APS Presentation Notes

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1. Introduction

Hello, my name is Brandon McKinzie. I'm an undergraduate at UC Berkeley and I'll be talking about research I did with the Nuclear Physics Group at UC Davis this past summer. The research focused on studying the polarization of the Upsilon meson and obtaining a systematic uncertainty for the Upsilon polarization at CMS, the details of which will be described in the following slides.

2. Physics Motivation

Before going into the details of polarization, it is important to understand the necessity of studying it in the first place. Our current cosmological models state that just microseconds after the big bang, the universe was in a state called the quark-gluon plasma, a see of freely interacting quarks and gluons not confined within the usual hadronic matter we are familiar with.

Clearly, scientists want to understand the property of this important state of matter, and a good place to start is identifying its temperature. One way we can do this is by studying which particles dissociate in the QGP, because we know from collider experiments at which temperatures such dissociation occurs. In particular, the Upsilon meson, the bound state of a bottom quark and an antibottom quark, is expected to sequentially dissociate in the QGP as a function of the temperature, with the higher-energy states dissociating more easily than the tightly bound ground state. This can also provide information regarding the level of quark deconfinement in the QGP, that is, how free the quarks truly are to interact with one another without sticking together in clumps of hadrons.

Thus, a thorough understanding of the Upsilon meson is required in order to make accurate predictions about the QGP. A current interesting unknown property of the Upsilon meson is the angle at which its daughter decay particles, back-to-back muons, are emitted with respect to the Upsilon's momentum in its rest frame.

As we will see, current leading experiments that have measured the polarization are in disagreement, and the inconclusivity of the data demands that a systematic uncertainty associated with the polarization is provided when one assumes the unpolarized case.

3. The Upsilon Meson

One last brief mention of the particle itself. Again, it is a bound state of a bottom-antibottom pair. Here I have made a Feynman diagram corresponding to the most common proposed method of Upsilon production, in which two gluons are picked up from neighboring hadrons and interact in such a way as to produce a bottom-antibottom state and an emitted gluon. We see that the Upsilon also has a notably large mass, about 10 times the size of a proton, truly massive. This allows for better estimations to be made regarding its properties in the nonrelativistic limit. Speaking of which, it NRQCD, our leading theory of how strongly interacting matter behaves, predicts strong transverse polarizations at high pT, which does not agree with experiments conducted on the JPSi particle. The hope is that the less-relativistic Upsilon will be a more decisive test of NRQCD.

4. Upsilon Polarization

Now we will begin exploring the polarization. Here we see an illustration of the Upsilon meson in its rest frame, where the horizontal axis is along its direction of momentum. The Upsilon is seen decaying to back-to-back leptons, in this case electrons (decays into dielectrons or dimuons are approximately equally probable), and the angle denoted theta star is the angle of polarization. This is what I am talking about when I say the polarization; I mean the angle of lepton decay.

Now, it turns out that the number of back-to-back leptons produced at a given angle is proportional to this expression here, 1 + alpha*cosine(theta), where the parameter alpha can take on values from -1 to 1, and this is what determines the degree of polarization. As you can see, alpha is defined as a ratio of production cross sections for the transverse and longitudinal polarization cases. Before I go any further, it is crucial to emphasize that transverse/polarizations are defined in exactly the opposite way you would expect. Fully transverse polarization actually corresponds to leptonic decay along the direction of Upsilon momentum. So just remember, it is that opposite of what it logically ought to be. Don't ask why, because I don't know!

Anyway, we can see that if full transverse polarization is assumed, alpha is one, and conversely it is -1 for full longitudinal polarization. It is 0 if the upsilon is unpolarized, which is the current assumption, i.e. that leptons are equally likely to decay at any angle with respect to the Upsilon. I will be making simulations and plots using different values of alpha for the rest of this presentation, so it is important to remember that alpha determines the direction/degree of polarization.

5. Contradiction in Data!

Here it is, the results from two independent collaborations at Fermilab colliding protons and antiprotons. The axes are the same on both plots. The x-axis is the transverse momentum of upsilon meson with respect to the beam pipe, and the y-axis is the familiar alpha polarization parameter, denoted as lambda on the left but meaning the same thing. Recall that points along the bottom of these plots are communicating longitudinal polarization results, points along zero are unpolarized, and close to 1 are transverse polarization. CDF reported roughly unpolarized results, within error bars of course. However, D0 seems to have found longitudinal polarizations suggested in the low pT regime, then rising up to 0 after. What makes this even more confusing is that NRQCD, our best theoretical model, predicts strong transverse polarizations in the high pT regime, which neither experiment observed! It seems we are in an inconclusive state with regard to knowledge of polarization.
Disclaimer: I'm not here to say I have the answer. However, I have made estimates for how wrong we might be if we continue to neglect the possibility of polarization.

6. Methodology

The plots I am about to show you were essentially constructed as outlined in this slide. I simulate millions of collisions in a program named PYTHIA and restrict my data collection to only those events which produced an Upsilon exclusively decaying into a dimuon. The Upsilon pT spectra is plotted for each of the three polarization cases, where a weight is applied to each data point corresponding to the proportionality introduced before. Then, each case is cut by allowing only muons in a certain pseudorapidity range in order to model the acceptance of a given detector. For CMS, this region is within 2.4. Finally, a ratio is taken of how many Upsilons were accepted divided by the total amount simulated, giving the percent acceptance. The systematic uncertainty, the goal of this research, is found by plotting the percent differences of the fully polarized cases compared with unpolarized. This will all become clear in later slides. What is important to remember is that this is all done by modeling data assuming certain physics such as polarization, and then calculating the percent upsilon yield we would actually observe for each case.

7. Polarization at STAR

In order to convince myself that I had the correct code, I tried to reproduce polarization studies already published by members of STAR for their detector. Here are my results, which mirror the results from the STAR member Thomas Ullrich. This data was simulated for center of mass energy per nucleon-pair of 200GeV. What you are looking at is months of accumulated coding and research, and I will briefly describe what these say, leaving more detail for my CMS results to follow. The axes of both plots are the same, with the x-axis being the Upsilon transverse momentum and the y-axis being the percent acceptance of simulated events as a function of the Upsilon momentum. As indicated by the legends, all red points correspond to longitudinally polarized data, blue is transverse, and black is unpolarized (what we assume to be the true case). MOMENTUM CROSSOVER!

Starting with the left plot, it appears that, for low Upsilon pT, we have a very high acceptance in the case of longitudinal polarization, meaning muons are emitted perpendicular to the direction of Upsilon momentum. This is intuitive; the upsilon at low pT is essentially traveling along the beam line, and if the muons shoot out perpendicular to that, we ought to see very many of them strike the detector. In the opposite scenario of transverse polarization, the muons are emitted along the beam line and never strike the detector at all.

The lower plot corresponds to the same data, but with more restrictions added. The baseline data is events satisfying a certain muon threshold pT, which is standard at particle detectors as a method of weeding out uninteresting events. We expect the invariant mass of the dimuon to be equal to the Upsilon at 9.46 GeV/c, so very low energy muons are less likely to have come from our Upsilon. When these restrictions are applied, we find this interesting roller coaster shape that is due to the asymmetric pT cuts applied as well as the restriction of the opening angle of decay. We will observe this shape more in the next slide. These plots are really just here to convince you that my results aren't garbage.

8. Polarization at CMS

This is it. These are the results I hope to find after months of work. The simulated data is at 2.76TeV per nucleon-pair, with 3 million Upsilon->Dimuon events collected. I calculate the error bars here using a Bayesian approach where the statistical error is approximated as the standard deviation of an efficiency distribution. Anyway.

The percent differences of Upsilon acceptance are the same as in the STAR case, which is the quantity that is important. The absolute values of acceptance may fluctuate depending on the parton-distribution-functions that are drawn from and other simulated quantities. The shape of the kinematic acceptance distribution is more complex aesthetically and this is likely due to the asymmetric pT cuts being different than before and with no restriction on the opening angle of decay. Also, the acceptance crossover occurs at the higher value of 5 GeV/c in comparison with the crossover around 3 for the STAR case. So an interesting conclusion there is that the systematic error associated with the polarization is different as a function of Upsilon pT from detector to detector (i.e. at different collision energies). One could clearly reduce the systematic error in their data analysis by restricting the analysis to Upsilons with pT near the 5 GeV range.

9. Systematic Uncertainty

Here I have taken the plots from the last slide and now plotted the percent difference of polarization extremes to the unpolarized case. This is a better visualization the systematic uncertainty, as it is being compared to the unpolarized case. Again we see the uncertainty go to zero just under 6 GeV/c, and the uncertainty approaching a maximum in the low pT regime. The maximum systematic uncertainty with no kinematic cuts is 12 percent for longitudinal polarization, and about 7 percent for transverse polarization. The uncertainty is lower when triggers are placed on the muon pT to allow only high energy muons, and both cases reach maximum uncertainties near 2-3 percent, peaking around 8 GeV/c. We also see that there are more crossovers of 0 percent uncertainty when muon pT thresholds are applied, allowing one a broader range of data to analyze with minimum uncertainty.