Special features

of the top polarization asymmetry in associated top-charged Higgs production at LHC.

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Models with two Higgs doublets (2HDM) are considered an interesting generalization of the Standard Model.

These models contain 3 neutral and two charged Higgs scalars. If no Supersymmetry is added, the 2HDM is described by 6 parameters (4 masses and two angles, alpha and beta, where tan beta is the ratio of the 2 vevs).

In the simplest Supersymmetric proposal (MSSM), there remain only 2 independent parameters, usually taken as one of the Higgs masses (possibly also MH+)
and tanbeta.

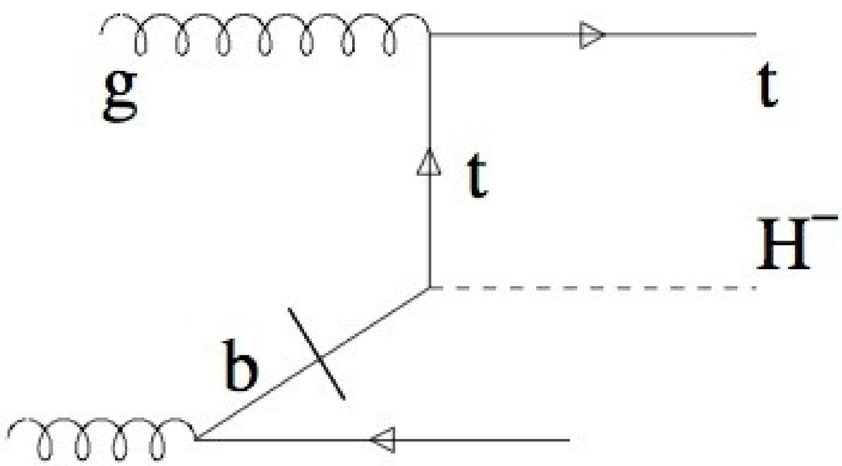
If the first "new" produced particle were a charged Higgs (relatively simply identifiable) ,measuring tanbeta would become "forte".

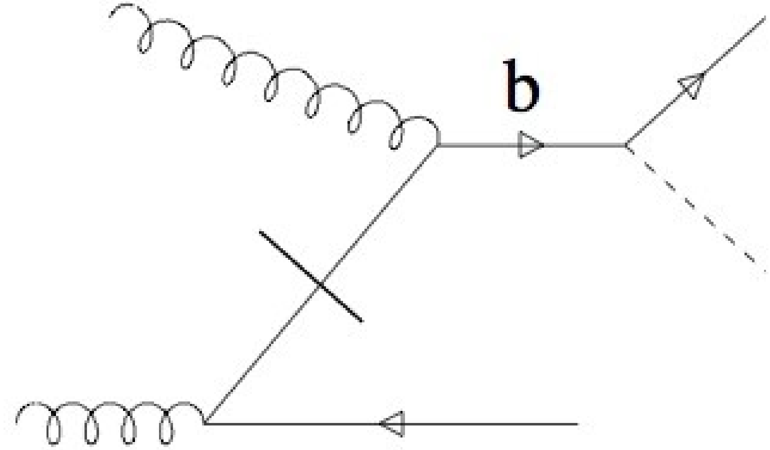
In the MSSM tanbeta can be determined measuring the cross section of Higgs production, (the Higgs mass from its decay products) which is typically proportional to tanbeta squared.

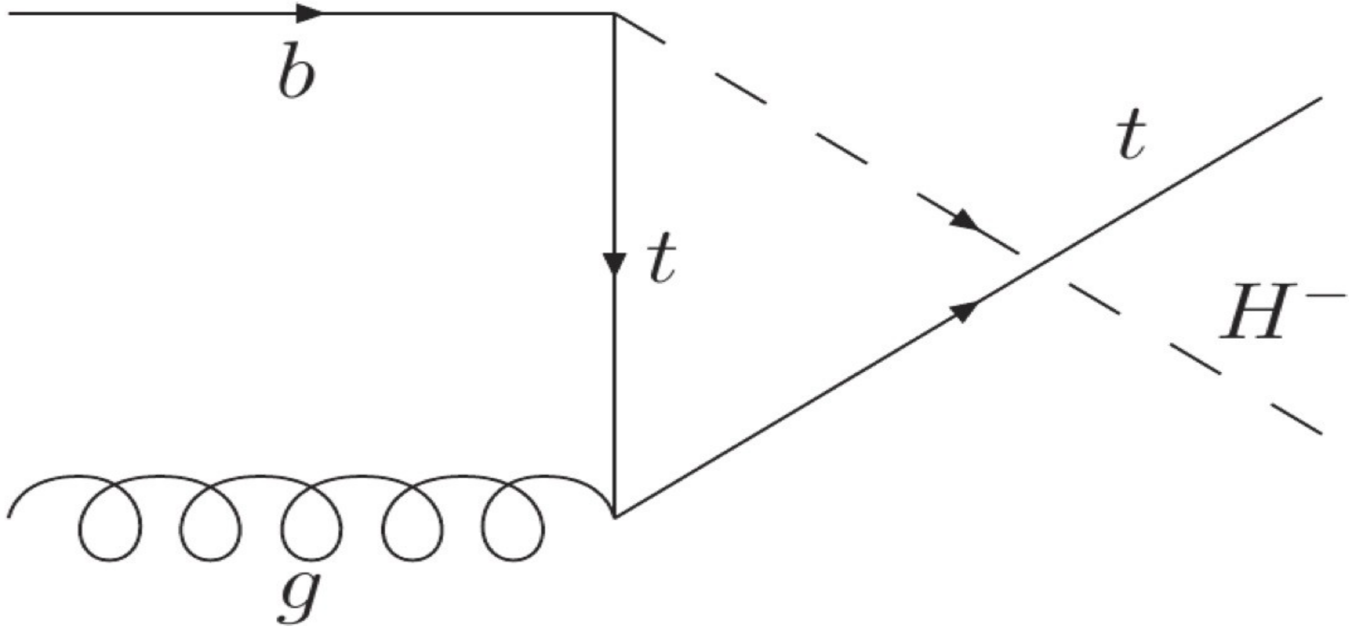
An interesting process for this purpose is the “associated” top-charged Higgs production, on which I will now concentrate.

The real process is pp---->$tH^-\bar{b}$ X, in the 4 Flavour Number scheme (4FN) at the partonic level gg---->$tH^-\bar{b}$ X. In the 5 Flavour Number scheme (5FN), the partonic process is bg---->tH (tree level Figures).

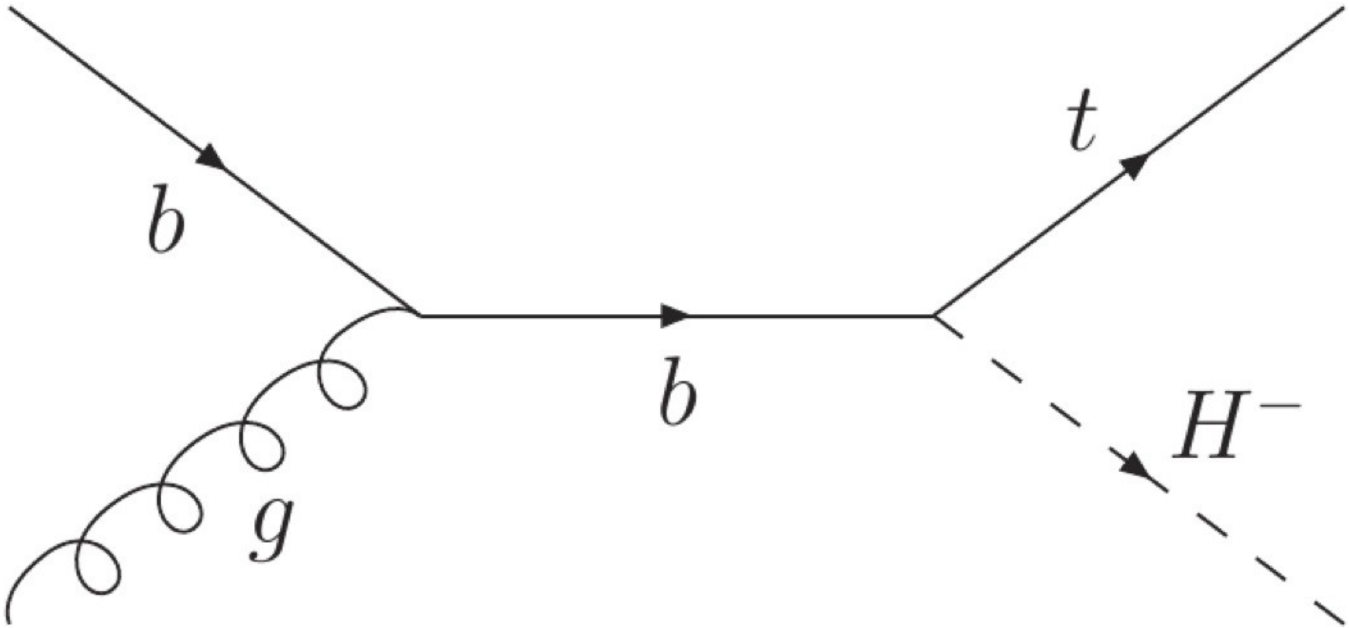
Full discussion in Berger, Han, Jing Jiang and Plehn,Phys.Rev.D71 115012,2005.


g
t
t
H⁻
b


b



b
t
t
H⁻
g


b
t
b
H⁻
g

To understand the main goals of the theoretical efforts to be described, a good starting point is to derive the MSSM expression of the relevant (t,b H=Higgs) Yukawa Lagrangian. In the notation of Carena, Garcia, Nierste and Wagner (Nucl.Phys.B577, 577-2000) this reads:

$$
-\mathcal{L}^{(0)}_{Yu}(b,t,H) = \Big\{ \frac{\sqrt{2}}{v}\Big[m_b \, tg\beta \, \bar{t}_L b_R H^+ + \frac{m_t}{tg\beta} \bar{b}_L t_R H^- \Big] + h.c. \Big\}
$$

$$
+ \Big\{ \frac{m_b}{v\cos\beta}\Big[\bar{b} b \left(-\sin\alpha \, h_0 + \cos\alpha \, H_0 \right) - i \bar{b}\gamma_5 b A_0 \, tg\beta \Big] + \frac{m_t}{v \sin\beta}\Big[\bar{t} t \left(\cos\alpha \, h_0 + \sin\alpha \, H_0 \right) + i \bar{t}\gamma_5 t A_0 \cos\beta \Big] \Big\}
$$

Here β, α are the usual MSSM Higgs sector angles, $v \equiv \sqrt{v_1^2 + v_2^2} \simeq 174\,GeV$ and $\mathcal{L}^{(0)}$ does not contain (future) radiative corrections. The Yukawa couplings $h_{b,t}$ are defined as

$$
h_b = \frac{m_b}{v_1}, \quad h_t = \frac{m_t}{v_2}; \quad tg\beta \equiv \frac{v_2}{v_1}
$$

($v_{1,2}$ are the neutral Higgses vevs).

More precisely:

$$h_0 = \cos\alpha\, h_u^0 - \sin\alpha\, h_d^0$$
$$H_0 = \sin\alpha\, h_u^0 + \cos\alpha\, h_d^0$$

$$A_0 = \cos\beta\, \chi_u^0 + \sin\beta\, \chi_d^0$$
$$H^+ = \cos\beta\, h_u^+ + \sin\beta\, h_d^{-*}$$

h_u^0, χ_u^0, h_u^+ are the neutral (real and Imaginary) and charged members of the H_u doublet (coupled to up quarks)
The $(\;)_d$ fields are those coupled to down quarks.

In the previous expression (where I assumed Vtb=1), ho, Ho, Ao are the physical neutral CP even and odd Higgses (CP is assumed to be conserved), H+ is the physical charged Higgs. In principle, there are six free parameters (the four masses and the two angles).In the MSSM at this lowest order only two parameters are independent, usually taken as MAo and tgbeta.

In a model with only 1 more(extra SM) Higgs Doublet and two different vevs like in the MSSM (2HDM) the six parameters are free.

Two different types of non Supersymmetric 2HDM are usually considered and called of Type2 (in my notation 2HDM2) and of Type1 (in my notation 2HDM1).

In the Type2 model the 2 doublets couple to different (up,down) quarks like in the MSSM. In the Type1 case all fermions couple to only one Higgs field.

The 2HDM1 couplings are obtained simply replacing Mb tanbeta with Mb cotbeta at page 9.

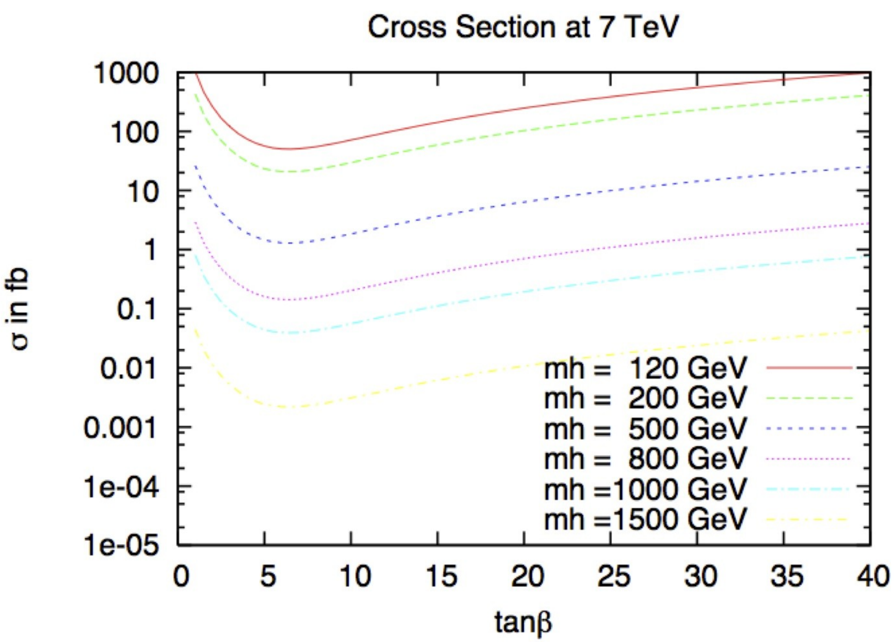
The tH cross section at tree level.

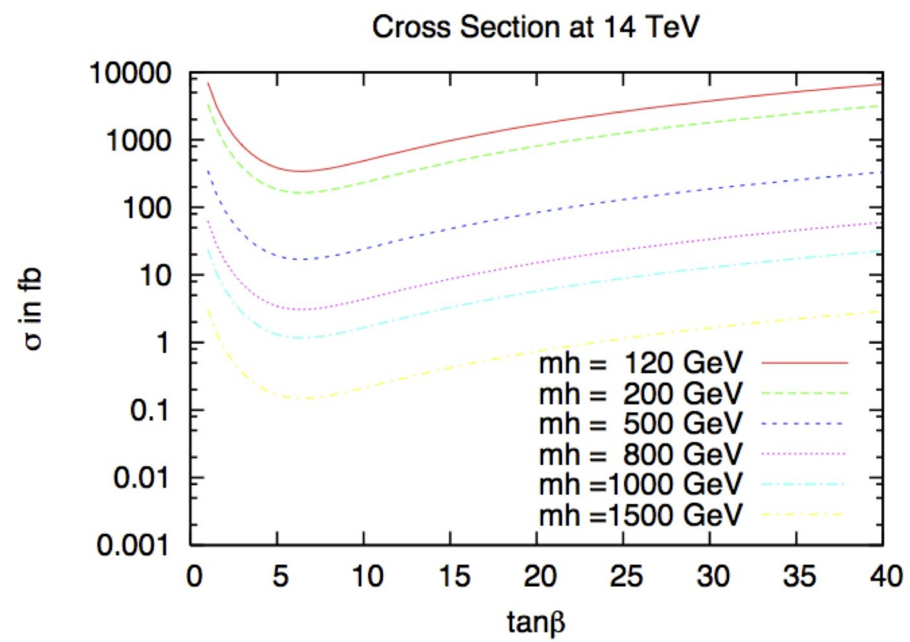
To derive the cross section for top-charged Higgs production at partonic tree level is relatively simple. From inspection of the Yukawa Lagrangian one knows that it will be proportional to (mt squared cotbeta squared + mb squared tanbeta squared) both in the MSSM and in the 2HDM2 schemes.

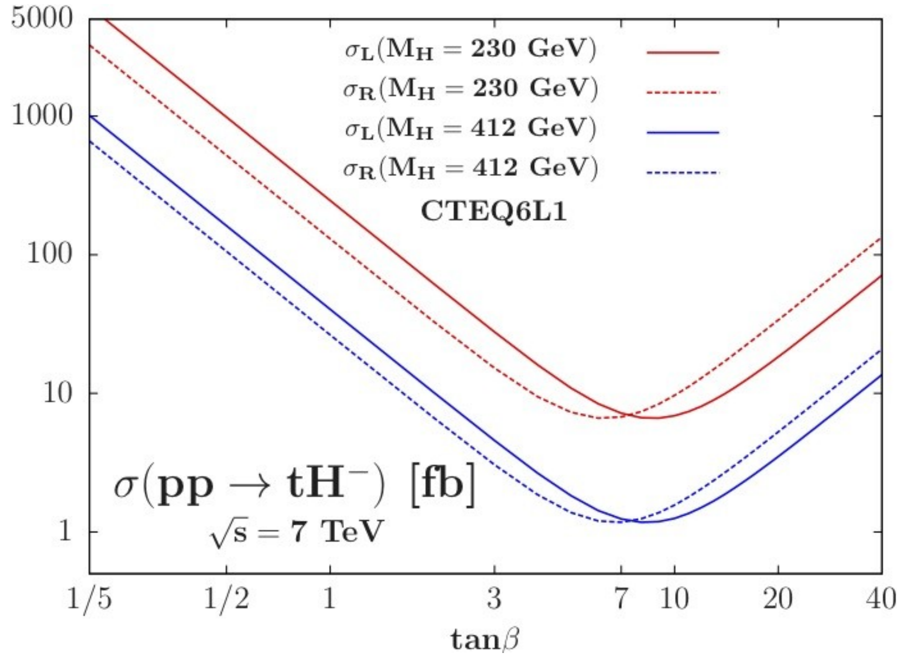
In the 5FN scheme the partonic cross sections are then folded with the gluon and the bottom pdfs, the latter one containing the collinear lns resummation, as discussed in the literature.

The results that I will show are taken from two papers. In the first one, Huitu,Rai,Rao, Rindani and Sharma, JHEP 1104 (2011)020, tH production in the MSSM is studied at tree level. In the second one, Baglio, Beccaria,Djouadi,Macorini,Mirabella,Orlando Renard,C.V., Phys.Lett.B 705(2011),212-216, it is studied at one loop.

In both papers, the first results are obtained using the CTEQ6L1 pdf. In the next Figures I will compare the tree level results, that are in satisfactory agreement and are given for LHC cm energies of 7 (Huitu also 14) TEV.


Cross Section at 7 TeV
σ in fb
tanβ
1000
100
10
1
0.1
0.01
0.001
1e-04
1e-05
0 5 10 15 20 25 30 35 40
mh = 120 GeV
mh = 200 GeV
mh = 500 GeV
mh = 800 GeV
mh =1000 GeV
mh =1500 GeV


Cross Section at 14 TeV
σ in fb
tanβ
10000
1000
100
10
1
0.1
0.01
0.001
0 5 10 15 20 25 30 35 40
mh = 120 GeV
mh = 200 GeV
mh = 500 GeV
mh = 800 GeV
mh =1000 GeV
mh =1500 GeV



5000
1000
100
10
1
$\sigma_L(M_H = 230\ \text{GeV})$
$\sigma_R(M_H = 230\ \text{GeV})$
$\sigma_L(M_H = 412\ \text{GeV})$
$\sigma_R(M_H = 412\ \text{GeV})$
CTEQ6L1
$\sigma(pp \to tH^-)$ [fb]
$\sqrt{s} = 7$ TeV
1/5
1/2
1
3
7
10
20
40
$\tan\beta$

As one sees, the tanbeta dependence of the cross section is rather strong and might lead to the idea of identifying from its measurement this parameter.

A problem to identify SUSY parameters is however the presence of strong interactions, that at NLO introduce in the theoretical estimate a "scale" uncertainty that is sometimes unfairly large.

Scale dependence of the tH cross section.

The calculation of the cross section will depend on the chosen factorisation (and renormalisation, usually identical) scales.

It has been estimated (S.Dittmaier et al.,arXiv:1101.0593) that the residual NLO QCD effect exhibits a residual scale uncertainty of the order of 10-20% at LHC with cm energy = 7 TEV.

Pdf dependence of the tH cross section.

The calculation of the cross section will also depend on the chosen parton pdf (CTEQ, MSTW, ABKM...).

It has been estimated (S.Dittmaier et al.,arXiv:1101.0593) that the residual NLO pdf uncertainty will be of the order of 10-20% at LHC with cm energy = 7 TEV.

The idea is to find an observable that is possibly independent of strong interactions uncertainties.

At the “glorious” LEP1 times such an observable was found (Lynn, C.V.,Phys.Rev-D35,3326-1987) : The Longitudinal Polarization Asymmetry (Alr(MZ)).

Question: is such an asymmetry meaningful in the considered tH process? In principle,yes (rates for tl and tr production are different).

A first discussion of possible measurements of top polarization asymmetry from charged slepton production, suggesting the “natural extension” of the work to the process of tH production, has been in fact provided by

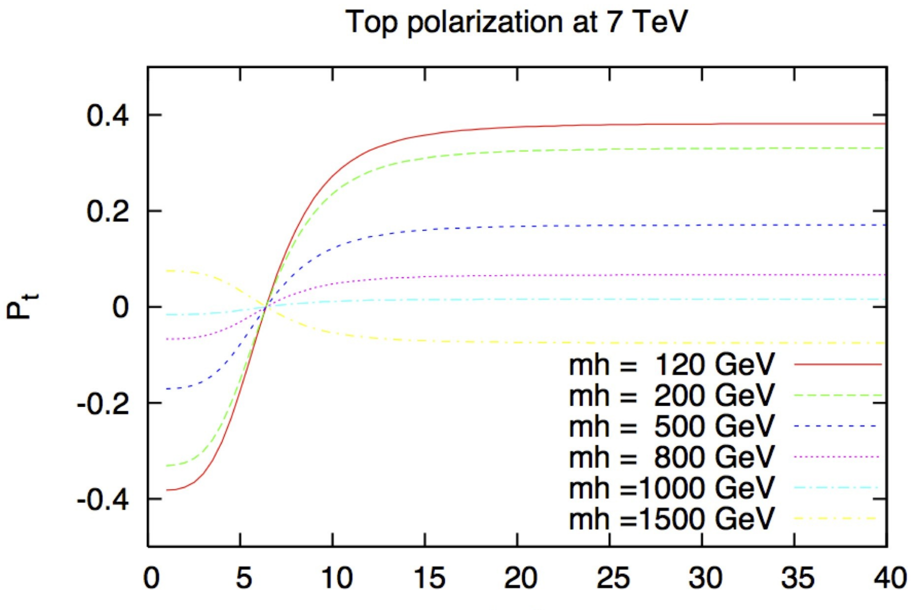
Arai, Huitu, Rai and Rao,
JHEP 1008 (2010) 082

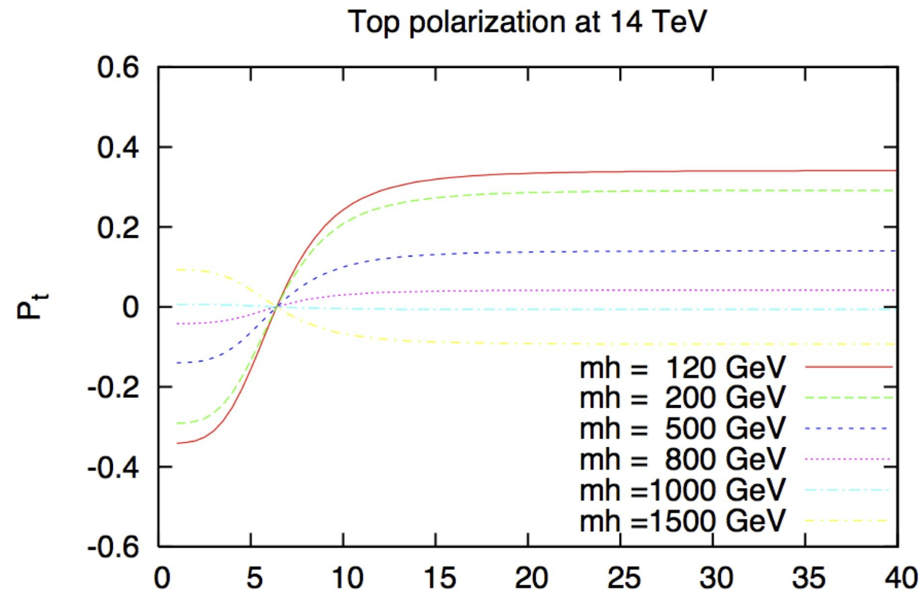
A detailed discussion for the tH process is actually given in the Huitu,Rai,Rao,Rindani,Sharma paper.

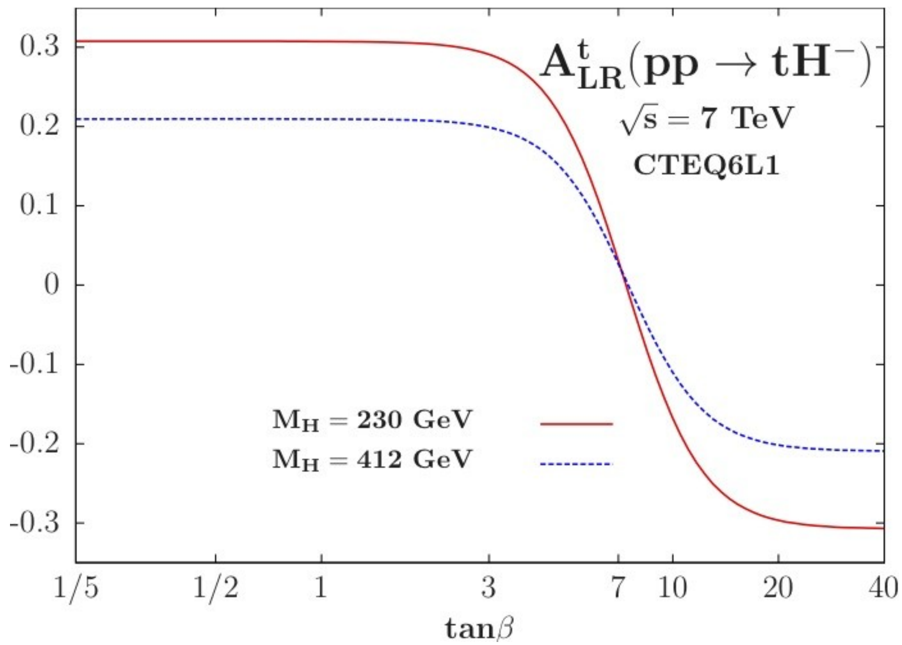
Next figures show the Huitu et al. and the Baglio et al. tanbeta dependence in the MSSM or 2HDM2 of the tree level Alr, defined as (Alr Baglio=-Pt Huitu):

Alr=(sigmatl-sigmatr)/(sigmatl+sigmatr)

Our hadronic cross sections have been computed by folding the partonic ones with the CTEQ6L1 leading order Pdf,(same as Huitu) for two values MH=230 and 412 (benchm. LS2 and SPS1a,see paper). The ren. and fact. scale mu0 is (Wagner) (MH+mt)/6, mb is in the MSbar system at mu0, mt=173.1. on shell. Huitu is similar....


Top polarization at 7 TeV
0.4
0.2
0
-0.2
-0.4
P_t
mh = 120 GeV
mh = 200 GeV
mh = 500 GeV
mh = 800 GeV
mh =1000 GeV
mh =1500 GeV
0
5
10
15
20
25
30
35
40


Top polarization at 14 TeV
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
P_t
mh = 120 GeV
mh = 200 GeV
mh = 500 GeV
mh = 800 GeV
mh =1000 GeV
mh =1500 GeV
0
5
10
15
20
25
30
35
40



$A^t_{LR}(pp \to tH^-)$
$\sqrt{s} = 7$ TeV
CTEQ6L1
$M_H = 230$ GeV
$M_H = 412$ GeV
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1/5
1/2
1
3
7
10
20
40
tanβ

A few remarks about the Alr (tree) tanbeta dependence.

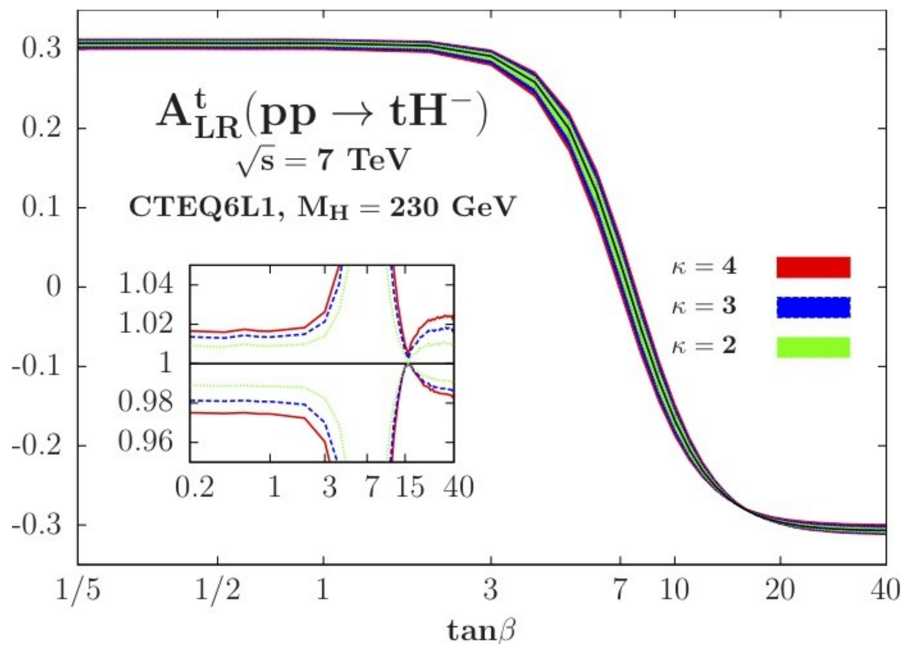
First of all: in the MSSM the lower bound on the neutral light h0 requires tanbeta>2-3. In a non Supersymmetric 2HDM the region 0.2<tanbeta<40-50 is allowed(Djouadi,Phys.Rept.459,1,2008)

Alr changes quickly sign when tanbeta varies between 3 and 20. It vanishes when tanbeta=sqroot(mt/mb).For tanbeta<3 or>20 it remains constant (and opposite, with the same modulus).

Scale dependence of Alr.

The yet uncalculated higher order QCD contributions to Alr can be estimated from its dependence on the factorization scale muf at which the process is evaluated. Starting from the previously chosen reference scale mu0 we have varied muf in the range mu0/k <muf < kmu0 with k=2,3,

Next Figure shows the variation of Alr when k varies in then range. As one sees, this variation is irrelevant.

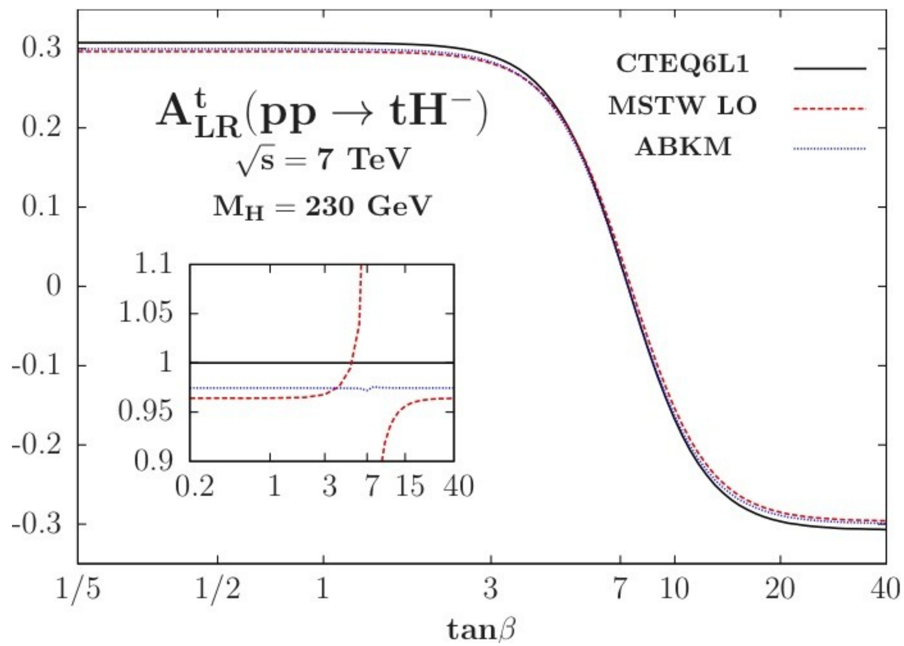


$A^t_{LR}(pp \to tH^-)$
$\sqrt{s} = 7$ TeV
CTEQ6L1, $M_H = 230$ GeV
$\kappa = 4$
$\kappa = 3$
$\kappa = 2$
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1.04
1.02
1
0.98
0.96
0.2
1
3
7
15
40
1/5
1/2
1
3
7
10
20
40
tanβ

PDF dependence of Alr.

We have given a qualitative investigation of the Alr dependence on the chosen pdf evaluating it with different parametrizations. In particular, we have chosen the CTEQ, the MSTW and the ABKM sets.

Next Figure shows the variation of Alr when the pdf is changed. As one sees,it is again irrelevant.



$A^t_{LR}(pp \to tH^-)$
$\sqrt{s} = 7$ TeV
$M_H = 230$ GeV
CTEQ6L1
MSTW LO
ABKM
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1/5
1/2
1
3
7
10
20
40
tanβ
1.1
1.05
1
0.95
0.9
0.2
1
3
7
15
40

NLO SUSY effects.

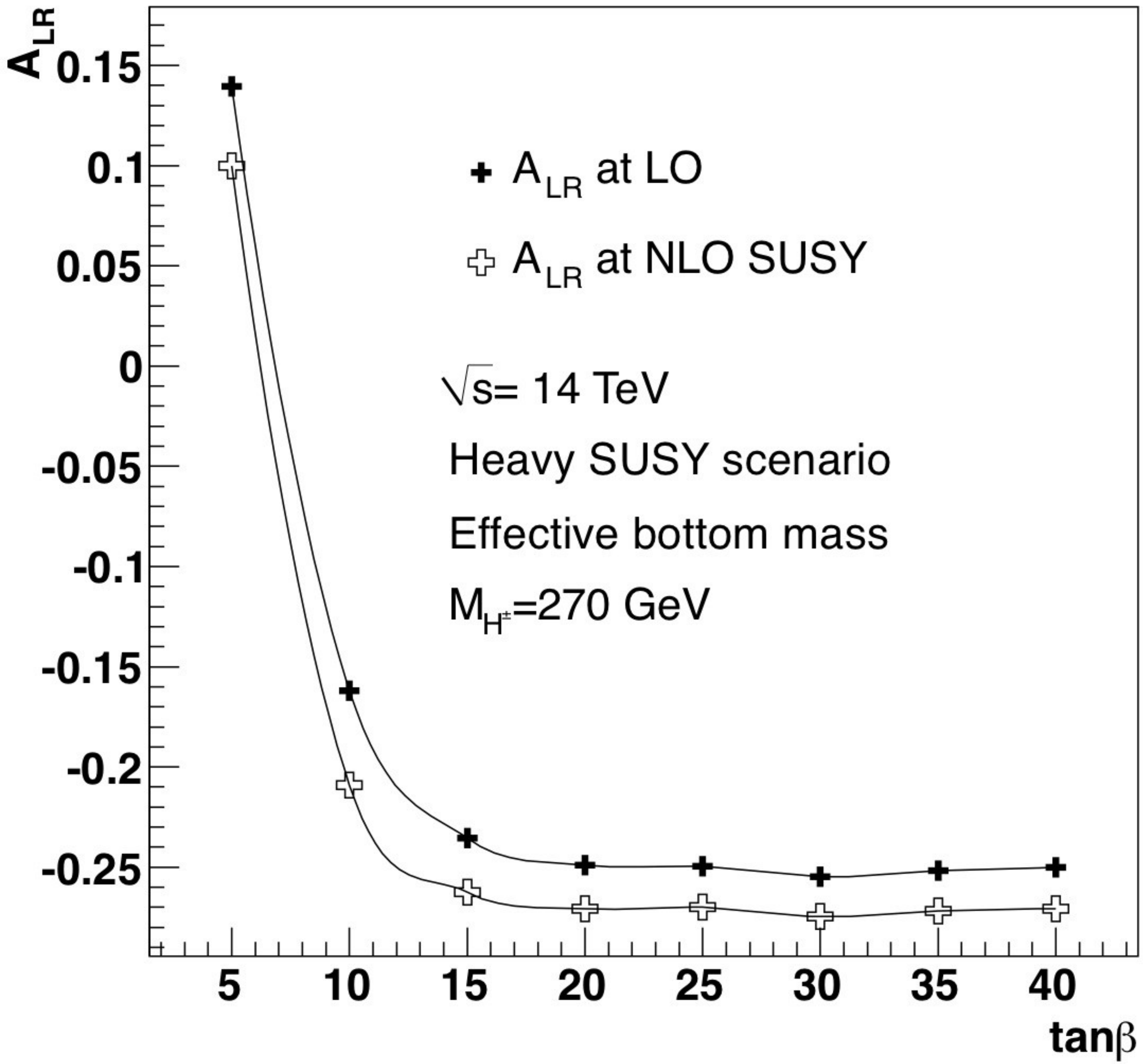
Having verified the apparent tree level scale and pdf “strong interaction inv ariance”, we have them moved to the estimate of the NLO SUSY effects.

With this purpose, we have performed an “Effective NLO estimate”, where the strong SUSY effect is provided by the Deltab parameter of Carena et al.

and EW MSSM effects are computed COMPLETELY (with also SM diagrams).

Next Figure shows the combined (QCD and EW) SUSY MSSM
one loop effect for a specific choice of (heavy spectrum) SUSY parameters
that was described in a previous paper (Beccaria,Macorini, Panizzi, Renard, C.V., Phys,Rev.D80 (2009) 053011),
where only the total tH cross section was computed at the complete EW one loop in the MSSM.

The chosen energy is 14 TEV.


A_{LR}
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
A_{LR} at LO
A_{LR} at NLO SUSY
$\sqrt{s}$= 14 TeV
Heavy SUSY scenario
Effective bottom mass
$M_{H^\pm}$=270 GeV
5
10
15
20
25
30
35
40
tanβ

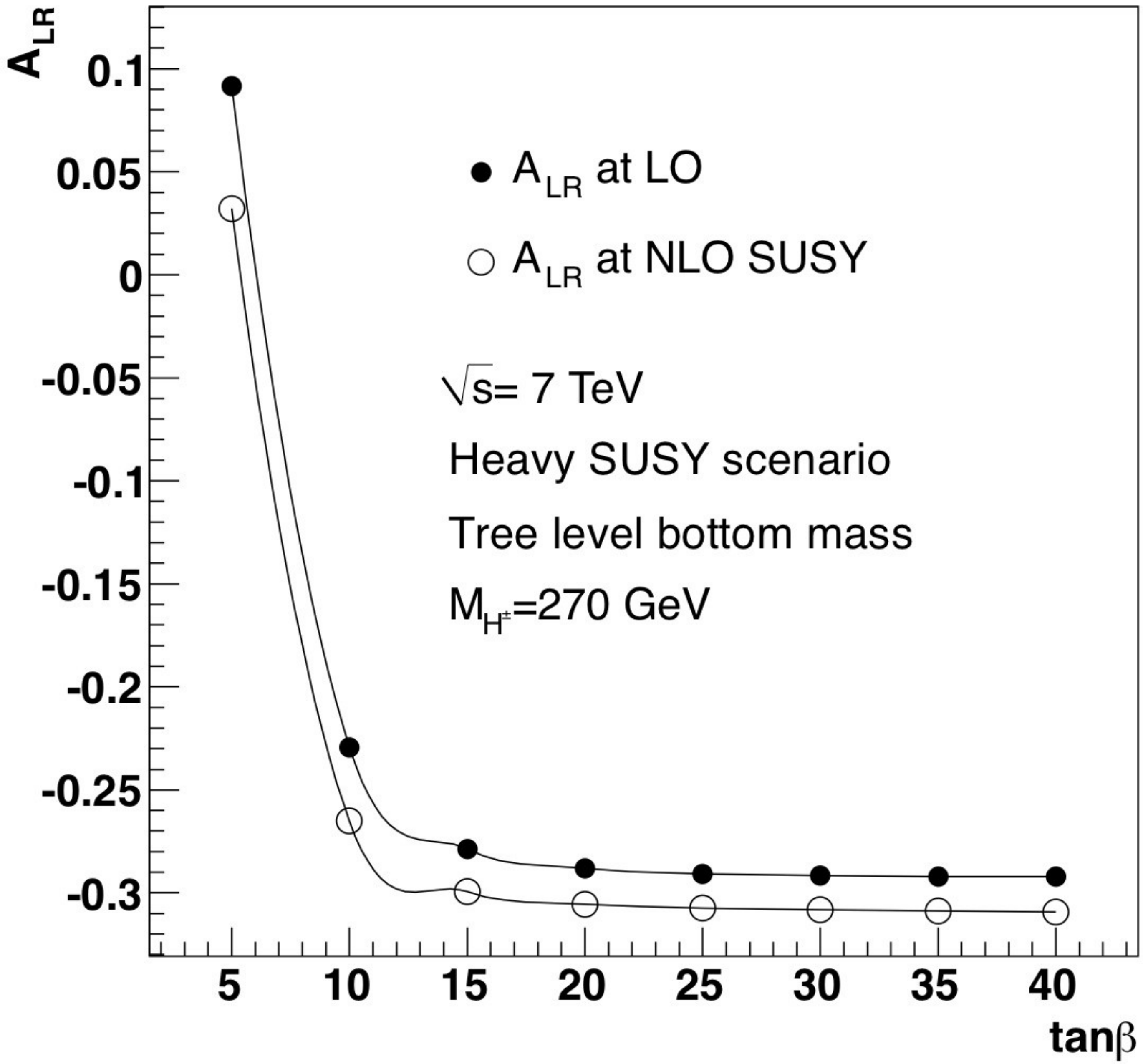
One sees that the SUSY effect is not small, particularly in the region around tanbeta=10, where it would be of a relative twenty percent.

Starting from this apparent feature, we have then performed a first estimate of the “Genuine EW NLO MSSM effects”, ignoring the Deltab contribution in the calculation.

The result is shown for the relevant 7 TEV pp energy.

The relevance of the 7 TEV value is that it is stated in the HUITU et al.paper that, although another observable (azimuthal asymmetry) would provide a simpler experimental test, it would be essentially tanbeta and MH+ independent at 7 TEV, where on the contrary:

"The top poòlarization is a a better probe of tanbeta than the azximuthal asymmetry".



A_LR
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
A_LR at LO
A_LR at NLO SUSY
√s= 7 TeV
Heavy SUSY scenario
Tree level bottom mass
M_H±=270 GeV
5
10
15
20
25
30
35
40
tanβ

As one sees from the Figure, the pure EW MSSM effect is essentially the same as the one that included the strong SUSY effect.

Apparently, the strong interaction effect has again cancelled

(expected from Alr (MZ).....).

This would make Alr a potential

clean detector of

GENUINE SUSY EW EFFECTS.

Conclusions.

Assuming that Supersymmetry will be "soon" discovered at LHC, a precise determination of its fundamental parameters (like for instance tanbeta) might be made more difficult by the unavoidable theoretical uncertainties due to the presence of strong interactions.

The aim of the paper that I have summarized is that of proposing to the experimental community an observable that might minimize those theoretical uncertainties, and provide a way of measuring “genuine SUSY effects”.

The work that has been done was undeniably limited. In this sense, a more acceptable conclusion is that, in my opinion, “The top polarization asymmetry is worth of being investigated both theoretically and experimentally in more detail”.