Measuring Azimuthal Angular Resolutions in $p^{\uparrow}+p \rightarrow$ jet + X and $p^{\uparrow}+ p \rightarrow$ jet + $\pi^{\pm}$ + X

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Abstract

Measurements of particle production from polarized-proton collisions at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) give insight into proton spin structure. One way to study spin effects such as those due to quark transversity or the Sivers parton distribution function is to analyze spin-dependent asymmetries in the final-state particles produced in transversely polarized-proton collisions. The large angular acceptance of the Solenoidal Tracker at RHIC (STAR) allows the reconstruction of full jets in addition to inclusive hadron production. Analyzing spin-dependent azimuthal asymmetries in $p^{\uparrow}+p \rightarrow$ jet + X (e.g. Sivers Mechanism) and $p^{\uparrow}+ p \rightarrow$ jet + $\pi^{\pm}$ + X allows one to isolate contributions from the Sivers and Collins effects. Measuring the resolution of the relevant azimuthal angles is critical to quantifying the systematic uncertainties of the asymmetry measurements. A useful means to study the resolutions and response of the STAR detector in light of pile-up backgrounds is to embed simulated events into real zero-bias data. In 2009 and 2011 STAR collected data from polarized-proton collisions at $\sqrt{s}$ = 500 GeV. These samples provide an opportunity to study the angular resolution of inclusive jets at 500 GeV from embedded simulated events, and the progress of these studies will be shown.

Spin Physics at STAR

The Relativistic Heavy Ion Collider (RHIC) (Figure 1), located at Brookhaven National Laboratory is the world's only machine capable of colliding high-energy beams of polarized protons. The Solenoidal Tracker at RHIC (STAR) (Fig. 2) utilizes these polarized-proton collisions to explore the so-called proton "spin crisis". It is known experimentally that the spin of the proton is ½ ħ, but it is known from deep inelastic scattering experiments that the quarks and anti-quarks inside the proton only contribute about 30% of the total proton spin. To account for the rest of the spin, we must consider the gluonic contribution and orbital angular momentum contribution of the proton's constituents. These contributions are summarized in the proton spin sum rule:

$$\frac{1}{2} = \int_0^1 dx \left[\frac{1}{2} \sum_q \underbrace{\left(\Delta q + \Delta \bar{q}\right)(x,\mu^2)}_{\text{Quark and Antiquark Spin Contribution}} + \underbrace{\Delta G(x,\mu^2)}_{\text{Gluon Spin Contribution}} \right] + \underbrace{L(\mu^2)}_{\text{Angular Momentum Contribution}}$$

Spin physics at STAR utilizes three main subsystems of the detector. The **E**ndcap **E**lectro**M**agnetic **C**alorimeter (EEMC) and the **B**arrel **E**lectro**M**agnetic **C**alorimeter (BEMC) measure neutral energies as well as electron energies within the pseudorapidity range of $1 < \eta < 2$ and $-1 < \eta < 1$ respectively. The **T**ime **P**rojection **C**hamber (TPC) rests within the BEMC, and is filled with a gas mixture (10% methane and 90% argon). Charged particles moving through the detector ionize the gas leaving electrons to drift in an electric field to the readout endcaps. This information is then used to reconstruct the paths of the charged particles through the TPC.

Figure 1: Brookhaven National Laboratory; the RHIC Collider is highlighted at the top.

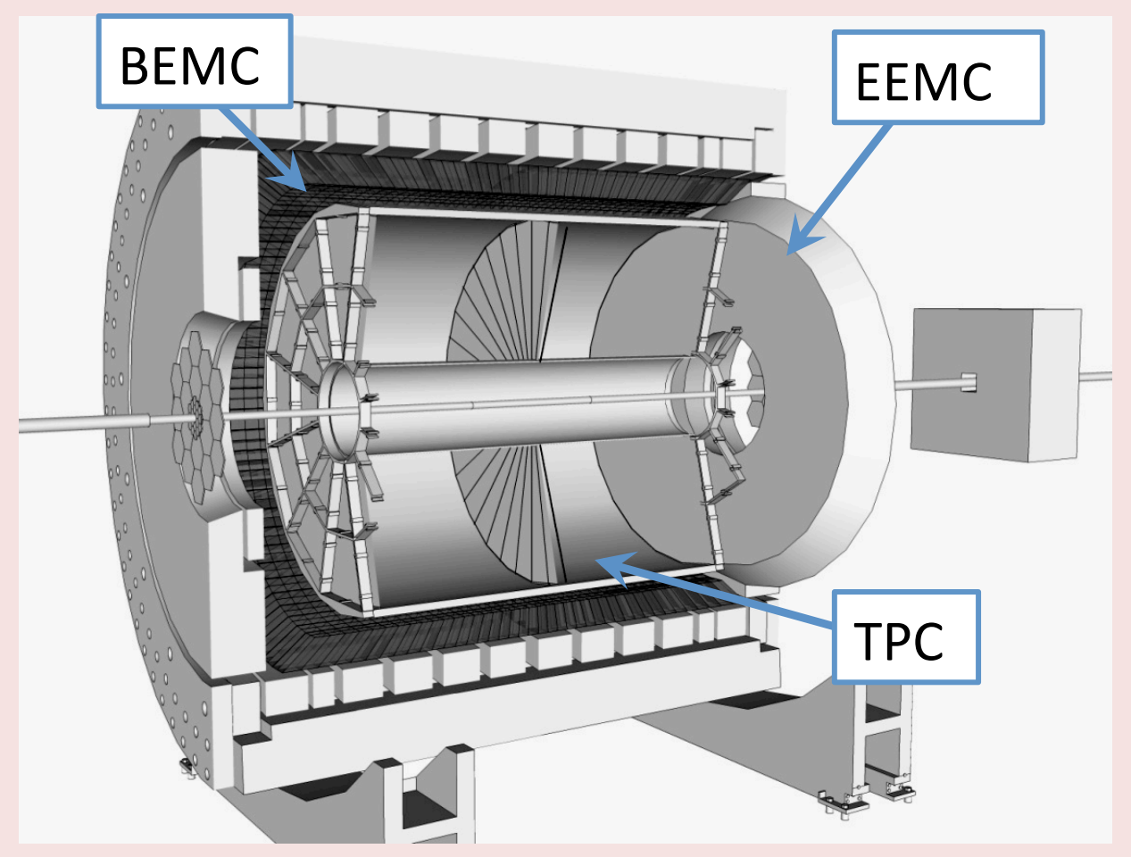


Figure 2: The STAR Detector; the BEMC, EEMC, and TPC are highlighted.

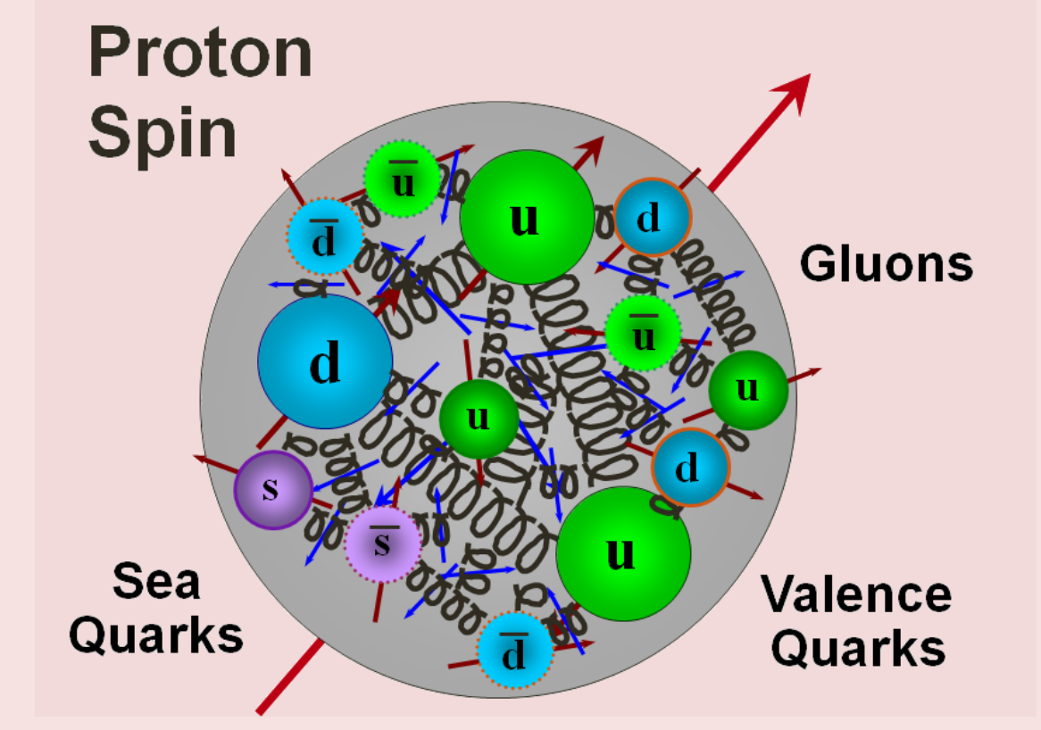
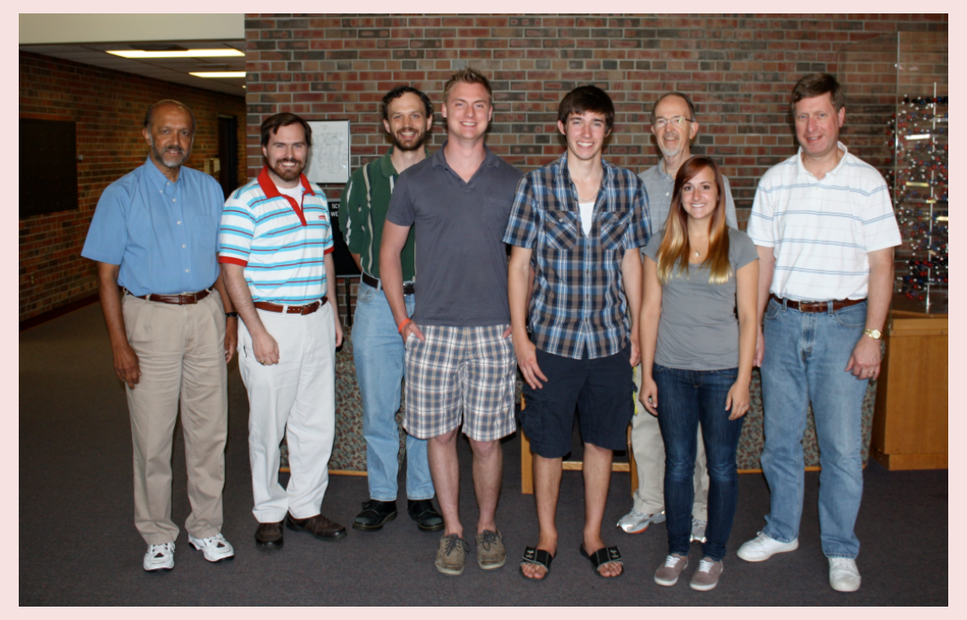


Figure 3: Diagram of the proton including valence quarks, sea quarks, gluons, and arrows representing spin.



STAR summer research group

Collins Effect, Sivers Effect, and Transversity

One way to study spin-effects is to analyze spin-dependent asymmetries in the final-state particles produced in polarized-proton collisions. The large angular acceptance of STAR allows the reconstruction of full jets, narrow cones of particles produced by scattered quarks and gluons. Analyzing spin-dependent azimuthal asymmetries in $p^{\uparrow}+p \rightarrow$ jet + X and $p^{\uparrow}+ p \rightarrow$ jet + $\pi^{\pm}$ + X allows one sensitivity to contributions from two pieces of proton spin structure: the effective transverse quark polarization (transversity) and the orbital motion of quarks and gluons. The Collins Mechanism produces an asymmetry in the distribution of charged particles inside the jet, while the Sivers mechanism produces an asymmetry in the jet production itself (Figure 4).

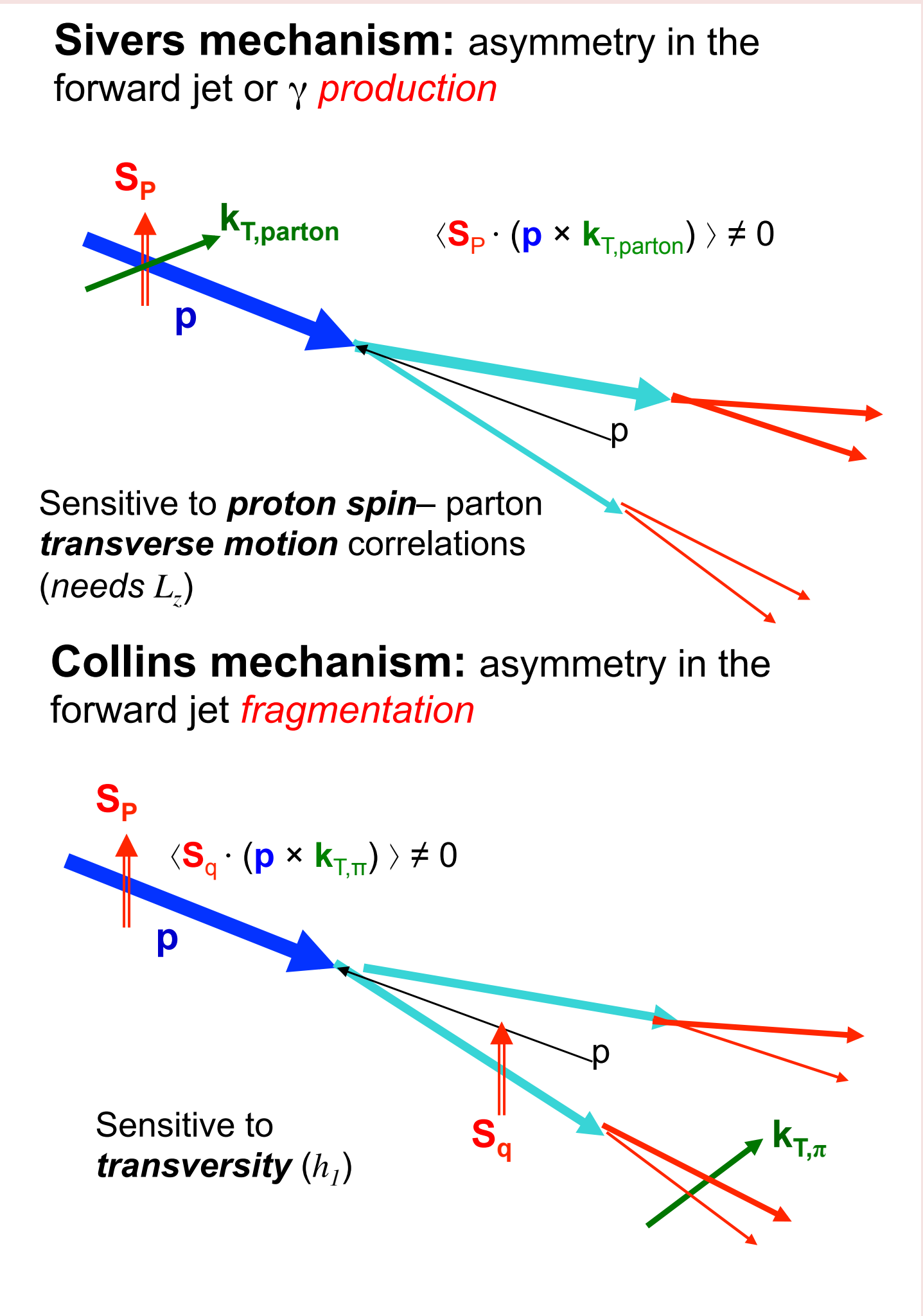


Figure 4: Pictorial representation for Collins and Sivers Mechanisms.

Quark transversity is a fundamental piece in understanding the spin structure of the proton. It is the measure of the quark transverse polarization inside a transversely polarized proton. This quantity can be extracted using the Collins asymmetry measurement and the Collins fragmentation function, which has been measured by the Belle Collaboration.

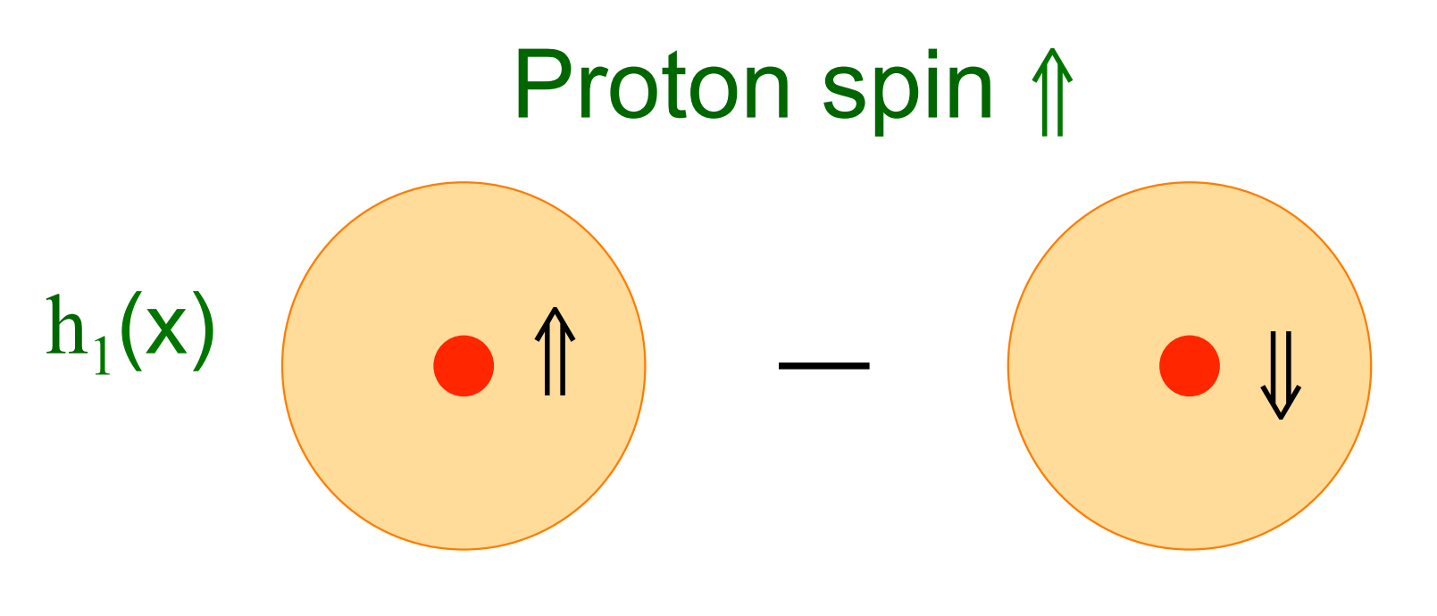


Figure 5: Pictorial representation for Transversity.

Embedding and Data Comparisons

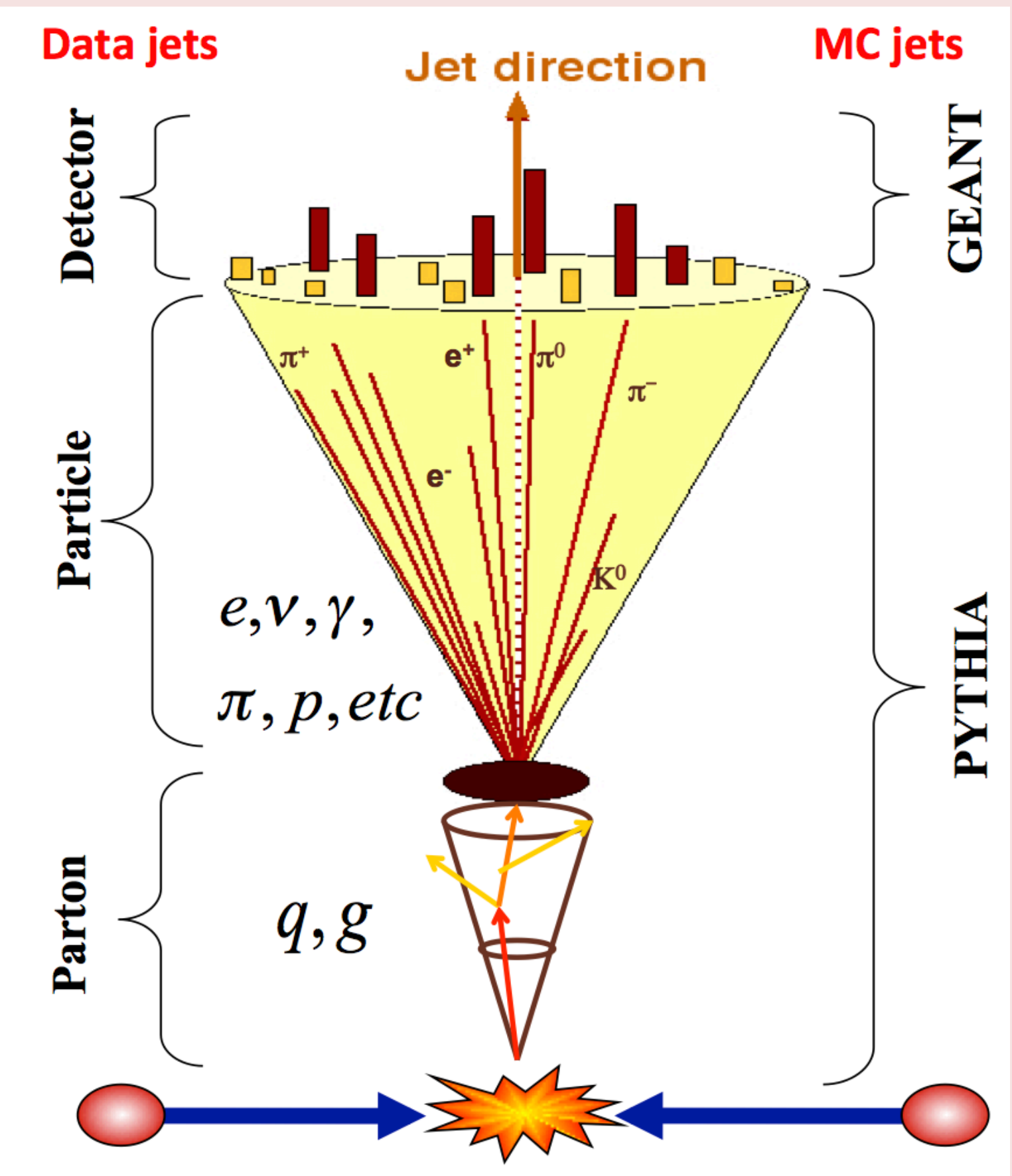


Figure 6: Pictorial representation contrasted data jets and simulated jets

Because the Sivers and Collins Mechanisms depend on azimuthal angles, measuring the resolutions of the relevant angles is critical to quantifying the systematic uncertainties of the asymmetry measurements. A useful means to study the resolutions and response of the STAR detector in light of pile-up backgrounds is to embed simulated events into real data. In 2009 and 2011, STAR collected data from polarized-proton collisions which provide an opportunity to compare jets reconstructed from real events to those from simulated events to ensure simulations accurately reflect real data.

First, jet events are simulated (using PYTHIA 6.426). The simulated detector response (created using GEANT 3.21/08) is then embedded into a data file for real events taken without preference for a particular detector trigger (zero bias data). This "embedded" event is then reconstructed in the same manner as real triggered events. The jets reconstructed from the embedding files are then matched to a known jet simulated for that event. Individual charged particles within these matched jets are then also matched to the particles from the simulated jet. The distributions of matched jets and particles are compared to those from real triggered data to see if the simulation realistically reproduces the data.

Figures 7-10 show the comparison of embedding to real data for reconstructed jet transverse momentum (P_T), charged particle P_T relative to the jet (J_T), and the fraction of the jet momentum carried the charged particle (z). The agreement for charged particle distributions is reasonable. Discrepancies in the jet P_T spectrum, because 2009 simulation was only for high- P_T triggered jets, show the need for lower P_T simulation from 2011 to include minimum-bias events.

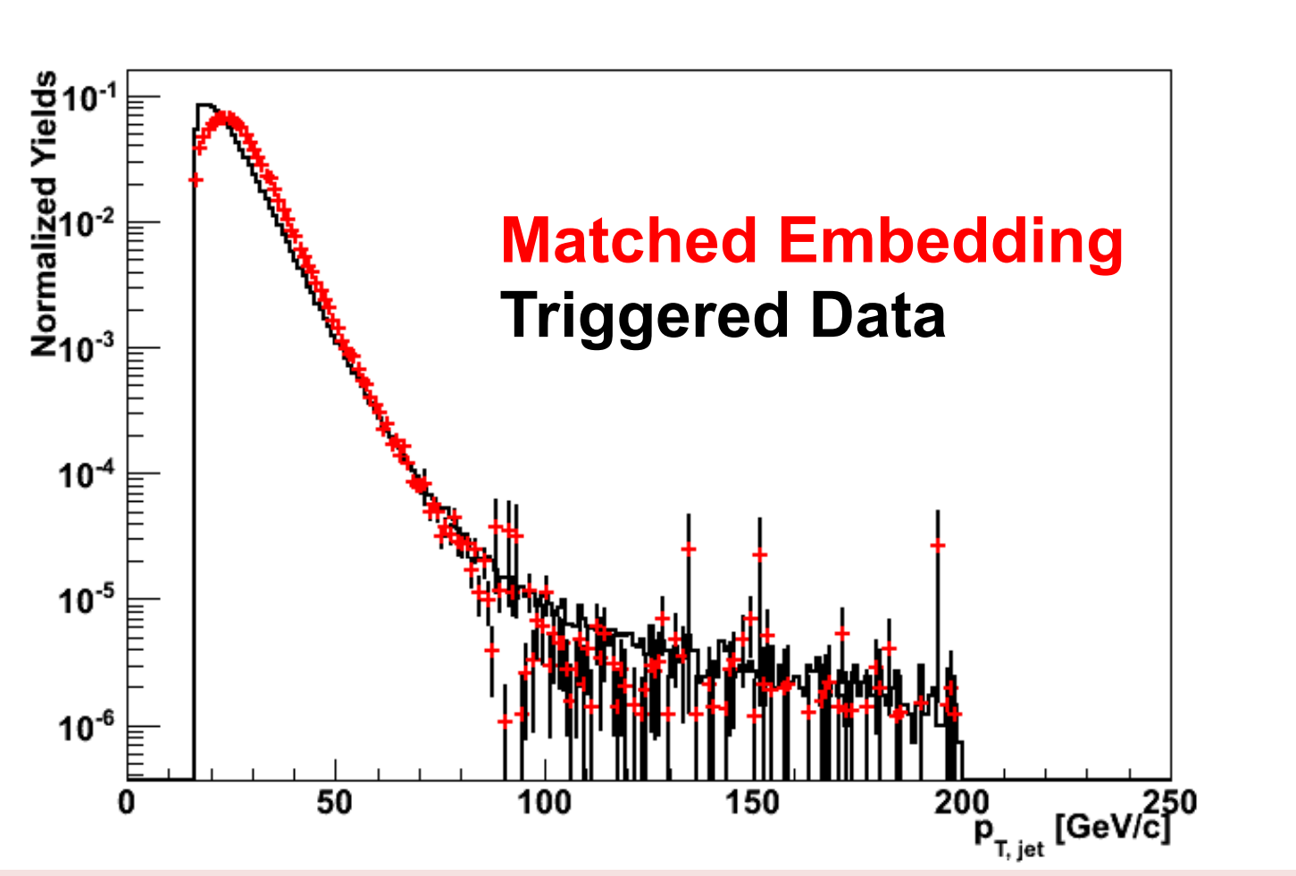


Figure 7: Normalized Yields vs. Jet P_T

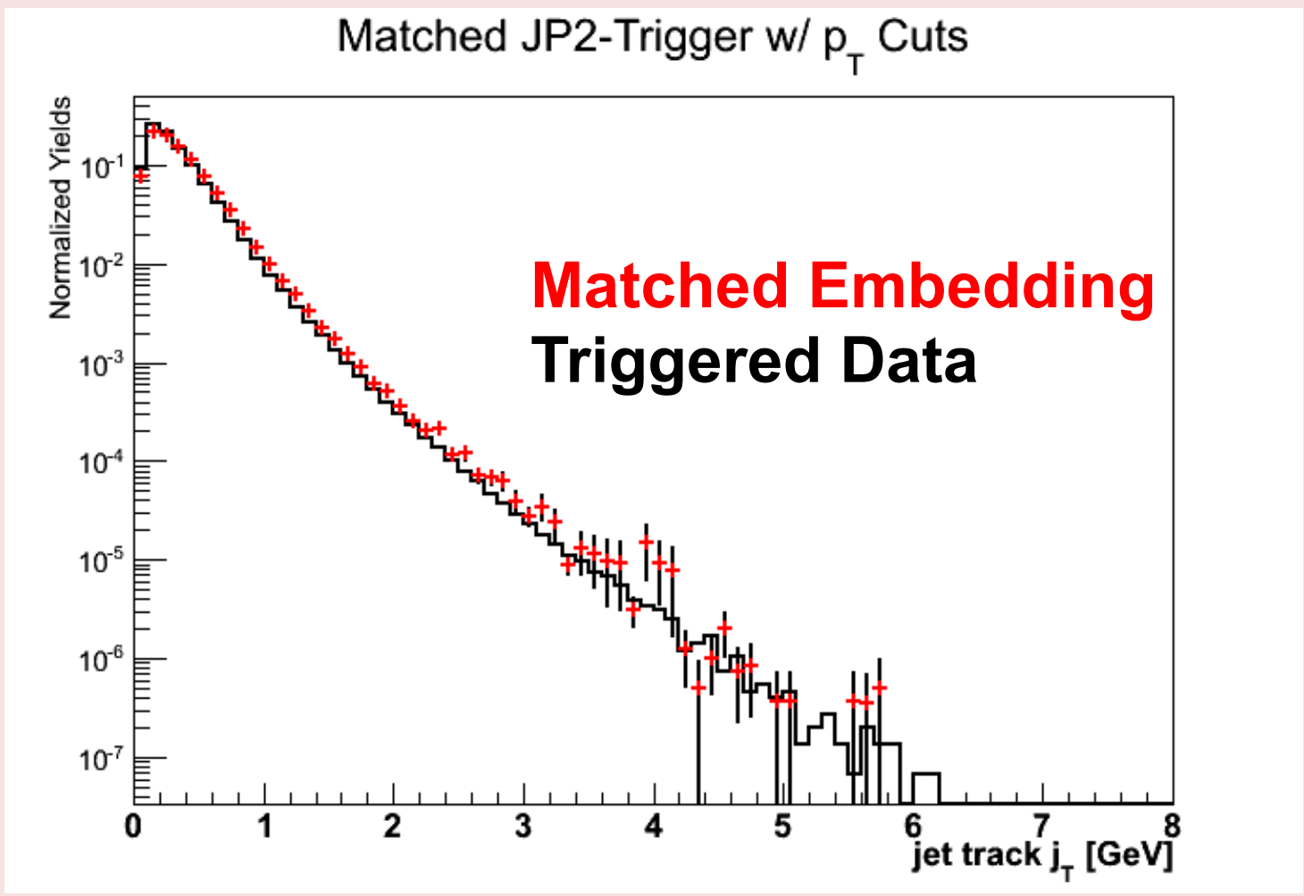


Figure 8: Normalized Yields vs. Relative Particle P_T

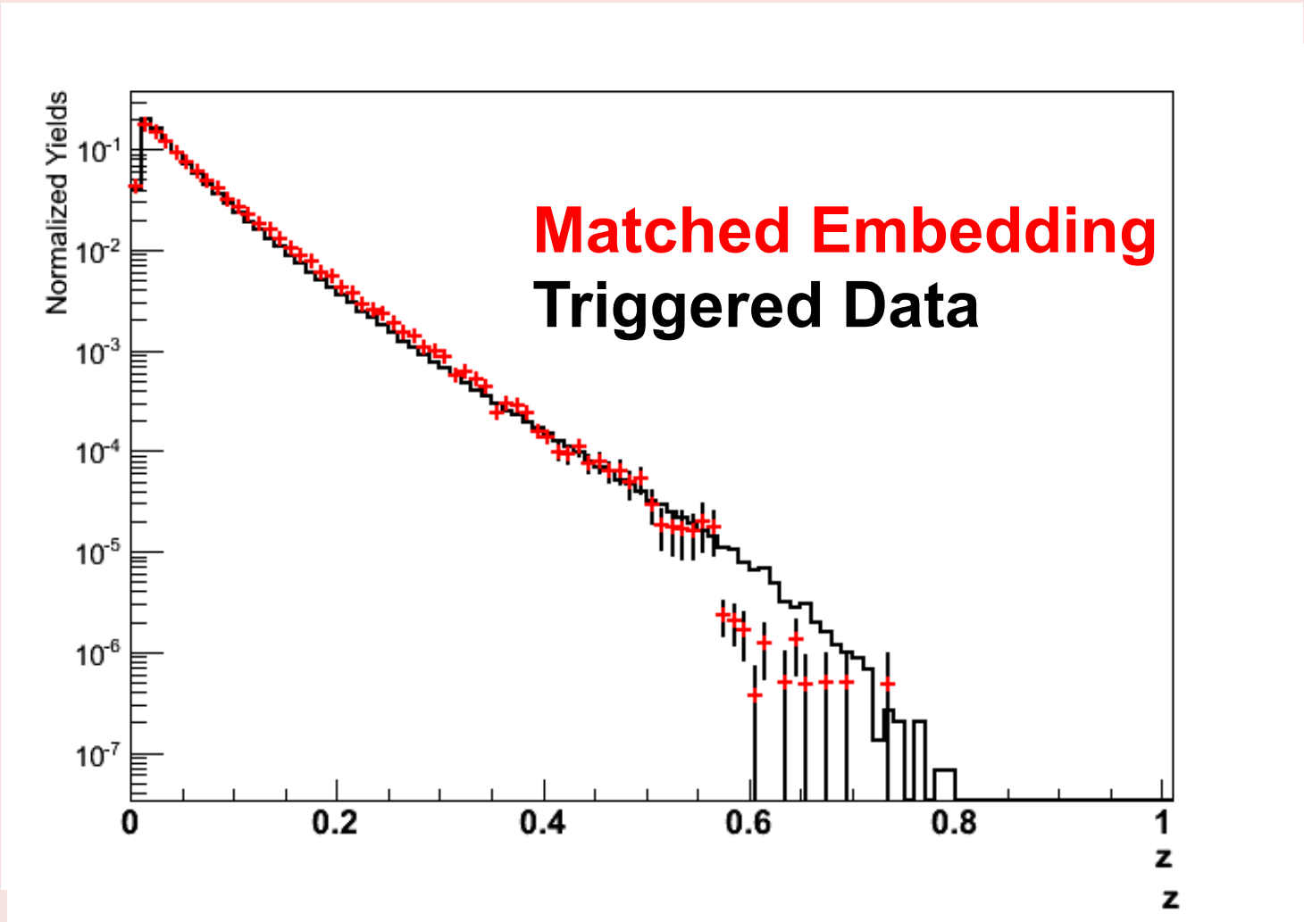


Figure 9: Normalized Yields vs. Jet Momentum Fraction

The resolutions in this project refer to the width of the distribution of $\phi_{reco} - \phi_{true}$ ($\Delta\phi$), or how precisely the true azimuthal angle can be "resolved". Detectors are not perfect, and the "true" distribution is effectively smeared over a range. The resolution can be used to correct for such an effect and is shown in Fig. 10 for minimum bias simulation. The top of the histogram shows the means and mean-errors of the $\Delta\phi$ distribution. These are fit with a constant the result of which, shown in the statistics window, gives the azimuthal shift. In this case, it's small, within one σ of zero, and yields a reasonable χ^2. So, in this case there is no significant "shift" away from the true distribution. The bottom shows the standard deviation for $\Delta\phi$. This is the resolution and indicates by how much the measured asymmetries are damped by an inability to measure the "true" azimuthal angle correctly every time. In this case the damping is ≤15%.

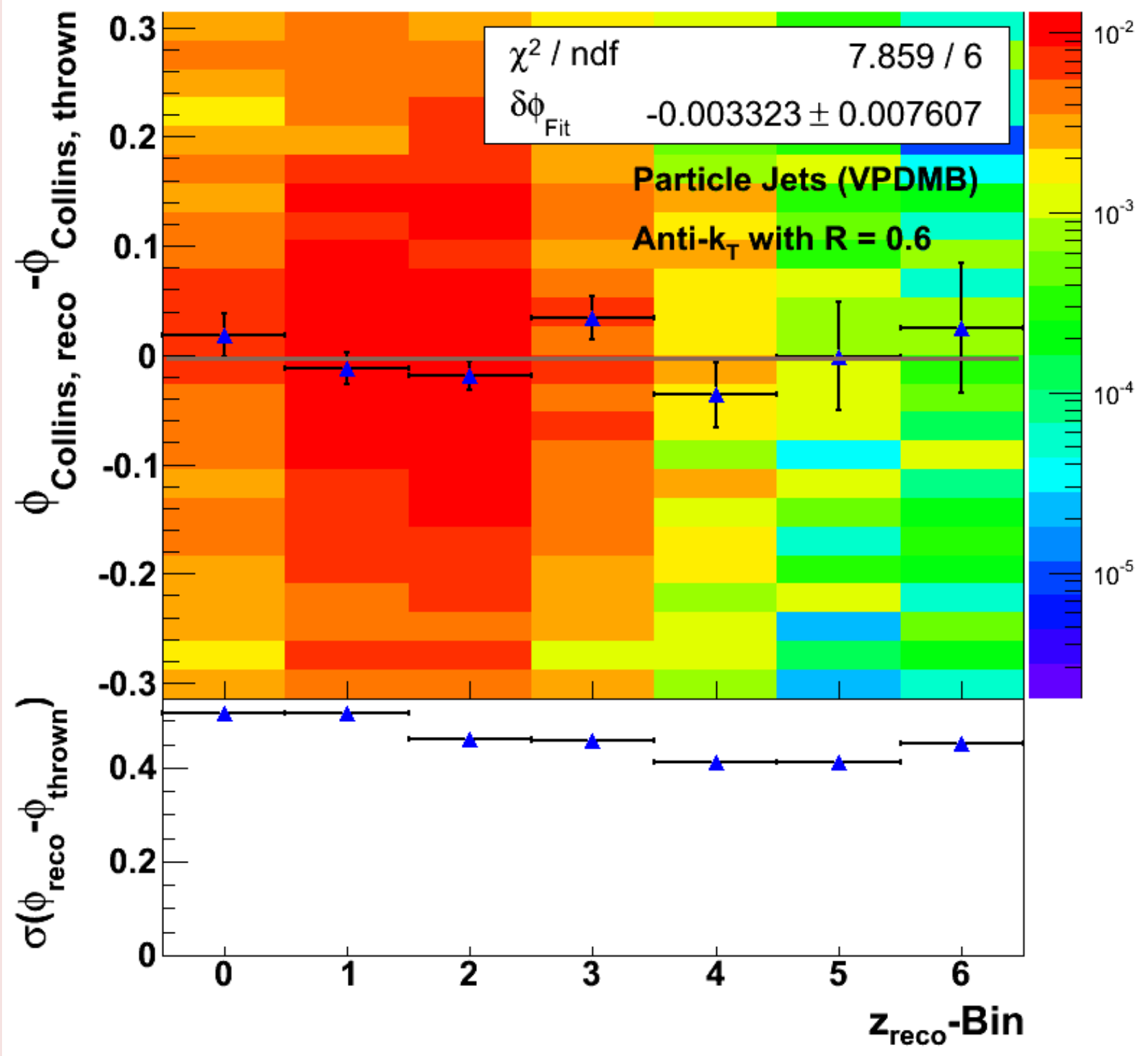


Figure 10: Two dimensional histogram of $\phi_{reco} - \phi_{true}$ vs. z_{reco}-Bin for the Collins- like angle. The z_{reco}-Bin edges are the following: 0, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8.