LHCP 2017

ETH zürich

Recent Developments in Monte-Carlos programs and in Resummation

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Outline

Resummation

- Quick word on "**numerical** resummation" aka PSMC
- **Automated analytical** resummations:
  - aMC implementation: **Threshold resummation**
  - aMC implementation: **Jet-veto cross-sections**

(cherry-picked) MC developments

- **BSM @ NLO QCD**, MSSM@NLO, OS subtraction
- Mixed **QCD+EW NLO** predictions
- **Plugins** in MG5_aMC

Resummation Zoo

Type	Pros	Cons
"Numerical" Parton showers	Resums generic observables Readily process-independent Accommodates hadronization	Poor formal control over accuracy Difficult to systematically improve
"Analytical" Process dependent	Higher formal accuracy (NNLL+) Harder to share with community	Limited applicability More error prone
"Analytical" Automated	Flexibly and easy to distribute Robust and widely applicable	Lower formal accuracy (NLL)

- The PSMC approach is mature and widely used
- Process dependent computations explored several aspects of factorization and help lay down different theoretical framework for resummation (SCET, TMD, etc...)
- Automated analytical approaches are relatively new and promising

Matching+Merging to PSMC

- Long history and many existing schemes already

  LO: MLM, CKKW-L **NLO**: FxFx, UNLOPS, MINLO, ...

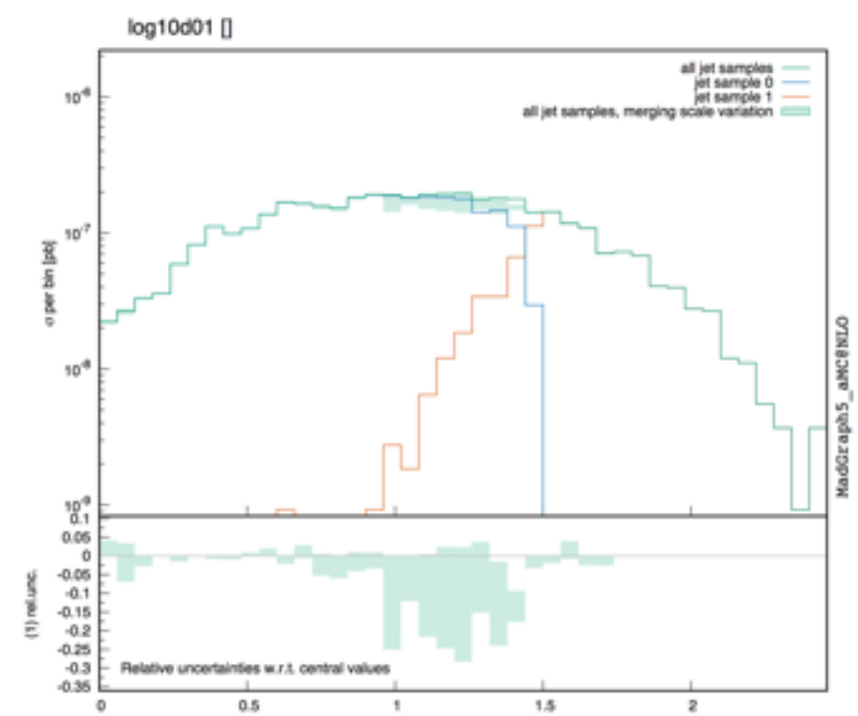
- Recent and overdue interface of PY8 to MG5aMC:

  Work from: V.H., O. Mattelaer, S. Prestel

  - Supports both MLM and CKKW-L for LO merging
  - Merging systematics computed on-the-fly
  - Parallelization of Pythia8 runs
  - Merging systematics weights propagated through HEPMC event files
  - Do-it-all Pythia8 driver.

    MLM p p > Z + {0,1}j

```
Cross-section :   1535 +- 4.319 pb
Nb of events :  10000
Pythia8 merged cross-sections are:
 > Merging scale = 10     : 653.9      +/- 1.7     [pb]
 > Merging scale = 20     : 698.42     +/- 1.7     [pb]
 > Merging scale = 30     : 712.55     +/- 1.7     [pb]
 > Merging scale = 40     : 709.02     +/- 1.7     [pb]
 > Merging scale = 50     : 706.56     +/- 1.7     [pb]
```



Automated threshold resummation

Work in progress: [P. Artoisenet, V.H., E. Laenen, F. Maltoni, L.Vernazza, P. Torrielli]

Earlier explorational work in this direction: arXiv:1507.06315 [D. Farhi, I. Feige, M. Freytsis, M. D. Schwartz]

- Earlier work for automated resummation in the programs:

  CAESAR : arXiv:0407286, [A.Banfi, G.P. Salam, G. Zanderighi]

  GENEVA : arXiv:0801.4028, [C.W. Bauer, F. J. Tackman, J.Thaler]

- Existing partially automated NLO+NNLL results, in Mellin space, featuring:

  ttH : arXiv:1510.01914, [A.Broggio, A. Ferroglia, Ben D. Pecjak, A. Signer, Li Lin Yang]

  ttZ : arXiv:1702.00800, [A.Broggio, A. Ferroglia, G.Ossola, Ben D. Pecjak, Ray D. Sameshimab]

- Work in progress for fully automated NLO+NLL

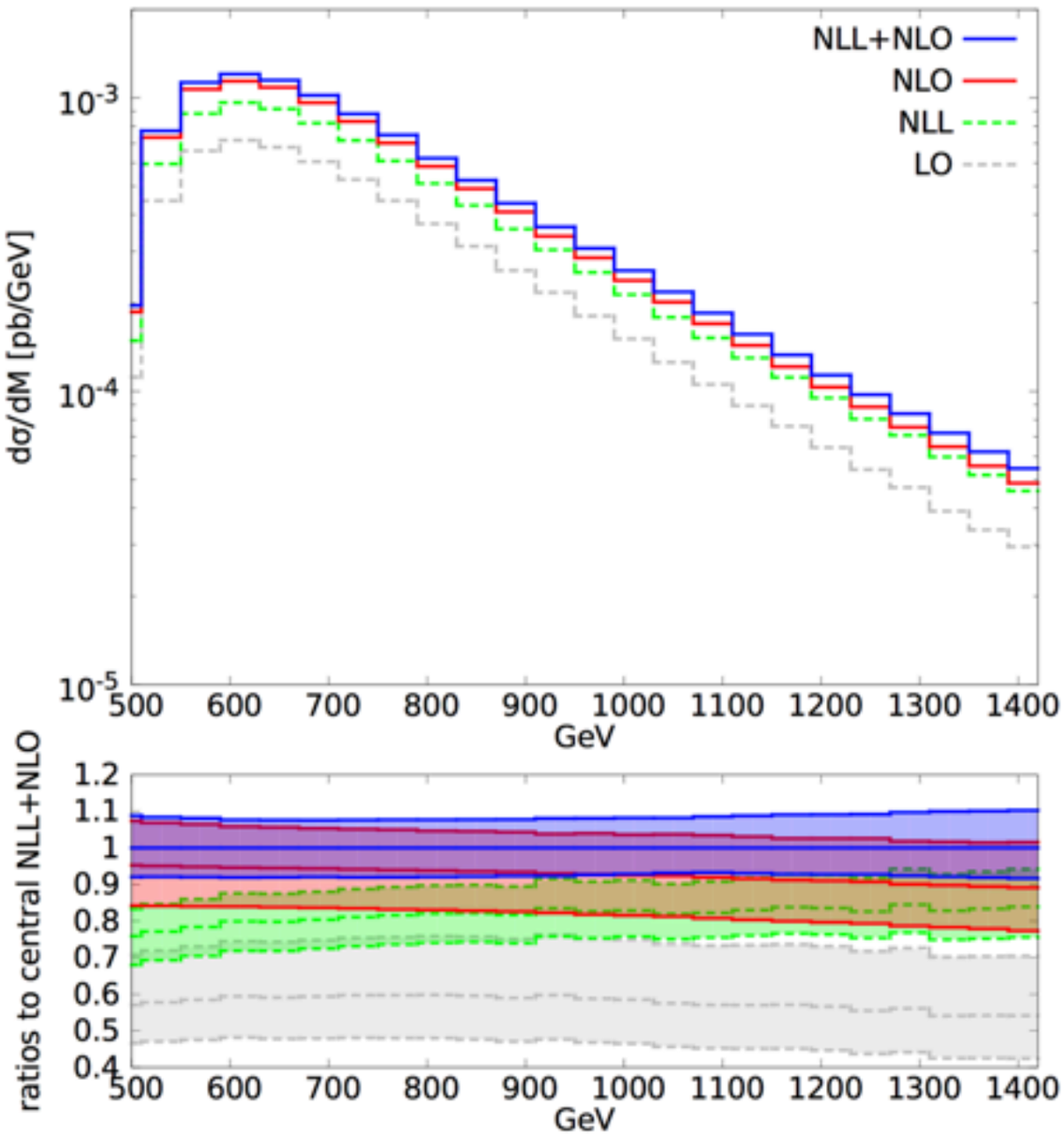
  - Applicable to **any** process with up to **two** colored **massive** final states.
  - Resums threshold logarithms in the limit: $z = \frac{M^2}{\hat{s}}, \quad \hat{s} \sim M^2 \gg \hat{s}(1-z)^2 \gg \Lambda^2_{\mathrm{QCD}}$
  - Full flexibility thanks to a reweighting approach in direct space, using SCET
  - Hard-functions extracted directly from matrix elements generated by MG5_aMC
  - Readily applicable to BSM, and arbitrary observables can be studied.
  - Usual matching prescription to fNLO: $d\sigma = d\sigma|_{\mathrm{NLL}} + (d\sigma|_{\mathrm{NLO}} - d\sigma|^{\mathrm{sub}}_{\mathrm{NLO}})$

Automated threshold resummation

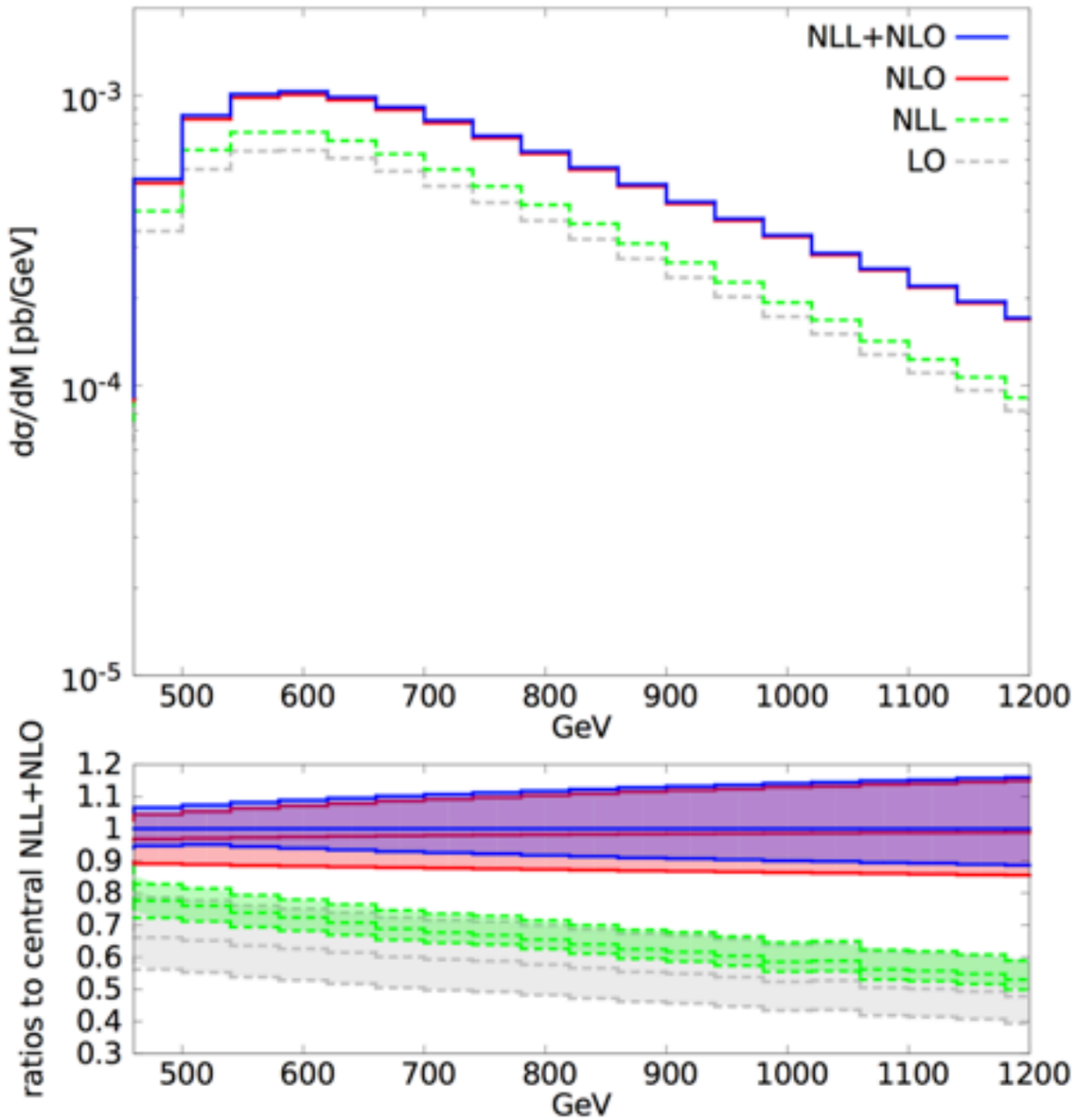
Work in progress: [P. Artoisenet, V.H., E. Laenen, F. Maltoni, L.Vernazza, P. Torrielli]

- Preliminary results @LHC13:

ttH



ttW



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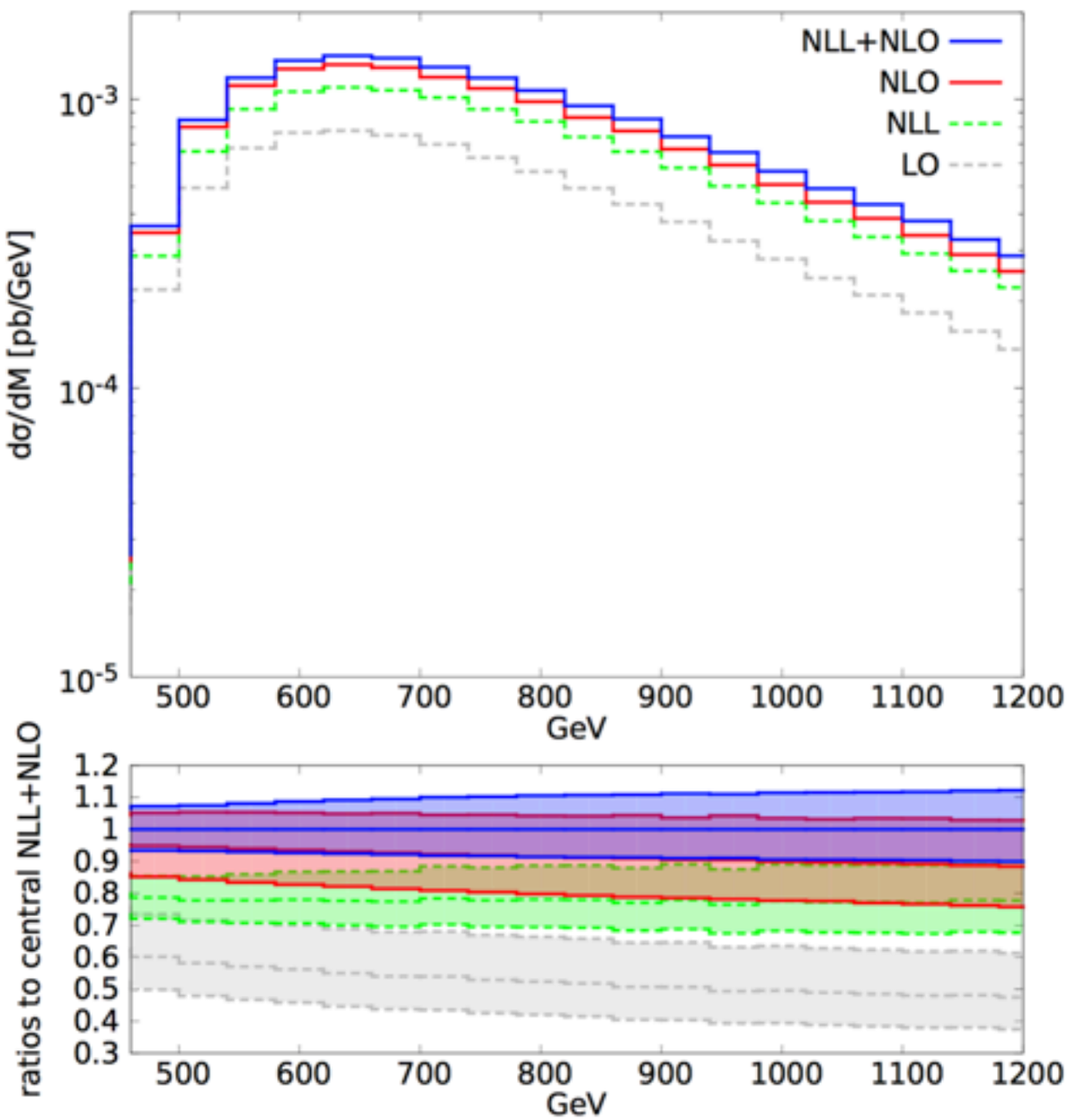

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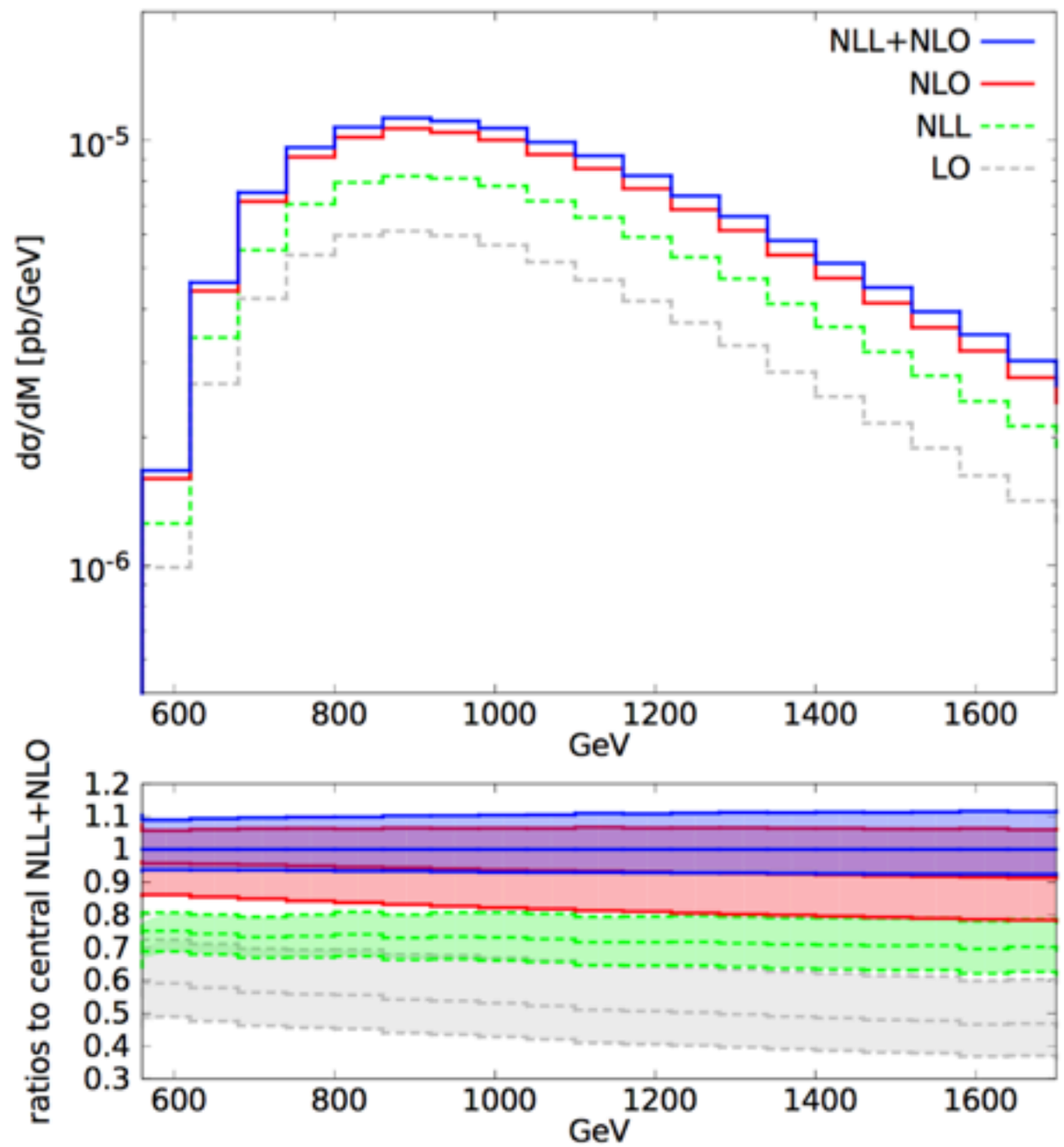
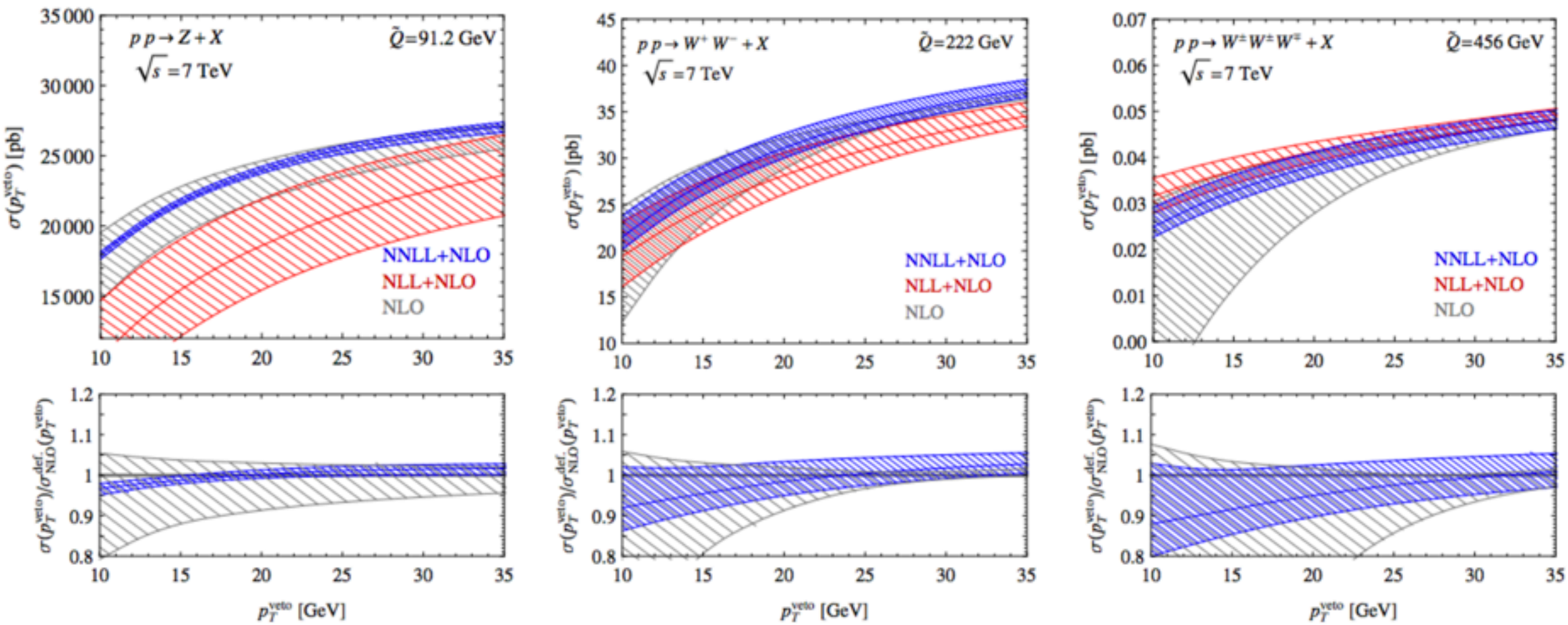


Automated jet-Veto resummation

Implemetation in MG5aMC, arXiv:1412.8408, [T.Becher, R.Frederix, M. Neubert, L.Rothen]

- Applicable to **any** with massive colorless final states
- NLO+NNLL accurate. Resums logarithms from the imposed jet veto: $log(p_T^{\rm veto}/Q)$
- SCET reweigthing approach, directly within the MG5_aMC integration framework.

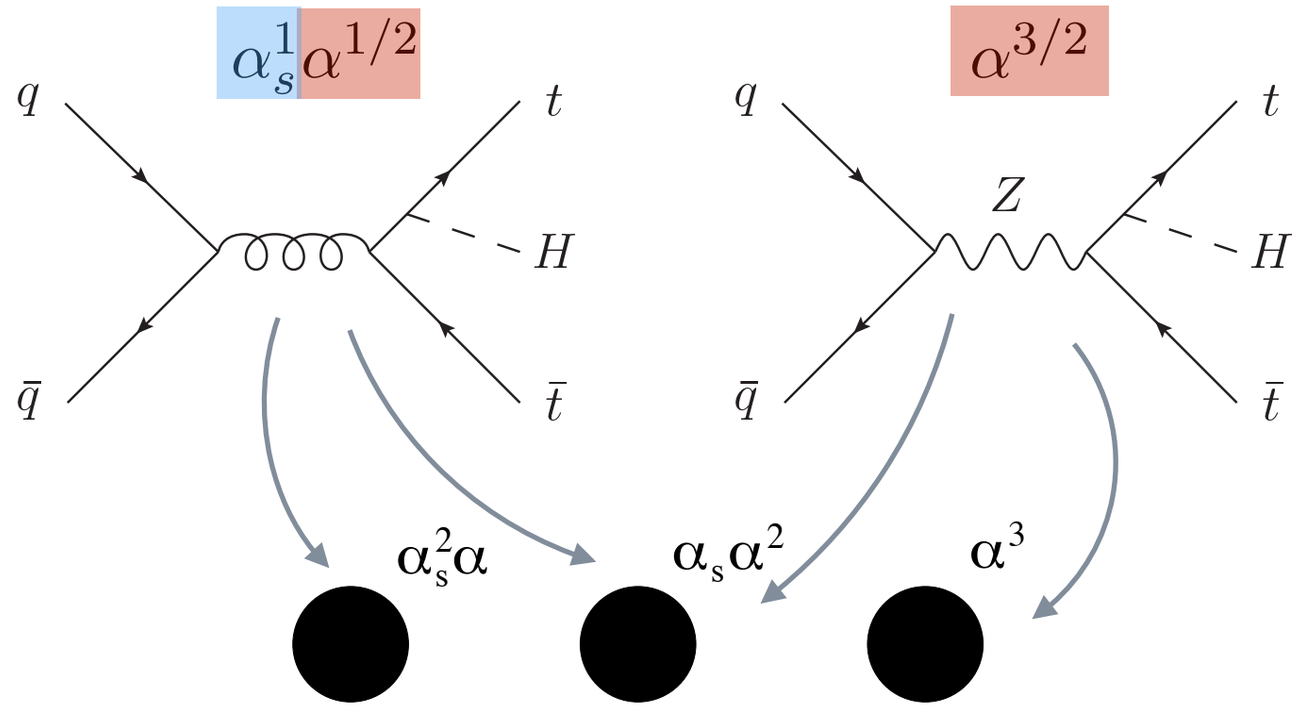


Mixed NLO QCD+EW
with
MG5_aMC

(See also recent progress made within the SHERPA+RECOLA framework
arXiv:1704.05783, [B. Biedermann, S.Bräuer, A. Denner, M. Pellen, S. Schumann, J. M. Thompson])

Structure of NLO EW-QCD corrections

The ttH case: S.Frixione, V.Hirschi, D. Pagani, H.-S. Shao, M. Zaro [arXiv:1504.03446]



LO

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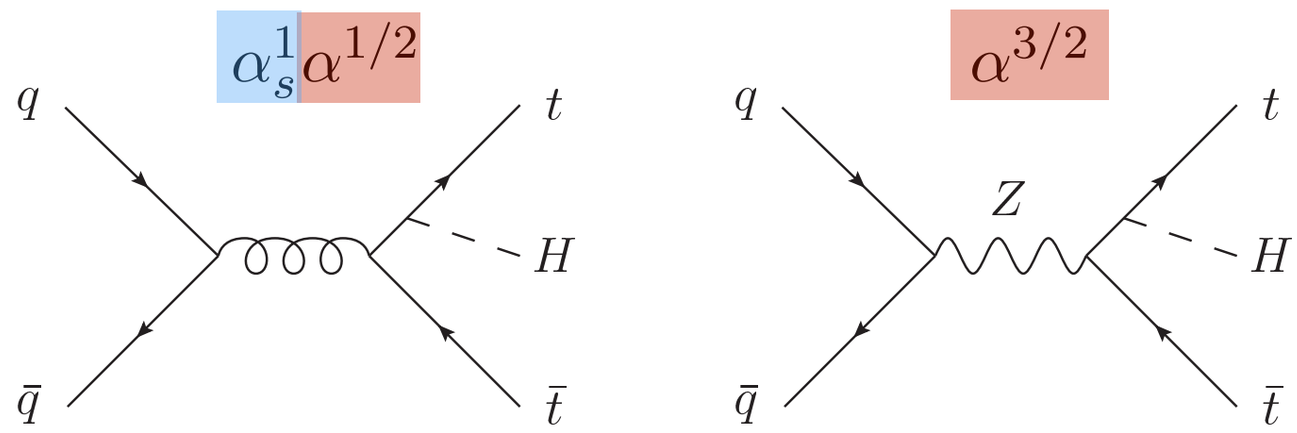

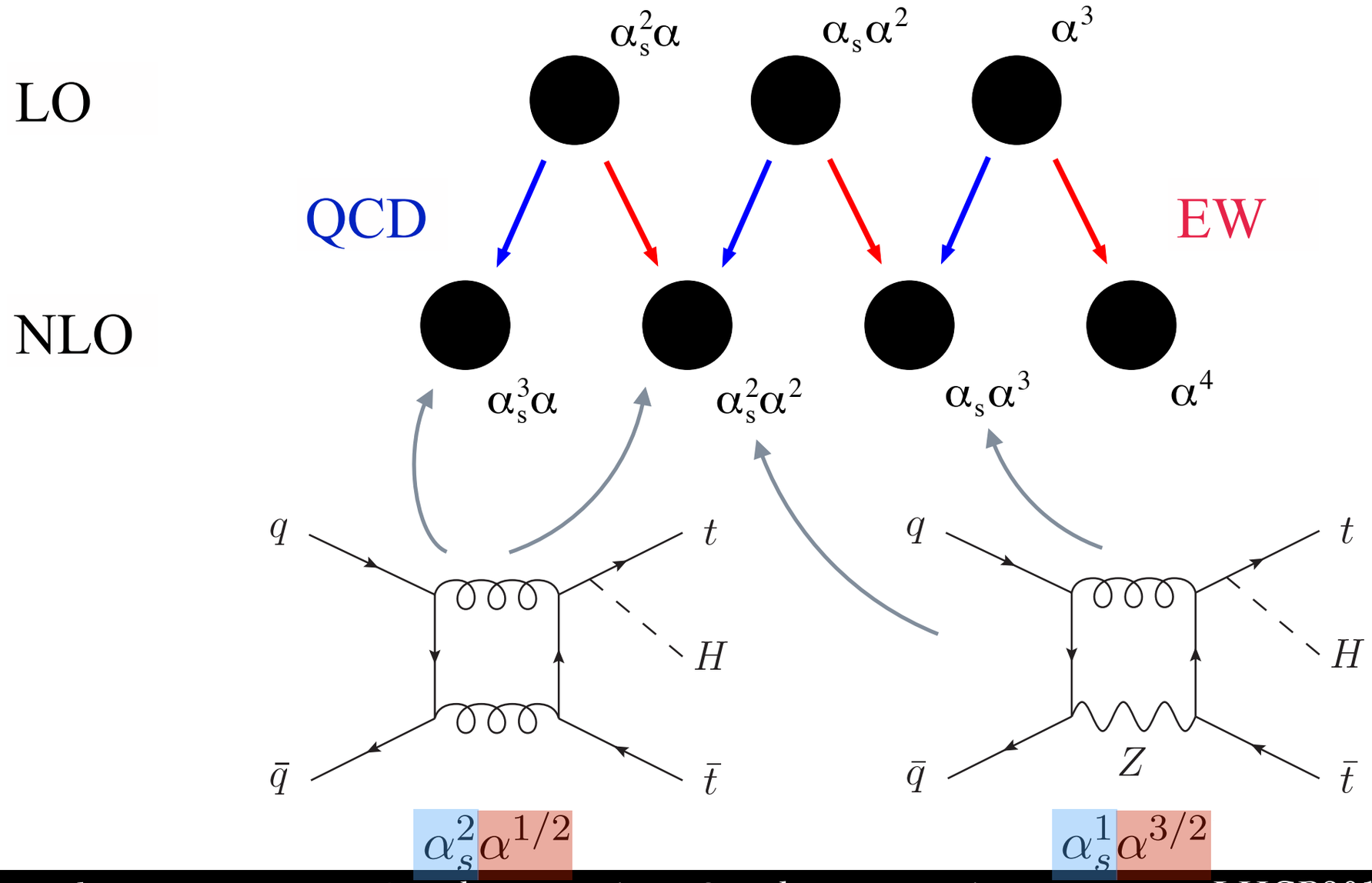

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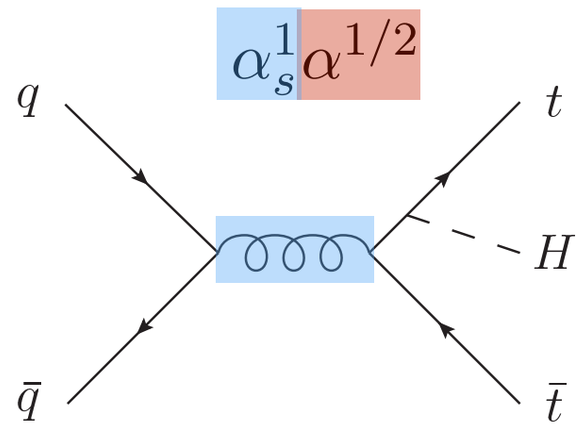
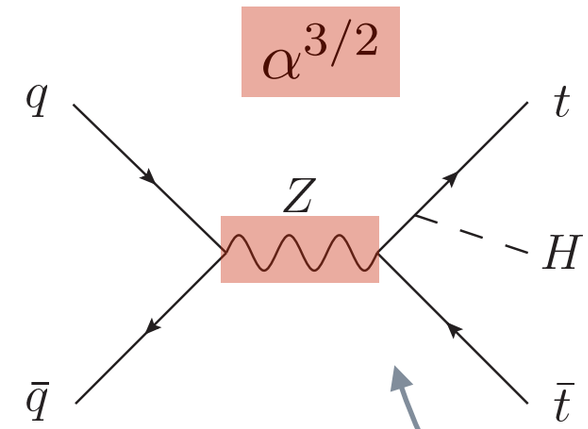
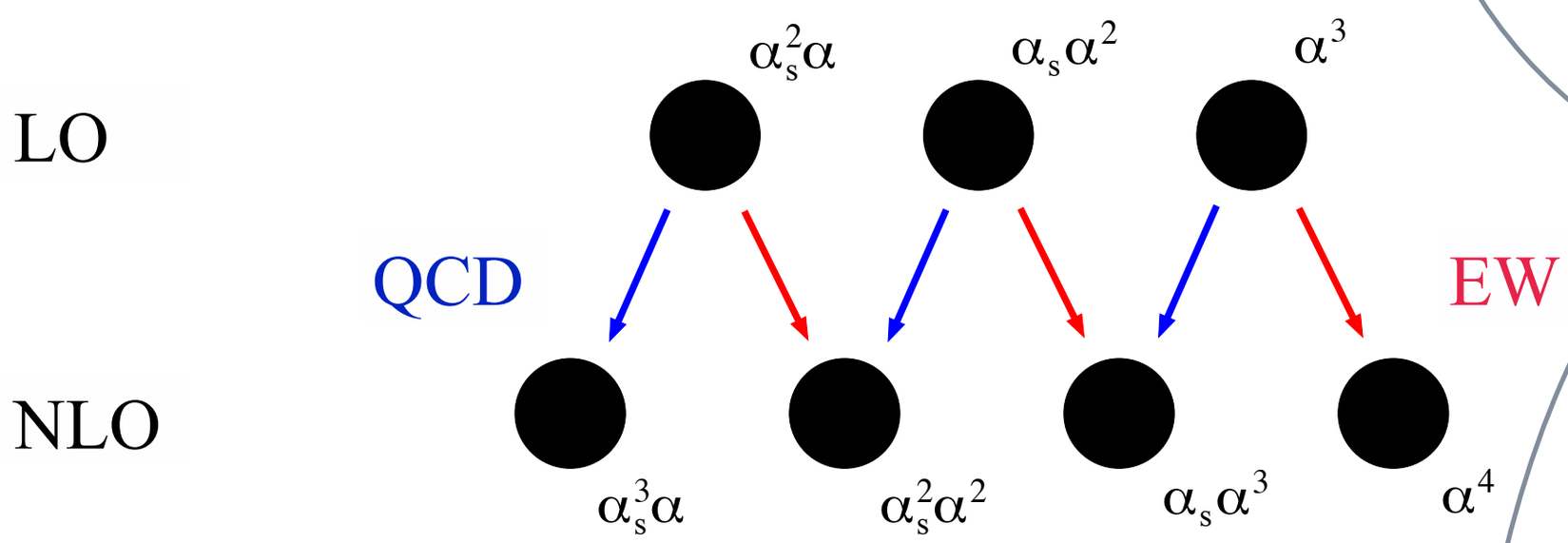
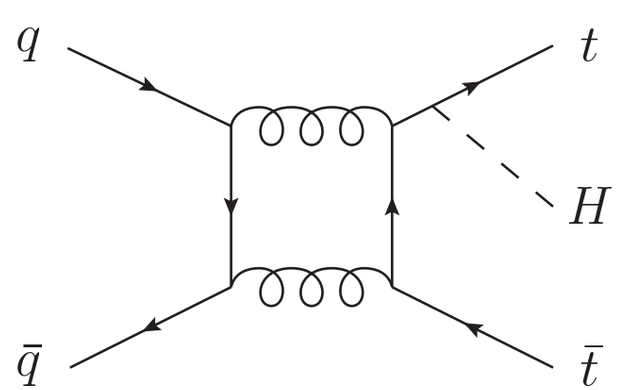


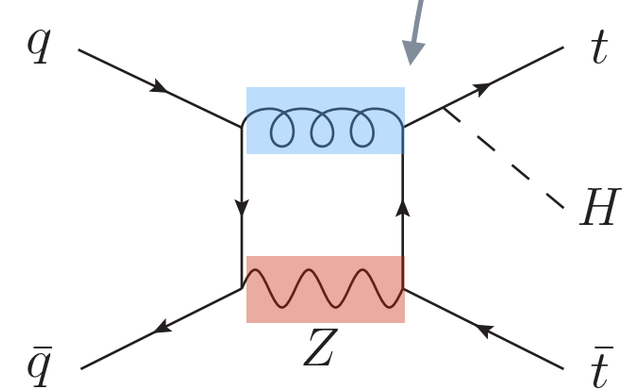




Photons lead to new IR singularities



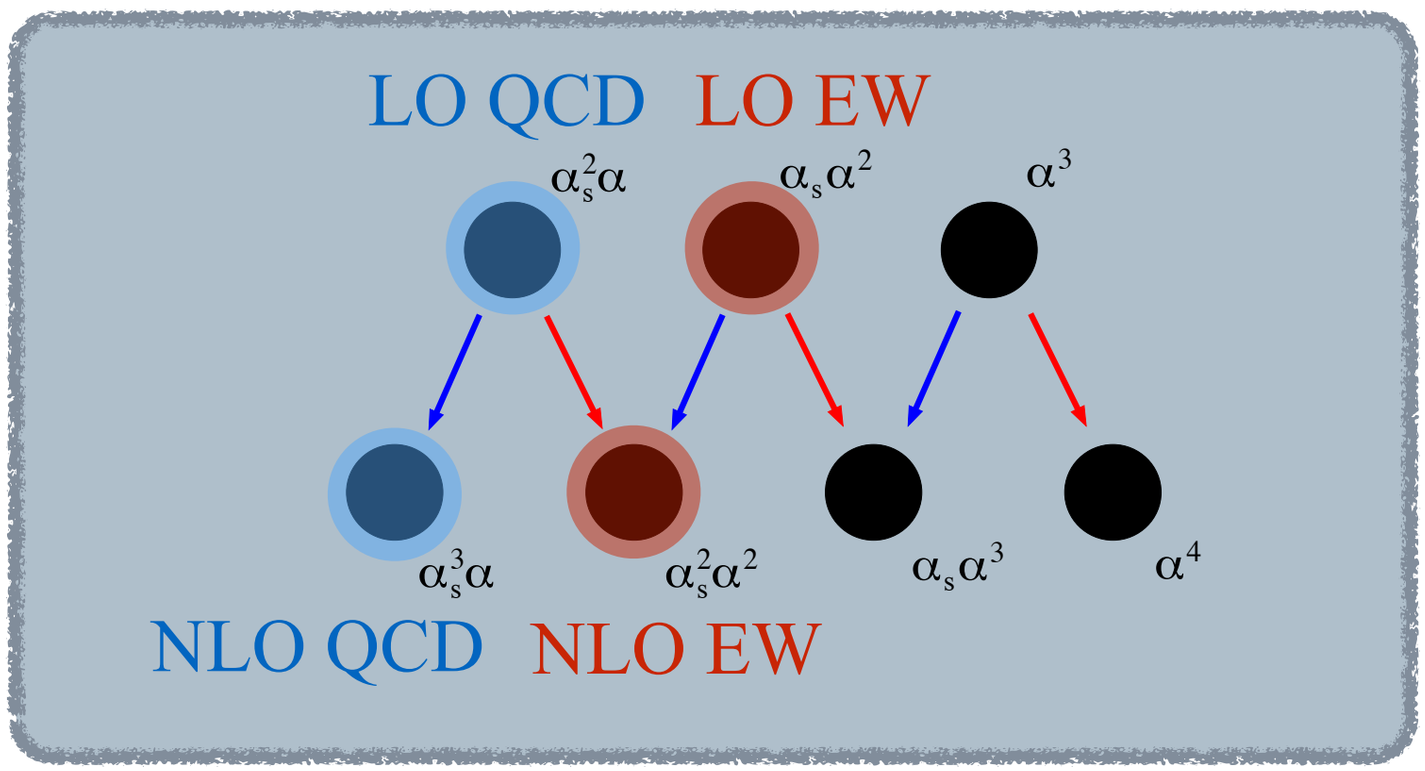
$\alpha_s^2\alpha^{1/2}$



$\alpha_s^1\alpha^{3/2}$

Automated NLO EW+QCD computations

```
MG5_aMC> define p = p b b~ a
MG5_aMC> generate p p > t t~ h [QCD QED]
MG5_aMC> output ttbarh_QCD_QED
MG5_aMC> launch
```



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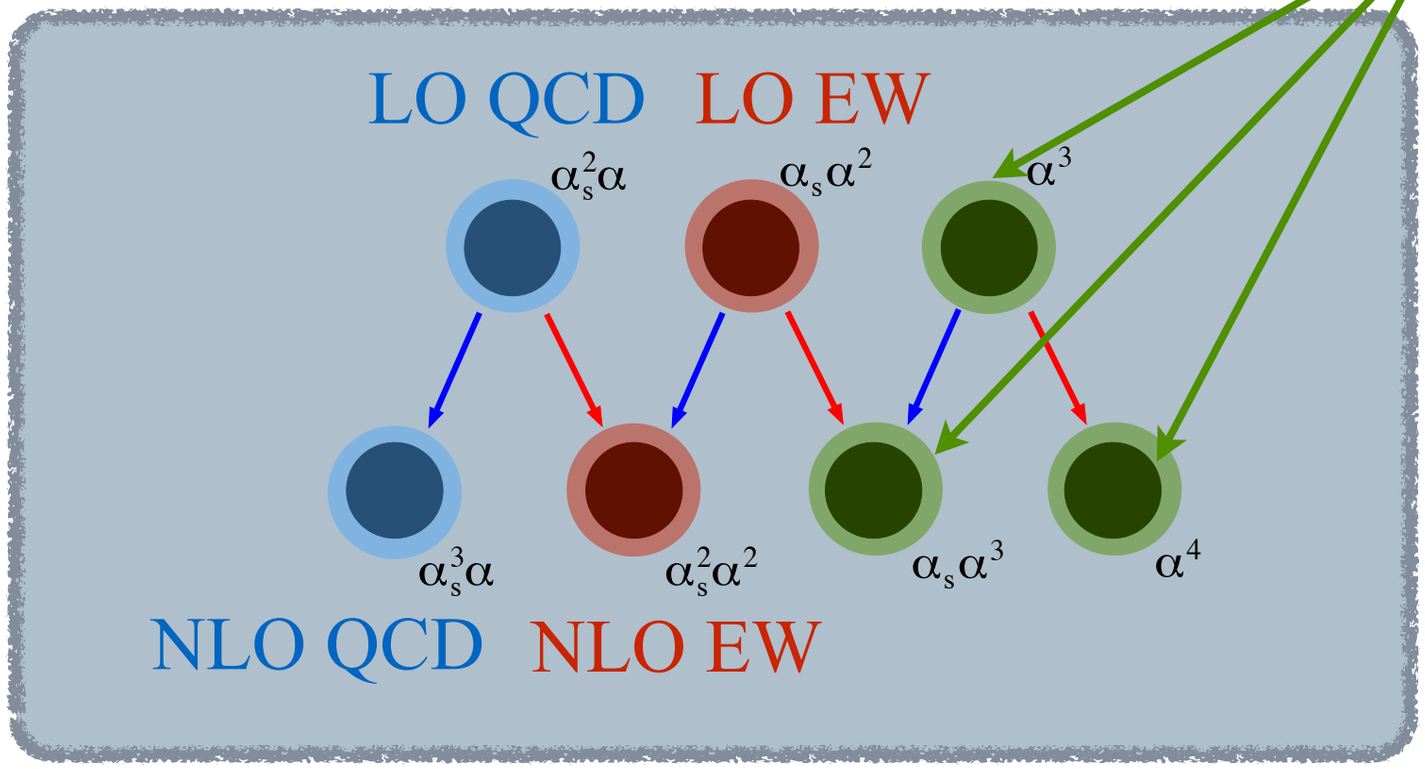
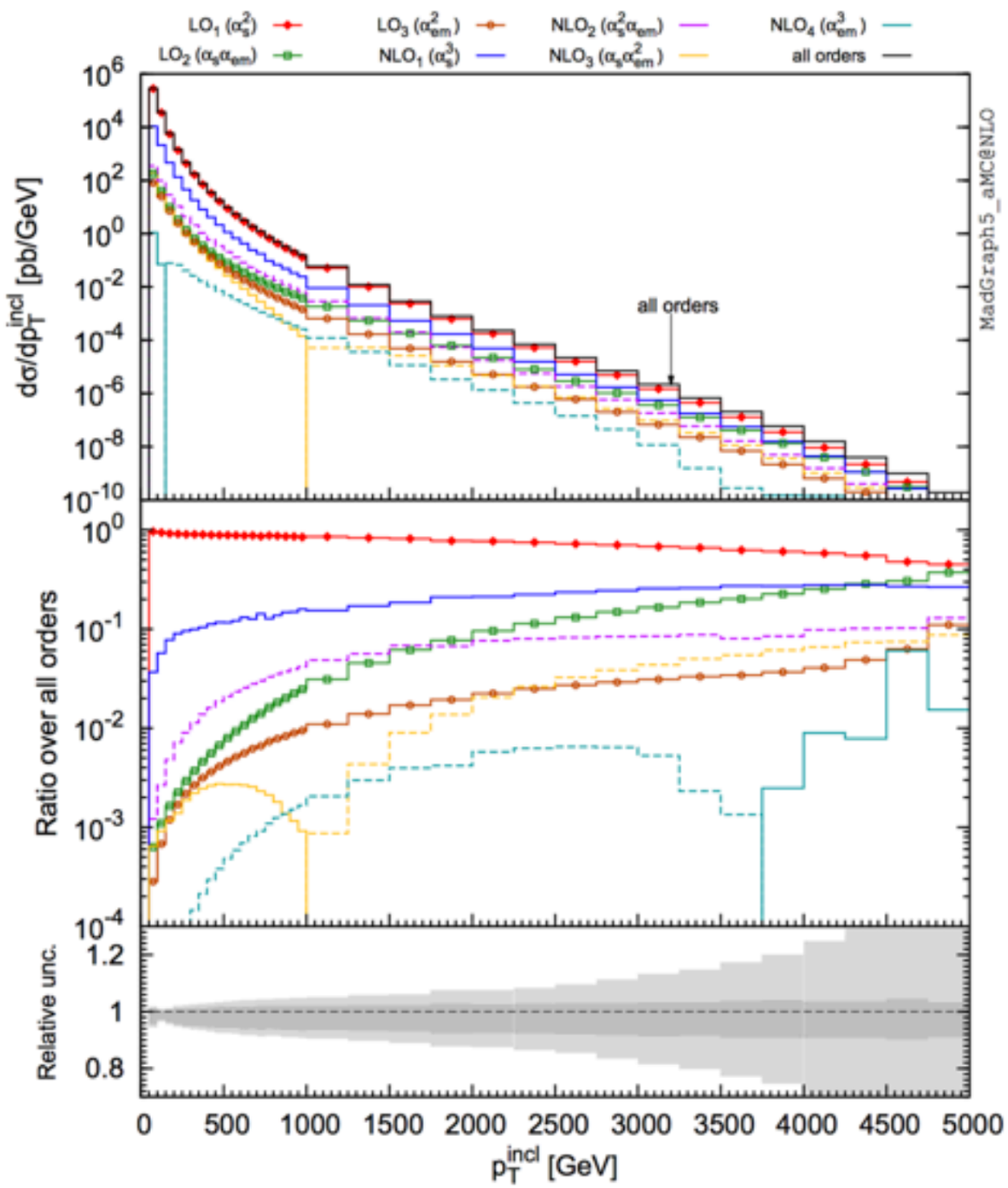
```

Next step: compute all blobs

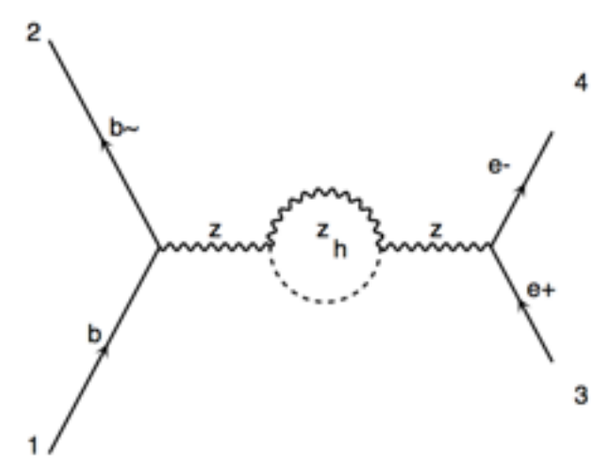


COMPLETE DIJET QCD+EW NLO CORRECTIONS

R. Frederix, S. Frixione, V. H., D. Pagani, H-S.Shao, M.Zaro [arXiv:1612.06548]



- All $\mathcal{O}(\alpha_s^m, \alpha^n), m+n=2,3$ contributions to dijet. Use G_μ-scheme
- Use democratic jets and proposed a novel definition of (anti-)tagged photons
- Necessitated large computing resources, 219 subprocesses
- Pheno conclusion: No significant Sudakov enhancement at LHC13, even at high Pt.
- This process involves the whole particle spectrum of the SM. Yes, even the Higgs!



BSM @ NLO QCD

WITH

MG5_aMC

(See also recent progress made for LO within the SHERPA framework)

arXiv:1412.647, [S. Höche, S. Kuttimalai, S. Schumann, F. Siegert]

From Lagrangian to NLO predictions

FeynRules: [A. Alloul, N. D. Christensen, C. Degrande, C. Duhr, B. Fuks , arXiv:1310.1921] , NLOCT: [C. Degrande, arXiv:1412.6955]

- UV counterterms:

  A) Automatically renormalize the lagrangian

$$\left.\begin{array}{ll} \text{Fields} & \phi_0 \to (1+\frac{1}{2}\delta Z_{\phi\phi}) + \sum_{\chi} \frac{1}{2}\delta Z_{\phi\chi}\chi \\ \text{ext. params} & x_0 \to x + \delta x \\ \text{int. params} & g(x) \to g(x+\delta x) \end{array}\right\} \quad \mathcal{L}_0 \to \mathcal{L} + \delta\mathcal{L}$$

  D) Derive and output the corresponding UV counterterms.

- R2 counterterms, necessary piece for one-loop reduction in 4D.
- Output a UFO model ready to be imported by many MC generators.
- Many BSM NLO predictions and UFO models already available:

  http://feynrules.irmp.ucl.ac.be/wiki/NLOModels

  Spin-2 simplified model, Vector-like quarks, Higgs-characterization, 2HDM, Simplified dark matter models, SUSY-QCD, etc...

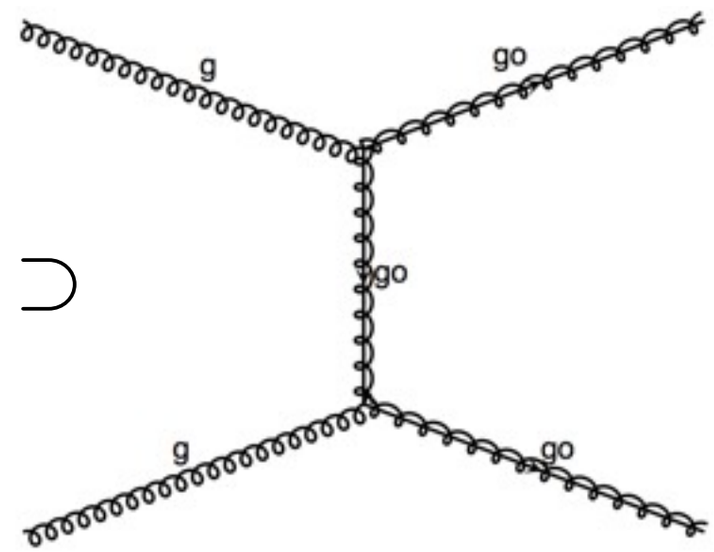
Towards full MSSM@NLO

SUSY QCD for the QCD sector only is already available in
C. Degrande, B. Fuks, V. H., J. Proudom, H-S.Shao [arXiv:1510.00391]

- Gluinos pair production...

$$\mathcal{L}_{\text{SQCD}} = D_\mu \tilde{q}_L^\dagger D^\mu \tilde{q}_L + D_\mu \tilde{q}_R^\dagger D^\mu \tilde{q}_R + \frac{i}{2}\bar{\tilde{g}} \not{D} \tilde{g}$$
$$- m_{\tilde{q}_L}^2 \tilde{q}_L^\dagger \tilde{q}_L - m_{\tilde{q}_R}^2 \tilde{q}_R^\dagger \tilde{q}_R - \frac{1}{2} m_{\tilde{g}} \bar{\tilde{g}} \tilde{g}$$
$$+ \sqrt{2} g_s \Big[- \tilde{q}_L^\dagger T (\bar{\tilde{g}} P_L q) + (\bar{q} P_L \tilde{g}) T \tilde{q}_R + \text{h.c.} \Big]$$
$$- \frac{g_s^2}{2} \Big[\tilde{q}_R^\dagger T \tilde{q}_R - \tilde{q}_L^\dagger T \tilde{q}_L \Big] \Big[\tilde{q}_R^\dagger T \tilde{q}_R - \tilde{q}_L^\dagger T \tilde{q}_L \Big]$$

$\supset$

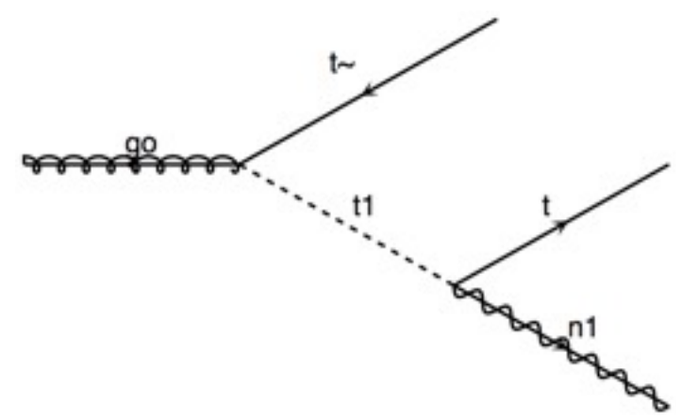


$\otimes$

- ... including the squark decay.

$$\mathcal{L}_{\text{decay}} = \frac{i}{2} \bar{\chi} \not{\partial} \chi - \frac{1}{2} m_\chi \bar{\chi} \chi$$
$$+ \sqrt{2} g' \Big[- \tilde{q}_L^\dagger Y_q (\bar{\chi} P_L q) + (\bar{q} P_L \chi) Y_q \tilde{q}_R + \text{h.c.} \Big]$$

$\supset$



Majorana flow, top quark mixing matrix renorm, SUSY restoring CT: Solved.

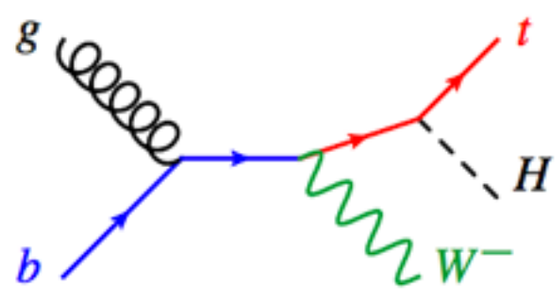
Towards complete SUSY Model for NLO

[work in progress] S. Frixione, B. Fuks, V. H., K. Mawatari, H-S. Shao, M. Zaro

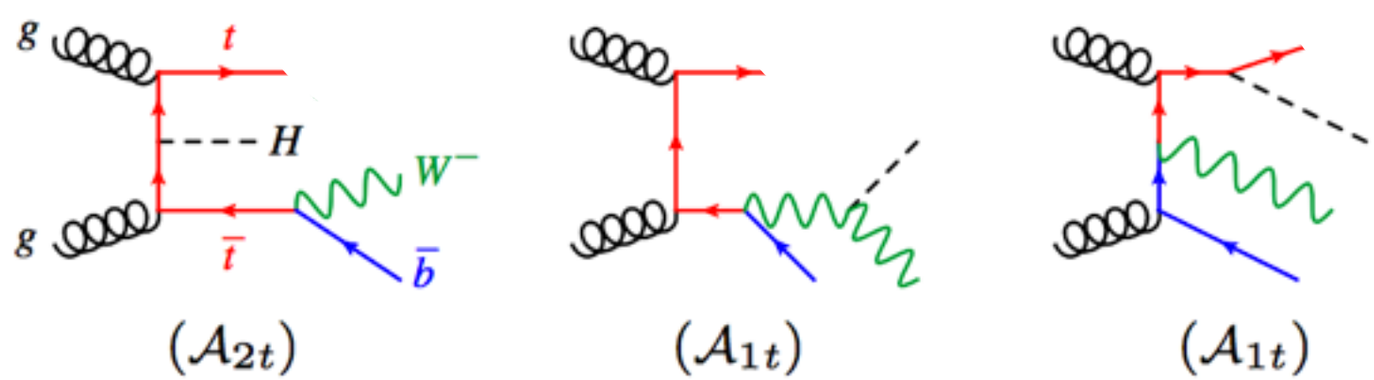
- Requires improvements in NLOCT and further validation of the complex mass scheme.
- A key component here is Onshell-Subtraction (OS) in aMC@NLO, which is now available, and was introduced in

F. Demartin, B. Maier, F. Maltoni, K. Mawatari, M. Zaro [arXiv:1607.05862]

LO ⊃



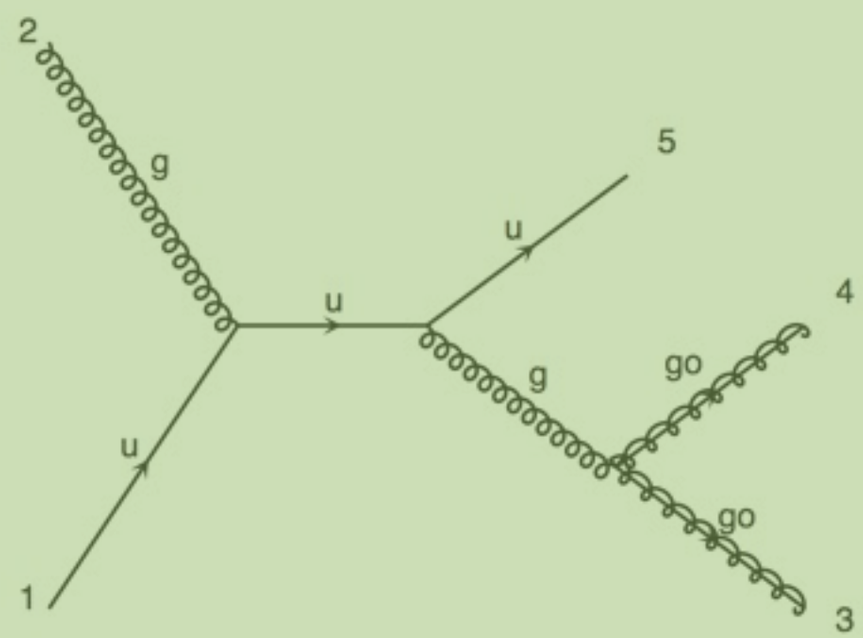
NLO (reals) ⊃



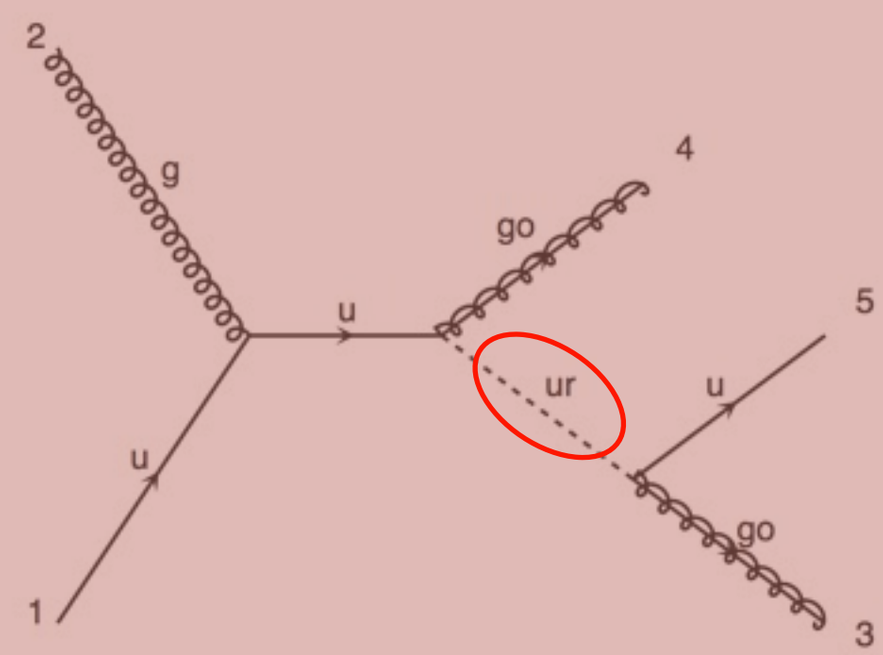
✗ ✓ ✓

Onshell subtraction for SUSY

Similar problem occurring in, e.g. $pp \to \tilde{g}\tilde{g}$



O.K, this is a legitimate QCD correction to the original Born process definition.



NO, this is simply the process $pp \to \tilde{g}\tilde{u}_R$ in disguise, Should be removed.

Plugins in MG5aMC

Structure developed by O.Mattelaer

https://cp3.irmp.ucl.ac.be/projects/madgraph/wiki/Plugin

MG5_aMC is a **framework** to **develop new ideas** for HEP,

Let people implement those themeselves!

- → Ideal projects for **students**
- → Dev. and maintenance **independent** from **MG5_aMC**
- → Also **authorship** of PLUGINS are more **properly credited**.
- → Flexible: can implement highly **complicated tasks:**
  Ex: MadDM, NLO+NLL resummation

Simplest plugin implementation:

```
import madgraph.interface.master_interface as \
                                master_interface

class NewInterface(master_interface.MasterCmd):

    def do_helloworld(self, line):
        """print hello world"""
        print "hello world " + line
```

→

```
./bin/mg5_aMC --mode=helloworld

MG5_aMC > helloworld LHCP2017

hello world LHCP2017
```

Conclusion

- **Resummation**
  - SCET-inspired approaches in direct-space are promising for automating the resummation of various logarithms:
    - NNLL+NLO jet veto resummation for weak bosonic final states
    - NLL+NLO threshold resummation in progress
  - Extraction of the hard-function directly from tree and loop MEs
  - Future plans include allowing for generic final states and going to NNLL
- **Monte-Carlo developments in MG5_aMC**
  - Completion of automated NLO QCD corrections in the full MSSM
  - Release and documentation of the various strategies for onshell substraction
  - Finalization of automated mixed EW+QCD NLO computations