CompHEP based event generators for colliders

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Outline

- Motivation
- Simplification of quark combinatorics
- Color information
- Interface to PYTHIA with the Les Houches standard
- MCDB for LHC and Tevatron processes
- The generator SingleTop
- The generaor for MSSM Higgs bosons in the intense coupling regime
- The generaor for sfermion pair production
- Concluding remarks

* On behalf of CompHEP collaboration
(http://theory.sinp.msu.ru/comphep)
E.B., Mikhail Dubinin, Lev Dudko, Slava Ilyin,
Alexander Kryukov, Victor Edneral, Victor Savrin,
Andrei Semenov, Sasha Sherstnev

The increase of the collider energies requires calculations of processes with more and more particles in the final state and with better and better precision (NLO, NNLO, resummation)

- LEP1 - basically 2 fermion (γ) physics
- LEP2 - basically 4 fermion (γ) physics
- Tevatron, LC and LHC - in many cases 4, 5, 6 and 8 fermion physics with additional hard photons and/or gluons (jets)
  - top pair production with decays - 6 fermions;
  - single top in the t-channel mode - 5 fermions;
  - strongly interacting Higgs sector in hadronic collisions- $pp \to q\bar{q}W^+W^-$ - 6 fermions
  - Yukawa coupling - $pp(e^+e^-) \to t\bar{t}H$ - 8 fermions
  - etc
    * Large number of diagrams
    * Large number of subprocesses (Tevatron, LHC)

    A number of automatic programs have been created in the past: CompHEP, GRACE, MadGraph, AlpGen, OMega ...


SUSY
Compositeness
Extra Dimensions

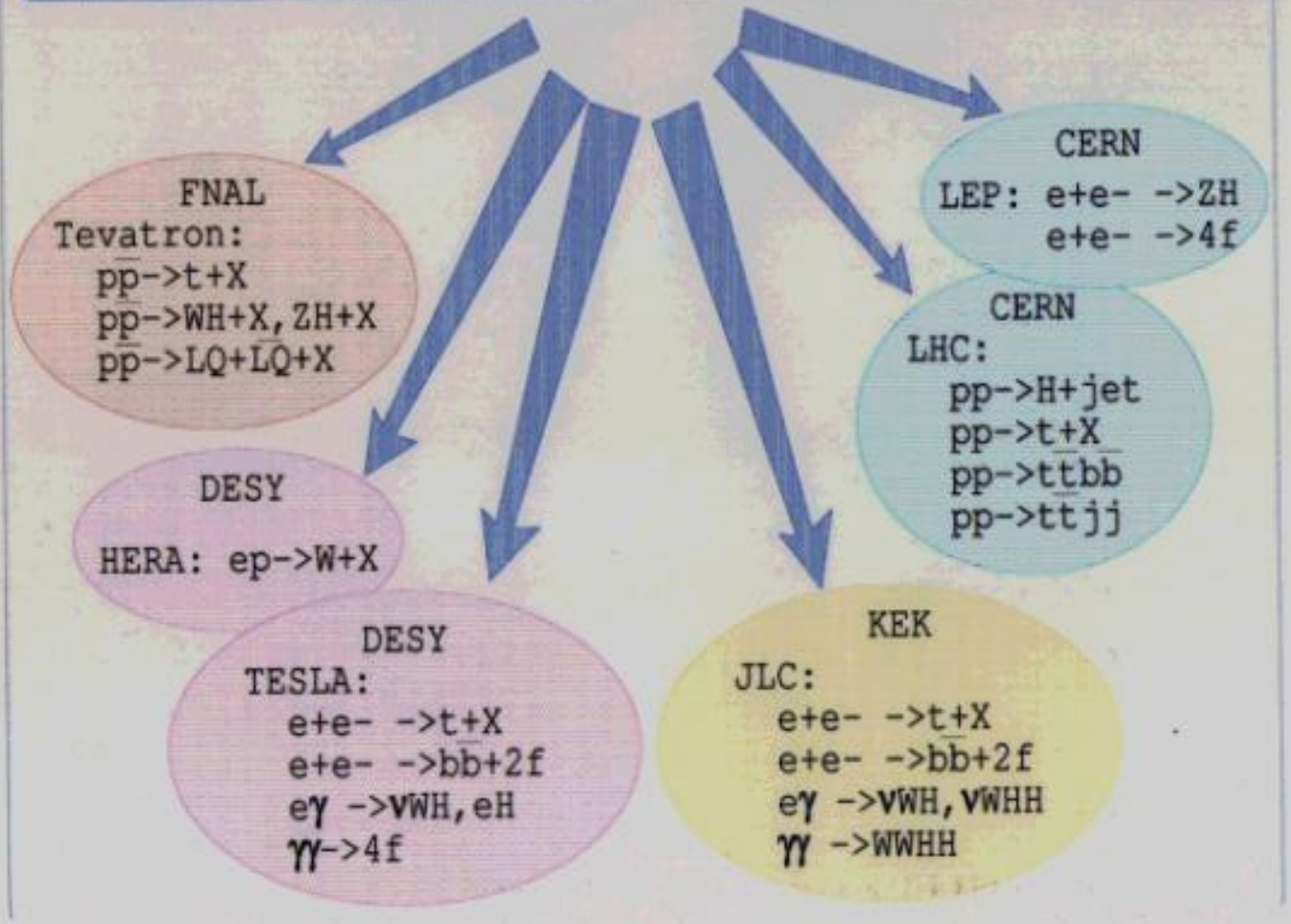
SINP MSU

CompHEP

The program for calculation of collision processes:

Lagrangian -> Feynman diagrams -> cross sections, events

http://theory.npi.msu.su/comphep



Simplification of Flavour Combinatorics in the Evaluation of Hadronic Processes

A serious computational problem is the large number of partonic subprocesses (Some of them are very much similar)

- many quark partons with different flavors
- many additional diagrams for each subprocess because of CKM quark mixing

Two approximations:

- $V_{CKM} \Longrightarrow \begin{pmatrix} V & 0 \\ 0 & 1 \end{pmatrix}, \quad V = \begin{pmatrix} \cos\vartheta_c & \sin\vartheta_c \\ -\sin\vartheta_c & \cos\vartheta_c \end{pmatrix}$

  where ϑ_c is the Cabbibo angle.
- $M_u = M_d = M_s = M_c = 0$

Basic ideas:

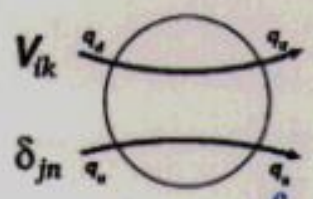
- rotation of down quarks, thus, transporting the mixing matrix elements from vertices of subprocess Feynman diagrams to the parton distribution functions
- diagrams are divided into gauge invariant classes with different topology of the quark line

New rules for convolution with structure functions depend on the topology of the gauge invariant class [a]

[a] E.B., V.Ilyin et al. JHEP 0005 (2000) 052

Examples

Scattering topology. 1st Rule



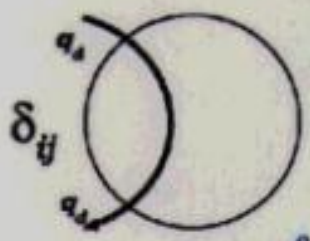
$$|\mathcal{D}_{sc}|^2 \Longrightarrow \int dx_1 dx_2\, [f_d(x_1)+f_s(x_1)]\, [f_{\bar{u}}(x_2)+f_{\bar{c}}(x_2)]\, |\mathcal{M}|^2$$

Annihilation CC topology. 2nd Rule

$$|\mathcal{D}_a^{CC}|^2 \Longrightarrow \int dx_1 dx_2 [f_d(x_1)\, f_{\bar{u}}(x_2)\, \cos^2\vartheta_c + f_s(x_1)\, f_{\bar{c}}(x_2)\, \cos^2\vartheta_c +$$

$$+ f_d(x_1)\, f_{\bar{c}}(x_2)\, \sin^2\vartheta_c + f_s(x_1)\, f_{\bar{u}}(x_2)\, \sin^2\vartheta_c] |\mathcal{M}|^2$$

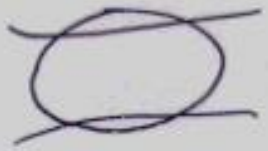
Annihilation NC topology. 3d Rule



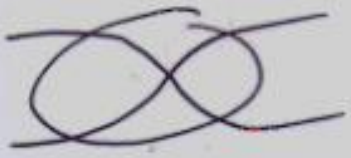
$$|\mathcal{D}_a^{NC}|^2 \Longrightarrow \int dx_1 dx_2\, [f_d(x_1)\, f_{\bar{d}}(x_2)+f_s(x_1)\, f_{\bar{s}}(x_2)]\, |\mathcal{M}|^2$$

The Exchange topology and all possible interferences between the above topologies lead to the same rules

There are 7 basic topologies:
(all form gauge invariant classes).



D_S Scattering



D_E^{cc}
D_E^{NC} Exchange

D_A^{cc}
D_A^{NC} Annihilation

One gets 3 basic Rules:
(for effective structure functions)

1. $|D_S|^2$; $|D_E^{NC}|^2$; $|D_E^{cc}|^2$

2. $|D_A^{cc}|^2$; $D_A^{cc} * D_S$; $D_A^{cc} * D_E^{cc}$; $D_S * D_E^{cc}$

3. $|D_A^{NC}|^2$; $D_A^{NC} * D_S$; $D_A^{NC} * D_E^{NC}$; $D_S * D_E^{NC}$

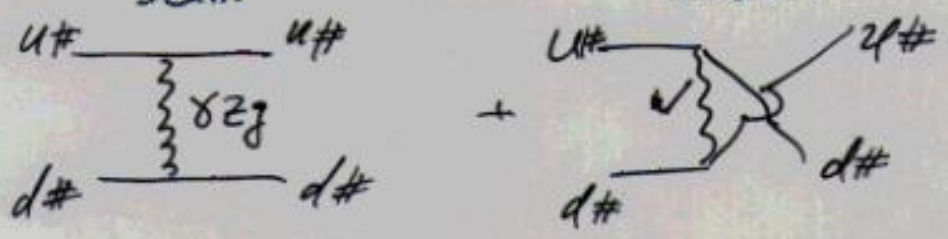
--**--

$\Rightarrow$ leads to scattering
(sum of structure functions)

$\Rightarrow$ leads to factor $\underline{\underline{2}}$.

$u\# d\# \to u\# d\#$

Scat.: Exch.:



u#, d# – effective model with only 1-st generation, no VCM, but with effective structure functions.

In the SM $\Rightarrow$ 16 subprocesses

$$\begin{cases} ud \to ud \\ ud \to cd \\ ud \to us \\ ud \to cs \end{cases} \qquad \begin{cases} cd \to cd \\ cd \to ud \\ cd \to cs \\ cd \to us \end{cases}$$

$$\begin{cases} us \to us \\ us \to cs \\ us \to ud \\ us \to cd \end{cases} \qquad \begin{cases} cs \to cs \\ cs \to us \\ cs \to cd \\ cs \to ud \end{cases}$$

It sum up all the subprocesses:

$$(f_u + f_c)(f_d + f_s) \cdot \left[M^2_{scat.} + M^2_{Exch} \right] +$$

$$+ \left(f_u f_d \cos^2\theta + f_u f_s \sin^2\theta + f_c f_d \sin^2\theta + f_c f_s \cos^2\theta \right) \cdot$$

$$\cdot \text{Interf.}(\text{scat} * \text{Exch}).$$

It is realized in the u#d# CompHEP model automatically.

Generation of color flows for events

For a fragmentation and hadronization PYTHIA needs in an information on color flows. PYTHIA format for color flows requires an indication of colorless pairs. In terms of QCD such sequence of colorless pairs, *color chain*, corresponds to one of the elements of the color basis taken in the limit $N_c = \infty$. CompHEP calculates exactly the cross section with number of colors $N_c = 3$ The following procedure is realised in CompHEP in order to match that:

$$M = \sum_d L_d T_d$$

where Feynman diagrams are summed, L_d is Lorentz part of the diagram, and T_d is its color structure.

$$|M|^2 = \sum_{d \otimes d'} L_{d \otimes d'} C_{d \otimes d'}$$

$L_{d \otimes d'} = L_d{}^* \cdot L'_d$, $L_{d \otimes d'} = L_d{}^* \cdot L'_d$, where $d \otimes d'$ is squared diagram contributed in the squared matrix element.

In the limit $N_c = \infty$ the color structures of diagrams can be decomposed over the elements of color basis (color chains):

$$T_d \Longrightarrow T_d^{N_c=\infty} = \sum_i C_d^i t_i$$

where basis elements are orthonormal, $t_i \otimes t_j = \delta_{ij}$. Thus squared matrix element is a sum of positive numbers:

$$|M_{N_c=\infty}|^2 = \sum_i k_i \,, \qquad k_i = |\sum_d L_d C_d^i|^2 \,, \qquad w_i = \frac{k_i}{\sum_j k_j}$$

For each unweighted event (phase space point) one generates the set of color chains t_i with the probability w_i.

CompHEP 4.2 - PYTHIA 6.2 interface

PYTHIA has the built-in data base of matrix elements for hard subprocesses which are basically of the $2 \to 2$ type. The CompHEP-PYTHIA interface allows to use processes $2 \to 3, 4, 5, 6$ computed by means of CompHEP as new processes for PYTHIA and include in this way ISR/FSR, hadronization (jet fragmentation), and decays as it is done in PYTHIA.

- CompHEP generates unweighted events and writes them to the file events_N.txt , where N is the number of working session
- The command mix_flows mixes randomly several subprocesses in one event flow according to their relative weights, $\sigma_i/\Sigma_j\sigma_j$, where σ_i is the cross section of the i-th subprocess, and writes events to the file Mixed.PEV . The file is ready to be read by PYTHIA 6.2...and containes the Les Houches accord information
- We provide the interface library libinterface62.a and an example of the main.f program. Using the standard unix make command the user links main.o, libinterface62.a and pythia62.o to the exe file generator.exe . The generator takes events from the file Mixed.PEV. The number of requested events to be generated after PYTHIA is defined by the user in the file INPARM.DAT

One has to be careful combining new higher order processes from CompHEP-PYTHIA to the standard PYTHIA processes when ISR/FSR are switched on.

MCDB - is the Monte Carlo events Data Base to store the parton level events for various Standard Model processes. New and flexible tool for the authors of MC generators to distribute MC events for the users. The standard place to keep the CompHEP events generated for the LHC and Tevatron

Monte-Carlo Events Data Base - Mozilla (Build ID: 2002062616)

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
QCD multijets
REQUESTS
PROGRAMS
FAQ

SEARCH THIS SITE

PROCESS Z/A*+BB WITH DECAYED Z/A*->MU+ MU-. 3 SAMPLES WITH DIFFERENT CUTS

We have prepared 3 different samples for the Z/A*(->mu+,mu-)+bB by the CompHEP generator. Every sample contains approximately 250k events. The samples differ in cut on mass of muon pair (see article).

published: 21/06/2003 | author: Alexandre Cherstnev | category: Z and n jets ..

W AND 2 JETS

The events sample (1 sample with ~270K events) are generated by CompHEP 41.10. The jets are u,d,s,c-quarks ang gluons but in some appoximation (see the article).

published: 02/06/2003 | author: Alexandre Cherstnev | category: W and n jets ..

REQUESTS TO CHANGE SOMETHING TECHNICAL IN MCDB

If you have some idea how to improve the MCDB, plase, share your opinion with us.

published: 25/05/2003 | author: Lev V. Dudko | category: REQUESTS ..

TT+2 JETS PROCESS

The events samples (20 samples with ~105K events per the sample) are generated by CompHEP 41.10. The jets are u,d,s,c-quarks ang gluons but in some appoximation (see the article)

published: 01/04/2003 | author: Viacheslav A. Ilyin | category: TOP ..

H+2JETS PROCESS

PUBLISH NEW DOCUMENT:

non authorized author
authorized author

HELP

Document: Done (0.672 sec)

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.

Generator SingleTop

E.B., L.Dudko, V. Savrin, A.Sherstnev

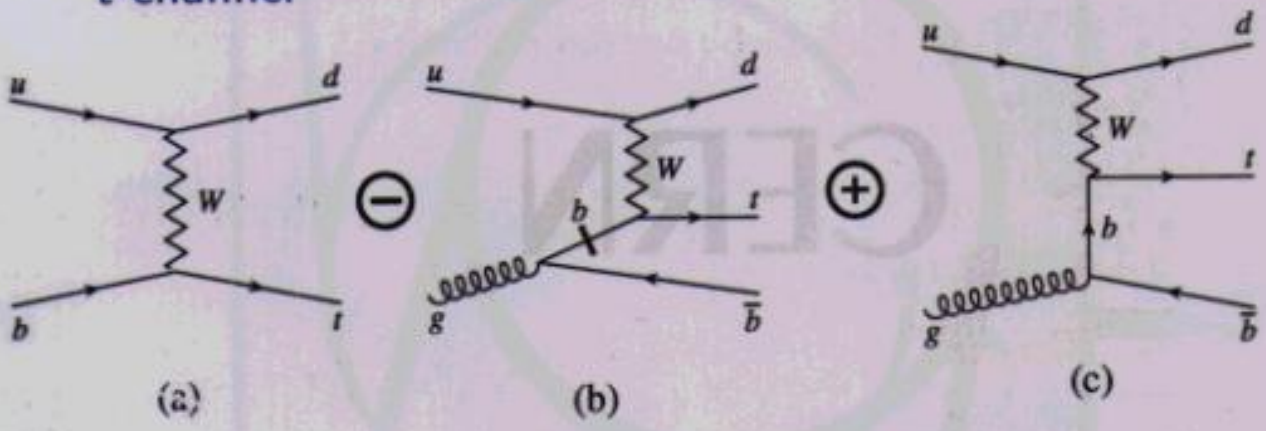
Three mechanisms of the single top production:

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

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

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

t-channel



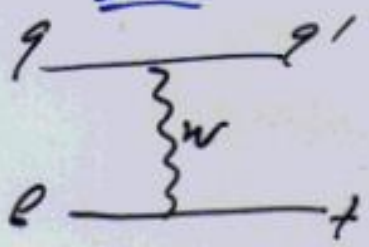
t-channel $\sigma_{\rm NLO} = 245\ pb \pm 27$ LHC

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

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

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

LO

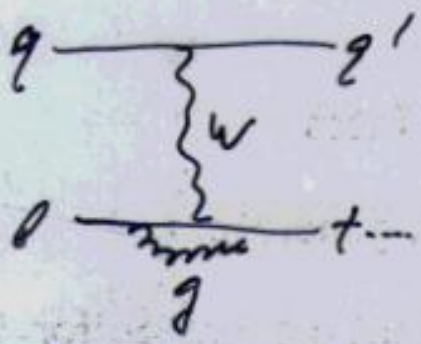


$\Rightarrow$ LO generator

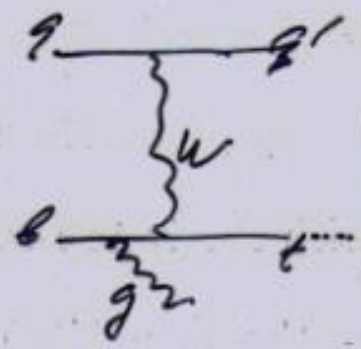
(Process in PYTHIA + ISR)

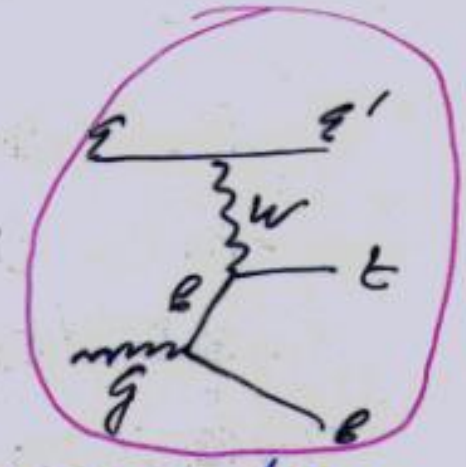
(second b $\rightarrow$ from ISR)

NLO



Loop part





Real corrections

Main loop corrections $\rightarrow$ low $p_\perp$ region

σ^{NLO} is computed (known)

Two conditions:

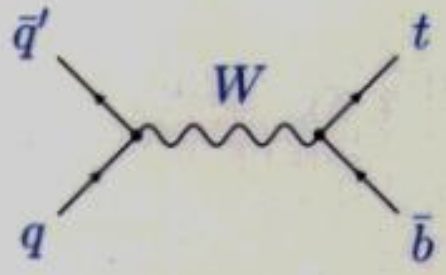
1. $\sigma_{NLO} = k\, \sigma_{2\to 2}\Big|_{p_\perp^b < p_{cut}^0} + \sigma^{ME}_{2\to 3}\Big|_{p_\perp^b > p_{cut}^0}$

correct normalization to NLO

2. Smooth distributions

- If $p_\perp^b < p_{cut}^0 \Rightarrow$ events directly from PYTHIA
- If $p_\perp^b > p_{cut}^0 \Rightarrow$ event from ME (CompHEP)

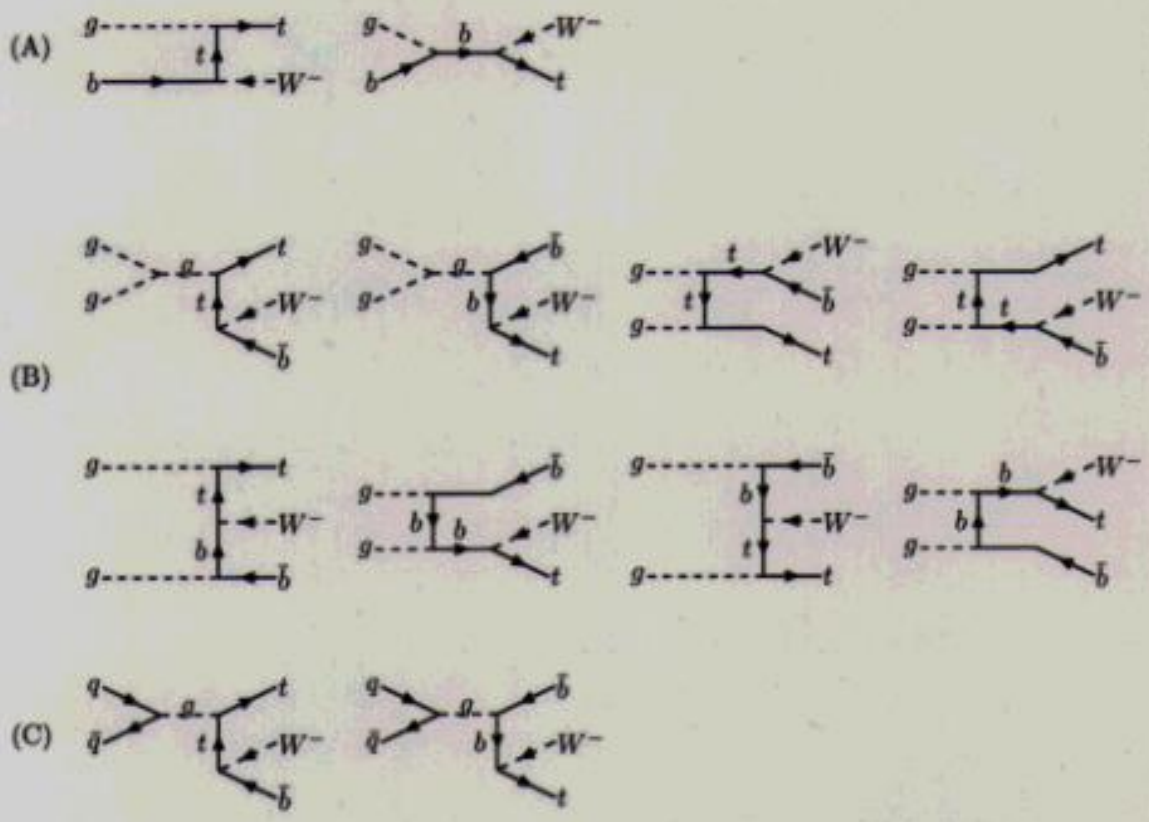
Diagram for s-channel single top production:



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

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

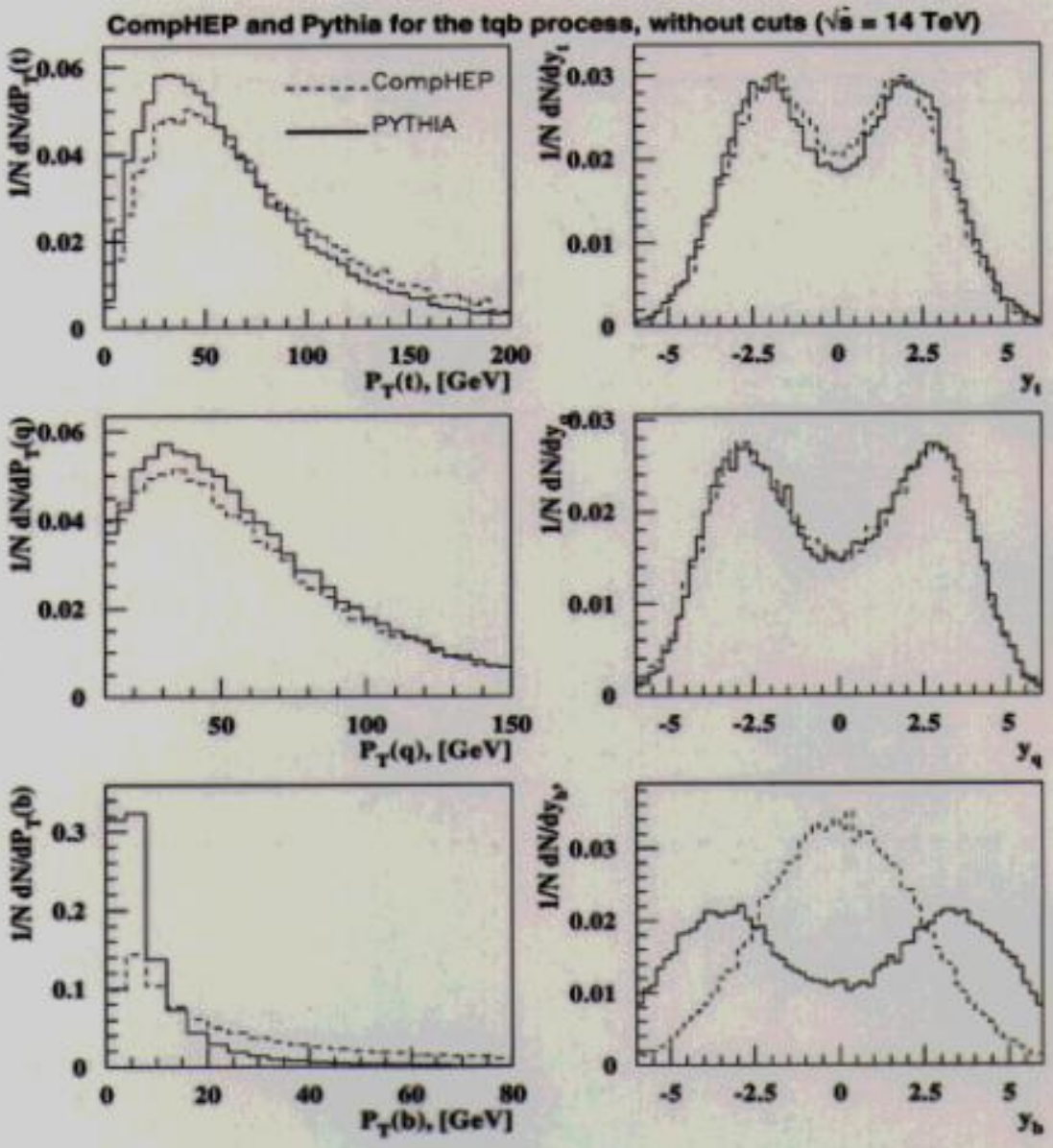
Diagrams for leading order $2 \to 2$ tW production (A) and $\mathcal{O}(1/log(m_t^2/m_b^2))$ $2 \to 3$ process (B), (C):



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

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

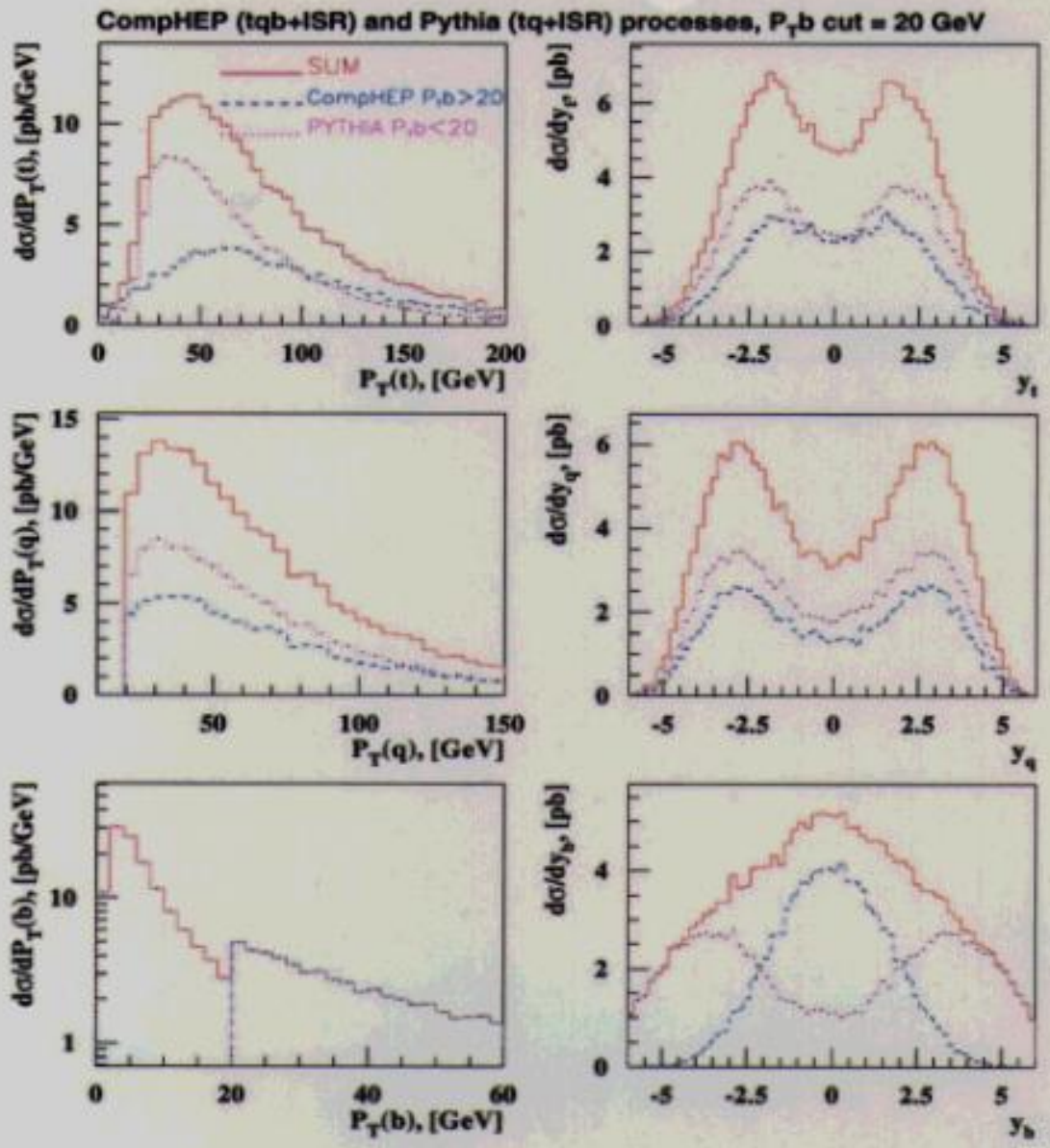
Analysis of Pythia ($2 \to 2$ + b-jet from ISR) and CompHEP ($2 \to 3$) distributions:



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

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

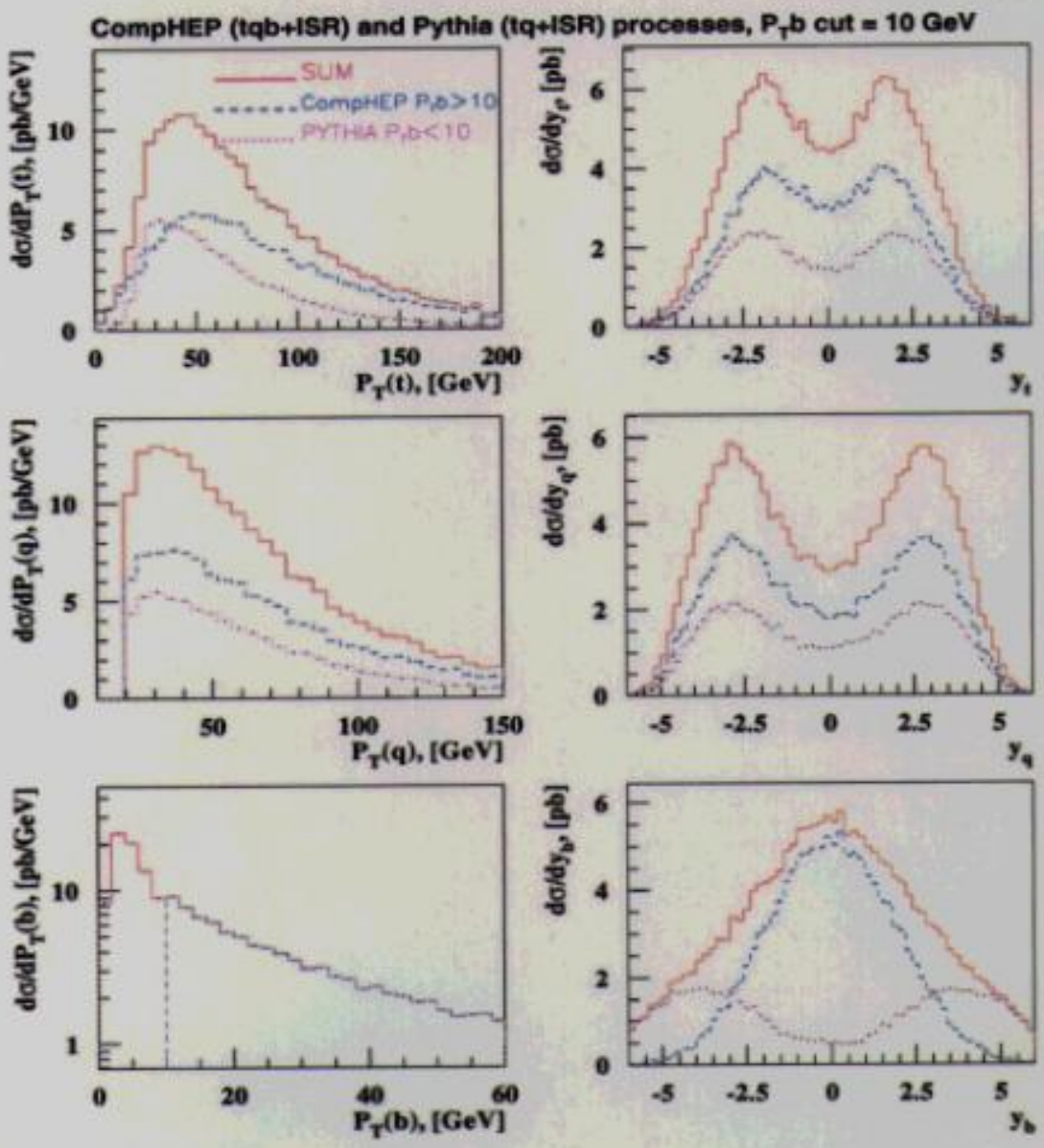
where, $\sigma_{\mathrm{CompHEP}}(2 \to 3)\,|_{P_T^b > 20\mathrm{GeV}, P_T^q > 20\mathrm{GeV}} \approx 88.7$ pb



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

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

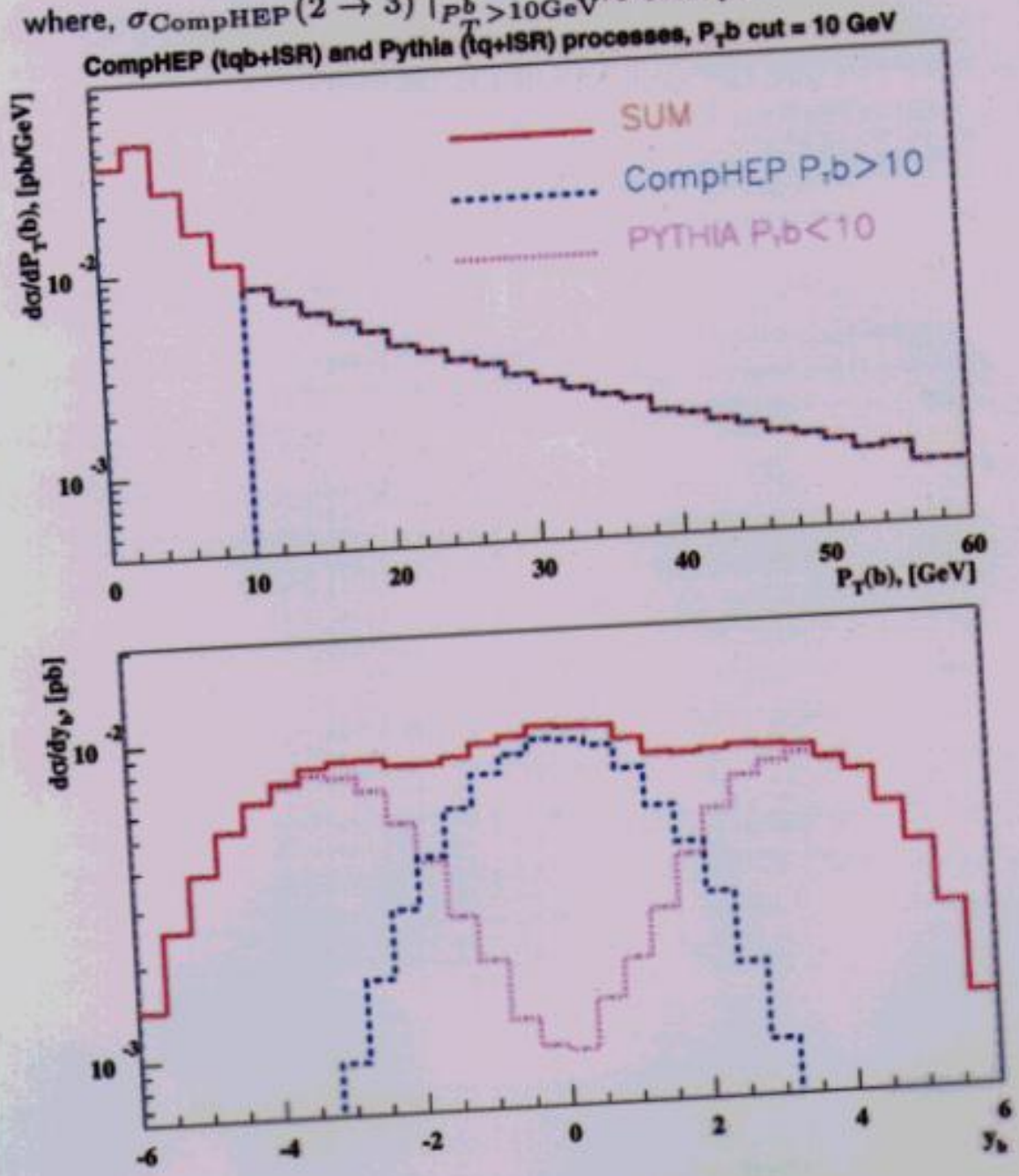
where, $\sigma_{\mathrm{CompHEP}}(2 \to 3)\,|_{P_T^b > 10\mathrm{GeV}, P_T^q > 20\mathrm{GeV}} \approx 124$ pb



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

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

where, $\sigma_{\mathrm{CompHEP}}(2 \to 3)\,|_{P_T^b > 10\mathrm{GeV}} \approx 0.08$ pb



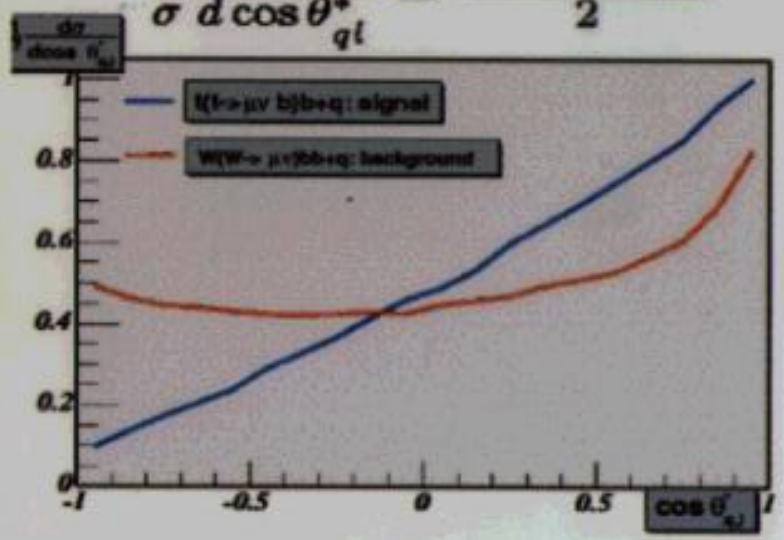
Spin_correlations:_theoretical_view

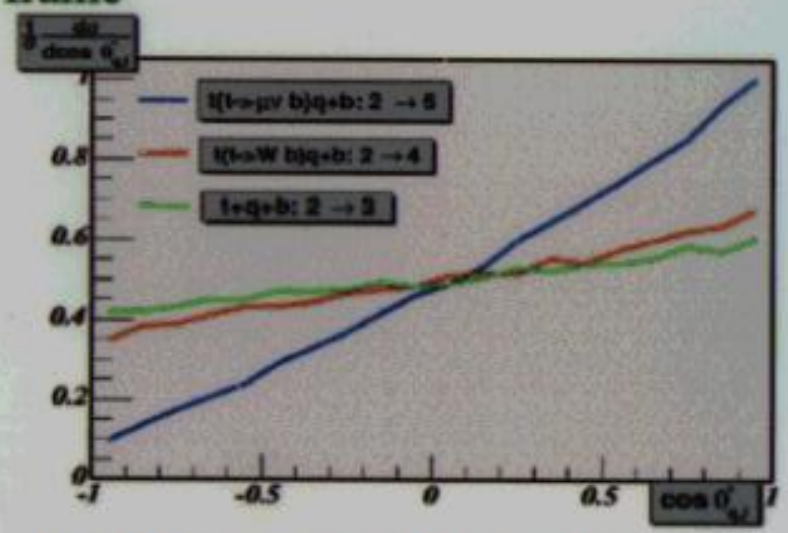
Single top quark is produced highly polarized via the Wtb vertex. Since top quarks do not have a time to form strong bound state, we can investigate a top polarization. There is a unique top spin decomposition axis in the top rest frame: momentum of lepton in top the rest frame from top decay: $t \to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

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:

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

Generated t-channel subprocesses (SingleTop):

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

$pp \to t\bar{b}(\bar{t}b) + \text{jet} + X$ $\quad$ $73.8pb(46.2pb)$ $\quad$ (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):

$pp \to t\bar{b}(\bar{t}b) + X$ $\quad$ $4.9pb(3.1pb)$ $\quad$ (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]

Monte-Carlo Events Data Base

Single top events generated by CompHEP (generator - SingleTop)

Author: E. Boos, L. Dudko (Eduard.Boos@cern.ch, Lev.Dudko@cern.ch)
Date of publication: 28/10/2002
Category: TOP
Print version
Pages: 1

View and download files uploaded with this document.

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

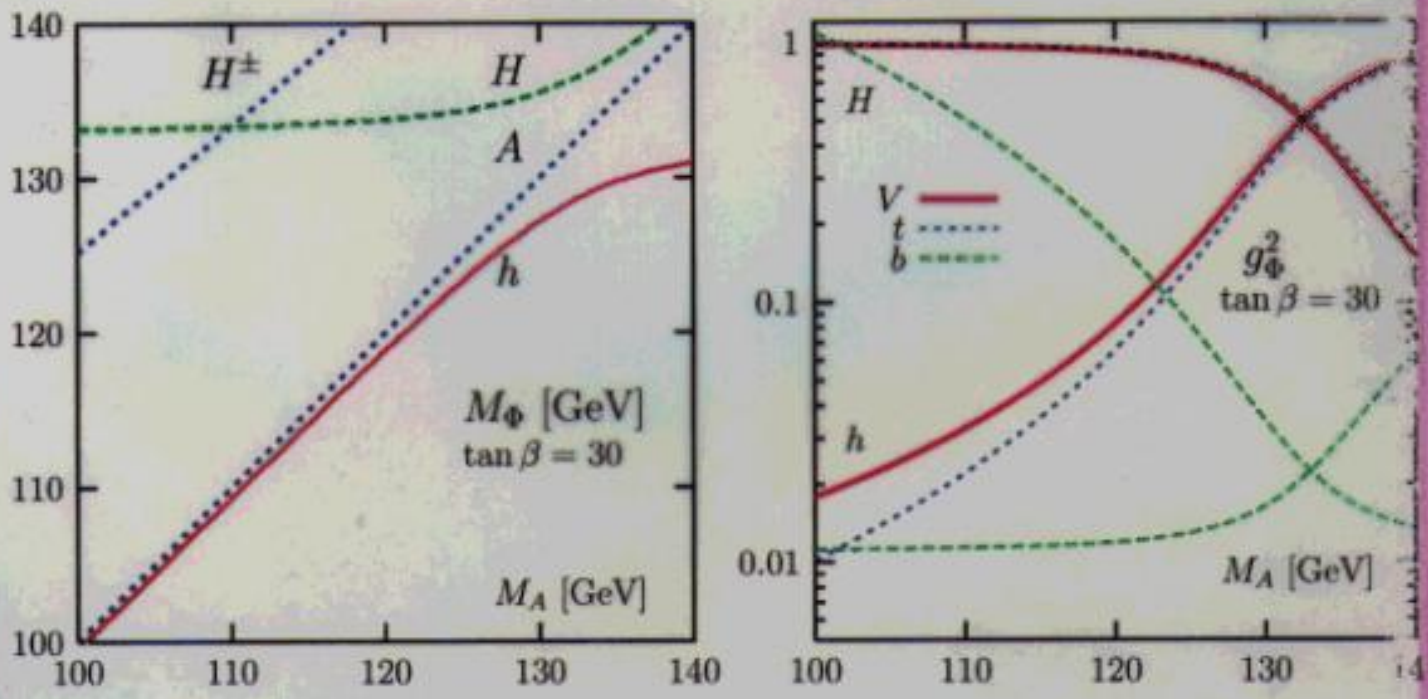
Size (kb)	file name	#events
14406	qtb_events.pev	61000
15647	qTb_events.pev	61000
29510	qtb+qTb_events_tot.pev	100000
8700	tb_events.pev	50000
8700	Tb_events.pev	50000
14128	tb+Tb_events_tot.pev	81000
35631	signal24_qtb_events.pev	124000
38693	signal24_qTb_events.pev	134000
57996	signal24_qtb+qTb_events_tot.pev	202000
22800	signal24_tb_events.pev	100000
22900	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

FeynHiggs (for parameters) →
CompHEP (for cross sections, distributions, events) →
CompHEP - PYTHIA interface →
PYTHIA - (for ISR/FSR, hadronization)
CMSJET - (for detector effects)

Intense-coupling regime of MSSM:
masses of the two CP-even h, H and of the CP-odd A boson are close to one another,
the value of $\tan\beta$ is large,
the Higgs bosons have strongly enhanced couplings to isospin down-type fermions and large total decay widths, so that the $\gamma\gamma, WW^*$ and ZZ^* decay modes of the three Higgs bosons are strongly suppressed.
(E.B., A.Djouadi, M.Mühlleitner, A.Vologdin;
E.B., A.Djouadi, A.Nikitenko)

The masses of the MSSM Higgs bosons (left) and the normalized couplings of the CP-even Higgs bosons to vector bosons and third-generation quarks (right) as a function of M_A and $tan\beta = 30$. For the b-quark couplings, the values $10 \times g_{\Phi bb}^{-2}$ are plotted.

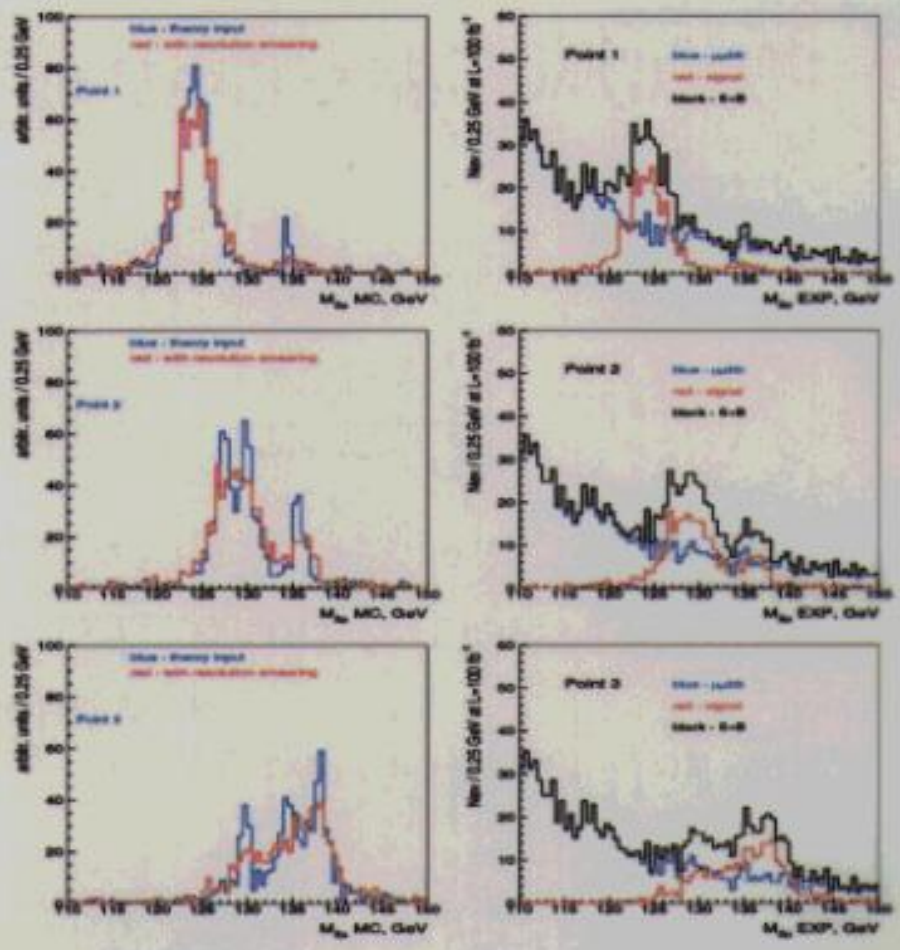


$pp \to \mu^+\mu^- b\bar{b}$ (4 fermions)

Signal and background events →

→ MCDB

for full CMS simulation

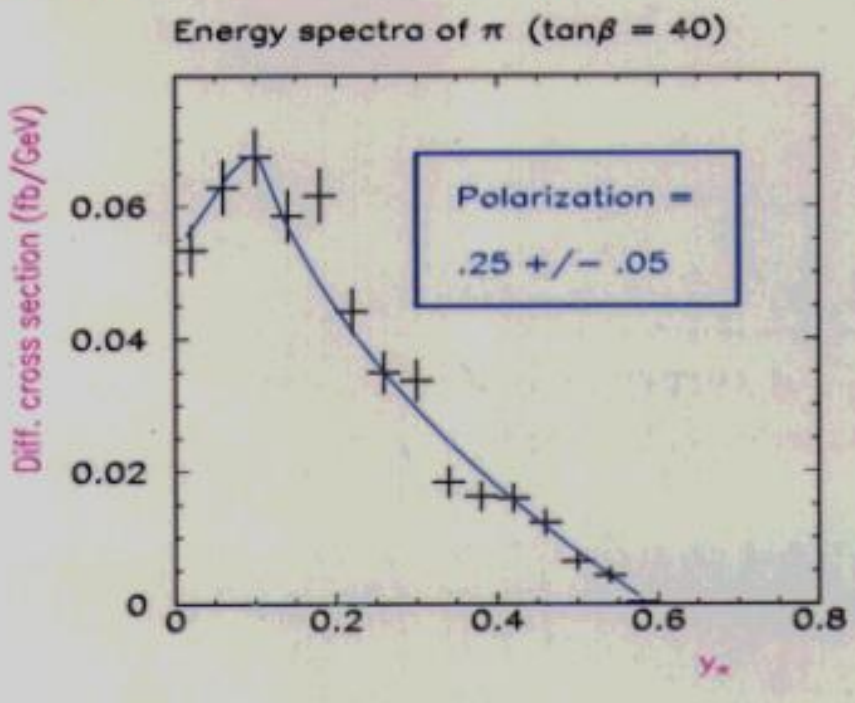


$\mu^+\mu^-$ pair invariant mass distributions for the signal before and after detector resolution smearing (left) and for the signal and the background (right) for P1, P2 and P3 parameter points.

CompHEP → CompHEP-PYTHIA interf. → PYTHIA
→ SIMDET

Cross checks with TAUA

The pion energy distribution with unweighted events



Number of unweighted events:
$N = \sigma(e^+, e^- \rightarrow \tilde{\tau}_1^-, \tilde{\tau}_1^+) * Br(\tilde{\tau}_1^- \rightarrow \tau, \tilde{\chi}_1^0) * Br(\tau \rightarrow \nu_\tau, \pi^-) * Lumi * Eff$

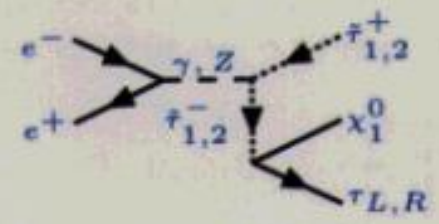
(N is about 800 events with assumed $Lumi = 500 fb^{-1}$ and Efficiency 30 %)

The fit gives for the tau polarization P about 25 ± 5 %

It leads to about 9% accuracy for $\tan\beta$ measurement

Fermion polarisation in sfermion decays

E.B., U.Martyn, G.Moortgat-Pick, M.Sachwitz, A.Vologdin, P.Zerwas



$$\sigma(e^+, e^- \to \tilde{\tau}^+_{1,2}, \tilde{\tau}^-_{1,2} \to \tilde{\tau}^+_{1,2}, \tau_{L,R}, \tilde{\chi}^0_1)$$

for τ_L and τ_R

$$\sigma_R = \sigma_0 \frac{\Gamma_R}{\Gamma_{tot}}, \; \sigma_L = \sigma_0 \frac{\Gamma_L}{\Gamma_{tot}}$$

$$\Gamma_{R,L} = \frac{e^2}{32\pi M_W^2 s_W^2} \frac{(M^2_{\tilde{\tau}_{1,2}} - M^2_{\tilde{\chi}^0_1})}{cos^2\beta M^3_{\tilde{\tau}_{1,2}}} (a^{R,L})^2$$

$$\sigma_0 = \sigma(e^+e^- \to \tilde{\tau}_i\tilde{\tau}_i) = \lambda^3 * f(...)$$

$\lambda = \sqrt{1 - 4M^2_{\tilde{\tau}_{1,2}}/s}$ - is a tipical threshold factor for a scalar particle pair production.

The coefficients $(a^{R,L})^2$ follows from the tau-stau-neutralino Lagrangian

$$\mathcal{L}_{\tau\tilde{\tau}\tilde{\chi}^0} = \sum_{i,j} \bar{\tau}_i \bar{\tau}[P_R a^L_{i,j} + P_L a^R_{i,j}]\tilde{\chi}^0_j + h.c.,$$

$i = 1, 2$ and $j = 1, 2, 3, 4$; $P_{R,L} = \frac{1 \pm \gamma_5}{2}$

Polarization degree of tau lepton $P_{\tilde{\tau}} = \frac{(a^R)^2 - (a^L)^2}{(a^R)^2 + (a^L)^2}$ is a function of mixing parameters in both Stau and Neutralino sectors.

Concluding Remarks and Problems

- CompHEP with the interface to PYTHIA is a powerful tool for a simulation of different physical processes at hadron and lepton colliders
- Important latest CompHEP improvements include MSSM, simplification of flavour combinatorics, generation of unweighted events with an information about color chains, Les Houches accord based interface, MCDB etc
- The CompHEP is the LO program. However it allows to include partly NLO corrections. NLO tree level $2 \to N+1$ corrections to the $2 \to N$ process can be computed. One can include NLO structure functions, loop relations between parameters, known K-factors, and existing from papers loop contributions as effective functions. However a correct matching to complete NLO is obviously a problem which has to be carefully considered in each particular physics case

A number of generators and simulations are done and some are in progress for Tevatron, LHC, LC