Production of squarks and gluinos at the LHC: The electroweak contributions

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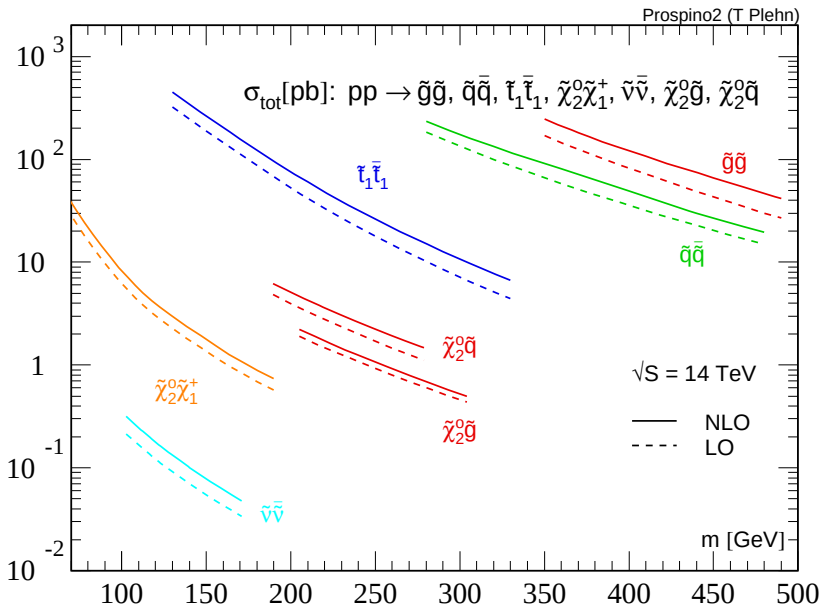
Outline

1. Introduction to **colored SUSY** particles @ LHC
   - Production processes
   - Status of higher order corrections.
2. **EW** contributions to **squark** and **gluino** production:
   - **EW tree-level** contributions.
   - **NLO EW** contributions of $\mathcal{O}(\alpha_s^2\alpha)$:
     EW-type & **QCD-type** corrections.
     $\rightarrow$ Treatment of **singularities**.
3. Numerical results: **Total cross-sections**
4. Conclusions

Colored SUSY particles @ hadron colliders

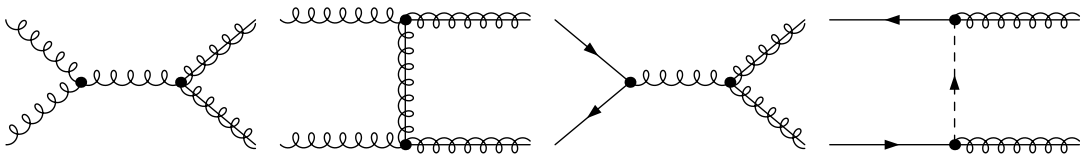
- Squarks and gluinos are strongly interacting particles
- Production rate depends on mass, color-representation and multiplicity.



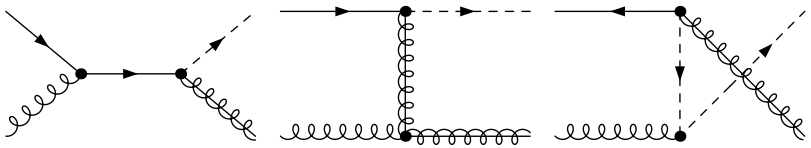
- Squarks, gluinos and top squarks have high production rate at hadron colliders.

Overview: Production processes @ LO

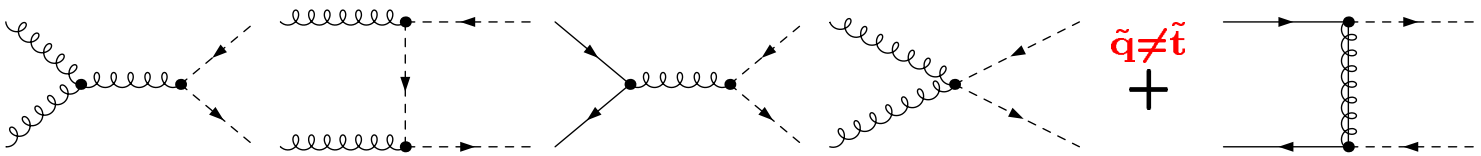
$\tilde{g}\tilde{g}$



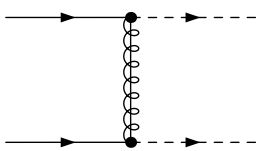
$\tilde{q}\tilde{g}$



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



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



[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 QCD:
  - Approximate **NNLO** corrections ($\tilde{q}\tilde{q}^*$)
  - **NLL** resummation
    $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$, $\tilde{q}\tilde{q}^*$, $\tilde{q}\tilde{q}$

  [Langenfeld, Moch '09],
  [Kulesza, Motyka '08'09],
  [Beneke, Falgari, Schwinn '07'09],
  [Beenakker, Brensing, Krämer, Kulesza, Laenen, Niessen '09]

- **LO EW** contributions, **LO one-loop**
  (Tree-level, loop induced, Higgs enhanced)
  $\mathcal{O}(\alpha_s\alpha + \alpha^2 + \alpha_s^2\alpha^2 + \alpha_s^4)$

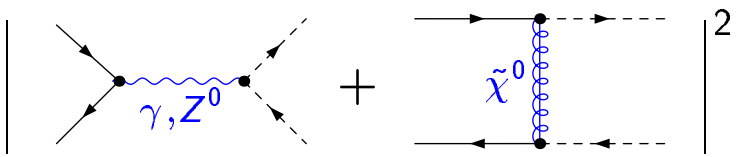
  [Bornhauser, Drees, Dreiner, Kim '07 '09],
  [Bozzi, Fuks, Klasen],
  [Arhib, Benbrik, Cheung, Yuan]

- $\mathcal{O}(\alpha_s^2\alpha)$: NLO EW corrections
  $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$, $\tilde{q}\tilde{q}^*$, $\tilde{t}\tilde{t}^*$, $\tilde{q}\tilde{q}$

  [Hollik, Kollar, Trenkel '07],
  [Beccaria et. al. '08],
  [Hollik, Mirabella '08],
  [Hollik, Mirabella, Trenkel '08],
  [Mirabella '09]
  [JG, Hollik, Mirabella, Trenkel (in preparation)]

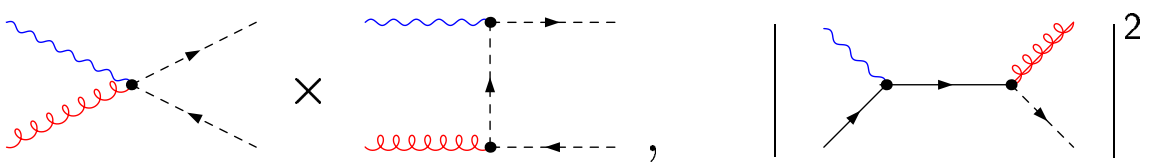
Squark & gluino production: EW production at Born level

- $\mathcal{O}(\alpha^2)$: pure EW tree-level contributions ($\tilde{t}\tilde{t}^*$, $\tilde{q}\tilde{q}^{(*)}$ prod.), e.g.



- $\mathcal{O}(\alpha_s\alpha)$: EW-QCD tree-level interferences ($\tilde{q}\tilde{q}^{(*)}$ prod.), e.g.

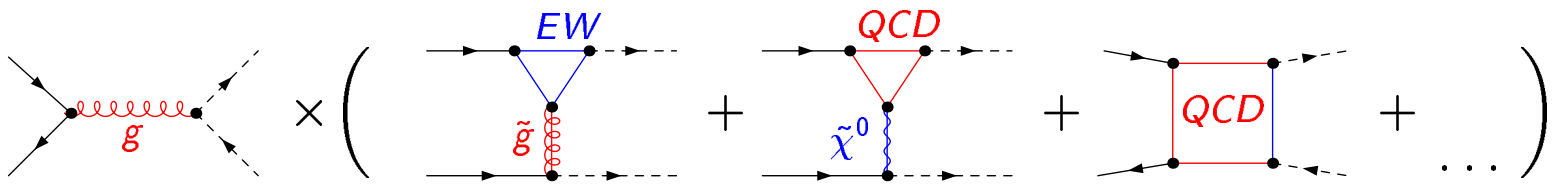
- $\mathcal{O}(\alpha_s\alpha)$: photon induced processes ($\tilde{t}\tilde{t}^*$, $\tilde{q}\tilde{q}^*$, $\tilde{g}\tilde{q}$ prod.), e.g.



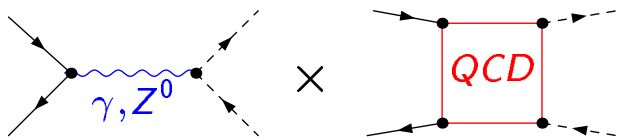
NLO EW: Contributions of $\mathcal{O}\left(\alpha_s^2\alpha\right)$

EW & QCD-like corrections have to be taken into account:

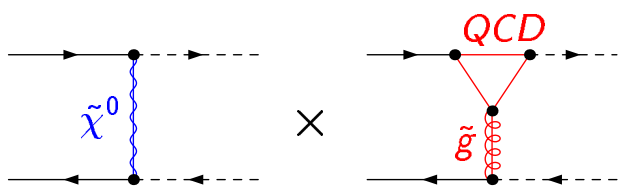
- QCD Born $\times$ 1-loop amplitude $\mathcal{O}\left(\alpha_s\alpha\right)$, e.g.



- EW Born $\times$ 1-loop amplitude $\mathcal{O}\left(\alpha_s^2\right)$, e.g.



only box diagrams lead to non-vanishing interferences



full QCD 1-loop amplitude

- Real photon, gluon and quark radiation.

Singularities & divergences

- **UV divergences**: Renormalization required.

  CTs have to be evaluated at $\mathcal{O}(\alpha)$ and $\mathcal{O}(\alpha_s)$, respectively.

  - **quarks, squarks, gluino** $\rightarrow$ **renormalized on-shell**
    Subtlety: Only three independent squark parameters for each generation. Treat LH down-type squark as dependent quantity.
  - $\alpha_s \rightarrow$ **$\overline{\text{MS}}$ with five flavors** (same definition as in pdf)
    Caution with $\hat{g}_s$: needs symmetry restoring counterterm.

- **IR singularities**:
  - Cancel after combining **virtual** and **real** corrections.

    [Methods: **mass regularization** & **phase space slicing**;
    gluonic corrections: **color correlations** in EW-QCD interferences.]

- **Collinear singularities**:
  - Real photon and gluon **bremsstrahlung**.
  - **Factorization** and **redefinition** of the **PDFs** at $\mathcal{O}(\alpha_s)$ and $\mathcal{O}(\alpha)$.

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**.

$$m(\tilde{u}_L) = 560\mathrm{GeV} \quad m(\tilde{d}_L) = 566\mathrm{GeV} \quad m(\tilde{g}) = 609\mathrm{GeV}$$
$$m(\tilde{u}_R) = 543\mathrm{GeV} \quad m(\tilde{d}_R) = 539\mathrm{GeV}$$

- **Renormalization scale** for α_s : $\mathcal{O}$(mass of external particles)
- **PDF** set: **MRST2004QED** [Martin, Roberts, Stirling, Thorne]

Total hadronic X-section

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

final state	σ^{LO} $\mathcal{O}(\alpha_s^2)$	$\Delta\sigma^{NLO}$ $\mathcal{O}(\alpha_s^2\alpha)$	$\Delta\sigma^{\gamma g/\gamma q}$ $\mathcal{O}(\alpha_s\alpha)$	$\Delta\sigma^{EW,LO}$ $\mathcal{O}(\alpha^2+\alpha_s\alpha)$	δ
$\tilde{g}\,\tilde{g}$	6187 fb	-4 fb	–	–	0.07%
$\tilde{g}\tilde{q}$	20827 fb	-238 fb	10 fb	–	-1.1 %
$\tilde{t}\tilde{t}^*$	2856 fb	-54 fb	42 fb	2 fb	-0.4 %
$\tilde{q}\tilde{q}^*$	2251 fb	-12 fb	24 fb	-37 fb	-1.1%
$\tilde{q}\tilde{q}$	5444 fb	-147 fb	–	413 fb	4.9 %

$$\delta = (\Delta\sigma^{NLO} + \Delta\sigma^{\gamma g/\gamma q} + \Delta\sigma^{EW,LO})/\sigma^{LO}$$

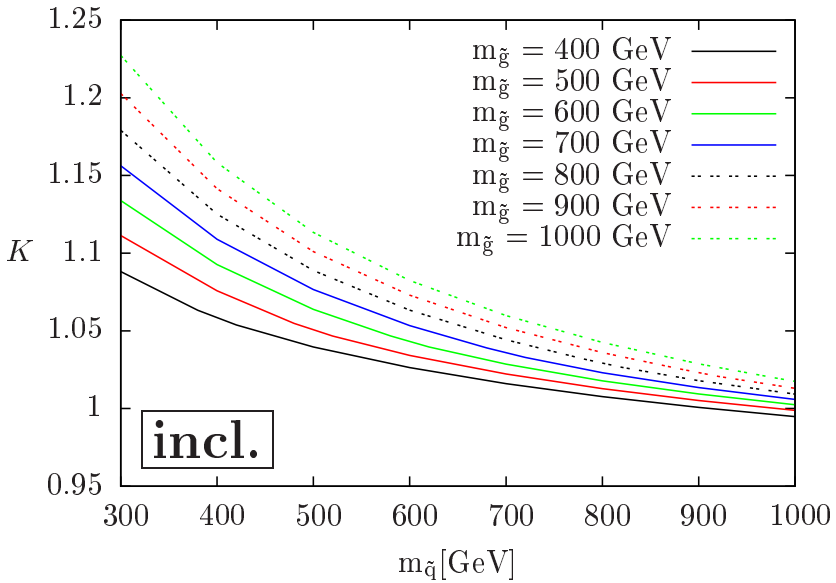
Total hadronic X-section, LL only

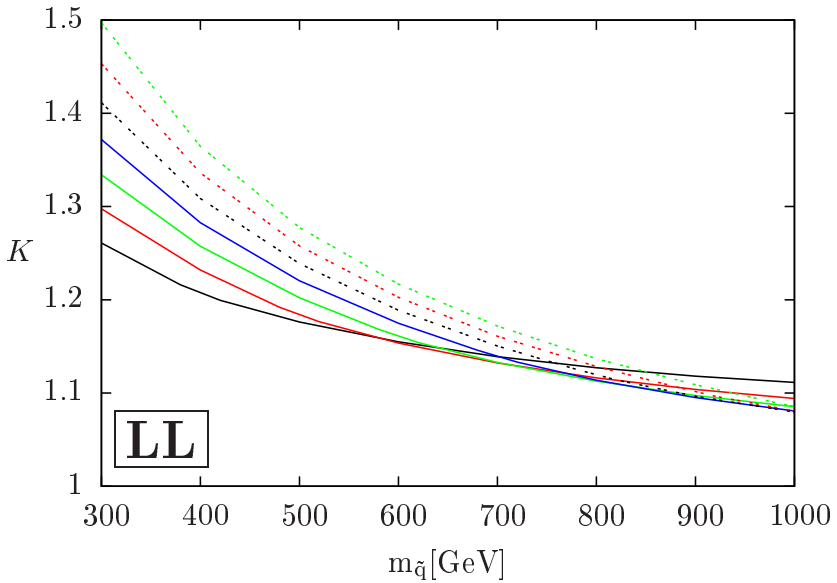
Born and **EW** contributions to the **total cross section**:

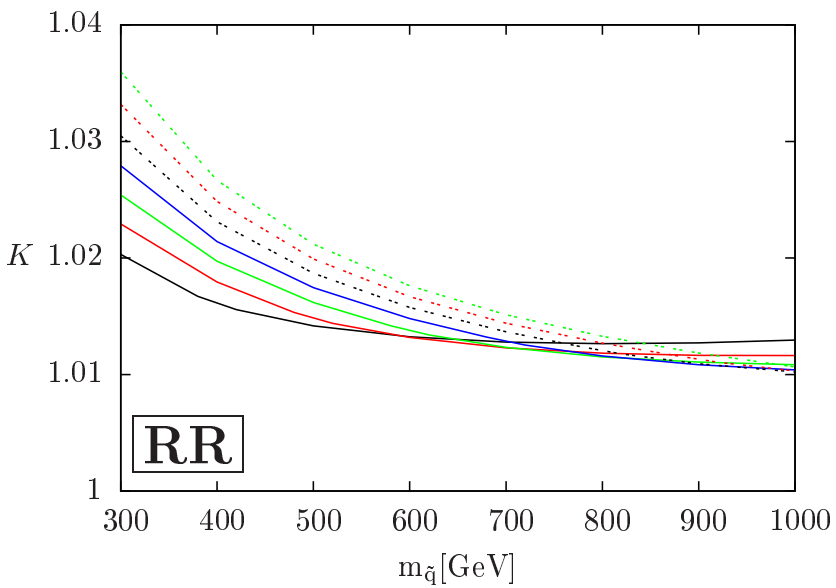
final state	σ^{LO} $\mathcal{O}(\alpha_s^2)$	$\Delta\sigma^{NLO}$ $\mathcal{O}(\alpha_s^2\alpha)$	$\Delta\sigma^{\gamma g/\gamma q}$ $\mathcal{O}(\alpha_s\alpha)$	$\Delta\sigma^{EW,LO}$ $\mathcal{O}(\alpha^2+\alpha_s\alpha)$	δ
$\tilde{g}\,\tilde{g}$	6187 fb	-4 fb	–	–	0.07%
$\tilde{g}\,\tilde{q}_L$	10010 fb	-248 fb	5 fb	–	$-$ 2.4 %
$\tilde{t}_2\tilde{t}_2^*$	186 fb	-31.6 fb	3.8 fb	0.3 fb	-14.8%
$\tilde{q}_L\,\tilde{q}_L^*$	1016 fb	-4 fb	11 fb	-80 fb	-7.1%
$\tilde{q}_L\,\tilde{q}_L$	1718 fb	-75 fb	–	379 fb	17.6%

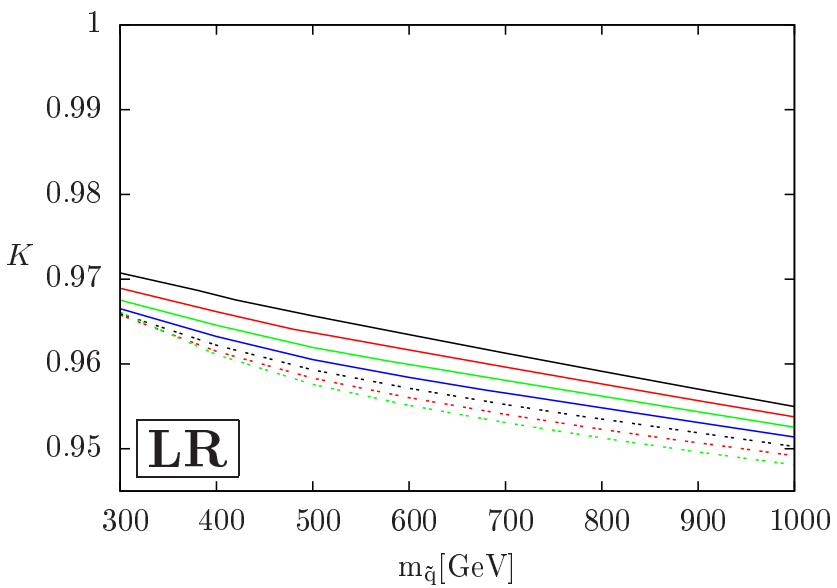
$$\delta = (\Delta\sigma^{NLO} + \Delta\sigma^{\gamma g/\gamma q} + \Delta\sigma^{EW,LO})/\sigma^{LO}$$

$\tilde{q}\tilde{q}$ production: $m(\tilde{q})$ and $m(\tilde{g})$ dependence









$$K = \sigma^{NLO}/\sigma^{LO}$$

[All other parameters are set to their SPS1a′ values.]

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 colored particle production.
- Size of **EW NLO** corrections depends on **squark chirality**:
  $\rightarrow$ Only a **few percent** in the **inclusive case**.
  $\rightarrow$ Can be $>$ **10%** in the case of **left-handed** particle production.
- EW corrections for $\tilde{q}\tilde{q}$ more important for **light squarks** and **heavy gluinos**.

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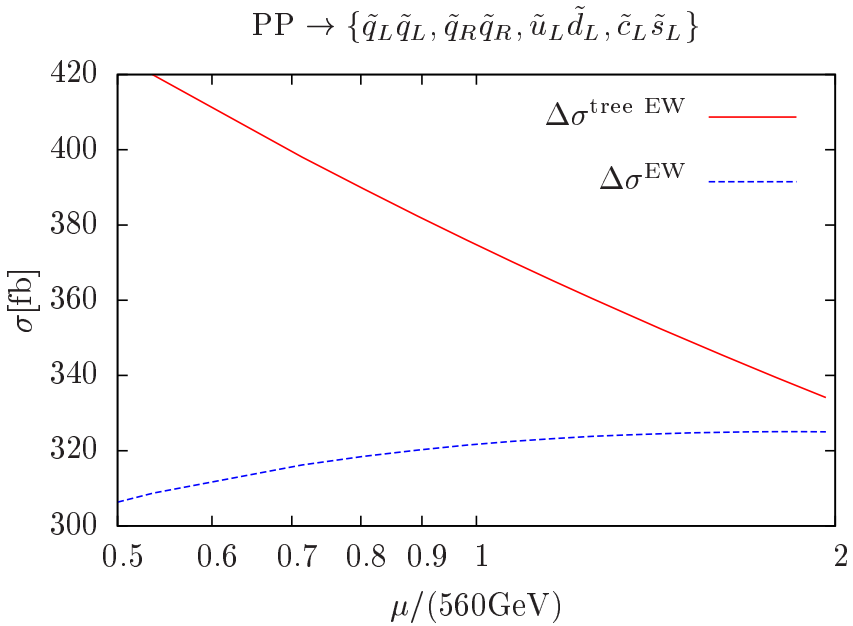
Thank you for your attention !!!

Backup Slides

Scale dependence

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

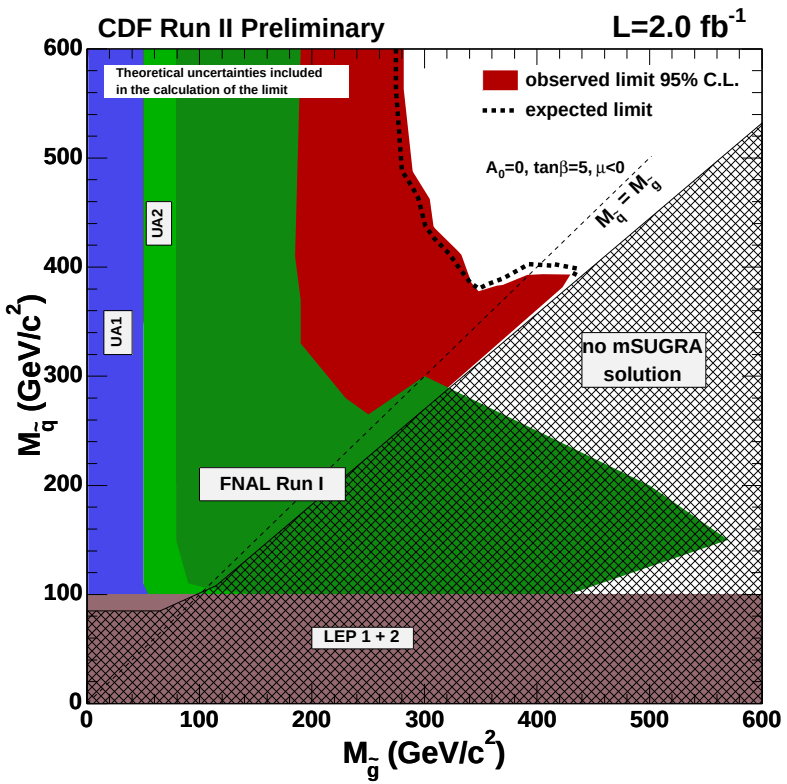


- Renormalization scale (μ_{ren}) is set equal to factorization scale (μ_{fac}).
- Scale dependence reduces when NLO EW corrections are taken into account.

Experimental Searches for Squarks and Gluinos

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

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

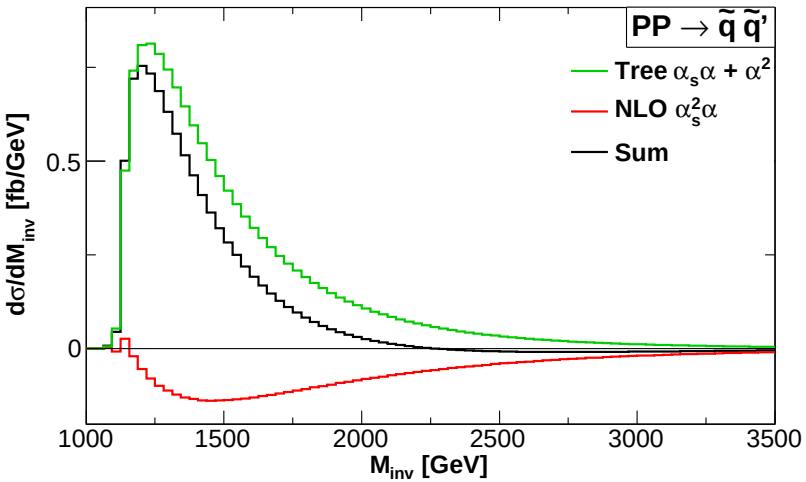


- Until now: agreement between experiment and SM predictions.

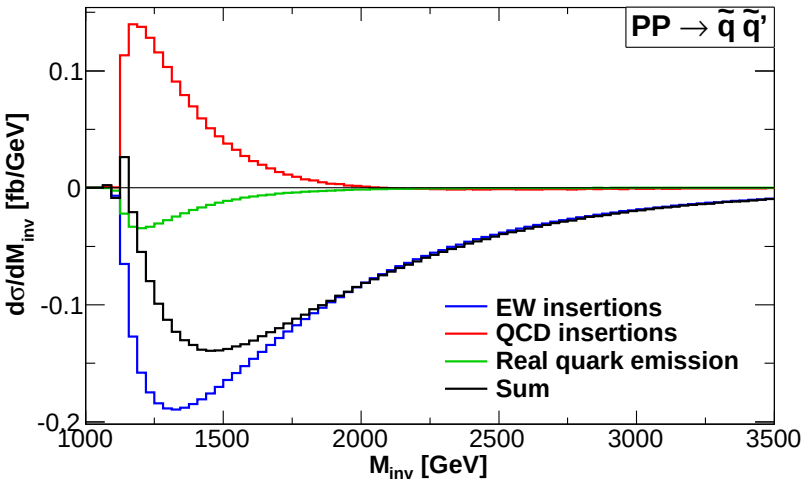
- Further analysis needs improved theoretical predictions.

M_{inv} distribution

Electroweak contributions

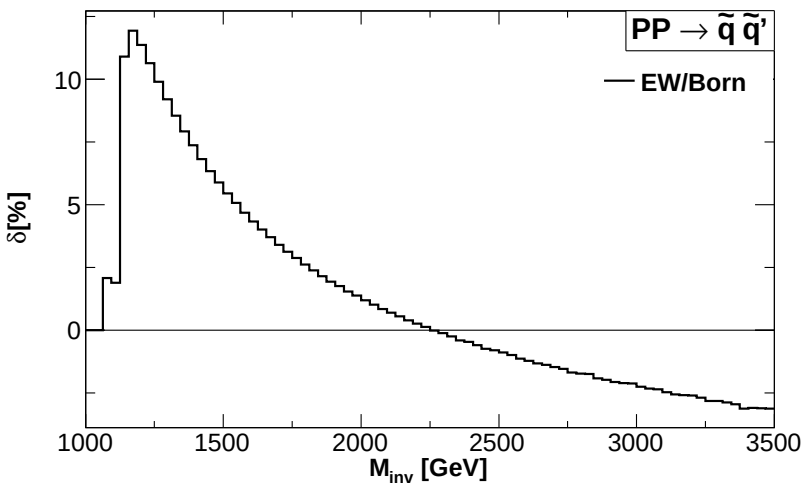


$\mathcal{O}(\alpha_s^2\alpha)$: different channels



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

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



M_{inv} distribution

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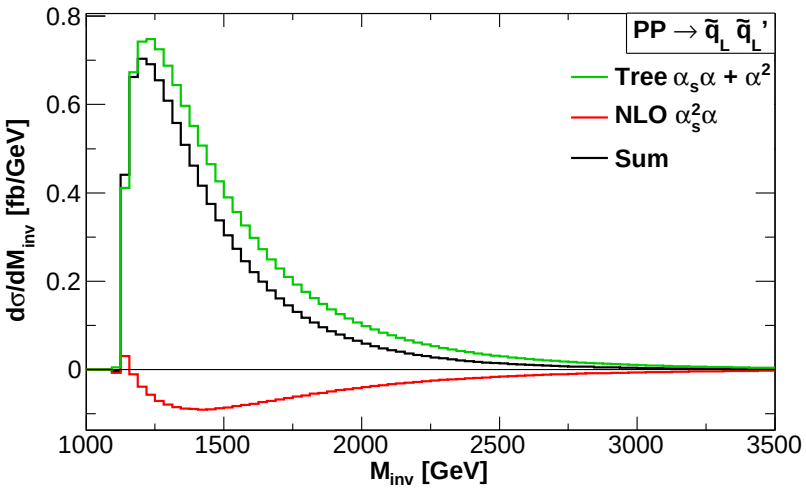
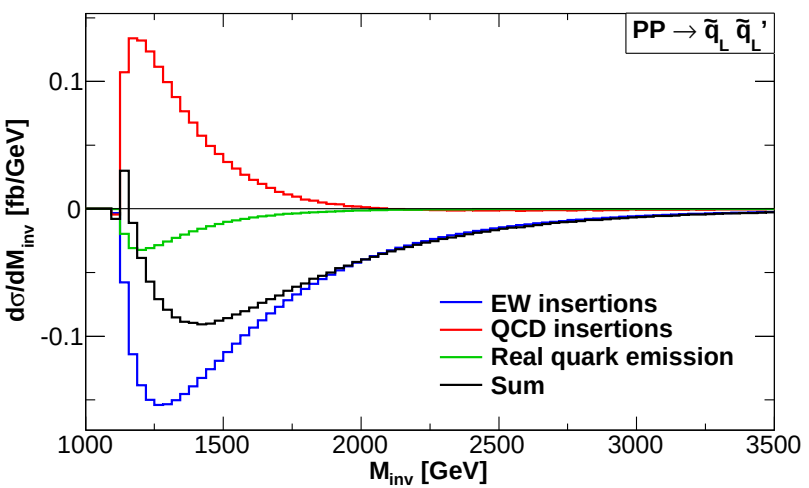
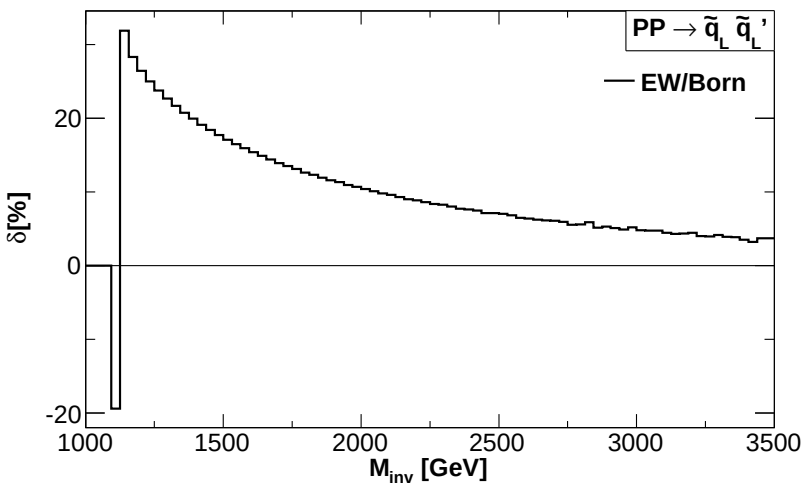


$\mathcal{O}(\alpha_s^2\alpha)$: different channels



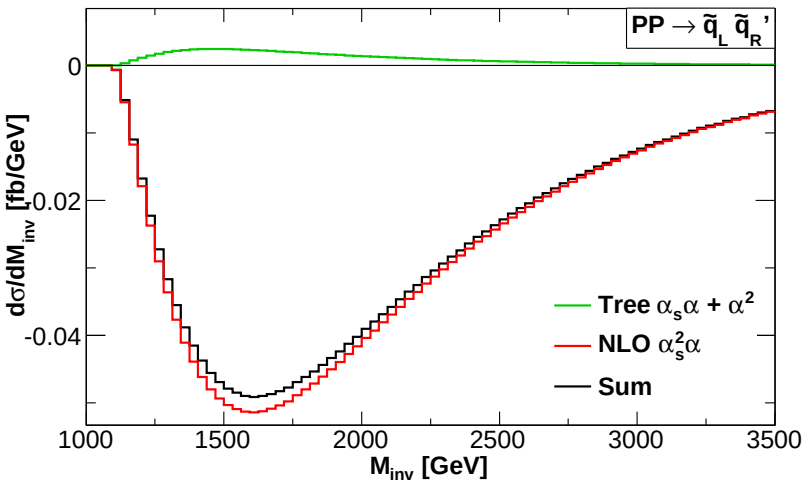
- Process: $\mathbf{PP \to \tilde{q}_L \tilde{q}'_L}$
- Contributions partially cancel!

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



M_{inv} distribution

Electroweak contributions



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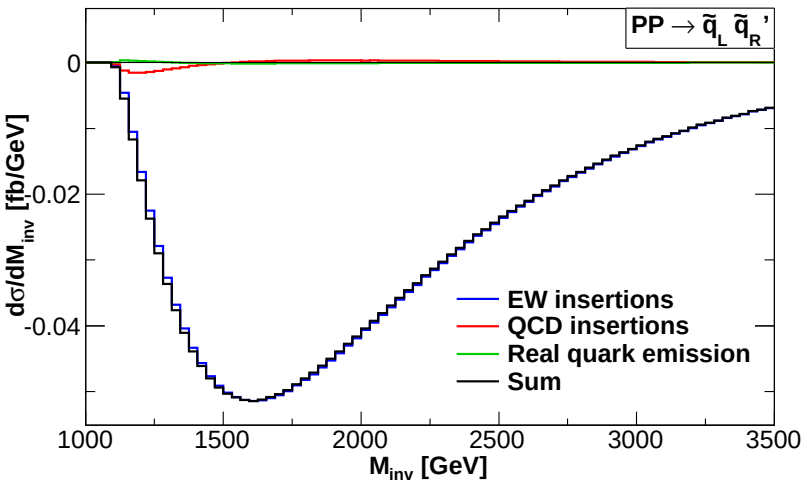
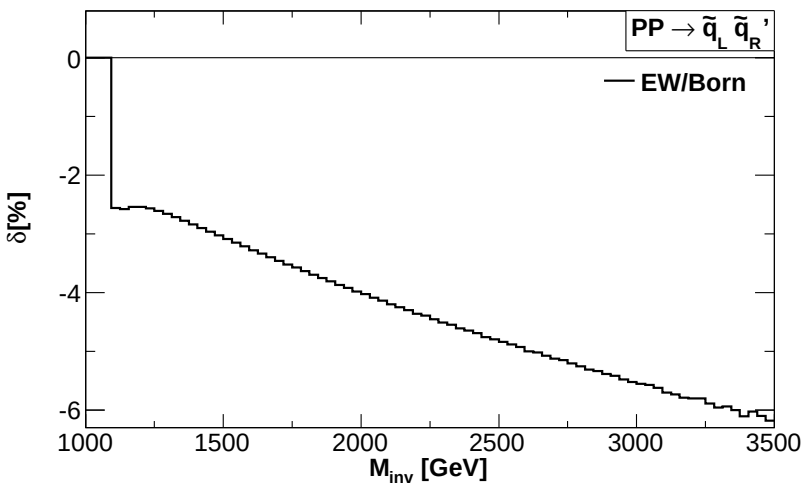


- Process: $\mathbf{PP \to \tilde{q}_L \tilde{q}'_R}$
- NLO EW contribution

  $\gg$

  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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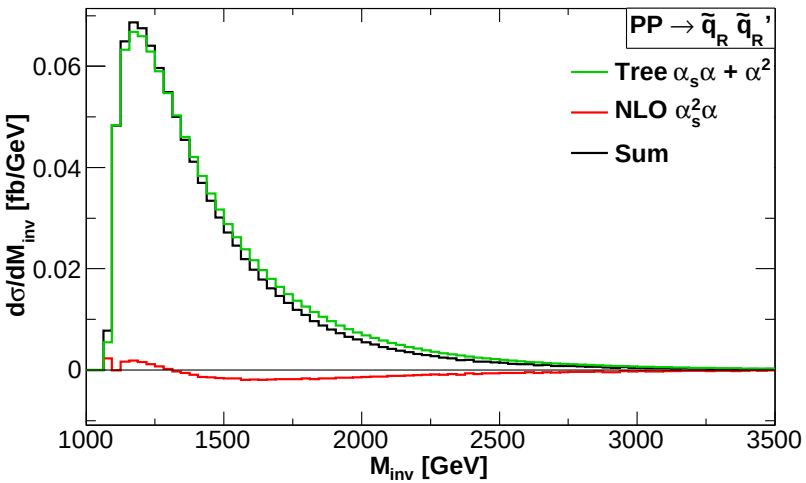
Electroweak contributions



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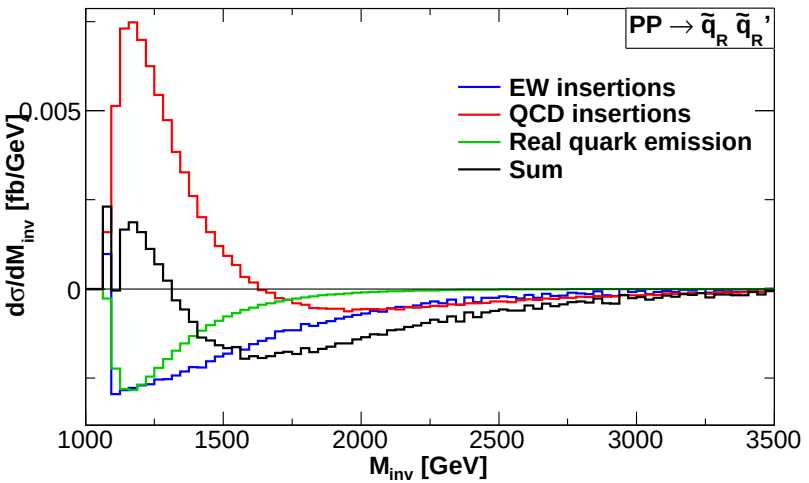

- Process: $\mathbf{PP \to \tilde{q}_R \tilde{q}'_R}$
- NLO EW contribution

$$\ll$$

tree-level EW contribution.

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