Neutralino Production at NLO with MadGOLEM

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Motivations

- Process: $pp \rightarrow \tilde{q}\tilde{\chi}_1 \rightarrow q\tilde{\chi}_1\tilde{\chi}_1$ source of monojet signatures
- Provides information on $q\tilde{q}\tilde{\chi}_1$ coupling
  - Reveals the nature of the LSP (bino or wino-like)
  - Bino (wino) coupling proportional to g' (g)
  - Extra info on this coupling would help DM direct detection bounds
- Associated production: semi-weak process, but favored by $m_{\tilde{\chi}_1} << m_{\tilde{q}}, m_{\tilde{g}}$
- Process not yet studied @NLO! Recent analysis @LO [Allanach, Grab, Haber arXiV:1010.4261]
- MadGOLEM: Fully automated tool to perform NLO (SUSY-QCD) in a process independent approach (main focus on SUSY models). Under development (Details cf. David Lopez-Val talk!)

NLO Schematically

$$\delta\sigma^{NLO} = \int_{n+1} d\sigma^{Real} + \int_n d\sigma^{Collinear} + \int_n d\sigma^{Virtual}$$

Real emission
Born matrix with n+1 partons

Collinear subtraction
From factorization of initial state collinear singularities

Virtual corrections
Interference term of 1-loop & Born matrix

UV divergent → Renormalization → Finite UV

IR divergent + IR divergent + IR divergent

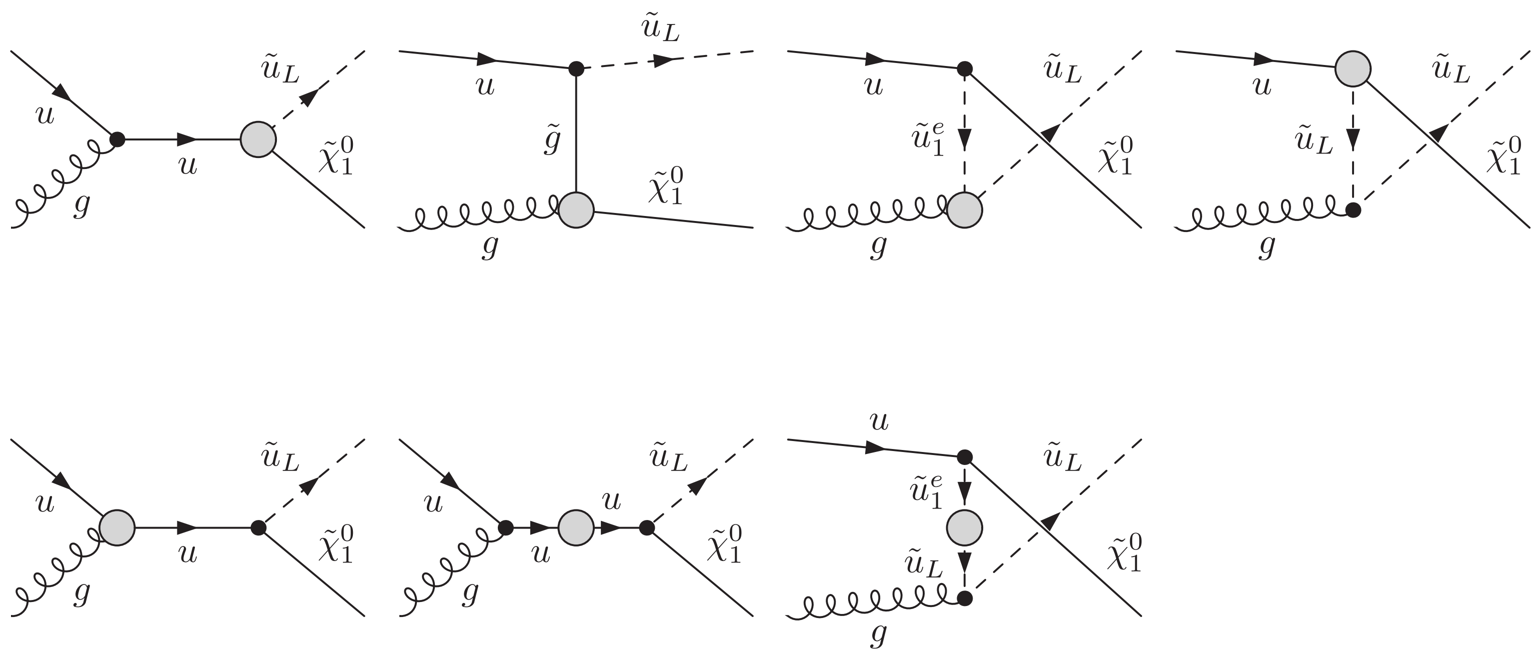
→ Finite and IR safe
(KLN & Factorization Theorem)

Problem:

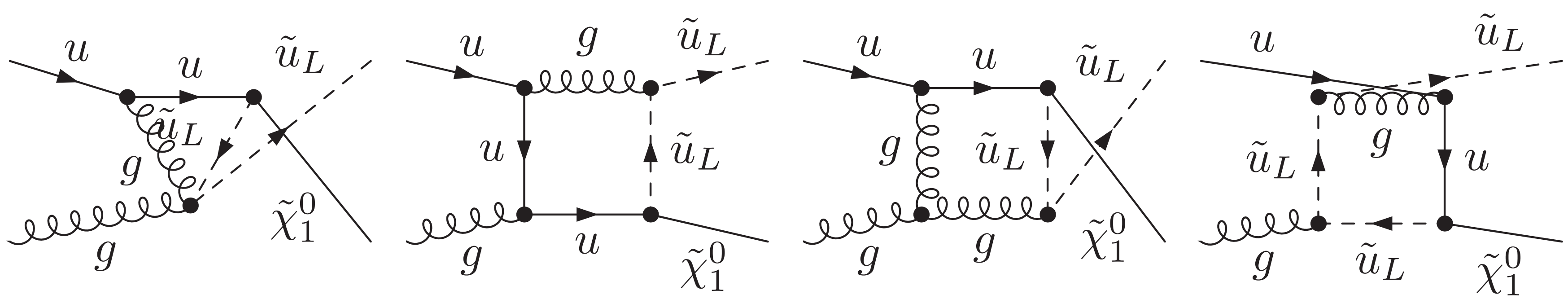
How to get finite individual contributions from MC methods?
Let's see explicitly all the MadGOLEM machinery working for $pp \to \tilde{q}\tilde{\chi}_1$!!!

Virtual corrections

- UV singularities arise from loop integrals that could be separated as:
  - Vertex and self energy corrections

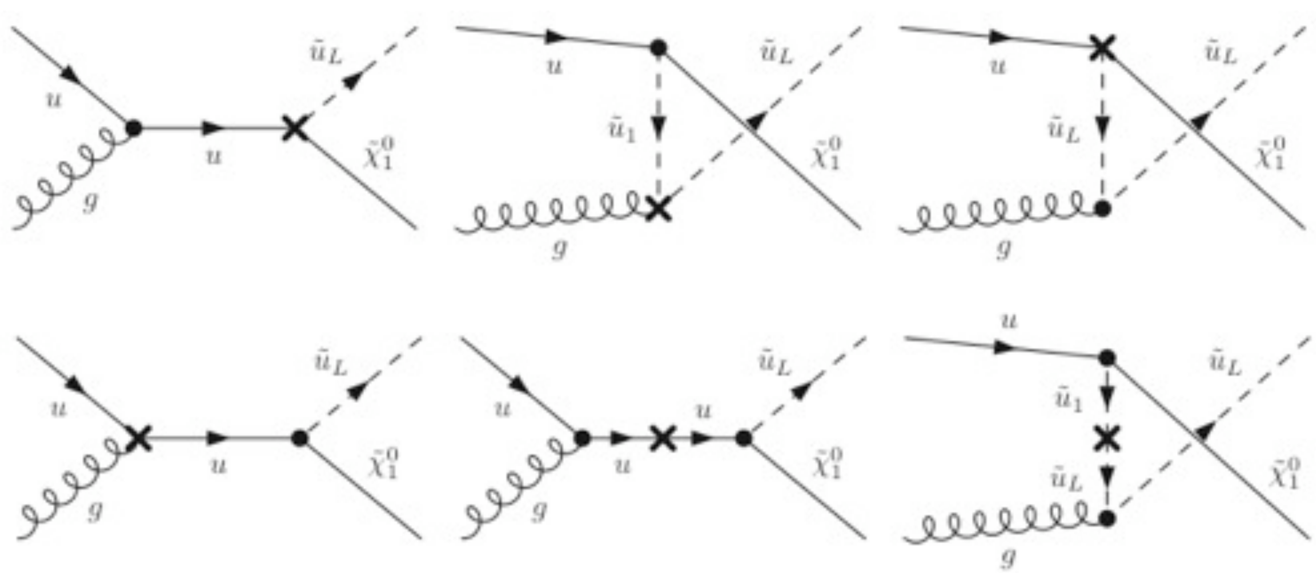


  - Box diagrams



Virtual corrections

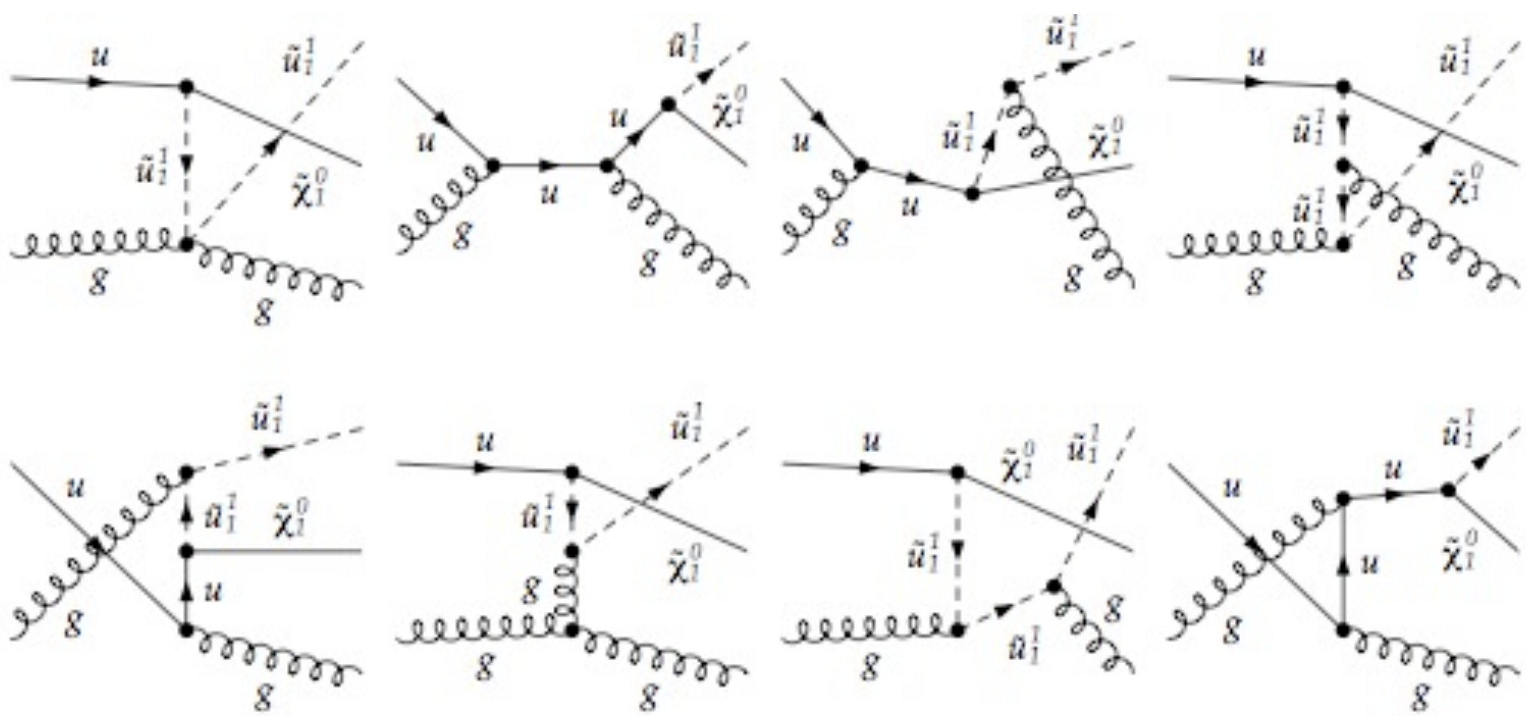
- Renormalization scheme:
  - α_s in the $\overline{MS}$ scheme, massive particles decoupled [Beenakker et.al. '97]
  - OS renorm. for massive particles & $\overline{MS}$ for massless
  - SUSY restoring counter term for $q\tilde{q}\tilde{\chi}_1$ coupling [Martin, Vaughn '93]
- Adding counter terms:



→ Virtual correction UV finite!

Real emission

- Real emission diagrams $pp \to \tilde{q}\tilde{\chi}_1 j$



→ Divergent for soft and collinear emission

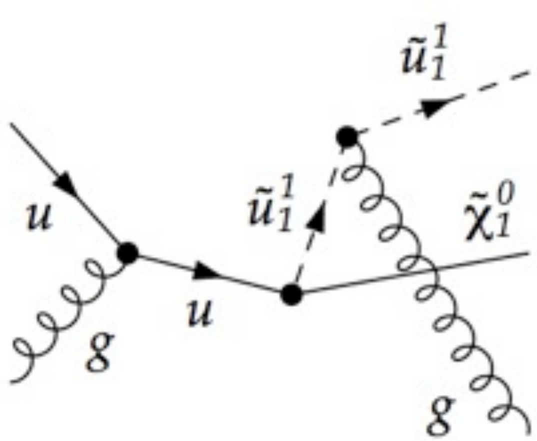
Real emission

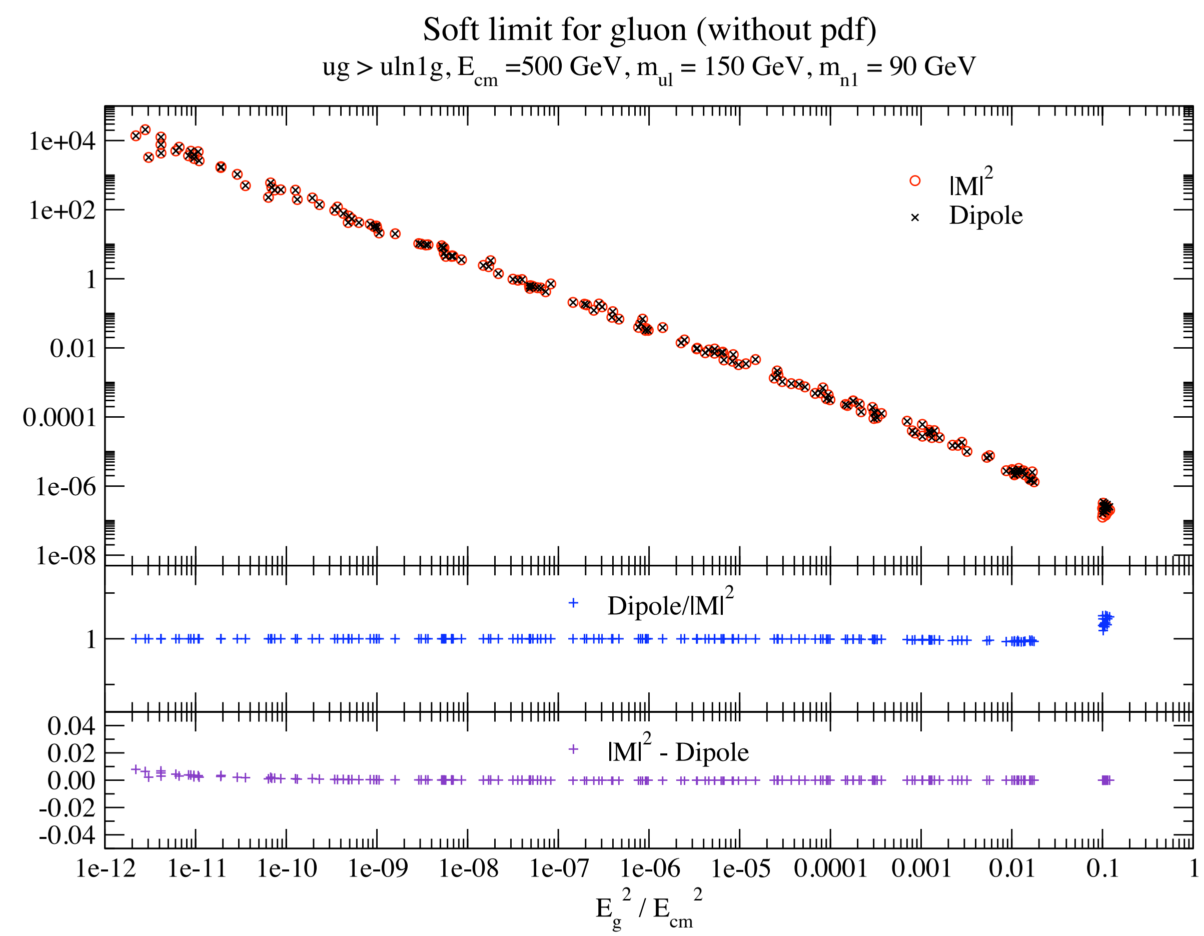
- Catani-Seymour Subtraction Method: construction of local counter terms using the universality of soft and collinear limits

$$|\mathcal{M}_{n+1}|^2 \to |\mathcal{M}_n|^2 \otimes V_{ij,k} \quad \Longrightarrow \quad d\sigma^A \equiv \sum_{dipoles} d\sigma^B \otimes dV_{dipole}$$

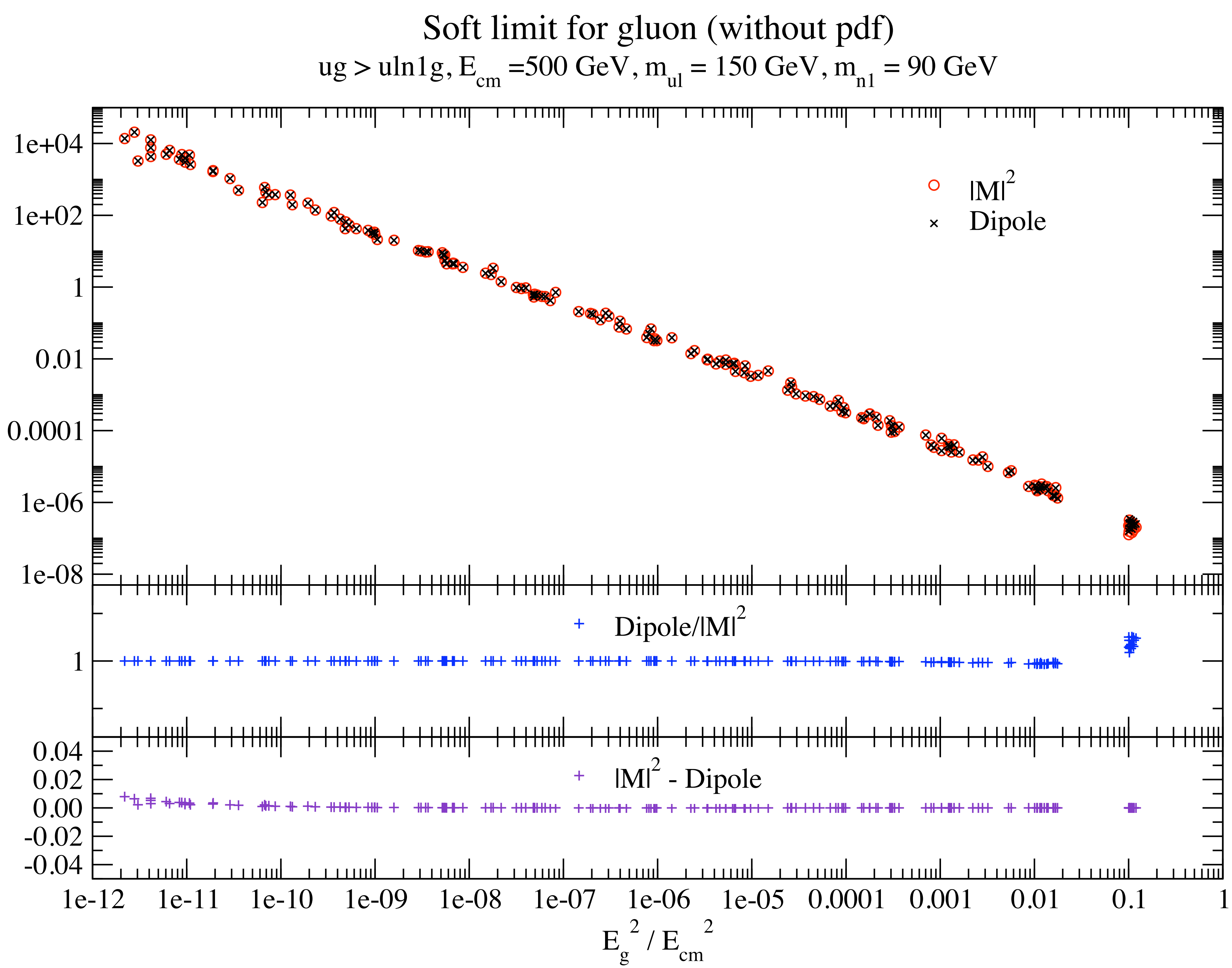
$$\delta\sigma^{NLO} = \int_{n+1} \left(d\sigma^{Real}_{\varepsilon=0} - d\sigma^A_{\varepsilon=0} \right) + \int_n \left(d\sigma^{Collinear} + d\sigma^{Virtual} + \int_1 d\sigma^A \right)_{\varepsilon=0}$$

- Let's see our CS SUSY dipole implementation working:





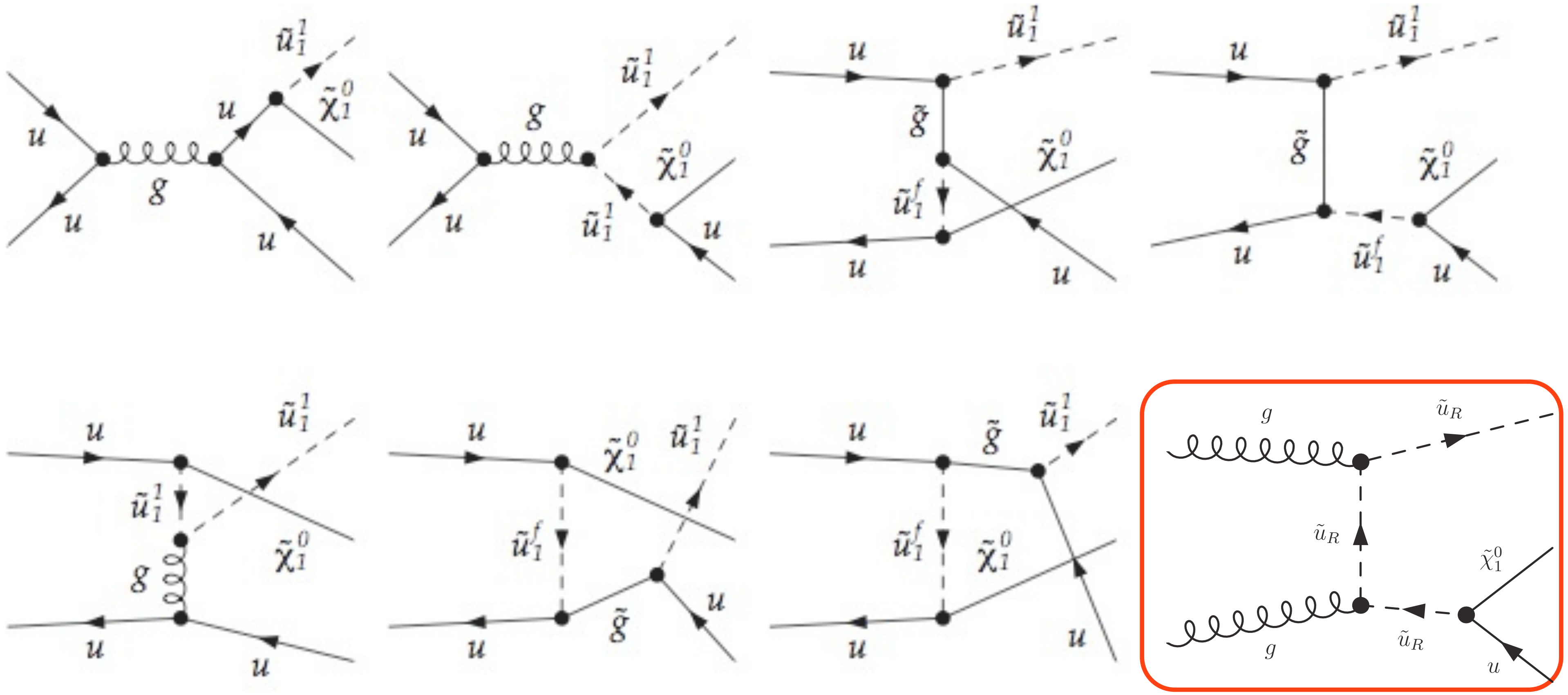
Real emission



- Divergency from $|M_{n+1}|^2$ is subtracted locally!

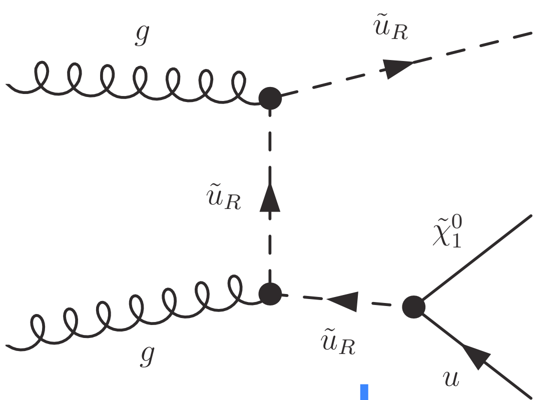
Real emission

- Real emission diagrams for $pp \to \tilde{q}\tilde{\chi}_1 j \; with \; j = q, \bar{q}$



Real emission: On-Shell Subtraction Method

- Differentiation between Off & On-shell production to avoid double counting [Beenakker, Hopker, Spira, Zerwas '97]

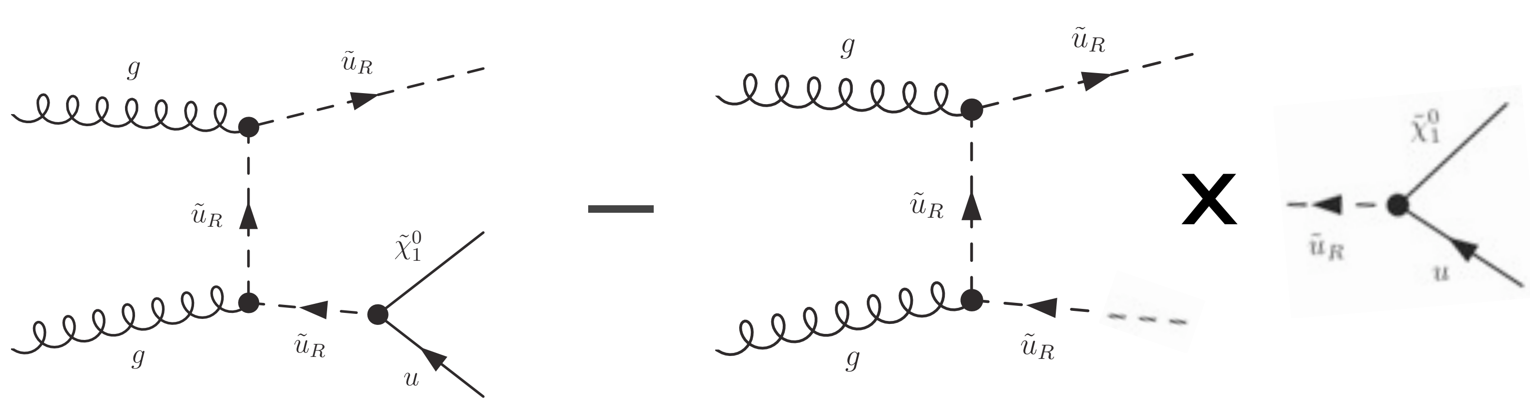


- $gg \to \tilde{q}\bar{\tilde{q}}^* \to \tilde{q}\chi_1\bar{q}$ Squark neutralino production
- $gg \to \tilde{q}\bar{\tilde{q}} * BR(\bar{\tilde{q}} \to \chi_1\bar{q})$ Squark pair production

$$\frac{i}{p^2 - m_{os}^2} \to \frac{i}{p^2 - m_{os}^2 + i m_{os}\Gamma_{os}}$$

Γ_{OS} is regarded as a regulator

- To avoid double counting subtract On-Shell amplitudes:

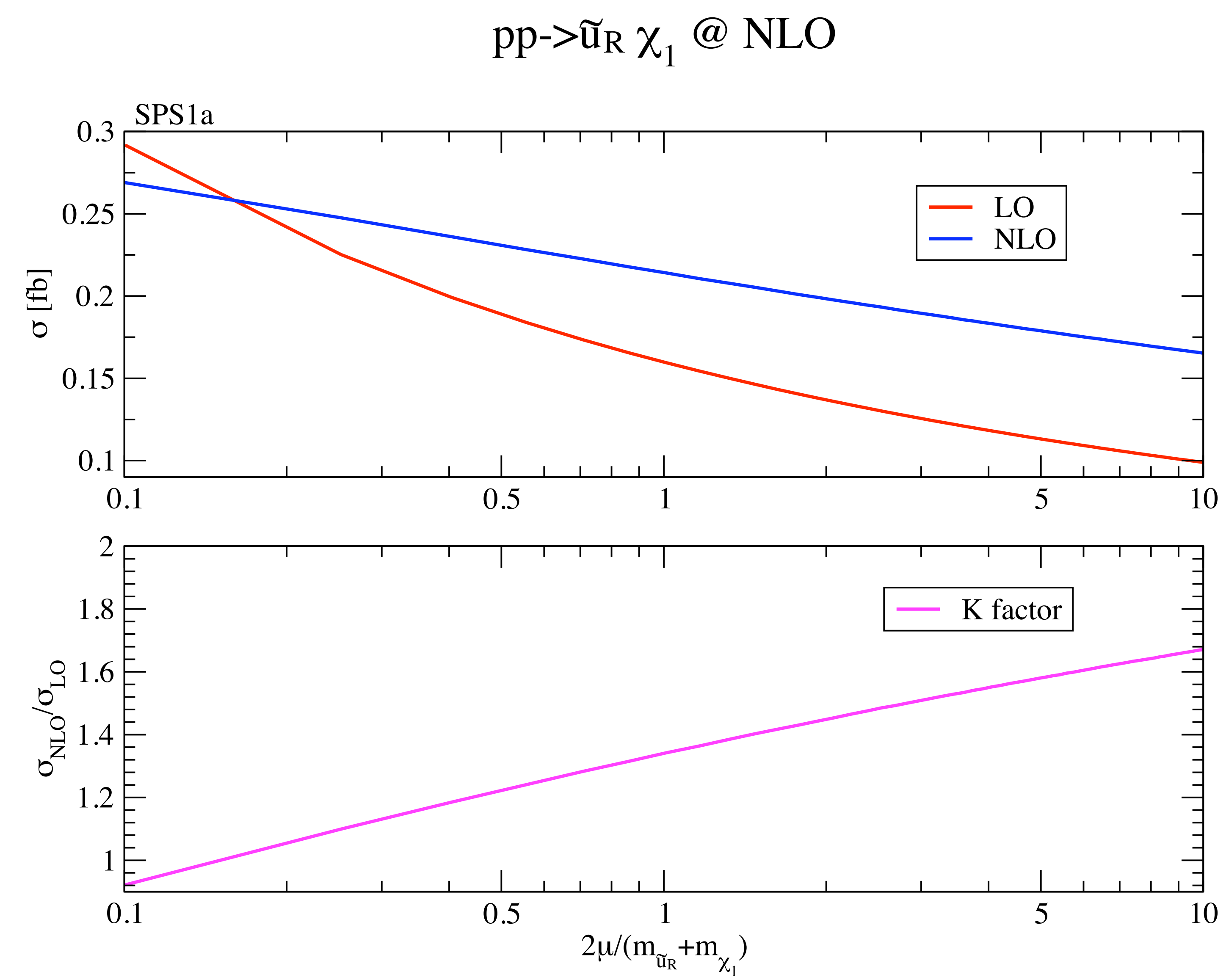


$\sigma(gg \to \tilde{q}\chi_1\bar{q})$ $\sigma(gg \to \tilde{q}\bar{\tilde{q}}) * BR(\bar{\tilde{q}} \to \chi_1\bar{q})$

After MadGOLEM take care of all this technical details automatically we can appreciate the importance of the NLO correction for this process...

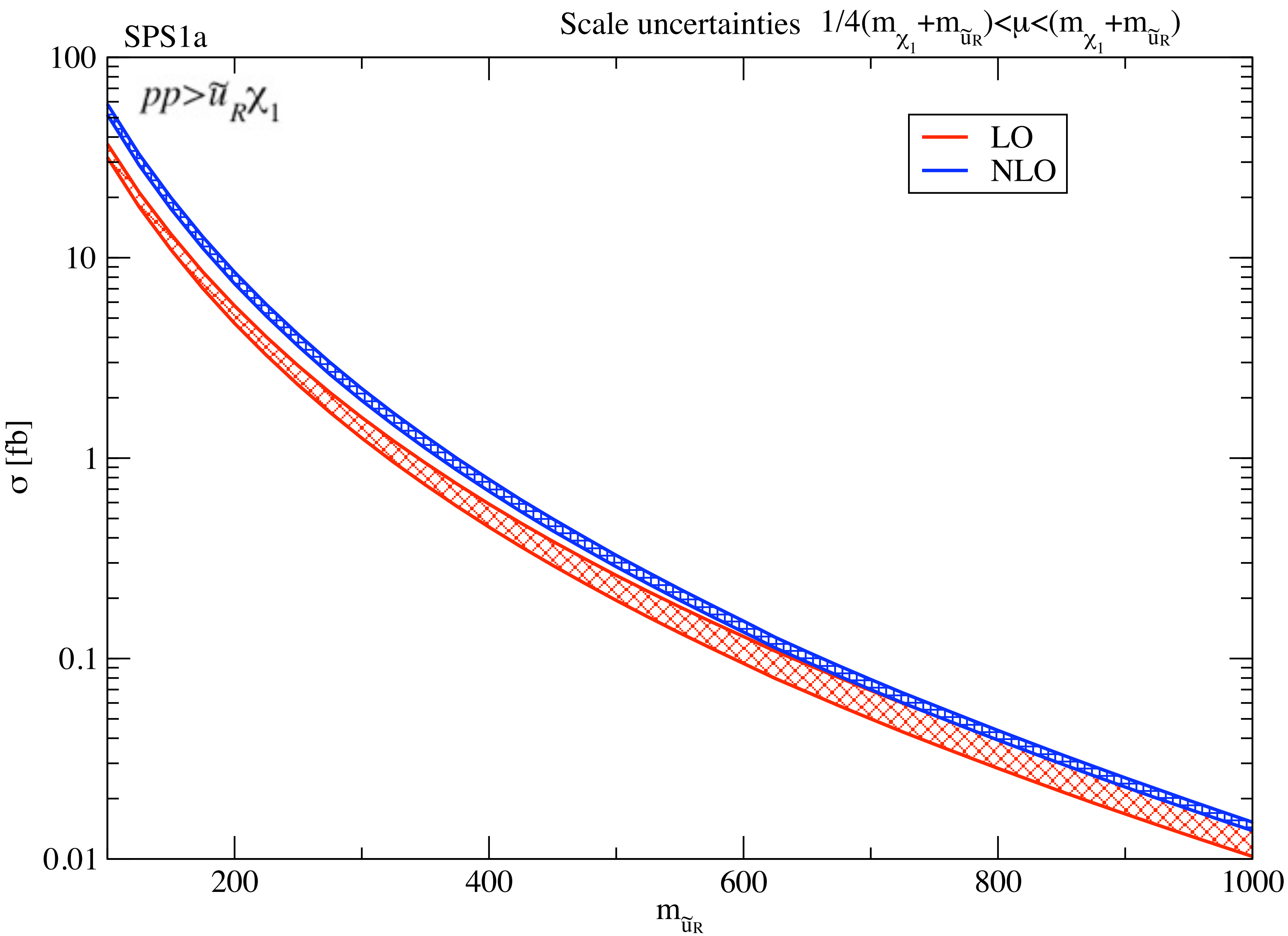
Scale Dependence

- Scale dependence at the LHC for $\mu_F = \mu_R = \xi \left(\frac{m_{\tilde{u}_R} + m_{\chi_1}}{2} \right)$ at LO and NLO



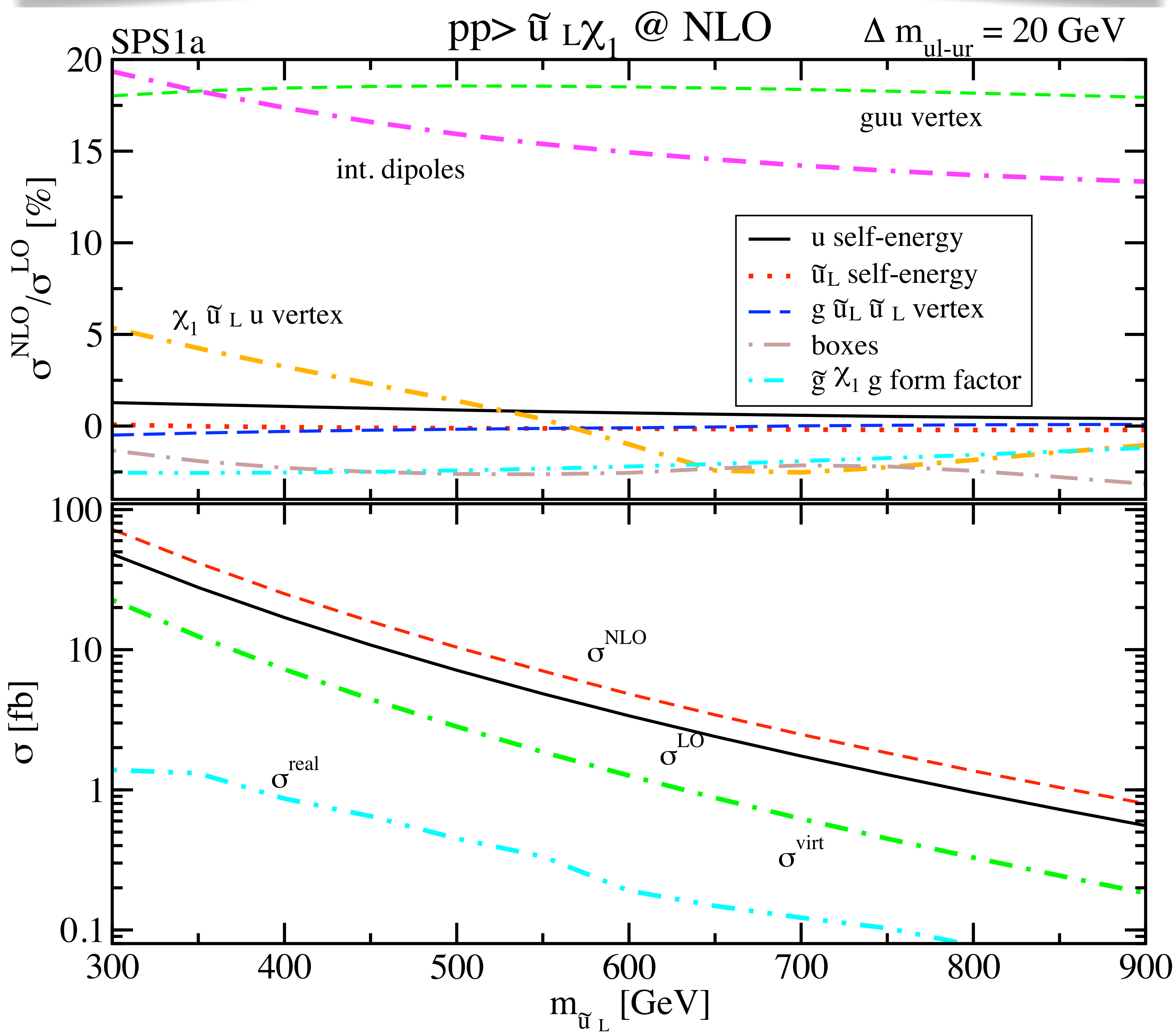
- Varying the scale up or down by a factor of 2 changes the cross section by **33%** in **LO** and by **7%** in **NLO**

Preliminary results



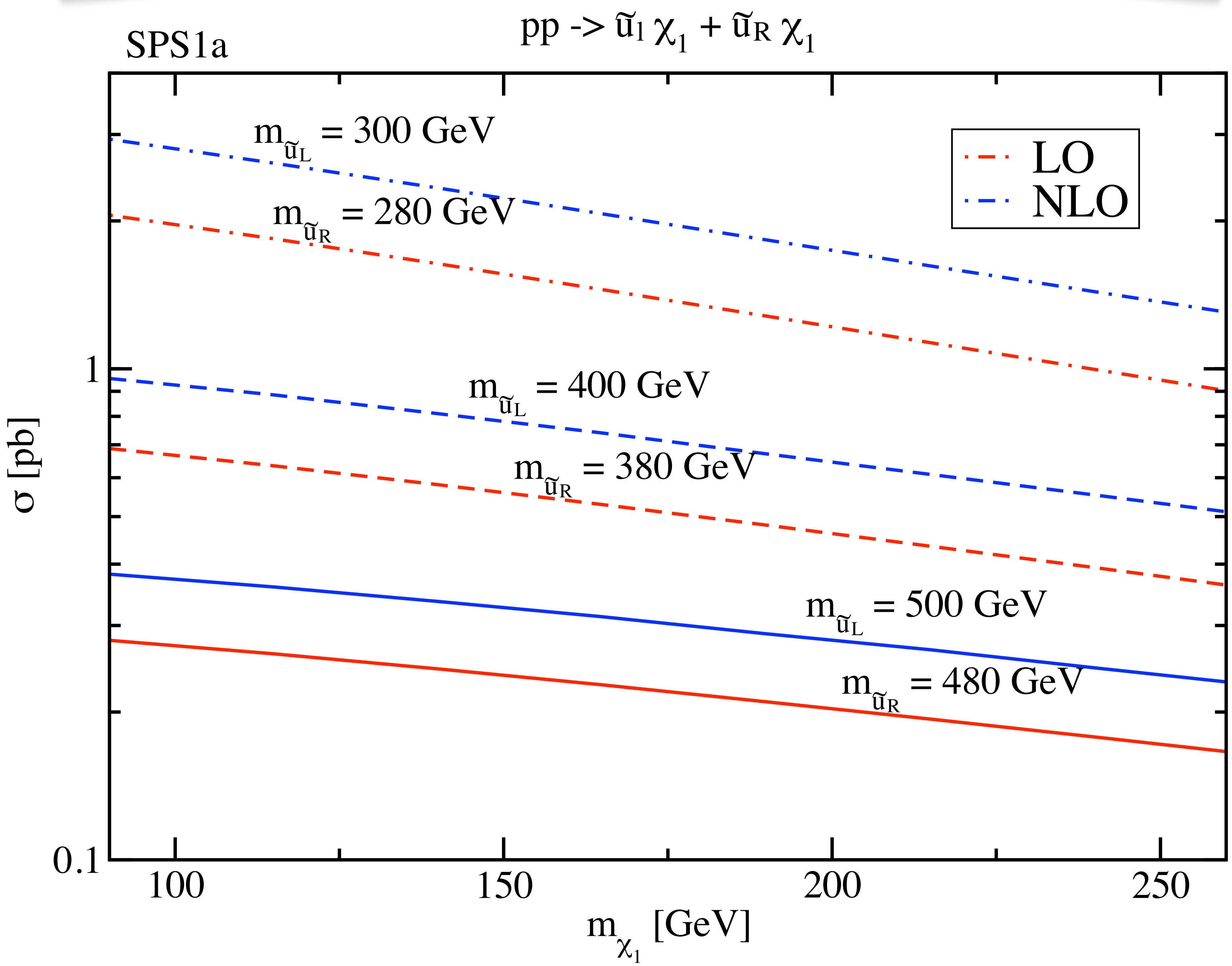
- The leading contribution for this process is $\tilde{q} = \tilde{u}_R$ final state.
  More then 80% of the Xsection ($g\left(\tilde{u}_R\chi_1 u\right) >> g\left(\tilde{u}_L\chi_1 u\right)$, bino like neutralino)
- Phase space suppression of the Xsection with $m_{\tilde{q}}$ and of the NLO corrections

Preliminary results



- Sub leading dependence from the virtual corrections with $m_{\tilde{q}}$ (main contribution come from loops without any mass scale!)

Preliminary results



- This also show the correlation $m_{1/2}$ vs m_0

Preliminary results

$$pp \to \tilde{q}\chi_1,\ \tilde{q} = \tilde{u}_R, \tilde{u}_L$$

	σ^{LO} [fb]	σ^{NLO} [fb]	K	$M_{\tilde{u}_L}$ [GeV]	$M_{\tilde{u}_R}$ [GeV]	$M_{\tilde{g}}$ [GeV]	$M_{\tilde{\chi}_1^0}$ [GeV]
SPS1a	160.339	216.647	1.351	561.119	549.259	607.714	96.688
SPS1b	22.178	29.743	1.341	871.658	850.474	938.211	161.764
SPS2	1.081	1.440	1.332	1554.313	1553.824	781.899	237.406
SPS3	24.475	32.868	1.343	853.684	831.809	935.268	160.546
SPS4	41.920	55.305	1.319	760.030	747.952	733.465	227.720
SPS5	74.398	100.282	1.348	674.953	657.290	721.612	231.186
SPS6	56.474	76.636	1.357	669.564	660.214	720.302	224.299
SPS7	18.063	24.261	1.343	895.986	874.580	950.032	268.970
SPS8	7.371	9.733	1.320	1113.372	1077.385	781.899	138.947
SPS9	5.246	6.930	1.321	1276.308	1281.497	1181.585	187.173

- High K factors for all SPS points K~1.3

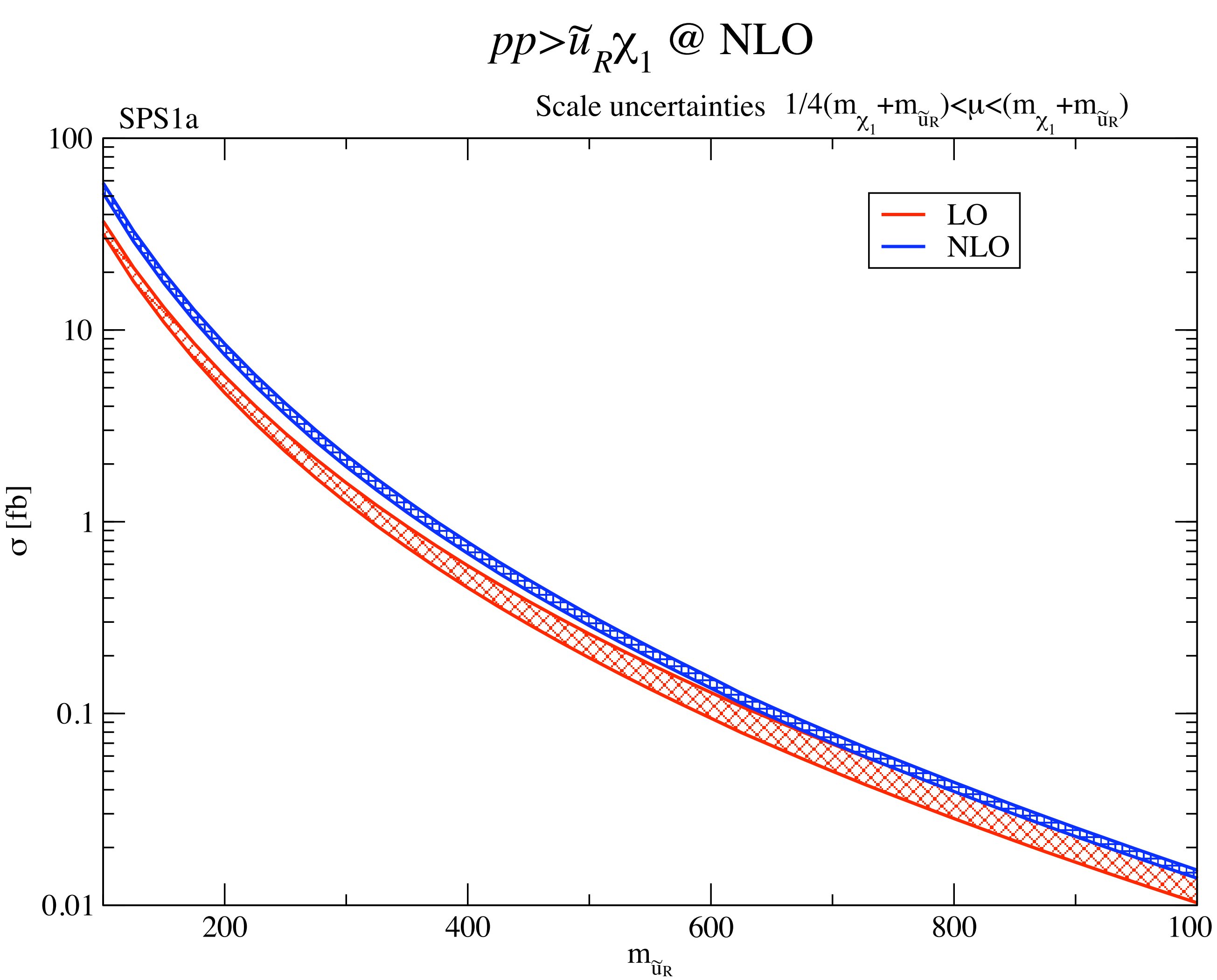
Summary

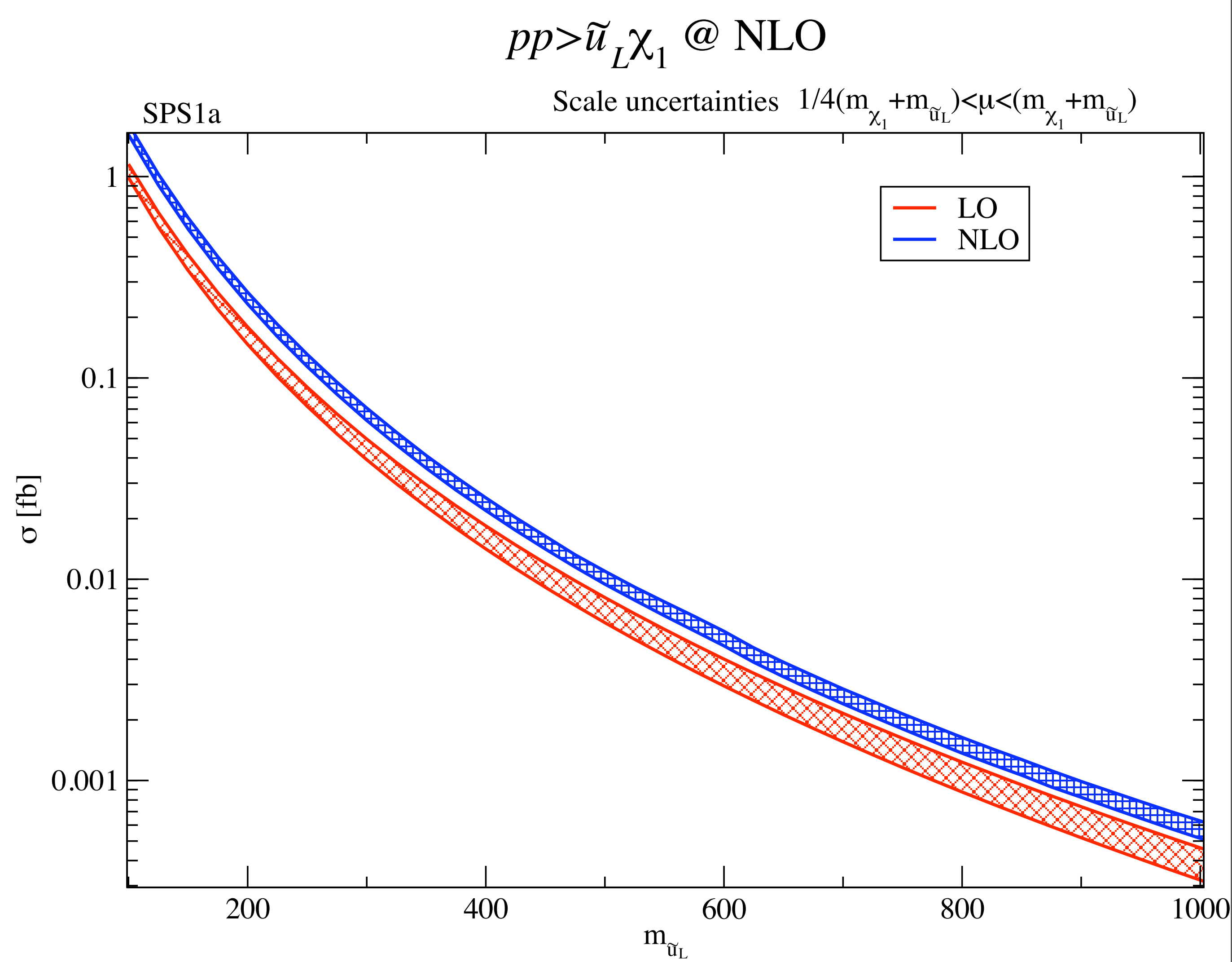
- MadGOLEM is ready for new physics analysis!
  - IR and UV divergencies properly treated
  - On-Shell Subtraction Method automated, avoids double counting
  - Consistence checks prove reliability

- $pp \to \tilde{q}\chi_1 \; @NLO$
  - Scale uncertainty reduced from ≈33% at LO to 7% at NLO
  - High K factors for all SPS points K~1.3

- Work in progress...
  - Detailed analysis of $pp \to \tilde{q}\tilde{\chi}_1$ at NLO

Backup slides



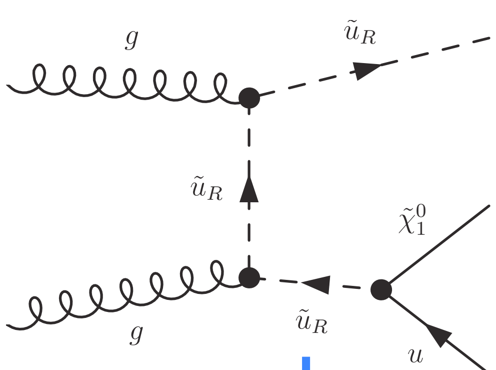


Backup slides

$$\sigma^{Real}(\Gamma_{os}) = \int_{n+1} d\Phi_{n+1} \left[\left(|\mathcal{M}_{res}|^2 - d\sigma^{os} \right) + 2Re\left[\mathcal{M}^*_{res} \mathcal{M}_{rem} \right] + |\mathcal{M}_{rem}|^2 - d\sigma^A \right]$$

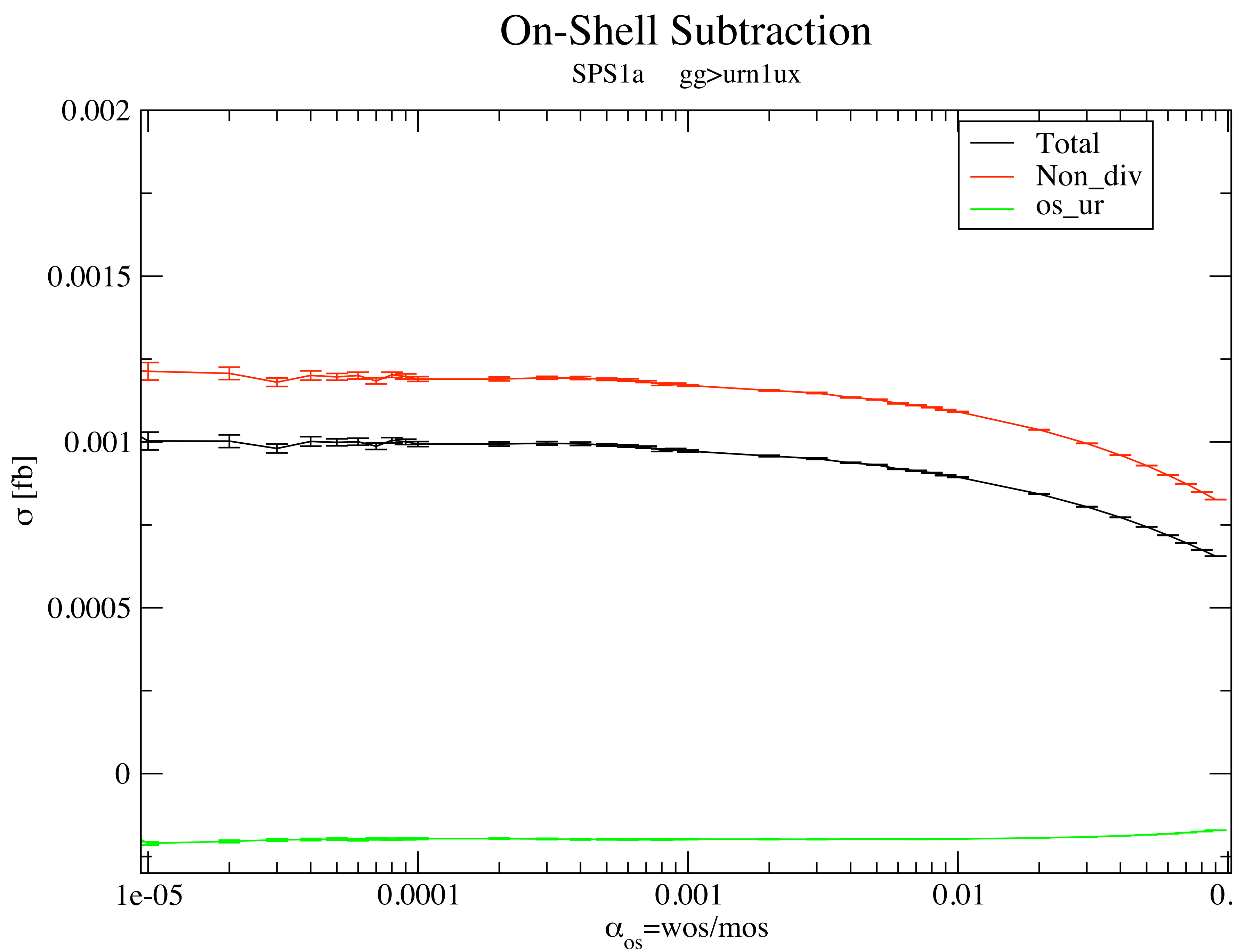
- gg>urn1ux

1 possible OS particle: ur



$$\frac{i}{p^2 - m^2_{OS}} \rightarrow \frac{i}{p^2 - m^2_{OS} + i m_{OS}\Gamma_{OS}}$$

Γ_{OS} is a regulator!



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- uux>ulxn1u

3 possible OS particles: go, ul, ur