Measurements of heavy quark production via single leptons at PHENIX

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for the PHENIX collaboration

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PHENIX HQ single lepton measurements

PHENIX measures *open* charm and bottom through single **e**$^{\pm}$ at mid-rapidity and **μ**$^{\pm}$ at forward rapidity.

Due to their large mass/early formation time heavy quarks are ideal probes for a wide ranges of studies:

- In heavy ions - measurement of medium effects:
  - Heavy quark energy loss (Nuclear modification factor, R_{AA})
  - Azimuthal anisotropy and collective motion (v_2)
  - Medium transport properties (viscosity/entropy ratio)
  - Open charm is a key to understanding charmonium production (suppression/recombination) (Capella et al. arXiv:0712.4331v1)
- In p+p:
  - Provide crucial baseline for heavy-ion measurements (R_{AA})
  - Test pQCD calculations (FONLL)

Talk by R. Averbeck

Talk by: S. Oda,

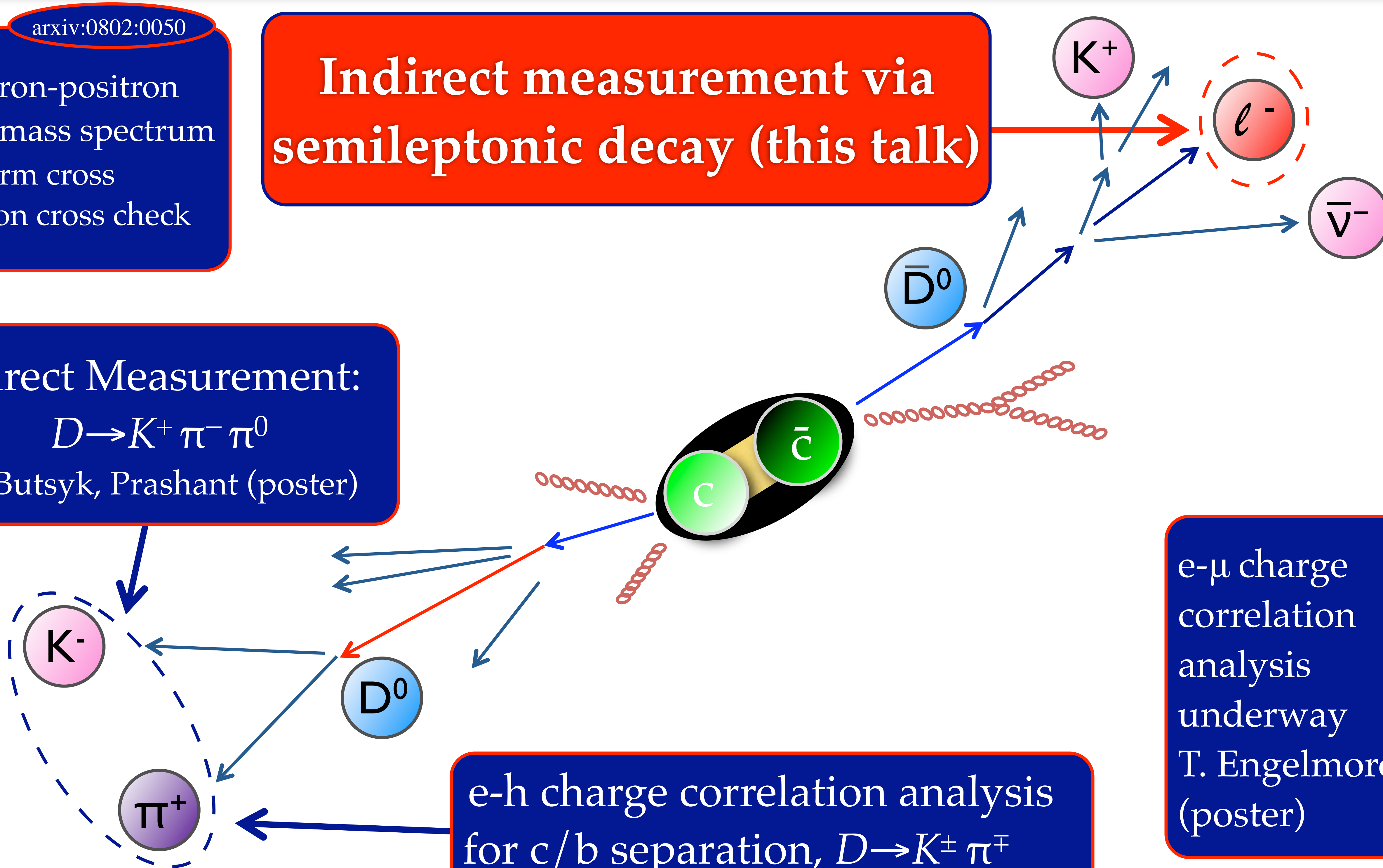
Open heavy flavor measurements

arxiv:0802:0050

electron-positron pair mass spectrum - charm cross section cross check

Indirect measurement via semileptonic decay (this talk)

Direct Measurement:
$D \rightarrow K^{+} \pi^{-} \pi^{0}$
S. Butsyk, Prashant (poster)

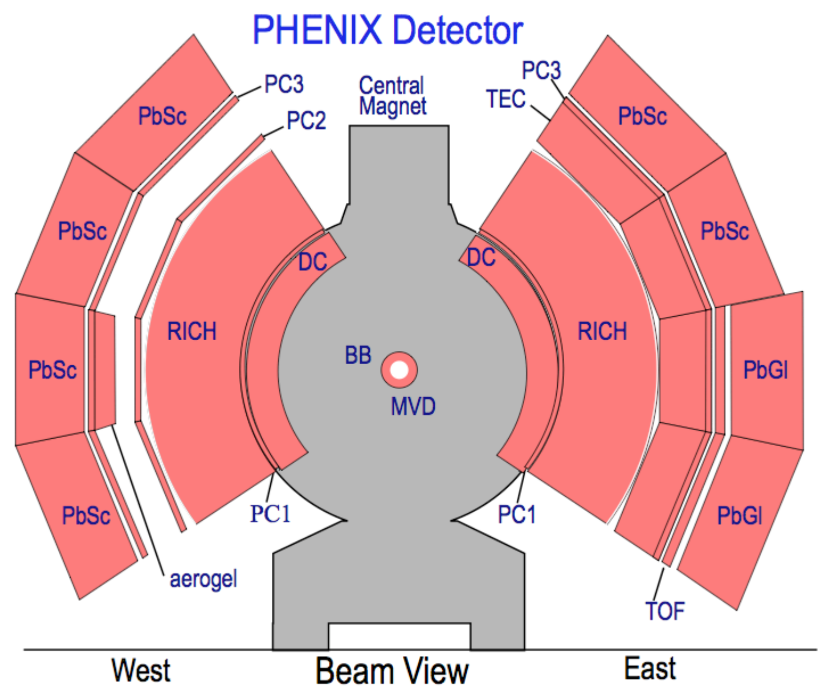


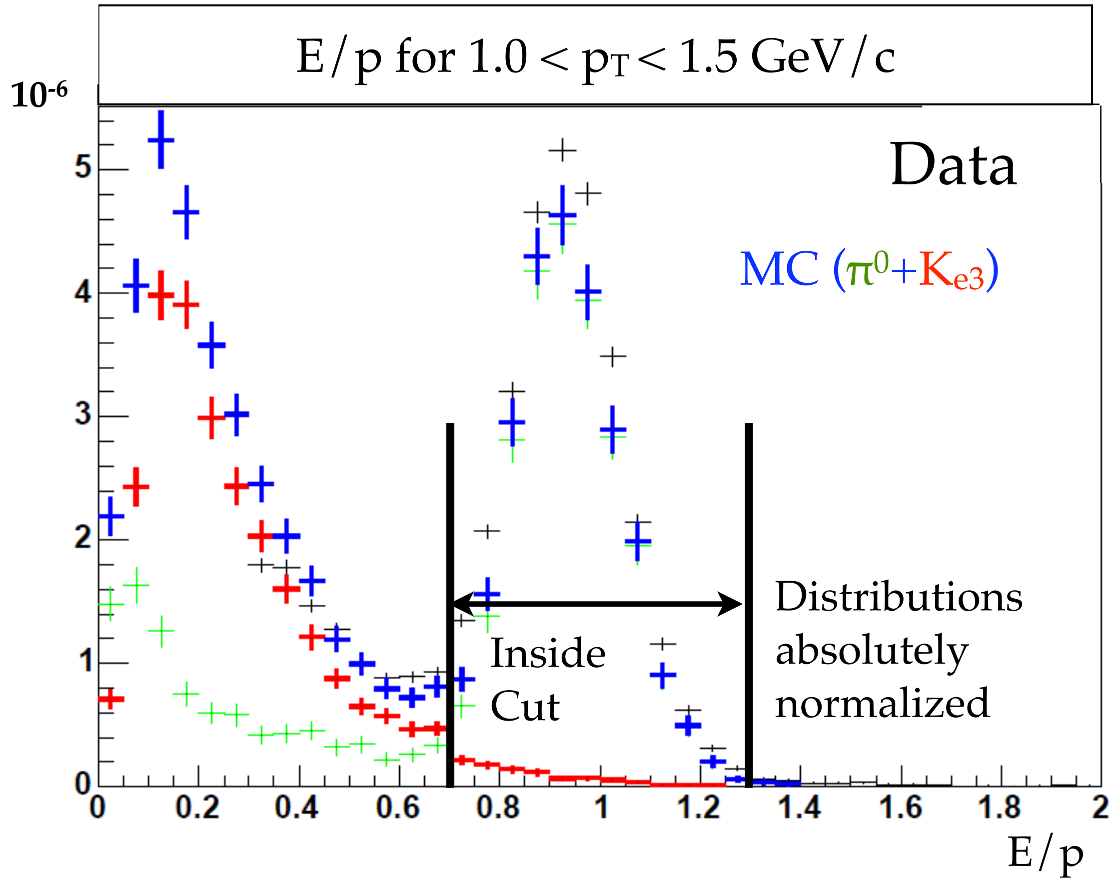
e-μ charge correlation analysis underway
T. Engelmore (poster)

e-h charge correlation analysis for c/b separation, $D \rightarrow K^{\pm} \pi^{\mp}$
Y. Morino (talk this session)

PHENIX electron identification

- $|\eta|<0.35$, $\Delta\phi=2\times\pi/2$, $p>0.2$ GeV/c
- PHENIX possesses clean electron identification
- EMCAL electron E/p peak at ~1 after applying RICH cut
- Absolutely normalized MC reproduces data well
- Negligible hadron contamination
- Efficiencies well understood

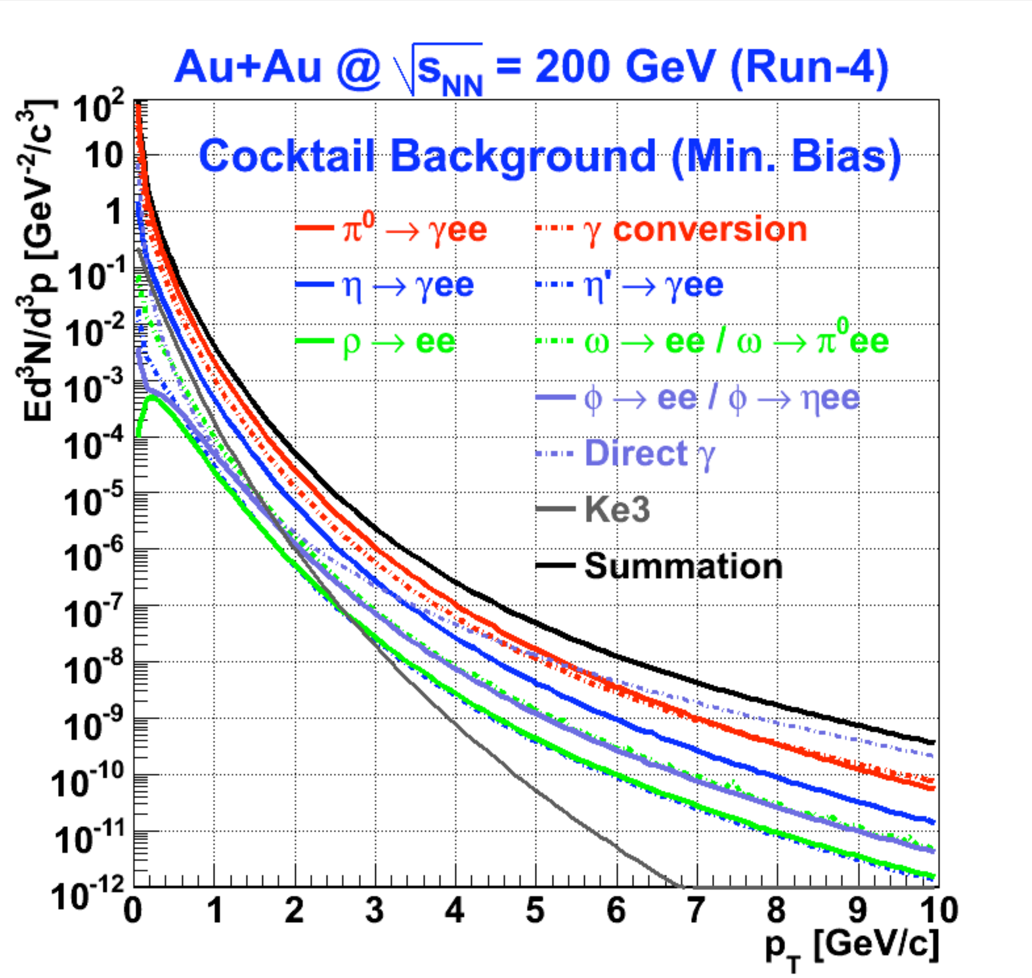




Backgrounds estimated with two separate methods

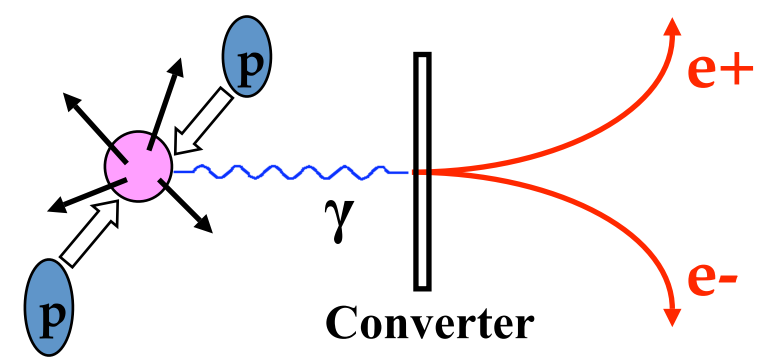
Cocktail method:

- "Cocktail" of backgrounds constructed from measured background sources
- Decay kinematics and photon conversions reconstructed by detector simulation.
- Negligible statistical error.



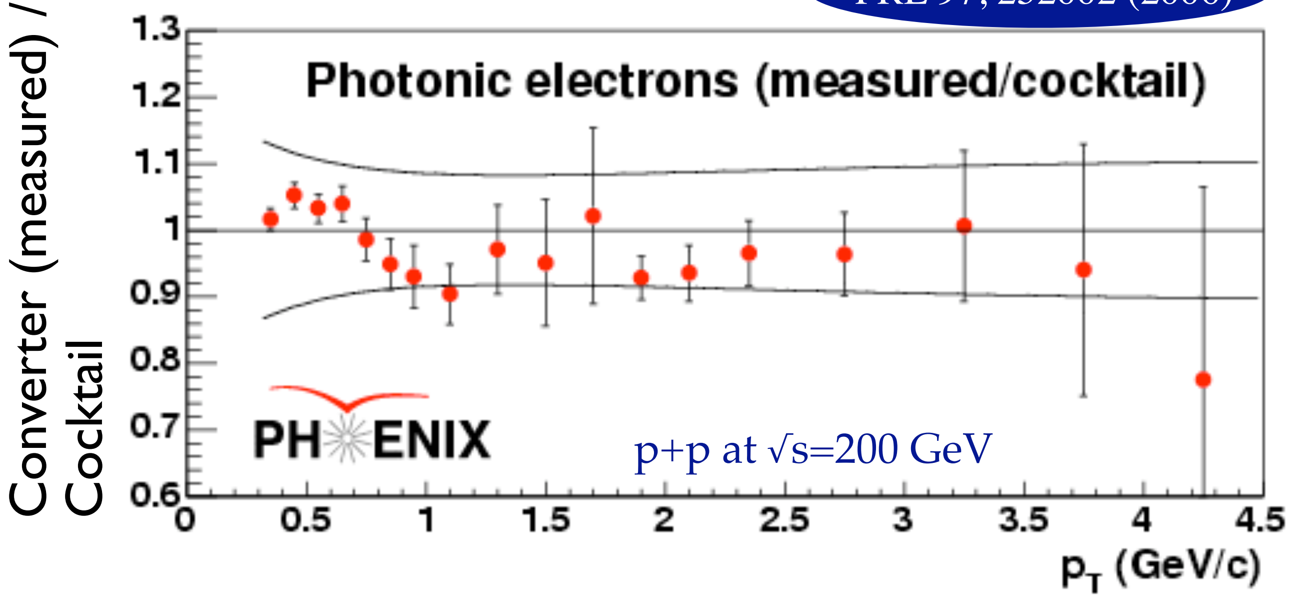
Converter method:

- Converter material of known thickness added to PHENIX acceptance for part of the run
- Multiplies the photonic electron background by a well determined factor



Cross checking the Cocktail/Converter methods

PRL 97, 252002 (2006)



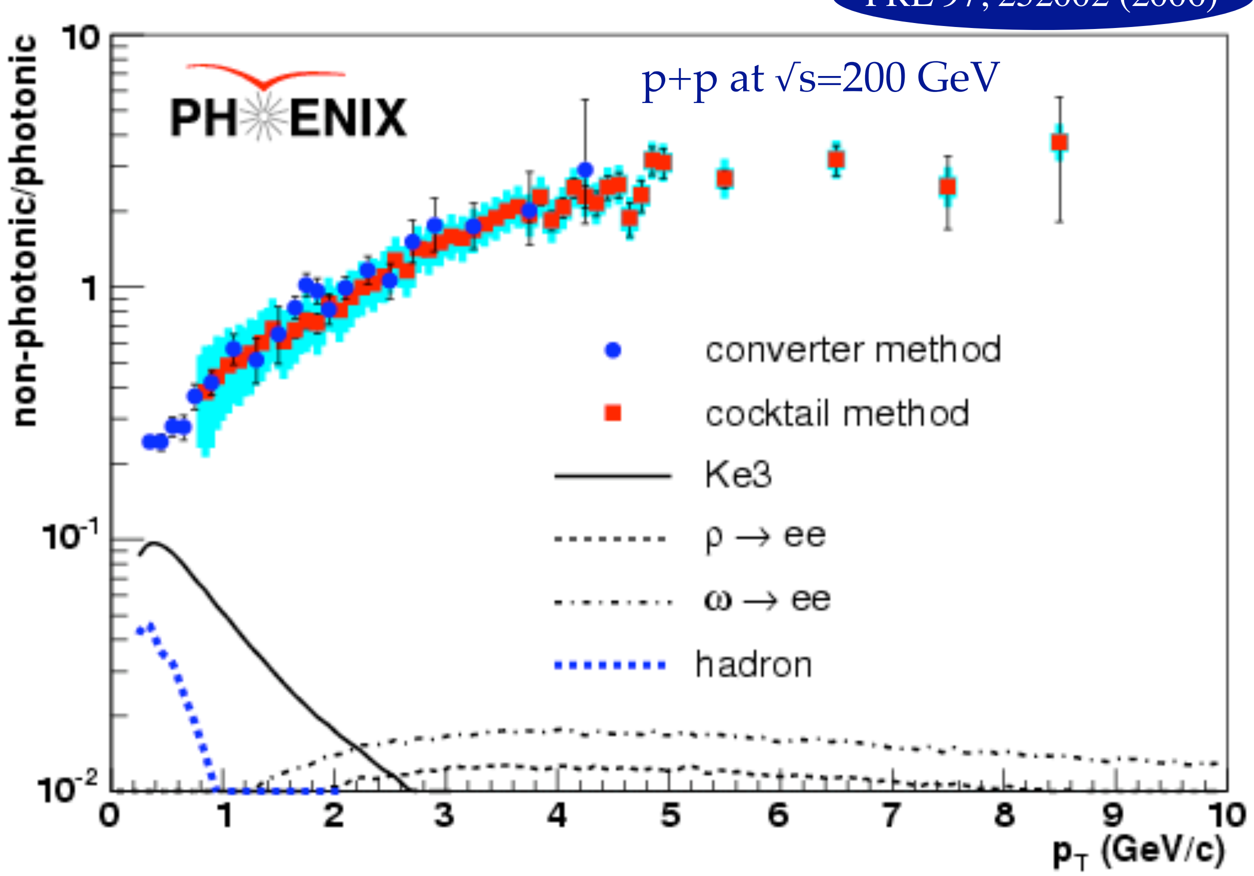
- Photonic electron estimates: measured converter/cocktail = 0.94±0.04
- Consistent within cocktail systematic error
- Used to re-normalize cocktail (reduces overall systematic uncertainty)

- Signal/background: 0.1 (low pT) to ~3 (high pT)

- Good signal/background due to small amount of conversion material in PHENIX acceptance.

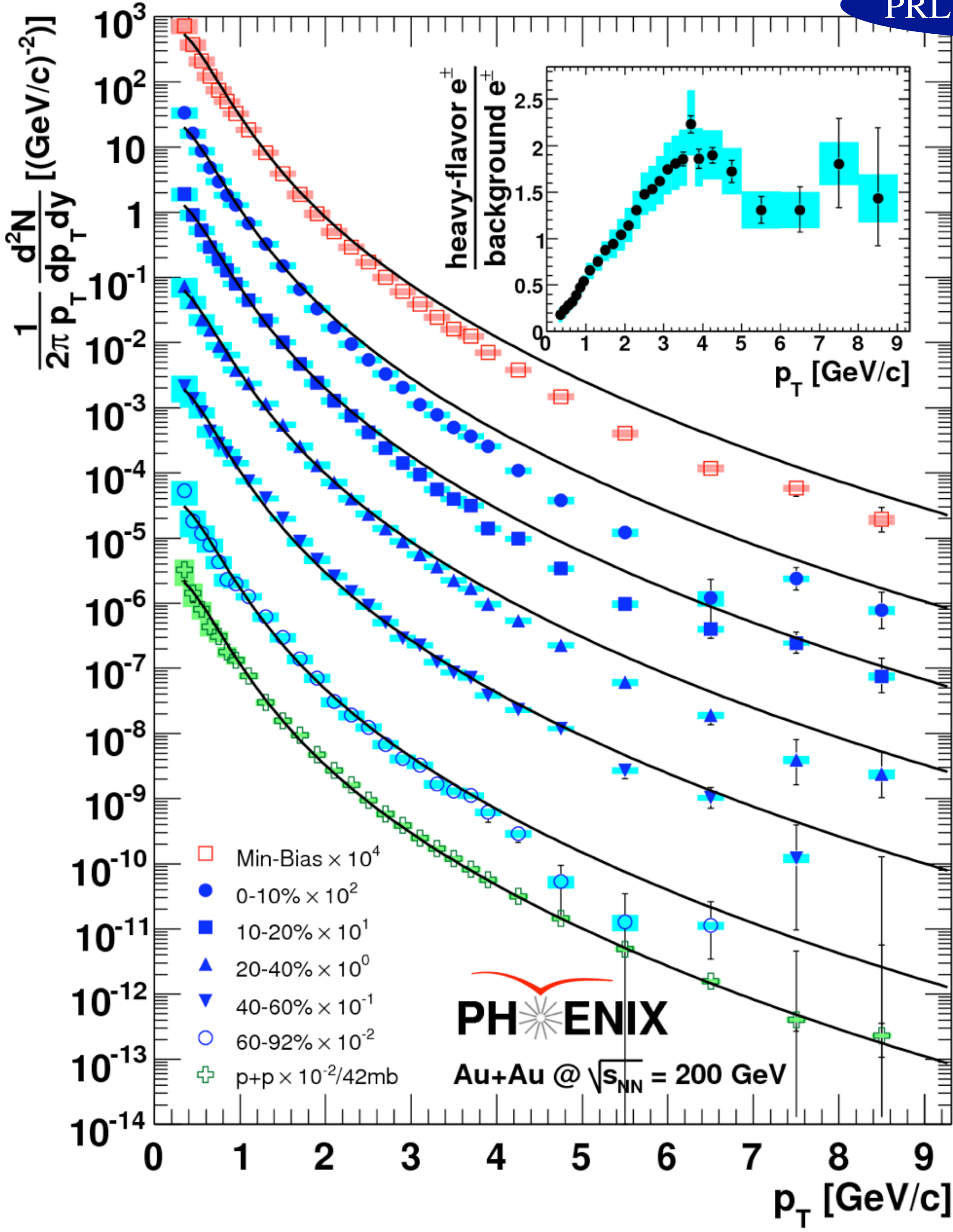
S/B provides a key input into the Au+Au HQ v_2 measurement.

PRL 97, 252002 (2006)



heavy flavor single electron spectra for p+p and Au+Au

PRL 98, 172301 (2007)



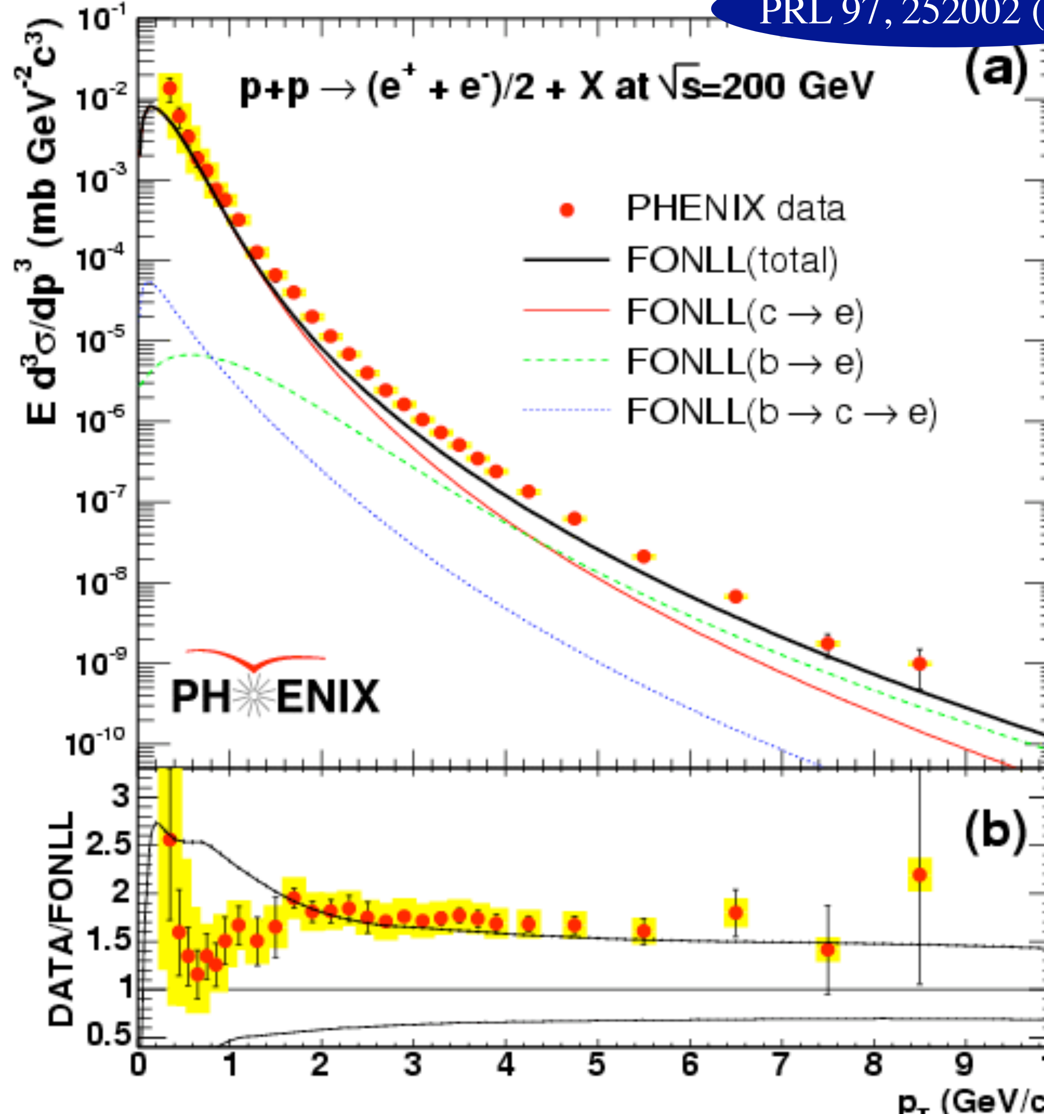
centrality bins:

min. bias.
0-10%
10-20%
20-40%
40-60%
60-92%

p+p reference scaled by 1.7

Clear suppression observed at high p_T

PRL 97, 252002 (2006)



FONLL - Fixed Order Next to Leading Log

PRL 95, 122001 (2005)

- HQ baseline reference for the Au+Au measurements
- $\sigma_{c\bar{c}} = 567 \pm 57(\text{stat}) \pm 224(\text{sys})\ \mu b$

PHENIX

e^+e^- pairs: charm cross section cross check

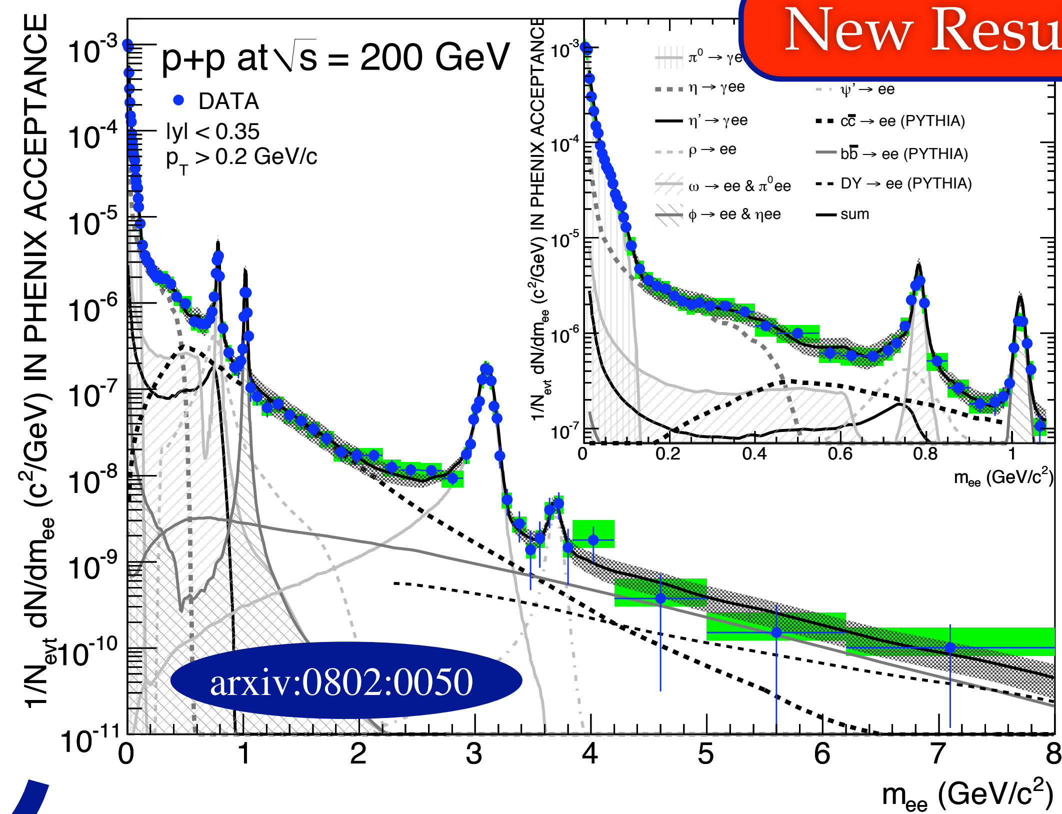
Measured e^+e^- pairs at y=0 from 0 to 8 GeV/c^2.

Charm cross sections (μb):

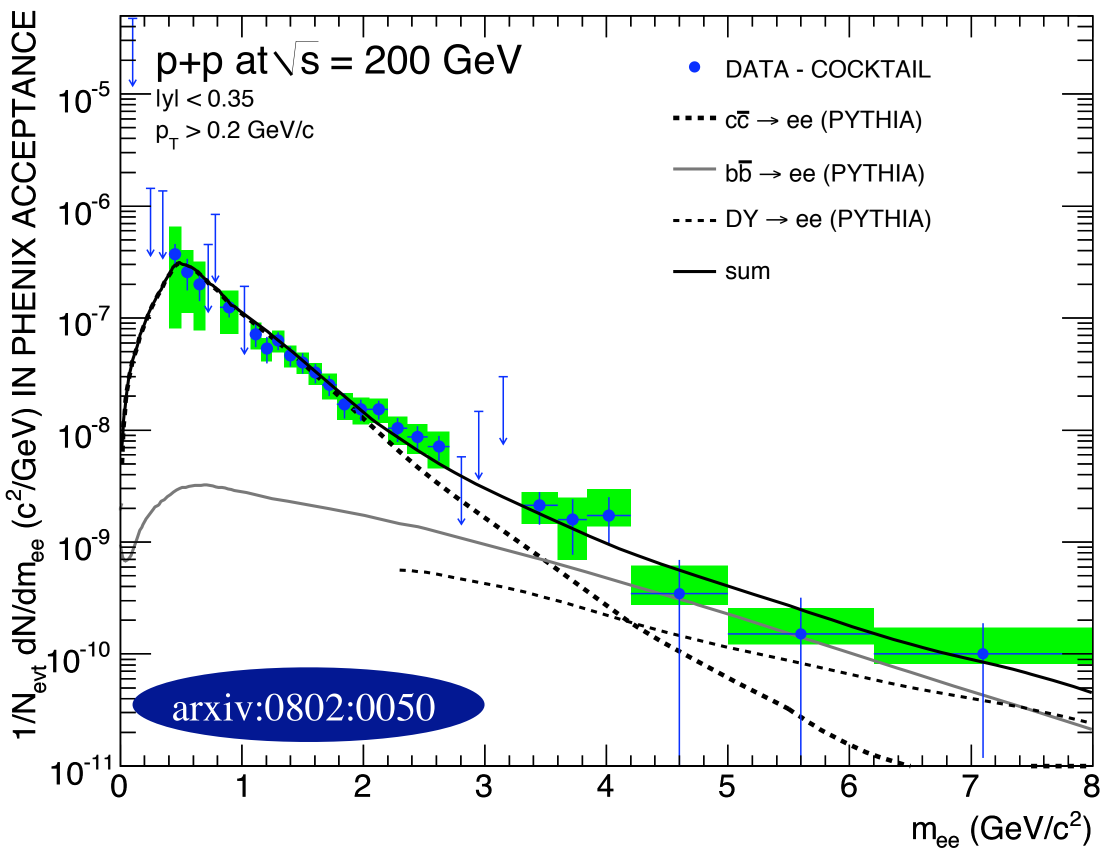
e^+e^- (2 methods):

1. $\sigma_{c\bar{c}} = 544 \pm 39(\text{stat}) \pm 142(\text{sys}) \pm 200(\text{model})$
2. $\sigma_{c\bar{c}} = 518 \pm 47(\text{stat}) \pm 135(\text{sys}) \pm 190(\text{model})$

New Results



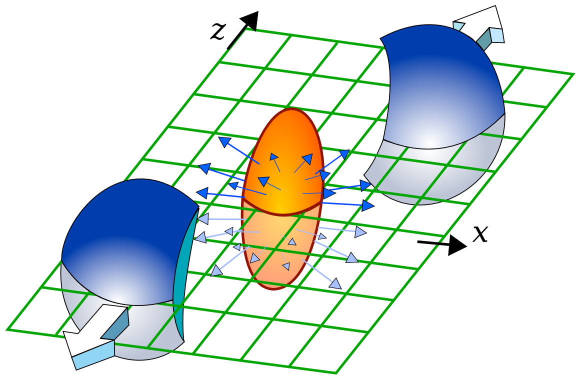
Subtracting contributions from: $\pi^0, \eta, \omega, \rho, \phi, J/\Psi, \Psi'$

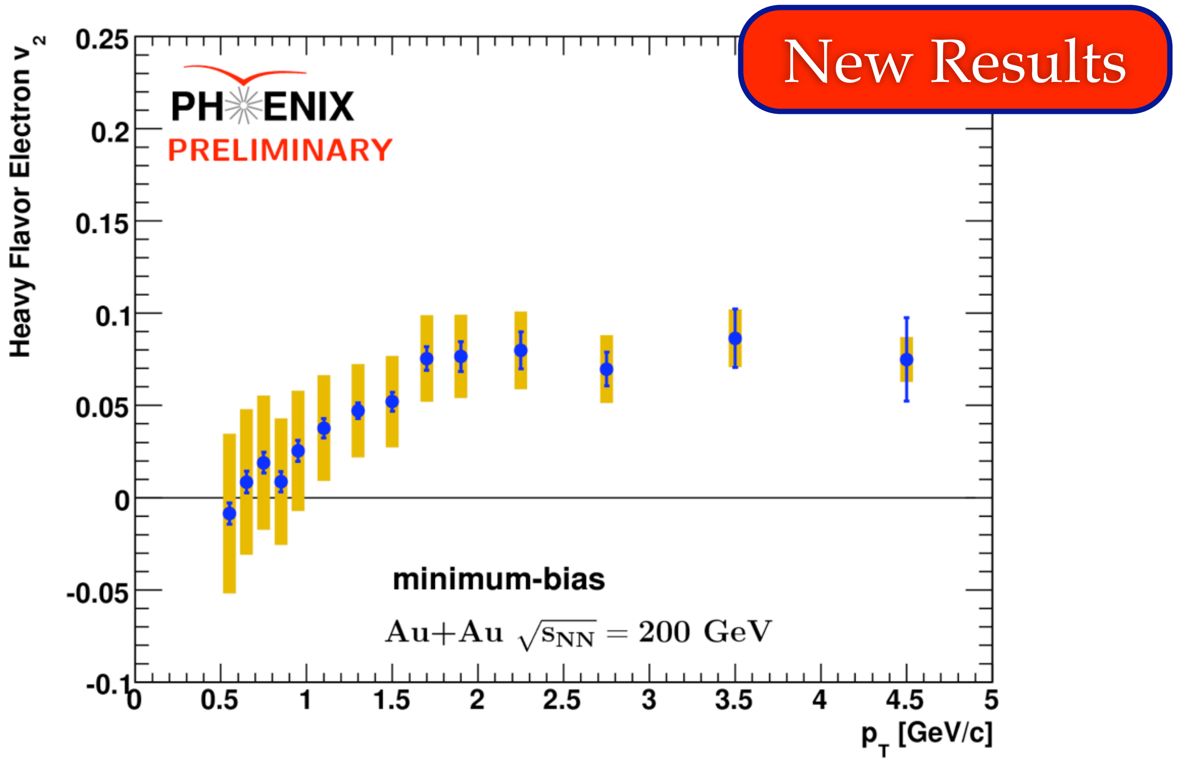


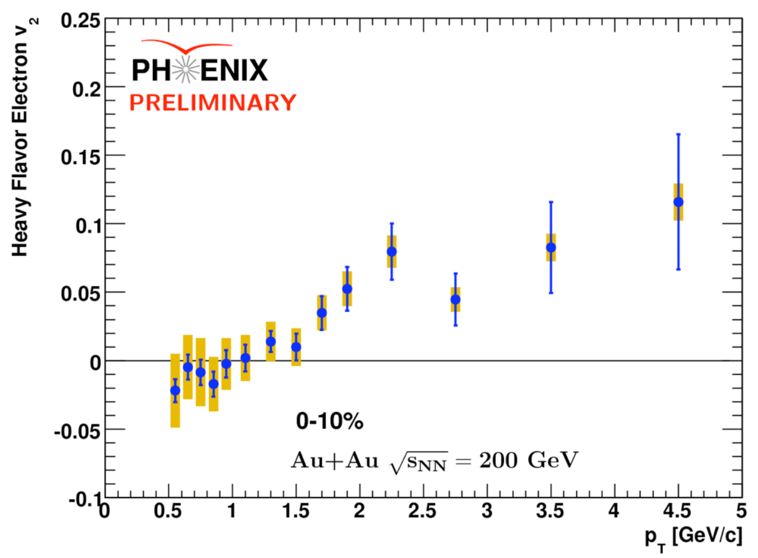
Consistent with the existing single electron charm estimate of:

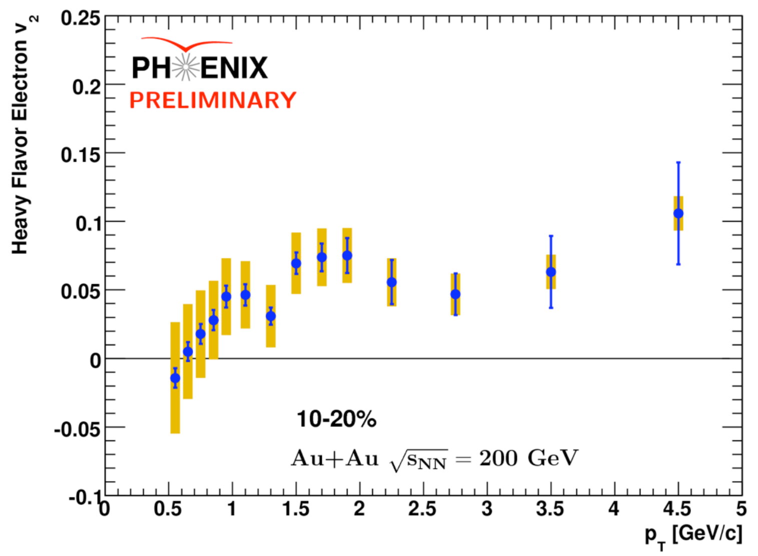
$\sigma_{c\bar{c}} = 567 \pm 57(\text{stat}) \pm 224(\text{sys})$ μb

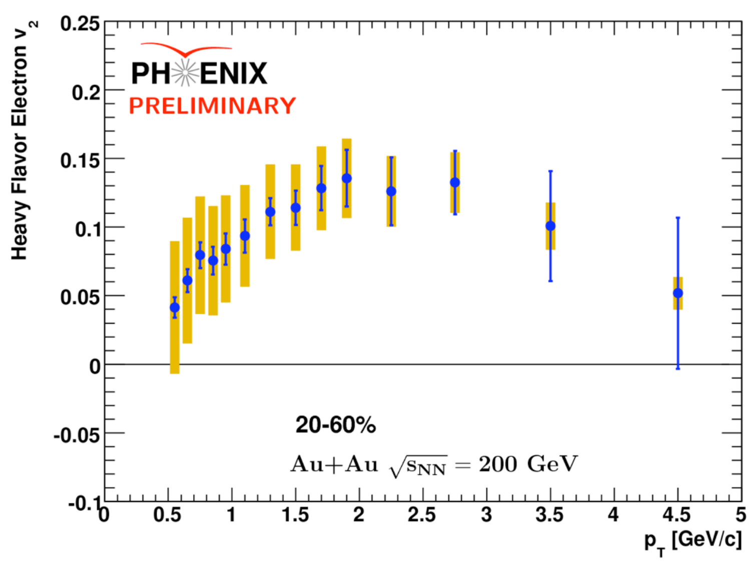
Collective motion in Au+Au: single electron v_2











- Reduced errors at high p_T due to new reaction plane detector.
- v_2 centrality dependence for heavy flavor $e^{\pm}$
- Non-zero v_2 at higher p_T. Bottom contributes meaningfully above p_T~3.0 GeV/c.

Additional details: R. Averbeck (talk) and A. Dion (poster)

Dominant sources of tracks in the muon arm

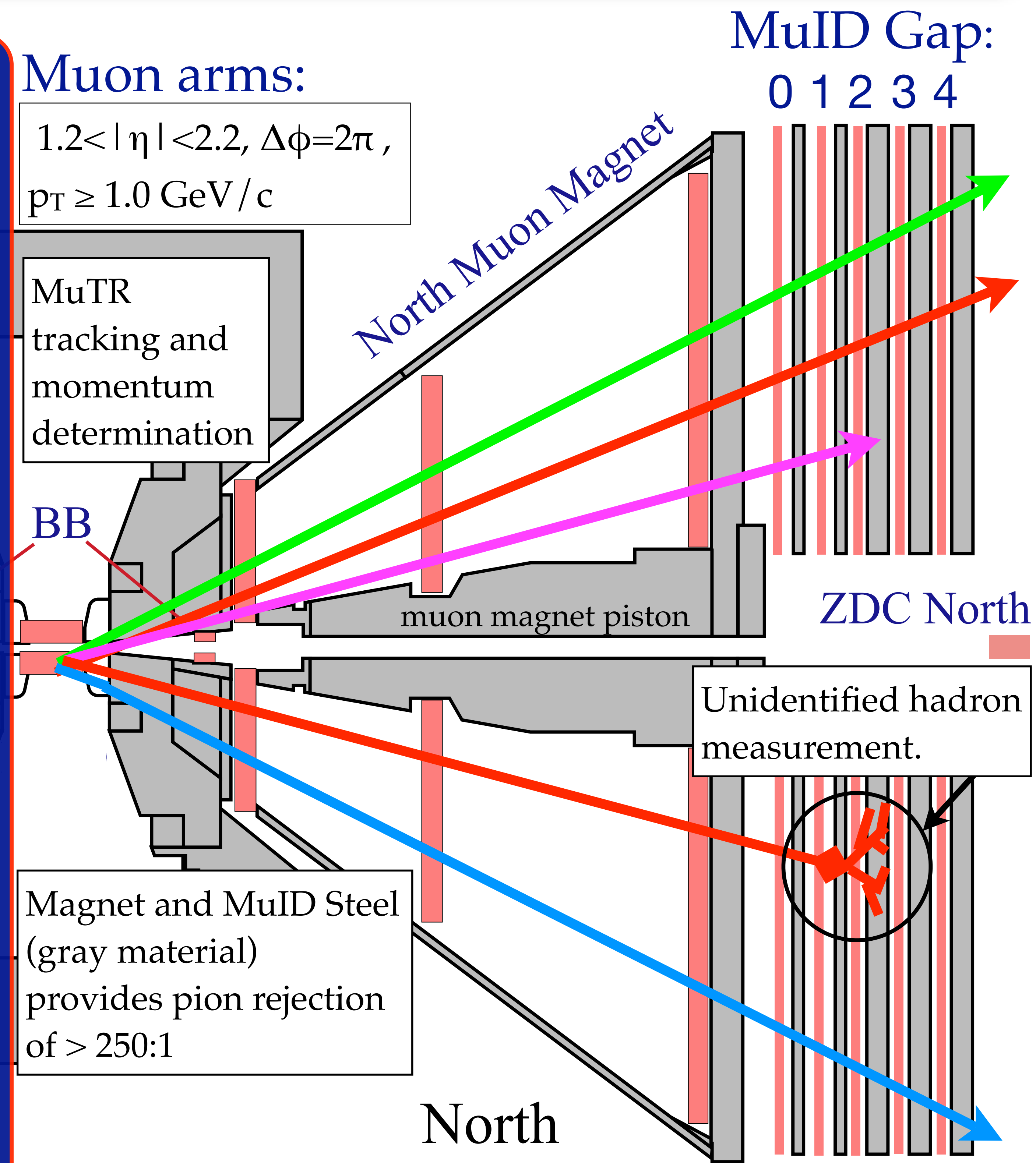
Muon from heavy flavor (the signal)

Hadron (does not interact and punches through the entire detector)

A muon from hadron decay

An interacting hadron (nuclear interaction)

A low energy muon that ranges out due to ionization energy loss (primarily hadron decay muons)



New single muon analysis methodology

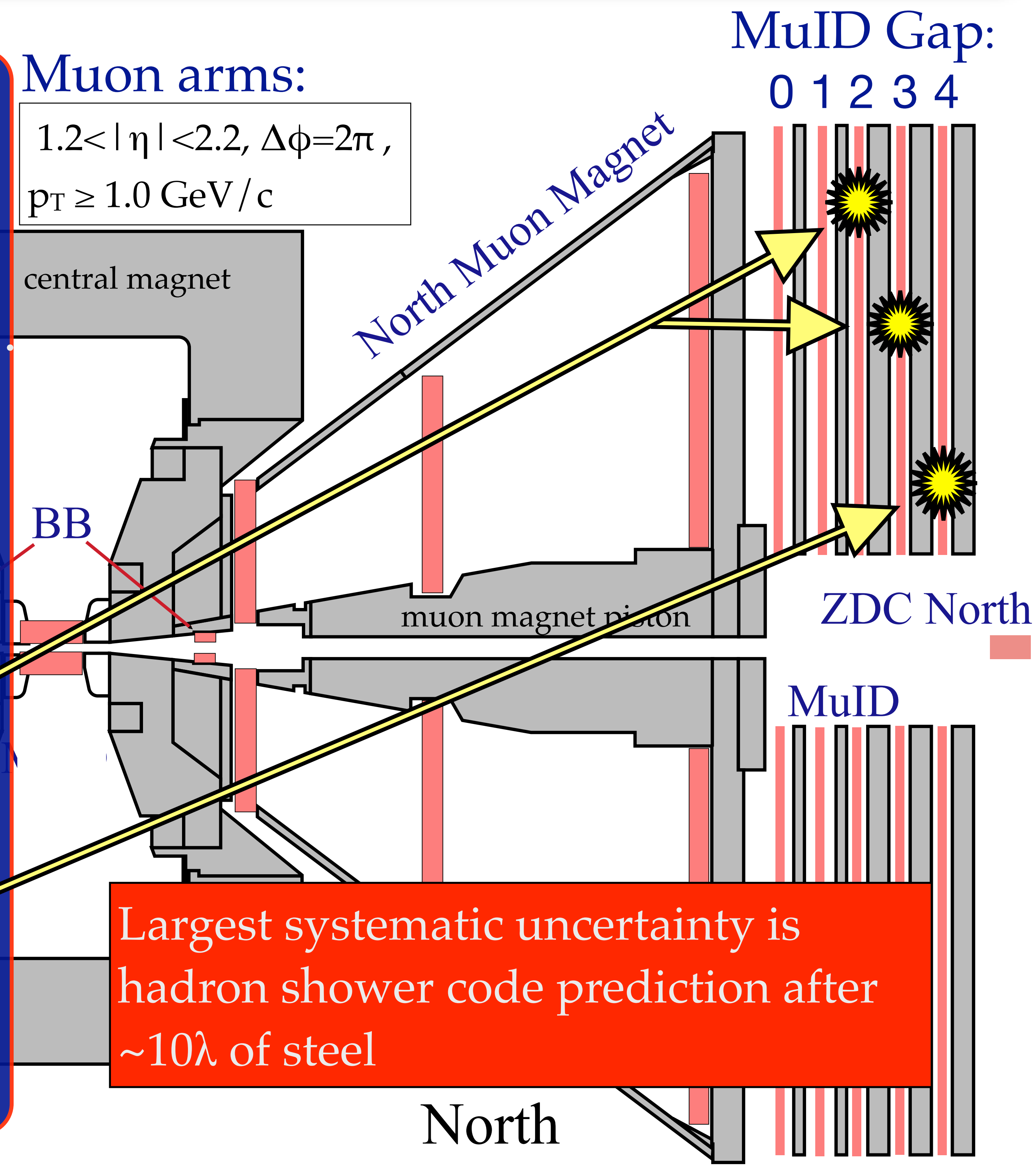
Heavy flavor single muons penetrate the entire detector (gap 4).

Simulate and subtract all known backgrounds with hadron "cocktail".

Normalize and "tune" input MC distributions by simultaneously matching data in:

1. stopped hadron distributions in gap 2 and gap 3

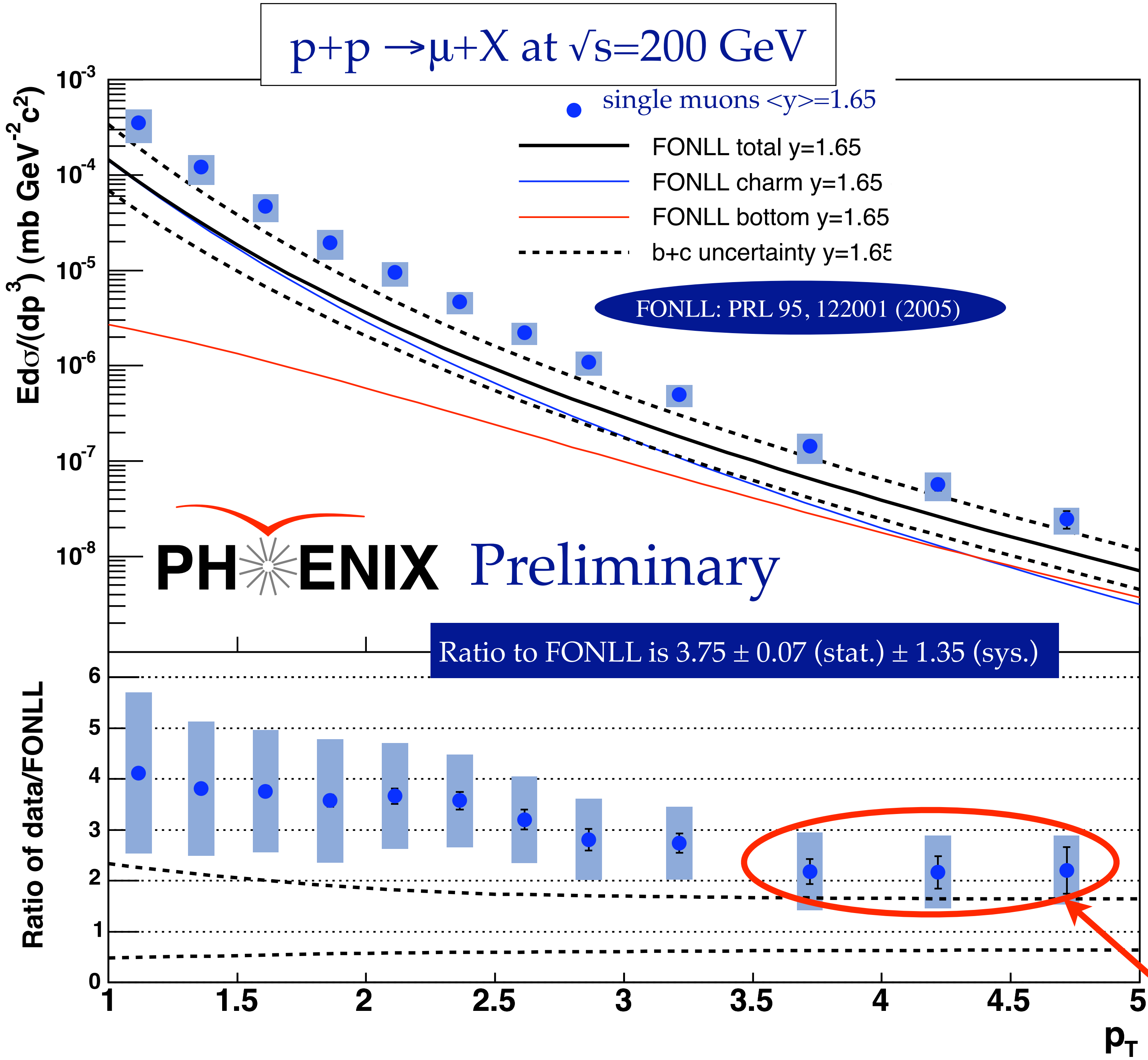
2. muons from hadron decay in gap 4 z-vertex distributions



Largest systematic uncertainty is hadron shower code prediction after ~10λ of steel

p+p single muon spectra

New Results



Independent forward / backward muon arm analyses in strong agreement and combined into single spectra.

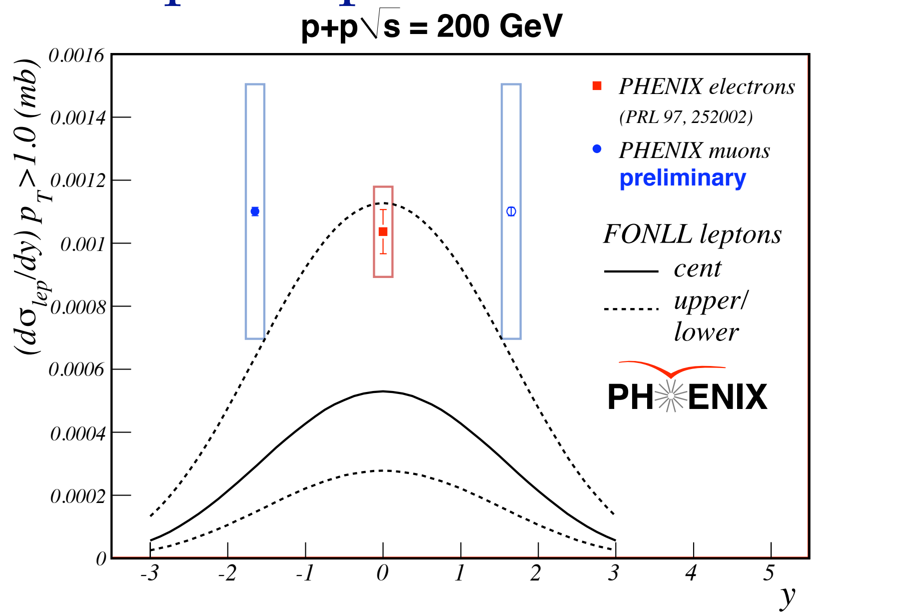
Consistent with the previous PHENIX single muon measurement. PRD 76, 092992 (2007)

Compared to FONLL c+b for <y>=1.65.

At larger p_T data / FONLL ratio ~ 2.

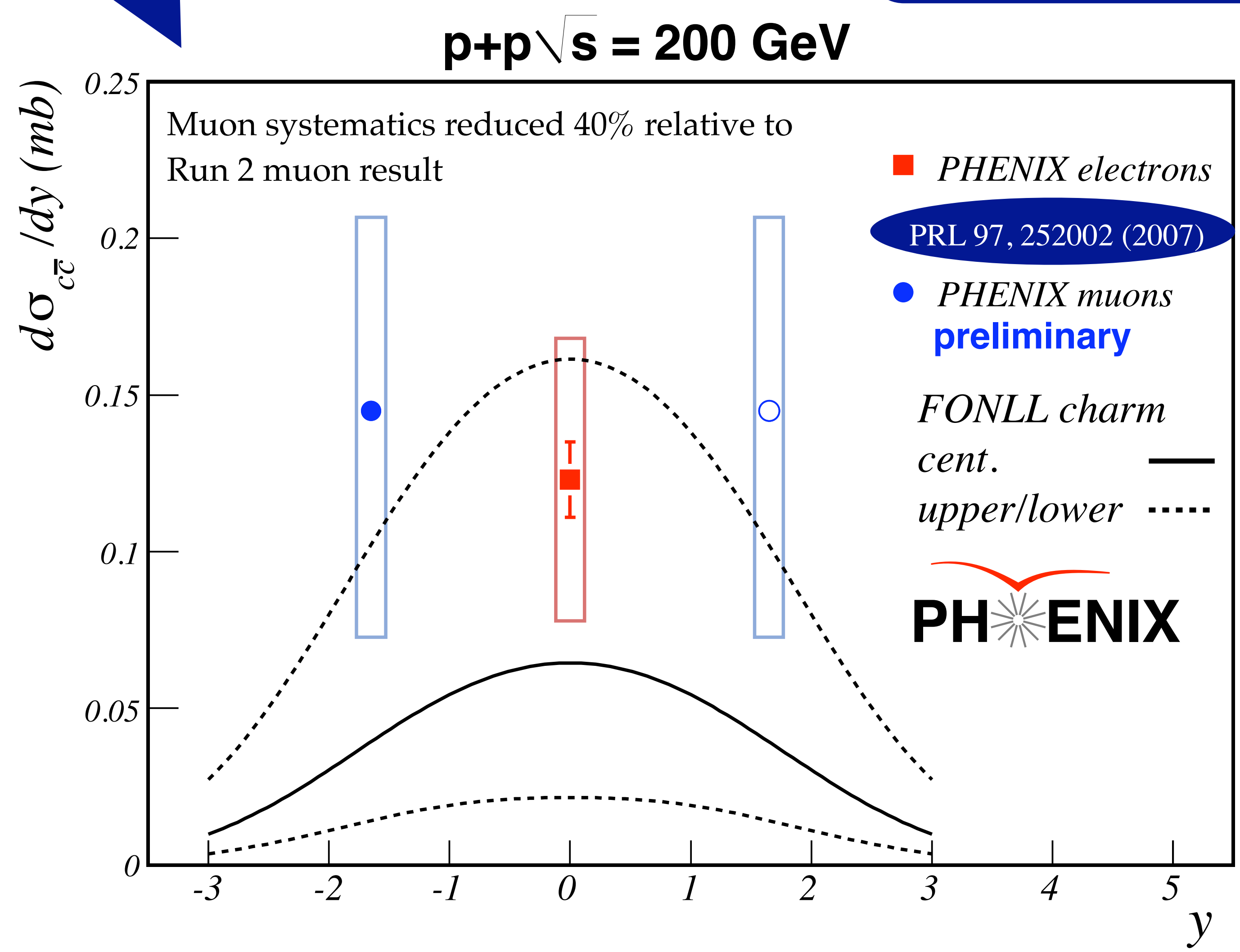
Integrated spectra: $d\sigma_{cc}/dy$ y=0 and y=1.65

leptons $p_T > 1.0$ GeV/c



Integrate the single muon spectra, extrapolate to p_T=0 and convert to $d\sigma_{c\bar{c}}/dy$ using FONLL.

New Result



Forward muon result in good agreement with the existing mid-rapidity single electron point.

$d\sigma_{c\bar{c}}/dy\,|_{y=0}$:
0.123 ± 9.8% (stat) +36.5% (sys)
$d\sigma_{c\bar{c}}/dy\,|_{y=1.65}$:
0.145 ± 1.1% (stat) +42.7%-49.8% (sys)

The future

Ongoing/Near term PHENIX single lepton analyses:

- Mid rapidity: single electron Cu+Cu, d+Au
- Forward rapidity: muon analyses with further refinements to the new approach shown in this talk : single muon Cu+Cu, Au+Au R_{AA} and v_2
- e-μ correlation combined mid and forward rapidity analysis (T. Engelmore poster)

UPGRADES:
PHENIX is embarking on a upgrades program, including silicon vertex tracking, that will drastically improve the wide assortment of heavy quark measurements.

Au+Au heavy flavor single electron R_{AA}

$$R_{\mathrm{AuAu}}(p_{\mathrm{T}}) = \frac{dN^e_{\mathrm{AuAu}}/dp_{\mathrm{T}}}{N_{\mathrm{col}} \cdot dN^e_{\mathrm{pp}}/dp_{\mathrm{T}}}$$

$$R_{\mathrm{AuAu}}(N_{\mathrm{part}}) = \frac{\int_{p'_{\mathrm{T}}}^{9.0} \frac{dN^e_{\mathrm{AuAu}}}{dp_{\mathrm{T}}} dp_{\mathrm{T}}}{N_{\mathrm{col}} \cdot \int_{p'_{\mathrm{T}}}^{9.0} \frac{dN^e_{\mathrm{pp}}}{dp_{\mathrm{T}}} dp_{\mathrm{T}}}$$

Suppression level is almost the same as π^0 and η at high p_T

Binary scaling works well for p_T>0.3 GeV/c. Integrated charm yield is unchanged.