Probing the "μ from ν" supersymmetric standard model with displaced multileptons from the decay of a Higgs boson at the LHC

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(Dated: August 11, 2013)

The "μ from ν" supersymmetric standard model ($\mu\nu$SSM) cures the μ-problem and concurrently reproduces measured neutrino data by using a set of usual right-handed neutrino superfields. Recently, the LHC has revealed the first scalar boson which naturally makes it tempting to test $\mu\nu$SSM in the light of this new discovery. We show that this new scalar while decaying to a pair of unstable long-lived neutralinos, can lead to a distinct signal with non-prompt multileptons. With concomitant collider analysis we show that this signal provides an intriguing signature of the model, pronounced with light neutralinos. Evidence of this signal is well envisaged with sophisticated displaced vertex analysis, which deserves experimental attention.

PACS numbers: 12.60.Jv, 14.80.Da, 12.60.Fr, 14.80.Ly

The $\mu\nu$SSM [1, 2] contains in the superpotential W, in addition to the Yukawa couplings for quarks and charged leptons of the minimal supersymmetric standard model (MSSM) [3], Yukawas for neutrinos and two additional type of terms involving the Higgs doublet superfields, $\hat{H}_u$ and $\hat{H}_d$, and the three right-handed neutrino superfields $\hat{\nu}^c_i$ [1, 2]:

$$W = \epsilon_{ab}(Y_{u_{ij}}\,\hat{H}^b_u\,\hat{Q}^a_i\,\hat{u}^c_j + Y_{d_{ij}}\,\hat{H}^a_d\,\hat{Q}^b_i\,\hat{d}^c_j + Y_{e_{ij}}\,\hat{H}^a_d\,\hat{L}^b_i\,\hat{e}^c_j + Y_{\nu_{ij}}\,\hat{H}^b_u\,\hat{L}^a_i\,\hat{\nu}^c_j - \lambda_i\,\hat{\nu}^c_i\,\hat{H}^a_d\hat{H}^b_u) + \frac{1}{3}\kappa_{ijk}\hat{\nu}^c_i\hat{\nu}^c_j\hat{\nu}^c_k\ . \quad (1)$$

The simultaneous presence of the last three terms in Eq. (1) gives rise to explicit breaking of R-parity (R_p). With only dimensionless trilinear couplings in W, the electroweak (EW) scale arises through the soft supersymmetry (SUSY)-breaking terms in the scalar potential. Thus all known particle physics phenomenology can be reproduced in the $\mu\nu$SSM with only one scale. Once the EW symmetry is spontaneously broken, the neutral scalars develop in general the following vacuum expectation values (VEVs): $\langle H^0_d\rangle = v_d$, $\langle H^0_u\rangle = v_u$, $\langle\tilde{\nu}_i\rangle = \nu_i$, $\langle\tilde{\nu}^c_i\rangle = \nu^c_i$. An effective interaction $\mu\,\hat{H}_d\hat{H}_u$, with $\mu \equiv \lambda_i\nu^c_i$, is generated through the fifth term of Eq. (1), solving the μ-problem of the MSSM [4] without introducing an extra singlet superfield as in the case of the next-to-MSSM (NMSSM) [5]. The sixth term in Eq. (1) avoids the existence of a Goldstone boson. It also generates EW-scale effective Majorana masses ($2\kappa\nu^c_i$) for right-handed neutrinos, which give rise to a TeV scale seesaw with $Y_\nu \sim 10^{-6}$ (like Y_e), and together with R_p violation ($\not{R}_p$) are instrumental in reproducing the measured neutrino mass squared differences and mixing angles [2, 6–8] at the tree level. This feature is unlike the bilinear $\not{R}_p$ model [9] where only one mass is generated at the tree level and loop corrections are necessary to generate at least a second mass and a PMNS mixing matrix compatible with experiments. In the bilinear model, the μ-like problem [10] is also augmented with three bilinear terms.

In the $\mu\nu$SSM as a consequence of the $\not{R}_p$, all the neutral fermions (scalars) mix together and there are 10 neutralino (8 CP-even and 7 CP-odd) mass eigenstates. Analyses of the $\mu\nu$SSM, with attention to the neutrino and LHC phenomenology have also been addressed in [2, 7, 8, 11–14]. Other analyses concerning cosmology such as gravitino dark matter and electroweak baryogenesis can be found in [15] and [16], respectively.

Thus the $\mu\nu$SSM is a well motivated SUSY model with enriched phenomenology and notable signatures, which definitely deserve rigorous analyses by the LHC collaboration. However, although SUSY searches remain one of the primary targets for the LHC, the discovery of a new scalar boson with a mass around 125 GeV by ATLAS [17] and CMS [18] collaborations has attracted the attention of the community. In spite of the observed decay rates of this particle compatible with those of the standard model (SM) Higgs boson, a departure from the SM predictions remains a possibility since new LHC data are being analysed.

We present a dedicated collider analysis together with detector simulation of an intriguing signal in the $\mu\nu$SSM featuring non-prompt multileptons at the LHC, arising from the beyond SM decay of a 125 GeV scalar into a pair of lightest neutralinos ($\widetilde{\chi}^0$). Since R_p is broken, each $\widetilde{\chi}^0$ decays into a scalar/pseudoscalar (h/P) and a neutrino (ν), with the h/P further driven to decay into $\tau^+\tau^-$, giving rise to a 4τ final state. Because of the value of Y_ν, $\not{R}_p$ is small and $\widetilde{\chi}^0$ decay leads to a displaced vertex (DV). We investigate the situation when the $\widetilde{\chi}^0$ decays inside the inner tracker and thereby yielding clean detectable signatures. Although $h/P \to b\bar{b}$ is dominant over a broad range of parameters, we stick to $2m_\tau \lesssim m_{h/P} \lesssim 2m_b$, which allows us to demonstrate two possible signatures characterised by: (i) high lepton multiplicity; and (ii) charged tracks originating from DVs, which can be explored through distinct experimental approaches.

It remains to elucidate, if a possible excess of four-lepton (e, μ coming from τ-decay) events is observed at the LHC, how to distinguish the $\mu\nu$SSM from other models. A dedicated measurement of the displaced charged tracks, in the first hand, can reject all possible similar final states with prompt leptons. In bilinear $\not{R}_p$ models with minimal superfield content, $\widetilde{\chi}^0$ with mass below m_W dominantly decays through $\ell W^*/\nu Z^*$ with $\ell = e, \mu, \tau$, while decay length (l_{DL}) scales as $1/m^4_{\widetilde{\chi}^0}$. In the $\mu\nu$SSM however, available lighter singlet like h/P states provide new two-body decay modes, $\widetilde{\chi}^0 \to h/P + \nu$, which can reduce l_{DL} by orders of magnitude, as hinted in [11]. This feature manifests notably in the regime $m_{\widetilde{\chi}^0} < 20$ GeV where bilinear $\not{R}_p$ models predict $l_{DL} \sim 100$ m [11], beyond detector coverage and thus mimic known missing energy ($\not{E}_T$) signature with conserved R_p. On the other hand, models with trilinear $\not{R}_p$ term, for example $\hat{L}_i \hat{L}_j \hat{E}^c_k$ [9], can produce moderate to large displaced vertex (1cm-3m) for $m_{\widetilde{\chi}^0} < 20$ GeV. Such a light $\widetilde{\chi}^0$ within minimal SUSY models, will however, give rise to high branching ratio for SM-like Higgs $\to \widetilde{\chi}^0\widetilde{\chi}^0$ decay mode. Since resulting final states contain visible particles this scenario is tightly constrained from experimental data. This problem is however ameliorated in the $\mu\nu$SSM since the said branching fraction can still remain suppressed due to predominant singlet composition of $\widetilde{\chi}^0$.

Wrapping up, moderately displaced ($\gtrsim 1$ cm) yet detectable charged tracks from a light $\widetilde{\chi}^0$, as appear in the $\mu\nu$SSM, are hardly possible with other minimal SUSY models with or without R_p. Non-minimal SUSY models with or without $\not{R}_p$ can however produce similar displaced final states. As an example, in the NMSSM these states can appear when a light next-to-lightest supersymmetric particle (NLSP) (produced directly or from Higgs decay) decays to a very light LSP (to yield small $\not{E}_T$) and a light scalar/pseudoscalar. This scenario in reality, however, is a hardly realistic choice with experimental measurement of invisible Z-decay width and other LEP (and LHC) measurements. On the contrary, non-minimal SUSY models with $\not{R}_p$ produce irreducible impostor for this specific signal. Nevertheless, there exists other unique decay modes, for example multilepton final states from long Higgs-to-Higgs cascade [13], which can provide distinctive signal of the $\mu\nu$SSM because more Higgses are present. Is is also worth remarking in this context that whereas the trilinear $\not{R}_p$ terms in the $\mu\nu$SSM are useful for reproducing neutrino data at tree level and for solving the μ-problem, trilinear $\not{R}_p$ terms such as $\hat{L}_i \hat{L}_j \hat{E}^c_k$ do not attempt to solve the μ-problem and generate neutrino masses only through loops.

The noticeable footprint of the $\mu\nu$SSM relies on the presence of light $\widetilde{\chi}^0$ and lighter h, P, which are experimentally feasible when predominantly singlet in nature. Concealing complex flavour structure and neglecting terms $\propto Y_\nu, \nu$ for smallness, $m_{\widetilde{\chi}^0} \sim 2\kappa\nu^c$, for $|2\kappa\nu^c| \ll |\mu|, |m_{\text{gaugino}}|$, which is favoured with small κ. Also, in the limit of moderately small λ (~ 0.1) singlet like h, P get already decoupled from the doublet sector and one gets from Ref. [2], $m^2_h \sim m^2_{\widetilde{\chi}^0} + m_{\widetilde{\chi}^0} A_\kappa/2$ and $m^2_P \sim -3 m_{\widetilde{\chi}^0} A_\kappa/2$. In the small λ limit, $\nu^c \sim 1$ TeV is also apparent as μ ($\sim 3\lambda\nu^c$) $\gtrsim 100$ GeV from chargino searches. Thus, in the region of interest, that is $2m_\tau \lesssim |m_{\widetilde{\chi}^0}| \lesssim 20$ GeV, naively $10^{-3} \lesssim |\kappa| \lesssim 10^{-2}$, and from the constraint $2m_\tau \lesssim m_P \lesssim 2m_b$ one also obtains $0.4 \lesssim |A_\kappa| \lesssim 30$ GeV. Among other relevant parameters, small $\tan\beta$ seems useful to evade LEP constraints. The aforesaid discussion is an artifact of the non minimal nature of the $\mu\nu$SSM and thus could be related to well studied [19, 20] corners of the NMSSM parameter space with a similar spectrum. Being precise, a light P in the NMSSM is related to a solution of the little hierarchy problem by using of small A_κ [20]. Light $\widetilde{\chi}^0$ and h, on the other hand, are related to revival of an approximate Peccei-Quinn symmetry of NMSSM in the limit of vanishing κ [19, 20]. Although, spectrum of the $\mu\nu$SSM is grossly enriched with three singlet $\hat{\nu}^c_i$ and $\not{R}_p$, still presence of light h, P and $\widetilde{\chi}^0$ in the model is well motivated with non-minimal nature. This region of parameter space also contains a clear finger print of the $\mu\nu$SSM through detectable DVs for a very light $\widetilde{\chi}^0$.

In what follows, neutralino mass eigenstates are denoted by $\tilde{\chi}^0_{1,\ldots,10}$, where $\tilde{\chi}^0_i$, with $i = 1, 2, 3$, coincide with the three left-handed neutrinos. $\tilde{\chi}^0_4$ has been identified as the lightest neutralino, with leading right-handed neutrino composition at the limit of small κ. CP-even (CP-odd) scalar mass eigenstates are denoted by $h_{1,\ldots,8}(P_{1,\ldots,7})$. In the chosen benchmark, h_4 is basically decoupled from the right-handed sneutrinos $\tilde{\nu}^c_i$ and is the lightest doublet-like Higgs. Three lightest scalar h_i (pseudoscalar P_i) states are the ones composed mainly of $\tilde{\nu}^c_i$.

As in Ref. [2], we eliminate eight soft masses in favor of the corresponding VEVs. We chose $\nu^c_i = 780\,\text{GeV}$, $\tan\beta \approx \frac{v_u}{v_d} = 3.7$ and $v \approx \sqrt{v^2_u + v^2_d} \approx 174\,\text{GeV}$. We assume gaugino mass unification at the GUT scale, and consider $M_2 = 500\,\text{GeV}$ at the EW scale. We have fixed the following universal soft parameters at low energy: $m_{\tilde{e}^c} = m_{\tilde{u}^c} = m_{\tilde{d}^c} = m_{\tilde{Q}} = 1\,\text{TeV}$, $A_\lambda = 990\,\text{GeV}$, $A_\kappa = 5\,\text{GeV}$, $A_e = A_d = -A_\nu = 1\,\text{TeV}$ and $A_u = 2.4\,\text{TeV}$. Chosen values for $m_{\tilde{Q}}$ and A_u are crucial for a sizable loop corrections to reach $m_{h_4} \sim 125$ GeV with selected λ_i. At the limit of moderately small λ (and small κ), the value of A_λ is relevant for doublet-singlet mixing. We have checked that for the chosen values of the parameters, A_λ can be varied in the range $980 \lesssim A_\lambda \lesssim 1040$ GeV without changing the studied signal significantly. The remaining soft parameters can be arbitrarily changed without altering significantly the discussion presented here.

The values of the low-energy dimensionless free parameters that we assume are: $\lambda_i = 0.11$, $\kappa_{111} = -0.0073$, $\kappa_{222} = -0.0075$, $\kappa_{333} = -0.0077$, setting all other κ_{ijk} to zero. κ_{iii} are taken to be pseudo-degenerate for simplicity. With universal κ_{iii}, only one linear combination of the right-handed neutrinos mix in an efficient way with the MSSM neutralinos. Then, depending on the sign of κ, $\tilde{\chi}^0_4$ or $\tilde{\chi}^0_6$ will have a significant MSSM neutralino component. In our benchmark point where $m_{\tilde{\chi}^0_4} \approx 9.6\,\text{GeV}$, $m_{\tilde{\chi}^0_5} \approx 11.5\,\text{GeV}$, $m_{\tilde{\chi}^0_6} \approx 11.9\,\text{GeV}$, MSSM neutralino admixture is sizable ($\sim$2%) in $\tilde{\chi}^0_4$ and we get $Br(h_4 \to \tilde{\chi}^0_4\tilde{\chi}^0_4) \approx 6\%$. If $\kappa_{iii} > 0$ were selected instead, then h_4 would decay mainly to $\tilde{\chi}^0_6\tilde{\chi}^0_6$, followed by fast decays $\tilde{\chi}^0_6 \to \tilde{\chi}^0_{4,5}\,\mu^+\mu^-$, $\tilde{\chi}^0_5 \to \tilde{\chi}^0_4\,\mu^+\mu^-$. Since the produced muons are soft, they are difficult to trigger due to their very low transverse momentum, p_{T}. Thus we stick to $\kappa_{iii} < 0$, so that the relevant signal would be produced by the $h_4 \to \tilde{\chi}^0_4\tilde{\chi}^0_4$ decay. In the scalar sector relevant masses are: $m_{P_1} \approx 3.6\,\text{GeV}$, $m_{P_2} \approx 3.8\,\text{GeV}$, $m_{P_3} \approx 5.5\,\text{GeV}$, and $m_{h_1} \approx 7.5\,\text{GeV}$, $m_{h_2} \approx 8.0\,\text{GeV}$, $m_{h_3} \approx 19.6\,\text{GeV}$ with $m_{h_4} \approx 125.7\,\text{GeV}$. Consequently, $\tilde{\chi}^0_4$ decays to $P_i+\nu$ is favourable with larger available phase space. Although, two-body decays of $\tilde{\chi}^0_4$ are kinematically possible, we have nevertheless computed the three-body decays for greater accuracy. With chosen mass spectrum, $Br(\tilde{\chi}^0_4 \to \sum_{i=1}^3 \tilde{\chi}^0_i\tau^+\tau^-) \approx 99\%$, while remaining 1% is shared between $\tilde{\chi}^0_i\mu^+\mu^-$ and $\tilde{\chi}^0_i q_j\bar{q}_j$. Thus, the schematic h_4 decay chain studied is $h_4 \to \tilde{\chi}^0_4\tilde{\chi}^0_4 \to 2h^*_i/P^*_i 2\nu \to 2\tau^+2\tau^-2\nu$.

The matrix $Y_{\nu_{ij}}$ and the VEVs of the left-handed sneutrinos, ν_i, are connected to the reproduction of neutrino-physics. The processes $h_i/P_i \to \ell^+\ell^-$, on the other hand, are, to a very good approximation, independent of $Y_{\nu_{ij}}$ (and ν_i). Hence, multiplicity of the charged leptons in the process is practically independent of ν_i and $Y_{\nu_{ij}}$. As a corollary, a range for $Y_{\nu_{ij}}$ and ν_i predicting correct neutrino physics is well anticipated without drastic alteration in the event topology with displaced multilepton.

For the studied benchmark point neutrino-sector parameters have been chosen to result $m_{\tilde{\chi}^0_3} \sim 4.9 \times 10^{-11}\,\text{GeV}$, giving a decay width $\Gamma_{\tilde{\chi}^0_4} \approx 6.7 \times 10^{-16}\,\text{GeV}^{-1}$, which corresponds to a proper lifetime $\tau_{\tilde{\chi}^0_4} \approx 10^{-9}$ s. One can avail the underlying relation between neutrino physics and $\tilde{\chi}^0_4$ decay kinematics in the $\mu\nu$SSM through a common set of parameters Y_ν, κ, λ, ν^c, gaugino masses, etc. [11, 12], to obtain shorter $\tau_{\tilde{\chi}^0_4}$ through an increase in absolute neutrino mass scale. Another viable handle to modify $\tau_{\tilde{\chi}^0_4}$ is through a change in $\tilde{\chi}^0_4$ composition, namely by altering relative dominance of gaugino masses, right-handed neutrino Majorana mass, $2\kappa\nu^c$ and the μ-parameter, $3\lambda\nu^c$ [7, 11, 12]. We have checked that variations in the benchmark point do not induce significant changes in the lepton multiplicity, but do affect $\Gamma_{\tilde{\chi}^0_4}$, *i.e.* $\tau_{\tilde{\chi}^0_4}$, which remains in the experimentally accessible range of mm to m.

For numerical studies, `PYTHIA (6.4.09)` [21] has been used as the MC event generator with default parton distribution function at 8 TeV center-of-mass energy ($\sqrt{s}$). The renormalisation/factorisation scale is set equal to the parton-level $\sqrt{s}$. The initial and final state radiation and multiple interactions are kept switched on. The mass spectrum and decays are computed with a custom-developed code. For the SM-like h_4, $gg \to h_4$ cross section (6.51 pb) is rescaled by the reduced coupling [13], yielding a next-to-next leading order $gg \to h_4$ production cross-section of 19.3 pb [22]. `PYTHIA` outputs are passed through `PGS4` [23] to simulate the detector response. All resulting distributions have been rescaled to an expected integrated luminosity of $\mathcal{L} = 20$ fb^{-1} corresponding to the full 2012 dataset.

The $\mu\nu$SSM is characterised by the production of several high-p_{T} leptons, as demonstrated in Fig. 1 (top), where the e, μ and hadronically decaying τ (τ^{had}) multiplicity distributions are drawn for leptons with $p_{\mathrm{T}} > 10\,\text{GeV}$. e and μ, are produced through the leptonic τ decays, although μ pair can appear directly through h_i/P_i decay. With the chosen decay mode the τ multiplicity is considerable even though the τ-identification efficiency is much lower ($\sim$ 50%) when compared to that of e and μ ($\gtrsim$ 95%). Occasionally highly collimated QCD jets can fake τ^{had}'s and, as a result, τ multiplicity exceeds the expected number of 4. This faking, however disappears with a higher p_{T} cut.

The p_{T} distributions of the leading and of the 3rd leading lepton are shown in the bottom row of Fig. 1. It is evident that the leading lepton is energetic enough to trigger the event, should a single-lepton trigger is deployed. The rest of the leptons have sufficient p_{T} to be selected by a multilepton-based analysis, such as the ones developed by CMS [24] and ATLAS [25]. For instance, for the third leading e, μ, and τ^{had}, around 0.05, 10 and 43 events with $p_{\mathrm{T}} > 10\,\text{GeV}$ are expected, respectively. Clearly, multi-electron signature is least promising.

Such analyses, apart from the requirement of at least three or four leptons (including taus), require a high value of $E_{\mathrm{T}}^{\mathrm{miss}}$ or of the scalar sum of reconstructed objects: leptons, jets and/or $E_{\mathrm{T}}^{\mathrm{miss}}$. For the chosen signal many neutrinos ($\gtrsim 6$) appearing in the final state from $\tilde{\chi}^0_4$ and from τ decay give rise to moderately high missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, as depicted in Fig. 2 (left). Besides $E_{\mathrm{T}}^{\mathrm{miss}}$, the scalar sum of the p_{T} of all reconstructed leptons, H_{T}^{ℓ}, is also high in such events, as shown in Fig. 2 (right). Alternatively, the sum of $E_{\mathrm{T}}^{\mathrm{miss}}$ and H_{T}^{ℓ} can

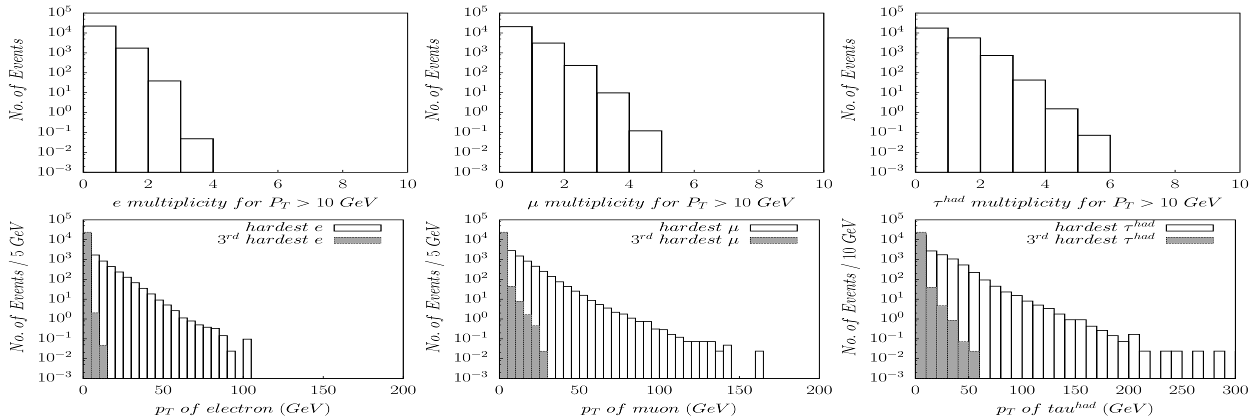

FIG. 1: Multiplicity (top row) for e (left), μ (middle) and hadronically decaying τ (right) with $p_{\rm T} > 10$ GeV. $p_{\rm T}$ distributions (bottom row) for the leading (white) and the 3$^{\rm rd}$ leading (light grey) e (left), μ (middle) and hadronically decaying τ (right). These plots correspond to $\sqrt{s} = 8$ TeV with $\mathcal{L} = 20$ fb^{-1}.

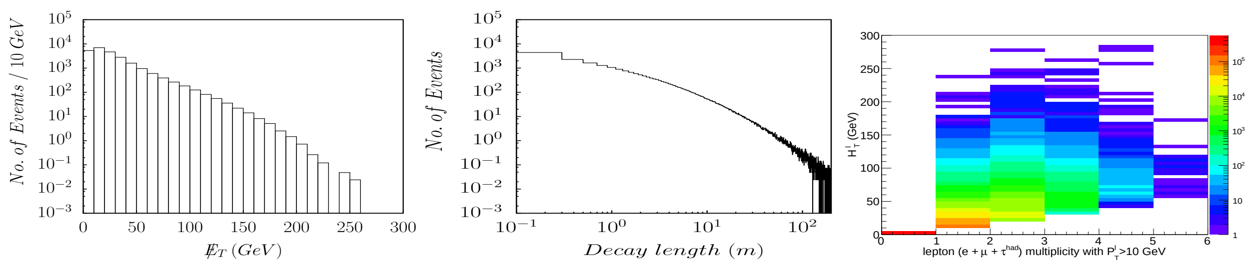

FIG. 2: $\not{E}_T$ distribution (left), $\tilde{\chi}^0_4$ decay-length distribution (middle) and $H^\ell_{\rm T}$ versus lepton multiplicity (right) for $\sqrt{s} = 8\,$TeV and $\mathcal{L} = 20\,$fb^{-1}.

be deployed for further background rejection. These observables can provide additional handles when selecting events with many leptons. Also the invariant masses, $m_{\ell^+\ell^-}$ and $m_{2\ell^+2\ell^-}$ are useful for the purpose of signal distinction.

A word of caution is due here. In the discussion on multilepton analyses so far, *prompt* leptons are selected after imposing an upper limit on the transverse and the longitudinal impact parameters, in order to reject cosmic-ray muons and insure good-quality track selection. Such a selection criterion should be relaxed or even reversed, if sensitivity to the $\mu\nu$SSM events is sought after. The reason stems from the long lifetime of the $\tilde{\chi}^0_4$ and hence the DV that its decay creates. This feature is quantified in the middle plot of Fig. 2, were the decay-length distribution is drawn. As expected from the proper decay length of $c\tau_{\tilde{\chi}^0_4} \approx 30$ cm, in a significant percentage of events, $\tilde{\chi}^0_4$ decays inside the tracker, *e.g.* 28% of events decay within 30 cm and 44% events within 1 m. Therefore, the $\mu\nu$SSM signal events will be characterised by displaced τ-leptons plus neutrinos. This distinctive signature opens up the possibility to exploit current or future variations of analyses carried out by ATLAS and CMS looking for a displaced muon and tracks [26] or searching for displaced dileptons [27] or muon jets [28] arising in Higgs decays to pairs of long-lived invisible particles.

The kinematics of the DVs and their products are demonstrated in Fig. 3. The $\tilde{\chi}^0_4$ boost, expressed by $\beta\gamma$, where β is $\tilde{\chi}^0_4$ velocity over c and γ the Lorentz factor, versus the pseudorapidity η is shown on the left. The shape reflects the fact that a single particle (h_4) is produced at the hard scattering of *pp* collisions, hence low momentum is expected in the central region. The average boost is comparable to the signal analysed in an ATLAS search for a muon and tracks originating from DVs [26]. The boost affects the efficiency with which such a DV can be reconstructed, since high $\tilde{\chi}^0_4$ boost leads to collimated tracks difficult to differentiate from primary vertices.

In the middle plot in Fig. 3, the spacial distribution of a DV is displayed in cylindrical coordinates. A large fraction of DVs falls in the inner-tracker volume of an LHC experiment, *i.e.* $\rho_{\rm DV} \lesssim 1$ m and $|z_{\rm DV}| \lesssim 2.5$ m, thus DVs arising in the $\mu\nu$SSM should be detectable at LHC, either with existing analyses [26–28] or via variations of those to search for displaced taus and $E_{\rm T}^{\rm miss}$.

In the right of Fig. 3, we show the correlation between the number of charged tracks in each DV, $N_{\rm trk}$, and their invariant mass, $m_{\rm DV}$. A selection of high-$N_{\rm trk}$ and high-$m_{\rm DV}$, has been demonstrated [26] to efficiently suppress background from long-lived SM particles (B-mesons, kaons). The modulation observed in $N_{\rm trk}$ is due to the one-prong or three-prong hadronic τ decays.

Summarizing, the $\mu\nu$SSM could be tested at the

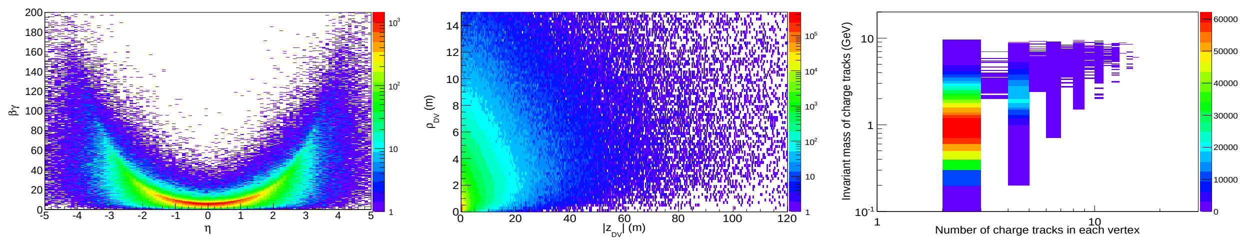

FIG. 3: $\beta\gamma$ versus η (left), $\rho_{\rm DV}$ versus $|z_{\rm DV}|$ (middle) and charged-track mass versus the number of charge particles in each vertex (right) for $\tilde{\chi}_4^0$ and for $\sqrt{s} = 8\,\text{TeV}$ and $\mathcal{L} = 20\,\text{fb}^{-1}$.

LHC through the production of a Higgs-like scalar with a mass about 125 GeV which decays into a pair of light long-lived neutralinos. Such events could be probed by ATLAS and CMS with the currently available 8 TeV data in two ways: either by looking for multilepton events produced in the SUSY cascade decay chain, when relaxing or even reversing the requirement for the leptons to come from the primary vertex, or by searching for tracks not-pointing back to the primary vertex, originating from a secondary vertex. In either case, a moderately high missing transverse energy due to multiple neutrinos is expected. In principle, other Higgs boson decay chains or other processes might have been addressed to test the $\mu\nu$SSM. However, we leave this necessary task for a future work [29].

PG thanks S. Biswas, K. Ghosh and C. B. Park for insightful discussions. The work of PG and CM was supported in part by the Spanish MINECO under grants FPA2009-08958 and FPA2012-34694, and under the 'Centro de Excelencia Severo Ochoa' Programme SEV-2012-0249, by the Comunidad de Madrid under grant HEPHACOS S2009/ESP-1473, and by the European Union under the Marie Curie-ITN program PITN-GA-2009-237920. The work of DL was supported by the Argentinian CONICET. The work of VM was supported by the Spanish MINECO under grant FPA2009-13234-C04-01 and by the Spanish AECID under PCI project A1/035250/11. The work of RR was supported by the Ramón y Cajal program of the Spanish MINECO and also thanks the support of the MINECO under grant FPA2011-29678. The authors also acknowledge the support of the MINECO's Consolider-Ingenio 2010 Programme under grant MultiDark CSD2009-00064.

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