High p_T Charged Hadron Spectrum in Au+Au Collisions at 200 GeV as Measured by PHENIX

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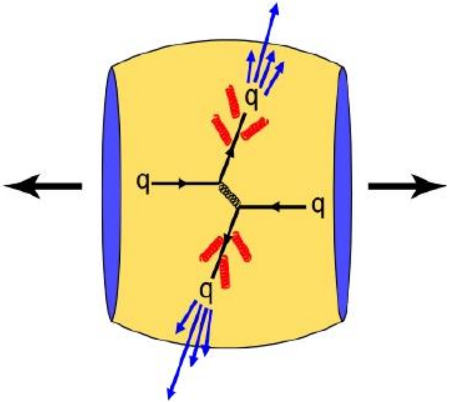
Motivation

-Hard scattering of partons in the initial stages of the collision produce hadrons with large transverse momentum
-Energy loss results in suppression of high p_T hadrons
-Measuring this suppression can give us information about the medium and partonic energy loss



Previous Measurements

-Previous measurement of charged hadrons at PHENIX was limited by background at high p_T

-Much of this background can be suppressed with the Silicon Vertex Tracker Upgrade (VTX)

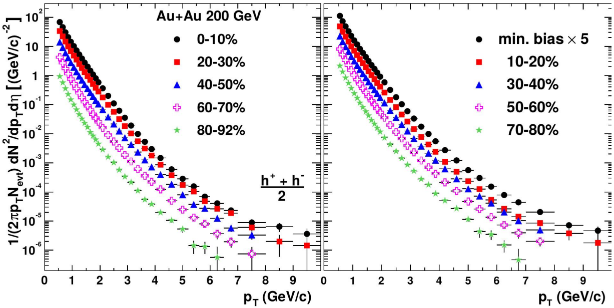


Figure : Charged hadron invariant yield as measured by PHENIX. Phys. Rev. C **69**, 034910 (2004)‘

Previous Measurements

-The spectrum of neutral pions has been measured at PHENIX out to much higher p_T.
- Charged hadrons and π^0s have different sources of systematic errors.
- Where the π^0 measurement is limited by shower merging, the charged hadron measurement is limited by DC momentum resolution.
- A complimentary charged hadron measurement would allow the comparison of the suppression of π^0 mesons to a combination of mesons and baryons
- Thus a high-p_T charged hadron measurement can contribute additional information.

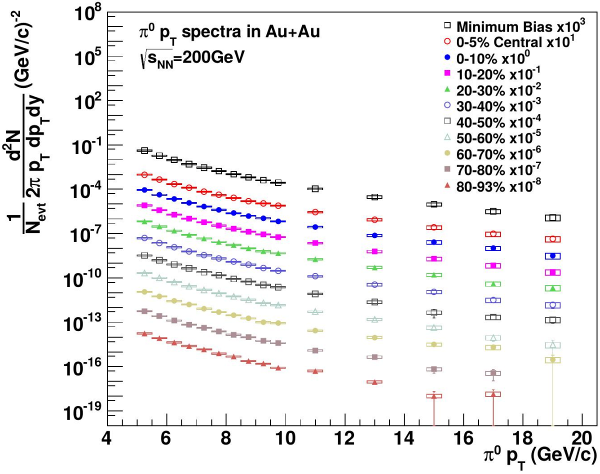


Figure : Neutral pion invariant yield as measured by PHENIX. Phys. Rev. C **87**, no. 3, 034911 (2013)

Background Sources

- The p_T reach of the charged hadron spectrum is limited by off-vertex background tracks from photon conversions and secondary products of weak decays.
- The tracking algorithm assumes that tracks originate from the collision vertex
- Consequently, off-vertex tracks may be misreconstructed with an arbitrarily large momentum
- These background tracks can be rejected by only selecting tracks that originate from the primary vertex
- This rejection is performed with the Silicon Vertex Tracker Upgrade (VTX) installed in PHENIX in Run-11.

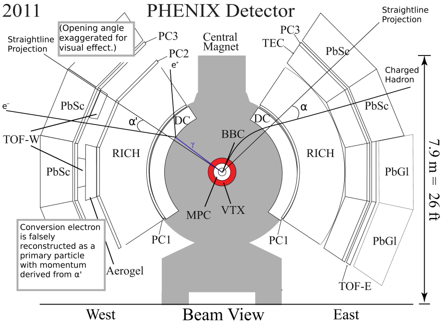


Figure : PHENIX as configured in Run-11

VTX

- Four layers of micropattern silicon detectors placed close to the beam pipe
- Capable of precision measurements of a track's distance of closest approach (DCA)
- DCA is calculated by projecting a track back to the collision vertex and measuring the smallest distance between the vertex and the track.

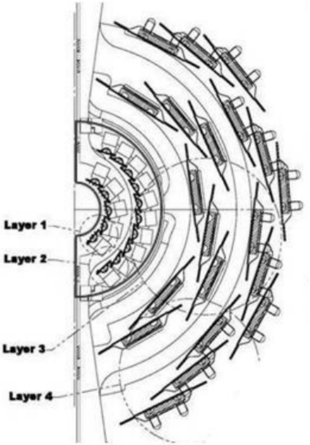


Figure : Cross section of one half of the PHENIX Silicon Vertex Tracker (VTX), with the beam direction perpendicular to the page.

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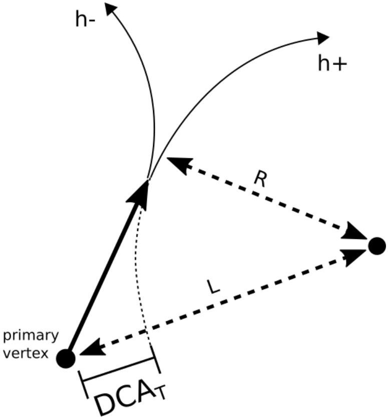


Figure : Distance of closest approach (DCA) is defined as $L - R$, where R is a track's bending radius and L is the distance from the primary vertex to the track's bending center.

VTX

- Rejection is accomplished by:
  - Selecting tracks with ≥ 4 hits in the VTX
  - Removing tracks with a large (DCA) in both transverse and longitudinal directions
  - Statistical subtraction of underlying combinatorial background shape, extrapolated from large DCA tracks (see next slide)
  - Fitting the DCA peak in the x-y plane to a Gaussian and integrating over tracks under the Gaussian peak

Data Set

- Analysis has been performed on $\sim 1.8e9$ AuAu events, comprising approximately half of the 2011 PHENIX data set

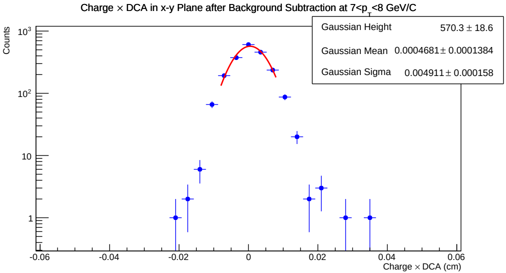
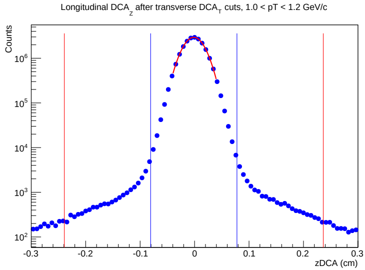


Figure : Charge × Distance of closest approach (DCA) in the transverse plane for $7 < p_T < 8$ GeV/c. Final DCA is fit to a Gaussian and integrated over $\pm$ 2 sigma.

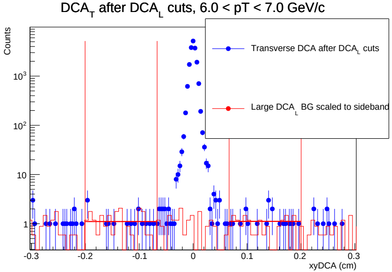
DCA Analysis

- The random DCA of background tracks can be factorized into longitudinal and transverse directions.
- The distance of closest approach in the longitudinal direction (DCA_L) is fit to a Gaussian.
- Tracks with $|DCA_L| < 2\sigma$ are considered good tracks (inside blue lines).
- Tracks with $|DCA_L| > 12\sigma$ (outside red lines) is considered large DCA_L.
- DCA_T from combinatorial background determined by scaling DCA_T of large DCA_L tracks up to the sidebands in DCA_T of the $|DCA_L| < 2\sigma$ tracks

DCA_L



DCA_T Combinatorial Background



Transverse DCA at High p_T

- The DCA of tracks with 3 hits in the VTX (Red) as compared to tracks with 4 hits (Blue).
- The 3 hit track distribution highlights the amount of background remaining before using the full rejection power of the VTX.

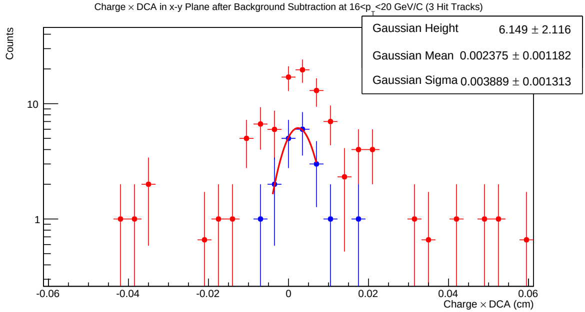


Figure : Charge × Distance of closest approach (DCA) in the transverse plane for $16 < p_T < 20$ GeV/c.

A Priori Background Estimate

- The remaining background after VTX rejection can be estimated from the effects of occupancy and multiple scattering on the tracking algorithm
- Measured signal and background are compared to the background estimate
- The background estimate matches the measured background reasonably well
- Indicating that for 4 hit tracks, the number of random associations after VTX rejection is very small compared to the number of real tracks.

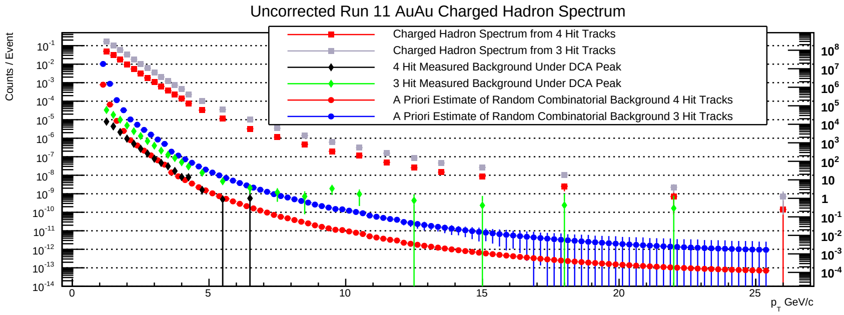


Figure : Estimate of remaining background tracks after VTX rejection.

 Uncorrected Run-11 AuAu Spectrum

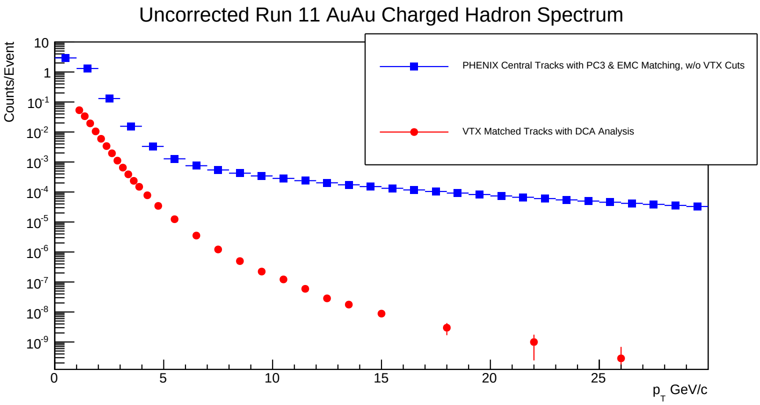


Figure : Uncorrected Run-11 AuAu p_T charged hadron spectrum measured with and without using VTX rejection.

- Background tracks are expected to have a randomly distributed or flat measured p_T distribution
- Without matching in the VTX, the flat background spectrum seems to dominate after 6 GeV/c (Blue)
- The spectrum of real tracks matched to the VTX extends to $>$ 20 GeV/c.

Conclusions

- Most of the background limiting the measurement of charged hadrons in PHENIX is from tracks which do not originate from the collision vertex. Using the VTX detector we can eliminate much of this background.
- Estimating the number of remaining background particles which do not originate from the collision vertex, but are still accidentally matched to hits in the VTX indicates that the number of such particles is very low compared to the signal.

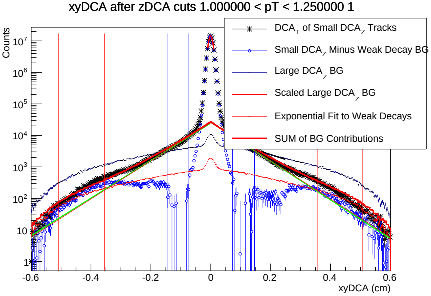
Outlook

- Need to estimate detector efficiency to finalize the fully corrected hadron yield.
- With the ability to measure charged hadrons out to higher p_T, we will able to study the energy loss of high p_T particles by considering R_{CP} for example.

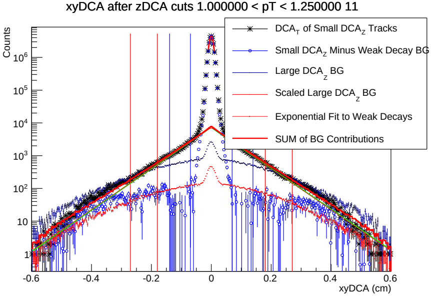
Backup Slides

- At low p_T (< 6 GeV/c) weakly decaying Λs and K^0s introduce an additional exponentially shaped background
- Presently the DCA contribution from Λs and K^0s is modeled by fitting to an exponential (solid green line) and subtracted (blue open circles).
- The remaining random combinatorial background is subtracted by matching the xyDCA distribution of large zDCA Tracks to the sidebands (red data points)

3 Hit Tracks



4 Hit Tracks



Estimate of Correlated Background Sources

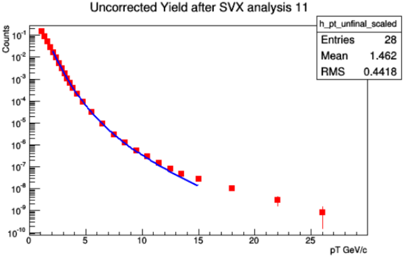
- The majority of the remaining background under the DCA peak can be accounted for by a random combination of off vertex DC tracks with vertex tracks in the VTX
-The spectrum of these background tracks can be estimated by multiplying the number of high quality PHCentral tracks times the number of true charged hadron tracks that randomly have the same spatial positions and angular trajectories within the search parameters. The spectrum of these tracks is given by:

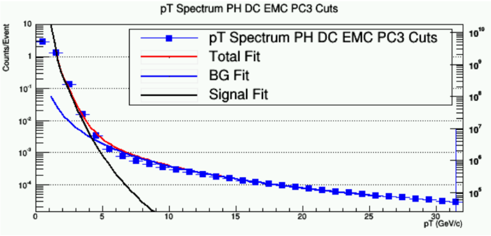
$$\frac{dN_{corr}}{dp_T} = N_{seed} \times P_{B3} \times C_0 \int_{p_T-\sigma_{DC}}^{p_T+\sigma_{DC}} \frac{dN_{SIG}}{dp_T} dp_T \tag{1}$$

where N_{seed} is the number of off-vertex central arm tracks. P_{B3} is the probability that the central arm track projection lands within the spatial position of the search window in B3. Lastly, $C_0 \int \frac{dN_{SIG}}{dp_T} dp_T$ is the number of true charged hadron tracks with the same p_T and thus azimuthal angle as the candidate central arm track within the drift chamber resolution.
-The drift chamber resolution is assumed to be $\frac{\delta p_T}{p_T} = 1.0\% + 1.0\% p_T$
-In addition, $\int \frac{dN_{SIG}}{dp_T} dp_T$ is normalized by C_0, the number of 4 hit VTX tracks, to take into account the efficiency of the VTX.

Number of PHCentral Background Tracks

-The number of off-vertex PHCentral background tracks N_{seed}, is estimated:
-First by fitting the spectra of signal tracks as found by the full VTX DCA analysis to a modified Hagedorn + Power Law called $F(p_T)$ (Left).
-Then the spectra of PC3&EMC matched DC tracks are fit to $\epsilon F(p_T) + a + b(p_T)^c$ (Right, Red Line).
-Where ϵ estimates the ACCXEFF of the VTX analysis and $G(p_T) = a + b(p_T)^c$ is a model of the background (Right, Blue Line)





A Priori Estimate of Combinatorial Background

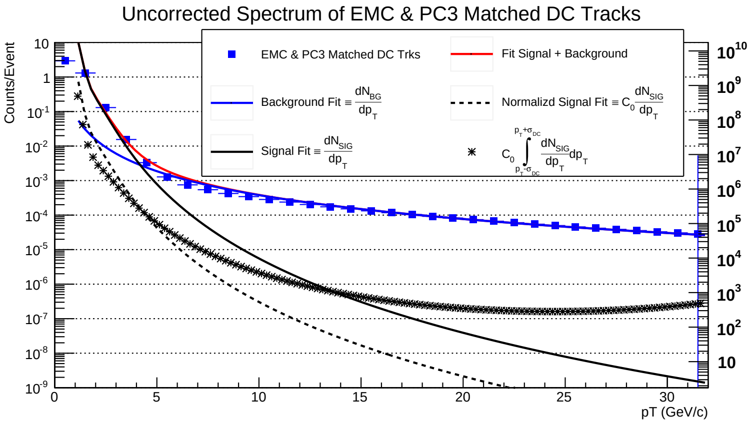
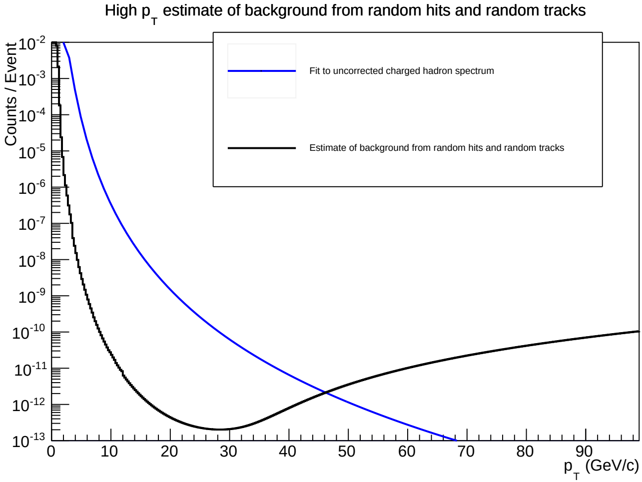


Figure : Spectrum of drift chamber tracks matched to the EMC and PC3. Tracks are fit to a model of the signal (black curve), a model of the background (blue curve), and their sum (red curve). The signal is then normalized by the number of VTX standalone tracks in the central arm acceptance (black dotted line), to model the spectrum of real charged hadrons leaving correlated hits in the VTX. Finally these tracks are smeared by the drift chamber resolution (black stars).

Extrapolation of A Priori BG Estimate to High p_T

-The background from random combinations of uncorrelated hits and correlated hits (track) appears to cross the signal at $p_T \sim 50$ GeV/c.



- Up to $16 < p_T < 20$ GeV a clear DCA peak is observed
- However, it is believed that the points well above 20 GeV are real (see previous slides)