Dark Sector Spectroscopy with Quantum-Gravitational Decoherence

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tu dortmund

Neutrinos, Flavors and Beyond?

How many Flavors
are there
?

Neutrinos, Flavors and Beyond?

Totally Decoupled Dark Sectors
?

How many Flavors are there
?

How Many Dark Matter Particles
?

Phenomenology of 10^{32} Dark Sectors

Gia Dvali[a,b,c*] and Michele Redi[d†]

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[c] Max-Planck-Institute for Physics

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Totally Decoupled Dark Sectors ?

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How many Dark Matter Particles ?

Gravity

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Neutrinos as Probes for Quantum Gravity

Quantum Gravity

Neutrinos

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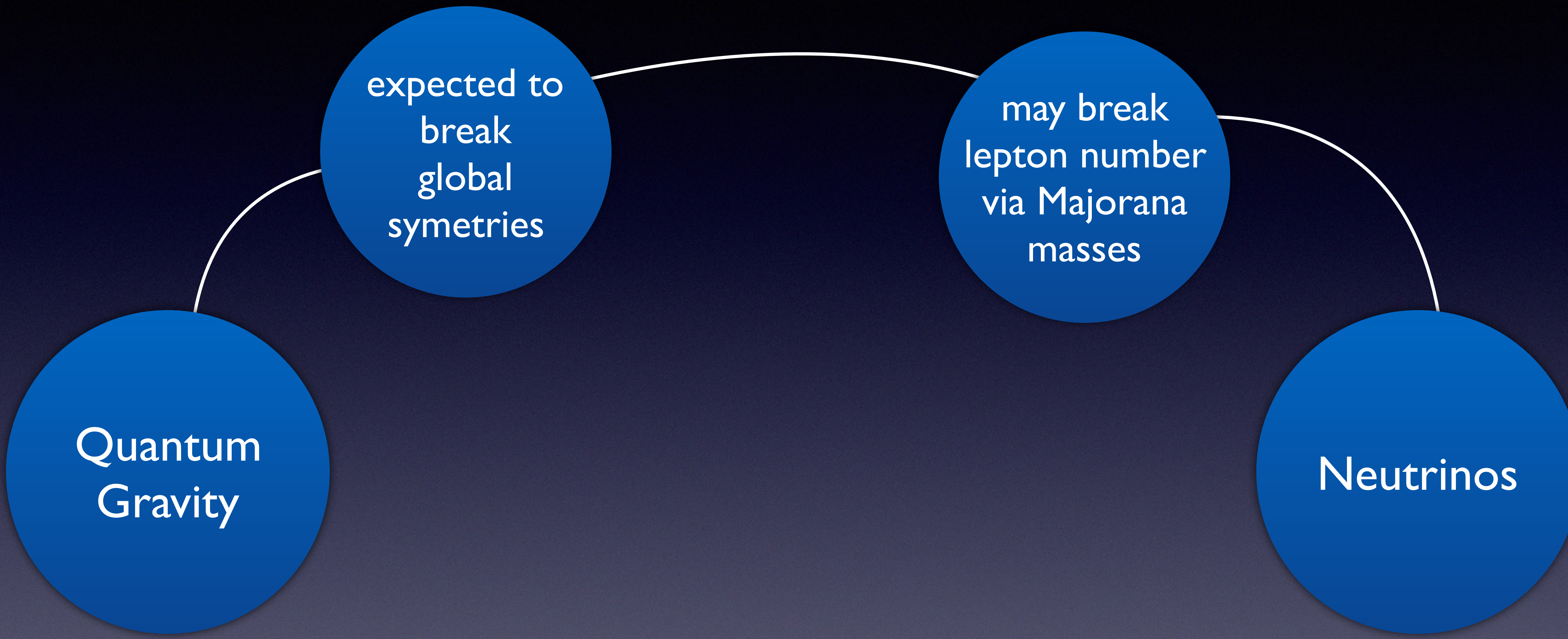
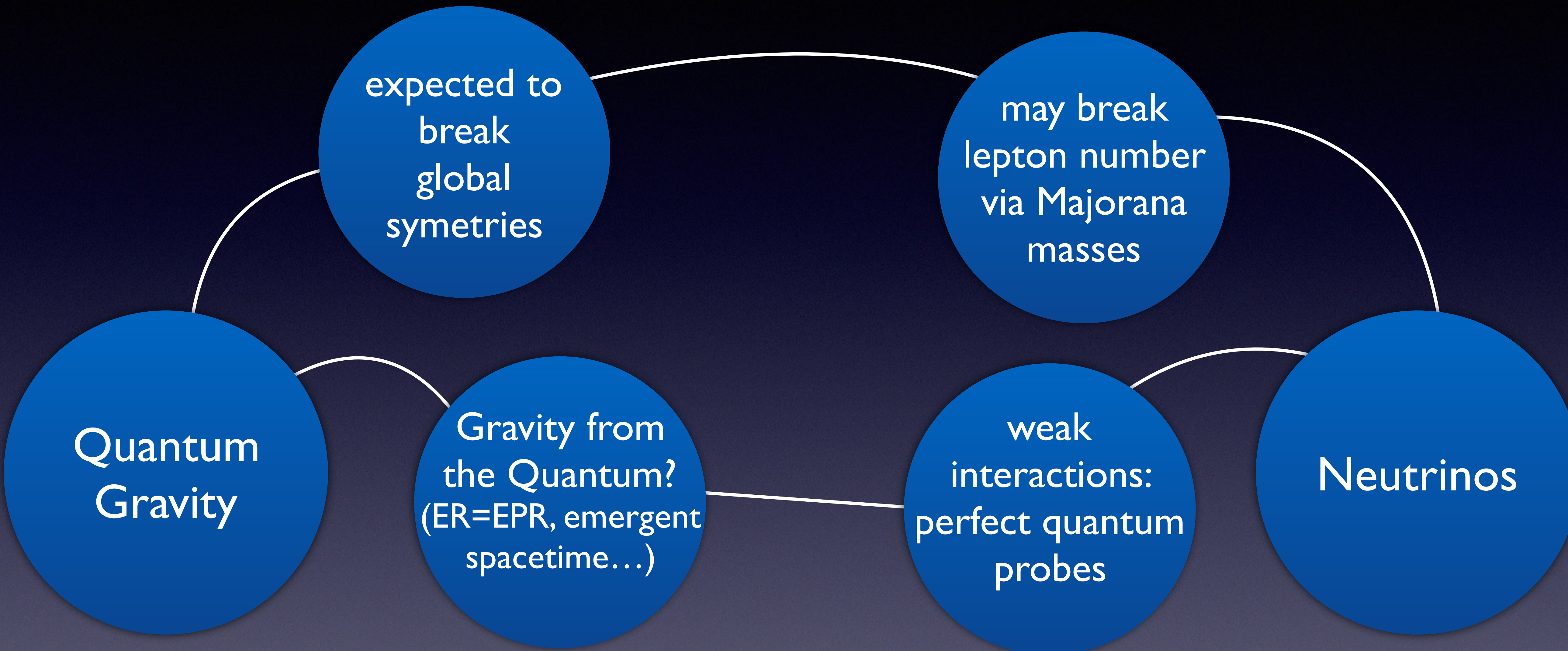


Neutrinos as Probes for Quantum Gravity



Neutrinos as Probes for Quantum Gravity

expected to break global symetries

may break lepton number via Majorana masses

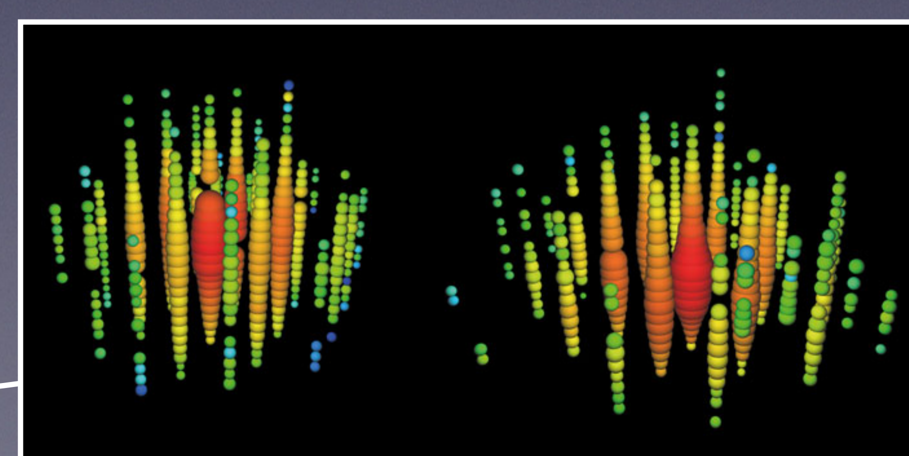
Quantum Gravity

Gravity from the Quantum? (ER=EPR, emergent spacetime…)

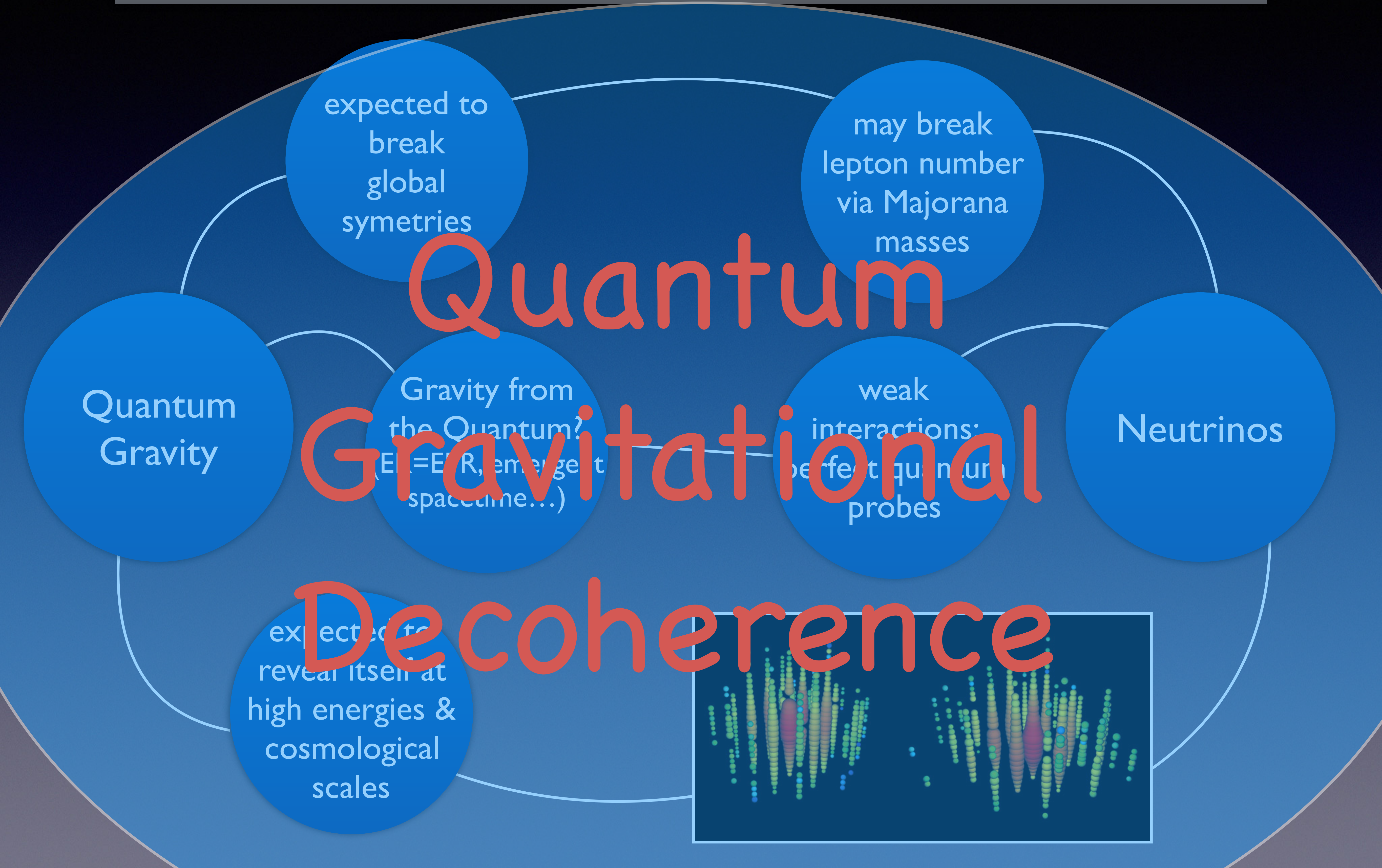
weak interactions: perfect quantum probes

Neutrinos

expected to reveal itself at high energies & cosmological scales



Neutrinos as Probes for Quantum Gravity



A Very Brief Outline

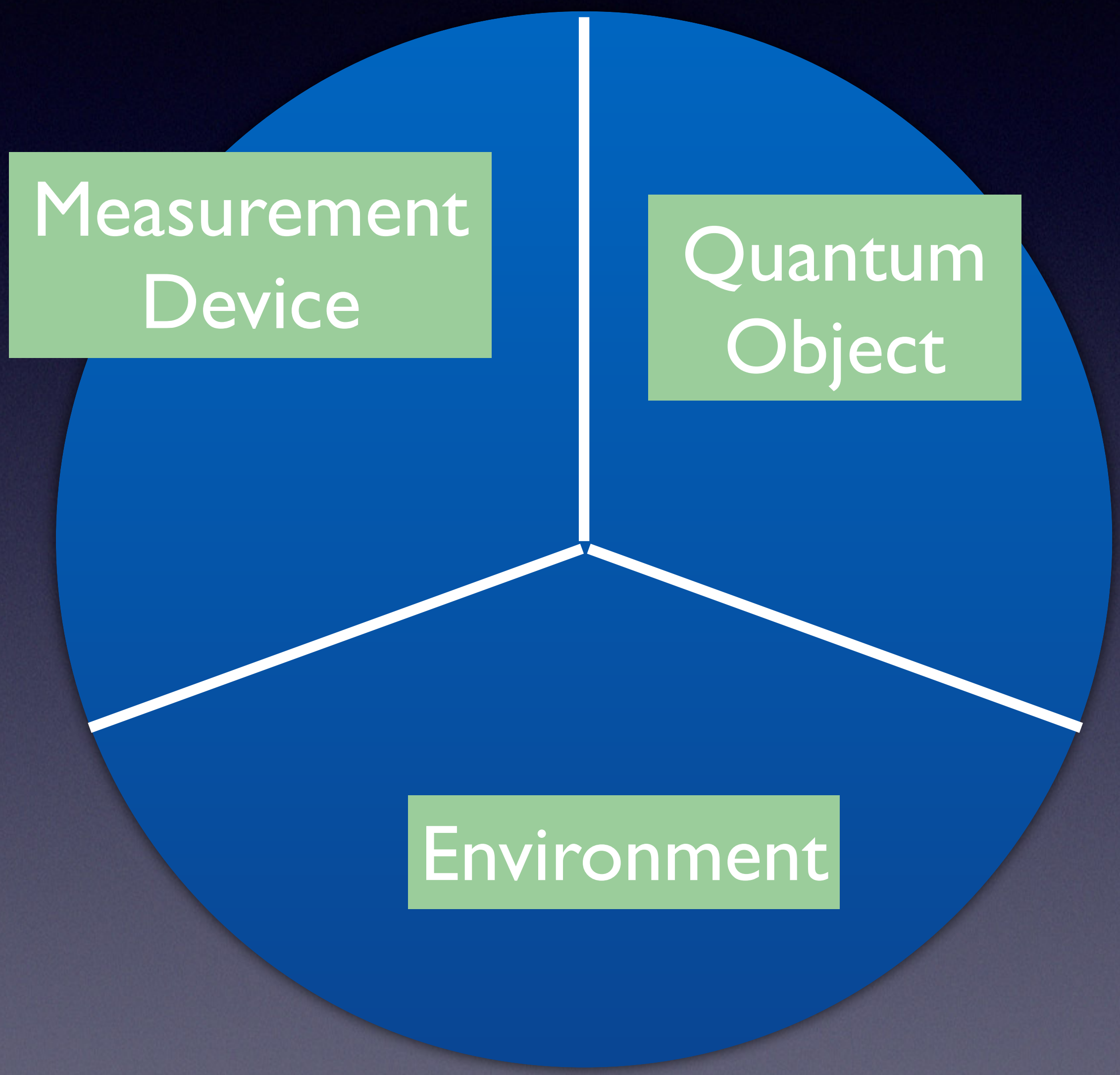
- What is Quantum-Gravitational Decoherence?
- How does it help to study Hidden Dark Sectors?

Decoherence

The
Universe

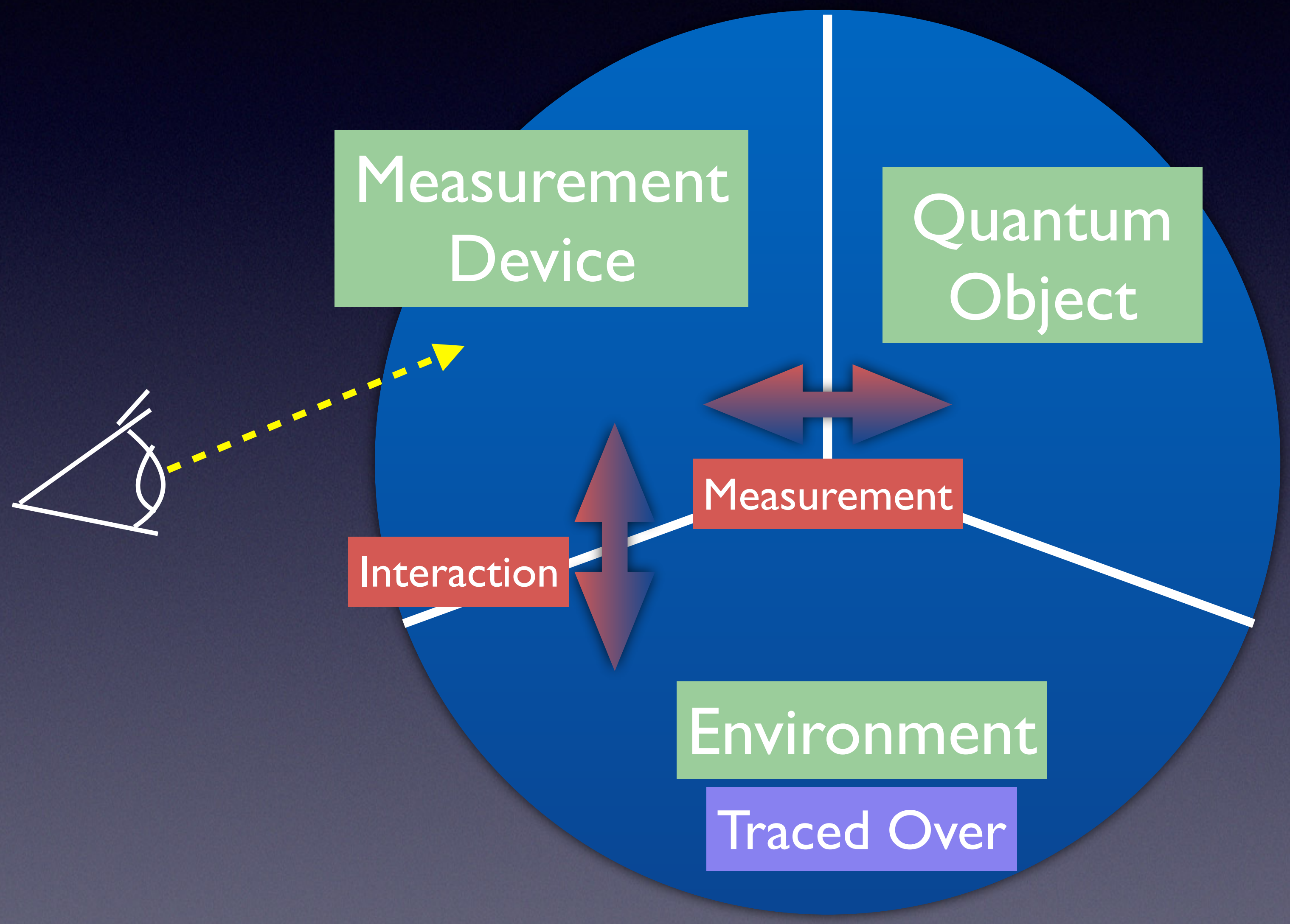
H.D. Zeh, Z. Phys. A 1970

Decoherence



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

Decoherence



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

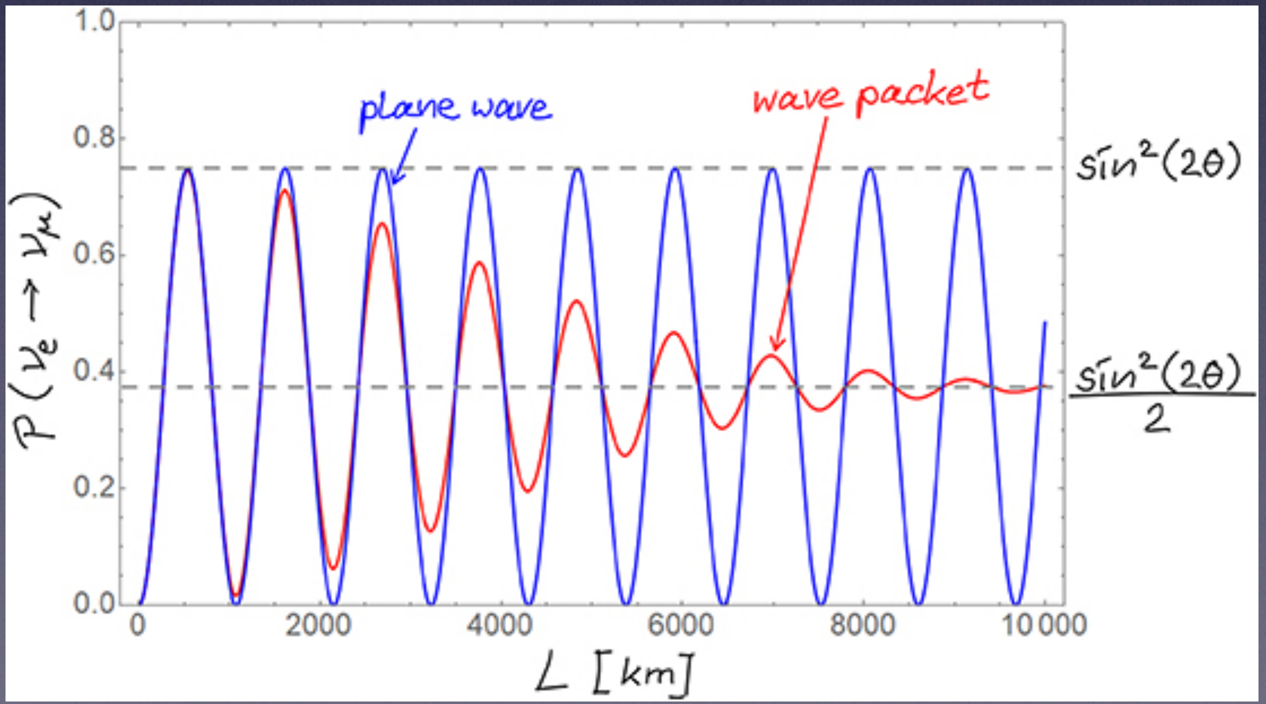
Decoherence

- 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

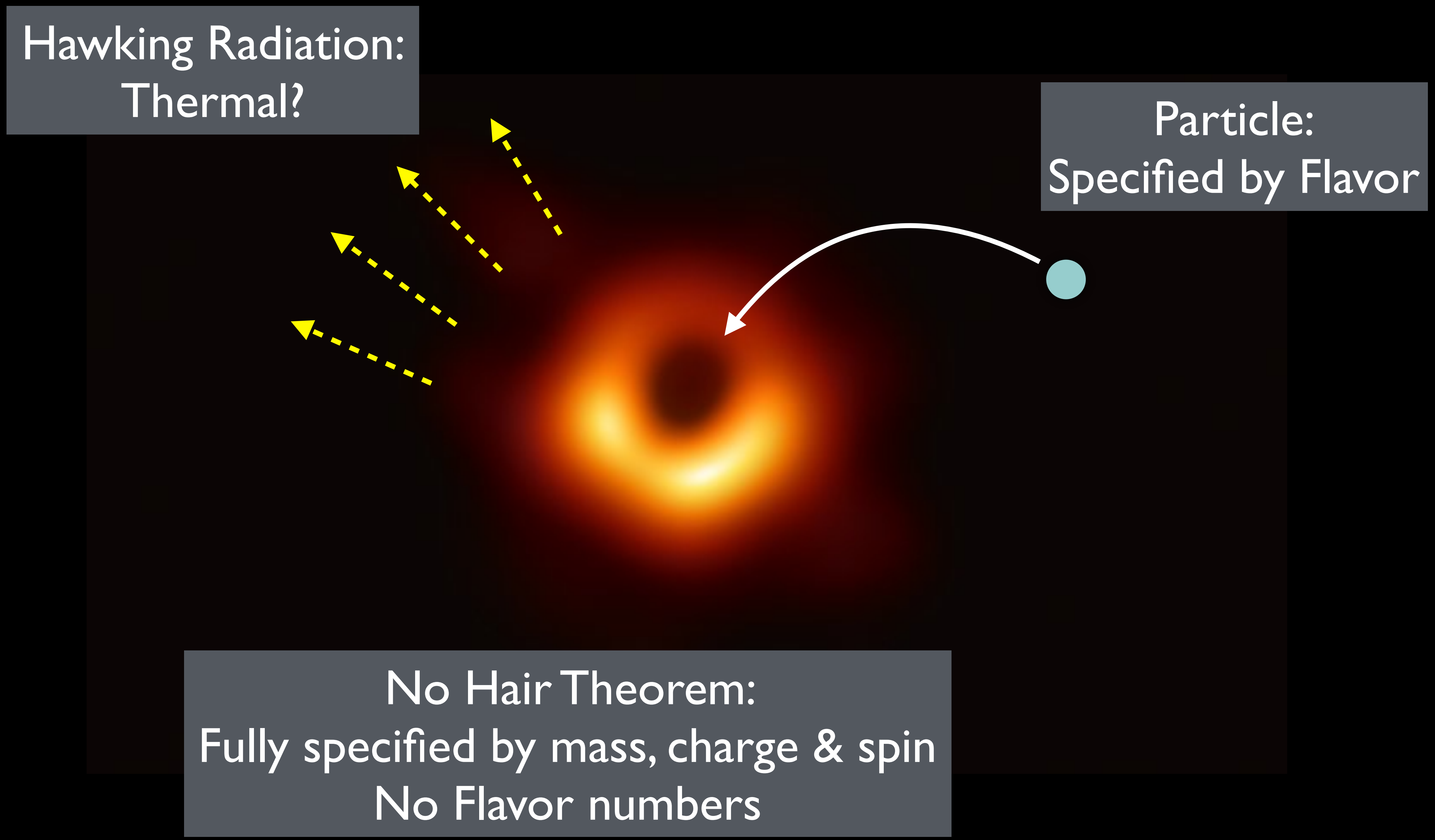
Neutrinos

- 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



Quantum Gravity: "Spacetime gets Quantum"

Einstein Equations

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} + \Lambda \, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Matter: Decribed by Quantum mechanics

Spacetime Geometry: Classical???

Quantum Gravity: "Spacetime gets Quantum"

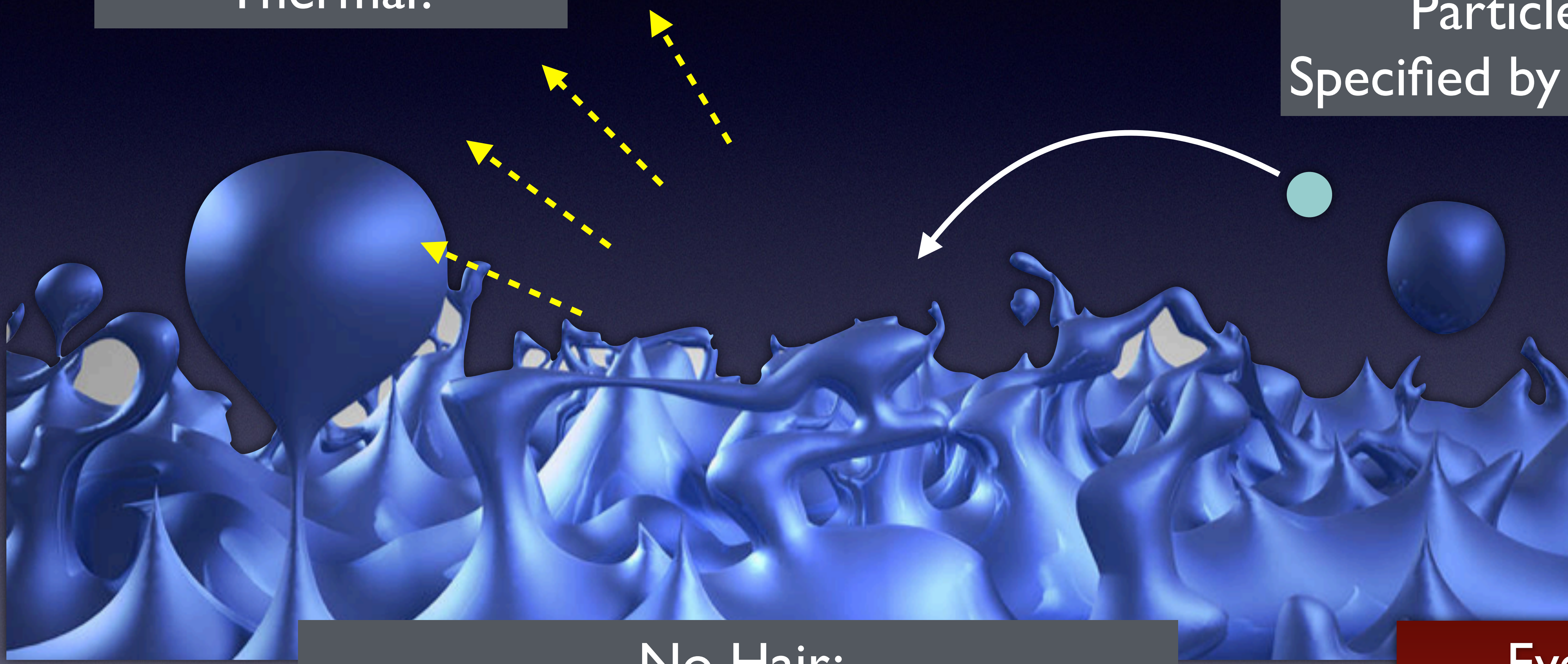
"quantum foam, made up not merely of particles popping into and out of existence without limit, but of space-time itself churned into a lather of distorted geometry"

(John Archibald Wheeler)

Quantum Gravity: "Spacetime gets Quantum"

Hawking Radiation:
Thermal?

Particle:
Specified by Flavor



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

Even for otherwise isolated systems!

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!

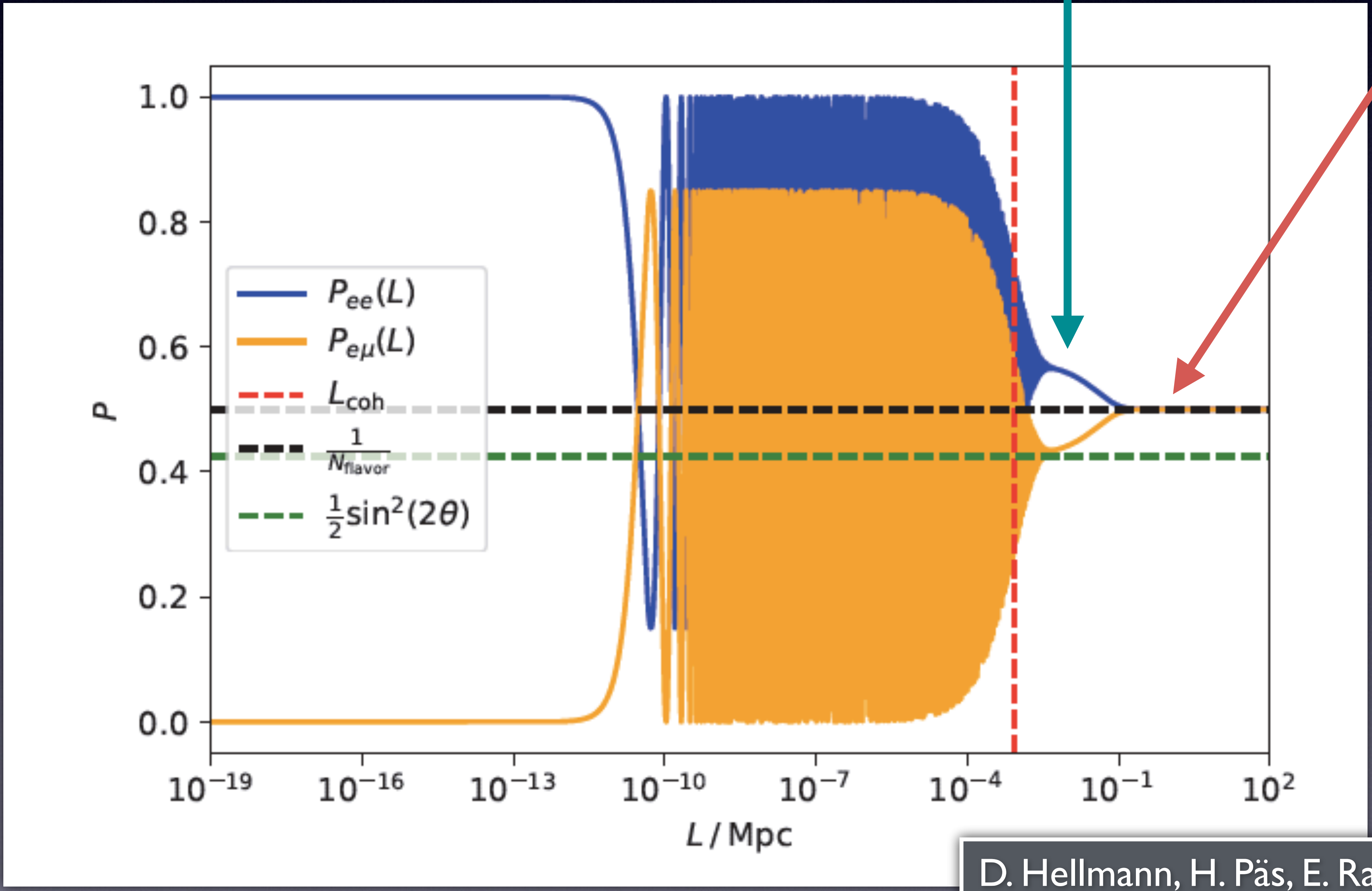
L. Anchordoqui, H. Goldberg, M. Gonzalez-Garcia, F. Halzen, D. Hooper, S. Sarkar, T. Weiler, PRD 2005

Quantum Gravitational Decoherence

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

Wave Package Separation Decoherence

Quantum-Gravitational Decoherence



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

Quantum Gravitational Decoherence

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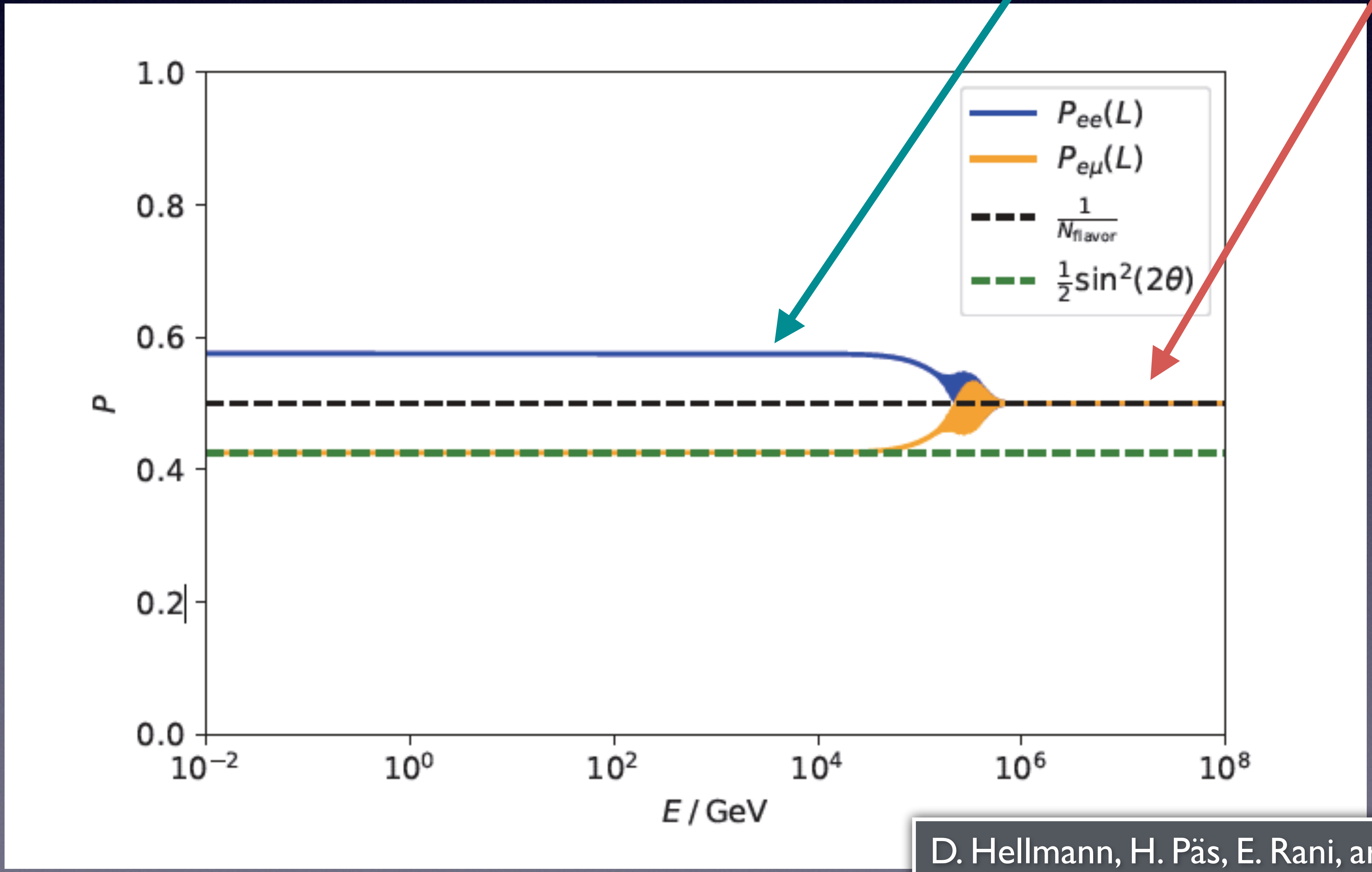
Wave Package Separation Decoherence

Quantum-Gravitational Decoherence



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

Why is it interesting now?

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

vs

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

- 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!

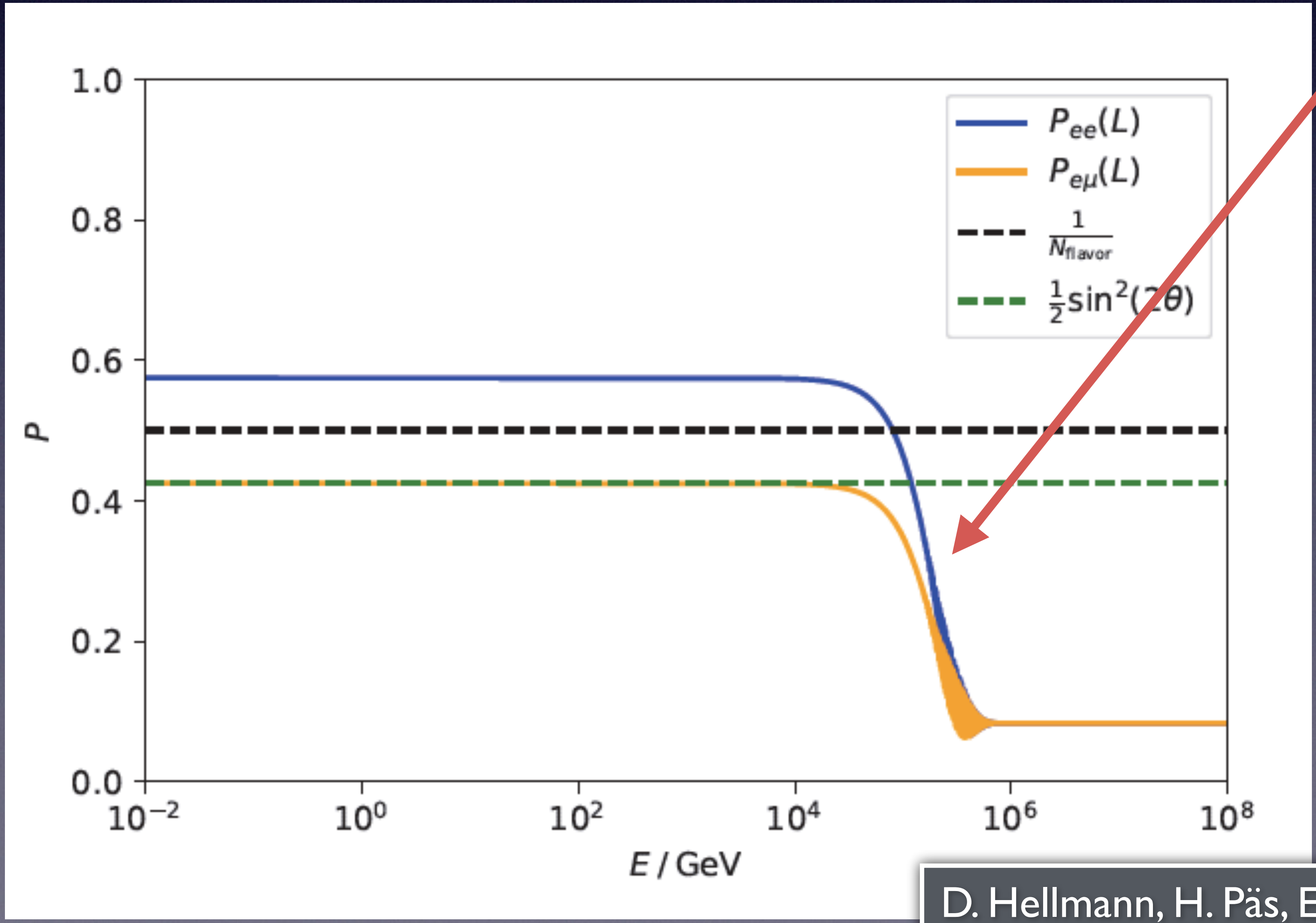
Quantum-gravitational decoherence
NOT
as an exotic phenomenon
BUT
as a tool to study hidden sectors!

Search for Hidden Particles

Adding N-2 additional dark Fermions:

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

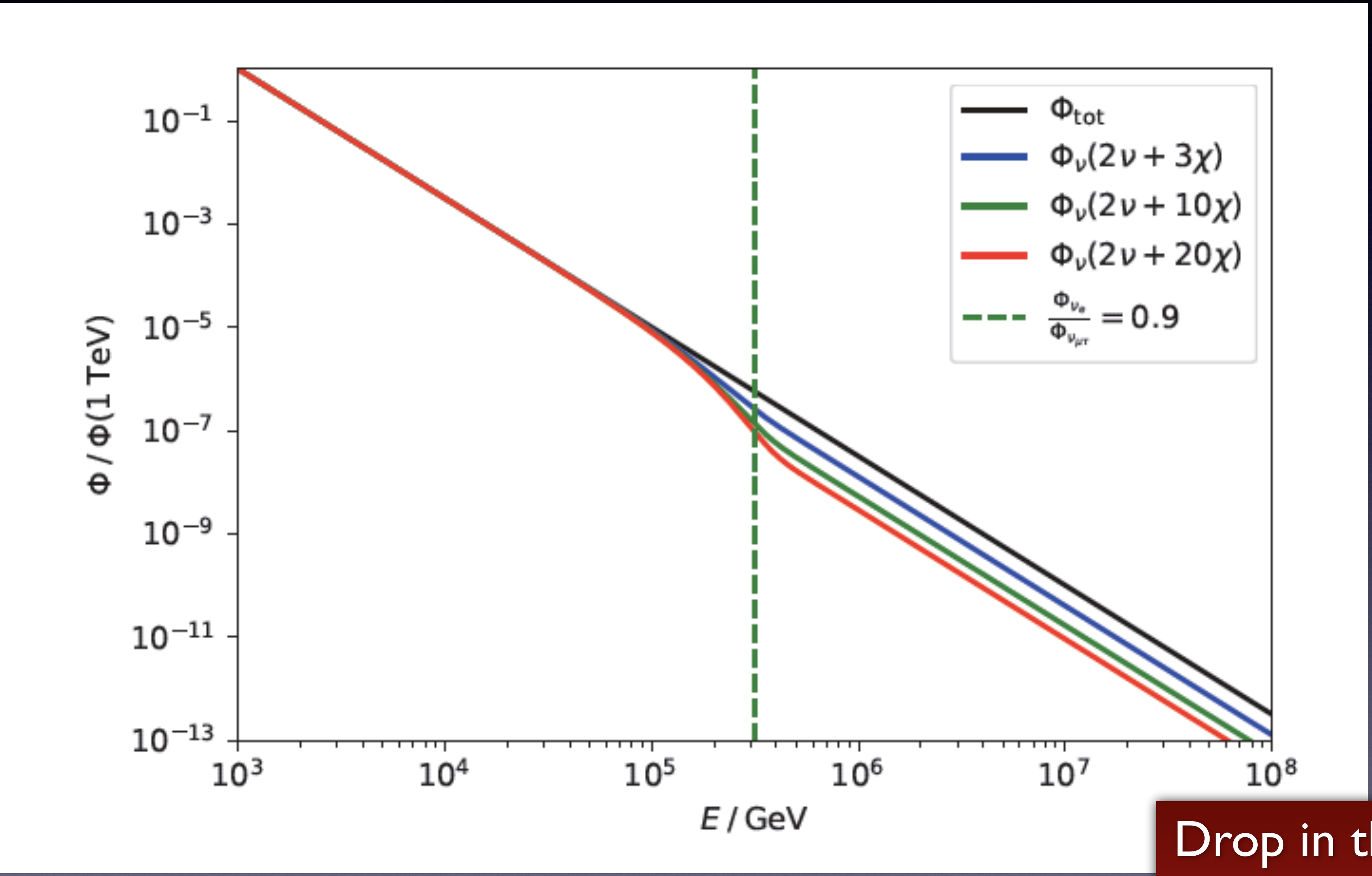
Democratic Flavor Distribution over ALL neutral fermions!



Drop in the Survival Probability!

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

Search for Hidden Particles



Drop in the Total Flux in the Energy Spectrum!

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

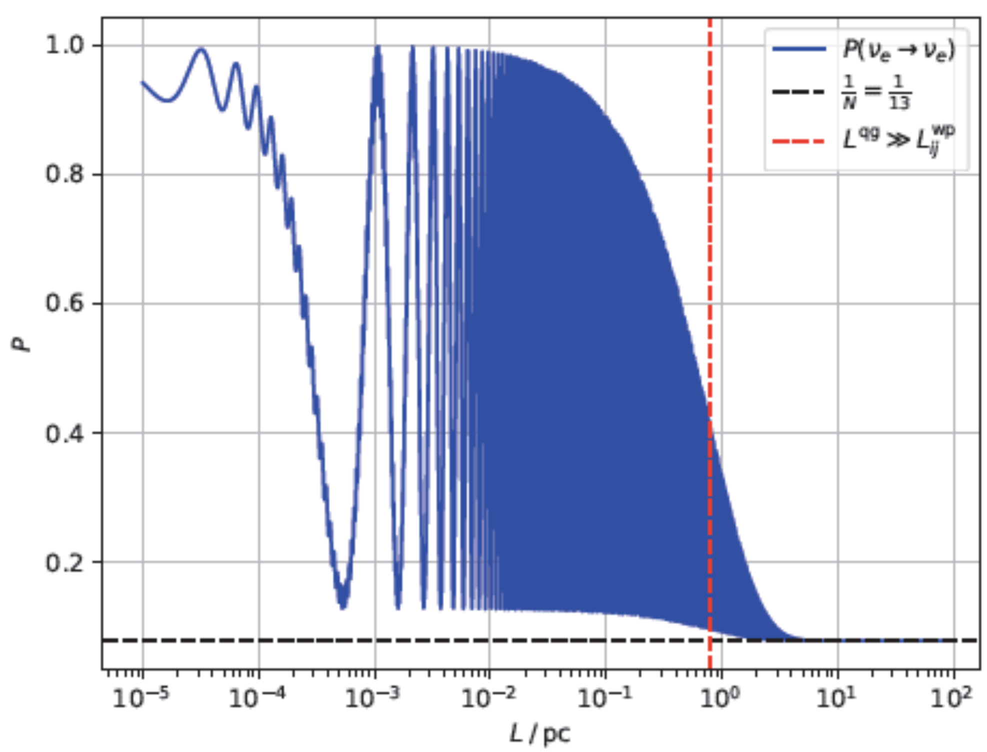
The 3ν Case

Analytic solution

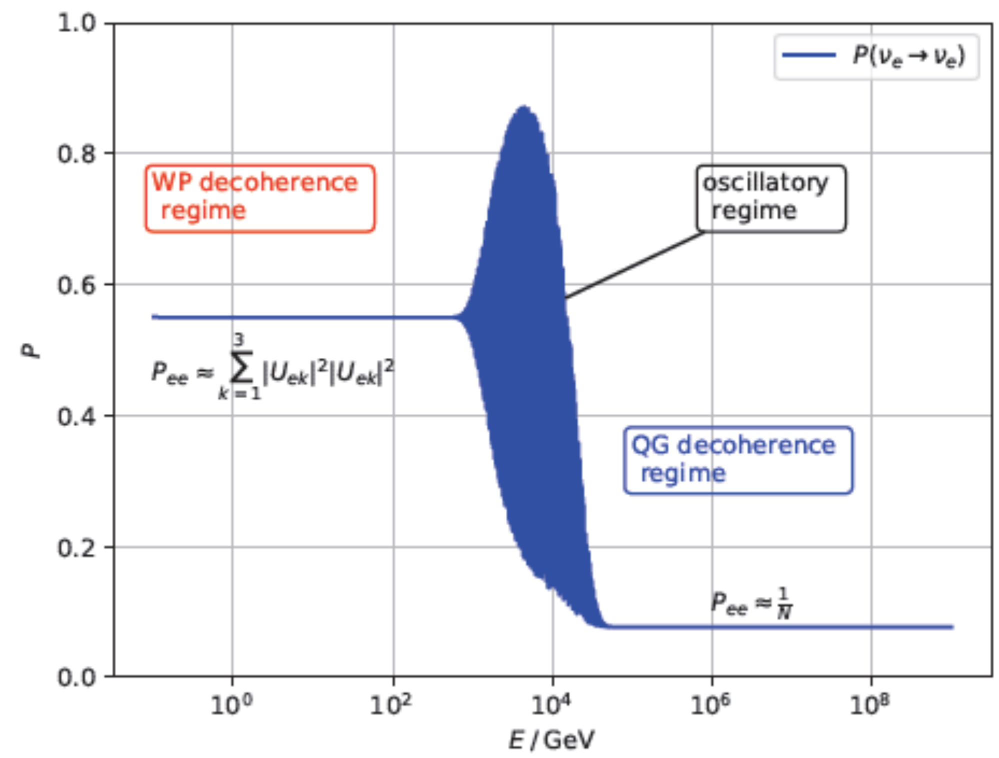
$$
\begin{aligned}
P_{\alpha\beta}(L) = &\frac{1}{N} + \frac{1}{2}(|U_{\alpha 1}|^2 - |U_{\alpha 2}|^2)(|U_{\beta 1}|^2 - |U_{\beta 2}|^2)e^{-\Gamma_{N(N-1)+1}L} \\
&+ \frac{1}{6}(|U_{\alpha 1}|^2 + |U_{\alpha 2}|^2 - 2|U_{\alpha 3}|^2)(|U_{\beta 1}|^2 + |U_{\beta 2}|^2 - 2|U_{\beta 3}|^2)e^{-\Gamma_{N(N-1)+2}L}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

D. Hellmann, H. Päs, E. Rani, work in progress

The 3ν Case



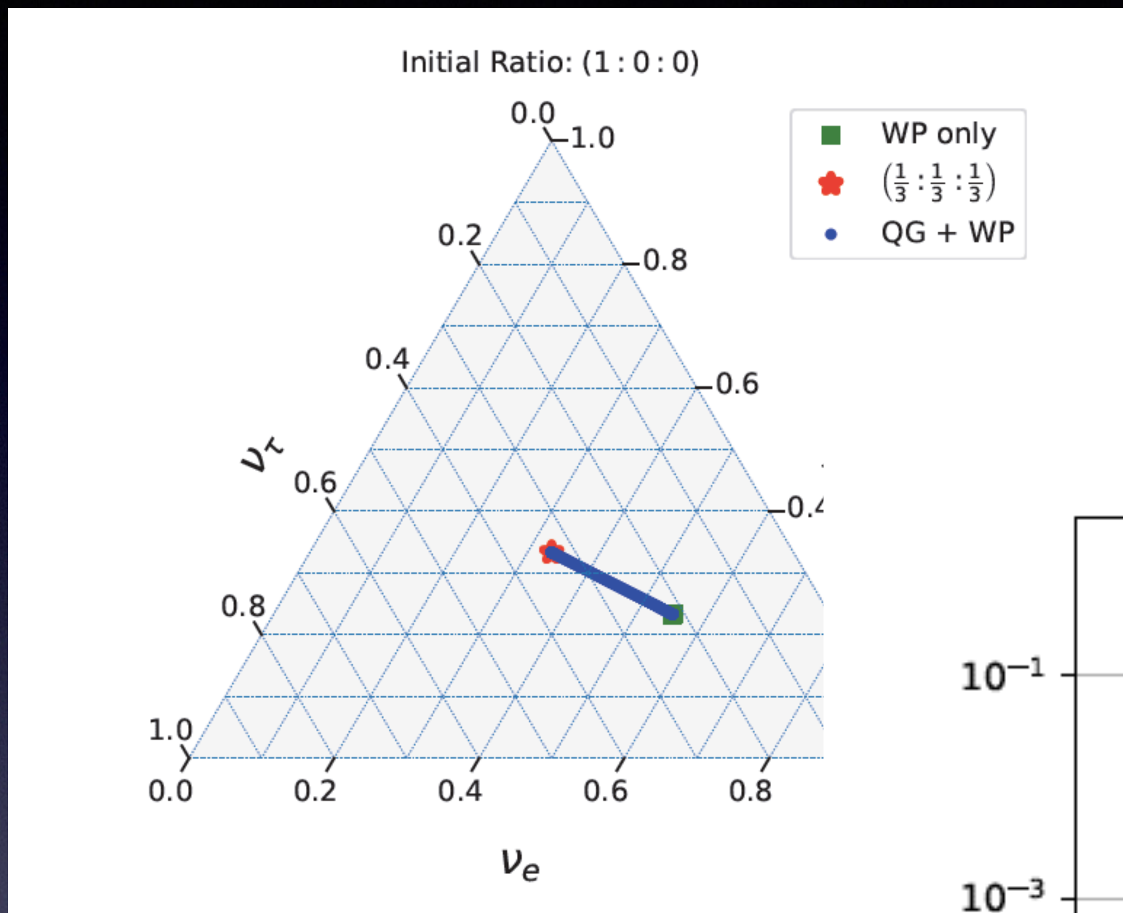
(a) The blue curve represents P_{ee} for variable base length and fixed energy $E = 1\,\mathrm{PeV}$.

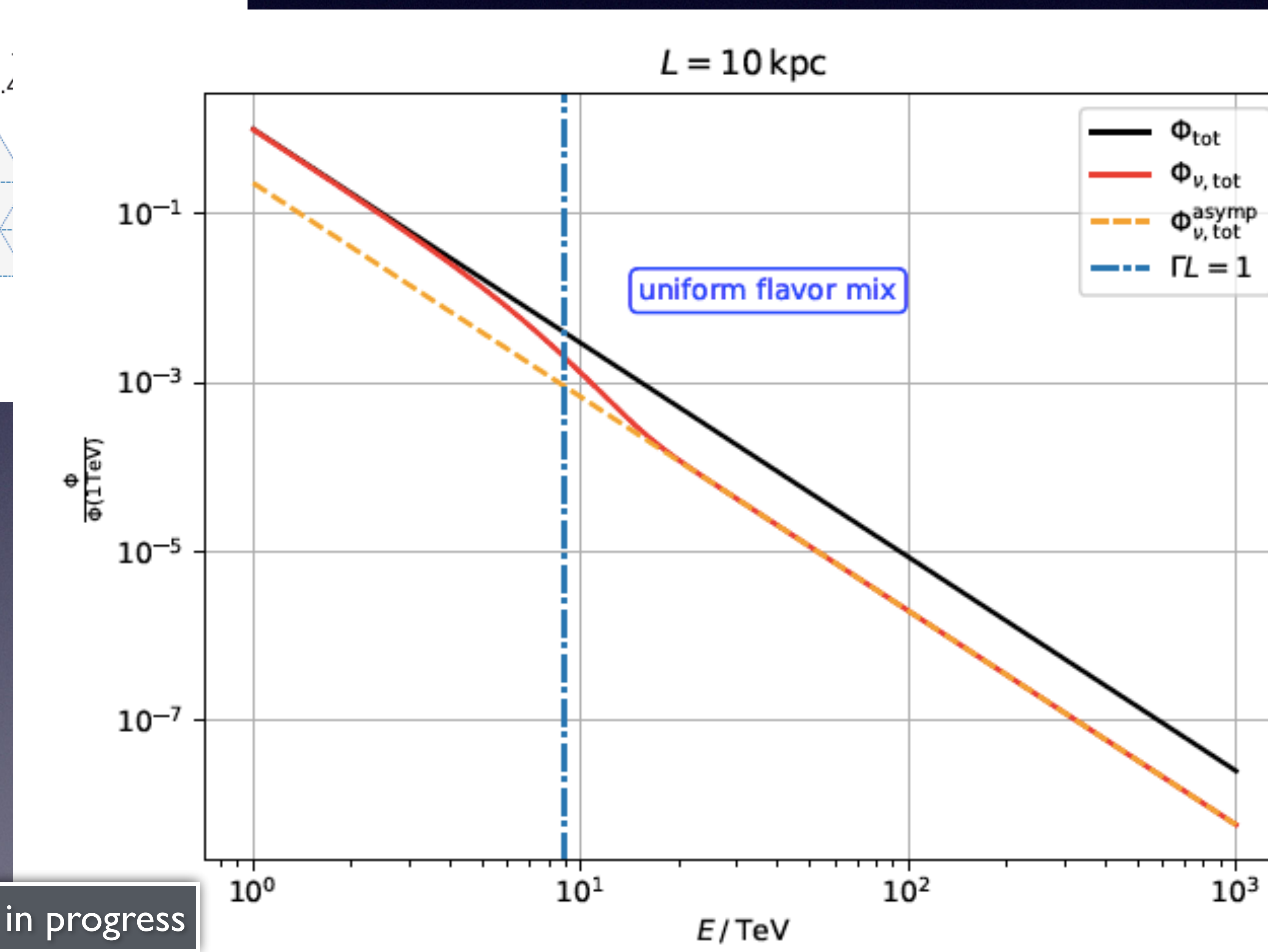


(b) The blue curve represents P_{ee} for variable energy and fixed base length $L = 2\,\mathrm{kpc}$.

D. Hellmann, H. Päs, E. Rani, work in progress

The 3ν Case





D. Hellmann, H. Päs, E. Rani, work in progress

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
- Future work: Dark sector spectroscopy, baryogenesis, CPT violation…
- Promising source: cosmic ν's from the CYGNUS spiral arm

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

Picture Credits: IceCube/NSF (IceCube), NASA (Spacetime Foam), EHT/ESO (Black Hole), IOP (Neutrino Decoherence), ESO/B. Tafreshi (Milky Way)