Rivet-ing Heavy-flavor-based Analyses from PHENIX

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Abstract

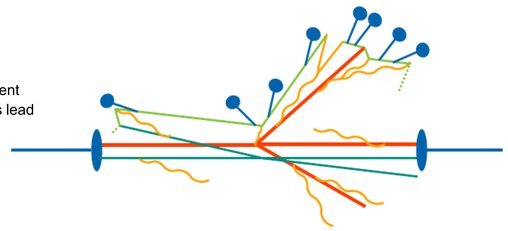
PYTHIA has been one of the more reliable event generators to model relativistic collisions. With an upgrade from the Fortran-based PYTHIA6 to a C++-based PYTHIA8, in addition to new physics processes, newer models based on Multi-Parton Interactions (MPI) have been implemented. In the process, the Monash tune of model parameters for PYTHIA8 works well for LHC energies. However, at RHIC energies, there is a significant difference between event generator models and experimental findings, specifically for heavy flavor production. We approach this problem by using the PROFESSOR tuning method to optimize the model parameters. Writing Rivet analyses to compare PYTHIA8 simulation to data allows PROFESSOR to calculate a goodness of fit function, which is sampled within our parameter space. Using a polynomial fit of the goodness of fit function on the model parameters, the optimal tune is calculated. We hope to use this to tune PYTHIA8 to better model physics at RHIC energies.

Event Generators

Event generators simulate the interactions of particles. They can simulate many different possible processes of particle production.

Event generators are a convenient way to simulate runs of large experiments. In addition, by comparing event generator output to experiment data we can gain an improved picture of the event structure.

A sample event from an event generator. Many processes lead to the blue final particles

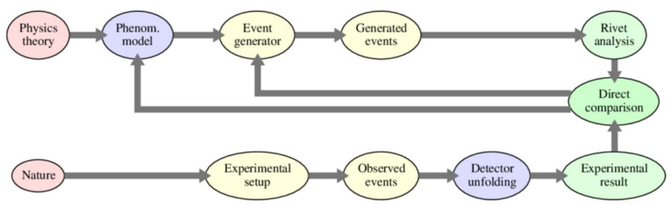


These event generators have free parameters which must be adjusted for the event generator to describe experimental data. Tuning an event generator involves finding a set of model parameters that works well for an experiment.

We work with the event generator PYTHIA8, which has been proven reliable, and the Monash tune works very well for energies found at the LHC.
However, at RHIC energies it does not describe experimental data, specifically for heavy flavor processes.
Our goal is to develop a tune of PYTHIA8 specifically for heavy flavor processes at RHIC.

Rivet

Rivet (Robust Independent Validation of Experiment and Theory) is a system for validating event generators and running analyses on experiments.



Rivet allows the following:

- Preserving analyses and making them easier to maintain.
- Makes results easier to reproduce
- Gives a common testing ground to compare different generators
- Allows testing of event generators against many different data sets

We will use Rivet to compare PYTHIA8 output to data, in order to tune PYTHIA8.

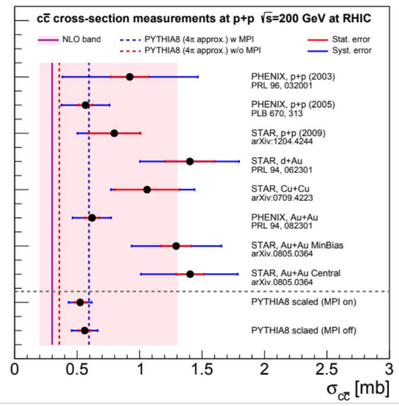
Comparing Event Generators to Experiment

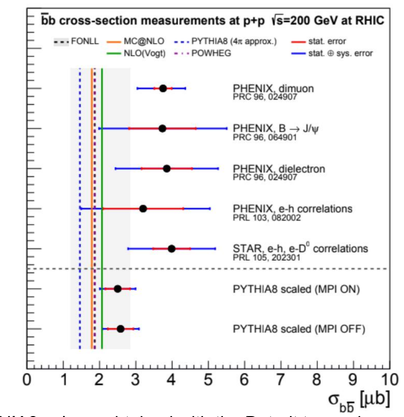
The invariant cross section is given by:

$$E\frac{d\sigma^3}{dp^3} = \frac{1}{2\pi p_T}\frac{1}{N_{events}}\frac{dN}{dp_T}\sigma_{pp}$$

where σ_{pp} is the cross section for proton-proton inelastic collisions at 200 GeV, which is 42 mb.

Particles in mid-rapidity are typically detected in the experiment. To calculate the total cross section, event generators are used to find the ratio of total cross section, and mid-rapidity cross section.

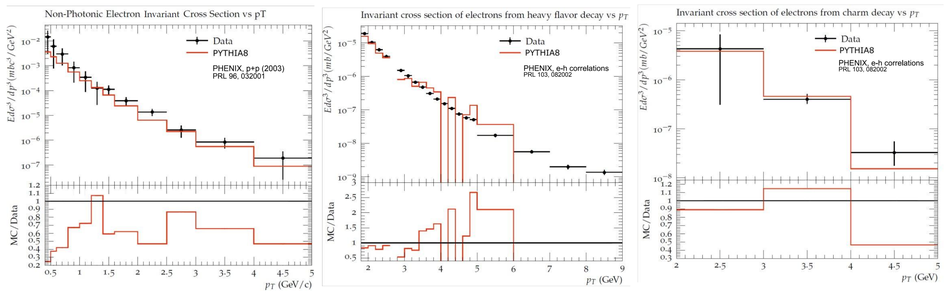




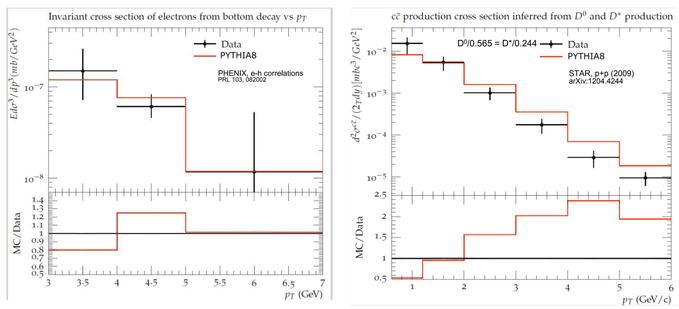
When looking at heavy flavor cross sections at RHIC, PYTHIA8 values, obtained with the Detroit tune, gives smaller results than we find from other models.

Rivet Analyses

Using Rivet, we can write analyses to compare PYTHIA8 output to data for heavy-flavor processes.



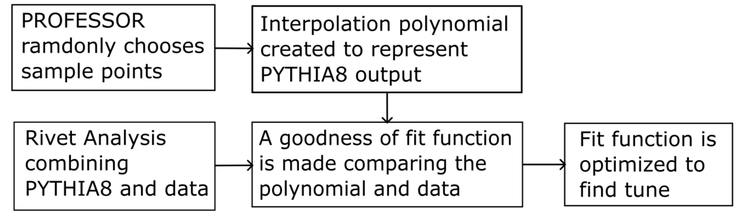
We see a noticeable difference between our output and our data, especially at low p_T. At higher p_T we see much more variance in event generator output, due to low sample size.



Next Steps: Tuning

For tuning PYTHIA8, we are working in a very large parameter space, with order 10 total potentially relevant parameters. The tuning process becomes an optimization problem and will be done using the PROFESSOR (procedure for estimating systematic errors) method.

First, the PROFESSOR method randomly samples the parameter space and runs the event generator at various points in it. With the output from these points, it runs a polynomial interpolation to approximate generator output.



We are using quadratic interpolation, as for each parameter our range is relatively narrowed down. Cubic interpolation is also possible but is significantly more computationally intensive.

Additionally, the parameter space can be split into subspaces to reduce computation time. These subspaces are optimized individually and later combined.

A goodness of fit function is used to compare the difference between the polynomial and experimental data. There are many functions that can be used for this, one of which is a χ^2 fit:

$$\chi^2(p) = \sum_o \omega_o \sum_b \frac{(f^{(b)}(p) - R_b)^2}{\Delta_b^2}$$

where ω are our weights, b is our bin, f(p) is our polynomial, R is our data, and Δ is the uncertainty.

The goodness of fit function is then optimized numerically, and the results are checked.

Summary and Thanks

We have developed Rivet analyses to compare event generator output and experimental data for heavy-flavor contributions. With these we will use the PROFESSOR tuning method to optimize model parameters for PYTHIA8.

I would like to thank Dr. Roli Esha and Professor Axel Drees for mentoring me on this project.

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