Simulation Studies of the Azimuthal-Angle Correlation of Muons at Forward Rapidity with Mid-rapidity Particles for Open-Charm Events in PHENIX

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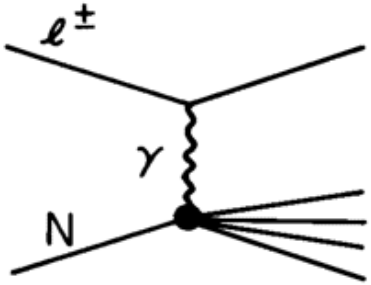
2. **Δg at RHIC**
3. **PHENIX detector**
4. **Multistage simulation**
5. **Simulation data analysis: φ correlation**
6. **Conclusion**

Physics Motivation

Deep-Inelastic Scattering data indicate that only a small fraction of the spin of the proton is carried by the quarks and anti-quarks



EMC: $$\Delta\Sigma = \int_0^1 dx \sum_i (\Delta q_i(x) + \Delta \bar{q}_i(x)) = 0.31 \pm 0.04$$

<u>The Spin Structure of the Proton</u>

$$\boxed{J_z^p = \frac{1}{2}\Delta\Sigma + \Delta G + L_z = \frac{1}{2}}$$

contribution of quarks and anti-quarks

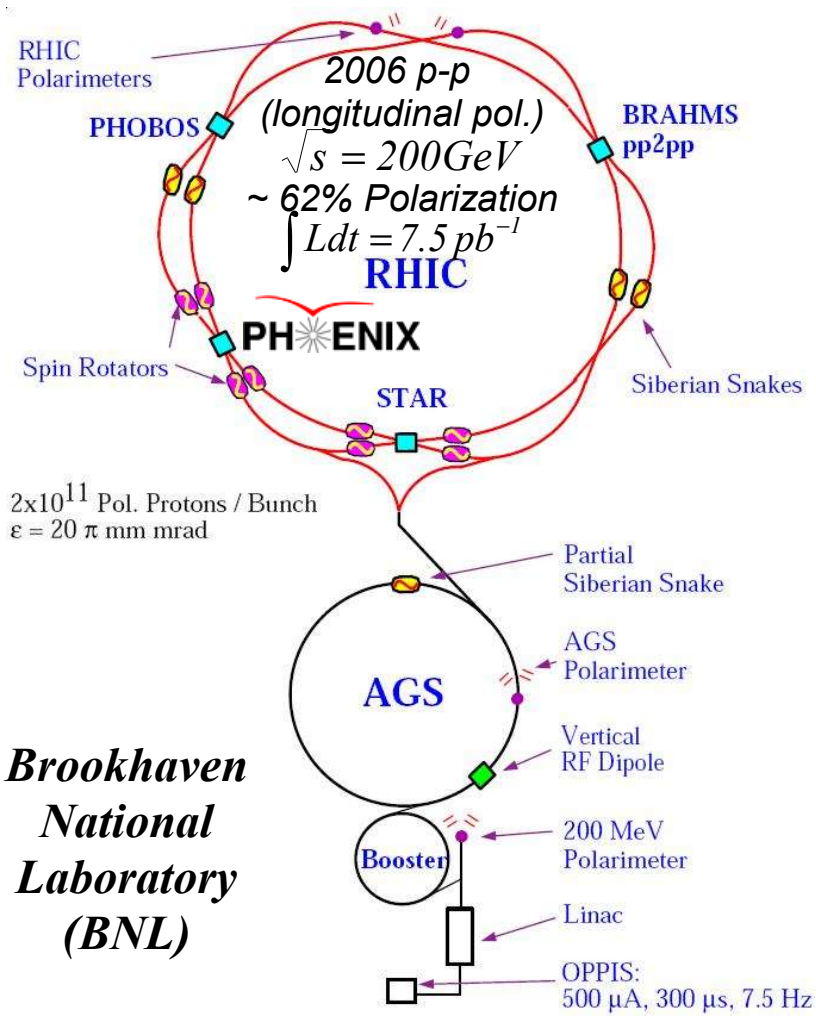
orbital angular momentum

polarized gluon distribution function

gluon contribution to the proton spin: $\Delta G = \int_0^1 dx\, \Delta g(x)$

Δg in Polarized Proton-Proton Collisions

Relativistic Heavy Ion Collider (RHIC)

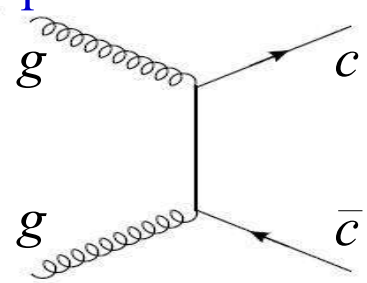


Brookhaven National Laboratory (BNL)

At RHIC energy and luminosity the collisions can clearly be interpreted as collisions of polarized quarks and gluons.

Heavy-Flavor (Charm) Production

- $q\bar{q} \to c\bar{c}$ is suppressed
- gluon-gluon processes dominate all other processes for $c\bar{c}$ production:



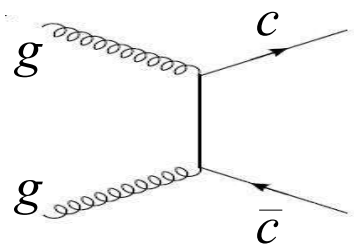
$$\to \mu^{\pm} + X$$

$$A_{LL} = \frac{\Delta g(x_1)}{g(x_1)} \times \frac{\Delta g(x_2)}{g(x_2)} \times \frac{\Delta\hat{\sigma}_{parton}}{\hat{\sigma}}$$

Double helicity asymmetry A_{LL} for inclusive muons was obtained from 200 GeV longitudinally polarized *p-p* 2003 and 2006 PHENIX data.

Inclusive Muon Candidates

Open-charm muons – muons originating from semi-leptonic decays of heavy-flavored mesons from open-charm production



$$\rightarrow D^0 \rightarrow K^- \ell^+ \nu_\ell$$

$$\rightarrow \overline{D}^0 \rightarrow K^+ \ell^- \overline{\nu}_\ell$$

$$(\ell^\pm = e^\pm, \mu^\pm)$$

Other open heavy-flavor muons – originating from bottom quark decays

Quarkonium muons – muons originating from quarkonium decays

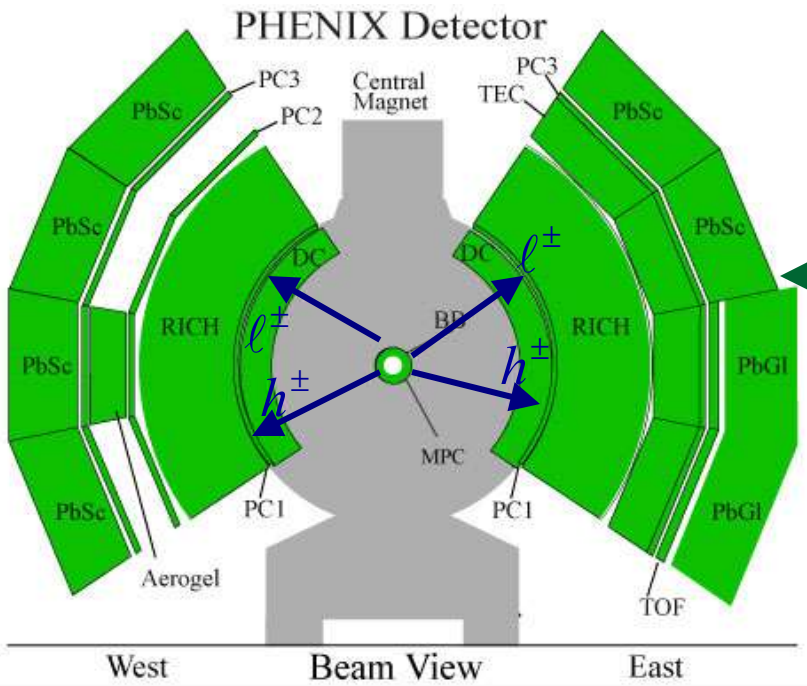
Decay muons – muons originating from the decays of $\pi^\pm$'s and $K^\pm$'s

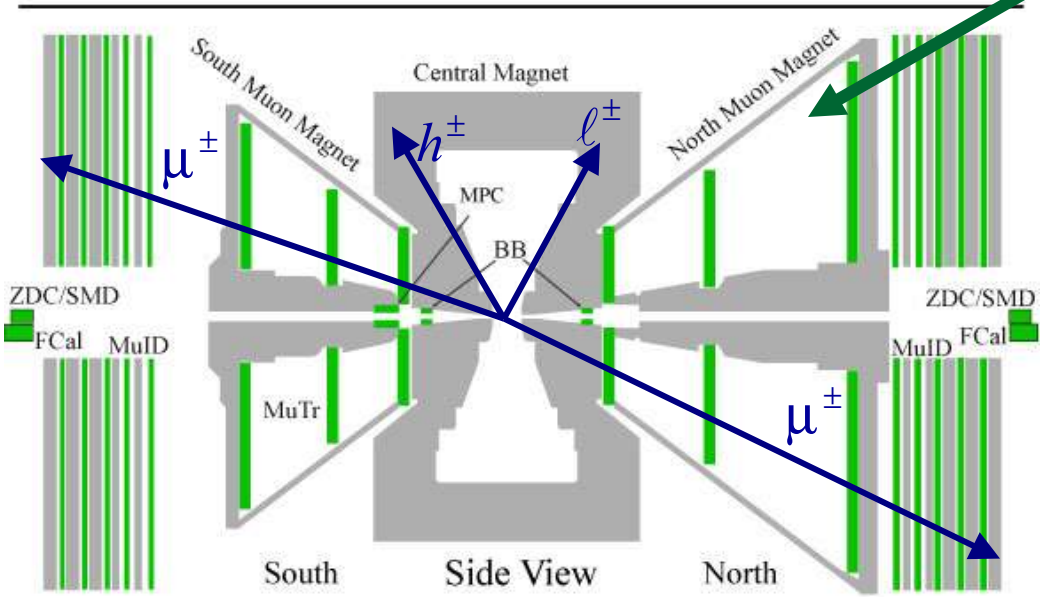
Punch-through – hadron tracks which reach the deepest Muon Identifier layer and have correctly reconstructed momenta

Background tracks – tracks arising from combinatoric associations of unrelated hits

How to discriminate between open-charm muons and other inclusive muon candidates?

Study correlations between tracks in the Muon Arms and $h^\pm / \ell^\pm$ in the Central Arm of the PHENIX Detector

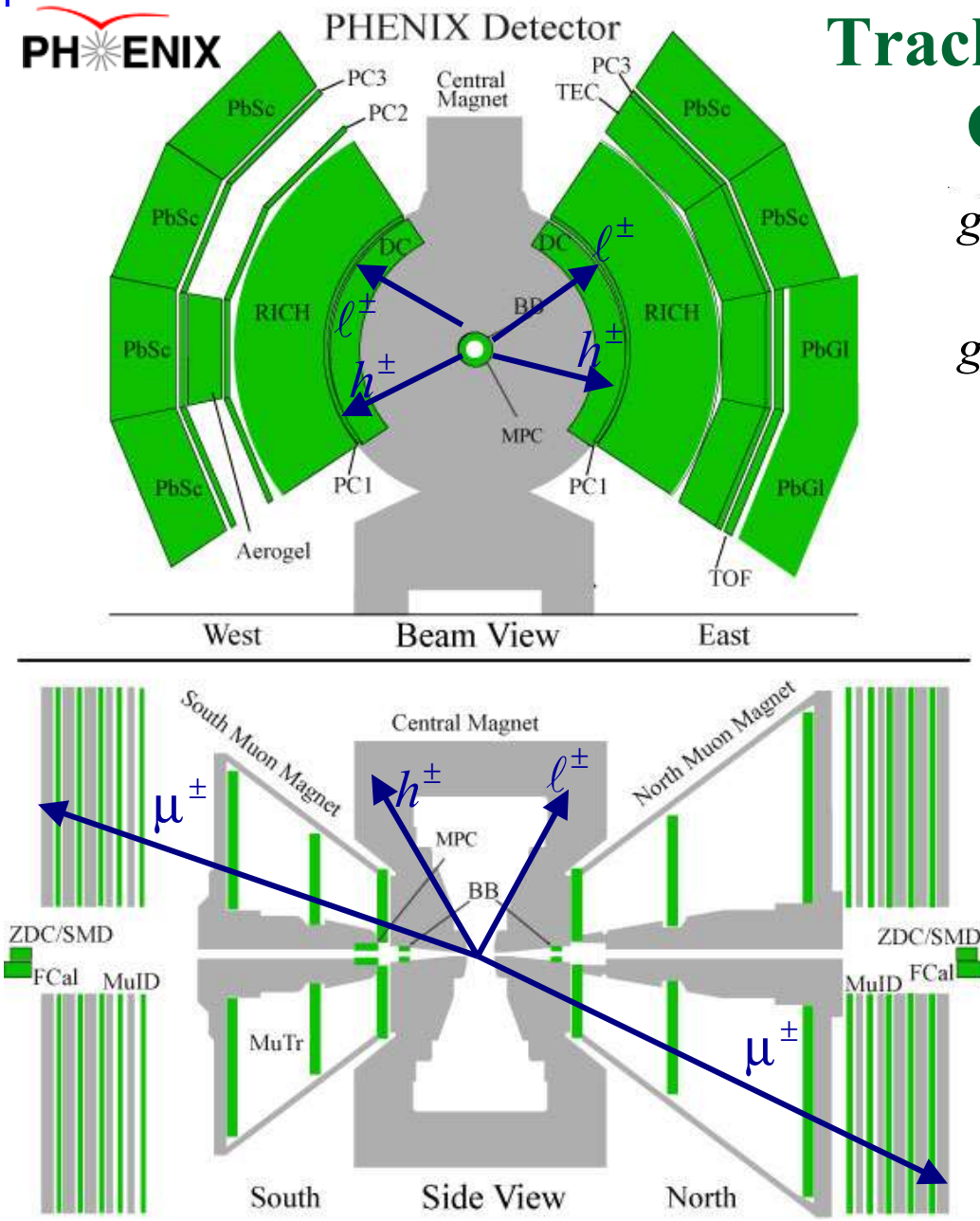


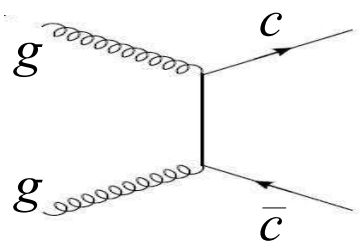


Two Central arms (East and West)
detect leptons, hadrons, photons at
$-0.35<\eta<0.35$ for each arm
azimuthal coverage $\pi/4$ for each arm

Two Muon arms (South and North)
detect muons at:
$-2.25<\eta<-1.15$ (South)
$1.15<\eta<2.44$ (North)
azimuthal coverage 2π for each arm
π/μ rejection $\sim 10^{-4}$

Track Correlation: Search for Open-Charm Muons





$$\rightarrow D^0 \rightarrow K^- \ell^+ \nu_\ell$$

$$\rightarrow \bar{D}^0 \rightarrow K^+ \ell^- \bar{\nu}_\ell$$

$$(\ell^{\pm} = e^{\pm}, \mu^{\pm})$$

$$\frac{\Gamma(c \rightarrow \mu^+ \text{anything})}{\Gamma(c \rightarrow \text{anything})} = 8.2 \pm 0.5\%$$

Due to the large m_C, the presence of relatively high-p_T decay products is one of the characteristic features of the charm events

Correlations between high-p_T muon at forward rapidity and other high-p_T particles at mid rapidity, originating in the decay of the same or the companion charm quark or anti-quark

Multistage Simulation to Study Track Correlation

Combined for both the Central arm (Drift Chamber) and the Muon arms together

1. **PYTHIA –** *p-p* collisions at $\sqrt{s} = 200 GeV$
2. **PISA –** simulates the PHENIX detector, tracks particles through the PHENIX
3. **Reconstruction chain –** simulates with as much realism as possible signal outputs from the PHENIX, then reconstructs these signal outputs using the same software used for real data
4. **Analysis Code –** developed to work with combined data from the Central arm and the Muon arms

<u>Simulation outputs produced and compared:</u>

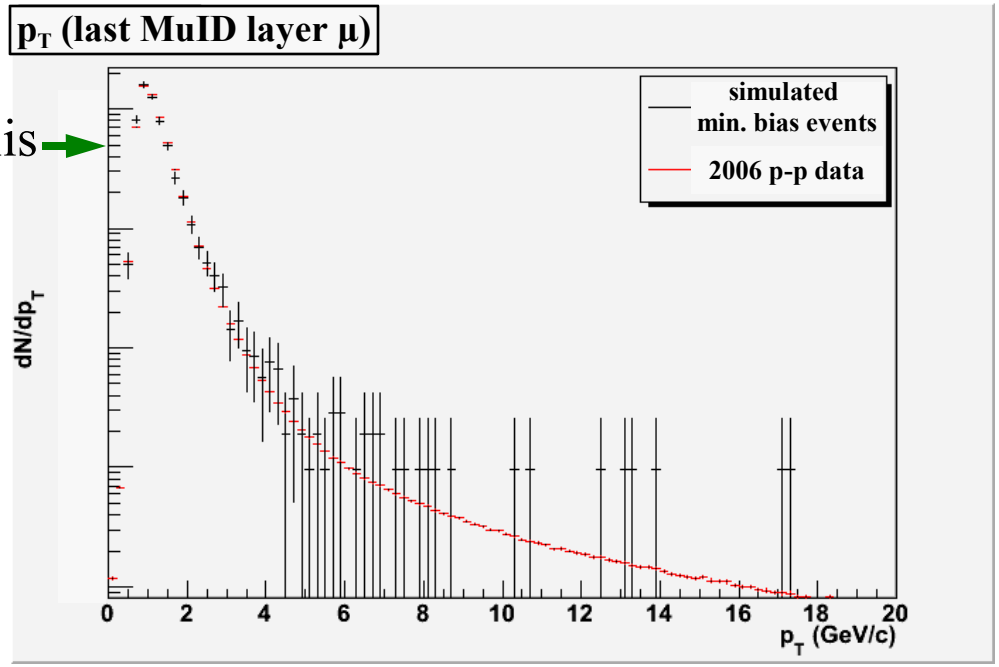
1. $c\bar{c}$ **production** – 14 M events
2. **minimum-bias** (i.e. mostly light-quark) – 13.1 M events
3. $b\bar{b}$ production (not used in the analysis yet) – 1 M events

Simulation Data Analysis

- ✓ Event and track quality cuts: the same as for real data
- ✓ Muon track selection: reach the deepest Muon Identifier layer

Simulation and real data agreement

arbitrary vertical axis



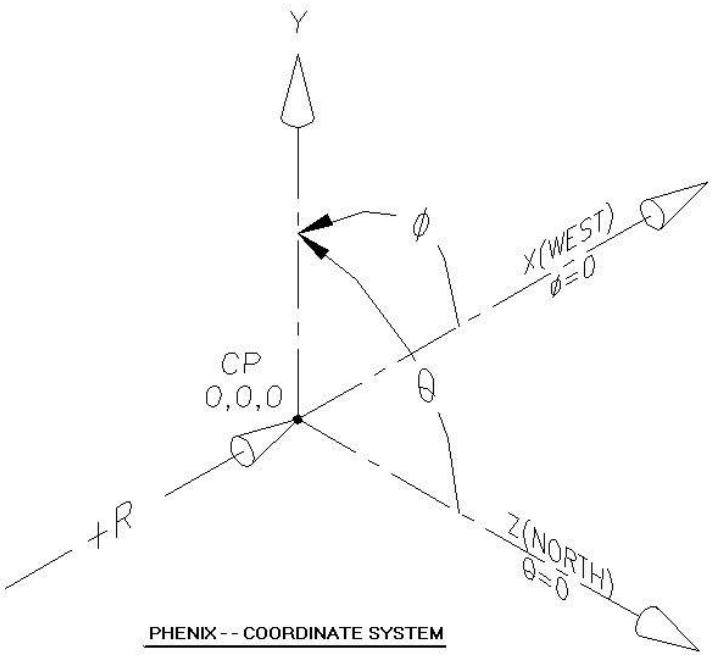
✓ **<u>From each event:</u> Muon Arm track (forward rapidity) with the maximum $p_T^{\mu(max)}$ and Central Arm track (mid rapidity) with the maximum $p_T^{h/l(max)}$**

<u>Azimuthal-Angle Correlation</u> of Muons at Forward Rapidity with Mid-rapidity Particles:

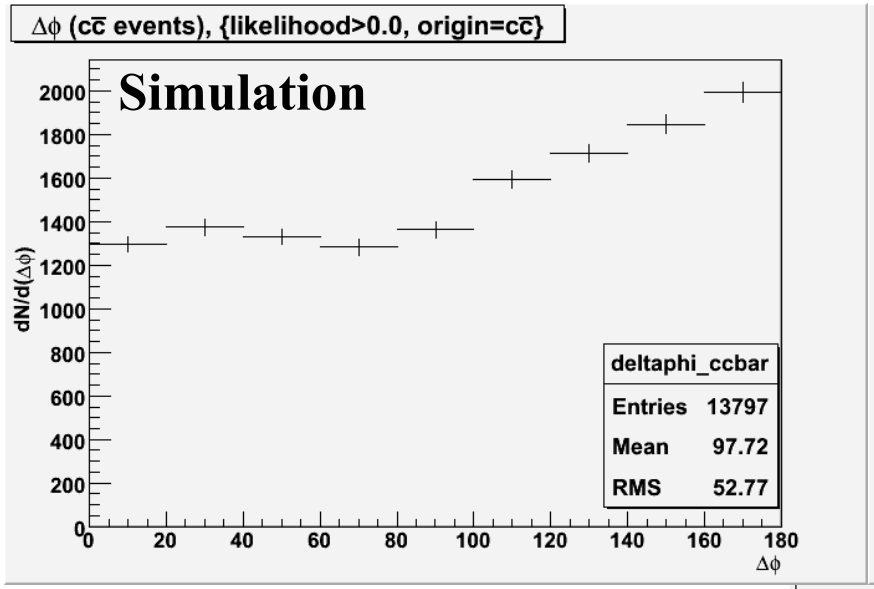
$$\Delta\varphi = \left| \varphi_{p_T^{\mu(max)}} - \varphi_{p_T^{h/\ell(max)}} \right|$$

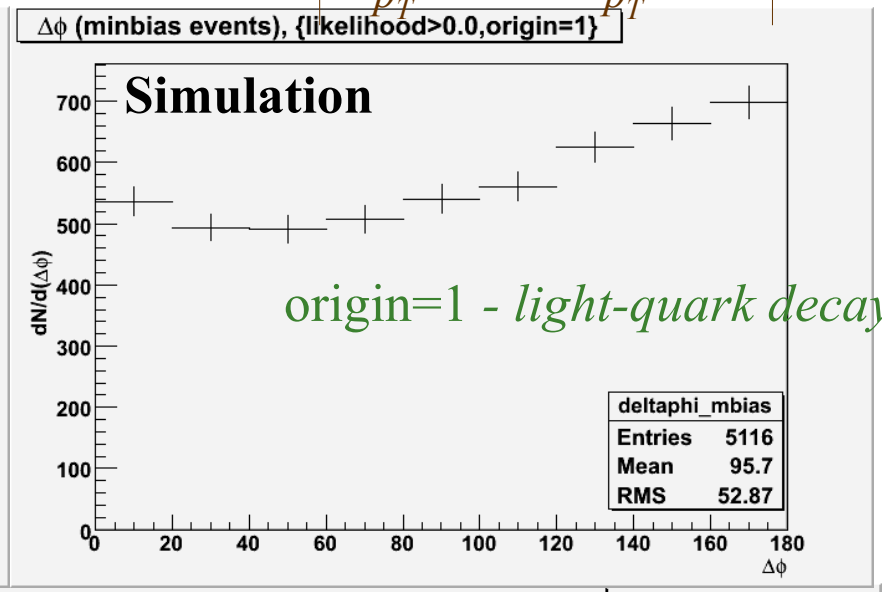
$p_T^{\mu(max)}$ - of the Muon-Arm track with the maximum-p_T in event

$p_T^{h/\ell(max)}$ - of the Central-Arm track with the maximum-p_T in event

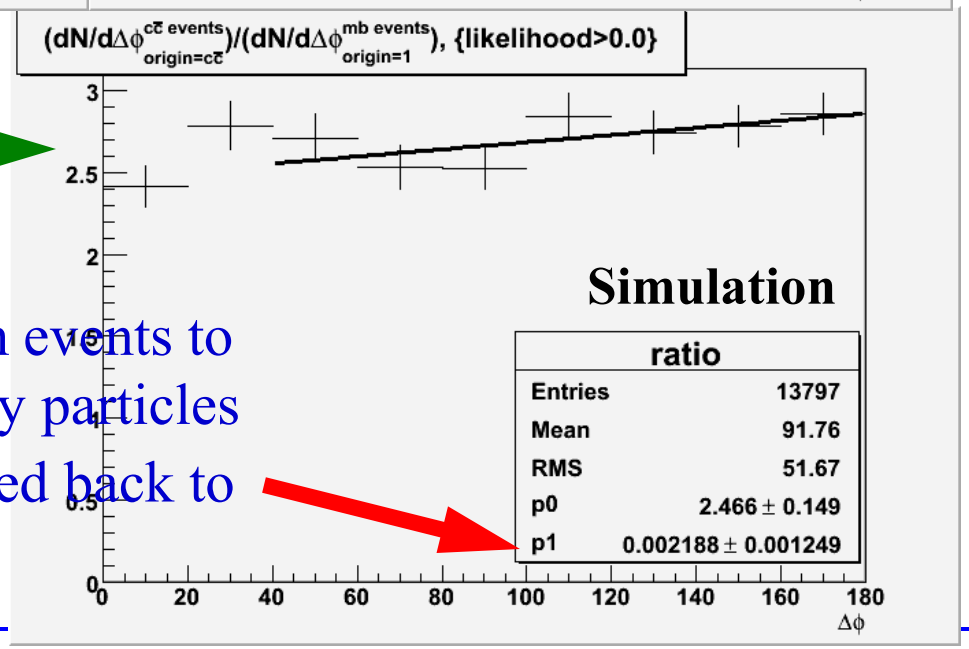


Azimuthal-Angle Correlation: $\Delta\varphi = \varphi_{p_T^{\mu\,(max)}} - \varphi_{p_T^{h/\ell\,(max)}}$





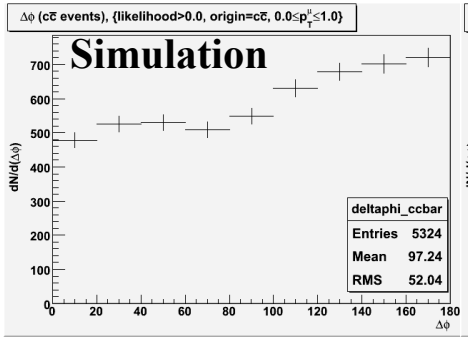
$$\frac{(dN/d\Delta\varphi^{c\bar{c}})}{(dN/d\Delta\varphi^{minbias})}$$



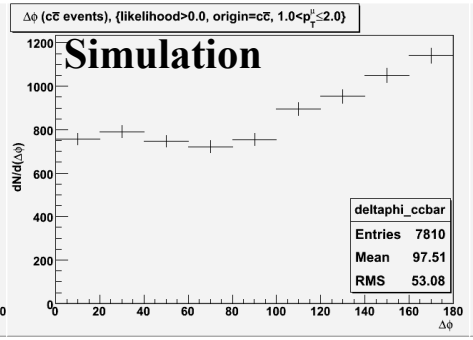
There is small tendency for charm events to have the maximum-p_T mid-rapidity particles and forward rapidity muons emitted back to back in azimuthal angle

$\Delta\varphi$: different muon p_T bins

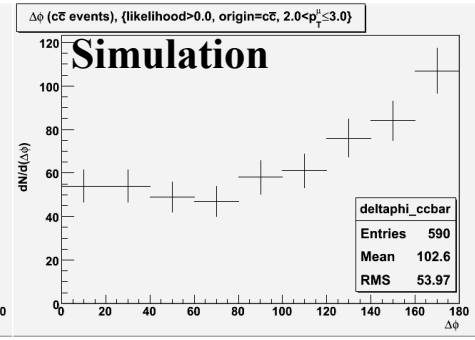
$c\bar{c}$ events, origin=$c\bar{c}$



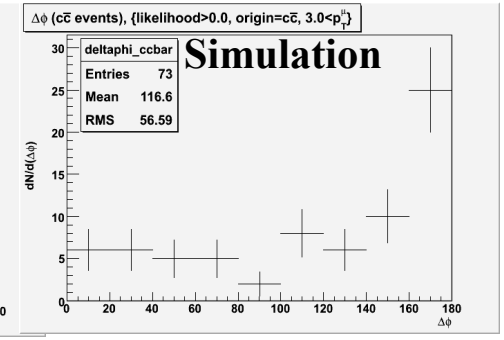
$0.0GeV < p_T^{\mu} \leq 1.0GeV$



$1.0GeV < p_T^{\mu} \leq 2.0GeV$

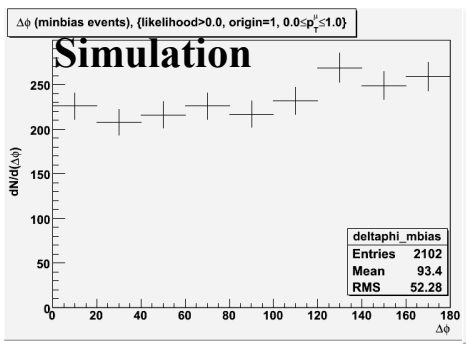


$2.0GeV < p_T^{\mu} \leq 3.0GeV$

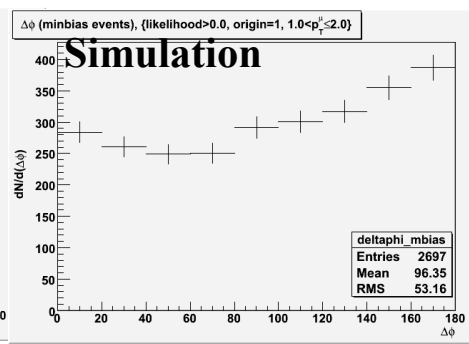


$3.0GeV < p_T^{\mu}$

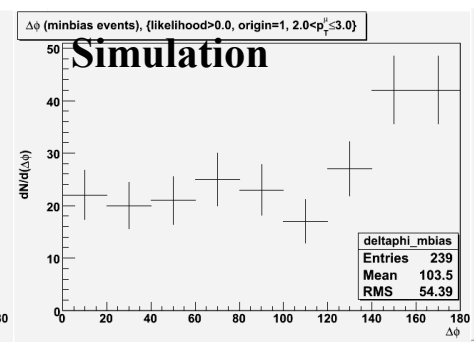
minbias events, origin=*light-quark decays*



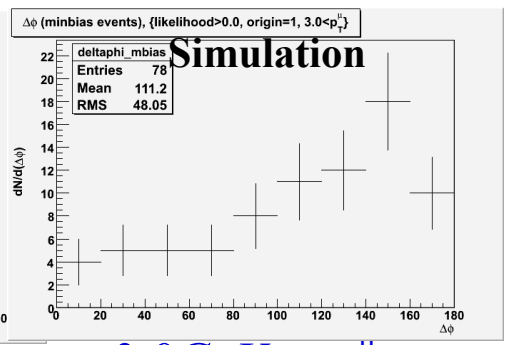
$0.0GeV < p_T^{\mu} \leq 1.0GeV$



$1.0GeV < p_T^{\mu} \leq 2.0GeV$

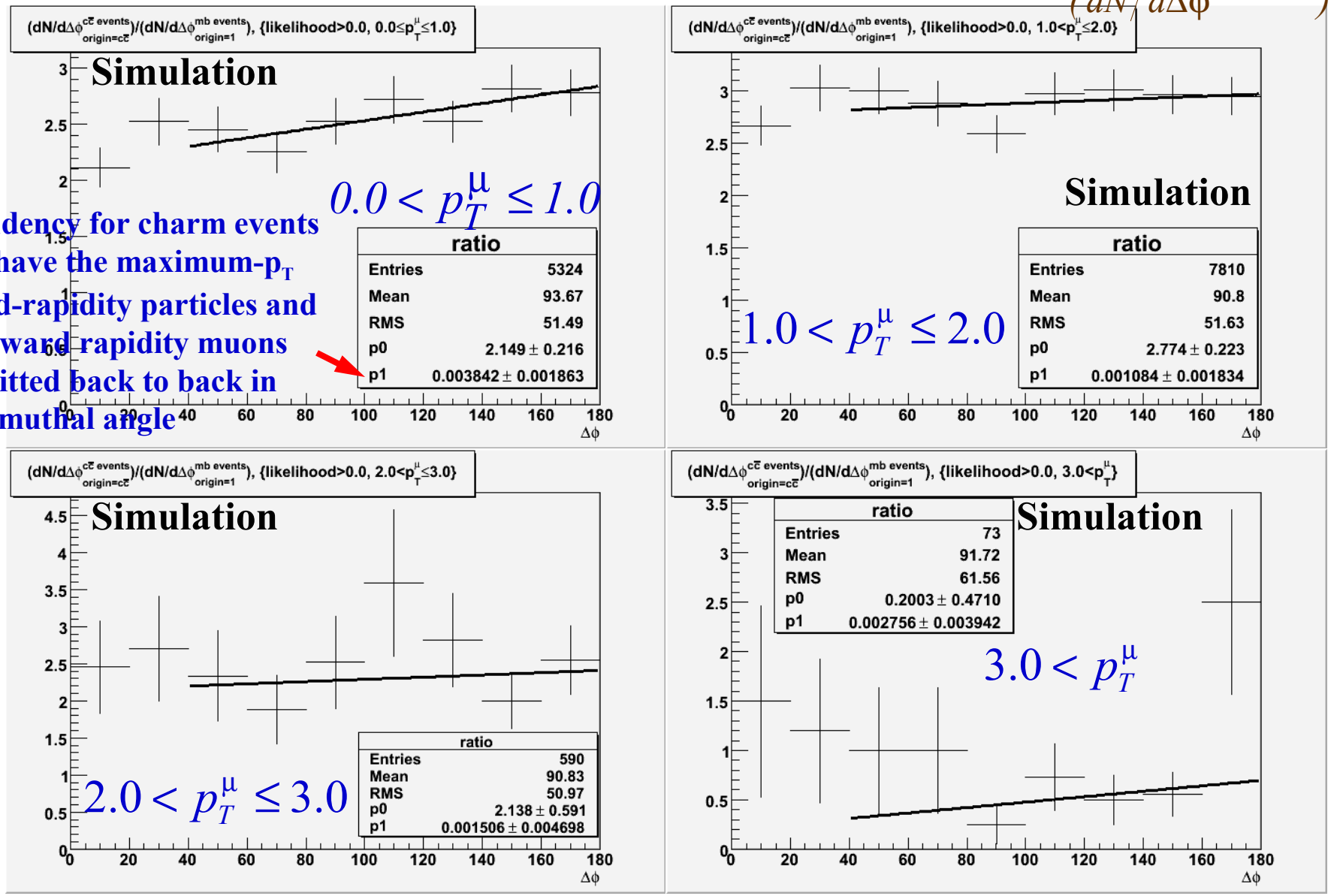


$2.0GeV < p_T^{\mu} \leq 3.0GeV$



$3.0GeV < p_T^{\mu}$

Ratios of the distributions from the page 11: $\frac{(dN/d\Delta\varphi^{cc})}{(dN/d\Delta\varphi^{minbias})}$



tendency for charm events to have the maximum-p_T mid-rapidity particles and forward-rapidity muons emitted back to back in azimuthal angle

Summary

- ✓ A multistage simulation (including the PHENIX detector response) has been conducted to investigate correlations between muon tracks at forward rapidity and charged hadron/lepton tracks at mid rapidity
- ✓ Two separate simulation outputs have been produced and compared: for charm ($c\bar{c}$) events and for minimum-bias (*i.e.* mostly light-quark) events
- ✓ The simulation indicates stronger tendency for charm events to have the maximum-p_T mid-rapidity particles and forward rapidity muon tracks emitted back-to-back in azimuthal angle φ only for low muon p_T
- ✓ It is not possible to use φ correlation by itself to develop selection criteria, but it is possible to do this in combination with other variables
- ✓ The ultimate goal is to develop multivariate selection criteria which can significantly enhance the charm content of a sample of single-muon events, by studying and comparing different kinematic quantities of the Muon Arm tracks (at forward rapidity) and the Central Arm tracks (at mid rapidity)