ are the two first Lagrangian bias parameters introduced by Matsubara (2008a).
$F_1$ and $F_2$ are fitted on the BigMDPL simulation for halos in the mass range log (M / $h^{-1}$ $M_\odot$) in [12.1-13.1].



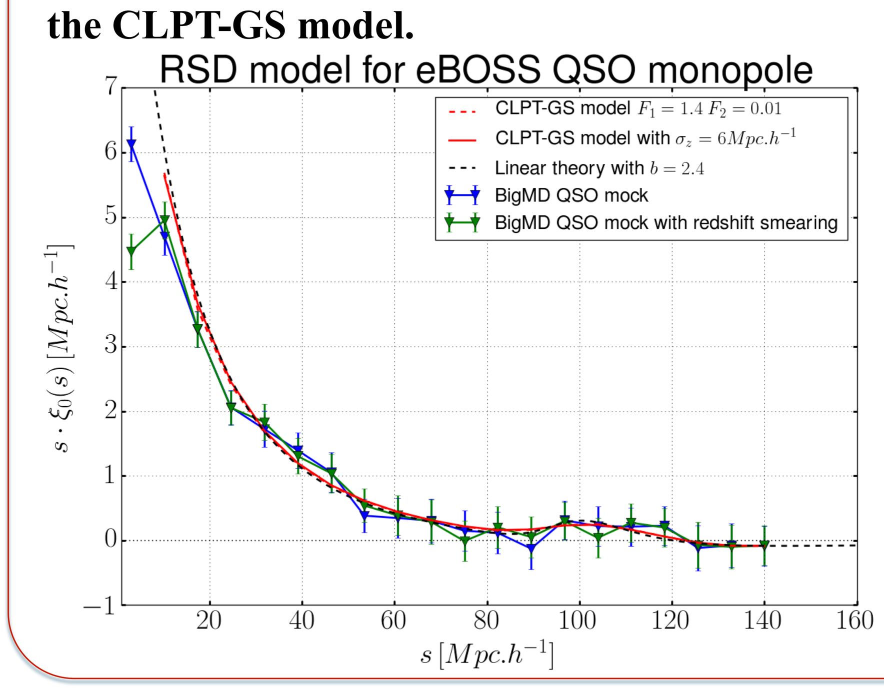



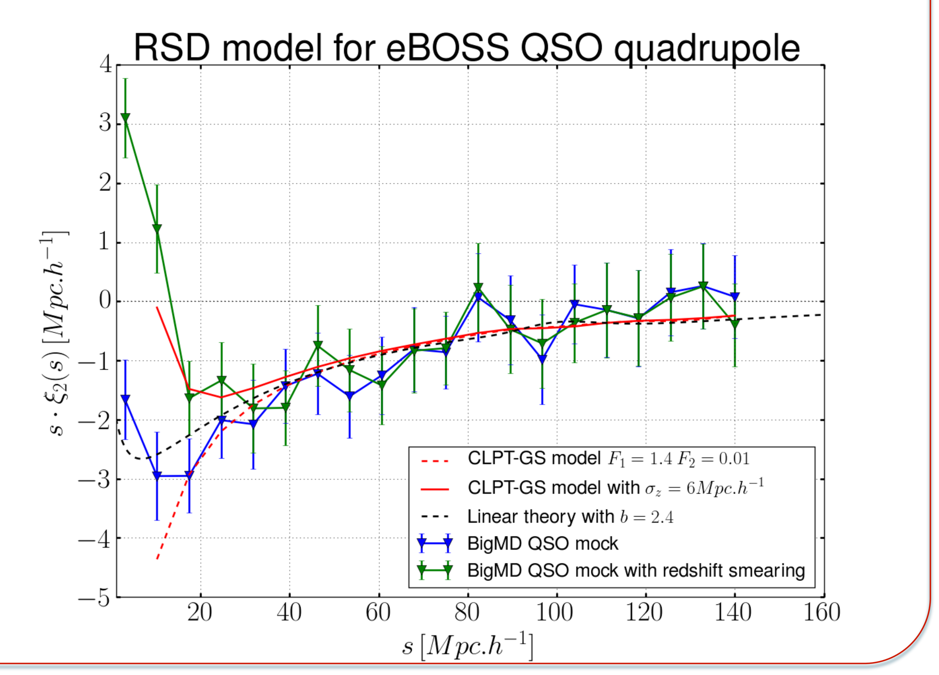

CLPT predictions for clustering and velocity statistics are then injected into a GS model to obtain the monopole and quadrupole of the 2-point correlation function (CLPT-GS model)

[2] https://github.com/wll745881210/CLPT GSRSD.git

### Monopole and quadrupole

CLPT-GS model predictions are compared to the BigMD lightcone mock based on the method developed by Rodriguez-Torres et al. (2015) that they are adapting for quasars to match the eBOSS sample. Redshift can be smeared according to the expected eBOSS resolution so that one can investigate redshift errors that affect data on small scales and which can also be included in the CLPT-GS model.



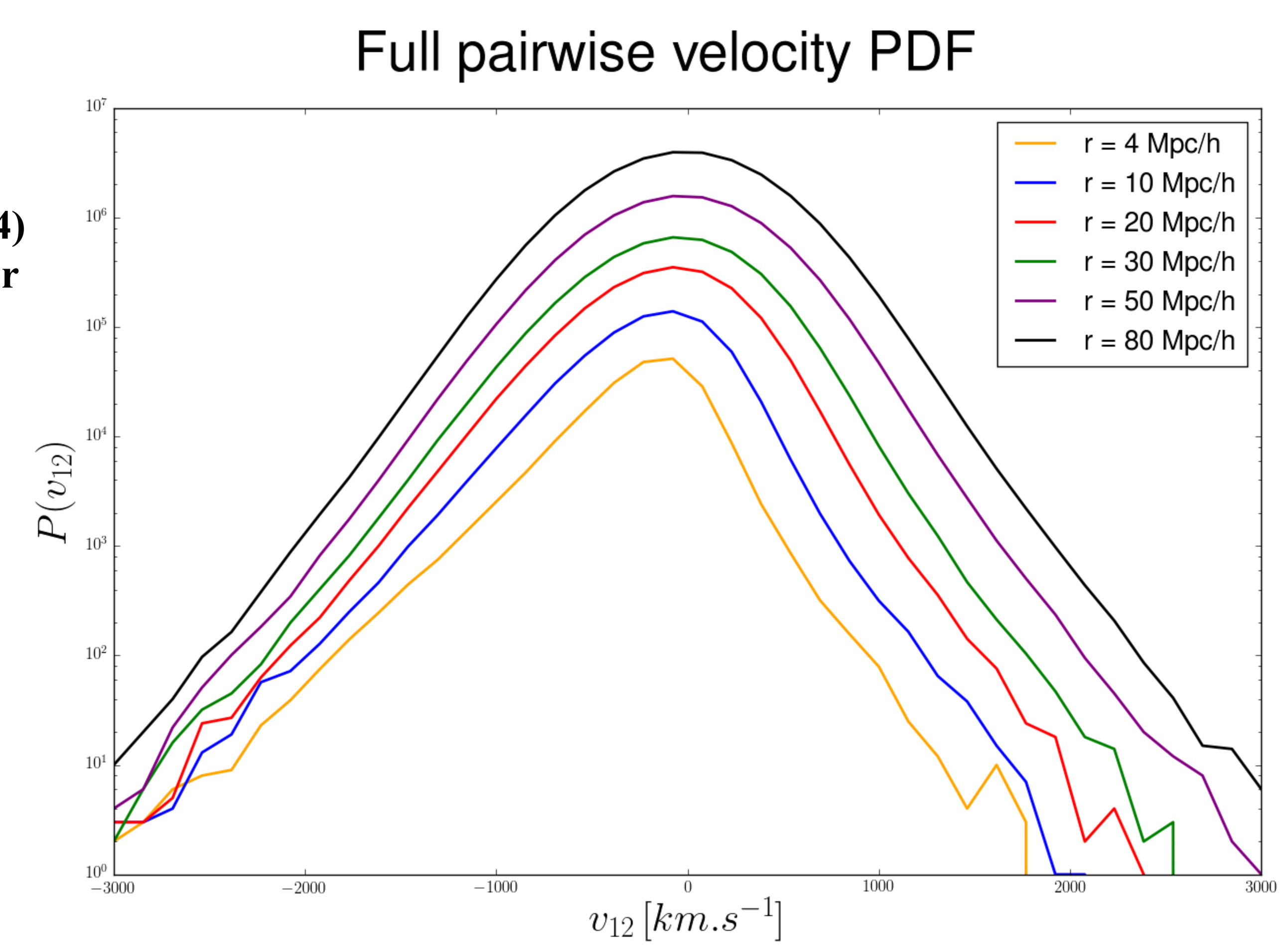




## Parametrization of the full pairwise velocity PDF using N-body simulations

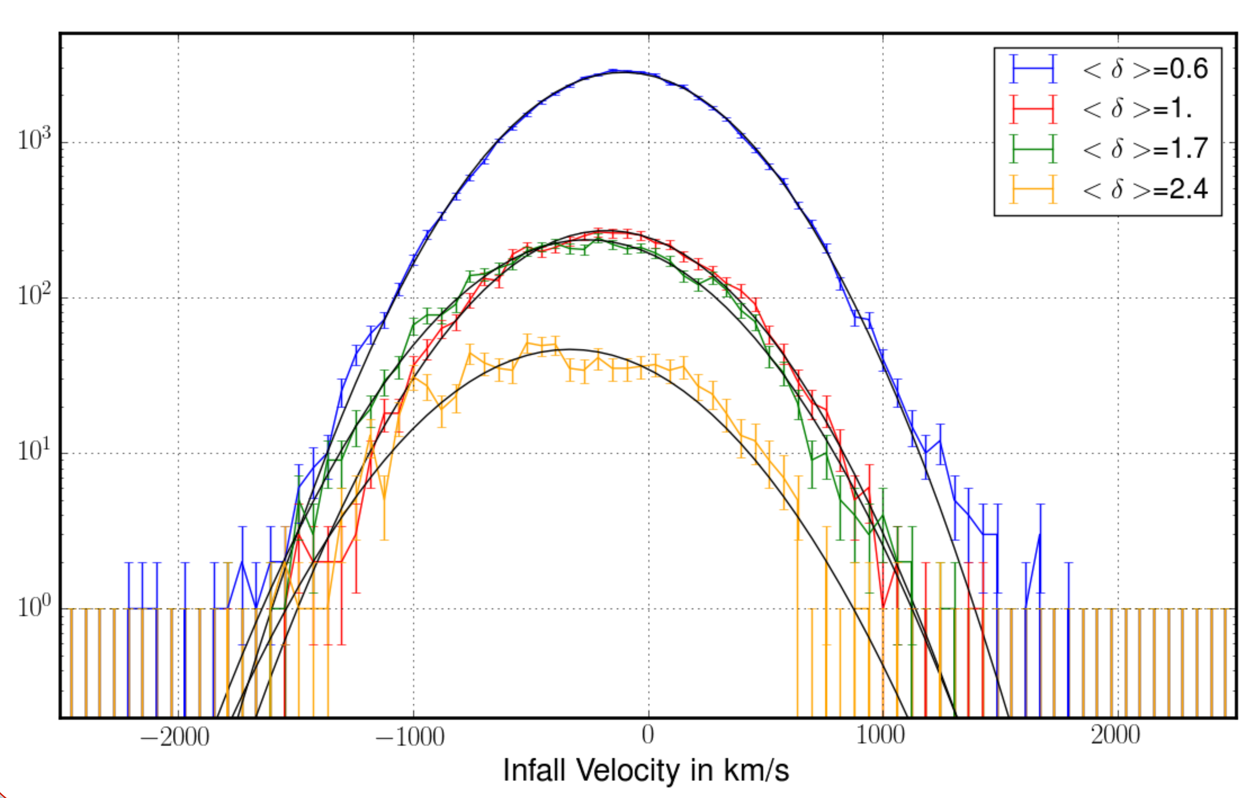
Properly describing the full pairwise velocity PDF s is clearly the central point in the description of RSD through the streaming model. Thanks to the development of N-body simulations, the behavior of the pairwise velocity distribution can be better understood and hence can be properly modeled. Ultimately, it could give access to the small scales of the correlation function where the effect of RSD is the largest and therefore put stronger constraints on modified gravity models.

### Physical meaning of the pairwise velocity PDF

The full pairwise velocity PDF of halo pairs is calculated at different scales using the BigMDPL simulation. As Scoccimarro (2004) showed, it is strongly non-Gaussian at all scales. The region where $v_{12} < 0$ corresponds to galaxies of pairs approaching each other as they fall towards and tend to be located in over-dense regions whereas galaxies of pairs flowing away from each other as they empty under-dense regions have a positive $v_{12}$ .
The presence of skewness and exponential tails at all scales clearly show that the Gaussian assumption made in the streaming model according to which P only depends on its first two moments is not satisfactory.
One way of improving RSD models would be to use the N-body simulations to find the relevant quantities to be injected in the description of the pairwise PDF such as local environment parameters.




### Impact of local environment: recovery of gaussianity




The pairwise velocity PDF of halo pairs is a complex function with skewness and kurtosis that vary substantially with scale. Using a series of collisionless N-body simulations, Tinker (2007) demonstrated that the shape of the velocity PDF is determined primarily by the distribution of local densities around a halo pair, and at fixed density the velocity DF is close to Gaussian and nearly independent of halo mass.
Following his approach, we used the MDPL2 simulation[2] to calculate the overdensity δ inside spheres of radius equal to the separation of the halo pairs. As δ increases, both the mean infall velocity and dispersion increase. At a fixed δ, the local velocity PDF does not show strong skewness and kurtosis, so that we can model it using a Gaussian approximation.