Electroweak Contributions to Squark Pair Production

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Outline

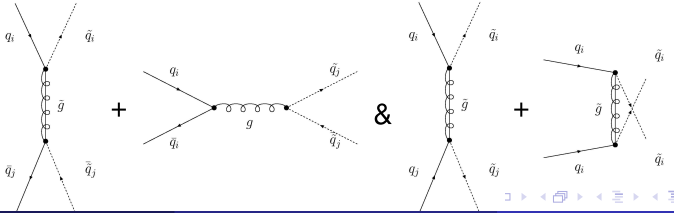
Squark Pair Production at the LHC

- large production cross section due to several production channels
- significant amount of first and second generation squarks
- cross section is dominated by SUSY QCD contributions

Production proceeds via:

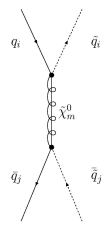
$$\begin{aligned} q_i q_j &\rightarrow \tilde{q}_i \tilde{q}_j \\ q_i \bar{q}_j &\rightarrow \tilde{q}_i \bar{\tilde{q}}_j, (i \neq j) \\ q_i \bar{q}_i &\rightarrow \tilde{q}_j \bar{\tilde{q}}_j \\ gg &\rightarrow \tilde{q}_i \bar{\tilde{q}}_j \quad i, j : \text{flavor indices}, q = u, d, \text{(S.Dawson et al.)} \end{aligned}$$

QCD contributions:



Electroweak Contributions

Taking into account the exchange of electroweak gauginos $\tilde{\chi}^+_n, \tilde{\chi}^0_m$:



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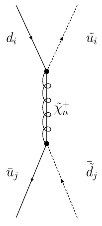

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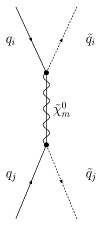

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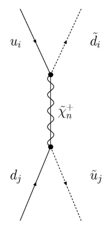

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(related work:Klasen et al.; 0704.1826 [hep-ph])

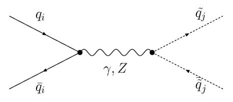
Rough estimate: $\frac{\alpha_s(m_Z)}{\alpha_W(m_Z)} = \frac{\alpha_s(m_Z)\sin^2(\theta_W)}{\alpha(m_Z)} = 127 \cdot 0.23 \cdot 0.12 \approx 4$

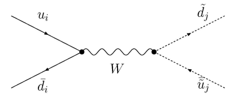
α_s: strong coupling constant

α: fine-structure constant

$\Longrightarrow$ Terms like $|\mathcal{M}^t_{\tilde{\chi}^0_m}|^2$ give only a marginal contribution ($\approx 1/16$)

$\boxed{\text{But:}}$ We have in addition interference between diagrams with gluino and gaugino exchange ($\approx 1/4$)

For complete calculation of the s-channel contributions you need in addition: 

, 

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New Interference Terms

$uu \to \tilde{u}\tilde{u}$:

$$
\begin{aligned}
|\mathcal{M}^t_{\tilde{g}} + \mathcal{M}^t_{\tilde{\chi}^0_m} + \mathcal{M}^u_{\tilde{g}} + \mathcal{M}^u_{\tilde{\chi}^0_n}|^2 \quad = \quad & |\mathcal{M}^t_{\tilde{g}}|^2 + |\mathcal{M}^t_{\tilde{\chi}^0_m}|^2 + |\mathcal{M}^u_{\tilde{g}}|^2 + |\mathcal{M}^u_{\tilde{\chi}^0_n}|^2 + \\
& \underbrace{2\mathcal{M}^t_{\tilde{g}}\mathcal{M}^{t*}_{\tilde{\chi}^0_m}}_{=0} + 2\mathcal{M}^u_{\tilde{\chi}^0_n}\mathcal{M}^{t*}_{\tilde{\chi}^0_m} + 2\mathcal{M}^t_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{g}} + \\
& 2\mathcal{M}^t_{\tilde{\chi}^0_m}\mathcal{M}^{u*}_{\tilde{g}} + 2\mathcal{M}^u_{\tilde{\chi}^0_n}\mathcal{M}^{t*}_{\tilde{g}} + \underbrace{2\mathcal{M}^u_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{\chi}^0_n}}_{=0}
\end{aligned}
$$

$\mathcal{M}^t_{\tilde{g}}, \mathcal{M}^t_{\tilde{\chi}^0_m}$: $\tilde{g}/\tilde{\chi}^0_n$ exchange-particle in the t-channel

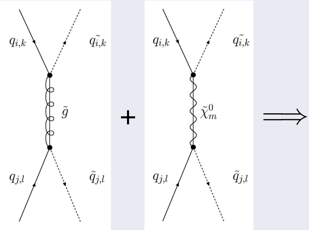
$\mathcal{M}^u_{\tilde{g}}, \mathcal{M}^u_{\tilde{\chi}^0_n}$: $\tilde{g}/\tilde{\chi}^0_m$ exchange-particle in the u-channel

$du \to \tilde{d}\tilde{u}$:

$$|\mathcal{M}^t_{\tilde{g}} + \mathcal{M}^t_{\tilde{\chi}^0_m} + \mathcal{M}^u_{\tilde{\chi}^+_n}|^2 = |\mathcal{M}^t_{\tilde{g}}|^2 + |\mathcal{M}^t_{\tilde{\chi}^0_m}|^2 + |\mathcal{M}^u_{\tilde{\chi}^+_n}|^2 + \underbrace{2\mathcal{M}^t_{\tilde{g}}\mathcal{M}^{t*}_{\tilde{\chi}^0_m}}_{=0} + 2\mathcal{M}^t_{\tilde{\chi}^0_n}\mathcal{M}^{u*}_{\tilde{\chi}^+_n} + 2\mathcal{M}^t_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{\chi}^+_j}$$

$\mathcal{M}^u_{\tilde{\chi}^+_n}$: $\tilde{\chi}^+_n$ exchange-particle in the u-channel

Terms like $\mathcal{M}^t_{\tilde{g}}\mathcal{M}^{t*}_{\tilde{\chi}^0_i}$ are zero due to color structure :



$$\boxed{C_F \propto t^a_{kk} t^a_{ll} = \mathrm{tr}[t^a]^2 = 0}$$

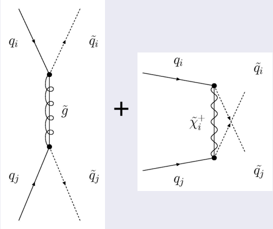
k, l: color flow

$t^a_{k,l}$: hermitian matrices, traceless

$[t^a, t^b] = i f^{abc} t^c$

f^{abc}: structure constant

Terms like $\mathcal{M}^{t}_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{\chi}^+_j}$ can give a seizable contribution:



$\Longrightarrow$

$$\boxed{c_1 c_2 c_3 c_4 \propto g_s g_s c_3 c_4 \propto \alpha_s c_3 c_4}$$

c_i: couplings of the vertices
g_s:$SU(3)_C$ coupling
c_3, c_4: EW coupling

In addition different weighting due to color factors:

- $|\mathcal{M}^{t}_{\tilde{g}}|^2$: $C_f = +2/9$
- $\mathcal{M}^{t}_{\tilde{g}}\mathcal{M}^{u}_{\tilde{g}}$: $C_f = -2/27$
- $\mathcal{M}^{t}_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{\chi}^+_j}$: $C_f = +4/9$

$\Longrightarrow$: interference terms have a two and six times larger relative color factor

Matrix element $\mathcal{M}^{t}_{\tilde{g}}\mathcal{M}^{u*}_{\tilde{\chi}} \propto \frac{1}{\hat{t}-m^2_{\tilde{g}}}\frac{1}{\hat{u}-m^2_{\tilde{\chi}^+_n}} m_{\tilde{g}} m_{\tilde{\chi}} \hat{s}$

$\hat{s}$: CM energy

$m_{\tilde{g}}$: gluino mass

$m_{\tilde{\chi}}$: exchange particle mass

$\Rightarrow$ Positive or negative contributions depending on the relative sign between the gluino and gaugino masses

$\Rightarrow$ possible distinction between AMSB and mSUGRA

Size of the EW contributions depends on the quantum numbers of the outgoing squarks:

For $k_c := \frac{\sigma_{\text{QCD+EW}}}{\sigma_{\text{QCD}}}$:

$q_i q_j \to \underbrace{\tilde{q}_{i,L}\tilde{q}_{j,L}}$ doublets under $SU(2)_L$

$q_i q_j \to \underbrace{\tilde{q}_{i,R}\tilde{q}_{j,R}}$ singlets under $SU(2)_L$

$q_i q_j \to \underbrace{\tilde{q}_{i,L}\tilde{q}_{j,R}}$ no mixing diagrams

$$\Longrightarrow k_{c,LL} > k_{c,RR} > k_{c,LR}$$

Weighting of the EW contributions for different final states

mSUGRA scenario Sps1a				
σ[pb]	total	$\tilde{q}_L\tilde{q}_L$	$\tilde{q}_R\tilde{q}_R$	$\tilde{q}_L\tilde{q}_R$
QCD	12.114	3.093	3.586	5.434
$QCD + EW$	12.608	3.561	3.609	5.438
k_c	1.041	1.151	1.006	1.001

$\Rightarrow$ Left-handed squark pairs gets the largest correction

Decay chain of left-handed squark pairs

$$
\begin{array}{lll}
\tilde{q}_l & \rightarrow & q'\tilde{\chi}_k^{\pm} \\
\tilde{q}_r & \not\rightarrow & q'\tilde{\chi}_k^{\pm} \\
 & & k = 1, 2
\end{array}
\quad \Longrightarrow \quad
\begin{array}{lll}
\tilde{\chi}_k^{+} & \rightarrow & l_i^{+}\tilde{\nu}_j, \quad k = 1, 2; i, j = 1, 2, 3 \\
\tilde{\chi}_k^{+} & \rightarrow & W^{+}\tilde{\chi}_l^{0}, k = 1, 2; l = 1, \cdots, 4 \\
\tilde{\chi}_k^{+} & \rightarrow & \cdots
\end{array}
$$

Decay channel into χ_k^{+}'s, which is suppressed for right-handed squarks

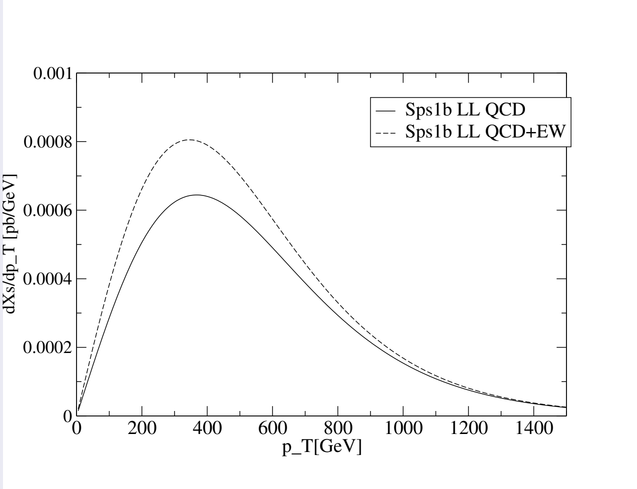
Cross sections for Sps-scenarios with and without EW contributions

Cross sections

Scenario	$QCD[pb]$		$QCD+EW[pb]$		k_c	
	total	$\tilde{q}_L\tilde{q}_L$	total	$\tilde{q}_L\tilde{q}_L$	total	$\tilde{q}_L\tilde{q}_L$
Sps1a	12.1147	3.0939	12.6086	3.5610	1.041	1.152
Sps1b	1.5702	0.4204	1.6626	0.5052	1.059	1.202
Sps2	0.0553	0.0132	0.0569	0.0146	1.029	1.106
Sps3	1.7377	0.4637	1.8407	0.5583	1.059	1.203
Sps4	3.0967	0.8127	3.2316	0.9388	1.042	1.155
Sps5	5.4249	1.4079	5.6798	1.6463	1.048	1.169
Sps1a*	12.1147	3.0939	11.7469	2.7717	0.967	0.896
Sps1b*	1.5702	0.4204	1.5024	0.3612	0.957	0.859
Sps2*	0.0553	0.0132	0.0541	0.0121	0.978	0.917
Sps3*	1.7377	0.4637	1.6623	0.3979	0.956	0.858
Sps4*	3.0967	0.8127	2.9964	0.7246	0.967	0.892
Sps5*	5.4249	1.4079	5.2375	1.2438	0.966	0.884

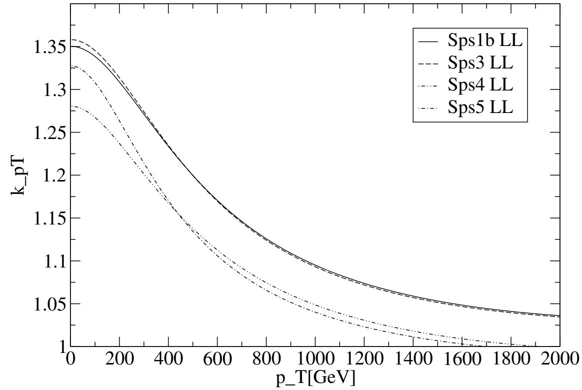
$\text{Spsx}^* - scenarios : m_{\tilde{g}} \rightarrow -m_{\tilde{g}}$

p_T-Spectrum



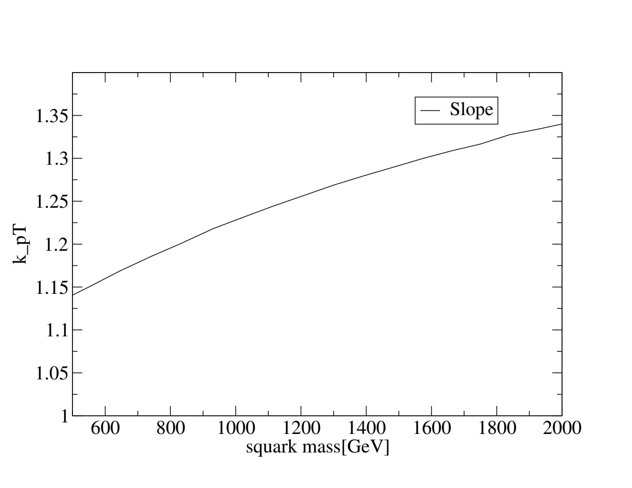
0.001
0.0008
0.0006
0.0004
0.0002
0
dXs/dp_T [pb/GeV]
0
200
400
600
800
1000
1200
1400
p_T[GeV]
Sps1b LL QCD
Sps1b LL QCD+EW

p_T-Spectrum



k_{p_T} increase with small p_T value due to propagators:
$P \propto \frac{1}{p_T^2 + m_{\tilde{\chi}}^2}$, $m_{\tilde{\chi}}$: mass of the exchange particle
$\Rightarrow$ EW propagators are considerably larger for small values of p_T

Slopes



Slope: $m_0 = -A_0 = 0.4 m_{1/2}$, $\tan\beta = 10$, $\mu > 0$

- Relative EW contributions increase with the squark mass due to propagators and Pdf's.

Summary:

- SUSY EW contributions can give a seizable correction to the squark pair production cross section
- up to 20% EW contribution for left-handed squark pair production
- correction is sensitive to relative sign between $\tilde{q}$ and $\tilde{g}$ mass, differences by more than 30%
- p_T spectrum has a steep increase for small p_T values
- correction increases with the squark mass