N-jettiness in electron-positron annihilation

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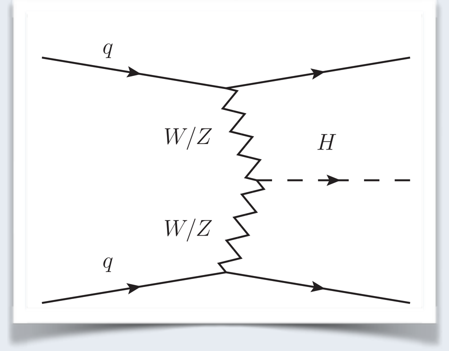
Introduction

In particle physics experiments at the Large Hadron Collider (LHC) interesting events, e.g., the ones signalling the creation of so far unknown particles have to be selected from enormous backgrounds.

- example: creation of a Higgs boson in vector boson fusion
- we expect only two jets to appear in the final state which stem from the two colliding quarks
- the colliding quarks can radiate gluons which can decay into even more partons, therefore in many cases more than two jets appear



creation of a Higgs boson in vector boson fusion

- it can be shown that the appearance of multi-jet final states is more likely in background processes than in the signal process

Suppression of the background can be achieved by applying a "**jet veto**", namely excluding those events that contain more jets than necessary (in this case two).

N-jettiness

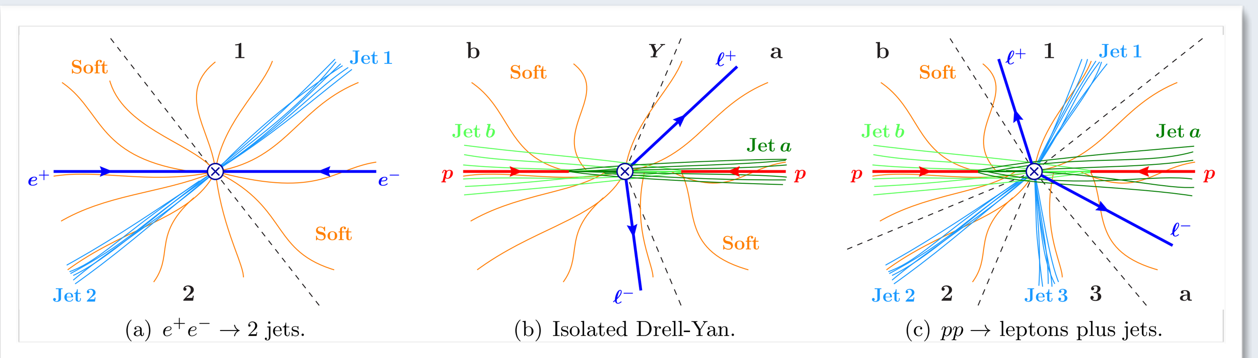
Jet vetos are essential at the LHC for many experimental analyses.

- the usual method for vetoing jets imposes cuts on the phase space of the final state particles to exclude configurations with too many jets
- the purpose of N-jettiness [1] is to enable vetoing of jets by imposing a cut on a single global event shape variable
- $\tau_N = 0$ in case of M=N

$$\tau_N(\Phi_M) = \sum_{k=1}^{M} \min_{i\in\{1,\ldots,N\}} \left\{ \frac{2q_i \cdot p_k}{Q^2} \right\}$$

- p_k are the momenta of the M final state particles
- q_i are the massless momenta of the N signal jets
- Q is the total incoming momentum

- $\tau_N \ll 1$ corresponds to an N-jet-like configuration



N-jettiness applied in different situations. Source: [1].

Method

Perturbation theory is the tool for computing theoretical predictions for high energy particle collisions. In a perturbative calculation we take the series expansion of physical quantities with respect to some small parameter (in this case the strong coupling, α_S).

- the approximation of the perturbative series by its first, second and third order terms is called Leading Order (LO), Next-to-Leading Order (NLO), and Next-to-Next-to-Leading Order (NNLO) approximation respectively

$$\sigma = \sigma^{\mathrm{LO}} + \sigma^{\mathrm{NLO}} + \sigma^{\mathrm{NNLO}} + \ldots$$

- in case of QCD the value of the expansion parameter is not very small numerically at currently accessible energies ($\alpha_S(M_Z) = 0.118$), therefore to make precise physical predictions higher order terms must be considered
- the perturbative expansion of the N-jettiness distribution in electron-positron annihilation reads

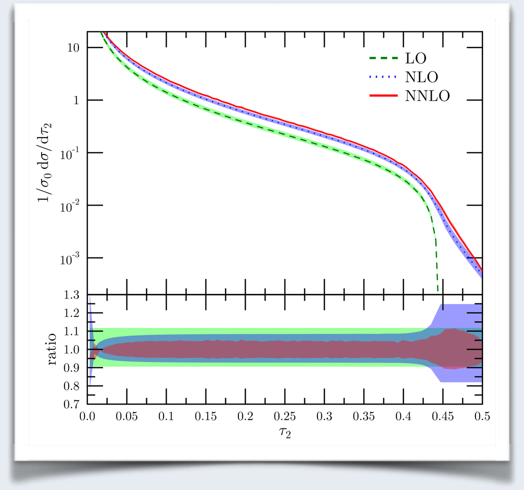
$$\frac{1}{\sigma_0}\frac{\mathrm{d}\sigma}{\mathrm{d}\tau_N} = \frac{\alpha_S}{2\pi}A(\tau_N) + \left(\frac{\alpha_S}{2\pi}\right)^2 B(\tau_N) + \left(\frac{\alpha_S}{2\pi}\right)^3 C(\tau_N) + \mathcal{O}(\alpha_S^4)$$

- the calculation of higher order terms is plagued by difficulties due to ultraviolet (UV) and infrared (IR) divergences that appear in intermediate steps, however, the KLN theorem guarantees the finiteness of the perturbative prediction for IR-safe observables
- we used the CoLoRFulNNLO method (Del Duca, GS, Trócsányi) [2,3] to calculate the finite physical cross section

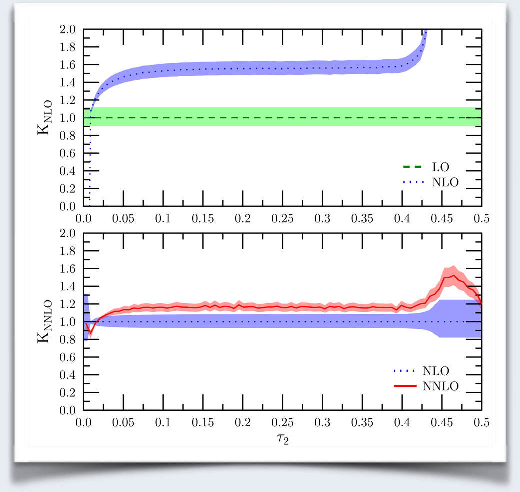
Predictions (preliminary)

Theoretical prediction for the 2-jettiness distribution at Q = M_Z center of mass energy.

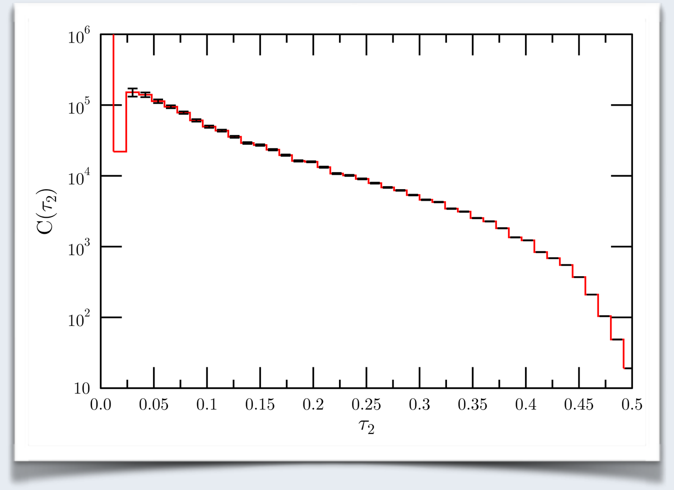
- the predictions were normalized by the cross section of the $e^+e^- \to$ quark+antiquark process (σ_0)
- the bands show the dependence on the renormalization scale, $\mu_R \in [Q/2, 2Q]$



2-jettiness distribution at LO, NLO and NNLO

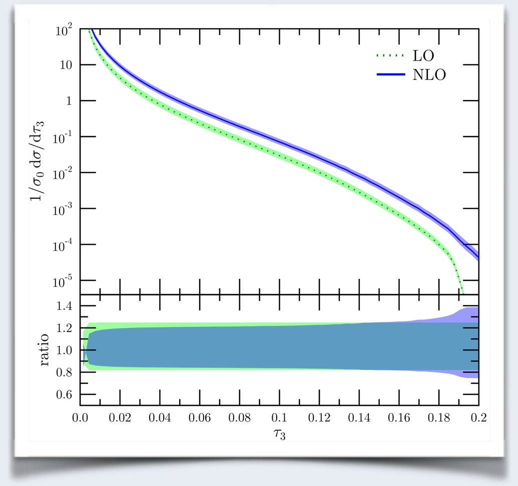


2-jettiness K factors ($K_{NLO} = \sigma_{NLO}/\sigma_{LO}$, $K_{NNLO} = \sigma_{NNLO}/\sigma_{NLO}$)

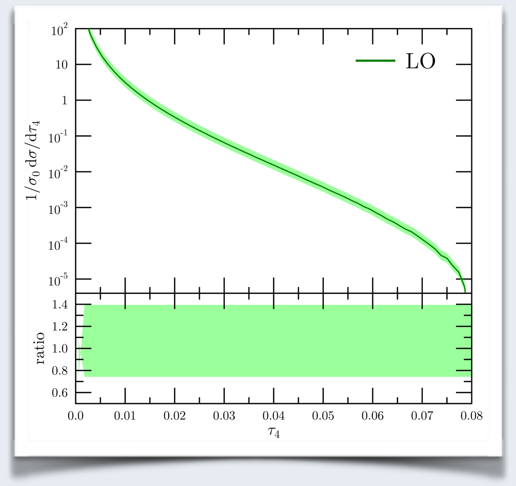


2-jettiness NNLO correction

Theoretical predictions for the differential cross section with respect to 3- and 4-jettiness



3-jettiness distribution at LO and NLO



4-jettiness distribution at LO

Conclusions

- We presented the first computation of 2-jettiness distribution in electron-positron annihilation up to NNLO in QCD.
- The NLO K factor for 2-jettiness is rather large (~1.6) and the LO scale variation badly underestimates the neglected higher order terms.
- The perturbative prediction stabilizes in NNLO.
- The results were obtained using the MCCSM code.

MCCSM

- The MCCSM (Monte Carlo for the CoLoRFulNNLO Subtraction Method) is a partonic Monte Carlo program which implements the CoLoRFulNNLO subtraction scheme.
- A flexible and user friendly program library written in F90.
- Currently available processes:
  - $e^+e^- \to$ 2 jet (Albers, AK, GS)
  - $e^+e^- \to$ 3 jet (AK, GS, Szőr, ZT) [4,5]
- The presented calculation was obtained in ~ 4.3 days on 2 x 48 Intel(R) Xeon(R) E5-2695 v2 @ 2.40 GHz CPUs.

Acknowledgments

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References

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