The EW Sudakov approximation in SHERPA

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April 13, 2016

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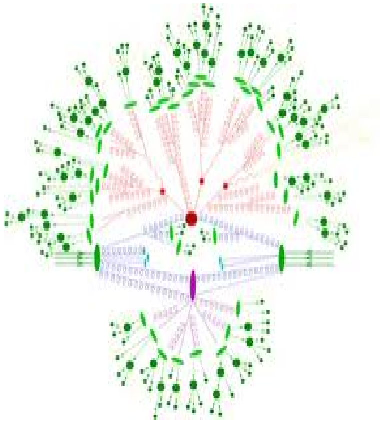
Overview

Why a Monte Carlo?

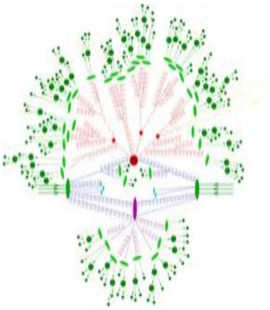
1. Analytical calculations deal with low numbers of final state particles.
2. Experiments have high multiplicity final state with jets and missing energy.
3. In order to test theoretical predictions we need a way to compare the 2.
4. Monte Carlo simulations provide this bridge between theory and experiment.



Precision Calculations in Monte Carlo Simulation

There are several components to a Monte Carlo simulation

- Hard Process - Perturbative.
- Underlying Event.
- Parton shower - All order resummation.
- Decays of unstable particles.
- Hadronisation.
- Decays of unstable hadrons.



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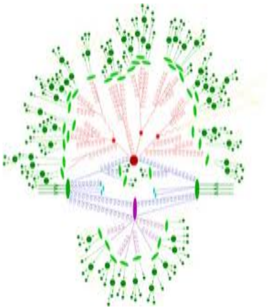


Numerical NLO Calculation

Numerical NLO

In a numerical implementation, divergences need to be dealt with at the integrand phase.

$$\sigma_{NLO} = \int (\mathrm{B} + \mathrm{V}) d\Phi_\mathrm{B} + \int \mathrm{R} d\Phi_\mathrm{R}$$

The integrals over V and R separately contain divergences, which will cancel after the integration has been performed.

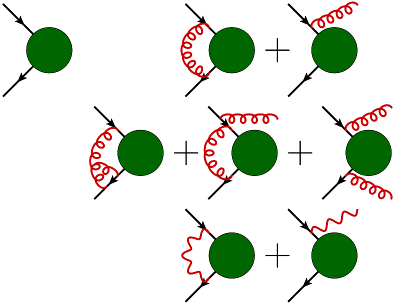
Subtraction Method

$$\sigma_{\mathrm{NLO}} = \int (\mathrm{B} + \mathrm{V} + \int \mathrm{S} d\Phi_1) d\Phi_{\mathrm{B}} + \int (\mathrm{R} - \mathrm{S}) d\Phi_{\mathrm{R}}$$

- Introduce a term that:
  1. Exactly matches the divergent structure of the real term.
  2. Does not introduce any additional divergences.
  3. Can be analytically integrated over the 1 parton subspace.
- Subtract this term from the real contribution.
- Integrate over the 1 parton sub space and add this in to the virtual term.

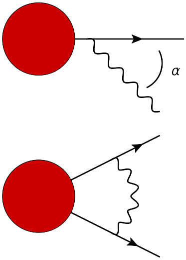
N(N)LO QCD and EW

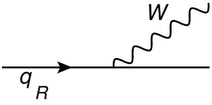
- Current Monte Carlo simulations are NLO QCD with a parton shower.
- Extending to NNLO QCD $\longrightarrow$ precision sensitive to EW corrections. $(\mathcal{O}(\alpha_s^2) \sim \mathcal{O}(\alpha))$



Considerations in NLO EW

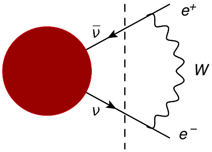
Masses of weak bosons regulate divergences





Weak interactions depend on helicity

Weak boson exchange can alter the external flavours



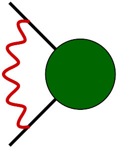
interferences with different Born MEs.

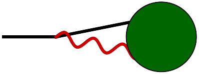
Sudakov Approximation

- The virtual contribution yields logarithms
  $\longrightarrow \log\left(\frac{s}{M_V^2}\right)$
  M_V is boson mass, $\sqrt{s}$ is COM energy.
- Divergent in limit of vanishing mass.
  $\longrightarrow$ therefore dominant in the high energy regime
- Outside of this regime, a full NLO EW calculation is necessary.
- Non-logarithmic contributions always at $\sim 1\%$ level, so EW Sudakov approximation is limited by this.

Contributing Diagrams - Mass Singularities

Relevant diagrams as shown in J. Math. Phys. 3, 650 (1962)





- Produced from the exchange of bosons.
- Bosons can become soft and/or collinear, giving logarithms.
- This leads to divergences for vanishing mass.
- Real contribution for $V = W^{\pm}, Z$ emission distinguishable.
- We are left with large logarithms of $\log s/M_V^2$.
- Call these Sudakov logarithms

One-Loop Approximation

hep-ph/0010201v3

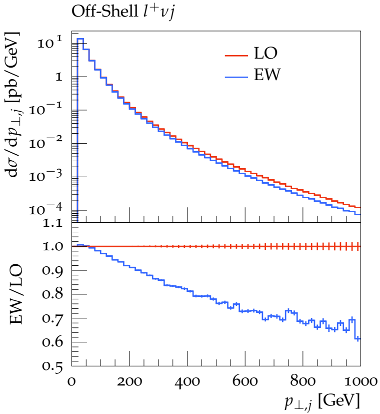
- My implementation follows A. Denner and S. Pozzorini.
- Analytical calculations for one and two loops for some processes available.
- First approximation is the one-loop calculation.

One-loop

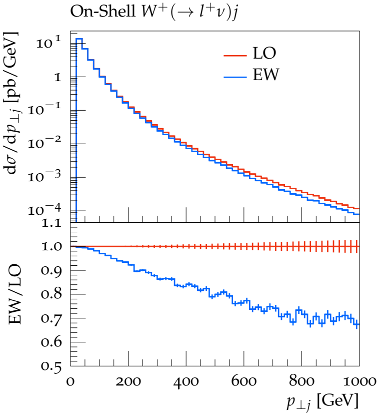
$$\frac{\alpha}{4\pi}\left[A\log^2\left(\frac{(p_i+p_j)^2}{M^2}\right)+B\log\left(\frac{(p_i+p_j)^2}{M^2}\right)\right]$$

p_i, p_j are the momenta for external legs i and j. M is the mass of the EW bosons.

Results - $pp \to Wj$ at 14 TeV LHC



Off-shell production



On-shell production

Sudakov Logarithmic Approximation vs. Full NLO

- Sudakov approximation is only valid in the high enery limit.
- Sudakov approximation is only valid for well-separated EW particles.
- Sudakov approximations do not capture full NLO behaviour.
- Sudakov approximation is far less computationally intensive.
- Sudakov approximations are simple to include on top of NLO QCD calculations.

$\longrightarrow$ Need implementations of both

NLO EW with SHERPA

arXiv:1511.08692, arXiv:1505.05704, arXiv:1412.5157

- There is currently an implementation (not public) of full NLO EW computations with SHERPA+OpenLoops
- Currently papers on V+jets
- Current work to also interface to Recola
- Recola generates NLO MEs and will be a loop provider in the interface.
- Aim to automate EW corrections in the same way as NLO QCD corrections.

Conclusions

- EW Corrections are of a similar size to NNLO QCD Corrections.
- EW Sudakov logarithms are a good approximation in the high-energy limit
- These have been implemented within SHERPA
- More accurate predictions require NLO EW + NLO QCD corrections.