# Technique for Performing High Accuracy Forward-Backward Multiplicity Correlation Measurements

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Motivation

Particle production in high energy collisions is governed by hard and soft interactions. The bulk of the interactions, which are soft, are difficult to describe fundamentally as they are non-perturbative. Effective models, like Pythia [1], are employed to describe experimental results. Precise and accurate measurements are crucial to test and tune the models.
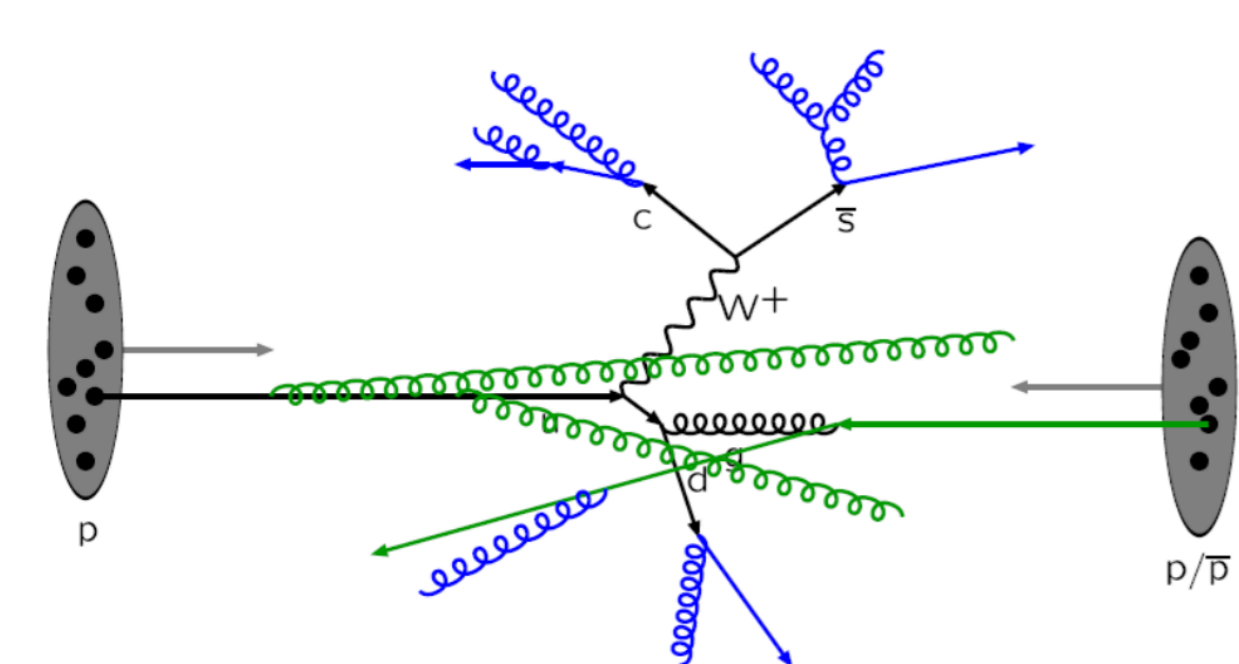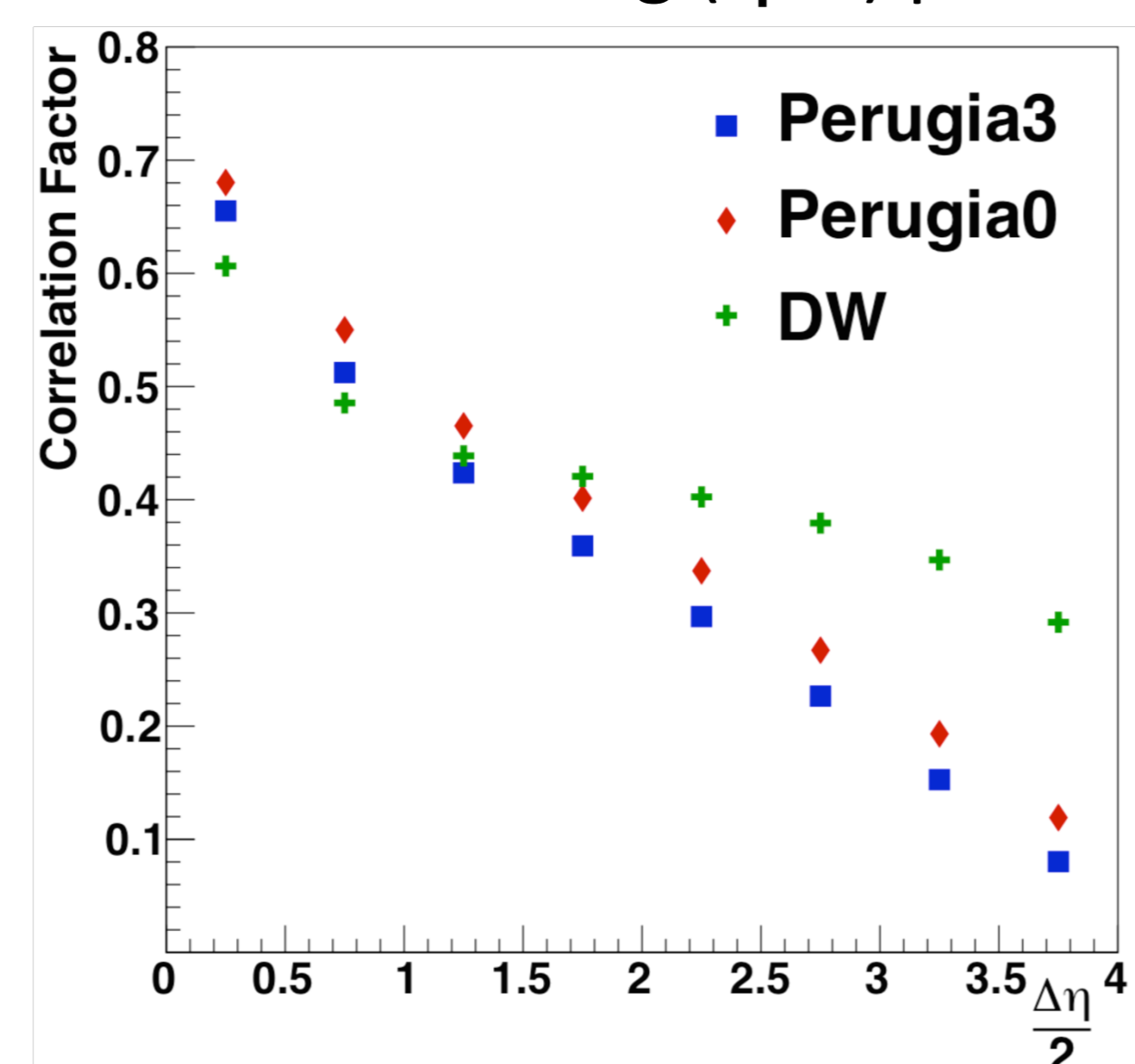
Various processes contribute to the particle production. The relative strengths of the processes will give rise to different observed multiplicity correlations.

Forward-Backward Correlation [2]:

$$b \equiv \mathrm{Cor}(N_f, N_b) = \frac{\mathrm{Cov}(N_f, N_b)}{\sqrt{\mathrm{Var}(N_f) \cdot \mathrm{Var}(N_b)}}$$

$$= \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\sqrt{(\langle N_f^2 \rangle - \langle N_f \rangle^2) \cdot (\langle N_b^2 \rangle - \langle N_b \rangle^2)}}$$

N_f and N_b are the number of forward moving ($\eta > 0$) and backward moving ($\eta < 0$) particles.
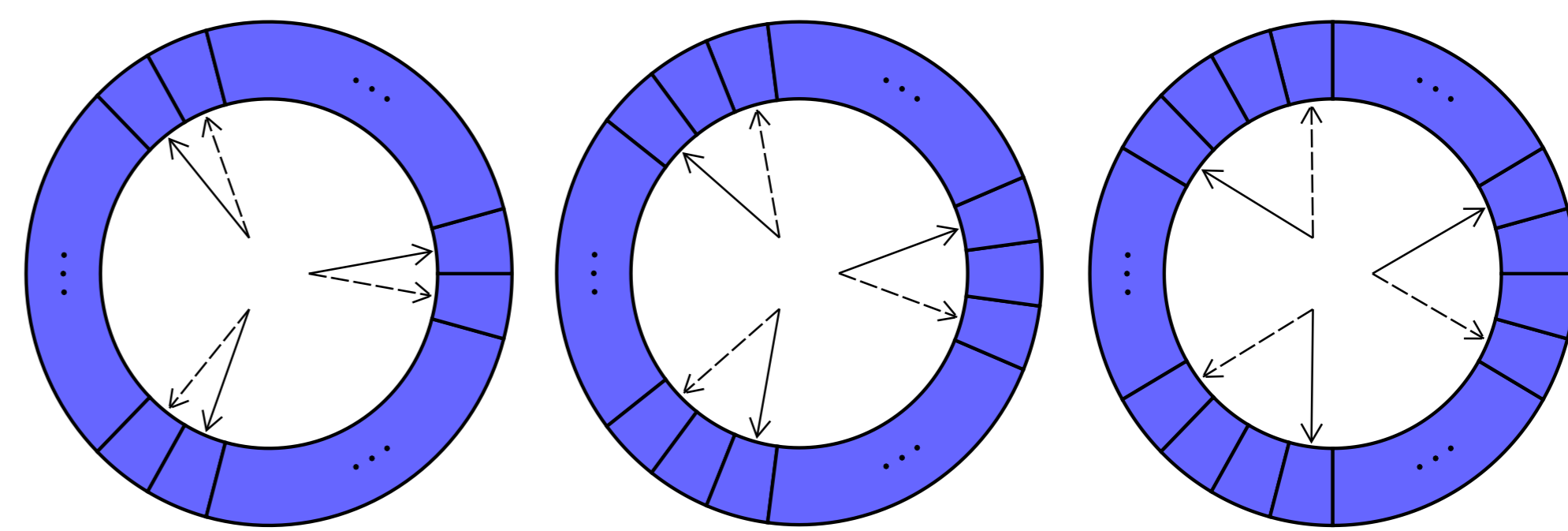

The correlation factors obtained with different tunes of Pythia are shown as a function of pseudorapidity separation. The tunes give similar values for small separations, but differ at large separations. Therefore, either high precision or large separations are required to determine the correct mix of the underlying processes.

Method

This method [3] incorporates typical detector effects like efficiency. The net effect on the observed number of particles and the correlation between the observed particles is computed. Complex detector effects (like efficiency gradients) are accounted for by segmenting the region such that efficiency is nearly constant in a segment. The net effect is determined by summing over the segments. Complicated equations result to compute pieces of the correlation factor (like the covariance) relating correlations between detected particles in two regions, r_1 and r_2 which could be f and b, to the primary particle correlations.
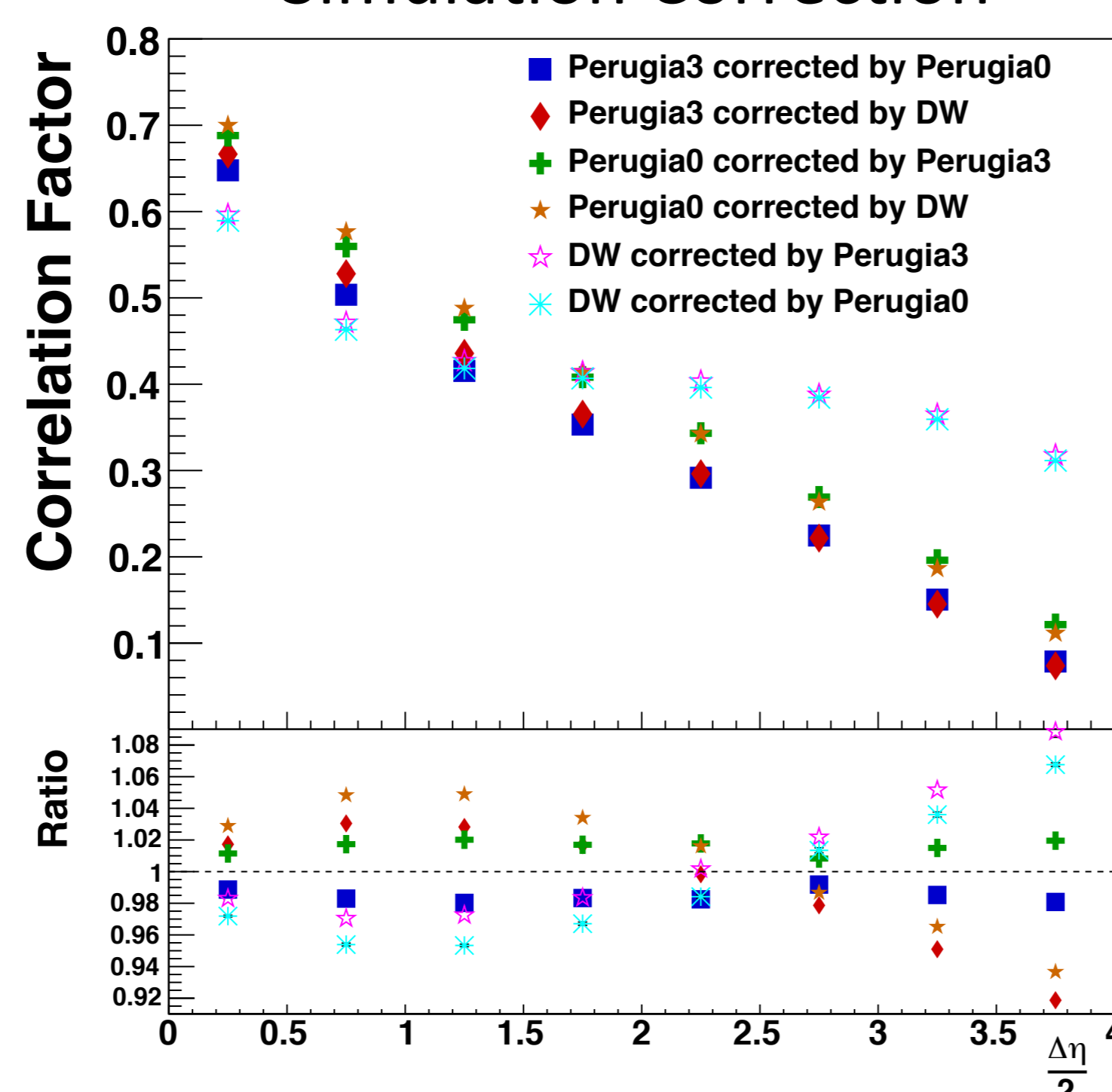
$$\mathrm{Cov}(N_{r_1}^P, N_{r_2}^P) =$$
$$m_\varphi \cdot \frac{\sum_{i_\varphi=1}^{m_\varphi} \mathrm{Cov}(N_{r_1,i_\varphi}^D, N_{r_2,i_\varphi}^D)}{\sum_{i_\varphi=1}^{m_\varphi} \varepsilon_{r_1,i_\varphi} \varepsilon_{r_2,i_\varphi}}$$
$$+ m_\varphi \cdot \sum_{s=1}^{m_\varphi-1} \left\{ \frac{\sum_{i_\varphi=1}^{m_\varphi-s} \mathrm{Cov}(N_{r_1,i_\varphi}^D, N_{r_2,i_\varphi+s}^D) + \sum_{i_\varphi=1}^{s} \mathrm{Cov}(N_{r_1,m_\varphi+i_\varphi-s}^D, N_{r_2,i_\varphi}^D)}{\sum_{i_\varphi=1}^{m_\varphi-s} \varepsilon_{r_1,i_\varphi} \varepsilon_{r_2,i_\varphi+s} + \sum_{i_\varphi=1}^{s} \varepsilon_{r_1,m_\varphi+i_\varphi-s} \varepsilon_{r_2,i_\varphi}} \right\}$$
$$- \delta_{r_1 r_2} \cdot m_\varphi \cdot \frac{\sum_{i_\varphi=1}^{m_\varphi} \varepsilon_{r_1,i_\varphi} \left(1 - \varepsilon_{r_1,i_\varphi}\right)}{\sum_{i_\varphi=1}^{m_\varphi} \varepsilon_{r_1,i_\varphi}^2} \cdot \frac{\sum_{i_\varphi=1}^{m_\varphi} \langle N_{r_1,i_\varphi}^D \rangle}{\sum_{i_\varphi=1}^{m_\varphi} \varepsilon_{r_1,i_\varphi}}$$

Rotational invariance is invoked to compute the net effect of efficiency on regions with equal angular separations and its net contribution in all azimuth. All separations are summed up to produce an accurate estimate of the primary correlation.
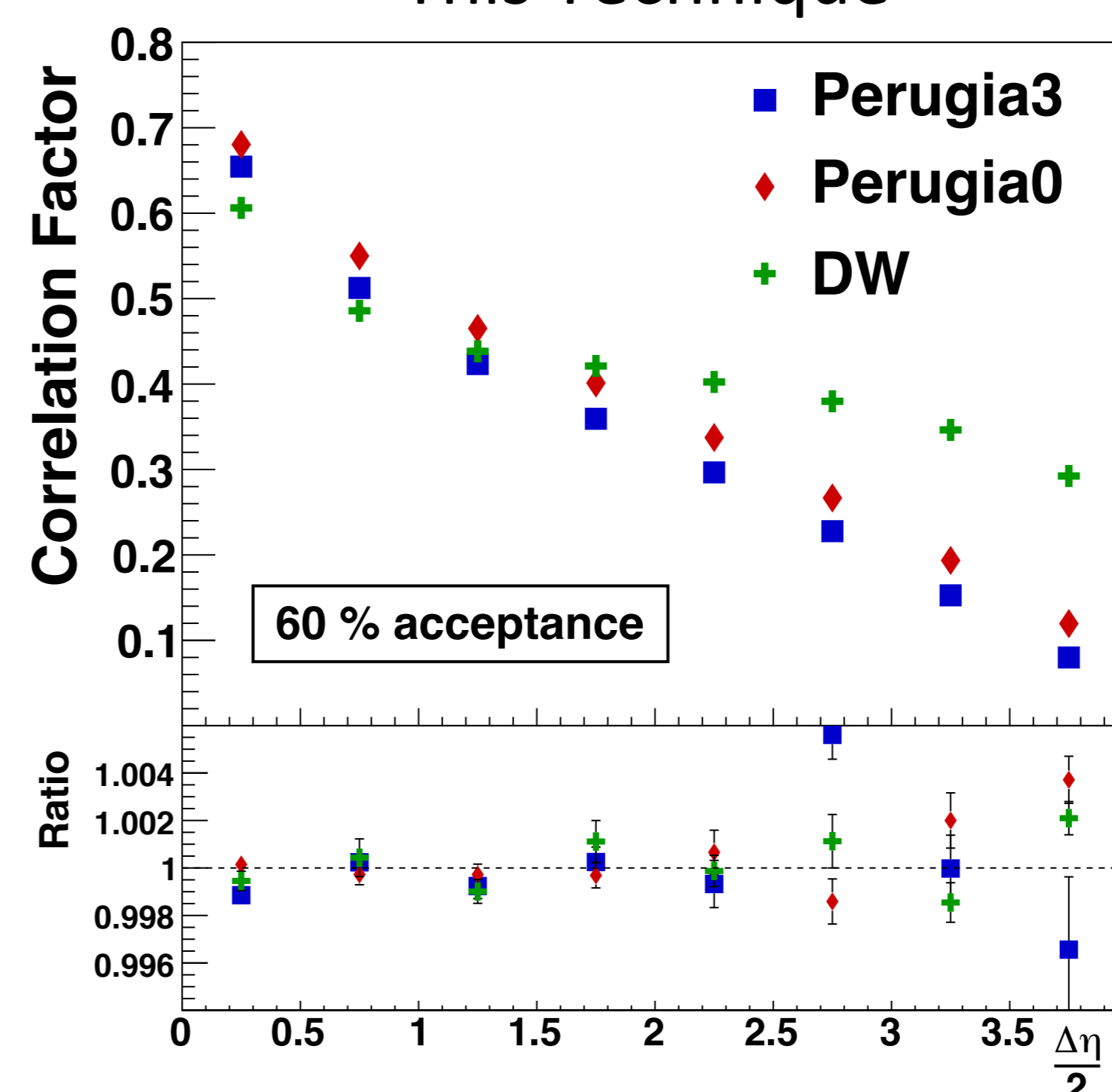
Performance

A common way to account for detector effects is to use a simulation to calculate both the true and detected values of an observable and use the ratio to scale the experimentally determined result. Such a method can, however, leave a significant dependence on the assumptions of the model and bias the result.

Simulation Correction

This Technique

60 % acceptance

In contrast, the technique presented here possesses no assumptions about the true correlations. The technique further shows that a simple division cannot capture the true complexity of how detector effects modify observed correlations. A quite significant improvement in accuracy can be achieved employing this technique reducing systematic errors on correlation measurements.

Particles are generated from three different Pythia tunes. The particles are then subjected to an acceptance of 60%. The observed correlations are related back to the primary correlations by using a different tune to account for acceptance or by the method present here. The ratio of the resultant correlation to the true correlation is shown in the bottom panels. **The accuracy of the technique presented here is about an order of magnitude better than that from correcting with the other tunes.**

Generality

The technique described here is not limited to forward-backward correlations. The method outlined is also applicable to azimuthal correlations and two particle correlations (used to investigate the ridge, for example). The efficiency can be a function of any measured parameter (angle, momentum, ...). The method requires greater than 50% azimuthal acceptance in every other variable to be applicable. The acceptance profile can, however, be non-uniform (including regions in azimuth with zero efficiency). This technique allows one to fully exploit the capability of their detector for correlation measurements, where one might otherwise give up due to low efficiency and large systematic errors.

[1] T. Sjostrand and M. van Zijl, Phys. Rev. **D36**, 2019 (1987)
[2] K. Wraight and P. Skands, Eur. Phys. J. **C71**, 1628 (2011), arXiv: 1101.5215
[3] K. Gulbrandsen and C. Søgaard, arXiv: 1408.3391

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