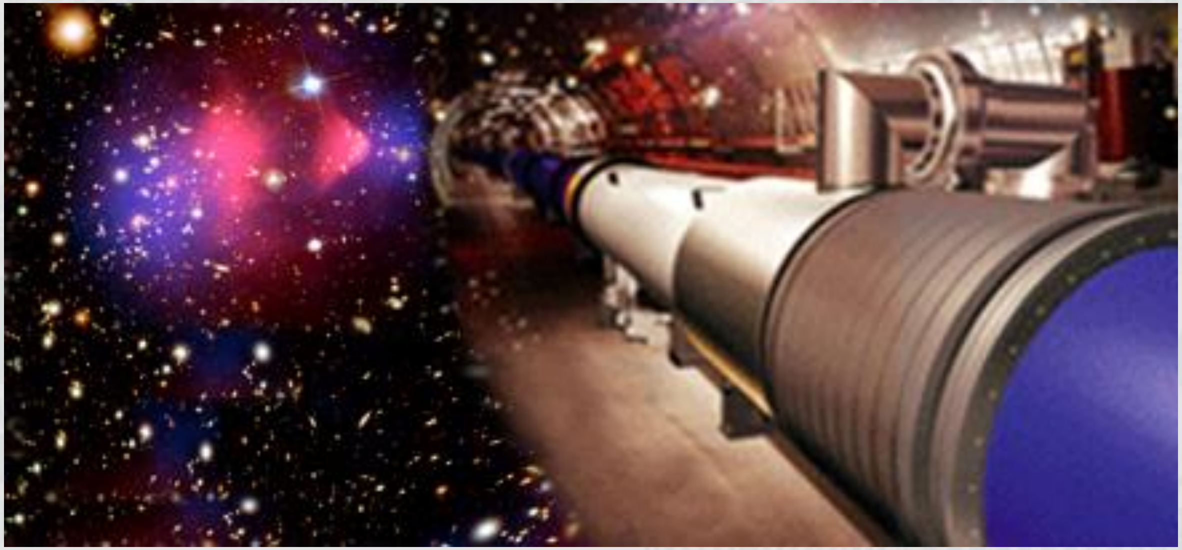
Hunting SUSY at the LHC and Dark Matter at the *Fermi* LAT with the μνSSM



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MultiDark
Multimessenger Approach for Dark Matter Detection

Fifth Workshop on Theory, Phenomenology and Experiments in Flavor Physics,
Capri, 23-25 May 2014

Why the $\mu\nu$SSM is an attractive SUSY scenario

Because simply including
right-handed neutrinos ***ν***, it solves the ***μ*** problem of the MSSM
(“***μ* from *ν*” Supersymmetric Standard Model - *μν*SSM**)
while simultaneously
explaining the origin of neutrino masses

Lopez-Fogliani, C. M. “Proposal for a supersymmetric standard model” PRL 97 (2006) 041801

μνSSM

In addition to the MSSM Yukawas for quarks and charged leptons, the $\mu\nu$SSM superpotential contains Yukawas for neutrinos, and two additional type of terms

$$W = \epsilon_{ab}\left(Y_u^{ij}\,\hat{H}_2^b\,\hat{Q}_i^a\,\hat{u}_j^c + Y_d^{ij}\,\hat{H}_1^a\,\hat{Q}_i^b\,\hat{d}_j^c + Y_e^{ij}\,\hat{H}_1^a\,\hat{L}_i^b\,\hat{e}_j^c + Y_\nu^{ij}\,\hat{H}_2^b\,\hat{L}_i^a\,\hat{\nu}_j^c\right) - \epsilon_{ab}\lambda^i\,\hat{\nu}_i^c\,\hat{H}_1^a\hat{H}_2^b + \frac{1}{3}\kappa^{ijk}\hat{\nu}_i^c\hat{\nu}_j^c\hat{\nu}_k^c\,,$$

Dirac neutrino masses

effective μ term generated by the VEVs of the **3** righ-handed sneutrinos

effective Majorana masses $M_M = \kappa_{ijk}\langle\tilde{\nu}_k^c\rangle$

with $\mu \equiv \lambda^i\langle\tilde{\nu}_i^c\rangle$.

No ad-hoc scales

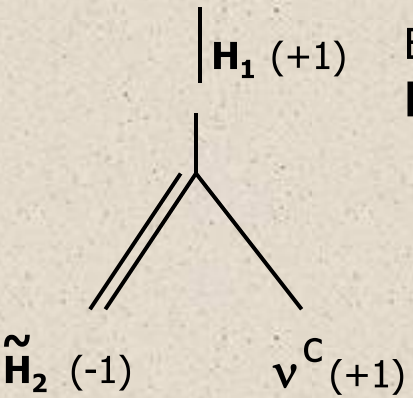
$m_\nu \sim m_D^2/M_M = (\mathbf{Y}_\nu\, H_2)^2/(k\,\nu_R) \sim (10^{-6}\,10^2)^2/10^3 = 10^{-11}$ GeV $= 10^{-2}$ eV

Like the electron Yukawa

Indeed we will also have the three heavy neutrinos with masses ~ EW

$$W = \epsilon_{ab}\left(Y_u^{ij}\,\hat{H}_2^b\,\hat{Q}_i^a\,\hat{u}_j^c + Y_d^{ij}\,\hat{H}_1^a\,\hat{Q}_i^b\,\hat{d}_j^c + Y_e^{ij}\,\hat{H}_1^a\,\hat{L}_i^b\,\hat{e}_j^c + Y_\nu^{ij}\,\hat{H}_2^b\,\hat{L}_i^a\,\hat{\nu}_j^c\right)$$

$$- \epsilon_{ab}\lambda^i\,\hat{\nu}_i^c\,\hat{H}_1^a\hat{H}_2^b + \frac{1}{3}\kappa^{ijk}\hat{\nu}_i^c\hat{\nu}_j^c\hat{\nu}_k^c\,,$$



Because of the simultaneous presence of these three terms in the μνSSM
R parity (+1 for particles and -1 for superpartners) **is explicitly broken**

i.e. SUSY particles do not appear in pairs

Size of the breaking:

is small because the EW seesaw implies $\mathbf{Y}_\nu \leq 10^{-6}$

Since R-parity is broken, the phenomenology of the μνSSM is going to be very different from the one of the MSSM/NMSSM

e.g., the <u>LSP is no longer stable</u> since it can decay
to two Standard Model particles

Once the electroweak symmetry is spontaneously broken, the neutral scalars develop in general the following VEVs:

$$\langle H_d^0 \rangle = v_d \,, \quad \langle H_u^0 \rangle = v_u \,, \quad \langle \widetilde{\nu}_i \rangle = \nu_i \,, \quad \langle \widetilde{\nu}_i^c \rangle = \nu_i^c \,. \qquad (2.7)$$

$v_d \sim$ EW, $v_u \sim$ EW, $\nu_i^c \sim$ EW

and one can define as usual:

$$H_u^0 = h_u + iP_u + v_u \,, \quad H_d^0 = h_d + iP_d + v_d,$$
$$\widetilde{\nu}_i^c = (\widetilde{\nu}_i^c)^R + i(\widetilde{\nu}_i^c)^I + \nu_i^c \,, \quad \widetilde{\nu}_i = (\widetilde{\nu}_i)^R + i(\widetilde{\nu}_i)^I + \nu_i \,.$$

8 minimization equations

$$0 = \frac{1}{4}G^2\left(\nu_i\nu_i + v_d^2 - v_u^2\right)v_d + m_{H_d}^2 v_d - a_{\lambda_i} v_u \nu_i^c + \lambda_i\lambda_j v_d \nu_i^c \nu_j^c$$
$$+ \lambda_i\lambda_i v_d v_u^2 - \lambda_j \kappa_{ijk} v_u \nu_i^c \nu_k^c - Y_{\nu_{ij}}\lambda_k \nu_i \nu_k^c \nu_j^c - Y_{\nu_{ij}}\lambda_j v_u^2 \nu_i \,,$$

$$0 = -\frac{1}{4}G^2\left(\nu_i\nu_i + v_d^2 - v_u^2\right)v_u + m_{H_u}^2 v_u + a_{\nu_{ij}}\nu_i\nu_j^c - a_{\lambda_i}\nu_i^c v_d$$
$$+ \lambda_i\lambda_j v_u \nu_i^c \nu_j^c + \lambda_j\lambda_j v_d^2 v_u - \lambda_j\kappa_{ijk} v_d \nu_i^c \nu_k^c + Y_{\nu_{ij}}\kappa_{ljk}\nu_i \nu_l^c \nu_k^c$$
$$- 2\lambda_j Y_{\nu_{ij}} v_d v_u \nu_i + Y_{\nu_{ij}} Y_{\nu_{ik}} v_u \nu_k^c \nu_j^c + Y_{\nu_{ij}} Y_{\nu_{kj}} v_u \nu_i \nu_k \,,$$

$$0 = m_{\widetilde{\nu}_{ij}^c}^2 \nu_j^c + a_{\nu_{ji}}\nu_j v_u - a_{\lambda_i} v_u v_d + a_{\kappa_{ijk}}\nu_j^c\nu_k^c + \lambda_i\lambda_j v_u^2 \nu_j^c + \lambda_i\lambda_j v_d^2 \nu_j^c$$
$$- 2\lambda_j\kappa_{ijk} v_d v_u \nu_k^c + 2\kappa_{lim}\kappa_{ljk}\nu_m^c \nu_j^c \nu_k^c - Y_{\nu_{ji}}\lambda_k \nu_j \nu_k^c v_d - Y_{\nu_{kj}}\lambda_i v_d \nu_k \nu_j^c$$
$$+ 2Y_{\nu_{jk}}\kappa_{ikl} v_u \nu_j \nu_l^c + Y_{\nu_{ji}} Y_{\nu_{lk}} \nu_j \nu_l \nu_k^c + Y_{\nu_{ki}} Y_{\nu_{kj}} v_u^2 \nu_j^c \,,$$

$$0 = \frac{1}{4}G^2(\nu_j\nu_j + v_d^2 - v_u^2)\nu_i + m_{\widetilde{L}_{ij}}^2 \nu_j + a_{\nu_{ij}} v_u \nu_j^c - Y_{\nu_{ij}}\lambda_k v_d \nu_j^c \nu_k^c$$
$$- Y_{\nu_{ij}}\lambda_j v_u^2 v_d + Y_{\nu_{il}}\kappa_{ljk} v_u \nu_j^c \nu_k^c + Y_{\nu_{ij}} Y_{\nu_{lk}} \nu_l \nu_j^c \nu_k^c + Y_{\nu_{ik}} Y_{\nu_{jk}} v_u^2 \nu_j \,.$$

Notice that in the last equation $\nu \to 0$ as $Y_\nu \to 0$, and since the coupling Y_ν **$Y_\nu \leq 10^{-6}$**, ν has to be very small. Using this rough argument we can also get an estimate of the value, $\nu \lesssim m_{\Gamma} \sim 10^{-4}$ GeV

Mass matrices in the $\mu\nu$SSM

e.g.:

"Neutralinos"

$$\chi^{0T} = (\tilde{B}^0, \tilde{W}^0, \tilde{H}_d, \tilde{H}_u, \nu_{R_i}, \nu_{L_i}),$$

Lightest neutralino ← $\tilde{\chi}^0_4$, $\tilde{\chi}^0_{5,6,7,8,9,10}$, $\tilde{\chi}^0_{1,2,3}$ mass eigenstates

"Neutral Higgses"

$$\mathbf{S}'_\alpha = (h_d, h_u, (\widetilde{\nu}^c_i)^R, (\widetilde{\nu}_i)^R)$$

$h_{4,5} \equiv h, H$, $h_{1,2,3}$, $h_{6,7,8}$

$$\mathbf{P}'_\alpha = \left(P_d, P_u, (\widetilde{\nu}^c_i)^I, (\widetilde{\nu}_i)^I\right)$$

$P_4 \equiv A$, $P_{1,2,3}$, $P_{5,6,7}$

Discovery of new physics at the LHC with the μνSSM

Bartl, Hirsch, Vicente, Liebler, Porod, JHEP 05 (2009) 120

Bandyopadhyay, Ghosh, Roy, PRD 84 (2011) 115022

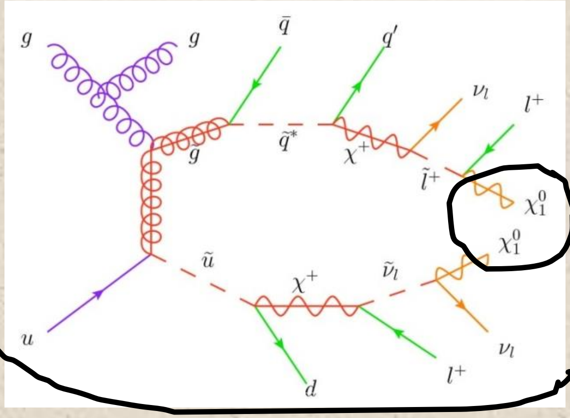
Fidalgo, Lopez-Fogliani, C.M., Ruiz de Austri, JHEP 10 (2011) 020

Lieber, Porod, NPB 855 (2012) 774

Ghosh, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, PRD 88 (2013) 015009

Ghosh, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, arXiv:1403.3675

After 3 years of LHC running, direct searches of SUSY based mainly on the existence of missing transverse momentum in the final state have failed to find a signal that exceeds the SM background



Time for experimentalists to look for RPV SUSY in more detail ?

The presence of RPV makes the collider phenomenology more complicated, because of the various choices for the "Lightest Supersymmetric Particle (LSP)" as well as the presence of new R-parity violating couplings

e.g.

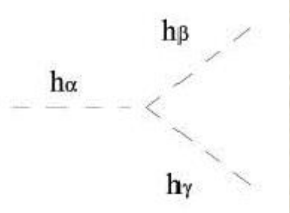
Not only neutralinos, but also sleptons, squarks, …, since all of them decay

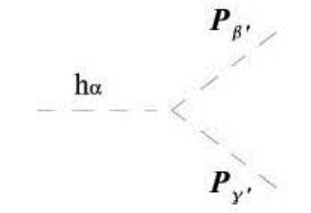
Higgs decays in the $\mu\nu$SSM (I)

Higgs-to-Higgs cascade decays can be more complicated since more Higgses are present compared to the NMSSM

$\mu\nu$SSM: 8 CP-even , 7 CP-odd

NMSSM: 3 CP-even , 2 CP-odd





Let us assume that we have enough energy to generate only one CP-even Higgs at a collider, i.e., only one Higgs, h_1, has mass below the threshold energy. Then the following decay is possible:

$$h_1 \to 2 \text{ Standard Model fermions} . \qquad (3.12)$$

In case that the second lightest Higgs, h_2, can be generated, the following cascade decay is possible if kinematically allowed:

$$h_2 \to 2h_1 \to 4 \text{ Standard Model fermions} . \qquad (3.13)$$

If the third lightest Higgs, h_3, can be generated, then if kinematically allowed we have the possibility

$$h_3 \to 2h_2 \to 4h_1 \to 8 \text{ Standard Model fermions} . \qquad (3.14)$$

The situation turns out to be more complicated if we take into account the decays to scalars that are not the ones immediately below in mass. Also we have the possibility of having light pseudoscalars entering in the game. In the $\mu\nu$SSM we have three/two (six/five including left-handed sneutrinos) pseudoscalars more than in the MSSM/NMSSM case, and they could be very light. Thus we may need to include the following decays (if kinematically allowed) into the cascades:

$$h_\alpha \to h_\beta h_\gamma , \qquad h_\alpha \to P_{\beta'} P_{\gamma'} , \qquad P_{\alpha'} \to P_{\beta'} h_\gamma , \qquad (3.15)$$

THESE ARE PROMPT DECAYS

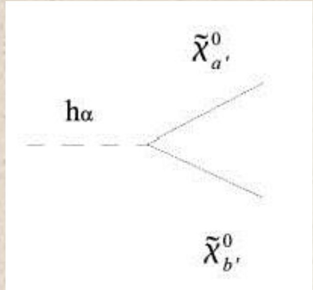
8 b-jets, **multijets**!
Unfortunately, it is difficult to disentangle this signal from the background

Working with a MSSM-like CP even Higgs, $h_{\rm MSSM}$, it will decay into $b\bar{b}$ or through the cascades typical of the NMSSM, $h_{MSSM} \to 2P \to 2b2\bar{b}$, in most of the cases. Nevertheless we will see that the following cascade is also possible: $h_{MSSM} \to 2h \to 4P \to 4b4\bar{b}$. In benchmark point 8 we will see that h_{MSSM} can decay with the following relevant cascades: $h_{MSSM} \to 2h_1 \to 4P_{1,2} \to 4\tau^+4\tau^-$, $h_{MSSM} \to 2P_3 \to 2b2\bar{b}$, because for the singlet-like pseudoscalars $P_{1,2}$ the decay into $b\bar{b}$ is kinematically forbidden, whereas for P_3 it is allowed. These cascades are genuine of the $\mu\nu$SSM.

Fidalgo, Lopez-Fogliani, C.M., Ruiz de Austri, JHEP 10 (2011) 020

Higgs decays in the μνSSM (II)

h_{MSSM} might have a sizeable branching ratio to two light neutralinos



Since R parity is broken, neutralinos may decay with a length large enough to show

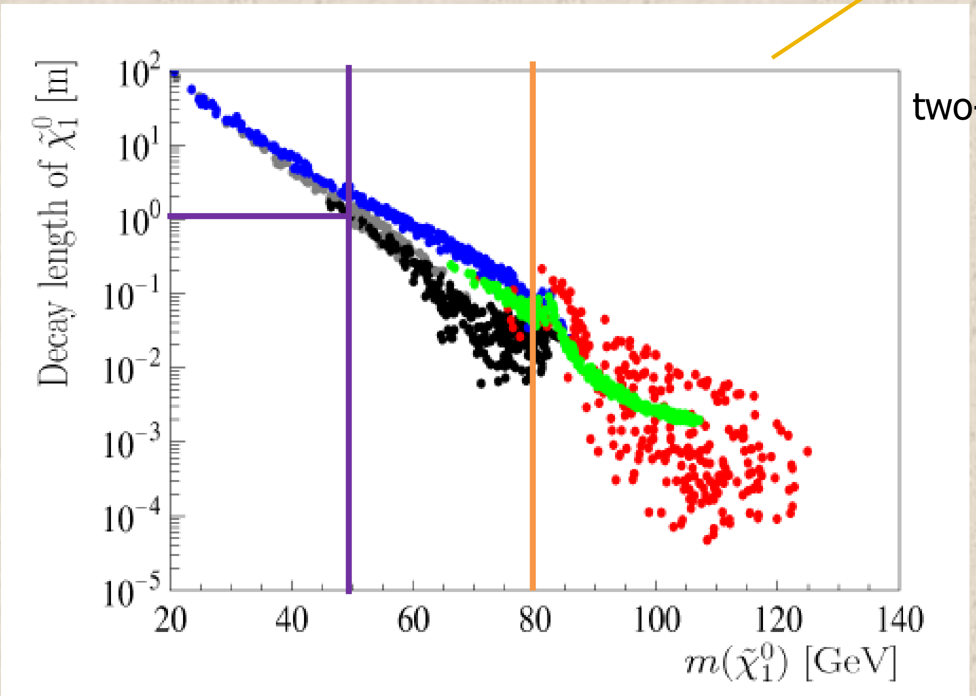
DISPLACED VERTICES

because RPV is small given the value of $Y_\nu \leq 10^{-6}$

kinematically forbidden

two-body decays, e.g.:

three-body decays, e.g.:



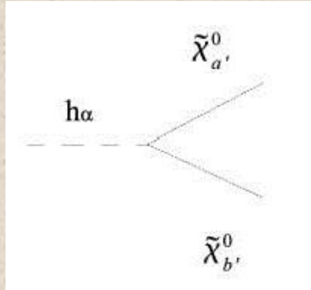
Bartl, Hirsch, Vicente, Liebler, Porod, JHEP 05 (2009) 120

The decay lenght is basically determined by the mass of the neutralino LSP and the neutrino masses

For 50 GeV decay lengths > 1 m, implying that a large fraction of ‘s will decay outside detectors

Higgs decays in the μνSSM (III)

But if one allows for lighter scalars, the decay length can be easily reduced since neutralinos can decay into a Higgs and a neutrino inside the detector



due to the mixing of the MSSM neutralinos and neutrinos

$$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2b2\bar{b}2\nu$$

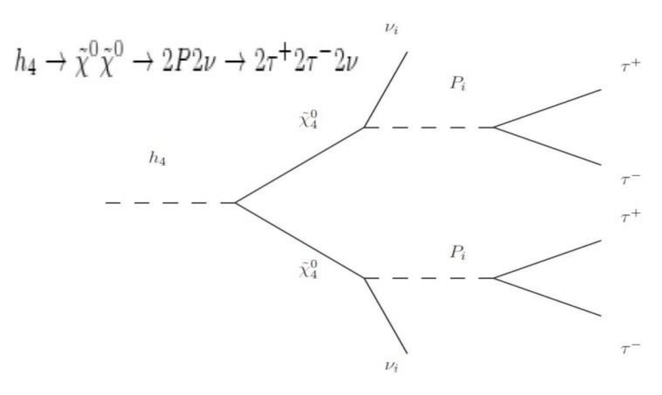
λ	κ_{111}	κ_{222}	κ_{333}	A_κ (GeV)	M_2 (GeV)
1.0×10^{-1}	3.1×10^{-2}	3.0×10^{-2}	2.9×10^{-2}	-1.0	-1.7×10^3
$\tan\beta$	A_λ (GeV)	ν_1 (GeV)	$\nu_{2,3}$(GeV)	Y_{ν_1}	$Y_{\nu_{2,3}}$
3.7	1.0×10^3	3.04×10^{-5}	1.18×10^{-4}	5.10×10^{-8}	2.95×10^{-7}
ν^c (GeV)	m_{h_1} (GeV)	m_{h_2} (GeV)	m_{h_3} (GeV)	m_{h_4} (GeV)	m_{P_1} (GeV)
8.0×10^2	46.0	47.9	49.5	116.6	14.6
m_{P_2} (GeV)	m_{P_3} (GeV)	$m_{\tilde{\chi}^0_4}$ (GeV)	$m_{\tilde{\chi}^0_5}$ (GeV)	$m_{\tilde{\chi}^0_6}$ (GeV)	—
14.8	16.6	46.7	48.4	50.3	—
$BR(h_4 \to \sum_{i,j=4}^{6} \tilde{\chi}^0_i \tilde{\chi}^0_j)$	$BR(\tilde{\chi}^0_4 \to \sum_{i=1}^{3} P_i \nu)$	$BR(P_{1,2,3} \to b\bar{b})$	$l_{\tilde{\chi}^0_4 \to}$ (cm)	—	—
0.005	1.0	0.93	12	—	—

Table 3: Relevant input parameters, masses and branching ratios of benchmark point 3.

Bartl, Hirsch, Vicente, Liebler, Porod, JHEP 05 (2009) 120

Fidalgo, Lopez-Fogliani, C.M., Ruiz de Austri, JHEP 10 (2011) 020

If the decay of the pseudoscalars into two b's is kinematically forbidden ($2m_\tau < m_P < 2m_b$): **multileptons**!



Benchmark point	Cascade	$\sigma(gg \to h_4) \times BR_{\text{cascade}}$ (fb)
1	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2b2\bar{b}2\nu$	270
	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2h2\nu \to 4P2\nu \to 4b4\bar{b}2\nu$	44
2	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2\tau^+ 2\tau^- 2\nu$	1620
3	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2b2\bar{b}2\nu$	70
4	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2b2\bar{b}2\nu$	5860
5	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P2\nu \to 2b2\bar{b}2\nu$	4870
6	$h_1 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2l2q2\bar{q}$	150
	$h_1 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2\nu 2l2\bar{l}$	80
	$h_1 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2\nu 2q2\bar{q}$	40
	$h_1 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 6\nu$	15
7	$h_4 \to 2P \to 2b2\bar{b}$	5450
	$h_4 \to 2h_1 \to 4P \to 4b4\bar{b}$	460
8	$h_4 \to 2P_3 \to 2b2\bar{b}$	1660
	$h_4 \to h_1 h_1 \to 4P_{1,2} \to 4\tau^+ 4\tau^-$	460
	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P_{1,2} 2\nu \to 2\tau^+ 2\tau^- 2\nu$	80
	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2h2\nu \to 4P_{1,2} 2\nu \to 4\tau^+ 4\tau^- 2\nu$	150
	$h_4 \to \tilde{\chi}^0_4 \tilde{\chi}^0_4 \to 2P_3 2\nu \to 2b2\bar{b}2\nu$	20

Table 9: Production cross section multiplied by branching ratios of the cascades, for the benchmark

Events with three or more prompt leptons are rarely produced by SM processes in pp collisions, because leptons are rarely produced at a pp collider

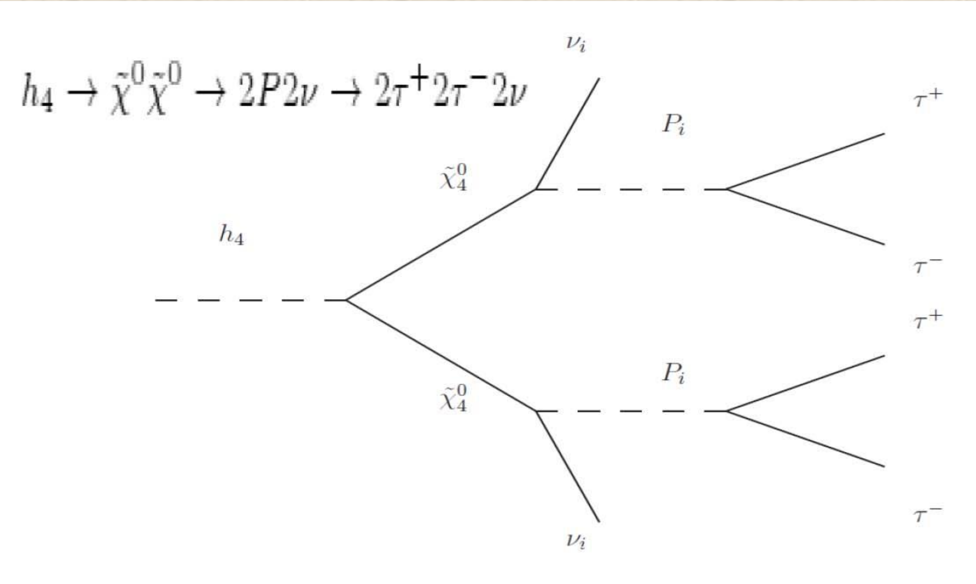
(SM background can be originated from the production of ZZ to 4leptons or $W^{+-}Z$ to 3 leptons,…)

It is therefore possible that physics processes beyond the SM at the LHC may first be observed in multilepton final states

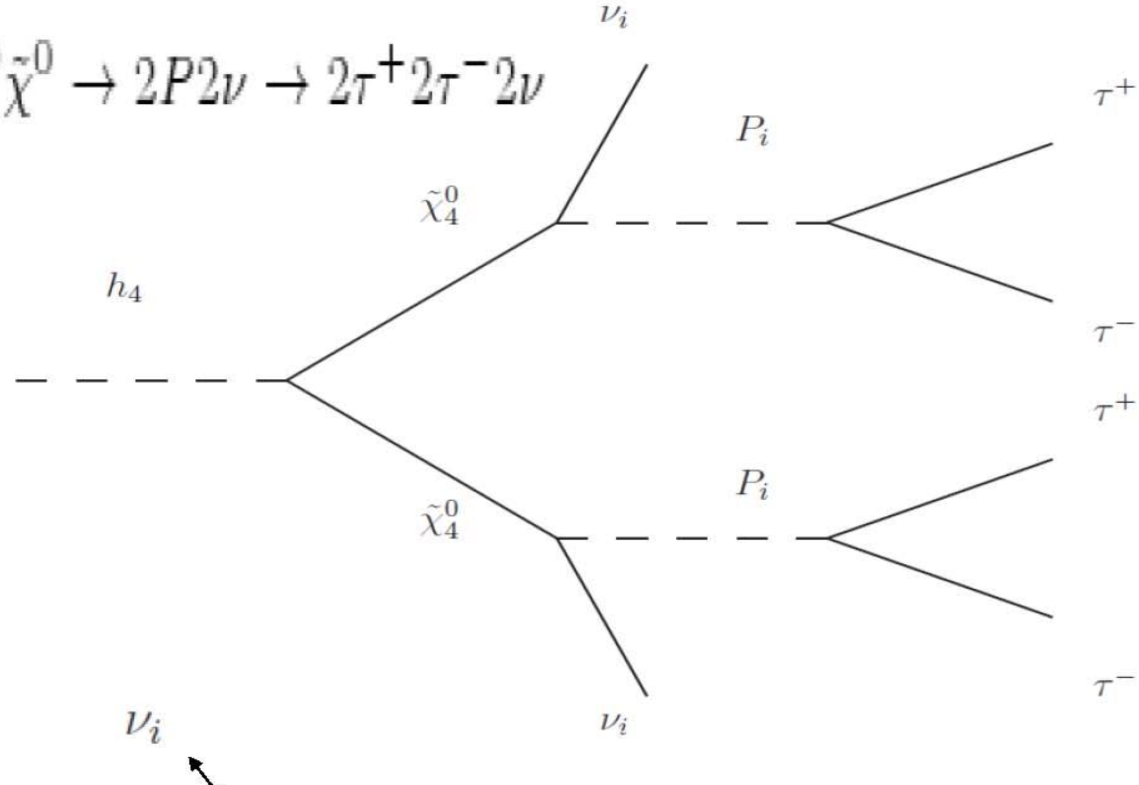
Strategy: Search for anomalous production of multilepton events based on data collected with the CMS and ATLAS experiments at the LHC

Actually, the previous signal provides an unmistakable signature of the **μνSSM**

Ghosh, Lopez-Fogliani, Mittsou, C.M., Ruiz de Austri, PRD 88 (2013) 015009



$h_4 \to \tilde{\chi}^0 \tilde{\chi}^0 \to 2P2\nu \to 2\tau^+ 2\tau^- 2\nu$



$$Br(\tilde{\chi}_4^0 \to \sum_{i=1}^{3} \tilde{\chi}_i^0 \tau^+ \tau^-) \approx 99\% \qquad Br(h_4 \to \tilde{\chi}_4^0 \tilde{\chi}_4^0) \approx 6\%$$

$$m_{\tilde{\chi}_4^0} \approx 9.6\,\mathrm{GeV} \qquad m_{P_1} \approx 3.6\,\mathrm{GeV},\ m_{P_2} \approx 3.8\,\mathrm{GeV} \quad m_{P_3} \approx 5.5\,\mathrm{GeV}$$

$$\tau_{\tilde{\chi}_4^0} \approx 10^{-9}\ \mathrm{s.} \qquad c\tau_{\tilde{\chi}_4^0} \approx 30\ \mathrm{cm},$$

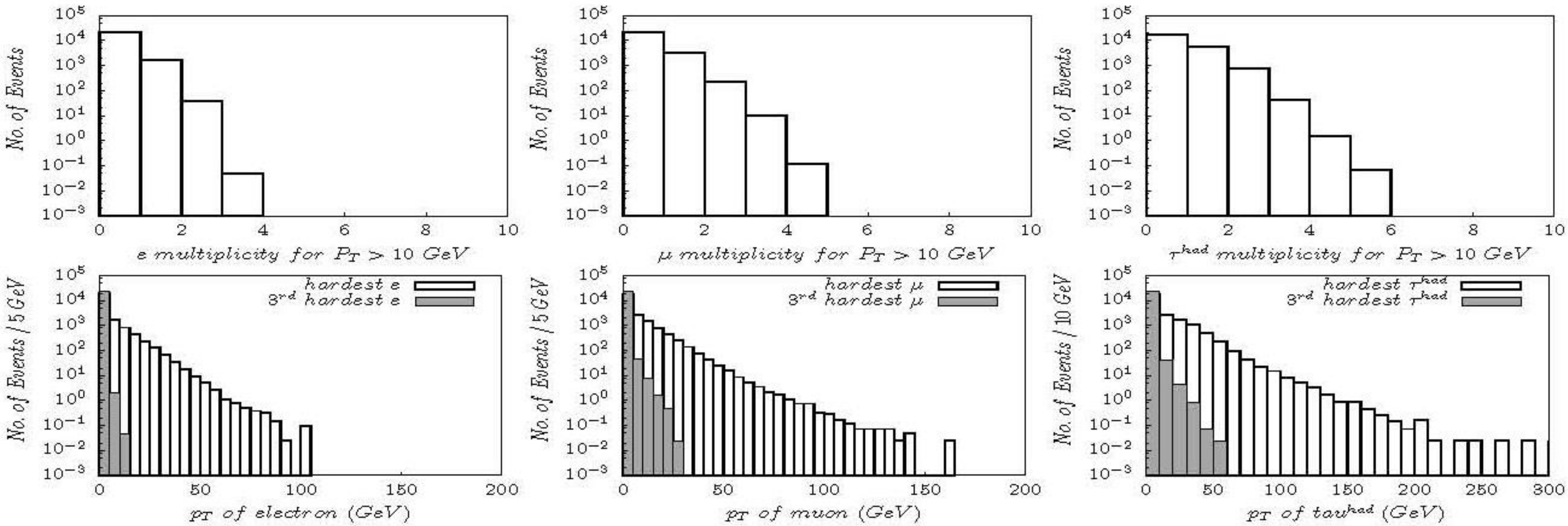


FIG. 1: Multiplicity (top row) for e (left), μ (middle) and hadronically decaying τ (right) with $p_T > 10$ GeV. p_T distributions (bottom row) for the leading (white) and the 3rd leading (light grey) e (left), μ (middle) and hadronically decaying τ (right). These plots correspond to $\sqrt{s} = 8$ TeV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

But other Higgs boson decay chains or many other processes might have been addressed to test the **μνSSM**

We leave this necessary task for future works

In models with R-parity violation the **LSP** is no longer stable

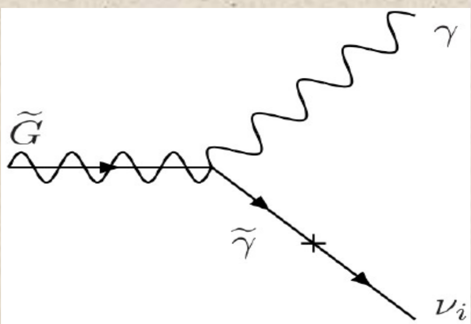
Thus the neutralino or the right-handed sneutrino
cannot be used as SUSY candidates for dark matter

• Gravitino as a DM candidate in models where R-parity is broken

Takayama, Yamaguchi, 2000

The gravitino LSP also decays through
the interaction gravitino-photon-photino (λ):

$$L_{int} = -\frac{i}{8M_{pl}}\bar{\psi}_\mu[\gamma^\nu,\gamma^\rho]\gamma^\mu\lambda F_{\nu\rho},$$



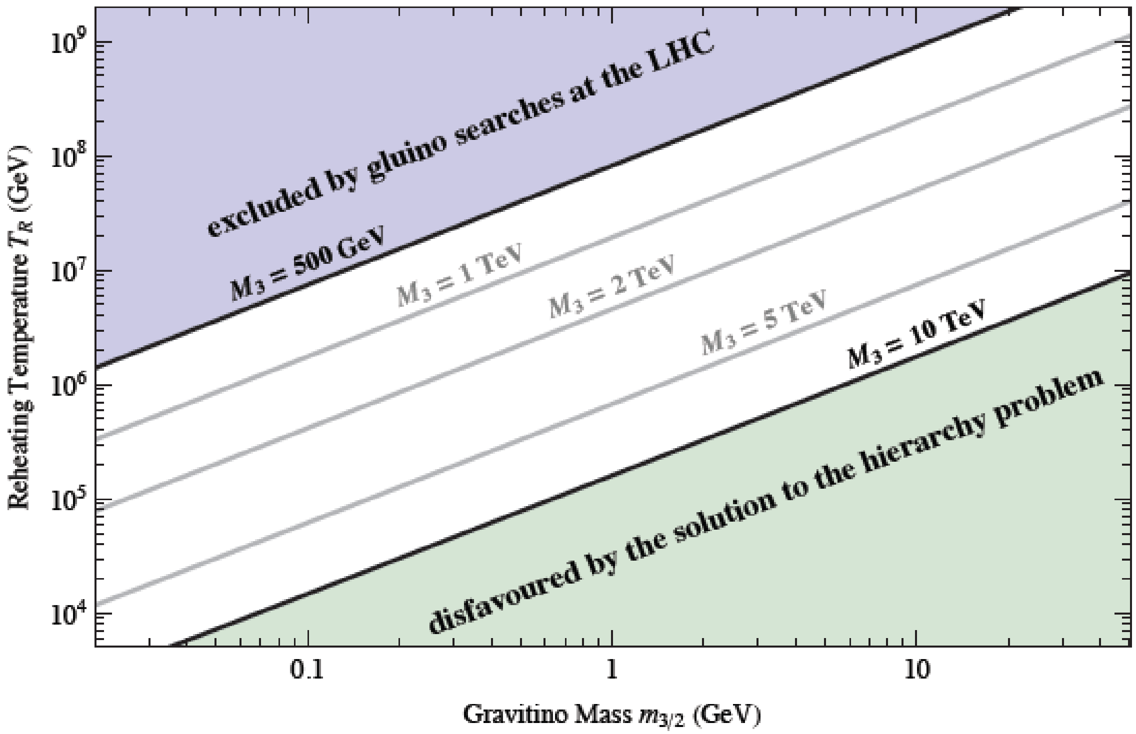
due to the photino-neutrino mixing
after sneutrinos develop VEVs ,
opening the channel

$$\Gamma(\psi_{3/2}\to\gamma\nu) = \frac{1}{32\pi}|U_{\tilde{\gamma}\nu}|^2\frac{m_{3/2}^3}{{M_{\rm P}}^2}\ .$$

Nevertheless, it is supressed both by the Planck mass and the small R-parity breaking, thus the lifetime of the gravitino can be longer than the age of the Universe (~10^{17} s)

$$\tau_{3/2} = \Gamma^{-1}(\tilde{G}\to\gamma\nu) \simeq 8.3\times 10^{26}\,\mathrm{sec}\times\left(\frac{m_{3/2}}{1\mathrm{GeV}}\right)^{-3}\left(\frac{|U_{\gamma\nu}|^2}{7\times 10^{-13}}\right)^{-1}.$$

gravitino relic density



If the gravitino is thermally produced its relic density can match the observed dark matter density tuning the reheating temperature after inflation.

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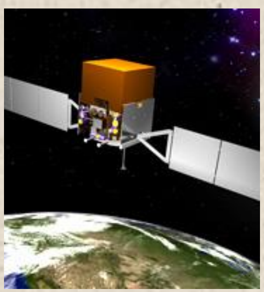
Detection of gravitino DM

- Decays of **gravitinos** in the galactic halo, at a sufficiently high rate, would produce gamma rays that could be detectable in future experiments



An experiment such as the ***Fermi* Large Area Telescope (LAT)**, might in principle detect this flux of gamma rays

Buchmuller, Covi, Hamaguchi, Ibarra, Yanagida, 07
Bertone, Buchmuller, Covi, Ibarra, 07
Ibarra, Tran, 08
Ishiwata, Matsumoto, Moroi, 08

$$\left[E^2 \frac{dJ}{dE}\right]_{\text{halo}} = \frac{2E^2}{m_{3/2}} \frac{dN_\gamma}{dE} \frac{1}{8\pi\tau_{3/2}} \int_{\text{los}} \rho_{\text{halo}}(\vec{l})d\vec{l}\,,$$

Since the gravitino decays into a photon and a neutrino, the former produces a monochromatic line at energies equal to $\mathbf{m_{3/2}/2}$

μνSSM gravitino dark matter

Choi, López-Fogliani, C.M., R. Ruiz de Austri,
"Gamma-ray detection from gravitino dark matter decay in the μνSSM", JCAP 03 (2010) 028

Gómez-Vargas, Fornasa, Zandanel, Cuesta, C.M., Prada, Yepes,
"CLUES on Fermi-LAT prospects for the extragalactic detection of μνSSM gravitino dark amtter",
JCAP 02 (2012) 001

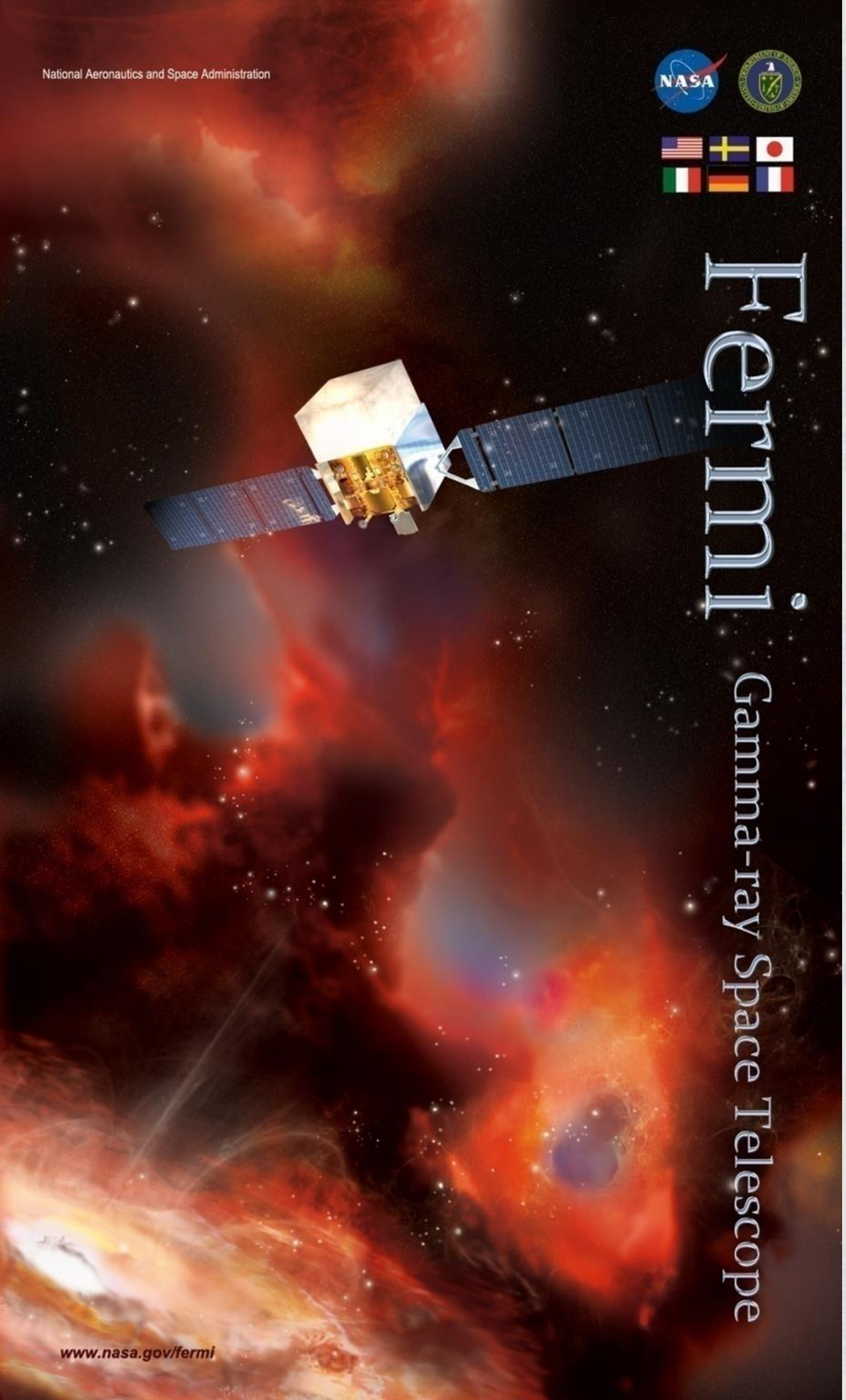
Neutrino content of the photino.

$$\tau_{3/2} \simeq 3.8 \times 10^{27}\,\mathrm{s} \left(\frac{|U_{\tilde{\gamma}\nu}|^2}{10^{-16}} \right)^{-1} \left(\frac{m_{3/2}}{10\,\mathrm{GeV}} \right)^{-3} .$$

In the $\mu\nu$SSM in order to reproduce neutrino data:

$$10^{-15} \lesssim |U_{\tilde{\gamma}\nu}|^2 \lesssim 5 \times 10^{-14} .$$

As a consequence, values of the gravitino mass larger than about **10 GeV** are disfavoured by *Fermi* LAT data



Fermi
Gamma-ray Space Telescope

MultiDark
Multimessenger Approach for Dark Matter Detection

Motivated by this result, together with Fermi LAT collaborators we perform the following search:

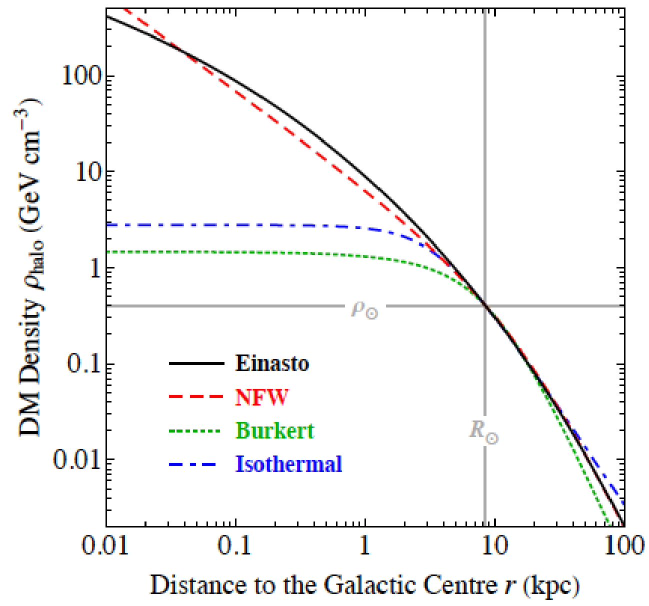
Search for 100 MeV to 10 GeV γ-ray lines in the *Fermi*-LAT data and implications for gravitino dark matter in the μνSSM

Category II Paper on Low Energy Line Search

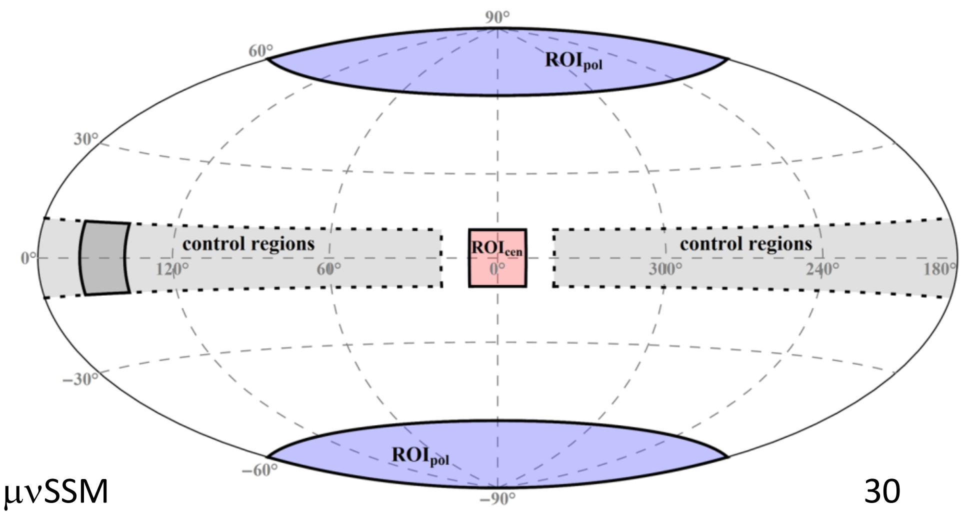
- Purpose:
- To perform a spectral search for γ-ray lines from 100 MeV to 10 GeV with the *Fermi*-LAT data
- This constrains models of gravitino decay. In particular, we focus on the μνSSM model
- People:
- -*Fermi*-LAT Collaboration: A. Albert (SLAC), E. Bloom (SLAC), E. Charles (SLAC), G. A. Gómez-Vargas (PUC-Santiago & INFN-Roma2), N. Mazziotta (INFN Bari) A. Morselli (INFN-Roma2)
- External: C. M. (UAM & IFT Madrid), M. Grefe (Hamburg), C. Weniger (GRAPPA Amsterdam)
- Data:
- 5.2 years of Pass 7 Reprocessed data
- Fit for lines from 100 MeV to 10 GeV
- Status:
- Approved by the internal referee. Sent to Fermi Publication Board. To be sent to JCAP when approved

Region of Interest (RoI) optimization

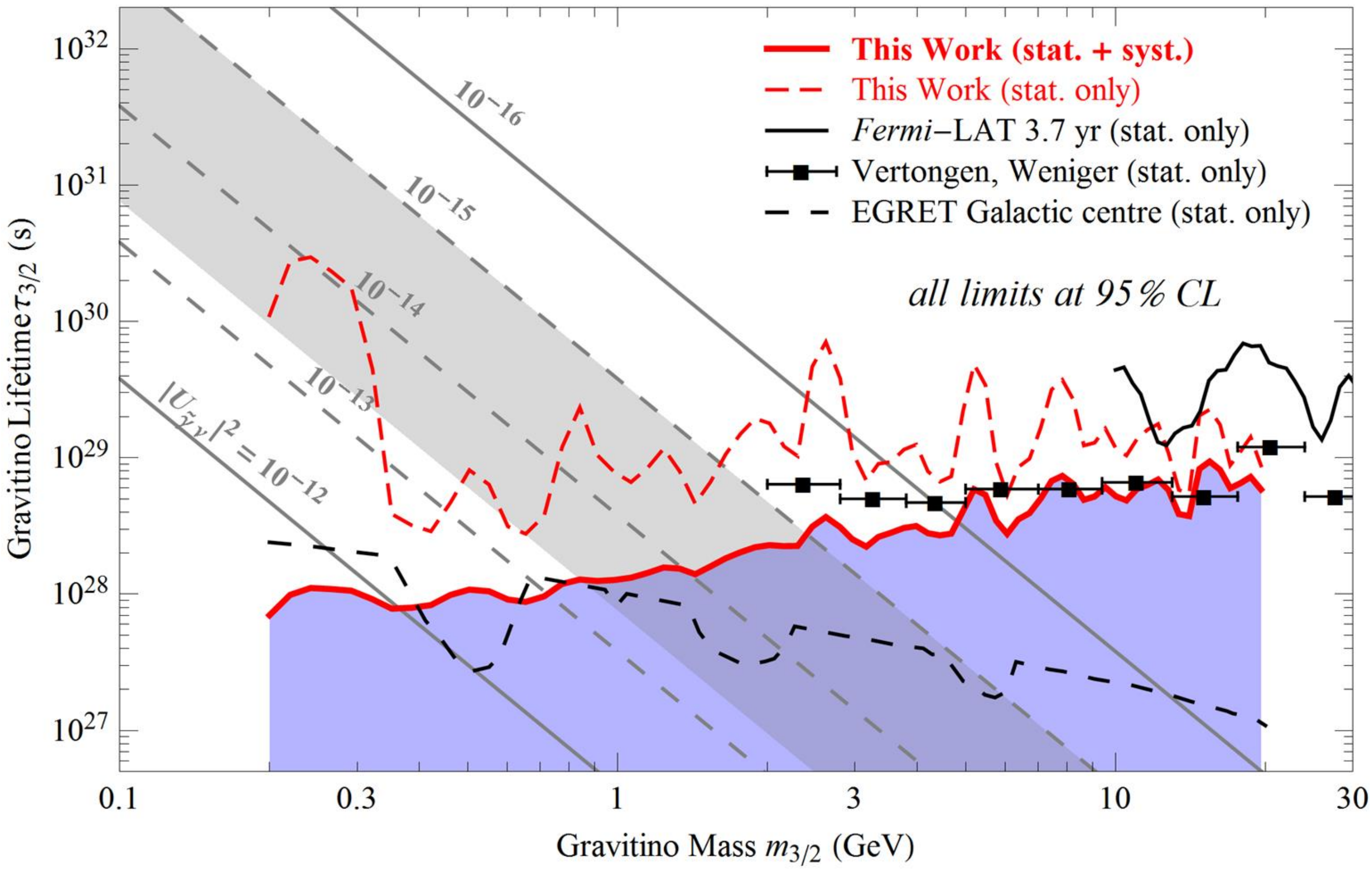
- Use Einasto profile as baseline, but present Jfactors for other profiles and the upper limit flux.



- Optimize **signal-to-background ratio** for decay ($\Psi_{3/2} \rightarrow \nu\gamma$)



Preliminary Limits for ROI_{pol} |b|>60º



The diagonal band shows the allowed parameter space for gravitino DM in the μνSSM.
The blue shaded region is excluded by limits derived in this work

μνSSM gravitinos with masses larger than about 5 GeV
or lifetimes smaller than about 10^{28} s are excluded as DM candidates

Conclusions

Solving the μ problem with **neutrinos** gives rise to a new SUSY model:

a "μ from ν" Supersymmetric Standard Model ($\mu\nu$SSM) $\hat{\nu}^c_i \, \hat{H}_1 \, \hat{H}_2$

Only one scale in the model: the soft SUSY-breaking scale ~ TeV

$\hat{\nu}^c_i \hat{\nu}^c_j \hat{\nu}^c_k$ A electroweak seesaw is generated dynamically (no Majorana masses have to be introduced by hand)

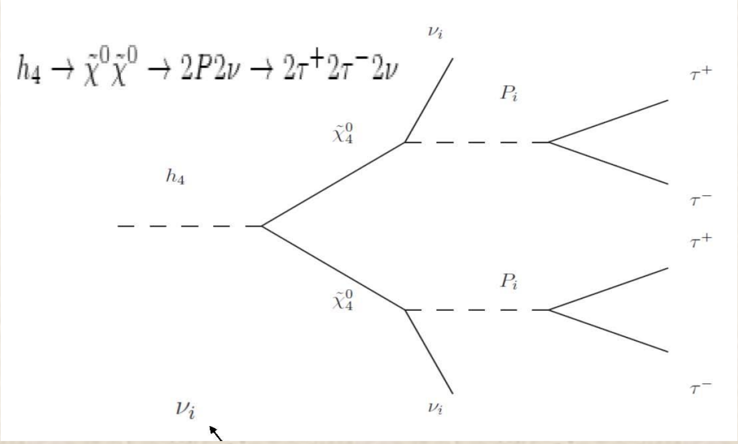
The phenomenology of this model is very rich, e.g.:

* More Higgses than in other models are present and therefore Higgs-to-Higgs cascade decays can be very interesting to search for new physics at the LHC

* The neutralino-LSP may decay within the detectors but with a length large enough to show a displaced vertex

* Multilepton events can be produced in the SUSY cascade decay chains

e.g.:



But other Higgs boson decay chains or many other SUSY processes can be addressed to test the **μνSSM**

Gravitino is an interesting dark matter candidate in the μνSSM

Fermi LAT data allow to constrain already the parameter space of the model

μνSSM gravitinos with masses larger than about 5 GeV or lifetimes smaller than about 10^{28} s are excluded as dark matter candidates

THE END