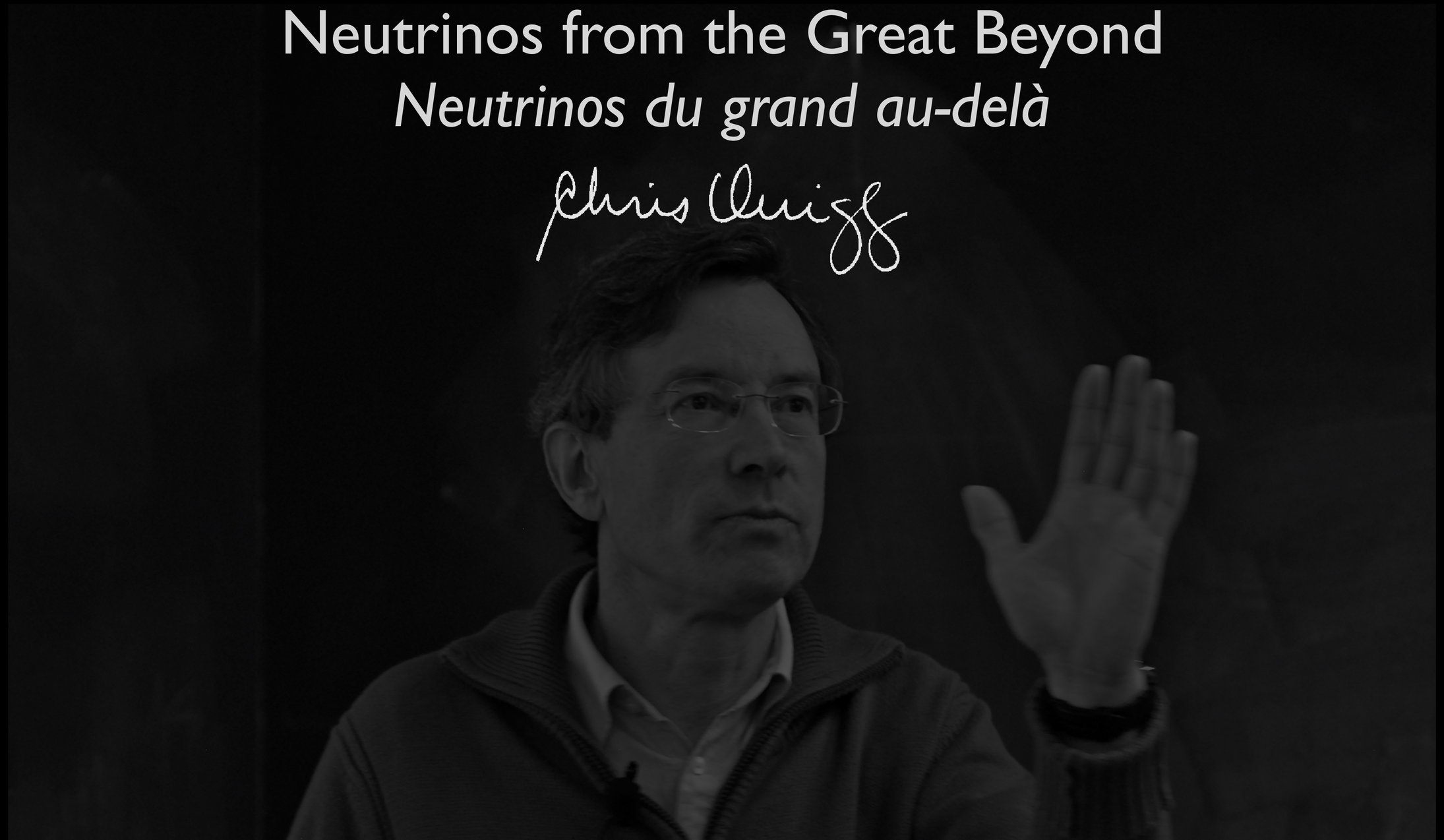
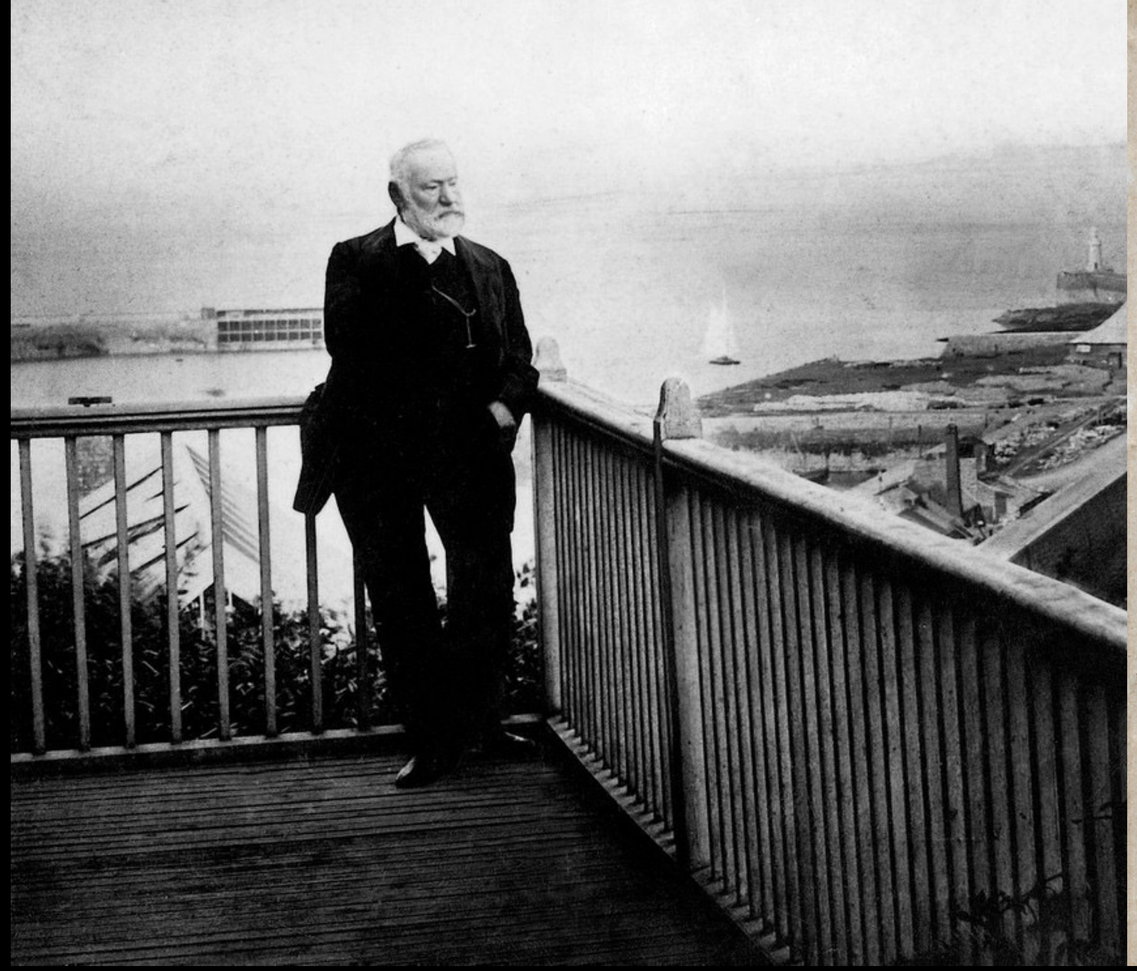
Neutrinos from the Great Beyond

Neutrinos du grand au-delà







LA PLURALITÉ DES MONDES HABITÉS,

ÉTUDE

OU L'ON EXPOSE LES CONDITIONS D'HABITABILITÉ DES TERRES CÉLESTES, DISCUTÉES AU POINT DE VUE DE L'ASTRONOMIE ET DE LA PHYSIOLOGIE ;

PAR

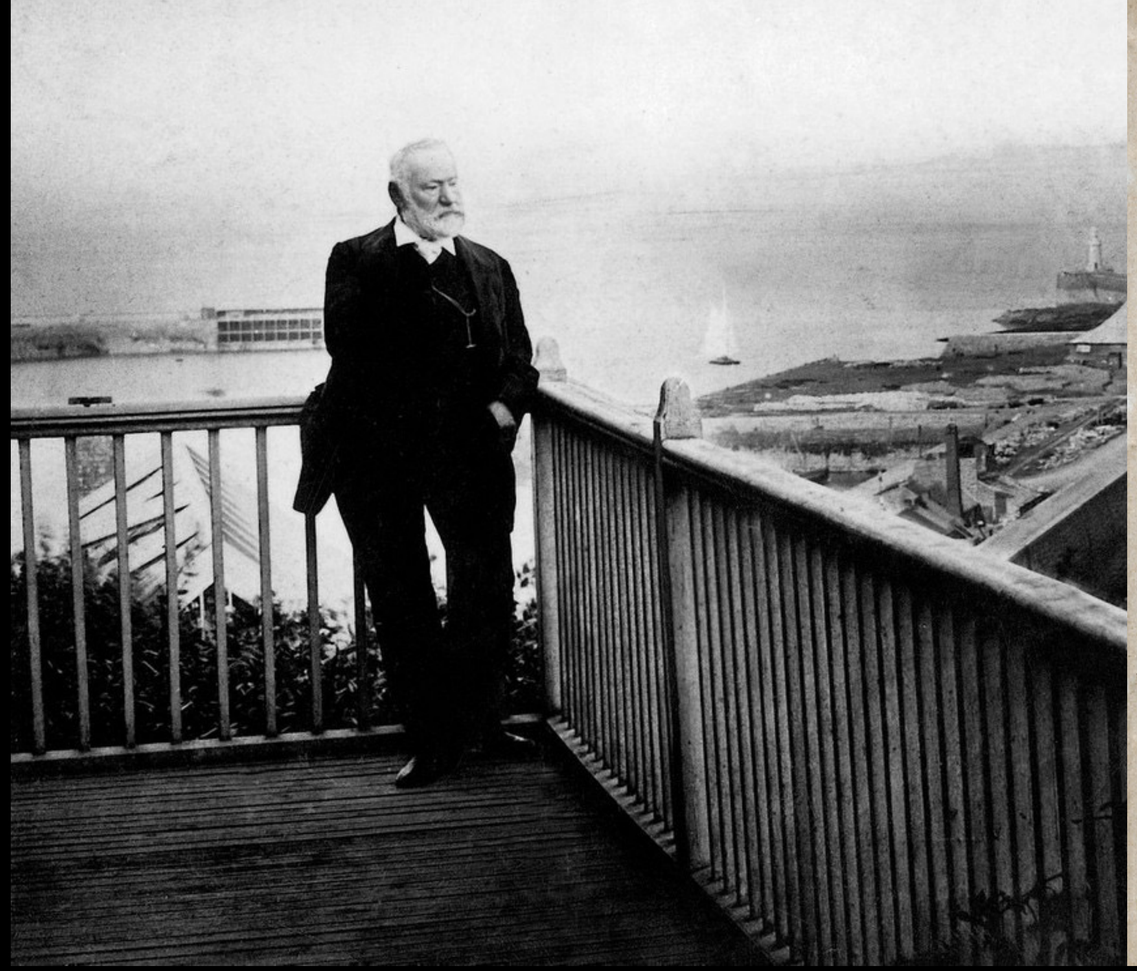
CAMILLE FLAMMARION,

ANCIEN CALCULATEUR A L'OBSERVATOIRE IMPÉRIAL DE PARIS, PROFESSEUR D'ASTRONOMIE, MEMBRE DE PLUSIEURS SOCIÉTÉS SAVANTES, ETC.

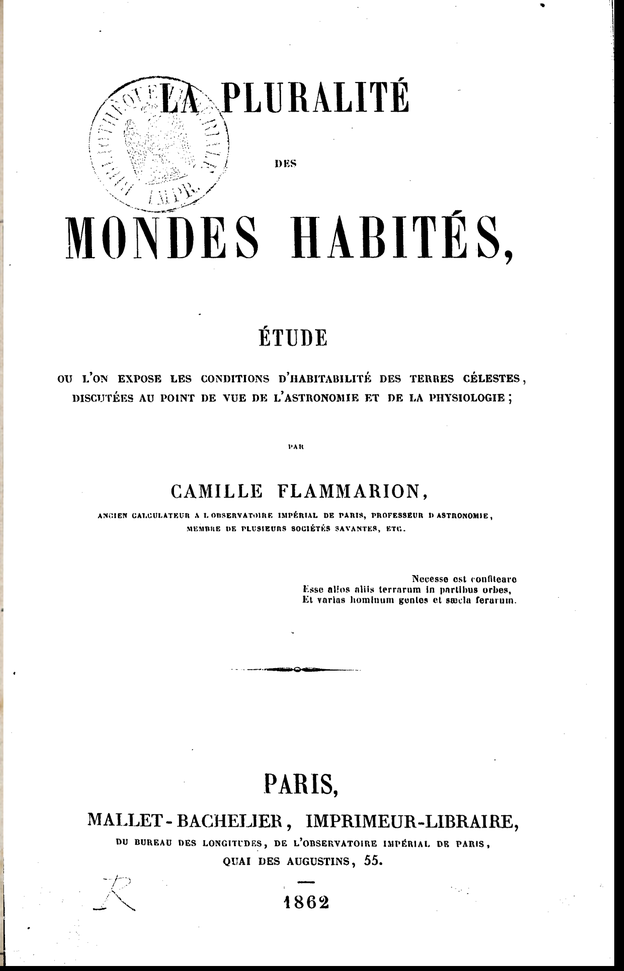
Necesse est confiteare
Esse alios aliis terrarum in partibus orbes,
Et varias hominum gentes et sæcla ferarum.

PARIS,
MALLET-BACHELIER, IMPRIMEUR-LIBRAIRE,
DU BUREAU DES LONGITUDES, DE L'OBSERVATOIRE IMPÉRIAL DE PARIS,
QUAI DES AUGUSTINS, 55.

1862







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Au delà du visible l'invisible, au delà de l'invisible l'inconnu.

—Victor Hugo, *Choses de l'infini* (1864)

Anticipating DUMAND, AMANDA, Nestor, Antares, Ice Cube …

UHE (> TeV) Sources: galactic cosmic rays on interstellar gas,

extragalactic cosmic rays on CMB, Blazars (AGN),

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$\nu_\ell N \to \ell + \ldots$

$$\frac{d^2\sigma}{dxdy} = \frac{2G_F^2 M E_\nu}{\pi}\left(\frac{M_W^2}{Q^2 + M_W^2}\right)^2 \left[xq(x,Q^2) + x\bar{q}(x,Q^2)(1-y)^2\right]$$

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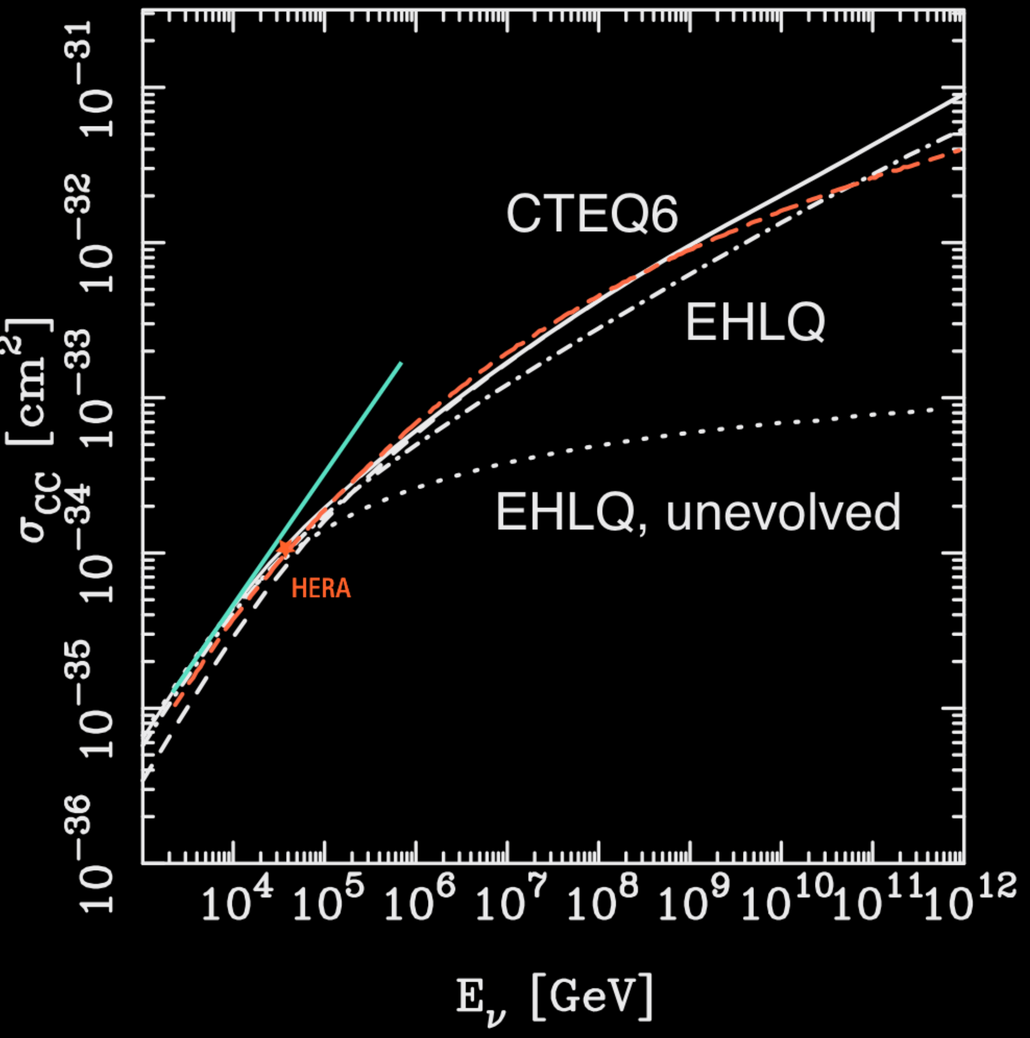
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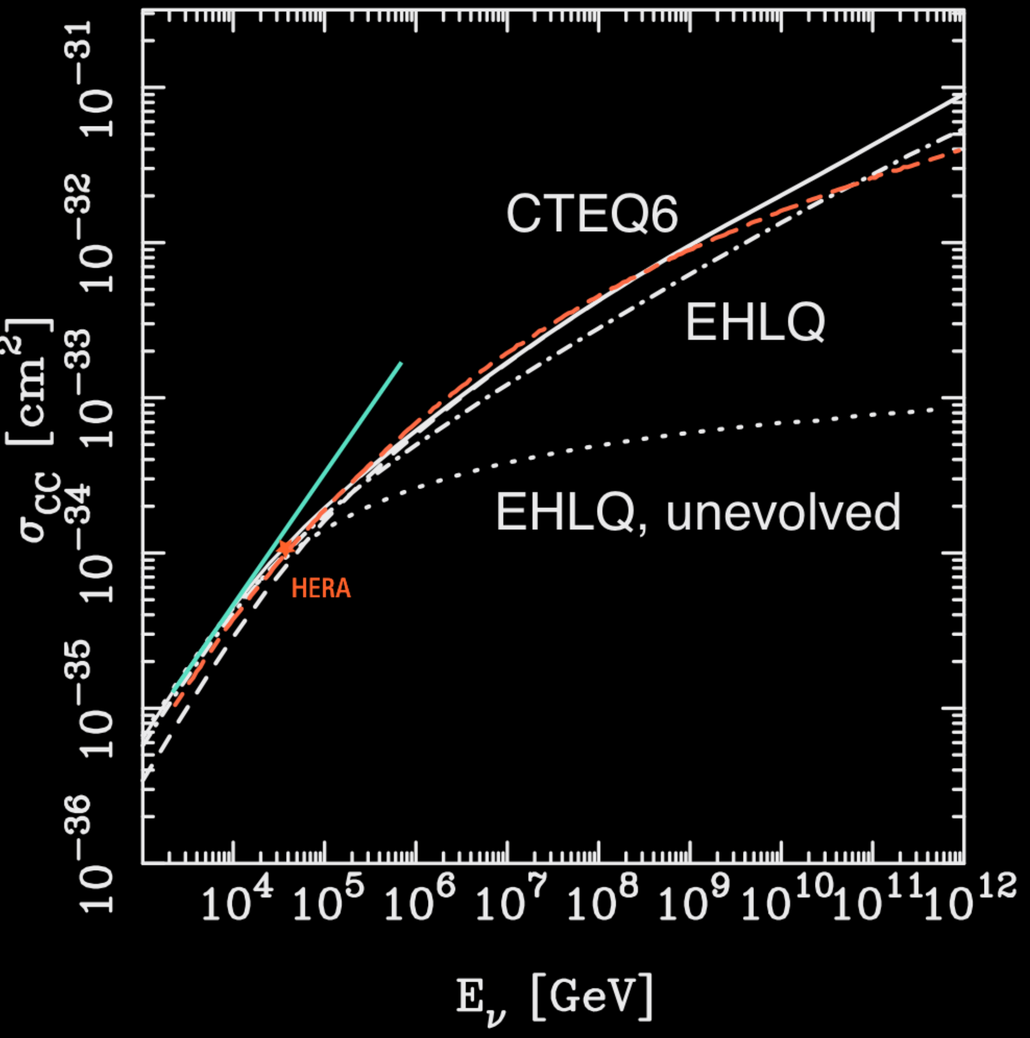
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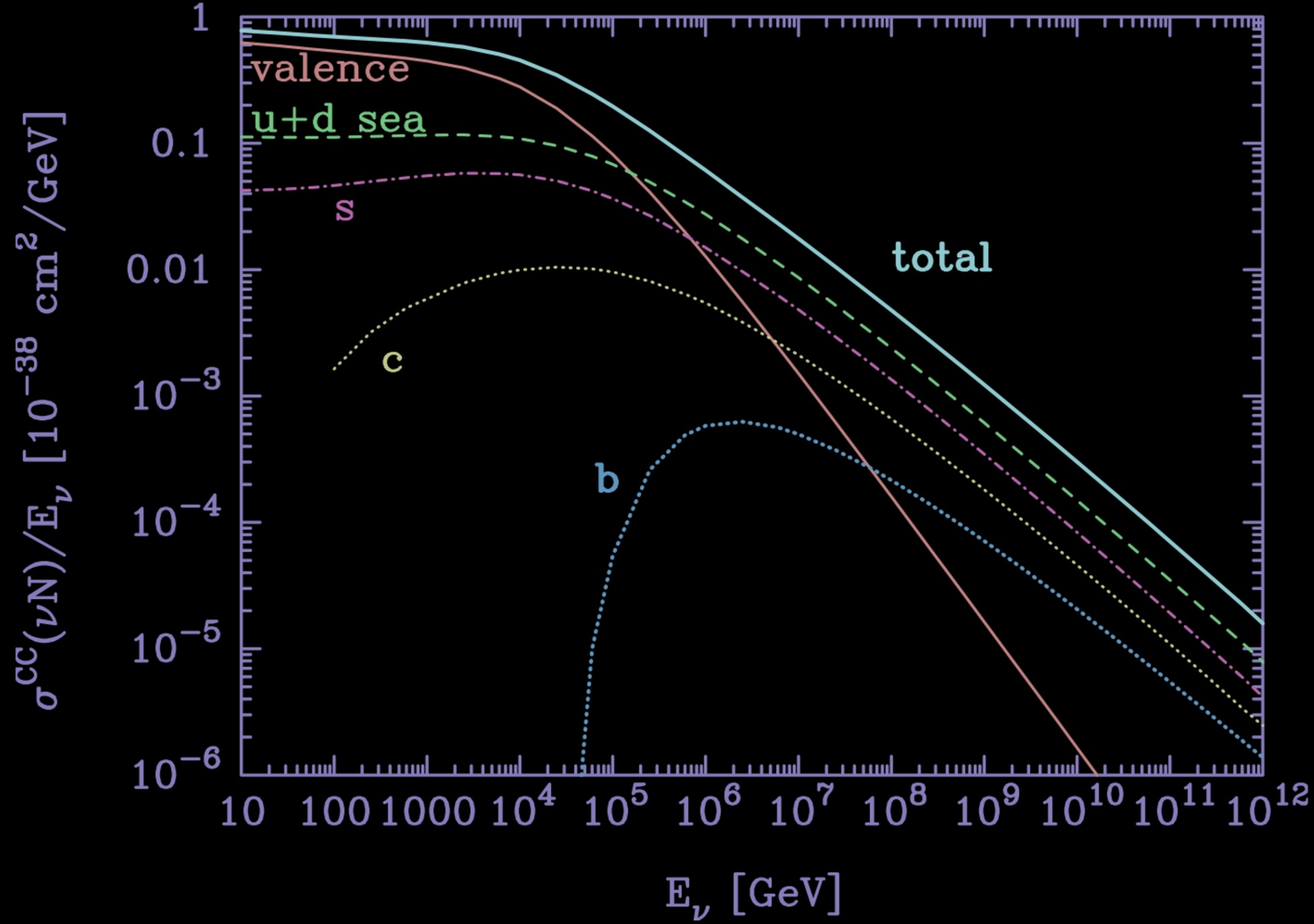
$$\rightsquigarrow xy \approx M_W^2/2ME_\nu$$

QCD evolution *enhances* UHE cross sections

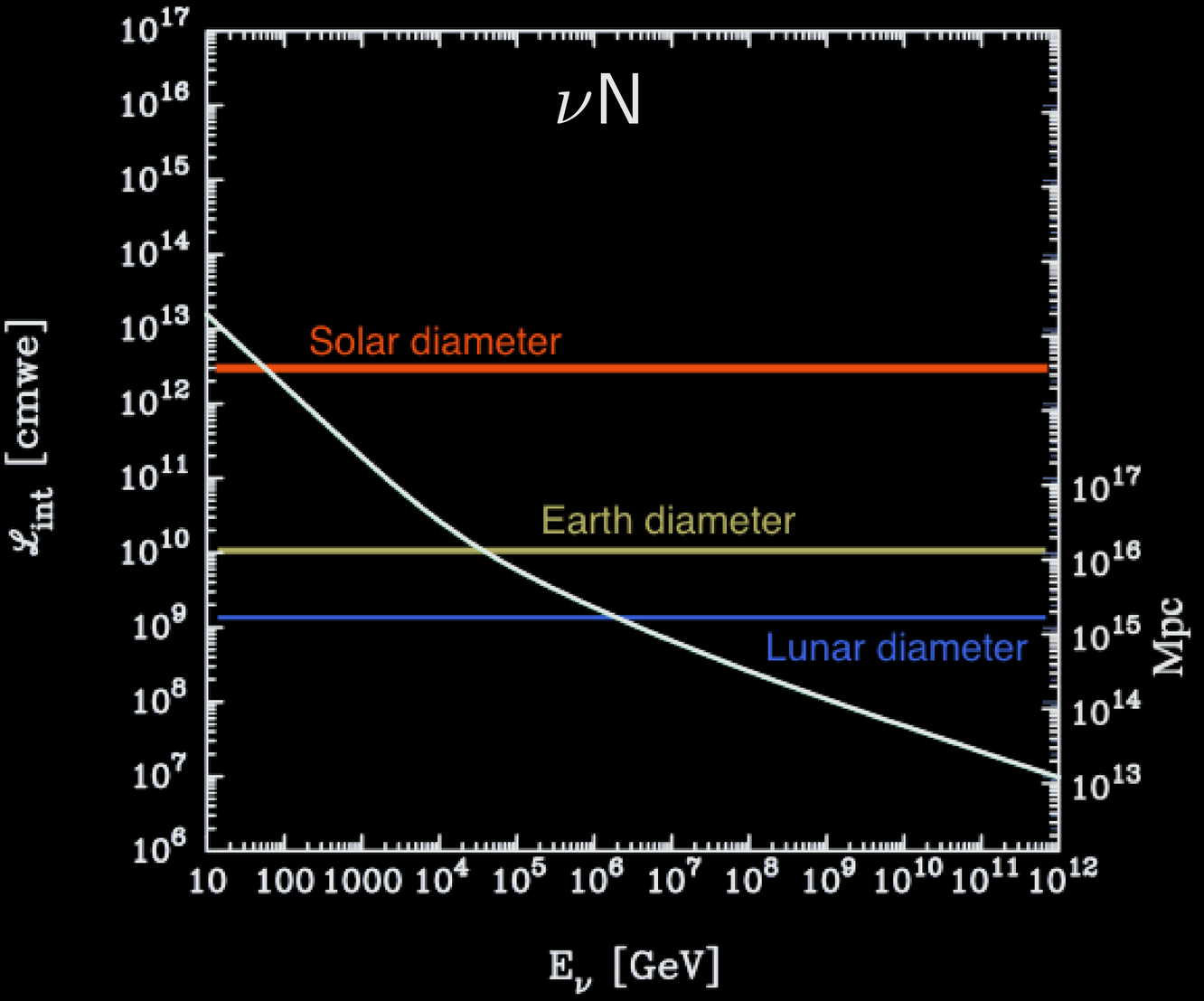


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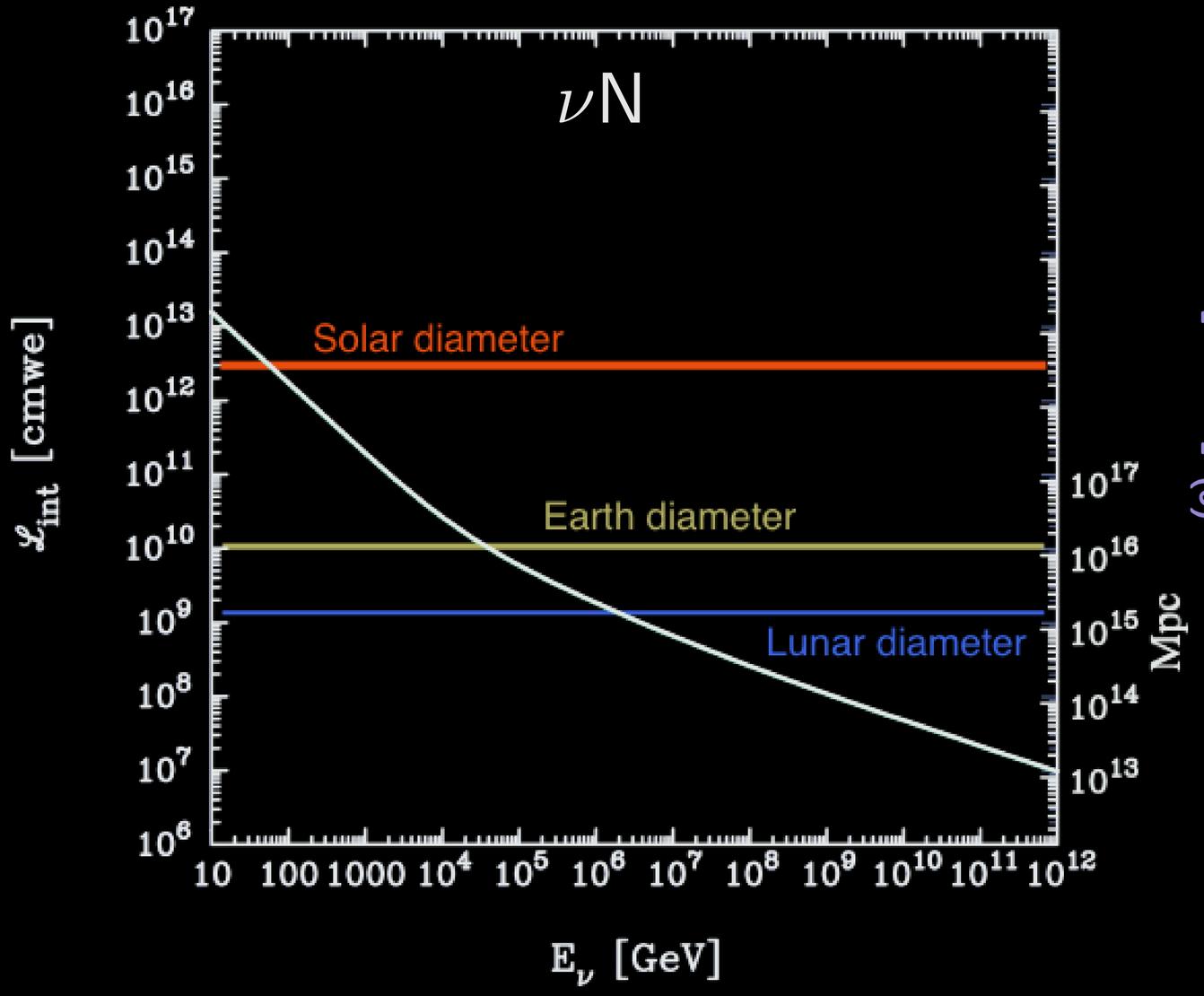


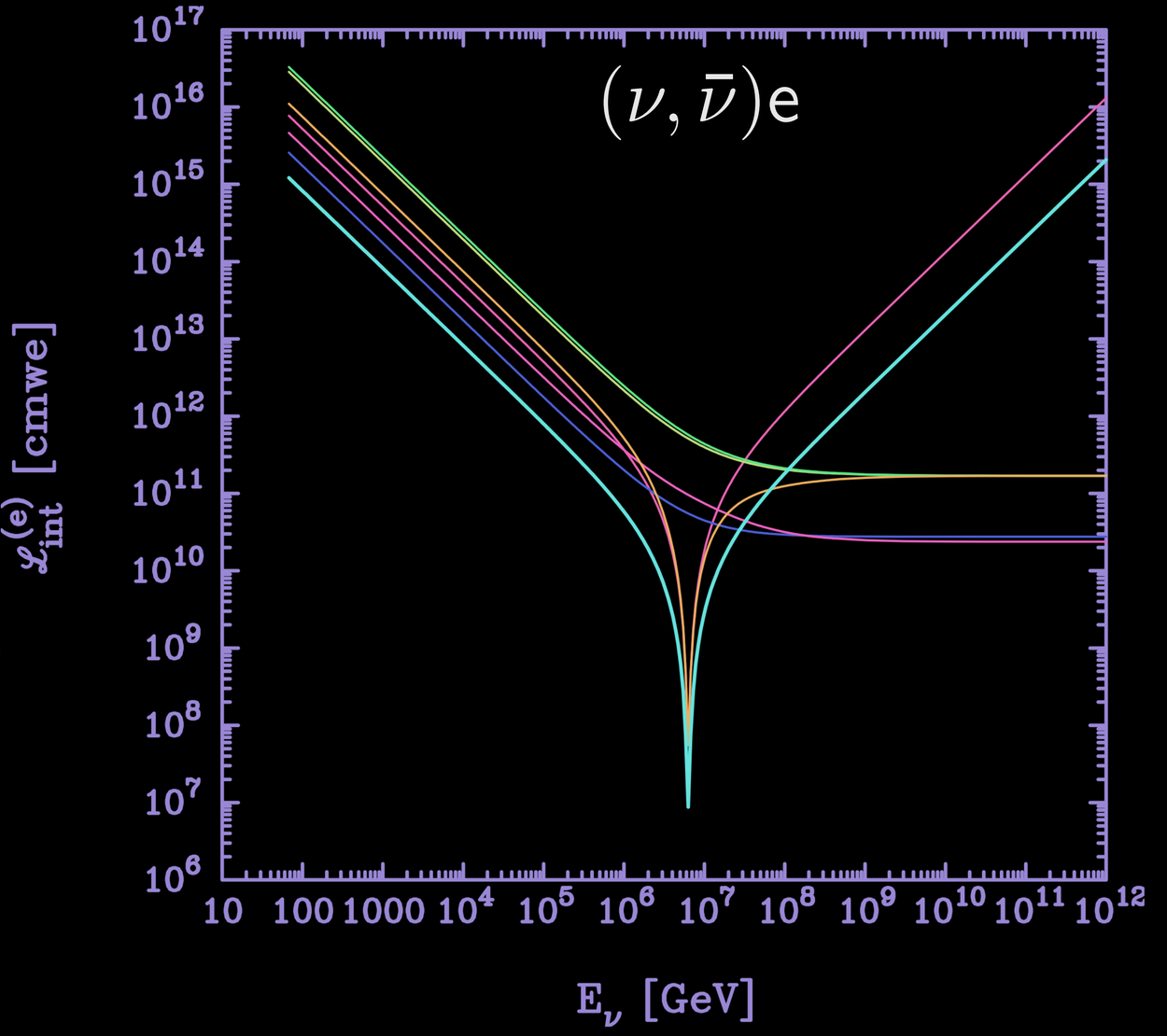


Interaction lengths

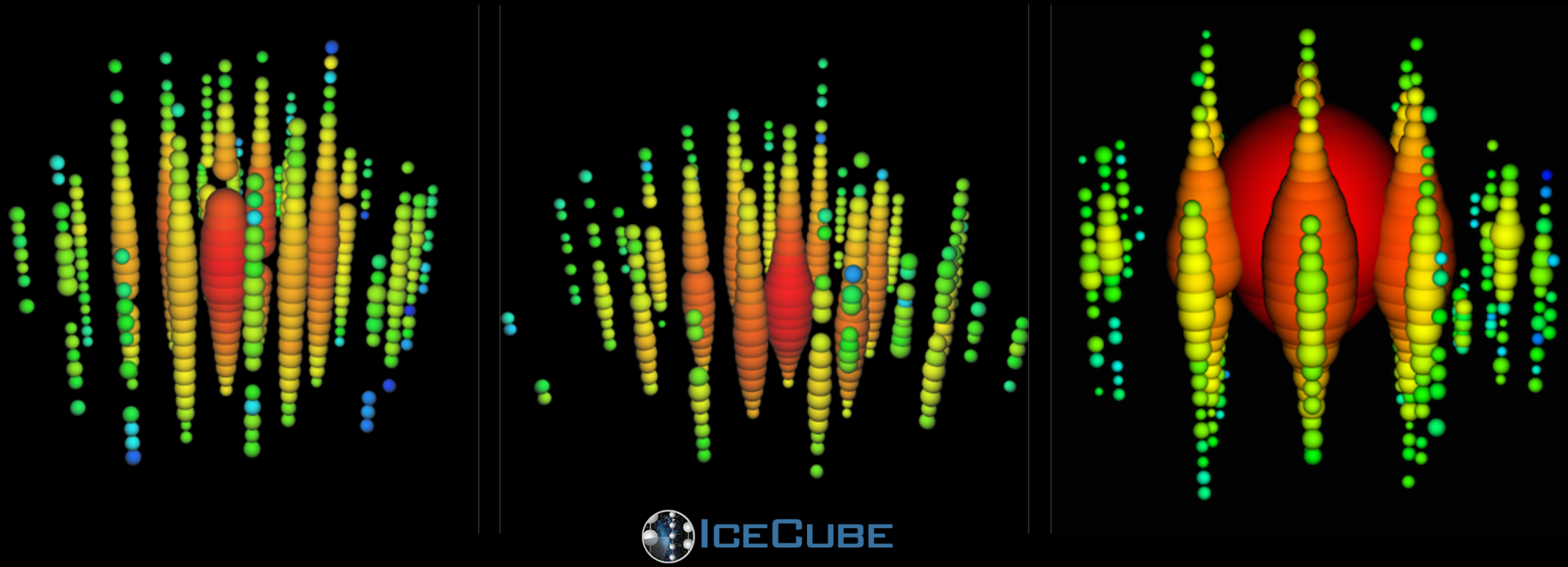


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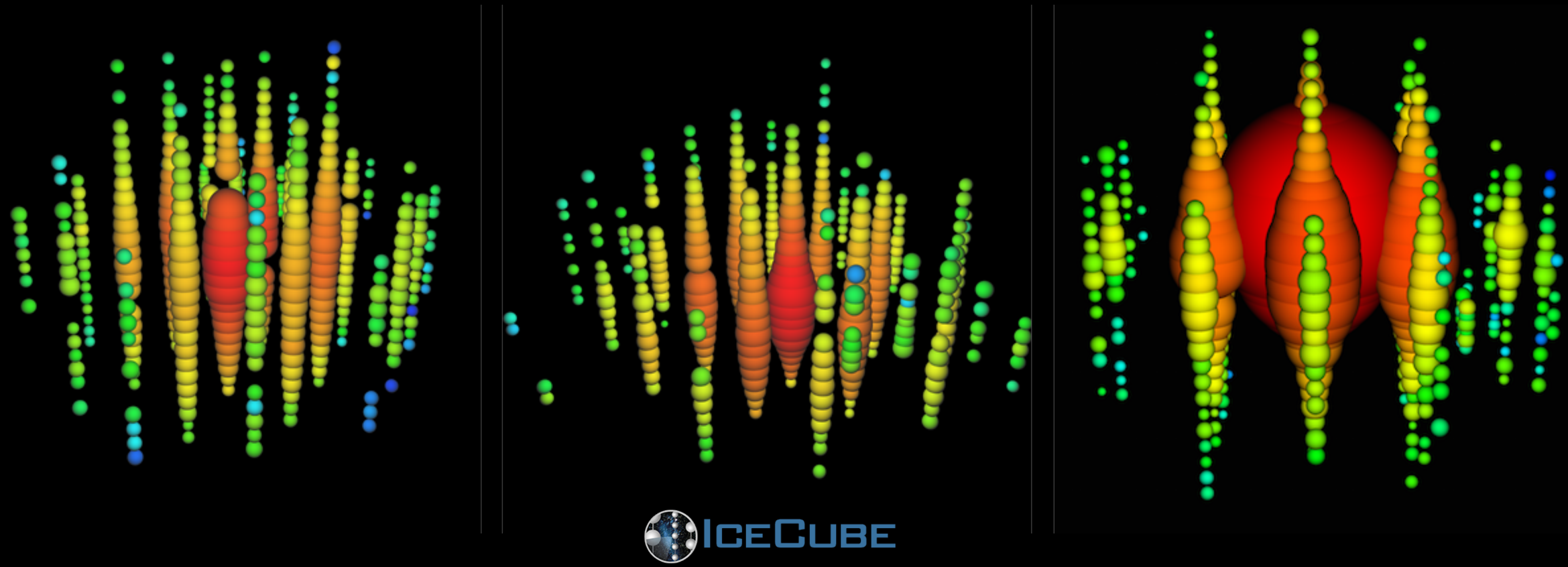




Recent detection of PeV (extraterrestrial) neutrinos



Recent detection of PeV (extraterrestrial) neutrinos



Historical goals: astronomical / astrophysical / particle physics

Prehistory

Conventional π-decay sources: $\Phi^0_{\text{std}} \equiv \{\varphi^0_e, \varphi^0_\mu, \varphi^0_\tau\} = \{\frac{1}{3}, \frac{2}{3}, 0\}$

1.8-PeV ν_τ decay length $\approx$ 87 m: double-bang signature

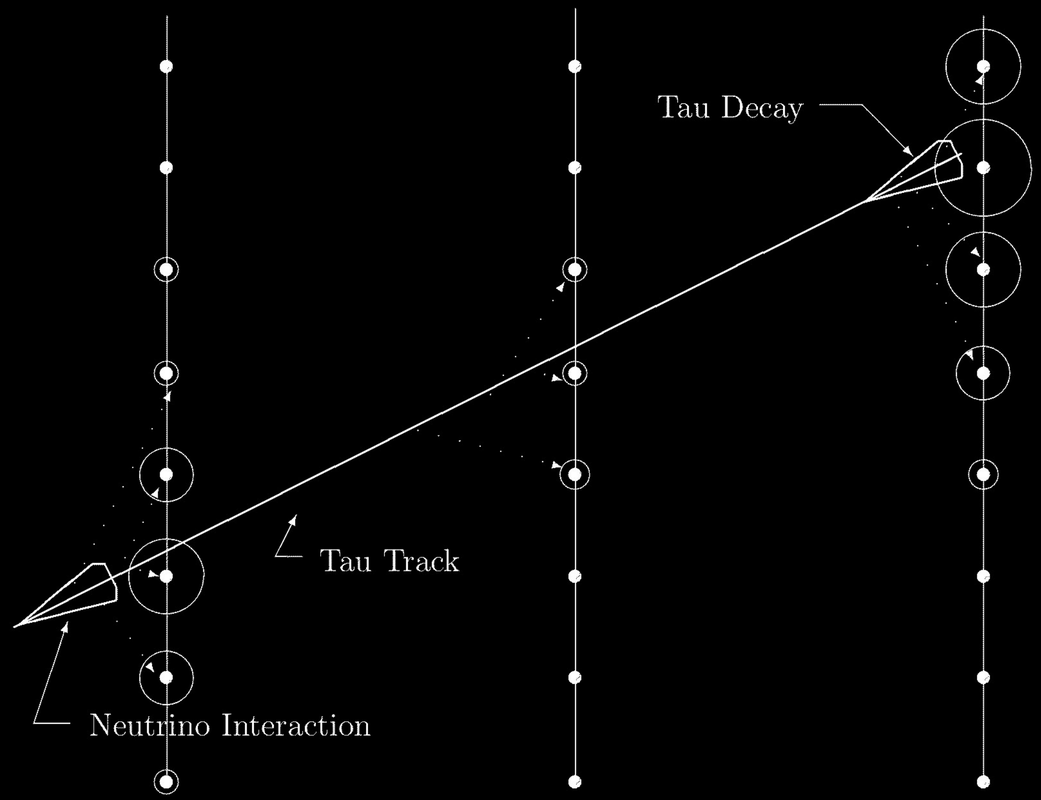
possibility to discover ν_μ-ν_τ oscillations

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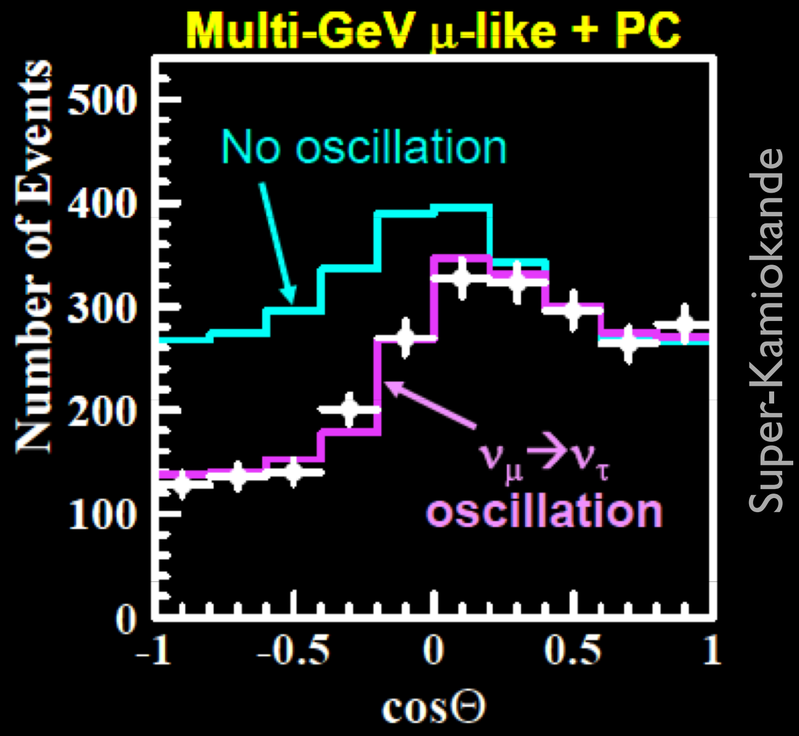
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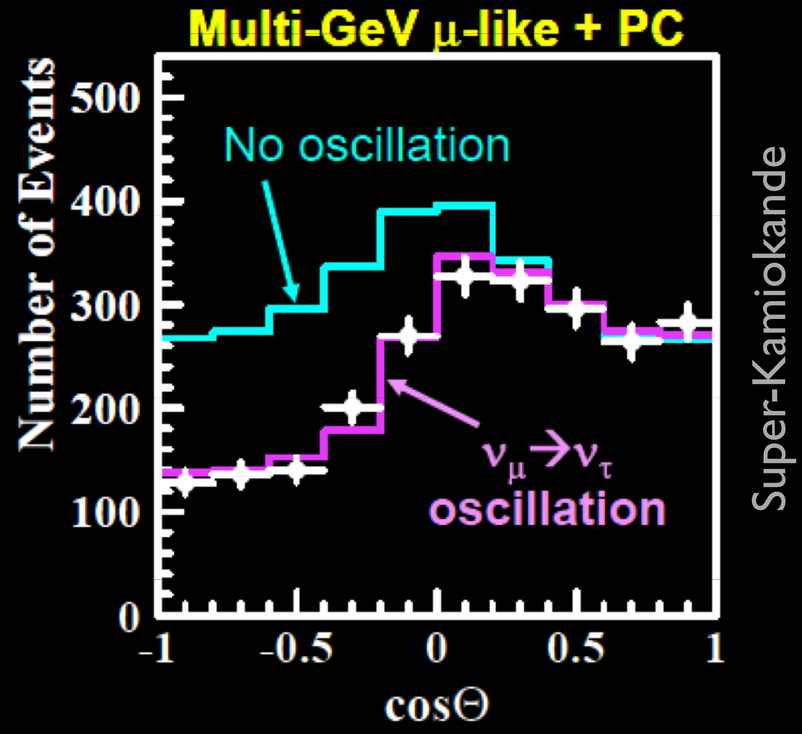
History

ν_μ-ν_τ oscillations discovered in atmospheric ν interactions



History

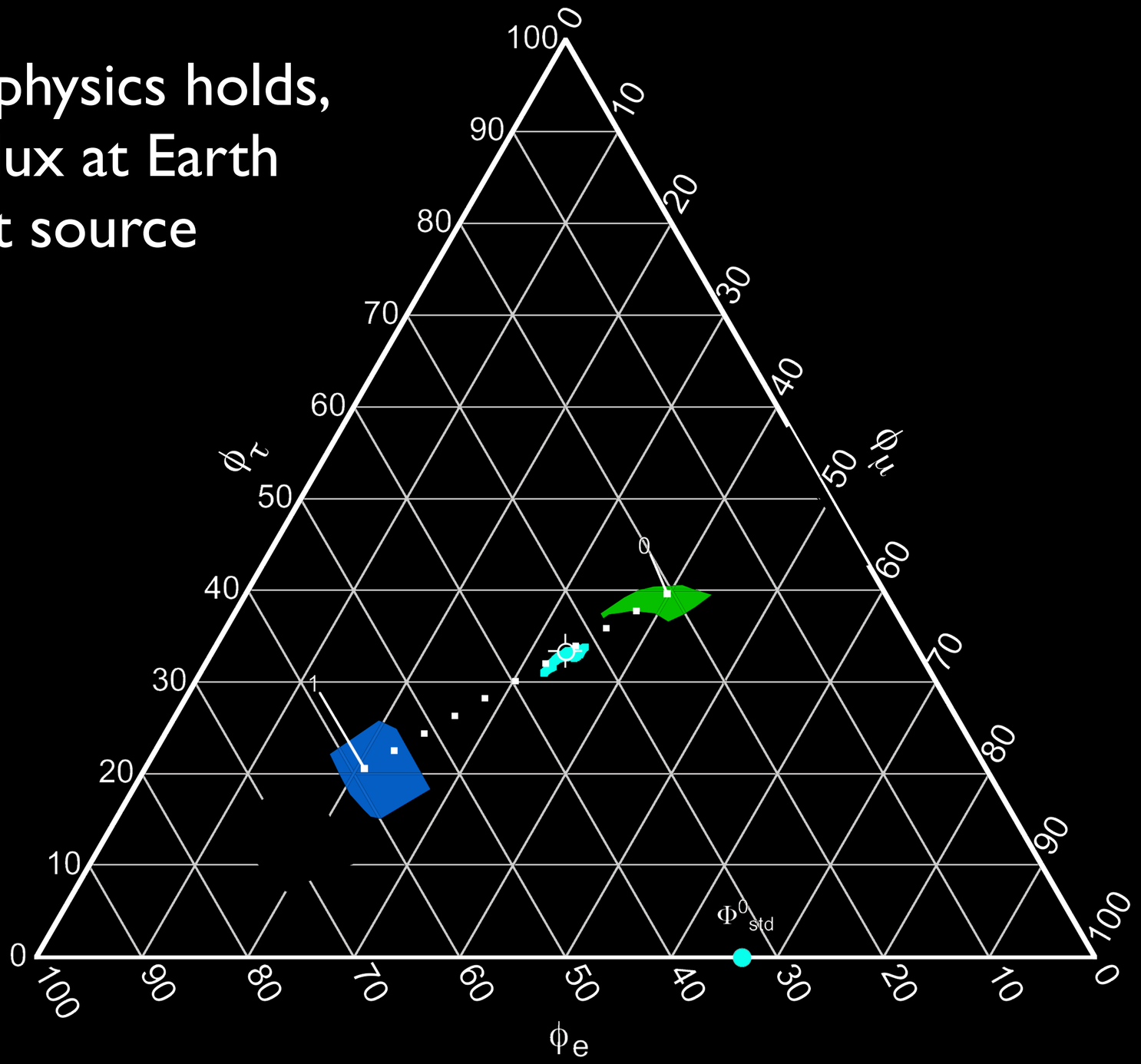
ν_μ-ν_τ oscillations discovered in atmospheric ν interactions



Vacuum oscillation length $4\pi E_\nu/|\Delta m^2| \ll$ intergalactic distances

At Earth, expect $\Phi \equiv \{\varphi_e, \varphi_\mu, \varphi_\tau\} = \left\{\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right\} \equiv \Phi_{\text{std}}$

If established physics holds,
might invert flux at Earth
to infer flux at source



Might neutrinos decay?

Nonradiative decays weakly constrained: $\tau/m > 10^{-4}$ s/eV

Simple (extreme) example: only lightest ν survives

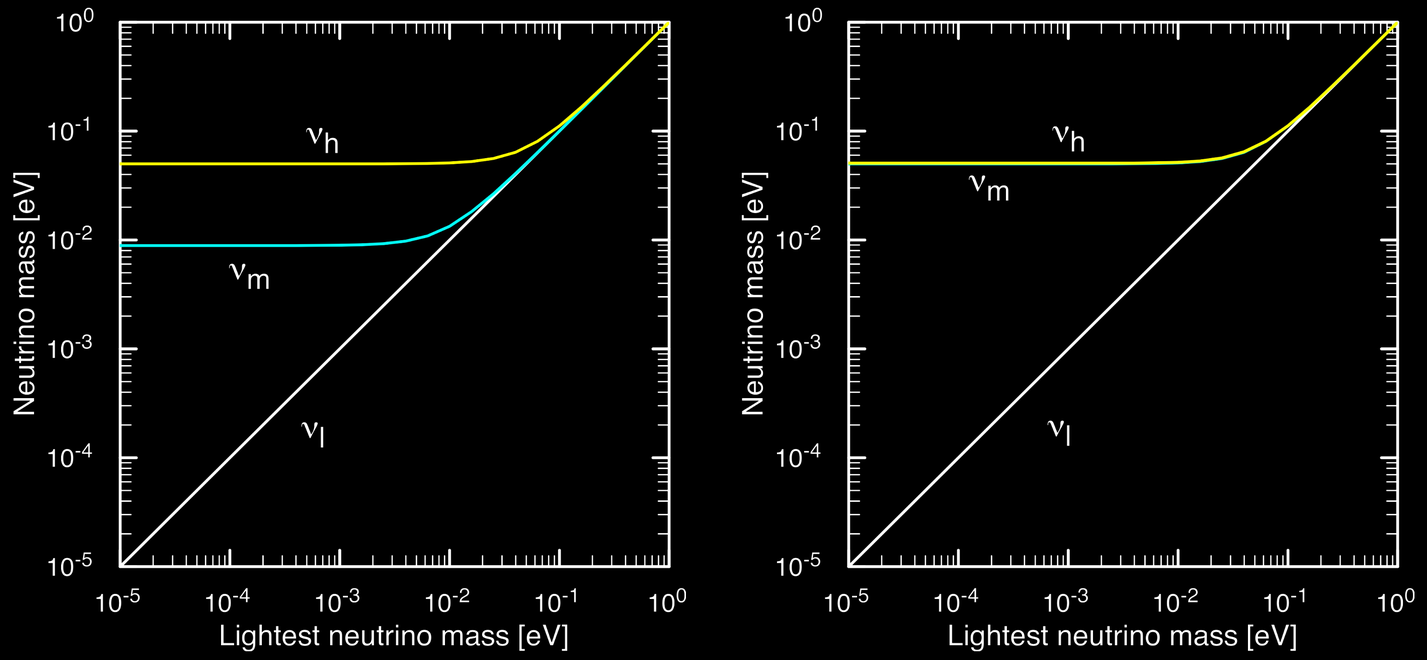
$$\Phi_{\rm normal} = \{|U_{e1}|^2, |U_{\mu 1}|^2, |U_{\tau 1}|^2\};\ \Phi_{\rm inverted} = \{|U_{e3}|^2, |U_{\mu 3}|^2, |U_{\tau 3}|^2\}$$

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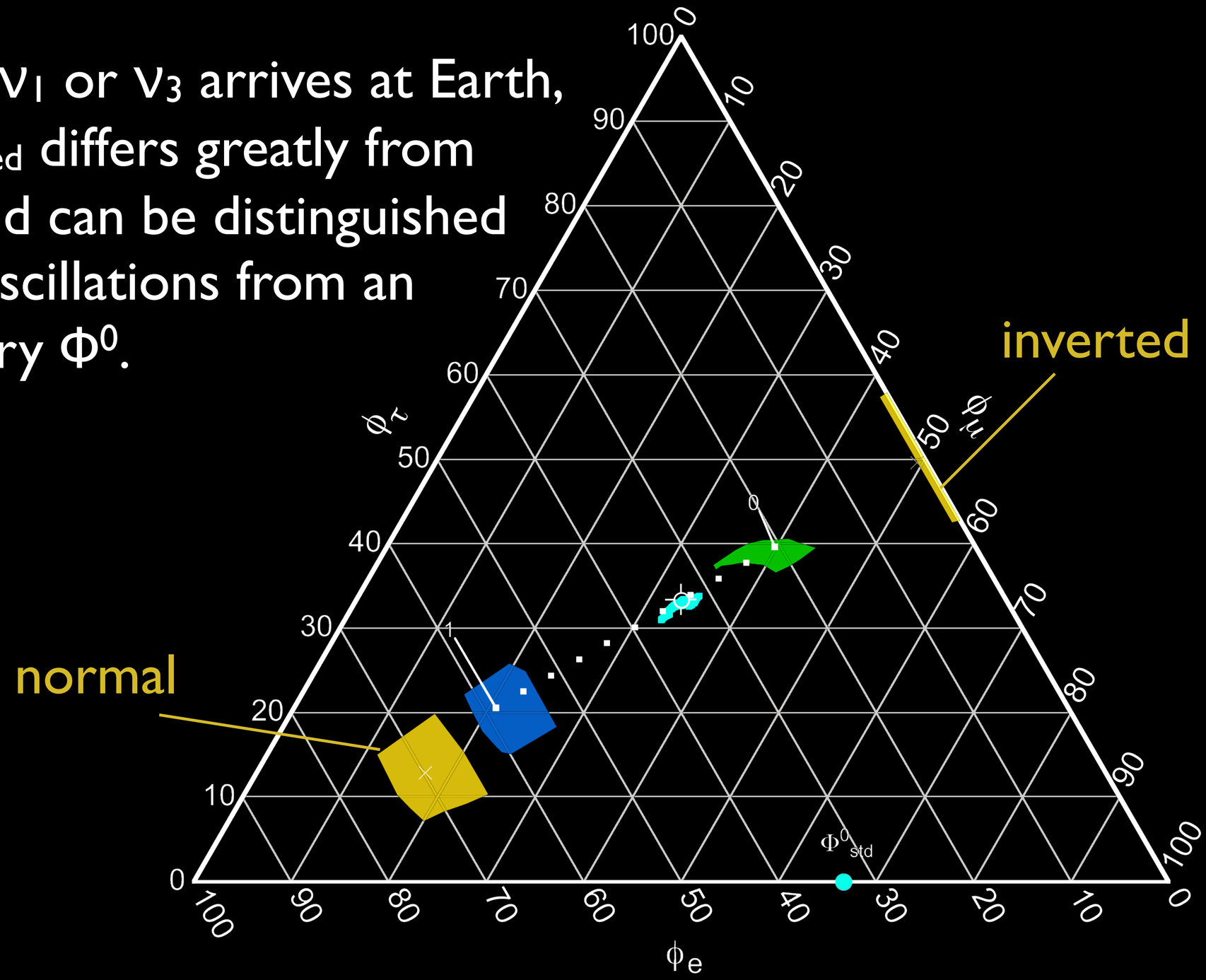
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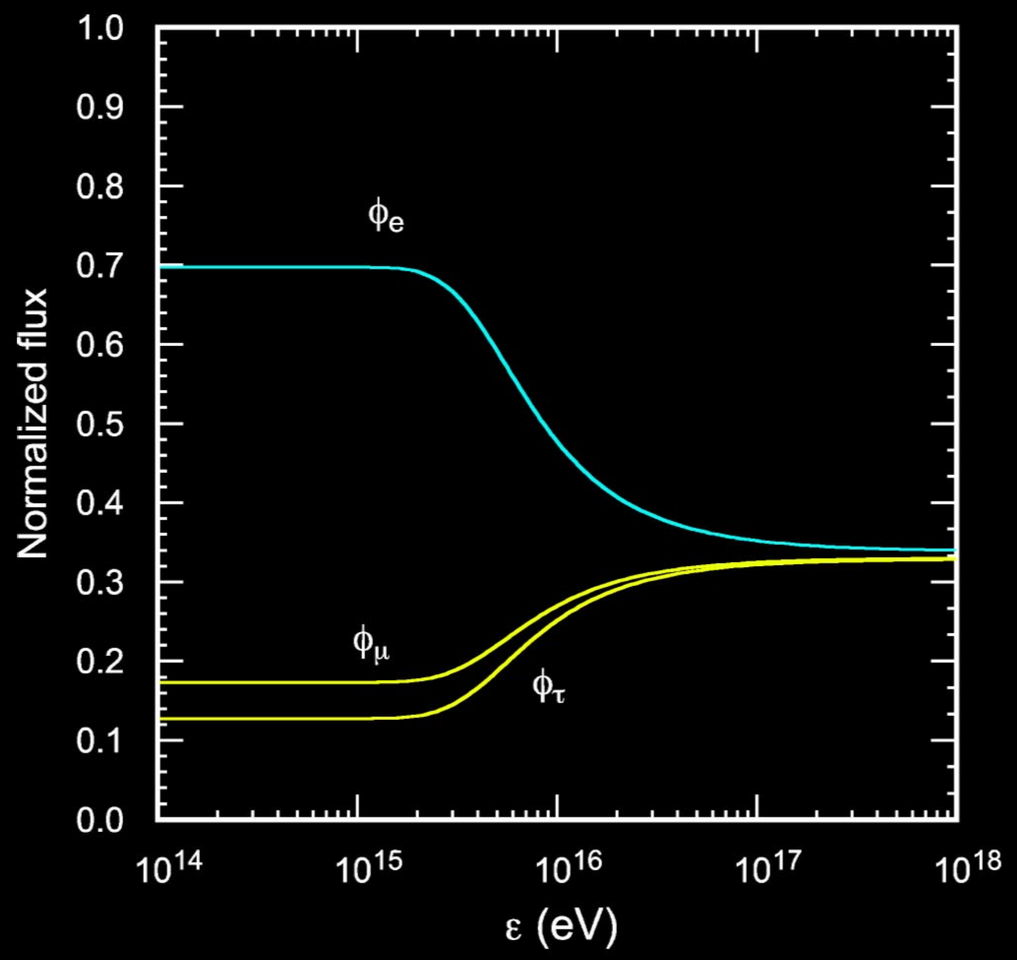
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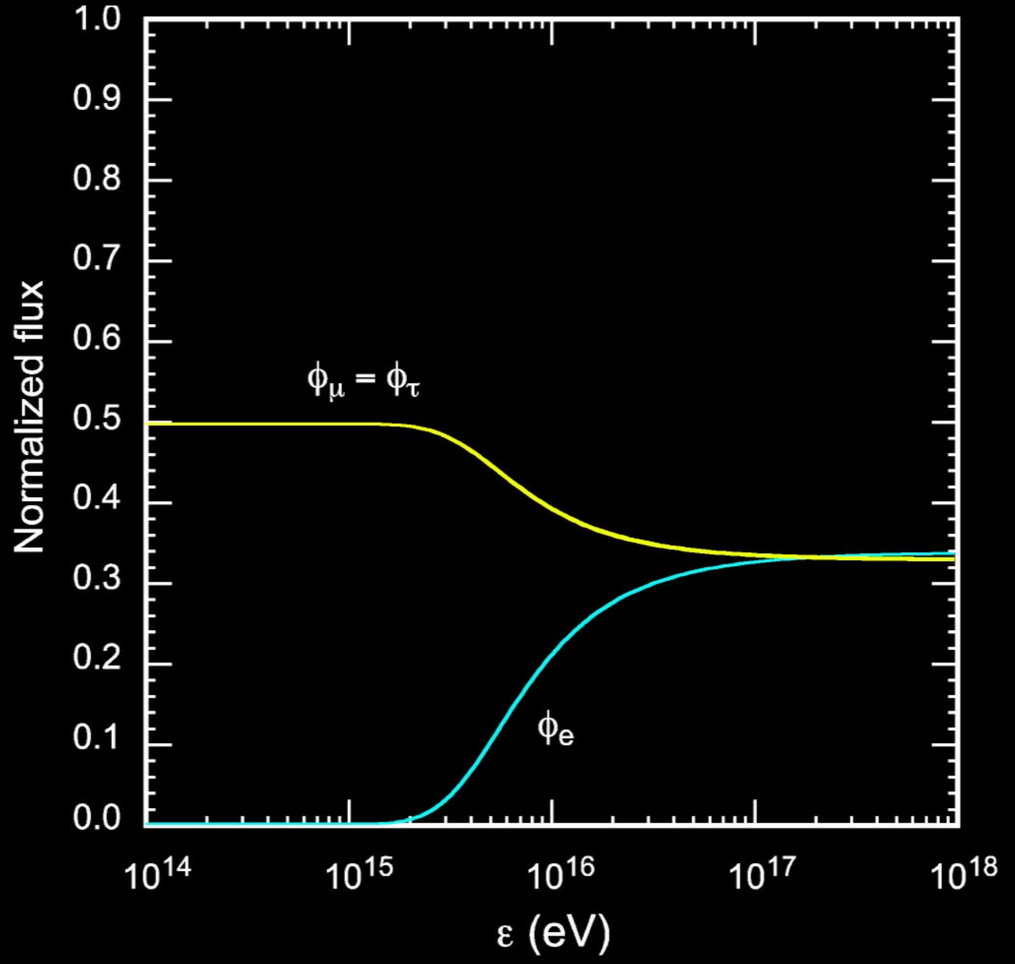


If only ν_1 or ν_3 arrives at Earth, $\Phi_{observed}$ differs greatly from Φ_{std}, and can be distinguished from oscillations from an arbitrary Φ^0.



Energy-dependent composition as marker of ν decays

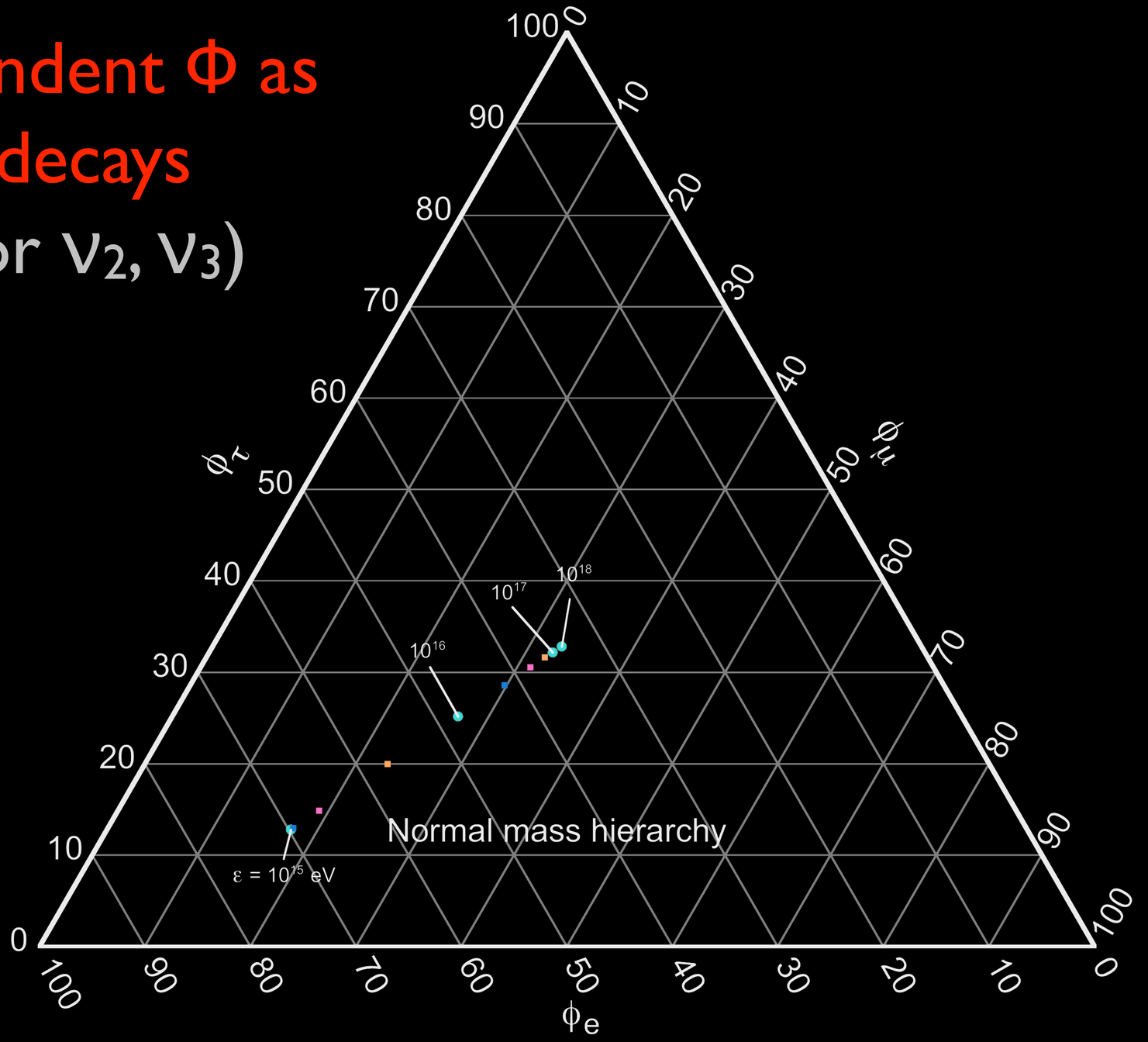




$$E_\nu = \varepsilon(1\ \mathrm{s/eV})/(\tau_\nu/m_\nu) \cdot L/(100\ \mathrm{Mpc})$$

Energy-dependent Φ as marker of ν decays

(same τ/m for ν_2, ν_3)



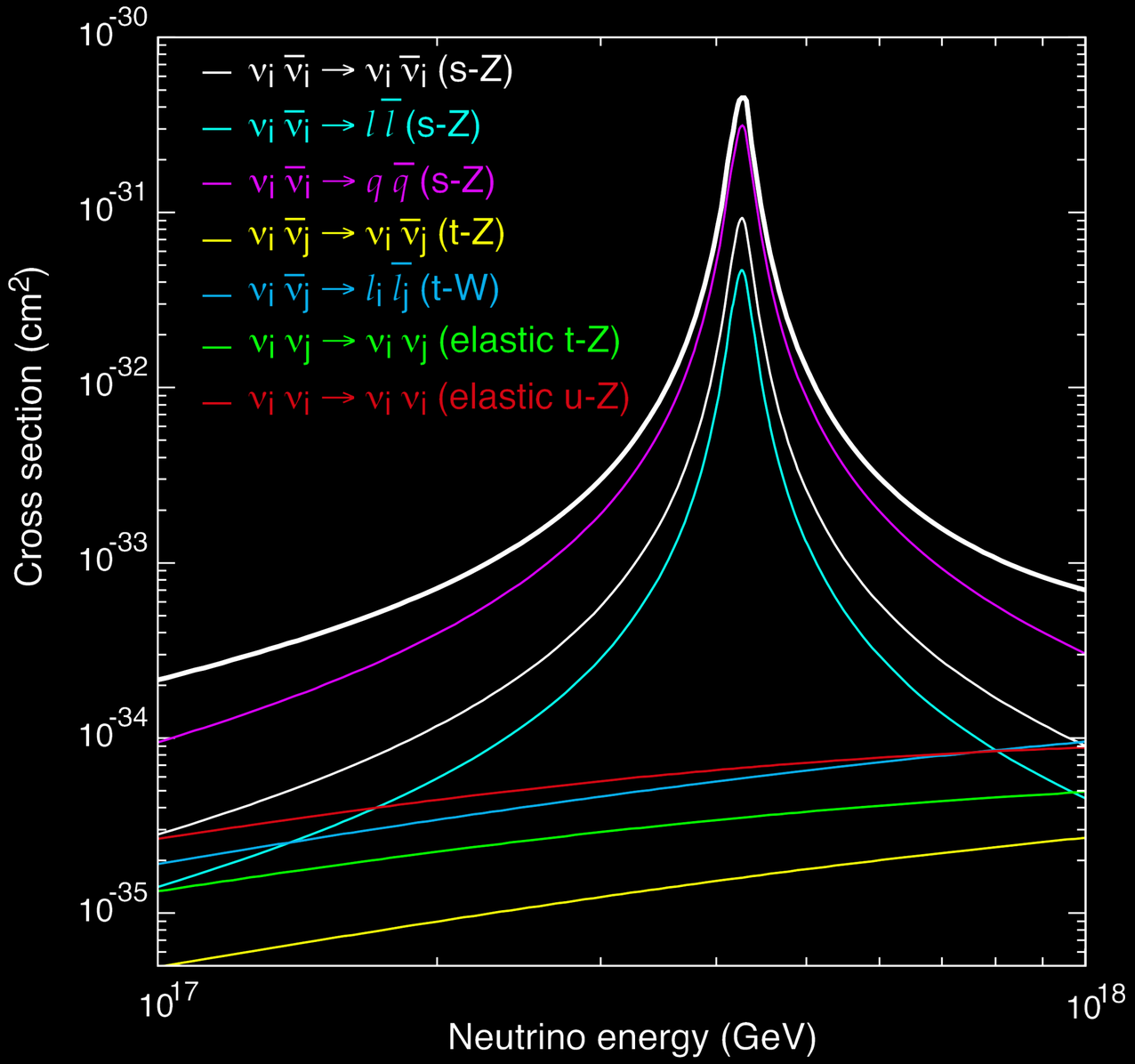
Cosmic neutrino relics

ν_i, $\bar{\nu}_i$ number density now: $56/\mathrm{cm}^3$, $\propto (1+z)^3$

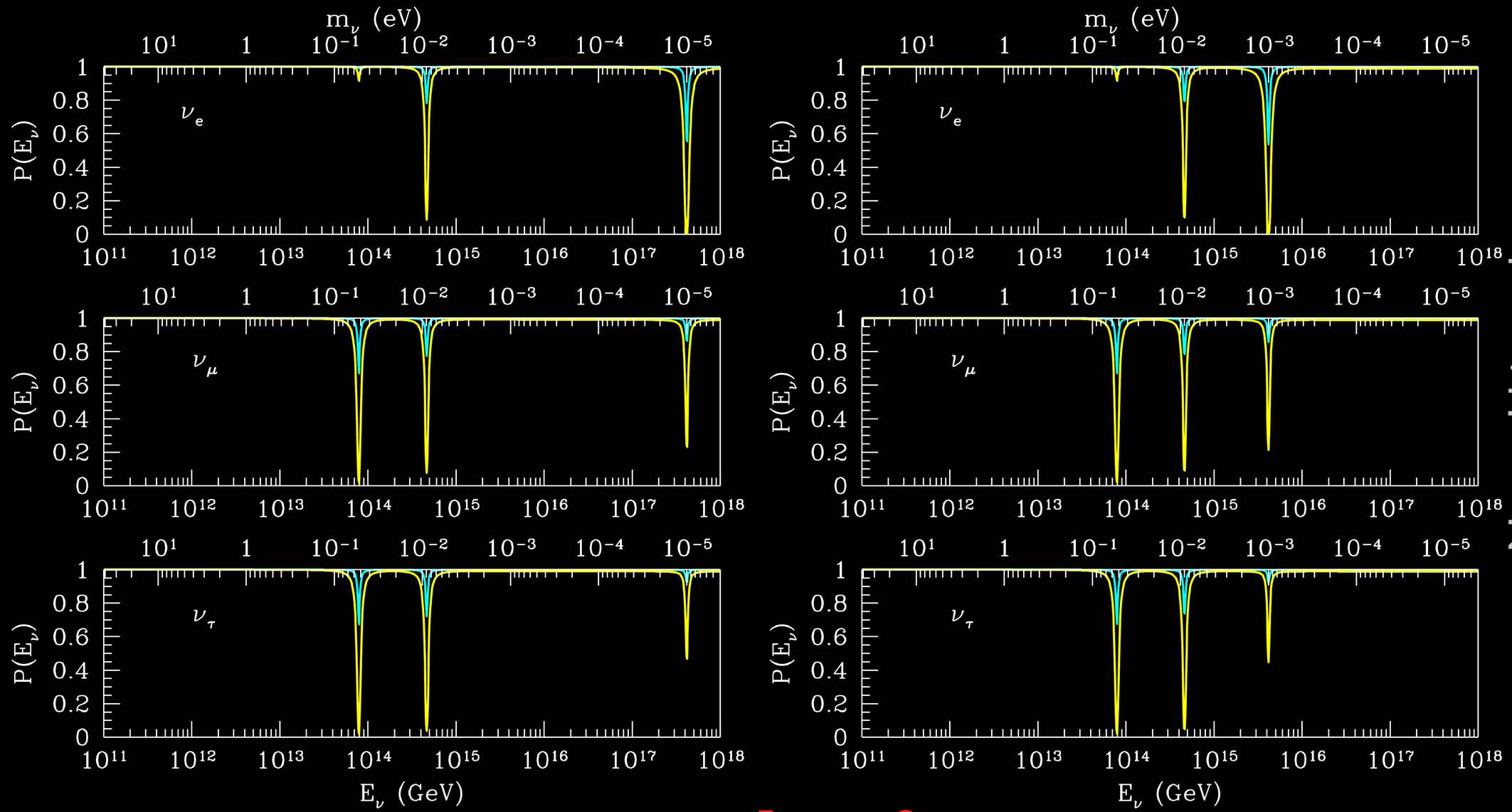
$T_{\nu 0} = 1.945\ \mathrm{K} = 1.697 \times 10^{-4}\ \mathrm{eV}$; $T_\nu \propto (1+z)$

How to detect?

UHE ν annihilation on ν relics ($m_\nu = 10^{-5}$ eV)

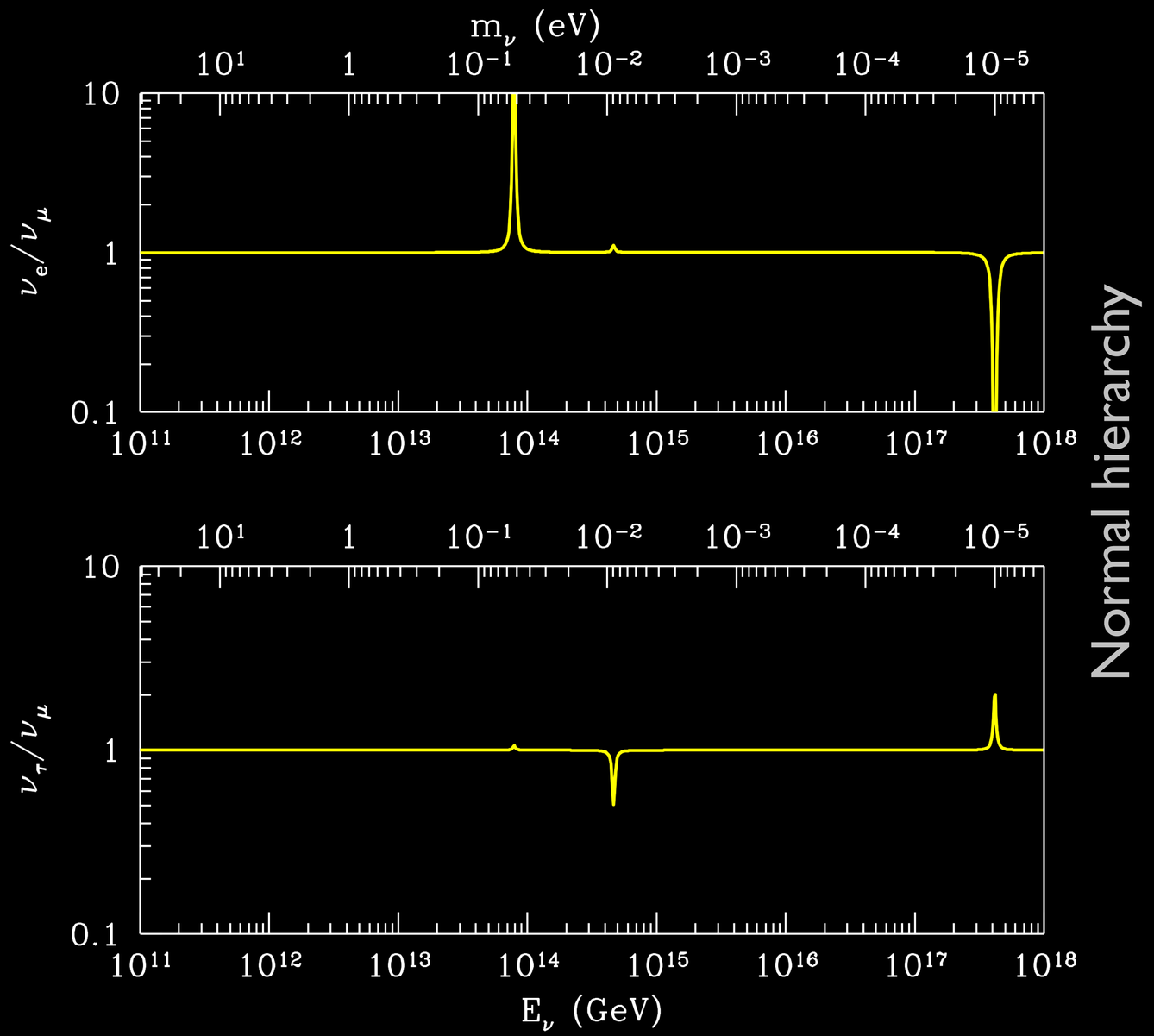


Fable: l-o-o-o-o-o-o-n-g path (10^4 or 10^5 Mpc) in current U



$m_\nu = (10^{-5}, 10^{-3})$ eV

Flavor ratios would probe the mass hierarchy …



Already hopeless, given the small neutrino masses

Must take into account evolution of universe to $z \approx 20$
to have thick enough target

Relic neutrinos are moving targets: Fermi motion

Narrow absorption lines smeared

Already hopeless, given the small neutrino masses

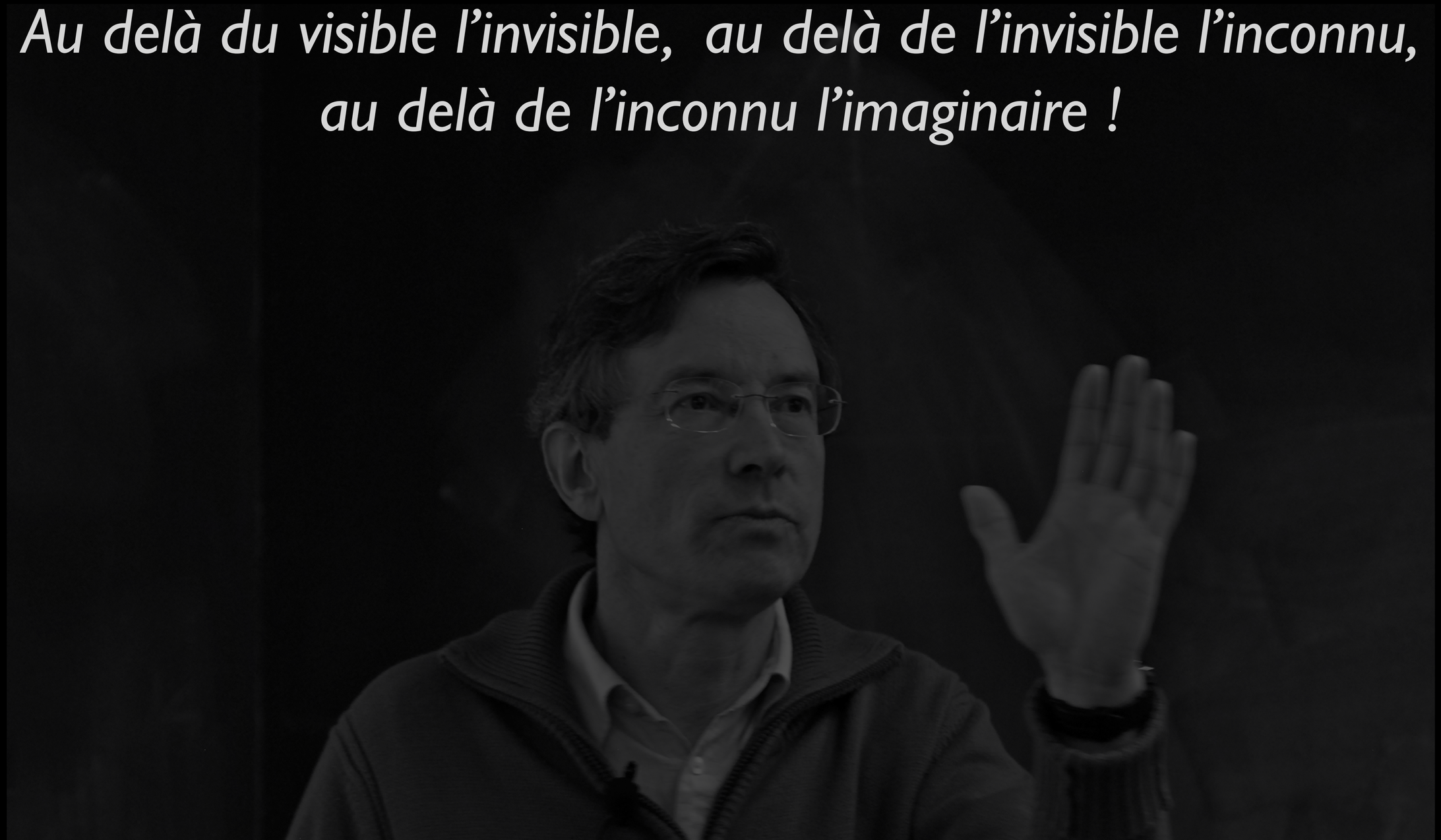
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Exploit Fermi motion? (Weinberg, 1962): $\nu_{relic} + {}^3H \rightarrow {}^3He + e^-$

Au delà du visible l'invisible, au delà de l'invisible l'inconnu, au delà de l'inconnu l'imaginaire !



Au delà du visible l'invisible, au delà de l'invisible l'inconnu, au delà de l'inconnu l'imaginaire !

