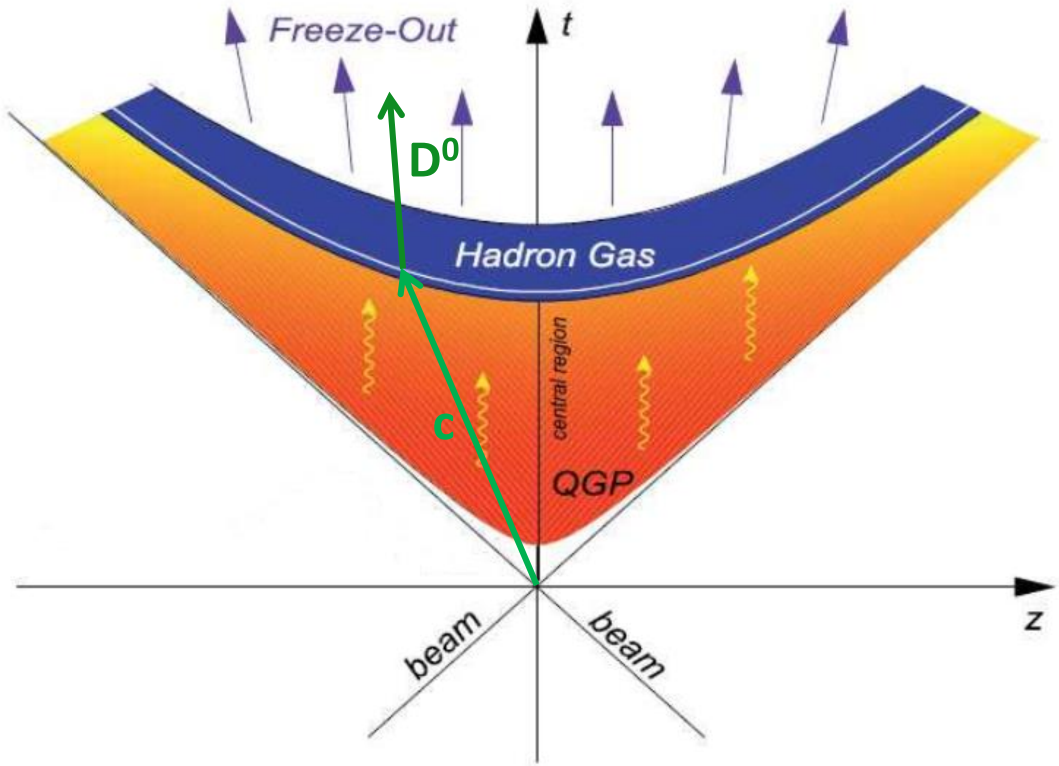
Heavy Flavor Measurements from PHENIX

Timothy Rinn

Heavy Flavor Quarks as Probe of QGP



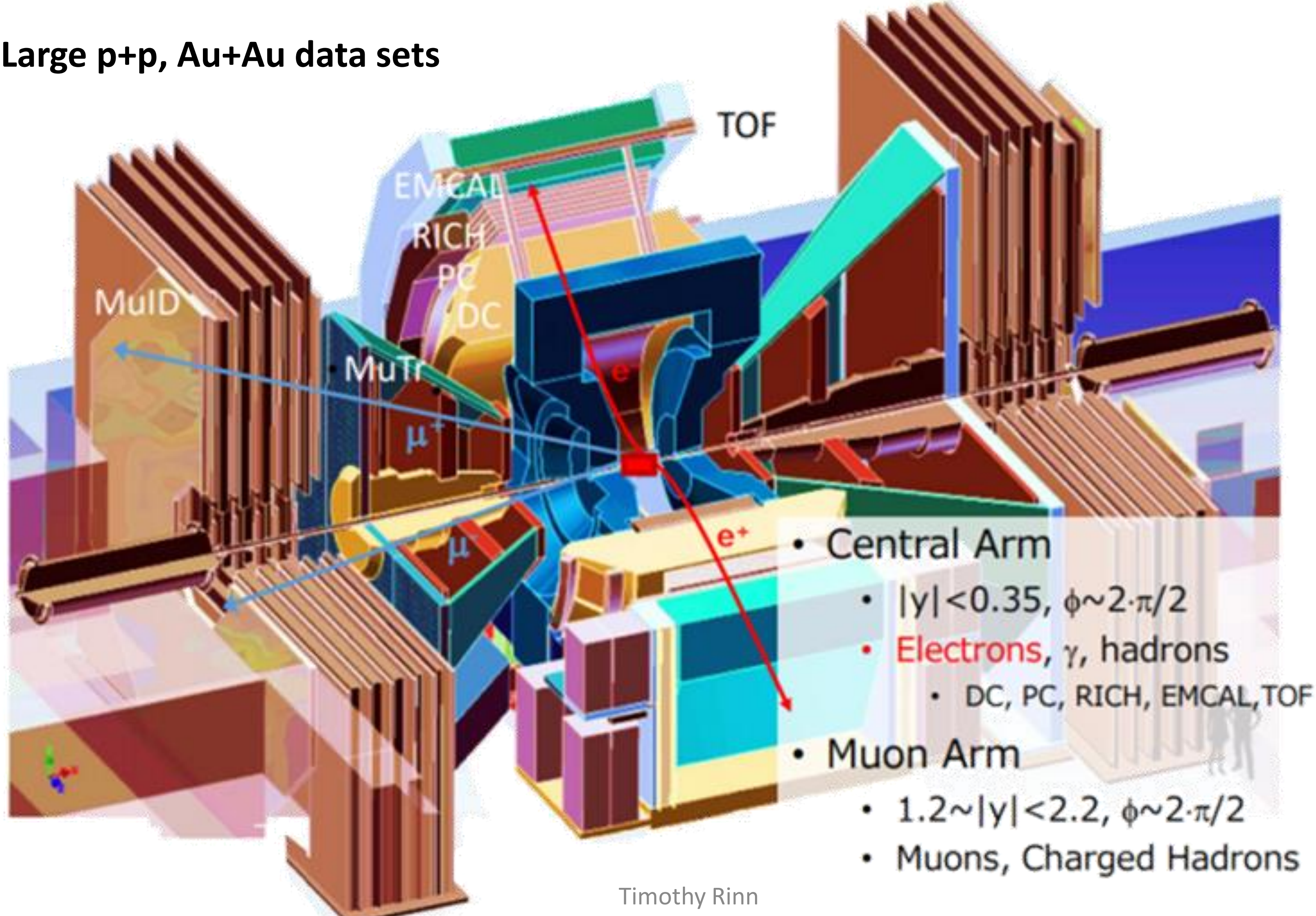
At RHIC energies heavy flavor quarks (bottom and charm) are primarily produced in initial hard scattering interactions

Experience full evolution of the QGP

Modifications to heavy flavor quarks are a powerful way to study properties of the QGP

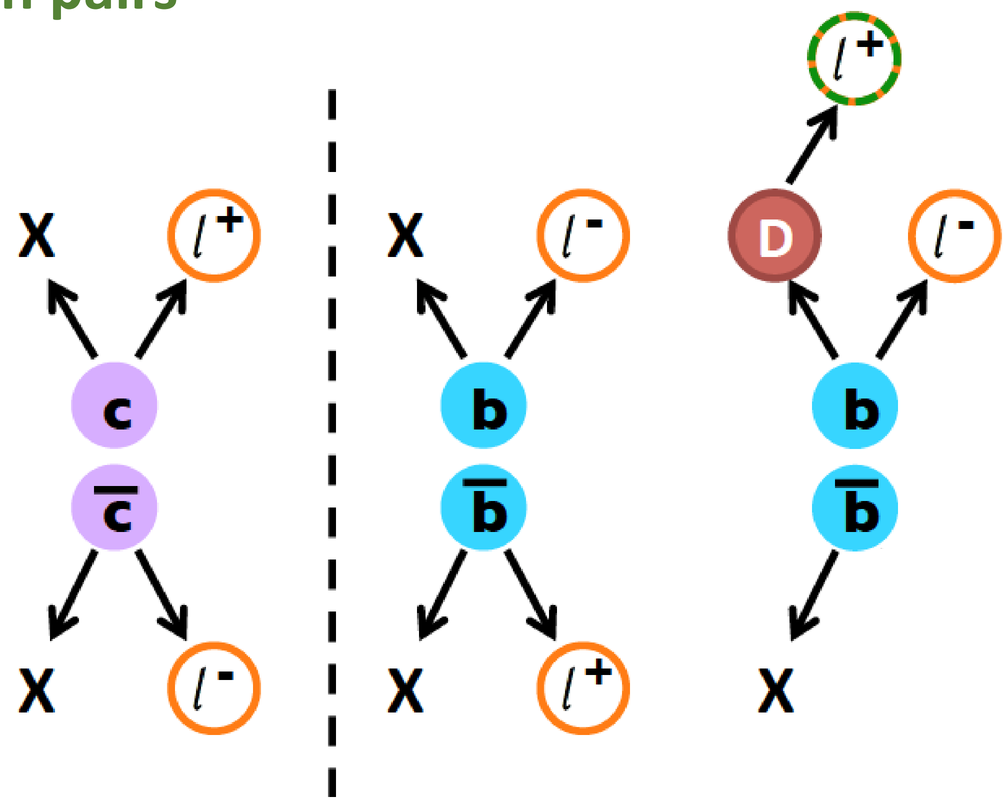
Studying Heavy Flavor in PHENIX

Large p+p, Au+Au data sets



Open Heavy Flavor via Di-Leptons

Semi-Leptonic decays of **Charm** and **Bottom** produce **opposite sign pairs**



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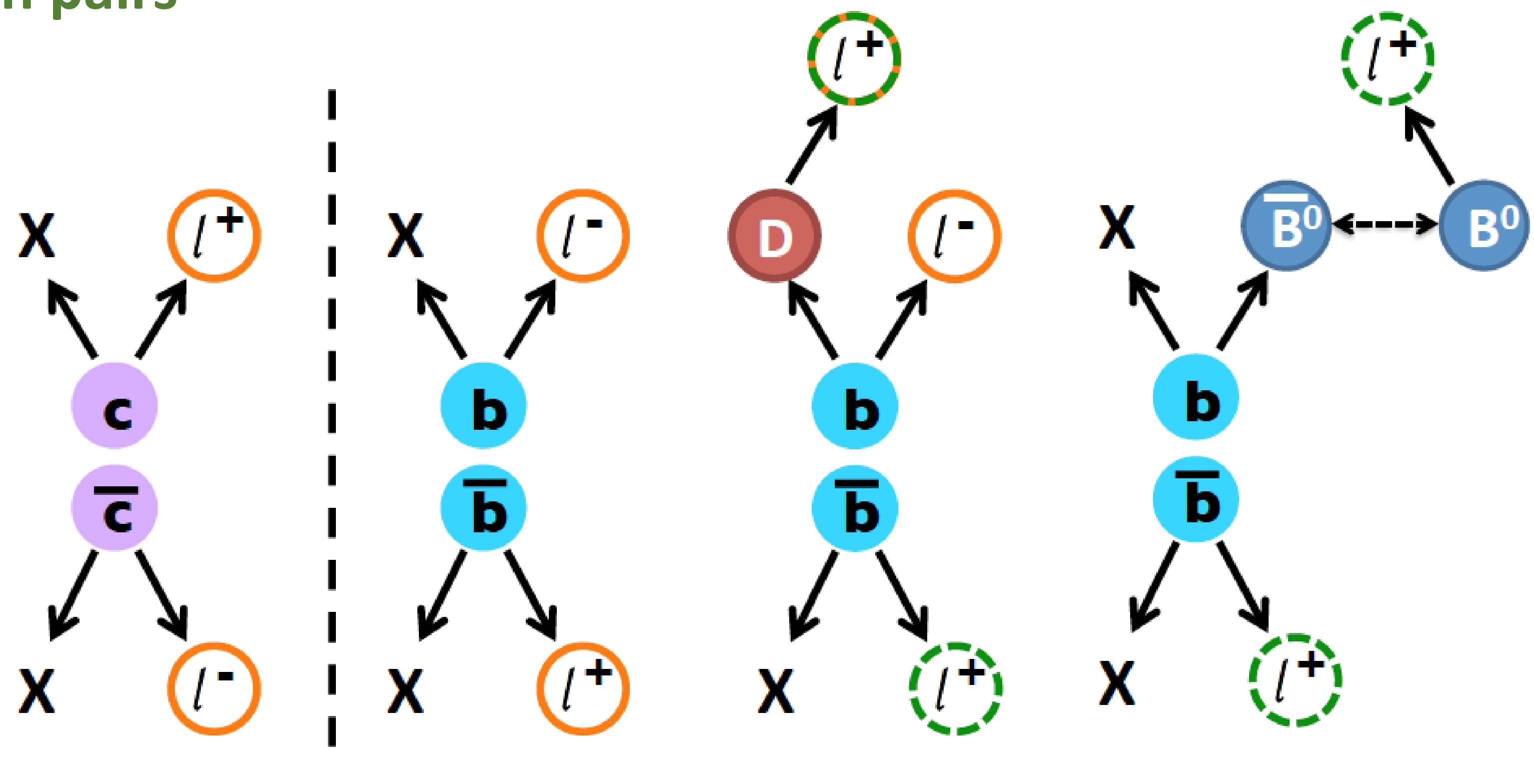
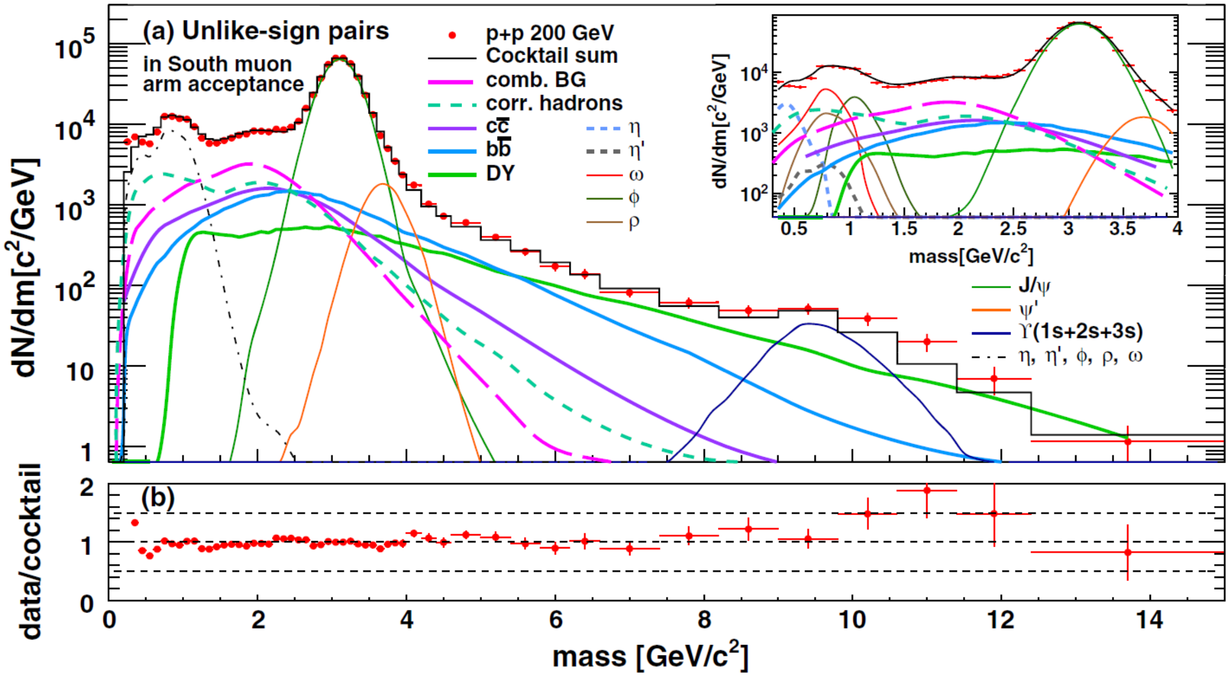


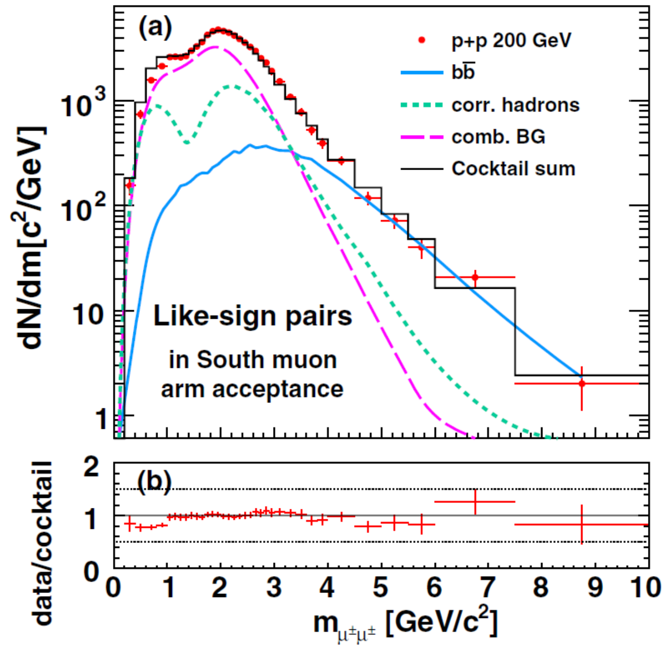
Semi-Leptonic decays **Bottom** can additionally produce **like sign pairs**

Open Heavy Flavor Like and Unlike Di-Muon Sign Pairs

Unlike Sign Pairs *PRD 99, 072003*



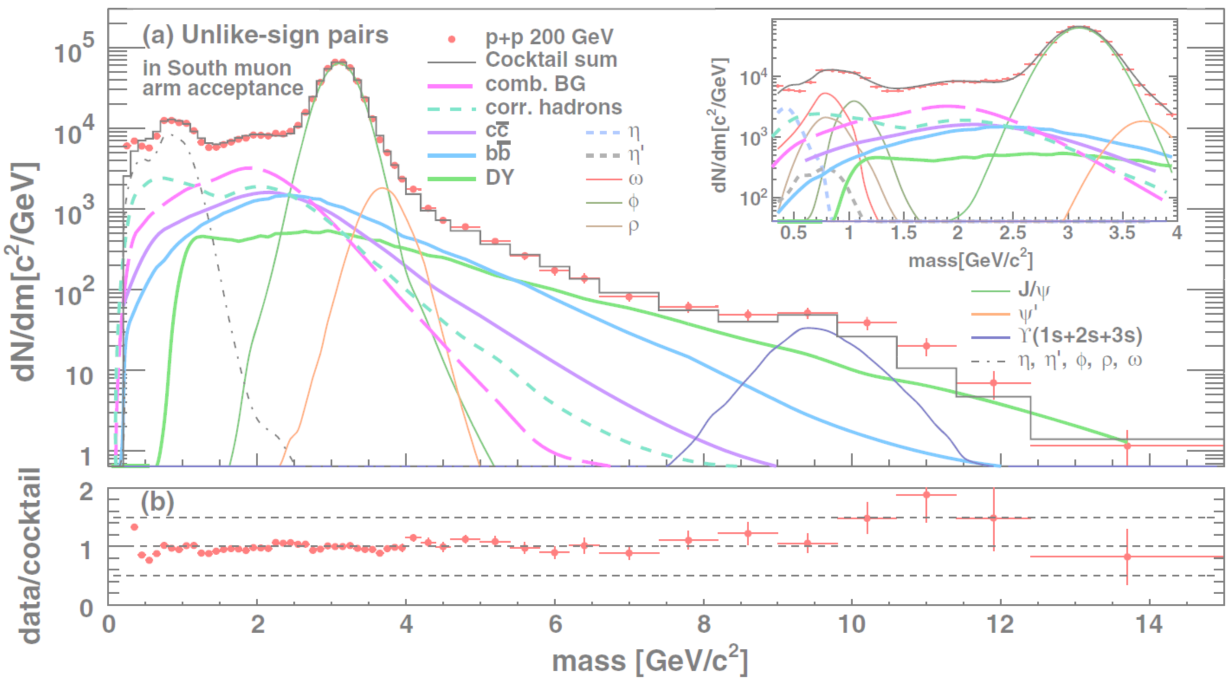
Like *PRD 99, 072003*



Di-muon mass cocktail describes both the like and unlike sign data

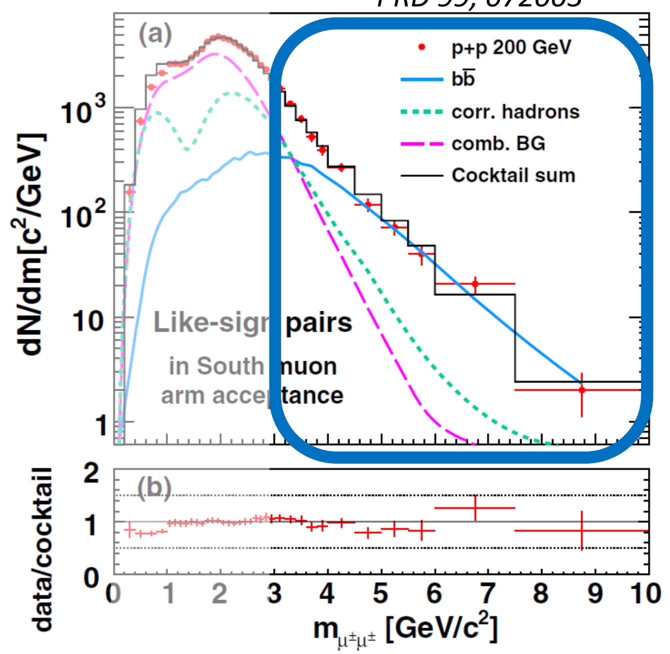
Open Heavy Flavor Like and Unlike Di-Muon Sign Pairs

PRD 99, 072003



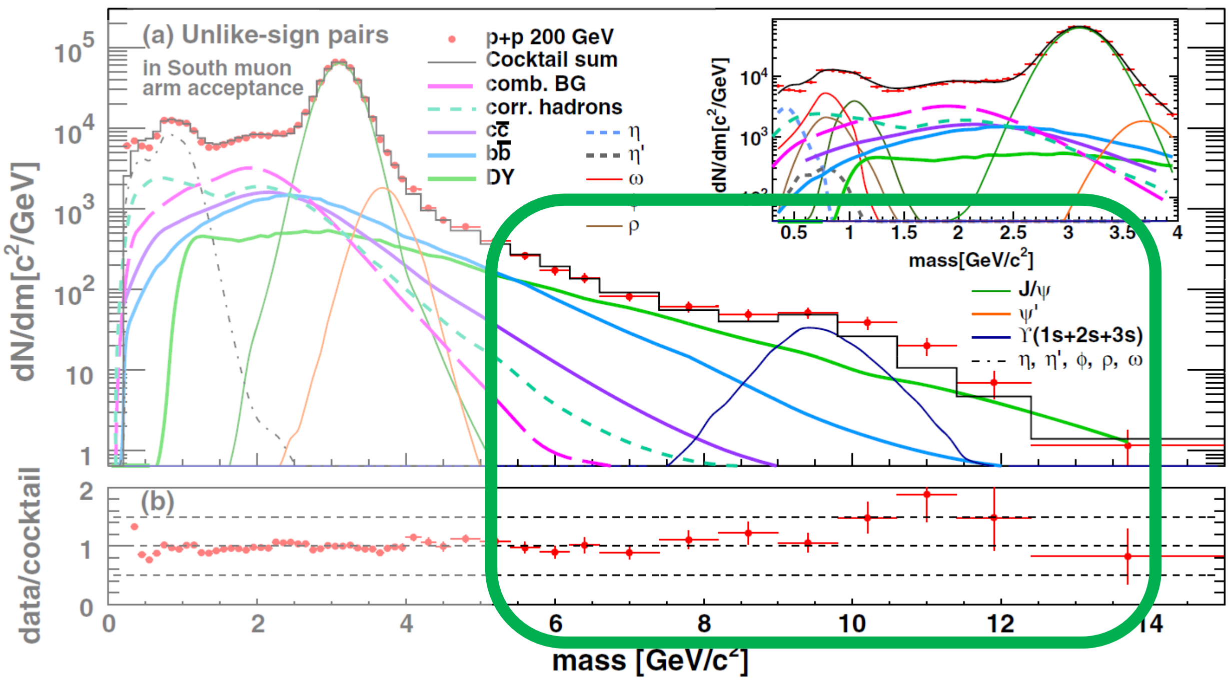
High mass **like-sign** pairs dominated by **Bottom**

PRD 99, 072003



Open Heavy Flavor Like and Unlike Di-Muon Sign Pairs

PRD 99, 072003



High mass **un-like sign** pairs dominated by **Drell-Yan**

High mass **like-sign** pairs dominated by **Bottom**

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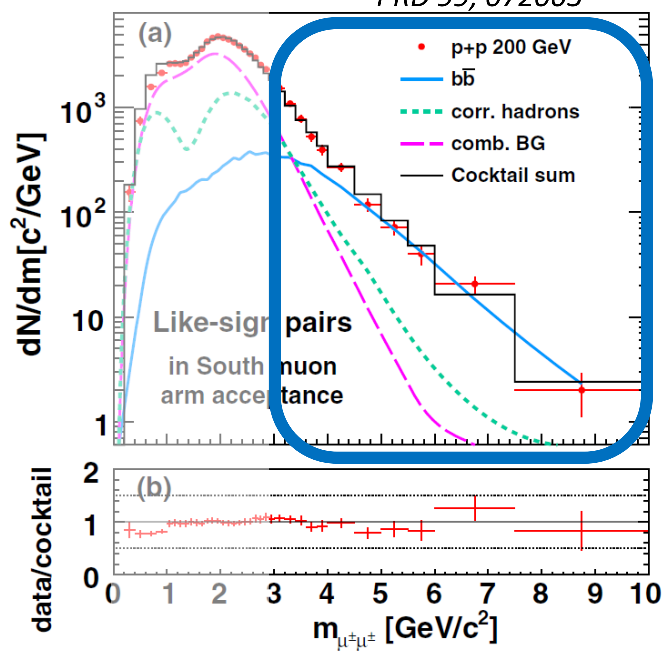

Open Heavy Flavor Like and Unlike Di-Muon Sign Pairs

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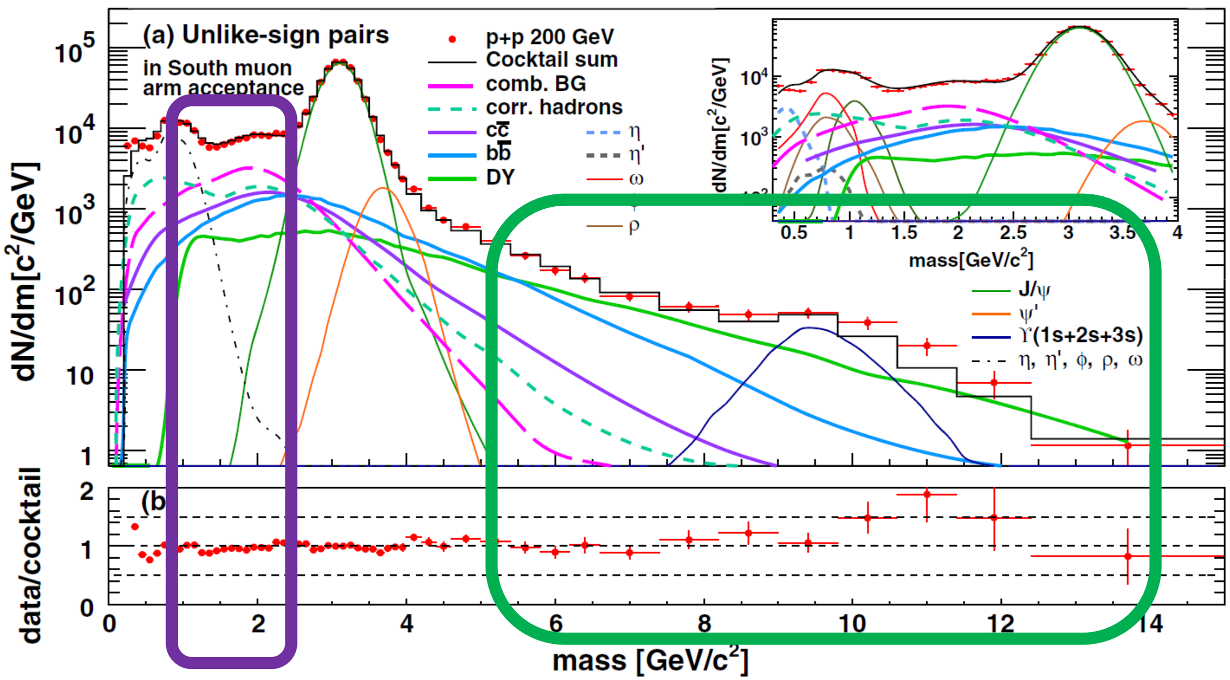
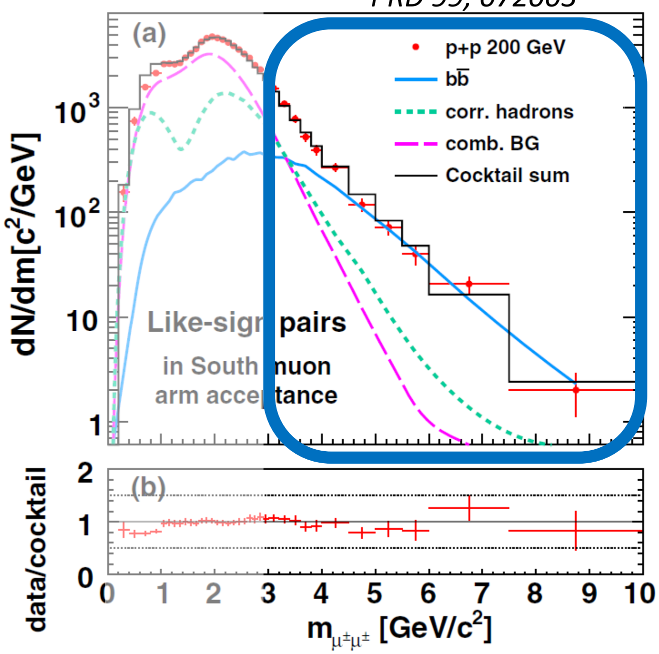


High mass **like-sign** pairs dominated by **Bottom**

PRD 99, 072003



Charm dominates the intermediate mass region

High mass **un-like sign** pairs dominated by **Drell-Yan**

$b\bar{b}$ cross section from like-sign dimuons

Using the like-sign dimuons a $b\bar{b}$ cross section was extracted

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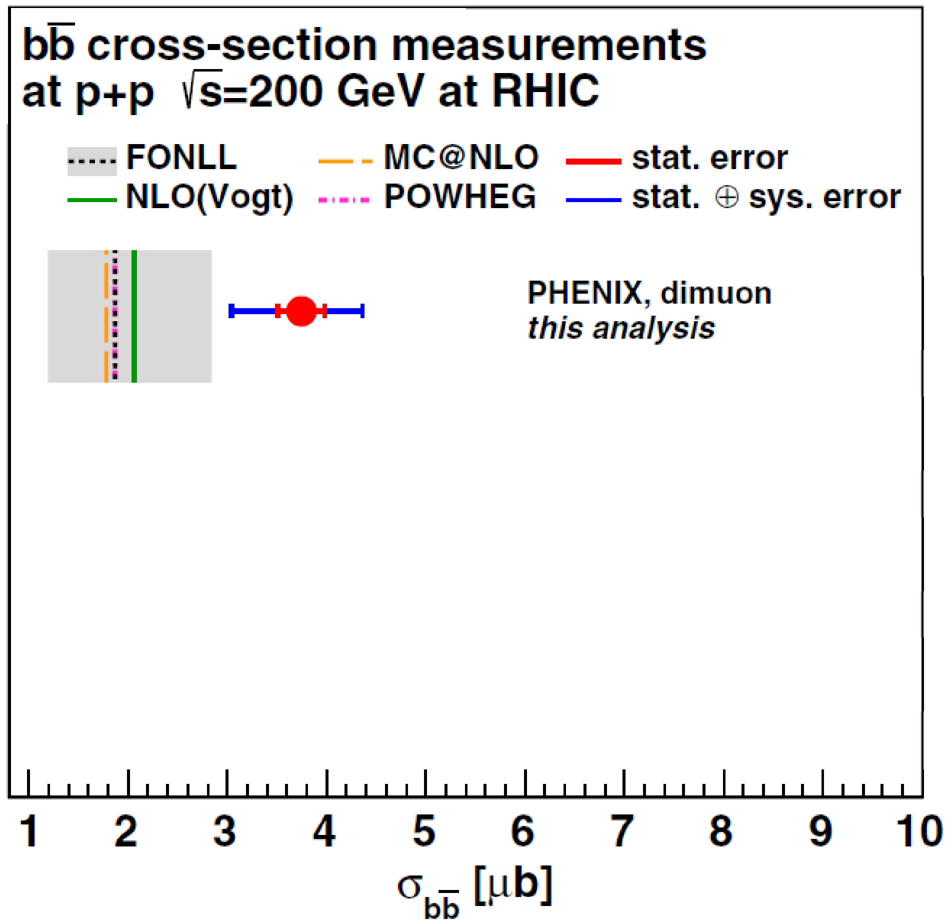

$b\bar{b}$ cross section from like-sign dimuons

Using the like-sign dimuons a $b\bar{b}$ cross section was extracted

Consistent with previous PHENIX measurements

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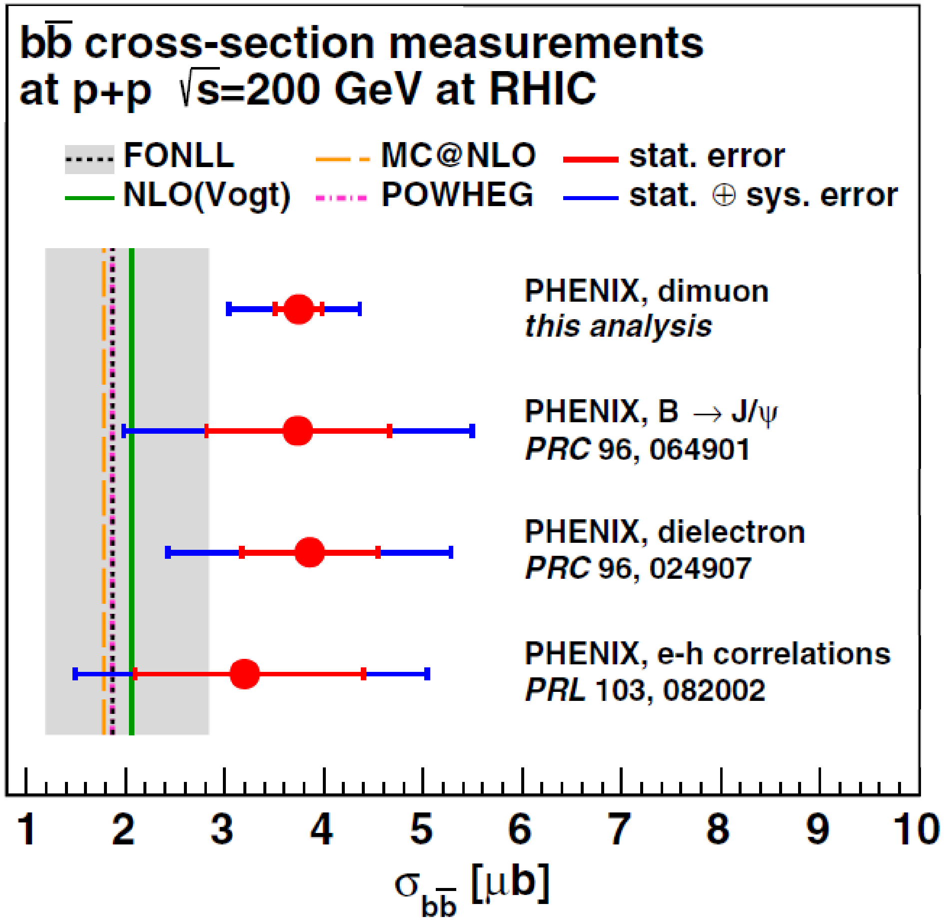

Rapidity dependence of $\sigma_{b\bar{b}}$

Measured $\sigma_{b\bar{b}}$ deviates from the central FONLL prediction by about a factor of 2

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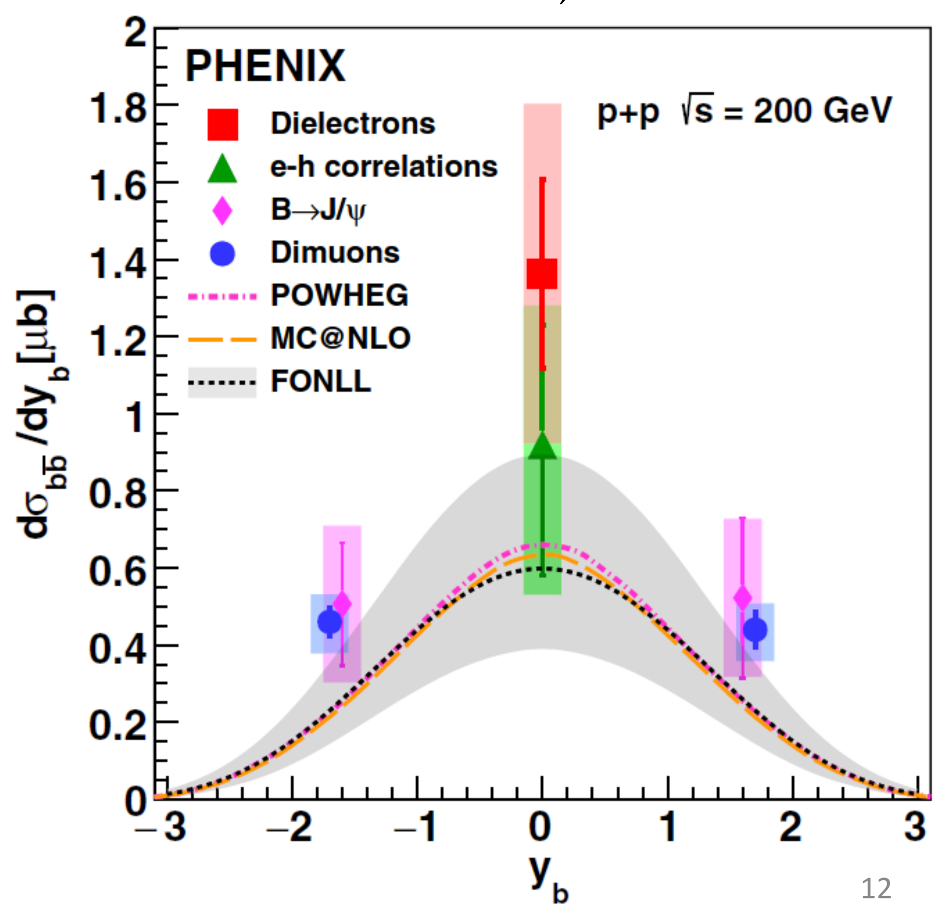
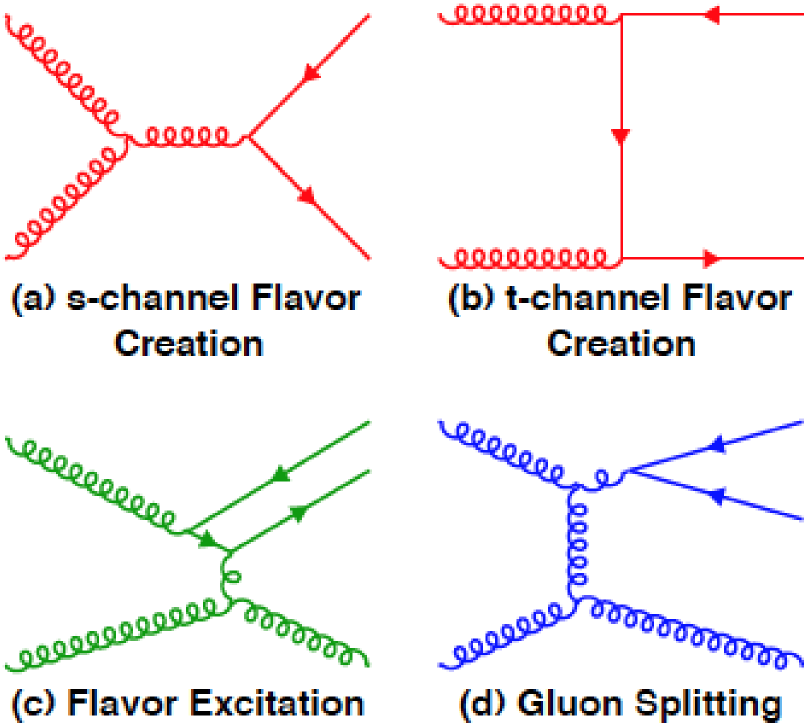
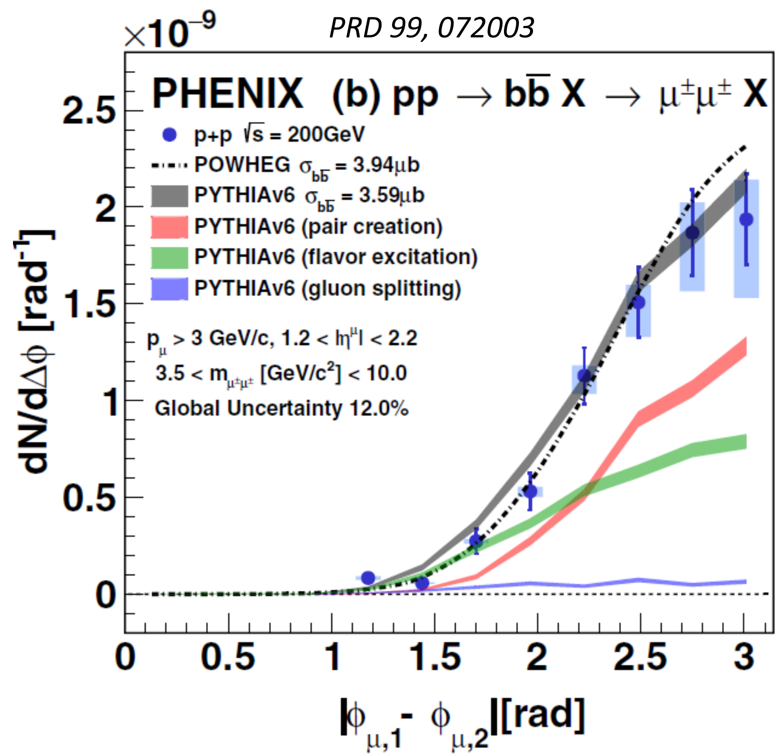


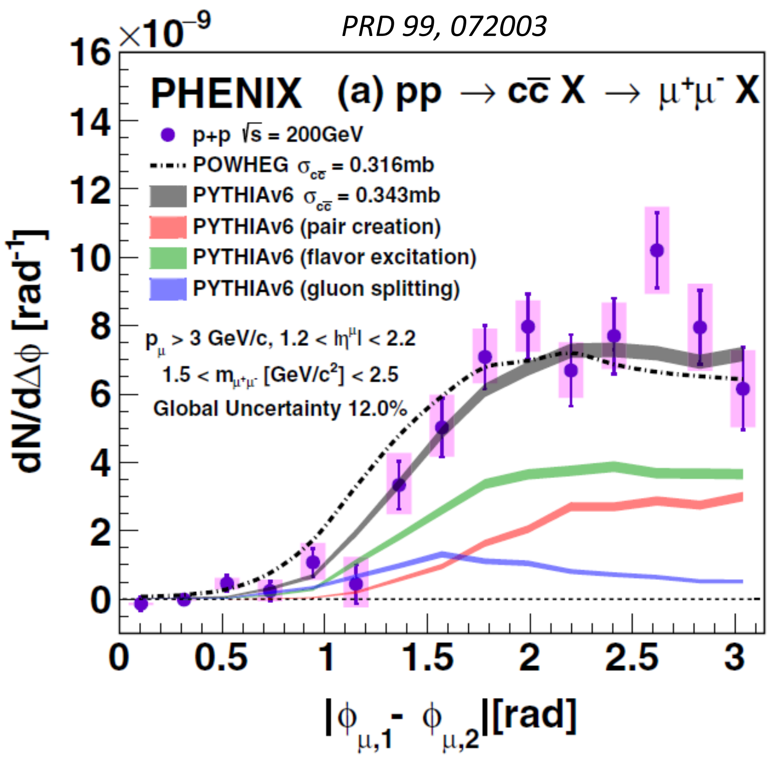
Heavy Flavor Azimuthal Correlations

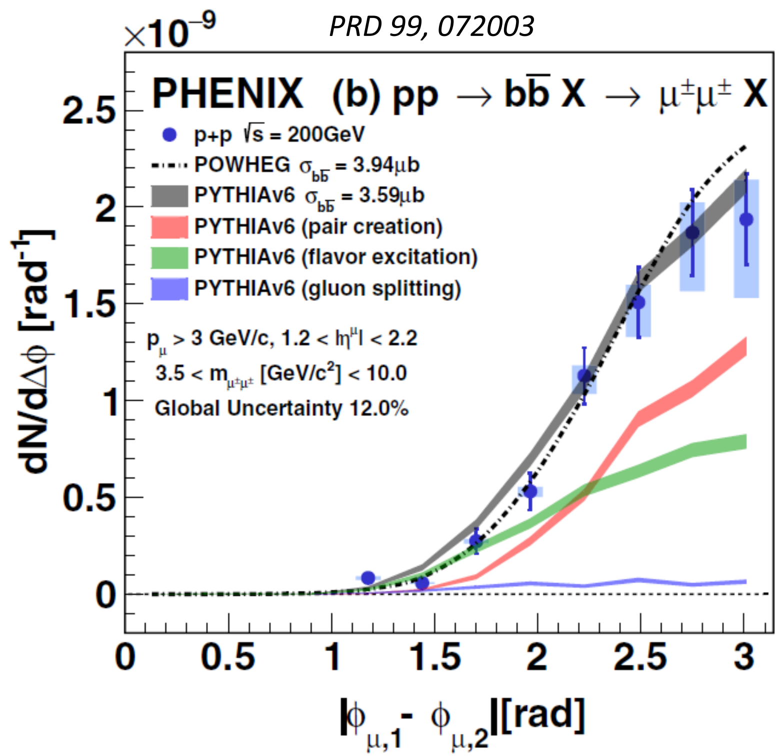




Contribution to $b\bar{b}$ production from gluon splitting at $\sqrt{s} = 200$ GeV is negligible at RHIC

Heavy Flavor Azimuthal Correlations





Heavy Flavor at $\sqrt{s} = 200$ GeV are produced by pair creation and flavor excitation

At LHC, gluon splitting dominates the heavy flavor production

Separating HF electrons in PHENIX

Charm and bottom have different, non zero life times

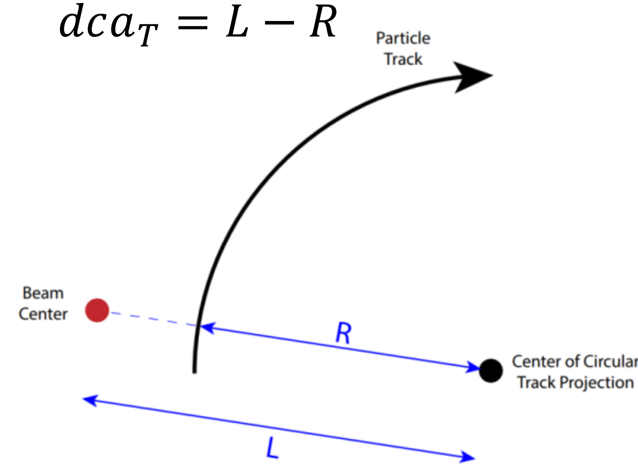
- $B^{\pm}c\tau = 491\ \mu m$
- $D^{\pm}c\tau = 312\ \mu m$

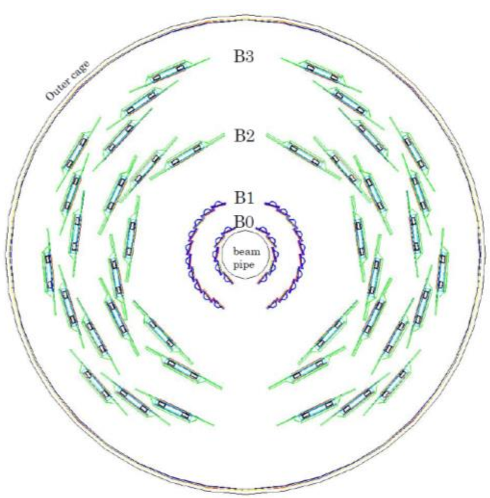
PHENIX cannot measure displaced vertexes directly.

- Using VTX can measure dca_T of electron tracks

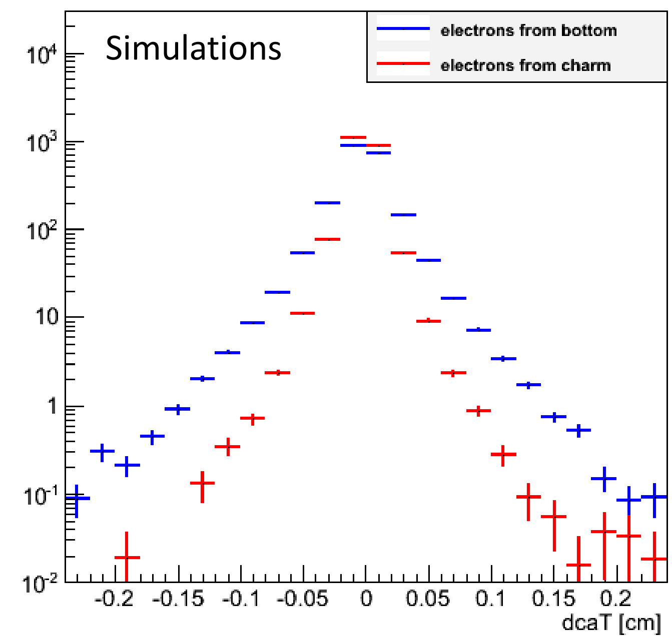
dca_T shape of bottom and charm electrons different

$$dca_T = L - R$$



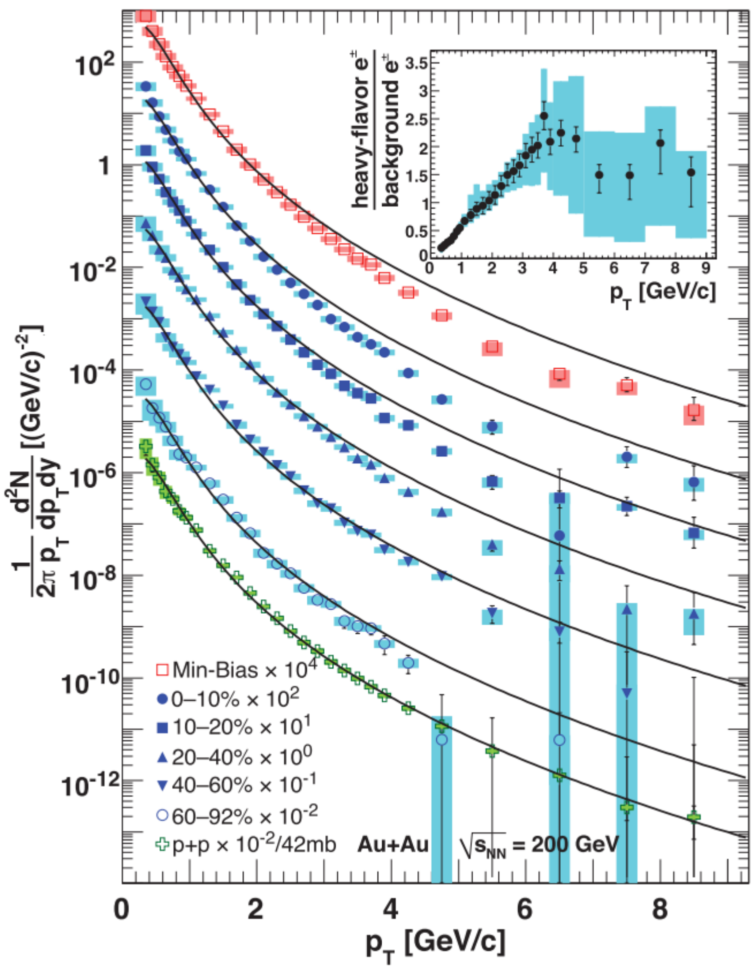


VTX: Measure track dca_T with ~100 μm resolution

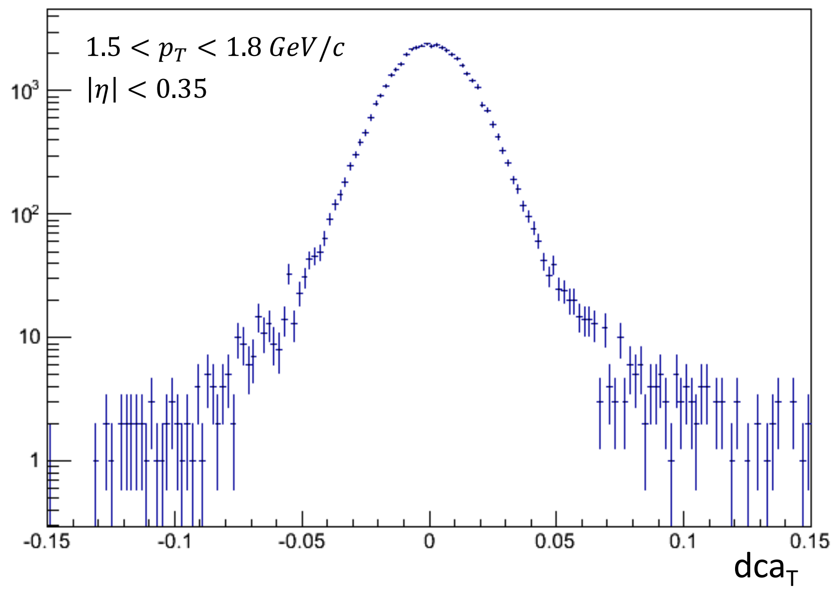


Analysis Strategy

Phys. Rev. C 84, 044905 (2011)



Bayesian unfolding technique simultaneously takes into account inclusive heavy flavor differential cross sections and measured electron dca_T distributions to extract parent charm and bottom hadron yields



Sources of Background

Photonic Electrons: π^0, η, direct γ

Shape determined using M.C.

Non-Photonic Electrons: j/ψ, *ke3*

Shape determined using M.C.

Hadron Contamination:

Shape from hadrons in data

High Multiplicity Background:

Not relevant in p+p, but affects Au+Au.

Bayesian unfolding extracts b and c after fixing the background contributions

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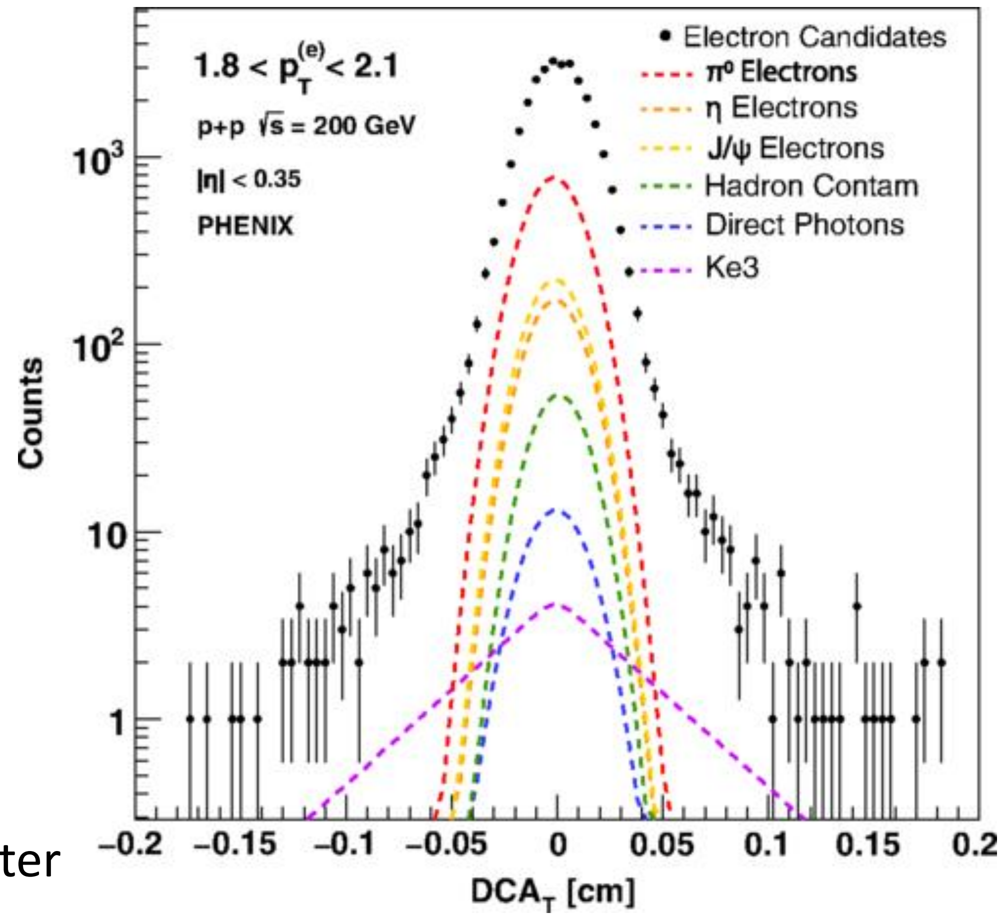

H.F. Hadron Differential Cross-Section

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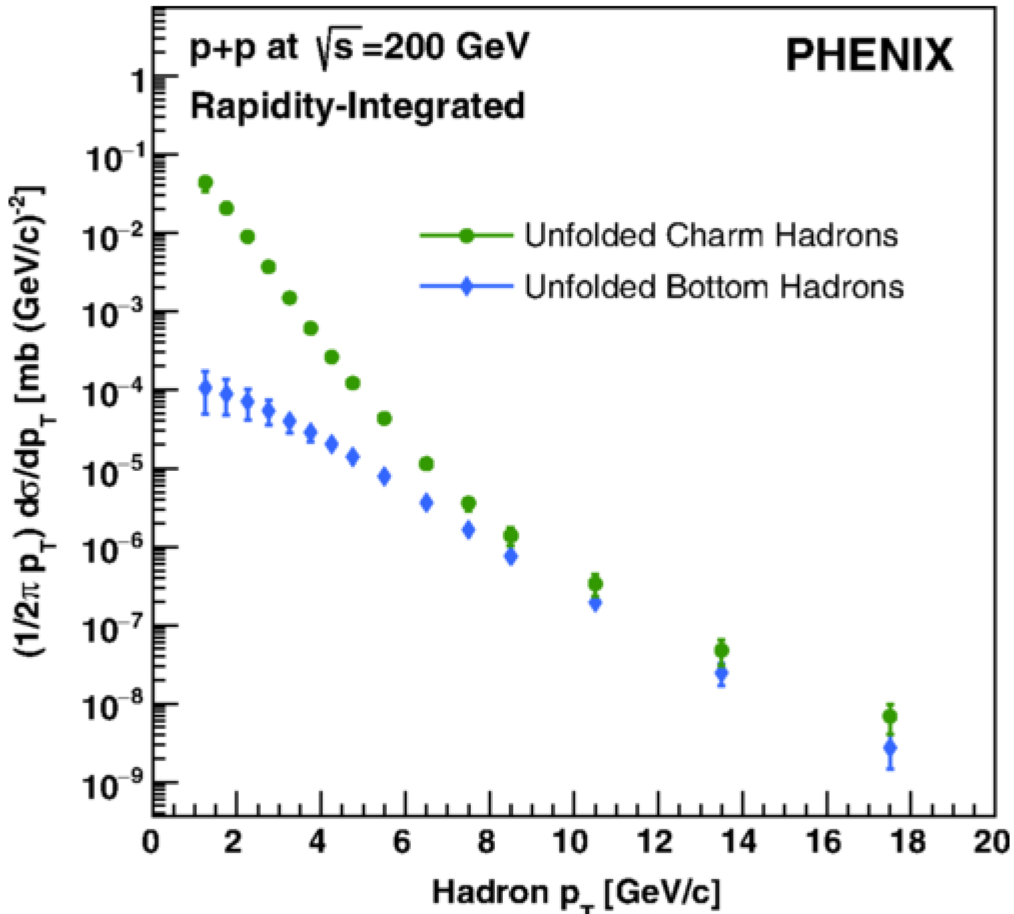


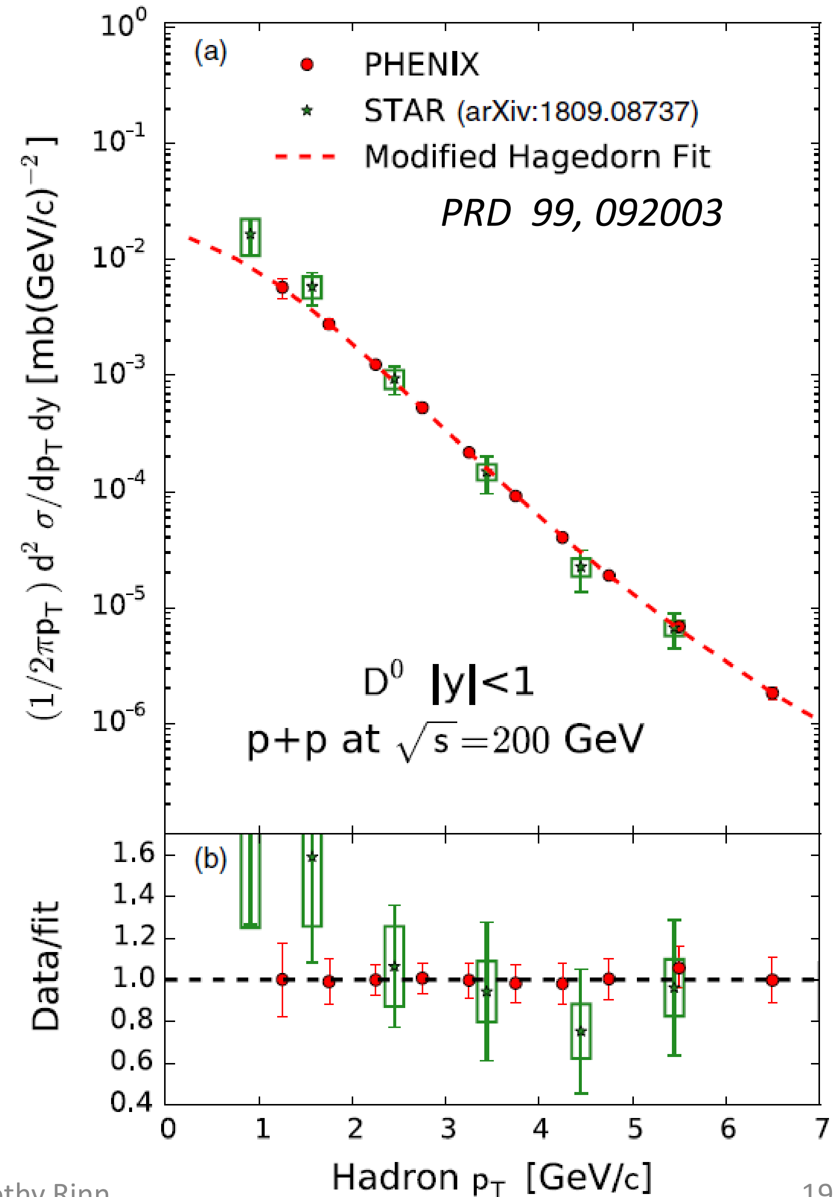
Rapidity integrated heavy flavor hadron differential cross sections were extracted using the unfolding

This result is model dependent, as it assumes the PYTHIA modeling of decay probabilities and rapidity distributions

D^0 Cross-Section Measurement

Using a pythia model combined with the unfolding result extracted D^0 yield for |y| < 1

Good agreement with STAR over comparable momentum range



Heavy Flavor Electron $\frac{d^2\sigma}{dp_T dy}$ p+p

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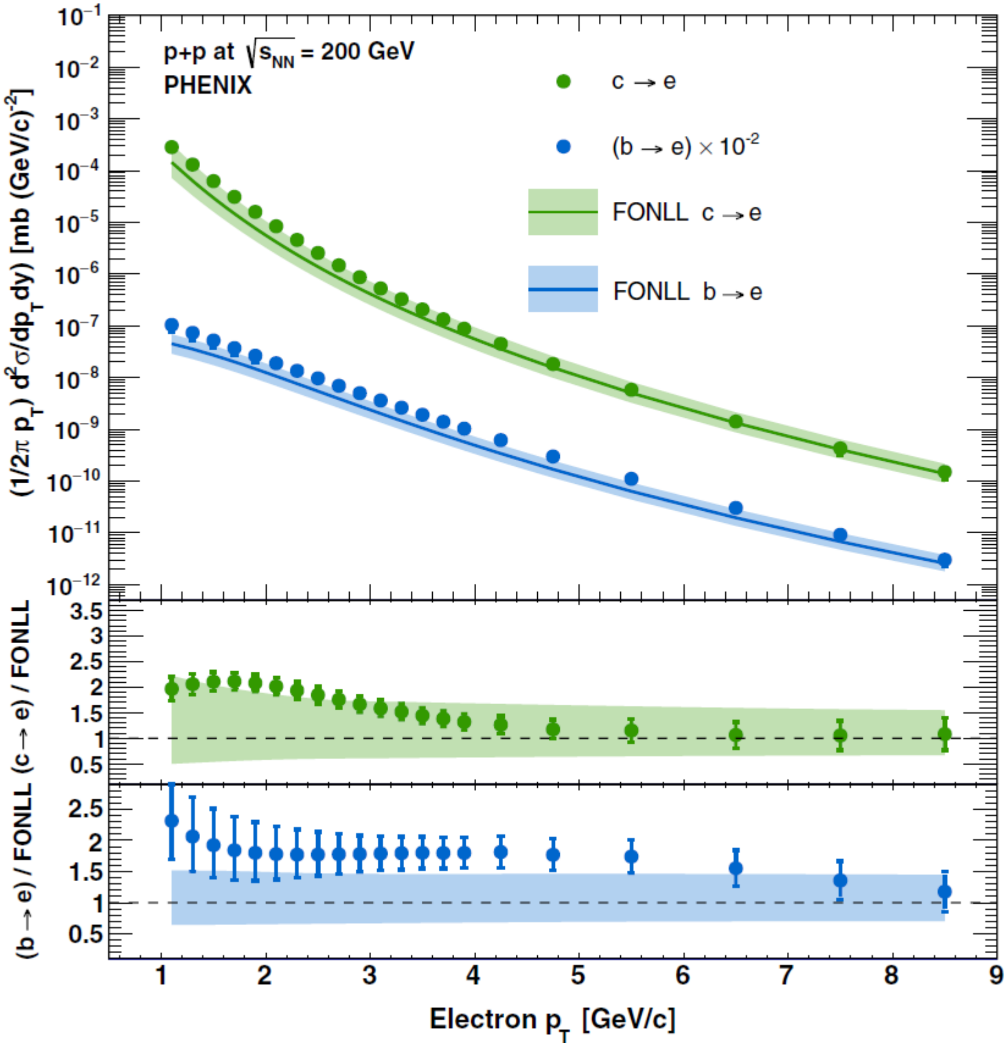

The extracted heavy flavor electron differential cross section systematically above the central FONLL prediction

Systematic Uncertainties

5 considered sources of uncertainty.

- Intrinsic uncertainty in the unfolding procedure
- Uncertainty to the prior
- Uncertainty due to the regularization parameter
- Uncertainty of the inclusive HF yield
- Uncertainty in the background cocktail

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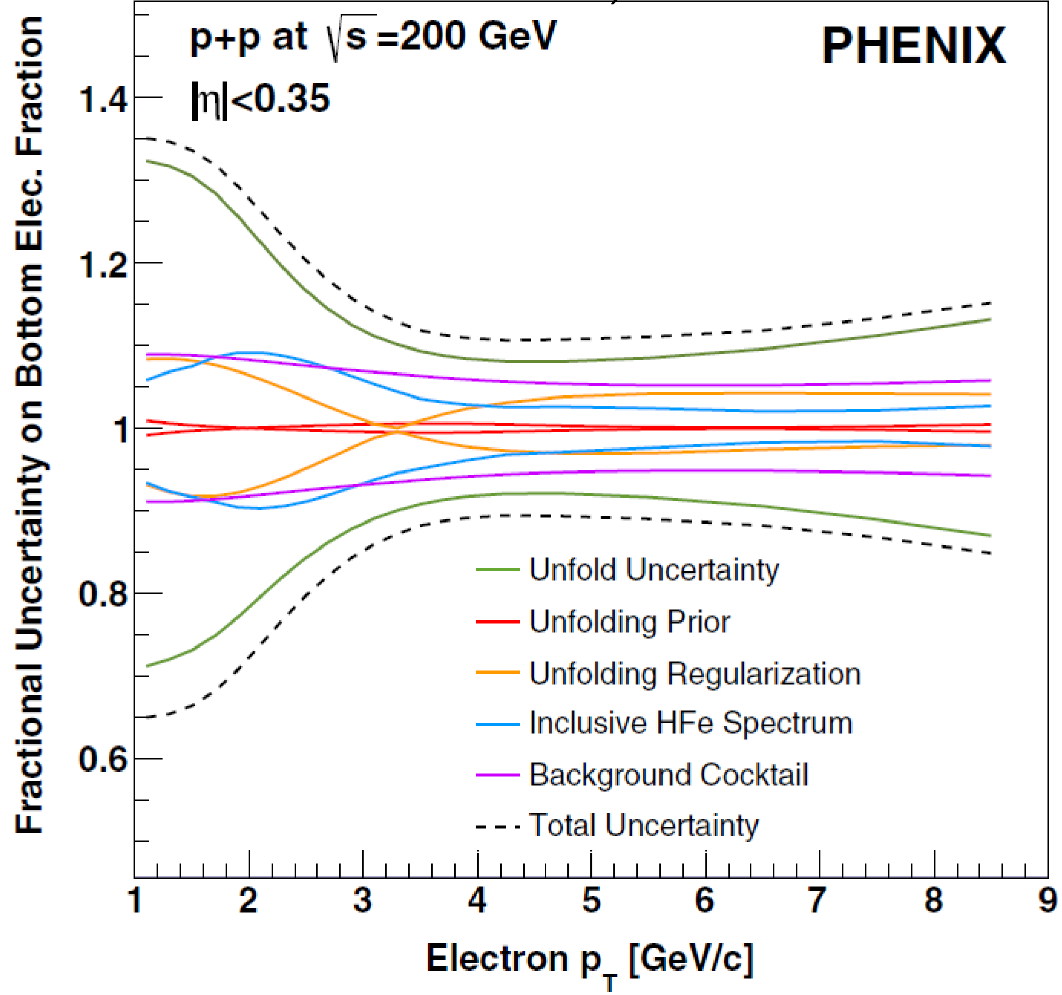

2015 p+p Bottom Electron Fraction

Extract continuous b-fraction result between 1 and 9 GeV

FONLL predictions are consistent with measurement

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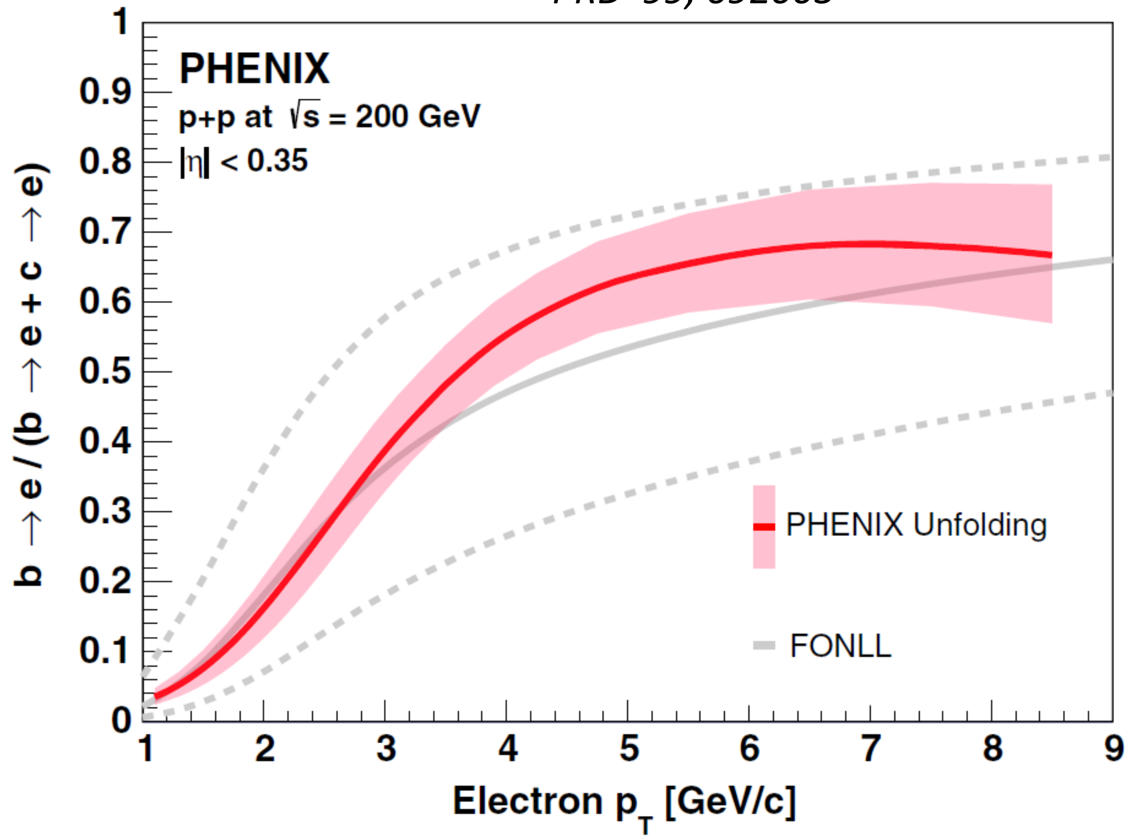

2015 p+p Bottom Electron Fraction

Extract continuous b-fraction result between 1 and 9 GeV

FONLL predictions are consistent with measurement

Observe consistency with previously published PHENIX measurements

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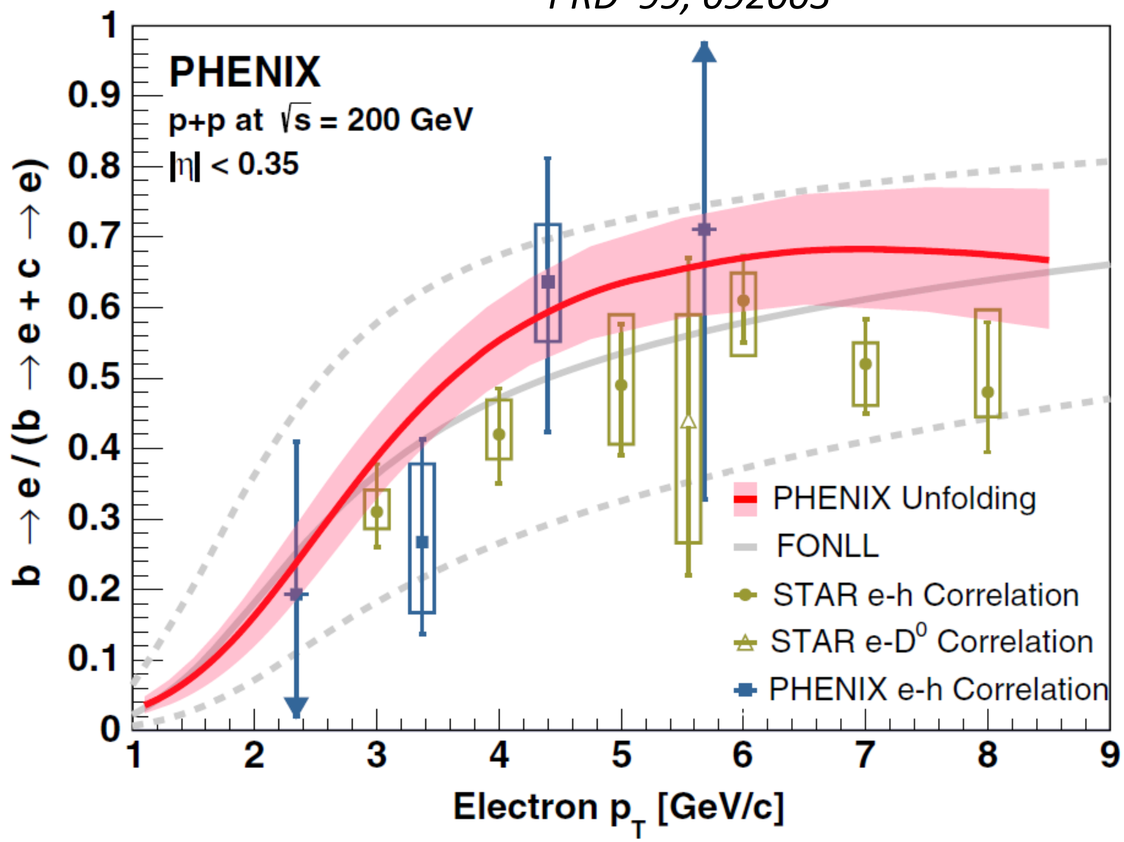
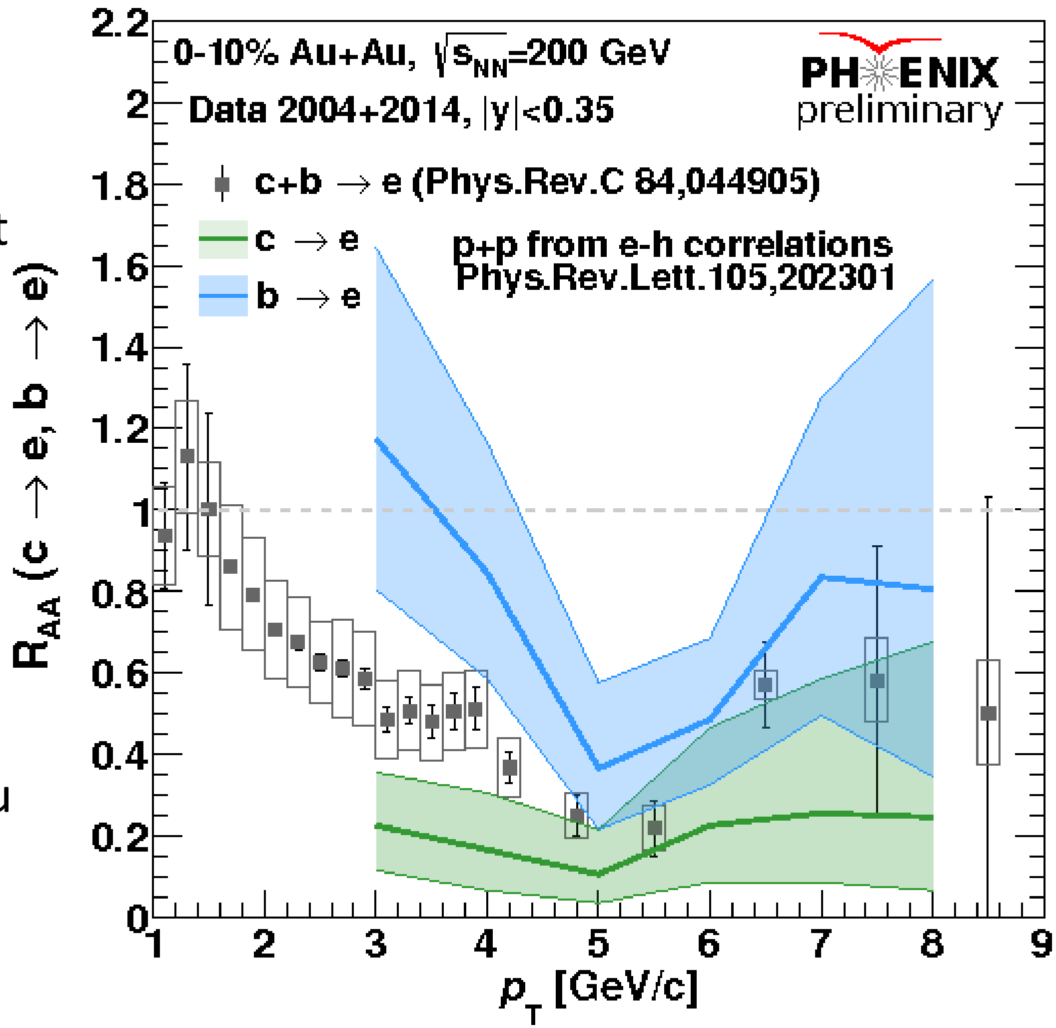


2014 Preliminary R_{AA} Central

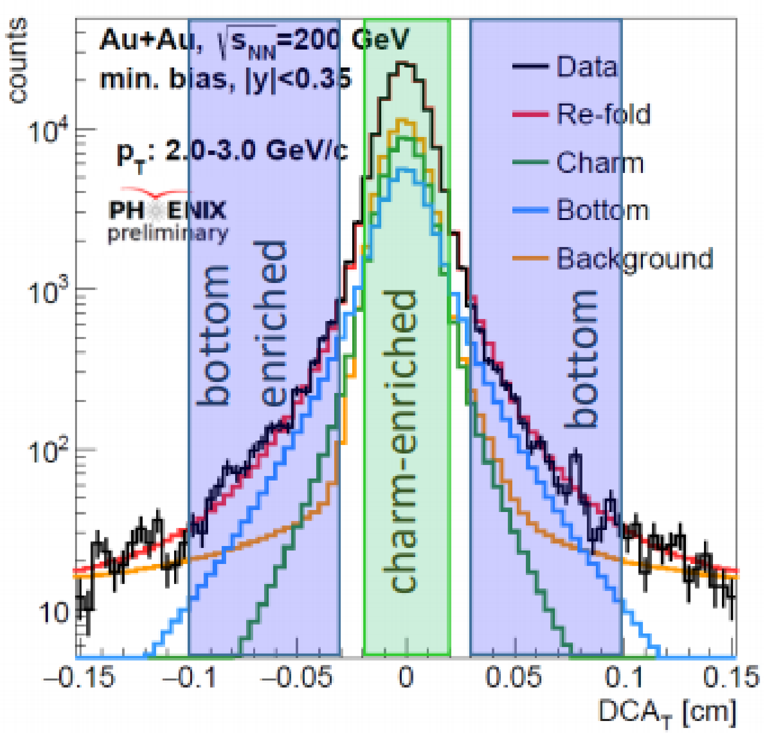
Preliminary R_{AA} calculated using STAR e-h correlation measurement as p+p reference

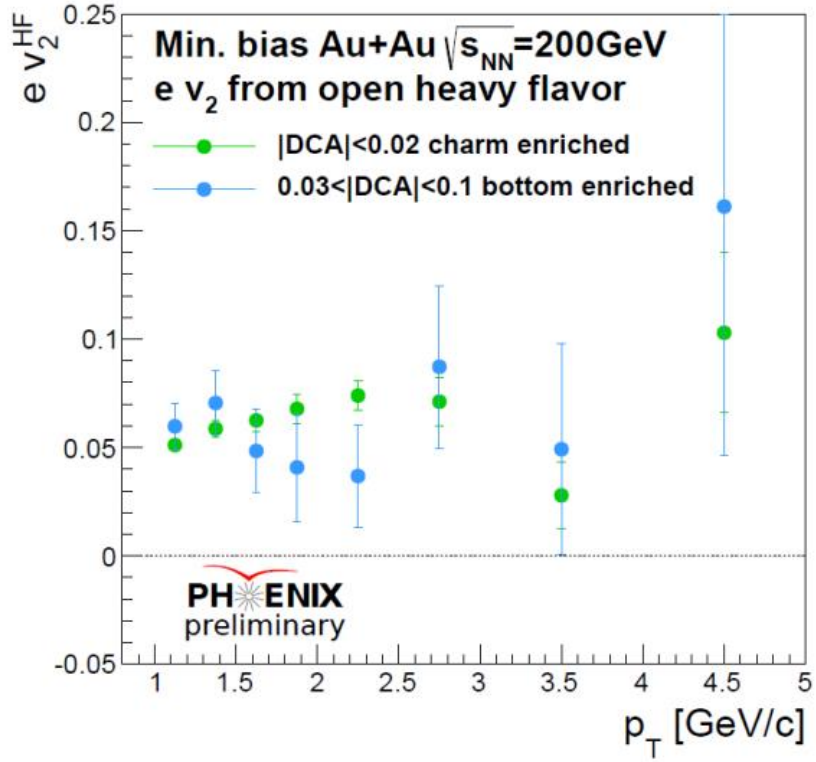
Observe suppression of charm relative to bottom at ~3 GeV/c

For publication result will be updated using the new p+p baseline as well as full 2014 Au+Au data set



Extracting Heavy Flavor v_2

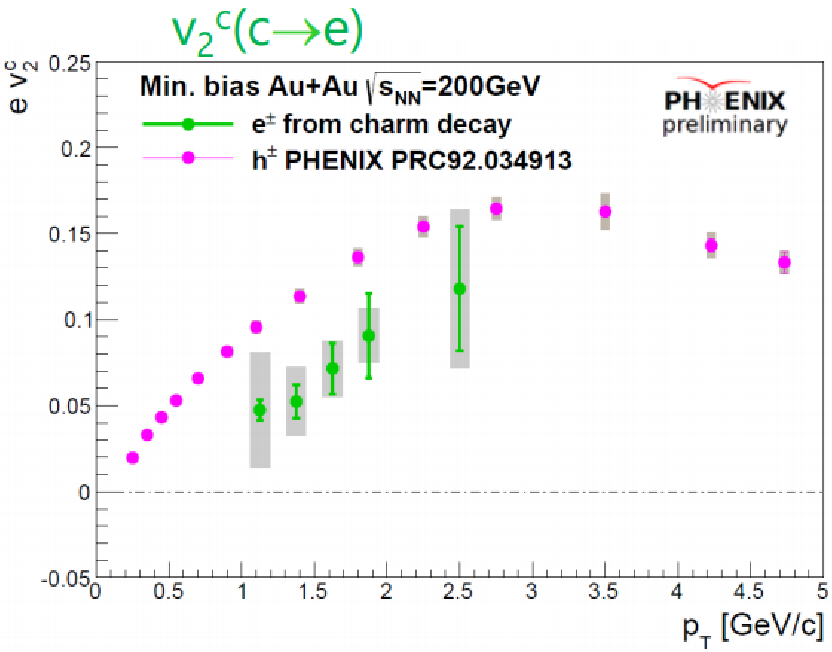


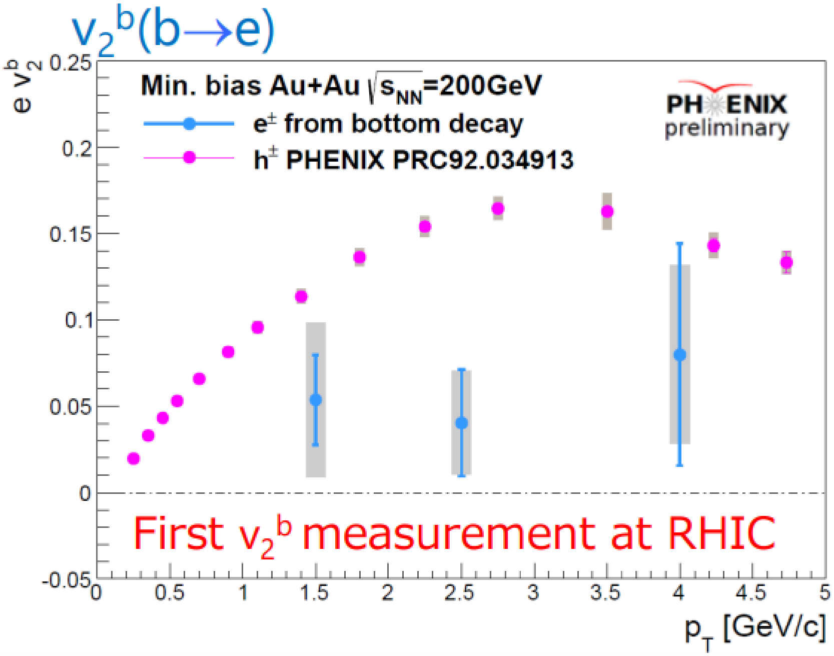


Measured the v_2 of the charm and bottom enriched regions of the electron dca_T distribution

Can solve system of equations to extract separated bottom and charm electron v_2

Bottom and Charm electron v_2





Observe significant non-zero charm electron v_2 though notably reduced compared to charged hadrons

Observe an indication for non-zero bottom electron v_2

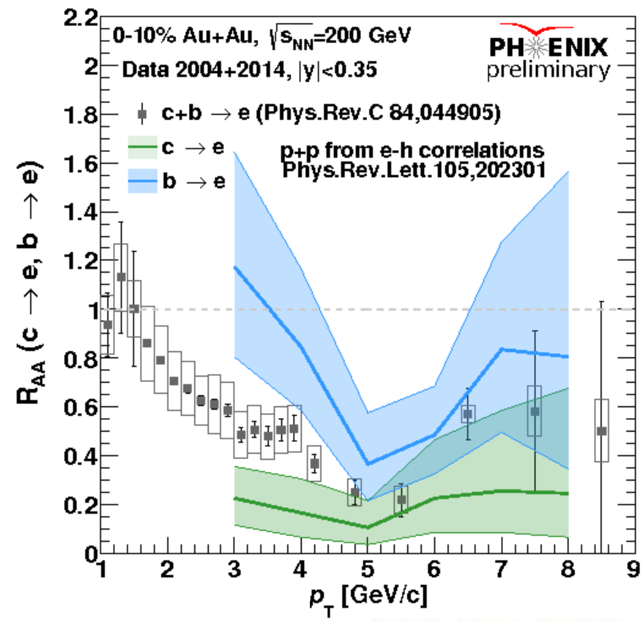
Summary

- p+p
  - Measured $\sigma_{b\bar{b}}$ factor of 2 higher than central FONLL calculation
  - Azimuthal correlation measurement of dimuons from HF is well described by PYTHIA
  - Differential cross section of heavy flavor electrons systematically higher than central FONLL predictions
  - Bottom electron fraction consistent with FONLL predictions
- Au+Au:
  - b->e are observed to be less suppressed than c->e at 3 GeV/c in 0-10% central events.
  - Observed non zero v_2 for electrons from charm and first measurements of v_2 for electrons from bottom at RHIC

But that is not all!

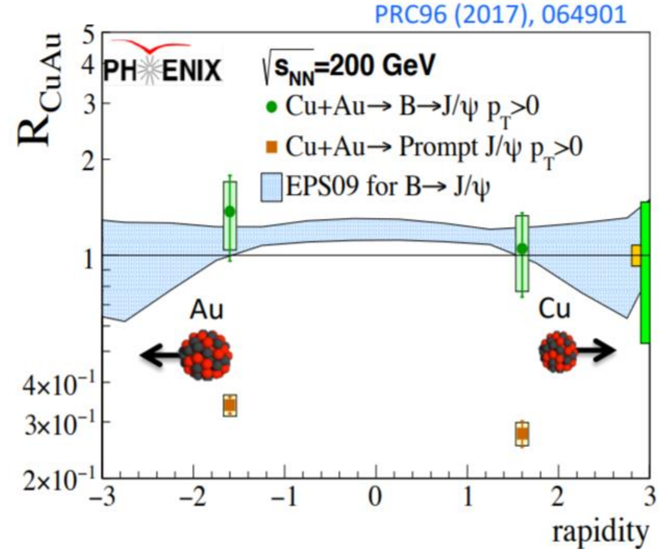
Outlook for the Near Future

- Finalized bottom and charm R_{AA} utilizing the full 2014 Au+Au data set combined with the 2015 p+p baseline measurement.



- $B \rightarrow J/\psi$ measurements utilizing the large 2014 Au+Au data set

PRC96 (2017), 064901



Backups

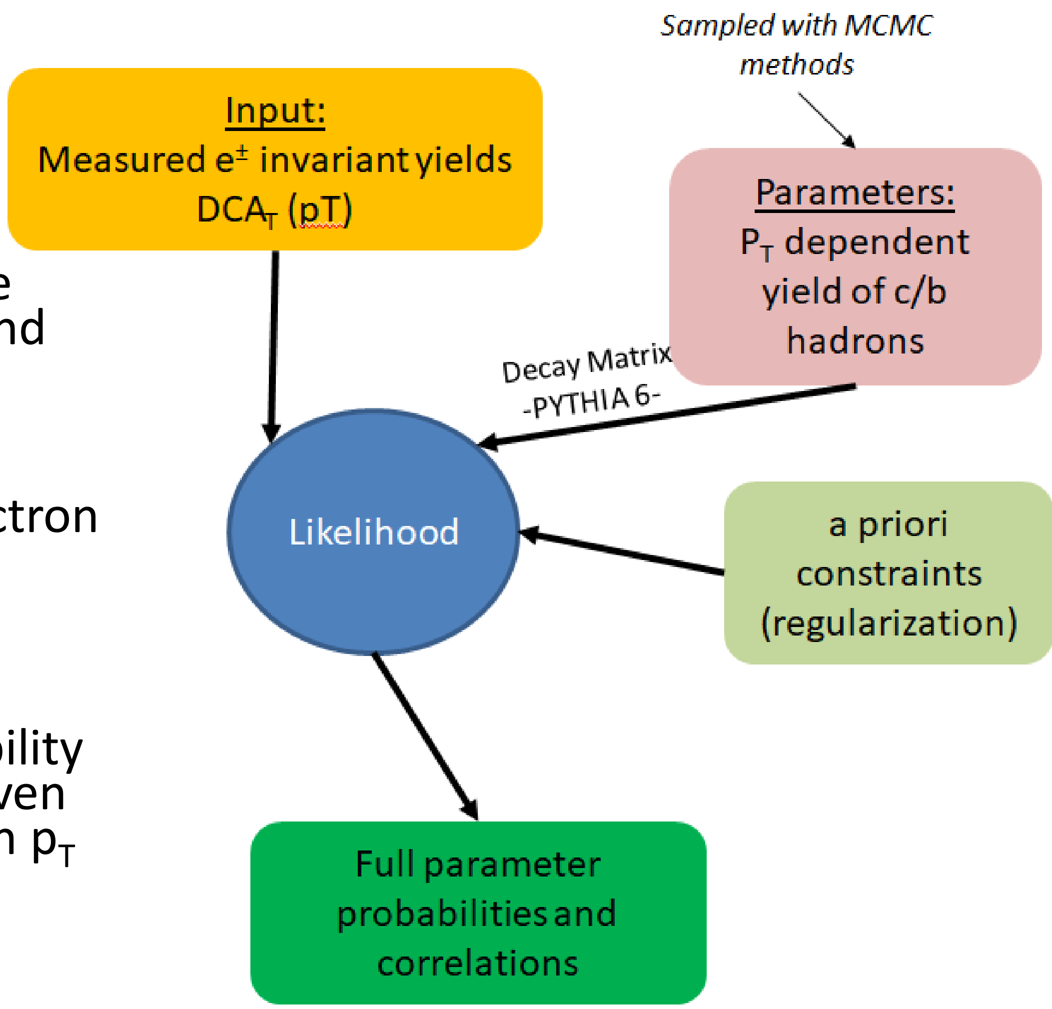
Unfolding

The unfolding uses Bayesian inference techniques to extract parent charm and bottom hadron p_T distributions

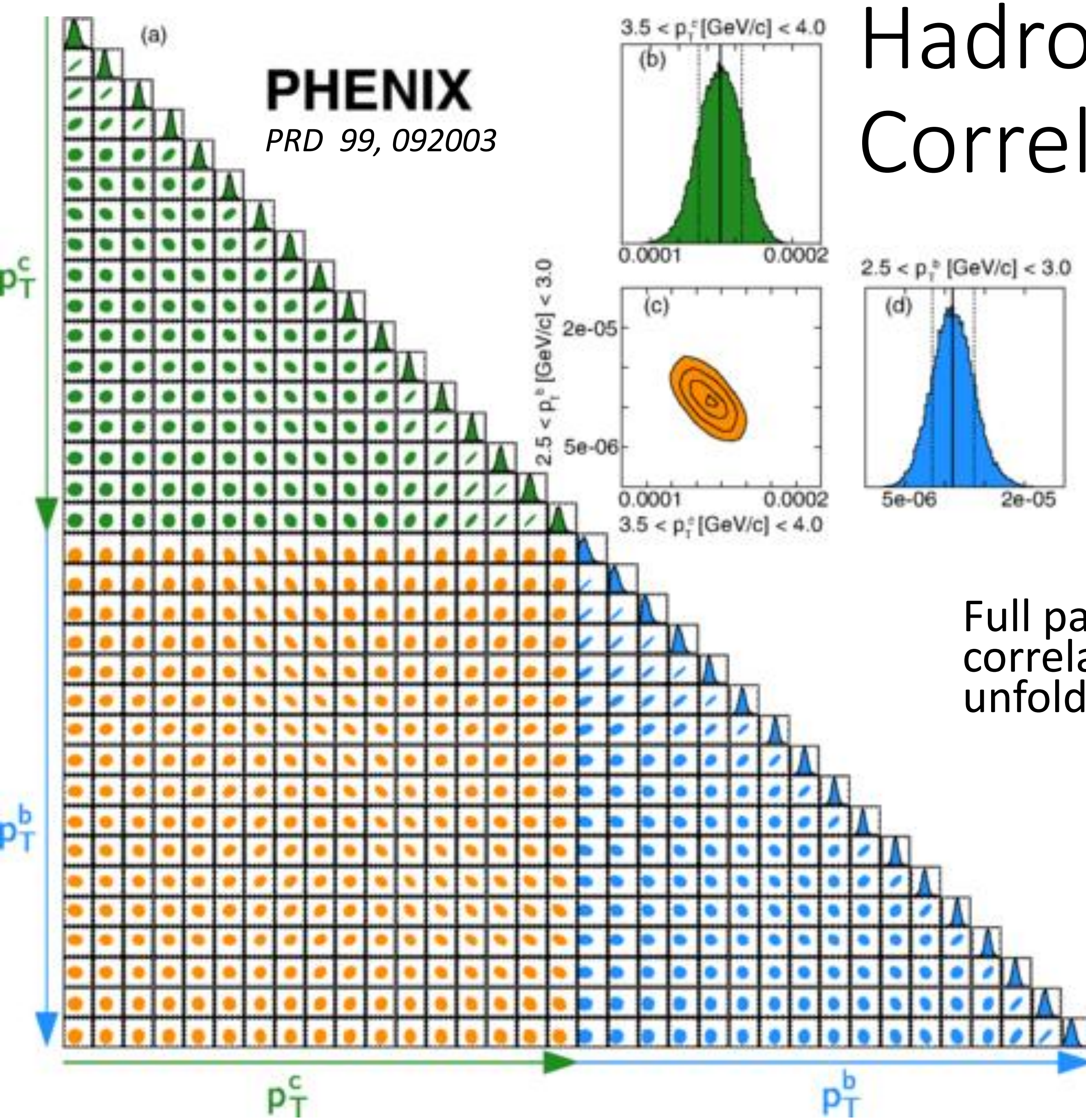
Done through simultaneous fit to electron invariant yield and electron DCA_T distributions

The decay matrix contains the probability of a bottom (charm) hadron with a given p_T to decay to an electron with a given p_T and DCA_T

- Bottom := $B^{\pm}$,B^0, B_s, Λ_b (Includes B->D->e)
- Charm := D^0, $D^{\pm}$, D_s, Λ_c
- Modeled h->e decays using PYTHIA-6



Hadron Correlations



Full parameter values and correlations from the unfolding procedure

dca_T Refold p+p: Low p_T

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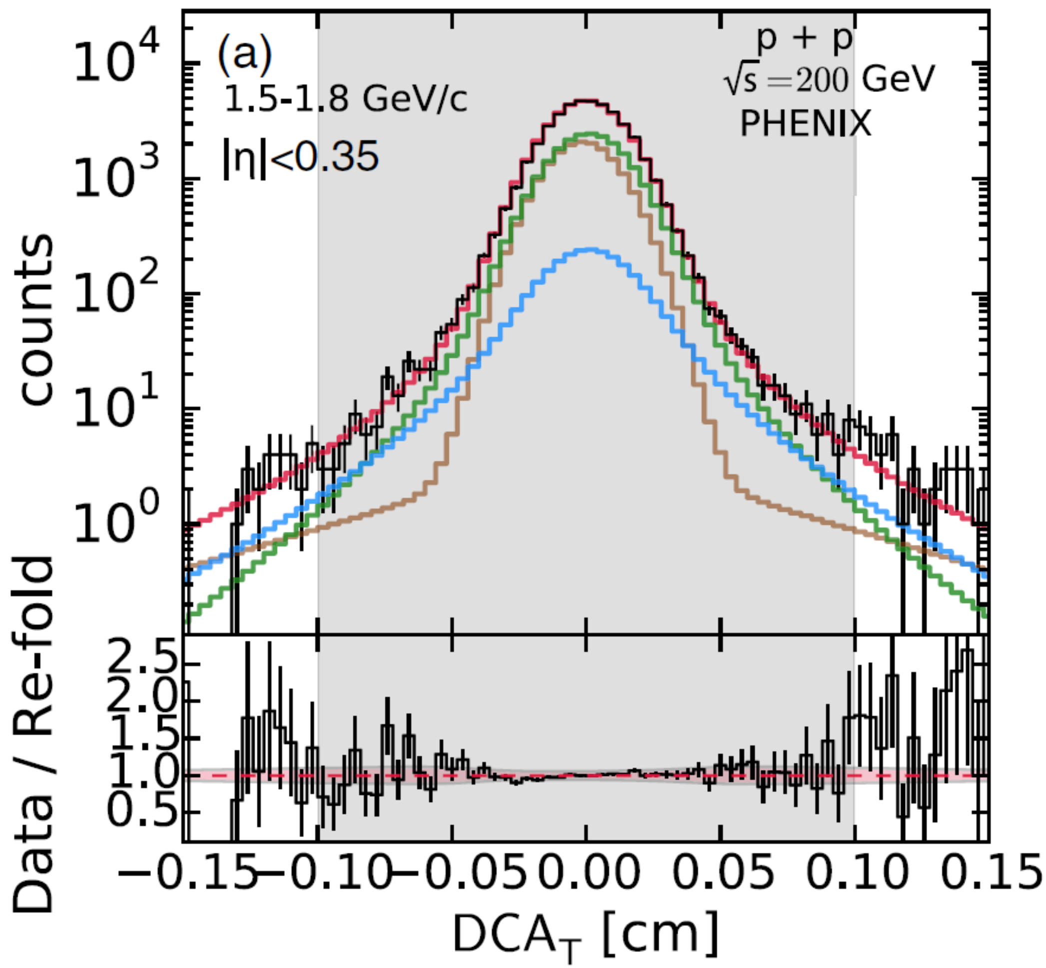
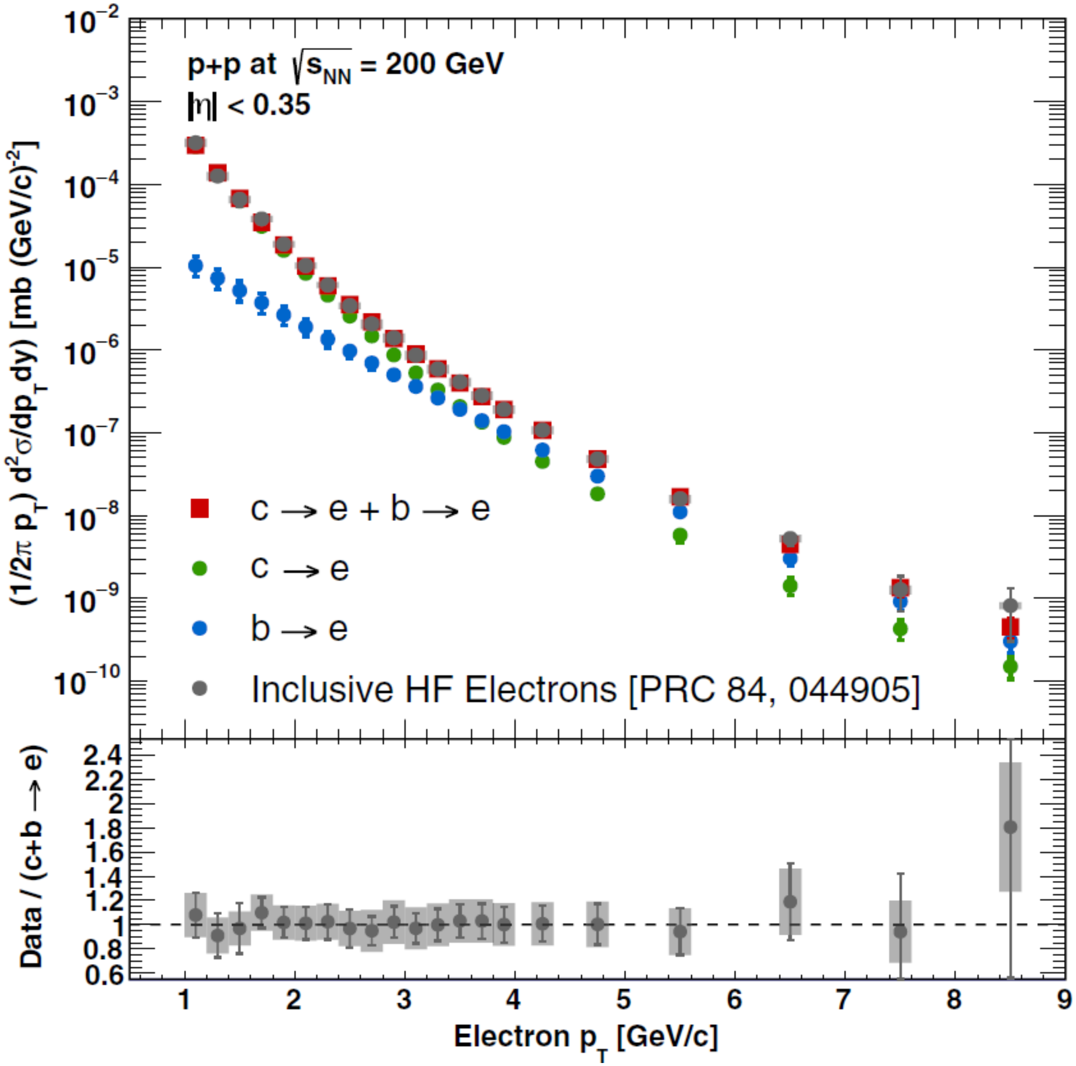


c->e:
Monte Carlo shape
Normalization from unfolding

b->e:
Monte Carlo shape
Normalization from unfolding

The charm and bottom yield predicted by the unfolding is consistent with electron measured DCA_T distributions.

Heavy Flavor Electron $\frac{d^2\sigma}{dp_T dy}$ Refold p+p



The bottom and charm electron yield measured using the unfolding agrees with the input inclusive differential cross section.

0-10% Central Au+Au b-Fraction

Parallel effort to do a similar analysis with the 2014 Au+Au data set

Observe agreement with theoretical models:

- Consistent with D(2πT) < 4, implies strong coupling in QGP
- Agreement with DGLV, contains both rad. + coll. energy loss in QGP