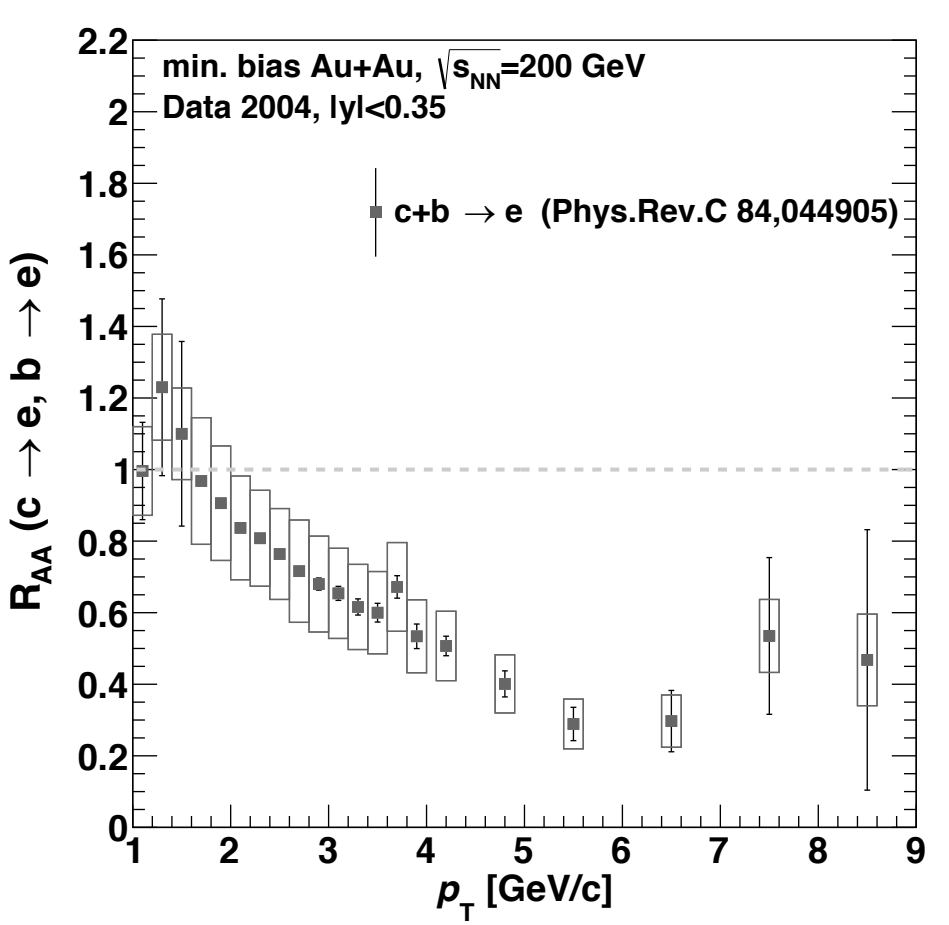
PHENIX measurements of single electrons from charm and bottom decays at midrapidity in Au+Au collisions

Kazuya Nagashima
for the PHENIX Collaboration
(Hiroshima University/RIKEN)

✓ Heavy Flavor Suppression

PHENIX measured strong suppression of HF→e



Heavy flavor energy loss

- Collisional energy loss ~ low p_T
  > Langevin approach
- Radiative energy loss ~ high p_T
  > Bethe-Heitler formula
  > Dead cone effect

Mass ordering (expected)

$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$ → $R_{AA}(u,d,s) < R_{AA}(c) < R_{AA}(b)$?

✓ Charm and Bottom Suppression

PHENIX found

$R_{AA}(b \rightarrow e) > R_{AA}(c \rightarrow e)$

[In 2014-2016]

PHENIX collected

AuAu (HF): 4.9nb^{-1}

pp: 23pb^{-1}

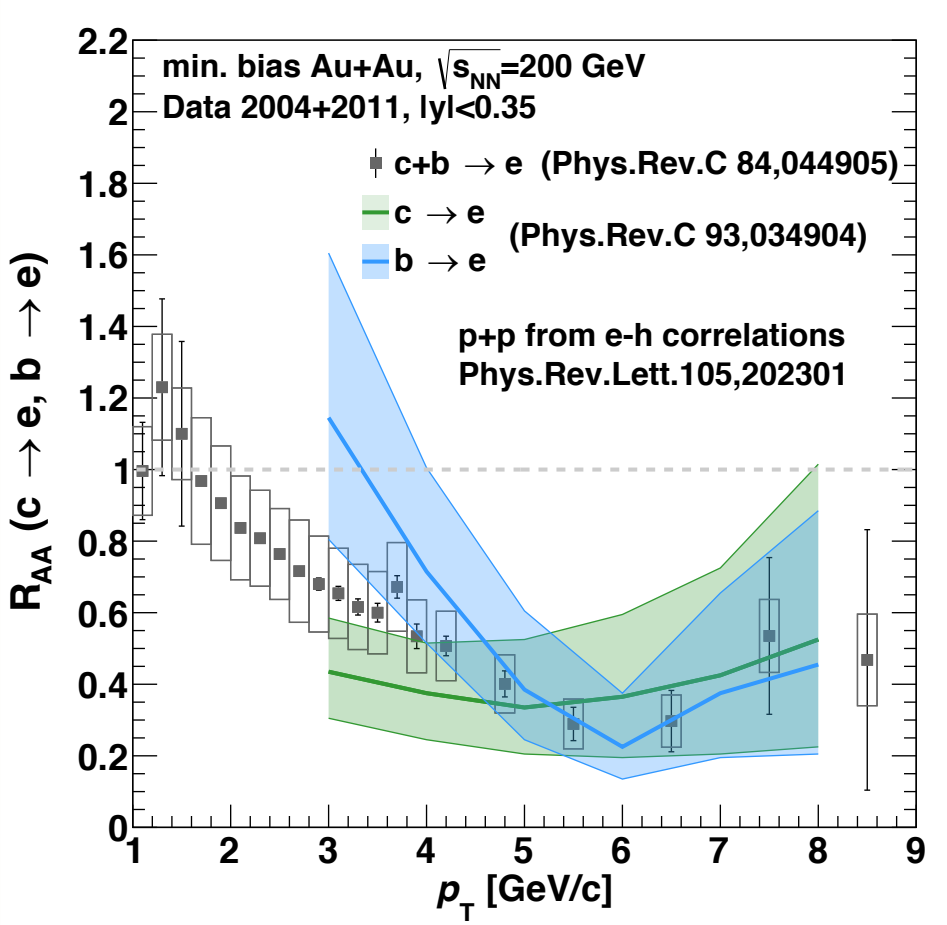
> high precision

> centrality dependence

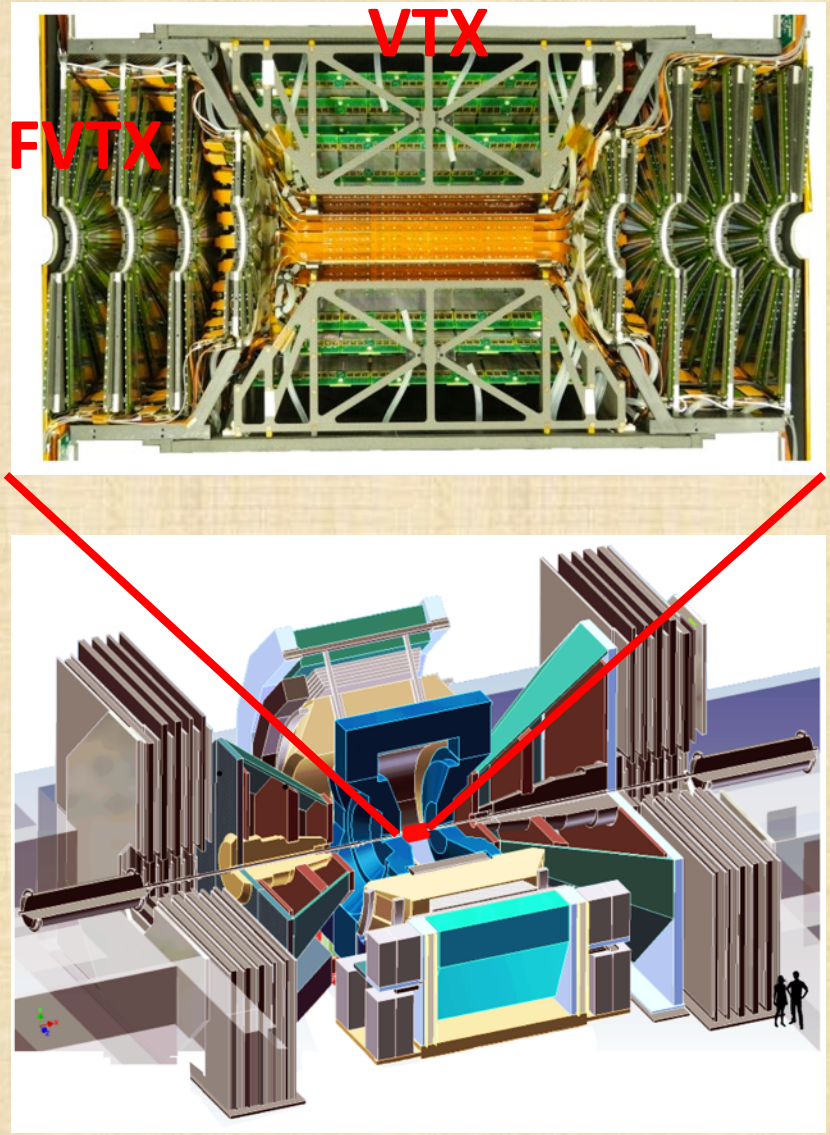
> flow measurement

provide strong constraint on QGP property

Today's result use 1/8 of full dataset



✓ PHENIX Silicon Vertex Detector (VTX)



Silicon Vertex Detector (VTX)

- installed in 2011
- 2 pixel layers + 2 strip layers
  (σ_ϕ = 14.4 μm) (σ_ϕ = 23 μm)
- precise collision vertex

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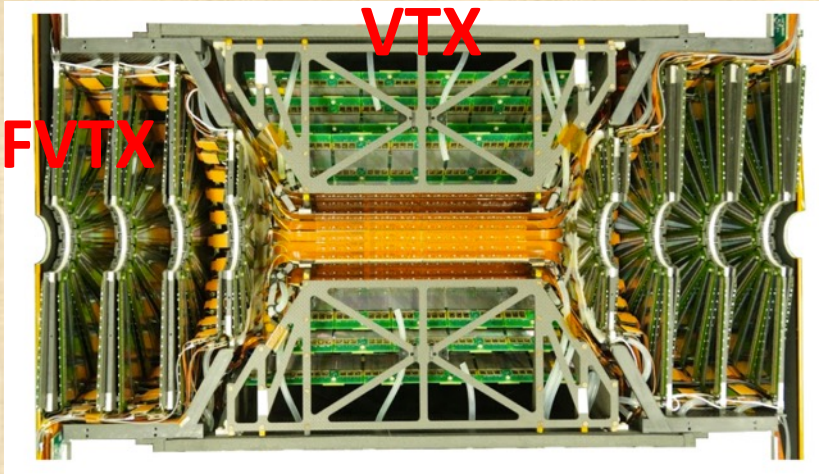

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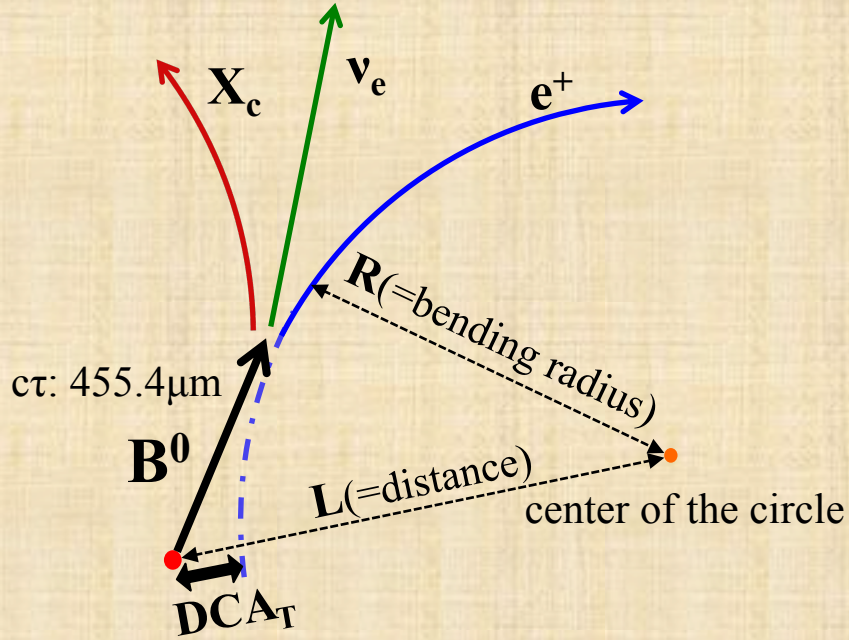


Precise displaced tracking

- Distance of Closest Approach(DCA)

$$DCA_T = L - R$$

- DCA analysis allows a separation of
  $B^0 \rightarrow e$ from $D^0 \rightarrow e$
  B^0 :cτ = 455.4 μm
  D^0 :cτ = 122.9 μm
- almost all BG from $DCA_T = 0$

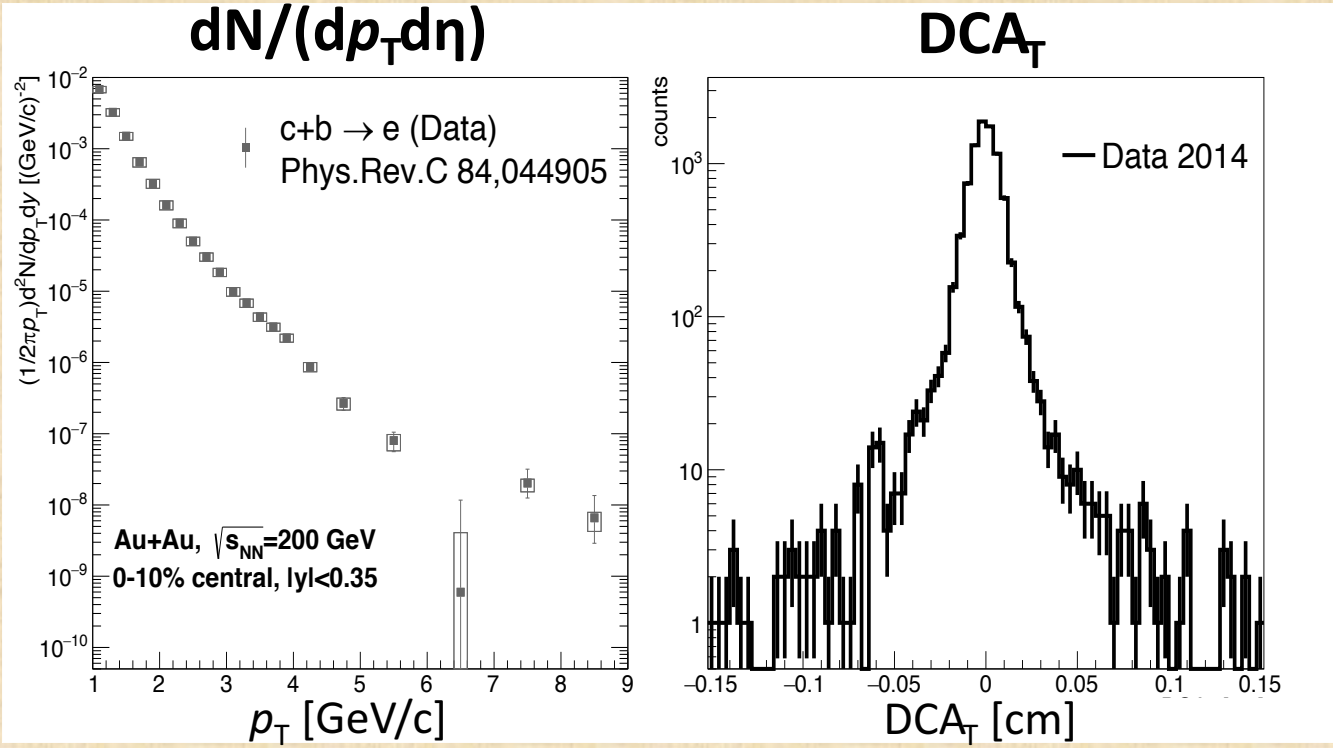
✓ Bayesian Inference Techniques

- Bayes' theorem $\boldsymbol{P(\theta|x) \propto P(x|\theta)\pi(\theta)}$
- Simultaneous fit to dN/dp_T and $DCA_T(p_T)$

Measured data
dN/dp_T, $DCA_T(p_T)$

↓

$\boldsymbol{P(x|\theta)\pi(\theta)}$
Likelihood



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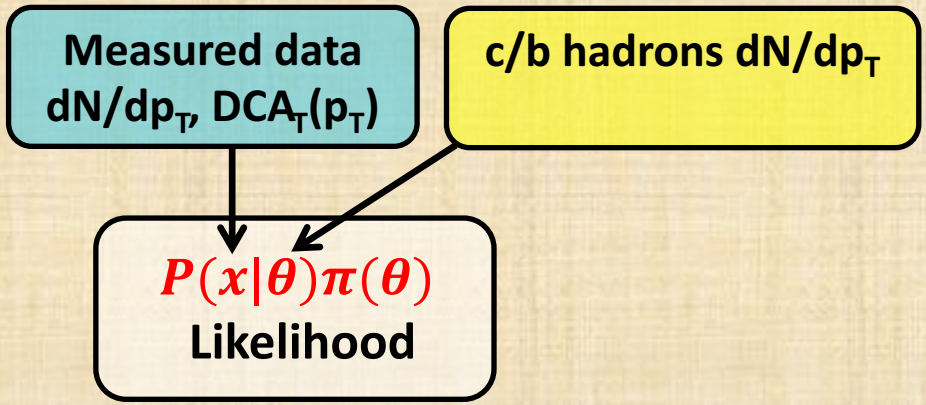

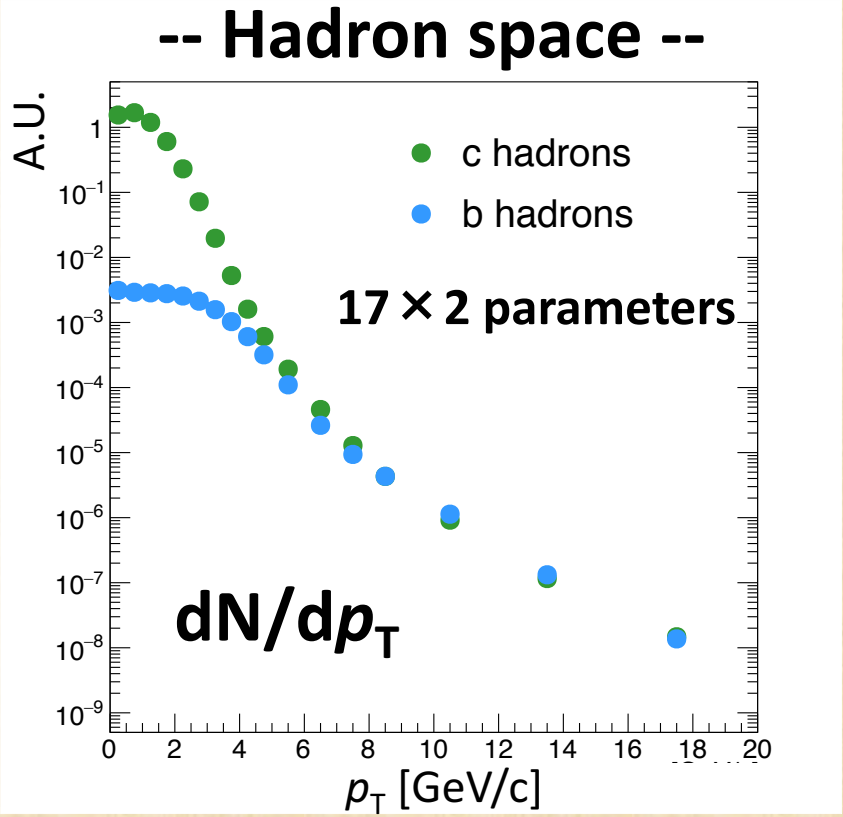

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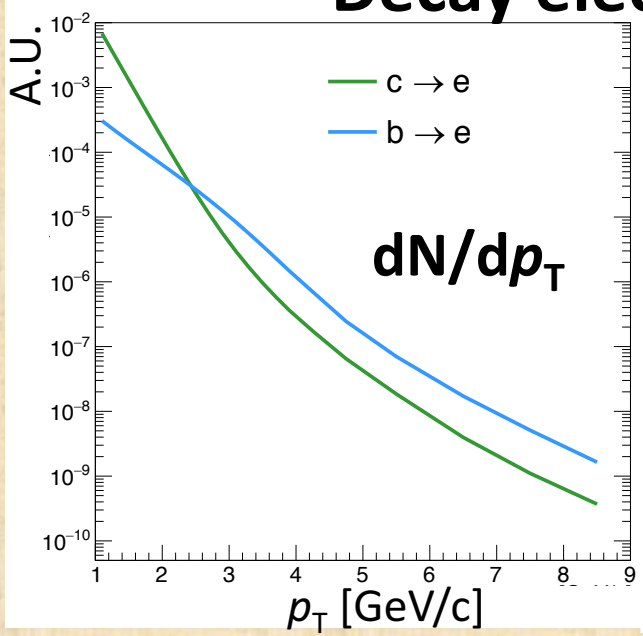
Measured data dN/dp_T, $DCA_T(p_T)$

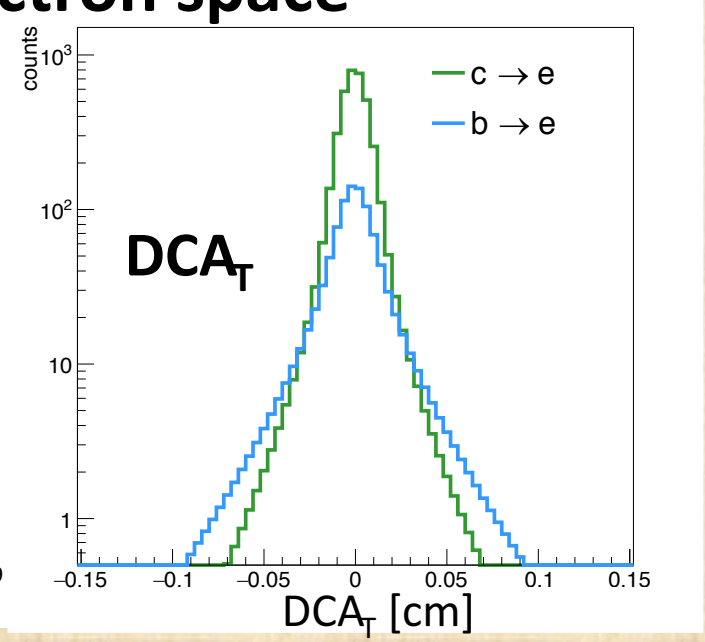
c/b hadrons dN/dp_T → electron space

$\boldsymbol{P(x|\theta)\pi(\theta)}$
Likelihood

From PYTHIA6 decay model

-- Decay electron space --





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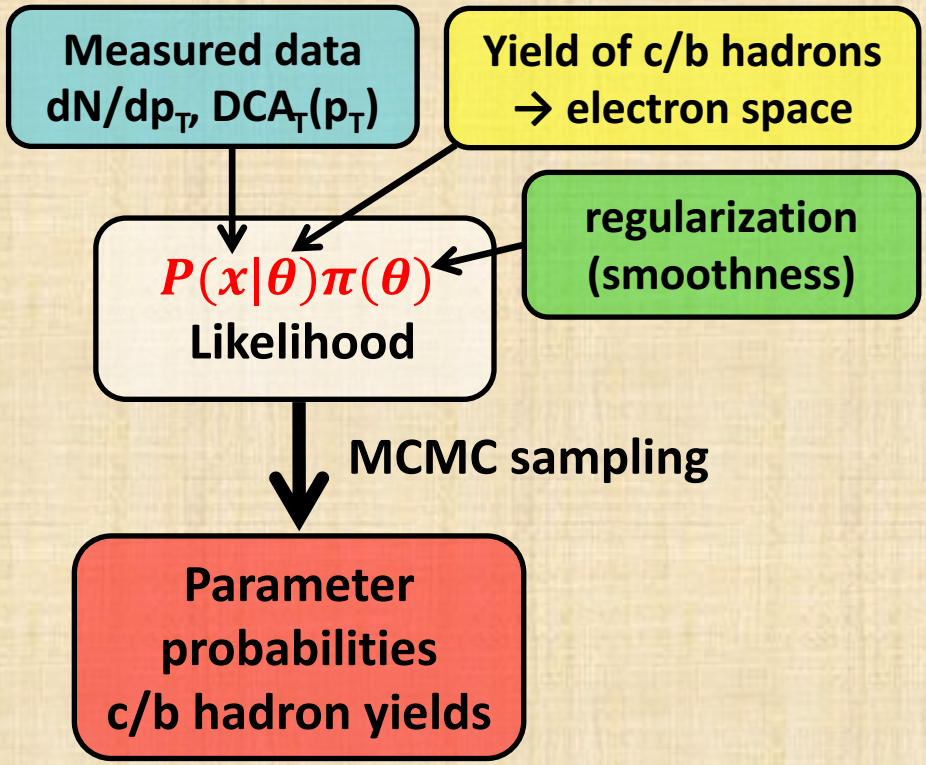
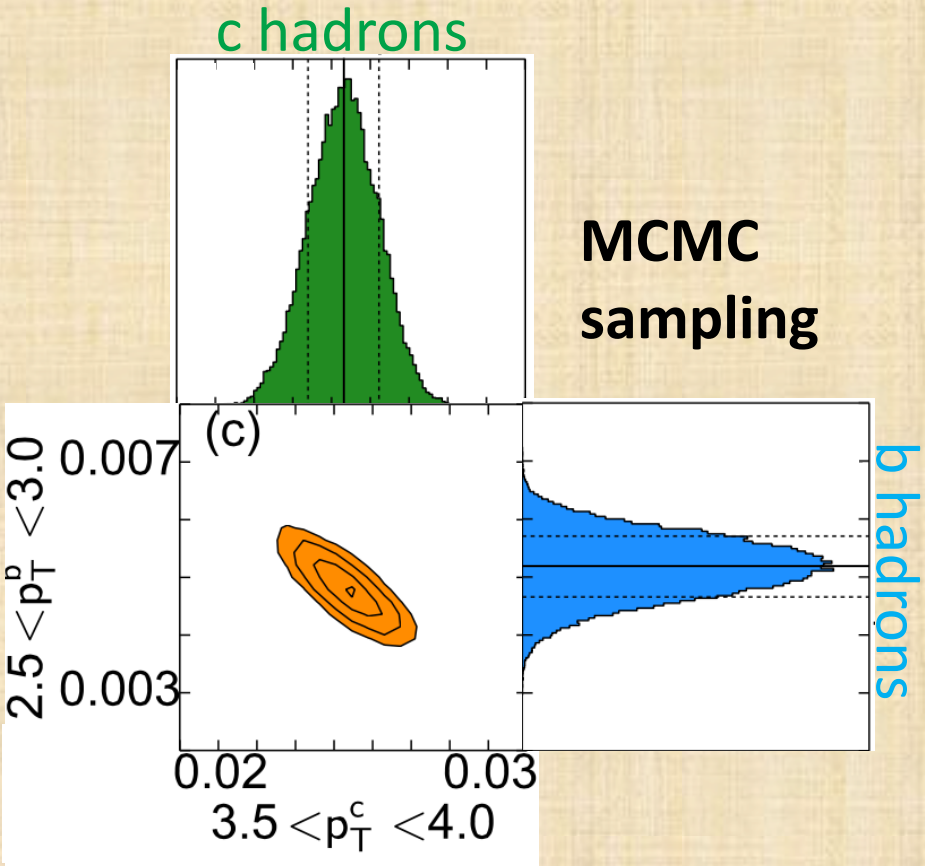
- Bayes' theorem $\boldsymbol{P(\theta|x) \propto P(x|\theta)\pi(\theta)}$
- Simultaneous fit to dN/dp_T and $DCA_T(p_T)$
- employ Markov Chain Monte Carlo (MCMC) for sampling





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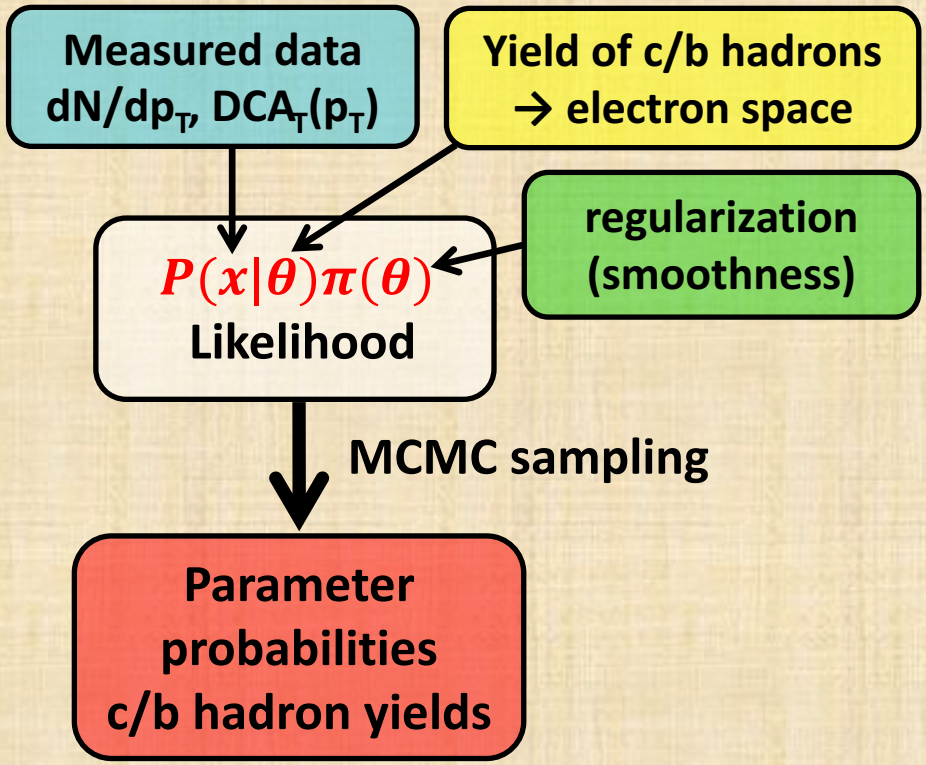
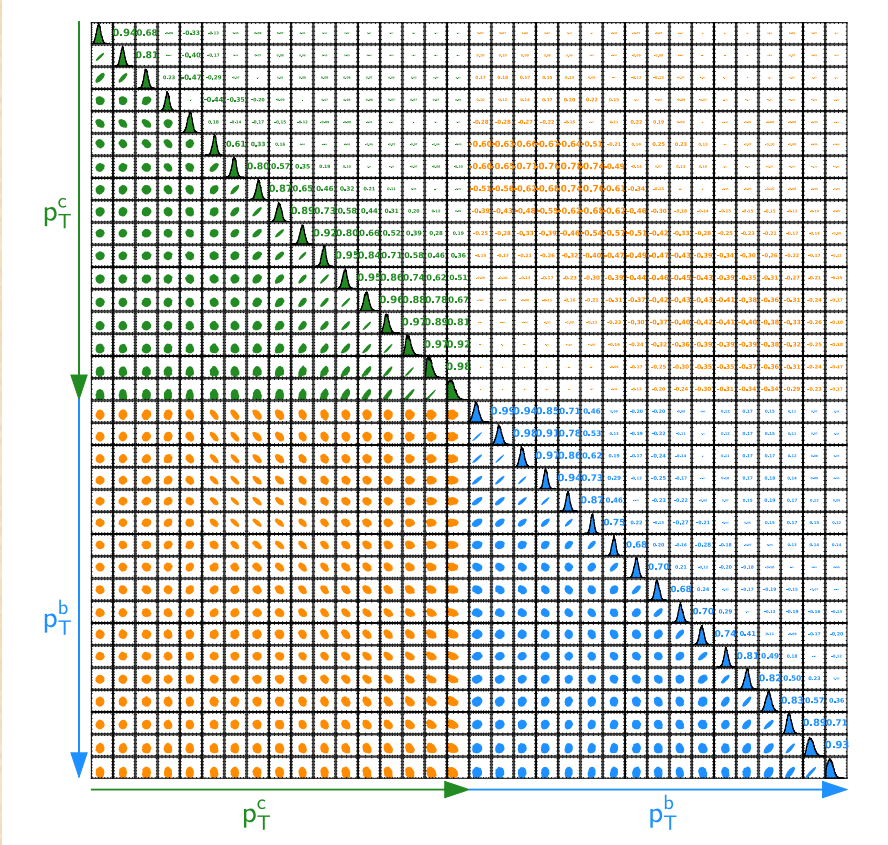
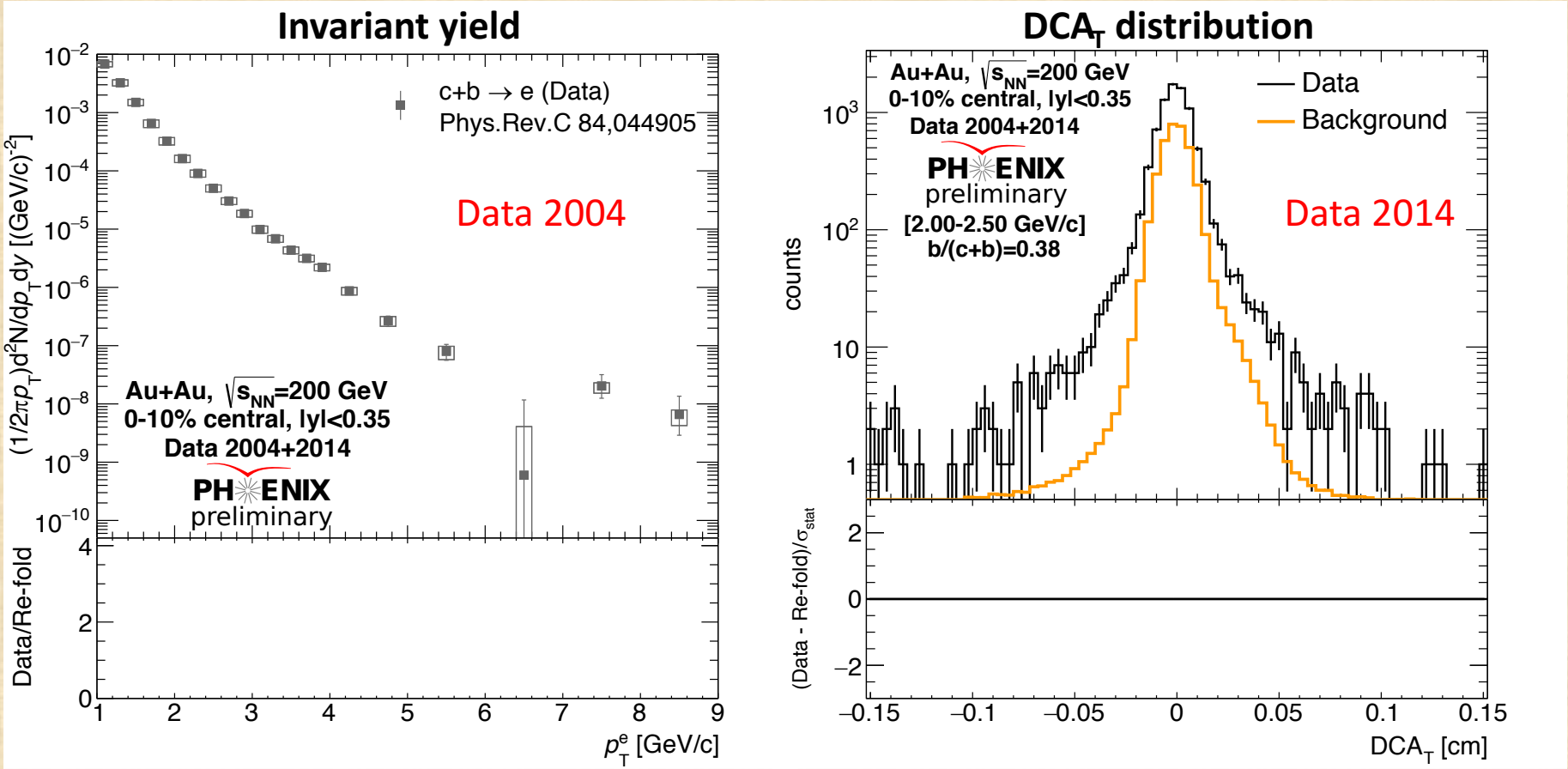




✓ Comparison to Data in 0-10% central



Simultaneous fit to Invariant yield and $DCA_T(p_T)$

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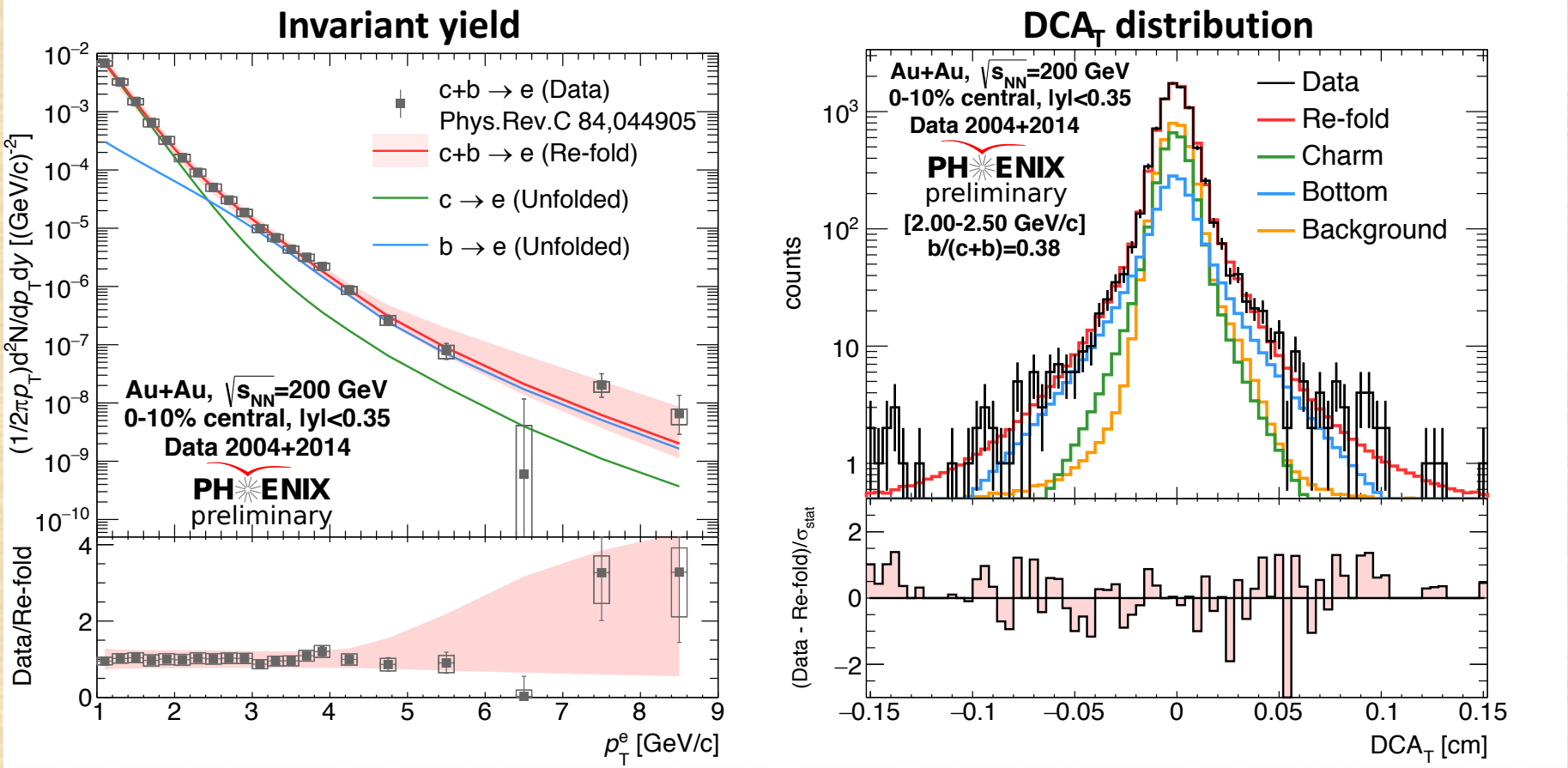

Simultaneous fit to Invariant yield and DCA$_T$(p_T)

Unfolding results agree well with measured data

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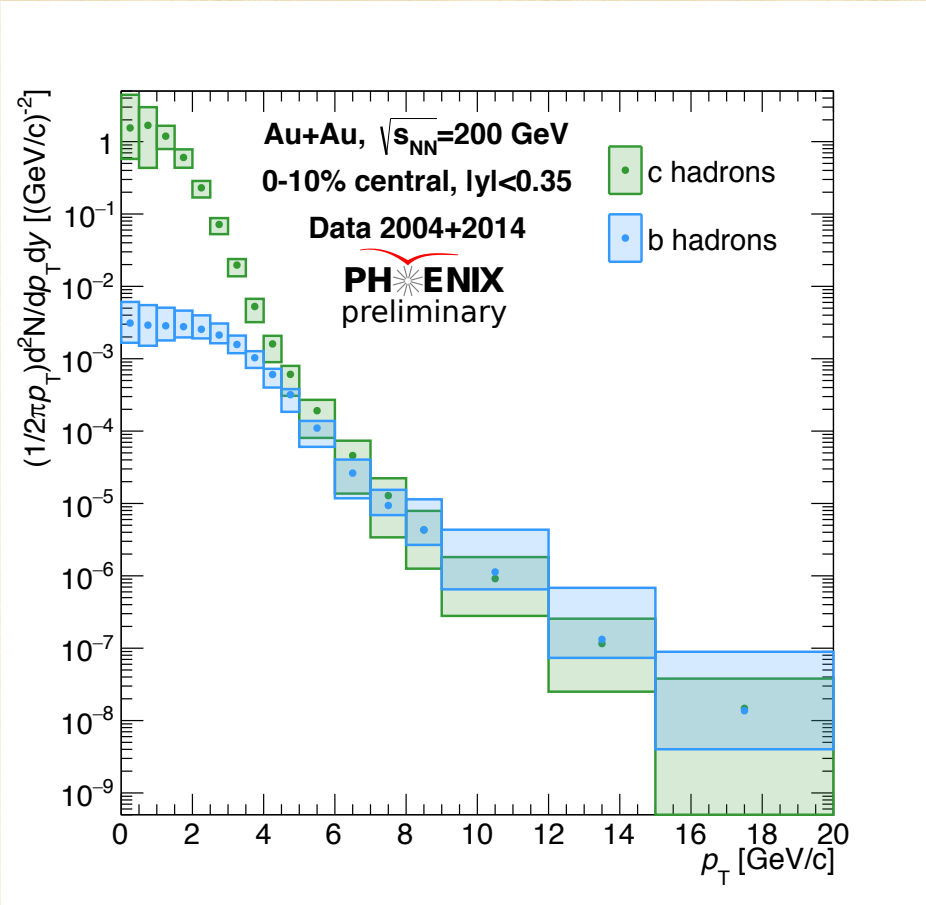

- Invariant yields of charm and bottom hadrons

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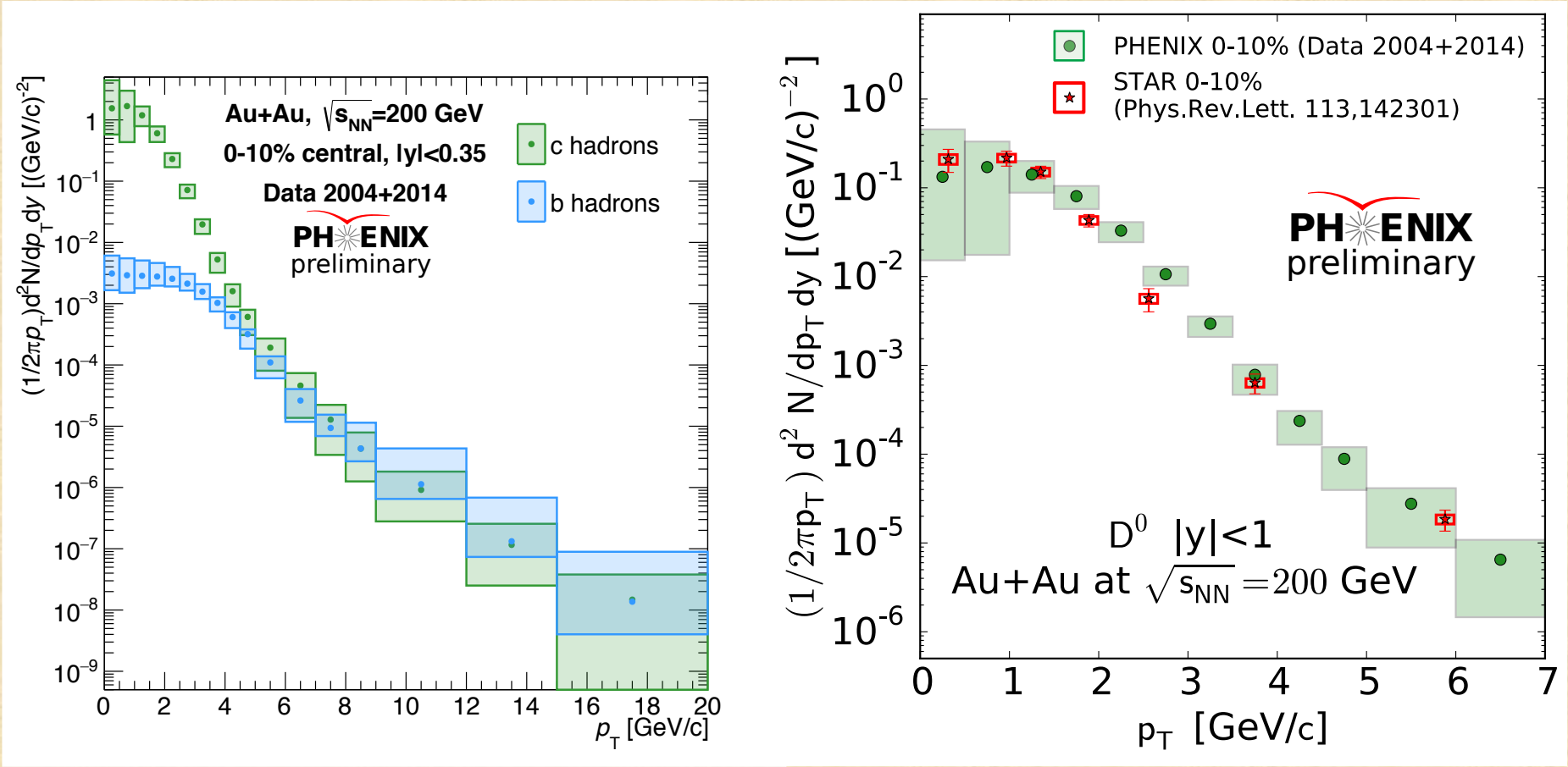


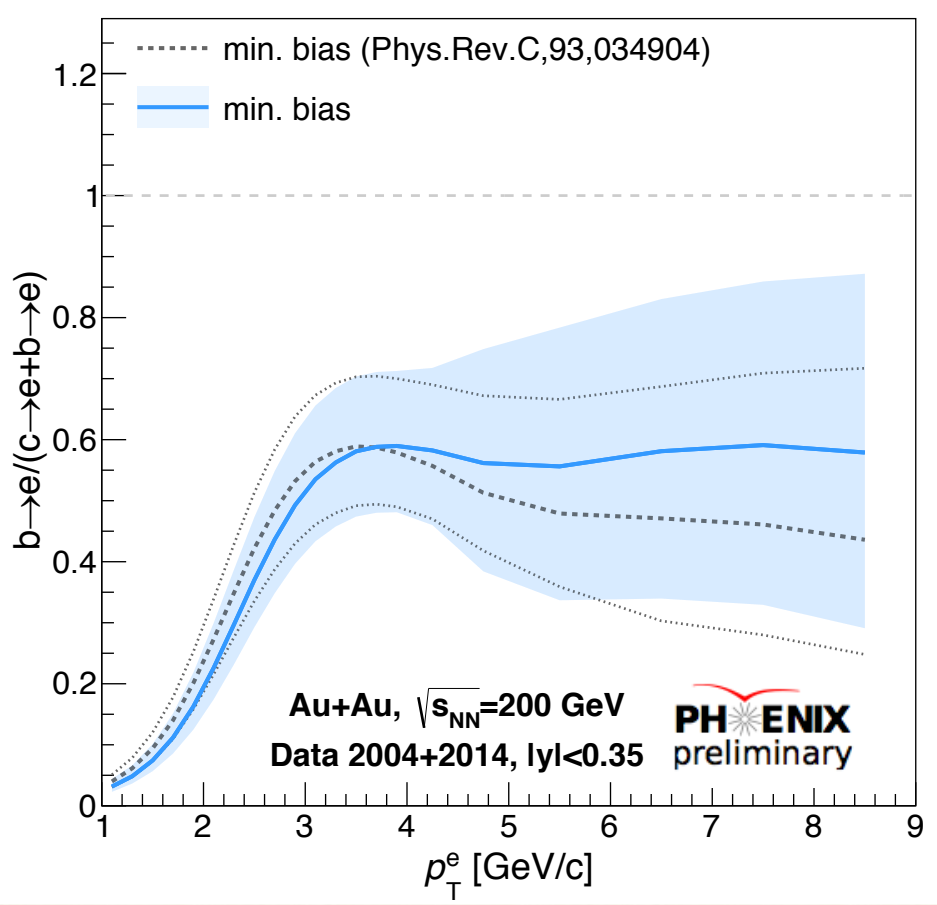
- Invariant yields of charm and bottom hadrons
- D^0 extracted from c hadrons and PYTHIA model

→ agree with the STAR direct measurement

✓ Bottom Electron Fraction

PHENIX published bottom electron fraction in MB AuAu (*Phys.Rev.C,93,034904*)

New result reproduce published result well



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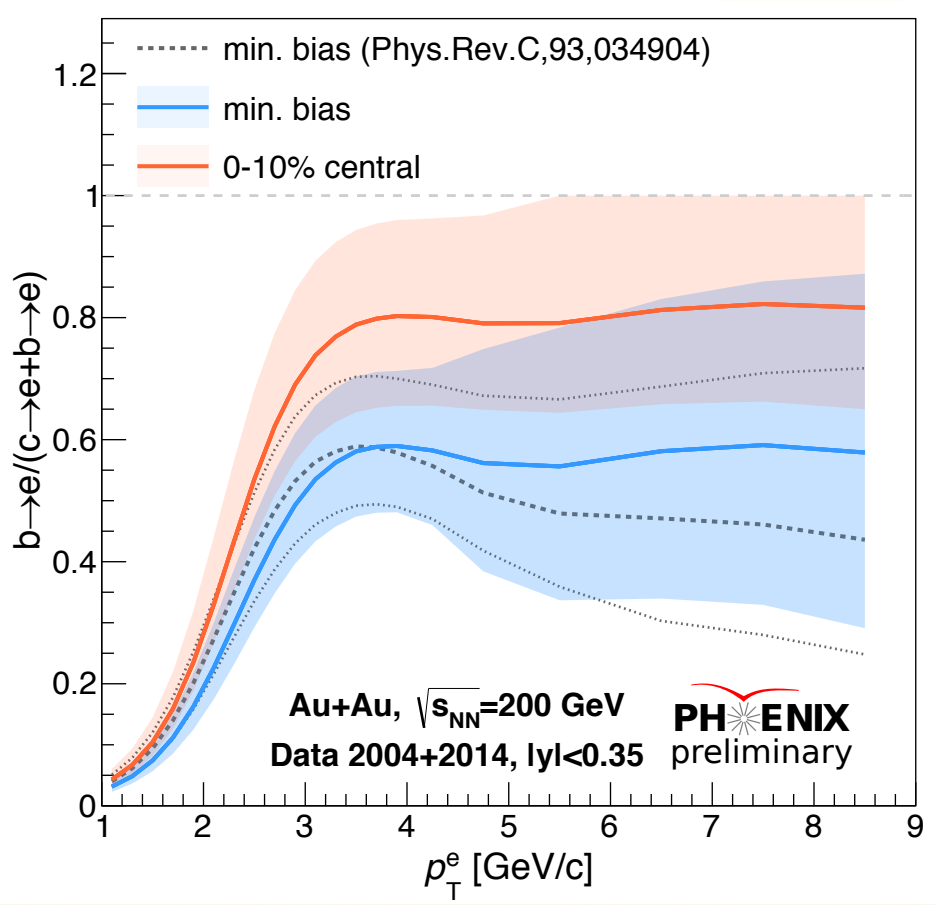
b-fraction in 0-10% AuAu seems higher than MB (consistent within uncertainty)
→ need more precision

New



✓ Charm and Bottom Suppression

R_{AA} of c→e and b→e

$$R_{AA}^{b\to e} = \frac{F_{AuAu}}{F_{pp}} R_{AA}^{HF}$$

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

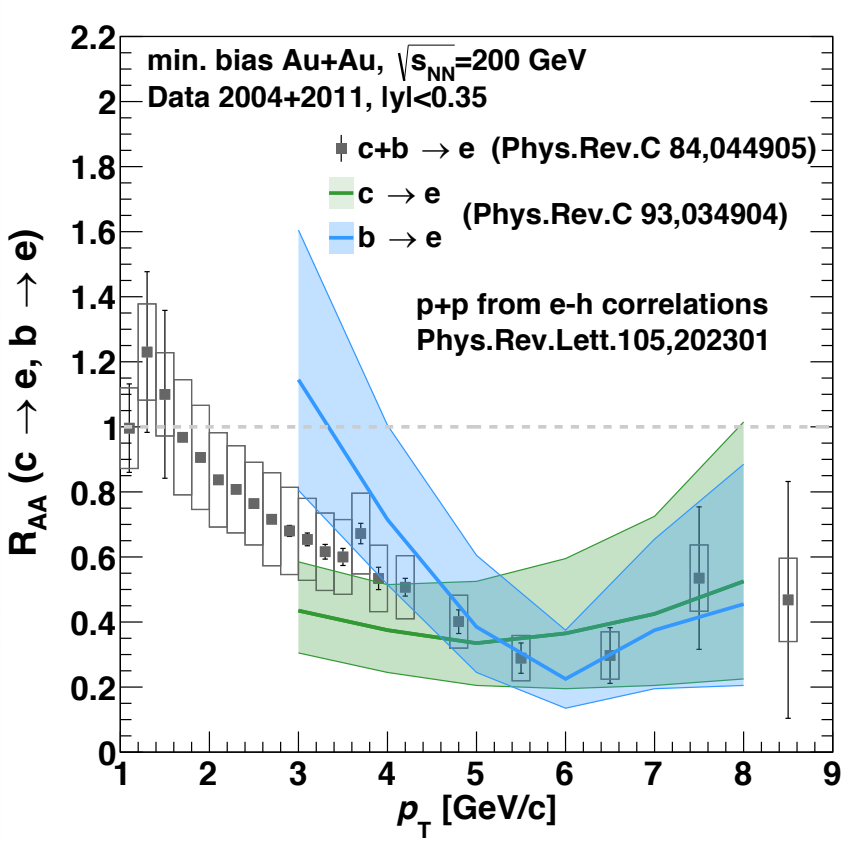
R_{AA}^{HF} : PHENIX measurement

F_{AuAu} : Unfolding result (1/4 of 2014 data)

F_{pp} : STAR e-h correlations (p_T: 3.0~8.0 GeV/c)

2004+2011 AuAu MB

Phys.Rev.C,93,034904



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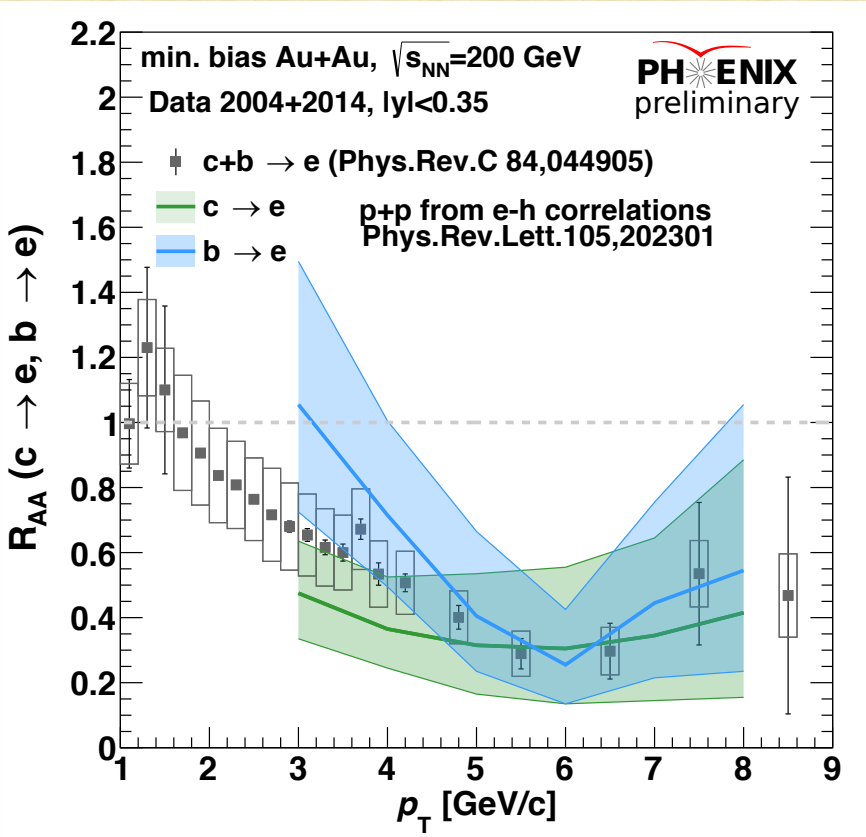

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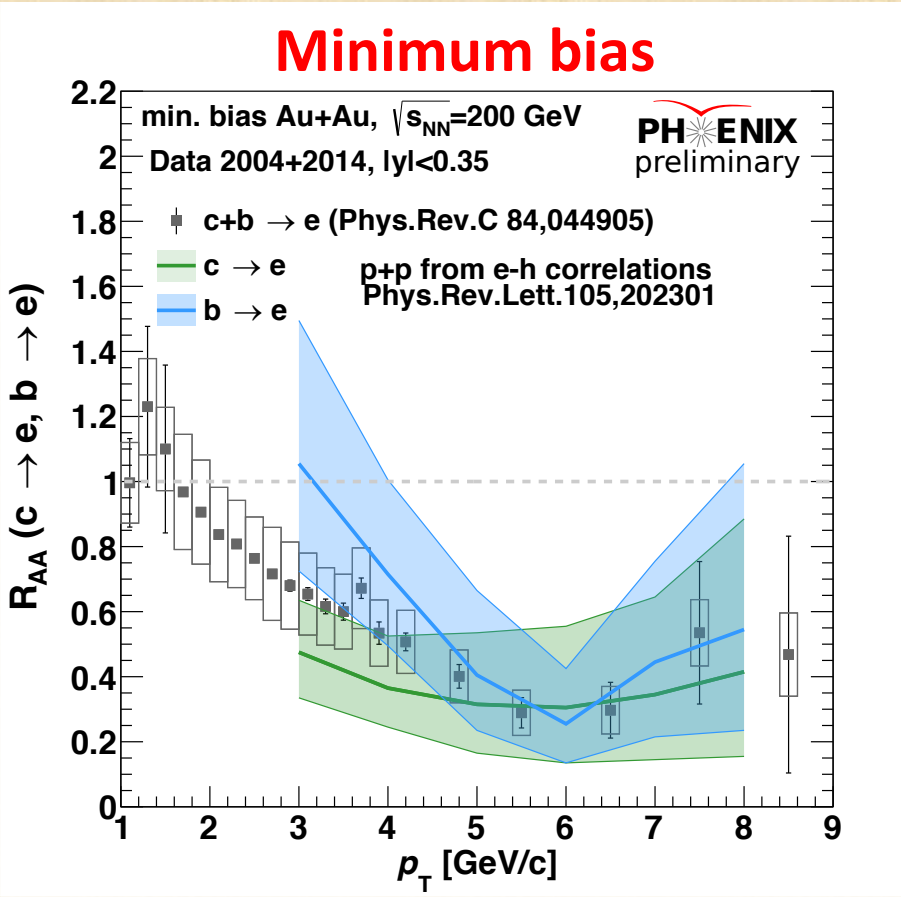

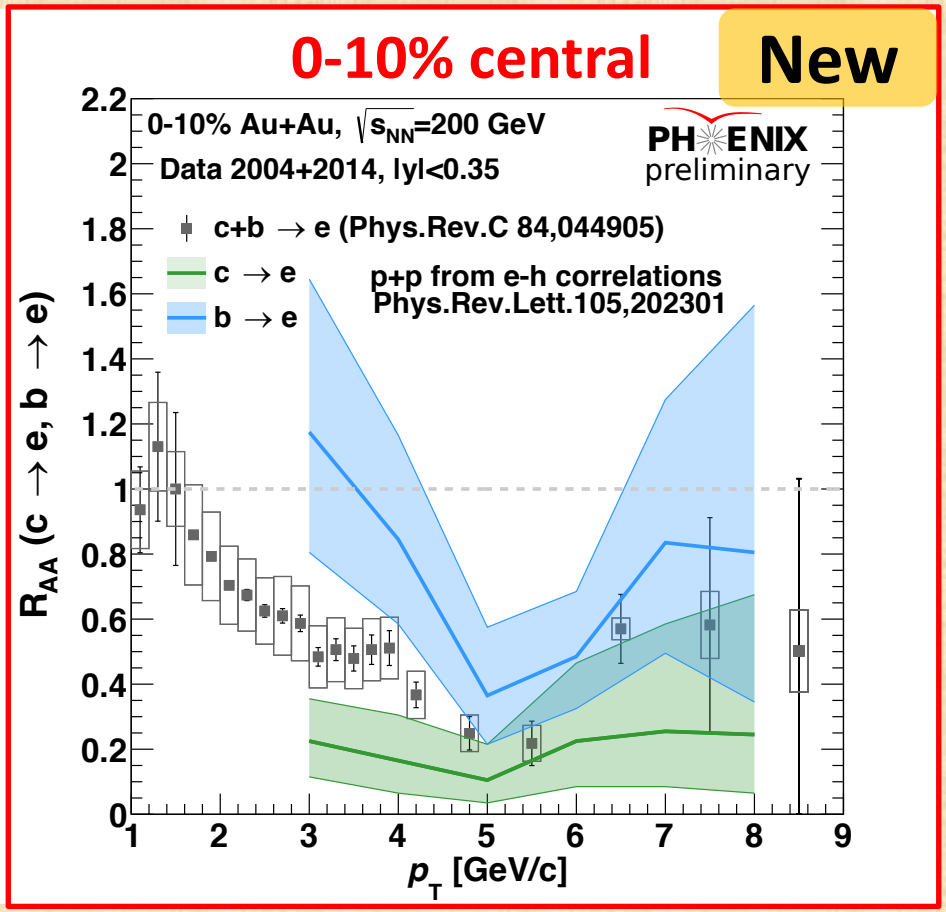

> b→e is less suppressed than c→e in 3.0-5.0 GeV/c (0-10% AuAu)

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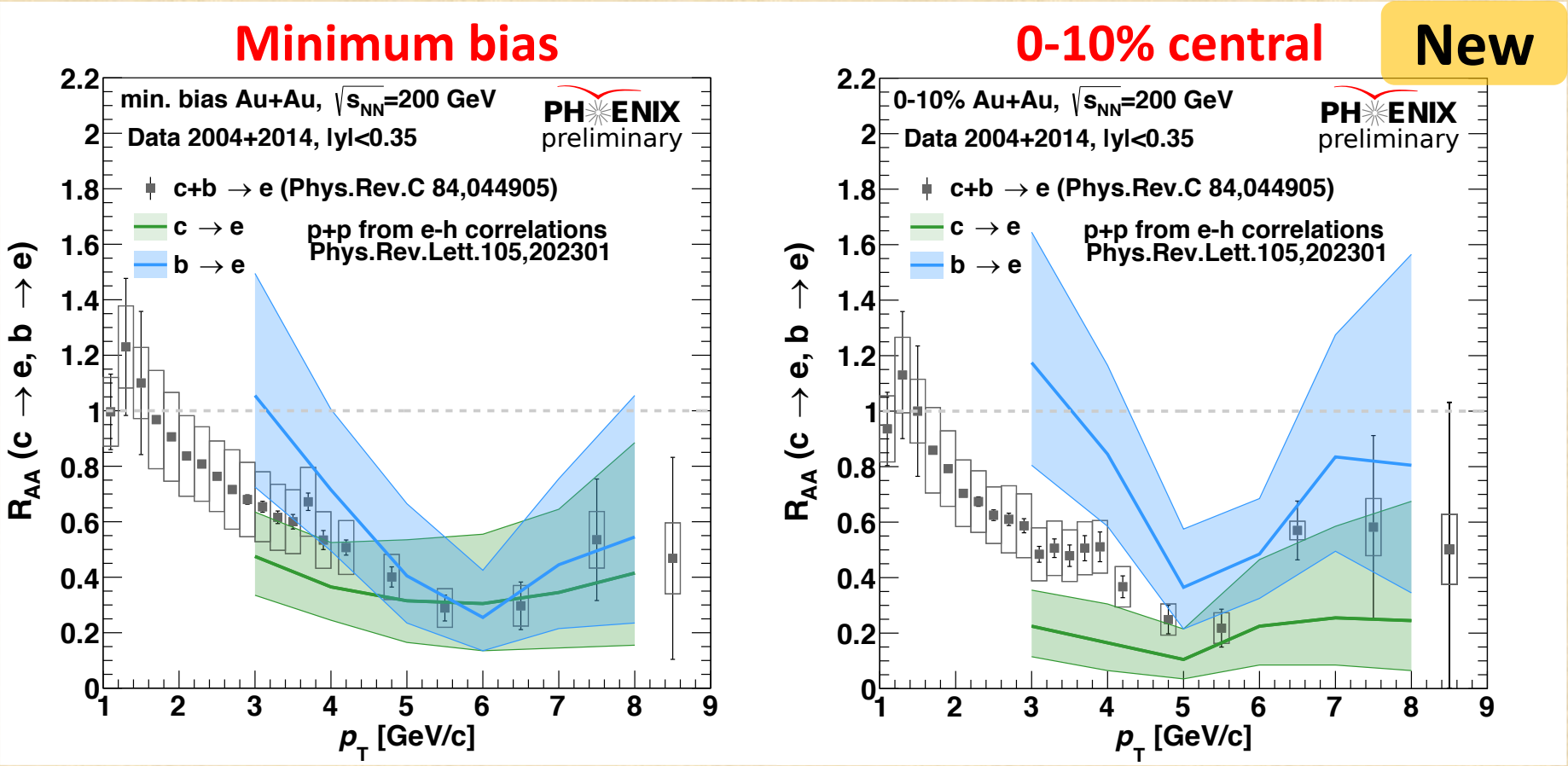


> b→e is less suppressed than c→e in 3.0-5.0 GeV/c (0-10% AuAu)

> c→e in 0-10% is suppressed stronger than c→e in MB

→ Other centrality results are ongoing

✓ Model Comparison in Bottom Fraction

[Theoretical models]

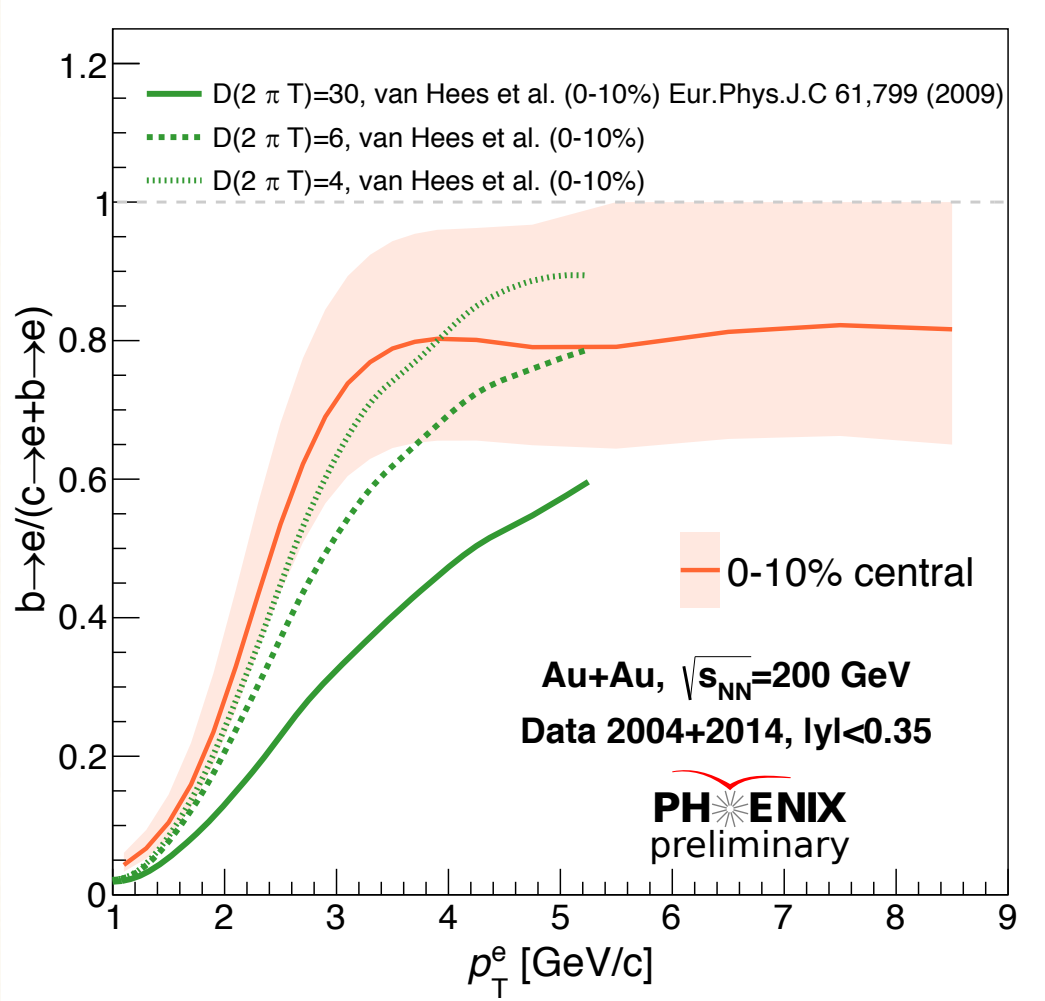
T-Matrix approach

> hadron resonance in QGP

> Diffusion coefficient: 4-30

→ D(2πT) < 4

→ strong coupling in QGP



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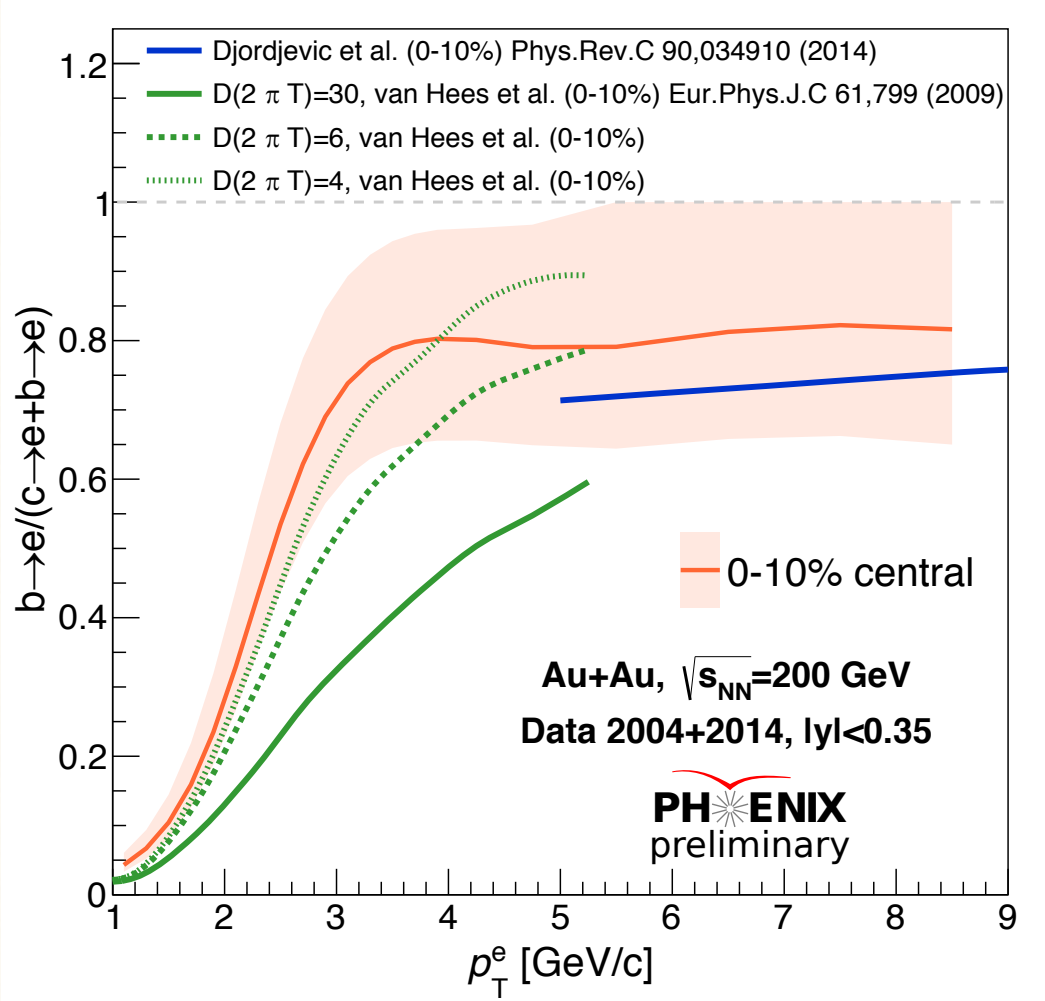
DGLV model

> rad. + coll. energy loss

> dynamical E-loss formalism

→ reasonable agreement



✓ Model Comparison in R_{AA}

0-10% central

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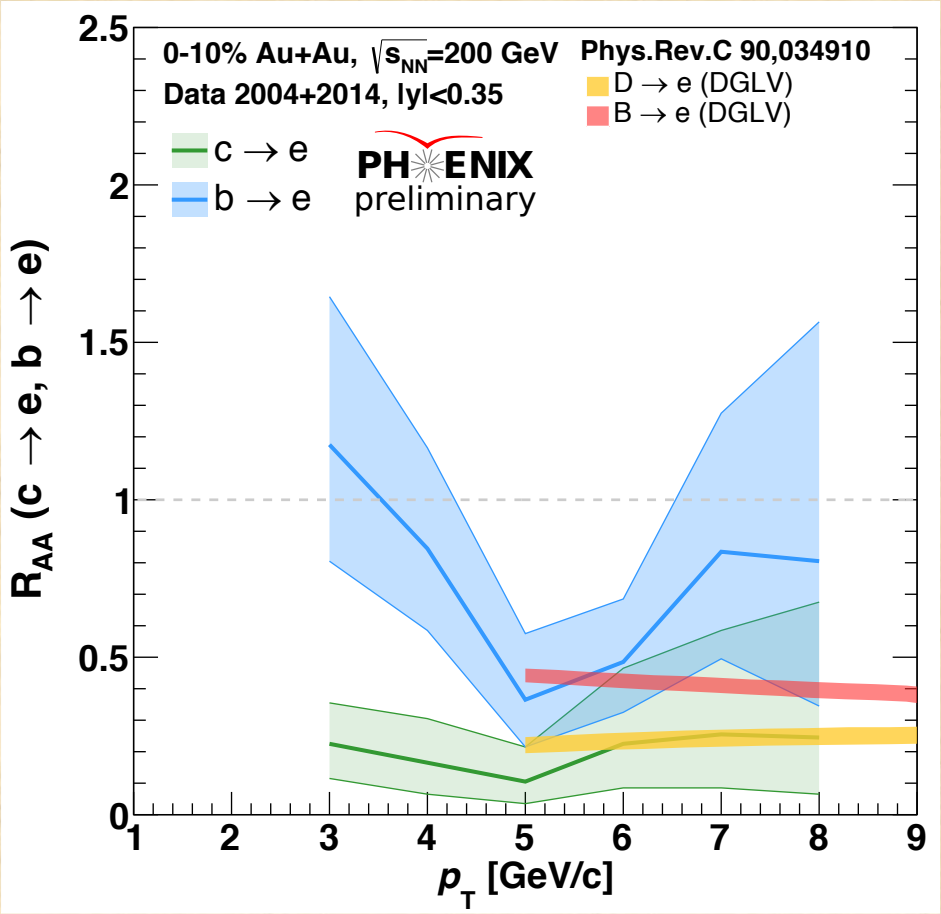

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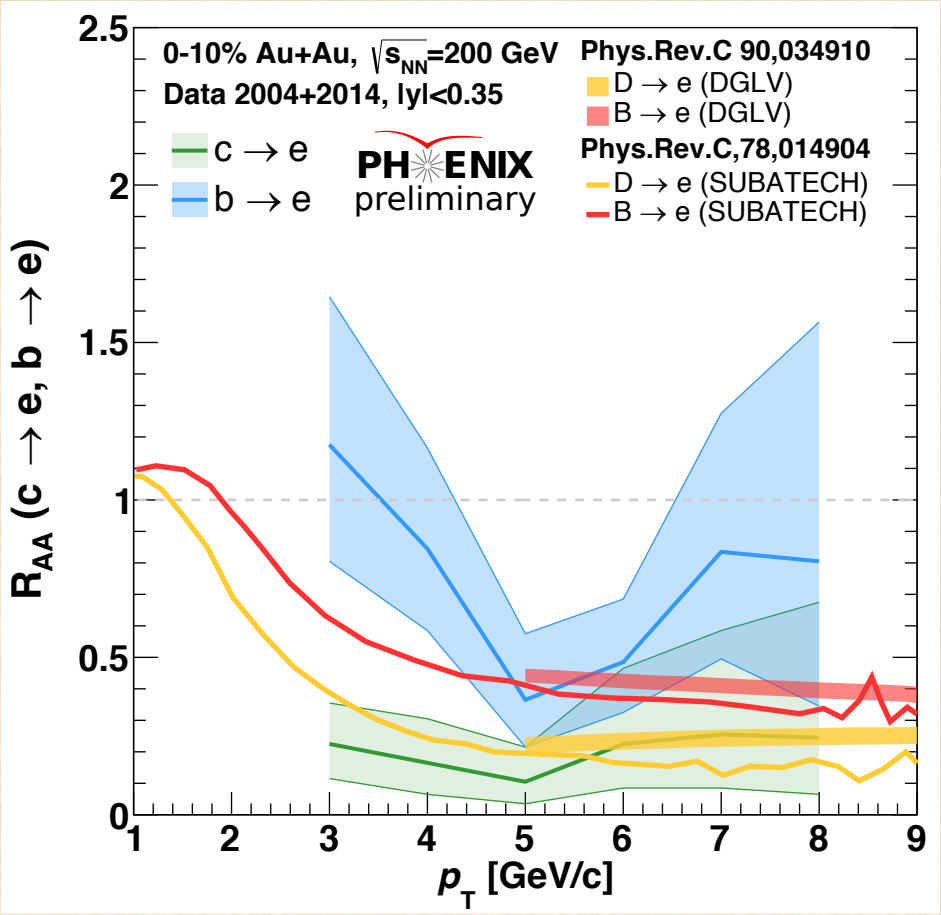
SUBATECH

> coll. + rad.(LPM)

> Hard Thermal Loop



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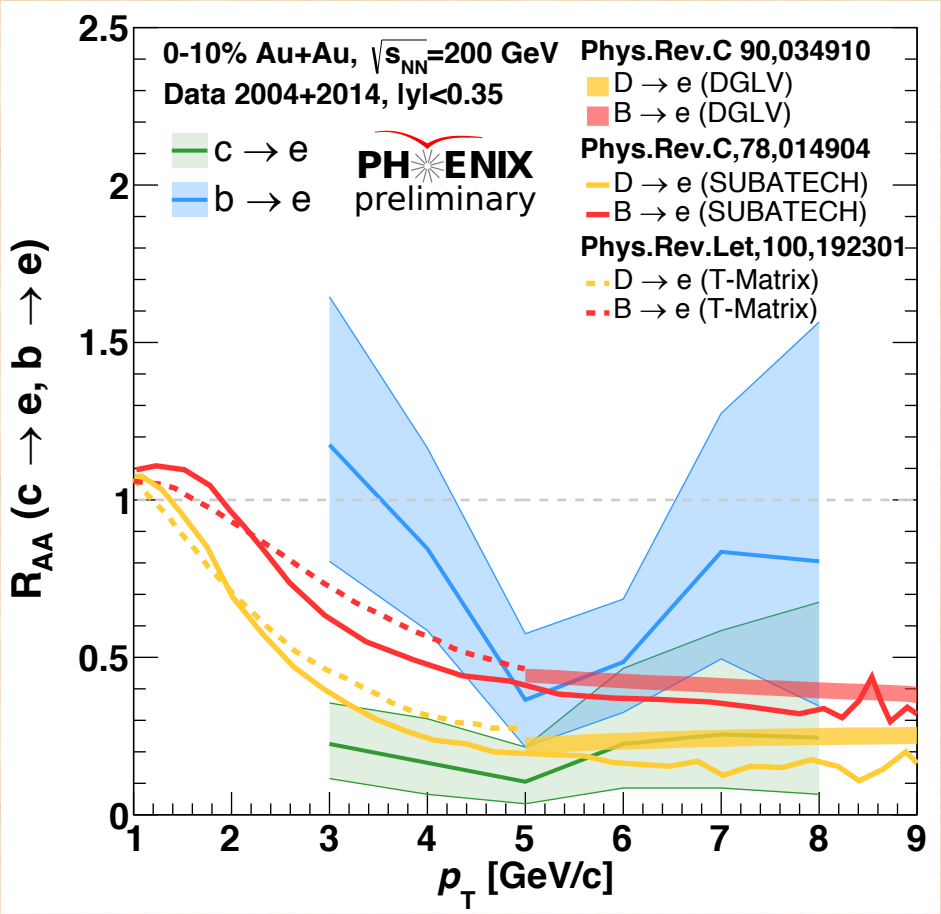

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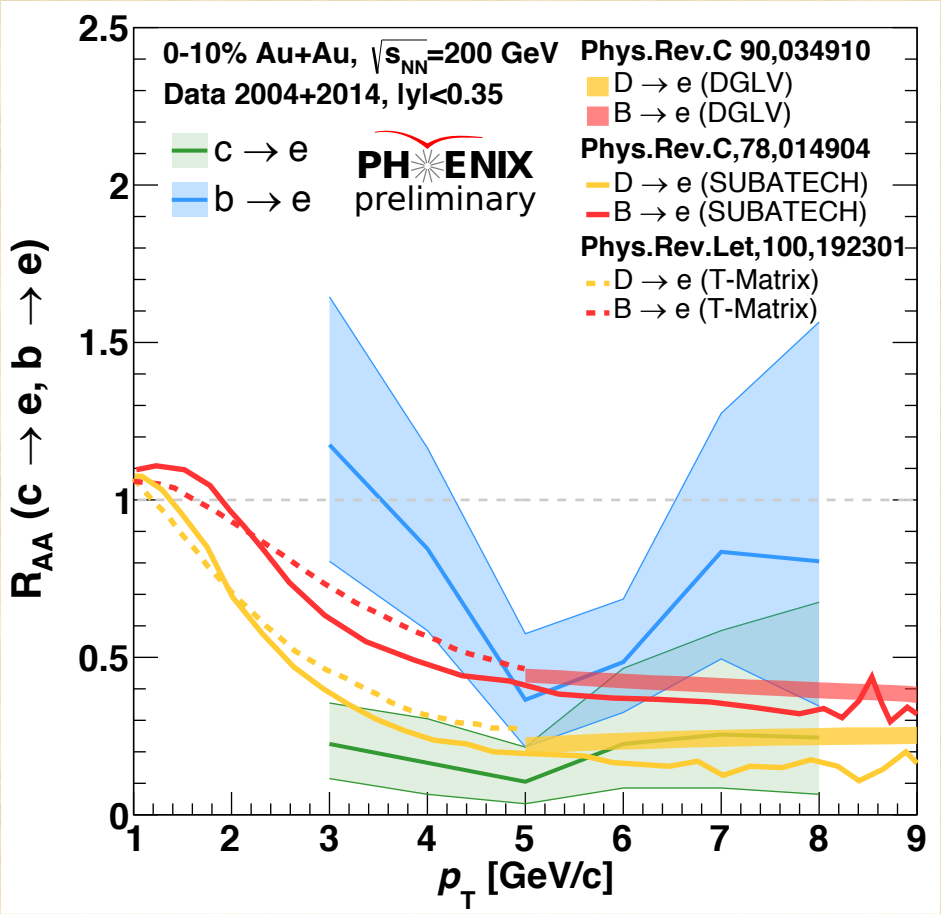


Theory: reasonable agreement, but need smaller diffusion?

Data: smaller uncertainty and broader p_T range (coming soon)

✓ Future Prospects

[Update points]

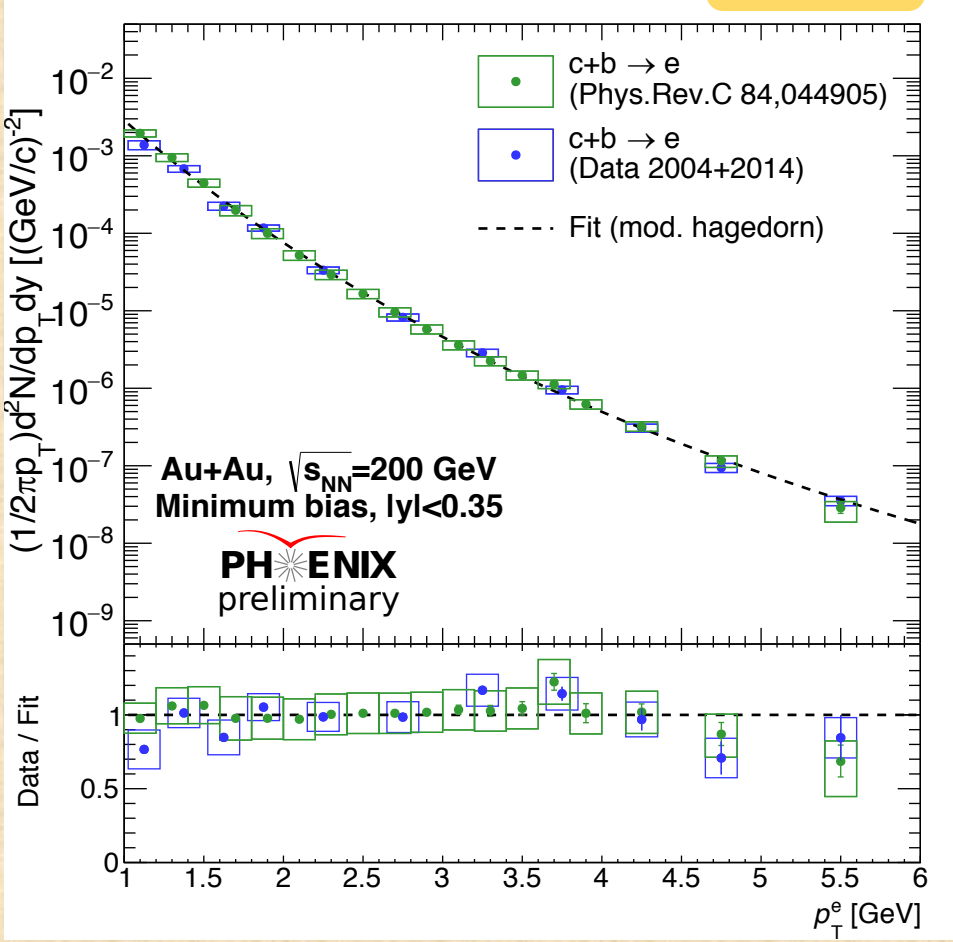
- use full statistics (× 8)
- new inclusive dN/dp_T
- new pp reference

> smaller systematic uncertainty

> broader p_T range (1-9 GeV/c) for R_{AA} of c→e, b→e

> R_{AA} of c and b hadrons

New



- PHENIX also measure B→J/ψ

> very low p_T B meson

→ see Cesar Silva's Talk (8.4 – Wed 16:30)

✓ Summary

- **Measurement of $R_{AA}^{c\to e}$ and $R_{AA}^{b\to e}$ in 0-10% AuAu**
  - $R_{AA}^{b\to e} > R_{AA}^{c\to e}$ (in 3.0-5.0 GeV/c)
  - $R_{AA}^{c\to e}$ (MB) > $R_{AA}^{c\to e}$ (0-10%)
- **Model Comparison**

  Bottom electron fraction

  > strong coupling in QGP (D(2πT) < 4)

  Nuclear modification factor R_{AA}

  > reasonable agreement, but needs smaller diffusion?
- **Future prospects**
  - Full dataset in AuAu and pp provide more precise
  - Measurement of $R_{AA}^{b\to e}$ and $R_{AA}^{c\to e}$ in broader p_T range ~1.0-9.0 GeV/c

→ **Final result is coming soon!!**

Thank you !!

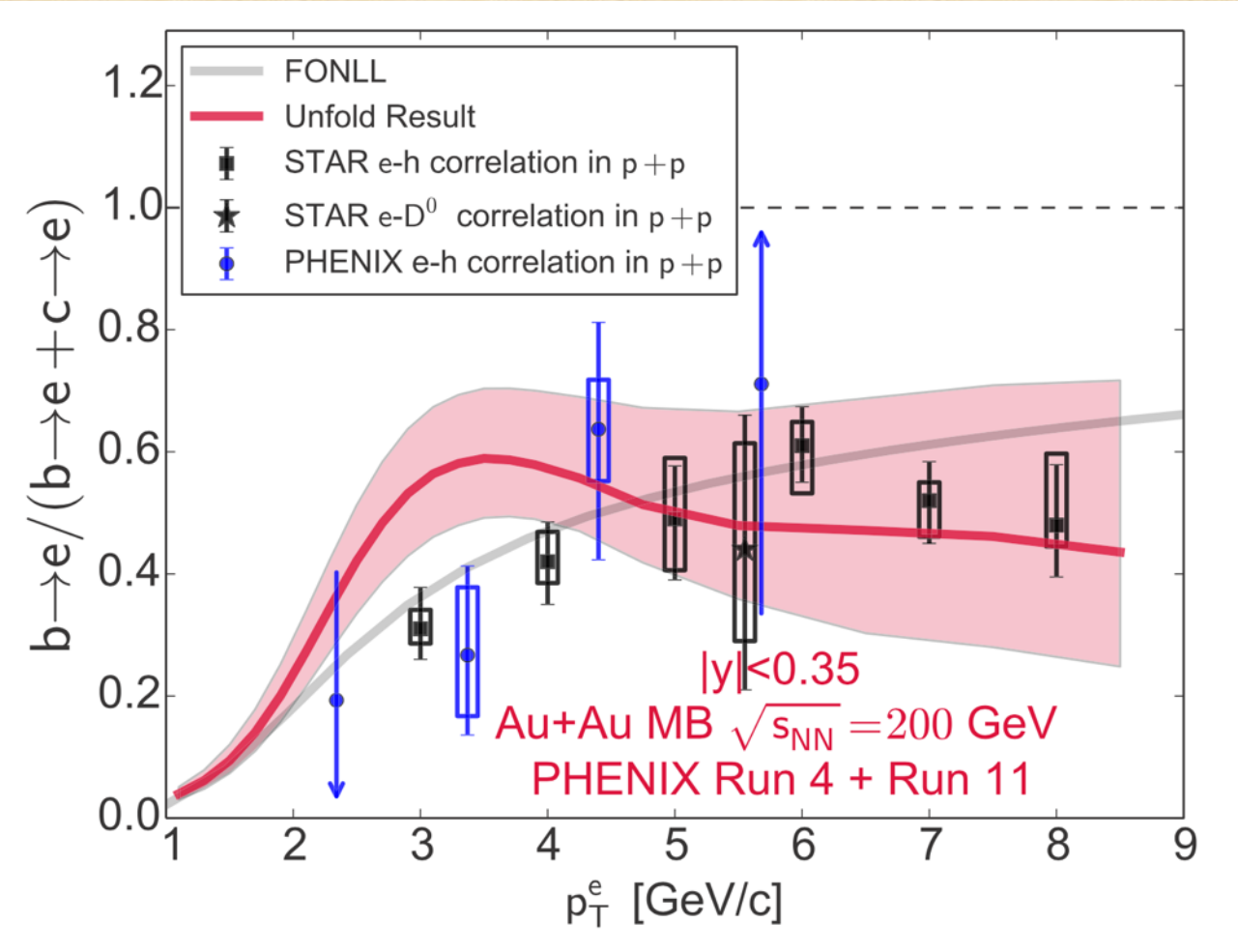
also see

B→J/ψ at forward
(Cesar Luiz da Silva, 8.4 – Wed 16:30)
HF in small system
(Sanghoon Lim, 8.4 – Wed 17:10)

✓ Backup

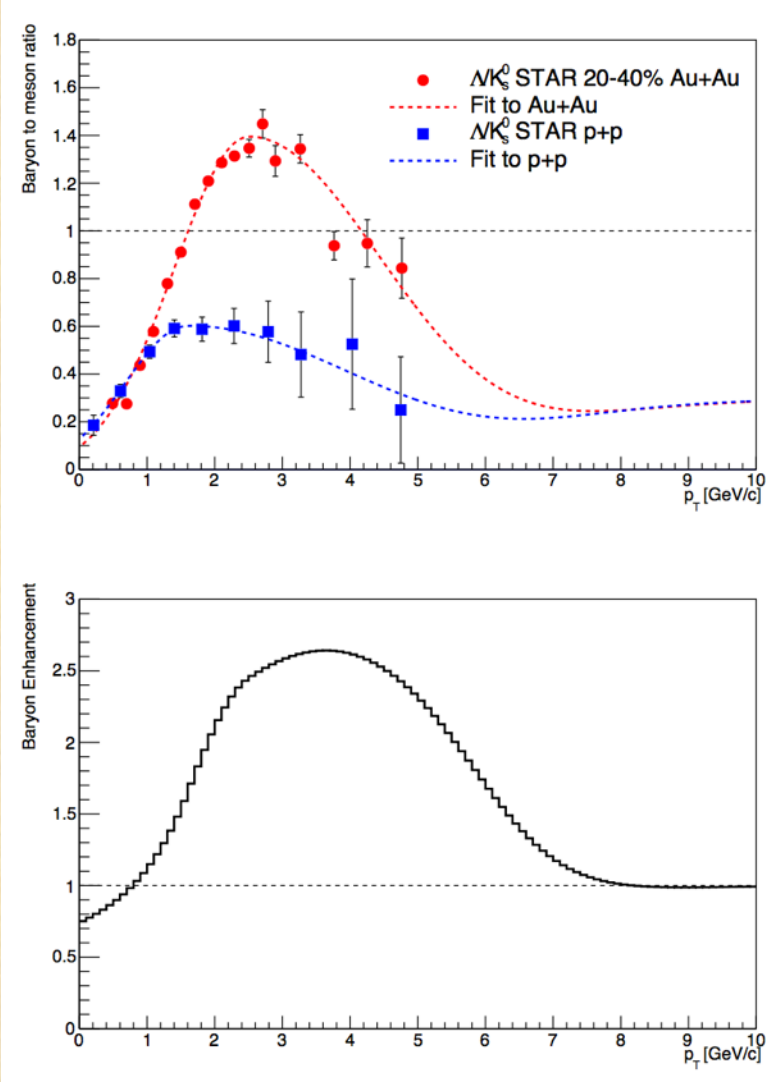
✓ Bottom Electron Fraction

Phys.Rev.C,93,034904



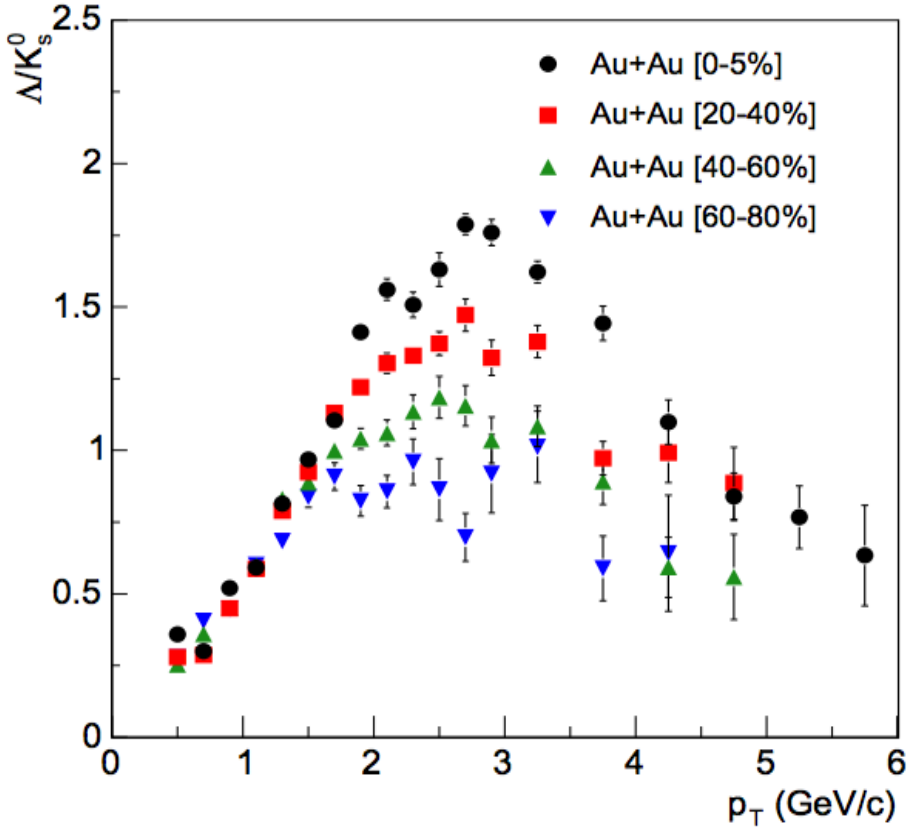
✓ Testing Possible Baryon Enhancement

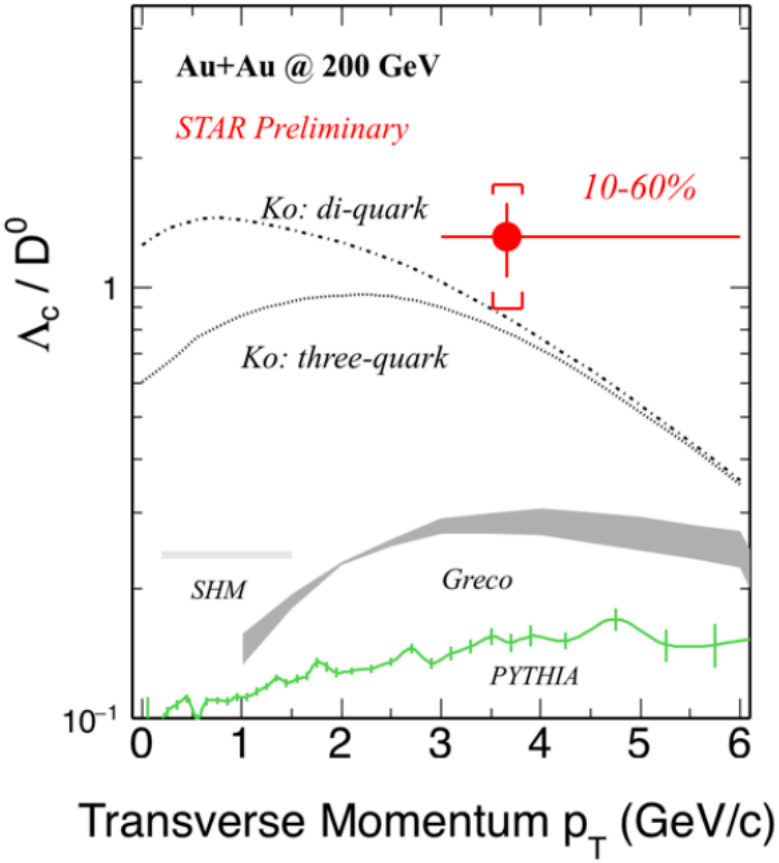
- Follow P. Sorensen and X. Dong
  (Phys Rev C 74, 024902 (2006))
- Λ/Ks ratio measured
  in STAR 20-40% Au+Au at 200 GeV
  and STAR in p+p at 200 GeV
  (arXiv:nucl-ex/0601042)
- Fit both data
- Fix asymptotic value to 0.3
  in both Au +Au and p+p
- Apply enhanced the ratio of
  Λ_c/D and Λb/B to the decay matrices.



✓ Baryon Enhancement

Talk by Long Zhou (@QM2017)





Charm baryon enhancement is similar to strangeness baryon enhancement

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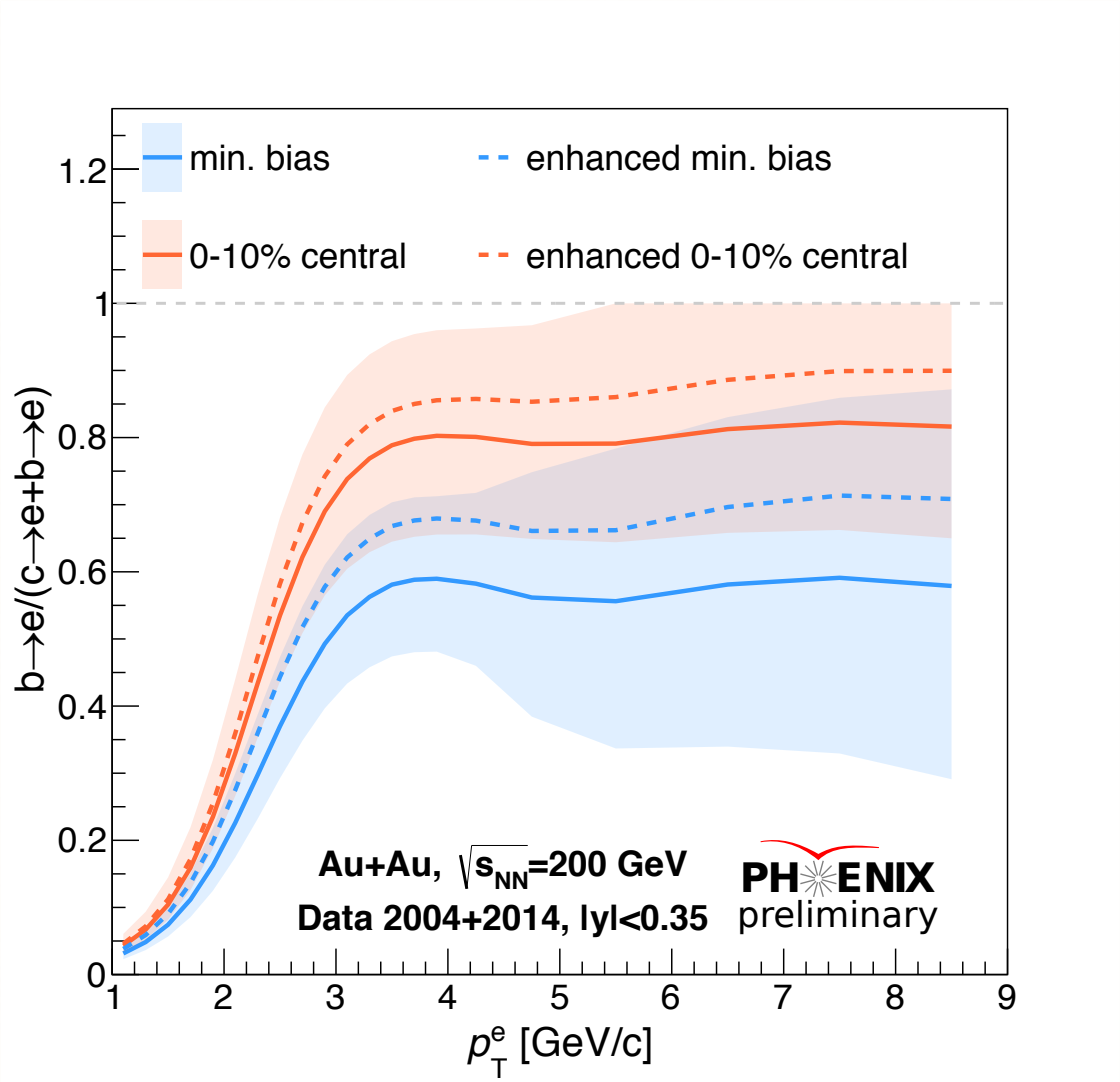

b-fraction increase when assuming enhanced baryon.

Covered by systematic uncertainty of the measurement

Not included additional uncertainty

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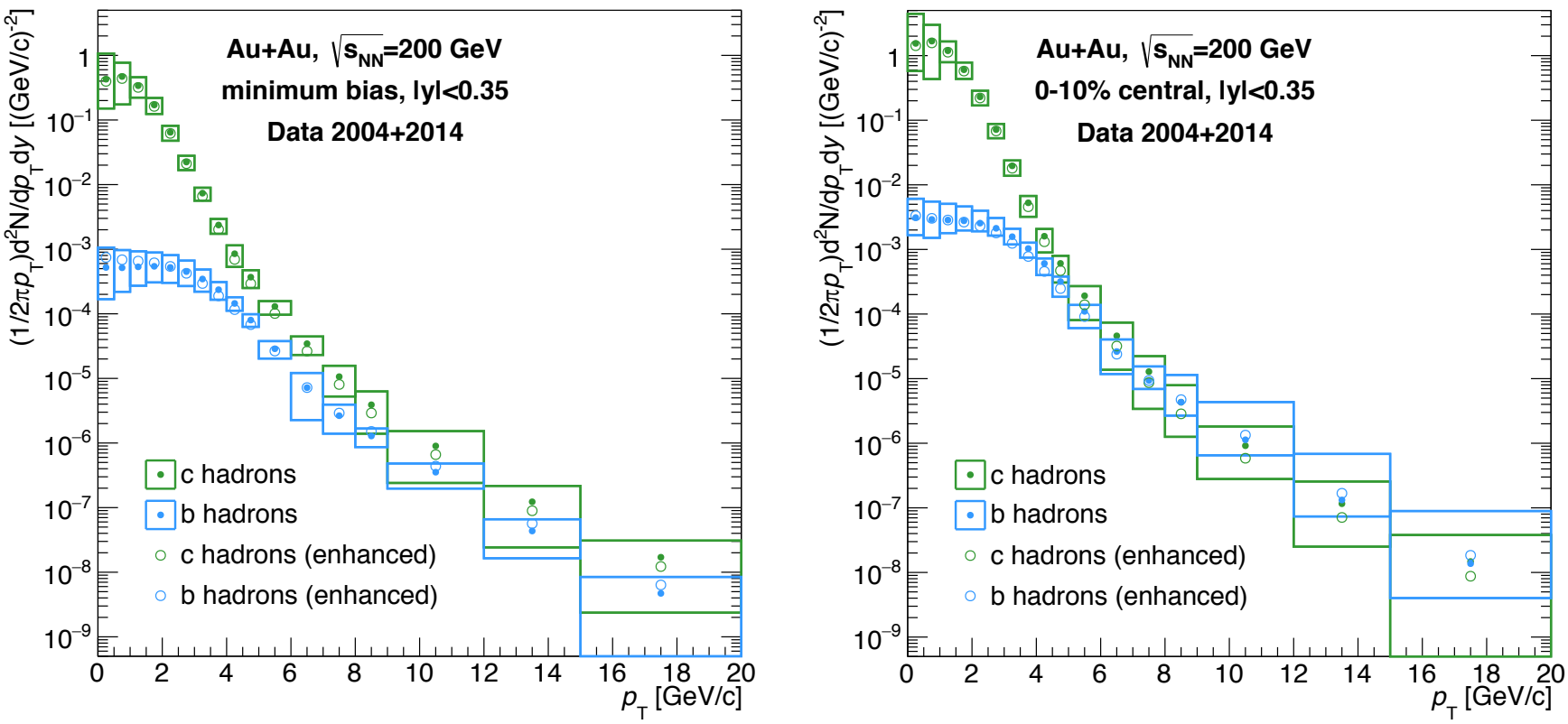

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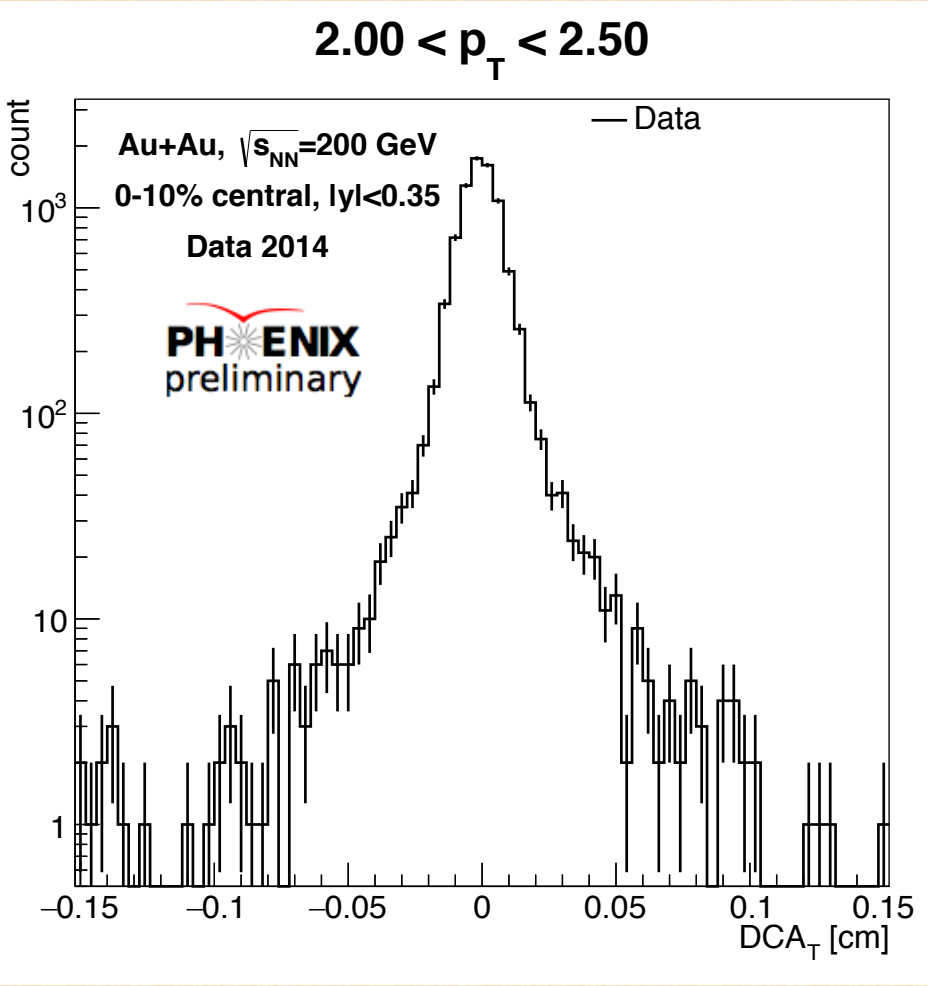
✓ New DCA_T Distribution in 0-10% AuAu

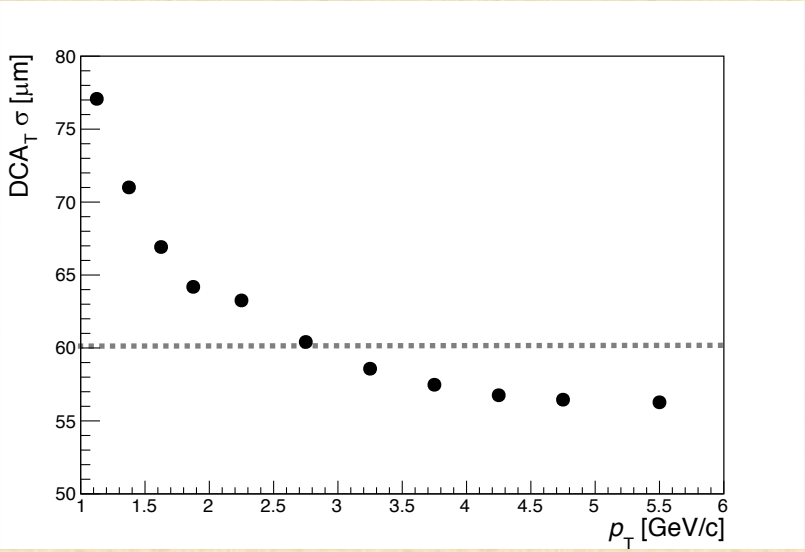


DCA_T distribution of electrons

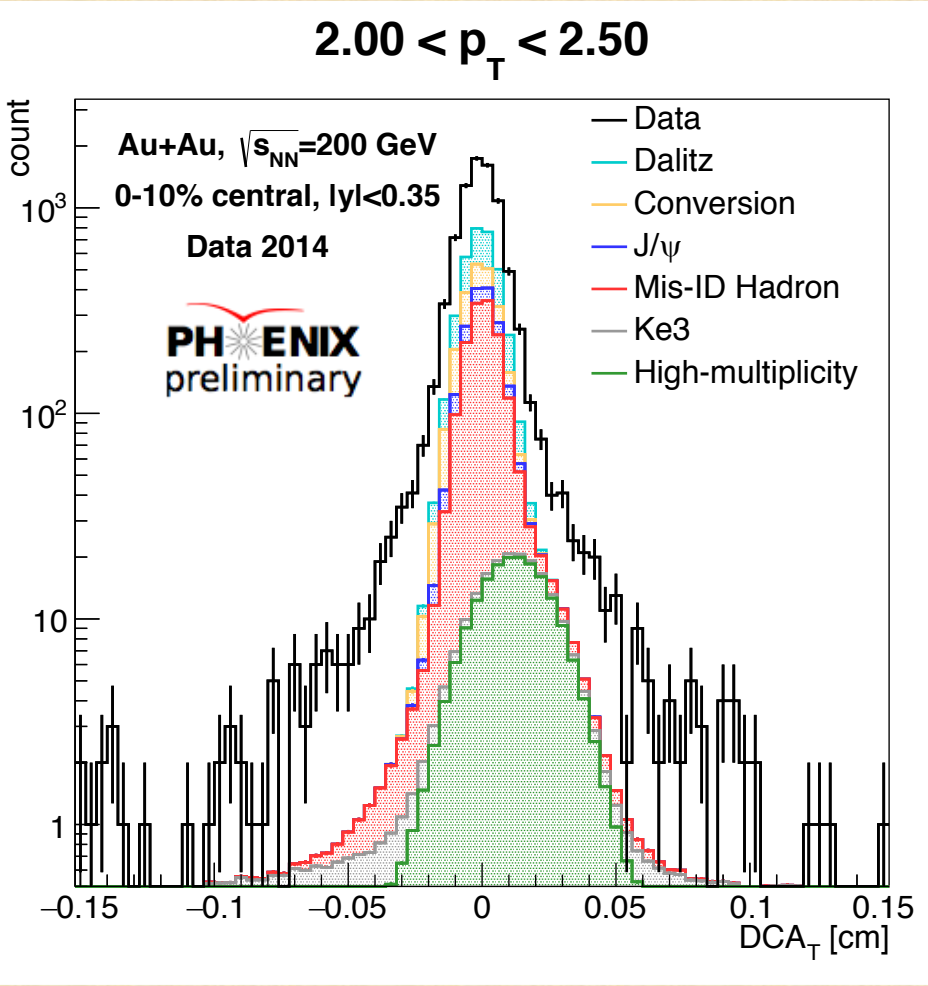
- $1.25 < p_T < 6.0$ GeV (9 binning)
- not corrected for PHENIX acceptance and efficiency

DCA_T resolution

- $\sigma = 0.006$ cm @ $p_T = 2.5$GeV/c



✓ New DCA_T Distribution in 0-10% AuAu



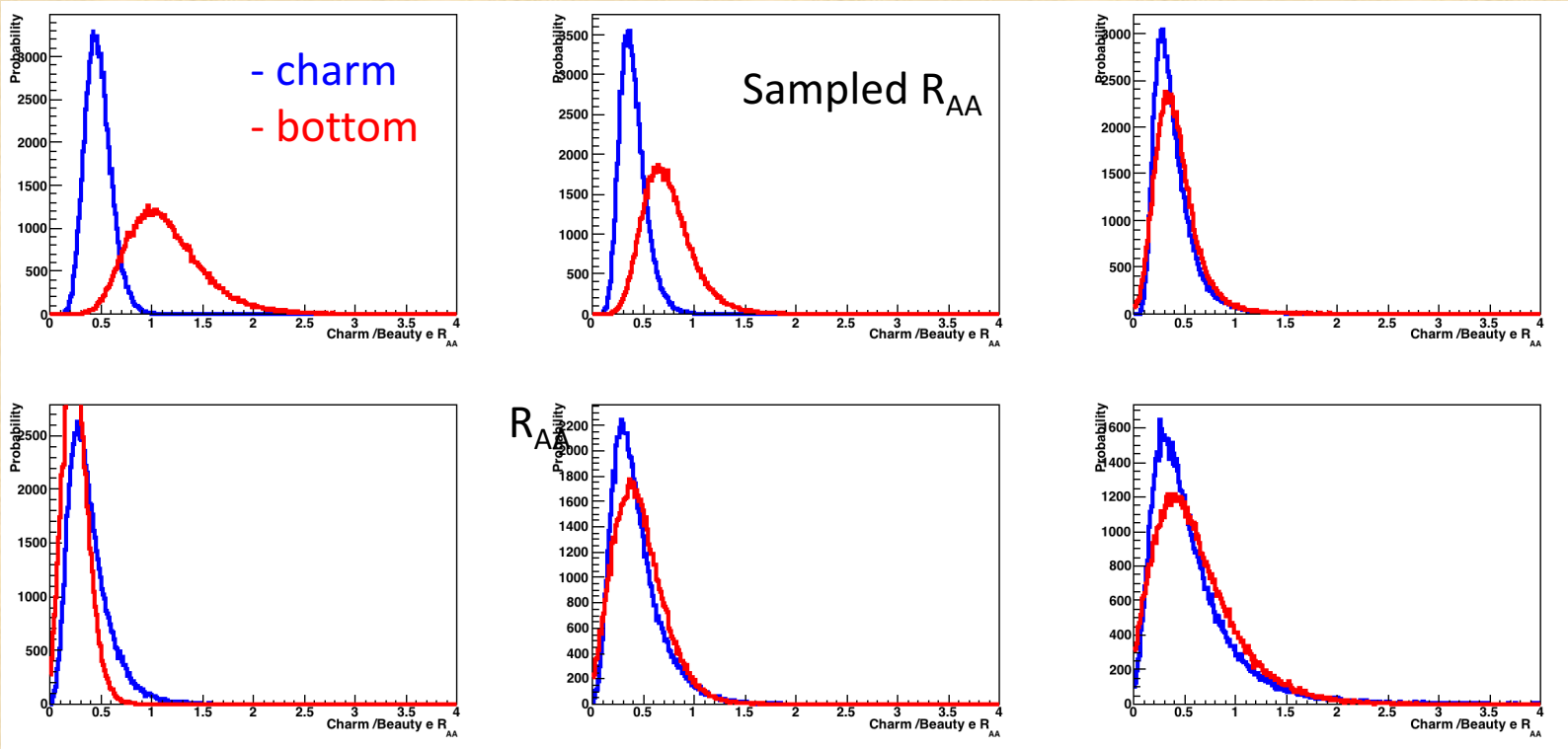
BG components

- Mis-reconstruction
  - > Mis-ID hadron
  - > High-multiplicity
- Prompt
  - > Dalitz, J/ψ
- Non-prompt
  - > Conversion, K_{e3}

Heavy flavor decay electron

- dominates at $|0.02| < DCA_T < |0.1|$

✓ MC Sampling for



- assuming Gaussian uncertainties of F_{AuAu}, F_{pp}, R_{AA}
- median and error get from MC sampling

$$R_{AA}^{b\to e} = \frac{F_{AuAu}}{F_{pp}} R_{AA}^{HF}$$

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

✓ Background Normalization

Non-photonic to photonic electron ratio R_{NP}

$R_{NP} = N_{NP} / N_P$

$N_P = (N_e^{iso} - \varepsilon_R * \varepsilon_I * N_e) / \varepsilon_R * (1-\varepsilon_I)$

$N_{NP} = (\varepsilon_R * N_e^{iso} - N_e) / \varepsilon_R * (1-\varepsilon_I)$

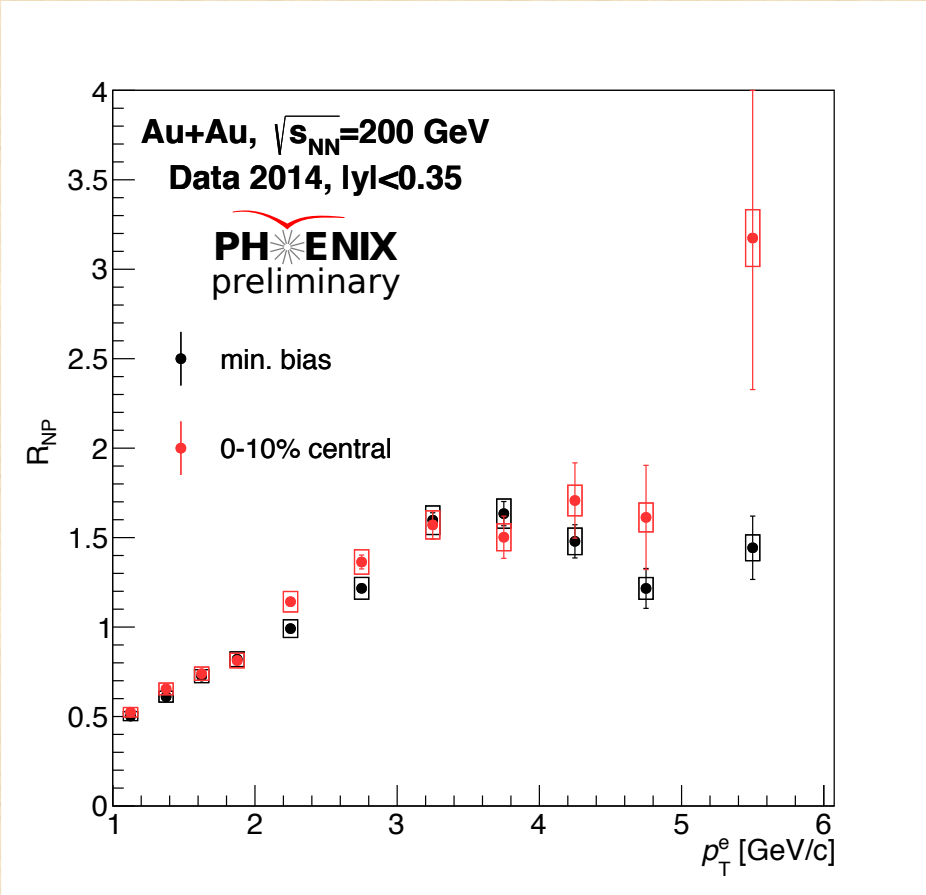
$N_e = N_{NP} + N_P$

$N_e^{iso} = \varepsilon_R * N_{NP} + \varepsilon_R * \varepsilon_I * N_P$

(applied isolation cut)

ε_I = single cut efficiency (calculated by MC method)

ε_R = randomly killed efficiency (calculated by data driven)



✓ Background Normalization

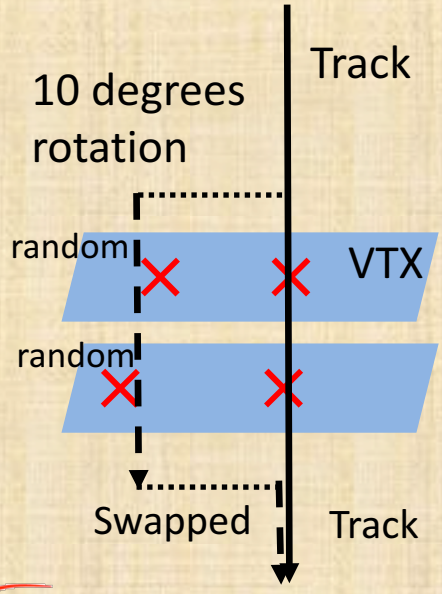
Track swapping method

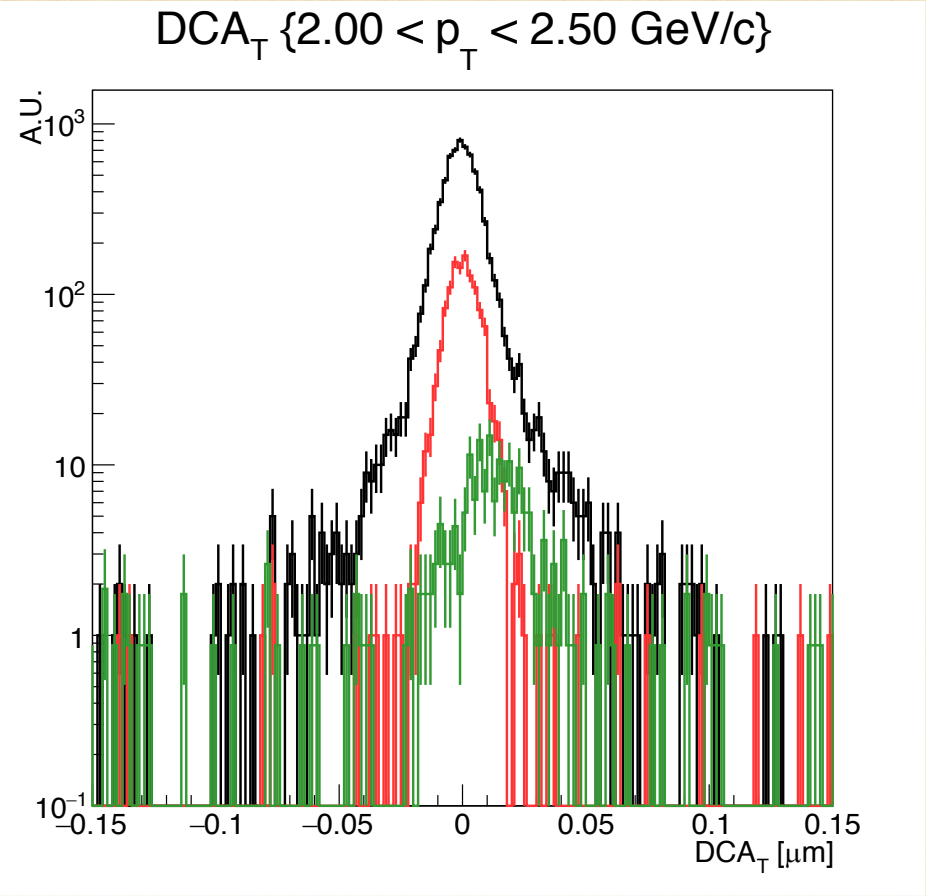
[Mis-ID hadron]

- Swapped at RICH
- opposite side RICH hit

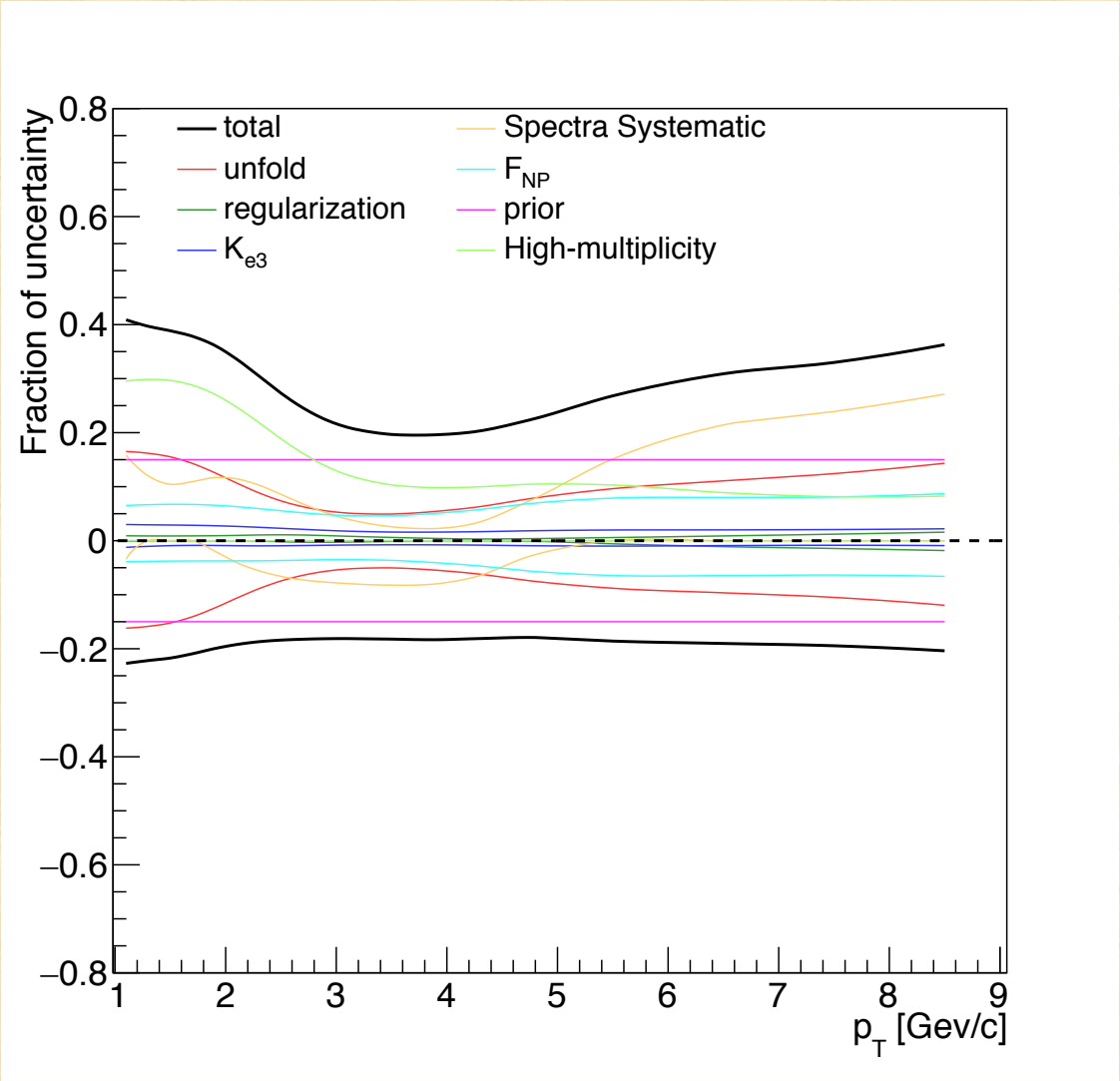
[High-multiplicity]

- Swapped at VTX
- 10 degree rotation

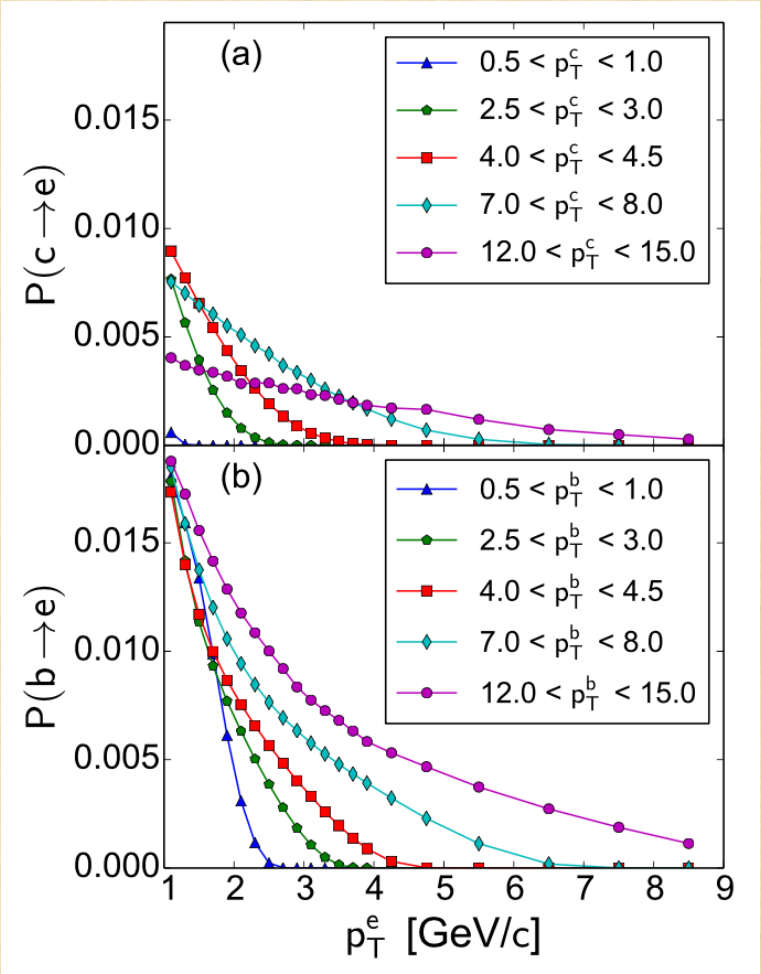


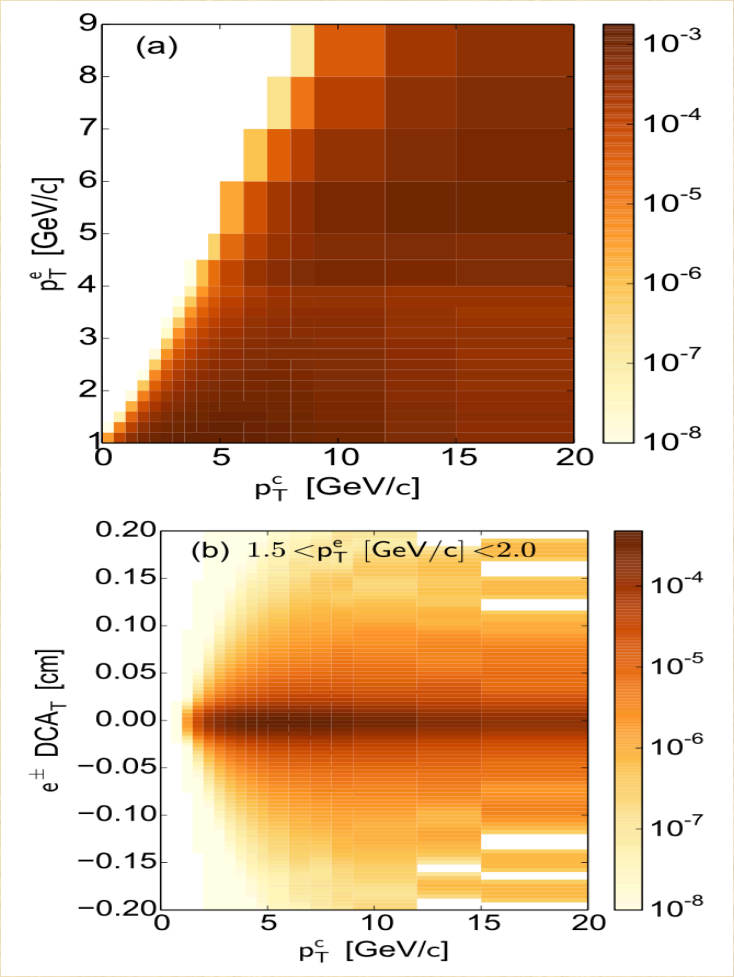


✓ Systematic Uncertainty of b-fraction

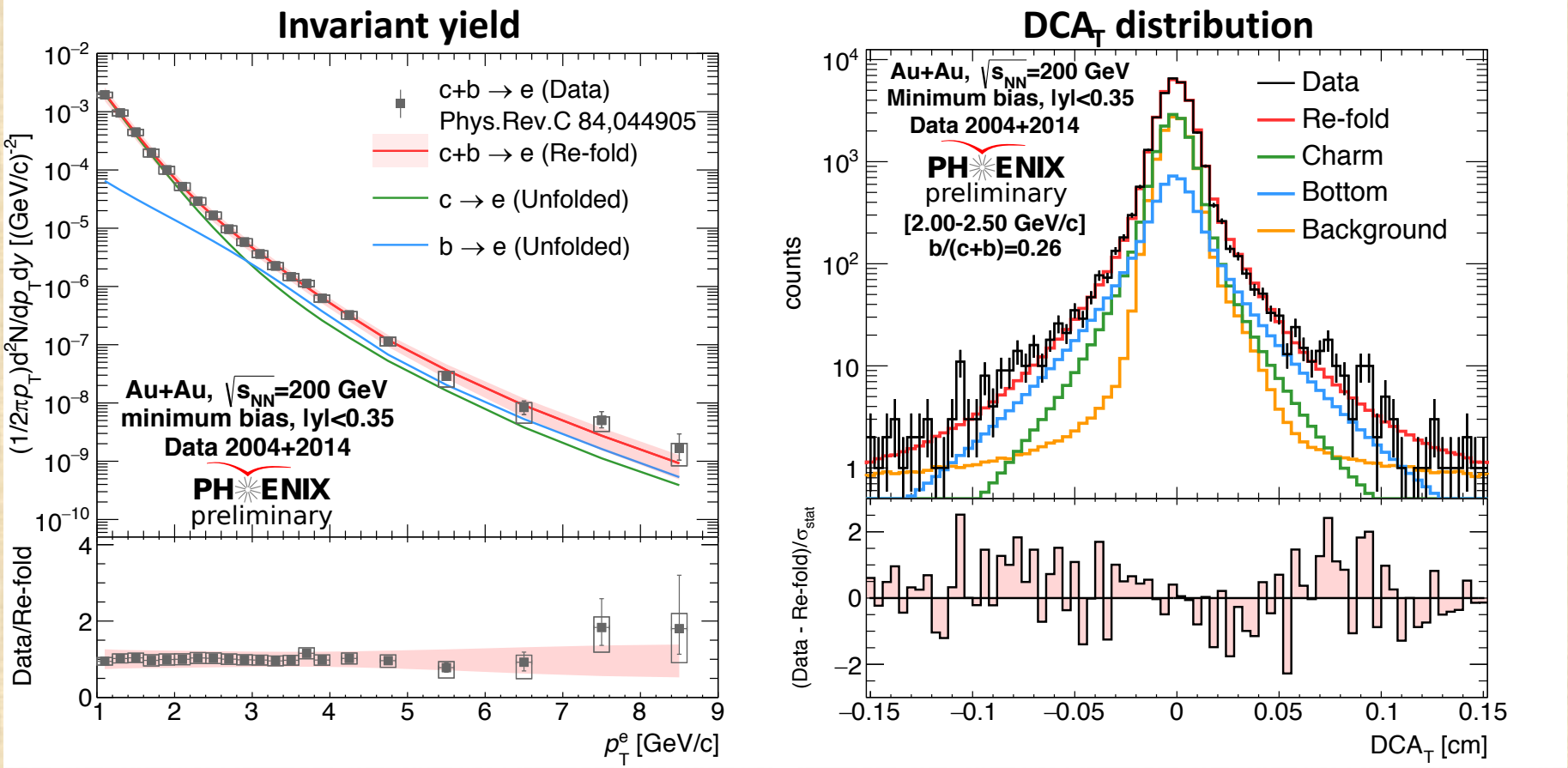


✓ Decay Probability



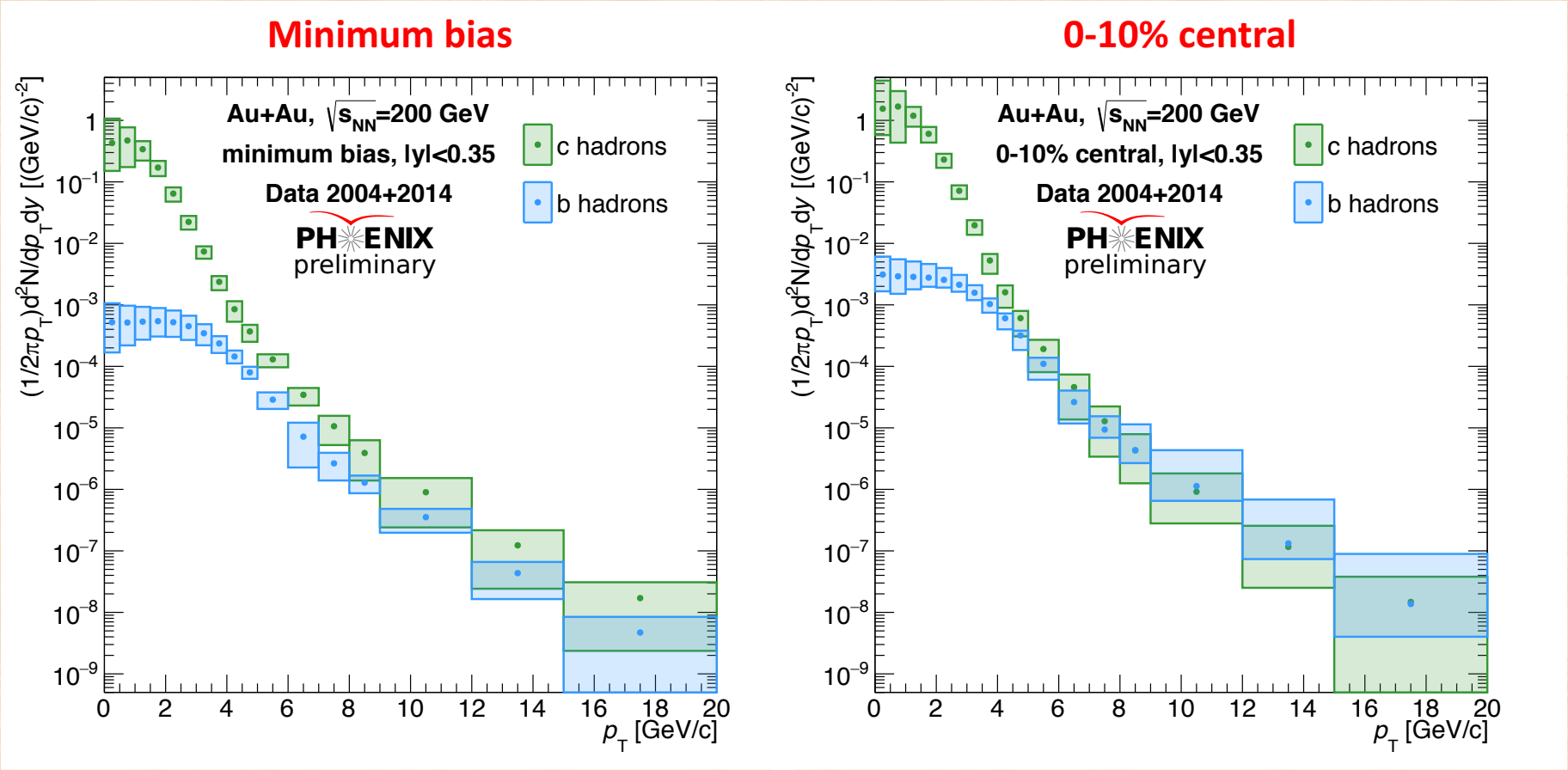


✓ Comparison to Data in minimum bias



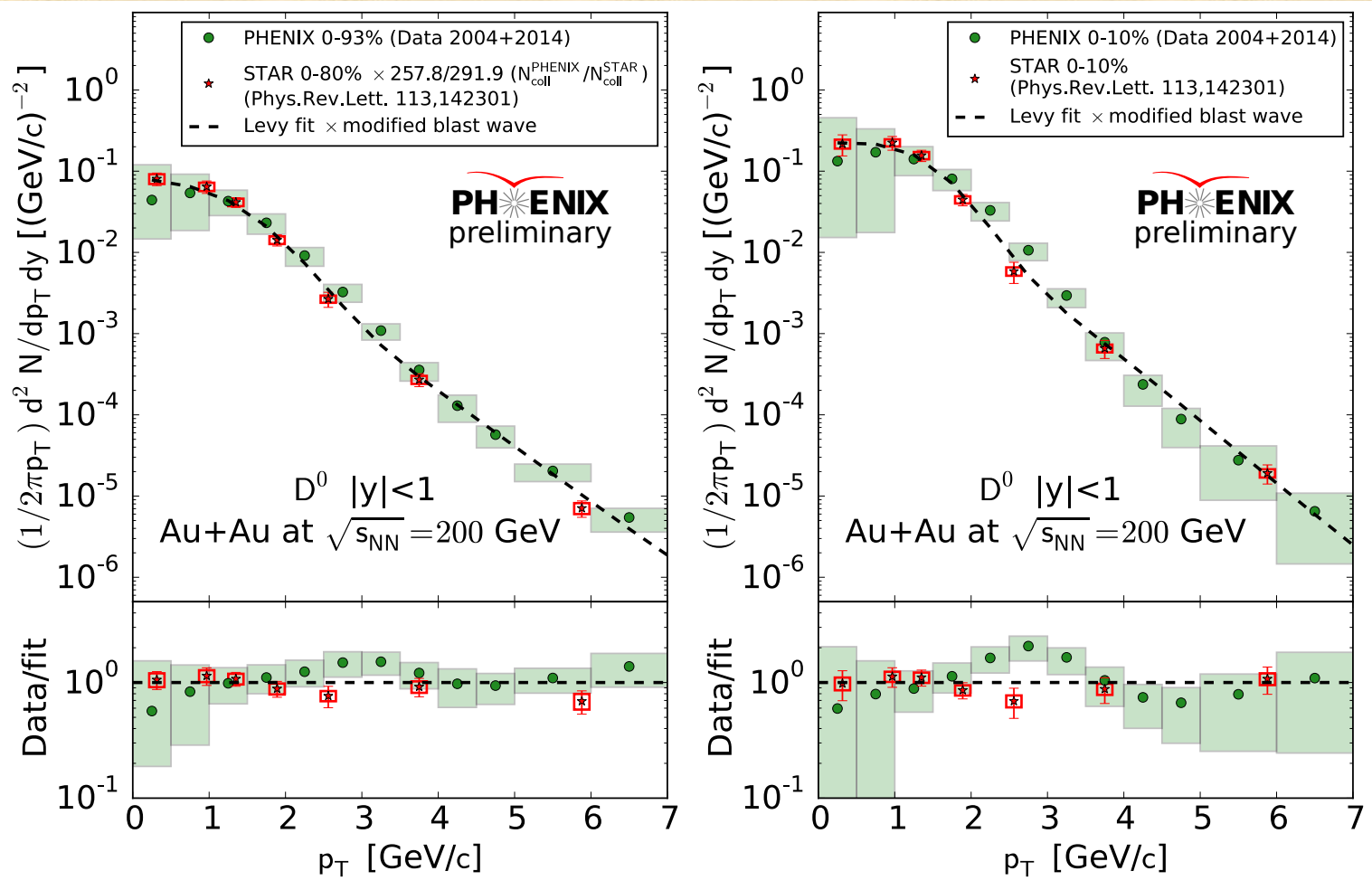
Unfolding results agree with measured data well

✓ Comparison to Data

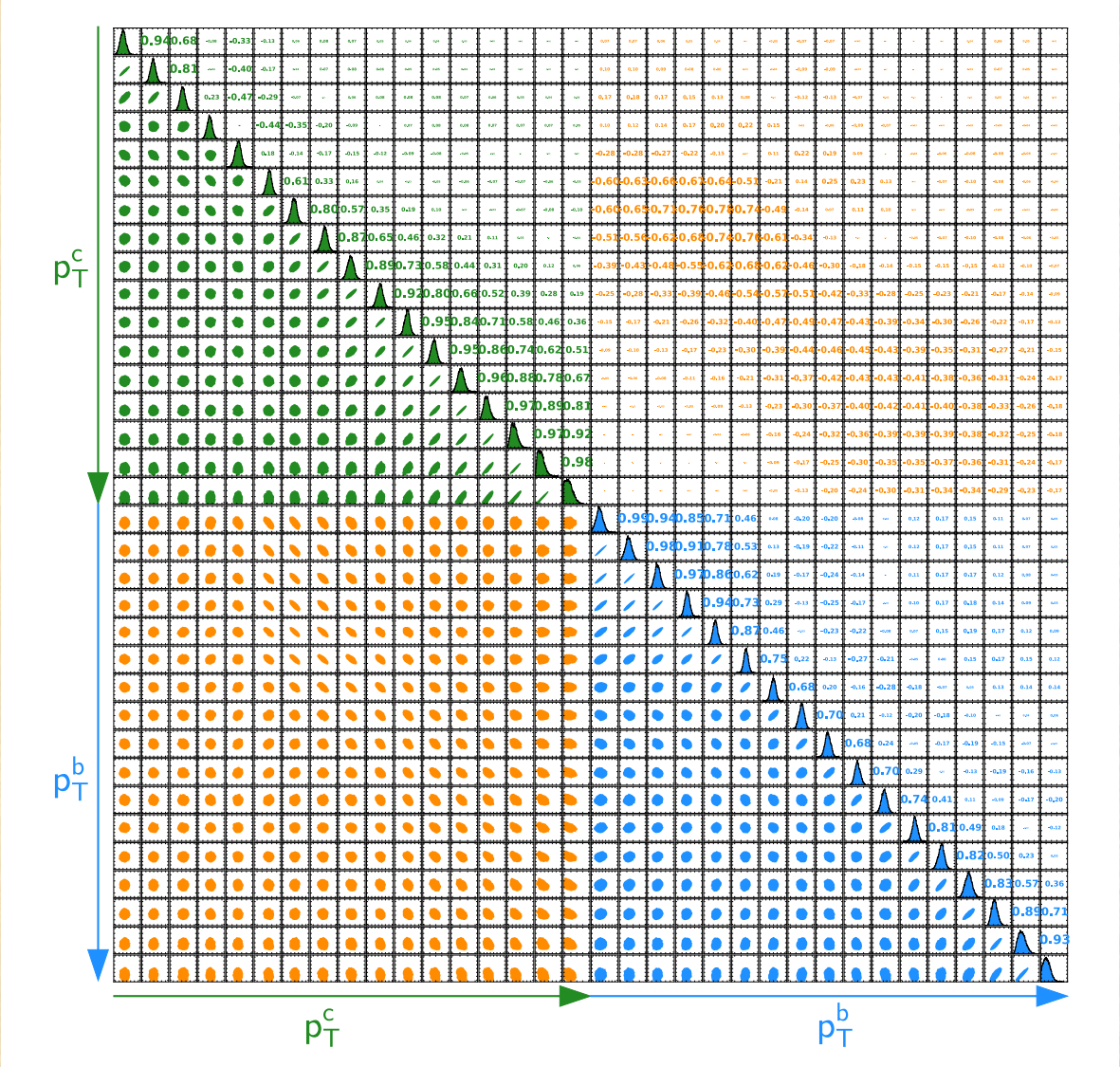


Invariant yields of charm and bottom hadrons

✓ Comparison to Measured Data



✓ Full probability distribution of parameters



[Diagonal]
Sampled yield

[Other]
Correlation between
c and b hadron yield

✓ Energy loss model

collisional energy loss

- parton elastic scattering
- Brownian motion via Langevin equation

$$\frac{d\vec{p}}{dt} = -\eta_D(p)\vec{p} + \vec{\xi}$$

η_D: friction coefficient
ξ: drift force

radiative energy loss

- Bathe-Heitler for gluon radiation

$$dP_0 \approx \frac{\alpha_s C_F}{\pi}\frac{d\omega}{\omega}\frac{dk_\perp^2}{k_\perp^2}$$

> Dead-Cone effect

- strong suppression of HF in small-angle radiation

$$\propto \frac{k_\perp^2 dk_\perp^2}{(k_\perp^2+\omega^2\theta_0^2)^2}, (\theta_0 \equiv \frac{M}{E})$$

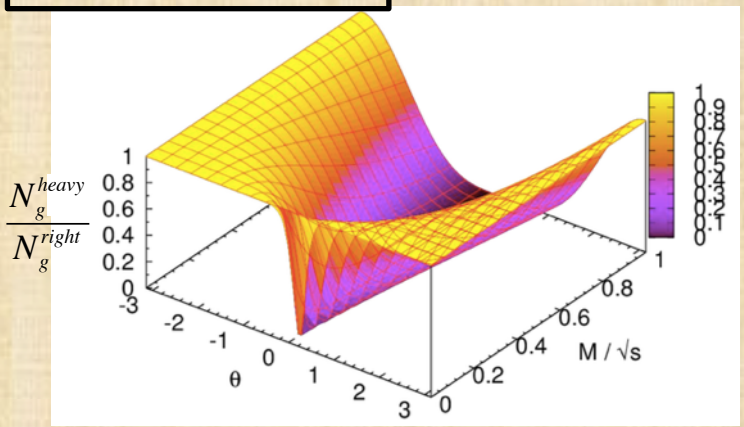
> Landau-Pomeranchuk-Migdal effect

- suppression in high density $\propto \frac{\lambda_{path}}{L_{form}}$

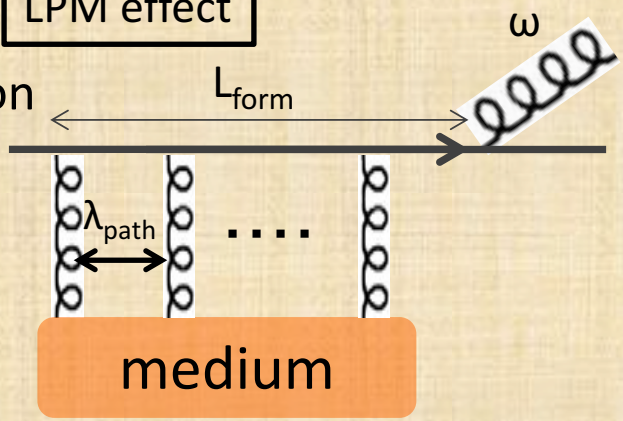
mass ordering

$\Delta E_g > \Delta E_{u,d,s} >(?) \Delta E_c >(?) \Delta E_b$

Dead-Cone effect



LPM effect



λ_{path}: mean free path
L_{form}: formation length