Berkeley Week 2024

11 March 2024

Neutrino Mass Measurement with Cosmic Gravitational Focusing (arXiv:2312.16972)

Collaboration with:

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(pronouns: He/Him/His)

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東京大学
THE UNIVERSITY OF TOKYO

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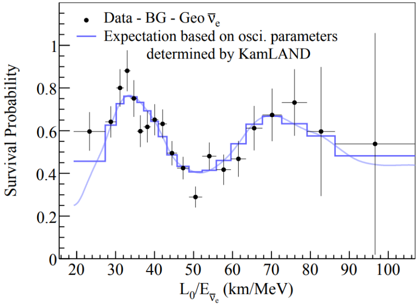

From Kamland Result
(Phys.Rev.Lett. 100 (2008))

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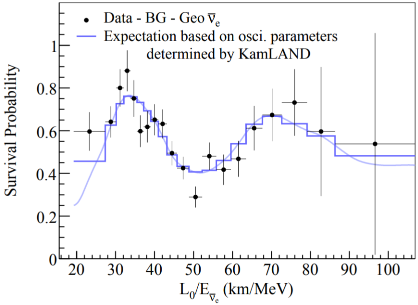

$$P_{ee} = 1 - \sin^2 2\theta \sin\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

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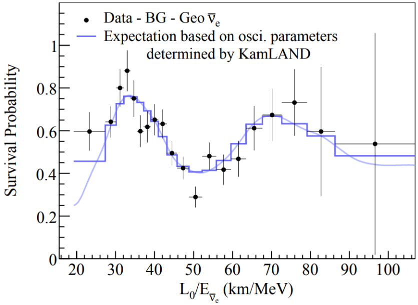

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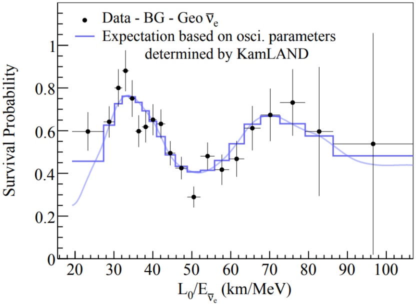

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Thus $m_{\nu_2} \neq m_{\nu_1}$

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What we know today:
(See PDG)

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To be solved by
T2HK + JUNO + DUNE

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- Flight time delay of Supernovae ν: We need a supernova and $m_\nu < 1\,$eV...

(J.-S. Lu et. al, "JCAP 05 (2015) 044")

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Future: $\sum m_\nu < 0.03\,\mathrm{eV}$ at 95% C. L.
(L. Amendola et al. , LRR 21 no. 1, (2018) 2)

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Complementary: Gravitational Focusing

Our work shows the power of complementing traditional cosmological measurements with the unexplored process of gravitational focusing between ν and DM.

(See: H.-M. Zhu et. al., PRL 113 (2014) 131301, C. Okoli et. al. MNRAS 468 no. 2, (2017) 2164–2175, and Pedro Pasquini et. al., arXiv:2312.16972)

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- In fact, $v_{\nu c}$ breaks (locally) the isotopy and generates a distinct δ_g signal.
(Imaginary part of the galaxy power spectrum)

Looks like a drag force

Let's check an intuitive picture

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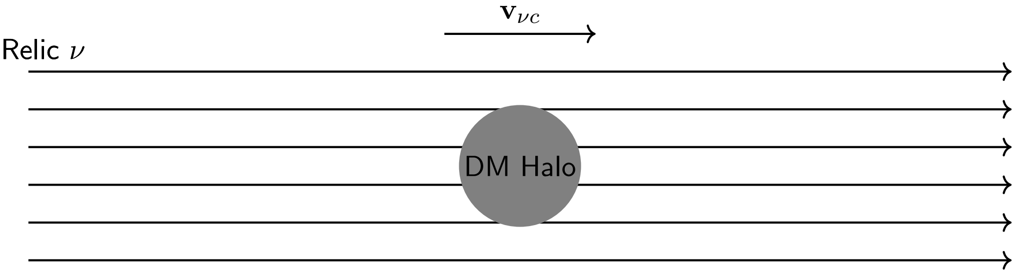

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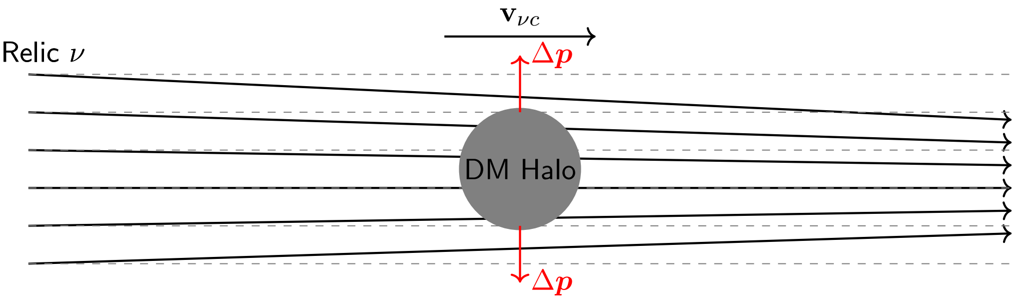

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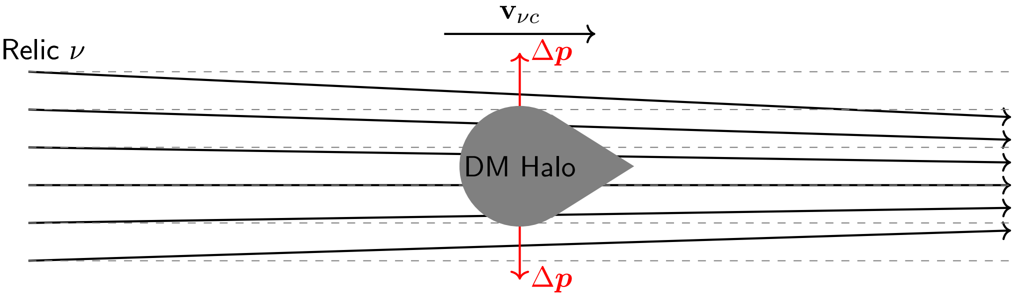

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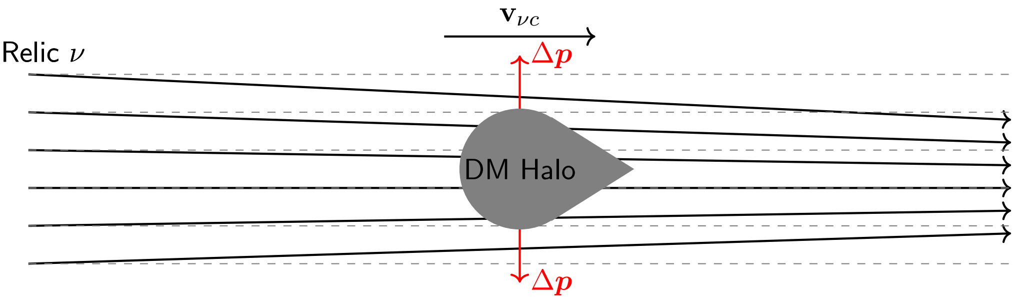

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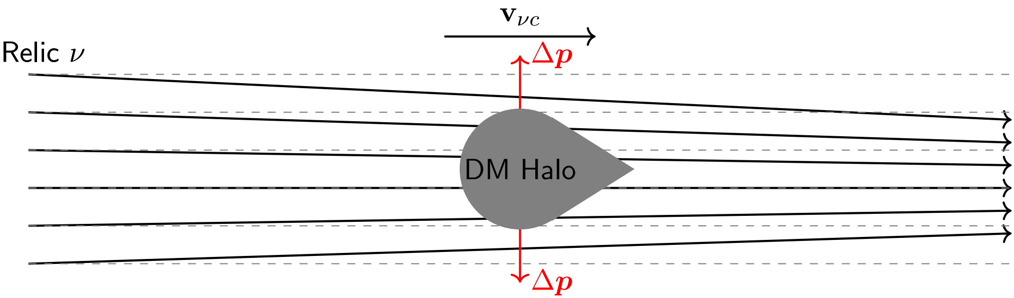

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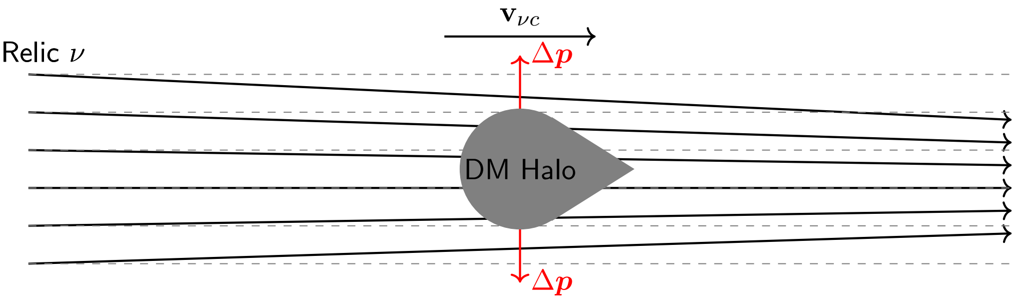

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$\propto m_\nu^4$!!!!!

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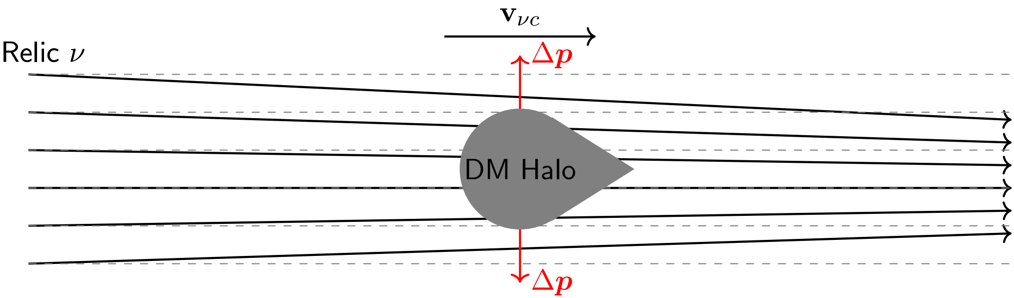

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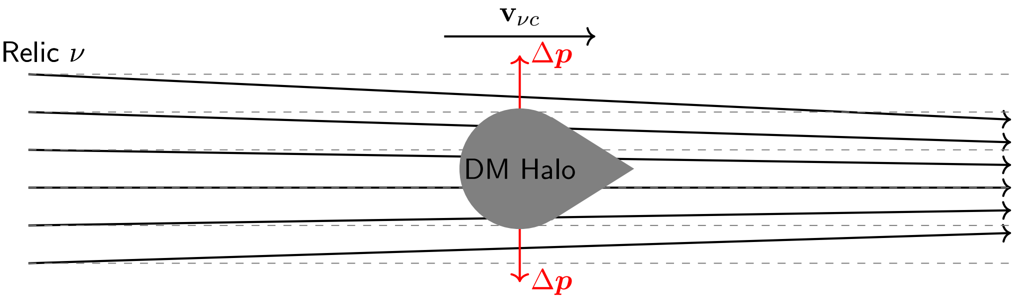

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$\exists\ \gamma$, but is small ($T_\gamma \ll m_\nu$)

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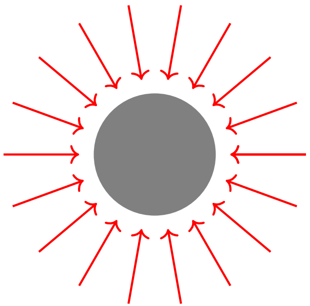

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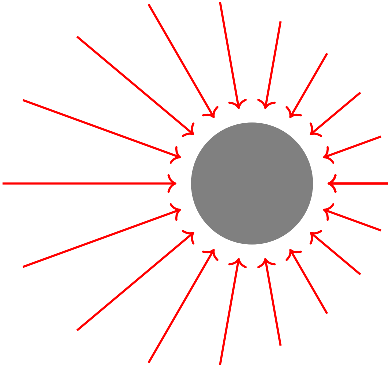

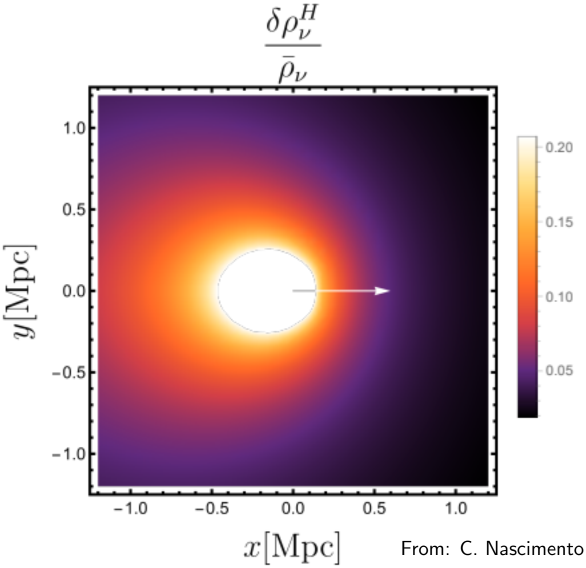

From: C. Nascimento & M. Loverde, JCAP 11 (2023) 036

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A non-zero relative velocity appears in small scales due to the mass difference of ν and DM!

$v_{\nu c}$ **power-spectrum (Classy package):**

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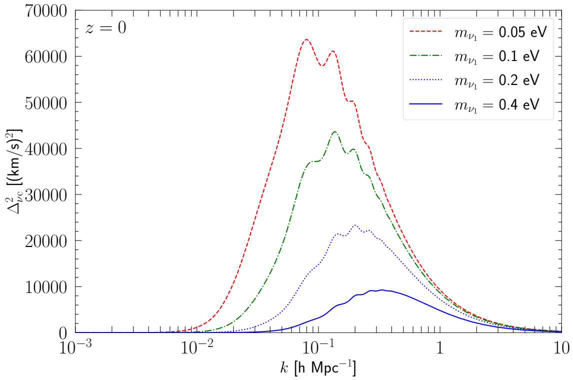

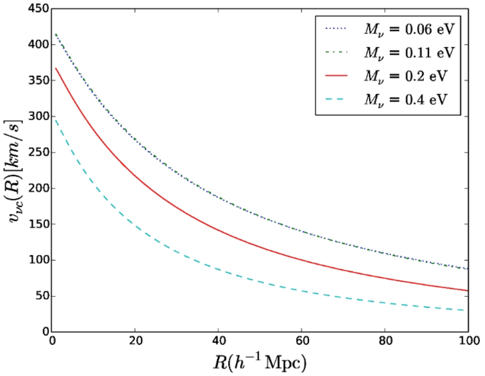

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$v_{\nu c} \neq 0$ also confirmed by N-body simulations (D. Inma et. al. PRD 92 no. 2, (2015) 023502)

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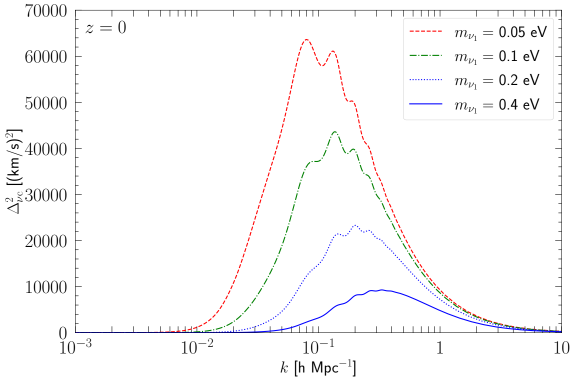

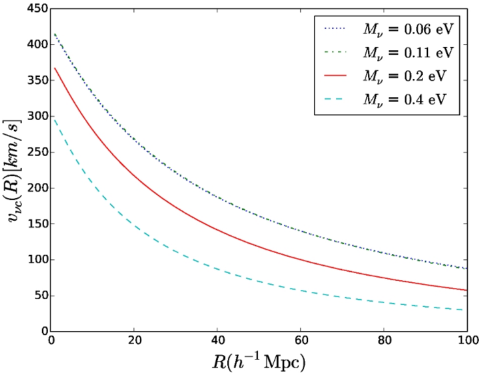

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Non-zero Im[δ_g]!

So, how to observe the effect?

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1) Local isotropy is broken ⇒ dipole term:

$$\delta(\boldsymbol{r}) \approx \delta^{(0)}(|\boldsymbol{r}|) + (\boldsymbol{v}_{\nu c} \cdot \boldsymbol{r})\delta^{(1)}(|\boldsymbol{r}|) \to \mathrm{Im}[\tilde{\delta}] \neq 0$$

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2) Galaxy distribution follows ν and DM:

$$\tilde{\delta}_g = b_c F_c \tilde{\delta}_c + b_\nu F_\nu \tilde{\delta}_\nu \qquad (F_a \equiv \rho_a/(\rho_c + \rho_\nu))$$

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3) We observe galaxy cross-correlation's imaginary part:

$$\mathrm{Im}\left[\langle \widetilde{\delta}_{g\alpha,\mathrm{RSD}} \widetilde{\delta}^*_{g\beta,\mathrm{RSD}} \rangle\right] \neq 0$$

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$$\mathrm{Im}\left[\widetilde{\delta}_{g\alpha,\mathrm{RSD}}\widetilde{\delta}^*_{g\beta,\mathrm{RSD}}\right] = -(b_c^\alpha b_\nu^\beta - b_\nu^\alpha b_c^\beta)\widetilde{\delta}^2_{m0}\widetilde{\phi} - (b_c^\alpha - b_c^\beta)\frac{\mu_{\boldsymbol{k}}^2}{H}\widetilde{\delta}_{m0}(\dot{\widetilde{\delta}}_{m0}\widetilde{\phi} + \widetilde{\delta}_{m0}\dot{\widetilde{\phi}}) + (b_\nu^\alpha - b_\nu^\beta)\frac{\mu_{\boldsymbol{k}}^2}{H}\dot{\widetilde{\delta}}_{m0}\widetilde{\delta}_{m0}\widetilde{\phi}$$

with $\tilde{\phi} \equiv \mathrm{Im}\left[\frac{\tilde{\delta}_m}{\tilde{\delta}_{m0}}\right] \propto |\boldsymbol{v}_{\nu c}| m_\nu^4$

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We optimized/illustrate the analysis for the DESI survey.

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Natural separation and $\neq b_c$!

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Halo mass can be inferred: X. Yang et al. AJ 909 no. 2, (2021) 143

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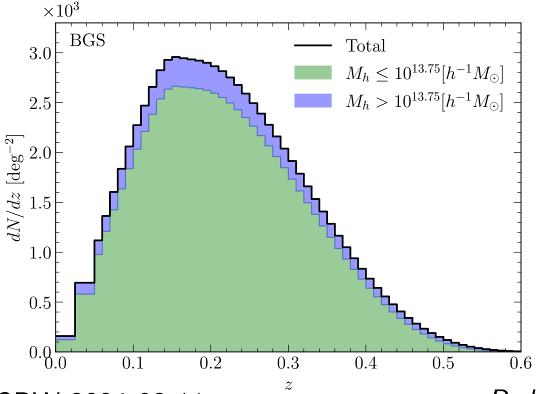

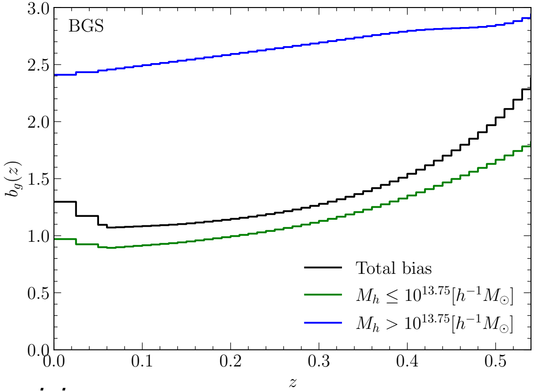

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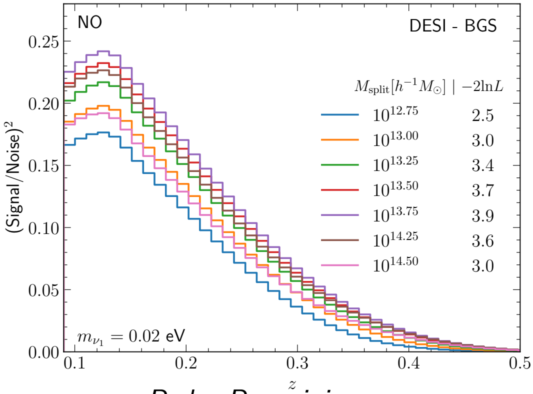
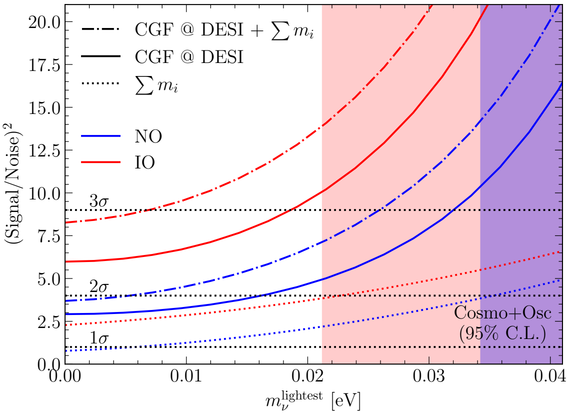


Almost 3σ for IO guaranteed!

Finally our result:



Dotted line: $\sum m_\nu < 0.13\,$eV 95% C.L. signal-like

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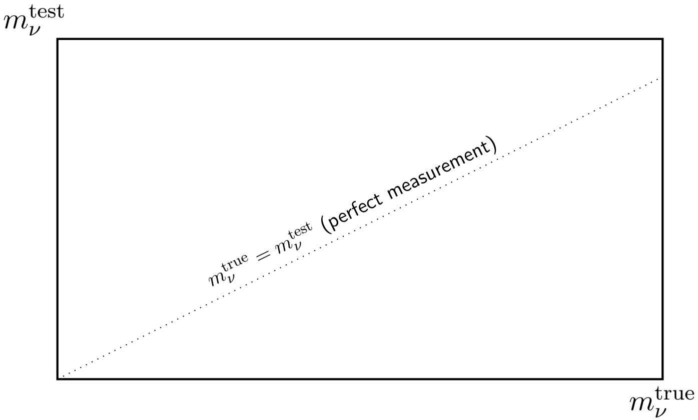

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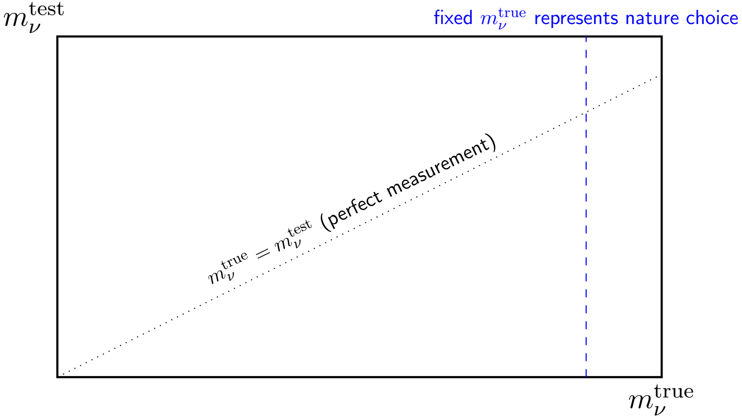

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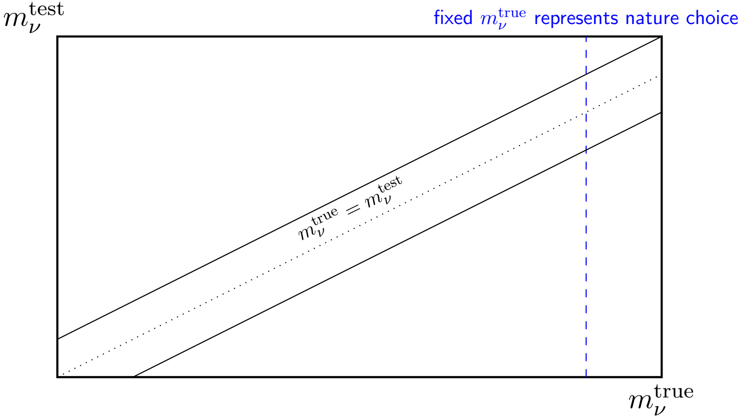

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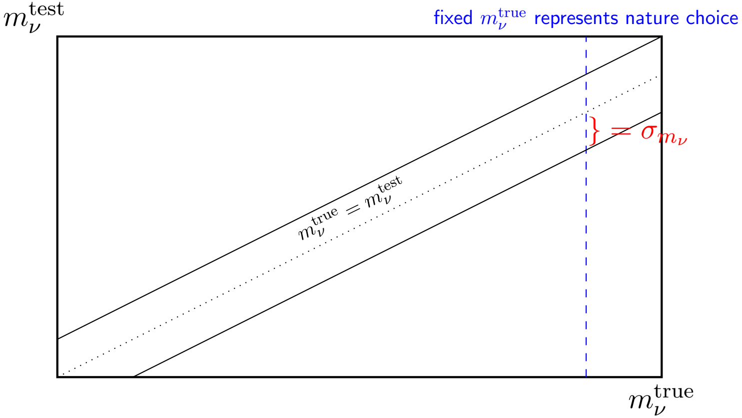

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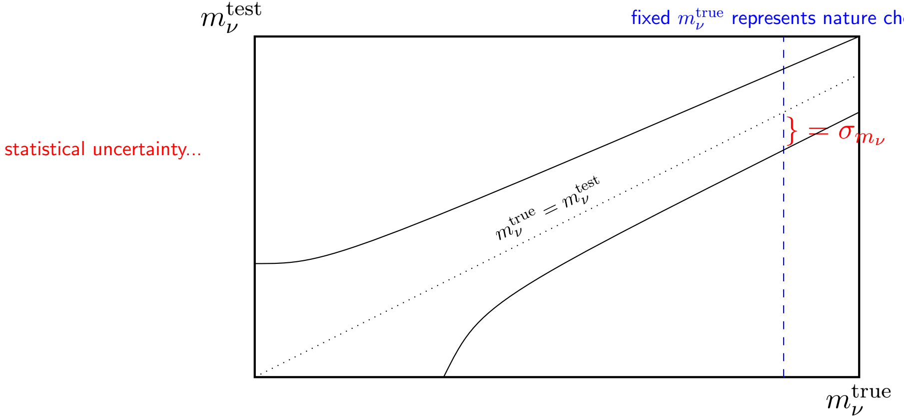

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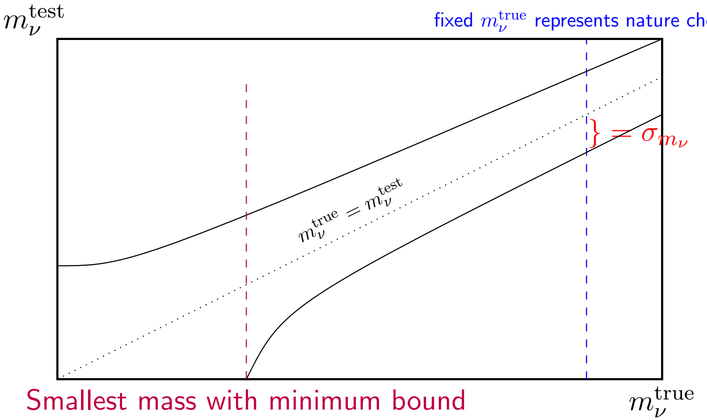

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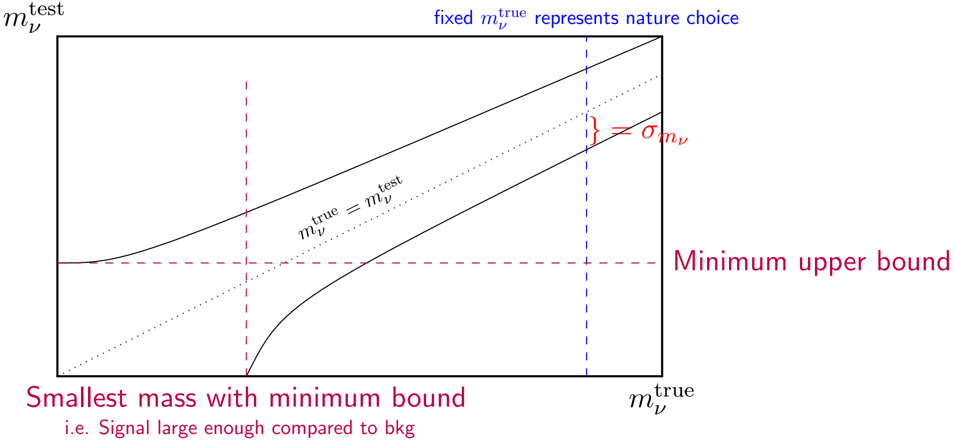
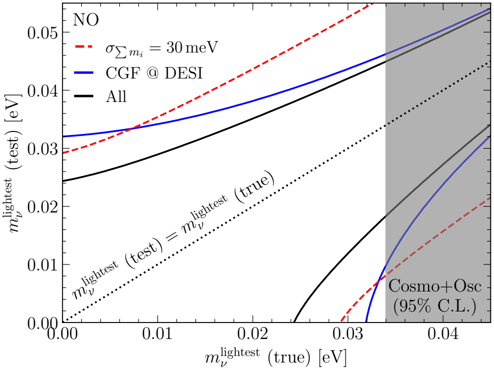
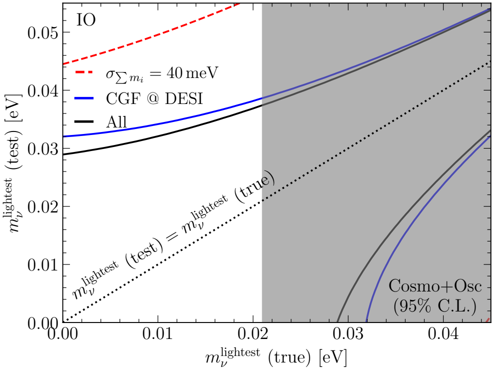


Synergy improves potential measurement!





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Any questions?

Founding Support:

Double First Class start-up fund (WF220442604), the Shanghai Pujiang Program (20PJ1407800), National Natural Science Foundation of China (No. 12090064), and Chinese Academy of Sciences Center for Excellence in Particle Physics (CCEPP). and the Grant-in-Aid for Innovative Areas No. 19H05810