Recent Heavy Flavor measurements in PHENIX

Heavy Flavor Workshop in High Energy Collisions 2017

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for the PHENIX collaboration
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- Introduction
- Displaced vertex measurements
  - VTX: c→e and b→e
  - FVTX: B→J/ψ
- Dilepton measurements
  - Dimuons
  - Dielectrons
- Summary

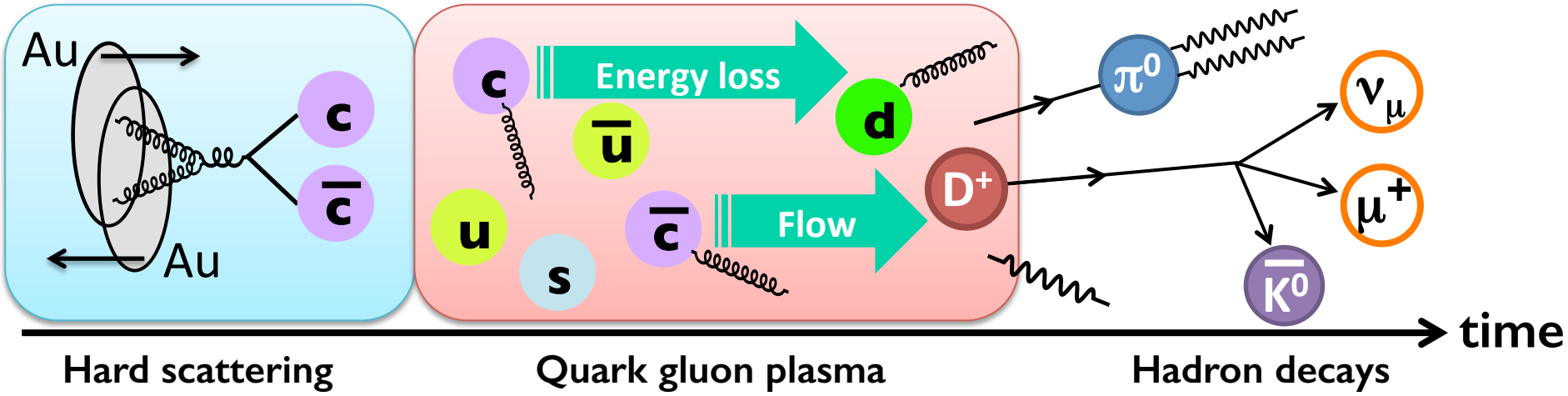
Why Heavy Flavor?

- p+p → No Nuclear Matter
  - Baseline measurement
- p/d+A → Cold Nuclear Matter
  - Initial state effects
  - Nuclear modification of PDFs
- A+A → Quark gluon plasma
  - Hot and cold nuclear matter effects

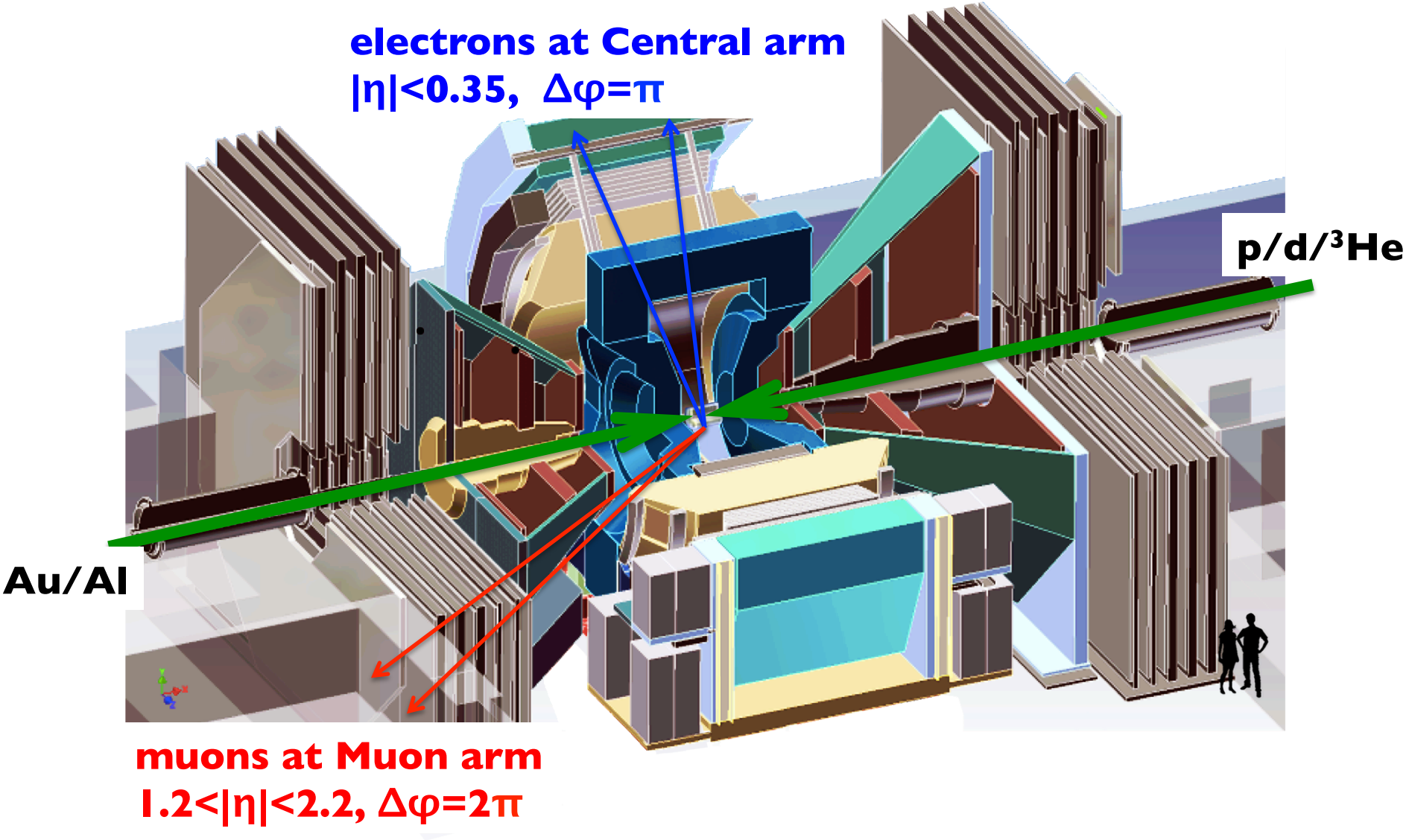
Heavy flavor produced at the early stages of the collision

- Classic probe to study cold and hot nuclear matter effects

Need good understanding HF in small systems to interpret A+A data!!



The PHENIX detector



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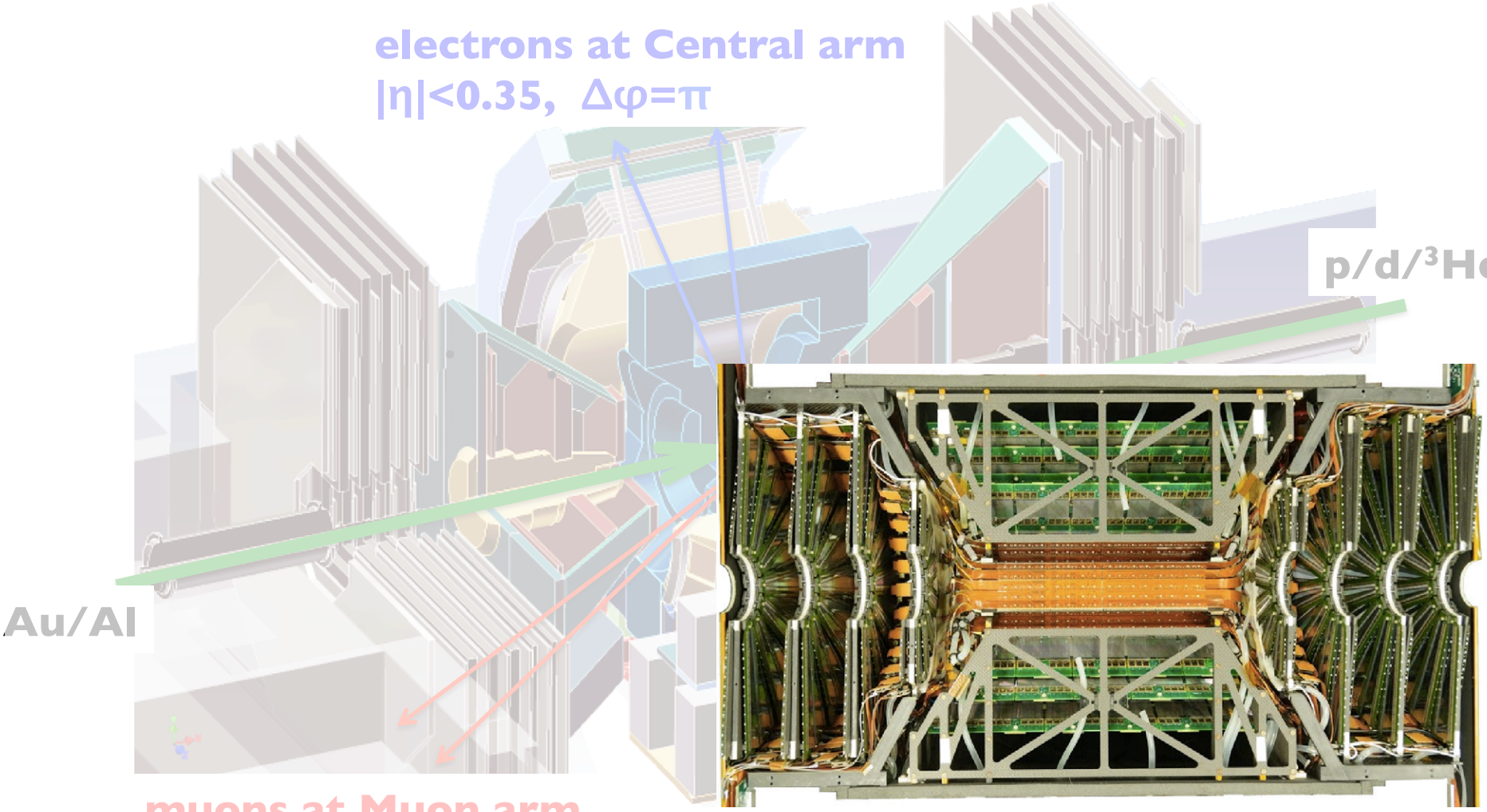


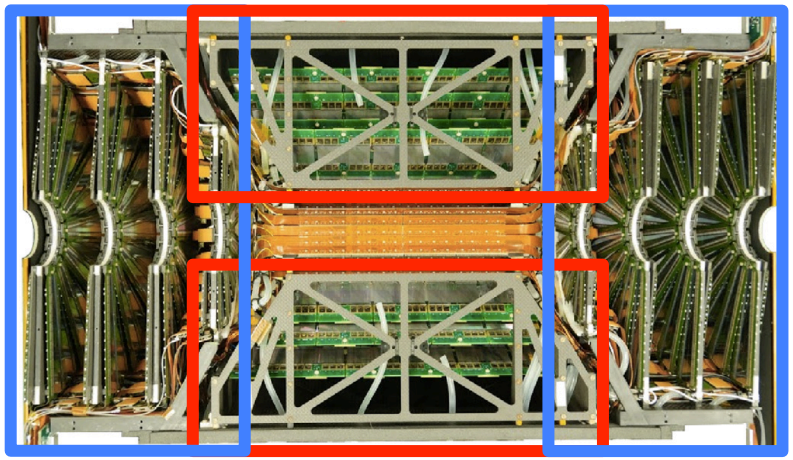
VTX and FVTX provide precise tracking/vertex

OPEN HEAVY FLAVOR

via displaced vertex measurement

- ***VTX: Mid-rapidity |y|<0.35***
  - ***Separated b→e and c→e in 0-10% Au+Au 200GeV***
- ***FVTX: Forward rapidity 1.2<|y|<2.2***
  - ***B→J/ψ in Cu+Au 200GeV and p+p 200GeV, 510GeV***

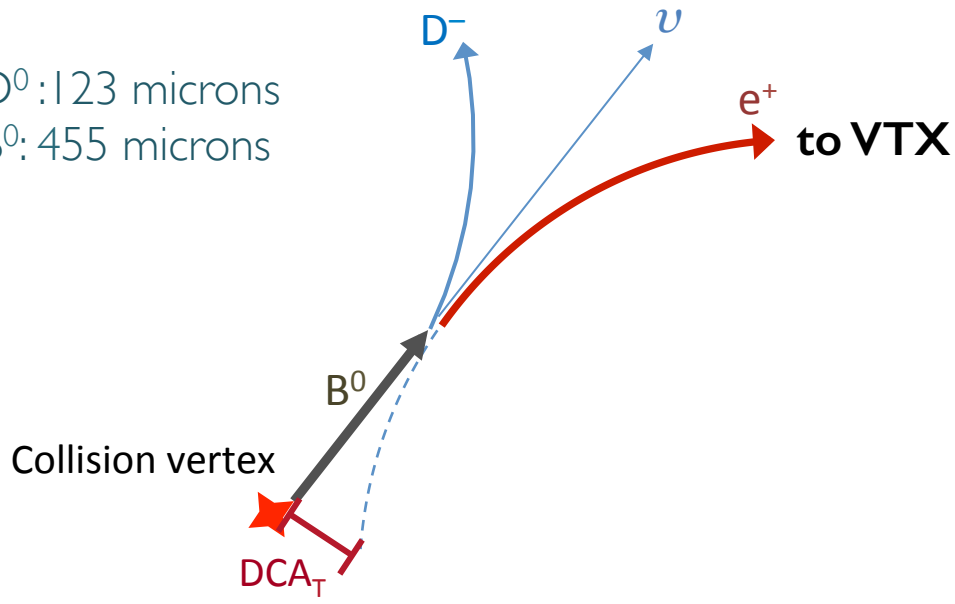
Measuring DCA

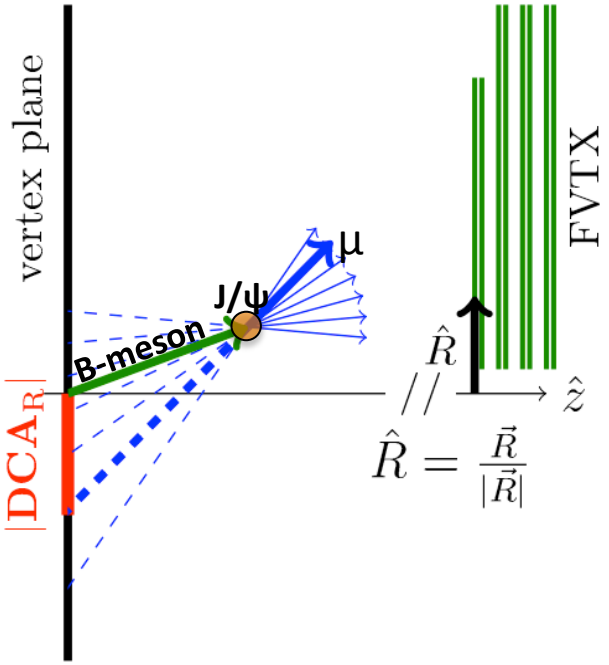


VTX and FVTX provide precise tracking/vertex

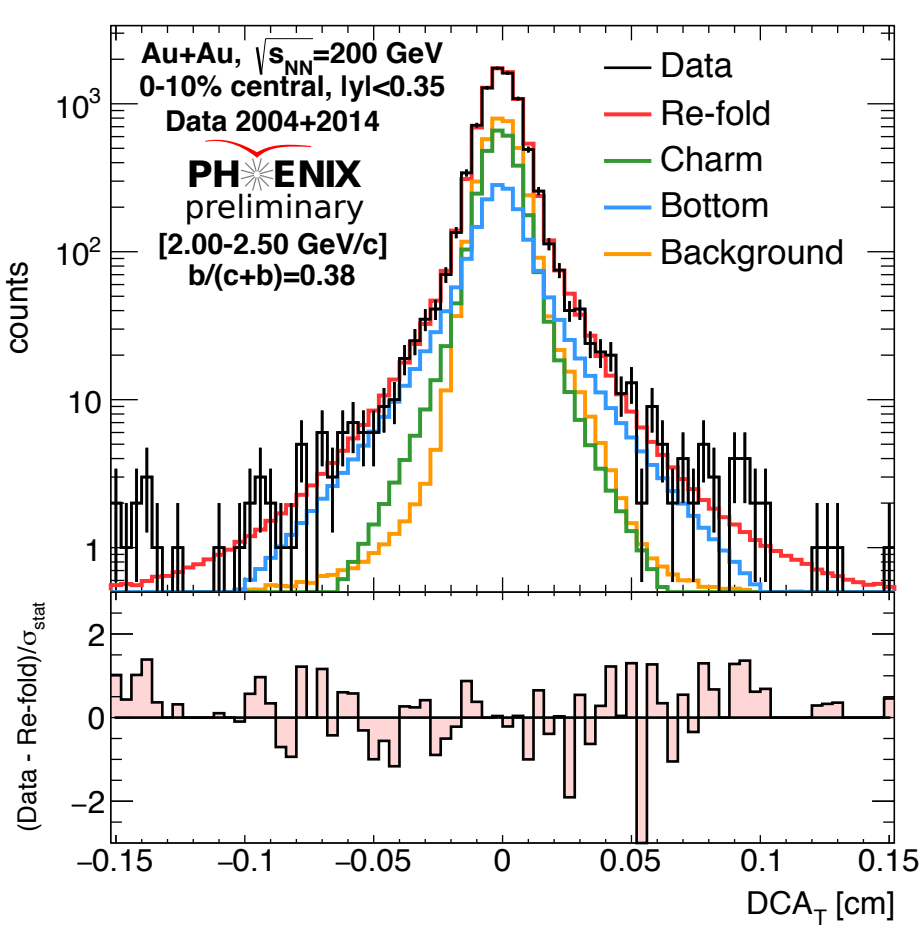
Distance of Closest Approach(DCA) of electron/muon tracks is determined using the VTX/FVTX

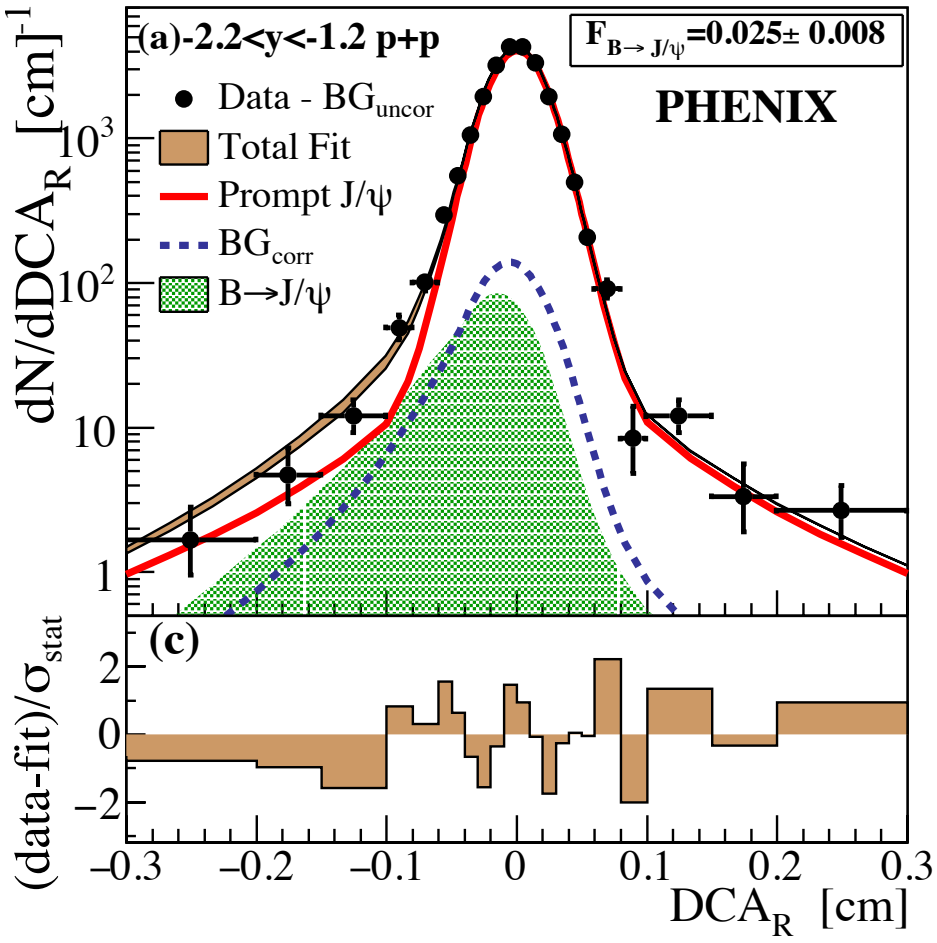
D^0 :123 microns
B^0: 455 microns





DCA distributions





Measurement of DCA allows separation of charm, bottom, and background components from fitting/unfolding techniques.

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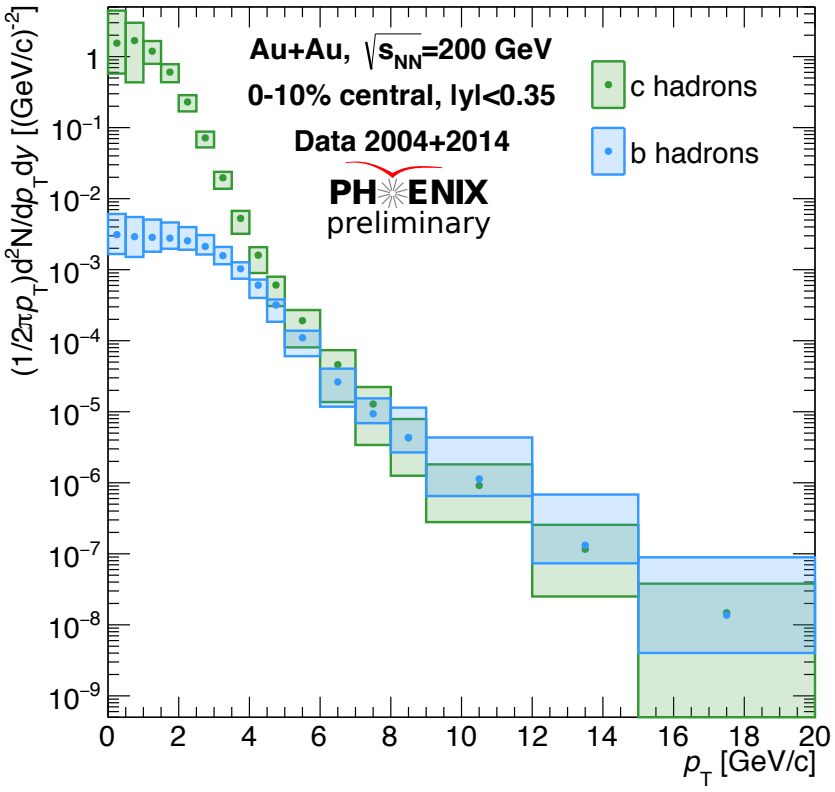
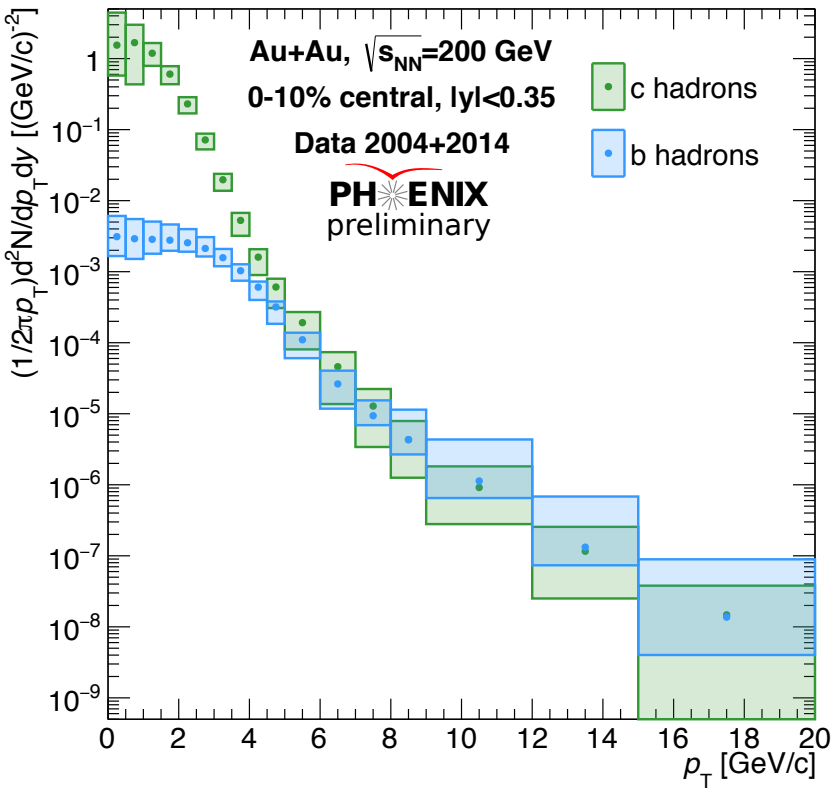
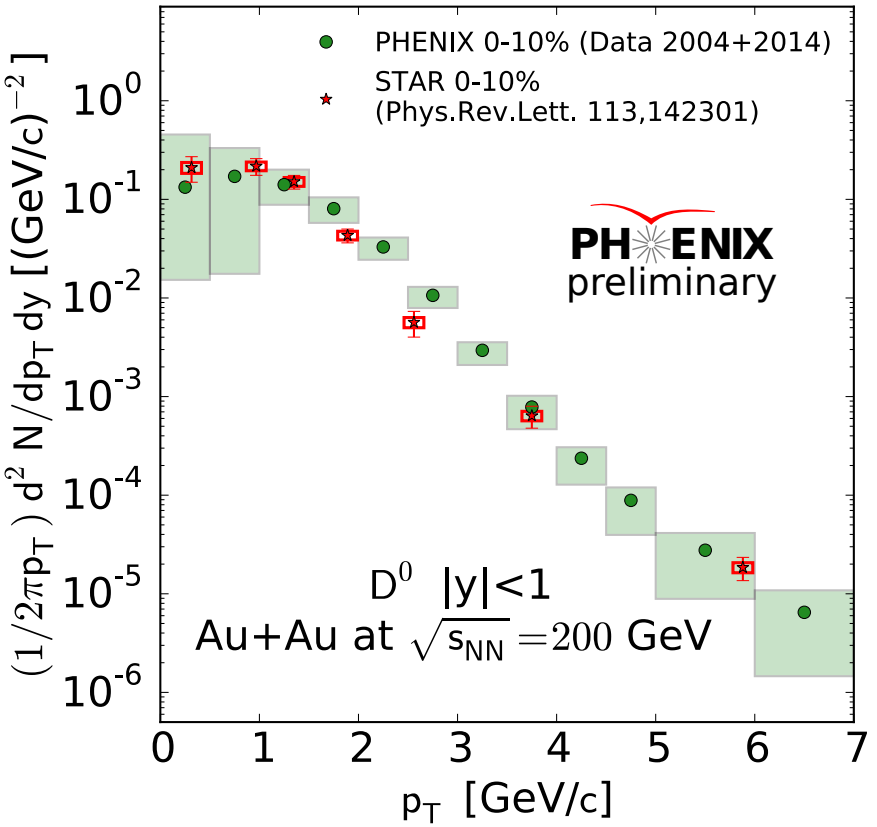
Charm and bottom hadron p_T for 0-10%



- ***Unfolded invariant yields of c- and b- hadrons***

Charm and bottom hadron p_T for 0-10%

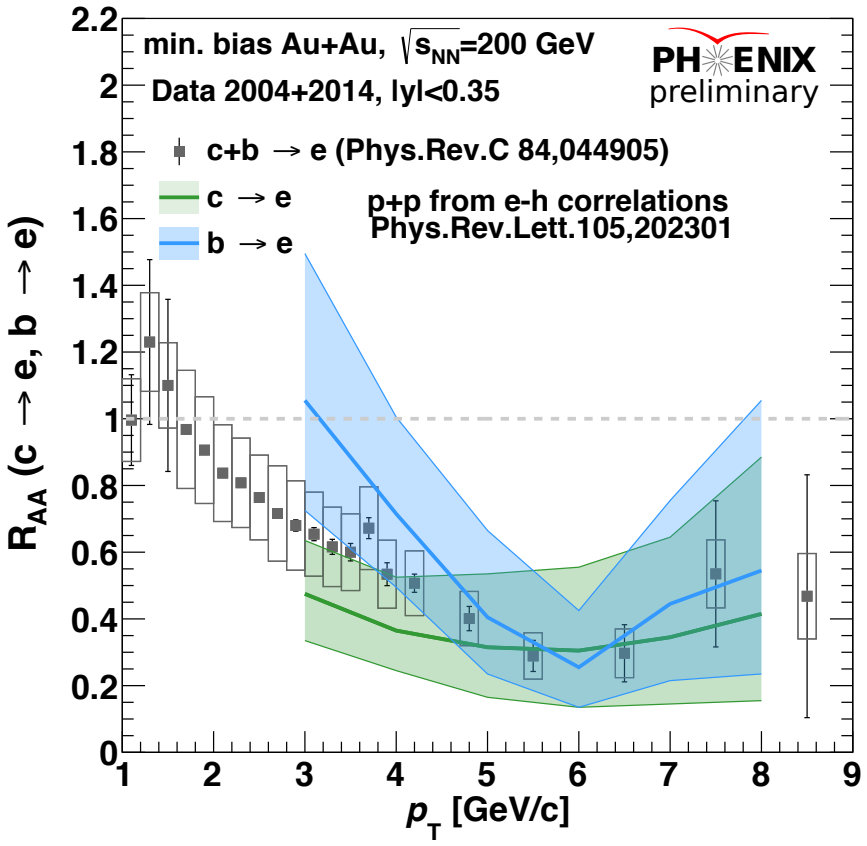




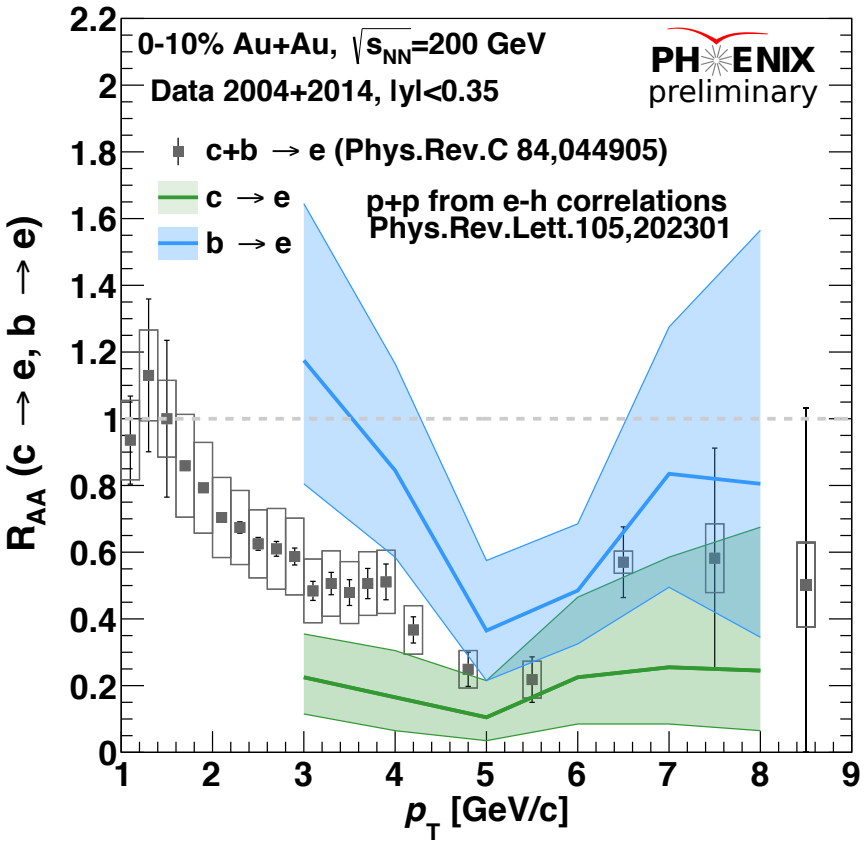
- ***Unfolded invariant yields of c- and b- hadrons***
- ***D^0 yield extracted from c-hadrons and PYTHIA.***
  - ***Consistent with STAR measurement***

Charm and bottom R_{AA}

Minimum bias



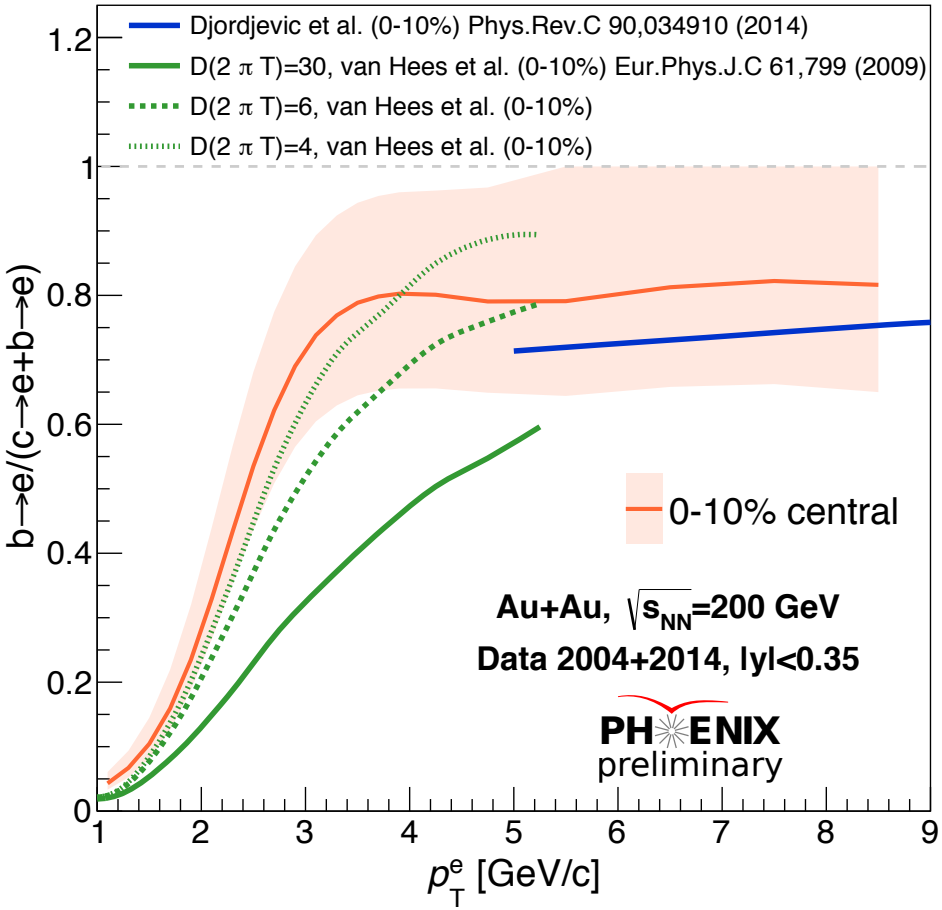
0-10% Central



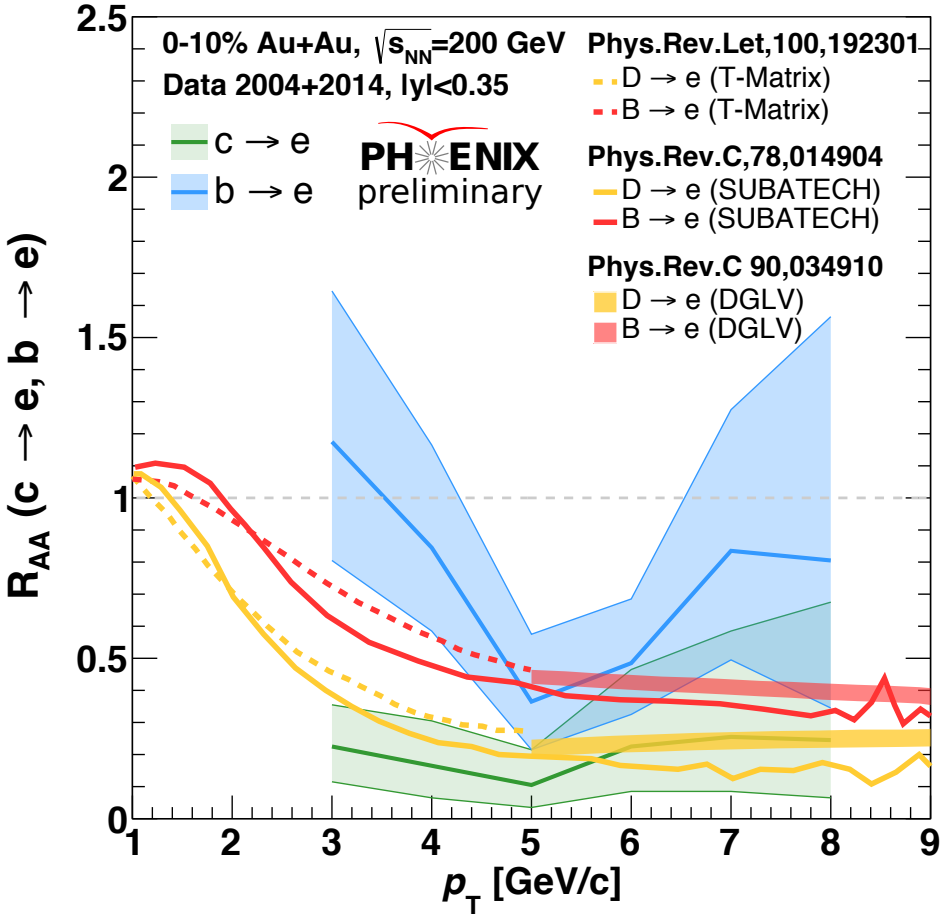
- ***b→e is less suppressed than c→e in 3.0-5.0 GeV/c in 0-10% Au+Au.***
- ***c→e in 0-10% is more strongly suppressed than in MB.***

Charm and bottom R_{AA}

Relative modification



Total modification



- ***Reasonable agreement with theory***
- ***Data prefers smaller diffusion parameter***

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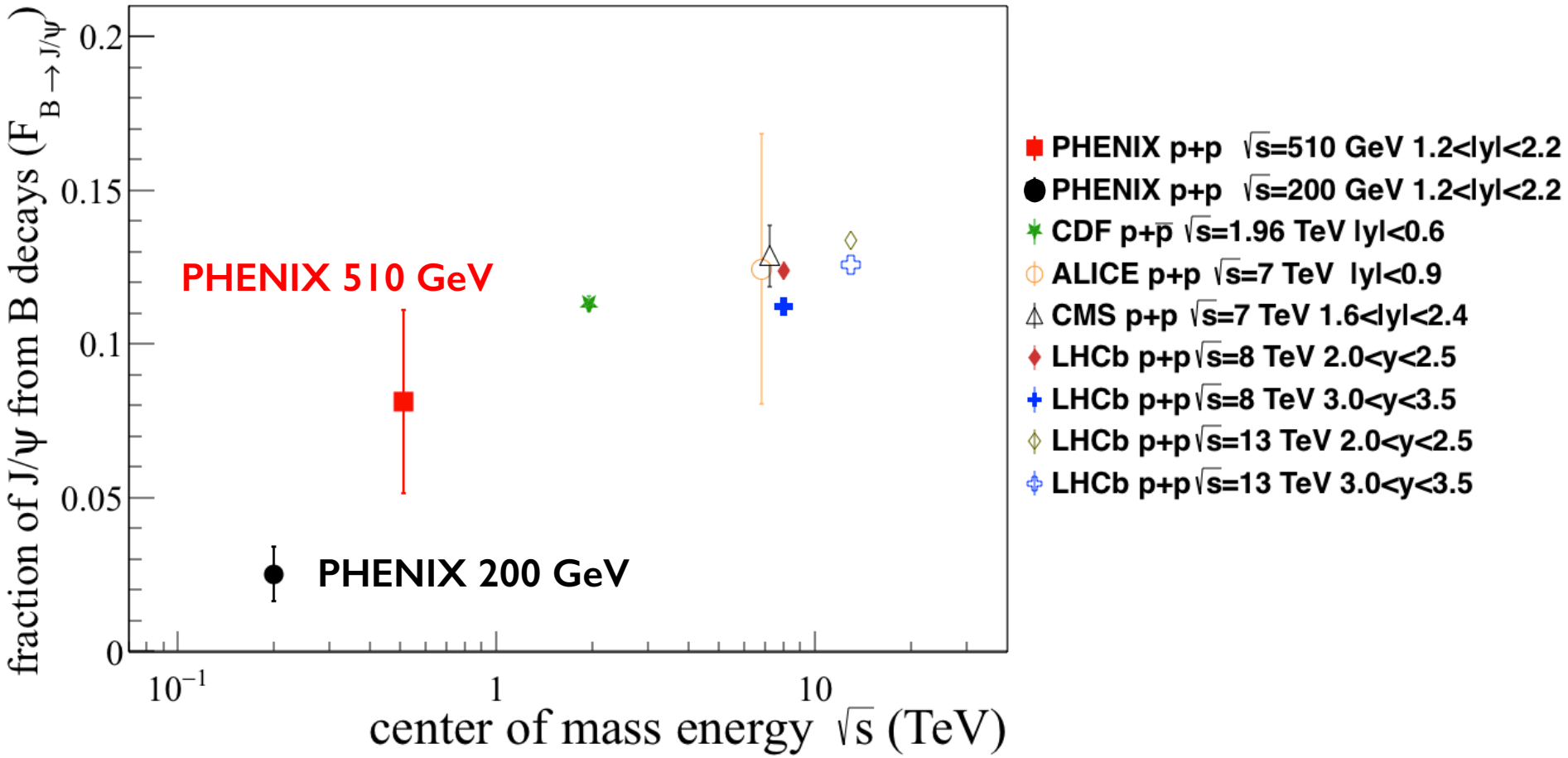
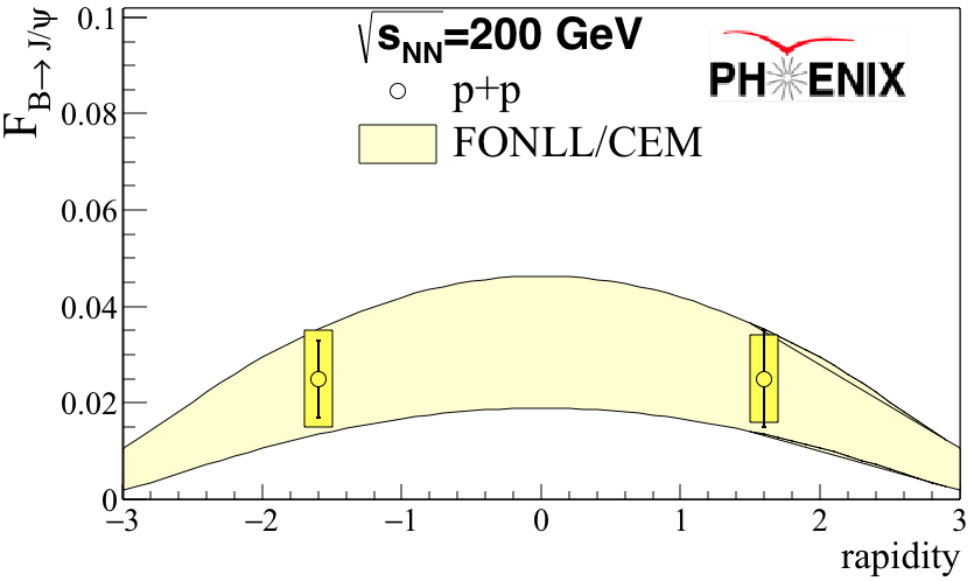
$F_{B\to J/\psi}$ in p+p



$F_{B\to J/\psi}$ in p+p

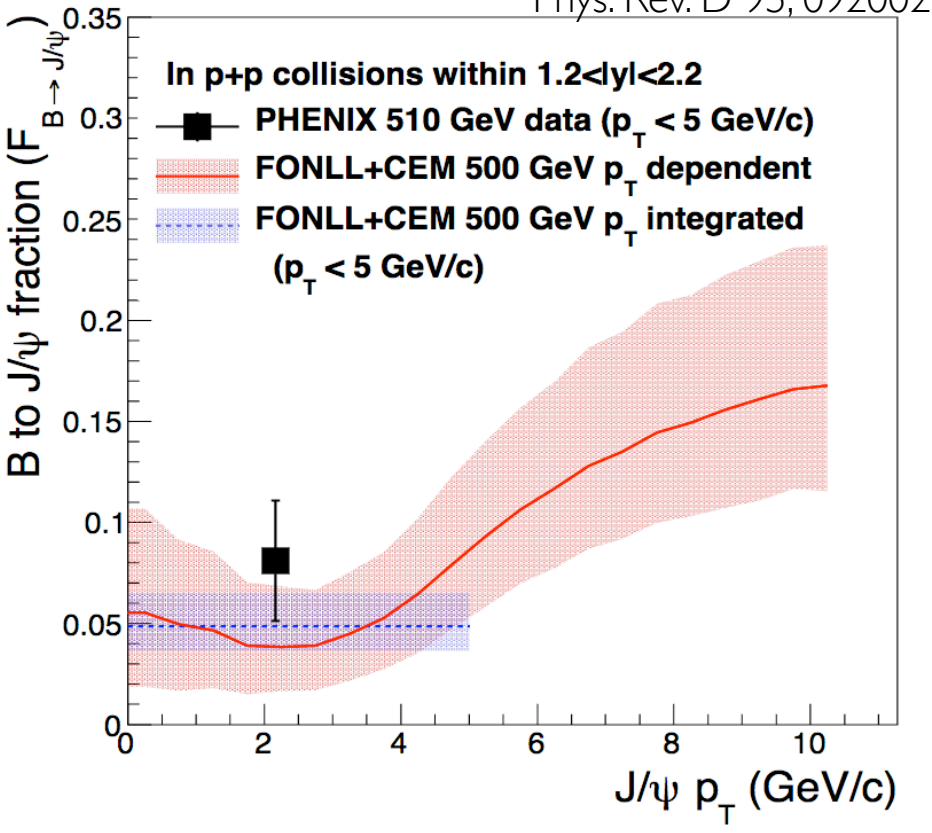
p+p 200 GeV

arXiv:1702.01085



p+p 510 GeV

Phys. Rev. D 95, 092002



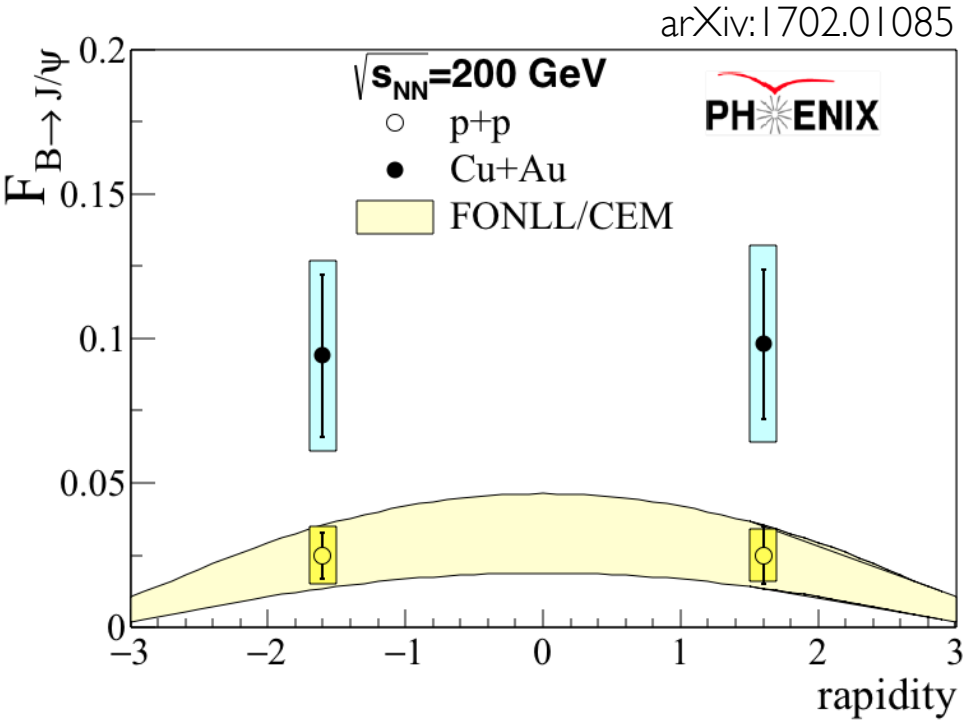
FONLL: [Cacciari, JHEP 05, 007 (1998)]
CEM: [R.Vogt et. al, Phys.Rep 462, 125 (2008)]

- ***Data is consistent with FONLL/CEM model calculation in p+p***

$F_{B\rightarrow J/\psi}$ in Cu+Au

- ***Non-prompt J/ψ enhanced in Cu+Au collisions relative to p+p***
- ***B-mesons are less suppressed than prompt J/ψ***

arXiv:1702.01085



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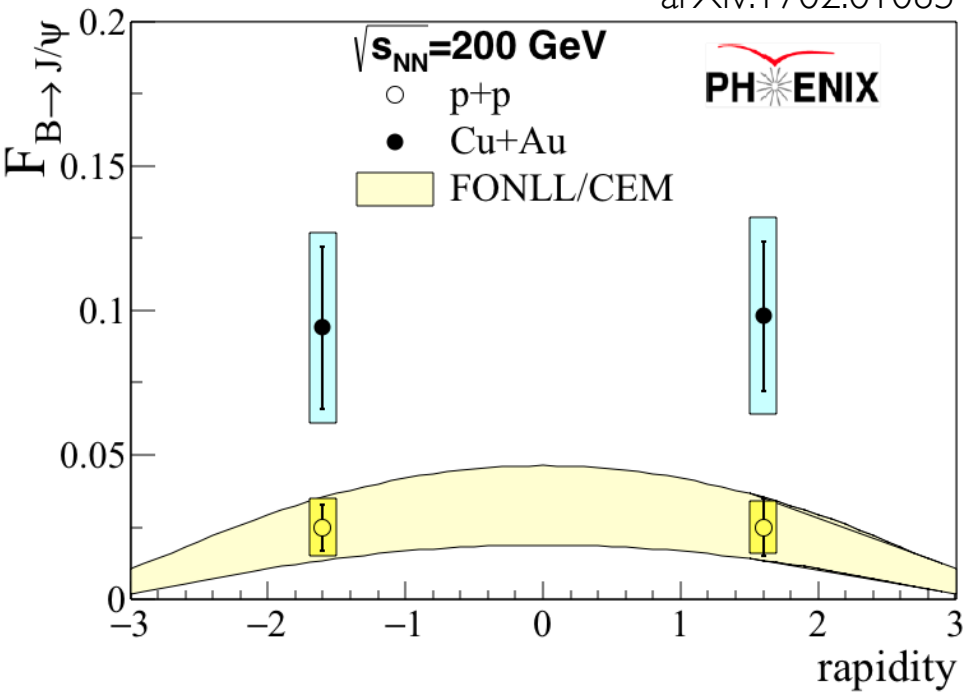
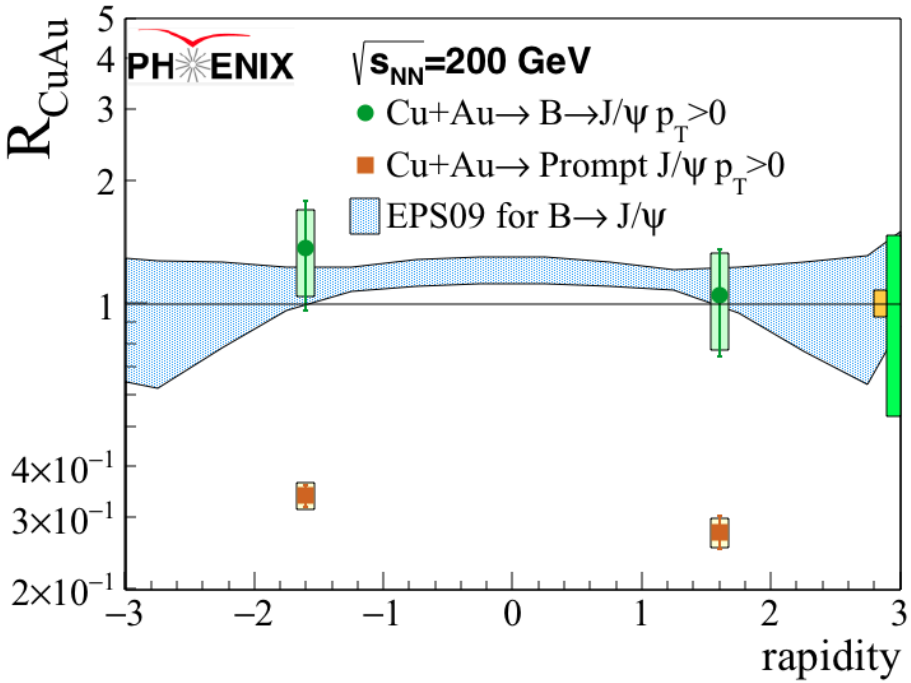




- ***Prompt J/ψ number not preserved***
  - ***breaking/melting in medium***
- ***B-meson R_{CuAu} is consistent with***
  - ***No nuclear modification***
  - ***EPS09 parametrization***

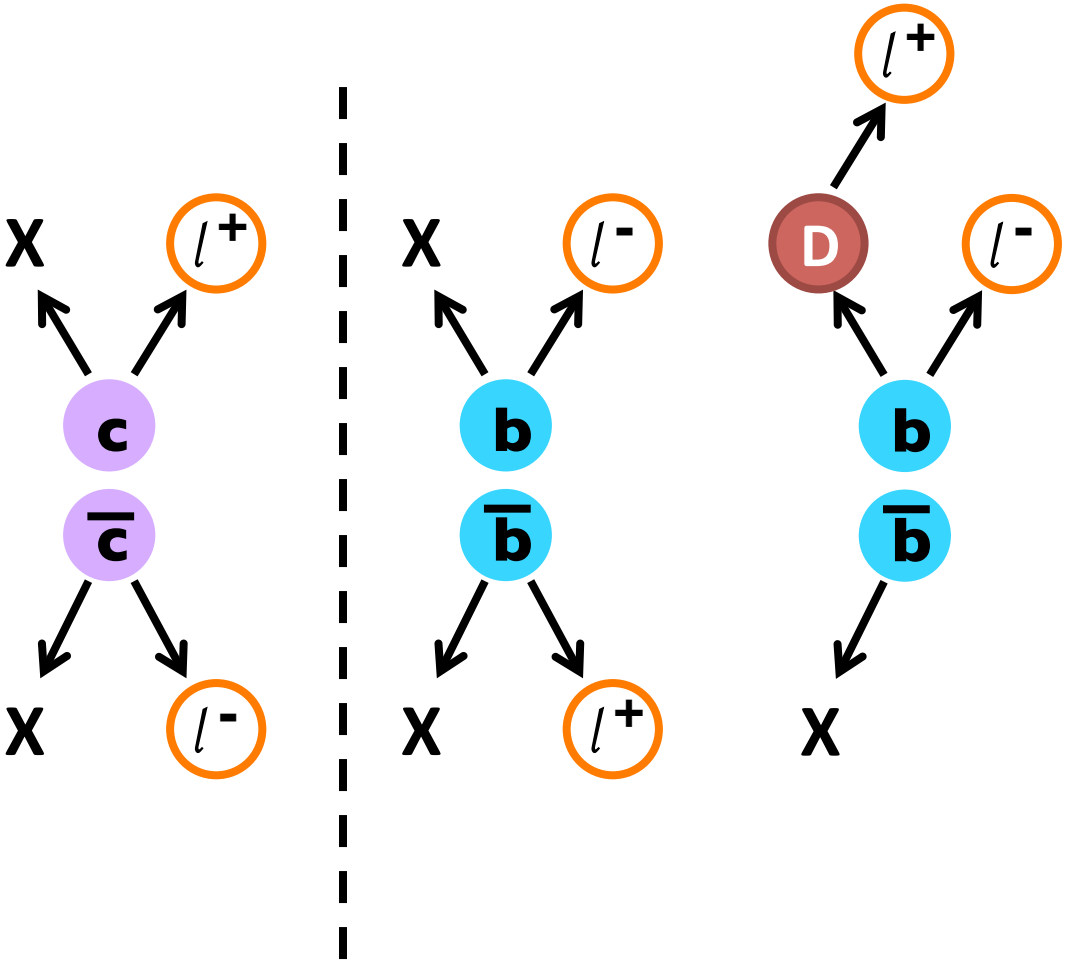
OPEN HEAVY FLAVOR

via dileptons

- ***Dimuons: Forward rapidity 1.2<|y|<2.2***
  - ***p+p 200GeV***
- ***Dielectrons: Mid-rapidity |y|<0.35***
  - ***p+p 200GeV, d+Au 200GeV***

Heavy flavor dileptons

Semi-leptonic decays from Charm and Bottom produce unlike-sign leptons pairs



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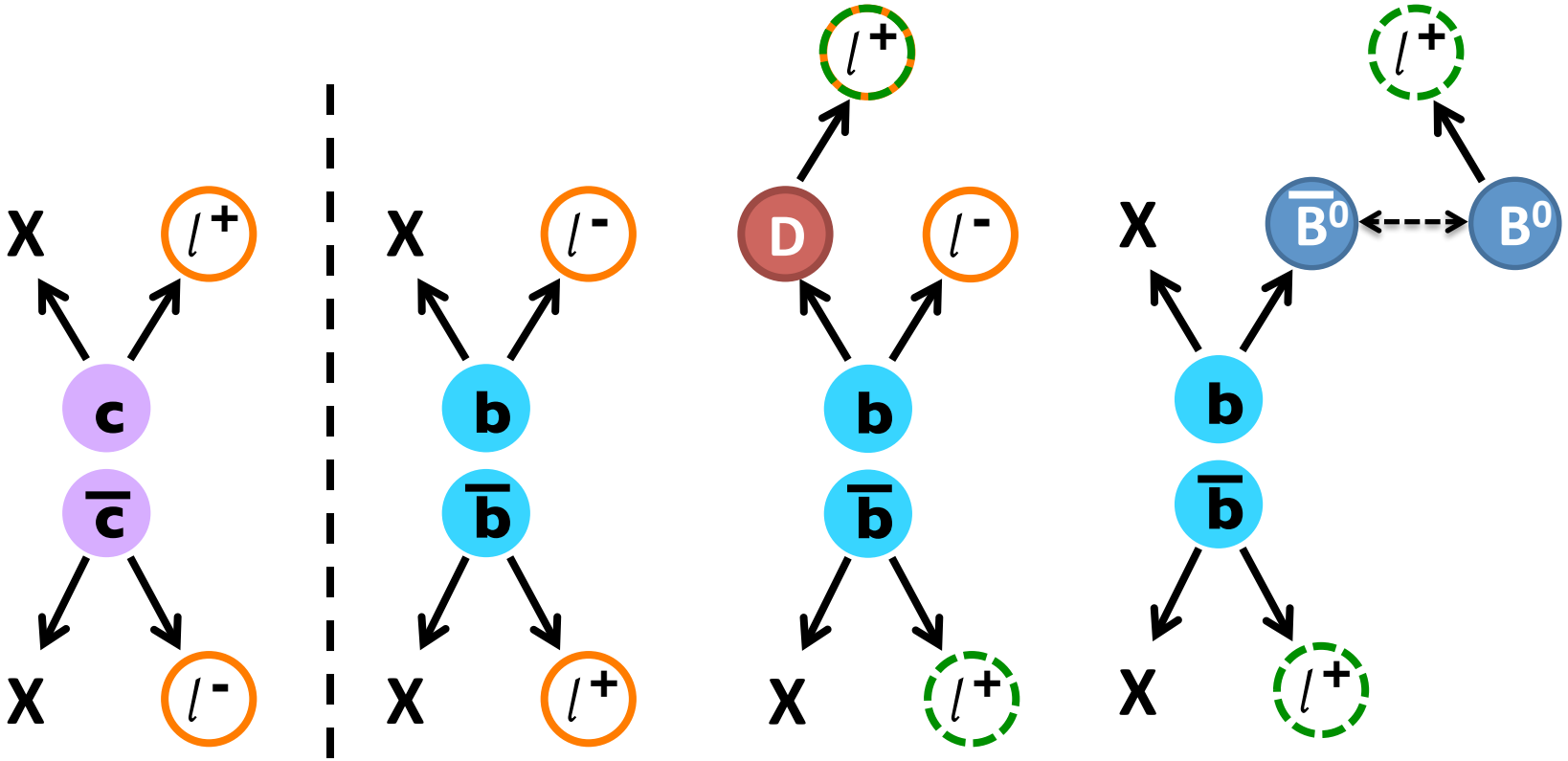

Semi-leptonic decays from Bottom can also produce like-sign lepton pairs

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via dileptons

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  - ***p+p 200GeV***
- ***Dielectrons: Mid-rapidity |y|<0.35***
  - ***p+p 200GeV, d+Au 200GeV***

Dimuon cocktail

- **Hadron decays**
  - η, η'
  - ϕ, ρ, ω
  - J/ψ, ψ(2s)
  - Υ(1s,2s,3s)
  - K^0, $K^{\pm}$, $\pi^{\pm}$
- **Heavy flavor**
  - Charm
  - Bottom
- **Drell-Yan**

Input rapidity/p_T distributions constrained by existing data whenever possible.

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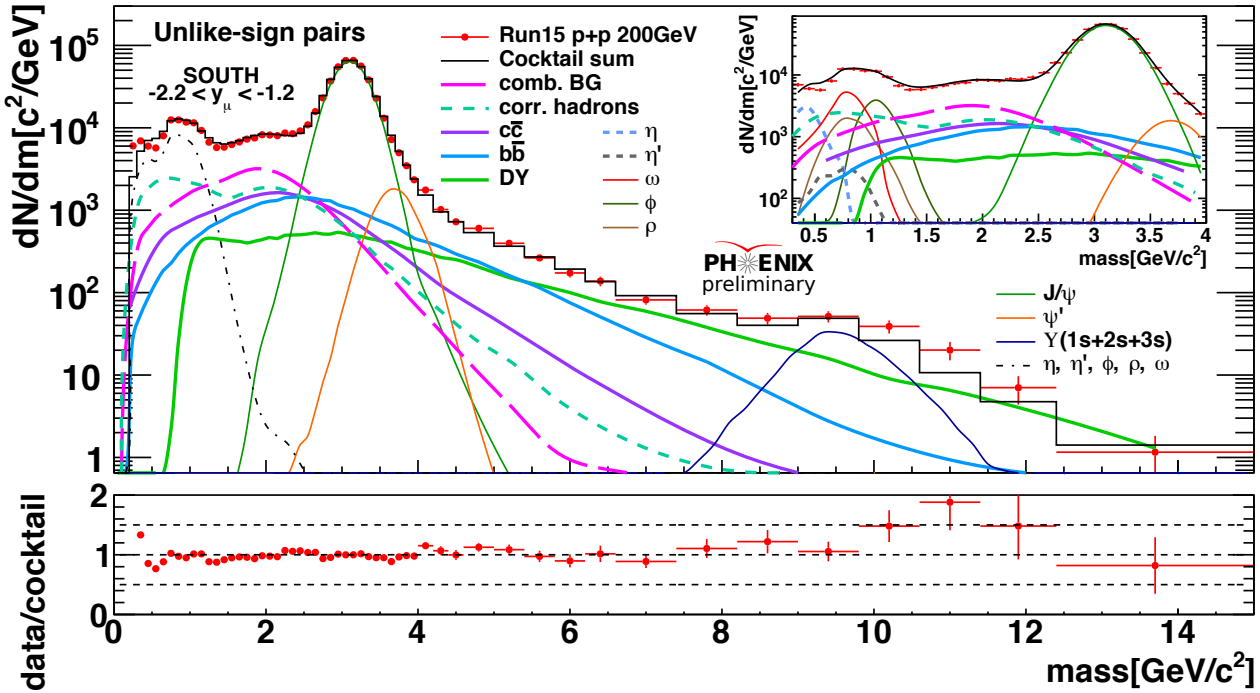
Input rapidity/p_T distributions constrained by existing data whenever possible.

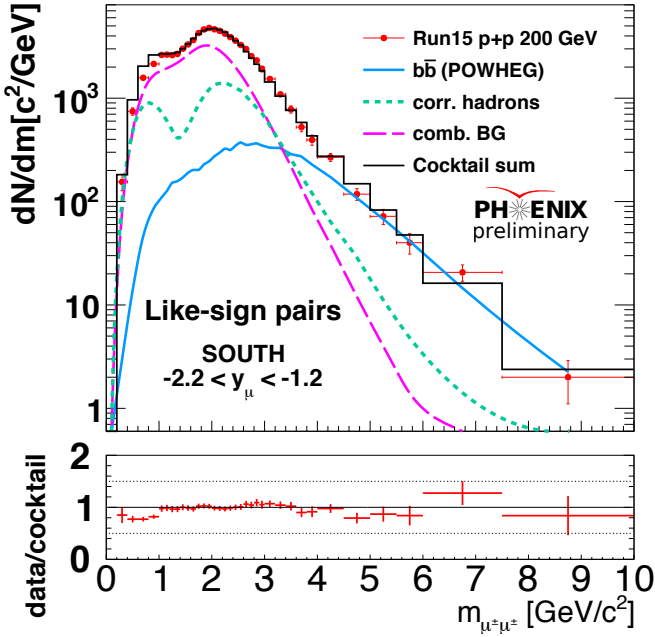
Simulations run through GEANT4 and reconstruction chain.

Normalizations of underlined components obtained via mass-p_T fit.

Cocktail and data comparison



Cocktail describes unlike-sign data well



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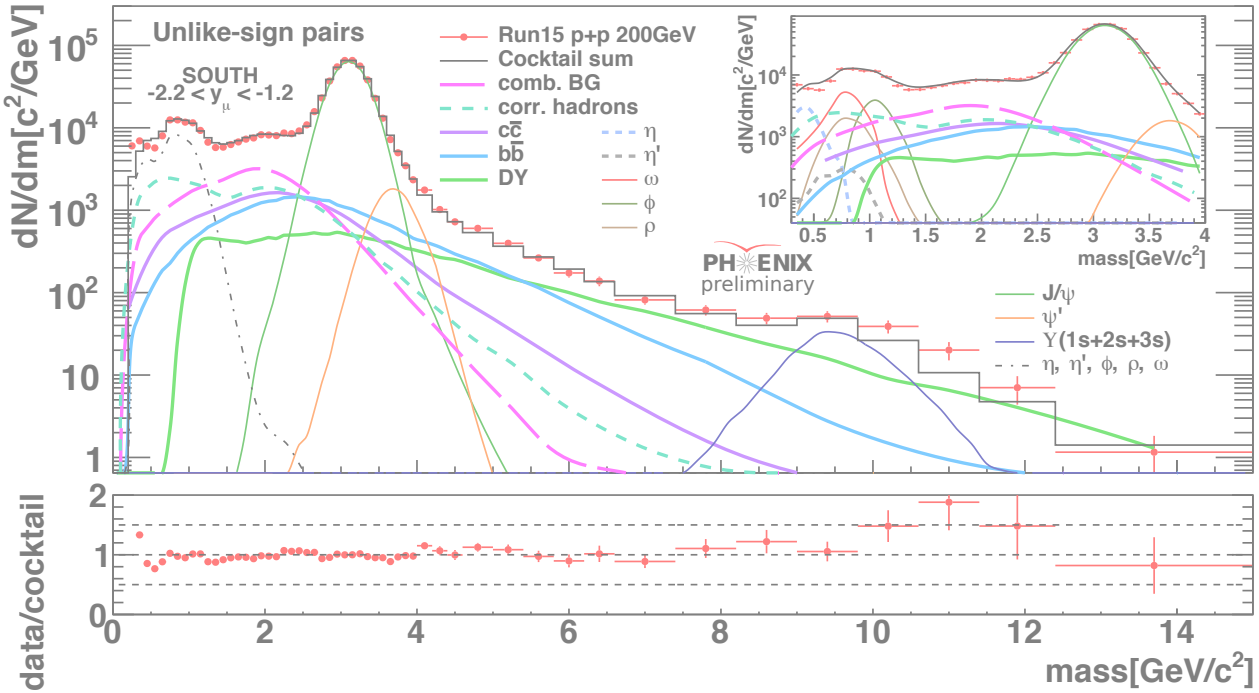
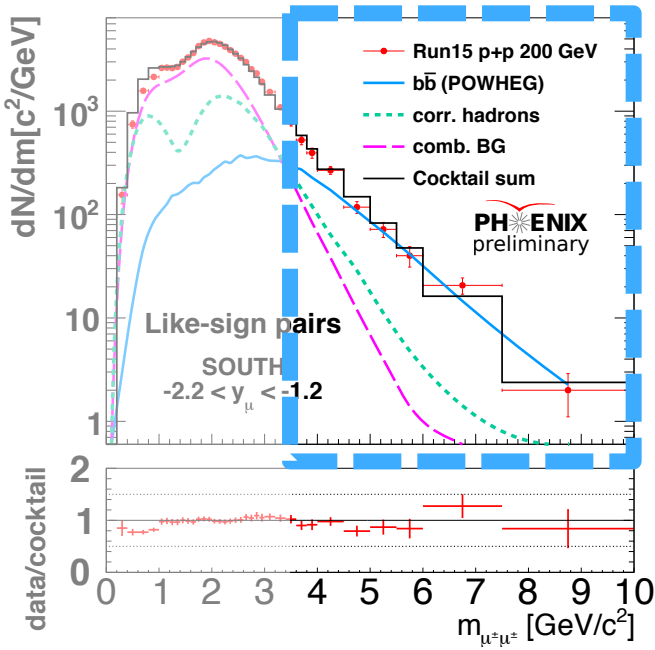


High mass like-sign pairs dominated by bottom



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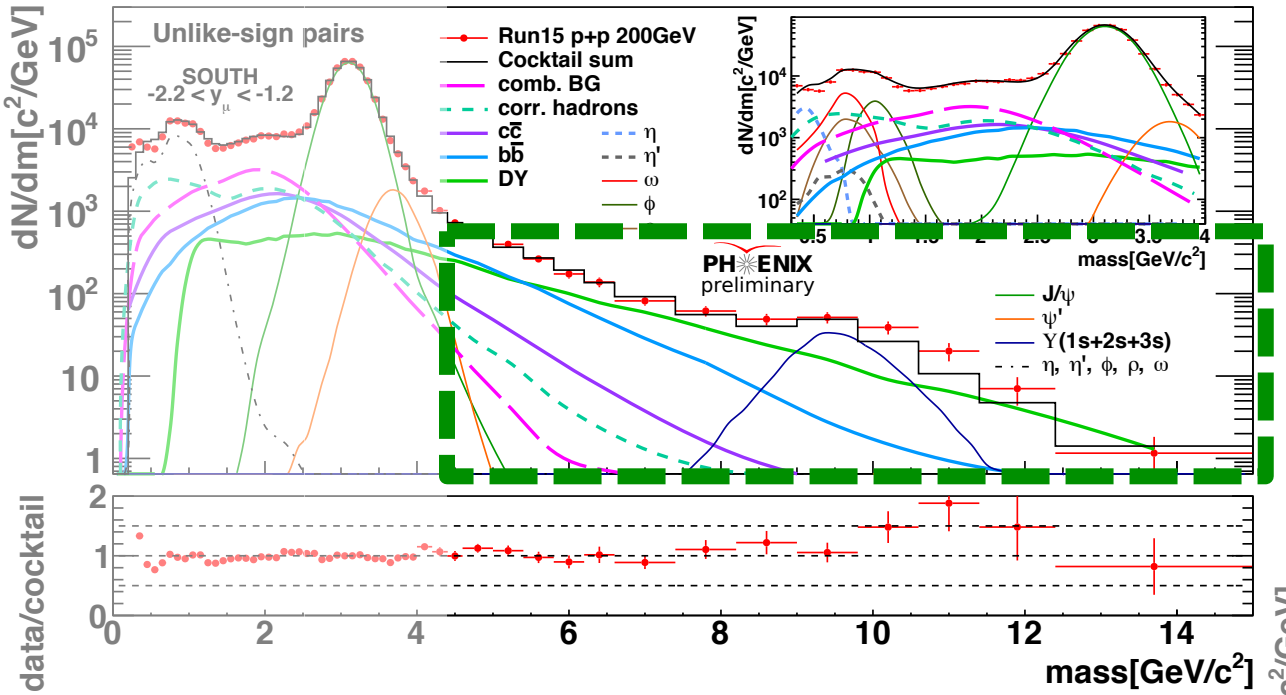
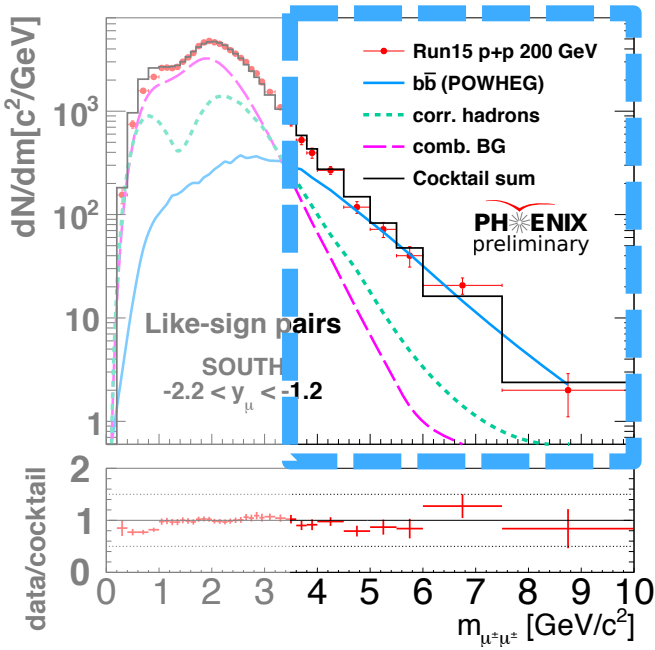


High mass unlike-sign pairs dominated by Drell-Yan

High mass like-sign pairs dominated by bottom



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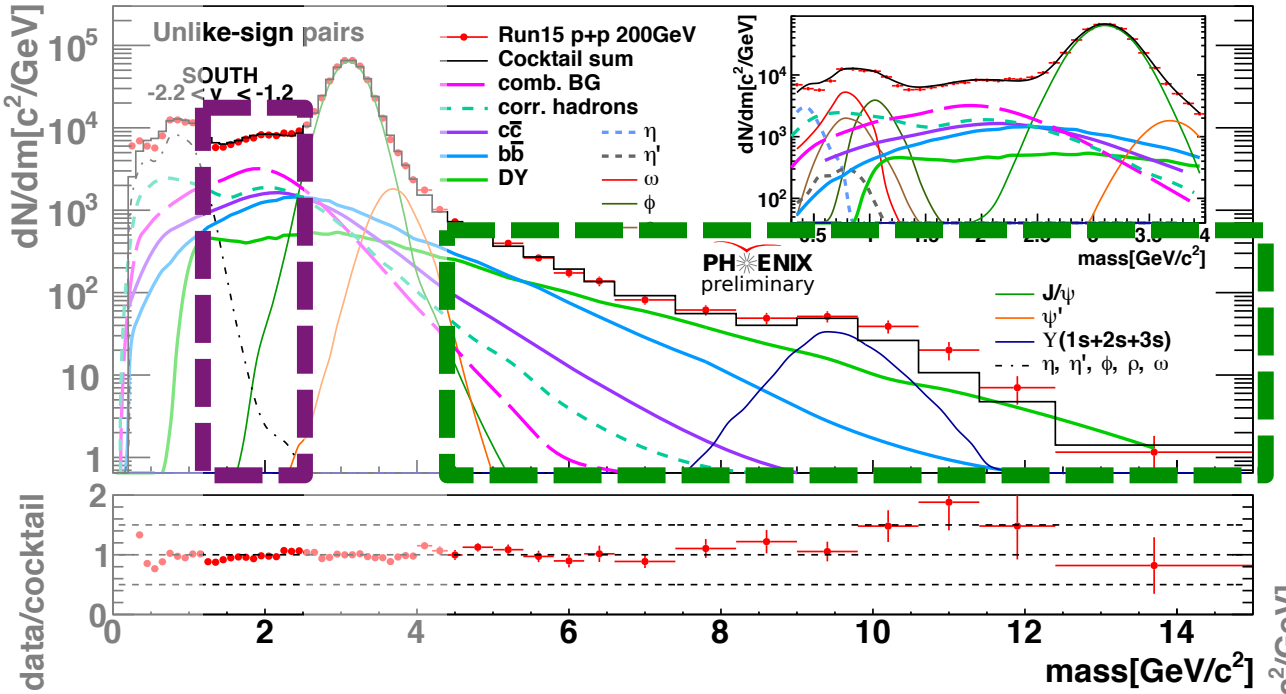
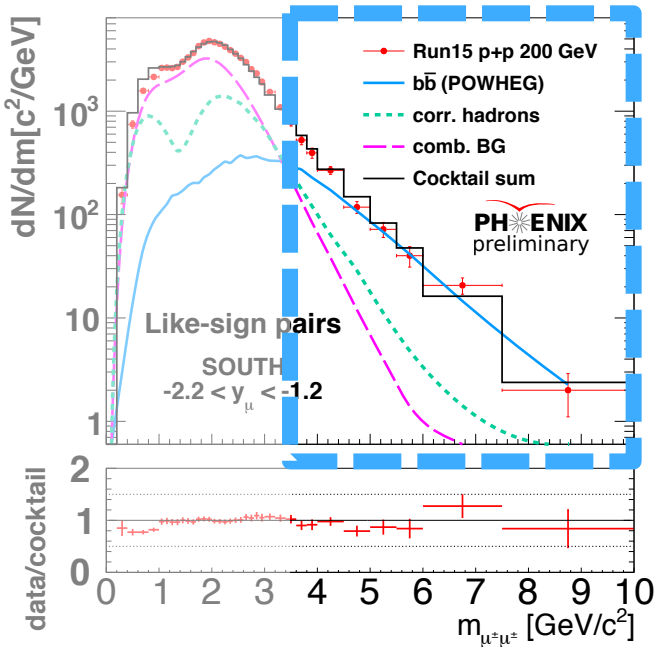


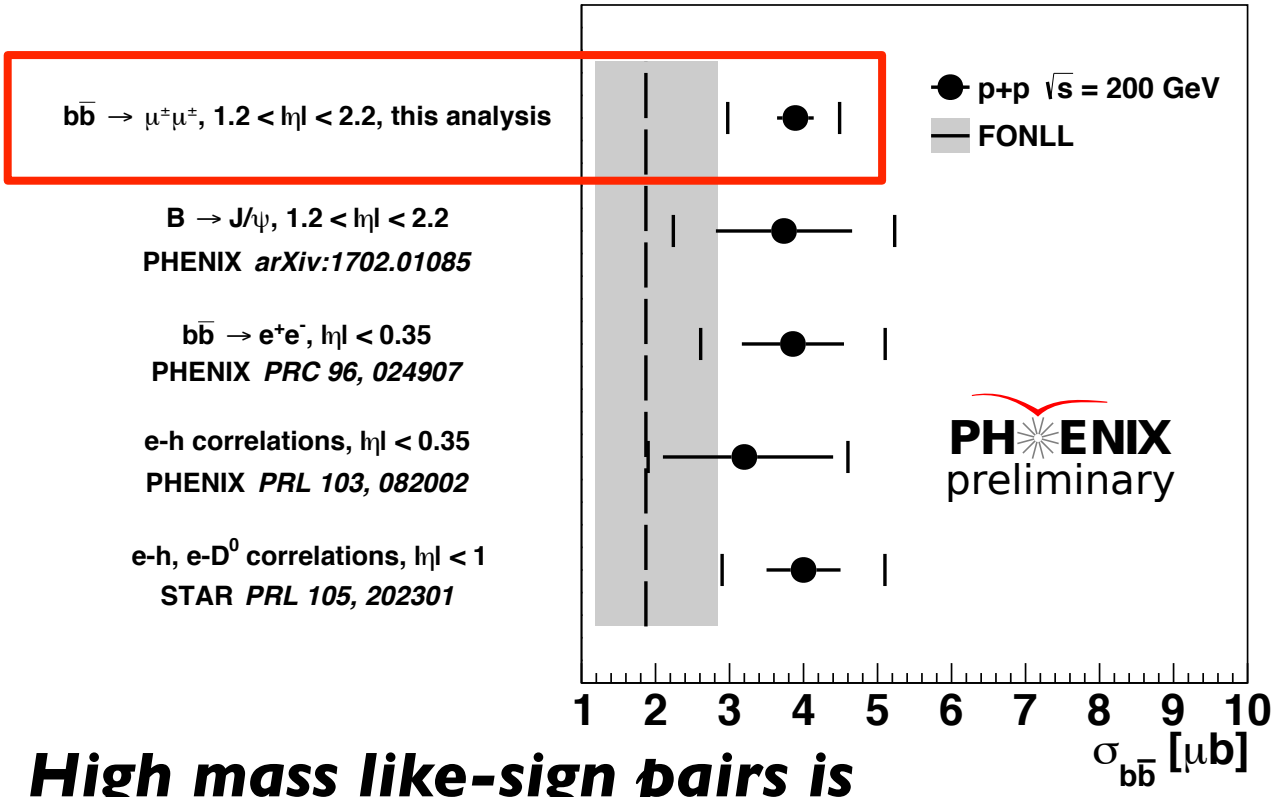
Charm S/B highest in intermediate mass region

High mass unlike-sign pairs dominated by Drell-Yan

High mass like-sign pairs dominated by bottom



Comparison with other RHIC measurements

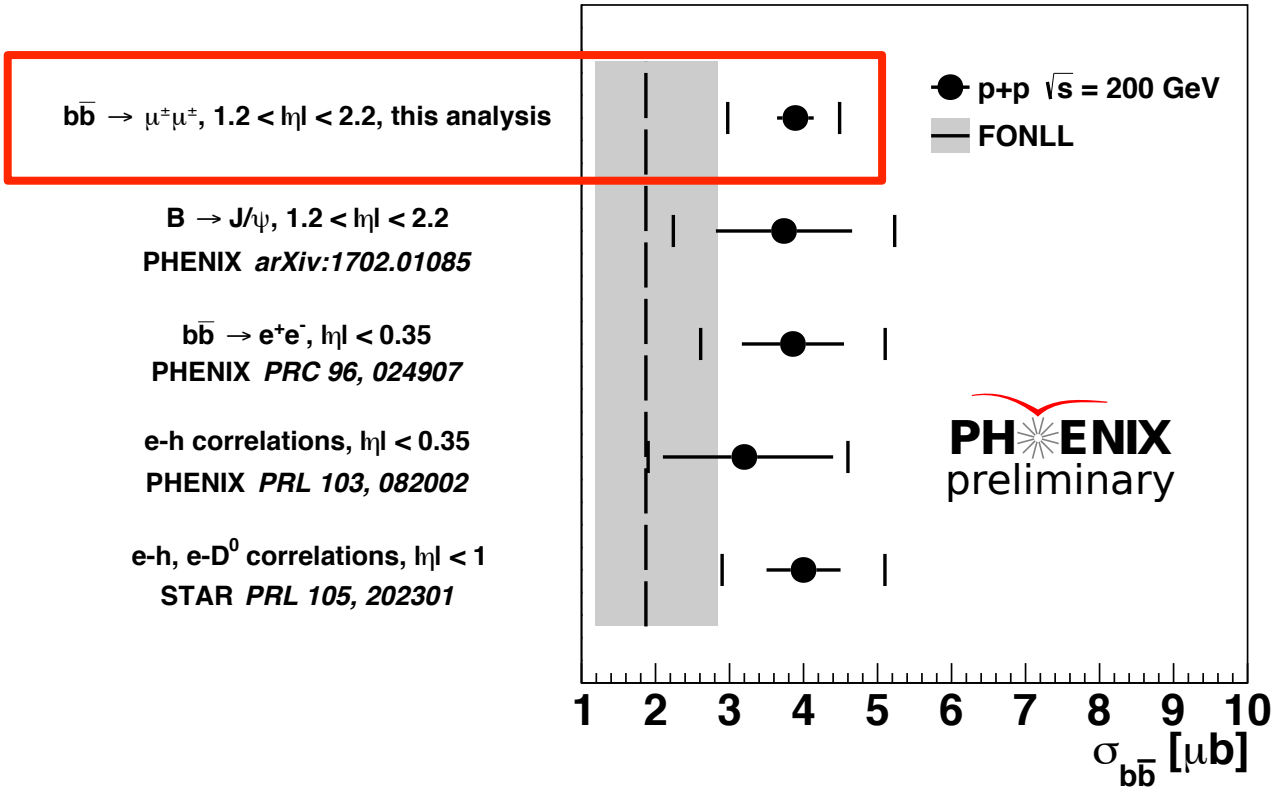


- ***σ_{bb} from dimuon measurement is consistent with other RHIC measurements***

High mass like-sign pairs is dominated by dimuon pairs from bottom:

- ***Extrapolate to 4π phase space to obtain total bottom x-section***

Comparison with other RHIC measurements



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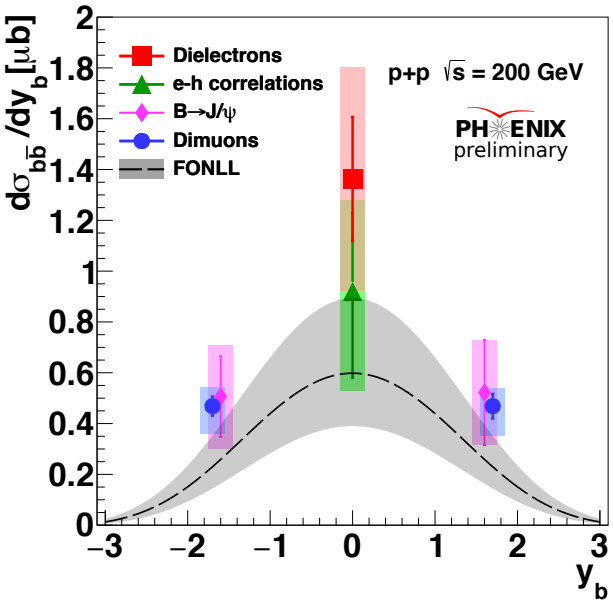
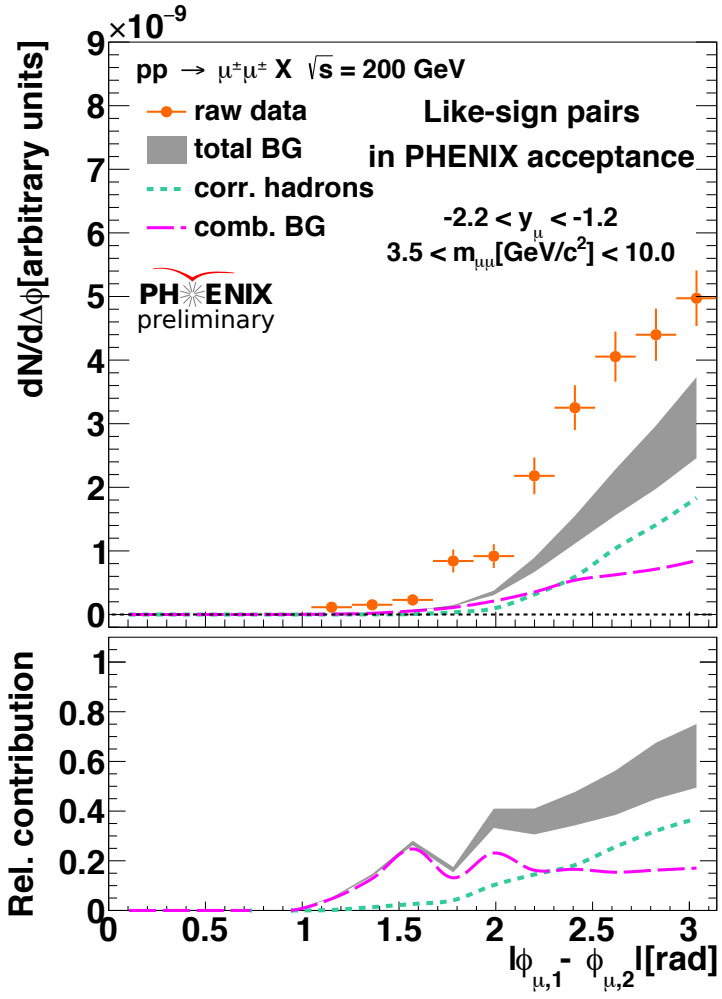
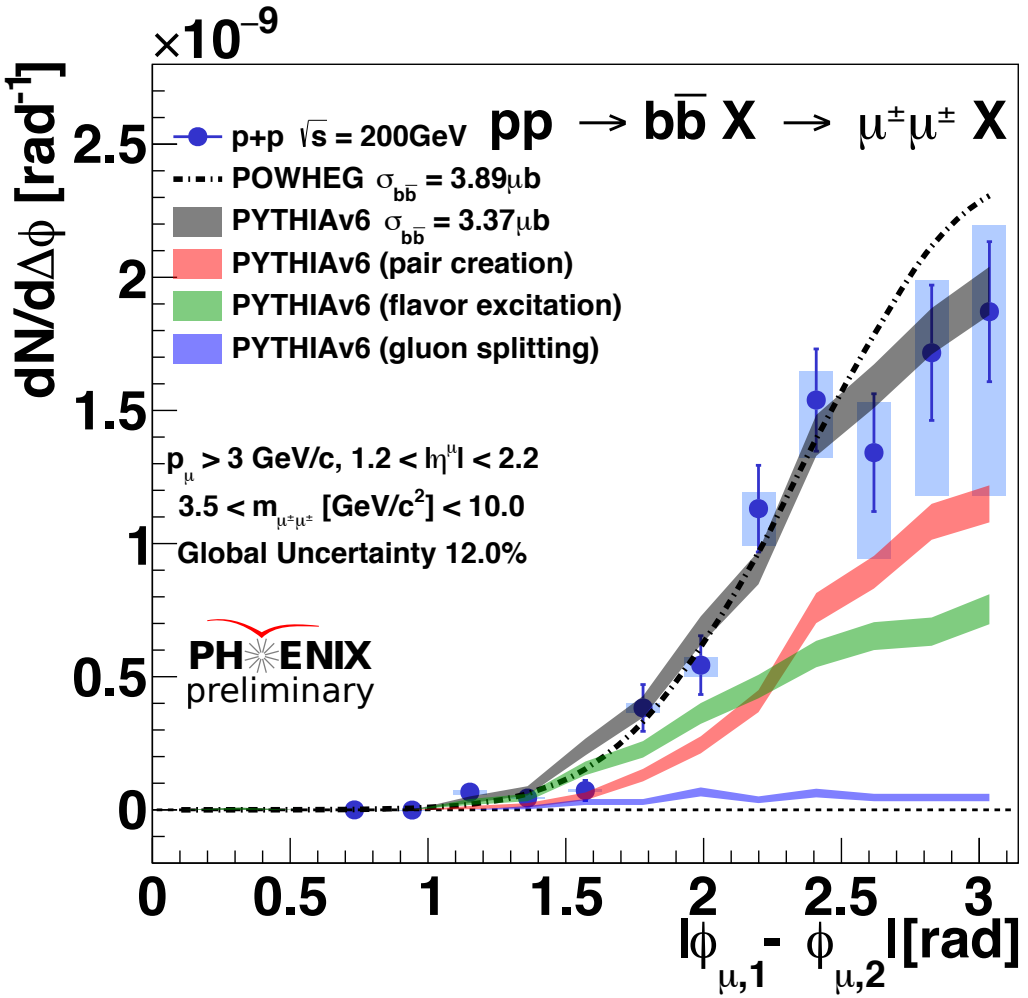


- ***Measured bb cross-section around a factor of 2 from central prediction of FONLL***

Bottom azimuthal correlations

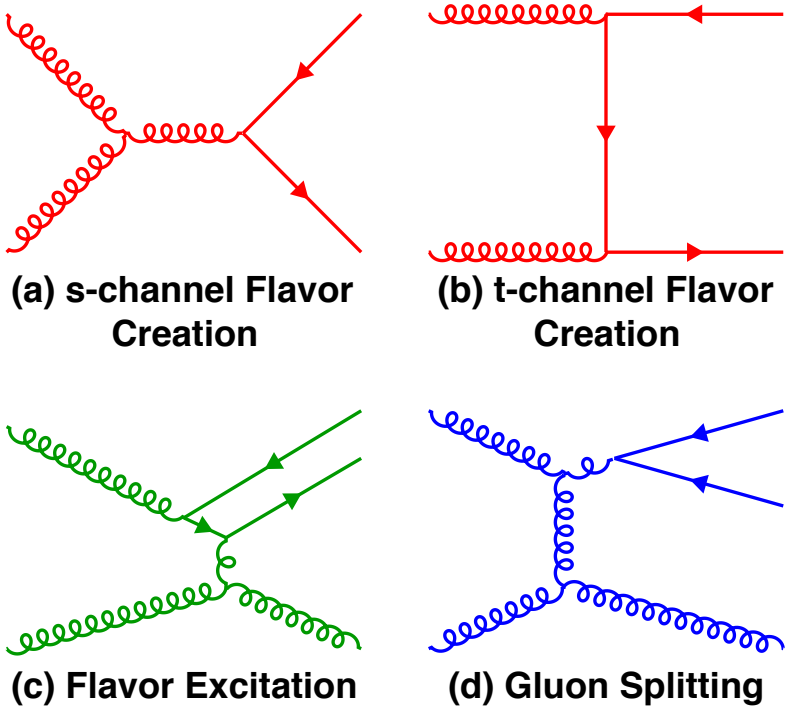


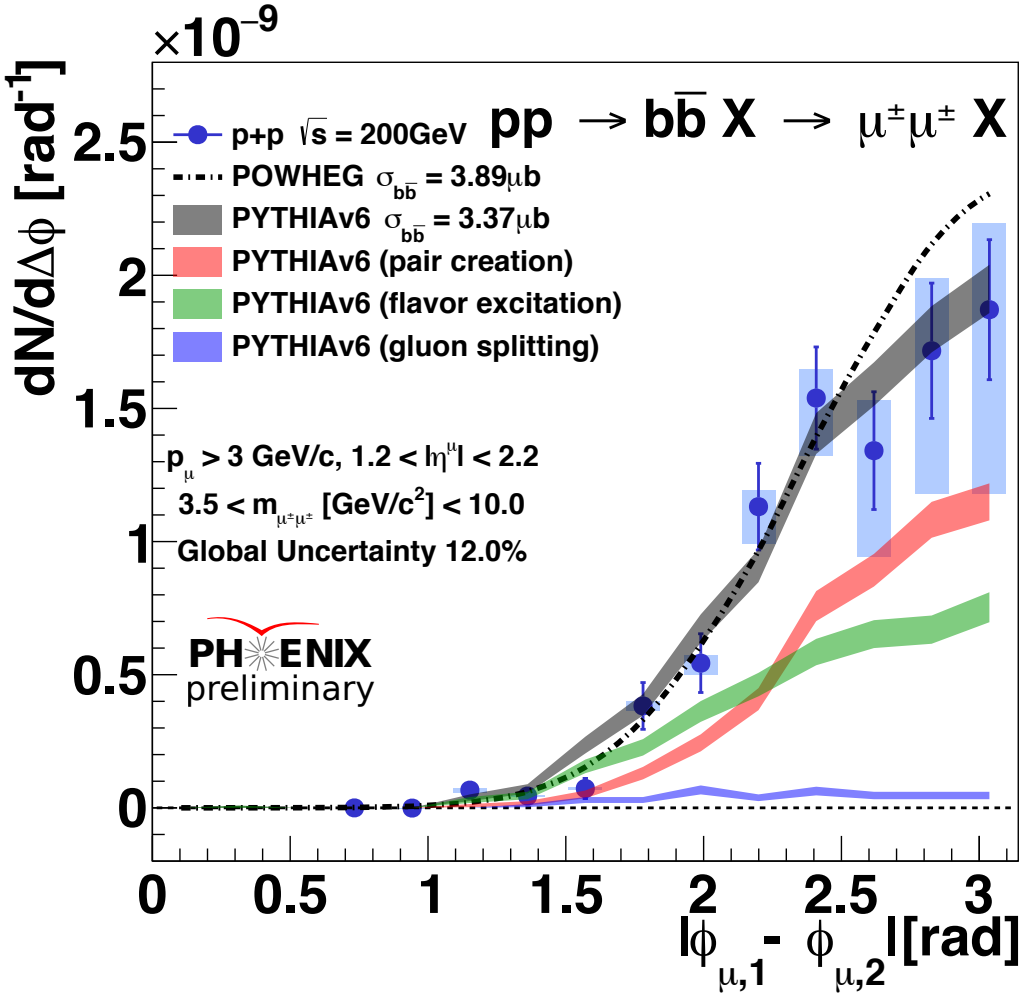


Subtract BG from data → **Eff. corrections** → **Combine arms** → **Corrected dimuon yield from bottom**

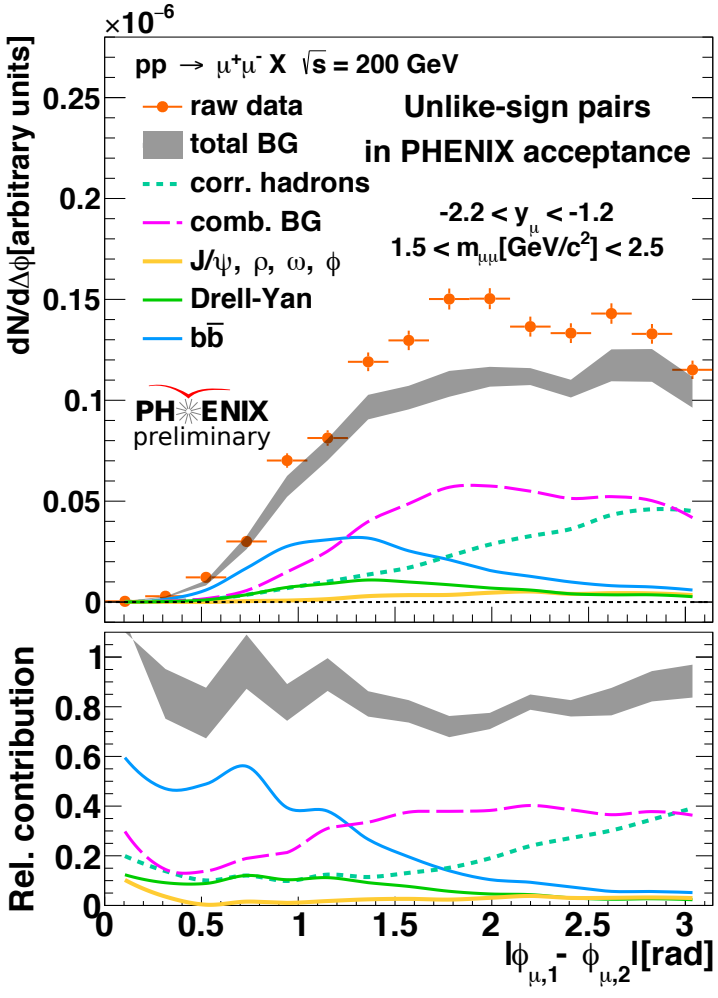
Bottom azimuthal correlations

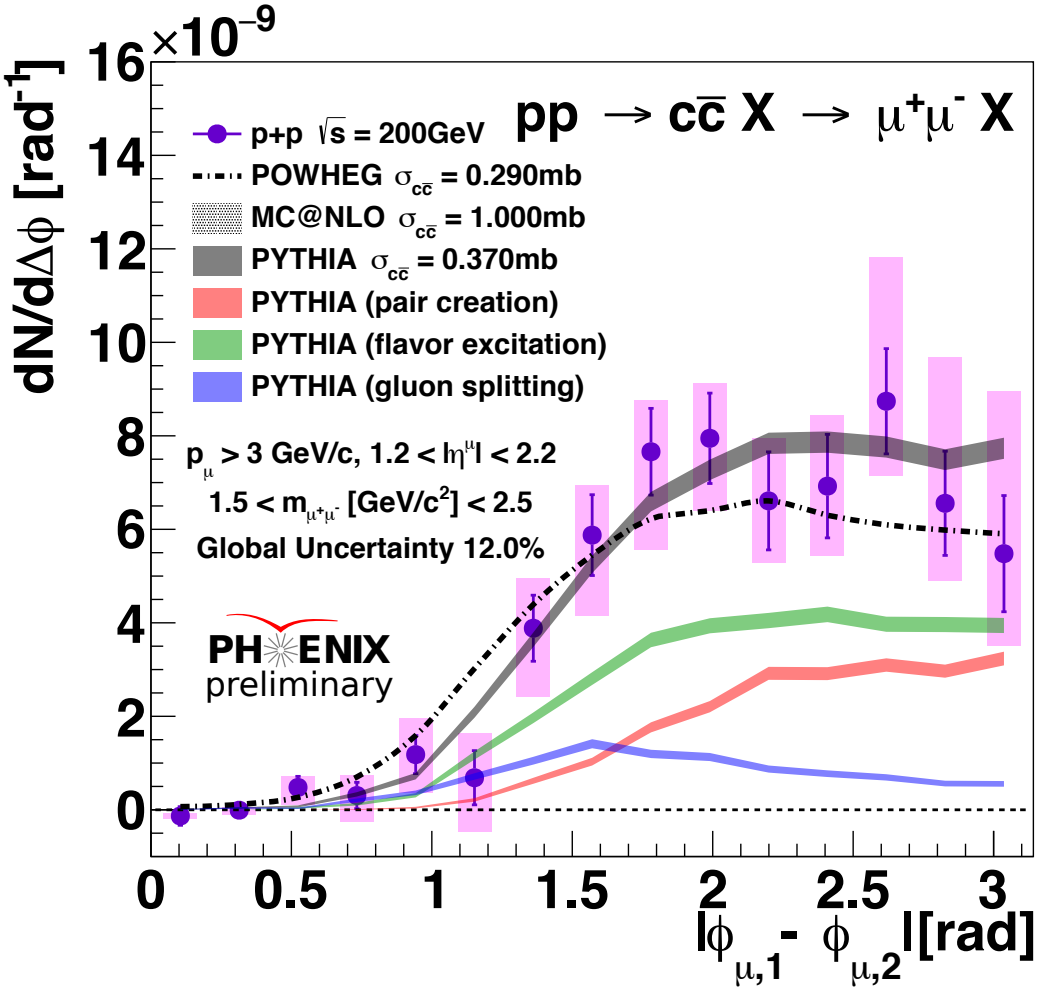
- ***bb from gluon splitting negligible at RHIC energies.***
- ***PYTHIA's NLO:LO ratio seems to describe data well.***





Charm azimuthal correlations

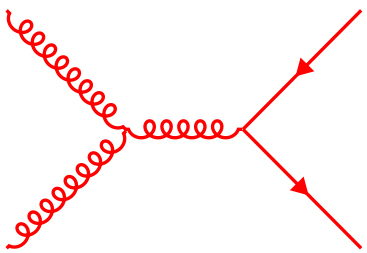




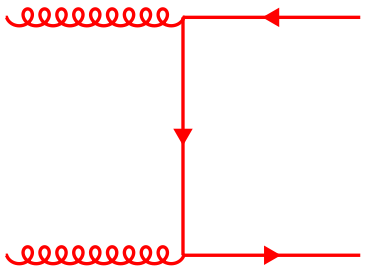
Subtract BG from data → **Eff. corrections** → **Combine arms** → **Corrected dimuon yield from charm**

Charm azimuthal correlations

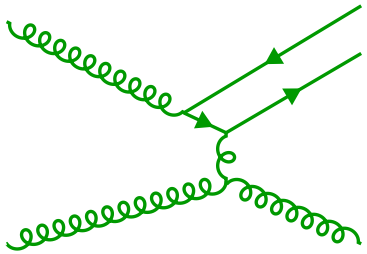
- ***PYTHIA's ratio of various processes describe charm data well also.***



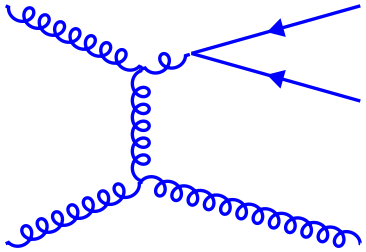
(a) s-channel Flavor Creation



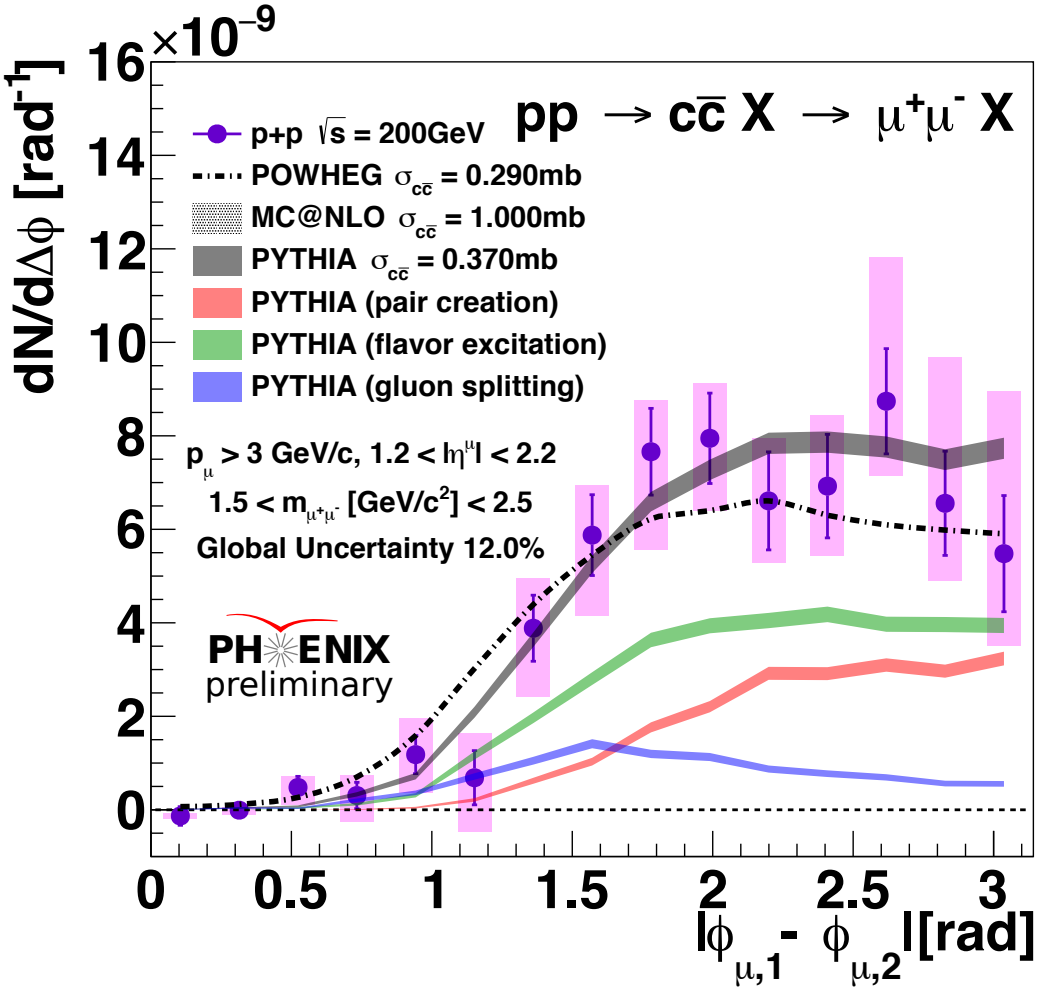
(b) t-channel Flavor Creation



(c) Flavor Excitation

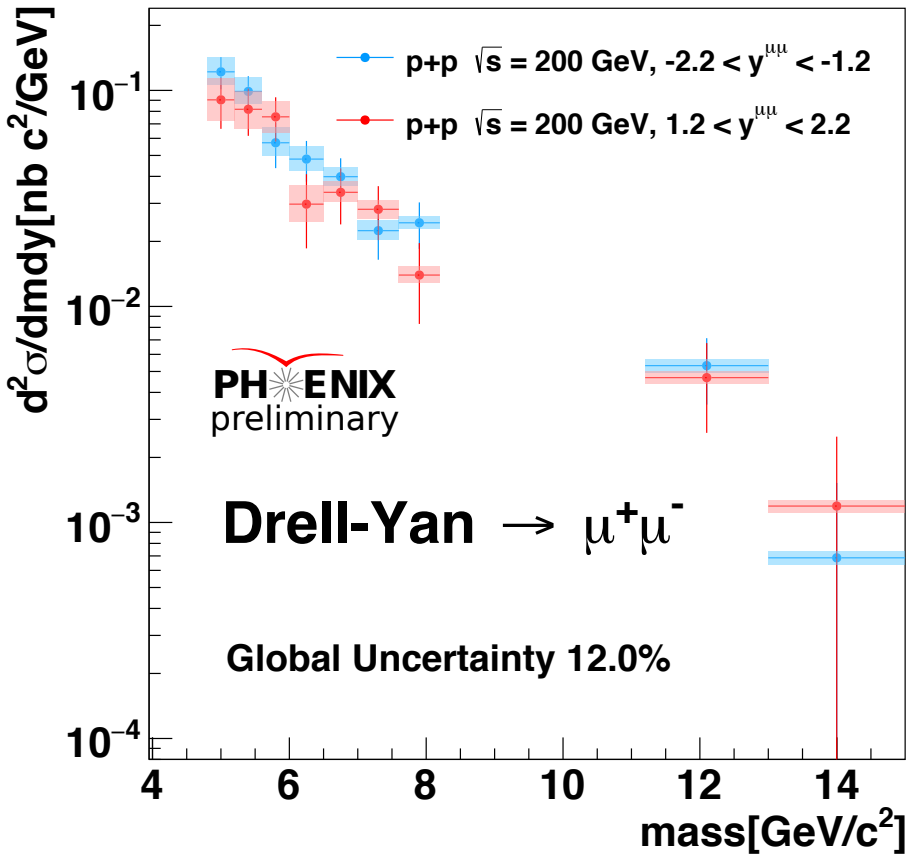


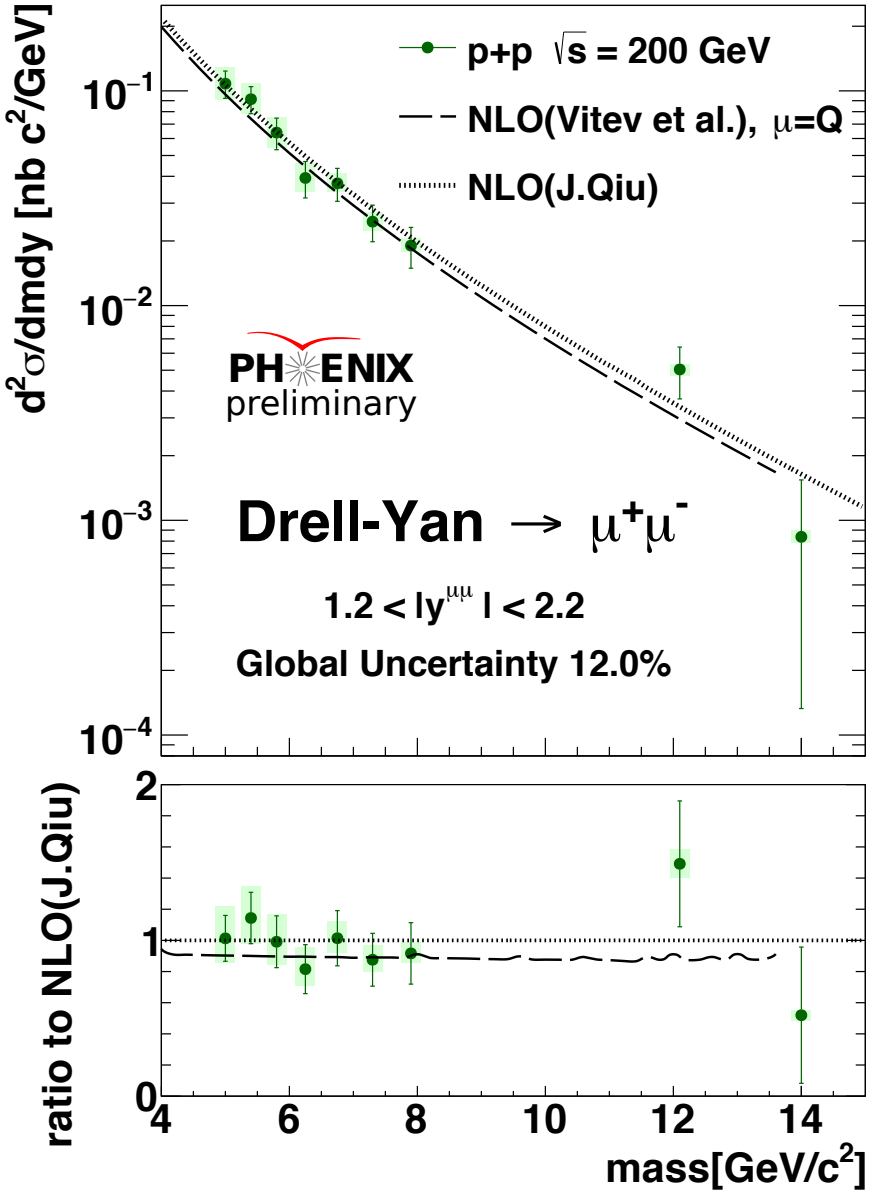
(d) Gluon Splitting



- ***Model dependence in extrapolated total charm cross-section is larger than bottom***

Aside: Drell-Yan cross-section





Drell-Yan measurement in good agreement with NLO calculations

OPEN HEAVY FLAVOR

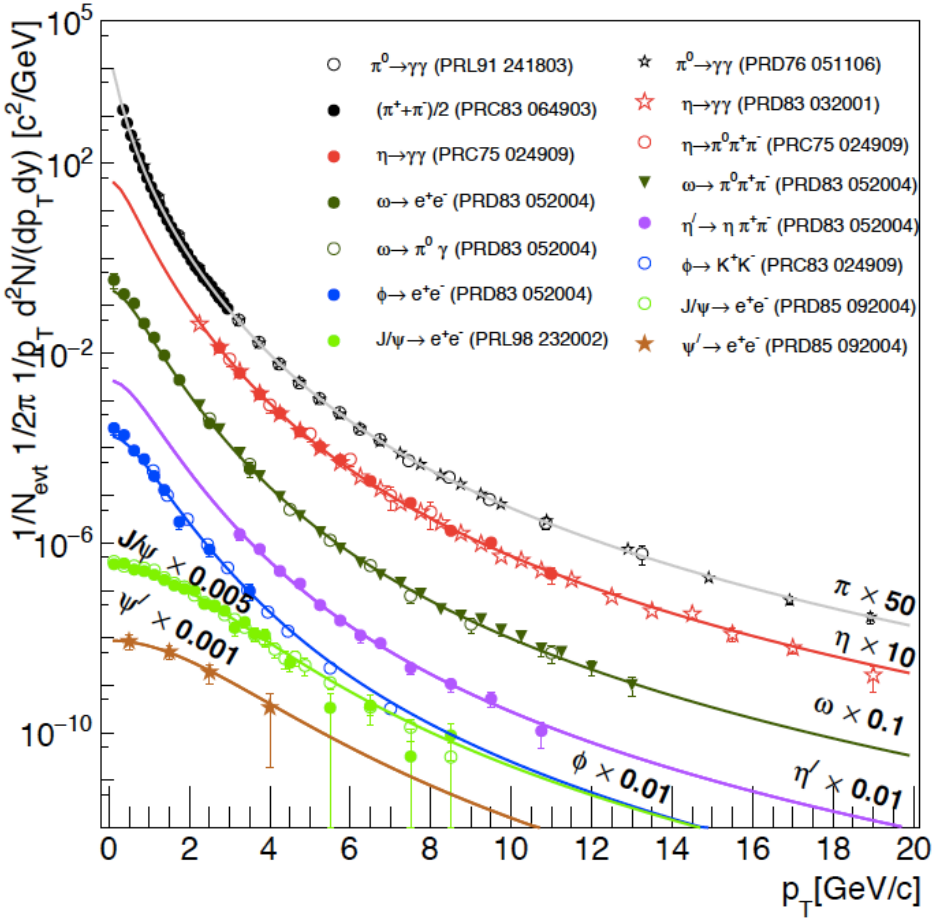
via dileptons

- ***Dimuons: Forward rapidity 1.2<|y|<2.2***
  - ***p+p 200GeV***
- ***Dielectrons: Mid-rapidity |y|<0.35***
  - ***p+p 200GeV, d+Au 200GeV***

Dielectron cocktail

- **Hadron decays**
  - η, η'
  - ϕ, ρ, ω
  - J/ψ, ψ(2s)
  - Υ(1s,2s,3s)
  - π^0
- **Heavy flavor**
  - Charm
  - Bottom
- **Drell-Yan**

Input rapidity/p_T distributions constrained by existing data whenever possible.



Dielectron cocktail

- **Hadron decays**
  - η, η'
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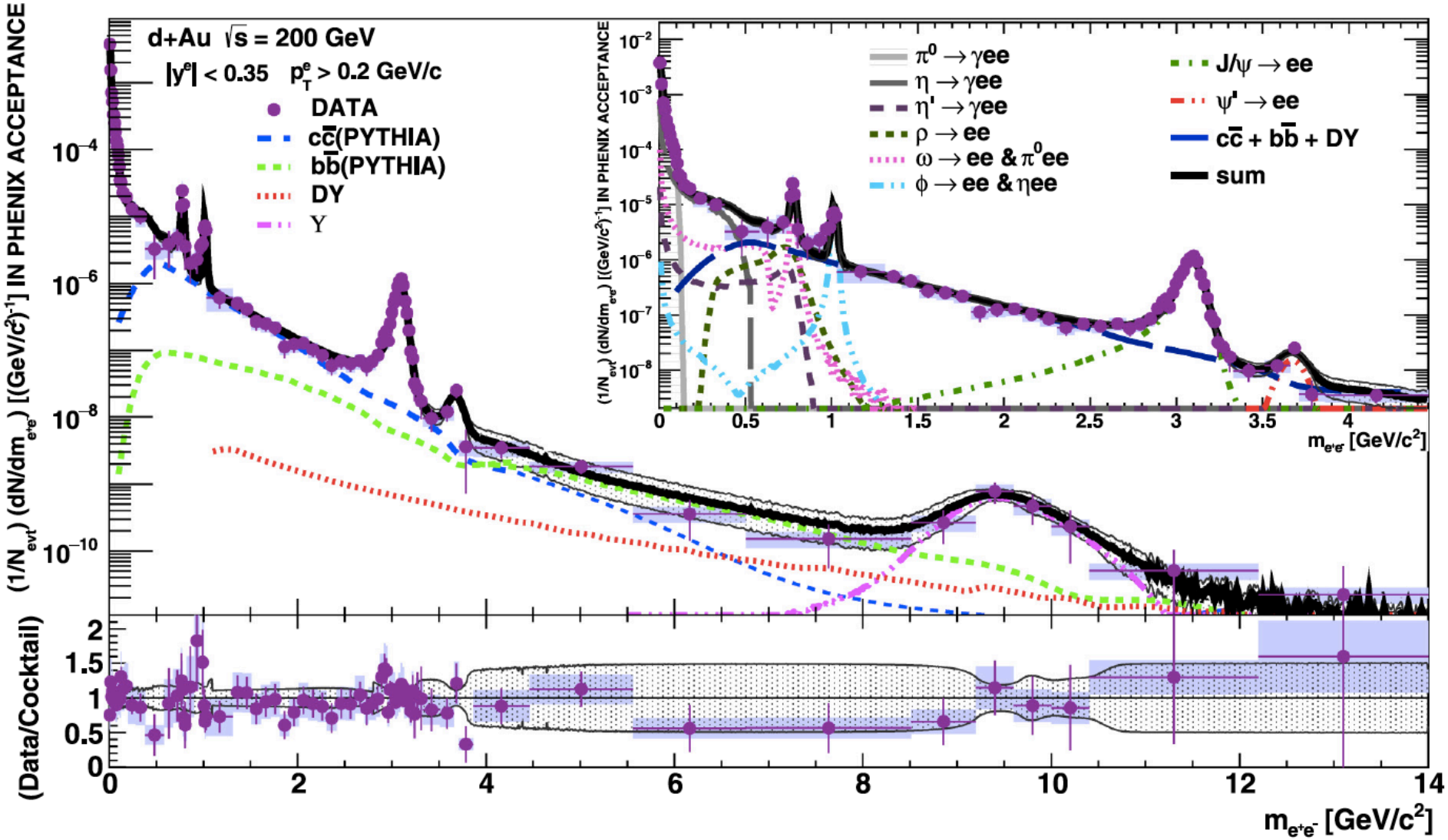
- **Heavy flavor**
  - Charm
  - Bottom
- **Drell-Yan**

Input rapidity/p_T distributions constrained by existing data.

Normalizations of underlined components constrained via mass-p_T fit to data.

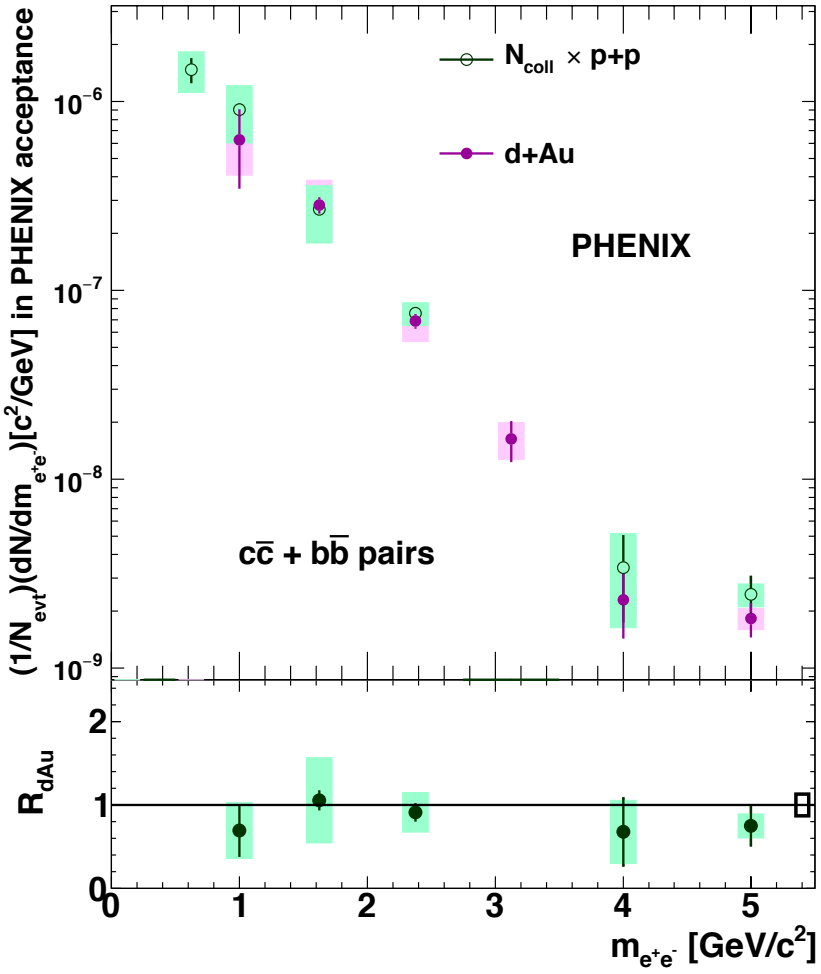
Dielectron mass spectrum in d+Au 200GeV



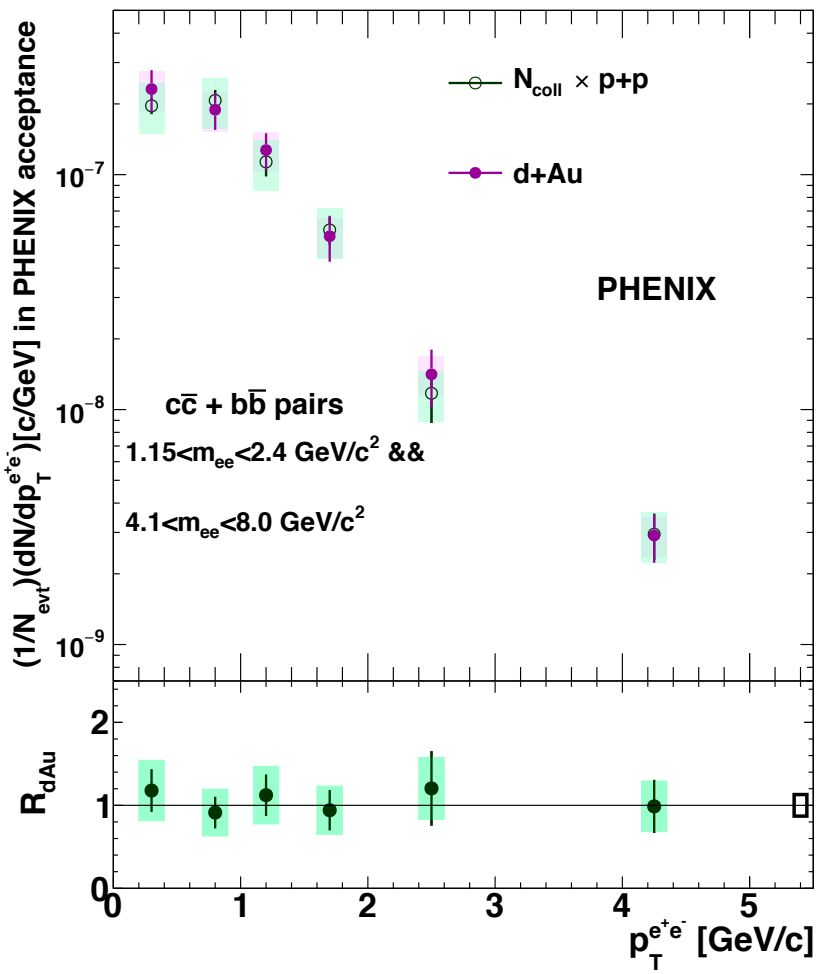
Data is consistent with cocktail

Nuclear modification of heavy flavor dielectrons

Mass distribution



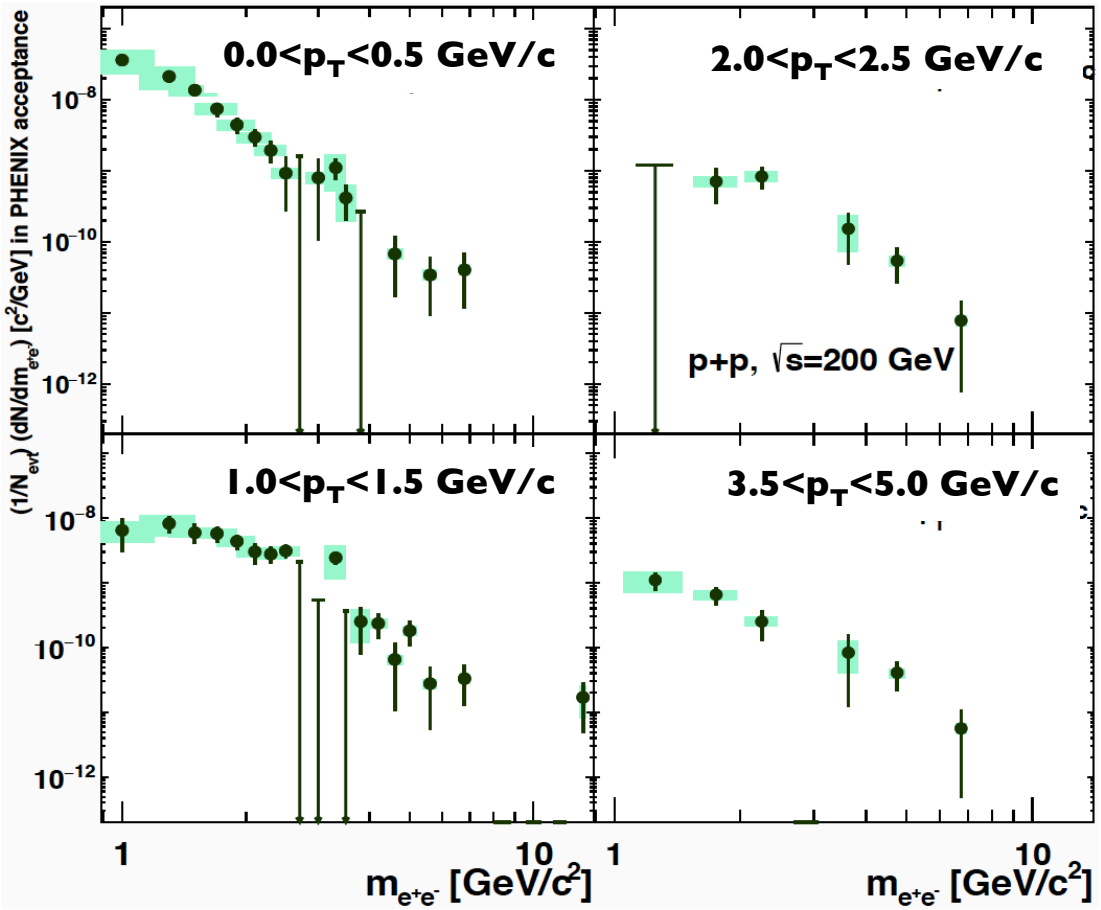
p_T distribution



No modification of dielectrons from open heavy flavor in d+Au collisions compared to p+p

Separation of charm and bottom components in mass and p_T

Fit Range: $1.15<m_{ee}<2.4$ GeV/c^2
&& $4.1<m_{ee}<8.0$ GeV/c^2



- ***Open charm and bottom yields determined by simultaneous fit in mass and p_T distributions***

Separation of charm and bottom components in mass and p_T

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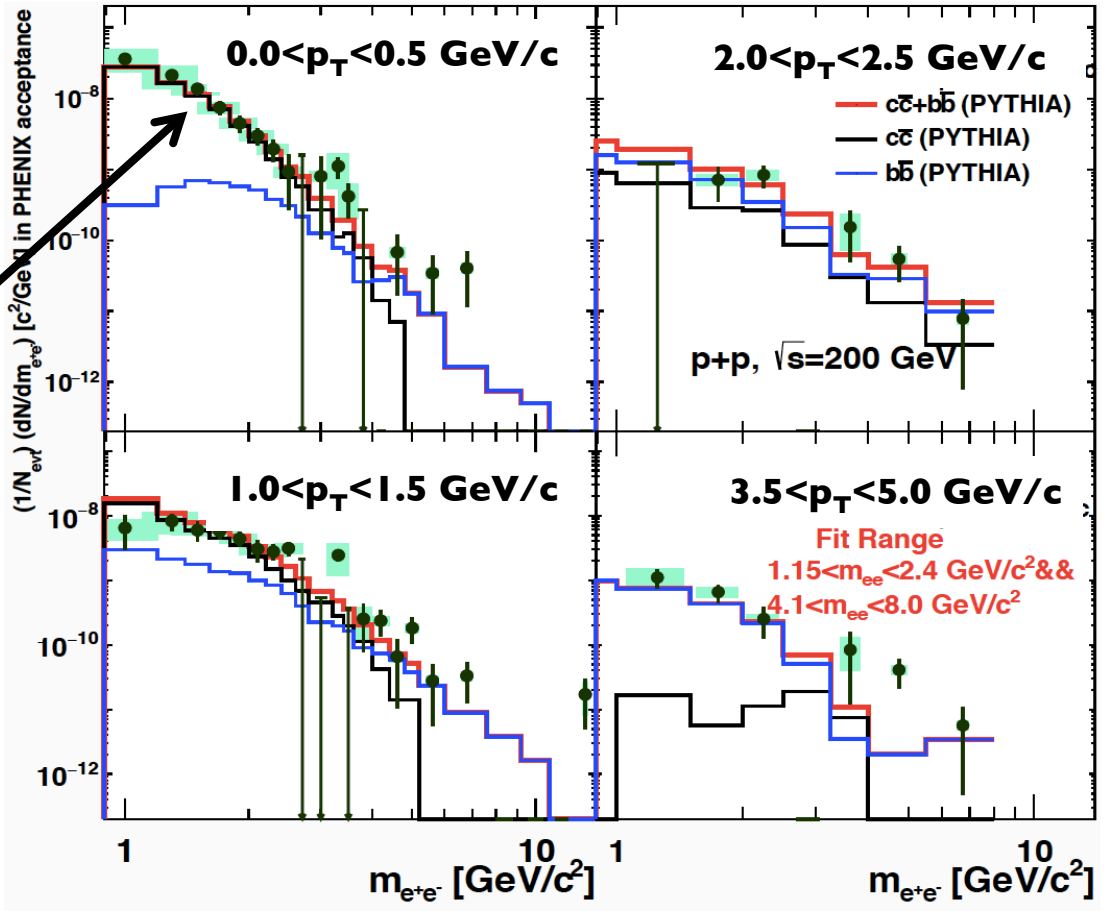
Charm + Bottom
Charm
Bottom

Charm dominates
Low pT, low mass



- ***Open charm and bottom yields determined by simultaneous fit in mass and p_T distributions***
- ***Three independent extractions based on different models: PYTHIA / MC@NLO / POWHEG***

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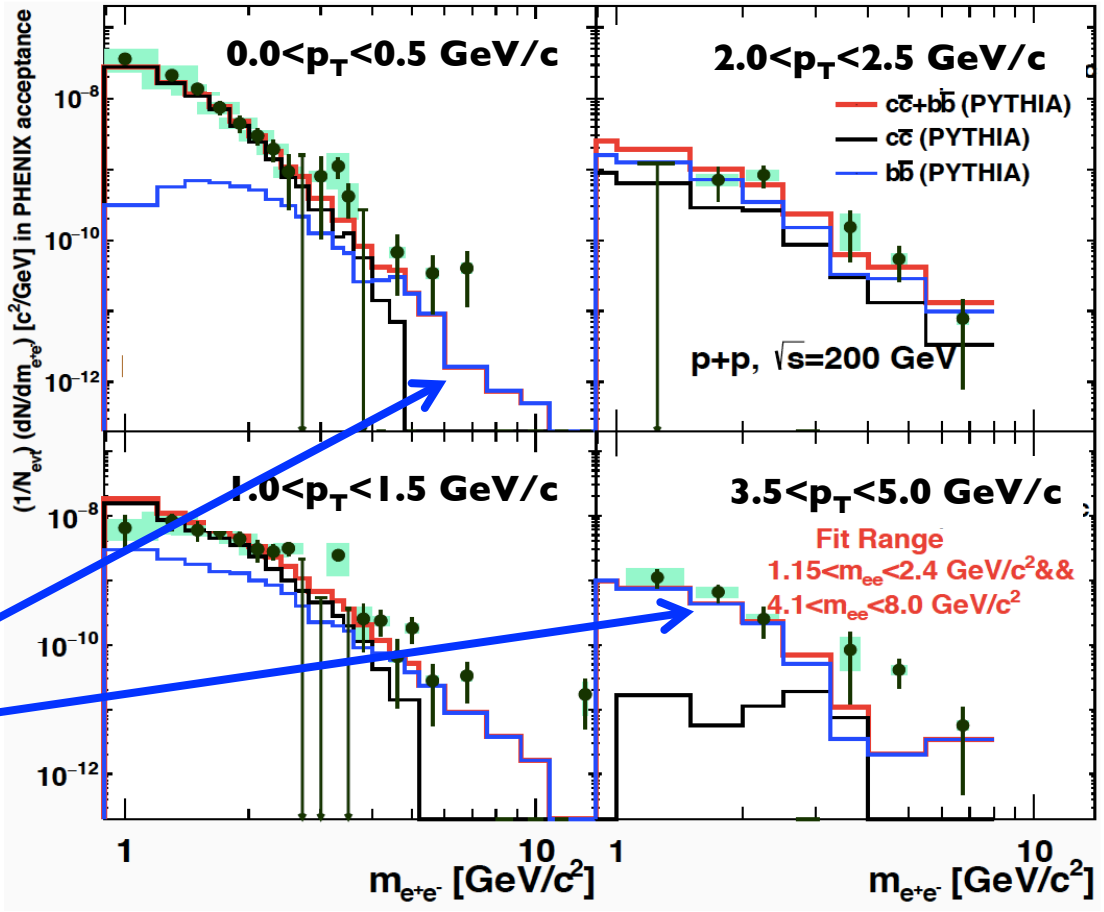
Charm + Bottom
Charm
Bottom

Charm dominates
Low pT, low mass

Bottom dominates
Low p_T, high mass
High p_T



- ***Open charm and bottom yields determined by simultaneous fit in mass and p_T distributions***
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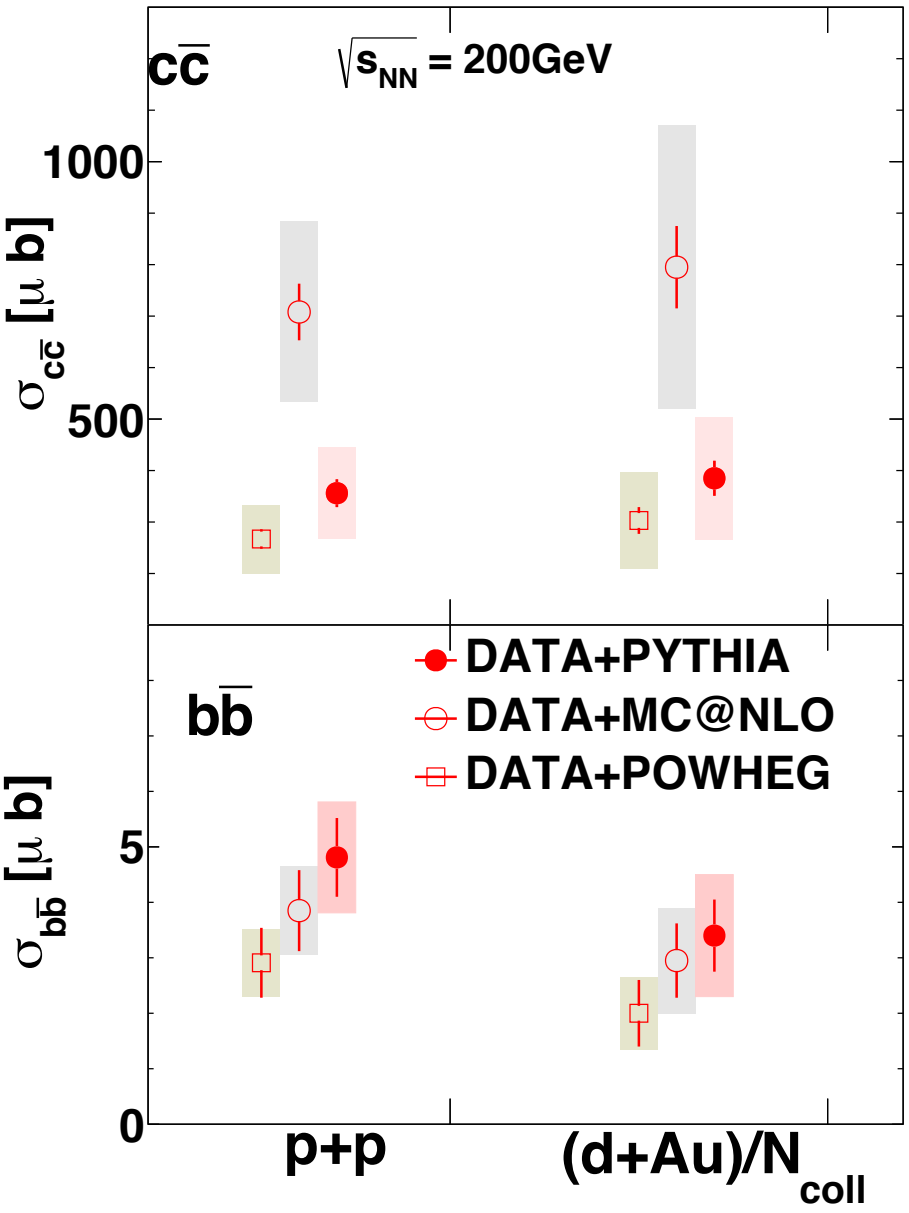
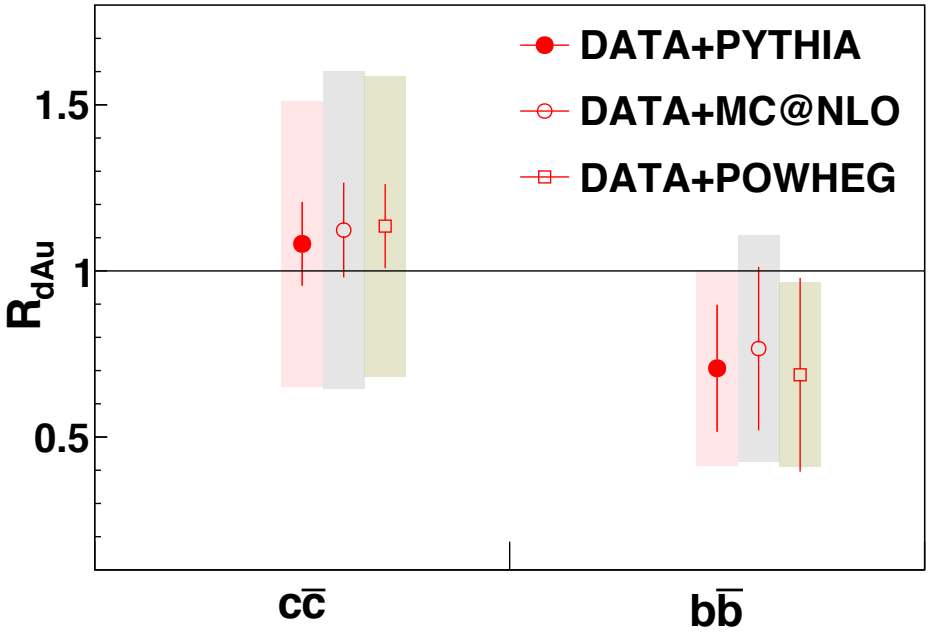
Extrapolation of charm and bottom cross-section and R_{dA}



Extrapolated charm cross section depends more strongly on model than bottom

→decay kinematics randomize the opening angle for bottom (m_q>>p)



No model dependence of R_{dA}

No modification in d+Au to within uncertainties

Summary and outlook

Summary

- **p+p**
  - **Azimuthal correlations of dimuons from charm and bottom well described by PYTHIA**
  - **Bottom cross-section at 200GeV a factor of 2 higher than FONLL calculations.**
- **p/d+A**
  - **No modification of charm and bottom dielectrons in d+Au to within systematic uncertainties.**
- **A+A**
  - **Total B-meson yield in Cu +Au collisions consistent with binary scaling of p+p**
  - **b→e is less suppressed than c→e in 3.0-5.0 GeV/c in 0-10% Au+Au.**

Summary and outlook

Summary

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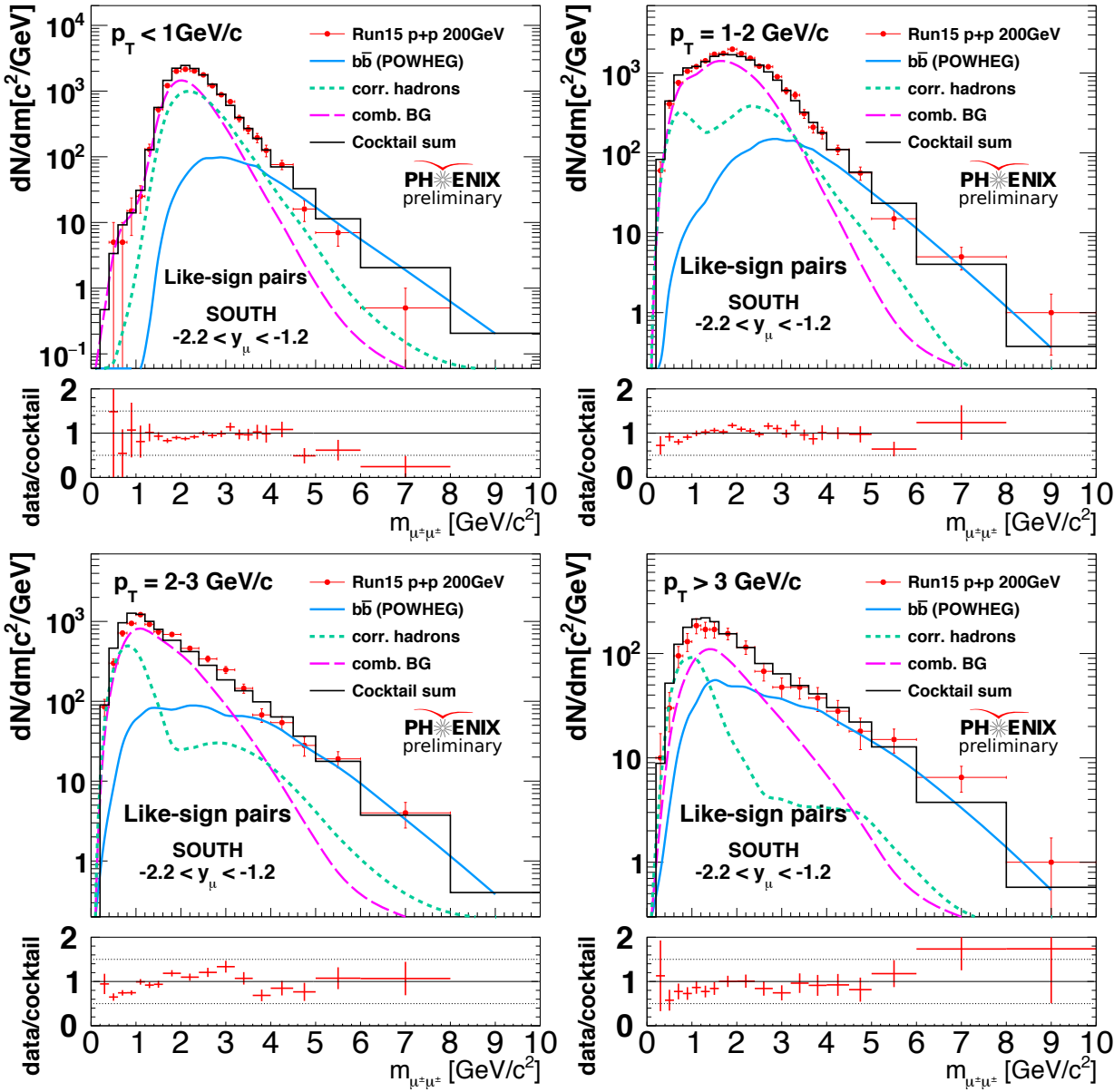
Outlook

- VTX
  - c, b→e separation in p+p, p+Au
  - c, b→e separation in Au+Au for all centralities
  - B→J/ψ in p+p, Au+Au
  - c, b→e v_n in Au+Au
- FVTX
  - c, b→e separation in p+p, p+Au, Au +Au
  - B→J/ψ in p+Au, Au+Au
- Dileptons
  - Heavy flavor correlations in p+Au
- Quarkonia
  - J/ψ cross-section in pA and ^{3}He+Au
  - J/ψ flow in d+Au
  - Upsilon in Au+Au (via FVTX)

BACKUP

Cocktail and data comparison

Cocktail describes data in mass and p_T for like-sign pairs



Cocktail and data comparison

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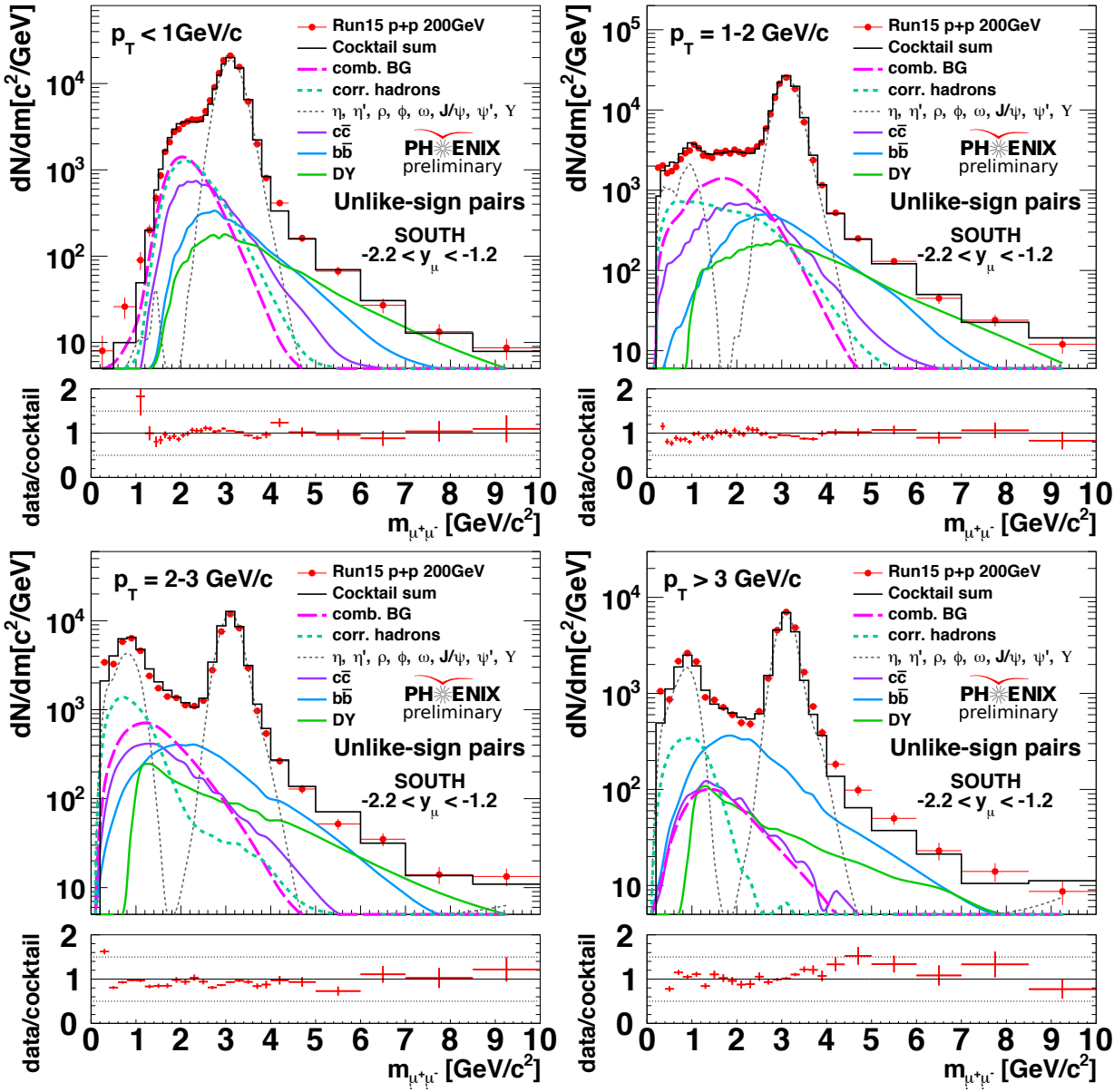
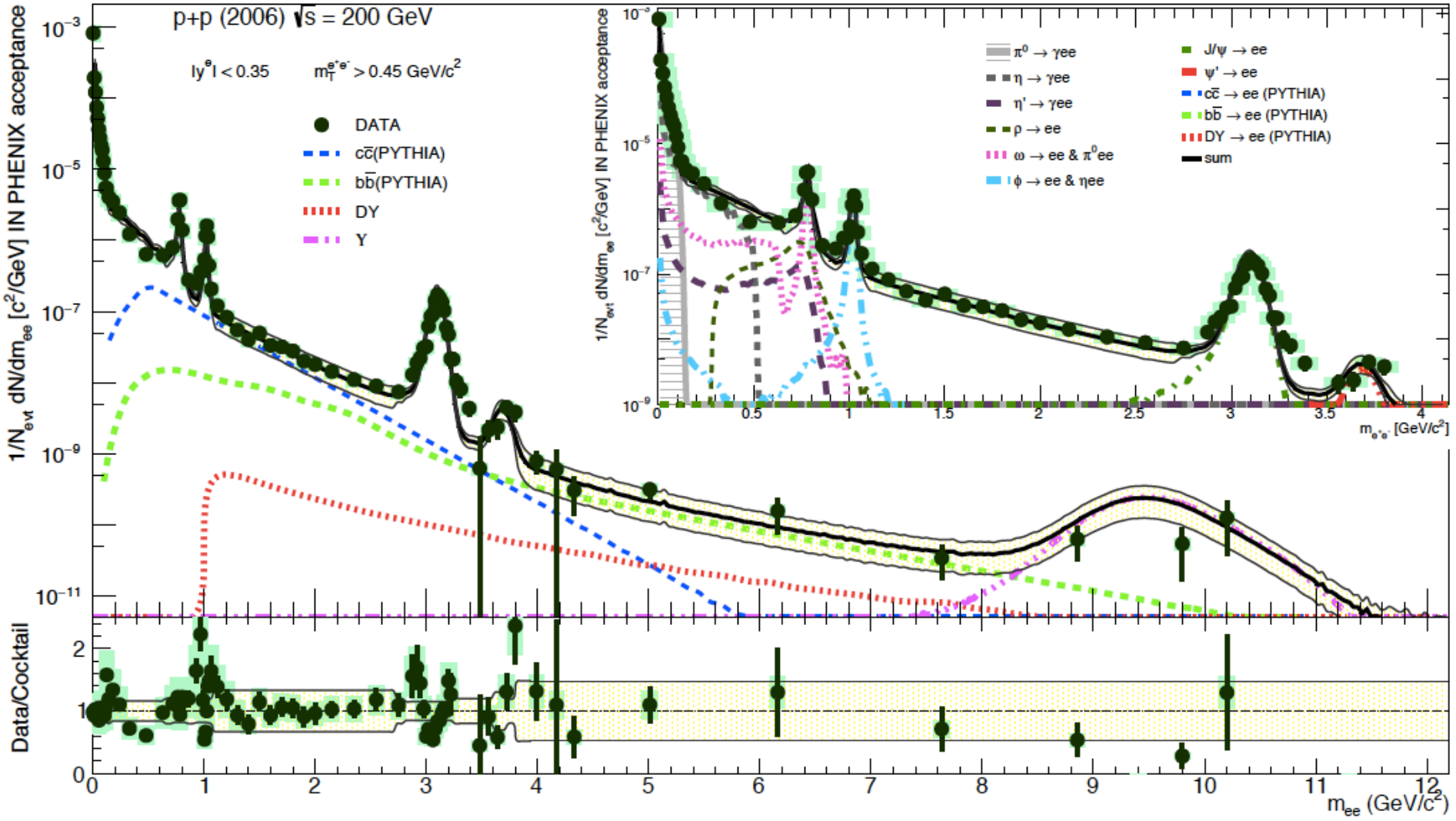
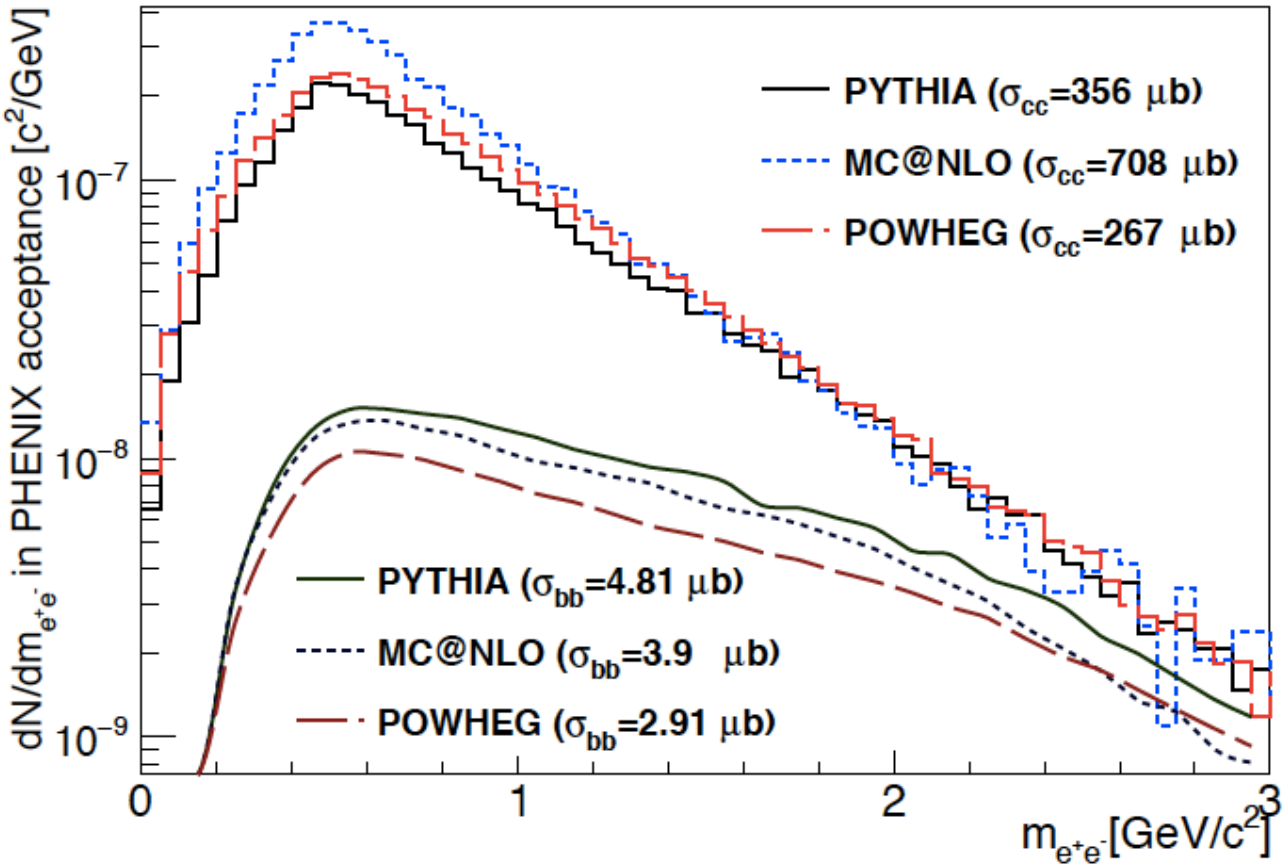


Dielectron mass spectrum in p+p 200GeV



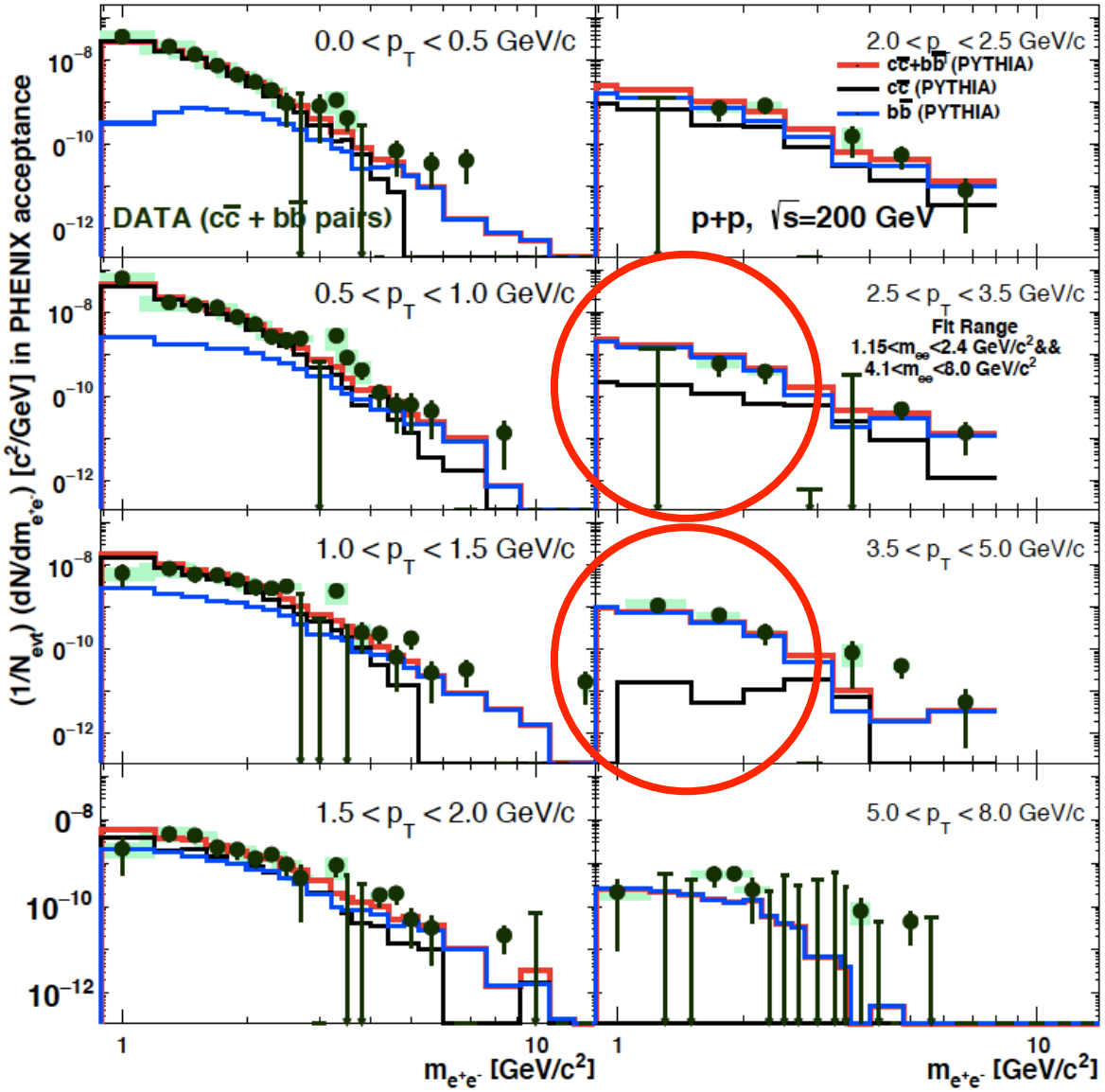
Data is consistent with cocktail

Model dependence in charm



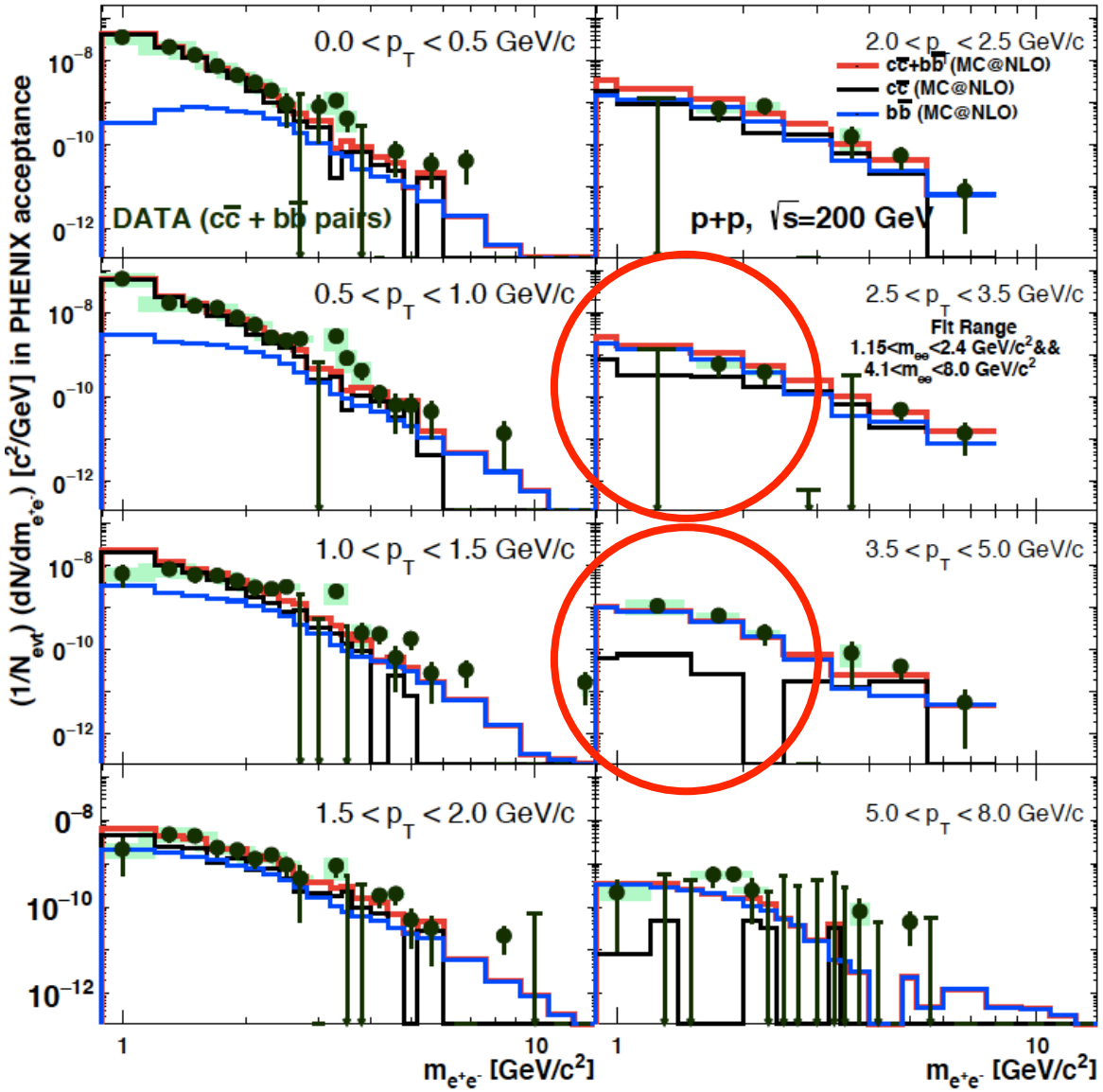
- ***Large model dependence at low mass, which dominates yield***

Model dependence in charm (PYTHIA)



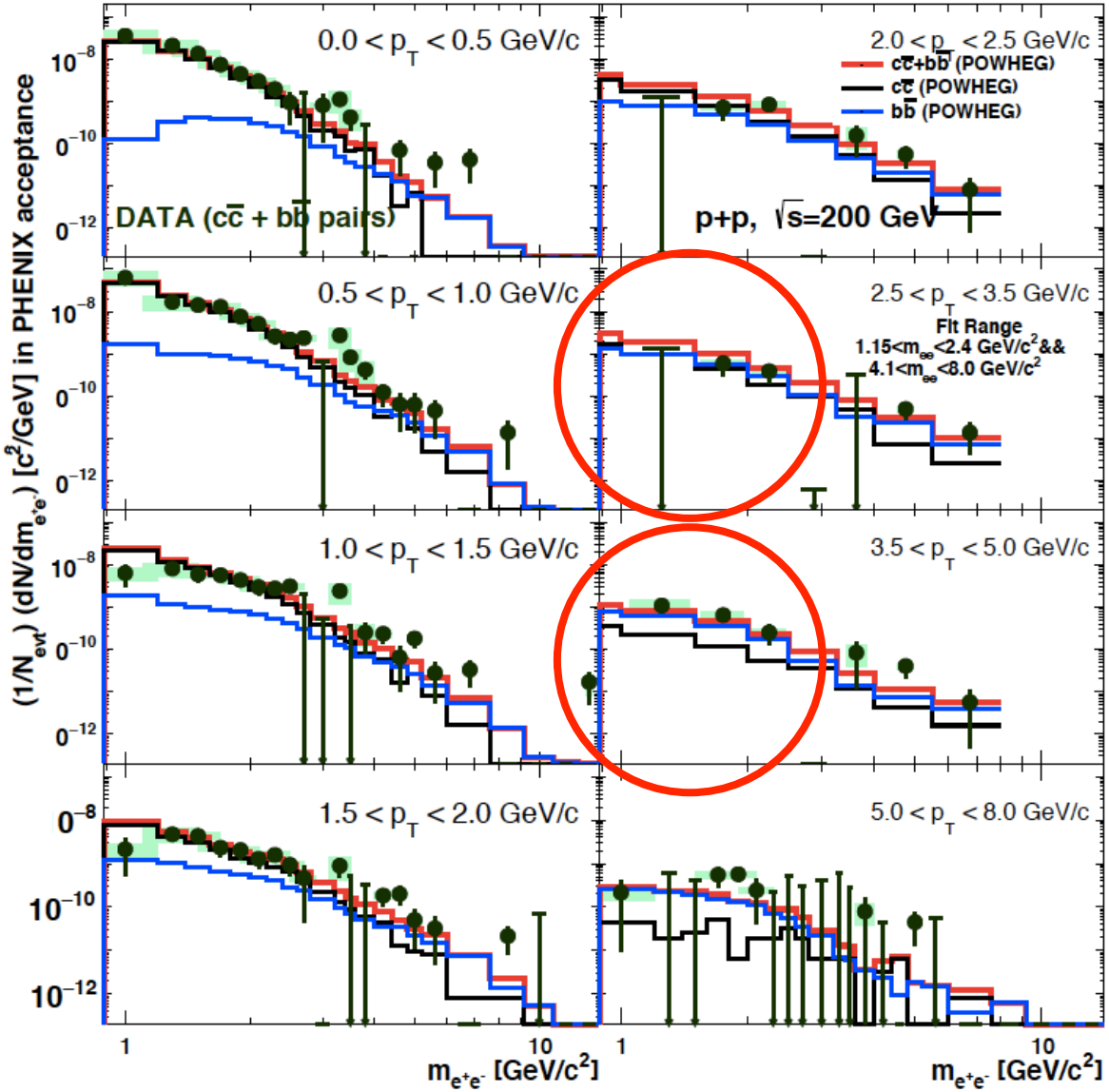
- ***Pair p_T distribution at intermediate mass region for charm is model dependent***
- ***Directly affects fitted bottom cross-section***

Model dependence in charm (MC@NLO)



- ***Pair p_T distribution at intermediate mass region for charm is model dependent***
- ***Directly affects fitted bottom cross-section***

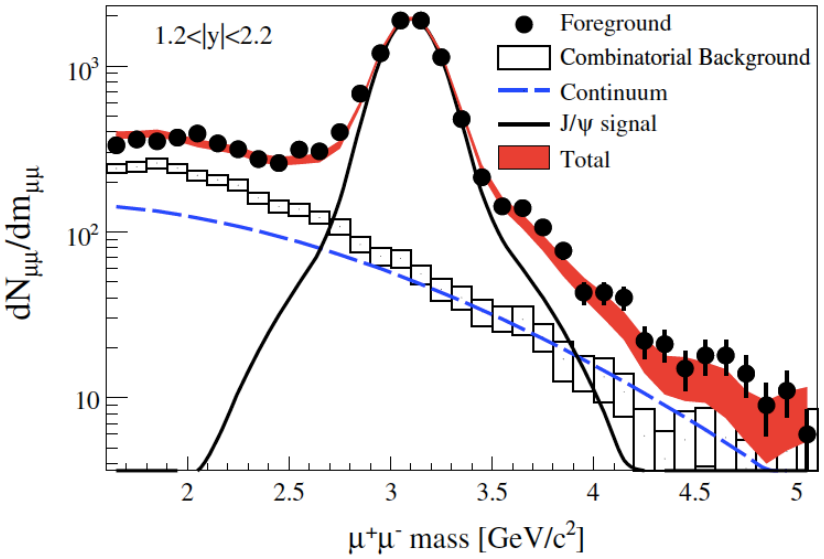
Model dependence in charm (POWHEG)



- ***Pair p_T distribution at intermediate mass region for charm is model dependent***
- ***Directly affects fitted bottom cross-section***

QUARKONIA

ψ(2s) extraction with FVTX



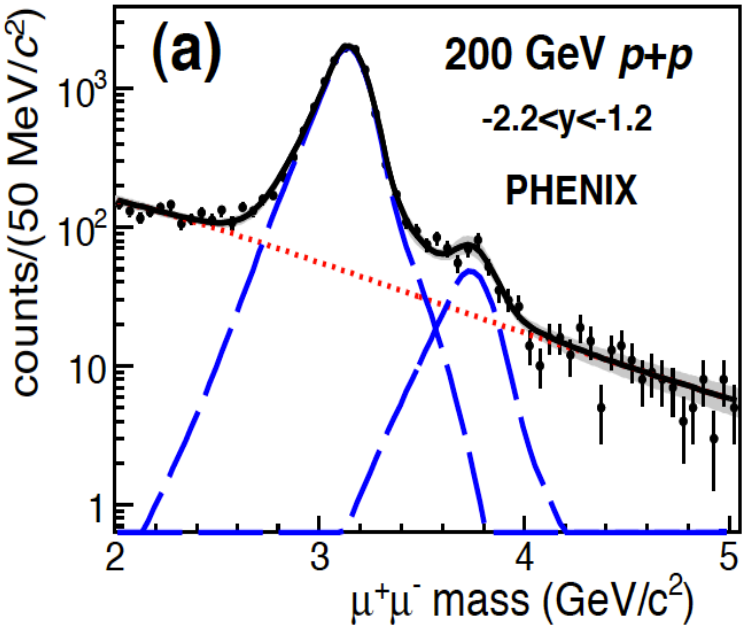
MuTr only

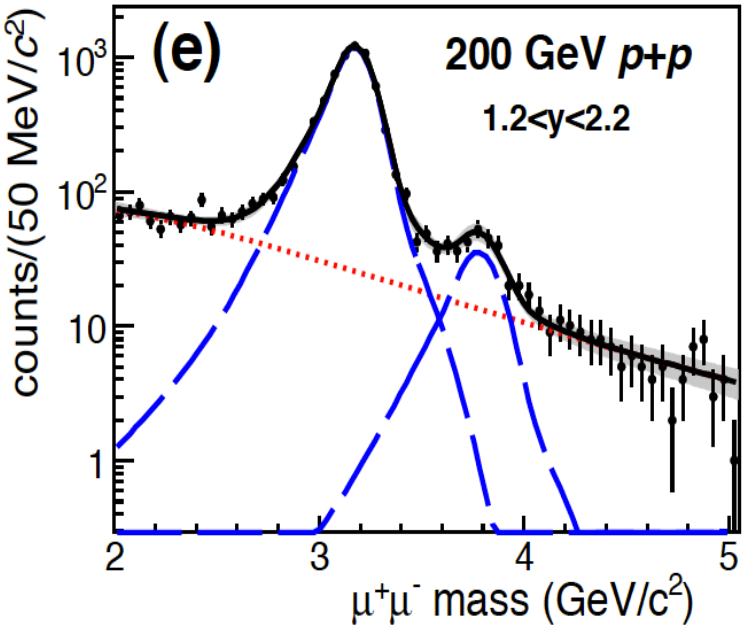
Phys. Rev. D 85, 092004

Resolve ψ(2S) by measuring opening angle in front of absorber

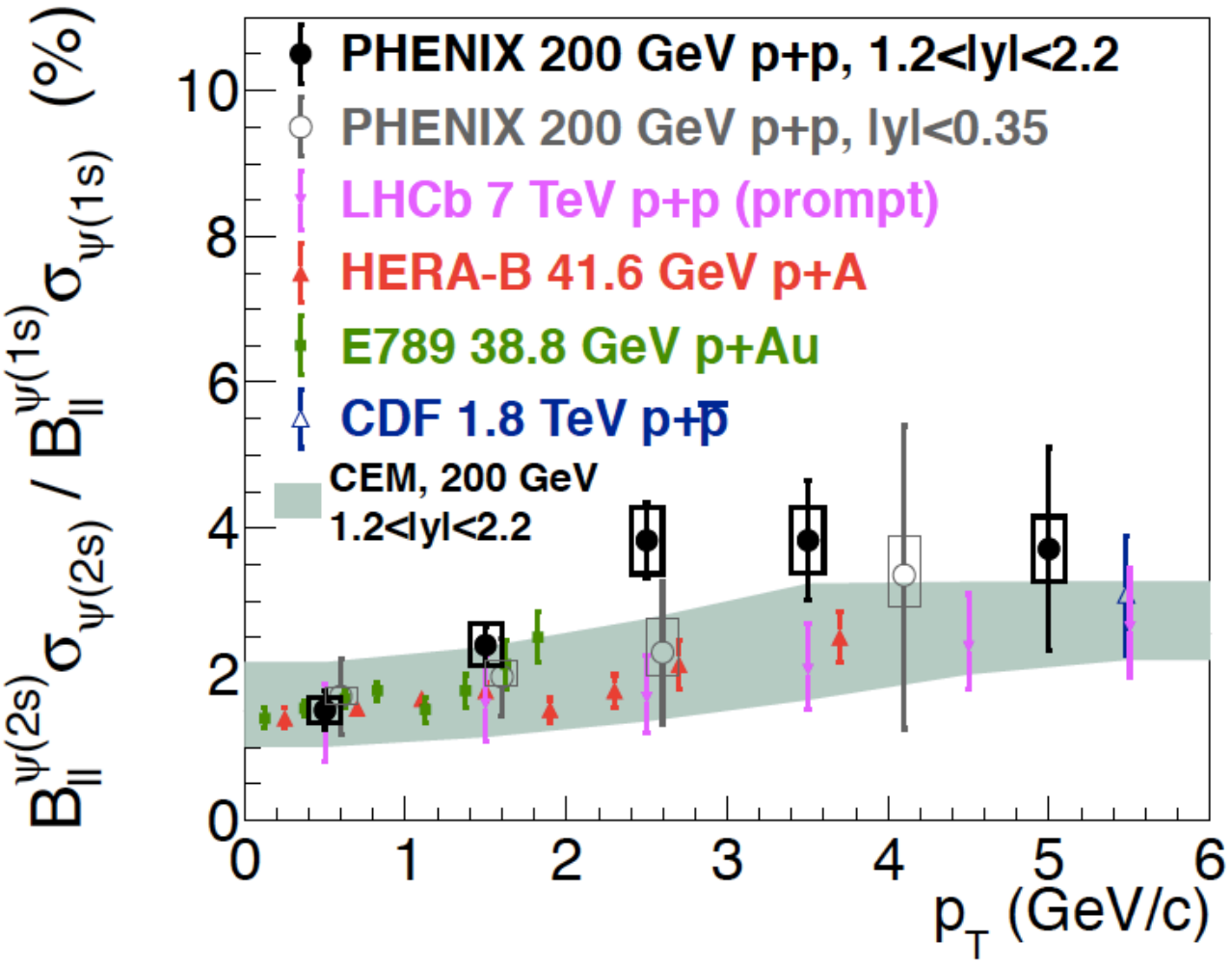
FVTX+MuTr

Phys. Rev. C 95, 034904



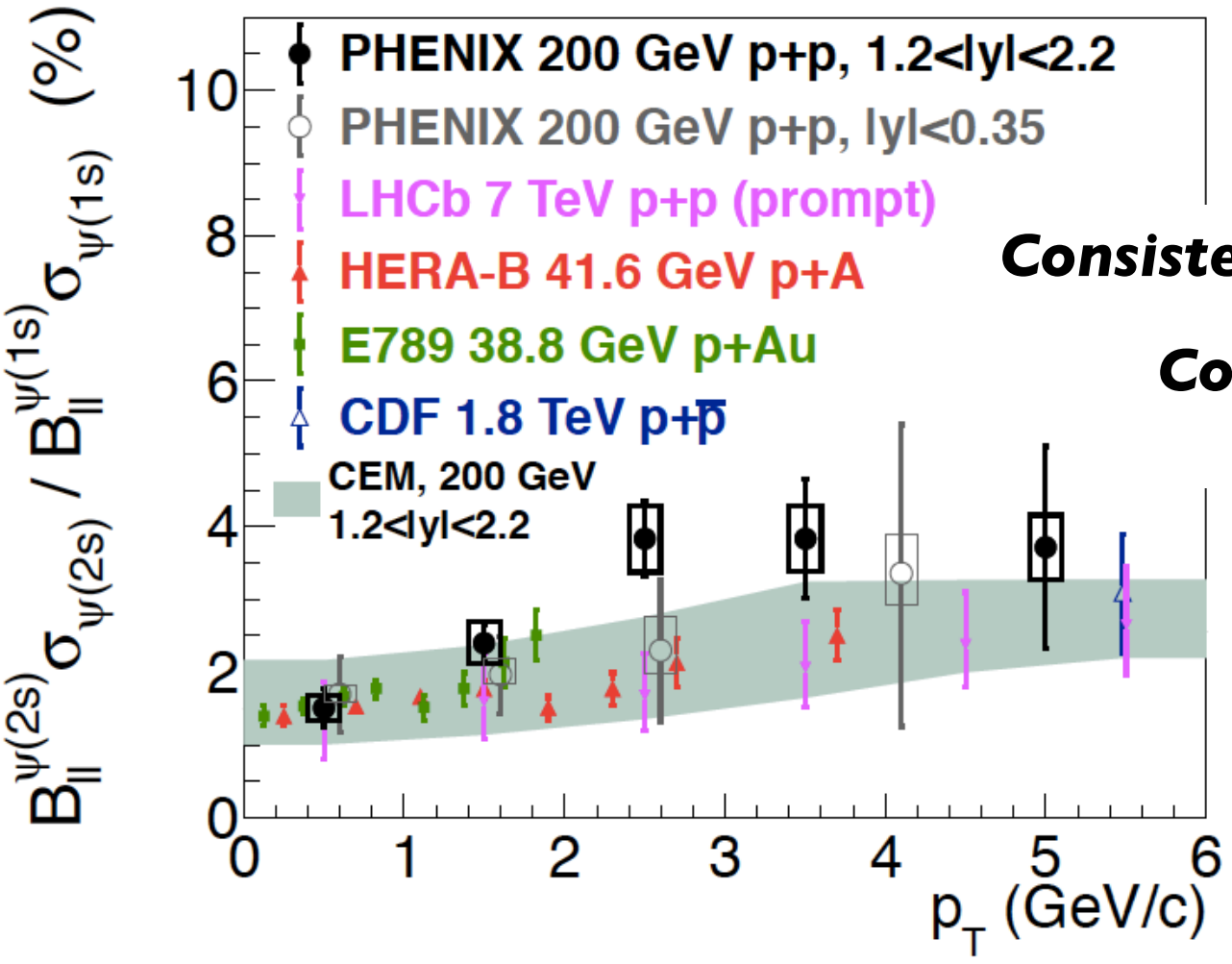


$\psi(2s)/\psi(1s)$ in p+p



Phys. Rev. C 95, 034904

$\psi(2s)/\psi(1s)$ in p+p

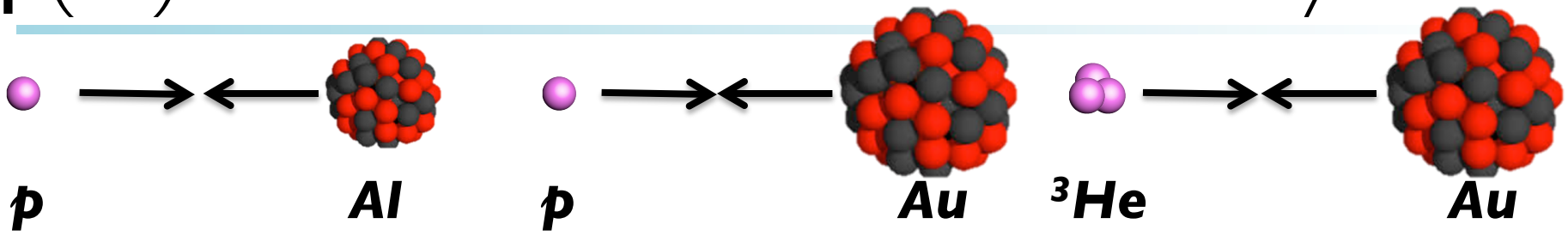


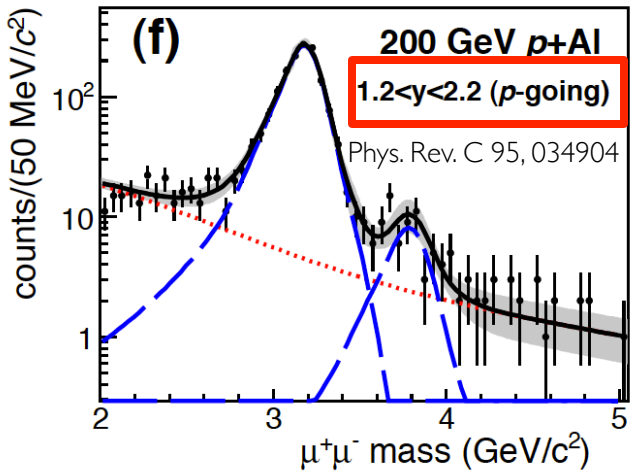
Consistent with world data

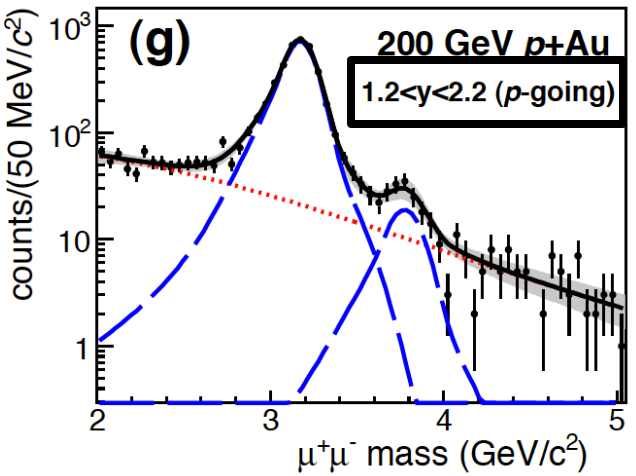
Consistent with CEM
(R. Vogt.)

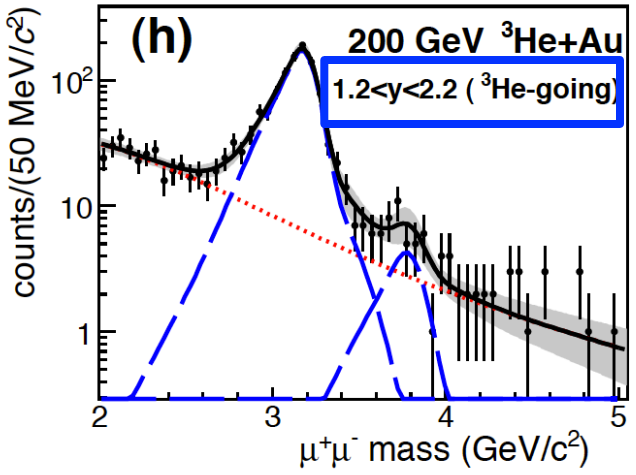
Phys. Rev. C 95, 034904

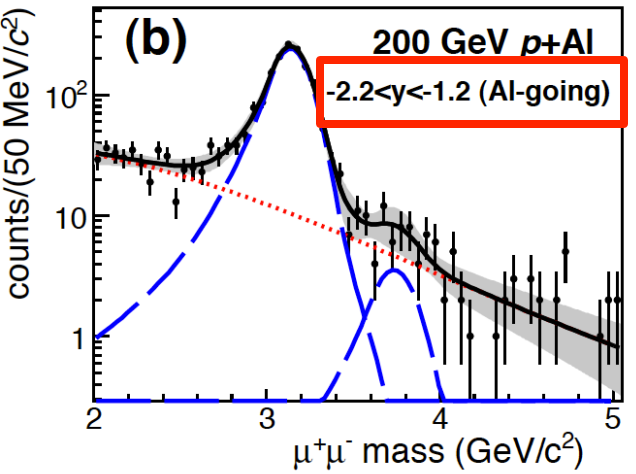
ψ(2s) at forward/backward in small systems

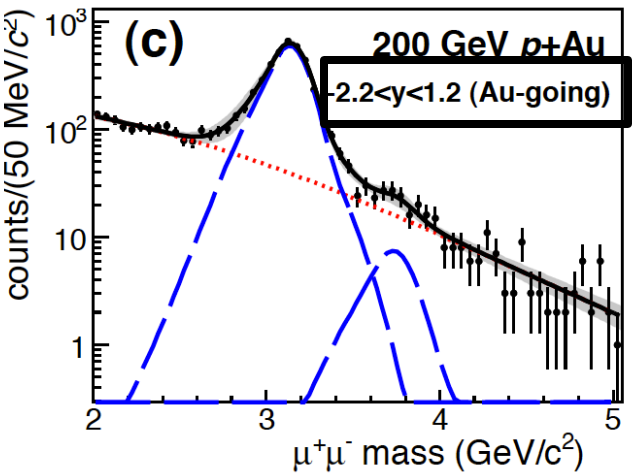


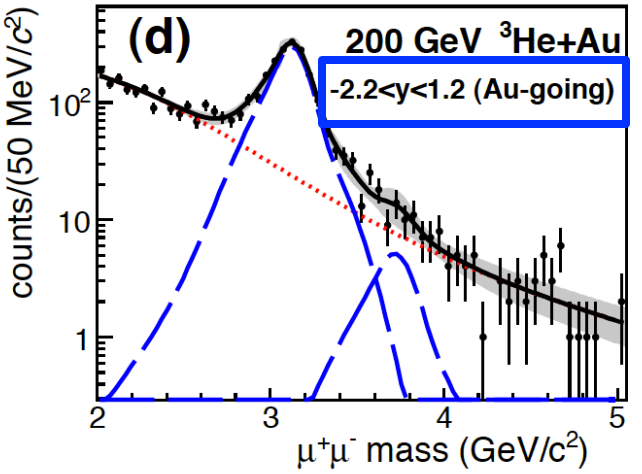






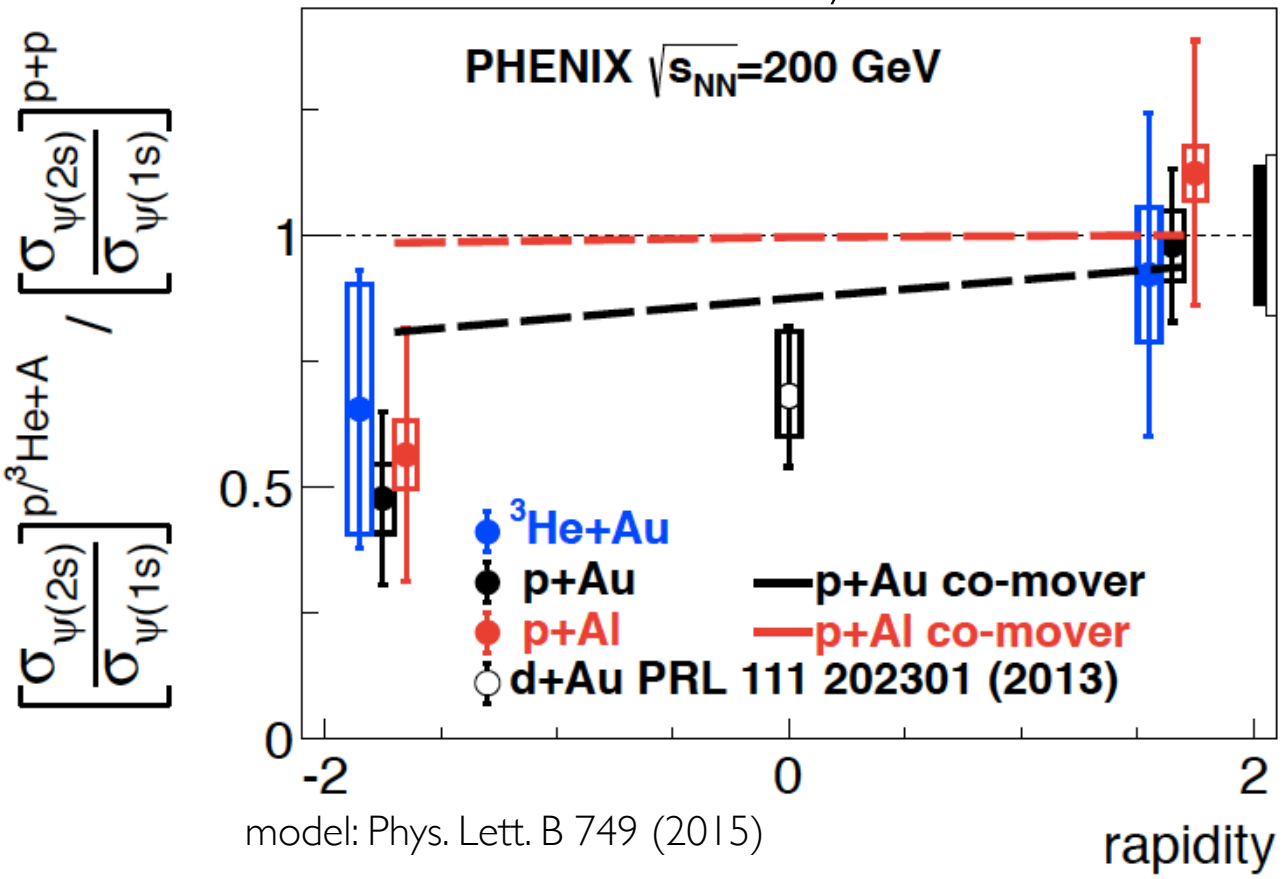






ψ(2s)/ψ(1s) in small systems

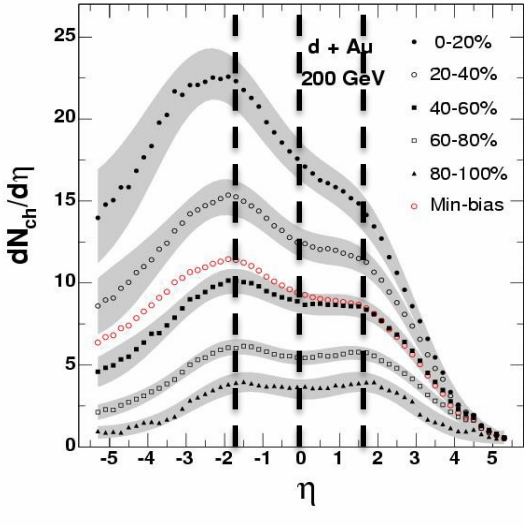
Phys. Rev. C 95, 034904



model: Phys. Lett. B 749 (2015)

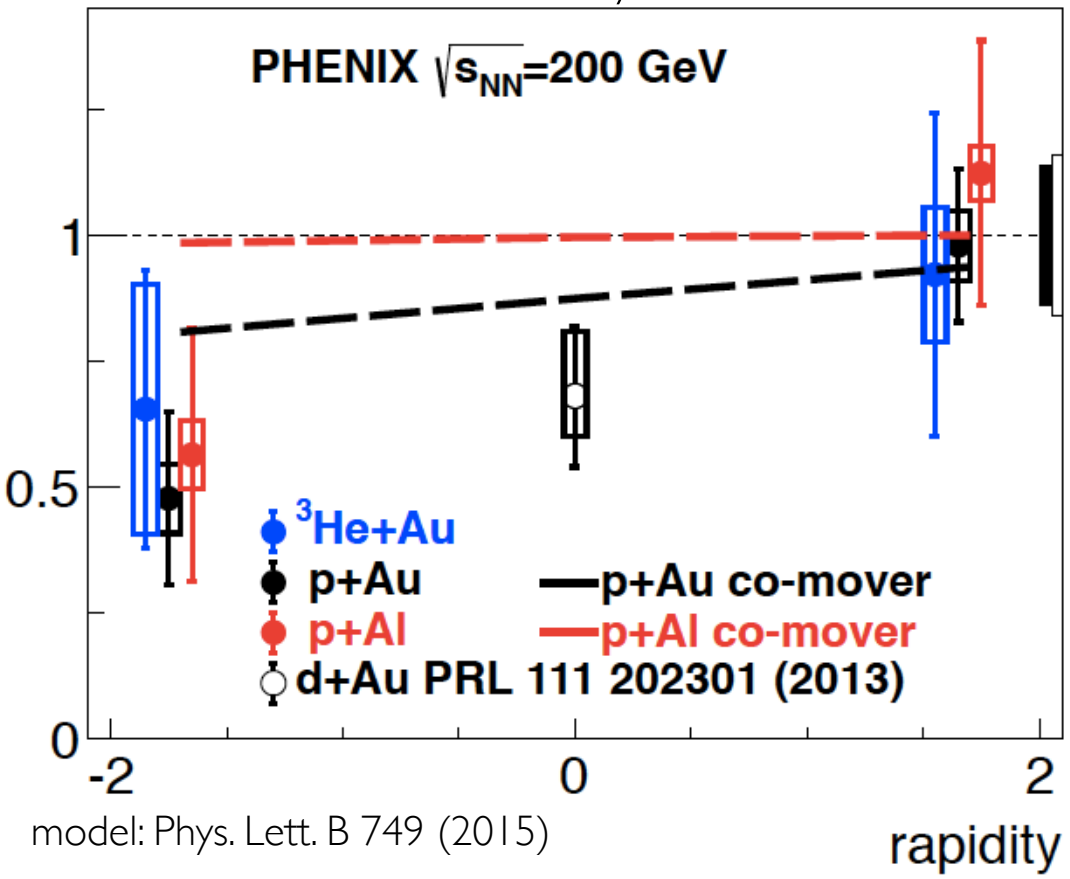
ψ(2s)/ψ(1s) in small systems

Phys. Rev. C 72, 031901



$$\left[\frac{\sigma_{\psi(2s)}}{\sigma_{\psi(1s)}}\right]^{p/^3He+A} \Big/ \left[\frac{\sigma_{\psi(2s)}}{\sigma_{\psi(1s)}}\right]^{p+p}$$

Phys. Rev. C 95, 034904



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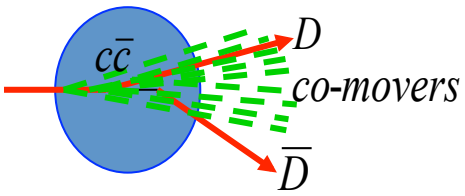
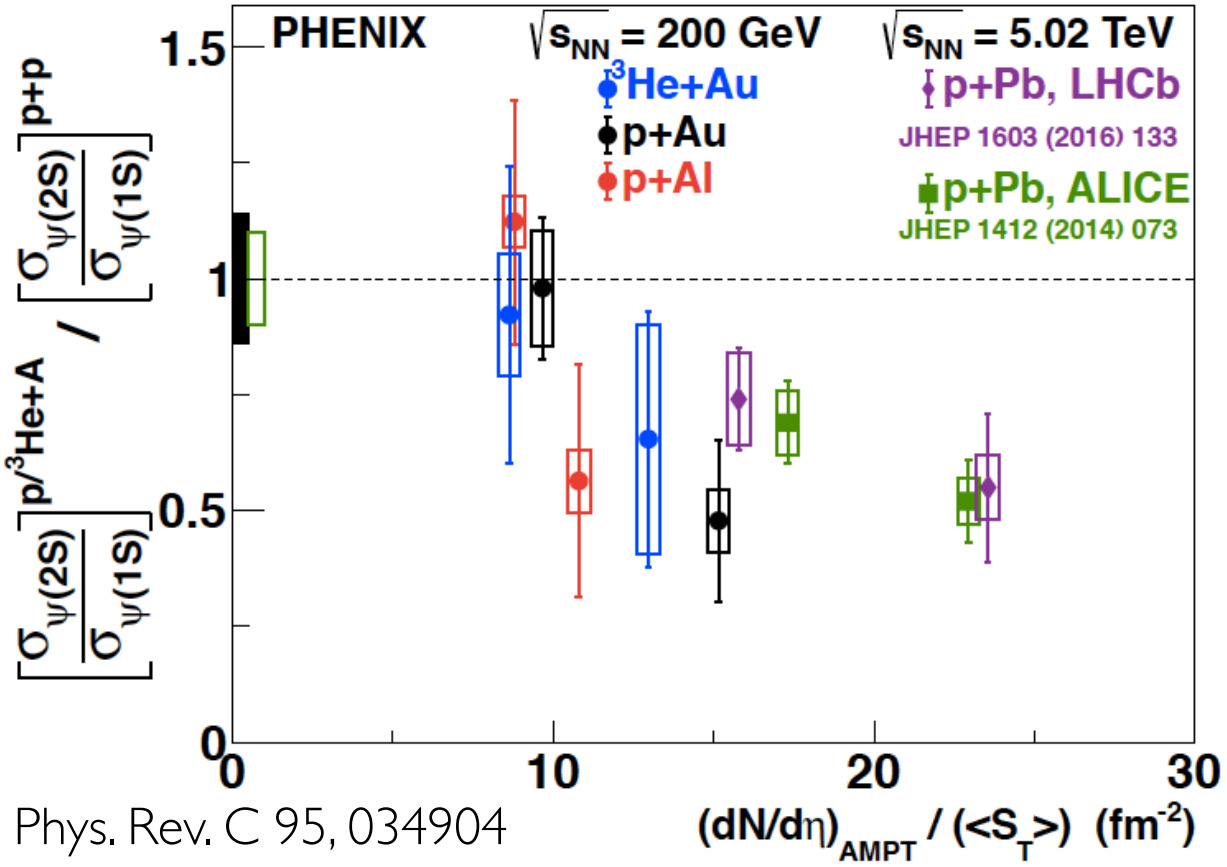


The co-mover dissociation model predicts a larger suppression of ψ(2S) at nucleus-going direction, but underestimate the magnitude.

ψ(2s)/ψ(1s) vs comover particle density



Phys. Rev. C 95, 034904

Relative suppression of ψ(2S) increases as the co-moving particle density increases.