Precise predictions for the LHC phenomenology

Silvia Ferrario Ravasio & Federico Granata

High-Energy Phenomenology Group
Department of Physics
Milano-Bicocca University

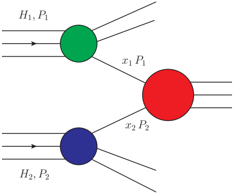
26/05/2016

QCD cross section

- Inside the LHC, two high-energy proton beams travel at 0.99999999 c before colliding; protons are composed by partons (quarks and gluons), that are affected by strong interactions, governed by QCD

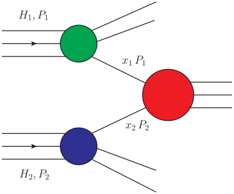
QCD cross section

- Inside the LHC, two high-energy proton beams travel at 0.99999999 c before colliding; protons are composed by partons (quarks and gluons), that are affected by strong interactions, governed by QCD
- Hard scattering events can be described in terms of free interacting partons



QCD cross section

- Inside the LHC, two high-energy proton beams travel at 0.99999999 c before colliding; protons are composed by partons (quarks and gluons), that are affected by strong interactions, governed by QCD
- Hard scattering events can be described in terms of free interacting partons



Factorization theorem

$$\sigma(P_1, P_2) = \sum_{i,j} \int_0^1 dx_1\, dx_2\, f_i^{H_1}(x_1)\, f_j^{H_2}(x_2)\, \hat{\sigma}^{ij}(x_1 P_1, x_2 P_2)$$

NLO QCD cross section

NLO QCD cross section

$$\sigma^{\mathrm{NLO}} = \int \frac{f(x_1)f(x_2)}{2\hat{s}} \left(\mathcal{B} + \frac{\alpha_S}{2\pi} \mathcal{V} \right) d\mathbf{\Phi}_n + \int \frac{f(x_1)f(x_2)}{2\hat{s}} \frac{\alpha_S}{2\pi} \mathcal{R} \, d\mathbf{\Phi}_{n+1}$$

NLO QCD cross section

NLO QCD cross section

$$\sigma^{\rm NLO} = \int \frac{f(x_1) f(x_2)}{2\hat{s}} \left(\mathcal{B} + \frac{\alpha_S}{2\pi} \mathcal{V} \right) d\mathbf{\Phi}_n + \int \frac{f(x_1) f(x_2)}{2\hat{s}} \, \frac{\alpha_S}{2\pi} \mathcal{R} \, d\mathbf{\Phi}_{n+1}$$

- $d\mathbf{\Phi}_n = dx_1 \, dx_2 \, d\Phi_n$

NLO QCD cross section

NLO QCD cross section

$$\sigma^{\rm NLO} = \int \frac{f(x_1)f(x_2)}{2\hat{s}} \left(\mathcal{B} + \frac{\alpha_S}{2\pi} \mathcal{V} \right) d\mathbf{\Phi}_n + \int \frac{f(x_1)f(x_2)}{2\hat{s}} \frac{\alpha_S}{2\pi} \mathcal{R} \, d\mathbf{\Phi}_{n+1}$$

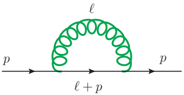
- $d\mathbf{\Phi}_n = dx_1 \, dx_2 \, d\Phi_n$
- $\mathcal{B} = |\mathcal{M}_B|^2$

NLO QCD cross section

NLO QCD cross section

$$\sigma^{\mathrm{NLO}} = \int \frac{f(x_1)f(x_2)}{2\hat{s}} \left(\mathcal{B} + \frac{\alpha_S}{2\pi} \mathcal{V} \right) d\mathbf{\Phi}_n + \int \frac{f(x_1)f(x_2)}{2\hat{s}} \frac{\alpha_S}{2\pi} \mathcal{R}\, d\mathbf{\Phi}_{n+1}$$

- $d\mathbf{\Phi}_n = dx_1\, dx_2\, d\Phi_n$
- $\mathcal{B} = |\mathcal{M}_B|^2$
- $\mathcal{V} = 2\,\mathrm{Re}\,(\mathcal{M}_V \mathcal{M}_B^*)$

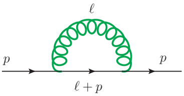


NLO QCD cross section

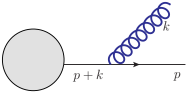
NLO QCD cross section

$$\sigma^{\mathrm{NLO}} = \int \frac{f(x_1)f(x_2)}{2\hat{s}}\left(\mathcal{B} + \frac{\alpha_S}{2\pi}\mathcal{V}\right) d\mathbf{\Phi}_n + \int \frac{f(x_1)f(x_2)}{2\hat{s}}\,\frac{\alpha_S}{2\pi}\mathcal{R}\, d\mathbf{\Phi}_{n+1}$$

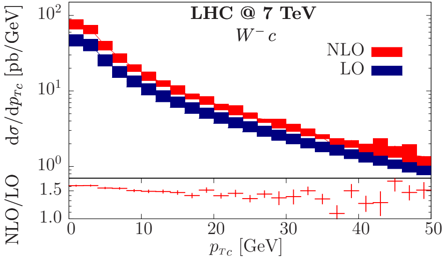
- $d\mathbf{\Phi}_n = dx_1\, dx_2\, d\Phi_n$
- $\mathcal{B} = |\mathcal{M}_B|^2$
- $\mathcal{V} = 2\,\mathrm{Re}\,(\mathcal{M}_V \mathcal{M}_B^*)$



- $\mathcal{R} = |\mathcal{M}_R|^2$



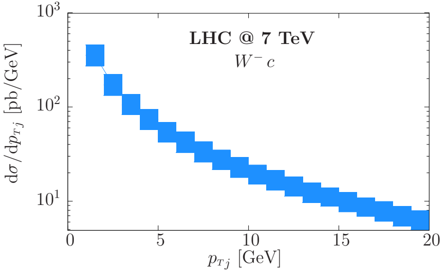
$pp \to W^- c \to e^- \bar{\nu}_e c$ @ 7 TeV



Transverse momentum of the charm jet

$$p_T = \sqrt{p_x^2 + p_y^2}$$

Transverse momentum of the radiation jet

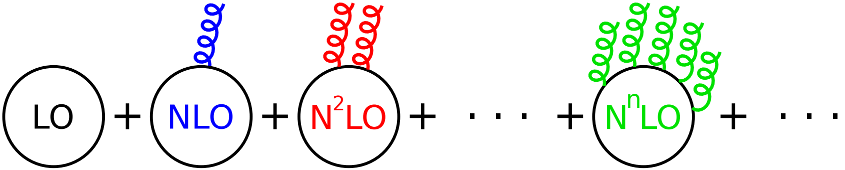


Shower Monte Carlo program vs Fixed order computations

- NLO computations have low particle multiplicity

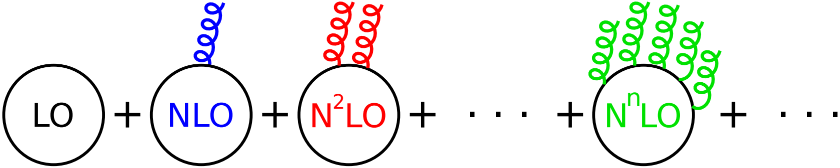
Shower Monte Carlo program vs Fixed order computations

- NLO computations have low particle multiplicity
- There are algorithms capable to resum to all order in perturbation theory all most important real and virtual emission corrections (in the leading log approximation), such resummation allows a higher number of particles in the final state



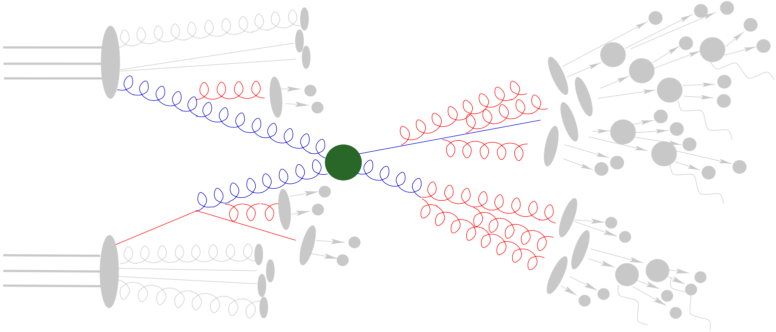
Shower Monte Carlo program vs Fixed order computations

- NLO computations have low particle multiplicity
- There are algorithms capable to resum to all order in perturbation theory all most important real and virtual emission corrections (in the leading log approximation), such resummation allows a higher number of particles in the final state

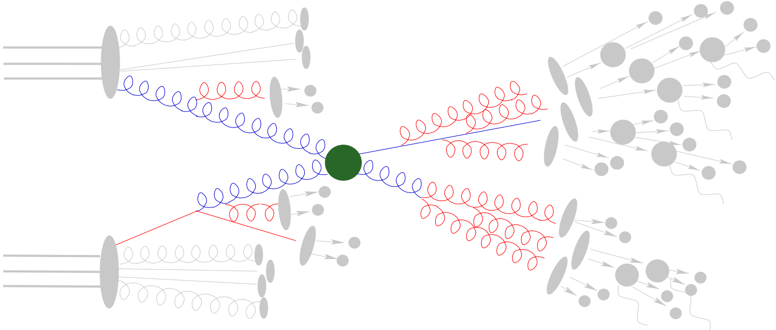


- These so called shower algorithms are implemented in Shower Monte Carlo (SMC) programs, which are suited for a direct comparison with the experimental data

- Sketch of a hadron-hadron collision as simulated by a MC event generator

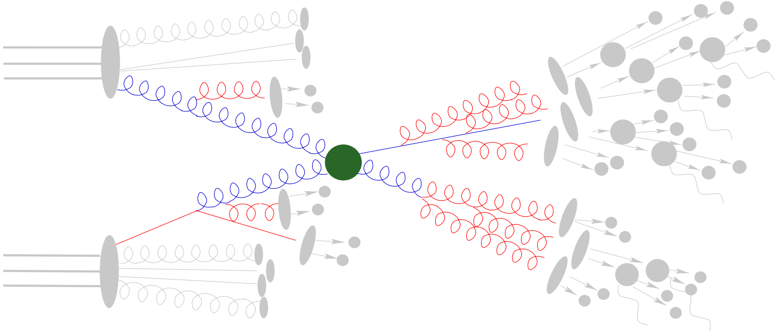


- Sketch of a hadron-hadron collision as simulated by a MC event generator



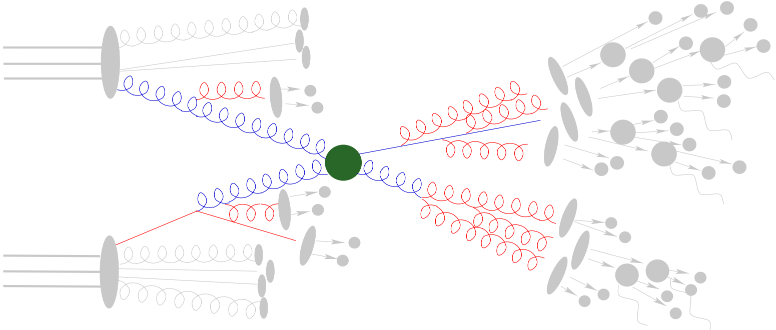
- SMC programs resum all the leading IR divergencies (Leading Log): in this way we obtain a better behavoiur in the IR region

- Sketch of a hadron-hadron collision as simulated by a MC event generator



- SMC programs resum all the leading IR divergencies (Leading Log): in this way we obtain a better behavoiur in the IR region
- SMC contain also phenomenological models of hadron formation and their decay

- Sketch of a hadron-hadron collision as simulated by a MC event generator



- SMC programs resum all the leading IR divergencies (Leading Log): in this way we obtain a better behavoiur in the IR region
- SMC contain also phenomenological models of hadron formation and their decay
- If we are interested in inclusive distributions (like, for example, the total cross sections), we should employ NLO computations

The POWHEG BOX

- It is possible to merge all the best features of fixed NLO computations and SMC to achieve exclusive final state generation together with the accuracy of an NLO computation

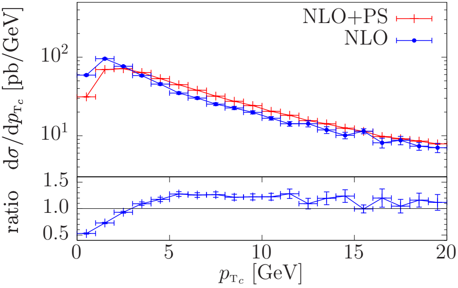
The POWHEG BOX

- It is possible to merge all the best features of fixed NLO computations and SMC to achieve exclusive final state generation together with the accuracy of an NLO computation
- In doing that, one may encounter the problem of overcounting the contribution of real radiation; one possible solution is represented by the POWHEG method, proposed by Paolo Nason and implemented in the POWHEG BOX code

The POWHEG BOX

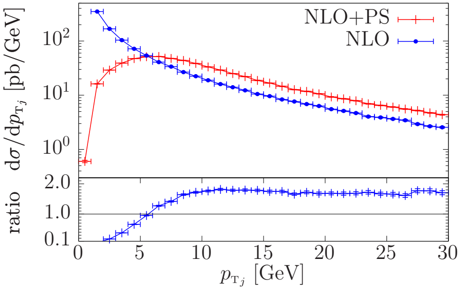
- It is possible to merge all the best features of fixed NLO computations and SMC to achieve exclusive final state generation together with the accuracy of an NLO computation
- In doing that, one may encounter the problem of overcounting the contribution of real radiation; one possible solution is represented by the POWHEG method, proposed by Paolo Nason and implemented in the POWHEG BOX code
- The basic idea in POWHEG is to generate the hardest emission first, and then feed the event to any shower generator for subsequent, softer radiation; the POWHEG output can be interfaced to any modern shower generator

$pp \to W^- c \to e^- \bar{\nu}_e c$ @ 7 TeV



Transverse momentum of the charm jet

Transverse momentum of the radiation jet

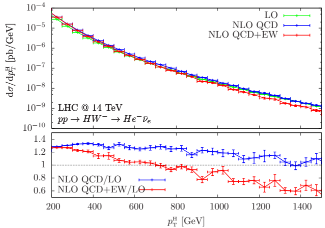


What has been done

- The POWHEG BOX can be used to integrate the partonic cross sections over the phase space and to convolute the result with the PDFs, obtaining fully-differential NLO cross sections

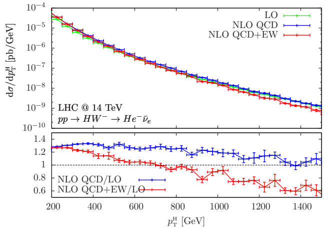
What has been done

- The POWHEG BOX can be used to integrate the partonic cross sections over the phase space and to convolute the result with the PDFs, obtaining fully-differential NLO cross sections
- The accuracy of the fixed order computations performed within the POWHEG framework can reach NLO QCD, NLO EW, NLO QCD+EW, approximate NNLO QCD



What has been done

- The POWHEG BOX can be used to integrate the partonic cross sections over the phase space and to convolute the result with the PDFs, obtaining fully-differential NLO cross sections
- The accuracy of the fixed order computations performed within the POWHEG framework can reach NLO QCD, NLO EW, NLO QCD+EW, approximate NNLO QCD



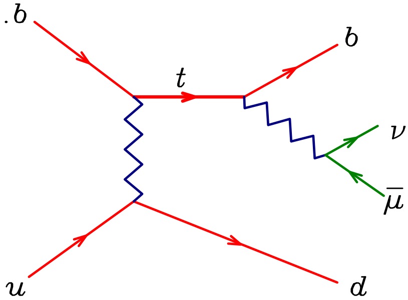
- POWHEG BOX can be used and as an event generator to merge consistently NLO computations with SMC programs: the two main PS programs are PYTHIA and HERWIG

What we are doing

- In the forthcoming version of POWHEG BOX, POWHEG BOX-RES, the phase space integration has been optimized and totally automatized

What we are doing

- In the forthcoming version of POWHEG BOX, POWHEG BOX-RES, the phase space integration has been optimized and totally automatized
- This new version of the code is particularly suited in case of heavy particles, like the top quark, because it enables a more precise extrapolation of their masses. We keep trace of the decay-history of the internal massive resonances that appear in the Feynman diagrams to optimize the numeric integration of their virtualities



What we will do

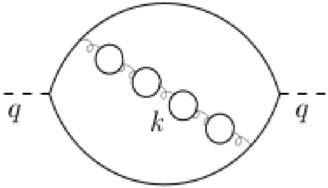
- The POWHEG BOX interface with the new version of HERWIG is still missing, but we need to build it in order to study the different behavior of the two main PS programs

What we will do

- The POWHEG BOX interface with the new version of HERWIG is still missing, but we need to build it in order to study the different behavior of the two main PS programs
- Both PYTHIA and HERWIG will be used to perform a detailed study of the processes that involve top quarks: nowadays the definition of the top mass contains still ambiguities that we want to reduce

What we will do

- The POWHEG BOX interface with the new version of HERWIG is still missing, but we need to build it in order to study the different behavior of the two main PS programs
- Both PYTHIA and HERWIG will be used to perform a detailed study of the processes that involve top quarks: nowadays the definition of the top mass contains still ambiguities that we want to reduce
- From the theoretical point of view, renormalons can represent an intrinsic limit to the definition of the top pole mass



Why top physics?

- The top mass is a crucial parameter for test of the SM and models of new physics

Why top physics?

- The top mass is a crucial parameter for test of the SM and models of new physics
- The study of the vacuum stability below the Plank scale within the SM also requires an accurate value: the SM vacuum lies between the border between the stable and meta-stable regions, and the dominant uncertainty is the one coming from the top mass!