MANCHESTER 1824

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Central exclusive production of long lived gluinos at the LHC

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HERA and the LHC 2006 - CERN.

Overview.

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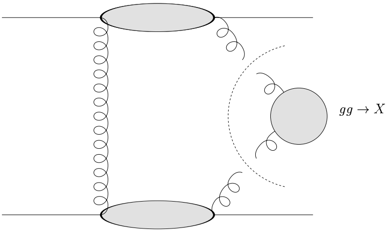
Gluino pair production with forward tagged Protons

- 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 $pp \to p + X + p$, 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 $pp \to p + X + p$ 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:

$$\mathcal{M}_{\text{subprocess}} = \frac{1}{N_C^2 - 1} \frac{1}{2} \left(\mathcal{M}^{++} + \mathcal{M}^{--} \right)$$

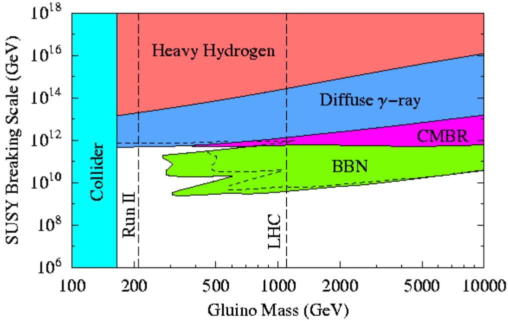
Long-lived gluinos

- Possible in 'Split Supersymmetry' (Arkani-Hamed and Dimopoulos hep-th/0405159).
  - Scalar super-partner are massive ($\gg 1$ 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:

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

  where $\beta_{\tilde{g}}$ and $|\boldsymbol{p}|$ 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:

$$K = \frac{Z_g}{1-\exp(-Z_g)}\left(1+\frac{Z_g^2}{4\pi^2}\right) \qquad Z_g = \frac{3\pi\alpha_s(\beta_{\tilde{g}}m_{\tilde{g}})}{\beta_{\tilde{g}}}.$$

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

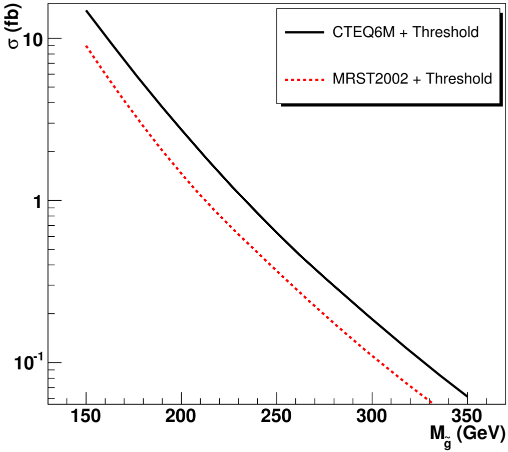
- Two sources of background to our signal:
  - Central exclusive production of heavy quarks, which then weak decay to muons.
  - Multiple pile up events faking the exclusive process. i.e. two single diffractive events ($pp \to p + X$) and a hard scattering ($pp \to X$) which produces a muon.

- 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.

Results - number of events and mass measurement

- Given the small backgrounds we only need a few events.
- Expect at least 10 events over 3 year high luminosity running ($100\ \mathrm{fb}^{-1}$ 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.