Implementing other physics models in FairShip

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June 13, 2016

Introduction

- Up to now sensitivity studies using the full simulation of the SHiP detector only performed for the sterile neutrino model
- Toy and back of the envelope calculations of sensitivities performed for other new physics models

- Precise estimations required for physics TDR

  $\rightarrow$ Multitude of new physics models documented in physics proposal need to be studied more accurately by simulating within our SHiP software framework

R-Parity violation and light neutralinos

- Benchmark models to study sensitivity of SHiP from de Vries, Dreiner, Scheier [arXiv:1511.07436]
- Model used previously to explain the NuTeV dimuon event excess through neutralino production from B-meson decays Dedes, Dreiner, Richardson [arXiv:hep-ph/0106199]
- Complementary to LHC SUSY searches as such models allow to probe sfermion masses up to $\mathcal{O}(10)$TeV

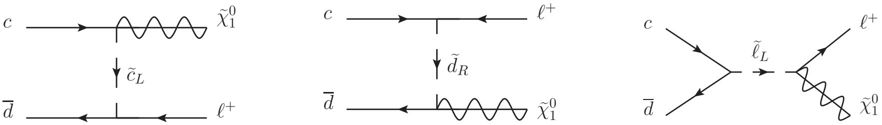


FIG. 1. Relevant Feynman Diagrams for $D^+ \to \tilde{\chi}_1^0 + \ell^+$

Benchmark modes

- Large overlap of production and decay signatures to HNL model already implemented in FairShip

  $\rightarrow$ Trivial extension of existing framework
- Main complication is the large amount of parameter space of the model

  $\rightarrow$ Hundreds of combinations of production and decay modes depending on quark and lepton flavour couplings

  $\rightarrow$ Literature splits into 5 benchmarks e.g [arXiv:1511.07436]

Channels considered

- Production: $D_{(s)}^{+} \rightarrow \tilde{\chi}_1^0 \mu^+$, $B^0 \rightarrow \tilde{\chi}_1^0 \bar{\nu}$, $B^+ \rightarrow \tilde{\chi}_1^0 (\mu^+, \tau^+)$
- Visible decay modes: $\tilde{\chi}_1^0 \rightarrow K^{(*)+}(\mu^-, \tau^-)$,
- Invisible decay modes: $\tilde{\chi}_1^0 \rightarrow (K_L^0, K_S^0, K^*) + (\nu, \bar{\nu})$, $\tilde{\chi}_1^0 \rightarrow (\eta, \eta', \phi) + (\nu, \bar{\nu})$

Production and decay widths

$$\Gamma(M_{ab} \to \tilde{\chi}_1^0 + l_i) = \frac{\lambda^{\frac{1}{2}}(m^2_{M_{ab}}, m^2_{\tilde{\chi}_1^0}, m^2_{l_i})}{64\pi m^3_{M_{ab}}} |G^{S,f}_{iab}|^2 (f^S_{M_{ab}})^2 (m^2_{M_{ab}} - m^2_{\tilde{\chi}_1^0} - m^2_{l_i}), \tag{38}$$

$$\Gamma(M^*_{ab} \to \tilde{\chi}_1^0 + l_i) = \frac{\lambda^{\frac{1}{2}}(m^2_{M^*_{ab}}, m^2_{\tilde{\chi}_1^0}, m^2_{l_i})}{3\pi m^3_{M^*_{ab}}} |G^{T,f}_{iab}|^2 (f^T_{M^*_{ab}})^2 \Big[m^2_{M^*_{ab}} (m^2_{M^*_{ab}} + m^2_{\tilde{\chi}_1^0} + m^2_{l_i}) - 2(m^2_{\tilde{\chi}_1^0} - m^2_{l_i})^2 \Big], \tag{39}$$

$$\Gamma(\tilde{\chi}_1^0 \to M_{ab} + l_i) = \frac{\lambda^{\frac{1}{2}}(m^2_{\tilde{\chi}_1^0}, m^2_{M_{ab}}, m^2_{l_i})}{128\pi m^3_{\tilde{\chi}_1^0}} |G^{S,f}_{iab}|^2 (f^S_{M_{ab}})^2 (m^2_{\tilde{\chi}_1^0} + m^2_{l_i} - m^2_{M_{ab}}), \tag{40}$$

$$\Gamma(\tilde{\chi}_1^0 \to M^*_{ab} + l_i) = \frac{\lambda^{\frac{1}{2}}(m^2_{\tilde{\chi}_1^0}, m^2_{M^*_{ab}}, m^2_{l_i})}{2\pi m^3_{\tilde{\chi}_1^0}} |G^{T,f}_{iab}|^2 (f^T_{M^*_{ab}})^2 \Big[2(m^2_{\tilde{\chi}_1^0} - m^2_{l_i})^2 - m^2_{M^*_{ab}} (m^2_{M^*_{ab}} + m^2_{\tilde{\chi}_1^0} + m^2_{l_i}) \Big]. \tag{41}$$

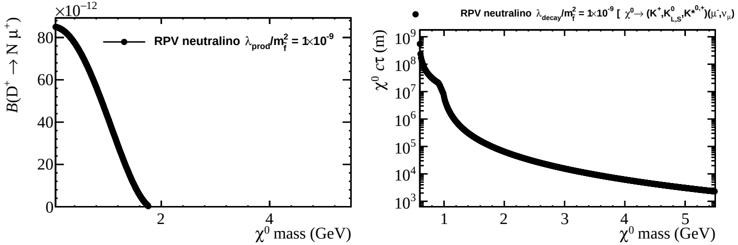
With the $G^{S,f}_{iab}$ given by e.g

$$\underbrace{\lambda'_{iab}\left(\frac{1}{2}\frac{g_{\tilde{u}_L}}{m^2_{\tilde{u}_{a_L}}} + \frac{1}{2}\frac{g^*_{\tilde{d}_R}}{m^2_{\tilde{d}_{b_R}}} - \frac{g_{\tilde{\ell}_L}}{m^2_{\tilde{\nu}_{i_L}}}\right)}_{\equiv G^{S,\ell}_{iab}},$$

- Assuming sfermion masses are degenerate then can set limits in with $\lambda_{iab}/m^2_{\tilde{f}}$ vs $m_{\tilde{\chi}_1^0}$ plane.

Some results

- Script in place to calculate decay widths and branching fractions for 5 benchmarks
- Can also calculate individual widths for user specific benchmark
- Integrated within FairShip. In the process of generating events within FairShip to test (not yet committed)



- For coupling $\lambda_{\rm prod}/m^2_{\tilde{f}} \sim \mathcal{O}(10^{-5}) - (10^{-9})\mathrm{GeV}^{-2}$, $\mathcal{B}(D^+ \to \chi^0\mu^+)$ $\sim \mathcal{O}(10^{-2}) - \mathcal{O}(10^{-10})$
- For coupling $\lambda_{\rm decay}/m^2_{\tilde{f}} \sim \mathcal{O}(10^{-5}) - (10^{-9})\mathrm{GeV}^{-2}$, proper decay length $\sim \mathcal{O}(mm) - \mathcal{O}(1000km)$
- In agreement with literature

Other models

Light Axino

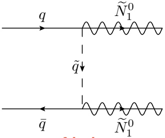
Ki Young Choi, work ongoing...

- Supersymmetric partner of the axion
- Exhibits very weak interactions and SHiP perfect place to search for this mode
- Mass ranges between MeV and a few GeV
- Part of the Physics proposal but no quantitative estimates

- Split into two cases: R-parity conserving and R-parity violating

Ki Young Choi, work ongoing...

R-parity conservation

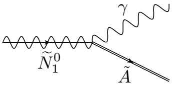


Production of light neutralinos

$pp \to \widetilde{N}_1^0 \widetilde{N}_1^0$

mono-photon

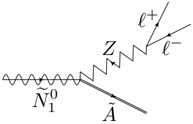
$\widetilde{N}_1^0 \xrightarrow{\text{long lived}} \tilde{A} + \gamma,$



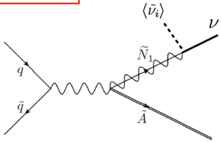
Decay of neutralino

charged tracks

$\widetilde{N}_1^0 \xrightarrow{\text{long lived}} \tilde{A} + \ell^+\ell^-,$



R-parity violation



Production of axino

$pp \to \tilde{A}\nu.$

Decay of axino

$\tilde{A} \xrightarrow{\text{long lived}} \nu + \ell^+\ell^-,$

$\tilde{A} \xrightarrow{\text{long lived}} \nu + \gamma,$

$$\tau_{\tilde{A}} \sim 1\mathrm{m} \left(\frac{|U_{\tilde{\gamma}\tilde{Z}}|\xi_i}{10^{-1}}\right)^{-2} \left(\frac{m_{\tilde{A}}}{10\mathrm{GeV}}\right)^{-3} \left(\frac{f_A}{10^5\mathrm{GeV}}\right)^2$$

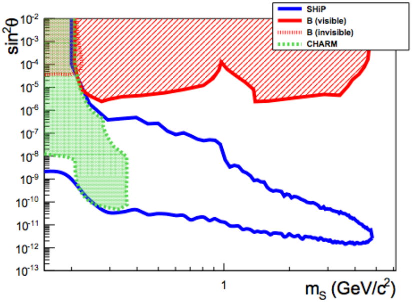
with $\xi_i = \langle\tilde{\nu}_i\rangle / v$ and $\langle\tilde{\nu}_i\rangle$ being the sneutrino vev

- Are there ways to produce through decays of charm and beauty hadrons? Under study

Dark Scalar

Gaia, work ongoing...

- Existing toy model already used to study sensitivities and understand detector acceptance
- Needs to be ported into FairShip



Conclusions

- RPV neutralino model: close to finalising implementation in FairShip, need to test production chain
- Once that is done move on to implementing Sgoldstino model
- Dark Scalar and Axino models also ongoing
- Many many more models need to be added:
- e.g Pseudo Dirac goldstinos, Dark photons, Axion Like Particles...
- Please contact Nico if interested