ALPGEN and BSM

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Outline

- ALPGEN as a tool for SM backgrounds
- General strategy for BSM processes in ALPGEN
- two examples of external processes
  - Heavy neutrino production
  - AlpOSET

Simulation of SM backgrounds

- ALPGEN is a LO matrix element event generator interfaced to Pythia and Herwig.
- At present, processes with up to 8 final state partons can be simulated with ALPGEN
- many BSM signatures involve complex final state topologies
- the efficiency in handling multi-parton matrix elements makes of ALPGEN an ideal tool for the simulation of complicated SM background processes to New Physics Models

An example: $HHjj$ production in VBF

R. Contino, C. Grojean, M. Moretti, F.P. and R. Rattazzi, work in progress

For $m_H \geq 150$ GeV an interesting signature is $3l + 4$ jets + missing p_{T}
Among the backgrounds we have:

- multi-boson + jets production ($4W + 2j, \ldots$)
- $t\bar{t}WW$
- $t\bar{t}W+$ jets
- $(Z^*/\gamma^* \to l^+l^-)W + 4$ jets

All these final states can be simulated with complete LO matrix elements in ALPGEN

Spin correlations are fully accounted for in top quark and vector boson decays whenever narrow width approximation is assumed

General strategy for BSM with ALPGEN

- modifications to the SM couplings (e.g. anomalous couplings of gauge bosons, heavy quarks) can be implemented directly without changing the general structure of the code
- the same happens for new heavy gauge bosons (Z', implemented in the next code release, W')
- more work would be needed for the implementation of more complex SM extensions implying richer particle spectra (e.g. SUSY)
  - the New Lagrangian could be implemented in the ALPHA package, which allows the numerical evaluation of scattering amplitudes in ALPGEN
  - alternatively, if you have your own matrix elements for new processes, they can be fitted into the ALPGEN generation structure, bypassing the internal procedure for matrix element calculation (next code release v2.2 will contain this flexibility)

R. Pittau, F. del Aguila and J. A. Aguilar-Saavedra

The Monte Carlo program `HvyN` allows to study heavy neutrino production processes at hadron colliders.

It can be downloaded from

`http://www.to.infn.it/ pittau/HVYN.tar.gz` or
`http://mlm.home.cern.ch/mlm/alpgen/`

and it is based on the `ALPGEN` package from which inherits the main features and the interface facilities

The code allows to study the following six processes, where an heavy Neutrino N (of Dirac or Majorana nature) is produced in association with a charged lepton or a neutrino

(1) $p\overset{(-)}{p} \to \ell_1 N \to \ell_1\, \ell_2\, W \to \ell_1\, \ell_2\, f\, \bar{f}'$
(2) $p\overset{(-)}{p} \to \ell_1 N \to \ell_1\, \nu_{\ell_2}\, Z \to \ell_1\, \nu_{\ell_2}\, f\, \bar{f}$
(3) $p\overset{(-)}{p} \to \ell_1 N \to \ell_1\, \nu_{\ell_2}\, H \to \ell_1\, \nu_{\ell_2}\, f\, \bar{f}$
(4) $p\overset{(-)}{p} \to \nu_{\ell_1} N \to \nu_{\ell_1}\, \ell_2\, W \to \nu_{\ell_1}\, \ell_2\, f\, \bar{f}'$
(5) $p\overset{(-)}{p} \to \nu_{\ell_1} N \to \nu_{\ell_1}\, \nu_{\ell_2}\, Z \to \nu_{\ell_1}\, \nu_{\ell_2}\, f\, \bar{f}$
(6) $p\overset{(-)}{p} \to \nu_{\ell_1} N \to \nu_{\ell_1}\, \nu_{\ell_2}\, H \to \nu_{\ell_1}\, \nu_{\ell_2}\, f\, \bar{f}$

The full $2 \to 4$ matrix element for the complete decay chain is implemented, so that spin correlations and finite width effects are correctly taken into account.

AlpOSET (M. Treccani)

Setup inside ALPGEN framework which allows generation and successive decay of On Shell particles with pure phase space contribution, neglecting Matrix Elements.

according to the ideas developed in N. Arkani-Hamed et al., arXiv:hep-ph/0703088

- Partonic Process with different initial states
- Pure phase space generation with threshold correction
- Mass, electric charge, color and spin (up to now, harmless)
- Decay chains with arbitrary Branching Ratios and arbitrary steps
- Up to 3 decay products for each decay step
- Interfaced with PYTHIA

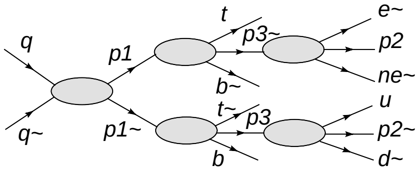
$$\Rightarrow \quad f(X) = 1 - \frac{1}{X}$$

$$X \equiv \frac{\hat{s}}{s_0}$$

Input example of a toy model

```
1
test_run
0
10000 4
90000
ih2 -1
newhardpr q_q~_p1_p1~
new1m 450
new1p 082
new2m 124
new2p 012
new3m 130
new3p 312
new1d1 b_b~_p2
new1d2 u_u~_p2
new1d3 t_b~_p3~
new1b1 0.25
new1b2 0.01
new1b3 0.74
new3d1 el~_ne~_p2
new3d2 u_d~_p2
new3b1 0.12
new3b2 0.88
ilhe 1
newME 0
```

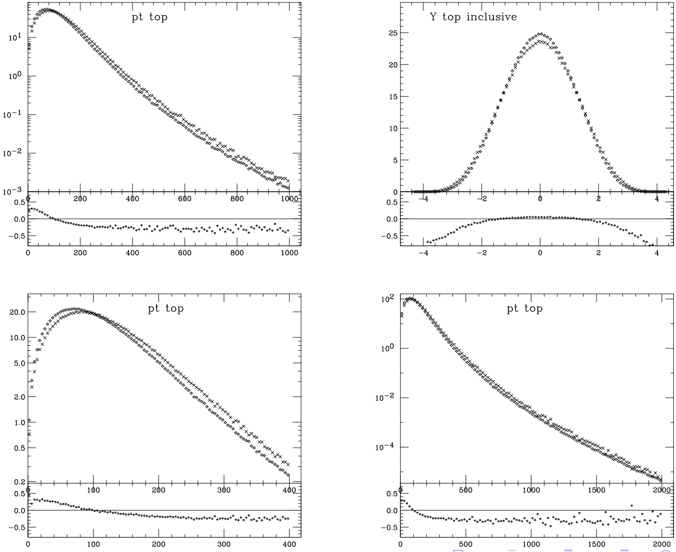
$\Longleftrightarrow$



LHC, $gg \to t\,\bar{t}$

$\times$ ME contribution

$\diamond$ AlpOSET



Good agreement

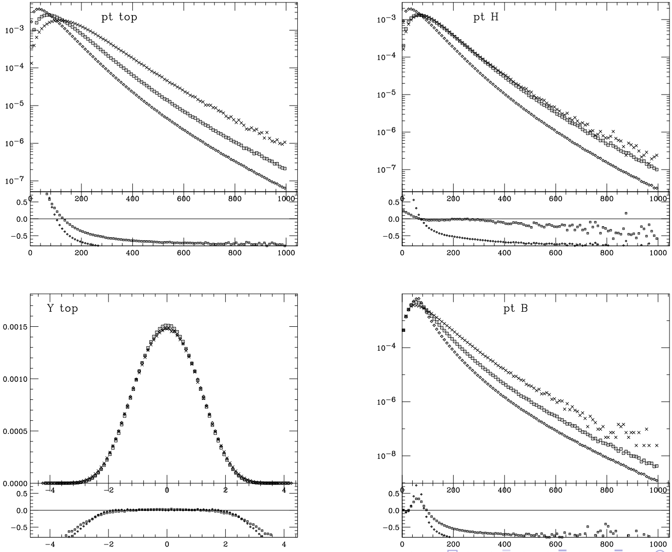
Differences $<$ 20%

LHC, $gg \to t\,\bar{t}\,H$

$\times$ ME contribution

$\diamond$ AlpOSET

$\square$ AlpOSET threshold corr.

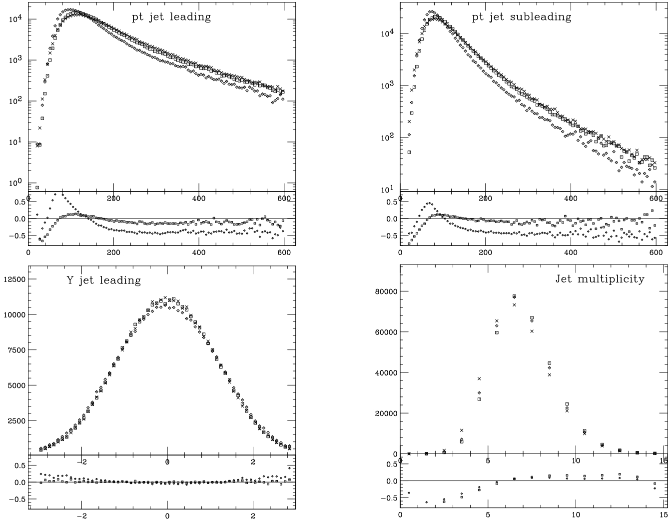


Y: good agreement

P_t: improved with threshold corr.

LHC, $gg \to t\,\bar{t}\,H$,Hadron Level

$\times$ ME contribution
$\diamond$ AlpOSET
$\square$ AlpOSET threshold corr.



$P_{T,min} = 20GeV, \Delta R = 0.7$

Y: good agreement

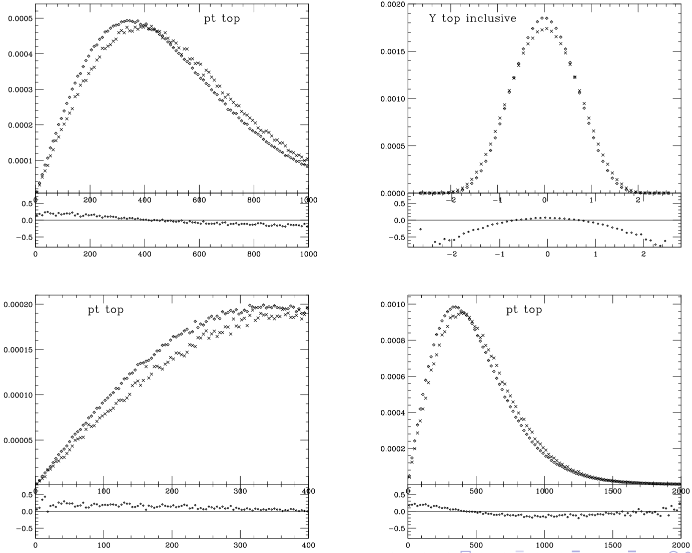
P_t: improved with threshold corr.

Better agreement

LHC, $gg \to t\,\bar{t}$ $\quad m_{top} = 992$ GeV

$\times$ ME contribution

$\diamond$ AlpOSET



Good agreement

in both P_t and Y

Summary

- ALPGEN is an ideal tool for SM background simulation to complicated final states arising in BSM scenarios

- next release will be flexible for the introduction of external BSM processes

- at present we have few working examples
  - top with generic $t - W - b$ couplings (already in v2.1x release)
  - Z'
  - Heavy neutrino production
  - AlpOSET

BACKUP SLIDES

The relevant subprocesses are

$$
\begin{aligned}
q\bar{q}' &\rightarrow W^\star \rightarrow \ell_1 N \\
q\bar{q} &\rightarrow Z^\star \rightarrow \nu_{\ell_1} N
\end{aligned}
$$

followed by the full decay chain.
The appropriate Lagrangian is

$$
\begin{aligned}
\mathcal{L}_W &= -\frac{g}{\sqrt{2}} \left(\bar{\ell}\gamma^\mu V_{\ell N} P_L N \; W_\mu + \bar{N}\gamma^\mu V_{\ell N}^* P_L \ell \; W_\mu^\dagger \right) \\
\mathcal{L}_Z &= -\frac{g}{2c_W} \left(\bar{\nu}_\ell \gamma^\mu V_{\ell N} P_L N + \bar{N}\gamma^\mu V_{\ell N}^* P_L \nu_\ell \right) Z_\mu \\
\mathcal{L}_H &= -\frac{g \, m_N}{2M_W} \left(\bar{\nu}_\ell \, V_{\ell N} P_R N + \bar{N} \, V_{\ell N}^* P_L \nu_\ell \right) H
\end{aligned}
$$

Input

Besides the usual ALPGEN's input values, the user should input the heavy neutrino mass (`mn`) and the absolute value squared of the three couplings $V_{\ell N}$ (`v21`, `v22` and `v23`), together with the minimum p_t (`ptlmin`) and the maximum value of $|\eta|$ (`etalmax`) of the charged leptons *not* coming from a decaying W, Z or H

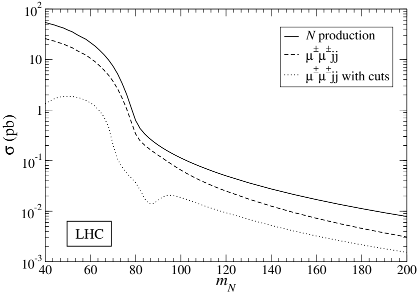
Furthermore the variable `ima` should be given the value 0(1) in case of Dirac(Majorana) heavy neutrinos

In addition, the variable `ilnv` should be set to 0(1) if a lepton number conserving(violating) process is considered (this is only relevant for process (1))

Numerical results

We introduce the following cuts to reproduce roughly the acceptance of the detector and give approximately the "effective" size of the observable signal:

$$
\begin{array}{rl}
\text{LHC}: & \begin{array}{lll} p_T^\mu \geq 10\ \text{GeV}\,, & |\eta^\mu| \leq 2.5\,, & \Delta R_{\mu j} \geq 0.4\,, \\ p_T^j \geq 10\ \text{GeV}\,, & |\eta^j| \leq 2.5\,, & \end{array} \\
\text{Tevatron}: & \begin{array}{lll} p_T^\mu \geq 10\ \text{GeV}\,, & |\eta^\mu| \leq 2\,, & \Delta R_{\mu j} \geq 0.4\,, \\ p_T^j \geq 10\ \text{GeV}\,, & |\eta^j| \leq 2.5\,, & \end{array}
\end{array}
\tag{1}
$$



Cross sections for heavy neutrino production at LHC (left) and Tevatron (right), as a function of the heavy neutrino mass, for $|V_{\mu N}| = 0.098$ and $|V_{eN}| = |V_{\tau N}| = 0$. The solid lines correspond to total μN cross section, the dashed lines include the decay to like-sign muons and the dotted lines are the same but including the kinematical cuts in Eq. (1).