The Dissertation Committee for Ryan Patrick Hannigan certifies that this is the approved version of the following dissertation:

Stranger Things at the LHC

Committee:

Christina Markert, Supervisor

Peter Onyisi

Richard Hazeltine

Chandrajit Bajaj

Stranger Things at the LHC

by

Ryan Patrick Hannigan, B.S.

Dissertation

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the degree of

Doctor of Philosophy

The University of Texas at Austin
May, 2023

To Jaynee, who unquestionably is the reason why this document exists.

Stranger Things at the LHC

Publication No. __________________

Ryan Patrick Hannigan, Ph.D.
The University of Texas at Austin, 2023

Supervisor: Christina Markert

Among the most mysterious of the four fundamental forces is the strong nuclear force. Responsible for both the binding together of nucleons within an atom, as well as the

Contents

List of Figures

List of Tables

Chapter One: Analysis Details

This chapter builds upon the analysis overview presented in the previous chapter by providing a much more detailed description of each component of the analysis. These components can be summarized as follows. First, a high-quality data sample of p–Pb collisions is selected, with events further differentiated by their multiplicity. Then, quality tracks are selected for the trigger and associated charged hadrons, and the Λ baryons are reconstructed from lower quality tracks using their characteristic decay topology. These Λ daughter tracks are identified as protons or pions using information from the TPC and TOF detectors. Within a given event, the trigger hadrons are then combined with either the associated charged hadrons or the Λ candidates to form pairs, where a distribution of their relative azimuthal angle ($\Delta\varphi \equiv \varphi_{trig.} - \varphi_{assoc.}$) and pseudorapidity ($\Delta\eta \equiv \eta_{trig.} - \eta_{assoc.}$) is filled for each pair. These h-Λ and h-h angular distributions are then corrected for a laundry list of detector effects using both data- and MonteCaro-driven methods. Further corrections are applied to the h-Λ distributions to account for the combinatorial background associated with the Λ reconstruction and the two-track merging effect, whereby one of the daughter tracks gets merged with the trigger hadron track, causing a h-Λ pair deficit at small angles.

The corrected h-Λ and h-h distributions are then projected onto the $\Delta\varphi$ axis to form 1-dimensional azimuthal correlation distributions. These distributions are used to extract the associated per-trigger yields of Λ baryons and charged hadrons in the near- and away-side of the jet, along with the uncorrelated underlying event (UE). Furthermore, the near- and away-side jet widths are extracted from the h-Λ and h-h $\Delta\varphi$ distributions using a von Mises fitting procedure. These observables are all measured in three event multiplicity percentiles (0-20%, 20-50% and 50-80%) and two associated p_{T} bins ($1.5 < p_{\mathrm{T}}^{\mathrm{assoc.}} < 2.5$ GeV/c and $2.5 < p_{\mathrm{T}}^{\mathrm{assoc.}} < 4.0$ GeV/c).

The structure of this chapter is the following. Section

The systematic uncertainties associated with this analysis are discussed in the next chapter.

1.1 Dataset and event selection

1.1.1 Dataset

Every event in this analysis was a p–Pb collision at $\sqrt{s_{\rm NN}} = 5.02$ TeV with data collected by the ALICE detector during the 2016 LHC run. This analysis uses the data from these runs with the "FAST" reconstruction, meaning the data was taken without the ITS's SDD subdetector due to issues with readout during this period. The total number of events (prior to any selection) is roughly 400 million. For the the efficiency studies, the analysis was performed using a standard purpose MC-generated production anchored to the dataset using the DPMJET [1] event generator. This production consists of around 400 million minimum bias events, which is roughly equivalent to data.

1.1.2 Event Selection

Events are selected by requiring the location of the primary collision interaction point (called the "primary vertex" or PV) to be no more than 10 cm from the center of the detector along the beam axis or "z"-direction. Furthermore, every event is required to have at least three reconstructed tracks that contributed to the reconstruction of the PV. This reduces the total number of events considered to approximately 350 million events, and a summary of the effects of these selection criteria can be seen in Table 1.1. The events are further separated into three charged particle multiplicity classes (0-20%, 20-50% and 50-80%) based off event activity in the forward-rapidity V0A detector.

Table 1.1: Number of events passing our criteria for each multiplicity bin considered. Here Z_{vtx} refers to the position of the PV along the beam (z) axis.

Multiplicity	Total evts.	Has 3 tracks	$\lvert Z_{vtx}\rvert <$ 10cm + 3 tracks	% Pass
0-20%	1.0E08	1.0E08	0.8E08	87%
20-50%	1.6E08	1.6E08	1.3E08	86%
50-80%	1.6E08	1.6E08	1.3E08	86%

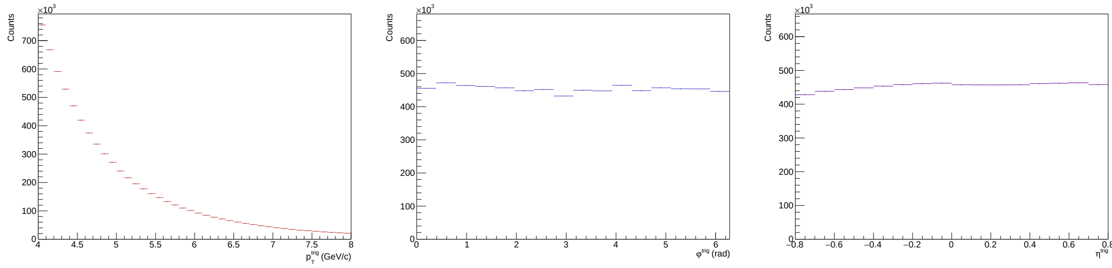

Figure 1.1: The p_{T} (left), φ (middle) and η (right) distributions for the trigger hadrons in the multiplicity range 0-20%.

1.2 Charged hadron track selection

1.2.1 Trigger track cuts

For any two-particle correlation analysis, the selection criteria of the trigger hadron is of utmost importance as any geometric biases introduced by the trigger selection could be reflected in the final correlation distributions. However, correlation analyses generally require large statistics, thus the selection criteria shown in Table 1.2 are applied to ensure the quality of the trigger hadron track while maximizing the statistics of the analysis. Furthermore, the trigger hadron tracks are required to be at midrapidity ($|\eta| < 0.8$) and have high[1] momentum with $4.0 < p_{\mathrm{T}}^{\mathrm{trig.}} < 8.0$ GeV/c, as the trigger is meant to serve as a proxy for a jet axis. Plots of the p_{T}, φ and η distributions for the trigger hadrons that pass these cuts in the 0-20% multiplicity bin can be seen in Figure 1.1.

Table 1.2: The track quality cuts applied to the trigger hadrons in this analysis.

Selection criterion	Value
TPC clusters	≥ 50
χ^2 per TPC cluster	< 4
Fraction of shared TPC clusters	< 0.4
DCA$_{xy}$	< 2.4 cm
DCA$_z$	< 3.2 cm
Accept kink daughters	No

[1] “High” in this case means high enough to guarantee the hadron is produced close (in $\Delta\varphi\Delta\eta$-space) to a jet axis.

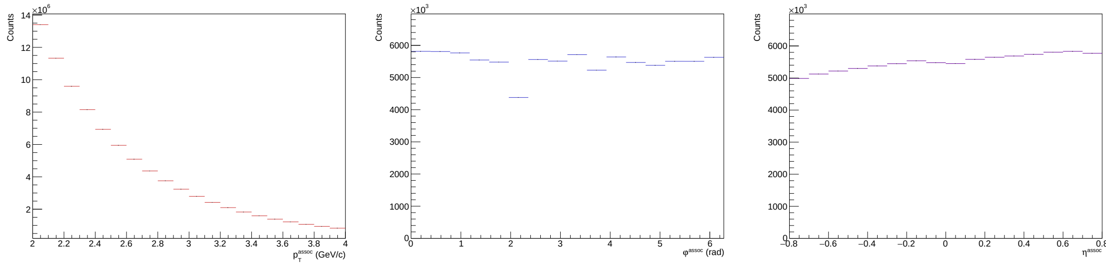

Figure 1.2: The p_{T} (left), φ (middle) and η (right) distributions for the associated hadrons in the multiplicity range 0-20%. The dips observed in the φ distribution are due to the TPC sector boundaries.

1.2.2 Associated hadron track cuts

To keep the results of this analysis more comparabile to previous measurements of the $\Lambda/\pi \approx \Lambda/\mathrm{h}$ ratio, the selection criteria for the associated hadrons are more strict than those for the trigger hadrons as the associated hadrons are meant to be "primary", meaning they did not originate from a weak decay. All associated hadrons are required to meet the ALICE standard track quality cuts for primary charged hadrons described in Table 1.3. Furthermore, the associated hadrons are selected only at midrapidity ($|eta| < 0.8$) in the momentum region $1.0 < p_{\mathrm{T}} < 4.0\mathrm{GeV}/c$, with further binning performed offline. The p_{T}, φ and η distributions for the associated hadrons that pass these cuts in the 0-20% multiplicity bin can be seen in Figure 1.2.

Table 1.3: The ALICE standard track quality cuts for primary charged hadrons, used for the selection of the associated hadrons in this analysis.

Selection criterion	Value
Crossed rows in TPC	≥ 80
Crossed rows/findable clusters in TPC	> 0.8
TPC clusters	≥ 80
ITS clusters	≥ 3
χ^2 per TPC cluster	< 4
χ^2 per ITS cluster	< 36
TPC and ITS refit required	Yes
DCA_{xy}	$< 0.0105 + 0.0350/p_{\mathrm{T}}^{1.1}$ cm
DCA_z	< 2 cm

1.3 Λ reconstruction

1.3.1 Characteristic V^0 decay topology

The Λ candidates in this analysis are reconstructed using their characteristic "V"-shaped decay topology, which is seen in the detector as two oppositely charged tracks originating from a common vertex which is sufficiently displaced from the PV (called the "secondary vertex" or SV). Such particles capable of being reconstructed via this topology are called "V^0"s: the V describing the decay shape and the 0 indicating that the particle is neutral. A diagram depicting a typical V^0 decay is shown in Figure **??**, with labels given for the most relevant kinematic variables.

The first and most important of these variables is the distance of closest approach (DCA) between the two tracks. This DCA needs to be small enough (relative to the tracking resolution) to ensure that the tracks originated from a common vertex. Another important variable is the transverse decay length of the V^0, which is the distance between the PV and the SV measured in the xy-plane. The importance of this variable is twofold: if the decay length is too small, then it may not even be possible to resolve the SV from the PV, plus it allows for the distinction between V^0s of differing decay lengths. The final relevant variable is the cosine of the pointing angle, which is the angle between the momentum vector of the V^0 and the vector pointing from the PV to the SV. This variable is important because V^0 candidates are generally required to be sufficiently collimated to ensure that the V^0 originated from the PV.

1.3.2 Λ Daughter Proton and Pion Track Cuts

Because of the longer decay length of the Λ ($c\tau \approx 10$ cm), the corresponding daughter proton and pion tracks generally have fewer hits in both the ITS and TPC, resulting in "lower quality" track parameters. Because of this, the cuts applied to the daughter tracks used to reconstruct Λ candidates are the least strict of all the track cuts in this analysis and are summarized in Table **??**. The daughter proton and pion are also required to be at midrapidity ($|\eta| < 0.8$) and have a minimum p_{T} of $p_{\mathrm{T}} > 0.15$ GeV/c.

- TPC refit flag enabled

- TPC crossed rows > 70
- (TPC crossed rows)/(findable clusters) > 0.8

All of these cuts are applied to the daughters of the reconstructed Λ, independent of the technique used for said reconstruction. For the correlation, the reconstructed Λ is selected only in the momentum region

Bibliography

[1] S. Roesler, R. Engel, and J. Ranft, "The monte carlo event generator DPMJET-III," in *Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications*, Springer Berlin Heidelberg, 2001. arXiv: `0012252 [hep-ph]` (cit. on p. 2).