Searches for SUSY EW effects in top production at the LHC

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“Flavour in the era of the LHC
CERN 7-10 November 2005
Main questions of this presentation

- It is possible to detect virtual Electroweak SUSY Signals (=VESS) at LHC (=ATLAS,CMS)??
  - Tentative answer from a theory-experiment collaboration (!)
    - M. Beccaria, S. Bentvelsen, M. Cobal, F.M. Renard, C. V
  - Alternative (~equivalent) question: it is possible to perform a “reasonably high” precision test of e.g. the MSSM at LHC (assumed preliminary SuSY discovery…)?
    - Wise attitude: Learn from the past!
Undeniably, in the recent years, crucial precision tests were performed at LEP1

- Particularly relevant, the study of $Z_{b\bar{b}}$ decay with its one-loop
  - $\Delta_{bv} \sim \alpha \frac{M_t^2}{M_W^2}$ top Yukawa coupling

- Useful variable: the ratio $\Gamma_b/\Gamma_h$
  - Eliminates several QCD effects
What we learned

- Two suggestions or indications:
  1) For precision (≈ 1 loop) tests, the top quark could be fundamental via its Yukawa coupling!
  2) To eliminate unwanted QCD effects, ratios of observables could be fundamental

- In the remaining part of this presentation, the validity of the two points will be discussed for LHC.

- Almost “obviously” for the processes of TOP PRODUCTION
First considered process: ttbar production (i.e. $pp \rightarrow t\bar{t}X$)

Preliminary investigation in the MSSM at 1 loop (ew)  
($\rightarrow$ search for virtual ew effects)

Question: can one find at the LHC a virtual SuSY effect which is the simple generalization of the $\sim M_t^2/M_W^2 \in \Delta_{bv}$ SM LEP1 effect?

Answer: YES, under special SuSY features
Top production at LHC

Top physics at LHC

- “Bread and butter” physics
- ‘Precision and new physics’
  - Top mass $M_t$, cross section $\sigma_t$ (ultimate goal: $\Delta M_t < 1$ GeV)
  - Consistency check of Higgs mass in Standard Model (with W-mass)

- 8 millions tt pairs/year (1 pair/second) at low luminosity!

\[ \sigma_{tt}^{\text{FNAL}} = 6.5 \text{pb} \ (1 \pm 5\%_{\text{scale}} \pm 7\%_{\text{PDF}}) \]

\[ \sigma_{tt}^{\text{LHC}} = 840 \text{pb} \ (1 \pm 5\%_{\text{scale}} \pm 3\%_{\text{PDF}}) \]
If SUSY is light..

Briefly: if e.g. All SuSY masses $\leq M_{\text{SuSY}} \equiv M \approx 400$ GeV, from an investigation of $d\sigma/dM_{tt}$ for $M_{tt\bar{t}} \approx 1$ TeV, "SuSY Yukawa" might be visible because of Sudakov logarithmic expansions

- (~valid for $M_{tt\bar{t}} >> M, M_t$) that appear at 1-loop

Diagrams for ew Sudakov logarithmic corrections to $gg \rightarrow tt\bar{t}$
If SUSY is light.

- Roughly and briefly (Sukadov stuff supposed to be known)
- The partonic Invariant Amplitude can be approximated (1 loop) by a “next to leading order” logarithmic expansion: NO QED here!

\[ A^{(1)}(\text{ew}) \equiv A^{(\text{Born})} \left[ 1 + |a_\sigma|(2\ln - \ln^2) + a_y \ln + \ldots \right] \]

\[ \sigma \equiv \text{gauge} \]

\[ y \equiv \text{Yukawa} \]

\[ \ln \equiv \ln \left( \frac{M^2_{\text{ttbar}}}{M^2} \right) \]

\[ a_\sigma \approx I_{3L}, \ Y.. \]

\[ a_y \equiv -[M_t^2 \cot^2 \beta + M_b^2 \tan^2 \beta] \ [2] \]

\[ \text{SM} \approx -M_t^2 \]

\[ \neq \text{SM!!!} \]
If SUSY is light...

- N.B.: the genuine SuSY “Sudakov” terms only affect LINEAR LNS (SQUARED LNS only from Standard Model)

- $M_{\text{susy}} = M \text{ (general)} \approx \ln M_i/M \text{ terms, constants}$
  $i=\text{SuSY sparticles.}$

- Equivalent to Next to leading order approximation

- Only $\text{tg} \beta$ remains as variable parameter of the expansion
A few details of the preliminary approximate treatment:

1) Assume $M_{\text{SuSY}} \leq 400 \text{ GeV}$

2) Compute the real (i.e. With PDF..) $d\sigma/dM_{tt} = \text{usual stuff (see paper..)}$

3) Take $\overline{q}q \rightarrow \overline{t}t$ in Born approximation ($\leq 10\% \sigma$) and compute to 1 loop $gg \rightarrow \overline{t}t$ for $M_{tt} \approx 1 \text{ TeV} (0.7 \text{ TeV} \leq M_{tt} \leq 1.3 \text{ TeV})$

4) Separate $t_L\overline{t} + t_R\overline{t}$ = “parallel spin” from $t_L\overline{t} + t_R\overline{t}$ = “anti-parallel spin”
From the previous figures, one sees a “decent” effect (10-15\% for large $\tan \beta$) in the $\sim$ 1 TeV region (“modulo” constant terms, that should not modify the shape)

A $\chi^2$ minimization program could be performed BUT..
  - With which error? (Alain B. Would say: “uncertainty”?)

Here the experimental component (Marina, Stan) GETS IN!
Top events are triggered and selected best when they decay semileptonically.

The kinematics of the neutrino can be recovered as the missing energy of the event.

2 out of 4 jets in event are b jets ~50% a priori purity (need to be careful with extra ISR/FSR jets)

- Remaining 2 jets can be kinematically identified (should form W mass) → possibility for further purification
Experimental study

- $10^6$ tt events generated with Pythia, and processed through the ATLAS detector fast simulation (5 fb$^{-1}$)

- Selection:
  - At least ONE lepton, $p_T > 20$ GeV/c , $|\eta| > 2.5$
  - At least FOUR jets $p_T > 40$ GeV/c , $|\eta| > 2.5$
    Two being tagged b-jets
  - Reconstruct Hadronic Top
    $|M_{jj} - M_W| < 20$ GeV/c ;
    $|M_{jjb} - M_t| < 40$ GeV/c
  - Reconstruct leptonic Top
    $|M_{jj} - M_W| < 20$ GeV/c ;
    $|M_{jjb} - M_t| < 40$ GeV/c

- Resulting efficiency: 1.5%
Higher order QCD effects

- NLO QCD effects (final state gluon radiation, virtual effects) spoil the equivalence of $M_{tt}$ with $\sqrt{s}$
  - The $tt$ cross section increases from 590 to 830 pb from LO to NLO
  - Also the shape gets distorted by NLO effects

- Effects of NLO QCD has been investigated using MC@NLO Monte Carlo (incorporates a full NLO treatment in Herwig)
  - $M_{tt}$ distributions generated in LO and NLO and compared
  - $M_{tt}$ value obtained at parton level, as the invariant mass of the top and anti-top quark, after both ISR and FSR. The LO and NLO total cross sections are normalised to each other.
Higher order QCD effects

- Deviations from unity entirely due to differences in $M_{tt}$ shape.

- Relative difference between $\sqrt{s}$ and $M_{tt}$ remains bounded (below roughly 5%) when $\sqrt{s}$ varies between 700 GeV and 1 TeV (chosen energy range).

- For larger $\sqrt{s}$, the difference raises up to a 10% limit when $\sqrt{s}$ approaches what we consider a realistic limit ($\sqrt{s} = 1.3$ TeV).
Systematic Uncertainties

**Main sources:**
- Jet energy scale uncertainty
- Uncertainties of jet energy development due to initial and final state showering
- Uncertainty on luminosity

**Jet energy scale:**
- A 5% miscalibration energy applied to jets, produces a bin-by-bin distortion of the $M_{tt}$ distribution smaller than 20%.
- Overestimate of error, since ATLAS claims a precision of 1%

**Luminosity**
- Introduces an experimental error of about 5%. At the startup this will be much larger.
Systematic Uncertainties

- **ISR and FSR**
  - The $M_{tt}$ distribution has been compared with the same distribution determined with ISR switched off. Same for FSR.
  - Knowledge of ISR and FSR: order of 10%, so systematic uncertainty on each bin of the $tt$ mass was taken to be 20% of the corresponding difference in number of events obtained comparing the standard mass distribution with the one obtained by switching off ISR and FSR.
  - This results in an error $< 20\%$

- **Overall error**
  - An overall error of about 20-25% appears realistically achievable.
  - Does not exclude that further theoretical and experimental efforts might reduce this value to a final limit of 15-10%.

Realistic $\chi^2$ minimization procedure for $tg\beta$ follows
From this preliminary analysis

- This type of investigations might be interesting in a LIGHT SuSY SCENARIO particularly for large $\tan\beta$. ("modulo" QCD but perhaps it does not change the slope of $d\sigma/dM_{tt}$.)
  - Bernreuther, Brandenburg, Si, Uwer, Nucl. Phys. B630, 81. 2004

- Next efforts:
  - A complete 1-loop ew SuSY (th.) calculation (almost completed)
  - A reduction of the overall (exp.) “uncertainty” $\Rightarrow 10\%$ limit..(perhaps!)
What about single top production?

Three SM processes. At partonic level:

1) $b u \rightarrow t d$ (t-channel) \[\sigma \approx 245 \text{ pb}\]

2) $b g \rightarrow t W$ ("associated" production) \[\sigma \approx 62 \text{ pb}\]

3) $u \overline{d} \rightarrow t \overline{b} b$ (s-channel) \[\sigma \approx 10 \text{ pb}\]
First qualitative study

- Under the same “LIGHT SuSY” + Sudakov (final i. Mass $\approx 1$ TeV) scenario

- Again, large effects found (see figures)

- But: a complete 1-loop investigation requested (particularly for tW, hardly visible at about 1 TeV...
First considered process

- \( pp \rightarrow tWX (\sigma \approx 62 \text{ pb}) \) (associated \( tW \) production)
  - ("exclusive") \( gb \rightarrow tW \) (partonic)

- Why this first?
  - Because of the "chinese attitude": after \( tW \) anything else will appear "bread and butter"
  - More than 200 1-loop graphs!

- Now, \( tW \) completed (ew 1-loop) including QED...

- A C++ program available: "MINSTREL"
  - Work done by M. Beccaria, G. Macorini, F.M. Renard, C.V.

- Figures being done (next week) for SU(1...6) ATLAS points
  - Preliminary ones: small SuSY effects (at LOW \( M_{tW} \))
First impressions

- No SuSY ew effects for SU(..) points in tW at low ( < 500 GeV) $M_{tW}$ (almost expected..)

- However: effect increases with $M_{tW}$, with the same parameters

- Other “better” points will be studied..

- Also: one notices that for $M_{tW} \geq 700$ GeV (and $\geq 1$ TeV) the slope is about almost the same as that of the Sudakov logarithmic plots
  - “only” an extra constant term
  - Precocious Sudakov effects?
First impressions

- This observation motivates the calculation of the complete 1-loop effect (done for tW) also in td ("t-channel") and ttbar (s-channel seems not promising…left in BORN?)

- The calculation is almost completed (M. Beccaria, G. Macorini, F.M. Renard, C.V.)

- First figures soon available (Xmas?,,,with gifts?)
Conclusions

- Top production at LHC might be sensitive to ew SUSY effects, particularly for “light SuSY”, large tanb and LARGE INVARIANT MASSES

- Tbbar and td production appear as best choice…

- tW could be a real precision test of e.g. tbW couplings…at least..OR OF DIFFERENT MODELS

- More precise results coming soon. …
Conclusions

- Ratio of observables? No time available
  - Could provide excellent EW precision tests

- Recent discussions recommended...
  - F. Hubaut, E. Monnier, P. Pralavorio, K. Smolek, V. Simak: “ATLAS sensitivity to top quark and W boson polarization in ttbar events”, hep-ex/0508061 and references therein

- Experimental study (analogous with the ttbar one) in progress (M. Cobal et al.)

- As one used to say: *Se son rose fioriranno...*