Electroweak contributions to squark–squark production at the LHC

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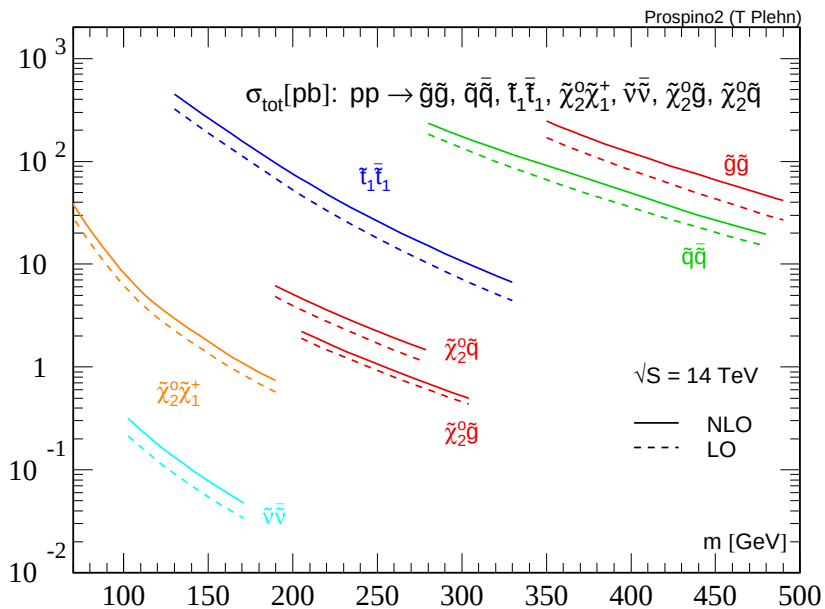
Outline

1. Introduction to **colored SUSY** particles @ LHC
2. **Squark–squark** production:
   - **EW tree-level** contributions and **NLO** contributions of $\mathcal{O}(\alpha_s^2\alpha)$.
     $\longrightarrow$ Careful treatment of interference terms.
   - Calculational details: **EW-type** & **QCD-type** corrections.
     $\longrightarrow$ Treatment of infrared and collinear singularities.
     $\longrightarrow$ Renormalization scheme used.
3. Numerical results: **total cross-section** and **differential distributions**.
4. Conclusions

Colored SUSY particles @ hadron colliders

- Squarks and gluinos are strongly interacting particles
- Production rate depends on mass, color-representation and multiplicity.

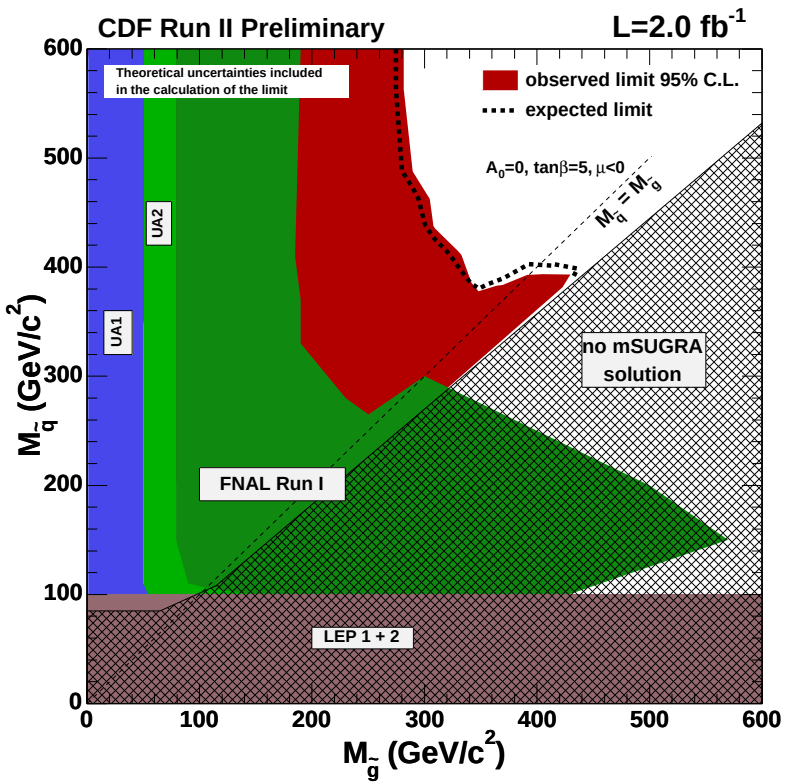


- Squarks, gluinos and top squarks have high production rate at hadron colliders.

Experimental Searches for Squarks and Gluinos

- **Squark** & **gluino** mass limits
  CDF, Tevatron Run II
  $m_{\tilde{g}} \geq 280\mathrm{GeV}$
  $m_{\tilde{q}} \geq 370\mathrm{GeV}$
  [CDF Note 9229]

- **Stop** mass limits
  CDF, Tevatron Run II
  $m_{\tilde{t}} \geq 132\mathrm{GeV}$ for $m_{\tilde{\chi}^0} = 132\mathrm{GeV}$
  [0707.2567 hep-ex]

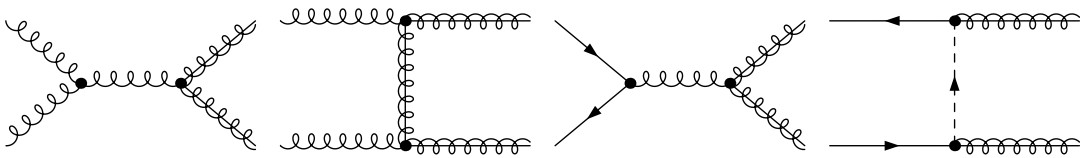


- Until now: agreement between experiment and SM predictions.

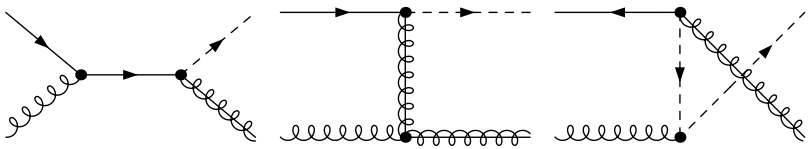
- Further analysis needs improved theoretical predictions.

Overview: Production Processes

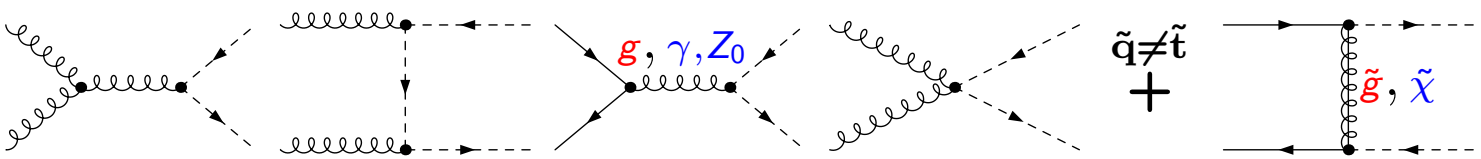
$\tilde{g}\tilde{g}$



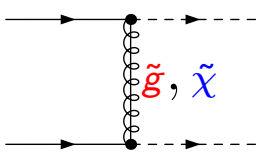
$\tilde{q}\tilde{g}$



$\tilde{q}_i\tilde{q}_i^*$



$\tilde{q}_i\tilde{q}_j$



[Kane & Leveille '82, Harrison & Llewellyn Smith '83,Reya & Roy '85 Dawson, Eichten, Quigg '85, Baer & Tata '85]

Status of higher order corrections

- $\mathcal{O}(\alpha_s^3)$: NLO QCD corrections for all production processes known
  [Beenakker, Höpker, Spira, Zerwas '95&'97],
  [Beenakker, Krämer, Plehn, Spira, Zerwas '98]
  → PROSPINO
- Beyond NLO:
  - Approximate **NNLO** corrections
  - **NNLL** resummation

  [Langenfeld, Moch '09],
  [Kulesza, Motyka '08'09],
  [Beneke, Falgari, Schwinn '07'09],
  [Beenakker, Brensing, Krämer, Kulesza, Laenen, Niessen '09]
- **Tree-level EW** contributions $\mathcal{O}(\alpha_s\alpha + \alpha^2)$

  [Bornhauser, Drees, Dreiner, Kim '07 '09]
- $\mathcal{O}(\alpha_s^2\alpha)$: NLO EW corrections:
  - Gluino pair production
  - Squark–gluino production
  - Squark–anti-squark production
  - Stop–anti-stop production

  [Hollik, Kollar, Trenkel '07],
  [Beccaria et. al. '08],
  [Hollik, Mirabella '08],
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  - **This talk: Squark–squark production**

  [Hollik, Kollar, Trenkel '07],
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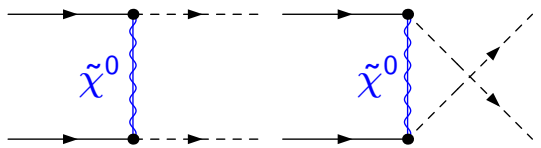
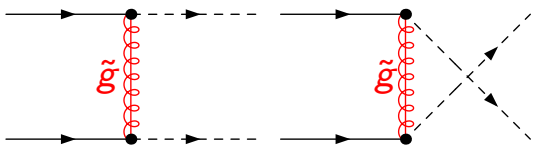
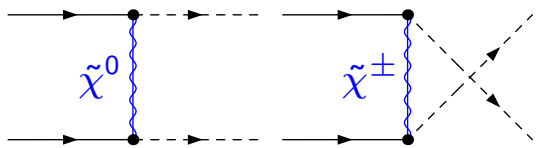
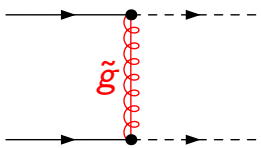
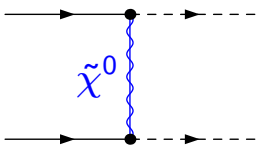
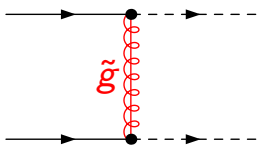
Squark–squark production: Born processes

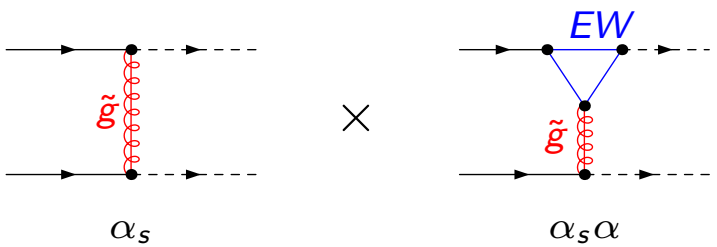
Subprocess	Electroweak contribution		Strong contribution
$\mathbf{qq \longrightarrow \tilde{q}_a \tilde{q}_b}$		+	
$\mathbf{qq' \longrightarrow \tilde{q}_a \tilde{q}'_b}$ same doublet		+	
$\mathbf{qq' \longrightarrow \tilde{q}_a \tilde{q}'_b}$ different doublet		+	

$\Rightarrow$ 36 different processes contribute.

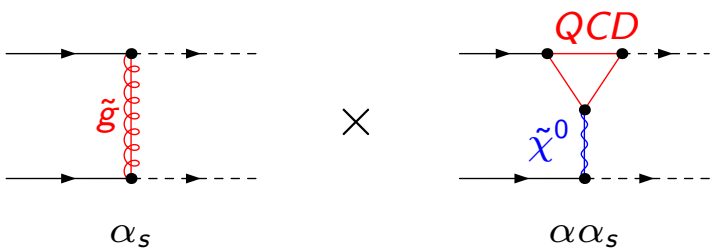
Interferences: Virtual corrections

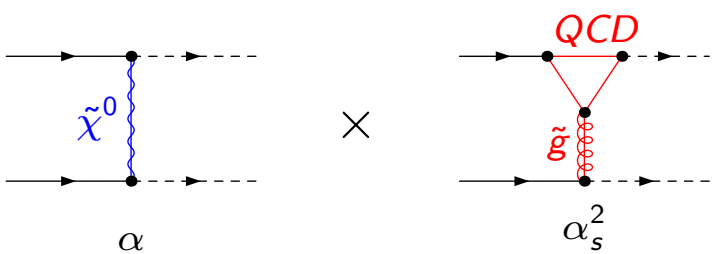
- Tree level contributions of $\mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_s\alpha) + \mathcal{O}(\alpha^2)$.
- We are interested in $\mathcal{O}(\alpha_s^2\alpha)$ accuracy.
- Therefore EW & QCD-like corrections have to be taken into account:

EW insertions:



QCD insertions:

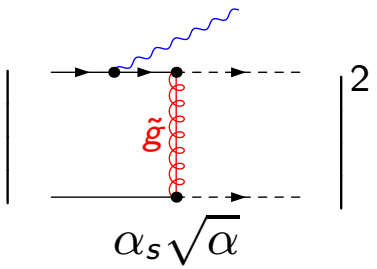




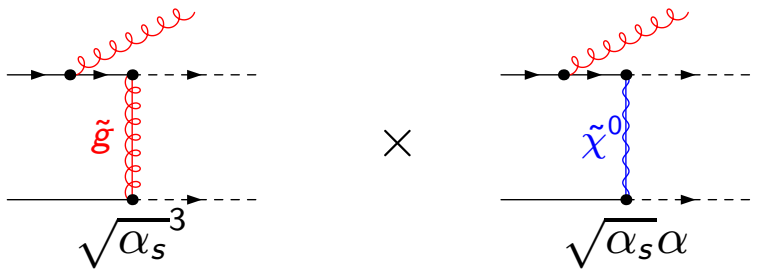
Interferences: Real emission

The following real emission diagrams contribute at $\mathcal{O}(\alpha_s^2\alpha)$

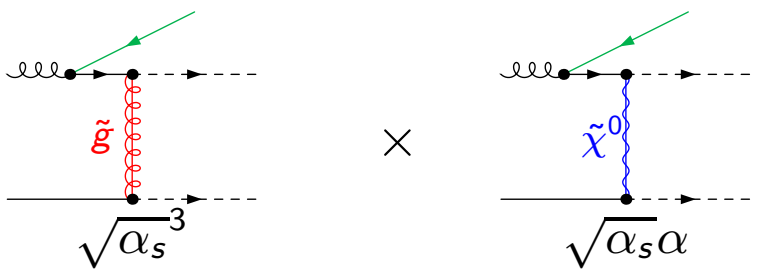
Photon bremsstrahlung



Gluon bremsstrahlung



Real quark radiation



UV-divergencies

- **quarks, squarks, gluino** $\rightarrow$ **renormalized on-shell**
- $\alpha_s \rightarrow$ **$\overline{\text{MS}}$ with five flavors** (same definition as in pdf)
  $\Rightarrow$ add finite parts to the counterterm to exclude the effects of heavy particles.

$$\delta g_s = -\frac{\alpha_s}{4\pi}\left[\frac{3}{2}\Delta + \frac{1}{3}Ln\left(\frac{m_t^2}{\mu^2}\right) + Ln\left(\frac{m_{\tilde{g}}^2}{\mu^2}\right) + \sum_{\tilde{f}^a}\frac{1}{12}Ln\left(\frac{m_{\tilde{f}^a}^2}{\mu^2}\right)\right]$$

Caution with $\hat{g}_s$ (scalar strong coupling – $q\tilde{q}\tilde{g}$ vertex):

- **SUSY demands $\hat{g}_s = g_s$** but $\overline{MS}$ spoils SUSY.
- Add symmetry restoring counterterm:

$$\delta\hat{g}_s = \delta g_s + \frac{\alpha_s}{3\pi}$$

Soft and collinear singularities

- Methods: **mass regularization** and **phase space slicing**.
  (in considered processes the gluon is Abelian like.)
- **Soft singularities** cancel by adding **virtual** and **real** corrections.
- Remaining **collinear singularities** have to be absorbed by **redefining the PDFs**.
- PDF set: MRST2004QED [Martin, Roberts, Stirling, Thorne]

Framework & Input parameters

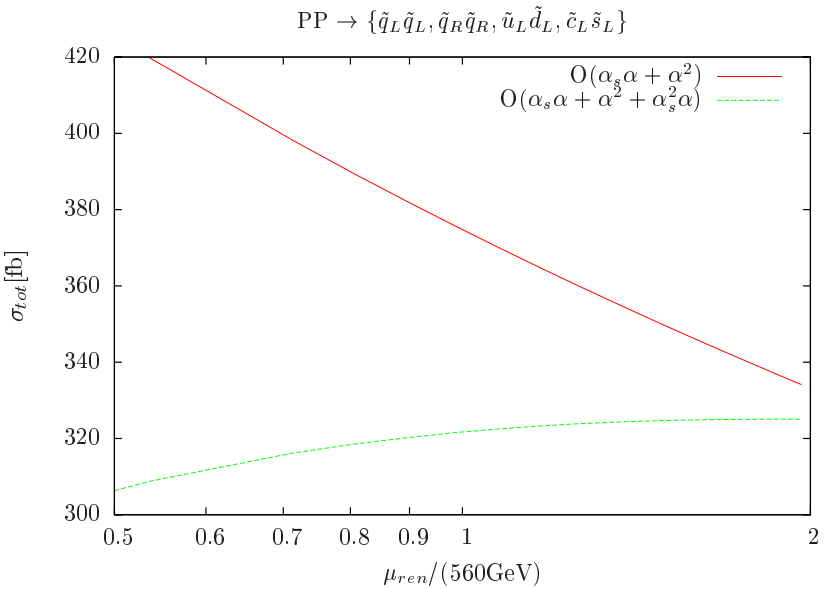
- Feynman diagrams and amplitudes were generated and calculated within the FeynArts/FormCalc/Looptools framework. [Hahn]
- Input: SPS1a' parameter set.
  - GUT-scale parameters evolved to 1TeV (softSUSY) [Allanach]
  - Compute OS parameters.

$$m(\tilde{u}_L) = 560\mathrm{GeV} \qquad m(\tilde{d}_L) = 566\mathrm{GeV}$$
$$m(\tilde{u}_R) = 543\mathrm{GeV} \qquad m(\tilde{d}_R) = 539\mathrm{GeV}$$

- Renormalization scale for α_s : $560\,GeV \quad (\mathcal{O}(m_{\tilde{q}}))$

Scale dependence

Scale dependence of EW tree-level and EW NLO cross section:
(Consider only processes with non vanishing tree-level interference.)



- Renormalization scale (μ_{ren}) is set equal to factorization scale (μ_{fac}).
- Scale dependence reduces when NLO EW corrections are taken into account.

Total hadronic X-section

Born and **EW** contributions to the total cross section:

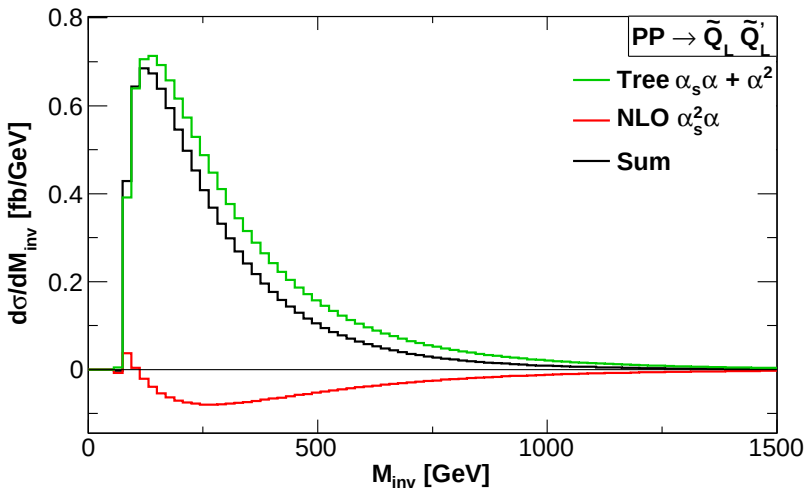
	$\sigma^{\text{Born}}_{\alpha_s^2}$	$\sigma^{\text{Tree EW}}_{\alpha_s\alpha+\alpha^2}$	$\sigma^{\text{NLO EW}}_{\alpha_s^2\alpha}$	δ_{tree}	$\delta_{\text{tree+NLO}}$
$\tilde{q}_L\tilde{q}'_L$	1632. fb	364. fb	-71. fb	22.3%	18.0%
$\tilde{q}_L\tilde{q}'_R$	1682. fb	2. fb	-69. fb	0.1%	-3.9%
$\tilde{q}_R\tilde{q}'_R$	1876. fb	31. fb	2. fb	1.7%	1.6%
$\tilde{q}\tilde{q}'$	5189. fb	397. fb	-141. fb	7.7%	4.9%

$$\delta_{\text{tree}} = \sigma^{\text{Tree EW}}_{\alpha_s\alpha+\alpha^2}/\sigma^{\text{Born}}_{\alpha_s^2}$$

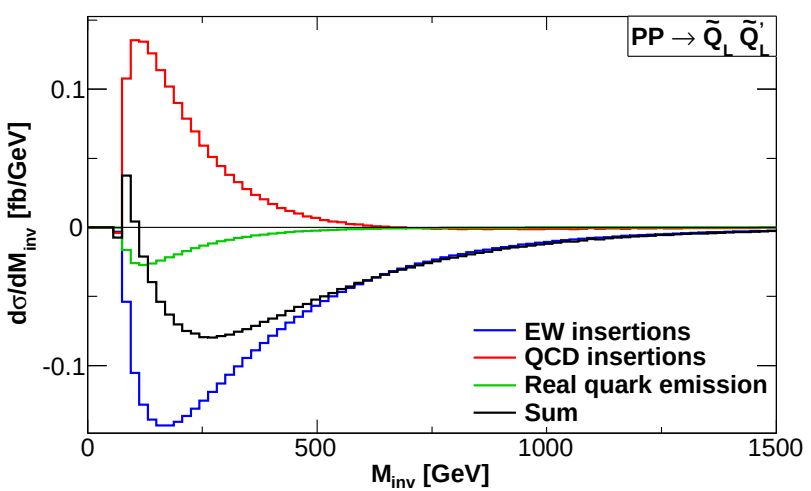
$$\delta_{\text{tree+NLO}} = (\sigma^{\text{Tree EW}}_{\alpha_s\alpha+\alpha^2} + \sigma^{\text{NLO EW}}_{\alpha_s^2\alpha})/\sigma^{\text{Born}}_{\alpha_s^2}$$

M_{inv} distribution

Electroweak contributions

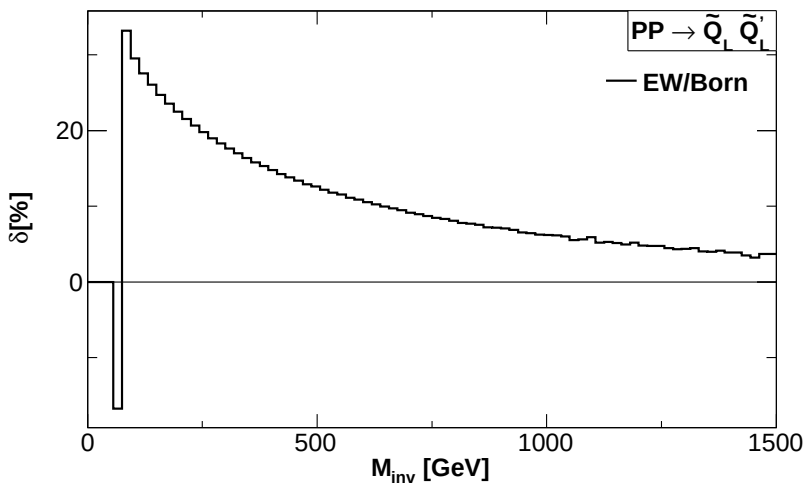


$\mathcal{O}(\alpha_s^2\alpha)$: different channels



- Process: $\mathbf{PP \to \tilde{q}_L \tilde{q}'_L}$
- Contributions partially cancel!

$$\delta = \mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$$



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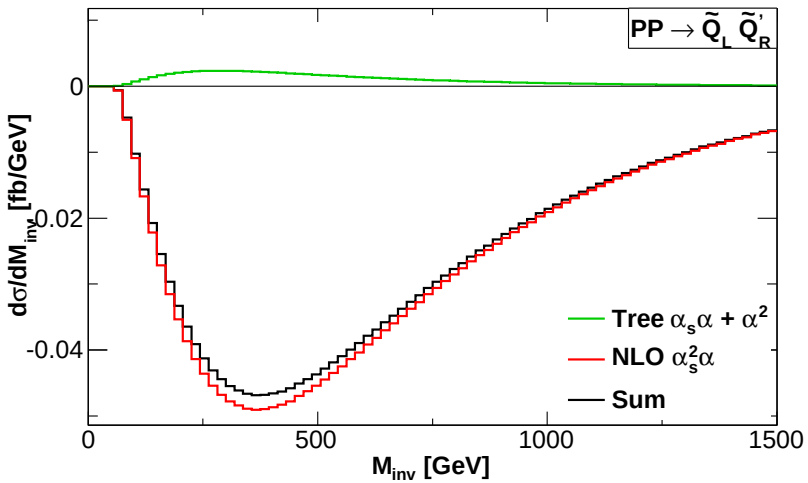

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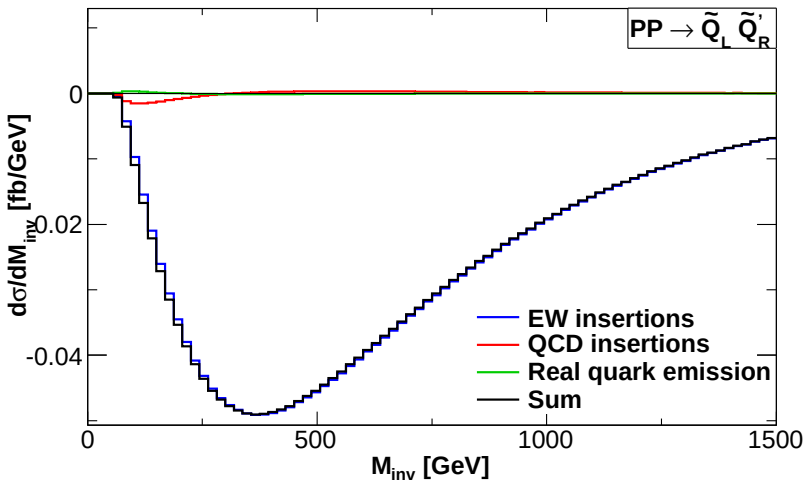
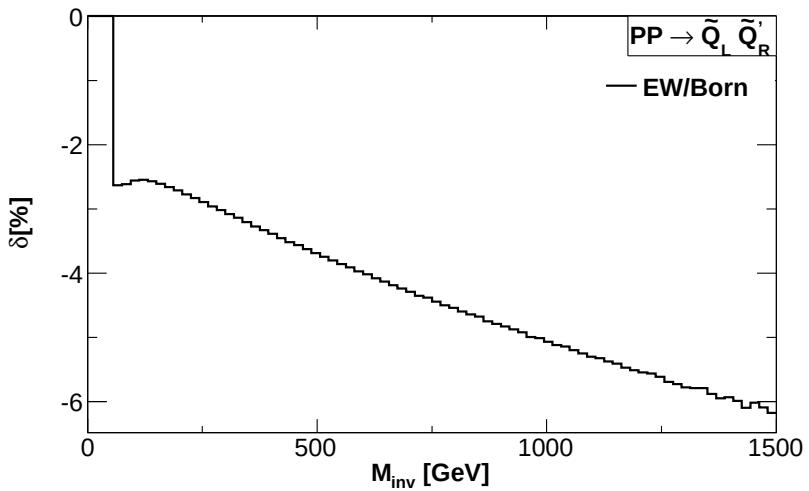


- Process: $\mathbf{PP \to \tilde{q}_L \tilde{q}'_R}$
- NLO EW contribution

  $\gg$

  tree-level EW contribution.

$$\delta = \mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$$



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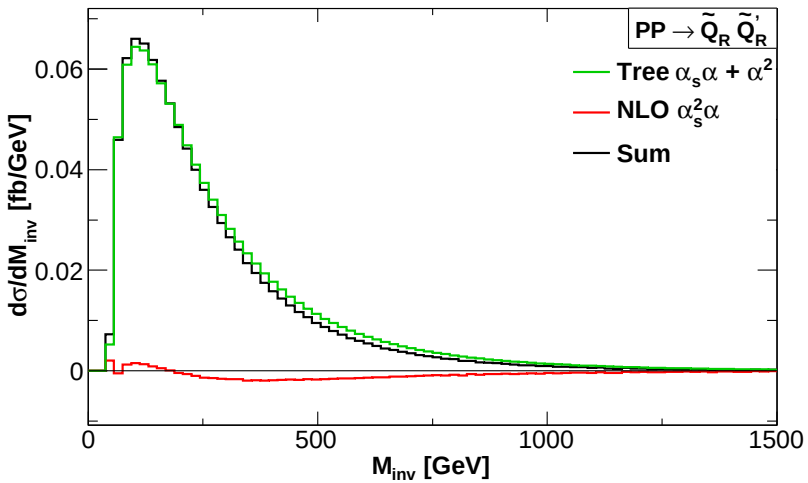

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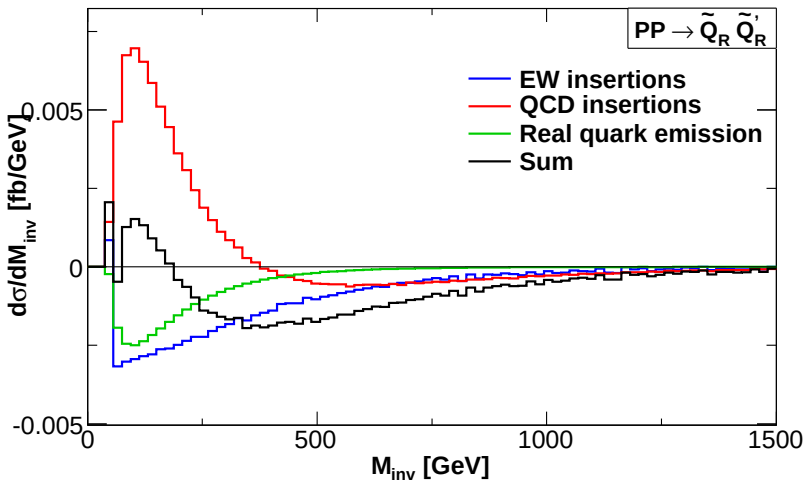

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- NLO EW contribution

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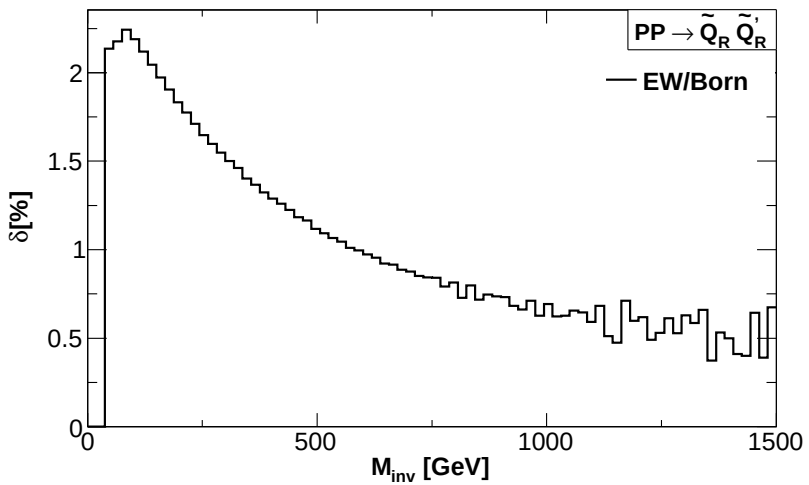

Summary & Conclusions

- Squarks and gluinos will be produced at a very high rate @LHC.
- **Presented:**
  EW contributions up to $\mathcal{O}(\alpha_s^2\alpha)$ to squark–squark production.
  $\longrightarrow$ Many different processes contribute (36).
  $\longrightarrow$ Known.
- Size of **EW NLO** corrections depends on **squark chirality**:
  $\longrightarrow \approx$ **4%** if one squark is **left-handed**.
  $\longrightarrow$ negligible if both squarks are right-handed.
- Corrections more important in **distributions**.
- Publication in preparation.

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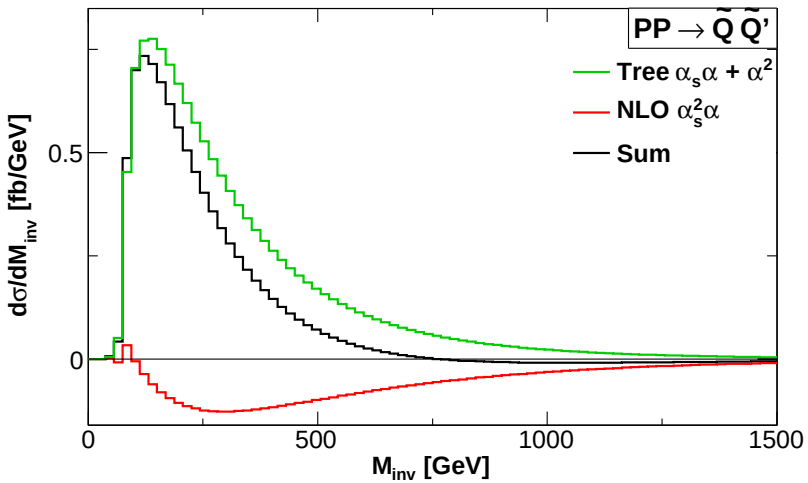
Thank you for your attention !!!

Backup Slides

M_{inv} distribution

Electroweak contributions



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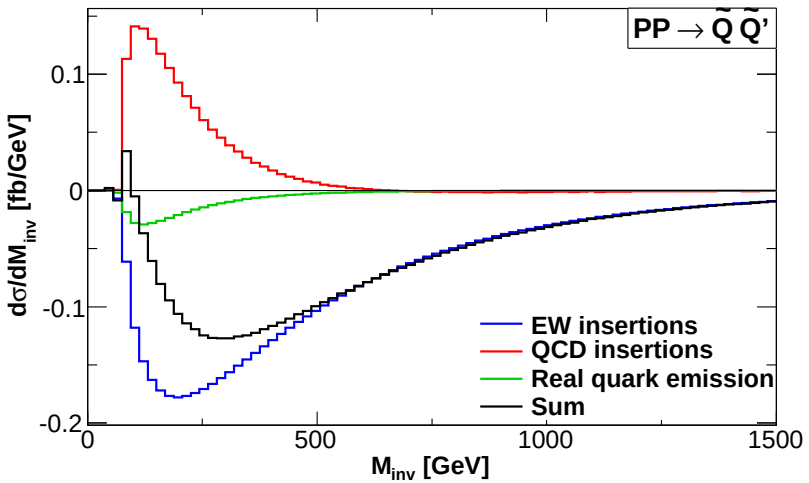
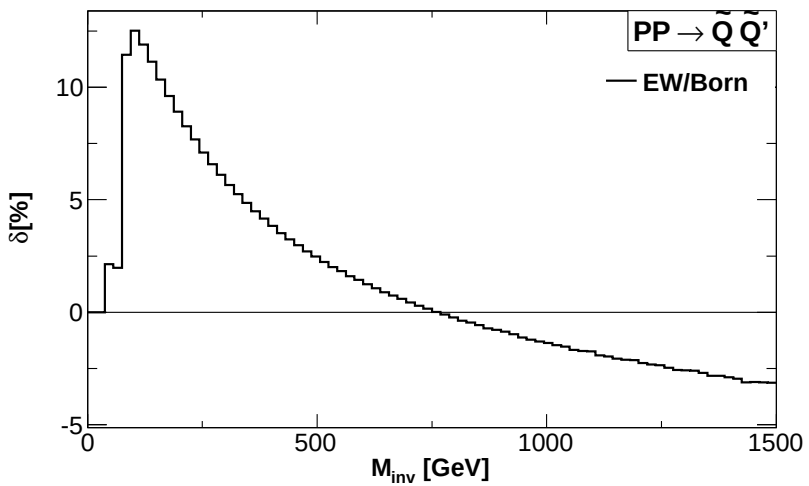


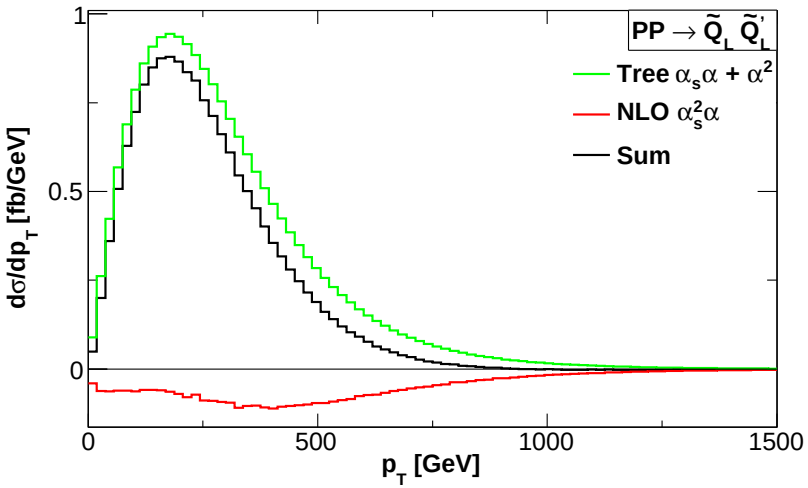
- Process: **PP** $\rightarrow \tilde{q}\tilde{q}'$ (summed over all processes)

$$\delta = \mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$$



P_{TH} distribution

Electroweak contributions



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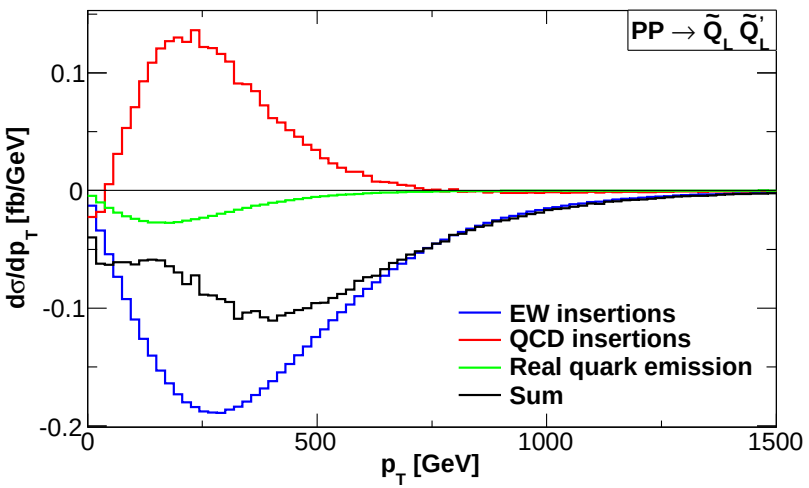

- Process: $\mathbf{PP \to \tilde{q}_L \tilde{q}'_L}$
- NLO corrections more significant at high p_T
- Contributions partially cancel!

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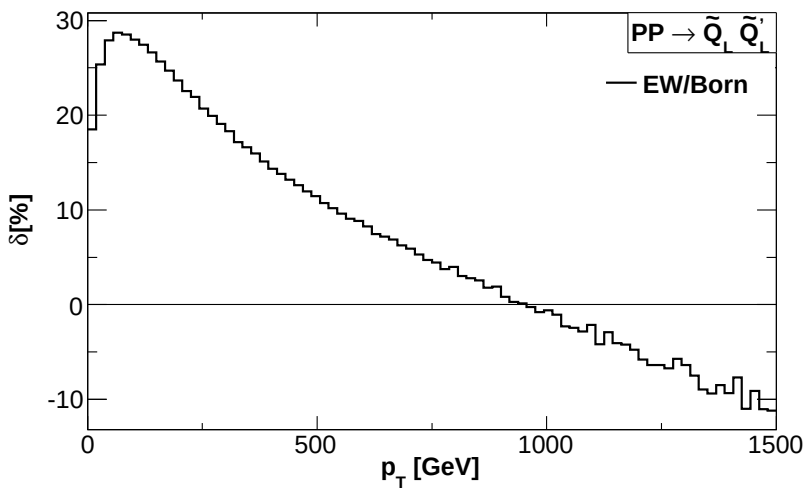

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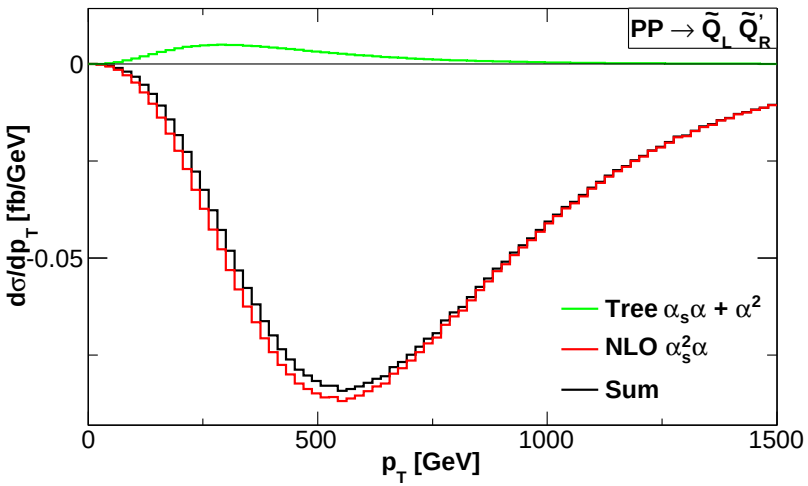
Electroweak contributions



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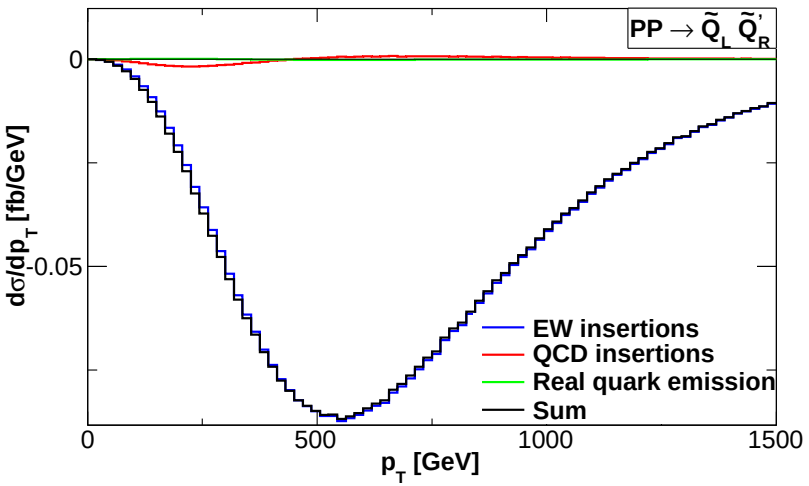

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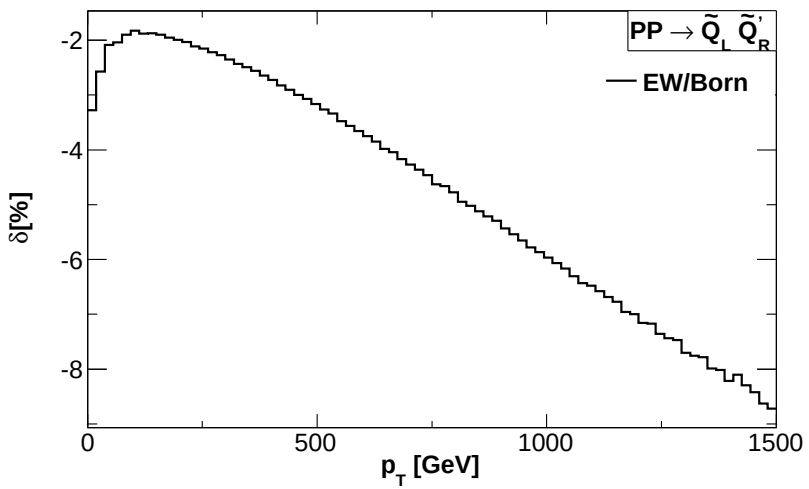
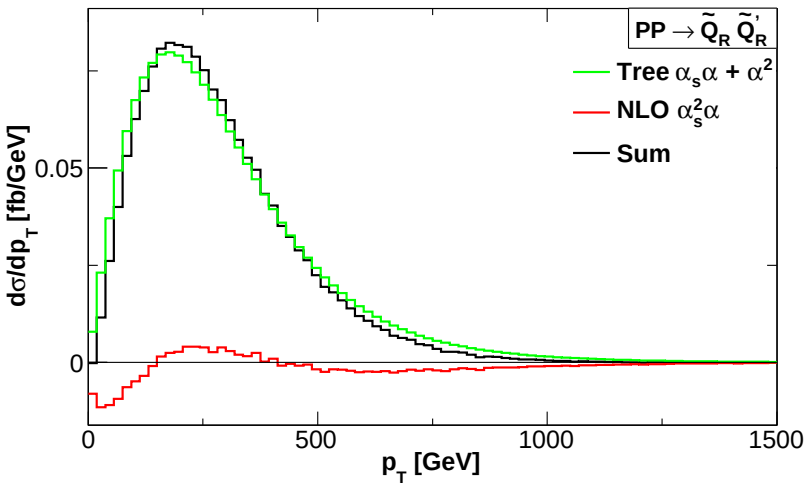
- NLO EW contribution
  $\gg$
  tree-level EW contribution.

$$\delta = \mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$$

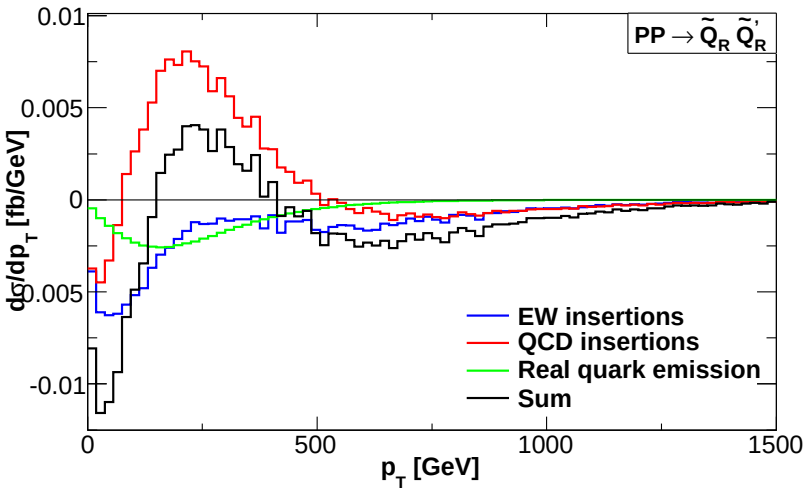


p_{TH} distribution

Electroweak contributions



$\mathcal{O}(\alpha_s^2\alpha)$: different channels



- Process: $\mathbf{PP \to \tilde{q}_R \tilde{q}'_R}$
- NLO EW contribution
  $\ll$
  tree-level EW contribution.

$$\delta = \mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$$