CompHEP for BSM

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Outline

Introductory remarks
BSM studies with CompHEP (examples)
Recent useful CompHEP 4.5 options
- **Symbolic and numerical batch modes**
- **Spin correlations (example)**
- **LHA formats (LHEF for event files, PDF LHA, SUSY LHA)**
- **Interfaces to PYTHIA, HERWIG, TAUOLA. Link to MCDB**
- **Distributions in various frames and ROOT plots**

FORM in CompHEP (examples)
Concluding remarks

Computations and simulations for LHC

A. SM processes (Backgrounds) as accurate as possible

B. Computation and simulation of large variety of BSM processes

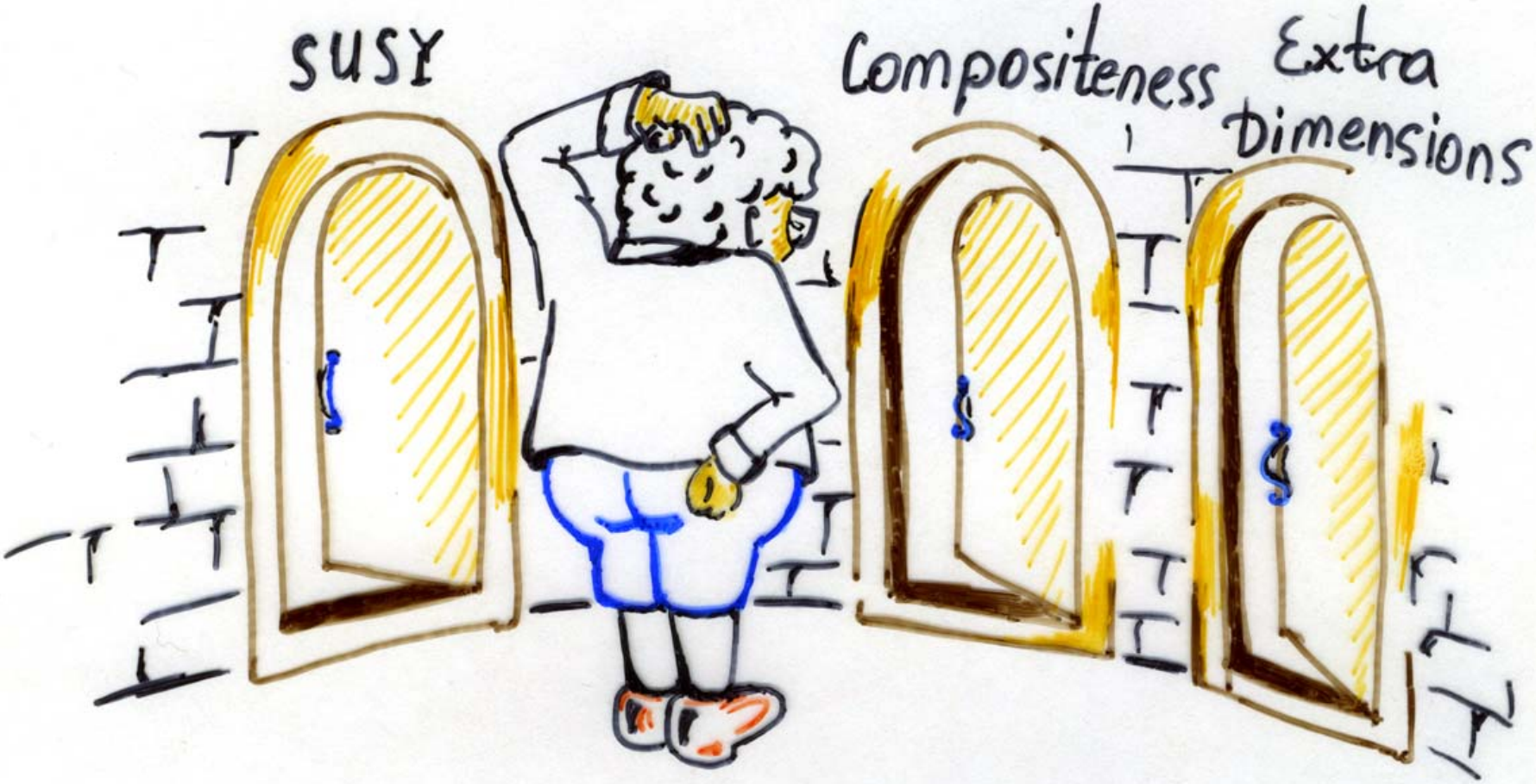
In many cases LO is not enough for BSM

NLO, NNLO computations of rates and distributions are needed but also not enough

One needs to have LO/NLO (in some cases NNLO) event generators which include (depending on physics case):

- **BSM parameters,**
- **spin correlations,**
- **finite particle masses,**
- **finite resonance widths,**
- **interferences,**
- **parton shower with proper matching,**
- **hadronization,**
- **underlying events,**
- **detector response**

Tevatron, LHC, ILC, CLIC ???



Victor Boos, 1999

CompHEP have been used for many BSM studies

CompHEP models for new physics

Compositeness

Excited leptons and quarks; fermion contact interactions; leptoquarks; anomalous triple and quartic gauge couplings; anomalous gamma-gamma-H, Z-gamma-H and self Higgs couplings; littlest Higgs with T-parity; anomalous Wtb and FCNC top quark couplings …..

SUSY

MSSM in various SUSY breaking scenarious in unitary and Feynman gauges, with and without R-parity, with and without CP ; sgoldstino; NMSSM; 2HD generic model…..

Extra dimensions

RS1 model and effective 4 particle Lagrangian for RS below KK threshold; UED model …..

Other exotics

Muonic photon; E6 isosinglet quark; generic charged scalar; Z', W' bosons; doubly charged Higgs; Dirac and Majorana heavy neutrinos; lepton flavor violated interactions; paraphoton…..

MSSM, NMSSM, 2HD generic model and some other models have been implemented by means of LanHEP

BSM in CompHEP

Why useful?

Simple structure of Feynman rules, easy to extend, LanHEP helps a lot

Symbolic and numerical computations and event simulation including BSM 2->2,3,…6 (1->2,3,…7) and even more using batch modes, cascade option, FORM based version

Symbolic answers for ME squared

specially useful to get formulas for simple 2->2 and 1->2,1->3 processes including BSM contributions and parameters (MATHEMATICA, REDUCE, FORM outputs)

Needed Interfaces, all LHA, LHEF, link to MCDB

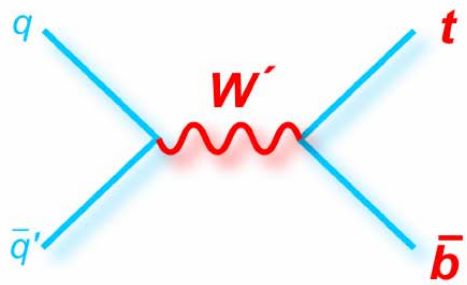
Very good introductory materials on CompHEP

A Particle Physics Tour with CompHEP
by Jeffrey D. Richman, UC Santa Barbara HEP page.
Lecture course
by Dan Green. US CMS - The LHC Physics Center page.
Practicum on Simulations
by Konstantin Matchev, University of Florida, Institute for Advanced Study

One of the very recent application.
"Fourth Family Neutrinos and the Higgs Boson" 0806.4003 [hep-ph] 25.06.08

D0 searches for W' boson in single top

$$L=\frac{V_{q_i q_j}}{2\sqrt{2}} g_W \bar{q}_i \gamma_\mu [a^R_{q_i q_j}(1+\gamma_5)+a^L_{q_i q_j}(1-\gamma_5)] W' q_j + H.C.$$



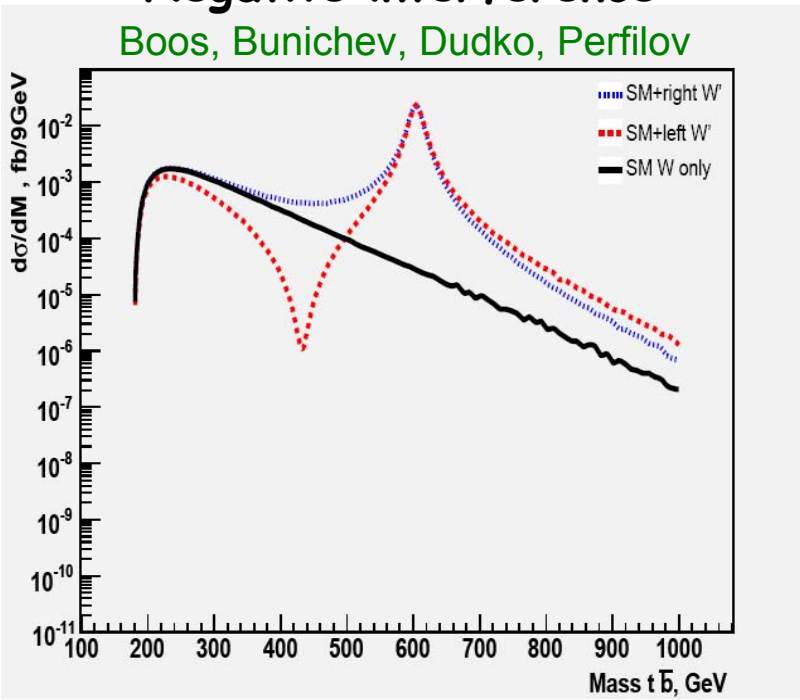
$a^R_{q_i q_j}, a^L_{q_i q_j}$ - *left and right couplings of W' to fermions*

$$|M|^2 = SM + 2\cdot a^L_{ud}\cdot a^L_{tb} + [(a^L_{ud})^2(a^L_{tb})^2+(a^R_{ud})^2(a^R_{tb})^2] W' + [(a^L_{ud})^2(a^R_{tb})^2+(a^R_{ud})^2(a^L_{tb})^2] W'$$

Interference of W and W'

Negative interference

Boos, Bunichev, Dudko, Perfilov



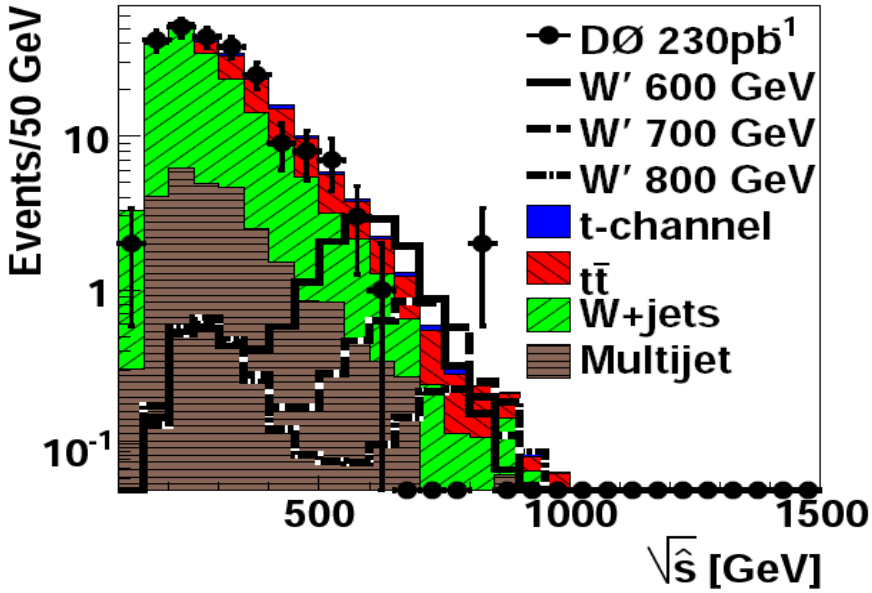
W' boson MC event samples from SingleTop (CompHEP) generator including all spin correlations between top production and decay

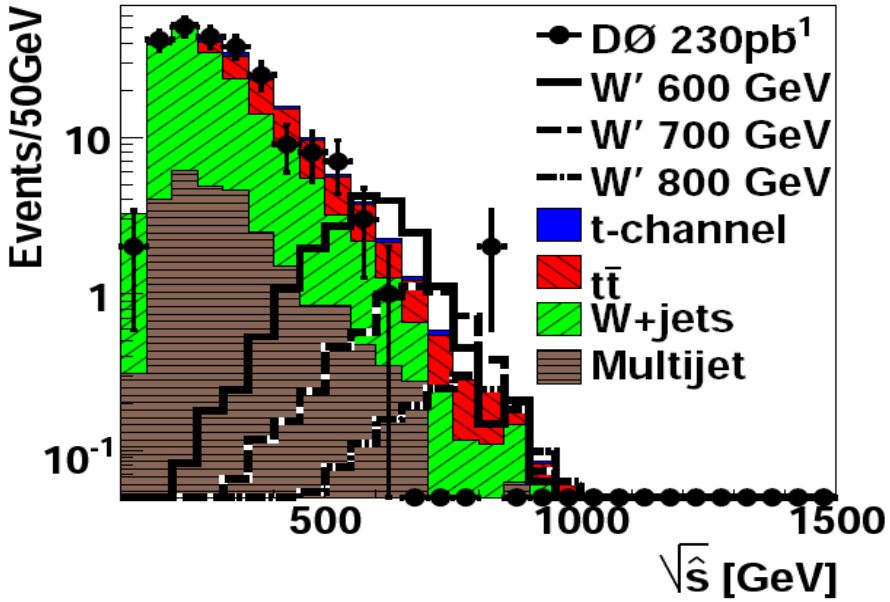
W'→tb first D0 results with 230 pb^{-1}

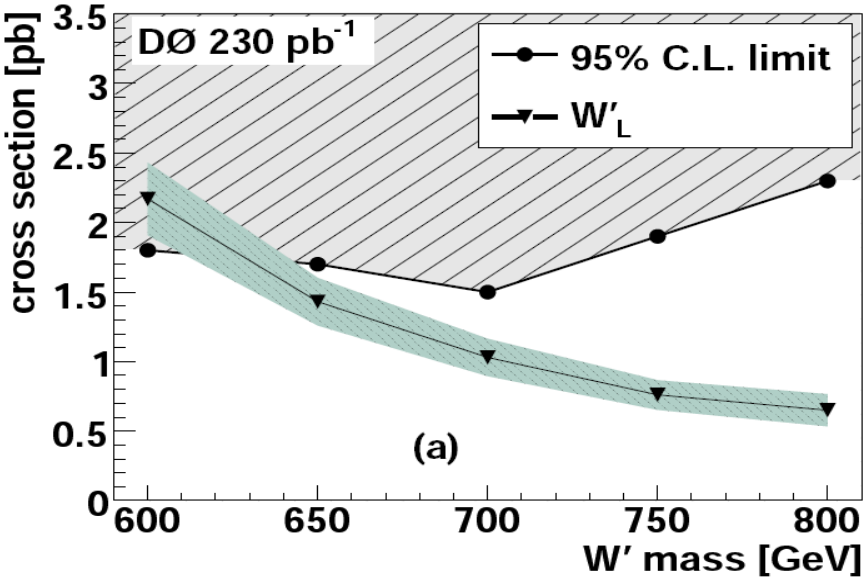
Phys. Lett. **B**, 641 (2006) 423-431

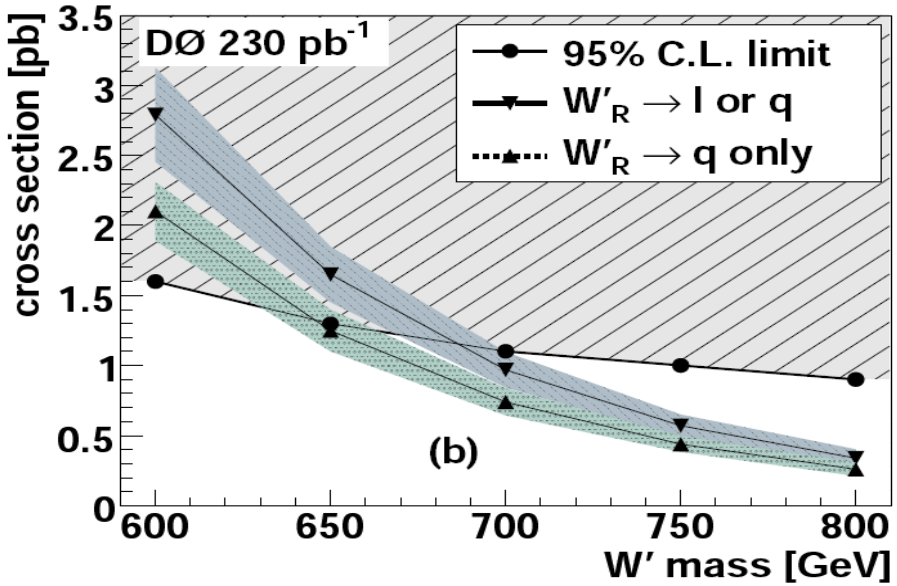
Limits on W' boson mass : MW' > 610 (630-670) GeV L(R)

D0Note 5002 R.Schwienhorst, M.Perfilov, V.Bunichev, E.Boos, L.Dudko





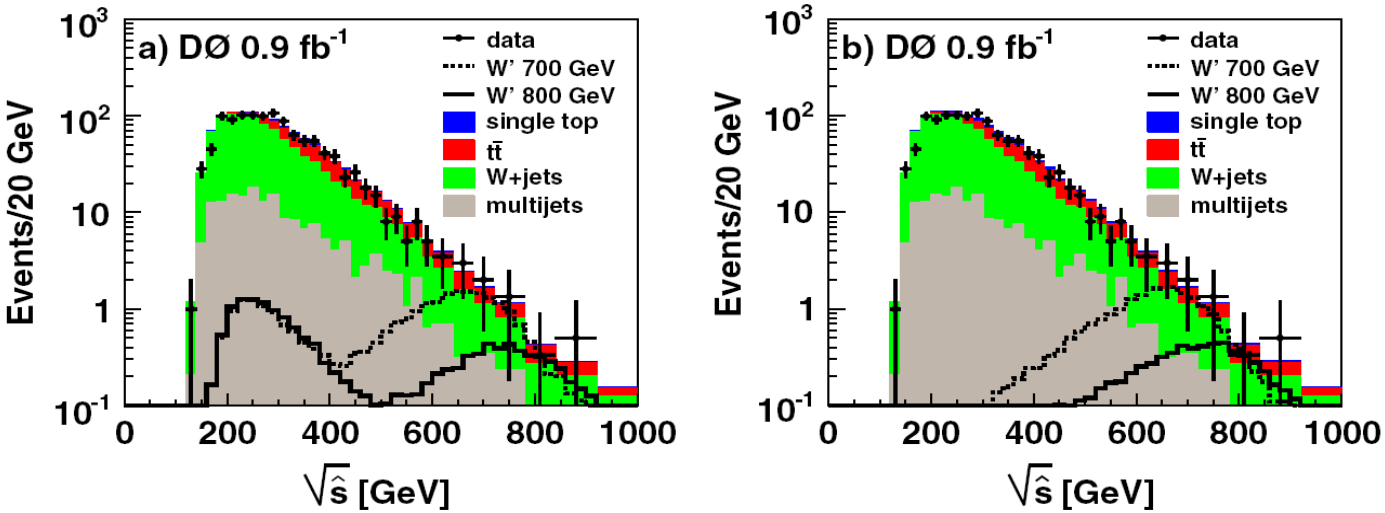


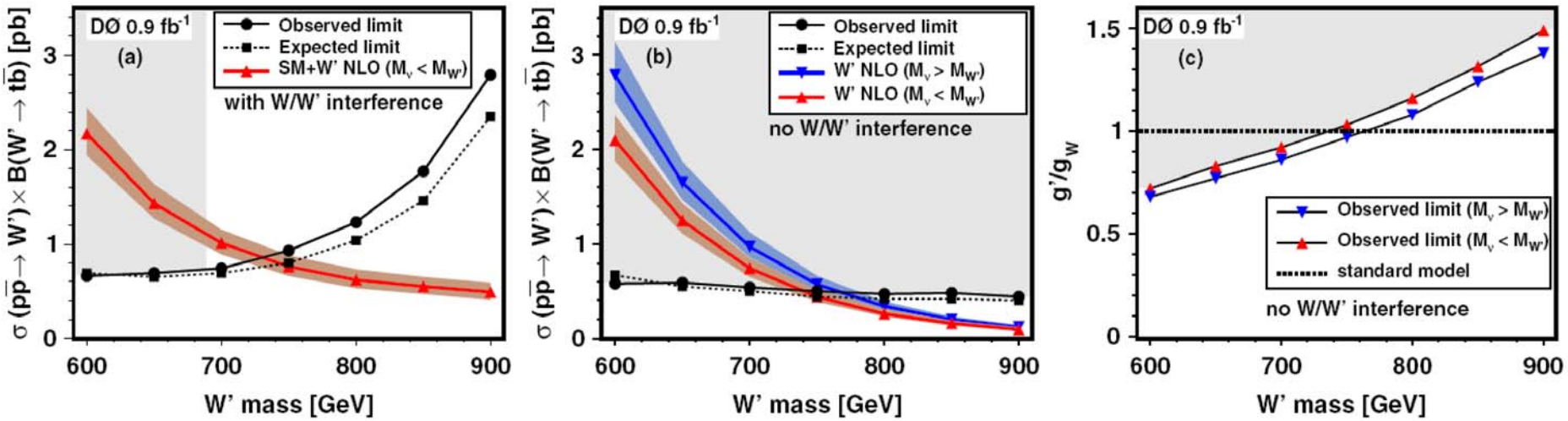


W'→tb results D0 2008, 0.9 fb^{-1}

Phys. Rev. Lett. 100, 211803 (2008)

D0Note 5602 T.Bose, M.Narain, E.Boos, V.Bunichev, L.Dudko, M.Perfilov





$$g' = g_W a^R_{ij}$$

Batch Modes in CompHEP 4.5

Both parts (symbolic & numerical) have batch regimes:

Perl scripts: symb_batch.pl and num_batch.pl

Why the scripts are useful?

Computations of many subprocesses – laborious task,
can be significantly simplified

Long/large-scale calculations:
GUI is not handy

Support of parallel calculations:
very helpful for N*CPU machines/computer clusters
(compatible with pbs/lsf ; grid in progress)

"Knowledge transfer":
theorists/phenomenologists can prepare model/process.dat/batch.dat
for further simulations by experimentalists

Many BSM model parameter points

Symbolic batch script

- 1st step!: ./symb_batch.pl –help

- All steps in process description
  (model, beams, final state, excluded/kept propagators) in the file process.dat
  Tweaking of diagram choice in GUI with -show diag

- One shot (./symb_batch.pl) -> executable file n_comphep.exe is ready for further numerical computations!

- Parallel calculations: -mp N means N symbolic calculations in parallel (1/N of the whole set of diagram per process)

- Monitoring option: -show stat shows how many diagrams have been calculated by the moment

- Very easy to use!

Numerical batch script

- Again, 1st step: ./num_batch.pl –help
  (long and detailed description, 5 pages). The script has lots of options (~30)!
- n_comphep.exe should be prepared!
  Configuration file is batch.dat in /results (based on session.dat files for individual subprocesses).
  It can be editted by hand or via GUI and ./num_batch.pl –add (customized subprocess added to batch.dat)
- Then ./num_batch.pl -run vegas (cross section calculation for ALL subrocesses) and ./num_batch.pl -run max,evnt (event generation)
- Parallel culculations available. Alone machine: -mp 3 (3 jobs are calculated simultaneously); computer clusters: -lsf and -pbs
- Many ways to present/monitor results (see help)
- Very easy to use!

In needed cases the CompHEP collaboration provides batch.dat as a GENERATOR

Short instruction for numerical calculations using batch mode:

1. Start Numerical GUI and EDIT parameters for the first subprocess:

```
cd results
./n_comphep
quite GUI (F9)
```

2. Run numerical batch script to create batch.dat configuration file in the directory results

```
cd ..
./num_batch.pl
```

3. If you need to change parameters for some specific subprocess(es) (say subprocesses number 3,5,7) do it via GUI:

```
cd results
./n_comphep
```

make the necessary changes for the first of these subprocess (number 3 in our case)

```
quit GUI (F9)
cd ..
./num_batch.pl --add --proc 3,5,7
```

The resulting batch.dat file has two sets of configuration parameters: for subprocesses 1,2,4,6,8... As for the subprocess 1 and for 3,5,7 as for the subprocess 3.

4. Run numerical calculations with the option -run. Some examples:

```
./num_batch.pl -run vegas  (calculates cross sections)
./num_batch.pl -nevnt N  (set the total number of requested events N=n1+n2+...+n_i
```

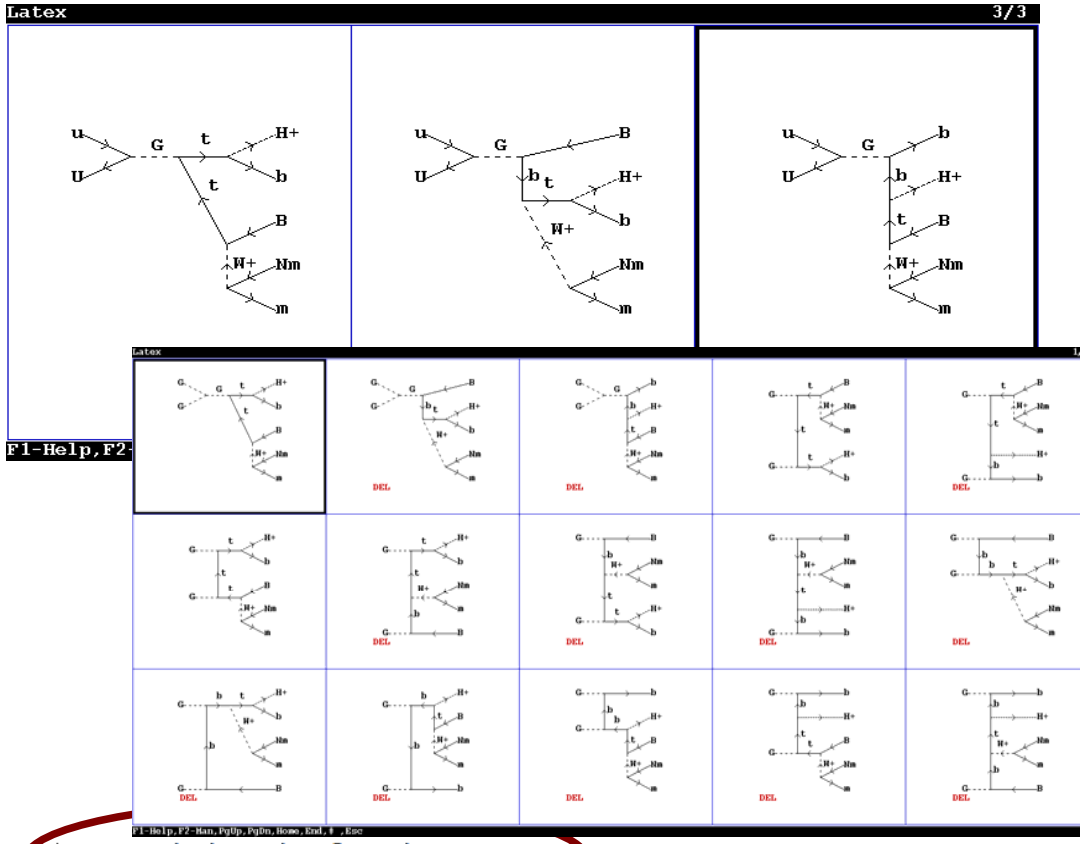
where n_i is event number for the subprocess “i” according to partial cross section, by default 10000 events are generated for each subprocess)

```
./num_batch.pl -run max,evnt -lhaef    (generation of N events)
```

Symbolical batch: pp->m,Nm,b,B,H+ with t->b,H+ and T->m,Nm,B MSSM, tb=0.5, MH+=150GeV (H+->t*b->2f+bB dominates)

- Prepare process.dat following toy example: all points well documented
- ./symb_batch.pl -show diag (to exclude several sub-leading diagrams)
  27 diagrams in 9 subprocesses (54 sqr. diag.) (15 G,G->m,Nm,b,B,H+ diagrams)
- ./symb_batch.pl -mp 2 calculate faster (2 times if you have 2*CPU machine)

```
#############################################################
#         Data file for symb_script.pl
#       For the symb_batch script version 1.0
#############################################################

#  You have to set the model number, which you are going to
#  The model number corresponds to the string number of the
#  in the CompHEP model menu in the GUI mode.
model number: 6

#  Beam name can be taken from a table of beams
#  (see CompHEP in the GUI regime). Energy unit is GeV
beam 1: p
beam 2: p
beam energy 1: 7000.0
beam energy 2: 7000.0

#  This string defines the final state of your process. Mode
#  particles and composite particles (see the corresponding
#  can be used.
final state: m,Nm,b,B,H+

#  If you'd like to exclude feynman diagrams with some model
#  particles (in propagators!), enter the particles here
exclude diagrams with: h,H,H3,u,d,c,s,A,Z

#  If you'd like to keep feynman diagrams with some model
#  particles (in propagators!), enter the particles here
#  Examples:
#keep diagrams with: t,b,Z,A
keep diagrams with:

#  If you enter no, s_comphep generates diagrams and does no
#  do symbolic calculations.
make symbolic calculations(yes/no): yes

#  If you enter no, comphep calculates all squared diagrams,
#  but n_comphep will not be created.
make n_comphep generator(yes/no): yes
```




```
[note]$ ./symb_batch.pl -show stat
Diagram statistics: total = 54, calculated = 44, deleted = 0
[note]$ Old n_comphep is deleted!
End of CompHEP symbolical session.
*** n_comphep creation details have been written to symb_batch.log
```

Numerical batch: pp->m,Nm,b,B,H+ in MSSM

- Prepare batch.dat: customize first process via GUI and execute ./num_batch.pl
- Customize differences in other subprocesses (if needed) via GUI and execute ./num_batch.pl –add -proc ... for the necessary subprocesses
- Start numerical calculations with ./num_batch.pl -run ...

```
#Subprocess 1 (u,U -> m,Nm,b,B,H+)
#Session_number 1
#Model_number 6
#Initial_state
  SQRT(S) 1.400000E+04
  Rapidity(c.m.s) 0.000000E+00
  StrFun1: PDF:cteq6l1(proton)
  StrFun2: PDF:cteq6l1(proton)

#Physical_Parameters
        EE = 3.122300000000000E-01
        SW = 4.730000000000000E-01
        MZ = 9.118840000000000E+01
      Mtop = 1.750000000000000E+02
        Mb = 4.620000000000000E+00
      wtop = 1.752400000000000E+00
        wW = 2.088950000000000E+00
        mu = 1.000000000000000E+03
       MG2 = 2.000000000000000E+02
       MG3 = 3.000000000000000E+02
       Mq3 = 1.000000000000000E+03
       Mu3 = 1.000000000000000E+03
       Md3 = 1.000000000000000E+03
      Atop = 0.000000000000000E+00
        Ab = 0.000000000000000E+00
       MH3 = 1.341600000000000E+02
        tb = 5.000000000000000E-01
        GG = 1.216002374681738E+00

#Width_scheme  0

#Kinematical_scheme
12 -> 57 , 346
57 -> 5 , 7
346 -> 6 , 34
34 -> 3 , 4

#Cuts
```

```
[note]$ ./num_batch.pl --show cs
List of available subprocesses:
Subprocess 1 (u,U -> m,Nm,b,B,H+): cross section [pb] = 6.2925e-01   +/- 1.30e-03 ( 2.06e-01 % )
Subprocess 2 (d,D -> m,Nm,b,B,H+): cross section [pb] = 3.8960e-01   +/- 8.15e-04 ( 2.09e-01 % )
Subprocess 3 (U,u -> m,Nm,b,B,H+): cross section [pb] = 6.2781e-01   +/- 1.55e-03 ( 2.47e-01 % )
Subprocess 4 (D,d -> m,Nm,b,B,H+): cross section [pb] = 3.8906e-01   +/- 9.31e-04 ( 2.39e-01 % )
Subprocess 5 (s,S -> m,Nm,b,B,H+): cross section [pb] = 6.6678e-02   +/- 1.43e-04 ( 2.14e-01 % )
Subprocess 6 (c,C -> m,Nm,b,B,H+): cross section [pb] = 3.0779e-02   +/- 6.58e-05 ( 2.14e-01 % )
Subprocess 7 (S,s -> m,Nm,b,B,H+): cross section [pb] = 6.6678e-02   +/- 1.43e-04 ( 2.14e-01 % )
Subprocess 8 (C,c -> m,Nm,b,B,H+): cross section [pb] = 3.0779e-02   +/- 6.58e-05 ( 2.14e-01 % )
Subprocess 9 (G,G -> m,Nm,b,B,H+): cross section [pb] = 1.4684e+01   +/- 3.59e-02 ( 2.44e-01 % )

 Total CS [pb] = 1.6914e+01   +/- 3.60e-02 ( 2.13e-01 % )
```

```
#Regularization
*** Table ***
 Regularization
 Momentum     |> Mass  <|> Width <| Power|
57            |Mtop     |wtop     |2.....
34            |MW       |wW       |2.....
346           |Mtop     |wtop     |2.....
==========================================
```

```
#QCD Lambda6 = 1.652000E-01  Scale = 175
#Vegas_calls 41472x5
#Vegas_integral  9.16788703338995469E+13 3.46369076228
#Distributions
*** Table ***
Distributions
  Parameter  |> Min bound <|> Max bound <|> Rest Frame
=========================================================

#Events 500 1 0.200000 2.000000 10000
#Random FA98C8AA370E

#VEGAS Grid  Vegas grid: dim=12  size=50
```

Simulation of cascade decay in CompHEP

1. Generate production events

CompHEP version 4.5

```
#PEVLIB_v.1.0 ==============================================
#CompHEP version 4.5
#PROCESS   u    U   -> m    Nm   b    B    H+
#Initial_state
  SQRT(S) 1.960000E+03
  Rapidity(c.m.s) 0.000000E+00
  StrFun1: PDF:cteq6l1(proton)
  StrFun2: PDF:cteq6l1(anti-proton)
#MASSES  0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0
.6200000000E+00 4.6200000000E+00 1.5003506470E+02
#Cross_section(Width) 1.842239E-01
#Number_of_events      55266
#-------------------------------------------------------------
#CompHEP version 4.5
#PROCESS   d    D   -> m    Nm   b    B    H+
#Initial_state
  SQRT(S) 1.960000E+03
  Rapidity(c.m.s) 0.000000E+00
  StrFun1: PDF:cteq6l1(proton)
  StrFun2: PDF:cteq6l1(anti-proton)
#MASSES  0.0000000000E+00 0.0000000000E+00 0.0000000000E+00 0
.6200000000E+00 4.6200000000E+00 1.5003506470E+02
#Cross_section(Width) 3.316660E-02
#Number_of_events      9948
```

2. Generate decay events

CompHEP version 4.5

```
#CompHEP version 4.5
#PROCESS   H+  -> E    ne   b    B
#Initial_state
  SQRT(S) 0.000000E+00
  Rapidity(c.m.s) 0.000000E+00
  StrFun1: OFF
  StrFun2: OFF
#MASSES  1.5003506470E+02 0.0000000000E+00 0.0000000000E+00 4.6200000000E+00 4
.6200000000E+00
#Cross_section(Width) 4.801043E-04
#Number_of_events     100000
#-------------------------------------------------------------
#Number_of_subprocesses = 1
#Total_cross_section_(pb) = 4.801043E-04
#Events_mixed_and_randomized = 100000
#Nproc ================== Events ==========================
 1  -2.3466858060E+01  4.4298254788E+01  3.9019414884E+01  5.1245802995E+00  6
.0883300482E+00 -2.8526782568E+01  5.1727835861E+00 -2.6188469731E+01 -1.09515
22465E-01  1.3169494175E+01 -2.4198115105E+01 -1.0383117092E+01  9.119E+01   (
5 4)
 1  -1.5191133328E+01  3.7733542463E+01  8.7906452591E+00  4.1633026493E+01  6
.7928012131E+00 -2.6654965530E+01 -2.5675368818E+0
91008E+01 -7.6652434728E-01 -1.8592615690E+01 -7.0
```

3. Run command “cascade”

slava@slava:~/H+_2008/old_format/pP-mNbBH+

Файл Правка Вид Терминал Вкладки Справка

```
charged Higgs, tree:  156.467255
              1-loop:  150.035065
-----------------------------------------------------
Delta rho total          :   6.80672253E-05
-----------------------------------------------------


End of CompHEP numerical session.
[slava@slava pP-mNbBH+]$
[slava@slava pP-mNbBH+]$
[slava@slava pP-mNbBH+]$ ./cascade production.txt decay.txt
```

File with glued events

CompHEP version 4.5

```
#PEVLIB_v.1.0 ==============================================
#CompHEP version 4.5
#PROCESS u   U -> m   Nm   b   B   E   ne   b   B
#Initial_state
  SQRT(S) 1.960000e+03
  Rapidity(c.m.s) 0.000000e+00
  StrFun1:PDF:cteq6l1(proton)
  StrFun2:PDF:cteq6l1(anti-proton)
#MASSES  0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 4.620000e+00 4.62
0000e+00 0.000000e+00 0.000000e+00 4.620000e+00 4.620000e+00
#Cross_section(Width) 1.842239e-01
#Number_of_events      55266
#-------------------------------------------------------------
#CompHEP version 4.5
#PROCESS d   D -> m   Nm   b   B   E   ne   b   B
#Initial_state
  SQRT(S) 1.960000e+03
  Rapidity(c.m.s) 0.000000e+00
  StrFun1:PDF:cteq6l1(proton)
  StrFun2:PDF:cteq6l1(anti-proton)
#MASSES  0.000000e+00 0.000000e+00 0.000000e+00 0.000000e+00 4.620000e+00 4.62
0000e+00 0.000000e+00 0.000000e+00 4.620000e+00 4.620000e+00
#Cross_section(Width) 3.316660e-02
#Number_of_events      9948
                                                              PgDn
```

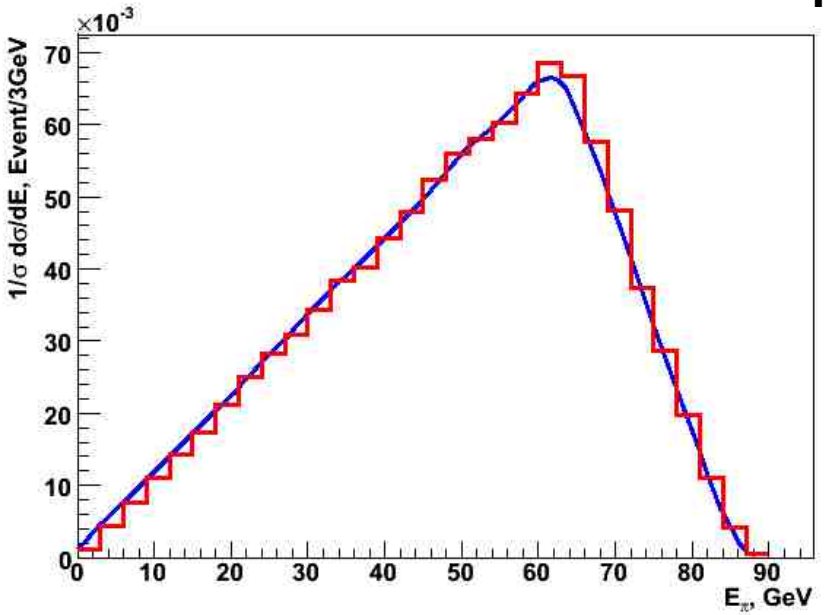
Cascade processes with scalar

MSSM parameters : $\tan\beta = 0.5, \quad M_{H^+} = 150$

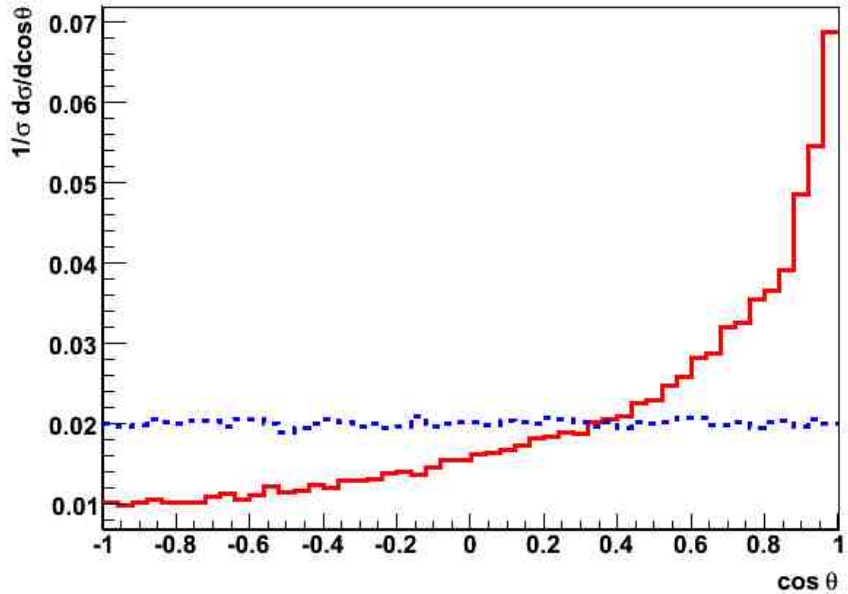
$$p\bar{p} \to t\bar{b} \to H^+ b\bar{b} \to \tau^+ \nu_\tau b\bar{b} \to \pi^+ \nu_\tau \bar{\nu}_\tau b\bar{b}$$

$$p\bar{p} \to t\bar{t} \to H^+ b W^- \bar{b} \to e^+ \nu_e b\bar{b}\, \mu^- \bar{\nu}_\mu b\bar{b}$$

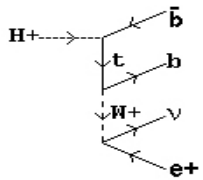
Tevatron



Pion energy spectra in the top rest frame.
Smooth line for complete process 2-5 build from weighted events,
stepped line for cascade process (2-3)*(1-3) build from two unweighted events flow.



Cosine of the angle between charged lepton and the opposite top direction in the top rest frame.
Dashed line for lepton from W^-,
solid line for lepton from H^+.



LHEF, LHAPDF, SUSY LHA

LHEF - the format adopted by almost all developer groups

hep-ph/060917

Now CompHEP supports 3 formats:

cpyth-1, cpyth-2 (for experiments, where the formats are used),
LHEF with HepML header .

There is a special option -- Generator (LHEF format) -- in the event menu in n_comphep.

All modern PDFs are available via LHAPDF: CTEQ, MRST, Alekhin PDF, etc.

Both options, LHAPDF and internal PDF, are available in CompHEP 4.5 with the same functionality in both regimes

SUSY LHA

The SLHA interface is implemented in SUGRA and GMSB models of CompHEP

(instead of ISASUSY in the previous versions)

By default the slhaScript file invokes suSpect

CompHEP-Interfaces

``CompHEP-interfaces'' package for both PYTHIA and HERWIG

for CPYTH1 (CMS) and CPYTH2 (ATLAS) formats

- Main goal: provide ISR/FSR, hadronization effects, and decays as in PYTHIA or HERWIG.

Interface libraries to PYTHIA6 and HERWIG6

Simple examples of main.f for both PYTHIA6 and HERWIG6 ;

FORTRAN code based on LHA1

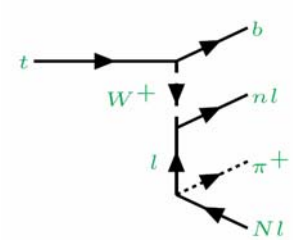
Interface to TAUOLA – not publicly available yet

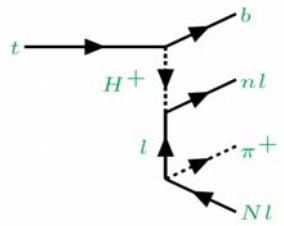
Example: polarized τ production in CompHEP, decay of polarized τ in TAUOLA

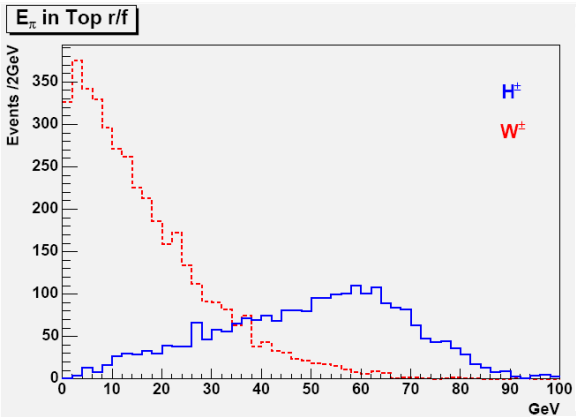
$$\tan\beta = 30\ (M_A = 130\ GeV),\ M_{H^\pm} = 146\ GeV$$

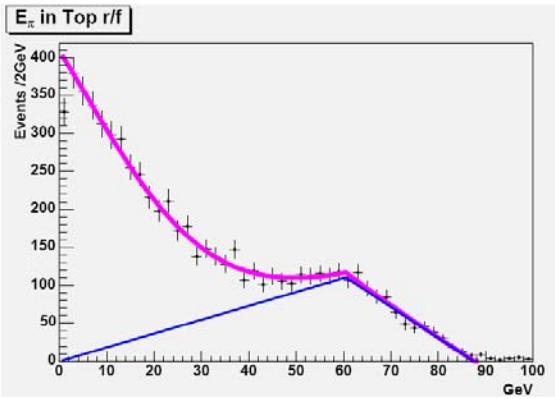
E.B., V.Bunichev, M.Carena, C.Wagner

$$e^+e^- \to t\bar{t} \to \tau\nu_\tau b\bar{b} + 2jets$$









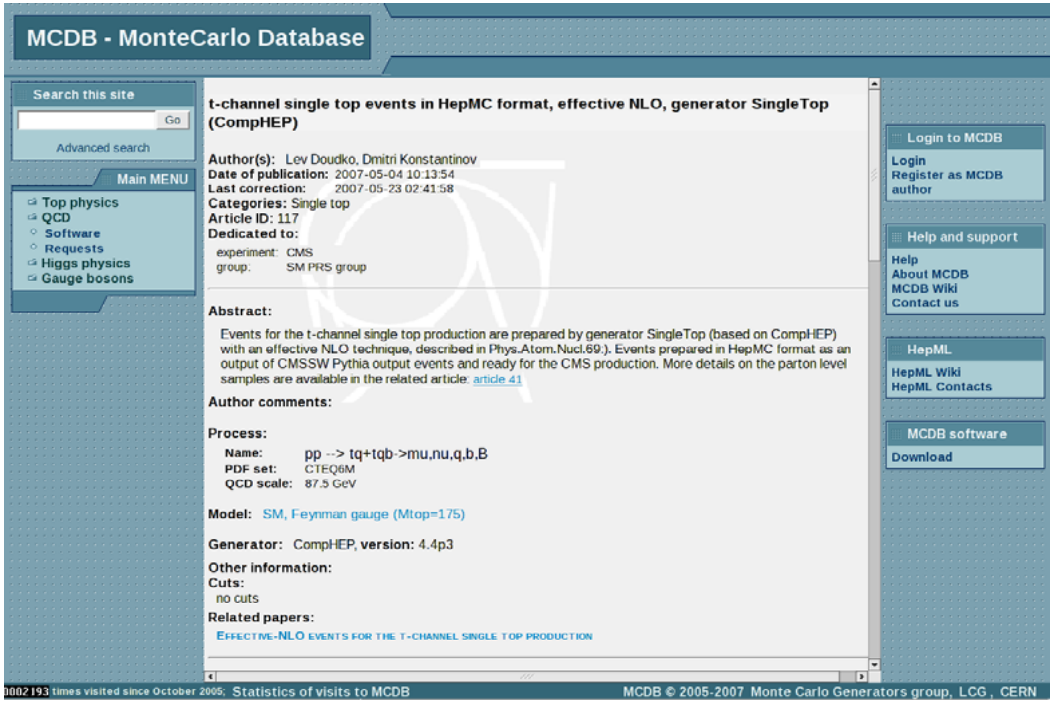
From signal+background fit: $M_{H^\pm} = 145.5$ +/- 0.9 GeV

MCDB — Knowledge Base

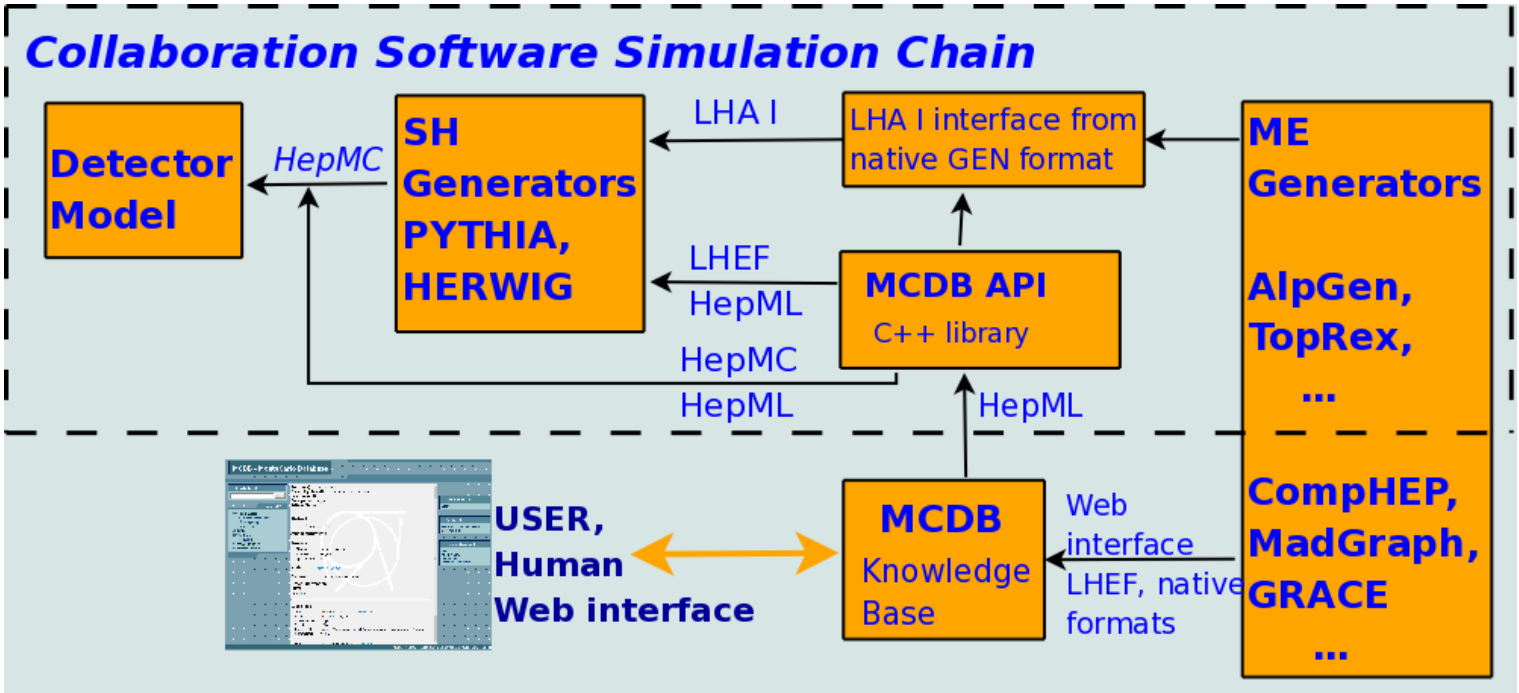
http://mcdb.cern.ch

Database of sophisticate MC simulated events and their description. It is Integrated with CMS software already

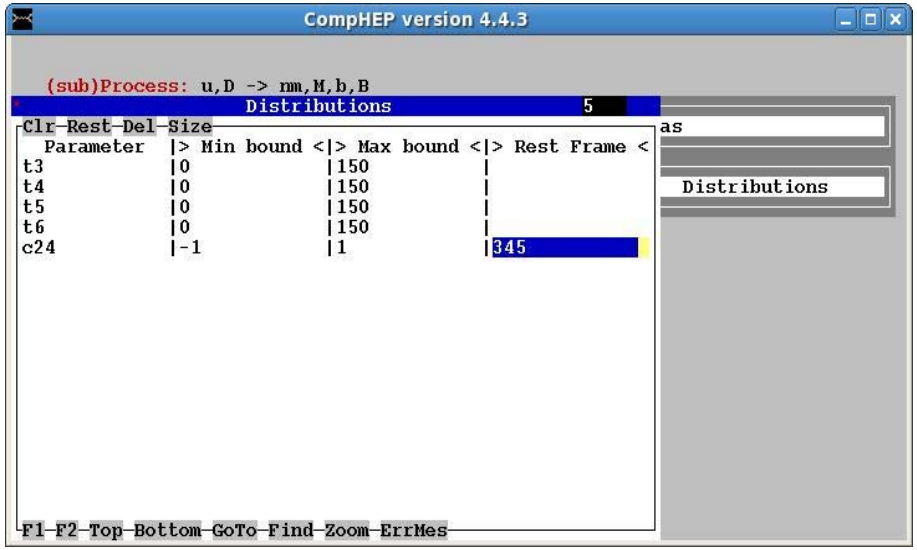
CompHEP group uses this project to distribute and document CompHEP events for LHC community



S.Belov, L.Dudko, A.Sherstnev et. al CPC178,222(2008)



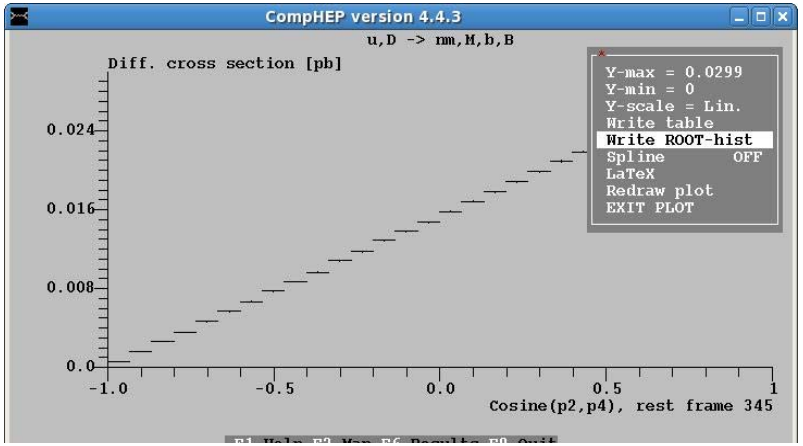
Plot distributions in the different rest frames



Distributions in user defined rest frame

Distributions in tables, built-in or ROOT histograms

s-channel single top as an example

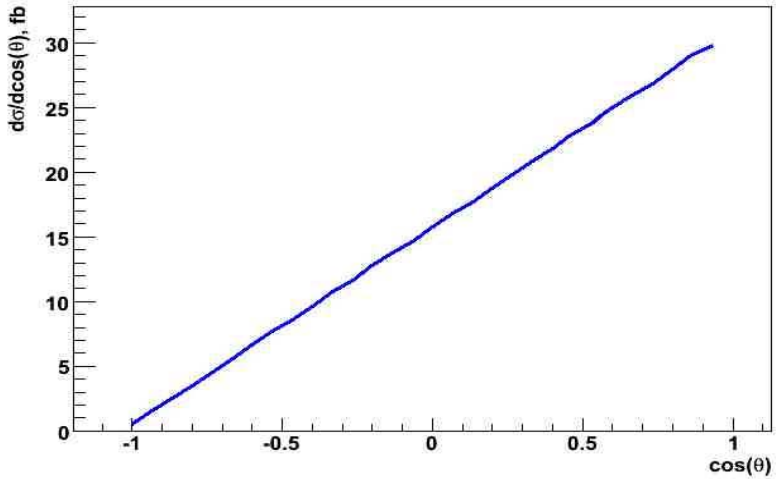


Plot ROOT-histograms

New option in the numerical menue -
"write root histogram"

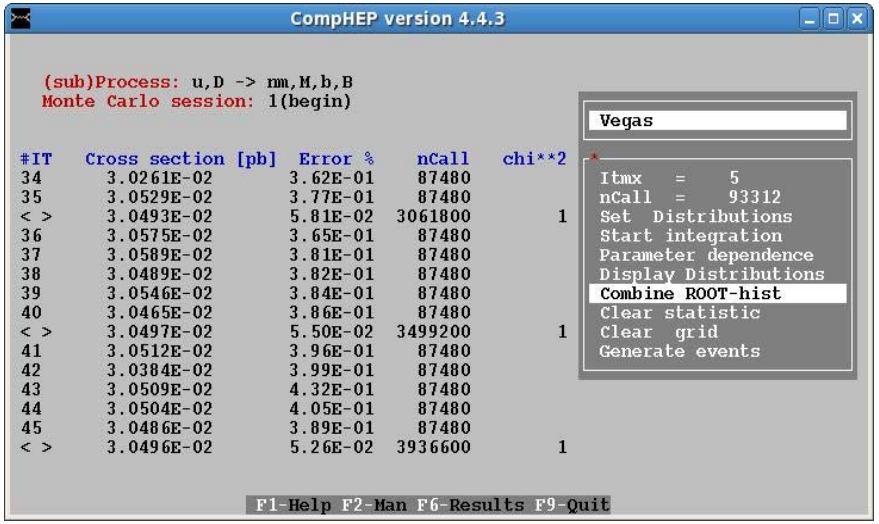
CompHEP generates **ROOT-script histogram**

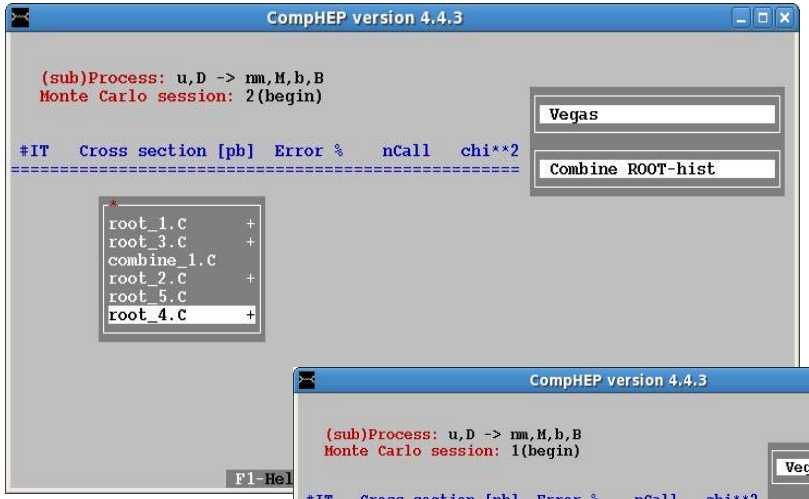
After running in ROOT -> histogram in postscript, jpeg and gif graphics formats

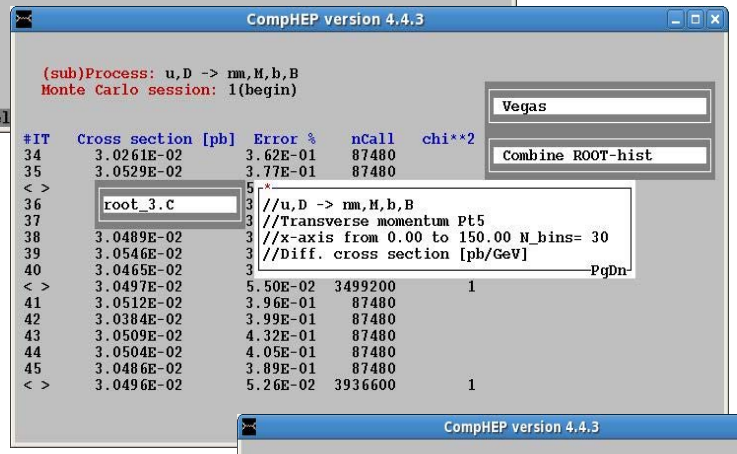


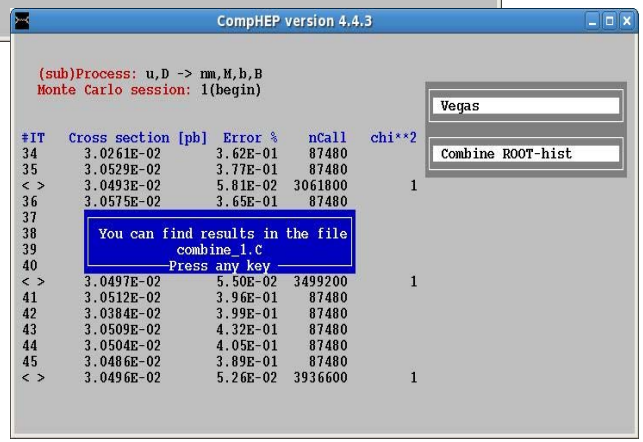
Superimpousing of histograms

In “vegas” integration menu new submenu “combine histograms” for superimposing ROOT-histograms

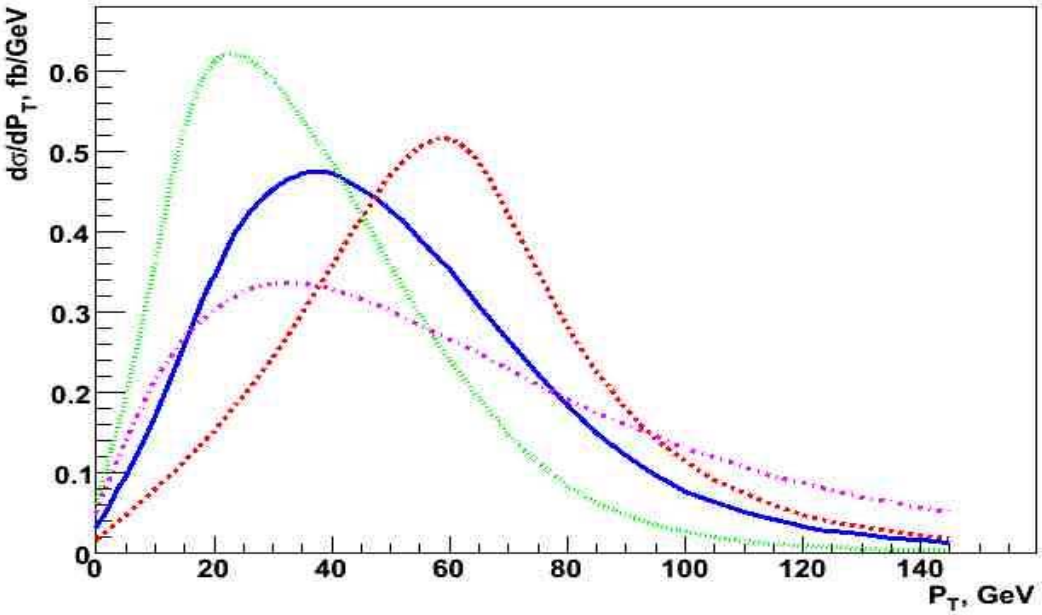




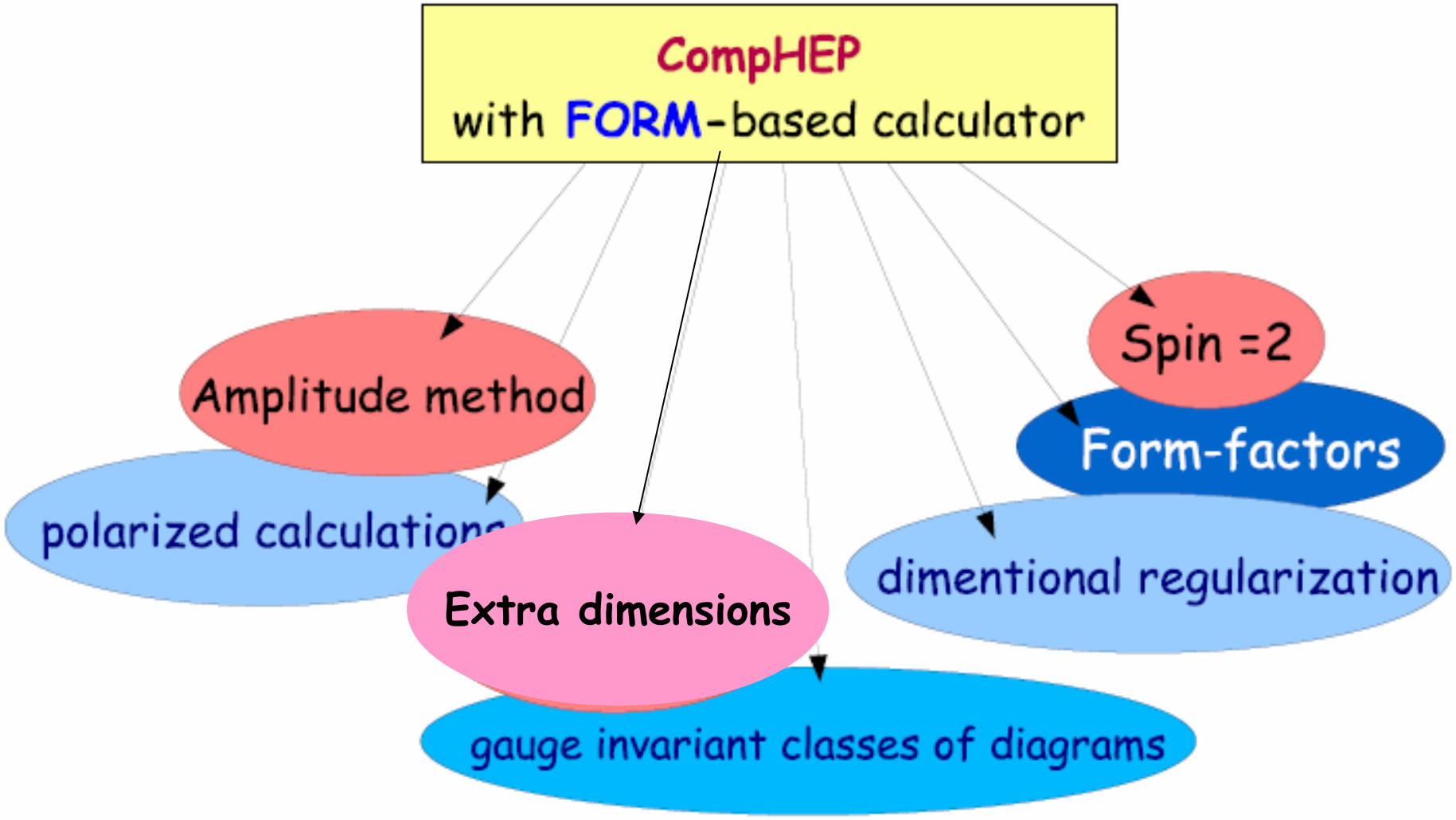




Pt distributions for all final particles



Two symbolic passes in CompHEP: standard and FORM based



Not publicly available yet

First application

Spin 2 graviton
all vertexes Gr-f-f, Gr-g-g, Gr-γ-γ, Gr-W+-W-, Gr-Z-Z

Symbolic and numerical checks

all Gr decay modes 1 → 2

all processes 2 → Gr → 2

few processes 2 → Gr → 4

Good agreement with O'MEGA/WHIZARD

Example with FORM based CompHEP

The effective "low-energy" Lagrangian below KK threshold

$$L_{eff} = \lambda\, J_{SM} * \Delta * J_{SM}, \qquad \lambda = \frac{1}{2} g^2 M^{-d} \left(\sum_{n \neq 0} \frac{(\psi^{(n)}(y_B))^2}{M_n^2} \right)$$

E.B, V.Bunichev, I.Volobuev, M.Smolaykov

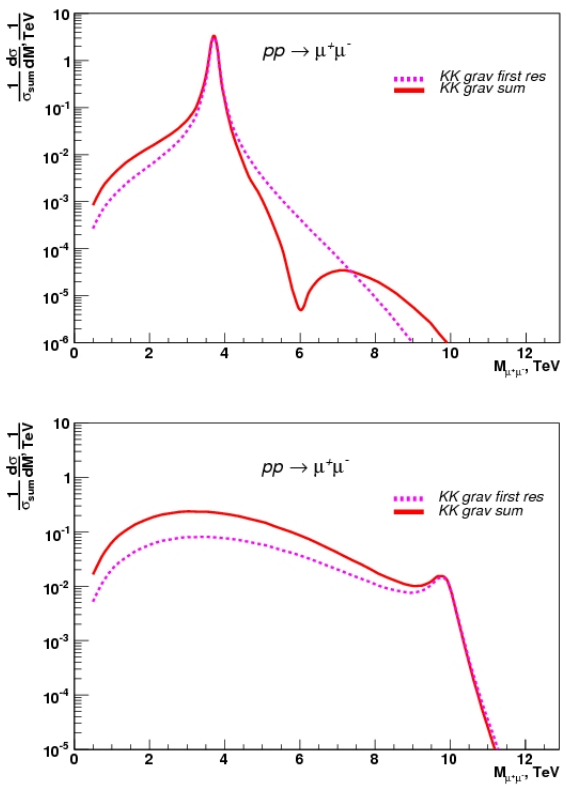
Models with gravity in the bulk

$$J_{SM} \to T_{\mu\nu} = 2 \frac{\delta L_{SM}}{\delta \gamma^{\mu\nu}} - \gamma_{\mu\nu} L_{SM}$$

$$L_{eff} = \frac{C}{M^4} T^{\mu\nu} \tilde{\Delta}_{\mu\nu,\rho\sigma} T^{\rho\sigma}$$

$$\tilde{\Delta}_{\mu\nu,\rho\sigma} = \eta_{\mu\rho}\eta_{\nu\sigma} + \eta_{\mu\sigma}\eta_{\nu\rho} - \left(\frac{2}{3} - \delta \right) \eta_{\mu\nu}\eta_{\rho\sigma}$$

New contact 4 SM particle interactions,
4 fermions, 4 bosons, 2 fermions 2 bosons



Dilepton invariant mass at LHC for RS1 model
M_{res} = 3.8 and 10 TeV

Concluding remarks on CompHEP for BSM

Large scale (parallel) computations for new physics using symbolic and numerical batch modes (2->2…6..(1->..7), many subprocesses)

Symbolic answers
useful for simple 2->2, 1->2, 1->3 new physics processes

All the Les Houches agreements (LHA, LHEF, SLHA, LHAPDF) are implemented

Interfaces to PYHTIA, HERWIG, (TAUOLA not yet public). Link to MCDB

Simple service for ROOT with useful options for quick analysis

Automatic FORM based public version to be completed

Spin correlations by gluing a production and decay for an intermediate resonance (for fermions to be completed)