Rapidity Gap Events in Squark Pair Production at the LHC

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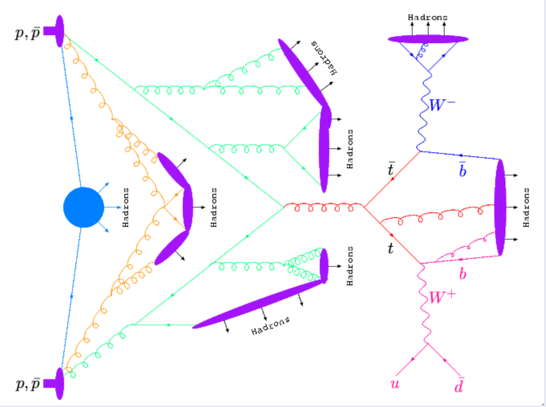
(arXiv: 0709.2544 & 0909.2595)

Search for Supersymmetry

- no direct experimental evidence for SUSY until now
- expectation that some of the SUSY particles will be found at the Large Hadron Collider (LHC) at CERN

Proton–proton collision at the LHC:



(P.Richardson)

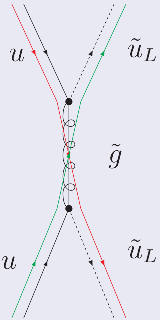
Squark Pair Production at the LHC

- (hopefully) a successful second LHC run
- TeV scale supersymmetry will be decisively tested at LHC
- even heavy squarks still have a reasonable cross section:
  - cross section is $\mathcal{O}(\alpha_s^2)$
  - many final states are accessible from two valence quarks

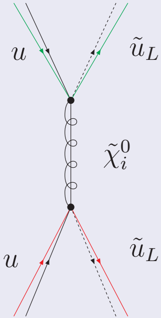
Also EW corrections at leading order might be important since:

- the interference terms between QCD and EW can be quite sizable
- an increase up to 20% for mSUGRA scenarios and two SU(2) doublet squarks
- an increase up to 50% for scenarios without gaugino mass unification and two SU(2) doublet squarks

Color connection of the final state squarks I: CNS and CS exchange



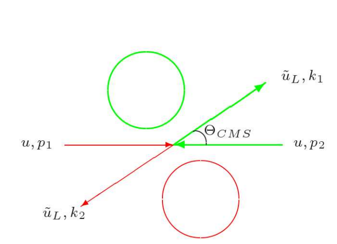
(a) color connected



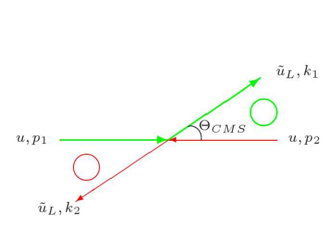
(b) not color connected

- **color connected:** color non-singlet CNS (gluino) exchange
- **not color connected:** color singlet CS (neutralino) exchange

Color connection of the final state squarks II: accelerated color charge in the CMS



(c) CNS-exchange



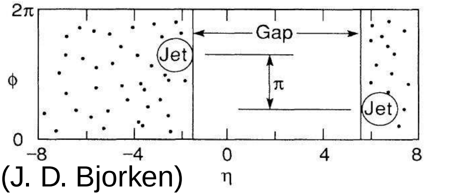
(d) CS-exchange

- t-channel: small Θ_{CMS} is preferred
- CNS-exchange: color charge scattered over angle $\pi - \Theta_{CMS}$
  $\Longrightarrow$ QCD radiation between the two outgoing squarks
- CS-exchange: color charge scattered over angle Θ_{CMS}
  $\Longrightarrow$ QCD radiation between squarks and beam remnants

Rapidity gap events:

- squarks decay and hadronize $\Rightarrow$ two high energetic jets
- not color connected (EW) events:
  - low particle activity/energy deposit between the two jets
  - rapidity region free of energy deposit (hadrons)

$\Longrightarrow$ Rapidity Gap Event



(J. D. Bjorken)

$\Longrightarrow$ Measurement of EW SUSY couplings

However:

- underlying event (UE) can fill up the gap
- uncertainties of the Monte Carlo generators

Numerical simulation:

- squark decay, hadronization, jet reconstruction & underlying event
- SPS1a $\Longrightarrow$ cross section is enhanced by about 13% (for LL)
- s-channel contributions are neglected
- integrated luminosity of $40fb^{-1}$

Used cuts:

- two hardest jets: $E_T > 100\text{GeV}$;
- missing $E_T > 100$ GeV
- rap gap between the two main jets: $\Delta\eta > 3.0$
- assume tau identification efficiency of 100%
- gap region defined as: $\min[\eta(j_1), \eta(j_2)] + 0.7 \leq \eta \leq \max[\eta(j_1), \eta(j_2)] - 0.7$
- at least two charged leptons of same sign $\Longrightarrow$ single out $SU(2)$ squark pairs

First observable:

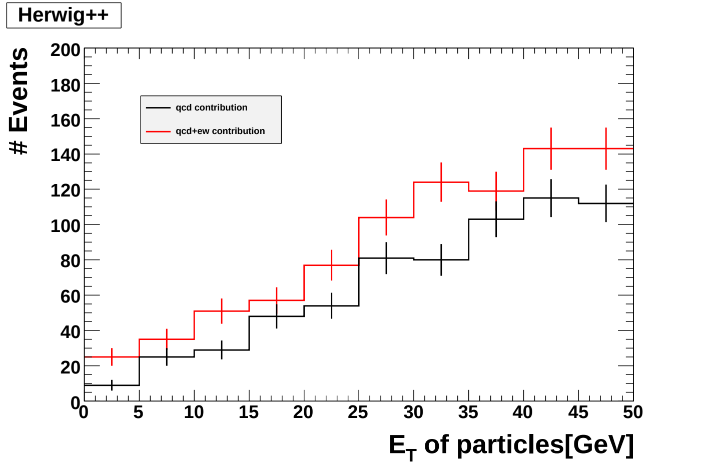
$E_{T,\mathrm{particles}}^{\mathrm{gap}}$:

- total transverse energy deposited in the gap region
- include photons and hadrons in the event (after hadronization and decay of unstable hadrons)
- does *not* include the leptons produced in $\tilde{\chi}^0$ and $\tilde{\chi}^\pm$ decays.

Inclusion of EW contributions:

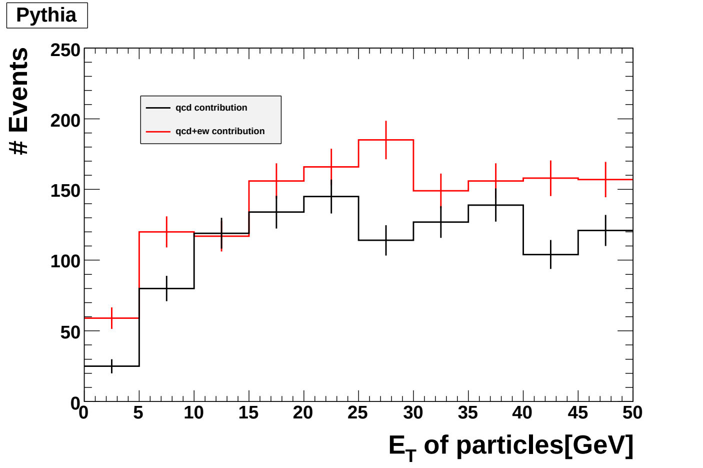
$\Longrightarrow$ should lead to increase of events with low $E_{T,\mathrm{particles}}^{\mathrm{gap}}$

Herwig++: E_T of all particles in the gap region



- including EW contributions increases the # of events in all bins
- first bin: inclusion of CS contributions increases the number of events by a factor of 2.8 ± 1.1

PYTHIA: E_T of all particles in the gap region



- EW contributions increases the # of events in nearly all bins
- first bin: inclusion of CS contributions increases the # of events by a factor of 2.36 ± 0.56

Comparison PYTHIA and Herwig++:

CS exchange leads to “gap” events with low energy deposite, BUT:

- PYTHIA predicts many more gap events
- PYTHIA: distribution quite flat beyond 20GeV
- Herwig++: distribution flattens out only at about 40GeV

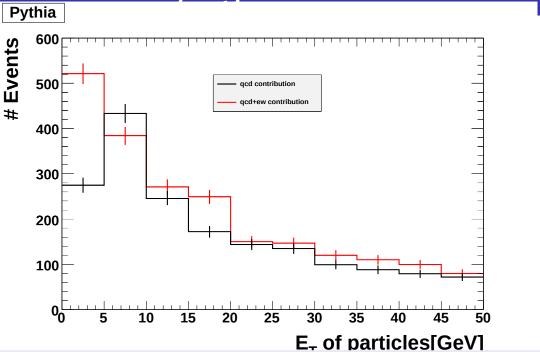
using different models for parton shower, hadronization & underlying event:

$\Longrightarrow$ difference between the two generators is as large as the effect from the CS events

$\Longrightarrow$ after you get first real data:

- use the higher bins to decide which generator describes the data better
- tune the generators to the data

PYTHIA without underlying event:



Low number of gap events $\Longrightarrow$ this is partly caused by UE:

- describes beam remnants
- with little or no phase space correlation with the primary jets

$\Longrightarrow$ deposit a significant amount of transverse momentum into the gap

- 521 (278) entries in the first 5 GeV bin for QCD+EW (QCD) simulation, as compared to 59 (25)
- UE thus leads to a gap "survival probability" of $\sim$ 10% at the LHC

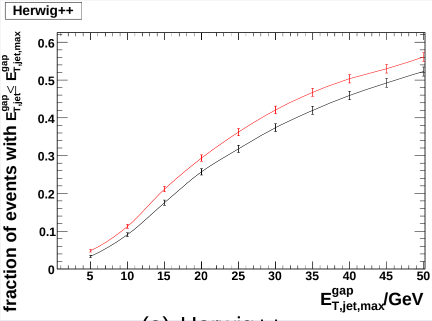
Second main observable:

fraction of events where most energetic jet in the gap region has $E_{T,jet}^{gap} \leq E_{T,jet,max}^{gap}$ (normalized to one)

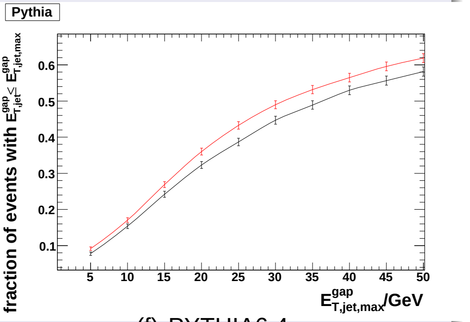
$\Longrightarrow$ reduce effect of underlying event:

- UE by itself generates few, if any, reconstructable jets
- consider only jets with $E_T \geq 5$ GeV $\Longrightarrow$ cut against UE
- reconstructed jets may also contain a few particles stemming from the underlying event

Minijet-veto against underlying event



(e) Herwig++



(f) PYTHIA6.4

- significant increase of the fraction of events without jet in the gap region once EW, CS exchange contributions are included
- effect is statistically most significant for $E_{T,\text{jet,max}}^{\text{gap}} \sim$ 20 to 40 GeV

Tuning with SM QCD

Problem:

Herwig++ vs. PYTHIA: systematical differences larger than the physical ones

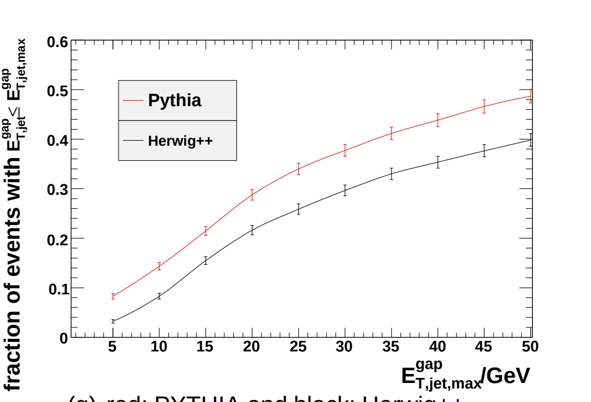
However:

PYTHIA and Herwig++ make similarly different predictions for standard QCD di–jet events

generated standard QCD di–jet events, where:

- p_T of the jets $>$ 500 GeV
  $\Longrightarrow$ kinematics & the relevant Bjorken$-x$ values are comparable to squark pair events
- We include ALL standard QCD 2 $\rightarrow$ 2 processes
- the large p_T & required large rapidity distance between hardest jets, require quite large Bjorken$-x$ values
  $\Longrightarrow$ enhances the contribution from $qq \rightarrow qq$ scattering: has same color structure as $qq \rightarrow \tilde{q}\tilde{q}$ in SUSY QCD

Minijet-veto for pure SM QCD 2 $\longrightarrow$ 2 processes



(g) red: PYTHIA and black: Herwig++

- PYTHIA again predicts less radiation
- threshold energy of 20 GeV: ratio of about 1.3
- reduction of systematical differences after tuning with SM data should be possible