Probing ULDM via ν Oscillations

NYUAD – WIS Conference

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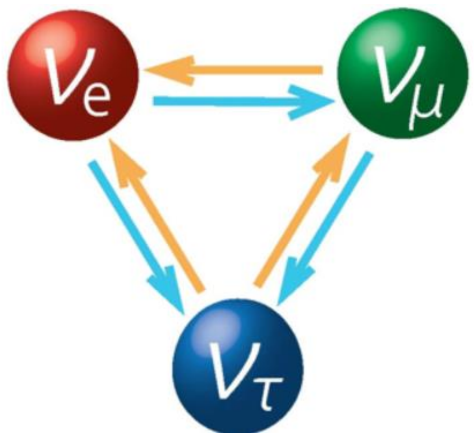
Neutrino Oscillations

Mixing angle

$m_2^2 - m_1^2$



- 2 - neutrino case:

$$P_{\alpha\beta} = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

- 3 - neutrino case :

$$P_{\alpha\beta} = \left|\sum_{i=1}^{3} U_{\alpha i}^* U_{\beta i} e^{i\frac{m_i^2 L}{2E}}\right|^2$$

$\alpha, \beta = e, \mu, \tau$

Mixing matrix (3 angles, 3 phases)

ULDM Effect on Neutrino Oscillations

- Consider the gauge singlet scalar field ϕ as an ULDM candidate

$$\mathcal{L}_\phi \sim \frac{z_{\alpha\beta}}{\Lambda} H H L_\alpha L_\beta + \frac{y_{\alpha\beta}}{\Lambda^2} \phi H H L_\alpha L_\beta$$

→

$$m_\nu = z v^2/\Lambda$$
$$\hat{y} = y v^2/\Lambda^2$$

- For ULDM $m_\phi < 0.1\ eV$

→

$$\phi = \phi_0 \sin(m_\phi t)$$
$$\phi_0 = \sqrt{2\rho_{\rm DM}}/m_\phi$$

- We define a small parameter $\eta \equiv \frac{\phi_0}{\Lambda}$. The ν parameters are modulated:

$$\Delta m^2_{ij} \to \Delta m^2_{ij}\left[1 + 2\eta \sin(m_\phi t)\right]$$
$$\theta_{ij} \to \theta_{ij} + \eta \sin(m_\phi t)$$

The Strategy

$$P_{\alpha\beta}\left(E,t\right) \approx P^0_{\alpha,\beta}\left(E\right) + \epsilon_{\alpha\beta}\left(E\right)\sin\left(m_\phi t\right)$$

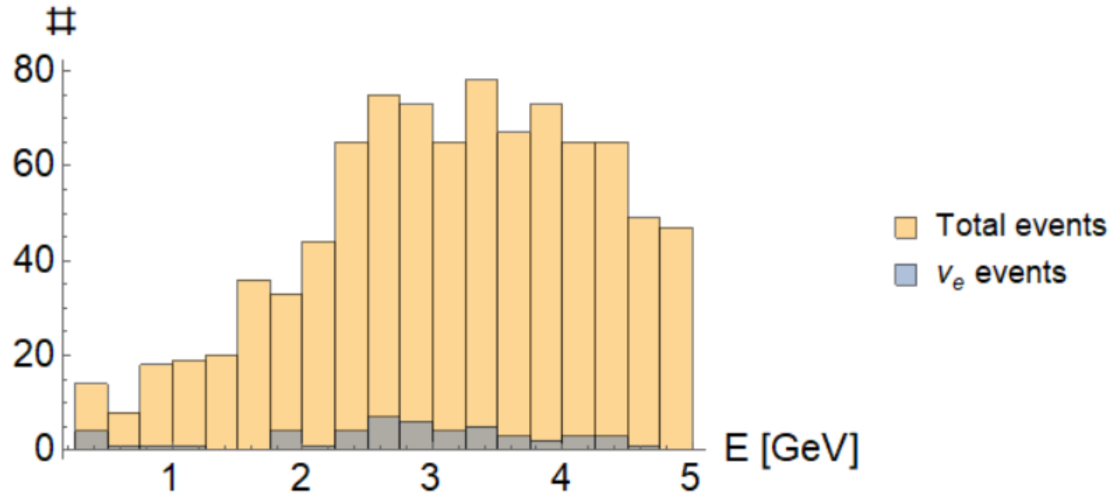
- Dividing some experiment lifetime to smaller time segments Δt.
- Choosing energy bin, and measuring $P_{\alpha\beta}$ in each Δt.

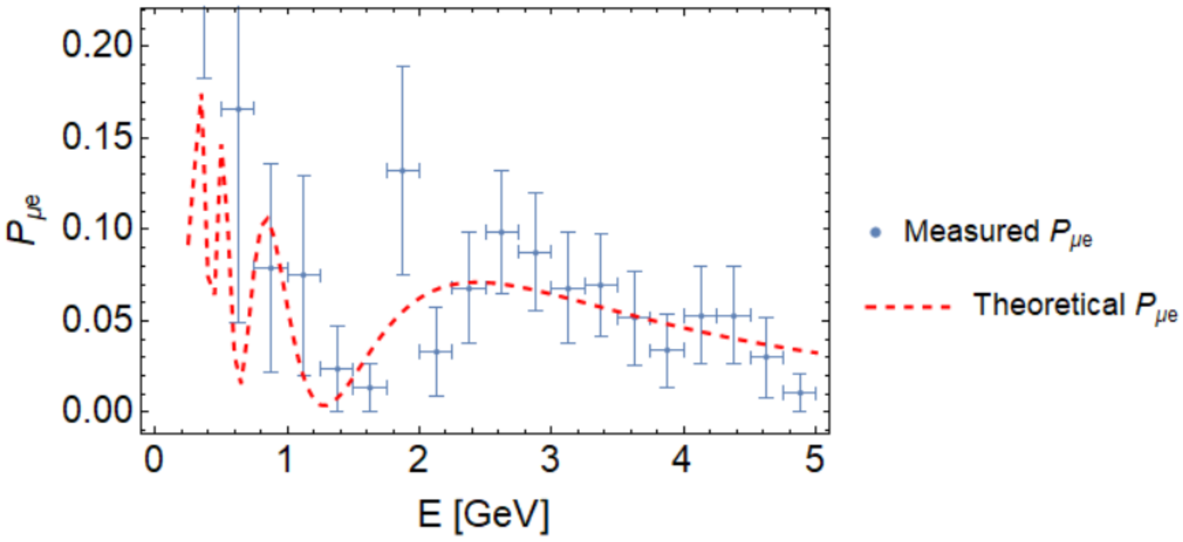
$$\langle P_{\alpha\beta}\left(E_0,t\right)\rangle = \frac{1}{\Delta E \Delta t}\int_{t-\frac{\Delta t}{2}}^{t+\frac{\Delta t}{2}}\int_{E_0-\frac{\Delta E}{2}}^{E_0+\frac{\Delta E}{2}} P_{\alpha\beta}\left(E,\tau\right) dE d\tau$$

- Looking for a significant periodic behavior of $< P_{\alpha\beta}\left(E_0,t\right) >$.

Simulating $P_{\alpha\beta}$ Measurements

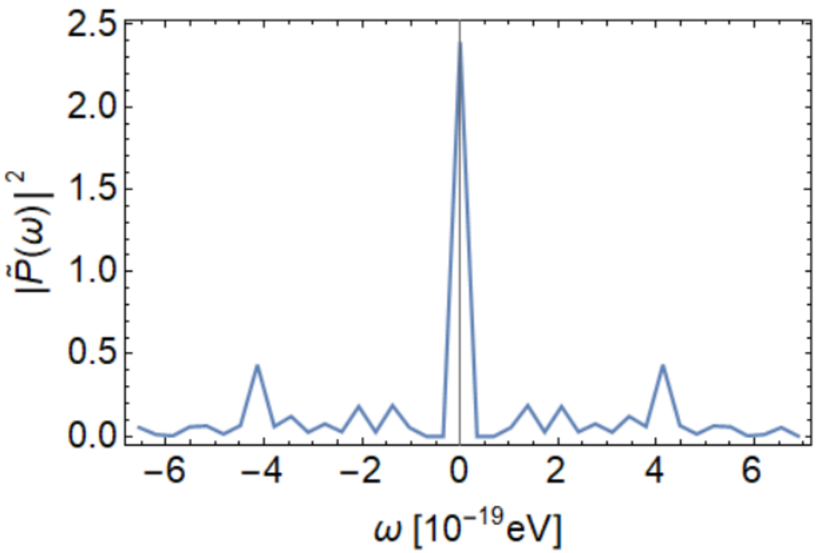
- Monte-Carlo simulation of $P_{\mu e}$ in DUNE, based on 10^3 events:





Fourier Analysis

- Performing discrete Fourier transform $$\tilde{P}_{\alpha\beta}(E,\omega) = \sum_{n=0}^{N-1} \langle P_{\alpha\beta}(E,t_n)\rangle e^{-i\frac{2\pi n}{N}\omega}$$
- An example for $2-\sigma$ Indication for $m_\phi = 4 \cdot 10^{-19} eV$ with $\eta = 0.1$:



Monte-Carlo simulation

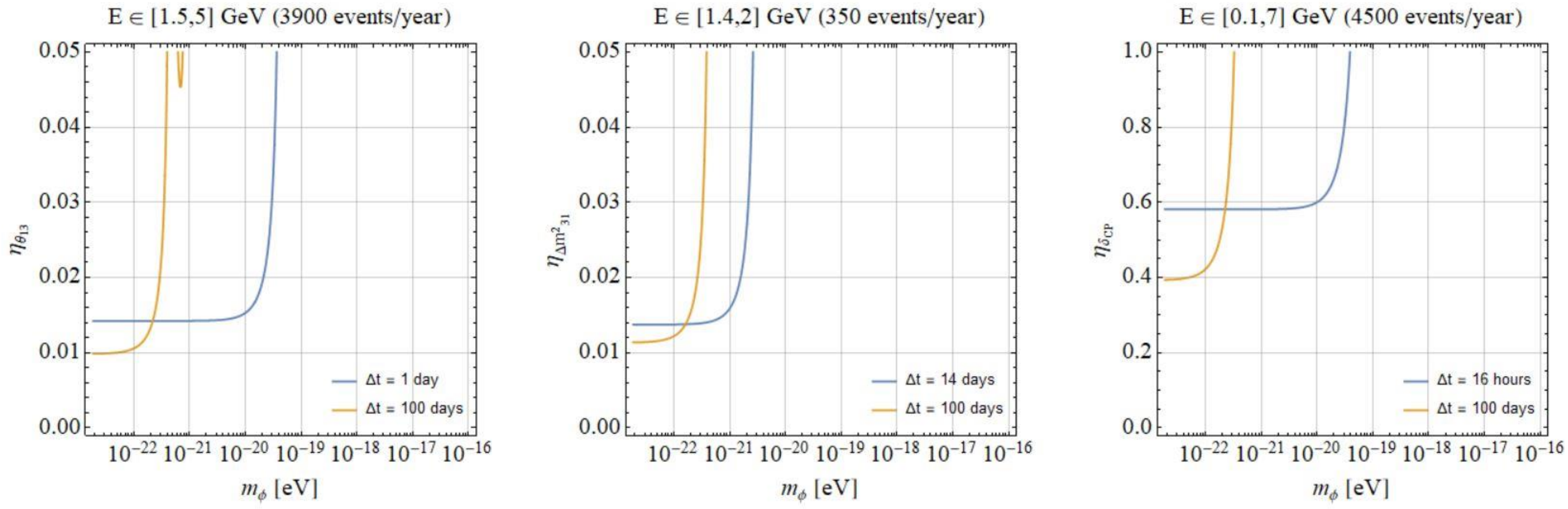
Analytic Solution

$$\mathrm{CL} = \left(1 - \exp\left\{-\frac{N_{\text{events}}\,\mathrm{sinc}^2\left(\frac{1}{2}m_\phi \Delta t\right)\left|\langle \epsilon\left(E\right)\rangle\right|^2}{4\left\langle P^0_{\alpha\beta}\left(E\right)\right\rangle\left(1-\left\langle P^0_{\alpha\beta}\left(E\right)\right\rangle\right)}\right\}\right)^{\frac{t_{\exp}}{\Delta t}}$$

- To increase signal significance:
  - Increase Δt
  - Probe energy bins with large $\epsilon(E)$
  - Probe energy bins with large N_{events}
  - Probe energy bins with $< P^0_{\alpha\beta}(E) >$ close to 0 or 1.

Results

DUNE: Total 6000 events/year, t_{exp} = 7 years



Thank You!