Electroweak Contributions to Squark Pair Production at the LHC

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Outline

MSSM particle spectrum

- each SM particle has a superpartner
- add a SU(2)-Higgs doublet with hypercharge $Y = -1$
- SUSY is not exact⇒have to be broken⇒adding soft-terms
- MSSM has 105 extra free parameters
- in mSUGRA 5 free parameters left ($m_0, m_{1/2}, A_0, \tan\beta, \mathrm{sgn}(\mu)$)

Superfield	Boson Fields	Fermionic Partners	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
$\hat{G}$	g	$\tilde{g}$	8	0	0
$\hat{V}$	W^a	$\tilde{W}^a$	1	3	0
$\hat{V}'$	B	$\tilde{B}$	1	1	0
$\hat{L}$	$\tilde{L}^j = (\tilde{\nu}, \tilde{e})_L$	$(\nu, e)_L$	1	2	-1
$\hat{E}$	$\tilde{E} = \tilde{e}_R^*$	$e_R^\dagger$	1	1	2
$\hat{Q}$	$\tilde{Q}^j = (\tilde{u}, \tilde{d})_L$	$(u, d)_L$	3	2	$\frac{1}{3}$
$\hat{U}$	$\tilde{U} = \tilde{u}_R^*$	$u_R^\dagger$	3^*	1	$-\frac{4}{3}$
$\hat{D}$	$\tilde{D} = \tilde{d}_R^*$	$d_R^\dagger$	3^*	1	$\frac{2}{3}$
$\hat{H}_1 = \hat{H}_d$	H_1^i	$(\tilde{H}_1^0, \tilde{H}_1^-)_L$	1	2	-1
$\hat{H}_2 = \hat{H}_u$	H_2^i	$(\tilde{H}_2^+, \tilde{H}_2^0)_L$	1	2	1

Gaugino Mass Eigenstates

- charginos $\chi_i^{\pm}$, $i = 1, 2$ are linear combination of charged winos and charged higgsinos
- neutralinos χ_i^0, $i = 1, 2, 3, 4$ are linear combinations of neutral wino, bino and neutral higgsinos
- gluinos $\tilde{g}$ are mass eigenstates

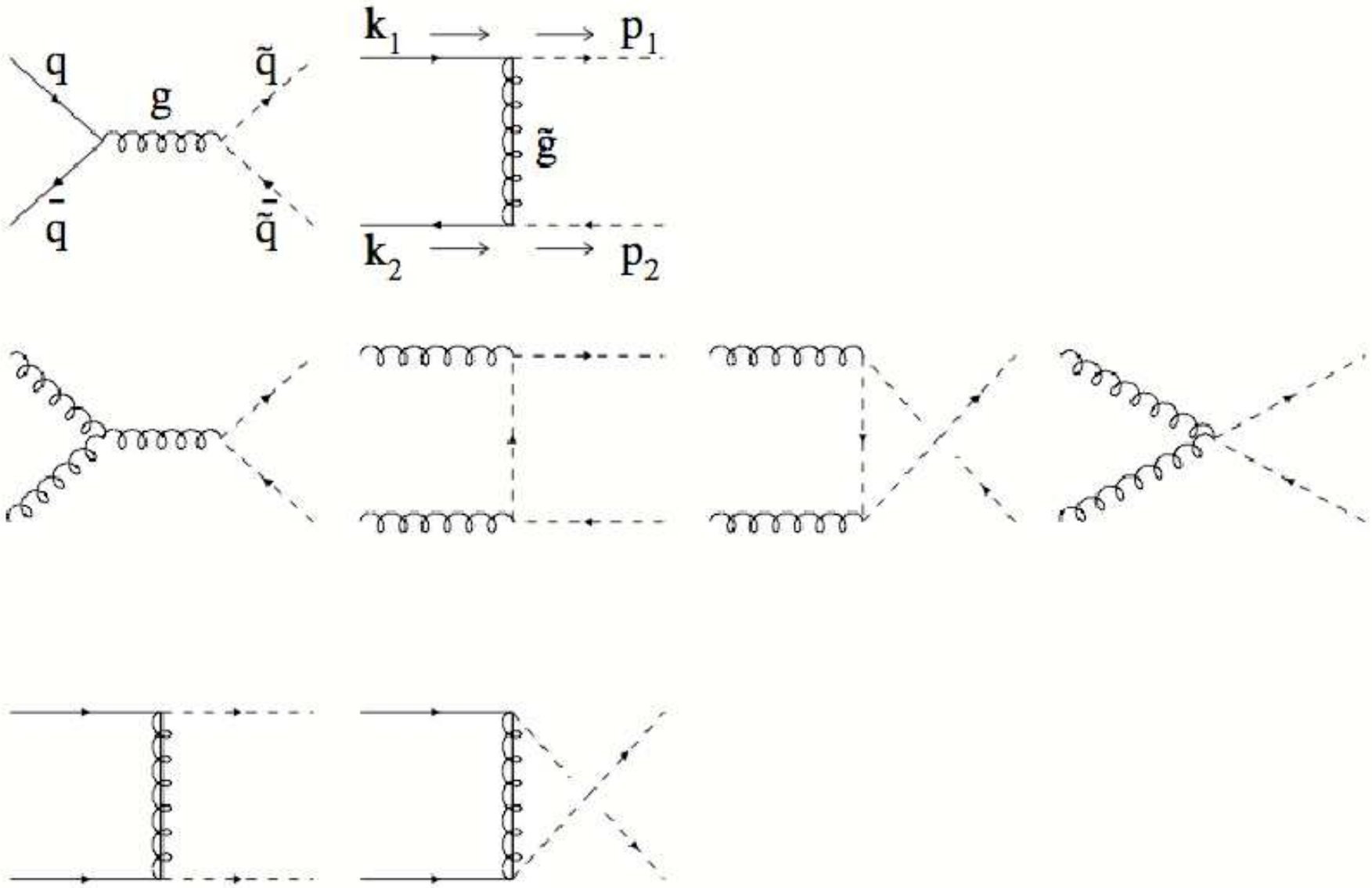
Squark Pair Production at the LHC

- TeV scale supersymmetry will be decisively tested at LHC
- cross section is $\mathcal{O}(\alpha_s^2)$, e.g.:

$$\begin{aligned} m_{\tilde{q}} &\approx 1000\,\mathrm{GeV} \\ \sigma &\approx 0.5\,\mathrm{pb} \\ \mathcal{L} &\approx 10\,\mathrm{fb}^{-1}\,\mathrm{per\,year} \\ N_{\mathrm{events}} &= \mathcal{L}\,\sigma \end{aligned}$$

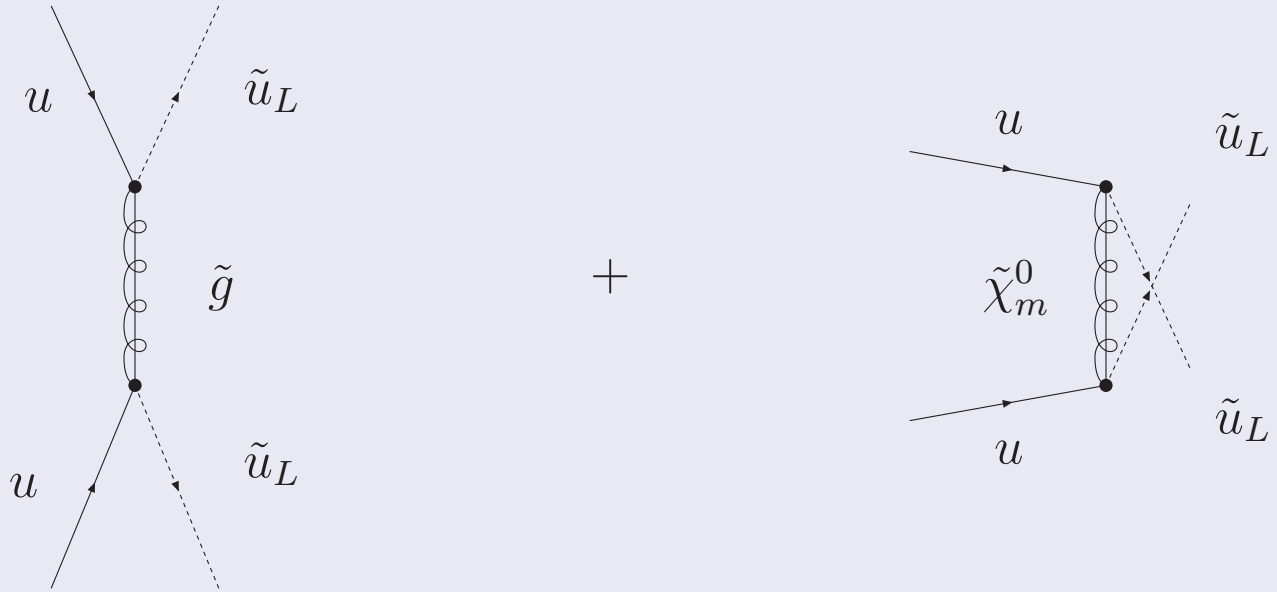
- 5000 events are expected at low luminosity

QCD Leading Order Squark Pair Production



Electroweak Contributions, 1st category of interference-terms:

- gluino t-channel and neutralino u-channel



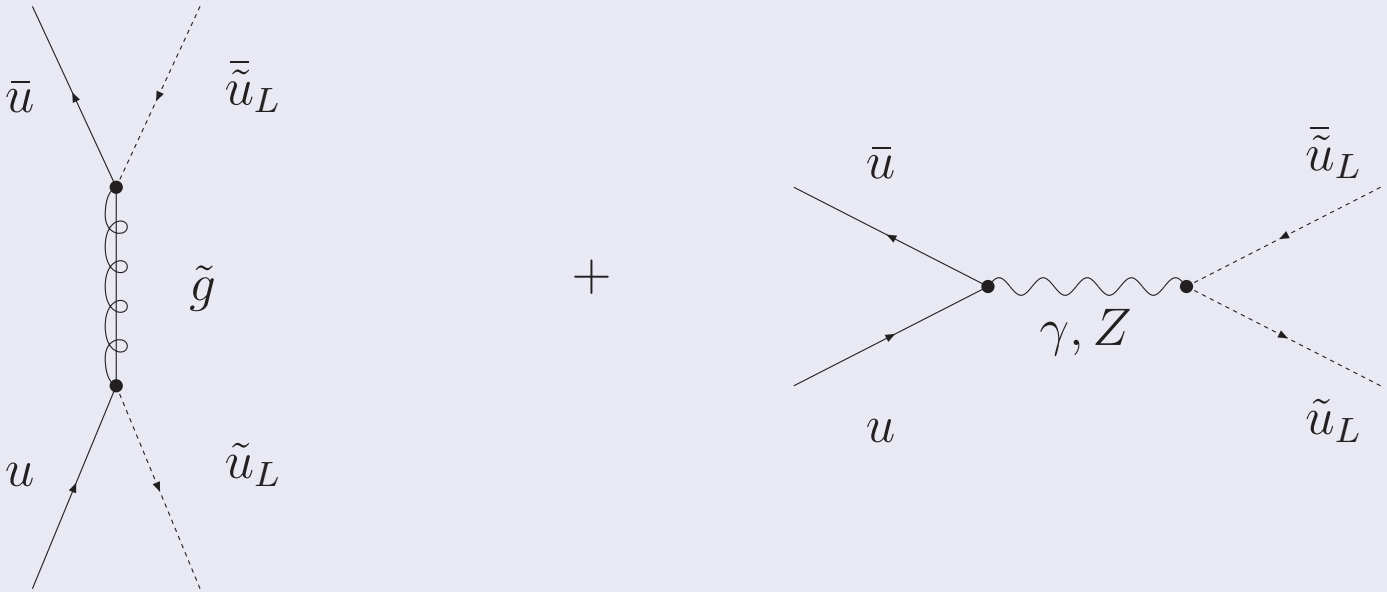
- interference term:

$$+(\text{color factor}) \times \frac{1}{\hat{t} - m^2_{\tilde{g}}} \frac{1}{\hat{u} - m^2_{\tilde{\chi}^0_m}} \times (\text{product of couplings}) \times m_{\tilde{g}}\, m_{\tilde{\chi}^0_m}\, \hat{s}$$

- you need a helicity flip, so $\tilde{q}$ are in s-wave, $\sigma \propto \beta = \sqrt{1 - \frac{4m^2_{\tilde{q}}}{\hat{s}}}$
- cross section is sizable due to two valence quarks

Electroweak Contributions, 2nd category of interference terms:

- gluino t- and electroweak s-channel



- interference term:

$$-(\text{color factor}) \times \frac{1}{\hat{t} - m_{\tilde{g}}^2} \frac{1}{\hat{s} - m_Z^2} \times (\text{product of couplings}) \times f(\hat{s}, \hat{t}, \hat{u}, m_{\tilde{q}}^2)$$

- no helicity flip, so final $\tilde{q}$ are in p-wave, $\sigma \propto \beta^3$
- small cross section due to anti-quark as initial state

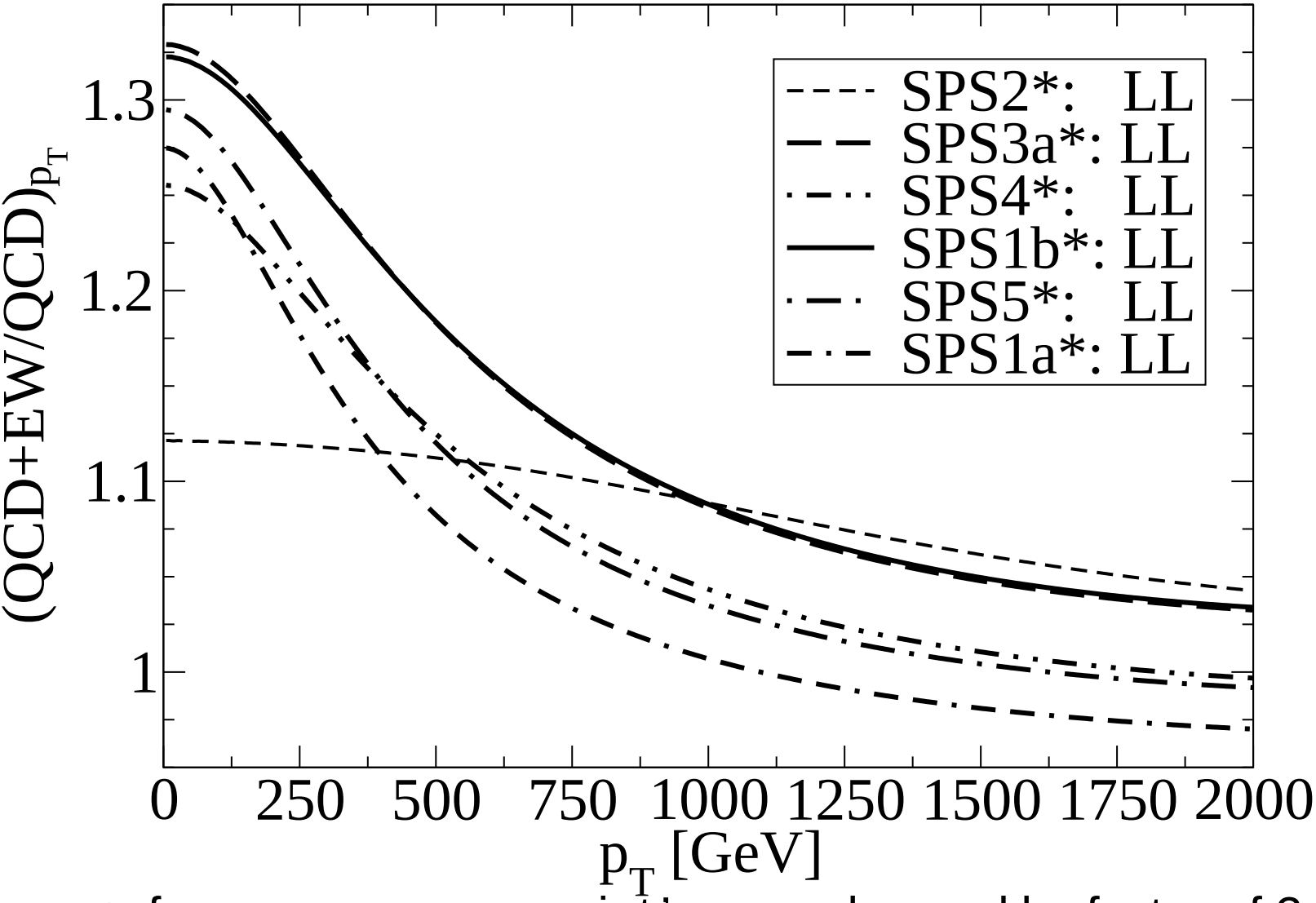
Numerical Results

Results

Scenario	m_0	$m_{1/2}$	$m_{\tilde{q}}$	QCD		QCD + EW		ratio	
				Total	LL	Total	LL	Total	LL
SPS 1a	100	250	560	12.11	3.09	12.55	3.50	1.036	1.133
SPS 1b	200	400	865	1.57	0.42	1.66	0.499	1.055	1.186
SPS 2	1450	300	1590	0.0553	0.0132	0.0567	0.0144	1.025	1.091
SPS 3	90	400	845	1.74	0.464	1.83	0.551	1.055	1.188
SPS 4	400	300	760	3.10	0.813	3.22	0.927	1.040	1.141
SPS 5	150	300	670	5.42	1.41	5.66	1.62	1.042	1.152

Remarks

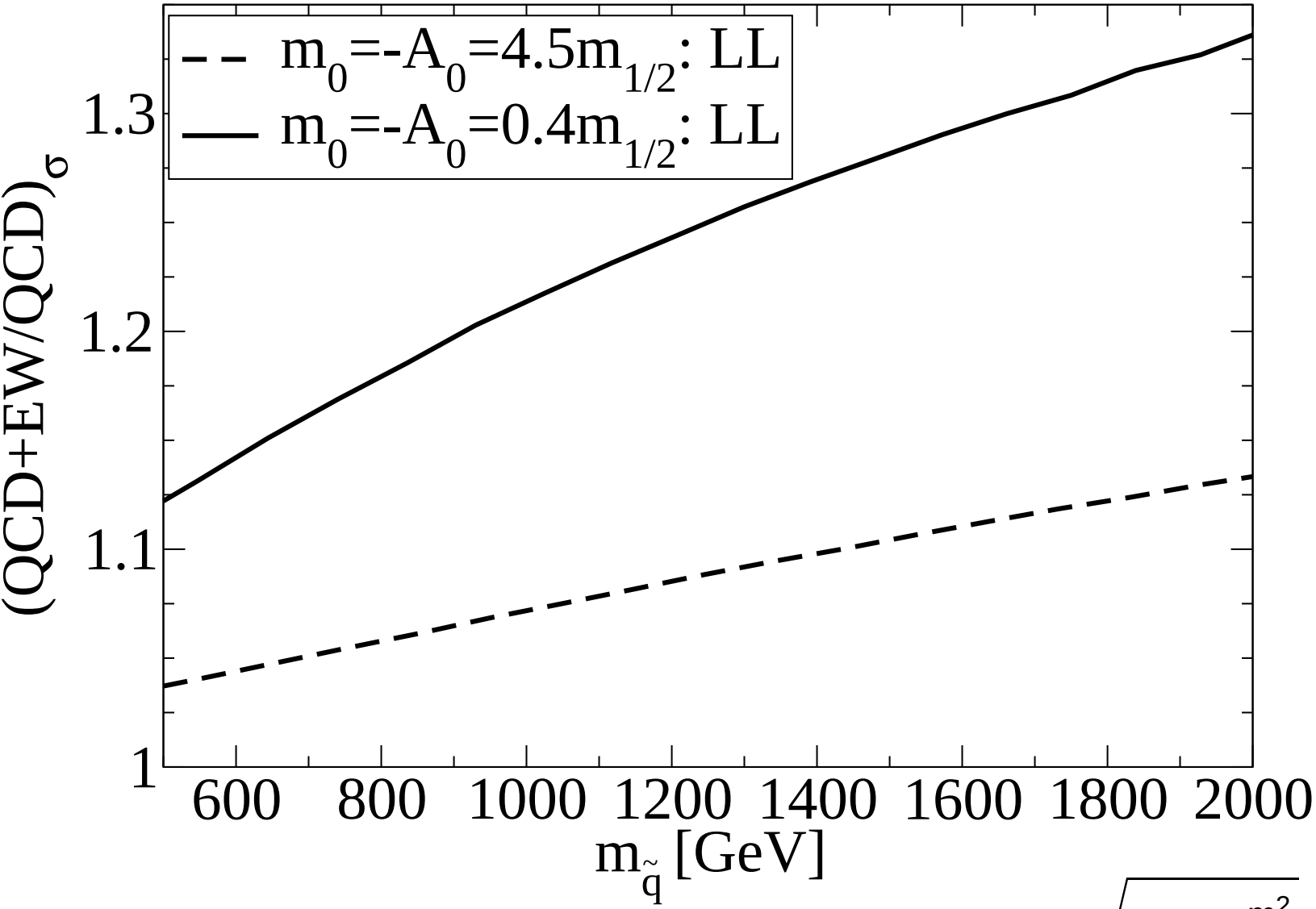
- EW contribution is more important for SU(2) doublet squarks, due to $\cot^2 \theta_w \approx 3.3$
- EW contribution depend on the ratio $m_{1/2}/m_0$
- EW contribution evidently become more important for heavier squarks if ratio $m_0/m_{1/2}$ remains roughly the same



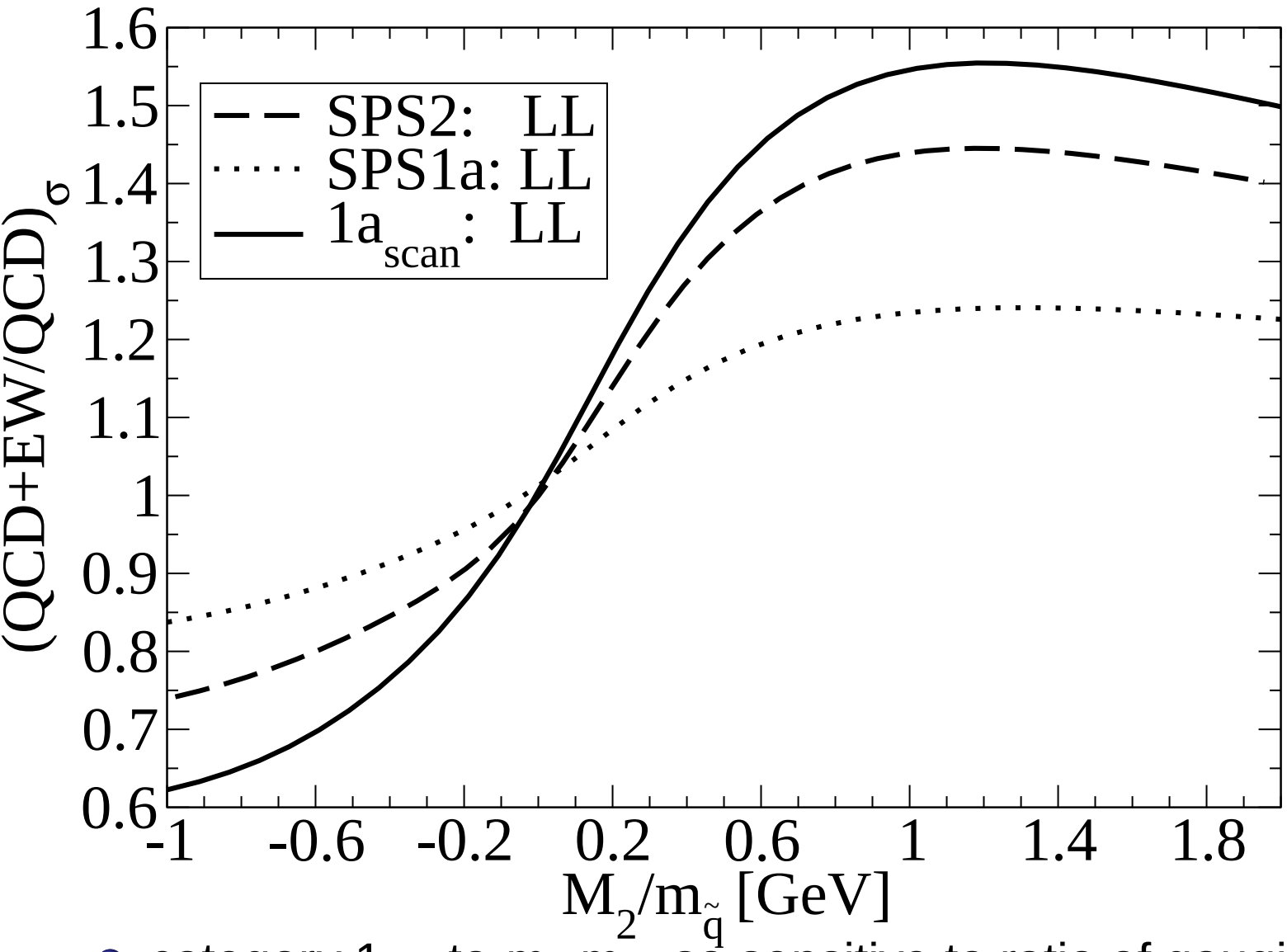
- for $m_{\tilde{q}} \approx m_{\tilde{g}} \gg m_{\tilde{W}}$, i.-t.'s are enhanced by factor of 2 for small p_T

$$\frac{\text{Propagator}-\text{EW}}{\text{Propagator}-\text{QCD}} \approx \frac{2p_T^2+m_{\tilde{q}}^2+M_{\tilde{g}}^2}{2p_T^2+m_{\tilde{q}}^2+M_{\tilde{W}}^2}$$

- enhancement vanishes for $2p_T^2 \gg m_{\tilde{q}}^2$ or $m_{\tilde{q}}^2 \gg M_{\tilde{g}}^2$ (SPS 2)



- destructive i.-t. of category 2 are $\propto \beta^3$, $\beta = \sqrt{1 - 4\frac{m_{\tilde{q}}^2}{\hat{s}}}$
- high $x \searrow$ flux of $\bar{\tilde{q}}$ more than $\tilde{q}$, so category 2 more suppressed
- sensitive to ratio of gaugino and squark masses due to helicity flip



- category 1 $\propto$ to $m_{\tilde{g}}\, m_{\tilde{\chi}}$, so sensitive to ratio of gaugino masses
- $M_2 (\Rightarrow m_{\tilde{\chi}})$ can be negative, change of sign of category 1 i.-t.'s
- maximum of curve is at $M_2 = m_{\tilde{q}}$: $\frac{M_2}{\hat{t} - M_2^2}$

Summary

- contribution with interference between t- and u-channel is dominant for SU(2)-doublets
- EW effects can reduce or enhance the total cross section by more than a factor of 1.5
- for gaugino mass unification, the enhancement factor is 1.3
- EW contribution might give a new, independent handle on the gaugino mass parameters