MC@LHC 06 Monte Carlo tools for LHC
CERN, July 17-26 2006

TopReX

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": Monte Carlo tools for the LHC",
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recent developments

- new processes:
  - $gg\,(q\bar{q}) \to t\bar{t}\gamma$
  - FCNC $u(c)g \to t$ - "direct top", $q\bar{q} \to t\bar{c}$, $gg \to t\bar{c}$, $gq \to tg$
  - $gg \to$ Box $\to ZZ$
- "heavy particle" matching (single top, FCNC, $H^{\pm} + jet$)
- several TopReX processes can be generated simultaneously

- at present TopReX could be used :
  - ◇ as a stand-alone generator (parton level)
  - ◇ with PYTHIA for hadronization, fragmentation, decays

- TopReX provides a simulation of "external" processes with PYTHIA

$gg\,(q\bar{q}) \to t\bar{t}$	$gg\,(q\bar{q}) \to t\bar{t}\gamma$
$qb \to q't \;+\; qg \to q't\bar{b}$	$gb \to tW,\;\; q\bar{q}' \to W^* \to t\bar{b}$
FCNC	$u(c)g \to t$ - "direct top"
$q\bar{q} \to t\bar{c}$	$gg \to t\bar{c}, gq \to tg$
$q\bar{q}' \to WQ\bar{Q}$	$gg(q\bar{q}) \to ZQ\bar{Q},\;\; Q = b, c$
$gg \to \text{Box} \to ZZ$	
$q\bar{q}' \to W^{\pm *}(+jet),$	$W \to \tau\nu$
$q\bar{q}' \to H^{\pm *}(+jet),$	$H^+ \to t\bar{b}(\tau\nu)$

top decay channels

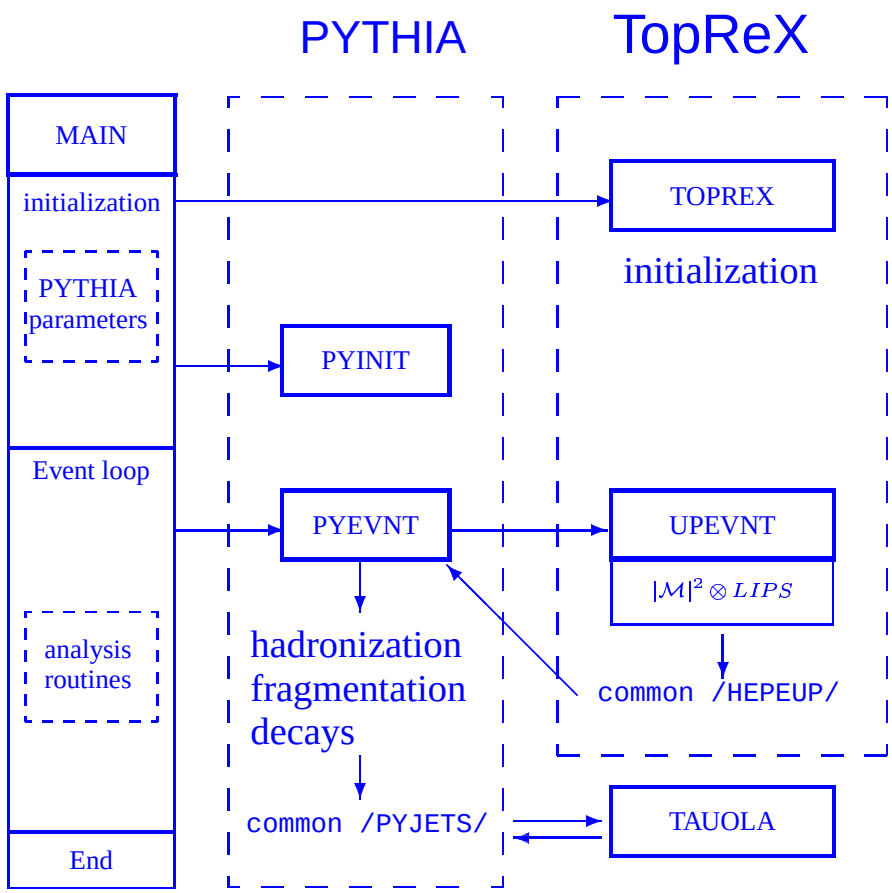
- $t \to bW^+$ with $W^\pm \to q\bar{q}'$, $\to \ell^\pm \nu_\ell$
- t-quark decays due to anomalous Flavor Changing Neutral couplings

$$
\begin{aligned}
t &\to g\, q, \quad q = u, c \\
t &\to \gamma\, q, \quad q = u, c \\
t &\to g\, Z, \quad q = u, c; \quad Z \to q\bar{q};\ \ell^+\ell^-;\ \nu\bar{\nu}
\end{aligned}
$$

- charged Higgs in top decays

$$
\begin{aligned}
t &\to bH^+ \\
t &\to bH^*(\to t^*\bar{b};\quad t^* \to bW^\pm) \ \Rightarrow\ t \to bW^\pm \bar{b}b, \text{with} \quad H^\pm \to q\bar{q}';\ \ell^\pm\nu_\ell
\end{aligned}
$$

Program flow chart



calculations of $|M|^2$

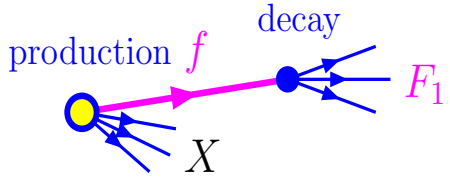
- the exact expressions for $|M|^2$ are used for all TopReX processes

- "smearing-mass" method (PYTHIA) is used to reproduce Breit-Wigner resonance shape (top)
  - ◇ $|M|^2$ is calculated with the default m_t
  - ◇ for each t_i-quark in the event the mass $\tilde{m}_t(t_i)$ is generated by using Breit-Wigner distribution $\left(\propto \frac{1}{(p^2_W - M^2_W)^2 + \Gamma^2_W M^2_W} \right)$
  - ◇ re-evaluate the energies of all t-quark(s) in the event

$$t\bar{t} \quad : \quad E^*(t) = E^*(\bar{t}) = \sqrt{\hat{s}}/2 \quad \Longrightarrow \quad \tilde{E}^*(t) = \frac{\sqrt{\hat{s}} + \tilde{m}^2(t) - \tilde{m}^2(\bar{t})}{2\sqrt{\hat{s}}}$$

can be used for event with any number of top quarks (t, $t\bar{t}$, ...)

- top quark decay (similar to TAUOLA package)



$|M|^2$ could be represented in the "factorized" form

$$|M(A \to F_1 + X)|^2 = \frac{\pi}{\Gamma_f m_f}\delta(p_f^2 - m_f^2) \times |M_P^0(A \to f + X)|^2 \ \ (1 + v_i h_i) \ \ |M_D^0(f \to F_1)|^2$$

$$|M_P(A \to f + X)|^2 = |M_P^0(A \to f + X)|^2(1 + (vs))$$

$|M^0|^2$ describes the production (decay) of **unpolarized** top-quark, $(p_f s) = 0$

- $t \to b\ell^+\nu \quad |M|^2 \propto \frac{(p_b p_\nu)(p_t p_\ell)}{(p_W^2 - M_W^2)^2 + \Gamma_W^2 M_W^2} \times \left[1 - \frac{m_t (p_\ell s)}{(p_t p_\ell)}\right] \Rightarrow v^\mu = -\frac{m_t p_\ell^\mu}{(p_t p_\ell)} \ \Rightarrow \ -\vec{n}_\ell^*$
- for $u\bar{d} \ \to \ t\bar{b}$ with $t \to b(W^*)\nu\ell \Longrightarrow$

$$|M|^2 \propto \frac{(p_u p_{\bar{b}})(p_t p_{\bar{d}})}{(p_{w1}^2 - M_W^2)^2 + \Gamma_W^2 M_W^2} \times \frac{(p_b p_\nu)(p_t p_\ell)}{(p_{w2}^2 - M_W^2)^2 + \Gamma_W^2 M_W^2} \times \left(1 + \vec{n}_\ell^* \vec{n}_{\bar{d}}^*\right)$$

$\vec{n}_\ell^*$ and $\vec{n}_{\bar{d}}^*$ are directions of ℓ^+ and $\bar{d}$-quark momenta in t-quark rest frame

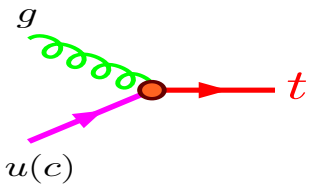
FCNC processes

single top production (in collaboration with P.M. Ferreira, A. Onofre and R. Santos)

$$\mathcal{L} = -g_s \frac{\kappa_g}{\Lambda} \bar{t}\sigma^{\mu\nu} T^a (f^g + h^g \gamma_5) q G^a_{\mu\nu} - e\frac{\kappa_\gamma}{\Lambda} t\sigma^{\mu\nu} (f^\gamma + h^\gamma \gamma^5) q\, A_{\mu\nu} - \frac{g\kappa_Z}{2\cos\theta_W} \bar{t}\gamma^\mu (f^Z - h^Z \gamma_5) q Z_\mu$$

$q = u, c$, Λ is the New Physics cut-off, $|f^V|^2 + |h^V|^2 = 1$

- "direct" top production ("charm–gluon fusion)

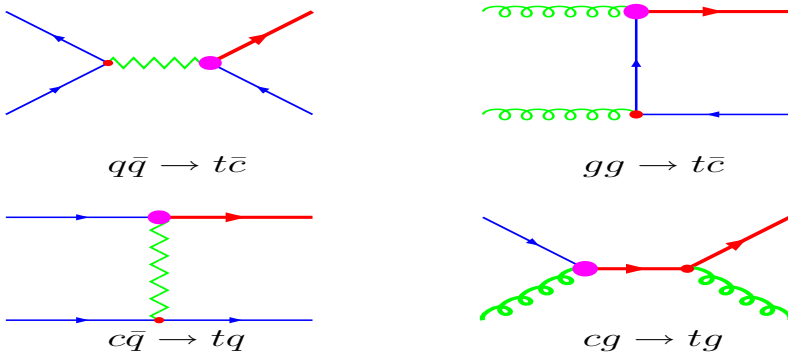


$\frac{\kappa_g}{\Lambda} = 1$ TeV^{-1}

$\sigma(ug \to t) \simeq 2 \cdot 10^4$ pb
$\sigma(\bar{u}g \to t) \simeq 5 \cdot 10^3$ pb
$\sigma(cg \to t) \simeq 3 \cdot 10^3$ pb

$\sigma_{SM}(t\bar{t}) = 830$ pb

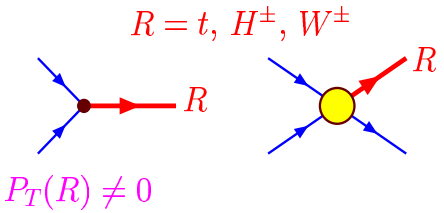
- $2 \to 2$ processes of single top production: $q\bar{q} \to t\bar{c}$, $gg \to t\bar{c}$, $cq \to tq$, $qg \to tg$



Heavy Particle matching

double counting problem

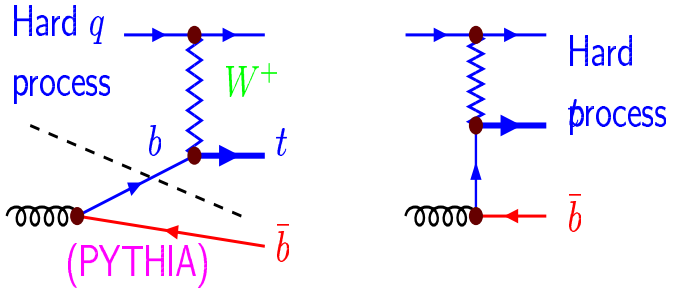
- $R(t, W^{\pm}, H^{\pm})$ production: $2 \to 1$ (P1) versus $2 \to 2$ (P2)



$2 \to 1\ qq'(qg, ...) \to R, p_T(R) \neq 0$ (PYTHIA)

$2 \to 2\ qq' ... \to R\, g(q, ...), p_T(R) \neq 0$ (hard process)

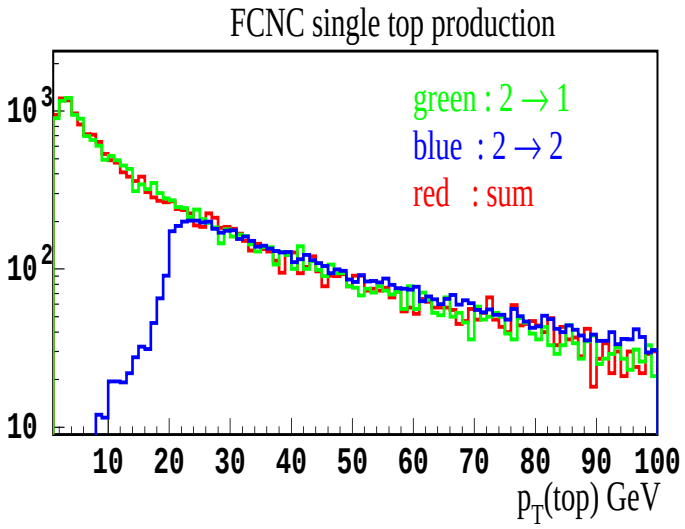
- single top production (SM) t-channel : $2 \to 2$ (P1) versus $2 \to 3$ (P2)

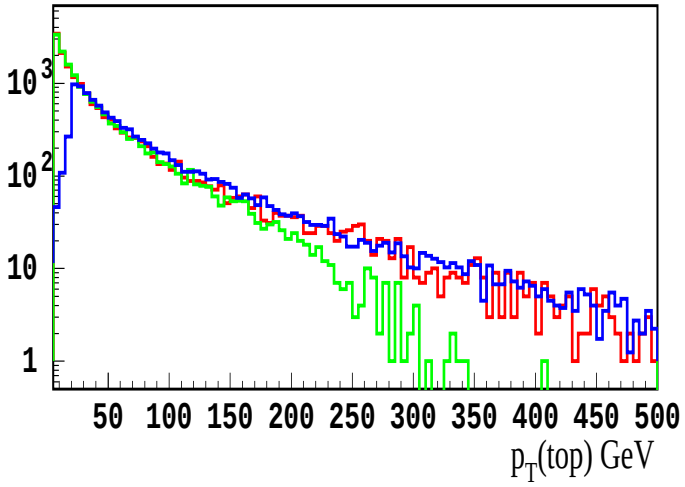


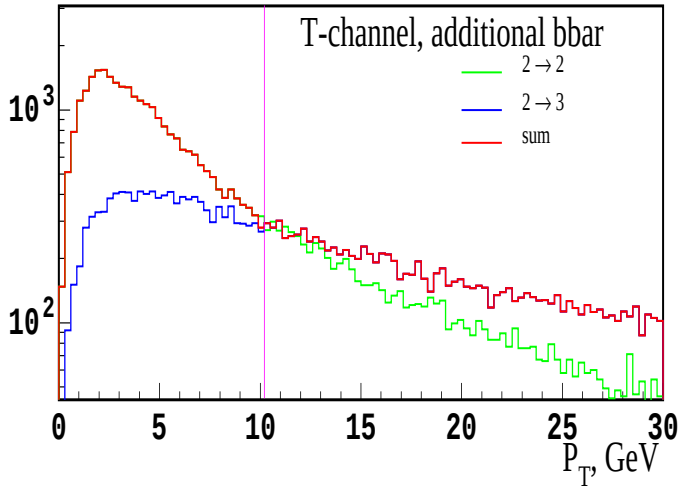
$2 \to 2\ qb \to q't\ +\ \bar{b}$ from PYTHIA

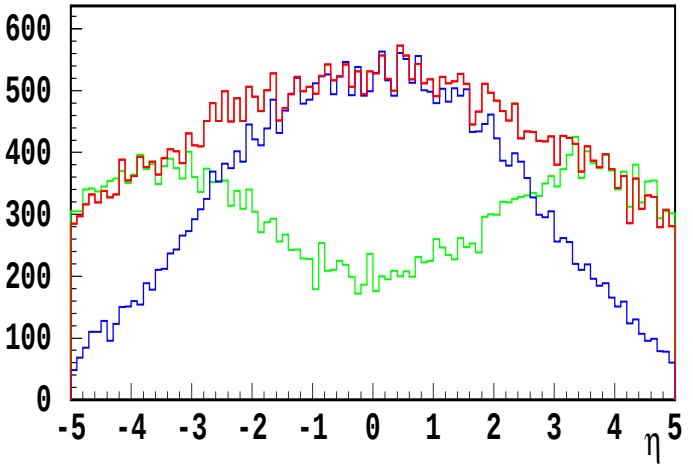
$2 \to 3\ qg \to q't\ +\ \bar{b}$ from the hard process

$$\sigma_{pp}(P1 + P2) = \sigma^{(P1)}(p_{\mathsf{T}}(\bar{b}, R)) < p_0) + \sigma^{(P2)}(p_{\mathsf{T}}(\bar{b}, R) \geq p_0)$$


FCNC single top production
green : 2 → 1
blue : 2 → 2
red : sum
10^3
10^2
10
10 20 30 40 50 60 70 80 90 100
p_T(top) GeV


10^3
10^2
10
1
50 100 150 200 250 300 350 400 450 500
p_T(top) GeV


T-channel, additional bbar
2 → 2
2 → 3
sum
10^3
10^2
0 5 10 15 20 25 30
P_T, GeV


600
500
400
300
200
100
0
-5 -4 -3 -2 -1 0 1 2 3 4 5
η

Conclusion

TopReX provides the simulation of

- $t\bar{t}$-pair production
- three subprocesses of electro-weak top production
- top production and decays due to FCNC interactions
- $WQ\bar{Q}$, $ZQ\bar{Q}$ production
- charged Higgs production

- spin properties of decaying t-quark are taken into account
- it is very easy to include new top decay channels

- “Heavy Particle” matching is developed