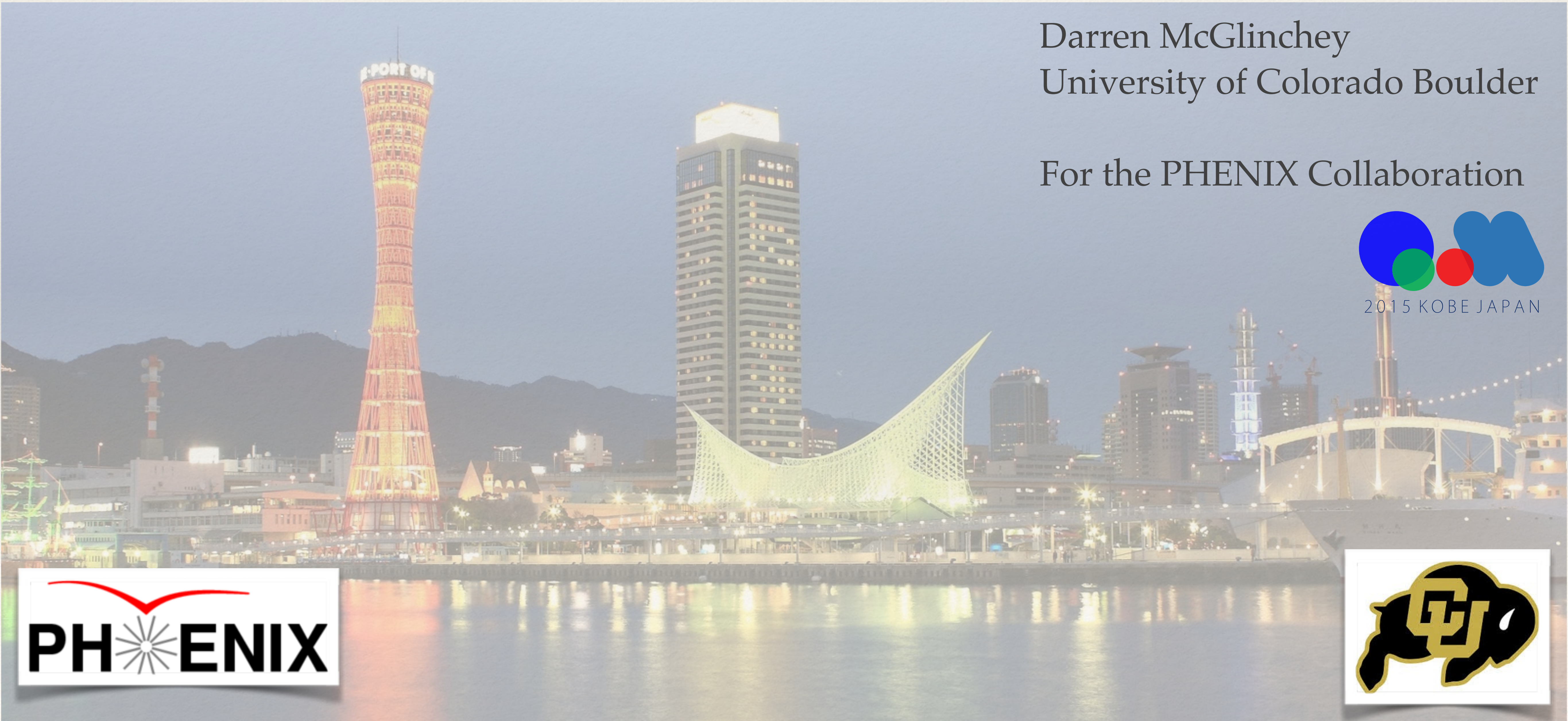
PHENIX measurement of single electrons from charm and bottom decays at midrapidity in Au+Au collisions

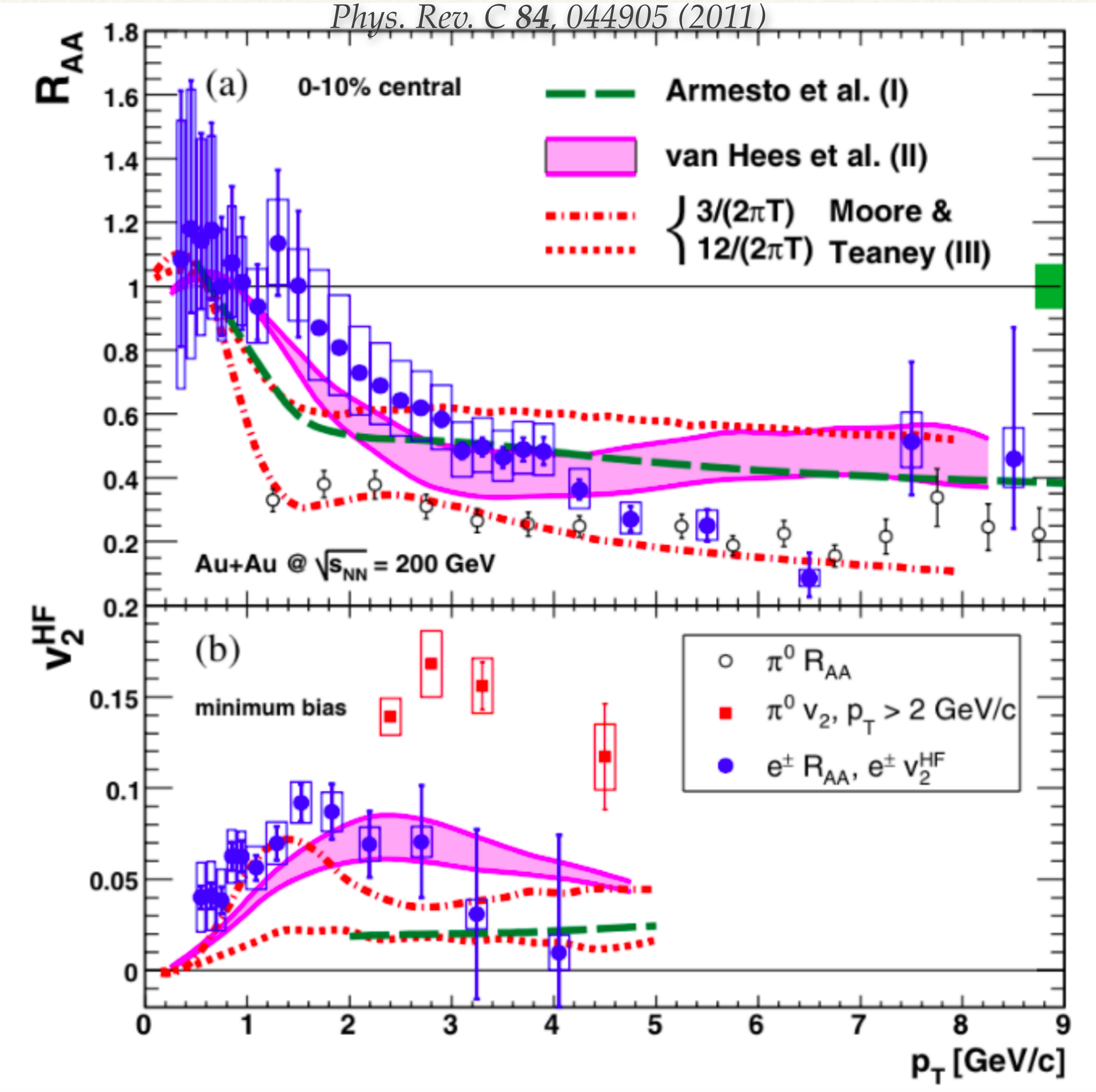


Darren McGlinchey
University of Colorado Boulder

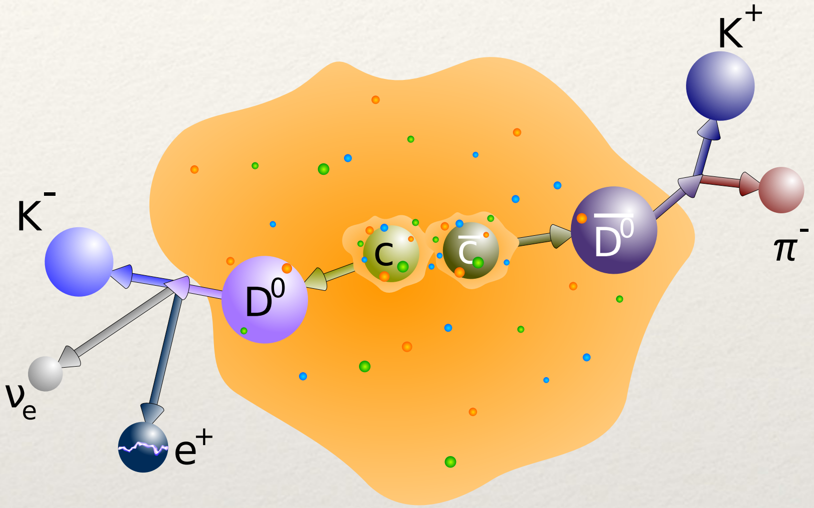
For the PHENIX Collaboration

2015 KOBE JAPAN

PHENIX Heavy Flavor Suppression


Phys. Rev. C **84**, 044905 (2011)

Single electrons from combined charm and bottom hadron decays strongly suppressed in **Au+Au**

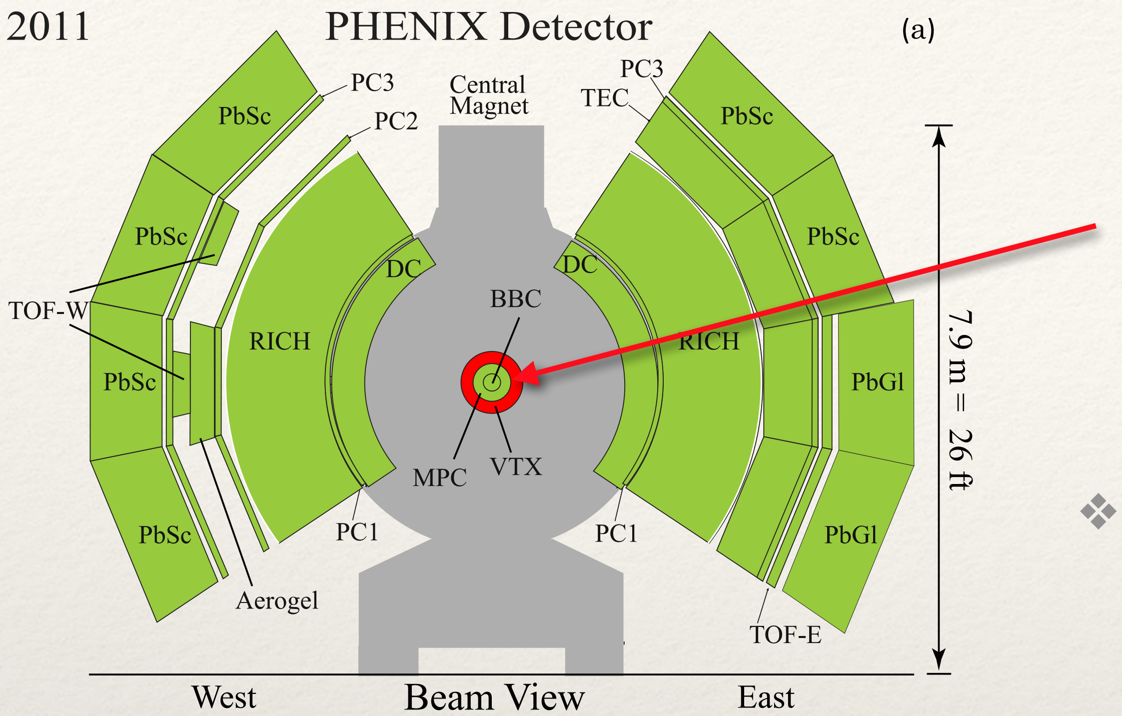


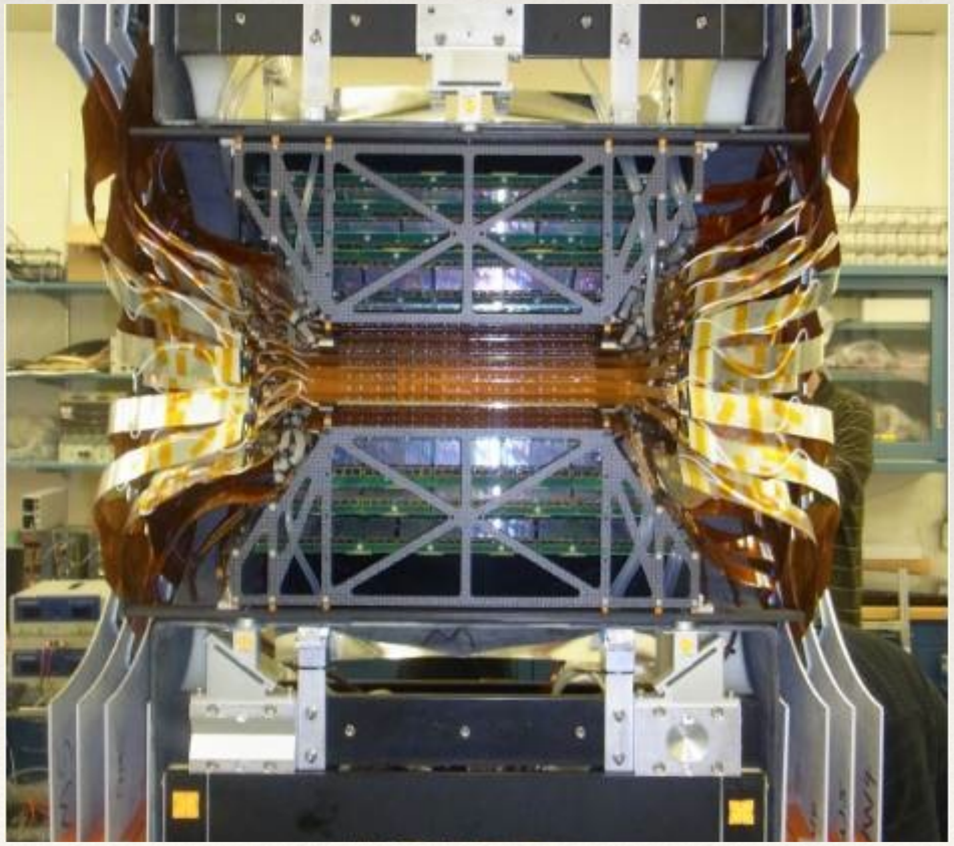
High-p_T expected to be dominated by bottom

Models expect less suppression than measured

Want to separate contribution from charm and bottom hadrons

PHENIX Silicon Vertex Detector (VTX)





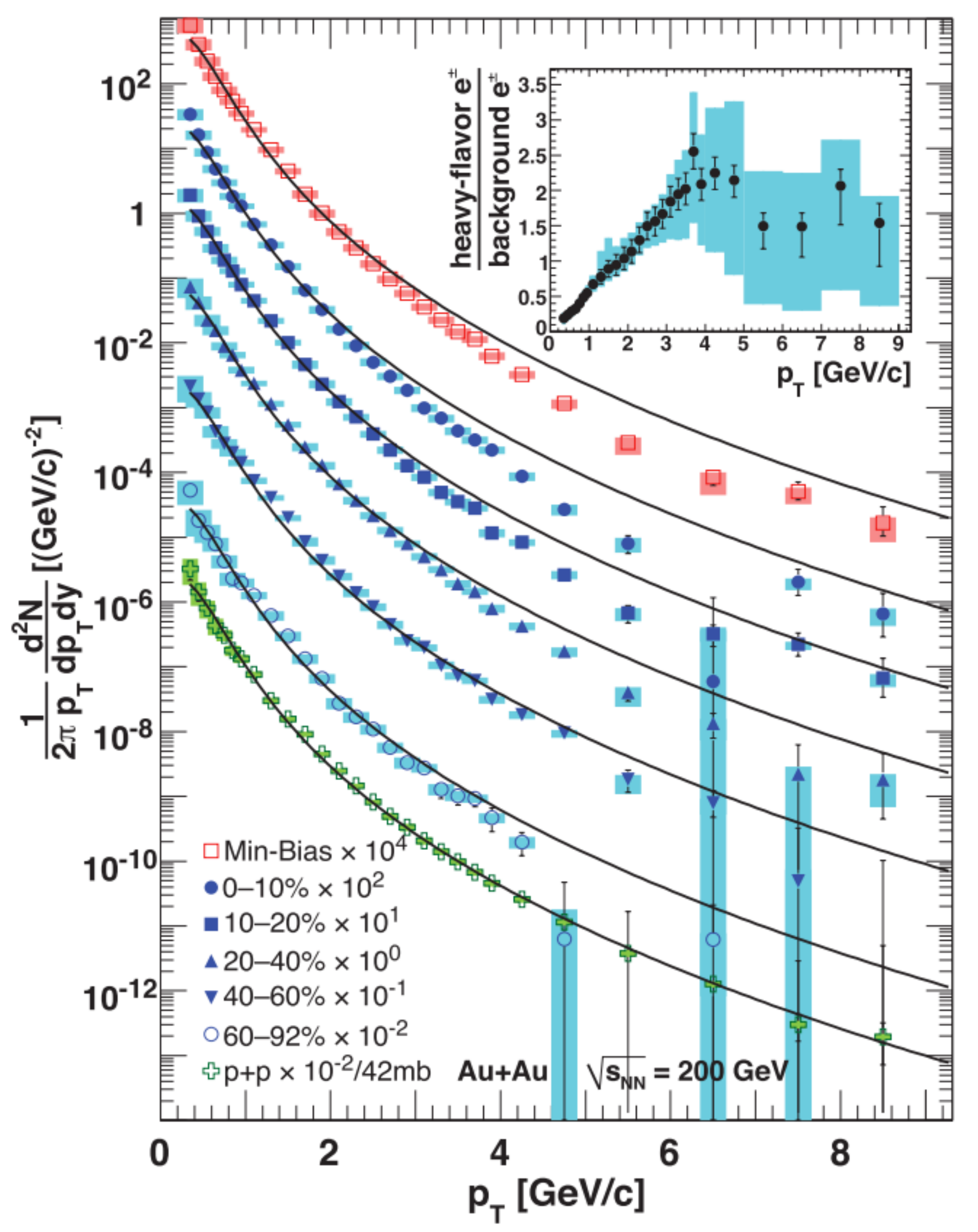
VTX installed in 2011 to measure precise displaced tracking

- 4 layers radially between 2.6 cm and 16.7 cm
  - Inner 2 layers composed of silicon pixels **$\sigma_{r\phi}=14.4\ \mu m$** resolution
  - Outer 2 layers composed of silicon strips, **$\sigma_{r\phi}=23\ \mu m$** resolution
- Reconstruct precise collision vertex as well as precise tracking

Analysis Strategy

- Use **published invariant yield** of single electrons from heavy flavor decays **$1.0 < p_T$ GeV/c < 9.0**
  - Higher p_T reach
  - Efficiency corrected (absolute normalization)
- Measure displaced tracking of electrons from **$1.5 < p_T < 5.0$**
  - Leverage differences in decay lifetimes
  - $B^{\pm}$ $c\tau = 491$ μm, $D^{\pm}$ $c\tau = 312$ μm
- Use Bayesian inference techniques (unfolding) to **simultaneously** take into account **both pieces**

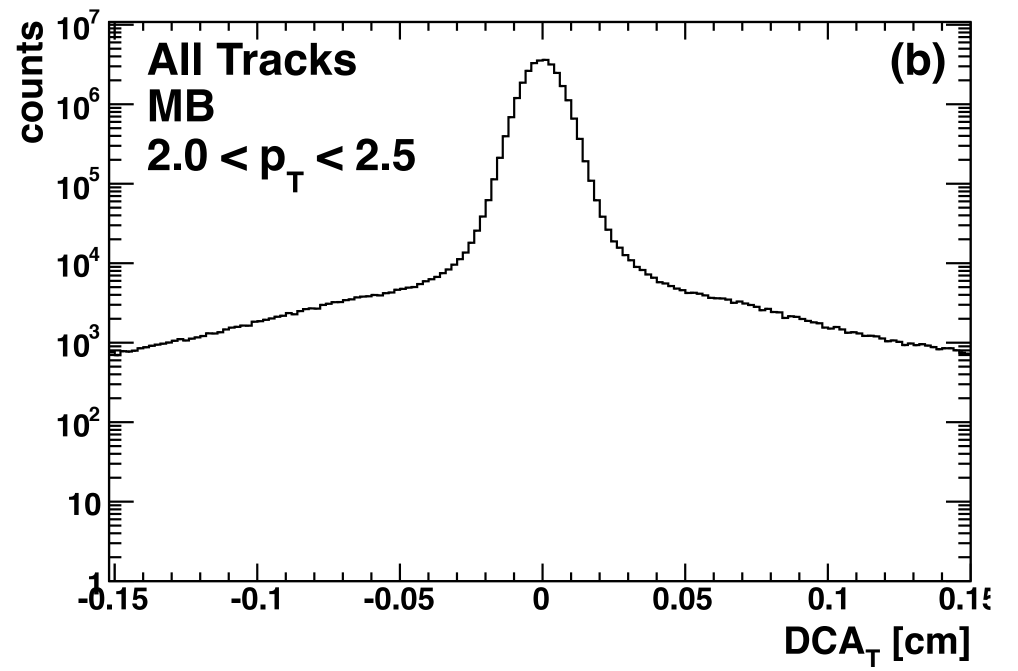
Phys. Rev. C ***84****, 044905 (2011)*



Measuring Displaced Tracking

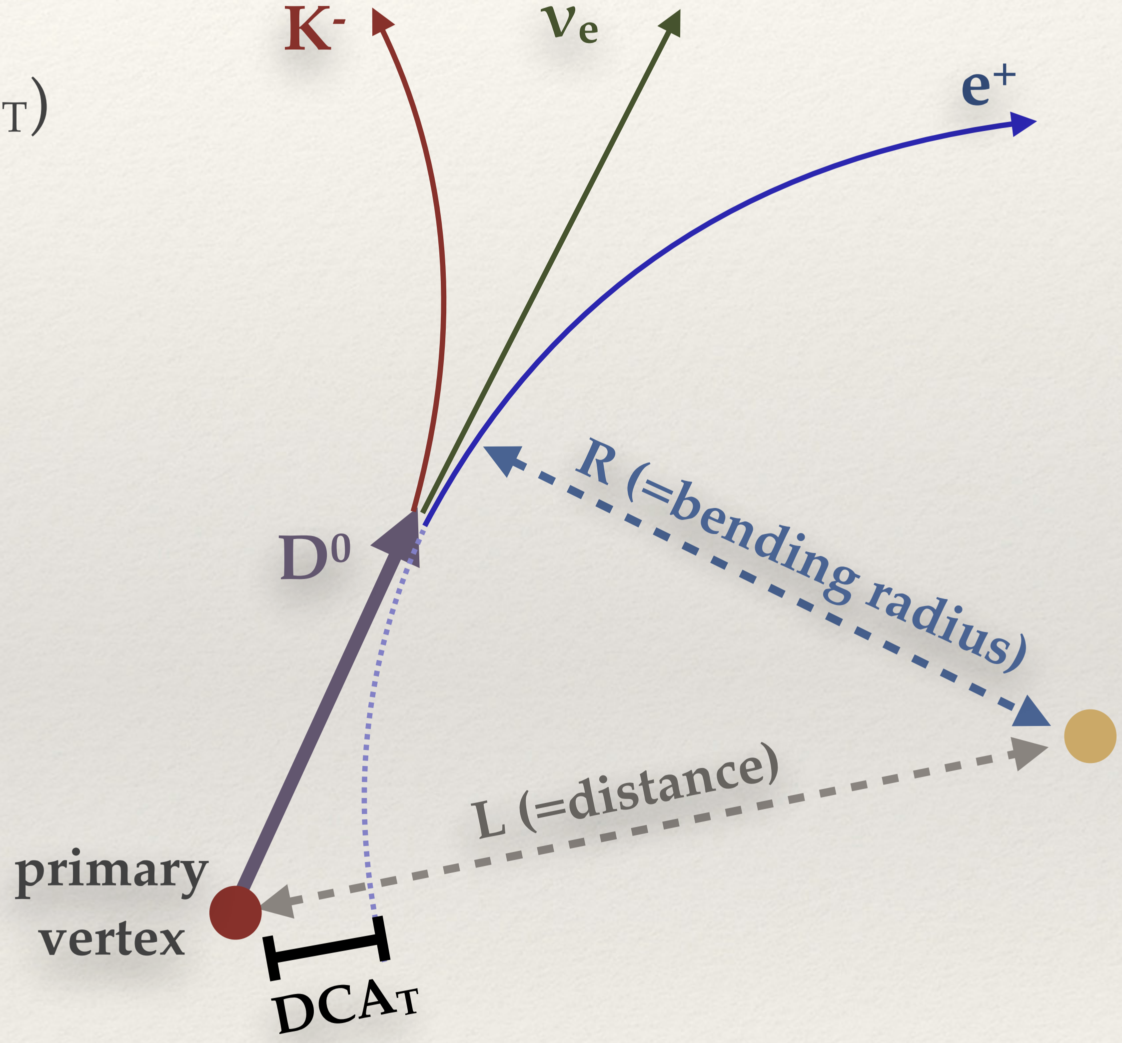
Calculate the Distance of Closest Approach (DCA) of a track to the collision vertex.

Calculated separately in transverse plane (DCA_T) and longitudinal plane (DCA_L)



DCA_T resolution ≈ 60 μm

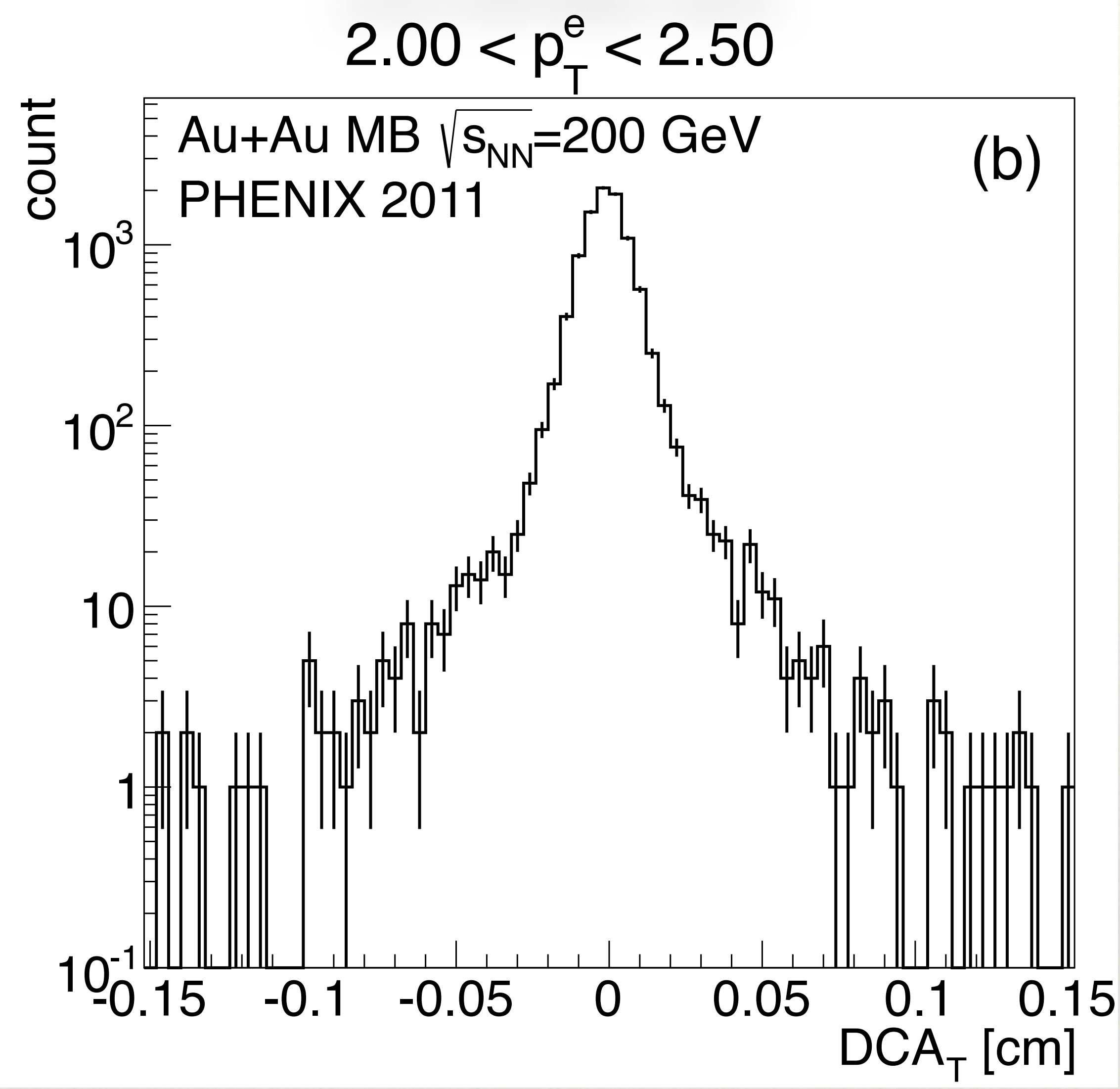
$DCA_T \equiv L - R$



DCA$_T$ Data

- Measure DCA$_T$ distribution of electrons from 2011 (Run 11) data set.
  - 5 electron p_T bins from $1.5 < p_T < 5.0$
  - no efficiency correction
- Determine normalized background contributions.

arXiv:1509.04662 (2015)



See poster by **H. ASANO - 0504**

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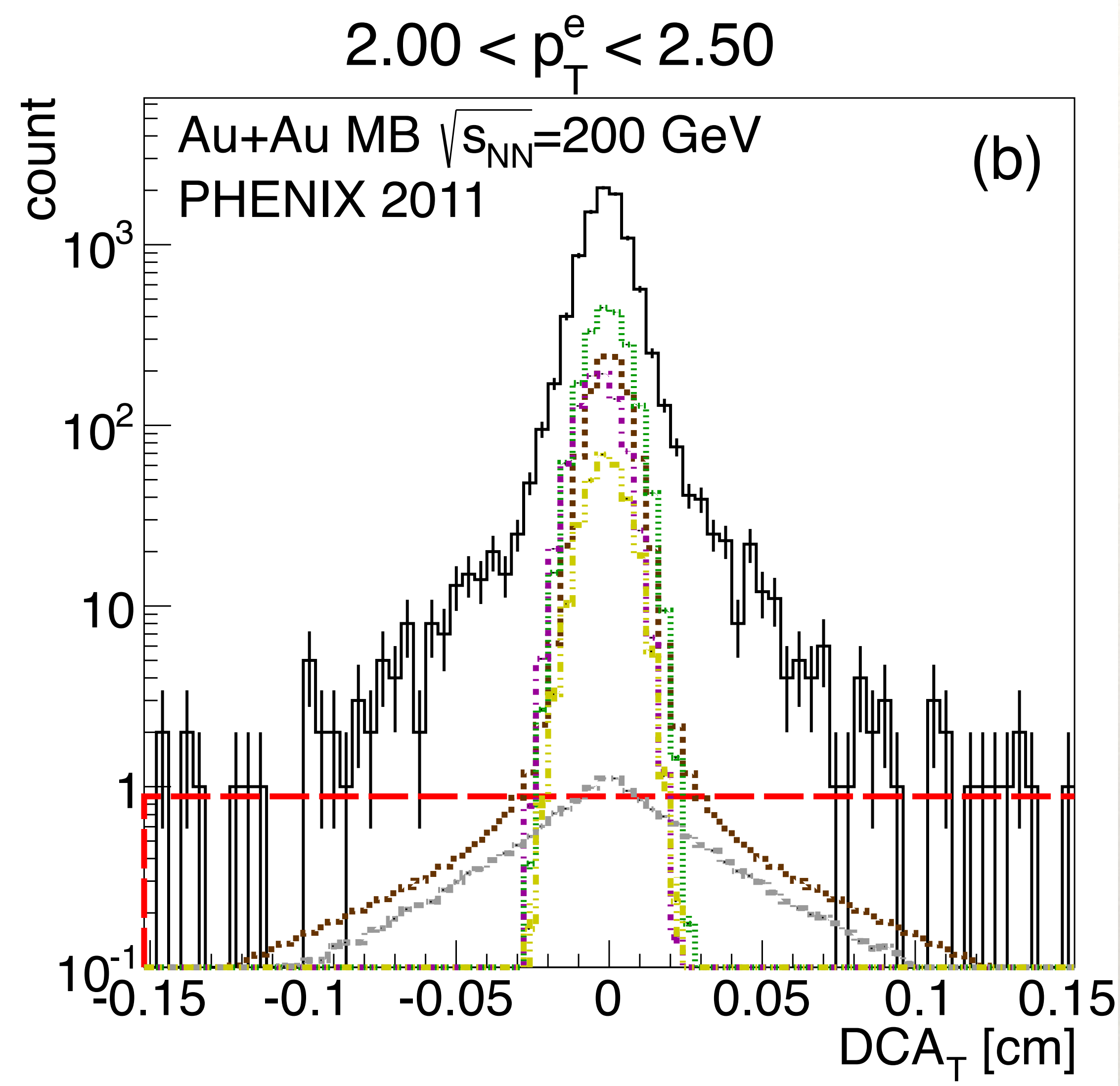


arXiv:1509.04662 (2015)

Mis-associated VTX Hits
Data Driven
Tracks with large DCA$_L$

Mis-identified hadron
Data Driven
RICH swap method

Prompt

Dalitz ($\eta, \pi \rightarrow e^+e^-\gamma$)
Measured yield
Monte Carlo shape

Conversion ($\gamma \rightarrow e^+e^-$)
~75% rejected
Monte Carlo shape

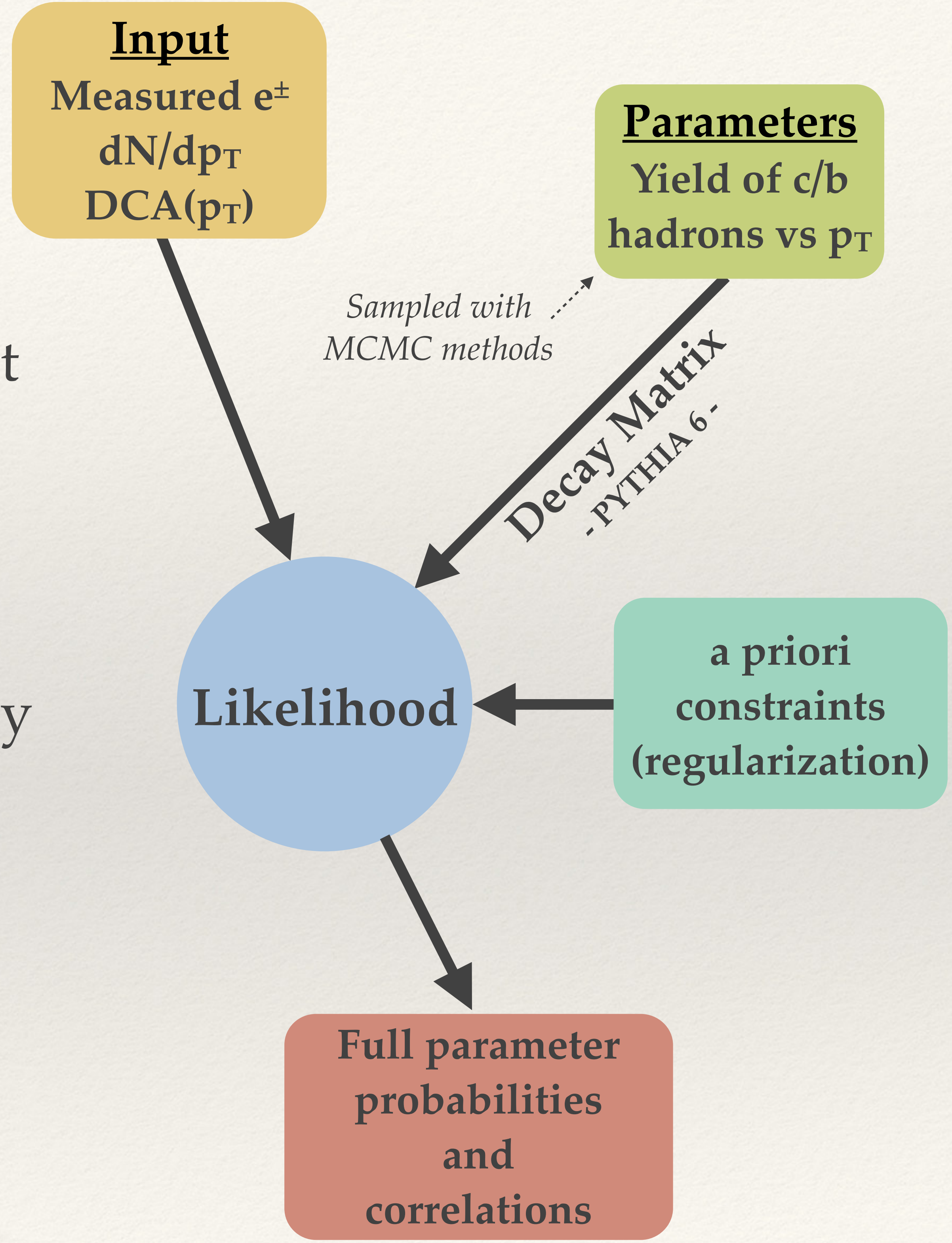
$J/\psi \rightarrow e^+e^-$
Measured yield
Monte Carlo shape

Ke3 ($K_s^0 \rightarrow e\nu\pi$)
Measured yield
Monte Carlo shape

See poster by **H. ASANO - 0504**

Unfolding (Bayesian Inference)

- Use **Bayesian inference methods** to determine parent charm and bottom hadron p_T distributions.
  - **Simultaneous fit** to electron invariant **yield** and 5 electron **DCA_T** distribution.
- Create matrix of probability for a charm (bottom) hadron with a given p_T to decay to electron with a given (p_T, DCA_T)
  - Model h→e decay with PYTHIA-6
  - charm := D^0, $D^{\pm}$, D_s, Λ_c
  - bottom := $B^{\pm}$, B^0, B_s, Λ_b (includes B→D→e)



Input
Measured $e^{\pm}$
dN/dp_T
$DCA(p_T)$

Parameters
Yield of c/b
hadrons vs p_T

Sampled with MCMC methods

Decay Matrix
- PYTHIA 6 -

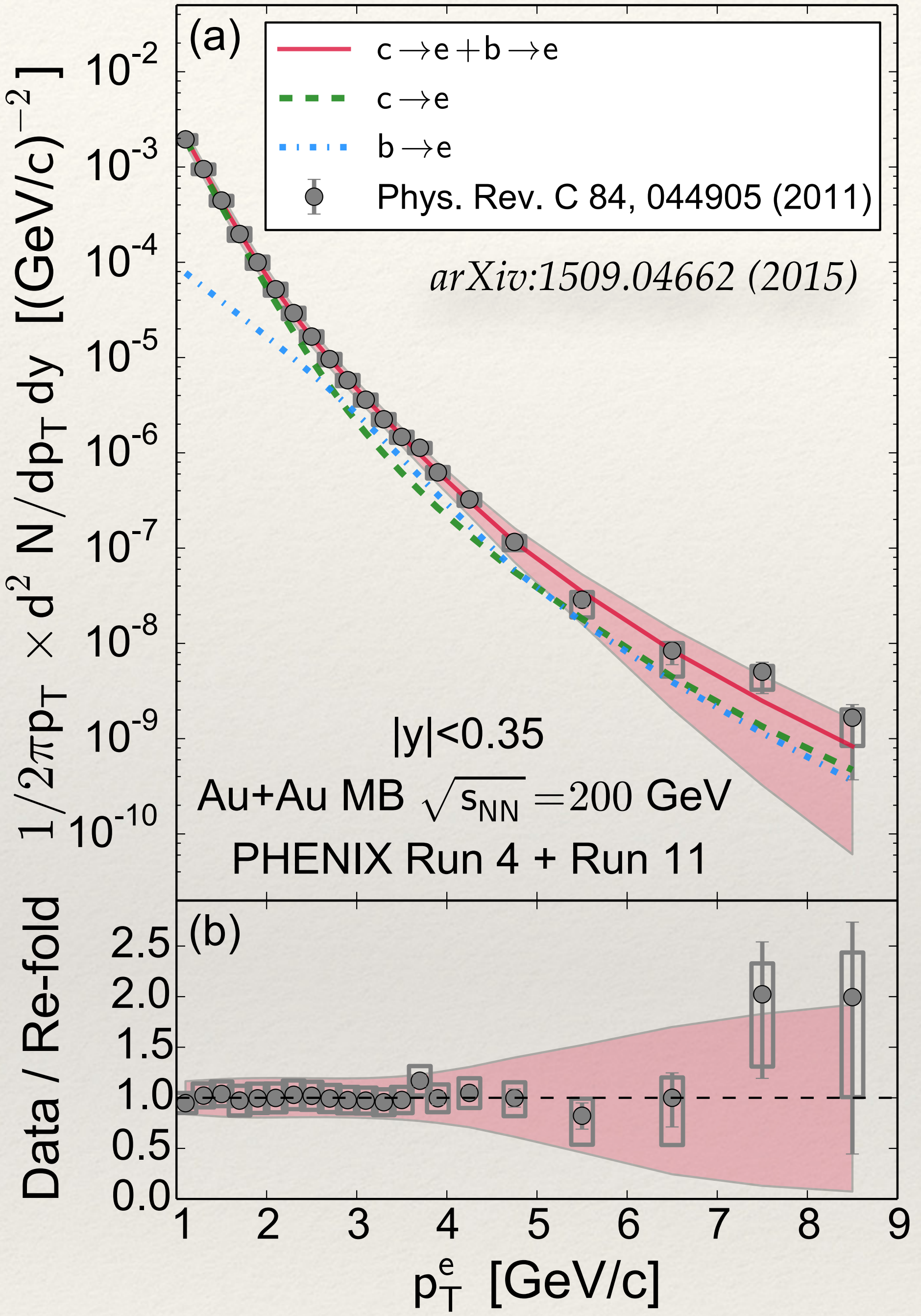
Likelihood

a priori
constraints
(regularization)

Full parameter
probabilities
and
correlations

See **D. MCGLINCHEY - 0535** poster for details

Comparison to Data



Data

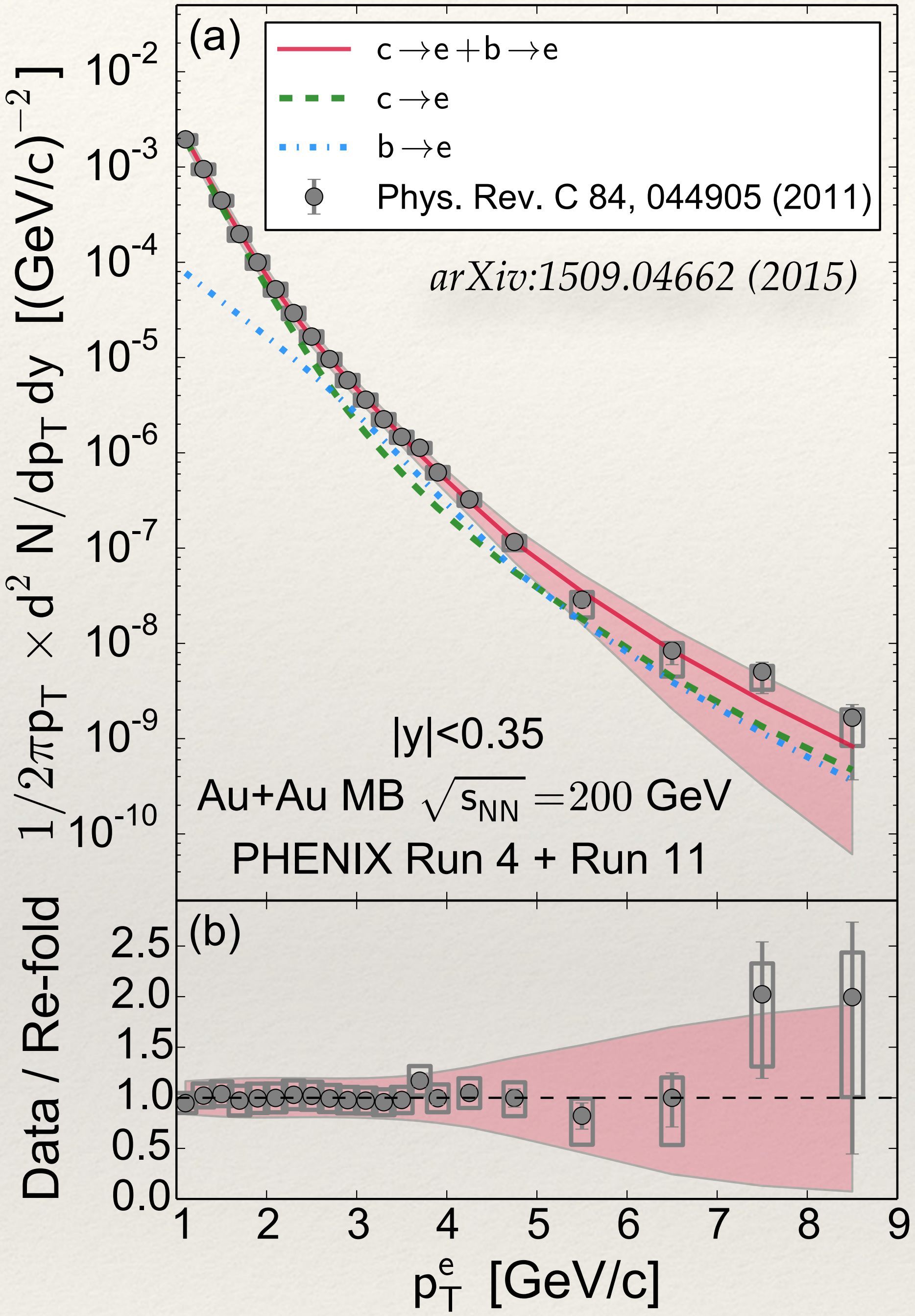
c→e

b→e

Total

Unfold gives good consistency with electron invariant yield

Comparison to Data



Data

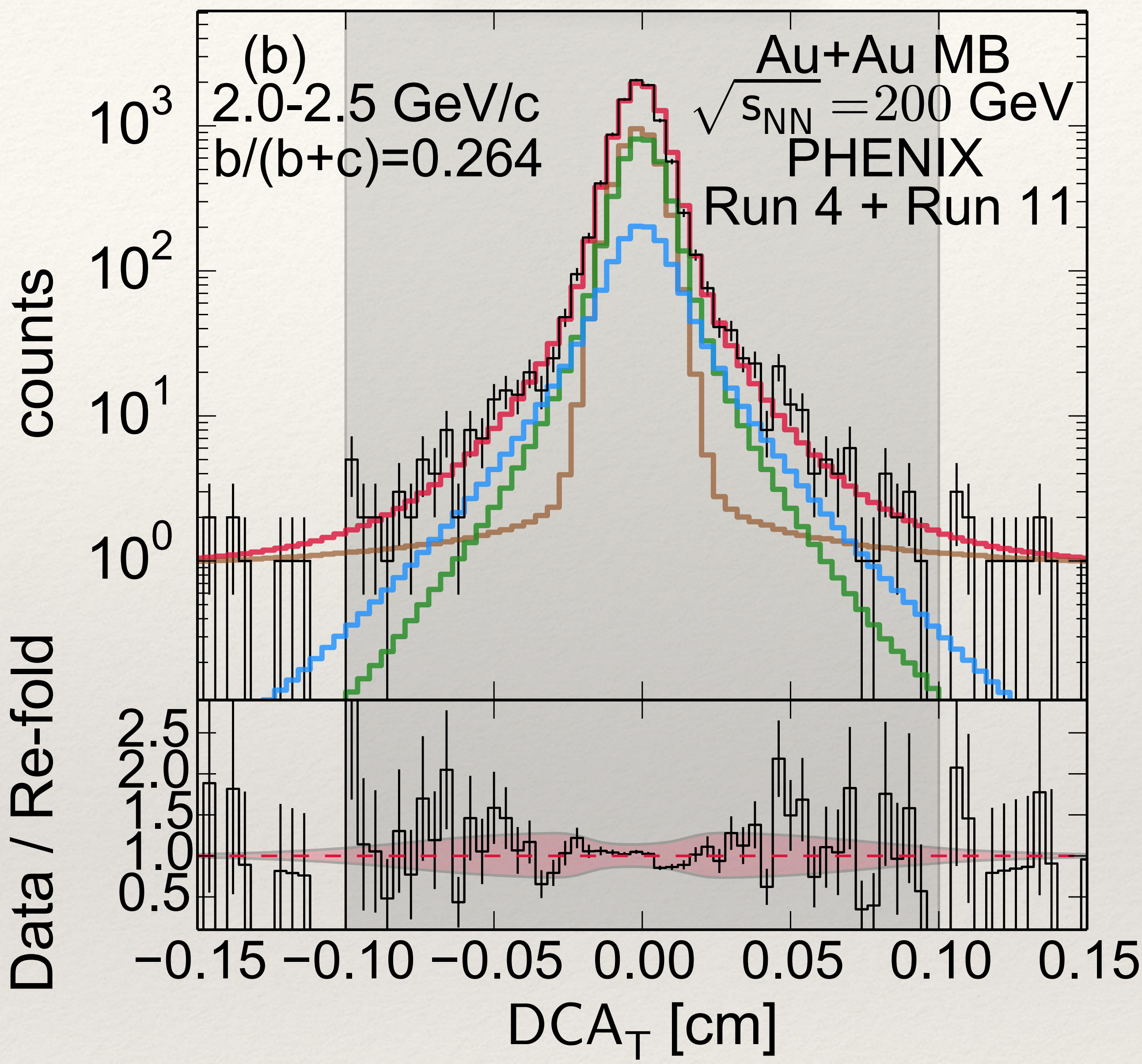
c→e

b→e

Total

Background Components

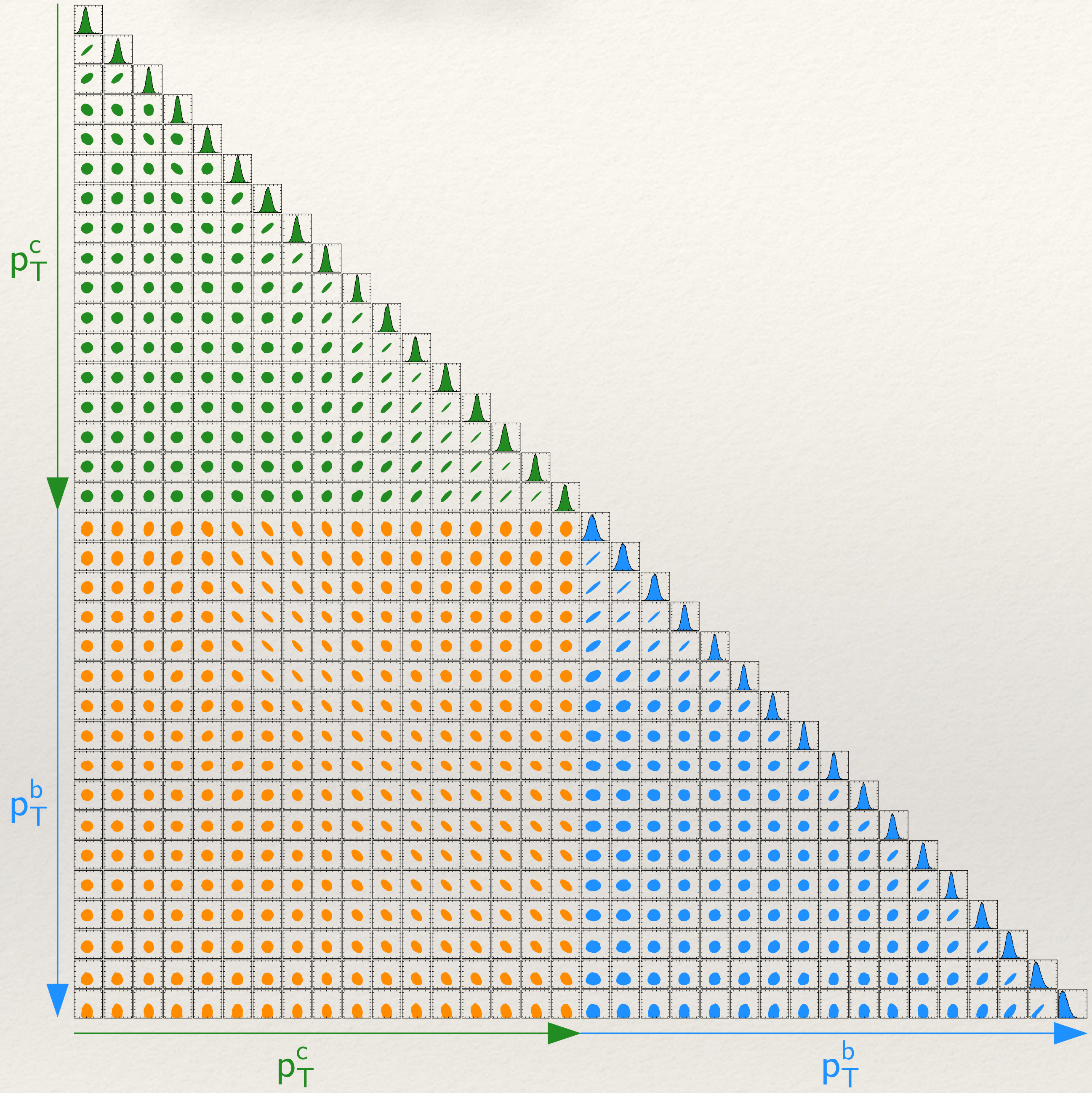
arXiv:1509.04662 (2015)



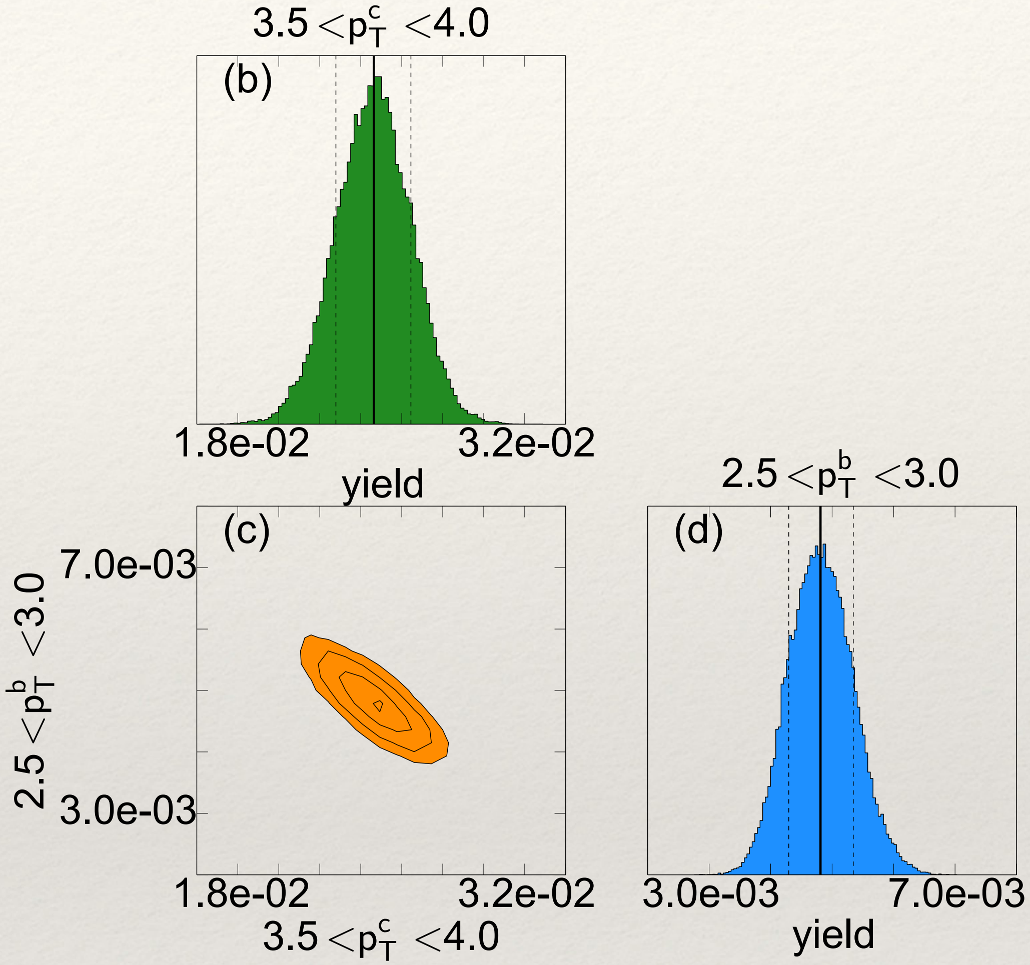
Unfold gives good consistency with electron invariant yield and DCA$_T$ data

Unfolded Hadron Yields

arXiv:1509.04662 (2015)



Example correlation

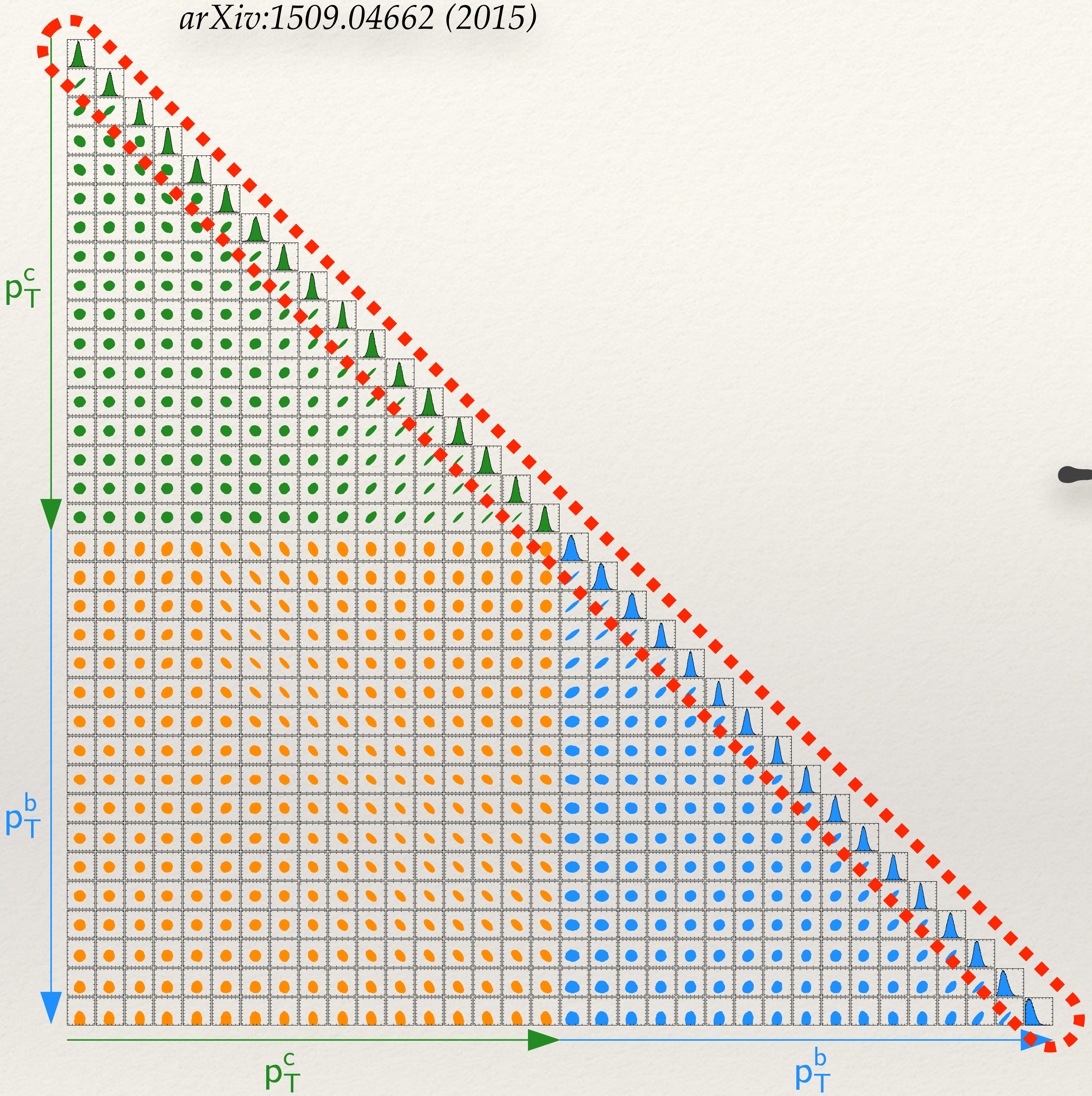


Invariant yield of **charm** and **bottom** hadrons vs p_T

*Includes **correlations** between **charm** and **bottom***

Unfolded Hadron Yields

arXiv:1509.04662 (2015)



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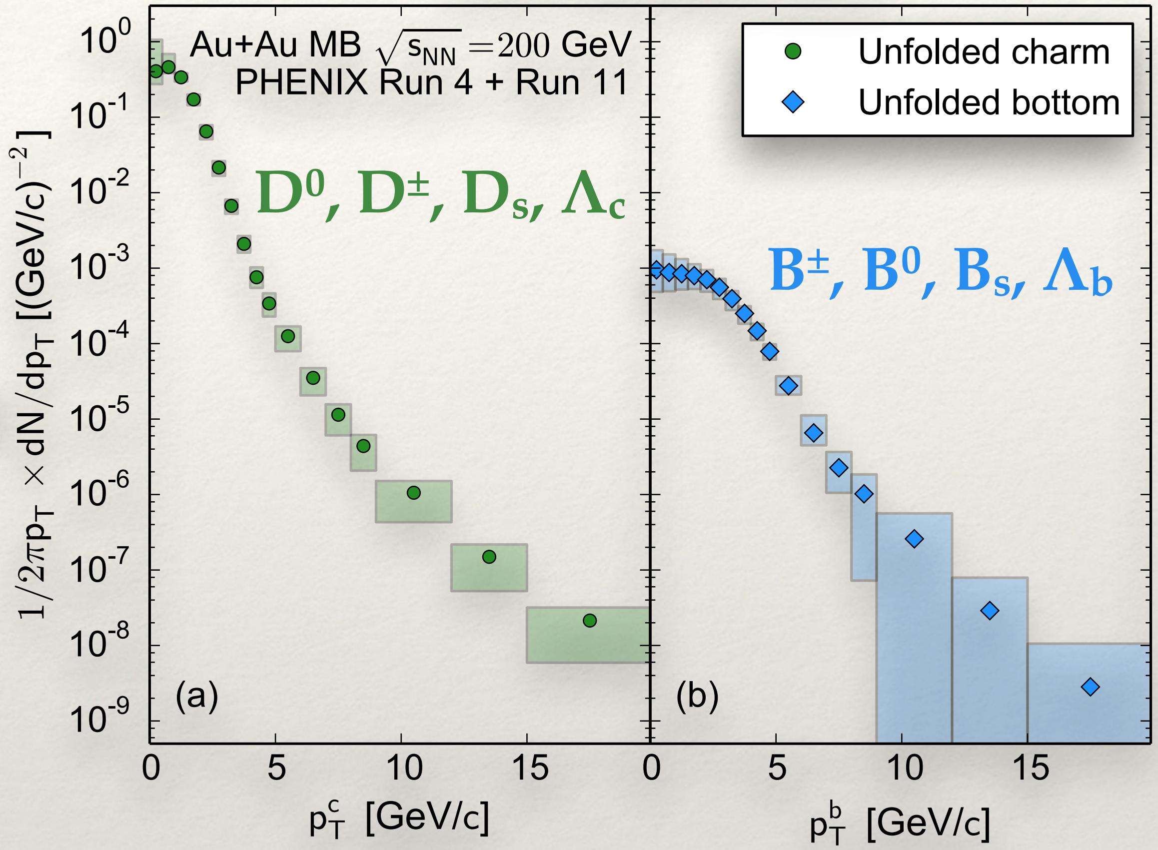
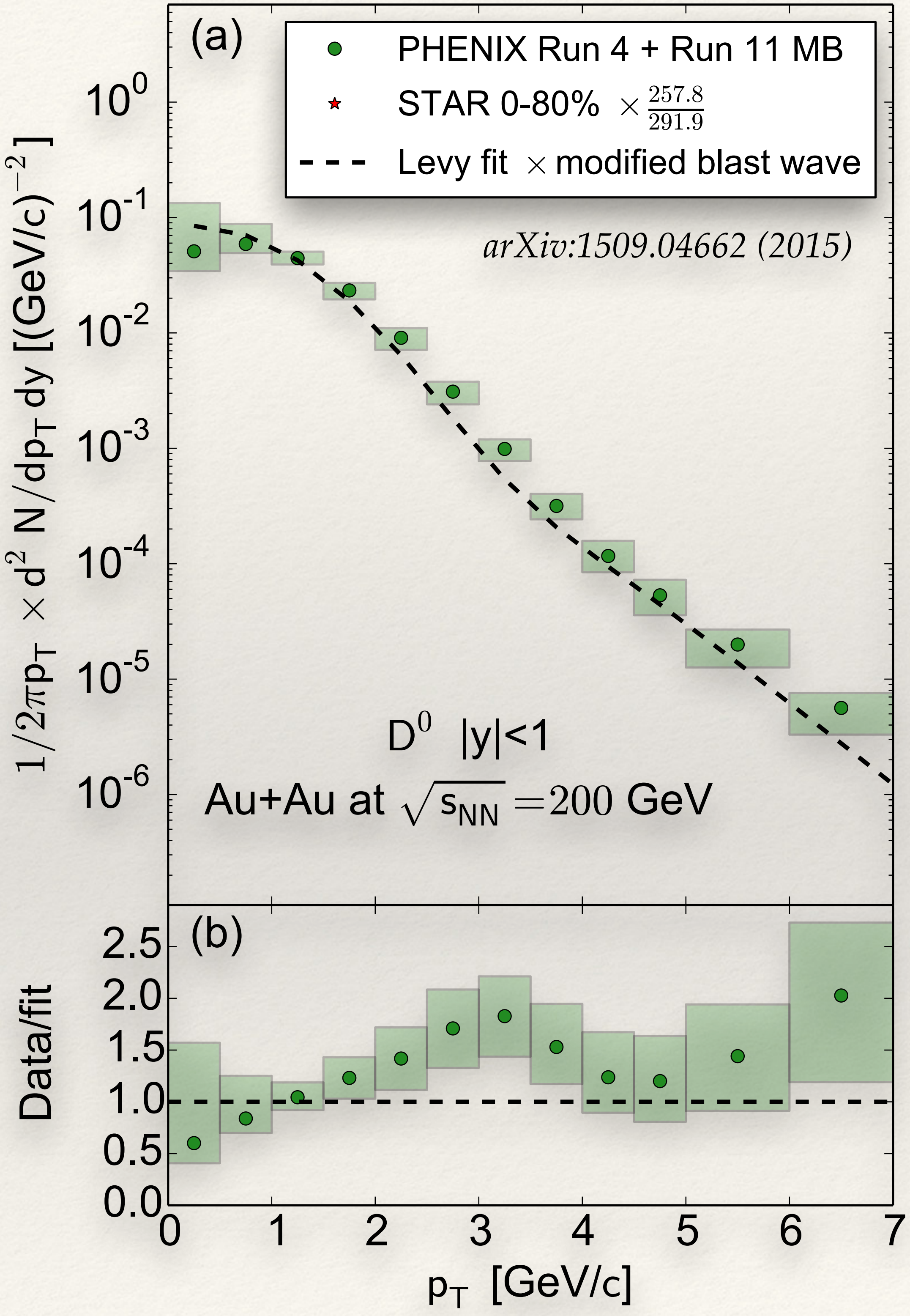


Invariant yield of **charm** and **bottom** hadrons vs p_T

*Includes **correlations** between **charm** and **bottom***

Agreement with Measured Data

Using PYTHIA + Unfolded charm hadron yield
Calculate D^0 yield within $|y|<1$

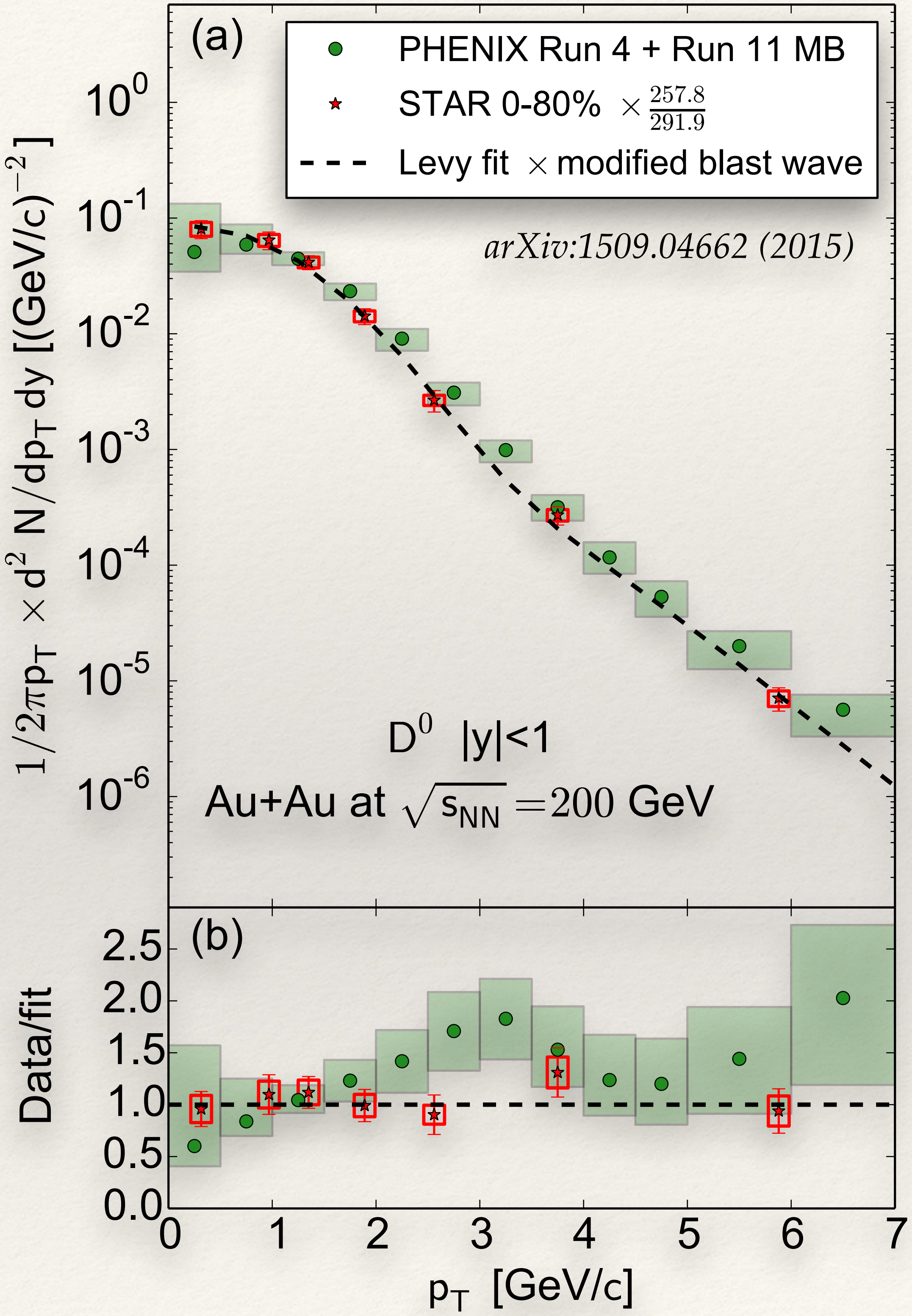


Agreement with Measured Data

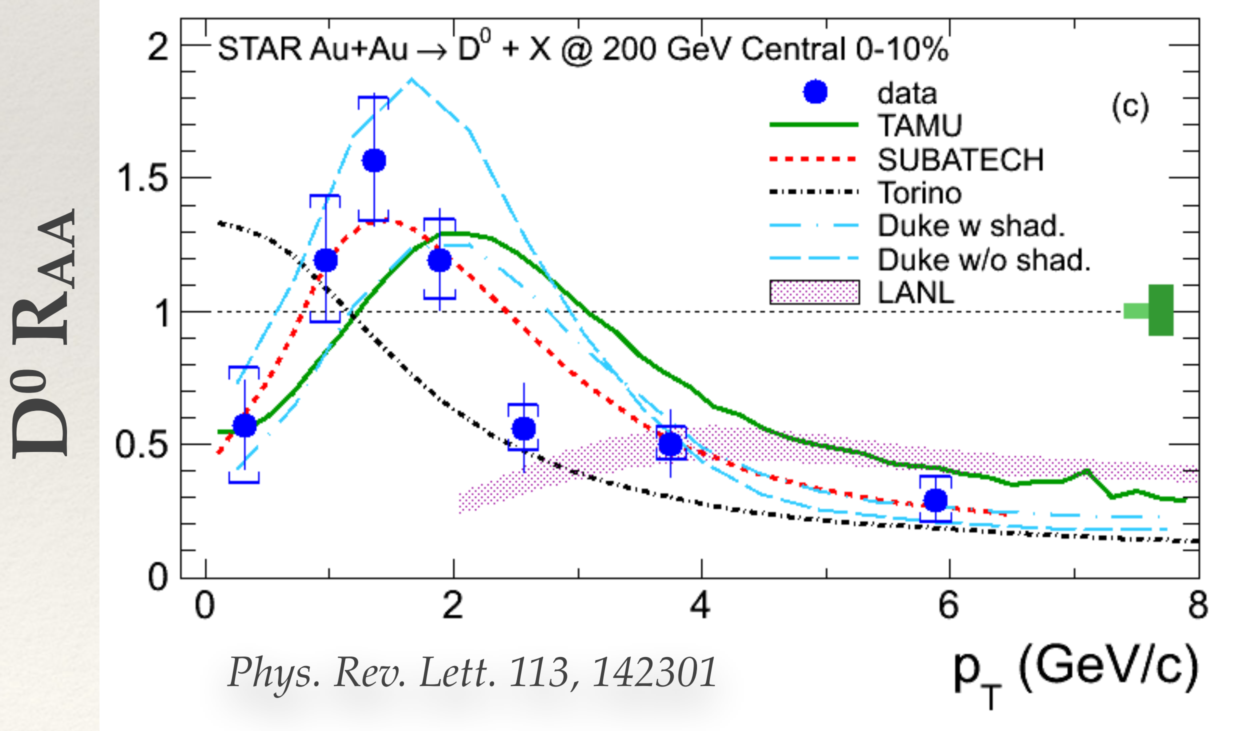
Using PYTHIA + Unfolded charm hadron yield
Calculate D^0 yield within |y|<1

Compare with D^0 measurement from STAR

Very good agreement over comparable p_T region!

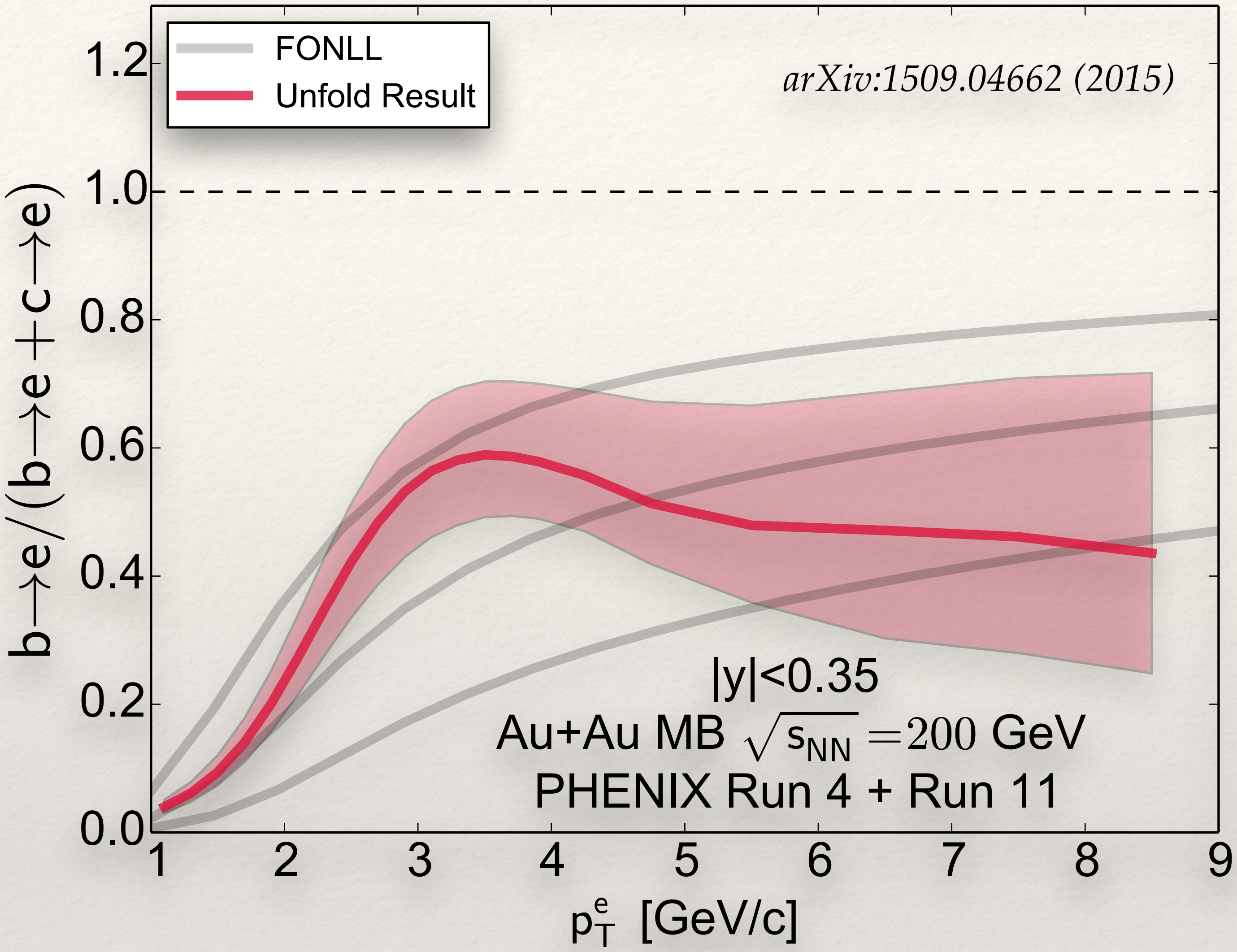


arXiv:1509.04662 (2015)



Phys. Rev. Lett. 113, 142301

Bottom Electron Fraction

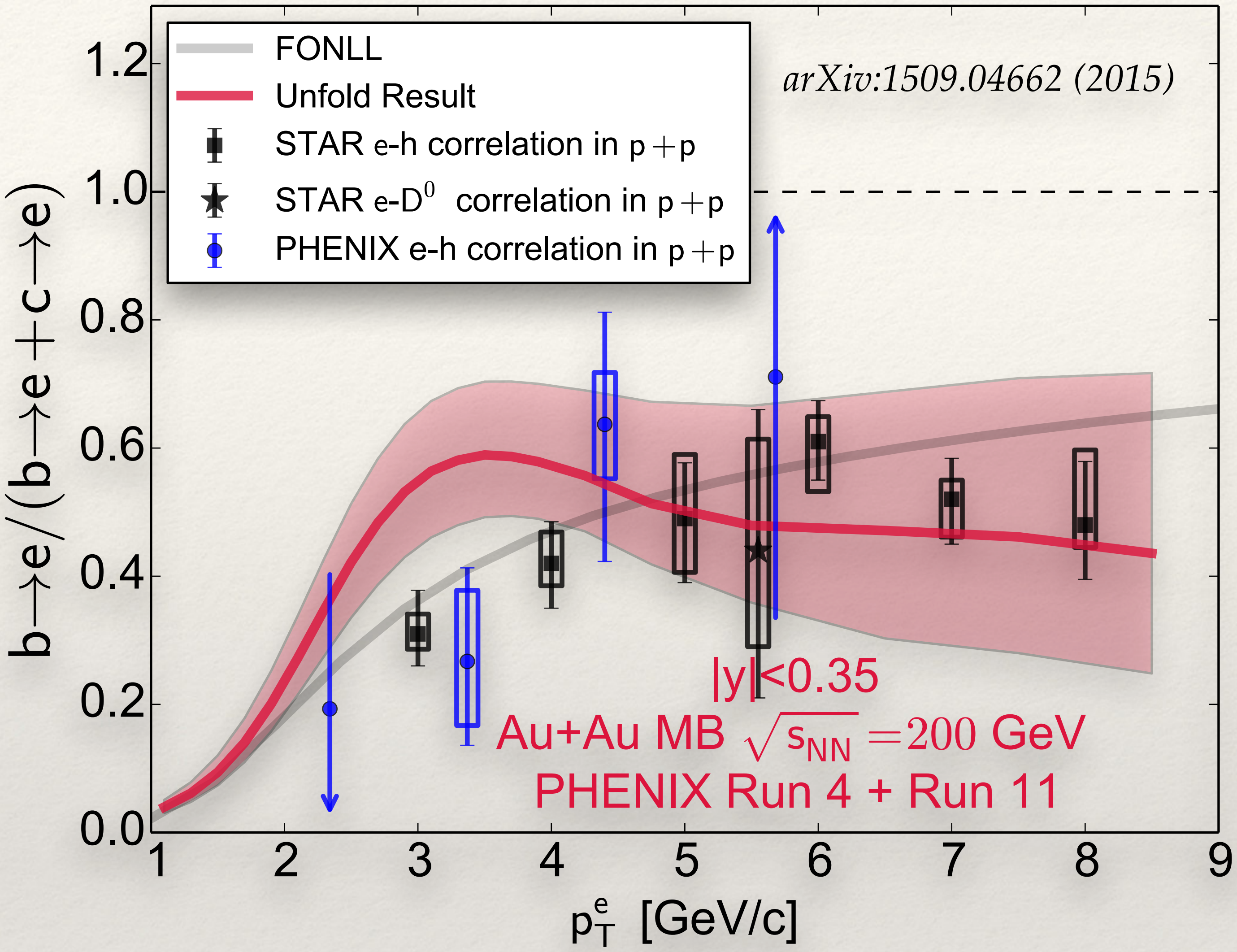


FONLL
Phys. Rev. Lett. 95, 122001 (2005)

Calculate fraction of electrons from bottom hadron decays

Apparent shape difference when compared to FONLL

Comparison to p+p Data



$$F = \frac{b \to e}{b \to e \; + \; c \to e}$$

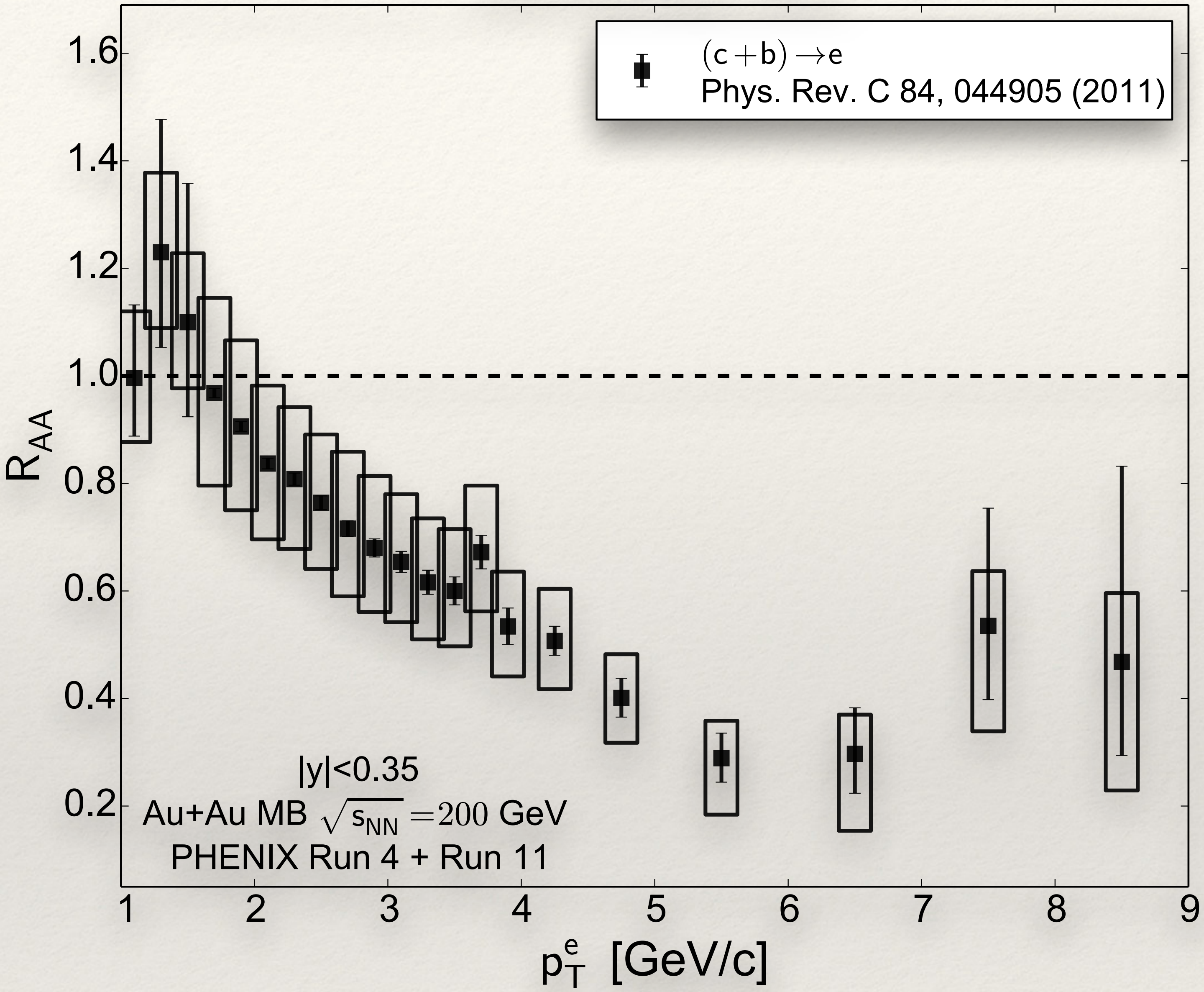
$F_{AuAu} > F_{pp}$ $\quad$ $F_{AuAu} \approx F_{pp}$

What does this imply about charm & bottom R_{AA}?

Heavy Flavor R_{AA}

- Ingredients:
  - Open heavy flavor R_{AA} := R^{HF}_{AA}
  - bottom electron fraction in Au+Au := F_{AuAu}
  - bottom electron fraction in p+p (STAR e-h correlations) := F_{pp}

arXiv:1509.04662 (2015)



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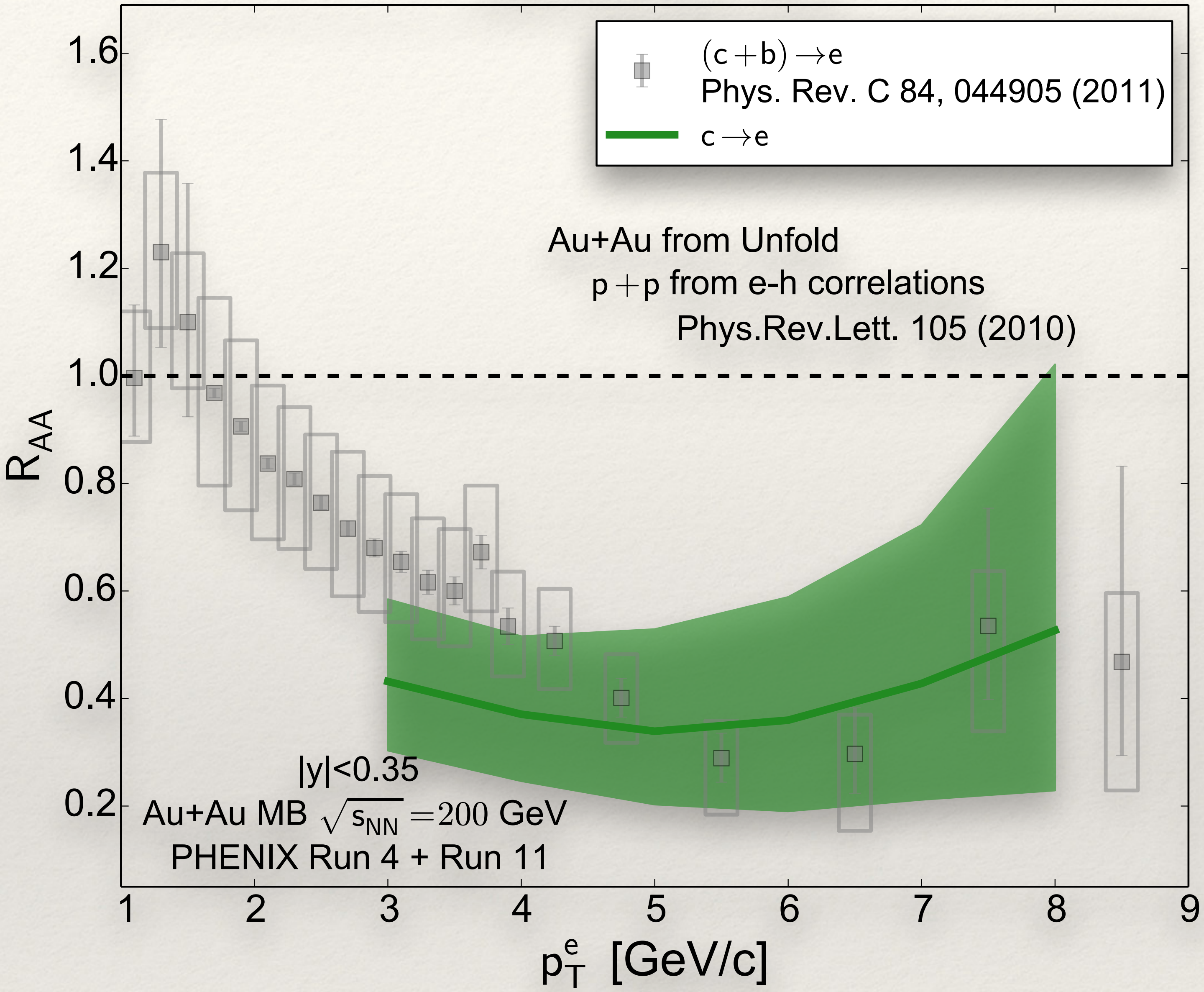
$$R_{AA}^{c\to e} = \frac{(1 - F_{AuAu})}{(1 - F_{pp})} R_{AA}^{HF}$$

arXiv:1509.04662 (2015)



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- Ingredients:
  - Open heavy flavor $R_{AA} := R^{HF}_{AA}$
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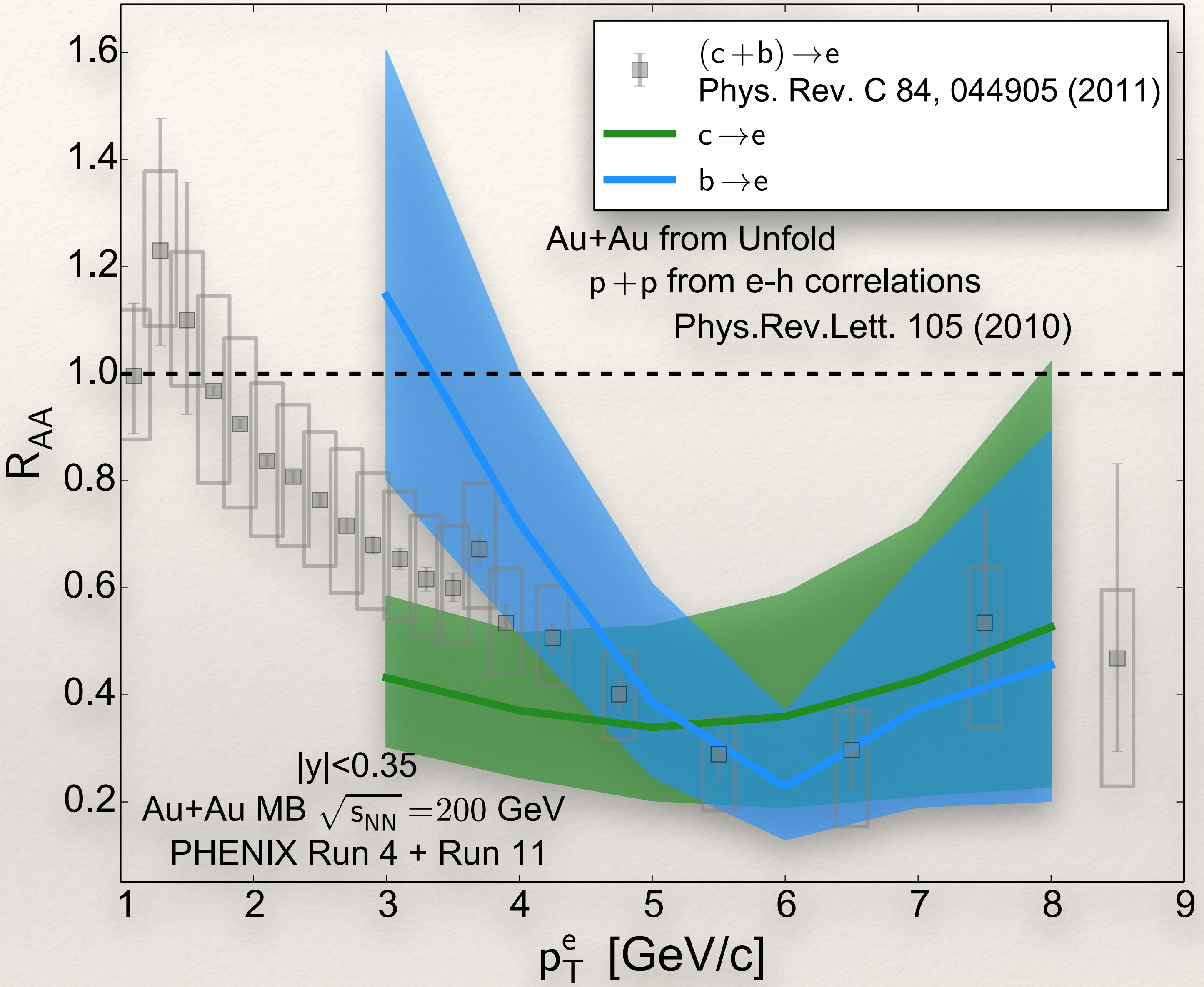
$$R^{c\rightarrow e}_{AA} = \frac{(1 - F_{AuAu})}{(1 - F_{pp})} R^{HF}_{AA}$$

$$R^{b\rightarrow e}_{AA} = \frac{F_{AuAu}}{F_{pp}} R^{HF}_{AA}$$

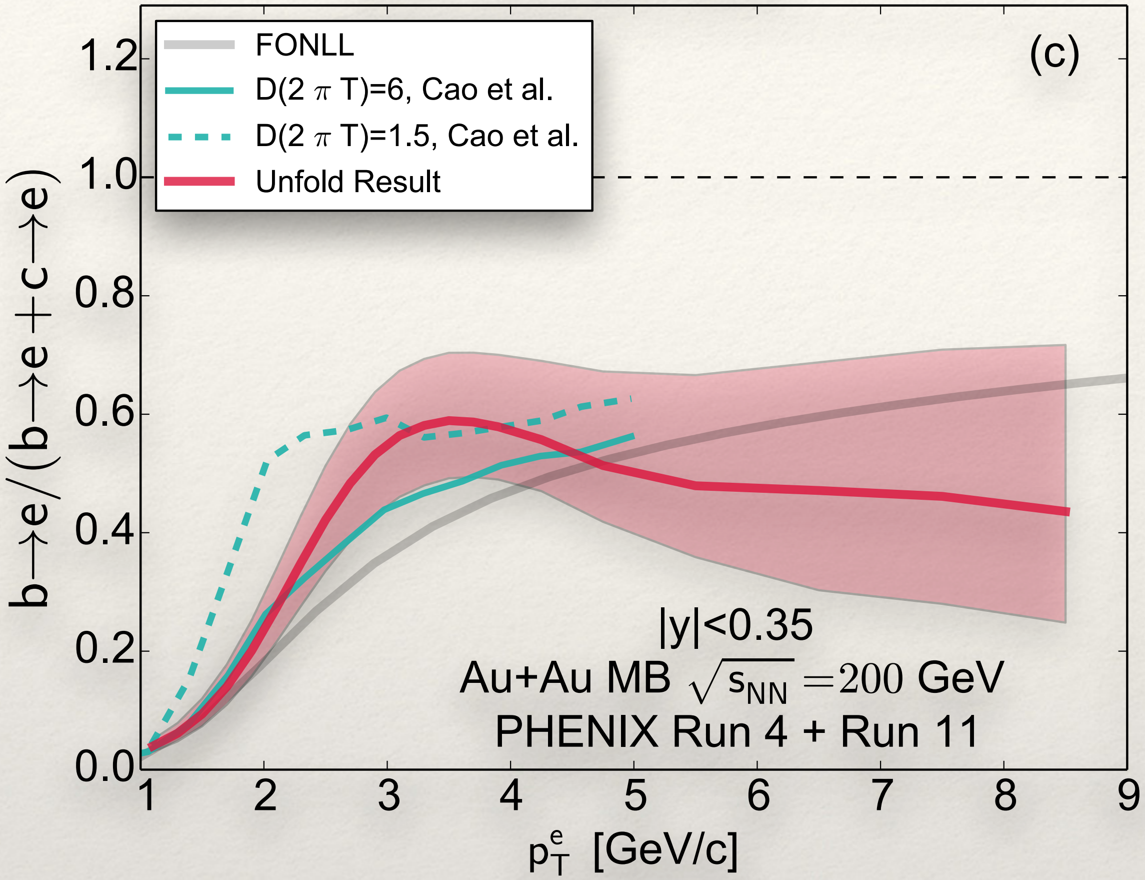
arXiv:1509.04662 (2015)



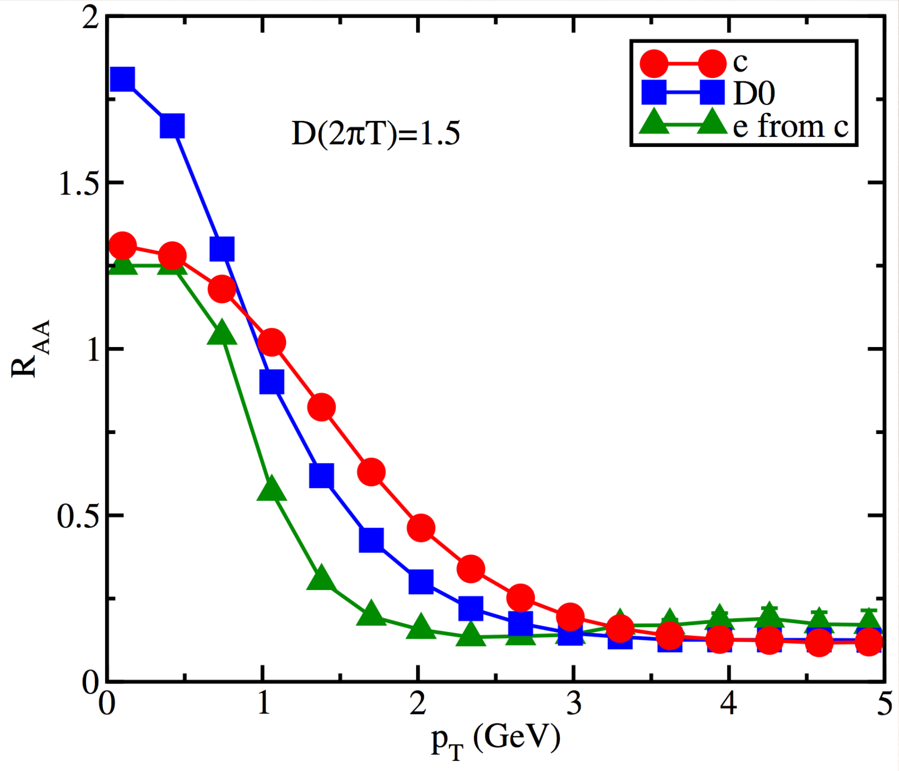
Electrons from bottom less suppressed than those from charm for $p_T < 4$ GeV/c
Similarly suppressed for $p_T > 4$ GeV/c

Model Comparisons

arXiv:1509.04662 (2015)



- Collisional energy loss via Langevin
  J. Phys. G: Nucl. Part. Phys. ***40*** *(2013) 085103*
- Depends sensitively on medium coupling
- Stronger coupling → quarks pushed by medium
- Causes peak in bottom electron fraction at low-p_T



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Model Comparisons

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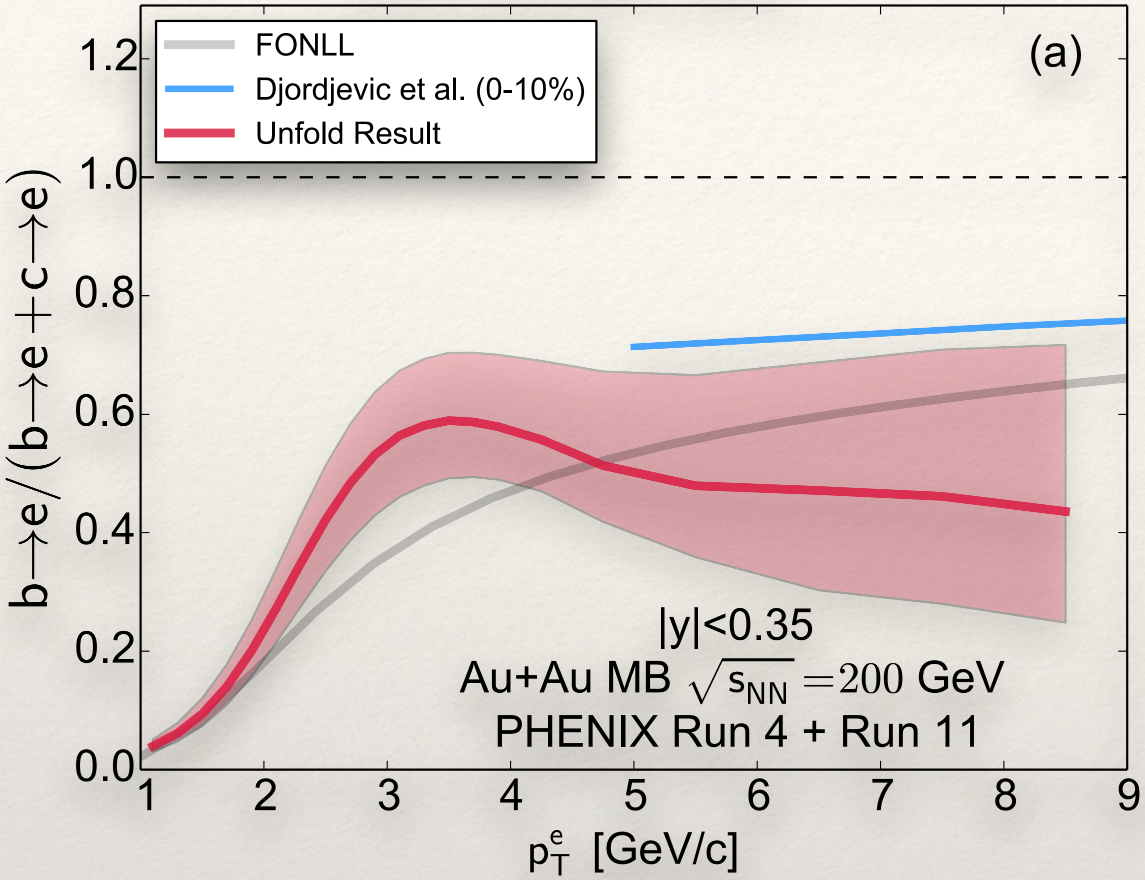
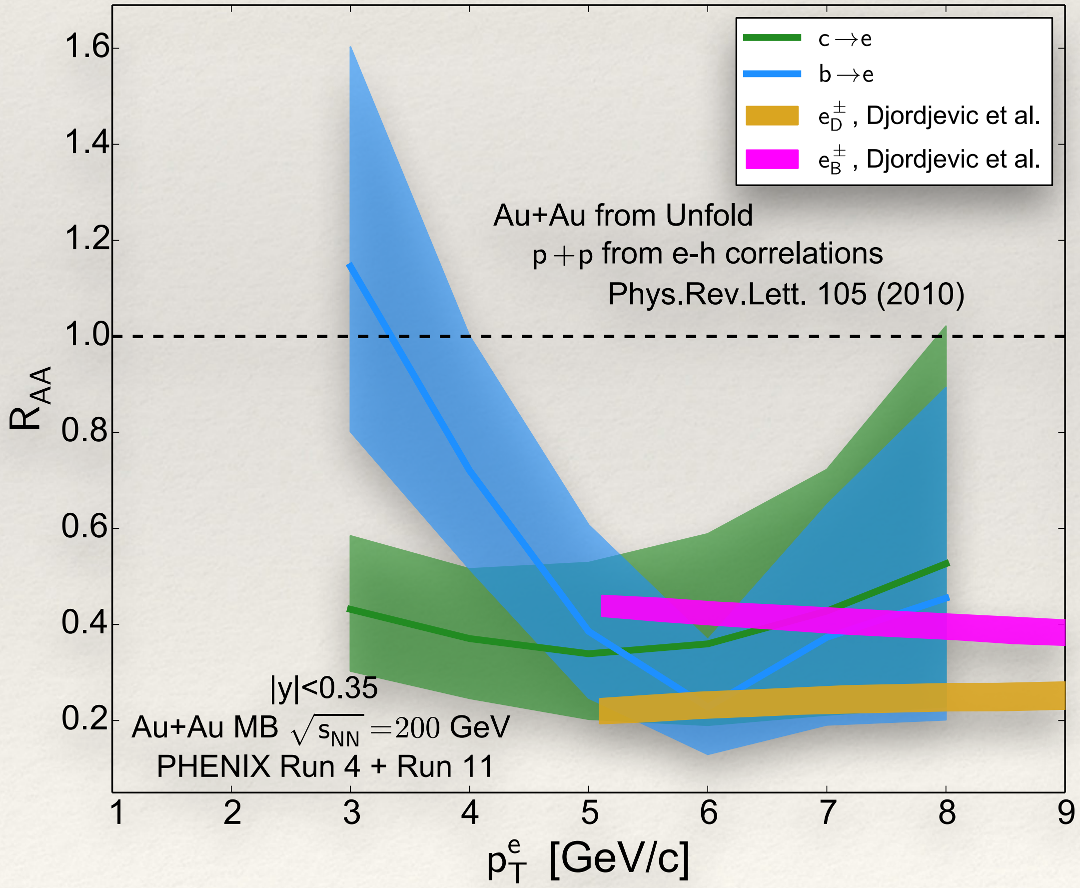


- Collisional + radiative heavy quark energy loss — *Phys. Rev. C 90, 034910 (2014)*
- Reasonable agreement with measured electron R_{AA}
- Only available for $p_T > 5$

NOTE: calculation is 0-10%, data is MB



Model Comparisons

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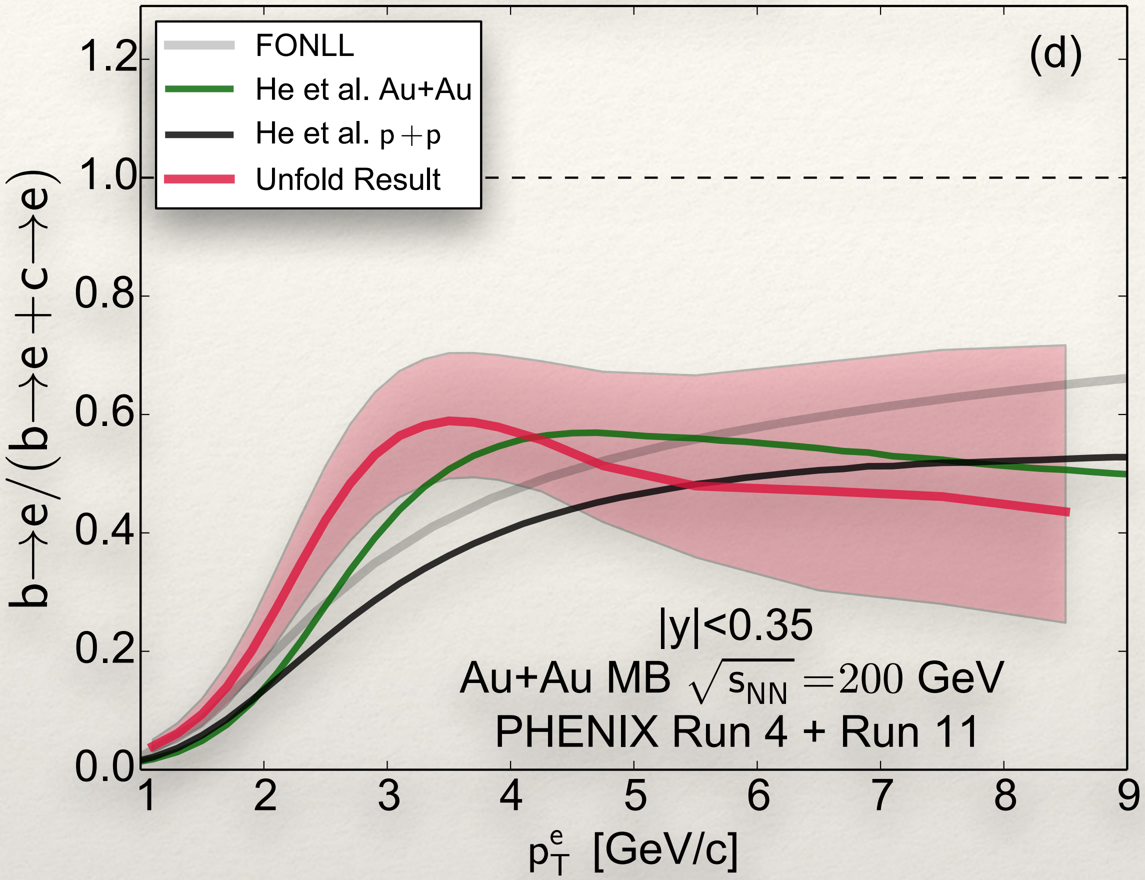
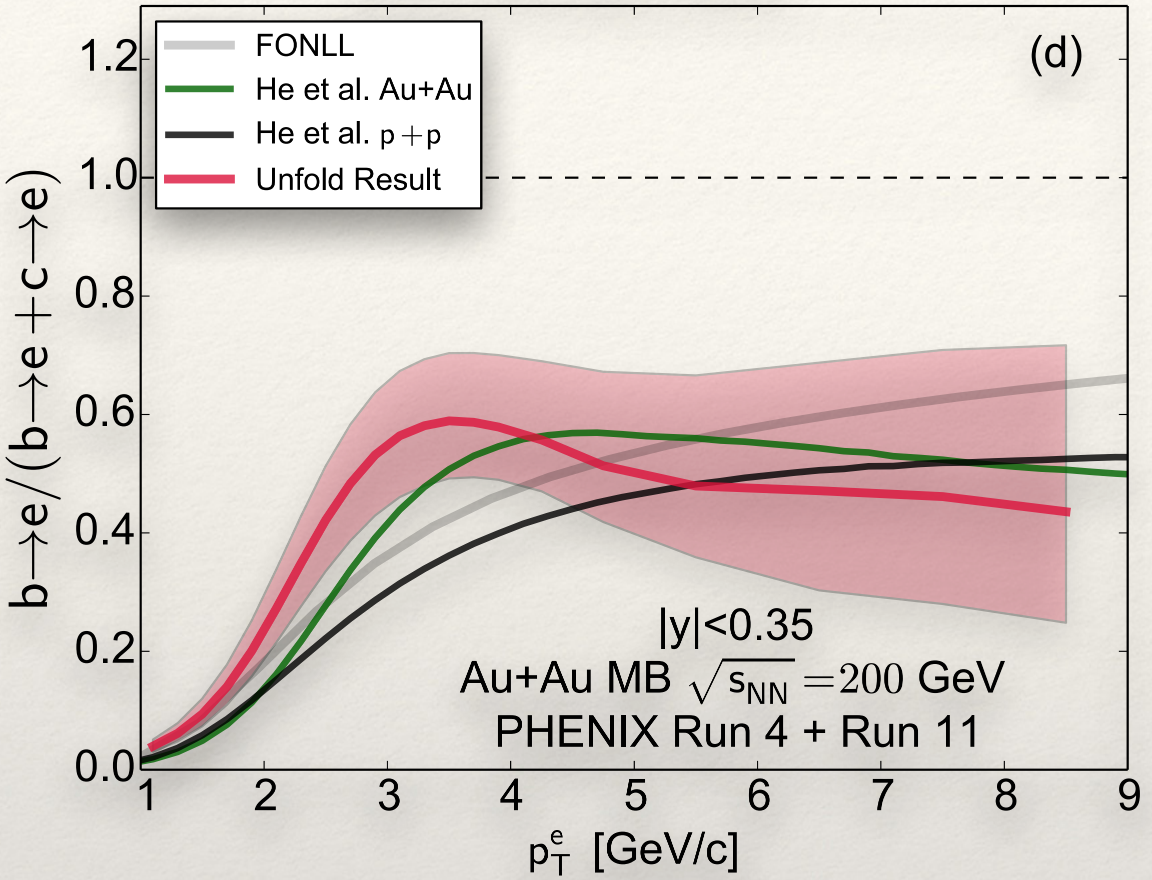


- Full non-perturbative heavy quark transport coefficient (T-matrix) — *Phys. Rev. Lett B 735, 445 (2014)*
- Ideal hydro which describes bulk observables
- Hadronic phase interactions
- p+p baseline differs from FONLL
- Qualitatively similar features observed in data

Model Comparisons

arXiv:1509.04662 (2015)



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- Ideal hydro which describes bulk observables
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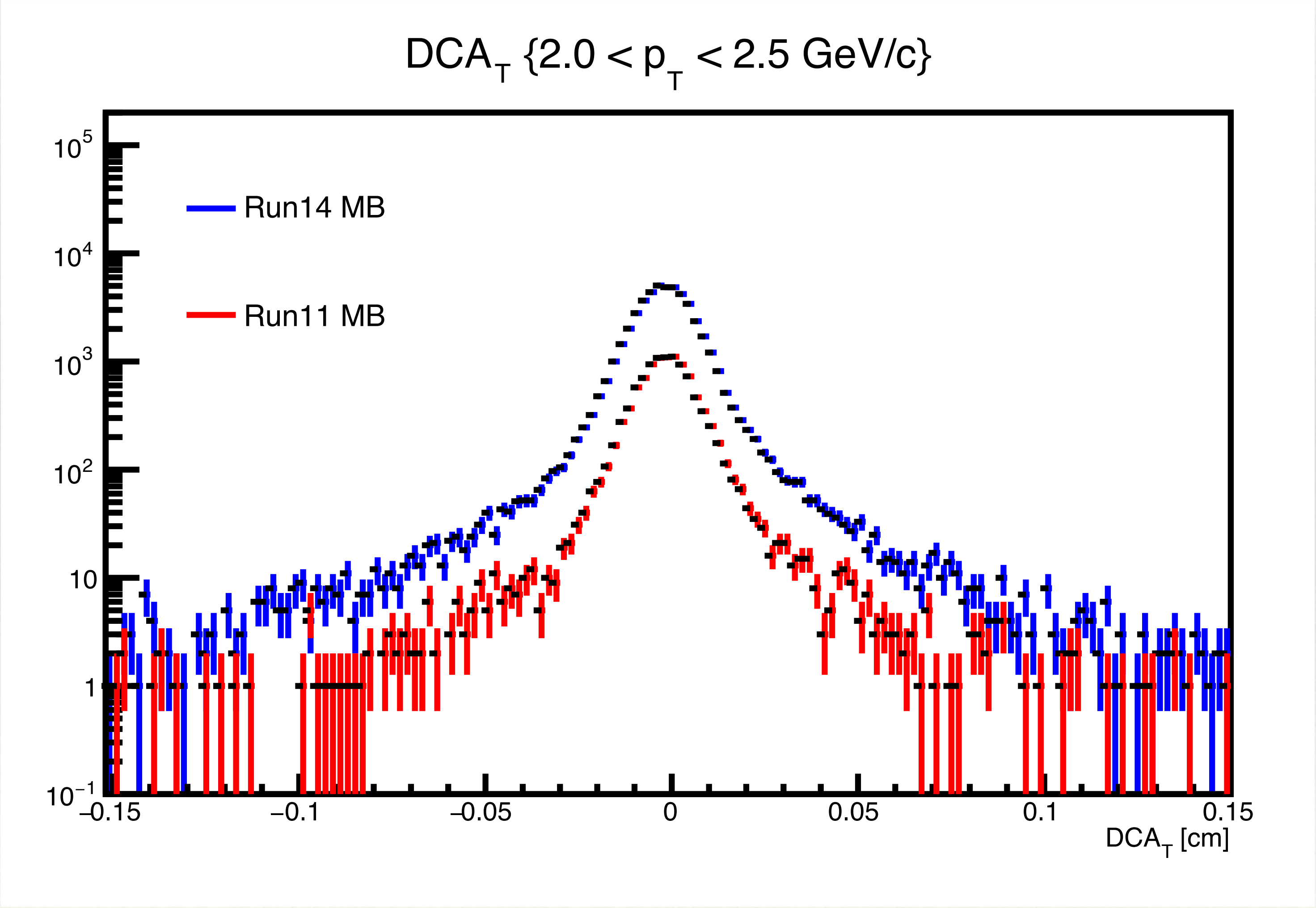
- p+p baseline differs from FONLL
- Qualitatively similar features observed in data

Need higher statistics Au+Au & p+p baseline to disentangle effects — Available from 2014 & 2015 data

Future Prospects

- Look forward to applying analysis techniques to 2014 Au+Au data and 2015 p+p data.
  - Detector performance improved in 2014/2015.
  - 2014 Au+Au data **x10** statistics compared to 2011.



See poster by **K. NAGASHIMA - 0540**

2011 Au+Au Data

~50% of 2014 Au+Au Data

Summary

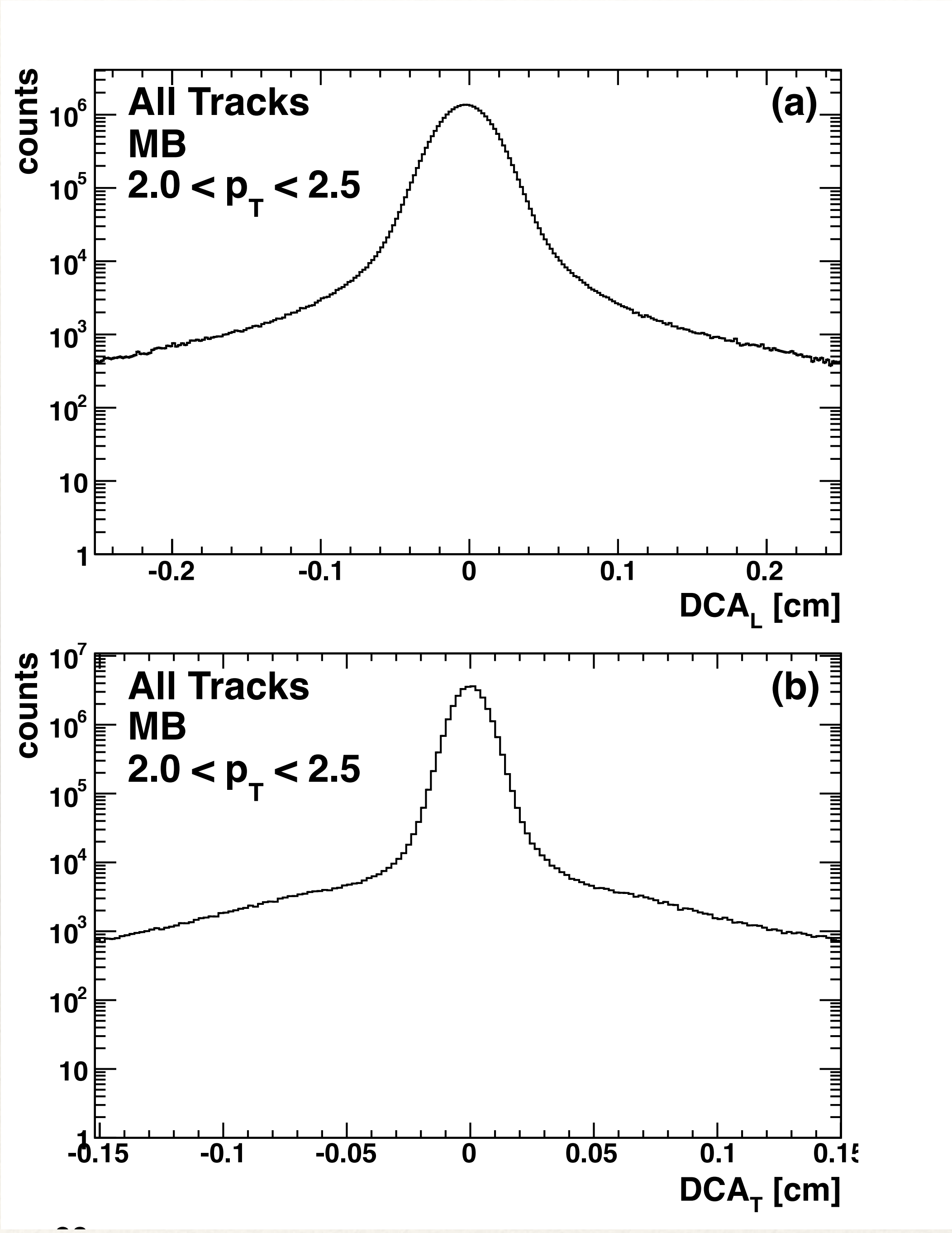
- First measurement of electrons from separated charm and bottom by PHENIX using unfolding techniques.
- Extracted charm and bottom hadron yields.
  - Compares well to STAR measurements of D^0 yield in Au+Au.
- Electrons from bottom decays are less suppressed than those from charm for $p_T < 4$ GeV/c, similarly suppressed for $p_T > 4$ GeV/c.
- Separated charm/bottom adds a new dimension for disentangling medium effects at RHIC.
- Expect high precision Au+Au as well as p+p baseline from 2014 & 2015 data sets.

Thank you!

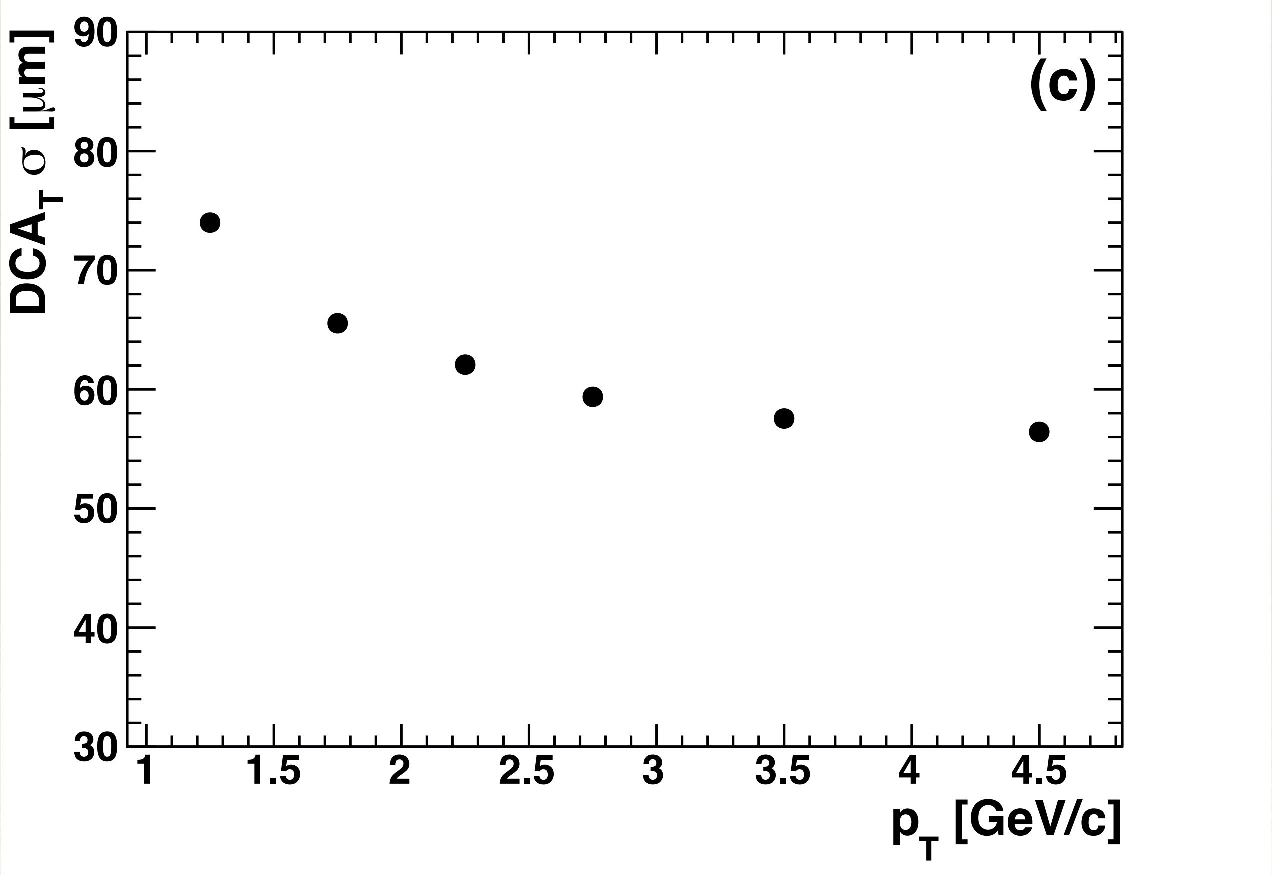
Also see posters by:

H. ASANO - 0504
T. HACHIYA - 0519
K. NAGASHIMA - 0540
D. McGLINCHEY - 0535

DCA

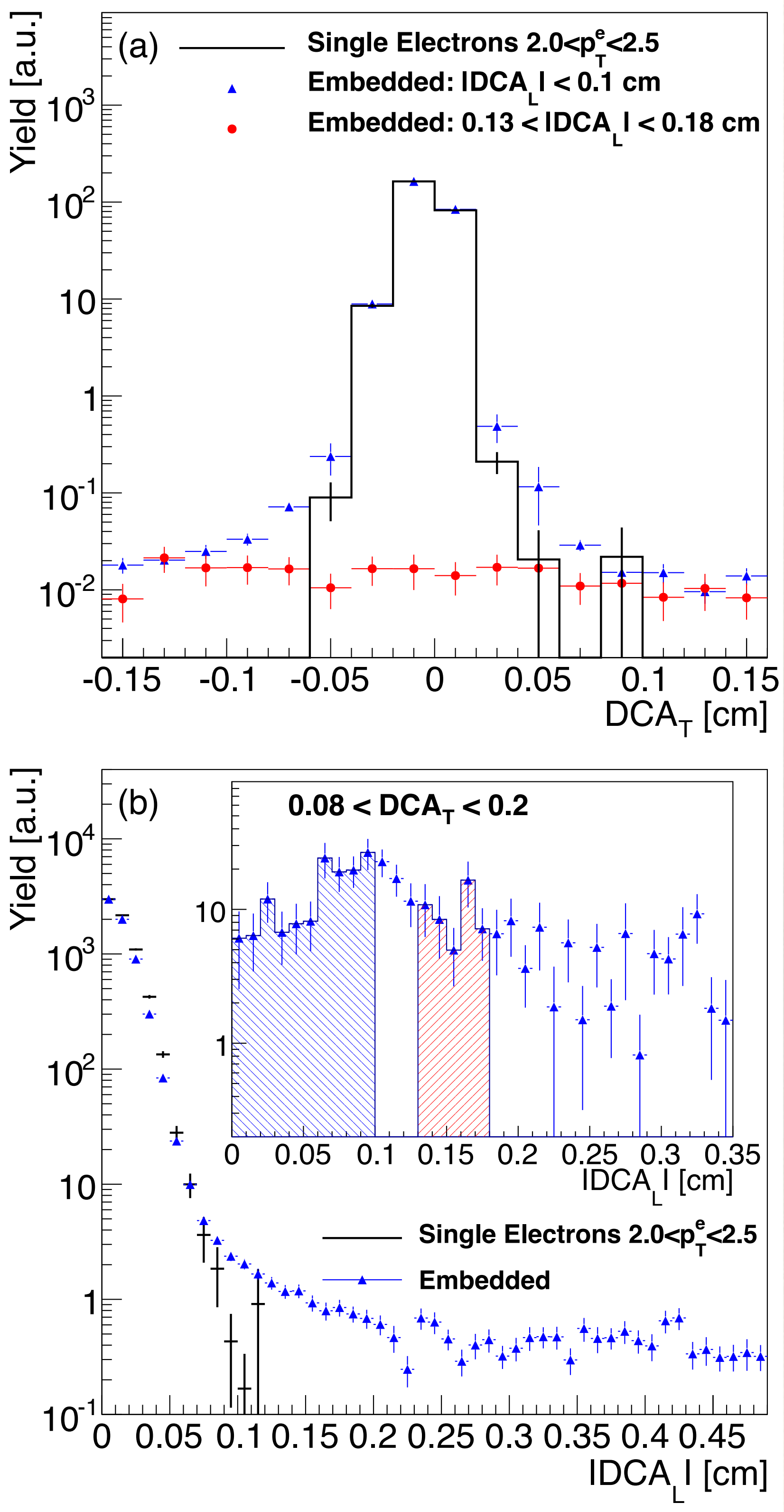


p_T dependence of DCA_T resolution is small > 1.5 GeV/c



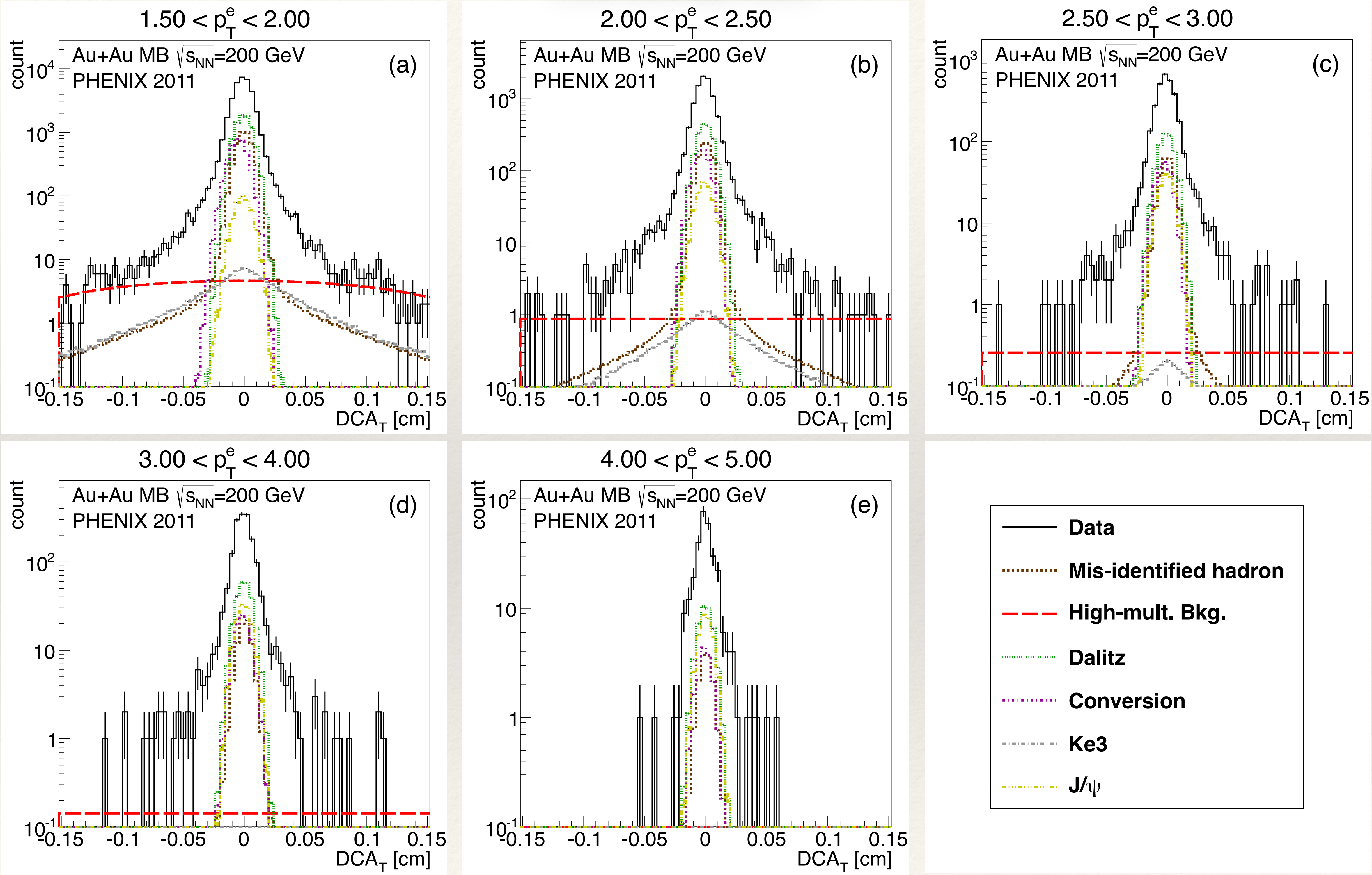
Random Background Estimation

- Tracks with large DCA_L dominated by mis-associated VTX hits.
- Confirmed with embedding simulations.
- Use the DCA_T distribution of tracks with $0.13 < |DCA_L| < 0.18$ cm to model the random background.



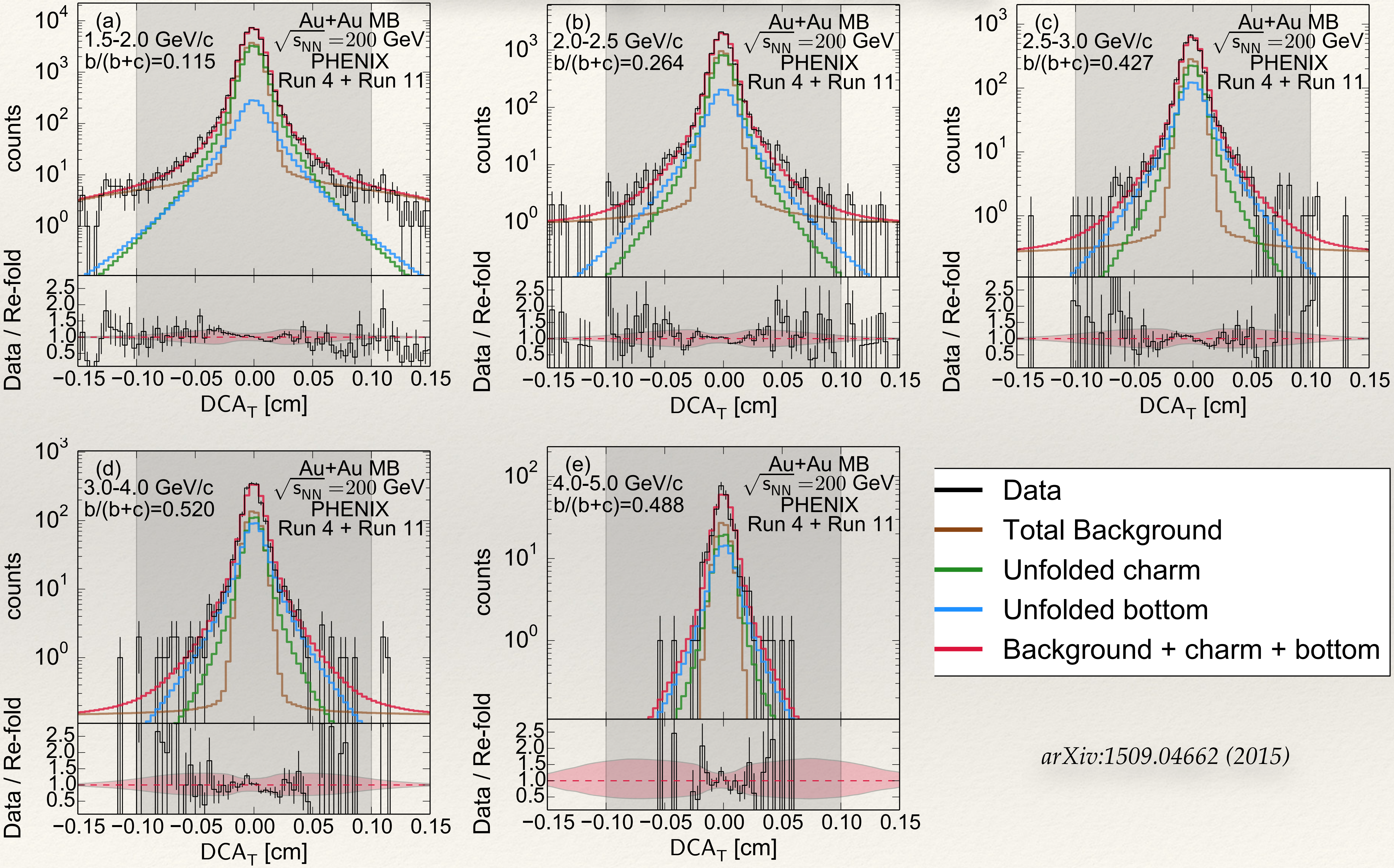
DCA$_T$ Background Contributions

arXiv:1509.04662 (2015)



Comparison to Data

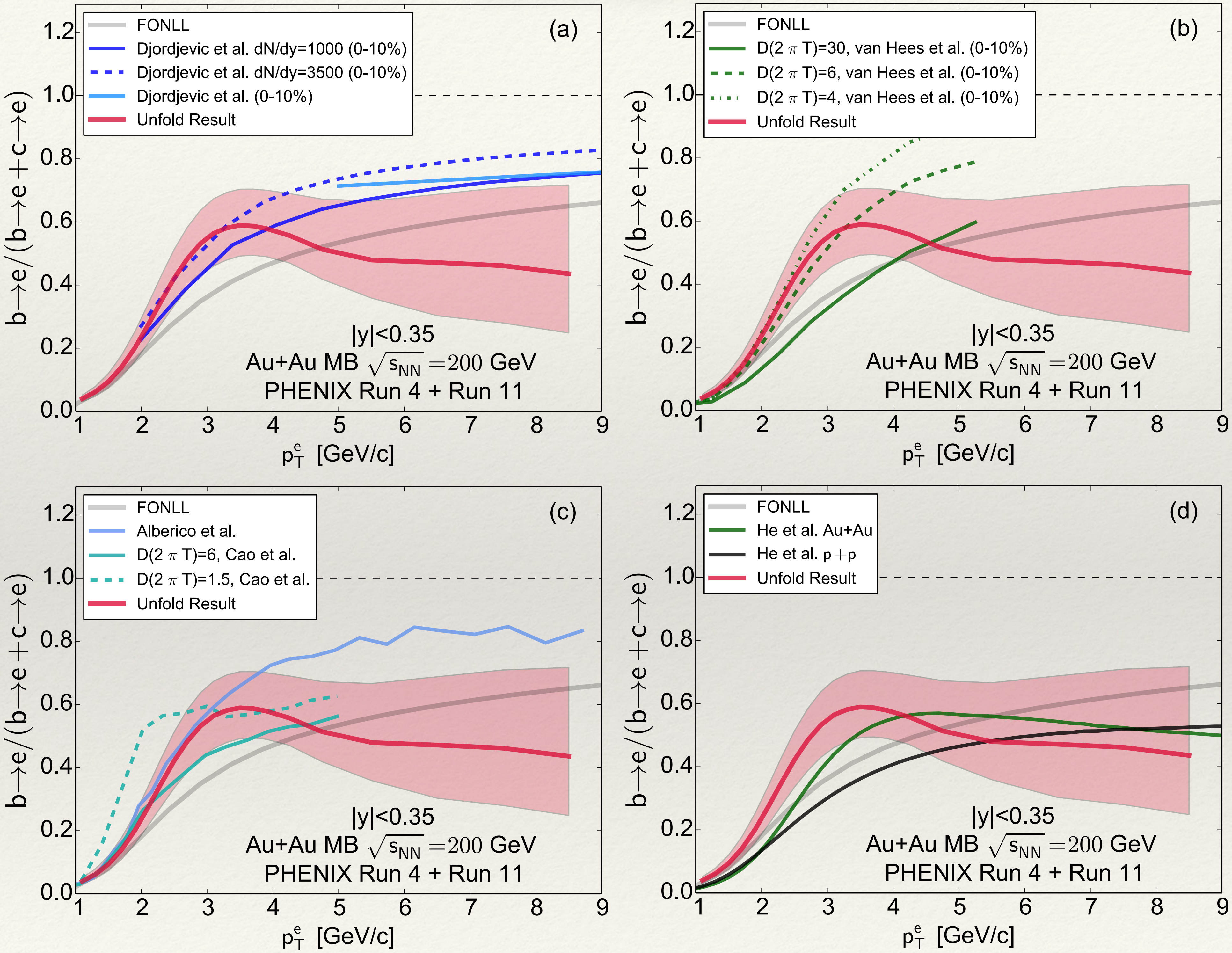
Reasonable agreement in all p_T bins



arXiv:1509.04662 (2015)

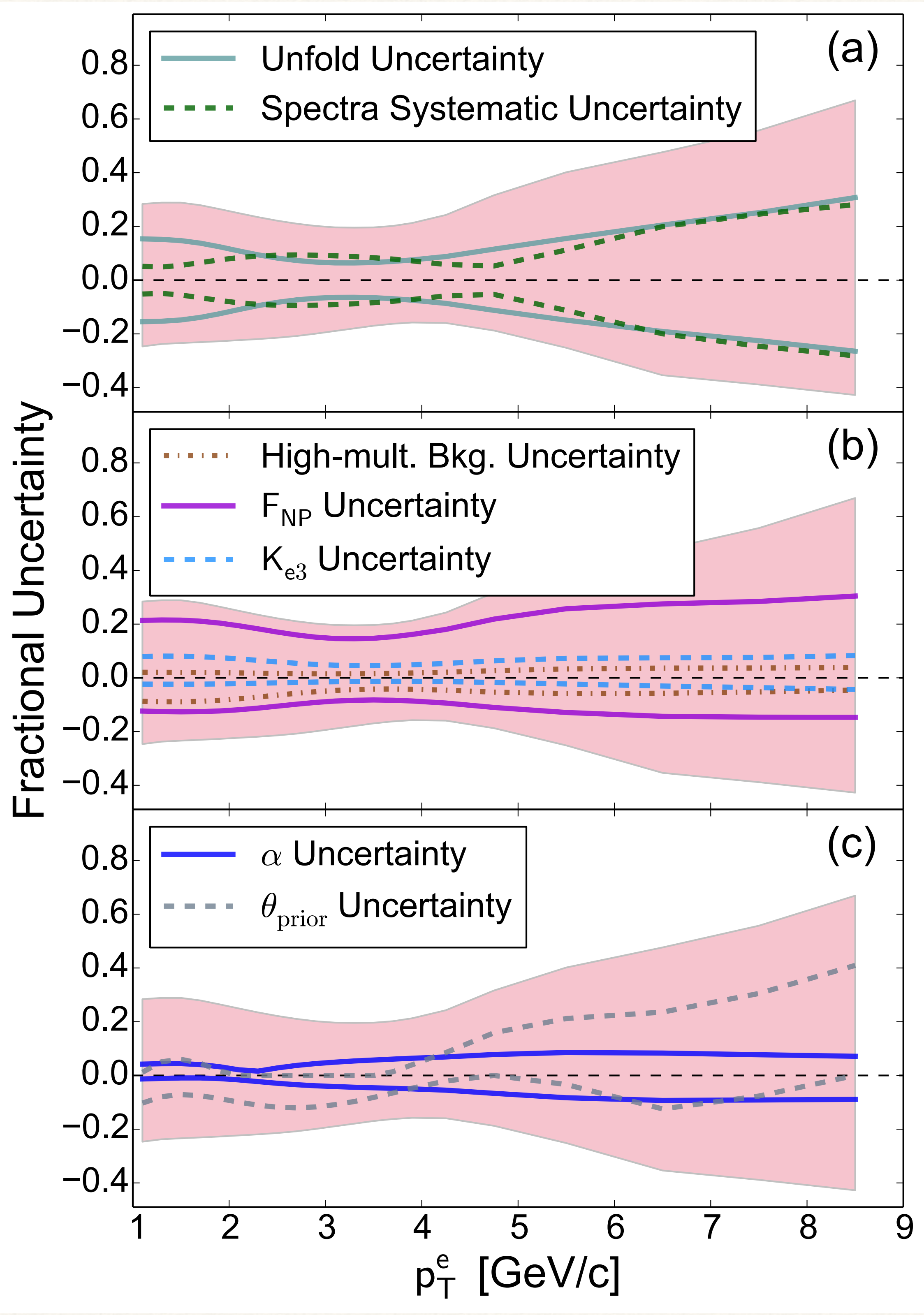
Model Comparisons

arXiv:1509.04662 (2015)

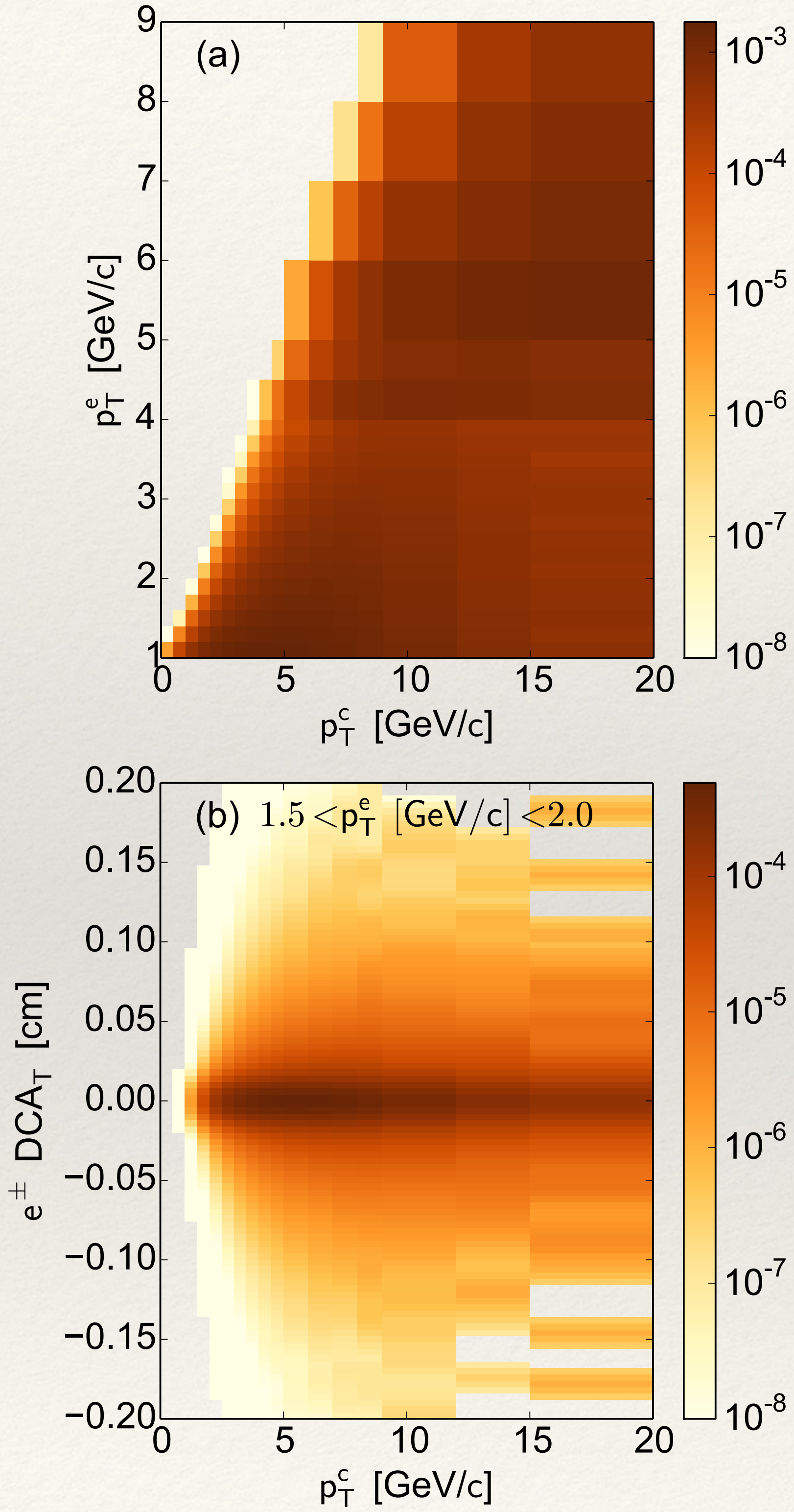


Systematic Uncertainties

- Unfold Uncertainty — due to statistical uncertainties on the data
- Spectra Systematic Uncertainty — vary HF invariant yield within systematic uncertainties
- High-mult. Bkg. Uncertainty — vary the normalization on the “Random” background component
- F_{NP} Uncertainty — vary the normalization of the photonics components
- K_{e3} Uncertainty — vary the normalization of the K_{e3} component
- α Uncertainty — vary the strength of the regularization constraint in the unfolding
- θ_{prior} Uncertainty — vary the shape of the hadron pT distribution used in the regularization

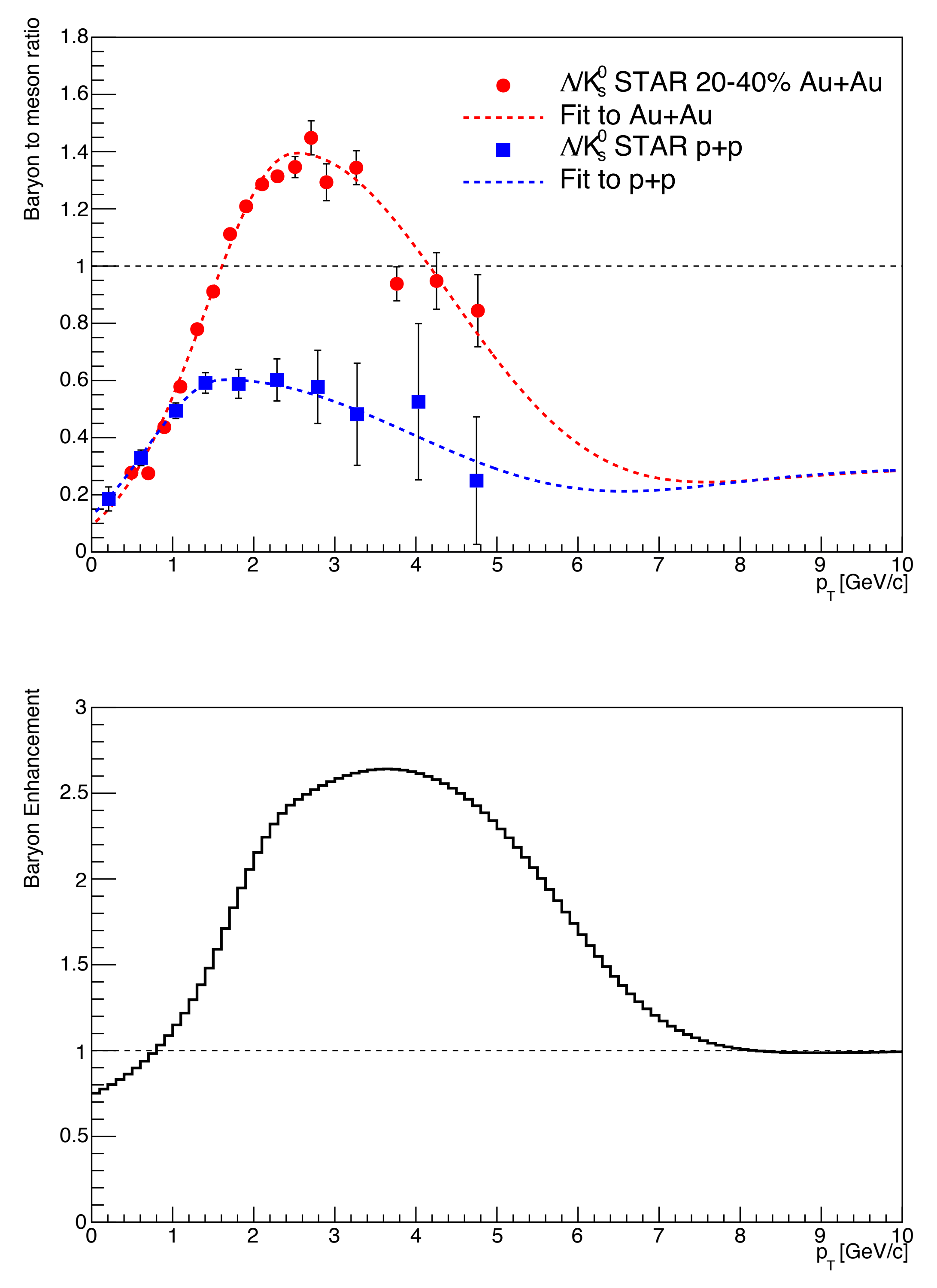


Decay Probabilities



- Decay matrices obtained from PYTHIA 6
  - Forced HF (MSEL=4,5)
  - charm := D^0, $D^{\pm}$, D_s, Λ_c
  - bottom := $B^{\pm}$, B^0, B_s, Λ_b (includes B→D→e)
  - Ratios of hadrons taken from PYTHIA (baryon enhancement tested)
  - Assumes dN/dy shape from PYTHIA

Testing Possible Baryon Enhancement I



- Follow P. Sorensen and X. Dong — *Phys Rev C 74, 024902 (2006)*
- Take the Λ/K_s ratio measured in STAR 20-40% Au+Au at 200 GeV. *(arXiv:nucl-ex/0601042)*
- Take the Λ/K_s ratio measured by STAR in p+p at 200 GeV. *(arXiv:nucl-ex/0601042)*
- Fit both components to parametrize over p_T.
- Fix asymptotic value to 0.3 in both Au+Au and p+p
- Use the ratio of the fits to enhance the Λ_c and Λ_b contributions in the decay matrices.

Testing Possible Baryon Enhancement II

- Including above enhancement causes an increase in the bottom electron fraction.
- Within systematic uncertainties of the measurement.
- Not included as an additional uncertainty.