

NLO QCD corrections to 4 b-quark production

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in collaboration with

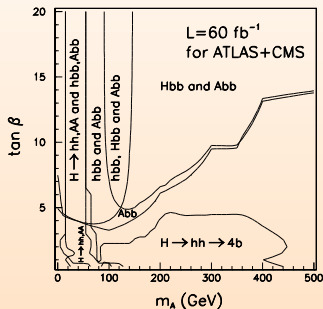
T.Binoth, A.Guffanti, J.P.Guillet, T.Reiter, J.Reuter

PHENO 2010, Madison, 5/10/2010



Motivation

4b Final State 5 σ LHC Discovery Contours
 $m_{\text{stop}}=1$ TeV, no squark mixing
 $m_t=175$ GeV, $\epsilon_{b\text{-log}}=0.6$, $\epsilon_{\text{mis-log}}=0.01$



[Dai, Gunion, Vega]

- NLO result reduces theoretical uncertainties. (scale dependence)
- For certain MSSM scenarios:
 $H \rightarrow b\bar{b}b\bar{b}$ enhanced.
- maybe the only discovery channel
- also important for other BSM scenarios
- important to know SM background

$$\underline{pp \rightarrow 4b + X}$$

$$LO : \left. \begin{array}{l} q \bar{q} \rightarrow 4b \\ g g \rightarrow 4b \end{array} \right\} \text{Virtual corrections.}$$

$$NLO : \left. \begin{array}{l} q \bar{q} \rightarrow 4b + g \\ g g \rightarrow 4b + g \\ q g \rightarrow 4b + q \end{array} \right\} \text{Real emission.}$$

Simplifications:

- b-quark massless
- neglect b-quark in initial state ($q \neq b$)

$q\bar{q} \rightarrow 4b + X$ [Binoth,NG,Guffanti,Guillet,Reiter,Reuter]

$$\sigma_{NLO} = \int_{n+1} \left(d\sigma^R \quad -d\sigma^A \right) + \int_n \left(d\sigma^B \quad +d\sigma^V \quad + \int_1 d\sigma^A \right)$$

2 independent calculations, both free of divergencies.

Virtual corrections:

GOLEM [Binoth et. al]

Real emission and Born:

MadGraph [Long,Stelzer], **Whizard** [Kilian,Ohl,Reuter]

Subtraction terms:

MadDipole [Frederix,Gehrmann,NG], **Whizard**

Integration:

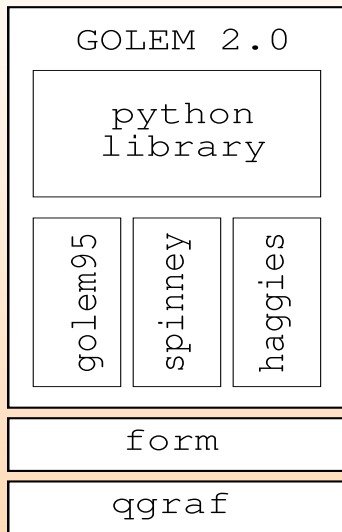
MadEvent [Maltoni,Stelzer]

- All ingredients stand alone applications → 'Plug and Play'.

Virtual corrections

General One Loop Evaluator for Matrix-Elements

- Based on Qgraf and Form
- Library for one-loop integrals (golem95)
- Matrix element generator for one-loop amplitudes
- Second, independent code based on FeynArts and FeynCalc for cross-checks



Subtraction terms

MadDipole : Package that automatically generates subtraction terms ($d\sigma^A$) and integrated subtraction terms ($\int_1 d\sigma^A$) in form of Catani-Seymour dipoles.

User: specify the NLO process

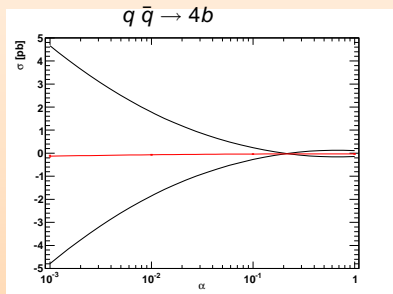
MadDipole: returns Fortran code for all necessary terms.

- Several checks
- Second implementation in Whizard.
 - Check against MCFM.
 - Varying the cut-parameter α of subtraction terms provides powerful checks on many levels.

- Subtraction terms are only needed near singularity
→ Cut away parts of phase space where there is no sing.
- Introduce parameter α : $\mathcal{D}_{ij} \rightarrow \mathcal{D}_{ij}\theta(\alpha > S_{ij})$ [Nagy,Trocsanyi]

Integrated subtraction terms also depend on α , total result however independent:

$$\int_{n+1} (d\sigma^R - d\sigma^A) + \int_n (\text{finite parts of int. dip.}) = \text{const}$$



Phase space integration

Numerical phase space integration done using MadEvent where GOLEM- and MadDipole-code has been plugged in.

- Sanity checks of correct interplay virtual \leftrightarrow reals by comparing Born and coefficients of $1/\epsilon$ - and $1/\epsilon^2$ -terms.
- Born cross section checked with Whizard.
- Calculation done using 't Hooft-Veltman- and \overline{MS} -scheme.
- Cut parameter set to $\alpha = 10^{-2}$.
→ Leads to increase of speed and stability of integration.
- Used $3 \cdot 10^8$ points for real emission, $1.2 \cdot 10^6$ for virtuals, parallelized in 30/60 runs.
- CPU time per ps point: $\sim 5ms$ for reals, $\sim 4s$ for virtuals.

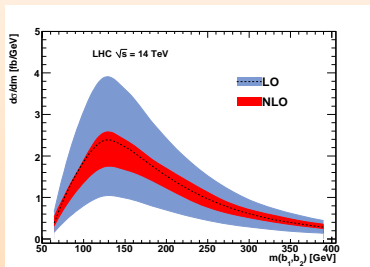
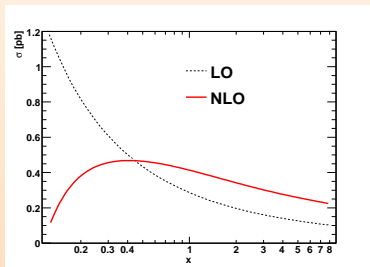
Results

Imposed cuts:

- K_T -algorithm with $R = 0.8$.
- $P_T \geq 30$ GeV, $|\eta| \leq 2.5$ $\Delta R > 0.8$.

Renormalization scale: $\mu_R = X \cdot \mu_0$, $\mu_0 = \sqrt{\sum_i P_{T,i}^2}$

Factorization scale: $\mu_F = 100$ GeV.

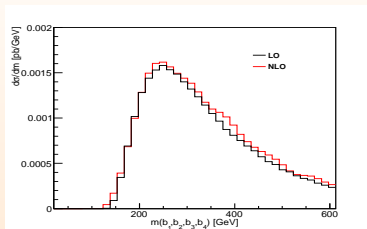
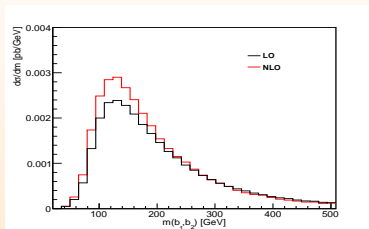


$$\mu_0/4 \leq \mu_R \leq 2\mu_0$$

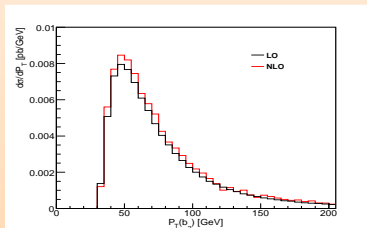
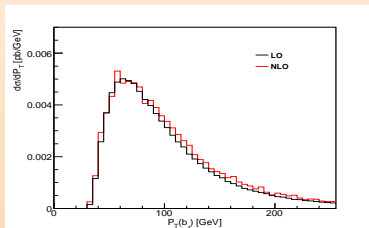


Looking at distributions: choose $\mu_R = \mu_0/2$.

Invariant mass distribution:



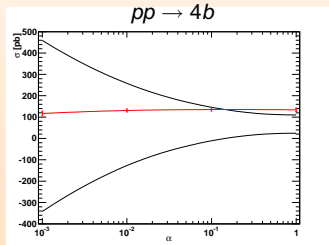
P_T -distribution



$$\underline{pp \rightarrow 4b + X}$$

Real emission part:

- Implementation with MadGraph/Dipole/Event finished and integration working



- CPU-time for real emission: ~ 20 ms per phase space point.
- Integration checked with HELAC/PHEGAS [Kanaki,Papadopoulos]

Virtual part:

- Working on comparison with second independent code.
- Second method for reduction of the integrand as another check
- Trying to reduce size and CPU time

Possible improvements:

- Instead of numerical integration take sample of unweighted events of the Born and perform reweighting with virtual corrections.
→ Faster and possibly avoids numerical problems.

Summary

- NLO QCD correction necessary for multi-leg final states at LHC
- Production of 4 b quarks important signal for MSSM/Higgs.
- Both virtual corrections and real emission / subtraction terms done in two different ways.
- Quark initiated case finished.
- Shapes of distributions stable under QCD corrections.
- For full $pp \rightarrow 4b$ further testing required.