New Physics Search at INO

Sanjib Kumar Agarwalla

sanjib@mri.ernet.in

Harish-Chandra Research Institute, Allahabad, India

work done in collaboration with

Rathin Adhikari and Amitava Raychaudhuri

Phys. Lett. B 642 (2006) 111, hep-ph/0608034

An ask

- Can upcoming neutrino experiments probe non-standard interactions (NSI) like $\not R$ supersymmetry?
- Can they become fatal in attempts to further sharpen the neutrino properties?

A possible experiment

CERN based β-beam neutrino source

+

The proposed India-based Neutrino Observatory (INO)

A baseline of $\sim$ 7152 Km

ν interacts with earth matter $\Rightarrow$ a possible ground for NSI

$\not{R}$ SUSY

In SUSY, gauge invariance does not imply baryon number (B) and lepton number (L) conservation and in general, R-parity (R $= (-1)^{3B+L+2S}$, S is the spin) is violated

In $\not{R}$ MSSM, we have the superpotential (conserving B) :

$$W_{\not{L}} = \sum_{i,j,k} \left(\frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \mu_i L_i H_u\right)$$

(Suppressing colour and $SU(2)$ indices)

- $i, \ j, \ k$ **are generation indices**
- L_i **and** Q_i **are** $SU(2)$**-doublet lepton and quark superfields respectively**
- E_i, D_i **denote the right-handed** $SU(2)$**-singlet charged lepton and down-type quark superfields respectively**
- H_u, **Higgs superfield which gives masses to up-type quarks**

$\not R$ SUSY

Focus on the trilinear L-violating term with λ' couplings

==

Expanding in standard four-component Dirac notation,
the quark-neutrino interaction lagrangian :

$$\mathcal{L}_{\lambda'} = \lambda'_{ijk} \left[\tilde{d}^j_L \, \bar{d}^k_R \nu^i_L + (\tilde{d}^k_R)^* (\bar{\nu}^i_L)^c d^j_L \right] + h.c.$$

The sfermion fields are characterized by the tilde sign
$\Rightarrow$ All the couplings are real, can be +ve or -ve

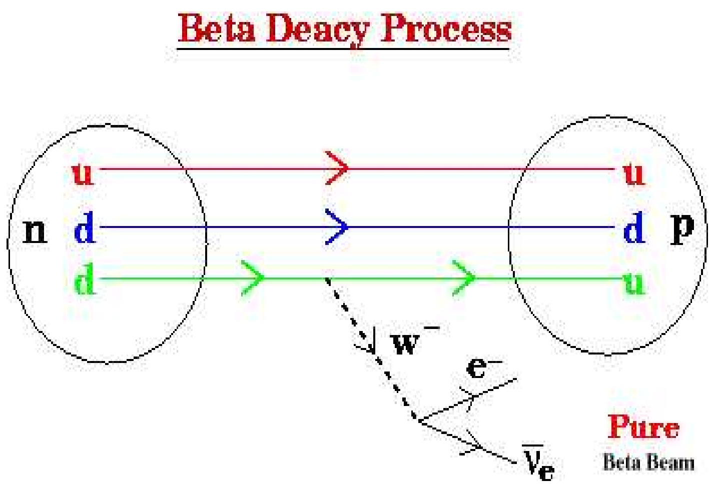
- ν interacts with electrons and d-quarks during propagation

(i) $\nu_i + d \rightarrow \nu_j + d$ & **(ii)** $\nu_i + e \rightarrow \nu_j + e$

(i) Through λ' *via* squark exchange for all i, j and in SM *via* Z exchange for $i = j$

(ii) In SM *via* W and Z exchange for $i = j$

What is Beta Beam?



Origin : beta decay of completely ionized, radioactive ions circulating in a storage ring

A pure, intense, collimated beam of ν_e or $\bar{\nu}_e$, no background

$$^8_5B \rightarrow {^8_4Be} + e^+ + \nu_e$$

- ^{8}B ion ($Q = 13.92$ MeV and $t_{1/2} = 0.77s$) with $\gamma = 350$
- Known energy spectrum, high intensity, low systematic errors, better collimation and higher energy of beam
- Useful decays : $\bar{\nu}_e$ (2.9×10^{18}/year) and ν_e (1.1×10^{18}/year)
- Feasible with existing CERN facilities or planned upgrades

Three-flavour oscillations

Neutrino flavour states $|\nu_\alpha\rangle$ **(**$\alpha = e, \mu, \tau$**) are related to the mass eigenstates** $|\nu_i\rangle$ **(**i **= 1, 2, 3) with masses** m_i **:**

$\Rightarrow$ $|\nu_\alpha\rangle = \sum_i U_{\alpha i} |\nu_i\rangle$ **;** U **is a** 3×3 **unitary (PMNS) matrix**

The neutrino flavour eigenstates evolve in time as :

$$i \frac{d}{dt} \begin{pmatrix} \nu_e(t) \\ \nu_\mu(t) \\ \nu_\tau(t) \end{pmatrix} = H \begin{pmatrix} \nu_e(t) \\ \nu_\mu(t) \\ \nu_\tau(t) \end{pmatrix},$$

$$where\ \ H = E \times \mathbf{1}_{3\times3} + U \left(\frac{M^2}{2E} \right) U^\dagger + R$$

Here E **is the neutrino energy,** R **is a** 3×3 **matrix reflecting the matter effect** $\;\&\;\; M^2 \;=\; \mathrm{diag}(m_1^2, m_2^2, m_3^2)$

NSI in Matter effect

$$R_{ij} = R_{ij}(SM) + R_{ij}(\lambda')$$

$$R_{ij}(SM) = \sqrt{2} G_F n_e \delta_{ij}(i,j=1) + \frac{G_F n_n}{\sqrt{2}} \delta_{ij},$$

$$R_{ij}(\lambda') = \sum_m \left(\frac{\lambda'_{im1}\lambda'_{jm1}}{4m^2(\tilde{d}_m)} n_d + \frac{\lambda'_{i1m}\lambda'_{j1m}}{4m^2(\tilde{d}_m)} n_d \right)$$

$\Rightarrow$ R **is a symmetric matrix**

$\Rightarrow$ n_e, n_n **and** n_d **respectively are the electron, neutron and down-quark densities in earth matter**

$\Rightarrow$ **Isoscalar earth matter,** $n_e = n_p = n_n$ **and** $n_d = 3n_e$

$\Rightarrow$ **Current bounds on the** $\not{R}$ **couplings imply,** λ' **induced contributions to** R_{11}, R_{12} **and** R_{13} **are several orders less than** $\sqrt{2} G_F n_e$

NSI in Matter effect

$\Rightarrow$ **In addition to the Standard Model contribution, we consider**

$$R_{23} = R_{32} = \frac{n_d}{4m^2(\tilde{d}_m)} \left(\lambda'_{2m1}\lambda'_{3m1} + \lambda'_{21m}\lambda'_{31m}\right) ,$$

$$R_{22} = \frac{n_d}{4m^2(\tilde{d}_m)} \left(\lambda'^{\,2}_{2m1} + \lambda'^{\,2}_{21m}\right) , \quad R_{33} = \frac{n_d}{4m^2(\tilde{d}_m)} \left(\lambda'^{\,2}_{3m1} + \lambda'^{\,2}_{31m}\right)$$

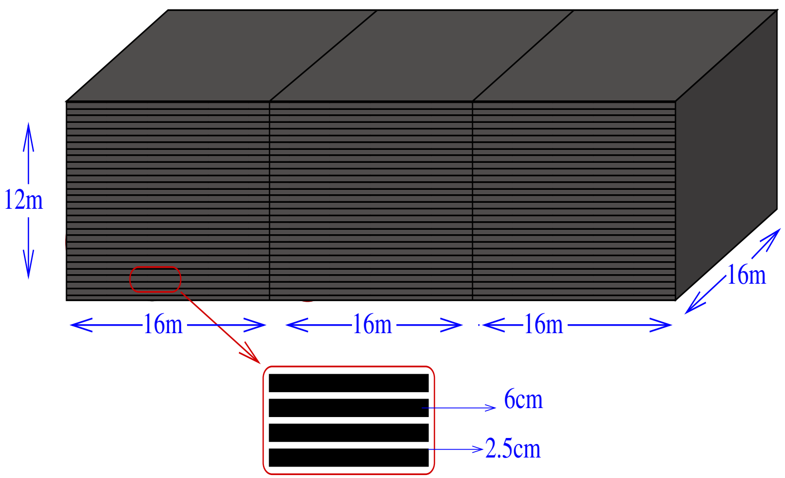
which are comparable to $\sqrt{2}G_F n_e$. One can see that $R_{23} \neq 0$ implies both R_{22} and R_{33} are non-zero

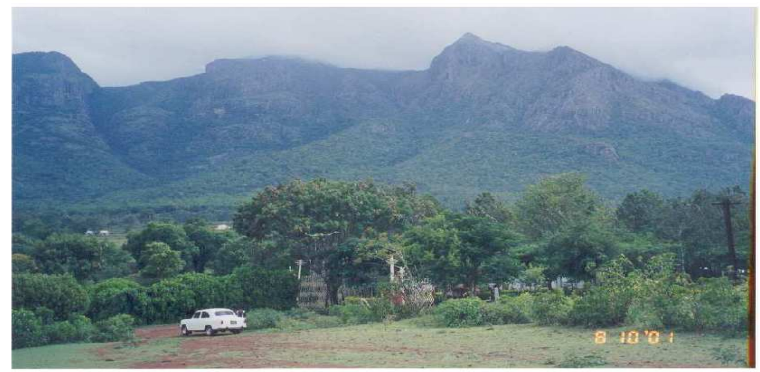
Current bounds : $|\lambda'_{221}, \lambda'_{231}| < 0.18$; $|\lambda'_{21m}| < 0.06$; $|\lambda'_{331}| < 0.58$; $|\lambda'_{321}| < 0.52$; $|\lambda'_{31m}| < 0.12$ **for down squark mass** $m_{\tilde{d}} = 100$ **GeV**

Recent BELLE data puts tight constrains on $|\lambda'_{21m}\lambda'^{*}_{31m}|$ and $|\lambda'_{2m1}\lambda'^{*}_{3m1}|$. This effectively makes R_{23} negligible

INO/ICAL

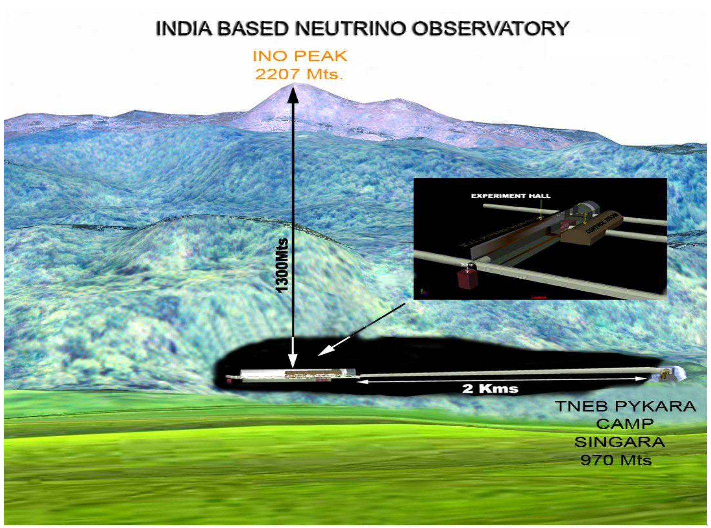
The India-based Neutrino Observatory





PUSHEP Site (Lat: N11.5°, Long: E76.6°)

PUSHEP-Bangalore: 250km



A 50 kton magnetized Iron calorimeter (ICAL) detector with excellent efficiency of charge identification ($\sim$ 95%) and good energy resolution $\sim$ 10% above 2 GeV

Few facts

- Average energy of the beam $\Rightarrow$ $\langle E_{\nu_e} \rangle \simeq$ 5 GeV

- CERN - INO long baseline $\Rightarrow$ huge matter induced contribution in $P_{e\mu}$ channel $\Rightarrow$ scope for NSI

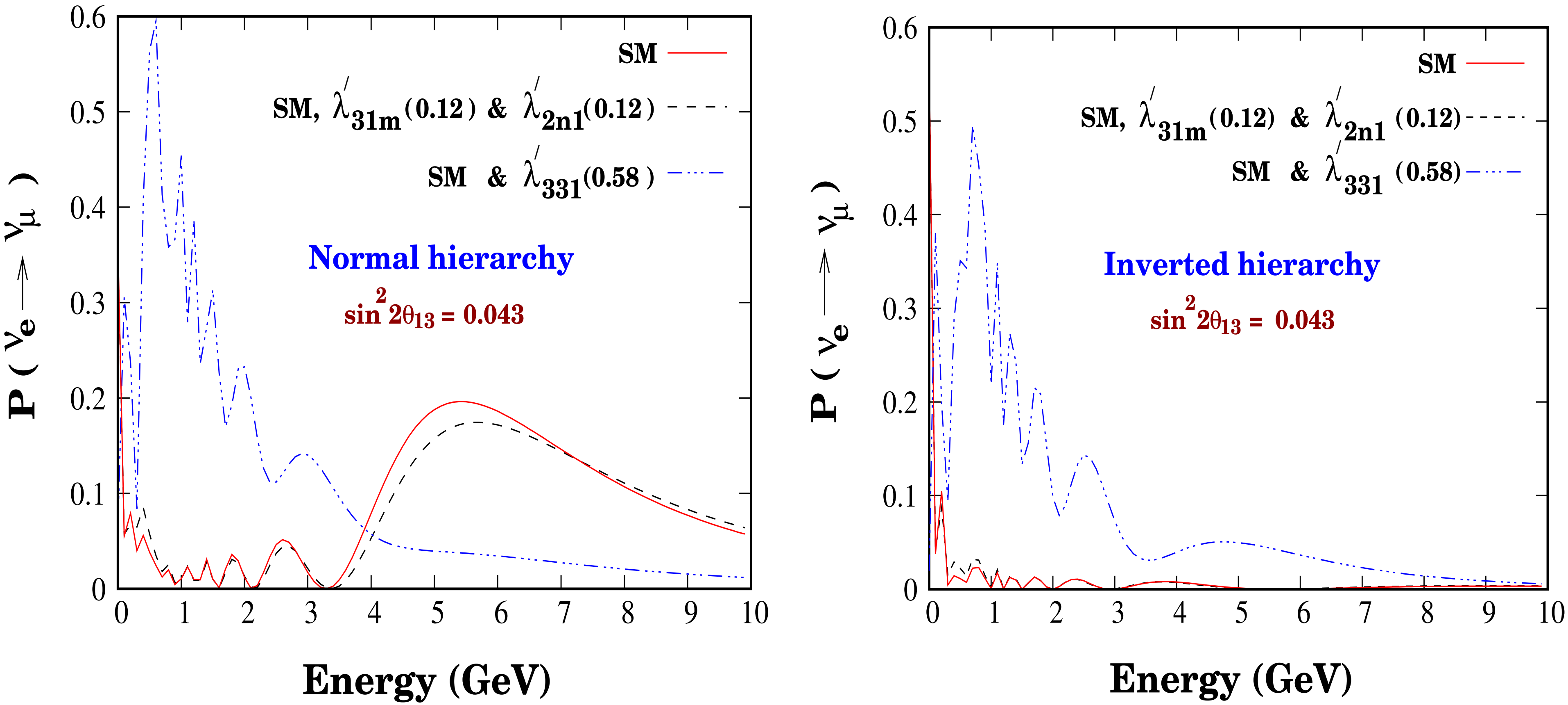
- Signal ($\nu_e \rightarrow \nu_\mu$) $\Rightarrow$ penetrating tracks of prompt muons

- Energy threshold $\Rightarrow$ 2 GeV $\&$ 5 years data sample

- We use exact 3-flav osc. prob with PREM profile, mixing parameters are at their best-fit values, except θ_{13}

- Latest bounds on $\not{R}$ couplings are obeyed

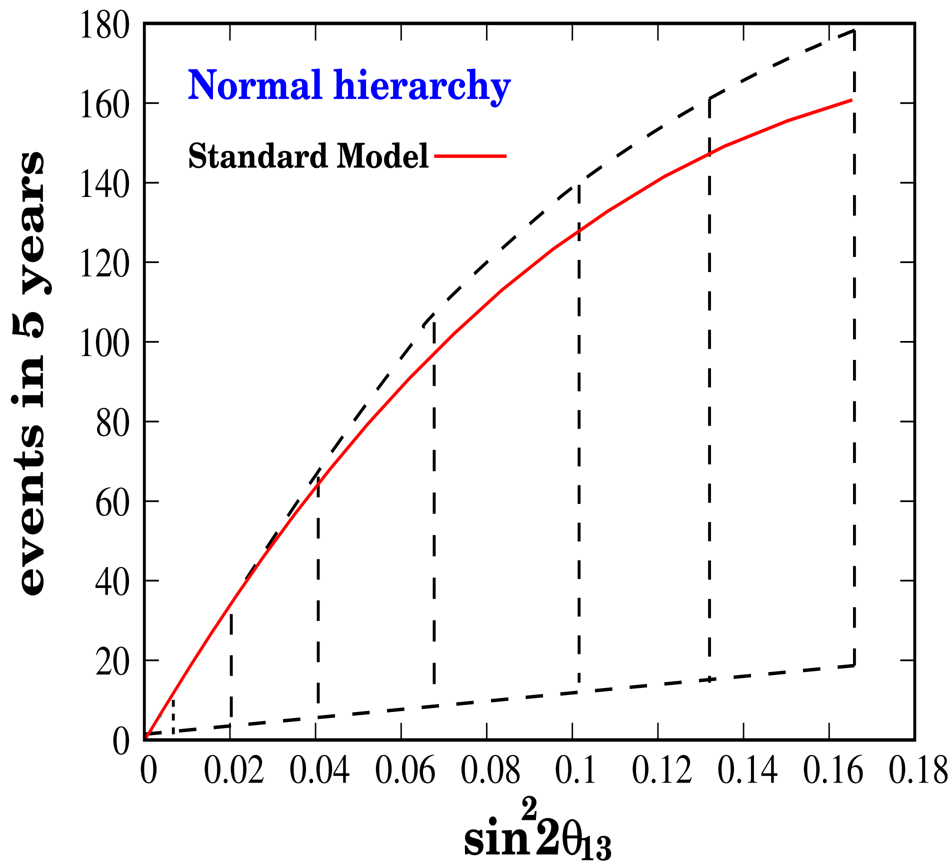
$P_{e\mu}$ .vs. E_ν

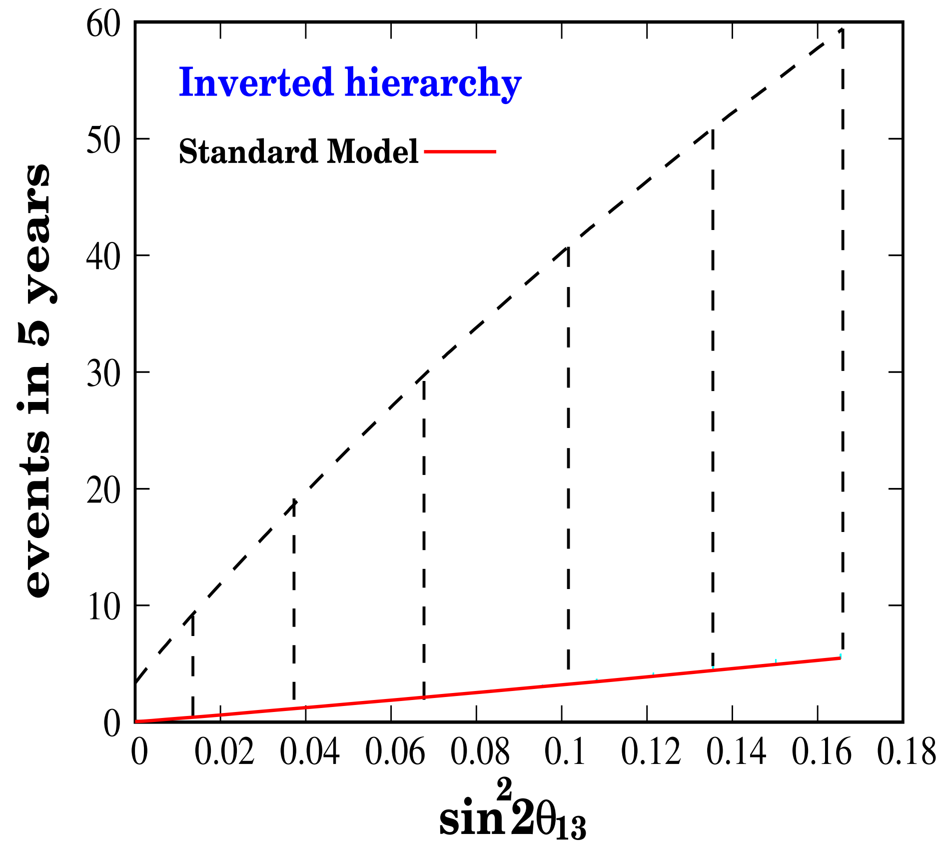


$P_{e\mu}$ for NH and IH

m can take any value, $n = 2$ or 3

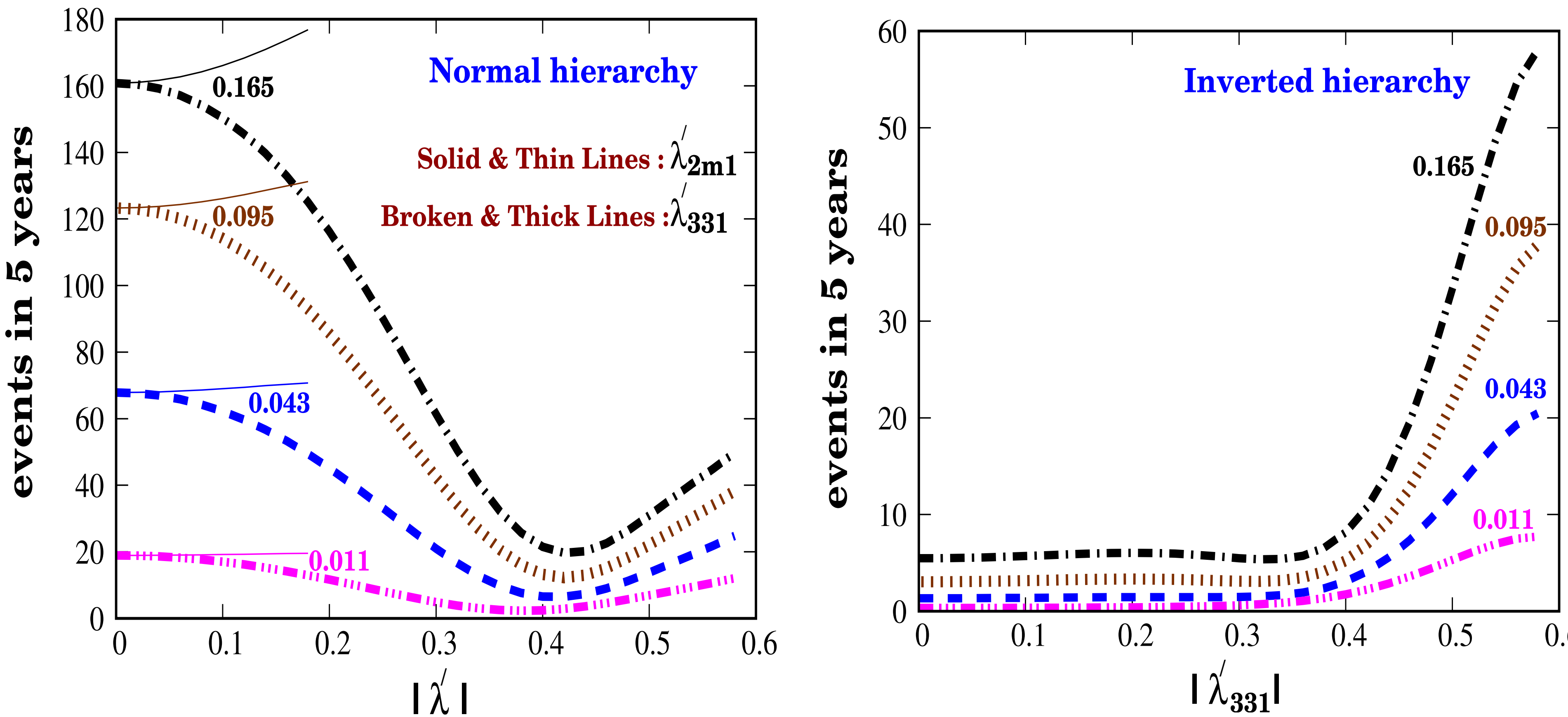
Extracting θ_{13} & $sgn(\Delta m^2_{31})$





Muon events .vs. $\sin^2 2\theta_{13}$ for NH and IH. The solid lines correspond to the SM. The shaded area is covered if the λ' couplings are varied over their entire allowed range

Constraining λ'



Event rates .vs. $|\lambda'|$, present singly, for NH and IH. The thick (thin) lines are for $|\lambda'_{331}|$ ($|\lambda'_{2m1}|$, $m =$2,3). The chosen $\sin^2 2\theta_{13}$ are indicated next to the curves

Conclusions

- $\not{R}$ SUSY is among several extensions of the SM crying out for experimental verification. It has flavour diagonal and flavour changing neutral currents, affect neutrino masses and mixing and leave their imprints in long baseline expts

  This is the focus of this work

- We consider a β-beam experiment with the source at CERN and the detector at INO . We find that the $\not{R}$ interactions may obstruct a clean extraction of the mixing angle θ_{13} or determination of the mass hierarchy unless the bounds on the λ' couplings are tightened

- On the other hand, one might be able to see a clean signal of new physics and put tighter constraints on the λ' couplings