DECAY PIPE EFFECTS FOR STERILE NEUTRINO SEARCHES

ALESSIO GIARNETTI

ESS neutrino Super Beam plus

ROMA TRE UNIVERSITÀ DEGLI STUDI

WP5 in-person meeting
24/05/2023

THE DUNE EXAMPLE

Baseline and other effects for a sterile neutrino at DUNE

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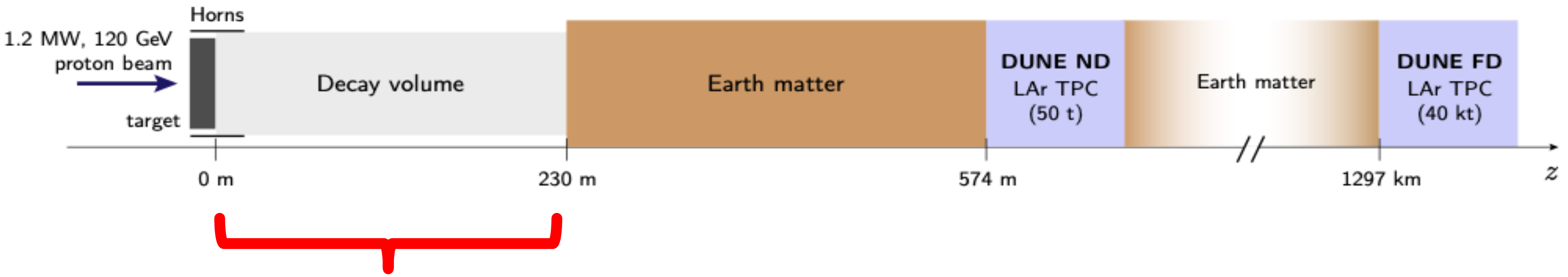


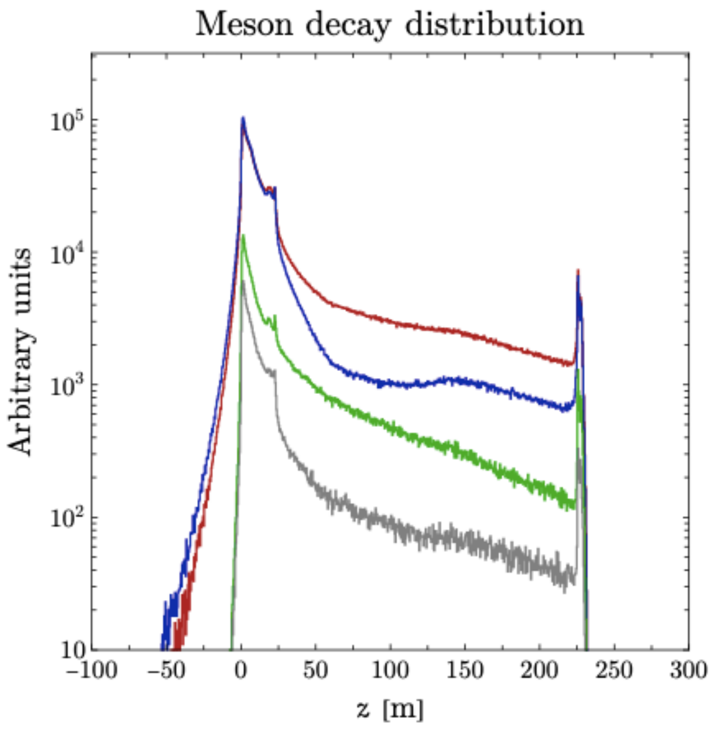
The decay volume lenght is not negligible in respect to the sterile neutrino oscillation baseline!

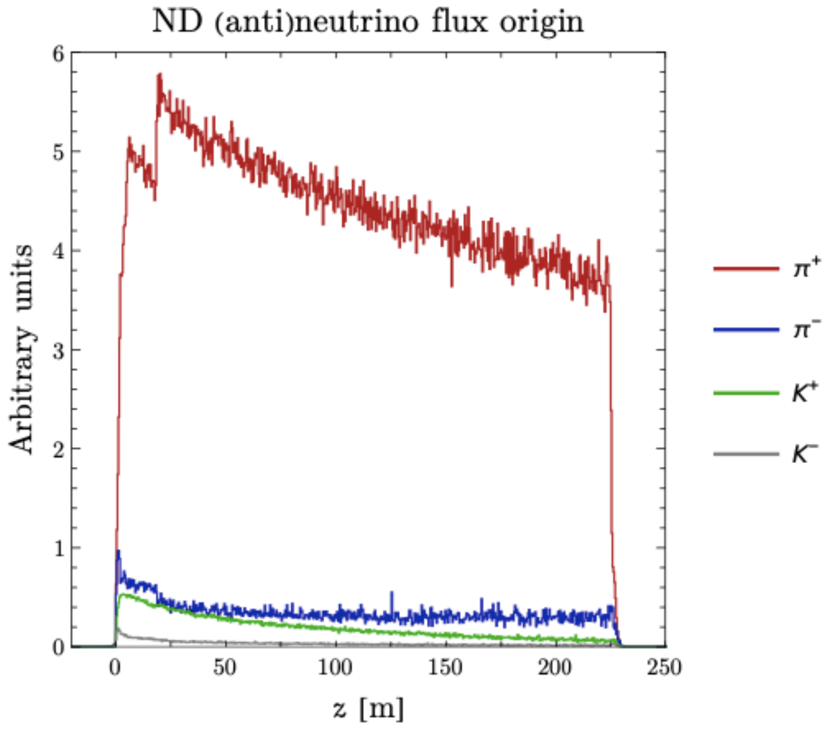
THE DUNE EXAMPLE

For a neutrino which travels for a distance L1 in the decay pipe and reaches the near detector placed at a distance L2 from the end of the pipe, we get

$$
\begin{aligned}
P_{\alpha\beta}^{\mathrm{SBL}} &= \left| \langle \nu_\beta | e^{-iH^{\mathrm{mat}} L_2} \, e^{-iH^{\mathrm{vac}} L_1} | \nu_\alpha \rangle \right|^2 \\
&= \Bigg| \langle \nu_\beta | \exp\left(-i \frac{\Delta \tilde{m}_{j1}^2}{2E} L_2\right) \left(\sum_j |\tilde{\nu}_j\rangle \langle \tilde{\nu}_j | \right) \left(\sum_\gamma |\nu_\gamma\rangle\langle \nu_\gamma | \right) \\
&\quad \times \exp\left(-i \frac{\Delta m_{k1}^2}{2E} L_1\right) \left(\sum_k |\nu_k\rangle\langle\nu_k| \right) |\nu_\alpha\rangle \Bigg|^2 \\
&= \left| \sum_\gamma \sum_{j,k} \tilde{U}_{\beta j} \tilde{U}_{\gamma j}^* U_{\gamma k} U_{\alpha k}^* \exp\left(-i \frac{\Delta m_{k1}^2 L_1 + \Delta \tilde{m}_{j1}^2 L_2}{2E}\right) \right|^2 .
\end{aligned}
$$

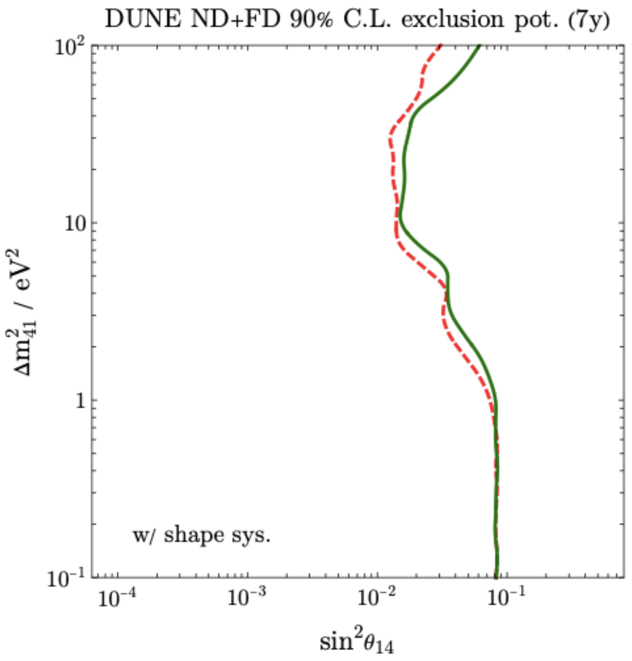
THE DUNE EXAMPLE

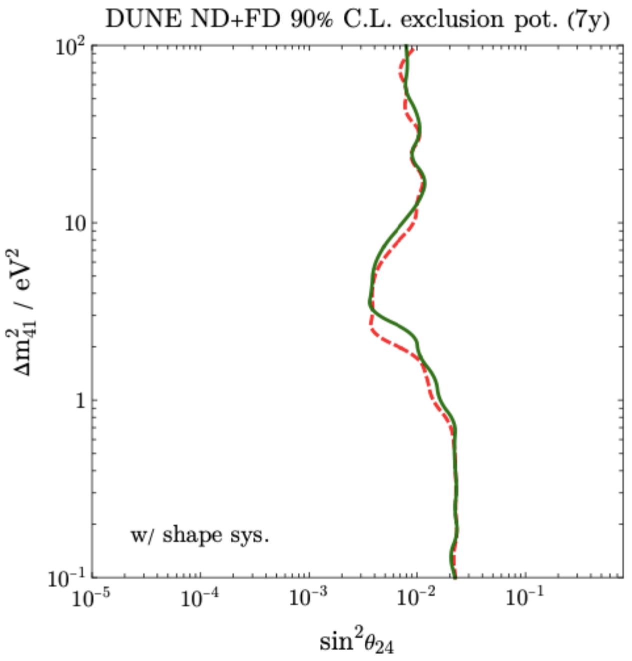




The fraction of neutrinos produced at each point of the decay pipe is crucial to compute the probabilities

THE DUNE EXAMPLE





Only a small effects on the sensitivity!

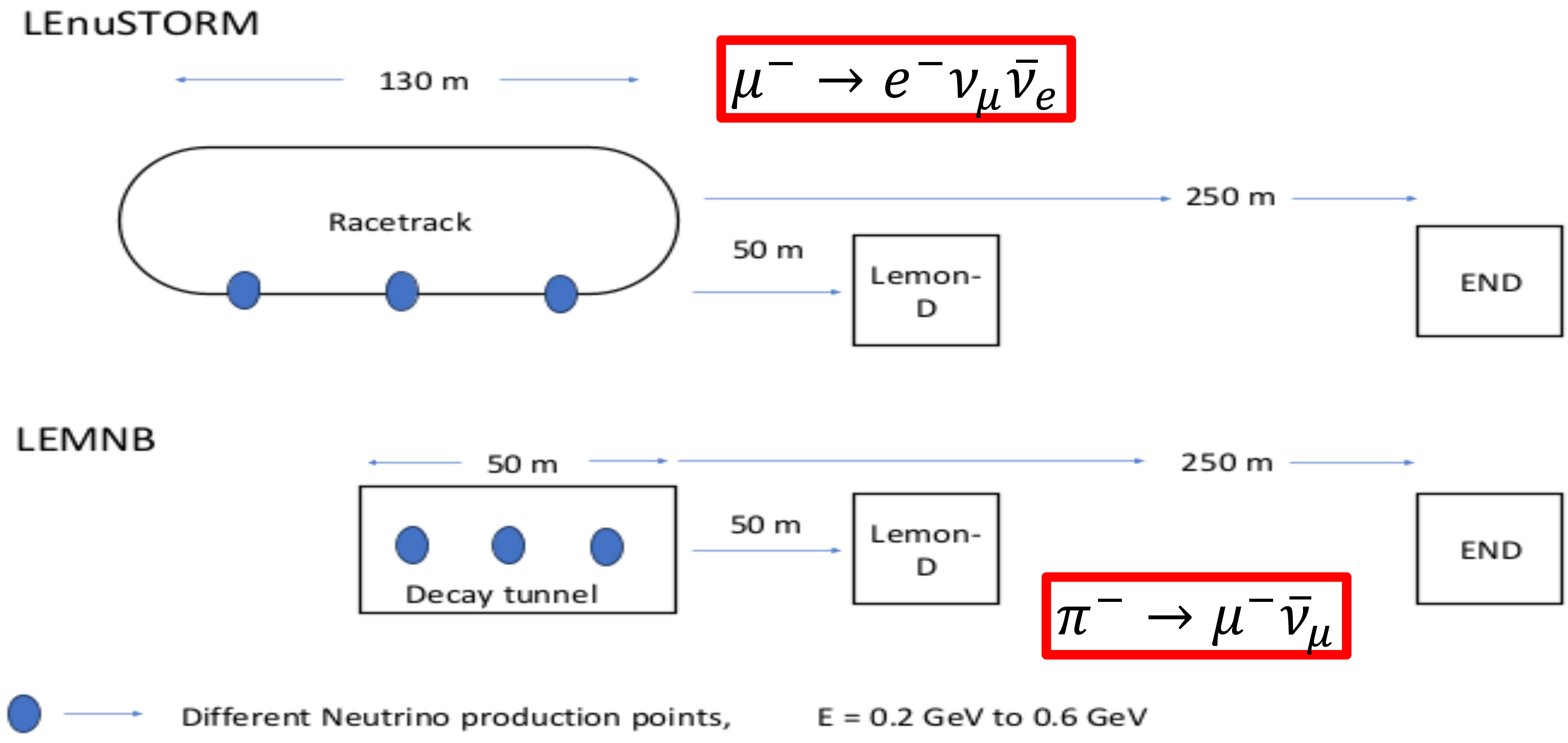
Indeed, for DUNE, the ND is at 570 m, thus for 2.5 GeV, we obtain that

$$1.27 * 1\, eV^2 * \frac{0.570\, m}{2.5\, GeV} \sim 0.3 \neq \frac{\pi}{2}$$

Far from the sterile oscillation maximum

THE EFFECT AT LENUSTORM AND LEMNB

LENUSTORM AND LEMNB GEOMETRY



OUR FUTURE GOAL

We don’t have the neutrino flux yet.

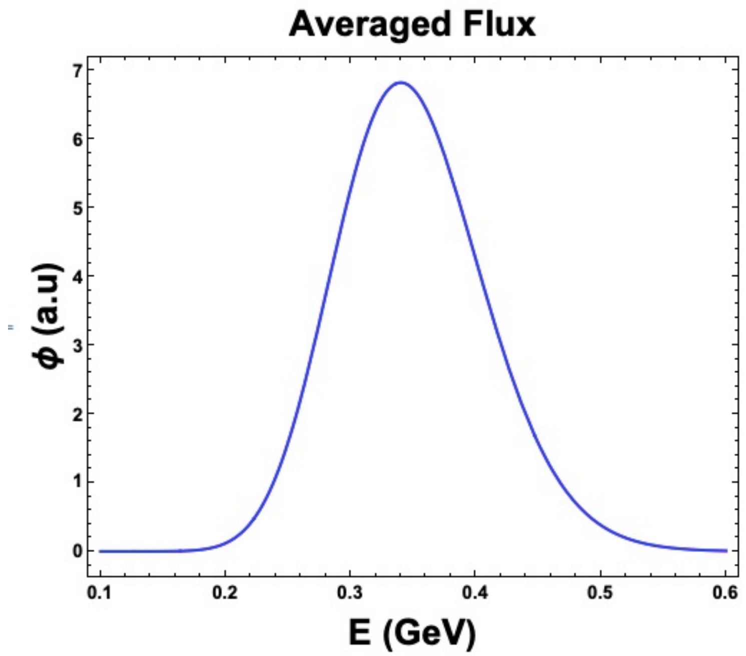
We need the neutrino flux produced in every point of the decay pipe!

THE EFFECT AT LENUSTORM

LENUSTORM CASE

Very simple approximation:

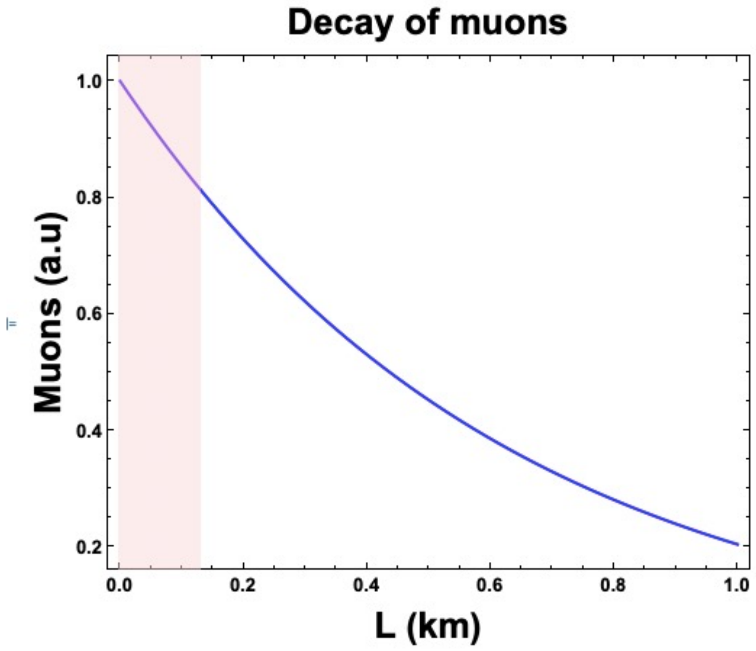
Final expected flux: $\phi(E) \sim Gaussian$



$$\psi(L, E) = \phi(E)\, d(L)$$

Amount of neutrinos from each point proportional to the number of remaining muons

$$d(L) \sim e^{-L/L_0}$$



L0 is the decay lenght of 450 MeV muons, 600 m

LENUSTORM CASE

We can estimate (very) roughly the neutrino spectra!

$$N_\alpha(E) \propto \int_0^{L_1} \psi_\beta(E,L) P_{\beta\alpha}(E, L_2 + L_1 - L)\, dL$$

L2 is the distance between the end of the pipe and the detector
L1 is the lenght of the pipe
L represent the point in which neutrinos are produced

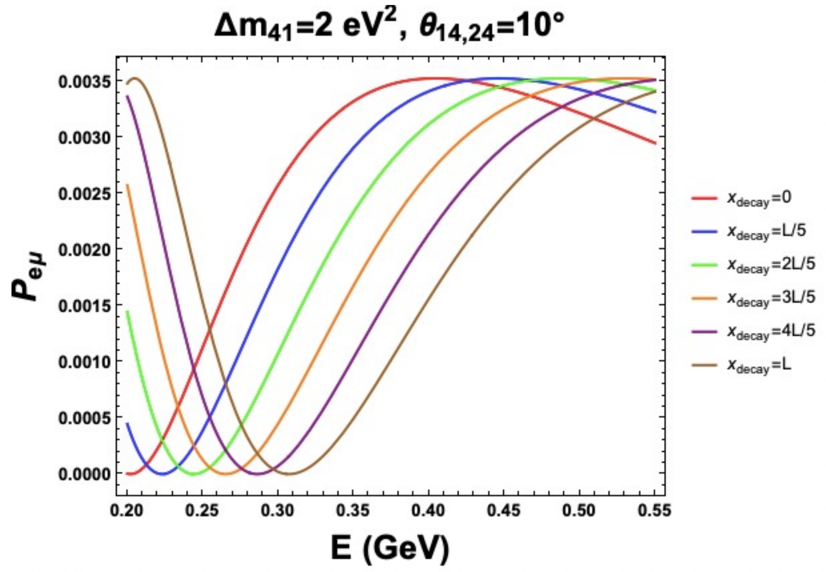
$$P_{e\mu} = 4\cos^2\theta_{14}\sin^2\theta_{14}\sin^2\theta_{24}\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

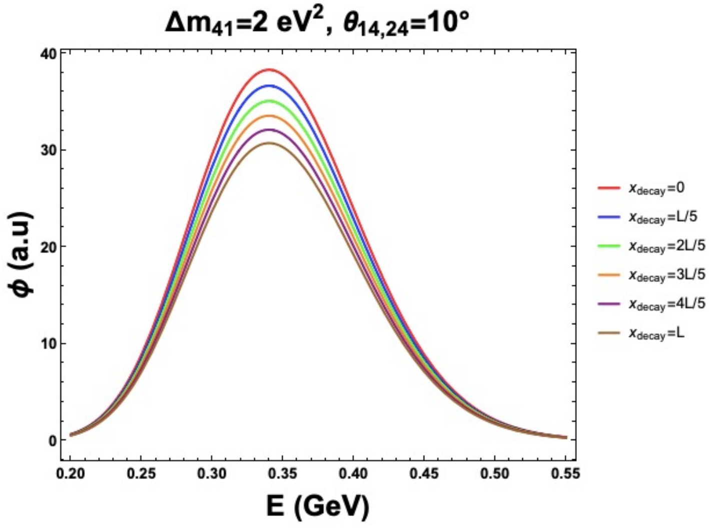
$$P_{\mu\mu} = 1 - 4\sin^2\theta_{24}\cos^2\theta_{14}(1-\sin^2\theta_{24}\cos^2\theta_{14})\sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

LENUSTORM CASE

LEnuSTORM FD: L2=250 m and L1=130 m

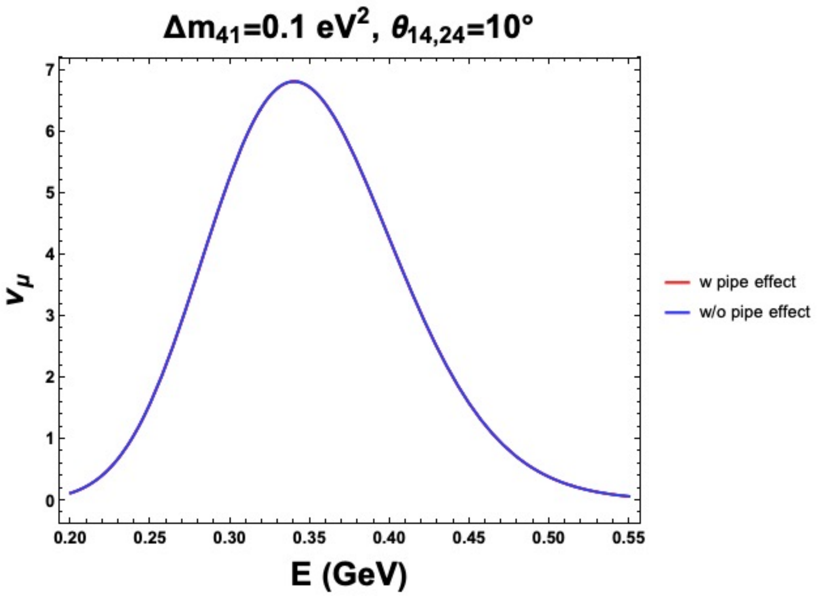
The example of the muon appearance: we show the dependence on the production point

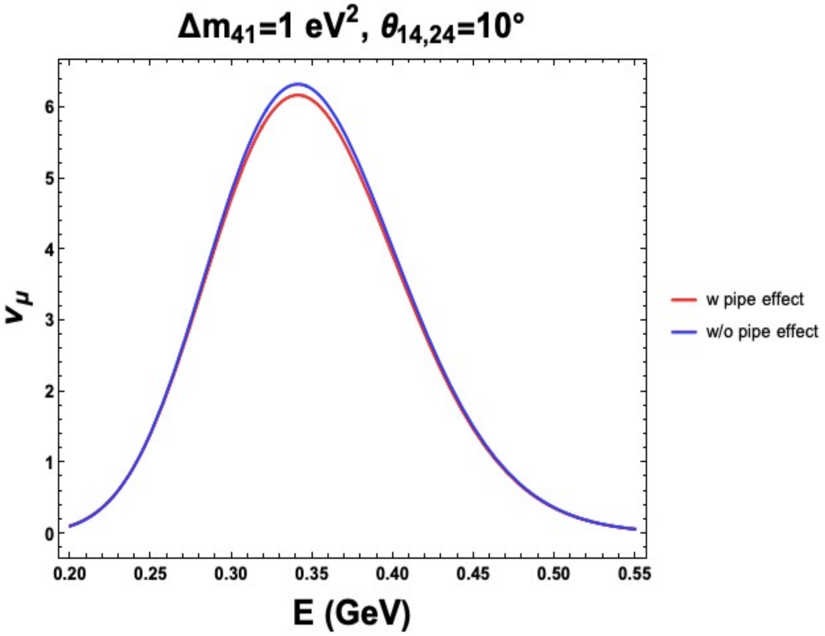


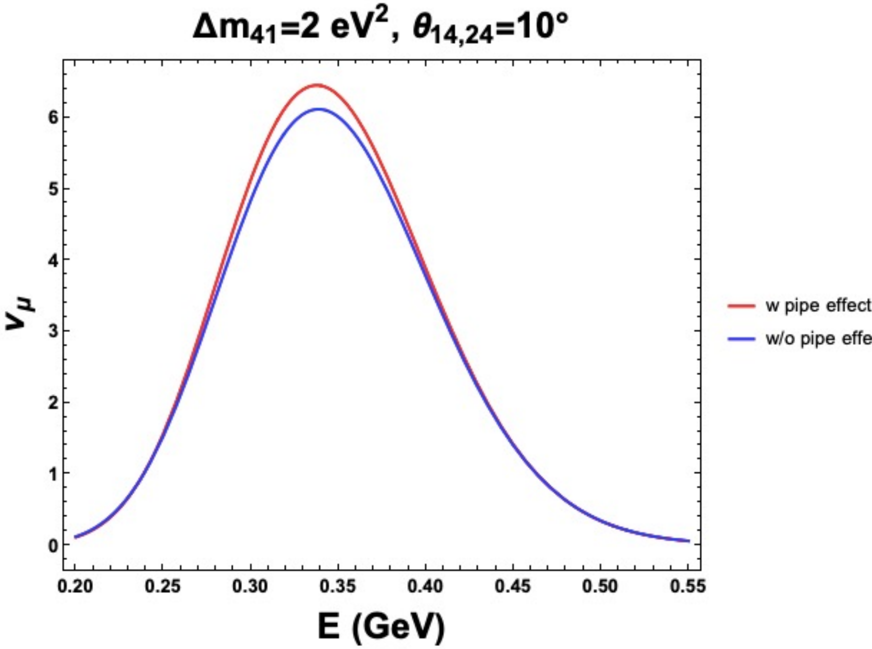


LENUSTORM CASE

LEnuSTORM FD: L2=250 m and L1=130 m, final disappearance spectra

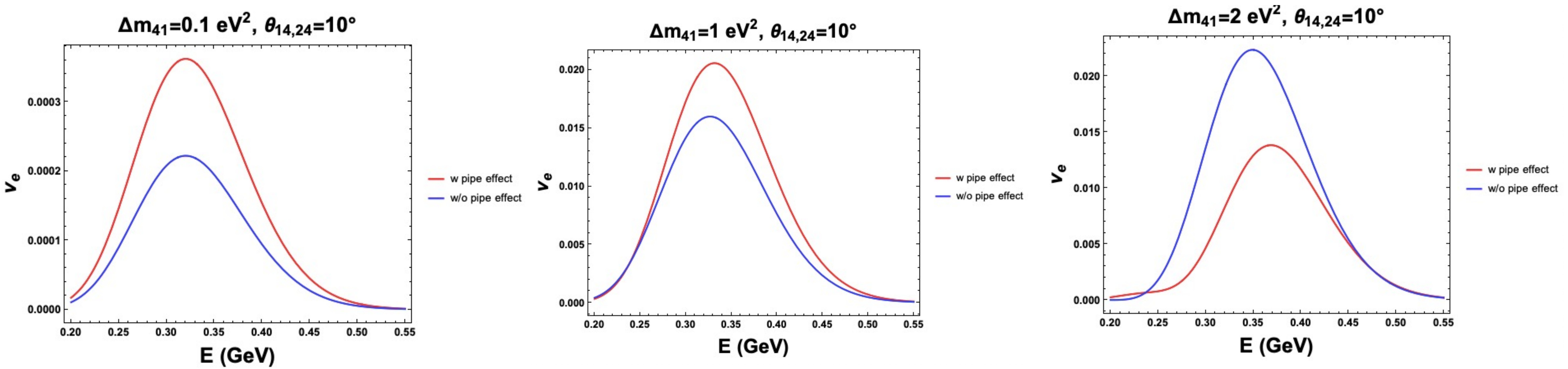






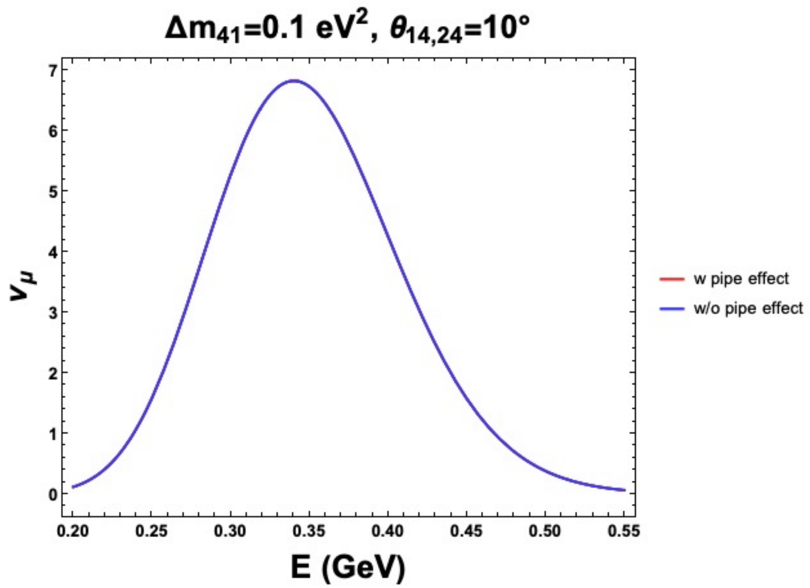
LENUSTORM CASE

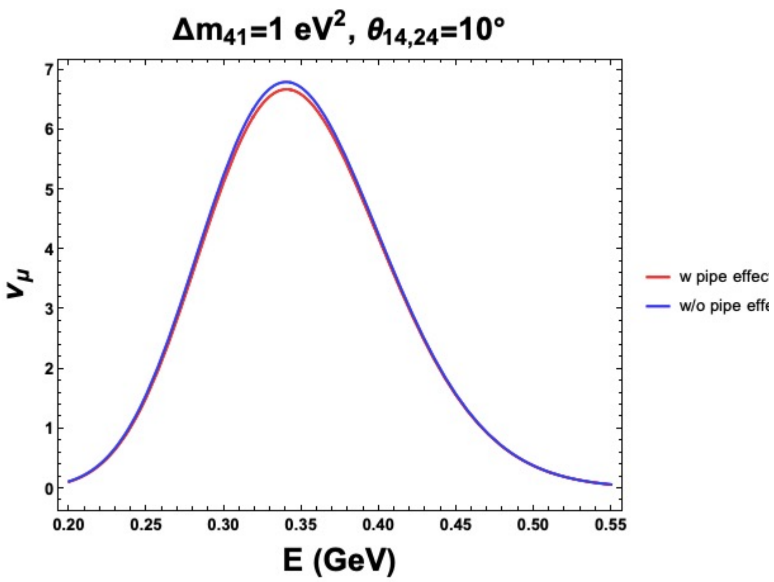
LEnuSTORM FD: L2=250 m and L1=130 m, final appearance spectra

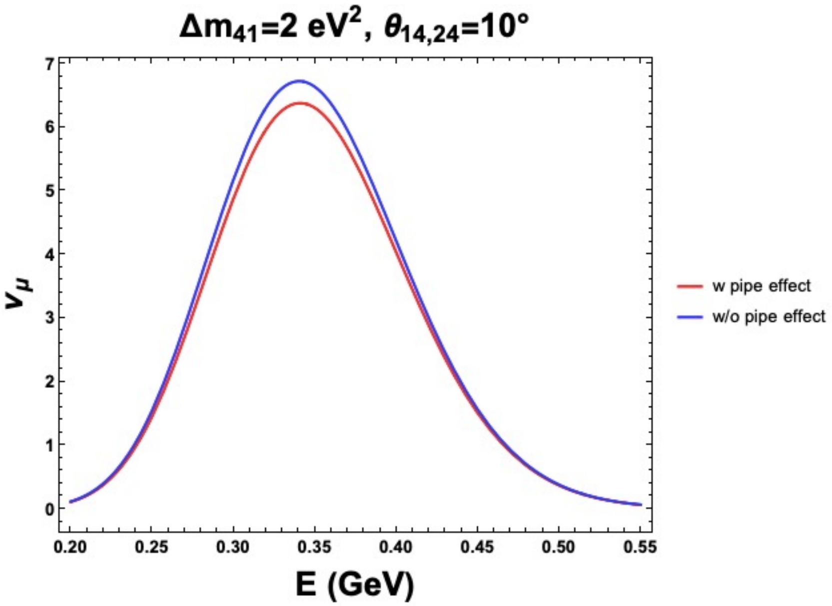


LENUSTORM CASE

LEnuSTORM ND: L2=50 m and L1=130 m, final disappearance spectra

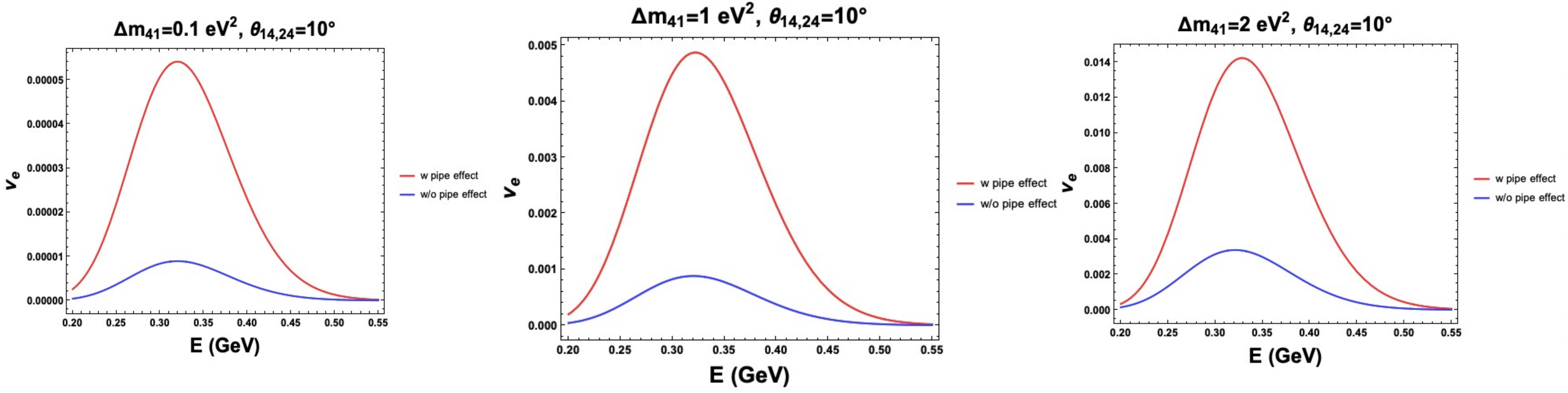






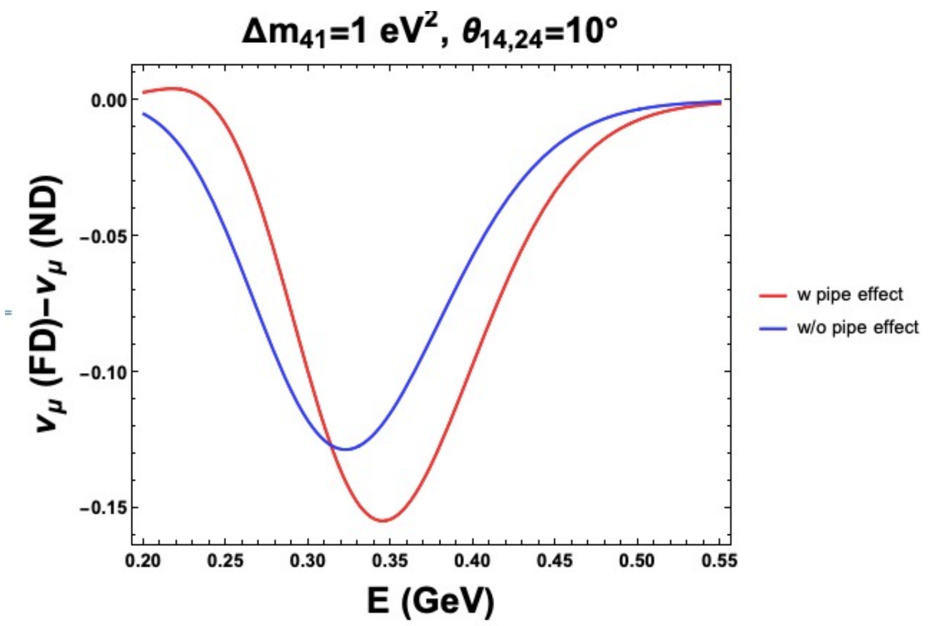
LENUSTORM CASE

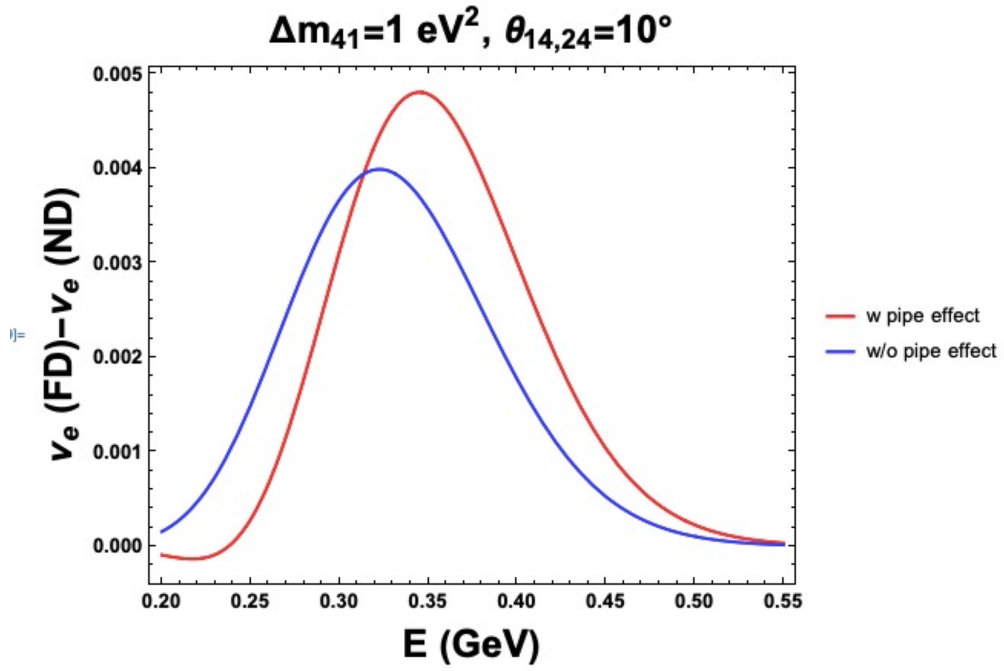
LEnuSTORM ND: L2=50 m and L1=130 m, final appearance spectra



LENUSTORM CASE

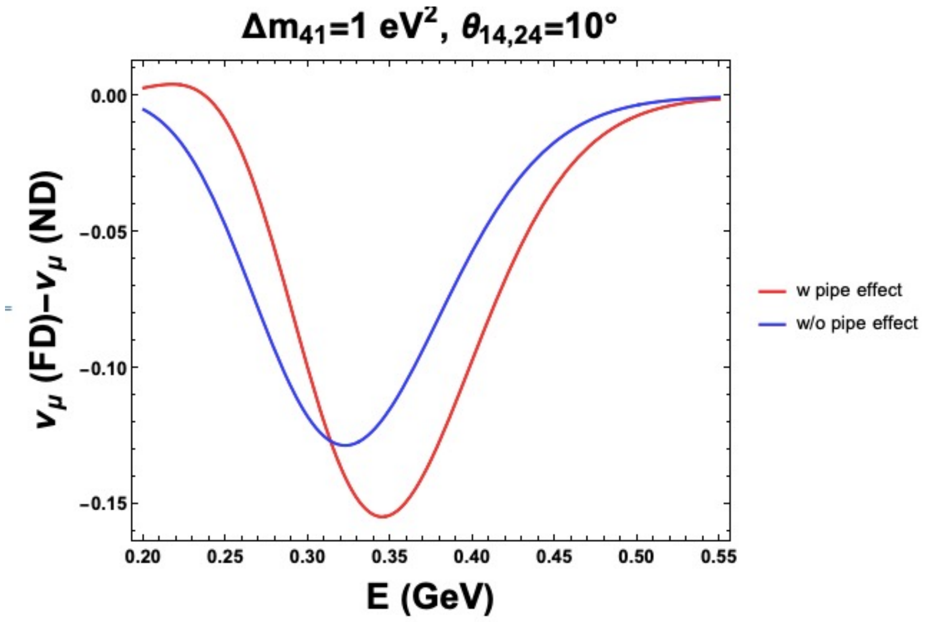
The difference between events at the ND and FD (without distance effect dumping of the flux)

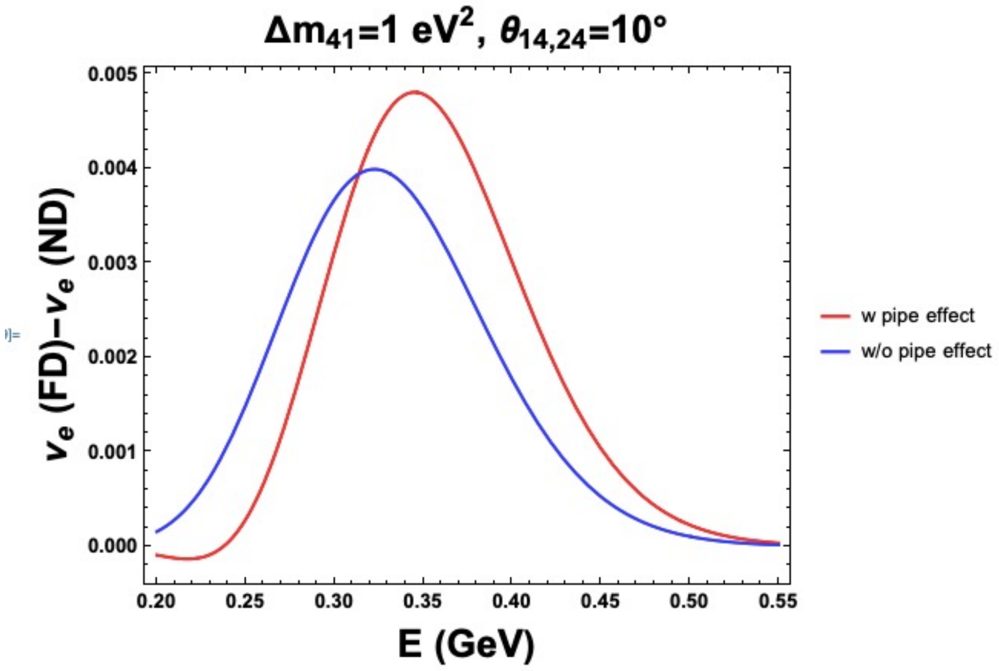




LENUSTORM CASE

The difference between events at the ND and FD
(without distance effect dumping of the flux)



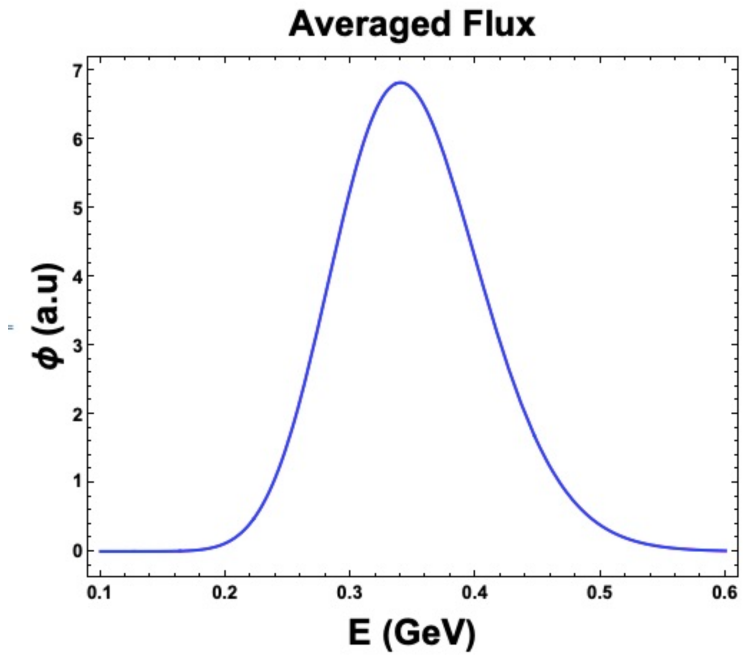


THE EFFECT AT LEMNB

LEMNB CASE

Again our approximation

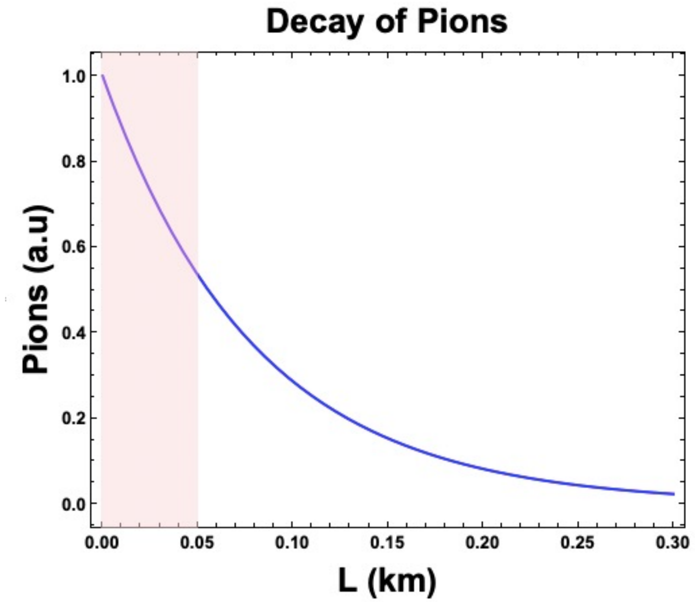
Final expected flux: $\phi(E) \sim Gaussian$



$$\psi(L, E) = \phi(E)\, d(L)$$

Amount of neutrinos from each point proportional to the number of remaining pions

$$d(L) \sim e^{-L/L_0}$$

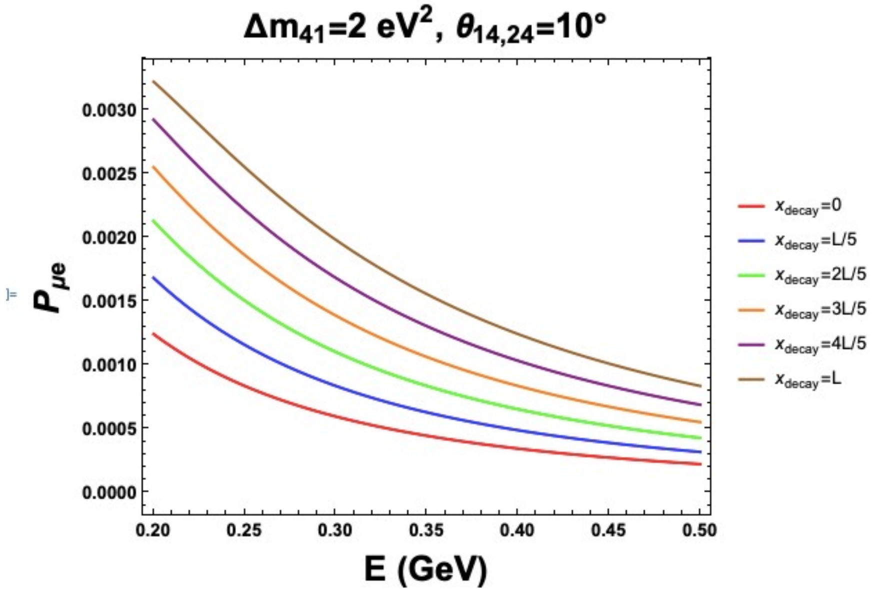


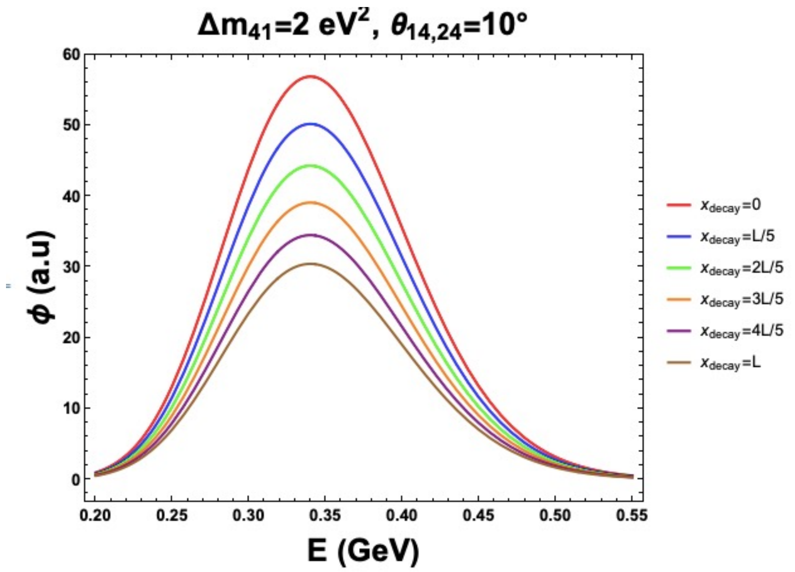
L0 is the decay lenght of 1 GeV pions, 10 m

LEMNB CASE

LEMNB FD: L2=50 m and L1=50 m

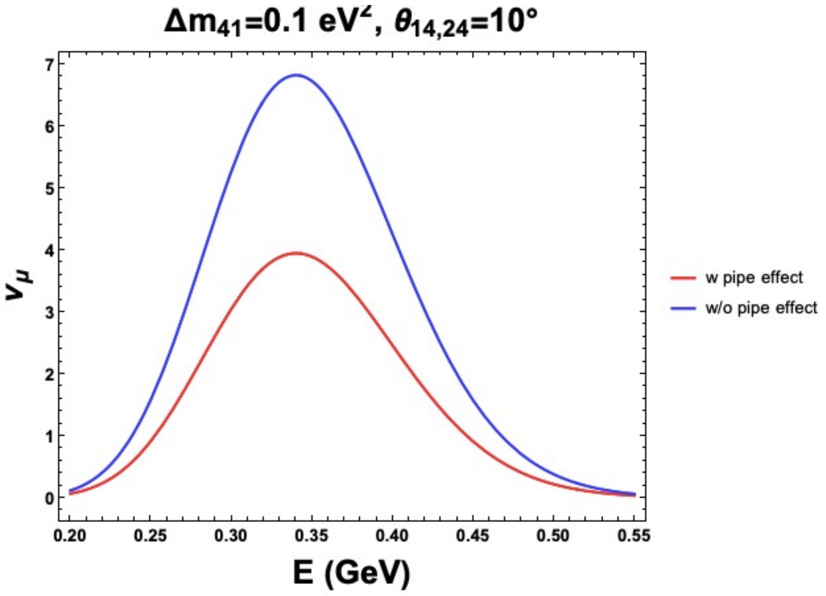
The example of the electron appearance: we show the dependence on the production point

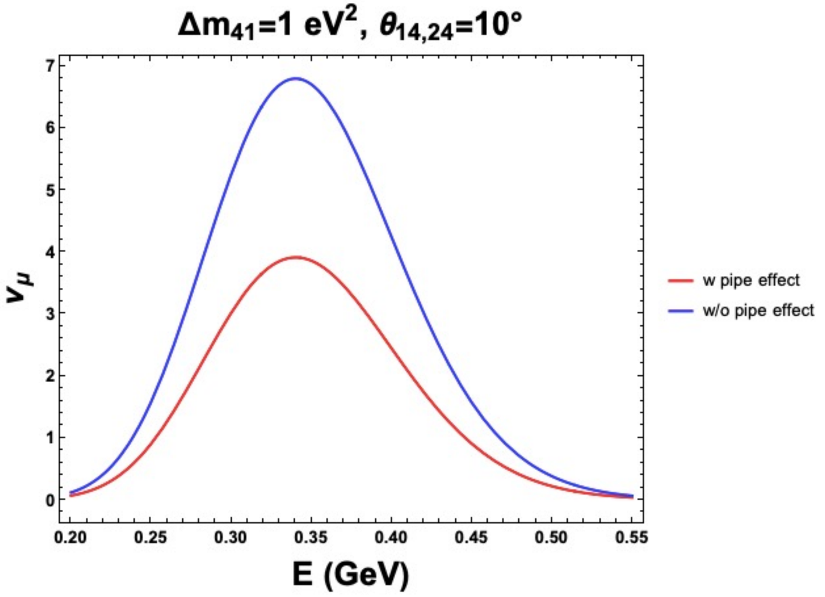


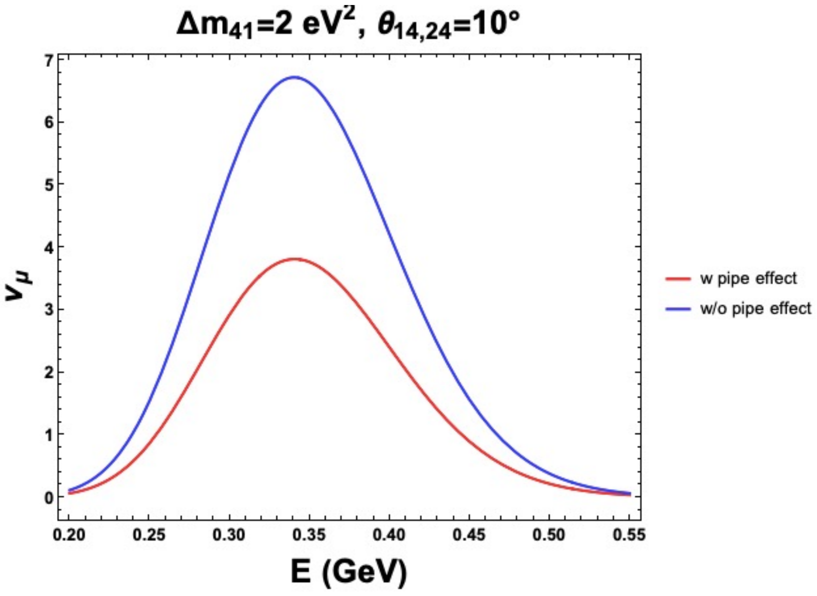


LEMNB CASE

LEMNB FD: L2=50 m and L1=50 m







LEMNB CASE

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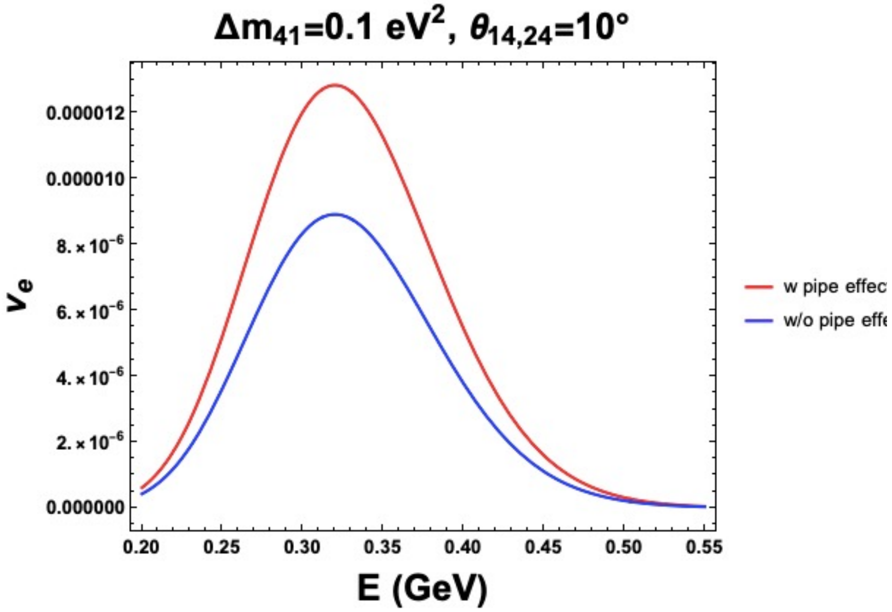

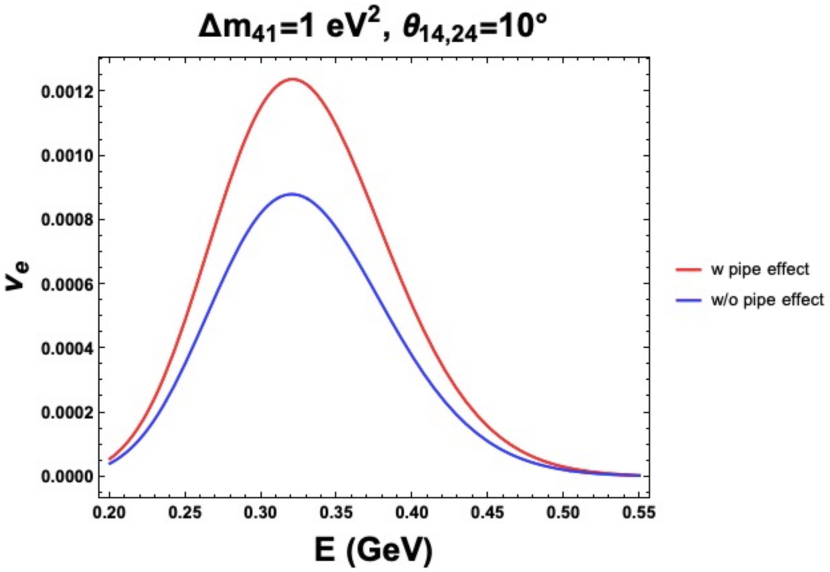

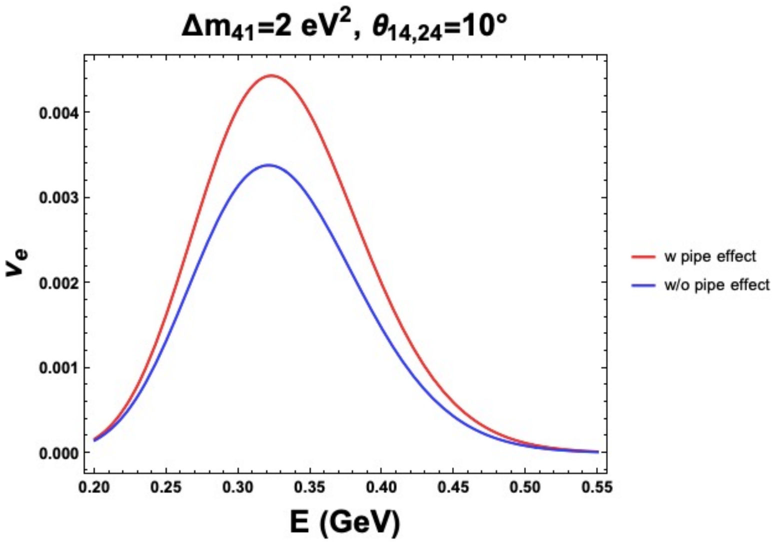

THANK YOU FOR YOUR ATTENTION