Impact of purity, completeness and probe covariances on the Euclid FoM

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Galaxy power spectrum modelling in the absence of spurious redshifts *z*

- P_{zs}: Power spectrum in redshift space

$$P_{\rm zs}(k,\mu,z) = \left[\frac{1}{1+(f(z)k\mu\,\sigma_{\rm p}(z))^2}\right]\left(b(z)\sigma_8(z)+f(z)\sigma_8(z)\mu^2\right)^2\frac{P_{\rm dw}(k,z)}{\sigma_8^2(z)}$$

- $\sigma_{\rm p}$: pairwise peculiar velocity along the line of sight

$$P_{\rm dw}(k,z) = [P_{\rm m}(k,z) - P_{\rm nw}(k,z)]\,{\rm e}^{-g_\mu k^2} + P_{\rm nw}(k,z)$$

BAO only × damping + Broadband

- $\sigma_{\rm v}$: non-linear damping of the BAO signal

$$g_\mu(k,\mu,z) = \sigma_{\rm v}^2(z)\left[1-\mu^2+\mu^2\,(1+f(z))^2\right]$$

$\sigma_{\rm p}$ and $\sigma_{\rm v}$ free nuisance parameters
with some level of BAO reconstruction for $\sigma_{\rm v}$

Effects of α-fraction of spurious unclustered z on γ-errors and FoMs

(GC_{sp} alone & $WL+GC_{ph}+WLxGC_{ph}+GC_{sp}$)

$$n_C = n(z),\, n_{NC} = \alpha\, n(z)$$

$$n_{tot}(z) = n_C + n_{NC} = (1+\alpha) n(z)$$

$$f_{amp} = \frac{n_{NC}}{n_{tot}(z)} = \frac{\alpha}{1+\alpha}$$

currently redshift independent

$$\tilde{P}_{obs}(z;\,k,\mu) = [1 - f_{amp}]^2\, P_{obs}(z;\,k,\mu)$$

$$= \left(\frac{1}{1+\alpha}\right)^2 P_{obs}(z;\,k,\mu)$$

$$\tilde{V}_{eff} = \left[\frac{n_{tot}\tilde{P}_{obs}}{1+n_{tot}\tilde{P}_{obs}}\right]^2 V_{survey} \longrightarrow V_{survey} \text{ for } n_{tot}\tilde{P}_{obs} >> 1$$

$f_{out} \equiv \alpha$ and 45% completeness

perfect knowledge of α assumed

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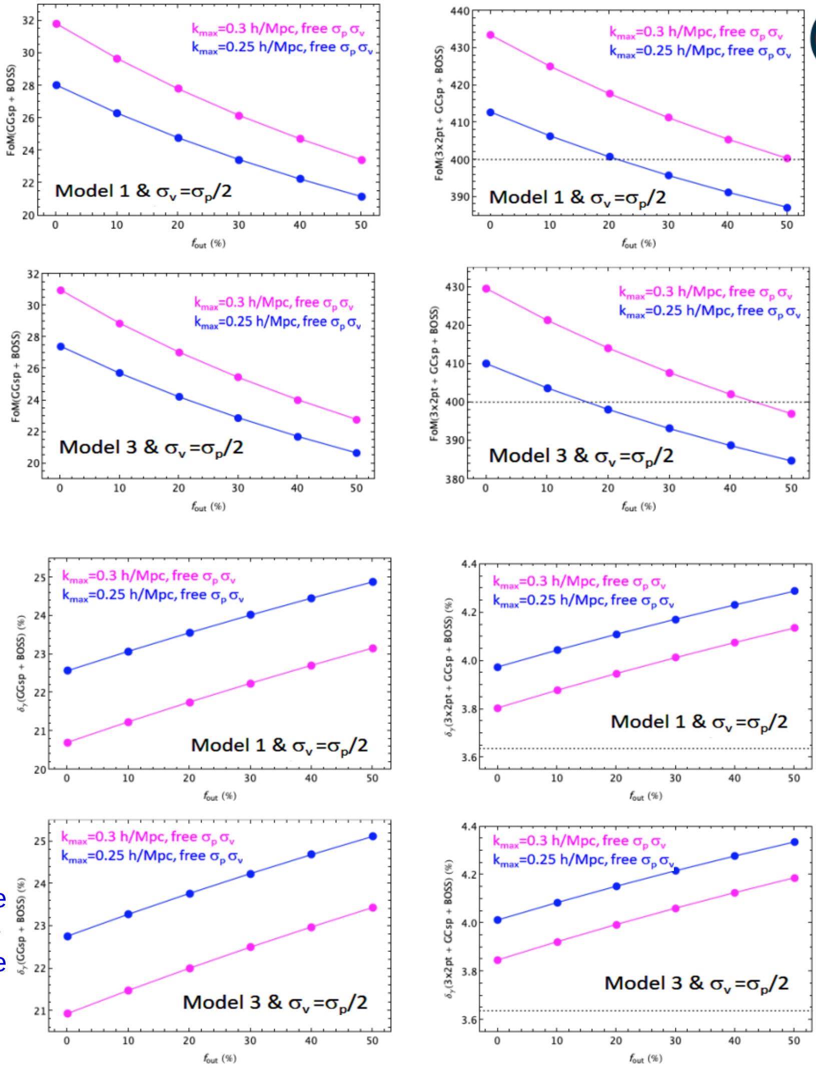

Effects of ε-fraction of incompleteness on γ-errors and FoMs

(GC_{sp} alone & $WL+GC_{ph}+WLxGC_{ph}+GC_{sp}$)

$$\tilde{V}_{\rm eff} = \left[\frac{(1-\varepsilon)n_{\rm tot}P_{\rm obs}}{1+(1-\varepsilon)n_{\rm tot}P_{\rm obs}}\right]^2 V_{\rm survey}$$

$f_{\rm inc} \equiv \varepsilon$ and 100% purity (or the one assumed in Pypelid)

currently redshift independent

perfect knowledge of ε assumed

FoM decreases more rapidly with decreasing purity wrt decreasing completeness

Same for the increase of γ-errors

Reduce completeness to improve purity??

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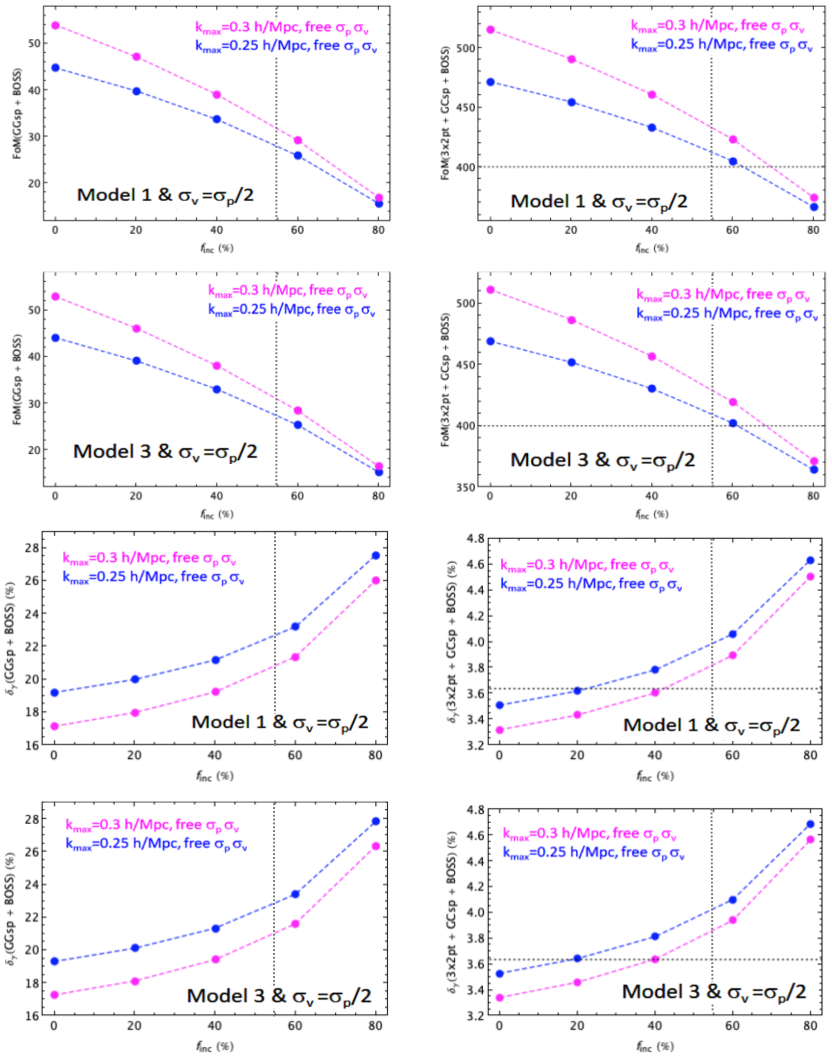

Euclid forecasts: accounting for 2D X 3D data covariances/correlations (really needed?)

- Forecasts are necessary to accurately plan the future analysis of *Euclid* data
- *Euclid* main probes:
  - Weak Lensing (WL)
  - Photometric $(\mathrm{GC_{ph}})$ and Spectroscopic $(\mathrm{GC_{sp}})$ Galaxy Clustering
- Cosmological observables: **statistical correlation functions** of given probes
- Previous Euclid forecast (IST:F) considered WL and $\mathrm{GC_{ph}}$ including their correlation

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Euclid forecasts: accounting for 2D X 3D data covariances/correlations

- Given two probes A and B
- **Cross-covariance**
  - covariant probes: combined information *less than* “their sum”
  - independent probes: combined information *equal to* “their sum”
  - overlap of information **worsens combined constraints**
- **Cross-correlation**
  - intended as the two-point cross-correlation function between A and B
  - contains **new cosmological information** —> improves constraints if present

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Euclid forecasts: accounting for 2D X 3D data covariances/correlations

- Observable used: tomographic angular (spherical harmonic transform) power spectra $C_{ij}^{AB}(\ell)$ under Limber approximation
- tomography: slices of sky at various depths (redshift bins) —> improves information gain

$$C_{ij}^{AB}(\ell) \simeq c \int_{z_{\rm min}}^{z_{\rm max}} {\rm d}z \frac{W_i^A(z) W_j^B(z)}{H(z)\chi^2(z)} P_{\delta\delta}\left[k = \frac{\ell + 1/2}{\chi(z)}, z\right]$$

- ℓ multipole moment
- $H(z)$ Hubble parameter
- $\chi(z)$ comoving distance
- $P_{\delta\delta}$ Fourier matter power spectrum

- $A, B = \{\mathrm{WL}, \mathrm{GC_{ph}}, \mathrm{GC_{sp}}\}$
- $W_i^A(z)$ weight function of probe A at tomographic bin i

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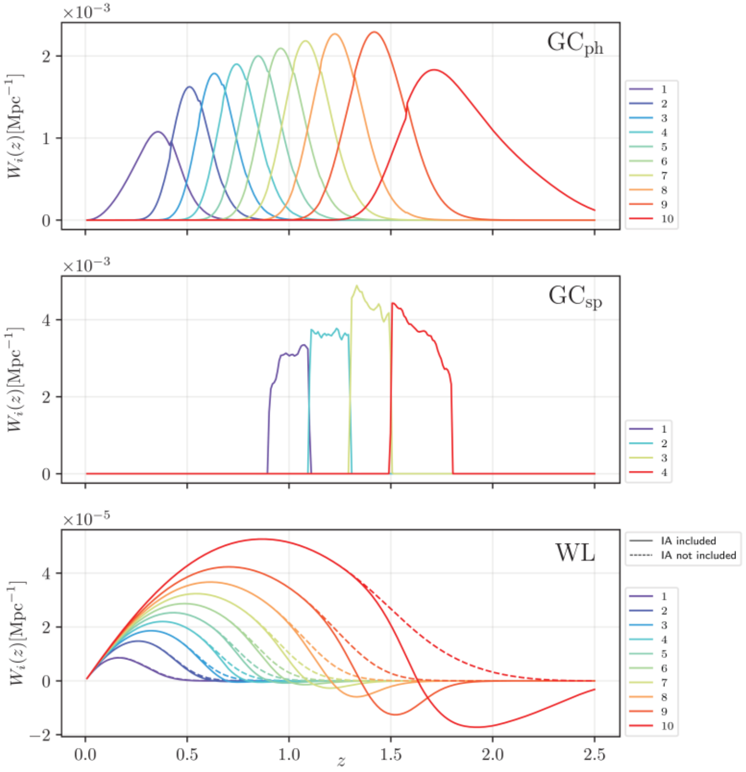
WL, GC$_{sp}$ & GC$_{ph}$ window functions

$$W_i^{\rm ph}(z) \longleftrightarrow n_i^{\rm ph}(z)$$

$$W_i^{\rm sp}(z) \longleftrightarrow n_i^{\rm sp}(z)$$

$$W_i^{\rm wl}(z) \longleftrightarrow n_i^{\rm ph}(z)$$

$n_i^A(z)$ is normalized galaxy density for sample A at bin i



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Fisher Matrix: two different approaches

- **(Full) Harmonic** (or 2D) approach
  - $\mathrm{GC_{sp}}$ autocorrelation treated as angular power spectrum
  - cross-covariance with other observables computed using $C(\ell)$'s
  - found to be negligible even with maximum number (40) of tomographic bins considered, which leads to
- **Hybrid** (2D + 3D) approach:
  - $\mathrm{GC_{sp}}$ auto-correlation as *3D power spectrum* ($\mathrm{GC_{sp}}(P_k)$) included as **independent** (neglecting cross-covariance)
  - here $\mathrm{GC_{sp}}$ 3D full potential is exploited, including RSD and AP
- cross-correlations $\mathrm{XC(GC_{ph}, GC_{sp})}$ and $\mathrm{XC(WL, GC_{sp})}$ always included as angular power spectra, in both approaches

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Fisher Matrix: 2D approach for GC_{sp}

- $\mathrm{GC_{sp}}$ treated with angular power spectrum ($\mathrm{GC_{sp}}(\mathrm{C}_\ell)$)
  - **pros**
    - cross-covariances and cross-correlations with WL and $\mathrm{GC_{ph}}$ are straightforward to compute
  - **cons**
    - loss of constraining power w.r.t. 3D power spectrum $\mathrm{GC_{sp}}(P_k)$ approach:
      - radial resolution partly lost due to integration along line of sight
      - redshift space distortions (RSDs) and Alcock-Paczynski (AP) effect not considered
- refined tomographic binning of $\mathrm{GC_{sp}}(\mathrm{C}_\ell)$ from 4 up to 40 bins
  - finer binning —> asymptotical recovery of radial information

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Fisher Matrix: observable combinations

- Using three probes WL, $\mathrm{GC_{ph}}$, $\mathrm{GC_{sp}}$ we have at most 6 combinations of observables
- three **auto-correlations**: $\mathbf{C}^{AA}(\ell)$, simply denoted as A

$$\left\{\mathbf{C}^{\mathrm{wlwl}}(\ell), \mathbf{C}^{\mathrm{phph}}(\ell), \mathbf{C}^{\mathrm{spsp}}(\ell)\right\}$$

- three **cross-correlations**: $\mathbf{C}^{AB}(\ell)$ with $A \neq B$, briefly denoted as $\mathrm{XC(A, B)}$

$$\left\{\mathbf{C}^{\mathrm{wlph}}(\ell), \mathbf{C}^{\mathrm{wlsp}}(\ell), \mathbf{C}^{\mathrm{phsp}}(\ell)\right\}$$

- shortcut definitions
  - $3 \times 2\mathrm{pt} \equiv [\mathrm{WL} + \mathrm{GC_{ph}} + \mathrm{XC(WL, GC_{ph})}]$
  - $6 \times 2\mathrm{pt} \equiv [\mathrm{WL} + \mathrm{GC_{ph}} + \mathrm{GC_{sp}} + \mathrm{XC(WL, GC_{ph})} + \mathrm{XC(WL, GC_{sp})} + \mathrm{XC(GC_{ph}, GC_{sp})}]$

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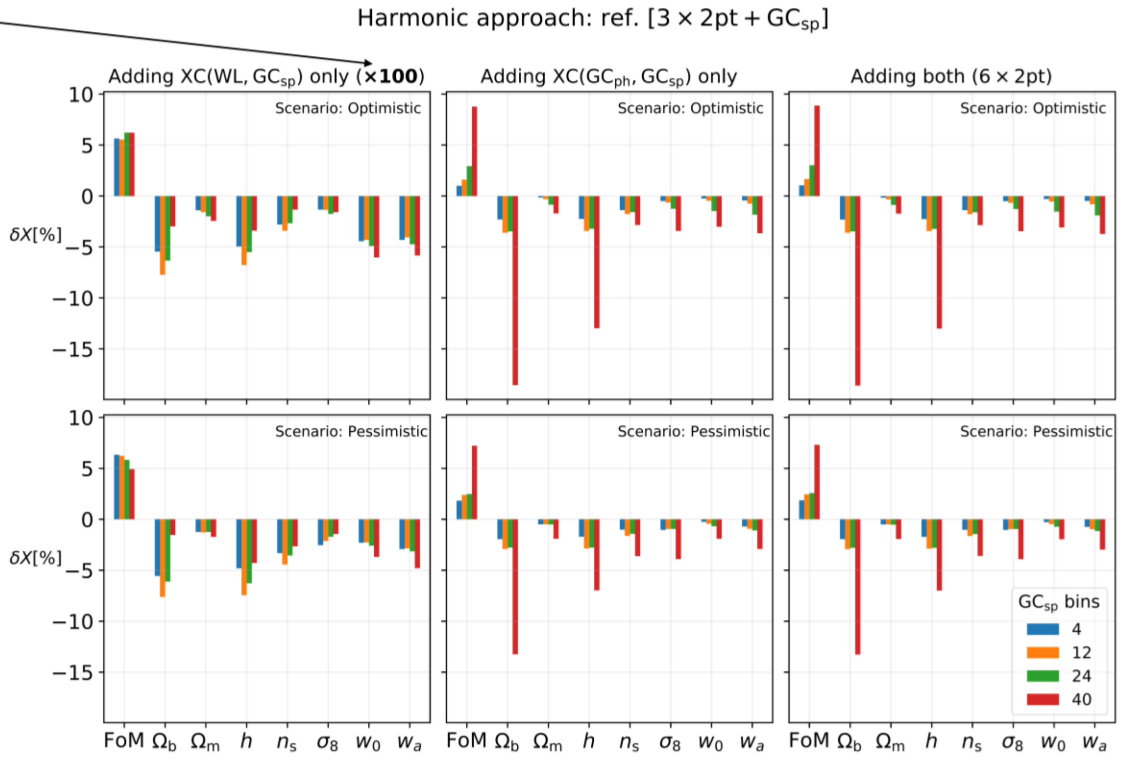
6x2pt-statistics: impact of cross-*correlations* with GC_{sp} (full 2D approach)

Note x100 amplification



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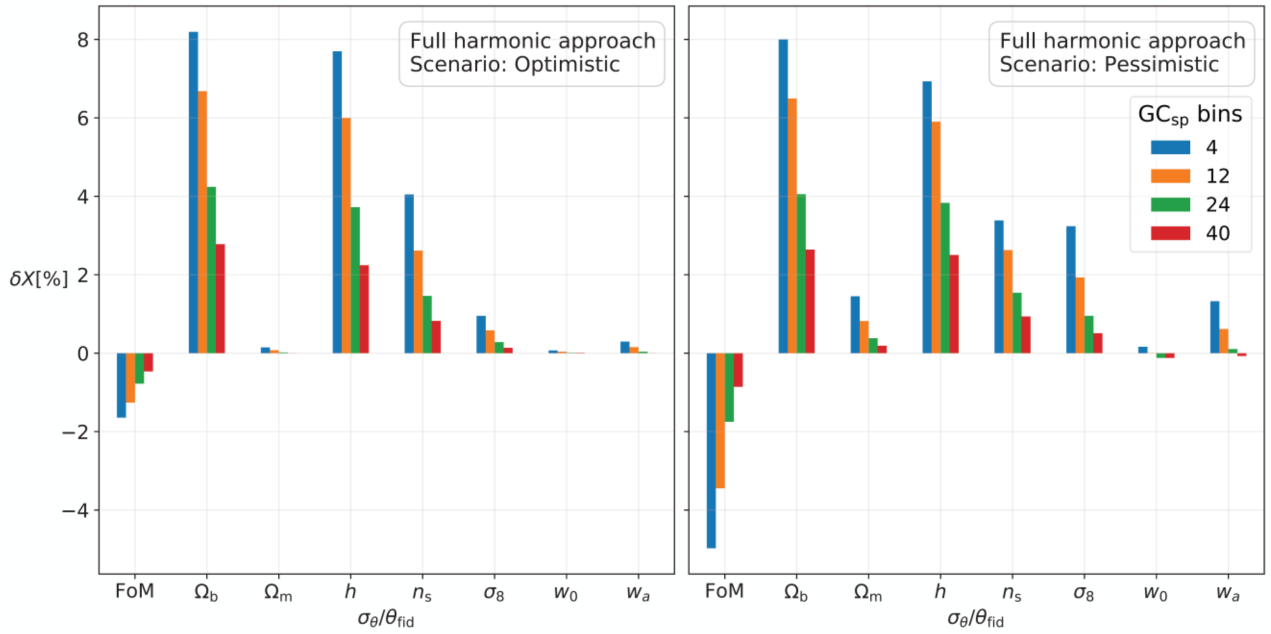
6x2pt-statistics: impact of cross-*covariance* with GC_{sp} (full 2D approach)

Cross-covariance impact: $[3 \times 2\text{pt} + GC_{sp}]$ vs $[3 \times 2\text{pt}] + [GC_{sp}]$



The increased z-binning is meant to account for radial info neglected in the GC_{sp} 2D-projection

Forecast settings in the full harmonic approach		
Optimistic	GC_{ph}	$10 \leq \ell \leq 3000$
	GC_{sp}	$10 \leq \ell \leq 3000$
	WL	$10 \leq \ell \leq 5000$
Pessimistic	GC_{ph}	$10 \leq \ell \leq 750$
	GC_{sp}	$10 \leq \ell \leq 750$
	WL	$10 \leq \ell \leq 1500$

If the full GC_{sp} X 2D-probe covariances are well approximated by the computation in the harmonic domain (eg Joachimi et al. 2021), then their impact would be even more negligible when radial information, i.e. when 3D-GCsp is not projected to the 2D angular space

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6x2pt statistics: lesson learnt

from the 2D angular approach…

$$\mathrm{Cov} = \begin{pmatrix} \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm spsp}, C^{\rm spsp}\right] \end{pmatrix}$$

…to the 2D+3D hybrid approach

$$\mathrm{Cov} = \begin{pmatrix} \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlwl}, P^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlph}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlph}, P^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm phph}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm phph}, P^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm wlsp}, P^{\rm spsp}\right] \\ \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[C^{\rm phsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[C^{\rm phsp}, P^{\rm spsp}\right] \\ \mathrm{Cov}\left[P^{\rm spsp}, C^{\rm wlwl}\right] & \mathrm{Cov}\left[P^{\rm spsp}, C^{\rm wlph}\right] & \mathrm{Cov}\left[P^{\rm spsp}, C^{\rm phph}\right] & \mathrm{Cov}\left[P^{\rm spsp}, C^{\rm wlsp}\right] & \mathrm{Cov}\left[P^{\rm spsp}, C^{\rm phsp}\right] & \mathrm{Cov}\left[P^{\rm spsp}, P^{\rm spsp}\right] \end{pmatrix}$$

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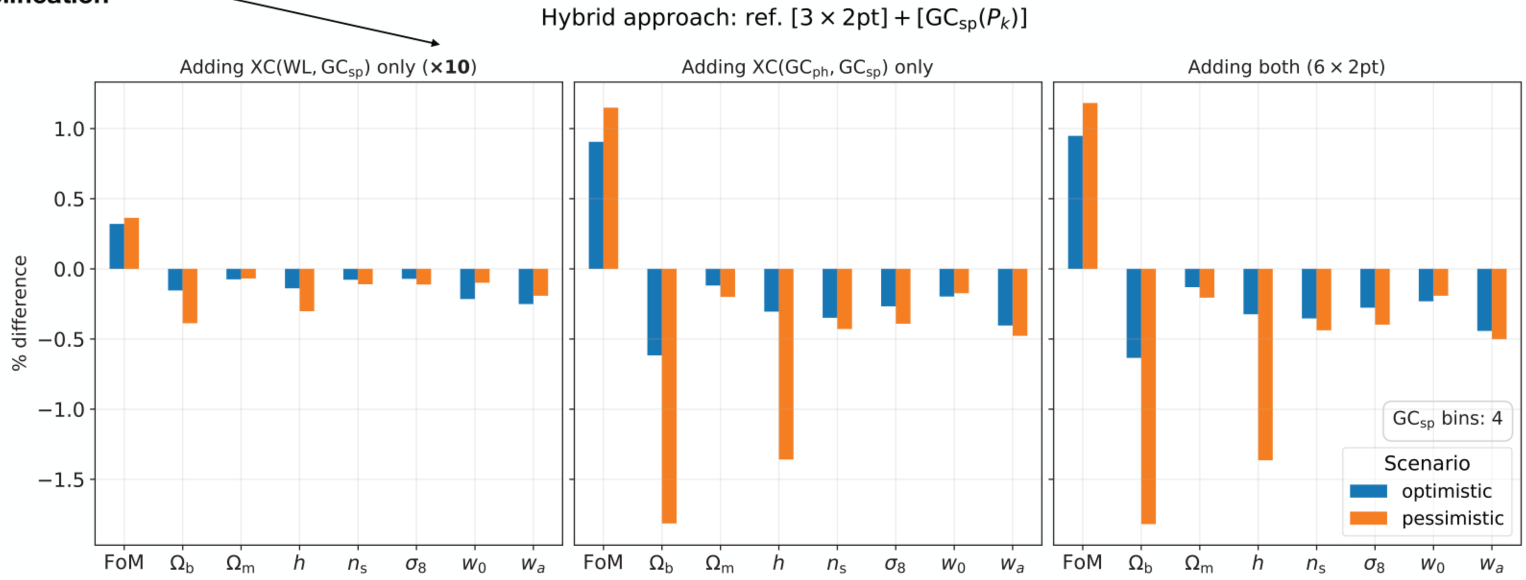
6x2pt-statistics: impact of cross-*correlations* with GC_{sp} (2D+3D hybrid approach)

Note x10 amplification



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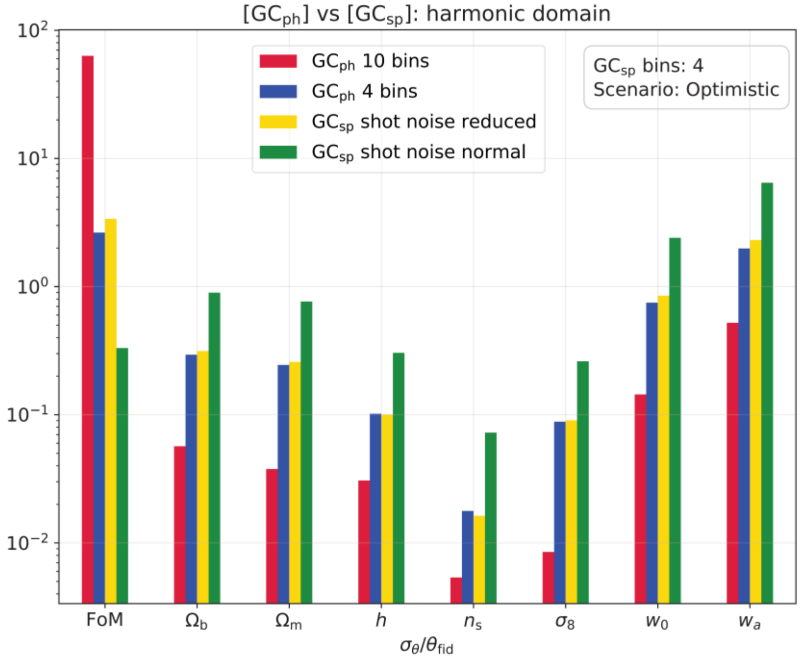
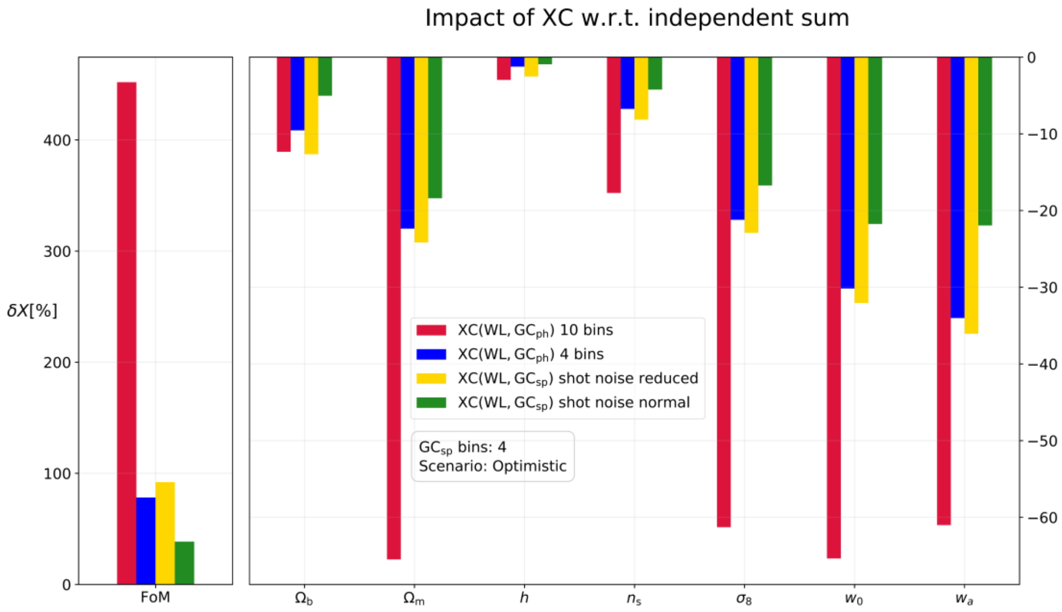
6x2pt-statistics: why 2D-3D cross covariances/correlations are negligible in Euclid?





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Euclid preparation: 6×2pt analysis of 3D and 2D data in *Euclid*

Euclid Collaboration: Luca Paganin⋆, Marco Bonici, Carmelita Carbone, Stefano Camera, Isaac Tutusaus, Davide Sciotti, Julien Bel, Stefano Davini, Silvano Tosi, Sergio Di Domizio, Gemma Testera, and others[1] ⋆⋆

(KP-GC-6 paper-4)

- The correlations between $\mathrm{WL}, \mathrm{GC}_{\mathrm{ph}}$ and $\mathrm{GC}_{\mathrm{sp}}$ do not affect significantly Euclid constraints
- **Cross-covariances** with $\mathrm{GC}_{\mathrm{sp}}$
  - always almost negligible (as computed by treating $\mathrm{GC}_{\mathrm{sp}}$ in harmonic domain)
- **Cross-correlations** $\mathrm{XC}(\mathrm{GC}_{\mathrm{ph}}, \mathrm{GC}_{\mathrm{sp}})$ and $\mathrm{XC}(\mathrm{WL}, \mathrm{GC}_{\mathrm{sp}})$
  - quite significant only when $\mathrm{XC}(\mathrm{WL}, \mathrm{GC}_{\mathrm{ph}})$ is not considered
  - refining tomographic binning of $\mathrm{GC}_{\mathrm{sp}}$ in harmonic space does not help considerably

Common 2D/3D mocks probably not needed in Euclid:
further computational costs avoided ☺

Activity in GC-WP:Likelihood (leads Bel&Carbone)

1) paper-1 "*Comparison between different GC likelihood recipes for* 2PCF-*statistics*": lead **Philippe Baratta (France, CPPM)**

2) paper-2 "*Comparison between different GC likelihood recipes for* P(k)-*statistics*": lead **Sylvain Gouyou-Beauchamps (France, CPPM)**

3) paper-3 "*Methods to speed up the GC likelihood pipeline (including 2pt-emulators), and comparison with standard techniques for parameter estimation*": leads **Marco Bonici & Carmelita Carbone (IASF Milan, Italy)**

4) paper-4 "*6×2pt analysis of 3D and 2D data in Euclid*": co-leads **Luca Paganin & Marco Bonici** (**Italy, INFN-GE/INAF-IASF Milan**) (collaboration with SPV3/WP:Photo)

5) paper-5 "*Estimator and likelihood of the GCph X GCsp*": lead **Marco Bonici** (**Italy, INAF-IASF Milan**) (collaboration with IST:L) (TBD)

6) paper-6 "*Construction of the cosmological covariance matrices for galaxy clustering 2pt statistics*": co-leads: **Linda Blot (Germany, MPA, Garching) & Ariel Sanchez (Germany, MPE, Garching)** (collaboration with GC-OULE3)

7) paper-7 "*Cross-covariance of spectroscopic and photo-z samples*" : lead **Julien Bel (France, CPT)**