EW NLO in SHERPA

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Outline

NLO Cross Section

$$\sigma_{NLO} = \int_m \mathrm{d}\sigma_{LO} + \int_{m+1} \mathrm{d}\sigma_R - \int_{m+1} \mathrm{d}\sigma_A + \int_m \mathrm{d}\sigma_V + \int_{m+1} \mathrm{d}\sigma_A$$

Building blocks of calculation

- real emission correction
  - m+1 particle matrix element
  - trivial for MC to calculate
- virtual correction
  - one-loop matrix element
  - difficult to calculate
  - $\rightarrow$ use someone else's!

Solution

- standardised interface to one-loop programs
- follow guidelines from Binoth Les Houches Accord

Interface between Monte Carlo and one-loop program - a win-win situation

Advantages for Monte Carlo event generator

- can provide NLO accuracy without having to calculate loop MEs

Advantages for one-loop provider

- efficient phase space integration
- event generation
- analysis framework

arXiv:1003.1241

Interface between Monte Carlo and one-loop program - how does it work?

- Before run-time
  - settings and parameters are agreed before run-time via an order-contract system
- During run-time
  - for each phase space point, the set of external momenta is passed from the MC to the one-loop provider
  - one-loop provider returns an array of pole coefficients

Extra considerations for EW

- treatment of resonances
  - complex mass scheme preferred
- mass regularisation
  - many providers of EW loop calculations prefer mass regularisation
  - requires more parameters and settings to be exchanged
- electroweak renormalisation scheme
  - examples include $\alpha(0)$, α_{G_μ}, or OLP-defined

NLO Cross Section

$$\sigma_{NLO} = \int_m d\sigma_{LO} + \int_{m+1} d\sigma_R - \int_{m+1} d\sigma_A$$
$$+ \int_m d\sigma_V + \int_{m+1} d\sigma_A$$

Building blocks of calculation

- real emission correction ☐
- virtual correction ☐
- cancellation of divergences ☐

NLO Cross Section

$$\sigma_{NLO} = \int_m d\sigma_{LO} + \int_{m+1} d\sigma_R - \int_{m+1} d\sigma_A + \int_m d\sigma_V + \int_{m+1} d\sigma_A$$

Building blocks of calculation

- real emission correction ☑
- virtual correction ☑
- cancellation of divergences ☐

NLO Cross Section

$$\sigma_{NLO} = \int_m d\sigma_{LO} + \int_{m+1} d\sigma_R - \int_{m+1} d\sigma_A + \int_m d\sigma_V + \int_{m+1} d\sigma_A$$

Building blocks of calculation

- Real emission correction
  - matrix element diverges for certain regions of phase space
  - due to divergence, cannot be integrated numerically
- Virtual correction
  - form of poles dependent on chosen regularisation scheme
    - for dimensional regularisation, $\frac{1}{\epsilon}$ poles, where $d = 4 - 2\epsilon$
    - for mass regularisation, divergence appears as $\log \frac{m^2}{Q^2}$

Problem: How do we cancel the divergences before integration?

NLO Cross Section

$$\sigma_{NLO} = \int_m d\sigma_{LO} + \int_{m+1} d\sigma_R - \int_{m+1} d\sigma_A + \int_m d\sigma_V + \int_{m+1} d\sigma_A$$

Building blocks of calculation

Solution: Catani-Seymour dipole subtraction

- define subtraction term which
  - exactly matches divergent behaviour of real emission matrix element in all divergent regions of the phase space
  - contains no other divergences and is otherwise convenient for Monte Carlo integration
- integrate subtraction term over one-particle phase space analytically to cancel poles in virtual contribution

hep-ph/9605323
hep-ph/9904440

Extra considerations for QED

Simpler terms

- subtraction terms have simpler structures than QCD as no colour correlations

Photon recombination

- subtraction procedure assumes collinear-safe observables
- similar to jet algorithm, photons collinear to charged final state particles must be recombined to form a pseudo-particle

Mass regularisation

- equivalent forms for integrated subtraction terms
- divergences appear as $\log \frac{m^2}{Q^2}$

Photon PDF

- for full NLO process, must include effects from initial state photons
- currently only one PDF set which includes QED effects - MRST 2004 QED

hep-ph/0411040

NLO Cross Section

$$\sigma_{NLO} = \int_m d\sigma_{LO} \quad + \quad \int_{m+1} (d\sigma_R - d\sigma_A)$$
$$+ \quad \int_m \left(d\sigma_V + \int_1 d\sigma_A \right)$$

Building blocks of calculation

- real emission correction ☑
- virtual correction ☑
- cancellation of divergences ☑

Simple test process

Implementation tested against RADY, a program for calculating radiative corrections to Drell-Yan processes at hadron colliders.

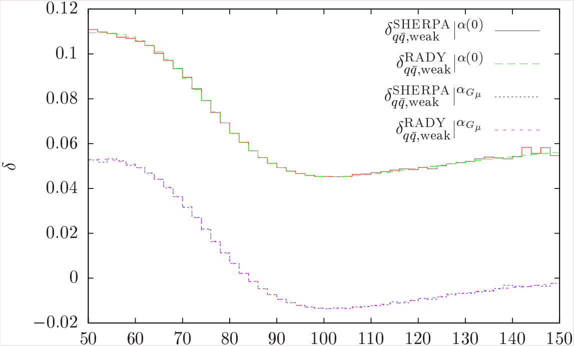


Figure: Comparison of weak correction factor in the $\alpha(0)$ and α_{G_μ} schemes to the di-lepton invariant mass distribution obtained by Sherpa and RADY

Simple test process

Implementation tested against RADY, a program for calculating radiative corrections to Drell-Yan processes at hadron colliders.

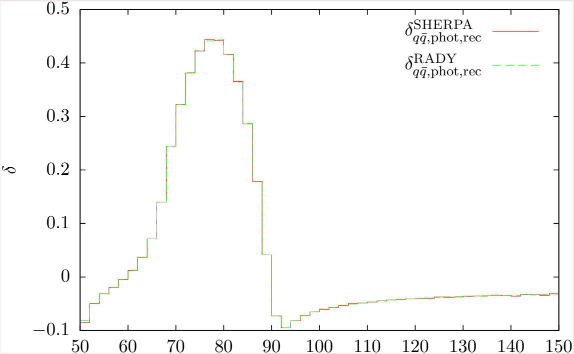
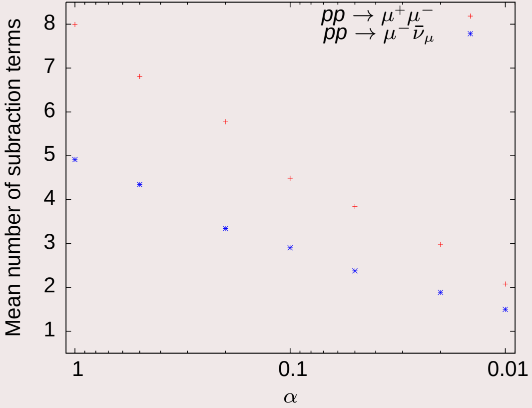


Figure: Comparison of photonic correction factor to the di-lepton invariant mass distribution with photon recombination in the OLP-defined scheme obtained by Sherpa and RADY

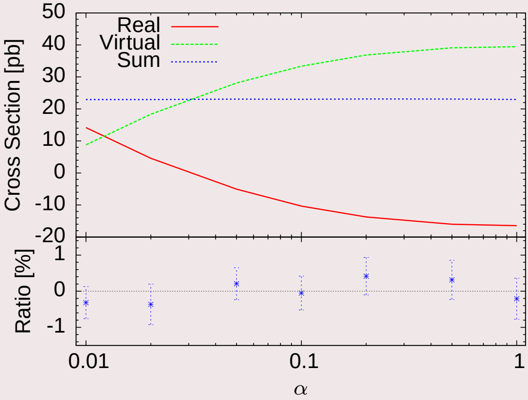
Phase space restriction

- Number of dipoles increases rapidly with number of external charged particles.
- Real subtraction dipole term required close to divergence, but unnecessary in finite areas of phase space.
- Introduce parameter α, which limits the phase space in which a dipole term contributes.
- α is an unphysical parameter, and full NLO result should be independent of it's value.

Impact of phase space restriction



Testing α variation



Technical cut-off

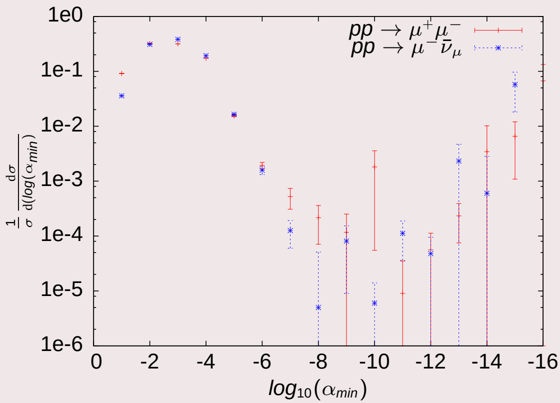
Problem: numerical instability

- In theory, close to divergence, subtraction term cancels real emission cross section.
- In practice, however, cancellation involves subtraction of one very large number from another.

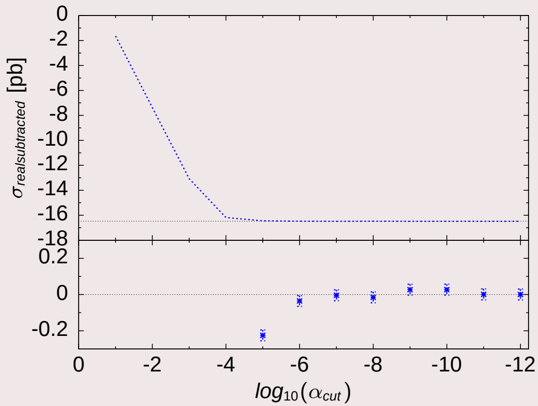
Solution: technical cut-off

- Introduce cut-off close to divergence, below which we assume contibution is negligible, as very large subtraction term is cancelling very large cross section.

Investigating α_{min}



Testing dependence of cross section on cut-off



Summary

- Standardised interface allows SHERPA to use external programs to calculate one-loop matrix elements.
- Catani-Seymour dipole subtraction fully automated in SHERPA to make divergent NLO contributions suitable for Monte Carlo integration.

Outlook

- For processes with massive final states, massive dipoles must be used for the subtraction terms. Currently extending SHERPA 's automated Catani-Seymour subtraction to include alpha-dependent massive dipoles.