sPHENIX | Note

tag: sPH-JS-2024-01
version: 1.4
DOI: unspecified
date: August 27, 2024

Using Random Cones to Characterize Jet Background Fluctuations in Au+Au $\sqrt{s_{NN}} = 200$ GeV Minimum Bias HIJING Simulations

Tanner Mengel

Abstract

This note outlines a study of underlying event fluctuations and jet background subtraction using random cones in simulated Au+Au $\sqrt{s_{NN}} = 200$ GeV minimum bias HIJING events. We compare the width of momentum residual δp_T across three background subtraction methods applied to random cones. The background subtraction methods used include the area method, multiplicity method, and iterative method.

1 Introduction

In order to understand the kinematics of jets produced in Au+Au collisions, the large, fluctuating underlying event of soft particles produced simultaneously with the jets must be understood and subtracted. While the average size of the underlying event can be measured and subtracted event by event using a variety of techniques [1, 2, 3], random fluctuations of the underlying event can increase or decrease the UE underneath on a jet-by-jet basis. The resulting over or under subtraction of the UE results in an overall increase in the jet energy resolution, with larger increases in events with a larger UE (i.e. central collisions). Therefore, understanding the size of these fluctuations is key to understanding the energy resolution of measured jets and highlights the need for unfolding of jet measurements using a realistic description of UE fluctuations to correct for the resolution.

This note describes a simulation study to characterize underlying event fluctuations using random cones in simulated HIJING events. Random cones are used to quantify the fluctuations of the UE expected in Au+Au data in terms of jet-like objects, without the bias of a given jet reclustering algorithm [4]. This technique is modelled after a similar analysis performed in ALICE to measure the underlying event fluctuations at LHC energies [4].

2 Simulation

The Monte Carlo (MC) samples used for this analysis are HIJING [5] minimum bias Au+Au events with an impact parameter b ranging from 0-20 fm and a simulated collision rate of 50 kHz.[1] The detector response for these events was simulated using GEANT4 [6]. This analysis uses towers from both the electromagnetic and hadronic calorimeters as inputs to the random cone reconstruction. The analysis is made over the entire sample, totaling 20 million MB HIJING events. Each HIJING event is required to have $|z_{\text{vrtx}}| < 10$ cm. This cut is implemented using the `PPG04EventSelector` [2] event selection module.

3 Cone Reconstruction

The cone axis is randomly selected within acceptance $|\eta_{\text{Cone}}| < 1.1$ - R where R = 0.4, and the full azimuthal range. Calorimeter towers within radius R of the cone axis are summed over resulting in the total cone transverse energy $p_{\text{T,Cone}} = \sum_{i=0}^{N} p_{\text{T,Tower}}$. Input towers from the electromagnetic calorimeter are required to have a minimum tower energy cut of $E_{\text{tower}} > 0.05$ GeV. There is no tower threshold cut for the hadronic calorimeter towers.

The procedure to construct random cones is the same for all background subtraction methods while the inputs differ between background subtraction methods. The inputs for the iterative subtracted cones are the subtracted calorimeter towers, rather than the un-subtracted towers

---

[1] This is the MDC2 type 4 with pileup. These files can be found on `sdcc` via the command '`CreateFileList.pl -type 4 -run 10 DST_CALO_CLUSTER DST_GLOBAL`'.

[2] This module is found in the `analysis/JS-Jet` directory. The link to this specific module is here PPG04EventSelector.

for the area and multiplicity method subtracted cones [3]. After construction each cone is then background subtracted using the three methods described in Sec. 3. The area of the cone is set by πR^2. The multiplicity method is altered for random cone subtraction because $\langle N_{\text{signal}} \rangle$ is assumed to be zero, rather than estimated from the reconstructed cone E_{T}. The E_{T} residual is calculated for each of the background subtraction methods

$$\delta E_{\text{T}}^{\text{Area}} = \sum_{i=0}^{N} E_{\text{T,Tower}} - \rho_{\text{Area}} \cdot (\pi R^2),$$

$$\delta E_{\text{T}}^{\text{Mult}} = \sum_{i=0}^{N} E_{\text{T,Tower}} - \rho_{\text{Mult}} \cdot (N_{\text{towers}}),$$

$$\delta E_{\text{T}}^{\text{Iter}} = \sum_{i=0}^{N} E_{\text{T,Sub. Tower}},$$

where ρ_{M} and ρ_{A} are the background densities for the multiplicity and area methods, N_{towers} is the number of towers within the cone radius with non-zero energy, $E_{\text{T,Sub. Tower}}$ is the energy of a tower after applying the iterative background subtraction method, and $A = \pi R^2$ is the area of a cone with radius R. The module used to reconstruct the random cones and subtract them is `RandomConeAna` [4]. After subtraction, the residuals are for each centrality class, where the centrality is determined by the percentile of the HIJING impact parameter b. Further detail on each of the background subtraction methods implemented in `RandomConeAna` is given in the following sections.

3.1 Iterative Method

The iterative subtraction method is based on Ref. [1]. The underlying event is determined individually for each layer of the calorimeter (EMCal, inner HCal, outer HCal) in strips of $\Delta\eta = 0.1$. First, the EMCal towers are "retowered" such that the geometry matches that of the HCals, with an equivalent area of 4x4 EMCal towers. Energy from each EMCal tower is added to the "retowered" tower weighted be the area overlap between the EMCal tower and the coverage of the particular tower using the HCal geometry. After retowering, anti-k_{T} is run over the towers with $R = 0.2$ to determine candidate jets in the event, referred to as "seeds". For the first iteration,

---

[3] The calorimeter tower objects used for each cone type are listed here:

1. Area and multiplicity method subtracted cones:
   - EMCAL: `CEMC_TOWERINFO_RETOWER`
   - IHCAL: `HCALIN_TOWERINFO`
   - OHCAL: `HCALOUT_TOWERINFO`
2. iterative subtracted cones:
   - EMCAL: `CEMC_TOWERINFO_RETOWER_SUB1`
   - IHCAL: `HCALIN_TOWERINFO_SUB1`
   - OHCAL: `HCALOUT_TOWERINFO_SUB1`

where the base object is used in the area and multiplicity subtracted cones and the `_SUB1` tower is used for the iterative subtracted cones.

[4] The module used to reconstruct these cones, subtract them and produce these plots are publicly available in the analysis repository here RandomConeAna

seed jets are defined as $R = 0.2$ jets with a maximum constituent energy divided by the mean constituent energy to be greater than 3. The average energy per tower is determined for each η strip, excluding towers within $\Delta R < 0.4$ of a seed from the calculation. The determination is done individually in each layer of the calorimeter. This average energy is then subtracted from each tower in the event, and the collection of $R = 0.2$ jets are re-analyzed after the first iteration of subtraction to determine the seeds for the second iteration. For the second iteration, the seeds are required to have a $p_{\mathrm{T}}^{\mathrm{sub}} > 7$ GeV. The average energy per tower is again determined, excluding the new set of seeds, and the towers are subtracted. These subtracted towers are then used as the input to the anti-k_{T} algorithm used to reconstruct jets, or in the case of this analysis the subtracted towers are studied directly. [5]

3.2 Area Method ($\rho_A * A$)

The area-based method, is based on Ref [3]. We denote cones subtracted using the area method as $\rho_A * A$ in the plot legends. The method corrects jet transverse energy by estimating the average energy density of the background per unit area ρ_{A} without taking η dependencies or hydrodynamical effects into account. The method can be expressed as

$$E_{T,\mathrm{jet}}^{\mathrm{Corr,\,A}} = \sum E_{T,\mathrm{tower}} - \rho_{\mathrm{A}} A_{\mathrm{jet}} \tag{1}$$

where the jet area A is computed utilizing "ghost" particles and ρ_{A} is the background energy density per unit area.

The average background tower energy ρ_{A} in an event is determined by finding the median of the average transverse energy per unit area of k_T jets within an event. First, k_T jets with resolution parameter $R = 0.4$ are reclustered from towers in the electromagnetic calorimeter, and both hadronic calorimeters using `TowerJetInput` objects with `JetReco` [6]. The two hardest of these k_T jets are omitted from the ρ_{A} calculation.

3.3 Multiplicity Method ($\rho_M * N$)

The multiplicity method is based on Ref. [2]. We denote cones subtracted using the area method as $\rho_M * N$ in the plot legends. It is a ρ-based background subtraction method similar to the area-based method. In this approach, we use the average transverse energy of "background" calorimeter towers $\langle E_T \rangle$ and the average excess tower multiplicity originating from background within the jet to subtract the background energy

$$E_{T,\mathrm{jet}}^{\mathrm{Corr,\,N}} = \sum E_{T,\mathrm{tower}} - \rho_{\mathrm{M}}(N_{\mathrm{towers}} - \langle N_{\mathrm{signal}} \rangle), \tag{2}$$

where N_{towers} is the observed number of towers within the jet, $\langle N_{\mathrm{signal}} \rangle$ is the average number of towers in a signal jet of a given $E_{T,\mathrm{jet}}^{\mathrm{raw}}$, and ρ_{M} represents the mean transverse energy per background tower.

---

[5] The procedure to reconstruct jets using the iterative method is in the macro HIJetReco.C.

[6] The `JetReco` module is a part of `coresoftware` and can be found here: JetReco. The module to calculate ρ_{A} is also in `coresoftware` found here: DetermineTowerRho.

The average background tower energy ρ_M in an event is determined using a calculation similar to ρ_A. k_T jets with resolution parameter $R = 0.4$ are reclustered from towers in the electromagnetic calorimeter, and both hadronic calorimeters.[7] The two hardest of these k_T jets are omitted from the ρ_M calculation. The average energy per tower is calculated from the remaining k_T jets and the median value of this distribution is taken to be the average transverse energy per background tower $\langle E_\mathrm{T}^\mathrm{Background} \rangle$. The parameter average number of signal towers in a jet $\langle N_\mathrm{signal} \rangle$ can be estimated with accuracy, as models for jets in proton-proton collisions [7] can adequately describe it. Our estimate of $\langle N_\mathrm{signal} \rangle$ is done through matching signal PYTHIA8 jets to the same jets which have been embedded in HIJING 20 fm, 50 kHz MDC2 simulation. The number of towers in the matched PYTHIA jets are then binned according to the raw uncorrected E_T of anti-k_T jets reconstructed from in the mixed event sample. Further corrections must be implemented for transition to tracking and particle-flow jets in the future. The regular EMCAL geometry is used to increase dynamic range of the $\langle N_\mathrm{signal} \rangle$ estimation.

4 Results

Results of cones reconstructed in simulated Au+Au $\sqrt{s_{NN}} = 200$ GeV minimum bias HIJING events are presented below. The momentum residual δp_T is presented for all background subtraction methods for 0-10% central events in Fig. 1 and 30-40% central events in Fig. 2. The centrality from these results are determined from the impact parameter percentile taken from HIJING. The width of all momentum residuals $\sigma(\delta p_T)$ as a function of HIJIING centralities is presented in Fig. 3.

---

[7] The module to calculate ρ_M the same used to calculate ρ_A found here: DetermineTowerRho.

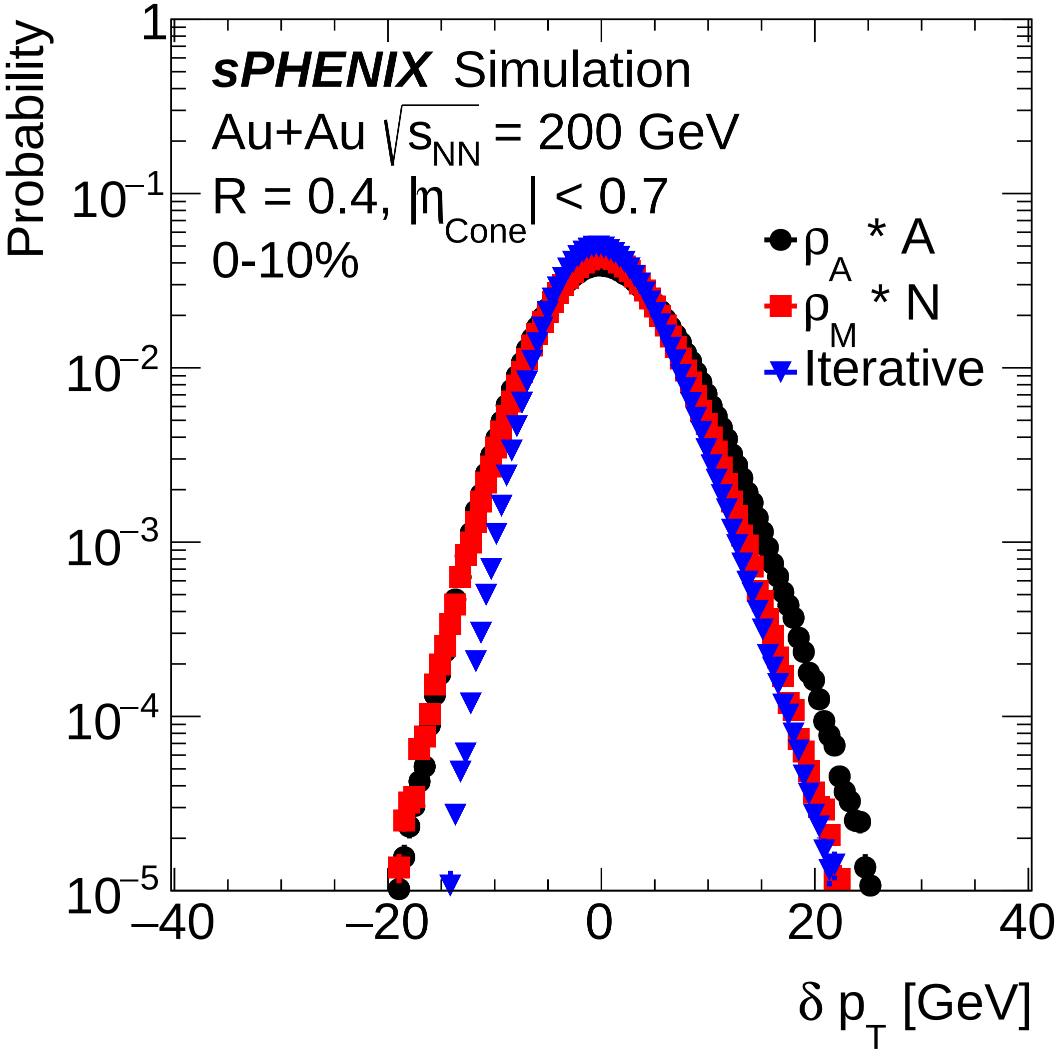

Figure 1: Momentum residual for random cones subtracted with all background subtraction methods in HIJING 0-10% central events.

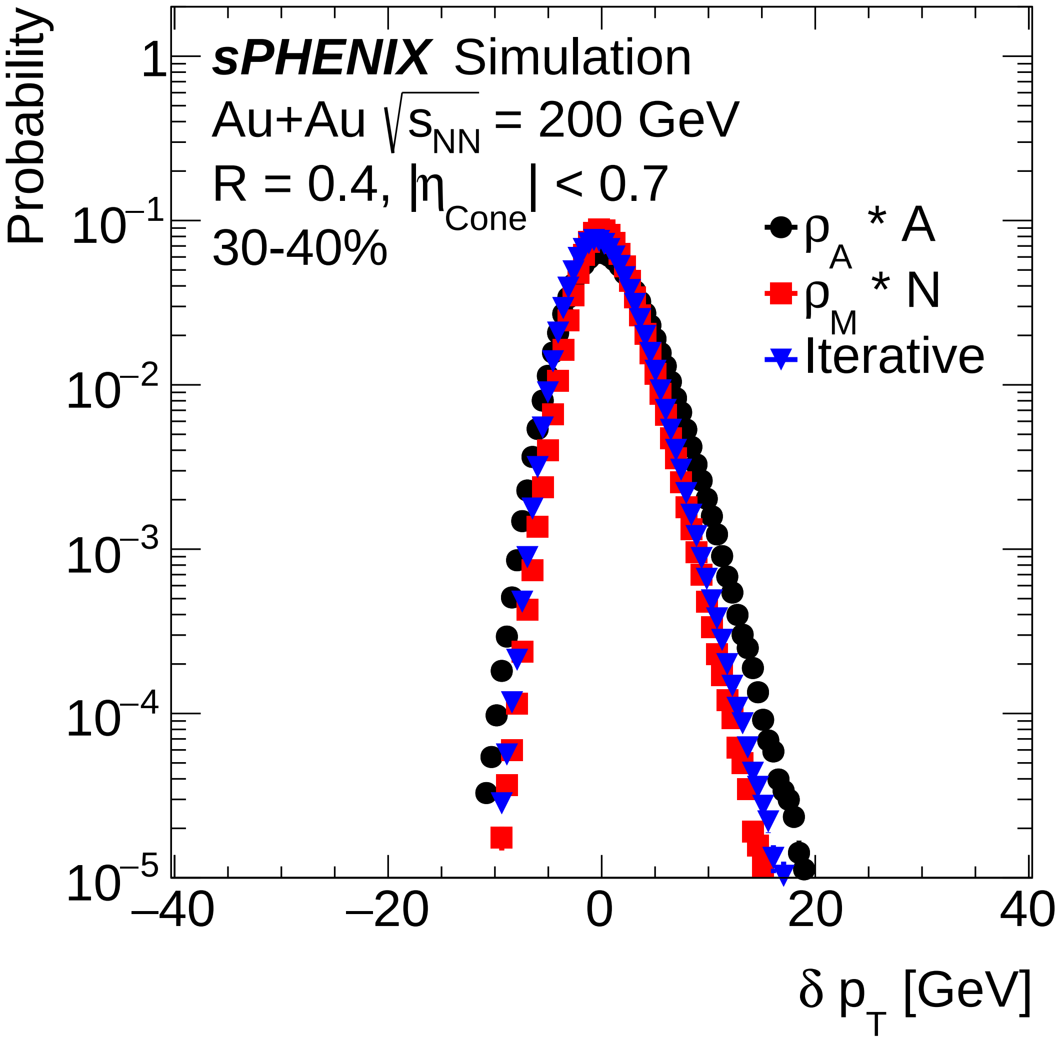

Figure 2: Momentum residual for random cones subtracted with all background subtraction methods in HIJING 30-40% central events.

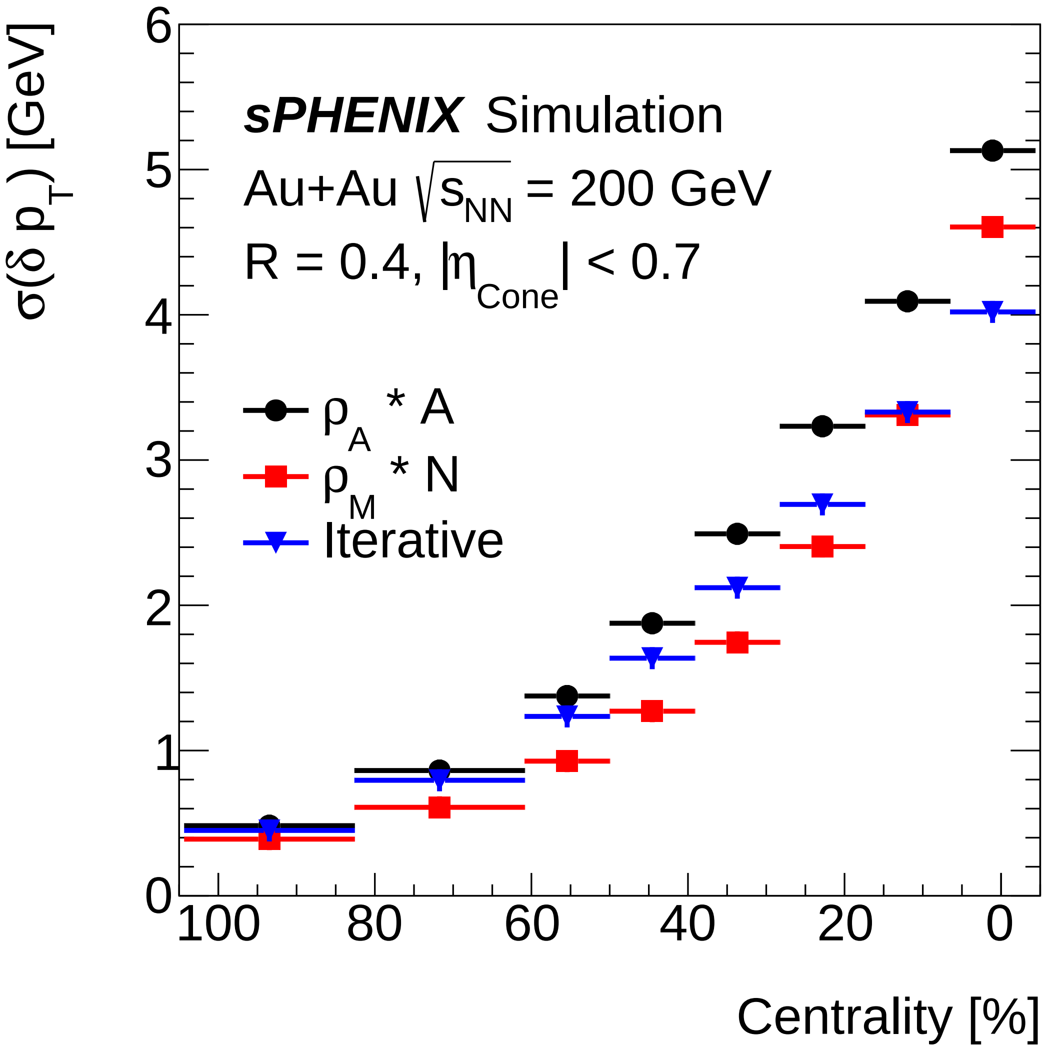

Figure 3: Width of momentum residuals for random cones subtracted with all background subtraction methods in HIJING as a function of HIJING centrality definition (percentage of max impact parameter)

References

[1] J. A. Hanks, A. M. Sickles, B. A. Cole, A. Franz, M. P. McCumber, D. P. Morrison, J. L. Nagle, C. H. Pinkenburg, B. Sahlmueller, P. Steinberg, M. von Steinkirch, and M. Stone. Method for separating jets and the underlying event in heavy ion collisions at the bnl relativistic heavy ion collider. *Phys. Rev. C*, 86:024908, Aug 2012. URL: `https://link.aps.org/doi/10.1103/PhysRevC.86.024908`, `doi:10.1103/PhysRevC.86.024908`. 1, 3.1

[2] Tanner Mengel, Patrick Steffanic, Charles Hughes, Antonio Carlos Oliveira da Silva, and Christine Nattrass. Interpretable machine learning methods applied to jet background subtraction in heavy-ion collisions. *Phys. Rev. C*, 108(2):L021901, 2023. `arXiv:2303.08275`, `doi:10.1103/PhysRevC.108.L021901`. 1, 3.3

[3] Matteo Cacciari, Gavin P. Salam, and Gregory Soyez. The Catchment Area of Jets. *JHEP*, 04:005, 2008. `arXiv:0802.1188`, `doi:10.1088/1126-6708/2008/04/005`. 1, 3.2

[4] Betty Abelev et al. Measurement of Event Background Fluctuations for Charged Particle Jet Reconstruction in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. *JHEP*, 03:053, 2012. `arXiv:1201.2423`, `doi:10.1007/JHEP03(2012)053`. 1

[5] Miklos Gyulassy and Xin-Nian Wang. Hijing 1.0: A monte carlo program for parton and particle production in high energy hadronic and nuclear collisions. *Computer Physics Communications*, 83(2):307–331, 1994. URL: `https://www.sciencedirect.com/science/article/pii/0010465594900574`, `doi:10.1016/0010-4655(94)90057-4`. 2

[6] S. Agostinelli et al. Geant4—a simulation toolkit. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 506(3):250–303, 2003. URL: `https://www.sciencedirect.com/science/article/pii/S0168900203013688`, `doi:10.1016/S0168-9002(03)01368-8`. 2

[7] Betty Bezverkhny Abelev et al. Charged jet cross sections and properties in proton-proton collisions at $\sqrt{s} = 7$ TeV. *Phys. Rev. D*, 91(11):112012, 2015. `arXiv:1411.4969`, `doi:10.1103/PhysRevD.91.112012`. 3.3