Progress Measuring Hadron-Hadron Event Shapes

Lester Pinera
University of Florida, P.O. Box 118440, Gainesville, FL, U.S.A.
CDF Collaboration

Presented here is a preliminary study on the feasability of measuring event shape observables in $p\bar{p}$ collisions. In particular, we examine the potential of a newly proposed set of "Indirectly Global" observables meant to reconcile the theoretical requirement of "globalness" with the realities of the hadron collider environment. Studies are carried-out using Pythia MC tuned to CDF minimum-bias data.

1. Introduction

Event Shapes have enjoyed a long and illustrious history as one of the most widely studied sets of QCD observables. This has been especially true in the context of e^+e^- and DIS experiments where theoretical predictions for both event shape means and distributions have abounded. Comparisons between theory and data in these settings fascilitated countless measurements of α_s and its renormalization group running, as well as color factor fits of the QCD gauge group, and more recently, studies of non-perturbative corrections to QCD.

By contrast, studies of event shapes at hadron-hadron colliders have been far less reaching. The earliest known studies were performed at the ISR in the late seventies and focused on tracing the emergence of jet-like structures in pp collisions [5]. It was only a decade later that event shapes would again be measured at a hadron-hadron collider, specifically during the Tevatron's Run I where variants of the broadening and thrust were measured by CDF and D0 respectively [6, 7]. Notably absent from all of these studies was a direct comparison to theory. This was in large part due to the intrinsic difficulties associated with the environment [3]. However, recently, a number of tools for investigating event shapes beyond leading order (and leading logarithm) have begun to be developed, thus inviting their measurement at hadron colliders.

Amongst these tools, is the advent of automated resummations [2], which should make possible the study of a wide set of observables . However, at present a technical restriction of this automated approach, and indeed of all fully NLL calculations, is that they apply only to "global" observables (i.e. sensitive to radiation in all directions). This requirement is in direct conflict with the realities of any collider experiment; namely the limited detector coverage at large rapidities. Fortunately, though, theorist have proposed a solution to this problem by introducing what they've termed "Indirectly Global Observables" [1]. These are quantities defined within a central region, but sensitive to emissions outside that region by way of a recoil term.

Below is a preliminary account of one newly proposed indirectly global observables (IGO hereafter), the central transverse thrust minor. Studies are performed using Pythia (Tune A) MC which has been tuned to the underlying event using CDF Data [4].

2. Indirectly Global Event Shapes

Presented below is the definition of the Central Transverse Thrust and Thrust Minor. By construction these quantities are IR&C safe. The "bare" observables are defined over particles within a central region, C, but are rendered sensitive to radiation outside C by the addition of a recoil term. The thrust at hadron colliders is defined as in the e^+e^- case

$$T_{\perp,C} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in C} |\vec{q}_{\perp i} \cdot \vec{n}_T|}{\sum_{i\in C} |\vec{q}_{\perp i}|}, \qquad \tau_{\perp,C} \equiv 1 - T_{\perp,C} \tag{1}$$

except that now we are restricted to the transverse plane. As usual, τ, ranges between 0 for events with narrow back-to-back jets and $\frac{1}{2}$ for events with a uniform distribution of momentum.

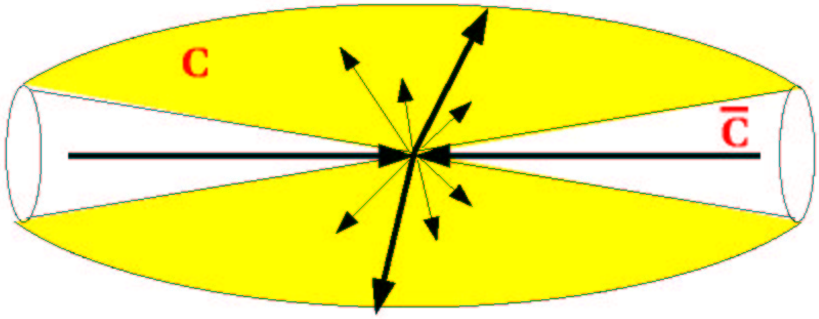


Figure 1: Central observables are defined over particles within a central region, C, but are rendered global by the addition of a recoil term also defined within C, but sensitive to the forward region,$\bar{C}$.

Having found the transverse thrust axis, n_T, for the event through the maximization above, we can then define the thrust minor:

$$T_{m,C} \equiv \frac{\sum_{i\in C} |\vec{q}_{\perp,i} \times \vec{n}_T|}{\sum_{i\in C} |\vec{q}_{\perp i}|} \tag{2}$$

If the thrust axis and beam direction define an event plane, then the thrust minor is a measure of radiation perpendicular to that plane. In the limit of 2 back-to-back jets $T_{\perp,m} \to 0$ while in the case of a uniformly distributed event $T_{\perp,m} \to \frac{2}{\pi}$. Finally, the recoil term is simply the vector sum of the transverse momentums within the central region:

$$R_{\perp,C} \equiv \frac{1}{\sum_{i\in C} |\vec{q}_{\perp i}|} |\sum_{i\in C} \vec{q}_{\perp i}| \tag{3}$$

Indirectly Global Observables are then constructed by adding to each "bare" event shape a power of the recoil.

$$\tau_{\perp,R} \equiv \tau_{\perp,C} + R_{\perp,C}, \qquad T_{m,R} \equiv T_{m,C} + R_{\perp,C} \tag{4}$$

3. Event Selection & Measurement

As pointed out in [3], the counterpart to $e^+e^- \to 2jet$ or DIS $[1+1]-jet$ events at hadron colliders is high-transverse momentum dijet production. While for these proceedings only Pythia MC is presented (and not data), it is worth noting that the event selection criteria is applied to the MC after detector simulation. It is therefore, worthwhile to outline the full event selection criteria.

- We require at least two jets in the central region ($|\eta_{jet1,2}| < 0.7$)[1]. With a cut placed on the hardness of the leading jet[2].
- We require events with a single primary vertex in order to avoid pile-up at high luminosities.
- We cut out events with large missing E_t significance, $\frac{\not{E}_T}{\sum |E_t|}$ [3].

[1] At the time of this conference, a cone based algorithm specific to CDF, JetClu, with R = 0.7 was used for the event selection. We recognize that this algorithm is not IRC safe and note our intention to switch to the Midpoint algorithm in the near future. However, we also claim a large overlap in the event population between the two.

[2] This cut will ultimately be varied between jet triggers.

[3] This cut is standard at CDF and is designed to cut-out events containing a large fraction of cosmics.

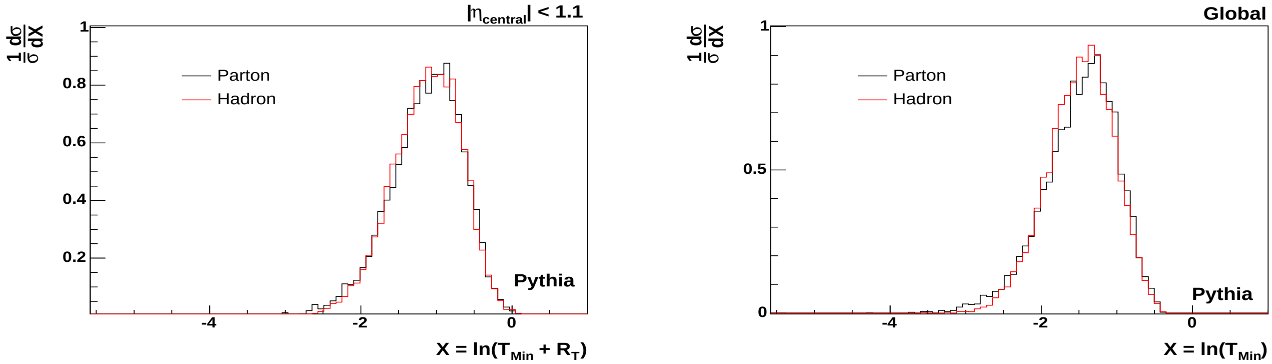


Figure 2: Distributions of the Indirectly Global & Global Thrust Minor at the parton and hadron levels obtained from Pythia ($2 \rightarrow 2$) MC tuned for the underlying event.

- Require $|Z_{vertex}| < 60cm$ so that the event is well contained within the detector.

Having described our event selection procedure it remains then for us to define a suitable central region. At the moment, CDF tracking can be reliably extended to a rapidity of 1.1, while calorimeter coverage, given the event selection above, will extend out to rapidities of 3.0. Both possibilities are investigated to determine the optimal measurement. We note also that in our studies we consider only tracks with $p_t > 300MeV$ (tracking efficiency is known to drop significantly below this threshold) and calorimeter towers with $E_t > 100MeV$. Furthermore, we also cut on the impact parameter, d_0, and radius of conversion, $R^2_{conv} \equiv \frac{d_0 q p_t}{.15B}$, of each track in order to remove ones arising from γ -conversions and secondary decays (K_s, Λ, etc.).

4. From Partons to Hadrons

In Fig. 2, the left-hand plot shows distributions of the indirectly global thrust minor at the parton and hadron levels of Pythia for $|\eta_{central}| < 1.1$. The plot immediately to the right shows the same distributions for the global observables (ie. $|\eta_{central}| \rightarrow \infty$). We note that in neither the indirectly global nor the global distributions do we observe a significant shift due to the hadronization model. Furthermore, Fig. 3 shows the distribution of the thrust minor, as calculated in Pythia at the parton level, to be in reasonable agreement with preliminary curves provided by theorists.

At this point it is worthwhile to explicitly mention how we define the two stages of MC production. The parton level includes all partons at the end of the parton shower. In the Pythia sample used, the shower cutoff (i.e. the limit on the virtuality of the partons before hadronization) is set to $Q = 1GeV$. The hadron level is then defined to be all stable particles after hadronization excluding neutrinos and photons. In addition, at this level we include neutral particles which decay to 2 photons (i.e. π^o, η. . .). Note that this definition of the hadron level differs slightly from the ones used in past event shape analyses [8]. There, the hadron level was defined by considering "stable particles ($\tau > 300ps$) after hadronization and decays".

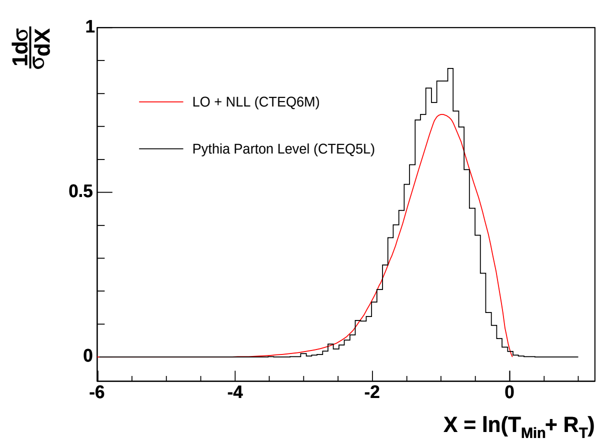


Figure 3: **Preliminary** theoretical predictions from $CAESAR$ compared to Pythia Parton Level.

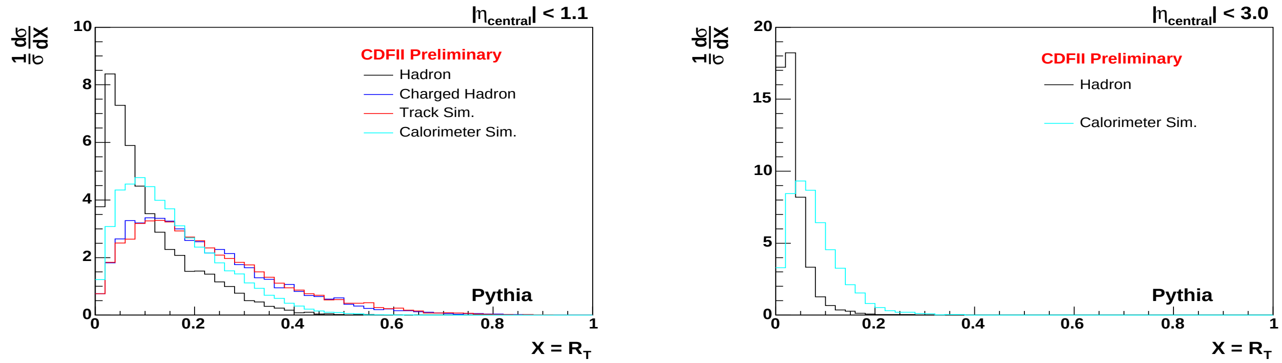


Figure 4: Distribution of the Recoil term as calculated at various levels of MC production for $|\eta_{central}| < 1.1$ (left) and $|\eta_{central}| < 3.0$ (right).

5. The Recoil Term

Fig. 4 shows distributions of the recoil term for a central region defined by $|\eta_{central}| < 1.1$. The curves shown are for MC at the hadron and charged hadron levels as well as after CDFII detector simulation. We observe that the recoil term is especially sensitive to the lose of neutral particles. As a result, the recoil term will have to be measured with the calorimeter. In the same figure we see that using the calorimeter clearly improves the measurement, however, there remains a significant difference between this and the hadron level. This discrepancy is likely due to imperfections in the detector (chimney, cracks) as well as the result of low p_t charged particles which never reach the central calorimeter .

In addition to troubles with its measurement, the recoil term itself remains a source of conceptual difficulties (at least for this experimenter). The term is simply added to each of the "bare" event shapes on an event-by-event basis. One would then expect there to be a clear correlation between each of the "bare" observables and the recoil. However, Fig. 5 shows the degree of correlation between the thrust minor and the recoil to be quite weak (the profile histogram on the right is even flatter for the other "bare" event shapes proposed). Furthermore, the term is common to all of the IGO's. If the central region is made small, then the significance of the recoil over the "bare" event shape becomes more prominent leaving ultimately a measurement of missing E_t for all the observables.

Because of the difficulties involved with the recoil, we have chosen to minimize it's contribution to the IGOs by defining the central region to be as wide as possible ($|\eta| < 3.0$). Fig. 4 (right) shows the distribution of the recoil term at the hadron and calorimeter levels for this central region. Clearly the calorimeter quantity still differs significantly from the hadron level distribution, however the role of the recoil in the indirectly global observables is reduced. Fig. 7 shows the correlation in the recoil term between the hadron and calorimeter levels in the MC.

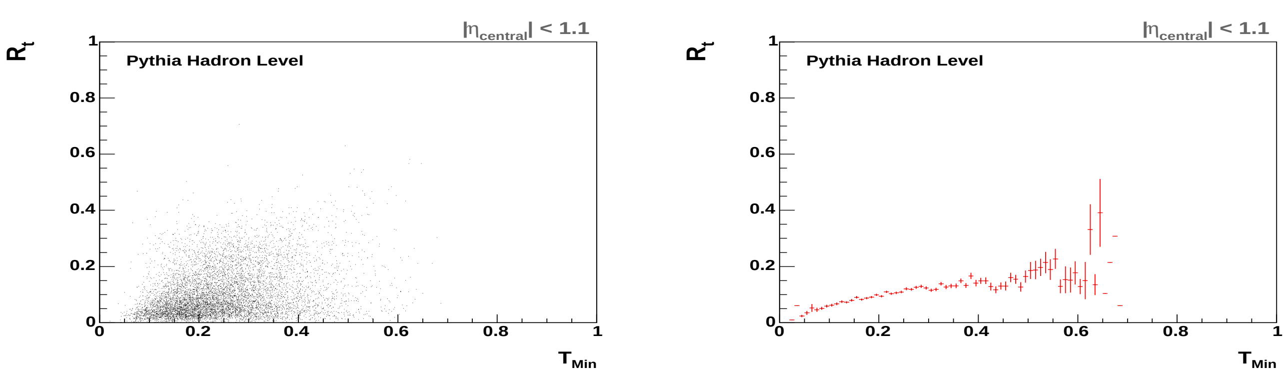
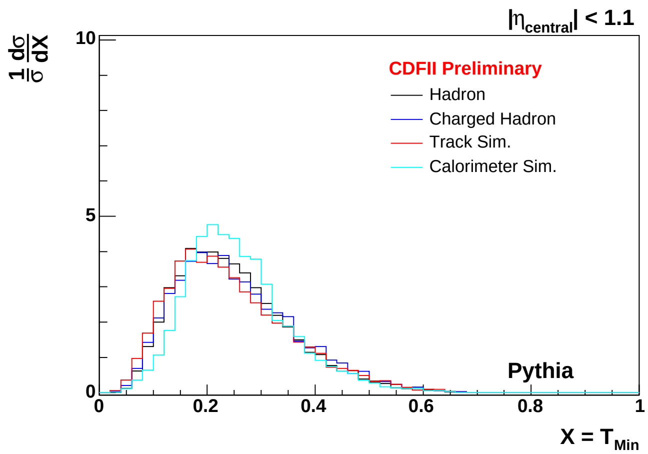


Figure 5: Correlation between the Recoil term and the Thrust Minor defined for $|\eta_{central}| < 1.1$.



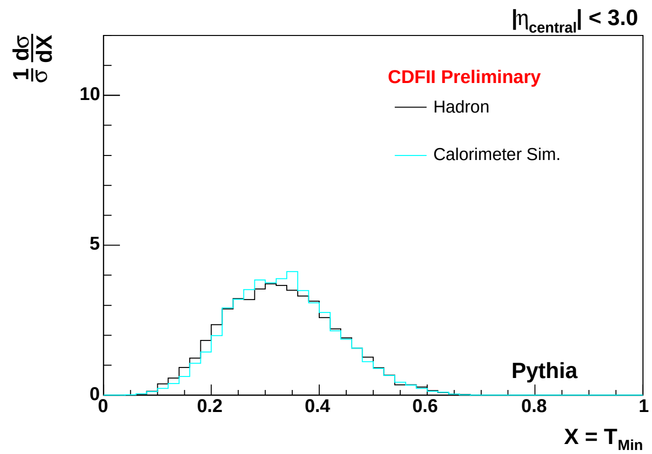


Figure 6: Distribution of the Thrust Minor as calculated at various levels of MC production for $|\eta_{central}| < 1.1$ (left) and $|\eta_{central}| < 3.0$ (right)

6. “Bare” Central Event Shapes

Fig. 6 (Left) shows the distribution of the transverse thrust minor defined for the central region $|\eta| < 1.1$ at various levels of MC production. In contrast to the recoil term, we observe that the "bare" event shapes themselves are largely insensitive to the loss of neutral particles. However, as described in the previous section, we have chosen to define the central region to be as wide as possible in order to minimize the recoil. As such, we will have to measure the "bare" event shapes using the calorimeter. Also in the same figure we see a direct comparison of the thrust minor using tracks and calorimeter towers. The discrepancy in the distributions between the two detectors is due to the fact that at the track level we benefit from the removal of gamma-conversions (e^+e^- tracks that arise from the interaction of low energy photons with the detector material) and tracks arising from secondary decays. Furthermore, the calorimeter distributions are affected by the magnetic field which ultimately bends the trajectory of charged particles. However, these effects are well understood and are incorporated into the detector simulation. Fig. 6 (Right) shows calorimeter and hadron level distributions for the "bare" thrust minor in the exteded central region $|\eta| < 3.0$. Finally, Fig. 8 shows the correlation in the thrust minor between the Hadron and Calorimeter level quantities.

7. Summary

In addition to providing further insight into the study of non-perturbative corrections to QCD, the study of event shapes at hadron colliders holds the potential to deepen our understanding of the underlying event. Preliminary studies have thus far focused on the proposed “indirectly global event shapes” which are defined for a limited “central” region. These studies have been carried out using Pythia ($2 \to 2$) MC which has been tuned to the underlying event using CDF data. The MC shows no significant shift in the event shape distributions between the perturbatively predicted parton level and the hadron level. The “bare” event shapes have been found to be largely insensitve to detector effects (as implemented in the CDFII simulation). The recoil term, however, suffers from significant systematic errors. From an experimental point of view, the measurement of the indirectly global observables will benefit from defining the central region to be as wide as possible, thus minimizing the significance of the recoil term in the measurement. Comparison to data is forthcoming.

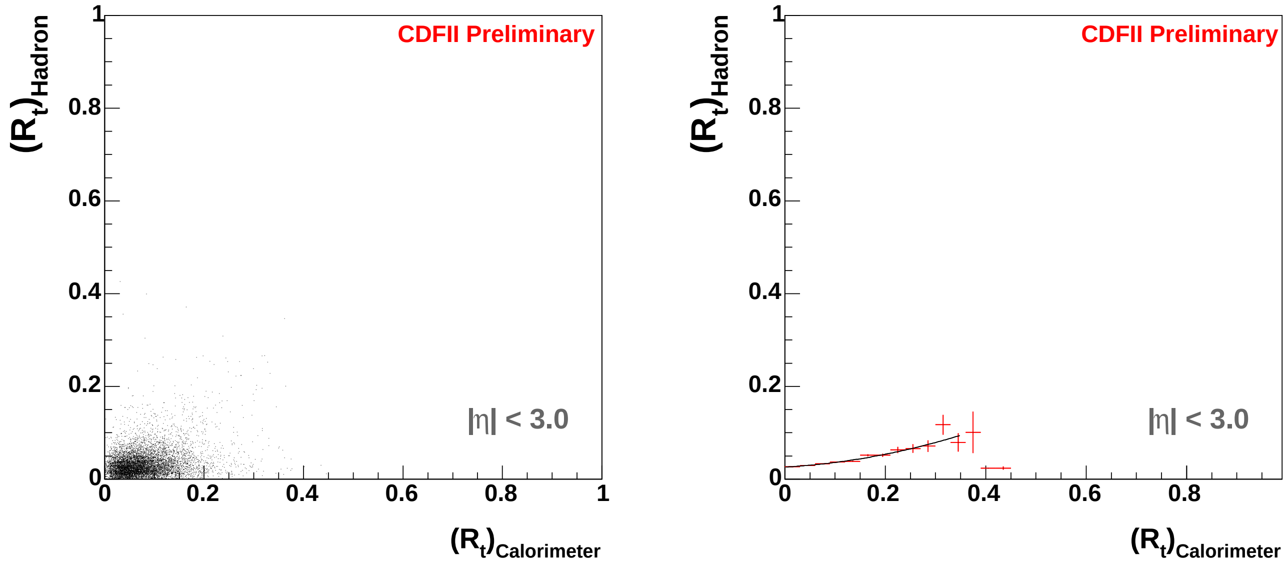


Figure 7: Correlation in the Recoil term between Hadron and Calorimeter Levels

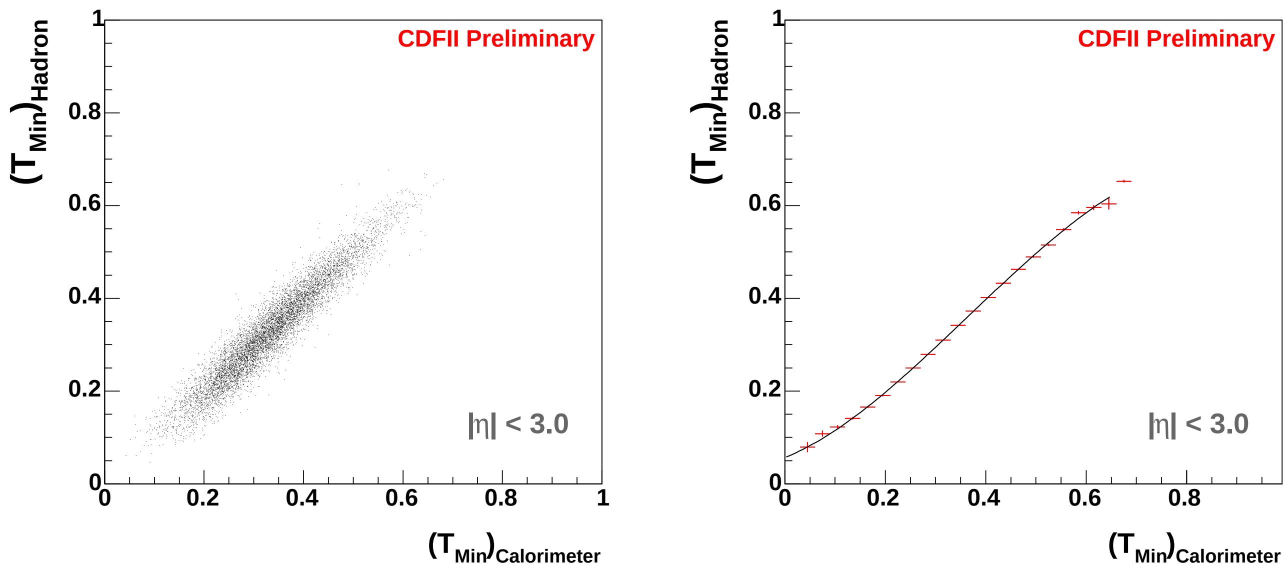


Figure 8: Correlation in the Thrust Minor between Hadron and Calorimeter Levels

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