Dark Sector Spectroscopy with Quantum-Gravitational Decoherence

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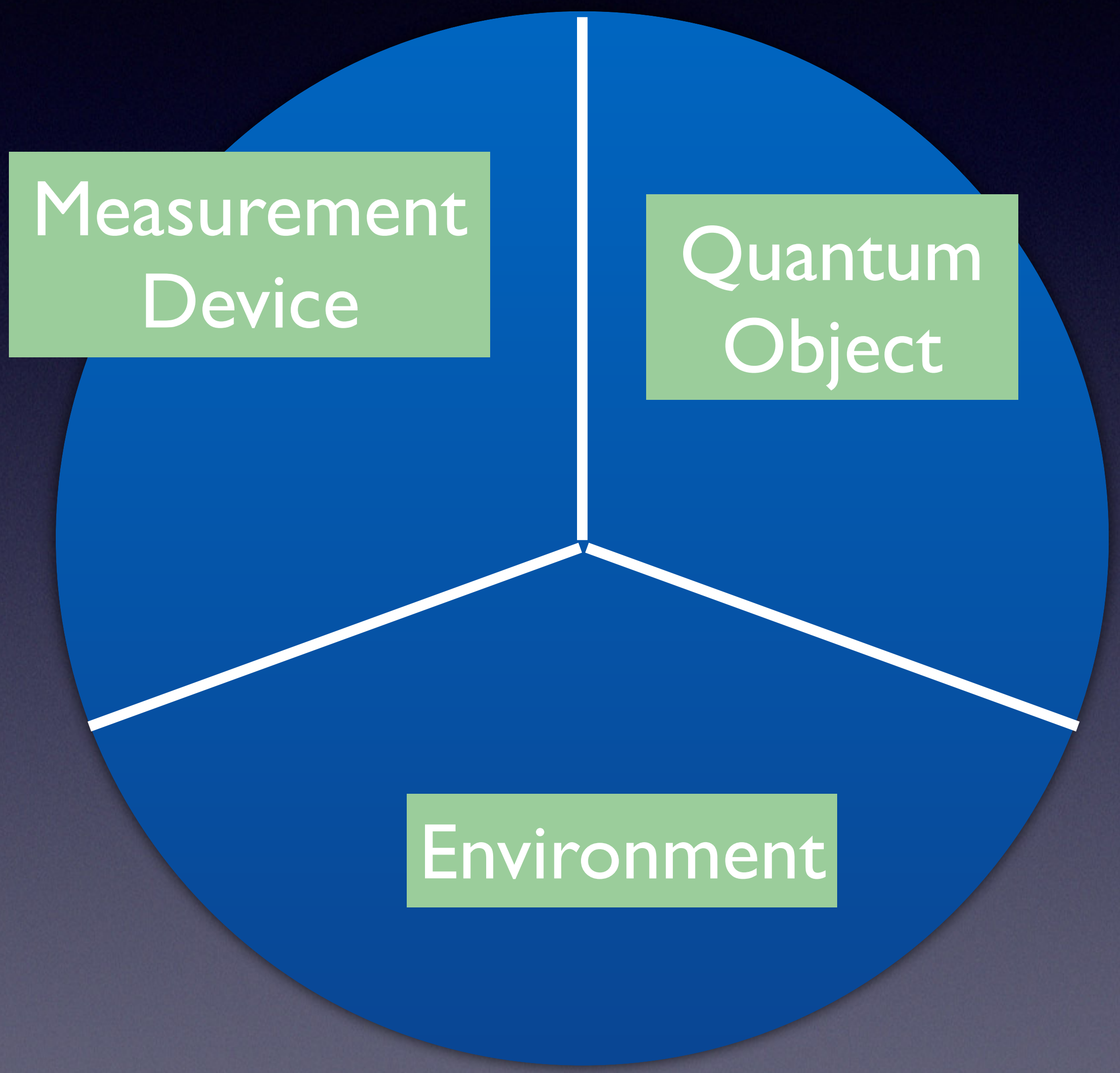
A Very Brief Outline

- What is Quantum-Gravitational Decoherence?
- How does it help to study Hidden Dark Sectors?

Decoherence

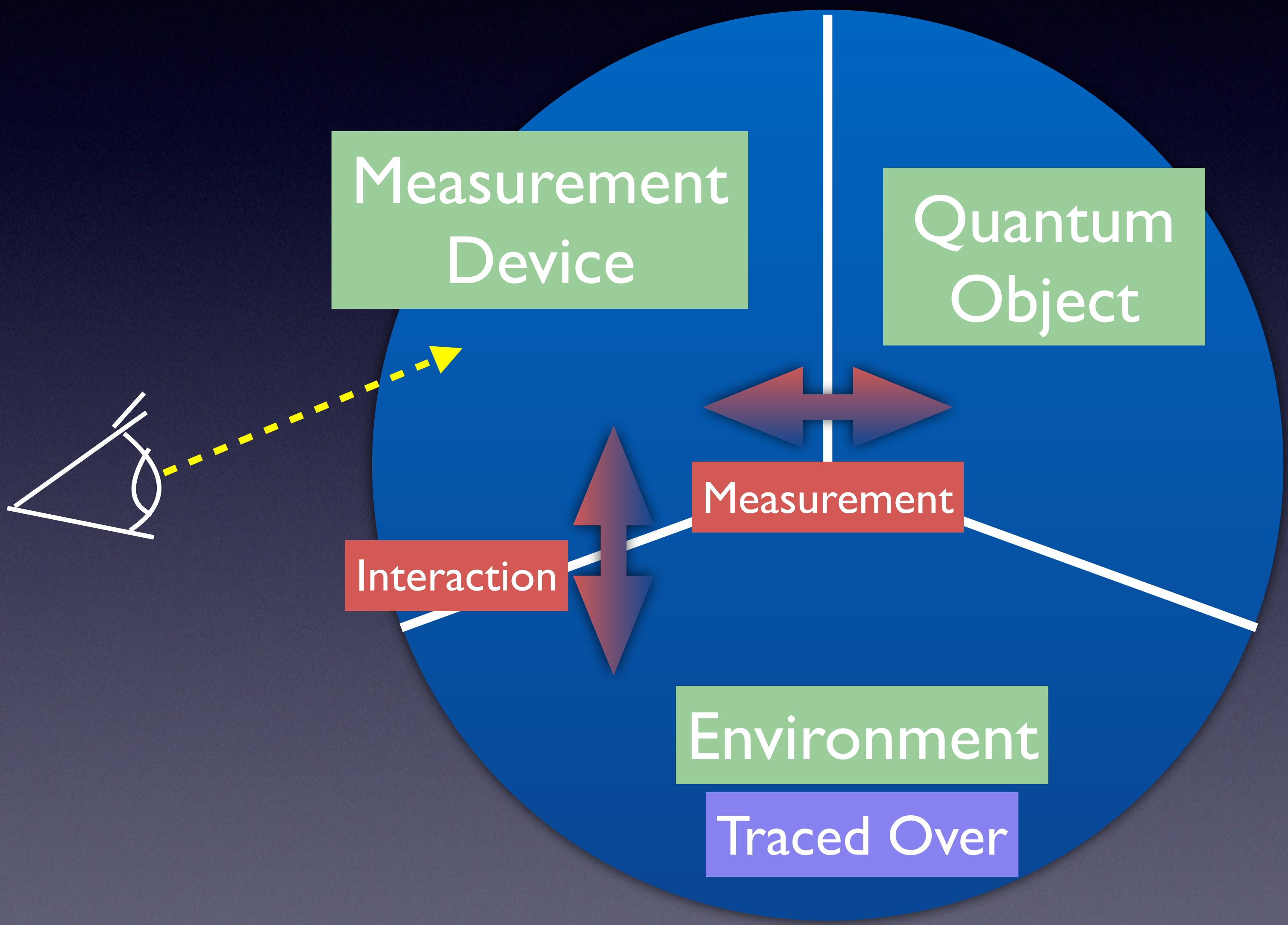
H.D. Zeh, Z. Phys. A 1970

Decoherence



H.D. Zeh, Z. Phys. A 1970

Decoherence



H.D. Zeh, Z. Phys. A 1970

Decoherence

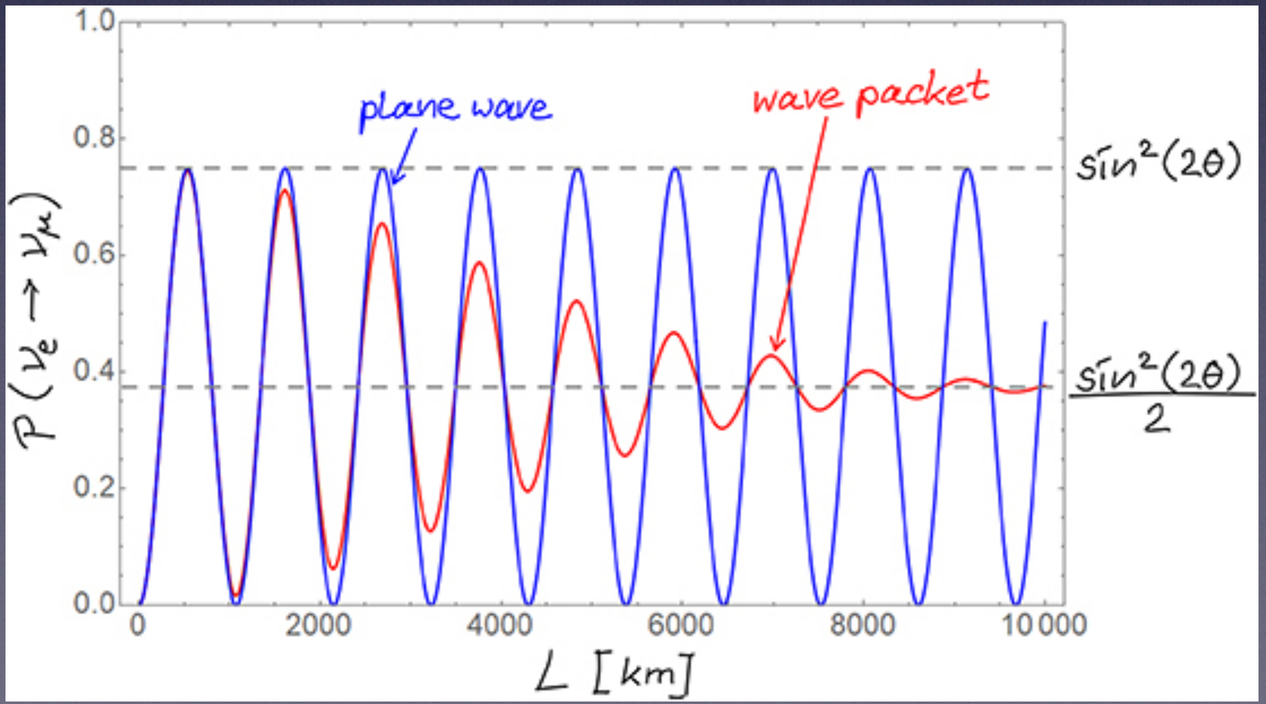
- Suppression of interference terms
- Looks like a quantum "collapse" for the observer
- One if not "the" defining process in the quantum-to-classical transition

H.D. Zeh, Z. Phys. A 1970

Neutrinos

Compare Ting Cheng's talk yesterday!

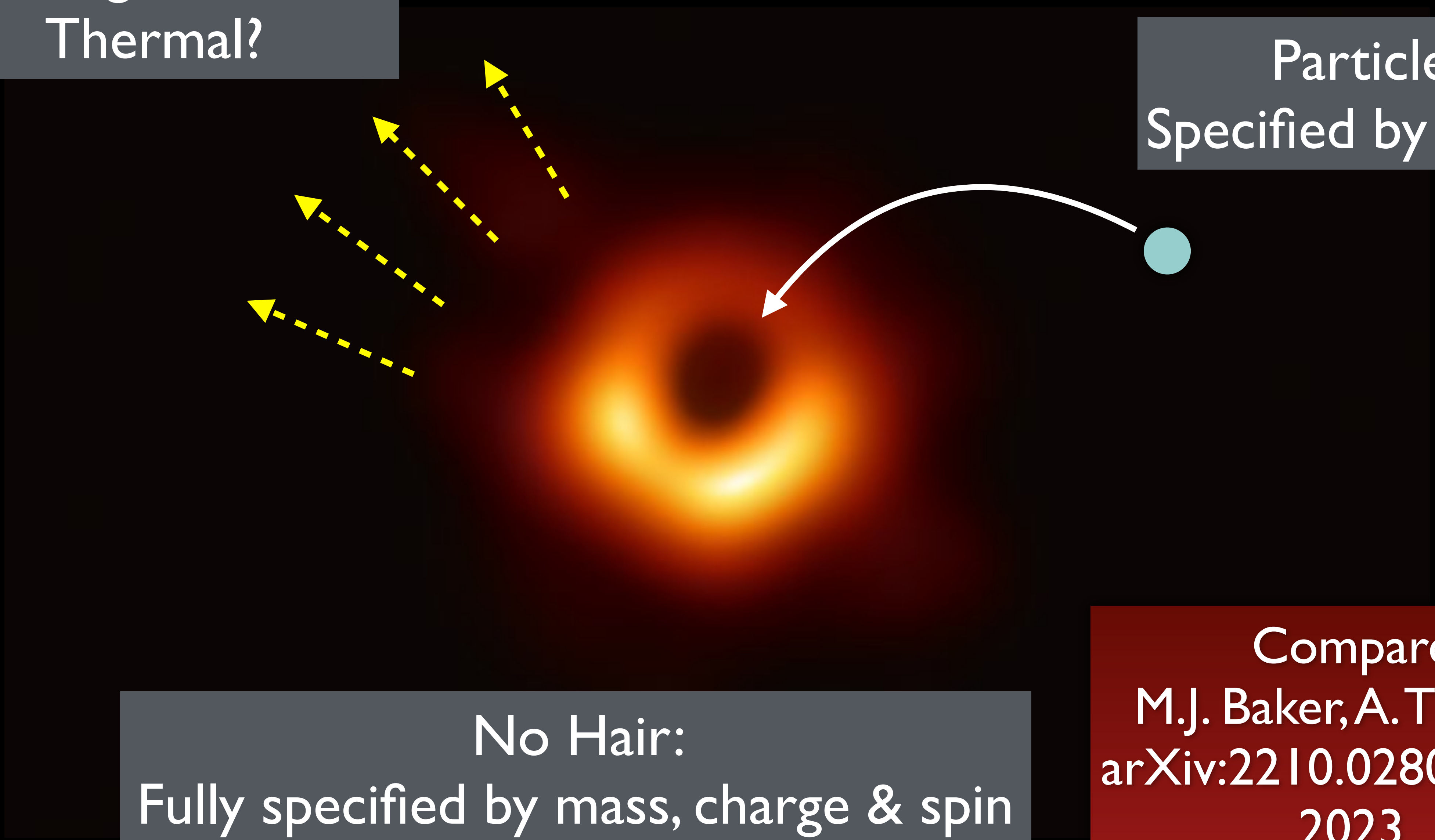
- Imperfect momentum measurement at production
- Wave packages getting separated & oscillations damped during propagation



F. Deppisch: "Neutrino Oscillations", IOP 2019

Decoherence at the Black Hole Horizon

Hawking Radiation:
Thermal?

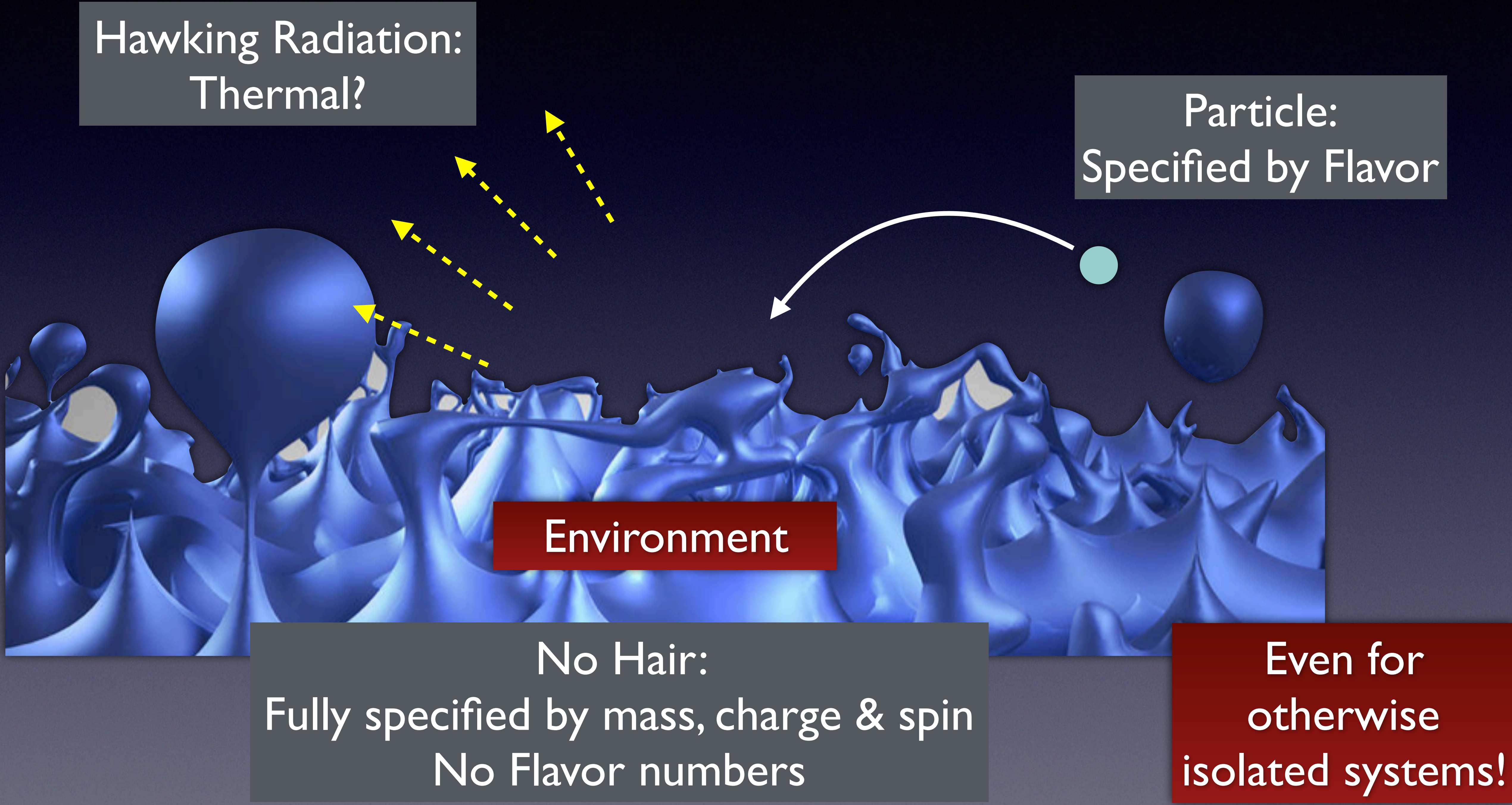


Particle:
Specified by Flavor

No Hair:
Fully specified by mass, charge & spin
No Flavor numbers

Compare
M.J. Baker, A. Thamm,
arXiv:2210.02805, JHEP
2023

Quantum Gravity: "Spacetime gets Quantum"



S. Hawking, Commun. Math. Phys. 1975, D. Page, PLB 1980

Quantum Gravitational Decoherence

- Can be modeled as a sink term in the evolution equation

$$\frac{\mathrm{d}}{\mathrm{d}t}\varrho(t) = -i[H,\varrho(t)] - \frac{1}{L_{\mathrm{coh}}}\left(1-\hat{D}\right)\varrho(t) - \mathcal{G}\varrho(t)$$

J. Ellis, J. Hagelin, M. Sredicki, D. Nanopoulos, 1984

- Violates all global quantum numbers!

Confirmed in AdS/CFT context!

D. Harlow, H. Ooguri, PRL 2019

- Entails a democratic flavor distribution!
- Depends exponentially on propagation distance

$$P_{ee}(L) = \frac{1}{2} + \frac{1}{2}\cos^2(2\theta)e^{-2\gamma L}$$

(2ν-approximation)

HV. Klapdor-Kleingrothaus, H. Päs, U. Sarkar, EPJ 2000

Great sensitivity at neutrino telescopes!

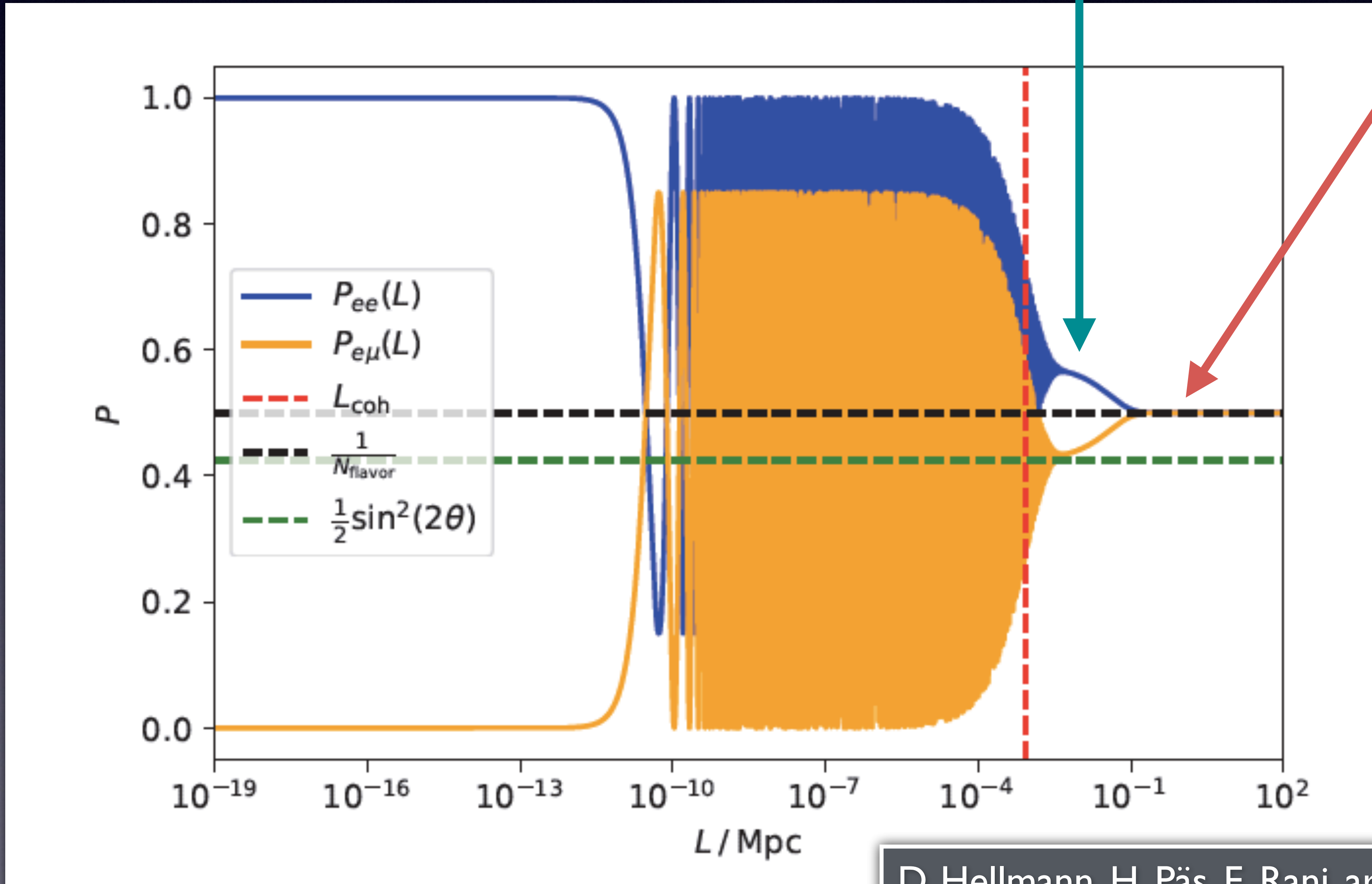
L. Anchordoqui, H. Goldberg, M. Gonzalez-Garcia, F. Halzen, D. Hooper, S. Sarkar, T. Weiler, PRD 2005

Quantum Gravitational Decoherence

$$\frac{\mathrm{d}}{\mathrm{d}t}\varrho(t) = -i[H,\varrho(t)] - \frac{1}{L_{\mathrm{coh}}}\left(1-\hat{D}\right)\varrho(t) - \mathcal{G}\varrho(t)$$

Quantum-Gravitational Decoherence

Wave Package Separation Decoherence



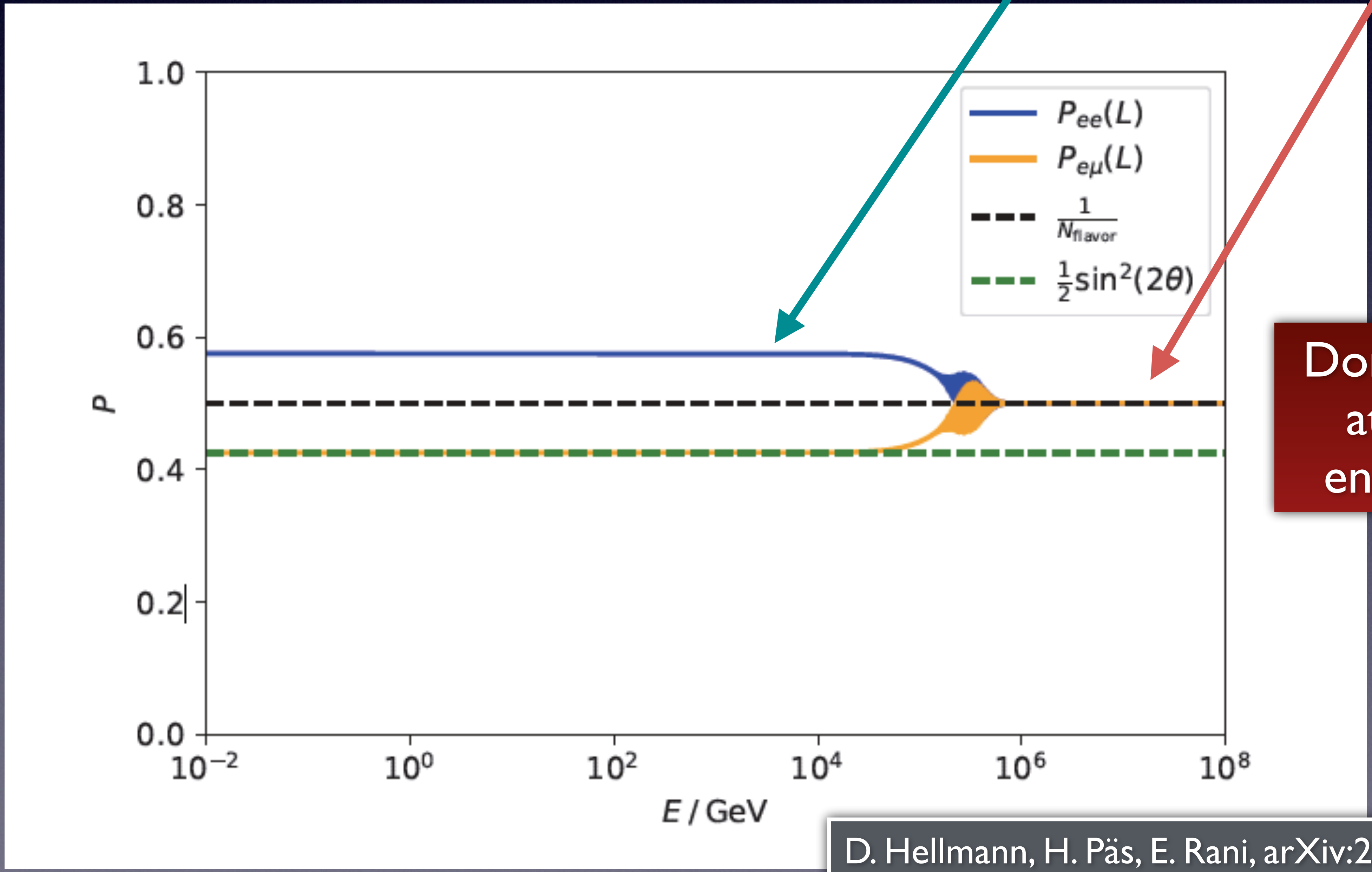
D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984, PRD 2022

Quantum Gravitational Decoherence

$$\frac{\mathrm{d}}{\mathrm{d}t}\varrho(t) = -i[H,\varrho(t)] - \frac{1}{L_{\mathrm{coh}}}\left(1-\hat{D}\right)\varrho(t) - \mathcal{G}\varrho(t)$$

Wave Package Separation Decoherence

Quantum-Gravitational Decoherence



Dominates at high energies!

D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984, PRD 2022

Why is it interesting now?

HV. Klapdor-Kleingrothaus, H. Päs, U. Sarkar, EPJ 2000

vs

D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984 , PRD 2022

- Recent results about Black Hole Information (emergent spacetime, firewalls, replica wormholes, ER=EPR…) that lacks concrete possibilities of experimental testing
- Discovery of PeV scale extragalactic neutrinos in the IceCube neutrino telescope
- Mounting cosmological evidence for dark matter without new particles found at the LHC!

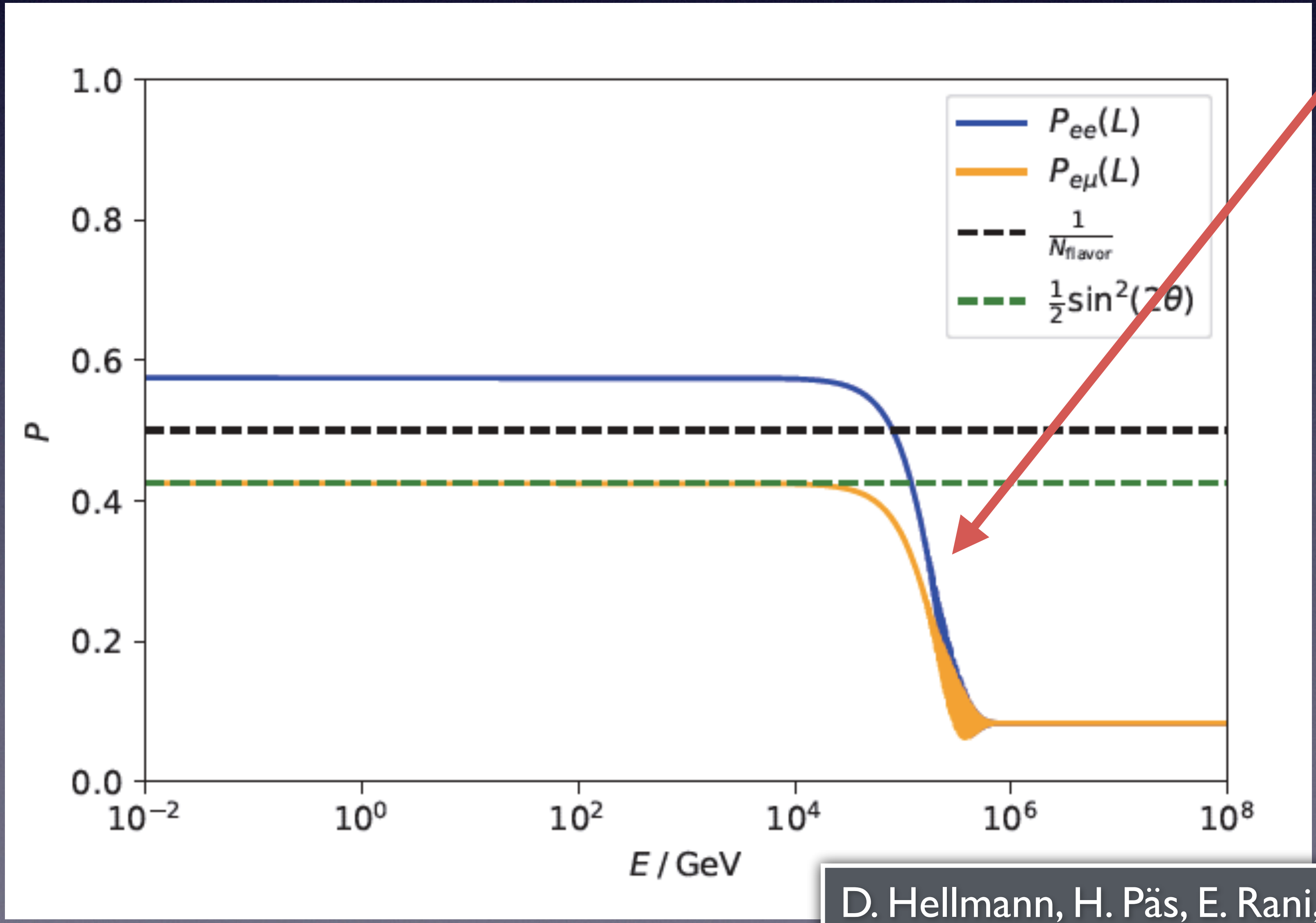
Quantum-gravitational decoherence
NOT
as an exotic phenomenon
BUT
as a tool to study hidden sectors!

Search for Hidden Particles

Adding N-2 additional dark Fermions:

$$P_{ee}(L) = \frac{1}{N} + \frac{N-2}{2N}e^{-2\gamma L} + \frac{1}{2}\cos^2(2\theta)e^{-2\gamma L} + \frac{1}{2}\sin^2(2\theta)e^{-\left(\gamma+\frac{1}{L_{\rm coh}}\right)L}\left\{\cos(\omega L) + \frac{\gamma}{\omega}\sin(\omega L)\right\}$$

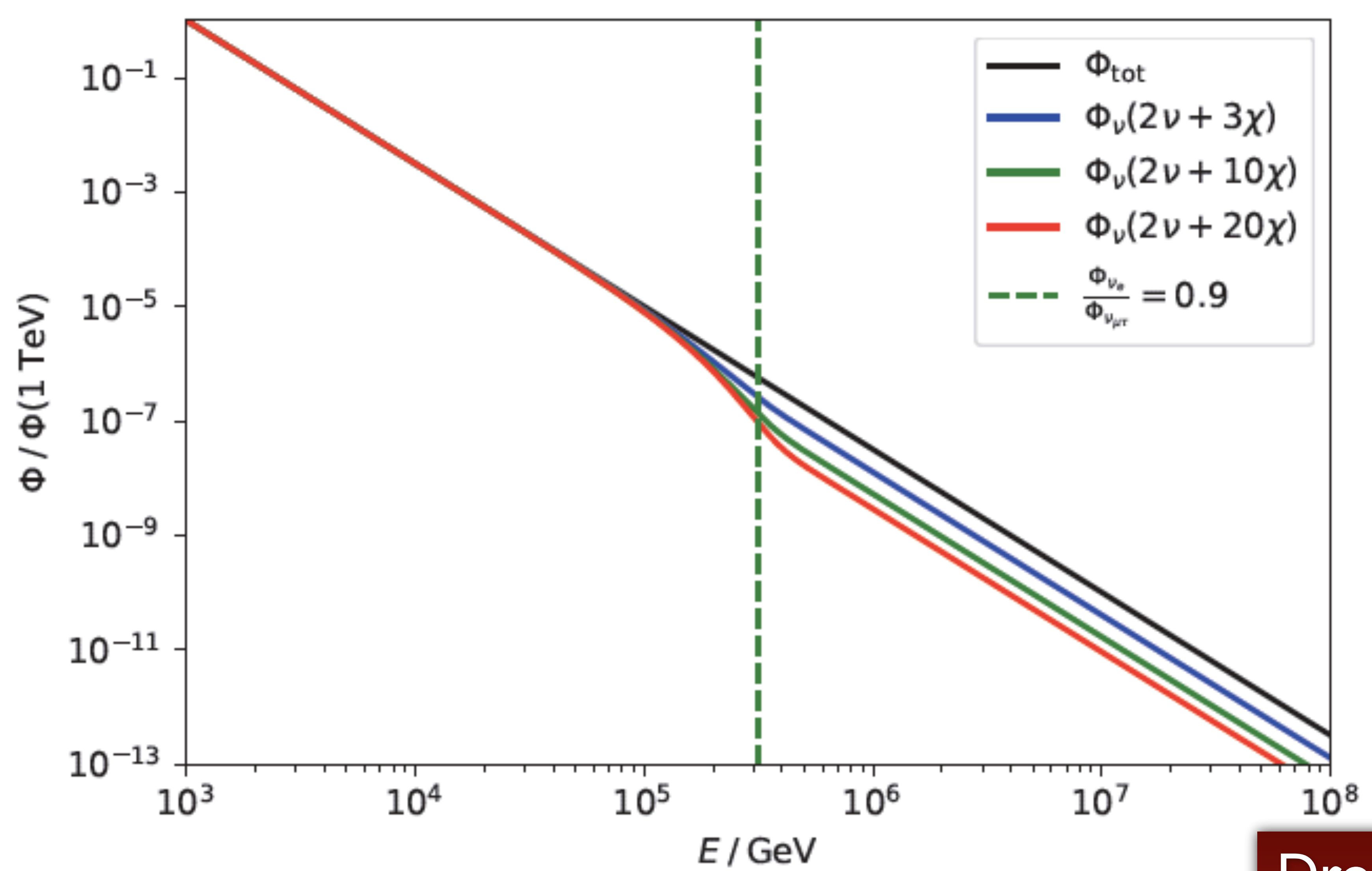
Democratic Flavor Distribution over ALL neutral fermions!



Drop in the Survival Probability!

D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984, PRD 2022

Search for Hidden Particles



D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984, PRD 2022

Drop in the Total Flux in the Energy Spectrum!

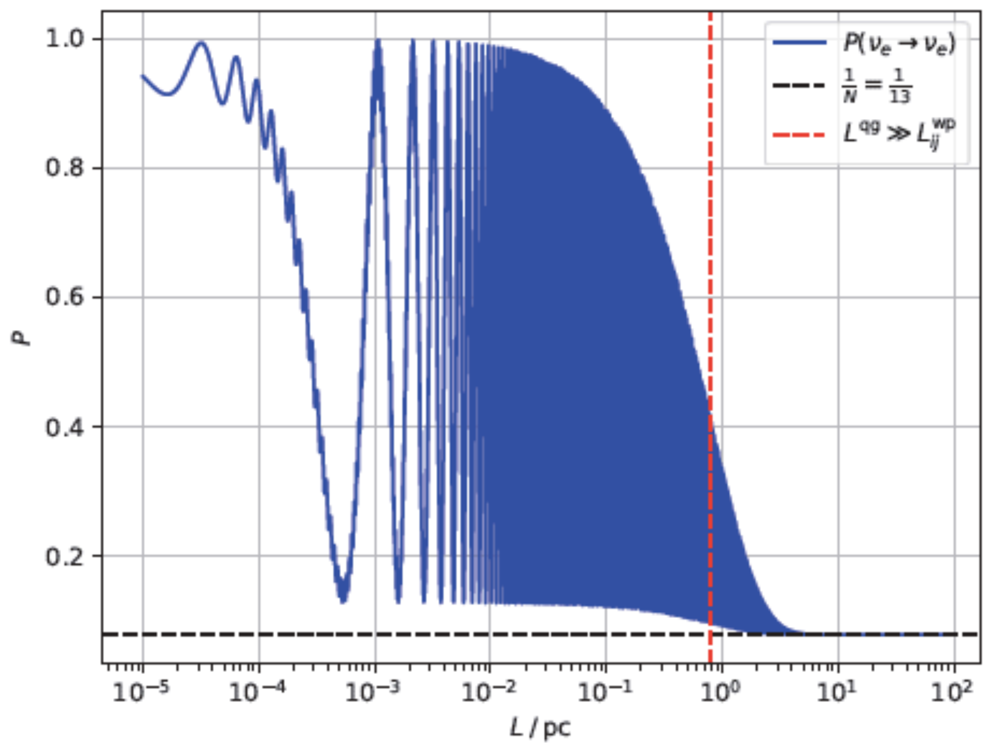
The 3ν Case

Analytic solution

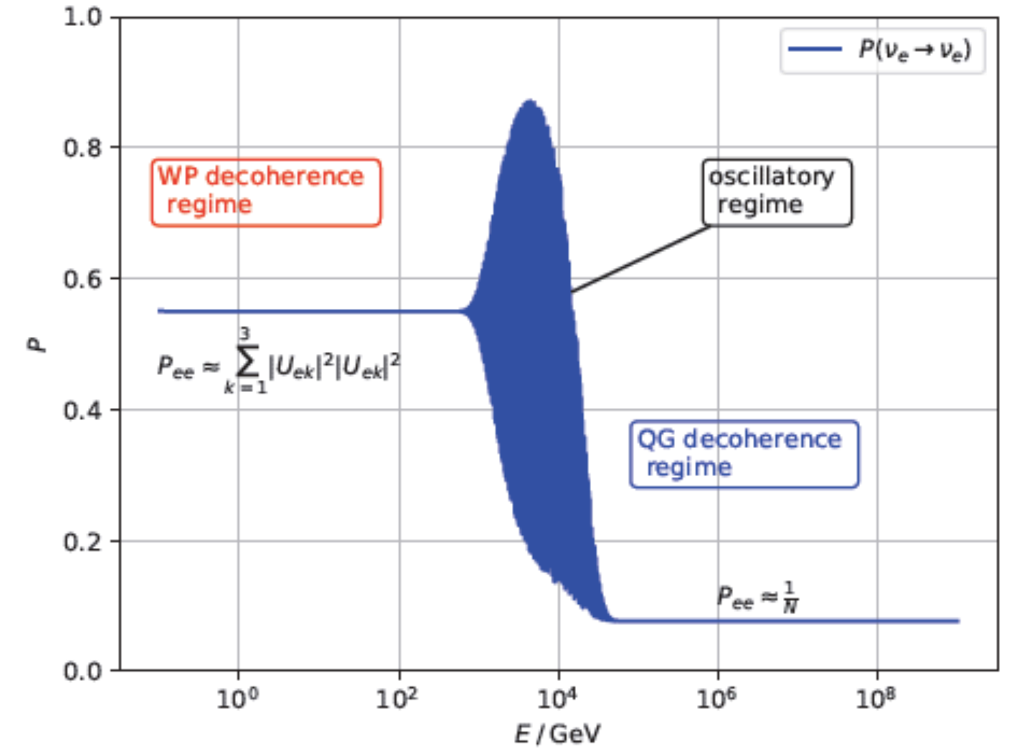
$$
\begin{aligned}
P_{\alpha\beta}(L) = & \frac{1}{N} + \frac{1}{2}(|U_{\alpha 1}|^2 - |U_{\alpha 2}|^2)(|U_{\beta 1}|^2 - |U_{\beta 2}|^2)e^{-\Gamma_{N(N-1)+1}L} \\
& + \frac{1}{6}(|U_{\alpha 1}|^2 + |U_{\alpha 2}|^2 - 2|U_{\alpha 3}|^2)(|U_{\beta 1}|^2 + |U_{\beta 2}|^2 - 2|U_{\beta 3}|^2)e^{-\Gamma_{N(N-1)+2}L} \\
& + \sum_{k=3}^{N-1} \frac{e^{-\Gamma_{N(N-1)+k}L}}{k(k+1)} \\
& + 2\sum_{j>i=1}^{3} \mathrm{Re}(U^*_{\alpha j}U_{\alpha i}U_{\beta j}U^*_{\beta i})e^{-\frac{L}{L_{ij}}} e^{-\bar{\Gamma}_{l+1\,l}L}\cos(\omega_{ij}L) \\
& + 2\sum_{j>i=1}^{3} \mathrm{Re}(U^*_{\alpha j}U_{\alpha i}U^*_{\beta j}U_{\beta i})\frac{\Delta\Gamma_{l+1\,l}}{\omega_{ij}} e^{-\frac{L}{L_{ij}}} e^{-\bar{\Gamma}_{l+1\,l}L}\sin(\omega_{ij}L) \\
& - 2\sum_{j>i=1}^{3} \mathrm{Im}(U^*_{\alpha j}U_{\alpha i}U_{\beta j}U^*_{\beta i})\frac{\Delta E_{ij}}{\omega_{ij}} e^{-\frac{L}{L_{ij}}} e^{-\bar{\Gamma}_{l+1\,l}L}\sin(\omega_{ij}L)
\end{aligned}
$$

D. Hellmann, H. Päs, E. Rani, arXiv:2208.11754, PRD 2022

The 3ν Case



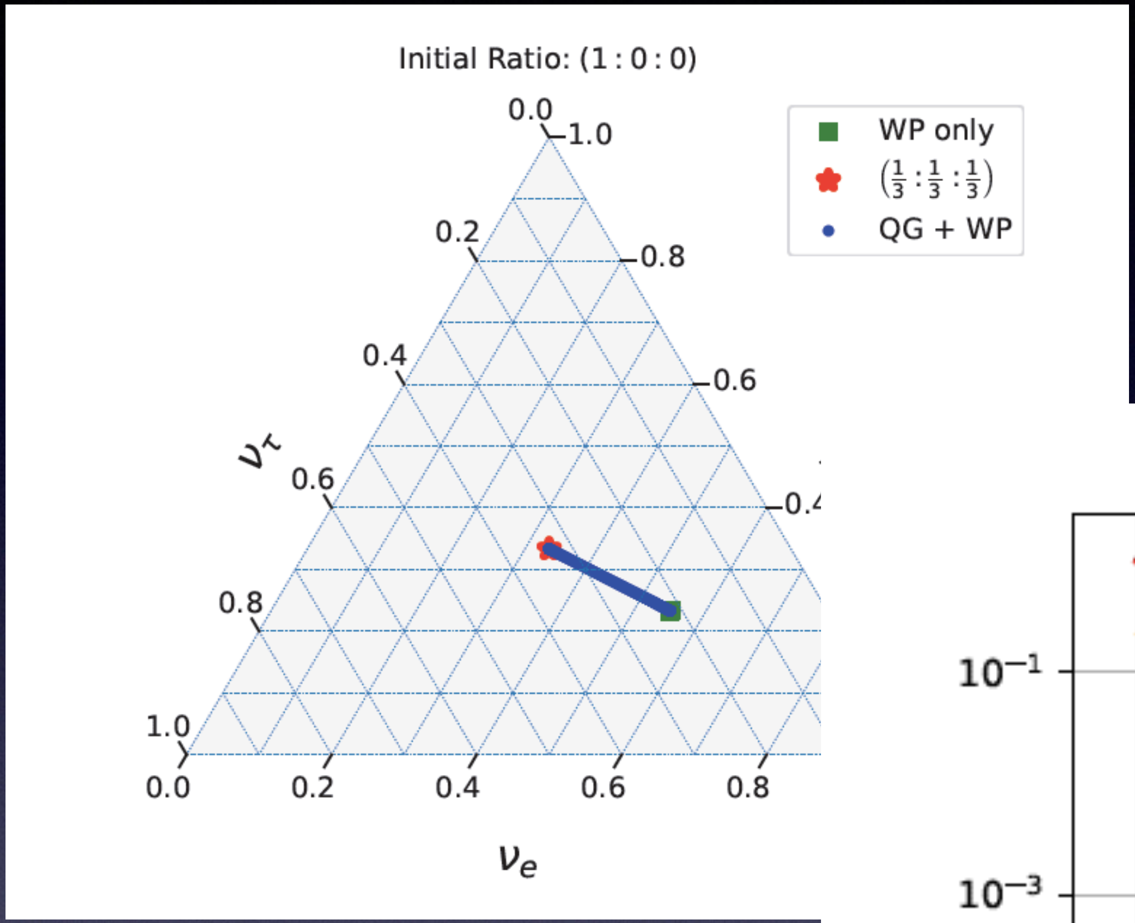
(a) The blue curve represents P_{ee} for variable base length and fixed energy $E = 1\,\mathrm{PeV}$.

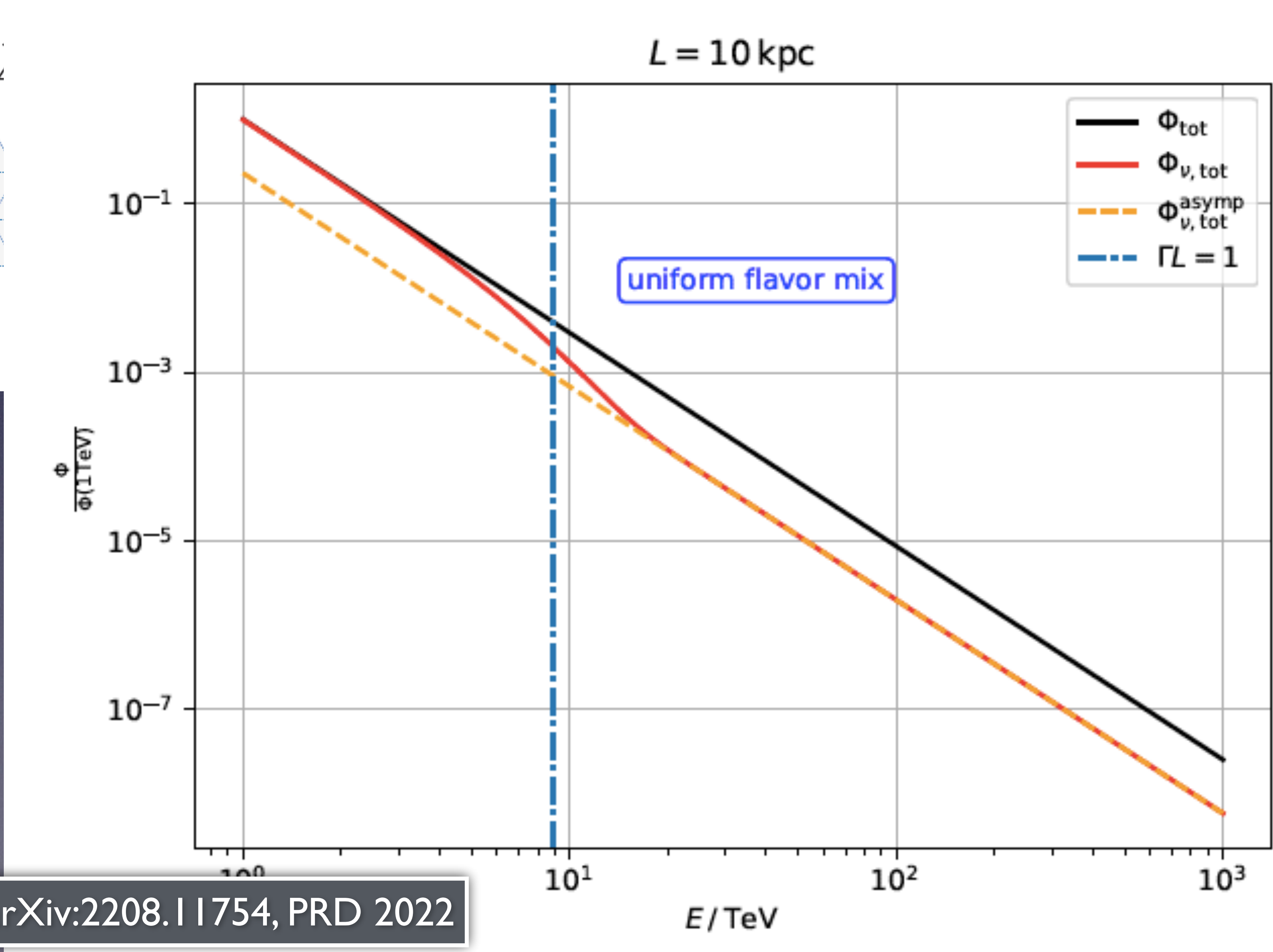


(b) The blue curve represents P_{ee} for variable energy and fixed base length $L = 2\,\mathrm{kpc}$.

D. Hellmann, H. Päs, E. Rani, arXiv:2208.11754, PRD 2022

The 3ν Case





D. Hellmann, H. Päs, E. Rani, arXiv:2208.11754, PRD 2022

Summary

- Quantum-Gravitational Decoherence and breaking of global symmetries: rather generic prediction of quantum gravity
- If not: New insights into black hole information processing
- If yes: Powerful tool to search for dark sectors virtually impossible to find with any other method
- Dominant effect at high energies!
- Promising source: cosmic ν's from the CYGNUS spiral arm

D. Hellmann, H. Päs, E. Rani, arXiv:2103.11984, PRD 2022

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Picture Credit: IceCube/NSF (IceCube), NASA (Spacetime Foam), EHT/ESO (Black Hole), IOP (Neutrino Decoherence)