Monte Carlo Simulations of R-parity Violating Supersymmetry Models

Peter Richardson,

supervised by H. Dreiner and M. Seymour.

Outline

- **Introduction to** $\not R_p$
- **Introduction to Angular Ordering**
- **R-Parity Violating Monte Carlo Simulations**
- **Angular Ordering in** $\not R_p$
- **Preliminary Results**
- **Conclusions**

Introduction to $\not{R}_{\rm p}$

- Most SUSY studies have been of the Minimal Supersymmetric Standard Model (MSSM)
- Simplest SUSY extension of the standard model

SM particle	Spin	SUSY particle	Spin
Electron	1/2	Selectron	0
Neutrino	1/2	Sneutrino	0
Up	1/2	Sup	0
Down	1/2	Sdown	0
Gluon	1	Gluino	1/2
Photon	1	Photino	1/2
Z	1	Zino	1/2 Neutralinos
Higgs	0	Higgsino	1/2
W^+	1	Wino	1/2 Charginos
H^+	0	Higgsino	1/2

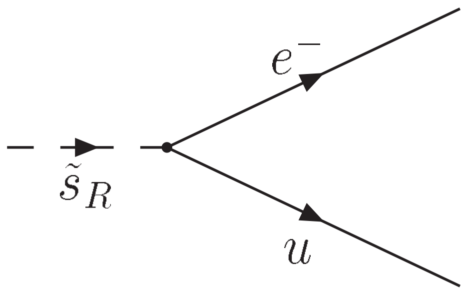
- In the MSSM R-parity is imposed by hand. It is a multiplicative discrete symmetry.

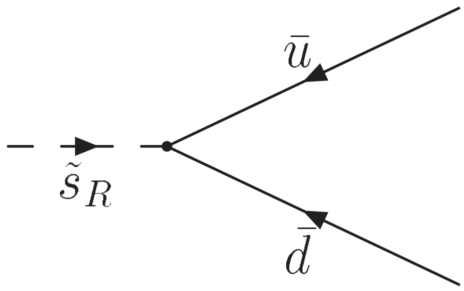
$$\mathbf{R_p} = (-1)^{3B+L+2S}$$

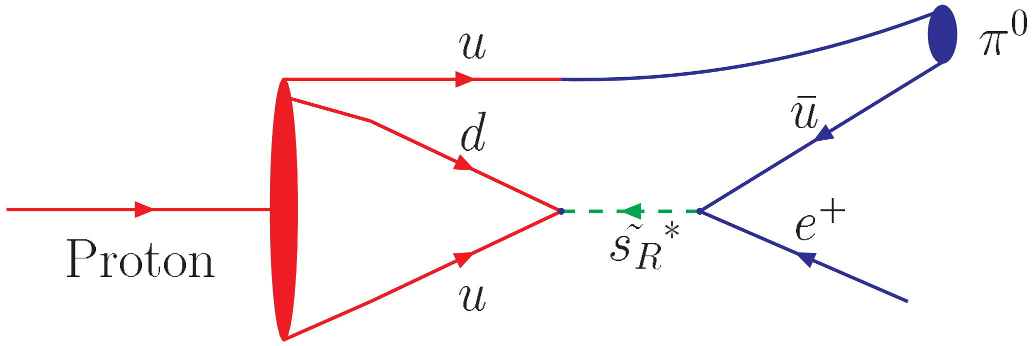
- SM particles $R_p = +1$, SUSY Particles $R_p = -1$

- This means that
  1. Sparticles are only produced in pairs
  2. The LSP is stable, and neutral (cosmology)
- Using the minimal particle content we can however violate R-parity

$$\mathbf{W}_{\not R_p} = \lambda_{ijk}\varepsilon^{ab}L_a^i L_b^j \overline{E}^k + \lambda'_{ijk}\varepsilon^{ab}L_a^i Q_b^j \overline{D}^k + \lambda''_{ijk}\varepsilon^{\alpha\beta\gamma}\overline{U}_\alpha^i \overline{D}_\beta^j \overline{D}_\gamma^k$$







- **Limits on the proton lifetime lead to**

$$\lambda'_{11k} \cdot \lambda''_{11k} \lesssim 2 \cdot 10^{-27}$$

- **Only natural way is if the LHS is zero**

- R_p **prevents proton decay by preventing both terms**

- **Instead impose a symmetry forbidding 2nd or 3rd terms**

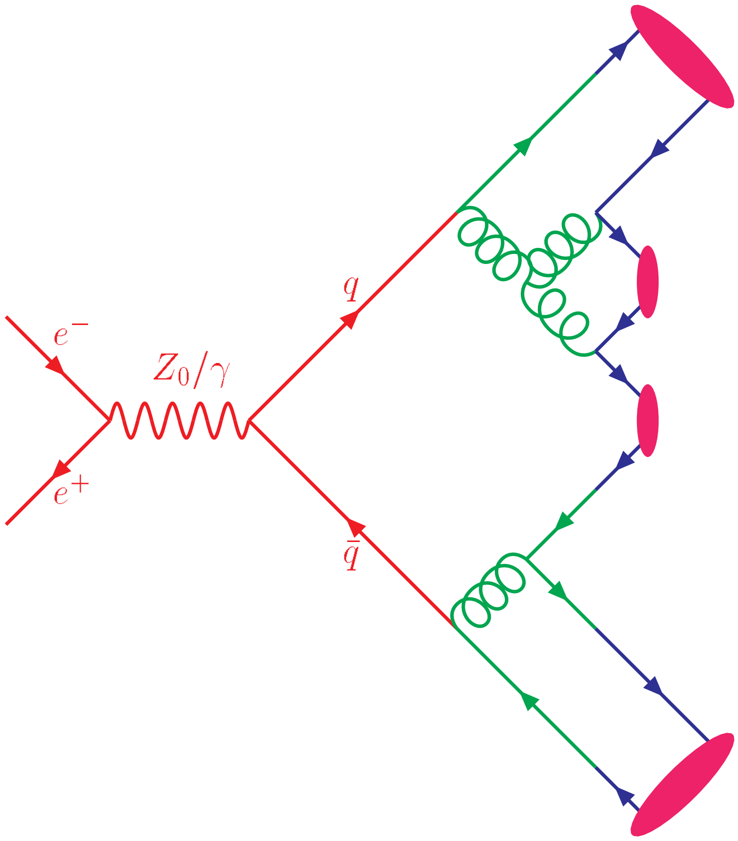
$$\text{e.g. Baryon Parity} \begin{array}{lcl} \{Q_i, U_i, D_i\} & \longrightarrow & -\{Q_i, U_i, D_i\} \\ \{L_i, E_i\} & \longrightarrow & \{L_i, E_i\} \end{array}$$

- **This means that**

  1. **Single Sparticles can be produced**
  2. **LSP can decay and need not be neutral**
  3. **Lepton or Baryon Number is Violated**

- **Different phenomenology to the MSSM which should be investigated**

Basic Idea of HERWIG



- There are three phases
  1. Hard Process
  2. Parton Shower
  3. Cluster Hadronization Model

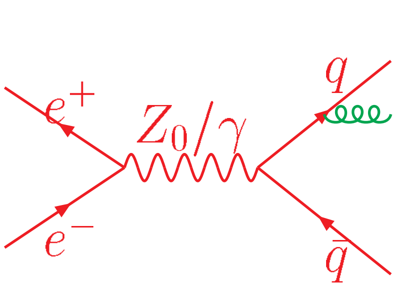
- Main Input
  1. Hard QCD Matrix Element
  2. Angular Ordering in Parton Shower
  3. Preconfinement (clustering of "colour connected" partons)

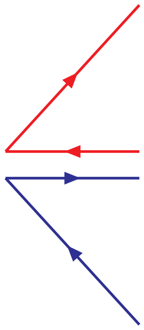
Angular Ordering

- **Two regions where emission of QCD radiation is enhanced**
  1. **Collinear Emission**
  2. **Soft Emission**

- **Consider the emission using the eikonal current**

  e.g. $e^- e^+ \longrightarrow q\bar{q}g$ **with radiation of an extra gluon**



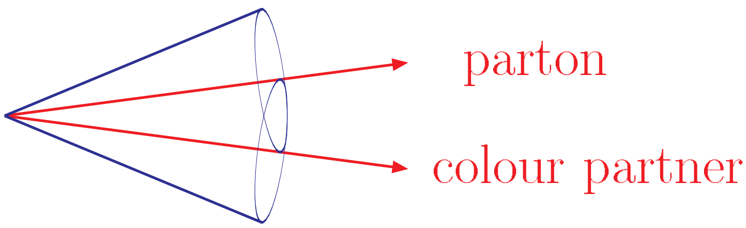


Colour Flow

$$\mathcal{M}^{e^+e^-\to q\bar{q}gg}(p_q, p_{\bar{q}}, p_g, k) = g_s m^{e^+e^-\to q\bar{q}g}(p_q, p_{\bar{q}}, p_g)\mathbf{J}(k)$$

- **We then get that**
  - **q and the g are colour connected**
  - **$\bar{q}$ and the g are anticolour connected**

- **QCD radiation only occurs in a cone up to the direction of the colour partner (Marchesini & Webber)**



R-Parity Violating Monte Carlo Simulations

- We will include a full Monte Carlo Simulation of $\not{R}_p$ in hadron-hadron in HERWIG collisions
- Currently only $\not{R}_p$ Monte Carlo in hadron-hadron is ISAJET, via forced decays.
- We include full matrix element calculations of the $\not{R}_p$ decay rates and hard processes.
- Will allow full simulation for arbitrary couplings for the first time.
- Particularly of interest to simulate $\not{B}$ for the LHC.

Included Processes

- **UDD Decays**
  - **Two-Body squark decays**

$$\tilde{u}_{i\alpha} \longrightarrow \bar{d}_j \bar{d}_k \quad \tilde{d}_{k\alpha} \longrightarrow \bar{u}_i \bar{d}_j$$

  - **Three-Body Decays**

Neutralino	$\tilde{\chi}^0 \longrightarrow u_i d_j d_k$
Chargino	$\tilde{\chi}^+ \longrightarrow u_i u_j d_k$
	$\tilde{\chi}^+ \longrightarrow \bar{d}_i \bar{d}_j \bar{d}_k$
Gluino	$\tilde{g} \longrightarrow u_i d_j d_k$

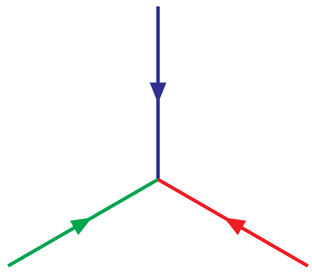
- **Resonant Squark Production via UDD**

$$\begin{array}{llll}
u_i d_j & \longrightarrow & \tilde{d}_k^* & \longrightarrow \tilde{\chi}^0 \bar{d}_k \\
 & & & \longrightarrow \tilde{g} \bar{d}_k \\
 & & & \longrightarrow \tilde{\chi}^+ \bar{u}_k \\
 & & & \longrightarrow W^+ \tilde{u}_k^* \\
 & & & \longrightarrow u_i d_j \\
 & \longrightarrow & \tilde{b}_2^* & \longrightarrow \ Z_0 \tilde{b}_1^* \\
d_j d_k & \longrightarrow & \tilde{u}_i^* & \longrightarrow \tilde{\chi}^0 \bar{u}_i \\
 & & & \longrightarrow \tilde{g} \bar{u}_i \\
 & & & \longrightarrow \tilde{\chi}^- \bar{d}_k \\
 & & & \longrightarrow W^- \tilde{d}_i^* \\
 & & & \longrightarrow d_j d_k \\
 & \longrightarrow & \tilde{t}_2^* & \longrightarrow \ Z_0 \tilde{t}_1^*
\end{array}$$

- **Processes from the other terms are also included**

Angular Ordering in $\not{R}_p$

- **Angular ordering in $\not{L}$ as in the MSSM.**
- **Angular Ordering in $\not{B}$ is more complicated.**
- **The colour flow is non-trivial at the UDD vertex.**
- **Three coloured objects form a singlet.**



- **There are no obvious pairs.**

1. Neutralino Decay

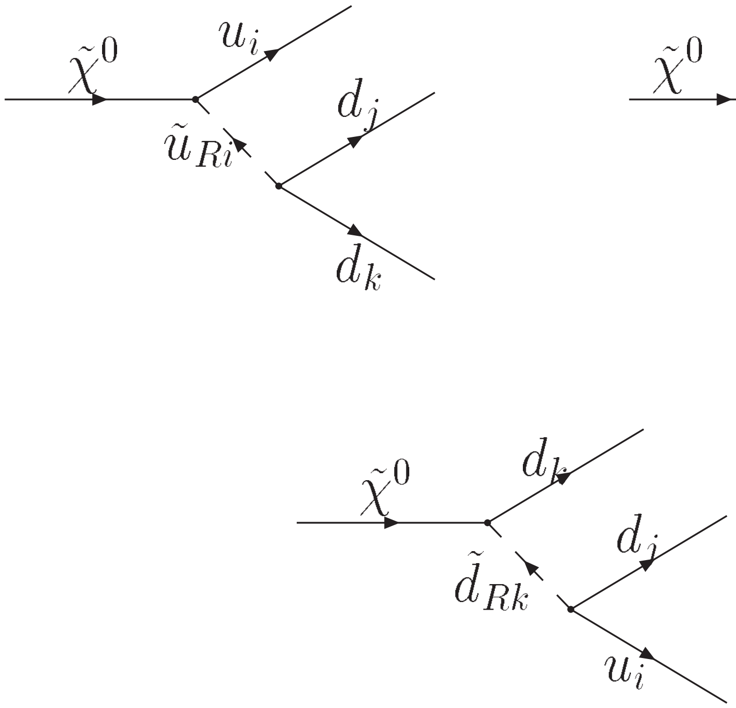


Figure 1: UDD decay of $\tilde{\chi}^0$.

- **The angular ordering procedure is to randomly colour connect a quark to either of the other quarks.**

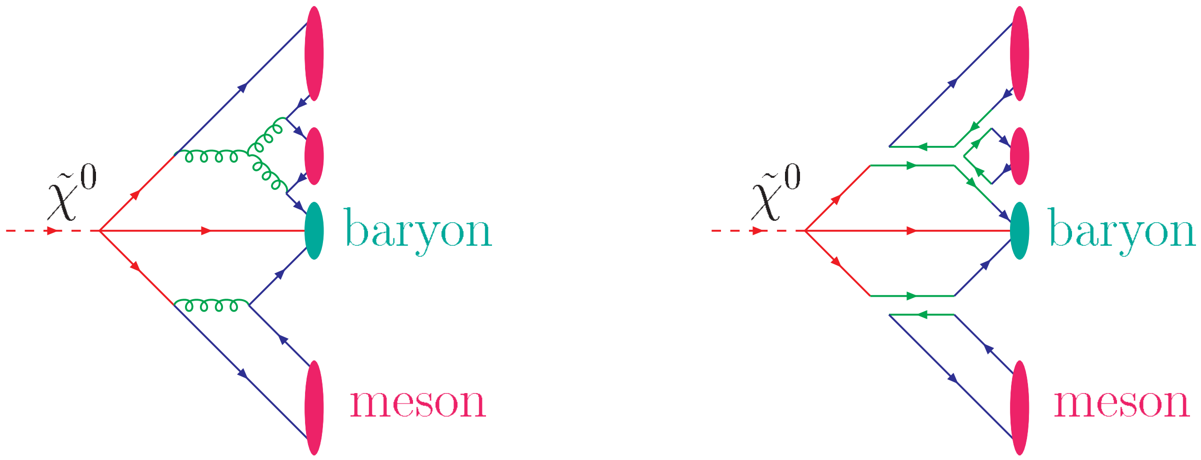


Figure 2: Hadronisation of a $\not{B}$ Neutralino Decay

Hadronization

The hadronization is done by forming two of the quarks left after the parton shower phase into a diquark. This is then formed into a colour singlet cluster with the remaining quark from the $\not{B}$

2. Squark Decays

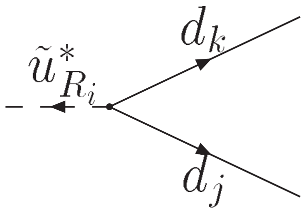


Figure 3: UDD decay of $\tilde{u}^*_R$.

- **Here we randomly take the other quark or the decaying antisquark to be the colour partner of the quark.**
- **The hadronization is more difficult**

Hadronization of $\not B$ squark decays

- There are two possibilities
- The squark is connected to a standard model particle or a SUSY particle which decays via a baryon number conserving mode

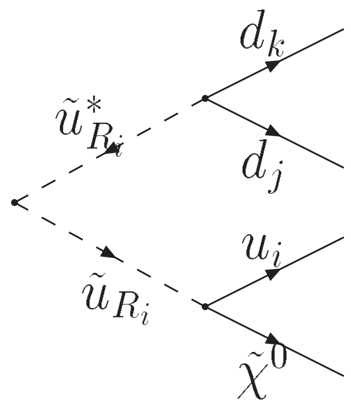


Figure 4: Hadronization with one $\not B$ decay.

- The three quarks are formed into a baryonic cluster as before
- The squark is connected to a second $\not B$ decay

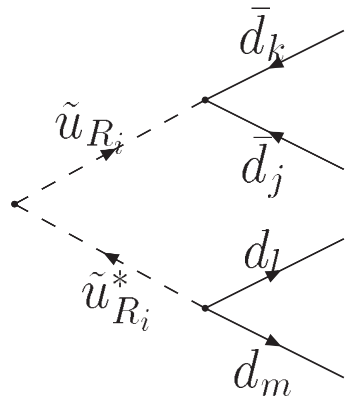


Figure 5: Hadronization with two $\not B$ decays.

- Here we need to form the quarks and antiquarks into two mesonic clusters at random

Preliminary Results

- There have been a number of studies of colour coherence effects

  CDF Phys. Rev. D50 5562

  D0 Phys. Lett. B414 419

- We look at the same variables for the $\not{R}_{\mathrm{p}}$processes.

- We consider the processes

$$
\begin{aligned}
u\bar{d} &\longrightarrow \tilde{\tau}^*_\alpha \longrightarrow u\bar{d} \\
d\bar{d} &\longrightarrow \tilde{\nu}^*_\tau \longrightarrow d\bar{d}
\end{aligned}
$$

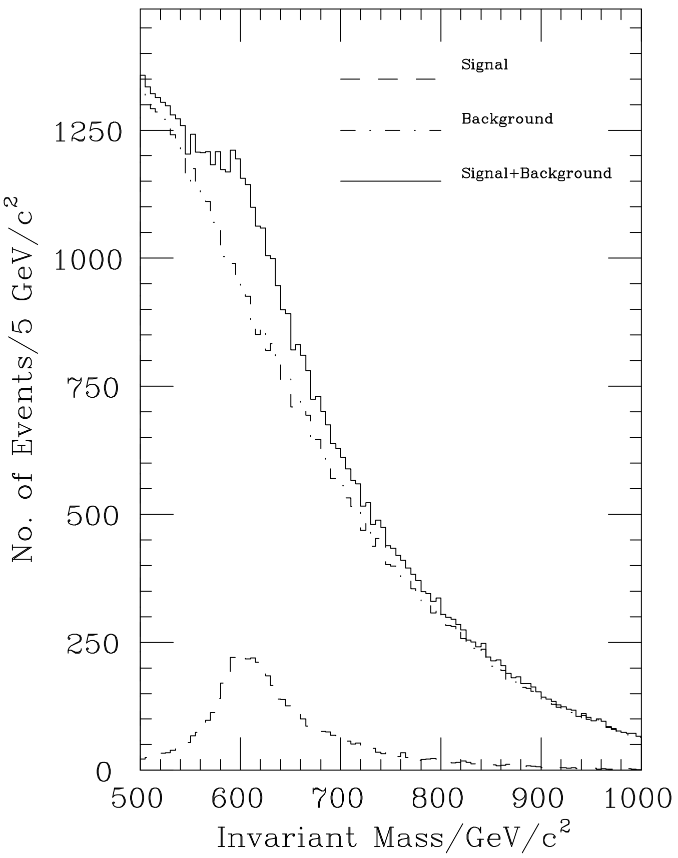
- We consider this at the SUSY point

$$M_0 = 600GeV/c^2,\ M_{1/2} = 200GeV/c^2,\ A_0 = 0GeV/c^2,\ \tan\beta = 10,\ sgn\mu +$$

- We also take $\lambda'_{311} = 1$ to be the only non-zero $\not{R}_{\mathrm{p}}$coupling.

- We can then consider a signal of two high p_t jets, and the QCD background to this process

- We impose a cut requiring the highest E_t jet to be above $190\,GeV$, and only consider jets with E_t above $10\,GeV$.
- We can then plot the invariant mass of the events.



- We can then look at the variables defined by CDF

- If we define the jets in the order of their E_t

  η_3 is the pseudo-rapidity of the third jet.

  $\Delta\eta = \eta_3 - \eta_2$ pseudo-rapidity difference

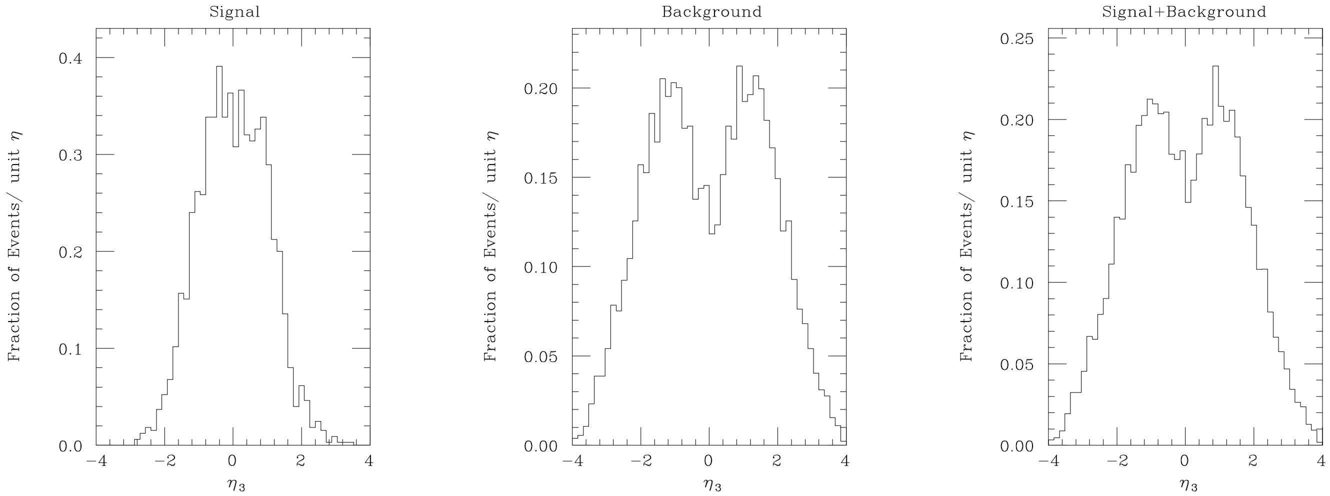
  $\Delta\phi = \phi_3 - \phi_2$ azimuthal difference

  $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ distance in (η, ϕ).

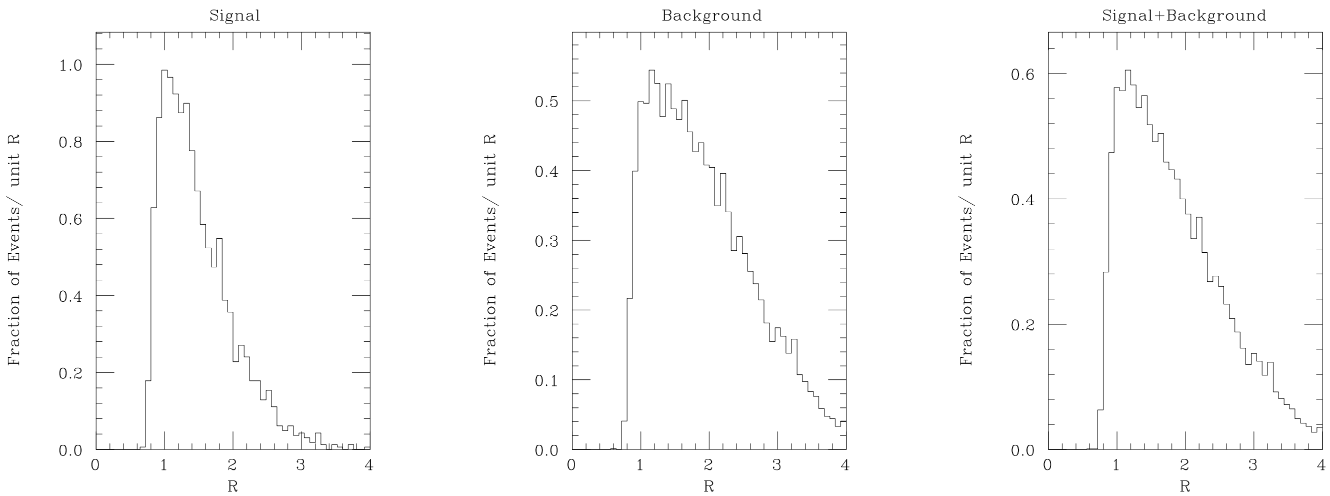
  $\Delta H = sgn(\eta_2)\Delta\eta$

  $\alpha = \tan^-1\left(\Delta H/|\Delta\phi|\right)$ azimuthal angle in $(|\Delta\phi|, \Delta H)$

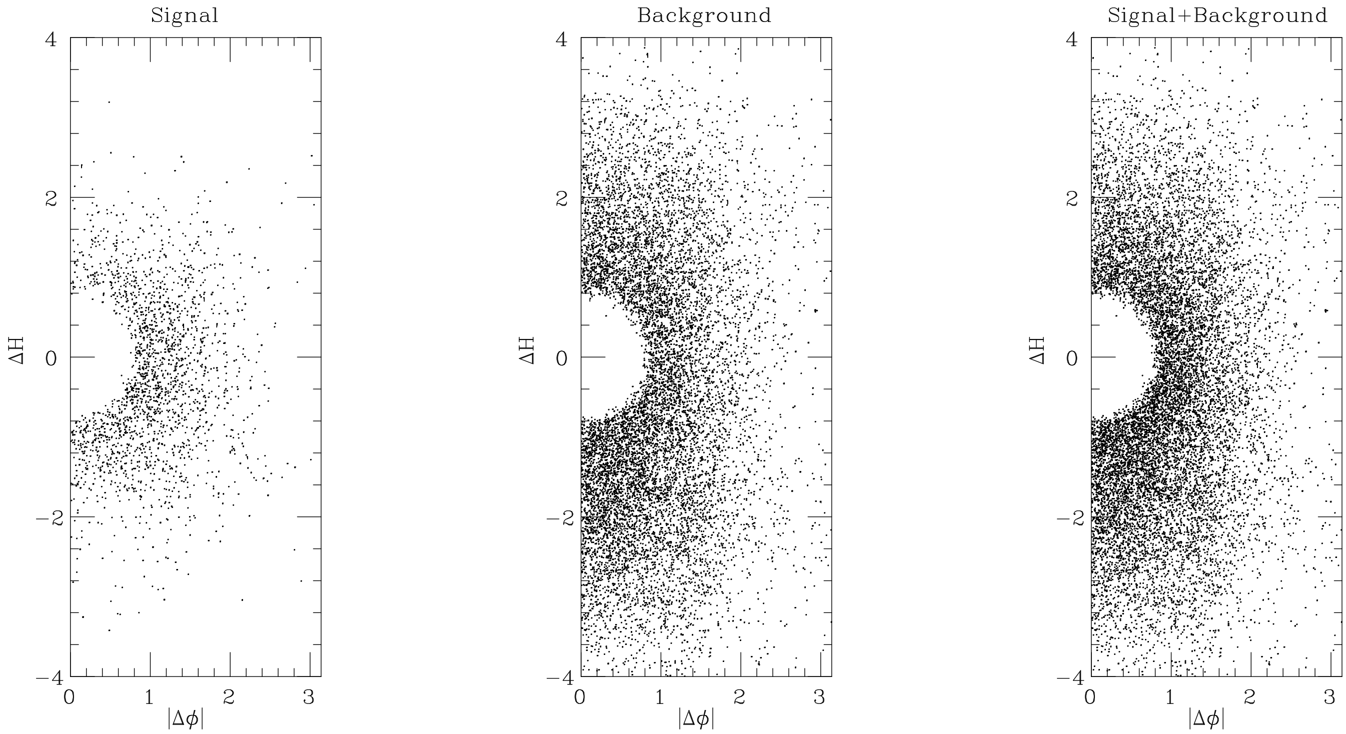
The η_3 distributions



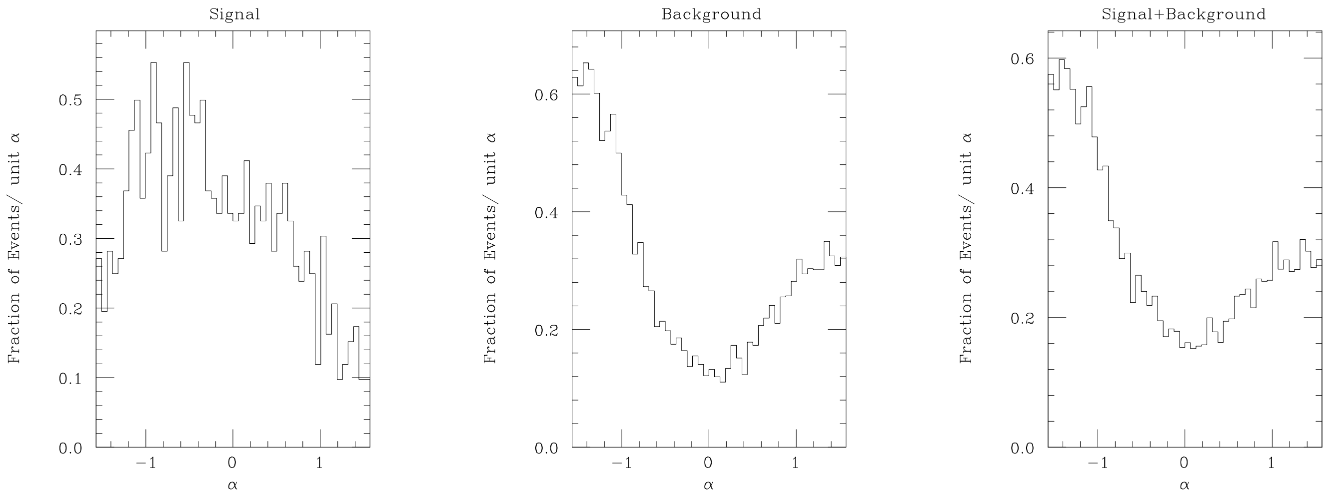
The R distributions



- **The distribution of events in the $(|\Delta\phi|, \Delta H)$ plane.**



- **The α distributions**



Conclusions

- The existing Monte Carlos for $\not{R}_p$ in hadron-hadron collisions include no hard processes and only include the decays via FORCE
- We have produced a Monte Carlo which
  1. Includes all the 2 and 3 body decays
  2. All the resonant hard processes
  3. Full treatment of the colour coherence effects in the production and decay
- This should be available soon.
- This will allow the full simulation of $\not{B}$ in hadron-hadron collisions for the first time.