Constraints on High Energy Neutrino density from Large Scale Structure

Alberto Gálvez Ureña, Federico Urban, David Alonso

CEICO, Institute of Physics of the Czech Academy of Sciences

FORTE

CHARLES UNIVERSITY

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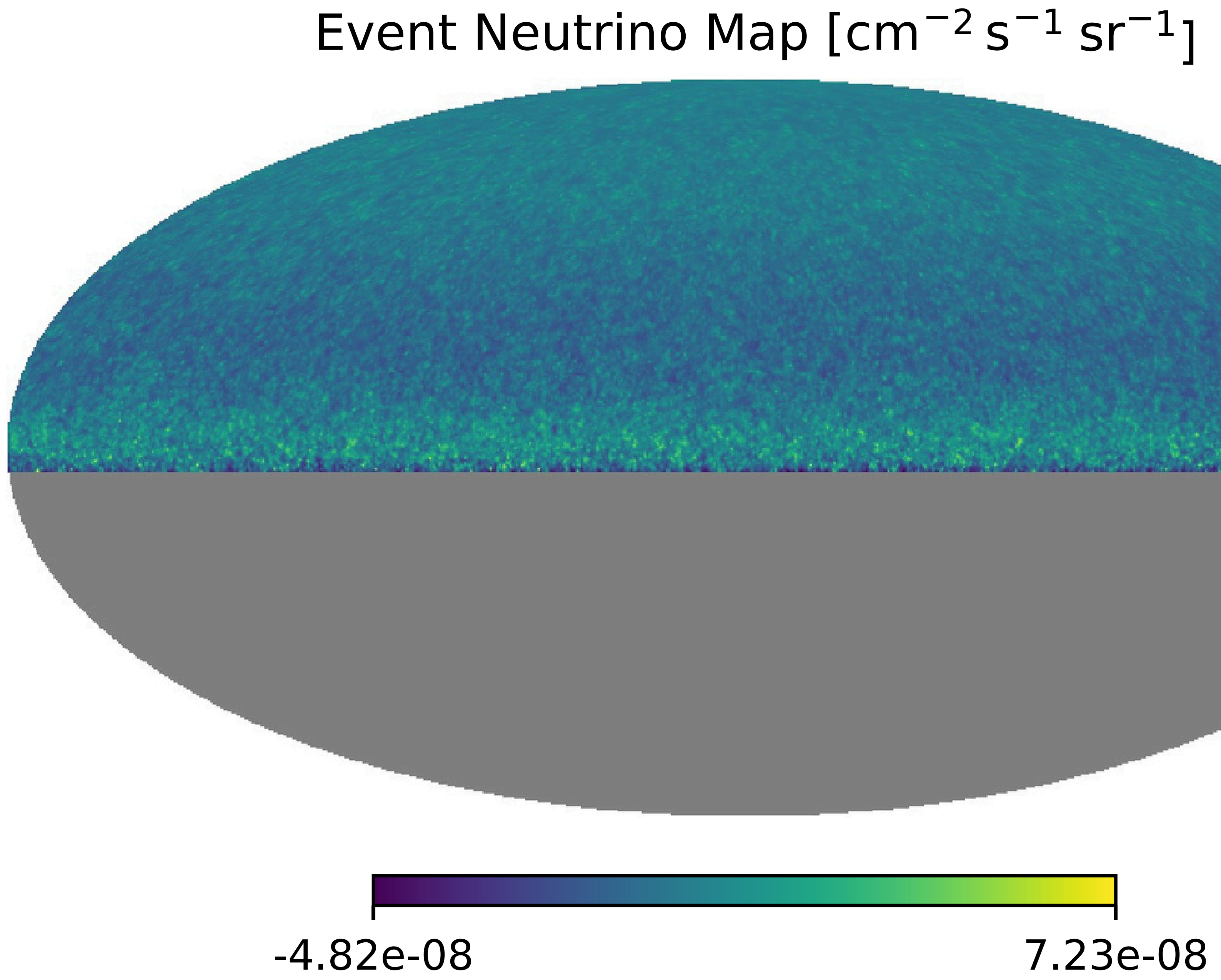
MINISTRY OF EDUCATION, YOUTH AND SPORTS

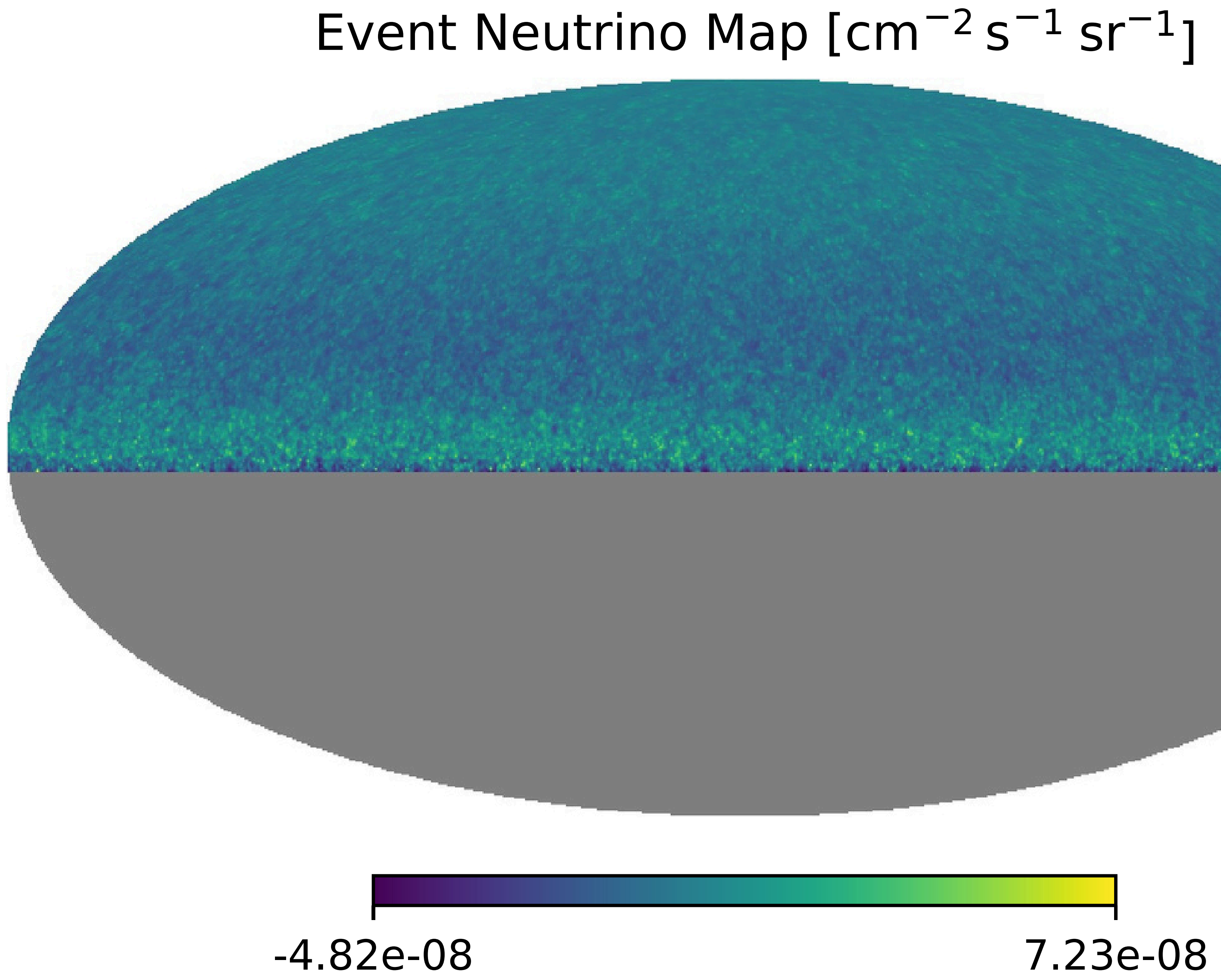
Neutrino Map



All-sky point-source IceCube data
Years: 2008-2018

10^3 to 10^6 GeV,
Declination > -5°

Neutrino Map



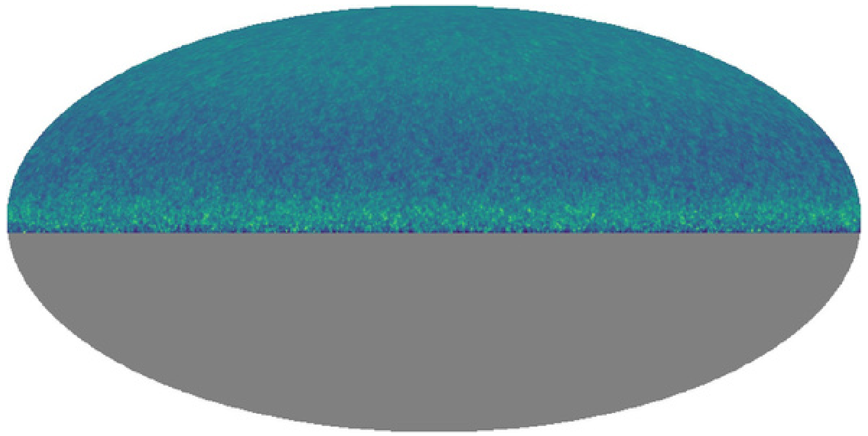
All-sky point-source IceCube data
Years: 2008-2018

10^3 to 10^6 GeV,
Declination > -5°

Most of the neutrino sources remain unknown → We can study their redshift distribution

Angular Harmonic Cross-Correlation

From data!



$$= \nu_{atm}(\theta,\phi) + \nu_{ast}(\theta,\phi) = \sum_{\ell m} Y_{\ell m}(\theta,\phi)\, a_{\ell m}^{\nu,\, atm} + \sum_{\ell m} Y_{\ell m}(\theta,\phi)\, a_{\ell m}^{\nu,\, ast}$$

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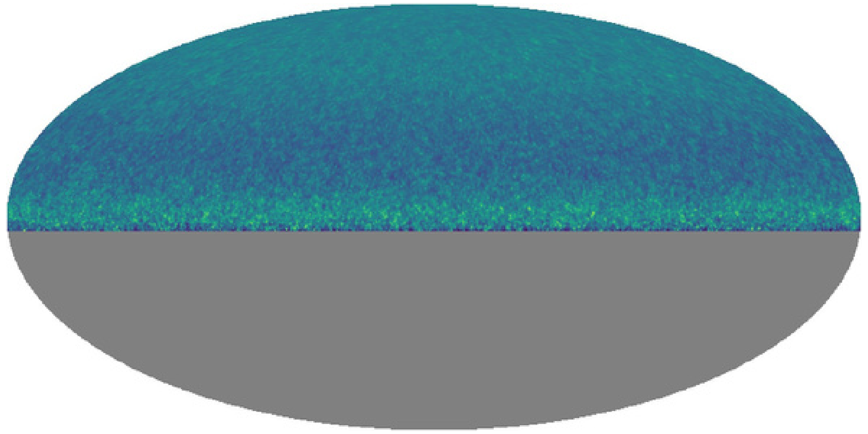

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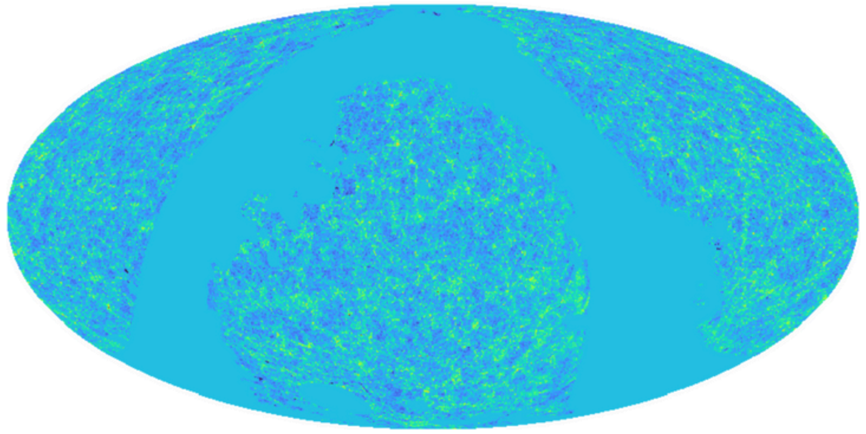

$$= \sum_{\ell m} Y_{\ell m}(\theta,\phi)\, a_{\ell m}^{gal}$$

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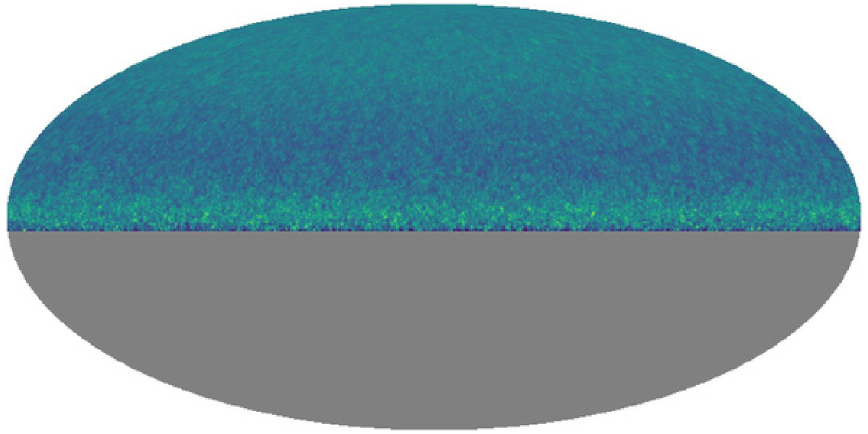

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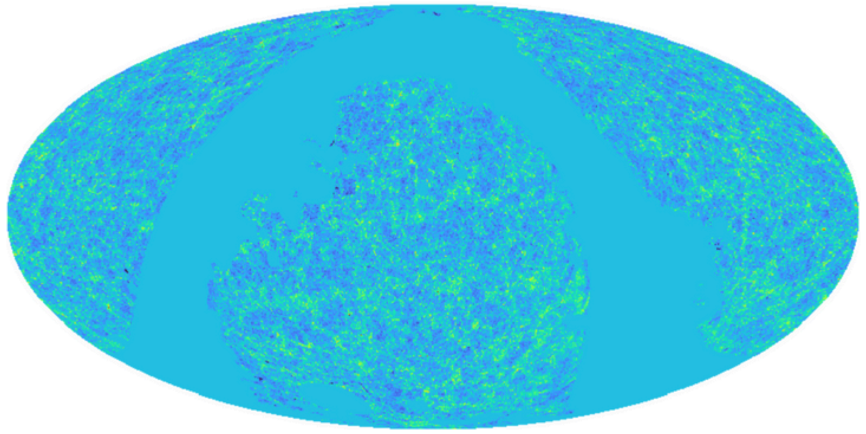

$$= \sum_{\ell m} Y_{\ell m}(\theta,\phi)\, a_{\ell m}^{gal}$$

$$C_\ell^{\nu\, g} = \cancelto{0}{C_\ell^{\nu_{atm}\, g}} + C_\ell^{\nu_{ast}\, g} = \frac{1}{2\ell+1}\sum_m a_{\ell m}^{\nu,\, ast}\,(a_{\ell m}^{gal})^*$$

$$C_\ell^{g\, g} = \frac{1}{2\ell+1}\sum_m a_{\ell m}^{gal}\,(a_{\ell m}^{gal})^*$$

Angular Harmonic Cross-Correlation

From Theory!

$$C_\ell^{\nu\,g} = b_g \int \frac{d\chi}{\chi^2} q_g(\chi) \frac{b_\nu\, \dot{\bar{n}}_\nu(z)}{4\pi(1+z)^{1-\beta}} P(k_\ell, z)$$

$$C_\ell^{g\,g} = b_g^2 \int \frac{d\chi}{\chi^2} \left[q_g(\chi)\right]^2 P(k_\ell, z)$$

Angular Harmonic Cross-Correlation

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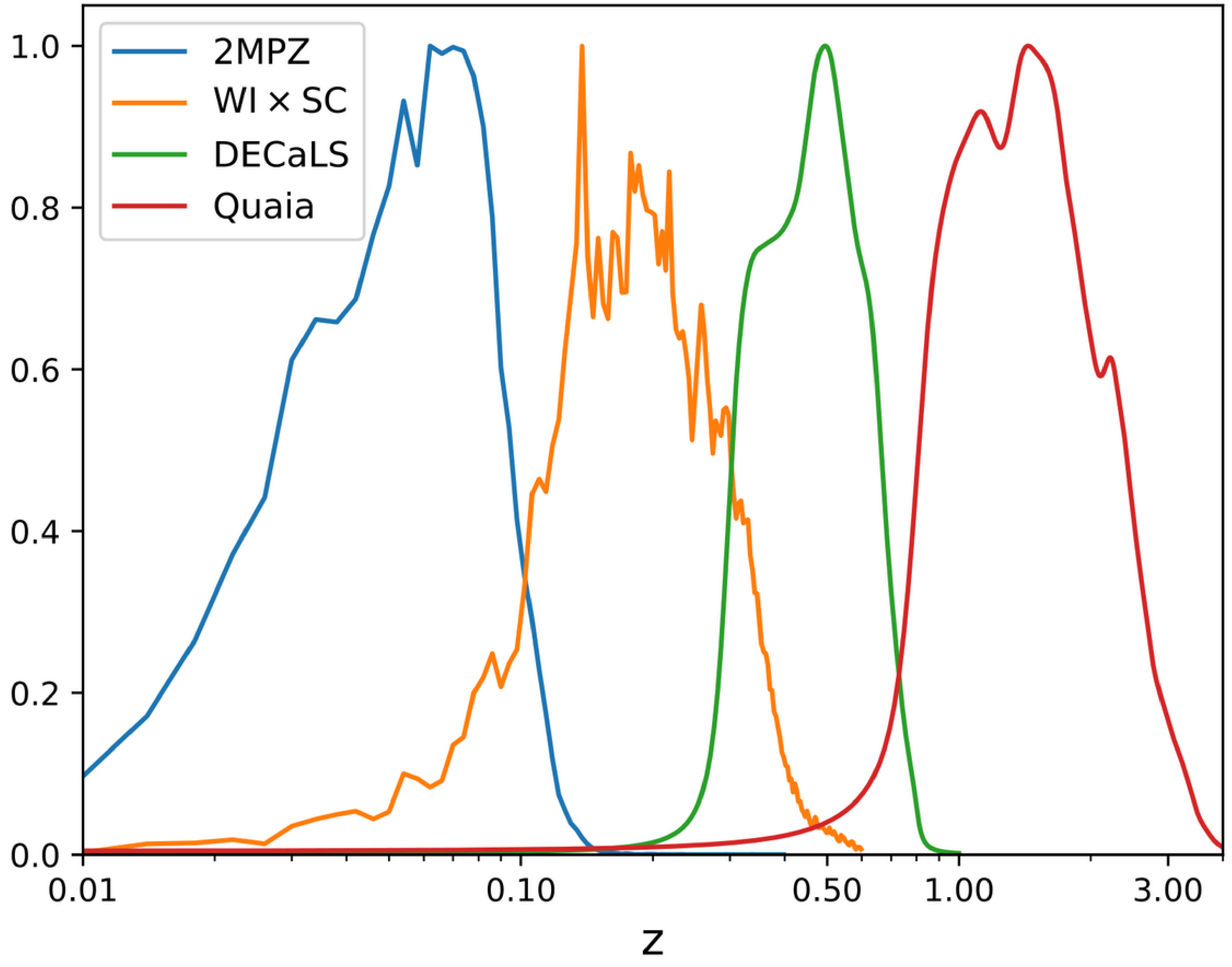

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$$C_\ell^{g\, g} = b_g^2 \int \frac{d\chi}{\chi^2} \left[q_g(\chi)\right]^2 P(k_\ell, z)$$

Power Law Model:

$$b_\nu \dot{\bar{n}}_\nu(z) = N b_\nu \,(1+z)^a \qquad \{N b_\nu,\, a\}$$

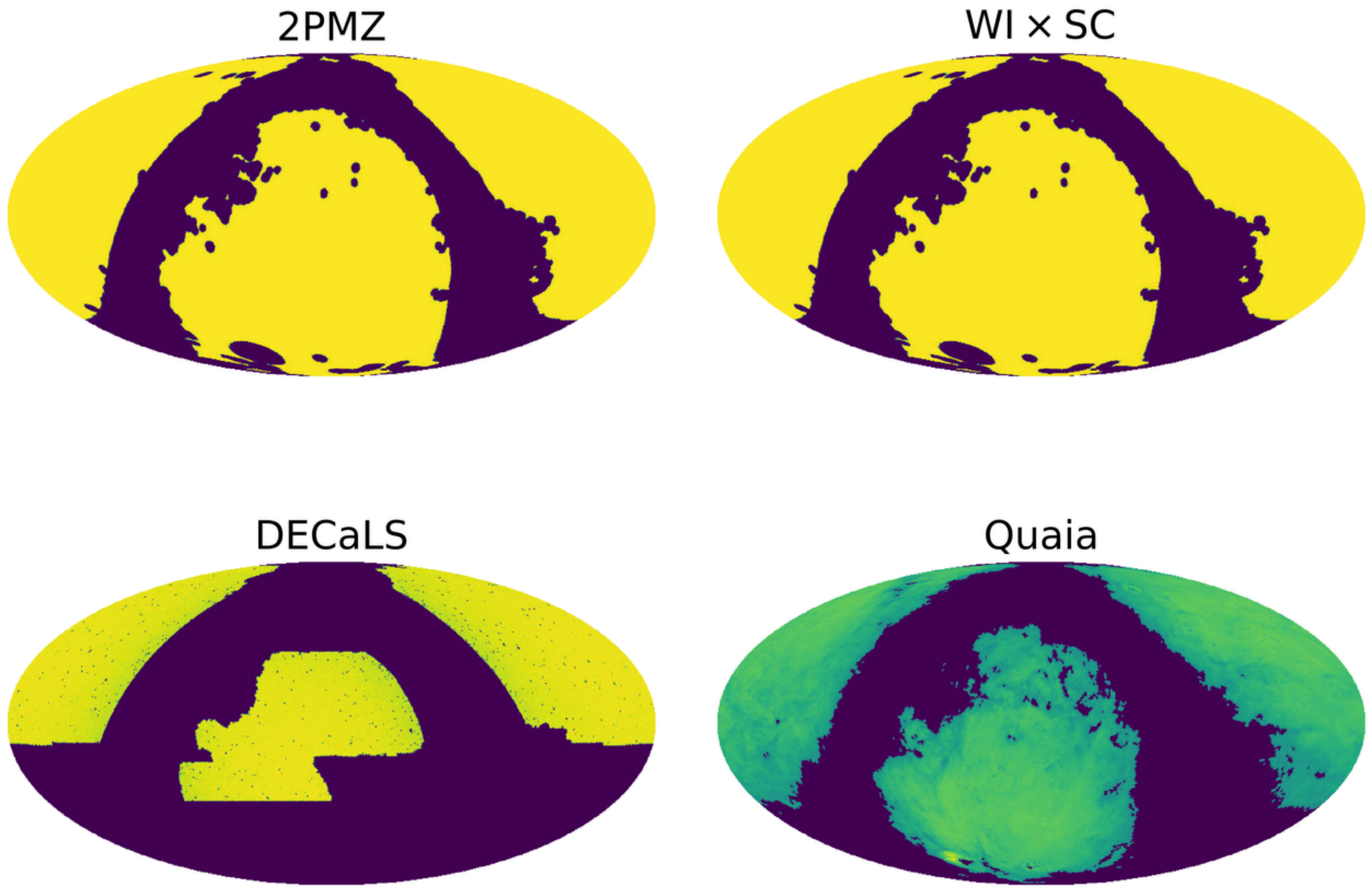
Peak Model:

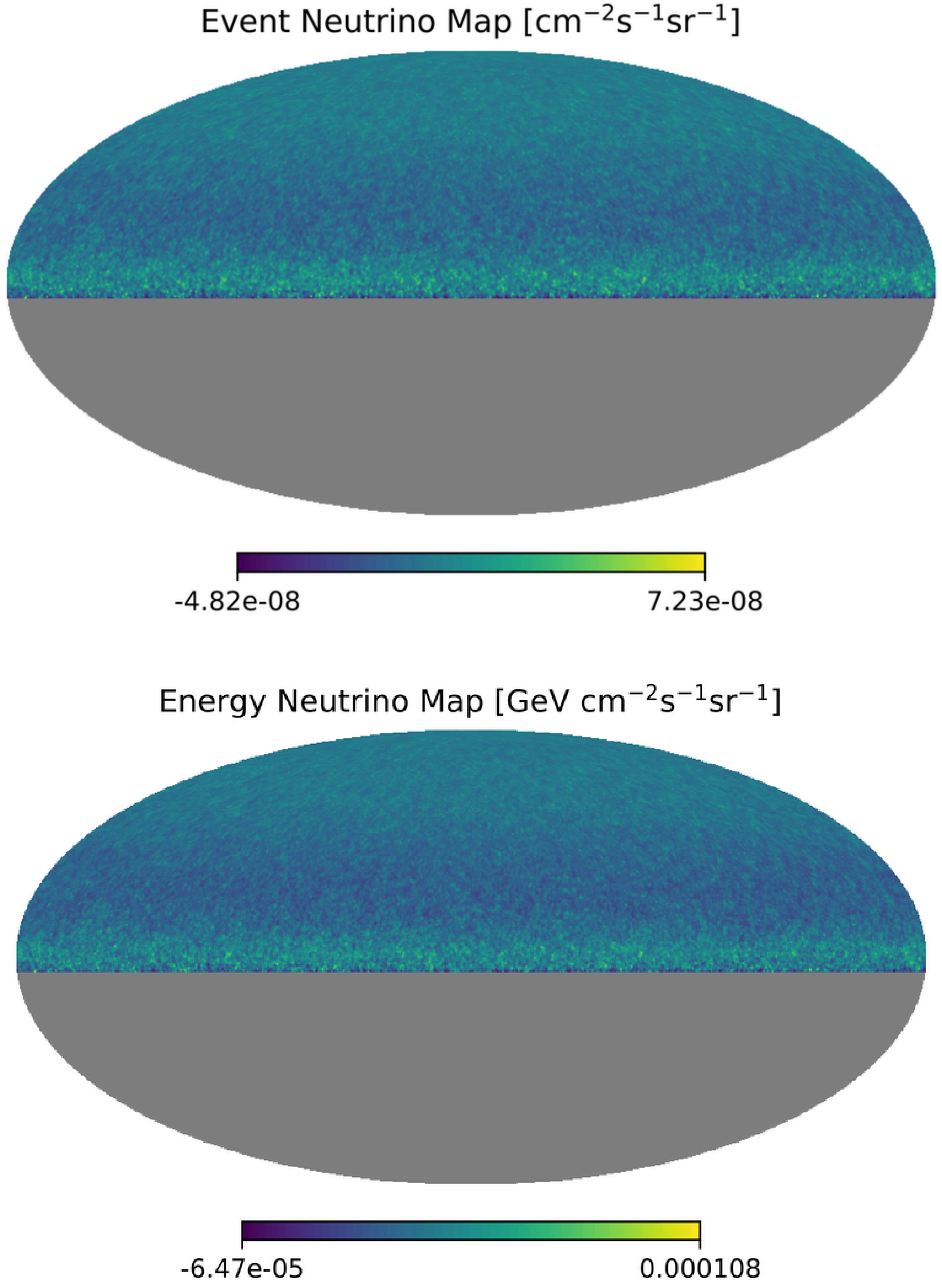
$$b_\nu \dot{\bar{n}}_\nu(z) = N b_\nu\, f_{\rm SFR}(z) \qquad \{N b_\nu\}$$

$$f_{\rm SFR}(z) \equiv \frac{(1+z)^{2.7}}{1 + ((1+z)/2.9)^{5.6}}$$

Tomographic Approach

Data Maps and Likelihood





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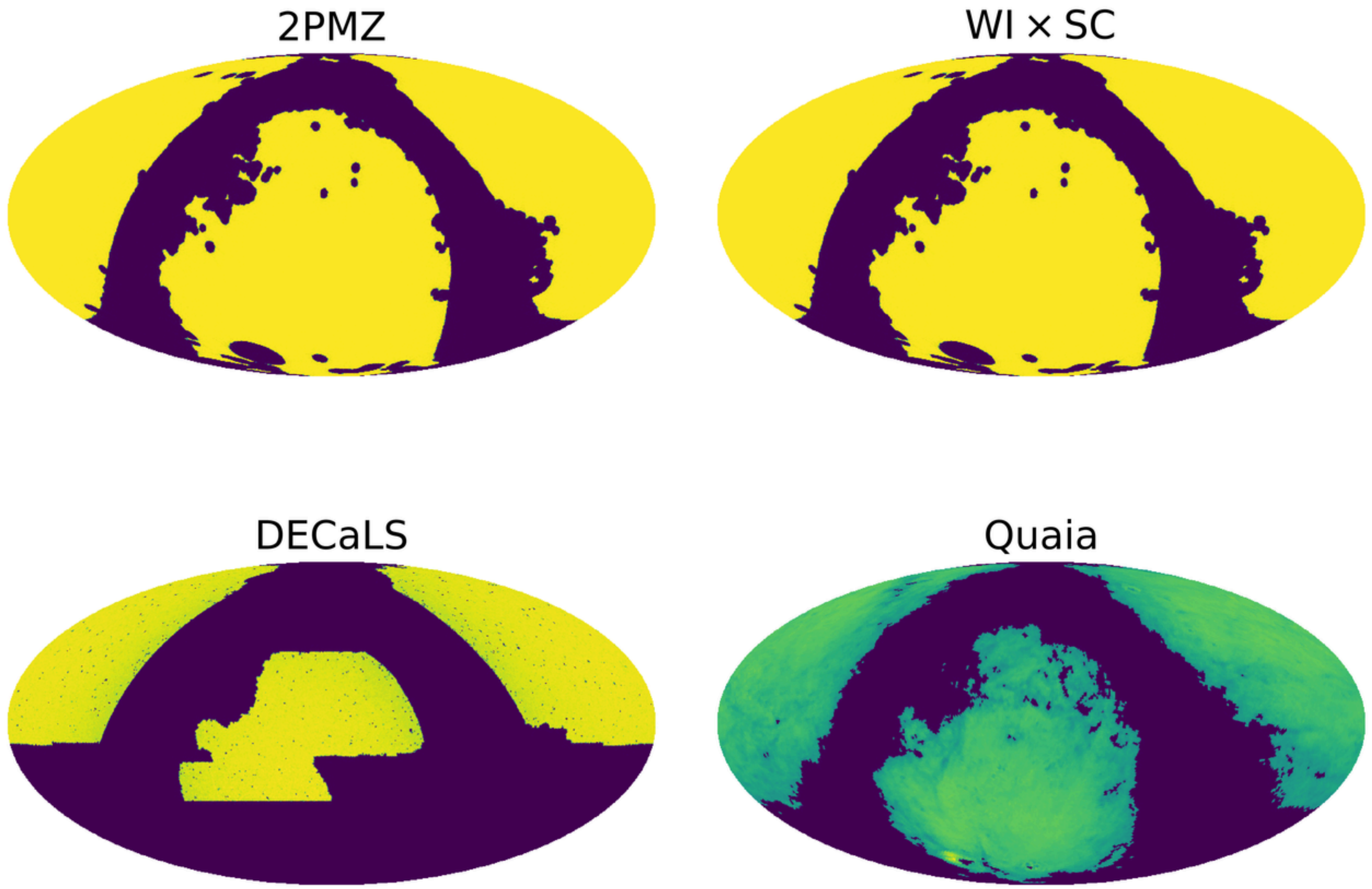
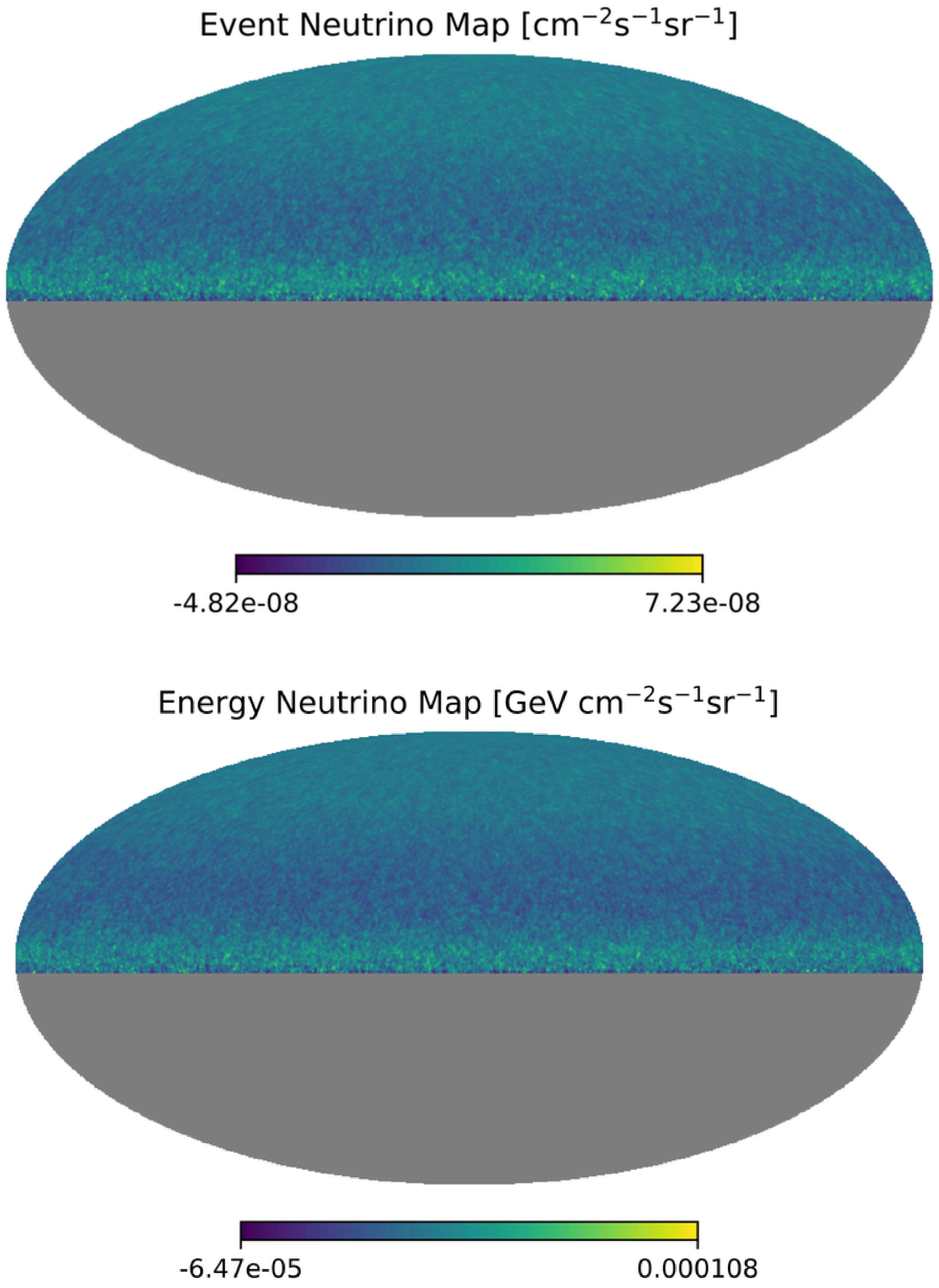
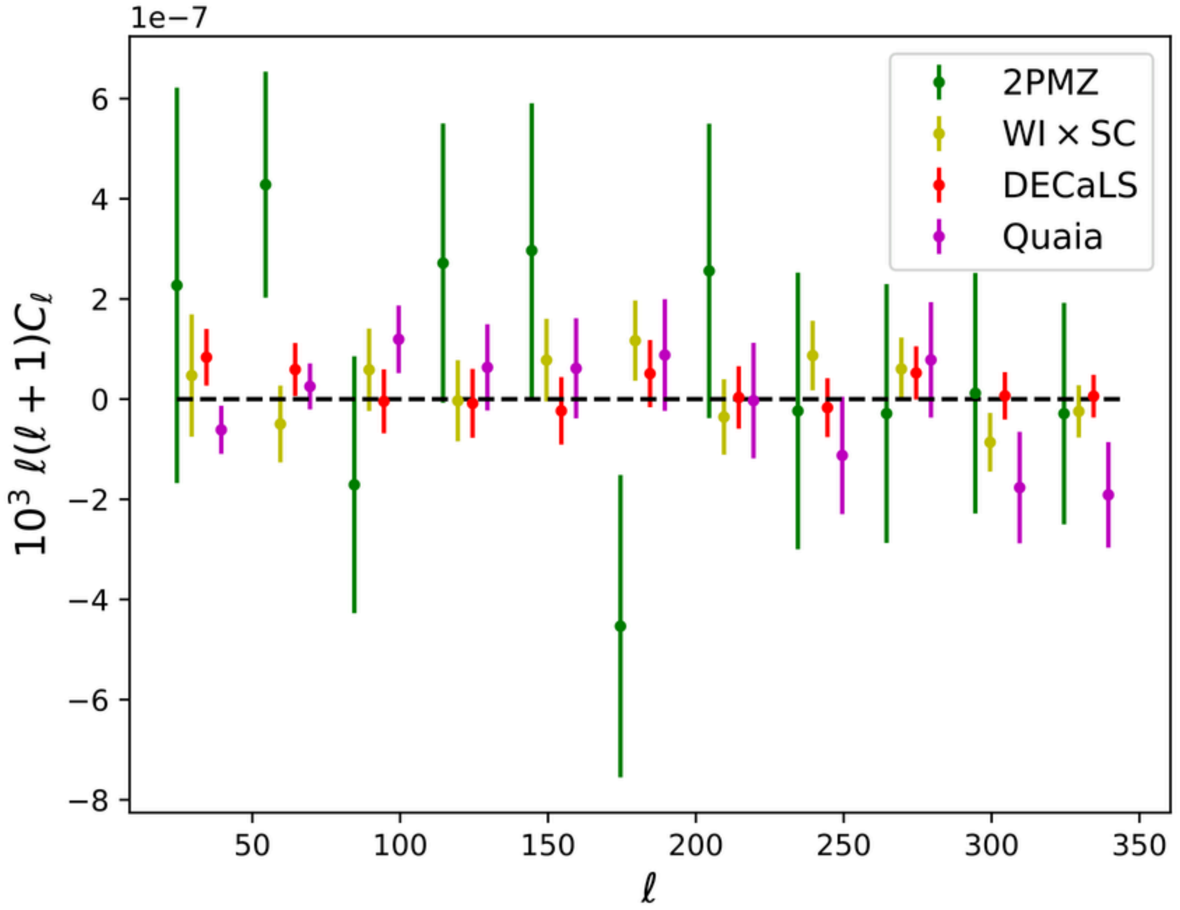
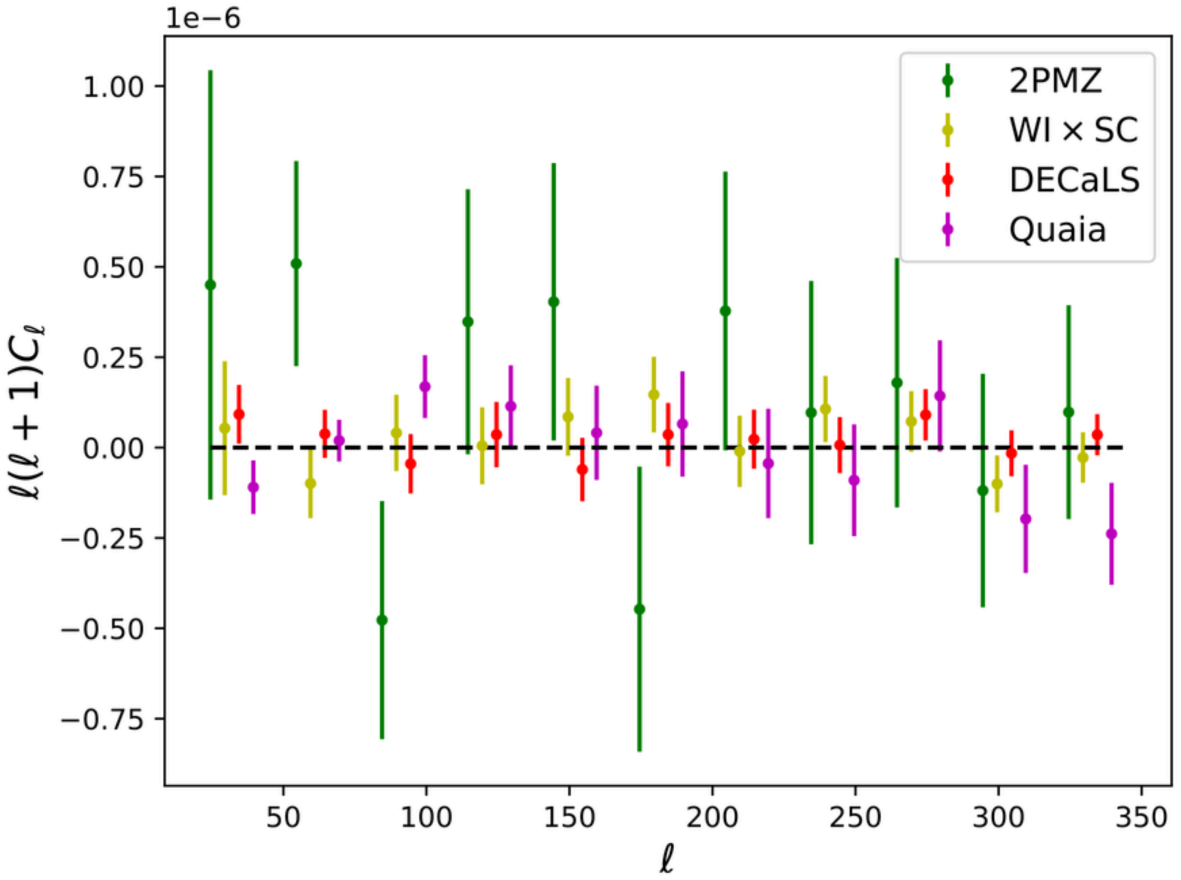




$$\mathcal{L}(\vec{\theta}) = -\frac{1}{2}\sum_{G}\left(\mathbf{C}_{D,G} - \mathbf{C}_{M,G}(\vec{\theta})\right)(\mathcal{M}_G)^{-1}\left(\mathbf{C}_{D,G} - \mathbf{C}_{M,G}(\vec{\theta})\right)$$

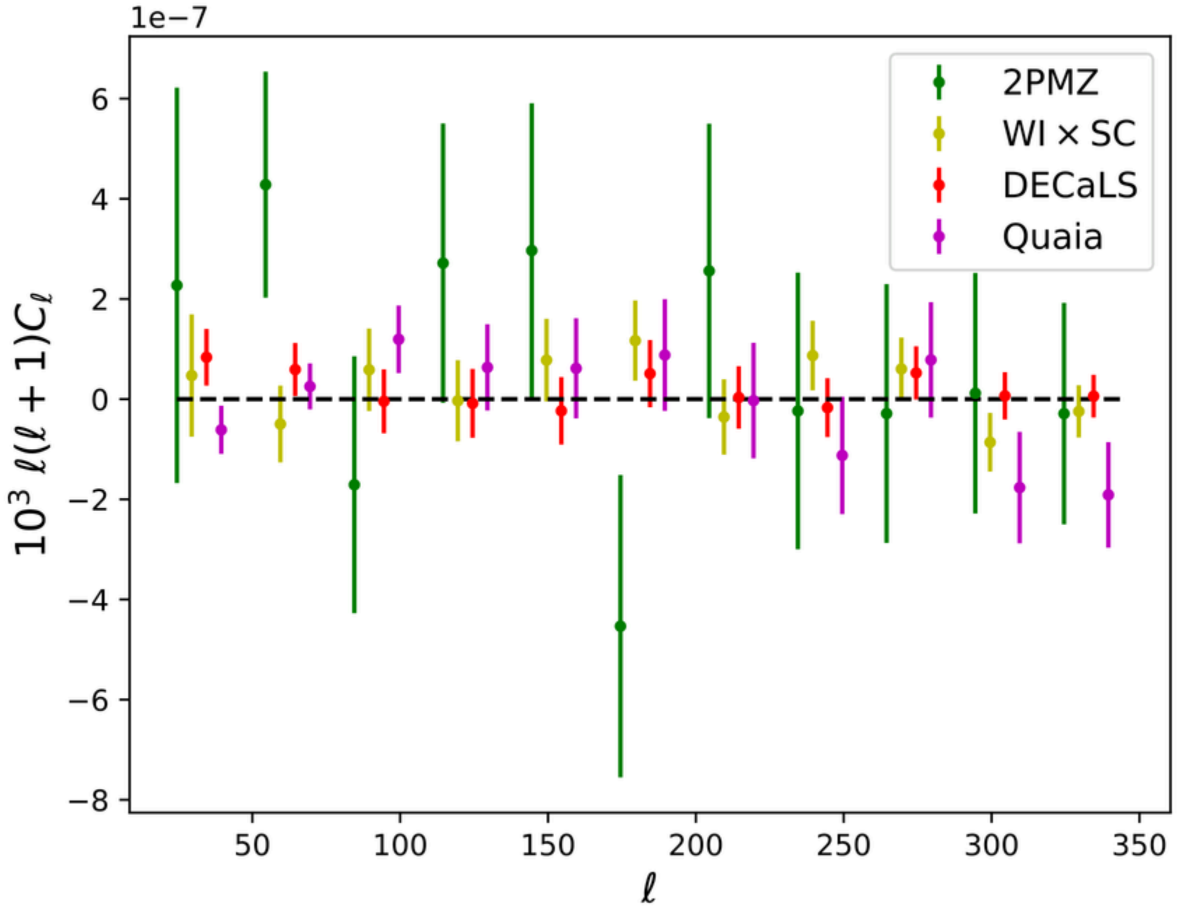
Results





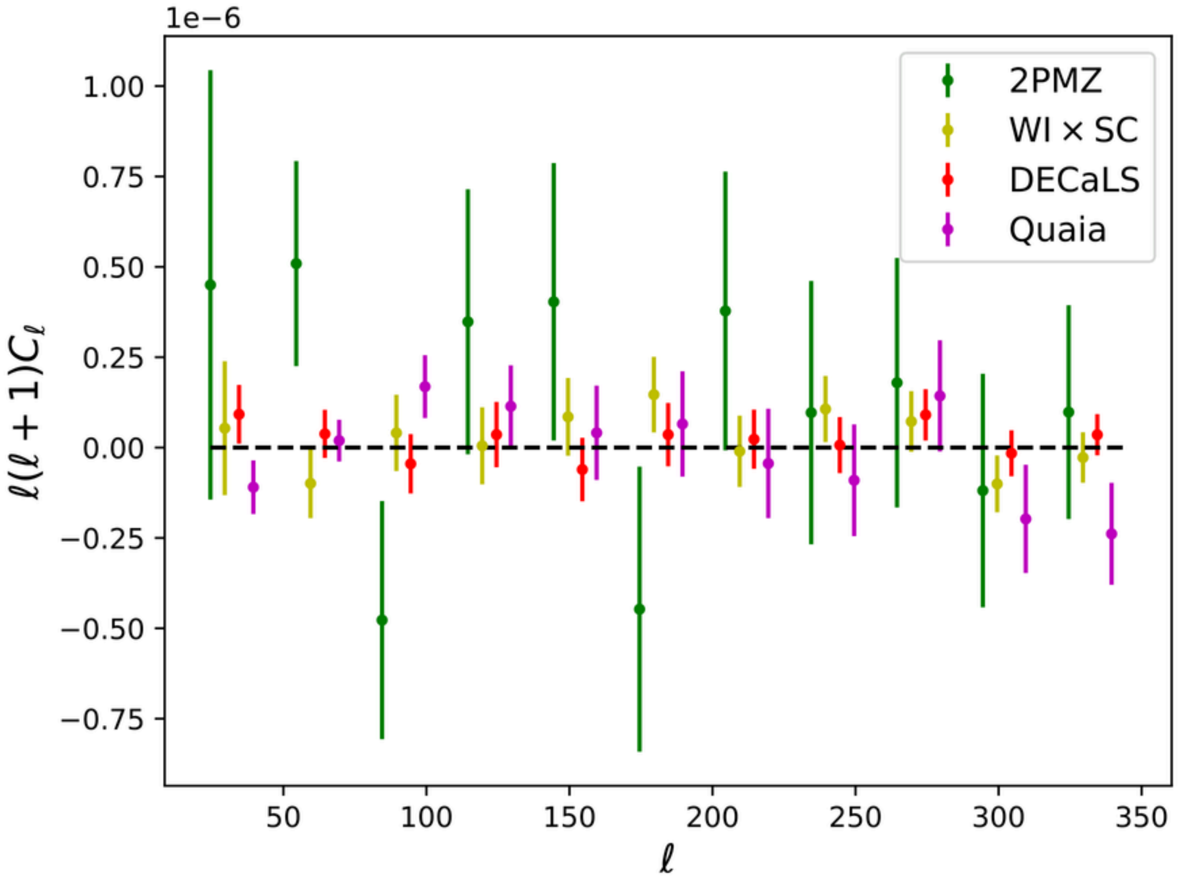
No significant Cross-Correlation

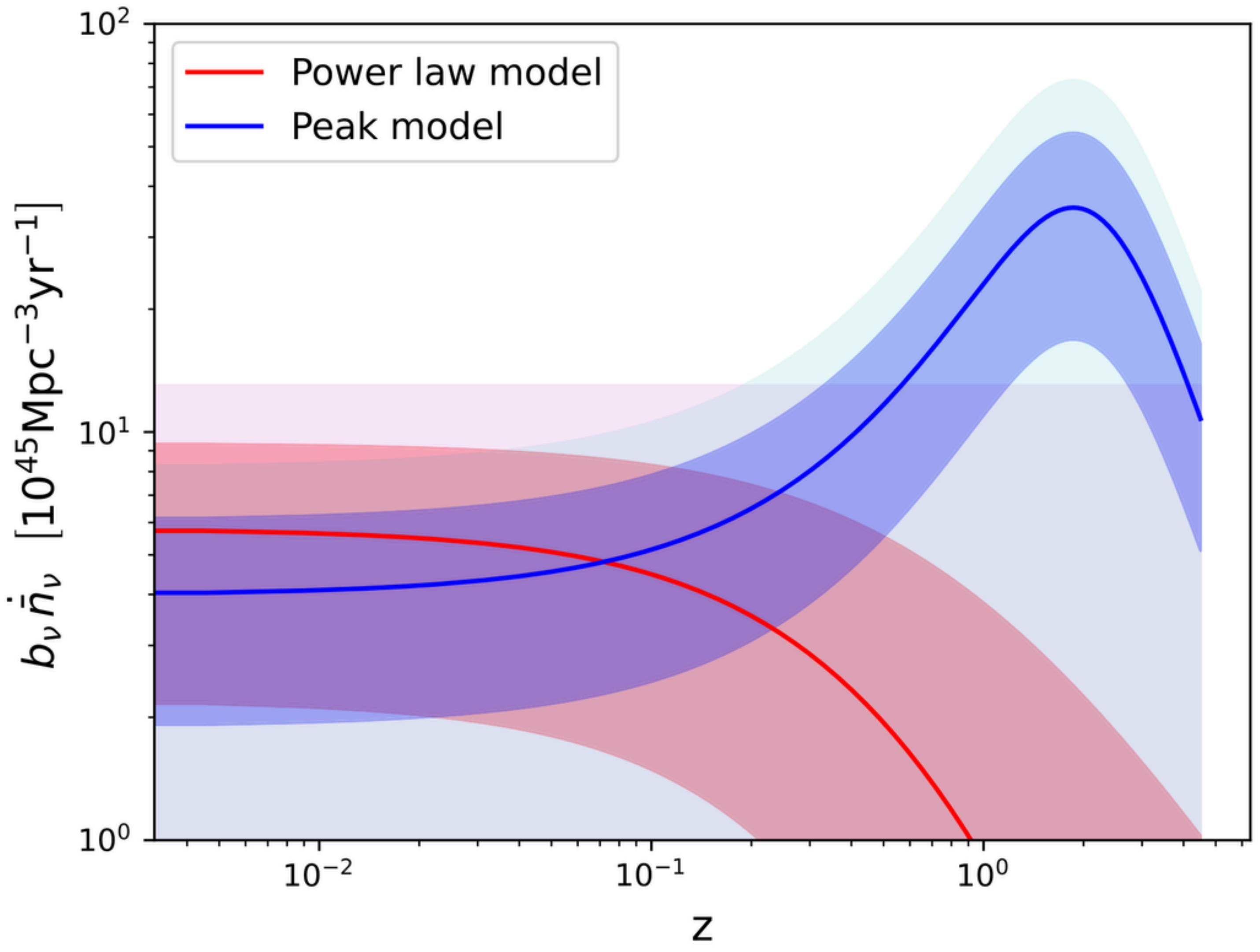
Results



No significant Cross-Correlation

We can still put constrains on each model





Tomographic Approach

Redshift Bins analyzed individually

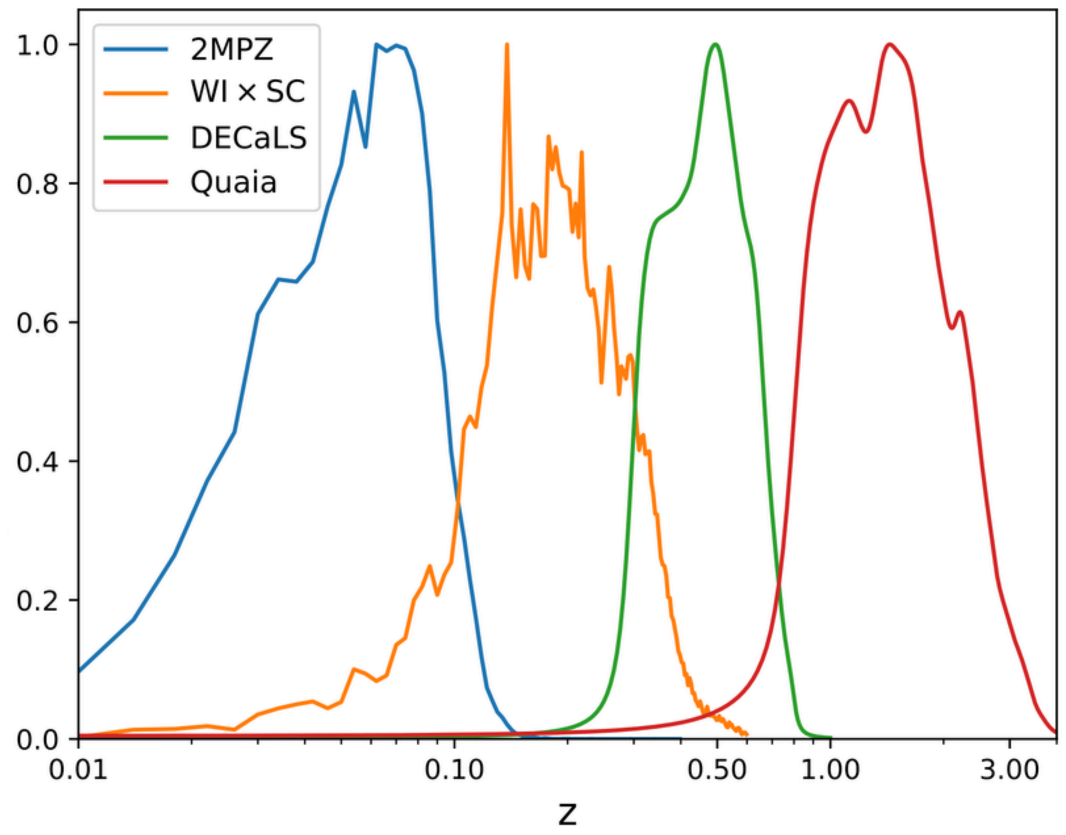
Neutrino Source Redshift distribution considered constant within each bin

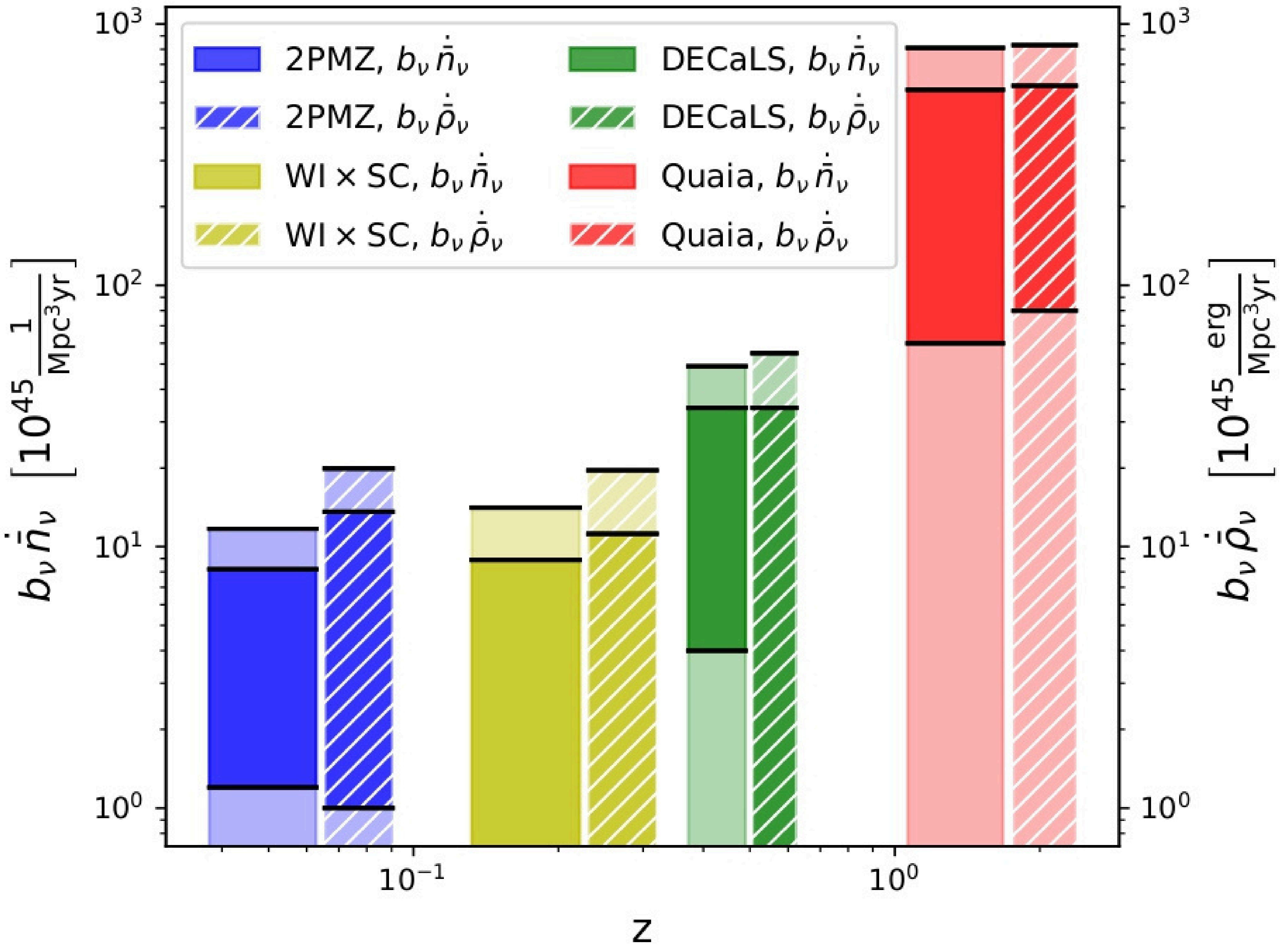
↓

Model independent constrains!

$$\mathcal{L}_G(b_\nu N)) = -\frac{1}{2}(\mathbf{C}_{D,G} - \mathbf{C}_{M,G}(b_\nu N))(\mathcal{M}_G)^{-1}(\mathbf{C}_{D,G} - \mathbf{C}_{M,G}(b_\nu N))$$

Tomographic Results





Thanks for your attention!

urena@fzu.cz

arXiv:2507.14926

Details of Neutrino Map

Each event contributes $1/A_{\text{eff}}$ or ϵ/A_{eff} ⟶ Generate the map for each season

$$\mathcal{I}(\mathbf{n}) = \frac{\sum_{i=1}^{10} \bar{A}^i_{\text{eff}}(\mathbf{n})\,\mathcal{I}^i(\mathbf{n})}{\Omega_{\text{pix}} \sum_{i=1}^{10} T_i\, \bar{A}^i_{\text{eff}}(\mathbf{n})}$$

$$\bar{A}^i_{\text{eff},p} = \frac{1}{\varepsilon_{\text{max}}^{\alpha+1} - \varepsilon_{\text{min}}^{\alpha+1}} \sum_{n=1}^{N} A_{\text{eff}}(\delta_p, \frac{\varepsilon_{n+1} - \varepsilon_n}{2})\,[\varepsilon_{n+1}^{\alpha+1} - \varepsilon_n^{\alpha+1}]$$

Results in Numbers

Considering a specific model

Model	Nb_ν	$N_\rho b_\nu$	a
Power law	5.8 ± 3.6	7.9 ± 6.3	-2.7 ± 1.4
Peak	4.0 ± 2.1	4.7 ± 3.6	

Tomographic results

	$z_{\rm av} \pm \sigma_z$	$b_\nu \dot{\bar{n}}_\nu$	$b_\nu \dot{\bar{\rho}}_\nu$
2MPZ	0.064 ± 0.026	4.7 ± 3.5	7.3 ± 6.3
WI×SC	0.23 ± 0.09	3.7 ± 5.2	2.8 ± 8.4
DECaLS	0.50 ± 0.13	19 ± 15	13 ± 21
Quaia	1.72 ± 0.66	310 ± 250	330 ± 250

Consistency tests

Model	Case	Nb_ν $\left[10^{45}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}\right]$	$N_\rho b_\nu$ $\left[10^{45}\,\mathrm{erg\,Mpc}^{-3}\,\mathrm{yr}^{-1}\right]$	a
Power law	10^3 GeV $\leq \varepsilon_o < 10^4$ GeV	5.6 ± 3.3	8.0 ± 5.8	-2.6 ± 1.4
	10^4 GeV $\leq \varepsilon_o < 10^5$ GeV	-0.018 ± 0.021	-0.48 ± 0.45	-2.7 ± 1.4
	$\varepsilon_o \geq 10^5$ GeV	0.00009 ± 0.00031	0.064 ± 0.064	-2.5 ± 1.4
	$\delta \geq +0°$	4.1 ± 3.4	5.2 ± 6.3	-2.7 ± 1.4
	$\delta \geq +5°$	1.4 ± 3.4	1.8 ± 6.4	-2.7 ± 1.4
Peak	10^3 GeV $\leq \varepsilon_o < 10^4$ GeV	4.0 ± 2.1	4.9 ± 3.5	
	10^4 GeV $\leq \varepsilon_o < 10^5$ GeV	-0.011 ± 0.013	-0.28 ± 0.25	
	$\varepsilon_o \geq 10^5$ GeV	0.00012 ± 0.00020	0.054 ± 0.038	
	$\delta \geq +0°$	2.7 ± 2.1	3.6 ± 3.7	
	$\delta \geq +5°$	1.1 ± 2.1	2.4 ± 3.9	