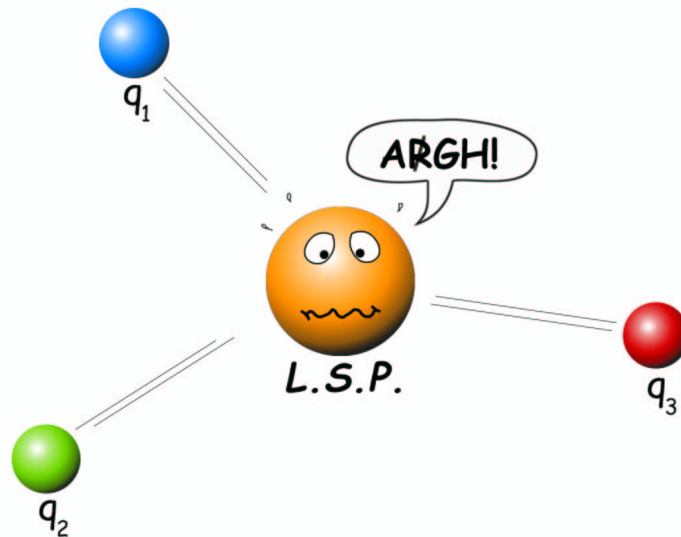# The Smoking Gun of BNV

Colour Topologies and String Hadronization in Baryon Number Violating Supersymmetry

P. Skands (speaker) & T. Sjöstrand, Lund University.

Overview

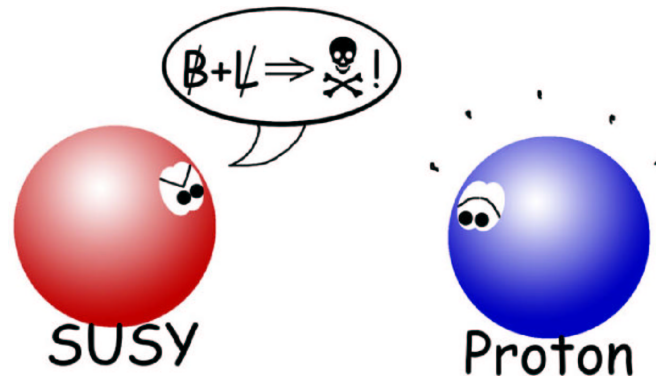1. BNV SUSY: Quick Intro.

2. BNV SUSY in PYTHIA.

3. Colour topologies and hadronization.

4. Properties and predictions.

5. Conclusion.

- Most general (MSSM) superpotential:

$$W = W_{\mathrm{MSSM}} + W_{\mathrm{BNV}} + W_{\mathrm{LNV}}$$

- But LNV+BNV makes bad cocktail!

- Most general (MSSM) superpotential:

$$W = W_{\mathrm{MSSM}} + W_{\mathrm{BNV}} + W_{\mathrm{LNV}}$$

- But LNV+BNV makes bad cocktail!

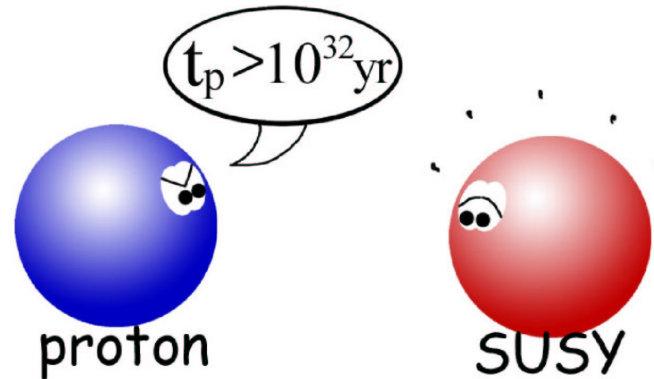$t_p > 10^{32} \mathrm{yr}$

proton   SUSY

- To save proton, R, B, or L cons. imposed.
  - $R \rightarrow$ CDM candidate, but no deep motivation.
  - B and L more robust with higher dimension operators.
- No clear-cut answer.

BNV SUSY: Quick Introduction

Baryon Number Violation in Superpotential:

$$W_{\mathrm{BNV}} = \lambda''_{ijk} \epsilon_{abc} \bar{U}_{ia} \bar{D}_{jb} \bar{D}_{kc}$$

(abc = colour, ijk = generation)

- Couplings between chiral multiplets.
  - Sfermions: 2-body decays.
  - Gauginos/Higgsinos: 3-body decays (via sfermion resonances).

- $\epsilon_{abc} \rightarrow$ 'baryonic' colour flow.

- (This talk is not about BNV in production.)

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UDD (λ''): $\sim$ 200 new decay chanels

$$\tilde{d}_j \to \bar{u}_i \bar{d}_k \;, \quad \tilde{\chi}_n^0 \to u_i d_j d_k, \; + \text{ c.c.} \quad , \; \tilde{g} \to u_i d_j d_k, \; + \text{ c.c.}$$

$$\tilde{u}_i \to \bar{d}_j \bar{d}_k \;, \quad \tilde{\chi}_n^+ \to u_i u_j d_k, \; \bar{d}_i \bar{d}_j \bar{d}_k$$

- Partial widths: tree-level ME's, massive t and b.

- Momentum distributions: isotropic 3-body phase space (good approx. when intermediate propagators way off shell, worse when only slightly off shell).

- Final state parton multiplicity increased by subsequent showers.

- Only MSSM pair production included.

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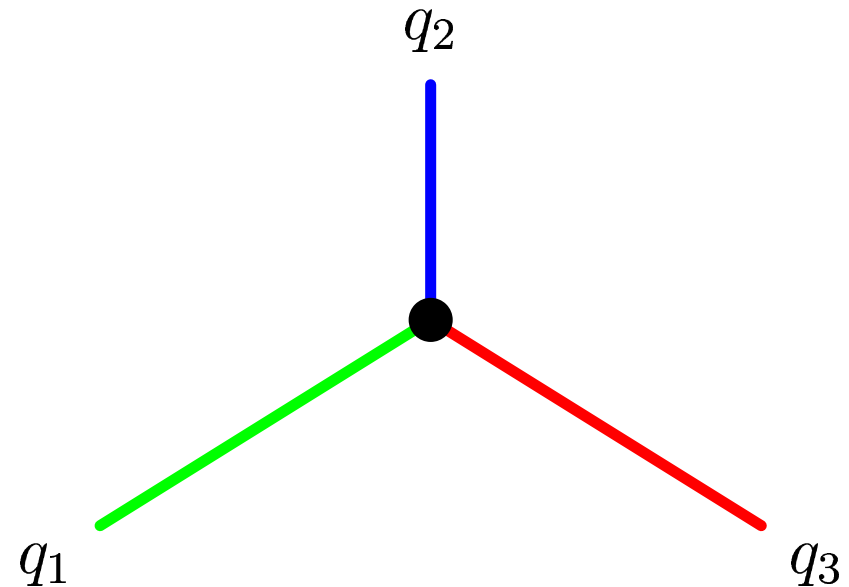4. Properties and predictions.

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'Ordinary' colour topology

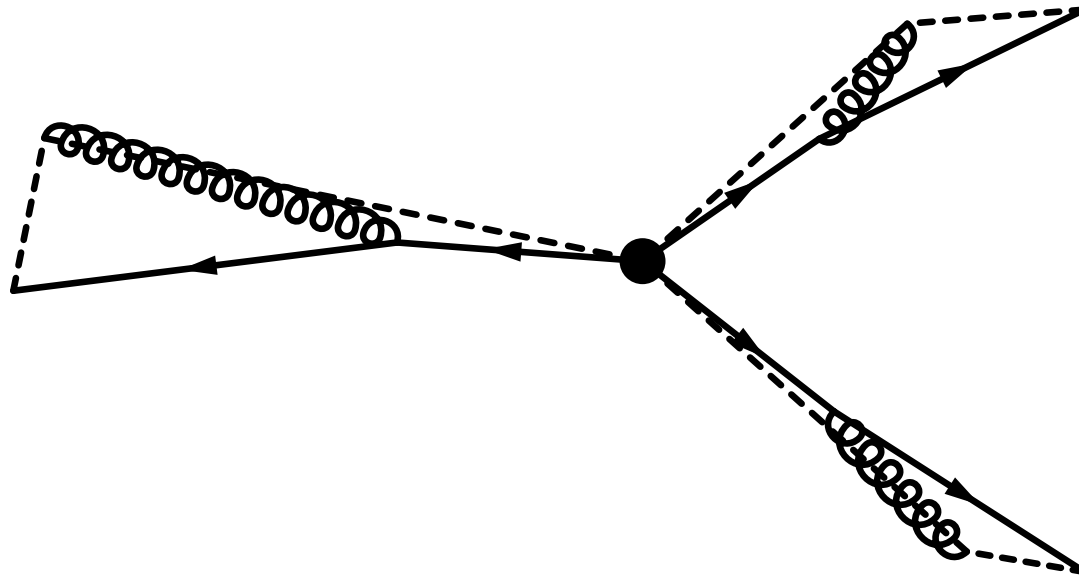(e.g. $Z^0 \rightarrow q\bar{q}$):

'Baryonic' colour topology

(e.g.):

q_2

$q \rule{3cm}{0.4pt} \bar{q}$

q_1 q_3

🔵 How does such a system fragment?

🔵 Could a Baryon excess be observed?

Colour topologies and hadronization

- Fundamental properties of QCD vacuum suggest string picture still applicable.

- String energy minimization + dipole picture $\implies$ picture of 3 string pieces meeting at a 'string junction'.

(Warning: This picture was drawn in a "pedagogical projection" where distances close to the center are greatly exaggerated!)

The Smoking gun!

- The movement of the string junction is crucial, it is the smoke of the BNV gun!

- A junction is a topological feature of the string confinement field: $V(r) = \kappa r$. Each string piece acts on the other two with a constant force, $\kappa \vec{e}_r$.

- $\implies$ in junction rest frame (JRF) the angle is $120°$ between the string pieces.

- Or better, 'pull vectors' lie at $120°$:

$$p^\mu_{\text{pull}} = \sum_{i=1,N} p^\mu_i e^{-\sum_{j=1}^{i-1} \frac{E_j}{\kappa}}$$

(since soft gluons 'eaten' by string)

Fragmentation
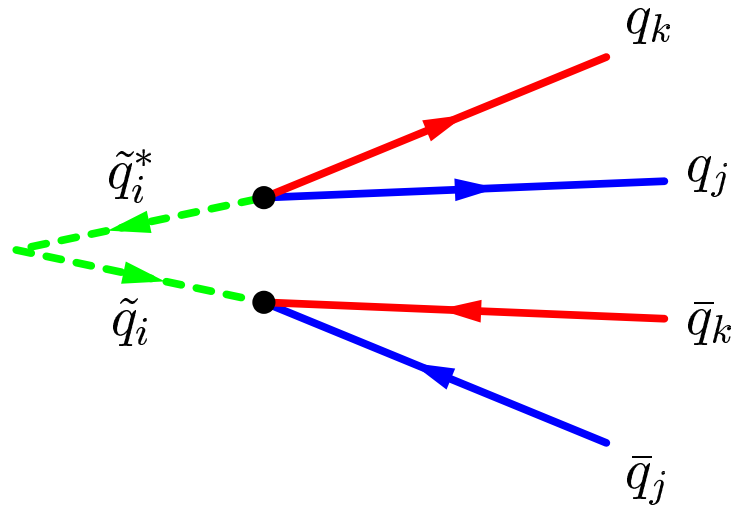
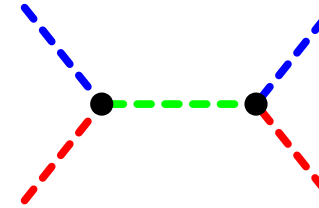- The movement of the string junction is crucial, it is the smoke of the BNV gun!
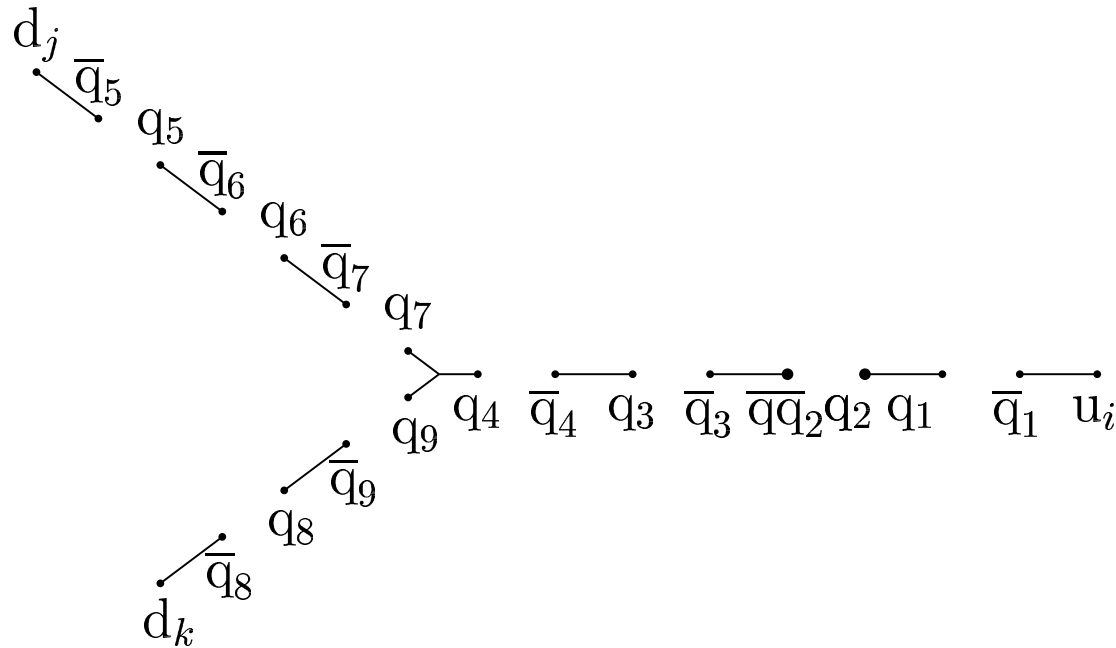
First 2 pieces fragmented outwards–in, junction baryon formed around junction, last string piece fragmented as ordinary $q\bar{q}$ string.
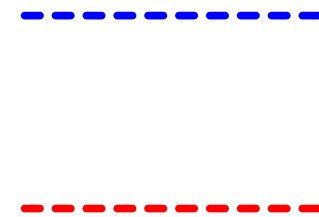
Intermezzo: more complicated topologies

- Stop pair production at an LC:

a) 2 J baryons

b) No J baryons

- Select: a) or b) based on string length measure.

- Stop pair production at an LC:

q_k

$\tilde{q}_i^*$

q_j

$\tilde{q}_i$

$\bar{q}_k$

$\bar{q}_j$

$\rightarrow$

a) 2 J baryons

b) No J baryons

- Select: a) or b) based on string length measure.

P

$m_{stop} = 50\ GeV$

$Pythia\ 6210$

$J\bar{J}$ perturbative breakup
2 junction baryons

$J\bar{J}$ string
2 junction baryons

$J\bar{J}$ annihilation
No junction baryons

γ_{stop}

- Colour flow in gluino decays:
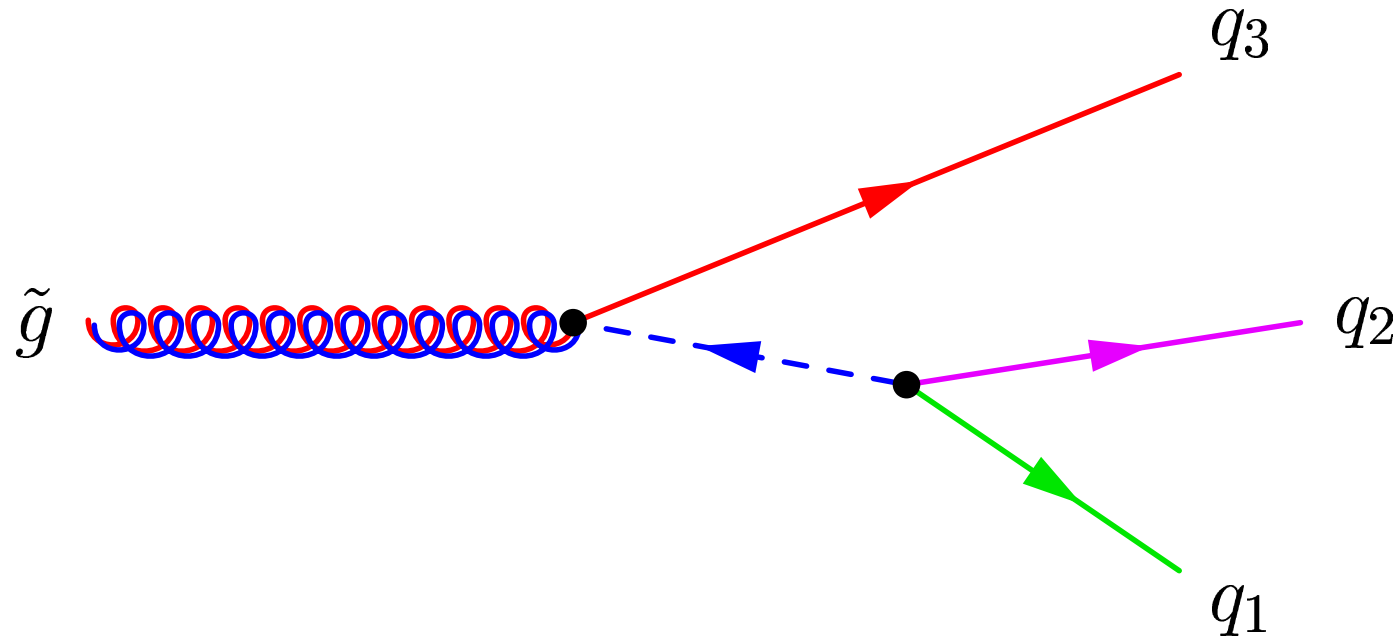
- Selected according to (off–shell) resonance propagators.

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Properties and Predictions

Dependence on Fragmentation assumptions:

$m_\chi = 96$ GeV — $\tilde{\chi}_1 \to u\, d\, s$ — Pythia 6209

- - + - - Default
- ✱ Fragmentation: Least Energetic Last
- ○ Junction Pull: $E_{norm} \to \infty$
- ▼ Junction Pull: $E_{norm} = 0.5$
- ✕ Junction Pull: CM Energies
- ▲ Junction Rest Frame = String CM

Junction Baryons

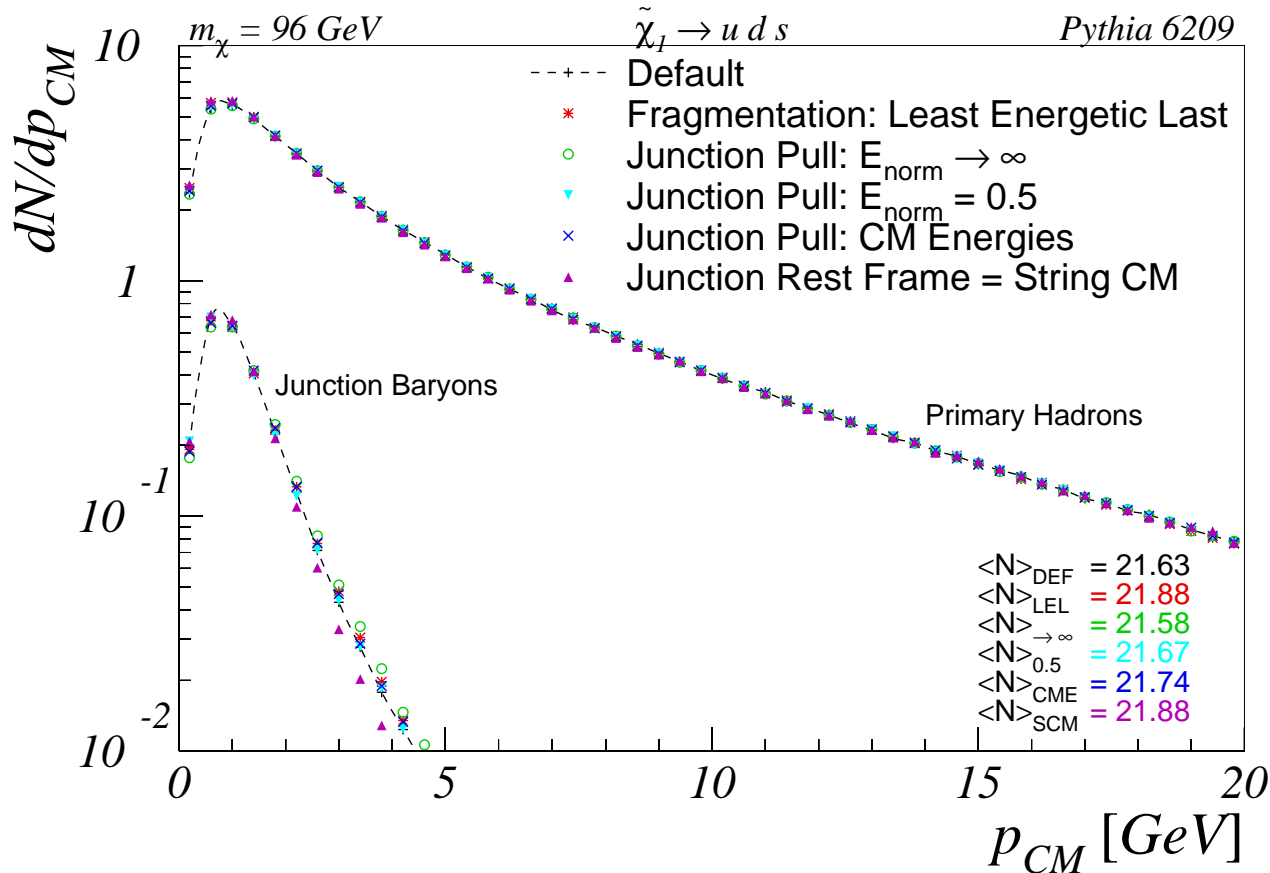Primary Hadrons

$\langle N \rangle_{DEF}$ = 21.63
$\langle N \rangle_{LEL}$ = 21.88
$\langle N \rangle_{\to \infty}$ = 21.58
$\langle N \rangle_{0.5}$ = 21.67
$\langle N \rangle_{CME}$ = 21.74
$\langle N \rangle_{SCM}$ = 21.88

● Description is assymmetric but differences are small.

Junction fragmentation implies:

$m_\chi = 96\ GeV$ $\tilde{\chi}_1 \to u\, d\, s$

- Pythia 6209 - Junction Baryons
- Pythia 6209 - "Ordinary" Baryons
- Herwig 6301 - Junction Baryons
- Herwig 6301 - "Ordinary" Baryons

$\langle N_{bary} \rangle_{Pythia} = 3.4$
$\langle N_{bary} \rangle_{Herwig} = 4.5$

Axis labels: dN/dp_{CM} vs $p_{CM}\ [GeV]$

• if leading jets are well separated, junction will be slow, and junction baryon will be at low momenta:

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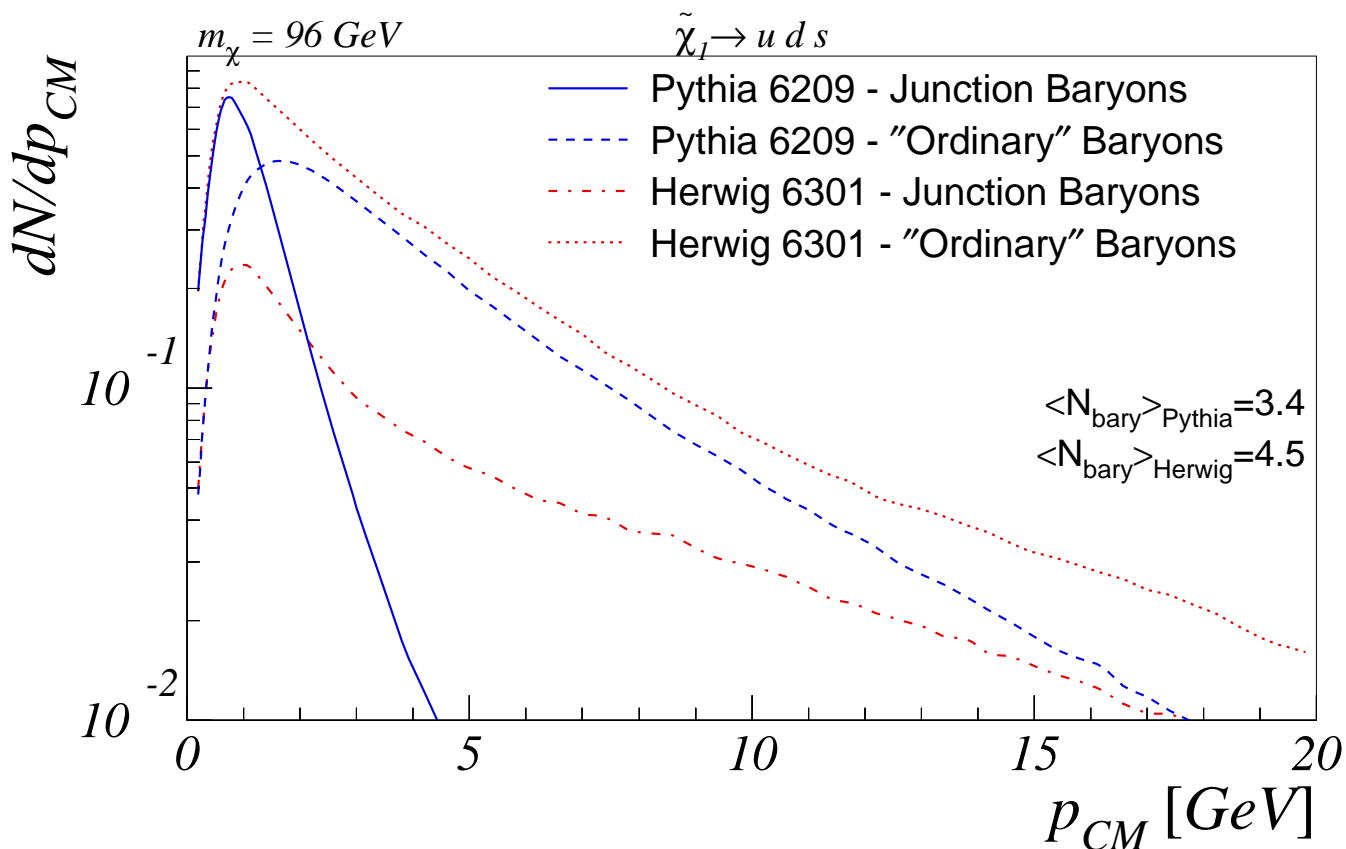
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Conclusion

- A model for BNV-SUSY allowing detailed studies available in PYTHIA.

- Special attention given to the non-perturbative aspects. Hadronization based on physical picture shows new aspects.

- Generic prediction (apologies to particle ID people!):
  The smoking Gun — slow baryons.

- Junction fragmentation also used for multiple interactions, see friday morning talk in QCD/Generators session.