Radiative Effects on Squark Pair Production at e^+e^- Colliders

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Introduction

* to understand the SUSY breaking mechanism
$\Longrightarrow$ precision measurement of masses and couplings

$$m^2_{\tilde{u}_L} = M^2_{\tilde{Q}} + m^2_u + \cdots$$

* Hadron colliders are good for discovery but not for precision measurements due to large backgrounds and cascade decays.

* Our goal is to study how well squark masses can be measure in e^+e^- colliders.

* At e^+e^-machines, masses can be determined through threshold scans or kinematical fittings.

* Kinematical fittings allow to study many different particles and also to determine the masses of decay products.

* We considered only the the case

$$\tilde{q} \longrightarrow q + \tilde{\chi}^0_1 \text{ (stable)}$$

* At e^+e^-machines

$$\begin{aligned} e^+e^- &\to \tilde{q}\tilde{q}^* \\ &\to q\,\tilde{\chi}^0_1\;\bar{q}\,\tilde{\chi}^0_1 \end{aligned}$$

Assuming R–parity conservation the $\tilde{\chi}^0_1$ leaves no signal in the detector.

* Feng and Finnell studied the jet energy distribution and the minimum squark mass distribution $m_{\tilde{q},min}$. (explain)

$$\begin{aligned} m^2_{\tilde{q},min} &= E_b^2 - |\vec{p}_3|^2 - |\vec{p}_4|^2 \\ &+2|\vec{p}_3||\vec{p}_4|(\cos\gamma\cos\delta - \sin\gamma\sin\delta) \end{aligned}$$

* Considering only detector resolution, they concluded that we should be able to determined the squark mass with an error of 0.5% for squarks masses of 200 GeV at a collider with $\sqrt{s} = 500$ GeV and $\mathcal{L} = 20$ fb^{-1}.

* We updated their analysis including ISR of photons, emission of hard gluons during the pair production, and gluon emission in the squark decay. For "stops" we also included fragmentation effects.

Radiative effects

$\ast$ ISR radiation of photons was treated using the leading-log resummed effective $e^{\pm}$ distribution function. We did not include beamstrahlung. The main effect of ISR is the cross section reduction by $\simeq 15\%$.

$\ast$ $e^+e^- \to \tilde{q}\tilde{q}^* g$: We regularized the IR divergences requiring $E_g \geq E_g^{min}$. We introduced QCD virtual corrections to $e^+e^- \to \tilde{q}\tilde{q}^*$ to cancel the dependence on the IR regulator. Hikasa

$\ast$ For $m_{\tilde{q}} = 300$ GeV, $\sqrt{s} = 800$ GeV, and $E_g^{min} = 1$ GeV $\Longrightarrow$ 18% of all squark pairs are produced together with a "hard" gluon.

$\ast$ Gluon radiation in squark decay: we used the $\tilde{q} \to q\tilde{\chi}_1^0 g$ matrix element given by Hikasa-Nakamura. We regulated the IR divergences using a gluon mass m_g.

$\ast$ The QCD virtual corrections cancel the IR divergence, however we are left with UV ones. These are canceled taking into account the full QCD-SUSY corrections. $\Longrightarrow$ the results depend on $\ln m_{\tilde{g}}$. (one extra parameter)

* Taking $m_g = 1$ GeV, $m_{\tilde\chi} = 50$ GeV, and $m_{\tilde g} = 450$ GeV $\Longrightarrow$ 90% of all squark decays contain a gluon.

* $\tilde t_1$ fragmentation: $\tilde t_1$ can be quite long–lived. It will then fragment into a "stop meson" before its decay. [Hikasa and Kobayashi]

* We modeled $\tilde t_1$ fragmentation using the Peterson fragmentation function

$$D_{\tilde t}(x) = \frac{1}{N} \frac{1}{x\left(1 - \frac{1}{x} - \frac{\epsilon_{\tilde t}}{1-x}\right)^2} \quad ,$$

where $\epsilon_{\tilde t} = \epsilon / m^2_{\tilde t_1}$, with $\epsilon \sim 0.1$ to 0.5 GeV^2.

* Unfortunately the choice of the fragmentation variable x is ambiguous for massive particles. We can take, for instance,

$$x = x_E \equiv \frac{E_{\tilde t_M}}{E_{\tilde t_1}} = \frac{2E_{\tilde t_M}}{\sqrt{s}} \quad ,$$

* Energy–momentum conservation is only global $\Longrightarrow$ fragmentation process changes the 4–momenta of all partons.

* The final results are rather insensitive to the choice of x

Results

* The emission of hard gluons can lead to final states with up to 5 visible partons.

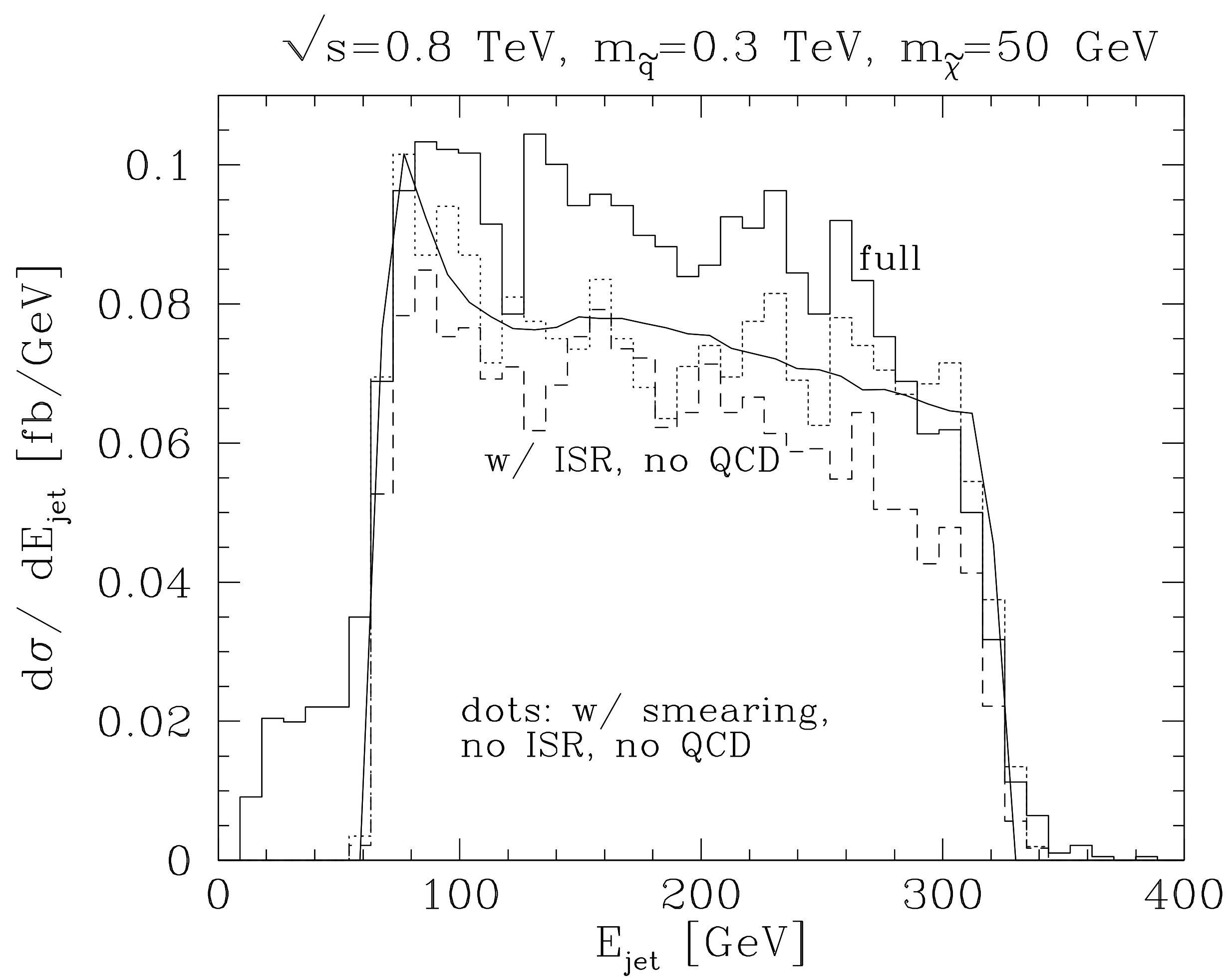
* We smeared the parton energy with a Gaussian error

$$\frac{\delta(E)}{E} = \frac{0.3}{\sqrt{E}} \oplus 0.01$$

* We applied the following cuts:

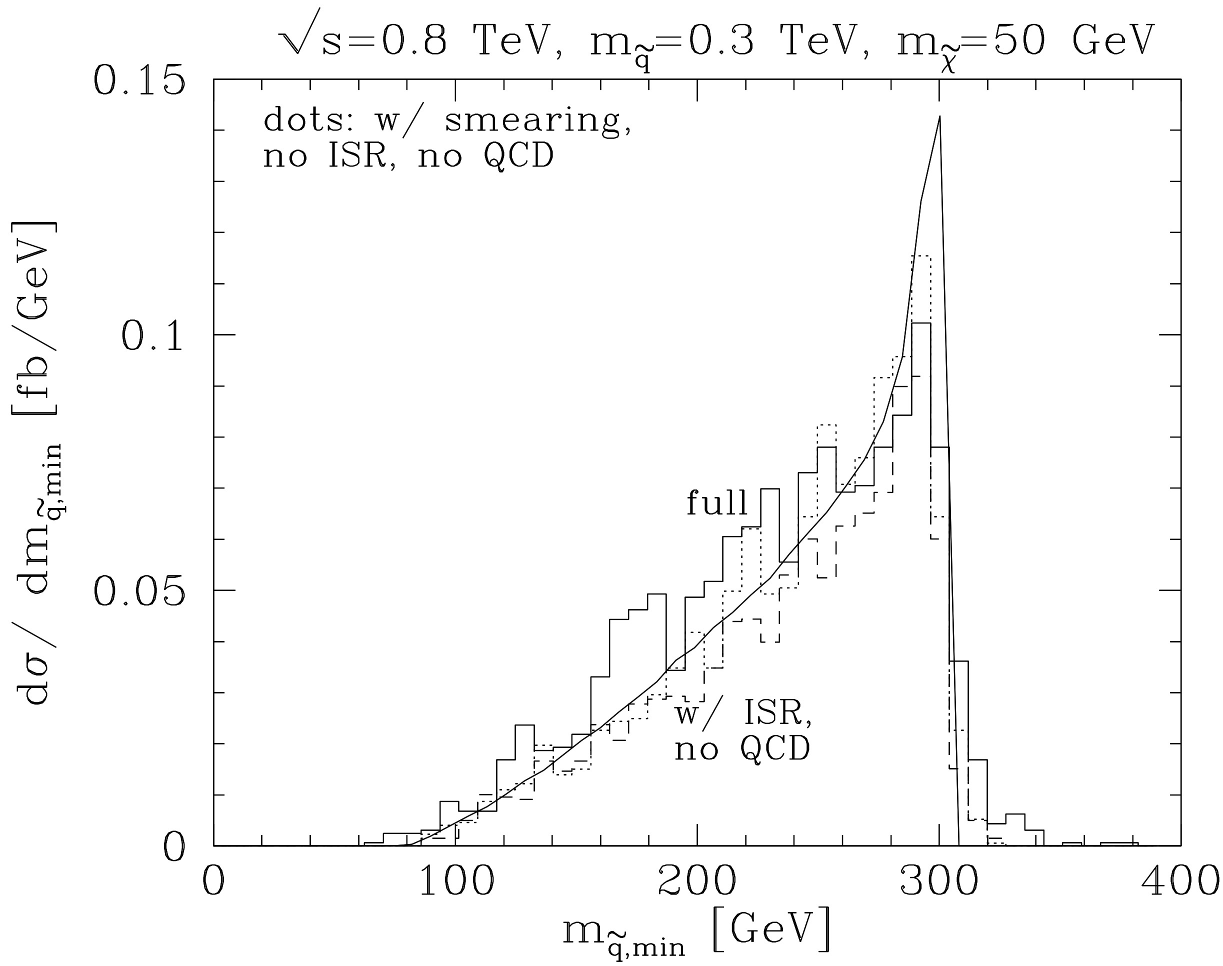
  - Our acceptance region is defined by $|\cos\theta| \leq 0.90$;
  - Using the Durham algorithm we group the partons into 2 jets;
  - The jet energies should be $E_j \geq 15$ GeV;
  - acoplanarity angle between the jets $\geq 30°$;
  - missing transverse momentum $\not{p}_T > 56$ GeV.

* Jet energy distribution



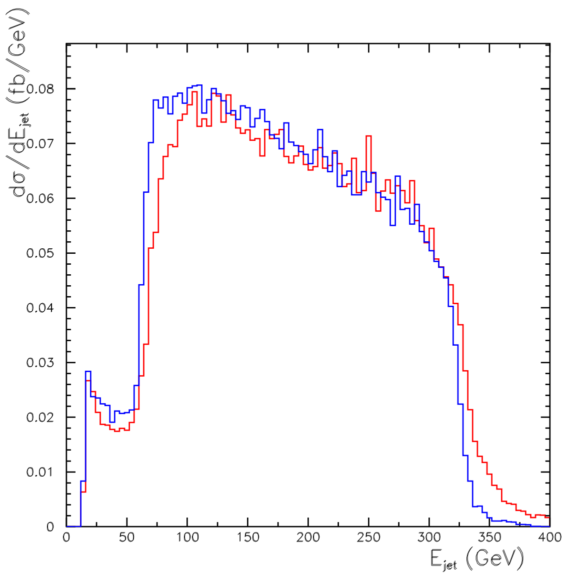
- Cuts distort the spectrum, eg small peak the the lower edge.
- $\sigma = 17.0$ (11.7) fb before (after) cuts, including all effects.
- ISR and detector resolution don't change the shape.
- Gluon emission changes the shape.
- Gluon emission increases σ by 24% (42%) before (after) cuts.

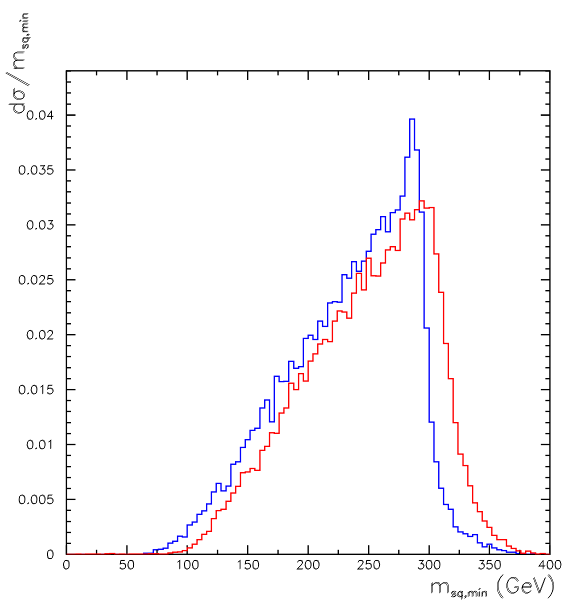
* $m_{\tilde{q},min}$ distribution:



* small leakage beyond the nominal end point ($m_{\tilde{q}}$);
* radiative effects broadens the distribution $\Longrightarrow$ increase the error on $m_{\tilde{q}}$.

* Adding fragmentation for stops:



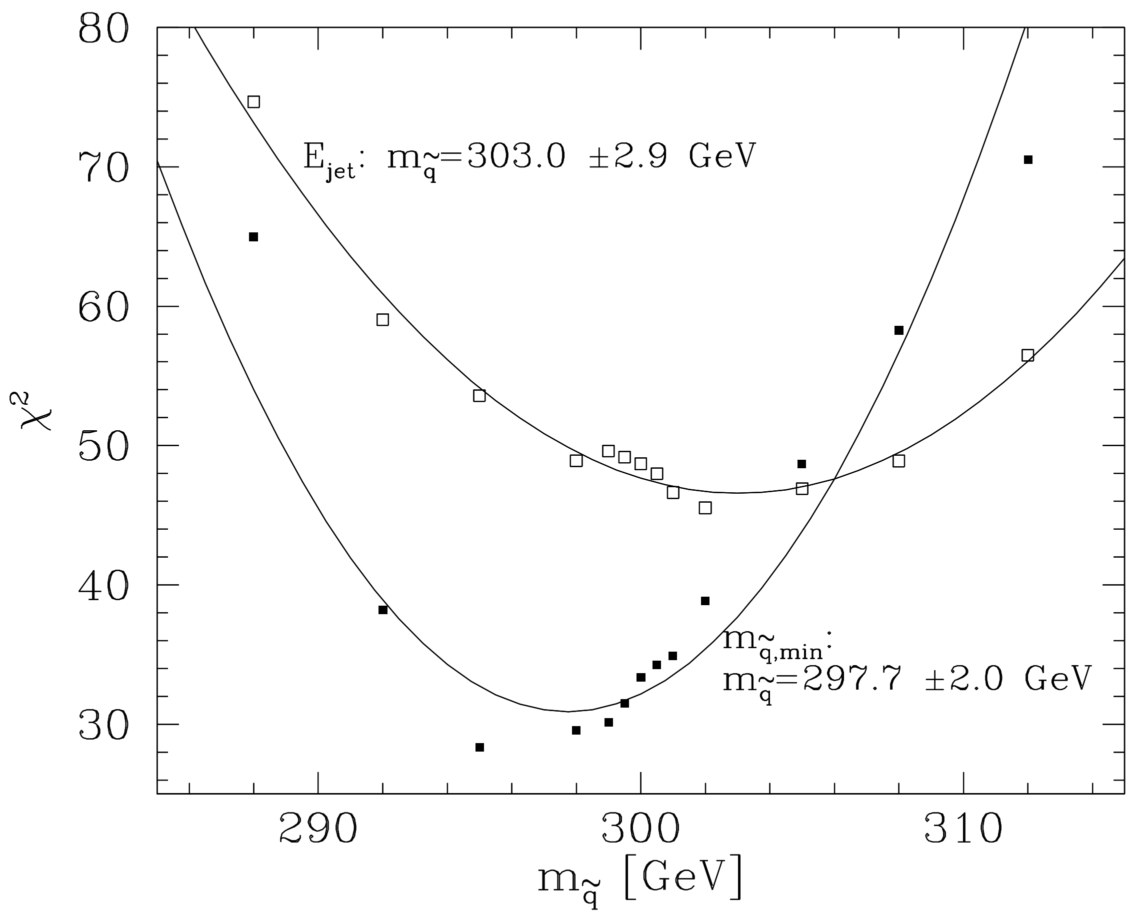


* E_{jet} distribution slightly modified;

* $m_{\tilde{q},min}$ spectrum gets broader.

less energy is lost with the LSP.

* Fitting procedure: Generated a luminosity of 50 fb^{-1} (852 events before cuts) and compared the data to 13 templates with different $m_{\tilde{q}} \implies \chi^2(m_{\tilde{q}})$.



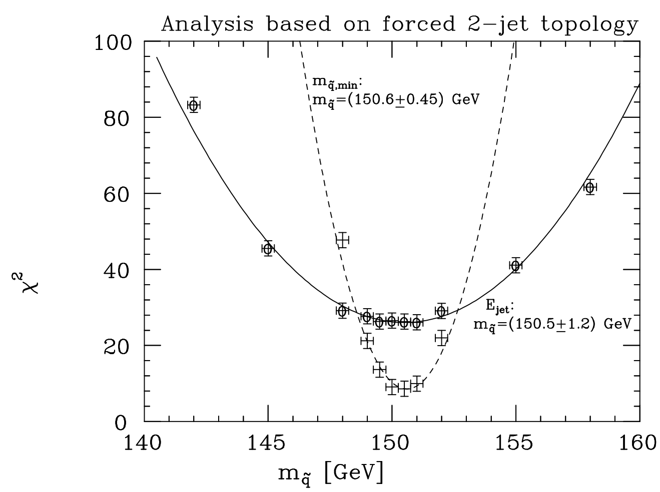
* A parabola is fitted to $\chi^2(m_{\tilde{q}}) \implies$ its minimum $\implies$ measured $m_{\tilde{q},0}$.

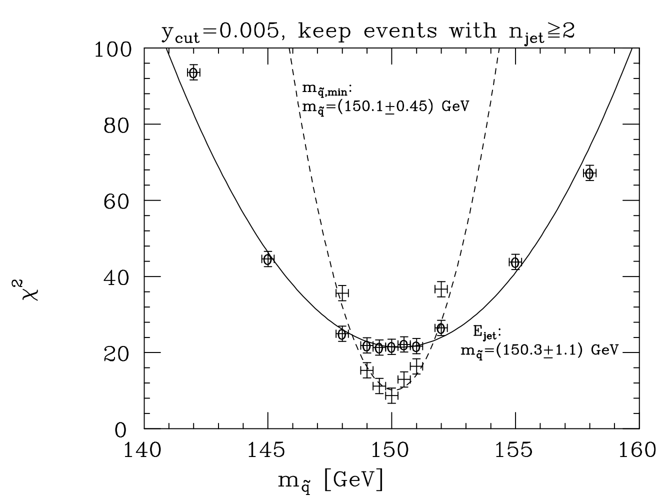
$\ast$ 1σ error: $\chi^2(m_{\tilde{q},0} \pm \delta m_{\tilde{q}}) = \chi^2_{min} + 1$.

$\ast$ $m_{\tilde{q},min}$ leads to better results than E_{jet}.

$\ast$ Just 50 fb^{-1} are enough to have statistical errors on $m_{\tilde{q}}$ less than 1%.

$\ast$ Details of the jet finding algorithm are not important.





Conclusions

* $m_{\tilde{q}}$ can be well determined even in the presence of radiative effects.

* Radiative effects lead to new systematic errors, eg α_s.

* We still have to study the effect of hadronization and uncertainties on the LSP mass.