NLO QCD corrections to 4 b-quark production

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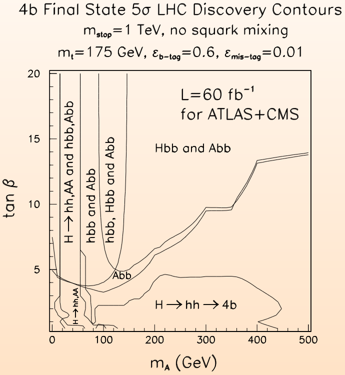
Outline

- **Motivation**
- $q\bar{q} \longrightarrow 4b$
  - **Calculation**
  - **Results**
- **Outlook** $pp \longrightarrow 4b$

Motivation

- NLO QCD corrections can lead to sizeable deviations from LO result.
  $\rightarrow$ LO result often just rough estimate.
- NLO result reduces theoretical uncertainties. (scale dependence)
- Precision measurements require precise theoretical predictions for SM contribution.
- BSM models (SUSY) naturally have multiparticle final states.
- NLO (NNLO) result desirable for important processes.
  $2 \rightarrow 4$ currently state of the art (NLO).

Motivation



[Dai,Gunion,Vega]

- 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

Calculation

$$\underline{pp \longrightarrow 4b \;\; + X}$$

$$\left.\begin{array}{rl} LO: & q\,\bar{q} \longrightarrow 4b \\ & g\,g \longrightarrow 4b \end{array}\right\} \text{Virtual corrections.}$$

$$\left.\begin{array}{rl} NLO: & q\,\bar{q} \longrightarrow 4b \;\; + g \\ & g\,g \longrightarrow 4b \;\; + g \\ & q\,g \longrightarrow 4b \;\; + q \end{array}\right\} \text{Real emission.}$$

Simplifications:

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

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

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

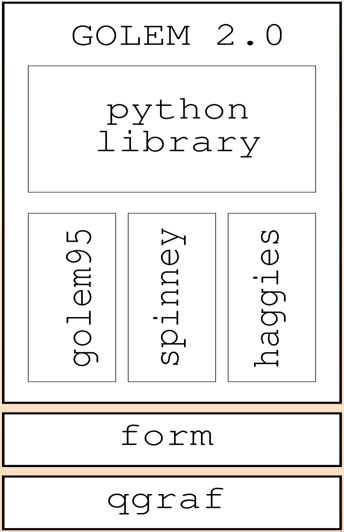
2 independent calculations, both free of divergencies.

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 $\to$ 'Plug and Play'.

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.

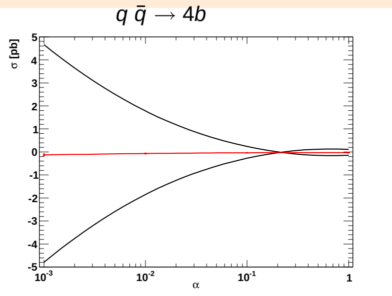
User: specify the NLO process
MadDipole: returns Fortran code for all necessary terms.

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
  $\longrightarrow$ Cut away parts of phase space where there is no sing.
- Introduce parameter α: $\mathcal{D}_{ij} \longrightarrow \mathcal{D}_{ij}\theta(\alpha > s_{ij})$ [Nagy,Trocsanyi]

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

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



Phase space integration

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

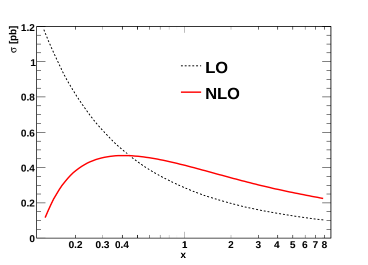
- Sanity checks of correct interplay virtual $\leftrightarrow$ reals by comparing Born and coefficients of $1/\epsilon$- and $1/\epsilon^2$-terms.
- Born cross section checked with Whizard.
- Calculation done using 't Hooft-Veltman- and $\overline{MS}$-scheme.
- Cut parameter set to $\alpha = 10^{-2}$.
  $\longrightarrow$ 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.

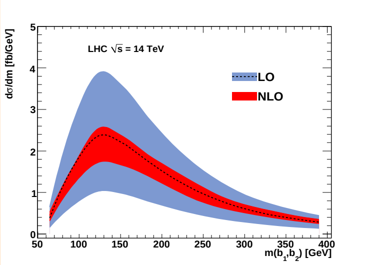
Imposed cuts:

- 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.

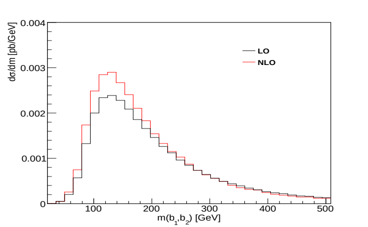


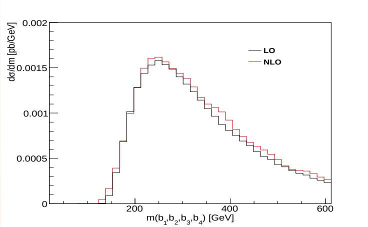


$$\mu_0/4 \leq \mu_R \leq 2\mu_0$$

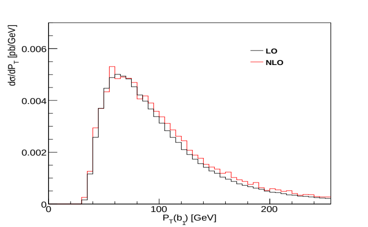
Looking at distributions: choose $\mu_R = \mu_0/2$.

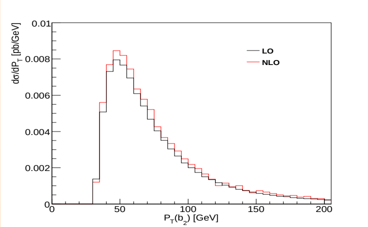
Invariant mass distribution:





P_T-distribution



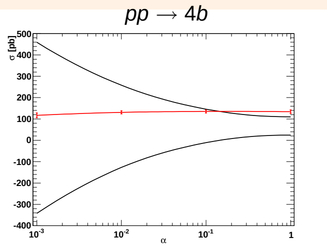


Outlook

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

Real emission part:

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



- CPU-time for real emission: $\sim$ 20ms per phase space point.
- Working on check with second implementation with HELAC/PHEGAS.

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.
  $\longrightarrow$ 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.