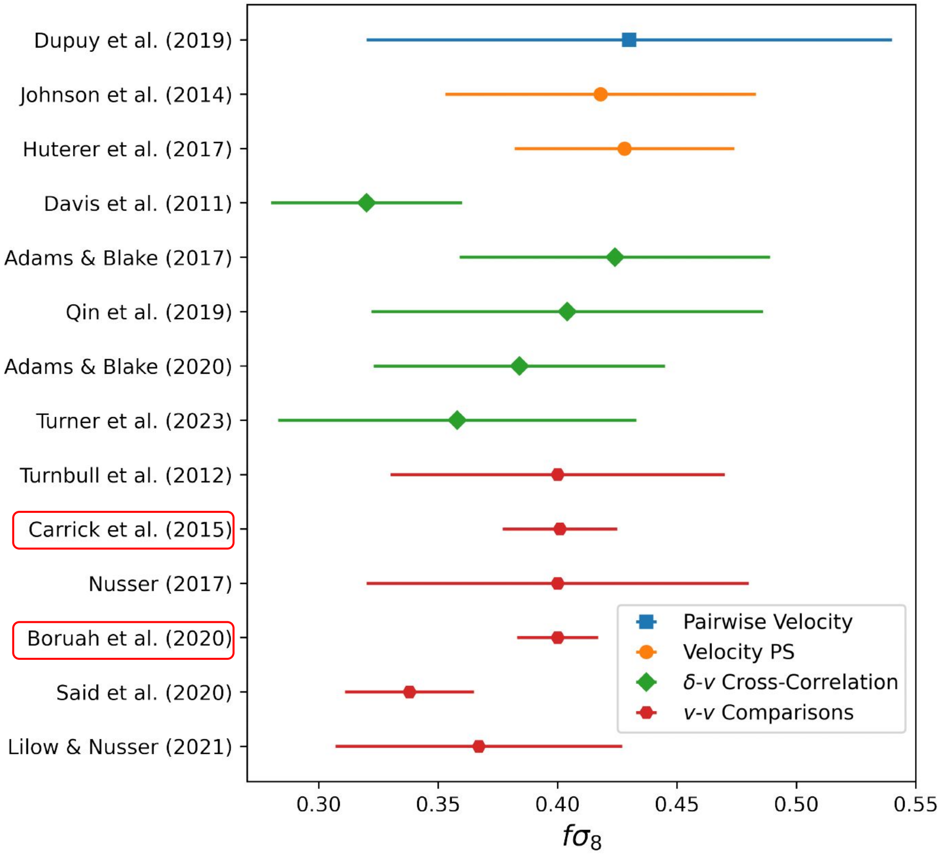
# Density-velocity method for $f\sigma_8$

Pauline Zarrouk (CNRS/LPNHE & Sorbonne Université)

1. Methodology
2. Density-velocity projects using ZTF DR2.5 SN Ia @LPNHE

# Methodology: literature and nomenclature



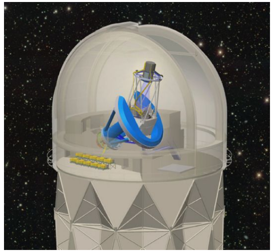

The following names correspond to the same method:

- density-velocity method/comparison
- velocity-velocity comparison
- reconstruction-and-scaling method

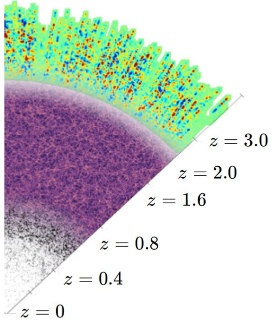
From A. Hollinger's PhD thesis (2023), see also figure 11 in Carreres et al. (2023)

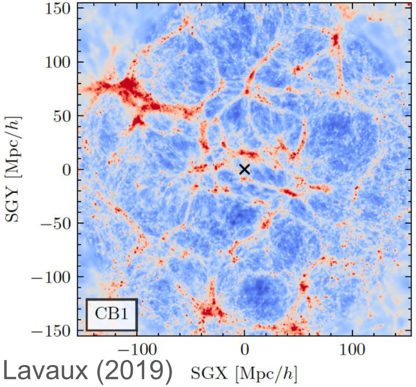
# Methodology: example of DESI x ZTF

Step 1: Build a model of the velocity field from the galaxy density field

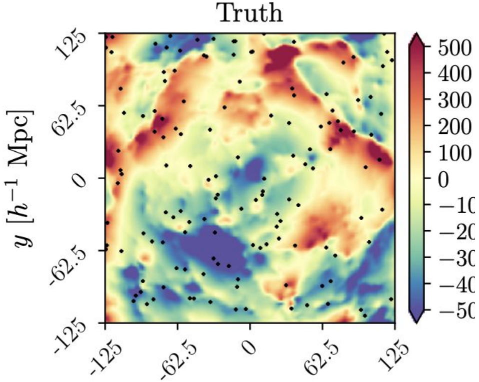


catalogue of galaxy redshifts




Jasche & Lavaux (2019)




Prideaux-Ghee et al. (2023)

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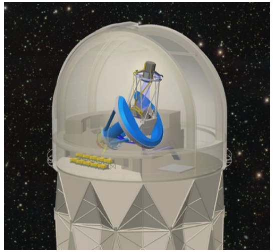

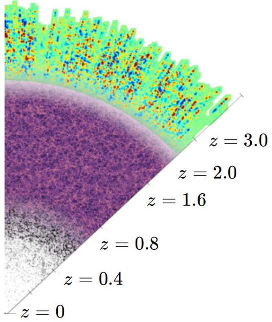


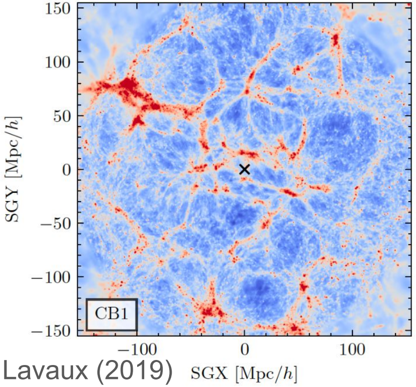


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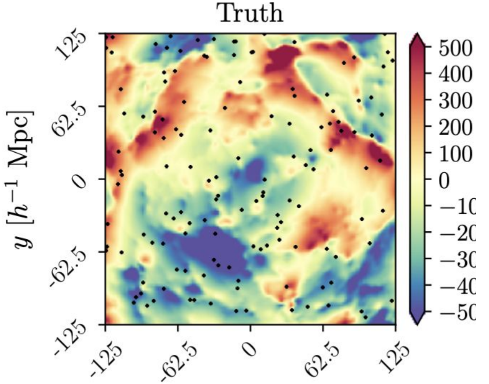
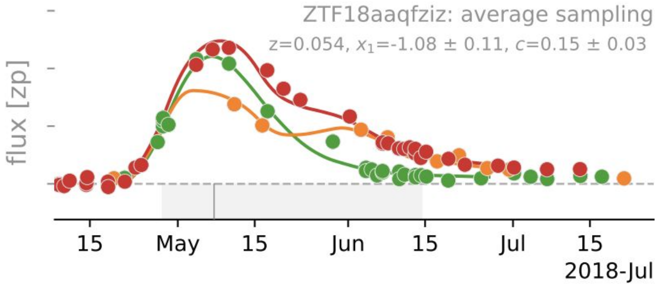



Prideaux-Ghee et al. (2023)

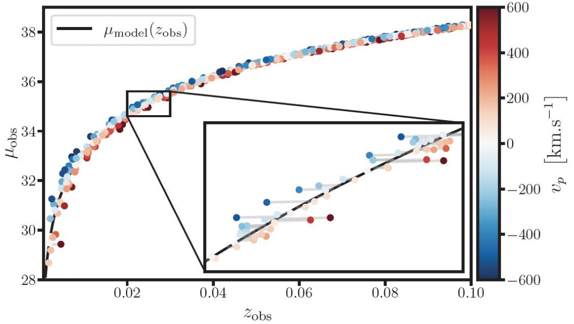
$f\sigma_8$

## Step 2: Compare with velocity measurements from direct distance tracers

Here SN Ia
but also TF, FP




Rigault et al. (2024)




Carreres et al. (2023)

# Methodology: Step 1

Build a **linear** model of the velocity field from the galaxy density field

linear growth rate of structures

$$v(\boldsymbol{r}) = \frac{H_0 f(\Omega_m)}{4\pi b_g} \int \delta_g(\boldsymbol{r}') \frac{(\boldsymbol{r}' - \boldsymbol{r})}{|\boldsymbol{r}' - \boldsymbol{r}|^3} d^3\boldsymbol{r}'.$$

galaxy bias

Amplitude of mass fluctuations within spheres of R = 8 Mpc/h → $\sigma_8$

$$\sigma^2(R, z) = \frac{1}{2\pi^2} \int_0^\infty k^2 P_{\rm lin}(K, z) |W(k; R)|^2 dk\,,$$

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→ Smooth the density field using a Gaussian kernel of width $R_G$: $W(k) = \exp\left(\frac{-k^2 R_G^2}{2}\right)$

Optimal smoothing scale that minimises the variance of the velocity field while ensuring a unbiased reconstruction is $R_G$= 3-5 Mpc/h (Carrick et al. 2015, Hollinger & Hudson 2021)

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→ **dominant source of systematics for 2M++: cosmic variance** (Holinger & Hudson 2021, Hollinger & Hudson 2023, Blake & Turner 2024) → **need mock-based covariance**

# Reconstruction methods for density and velocity fields

Comparison of reconstruction methods against catalogues of direct distance tracers (Stiskalek et al. *in prep)*

Reconstruction methods considered:

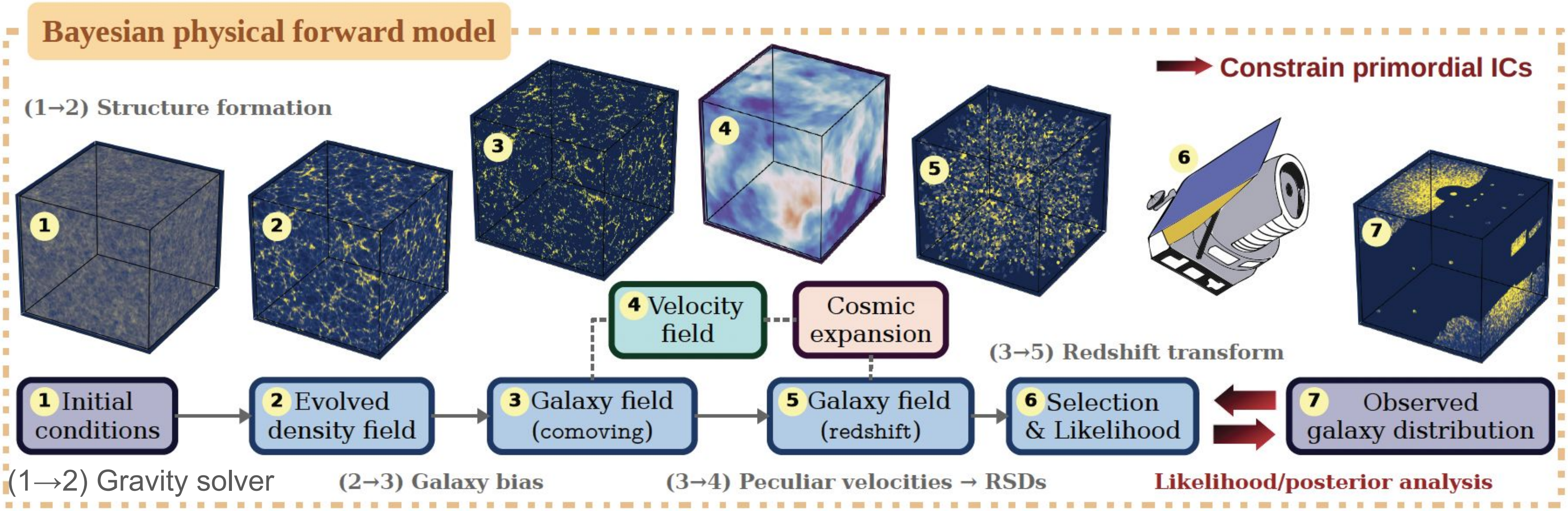
- **linear theory 2M++:** luminosity-weighted density field derived from the positions of galaxies in 2M++ assuming linear theory (Carrick et al. 2015)
- **neural-network 2M++** from Lilow et al. (2024)
- **CSiBORG (constrained simulations in BORG) 2M++**: obtained by imposing the initial conditions on the density field derived from BORG applied to 2M++. See Jasche & Lavaux (2019), Bartlett et al. (2021), Stopyra et al. (2024)
- **constrained realisations Cosmicflows-2**: Sorce (2018, 2020)
- **HMC forward-modelling Cosmicflows-4:** Courtois et al. (2023)

Data considered:

- Tully-Fisher
- **SN Ia**: LOSS, Foundation → $M_{SN}$, x0 (stretch), x1 (colour)

# What is BORG?

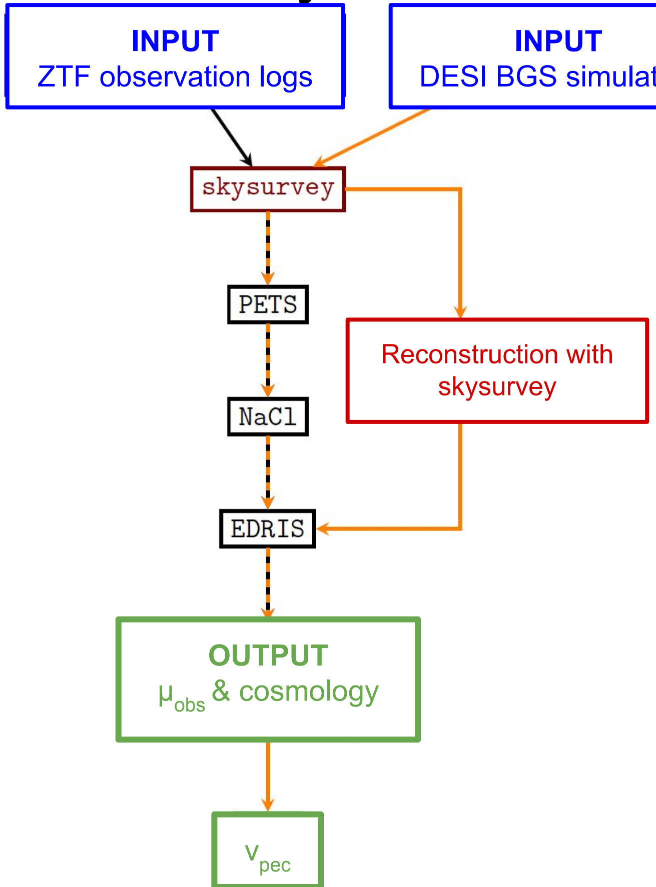
BORG: Bayesian Origin of Reconstruction Galaxies
Jasche & Wandelt (2013), Jasche & Lavaux (2019)




(1→2) Gravity solver

# Methodology: Step 2

**Peculiar velocity measurements from ZTF DR2.5 SN Ia @LPNHE**




The goal is twofold:

- Use one single pipeline for all cosmological measurements from ZTF DR2.5 SN Ia, including peculiar velocities

→ Lemaitre pipeline

- Provide unbiased peculiar velocity measurements by first testing the pipeline on simulations

Work led by Antoine Gilles--Lordet, Mahmoud Osman, Pauline Zarrouk and Nicolas Regnault

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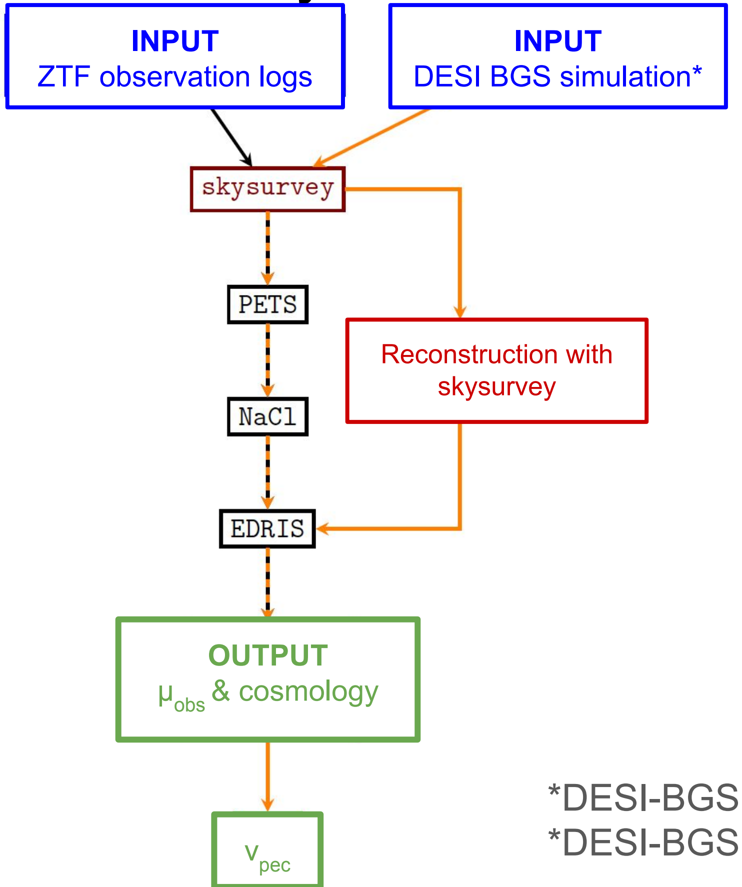
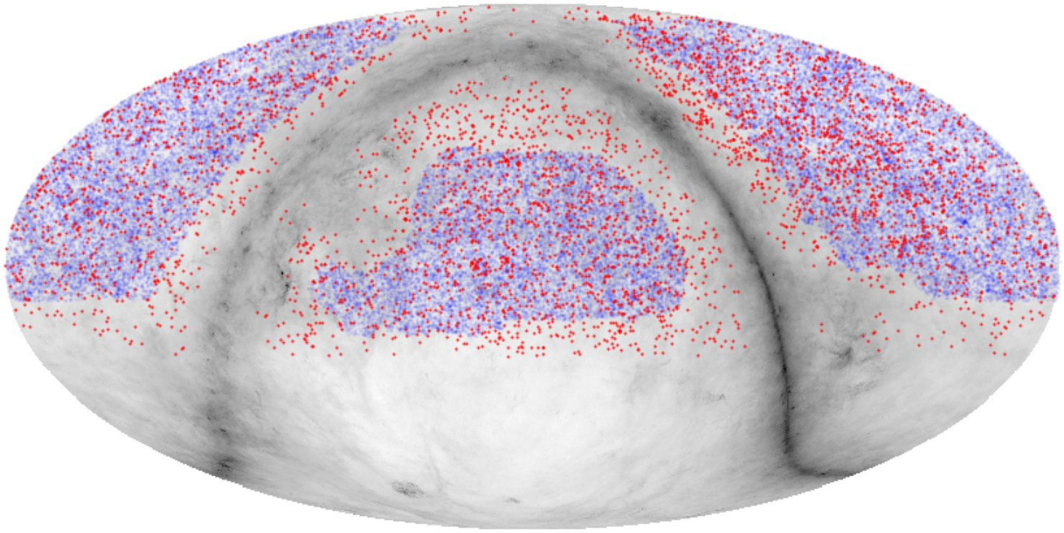



Joint DESI BGS x ZTF SN Ia simulations



*DESI-BGS Uchuu (Prada et al. 2024)
*DESI-BGS AbacusSummit (Smith et al. 2024)

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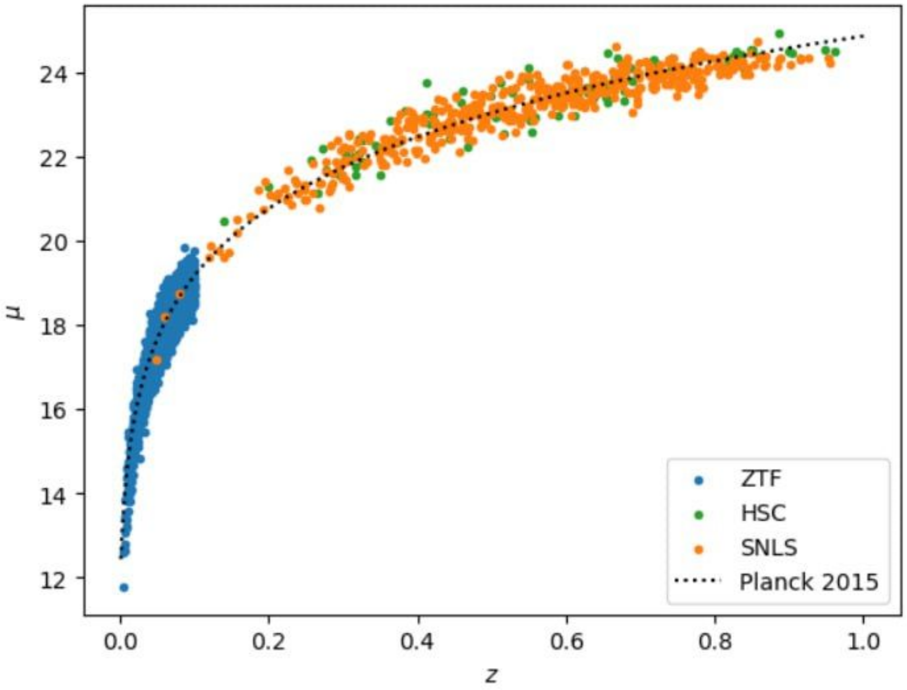


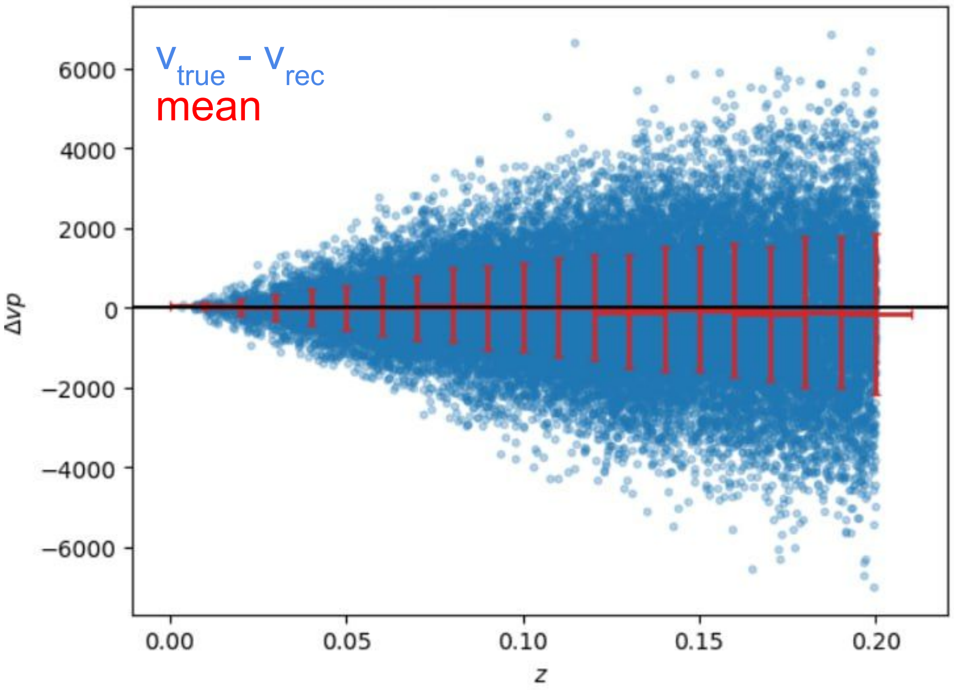


Next steps: perform systematic tests of $v_{pec}$ measurements with Lemaitre pipeline following the Data Challenge plan (Mahmoud)

# Density-velocity projects @ LPNHE using ZTF DR2.5 SN Ia

**Using 2M++ for Step 1**

- Use CSiBORG-2M++ for the reconstruction of the density and velocity fields
- compare with peculiar velocities measurements from ZTF DR2.5 SN Ia
- Goal: measure $f\sigma_8$
    - generate ZTF SN Ia within these constrained simulations using skysurvey
    - use full covariance from CSiBORG 2M++ x ZTF SN Ia
    - timeline: July-Sept 2025

**Using DESI BGS for Step 1**

- Field-level inference using BORG applied to the DESI BGS at $z < 0.2$ to reconstruct the initial conditions and the density and velocity fields → create CSiBORG-DESI BGS
- compare with peculiar velocities measurements from ZTF DR2.5 SN Ia
- Goal: measure $f\sigma_8$
    - timeline: post DR2.5

**Next:** Towards joint density and velocity field-level inference using BORG

Thanks for your attention!