Electroweak Corrections to squark-antisquark pair production at the LHC

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In collaboration with W. Hollik.

Outline

- Motivations
- Closer look into (diagonal) squark pair production
  - State of the art
  - squark pair production at parton level
  - IR divergencies
- Numerical Analysis
- Conclusions

Electroweak Corrections to squark-antisquark pair production at the LHC

- LHC . . . "The" event of 2008

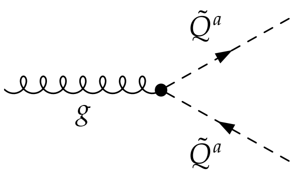
↪ Proton proton collider at 14 TeV.

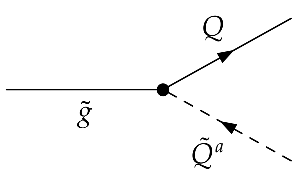
↪ Multi purpose collider . . . Among the major goals SUSY searches

Electroweak Corrections to squark-antisquark pair production at the LHC

- Squarks . . . why?

↪ SUSY partners of quarks.

↪ Colored particles 



. . .

↪ . . . detectable (Same sign di-lepton signal, $\not{E}_T$, jet multiplicity)

Electroweak Corrections to squark-antisquark pair production at the LHC

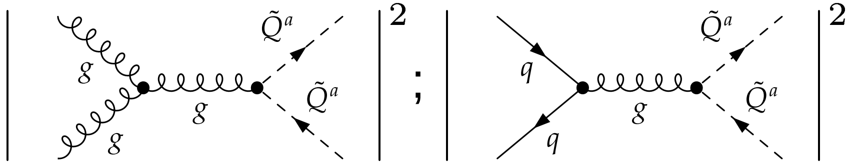
- EW corrections . . . why?

$\hookrightarrow$ Formally higher order with respect to QCD corrections (already available) but . . .

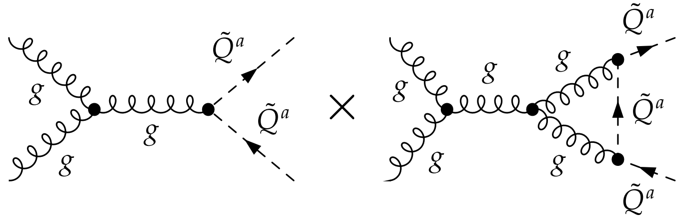
$\hookrightarrow$ . . . potentially important for distributions

- $PP \to t\bar{t}$ in SM: EW contribution to p_T distribution from -5 to -15 %
  [Kühn *et al* '06]
- $PP \to W\ j$ in SM: EW corrections on p_T distribution amount up to 40%.
  [Kühn *et al* '07, Hollik *et al* '07]

Diagonal squark PP, status

- $\mathcal{O}(\alpha_s^2)$: 

[Baer and Tata '85]

- $\mathcal{O}(\alpha_s^3)$: 

[Beenakker *et al* '96, '98]

$\hookrightarrow$ big positive corrections to the total cross section (from 5 to 90 %)

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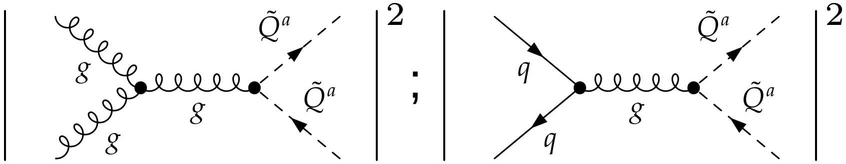
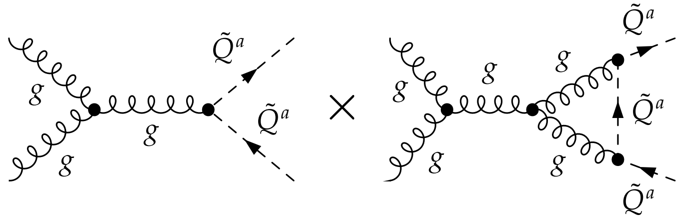
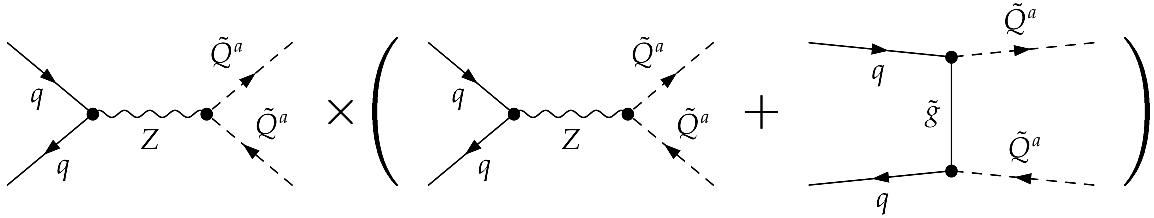
- $\mathcal{O}(\alpha_s^2)$: 

[Baer and Tata '85]

- $\mathcal{O}(\alpha_s^3)$: 

[Beenakker *et al* '96, '98]

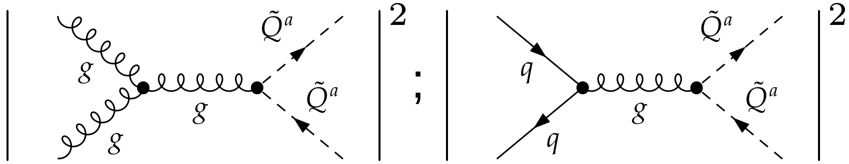
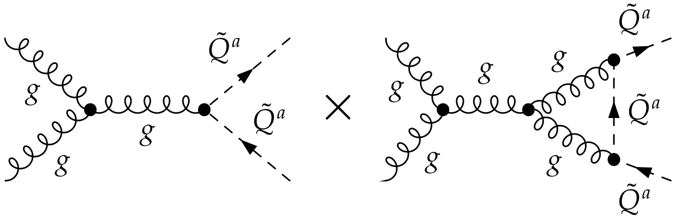
  ↪ big positive corrections to the total cross section (from 5 to 90 %)

- $\mathcal{O}(\alpha_s\alpha + \alpha^2)$: 

[Bornhauser *et al* '07]

  ↪ sizable negative corrections to the total cross section

Diagonal squark PP, status

- $\mathcal{O}(\alpha_s^2)$:  [Baer and Tata '85]
- $\mathcal{O}(\alpha_s^3)$:  [Beenakker *et al* '96, '98]

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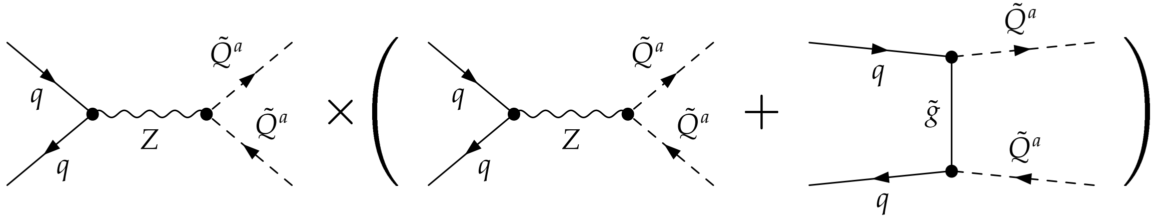
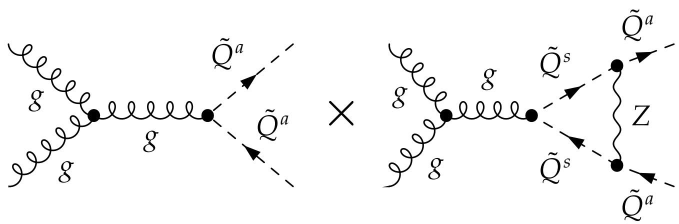
- $\mathcal{O}(\alpha_s\alpha + \alpha^2)$:  [Bornhauser *et al* '07]

  $\hookrightarrow$ sizable negative corrections to the total cross section
- $\mathcal{O}(\alpha_s^2\alpha)$: <u>stop case only</u>  [Hollik *et al* '07]

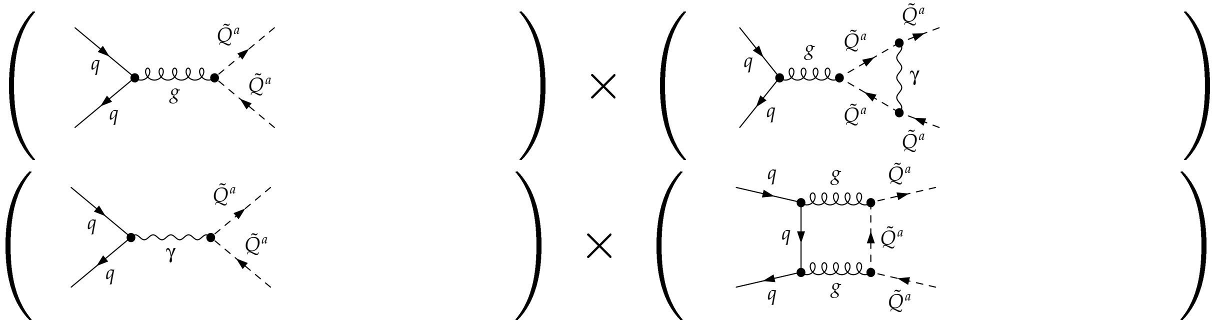
  $\hookrightarrow$ $10-20$ % level in p_T & Invariant Mass distributions
- $\mathcal{O}(\alpha_s^2\alpha)$ corrections for arbitrary squarks are still missing . . .

  . . . And the generalization from the stop case is not trivial!

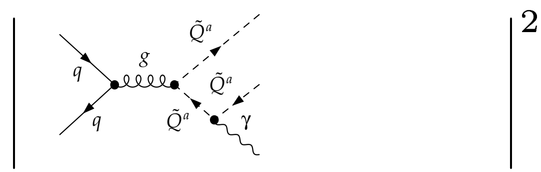
Diagonal squark PP at the parton level

Stop case, $\mathcal{O}(\alpha_s^2\alpha)$

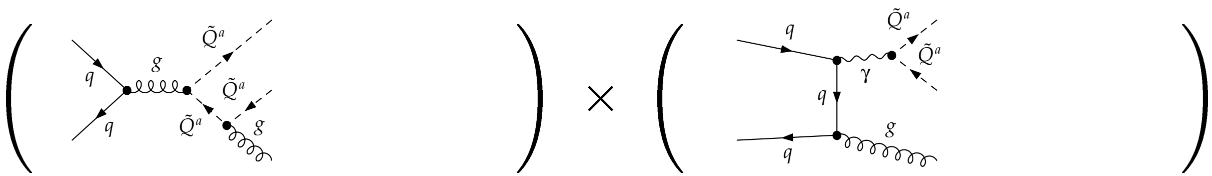
- $q\overline{q} \to \tilde{Q}^a\tilde{Q}^{a*}$



- $q\overline{q} \to \tilde{Q}^a\tilde{Q}^{a*}\gamma$



- $q\overline{q} \to \tilde{Q}^a\tilde{Q}^{a*}g$



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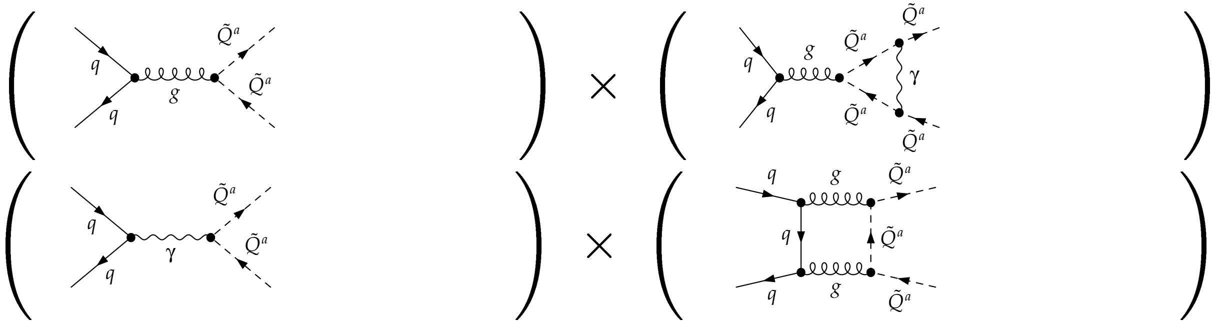

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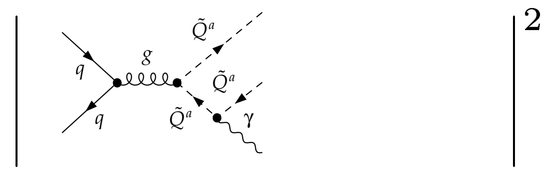

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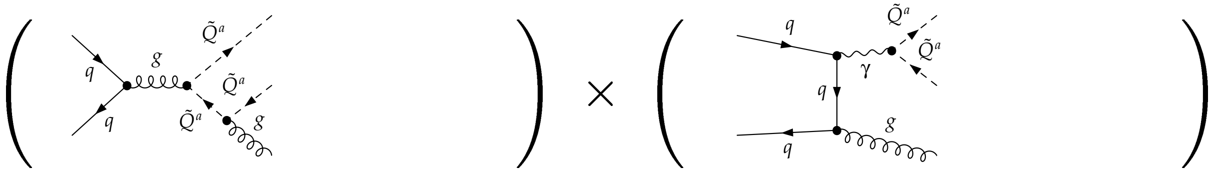
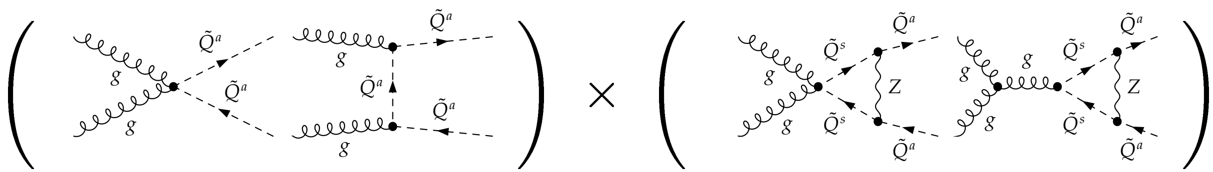


- $gg \to \tilde{Q}^a\tilde{Q}^{a*}$



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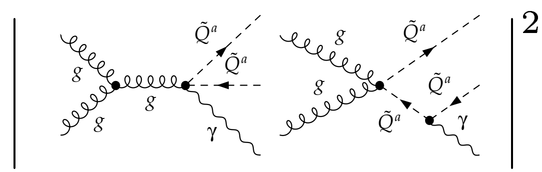
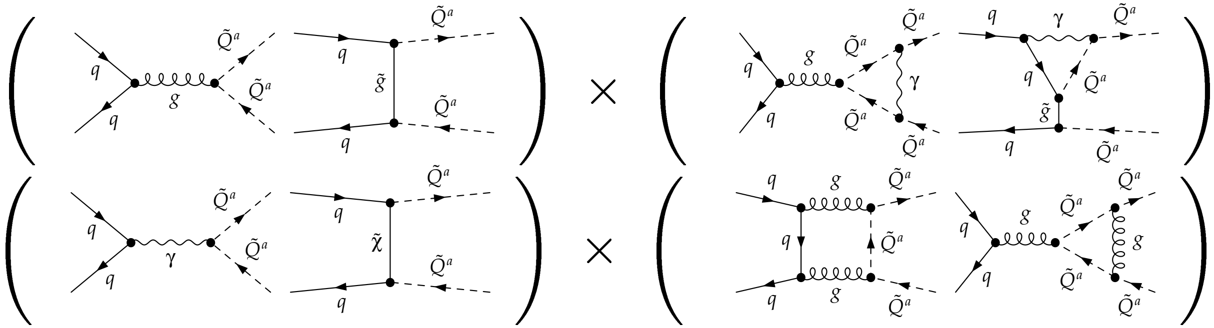


Diagonal squark PP at the parton level

General case, $\mathcal{O}(\alpha_s^2\alpha)$

- $q\bar{q} \to \tilde{Q}^a\tilde{Q}^{a*}$



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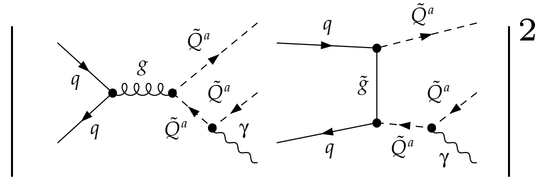

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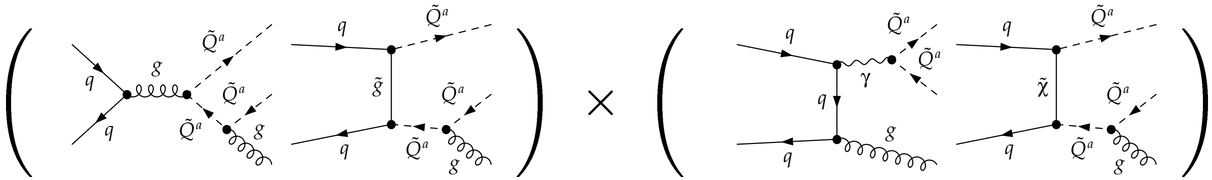

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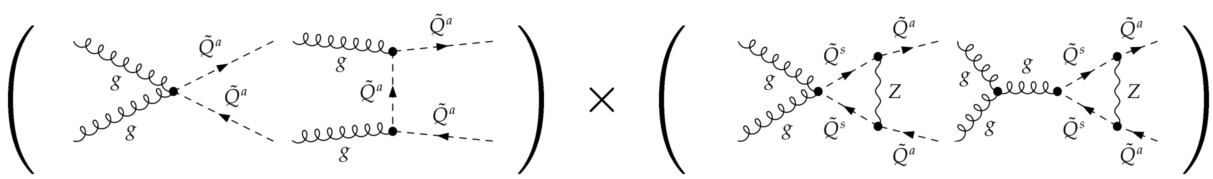

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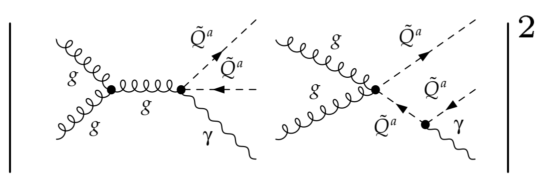

Diagonal squark PP at the parton level

General case, $\mathcal{O}(\alpha_s^2\alpha)$

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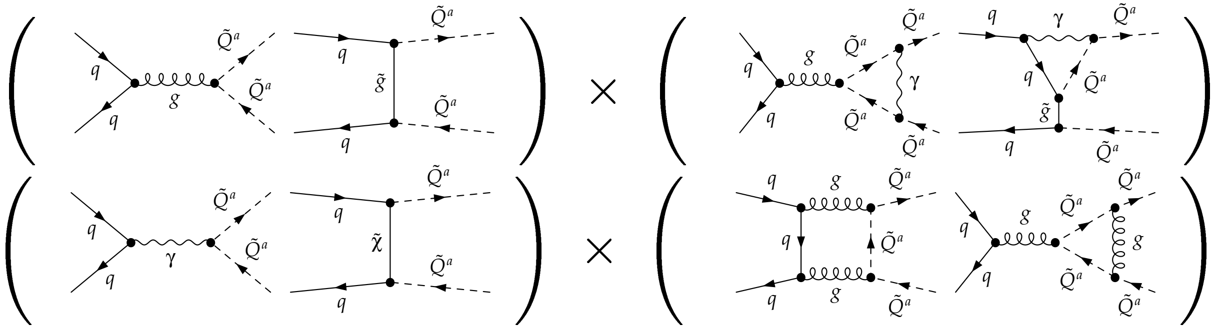

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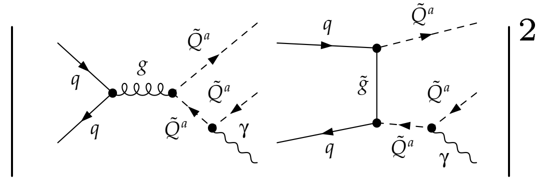

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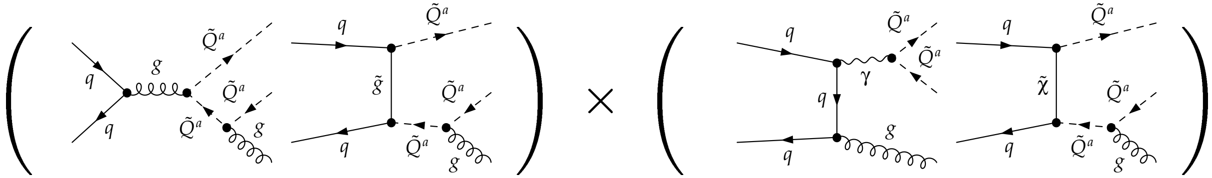

($q = Q$) $\Longrightarrow$ (tree level QCD (EW) with $\tilde{g}$ ($\tilde{\chi}^0$) in the T-channel)

((q, Q) SU(2) doublet) $\Longrightarrow$ (tree level EW with $\tilde{\chi}^+$ in the T- channel)

Numerically Speaking: New interferences can be important (from $\mathcal{O}(\alpha_s\alpha)$ experience)

Diagonal squark PP at the parton level

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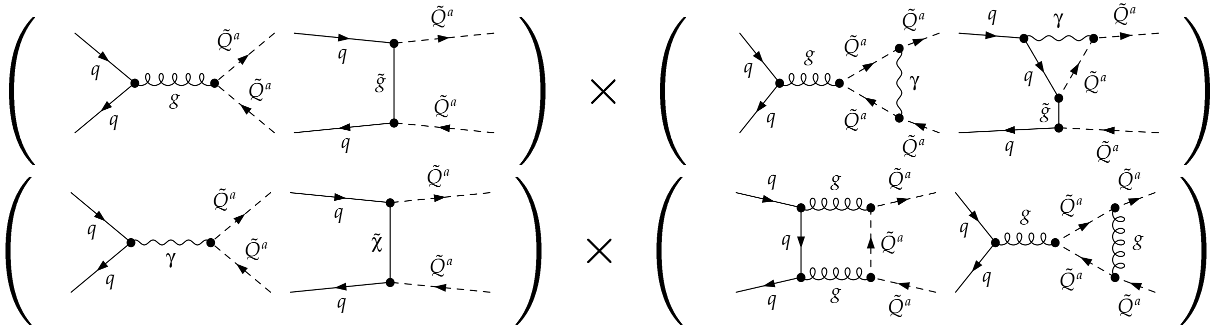

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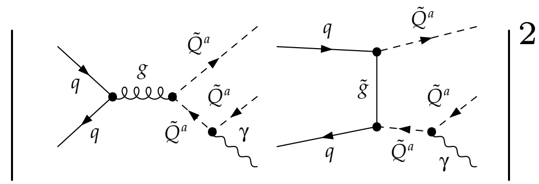

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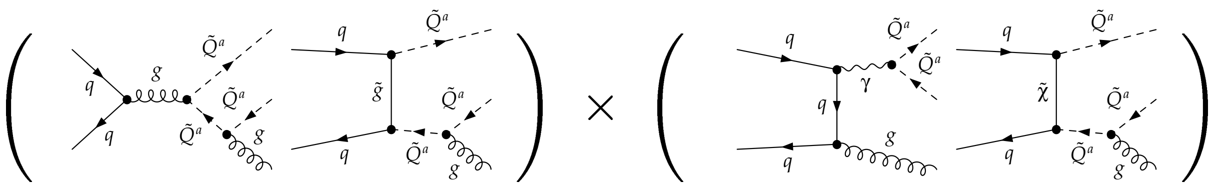


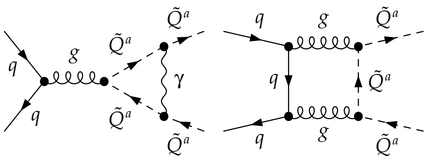
($q = Q$) $\Longrightarrow$ (tree level QCD (EW) with $\tilde{g}$ ($\tilde{\chi}^0$) in the T-channel)

((q, Q) SU(2) doublet) $\Longrightarrow$ (tree level EW with $\tilde{\chi}^+$ in the T- channel)

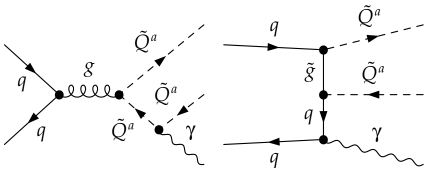
Technically speaking:

- Full one loop QCD corrections needed
- New UV divergencies $\Rightarrow$ $\delta\alpha_s$ & new CTT's enter the game
- Richer IR structure (more on this later)

IR & Collinear Divergences



$\ldots \rightsquigarrow$ IR & Collinear singularities to $q\overline{q} \to \tilde{Q}^a \tilde{Q}^{a*}$



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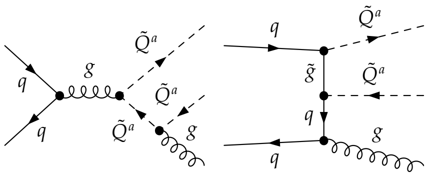

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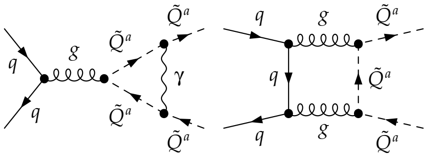
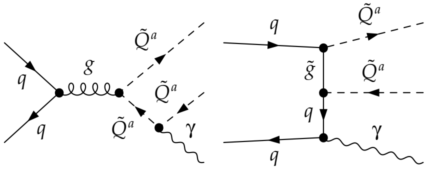
IR & Collinear Divergences



. . . $\rightsquigarrow$ IR & Collinear singularities to $q\bar{q} \to \tilde{Q}^a \tilde{Q}^{a*}$ +



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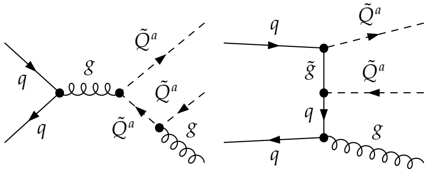
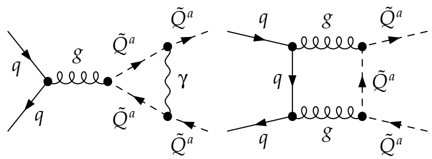


. . . $\rightsquigarrow$ IR & Collinear singularities to $q\bar{q} \to \tilde{Q}^a \tilde{Q}^{a*}g$ +

PDF factorization =

[KLN theorem] IR & Collinear Safe

IR & Collinear Divergences



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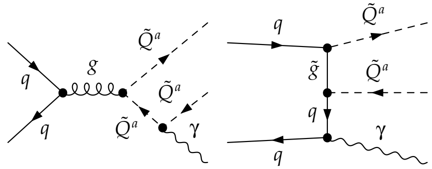

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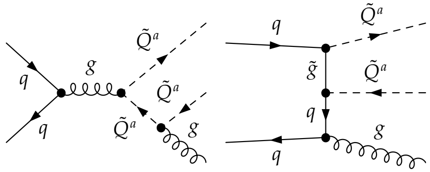


. . . $\rightsquigarrow$ IR & Collinear singularities to $q\bar{q} \to \tilde{Q}^a \tilde{Q}^{a*}g$ **+**

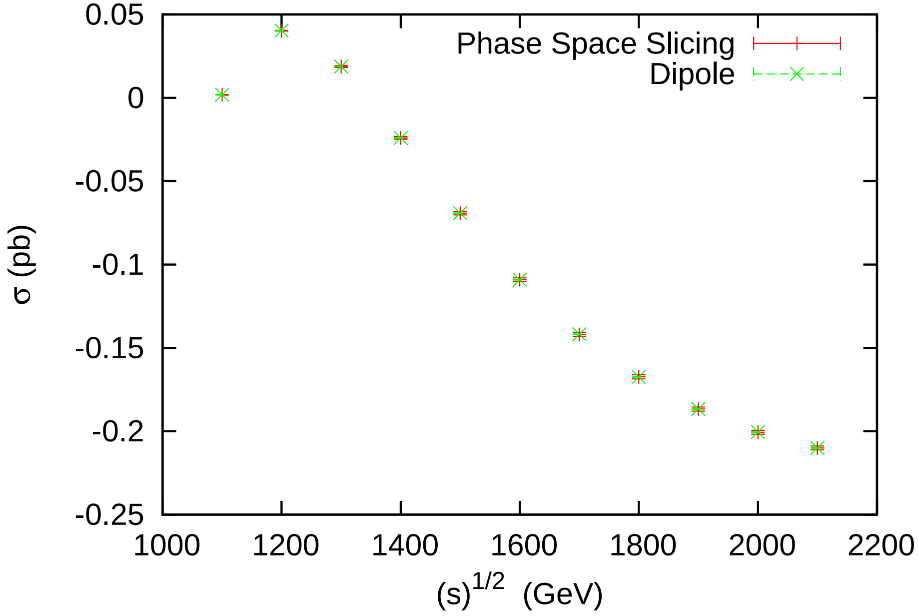
PDF factorization **=**

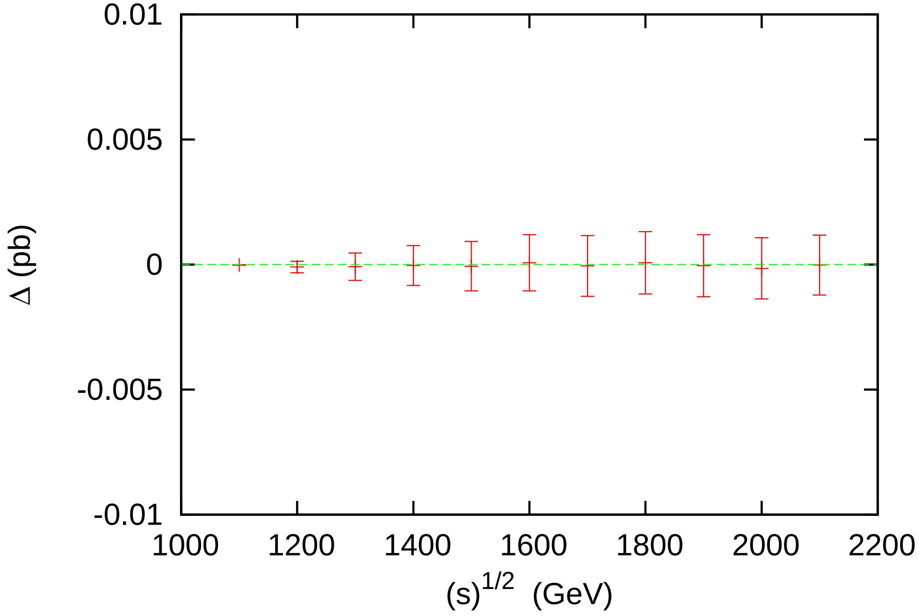
[KLN theorem] IR & Collinear Safe

- Mass regularization in both cases (g singularities essentially Abelian)
- Two methods for γ (g) phase space integration: { Phase Space Slicing / Dipole Formalism }
- Colour Algebra introducing color-charge operators in color space

IR & Collinear Divergences

cross check, $u\overline{u} \to \tilde{u}^a \tilde{u}^{a*} g$



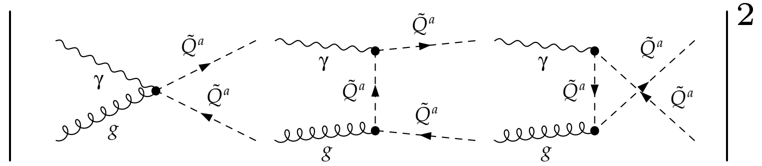


$\Delta = ($Dipole – Slicing$)$, point SPS1a$'$

Numerical Results

General Informations

- The $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ interference contributions have been included
  $\hookrightarrow$ their importance already known [Bornhauser *et al*]
- The photon induced process $g\gamma \to \tilde{Q}^a\tilde{Q}^{a*}$:

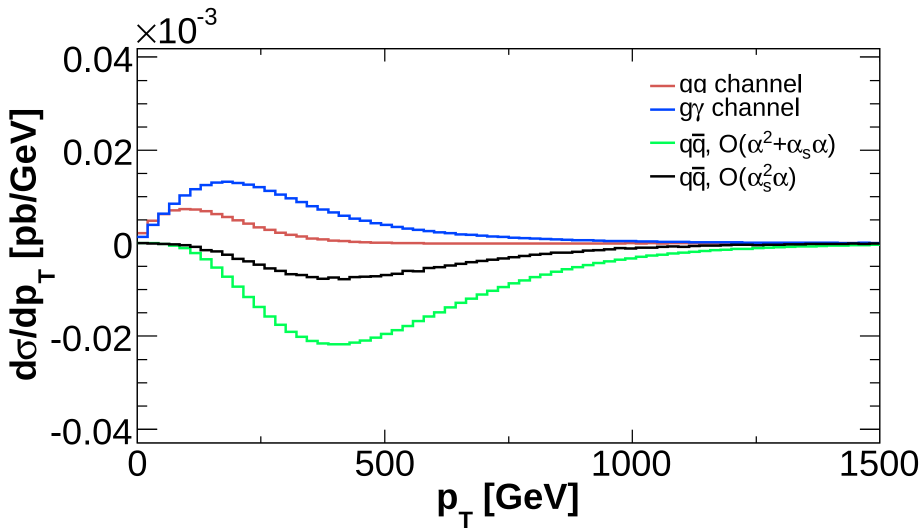


  has been included
  $\hookrightarrow$ in the stop case important [Hollik *et al*]

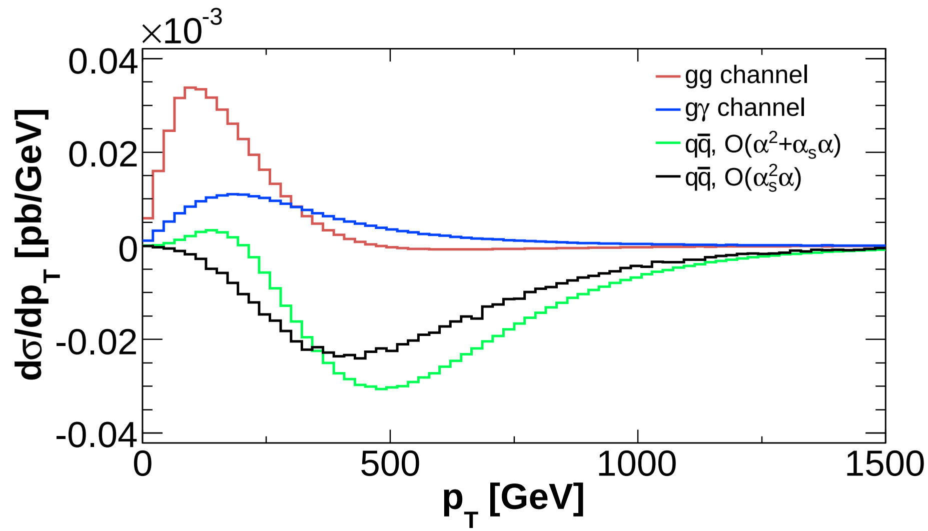
Numerical Results

Dependence on the Chirality (Transverse Momentum distribution), $\left[\delta = \frac{\mathcal{O}^{\mathrm{NLO}} - \mathcal{O}^{\mathrm{LO}}}{\mathcal{O}^{\mathrm{NLO}}}\right]$

$\tilde{u}^R$, point SPS1a′



$\tilde{u}^L$, point SPS1a′



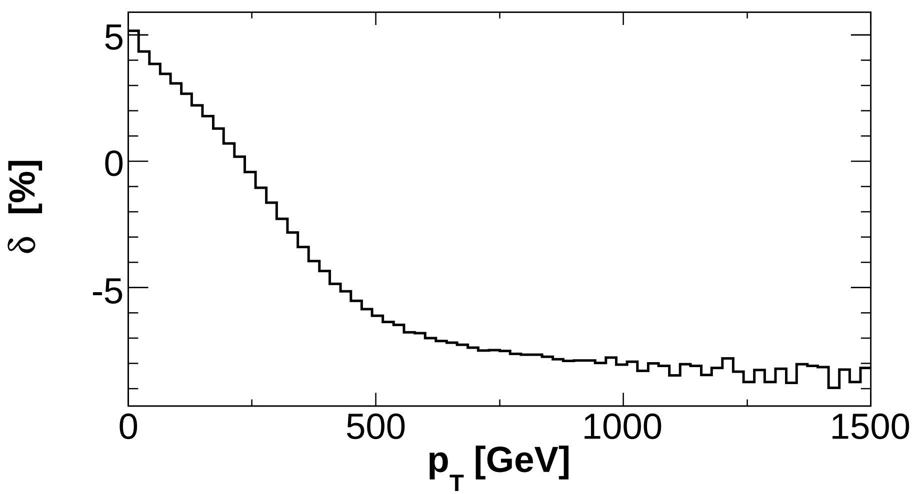
- $g\gamma$ channel chirality-independent, the others more important in the $\tilde{u}^L$ case
- $\mathcal{O}(\alpha_s^2\alpha)$ & $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ comparable (at least in the left handed case)
- $q\overline{q}$ @ $\mathcal{O}(\alpha_s\alpha^2)$ have different sign in the low p_T region in the two cases

$\hookrightarrow$ ($d\overline{d} \rightarrow \tilde{u}^L\tilde{u}^{L*} > 0$, $d\overline{d} \rightarrow \tilde{u}^R\tilde{u}^{R*} = 0$)

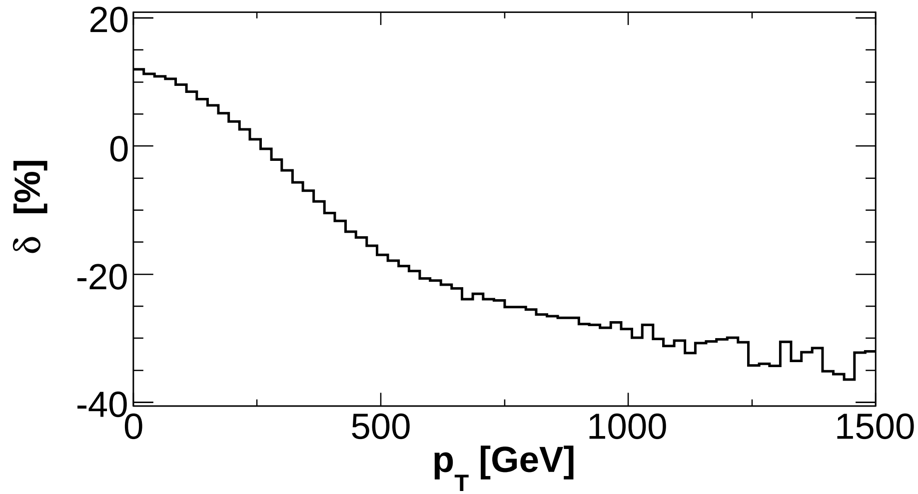
Numerical Results

Dependence on the Chirality (Transverse Momentum distribution), $\left[\delta = \frac{\mathcal{O}^{\text{NLO}} - \mathcal{O}^{\text{LO}}}{\mathcal{O}^{\text{NLO}}}\right]$

$\tilde{u}^R$, point SPS1a$'$



$\tilde{u}^L$, point SPS1a$'$

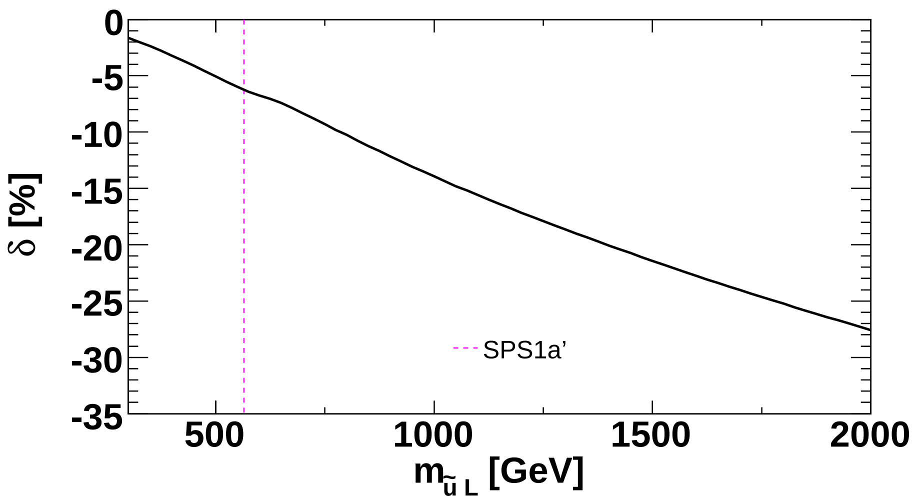


- $g\gamma$ channel chirality-independent, the others more important in the $\tilde{u}^L$ case
- $\mathcal{O}(\alpha_s^2\alpha)$ & $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ comparable (at least in the left handed case)
- $q\bar{q}$ @ $\mathcal{O}(\alpha_s\alpha^2)$ have different sign in the low p_T region in the two cases
  $\hookrightarrow$ ($d\bar{d} \to \tilde{u}^L\tilde{u}^{L*} > 0$, $d\bar{d} \to \tilde{u}^R\tilde{u}^{R*} = 0$)
- $\%$ contributions of NLO EW corrections are important in the left handed case.

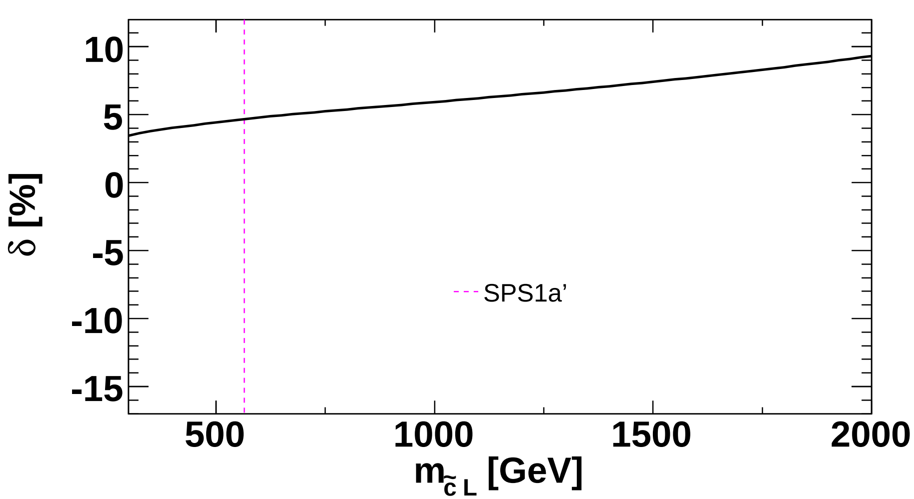
Numerical Results

Dependence on the Flavour (Total Cross Section Vs squark mass), $\left[\delta = \frac{\mathcal{O}^{\text{NLO}} - \mathcal{O}^{\text{LO}}}{\mathcal{O}^{\text{NLO}}}\right]$

$\tilde{u}^L$



$\tilde{c}^L$

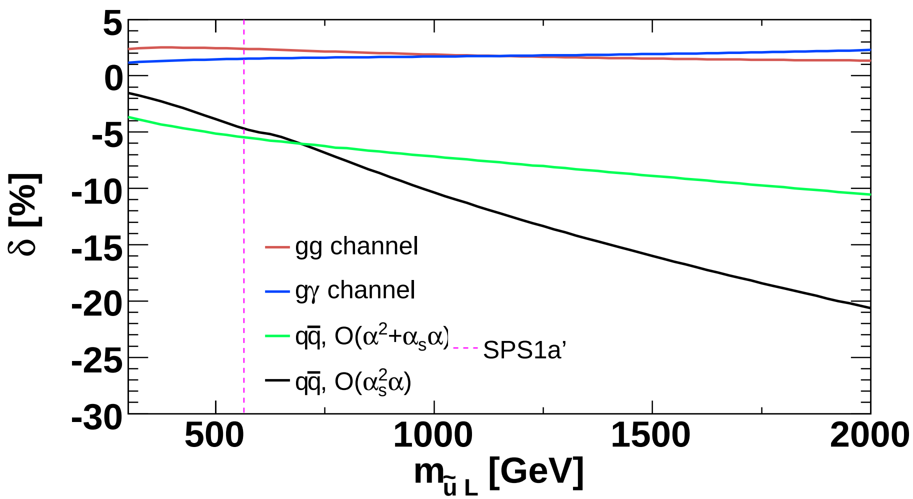


- NLO EW corrections differ in the two cases
  - $\tilde{u}$: Negative, enhanced if $m_{\tilde{u}}$ big
  - $\tilde{c}$: Positive, below $10\ \%$

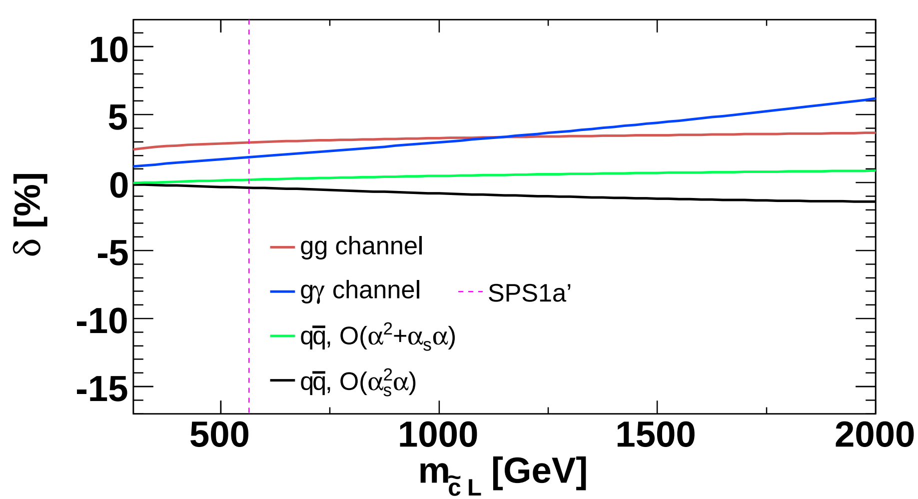
Numerical Results

Dependence on the Flavour (Total Cross Section Vs squark mass), $\left[\delta = \frac{\mathcal{O}^{\text{NLO}} - \mathcal{O}^{\text{LO}}}{\mathcal{O}^{\text{NLO}}}\right]$

$\tilde{u}^L$



$\tilde{c}^L$



- NLO EW corrections differ in the two cases
  - $\tilde{u}$: Negative, enhanced if $m_{\tilde{u}}$ big
  - $\tilde{c}$: Positive, below $10\ \%$
- The leading channels are different in the two cases (PDF suppression for $\tilde{c}$)
- $\tilde{u}$ case: $q\bar{q}$ @ $\mathcal{O}(\alpha_s^2\alpha)$ leading at high $m_{\tilde{u},L}$ values

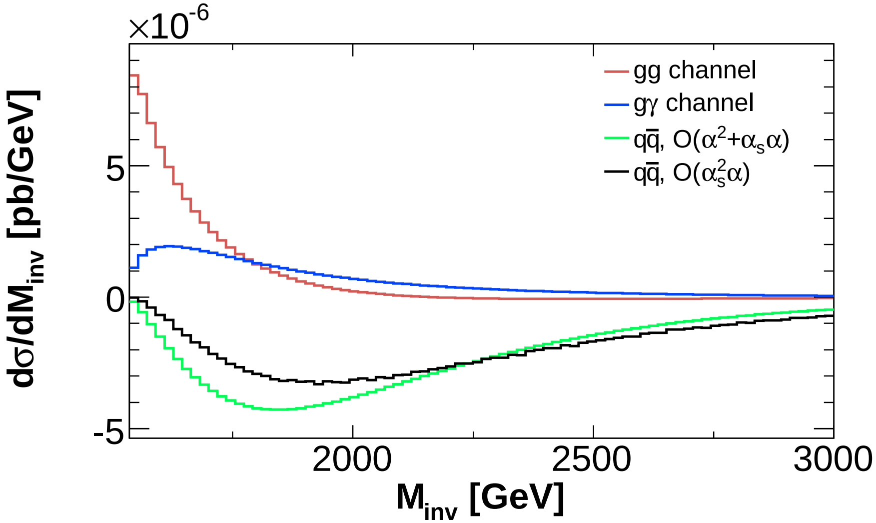
$\hookrightarrow$ Sudakov enhancement + enhancement of $q\bar{q}$ channel @ LO.

$\hookrightarrow$ $q\bar{q}$ channel @ $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ suppressed at high $m_{\tilde{u},L}$ values

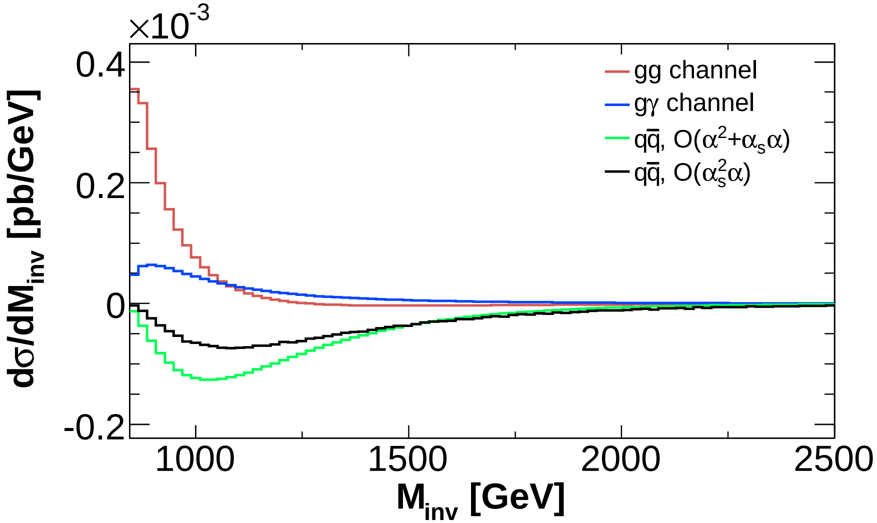
Numerical Results

Dependence on the Benchmark Point (Invariant Mass distribution for $\tilde{u}^L$ prod.)

point SU1, $m_{\tilde{u},L} = 766$ GeV



point SU4, $m_{\tilde{u},L} = 420$ GeV

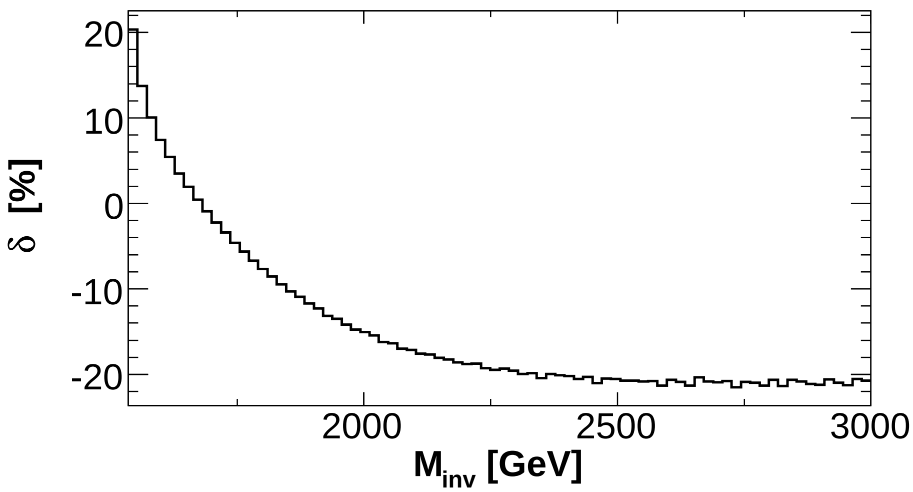


- The size of the contributions decrease as the squark mass increases
- Corrections dominated by $\begin{cases} gg, \quad g\gamma \\ q\,\bar{q} \end{cases}$ channels in the $\begin{cases} \text{low} \\ \text{high} \end{cases}$ M_{inv} region

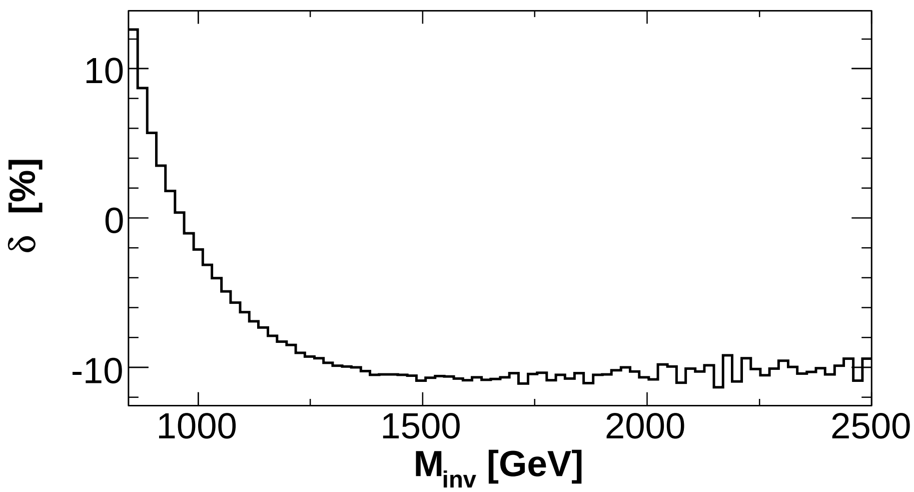
Numerical Results

Dependence on the Benchmark Point (Invariant Mass distribution for $\tilde{u}^L$ prod.)

point SU1, $m_{\tilde{u},L} = 766$ GeV



point SU4, $m_{\tilde{u},L} = 420$ GeV



- The size of the contributions decrease as the squark mass increases
- Corrections dominated by $\left\{ \begin{array}{l} gg, \quad g\gamma \\ q\,\bar{q} \end{array} \right.$ channels in the $\left\{ \begin{array}{l} \text{low} \\ \text{high} \end{array} \right.$ M_{inv} region
- NLO EW corrections are sizable, their importance increase as the squark mass increases

Conclusions & Outlook

- (diagonal) squark-antisquark pair production is an important process in the hunting for SUSY
- $\mathcal{O}(\alpha_s^2\alpha)$ corrections to this process are available for arbitrary squark-antisquark pair
- They strongly depend on flavour, chirality and mass of the final states
- They can give rise to sizable corrections not only to the distributions but also to the total cross section.

road map:

- Compute the $\mathcal{O}(\alpha_s^2\alpha)$ corrections to other processes of production of SUSY colored particle:
  - gluino pair production $\rightarrow$ completed
  - associated production of a squark and a gluino $\rightarrow$ w.i.p.
  - (non diagonal) squark pair production $\rightarrow$ on the wish list
- Link these corrections to PROSPINO