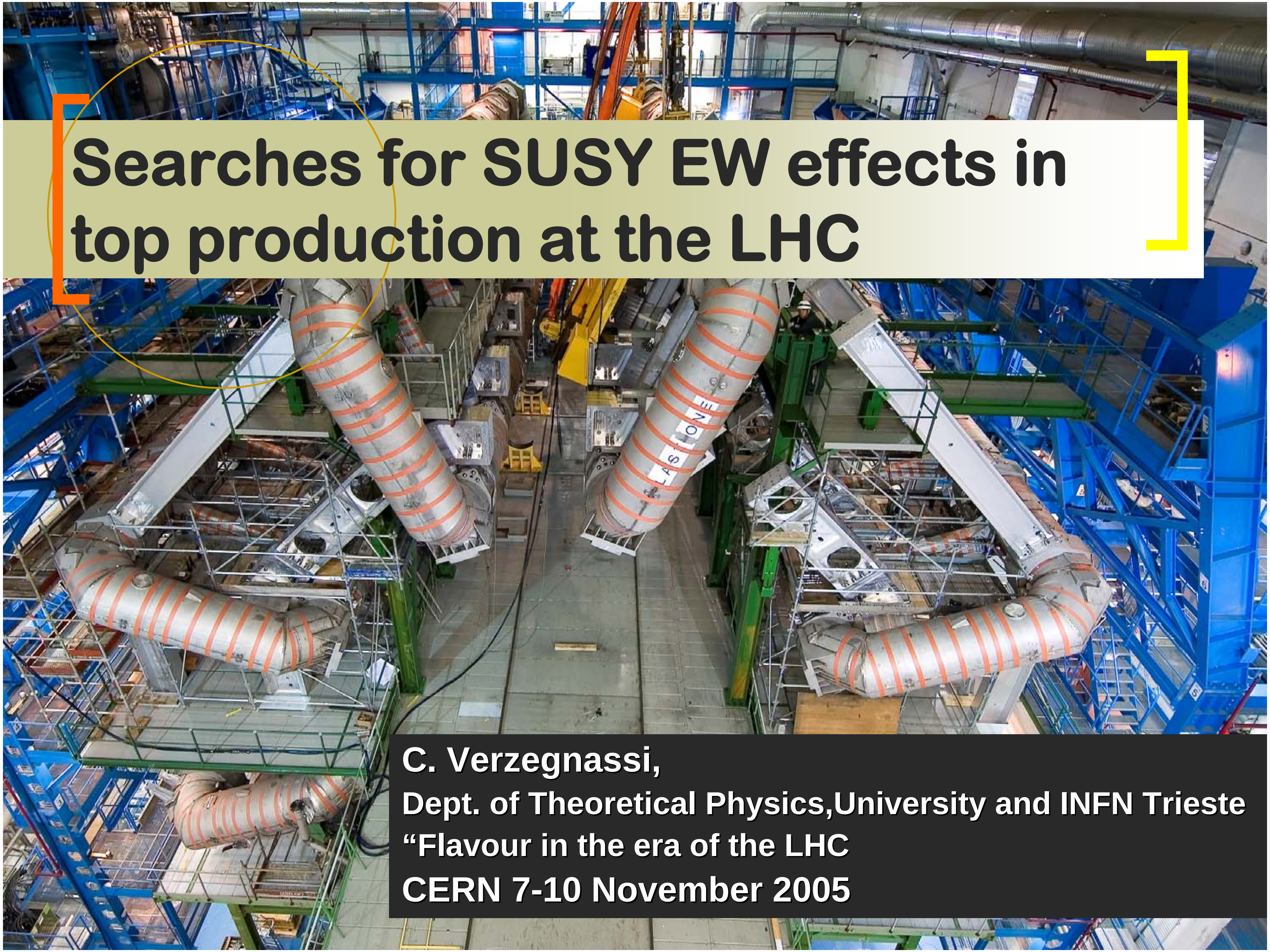

Searches for SUSY EW effects in top production at the LHC

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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 Phys. Rev. D71, 073003, 2005.***
- 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!

Past experience

- Undeniably, in the recent years, crucial precision tests were performed at LEP1
  - Particularly relevant, the study of Z_{bbar} decay with its one-loop
    - **Δ_{bv} ~α M_t^2/M_W^2 top Yukava coupling**
  - Useful variable: the ratio Γ_b/Γ_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

Suggestion

- First considered process: ttbar production (i.e. pp →ttX)
- Preliminary investigation in the MSSM at 1 loop (ew) (→ search for virtual ew effects)
- Question: can one find at the LHC a virtual SuSY effect which is the simple generalization of the ~ $M_t^2/M_W^2 \in \Delta_{bv}$ SM LEP1 effect?
- Answer: YES, under special SuSY features

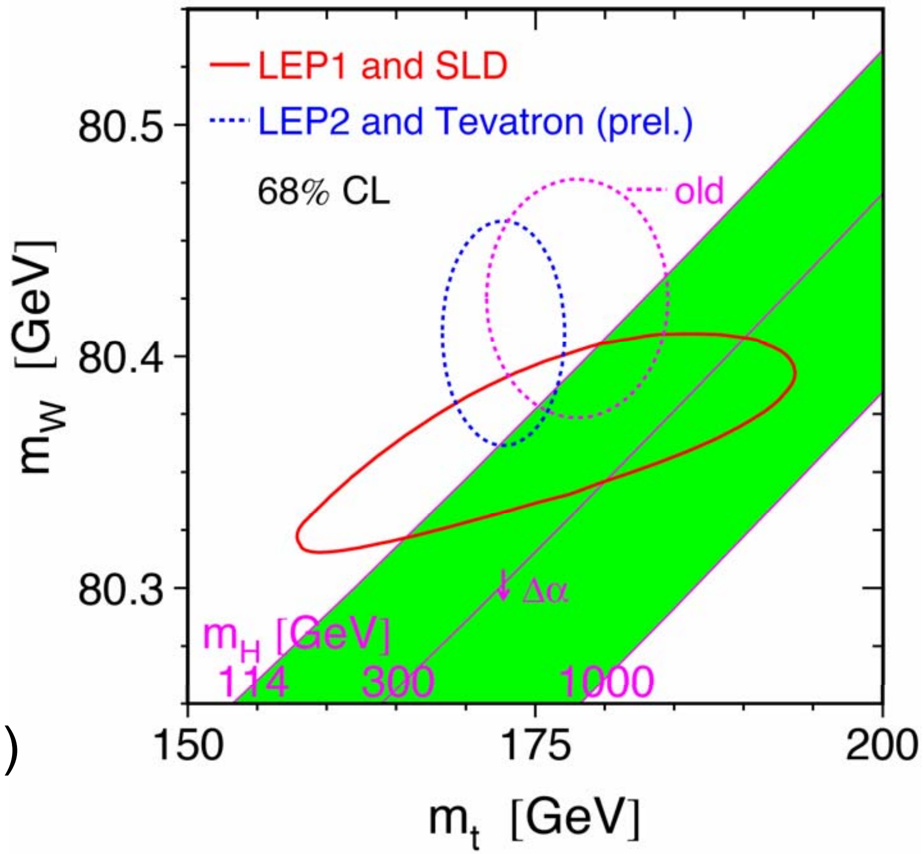
Top production at LHC

- **Top physics at LHC**
  - "Bread and butter" physics

σ_{tt}^{FNAL} = 6.5pb (1 ± $5\%_{scale}$ ± $7\%_{PDF}$)

σ_{tt}^{LHC} = 840pb (1 ± $5\%_{scale}$ ± $3\%_{PDF}$)

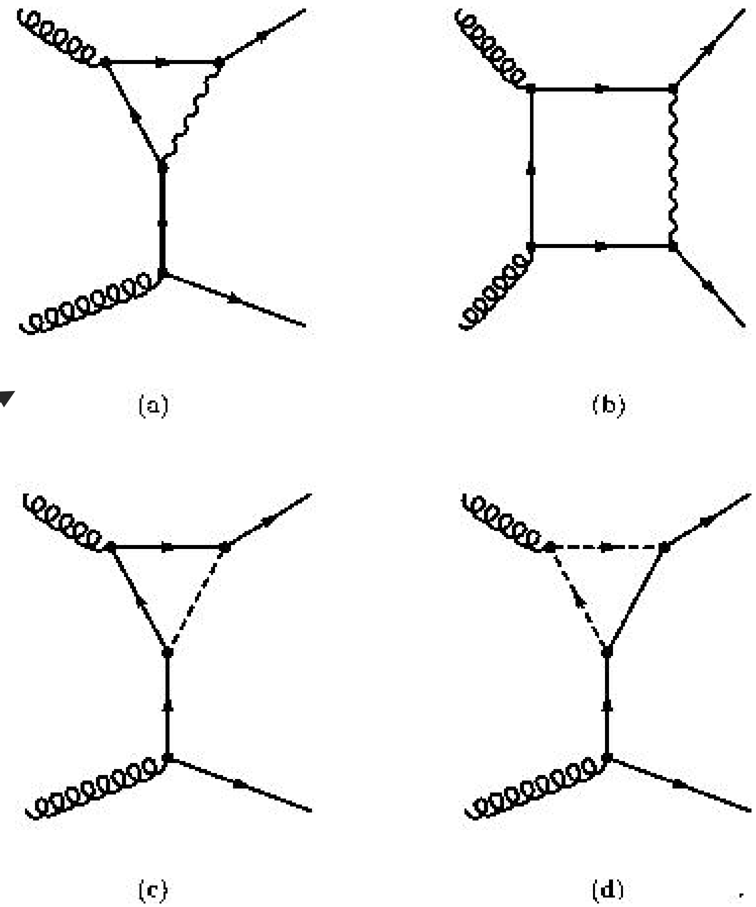
  - **'Precision and new physics'**
    - ✓ Top mass M_t, cross section σ_t (ultimate goal: ΔM_t<1 GeV)
    - ✓ Consistency check of Higgs mass in Standard Model (with W-mass)



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

If SUSY is light..

- Briefly: if e.g. All SuSY masses $\leq M_{SuSY} \equiv M \cong 400$ GeV, from an investigation of $d\sigma/dM_{tt}$ for $M_{ttbar} \cong 1$ TeV, "SuSY Yukawa" might be visible because of Sudakov logarithmic expansions
  - (~valid for $M_{ttbar} >> M, M_t$) that appear at 1-loop



Diagrams for ew Sudakov logarithmic corrections to gg →ttbar

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!

$A^{(1)(ew)} \cong A^{(Born)} [\ 1+|a_\sigma|(2\ln-\ln^2)+a_y\ln+\ldots]$ $\quad\sigma \equiv$ gauge

$y \equiv$ Yukawa

$\ln \cong \ln\ (M^2_{ttbar}/M^2)$

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

$a_y \cong -[M^2_t \mathrm{cotg}^2\beta + M^2_b \mathrm{tg}^2\beta]$ [2] $\Big\}\ \neq$ SM!!!

SM $\approx -M^2_t$

If SUSY is light..

- N.B.: the genuine SuSY "Sudakov" terms only affect LINEAR LNS (SQUARED LNS only from Standard Model)
- Msusy = M (general) (neglected $\approx$ ln Mi/M terms, constants) i=SuSY sparticles.
- Equivalent to Next to leading order approximation
- Only tgβ remains as variable parameter of the expansion

Few details..

- A few details of the preliminary approximate treatment:

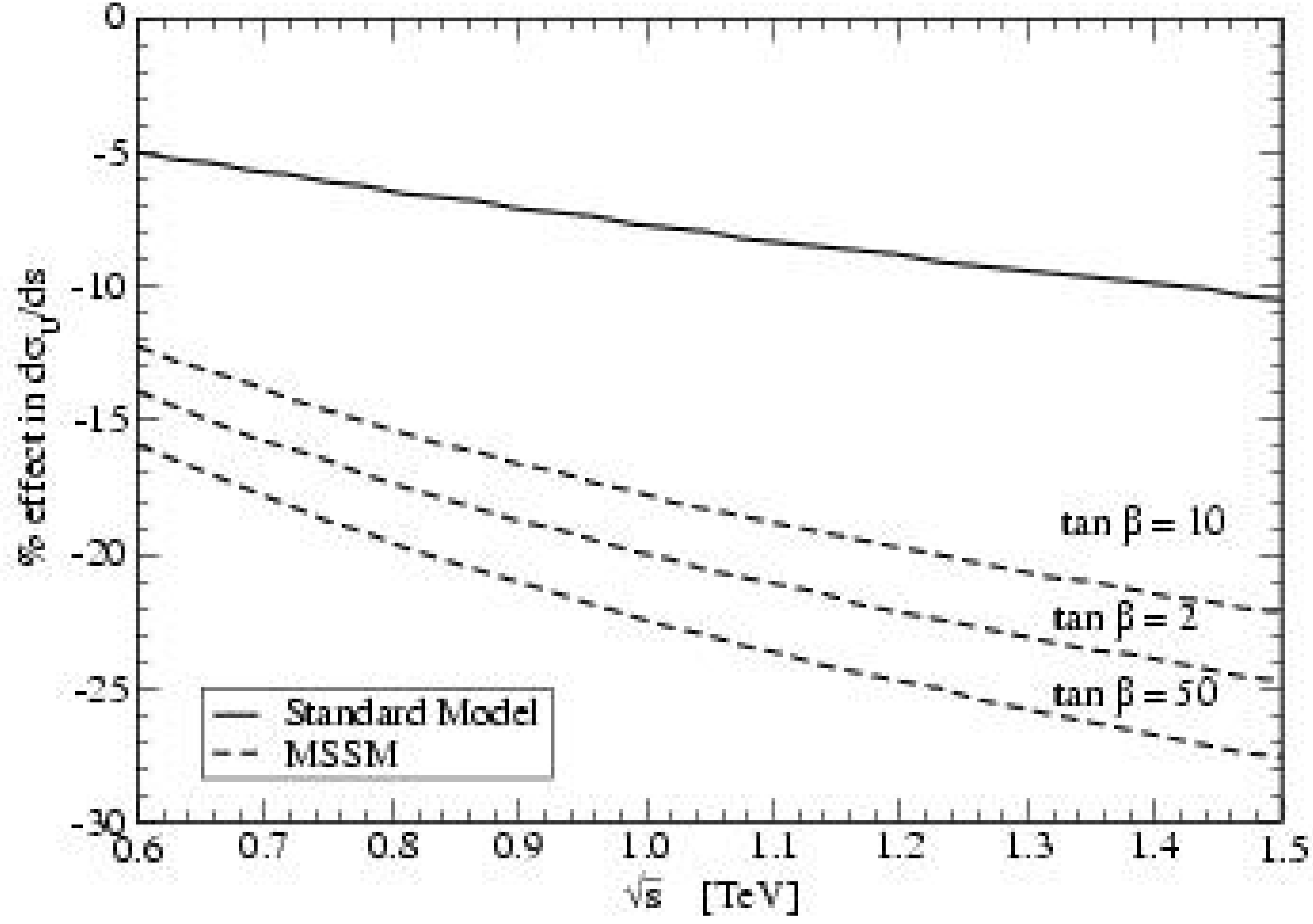
1) Assume $M_{SuSY} \leq 400$ GeV

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

3) Take qqbar $\rightarrow$ ttbar in Born approximation ($\leq$ 10% σ) and compute to 1 loop gg $\rightarrow$ttbar for $M_{ttbar} \approx$ 1 TeV (0.7 TeV $\leq M_{ttbar} \leq$ 1.3 TeV)

4) Separate $t_L tbar_L + t_R tbar_R$ = "parallel spin" from $t_L tbar_R + t_R tbar_L$ = "anti-parallel spin"

% Effect



0
-5
-10
-15
-20
-25
-30
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
% effect in dσU/ds
√s [TeV]
tan β = 10
tan β = 2
tan β = 50
Standard Model
MSSM

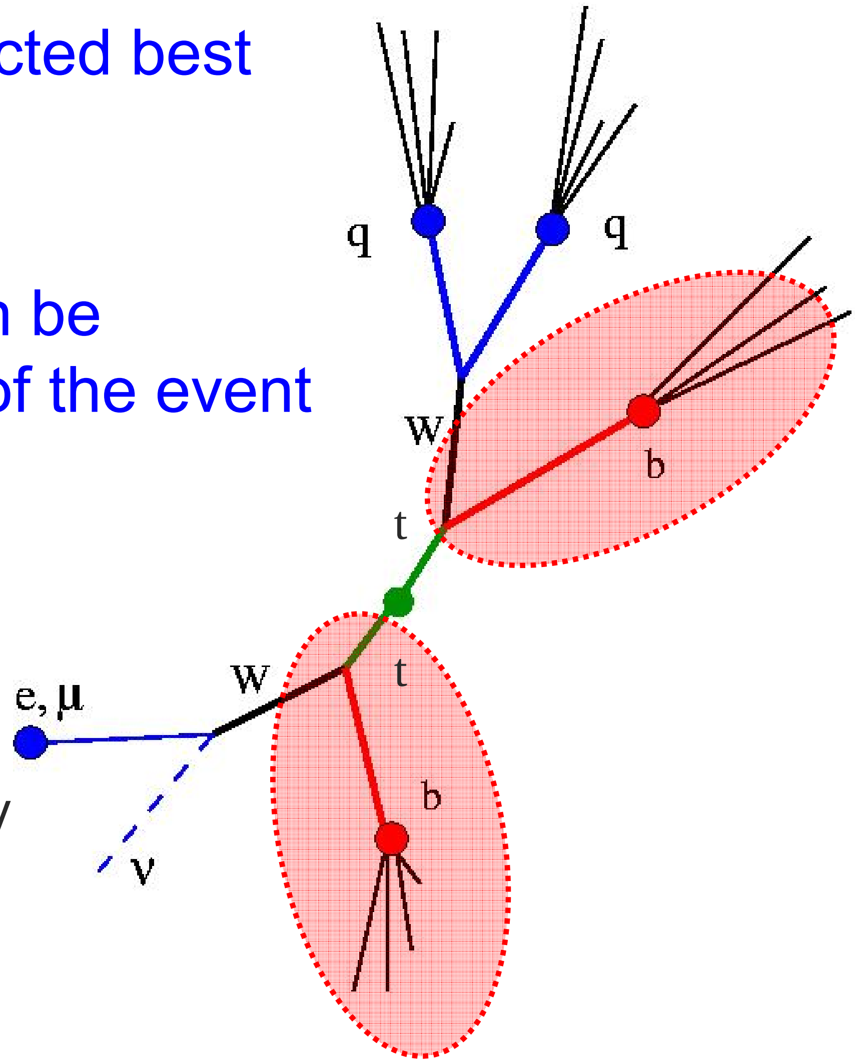
- From the previous figures, one sees a "decent" effect (10-15% for large tgβ) in the $\sim$ 1 TeV region ("modulo" constant terms, that should not modify the shape)

- A χ^2 minimization program could be performed BUT..
  - With which error? (Alain B. Would say: "uncertainty"?)

- Here the experimental component (Marina, Stan) GETS IN!

Ttbar kinematics (experiment figure)

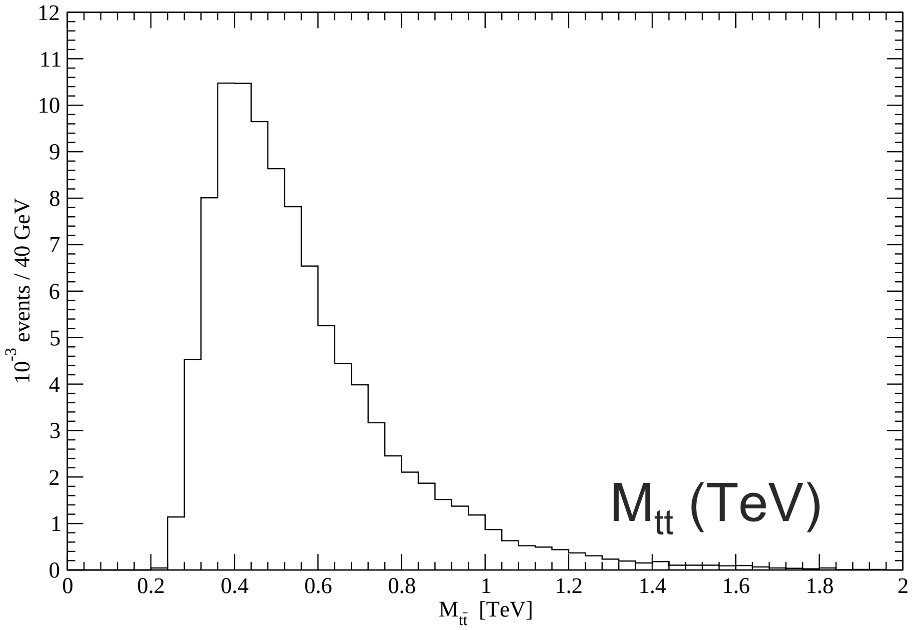
- Top events are triggered and selected best when they decay semileptonically
- The kinematics of the neutrino can be recovered as the missing energy of the event
- 2 out of 4 jets in event are b jets ~50% a priori purity (need to be careful with extra ISR/FSR jets)
  - Remaining 2 jets can be kinematically 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
  - Reconstructio 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

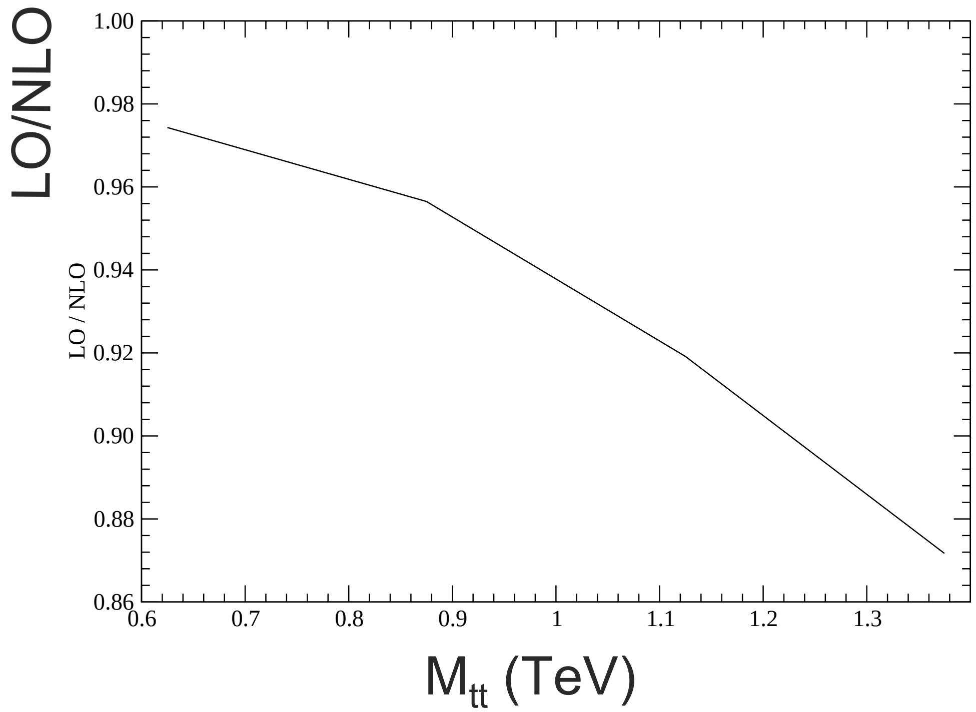
- Effects of NLO QCD has been investigated using MC@NLO Monte Carlo (incorporates a full NLO treatment in Herwig)
  - Mtt distributions generated in LO and NLO and compared
  - Mtt value obtained at parton level, as the invariant mass of the top and anti-top quark, after both ISR and FSR. The LO and 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 √s and M_{tt} remains bounded (below roughly 5%) when √s varies between 700 GeV and 1 TeV (chosen energy range).

- For larger √s, the difference raises up to a 10 % limit when √s approaches what we consider a realistic limit (√s =1,3 TeV)



Systematic Uncertainties

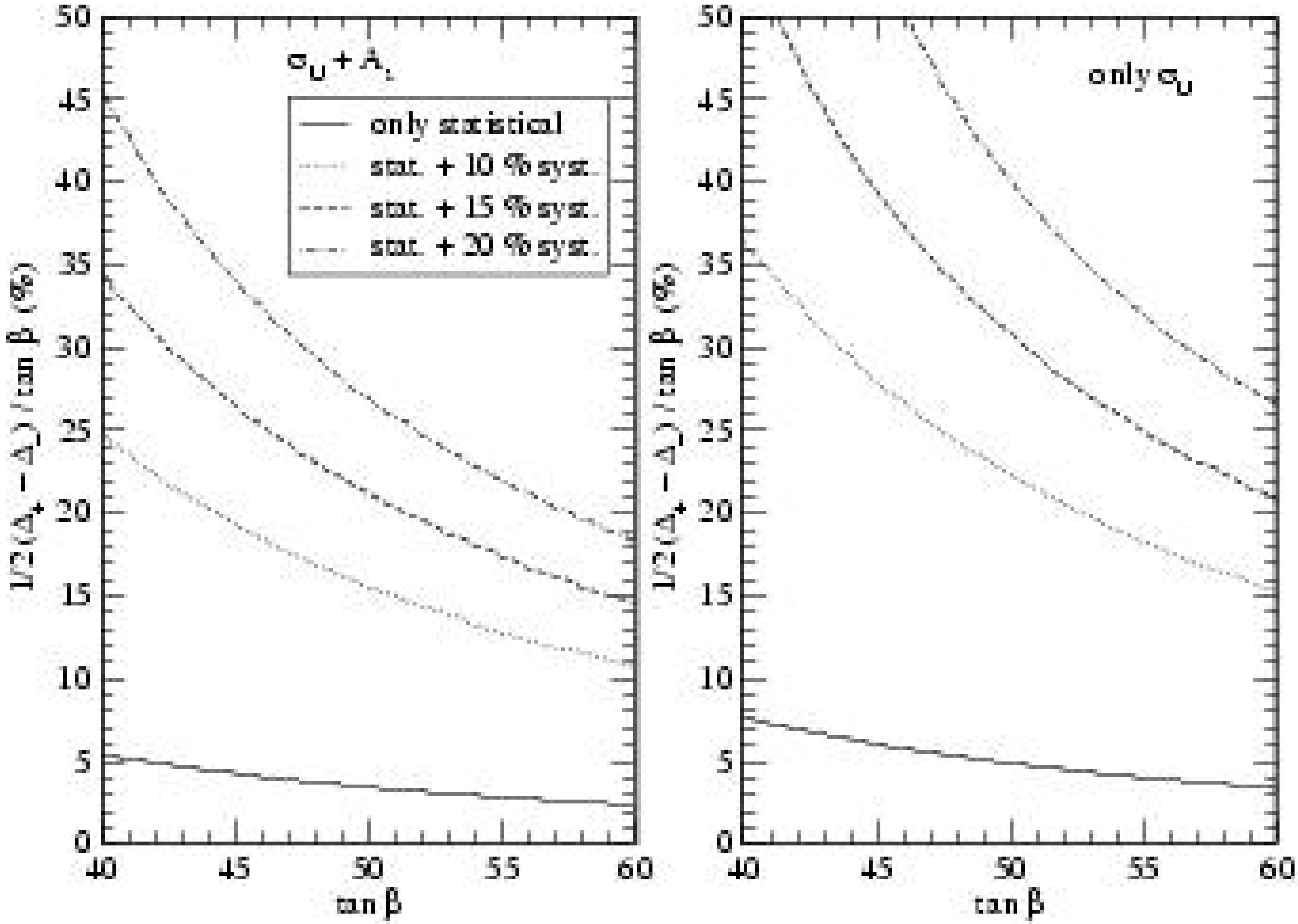
- Main sources:
  - Jet energy scale uncertainty
  - Uncertainties of jet energy development due to initial and final state showering
  - Uncertainty on luminosity
- Jet energy scale:
  - A 5% miscalibration energy applied to jets, produces a bin-by-bin distorsion of the M_{tt} distribution smaller than 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 evts 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 χ^2 minimization procedure for tgβ follows →



$\sigma_U + A_1$
only statistical
stat. + 10 % syst.
stat. + 15 % syst.
stat. + 20 % syst.
only σ_U
$1/2(\Delta_+ - \Delta_-)$ / tan β (%)
tan β

From this preliminary analysis

- This type of investigations might be interesting in a LIGHT SuSY SCENARIO particularly for large tgβ. ("modulo" QCD but perhaps it does not change the slope of $d\sigma/dM_{tt}$..)
  - Bernreuther, Brandemburg, 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:

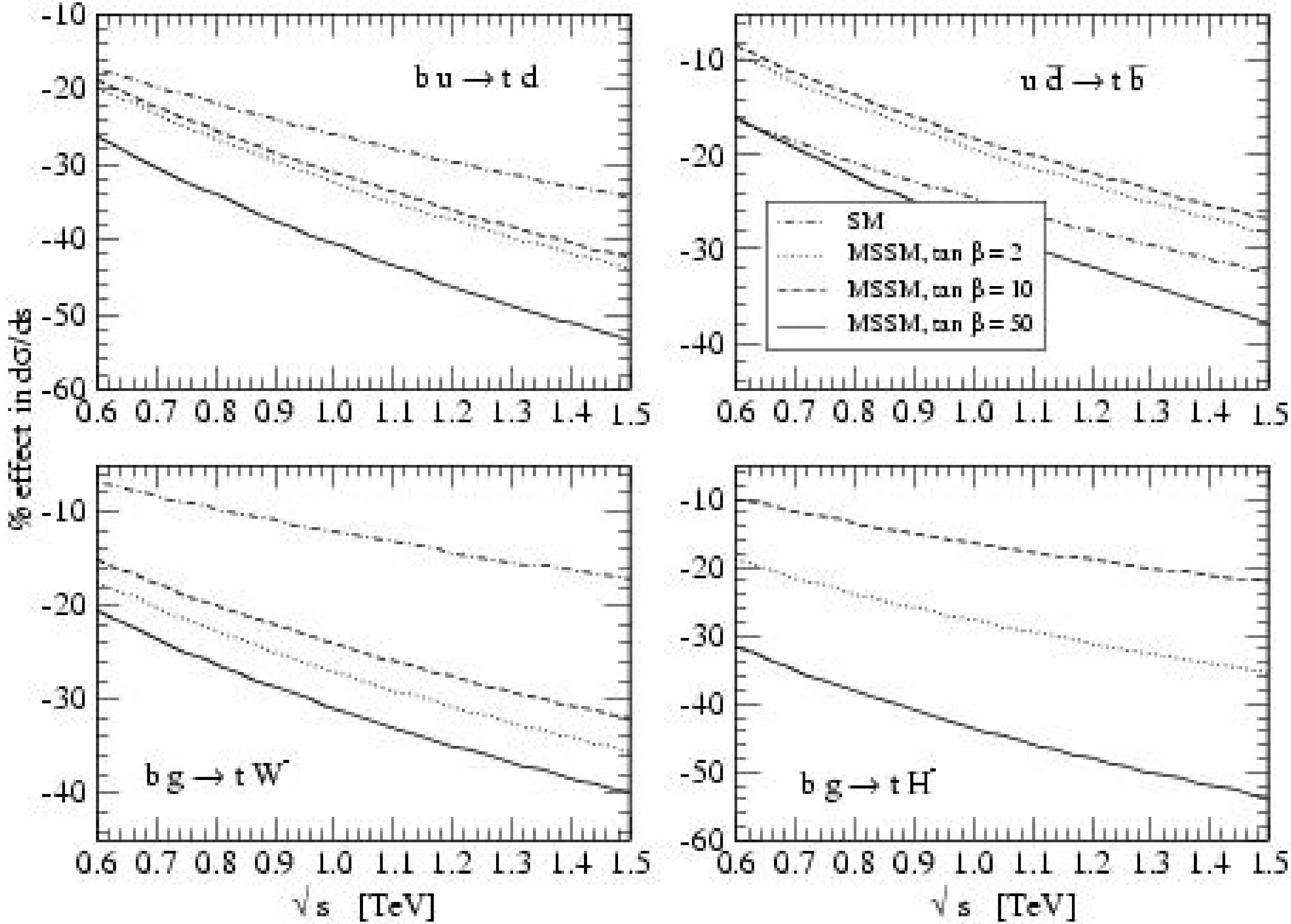
1) bu→td (t-channel) $\sigma \approx 245$ pb

2) bg→tW (“associated” production) $\sigma \approx 62$ pb

3) udbar→tbbar (s-channel) $\sigma \approx 10$ pb

First qualitative study

- Under the same "LIGHT SuSY" + Sudakov (final i. Mass ≈ 1 TeV) scenario
  - M. Beccaria, F.M. Renard, C.V., Phys. ReV. D71, 093008, 2005 and Phys. ReV. D71, 033005, 2005
- Again, large effects found (see figures)
- But: a complete 1-loop investigation requested (particularly for tW, hardly visible at about 1 TeV...)

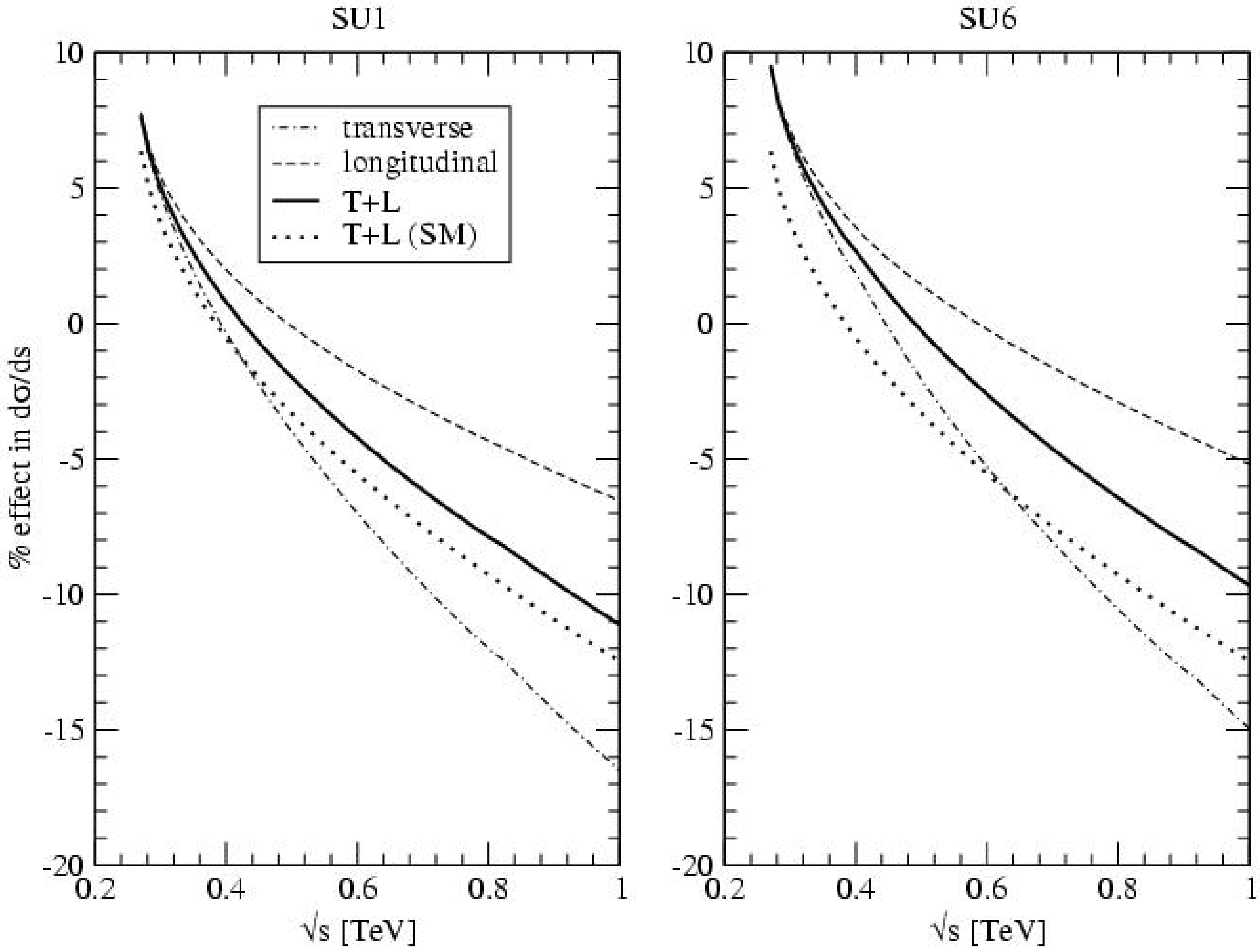


b u → t d
u d̄ → t b̄
SM
MSSM, tan β = 2
MSSM, tan β = 10
MSSM, tan β = 50
b g → t W⁻
b g → t H⁻
% effect in dσ/ds
√s [TeV]

First considered process

- pp $\rightarrow$ tWX ($\sigma \approx$62 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}!!)

Preliminary, M. Beccaria



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 ≥ 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*…