Analytical Study of Planar Flow

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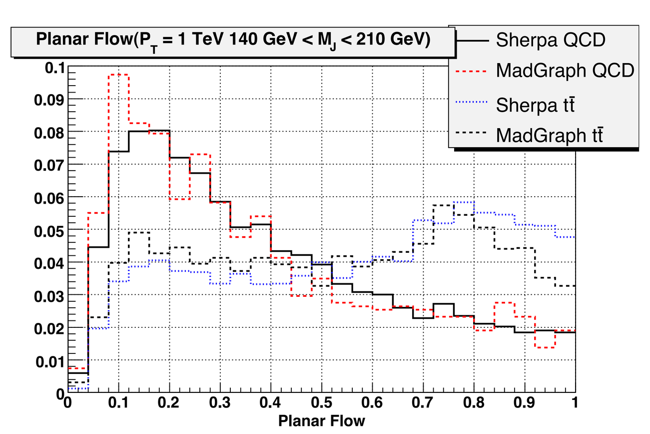
Introduction

At the LHC heavy SM particles will be frequently produced with a transverse momentum greatly exceeding their rest mass. In a typical Beyond the Standard Model (BSM) scenario an unknown heavy resonance X_{heavy} decays to highly boosted particles with intermediate masses that then decay to light quarks

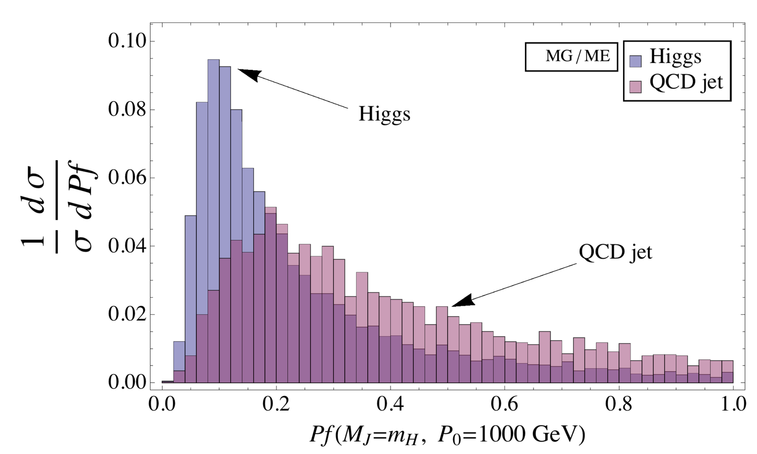
$$X_{heavy} \to Y_{interm.} \to \text{jets}$$

where $Y_{interm.}$ may be a SM particle (*W*, *Z*, top) or a BSM particle. The reconstruction of hadronic decays of boosted objects $Y_{interm.}$ is particularly challenging and require and analysis of the substructure of the produced jet.

Planar flow [1] represent a valuable tool in the analysis of the jet substructure and the separation of the QCD background .



Planar flow distribution for QCD and tops jets



Planar flow distribution for Higgs and QCD jets

In this work we provide and study an analytical expression for the jet cross section at fixed jet mass m and planar flow P_f.

Planar Flow

In order to define the planar flow observable we introduce for a given jet the matrix I_w

$$I_w^{kl} = \frac{1}{m} \sum_i w_i \frac{p_{i,k}}{w_i} \frac{p_{i,l}}{w_i}$$

where m is the jet mass, w_i the energy of the particle i and $p_{i,k}$ is the projection of its momentum on the plane perpendicular to the jet axis. Given I_w planar flow is defined as

$$P_f = \frac{4 \det (I_w)}{\operatorname{tr} (I_w)^2} = \frac{4\lambda_1\lambda_2}{(\lambda_1 + \lambda_2)^2}$$

where $\lambda_{1,2}$ are the eigenvalues of I_w

Analytic Expression

In the collinear limit the amplitude matrix element factorize as

$$|M(2 \to n)|^2 \simeq \frac{4}{s_{123}^2} (4\pi\alpha)^2 \, |M(2 \to n-2)|^2 \, \langle P_{1\to 3} \rangle$$

where $\langle P_{1\to3}\rangle$ is the 1 to 3 splitting function [2]. The reason to use the 1 to 3 rather then the more familiar 1 to 2 splitting function is that it allow to go beyond the angular ordered approximation $\theta_i \ll \theta_j$, approximation that break down in the region of large planar flow.

In the collinear limit the jet cross section at fixed jet mass and planar flow is

$$\frac{1}{\sigma_0} \frac{d\sigma}{dP_f \, dm^2} (P_f, m^2) =$$

$$\frac{1}{m^4} \frac{\alpha^2}{\pi^3} \int d\theta_1 d\theta_2 d\phi \, \frac{1}{z_3} \bar{p}_1 \bar{p}_2 \theta_1 \theta_2 J \left(\bar{p}_1, \bar{p}_2, \theta_1, \theta_2\right) \cdot \langle P_{1\to3} \rangle \left(\bar{p}_1, \bar{p}_2, \theta_1, \theta_2\right)$$

where J is a Jacobian factor, θ_1, θ_2 are angles between the partons momenta and the jet axis and $\bar{p}_1, \bar{p}_2$ are functions that parametrize the jet mass and planar flow constraints.

The previous equation is well described by the following fitting formula

$$A \left(\frac{C_A^2 \alpha^2}{\pi^3} \right) \frac{q^2}{m^4 P_f} \log \left[B \frac{2qR}{m} \frac{1}{P_f} \right]$$

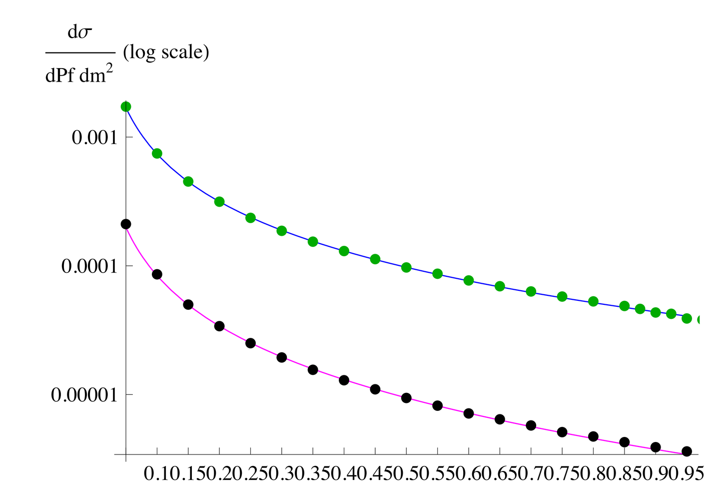
where $C_A = N_c = 3$ is a Casimir. The fit parameters $A \approx 0.4,\ B \approx 1.4$ and $A \approx 0.06,\ B \approx 0.4$ describe well gluon and quarks jets respectively.

Conclusion

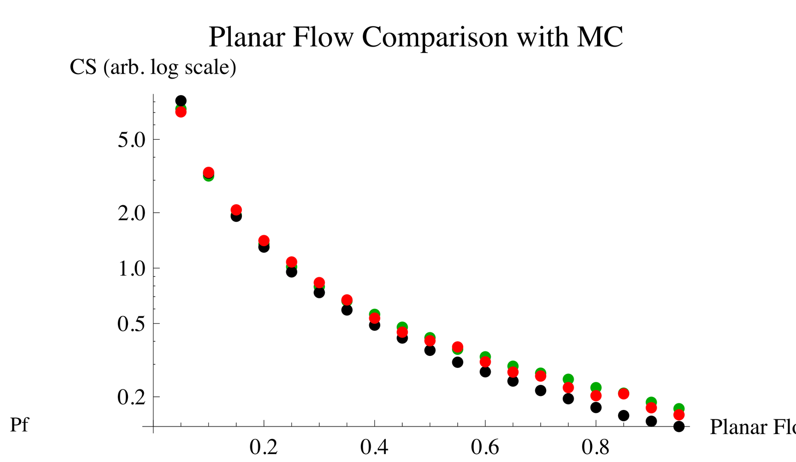
Highly boosted particles are important signals of new Physics, planar flow turn out to be a valuable observable for the study of jet substructures produced by boosted objects.

We have derived an analytical description of planar flow.

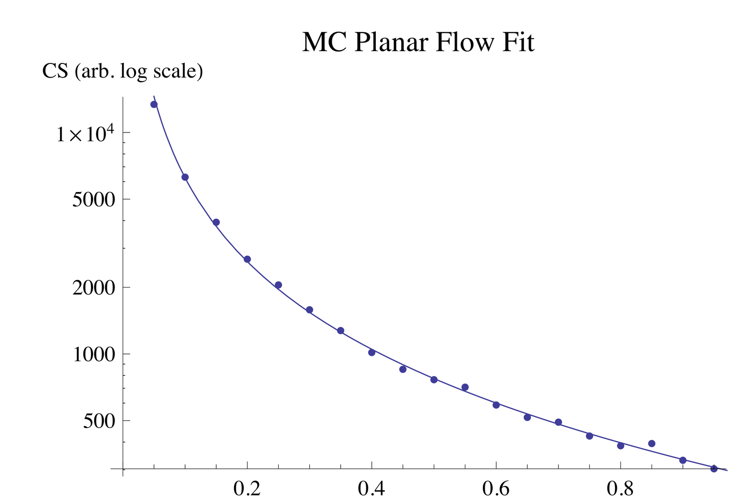
The fitting formula and a comparisons with Monte Carlo simulation is shown in the following figures.



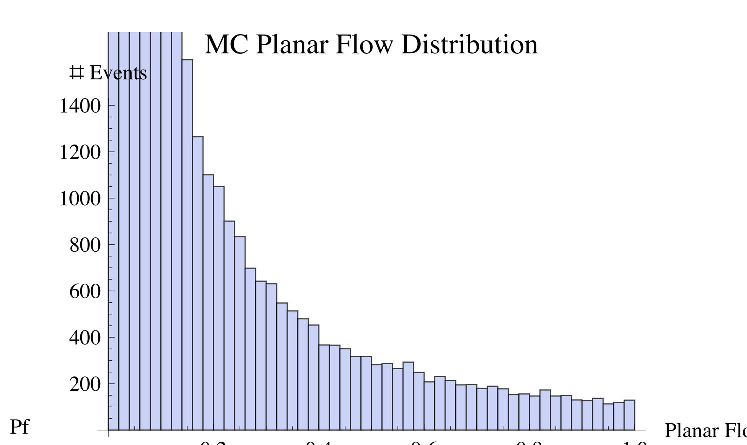
Jet cross section at fixed mass and planar flow. The top line is for gluon jets and the bottom for quark jets.



Comparison of planar flow distribution between analytical expressions (green, blue) and Monte Carlo .



Planar flow distribution from a Monte Carlo simulation with superimposed the fitting equation.



Planar flow distribution from a Monte Carlo simulation .

References

[1] L. G. Almeida, S. J. Lee, G. Perez *et al.*, *Substructure of high-pT Jets at the LHC*, Phys. Rev. **D79**, 074017 (2009) [SPIRES].

[2] S. Catani and M. Grazzini, *Collinear Factorization and Splitting Functions for Next-to-next-to-leading Order QCD Calculations*, Phys. Lett. B **446**, 143 (1999) [hep-ph/9810389];