

A glimpse at MadGolem: Automated NLO calculations @ BSM

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ITP - Universität Heidelberg



GDR Terascale meeting 2013 @ **Montpellier** - May 14th 2013

Outline

- 1 A glimpse at MadGolem: the tool from inside
- 2 A glimpse at MadGolem – the tool in use
- 3 A glimpse at MadGolem – phenomenology applications
- 4 One final glimpse

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References

♠ Based on the following publications:

BSM Phenomenology studies

- $pp \rightarrow \tilde{q}\chi$: Phys. Rev. D84 075005, arXiv:1108.1250 [hep-ph]
- $pp \rightarrow \tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$: Phys. Rev. D87 014002, 1211.0296 [hep-ph]
- $pp \rightarrow GG^*$: Phys. Rev. D85 114024, arXiv:1203.6358 [hep-ph]
- $pp \rightarrow l_8l_8$: arXiv:1303.0845 [hep-ph]

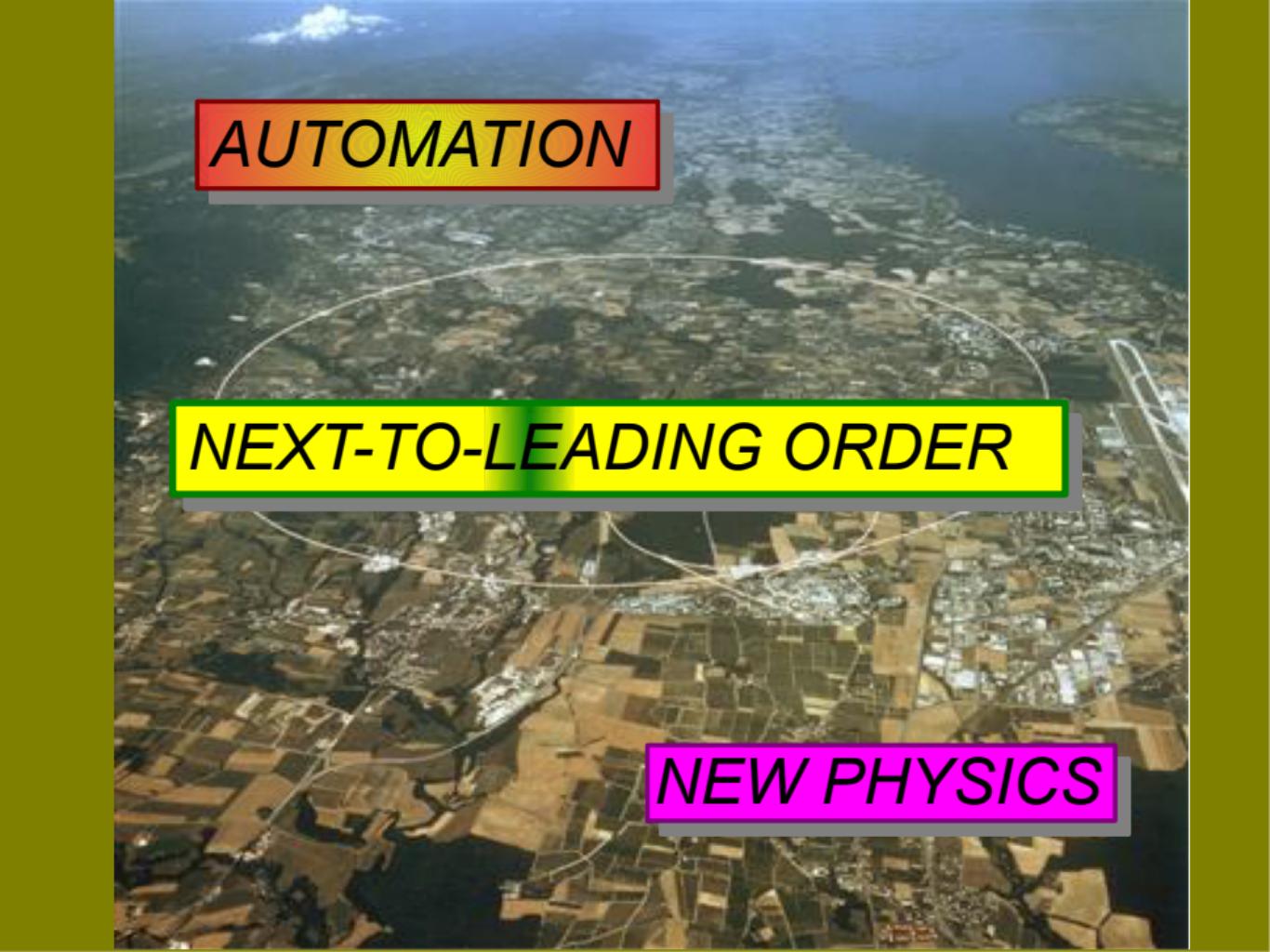
PhD Thesis

- Dorival Gonçalves Netto, *NLO predictions for new physics at the LHC*, University of Heidelberg (2013)
- Iain Wigmore, *The automated calculation of one-loop processes*, University of Edinburgh (2013)

For a brief overview cf. arXiv:1209.2797 [hep-ph]

Our aim





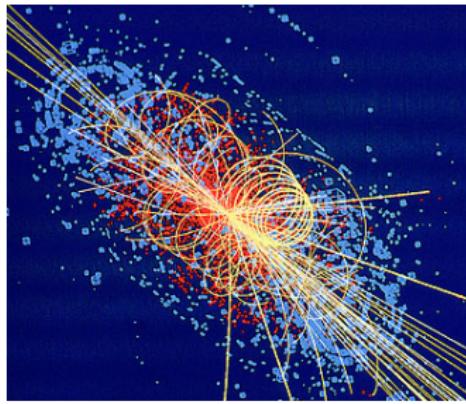
AUTOMATION

NEXT-TO-LEADING ORDER

NEW PHYSICS

MadGolem's motivations

It's about Physics



It's about Techniques



MadGolem's motivations

It's about physics ...

- Heavy colored states as a **BSM hallmark**:
 - ♠ SUSY \Rightarrow squarks&gluinos ;
 - ♠ Compositeness \Rightarrow sgluons&colorons ;
 - ♠ Extra dim. \Rightarrow KK gluons ;
- QCD corrections quantitatively relevant : $K \sim 1.5$
- QCD corrections qualitatively relevant: scale dependence, kinematics. . .

MadGolem's motivations

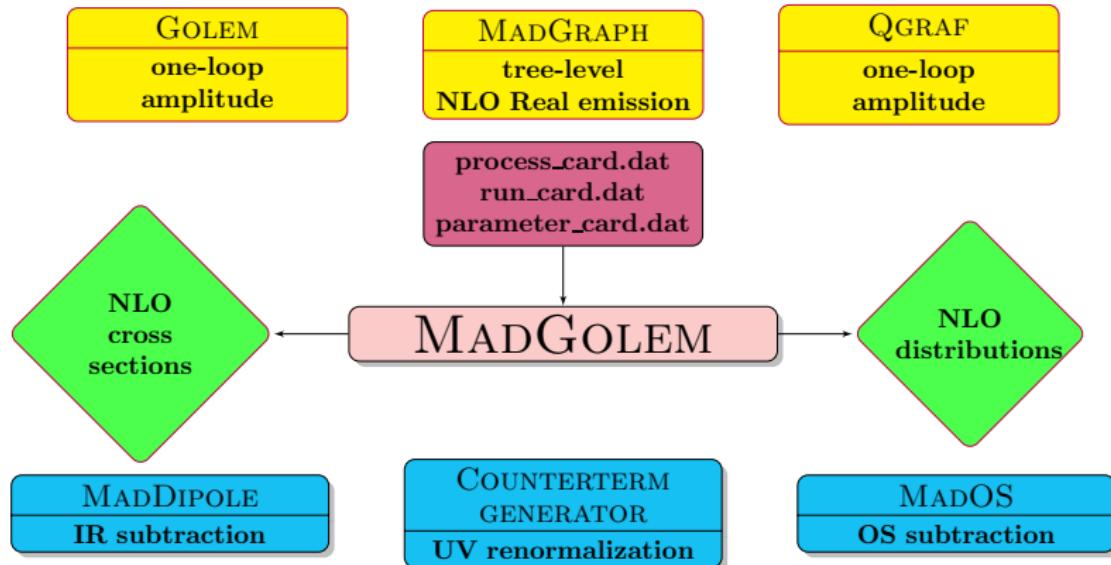
It's about physics ...

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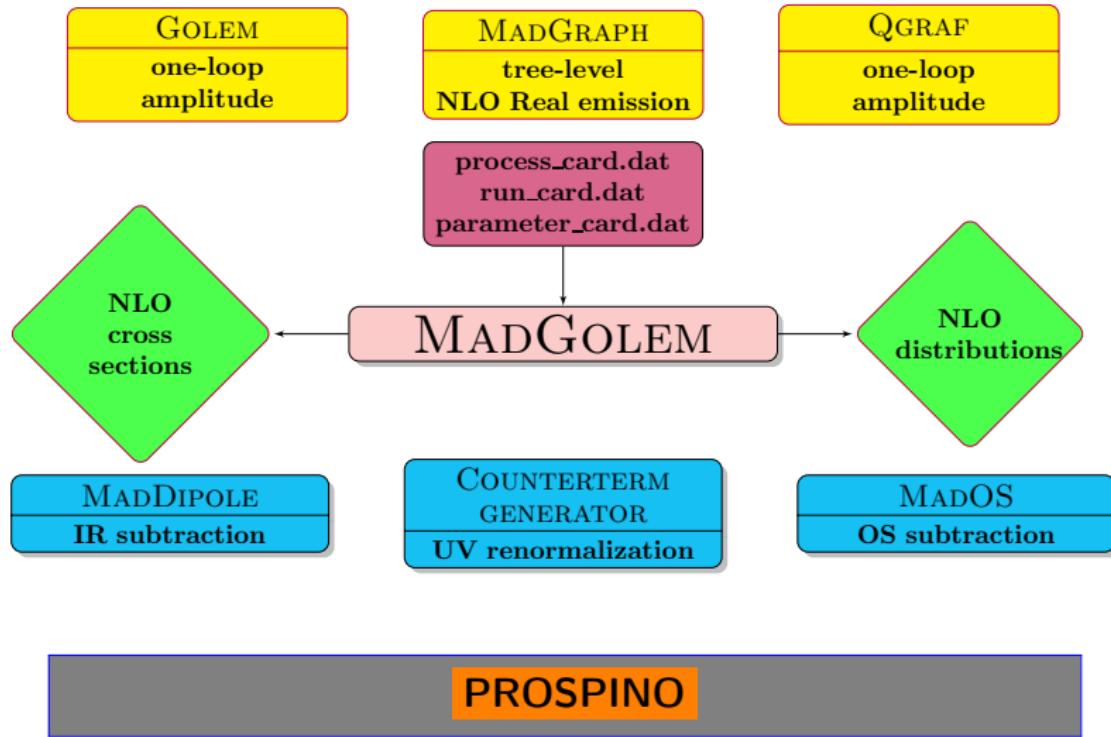
... and about **techniques** !

- Many models & processes \leftrightarrow analogue technical challenges
- Cost & time saving, robustness, accessibility, validation, EXP-TH interchange:
MadGolem; MadLoop/MG5 [Hirsch et al., arXiv:1103.0621]; GoSam [Cullen et al., arXiv:1111.2034]; HELAC-NLO [Bevilacqua et al., arXiv:1007.4918]; aMC@NLO [Frederix et al. arXiv:1104.5613]

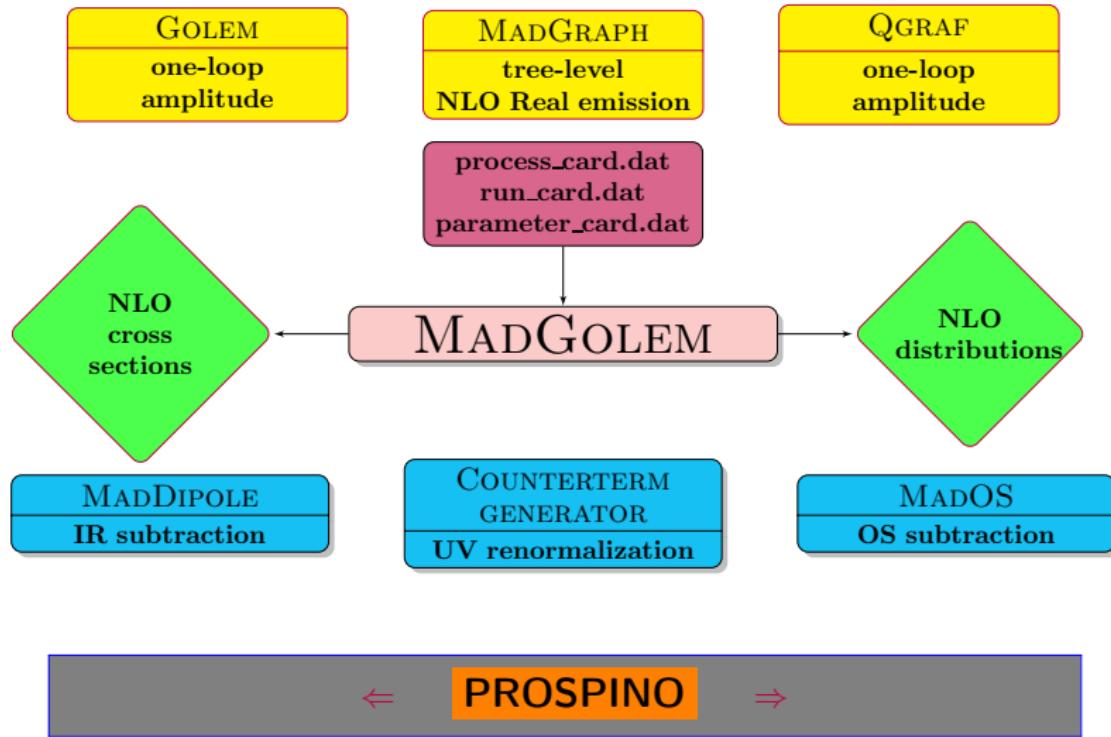
MadGolem's architecture: modules and flowchart



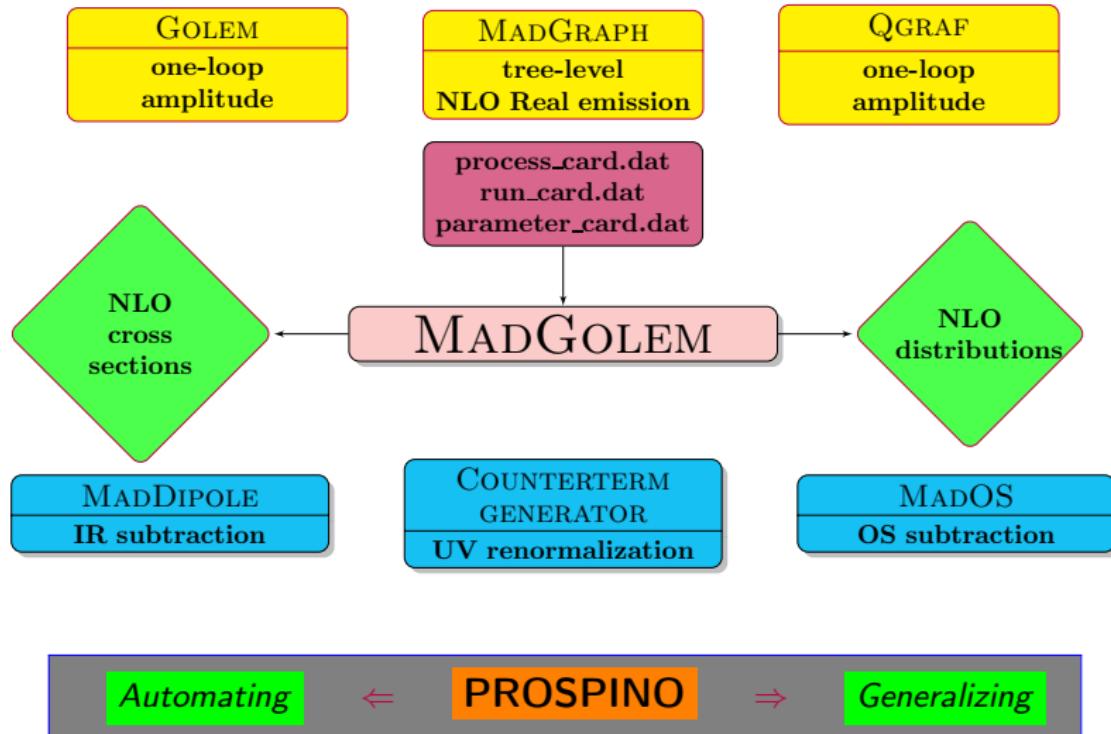
MadGolem's architecture: modules and flowchart



MadGolem's architecture: modules and flowchart



MadGolem's architecture: modules and flowchart



Handling the loops

Handling the loops



Handling the loops



GENERATION



Qgraph

[Nogueira]

Model files

FORTRAN

Feynman diagrams

Handling the loops



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TRANSLATION



Qgraf-Golem

Feynman diagrams

BASH,PERL,FORM

Amplitude

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CALCULATION



Golem [Binoth et al.]

Amplitude

BASH,PERL,FORM,MAPLE

Reduced amplitude

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CALCULATION



Golem [Binoth et al.]

Amplitude

Reduced amplitude

$$\mathcal{M}^{\text{NLO}} = \underbrace{\mathcal{M}_{[\text{color}/\text{helicity}/\text{1L-function}]}_{\text{partial amplitudes}}} \times \underbrace{\mathcal{B}_{\text{color}} \otimes \mathcal{B}_{\text{hel}} \otimes \mathcal{B}_{\text{1Lfunction}}}_{\text{basis}}$$

Tailoring the tool 4BSM phenomenology

♠ *Analytical results accessible at any time*

♠ *Dedicated coding: efficient generation & numerical evaluation*

- Loop filtering – Automatic removal of vanishing partial amplitudes from further analytical processing
- Grouping of topologically equivalent one-loop diagrams
- Handling of iterative structures
- Amplitude coefficients as split dynamic libraries loaded at runtime

♠ *Genuine New Physics structures treatable*

- Majorana fermions (clashing arrows !)
- complex color & spin structures

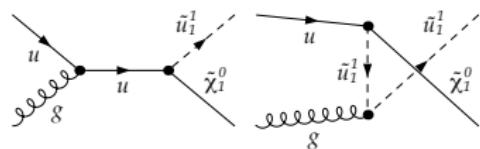
♠ *Most easily interfaced with MG tools : FeynRules, MadAnalysis, ...*

Handling the loops

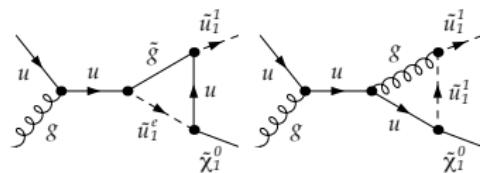
But everything diverges @ NLO !!



...but everything diverges @ NLO !!



tree-level

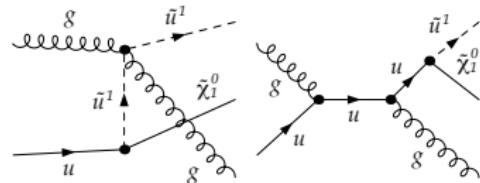


virtual corrections $\mathcal{O}(\alpha_{ew} \alpha_s^2)$



MSSM renormalization

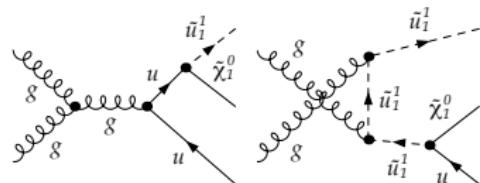
& SUSY-restoration



real corrections $\mathcal{O}(\alpha_{ew} \alpha_s^2)$



ii , fi & if dipoles



OS divergent real corrections $\mathcal{O}(\alpha_{ew} \alpha_s^2)$



OS subtraction

Handling the divergences

UV divergences & Renormalization



Counter terms \Rightarrow tree-level diagrams + $\underbrace{\mathcal{O}(\alpha_s) \text{ 2-point functions}}$

Handling the divergences

UV divergences & Renormalization



Counter terms \Rightarrow tree-level diagrams + $\underbrace{\mathcal{O}(\alpha_s) \text{ 2-point functions}}_{\delta Z_{g_s}, \delta Z_\psi \sim \Sigma_\psi}$



Handling the divergences

UV divergences & Renormalization

- ♣ Counter terms \Rightarrow tree-level diagrams + $\underbrace{\mathcal{O}(\alpha_s) \text{ 2-point functions}}_{\delta Z_{g_s}, \delta Z_\psi \sim \Sigma_\psi}$
- ♣ Renormalization scheme : **masses @ OS**, **g_s @ $\overline{\text{MS}}$** with

decoupled heavy colored-states [Beenakker et al, Berge et al] & SUSY restoration.



Handling the divergences

UV divergences & Renormalization

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IR divergences

- ♣ Dipole Subtraction:
[Catani, Seymour; Catani, Dittmaier, Seymour, Trocsanyi]
- ♣ Extended **MadDipole** module [Frederix, Gehrmann, Greiner '07] for novel heavy colored particles – including α -dependence

Handling the IR divergences

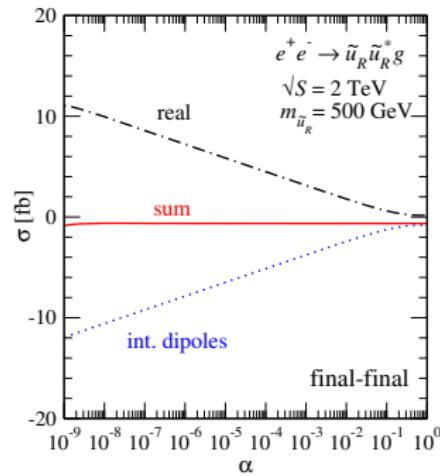
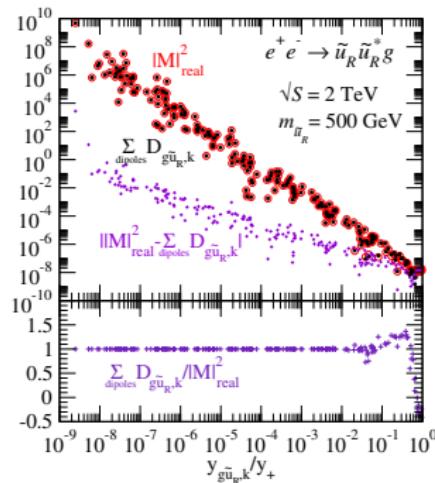
心脏病状的IR subtraction performance

- α -independent results [Nagy, Trócsányi]
- Numerically stable , robustly convergent – deep into the soft/collinear region

Handling the IR divergences

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Handling the OS Divergences

Automatized Prospino OS Subtraction [Beenakker, Höpker, Spira, Zerwas]

$$\begin{aligned} d\sigma^R &\longrightarrow \left. d\sigma^R \right]_{\text{regular}} + \left. d\sigma^{R*} \right|_{\mathcal{O}(1/(p^2 - m^2))} \\ ug \rightarrow \tilde{u}_L \tilde{\chi}_1 j &+ uu \rightarrow \tilde{u}_L \tilde{u}_L^* \rightarrow \tilde{u}_L \tilde{\chi}_1 j \end{aligned}$$

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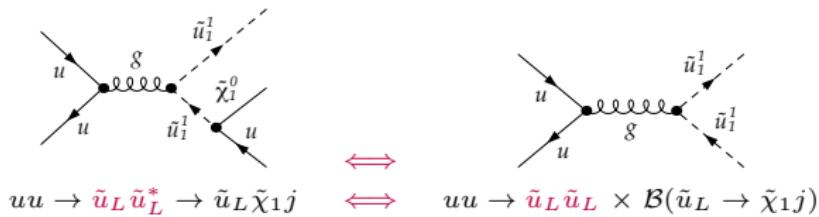
$$\sigma = \int_{m+1} d\sigma^R \longrightarrow \int_{m+1} \left[d\sigma^R + d\sigma^{R*}(\Gamma \tilde{u}_L) - d\sigma^{OS}(\Gamma \tilde{u}_L) \right]$$

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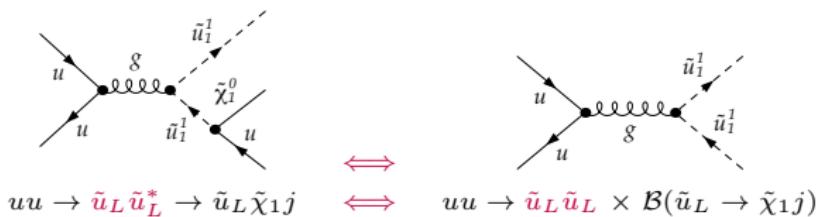


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$$\frac{d\sigma^{OS}}{dM^2} = \sigma^{Born} \frac{m_{\tilde{u}_L} \Gamma_{\tilde{u}_L}/\pi}{(M^2 - m_{\tilde{u}_L}^2) + m^2 \Gamma_{\tilde{u}_L}^2} + \mathcal{O}\left(\frac{1}{(M^2 - m_{\tilde{u}_L}^2)}\right)$$

- Pointwise subtraction of the OS poles – analogue to CS dipoles
- Avoids double-counting & preserves gauge invariance & spin correlations
- $\Gamma_{\tilde{u}_L}$ as regulator \Rightarrow dependence cancels in the final results

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Running MadGolem

3-stage procedure – 3 interfaces ↔ 3 executables

Stage 1: PROCESS GENERATION

process_card ↔ ./newprocess_snlo

Running MadGolem

```

lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cp -r Template_nlo/ stop-pair
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cd stop-pair/
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>./bin/newprocess_snlo
Running....
.....tar cf madevent.tar Cards HTML SubProcesses bin lib Source Events index.html README
eVersion.txt MGMEVersion.txt
rm -f madevent.tar.gz
gzip madevent.tar
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>cd SubProcesses/
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/SubProcesses>l
addintegral_driver.f finitermsusy.f      MGVersion.txt      projection.f
addmothers.f     fort.28      minputdipoleqd.mg    python_data.txt
alphas_bsm.f     fort.37      myamp.f          qgraf_golem.sty
auto_dsig.f      fort.71      onshellsum.f      qgraf_model
check_dip.f      genps.f      onshellsum_tmp.f  qgraf_model_counterterms
check_dip_qed.f  genps.inc@ P0_gg_tltlx/      qgraf_model_hdim
check_intdip.f   getpdf.f     P0_uux_tltlx/    qgraf_model_loop
check_sa.f       golem_input.dat P0_uxu_tltlx/   randinit
cluster.f        initcluster.f P1_gg_tltlx/    reweight.f
cluster.inc      interactions.dat@ P1_uux_tltlx/   run.inc
coloredparticles.dat interactions-qgraf.dat@ P1_uxu_tltlx/  run.inc.bak@
coupl.inc@       myfile      P2_gg_tltlxg/   selfenergy_ct.dat@
cuts.f          myfile_dip   P2_gu_tltlxu/  setcuts.f
cuts.f-def      myfile_dip_qed P2_gux_tltlxu/ setscales.f
cuts.inc@       myfile_dlhapdf P2_ug_tltlxu/ shrinktops.f
dbook.f         myfile_dynamic P2_uux_tltlxg/ status
dbook.inc       myfile_lhapdf  P2_uxg_tltlxu/ subproc.mg
dipole.inc      myfile_lo_vegas P2_uxu_tltlxg/ subproc.txt
dipole.inc-def  myfile_mo    P3_gg_tltlxg/  sudakov.inc

```

The screenshot shows a terminal window with a blue border. The command history at the top includes:

- `lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cp -r Template_nlo/ stop-pair`
- `lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cd stop-pair/`
- `lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>./bin/newprocess_snlo`
- `Running....`

Below this, the terminal lists files in the current directory, grouped by extension and type. The output is color-coded: green for Fortran files, cyan for C/C++ files, and blue for other files like XML and Python scripts.

Running MadGolem

File Edit View Scrollback Bookmarks Settings Help

GNU nano 2.2.4 File: Cards/proc_card.dat lin50c :

```

pp>tltl~    @0 # for LO
QCD=99      # Max QCD couplings
QED=0       # Max QED couplings
HDIM=0      # Max effective higher dimensional couplings
end_coup   # End the couplings input

pp>tltl~    @1 # for NLO (tree-level squared)
QCD=99      # Max QCD couplings
QED=0       # Max QED couplings
HDIM=0      # Max effective higher dimensional couplings
end_coup   # End the couplings input

pp>tltl~j   @2 # for NLO (virtual+integrated-dipole)
QCD=99      # Max QCD couplings
QED=0       # Max QED couplings
HDIM=0      # Max effective higher dimensional couplings
end_coup   # End the couplings input

pp>tltl~j   @3 # for NLO (unintegrated-dipole)
QCD=99      # Max QCD couplings
QED=0       # Max QED couplings
HDIM=0      # Max effective higher dimensional couplings
end_coup   # End the couplings input

done        # this tells MG there are no more procs

# End PROCESS # This is TAG. Do not modify this line
#####
# Model information +
#####
# Begin MODEL # This is TAG. Do not modify this line
mssm_nlo
# End MODEL # This is TAG. Do not modify this line

```

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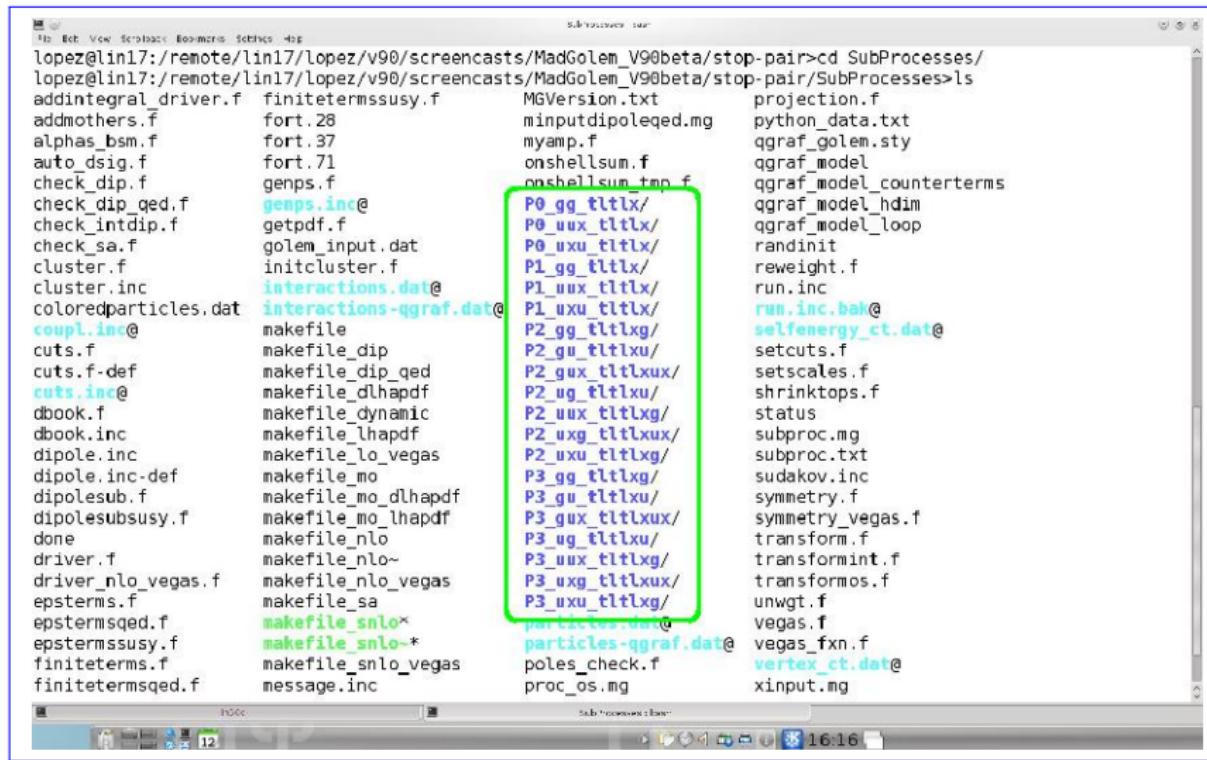
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lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cp -r Template_nlo/ stop-pair
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta>cd stop-pair/
Lopez@Lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>./bin/newprocess_nlo
Running...
.....tar cf madevent.tar Cards HTML SubProcesses bin lib Source Events index.html README
eVersion.txt MGMEVersion.txt
rm -f madevent.tar.gz
gzip madevent.tar
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>cd SubProcesses/
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/SubProcesses>ls
addintegral_driver.f finitermsusy.f MGVersion.txt projection.f
addmothers.f fort.28 minputdipoleqd.mg python_data.txt
alphas_bsm.f fort.37 myamp.f qgraf_golem.sty
auto_dsig.f fort.71 onshellsum.f qgraf_model
check_dip.f genps.f onshellsum_tmp.f qgraf_model_counterterms
check_dip_qed.f genps.inc@ P0_gg_tltlx/ qgraf_model_hdim
check_intdip.f getpdf.f P0_uux_tltlx/ qgraf_model_loop
check_sa.f golem_input.dat P0_uxu_tltlx/ randinit
cluster.f initcluster.f P1_gg_tltlx/ reweight.f
cluster.inc interactions.dat@ P1_uux_tltlx/ run.inc
coloredparticles.dat interactions-qgraf.dat@ P1_uxu_tltlx/ run.inc.bak@
coupl.inc@ makefile P2_gg_tltlxg/ selfenergy_ct.dat@
cuts.f makefile_dip P2_gu_tltlx/ setcuts.f
cuts.f-def makefile_dip_qed P2_gux_tltlxux/ setscales.f
cuts.inc@ makefile_dlhapdf P2_ug_tltlxu/ shrinktops.f
dbook.f makefile_dynamic P2_uux_tltlxg/ status
dbook.inc makefile_lhapdf P2_uxg_tltlxux/ subproc.mg
dipole.inc makefile_lo_vegas P2_uxu_tltlxg/ subproc.txt
dipole.inc-def makefile_mo P3_gg_tltlxg/ sudakov.inc

```

The screenshot shows a terminal window with a blue border. Inside, a command is being run to copy files from a 'Template_nlo' directory to a 'stop-pair' directory. The user then changes into the 'stop-pair' directory and runs a script named 'newprocess_nlo'. This starts a process labeled 'Running...'. The terminal then lists all files in the current directory, which includes various Fortran source files, a few text files, and several subdirectories. A red rectangular box highlights the command line and the file listing. The bottom of the terminal window shows the system's taskbar with icons for the desktop environment.

Running MadGolem



```

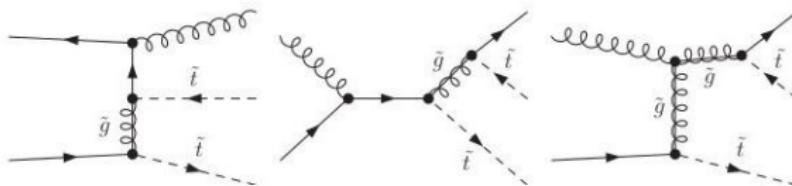
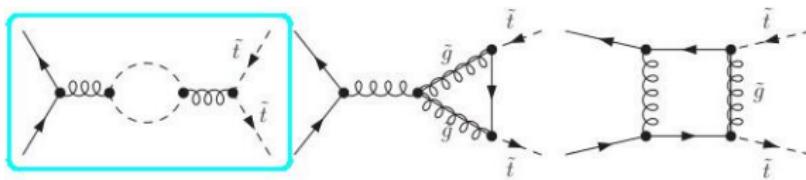
lopez@lin17:~/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair>cd SubProcesses/
lopez@lin17:~/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/SubProcesses>ls
addintegral_driver.f   finitetermssusy.f      MGVersion.txt      projection.f
addmothers.f          fort.28                 minputdipoleqed.mg  python_data.txt
alphas_bsm.f          fort.37                 myamp.f            qgraf_golem.sty
auto_dsig.f           fort.71                 onshellsum.f       qgraf_model
check_dip.f           genps.f                onshellsum_tmp.f  qgraf_model_counterterms
check_dip_qed.f       genps.inc@             P0_gg_tltlx/       qgraf_model_hdim
check_intdip.f        getpdf.f               P0_uux_tltlx/      qgraf_model_loop
check_sa.f            golem_input.dat       P0_uxu_tltlx/      randinit
cluster.f             initcluster.f         P1_gg_tltlx/       reweight.f
cluster.inc           interactions.dat@     P1_uux_tltlx/      run.inc
coloredparticles.dat  interactions-qgraf.dat@ P2_gg_tltlxg/     run.inc.bah@
coupl.inc@           myfilee               P2_gu_tltlxu/      selfenergy_ct.dat@
cuts.f               myfilee_dip           P2_gux_tltlxu/    setcuts.f
cuts.f-def            myfilee_dip_qed      P2_ug_tltlxu/     setscales.f
cuts.inc@            myfilee_dlhapdf      P2_uxx_tltlxg/    shrinktops.f
dbook.f              myfilee_dynamic      P2_uxg_tltlxu/    status
dbook.inc            myfilee_lhapdf       P2_uxu_tltlxg/    subproc.mg
dipole.inc           myfilee_lo_vegas    P3_gg_tltlxg/     subproc.txt
dipole.inc-def       myfilee_mo           P3_gu_tltlxu/     sudakov.inc
dipolesub.f          myfilee_mo_dlhapdf  P3_gux_tltlxu/    symmetry.f
dipolesubsusy.f      myfilee_mo_lhapdf   P3_ug_tltlxu/     symmetry_vegas.f
done                 myfilee_nlo          P3_uxx_tltlxg/    transform.f
driver.f             myfilee_nlo~         P3_uxg_tltlxu/    transformint.f
driver_nlo_vegas.f   myfilee_nlo_vegas   P3_uxu_tltlxg/    transformos.f
epsterms.f           myfilee_sa          particles.dat@  unwgt.f
epstermsqed.f        myfilee_snlo*       particles-qgraf.dat@ vegas.f
epstermsqed.f        myfilee_snlo*       poles_check.f    vegas_fxnf
finiteterms.f         myfilee_snlo_vegas  proc_os.mg      vertex_ct.dat@
finitetermsqed.f     message.inc

```

The screenshot shows a terminal window with a list of files and directories. A green rectangular box highlights a specific folder path: `P3_uxu_tltlxg/`. This path is part of a larger list of subdirectories under `SubProcesses`, which includes `P0_gg_tltlx/`, `P0_uux_tltlx/`, `P0_uxu_tltlx/`, `P1_gg_tltlx/`, `P1_uux_tltlx/`, `P1_uxu_tltlx/`, `P2_gg_tltlxg/`, `P2_gu_tltlxu/`, `P2_gux_tltlxu/`, `P2_ug_tltlxu/`, `P2_uxx_tltlxg/`, `P2_uxg_tltlxu/`, `P2_uxu_tltlxg/`, `P3_gg_tltlxg/`, `P3_gu_tltlxu/`, `P3_gux_tltlxu/`, `P3_ug_tltlxu/`, `P3_uxx_tltlxg/`, `P3_uxg_tltlxu/`, and `P3_uxu_tltlxg/`.

Feynman diagrams @NLO

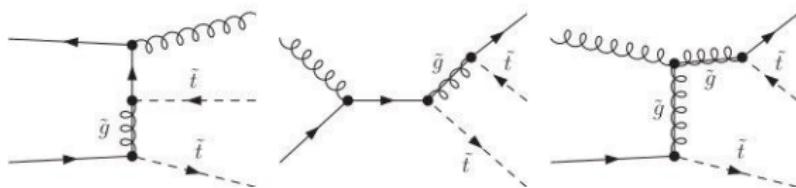
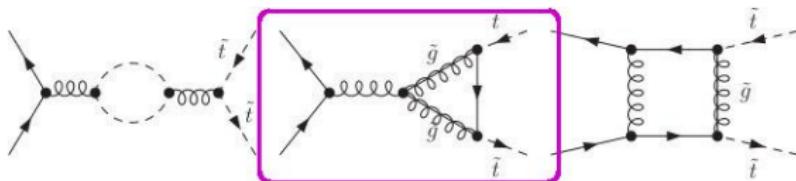
- **Virtual corrections** – $\mathcal{O}(\alpha_s)$ virtual gluon/gluino/squark exchange
- **Real corrections**: quark and gluon emission off the initial partons and the final-state squark



- i) **self-energy insertions**; ii) vertex corrections; iii) box diagrams; iv) real emission

Feynman diagrams @NLO

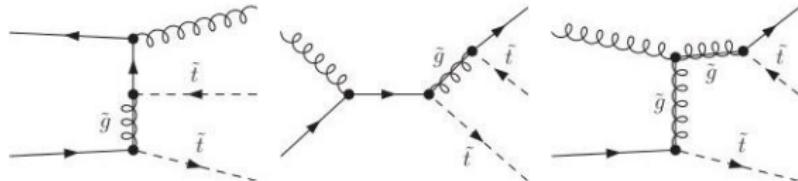
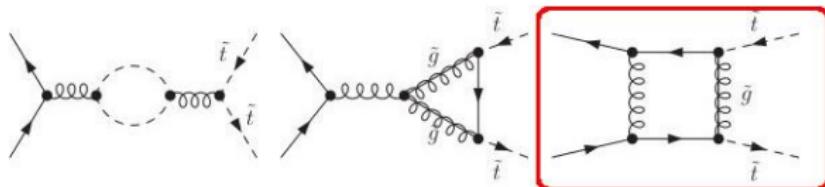
- **Virtual corrections** – $\mathcal{O}(\alpha_s)$ virtual gluon/gluino/squark exchange
- **Real corrections**: quark and gluon emission off the initial partons and the final-state squark



- i) self-energy insertions; ii) **vertex corrections**; iii) box diagrams; iv) real emission

Feynman diagrams @NLO

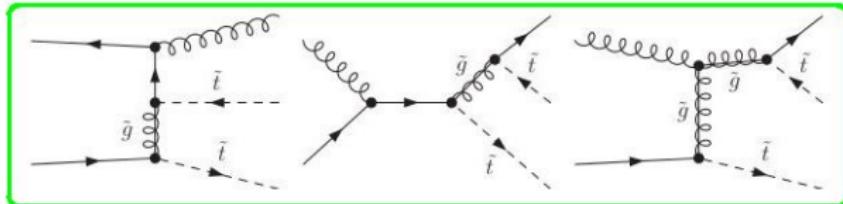
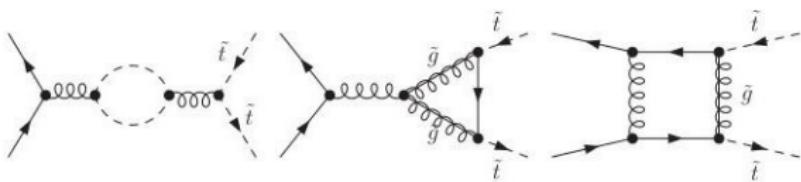
- **Virtual corrections** – $\mathcal{O}(\alpha_s)$ virtual gluon/gluino/squark exchange
- **Real corrections** : quark and gluon emission off the initial partons and the final-state squark



i) self-energy insertions; ii) vertex corrections; iii) **box diagrams** ; iv) real emission

Feynman diagrams @NLO

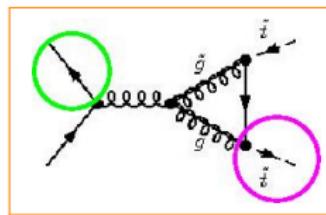
- Virtual corrections – $\mathcal{O}(\alpha_s)$ virtual gluon/gluino/squark exchange
- Real corrections : quark and gluon emission off the initial partons and the final-state squark



- self-energy insertions
- vertex corrections
- box diagrams
- real emission**

Feynman diagrams @NLO

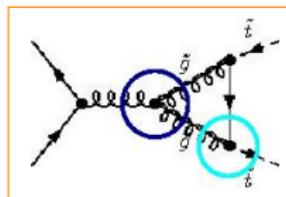
The Feynman diagrams get generated ...



```
+ 1 *
inp([field.u], idx1r2, p1) *
inplorentz(+1, iv1r2L1, p1, ZERO ) *
inpcolor(1, iv1r2C3) *
inp([field.ux], idx1r1, p2) *
inplorentz(-1, iv1r1L1, p2, ZERO ) *
inpcolor(2, iv1r1C3) *
out([field.tl], idx2r3, p3) *
outlorentz(+0, iv2r3L0, p3, MT1 ) *
outcolor(1, iv2r3C3) *
out([field.tlx], idx3r3, p4) *
outlorentz(-0, iv3r3L0, p4, MT1 ) *
outcolor(2, iv3r3C3) *
vertex(iv1,GG ,ONE,
[field.ux], idx1r1, -1, p2, iv1r1L1, -3, iv1r1C3,
[field.u], idx1r2, +1, p1, iv1r2L1, +3, iv1r2C3,
```

Feynman diagrams @NLO

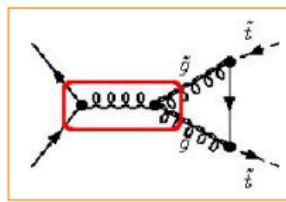
The Feynman diagrams get generated ...



```
[field.u], idx1r2, +1, p1, iv1r2L1, +3, iv1r2C3,
[field.g], idx1r3, +2, -p1-p2, iv1r3L2, +8, iv1r3C8) *
vertex(iv2,GT1GOP ,ONE,
[field.go], idx2r1, +1, k1+p3, iv2r1L1, +8, iv2r1C8,
[field.t], idx2r2, +1, -k1, iv2r2L1, +3, iv2r2C3,
[field.tlx], idx2r3, -0, -p3, iv2r3L0, -3, iv2r3C3) *
vertex(iv3,GT1GOM ,ONE,
[field.tx], idx3r1, -1, k1, iv3r1L1, -3, iv3r1C3,
[field.go], idx3r2, +1, -k1+p4, iv3r2L1, +8, iv3r2C8,
[field.tl], idx3r3, +0, -p4, iv3r3L0, +3, iv3r3C3) *
vertex(iv4,GGI ,ONE,
[field.go], idx4r1, +1, -k1-p3, iv4r1L1, +8, iv4r1C8,
[field.go], idx4r2, +1, k1-p4, iv4r2L1, +8, iv4r2C8,
[field.g], idx4r3, +2, p1+p2, iv4r3L2, +8, iv4r3C8) *
prop([field.g], idx4r3, idx1r3) *
propcolor(+8, iv4r3C8, iv1r3C8) *
```

Feynman diagrams @NLO

The Feynman diagrams get generated ...



```
[field.go], idx4r2, +1, k1-p4, iv4r2L1, +8, iv4r2C8,
[field.g], idx4r3, +2, p1+p2, iv4r3L2, +8, iv4r3C8) *
prop([field.g], idx4r3, idx1r3) *
propcolor(+8, iv4r3C8, iv1r3C8) *
proporentz(+2, -p1-p2, ZERO , iv4r3L2, iv1r3L2) *
prop([field.t], idx3r1, idx2r2) *
propcolor(+3, iv3r1C3, iv2r2C3) *
proporentz(+1, -k1, TMASS , iv3r1L1, iv2r2L1) *
prop([field.go], idx4r1, idx2r1) *
propcolor(+8, iv4r1C8, iv2r1C8) *
proporentz(+1, k1+p3, MGO , iv4r1L1, iv2r1L1) *
prop([field.go], idx4r2, idx3r2) *
propcolor(+8, iv4r2C8, iv3r2C8) *
proporentz(+1, -k1+p4, MGO , iv4r2L1, iv3r2L1)
;
*-#] diagram4:
```

Running MadGolem

3-stage procedure – 3 interfaces \leftrightarrow 3 executables

Stage 1: PROCESS GENERATION

process_card \leftrightarrow ./newprocess_snlo

Stage 2: AMPLITUDE CALCULATION

./run_golem_pl

- ♣ At this point the user is able to:
 - Select diagram topologies \Rightarrow detailed analysis of the virtual corrections
 - Access the **analytical output** in several stages \Rightarrow very useful for cross-checking (and to dig out some physics!)

Feynman diagrams @NLO

... further translated ...

```

File Edit View Tools Settings Help
New Open Save Save As Close Undo Redo Enlarge Font Find Next Find Previous Find Go to Line

G diagram4 = + Den( - k1 - k2,0)*intM(Den(q1,TMASS2),Den(k3 + q1,MG02)
,Den( - k4 + q1,MG02))*SUNF(Glu19,Glu17,Glu18)*SUNSum(Col10,3)*
SUNSum(Glu17,8)*SUNSum(Glu18,8)*SUNSum(Glu19,8)*SUNT(Glu17,Col3,
Col10)*SUNT(Glu18,Col10,Col4)*SUNT(Glu19,Col2,Col1)*GG2*scalar3*
scalar4*Pi^(-2) * ( 1/64*Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,
0,1)*g_(2,7_,k4,Lor5,k3,q1)*i_*GT1GOP1*GT1GOM2*GGI2 + 1/64*
Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,k4,Lor5,
k3)*i_*TMASS*GT1GOP2*GT1GOM2*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,
7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,k4,Lor5,k3)*i_*TMASS*GT1GOP1*
GT1GOM2*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,
1)*g_(2,7_,k4,Lor5,q1,q1)*i_*GT1GOP1*GT1GOM2*GGI2 + 1/64*
Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,k4,Lor5,
q1)*i_*TMASS*GT1GOP2*GT1GOM2*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,
7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,k4,Lor5,q1)*i_*TMASS*GT1GOP1*
GT1GOM2*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,
1)*g_(2,7_,k4,Lor5)*i_*MG0*TMASS*GT1GOP2*GT1GOM2*GGI2 + 1/64*
Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,q1,k4,
Lor5,k3)*i_*GT1GOP2*GT1GOM1*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,
7_,Lor5)*Spinor(k2,0,1)*g_(2,7_,q1,k4,Lor5,q1)*i_*GT1GOP2*
GT1GOM1*GGI2 + 1/64*Spinor(k1,0,-1)*g_(2,7_,Lor5)*Spinor(k2,0,
1)*q_(2,7_.a1.k4.Lor5)*i_*MG0*GT1GOP2*GT1GOM1*GGI2 - 1/64*

```

Feynman diagrams @NLO

and analytically reduced

```

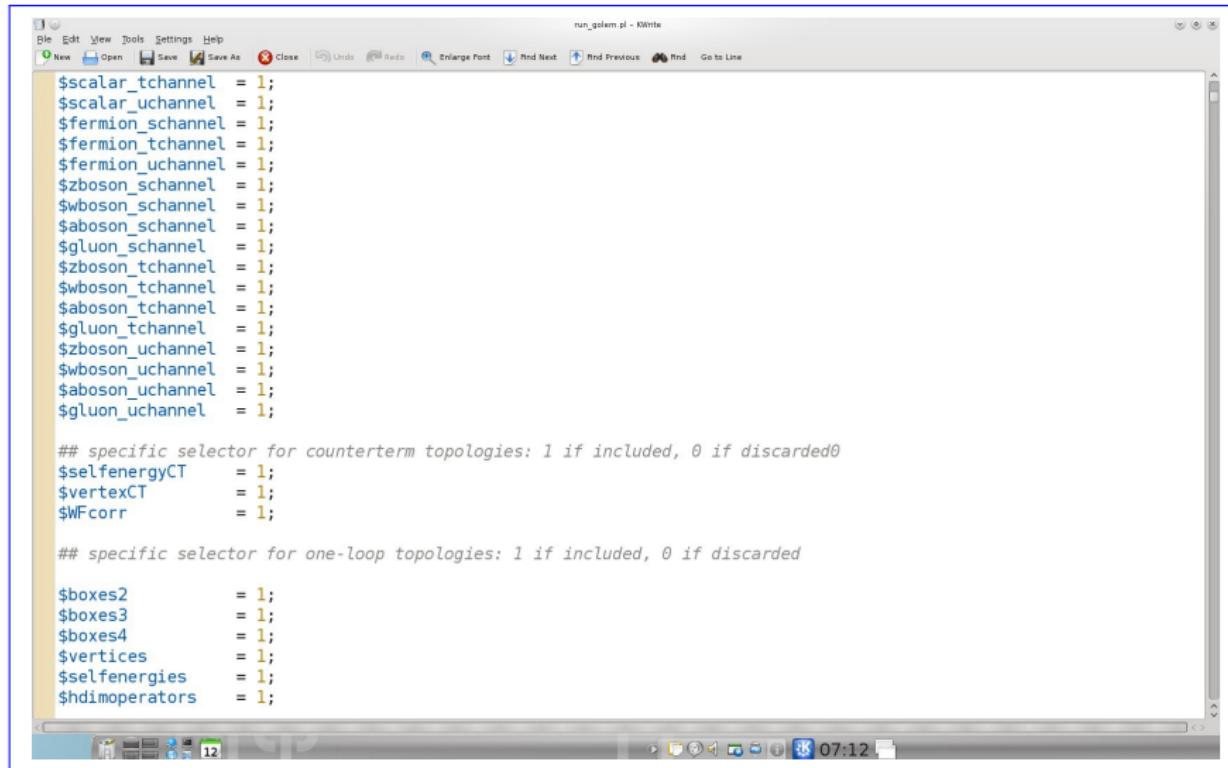
File Edit View Insert Go Lang Help
4PF_2007_AutoRun_Uncut.m - Open
File Open Save Save As... Save All... Data Units Edit Characters Text Tools Help The Player File Help File Help
FUN[ 4] := BUBd4(S12,MG02,MG02):
FUN[ 5] := BUBd4(S12,MT12,MT12):
FUN[ 6] := BUBd4(S12,TMASS2,TMASS2):
FUN[ 7] := TADD4(MT12):
FUN[ 8] := TRID4(MT12,MT12,S12,MT12,0,0):
FUN[ 9] := TRID4(MT12,MT12,S12,TMASS2,MG02,MG02):
FUN[ 10]:= TRID4(MT12,S12,MT12,MT12,MT12,0):
FUN[ 11]:= TRID4(MT12,S12,MT12,TMASS2,TMASS2,MG02):
#
# 2 non-zero out of 4 helicity amplitudes found
# 1 unique helicity amplitudes found
#
NUM_HELIS := 4:
base_helis := [2, 3]:
unique_helis := [2]:
symmetry_helis := [[2, 3]]:
HELI[ 2]:= [1, -1, 5, 5]:
HELI[ 3]:= [-1, 1, 5, 5]:
#
ReferenceVector := [k3b, k3b, k1, k1]:
FINAL_GRAPH_LIST := [2, 3, 4, 5, 6, 7]:
#
GRAPH_COEFF[ 4, 2, 1, 1, 2] := -1/16*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1):
GRAPH_COEFF[ 4, 2, 2, 1, 2] := 3/16*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1+MT12*GT1GOP2*GT1GOM1):
GRAPH_COEFF[ 4, 2, 1, 1, 4] := 1/32*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2):
GRAPH_COEFF[ 4, 2, 2, 1, 4] := -3/32*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2):
GRAPH_COEFF[ 4, 2, 1, 1, 9] := -1/16*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(-MG0^2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2):
GRAPH_COEFF[ 4, 2, 2, 1, 9] := 3/16*GG2*GGI2*(S23^2-2*MT12*S23+MT12^2+S23*S12)*(-MG0^2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2-2*MT12*GT1GOP1*GT1GOM2):
SPINOR_FAC[ 4, 2] := InvSpab(k2,k3)*InvSpbb(k1,k3):

```

Running MadGolem

```
Lopez@lin50c:/remote/lin17/Lopez/v90/screenshots/MadGolem_V90beta/stop-pair/GOLEMproc>perl run_golem.pl  
Working on subprocess contained in ./../SubProcesses/P2_gg_tttxg/  
Number of tree-level diagrams before topology selection: 4  
Number of higher dimensional contributions before topology selection: 0  
Number of one-loop diagrams before topology selection: 856  
WARNING: 84 loop diagrams proportional to squark quartic couplings removed  
Number of one-loop diagrams after topology selection: 678  
WARNING: singlet-octet mixing self-energies in the S-channel automatically removed  
WARNING: singlet-octet self-energies in the U-channel automatically removed  
WARNING 462 spurious loop diagrams with wrong power-counting on g_s were removed  
Number of loop diagrams after grouping common structures: 170  
Number of counterterm diagrams before topology selection: 18  
ntreegraphs: 4  
ncountergraphs: 18  
nloopgraphs: 170  
nhdimgraphs: 0  
Particle names: g g tl tlx  
Particle types: 2 2 0 0  
Masses: 0 0 MT1 MT1  
Colour Structure:  
Colours: 8 8 3 3  
I index: [ Col012, Col022, Col4 ]  
J index: [ Col011, Col021, Col3 ]  
Spin-Colour average * Symmetry factor: 256  
** Distinct IR poles & UV poles  
*** Process-Dependent Reference Vectors being used  
***** WORKING ON TREE GRAPHS... *****  
Making directories...  
Pre processing input files...  
Teste stop pair: ooch
```

Running MadGolem



The screenshot shows a KWrite text editor window with a blue border. The title bar reads "run_golem.pl - KWrite". The menu bar includes File, Edit, View, Tools, Settings, Help, and several icons for file operations like Open, Save, Undo, Redo, and Find. The main text area contains a Perl script with various variables set to 1 and comments explaining specific selector logic for counterterm and one-loop topologies.

```
$scalar_tchannel = 1;
$scalar_uchannel = 1;
$fermion_schannel = 1;
$fermion_tchannel = 1;
$fermion_uchannel = 1;
$zboson_schannel = 1;
$wboson_schannel = 1;
$aboson_schannel = 1;
$gluon_schannel = 1;
$zboson_tchannel = 1;
$wboson_tchannel = 1;
$aboson_tchannel = 1;
$gluon_tchannel = 1;
$zboson_uchannel = 1;
$wboson_uchannel = 1;
$aboson_uchannel = 1;
$gluon_uchannel = 1;

## specific selector for counterterm topologies: 1 if included, 0 if discarded0
$selfenergyCT = 1;
$vertexCT = 1;
$WFCcorr = 1;

## specific selector for one-loop topologies: 1 if included, 0 if discarded

$boxes2 = 1;
$boxes3 = 1;
$boxes4 = 1;
$vertices = 1;
$selfenergies = 1;
$hdimoperators = 1;
```

Running MadGolem

```

File Edit View Bookmarks Sources Help > bash
step 12 bash
libcoeffs_all_107.so* libcoeffs_all_140.so* libcoeffs_all_1.so* libcoeffs_all_53.so* libcoeffs_all_
libcoeffs_all_108.so* libcoeffs_all_141.so* libcoeffs_all_20.so* libcoeffs_all_54.so* libcoeffs_all_
libcoeffs_all_109.so* libcoeffs_all_142.so* libcoeffs_all_21.so* libcoeffs_all_56.so* libcoeffs_all_
libcoeffs_all_10.so* libcoeffs_all_143.so* libcoeffs_all_22.so* libcoeffs_all_58.so* libcoeffs_all_
libcoeffs_all_110.so* libcoeffs_all_144.so* libcoeffs_all_23.so* libcoeffs_all_59.so* libcoeffs_all_
libcoeffs_all_111.so* libcoeffs_all_145.so* libcoeffs_all_24.so* libcoeffs_all_60.so* libcoeffs_all_
libcoeffs_all_112.so* libcoeffs_all_146.so* libcoeffs_all_25.so* libcoeffs_all_62.so* libcoeffs_all_
libcoeffs_all_113.so* libcoeffs_all_147.so* libcoeffs_all_26.so* libcoeffs_all_64.so* libcoeffs_all_
libcoeffs_all_114.so* libcoeffs_all_148.so* libcoeffs_all_27.so* libcoeffs_all_71.so* libcoeffs_all_
libcoeffs_all_115.so* libcoeffs_all_149.so* libcoeffs_all_28.so* libcoeffs_all_75.so* libcoeffs_all_
libcoeffs_all_116.so* libcoeffs_all_14.so* libcoeffs_all_29.so* libcoeffs_all_80.so* libcoeffs_all_
libcoeffs_all_117.so* libcoeffs_all_150.so* libcoeffs_all_2.so* libcoeffs_all_81.so* mass_f90.inc
libcoeffs_all_118.so* libcoeffs_all_151.so* libcoeffs_all_30.so* libcoeffs_all_82.so* store/
libcoeffs_all_119.so* libcoeffs_all_152.so* libcoeffs_all_31.so* libcoeffs_all_83.so* store_hdmi/
libcoeffs_all_11.so* libcoeffs_all_153.so* libcoeffs_all_32.so* libcoeffs_all_84.so* store_tree/
libcoeffs_all_120.so* libcoeffs_all_154.so* libcoeffs_all_33.so* libcoeffs_all_85.so* virtual_correc_
libcoeffs_all_121.so* libcoeffs_all_155.so* libcoeffs_all_34.so* libcoeffs_all_86.so* virtual_dummy.
libcoeffs_all_122.so* libcoeffs_all_156.so* libcoeffs_all_35.so* libcoeffs_all_87.so*
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/GOLEMproc/for/cd store
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/GOLEMproc/for/store>ls
ct_1/    loop_11/   loop_15/   loop_19/   loop_22/   loop_26/   loop_3/    loop_33/   loop_37/   loop_40/   loop_44/
ct_2/    loop_12/   loop_16/   loop_2/    loop_23/   loop_27/   loop_30/   loop_34/   loop_38/   loop_41/   loop_45/
ct_3/    loop_13/   loop_17/   loop_20/   loop_24/   loop_28/   loop_31/   loop_35/   loop_39/   loop_42/   loop_46/
loop_10/   loop_14/   loop_18/   loop_21/   loop_25/   loop_29/   loop_32/   loop_36/   loop_4/    loop_43/   loop_5/
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/GOLEMproc/for/store>cd loop_12
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/GOLEMproc/for/store/loop_12>ls
c22_PMSS_g_12_l_1.f90 c22_PMSS_g_12_l_2.f90 coup_f90.inc Makefile_12 mass_f90.inc
lopez@lin17:/remote/lin17/lopez/v90/screencasts/MadGolem_V90beta/stop-pair/GOLEMproc/for/store/loop_12>

```

Icons_12_bash Index: 07:22

Running MadGolem

```

File Edit View Scrollback Bookmarks Settings Help
lopez@lin50c:/remote/lin17/Lopez/v90/screencasts/MadGolem_V90beta/test-stop-pair/SubProcesses> cd P2_uwu_tltlxp/
lopez@lin50c:/remote/lin17/Lopez/v90/screencasts/MadGolem_V90beta/test-stop-pair/SubProcesses> ls
addmothers.f@ dipol011.f libcoeffs_all_116.so* libcoeffs_all_14.so* libcoeffs_all_29.so* libcoeffs_all_80.so*
auto_dsig.f dipol011.ps libcoeffs_all_117.so* libcoeffs_all_150.so* libcoeffs_all_2.so* libcoeffs_all_81.so*
auto_dsig_nlo.f dipol012.f libcoeffs_all_118.so* libcoeffs_all_151.so* libcoeffs_all_30.so* libcoeffs_all_82.so*
auto_dsig_nlo.f.bak dipol012.ps libcoeffs_all_119.so* libcoeffs_all_152.so* libcoeffs_all_31.so* libcoeffs_all_83.so*
card.jpg dipole.inc@ libcoeffs_all_111.so* libcoeffs_all_153.so* libcoeffs_all_32.so* libcoeffs_all_84.so*
cluster.@ dipolesubsusy.f@ libcoeffs_all_120.so* libcoeffs_all_154.so* libcoeffs_all_33.so* libcoeffs_all_85.so*
cluster.inc@ dipolsum.f libcoeffs_all_121.so* libcoeffs_all_155.so* libcoeffs_all_34.so* libcoeffs_all_86.so*
coloramps.inc dname.mg libcoeffs_all_122.so* libcoeffs_all_156.so* libcoeffs_all_35.so* libcoeffs_all_87.so*
configs.inc driver_nlo_vegas.f libcoeffs_all_123.so* libcoeffs_all_157.so* libcoeffs_all_36.so* libcoeffs_all_88.so*
coupl_f90.inc driver_nlo_vegas.f.bak libcoeffs_all_124.so* libcoeffs_all_158.so* libcoeffs_all_37.so* libcoeffs_all_89.so*
coupl.inc@ epsternsusy.f@ libcoeffs_all_125.so* libcoeffs_all_159.so* libcoeffs_all_38.so* libcoeffs_all_92.so*
cuts.@ finitermsusy.f@ libcoeffs_all_126.so* libcoeffs_all_15.so* libcoeffs_all_39.so* libcoeffs_all_93.so*
cuts.inc@ genps.f@ libcoeffs_all_127.so* libcoeffs_all_160.so* libcoeffs_all_3.so* libcoeffs_all_94.so*
dbook.@ genps.inc@ libcoeffs_all_128.so* libcoeffs_all_161.so* libcoeffs_all_40.so* libcoeffs_all_95.so*
dbook.inc@ getpdf.f libcoeffs_all_129.so* libcoeffs_all_162.so* libcoeffs_all_41.so* libcoeffs_all_96.so*
decayBW.inc golem_input.dat libcoeffs_all_12.so* libcoeffs_all_163.so* libcoeffs_all_42.so* libcoeffs_all_97.so*
diagrams.html initcluster.@ libcoeffs_all_130.so* libcoeffs_all_164.so* libcoeffs_all_43.so* libcoeffs_all_98.so*
dipol001.f intdipoles.f libcoeffs_all_131.so* libcoeffs_all_165.so* libcoeffs_all_44.so* libcoeffs_all_99.so*
dipol001.ps iproc.dat libcoeffs_all_132.so* libcoeffs_all_166.so* libcoeffs_all_45.so* libcoeffs_all_9.so*
dipol002.f leshouche.inc libcoeffs_all_133.so* libcoeffs_all_167.so* libcoeffs_all_46.so* libcoeffs_all_ct_10.so*
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dipol003.ps libcoeffs_all_102.so* libcoeffs_all_136.so* libcoeffs_all_170.so* libcoeffs_all_49.so* libcoeffs_all_ct_13.so*
dipol004.f libcoeffs_all_103.so* libcoeffs_all_137.so* libcoeffs_all_171.so* libcoeffs_all_4.so* libcoeffs_all_ct_14.so*
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dipol006.f libcoeffs_all_107.so* libcoeffs_all_140.so* libcoeffs_all_1.so* libcoeffs_all_53.so* libcoeffs_all_ct_18.so*
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dipol007.f libcoeffs_all_109.so* libcoeffs_all_142.so* libcoeffs_all_21.so* libcoeffs_all_56.so* libcoeffs_all_ct_2.so*
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dipol008.ps libcoeffs_all_112.so* libcoeffs_all_145.so* libcoeffs_all_24.so* libcoeffs_all_60.so* libcoeffs_all_ct_5.so*
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dipol010.f libcoeffs_all_115.so* libcoeffs_all_148.so* libcoeffs_all_27.so* libcoeffs_all_71.so* libcoeffs_all_ct_8.so*
dipol010.ps libcoeffs_all_116.so* libcoeffs_all_149.so* libcoeffs_all_28.so* libcoeffs_all_7.so* libcoeffs_all_ct_9.so*
lopez@lin50c:/remote/lin17/Lopez/v90/screencasts/MadGolem_V90beta/test-stop-pair/SubProcesses/P2_uwu_tltlxp/
```

Running MadGolem

3-stage procedure – 3 interfaces ↔ 3 executables

Stage 1: PROCESS GENERATION

process_card ↔ ./newprocess_snlo

Stage 2: AMPLITUDE CALCULATION

./run_golem_pl

- ♣ At this point the user is able to:
 - Select diagram topologies ⇒ detailed analysis of the virtual corrections
 - Access the **analytical output** in several stages ⇒ very useful for cross-checking (and to dig out some physics!)

Stage 3: NUMERICAL EVALUATION

param_card.dat, run_card.dat ↔ ./generate_events_nlo 2 2 myrun

Running MadGolem

```

lopez@lin50c:~/remote/lin17/lopez/v90/screenshots/MadGolem_V90beta/test-stop-pair>./bin/generate_events_nlo 2 2
Sat Apr  6 17:39:30 CEST 2013
Calculating NLO cross sections
Cleaning SubProcesses.....
Compiling libraries
Working on subprocess:
  P0_uxu_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P0_uux_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P0_gg_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P1_uxu_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P1_uux_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P1_gg_tltlx  waiting until less then 2 jobs are running to launch, now 0
  P2_uxu_tltlxg /usr/bin/ld: dynamic variable `__constante_MOD_s_null' is zero size
/usr/bin/ld: virtual_corrections.o(.text+0x75e4): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0x93d3): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0xb210): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0xd053): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0xe36f): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0xf676): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0x1097b): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0x11c82): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'
/usr/bin/ld: virtual_corrections.o(.text+0x12f87): unresolvable R_X86_64_32S relocation against symbol `__constante_MOD_s_null'

```

Running MadGolem

MadGolem results

K-factor=(P1+P2+P3)/P1 = 1.647

Total LO cross section 204.221

Total NLO cross section 336.318

| Graph | Cross Sect(fb) | Error(fb) | Events (K) | Eff | Unwgt. | Luminosity |
|---|----------------|-----------|------------|-----|--------|------------|
| NLO CONTRIBUTION: TREE-LEVEL SQUARED | | | | | | |
| P1_gg_tttx | 187.220 | 0.438 | 0/0.0 | | | 0.00 |
| P1_uux_tttx | 22.421 | 0.029 | 0/0.0 | | | 0.00 |
| P1_uxu_tttx | 22.411 | 0.029 | 0/0.0 | | | 0.00 |
| total NLO (tree-level squared) = 232.05199999999999 | | | | | | |
| LEADING ORDER | | | | | | |
| P0_gg_tttx | 150.570 | 0.348 | 0/0.0 | | | 0.00 |
| P0_uux_tttx | 26.833 | 0.035 | 0/0.0 | | | 0.00 |
| P0_uxu_tttx | 26.818 | 0.035 | 0/0.0 | | | 0.00 |
| total LO = 204.221000000000003 | | | | | | |
| NLO CONTRIBUTION: Virtual part | | | | | | |
| P2_gg_tttxq | 104.190 | 0.448 | 0/0.0 | | | 0.00 |
| P2_uuxx_tttxq | 2.366 | 0.013 | 0/0.1 | | | 0.00 |
| P2_uxux_tttxq | 2.119 | 0.012 | 0/0.1 | | | 0.00 |
| P2_gux_tttxux | -0.283 | 0.003 | 0/0.0 | | | 0.00 |
| P2_uxg_tttxux | -0.298 | 0.003 | 0/0.0 | | | 0.00 |
| P2_guu_tttxu | -1.195 | 0.043 | 0/0.0 | | | 0.00 |
| P2_uug_tttxu | -1.312 | 0.044 | 0/0.0 | | | 0.00 |
| total NLO (virtual part) = 105.57695000000001 | | | | | | |
| NLO CONTRIBUTION: Real part | | | | | | |
| P3_gg_tttxq | 1.523 | 0.024 | 0/0.2 | | | 0.00 |
| P3_uuxx_tttxq | 0.689 | 0.003 | 0/0.0 | | | 0.00 |
| P3_uxux_tttxq | 0.688 | 0.003 | 0/0.0 | | | 0.00 |
| P3_gux_tttxux | -0.111 | 0.001 | 0/0.0 | | | 0.00 |
| P3_uxg_tttxux | -0.112 | 0.001 | 0/0.0 | | | 0.00 |
| P3_uug_tttxu | -1.996 | 0.014 | 0/0.0 | | | 0.00 |

♠ And the user
retrieves the results !

Outline

- 1 A glimpse at MadGolem: the tool from inside
- 2 A glimpse at MadGolem – the tool in use
- 3 A glimpse at MadGolem – phenomenology applications
- 4 One final glimpse

Portraying BSM phenomenology

First **complete** fully automated NLO calculations of **BSM $2 \rightarrow 2$**

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[arXiv:1108.1250](#)

$$pp \rightarrow GG^*$$

[arXiv:1203.6358](#)

$$pp \rightarrow [\tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}]$$

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$$pp \rightarrow l_8\bar{l}_8$$

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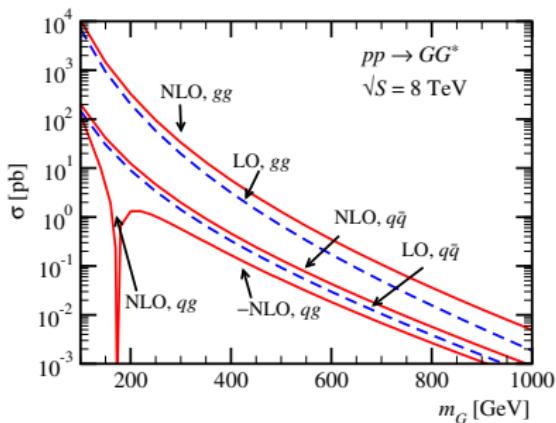
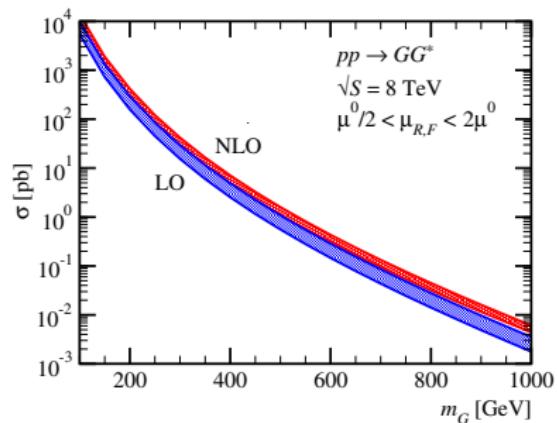
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- **Total NLO rates and K factors**
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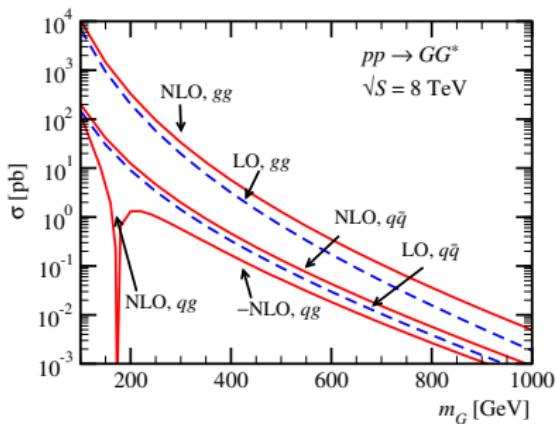
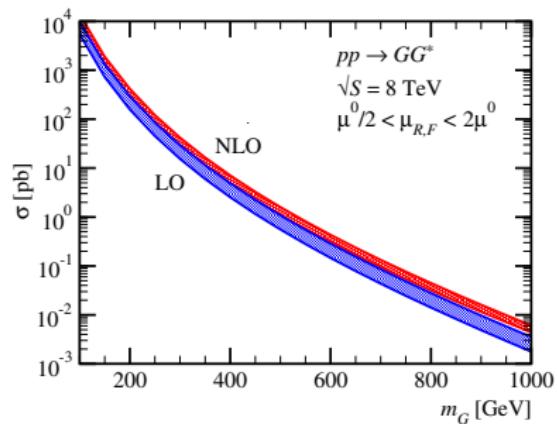
NLO rates & K-factors



- Dominance of $gg \rightarrow GG^*$ \Rightarrow larger color charges & s-wave kinematics
- Large rates: $\sigma \sim \mathcal{O}(1) \text{ pb}$ for $m_G = 0.5 \text{ TeV}$
 $[\sigma(gg \rightarrow \tilde{t}\tilde{t}^*)/\sigma(gg \rightarrow GG^*) \simeq 1/20]$
- Sizable NLO effects: $K \gtrsim 1.5$ – as compared to squark-pairs $[K(\tilde{q}\tilde{q}) \sim 1.3]$
- Decreasing rates & Growing K-factor with $m_G \iff$ Threshold enhancements

Gonçalves-Netto, DLV, Mawatari, Plehn, Wigmore, PRD 85 (2012) 114024 arXiv:1203.6358
[hep-ph]

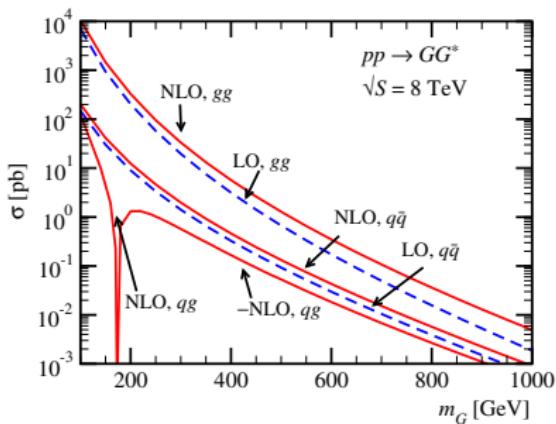
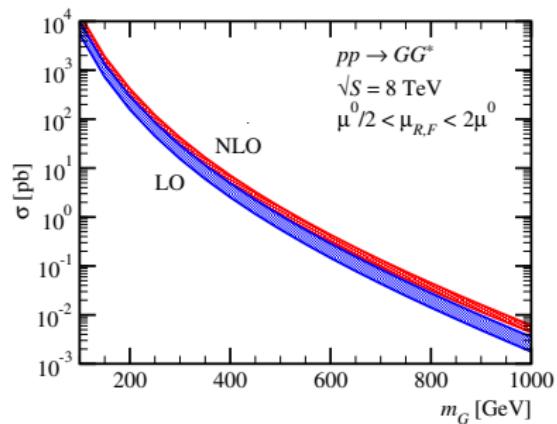
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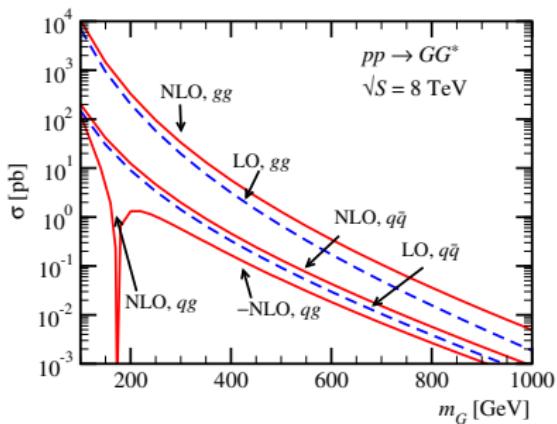
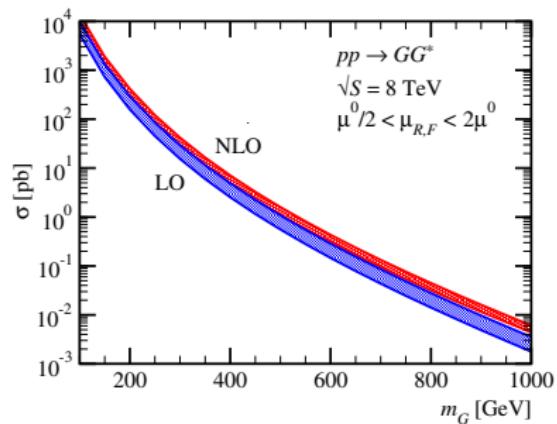
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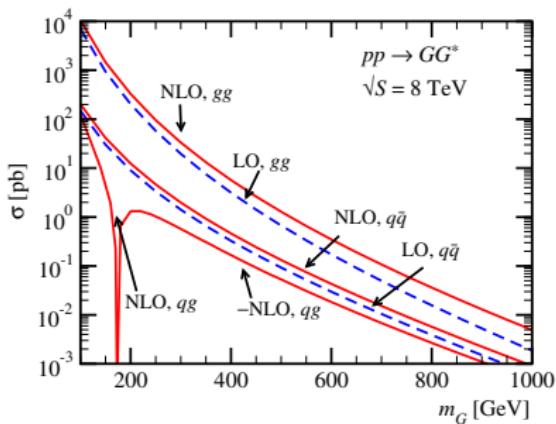
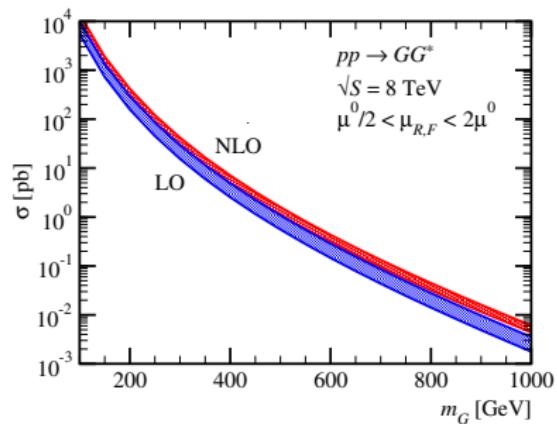
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Parameter space survey

$$pp \rightarrow \tilde{u}_L \tilde{u}_L$$

| MSSM benchmark | $\tilde{u}_L \tilde{u}_L$ | | | $\tilde{u}_L \tilde{u}_R$ | | |
|-----------------------|---------------------------|-----------------------|------|---------------------------|-----------------------|------|
| | σ^{LO} | σ^{NLO} | K | σ^{LO} | σ^{NLO} | K |
| CMSSM 10.2.2 | 26.2 | 32.9 | 1.25 | 26.2 | 35.0 | 1.33 |
| CMSSM 40.2.2 | 22.8 | 29.3 | 1.28 | 25.2 | 34.4 | 1.36 |
| CMSSM 40.3.2 | 14.8 | 20.4 | 1.37 | 23.1 | 34.0 | 1.47 |
| mGMSB 1.2 | 85.3 | 107.1 | 1.26 | 99.7 | 134.2 | 1.35 |
| mGMSB 2.1.2 | 73.9 | 97.7 | 1.32 | 113.9 | 160.4 | 1.41 |
| mAMSB 1.3 | 16.8 | 21.5 | 1.28 | 16.1 | 22.0 | 1.37 |

σ in fb, \sqrt{S} in TeV, m in GeV;

MSSM benchmarks from [\[Abdus Salam et al. arXiv:1109.3859\]](#)

Gonçalves-Netto, DLV, Mawatari, Plehn, Wigmore, [arXiv:1211.0286](#)

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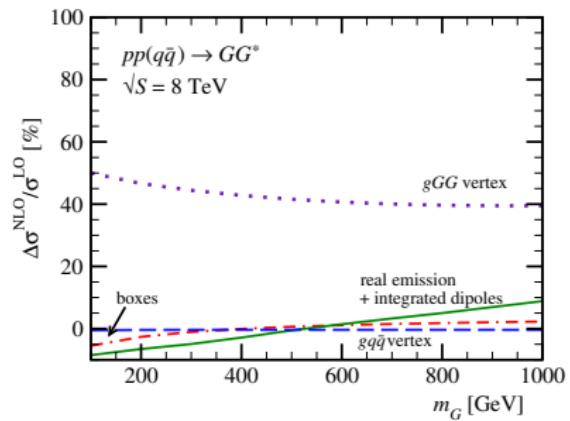
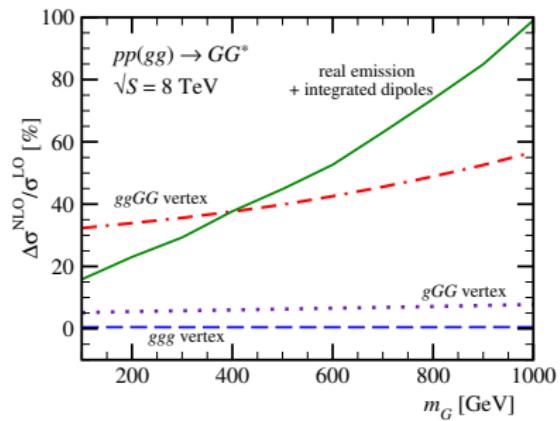
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Anatomy of the virtual corrections

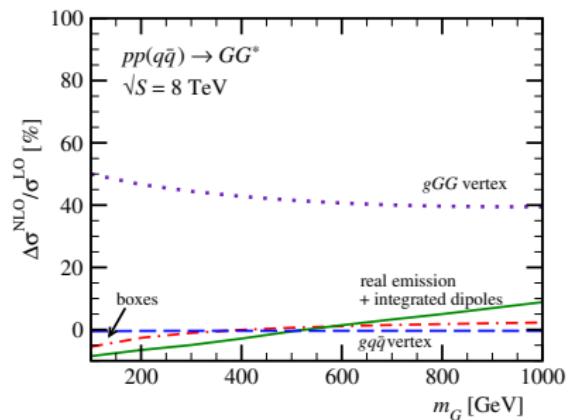
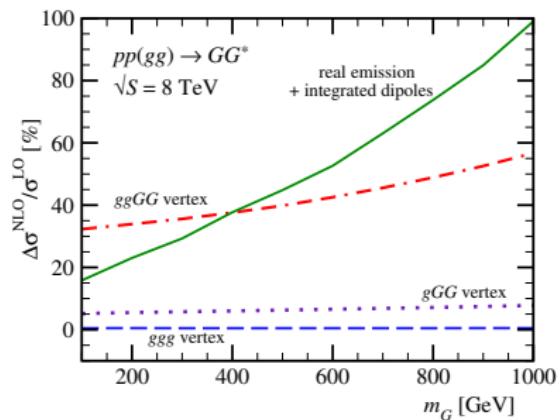
$pp \rightarrow GG^*$



♣ Dominance of the gGG & $ggGG$ vertex corrections and the real gluon emission

Anatomy of the virtual corrections

$pp \rightarrow GG^*$



♣ Dominance of the gGG & $ggGG$ vertex corrections and the real gluon emission

♣ Sensitivity to threshold enhancements $\iff \beta = \sqrt{1 - \frac{4m^2}{s}}$

- Coulomb singularity $\sigma \sim \pi/\alpha_s \beta$ from long-range virtual gluon exchange

- Log-enhancement from gluon real emission $\sigma \sim [A \log^2(\beta) + B \log(8\beta^2)]$

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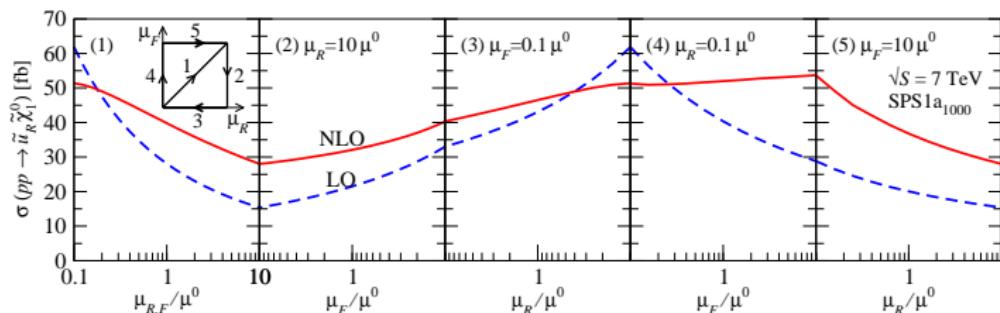
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- **Anatomy of the NLO quantum effects** – separated contributions for each one-loop topology & partonic sub-channel
- **Analytical expression for the one-loop amplitudes**
- **Scale dependences**
- **NLO distributions** & comparison to jet merging

Scale dependences

$$pp \rightarrow \tilde{u}_L \tilde{\chi}_1$$



- Canonical estimate of the theory uncertainties: $\Delta\sigma^{\text{th}} = \sigma(\mu = \mu_0/2) - \sigma(\mu = 2\mu_0)$
 - Remarkable scale stabilization
- $$\Delta\sigma^{\text{LO}}/\sigma^{\text{LO}} \sim \mathcal{O}(80\%) \Rightarrow \Delta\sigma^{\text{NLO}}/\sigma^{\text{NLO}} \sim \mathcal{O}(30\%)$$
- Larger sensitivity to μ_R

Binoth, Gonçalves-Netto, DLV, Mawatari, Plehn, Wigmore, PRD 84 (2011)
075005 arXiv:1108.1250 [hep-ph]

Portraying BSM phenomenology

First **complete fully automated NLO calculations** of **BSM $2 \rightarrow 2$**

$$pp \rightarrow \tilde{q}\tilde{\chi}_0$$

[arXiv:1108.1250](#)

$$pp \rightarrow GG^*$$

[arXiv:1203.6358](#)

$$pp \rightarrow [\tilde{q}\tilde{q}, \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}]$$

[arXiv:1211.0311](#)

$$pp \rightarrow l_8\bar{l}_8$$

[arXiv:1303.0845](#)

BSM phenomenology @ NLO

- **Total NLO rates and K factors**
- **unconstrained Parameter space surveys**
- **Anatomy of the NLO quantum effects** – separated contributions for each one-loop topology & partonic sub-channel
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- **NLO distributions & comparison to jet merging**

NLO distributions & Comparison to multi-jet merging



(fixed-order) NLO

VS

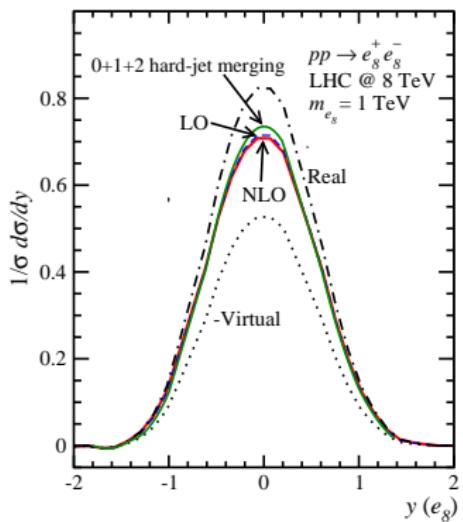
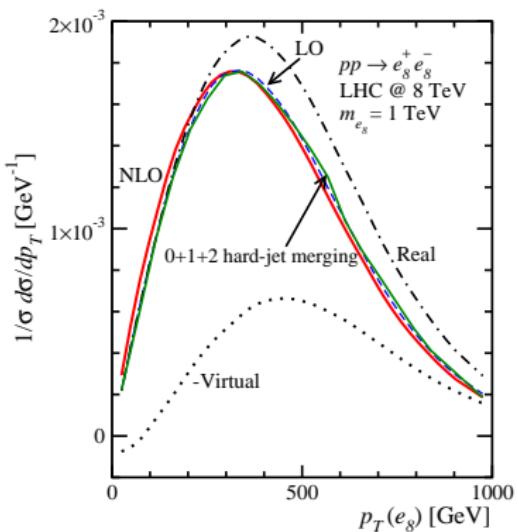
multi-jet merging

arXiv:1303.0845

$$\frac{d\sigma}{dp_T} \Big|_{pp \rightarrow e_8^+ e_8^- \text{ @NLO}}$$

VS

$$\frac{d\sigma}{dp_T} \Big|_{pp \rightarrow e_8^+ e_8^- + 2j} \text{ (MLM)}$$



NLO distributions & Comparison to multi-jet merging



(fixed-order) NLO

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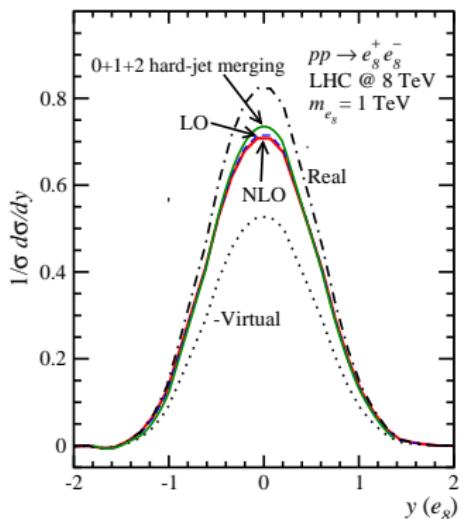
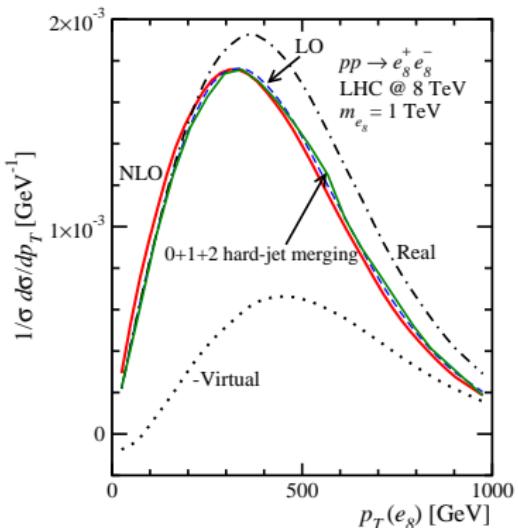
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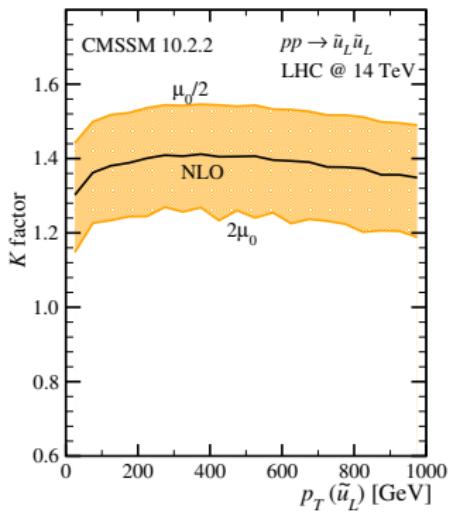
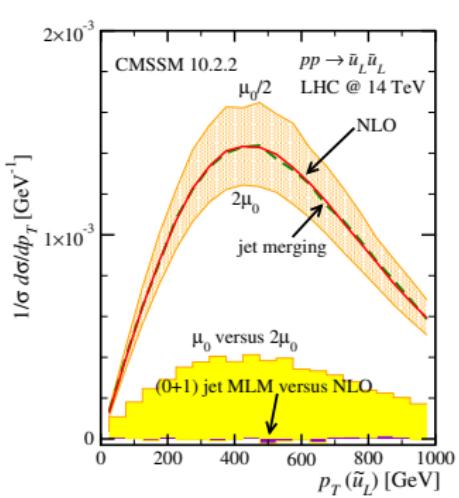


- Normalized distributions in **very good agreement**
- Common to **heavy particle** production – [Plehn, Rainwater, Skands '07], [Alwall, de Visscher, Maltoni '09]

Distributions & Theoretical uncertainties

$$pp \rightarrow \tilde{u}_L \tilde{u}_L$$

- Scale dependence on a bin-by-bin basis - $\frac{d\sigma}{dp_T}|_{\mu=\mu_0/2} - \frac{d\sigma}{dp_T}|_{\mu=2\mu_0}$
- \Rightarrow Theoretical uncertainties from the distribution viewpoint



Gonçalves-Netto, DLV, Mawatari, Plehn, Wigmore, arXiv:1211.0311

2D distributions

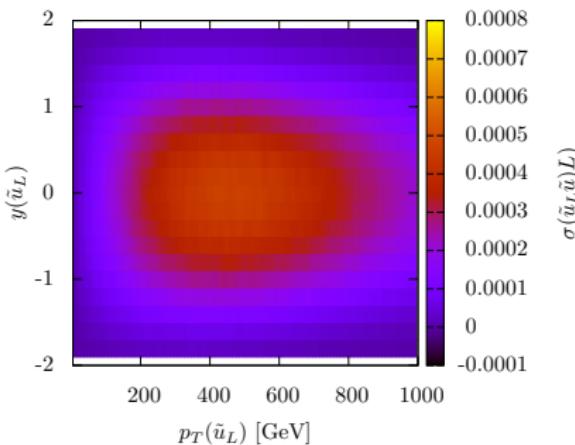
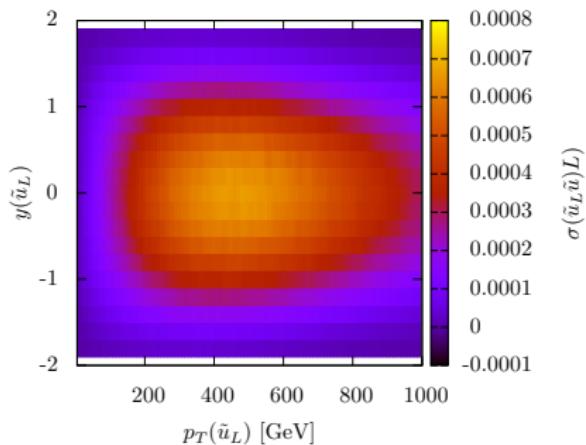
$$pp \rightarrow \tilde{u}_L \tilde{u}_L$$

Cross-section behavior across a p_T/y patch

$$- \frac{d\sigma}{dp_T dy}$$



Correlated observables at reach !



Gonçalves-Netto, DLV, Mawatari, Plehn, Wigmore, arXiv:1211.0311

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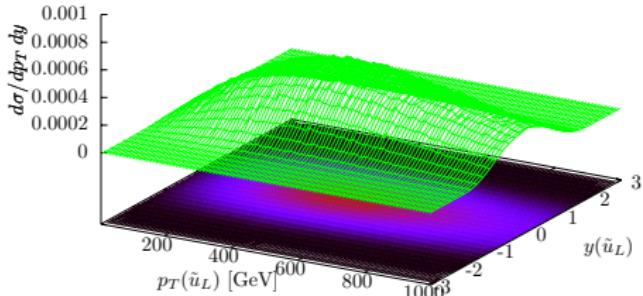
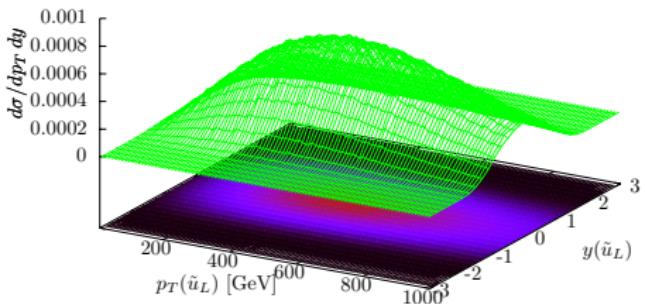


Cross-section behavior across a p_T/y patch

$$\frac{d\sigma}{dp_T dy}$$



Correlated observables at reach !



Outline

- 1 A glimpse at MadGolem: the tool from inside
- 2 A glimpse at MadGolem – the tool in use
- 3 A glimpse at MadGolem – phenomenology applications
- 4 One final glimpse

Take-home ideas

THE TOOL

MadGolem

- automates the calculation of NLO cross-sections and distributions for generic $2 \rightarrow 2$ processes
- Analytical, Feynman-diagrammatic one-loop amplitudes
- Fully automated UV renormalization, and subtraction of IR and OS divergences
- Highly modular, independent add-on to MadGraph/MadEvent
- Tailored for BSM studies:
 - Majorana fermions
 - SUSY-restoration
 - effective $\hat{O}^{d>4}$ operators
 - most easily extendable to new models.
- Tailored for NLO analyses:
 - NLO rates, K-factors & structure , scale dependences , distributions

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And looking ahead . . .



Future plans

Ongoing & next-in-line progress directions

- Prepare, release & support process-specific standalone modules
- Extend the supported BSM structures & scenarios: e.g. *higher-dimensional operators* for EFTs
- Consider some further phenomenology applications –
3rd generation squarks & 4 VS 5 flavor schemes
- Streamlining MadGolem with the MadGraph-based tools: FeynRules, MadAnalysis5, MadWeight, KaBoom

Thanks a lot !!

MadGolem contributes to extending bridges



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Theory

Experiment

Thanks a lot !!

MadGolem contributes to extending bridges



Theory

MERCI BEAUCOUP !!

Experiment