NLO generator SingleTop

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Outline

- Introduction
- Basic single top processes and rates
- Problems with single top event generators
- SingleTop - the new NLO event generator for LHC (for Tevaron RUNII - ready soon)
- Conclusions

SingleTop is based on latest versions of
CompHEP
PYTHIA
CompHEP-PYTHIA interface (Les Houches Accord)

first version:
E.Boos, L.Dudko, and V.Savrin, SingleTop - the new event generator for single top quark production at LHC. CMS Note 2000/065

Tevatron results in RUN1:

- The 95% Confidence Level Limit on single top production cross section :
  13.5 pb by CDF (preliminary)

  39 pb (17 pb Neural Network) (s-channel) and 58 pb (22pb Neural Network) (W-gluon fusion) by D0 (published)

  Extracted cross section of single top production by the likelihood fit (CDF):
  $\sigma = 5.2^{+4.9}_{-3.4}$ pb
  SM prediction: $\sigma_{SM} = 2.43 \pm 0.32$ pb

Single top is expected to be discovered in RUN2

- Top decays much faster than a typical time-scale for a formation of the strong bound states. So, top provides, in principle, a very clean source for a fundamental information.

- In single top production processes Top is expected to be produced with a high degree of polarization

- Correlations in Top production and decay determine by the Wtb coupling structure and unique in the Standard Model

The main goals to search for single top:

- Independent electroweak channel of the top quark production
- Direct $|V_{tb}|$ CKM matrix element measurement
- Significant background to Higgs and many "new physics" (MSSM) processes
- Unique spin correlations properties
- Process of interest for "New physics"
  - W_{tb} anomalous couplings
  - FCNC
  - New strong dynamics
  - R-parity violating SUSY effects
  - effect of Kaluza-Klein excited W-boson and W'

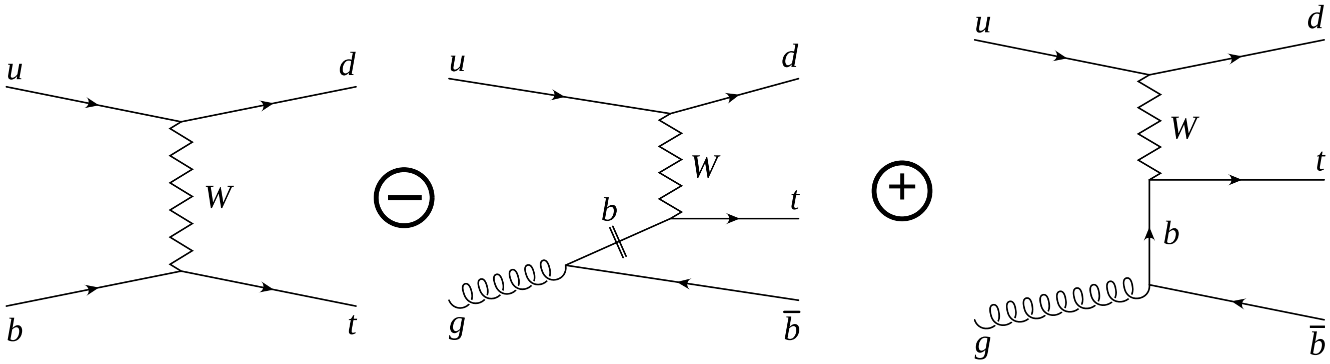
Three mechanisms of the single top production:

t-channel ($Q_W^2 < 0$)

s-channel ($Q_W^2 > 0$)

associated tW ($Q_W^2 = M_W^2$)

t-channel



(a) (b) (c)

t-channel $\sigma_{\rm NLO} \ = \ 245 \ pb \ \pm \ 27$ LHC

($2.4 \ pb \ \pm \ 0.4$ Tevatron)[a]

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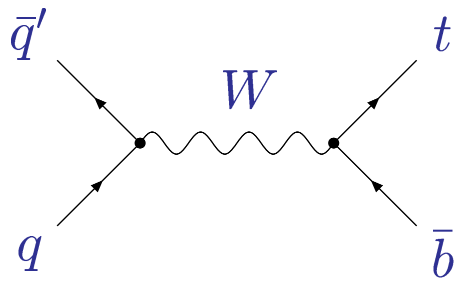
[a] S.Willenbrock *et al* Phys.Rev. **D56** (1997) 5919-5927

Diagram for s-channel single top production:



s-channel $\sigma_{\mathrm{NLO}} \; = \; 10.2 \; pb \; \pm \; 0.7$ LHC
$(0.88 pb \; \pm 0.05$ Tevatron$)$[a]

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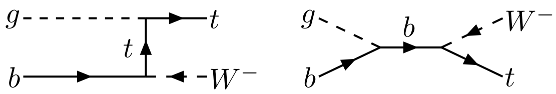
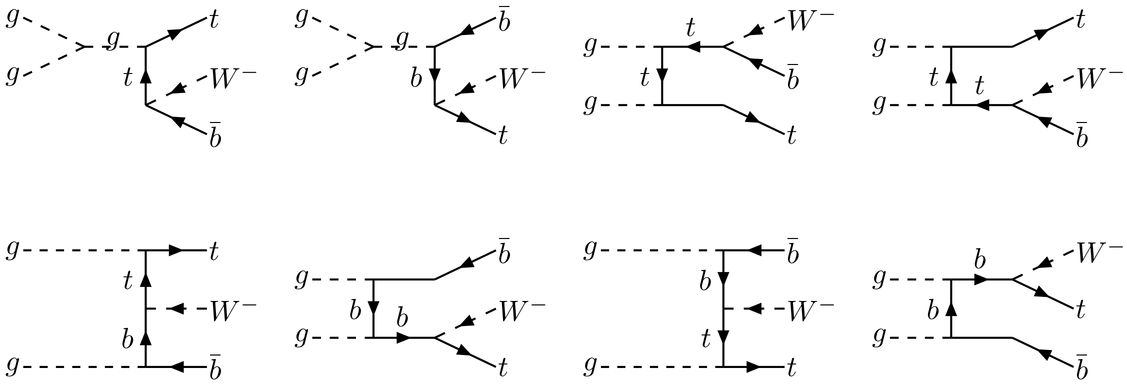
[a] M.Smith, S.Willenbrock Phys.Rev. **D54** (1996) 6696-6702

Diagrams for leading order $2 \to 2$ tW production (A) and $\mathcal{O}(1/log(m_t^2/m_b^2))$ $2 \to 3$ process (B), (C):

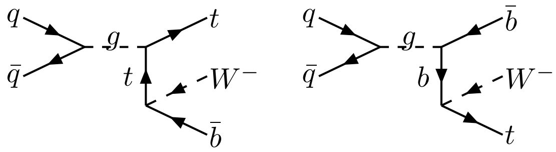
(A)



(B)



(C)



$\sigma(tW + X) = 62.0^{+16.6}_{-3.6}$ pb [a]

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[a] A.Belyaev, E.Boos Phys.Rev.**D63** (2001) 034012

The_best_experimental_signatures

- t- and s-channels: $l^{\pm} + \not{E}_T + b\bar{b}(j)$, where l – electron or muon

  Backgrounds:

  - ➔ tt pairs (~ 800 pb);
  - ➔ W+jets and WZ+jets (all cross sections are in LO):
    $P_T^{jets} > 20\ GeV,\ |\eta^{jets}| < 5.0, \Delta R(j,j') > 0.5$

    - Wjj (2160 pb) and Wjjj (~ 760 pb),
    - Wbb (~ 29 pb) and Wbb+j (~ 32.2 pb),
    - WZ (~26.1 pb) and WZ+j (~24.6 pb),
  - ➔ QCD multijets "fake" backgrounds:

    - bb+j (~456 nb) and bb+jj (~360 nb)

- tW-process: $l^{\pm}, l^{\mp} + \not{E}_T + b(\bar{b})$ and $l^{\pm} + \not{E}_T + jjb(\bar{b})$

  Backgrounds:

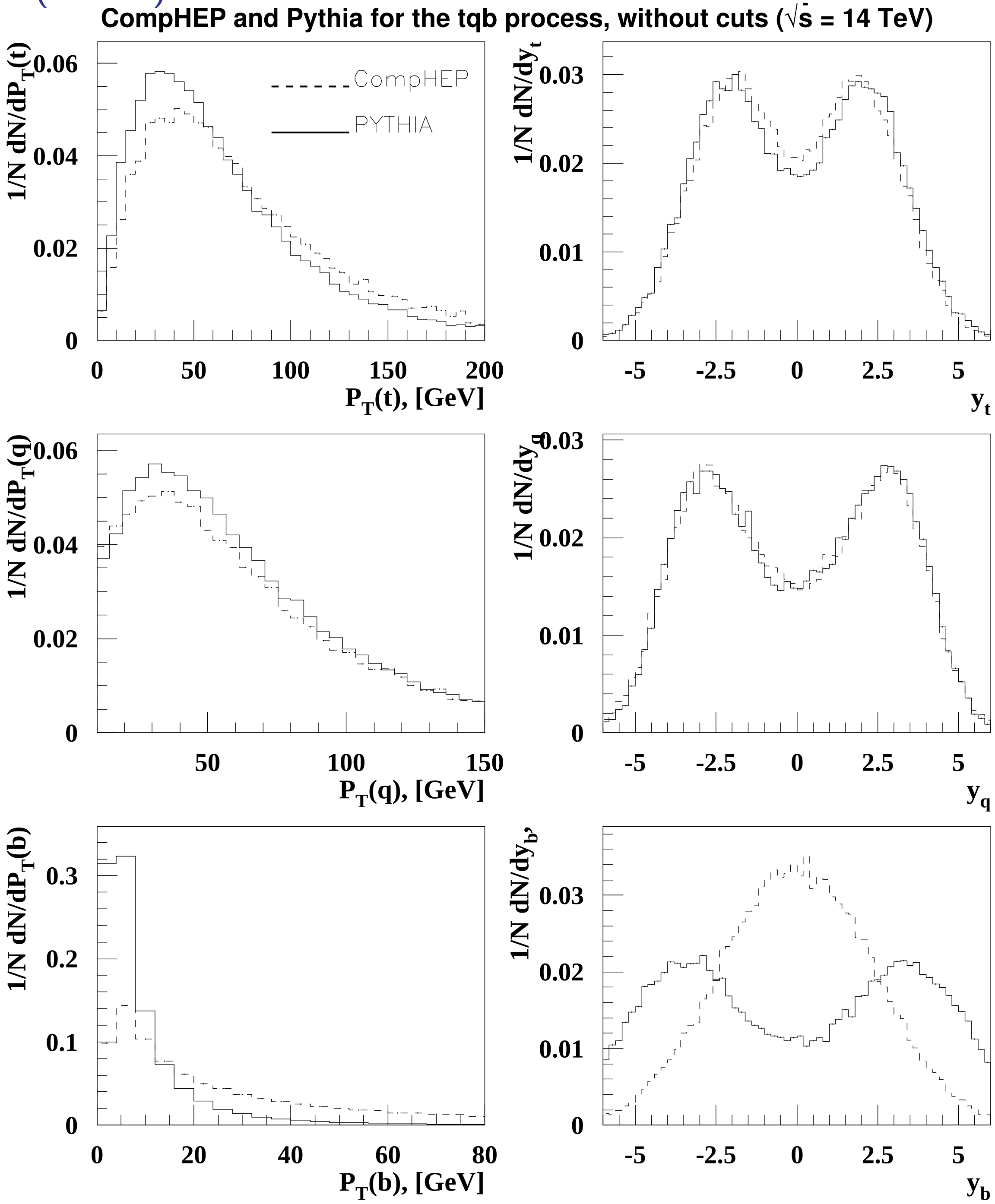
  - ➔ tt pairs, WW+b(b) and WW+j(j).

Single top generators: ONETOP, TopRex, generators based on MADGRAPH, PYTHIA, CompHEP (SingleTop)

Problems and requirements:

- Negative weights when subtraction method is used.
- "Reasonable" matching of the LO and NLO calculations at the generator level.
- Correct spin correlations.
- Separation Top and antiTop since the rates are different.
- Anomalous Wtb and FCNC couplings.

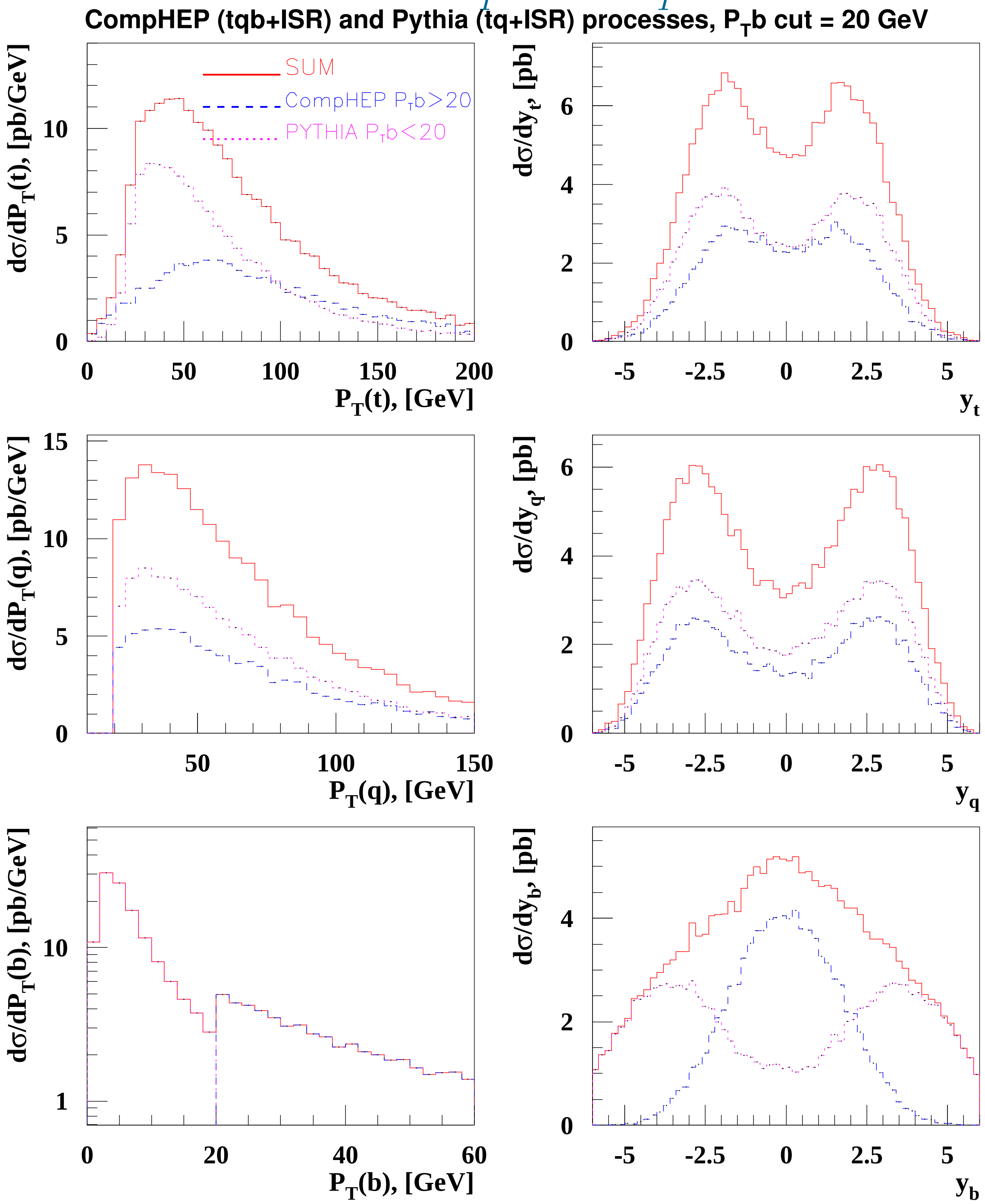
Analysis of Pythia ($2 \to 2$ + b-jet from ISR) and CompHEP ($2 \to 3$) distributions:



Matching of Pythia ($2 \to 2$) and CompHEP ($2 \to 3$) distributions:

$\sigma_{\text{PYTHIA}}(2 \to 2) = \sigma_{\text{NLO}} - \sigma_{\text{CompHEP}}(2 \to 3) \mid_{P_T^b > cut(P_T^b)}$,

where, $\sigma_{\text{CompHEP}}(2 \to 3) \mid_{P_T^b > 20\text{GeV}, P_T^q > 20\text{GeV}} \approx 88.7$ pb

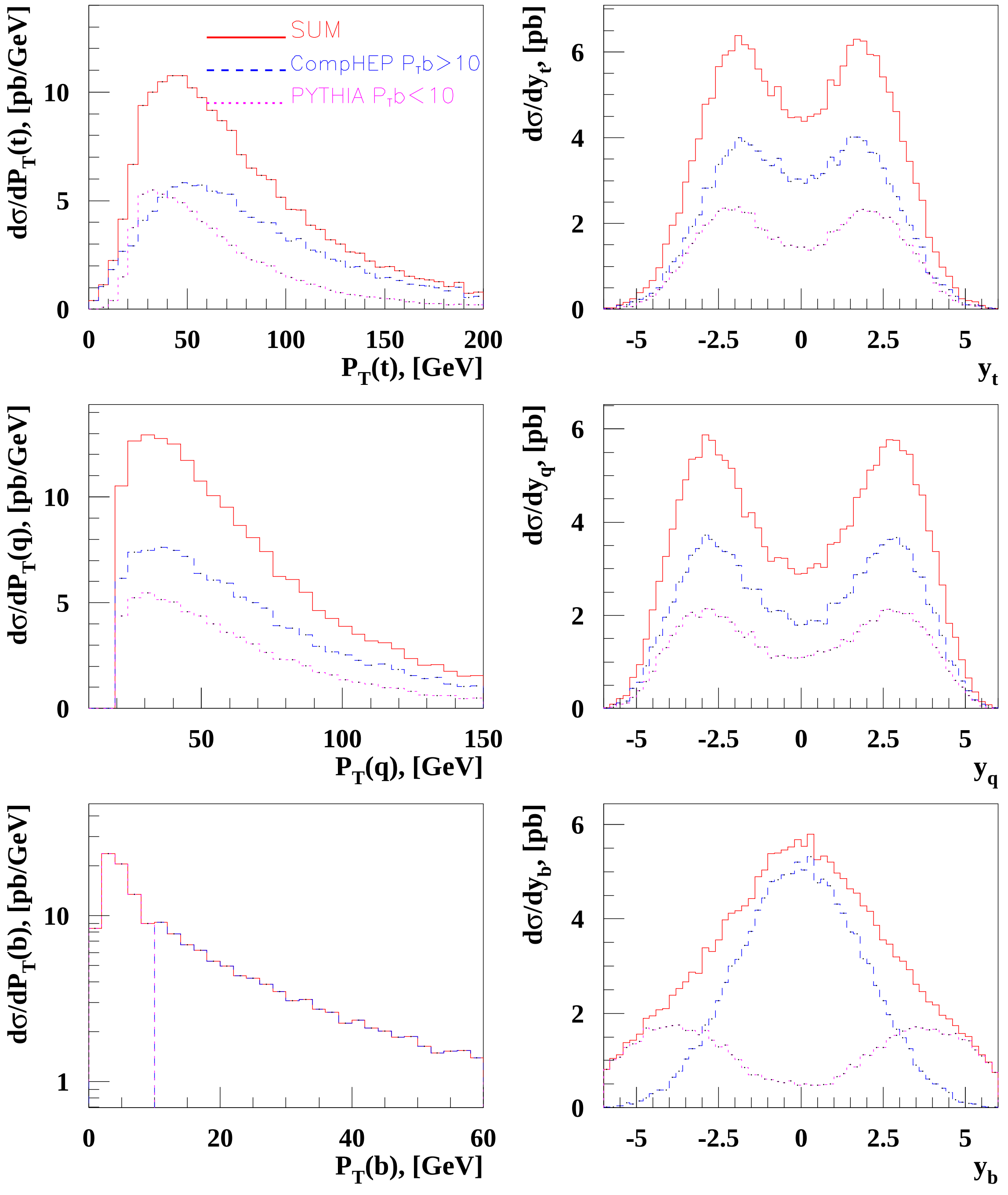


Final matching of Pythia $(2 \to 2)$ and CompHEP $(2 \to 3)$ distributions:

$\sigma_{\rm PYTHIA}(2 \to 2) = \sigma_{\rm NLO} - \sigma_{\rm CompHEP}(2 \to 3)\mid_{P_T^b > cut(P_T^b)}$,

where, $\sigma_{\rm CompHEP}(2 \to 3)\mid_{P_T^b > 10{\rm GeV}, P_T^q > 20{\rm GeV}} \approx 124$ pb

CompHEP (tqb+ISR) and Pythia (tq+ISR) processes, P_Tb cut = 10 GeV



Generated t-channel subprocesses (SingleTop):

Cuts: $P_T^b > 10$ GeV, $P_T^{jet} > 20$ GeV, $\Delta R(j,j') > 0.5$

$$pp \to t\bar{b}(\bar{t}b) + \text{jet} + X \qquad 73.8pb(46.2pb) \tag{1}$$

$$Subprocesses:$$

$ug \to dt\bar{b}$	$ug \to st\bar{b}$	$\bar{d}g \to \bar{c}t\bar{b}$	$u\bar{d} \to gt\bar{b}$
$gu \to dt\bar{b}$	$gu \to st\bar{b}$	$g\bar{d} \to \bar{c}t\bar{b}$	$u\bar{s} \to gt\bar{b}$
$cg \to dt\bar{b}$	$cg \to st\bar{b}$	$\bar{s}g \to \bar{c}t\bar{b}$	$\bar{d}c \to gt\bar{b}$
$gc \to dt\bar{b}$	$gc \to st\bar{b}$	$g\bar{s} \to \bar{c}t\bar{b}$	$\bar{s}c \to gt\bar{b}$
$\bar{d}g \to \bar{u}t\bar{b}$			$\bar{d}u \to gt\bar{b}$
$g\bar{d} \to \bar{u}t\bar{b}$			$\bar{s}u \to gt\bar{b}$
$\bar{s}g \to \bar{u}t\bar{b}$			$c\bar{d} \to gt\bar{b}$
$g\bar{s} \to \bar{u}t\bar{b}$			$c\bar{s} \to gt\bar{b}$
$59.7(34.4)\ pb$	$6.6(4.4)\ pb$	$5.4(6.2)\ pb$	$2.2(1.3)\ pb$

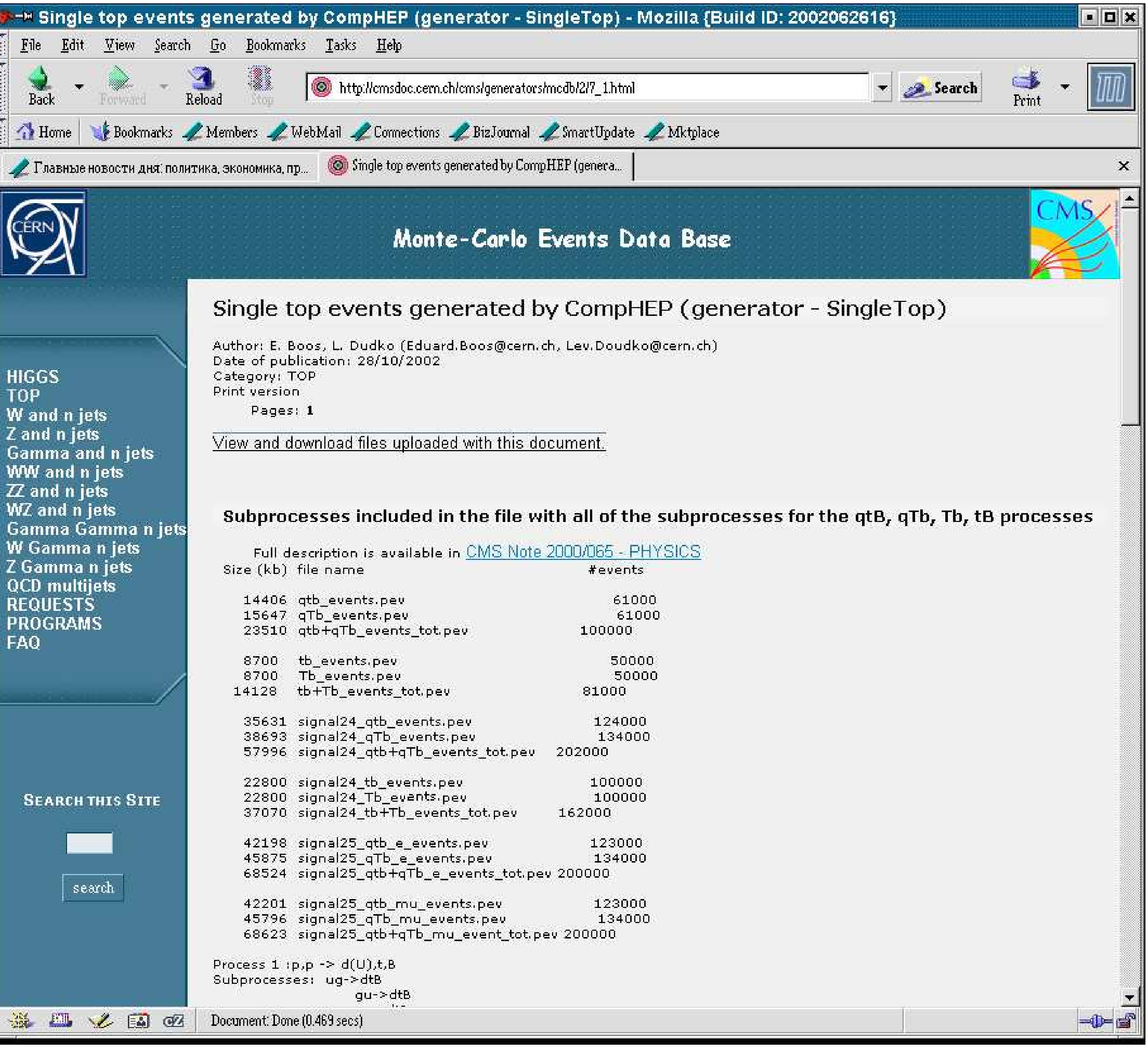
Generated s-channel subprocesses (SingleTop):

$$pp \to t\bar{b}(\bar{t}b) + X \qquad 4.9pb(3.1pb) \tag{2}$$

$$Subprocesses:$$

$\bar{d}u \to t\bar{b}$	$u\bar{d} \to t\bar{b}$	$\bar{d}c \to t\bar{b}$	$c\bar{d} \to t\bar{b}$
$\bar{s}u \to t\bar{b}$	$u\bar{s} \to t\bar{b}$	$\bar{s}c \to t\bar{b}$	$c\bar{s} \to t\bar{b}$

http://cern.ch/mc



Single top events generated by CompHEP (generator - SingleTop) - Mozilla {Build ID: 2002062616}

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Monte-Carlo Events Data Base

HIGGS
TOP
W and n jets
Z and n jets
Gamma and n jets
WW and n jets
ZZ and n jets
WZ and n jets
Gamma Gamma n jets
W Gamma n jets
Z Gamma n jets
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Single top events generated by CompHEP (generator - SingleTop)

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Subprocesses included in the file with all of the subprocesses for the qtB, qTb, Tb, tB processes

Full description is available in CMS Note 2000/065 - PHYSICS

Size (kb)	file name	#events
14406	qtb_events.pev	61000
15647	qTb_events.pev	61000
23510	qtb+qTb_events_tot.pev	100000
8700	tb_events.pev	50000
8700	Tb_events.pev	50000
14128	tb+Tb_events_tot.pev	81000
35631	signal24_qtb_events.pev	124000
38693	signal24_qTb_events.pev	134000
57996	signal24_qtb+qTb_events_tot.pev	202000
22800	signal24_tb_events.pev	100000
22800	signal24_Tb_events.pev	100000
37070	signal24_tb+Tb_events_tot.pev	162000
42198	signal25_qtb_e_events.pev	123000
45875	signal25_qTb_e_events.pev	134000
68524	signal25_qtb+qTb_e_events_tot.pev	200000
42201	signal25_qtb_mu_events.pev	123000
45796	signal25_qTb_mu_events.pev	134000
68623	signal25_qtb+qTb_mu_event_tot.pev	200000

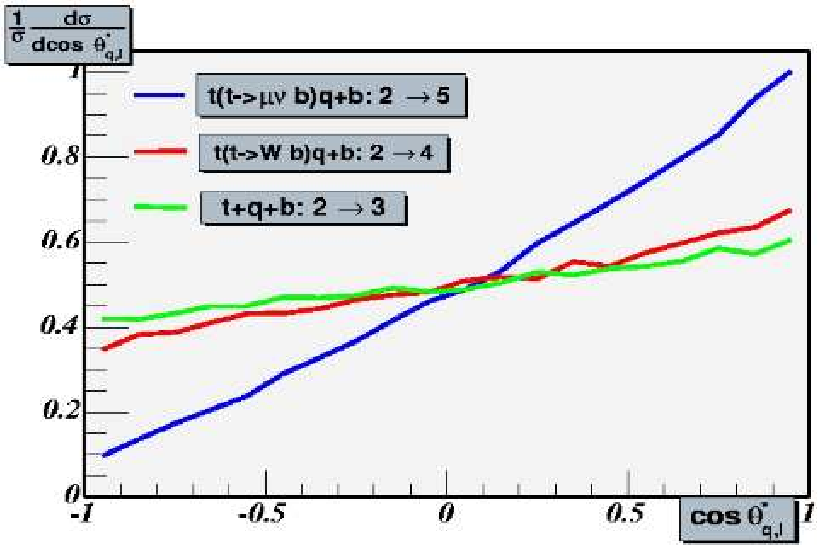
Process 1 :p,p -> d(U),t,B
Subprocesses: ug->dtB
gu->dtB

Document: Done (0.469 secs)

Spin_correlations:_theoretical_view

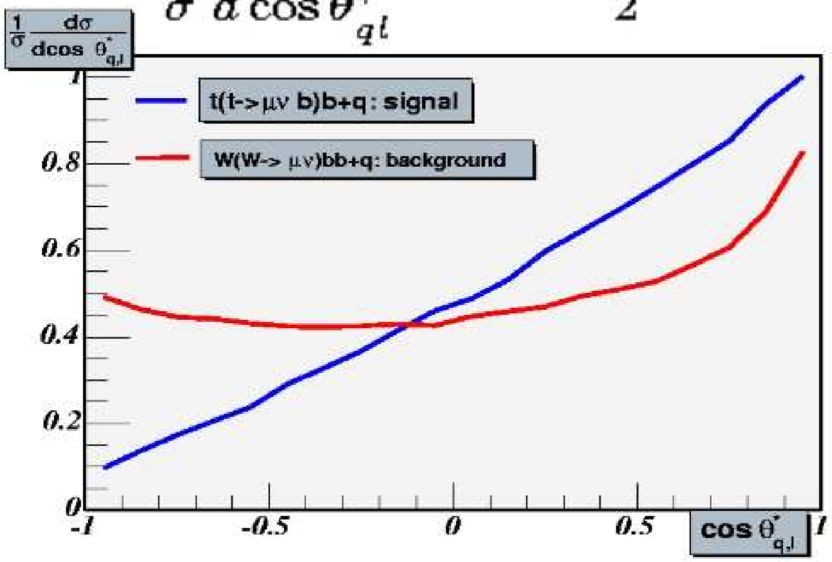
Single top quark is produced highly polarized via the Wtb vertex. Since top quarks do not have a time to form strong bound state, we can investigate a top polarization. There is a unique top spin decomposition axis in the top rest frame: momentum of lepton in top the rest frame from top decay: $t \to b\, l\, \nu_l$

For t-channel the best variable θ^*_{ql} - angle between lepton and quark momenta in the top rest frame



The top polarization can be defined as parameter P in a distribution

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*_{ql}} = \frac{1+P\cos\theta^*_{ql}}{2}$$



In ideal theoretical situation we have for t-channel:

$$P_{top} \approx 90\%$$

Conclusions

- Study of Single Top Quark production at the LHC provides a large number of possibilities to measure top properties like couplings, width etc and to search for various new physics effects.
- Single top is an important part of the total top production rate (about 1/3), and it gives a significant background to many physics processes like Higgs, MSSM etc.
- Therefore one has to simulate Single top signal accurately in a hole region of the phase space taking into account known NLO corrections, spin correlations between top production and its subsequent decay, at the next step - possible anomalous couplings (Wtb, FCNC). SingleTop is a step in that direction.