Top Polarization in third generation squark decays.

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SUSY 2013

- Introduction.

- Expected top polarisation in stop/sobottom decays.

- Effect of polarization on kinematic distributions of the decay products of the top.

- Possible probes of this polarisation.

Based on :

1. G. Belanger, R. M. Godbole, L. Hartgring and I. Niessen, JHEP **1305**, 167 (2013)[arXiv:1212.3526]

2.G. Belanger, R. M. Godbole, S. Kraml and S. Kulkarni, arXiv:1304.2987 [hep-ph].

- Strong constraints on the masses of the first two generation of squarks.

- Those do not apply directly to the third generation squarks due to differences in processes contributing to the production and different final states..

- For stops the final states containing top quarks accessible only for heavy stops and *further* need not always have the largest branching ratio.

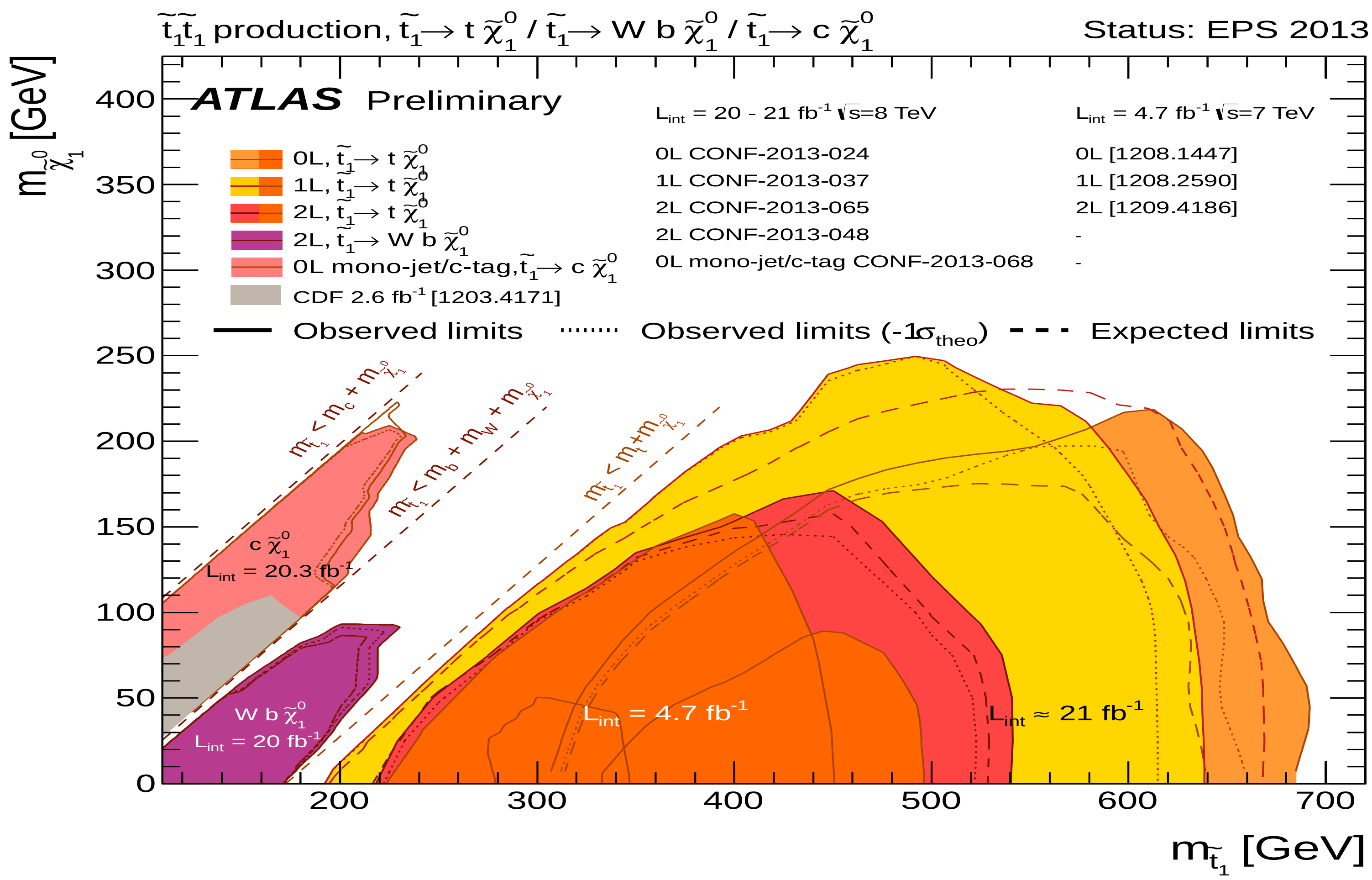
- Separate, dedicated search strategies for third generation squarks needed and of course are in place.

- Both $\tilde{t}/\tilde{b}$ CAN have a top quark in the final state.

- The final states $\tilde{b}, \tilde{t}$ decays are b–quark rich, lepton rich!

- Both the features used to look effectively for these.

Remember: light stops is one of the sparticle being looked for desperately for 'natural' SUSY.


t̃₁t̃₁ production, t̃₁→ t χ̃⁰₁ / t̃₁→ W b χ̃⁰₁ / t̃₁→ c χ̃⁰₁
Status: EPS 2013
ATLAS Preliminary
L_int = 20 - 21 fb⁻¹ √s=8 TeV
L_int = 4.7 fb⁻¹ √s=7 TeV
0L, t̃₁→ t χ̃⁰₁
1L, t̃₁→ t χ̃⁰₁
2L, t̃₁→ t χ̃⁰₁
2L, t̃₁→ W b χ̃⁰₁
0L mono-jet/c-tag, t̃₁→ c χ̃⁰₁
CDF 2.6 fb⁻¹ [1203.4171]
0L CONF-2013-024
1L CONF-2013-037
2L CONF-2013-065
2L CONF-2013-048
0L mono-jet/c-tag CONF-2013-068
0L [1208.1447]
1L [1208.2590]
2L [1209.4186]
-
-
Observed limits
Observed limits (-1σ_theo)
Expected limits
c χ̃⁰₁
L_int = 20.3 fb⁻¹
W b χ̃⁰₁
L_int = 20 fb⁻¹
L_int = 4.7 fb⁻¹
L_int ≈ 21 fb⁻¹
m_t̃₁ < m_c + m_χ̃⁰₁
m_t̃₁ < m_b + m_W + m_χ̃⁰₁
m_t̃₁ < m_t + m_χ̃⁰₁
m_χ̃⁰₁ [GeV]
m_t̃₁ [GeV]

EPS-result.

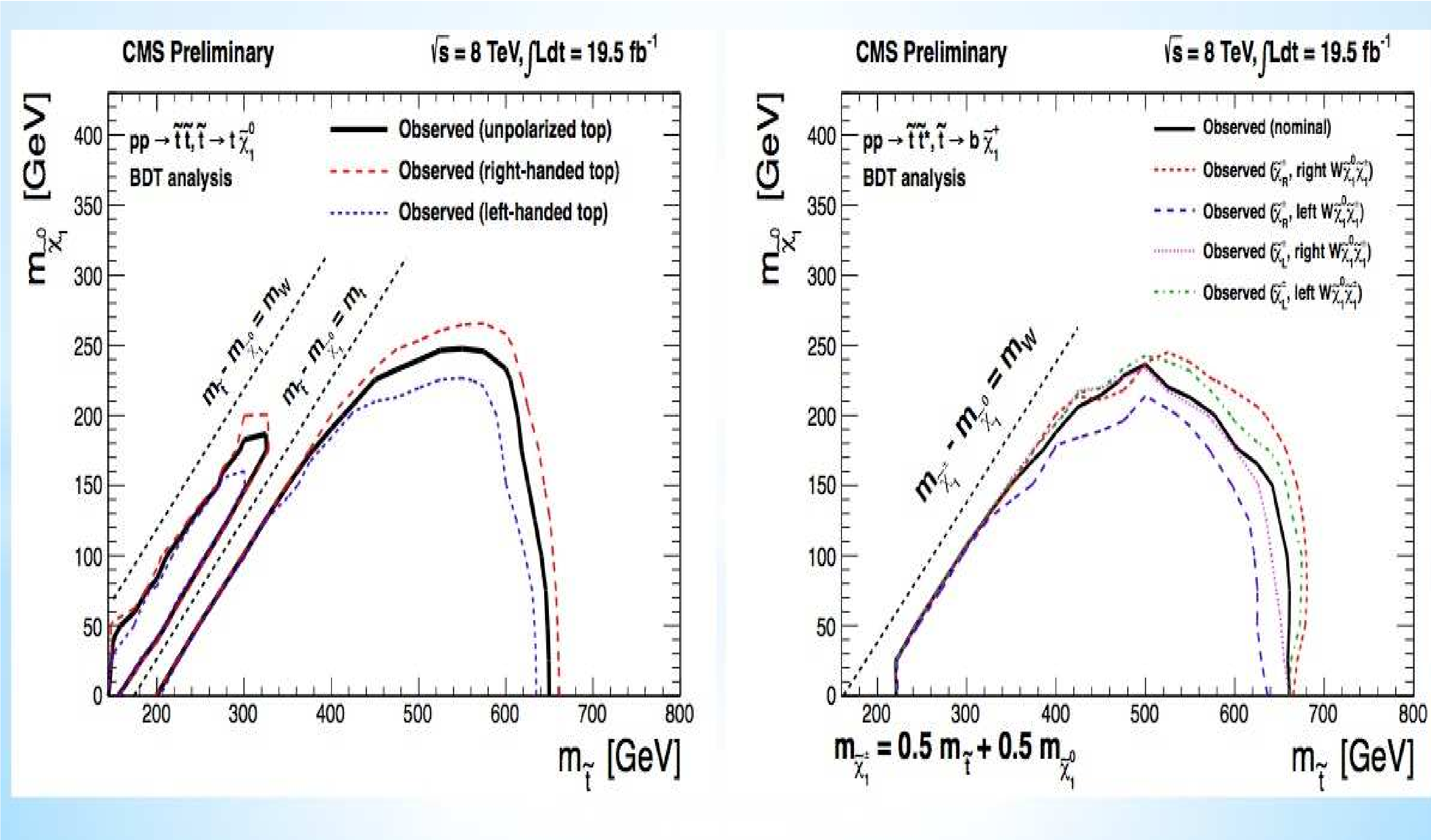
The top quark produced in the decays of $\tilde{t}$ AND $\tilde{b}$ are necessarily polarized.

Three observations:

Apart from the single top, all the other top quarks produced by the SM processes are unpolarized.

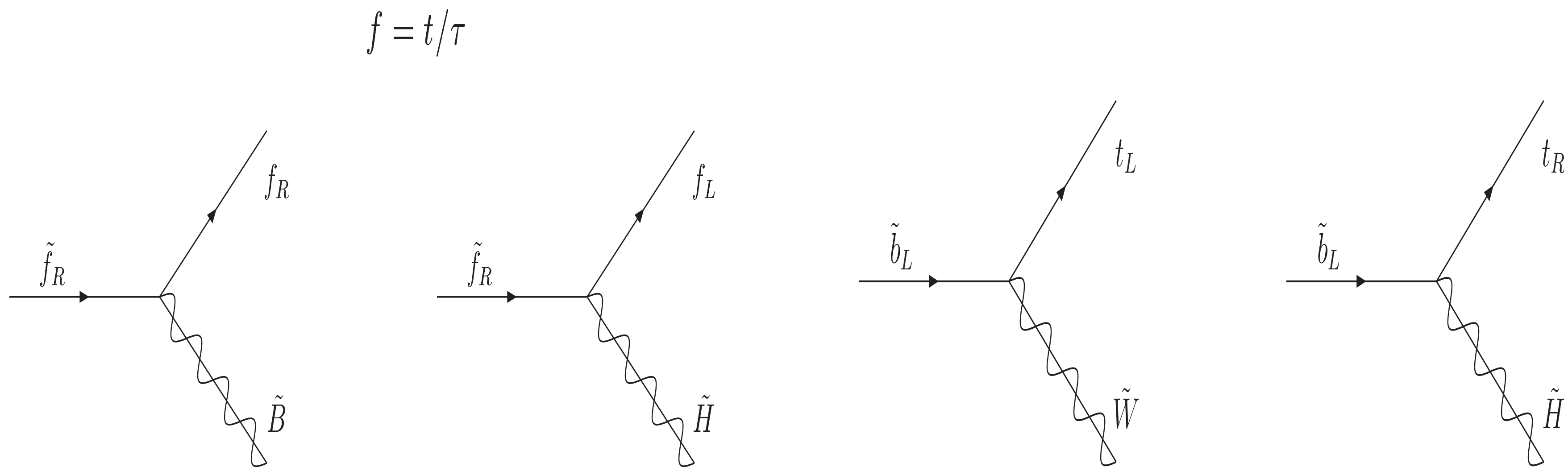
In SUSY the expected top polarization depends on many things, among them on the mixing in the sfermion sector as well as on the mixing in the EWiikno sector.

Kinematics of the decay products of top depends on its polarization. Hence this can have effect on search strategies.



In the leptonic channel the limits could depend on the assumed polarisation of top quark produced in the stop decay.

$\tau(t)$ produced in stau/stop decay. M. Nojiri, PRD **51** (1995) 6281 [hep-ph/9412374]



□ In MSSM mass eigenstates of $\tilde{f}$ (sleptons/squarks) $\tilde{f}_1, \tilde{f}_2$, are mixtures of $\tilde{f}_L$ and $\tilde{f}_R$, $f = t, \tau$.

□ The $\tilde{\chi}_j^{\pm}, j = 1, 2$, $\tilde{\chi}_j^0, j = 1, 4$ are mixtures of higgsinos and gauginos.

□ Couplings of sfermions with higgsinos flip chirality whereas those with gauginos do not.

- **The helicity of the fermion produced in the decay of the sfermion decided by the character of the sfermions as well as the neutralino/chargino**.

□ Net helicity of produced f in the decay $\tilde{f}_i \to \tilde{\chi}_j^0 f$ AND $\tilde{f}_i \to \tilde{\chi}_j^{\pm} f'$ depends on the L–R mixing in the sfermion sector and on the gaugino-higgsino mixing.

In the so called Helicity basis, the polarization of the top quark in the decay $\tilde{t} \to t\tilde{\chi}_1^0$ is given by:

$$P_t = \frac{\sigma(+,+) - \sigma(-,-)}{\sigma(+,+) + \sigma(-,-)}$$

where $\sigma(+.+), \sigma(-,-)$ are the cross-sections for producing a positive helicity and negative helicity top quark.

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

The couplings G_i^L, G_i^R are given by:

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

f_1, f_2 are kinematic factors involving the Källen function.

$f_1 \to 1, f_2 \to 0$ if m_t is negligible. So essentially arise from the finite mass of the top quark.

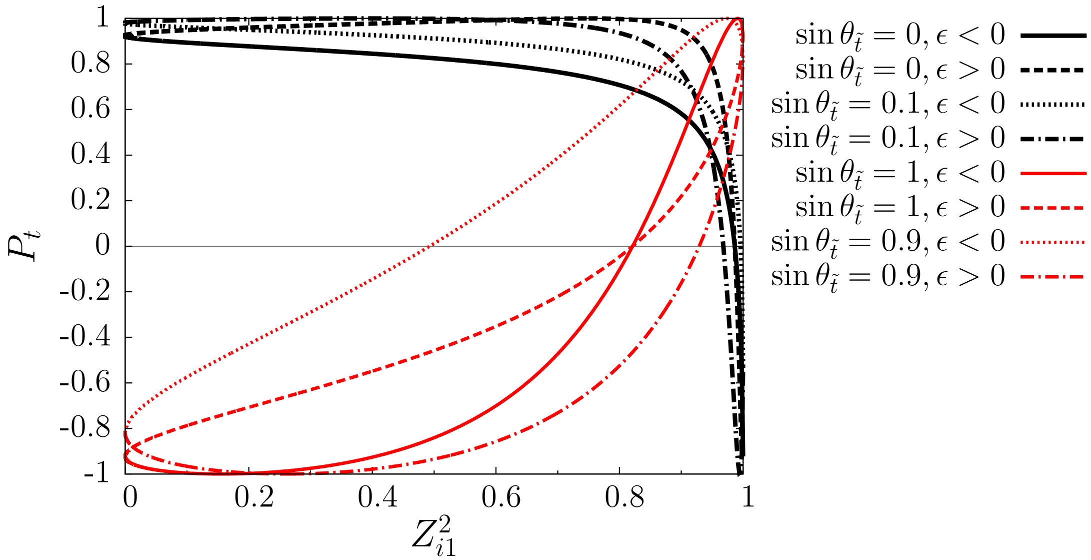
Top polarization depends on the Z_{i1}, Z_{i2}, Z_{i4} and $\sin\theta_{\tilde{t}}$.

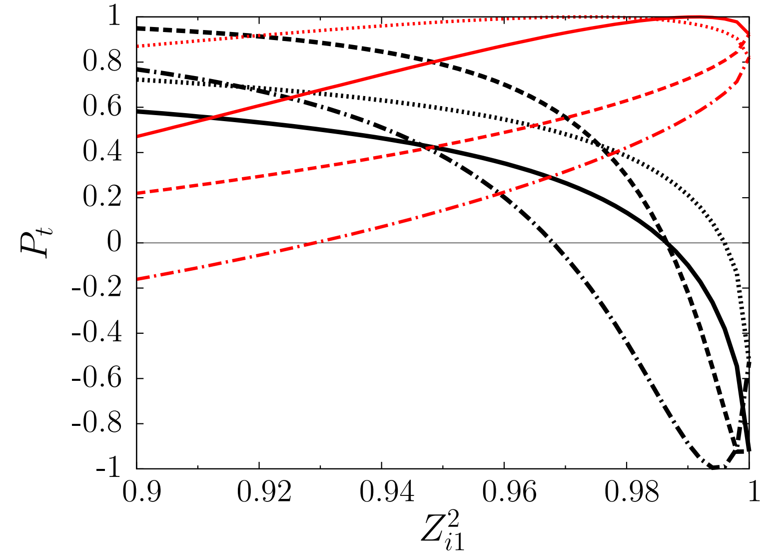
Also on the velocity of the top quark and hence on the mass difference between $m_{\tilde{t}}$ and $m_{\tilde{\chi}_1^0}$.

In a non obvious way also on the boost with which the stop is produced.

A pure Wino will always give $P_t = -f_1$ in the stop rest frame.

<u>What is it for a neutralino with a Bino-Higgsino case?</u>



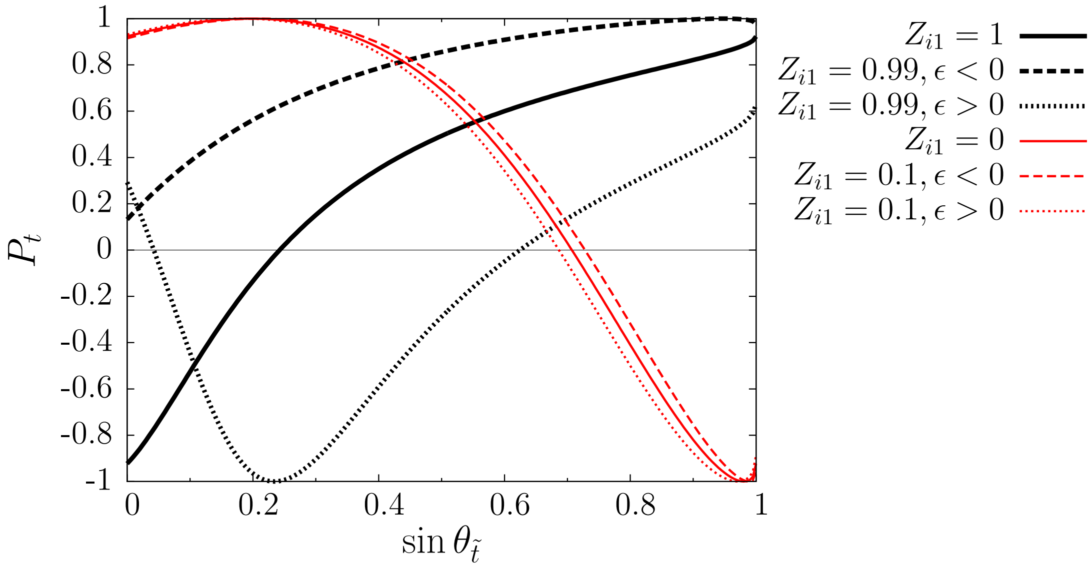


Only for demonstration take $Z_{i2} = 0$ and $Z_{i4} = \epsilon\sqrt{1 - Z_{i1}^2}$.

$m_t = 173.1 GeV, \tan\beta = 10$ and $m_{\tilde{\chi}} = 200$ for $m_{\tilde{t}} = 500$ GeV.

The zoom shows the behavior for large bino-content.

Right handed stops produce a negative top polarization when they decay to a higgsino and a positive polarization when they decay to a bino.

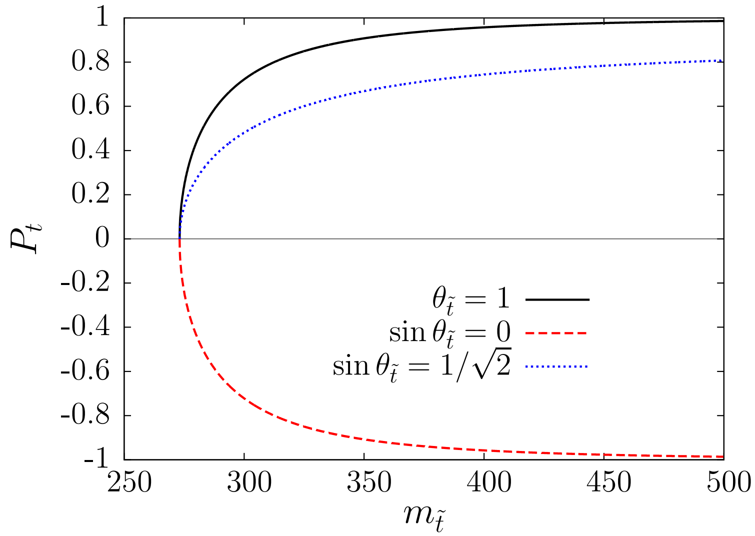


Two cases:

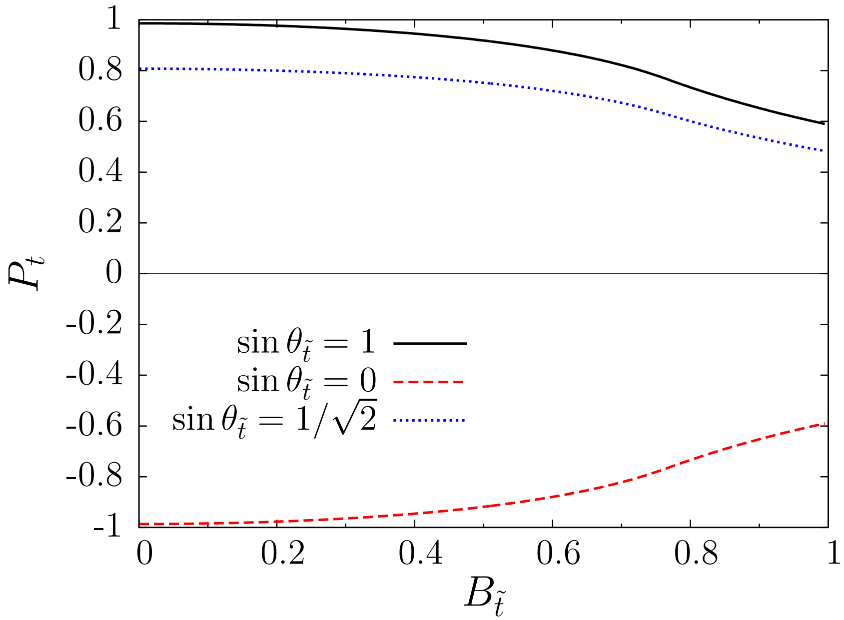
Pure Bino state and a mixed state:

Dominant Higgsino : polarization not very sensitive to the neutralino content.

For $Z_{i1} \simeq 1$ the polarization is very sensitive to the changes in Z_{i1}.



For a fixed neutralino mass of 100 GeV and $\tan\beta = 10$. Polarization in the stop rest frame, for a pure Bino state.



Stop boost tends to reduce the polarization.

However, for the values of stop and neutralino masses now being considered for searches this effect is not so drastic.

All these statements are bit academic. What is really important is to quantify the effect of this polarization on the kinematics of the decay products.

Two aims:

1)once we see the signal see if we can use this to understand the stop sector

2)right now see what is the effect of this polarization on the top decay products and hence on search strategies.

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_f} = \frac{1}{2}\left(1 + P_t\kappa_f \cos\theta_f\right),$$

θ_f is the angle between the f momentum and the top spin direction, P_t is the degree of top polarization, κ_f is the "analyzing power" of the final-state particle f.

The analyzing power k_f for various channels is given by:

$$\kappa_b = -\frac{m_t^2 - 2m_W^2}{m_t^2 + 2m_W^2} \simeq -0.4$$

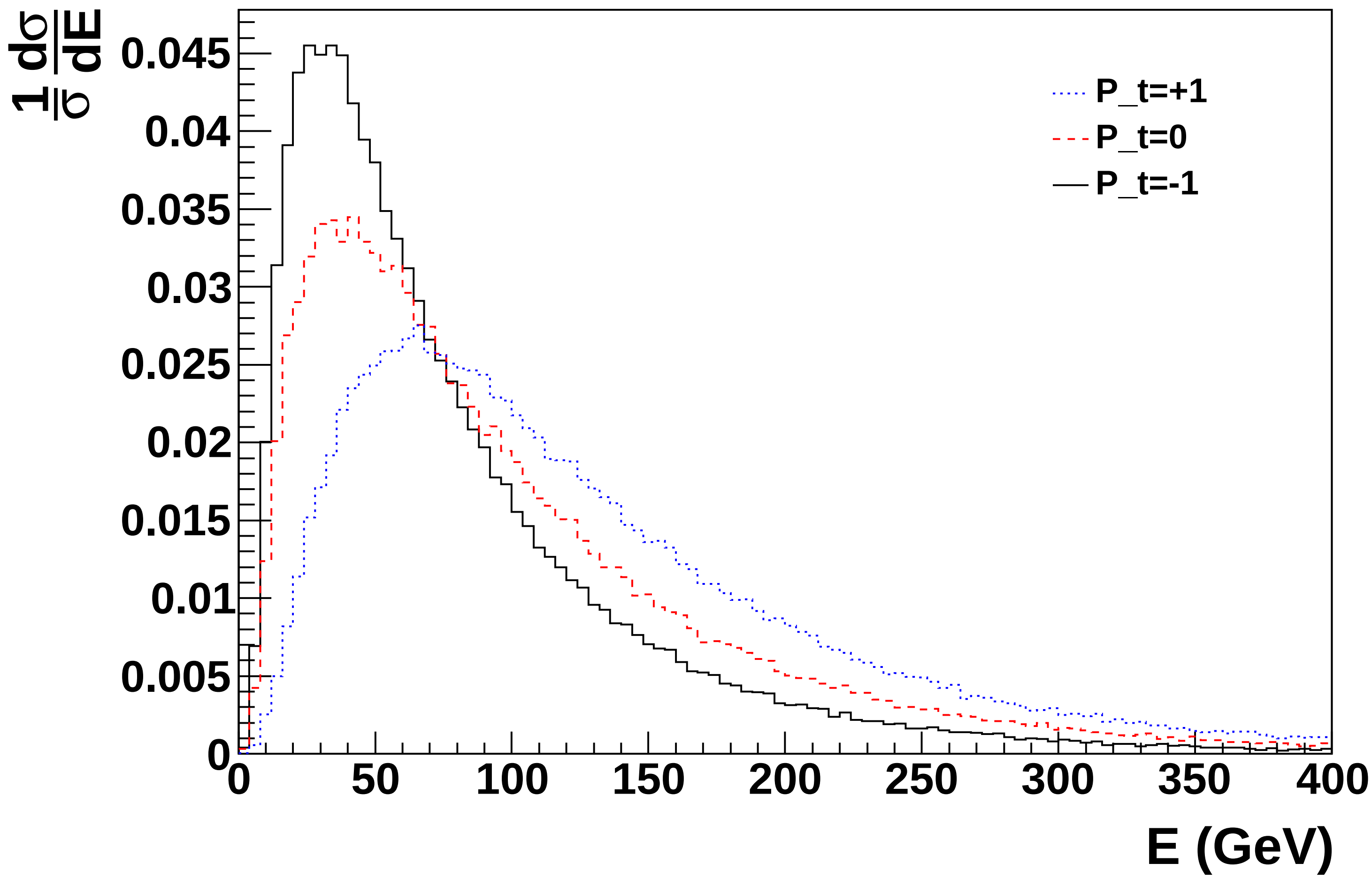
$$\kappa_W = -\kappa_b \simeq 0.4$$

$$\kappa_{\ell+} = \kappa_d = 1; \qquad \kappa_u = \kappa_{\nu_l} = -0.31$$

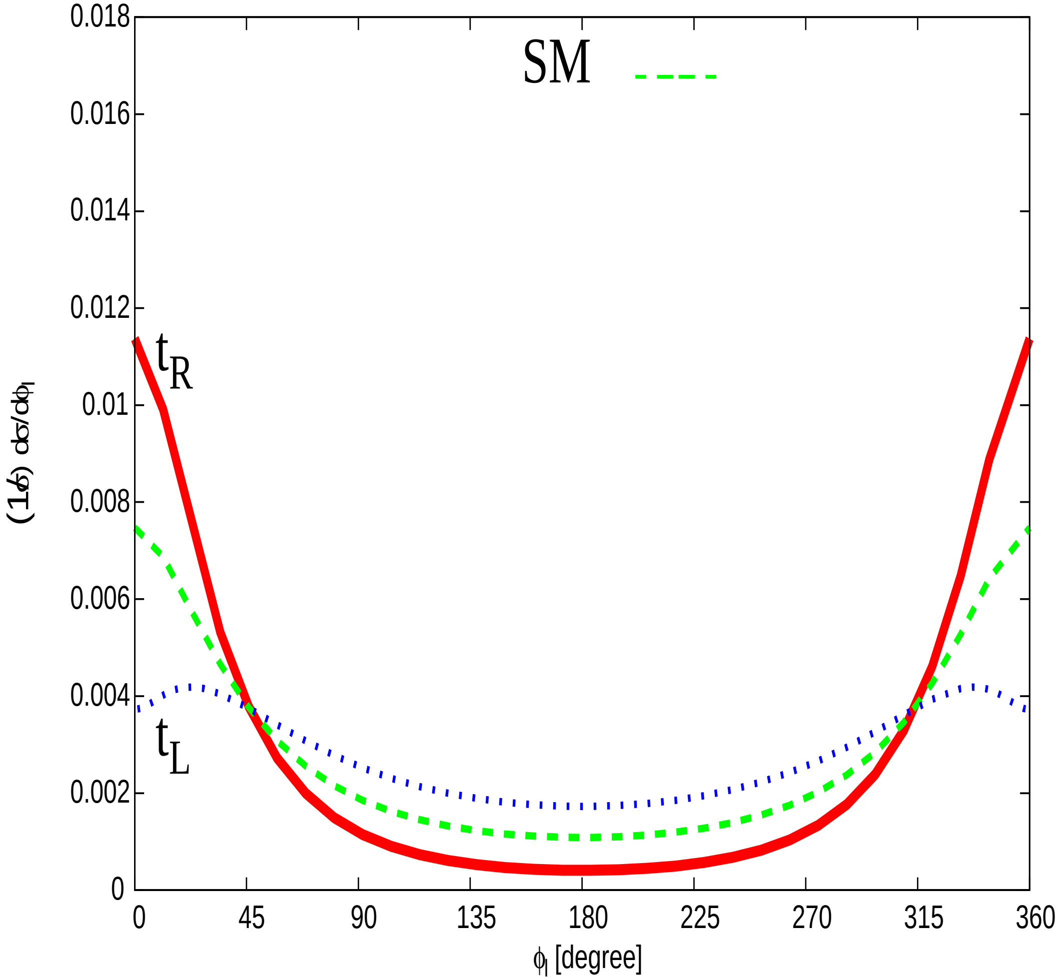
This can give rise to different distributions in the laboratory frame.

The energy and p_T distributions and also angular distributions.

Angular distributions have the advantage of being a faithful mirror of polarization.



For the negatively polarised top distributions peak at lower values of energy.



Distribution in ϕ_l, the azimuthal angle, defined with respect to the $t\bar{t}$ production plane, with beam direction as the z axis.

The two curves correspond to the top completely Left handed or right handed.

What do we do and show?

We choose a set of bench mark points for stop pair production.

Calculate direct stop pair production in $pp \to \tilde{t}_1\tilde{t}_1$ for the bench mark point.

Consider the decay $\tilde{t} \to t\chi_1^0$.

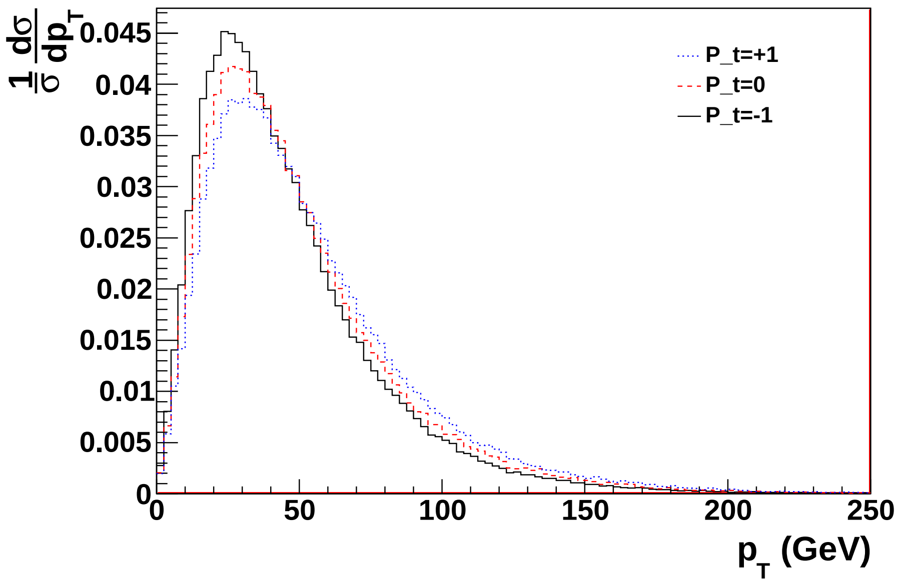
Calculate the top polarization as

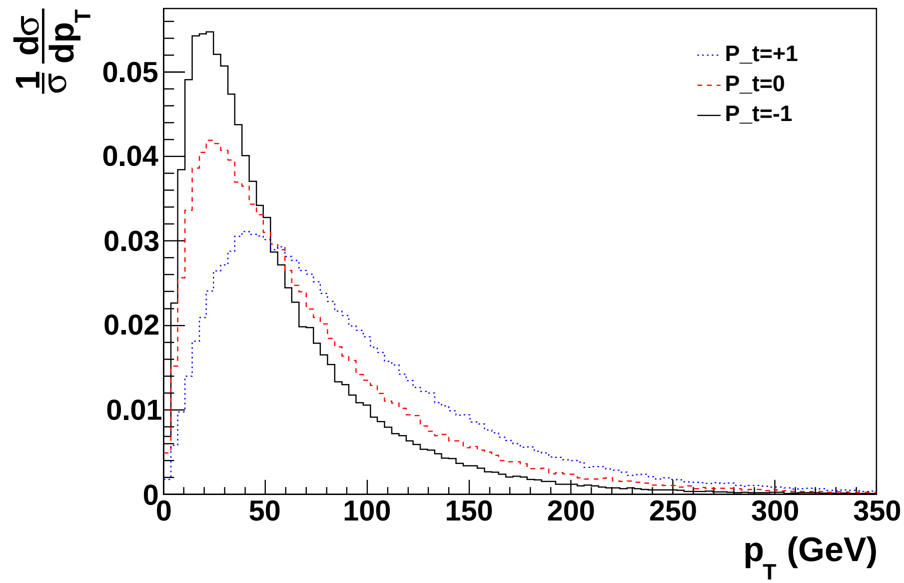
$P_t = \frac{\sigma(+,+)-\sigma(-,-)}{\sigma(+,+)+\sigma(-,-)}$

P_t	$m_{\tilde{t}}$ (GeV)	$m_{\tilde{\chi}_1^0}$ (GeV)	$\sin(\theta_{\tilde{t}})$	Z_{i1}	Z_{i4}	$\tan(\beta)$
1	500.0	318.6	0.998	0.958	-0.176	7.8
0.5	500.0	321.1	0.998	0.988	-0.0866	7.8
0	500.0	320.5	-0.124	0.975	-0.128	10.0
-0.5	501.1	319.2	0.995	0.440	-0.618	20.0
-0.8	502.0	319.3	-0.0988	0.0232	-0.190	35.0
1	500.7	130.2	0.9928	0.9976	-0.1883	10.
0.5	499.6	129.7	0.9987	0.9164	-0.2112	29.6
0	500.1	129.3	-0.05954	0.9729	-0.1017	35.0
-0.5	500.1	130.3	-0.05948	0.9865	-0.06113	35.0
-1	499.4	130.0	-0.05911	0.9990	-0.007184	35.0

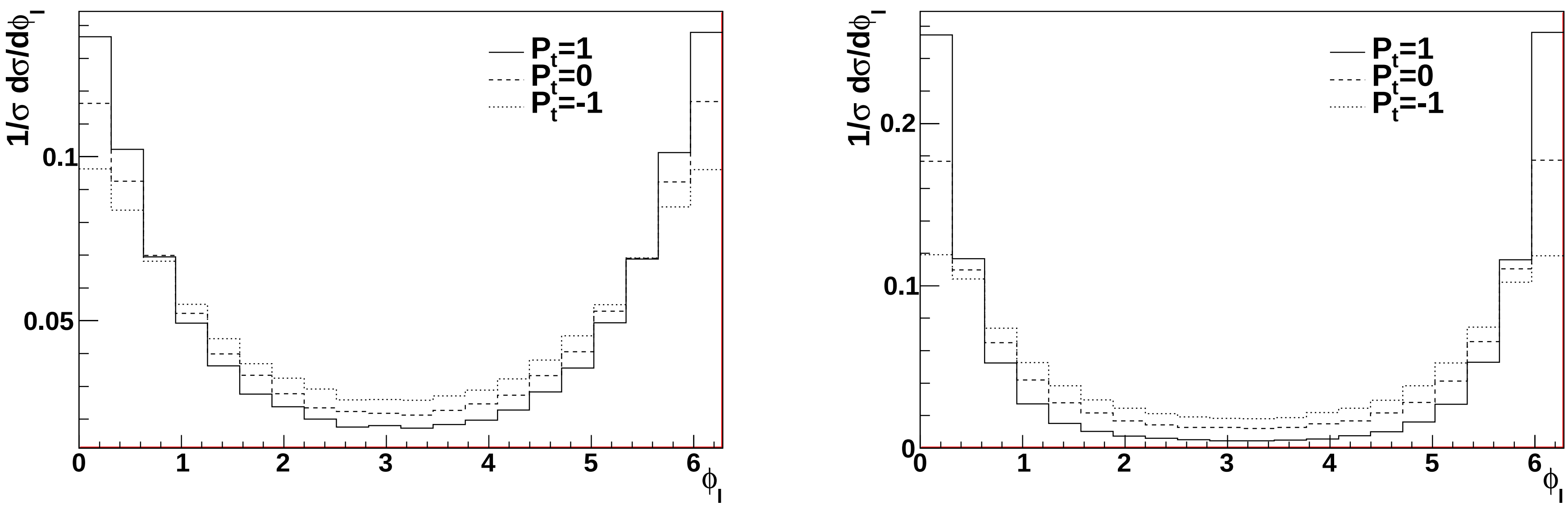
First 5 small mass difference.

Lower 5 large mass difference.





Left corresponds to a small mass difference case and right corresponds to a large mass difference case.



Can be used to construct asymmetries which can measure polarization and we construct this and others.

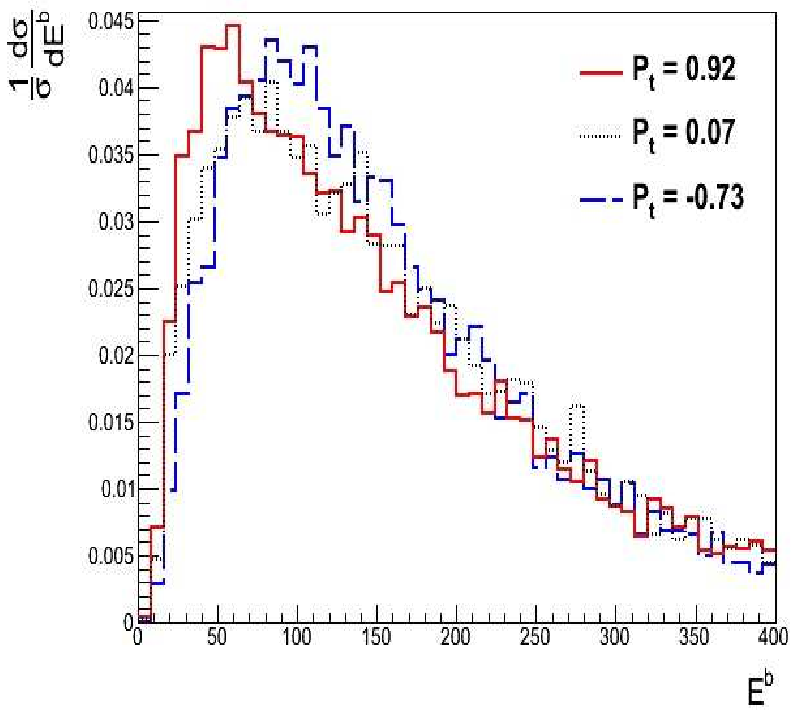
$\tilde{b} \to t\tilde{\chi}_i^-$

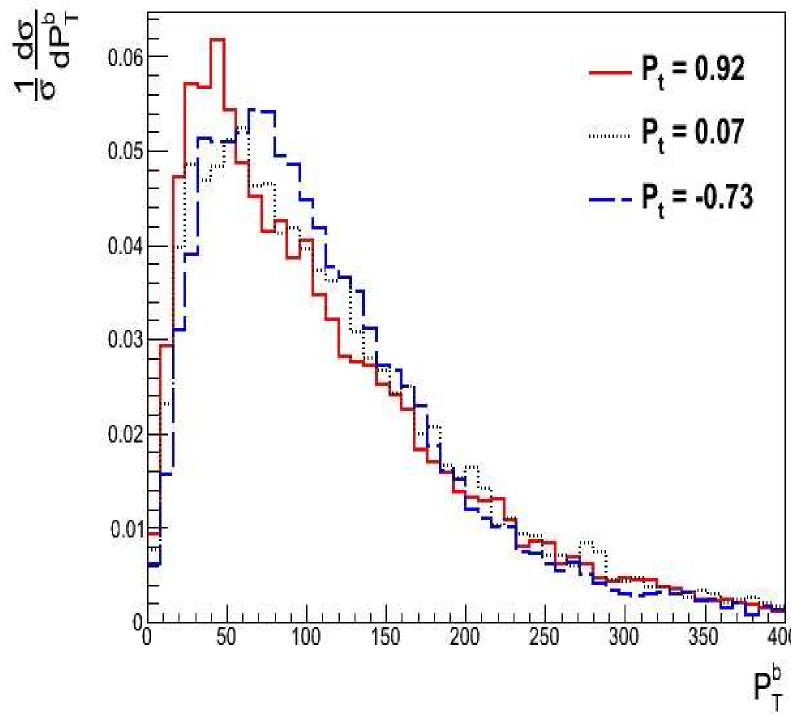
Polarization depends on the composition of the chargino and the bottom.

In addition in the 'natural' scenario likely that $\tilde{b}$ and $\tilde{t}$ both will have comparable masses.

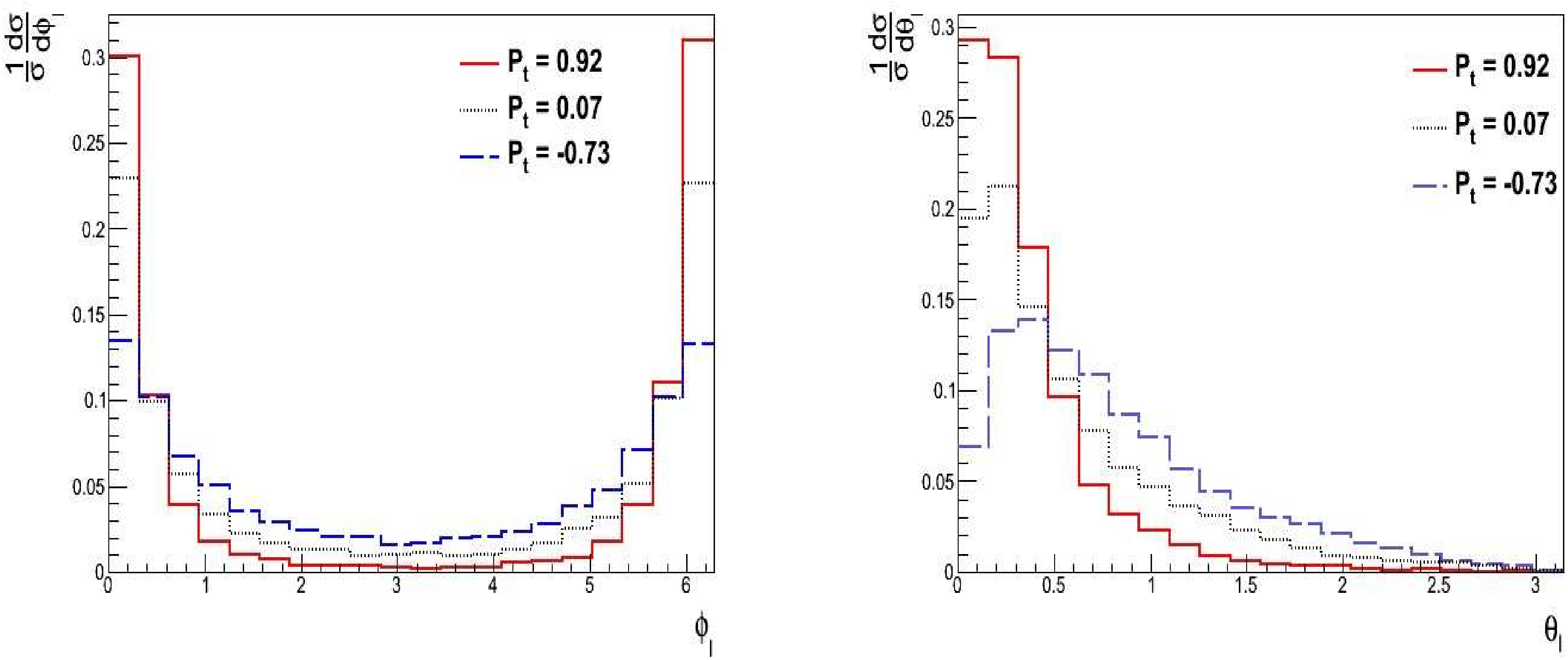
We study dependence on the parameters of this polarization.

Choose benchmarks for similar stop/sbottom mass



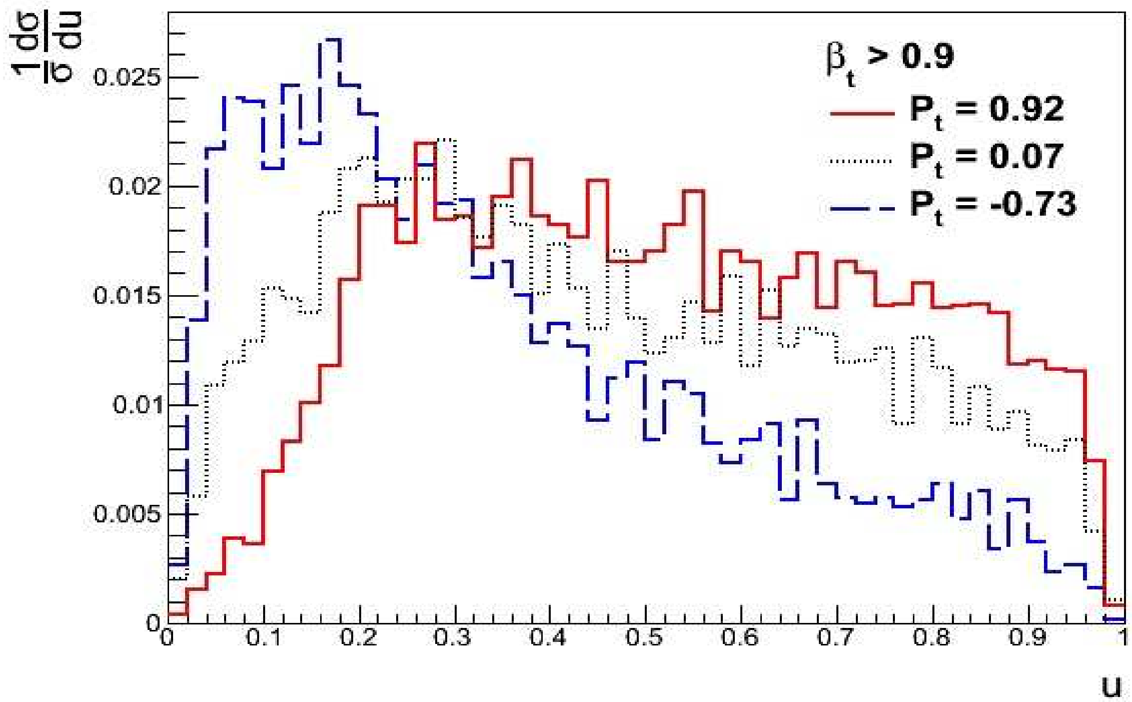


b-jet energy and p_T affected in opposite way than the lepton, though effect less severe. May be one can use the feature to gain the efficiency lost due to softening of the lepton spectrum.



Distributions in θ_l: angle made by the lepton with the top direction and ϕ_l defined earlier.

$u = E_l/(E_b + E_l)$ for $\beta_t \to 1$ tracks the polarization too! (Shelton).



In 'natural' SUSY the top quarks resulting from sfermion decays are polarised.

The polarization of the top quarks depends on the sfermion mixing, gaugino-higgsino mixing, mass difference of the sefermion and EWikino as well as the boost of the produced sfermions

The polarisation affects the kinematic spectrum of the decay products. Negative polarisation softens the lepton spectrum but hardens the b-jet spectrum.

The polarization leads to asymmetries in the different distributions measured in the lab frame. Can be used as a measure of top polarisation.

SM top quarks either left polarised or unpolarised. For higgsino dominated chargino the top in sbottom decay will have a different polarization. Can be employed to increase the sensitivity.