Precision tools for the LHC: resummation and MC generators.

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Outline

Outline

Soft and collindear radiation (1)

We consider the production of a colorless final state F:

* with an invariant-mass M,
* with a transverse momentum q_T.

- The partonic invariant-mass and transverse-momentum distributions at $\mathcal{O}(\alpha_s)$:

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}M^2} = \hat{\sigma}^{(0)}(M)\,\delta(1-z) + \alpha_s\,\hat{\sigma}^{(1)}(M,z) + \mathcal{O}(\alpha_s^2),$$

$$\frac{\mathrm{d}^2\hat{\sigma}}{\mathrm{d}M^2\,\mathrm{d}q_T^2} = \hat{\sigma}^{(0)}(M)\,\delta(q_T^2)\delta(1-z) + \alpha_s\,\hat{\sigma}^{(1)}(M,z,q_T) + \mathcal{O}(\alpha_s^2),$$

where $z = M^2/s$.

Problem: soft and collinear radiation.

Soft and collindear radiation (2)

Problem: soft and collinear radiation.

- Qualitative point of view.
  - * Related to the emission of:
    - ◇ a parton parallel-moving to the emitting one.
    - ◇ a parton with vanishing four-momentum.

  $\equiv$ experimentally undistinguishable states.

- Quantitative point of view.
  - * Related to the infrared singularities.
    - ◇ $\alpha_s^n \left(\frac{\ln^m(1-z)}{1-z} \right)_+$ and $\frac{\alpha_s^n}{q_T^2} \ln^m \frac{M^2}{q_T^2}$ terms in the distributions.
    - ◇ Large at $z \lesssim 1$ or small q_T.

  Fixed-order theory unreliable in these kinematical regions.

Precision predictions require resummation to all orders or parton showers.

Outline

Resummation

- Conjugate spaces introduced:
  * Mellin transform: N variable conjugate to $\tau = M^2/s_h$.
  * Fourier transform: Impact-parameter b conjugate to q_T.

* Hadronic cross sections: convolutions $\rightarrow$ products.
* Factorization of the soft-collinear radiation in a **Sudakov form factor**.

$$\mathcal{W}_{ab}(N,b) \quad = \quad \mathcal{H}_{ab}(N) \exp\Big\{\mathcal{G}(N,b)\Big\}.$$

- The $\mathcal{H}$-coefficient:
  * Can be computed perturbatively as series in α_s, from fixed-order results.
  * Is process-dependent.
  * Contains real and virtual collinear radiation, hard contributions.
- The Sudakov form factor $\mathcal{G}$:
  * Can be computed perturbatively as series in α_s log.
  * Is process-independent (universal).
  * Contains the soft-collinear radiation.

Parton showers: initial state radiations

- The shower is built through a Monte Carlo technique:
  - * Backwards evolution scheme: start from the hard-scattering partons.
  - * Ordering of the partons (virtualities, p_T, emission angles,...).
  - * **Branching or not branching ? $\Rightarrow$ Sudakov form factor.**
- Resummed Sudakov vs. shower Sudakov:
  - * **Different order of the series in** α_s log.
  - * Resummation: next-to-next-to-leading logarithms are known.
  - * Parton showers: only leading logarithms are included.

Matching to the fixed order

- Fixed-order calculations.
  * Reliable far from the critical kinematical regions ($z \ll 1$, $q_T \gg 0$).
  * Spoiled in the critical regions ($z \sim 1$, $q_T \sim 0$).
- Resummation / parton showers.
  * Needed in the critical regions.
  * Not justified far from the critical regions.
- Intermediate kinematical regions:
  * Both fixed order and resummation / parton showers contribute.

Information from both fixed order and resummation / parton shower is required.
$\Rightarrow$ consistent matching procedure.

Monte Carlo and resummation for BSM processes

- Soft and collinear radiation.
  - ☛ **Resummation: next-to-leading logarithms.**
  - * Parton showers in general: leading logarithms.
  - * If we have momentum conservation at each branching ⇒ **(leading logs)**$_+$.
    e.g. PYTHIA.
- Matched with matrix elements.
  - ☛ **Resummation: next-to-leading order.**
  - * Monte Carlo codes in general: leading order.
  - ☛ **Sometimes next-to-leading order: e.g. MC@NLO and POWHEG.**
- Comparison: resummation vs. PYTHIA vs. MC@NLO.
  - * PYTHIA: nice process library.
  - * MC@NLO: one of the state-of-the-art Monte Carlo generators.
  - * Resummation: best precision.

Remark

Too small process libraries in MC@NLO and resummation codes.

Summary of the three codes

- PYTHIA: [Sjöstrand, Mrenna, Skands (2006)]
  - * Parton showers ordered either by virtualities or by p_T.
  - * Momentum conservation at each branching.
  - * Matched with leading order matrix elements.

PYTHIA: Leading order + leading logarithms + momentum-conservation.

- MC@NLO: [Frixione, Webber (2002)]
  - * Parton showers ordered by angles (HERWIG [Corcella *et al.* (2001)]).
  - * Matched with next-to-leading order matrix elements.

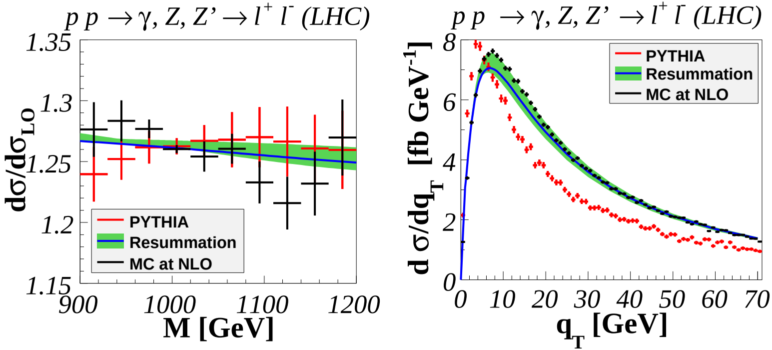
MC@NLO: Next-to-leading order + leading logarithms.

- Resummation for BSM: [BenjF, Klasen, Ledroit, Li, Morel (2008)]
  - * Next-to-leading logarithmic Sudakov.
  - * Matched with next-to-leading order matrix elements.

BSM Resummation: Next-to-leading order + next-to-leading logarithms.

Outline

Z' production: PYTHIA, MC@NLO and joint resummation

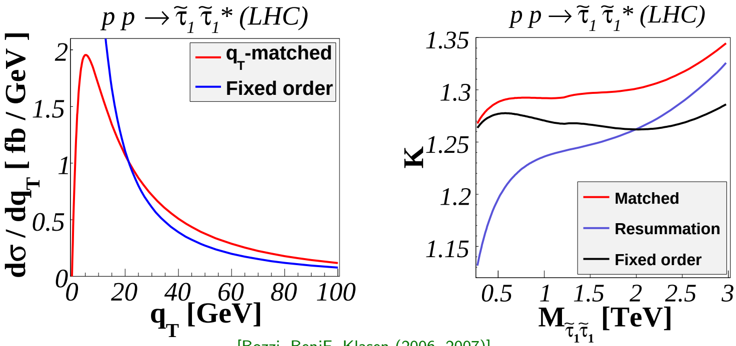


[BenjF, Klasen, Ledroit, Li, Morel (2008)]

- PYTHIA: mass-spectrum multiplied by a K-factor of 1.26.
- PYTHIA q_T-spectrum much too soft, peak not well predicted.
- Good agreement between MC@NLO and resummation.

NLO matrix elements are a great improvement.

Resummation for slepton pair production



[Bozzi, BenjF, Klasen (2006, 2007)]

- SUSY scenarios: slepton masses ≈ 100-200 GeV.
- Resummation effects:
  - * Finite results at small q_T.
  - * Resummation effects important even at intermediate q_T.
  - * Small M: $\mathrm{d}\sigma^{(\mathrm{res})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$ $\equiv$ perturbative theory.
  - * Large M: $\mathrm{d}\sigma^{(\mathrm{F.O.})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$ $\equiv$ pure resummation.

Outline

Summary - Outlook

- Soft and collinear radiation:
  * Large logarithmic corrections.
  * Parton showers and resummation are required.
  * Correct quantification of those radiation.

- Precision predictions for BSM theories
  * PYTHIA is (often) not enough.
  * MC@NLO reaches (almost) the same precision level as resummation.
    BUT: easier implentation in the analysis chains of any experiment.

Outlook

Implementation of other processes in the precision tools.

* Resummation.
* MC@NLO.
* POWHEG?