Generating Simplified Models with PYTHIA, Scanning Parameter Space and Presenting the Results

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Fermilab

Simplified Models

- Process:

$$A_{SM} + B_{SM} \rightarrow C_{SM/NP} + D_{SM/NP}$$

- Particles:

$$\text{Color} - \text{Charge} - \text{Mass}$$

- Decays:

$$D \rightarrow E \rightarrow \cdots$$

Generate models quickly

Choose masses smartly

Present results usefully

Particle Properties

```
BLOCK QNUMBERS 9900001 # blobon
                 1 0 # 3 times electric charge
                 2 1 number of spin states (2S+1)
                 3 1 # colour rep (1:singlet,3:triplet,8:octet)
                 4 1 # Particle/Antiparticle distinction (0=own anti)
BLOCK QNUMBERS 9900002 # 1blob
                 1 6 # 3 times electric charge
                 2 1 number of spin states (2S+1)
                 3 1 # colour rep (1:singlet,3:triplet,8:octet)
                 4 1 # Particle/Antiparticle distinction (0=own anti)
BLOCK QNUMBERS 9900004 # 3blob
                 1 3 # 3 times electric charge
                 2 1 number of spin states (2S+1)
                 3 3 # colour rep (1:singlet,3:triplet,8:octet)
                 4 1 # Particle/Antiparticle distinction (0=own anti)

BLOCK MASS
          9900001   700.
          9900002   250.
          9900004   200.
```

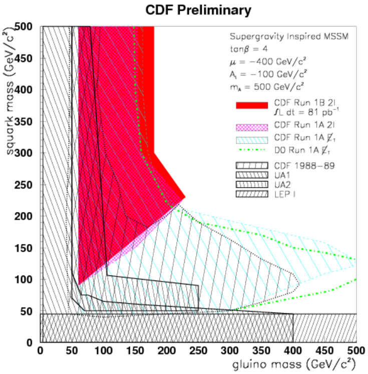
Process and Decays

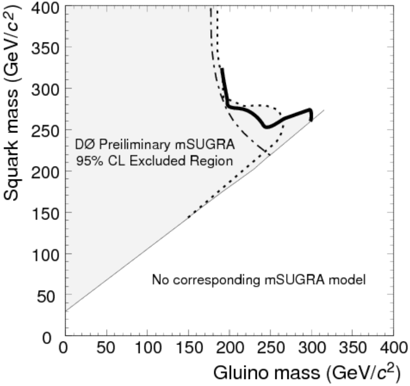
```
DECAY 9900001  1.00 !  SPECIAL PROCESS PARTICLE
        0.50000         2      21     21
        0.50000         2      9900004    -9900004

DECAY 9900002  1.00
        1.00000         2     -11   -11
DECAY 9900004  1.00
        1.00000         3     1      12    -11
```

MSUB(482)=1 (MSUB(481)=1 for $2 \to 1 \to 2$)

```
                          Event listing (summary)

  I particle/jet KS      KF  orig    p_x       p_y       p_z       E         m

  1 !p+!        21    2212     0    0.000     0.000 3500.000 3500.000     0.938
  2 !p+!        21    2212     0    0.000     0.000-3500.000 3500.000     0.938
==============================================================================
  3 !g!         21      21     1    0.000     0.000  346.253  346.253     0.000
  4 !g!         21      21     2    0.000     0.000 -251.033  251.033     0.000
  5 !g!         21      21     3    0.000     0.000  346.253  346.253     0.000
  6 !g!         21      21     4    0.000     0.000 -251.033  251.033     0.000
  7 !3blobbar!  21-9900004     0   63.948    56.573  248.709  330.873   200.827
  8 !3blob!     21 9900004     0  -63.948   -56.573 -153.489  266.413   200.317
  9 !nu_ebar!   21     -12     7  -21.366    90.760  108.690  143.204     0.000
 10 !e-!        21      11     7   17.823   -48.509   84.768   99.279     0.001
 11 !dbar!      21      -1     7   67.491    14.322   55.251   88.391     0.330
 12 !nu_e!      21      12     8   17.328    58.108  -89.542  108.142     0.000
 13 !e+!        21     -11     8  -44.455   -62.735  -53.684   93.776     0.001
 14 !d!         21       1     8  -36.821   -51.946  -10.263   64.495     0.330
==============================================================================

 (etc)
```

mSUGRA transformed to an OSET





$\tilde{G} \to \tilde{N} g$

$g \equiv$ visible, light particle

$\tilde{N} \equiv$ invisible, heavy particle

In the rest frame of $\tilde{G}$, the visible momentum from the decay is:

$$p_v = \frac{M_{\tilde{G}}^2 - M_{\tilde{N}}^2}{2M_{\tilde{G}}} = \frac{M_{\tilde{G}}}{2}(1 - r^2), r = M_N/M_G$$

Assume $\tilde{G}$ is produced in pairs and at threshold

max visible momentum is $M_G(1 - r^2)$

Motivation behind the discriminant known as R, or “the razor.”

Expectations

Models with similar values of p_v yield similar kinematic distributions?

The event rate will depend upon coupling strength, spin, incoming partons, etc., but not (so much) acceptance

Propose to scan parameter space (and present results limits?) on $\sigma \times BR^2$ in the $M_G - p_v$ plane

Model lines defined by orthogonal directions in this space

Alternative to $\Delta M = M_G(1 - r)$

Definitions

The physical observable shown is the magnitude of the missing transverse momentum mM_T, defined using observed jets:

$$mH_T = \left| \sum_i \vec{p}_{Ti} \right|.$$

For one-step decays, one could alternatively show the H_T, defined as the sum of the magnitude of the individual jet transverse momenta;

$$H_T = \sum_i \left| \vec{p}_{Ti} \right|.$$

Results with PYTHIA and FASTJET anti-kT jets[1]

[1] For speed and simplicity, the multiple-interaction model of PYTHIA is not simulated

$p_v = M_G(1 - r^2) =$175 GeV (left) versus $\Delta M = 100$ GeV (right)

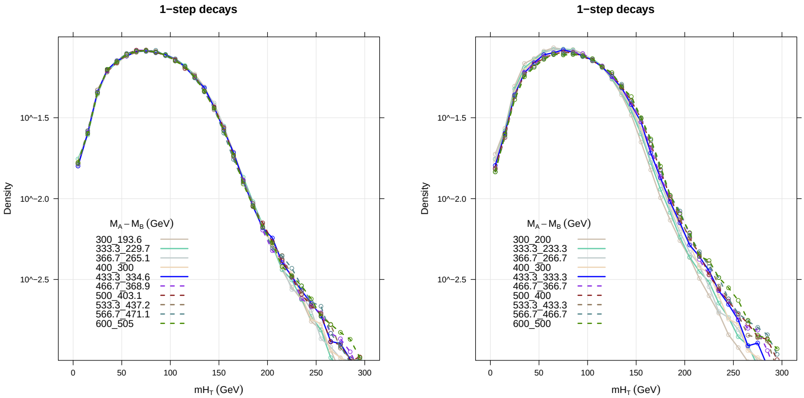


Figure: Distributions of the missing vector transverse momentum mH_T: (left) for a fixed value of the p_v; (right) for a fixed mass splitting.

$p_v = 300$ GeV (left) versus $\Delta M = 200$ GeV (right)

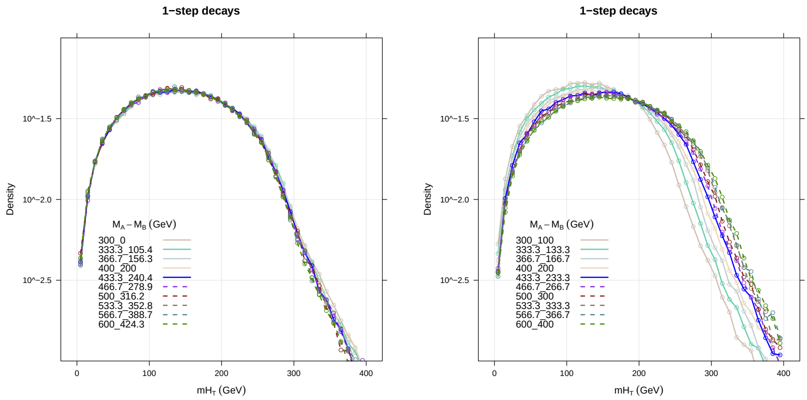
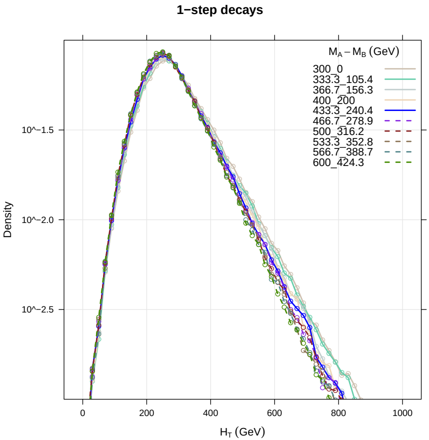
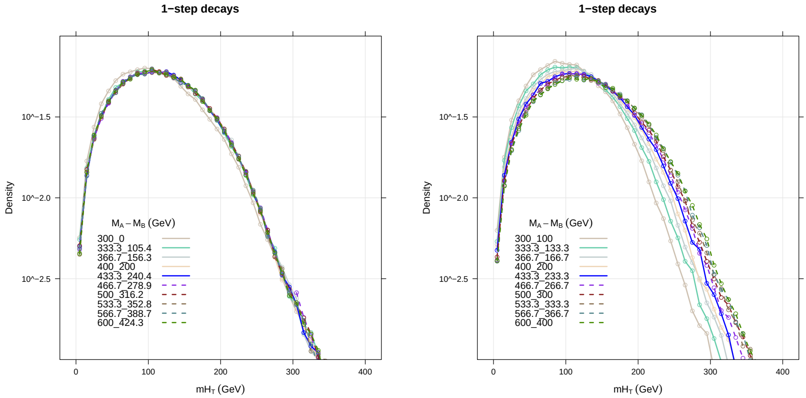


Figure: Distributions of the missing vector transverse momentum mH_T: (left) for a fixed value of the p_v; (right) for a fixed mass splitting. Similar to Fig. 1, but with a larger mass splitting.

Finally, we note that for such 2-body decays, the H_T and mH_T distributions are highly correlated:



$p_v = 300$ GeV (left) versus $\Delta M = 200$ GeV (right)



The tight correlation between mH_T and H_T is reduced.

$\tilde{G} \to q_1 \tilde{Q} \to \tilde{q}_1 q_2 N$

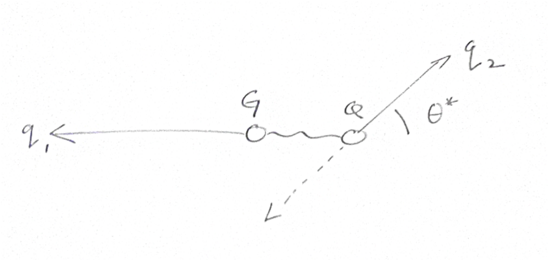


Figure: The kinematic setup for two-step decays.

$$\vec{p}_v = \hat{z}(p_{q_1} + \gamma_Q(p^* \cos\theta^* + \beta_Q E^*)) + \hat{\perp} p^* \sin\theta^*$$

$$-p_{q_1} = p_Q = \frac{M_g^2 - M_Q^2}{2M_g}; p^* = \frac{M_Q^2 - M_N^2}{2M_Q}$$

“Best” result

Average over a (flat) decay in the rest frame of the cascade particle:

$$\langle p_v \rangle = \frac{M_G}{2(1-a^2)(1-b^2)} \left(1 - a^4 b^4 - (a^2+b^2)|a^2-b^2| + 4a^2 b^2 \log\left(\frac{2a^2b^2}{a^2+b^2-|a^2-b^2|} \right) \right),$$

$a = M_Q/M_G$ and $b = M_N/M_Q$

pair production $\rightarrow 2\langle p_v \rangle$

(M_G, p_v) = (400, 260) GeV (left) and (500, 375) GeV (right)

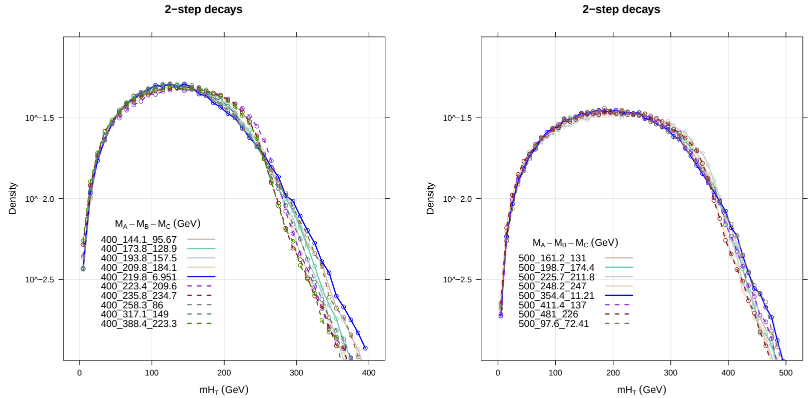


Figure: mH_T distributions for fixed mother mass and visible momentum p_v

As a first step, consider the decay $C^{\pm} \to \ell^{\pm}\tilde{\nu}$.

$$p_v = \frac{M_C}{2}\left(1 - \frac{M_\nu^2}{M_C^2}\right).$$

A related decay chain is $C^{\pm} \to \nu L^{\pm} \to \ell^{\pm} N$. The above derivation needs a modification to handle the loss of momentum from neutrinos.

$$p_v = \frac{M_C}{2}\left(1 - \frac{M_N^2}{M_L^2}\right)\frac{1}{2}\left(1 + \frac{M_L^2}{M_C^2}\right).$$

The distributions for fixed p_v are **not** "constant"

- PYTHIA can easily generate simplified models
- The sensitivity of distributions to masses appears in ratios of squares
- Certain decay sequences yield “invariants” under the exchange of these ratios
- We can use this to sample model-space efficiently, or to present results that reflect the sensitive parameters