CompHEP, version 4.5

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For CompHEP Collaboration:

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Outline

- **CompHEP overview**
- **New features in version 4.5**
- **Usage in D0, CMS, ILC**

History

CompHEP project
has started In 1989
in Moscow State University

The main purpose is
to make Calculations in HEP
Automatic and
Model independent

Motivations

Large number of Feynman diagrams and large number of subprocesses require automation

Goals:

- Automation of tree level diagram calculations
- "Unification" of symbolical and numerical calculation (in UI) – a full computational chain for phenomenologists
- Interfacing to other generators (for showering and hadronization) and further (full simulation)
- Interfacing to NLO codes: cross section calculators, mass spectrum calculators

Community projects: CompHEP, GRACE, MadGraph, AlpGen, Omega/WHIZARD, Sherpa/Amegic, etc.

CompHEP conception

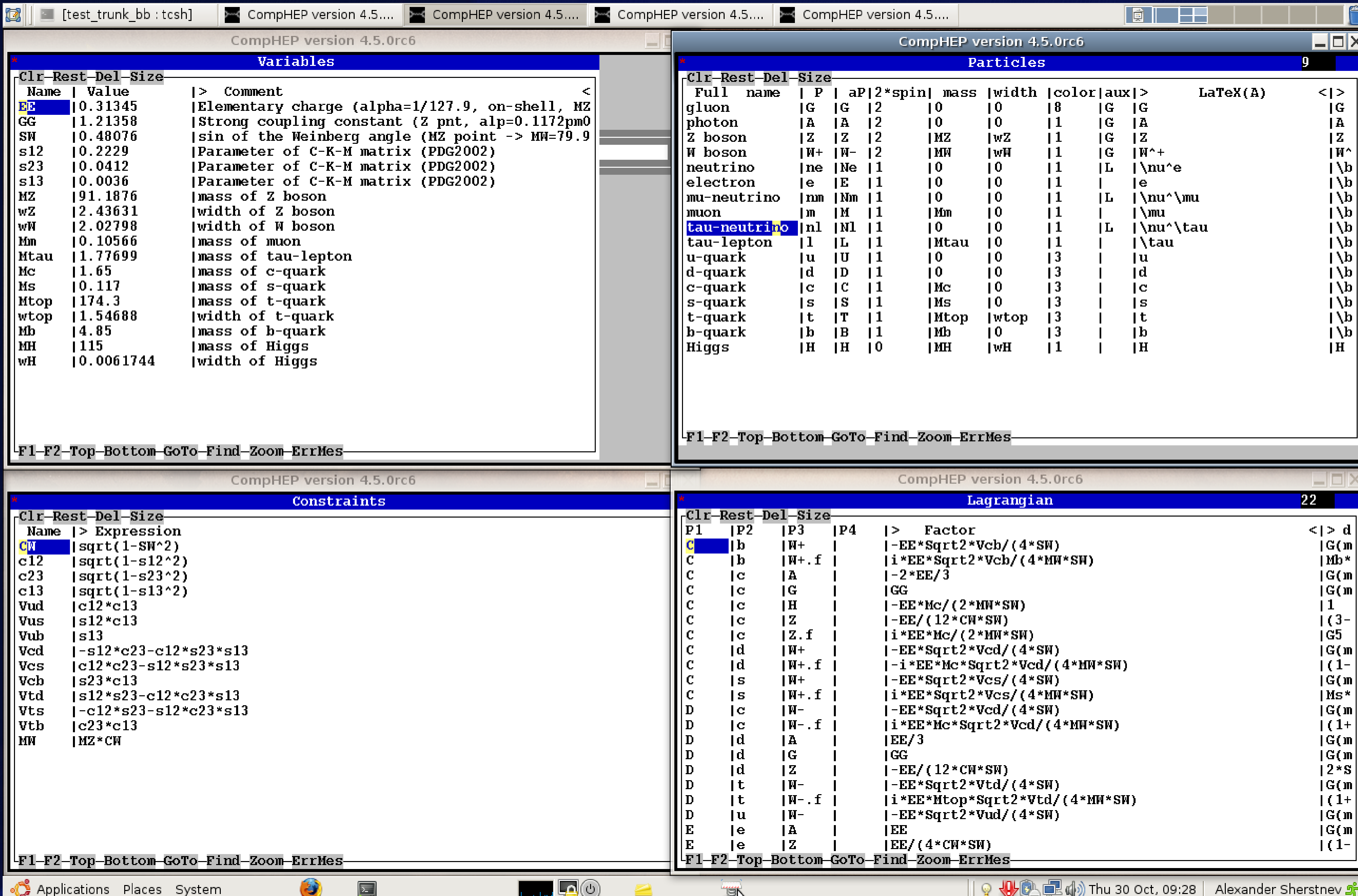
- CompHEP constructs tree level Feynman diagrams for a given parton process
- Symbolical calculations of the Feynman diagrams squared
- Automated preparation of binary for numerical calculations by Monte-Carlo technique (based on C code): cross sections, distributions, events
- Model independence: Model description files are input for CompHEP. CompHEP can work with 0,1/2,1-spin particles, Majorana and Dirac spinors, 3- and 4- vertices with fields, derivatives of fields, functions of parameters
- "Universal", build-in symbolic calculator: CompHEP can calculate N^2 tree level diagrams for any process 1, 2→M. N and M are limited by computer resources only
- User-friendly interface: GUI for both symbolic and numerical parts, comprehensive build-in help (F1), batch scripts

CompHEP Model

CompHEP Model defines particles and their interactions.
Technically CompHEP model is a set of 5 text files (tables)

- A set of fundamental particles: names, mass/width, spin, charges
- Numerical model parameters: mass/width values, couplings, mixing parameters, etc.
- Constrains: relations between the parameters
- Lagrangian: a set of all interaction vertexes
- Composite particles: proton, artificial useful particle combinations

CompHEP SM Model



Basic and user-defined CompHEP Models

- Simple training models: QED, Effective 4-fermion Fermi model
- SM in two different gauges: unitary gauge and t 'Hooft-Feynman gauge. Flavour simplified SM model (#-model)
- SUSY Models: unconstrained MSSM (again in two gauges); SUGRA model; GMSB model

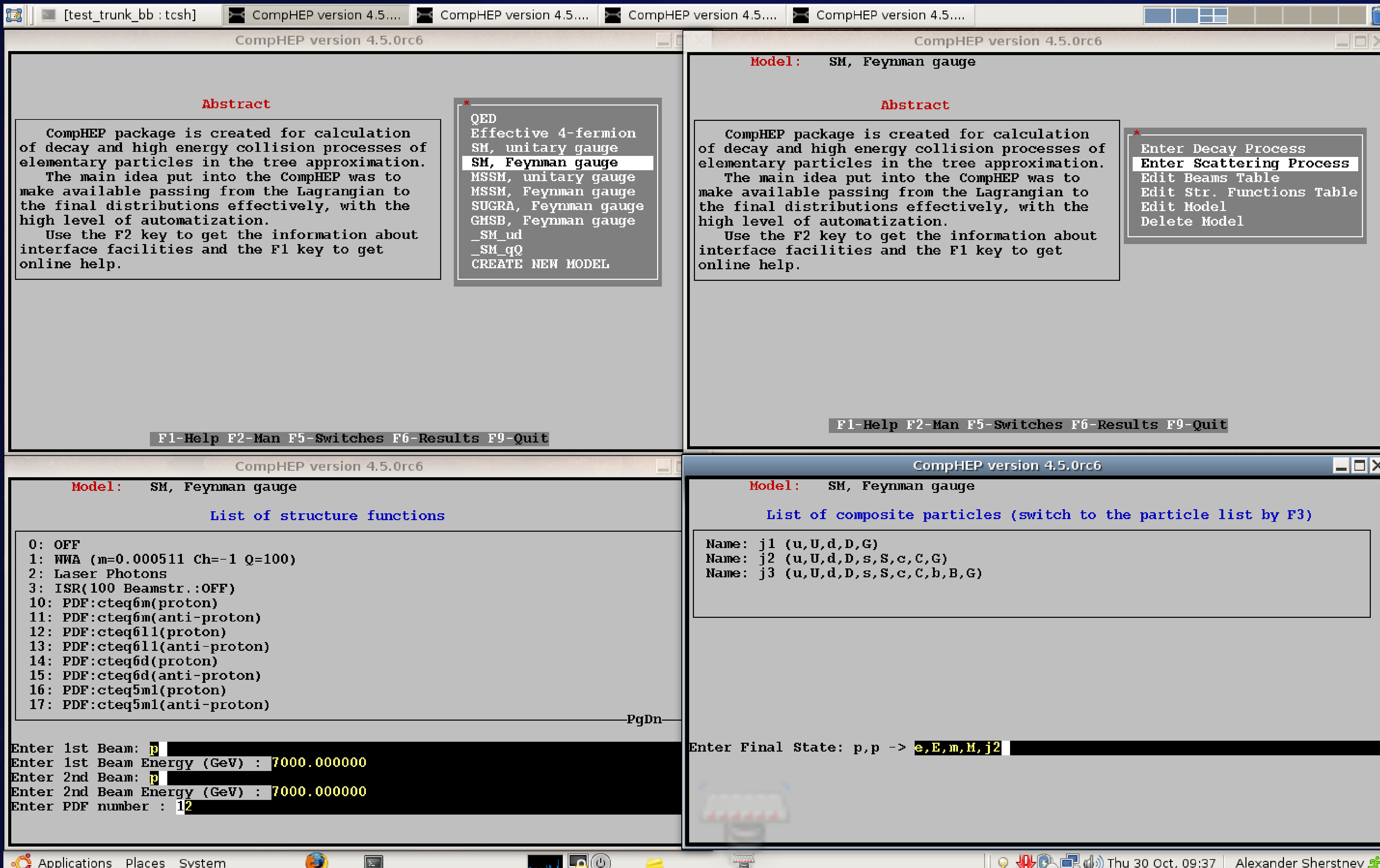
New (user-defined) Models

- Simple way (if your model is relatively simple): add new particles/params/vertices
- For more complicated models: **LanHEP** – a program for generation of Feynman rules for user-defined model (**developed by A.Semenov**)
  - Works with super-multiplets and superpotential
  - Generates all needed files for CompHEP (also FeynArts and LaTeX format)
  - Several options for self-checking (charge conservation, BRST invariance, etc.)
  - Has been used for CompHEP SUSY models and many other BSM models

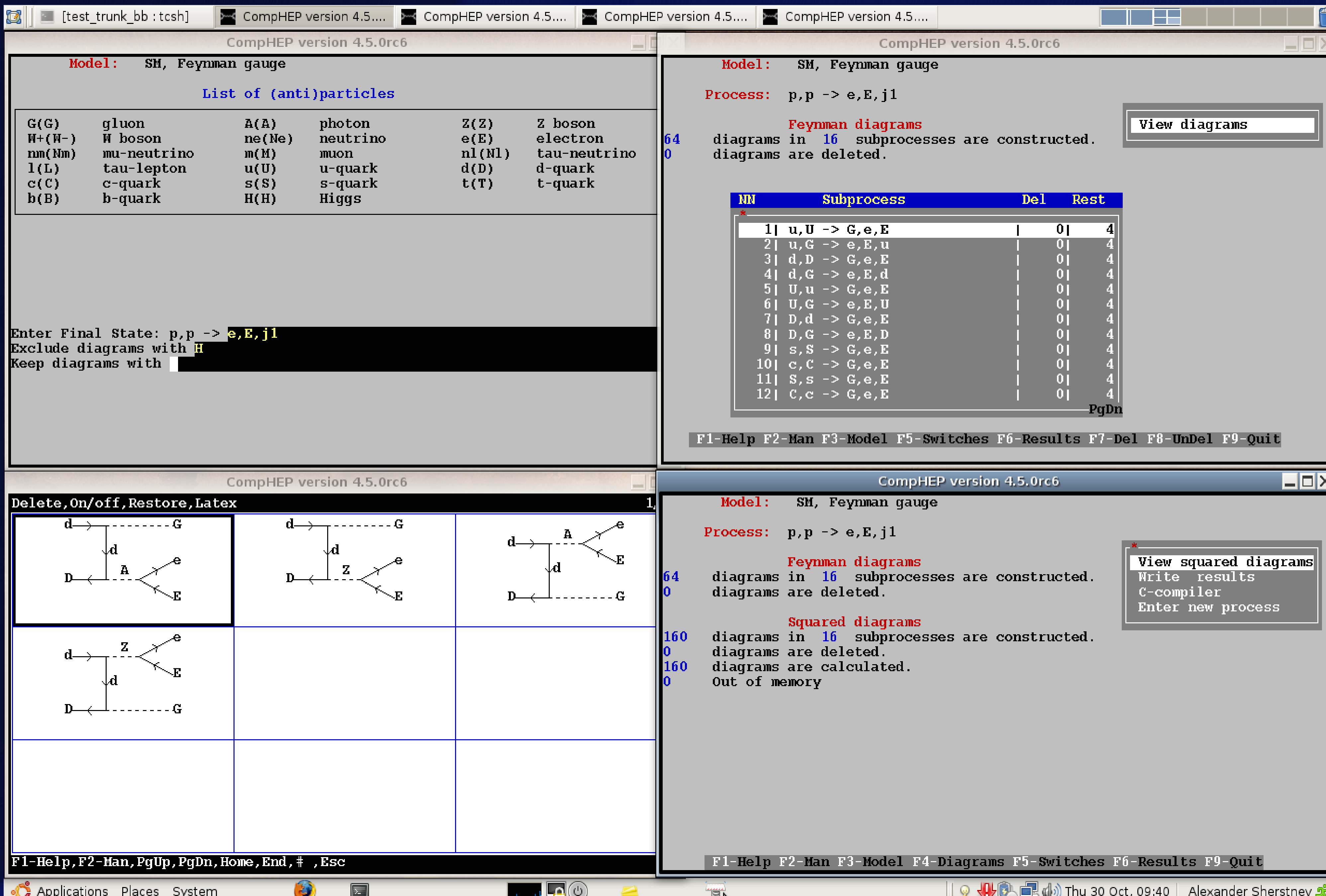
CompHEP BSM Lagrangians

- Complete Leptoquark model. Includes Yukawa couplings for all types of LQ, gauge couplings and anomalous gauge couplings for vector LQ (by request)
- Top quark Lagrangian with anomalous couplings as follows from the dimension 6 effective operators (by request)
- Excited fermion Model (by request)
- Complete two-Higgs-doublet Model with conserved or broken CP invariance (by request)
- RS1 model and effective 4 particle Lagrangian for RS below KK threshold
- UED model (Matchev et al.)
- Minimal Higgsless Model (Chivukula et al.)
- Exotics: Muonic photon; para-photon; E6 isosinglet quark; Z’, W’ bosons; doubly charged Higgs, color octet pseudoscalars, Inert Douplet Model, etc.

Symbolic calculations



Symbolic calculations (2)

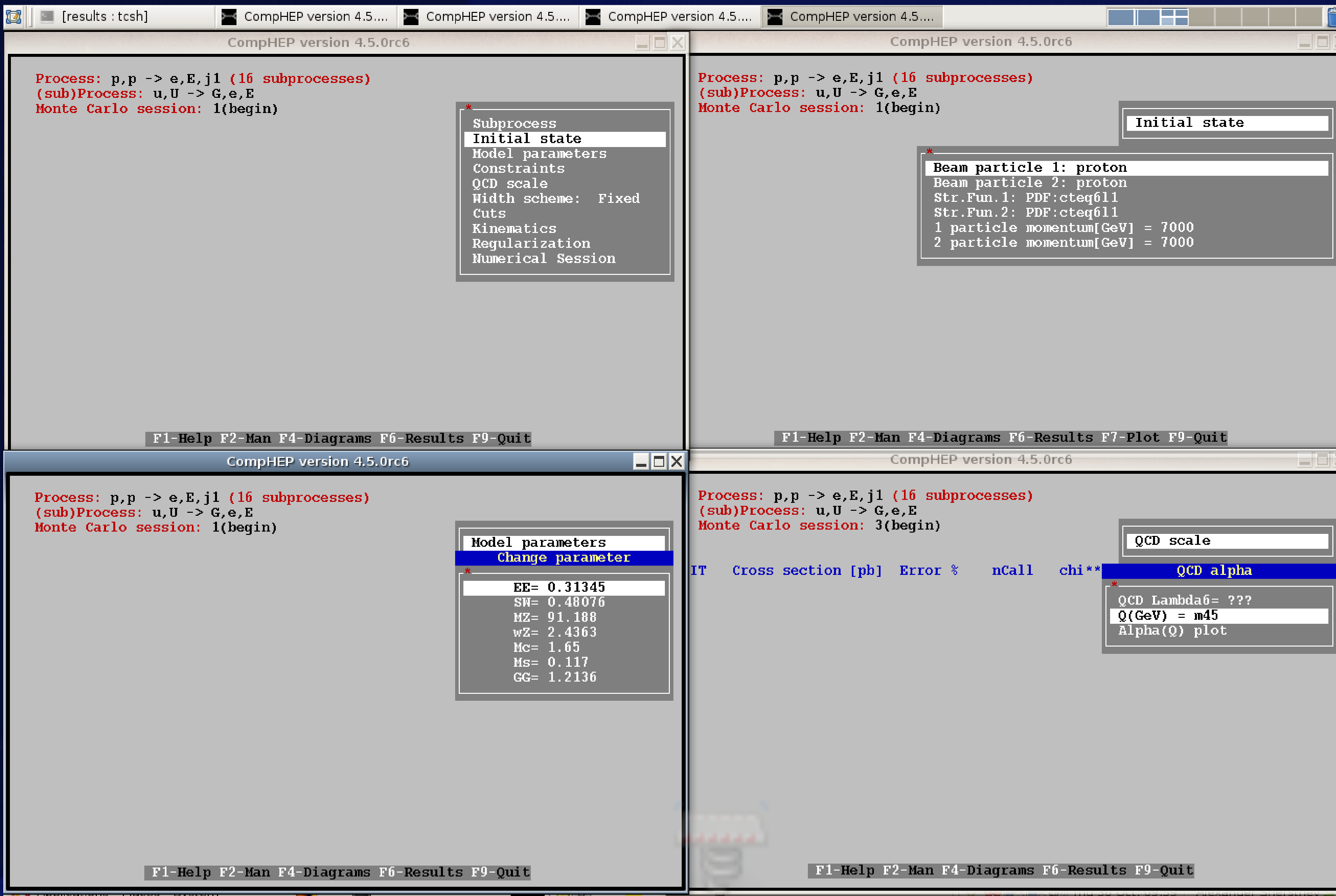


Numerical calculations

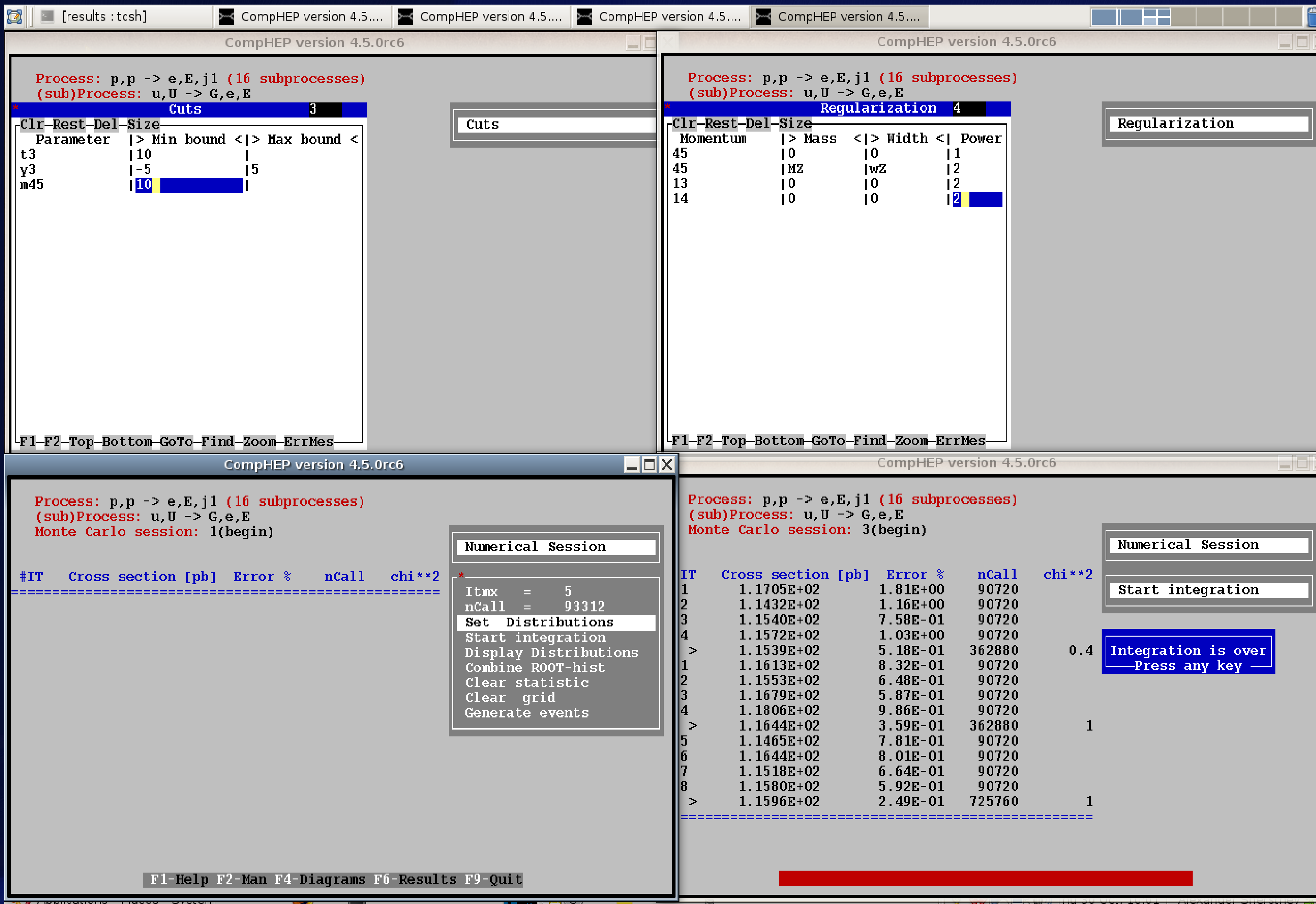
- **Customize numerical MC generator:** The most complicated part: do proper phase space sampling (regularizations + kinematics), set necessary kinematic cuts, Q^2, PDF set, etc. Main goals – to improve efficiency of MC calculation and describe physics task. User may change model parameters and set kinematic cuts
- **Calculate full cross section and distributions:** CompHEP uses an improved version of the adaptive VEGAS algorithm for MC calculations. User may order different variables (P_T, inv. mass, rapidity, etc.) for histogramming
- **Generate events:** As soon as CompHEP customized, events can be generated for the subprocess. User set a number of the events They are kept to text files.

If the process consists of some subprocesses, the procedure is applied to the each subprocess.

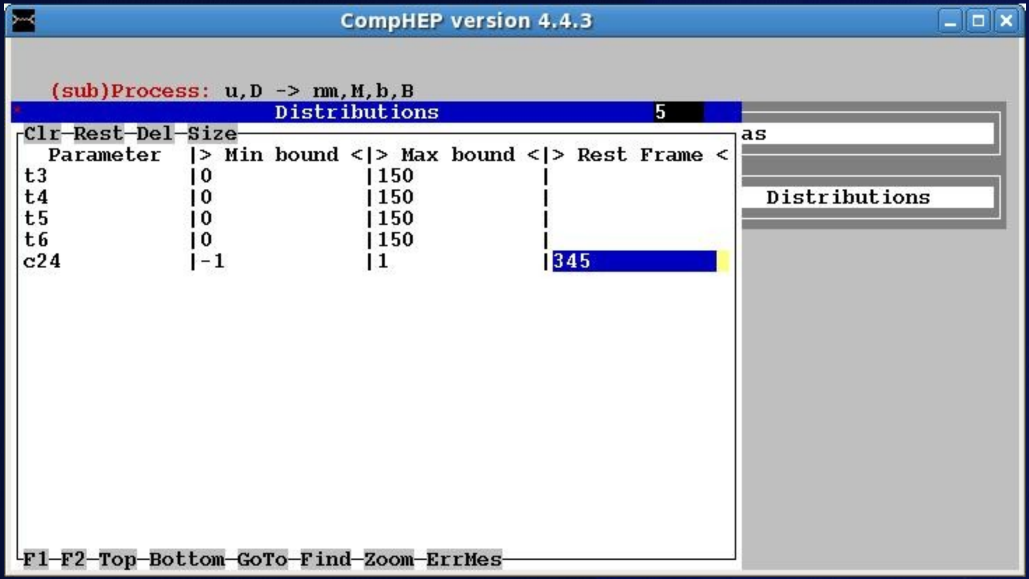
Numerical calculations (2)



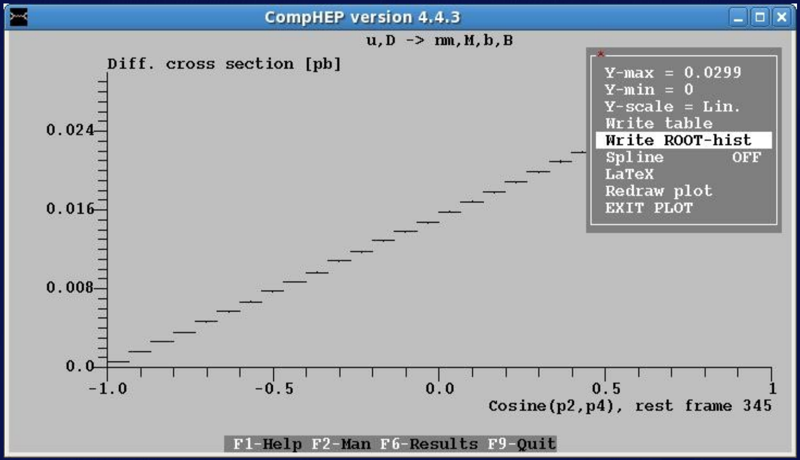
Numerical calculations (3)

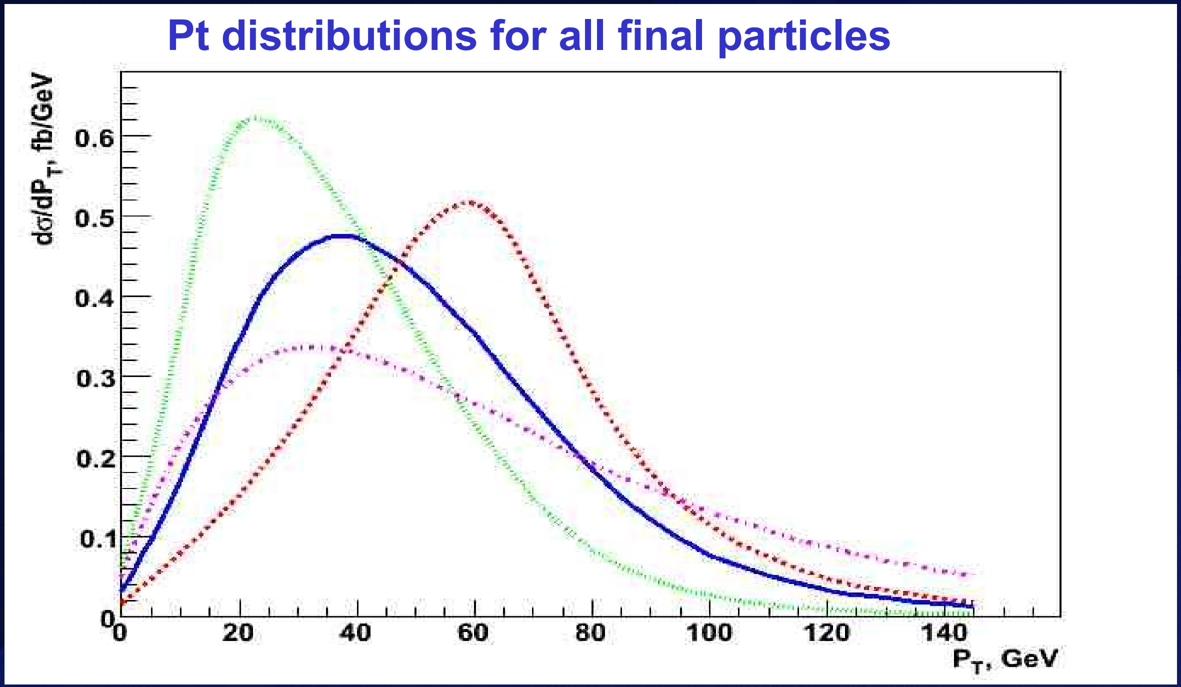


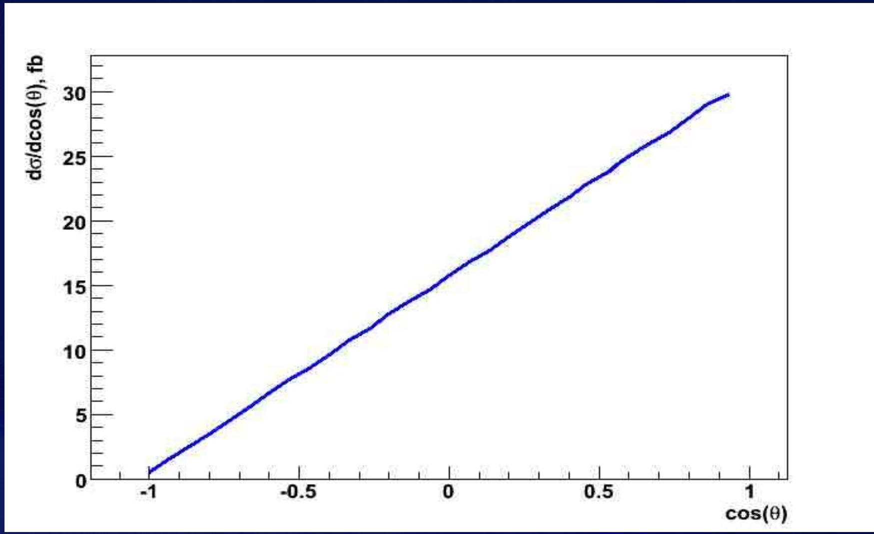
Distributions in CompHEP (ROOT interface)



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



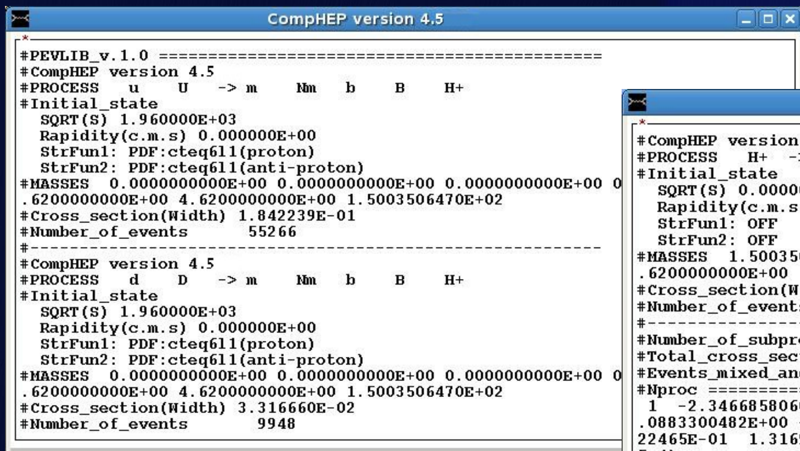




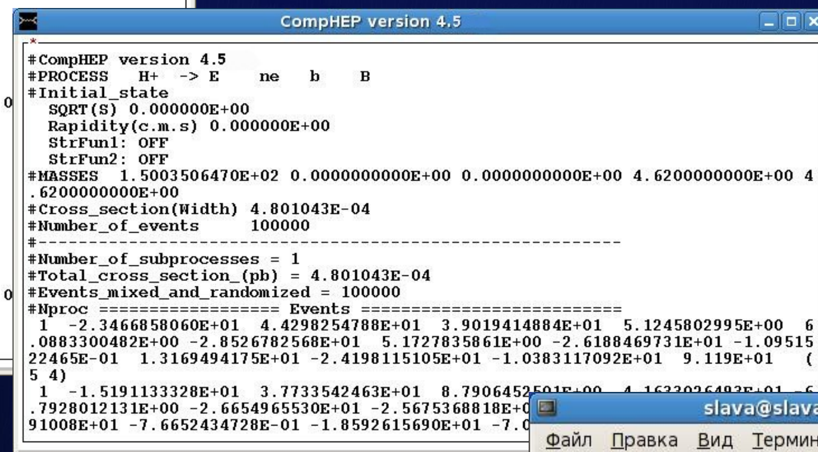
In "vegas" integration menu new submenu "combine histograms" for superimposing ROOT-histograms

Simulation of cascade decay in CompHEP

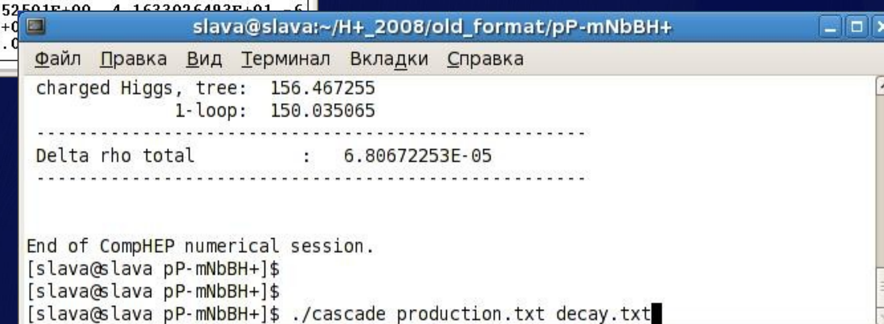
1. Generate production events



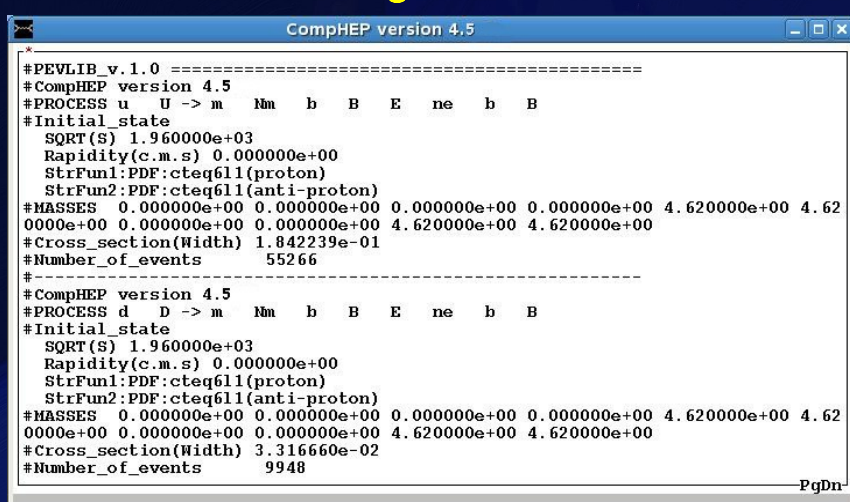
2. Generate decay events



3. Run command “cascade”



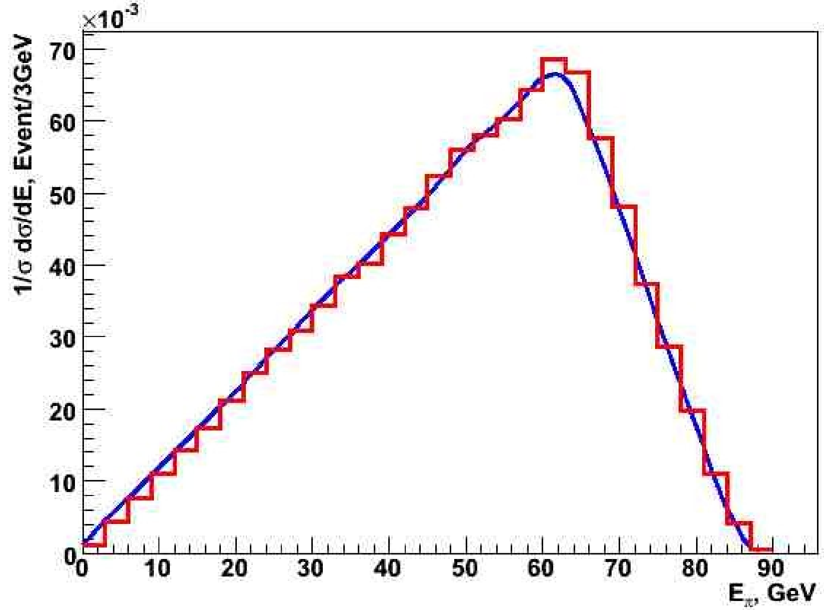
File with glued events



Cascade processes with scalar

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

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



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.

Batch system in CompHEP

Both symbolic & numerical parts have batch scripts:
Perl scripts: symb_batch.pl and num_batch.pl

Why the scripts are useful?

- Computations of many subprocesses – laborious task, can be significantly simplified especially for hadron colliders
- **Long/large-scale calculations:** GUI is not too handy
- **Support of parallel calculations**: very helpful for multi-CPU machines/computer clusters (pbs/lsf is available; grid in progress)
- **"Knowledge transfer":** theorists/phenomenoligists can prepare model/process.dat/batch.dat for further simulations by experimentalists

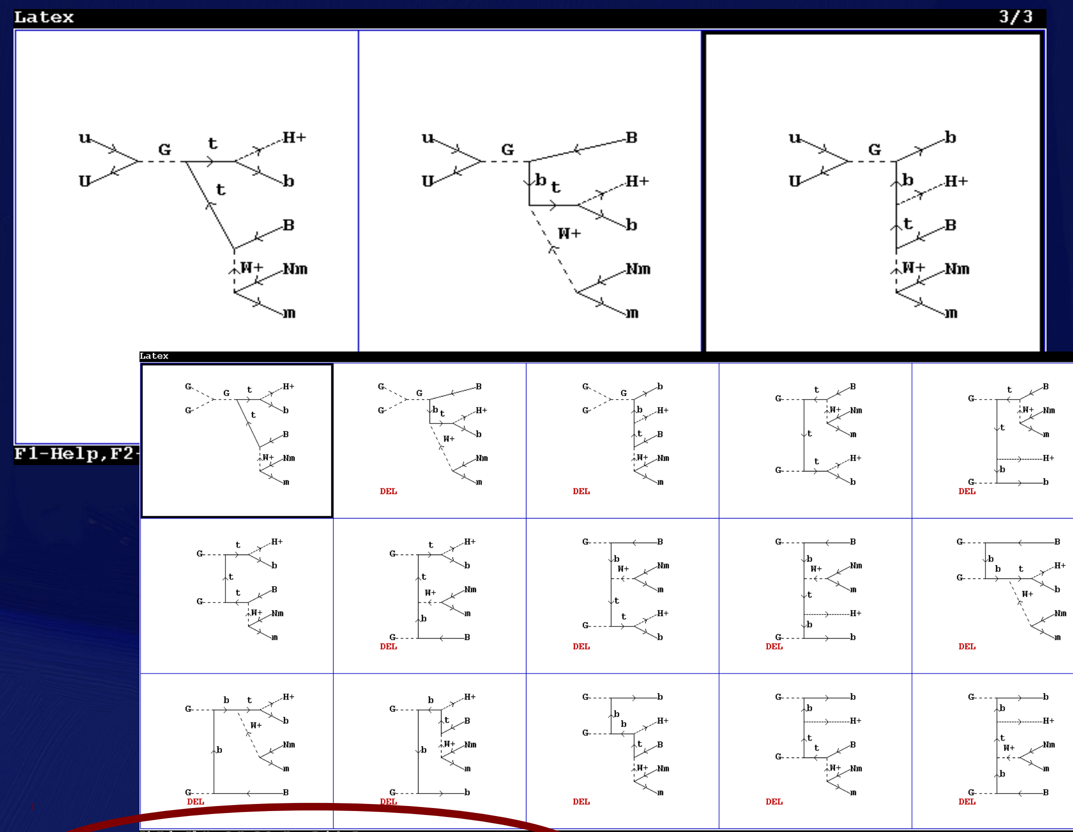
Symbolical batch: pp->m,Nm,b,B,H+ with t->b,H+ and T->m,Nm,B MSSM, tb=0.5, MH+=150GeV (H+->t*b->2f+bB dominates)

- 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 r
#  in the CompHEP model menu in the GUI mode.
model number: 6

#  Beam names 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 t
#  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
```

Les Houches Agreements

LHEF, LHAPDF, SUSY LHA, BSM LHA

- **LHA I** is implemented in CompHEP-Interfaces
- **LHEF** - the format adopted by many developer groups (hep-ph/060917). Now CompHEP supports 3 event formats: cpyth-1, cpyth-2 (for experiments, where the formats are used), and 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. By default, the slhaScript file invokes SUSPECT
- **BSM LHA** is still being implemented

HepML

- Unified XML format of MC event files metadata
  - to keep comprehensive information on event
  - to store generator input parameters and setup
  - an effort to fix a unified extensible way of MC events description
  - the LHEF standard permits XML code in event file headers
- Main purposes:
  - to unify MC event files description (parton and particle levels of MC simulation)
  - to facilitate passing information from Matrix Element generators to Shower generators
  - to simplify MC generators tuning and testing
- Contributors
  - CEDAR http://www.cedar.ac.uk
  - LCG MCDB http://mcdb.cern.ch
- Homepage https://twiki.cern.ch/twiki/bin/view/Main/HepML

CompHEP can generate HepML code!

CompHEP-interfaces package

The CompHEP-Interfaces includes two interfaces for PYTHIA and HERWIG, These interfaces allow us to use processes computed by CompHEP as external processes in PYTHIA/HERWIG

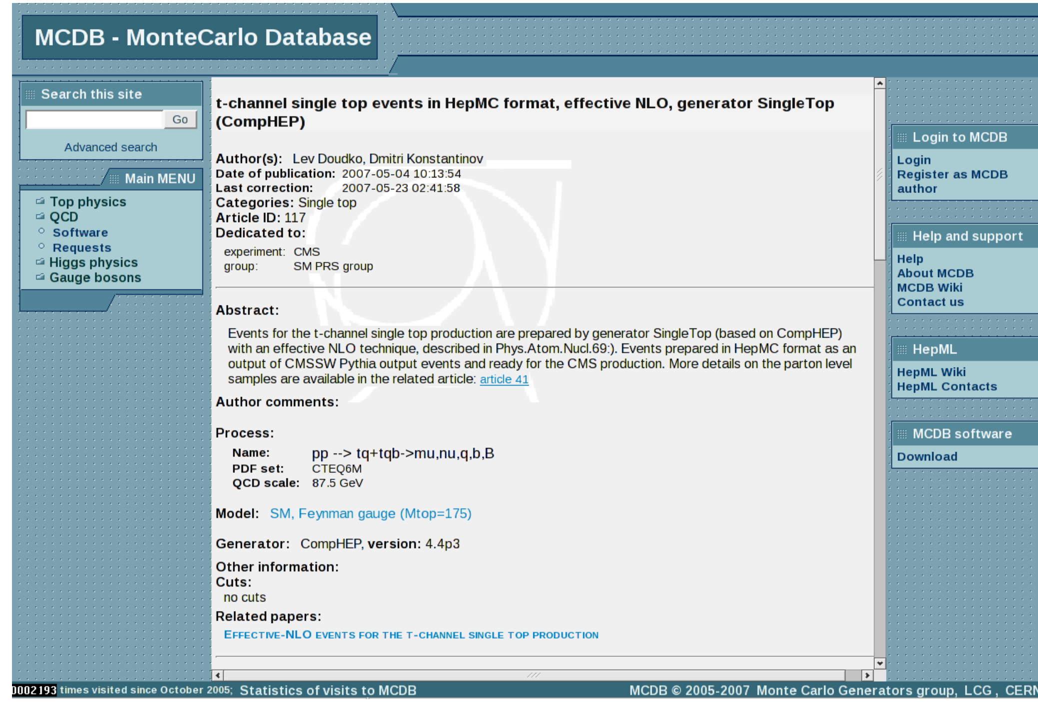
Main goal: provide ISR/FSR, hadronization (jet fragmentation), and decays as it is done in PYTHIA/HERWIG

- CompHEP generates unweighted events (event files)
- The command *mix_flows* mixes several event files in one event file
- Some governing parameters (Event file name, the number of events and first event) are kept in the file **INPARM.DAT**
- A matching code for ME events and showers in PYTHIA are being developed in the package
- Simple routines for toy analysis are provided
- Program to translate data to ROOT file (record looks like LHA I)
- TAOLA interface available (by request)

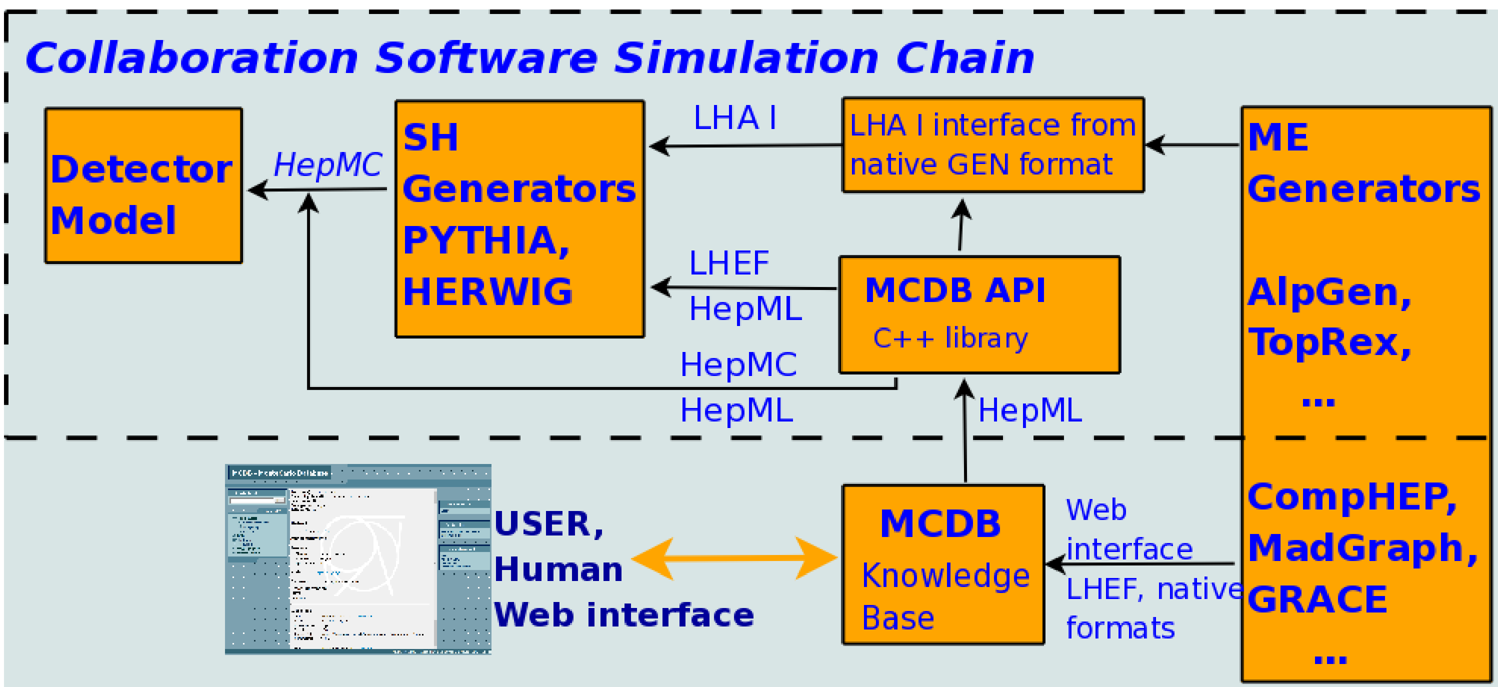
MCDB — Knowledge Base

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

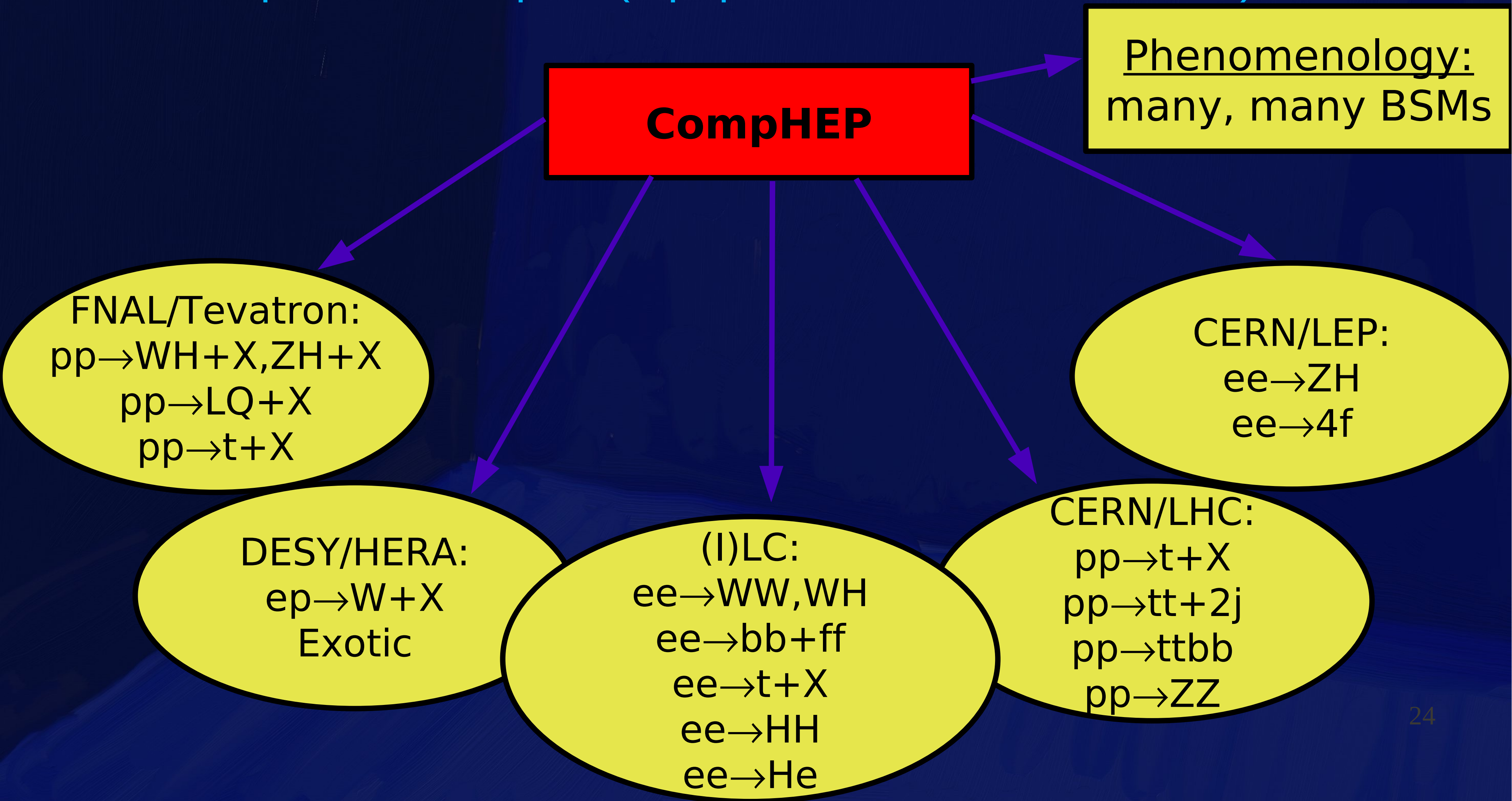


S.Belov, L.Dudko, A.Sherstnev et. al CPC178,222(2008)

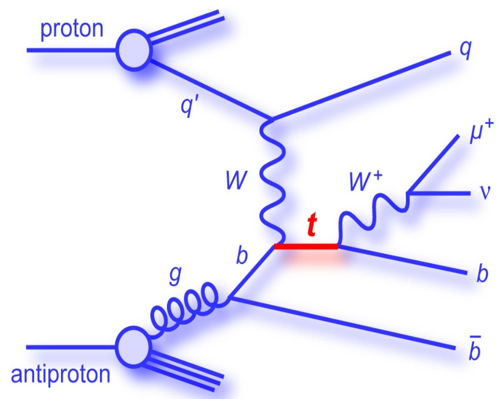


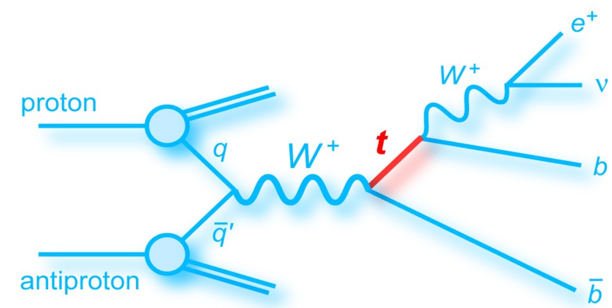
CompHEP
(Computation in High Energy Physics)

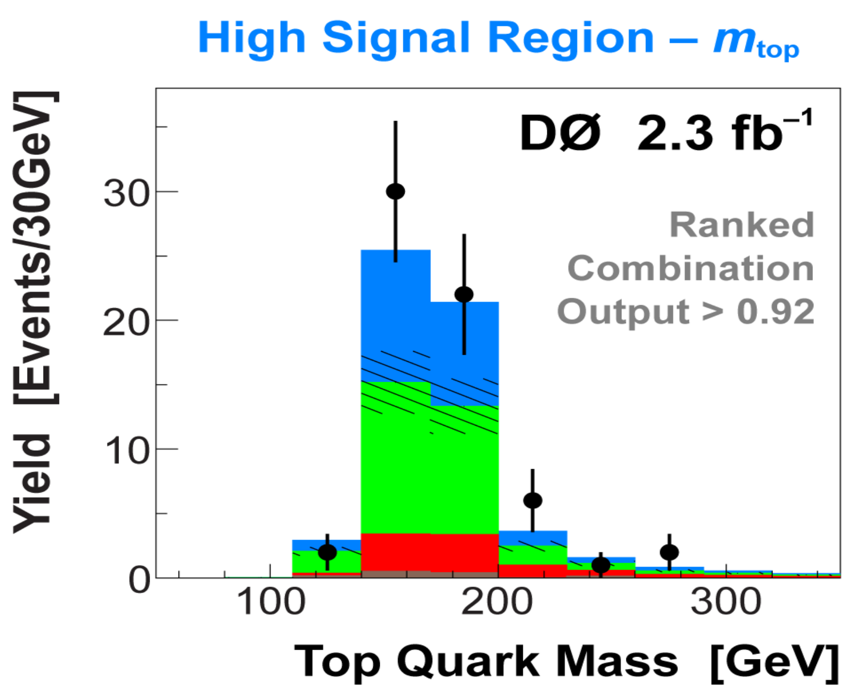
Incomplete list of processes simulated with
CompHEP in the past (3 papers have ~1000 citations):

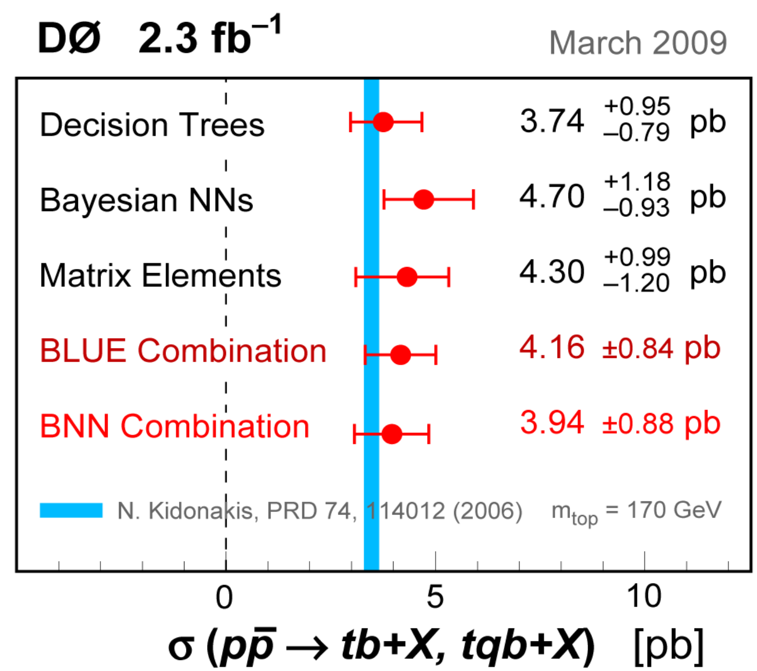


Observation of Single Top Quark Production









D0 Collaboration (V.M. Abazov *et al.*). **Phys.Rev.Lett.103:092001,2009**.

Search for anomalous top quark couplings with the D0 detector

vector left and right couplings

$$\mathcal{L}_{tbW} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b}\,\gamma^\mu \left(f_1^L P_L + f_1^R P_R\right) t - \frac{g}{\sqrt{2} M_W} \partial_\nu W_\mu^- \bar{b}\,\sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R\right) t \quad + \; h.c.$$

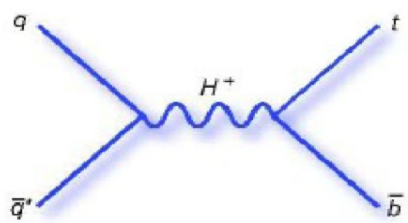
tenzor left and right couplings

$$P_{L,R} = 1/2 \cdot (1 \mp \gamma_5) \quad , \quad \sigma^{\mu\nu} = i/2 [\gamma^\mu, \gamma^\nu]$$

Scenario	Coupling	Coupling limit if $f_1^L = 1$
(L_1, R_1)	$\lvert f_1^L \rvert^2 = 1.27^{+0.57}_{-0.48}$	
	$\lvert f_1^R \rvert^2 < 0.95$	$\lvert f_1^R \rvert^2 < 1.01$
(L_1, L_2)	$\lvert f_1^L \rvert^2 = 1.27^{+0.60}_{-0.48}$	
	$\lvert f_2^L \rvert^2 < 0.32$	$\lvert f_2^L \rvert^2 < 0.28$
(L_1, R_2)	$\lvert f_1^L \rvert^2 = 1.04^{+0.55}_{-0.49}$	
	$\lvert f_2^R \rvert^2 < 0.23$	$\lvert f_2^R \rvert^2 < 0.23$

D0 Collaboration (V.M. Abazov *et al.*). **Phys.Rev.Lett.102:092002,2009**.

Search for charged Higgs bosons decaying to the top and botom quarks in p anti-p collisions

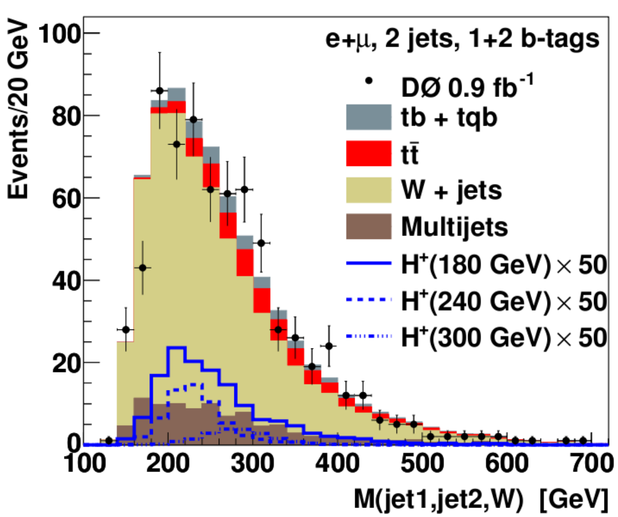


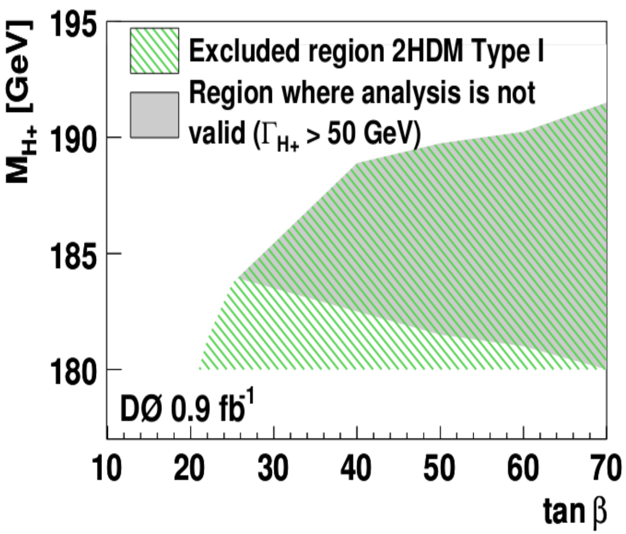
- General interaction of charged scalar to fermions:

$$\mathcal{L} = \frac{g_w V_{q_i q_j}}{2\sqrt{2}} H^+ \overline{q}_i \left(a^L_{q_i q_j}(1-\gamma^5) + a^R_{q_i q_j}(1+\gamma^5)\right) q_j + \text{H.c.}$$

- Squared ME for $u\bar{d} \rightarrow t\bar{b}$

$$|M|^2 = g_w^4 V_{tb}^2 V_{ud}^2 ({a^L_{ud}}^2 + {a^R_{ud}}^2) \left[\frac{({a^L_{tb}}^2 + {a^R_{tb}}^2)(p_u p_d)(p_t p_b) - 2M_t M_b a^L_{tb} a^R_{tb} (p_u p_d)}{(\hat{s} - M_{H+}^2)^2 + \Gamma_{H+}^2 M_{H+}^2} \right]$$



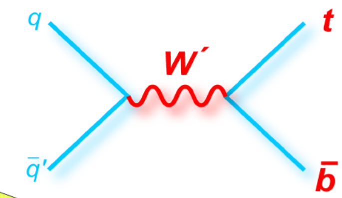


D0 Collaboration (V.M. Abazov et al.) Phys.Rev.Lett.102:191802,2009.

Search for W-prime Boson Resonances Decaying to a Top Quark and a Bottom Quark.

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

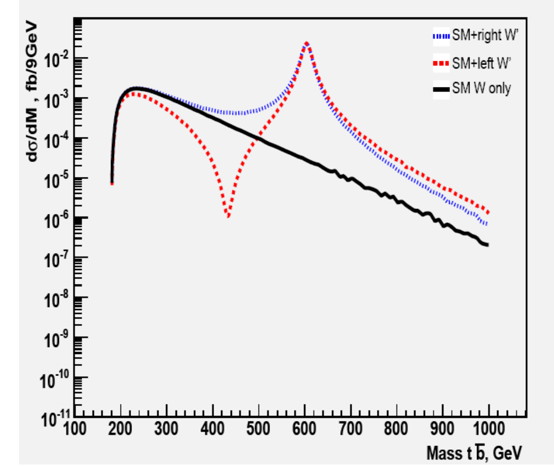
$a^R_{q_iq_j}, a^L_{q_iq_j}$ - *left and right couplings of W' to fermions*



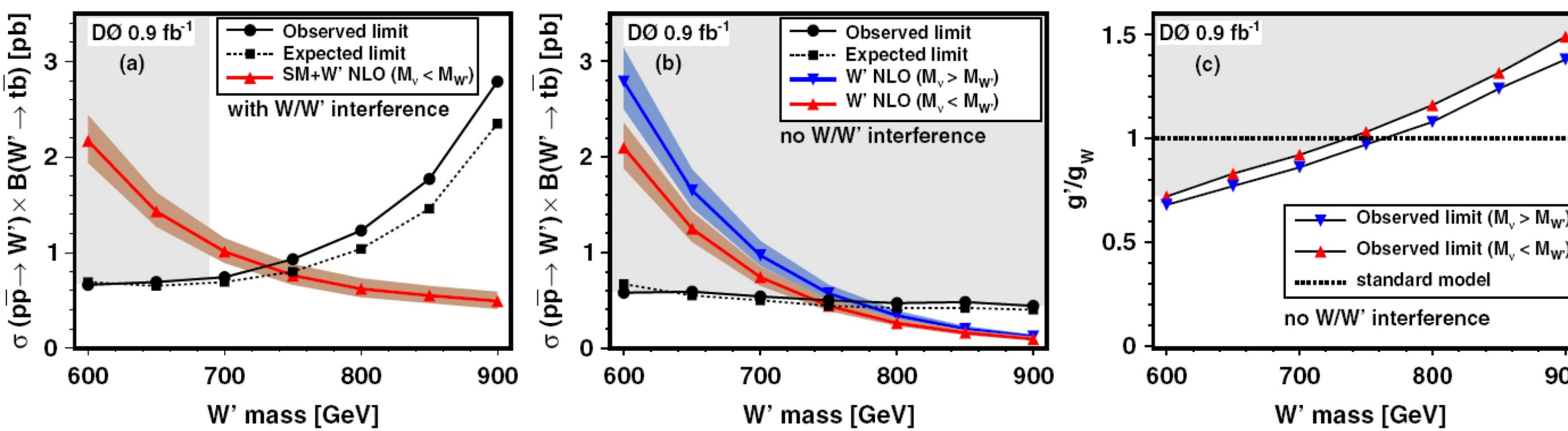
$$|M|^2 = SM + 2\cdot a^L_{ud}\cdot a^L_{tb}$$ Interference of W and W' $+$

$$+ [(a^L_{ud})^2(a^L_{tb})^2+(a^R_{ud})^2(a^R_{tb})^2]\; W' + [(a^L_{ud})^2(a^R_{tb})^2+(a^R_{ud})^2(a^L_{tb})^2]\; W'$$

Destructive interference



W'→tb D0 results 0.9 fb^{-1}



D0 Collaboration (V.M. Abazov et al.). Phys. Rev. Lett. 100, 211803 (2008)

Search for production of single top quarks via flavor-changing neutral currents at the Tevatron.

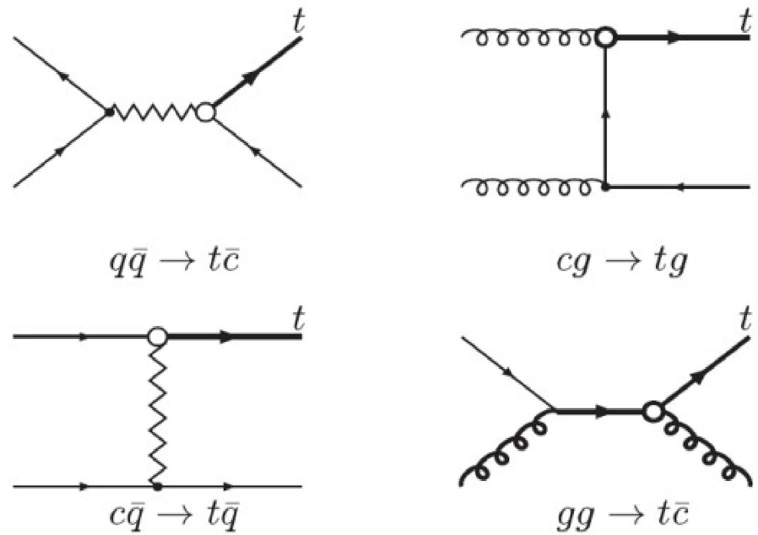
$$\frac{\kappa_f}{\Lambda} g_s \bar{f} \sigma^{\mu\nu} \frac{\lambda^a}{2} t G^a_{\mu\nu} + h.c.$$

f: *u*-quark, or *c*-quark

G: gauge field tensor of gluon

κ_f: strength of $\bar{t}ug$ or $\bar{t}cg$ couplings

Λ: scale of new physics



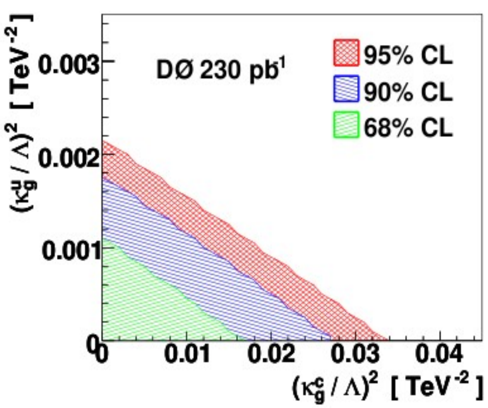


FIG. 2: Exclusion contours at various levels of confidence using 230 pb^{-1} of D0 data in both the electron and muon channels (color online).

TABLE V: Upper limits on κ_g^c/Λ and κ_g^u/Λ, at 95% C.L.

	Observed (expected) limits [TeV^{-1}]	
	κ_g^c/Λ	κ_g^u/Λ
Electron channel	0.16 (0.19)	0.046 (0.052)
Muon channel	0.21 (0.21)	0.049 (0.050)
Combined	**0.15 (0.16)**	**0.037 (0.041)**

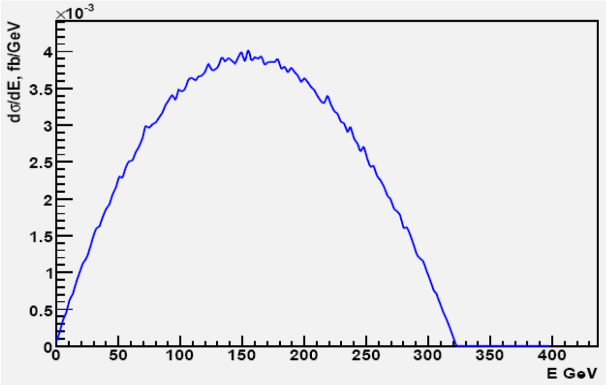
D0 Collaboration (V.M. Abazov et al.) Phys.Rev.Lett.99:191802,2007

Prospects of a Search for a New Massless Neutral Gauge Boson at the ILC

$$\frac{1}{M^2} P_{\mu\nu} \left(\bar{q}_L \sigma^{\mu\nu} C_u \tilde{H} u_R + \bar{q}_L \sigma^{\mu\nu} C_d H d_R + \bar{l}_L \sigma^{\mu\nu} C_e H e_R + h.c \right)$$

The Feynman rules for the fermion-fermion-γ' vertices $\frac{c_f}{M^2} \cdot m_f \cdot p_\nu^{\gamma'} (\gamma^\nu \gamma^\mu - \gamma^\mu \gamma^\nu)$

The signal reaction $e^+e^- \to t\ \bar{t}\ \gamma'$



γ ′ energy distribution

Background $e^+e^- \longrightarrow t\bar{t}\gamma$ $e^+e^- \longrightarrow t\bar{t}\nu\bar{\nu}$

Experimental limits for the paraphoton coupling parameter at 95% CL that may be reached at the ILC

ILC (√s=0.5 TэВ, L = 500 fb⁻¹): $\frac{M}{\sqrt{c_t}} = 0.33$ *ILC (√s=1 TэВ L = 1000 fb⁻¹):* $\frac{M}{\sqrt{c_t}} = 0.61$

E. Boos, V. Bunichev,, H.J. Schreiber, Phys.Rev.D78:015007,2008

Prospects of mass measurements for neutral MSSM Higgs bosons in the intense-coupling regime at a linear collider.

$\tan\beta=\upsilon_1/\upsilon_2>10$, $M_h \sim M_A \sim M_H \sim 100\text{-}140$ GeV.

Mass measurements for CP–even h and H: $e^+e^- \to Z^0, h/H \to l^+l^-b\bar{b}$

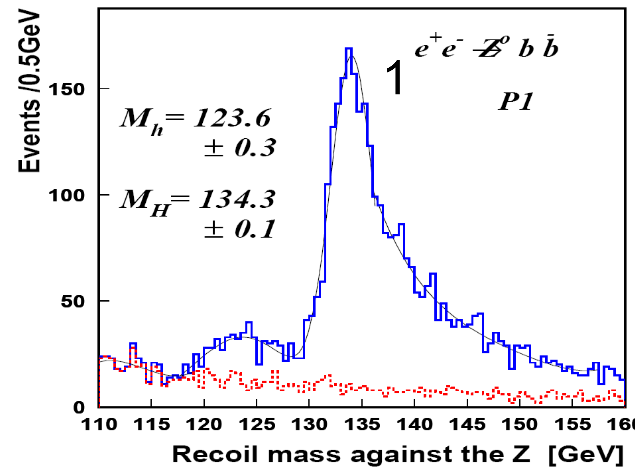
recoil mass method:

$$M_{h/H} = \hat{s} - 2\sqrt{\hat{s}}E_{Z^0} + M_{Z^0},$$

$$E_{Z^0} = E_{l^+} + E_{l^-}$$

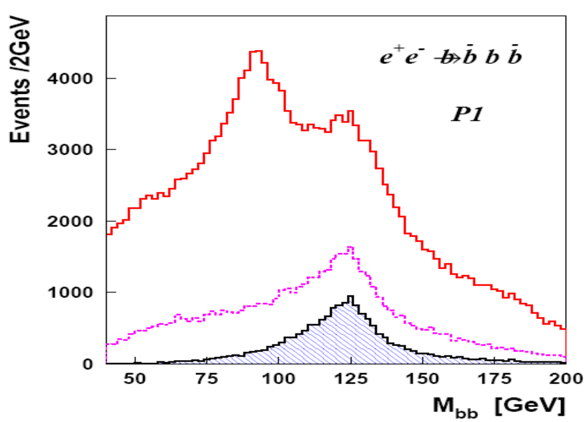
Accuracy of h and H mass measurement:

~100-300 МэВ

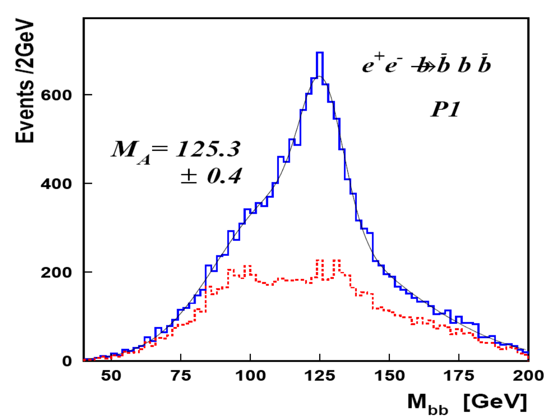


Mass measurements for CP–odd A: $e^+e^- \to A + h/H \to b\bar{b}b\bar{b}$

Combinatorial bkgr.



Combinatorial mass-difference algorithm



accuracy of A mass measurement:

~300-500 MeV

E. Boos, V. Bunichev, A. Djouadi , H.J. Schreiber, Phys.Lett.B622:311-319,2005

Impact of tau polarization on the study of the MSSM charged Higgs bosons in top quark decays at the ILC

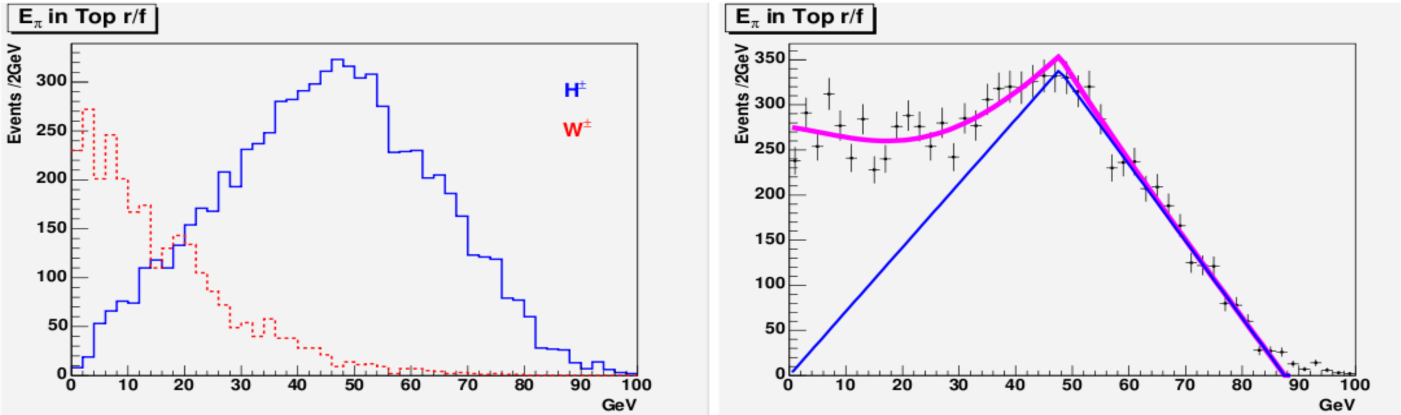
$$p\bar{p} \quad \rightarrow \quad t\bar{t} \quad \rightarrow \quad H^+bW^-\bar{b}$$

τ-lepton polarization in decay: $H^+ \rightarrow \tau^+\nu, \quad \tau^+ \rightarrow \pi^+\bar{\nu}$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dy_\pi} = \frac{1}{x_{max}-x_{min}}\begin{cases} (1-P_\tau)log\frac{x_{max}}{x_{min}} + 2P_\tau y_\pi(\frac{1}{x_{min}} - \frac{1}{x_{max}}), & 0 < y_\pi < x_{min} \\ (1-P_\tau)log\frac{x_{max}}{y_\pi} + 2P_\tau(1 - \frac{y_\pi}{x_{max}}), & x_{min} < y_\pi \end{cases}$$

where $y_\pi = \frac{2E_\pi^{top}}{M_{top}}$, $x_{min} = \frac{2E_\tau^{min}}{M_{top}}$, $x_{max} = \frac{2E_\tau^{max}}{M_{top}}$, $E_\tau^{min} = \frac{M_R^2}{2M_{top}}$, $E_\tau^{max} = \frac{M_{top}}{2}$.

For the W boson, $P_\tau = -1$, and for the charged Higgs boson, $P_\tau = 1$.



fit of the shape of the pion energy spectrum yields the charged Higgs boson mass with an accuracy of about 1 GeV

Generated $\pi^\pm$ energy spectra (left plots) and the fit (right plots)

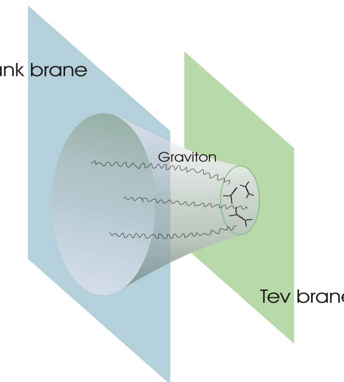
E. Boos, V. Bunichev, M.S. Carena, C.E.M. Wagner, LCWS-2005-0213, Jul 2005. 6pp, hep-ph/0507100

Testing extra dimensions below the production threshold of Kaluza-Klein excitations.

Effective contact interraction KK gravitons and SM fields

$$L_{eff} = \left(\frac{0.91}{\Lambda_\pi^2 m_1^2} \right) T^{\mu\nu} \cdot \Delta_{\mu\nu,\rho\sigma} \cdot T^{\rho\sigma},$$

$$\Delta_{\mu\nu,\rho\sigma} = \tfrac{1}{2}\eta_{\mu\rho}\eta_{\nu\sigma} + \tfrac{1}{2}\eta_{\eta\sigma}\eta_{\nu\rho} - (\tfrac{1}{3} - \tfrac{\delta}{2})\eta_{\eta\nu}\eta_{\rho\sigma}$$



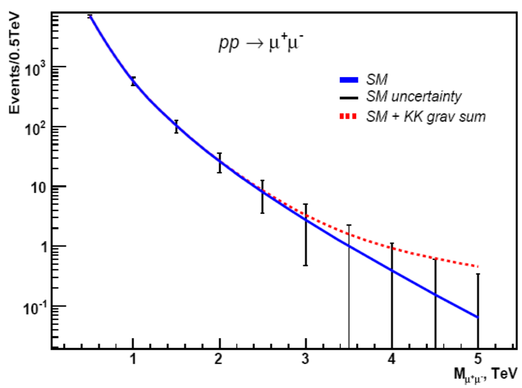
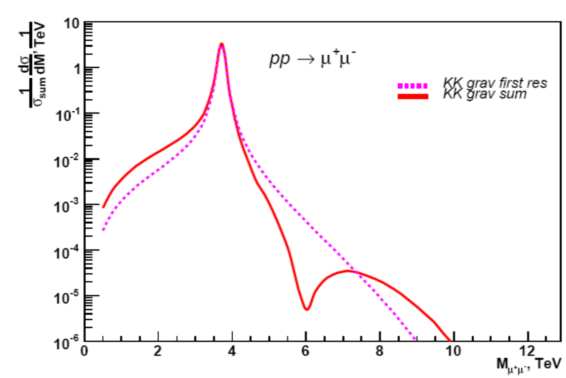


Table 1: Experimental limits for the coupling parameter at 95% CL that may be reached at the Tevatron and the LHC using Drell-Yan process for some values of integrated luminosity L.

TEVATRON ($\sqrt{s} = 1.96\ TeV$)		LHC ($\sqrt{s} = 14\ TeV$)	
$L,\ fb^{-1}$	$\frac{0.91}{\Lambda_\pi^2 m_1^2}$ at 95% $CL,\ TeV^{-4}$	$L,\ fb^{-1}$	$\frac{0.91}{\Lambda_\pi^2 m_1^2}$ at 95% $CL,\ TeV^{-4}$
1	1.185	10	$0.238 \cdot 10^{-2}$
2	0.995	20	$0.203 \cdot 10^{-2}$
3	0.900	30	$0.184 \cdot 10^{-2}$
5	0.790	50	$0.164 \cdot 10^{-2}$
10	0.664	100	$0.140 \cdot 10^{-2}$

interference between
the first KK mode and the rest KK tower



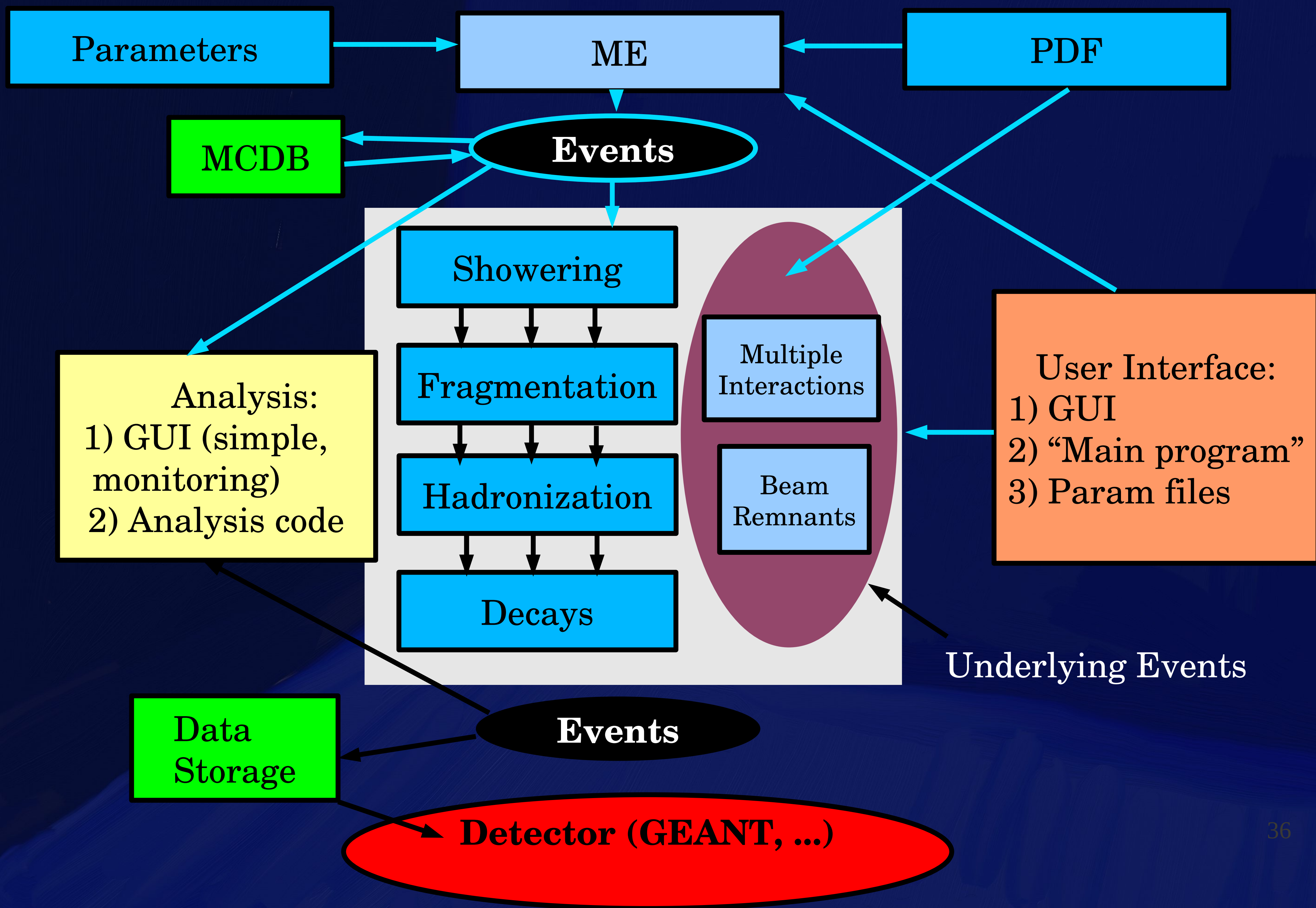
E. Boos, V. Bunichev, I. Volobuev, M. Smolyakov, Phys.Rev.D79:104013,2009.

Concluding Remarks

- CompHEP with the interface to PYTHIA/HERWIG is a powerful tool for a simulation of SM/BSM physics at hadron and lepton colliders
- CompHEP can calculate cross sections, build different distributions, and generate un-weighted events
- CompHEP is compatible with all modern “Monte-Carlo industry” standards (Les Houches Accords 1, 2, 3, LHE). The CompHEP-Interfaces can be easily used and included to experimental environments
- Parallel computations both in symbolic and numerical modules are implemented as part of batch scripts
- CompHEP is integrated in D0 Environment and used in Run I and Run II
- More information on the new features in 4.5 is in arXiv:0901.4757

Backup slides

Modern Monte-Carlo Chain



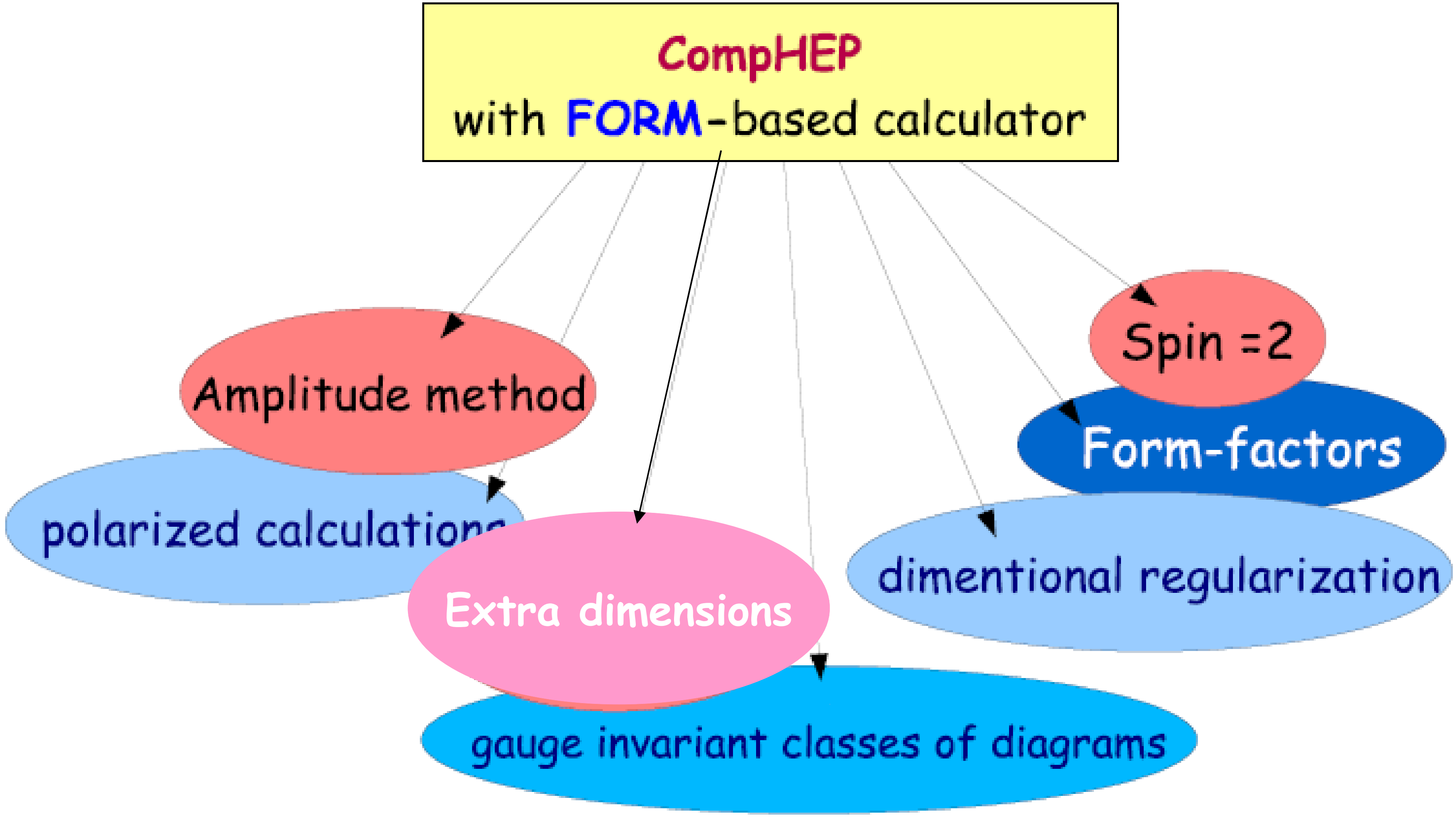
Les Houches Agreements

There are many MC generators with their own advantages and application areas. Often we are forced to use several generators for reliable calculations:

Problems:

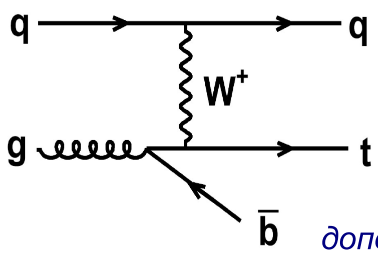
- Interfacing some MC codes (ME and SH generators): Les Houches Accord 1, Les Houches Event format
- Les Houches Accord 2: uniform interface to different PDF sets (LHAPDF package)
- Les Houches Accord 3: Interfacing SUSY codes to MC generators for parameters, spectrum, decays (SPA).
- BSM Les Houches Accord: fixing of parameter record for BSM
- Matching ME (LO/NLO) and SR(NL): CKKW, MC@NLO, Mrenna-Richardson, MLM, ...

Two symbolic passes in CompHEP: standard and FORM based



Монте-Карло генератор SingleTop.
NLO (следующее за лидирующим) приближение.

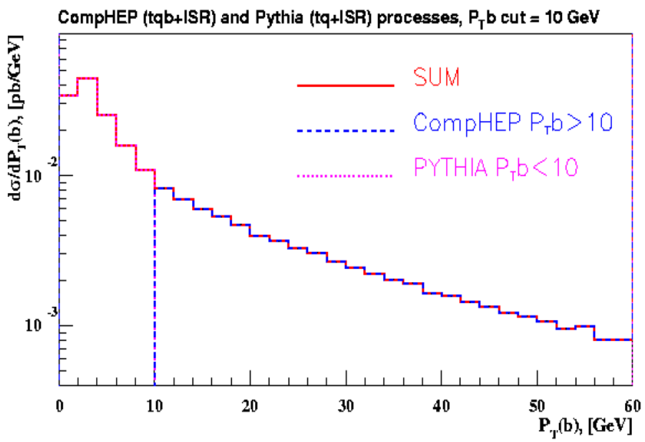
Лидирующий t-канальный процесс в NLO приближении:



дополнительный b-кварк

События с $P_T(b) < P_T^0$ *(жёсткая область) моделируются в пакете CompHEP.*
События с $P_T(b) < P_T^0$ *(мягкая область) моделируются в программе партонных ливней Pythia.*

Комбинирование событий CompHEP и Pythia:



Относительные вклады процессов из Pythia и CompHEP определяются из условий нормировки к общему NLO сечению

$$\sigma_{NLO} = K \cdot \sigma_{Pythia}\Big|_{P_T(b) < P_T^0} + \sigma_{CompHEP}\Big|_{P_T(b) > P_T^0} .$$

P_T^0 -некоторое значение поперечного импульса дополнительного b-кварка
К-фактор подбирается из условия гладкости распределения $P_T(b)$

Генератор SingleTop адекватно моделирует NLO поправки.
Благодаря корректному алгоритму нормировки сечений и сшивки фазового пространства отсутствуют события с отрицательными весами и нет двойного учёта событий

General information and references

- CompHEP collaboration: E. Boos, V. Bunichev, M. Dubinin, L. Dudko, V. Ilyin, A. Kryukov, V. Edneral, V. Savrin (Moscow State), A. Semenov (JINR, Dubna), A.S. (Moscow State and Oxford University)
- CompHEP homepage: http://comphep.sinp.msu.ru
- References:
  - CompHEP 4.5 Status Report. E.Boos et al. arXiv:0901.4757
- CompHEP: E. Boos et al., Nucl.Inst.Meth. A534:250 (2004) [hep-ph/0403123]
- LanHEP: A. Semenov, Nucl.Inst.Meth. A393:293 (1997) [hep-ph/0403123]; 0805.0555 (hep-ph)
- CompHEP-Interfaces: A.Belyaev et al., hep-ph/0101232
- MCDB/HepML: S.Belov et al. Comput.Phys.Comm. 178:222 [hep-ph/0703287]

Event generation

- Events – phase space points, distributed according to $|M|^2$
- Monte-Carlo technique
- adaptive importance sampling method VEGAS
- For event generation: + stratified sampling
- Von Neumann (rejection) sampling:
  - If g(x) – importance sampling function
  - $|M|^2 = f(x)$ – matrix element squared
  - Find $\omega_{max}(x_0) = f(x_0)/g(x_0)$ and compare $\rho=\omega(x_i)/\omega_{max}=\omega_i/\omega_{max}$ and random number R
  - If $\rho > R$ – accept the point

Iterative Rejection sampling

- Usual efficiency in CompHEP – 0.1-1%.

What can we do with “waste”?

- Repeat the von Neumann procedure with the waste – rejected events!
- But importance sampling function is unknown...
- There is a way to calculate it

$$\omega_1 = \frac{N_{rej}\,\omega_0}{N_{tot} - N_{act}\,\omega_0 / I_{tot}}$$

- We can do several iterations, but should stop at some step.
- Stopping rule: $|I_0 - I_f| \geqslant \Delta I_0 + \Delta I_f$
- Real benefit: from 20% to 1000% of extra events **without** extra calculations of $|M|^2$

more details in 0807.2823

Symbolic parallel calculations

- Main idea:
  - symbolic calculation of one diagram is an independent task. The only unified point is the final binary data file.
  - Several calculation flows can be running at one time for several sub-sets of diagrams. The final point is to collect the binary data file
- Implemented in ./symb_batch.pl with the option -mp
- 1st step!: ./symb_batch.pl –help
- Parallel calculations on one machine: -mp N means N symbolic calculations in parallel
- Batch system version (pbs/lsf) is being implemented
- Very easy to use!

Numerical parallel calculations

- Again, 1st step: ./num_batch.pl –help (long and very detailed description). The script has lots of options (~30)!
- n_comphep.exe should be prepared! Main file is batch.dat in /results (based on session.dat). It can be edited 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 calculations available. Alone machine (useful for multi-CPU desktops): -mp 3 (3 jobs are calculated simultaneously); computer clusters (with a batch system installed): -lsf and -pbs
- Many ways to present and monitor results and calculation process (see help)
- Very easy to use!

MCDB – Monte-Carlo events Data Base

Team: S.Belov, L. Dudko, A.Ribon, A.S. (JINR, MSU, CERN, Oxford)

Motivation:

- Verified MC simulation of complicated processes requires sophisticated expertise and expert knowledge
- A physics group in a collaboration requests experts and/or MC generator authors to create MC samples for the particular process
- The same physics processes are investigated by various physics groups, the same MC samples can be used in different analyses

The main motivation – to make MC event samples, prepared by experts, available for various physics groups

MCDB tasks:

- The database has to be available via the Web and Grid
- Using CASTOR/GRID technologies to keep/upload/download MC samples
- Simple and intuitive interface for events authors and end-users to find and manipulate event samples

MCDB: technical details

- Frontends: a Web site (mcdb.cern.ch) and API (via HepML) and Grid
- Backend: SQL for metadata and CASTOR for data
- Keep parton and particle level events with standard interface to the next level of simulation (PYTHIA/HERIWG, simu. software), based on LHA I
- Store detailed documentation for each set of event samples
- Provide communication between users and experts via MCDB web pages
- Direct programing interface of the collaboration software to LCG MCDB
- Divided in two zones:
  - **public area:** users can search for/browse the DB and download event files
  - **restricted area:** authors (experts) change MCDB content: upload and describe new event files, change the existed files and reply to user's comments

MCDB encourages end-users to cite event sample author's papers in case the events are used in physics analyses!

Paper: hep-ph/0703287