Single top production at LHC : a complete one-loop calculation in the MSSM.

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A rather peculiar feature of the potential LHC outcomes is that of being able to provide from proton-proton collisions a relevant information on the charged weak current interactions of the top quark.

This information will be offered by the study of the process of SINGLE TOP PRODUCTION.

A short summary of conventions now follows. A full and exhaustive illustration can be found in the very recent paper :”Top quark physics at LHC”, W.Bernreuther, J.Phys.G35, 083001,2008.

One usually defines three types of “single top” production processes:

a)t-channel

b)associated tW production

c)s-channel

(Figure, W.Bernreuther...).

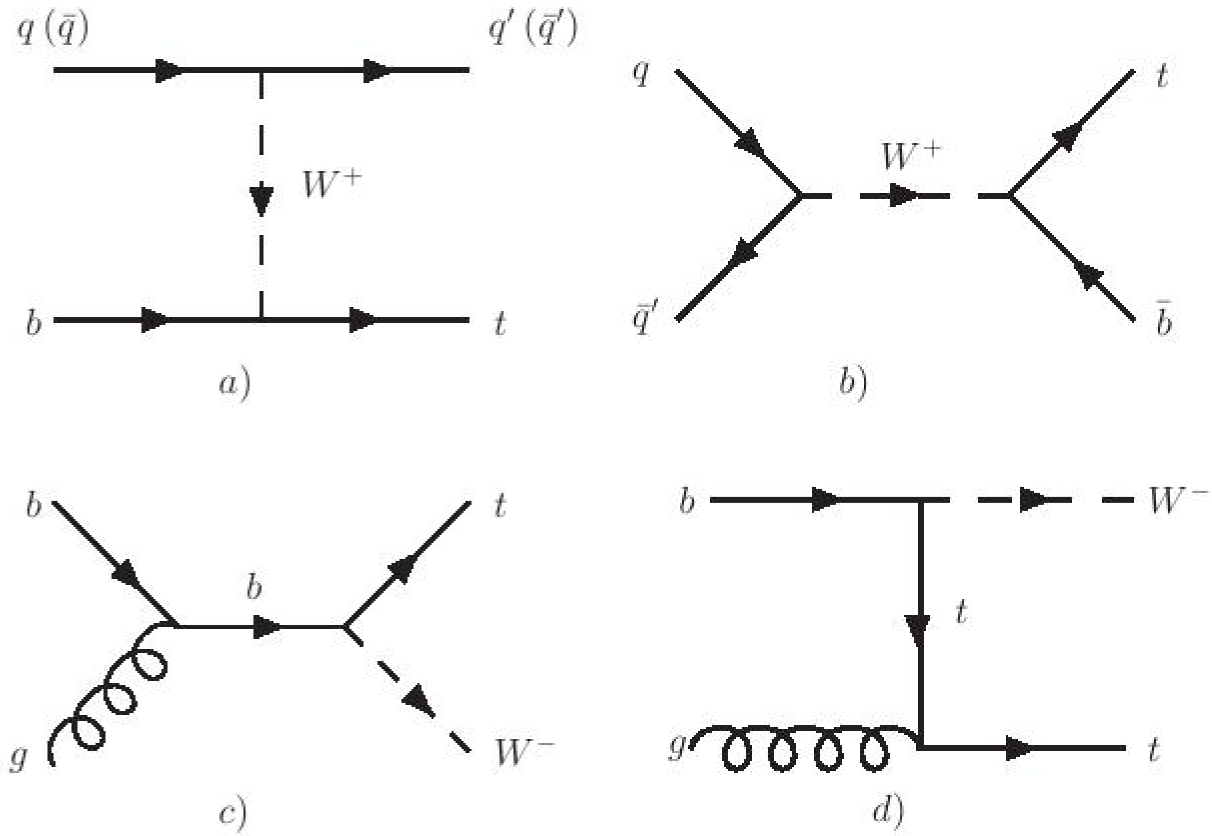
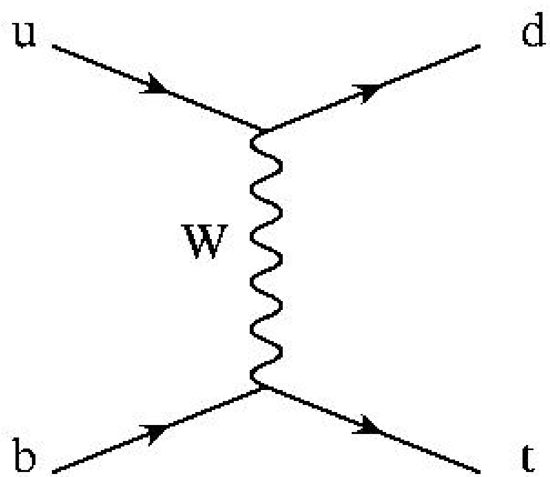


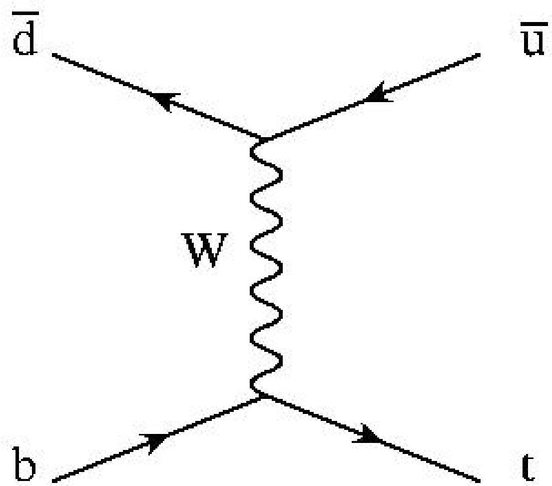
Figure 8: Lowest order Feynman diagrams for single-top-quark production processes: t channel (a), s channel (b), and associated tW production (c,d).

Usually, one calls "single top t-channel process" the sum of the two processes of single top and single antitop production.

Eight processes give the expectedly dominant contributions.

For top production, the two main processes are the following ones:


u
d
W
b
t



d̄
ū
W
b
t

Theoretical SM calculations (Born+NLO QCD).

The t-channel production has the largest rate: roughly, 240 pb , not much less than the top-antitop one (about 830 pb).

Note that the single top rate (about 150 pb) is different at LHC (proton-proton) from the antitop one(about 90 pb).

The tW production has a rate of about 65 pb (top=antitop rate).

The s-channel has a (top+antitop)rate of approximately 10 pb.

(See:M.Cristinziani,G.Petrucciani, “Single top:prospects at LHC”,arXiv:0808.0565v1).

Why is the single top production interesting?

Because it provides a unique (first) way of measuring the W-top-bottom CKM coupling Vtb, since clearly e.g.the 3 total rates will all be proportional (Born level) to|Vtb| squared.

This is the only poorly measured SM parameter of the CKM matrix. Assuming unitarity and 3 families, it should be very close to one (0.999...).From very recent CDFresults(T.Aaltonen...XiV:0809.2581 v1) of t- and s-channels, one gets $|V_{tb}|>0.66$ at 95% C.L.

The available predictions give also an estimate of the various theoretical "errors" (better, "uncertainties"). These come from scale uncertainties, PDF uncertainties, mt uncertainty. Roughly, one expects for the total rates :

1) t-channel: 240 +- 10(th)

2) tW: 65 +- 7(th)

3)s-channel: 10 +- 1(th).

Several estimates exist of the expected experimental accuracies. In general, they depend on the assumed integrated luminosity and vary with the process.
It appears (ATLAS NOTE ATL-PHYS-PUB-2007-XXX, July 2008) that the most favourable situation corresponds to the t-channel, the worst one to the s-channel.For 1 fb-1, one expects an overall uncertainty of a relative 20 percent (t-channel),50 percent (tW), 90 percent (s-channel). For10 fb-1 the uncertainties are roughly halved.
Experimental goal for the t-channel:” to reach a precision at the few percent level” (ATLAS NOTE....).

It appears in conclusion that the t-channel process has an optimal (theory+experiment) uncertainty situation, possibly at the few percent level.

Incidentally, NLO QCD effects are rather modest,at the five percent level.

At this level of accuracy, a natural question that arises is:

What is the size of the NLO electroweak effects? Could they be at a visible (say, more than five percent) level?

A priori, this possibility cannot be excluded. From a partial analysis performed for the dominant t-channel process in the MSSM it was found that for “asymptotic” accelerator energies large negative effects on the rate ,of order ten percent (or more) were generated by the supposedly leading negative double Sudakov weak logarithms produced by a subset of weak one-loop diagrams. (M.Beccaria, F.M.Renard, C.V., Phys.Rev.D71, 033005, 2005).

A more complete one-loop calculation is however nowadays requested.

The long calculation was performed in a recent paper (all details there):
M.Beccaria, C.M.Carloni-Calame,G.Macorini,E.Mirabella, F.Piccinini,F.M.Renard, C.V., Phys.Rev.D77:113018,2008.

It was performed in the MSSM, mSugra symmetry breaking scheme, for a choice of twelve typical SUSY benchmark points (Table). All one loop electroweak effects from self-energies, vertices, boxes, QED soft and hard radiation, SUSY QCD were computed (killing divergences of every kind).

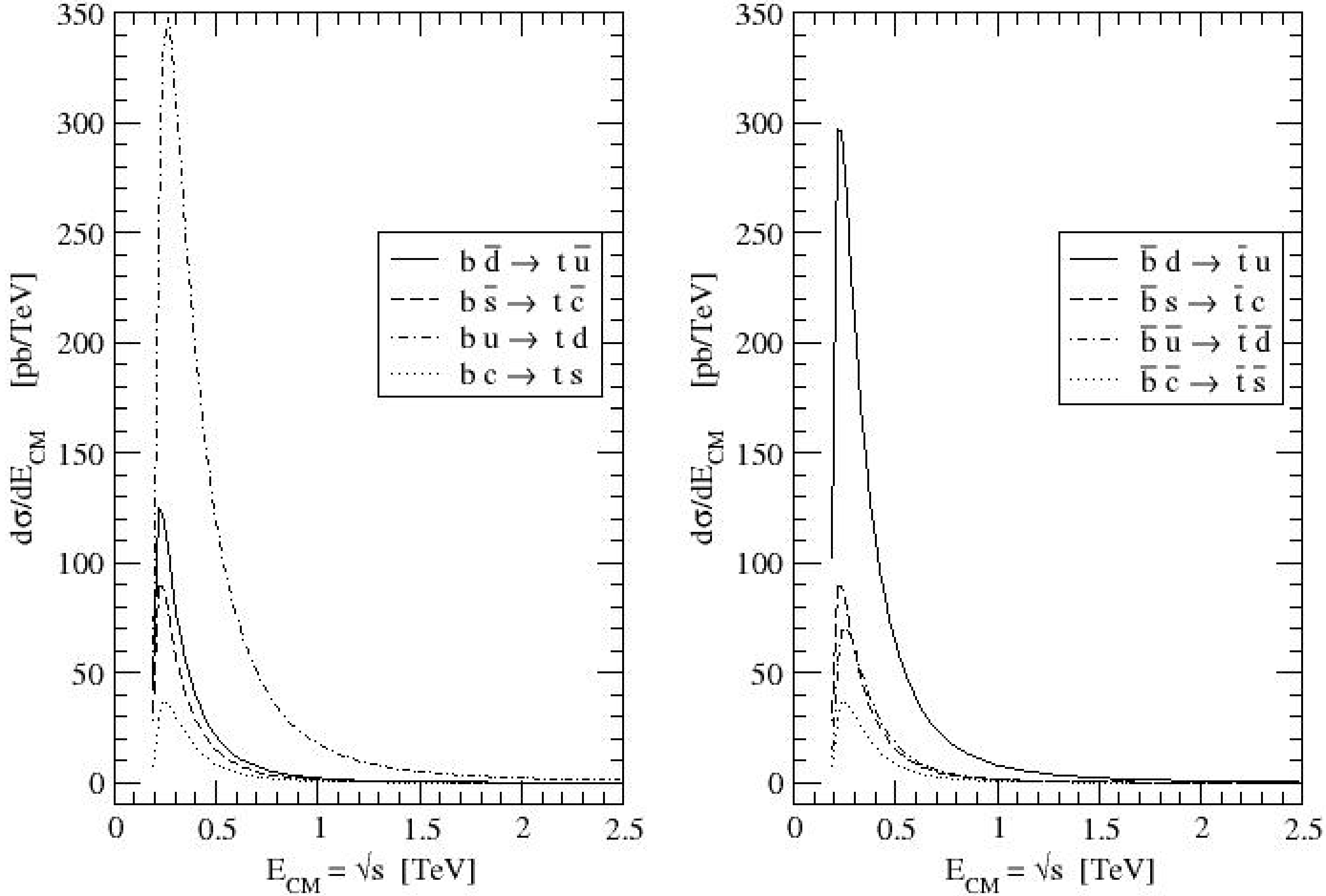
mSUGRA scenario	m_0	$m_{1/2}$	A_0	$\tan\beta$	sign μ	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$
LS1	300	150	-500	10	+	214.6	460.5	377.1	444.7
LS2	300	150	-500	50	+	224.7	430.4	301.6	399.3
SPS1a	100	250	-100	10	+	399.7	585.5	515.7	546.6
SPS1a'	70	250	-300	10	+	367.3	581.9	504.4	541.7
SPS1a slope	$0.4m_{1/2}$	250	$-0.4m_{1/2}$	10	+	399.7	585.5	515.7	546.6
SPS2	1450	300	0	10	+	921.4	1289	1279	1540
SPS3	90	400	0	10	+	645.2	840.3	790.1	823.7
SPS4	400	300	0	50	+	540.1	692.5	614.9	687.2
SPS5	150	300	-1000	5	+	279.0	651.2	566.3	651.1
SPS6	150	300	0	10	+	494.6	675.6	617.0	649.4
SU1	70	350	0	10	+	566.4	754.0	698.6	729.8
SU6	320	375	0	50	+	634.1	794.7	712.1	785.8

TABLE I: mSUGRA benchmark points and masses of stops and sbottoms (all the values are in GeV)

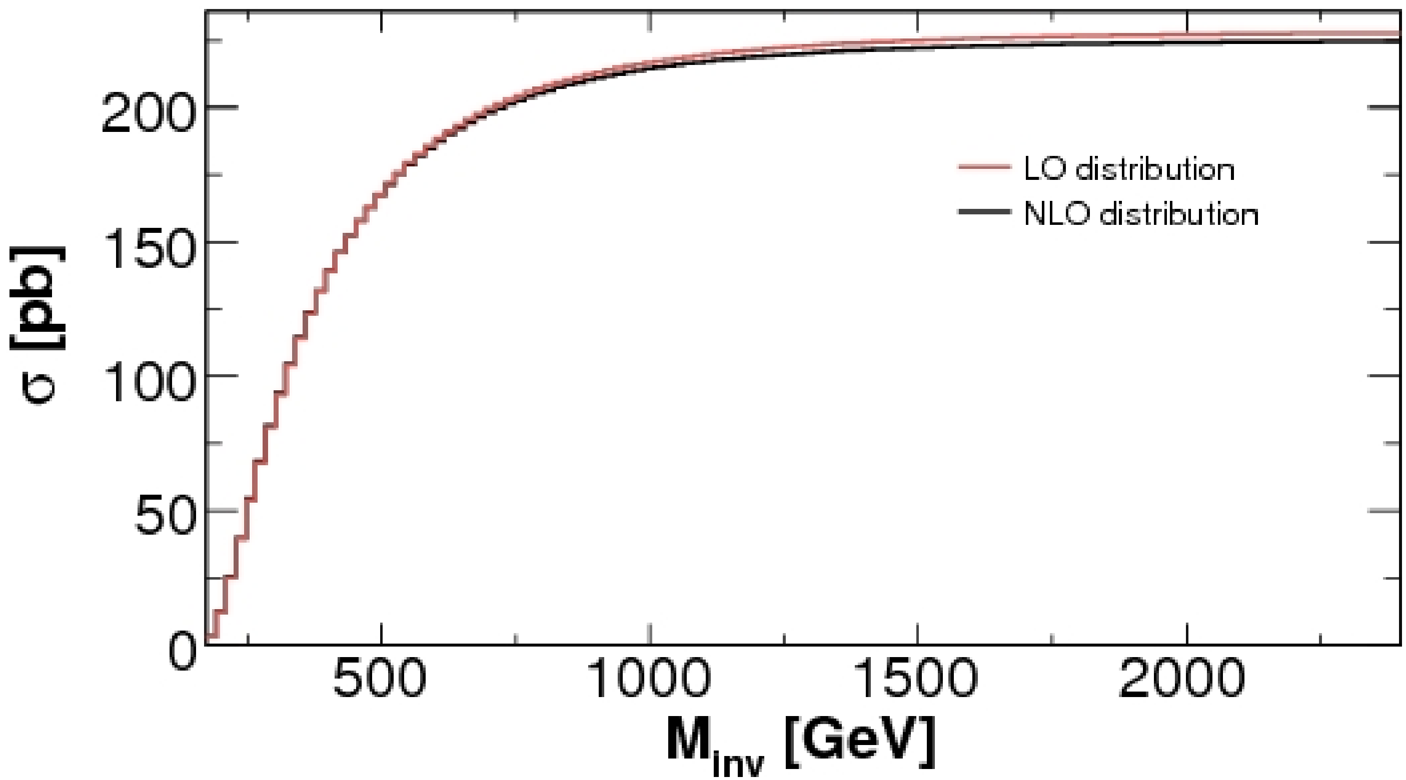
The results of our calculation (8 processes) are shown in the next Figures. They can be summarized by the (sad?) statement:

The complete one-loop electroweak effect is "LHC irrelevant", at the (-two) percent level in the total rate, (also in the invariant mass distribution), both in the SM and in the MSSM, mSUGRA . Typical SUSY effect for SU6 (shown).

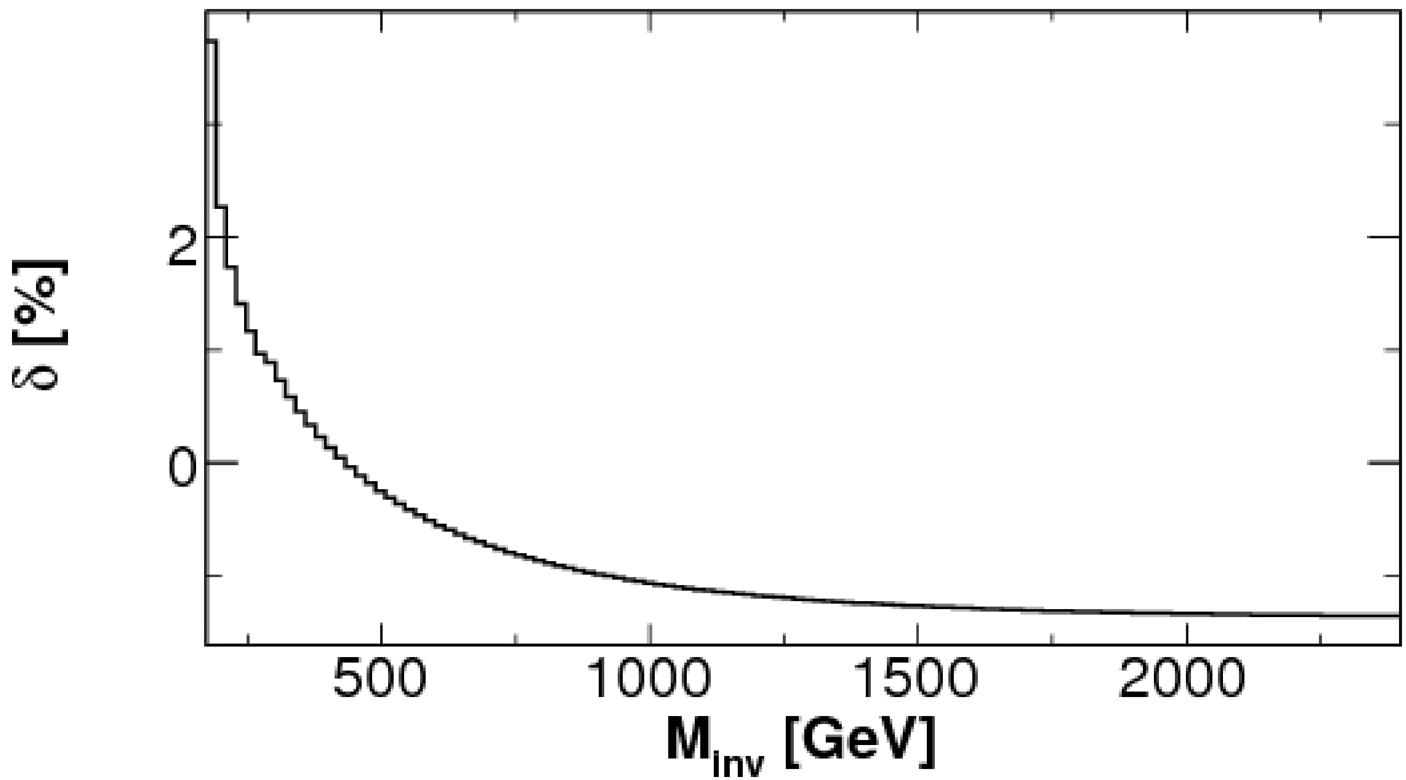
SUSY alone remains below the one percent level (SUSY QCD at the permille level, agrees with J.J.Zhang,C.Li,Z.Li,L.L.Yang,Ph.Rv.D75 ,014020,2007).

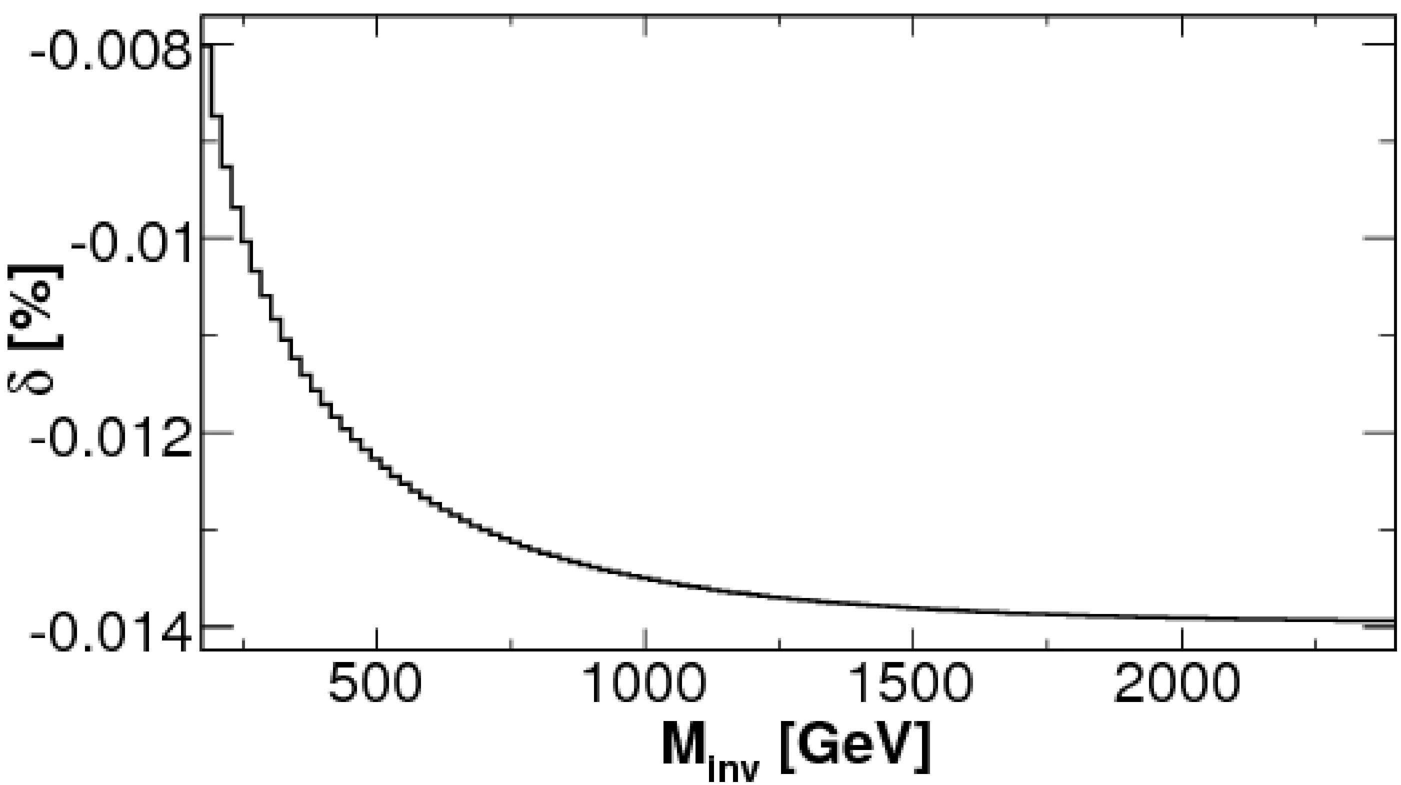


$d\sigma/dE_{CM}$ [pb/TeV]
$E_{CM} = \sqrt{s}$ [TeV]
b $\bar{d}$ → t $\bar{u}$
b $\bar{s}$ → t $\bar{c}$
b u → t d
b c → t s
$\bar{b}$ d → $\bar{t}$ u
$\bar{b}$ s → $\bar{t}$ c
$\bar{b}$ $\bar{u}$ → $\bar{t}$ $\bar{d}$
$\bar{b}$ $\bar{c}$ → $\bar{t}$ $\bar{s}$



LO distribution
NLO distribution
σ [pb]
200
150
100
50
0
500
1000
1500
2000
M_inv [GeV]


δ [%]
2
0
500
1000
1500
2000
M inv [GeV]


-0.008
-0.01
-0.012
-0.014
δ [%]
500
1000
1500
2000
M_{inv} [GeV]

Possible explanation of the vanishing effect: cancellation between a negative term of Sudakov kind and a positive QED enhancement.

Consequence: electroweak one-loop effects can be safely neglected for the t-channel process in the SM and in the mSUGRA MSSM.

Born + NLO SM QCD is enough.

But for different SUSY models no investigation exists....could be interesting to find visible effects...

What about tW production?

Identical prejudice of a partial sizeable negative one-loop asymptotic Sudakov effect (M.Beccaria...2005 Phys.Rev.D71 quoted paper).

Complete one-loop calculation in the mSUGRA MSSM:

M.Beccaria,C.M.Carloni Calame, G.Macorini,G.Montagna,F.Piccinini,F. M.Renard, C.V., Eur.Phys.J.C53:257,2008. (details there).

Briefly:one finds for the rate a slightly larger effect (roughly, six percent SM , with an extra six percent from SUSY QCD(J.J.Zhang et al., previous quoted paper). But the expected experimental “error” is much larger..and the size of the rate is much smaller...----> one loop electroweak again “LHC irrelevant”.
(again, valid in mSUGRA MSSM).

For the s-channel : the (Born) rate is so small that a one-loop electroweak calculation appears to be a loss of time (--->of money).

A possibly interesting question could be: what is the rate of the total (t-channel+tW+s-channel) LHC single top production?

(separate channels not simple to identificate...top-antitop "background"...).

Next tables give values at Born SM level (SM QCD to be added) for 10 TEV (possibly interesting),mtop=172 and 175 GEV.

(G.O.Dovier, presented at ATLAS top group meeting, CERN, September 2008).

10 TeV	
s-channel	4.8 pb
t-channel	149.6 pb
tW	32.0 pb
Overall	186.4 pb

10 TeV	
s-channel	4.5 pb
t-channel	147.0 pb
tW	31.2 pb
Overall	182.7 pb

Conclusions.

The overall one-loop electroweak effect has been computed for single top production in the dominant t-channel and tW production cases in the SM and in the mSUGRA MSSM. At the expected LHC accuracy, the effect is negligible.For the derivation of Vtb, the theoretical description in these models appears reasonably simple.

A determination at the few percent level appears thus realistically experimentally performable.