Top polarization in squark decays

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GB, R. Godbole, S. Kraml, S. Kulkarni, arXiv:1304.2987
GB, R. Godbole, L. Hartgring, I. Niessen, arXiv:1212.3526 (JHEP)

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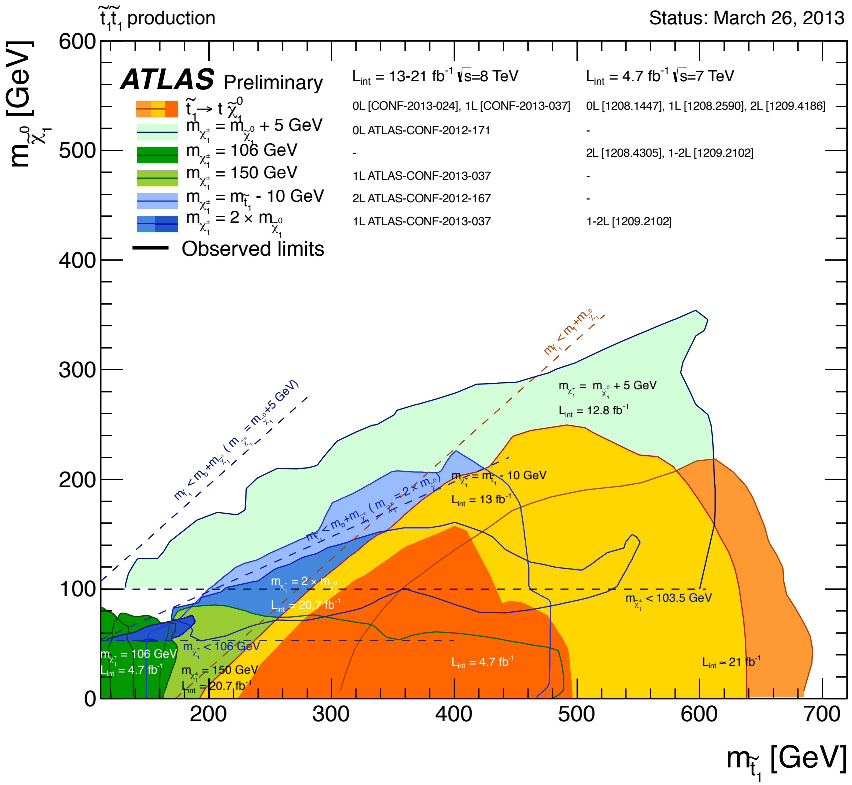
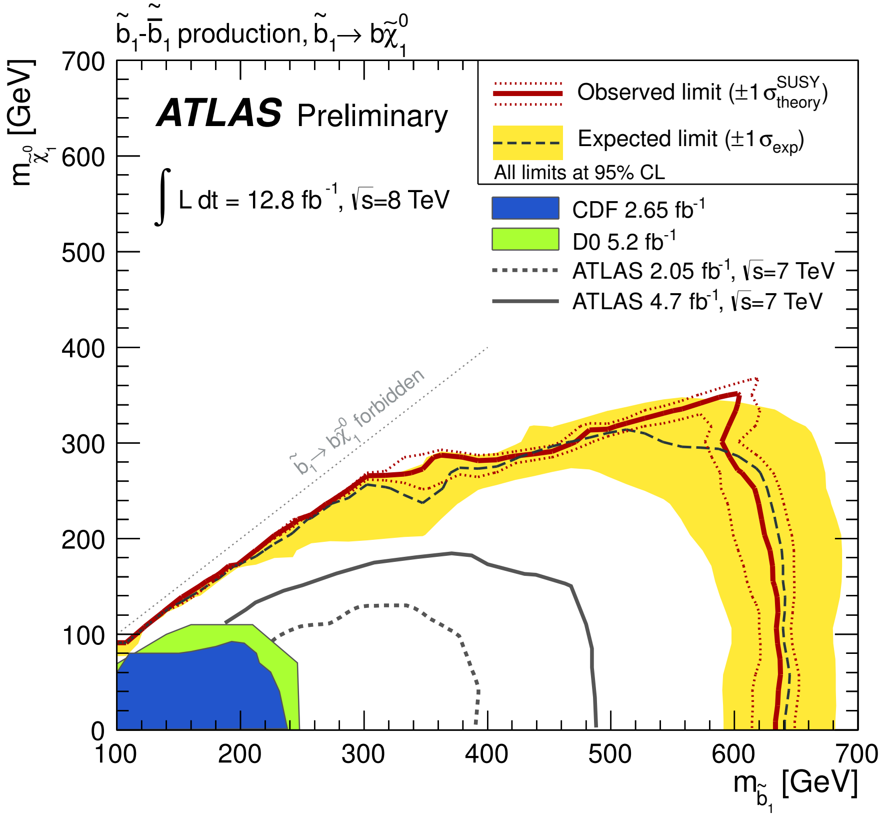
Introduction

- The Higgs discovered at LHC - BSM?
- In SUSY, third generation squarks play important role in Higgs sector, mixing is important
- Search for 3rd generation squarks vital to understand the Higgs

- Harder than for light squarks :
  - gg- squark pair production drops rapidly with energy
  - squark/gluino production is much smaller than for light squarks
  - decay involves top quarks, then generic $E_T$miss+jet search not applicable

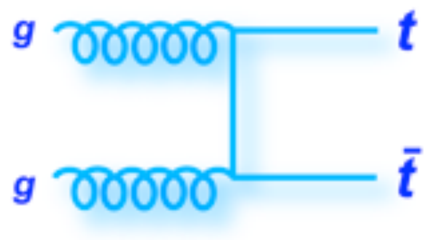
Current limits

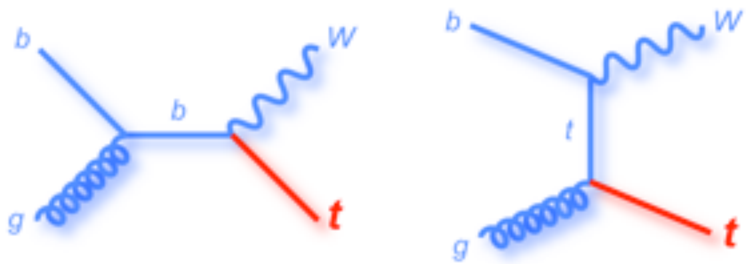




Top polarization

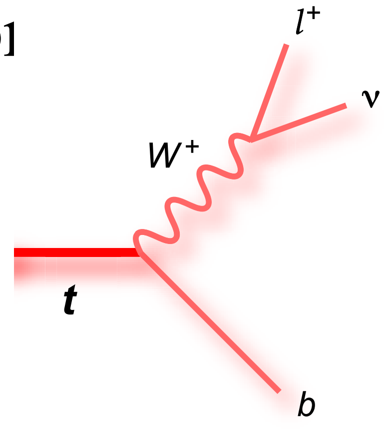
- Useful probe of new physics at collider : sensitive to helicity structure of production process
- SM
  - pair produced tops are unpolarized
  - Single production (polarization -1)





- SUSY
  - Top produced in decay of stops and sbottoms can take any value - depends on squark mixing and neutralino/ chargino content

- At LHC production independent of squark mixing angle. BR and top polarization only way to extract info on mixing
  – squark mixing important for Higgs
  – nature of neutralino/chargino important for dark matter



- Measure of top polarization
  – Correlation between top polar and angular distribution of decay lepton - not affected by QCD corections (Jesabek,Kuhn 1989) or NP in decay (Grzadkowski 2001)
  – Energy fraction of decay leptons (Berger et al 1207.1101)
  – use boosted top and jet substructure

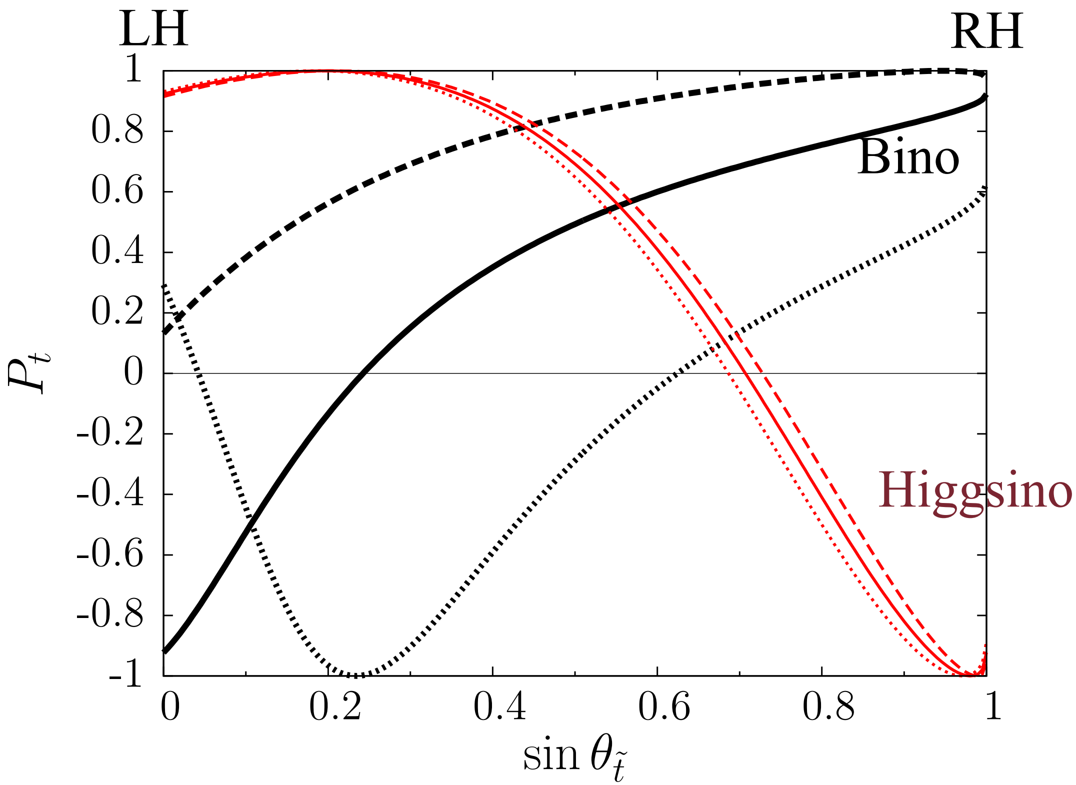
Top polarization in

$$\tilde{t}_1 \to t\,\tilde{\chi}_i^0$$

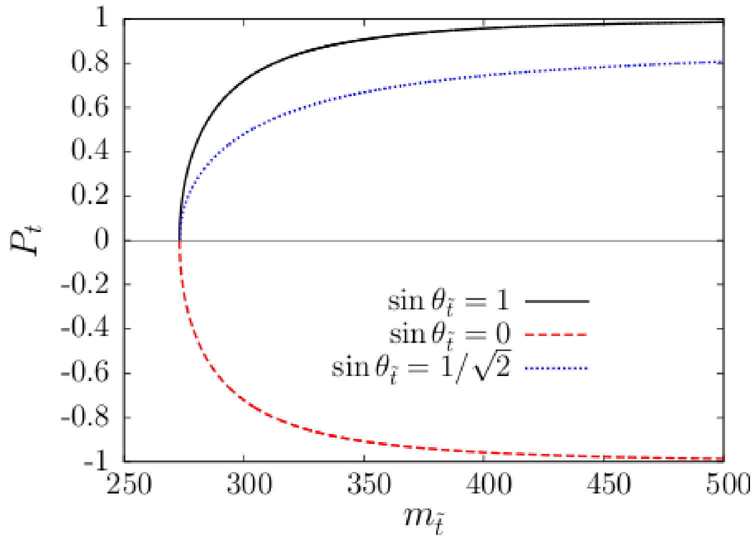
- Polarization

$$P_t(\tilde{t}_1 \to t\,\tilde{\chi}_i^0) = \frac{\left((G_i^R)^2 - (G_i^L)^2\right) f_1}{(G_i^R)^2 + (G_i^L)^2 - 2G_i^R G_i^L f_2}$$

$$\begin{aligned} G_i^L &= -\sqrt{2} g_2 \left(\frac{1}{2} Z_{i2} + \frac{1}{6}\tan\theta_W Z_{i1}\right)\cos\theta_{\tilde{t}} - \frac{g_2 m_t}{\sqrt{2} M_W \sin\beta} Z_{i4}\sin\theta_{\tilde{t}} \\ G_i^R &= \frac{2\sqrt{2}}{3} g_2 \tan\theta_W Z_{i1}\sin\theta_{\tilde{t}} - \frac{g_2 m_t}{\sqrt{2} M_W \sin\beta} Z_{i4}\cos\theta_{\tilde{t}}\,, \end{aligned}$$



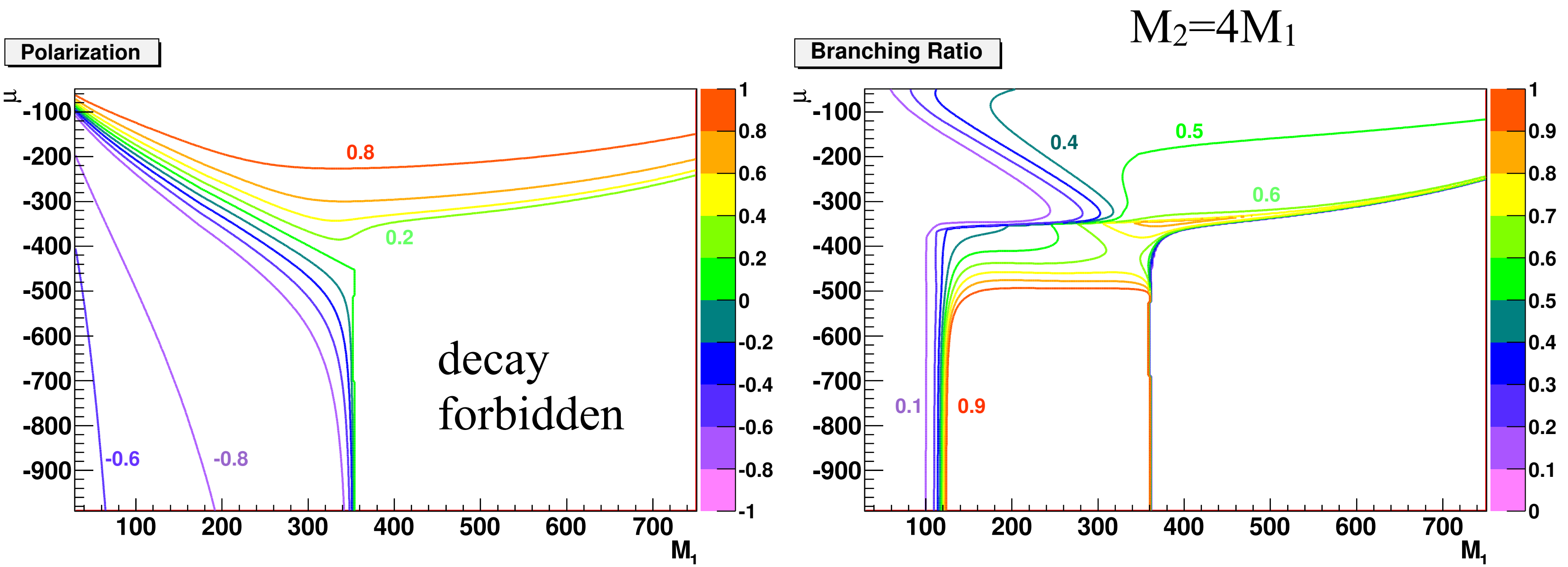
Mass difference



Mχ=100GeV
pure bino

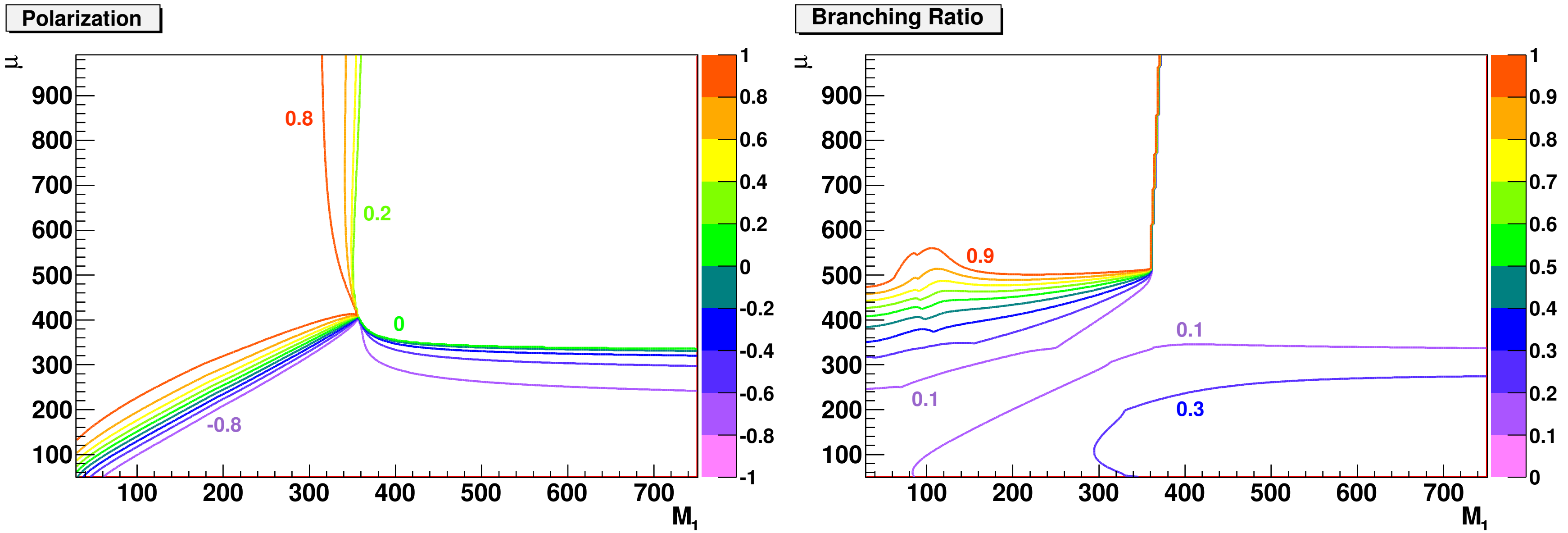
- Kinematic effects can reduce significantly polarization, f_1->0 for small Δm (here in stop rest frame)

Benchmark : LH stop m=520GeV



- Note: for higgsino LSP($\mu < M_1$), BR for decay $t\chi_2$ is as large as $t\chi_1$ and polarization is about the same

Benchmark : RH stop m=508GeV



- For higgsino LSP, BR for decay tχ^2 is similar to tχ^1, so is polarization, however also decay into bχ^+(proportional top Yukawa)

Top polarization in Sbottom -> top+chargino

Top polarization

- For a higgsino-like chargino

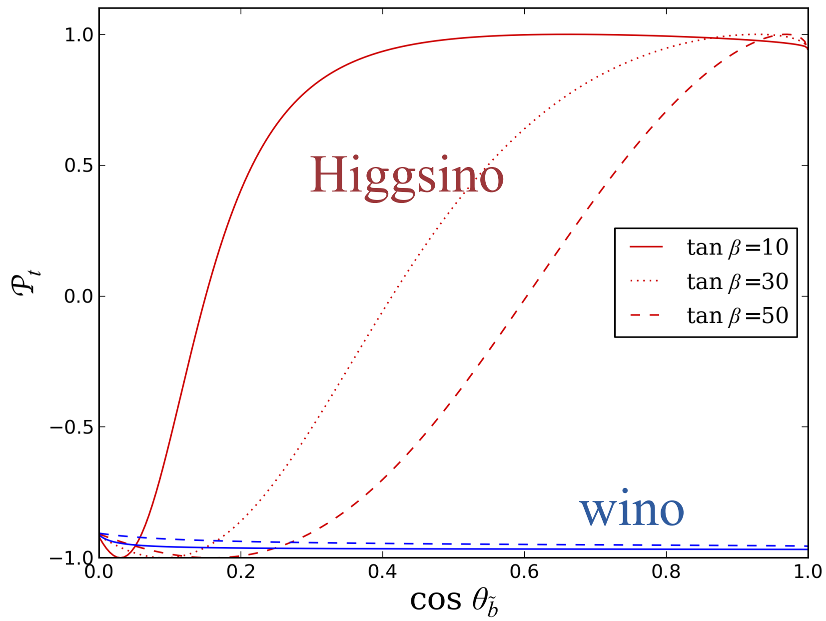
$$\mathcal{P}_t = \frac{((h_t\ \cos\theta_{\tilde{b}})^2 - (h_b\ \sin\theta_{\tilde{b}})^2)\ f_1}{[(h_t\ \cos\theta_{\tilde{b}})^2 + (h_b\ \sin\theta_{\tilde{b}})^2 - h_t\, h_b\ \sin 2\theta_{\tilde{b}}\ f_2]}$$

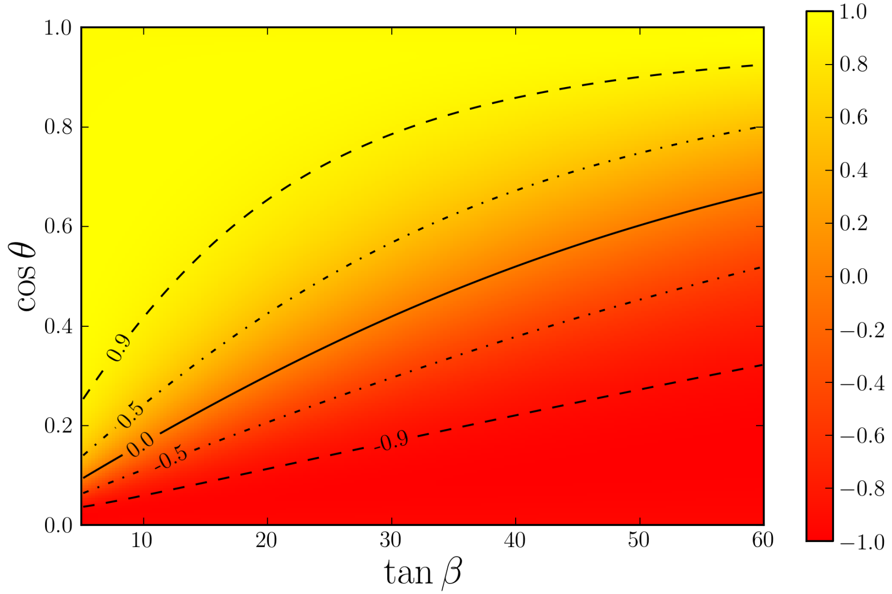
- Dependence on sbottom mixing

$$\begin{array}{lcl} \tilde{b}_L & : & \cos\theta_{\tilde{b}} = 1\,, \quad \mathcal{P}_t \to +f_1 \\ \tilde{b}_R & : & \cos\theta_{\tilde{b}} = 0\,, \quad \mathcal{P}_t \to -f_1 \end{array}$$

- For a wino-like chargino : coupling only to LH sbottom and LH top --> P_t=-1 for any mixing

Top polarization



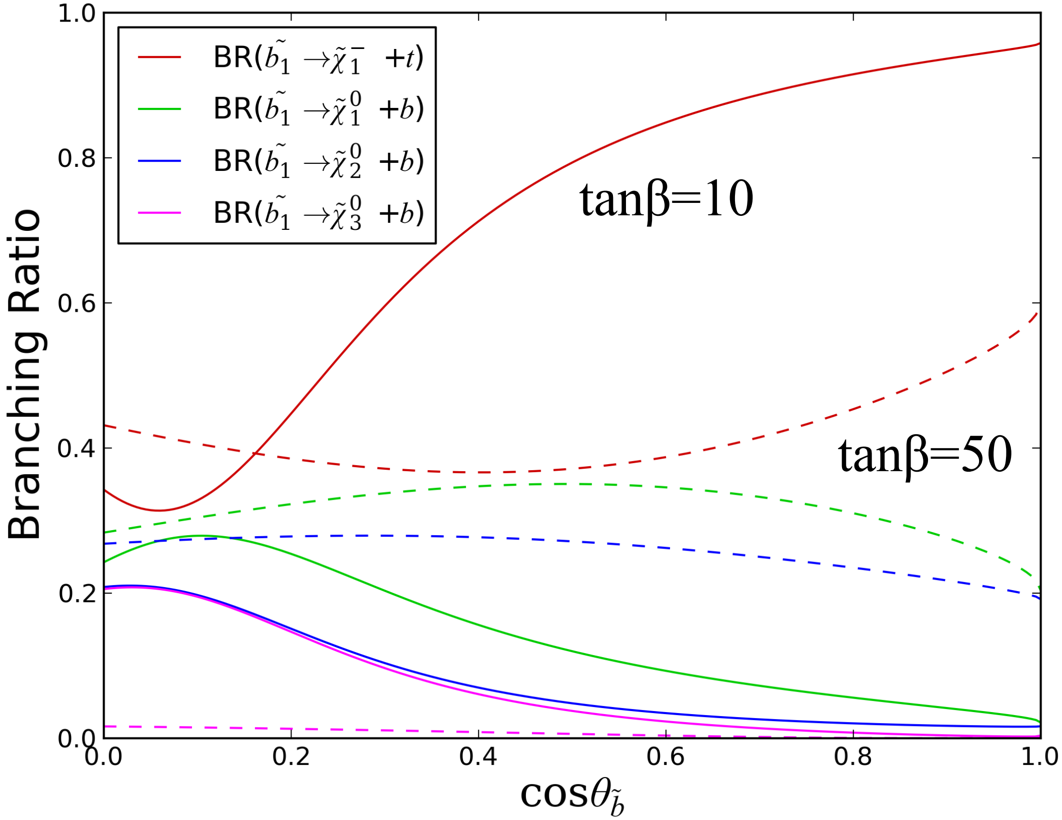


LH

Higgsino,
μ=350 GeV, M_2=1TeV

- At large tanβ, both Yukawa couplings contribute

Branching ratios



- For μ<M_2, top/chargino dominant everywhere

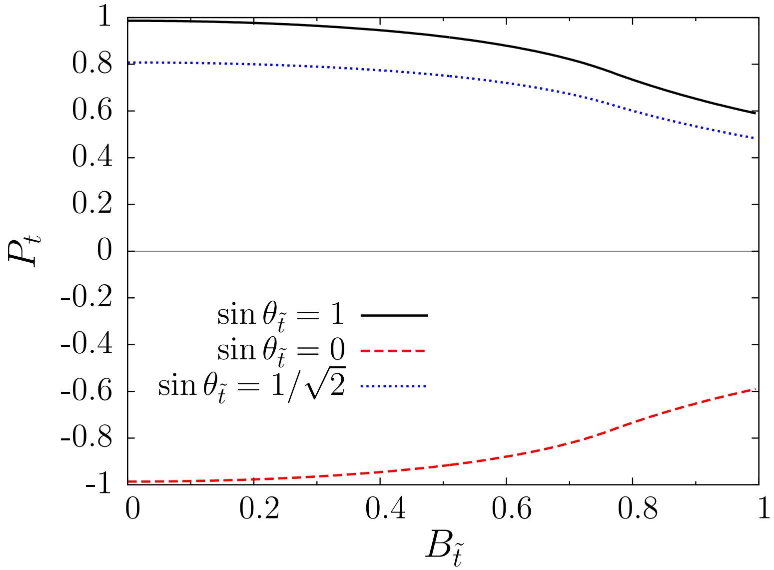
Numerical analysis

- Many processes lead to tops in final state
  - sbottom1,2 decays, stop decays etc..
- Sometimes final states hard to distinguish, e.g. in higgsino/wino case (decay of χ^2,χ^+ into LSP lead to soft decay products which can be missed)

$$
\begin{aligned}
pp &\rightarrow \tilde{b}_1\tilde{b}_1^*, \quad \tilde{b}_1 \rightarrow t\,\tilde{\chi}_1^- \\
pp &\rightarrow \tilde{b}_2\tilde{b}_2^*, \quad \tilde{b}_2 \rightarrow t\,\tilde{\chi}_1^- \\
pp &\rightarrow \tilde{t}_1\tilde{t}_1^*, \quad \tilde{t}_1 \rightarrow t\,\tilde{\chi}_{1,2}^0
\end{aligned}
$$

- Will compute the net top polarization : include all relevant processes+BR + boost to lab frame

Boost



$$B_{\tilde{t}} = \frac{|\boldsymbol{p}_{\tilde{t}}|}{E_{\tilde{t}}}$$

- Reduction of polarization for boosted squark

Benchmarks

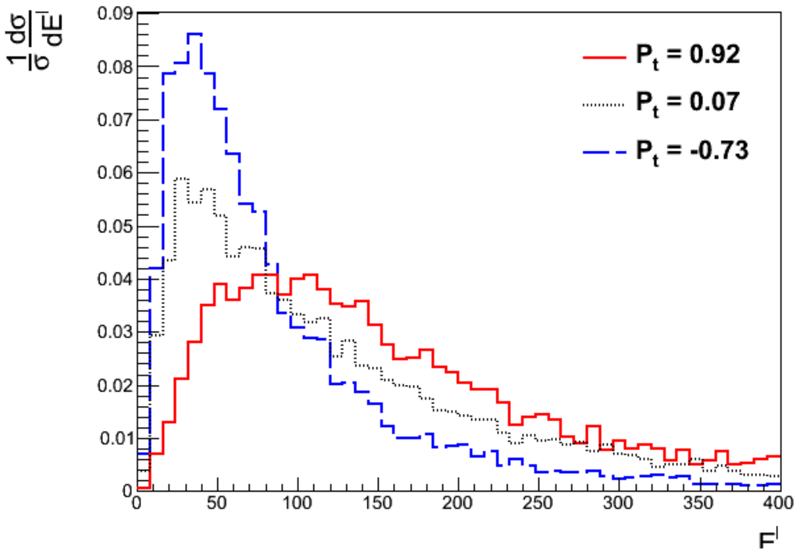
	bm-2	bm-5	bm-6
$M_{\tilde{Q}_3}$	1300	582	850
$M_{\tilde{D}_3}$	572	1500	601.5
M_1	500	200	500
μ	350	150	350
$m_{\tilde{b}_1}$	650	650	650
$m_{\tilde{b}_2}$	1330	1538	885
$\cos\theta_{\tilde{b}}$	0.006	0.999	0.020
$m_{\tilde{t}_1}$	1236	634	820
$\cos\theta_{\tilde{t}}$	0.85	0.996	0.96
$m_{\tilde{\chi}_1^-}$	353	144	352
$m_{\tilde{\chi}_1^0}$	343	126	343
$m_{\tilde{\chi}_2^0}$	358	159	357

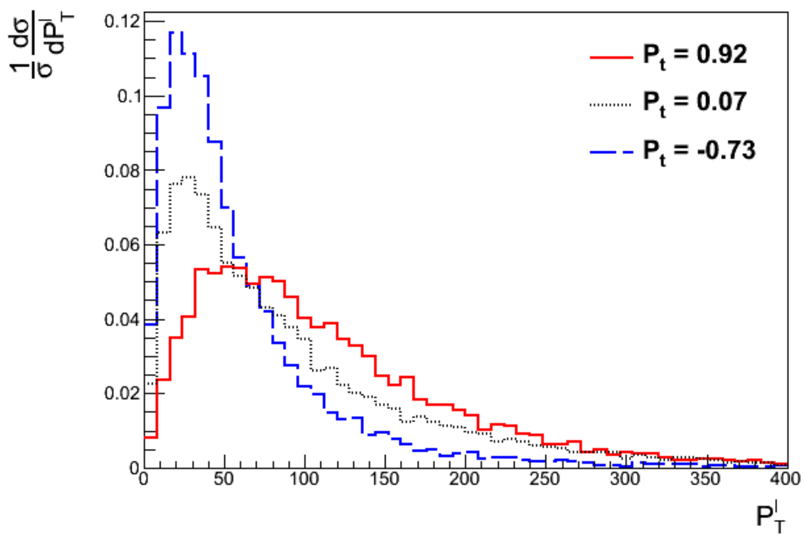
	bm-2	bm-5	bm-6
$\sigma(pp \to \tilde{b}_1\tilde{b}_1^*)$ [pb]	0.137	0.137	0.137
$\sigma(pp \to \tilde{t}_1\tilde{t}_1^*)$ [pb]	0.002	0.157	0.033
$\mathrm{BR}(\tilde{b}_1 \to t\,\tilde{\chi}_1^-)$	0.34	0.72	0.32
$\mathrm{BR}(\tilde{b}_1 \to t\,\tilde{\chi}_2^-)$	–	0.16	–
$\mathrm{BR}(\tilde{t}_1 \to t\,\tilde{\chi}_1^0)$	0.33	0.27	0.47
$\mathrm{BR}(\tilde{t}_1 \to t\,\tilde{\chi}_2^0)$	0.35	0.40	0.42
$\mathcal{P}_t\,(\tilde{b}_1 \to t\,\tilde{\chi}_1^-)$	-0.92	0.99	-0.98
$\mathcal{P}_t\,(\tilde{b}_1 \to t\,\tilde{\chi}_2^-)$	–	-0.29	–
$\mathcal{P}_t\,(\tilde{t}_1 \to t\,\tilde{\chi}_1^0)$	0.40	0.99	0.94
$\mathcal{P}_t\,(\tilde{t}_1 \to t\,\tilde{\chi}_2^0)$	0.50	0.99	0.99
$\widehat{\mathcal{P}}_t\,(\mathrm{total})$	-0.73	0.92	0.07
A_{θ_l}	0.14	0.80	0.47
A_{ϕ_l}	0.57	0.92	0.76

$M_2 = 2M_1$

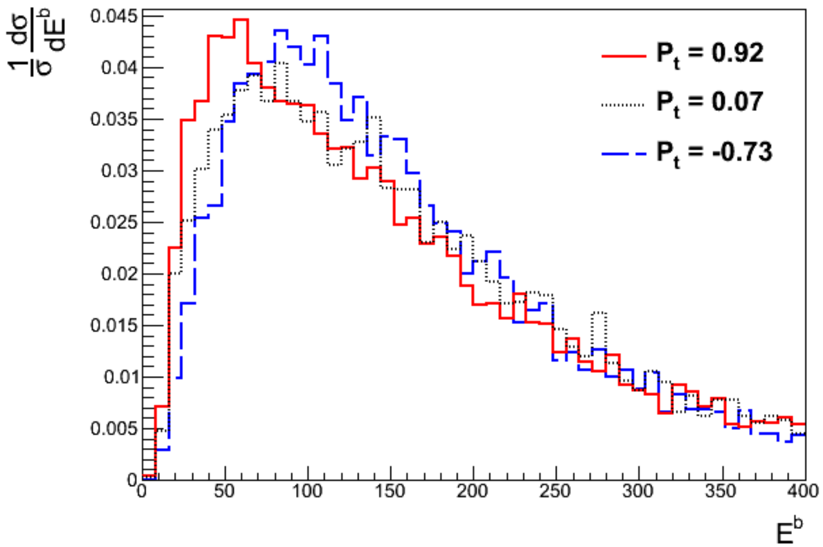
Tools : SoftSUSY, micrOMEGAs, Prospino, MadGraph

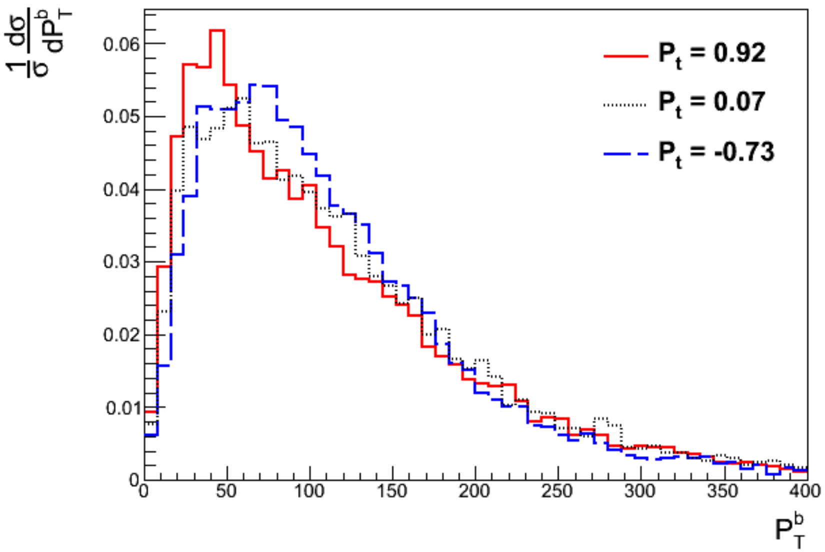
Top polarization : impact on lepton distributions





Top polarization : impact on b distributions



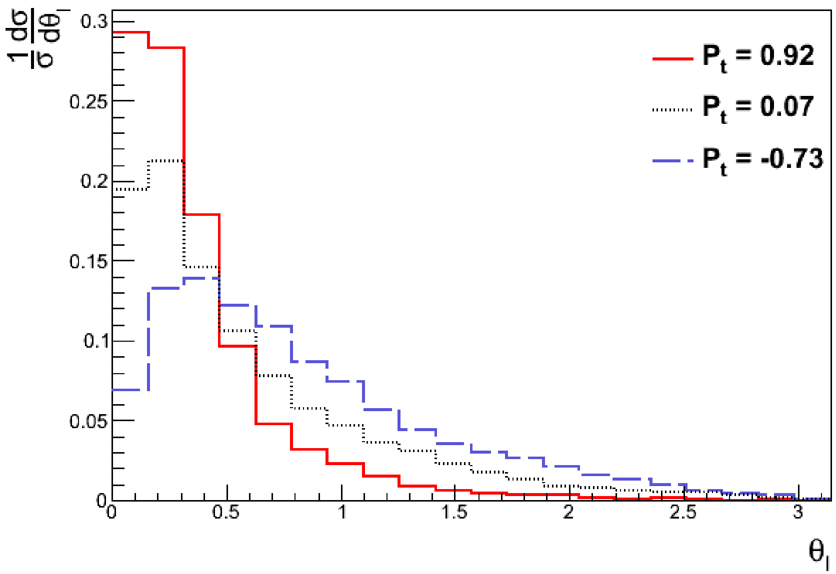


Observables

- Asymmetries constructed from lepton angular distributions in the lab frame can probe the top polarization

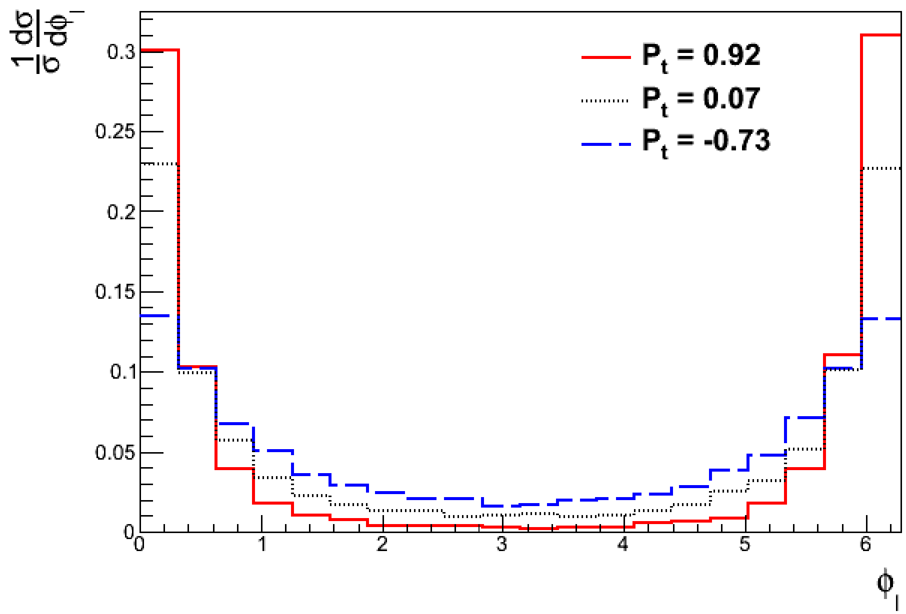
$$A_{\theta_l} = \frac{\sigma(\theta_l < \pi/4) - \sigma(\theta_l > \pi/4)}{\sigma(\theta_l < \pi/4) + \sigma(\theta_l > \pi/4)}$$

$\widehat{\mathcal{P}}_t$ (total)	-0.73	0.92	0.07
A_{θ_l}	0.14	0.80	0.47
A_{ϕ_l}	0.57	0.92	0.76



Observables

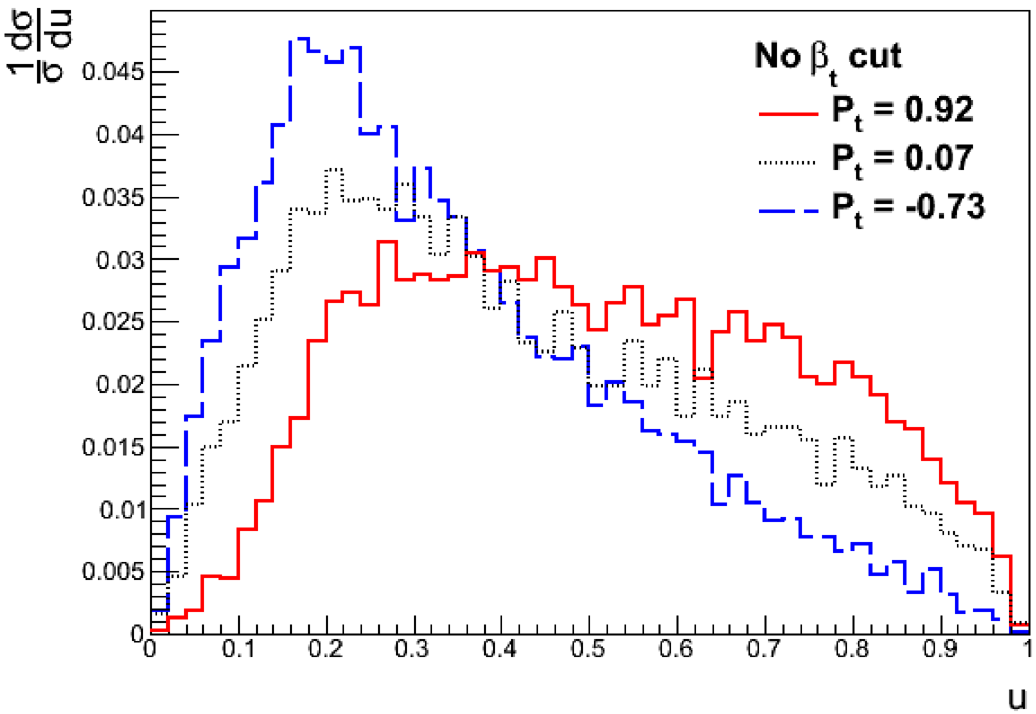
$$A_{\phi_l} = \frac{\sigma(\cos\phi_l > 0) - \sigma(\cos\phi_l < 0)}{\sigma(\cos\phi_l > 0) + \sigma(\cos\phi_l < 0)},$$



- Azimuthal asymmetry

- Observables sensitive to top polarization

$$z = \frac{E_b}{E_t}, \quad u = \frac{E_l}{E_l + E_b}$$



Conclusion

- Polarization dependent observables can be used to extract information on squark and neutralino/chargino composition once a signal is observed.

- Taking into account top polarization affects the reach in searches for squarks