Estimating shape-like systematics for the Large Extra Dimensions Searches in DUNE

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DUNE BSM Physics WG Meeting
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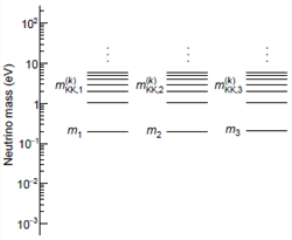
In coll. with A. Sousa, E. Fernandez-M, S. Rosauro

Model signatures/consequences

LED model (Davoudiasl et. al 2002) :

- In this model, three bulk right-handed neutrinos coupled (via Yukawas's) to the three active brane neutrinos.
- After compactification of the effective extra dimension, from the four dimensional (brane) point of view, the right-handed neutrino appears as an infinite tower of sterile neutrinos or Kaluza-Klein modes.



Phenomenological consequences:

- The sterile-active mixings and the new oscillation frequencies modify the active 3ν-oscillations therefore distorting the neutrino event energy spectrum.
- Departures from the standard oscillations due to the existence of LED can then be probed at neutrino oscillation experiments (Long & Short baselines).

Vacuum probabilities

Three-active neutrino oscillation probability:

$$P_{\nu_\alpha \to \nu_\beta} = \left| \sum_{k=1}^{3} U^*_{\alpha k} U_{\beta k} \exp\left(-i \frac{m_k^2}{2E} \right) \right|^2$$

LED oscillation probability, n-KK modes:

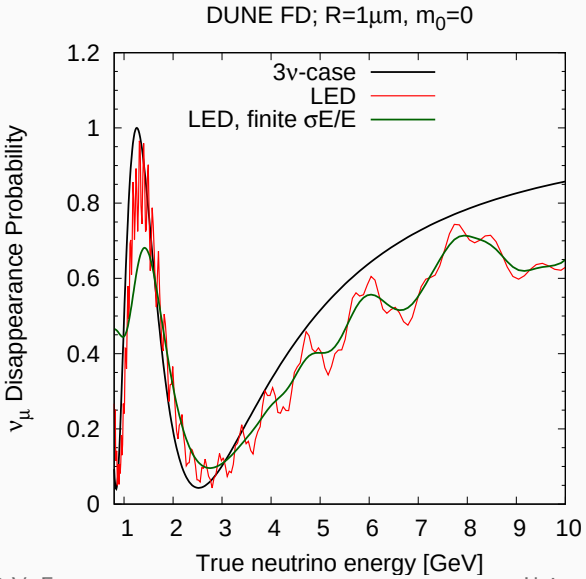
$$P_{\nu_\alpha \to \nu_\beta} = \left| \sum_{k=1}^{3} \sum_{n=0}^{\infty} U^*_{\alpha k} U_{\beta k} \left(L_k^{0n} \right)^2 \exp\left(-i \frac{\left(\lambda_k^{(n)} \right)^2}{2E R^2} \right) \right|^2$$

& $\lambda_k^{(n)}$ is obtained from $\boxed{\lambda_k^{(n)} - \pi (m_k^D R)^2 \cot(\pi \lambda_k^{(n)}) = 0}$ with $\boxed{\lambda_k^{(n)} \in [n, n + 1/2]}$. We can then make the identification:

$\boxed{m_k^{(n)} = \frac{\lambda_k^{(n)}}{R} \overset{n \gg 1}{\to} \frac{n}{R}}$, and for the 'modified' mixing $\boxed{U_{\alpha k} L_k^{0n}}$

Four free parameters m_1^D, m_2^D, m_3^D and R in the theory, reduced to two m_0 and R .
For '$n = 0$' and '$m^D R \ll 1$', 3ν-flavor phenomenology must be satisfied Davoudiasl et. al 2002.

Main features



Most active (sterile) case corresponds to $n = 0$ ($n \ll 1$). The standard 3ν-neutrino oscillations are recovered in the limit $R \to 0$.

- Global reduction of survival probabilities, which is typically noticeable at high energies (Machado et. al 2011).
- Appearance of modulations and fast oscillations to Kaluza-Klein states.
- These shape-like features can be exploited at the analysis level. This have been done in MINOS (2016).
- Sensitivity analyses for several osc. Exps (Machado et. al 2011), IceCube (Esmaili et. al. 2014), DUNE (Berryman et. al 2016... "revamped" for DUNE FD TDR & ND CDR), and SBN (Stenico, DVF, Peres 2018).

Previous DUNE setup

$40kt \times (3.5yr(\nu) + 3.5yr(\bar{\nu})) \times 1.07MW = 300\, kt\, MW\, years$ of exposure

Information considered in the analysis:

- Signal: CC, ν and $\bar{\nu}$, appearance and disappearance oscillation channels included in the analysis.
- Only FD information is considered, but ND fixes the flux normalization.

Systematics

T. Alion et. al. arxiv:1606.09550 → First GLoBES files release.

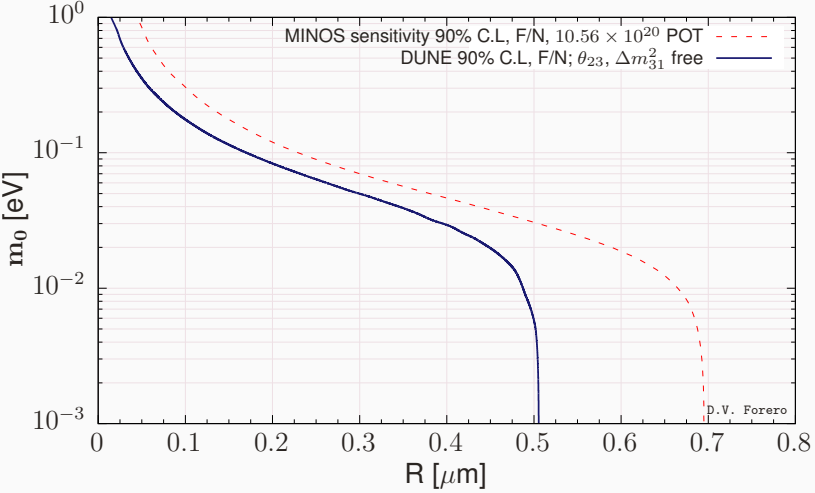
- Signal normalization systematical errors:
  $\sigma(\nu_e) = 0.02$, $\sigma(\bar{\nu}_e) = 0.02$, $\sigma(\nu_\mu) = 0.05$, $\sigma(\bar{\nu}_\mu) = 0.05$.
- Background normalization systematical errors:
  $\sigma(\nu_\mu) = 0.05$, $\sigma(\nu_e) = 0.05$, $\sigma(\nu_\tau) = 0.2$, $\sigma(\bar{\nu}_e) = 0.05$ & $\sigma(NC_{dis}) = 0.1$.
- At this point, bin-to-bin uncorrelated systematics (or SHAPE syst.) not included!

Fluxes

- The "Optimized Engineered Nov2017".

DUNE Sensitivity to LED; 300 kt-MW-years of exposure

DUNE TDR arxiv:2002.03005



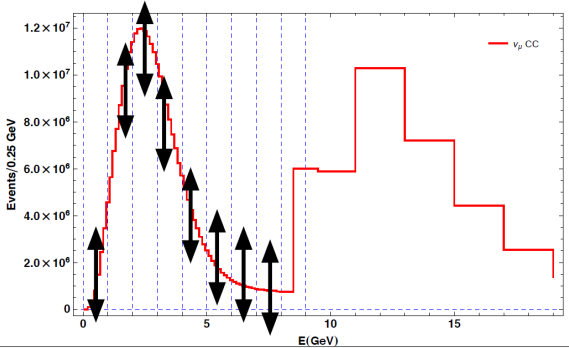
Thanks to S. De Rijck we can show MINOS sensitivity result (Asimov data).

Work in progress...

Shape systematics in GLoBES

Define energy points, p_E, and size of the systematic, s, at each p_E

E.g. One uncorrelated systematic every GeV



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Current DUNE setup

$40kt \times (6.5yr(\nu) + 6.5yr(\bar{\nu})) \times 1.2MW$=624 kt-MW-yrs of exposure $\equiv$ 10 yrs(staged)

Information considered in the analysis:

- Signal: CC, ν and $\bar{\nu}$, appearance and disappearance oscillation channels included in the analysis.
- Only FD information is considered, but ND fixes the flux normalization.

Systematics

B. Abi, et. al, arxiv:2103.04797 $\rightarrow$ Latest GLoBES files: E_{rec} binwidth= (TDR binwidth)/2.

- Signal normalization systematical errors:
  $\sigma(\nu_e) = 0.02$, $\sigma(\bar{\nu}_e) = 0.02$, $\sigma(\nu_\mu) = 0.05$, $\sigma(\bar{\nu}_\mu) = 0.05$.
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- bin-to-bin uncorrelated systematics (or SHAPE syst.) included, as explained in slide 9.

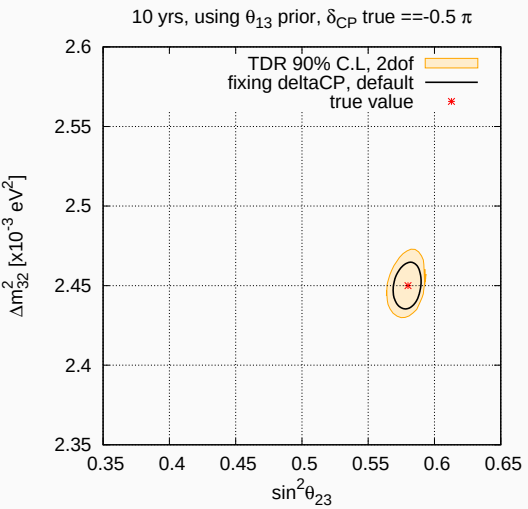
Fluxes

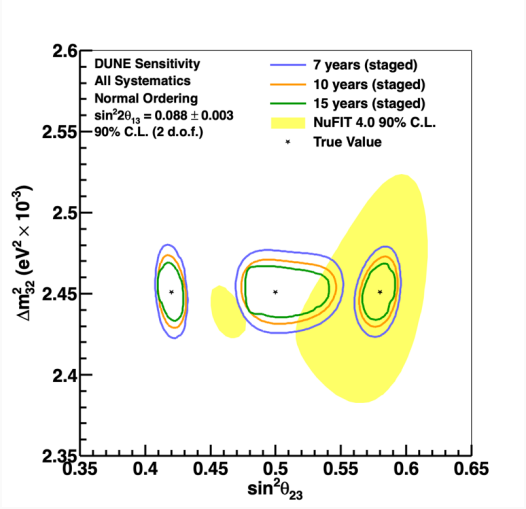
- The "Optimized Engineered Nov2017".

Estimating the level of the 'shape' systematics

Atmospheric plane, the importance of the shape systematics

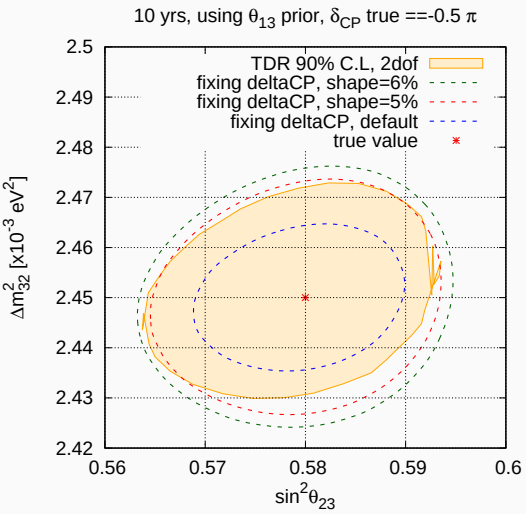
LBL phys. Potential of the DUNE Exp. arxiv:2006.16043, FIG. 26

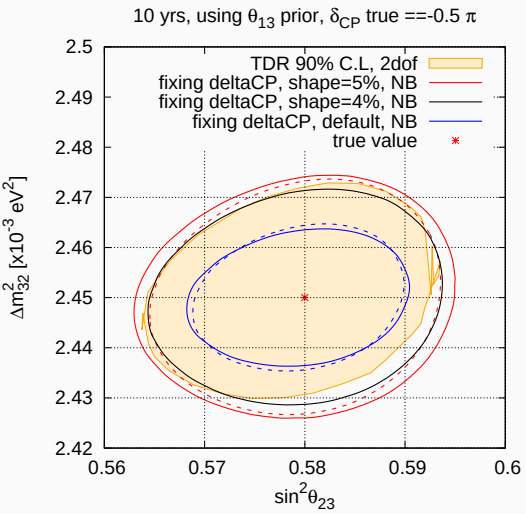




Estimating the level of the 'shape' systematics

ZOOMING IN the Atmospheric plane, when using TDR binning result quoted as 'NB'





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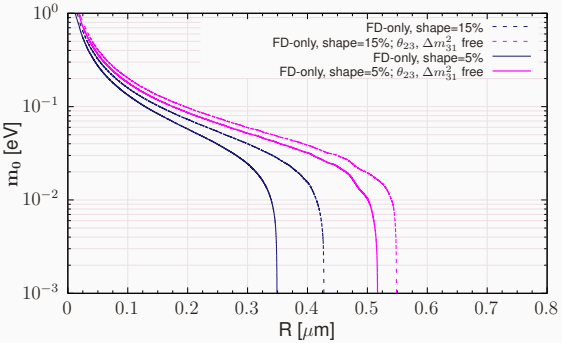
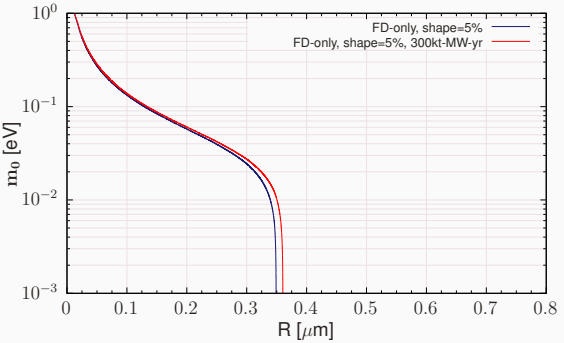
DUNE Sensitivity to LED, preliminary results

FD-Only, with TDR binning & 2 KK modes

624 kt-MW-years of exposure ≡ 10 yrs (staged). DUNE 90% of C.L for 2 d.o.f:





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Present & Near Future Plans

Presented at the DUNE Coll. Meeting in May 2021

- We (A. Sousa, E. Fernandez-M, M. Blennow & S. Rosauro), and also Michael Wallbank, Jeremy Hewes and Callum Wilkinson had discussions on what it is needed to include a realistic set of systematics for the 2-detector analysis.
- Callum Wilkinson and Elizabeth Worcester provided us with the FULL systematical errors used in the 3-flavor neutrino analysis (for the TDR) in the form of covariance matrices (using CAFAna).
- A less than a week ago, Michael Wallbanck, Jeremy Hewes & Herilala Razafi 'translated' the covariance matrices into a format that can be included into our LED analysis in GLoBES.

Plans:

- To understand the departures from 3-flavor results in arxiv:2006.16043, FIG. 26 obtained when estimating of the level of systematics, using GLoBES files (first procedure).
- To implement the covariance matrices for the 2-detector analysis including LED (second procedure).
- First procedure is considered as a cross check of the second one, at least for the FD-only sensitivity to LED.

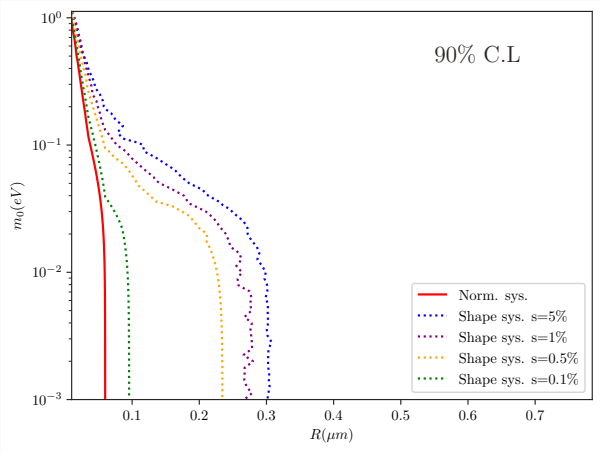
Thank you for your attention!

Back up

Towards a two-detector fit

First results for 2 KK modes, with the old binning

Includding a shape-like systematic error in the signal (uncorrelated between detectors) in the ND.



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