MC@NLO
Combining NLO-calculations and Parton Showers at HERA

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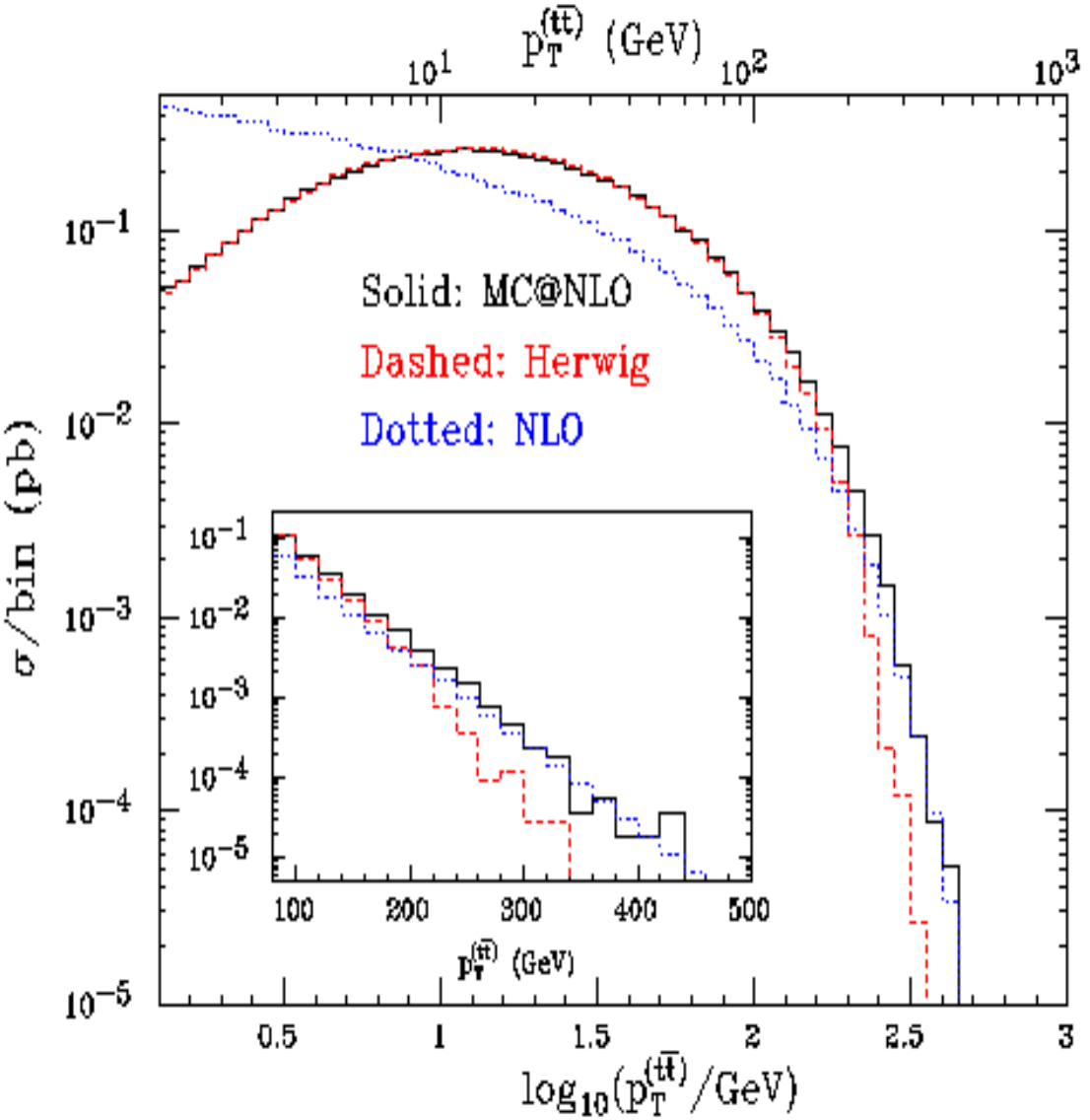
Overview

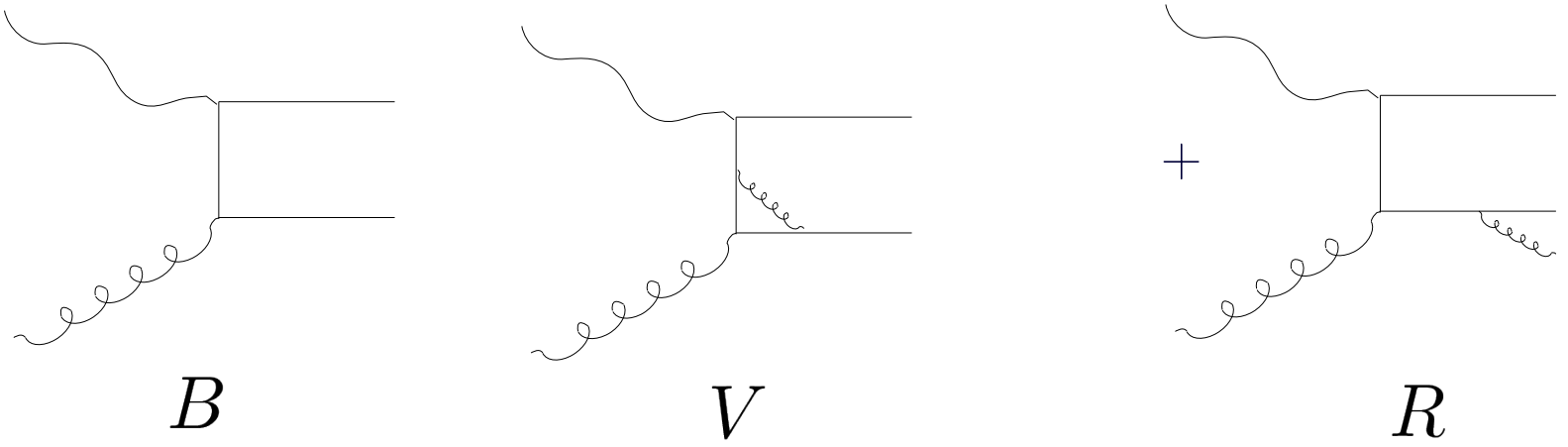
- Brief introduction
- Calculation of MC subtraction terms

Why MC@NLO?

- For large Pt of the top-pair:
  - MC is not likely to produce very hard parton because of “dead cone” effects
  - Not a problem for NLO
- For smaller Pt :
  - MC is effectively resumming to all orders through Sudakov Form factors and reliably producing soft partons
  - This is impossible for NLO-calculation



Next to Leading Order (NLO) MEs for BGF



B V R

- Amplitudes for Born and Virtual Corrections interfere:

$$|A_m|^2 = \underset{\propto \alpha_s}{B^*B} + \underset{\propto \alpha_s^2}{(B^*V + V^*B)} + \underset{\propto \alpha_s^4}{V^*V}$$

$$|A_{m+1}|^2 = \underset{\propto \alpha_s^2}{R^*R}$$

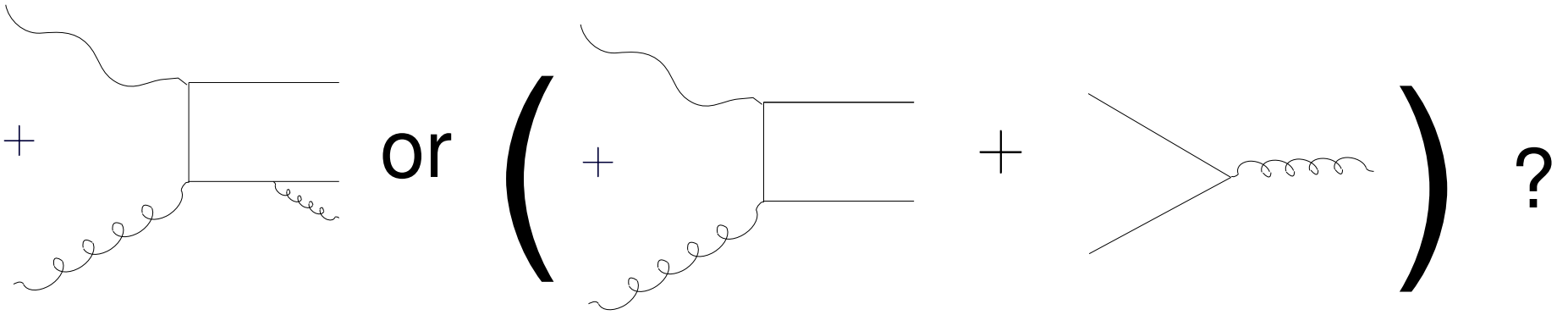
NLO calculation Subtraction

$$\sigma = \int_{m+1} \left(d\sigma^{\mathrm{Real}} - d\sigma^{\mathrm{Subtr}} \right) + \int_{m} \left(d\sigma^{\mathrm{Born}} + d\sigma^{\mathrm{Virtual}} + \sigma^{\mathrm{subtr}} \right)$$

Event Counter Event

- A term is subtracted and added which exactly cancels the divergencies
- The second term includes the virtual corrections. These yield a negative contribution to the cross-section.
- To cope with the numerical instabilities the negative weights may give rise to, for each event in the calculation the EVENT and the COUNTER EVENT are calculated separately and then added

MC@NLO Double Counting



- For real emissions there is a problem with double counting when combining the NLO ME with parton-showers
- To avoid double counting the contribution from the MC parton shower has to be calculated and subtracted from the contribution from the NLO ME.
- These terms are in MC@NLO called MC-subtraction terms
- The terms are MC-generator dependent. MC@NLO is using Herwig as MC
- The terms are process dependent. At the moment only heavy quark production is considered for HERA.

MC-subtraction terms for ep-scattering

- In ep-scattering two parts have to be considered separately:
  - the hadronic interaction where the photon splits into a hadronic quark-antiquark system which then interacts with the proton
  - the direct interaction where a parton from the proton collides directly with the photon
- MC@NLO already exists for heavy quark production in pp-scattering. Therefore the hadronic part of ep-scattering is only a matter of replacing the PDF from one of the protons into an electron PDF. No new MC-subtraction terms have to be calculated
- The direct case is on the other hand something new and there the MC-subtraction terms have to be calculated

Calculation of MC-subtr. terms direct case

- The MC subtraction terms for HERWIG all have the same general structure:

$$\sigma_{\mathrm{MC}} = \sigma_{\mathrm{Born}}^{(s,t,u)} \times P_{\mathrm{A.P.}}(z) \times \{\mathrm{PhaseSpace}, \mathrm{couplings\ etc.}\}$$

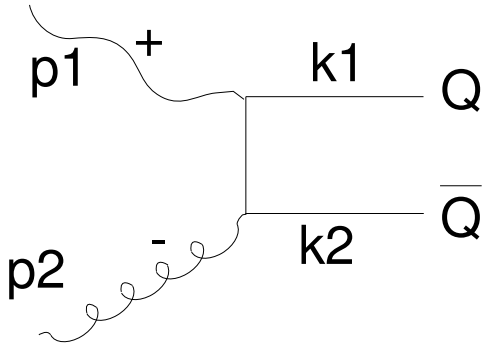
- Two main processes at direct case:
  - Photon-Gluon scattering
  - Photon-Quark/Antiquark scattering
- HERWIG treats all energy flows as distinct processes. Define:

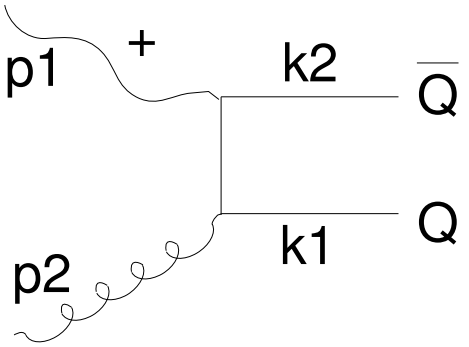
$$d\sigma_{pp}^{(t)} \equiv d\sigma_{pp} \frac{u/t}{u/t + t/u} \qquad d\sigma_{pp}^{(u)} \equiv d\sigma_{pp} \frac{t/u}{u/t + t/u}$$

$$d\sigma_{pp} = d\sigma_{pp}^{(t)} + d\sigma_{pp}^{(u)}$$

where t and u defines the energy flow of the Born diagram.

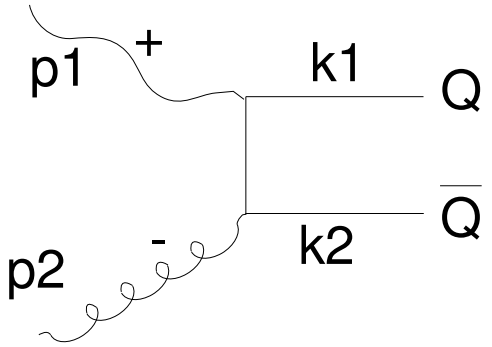
MC subtraction terms pg-scattering

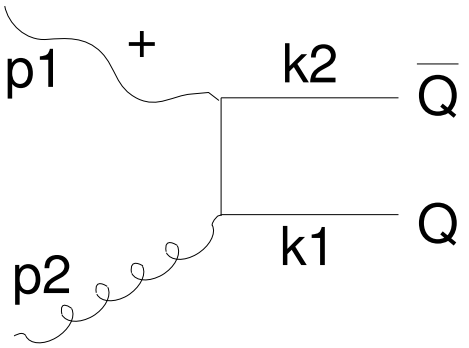




- Two diagrams at Born level
- Emissions possible from – leg and from outgoing legs (no QCD-emission from photon)

MC subtraction terms pg-scattering



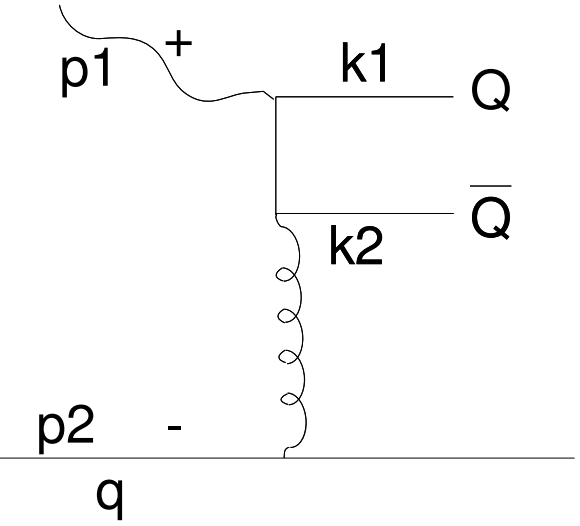


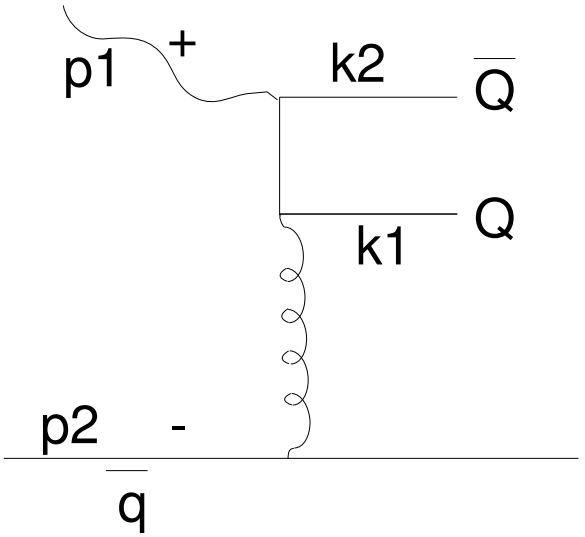
Initial state radiation: $- : d\sigma_{\gamma g} \left[\frac{1}{2} t + \frac{1}{2} u \right] \cdot P_{gg}$

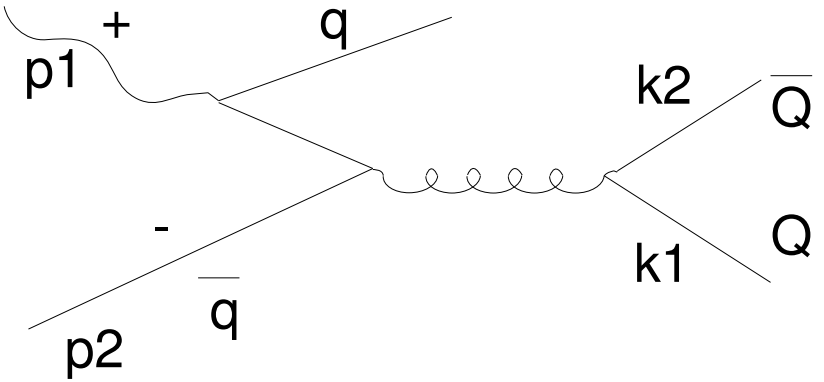
Final state radiation: $Q : d\sigma_{\gamma g} \left[u \right] \cdot P_{qq}$

$\bar{Q} : d\sigma_{\gamma g} \left[t \right] \cdot P_{qq}$

MC subtraction terms pq-scattering

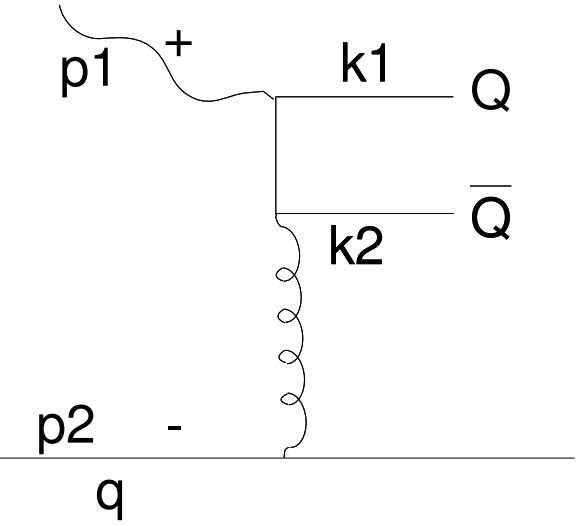


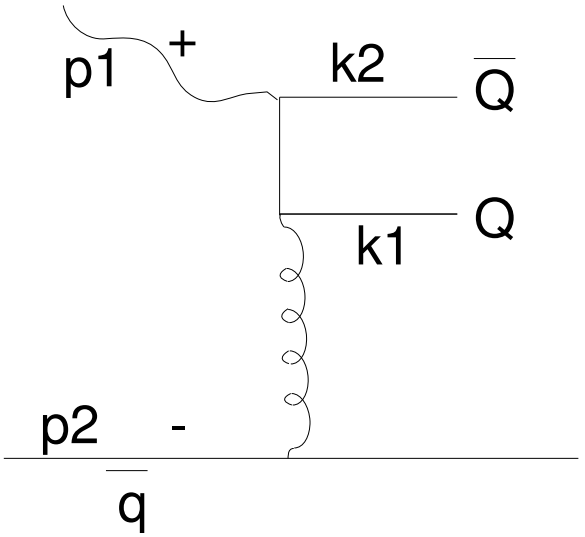


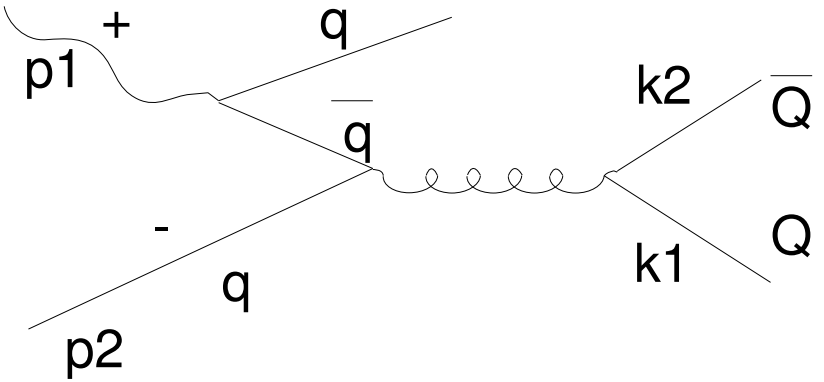


- Three diagrams for γq-scattering, only with initial state radiation
- In the first two diagrams only radiation from the – leg. Born is photon-gluon.
- In the third diagram only radiation from + leg. Here electromagnetic "splitting function" has to be used. Born is quark-antiquark

MC subtraction terms pq-scattering







$$- : d\sigma_{\gamma g}\left[\frac{1}{2}t + \frac{1}{2}u\right] \cdot P_{gq}$$

$$+ : d\sigma_{\bar{q}q}\left[u\right] \cdot P_{\gamma \to q\bar{q}}$$

$$P_{\gamma \to q\bar{q}} = \frac{T_f}{N_C} \cdot P_{qg}$$

Summary, Status and Outlook

- When combining NLO-MEs and Parton Showers the main problem has to do with double counting.
- To avoid this MC-subtraction terms have to be calculated and subtracted
- MC@NLO is being constructed for HERA
- For Point-Like photon this is a trivial adaptation
- For the Hadronic Photon the MC-subtraction terms have been calculated but not yet fully tested.
- Hopefully a running version of MC@NLO for HERA will exist spring 2007.