# Combining probes : cluster counts and galaxy power spectrum

THE DARK ENERGY SURVEY

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# Outline

**Introduction**

**I. Covariance of galaxy spectrum and cluster counts**

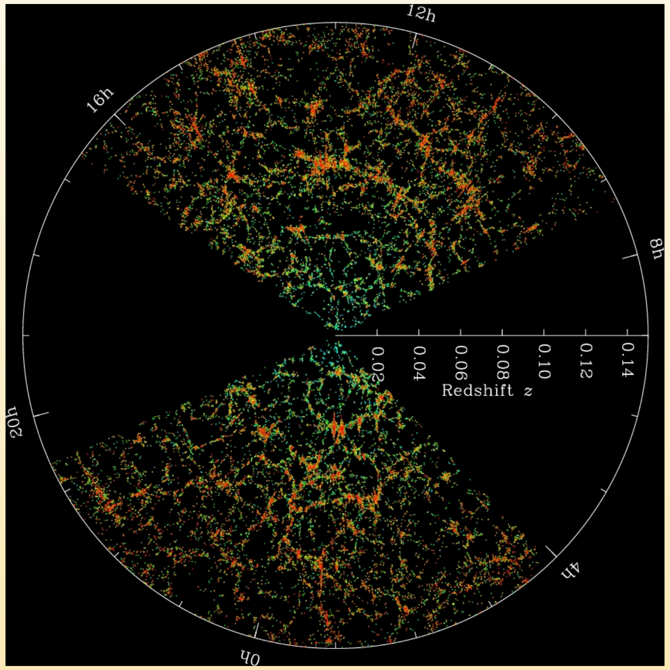
**II. Results and Fisher analysis**

arxiv:1407.1247 (conf proceeding)

# Introduction

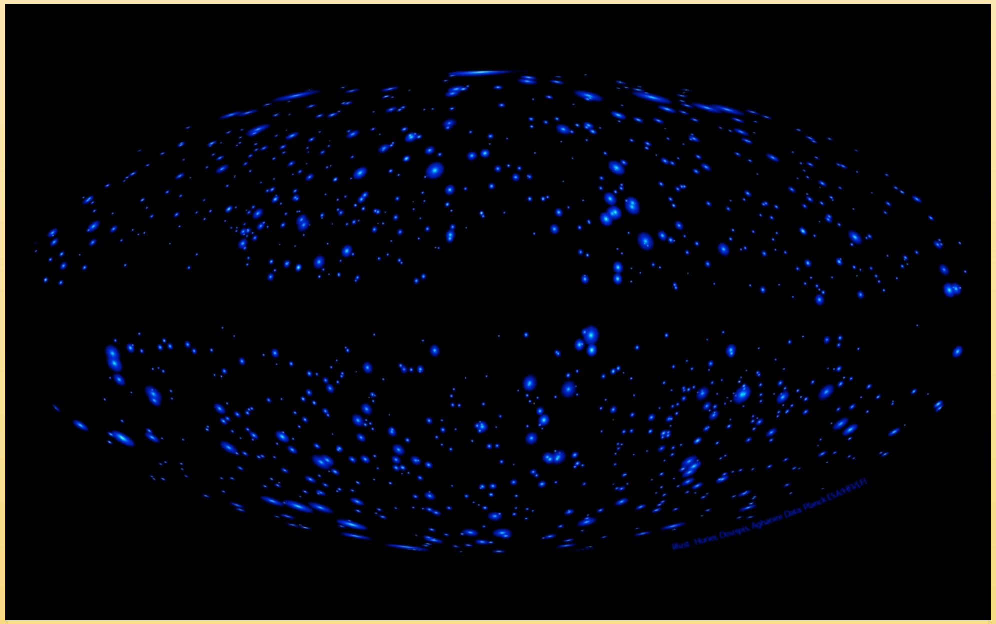
**Galaxy clustering (2-point function) :**

correlation of galaxy density field
redshift spectro (e.g. SDSS) or photo (DES).
Probes matter power spectrum and galaxy formation.




**Number counts (1-point function) :**

abundances of galaxy clusters.
Detection from microwave to X-rays.
Probes growth function and geometry.



See talk by Marcos Lima

# I. Combining probes

$$\mathbf{X} = \begin{pmatrix} N_{\rm cl} \\ C_\ell^{\rm gal} \end{pmatrix}$$

$N_{cluster}(i_M, i_z)$

$C_l^{gal}(i_z) \leftrightarrow w(\theta, i_z)$

Motivations:

- mitigate super-sample covariance of $C_l^{gal}$ on small scales.
- break degeneracy between mass function an HOD.
- future : modified gravity, $f_{NL}$.

$$\mathrm{Cov}\left(\mathbf{X},\mathbf{X}\right) = \begin{pmatrix} \mathrm{Cov}\left(N_{\rm cl}, N_{\rm cl}\right) & \mathrm{Cov}\left(N_{\rm cl}, C_\ell^{\rm gal}\right) \\ \mathrm{Cov}\left(C_\ell^{\rm gal}, N_{\rm cl}\right) & \mathrm{Cov}\left(C_\ell^{\rm gal}, C_\ell^{\rm gal}\right) \end{pmatrix}$$

# I. Covariance of the galaxy spectrum and cluster counts

Cluster count is the monopole of the halo density field

$$\hat{N}_{\rm cl}(i_M, i_z) = \overline{N}_{\rm cl}(i_M, i_z) + \frac{1}{\Omega_S} \int dM\, d^2\hat{n}\, dz\, r^2 \frac{dr}{dz} \frac{d^2 n_h}{dM\, dV}\, \delta_{\rm cl}(\mathbf{x}, z | M, z)$$

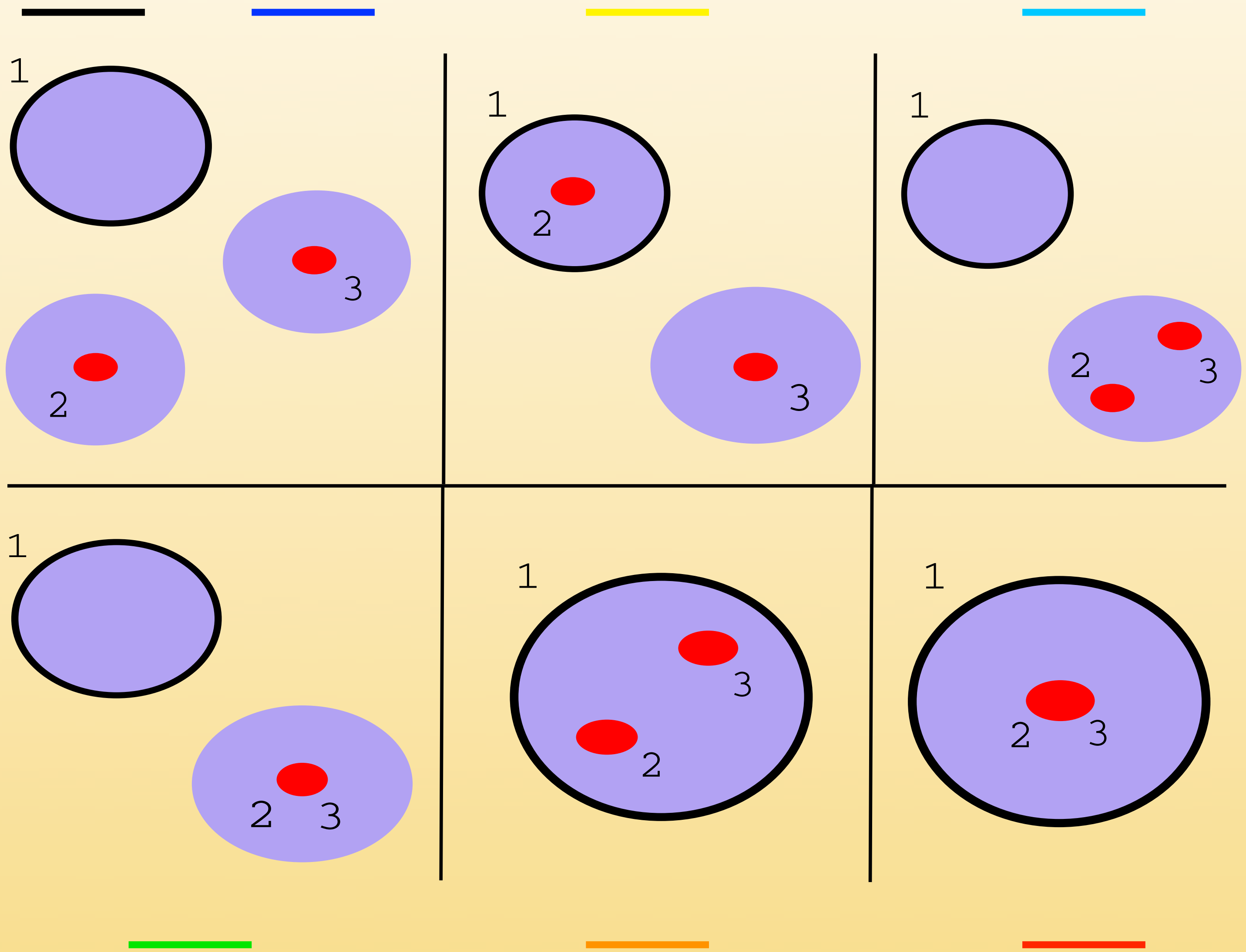
$$\mathrm{Cov}\left(\hat{N}_{\rm cl}(i_M, i_z), \hat{C}_\ell^{\rm gal}(j_z, k_z)\right) = \int \frac{dM_1\, dz_{123}}{4\pi} \frac{dV}{dz_1} \left.\frac{d^2 n_h}{dM\, dV}\right|_{M_1, z_1} b_{0\ell\ell}^{\rm hgg}(M_1, z_{123})$$

Galaxy angular power spectrum between two redshift bins (in the following $j_z = k_z$)

Cluster count in a bin of mass ($i_M$) and redshift ($i_z$)

Halo-galaxy-galaxy angular bispectrum

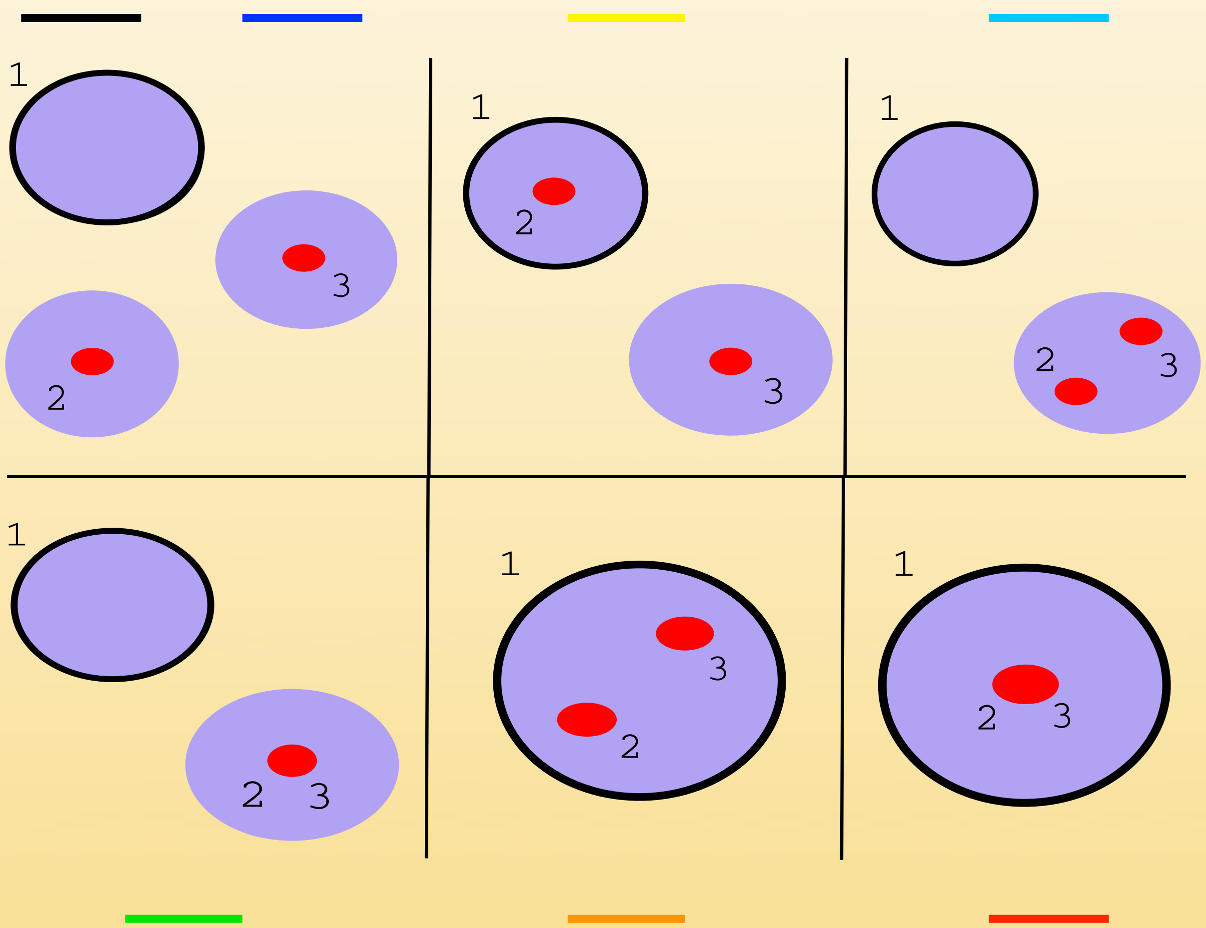
# I. Diagrammatic method for the hgg bispectrum




Ex: $$B_{\rm hgg}^{2h-1h2g}(k_{123}|M_1,z_{123}) = \frac{\delta_{z_2,z_3}}{\overline{n}_{\rm gal}^2(z_2)}\int dM\,\frac{d^2n_h}{dM\,dV}\langle N_{\rm gal}(N_{\rm gal}-1)(M)\rangle\,u(k_2|M)\,u(k_3|M)\,P_{\rm halo}(k_1|M_1,M,z_1,z_2)$$

Ingredients : cosmology, halo model, Halo Occupation Distribution (HOD)

# I. Physical interpretation of the diagrams / terms




3-halo, 2h-1h2g and 2h-1h1g :
how large scale structure modulates together cluster counts and the 2h, 1h or shot-noise part of the power spectrum.

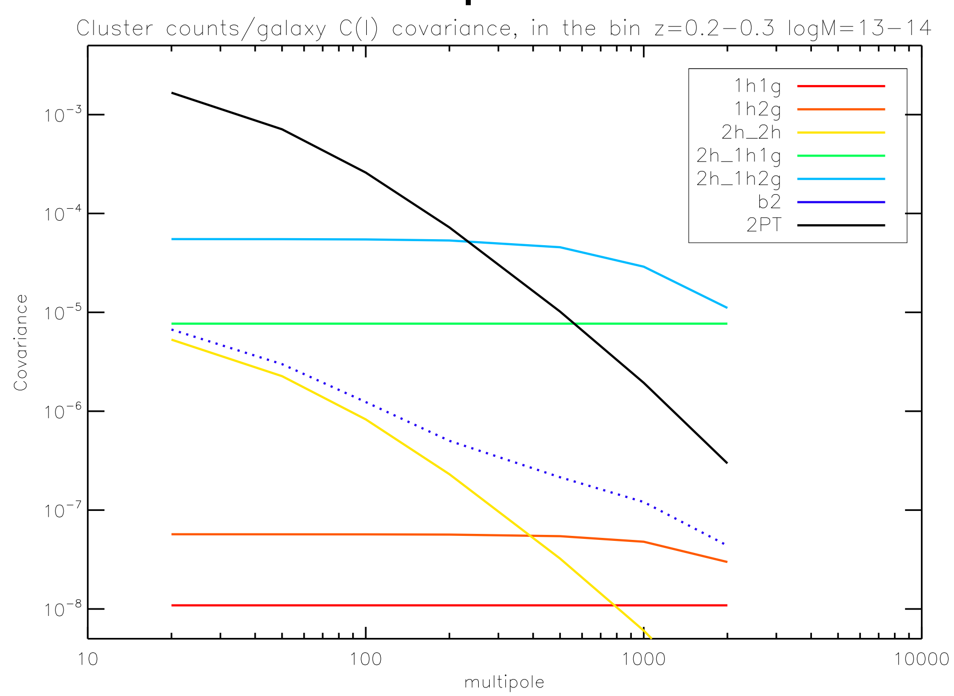
2h-2h, 1h2g and 1h1g :
how many clusters source the 2h, 1h or shot-noise part of the power spectrum.

Super-sample covariance (SSC) : sum of 3-halo, 2h-1h2g and 2h-1h1g terms. Reaction to long wavelength modes (background change).

$$\mathrm{Cov}_{\mathrm{SSC}}\left(\hat{N}_{\mathrm{cl}}(i_M,i_z),\hat{C}_\ell(j_z)\right)=\int\frac{\mathrm{d}V_{12}\,\overline{n}_{\mathrm{gal}}(z_2)^2}{\Delta N_{\mathrm{gal}}(j_z)^2}\,\frac{\partial n_h}{\partial\delta_b}(i_M,z_1)\,\frac{\partial P_{\mathrm{gal}}(k_\ell|z_2)}{\partial\delta_b}\,\sigma^2_{\mathrm{proj}}(z_1,z_2)$$

# II. Ideal results I : scale dependence of the covariance

1

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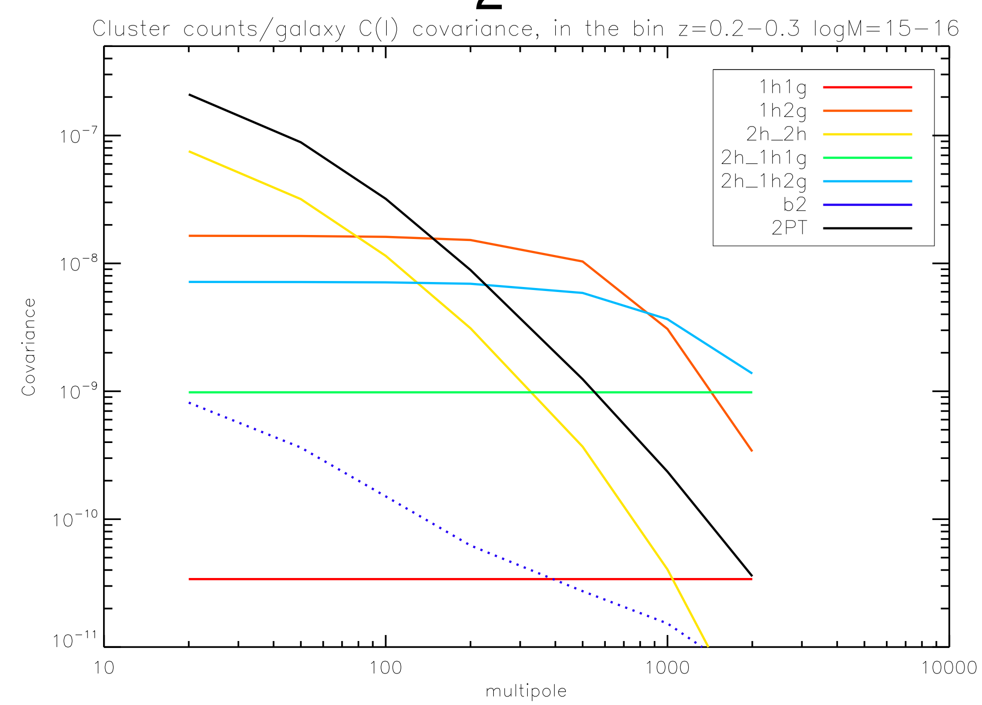
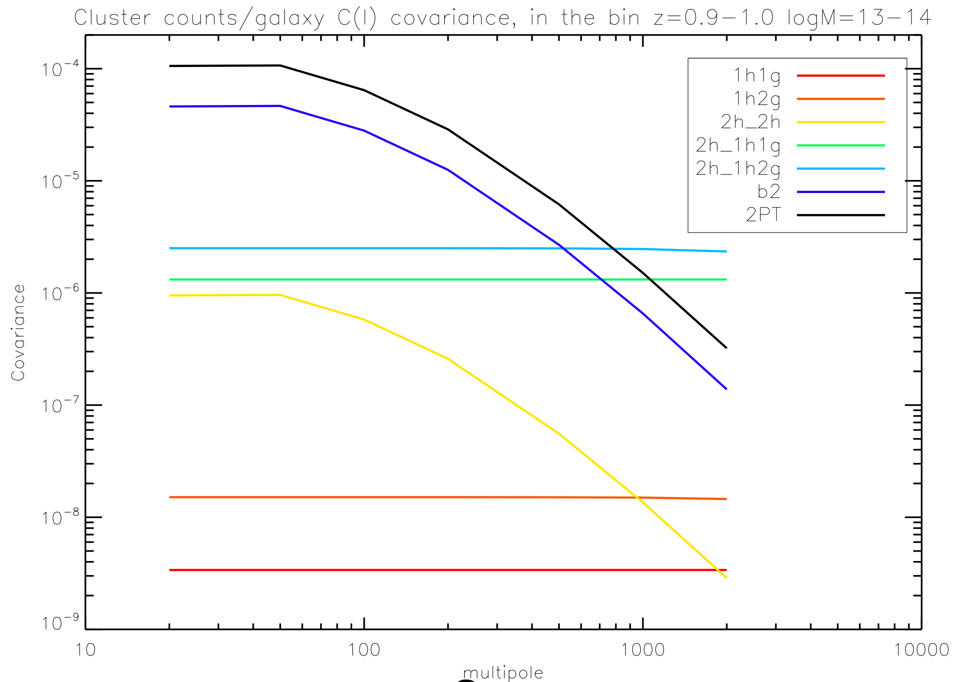



3

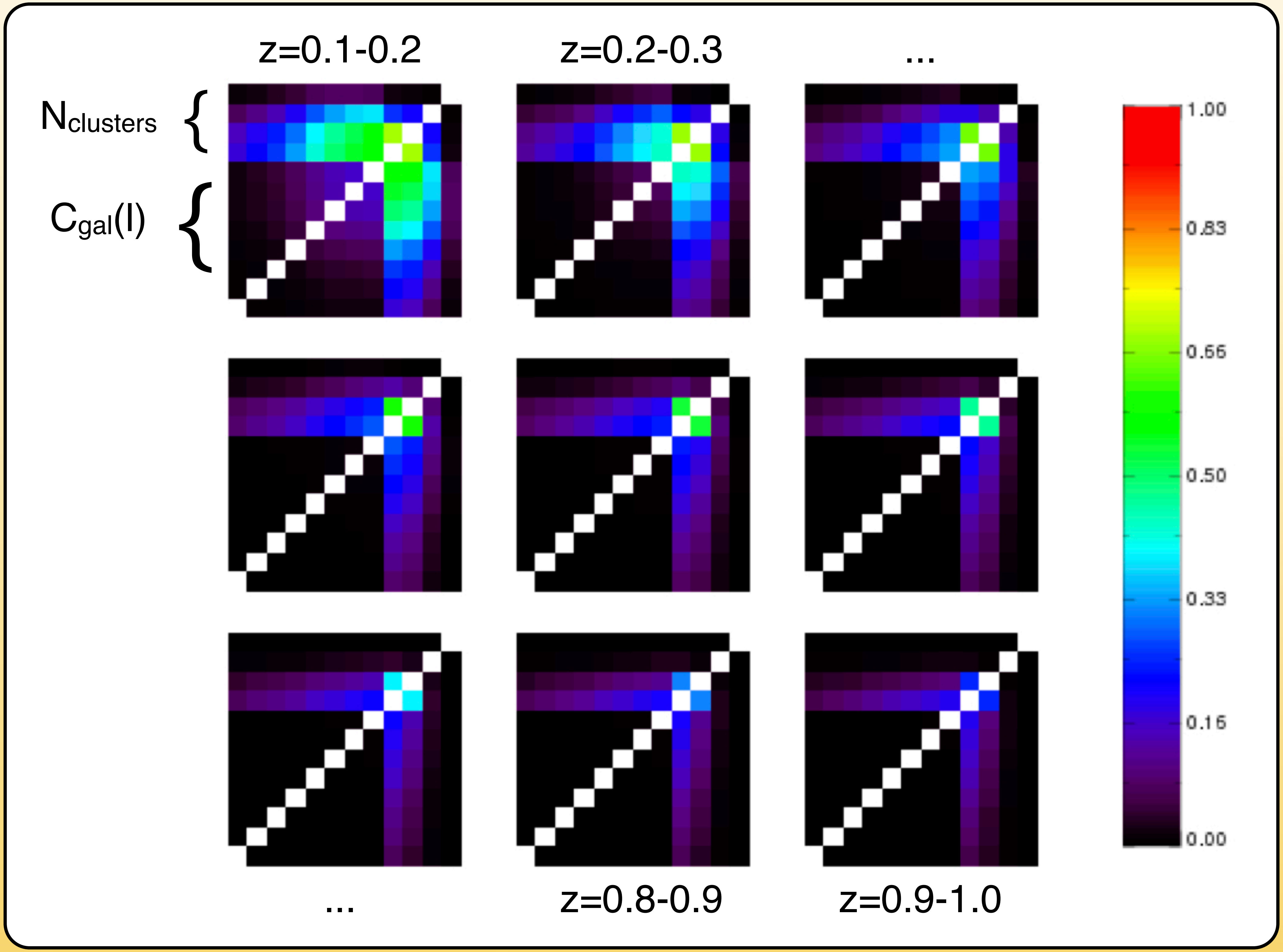
1 : z=0.2-0.3 and log($M/M_{sun}$) = 13-14

2 : z=0.2-0.3 and log($M/M_{sun}$) = 15-16

3 : z=0.9-1.0 and log($M/M_{sun}$) = 13-14

3h : 2PT & b2, 2h-1h2g, 2h-1h1g, 2h-2h, 1h2g, 1h1g

# II. Ideal results II : joint covariance matrix




9 z-bins z=0.1-1.0

4 logM bins
logM = 14-16

8 multipoles
l=30-300

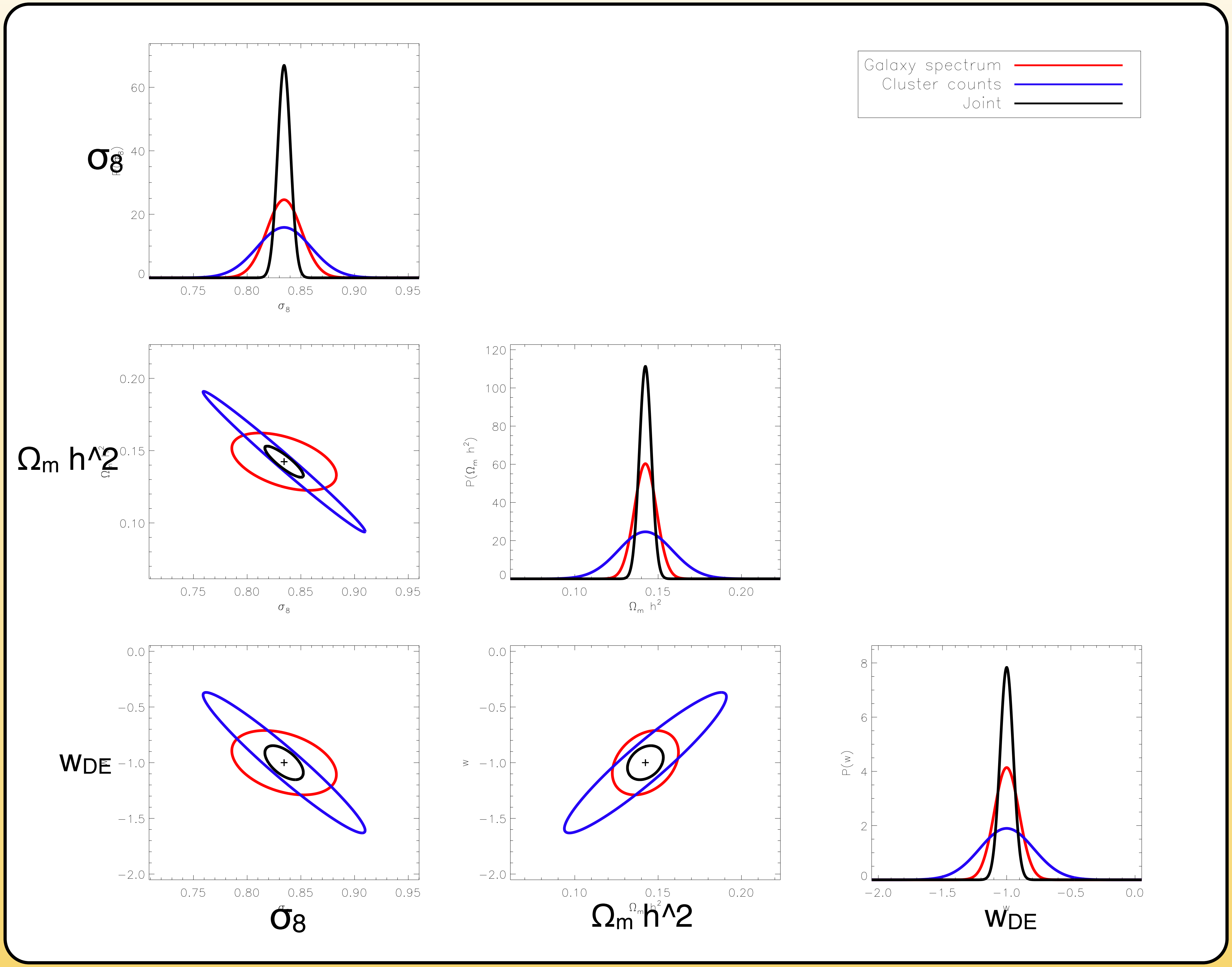
no photo-z errors, purity nor completeness

full cluster autocov (shot-noise, sample variance)

full crosscov

galaxy autocov : Gaussian, SSC, 1h trispectrum

# II. Fisher analysis : cosmology




$C_{gal}(l)$ constraints

$N_{cl}$ constraints

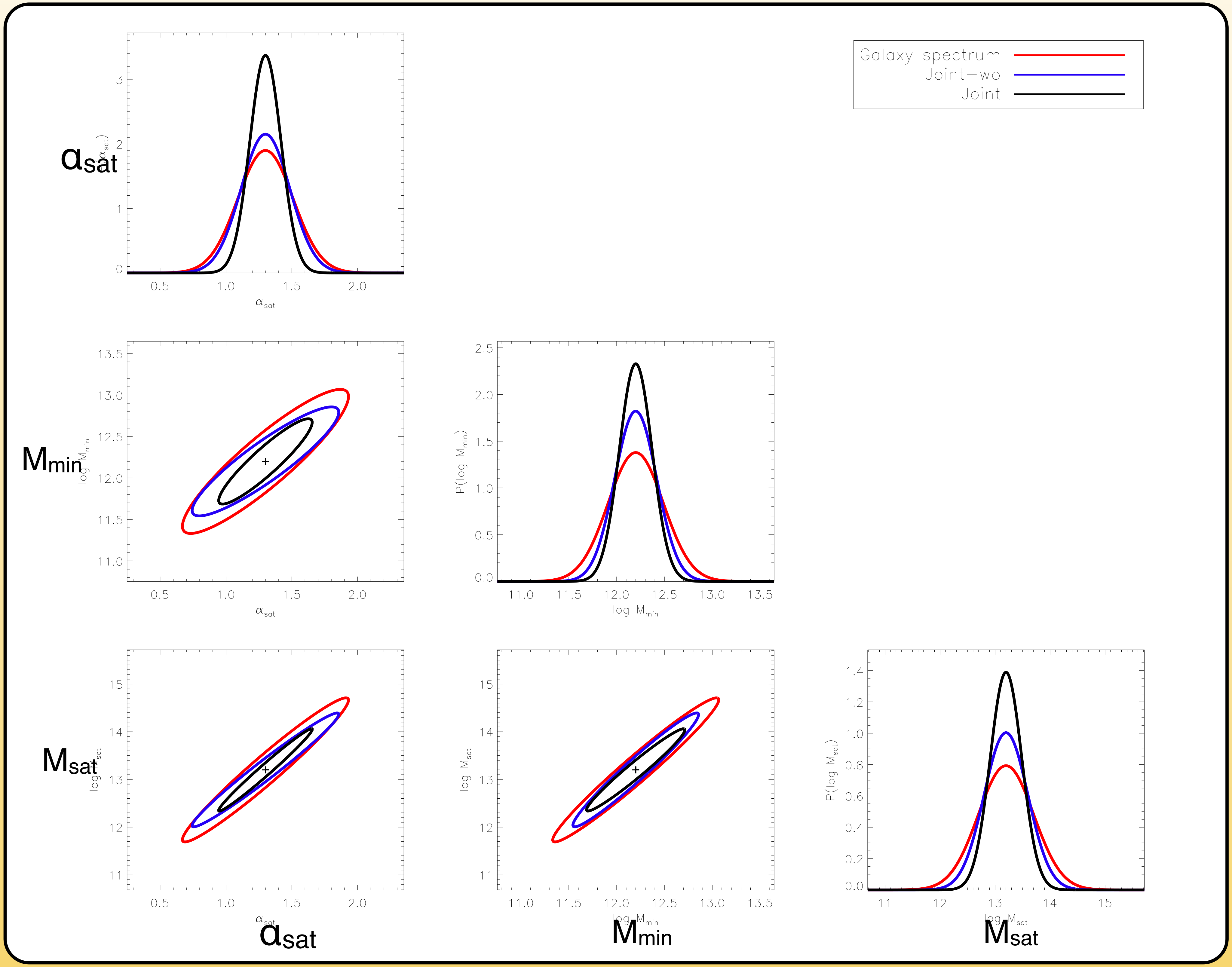
Joint constraints

after marginalisation over HOD parameters

$S/N(C_l^{gal}) = S/N(N_{cl})$

Joint constraints better than if probes were independent

# II. Fisher analysis : HOD




$C_{gal}(l)$ constraints

Joint independent constraints (crosscov=0)

Joint full constraints (with crosscov)

after marginalisation over cosmological parameters ($\sigma_8$, $\Omega_m$ h^2, $w_{DE}$)

$S/N(C_{gal}(l)) = S/N(N_{cl})$

Joint constraints better than if probes were independent

# Conclusions

- Cluster counts - galaxy spectrum cross-covariance with a diagrammatic formalism

- Full non-linear model is needed : HM+HOD

- Cross-covariance is not negligible and creates a synergy between the probes

- Joint non-Gaussian likelihood

- Future : MC pipeline for realistic forecasts and application to DES data

Thanks for your attention