New Physics (SUSY & Non SUSY) and Top Properties.

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- What new physics and what top properties?

- Use of top polarisation/spin spin correlations through kinematic distributions of the decay products of the top, to probe new physics and/or modified top couplings!

- Probes of modified top couplings from cross-sections and/or top distributions.

- Correlation between the probes of top polarisation and the anomalous top decay vertices.unambiguous determination of anom. couplings of the top?

4th July : Higgs independence day! A scalar related to the EWSB seems to be found ☺

It is but the first step in unravelling the puzzle that is EWSB

Study of the properties of this Higgs scalar are of utmost important !

Whenever we try to use measured properties of the Higgs to understand the SM and Beyond the SM **Top quark** is **ubiquitous**.

Now we know the size of **SELF** coupling $\lambda = \frac{m_h}{\sqrt{2}v} \simeq 0.36$.

$m_t \simeq m_h \simeq m_W \simeq \mathcal{O}(v)$

Higgs is observed to be weakly coupled.!

So electroweak scale seems to be stable under radiative corrections .

Keeping this scale stable WAS one of the motivations of expecting physics beyond the SM.

- Dark Matter makes up 23% of the Universe.!
- Direct evidence for the nonzero ν masses
- Quantitative explanation of the Baryon Asymmetry in the Universe!
- Cosmic Acceleration?

- **Instability of the EW scale under radiative corrections.**
- Need to get a basic understanding of the flavour Issue
- Unification of couplings
- Inclusion of Gravity in the picture?
- Dark Energy!

The ones above the line are the observational reasons to expect the BSM!

The ones below the line are the asthetic theoretical reasons!

The one in bold face is the ONLY one which **requires** TeV scale new physics!

We have a **light** Higgs but **NO** evidence **so far** for **BSM** physics we expected.

So properties of the Higgs sector may be the window to the BSM land !

Whenever, one starts analyzing the observed features of the Higgs sector, the ubiquitous top plays an important role everywhere!

Remember! Within the SM, for the measured mass of the observed scalar, the conclusion about the state of the vacuum depends on m_t due to its large Yukawa couplings.

Top quark has an important role to play in almost all the ideas of BSM! **Along with the Higgs properties the Top properties may carry the imprint of the BSM physics!**

Studying the top properties is ONE way towards BSM!

How does BSM affect the produced top?

We must then have some idea how the BSM affects the properties of the top quark that is produced at the colliders.

BSM has new particles and almost always there are partners of the top scalar top $\tilde{b}$ in SUSY, spin 1/2 T in Composite Higgs models / UED models.

Most BSM options involve new particles, for example $H^{\pm}$, Z'.

Tree level couplings of the t quark to these new particles have different chiral structure than in the SM!

In the SM:

$\bar{t}t$ couplings with a gauge boson

Either pure vector for a gluon (QCD) : $\mathcal{L}^{int} \sim \bar{t}_{L/R}\gamma^{\mu}t_{L/R}G_{\mu}$

V-A for a Z: $\bar{t}_{L/R}\gamma\mu t_{L/R}Z_{\mu}$ and $\bar{t}_{L/R}\gamma\mu\gamma_5 t_{L/R}Z_{\mu}$

Pure left handed for W: $\bar{t}_L\gamma^{\mu}b_L W_{\mu}$

AND

The chirality flipping $t\bar{t}h$ coupling: $\bar{t}_L t_R h$

Properties of the top produced in the processes involving the new BSM particles can be different from the top quarks produced via the SM processes and can carry the imprint of the BSM.

Since all the BSM options address the issue of EWSB, in many of them, the couplings of the top quark to the new particles can have a different chiral structure than the SM case.

Recall that **at the LHC** all the SM $t\bar{t}$ production via QCD will produce unpolarized top quarks! Only the single top will be polarized and the polarization completely predicted!

Hence polarization of the produced top quarks can be a very important discriminator of BSM physics.

When t and $\bar{t}$ are produced, a useful observable is top spin correlation:

(Bernreuther, Uwer, Si: extensive calculations)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_a d\cos\theta_b} = \frac{1}{4}(1 + B_1\cos\theta_a + B_2\cos\theta_b - C\cos\theta_a\cos\theta_b)$$

This has been very well studied theoretically (for example: $t\bar{t}H$, $t\bar{t}$ produced in RS Graviton decay etc.)

It is conceivable that single top polarization can give better statistics

Happy coincidence:

The happy coincidence is that top quark is the only quark whose polarisation we can measure quite easily.

Why? The top quark being very heavy decays before it hadronises. The decay products therefore carry memory of the direction of the top spin!

One can measure these either by reconstructing the top rest frame OR kinematical distributions in the laboratory.

Measurements are on spin correlations available from the Tevatron and the LHC: CDF conference note 10719, D0: PRL, 108, 032004, (2012), ATLAS: 1307.6511 (Submitted to PRL)..

General studies in terms of effective operators is the most popular. Particularly since we scale of new physics is being pushed higher!

J.A. Aguilar-Saavedra, NPB,843, (2011), 638, + J. Bernabeu, NPB 840 (2010), 349...., C. Degrande, N. Greiner, W. Kilian, O. Mattelaer, H. Mebane, T. Stelzer, S. Willenbrock and C. Zhang, Annals Phys. **335**, 21 (2013)

$$\mathcal{L}^{eff} = \sum \frac{C_i}{\Lambda^2} \mathcal{O}_i$$

Various studies exist. I will talk only in terms of the strengths of anom. couplings which can then be translated in terms of the scale of new physics! Operators involving Higgs expected to have smaller suppression!

A partial summary of LHC prospects available in J. Adelman et al, 1309.1947, 1308.5274 More references as we go along.

General $\bar{t}bW$ vertex can be written as

$$\Gamma^\mu = \frac{g}{\sqrt{2}} \left[\gamma^\mu (f_{1L} P_L + f_{1R} P_R) - \frac{i\sigma^{\mu\nu}}{m_W} (p_t - p_b)_\nu \, (f_{2L} P_L + f_{2R} P_R)\right].$$

In SM, $f_{1L} = 1$, $f_{1R} = f_{2L} = f_{2R} = 0$.

Deviations from these values will denote "anomalous" couplings

Older limits: Bernreuther W., J. Phys. G., Nucl. Part. Phys. 35 (2008) Only f_{2R} can be nontrivial. $-0.57 < f_{2R} < 0.15$

CMS constraint: $-0.070 \pm 0.053(+0.073 - 0.081)$ Using W-helicity fractions from t-decay in $t\bar{t}$ events.

Will discuss probing CP violation in this as well as effects of this on probes of top polarisation.

$$\phi f \bar{f} \quad : \quad -\bar{f}(a_f + i b_f \gamma_5) f \frac{g m_f}{2 m_W}, \quad \textbf{(mixedCP)}$$

$$\phi^+ \bar{t} b \quad : \quad (m_b \tan\beta \bar{t}_L b_R + \bar{t}_R b_L m_t \cot\beta) \frac{g}{\sqrt{2} M_W} \quad \textbf{(Type II 2HDM)}$$

In the SM $a_f = 1, b_f = 0$

In 2HDM and SUSY: There exist both CP even and CP odd scalars.

For a pure CP even state $b_f = 0$. For a pure CP odd state $a_f = 0$. For case of CP violation both a_f, b_f nonzero simultaneously.

The charged Higgs vertex involves t of both chiralities.

WIll discuss probing this through top polarisation.

Top chromomagnetic or chromoelectric dipole moment:

$$\Gamma^{\mu} = \frac{g_s}{m_t}\, \sigma^{\mu\nu} \left(\rho + i\rho' \gamma_5\right) q_{\nu}$$

q 4 momentum of the gluon and color matrices left out.

$\rho = \rho' = 0$ in the SM at tree level.

ρ' : CP violating arises in the SM only at three loop level.

ρ Arises at one loop level in the SM.

Examples of BSM predictions: MSSM: J. M. Yang and C. S. Li, Phys. Rev. D **54**, 4380 (1996) 2HDM: R. Martinez and J. A. Rodriguez, Phys. Rev. D **65**, 057301 (2002)

The new couplings affect rates of production of top pair, single top AND Higgs!

Can be used to probe these couplings: Some of the recent papers:

Top pair: S.K. Gupta, G. Valencia PRD 81, 034013, 2010, S.K. Gupta, G. Valencia, A.S. Mete, PRD80, 2009, 034013, Z. Hioki and K. Ohkuma, EPJC, 71, 2011, 1535 , .. D. Choudhury and P.Saha, Pramana, 77, 2011, 1079 S. Biswal, S.D. Rindani, P. Sharma, hep-ph/1211.4075, Baumgart and Tweedi, hep-ph/1212.4888

Higgs signal strength: C. Grojean et al, 1205.1065, P. Saha and D. Choudhury, 1201,4130

The papers in this color consider rates. Already interesting constraints. BUT depend on QCD uncertainties on the rates. The papers in in this color consider either polarisation and/or spin spin correlations.

Important to use these cross-checks. Also CP violation can be probes unambiguously ONLY using polarisation. Will discuss this time permitting.

M. Perelstein and A. Weiler, JHEP **0903**, 141 (2009), B. Bhattacherjee, S. K. Mandal and M. Nojiri, JHEP **1303**, 105 (2013), G. Belanger, R. M. Godbole, L. Hartgring and I. Niessen, JHEP **1305**, 167 (2013), G. Belanger, R. M. Godbole, S. Kraml and S. Kulkarni, arXiv:1304.2987 [hep-ph]

In these relationship of expected polarization on model parameters as well as measurement strategies explored and effects of polarization on kinematics of the decay products considered.

E. L. Berger, Q. -H. Cao, J. -H. Yu and H. Zhang, PRL **109**, 152004 (2012),

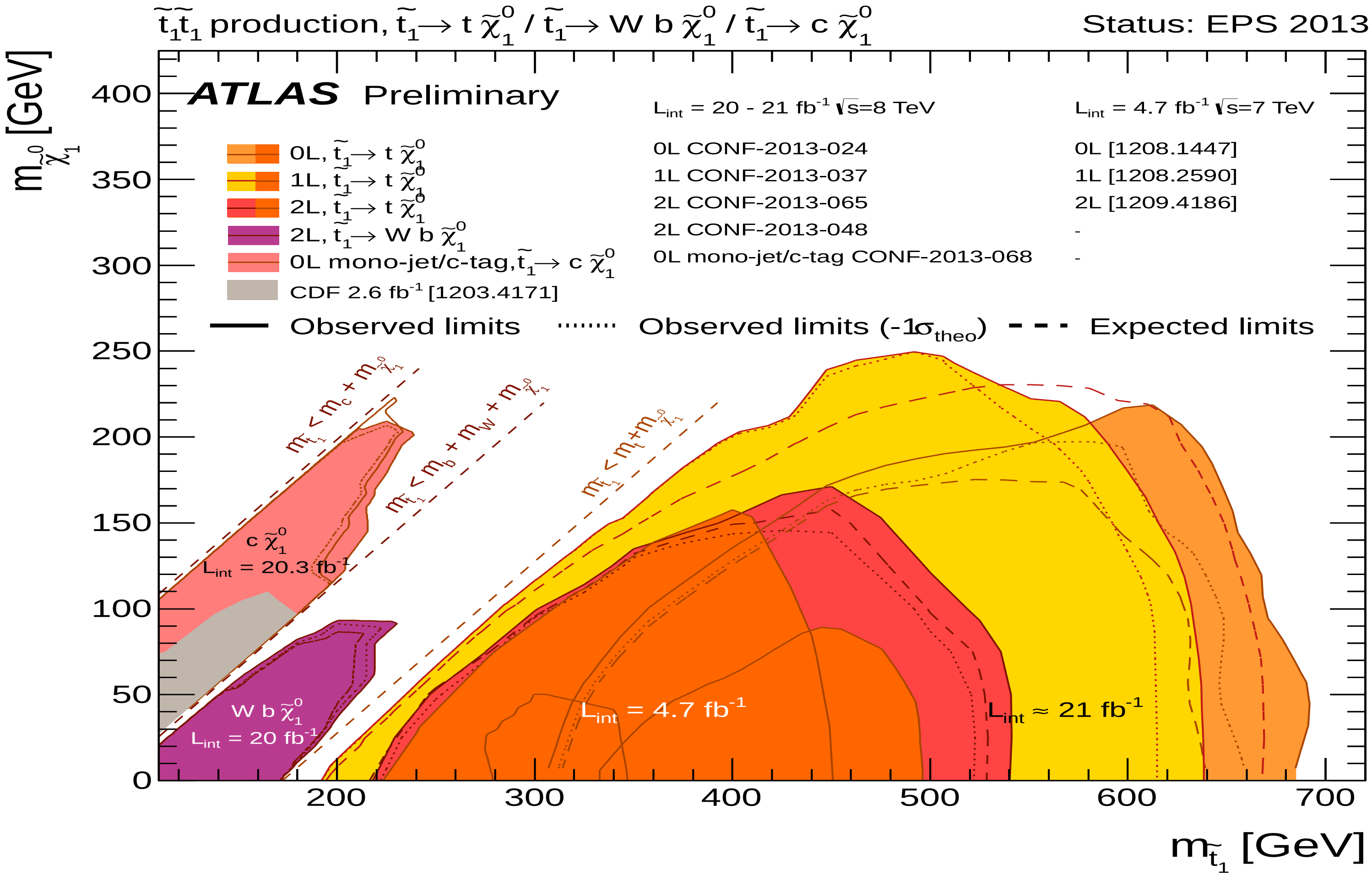
Here mainly effect on decay kinematics explored.

- 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..

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

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


$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to t\,\tilde{\chi}_1^0$ / $\tilde{t}_1 \to W\,b\,\tilde{\chi}_1^0$ / $\tilde{t}_1 \to c\,\tilde{\chi}_1^0$
Status: EPS 2013
ATLAS Preliminary
L_{int} = 20 - 21 fb^{-1} $\sqrt{s}$=8 TeV
L_{int} = 4.7 fb^{-1} $\sqrt{s}$=7 TeV
0L, $\tilde{t}_1 \to t\,\tilde{\chi}_1^0$
1L, $\tilde{t}_1 \to t\,\tilde{\chi}_1^0$
2L, $\tilde{t}_1 \to t\,\tilde{\chi}_1^0$
2L, $\tilde{t}_1 \to W\,b\,\tilde{\chi}_1^0$
0L mono-jet/c-tag, $\tilde{t}_1 \to c\,\tilde{\chi}_1^0$
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 ($-1\sigma_{theo}$)
Expected limits
$m_{\tilde{t}_1} < m_c + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_b + m_W + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$
c $\tilde{\chi}_1^0$
L_{int} = 20.3 fb^{-1}
W b $\tilde{\chi}_1^0$
L_{int} = 20 fb^{-1}
L_{int} = 4.7 fb^{-1}
L_{int} ≈ 21 fb^{-1}
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [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.

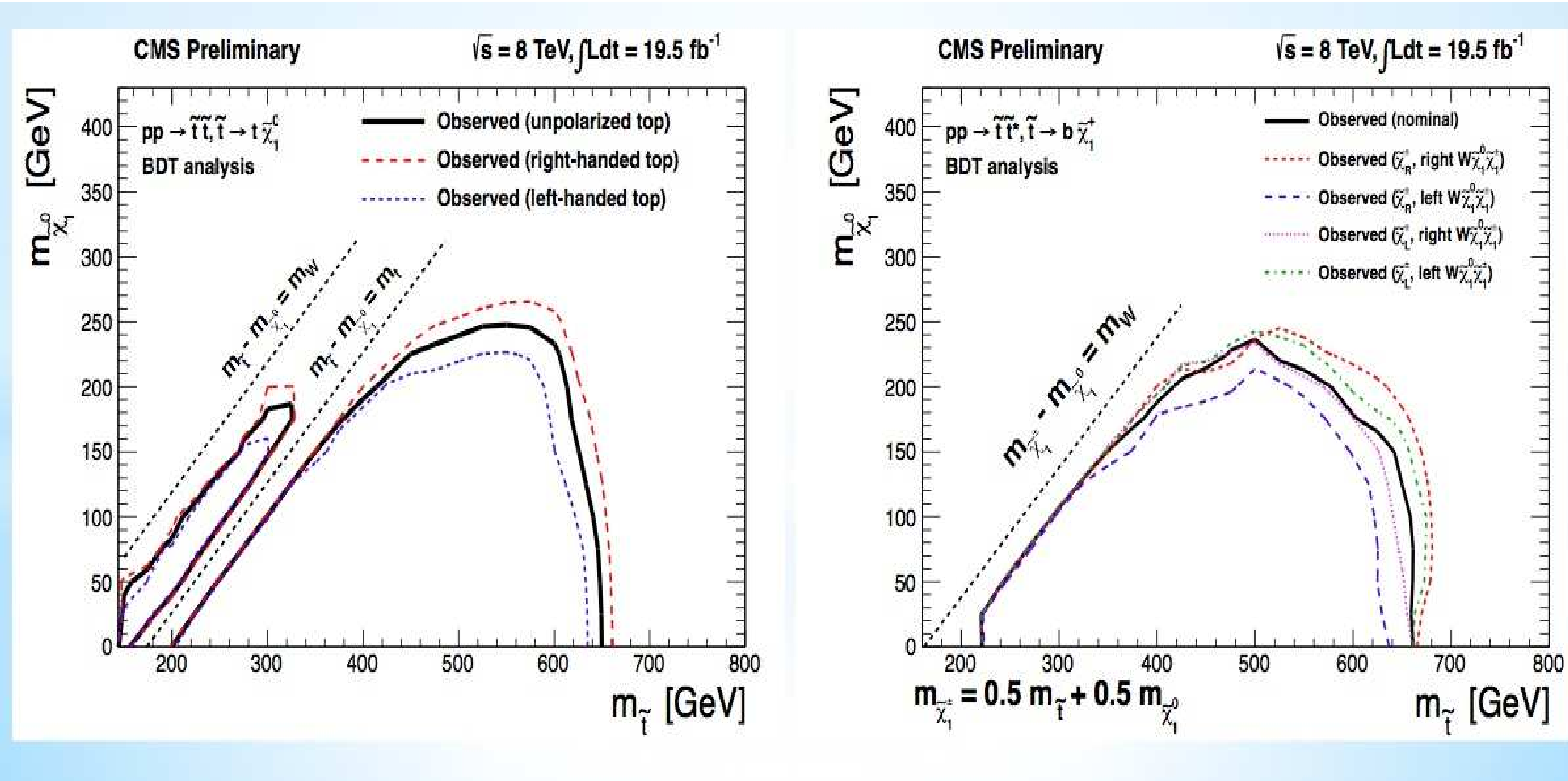
In SUSY the expected top polarization depends on many things, among them on the mixing in the sfermion sector as well as on the mixing in the EWiikno sector.

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

So this polarization important from two points of views:

1)Effect on search strategy

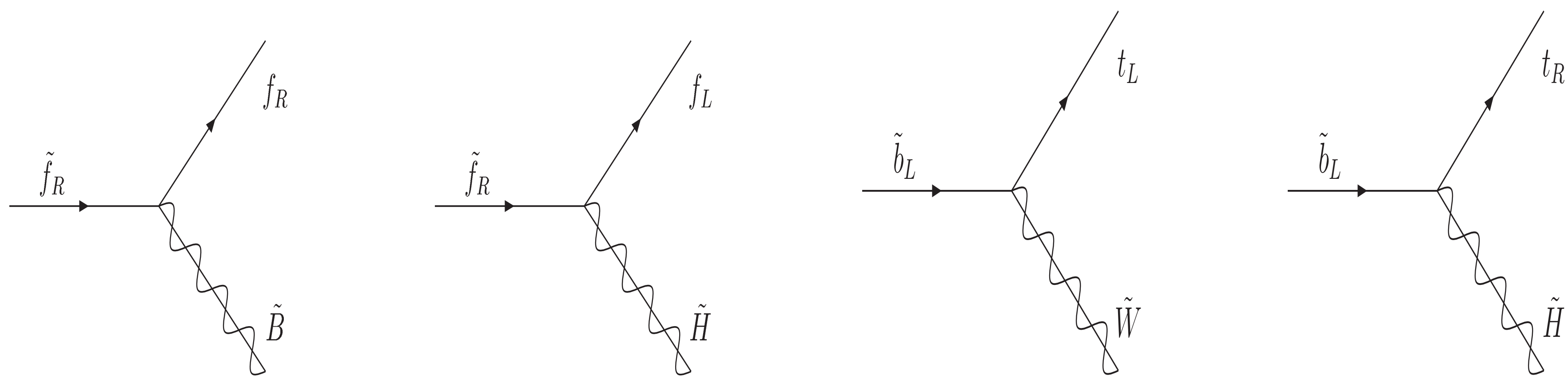
2)Once the stop is found how to use measured polarization to get information on model parameters.



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]

$f = t/\tau$



- 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**.

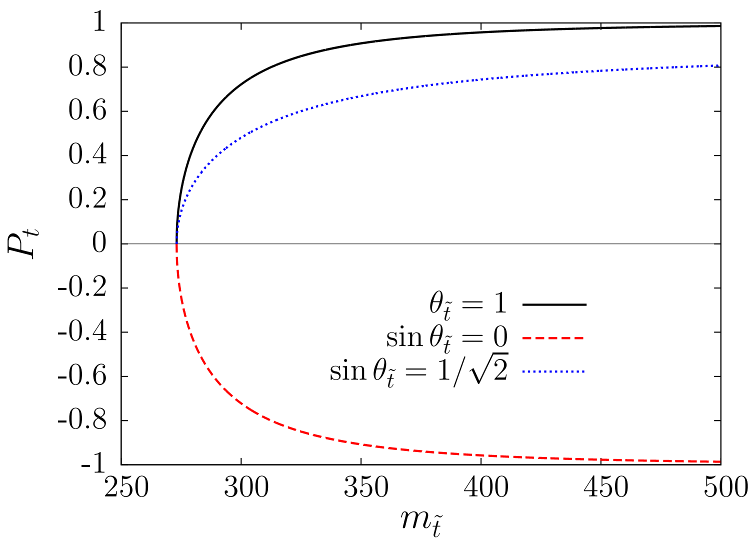
□ Net helicity of produced f in the decay $\tilde{f}_i \to \tilde{\chi}_j^0 f$ AND $\tilde{f}_i \to \tilde{\chi}_j^{\pm} f'$ depends on the L–R mixing in the sfermion sector and on the gaugino-higgsino mixing.

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

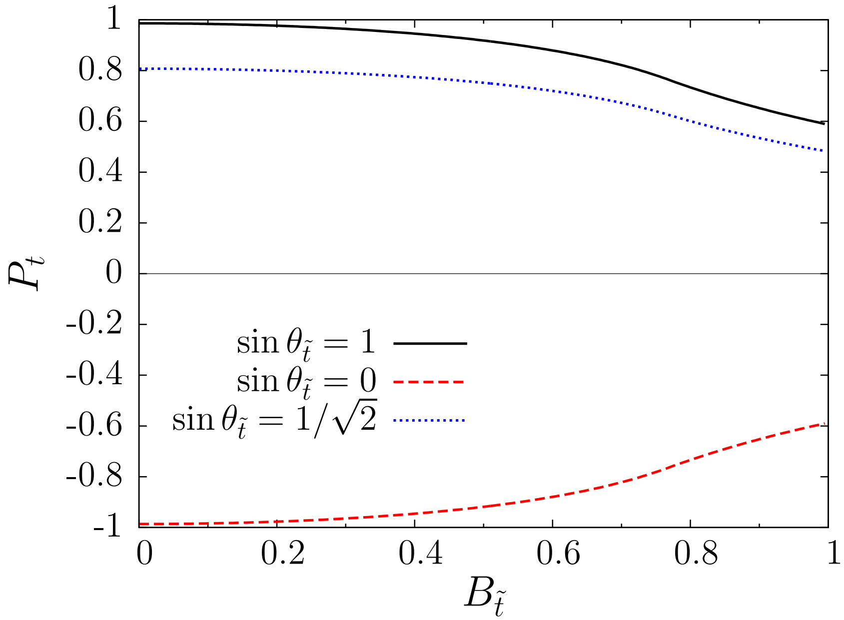
Depends on the kinematics, ie. the masses involved. This comes because of the difference in helicity and chirality. So essentially arise from the finite mass of the top quark.

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.

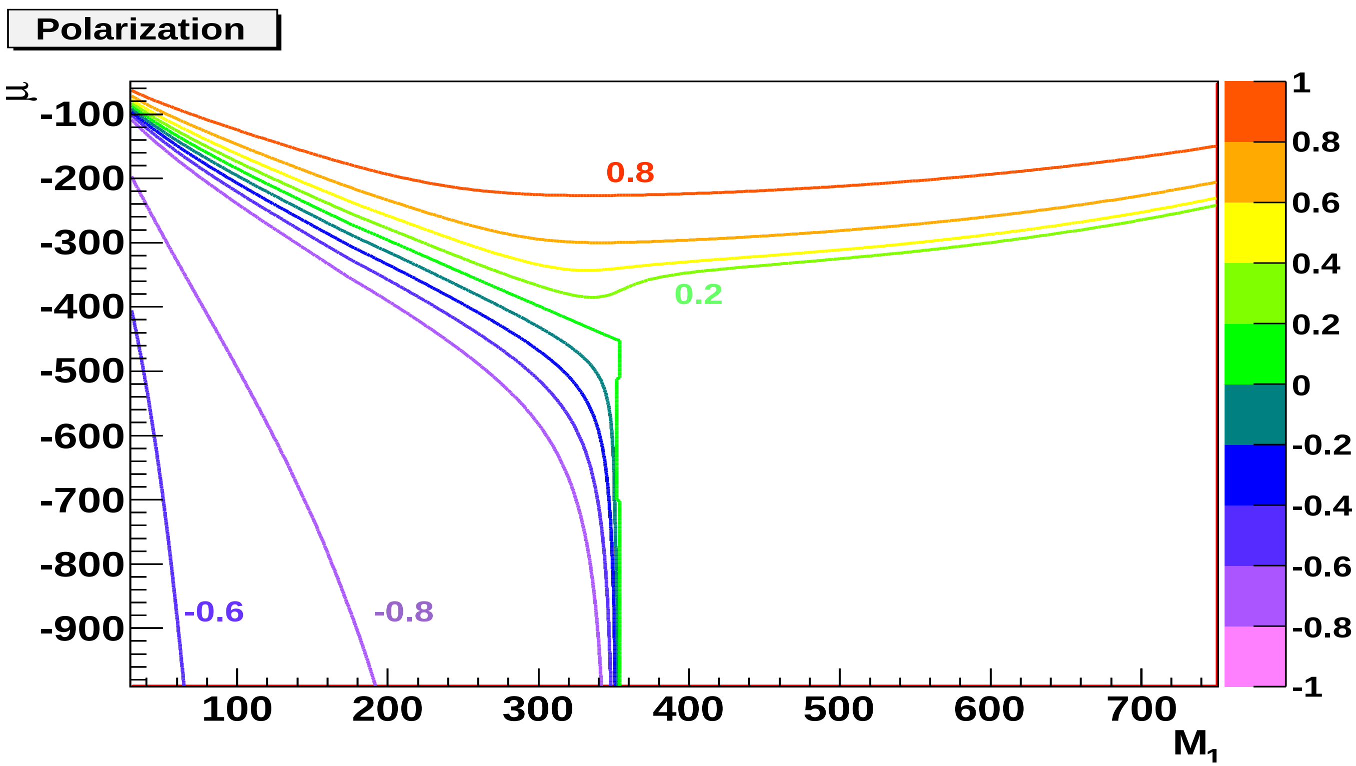


For a fixed neutralino mass of 100 GeV and $\tan\beta = 10$. Polarization in the stop rest frame, for a pure Bino state.



Stop boost tends to reduce the polarization.

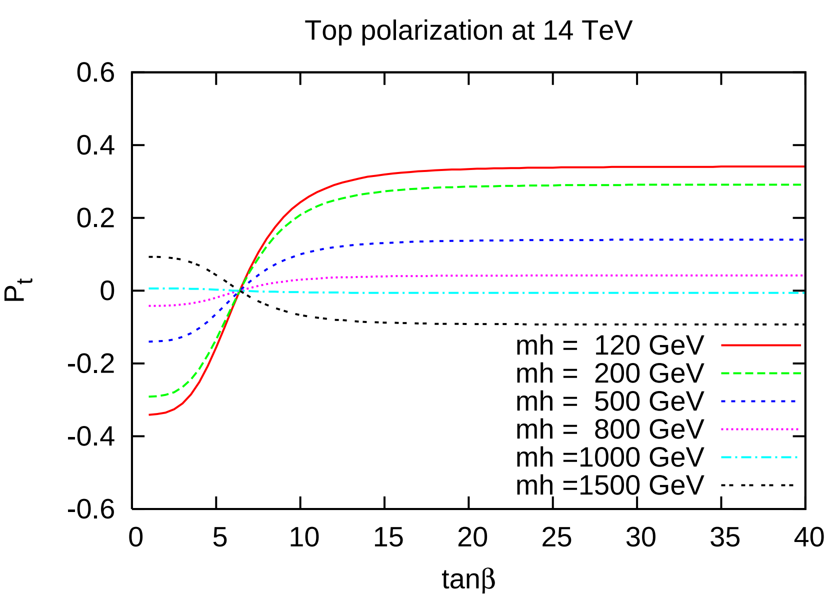
However, for the values of stop and neutralino masses now being considered for searches this effect is not so drastic.

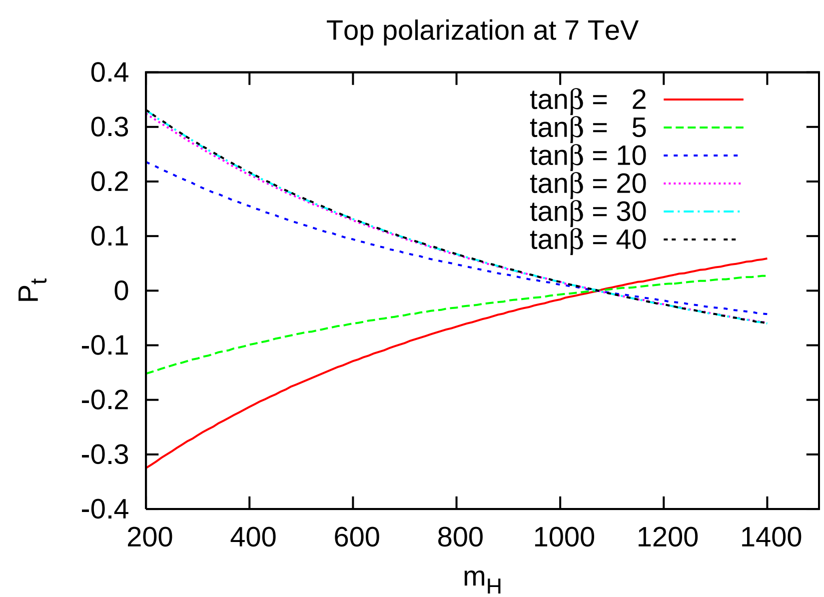


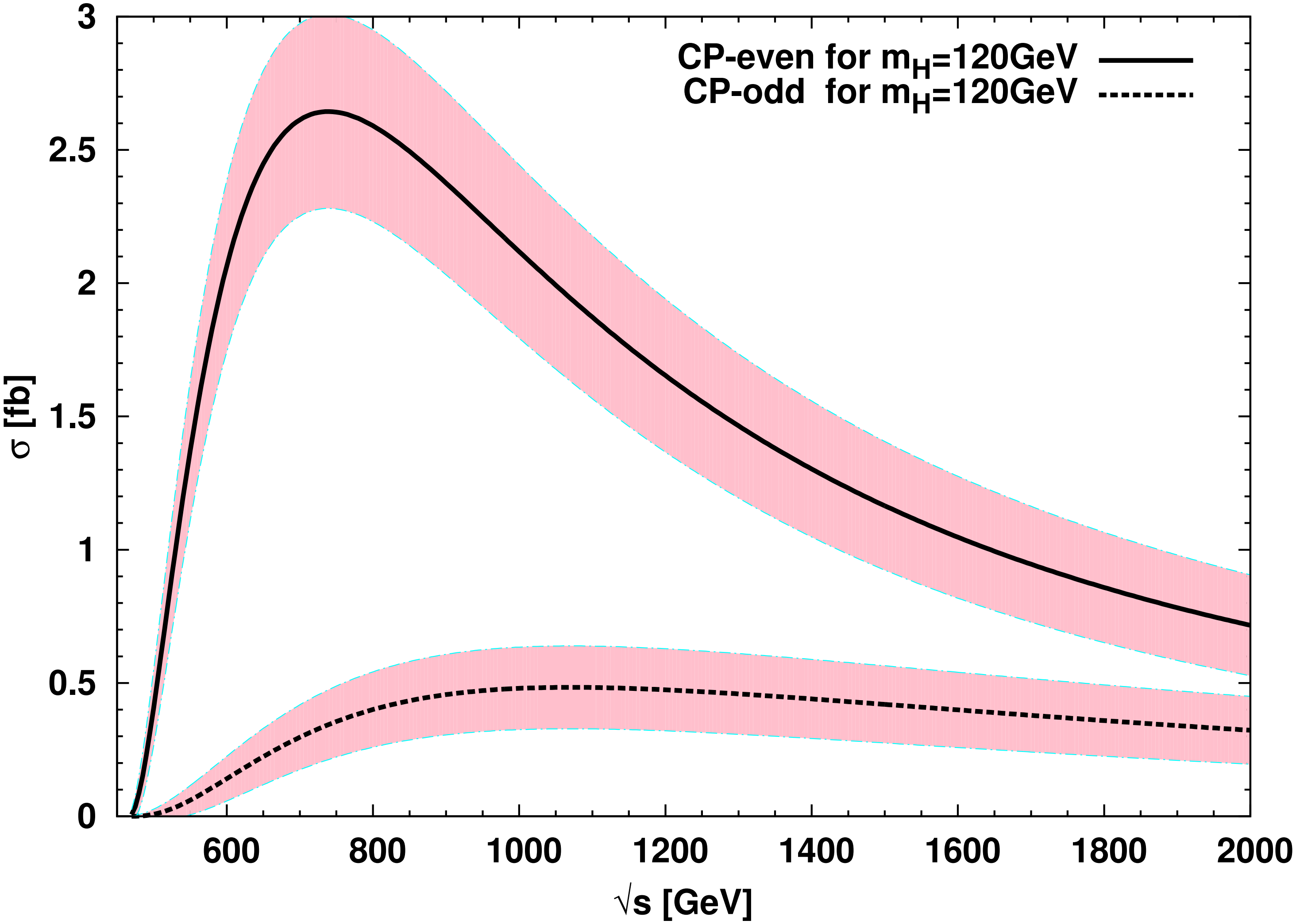
Belanger, Godbole, Niessen, Hartring: 1212.3526

$W^- t$ production : t will be left polarised, $H^- t$ production: t polarisation depends on $\tan\beta$, and m_t.

Extracting charged higgs couplings: K. Huitu, S. Kumar Rai, K. Rao, S. D. Rindani and P. Sharma, JHEP **1104**, 026 (2011), [arXiv:1012.0527 [hep-ph].






CP-even for m_H=120GeV
CP-odd for m_H=120GeV
σ [fb]
√s [GeV]
0
0.5
1
1.5
2
2.5
3
600
800
1000
1200
1400
1600
1800
2000

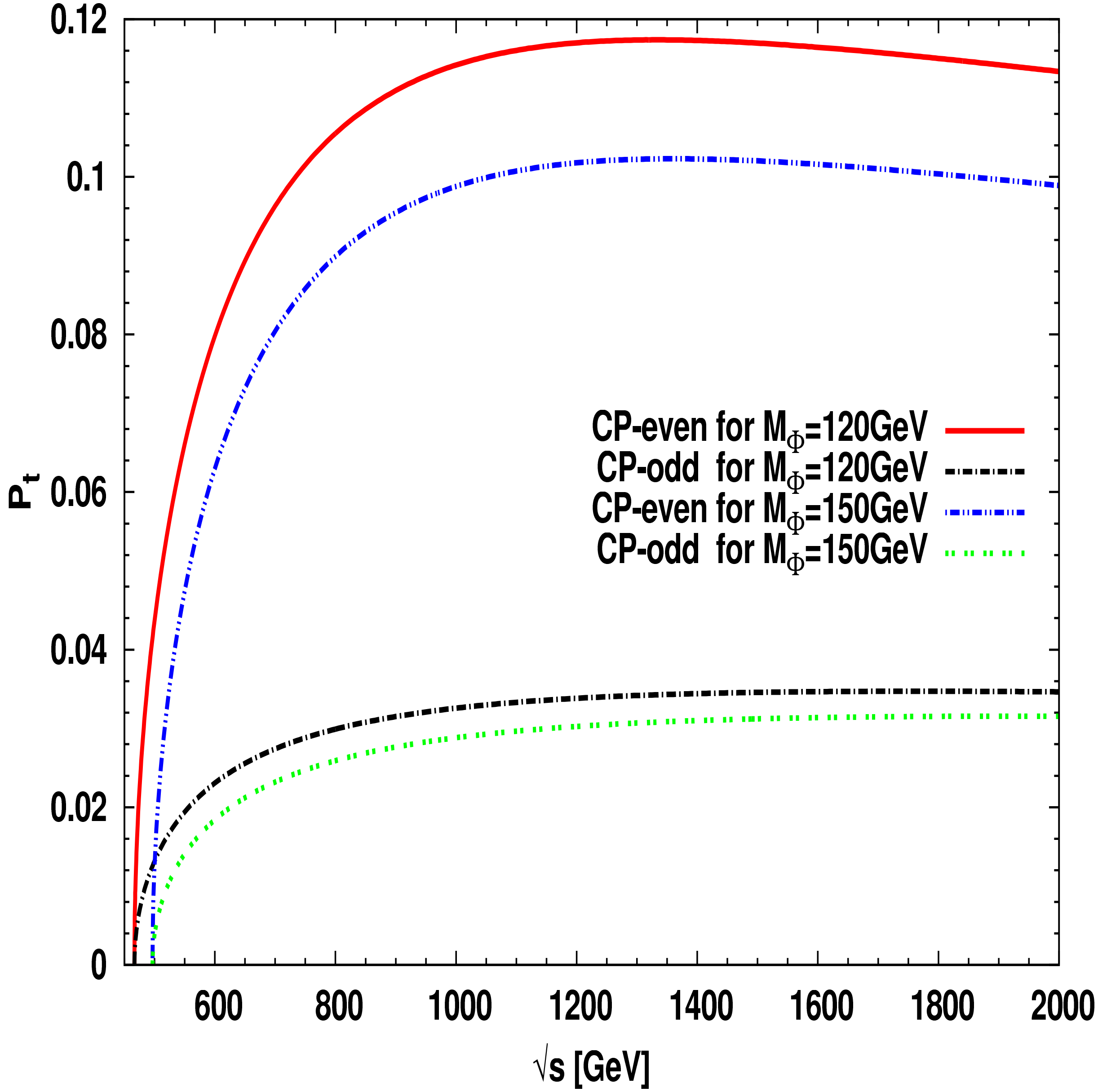
Threshold dependence very different for scalar and pseudoscalar. Steep dependence (S vs P wave).

Define $\rho = 1 - 2m_t/\sqrt{s} - M_\Phi/\sqrt{s}$

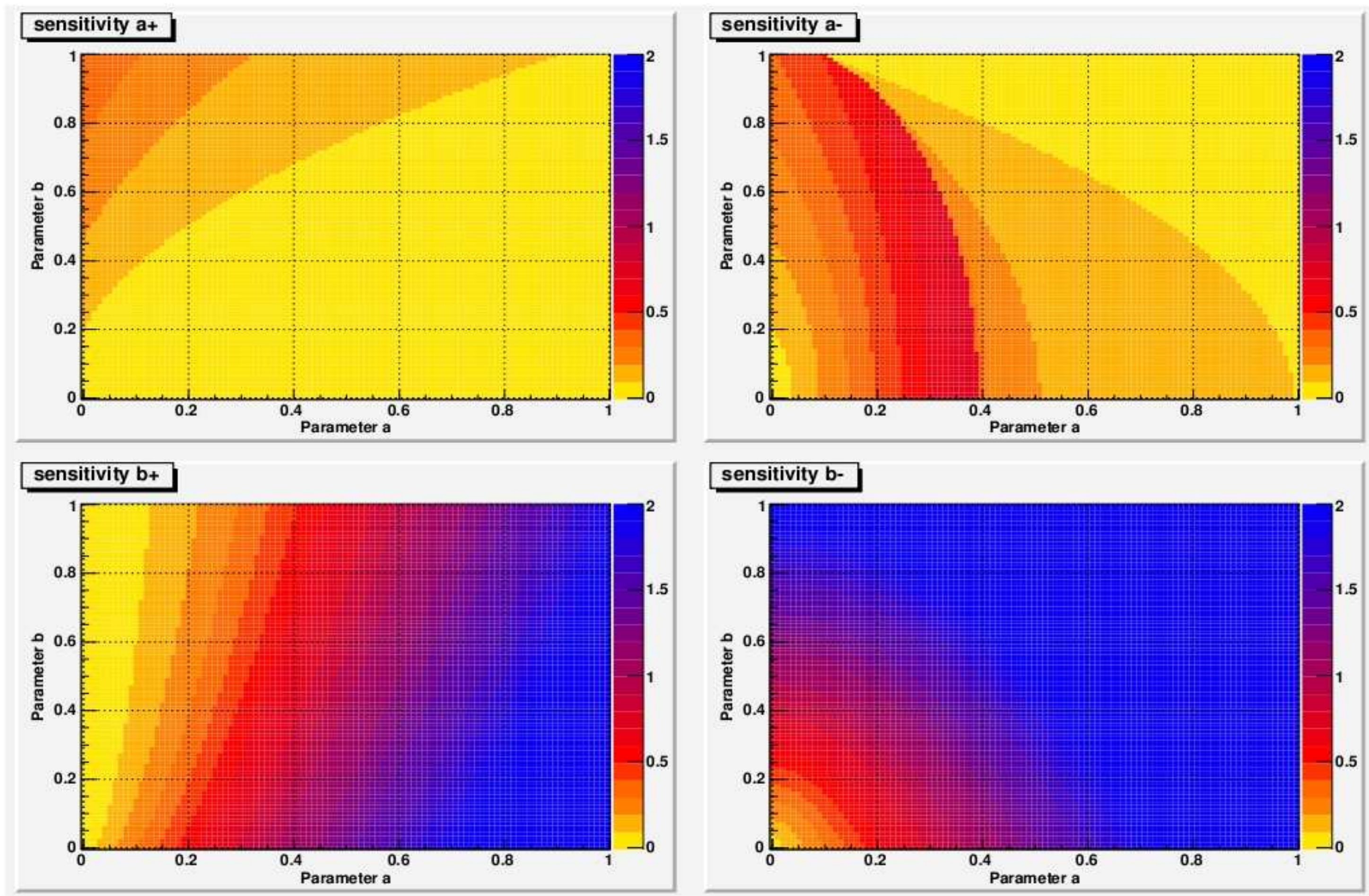
$$F_1^H = -F_2^H \simeq 12 \left[m_t^2/(M_H\sqrt{s})\right]^{3/2} \rho^2 \quad F_1^A = -F_2^A \simeq 4 \left[m_t^4/(M_A s\sqrt{s})\right]^{1/2}$$

May be just two measurements, at 500 and (say) 800, would see the difference. For $M_\phi = 120$ GeV, the ratios for H and A are 7.5 and 63, as $\sqrt{s}$ changes from 500 to 800 GeV.

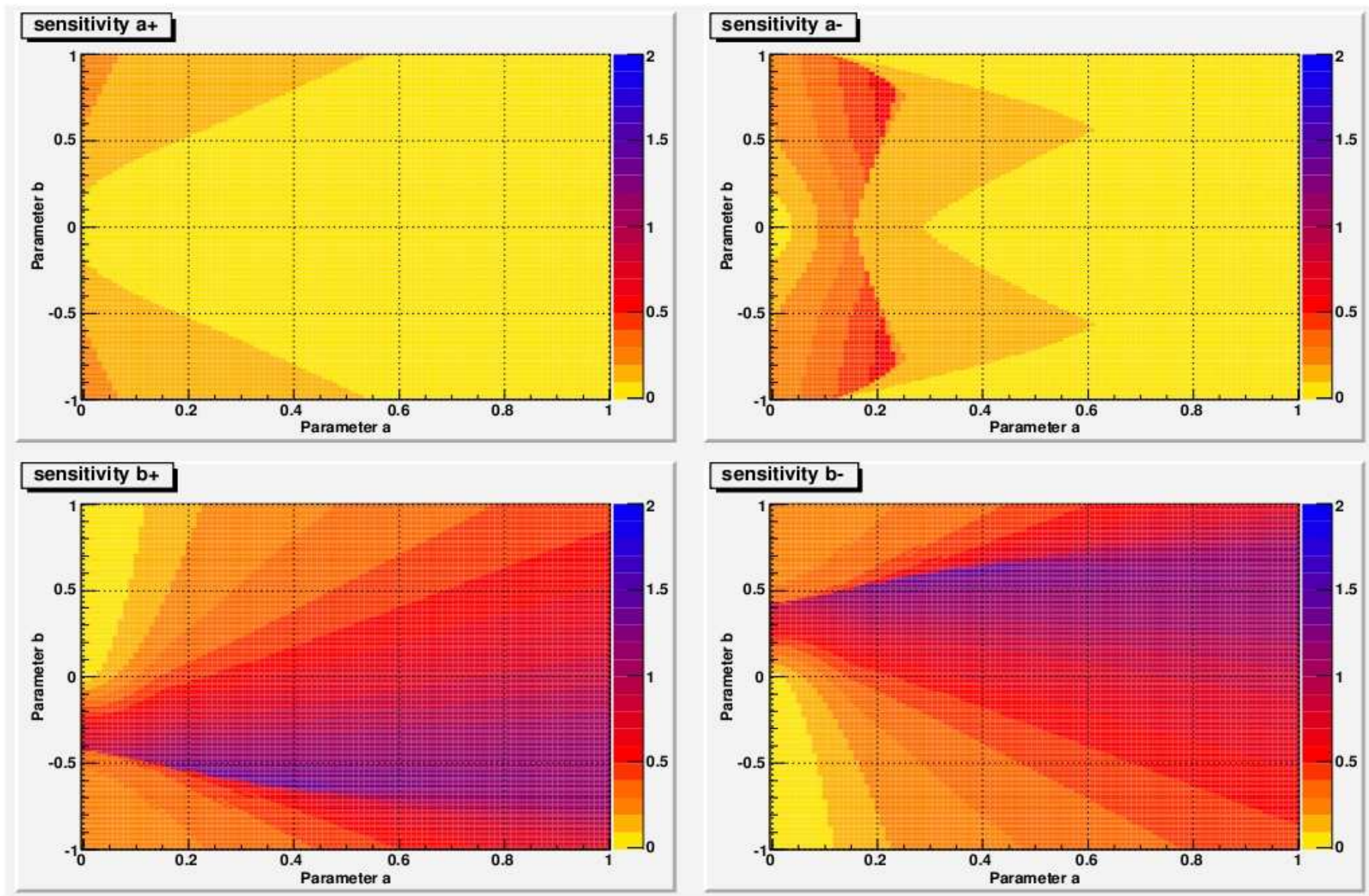
Recall: radiative corrections are also substantial. So taking ratios is a good idea. Polarisation shows similar energy dependence and is again different for H(b=0,a=1) and A(b=1,a=0).


0.12
0.1
0.08
0.06
0.04
0.02
0
P_t
600
800
1000
1200
1400
1600
1800
2000
$\sqrt{s}$ [GeV]
CP-even for M_Φ=120GeV
CP-odd for M_Φ=120GeV
CP-even for M_Φ=150GeV
CP-odd for M_Φ=150GeV

With just cross-section a is well restricted, b not very well. For $\sqrt{s} =$ 800 GeV with ILC TDR choice of polarisation, 1-σ.


sensitivity a+
sensitivity a-
sensitivity b+
sensitivity b-
Parameter a
Parameter b

Adding information on p_t helps. Polarisation crucial, interplay between σ and p_t helps decrease the error on a. At this energy up-down asymmetry does not do much.


sensitivity a+
sensitivity a-
sensitivity b+
sensitivity b-
Parameter a
Parameter b
0
0.2
0.4
0.6
0.8
1
-1
-0.5
0.5
1.5
2

Various new physics explanations suggested.

Could be just due to the loop effects in the SM?

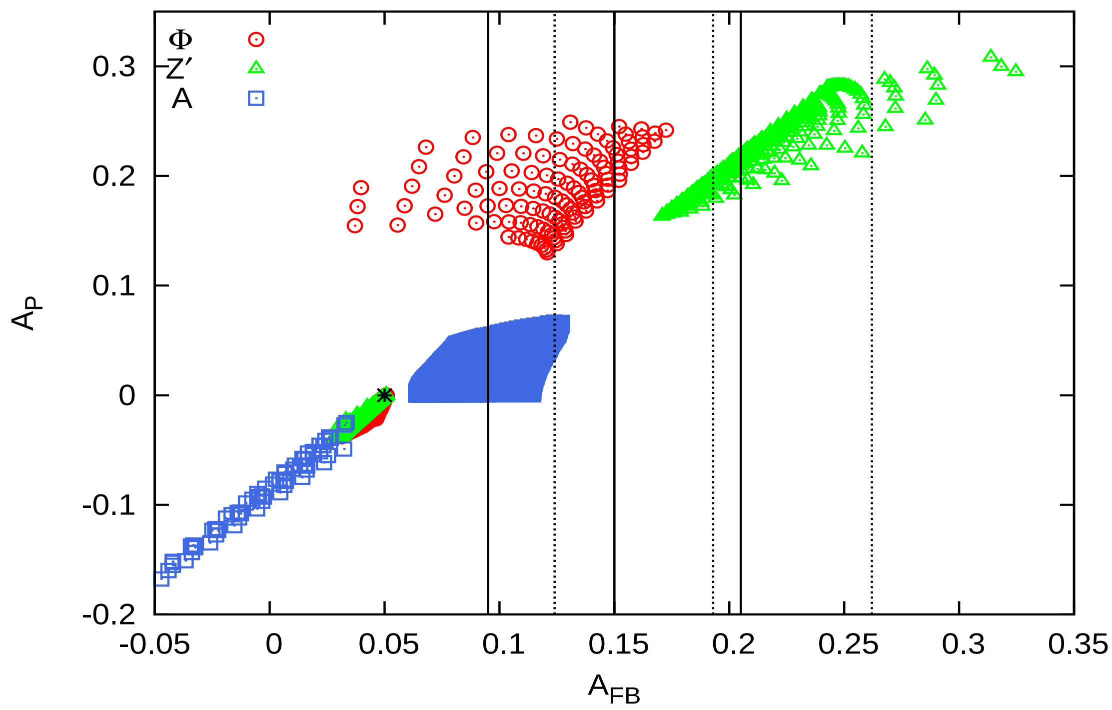
Could be due to t channel exchange of light objects

Could be due to s channel vector production?

The new interactions have different chiral structure.

Some times the A^t_{FB} simply comes from kinematical effects sometimes from parity violating effects.

One can use top polarization to distinguish among them!



In all the three different models expected top polarisation quite different for different physics explanations.

Corrleation between top polarisation and FB asymmetry quite different.

Exploring Measurement of top polarisation a useful tool to get information on production mechanism.

Φ : Tait et al colour triplet/sextet scalar Z': Murayama, Wells t–channel vector A: Flavour nonuniversal axigluons.

There are more analyses which have looked at the polarisation:

J. Cao, L. Wu, J. M. Yang, arXiv:1011.5564 [hep-ph] (three specific models). Only for LHC, also correlation with $\sigma_{t\bar{t}}$ is not implemented.

D. -W. Jung, P. Ko, J. S. Lee, arXiv:1011.5976 [hep-ph], model independent analysis Masses not large enough. Direct contact of the models with this analysis?.

D. Krohn et al, arXiv:1105.3743

New analysis where spin spin correlations are used:

M. Baumgart, B. Tweedie [arXiv:1104.2043 [hep-ph]]

E. L. Berger, Q. -H. Cao, C. -R. Chen and H. Zhang, PRD **88** (2013) 014033: correlation of A^t_{FB} with A^{ll}_{FB} caused by polarization.

Polarisation can be measured by studying the decay distribution of a decay fermion f in the rest frame of the top:

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

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

κ_f depends on the weak isospin and the mass of decay product f.

The analyzing power k_f for various channels is given by:

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

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

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

- **The charged lepton or d quark has the best analysing power**

Leading QCD corrections to κ_b and κ_u, κ_d are of order a few per cent. QCD corrections decrease $|\kappa|$ [Brandenburg,Si,Uwer 2002]

κ also affected by corrections to the form of the tbW coupling ("anomalous couplings")

It is useful to have a way of measuring polarization independent of such corrections.

Also useful is distribution in lab. frame, rather than in top rest frame.

The angular distribution of charged leptons (down quarks) from top decay in the rest frame not affected by anomalous tbW couplings (to linear order) Rindani, Singh, Godbole is:

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

Angular distributions of the decay lepton in the lab are not affected by the anomalous parts of the tbW vertex. (Observed first in different processes: Hioki and B. Grzadkowski, Rindani) Followed by (Ohkuma, R. Singh et al) A general analysis: RG, S. Rindani and R. Singh. Now a general argument: R.G., M. Peskin,S. Rindani, R. Singh

On the other hand the decay lepton energy distributions in the laboratory contain some piece due to the anomalous couplings as well.

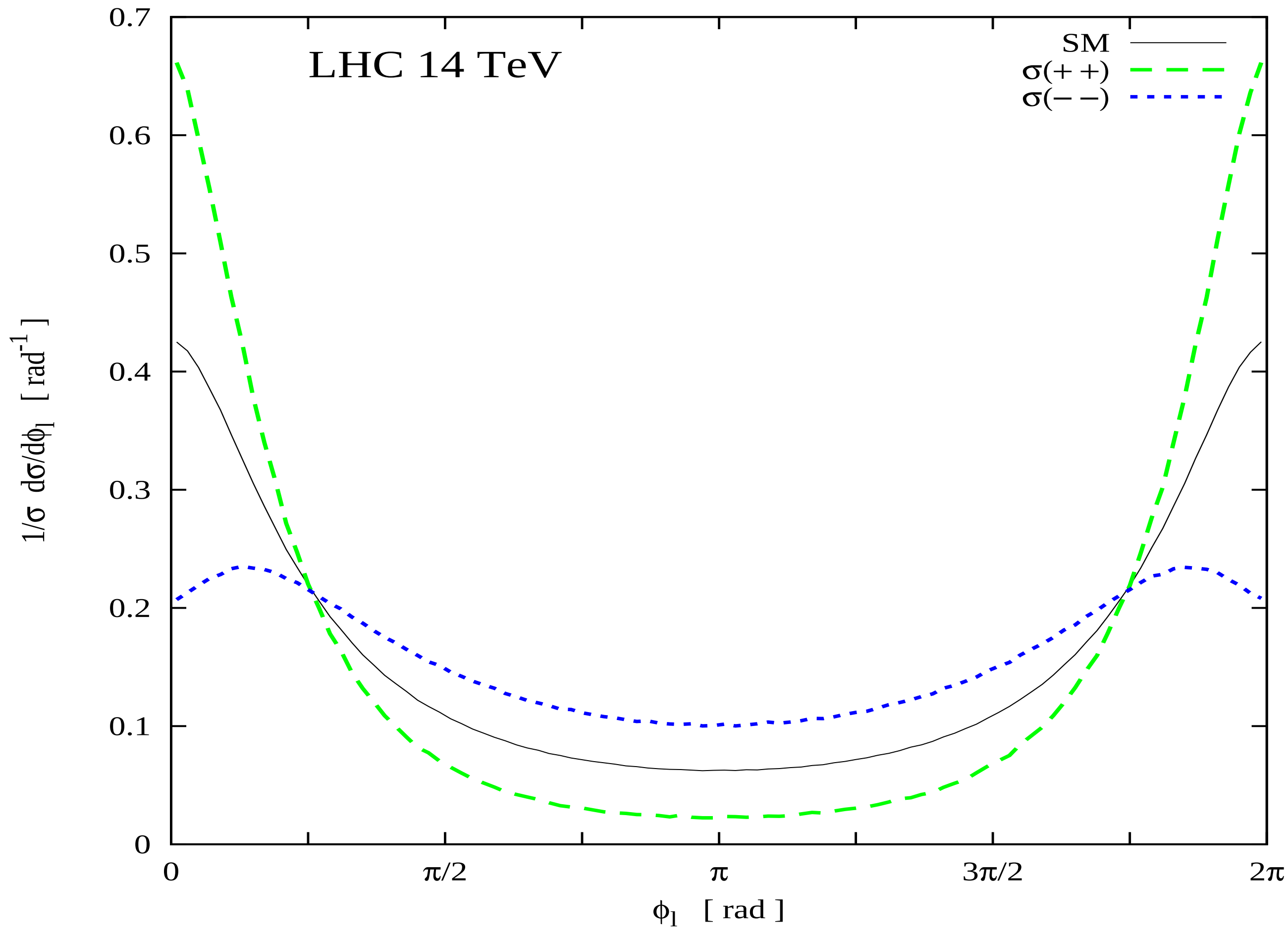
Different candidates:

1) Angle between top and the decay lepton in the lab:

2) Angle between the decay lepton and the beam direction

This can work ONLY for an asymmetric collider : i.e there is a preferred direction. (Tevatron)

This can not happen at LHC: $x_1 - x_2$ symmetrisation will wipe it out.


LHC 14 TeV
SM
σ(+ +)
σ(− −)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/σ dσ/dφl [rad-1]
0
π/2
π
3π/2
2π
φl [rad]

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 being completely Left handed or right handed, dropping all other effects on phi distriutions.

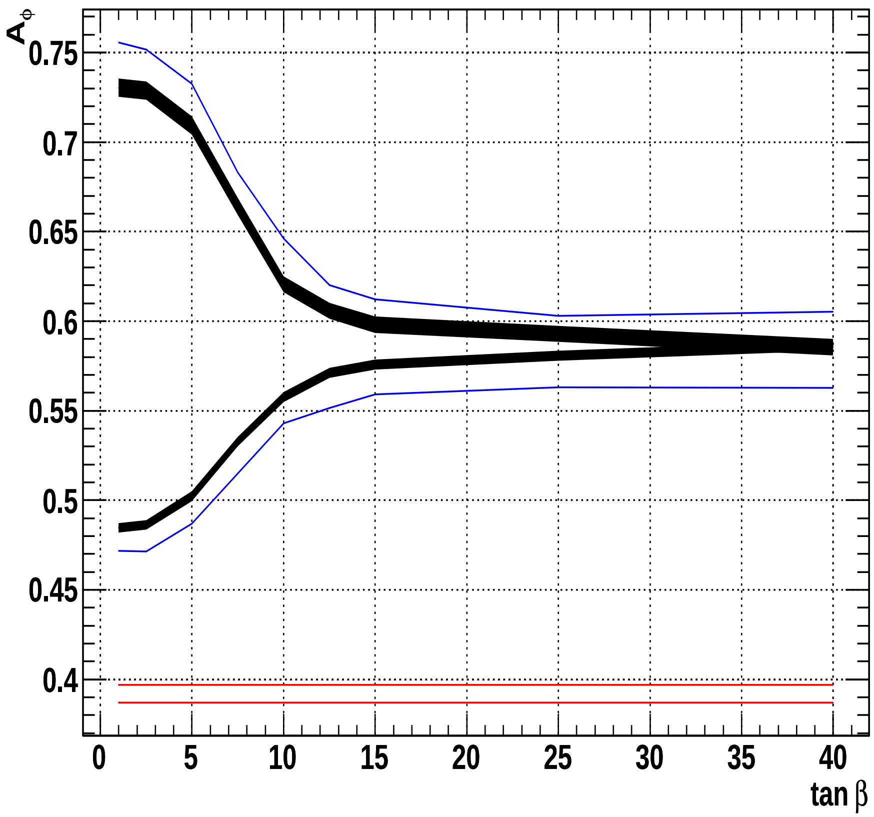
The choice of beam direction (ie. +ve or -ve) is not relevant as the distribution symmetric for ϕ_l to $2\pi - \phi_l$.

In practice effects of finite polarization and/or spin coherence effects from off diagonal elements need to be included.

Construct an asymmetry which will reflect polarisation.

$$\mathcal{A} = \frac{1}{\sigma}\left[\sigma(\phi_l < \pi/2) + \sigma(\phi_l > 3\pi/2) - \sigma(\pi/2 < \phi_l < 3\pi/2)\right]$$

Azimuthal asymmetries:



Separation between W^-t and H^-t for this observable is clear.

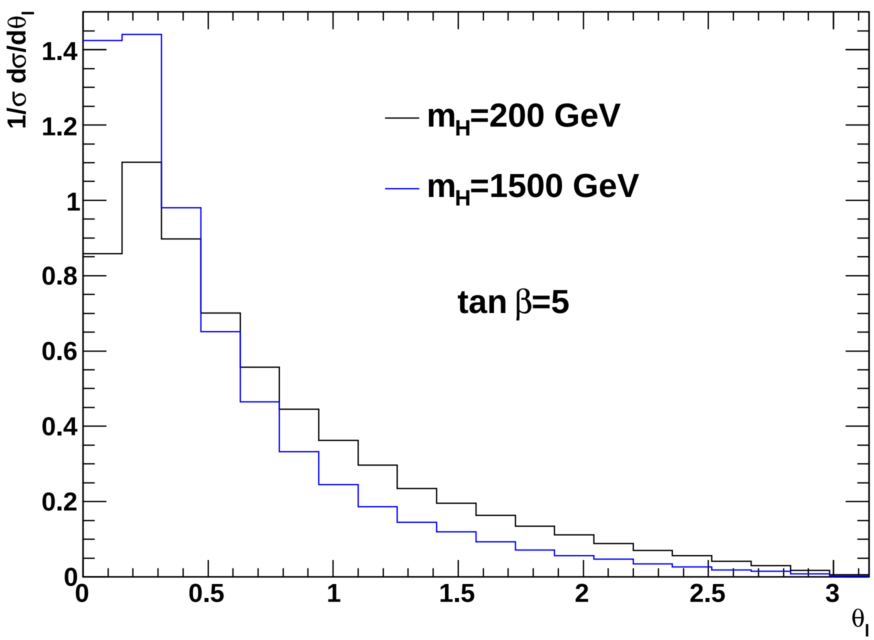
Thin line: LO result, thick black: NLO.

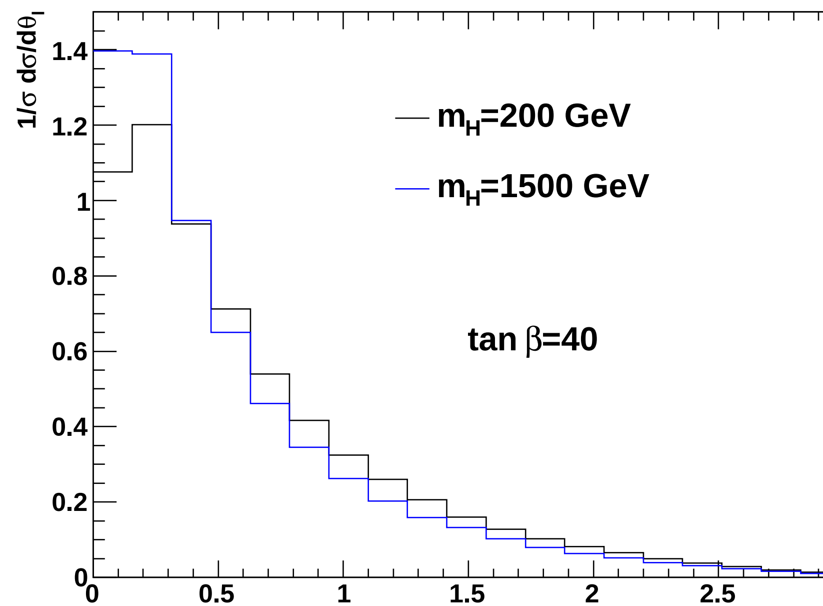
$M_{H^-} = 200$ lower curves, $M_{H^-} = 1500$ upper curves.

Constant contours at the bottom W^-t.

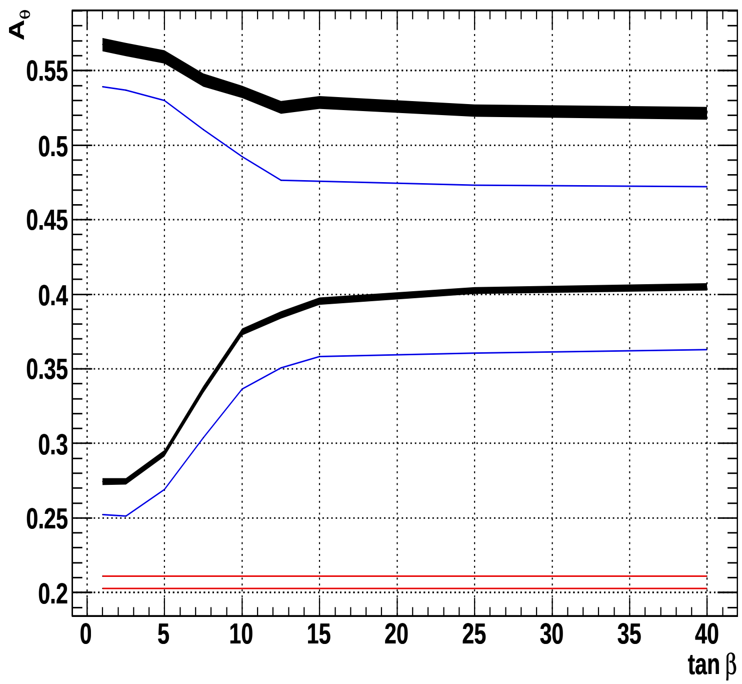
Correspond to different schemes to adjudge the effect of interference effects at NLO. Only if the two are close is the isolation of W^-t considered free of these ambiguities.

Polar angle wrt top direction:





Polar asymmetries:



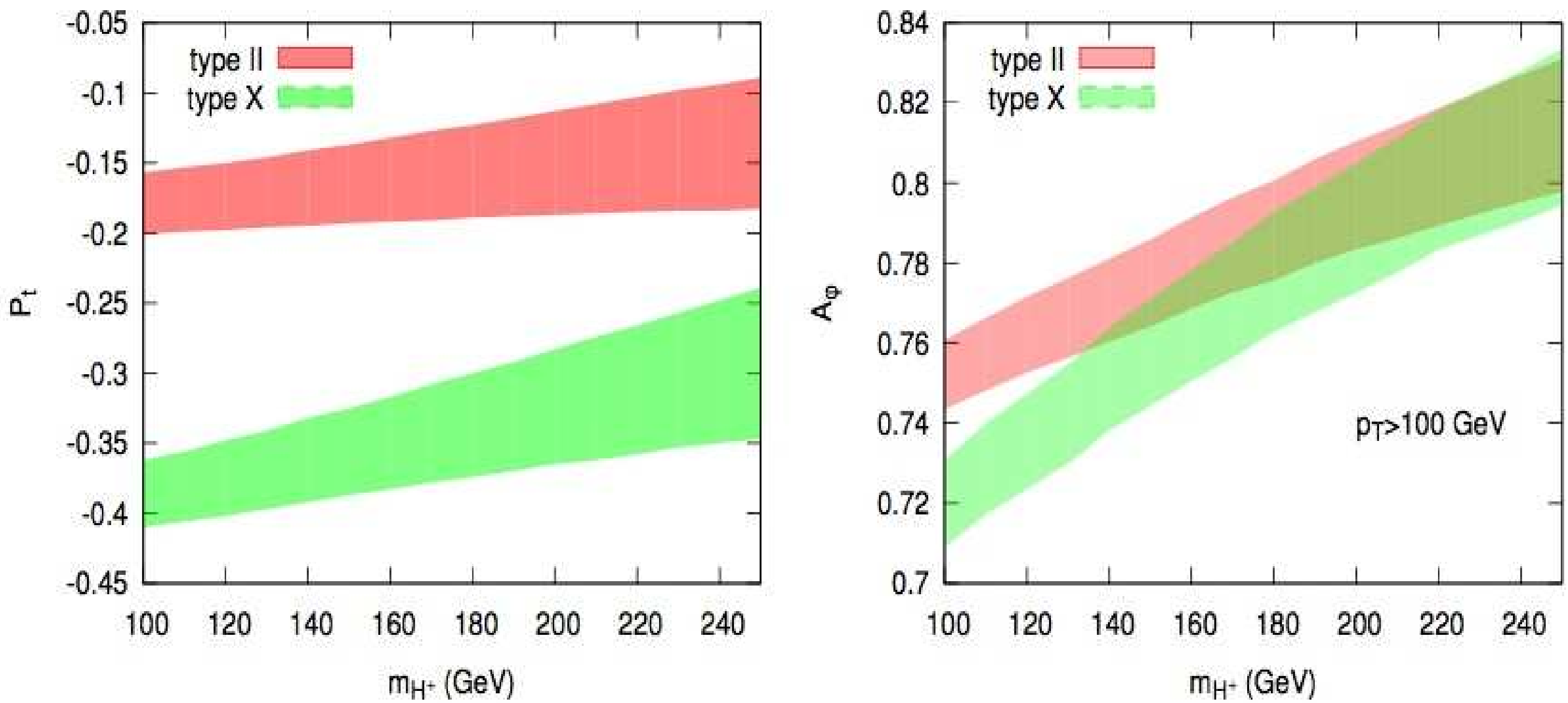
Thin line: LO result, thick black: NLO.

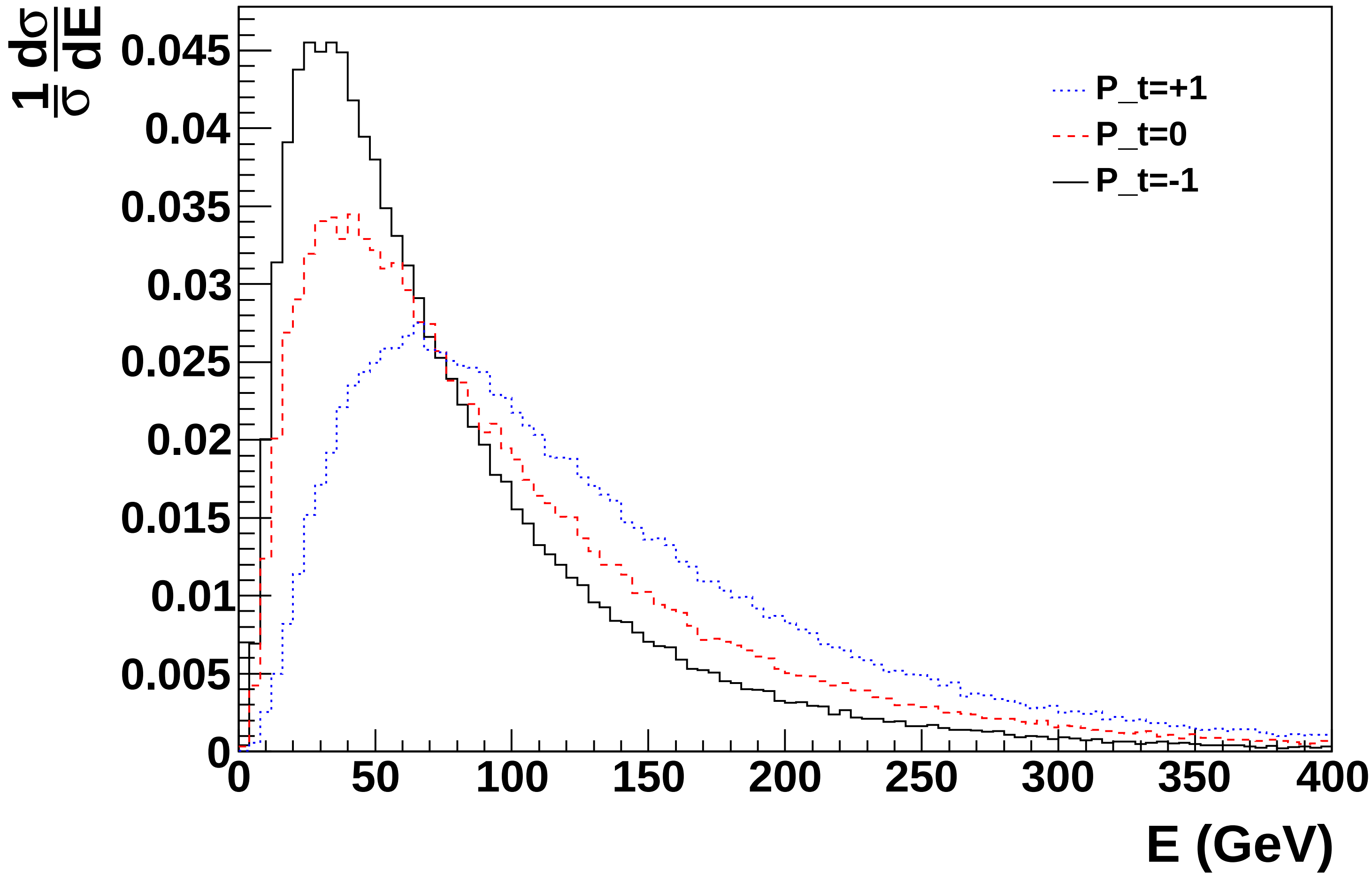
$M_{H^-} = 200$ lower curves, $M_{H^-} = 1500$ upper curves.

Constant contours at the bottom W^-t.

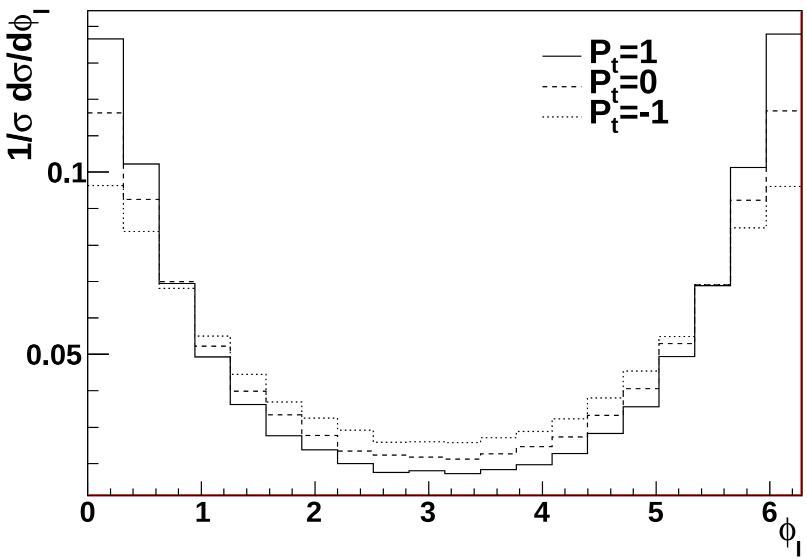
Correspond to different schemes to adjudge the effect of interference effects at NLO. Only if the two are close is the isolation of W^-t considered free of these ambiguities.

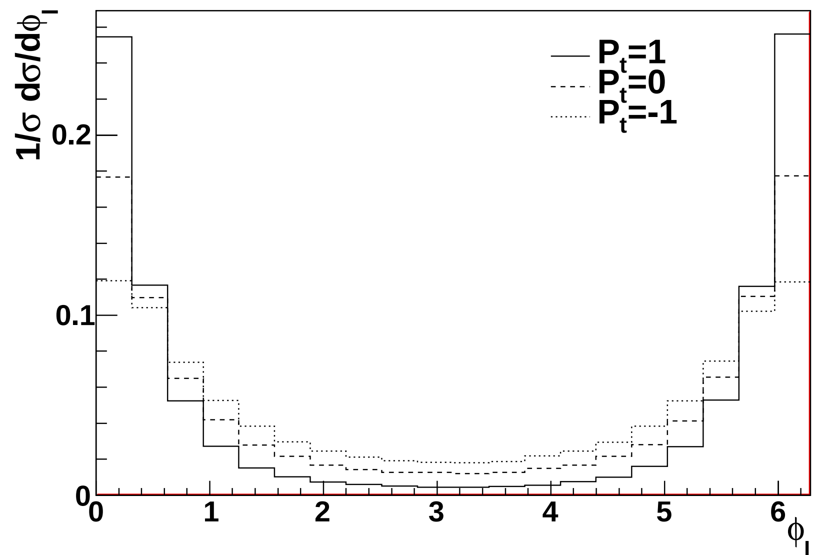
hep-ph/1307.1158v1





For the negatively polarised top distributions peak at lower values of energy. Effect small for smaller mass differences.





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

Systems with large invariant mass of $t\bar{t}$ can produce highly boosted tops – with collimated decay products Lian-Tao wang, Thaler; G. Perez, Sterman..

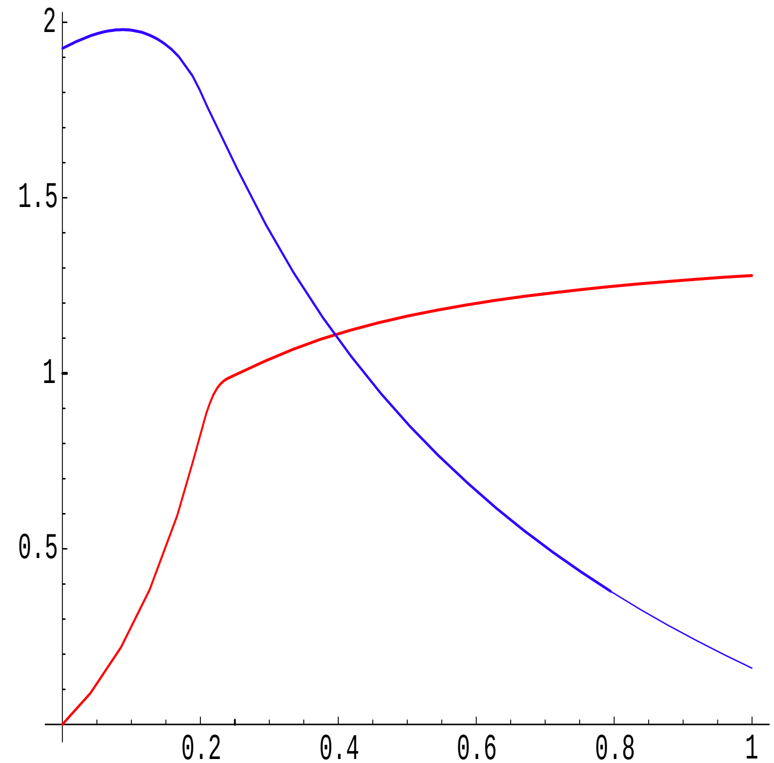
Collimated leptonic top quarks allow the energy of the lepton and the b-jet to be separately measured, but not the angular distributions.

The momentum fraction of the visible energy carried by the lepton provides a natural polarimeter.

$u = E_\ell/(E_\ell + E_b)$,

[J. Shelton arXiv:0811.0569]

$(1/\Gamma)(d\Gamma/du)$ as a function of u.



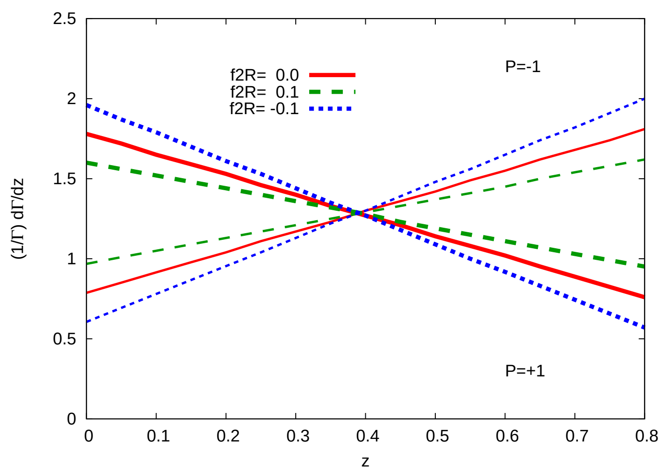
Blue line: Negative helcity top

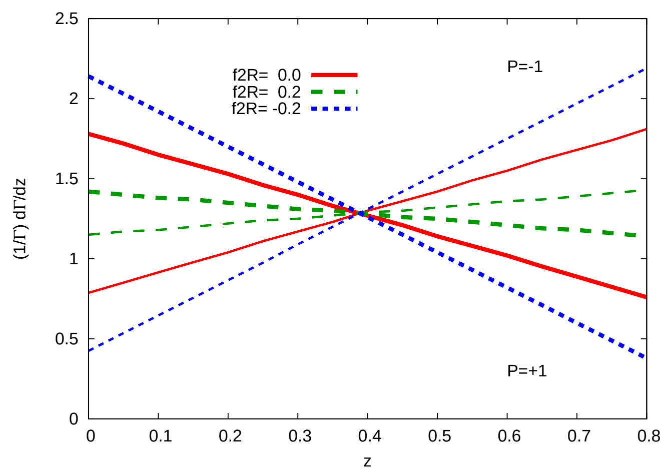
Red line: positive helicity top

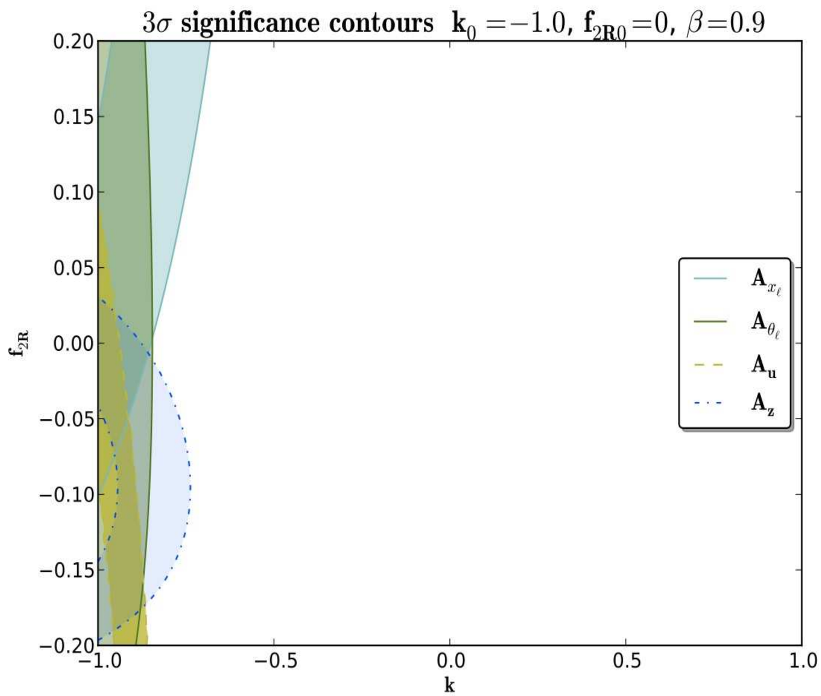
$\beta = 1$

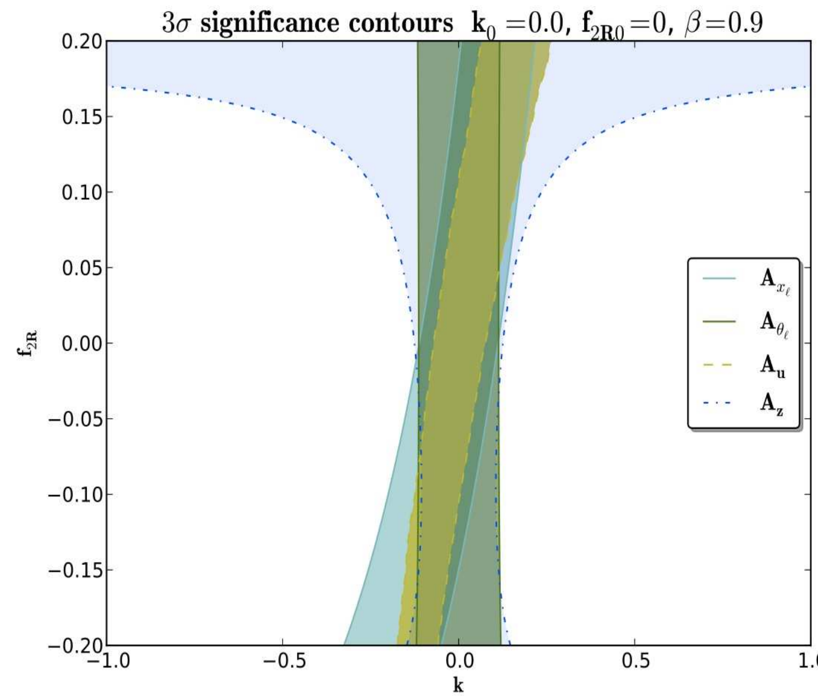
$$\frac{1}{\Gamma}\frac{d\Gamma}{dz} = \frac{m_t^2}{\beta(m_t^2 - m_w^2)}\left(1 + P_t\kappa_b\left(-\frac{1}{\beta} + \frac{2m_t^2 z}{\beta(m_t^2 - m_w^2)}\right)\right)$$

with $\kappa_b = -0.406 + 1.43 f_{2R}$.

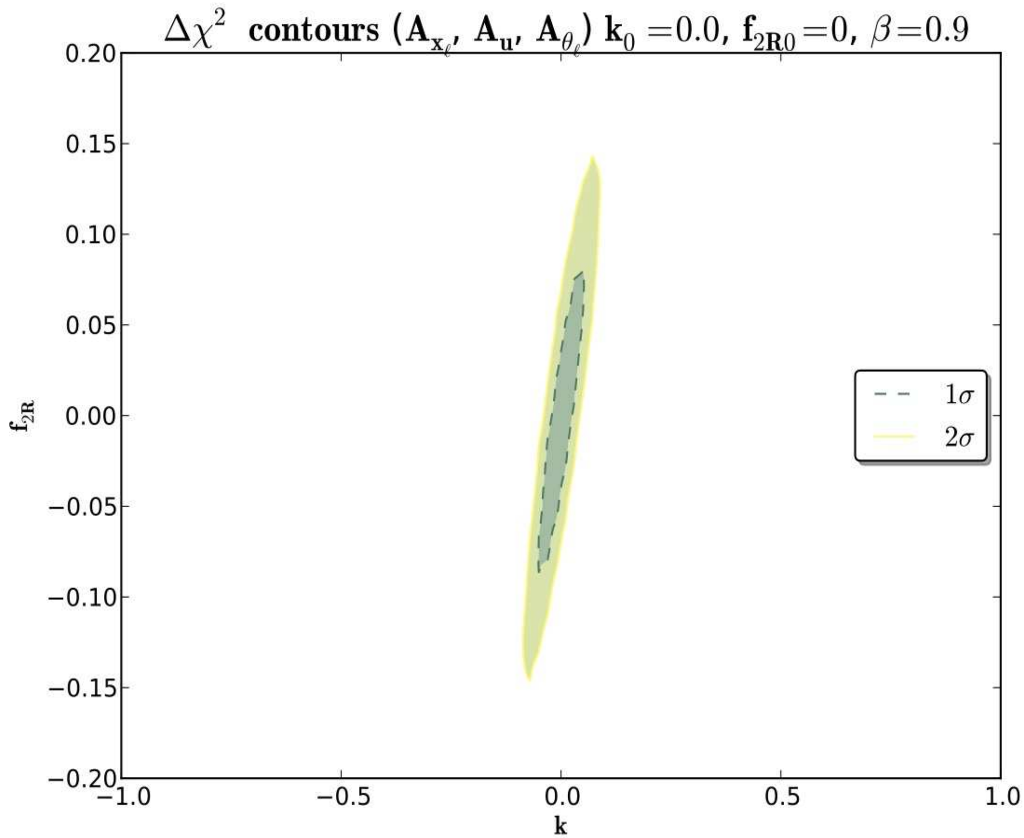








Used $t\bar{t}$ events with inv. mass between 1500 and 2000 GeV. FOr 100^{-1} fb.


$\Delta\chi^2$ contours (A_{x_ℓ}, A_u, A_{θ_ℓ}) k_0 =0.0, f_{2R0}=0, β=0.9
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
f_{2R}
−1.0
−0.5
0.0
0.5
1.0
k
1σ
2σ

- BSM physics affects properties of the top quark produced.

- Kinematic properties of the produced top, cross-sections etc can be used to probe the BSM

- In addition polarization of the top quark provides an excellent probe for BSM

- Secondary decay lepton angular distributions are the most faithful polariometers, robust to effects of non standard tbW couplings as well as higher order corrections.

- At the LHC ϕ distibutions can be used to construct obeservables which probe polarization.

- The parameters of a 2HDM can be determined using the top polarization and the asymmetries

- Use of energy dependence of the total $t\bar{t}\Phi$ cross-section, along with the polarization can help establishing CP of the scalar state should it be a CP eigenstate

- Top quarks produced in the stop/sbottom decays are polarized and polarization affects kinematic distributions of the decay products. This can affect the search strategy and also can be used to measure the polarisation when we find the stops/sbottoms.

- For boosted tops z, u distributions are more useful.

- The energy distributions of the decay leptons and hence the z, u distributions are sensitive to anomalous tbW couplings.

- Simultaneous study of different asymmetries can be used to determine both the polarization and the anom. tbW coupling.