Electroweak contributions to squark and gluino production processes at the LHC

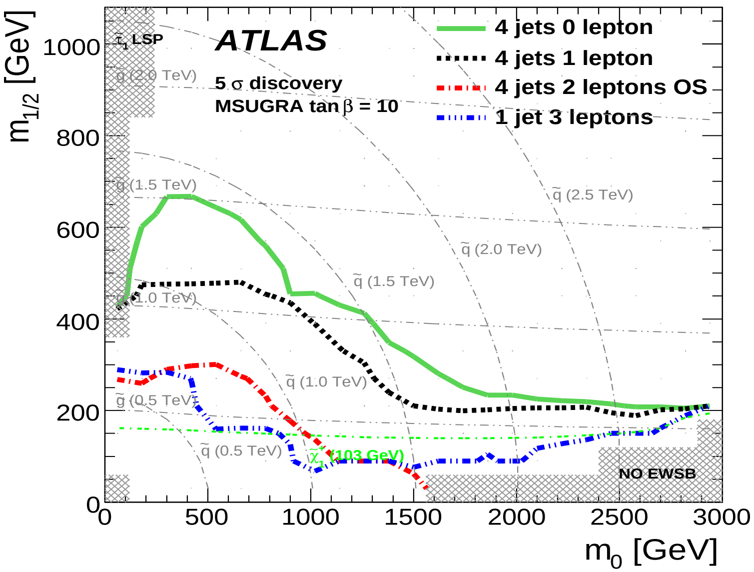
Edoardo Mirabella

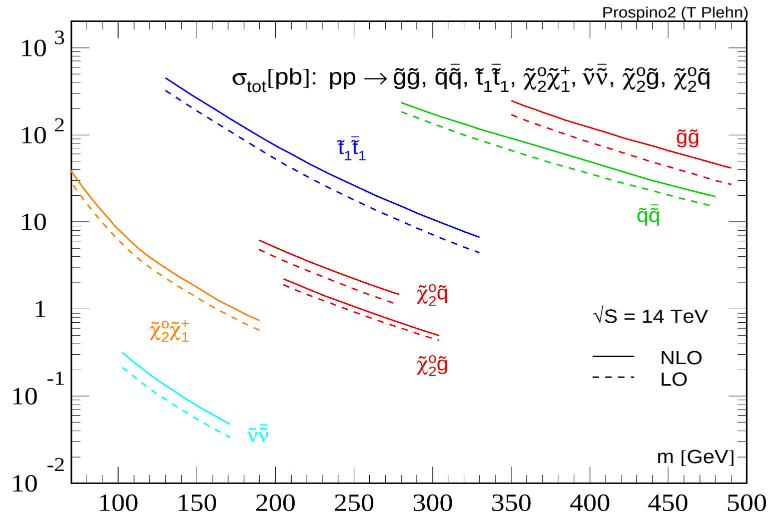
In collaboration with J. Germer, W. Hollik & M. Trenkel

Outline

- Motivations
- Production of squarks and gluinos
  - QCD contributions
  - EW contributions
- Closer look into EW contributions
  - UV divergences
  - IR divergences
- Numerical discussion
- Conclusions

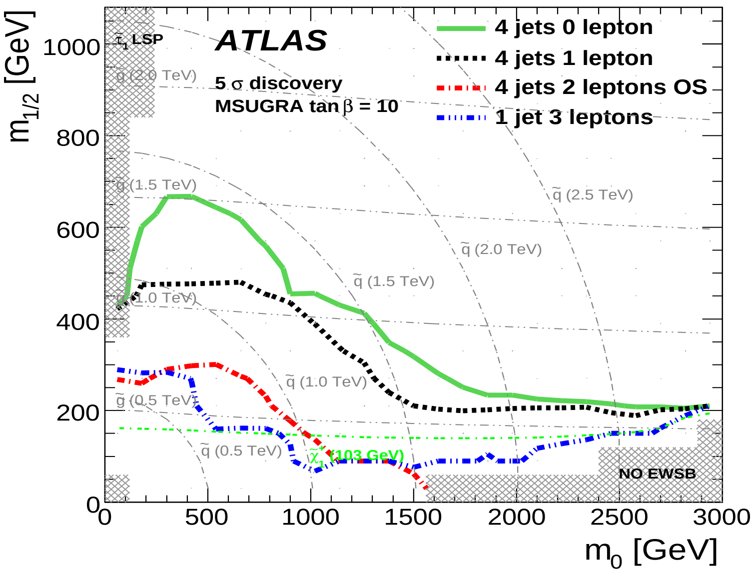
Motivations

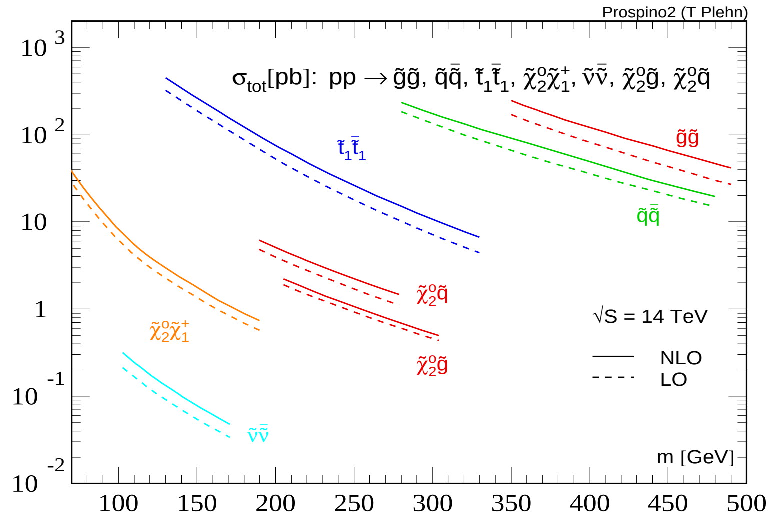




- TeV-scale SUSY will be tested @ LHC . . .
- . . . mainly via direct production of coloured SUSY particles

Motivations





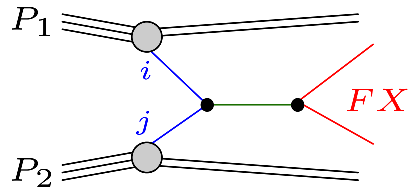
- TeV-scale SUSY will be tested @ LHC . . .
- . . . mainly via direct production of coloured SUSY particles
- Electroweak Contributions
  - chirality, flavour, scenario dependent
  - can become numerically important
  - if small, reliable estimation of the theoretical error

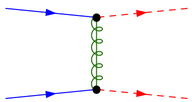
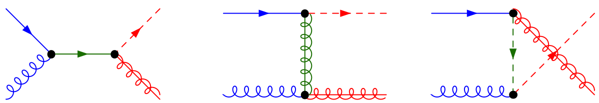
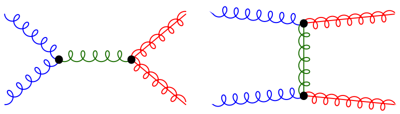
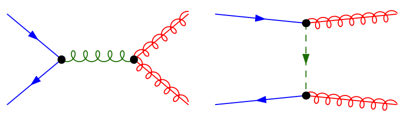
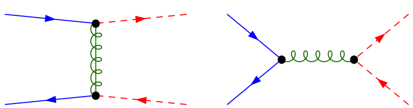
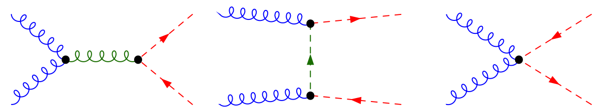
⇝ investigation needed

Squark and Gluino production – QCD

- The main formula, from hadron to parton level:

$$d\sigma_{P_1P_2\to FX} = \sum_{i,j}\int dx_1\, dx_2\, f_{i|P_1}(x_1)\, f_{j|P_2}(x_2)\, d\hat{\sigma}_{ij\to FX}$$

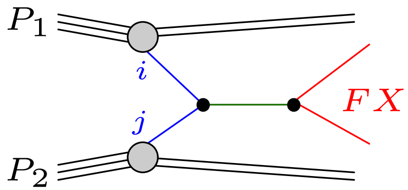


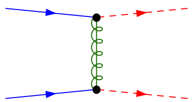
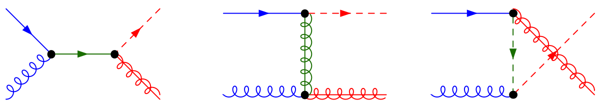
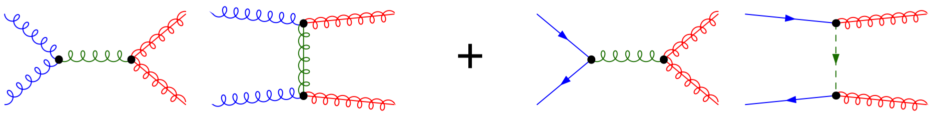
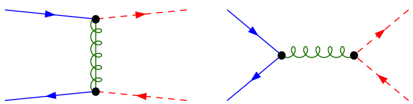
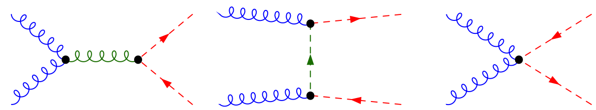
- LO is QCD based, of $\mathcal{O}(\alpha_s^2)$ [Kane & Leveille '82] [Harrison & Llewellyn Smith '83] [Reya & Roy '85] [Dawson *et al.* '85] [Baer & Tata '85]
  - $F = \tilde{q}\tilde{q}' \;\&\; \tilde{q}^*\tilde{q}'^*$ 
  - $F = \tilde{g}\tilde{q} \;\&\; \tilde{g}\tilde{q}^*$ 
  - $F = \tilde{g}\tilde{g}$  + 
  - $F = \tilde{q}\tilde{q}'^*$  $\cdot\delta_{\tilde{q}\tilde{q}'}$ + $\Big($  $\Big)\cdot\delta_{\tilde{q}\tilde{q}'}$

Squark and Gluino production – QCD

- The main formula, from hadron to parton level:

$$d\sigma_{P_1 P_2 \to F X} = \sum_{i,j} \int dx_1 \; dx_2 \; f_{i|P_1}(x_1) \; f_{j|P_2}(x_2) \; d\hat{\sigma}_{ij \to F X}$$

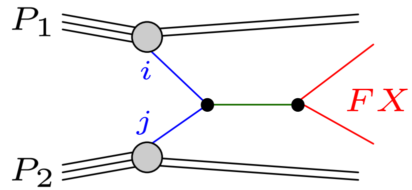


- LO is QCD based, of $\mathcal{O}(\alpha_s^2)$ [Kane & Leveille '82] [Harrison & Llewellyn Smith '83] [Reya & Roy '85] [Dawson *et al.* '85] [Baer & Tata '85]
  - $F = \tilde q \tilde q^{'}$ & $\tilde q^{*} \tilde q^{'\,*}$ 
  - $F = \tilde g \tilde q$ & $\tilde g \tilde q^{*}$ 
  - $F = \tilde g \tilde g$ 
  - $F = \tilde q \tilde q^{'\,*}$  $\cdot \delta_{\tilde q \tilde q'}$ + $\Big($  $\Big) \cdot \delta_{\tilde q \tilde q'}$

- NLO QCD corrrections, of $\mathcal{O}(\alpha_s^3)$ [Beenakker *et al.* '96, '97, '98]
  - scale dependence is reduced
  - K-factor from 1.2 to 1.4
  - NLO QCD total cross section publicly available [PROSPINO, Beenakker, Höpker & Spira, '97]

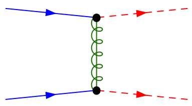
Squark and Gluino production – QCD

- The main formula, from hadron to parton level:

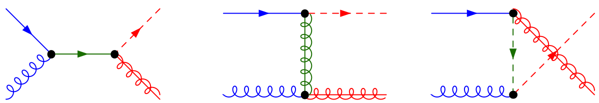


$$d\sigma_{P_1P_2\to FX} = \sum_{i,j}\int dx_1\, dx_2\, f_{i|P_1}(x_1)\, f_{j|P_2}(x_2)\, d\hat\sigma_{ij\to FX}$$

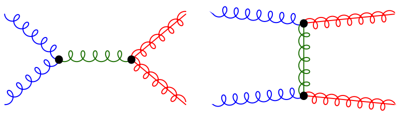
- LO is QCD based, of $\mathcal{O}(\alpha_s^2)$ [Kane & Leveille '82] [Harrison & Llewellyn Smith '83] [Reya & Roy '85] [Dawson *et al.* '85] [Baer & Tata '85]
  - $F = \tilde q\tilde q'$ & $\tilde q^*\tilde q'^*$



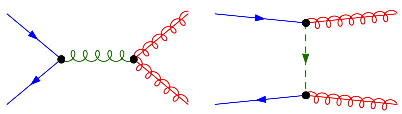
  - $F = \tilde g\tilde q$ & $\tilde g\tilde q^*$



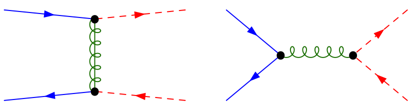
  - $F = \tilde g\tilde g$



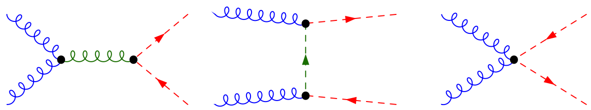
+



  - $F = \tilde q\tilde q'^*$



$\cdot\delta_{\tilde q\tilde q'}$ + $\Bigg($



$\Bigg)\cdot\delta_{\tilde q\tilde q'}$

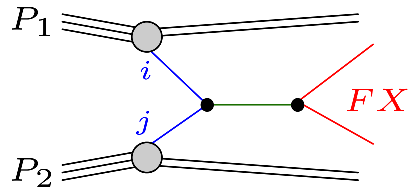
- Beyond NLO QCD
  - $F = \tilde q\tilde q'^*$: approximate NNLO corrections [Langenfeld, Moch '09]
  - NLL resummation [Kulesza, Motyka '08, '09] [Beneke, Falgari & Schwimm '07, '09, '10] [Beenakker *et al.* '09]

    ⇝ see the talk of Silja Brensing

Squark and Gluino production – tree level EW

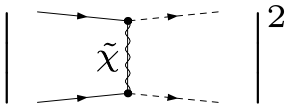
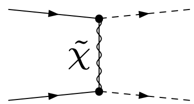
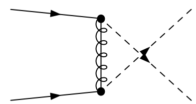
- The main formula, from hadron to parton level:

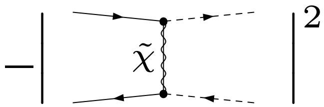
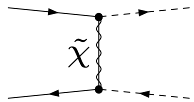
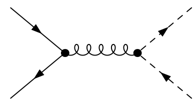
$$d\sigma_{P_1 P_2 \to FX} = \sum_{i,j} \int dx_1\, dx_2\, f_{i|P_1}(x_1)\, f_{j|P_2}(x_2)\, d\hat{\sigma}_{ij\to FX}$$



- Contributions of $\mathcal{O}(\alpha_s\alpha + \alpha^2)$ [Bozzi *et al.* '07] [Alan, Cankocak, & Demir '07] [Bornhauser *et al.* '07] [Hollik, Kollar & Trenkel '07] [Hollik, EM '08] [Hollik, EM & Trenkel '08] [Germer, Hollik, EM & Trenkel '10]

  - Contributions from qq-, $q\bar{q}$-initiated processes:

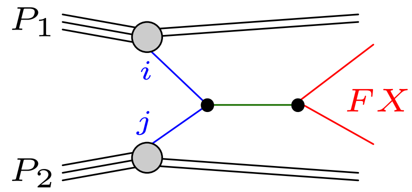
$F = \tilde{q}\tilde{q}'$ & $\tilde{q}^*\tilde{q}'^*$ $\mathcal{O}(\alpha^2)$ $\rightsquigarrow$  $\mathcal{O}(\alpha_s\alpha)$ $\rightsquigarrow$  $\cdot$  $\cdot\, \delta_{\tilde{q}\tilde{q}'}$

$F = \tilde{q}\tilde{q}'^*$ $\mathcal{O}(\alpha^2)$ $\rightsquigarrow$  $\mathcal{O}(\alpha_s\alpha)$ $\rightsquigarrow$  $\cdot$  $\cdot\, \delta_{\tilde{q}\tilde{q}'}$

Squark and Gluino production – tree level EW

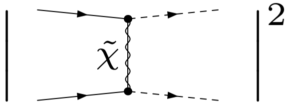
- The main formula, from hadron to parton level:

$$d\sigma_{P_1 P_2 \to F X} = \sum_{i,j} \int dx_1\, dx_2\, f_{i|P_1}(x_1)\, f_{j|P_2}(x_2)\, d\hat{\sigma}_{ij \to F X}$$

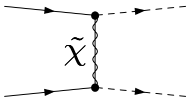


- Contributions of $\mathcal{O}(\alpha_s \alpha + \alpha^2)$ [Bozzi *et al.* '07] [Alan, Cankocak, & Demir '07] [Bornhauser *et al.* '07] [Hollik, Kollar & Trenkel '07] [Hollik, EM '08] [Hollik, EM & Trenkel '08] [Germer, Hollik, EM & Trenkel '10]
  - Contributions from qq-, $q\bar{q}$-initiated processes:

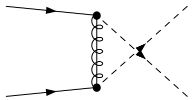
$F = \tilde{q}\tilde{q}' \;\&\; \tilde{q}^*\tilde{q}'^*$ $\quad \mathcal{O}(\alpha^2) \rightsquigarrow$



$\mathcal{O}(\alpha_s \alpha) \rightsquigarrow$

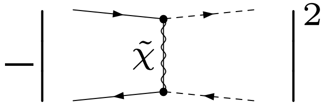


$\cdot$

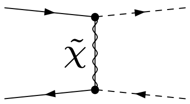


$\cdot\, \delta_{\tilde{q}\tilde{q}'}$

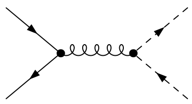
$F = \tilde{q}\tilde{q}'^*$ $\quad \mathcal{O}(\alpha^2) \rightsquigarrow$



$\mathcal{O}(\alpha_s \alpha) \rightsquigarrow$



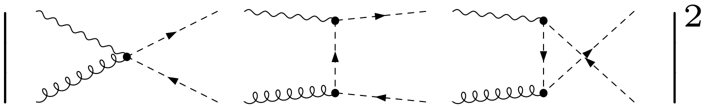
$\cdot$



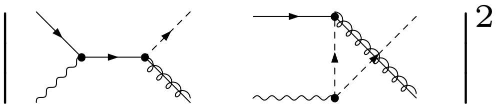
$\cdot\, \delta_{\tilde{q}\tilde{q}'}$

  - Contributions from photon-induced processes:

$F = \tilde{q}\tilde{q}'^*$ $\quad \mathcal{O}(\alpha_s \alpha) \rightsquigarrow$



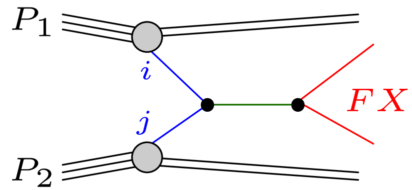
$F = \tilde{g}\tilde{q} \;\&\; \tilde{g}\tilde{q}^*$ $\quad \mathcal{O}(\alpha_s \alpha) \rightsquigarrow$



Squark and Gluino production – NLO EW

- The main formula, from hadron to parton level:

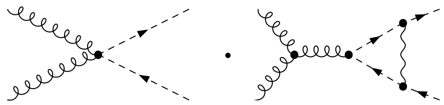
$$d\sigma_{P_1 P_2 \to F X} = \sum_{i,j} \int dx_1\ dx_2\ f_{i|P_1}(x_1)\ f_{j|P_2}(x_2)\ d\hat{\sigma}_{ij\to FX}$$

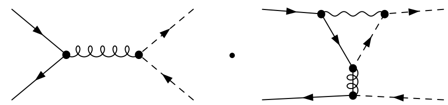


- NLO EW are of $\mathcal{O}(\alpha_s^2\alpha)$ [Beccaria *et al.* '07] [Hollik, Kollar & Trenkel '07] [Hollik, EM '08] [Hollik, EM & Trenkel '08] [EM '09] [Germer, Hollik, EM & Trenkel '10]

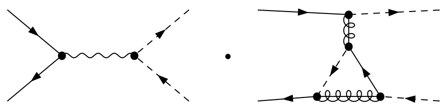
Virtual Corrections ($F = \tilde{q}\tilde{q}^*$ case)

- QCD Born $\times$ 1-loop EW:





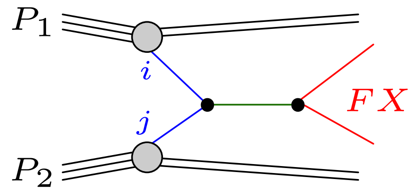
- EW Born $\times$ 1-loop QCD:



Squark and Gluino production – NLO EW

- The main formula, from hadron to parton level:

$$d\sigma_{P_1 P_2 \to F X} = \sum_{i,j} \int dx_1 \, dx_2 \, f_{i|P_1}(x_1) \, f_{j|P_2}(x_2) \, d\hat{\sigma}_{ij \to F X}$$

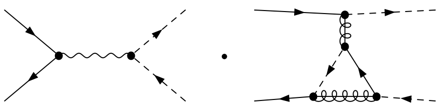


- NLO EW are of $\mathcal{O}(\alpha_s^2 \alpha)$ [Beccaria *et al.* '07] [Hollik, Kollar & Trenkel '07] [Hollik, EM '08] [Hollik, EM & Trenkel '08] [EM '09] [Germer, Hollik, EM & Trenkel '10]

Virtual Corrections ($F = \tilde{q}\tilde{q}^*$ case)

- QCD Born $\times$ 1-loop EW:

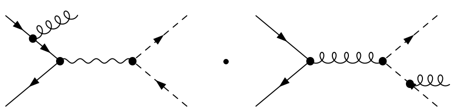
- EW Born $\times$ 1-loop QCD:



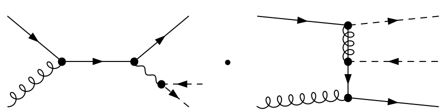
Real Corrections ($F = \tilde{q}\tilde{q}^*$ case)

- photon emission ($X = \gamma$):

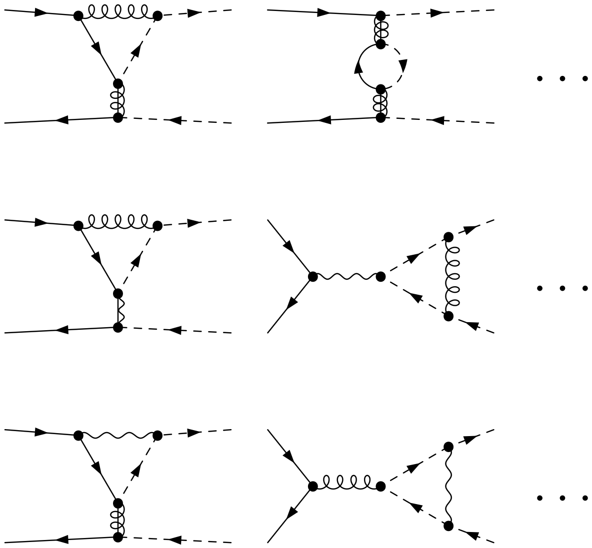
- gluon emission ($X = g$):



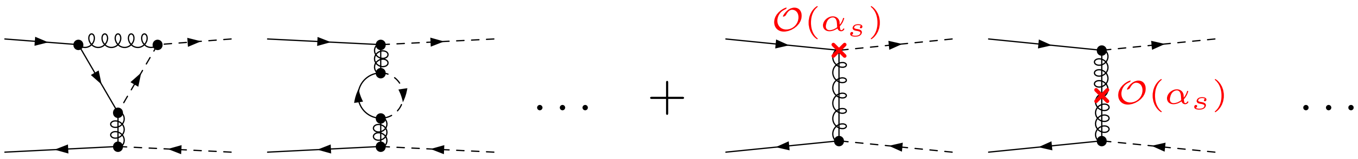
- quark emission ($X = q$):



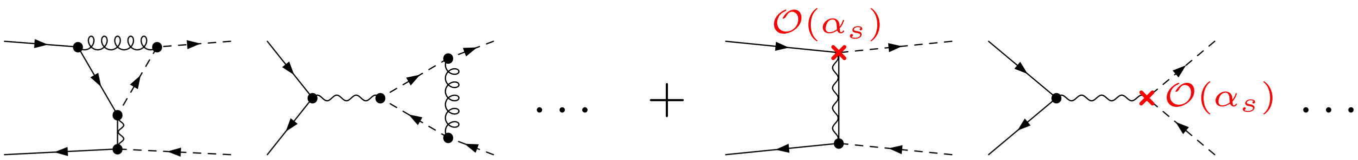
UV Divergences



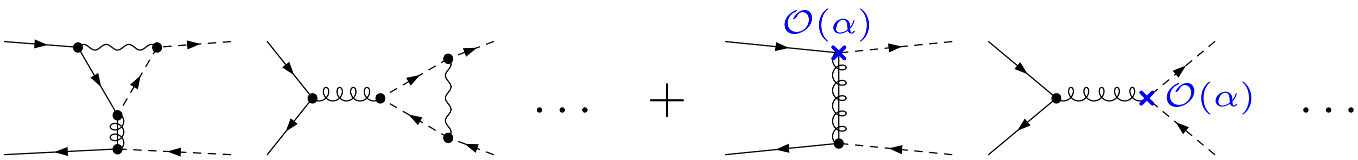
UV Divergences



$\longrightarrow$ UV finite

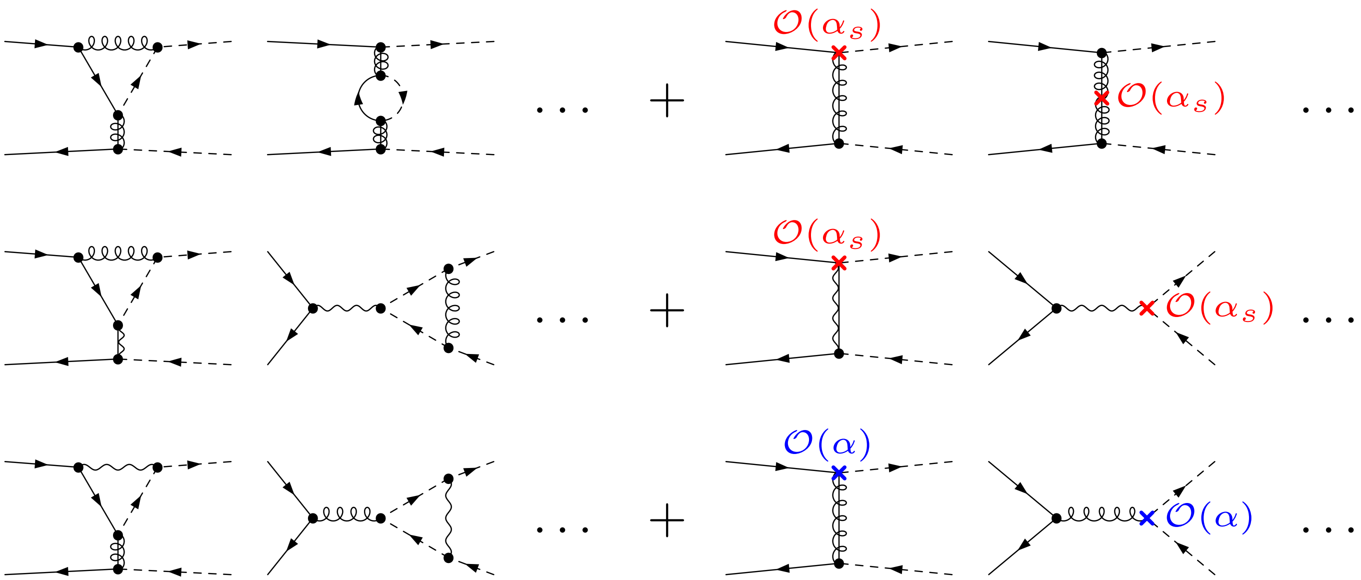


$\longrightarrow$ UV finite



$\longrightarrow$ UV finite

UV Divergences



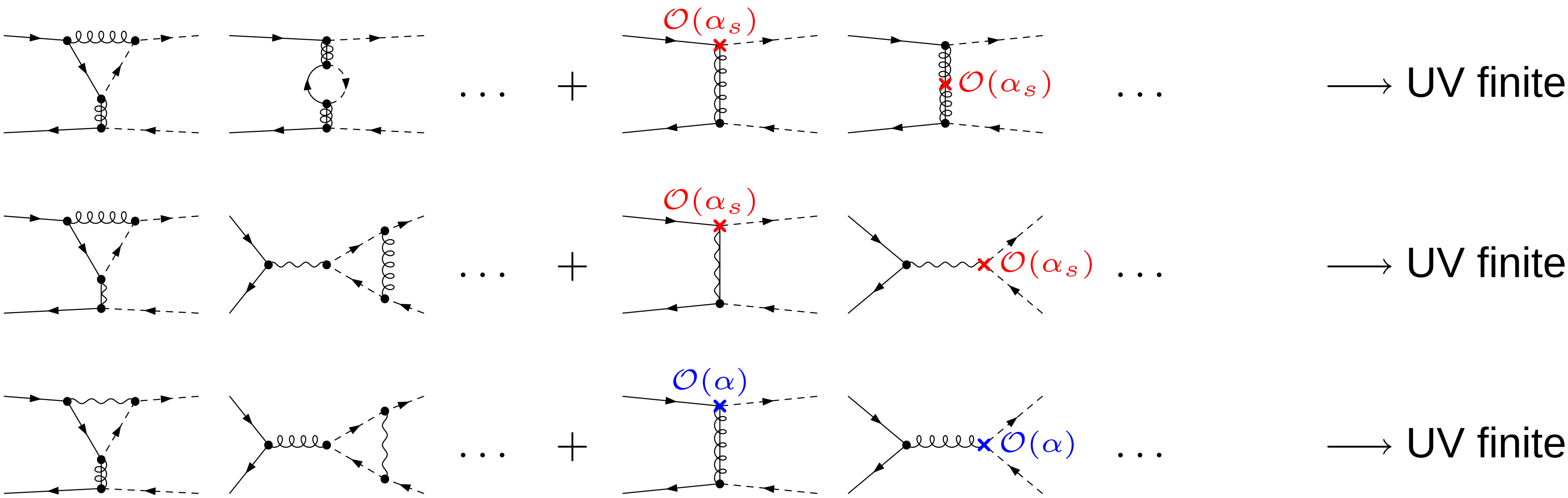
$\longrightarrow$ UV finite

$\longrightarrow$ UV finite

$\longrightarrow$ UV finite

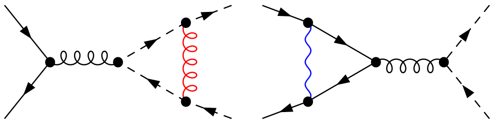
- α_s in the $\overline{\text{MS}}$ scheme
  - top, squarks, and gluino decoupled [Beenakker *et al.* '97]
  - SUSY restoring term in the $q\ \tilde{q}\ \tilde{g}$ ct [Hollik, Stockinger '01]

UV Divergences

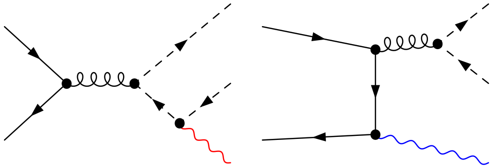


- α_s in the $\overline{\text{MS}}$ scheme
  - top, squarks, and gluino decoupled [Beenakker *et al.* '97]
  - SUSY restoring term in the $q\ \tilde{q}\ \tilde{g}$ ct [Hollik, Stockinger '01]
- Renormalization of the squark $\&$ quark sectors:
  - First two generations $\longrightarrow$ on-shell
  - Third generation $\longrightarrow$ four different schemes
    - check of their reliability [Heinemeyer *et al.* '05] [Heinemeyer, Rzehak $\&$ Schappacher '10]
      $\rightsquigarrow$ see the talk of Sven Heinemeyer

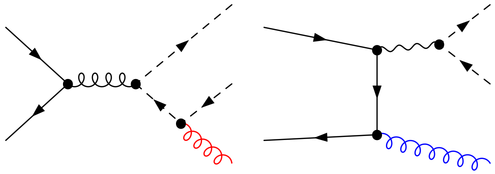
IR & Collinear Divergences



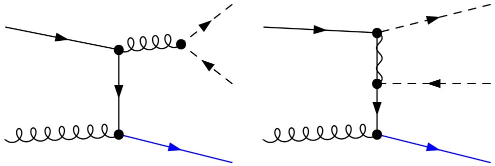
$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^*$



$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^*\gamma$

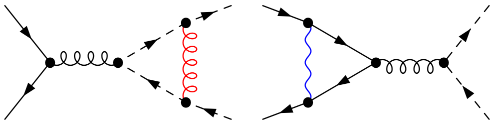


$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^* g$

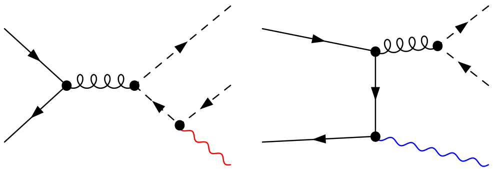


$\ldots \rightsquigarrow$ Collinear singularities in $q' g \longrightarrow \tilde{q}\tilde{q}^* q'$

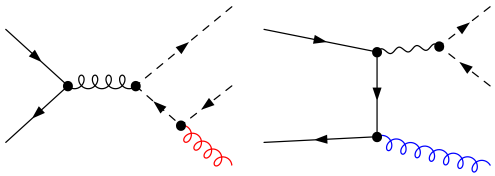
IR & Collinear Divergences



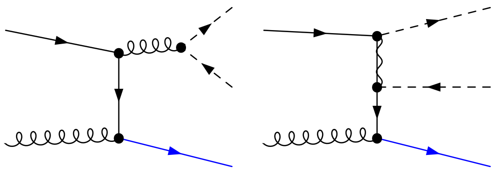
$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^*$ +



$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^*\gamma$ +



$\ldots \rightsquigarrow$ IR & Collinear singularities in $q'\overline{q}' \longrightarrow \tilde{q}\tilde{q}^*g$ +



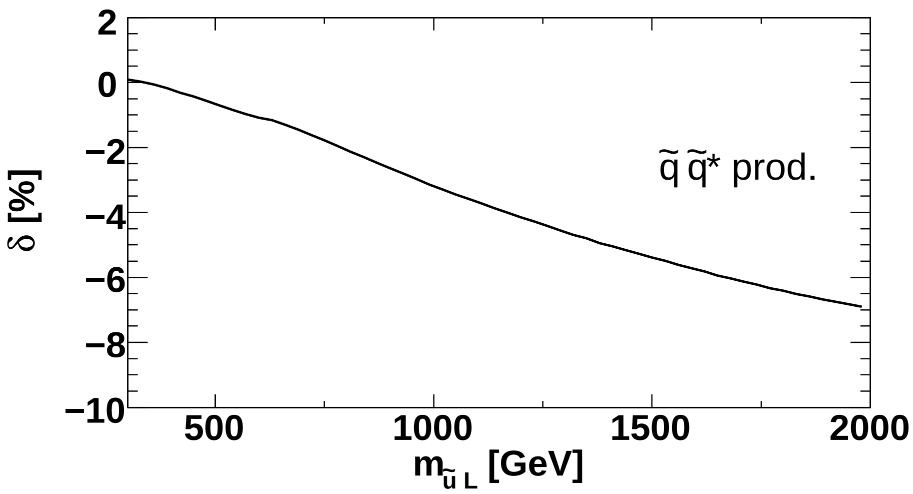
$\ldots \rightsquigarrow$ Collinear singularities in $q'g \longrightarrow \tilde{q}\tilde{q}^*q'$ +

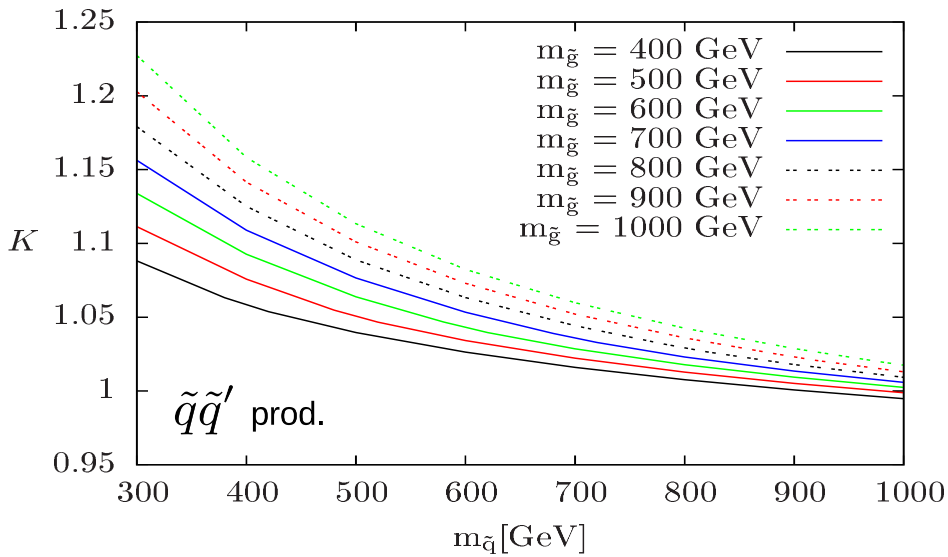
PDF factorization =

[BN & KLN theorems] IR & Collinear Safe

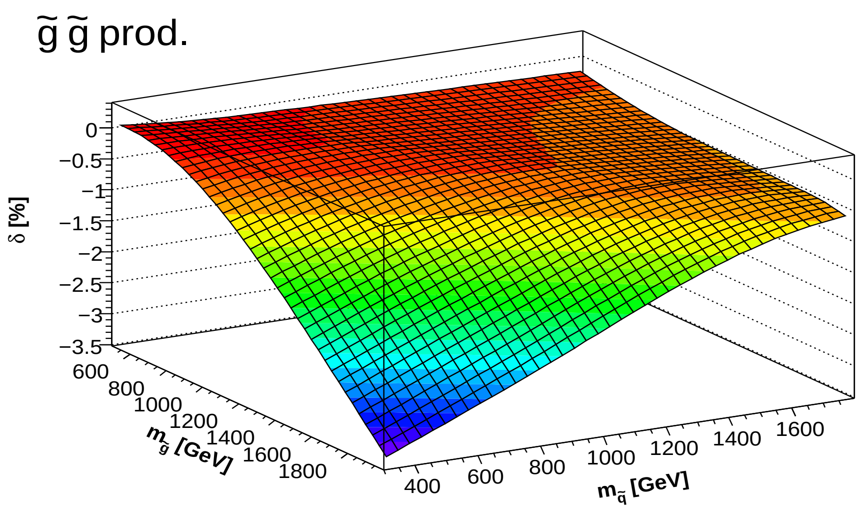
- IR & Collinear singularities
  - regularized by mass regularization
  - Extracted using both phase space slicing & dipole subtraction

Numerical Results – Cross Section *Vs* squark / gluino mass





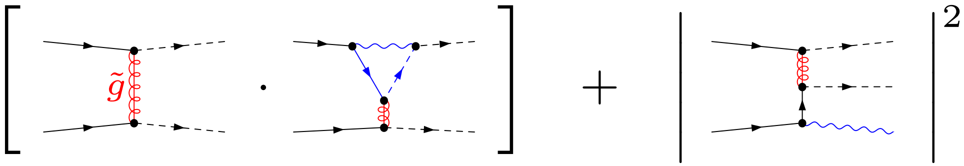
- $\sim$ SPS1a$'$ scenario
- $\delta = \sigma^{\text{EW}}/\sigma^{\text{LO}}(\%) \qquad K = \sigma^{\text{EW}}/\sigma^{\text{LO}} + 1$
- EW contributions
  - $\tilde{q}\tilde{q}^*$, $\tilde{g}\tilde{g}$: grow with the mass
    (key role of $q\bar{q}$ channel)
  - $\tilde{q}\tilde{q}'$: important if $m_{\tilde{q}}$ small
    (key role of $\tilde{q}_L \tilde{q}'_R$ production)
  - $\tilde{g}\tilde{q}$: $|\delta| \sim 1\%$ if $m_{\tilde{q}} \leq 1200$ GeV
    (not shown here)



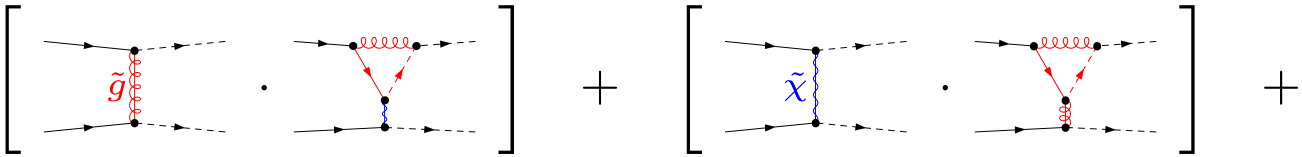
Numerical results – $\mathrm{PP} \to \tilde{\mathrm{q}}\tilde{\mathrm{q}}'$

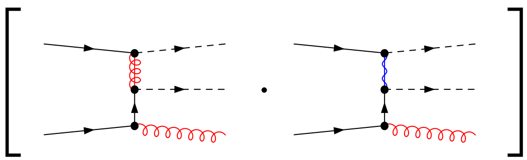
$PP \to \tilde{q}\tilde{q}'$ @ NLO EW can be split into three sets $\left\{ \begin{array}{l} \text{UV, IR \& Collinear safe} \\ \text{gauge invariant} \end{array} \right.$

EW insertions

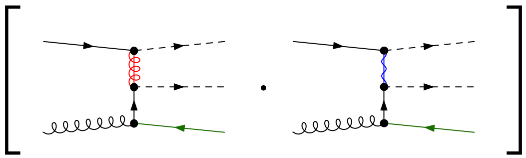


QCD insertions

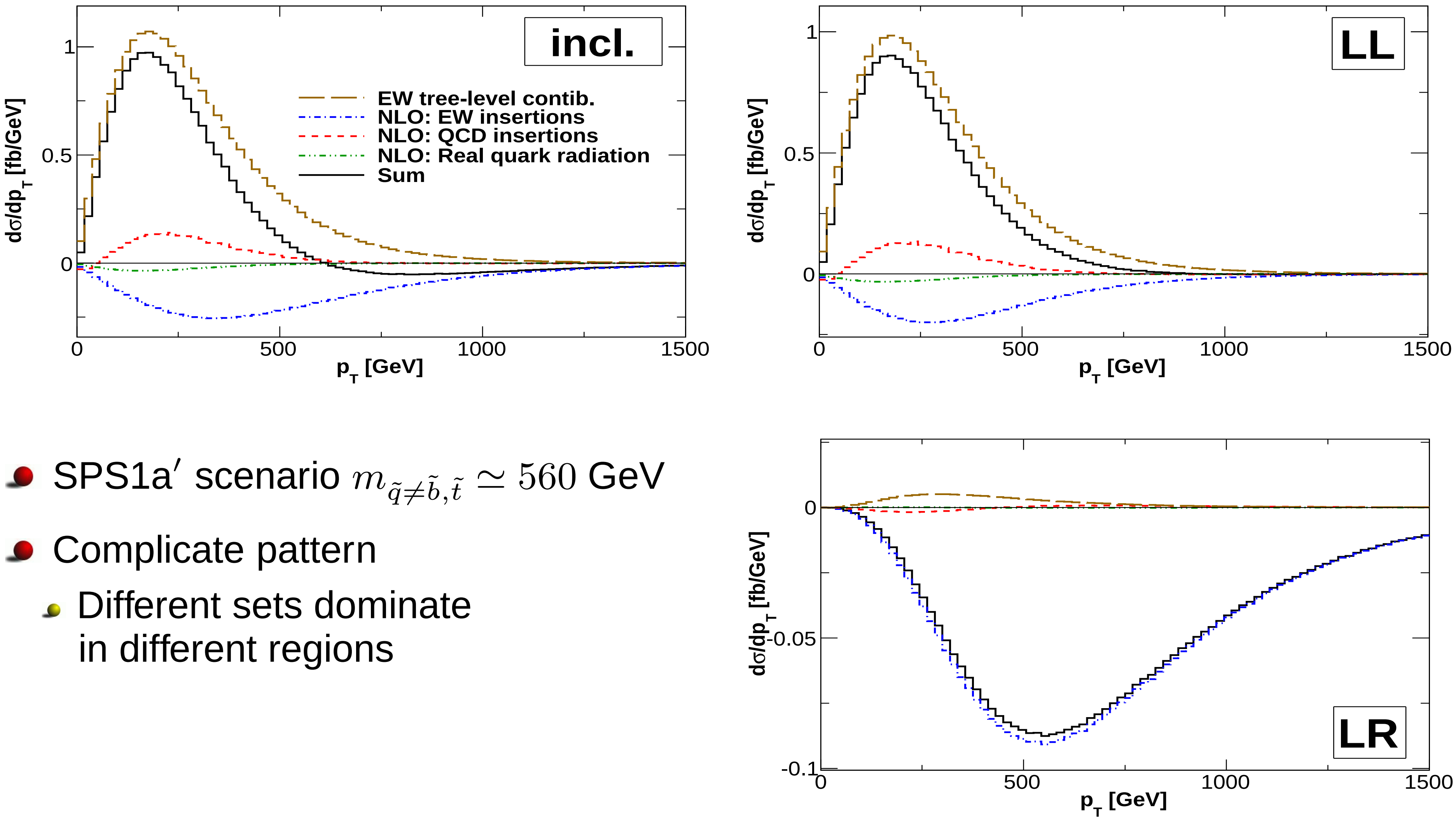




real quark emission

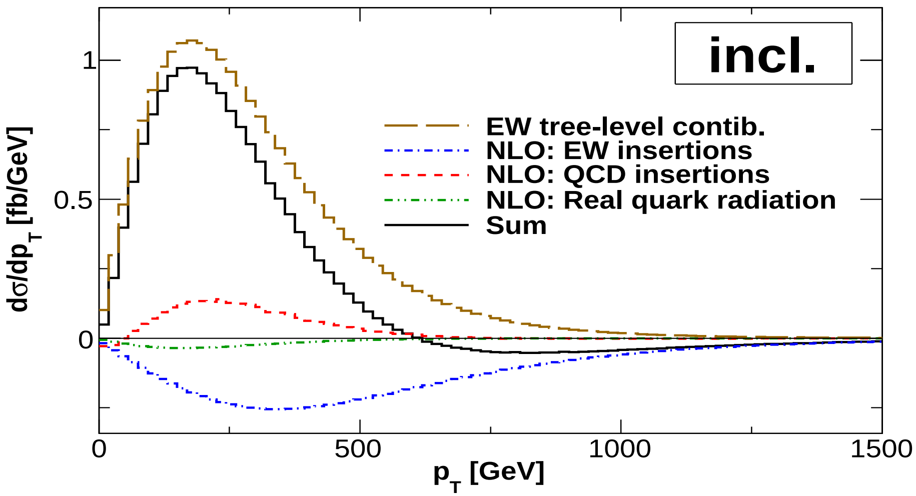


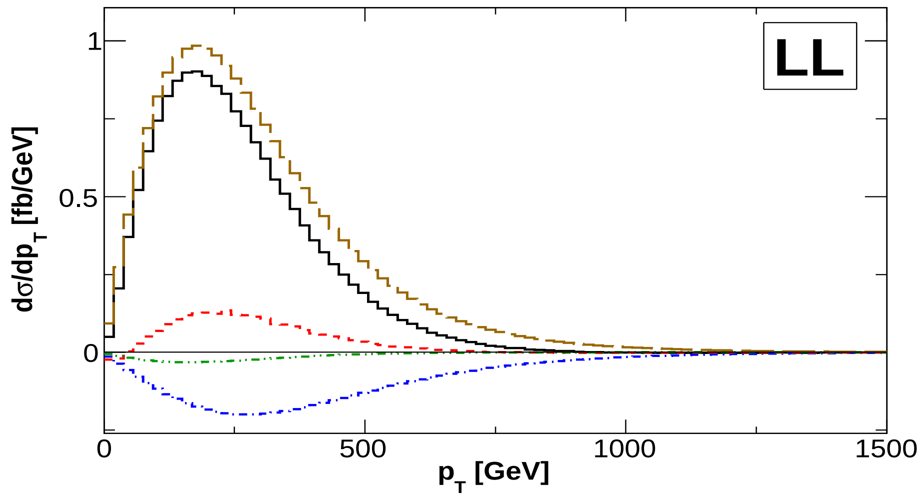
Numerical results – $PP \to \tilde{q}\tilde{q}'$



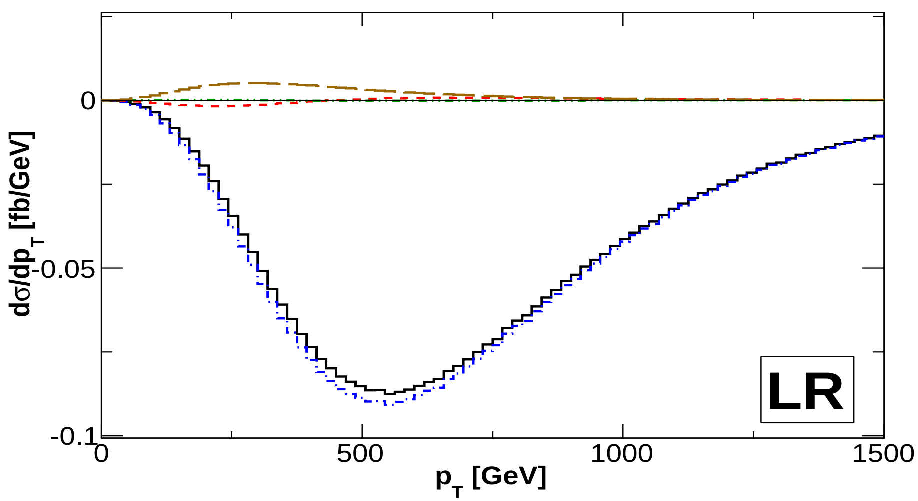
- SPS1a′ scenario $m_{\tilde{q}\neq\tilde{b},\tilde{t}} \simeq 560$ GeV
- Complicate pattern
  - Different sets dominate in different regions

Numerical results – $PP \to \tilde{q}\tilde{q}'$

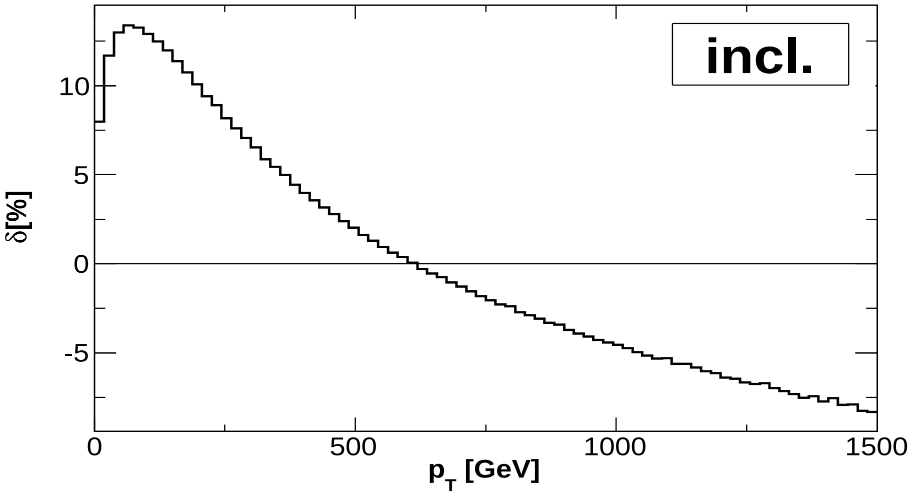


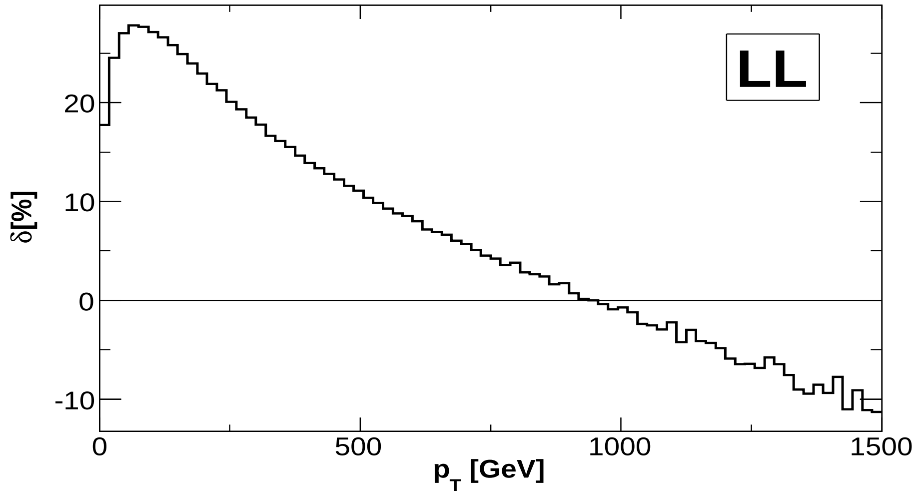


- SPS1a′ scenario $m_{\tilde{q}\neq\tilde{b},\tilde{t}} \simeq 560$ GeV
- Complicate pattern
- Chirality-dependent
  - bigger corrections in the LL case w.r.t. the LR & RR case
  - different sets depend differently on the chirality

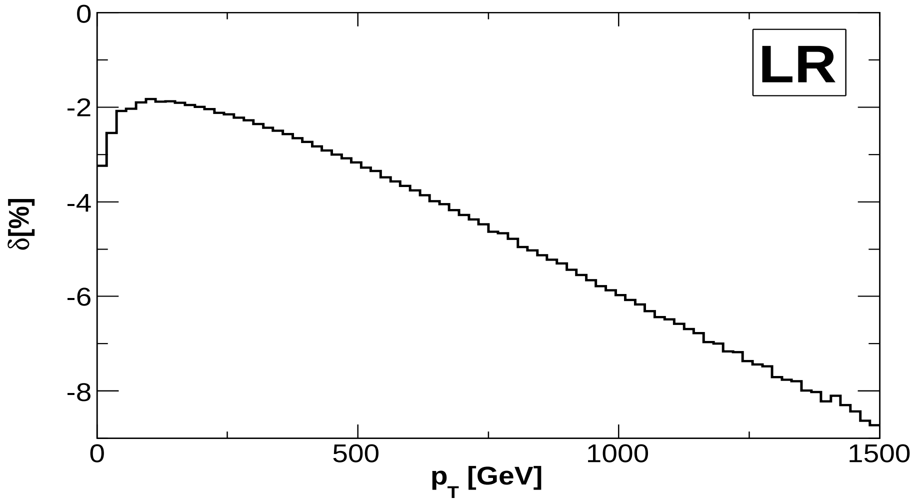


Numerical results – $\mathrm{PP} \to \tilde{q}\tilde{q}'$

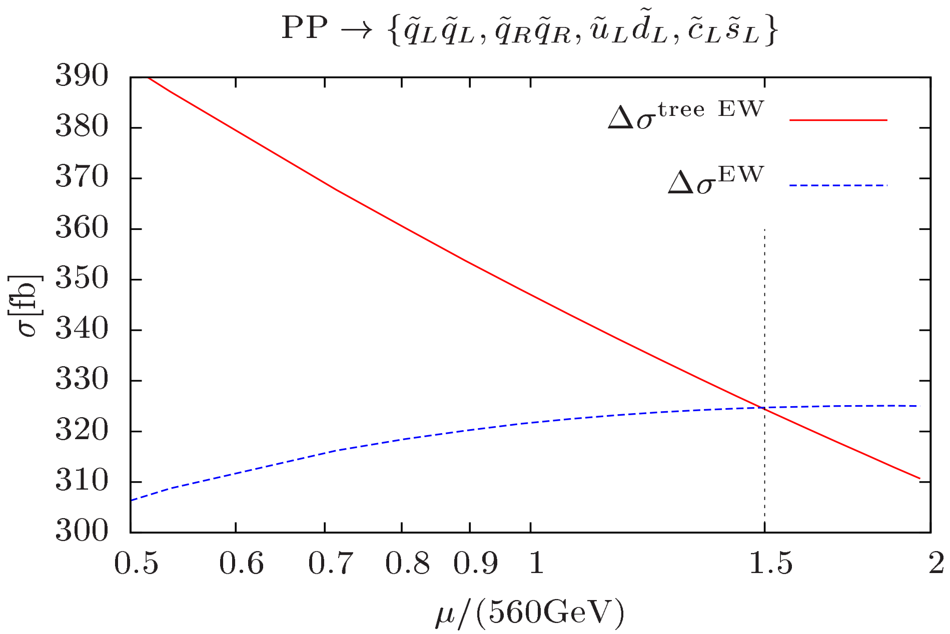


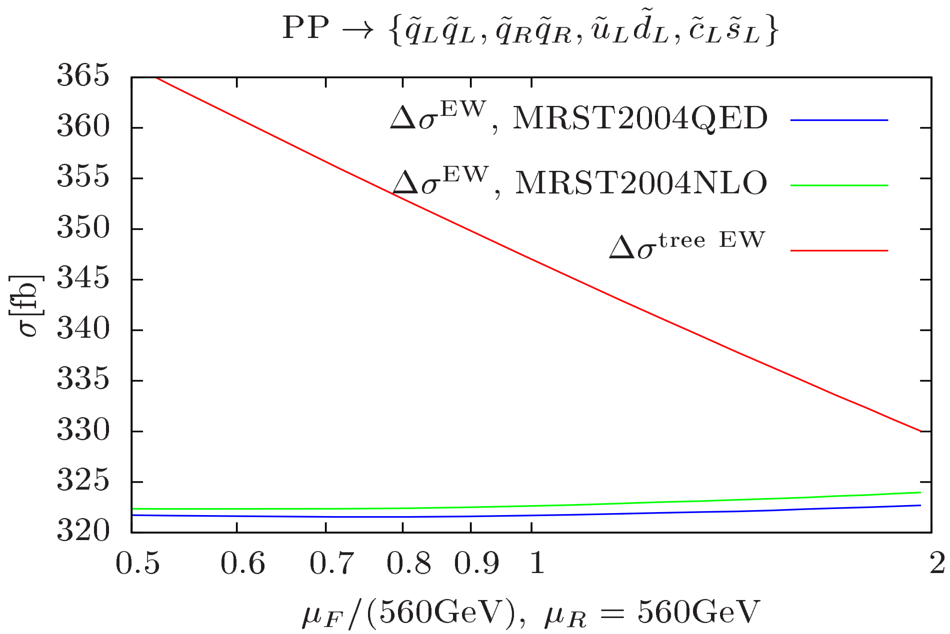


- SPS1a$'$ scenario $m_{\tilde{q}\neq\tilde{b},\tilde{t}} \simeq 560$ GeV
- $\delta = \frac{d\sigma^{\text{EW}}}{dp_T} / \frac{d\sigma^{\text{LO}}}{dp_T} (\%)$
- EW contributions
  - LL: important when $p_T \leq 250$ GeV
  - LR: below $10\ \%$
  - $\tilde{q}\tilde{q}'$: above $10\ \%$ if p_T small



Scale dependence

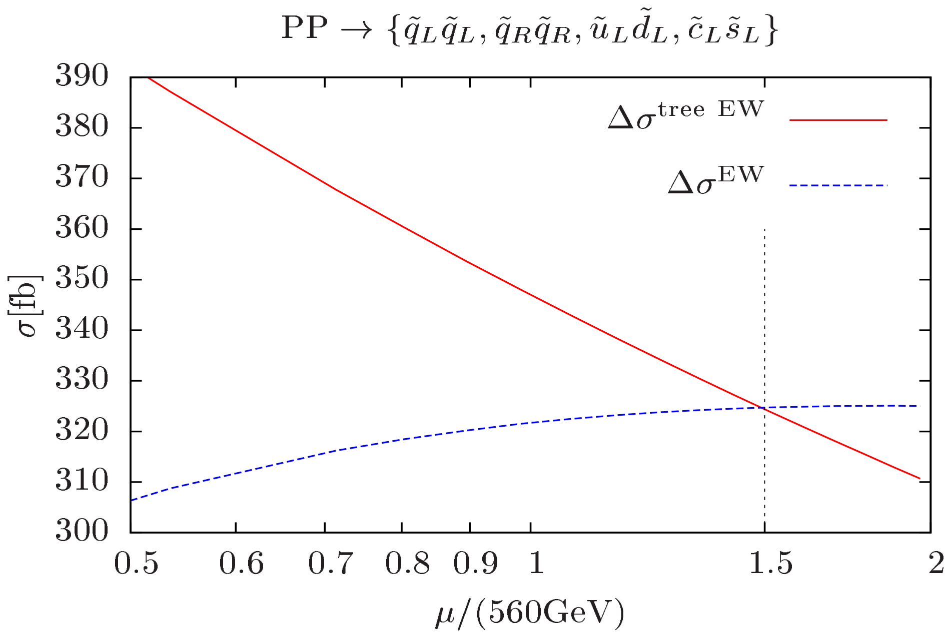


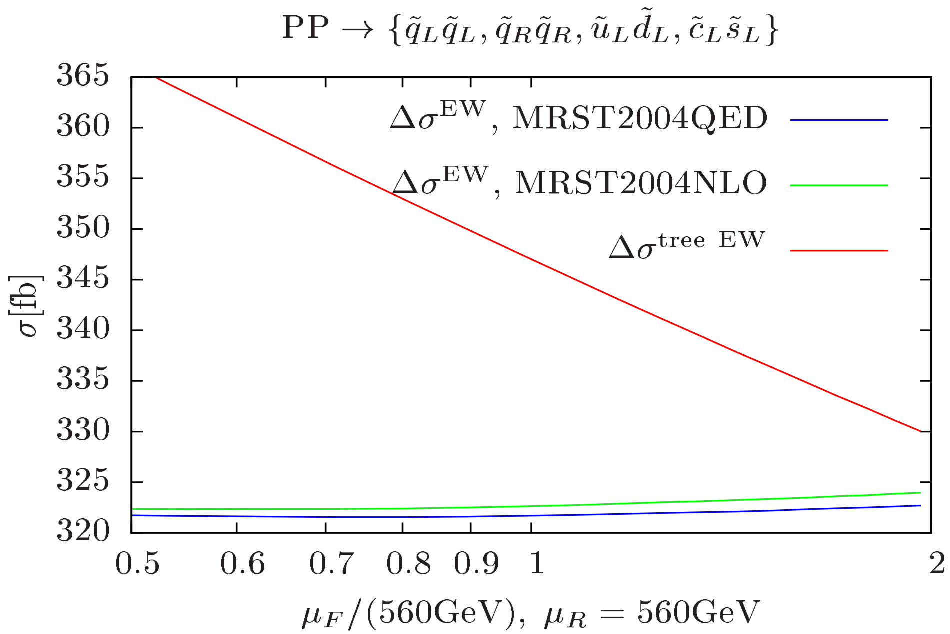


- SPS1a$'$ scenario $m_{\tilde{q}\neq\tilde{b},\tilde{t}} \simeq 560$ GeV
- $\Delta\sigma^{\text{EW}} = \Delta\sigma^{\text{tree EW}} + \Delta\sigma^{\text{NLO EW}}$
- PDF sets used $\longrightarrow$ MRST2001LO (LO QCD)
  $\longrightarrow$ MRST2004NLO (NLO QCD)
  $\longrightarrow$ MRST2004QED (NLO QCD & NLO EW)

- reduced scale dependence @ NLO EW
- if $\mu \sim m_{\tilde{q}}/2$ NLO EW $\mathcal{O}(20\%)$
  $\rightsquigarrow$ NLO EW needed for reliable predictions .

Scale dependence





- SPS1a$'$ scenario $m_{\tilde{q}\neq\tilde{b},\tilde{t}} \simeq 560$ GeV
- $\Delta\sigma^{\text{EW}} = \Delta\sigma^{\text{tree EW}} + \Delta\sigma^{\text{NLO EW}}$
- PDF sets used $\to$ MRST2001LO (LO QCD)
  $\to$ MRST2004NLO (NLO QCD)
  $\to$ MRST2004QED (NLO QCD & NLO EW)

- μ_F dependence almost cancelled @ NLO EW
- QED evolution of the PDF not important . . .

  . . . as expected [Kripfganz, Perlt '88] [Spiesberger '95] [Bauer, Keller, Wackeroth '98] [Roth, Weinzerl '04]

Conclusions

- Direct prodution of squarks and gluinos
  - important discovery channels for TeV-scale SUSY
- EW contributions to these processes:
  - under investigation ($\tilde{b}\tilde{b}^*$ in preparation)
  - chirality dependent
    - enhanced if $\tilde{q}_L$ in the final state
  - can become numerically important $\cdots$
    - $\cdots$ in particular in the distributions
  - $\tilde{q}\tilde{q}'$: scale dependence of the tree-level EW reduced by NLO EW

Backup Slides

Phase Space Slicing & Dipole

Consider the process $q' \ \bar{q}' \ \rightarrow \ \tilde{q}^{a} \ \tilde{q}^{a*} \ \gamma$

$$\sigma_{q'\overline{q}' \rightarrow \tilde{q}^a \tilde{q}^{a*} \gamma} = \int d\Phi_3 \ |\mathcal{M}|^2$$

$d\phi_3$ = phase space measure

Consider the process $q' \ \bar{q}' \ \rightarrow \ \tilde{q}^a \ \tilde{q}^{a*} \ \gamma$

$$\sigma_{q'\bar{q}'\rightarrow\tilde{q}^a\tilde{q}^{a*}\gamma} = \int_{\substack{E_\gamma \,>\, \Delta E \\ \theta_{q\gamma},\, \theta_{\bar{q}\gamma} \,<\, \Delta\theta}} d\Phi_3 \ |\mathcal{M}|^2 + \boxed{\int_{\text{singular region}} d\Phi_3 \ |\mathcal{M}|^2}$$

computed in eikonal approx.

$d\phi_3$ = phase space measure
$\theta_{i\gamma}$ = angle between γ and i
E_γ = energy of γ

- Phase Space Slicing. The photon phase space is divided into two parts introducing cuts:
  - regular region integrated numerically
  - singular region eikonal approximation after mass regularization
  - Remarks:
    + Intutive method
    – Cuts have to be small (eikonal approximation) . . .
    – . . . But not too much (numerical instabilities)

Consider the process $q' \ \bar{q}' \ \rightarrow \ \tilde{q}^a \ \tilde{q}^{a*} \ \gamma$

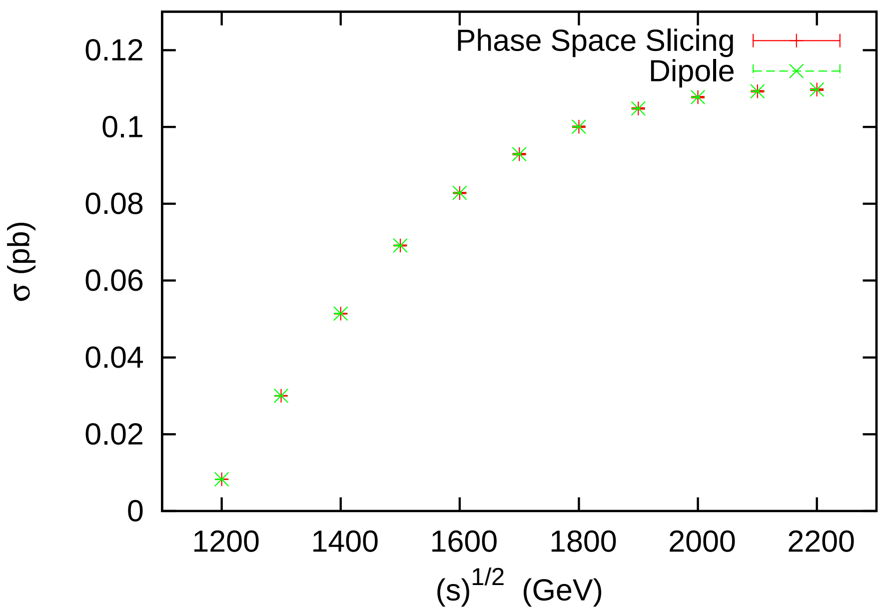
$$\sigma_{q'\bar{q}'\rightarrow\tilde{q}^a\tilde{q}^{a*}\gamma} = \int d\Phi_3 \left[\, |\mathcal{M}|^2 - |\mathcal{M}_{\text{sub}}|^2 \, \right] + \boxed{\int d\Phi_3 |\mathcal{M}_{\text{sub}}|^2}$$

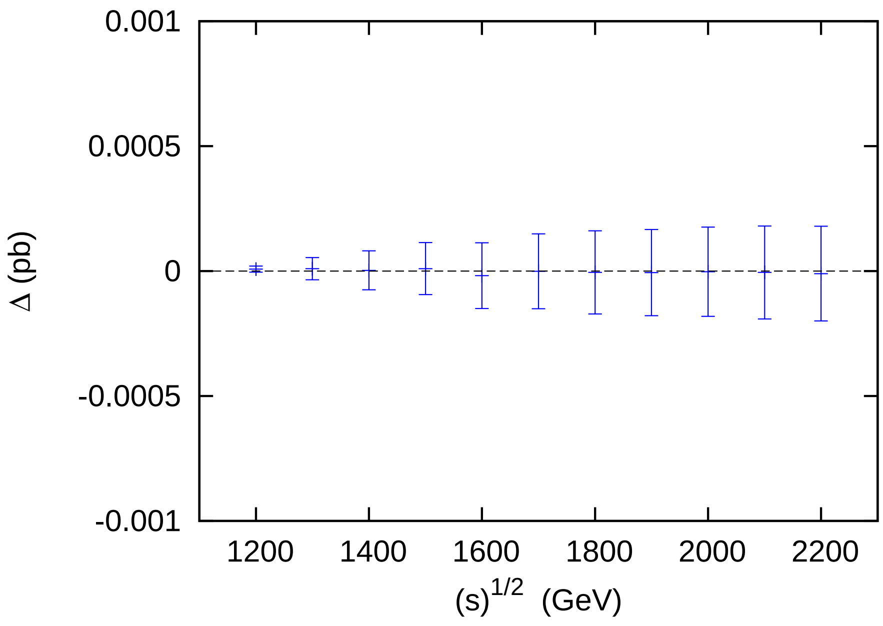
exactly computed

$d\phi_3$ = phase space measure

- Subtraction method. Add and subtract a function $\mathcal{M}_{\text{sub}}$ such that
  - $i)$ $\mathcal{M}_{\text{sub}}$ and $\mathcal{M}$ have same singularity structure
  - $ii)$ $\mathcal{M}_{\text{sub}}$ easy enough to be analitically computed
  - $(|\mathcal{M}_{\text{sub}}|^2 - |\mathcal{M}|^2)$ is regular and evaluated numerically
  - $\int d\Phi_3 |\mathcal{M}_{\text{sub}}|^2$ exactly evaluated (after mass regularization)
  - Remarks:
    - + All numerics involve regular functions
    - + No cut off are needed
    - + leads to more precise results

- Slicing $\&$ Subtraction
  - Two completely different approaches to the problem
  - Their comparison is a non trivial check for IR treatment
- Result of the comparison for the process $u\overline{u} \rightarrow \tilde{u}^L \tilde{u}^{L*} \gamma$





Δ = (Dipole − Slicing), point SPS1a′

Renormalizing the strong coupling

$$\mathcal{L}_{\text{strong}} = -\frac{1}{4} G^A_{\mu\nu} G^{A,\mu\nu} + g_s T^A \bar{\Psi}_u \gamma^\mu \Psi_u G^A_\mu$$
$$- \sqrt{2}\hat{g}_s \left[T^A \bar{\Psi}^A_{\tilde{g}}\, \omega_- \,\Psi_u \Phi^*_{\tilde{u},L} + h.c. \right] + \ldots$$

one field and two couplings to reparametrize:

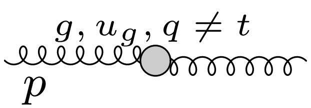
$$G^A_\mu \to \left(1 + \frac{\delta Z_G}{2}\right) G^A_\mu, \qquad g_s \to g_s + \delta g_s, \qquad \hat{g}_s \to \hat{g}_s + \delta \hat{g}_s$$

$$\mathcal{L}_{\text{strong}} = -\tfrac{1}{4}G^A_{\mu\nu}G^{A,\mu\nu} + g_s T^A \bar{\Psi}_u \gamma^\mu \Psi_u G^A_\mu - \sqrt{2}\hat{g}_s \left[T^A \bar{\Psi}^A_{\tilde{g}}\, \omega_-\, \Psi_u \Phi^*_{\tilde{u},L} + h.c.\right] + \ldots$$

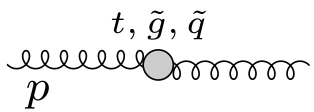
one field and two couplings to reparametrize:

$$G^A_\mu \to \left(1+\frac{\delta Z_G}{2}\right)G^A_\mu, \qquad g_s \to g_s + \delta g_s, \qquad \hat{g}_s \to \hat{g}_s + \delta\hat{g}_s$$

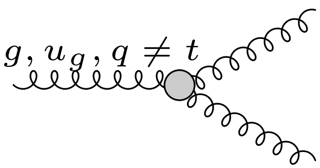
- Definition of δg_s, δZ_G:



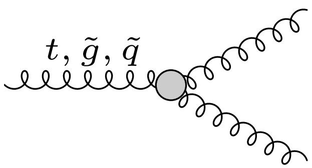
$|\Delta \quad +$



$|\Delta - \ln(M^2/\mu^2) \quad \stackrel{!}{=} \quad 0$



$|\Delta \quad +$



$|\Delta - \ln(M^2/\mu^2) \quad \stackrel{!}{=} \quad 0$

  - Divergences within DREG, $\Delta = 2/\epsilon - \gamma + \ln 4\pi$
  - $\overline{\text{MS}}$ (DREG + UV poles subtraction) if light particles in loops
  - Zero momentum subtraction scheme if heavy particles in loops
    $\hookrightarrow$ SM-like running of g_s

$$\mathcal{L}_{\text{strong}} = -\ \tfrac{1}{4} G^A_{\mu\nu} G^{A,\mu\nu} \ +\ g_s T^A \bar{\Psi}_u \gamma^\mu \Psi_u G^A_\mu$$
$$-\ \sqrt{2}\hat{g}_s \left[T^A \bar{\Psi}^A_{\tilde{g}}\ \omega_-\ \Psi_u \Phi^*_{\tilde{u},L} + h.c. \right]\ +\ \ldots$$

one field and two couplings to reparametrize:

$$G^A_\mu \to \left(1 + \frac{\delta Z_G}{2}\right) G^A_\mu, \qquad g_s \to g_s + \delta g_s, \qquad \hat{g}_s \to \hat{g}_s + \delta \hat{g}_s$$

- Definition of $\delta \hat{g}_s$:
  - Owing to SUSY should be a dependent parameter

    $\hookrightarrow \hat{g}_s \ = \ g_s; \qquad \delta \hat{g}_s \ = \ \delta g_s$
  - But DREG spoils SUSY @ NLO [Beenakker *et al.*'96,98]

    $\hookrightarrow$ SUSY restored setting: $\quad \hat{g}_s \ = \ g_s + g_s \frac{\alpha_s}{3\pi}; \quad \delta \hat{g}_s \ = \ \delta g_s$
  - The mismatch between g_s and $\hat{g}_s$ is reabsorbed into $\delta \hat{g}_s$:

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