Central exclusive production of long lived gluinos at the LHC

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Overview.

Gluino pair production with forward tagged Protons

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Gluino pair production with forward tagged Protons

- There is increasing interest in equipping the LHC with additional detectors $\sim 220$ m (TOTEM) and 420 m (FP420) down the beam pipe.

- One principal reason is to study the process $pp \rightarrow p + X + p$, where $X$ is a system central in rapidity and the + denote rapidity gaps.

- We consider the case where $X$ is a pair of long lived gluinos.

- Requires at least one detector at $\sim 220$ m and one at 420 m for low central system masses.
The Durham Model

• Perturbative QCD model of $pp \rightarrow p + X + p$ due to Khoze, Martin and Ryskin (hep-ph/0111078).

• We use the ExHuME Monte Carlo to calculate cross-sections (Monk and Pilkington hep-ph/0502077).

• The cross-section factorizes into two parts:
  - $d\hat{\sigma}(\hat{s}, y)$ from the hard gluon-fusion sub-process.
  - An ‘effective luminosity’ part, $d\mathcal{L}(\hat{s}, y)/dyd\hat{s}$, from the rest of the diagram.

$$\hat{s} \frac{d\sigma}{dyd\hat{s}} = \frac{d\mathcal{L}(\hat{s}, y)}{dyd\hat{s}} d\hat{\sigma}(\hat{s}, y)$$
The sub-process cross-section

- Considering scattering through very small angles and protons intact after interaction, hence:
  - There is an effective $J_z = 0$ selection rule on the fusing gluons ($z$ is along the proton collision axis).
  - Central system is produced in a colour singlet state.

- The effective luminosity is normalised such that the sub-process amplitude is averaged over gluon helicities and colours:

$$\mathcal{M}_{\text{subprocess}} = \frac{1}{N_C^2 - 1} \frac{1}{2} (\mathcal{M}^{++} + \mathcal{M}^{--})$$
Long-lived gluinos

- Possible in ‘Split Supersymmetry’ (Arkani-Hamed and Dimopoulos hep-th/0405159).
  - Scalar super-partners are massive (≫ 1 TeV).
  - Sfermions and one finely tuned Higgs are allowed to have TeV scale masses.
  - Hence the gluino can be long-lived since it decays through the scalar super-partners.
Constraints on the gluino lifetime and mass

Collider limits
If gluinos long-lived (on collider timescales) then $m_{\tilde{g}} > 170$ GeV from searches at the Tevatron (Hewett et. al. hep-ph/0408248).

Cosmological constraints on the gluino lifetime
- Early Universe cosmology can place upper bounds on the gluino lifetime.
- Plot corresponds to $\tau_{\tilde{g}} < 10^6$ years for $m_{\tilde{g}} < 500$ GeV and $\tau_{\tilde{g}} < 100$ s for $m_{\tilde{g}} > 500$ GeV (Arvanitaki et. al. hep-ph/0504210).
Possibilities

- Gluinos can be produced in a bound state, ‘Gluinonium’, or hadronize individually to ‘R-hadrons’.

- We first considered the production of the lowest accessible bound state, $^3P_0$.

- Modeled interaction using a coulomb-like potential:

\[ V(r) = -\frac{3\alpha_s}{r} \]

- Unfortunately the rate is (just) too small to be observable at the LHC. So turn our attention to open production.
The open production cross-section

- Calculated the subprocess cross-section to lowest order:

\[
\left( \frac{d\hat{\sigma}}{d\Omega} \right)_{\text{CM}} = \frac{9}{32} \frac{\alpha_s^2(\mu) m_{\tilde{g}}^2 \beta_{\tilde{g}}^3}{(m_{\tilde{g}}^2 + |\bm{p}|^2 \sin^2 \theta)^2} K,
\]

where \( \beta_{\tilde{g}} \) and \(|\bm{p}|\) are the CM speed and momentum of the gluinos.

- Following NLO calculations (Beenakker et. al. hep-ph/9610490), we evaluate the running coupling at scale \( \mu = \frac{1}{5} m_{\tilde{g}} \).

- \( K \) is a threshold correction factor which we take to be:

\[
K = \frac{Z_g}{1 - \exp(-Z_g)} \left( 1 + \frac{Z_g^2}{4\pi^2} \right) \quad Z_g = \frac{3\pi \alpha_s(\beta_{\tilde{g}} m_{\tilde{g}})}{\beta_{\tilde{g}}}.\]
R-hadrons - spectrum

- Gluinos can form colourless bound states with gluons ($\tilde{g}g$), as well as ‘R-mesons’ ($\tilde{g}q\bar{q}$) and ‘R-Baryons’ ($\tilde{g}qqq$).

- Expected that hadronic interactions in the detector will convert R-mesons $\rightarrow$ R-Baryons, but not visa versa. Therefore, most reach muon chambers as R-Baryons.

- Charged R-hadrons will look like a muon within a jet, though much slower and more isolated.
R-hadrons - detection and triggering (1)

- Difficult to trigger on, as leave little energy in the detector.

- Must use muon chambers, but R-hadrons can be very slow! Need to ensure they arrive in the same bunch crossing.

- We make the cuts:
  - Pseudo-rapidity of each R-hadron, $|\eta| < 2.4$ (limit of muon trigger)
  - Fastest R-hadron velocity $0.6 < \beta < 0.9$ (in time to trigger plus removes muon background)
  - Slower R-hadron velocity $0.25 < \beta < 0.9$ (in the same event record)
R-hadrons - detection and triggering (2)

- Only charged R-hadrons will pass the muon trigger. Should all be R-baryons at the muon chambers - multiply cross-section by 0.75 (ratio of charged to neutral R-baryons).

- Don’t need to worry about passing the muon $p_T$ trigger. Works by measuring the curvature of tracks and assumes they are muons.

- Must also include efficiencies of the muon chambers ($\sim 60\%$) and proton detector acceptance, 20-50% depending on the mass of the central system.
Backgrounds

- Two sources of background to our signal:
  - Central exclusive production of heavy quarks, which then weak decay to muons.
  - Multiple pile up events faking the exclusive process. i.e. two single diffractive events \((pp \rightarrow p + X)\) and a hard scattering \((pp \rightarrow X)\) which produces a muon.

- Kinematic matching between the proton and central detectors significantly reduces both backgrounds. Good timing from the proton detectors also significantly reduces the pile up background.

- In addition, central exclusive di-quark production is suppressed by \(m_q^2/\hat{s}\).

- The \(\beta < 0.9\) cut is extremely powerful and renders the remaining background negligibly small.
Results - the cross-section after cuts

This plot does not include the muon and proton detector efficiency factors.
• Given the small backgrounds we only need a few events.

• Expect at least 10 events over 3 year high luminosity running \((100 \text{ fb}^{-1} \text{ per year})\) for gluino masses up to 350 GeV.

• This is sufficient for a mass measurement of better than 1%!

• Mass measurement is complementary to inclusive production in this mass region (Kilian et. al. hep-ph/0408088), as we avoid systematic uncertainties due to modeling the energy loss in the detector.