Electroweak corrections to squark and gluino production at the LHC

Universität Zürich[UZH]

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work in collaboration with:
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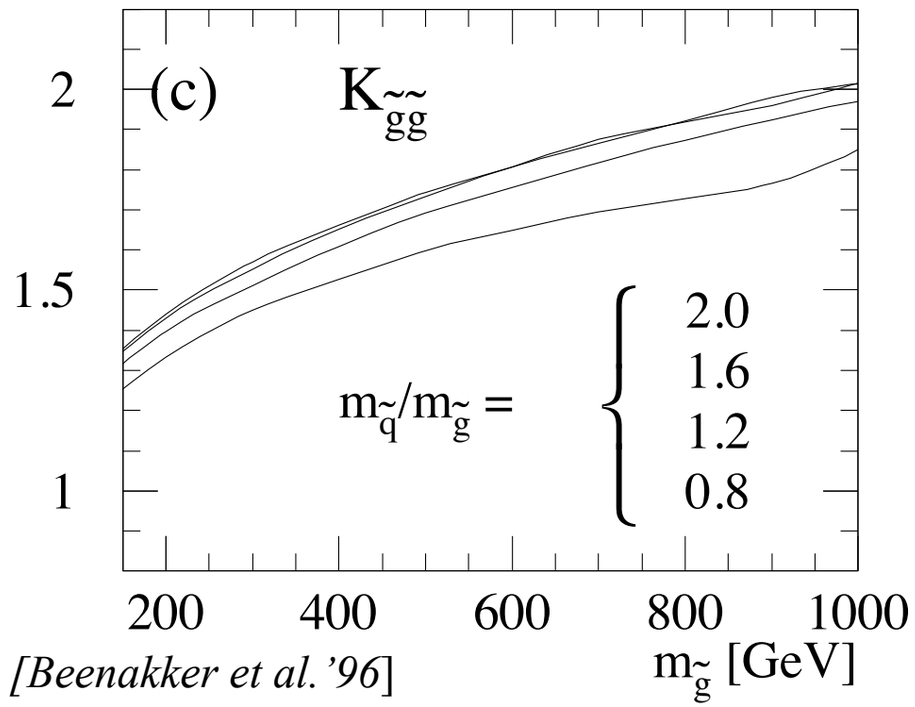
Annual Meeting of the Helmholtz Alliance "Physics at the Terascale"
DESY, Hamburg, 18th of November 2015

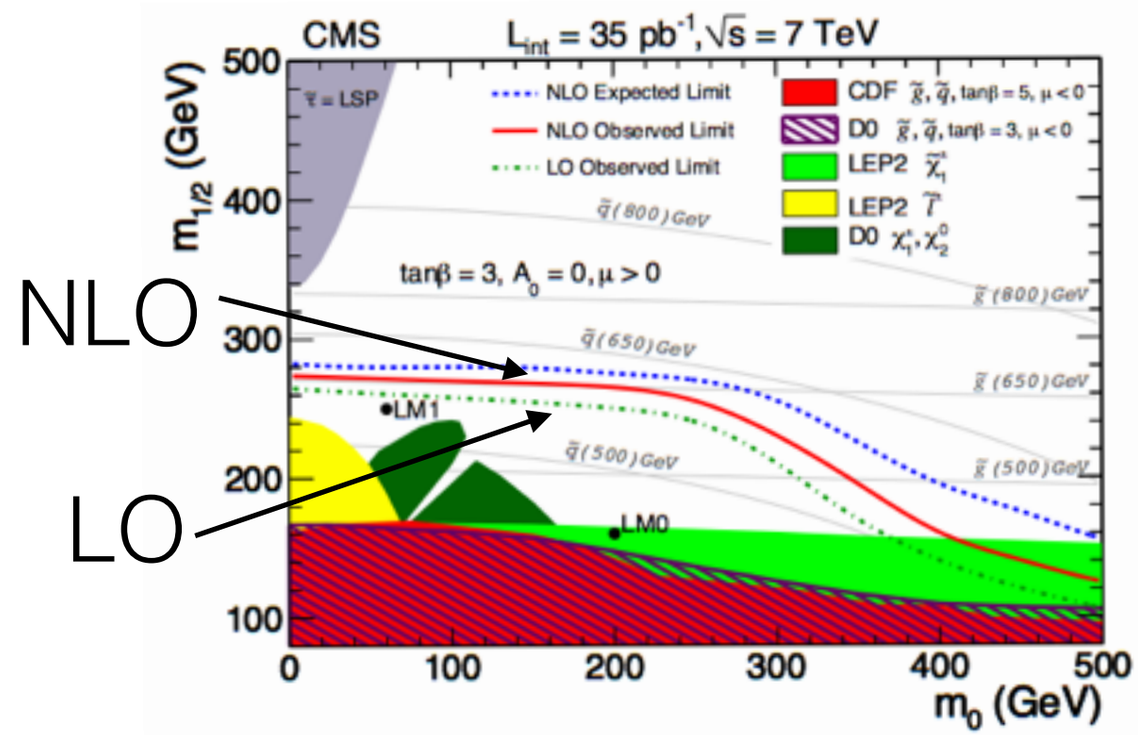
Why higher orders for SUSY processes?

Corrections can be large!

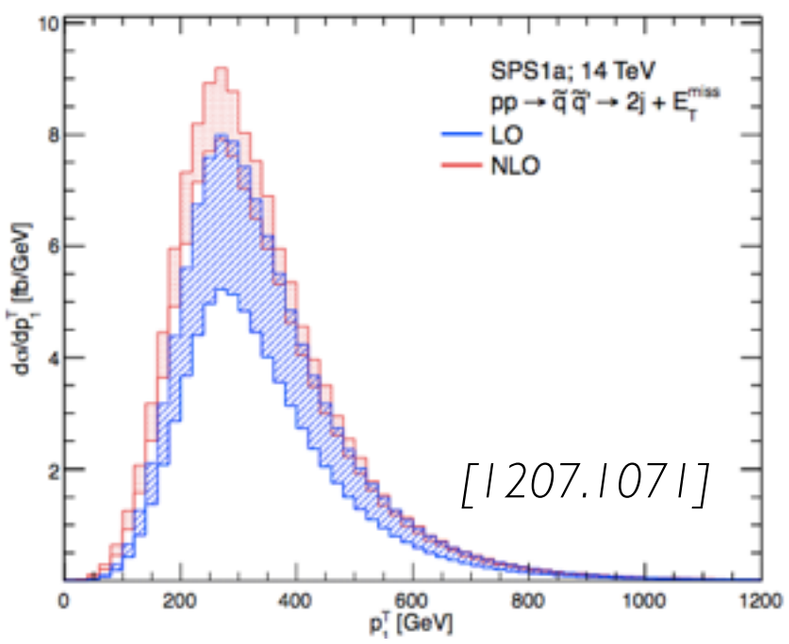


[Beenakker et al.'96]

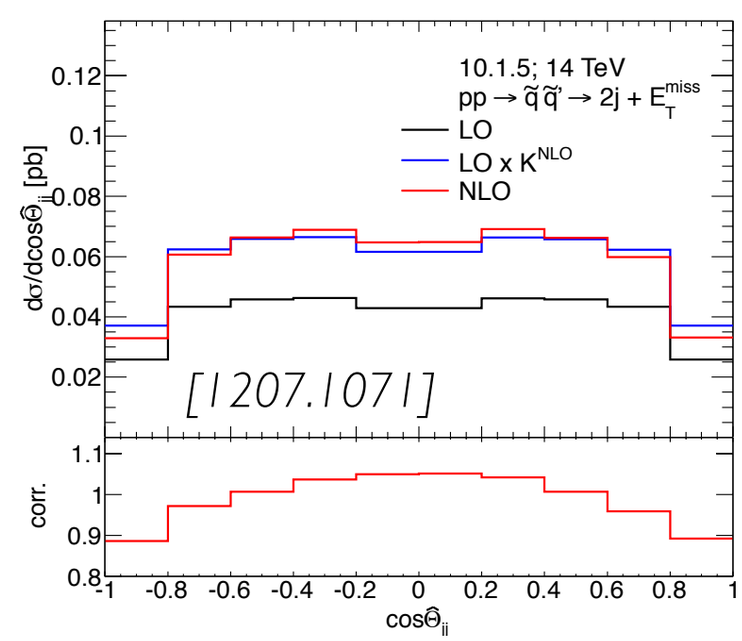
Accurate exclusion limits.



Study & reduce theoretical uncertainties.



Necessary for parameter determination.



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NLO QCD

Automation

production x decay

NLO+PS

[Beenakker, Höpker, Spira, Zerwas'96] [Beenakker, Krämer, Plehn, Spira, Zerwas'97] [Beenakker,Klasen, Krämer, Plehn, Spira, Zerwas'99][Berger, Klasen, Tait'00][Spira'02] [Goncalves-Nelo, Lopez-Val, Mawatari, Plehn, Wigmore'12] [Gavin, Hangst, Krämer, Mühlleitner, Popenda, Spira '12,'14] [Hollik, JML, Pagani'12] [Goncalves-Nelo, Lopez-Val, Mawatari, Plehn'14] [Degrande, Fuks, Hirschi,Proudom, Shao'14] [Pfoh'13][Beneke, Falgari, Piclum, Schwinn, Wever'13] [Borschensky, Krämer, Kulesza, Mangano, Padhi, Plehn, Portell'14] [Kulesza, Motyka '09-'10][Beenakker, Brensing, Kulesza, Krämer, Laenen, Niessen'09-10] [Beenakker, Janssen, Krämer, Kulesza, Laenen, Lepoeter, Niessen, Thewes, Van Daal'13] [Beenakker, Borschensky, Krämer, Kulesza, Laenen, Thewes, Theeuwes'14] [Langenfeld, Moch'09] [Langenfeld'09] [Langenfeld, Moch, Pfoh'12] [Broggio, Ferroglia, Neubert, Vernazza, Yang'13] [Beenakker, Borschensky, Krämer, Kuleza, Laenen, '15], ...

Study & redu ion.

NLO+NLL

SCET

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approx. NNLO

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.....

NLO EW

Study & redu

NLO+NLL

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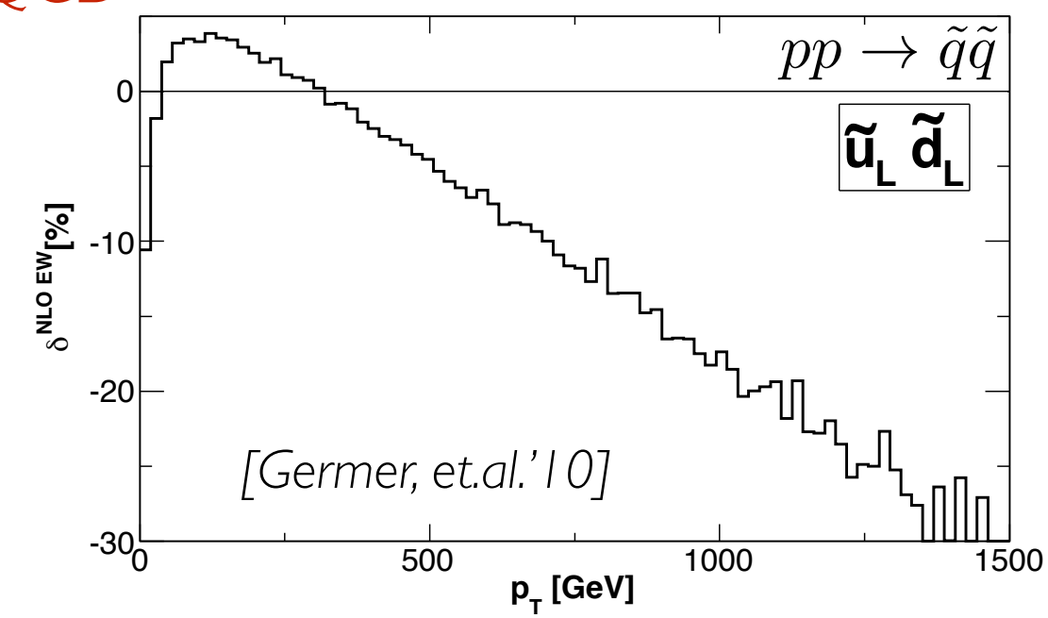
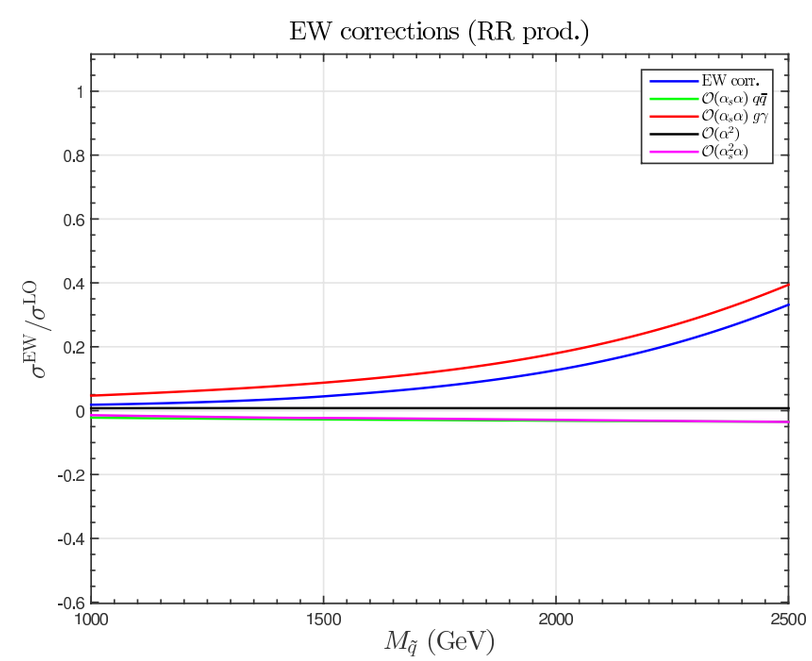
Why EW corrections?

- Formally suppressed by α/α_s with respect to QCD and numerically $\mathcal{O}(\alpha) \sim \mathcal{O}(\alpha_s^2) \Rightarrow$ NLO EW ~ NNLO QCD



- Possible large (negative) enhancement due to universal virtual Sudakov logs at high energies:
  NLO EW ~ $-\alpha \log^2\left(\frac{M_V^2}{\hat{s}}\right)$

- Possible large (positive) enhancement due to photon initiated production

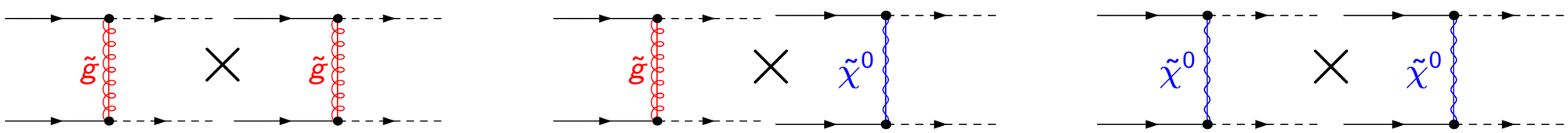


What are EW corrections?

LO

LO EW

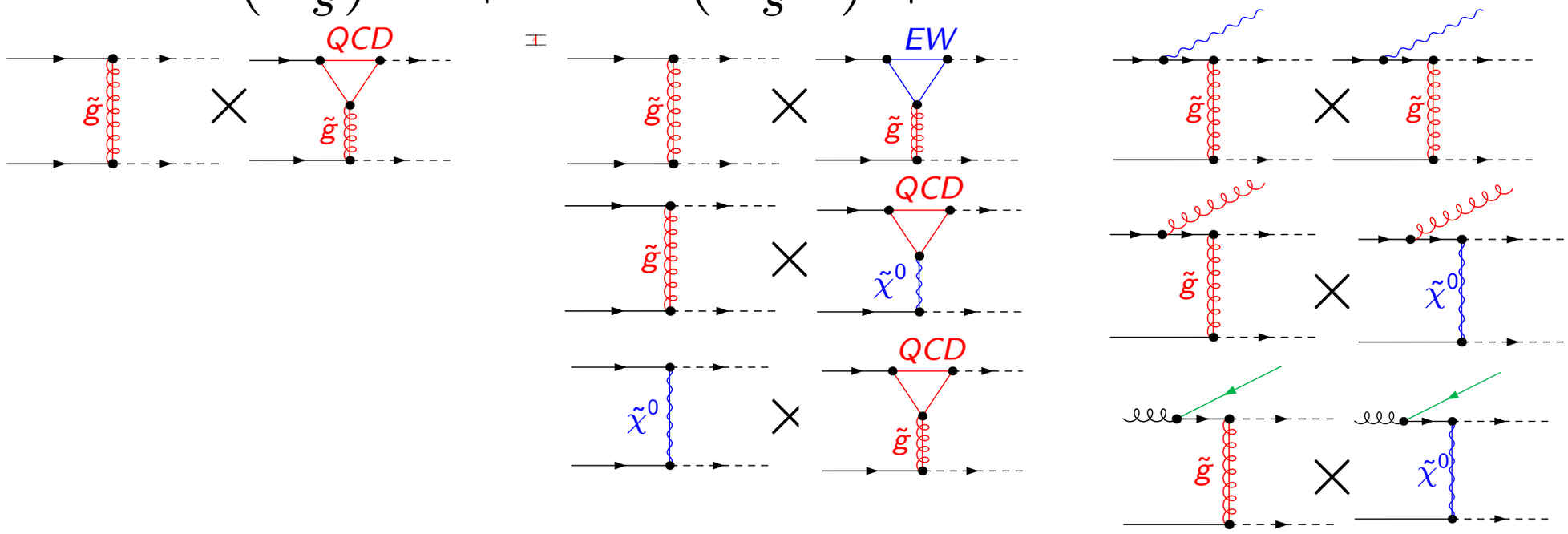
$$d\sigma = d\sigma(\alpha_s^2) \quad + \quad d\sigma(\alpha_s\alpha) \quad + \quad d\sigma(\alpha^2) \quad +$$



NLO QCD

NLO EW

$$d\sigma(\alpha_s^3) \quad + \quad d\sigma(\alpha_s^2\alpha) + \ldots$$



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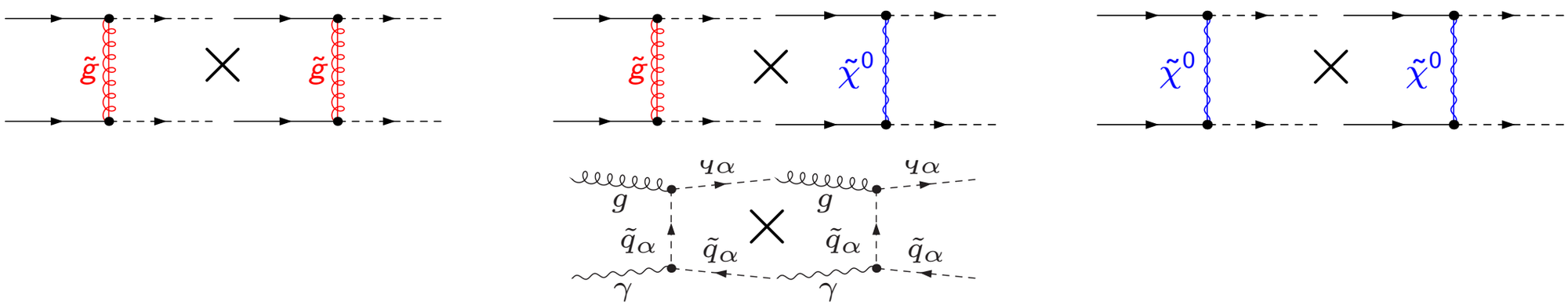

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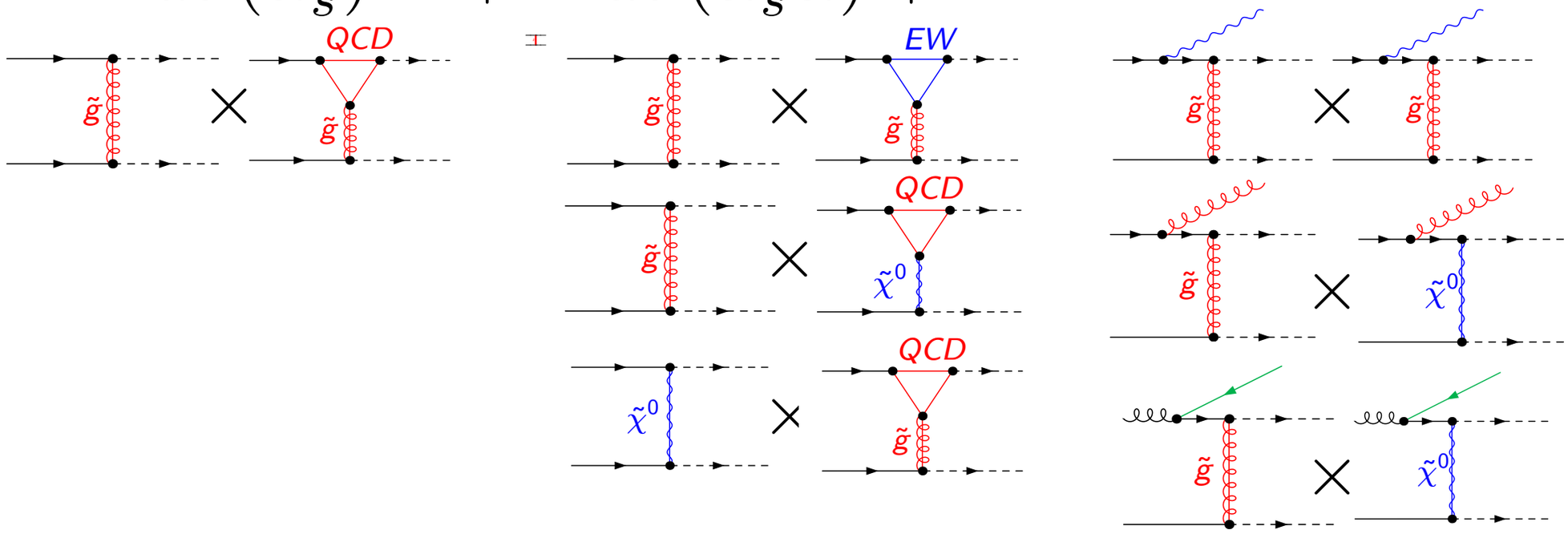

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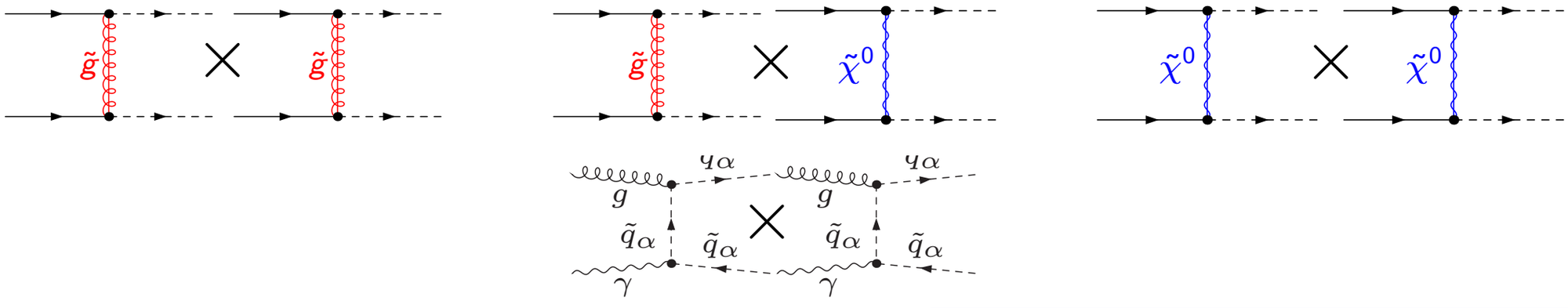
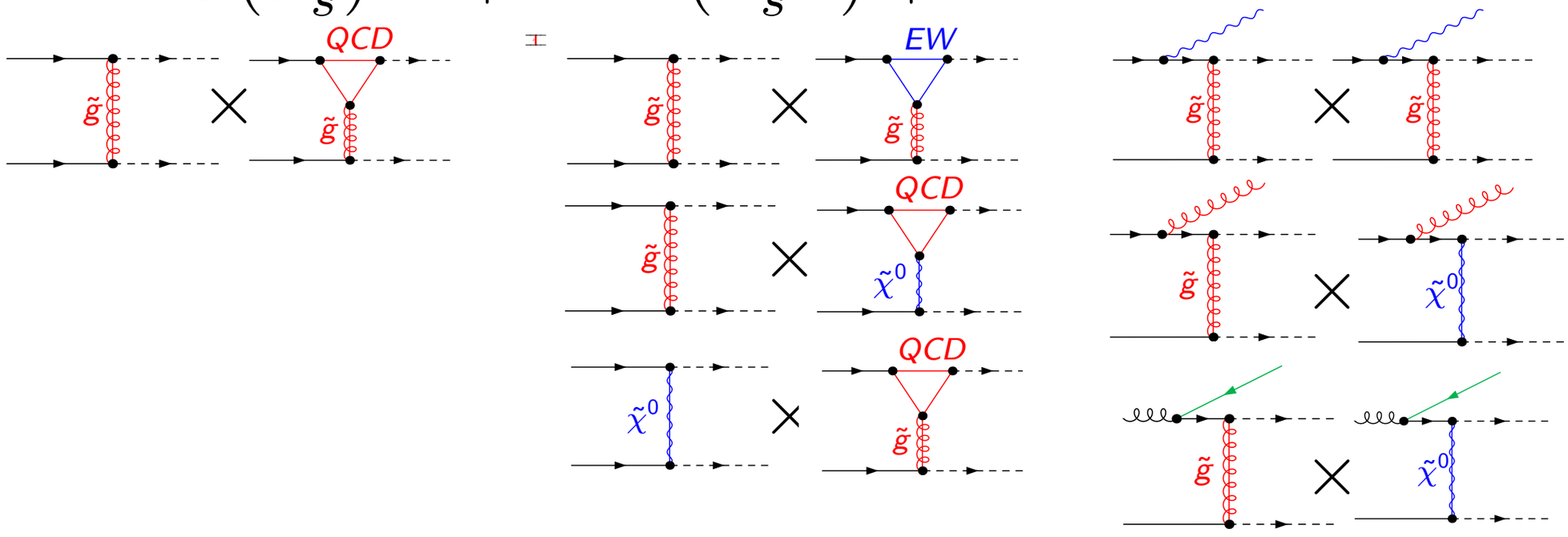


NLO QCD

NLO EW

Depend on (almost) all MSSM parameters!

$$d\sigma(\alpha_s^3) \quad + \quad d\sigma(\alpha_s^2\alpha) + \ldots$$



EW corrections to colored Sparticle Prodcution at the LHC

Tree-Level contributions $d\sigma(\alpha_s\alpha) + d\sigma(\alpha^2)$ investigated by
[Bornhauser, Drees, Dreiner, Kim '07, '09] & *[Ahrib, Benbrik, Cheung, Yuan '10]*

Extensive work has gone into the calculation of NLO EW $d\sigma(\alpha_s^2\alpha)$ corrections

$\tilde{g}\tilde{g}$	*[Mirabella '09]*	★
$\tilde{g}\tilde{q}_\alpha$	*[Hollik, Mirabella, Trenkel '09]*	★
$\tilde{q}_\alpha\tilde{q}^*_\alpha$	*[Hollik, Mirabella '08]*	★
$\tilde{t}_\alpha\tilde{t}^*_\alpha$	*[Hollik, Kollar, Trenkel '08; Germer, Hollik, JML, Mirabella '14]*	★
$\tilde{b}_\alpha\tilde{b}^*_\alpha$	*[Germer, Hollik, Mirabella '11]*	★
$\tilde{q}_\alpha\tilde{q}'_\beta$	*[Germer, Hollik, Mirabella, Trenkel '10]*	★
$\tilde{q}_\alpha\tilde{q}'^*_\beta, \alpha \neq \beta$		★

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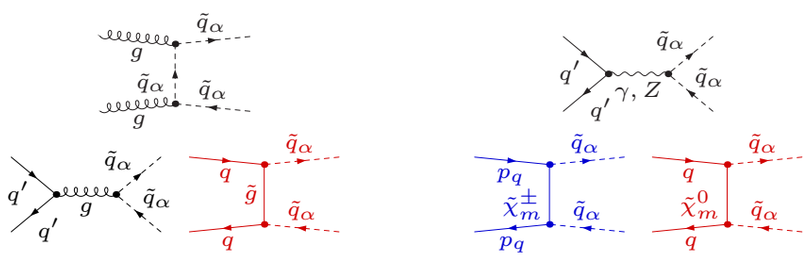
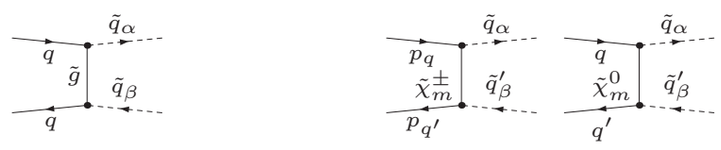
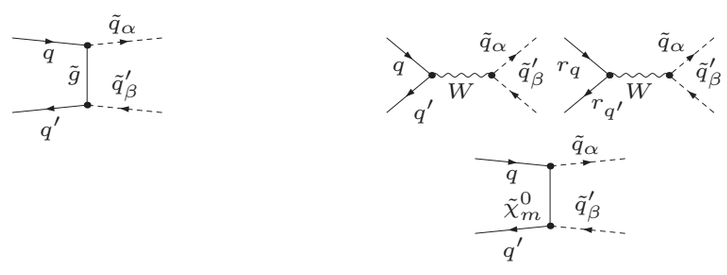
(Almost) all processes implemented in the Monte-Carlo **SUSYHELL**

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ classification

left- and right-handed squarks have a very different phenomenology/decays

all (light) flavours and chiralities treated independently $\Longrightarrow$ 64 different final states

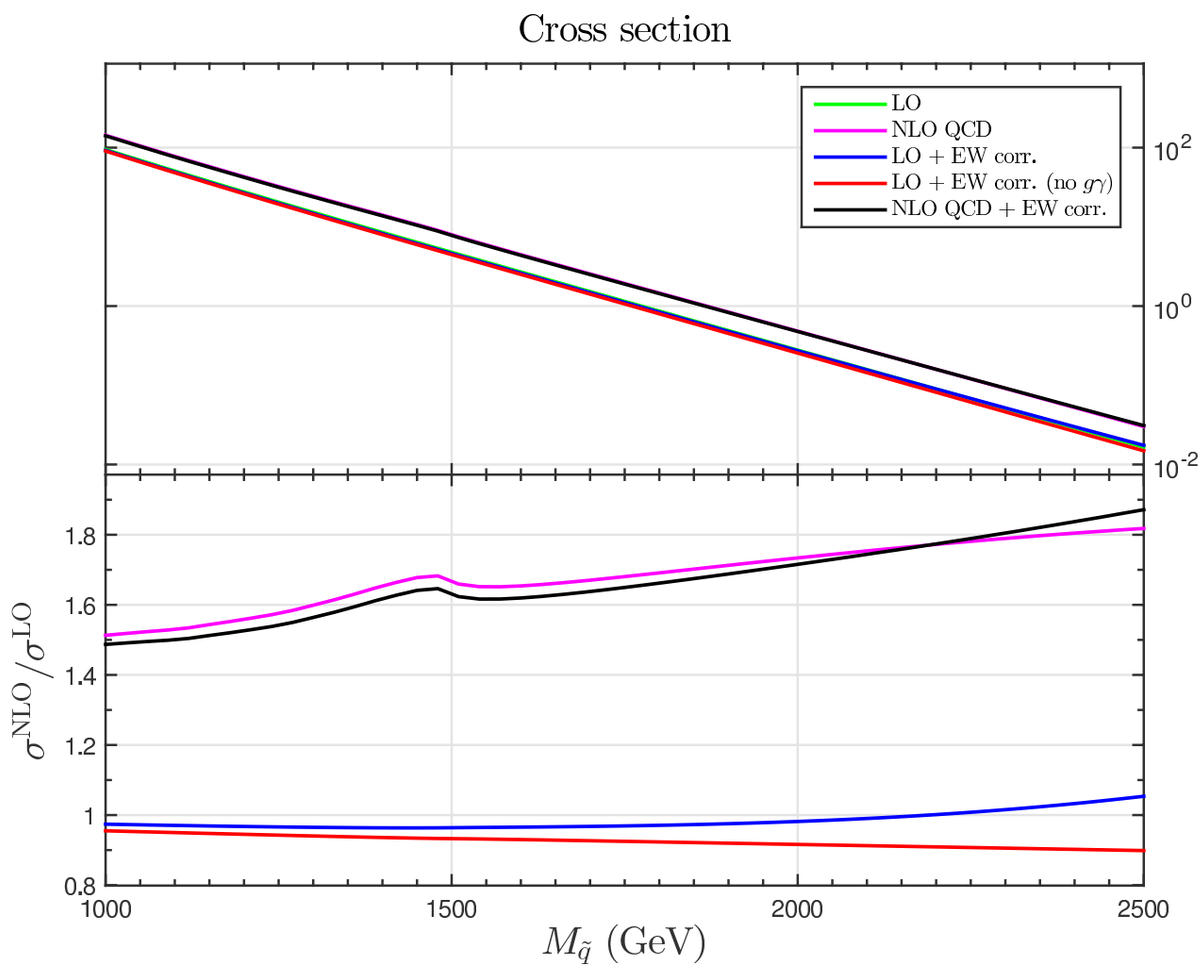
Processes	Channels $\mathcal{O}(\alpha_s)$	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha_s^{1/2}\alpha^{1/2})$ γ-ind.
$\tilde{u}_L\tilde{u}_L^*$-type			
$\tilde{u}_L\tilde{c}_L^*$-type			
$\tilde{u}_L\tilde{d}_L^*$-type			
$\tilde{u}_L\tilde{u}_R^*$ and $\tilde{u}_L\tilde{s}_L^*$-type			

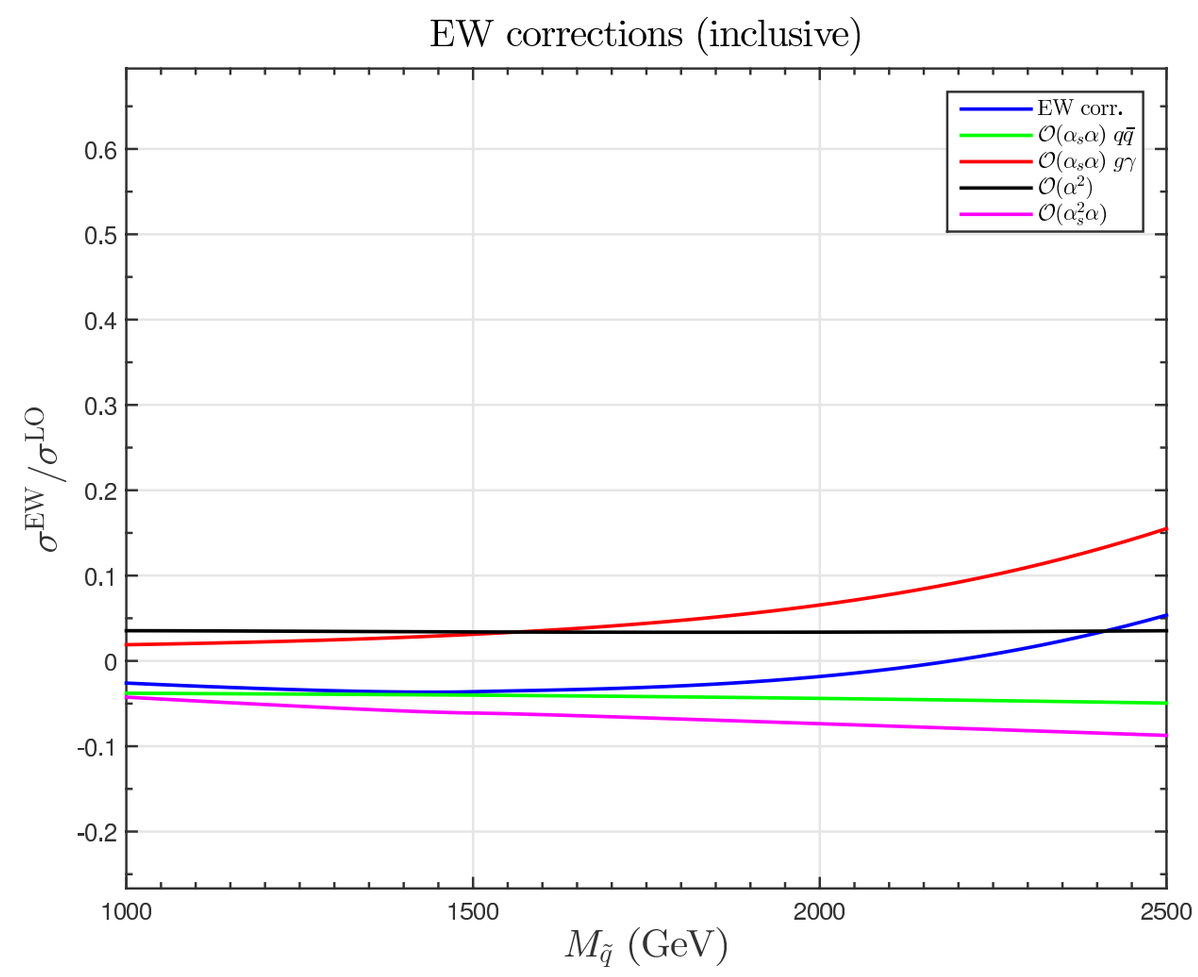
Technical details:

- Amplitudes: FeynArts/FormCalc
- IR-subtraction: mass regularization / phase-space slicing
- all masses renormalized on-shell
- SUSY restoring counterterms included

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ inclusive results

m_{A_0}	700 GeV	$\tan\beta$	20
X_t	$2M_{\tilde{q}_3}$	μ	350 GeV
M_2	350 GeV	$m_{\tilde{g}}$	1500 GeV
$M_{\tilde{q},\mathrm{L}}$	1500 GeV	$M_{\tilde{q},\mathrm{R}}$	1500 GeV
$M_{\tilde{q}_3}$	500 GeV	$M_{\tilde{\ell}_3}$	1000 GeV
$M_{\tilde{\ell}}$	500 GeV		

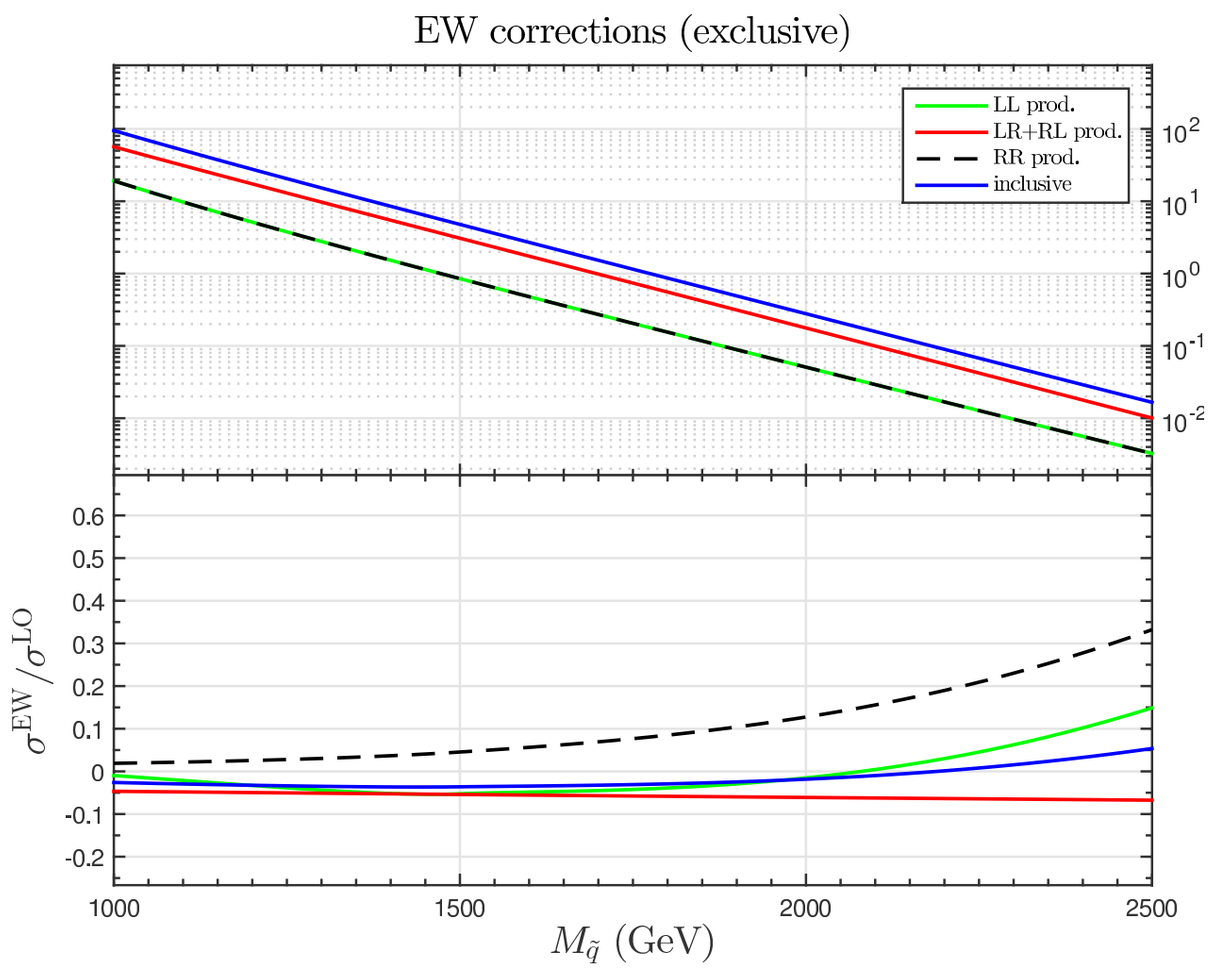




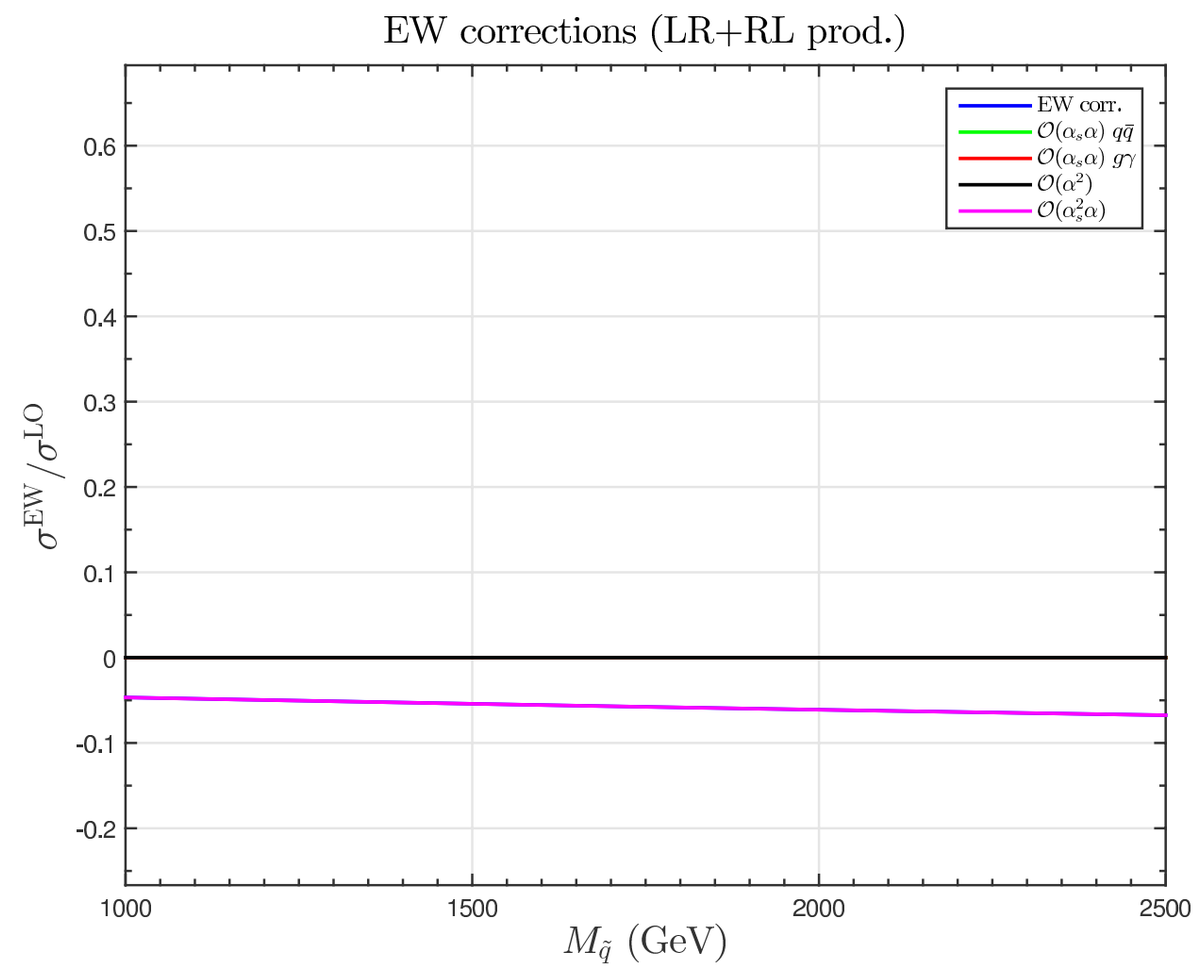
- compensation between (negative) NLO EW and γ - induced production
- overall inclusive EW corrections below 10%

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ inclusive results

incl. = LL + RR + (LR+RL)



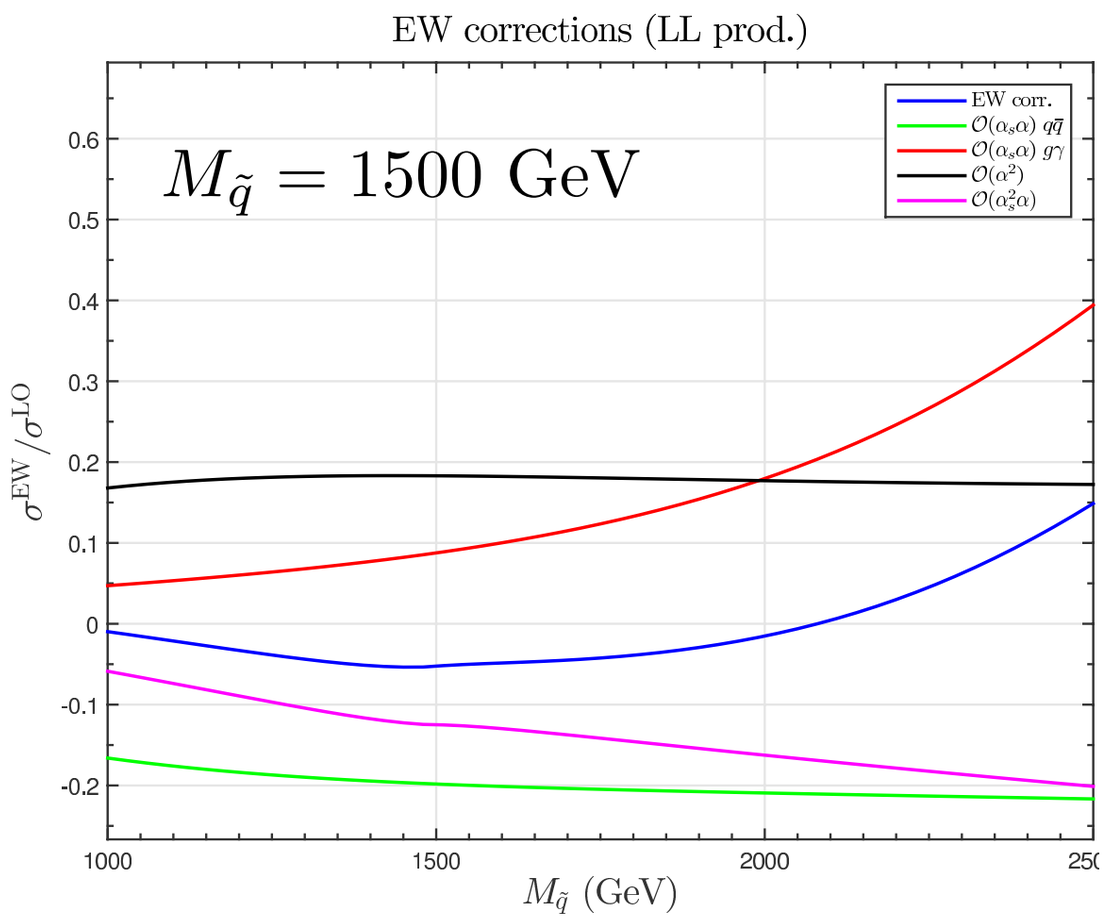
LR+RL



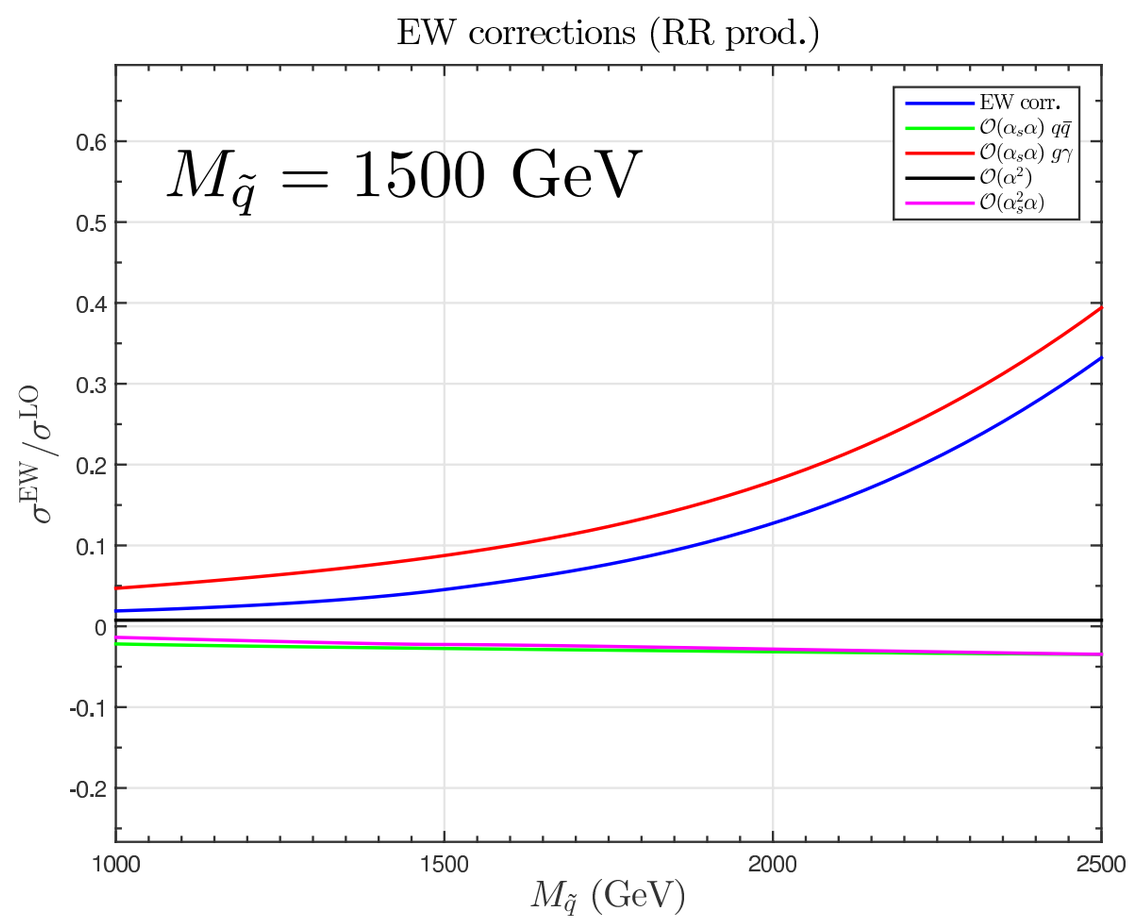
- inclusive cross-section dominated by LR+RL
- no LO EW for LR+RL!
- NLO EW corrections below 10%

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ inclusive results

LL



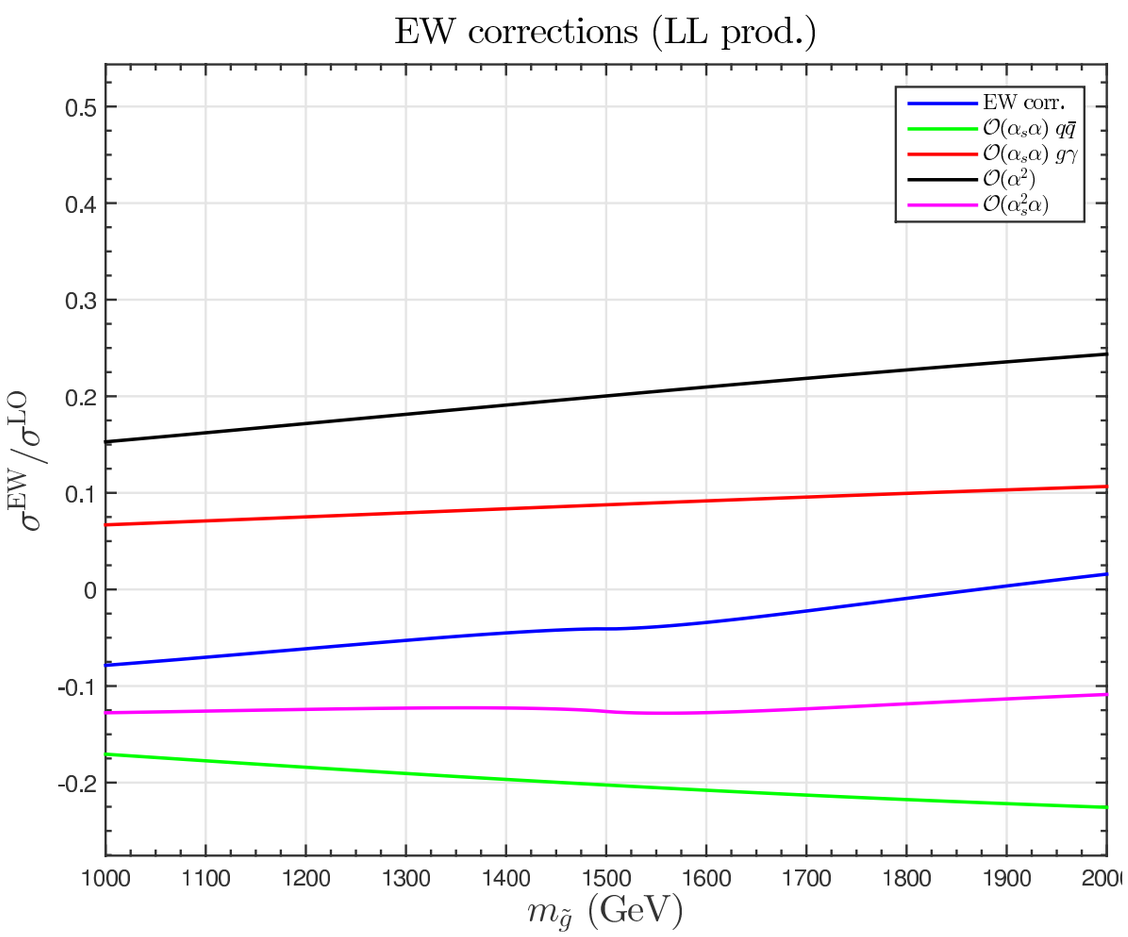
RR



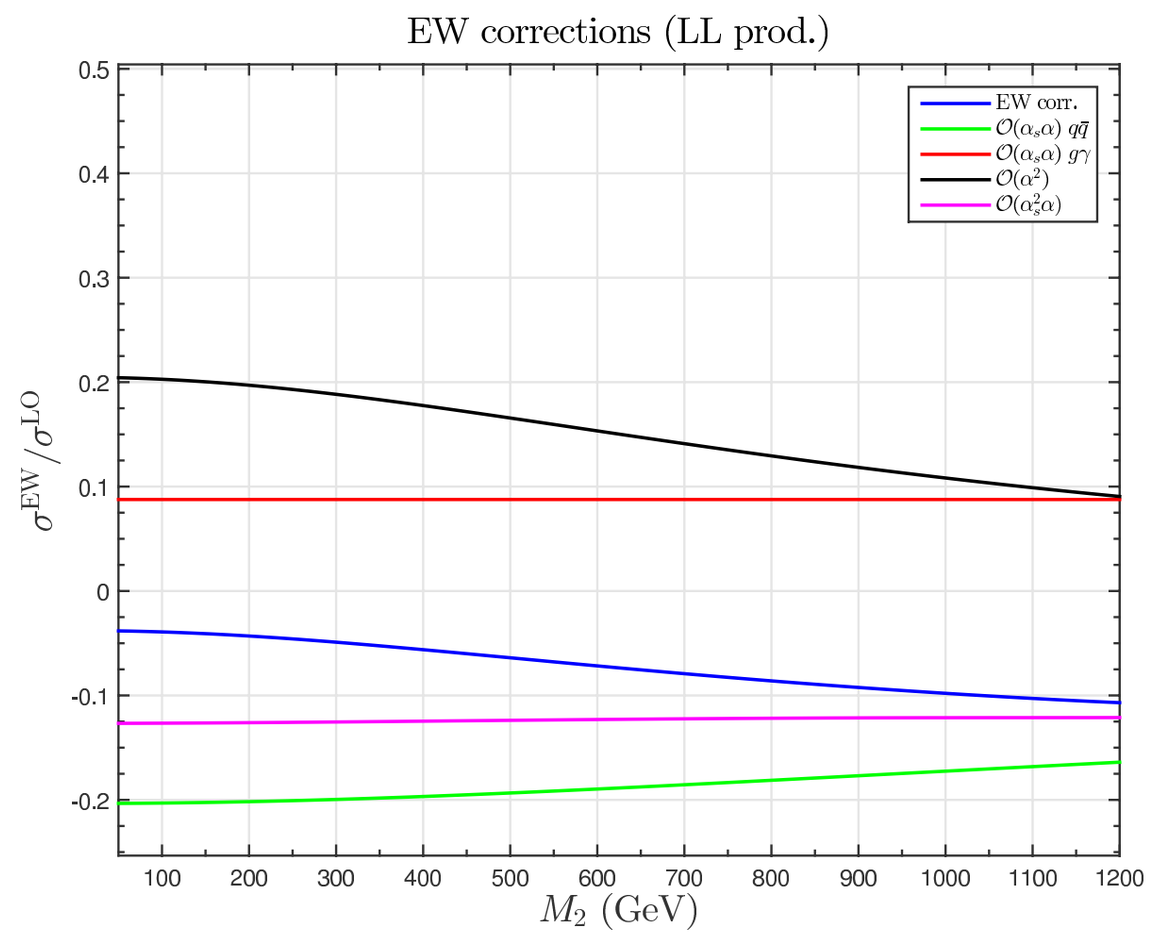
- LL: compensation between sizeable individual contributions
- RR: large overall effect from γ -induced production

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ inclusive results

Indirect dependence on most MSSM parameters negligible.



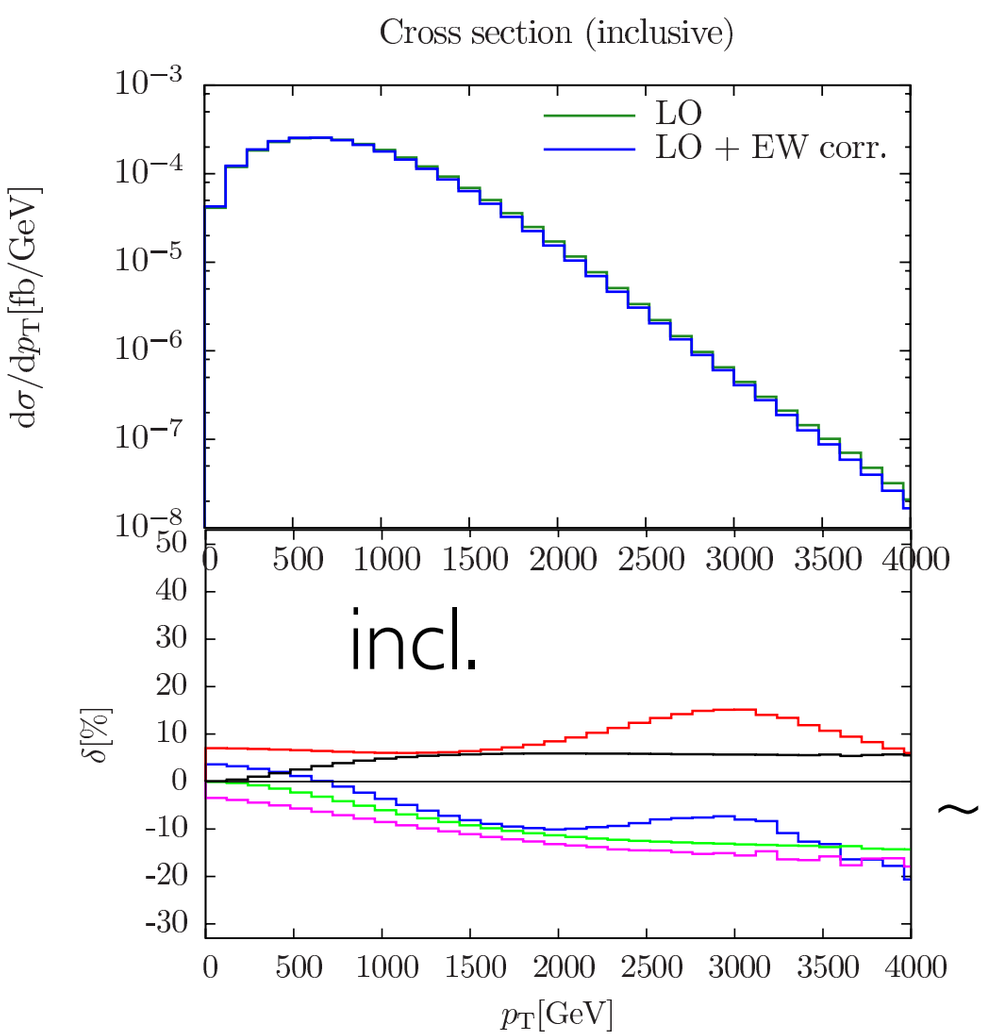
$m_{\tilde{g}}$



M_2

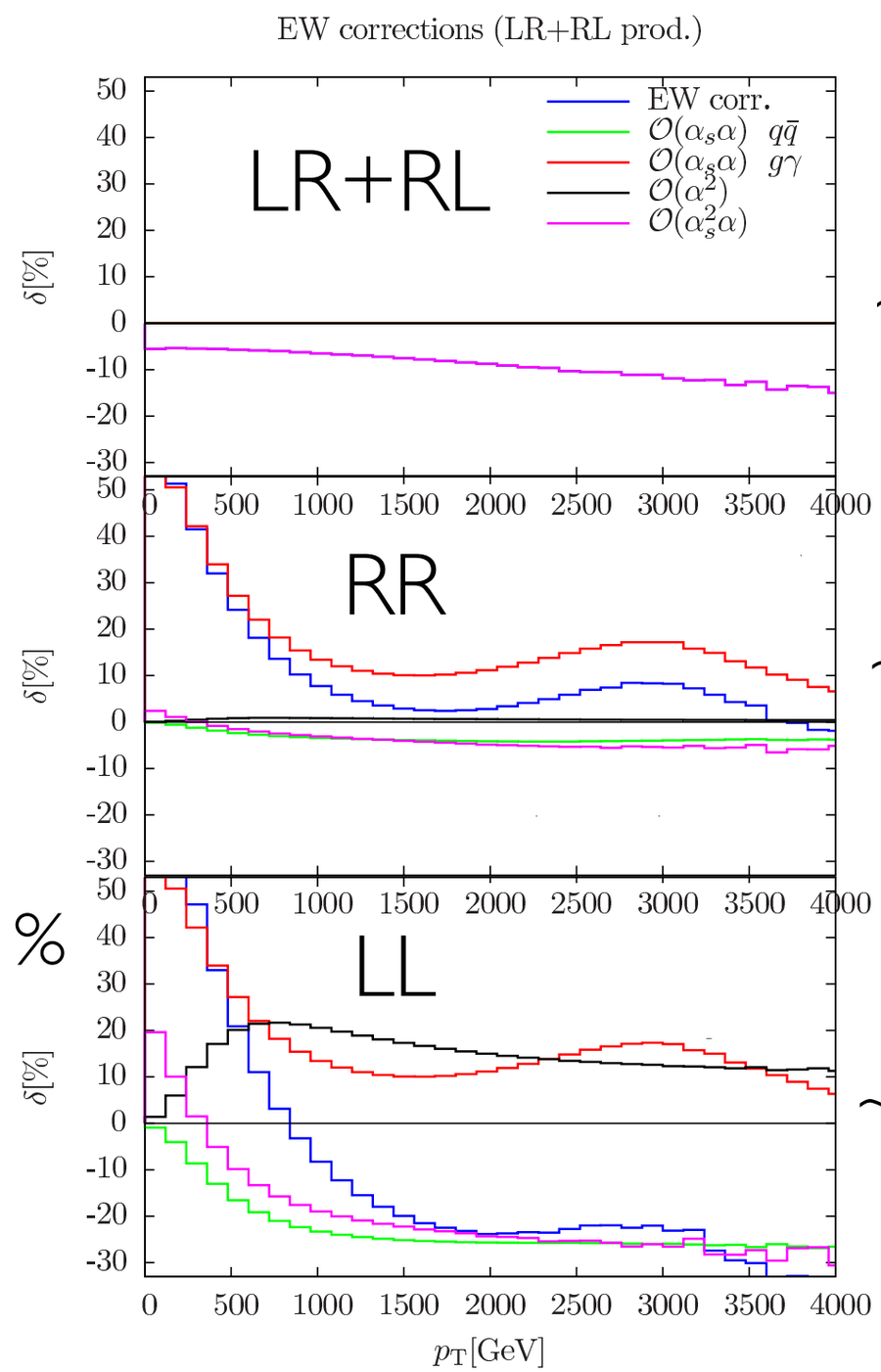
$$m_{\tilde{g}} \uparrow \implies \sigma^{\rm LO} \downarrow \implies \sigma^{\rm LO\ EW}/\sigma^{\rm LO} \uparrow$$

$\tilde{q}_\alpha \tilde{q}'^*_\beta$ differential results: pT-squark



~-10 %

$$M_{\tilde{q},\mathrm{L}} = M_{\tilde{q},\mathrm{R}} = 2000 \text{ GeV}$$



~-10 %

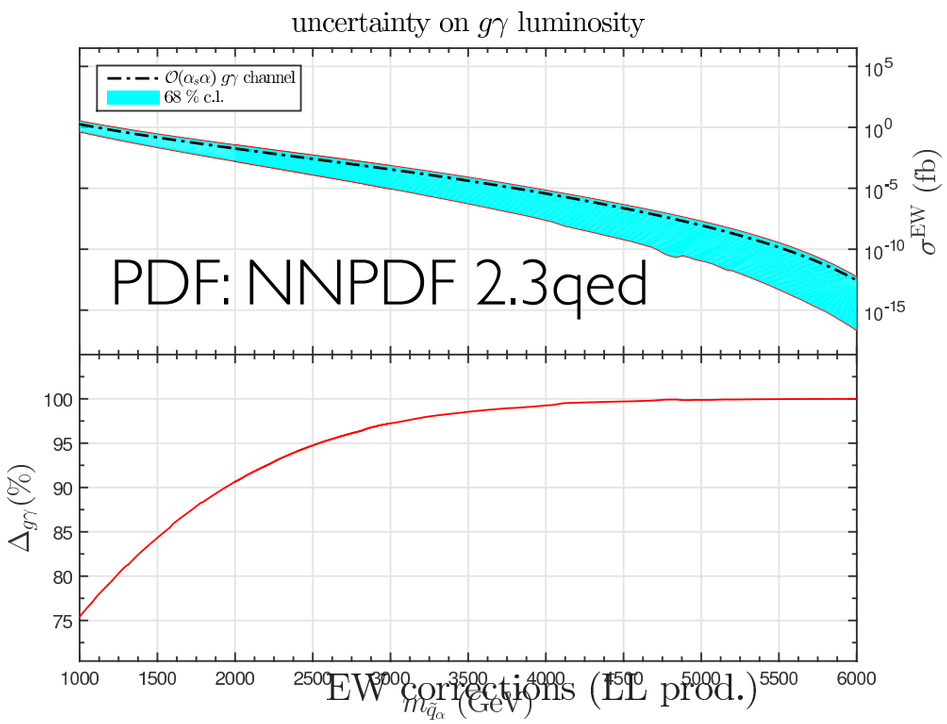
~50 % - 0%

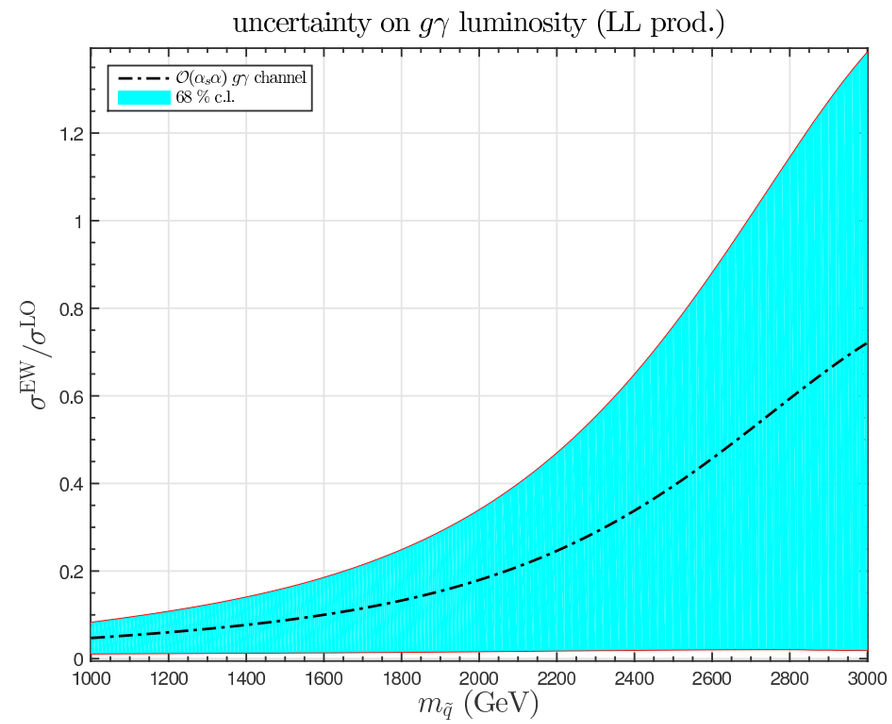
~50 % - -20%

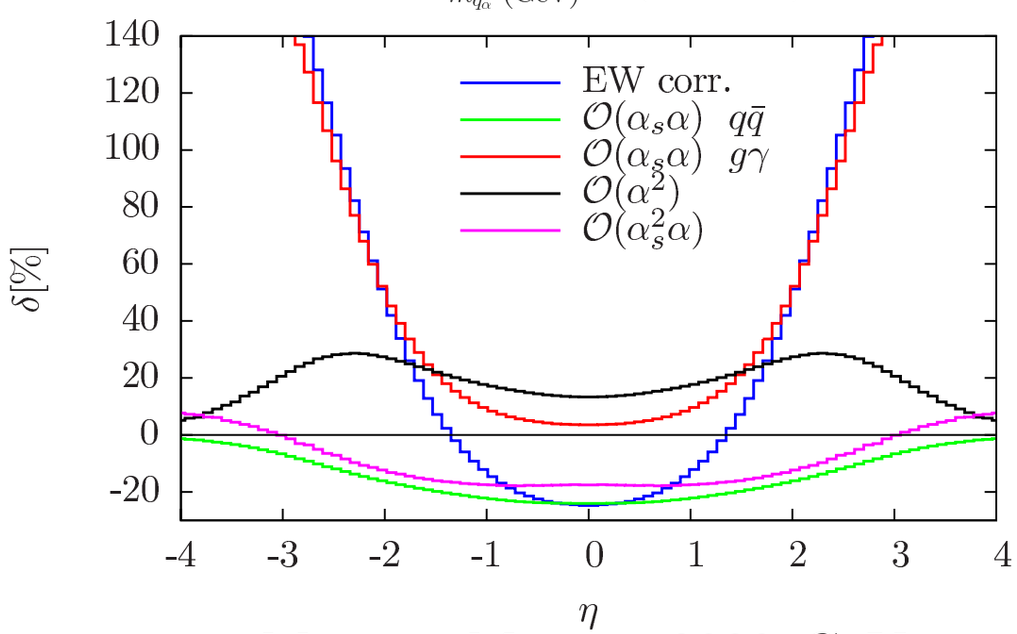
[Hollik, Mirabella, JML, Pagani '15]

$\tilde{q}_\alpha \tilde{q}'^*_\beta$: photon initiated production

Large contributions from γg - initial state. BUT……







$$M_{\tilde{q},\mathrm{L}} = M_{\tilde{q},\mathrm{R}} = 2000 \text{ GeV}$$

$\Longrightarrow$ large uncertainties of total cross section due to γ - PDF

$\Longrightarrow$ largest effects in the forward region (need to consider squark decays)

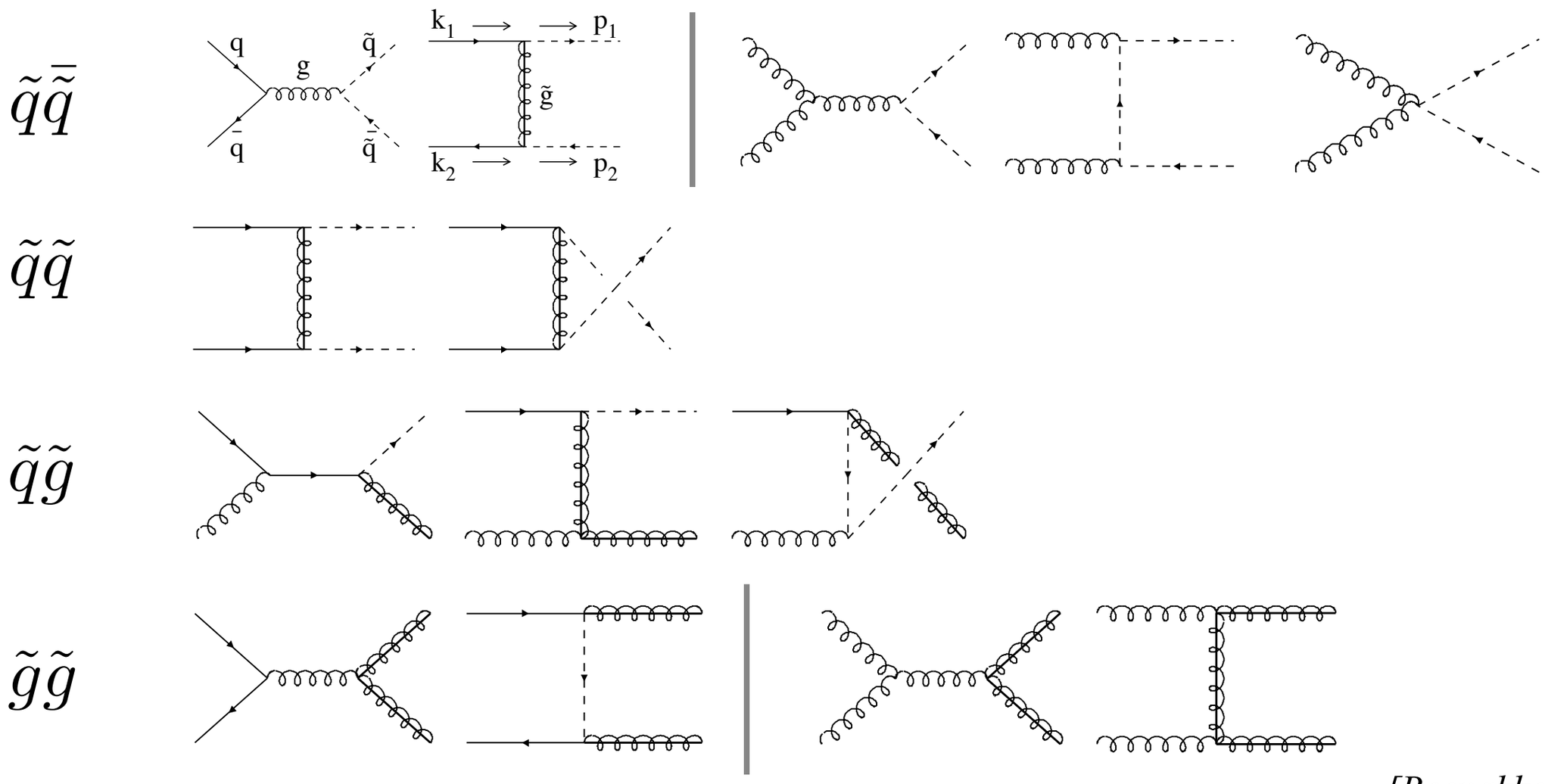
Conclusions

- Electroweak corrections for all squark and gluino production channels known up to $O(\sigma_s^2 \alpha)$
- NLO EW corrections non-negligible for left-handed squarks
- Large contributions from photon initial states for LL & RR production

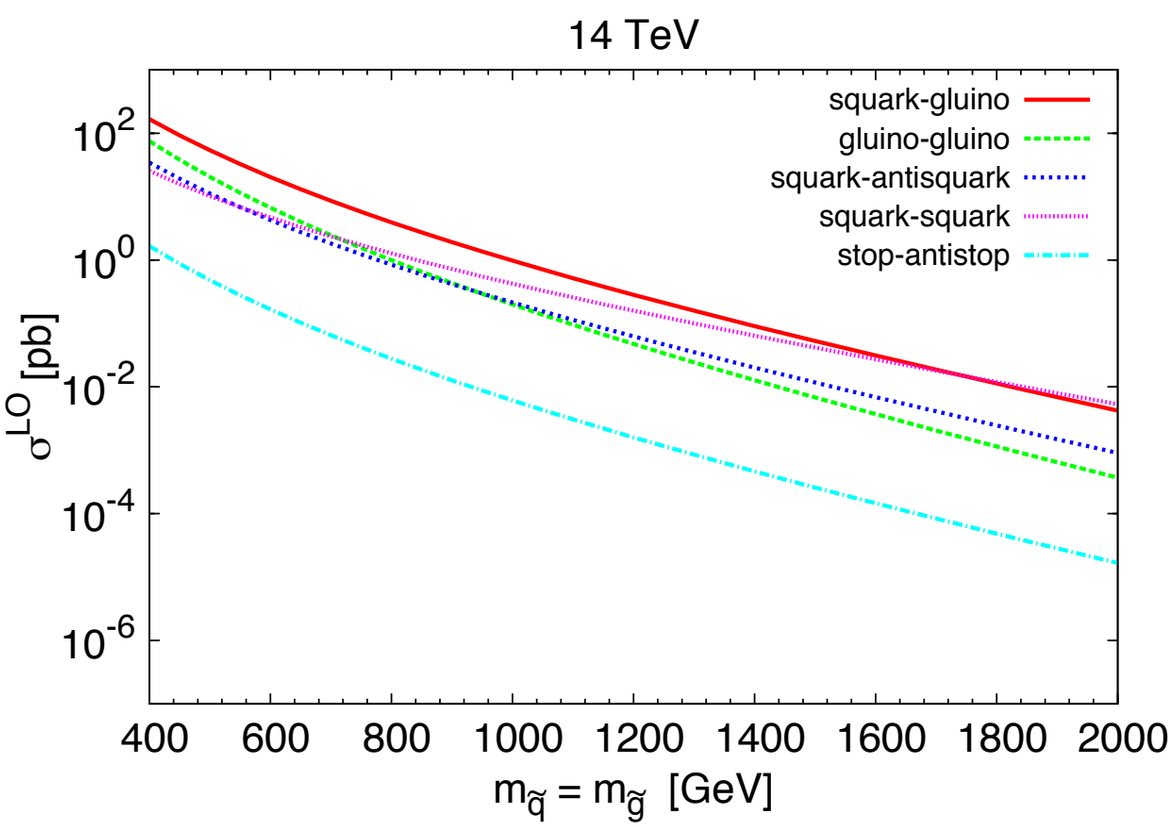
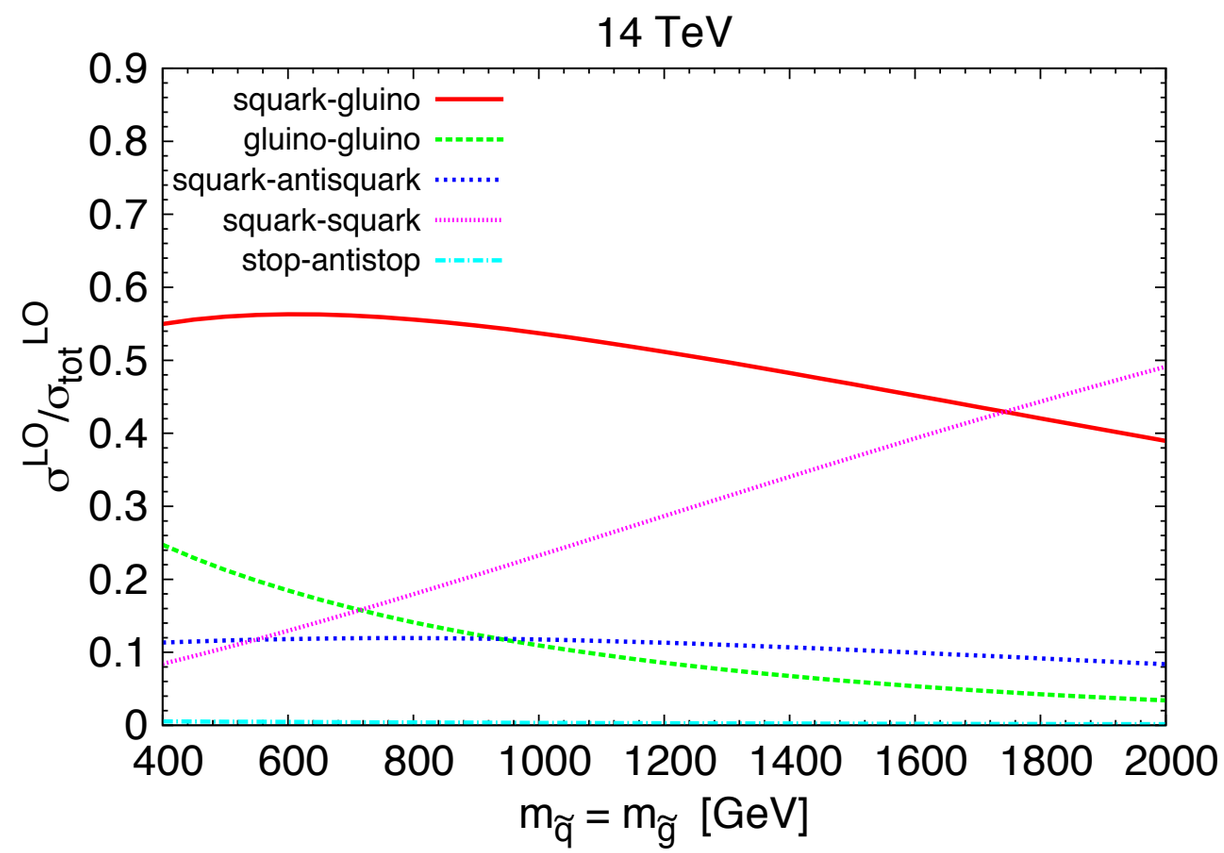
- Outlook:
  - Code will be made publicly available once there is a clear sign for SUSY
  - ….or maybe even before.
  - Phenomenology combining all channels / cross-section grids
  - production x decay @ NLO QCD + EW

BACKUP

Colored Sparticle Prodcution at the LHC



[Beenakker et al.'96]

- For large / decoupled $m_{\tilde{g}}$ squark-antisquark channel is dominant!

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