Spin Asymmetries in Squark and Gluino Production

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FUTURE pp AND SPIN PHYSICS AT RHIC

Outline

1. Introduction
   - SUSY
   - SUSY Particle Decay
2. Asymmetries
   - Production Process
   - Spin Asymmetries
3. Results
   - Scale and Particle Mass Dependences
   - Rapidity and Transverse Momentum Distributions
   - Statistical Accuracy

What is Supersymmetry

- Symmetry relating fermions and bosons
- New particles are predicted with
  - same quantum numbers (same gauge interactions)
  - spin differs by 1/2
- $q \rightarrow \tilde{q}$ (squark) and $g \rightarrow \tilde{g}$ (gluino)
- No new particles have been detected so far
  $\Rightarrow$ symmetry is broken
- Supersymmetry is a good candidate for new physics beyond the standard model because it
  - can be compatible with GUT
  - can explain the low scale of electroweak symmetry breaking
  - can provide candidates for dark matter

Common properties

- There are a lot of SUSY models
- Common features of most models
  - Lightest Supersymmetric Particle (LSP) is color and electrically neutral and weakly interacting
    $\Rightarrow$ LSP escapes the detector
  - $m_{\tilde{q}} > m_{\tilde{g}}$
  - At hadron colliders most particles produced are gluinos and squarks
  - The QCD production rate of squarks and gluinos is mainly a function of the strong coupling and their masses

MSSM

- Simplest model (smallest particle content) is the MSSM
- It is based on the assumptions
  - Unification of scalar masses
  - 2 Higgs doublets
  - R-Parity
  - ...
- Tevatron predicts mass bounds for the MSSM
  - squark mass $m_{\tilde{q}} > 250$ GeV
  - gluino mass $m_{\tilde{g}} > 195$ GeV

$\Rightarrow$ the MSSM squarks and gluinos will not be produced at RHIC

Non Minimal Supersymmetric Models

These mass bounds are substantially weakened in less restrictive models

- More Higgs particles
- More superparticles
- R parity violating models
  - R parity is weakly violated
  - new vertices, but not relevant for production
- The QCD production rate of squarks and gluinos is a function of (at LO)
  - strong coupling
  - their masses

$\Rightarrow$ non MSSM squarks and gluinos could be produced at RHIC 

Squark Decay

Squark Decay (assuming R-Parity)

- if $m_{\tilde{q}} > m_{\tilde{g}}$: SU(3) decay into gluino and quark

$$\tilde{q} \to q\tilde{g}$$

- if $m_{\tilde{q}} < m_{\tilde{g}}$: SU(2) decay into neutralino or chargino

$$\tilde{q} \to q\,\tilde{\chi} \qquad \text{or} \qquad \tilde{q} \to q'\tilde{W} \to q'\,l\,\tilde{\chi}$$

Gluino Decay

- Gluinos can only decay through strong interaction

$$\tilde{g} \to \bar{q}\tilde{q}, q\bar{\tilde{q}}$$

The squark is either

  - virtual when $m_{\tilde{g}} < m_{\tilde{q}}$
  - real when $m_{\tilde{g}} > m_{\tilde{q}}$

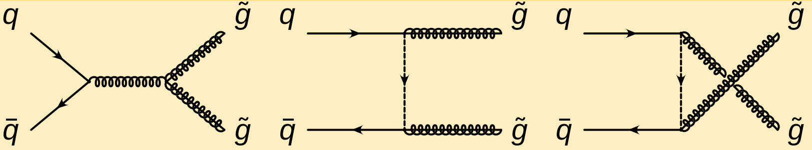
$$\tilde{g} \to \bar{q}\tilde{q}, q\bar{\tilde{q}} \to \begin{array}{l} q\bar{q}\tilde{\chi}, \\ q\bar{q}'\tilde{W} \to q\ q'\ l\ \tilde{\chi} \end{array}$$

- Trough squark-quark loop $\tilde{g} \to g\ \tilde{\chi}$

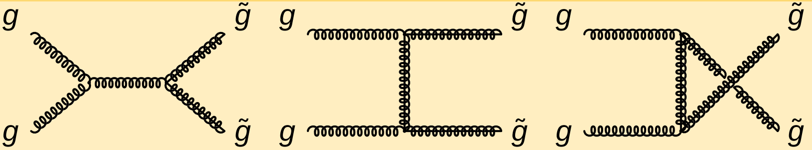
Gluino Production

- The gluinos are Majorana fermions

$q + \bar{q} \to \tilde{g} + \tilde{g}$



$g + g \to \tilde{g} + \tilde{g}$

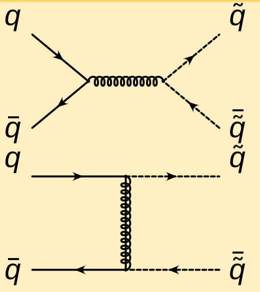


- Same charged lepton signature

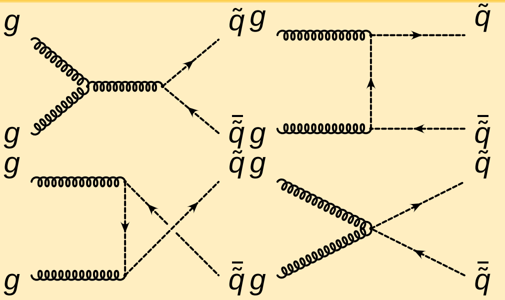
Squark-Antisquark Production

- We consider only 5 light squark flavors (no top) with degenerated mass $m_{\tilde{q}}$

$q + \bar{q} \to \tilde{q} + \bar{\tilde{q}}$



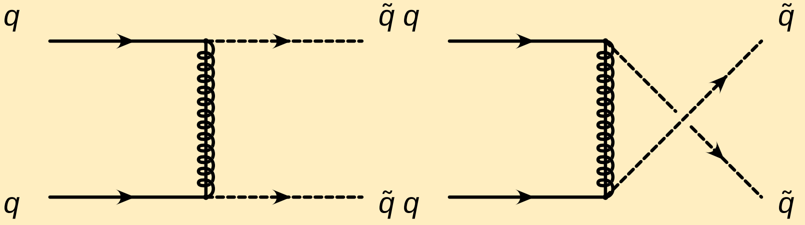
$g + g \to \tilde{q} + \bar{\tilde{q}}$



Squark-squark Production

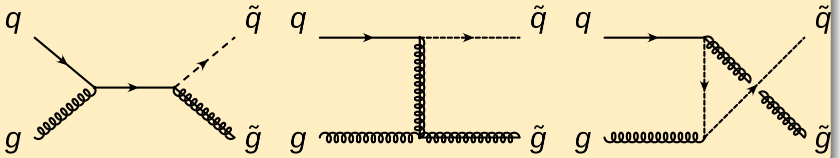
- Since the gluinos are Majorana fermions
  $\Rightarrow$ fermion number conservation can be violated

$q + q \rightarrow \tilde{q} + \tilde{q} \quad (\bar{q} + \bar{q} \rightarrow \bar{\tilde{q}} + \bar{\tilde{q}})$



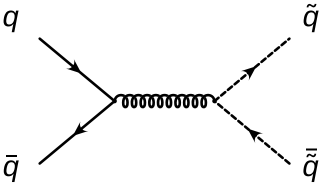
Squark-Gluino Production

$q + g \rightarrow \tilde{q} + \tilde{g}$



- Same charged lepton signature

Partonic cross sections



$$\rightarrow \begin{cases} |M^{++}|^2 \\ |M^{-+}|^2 \\ |M^{+-}|^2 \\ |M^{--}|^2 \end{cases}$$

$+, -$: long. spin

- Total partonic cross section

$$\hat{\sigma} = \int \frac{|M^{++}|^2 + |M^{--}|^2 + |M^{+-}|^2 + |M^{-+}|^2}{F} dQ$$

- Partonic polarization difference

$$\Delta\hat{\sigma} = \int \frac{|M^{++}|^2 + |M^{--}|^2 - |M^{+-}|^2 - |M^{-+}|^2}{F} dQ$$

Hadronic cross sections II

$$A_{\mathrm{th}} = \frac{\int_0^1 dx_1 dx_2 \Delta\hat{\sigma}(x_1,x_2)\Delta f_{p_1}(x_1)\Delta f_{p_2}(x_2)}{\int_0^1 dx_1 dx_2 \hat{\sigma}(x_1,x_2) f_{p_1}(x_1) f_{p_2}(x_2)}$$

$$f = f^+ + f^-, \qquad \Delta f = f^+ - f^-$$

- The asymmetry is independent of the absolute normalization
- The asymmetry is less sensitive to higher order corrections

We consider

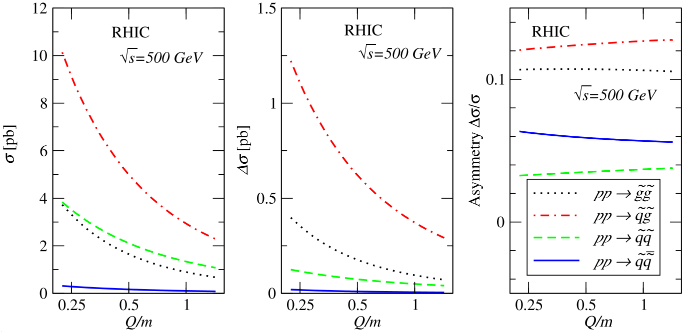
- 5 light quark flavors (no top quarks)
- Leading order (LO) cross section

Scale dependence

- Factorization scale=renormalization scale=Q

Parameters

- $\sqrt{S} = 500$ GeV
- $m_{\tilde{g}} = 80$ GeV
- $m_{\tilde{q}} = 100$ GeV



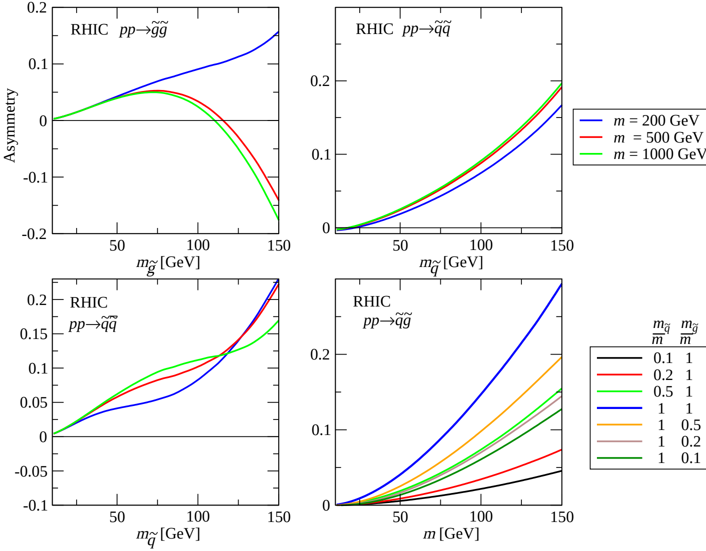
- The scale dependence of the asymmetry is weaker than for the total production cross section.

$\Rightarrow$ Indication for small corrections due to higher order corrections

Sparticle Mass Dependence

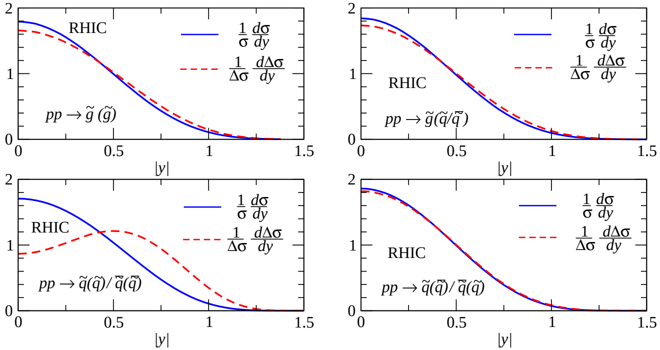
Parameters

- $\sqrt{S} = 500$ GeV



Rapidity Distribution

$\sqrt{S} = 500$ GeV, $m_{\tilde{g}} = 80$ GeV, $m_{\tilde{q}} = 100$ GeV

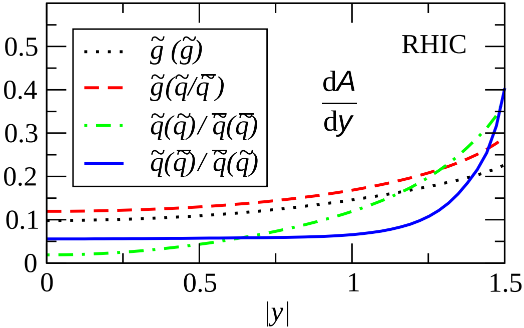


- The rapidity distribution of the asymmetries largely follows the distribution of the total cross section.

Asymmetry as Function of the Rapidity

Parameters

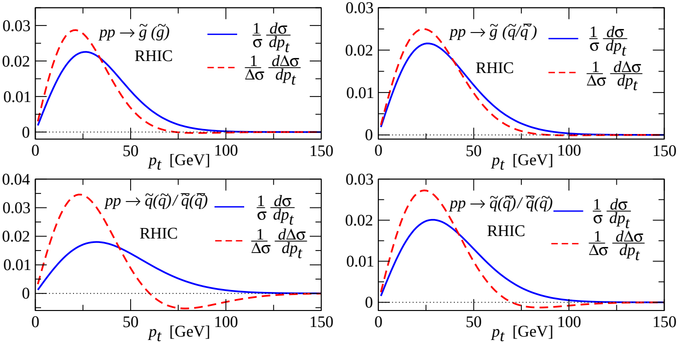
- $\sqrt{S} = 500$ GeV
- $m_{\tilde{g}} = 80$ GeV
- $m_{\tilde{q}} = 100$ GeV



- The asymmetry almost constant over a large rapidity range
- The asymmetry grows for large rapidities

Transverse Momentum Distribution

$\sqrt{S} = 500$ GeV, $\quad m_{\tilde{g}} = 80$ GeV, $\quad m_{\tilde{q}} = 100$ GeV

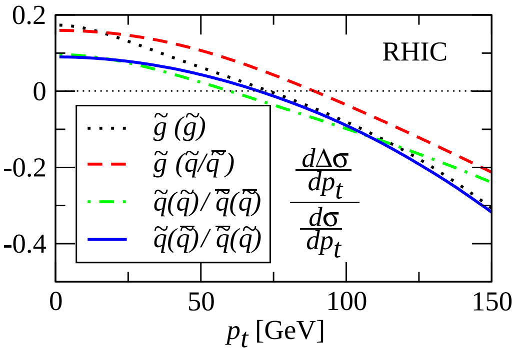


- The asymmetry is positive for small p_T and negative for high p_T

Asymmetry as Function of the Transverse Momentum

Parameters

- $\sqrt{S} = 500$ GeV
- $m_{\tilde{g}} = 80$ GeV
- $m_{\tilde{q}} = 100$ GeV



- The asymmetry changes sign for high p_T

Statistical Accuracy I

Asymmetry

$$A_{\text{exp}} = \frac{1}{P_1 P_2} \frac{N_+ - N_-}{N_+ + N_-}$$

$$N_+ = N^{++} + N^{--} \quad N_- = N^{+-} + N^{-+}$$

- N^{++}, ... ,N^{--}: number of counts (normalized)
- P_1, P_2: Polarization of the beams

Statistical error

$$\Delta A^2_{\text{exp}} = \frac{4(N_+ N_-)}{N^2 P_1^2 P_2^2} = \frac{1}{N P_1^2 P_2^2} - \frac{A^2}{N^2} \qquad \Delta A_{\text{exp}} \simeq \frac{1}{\sqrt{N}} \frac{1}{P^2}$$

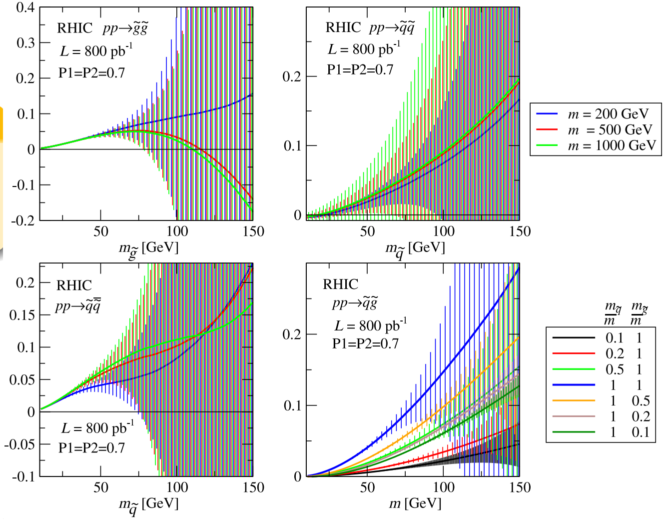
Statistical Accuracy II

RHIC

$\sqrt{S} = 500$ GeV

Parameters

- Design luminosity $L = 800\ \text{pb}^{-1}$ (4 years)
- Polarization $P = 0.7$



Conclusion

- The asymmetries for the $\tilde{q}\tilde{q}$, $\tilde{q}\bar{\tilde{q}}$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$ production are sizable for a certain range of sparticle masses
- They only depend on the masses of the squarks and gluinos
- These asymmetries have a small scale dependence and are independent of the absolute normalization
- There is a range where the asymmetry might be measurable (from the statistical point of view) for the design luminosity and polarization

Outlook

- The mass range of sparticles where the asymmetries are measurable is unlikely
- Measuring asymmetries for sparticle masses of about 200 GeV would require the polarization of Tevatron or LHC

Further possibilities

- Some final states may be indistinguishable
  $\Rightarrow$ sum of the processes better statistics
- It is possible to obtain event samples significantly enriched in L- or R- squarks

Further Hope

- More luminosity
- Higher center of mass energy
- Better polarization

Top-Squark Production

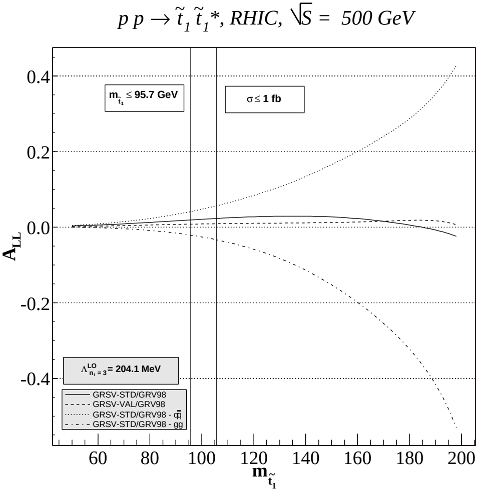
Non-Diagonal and Mixed Squark Production at Hadron Colliders **PRD 72,2005**

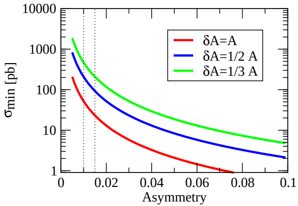
G. Bozzi, B. Fuks, M. Klasen

What is different?

- L- and R-Squarks mixing is proportional to the mass of the corresponding quark
  - mixing negligible for u, d, s, c, b
  - mixing not negligible for t
- Mass eigenstates $\tilde{t}_1, \tilde{t}_2$
- Lighter $\tilde{t}_1$ is in many models the lightest squark
- Total and polarized cross sections depend on the mixing angle

Their results





$L = 800pb^{-1}$, $P = 0.7$

- $m_{t_1} < 95.7$ excluded (PDB)
- Cross section orders of magnitude too small

Thanks for your attention