Measuring the Leptonic CP Phase in Neutrino Oscillations with Non-Unitary Mixing

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1-5 august 2016

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[2]Instituto de Fisica Corpuscular (IFIC) - Spain

Two basis! Mass and Flavor

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[5] Phys. Rev. Lett. **81**, 1158 (1998)

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Neutrinos have Mass

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http://lbne.fnal.gov/

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$\nu_\alpha, \quad \alpha = e, \mu, \tau, 4, 5 ... N$

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And they Oscillate!

There are two basis:

$$\nu_\alpha = U_{\alpha i} \nu_i$$

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There are two basis:

Mixing Matrix

$$\nu_\alpha = U_{\alpha i}\nu_i$$

U mixing is unitary. But parts of it not!

$$U_{\alpha i}$$

$$\alpha = e, \mu, \tau, 4, 5 \ldots N \qquad i = 1, 2, 3 \ldots N$$

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$$U^{N \times N} = \begin{pmatrix} N & W \\ V & T \end{pmatrix}$$

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Non-Unitary
Acessible through Oscillation[1]

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Fear Not: only more 6 parameters needed!

It can be shown that[2]:

$$N = \begin{pmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} . U_{\text{PMNS}}$$

[2] F. J. Escrihuela et. al., Phys. Rev. D92, 053009 (2015)

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Only 3 (α_{11}, α_{22} and α_{21}) are acessible through $\nu_{e(\mu)} \to \nu_{\mu(e)}$

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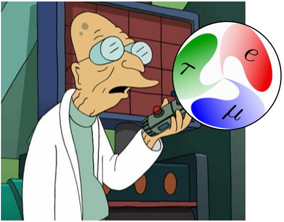
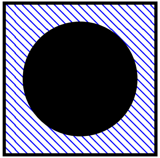
In unitary: Probability add to 1

Neutrino Source

Unitary Propagation:

Neutrino Detector





In non-unitary: Probability Don't add to 1

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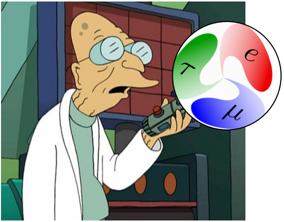
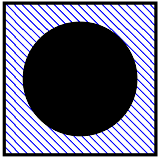
Neutrino Detector





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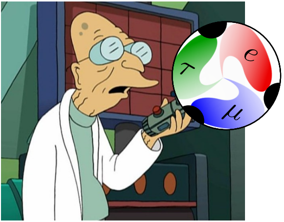

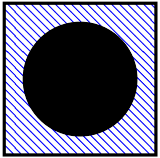

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Non-unitary basis is not Orthogonal!

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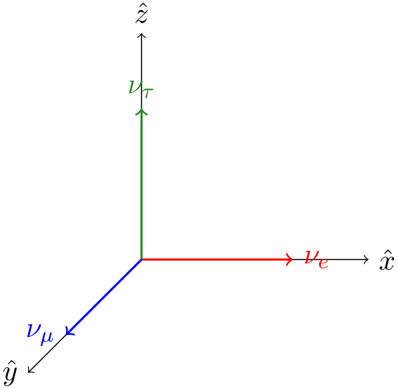

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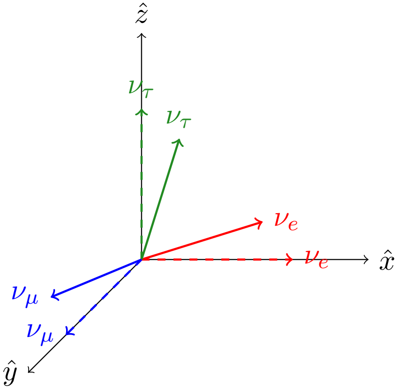

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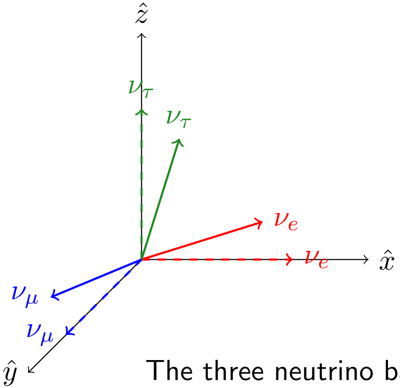

The three neutrino basis is not orthogonal!

New Phenomenon: 0-Distance and CP-phase

This means that you can have 0-distance ‘oscillation’ (transition):

[3] F. Ge, P. Pasquini, et. al., ARXIV:1605.01670

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$$(S_{\alpha\beta} = \langle \nu_\alpha^{\text{unitary}}(L) | \nu_\beta^{\text{unitary}}(L) \rangle)$$

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$P_{ee}(0) = 1$

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→ Survival Prob. $P_{ee}(0) = 1$

↓ Complex parameter with a **new** CP phase (ϕ)!

[3] F. Ge, P. Pasquini, et. al., ARXIV:1605.01670

ϕ can mimic δ_{CP}

Why do we care?

[4] Miranda, O. G., et. al., ARXIV:1604.05690

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Non-unitary can lead to CP-phase ambiguity[4]!

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That's because $|\alpha_{21}|$ can be as large as[2] $\sim 3\%$

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We can see that by two plots:

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$P_{\mu e}$ for differents δ_{CP} and ϕ.

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The ration R between the contributions of $\delta_{\rm CP}$ and ϕ to $P_{\mu e}$

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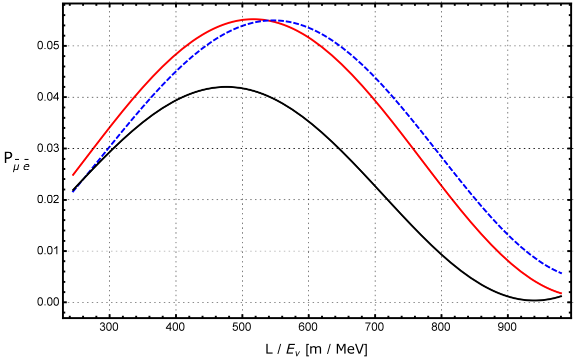

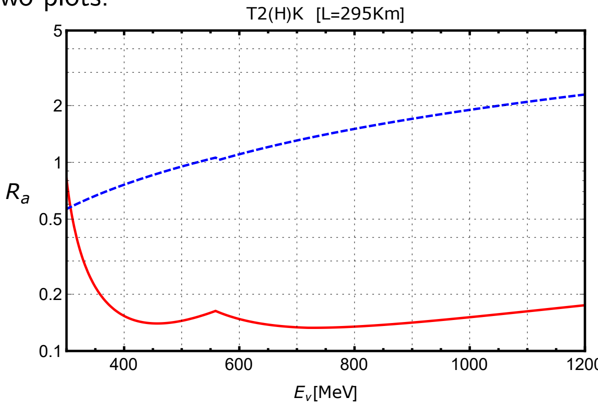

$P_{\mu e}$: $\delta_{CP} = 0$ and $\alpha_{21} = 0$, $\delta_{CP} = 3\pi/2$ and $\alpha_{21} = 0$, $\delta_{CP} = 0$ and $\alpha_{21} = 0.02$

R_a: $\alpha = 2.5\%$ and R: c_ϕ and s_ϕ and $c_{\phi+\delta}$ and $s_{\phi+\delta}$ contributions.

From: [3] F. Ge, P. Pasquini, et. al., ARXIV:1605.01670

T2(H)K experiment is awesome!

What about in Experimental Setup?

From: [5] Abe, K. and others, PTEP **2015**, no. 4, 043C01 (2015)

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one of T2K and T2HK goal is to measure δ_{CP}

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The experiment consists of neutrinos flux from pion decay at Tokay

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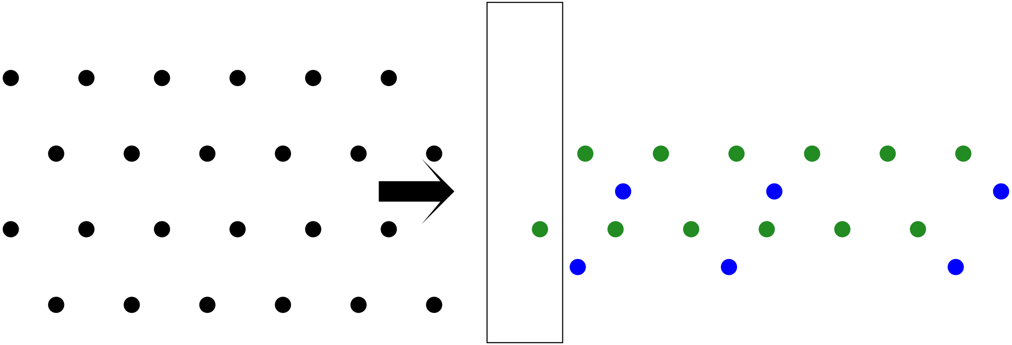
Neutrinos from Pion Decay[5]



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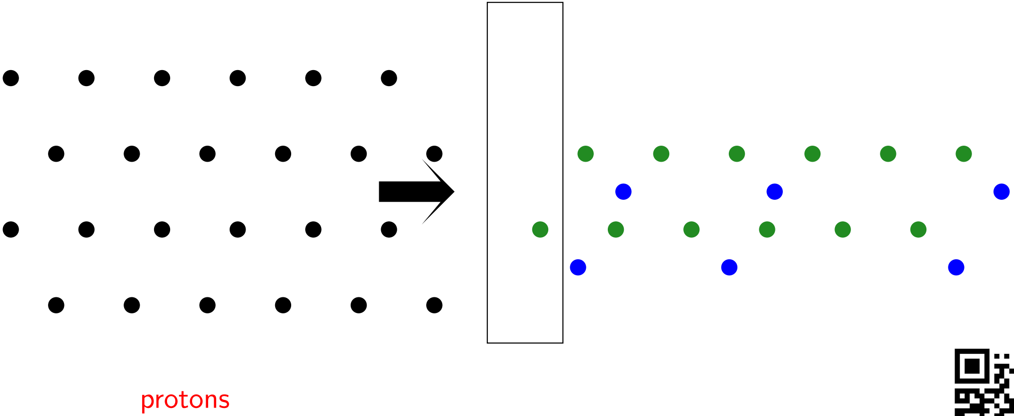

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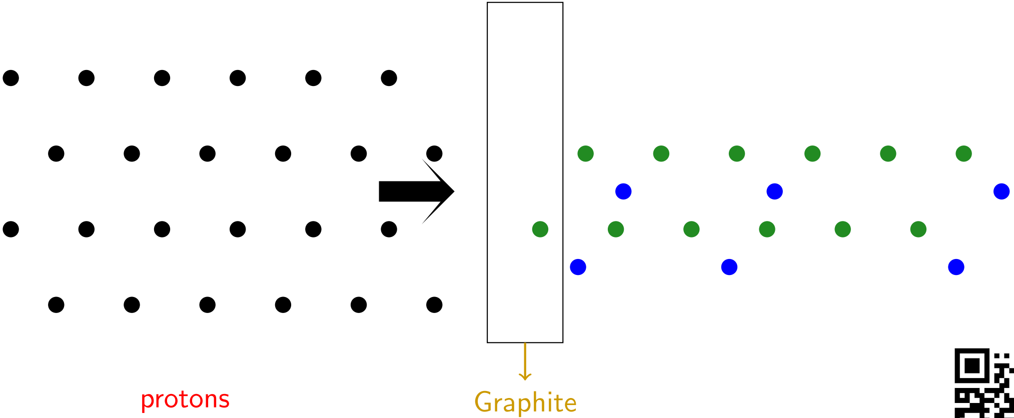

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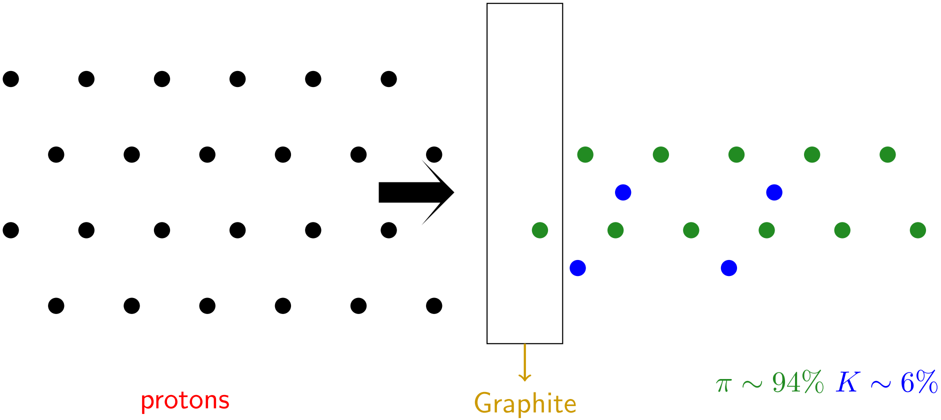

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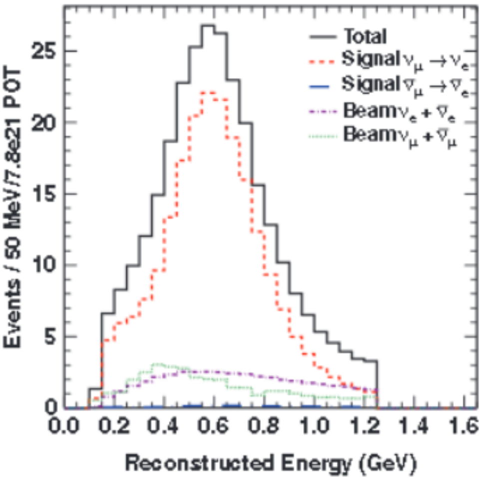

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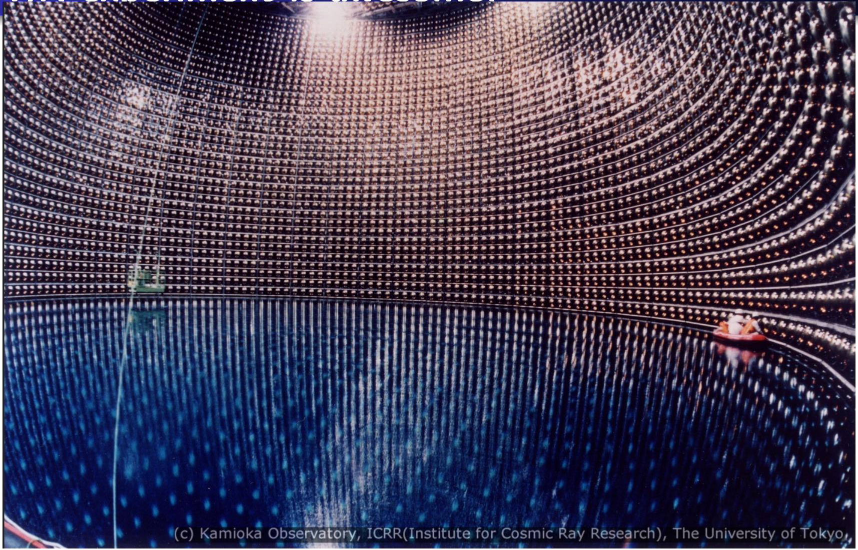

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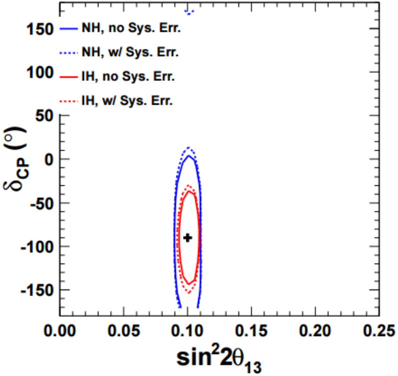

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We performed the analysis on T2K and T2HK considering non-unitary:

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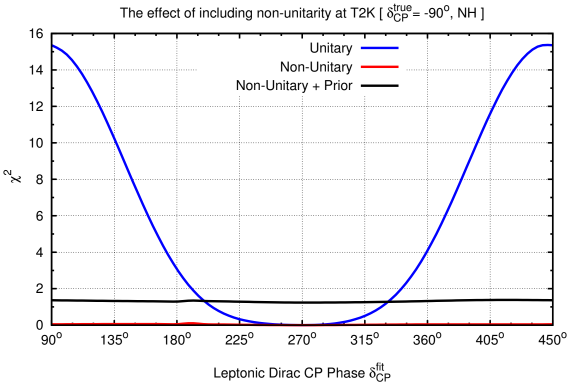

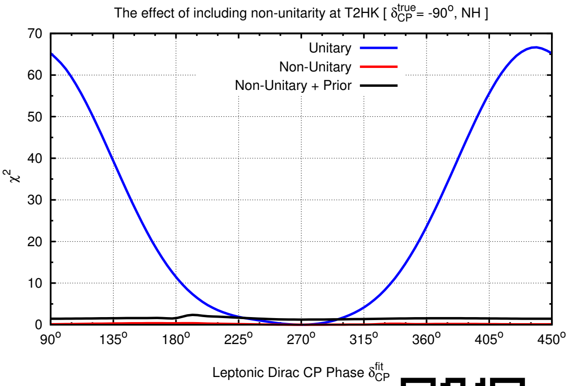

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μDAR to T2K rescue

Should we give up on T2(H)K δ_{CP}?

From: [6] J. Evslin at. al., JHEP 02, 137 (2016)

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Not yet!

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So what happens to the δ_{CP} sensibility?

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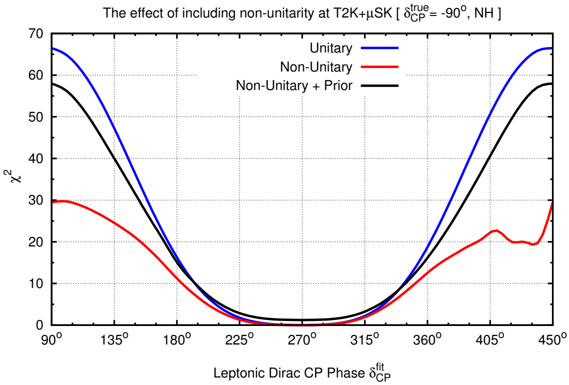

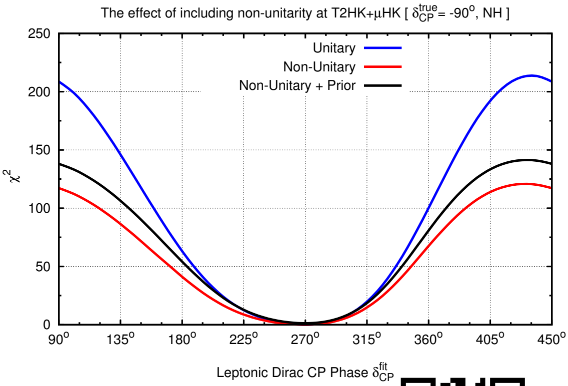

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Conclusion

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T2K and T2HK sufer from this and looses sensibility.

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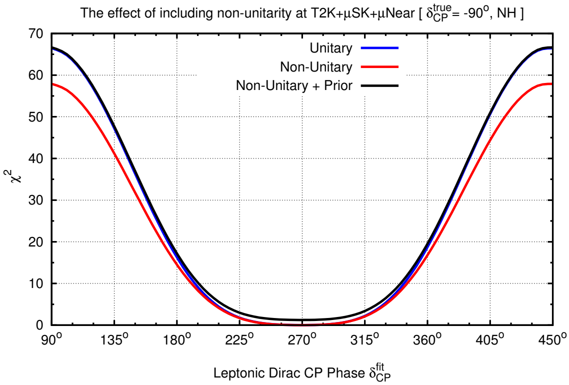
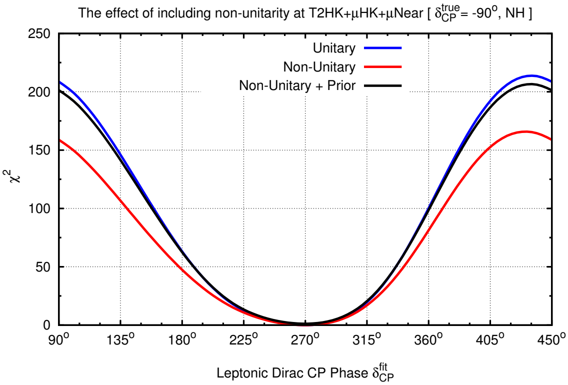
It is possible to recover T2(H)K sensibility by couple it to μDAR

Appendix

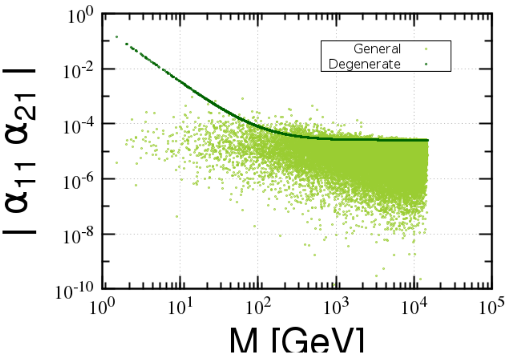
Using a very near detector (20 m) to probe $P_{\mu e}(0) = |\alpha_{21}|^2$





Appendix

Model Dependent Couplings



DUNE Sensibility?