- in collaboration with O. Panella (INFN,Perugia)
- PRD 79, 056001 (2009) and work in progress...

SUSY LFV from the Higgs sector at a Photon Collider and LHC

(and the Dark Matter connection)

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Outline

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SUSY SEE-SAW MECHANISM

- The superpotential W contains three $SU(2)_L$ singlet neutrino superfields N_i

$$W = (Y_\nu)_{ij}\varepsilon_{\alpha\beta}H_2^\alpha N_i L_j^\beta + \frac{1}{2}(M_R)_i N_i N_i.$$

- RGE evolution from the GUT scale down to M_R induce *off-diagonal* matrix elements in charged sleptons mass matrix $(m^2_{\tilde{L}})_{ij}$. [Borzumati,Masiero, Hisano]

$$(m^2_{\tilde{L}})_{ij} \simeq -\frac{1}{8\pi^2}(3+a_0^2)m_0^2(Y_\nu^\dagger Y_\nu)_{ij}\ln\left(\frac{M_{GUT}}{M_R}\right).$$

- gauge-mediated LFV effects arise in the the gaugino-slepton-lepton vertex after diagonalization of the mass matrices.

HIGGS LFV LOOP INDUCED COUPLINGS

- LFV Yukawa coupling of the type $\bar{L}^i_R L^j_L H^*_u$ are induced at loop level: sizable at large tan β [Babu, Kolda,Brignole,Rossi].
- In the mass-eigenstate basis for both leptons and Higgs bosons, the effective LFV interactions are described by the lagrangian:

$$-\mathcal{L} \simeq (2G_F^2)^{\frac{1}{4}} \frac{m_{l_i}}{\cos^2\beta} \left(\Delta_L^{ij} \bar{l}_R^i l_L^j + \Delta_R^{ij} \bar{l}_L^i l_R^j\right) \left(\cos(\beta-\alpha)h^0 - \sin(\beta-\alpha)H^0 - iA^0\right)$$

- Δ^{ij} terms are induced at one loop level by the exchange of gauginos and sleptons. In the mass insertion (MI) approximation [Paradisi]:

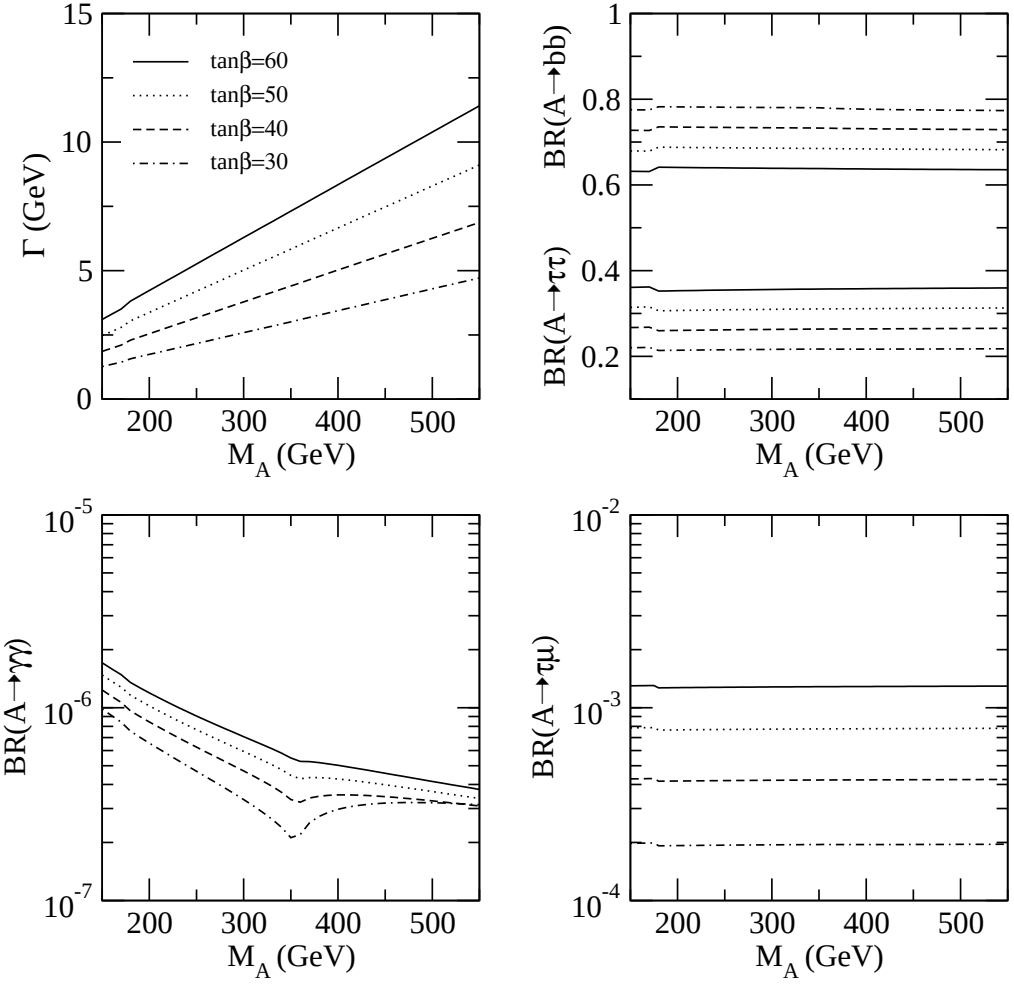
$$\Delta_L^{ij} \propto -\frac{g'^2}{16\pi^2}\delta_{LL}^{ij}\left[f_L^{loop}(\mu, M_1, M_2, M_R, M_L)\right] \qquad \delta_{LL}^{ij} = \frac{(m_R^2)^{ij}}{m_L^2}$$

$$\Delta_R^{ij} \propto \frac{g'^2}{16\pi^2}\delta_{RR}^{ij}\left[f_R^{loop}(\mu, M_1, M_2, M_R, M_L)\right] \qquad \delta_{RR}^{ij} = \frac{(m_R^2)^{ij}}{m_R^2}$$

Outline

HEAVY NEUTRAL HIGGS LFV DECAYS

$M_{SUSY} = M_{1,2,3} = 1$ TeV, $\mu = 2$ TeV, $\Delta^2 = |\Delta_L^{32}|^2 + |\Delta_R^{32}|^2 = 10^{-6}$.

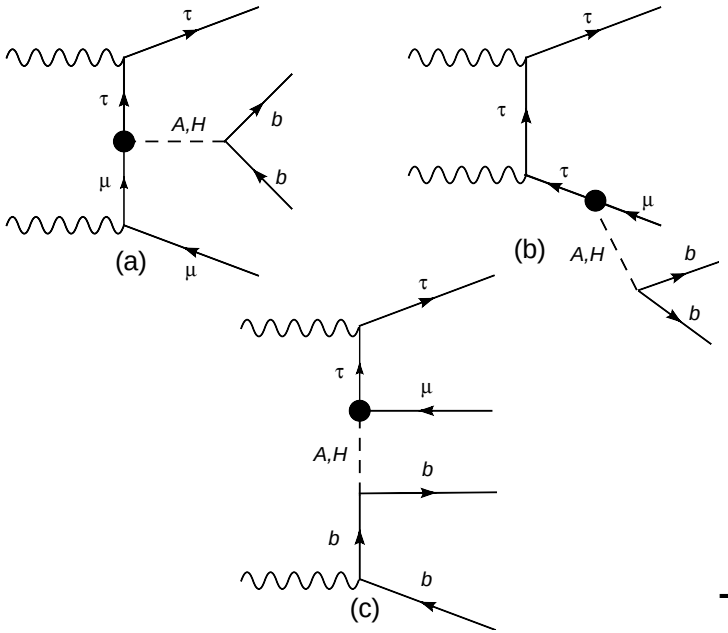


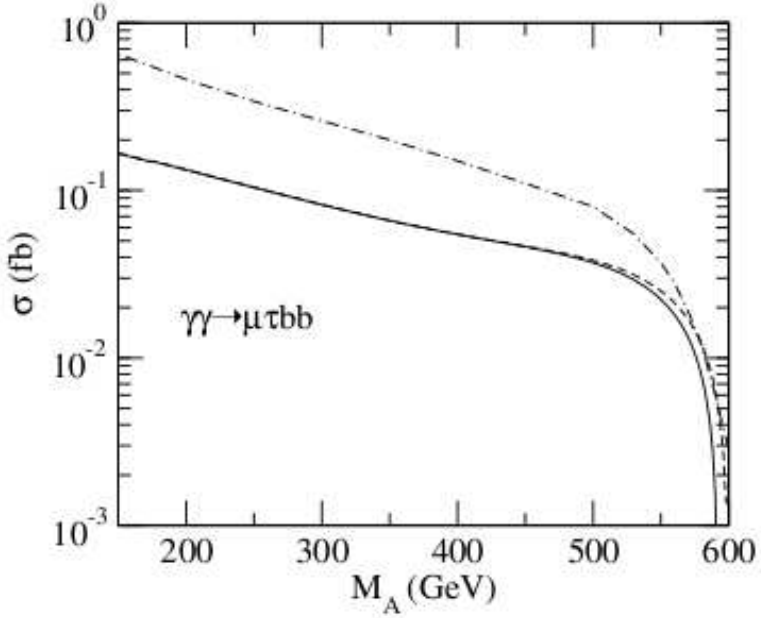
- $\Gamma(A \to \tau^+\tau^-) = \frac{1}{8\pi}\frac{m_\tau^2}{v^2} M_A t_\beta^2$
- $\Gamma(A \to \tau^+\mu^-) = \frac{1}{8\pi}\frac{m_\tau^2}{v^2} M_A t_\beta^4 \frac{\Delta^2}{2}$
- $\mathcal{B}(A \to \mu\tau) = t_\beta^2 \Delta^2 \mathcal{B}(A \to \tau^+\tau^-)$

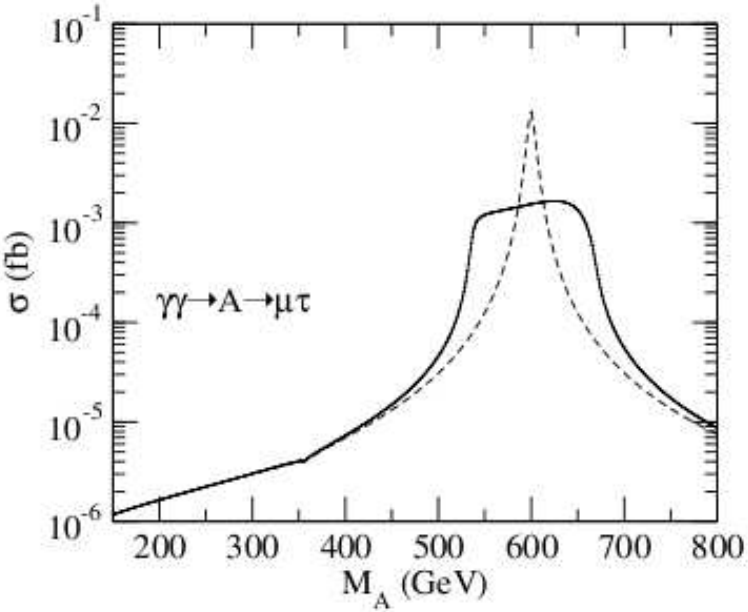
i) $\Gamma_{tot} \approx$ few GeV, $\lesssim$ the expected resolution of the $b\bar{b}$ invariant mass

ii) $\Gamma_{tot} \approx \Gamma(A \to b\bar{b}) + \Gamma(A \to \tau\tau)$ while $A \to \gamma\gamma$ is suppressed;

$\gamma\gamma$ COLLISIONS AT ILC







TESLA(800):

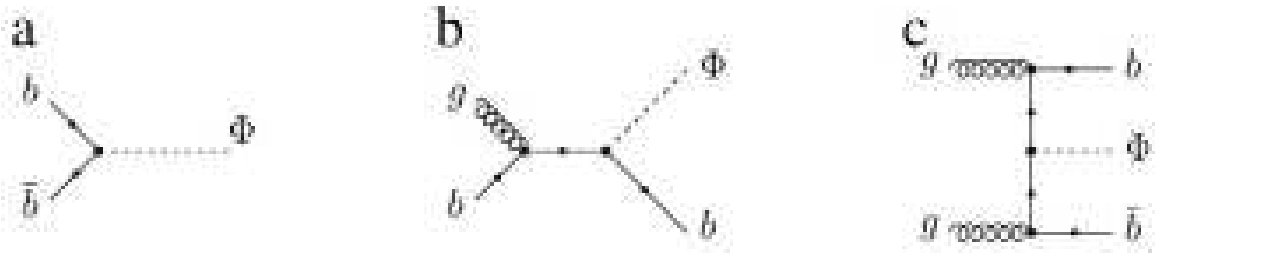
$\sqrt{s_{ee}} = 800\ \text{GeV} \rightarrow \sqrt{s_{\gamma\gamma}} = 600\ \text{GeV}$

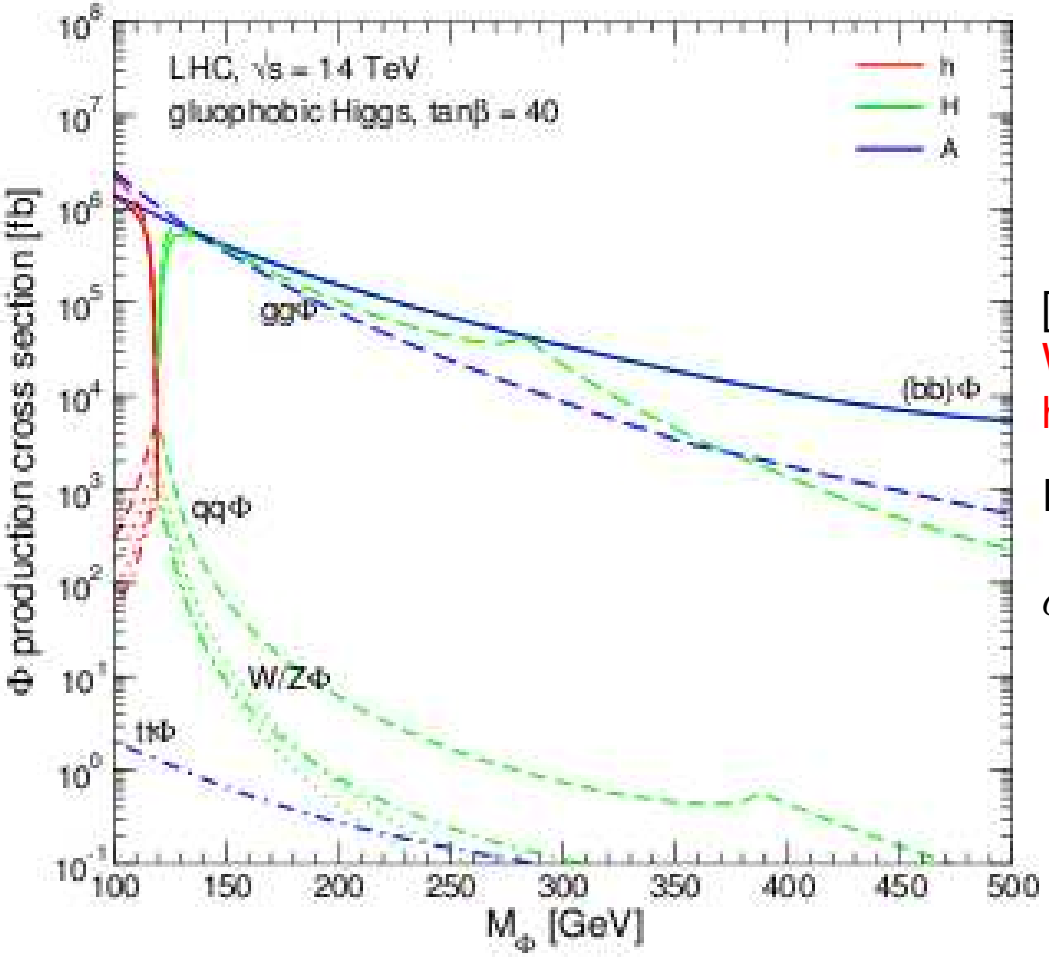
$$\sigma = \int P_{\gamma/\mu}(x) P_{\gamma/\tau}(y) \frac{4\pi s_{\mu\tau}}{M_A^2} \frac{\Gamma(A\rightarrow\tau\mu)\Gamma(A\rightarrow b\bar{b})}{(S_{\mu\tau}-M_A^2)^2+(\Gamma_A M_A)^2}$$

$$P_{\gamma\ell}(x) = \frac{\alpha}{2\pi}[x^2+(1-x)^2]\log\left(\frac{\mu_F^2}{m_\ell^2}\right)$$

$$\sigma = 8\pi \frac{\Gamma(A\rightarrow\gamma\gamma)\Gamma(A\rightarrow\tau\mu)}{(S_{\gamma\gamma}-M_A^2)^2+(\Gamma_A M_A)^2}(1+\lambda_1\lambda_2)$$

PP COLLISIONS AT LHC





[Hahn,Heinemeyer,Maltoni, Weiglin,Willenbrock, hep-ph/0607308]

Implemented in FeynHiggs

$$\sigma^{MSSM} = \sigma^{SM}(bb \to \Phi) \times \frac{\Gamma(\Phi \to b\bar{b})^{MSSM}}{\Gamma(\Phi \to b\bar{b})^{SM}}$$

Outline

SUSY PARAMETERS SPACE AND CONSTRAINTS

MSSM parameters:

- 500 GeV<μ<5 TeV
- 150 GeV<m_1, m_2<2.5 TeV
  1 TeV<m_3<5 TeV
- 100 GeV<m_A<1 TeV
- 20<tan β<60
- 1 TeV<$m_{\tilde{q}}$<5 TeV
- 300 GeV<$m_{\tilde{\ell}}$<1.5 TeV
- -2< $\frac{A_q}{m_{\tilde{q}}}, \frac{A_l}{m_{\tilde{l}}}$< 2

- $\delta^{32}_{LL,RR} = 0.5$

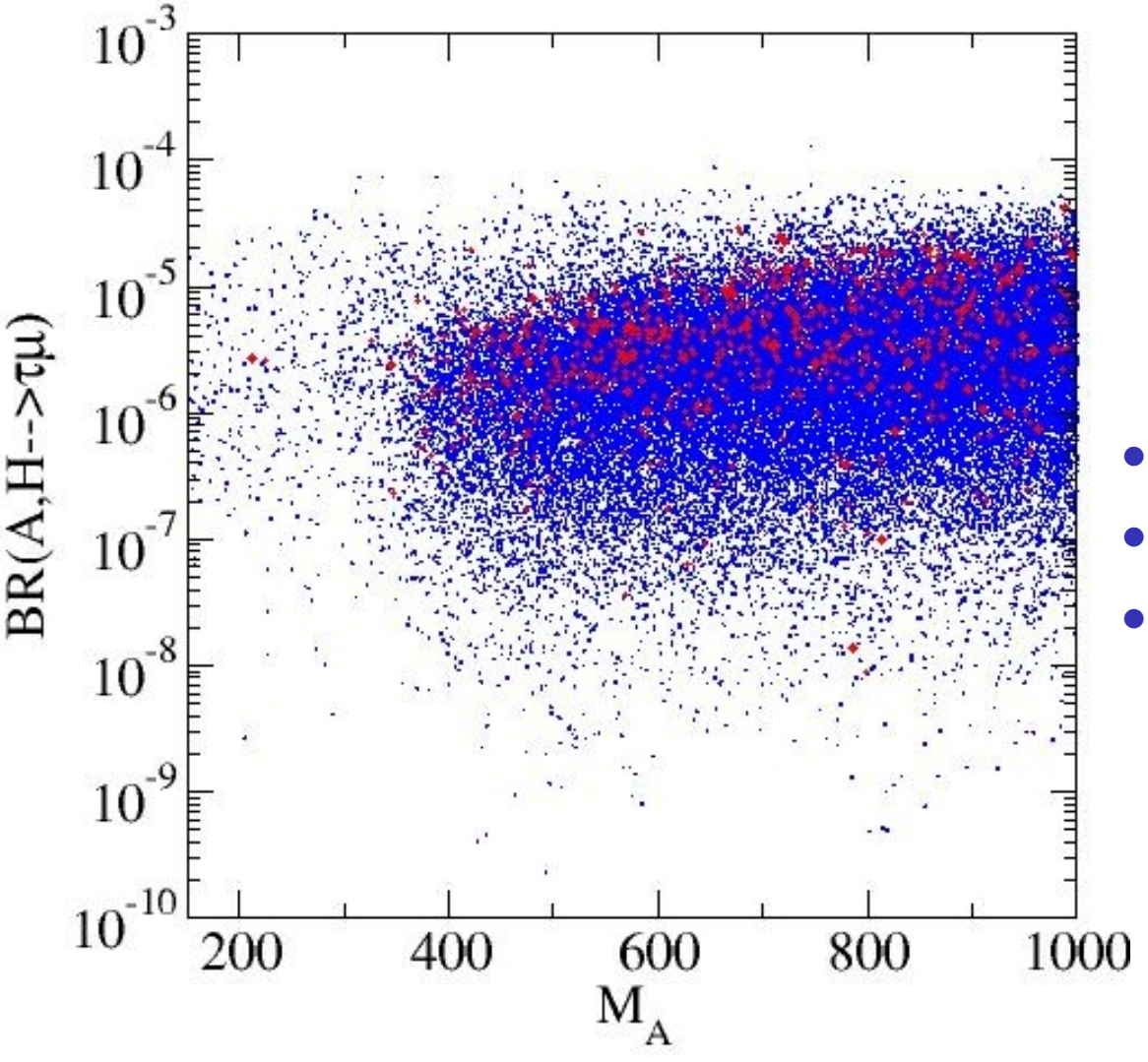
Constraints:

- LEP, TEVATRON bounds on sparticle masses
- LEP bound on light Higgs: $m_h > 114.4$ GeV
- B physics observables:
  - $0.995 < R(b \to s\gamma) < 1.24$
  - $BR(B \to \mu^+\mu^-) < 4.7 \times 10^{-8}$
  - $0.85 < R(B^{\pm} \to \tau\nu) < 1.24$
- LFV τ decays
  - $B(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$
  - $B(\tau \to \mu\eta) < 5 \times 10^{-8}$
  - $B(\tau \to \mu\mu\mu) < 3.2 \times 10^{-8}$
- Muon anomalous magnetic moment:
  $a_\mu^{MSSM} = (g-2)^{MSSM}/2 < 4 \times 10^{-9}$
- WMAP on relic density:
  $0.09 < \Omega h^2 < 0.13$

TOOLS

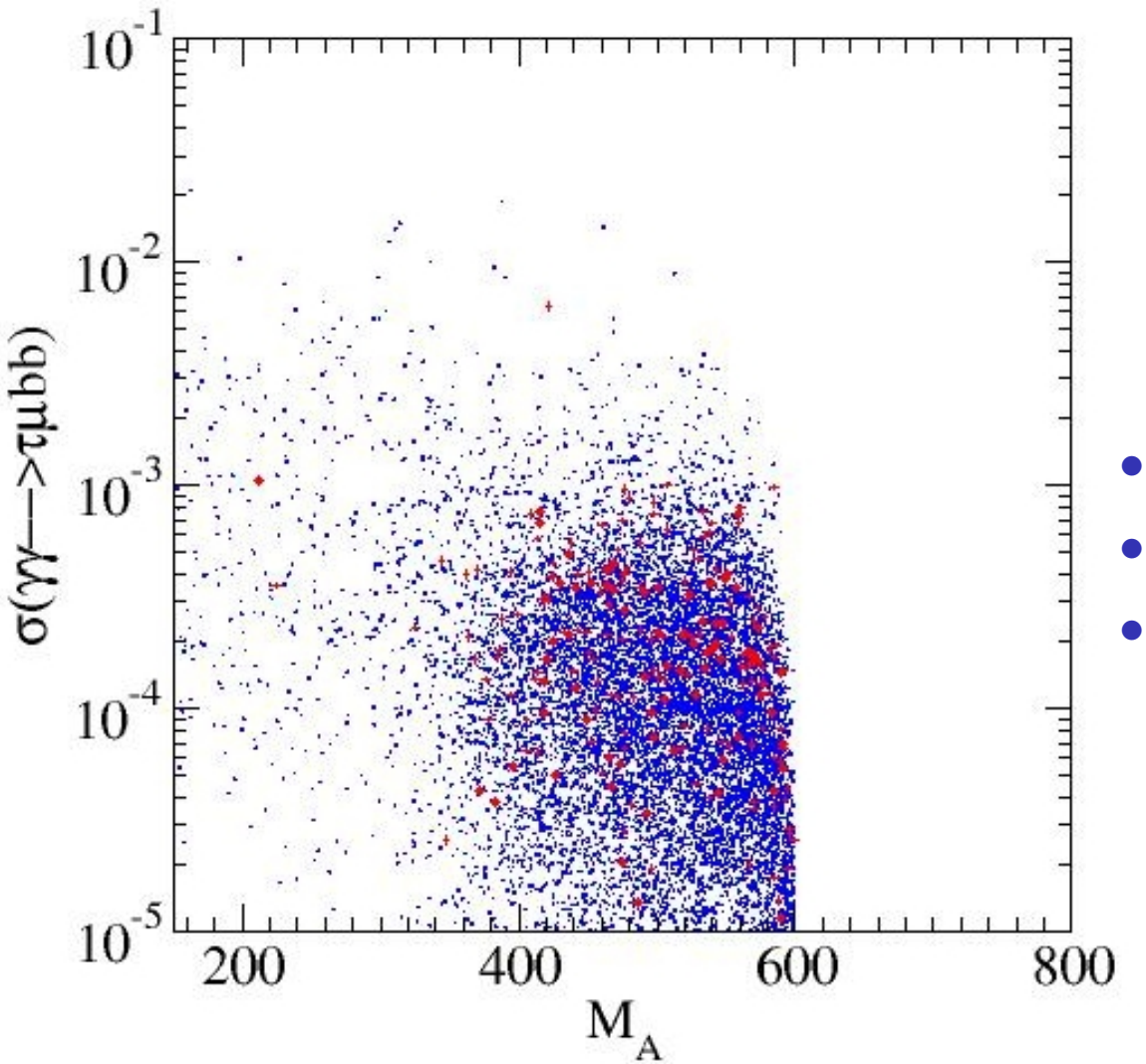
- DarkSusy[Gondolo,Edsjo,Ullio,Bringmann,Baltz,Schelke,Duda]
  - Accelerator bounds
  - $b \longrightarrow s\gamma$
  - relic density
  - direct and indirect dark matter detection
- FeynHiggs[Heinemeyer,Hollik,Rzehak,Weiglin]
  - Susy and Higgs mass spectrum
  - Higss width and branching ratios
  - MSSM muon g-2
  - Higgs production cross sections

LFV DECAYS



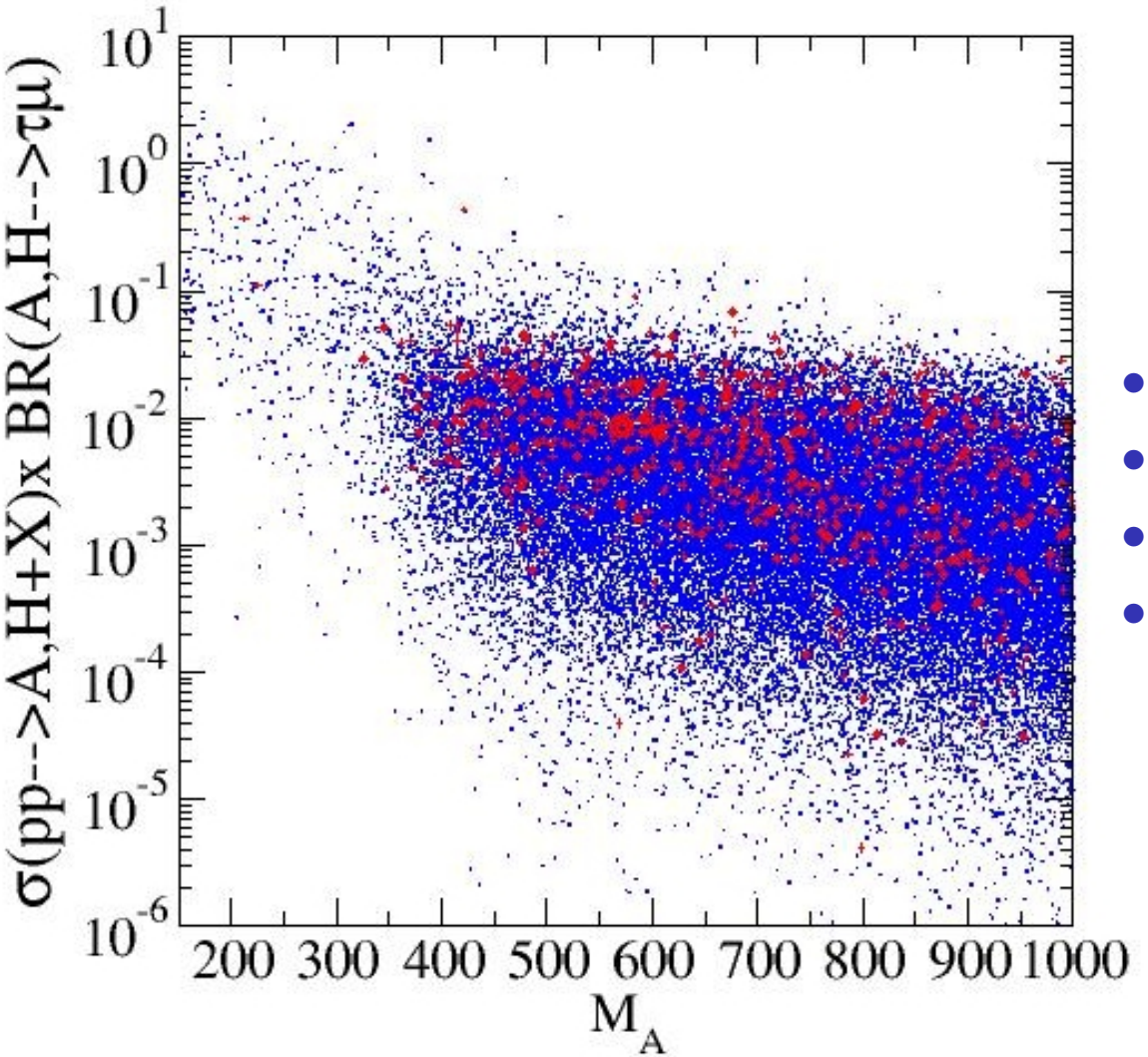
- Blue points:$\Omega h^2 < 0.13$
- Red points:$0.09 < \Omega h^2 < 0.13$
- $BR(A, H \to \mu\tau) \simeq 10^{-5} - 10^{-6}$

LFV IN $\gamma - \gamma$



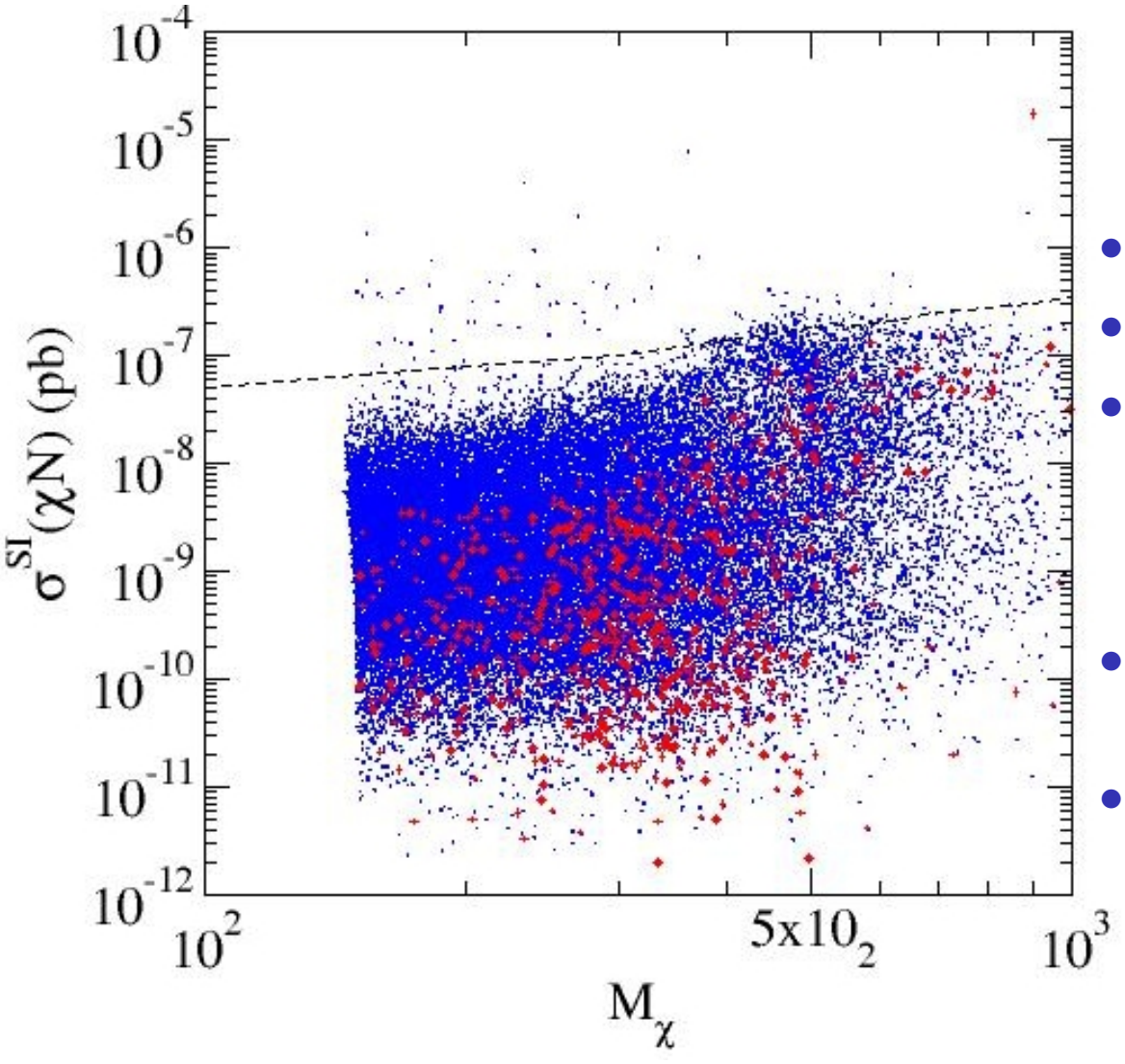
- Blue points: $\Omega h^2 < 0.13$
- Red points: $0.09 < \Omega h^2 < 0.13$
- $\sigma^{max} \simeq 10^{-2}$ fb

LFV IN $p - p$



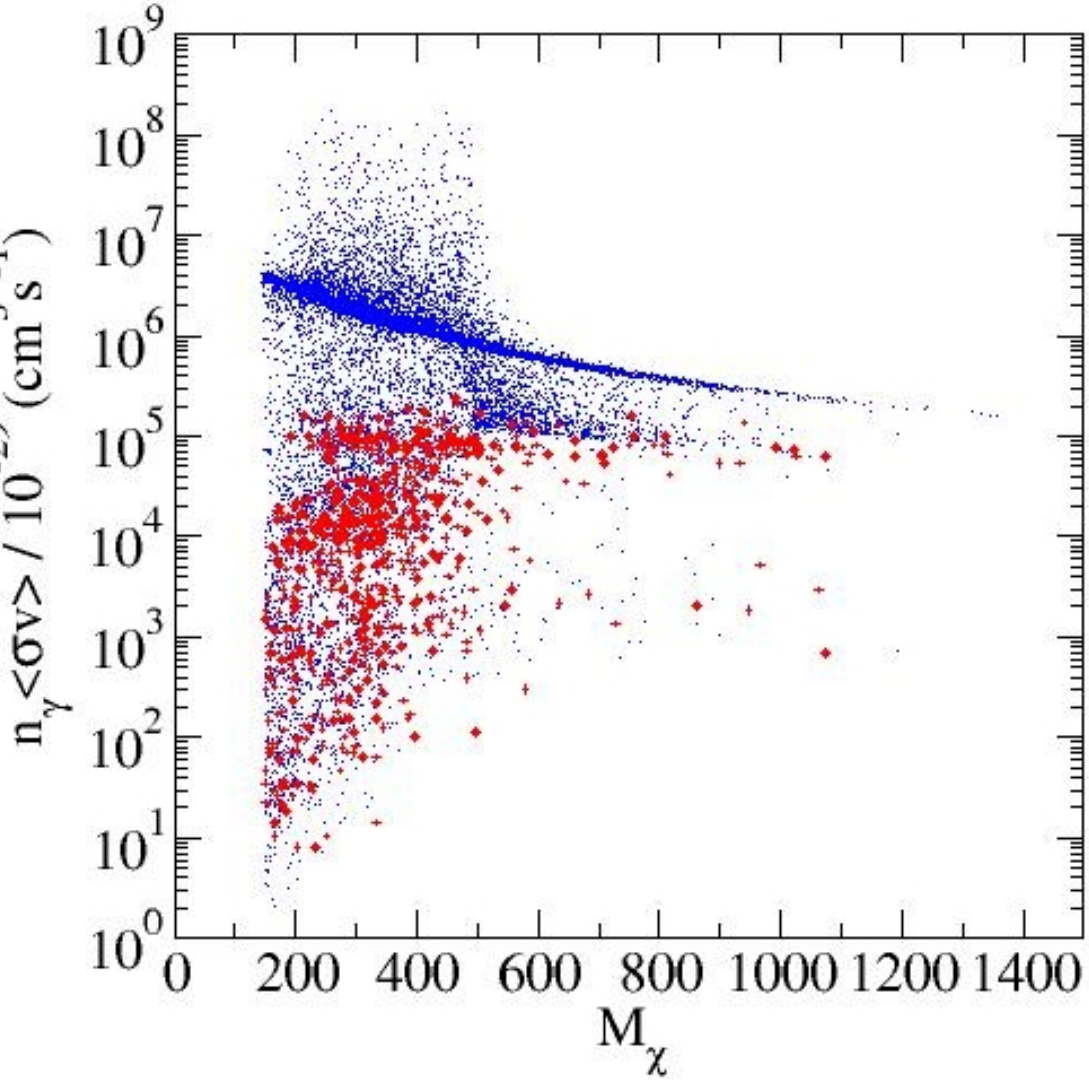
- Blue points: $\Omega h^2 < 0.13$
- Red points: $0.09 < \Omega h^2 < 0.13$
- $\sigma^{max} \simeq 10^{-1} - 10^{-2}$ fb
- less optimistic results then other papers... [Brignole-Rossi, Diaz-Cruz,Ghosh,Moretti]

$\chi - N$ SPIN INDIPENDENT CROSS SECTION



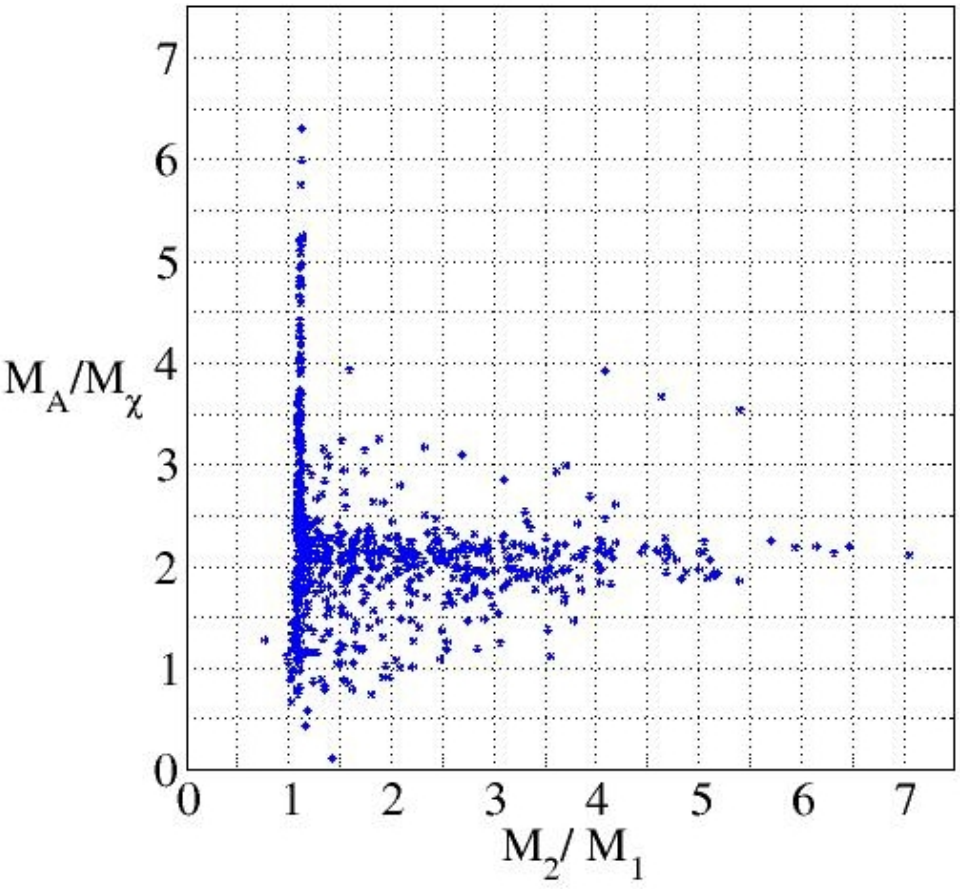
- Blue points: $\Omega h^2 < 0.13$
- Red points: $0.09 < \Omega h^2 < 0.13$
- with heavy squarks $\chi - N$ h, H exchange dominates: at large $\tan\beta$ $\sigma^{SI} \propto \tan^2\beta / M_A^4$ [Carena,Menon,Wagner]
- Dashed line: present CDMS limit PRL102, 011301 (2009)
- SuperCDMS and XENON1T will reach 10^{-11} pb sensitivity

$\chi - \chi$ ANNHILATION INTO PHOTONS



- Blue points: $\Omega h^2 < 0.13$
- Red points: $0.09 < \Omega h^2 < 0.13$
- $E_\gamma > 1$GeV
- monochromatic lines from $\gamma\gamma$, $Z\gamma$ final states not shown (too small cross section)
- red points: similar to mSUGRA results [Sanchez-Conde,Gomez et al.]

HINTS ON SUSY MODELS



- $0.09 < \Omega h^2 < 0.13$
- $M_A \simeq 2M_\chi$ mSUGRA funnel region annhilation into fermion dominated h, A, H resonant s-channel exchange
- $M_1 \simeq M_2$ different from standard GUT relation

Outline

Summary

- The search of LFV effects mediated by SUSY heavy Higgs A, H at large $\tan\beta$ at $\gamma\gamma$ and $p-p$ colliders requires the full luminosity of the machines and at most some tens of events can be expected: a second step after the discovery.
- Better prospects in $e\gamma$ collisions? See Koiji Tsumura talk in the SUSY session.
- In the meantime...A, H effects are important for neutralino dark matter!