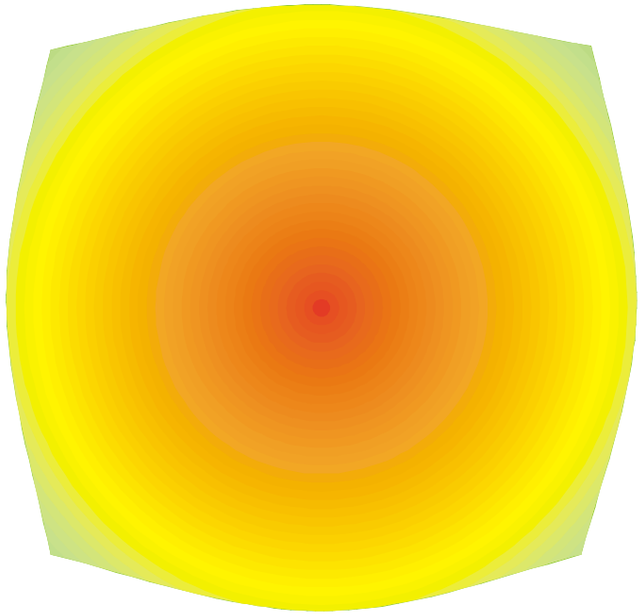
Correlations of Heavy Flavor Electrons in Au+Au & p+p Collisions in PHENIX

Anne M. Sickles
for the PHENIX Collaboration
February 7, 2011

PHENIX arXiv:1011.1477

BROOKHAVEN
NATIONAL LABORATORY

What is our goal?



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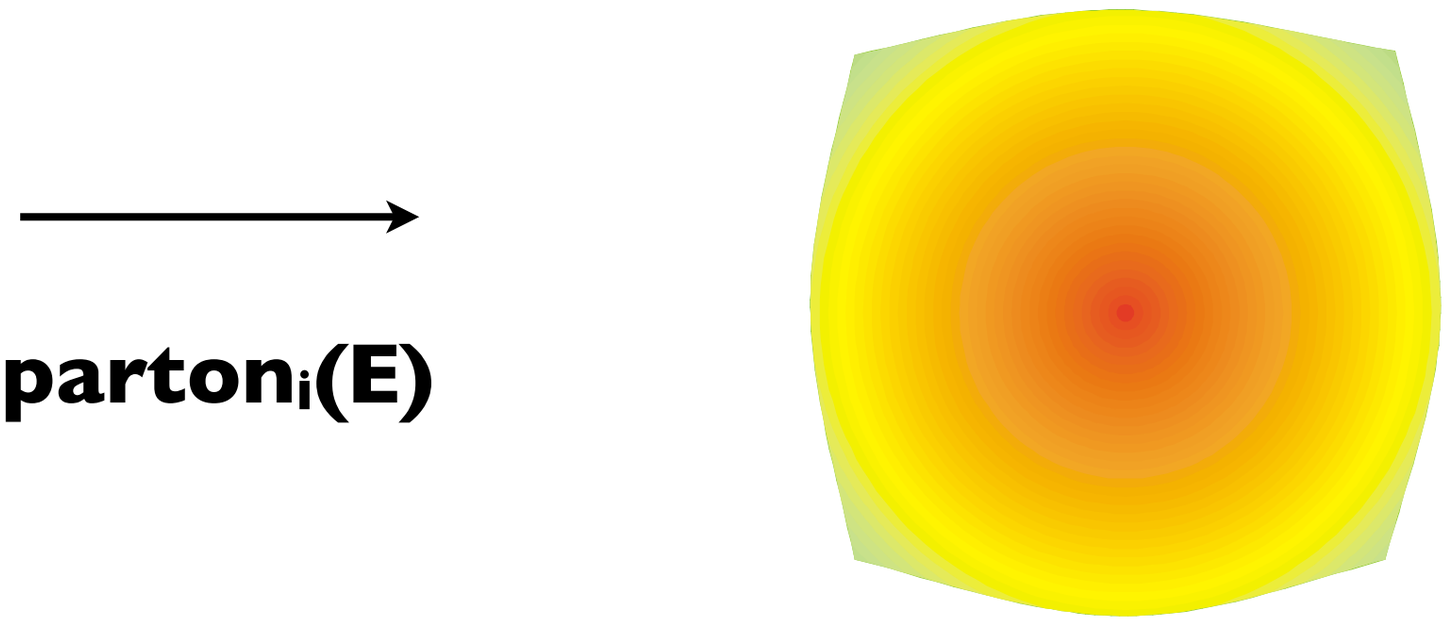

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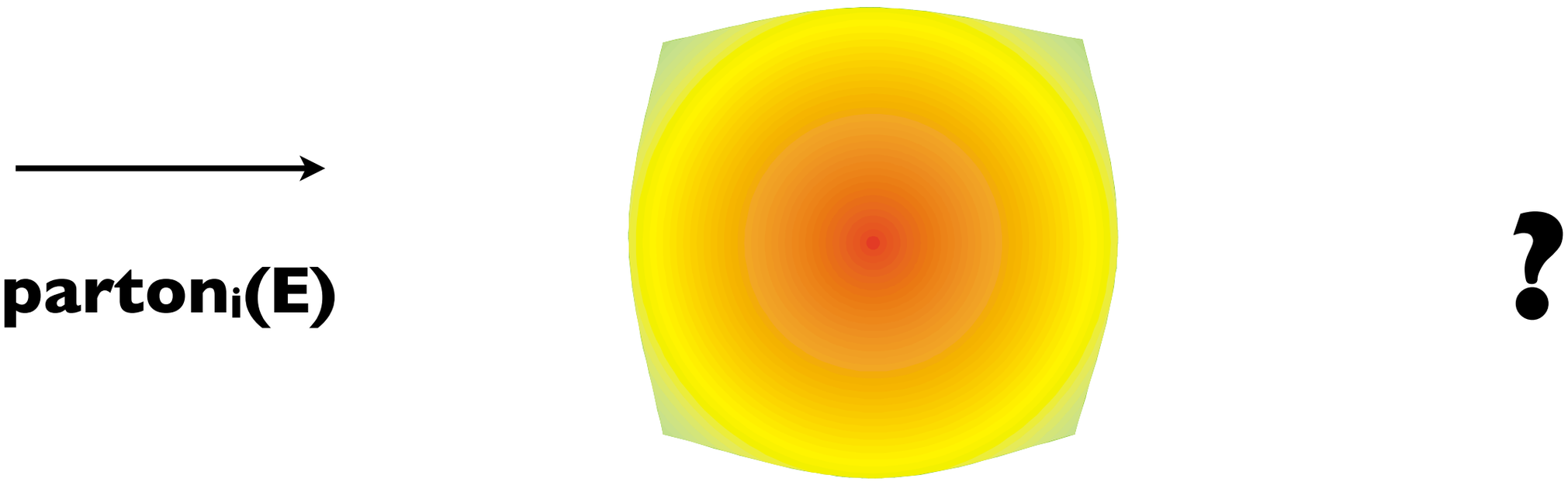

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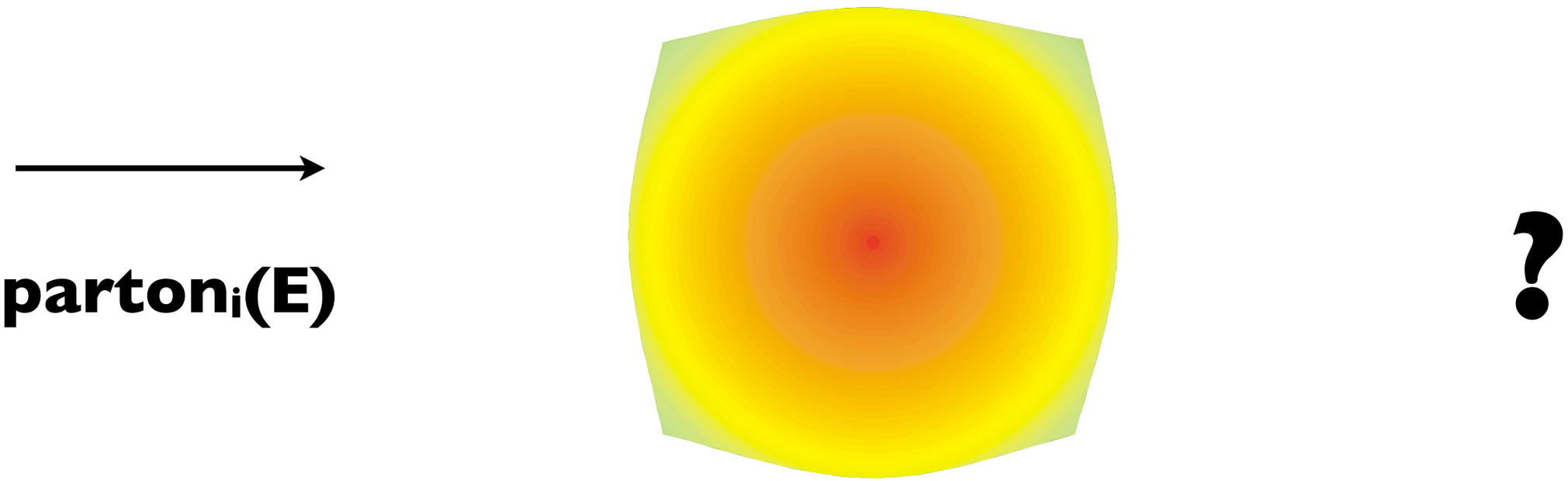
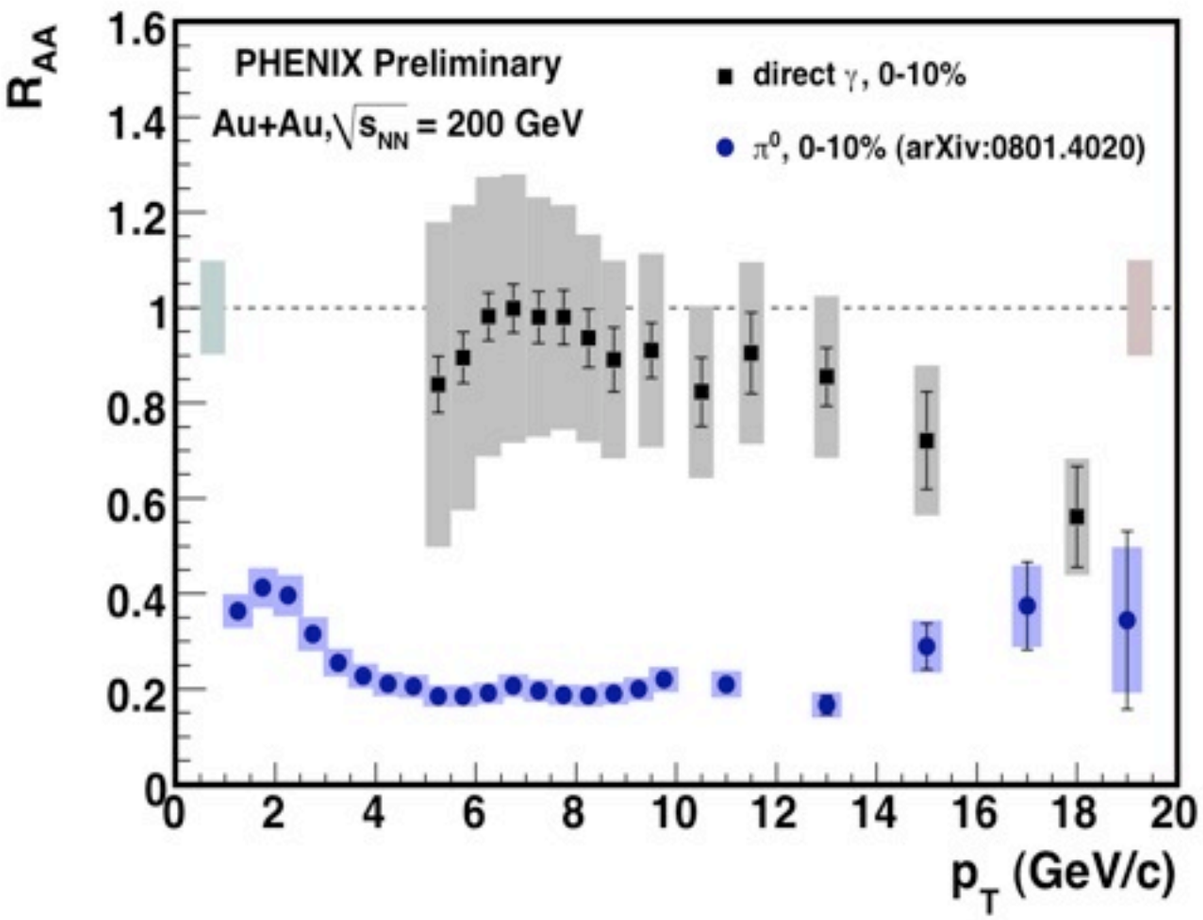
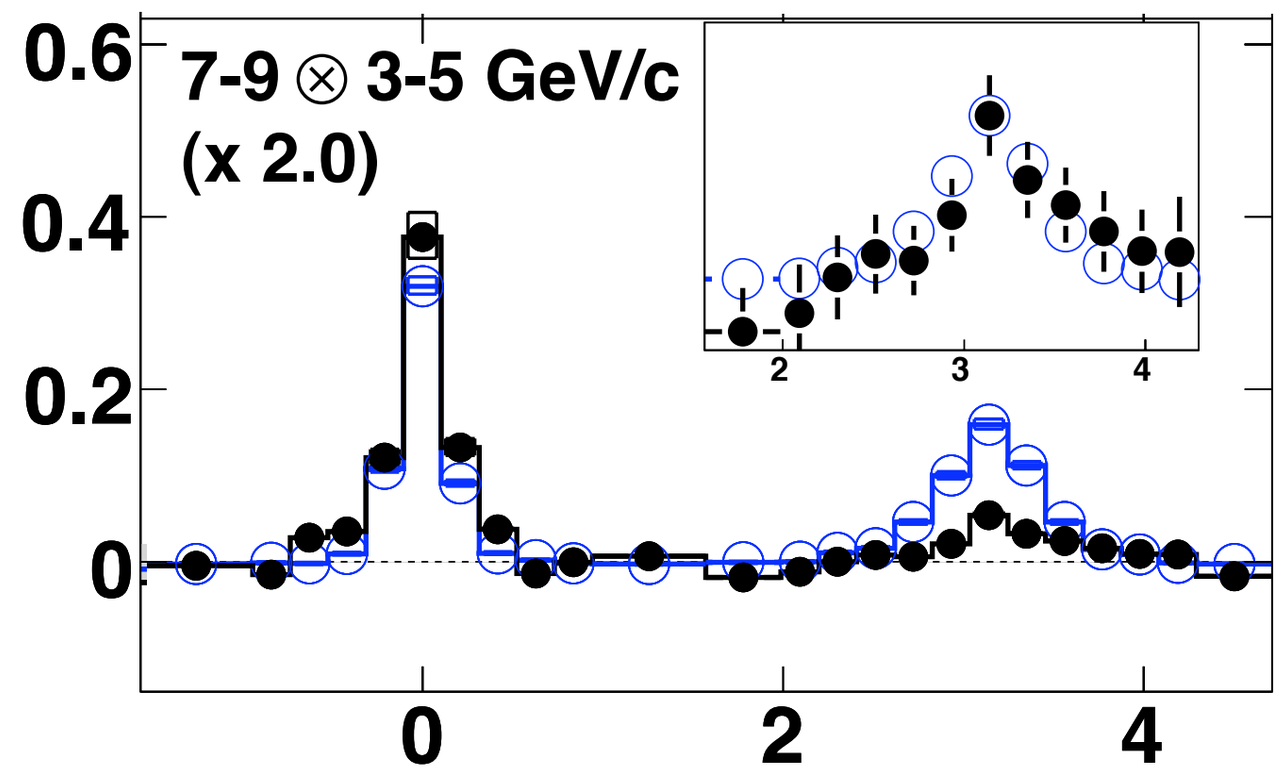


→determine the mechanism(s) of energy loss

→determine the strength of the interactions

hard scattering via particle probes





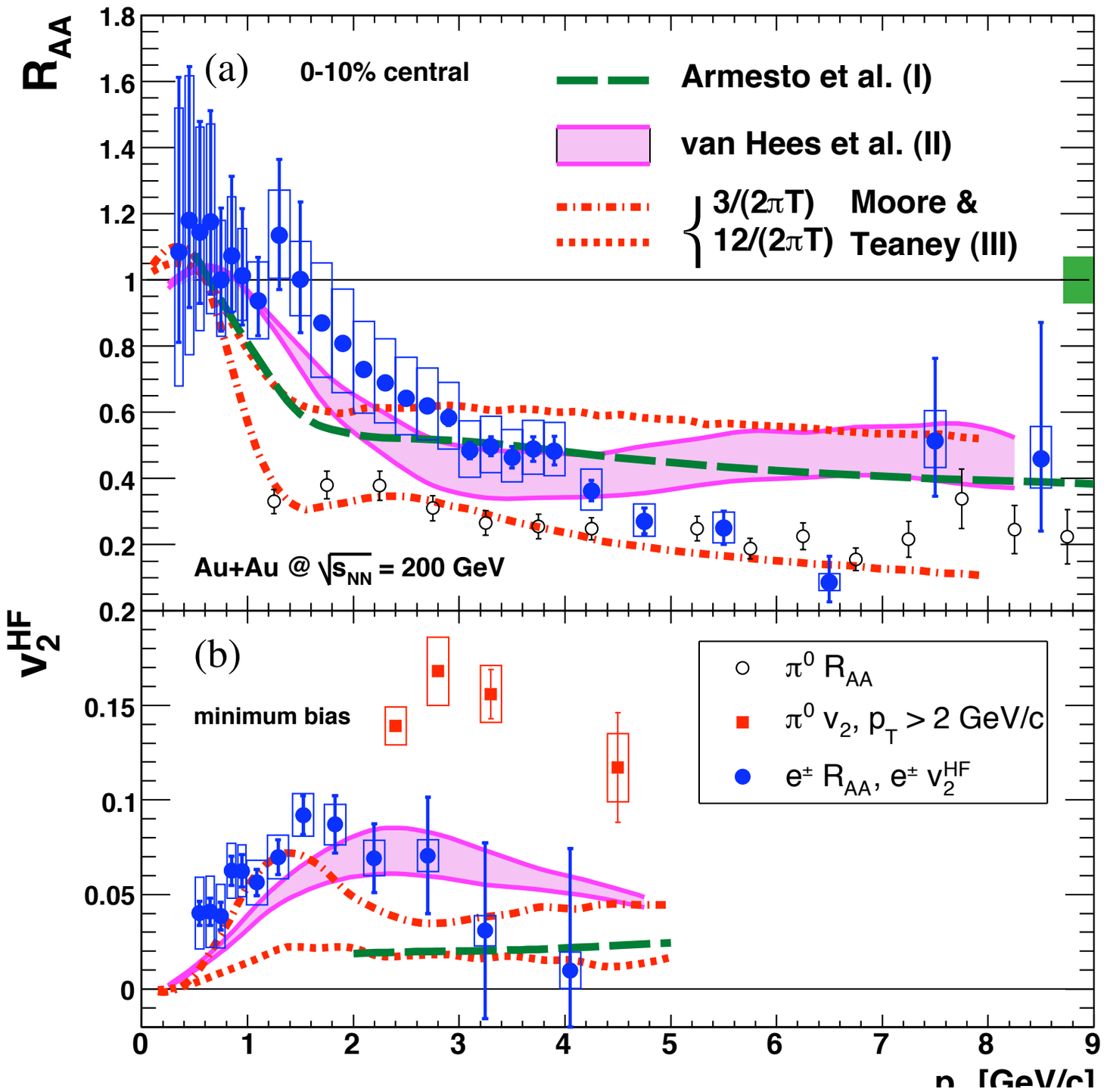
PHENIX PRL 104 252301 (2010)

heavy flavor

- collectivity and suppression
- not expected from radiative energy loss
- raises lots of questions:
  - c/b mixture in $e^{\pm}$
  - correlations
  - new theoretical ideas?
  - initial state effects?
    - see M. Durham (Thursday)

PRL 98 172301 2007

heavy flavor



PRL 98 172301 2007

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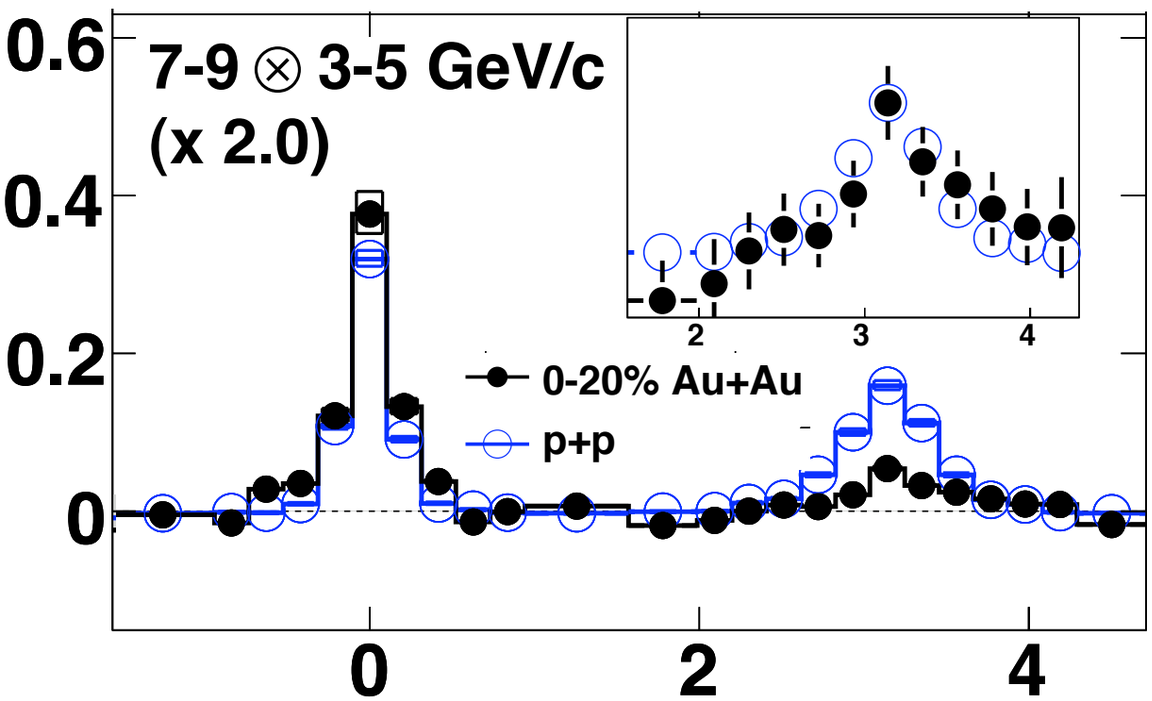
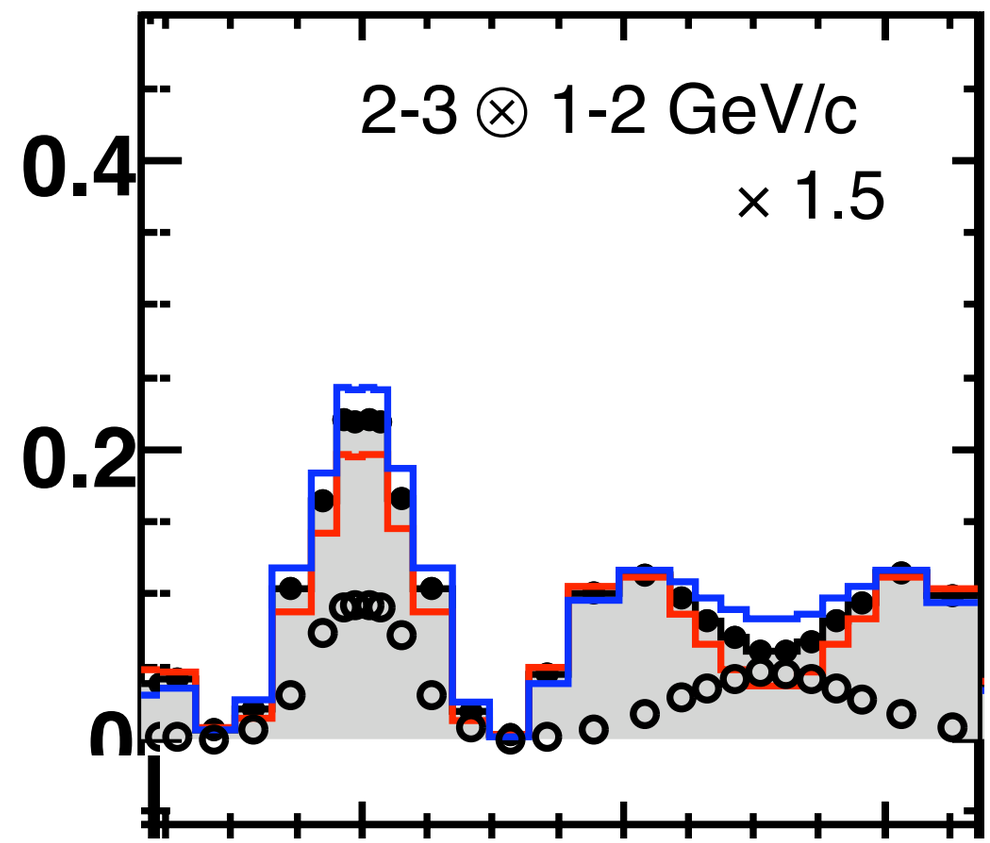
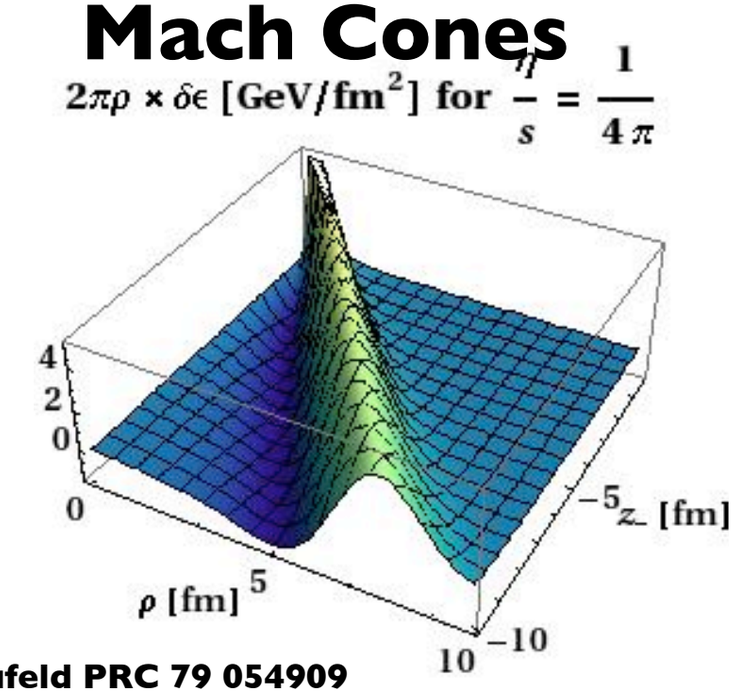
double peak structure





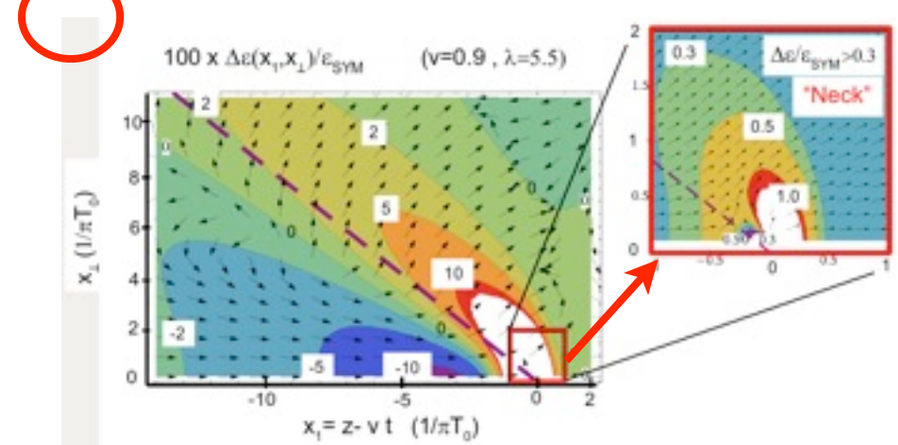
double peaks

Mach Cones



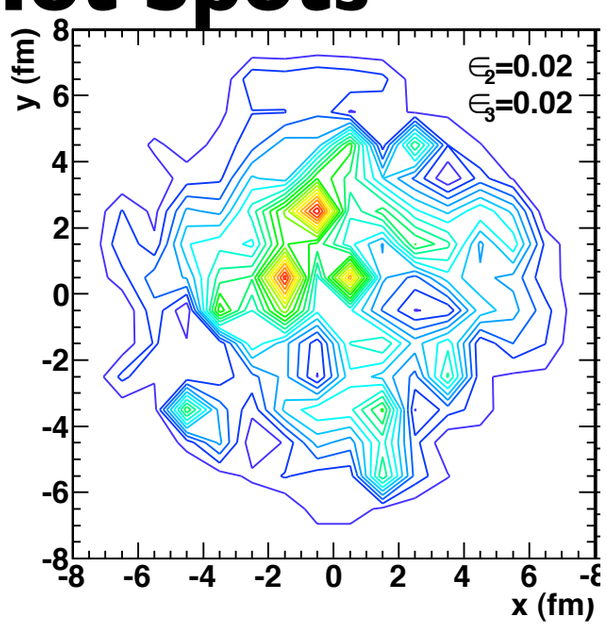
Neufeld PRC 79 054909

AdS/CFT



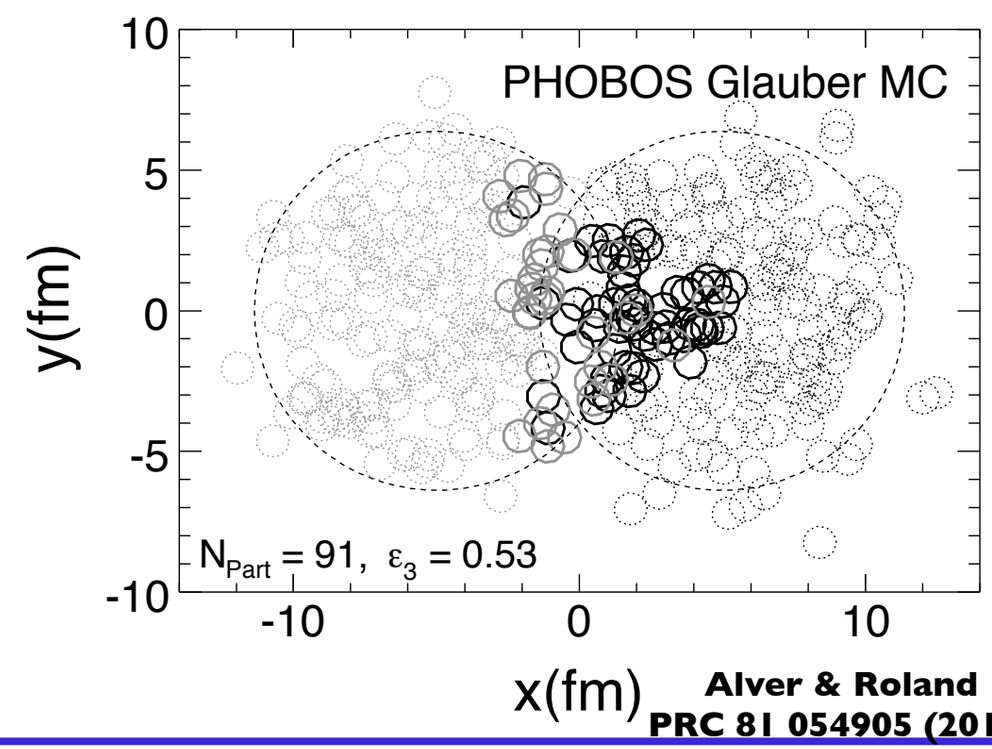
Noronha et al, PRL 102 102301 (2009)

Hot Spots



Ma & Wang 1011.5249

Initial State Fluct.



Alver & Roland PRC 81 054905 (2010)

double peaks

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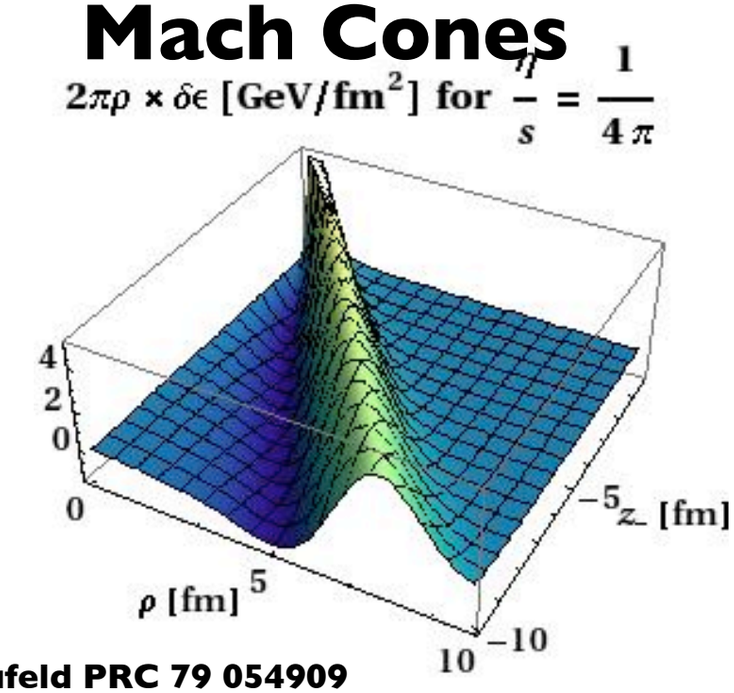
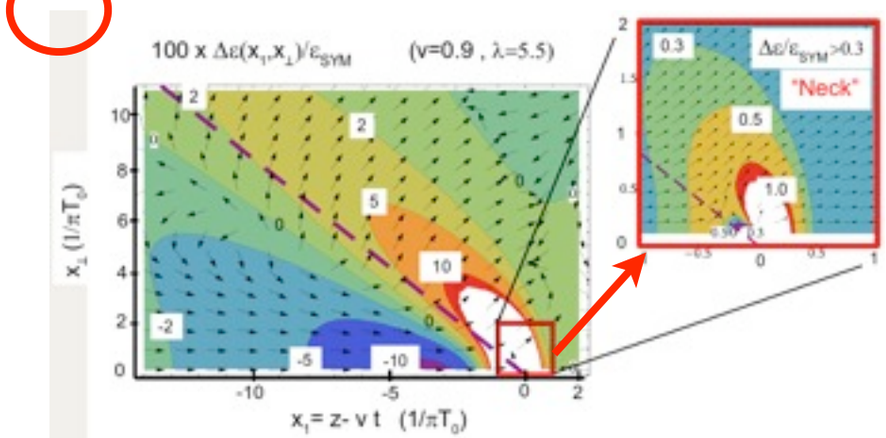


Neufeld PRC 79 054909

$$cos\theta_M = \frac{\bar{c}_s}{v_{jet}}$$

b-b correlations can determine if correlations follow Mach's Law

AdS/CFT



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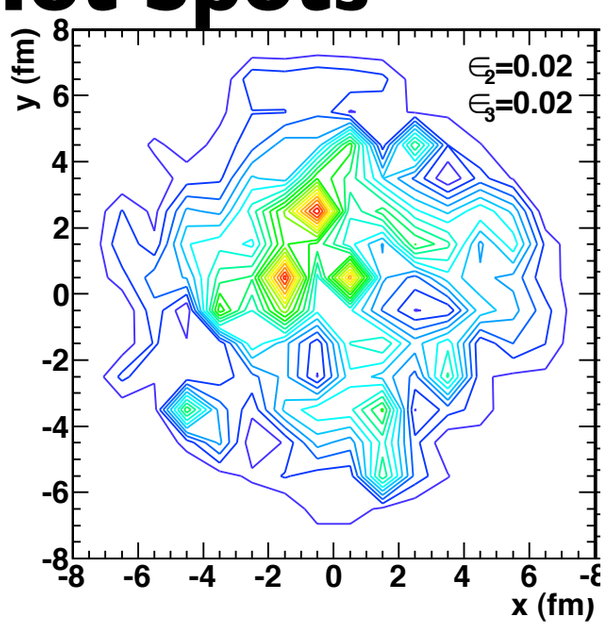

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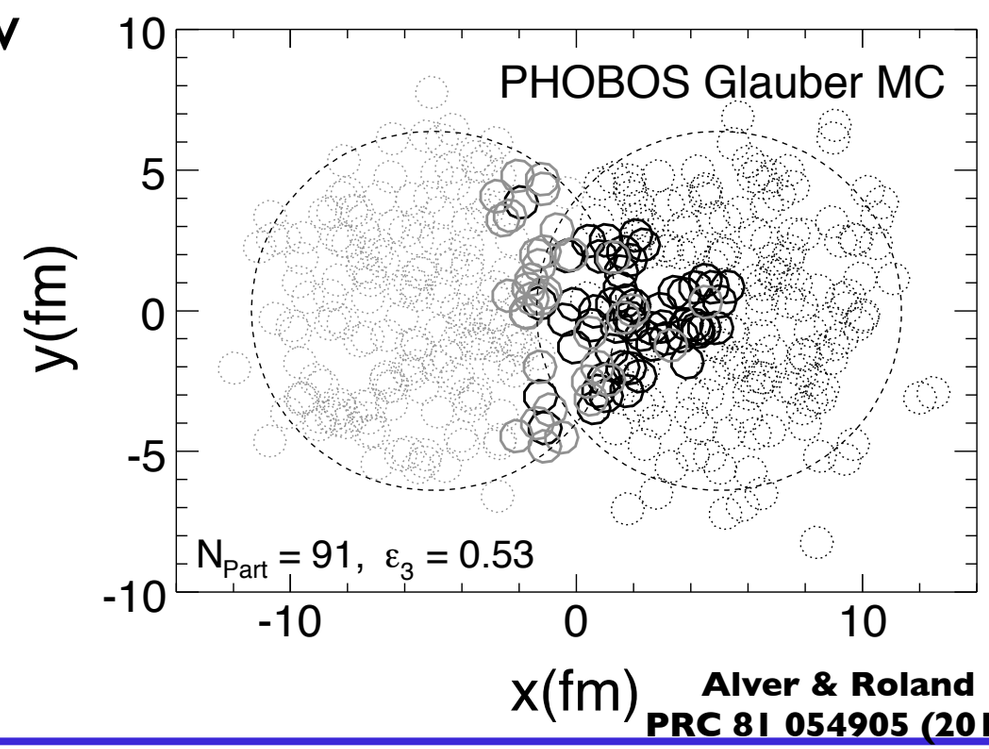
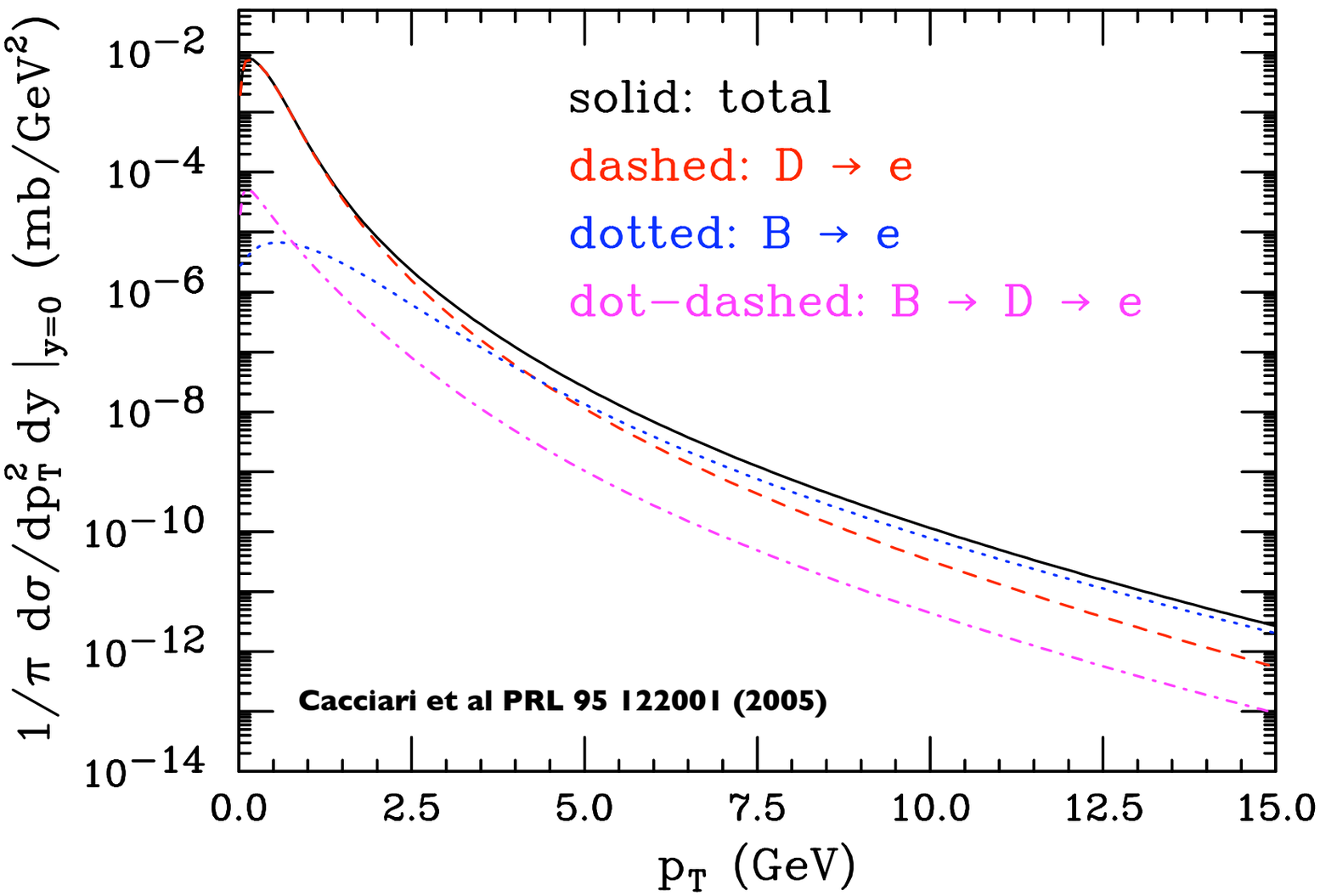


Alver & Roland PRC 81 054905 (2010)

charm & bottom: theory

$e^{\pm}$ from c & b p+p $\sqrt{s}$=200 GeV

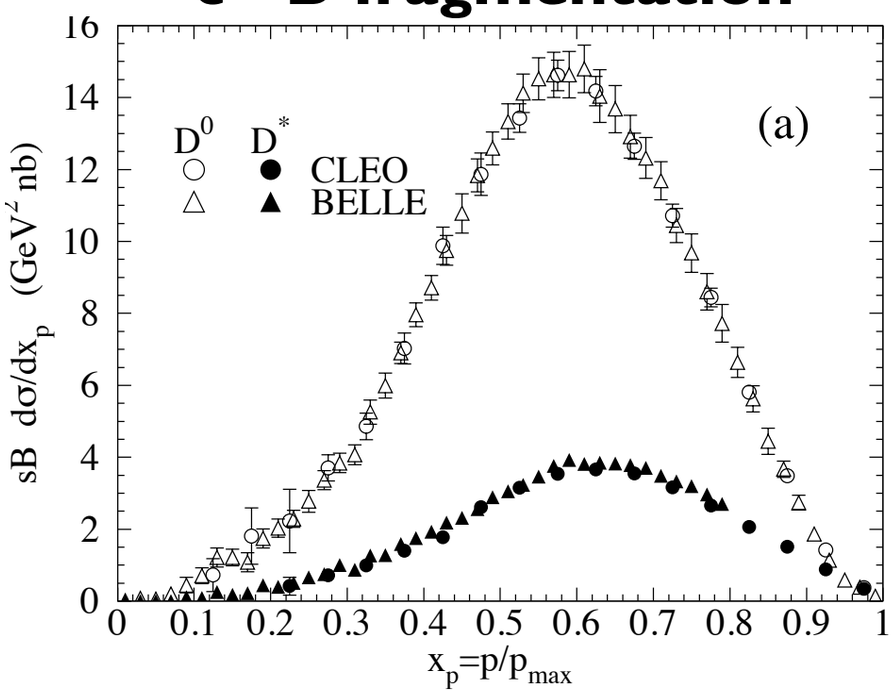


knowledge of relative c/b contributions crucial for understanding energy loss in Au+Au collisions

quarks to electrons

quarks to electrons

c→D fragmentation



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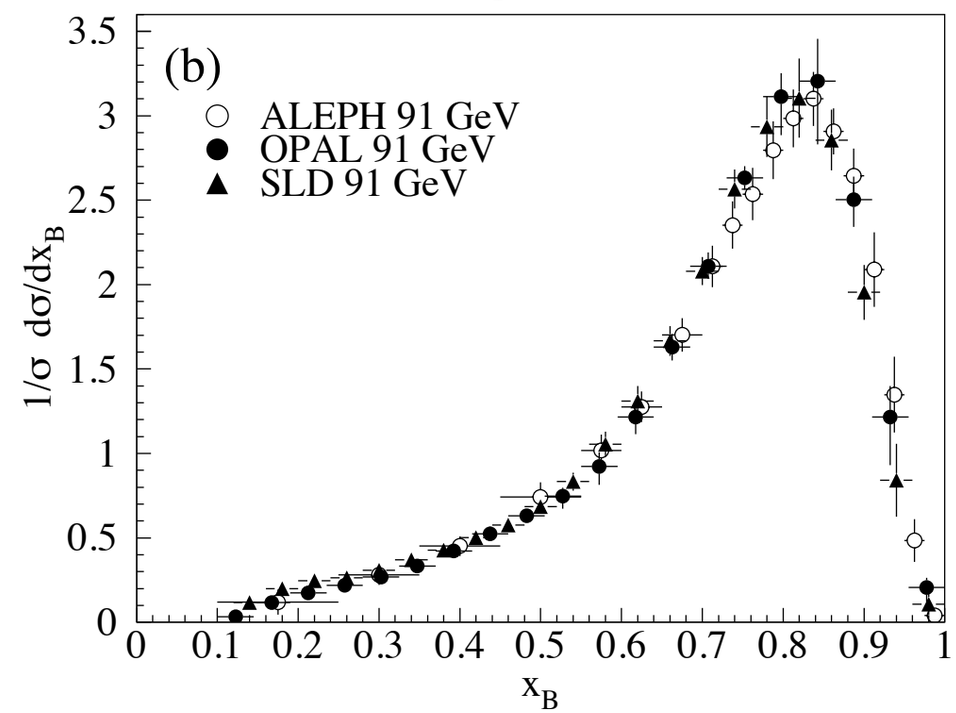

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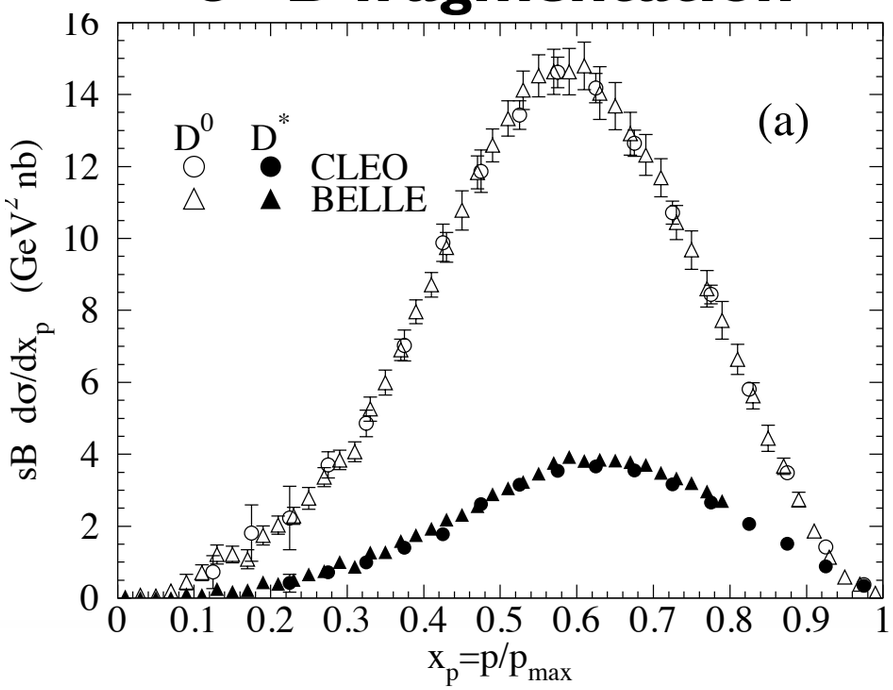

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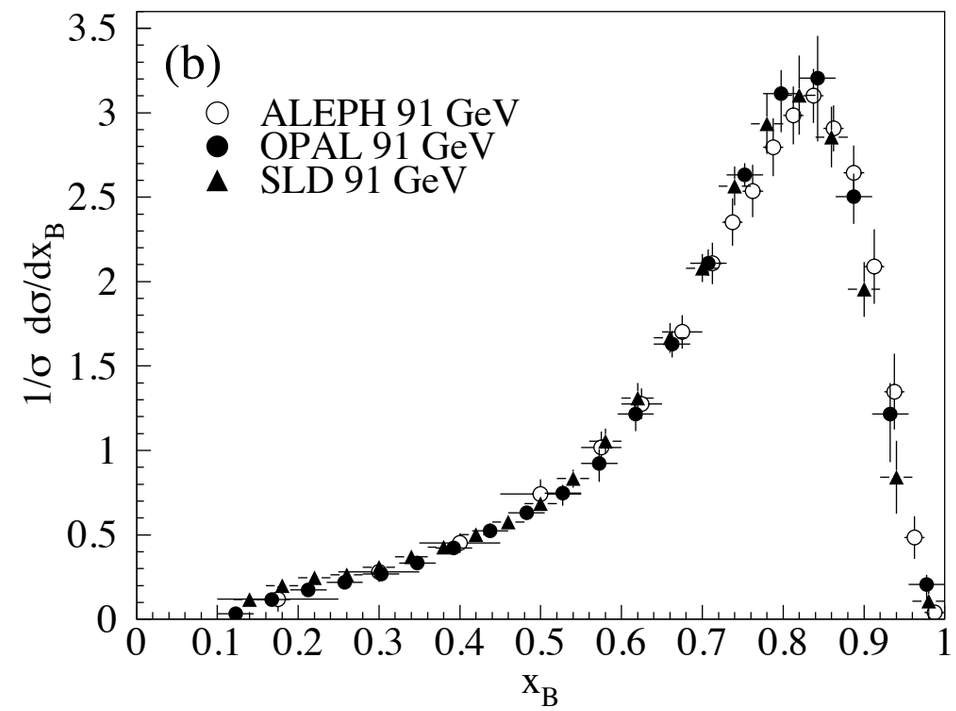

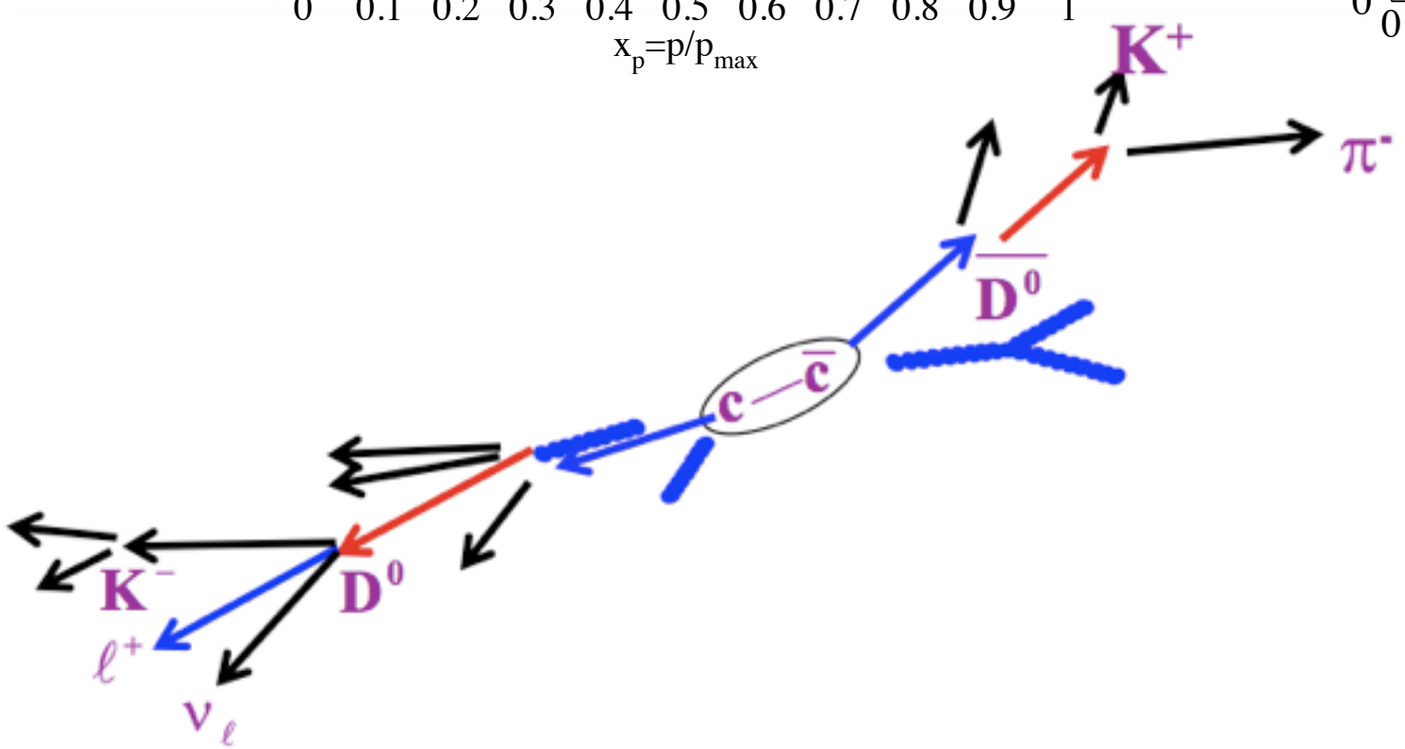

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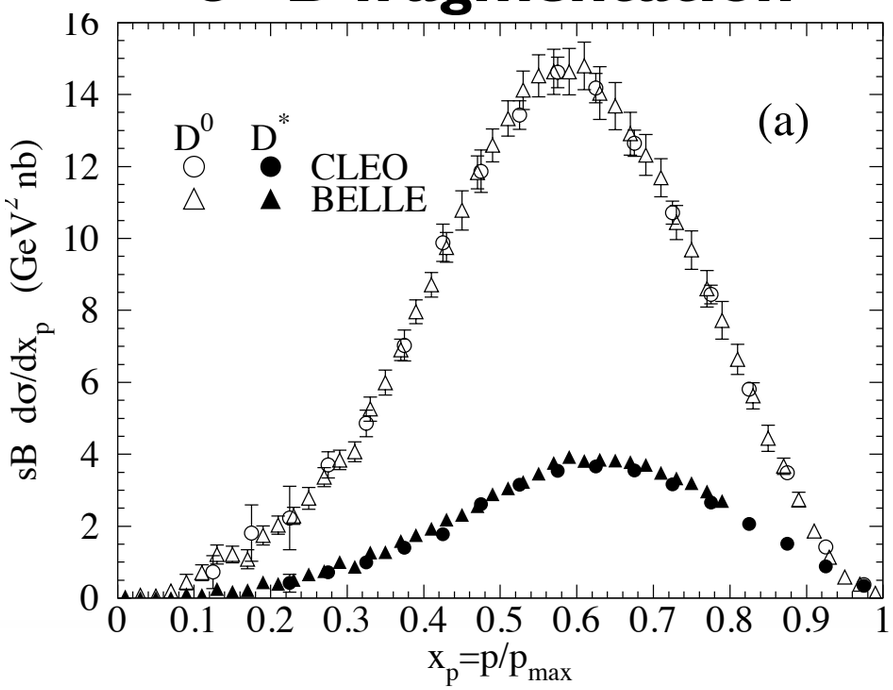

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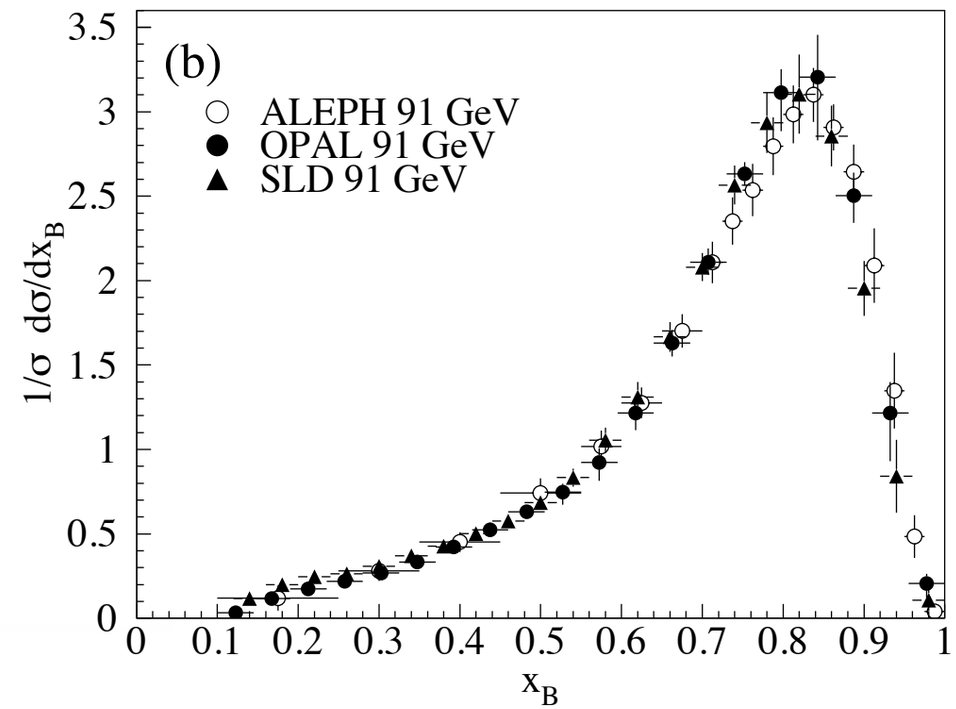
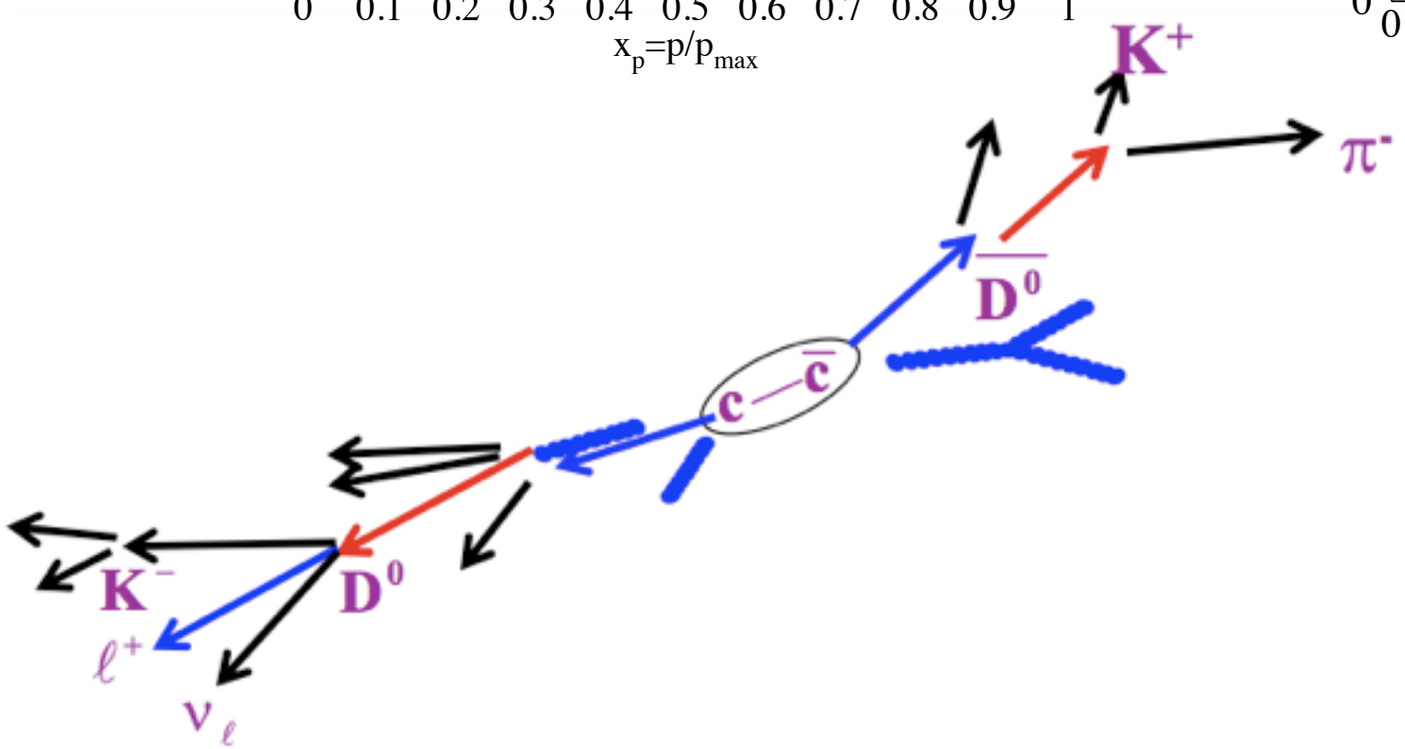
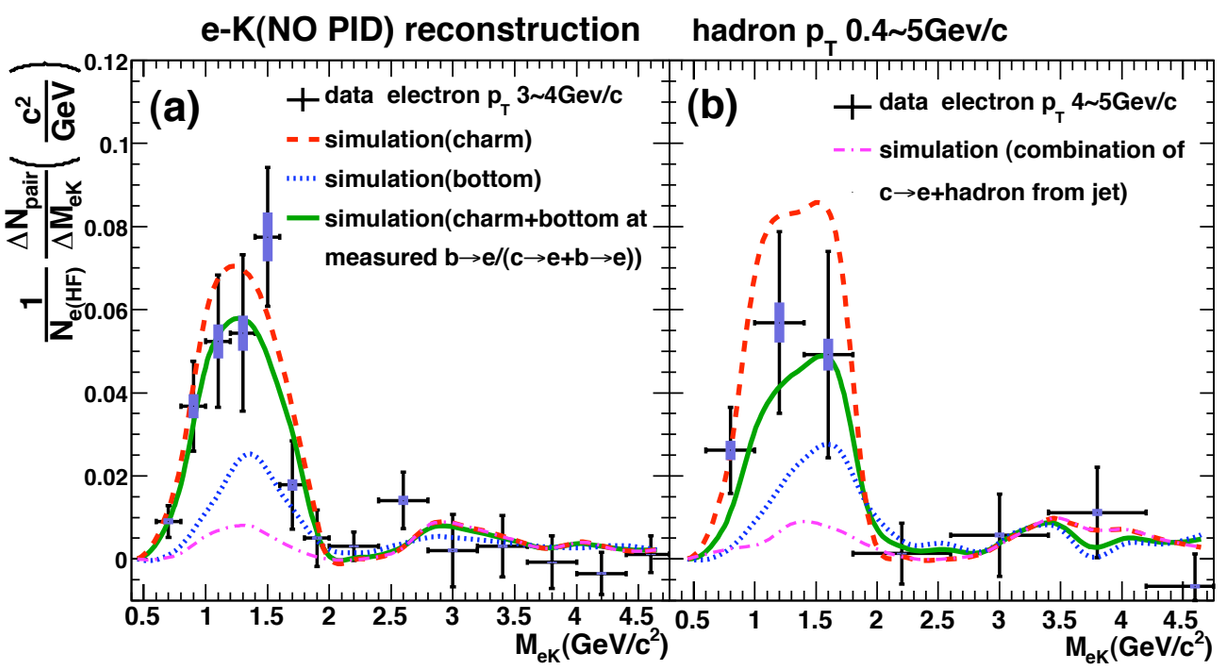
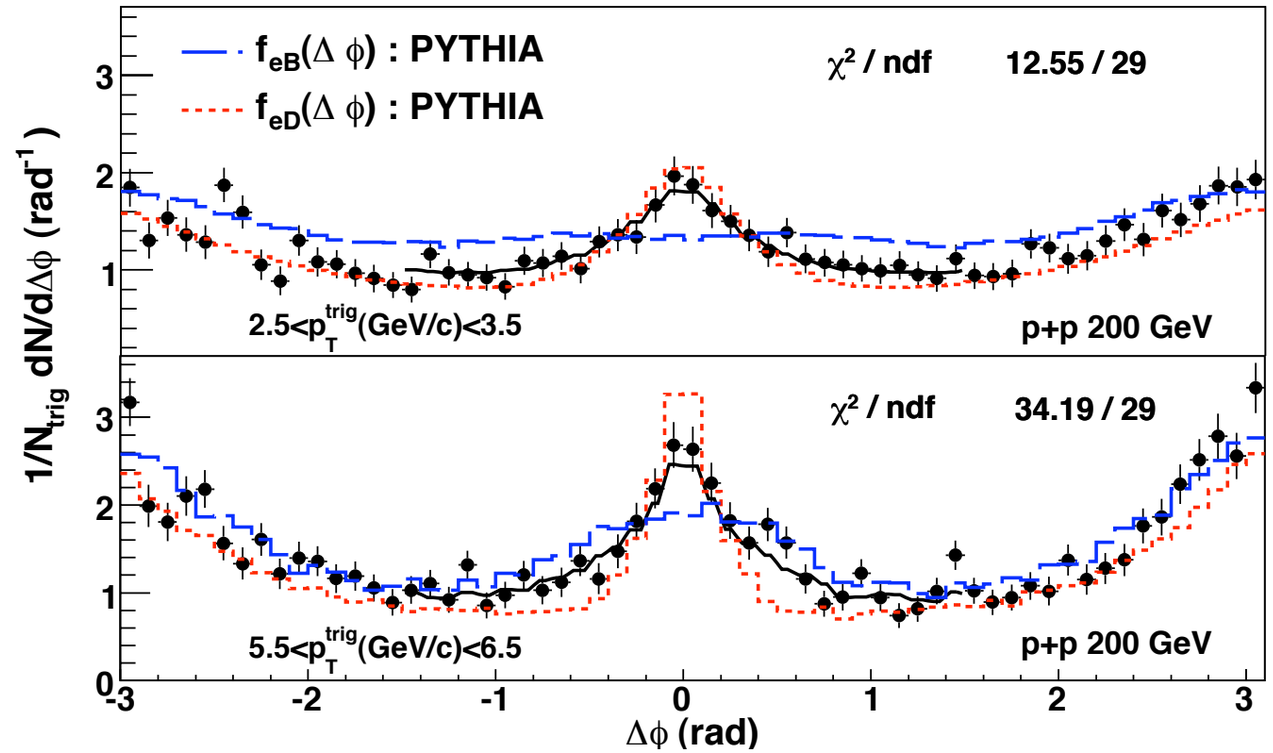




- small angle e-h correlations dominated by D & B decay products

model the near side





- introduces a dependence on MC for decays and particle mix
  - PYTHIA to handle decays

PHENIX PRL 103 082002 (2009)
STAR: PRL 105 202301 (2010)

charm vs. bottom: experiment

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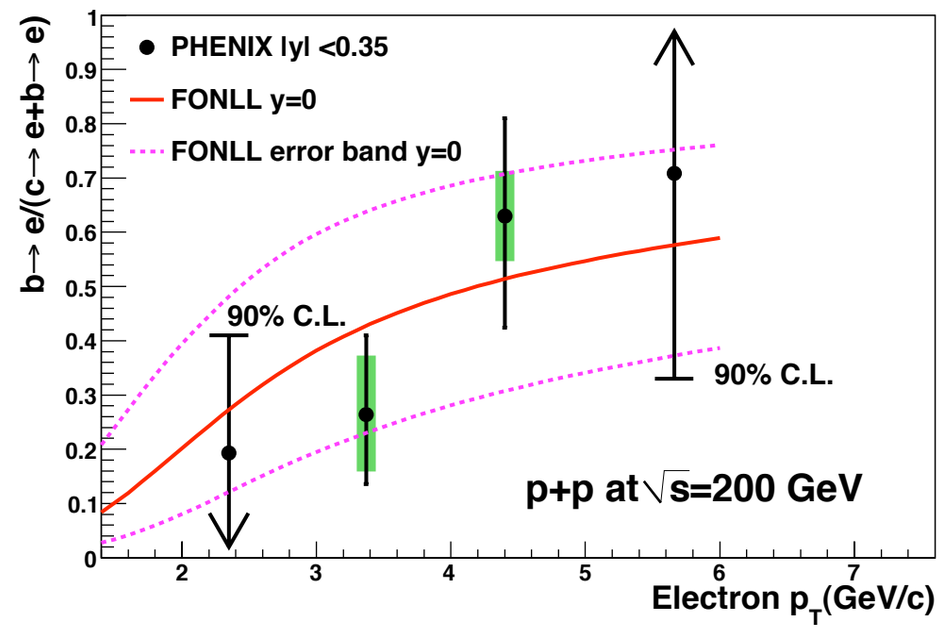

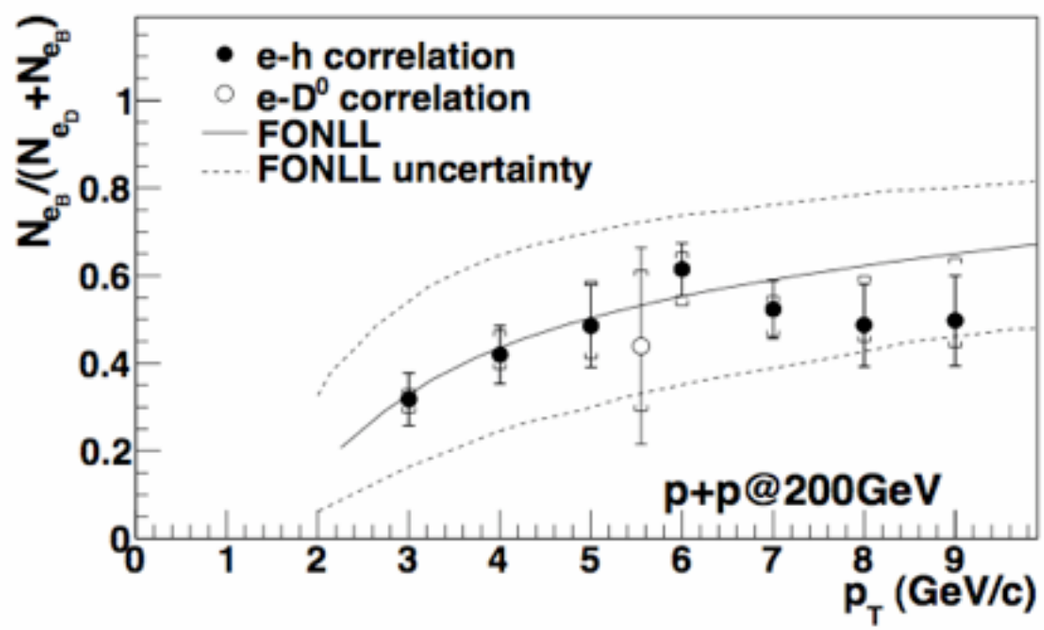

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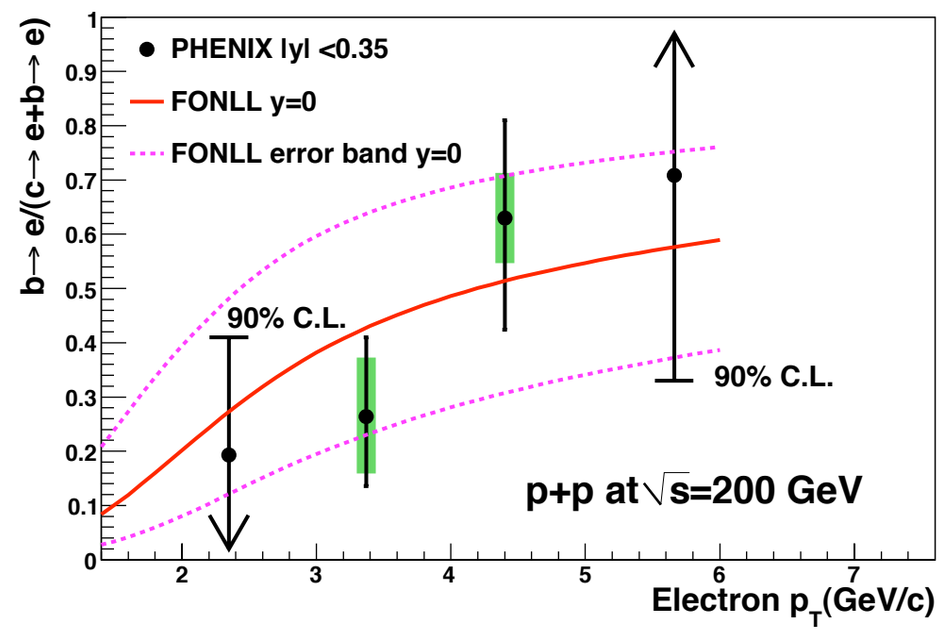

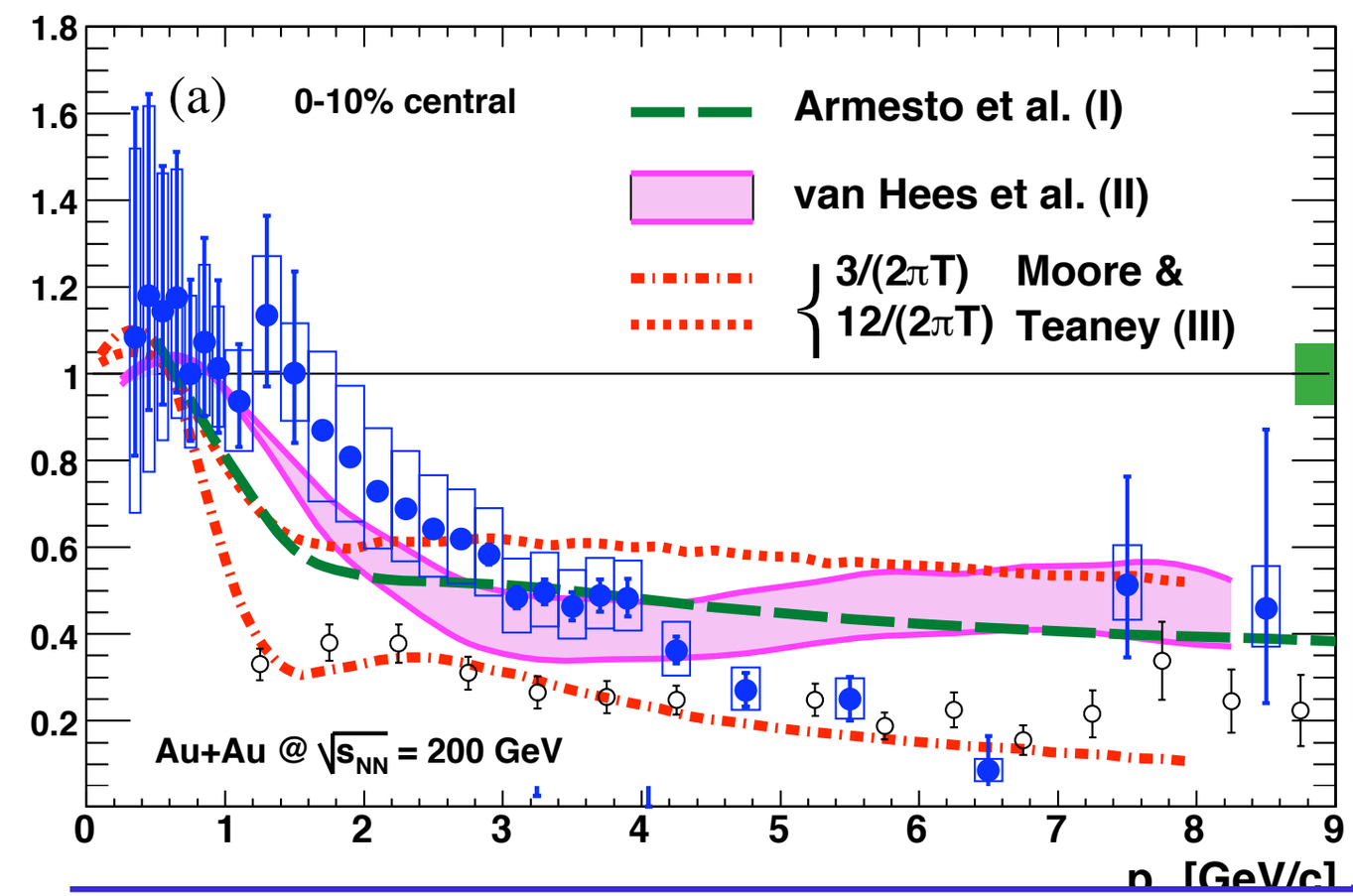

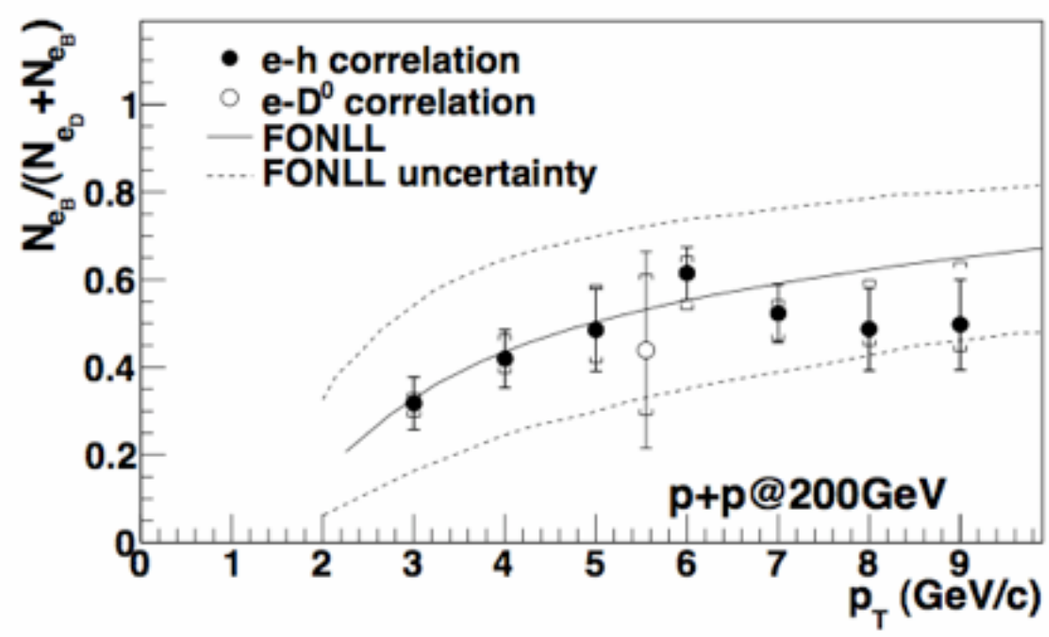

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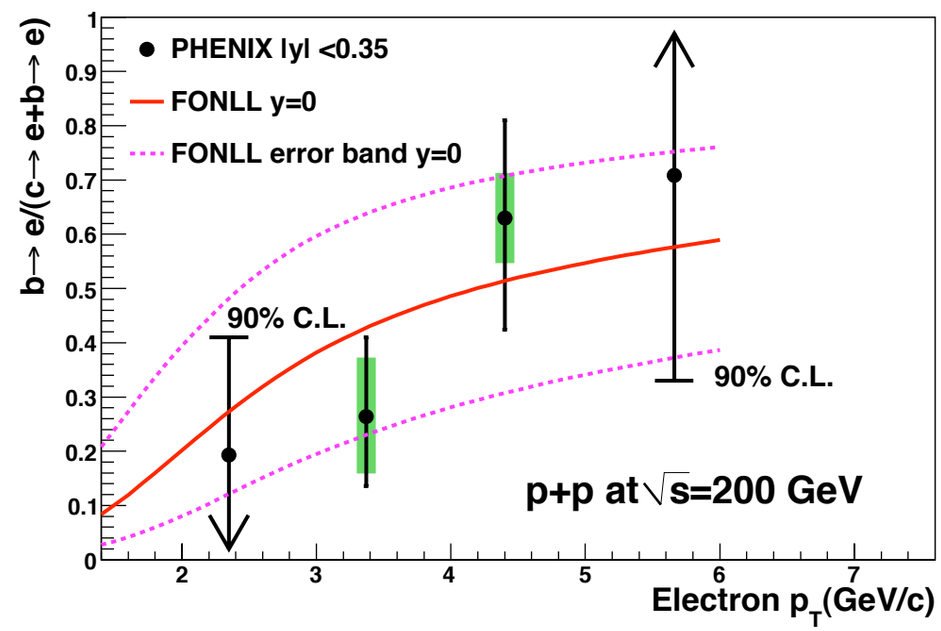
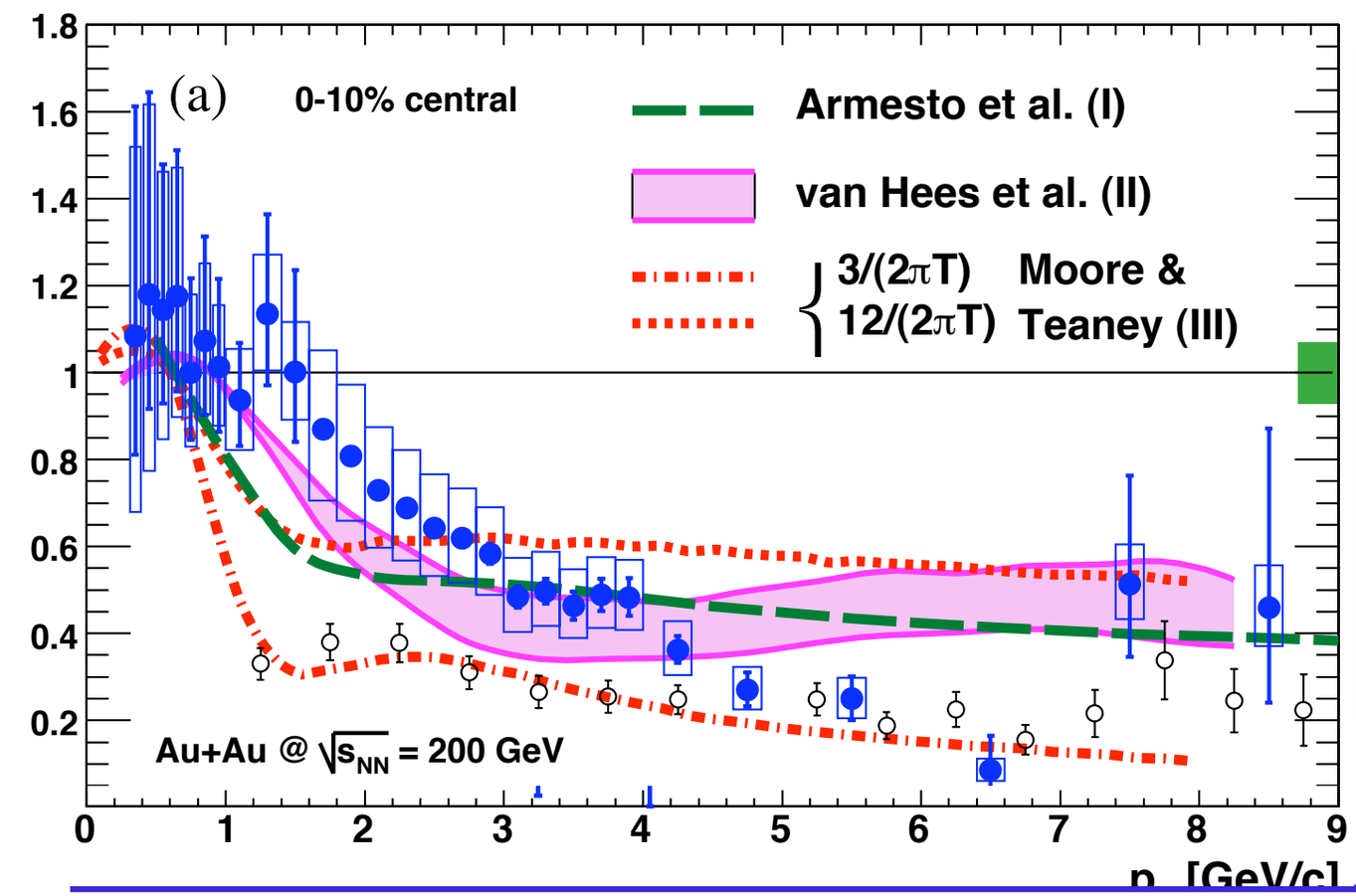
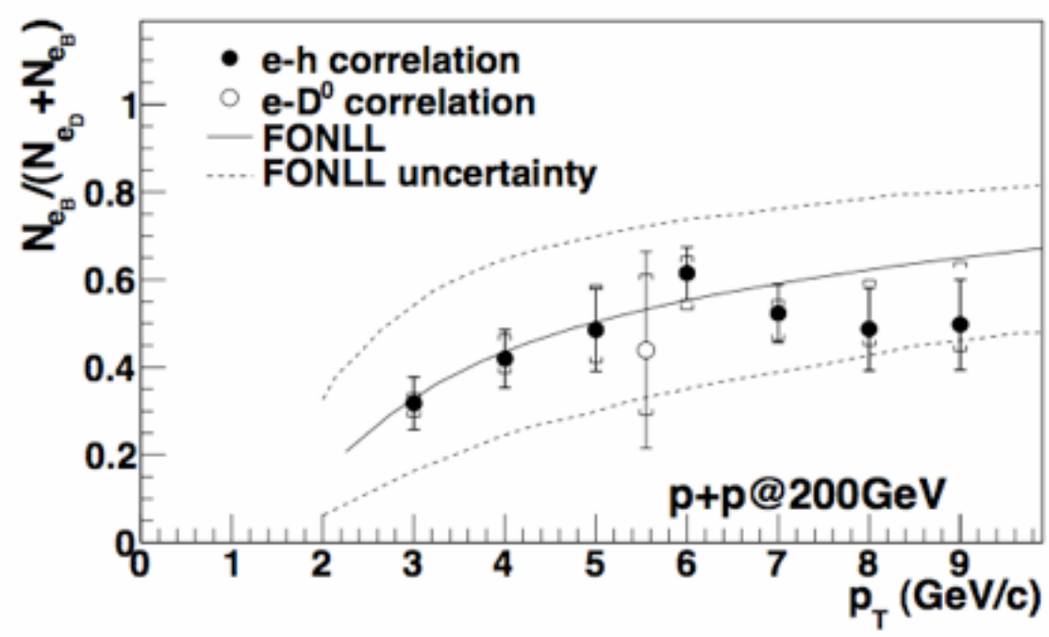
charm vs. bottom: experiment

- suppression large even as electrons become dominated by bottom at high p_T
  - b fraction well described by FONLL







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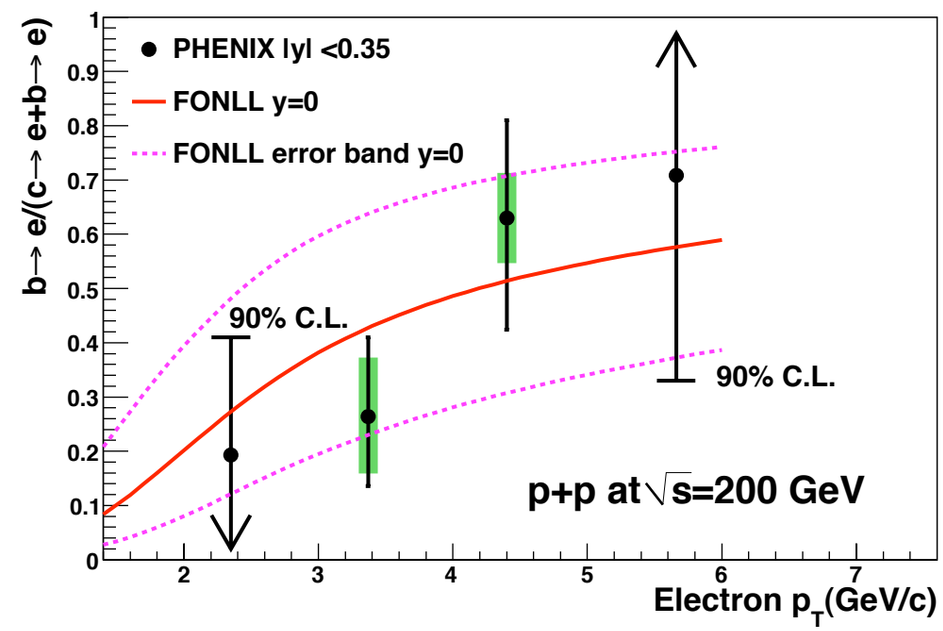

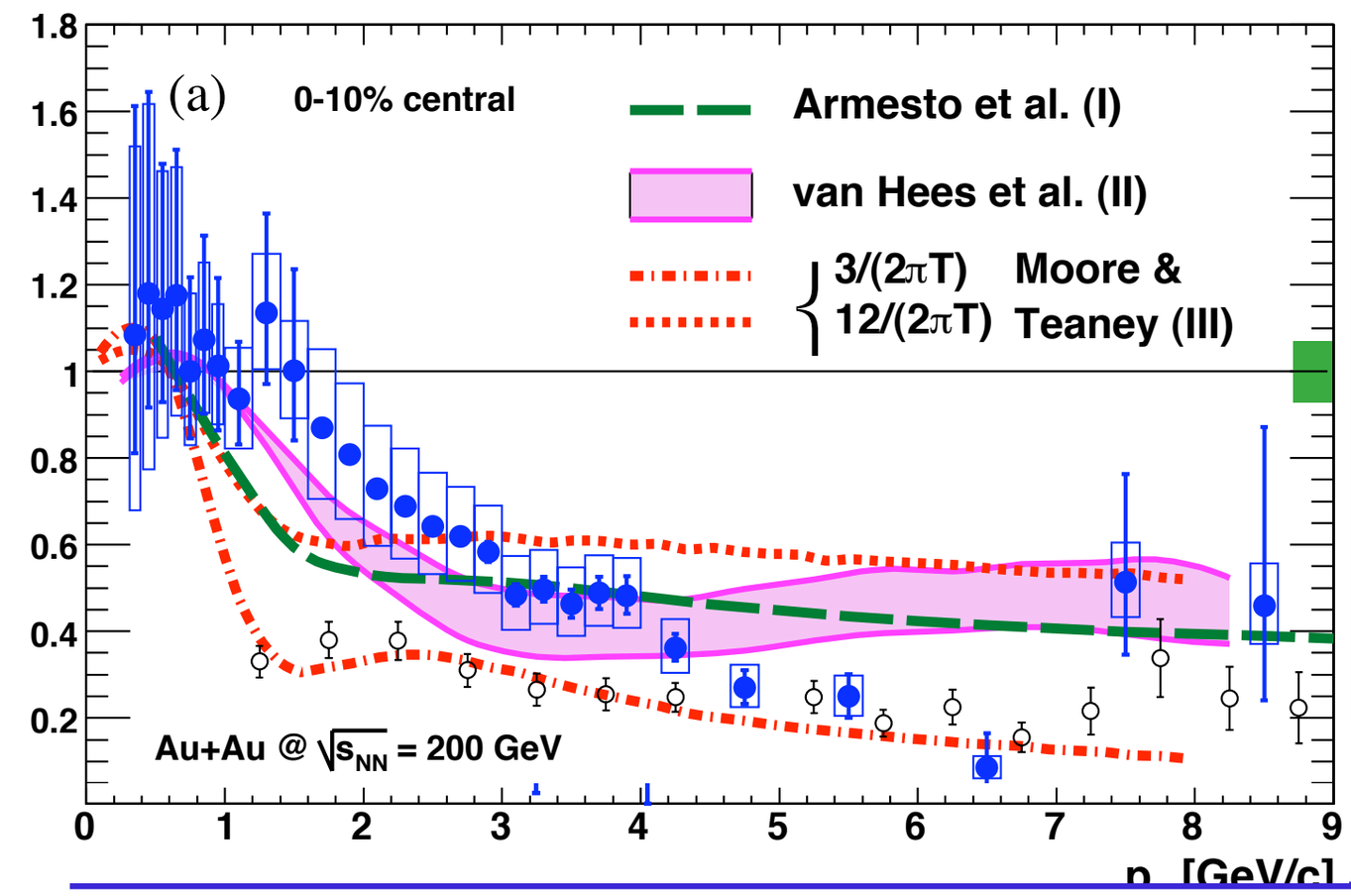

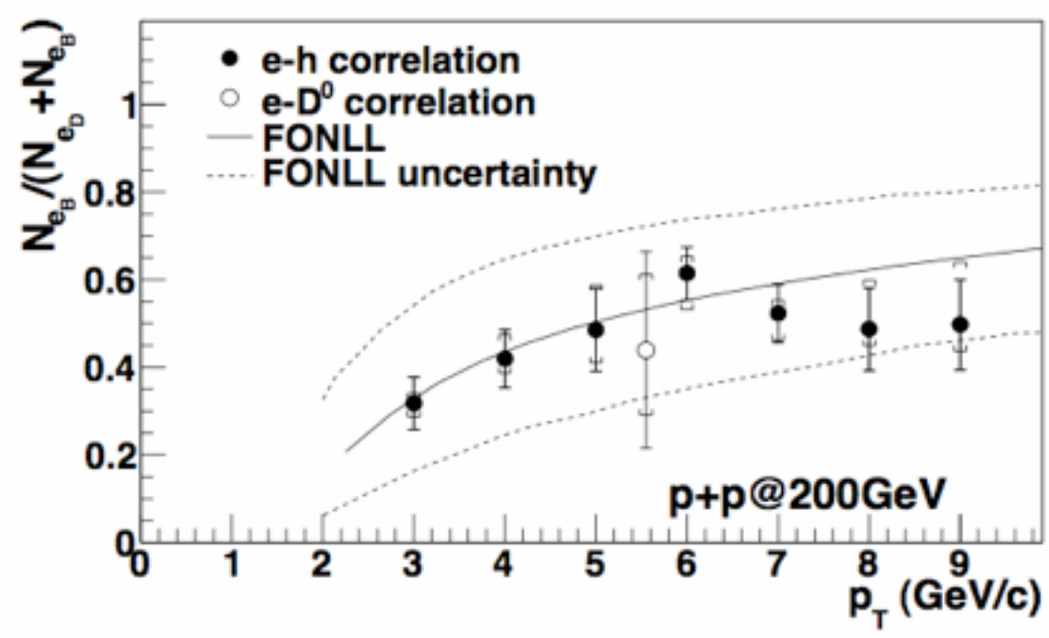

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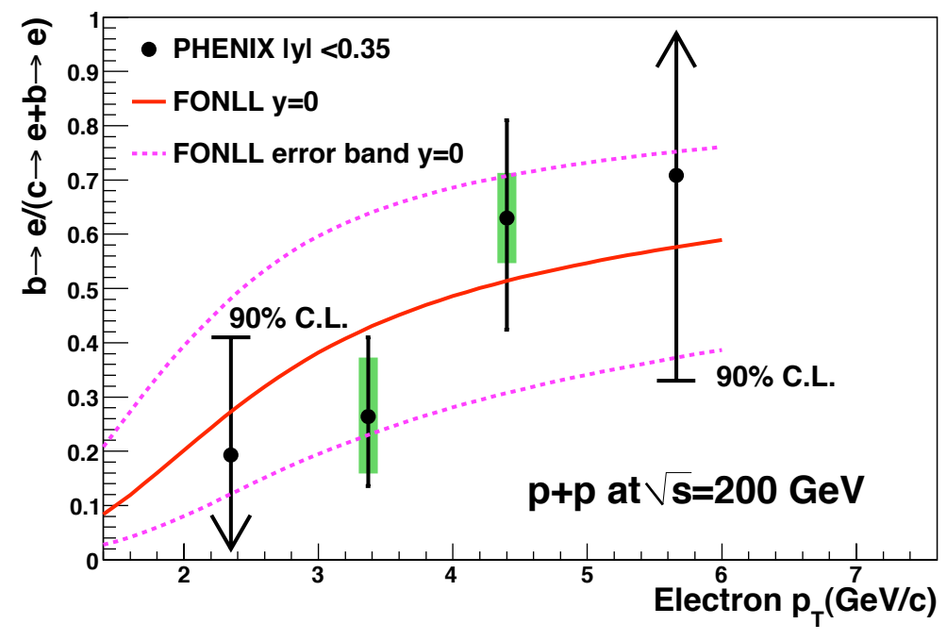

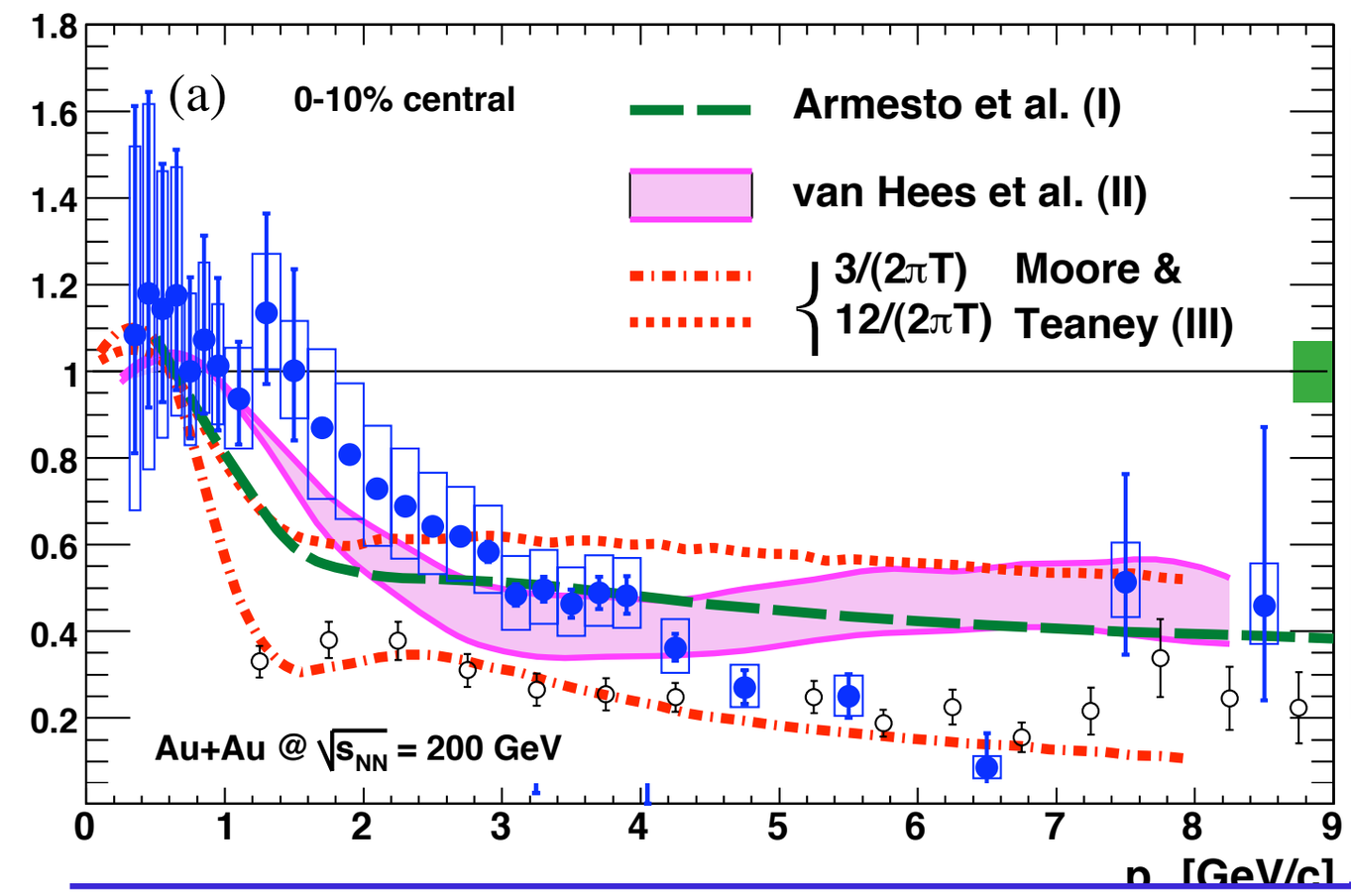

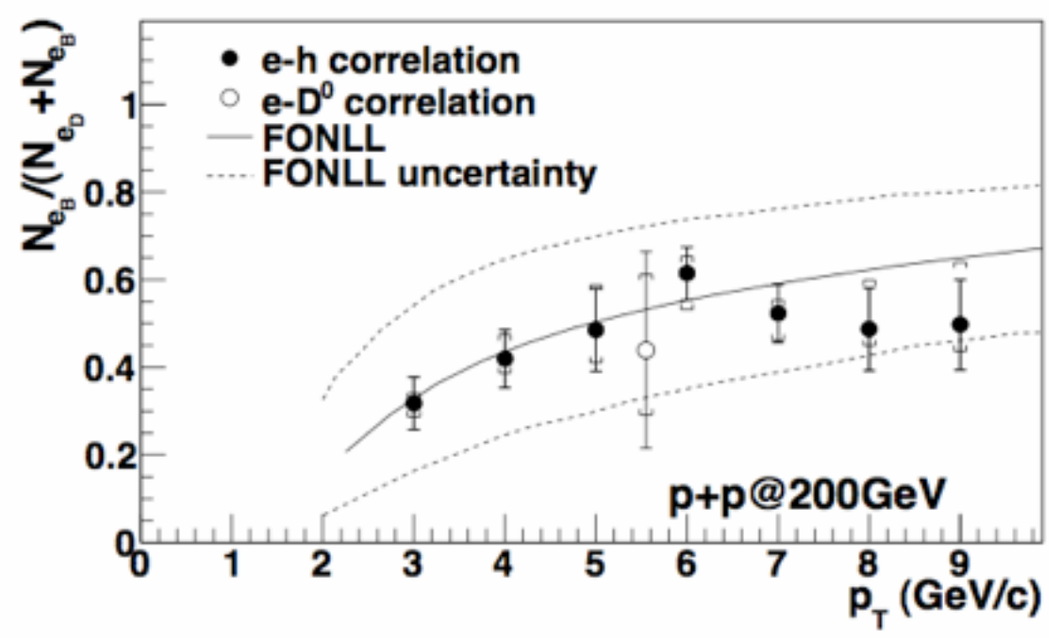

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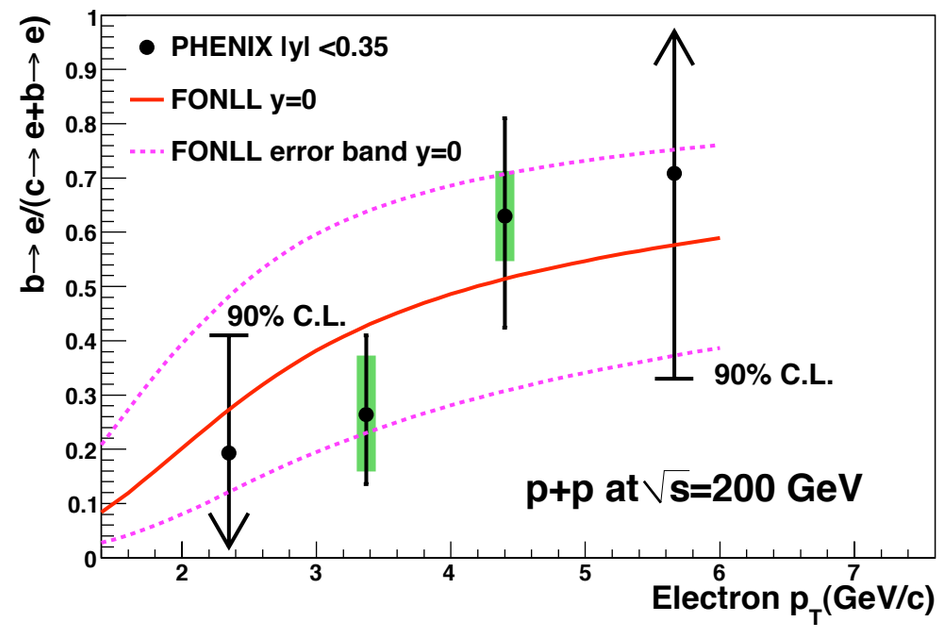

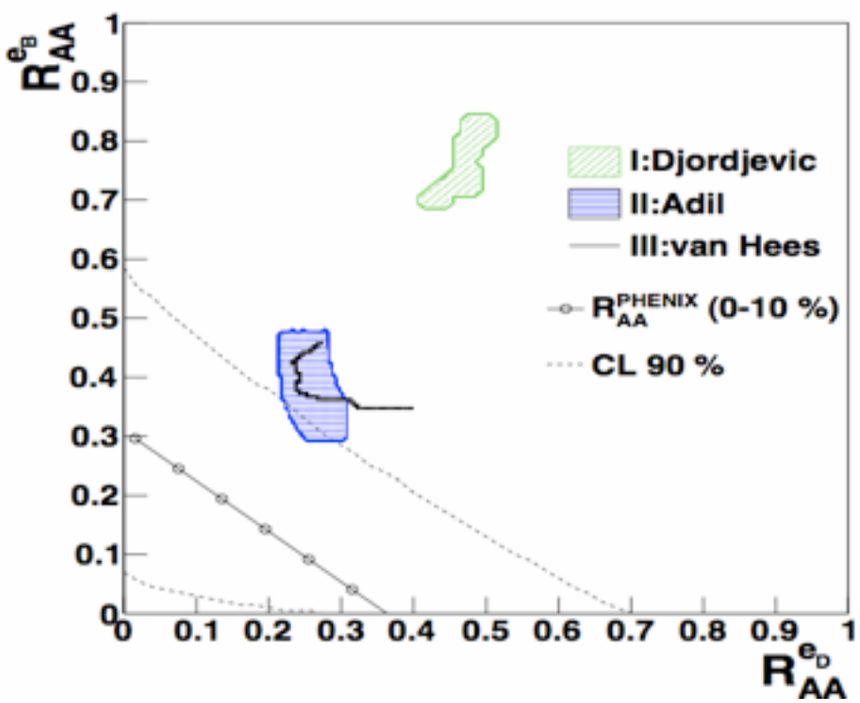

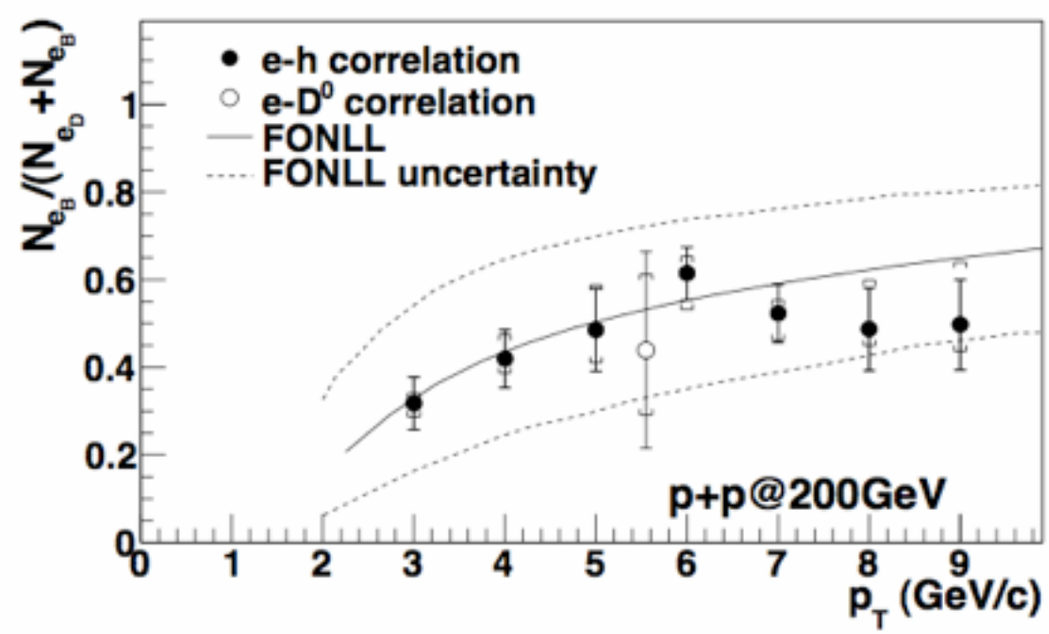

bottom is suppressed?!

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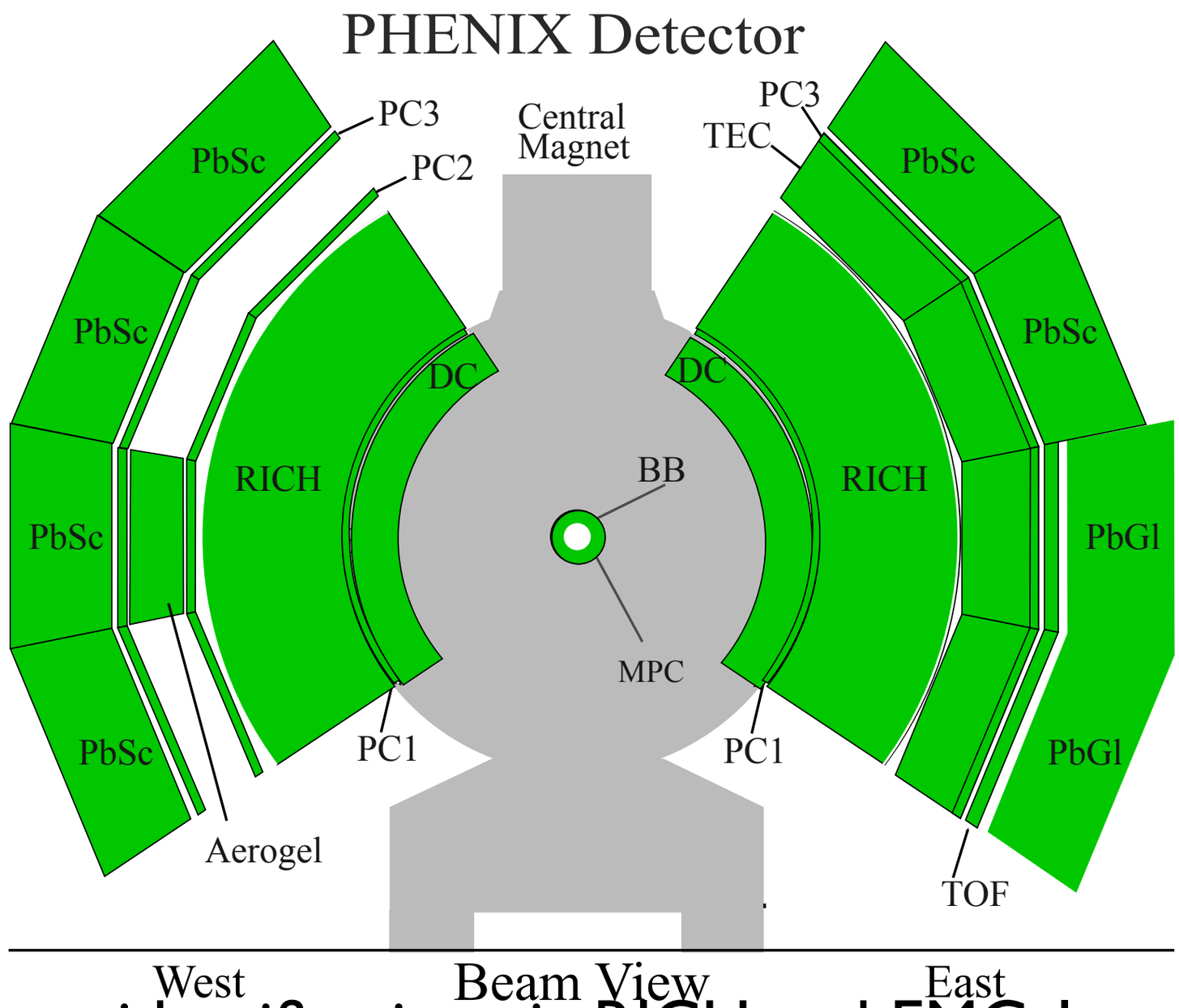
Electron Measurement



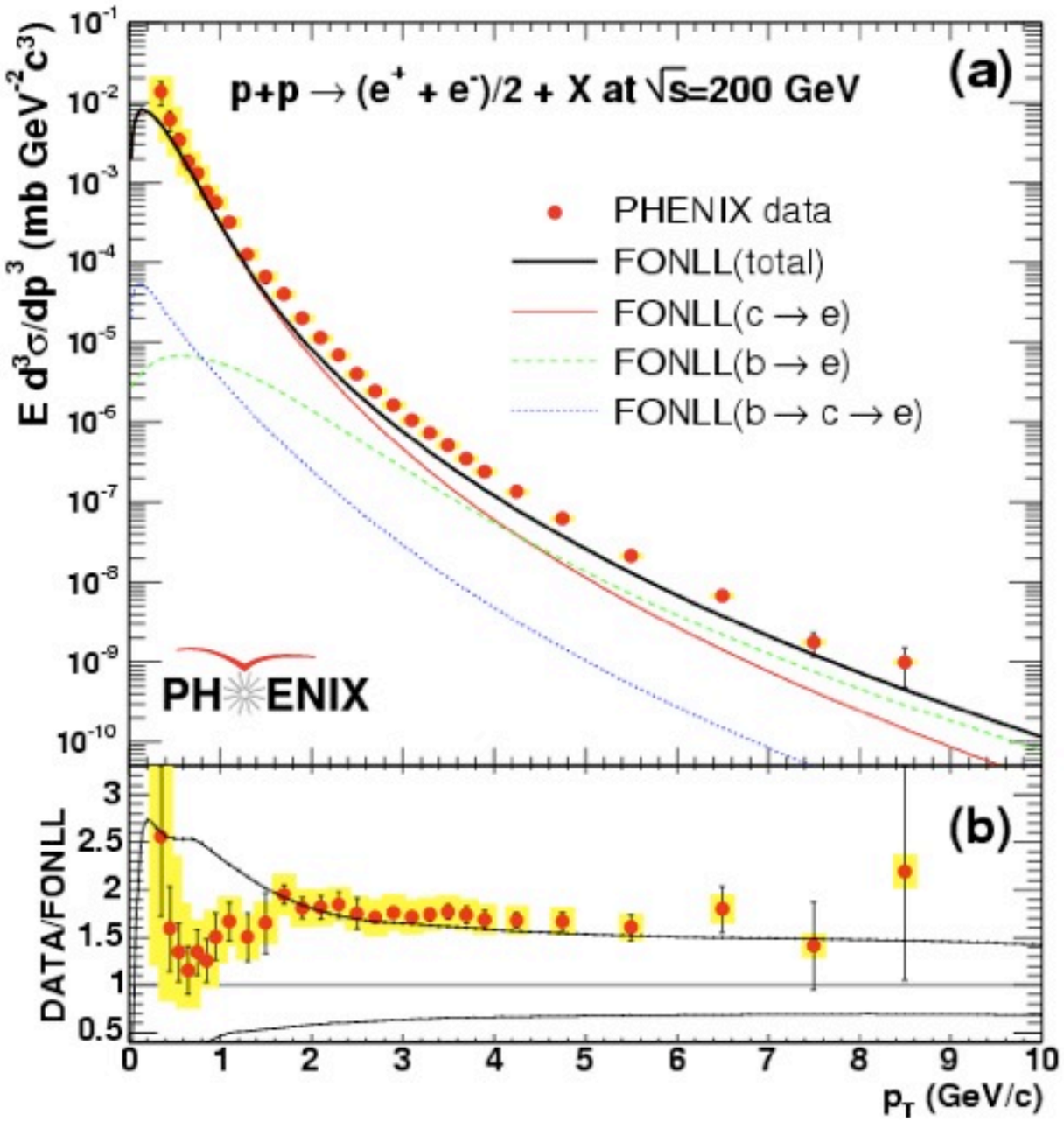
- electron identification via RICH and EMCal
- residual hadron contamination: <1% p+p, <3% Au+Au

two types of electrons

PHENIX, PRL 97 252002 (2006)

two types of electrons

Heavy Flavor



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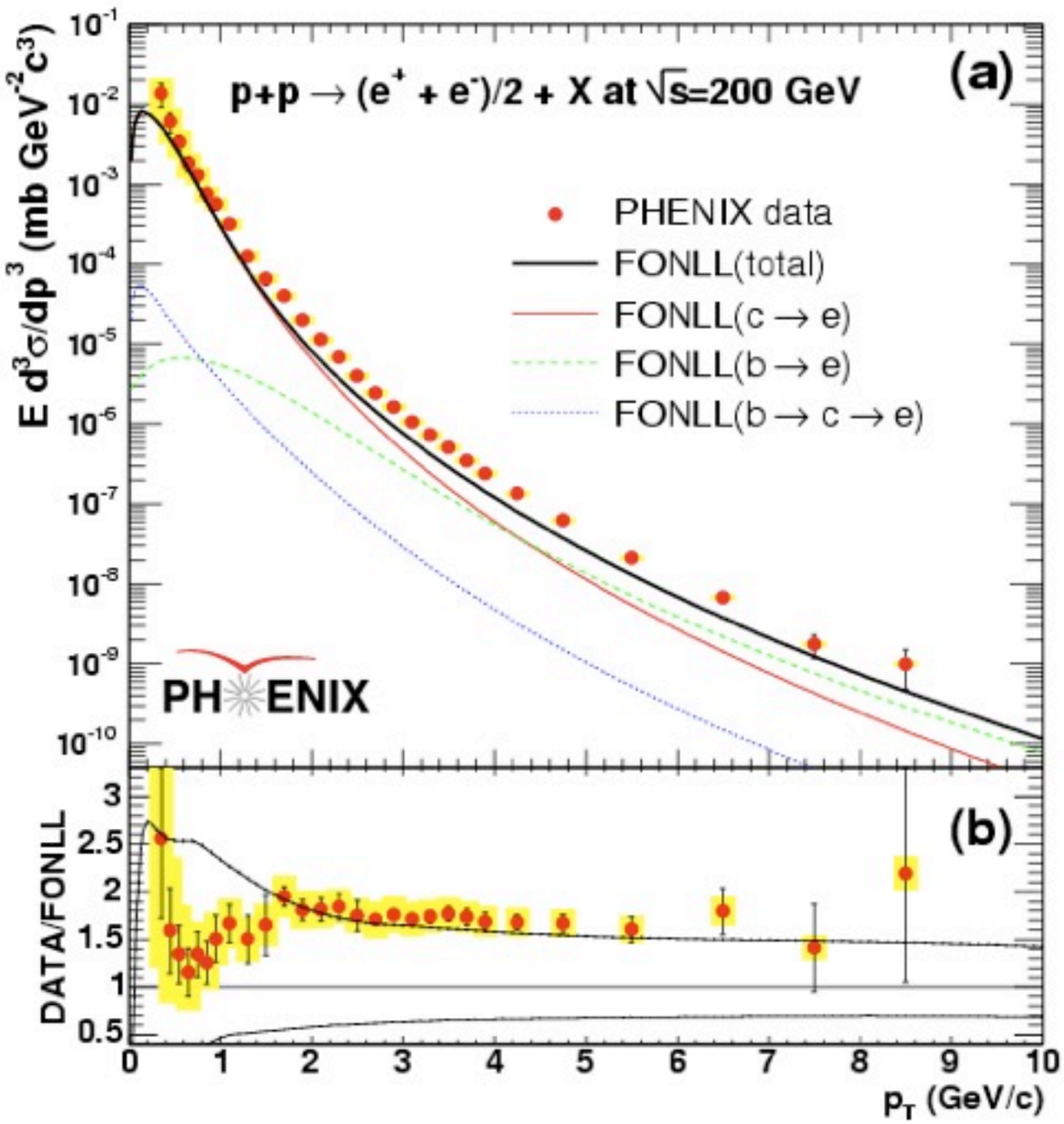
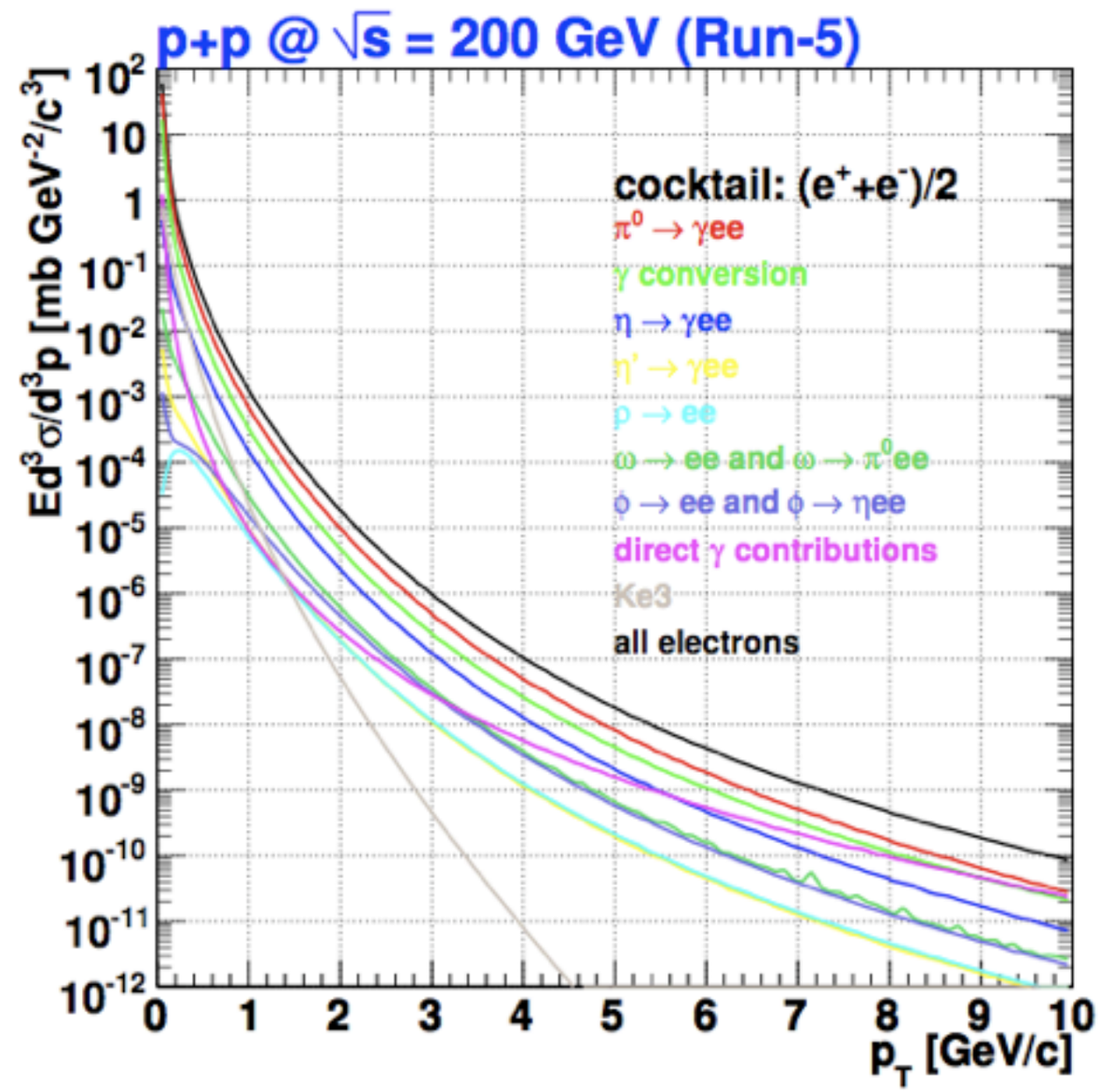
Heavy Flavor



Photonic Electrons



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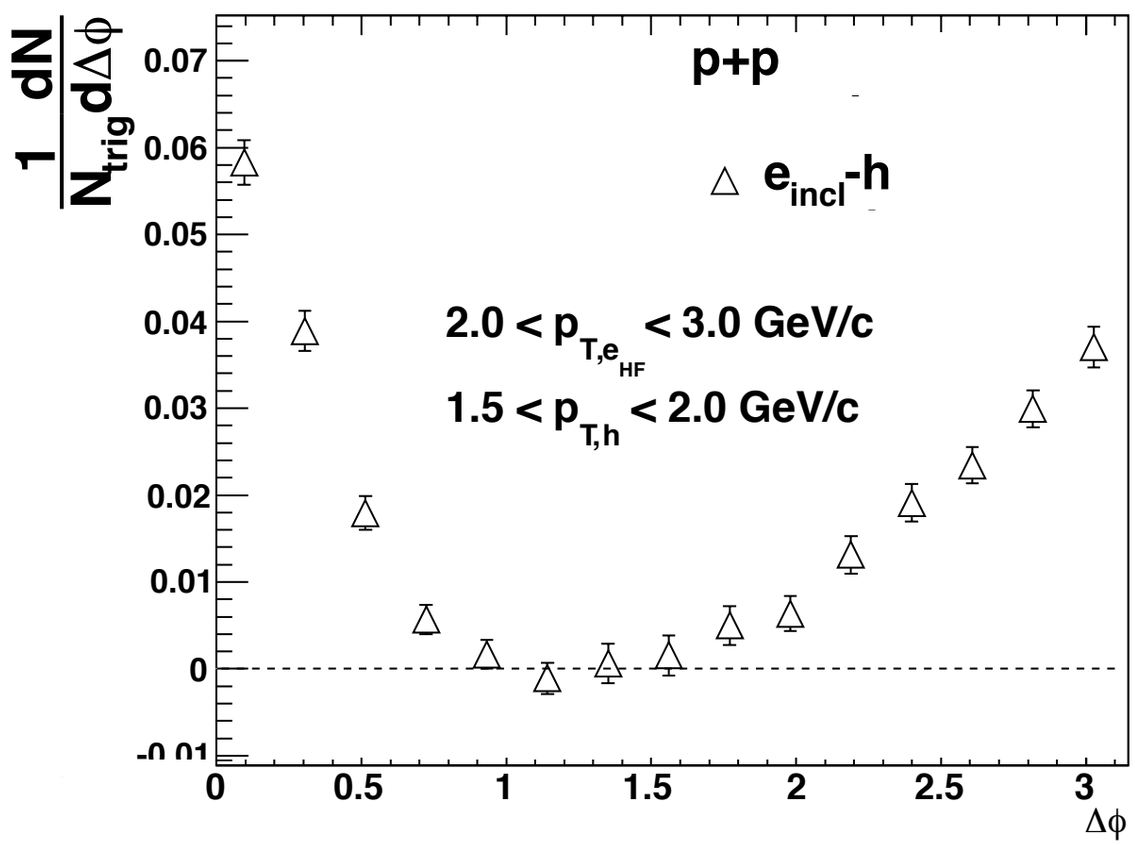
inclusive electron correlations

$$Y_{e_{incl}-h}$$

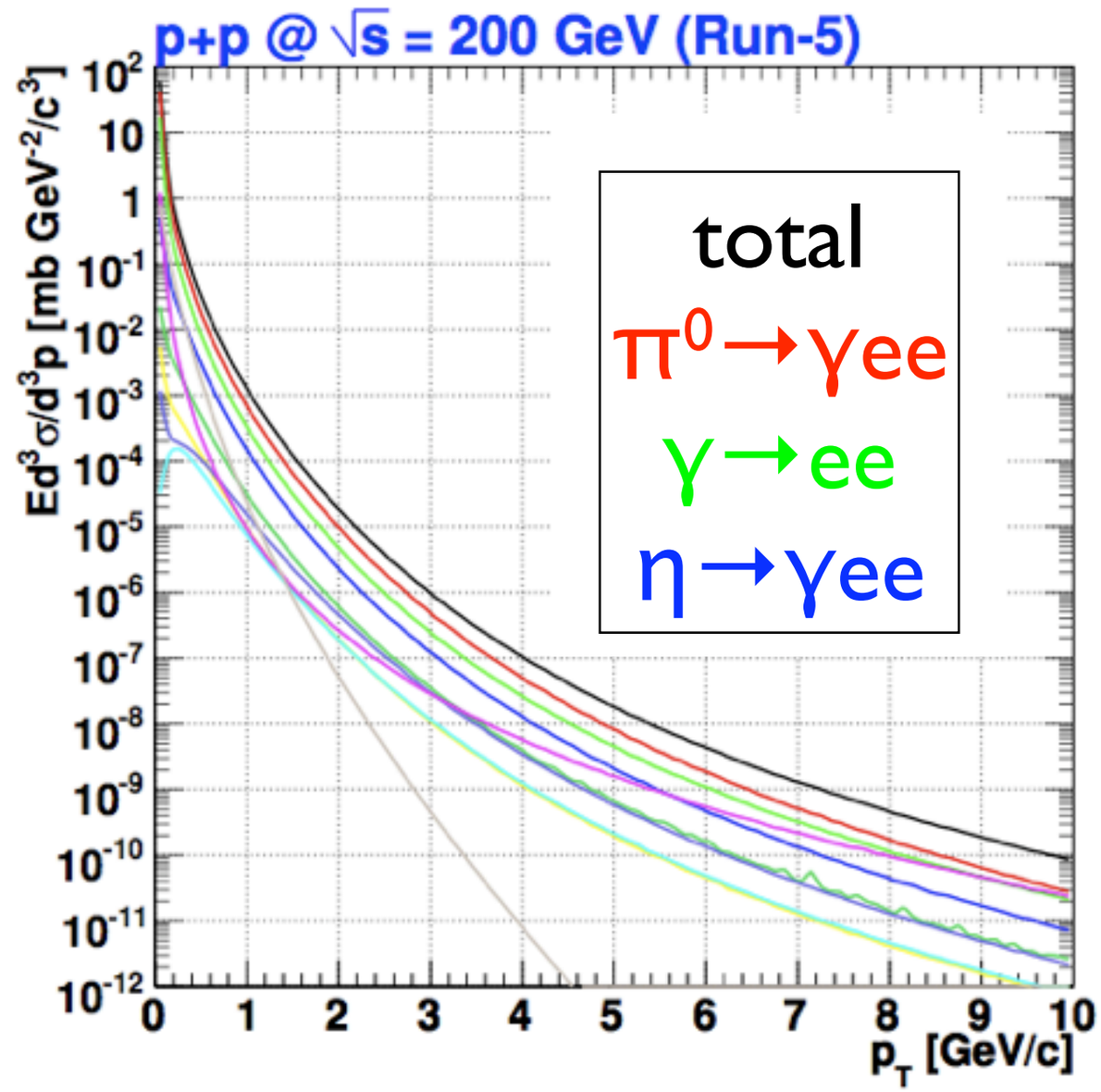


arXiv:1011.1477

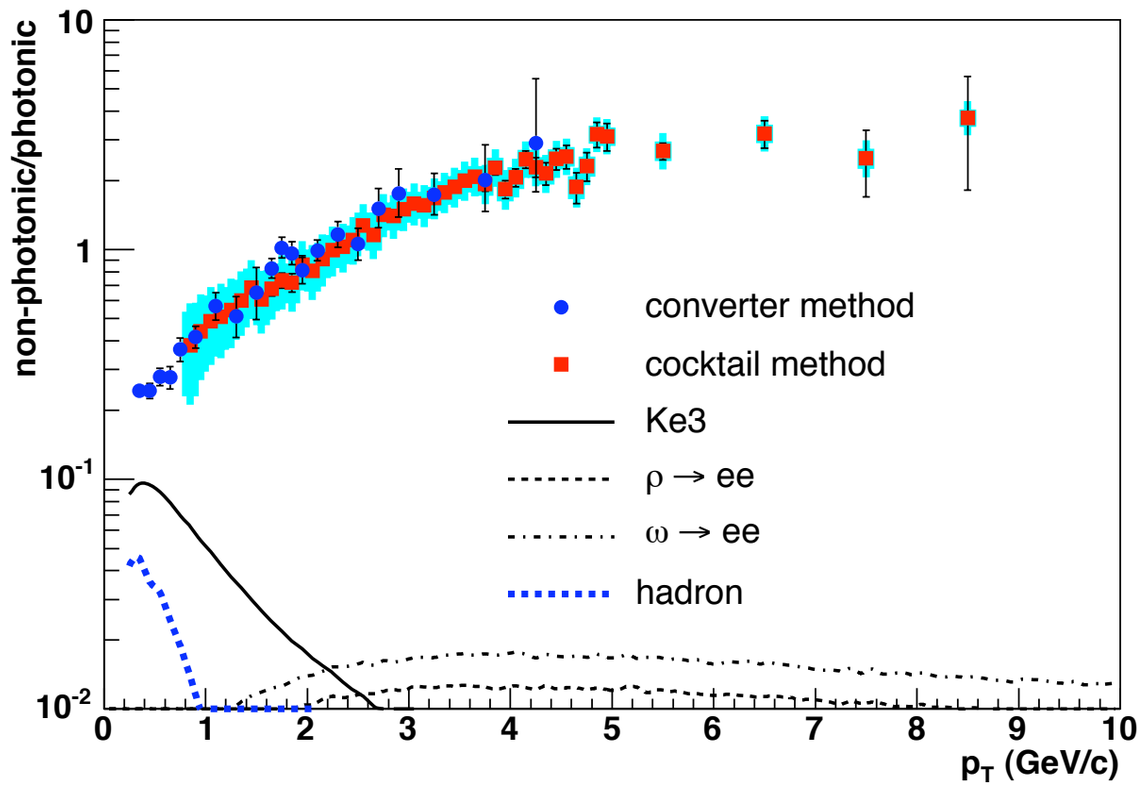
photonic electrons

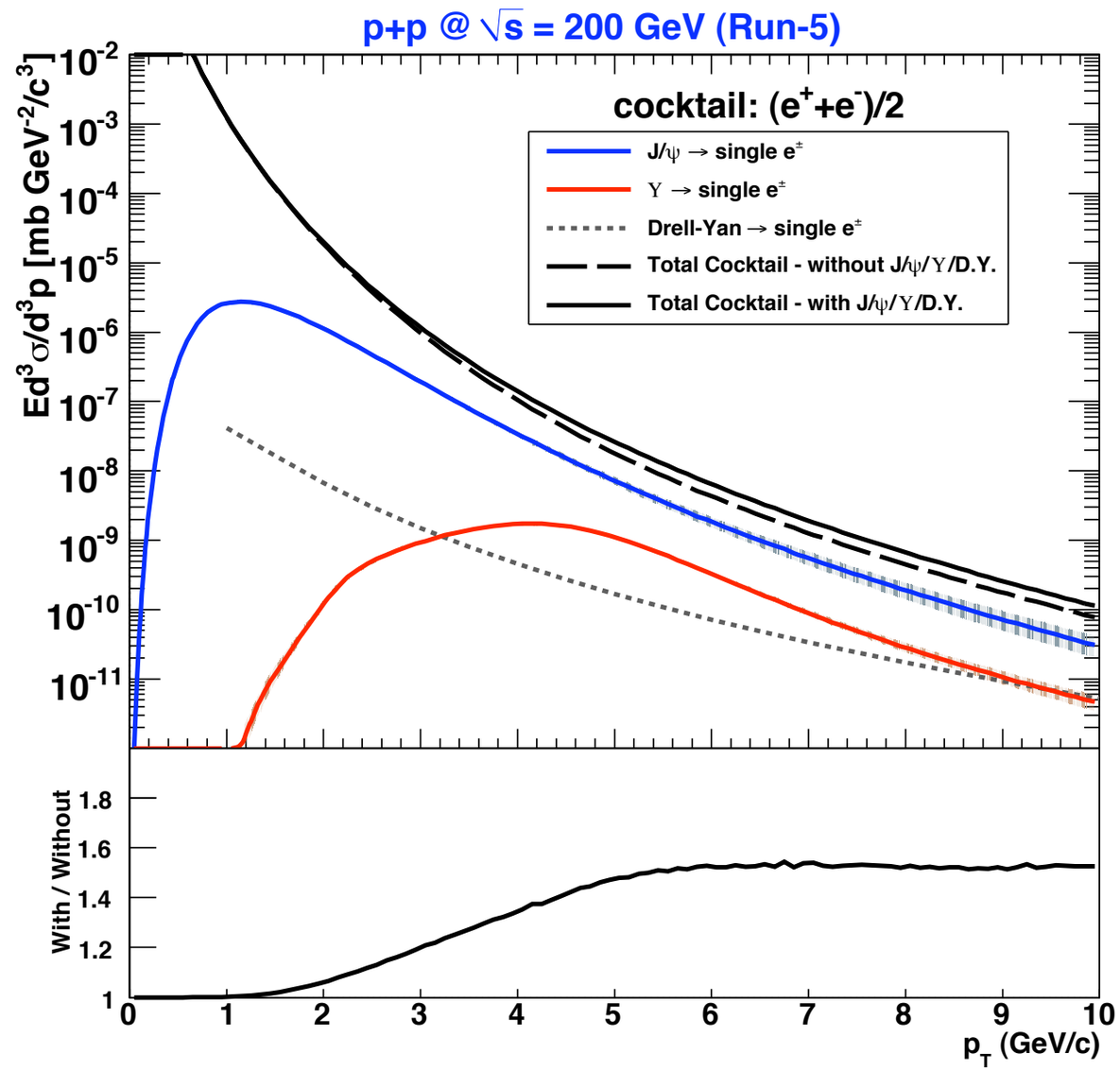
- p_T < 5GeV/c:
  - →dominantly from π^0s
- measure *photon*-h correlations
  - also dominantly from π^0s
  - use MC to map between $e_{phot}(p_T)$ & $\gamma_{inc}(p_T)$

$$\Upsilon_{e_{phot}-h}$$



relative contributions



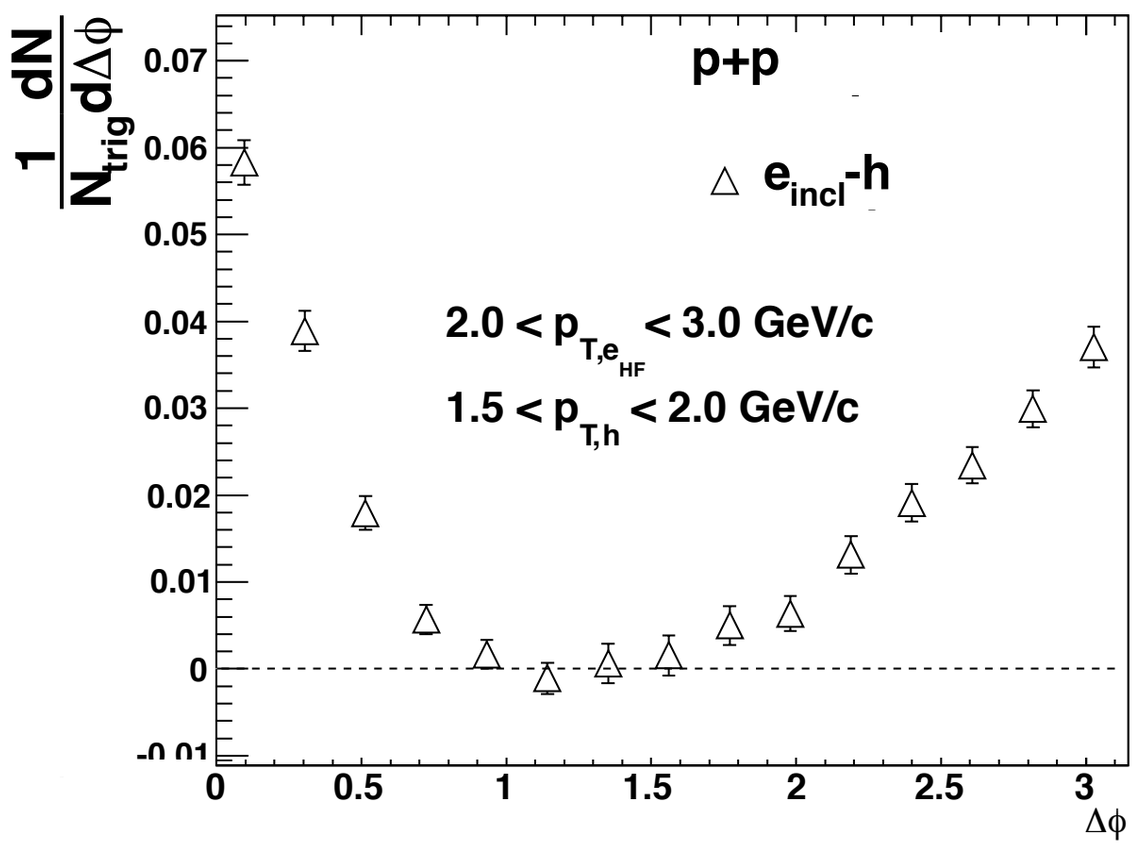


- S/B ~ 1 in the p_T range of interest
- J/ψ contributions also significant toward high p_T

PHENIX PRL 97 252002 (2006)
1005.1627[nucl-ex]

inclusive electron correlations

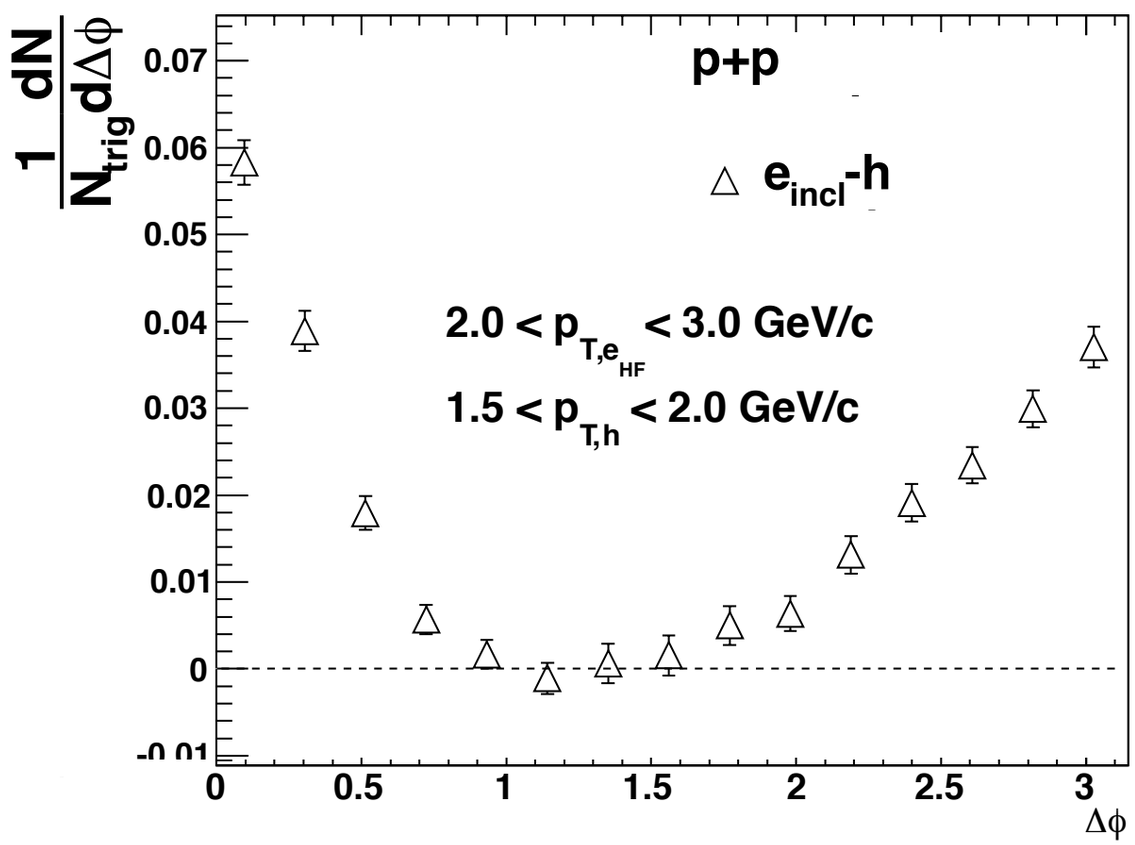
$$Y_{e_{incl}-h}$$



arXiv:1011.1477

inclusive electron correlations

$$Y_{e_{incl}-h} = \frac{N_{e_{HF}} Y_{e_{HF}-h} + N_{e_{bkg}} Y_{e_{bkg}-h}}{N_{e_{HF}} + N_{e_{bkg}}}$$



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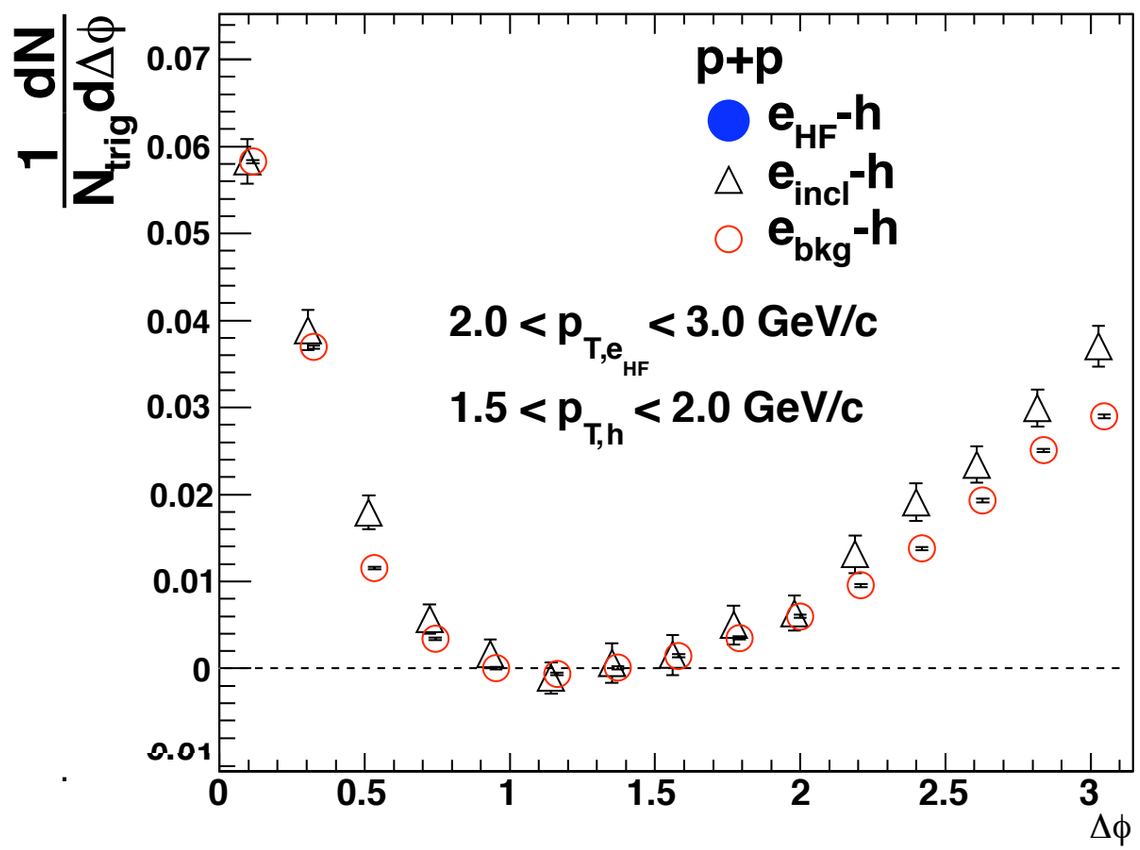

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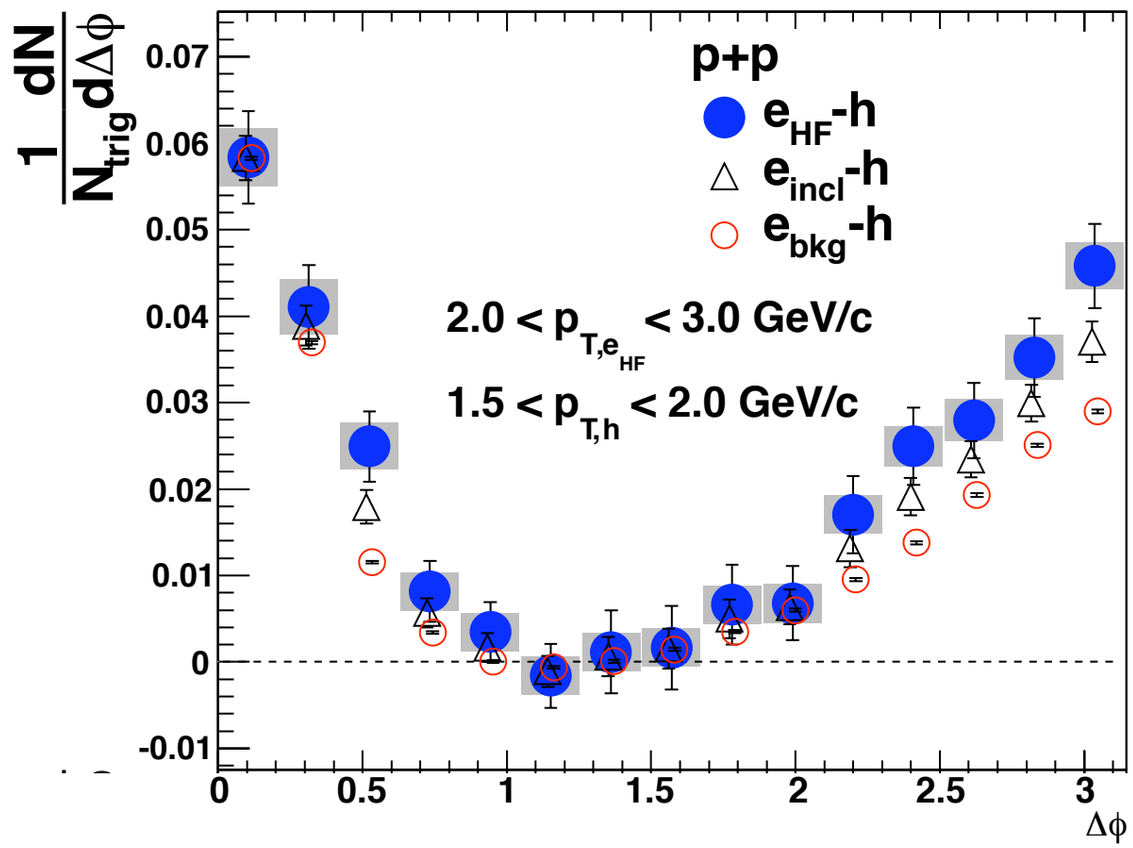
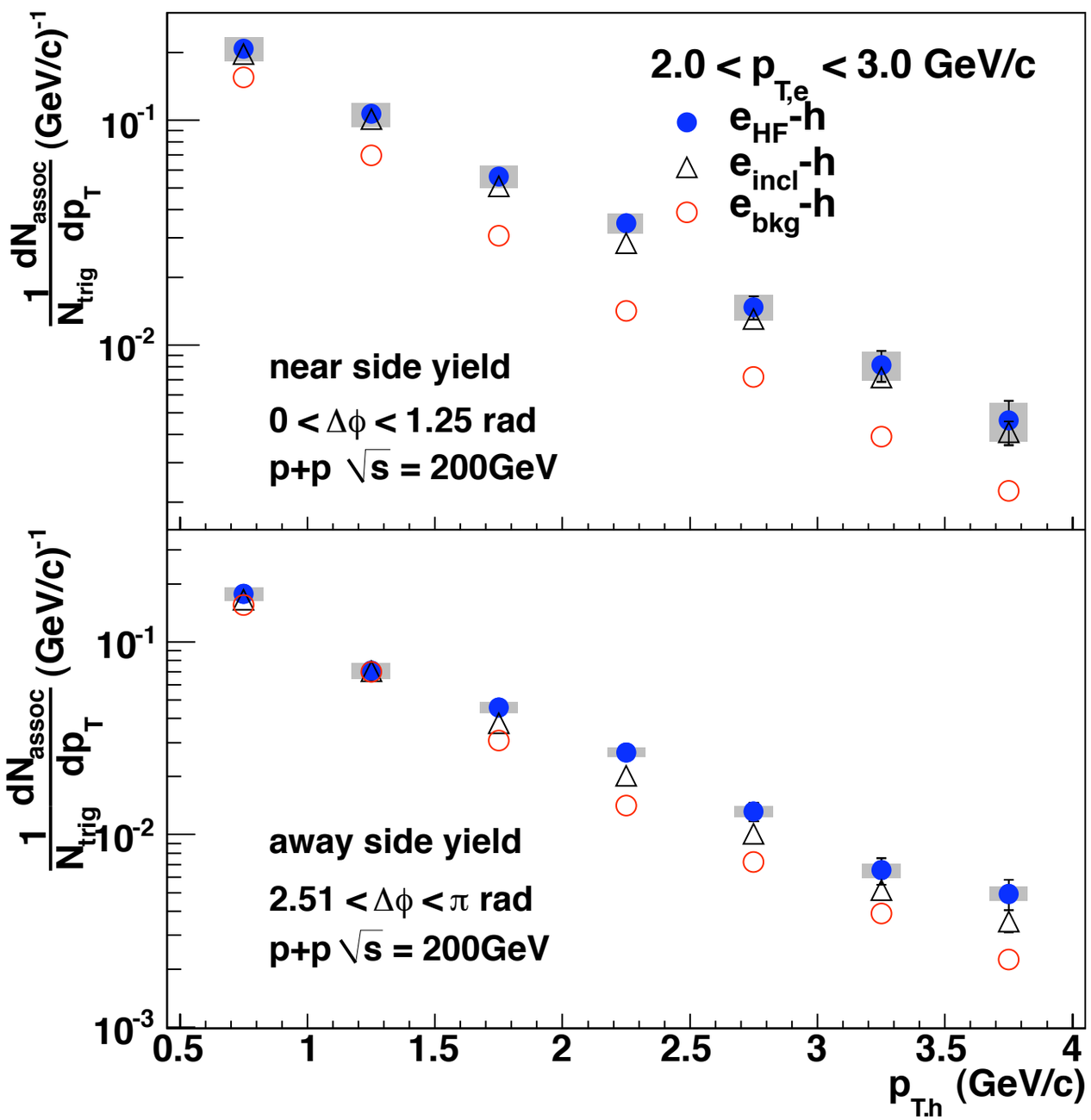


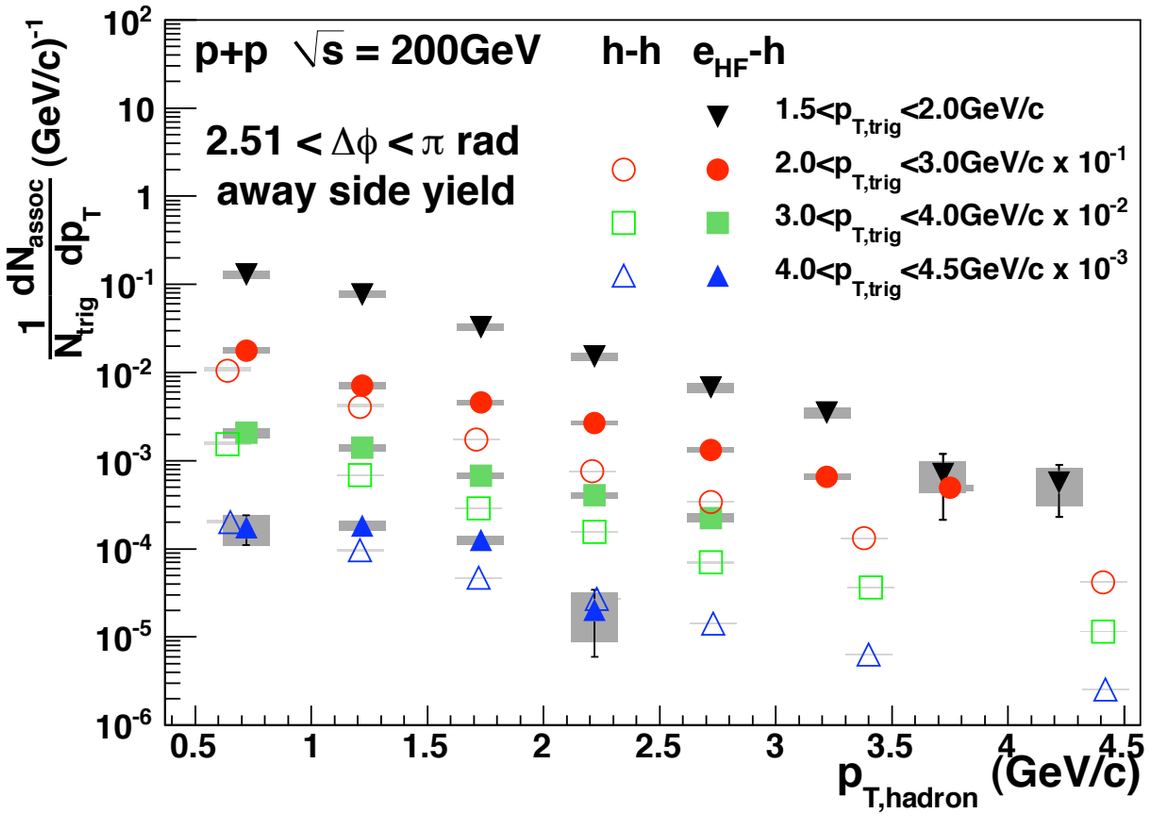
arXiv:1011.1477

jet-like correlations



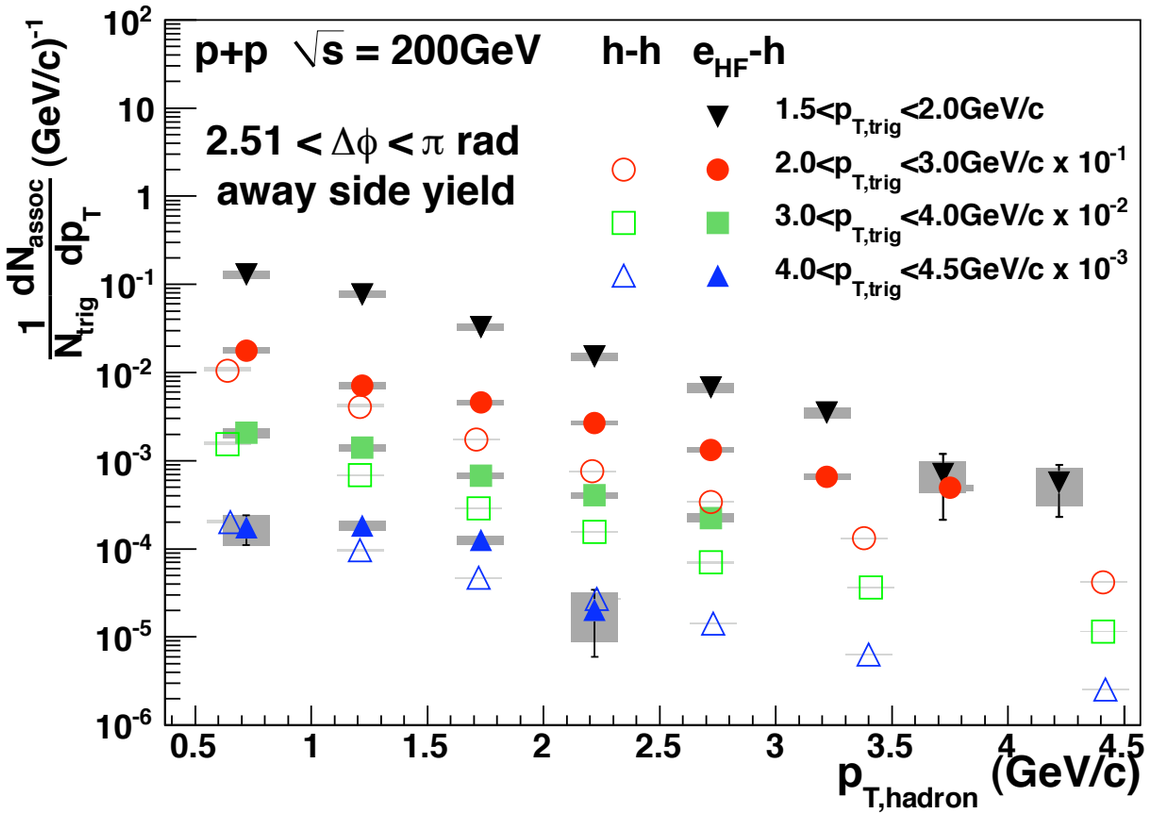
PHENIX: 1011.1477

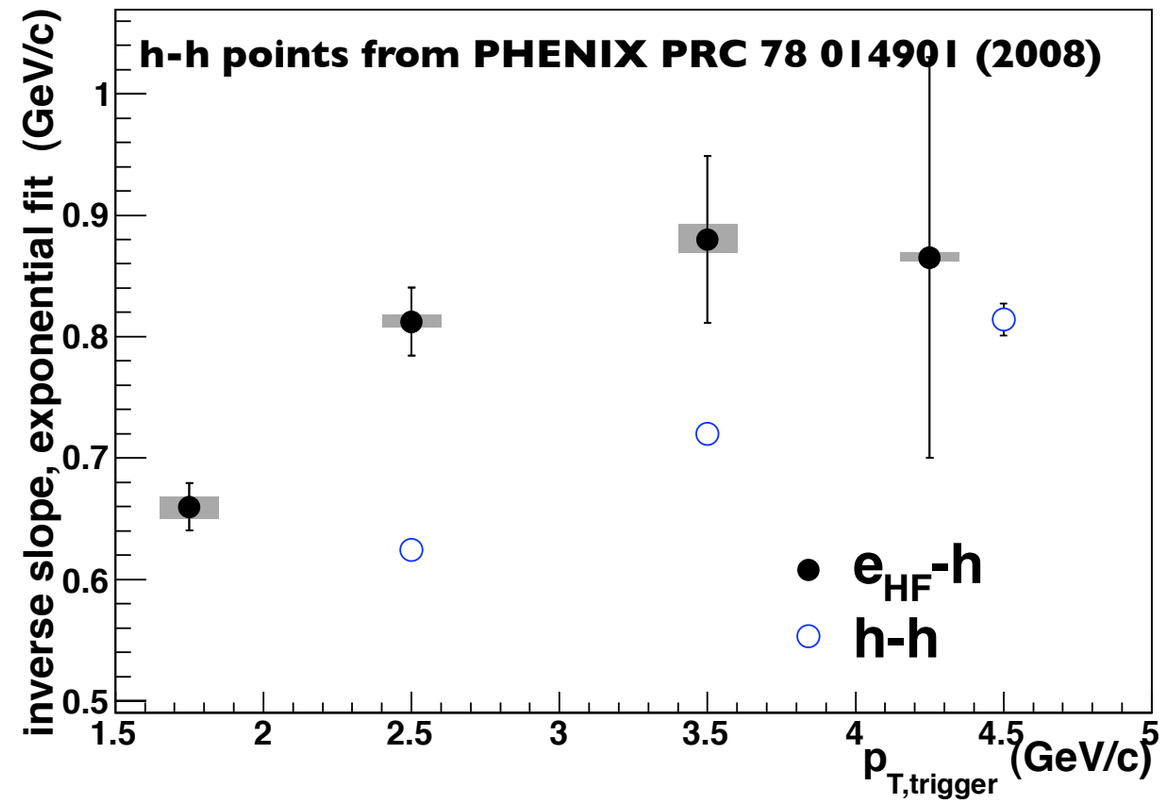
p+p alone...



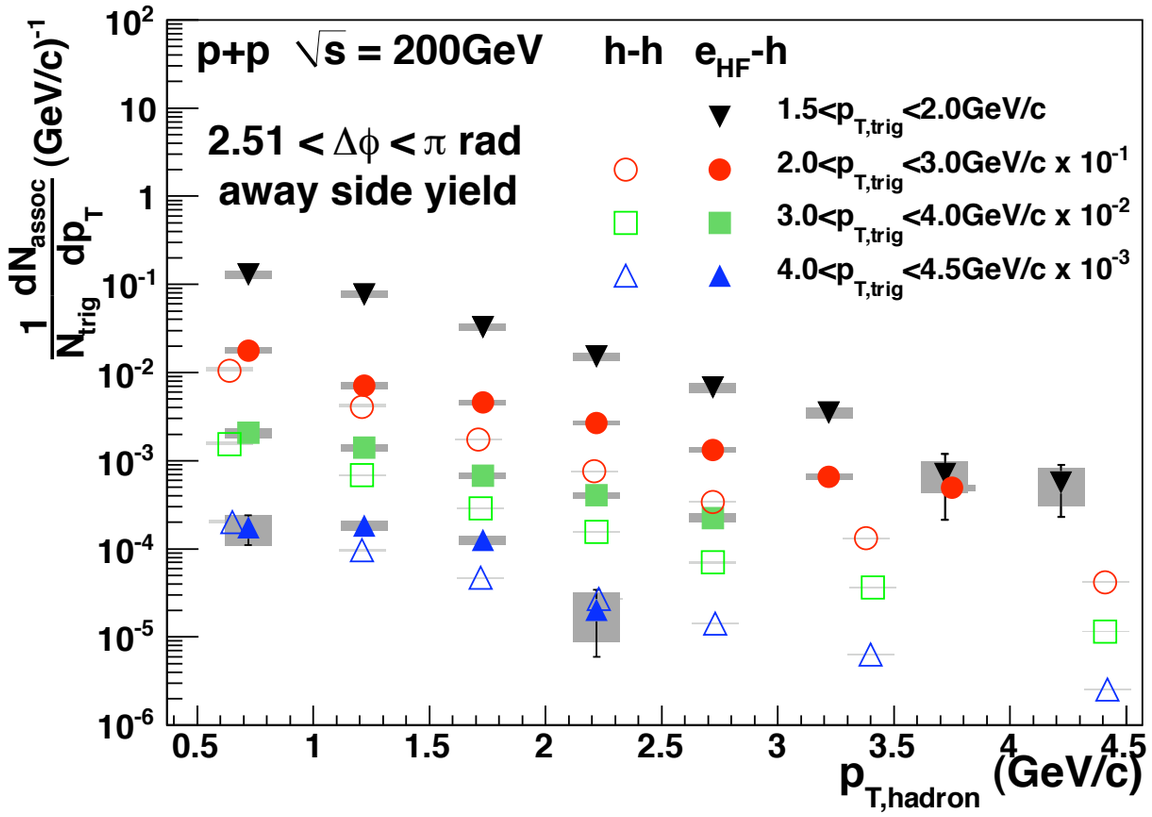
h-h points from PHENIX PRC 78 014901 (2008)

p+p alone...


p+p √s = 200GeV
h-h e_HF-h
2.51 < Δφ < π rad
away side yield
1.5<p_T,trig<2.0GeV/c
2.0<p_T,trig<3.0GeV/c x 10^-1
3.0<p_T,trig<4.0GeV/c x 10^-2
4.0<p_T,trig<4.5GeV/c x 10^-3
1/N_trig dN_assoc/dp_T (GeV/c)^-1
p_T,hadron (GeV/c)


h-h points from PHENIX PRC 78 014901 (2008)
e_HF-h
h-h
inverse slope, exponential fit (GeV/c)
p_T,trigger (GeV/c)

p+p alone...



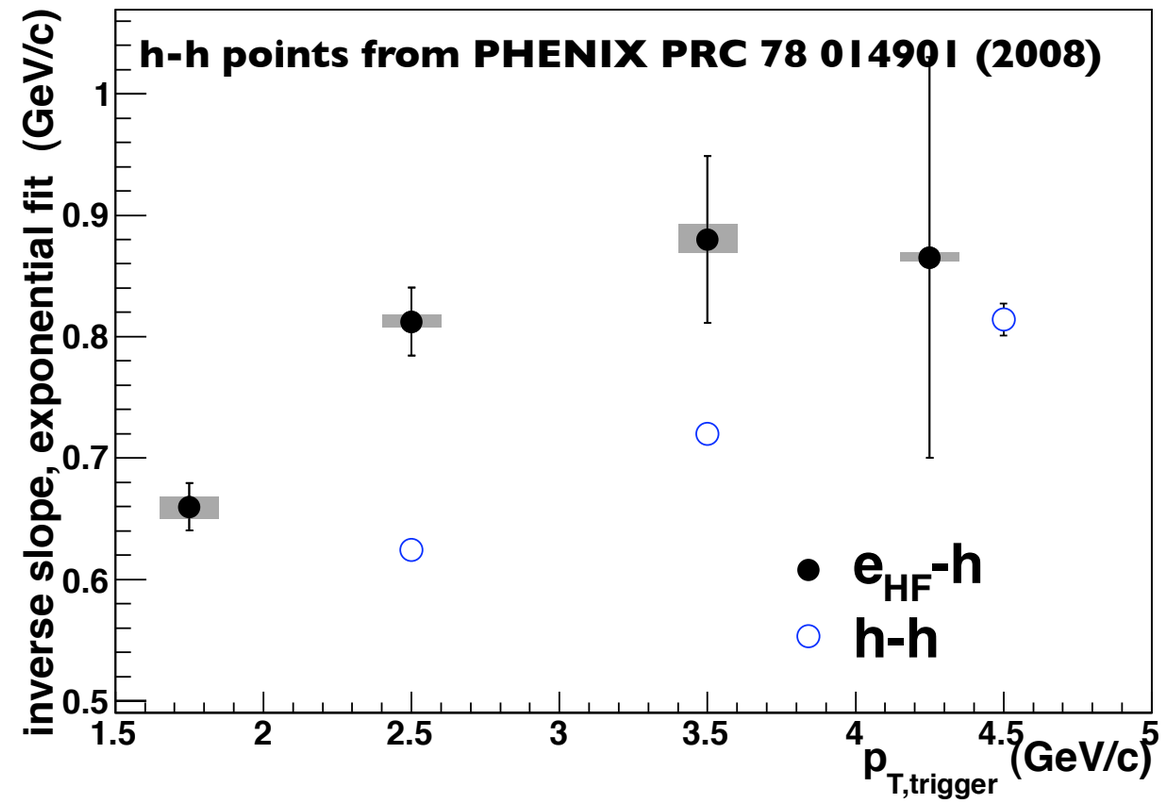
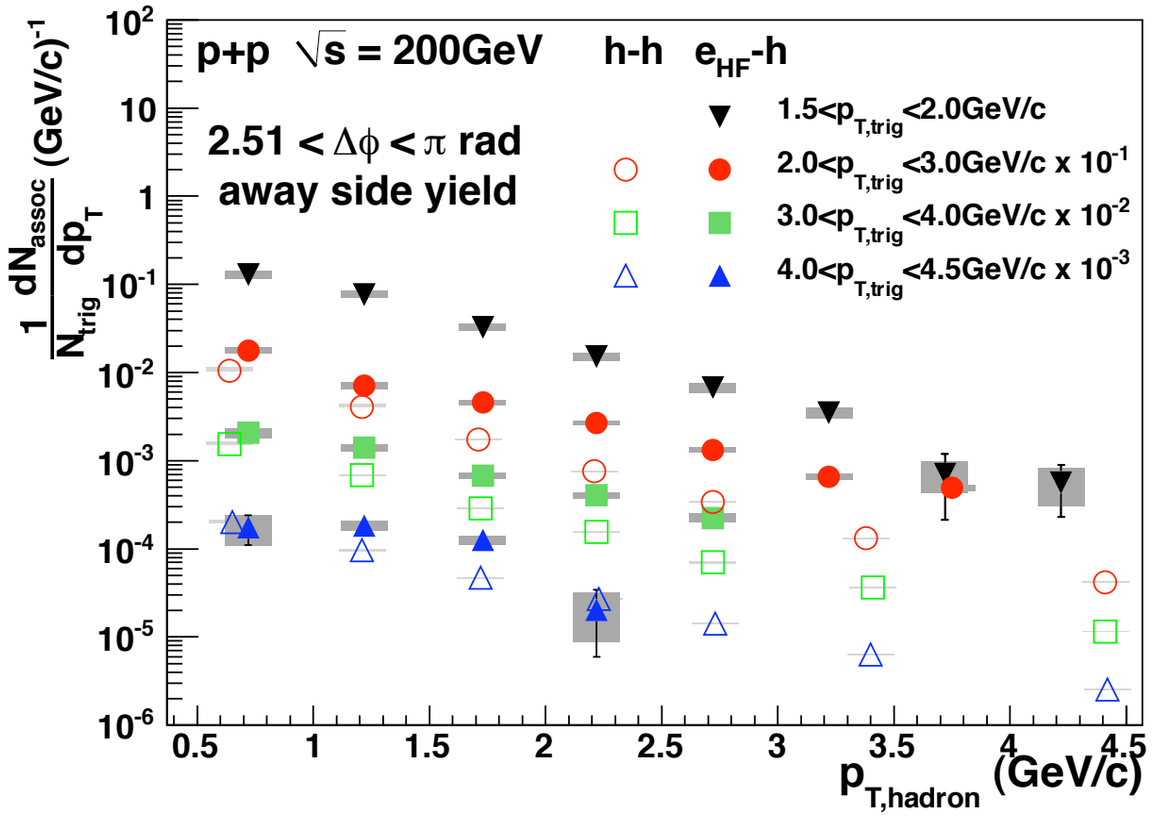
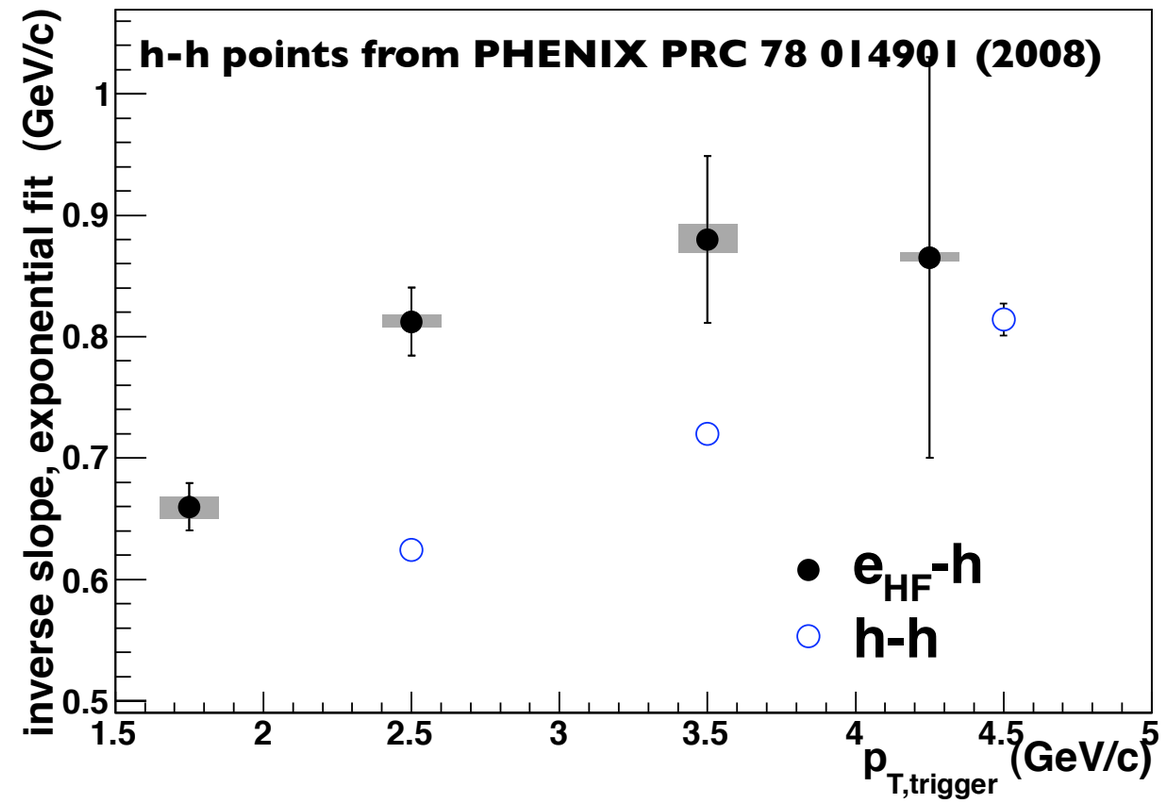


TABLE III: Mean transverse momentum of the parent D and B mesons contributing to the heavy-flavor electron p_T bins used here. They are combined according to the fraction of heavy-flavor electrons from b quarks, $\frac{b\to e}{(c\to e+b\to e)}$ according to the FONLL calculations [31] (as shown in Ref. [29]) to determine the mean heavy meson transverse momentum.

$p_{T,e}$ (GeV/c)	$\langle p_T\rangle_D$ (GeV/c)	$\langle p_T\rangle_B$ (GeV/c)	$\frac{b\to e}{(c\to e+b\to e)}$	$\langle p_T\rangle_{meson}$ (GeV/c)
1.5-2.0	3.4	4.4	0.15	3.6
2.0-3.0	4.1	4.7	0.26	4.3
3.0-4.0	5.6	5.6	0.42	5.6

p+p alone...





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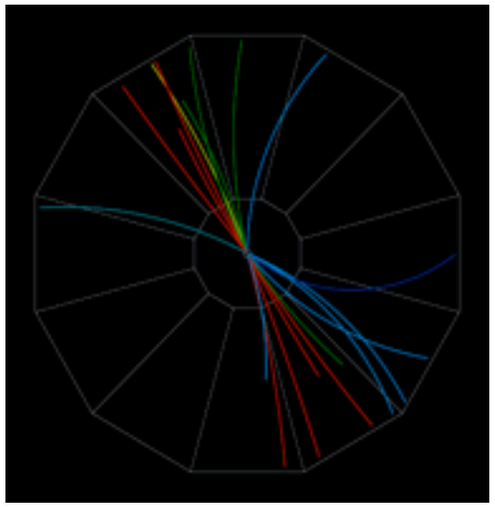
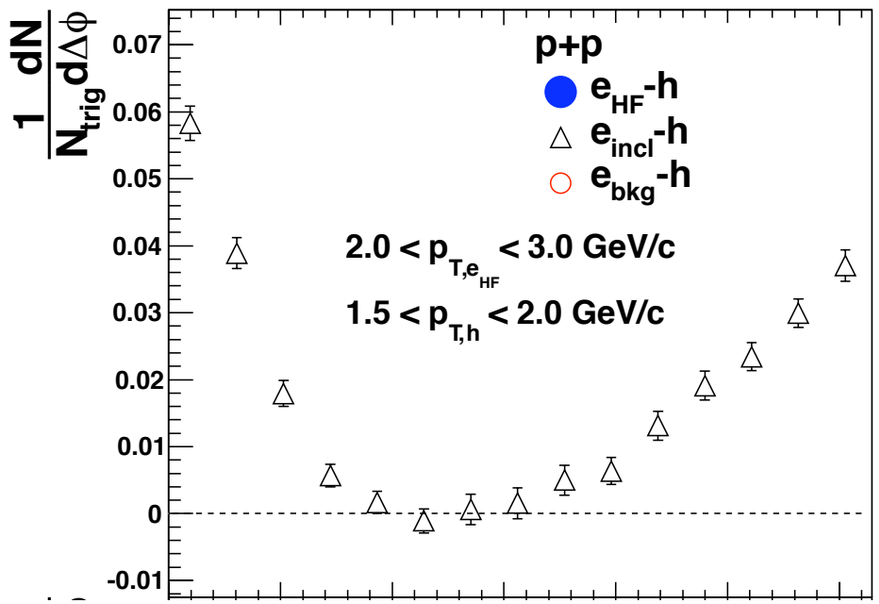
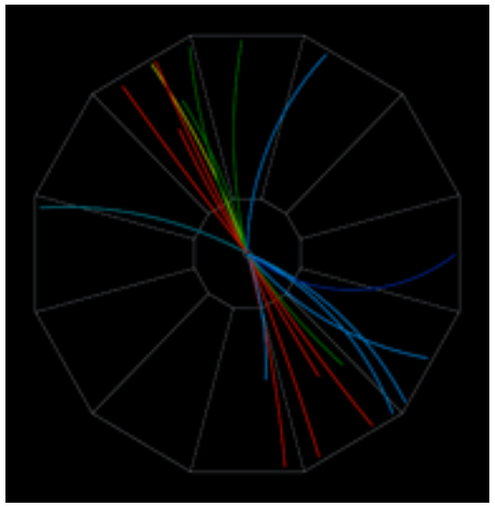
combinatoric background

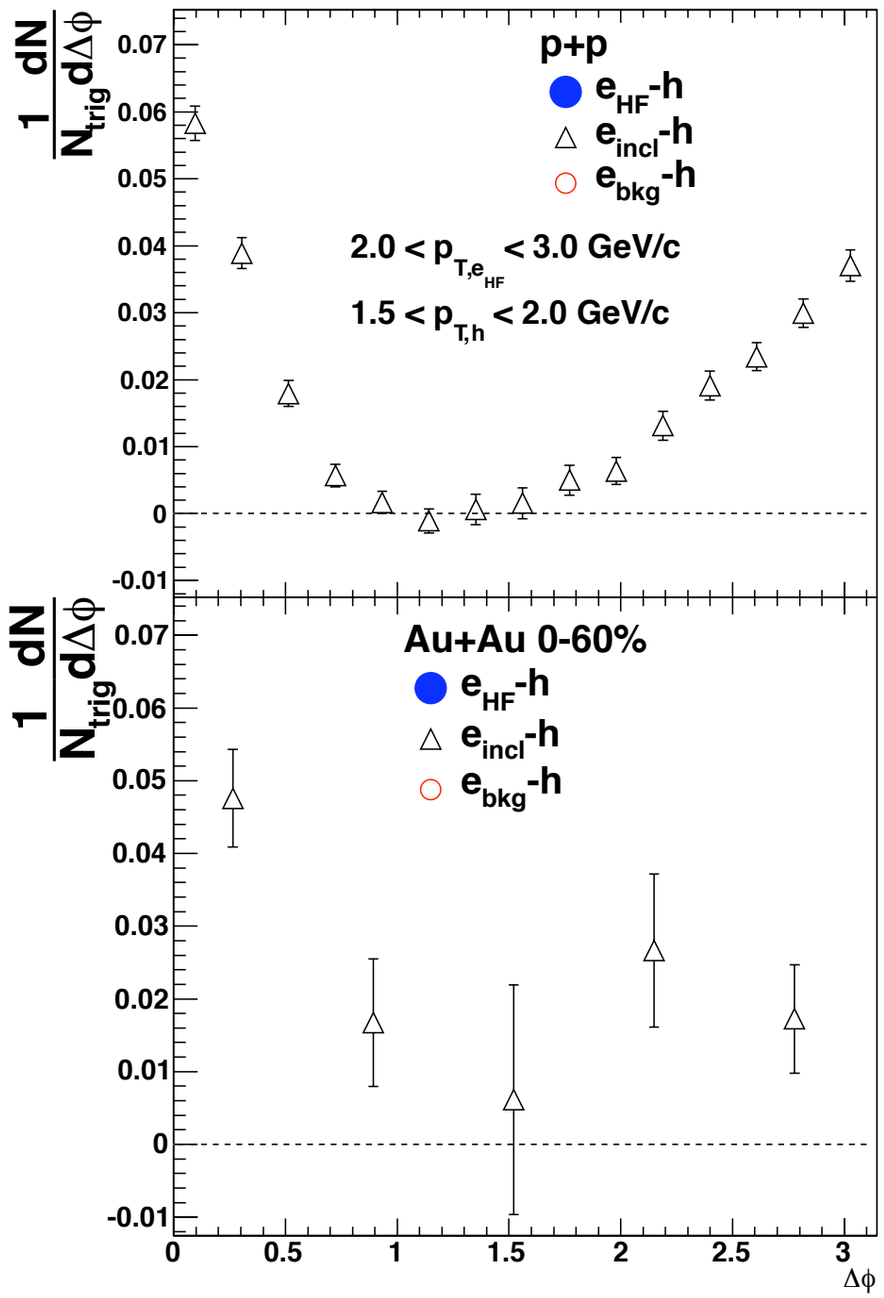


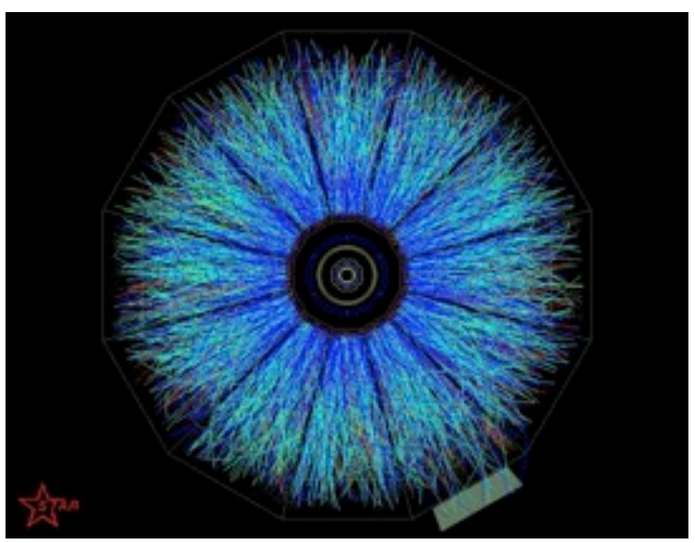


jet S/B > 1

combinatoric background







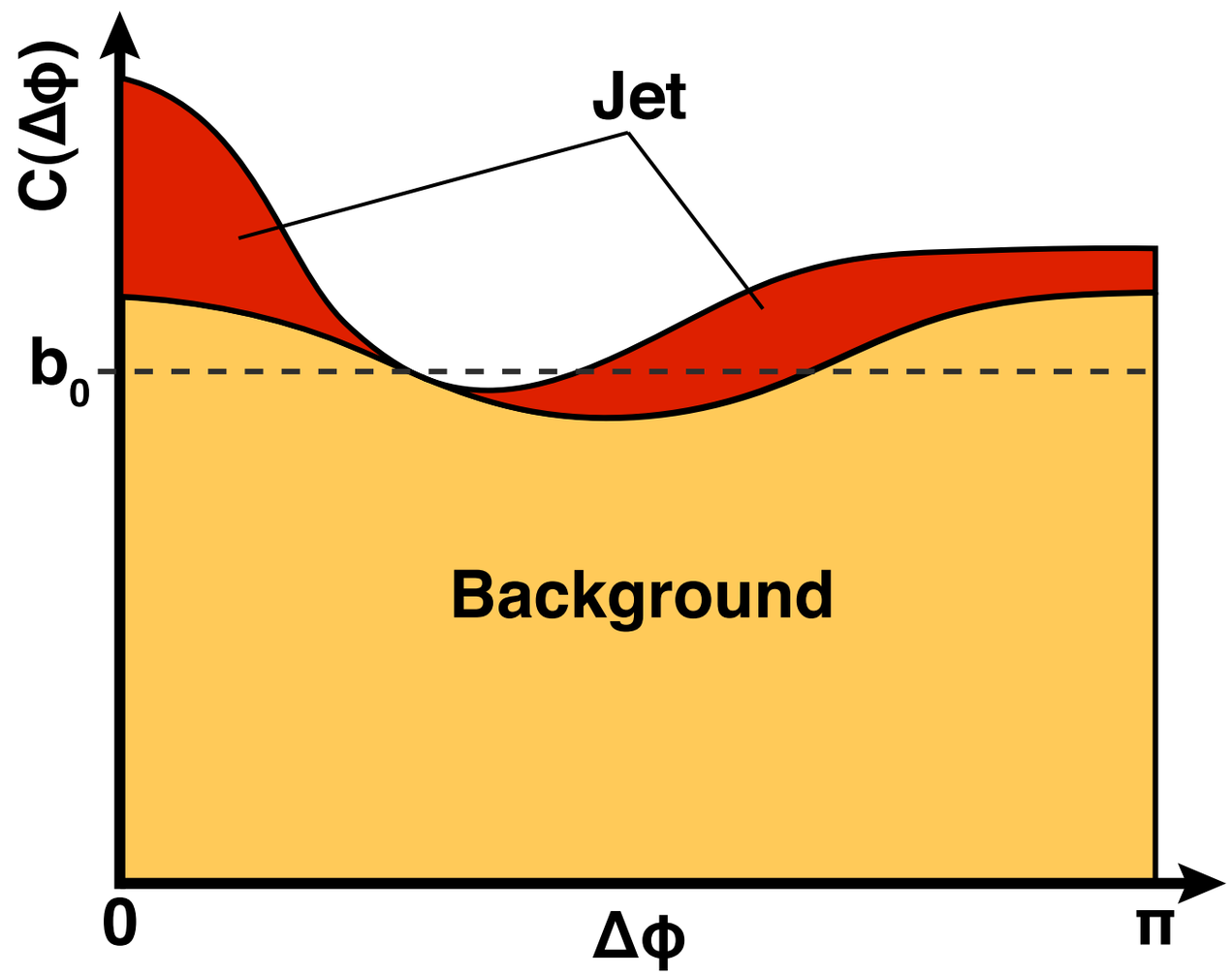
jet S/B > 1

jet S/B ~ 1%

absolute background subtraction

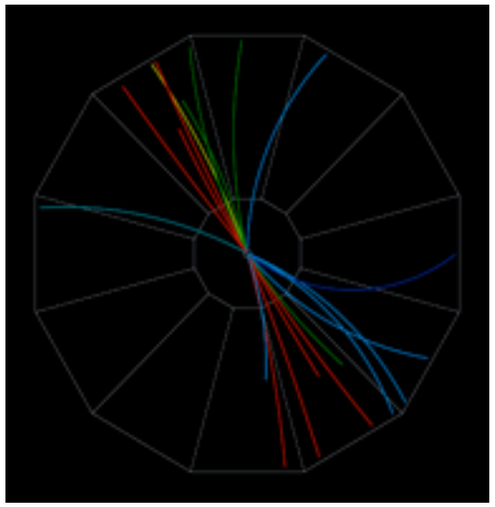
combinatoric background = $b_0(1+2v_{2A}v_{2B}\cos(2\Delta\phi))$

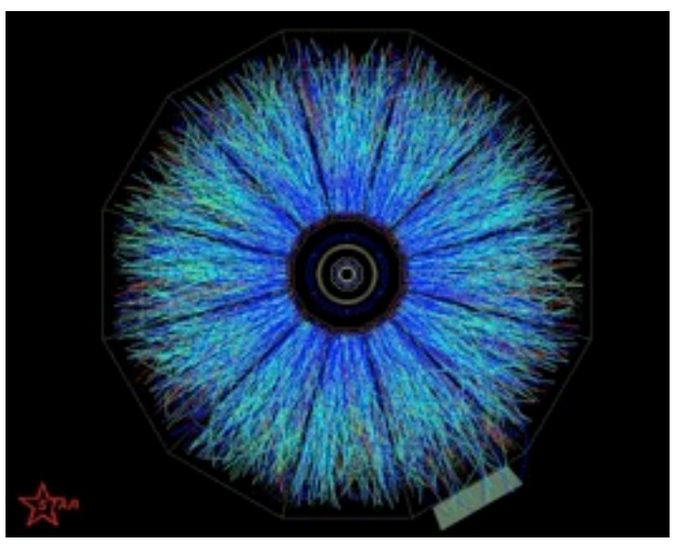
- b_0 can be calculated in HI collisions (no fudge factors) w/ negligible statistical errors
  - depends on the centrality fluctuations
- generally very close to ZYAM, however some significant advantages
  - wide jets
  - poor statistics

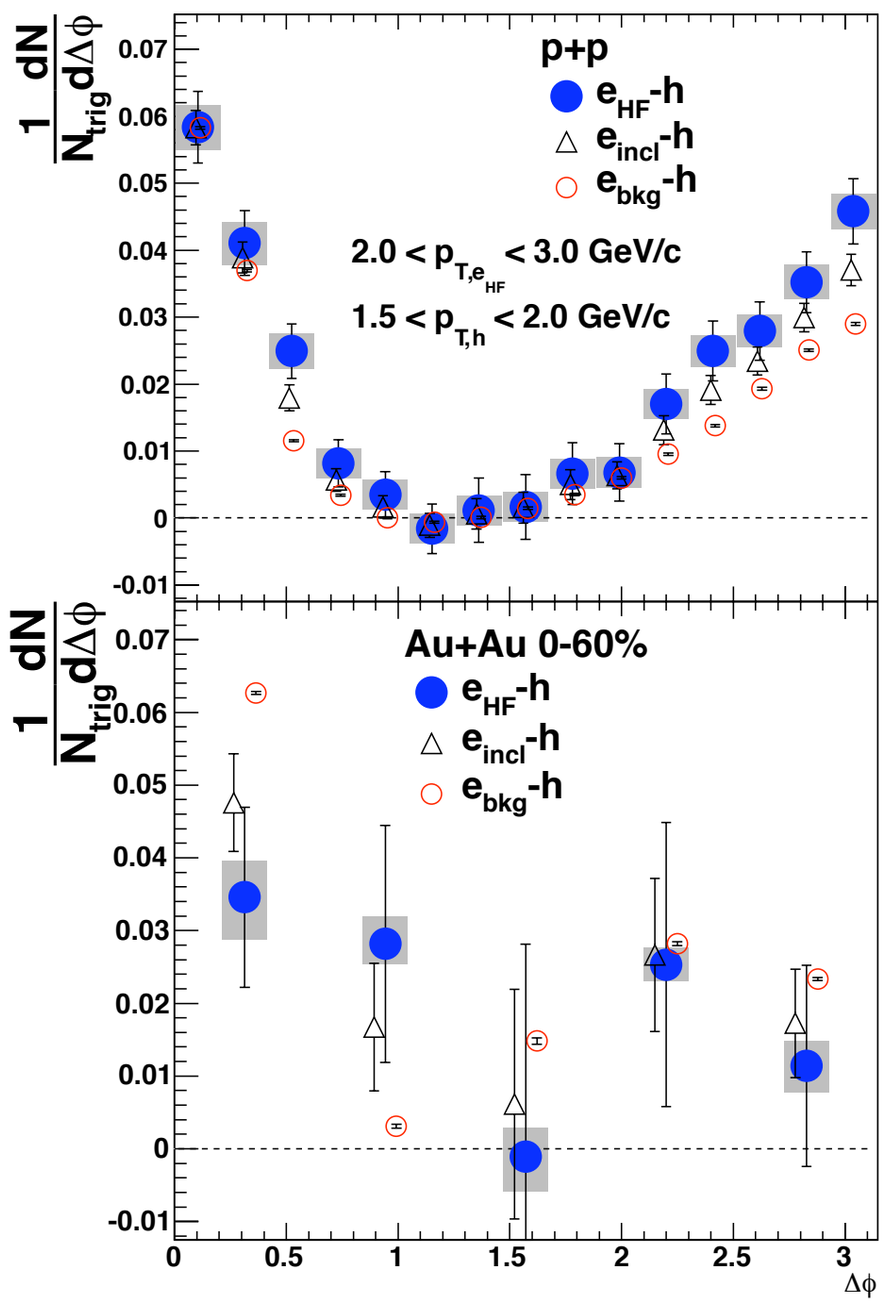


AMS, McCumber, Adare PRC 81 014908 (2010)

combinatoric background



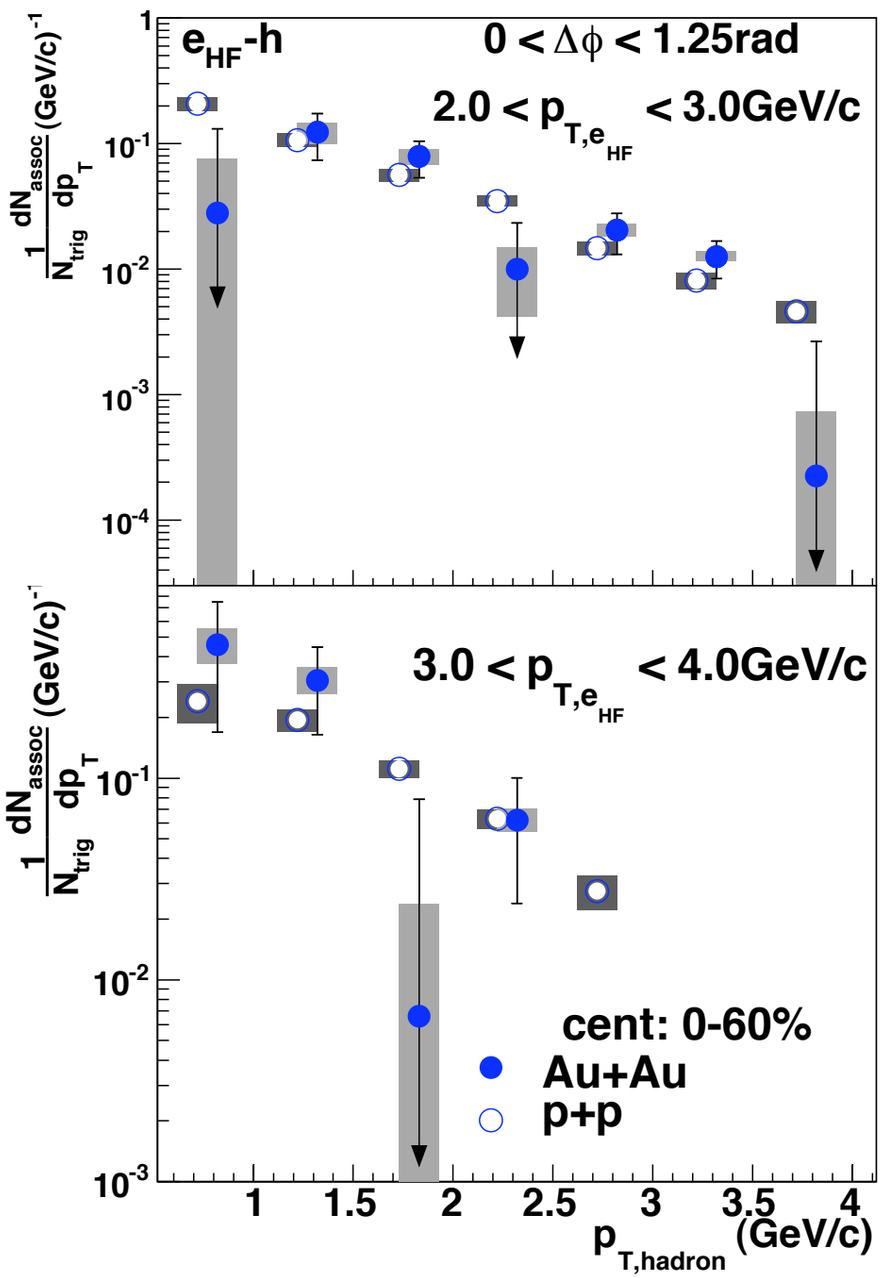




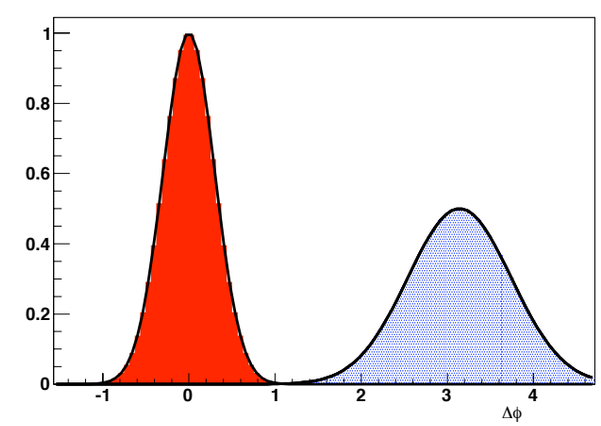
jet S/B > 1

jet S/B ~ 1%

e-h: same side correlations

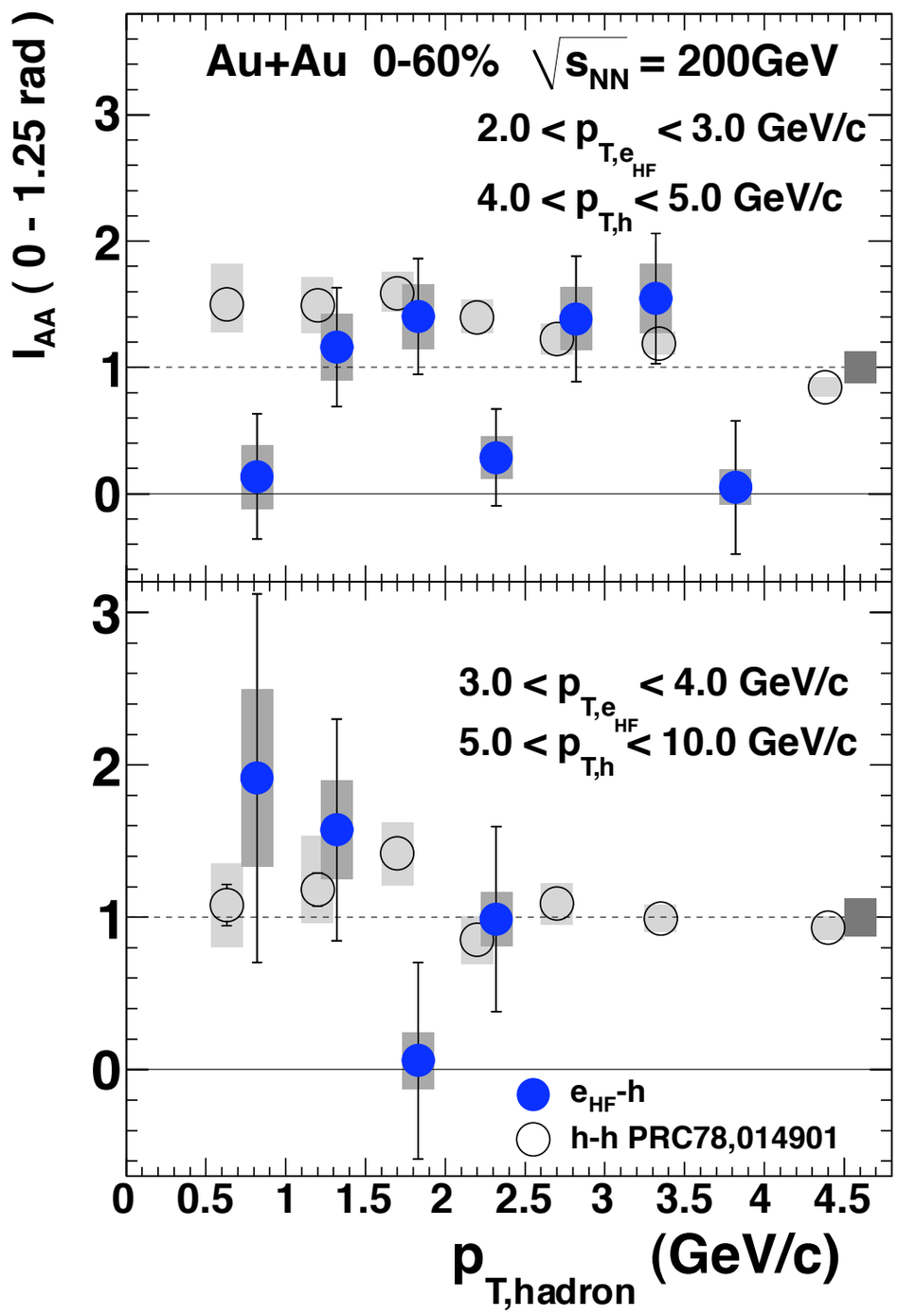


- no evidence for any modification
- consistent with hadron triggered



PHENIX: 1011.1477

e-h: same side correlations



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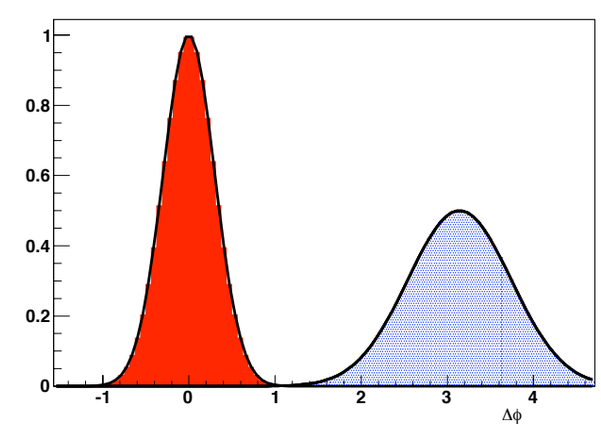
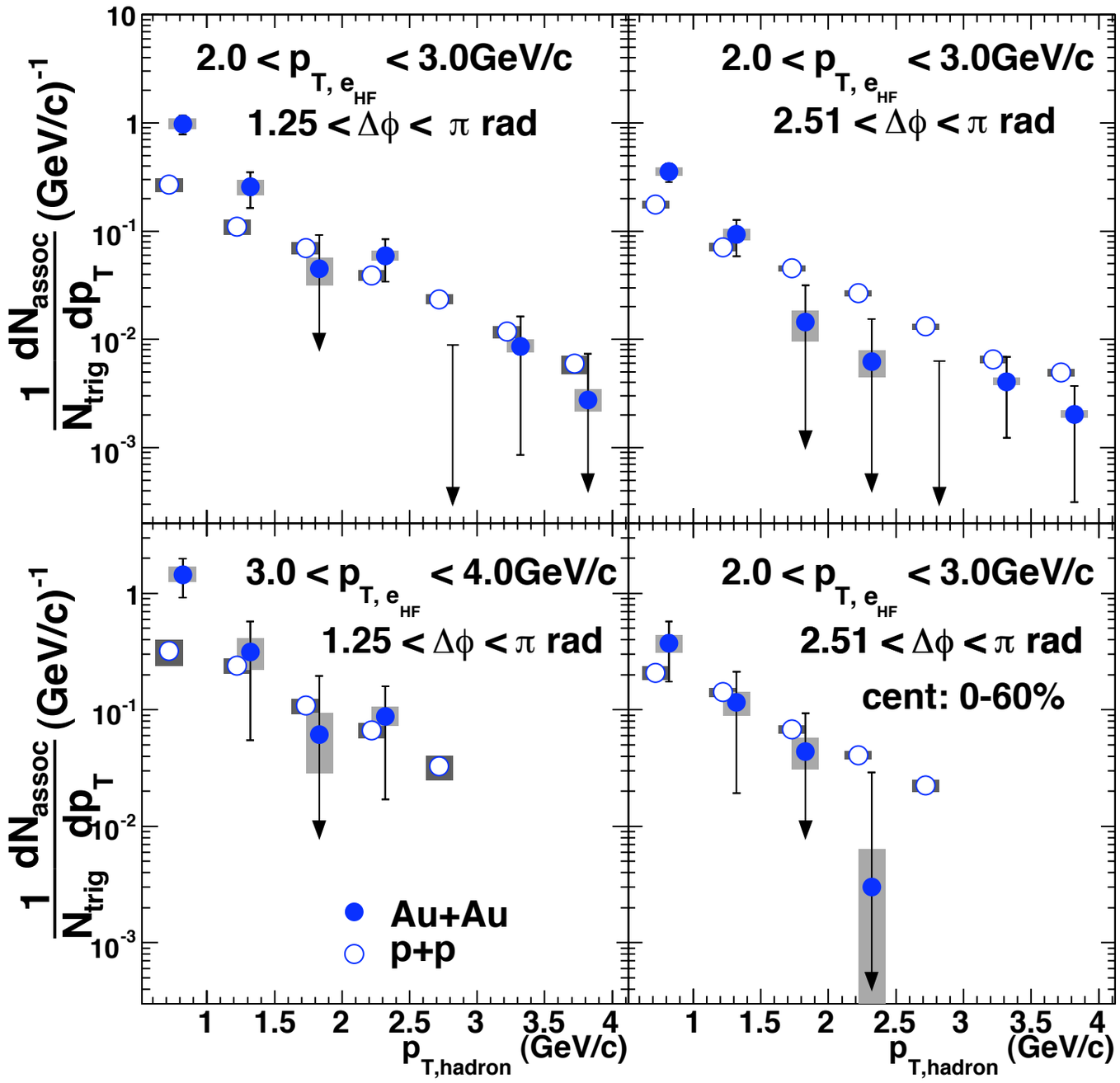


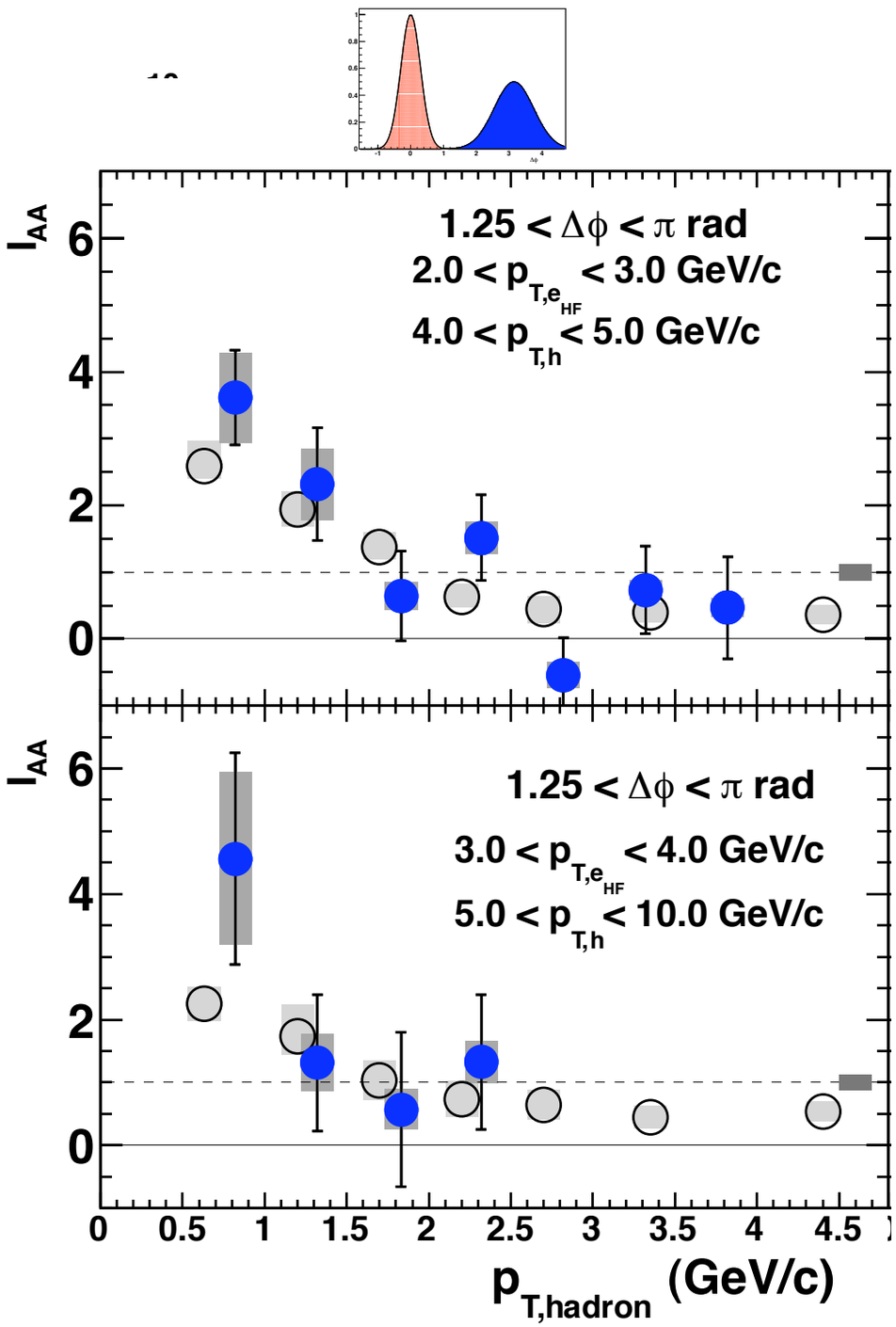
PHENIX: 1011.1477

e-h: opposite side correlations



PHENIX: 1011.1477

e-h: opposite side correlations



PHENIX: 1011.1477

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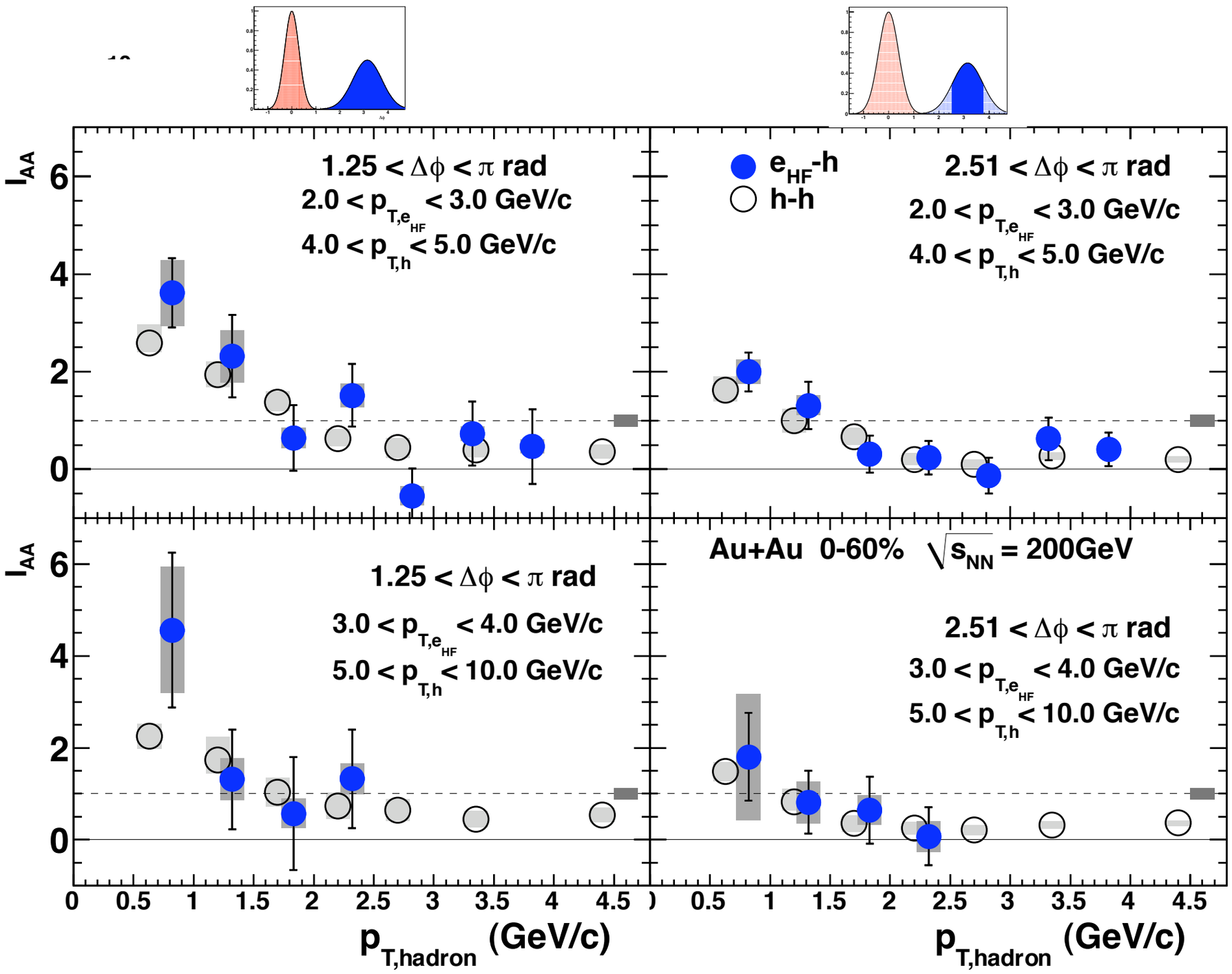
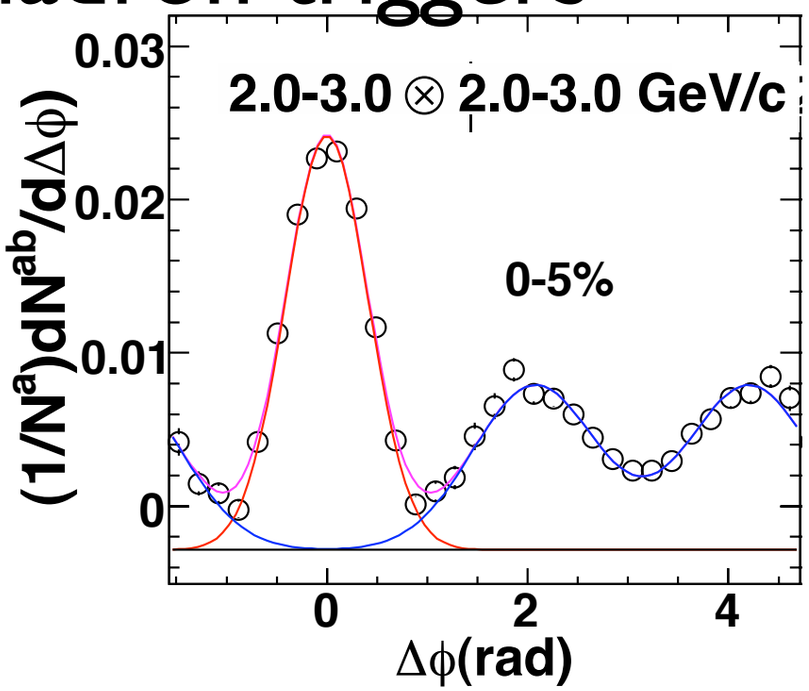


PHENIX: 1011.1477

shape modifications

hadron triggers

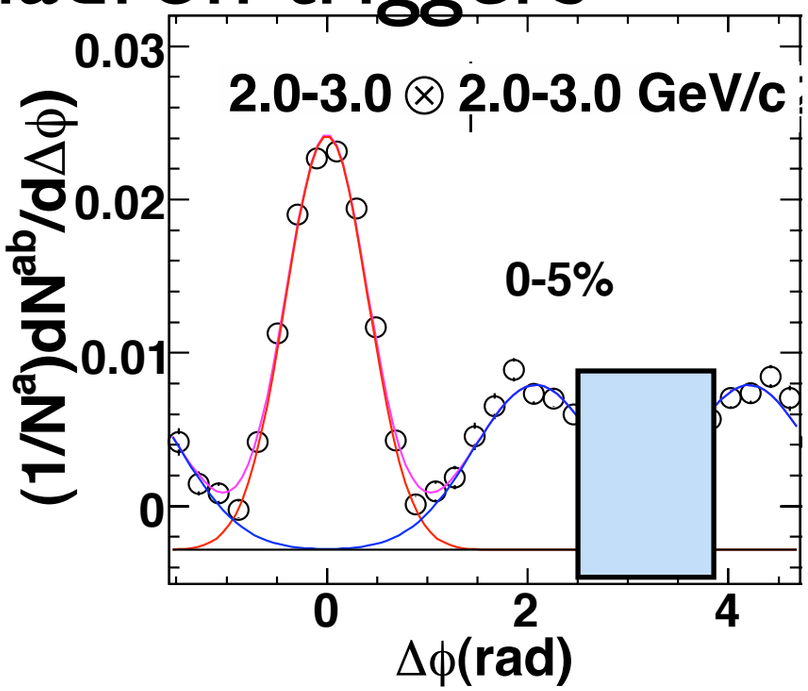


n.b. not exactly comparable
(head, shoulder definitions
slightly different)

PRC 78 014901
1011.1477[nucl-ex]

shape modifications

hadron triggers



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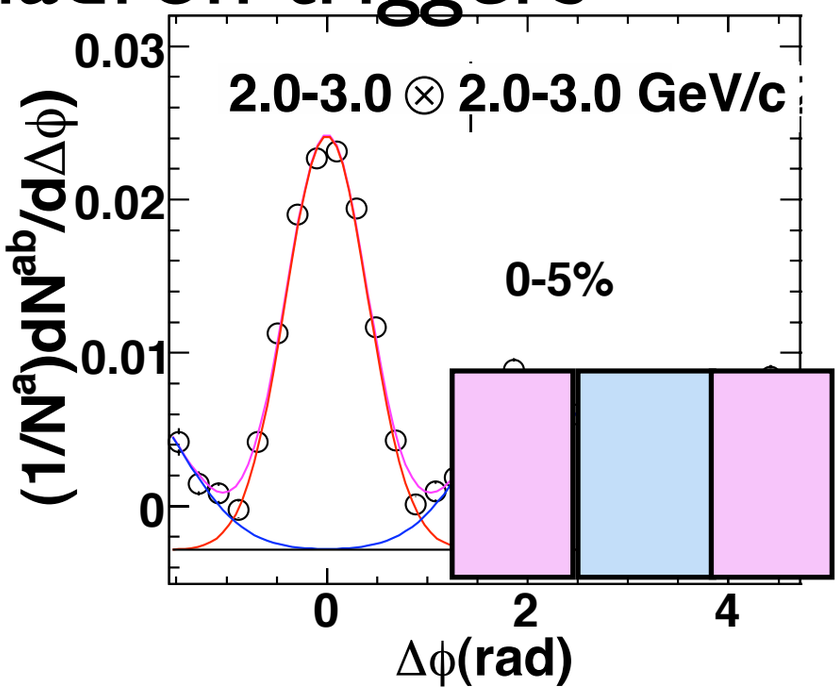

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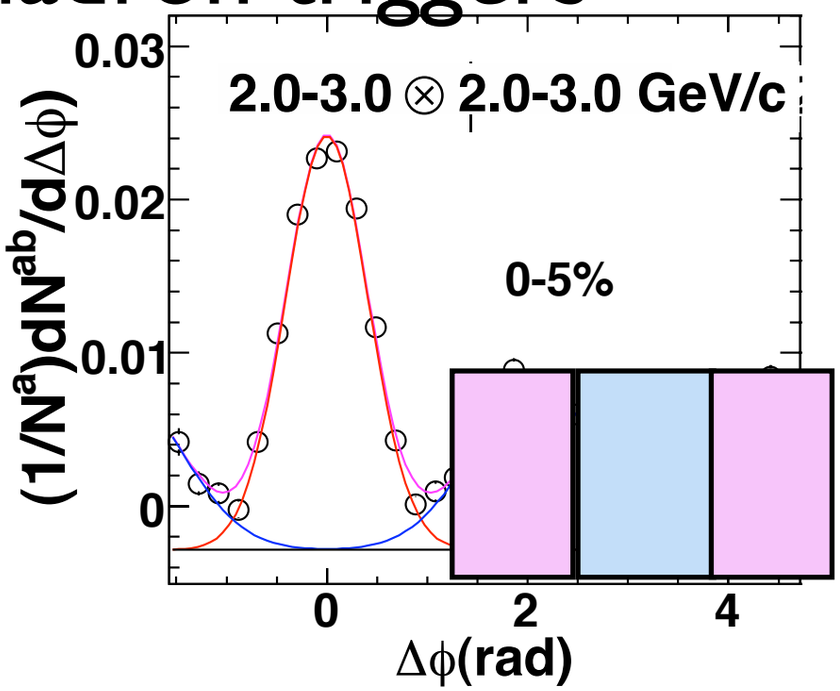

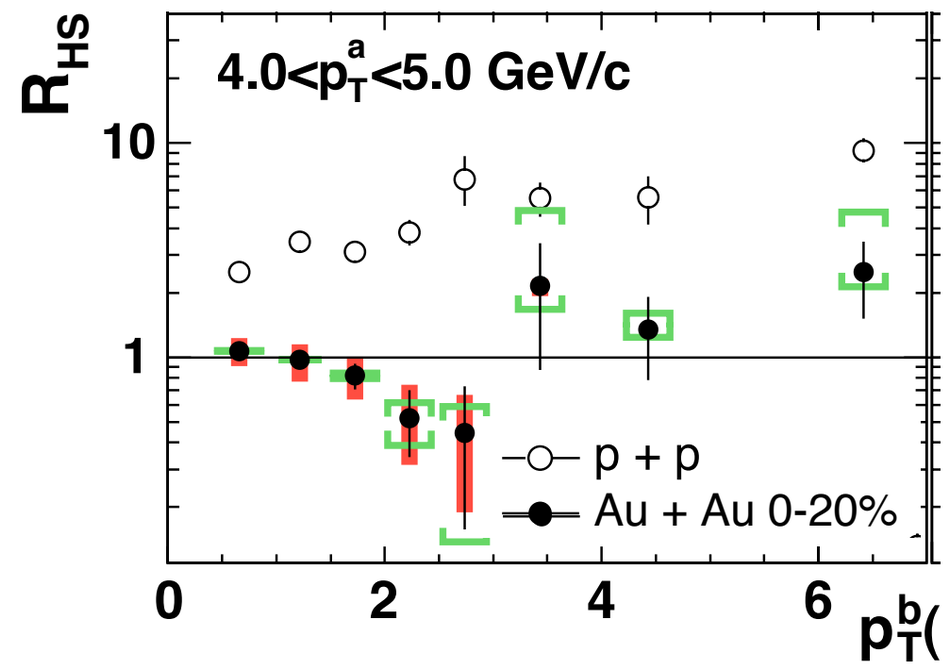

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PRC 78 014901
1011.1477[nucl-ex]

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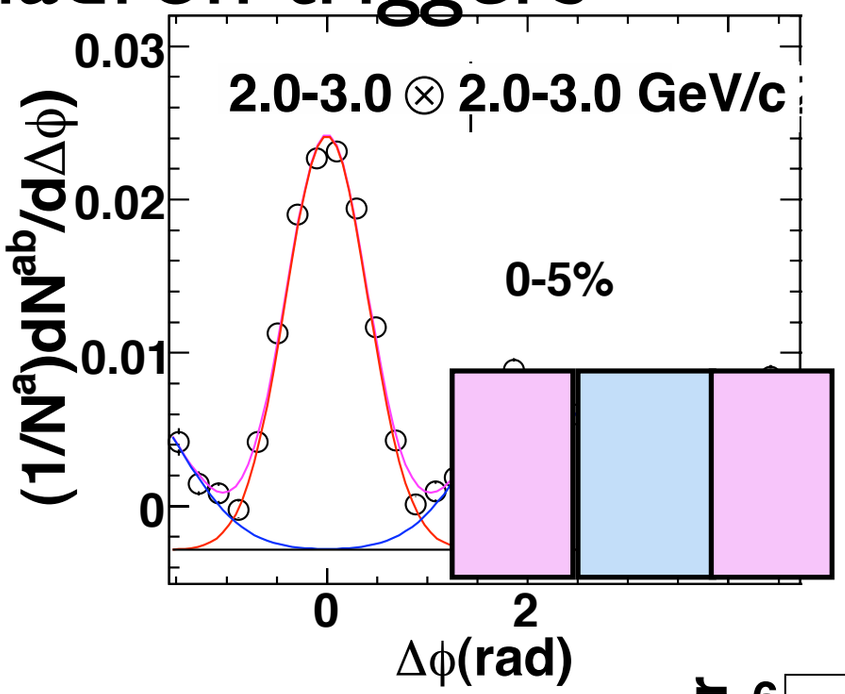
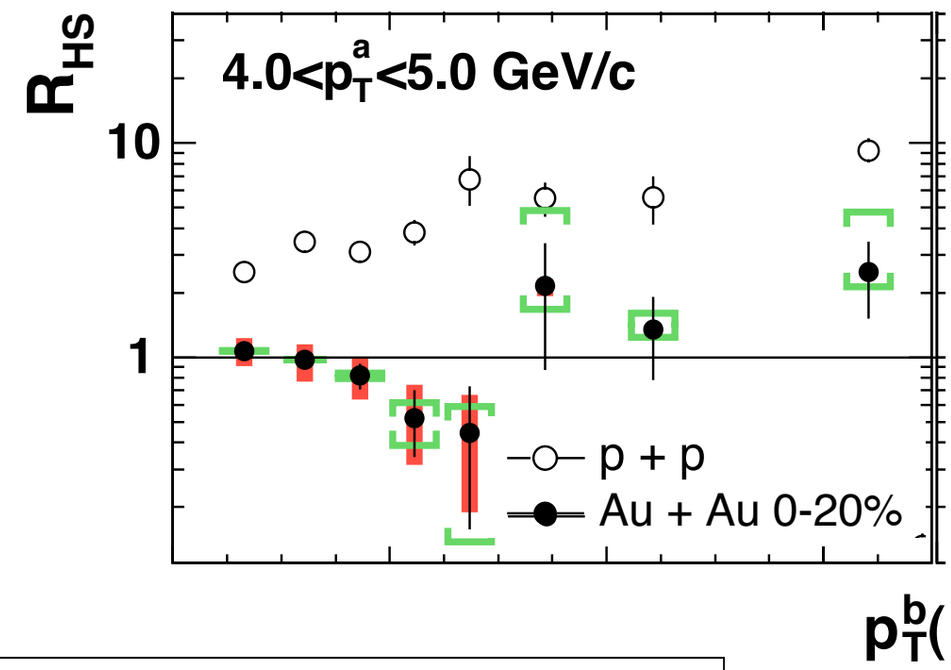
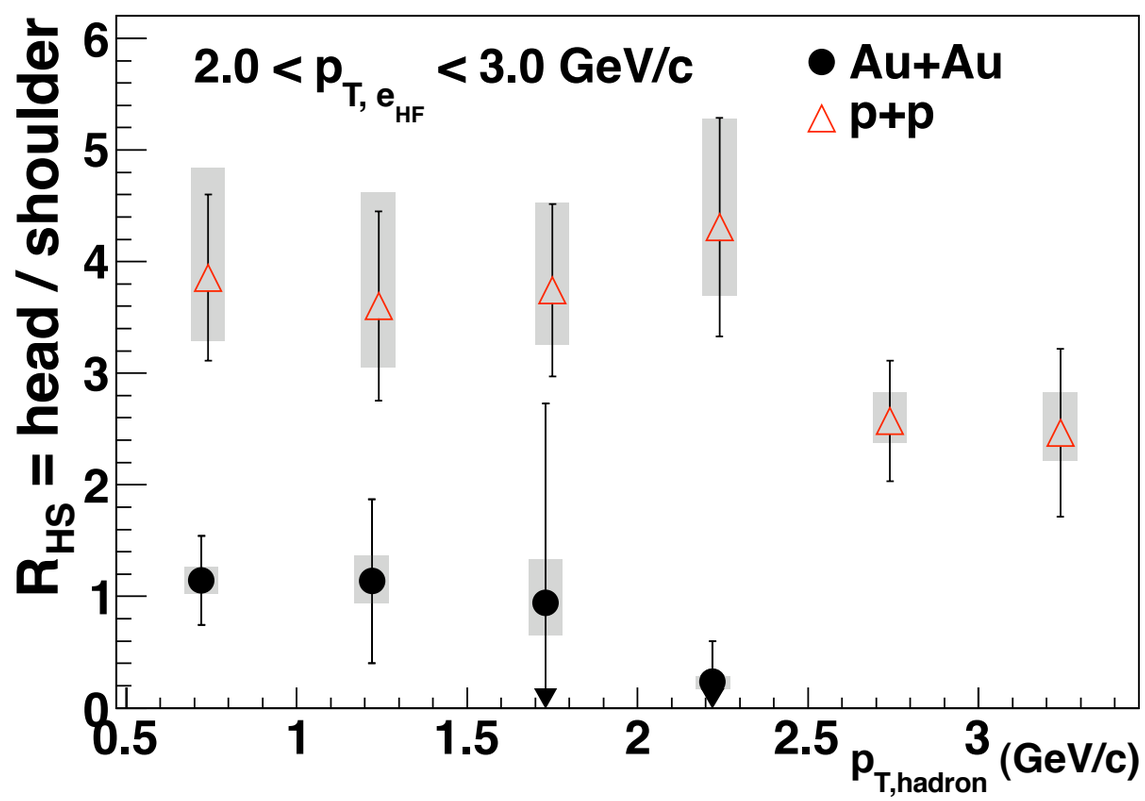




electron triggers



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PRC 78 014901
1011.1477[nucl-ex]

not unexpected

heavy quark production diagrams

not unexpected

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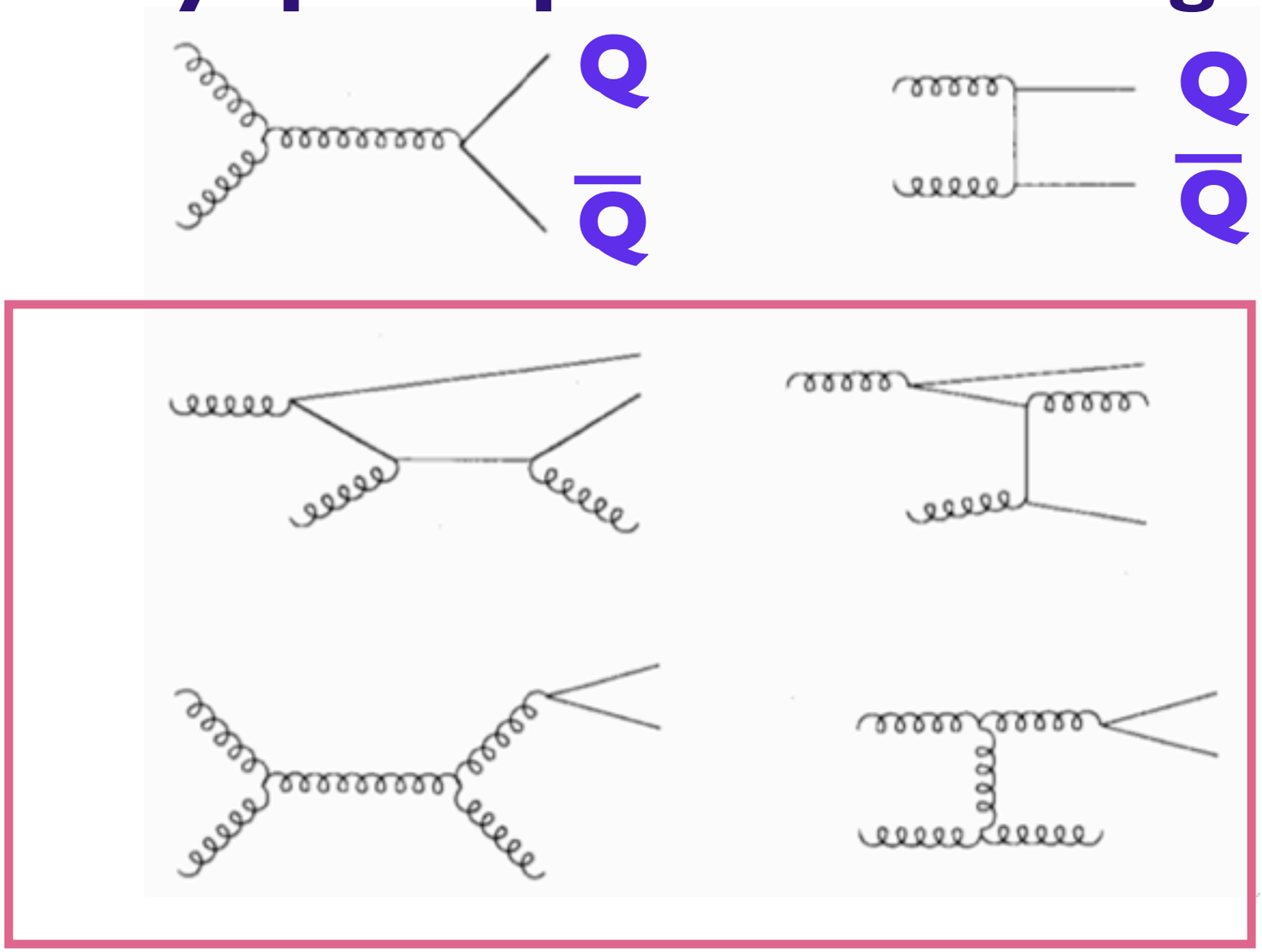
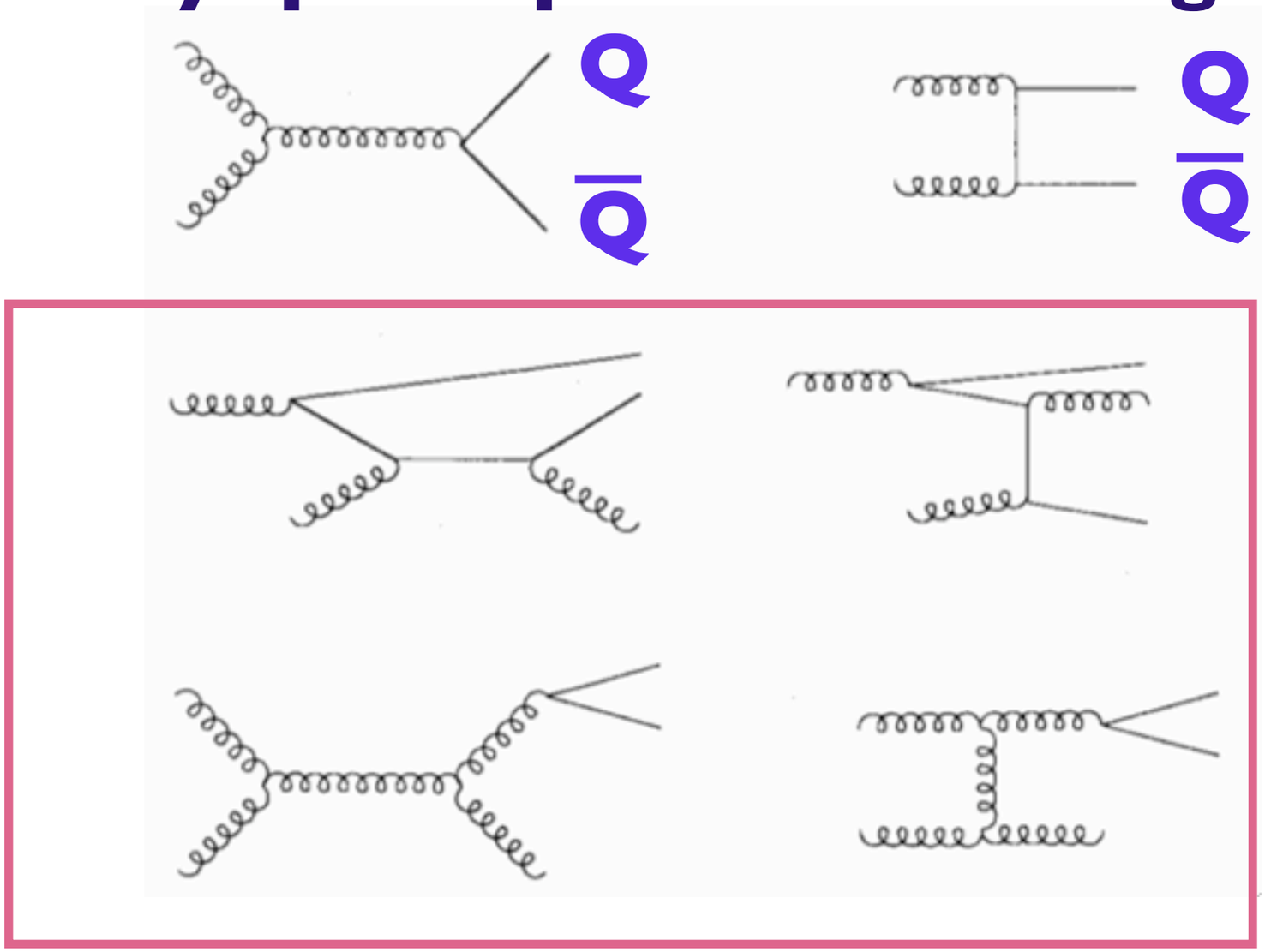


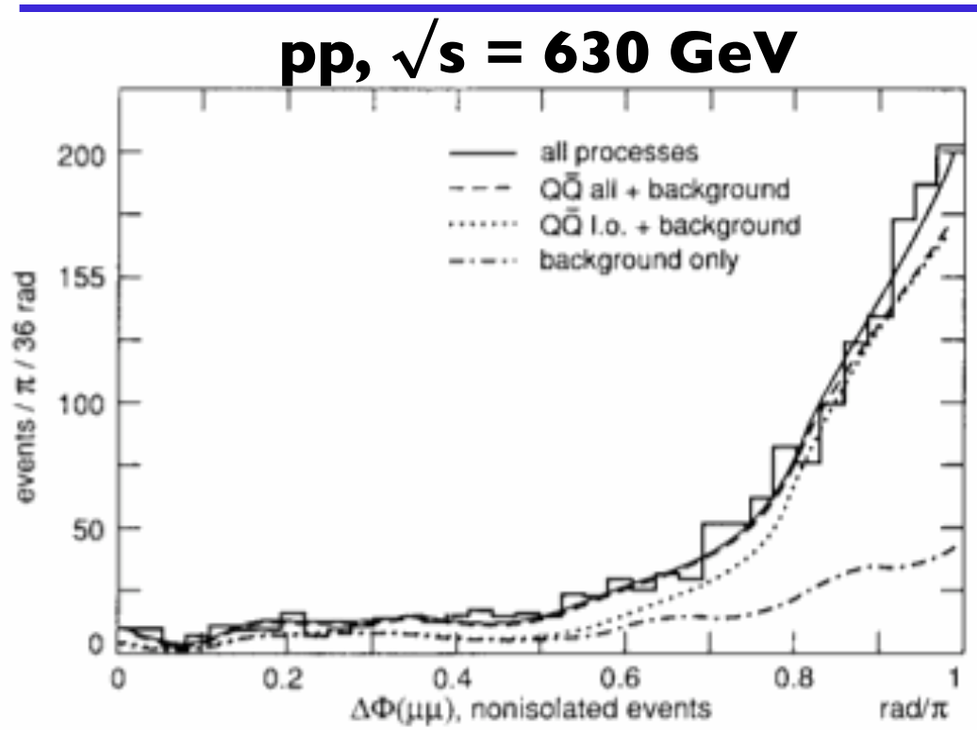
not unexpected

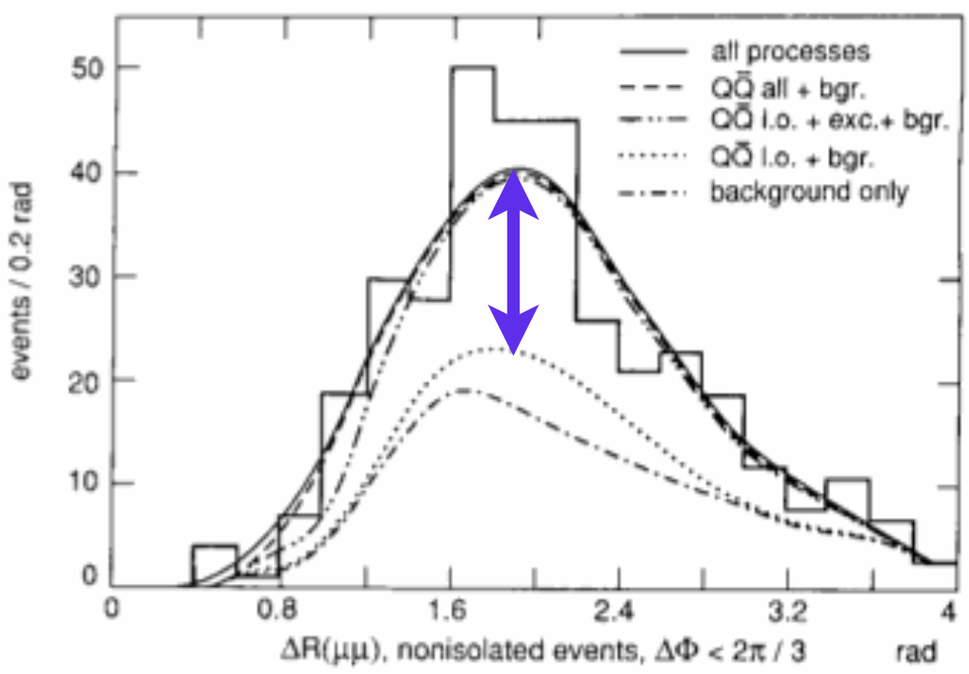
heavy quark production diagrams



sizable contributions from NLO effects

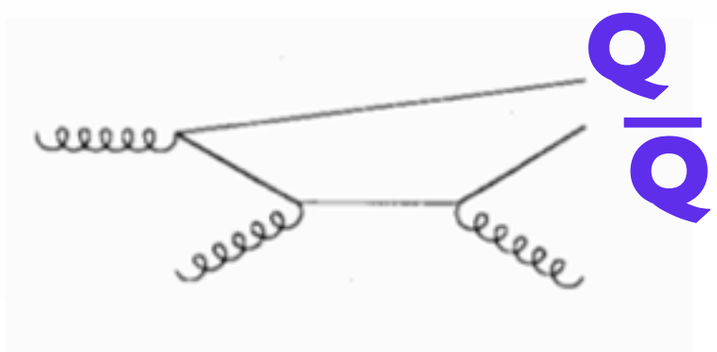
μμ Correlations @ UA1





- fit with ISAJET
- 20-35% "higher order"
- similar sorts of measurements @ Tevatron

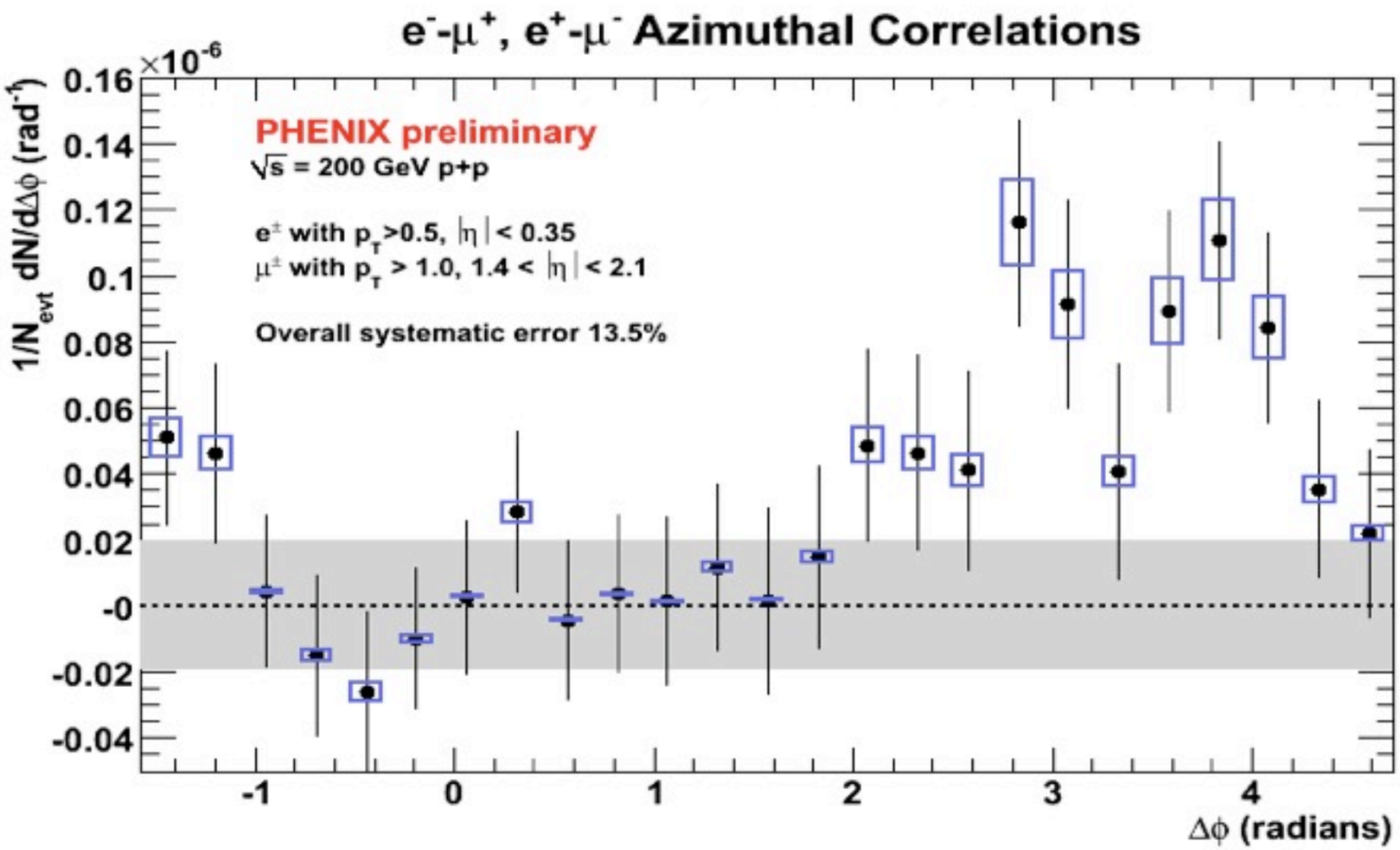
$p_{T\mu}^{high}$ range [GeV/c]	p_{Tb} range [GeV/c]	$b\bar{b}$ nonisol. $m_{\mu\mu} > 4$ GeV/c^2 [events]	'high.ord.' fraction [%]
All	$\gtrsim 6$	829 ± 58	26.2 ± 4.0
3–5	$\gtrsim 6$	402 ± 37	24.6 ± 8.5
5–7	$\gtrsim 8$	286 ± 23	31.2 ± 5.4
7–10	$\gtrsim 11$	103 ± 12	35.2 ± 5.1
10–20	$\gtrsim 15$	32 ± 6	21.3 ± 12.4



UA1, Z Phys C 61 41 1994

e-μ correlations

- sensitive to correlated charm at forward/mid-rapidity



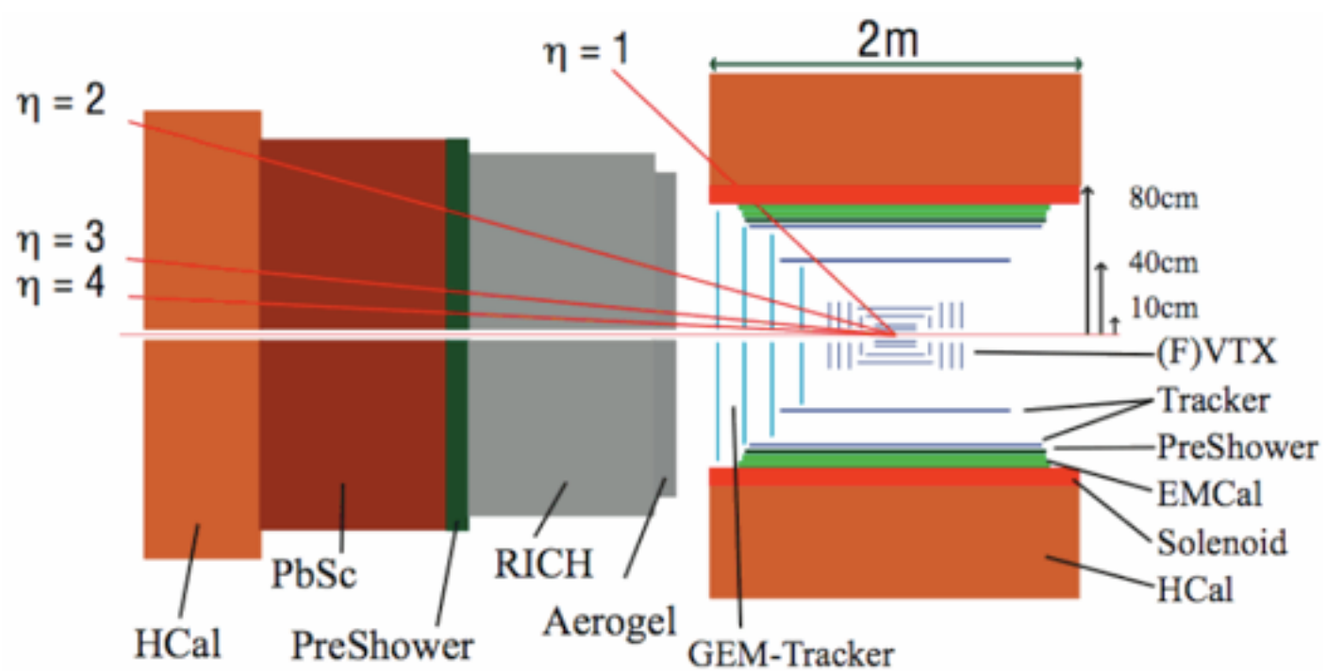
T. Engelmore, QM09

Near Term Future

- Silicon Vertex Detector
  - e-h and e-e correlations to understand HF production
    - here 500 GeV p+p data provides a good opportunity
      - increased HF cross sections and different collision energy → useful input for understanding HI data at 200 GeV

sPHENIX

- jets offer huge rate advantages and a reduction of biases from spectra & correlations
- however need a real jet detector for RHIC
  - high rate, hadronic calorimetry, heavy flavor tagging, large acceptance
  - suited to systematic studies (system size, energy, etc)



see C. Aidala, Tuesday

outlook

outlook

- heavy flavor is one of the best tools to understand how partons interact with the QGP

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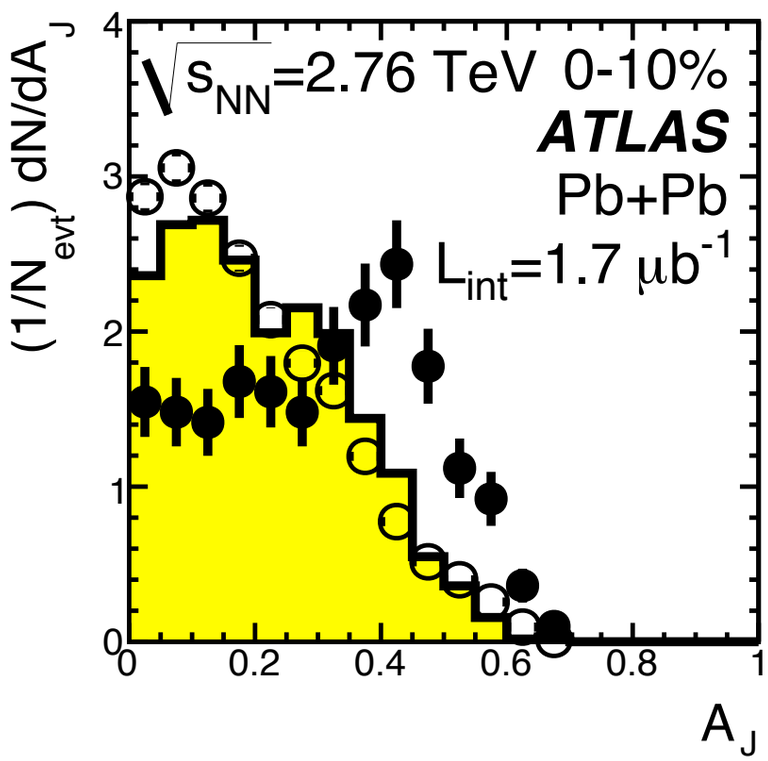
- experimentally very challenging
  - rate
  - charm & bottom mixture
  - different production configurations
  - measurement via single electrons

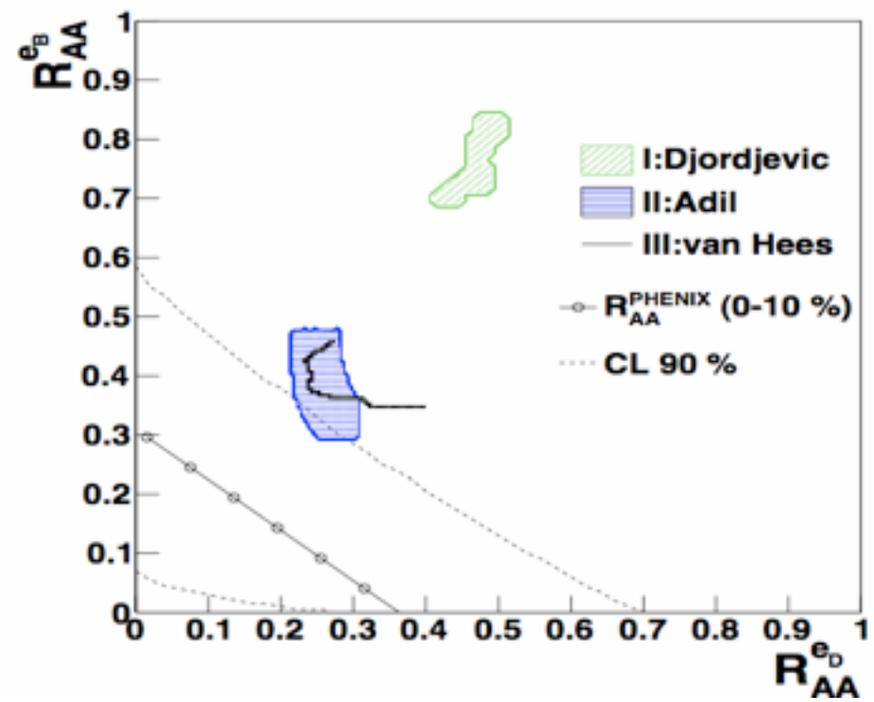
outlook

- heavy flavor is one of the best tools to understand how partons interact with the QGP
- experimentally very challenging
  - rate
  - charm & bottom mixture
  - different production configurations
  - measurement via single electrons
- investigations are still in their early stages
  - vertex upgrades at RHIC & LHC provide big improvements!
  - correlations will be key

heavy flavor and the LHC

- ATLAS di-jet results and bottom suppression at RHIC both point to the strong quenching ability of the matter





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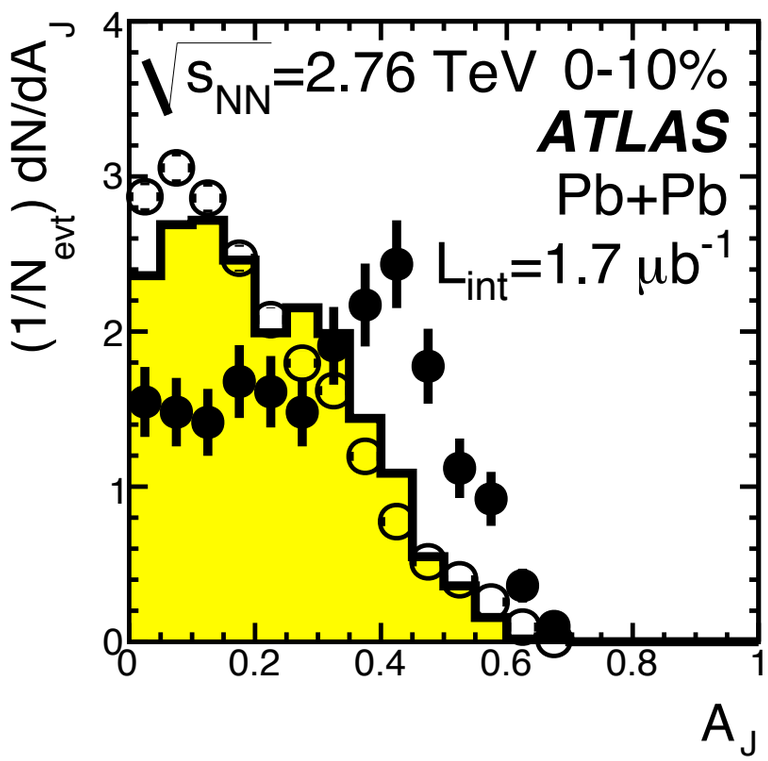
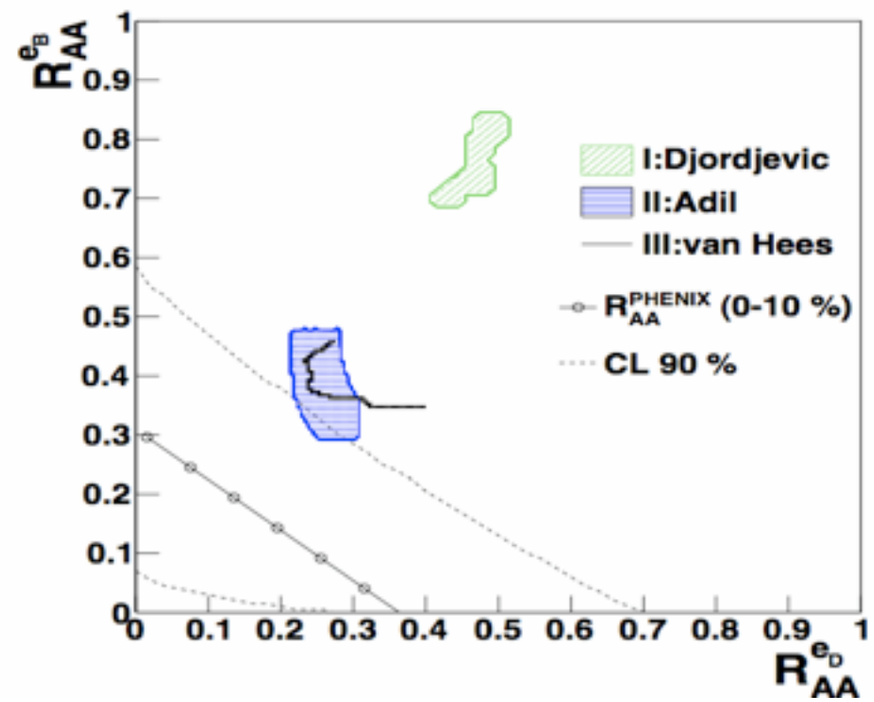
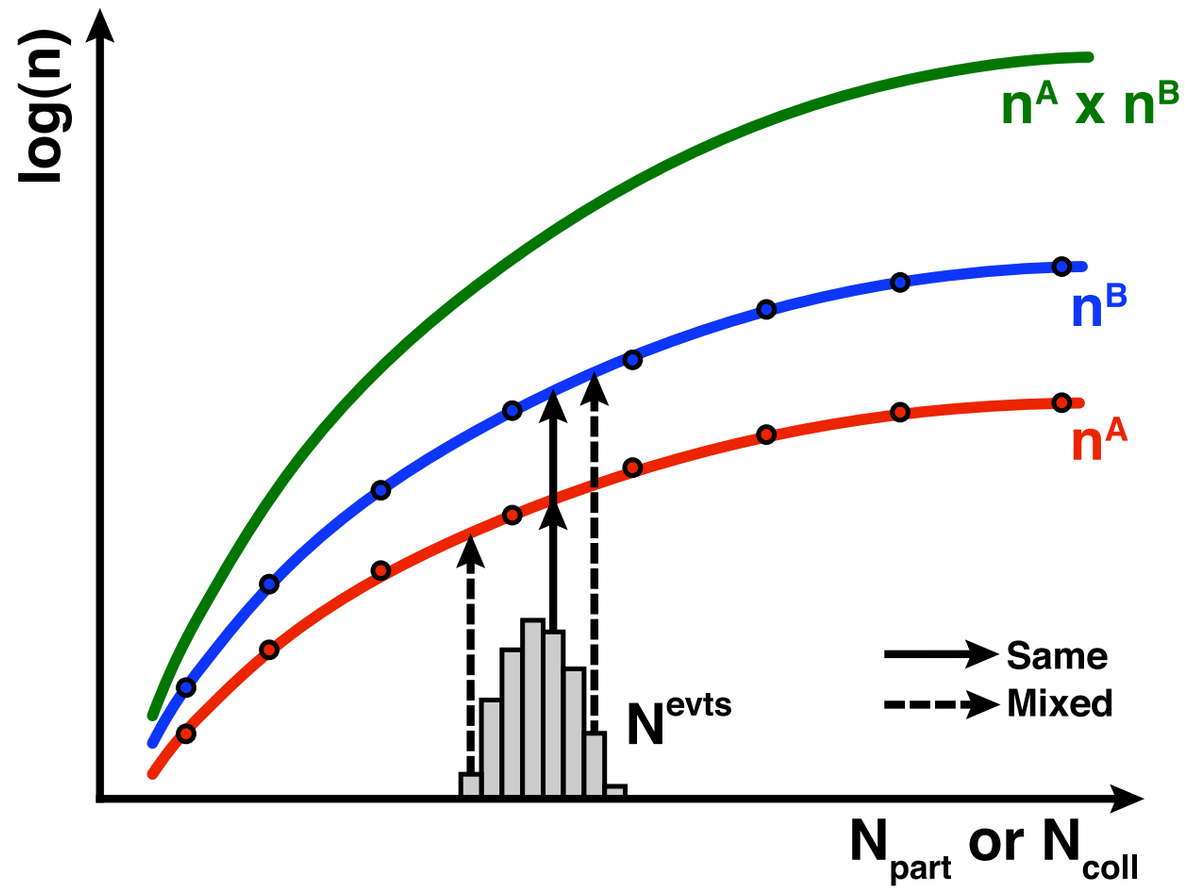




what will *b*-jets look like at the LHC?

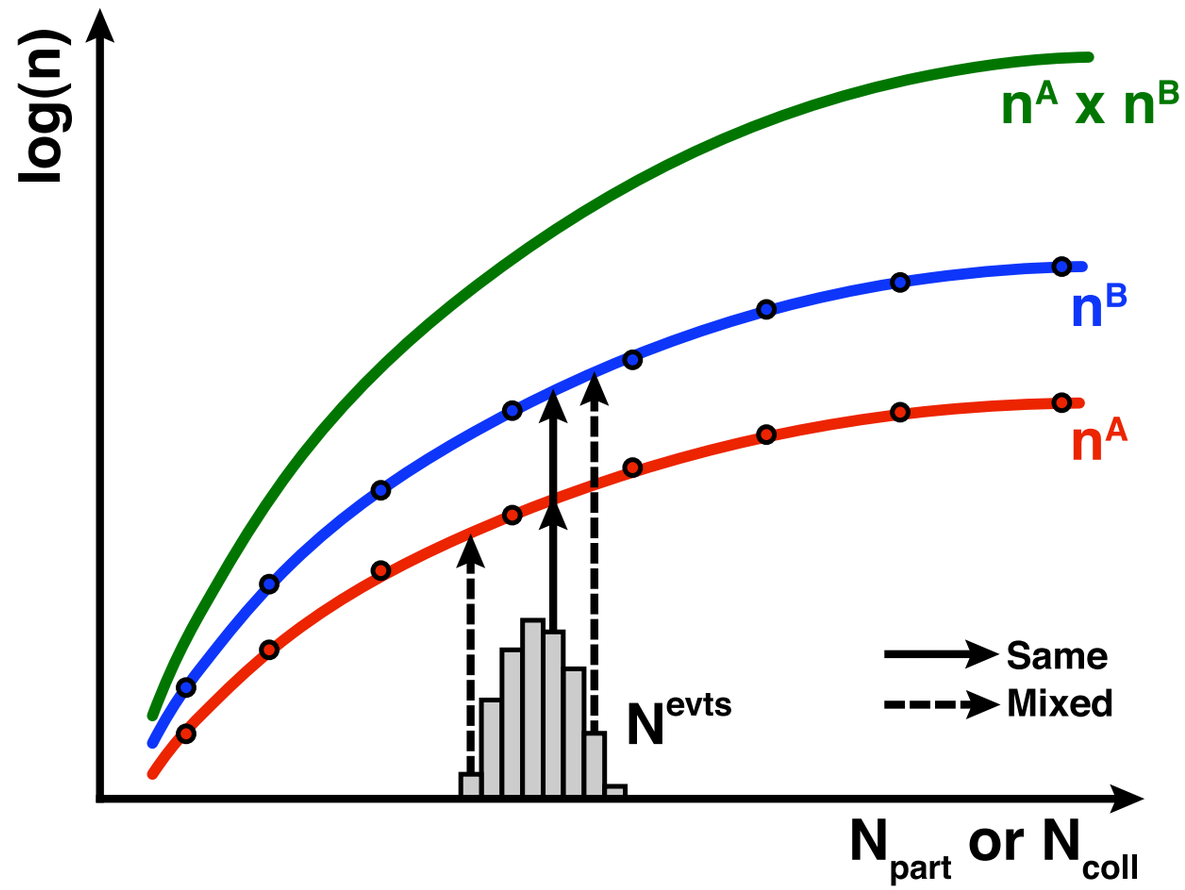
b_0 determination



AMS, McCumber, Adare PRC 81 014908 (2010)

b_0 determination

- in general $b_0 \sim \langle n_{trig} \rangle \langle n_{assoc} \rangle$



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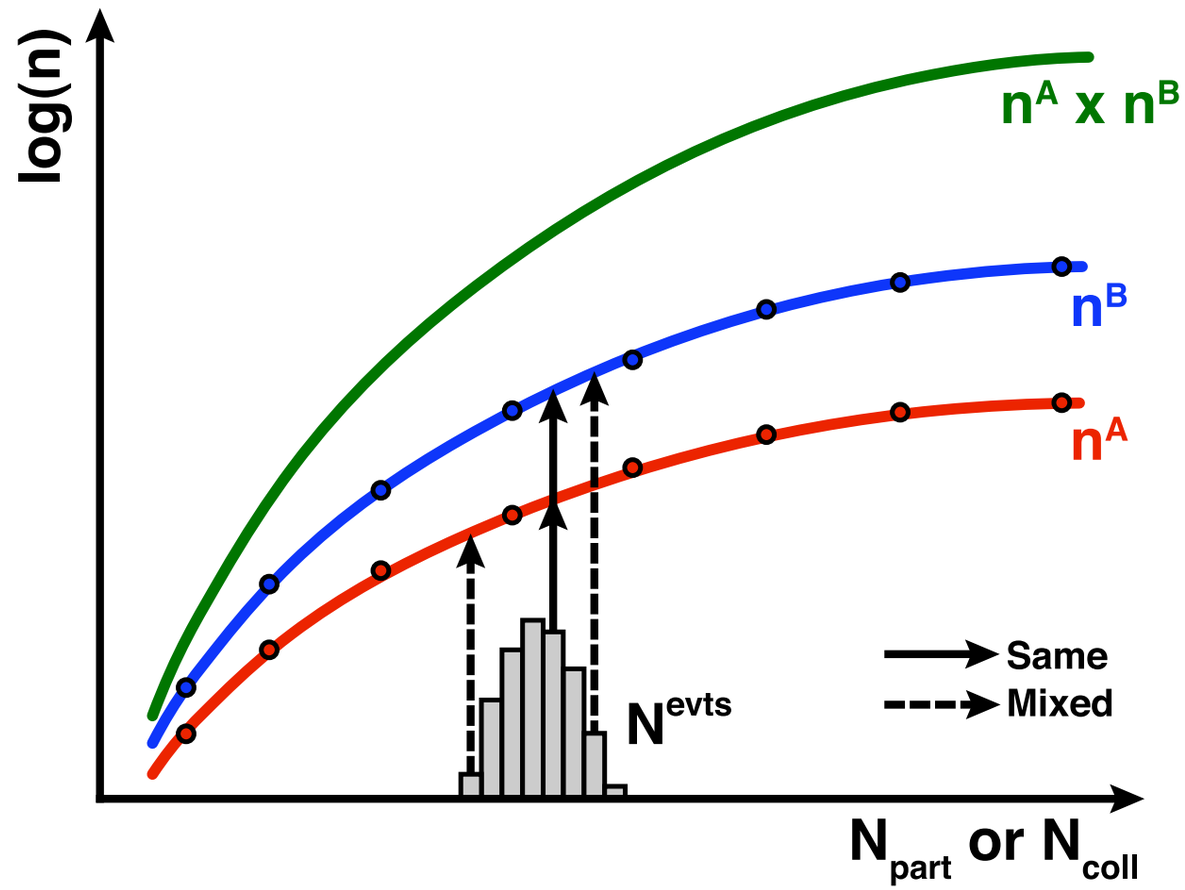

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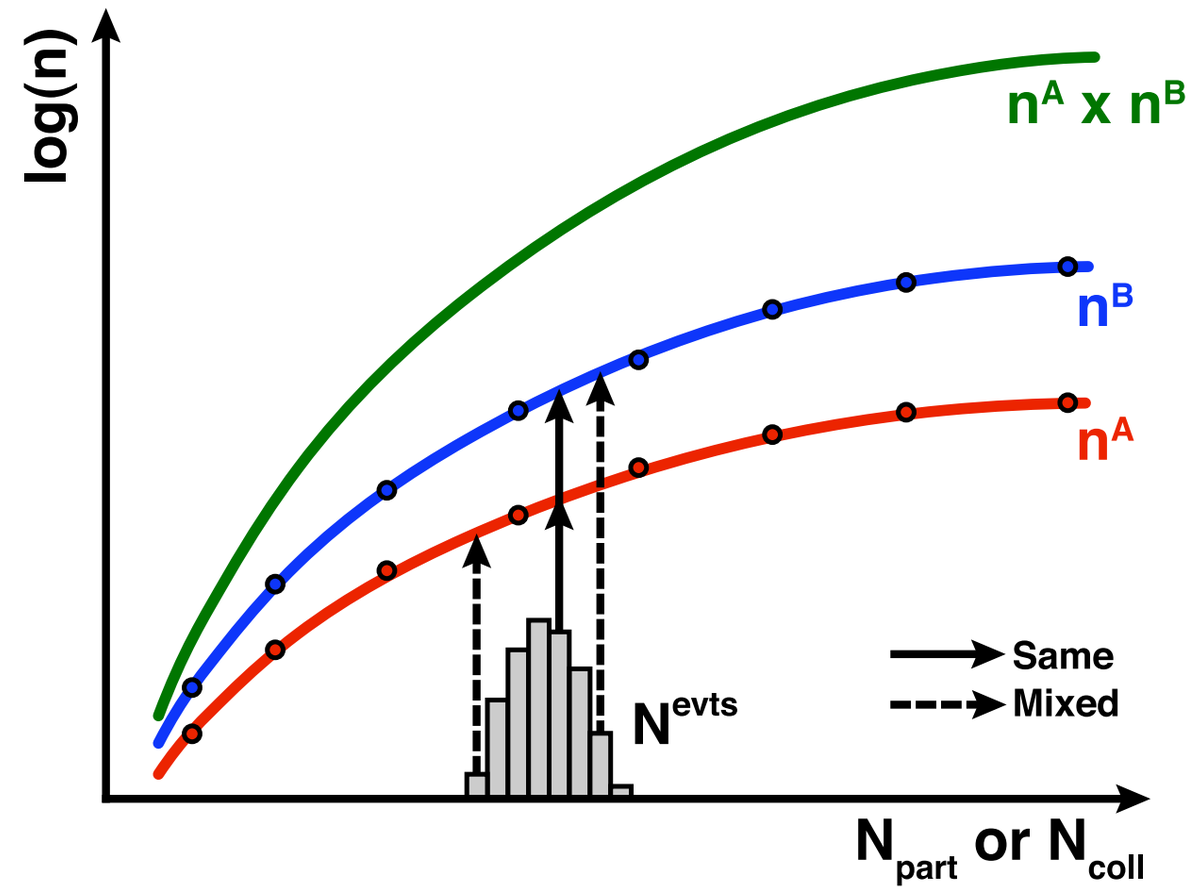

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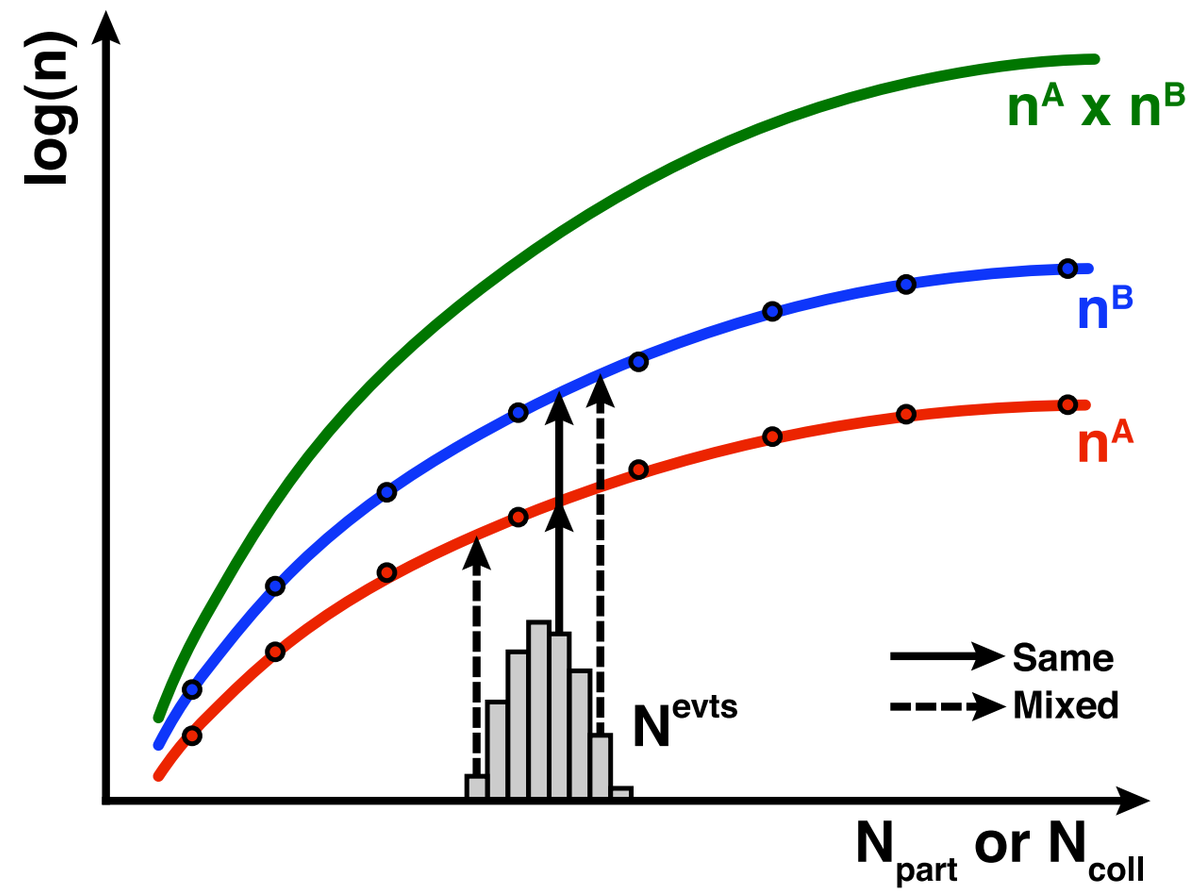

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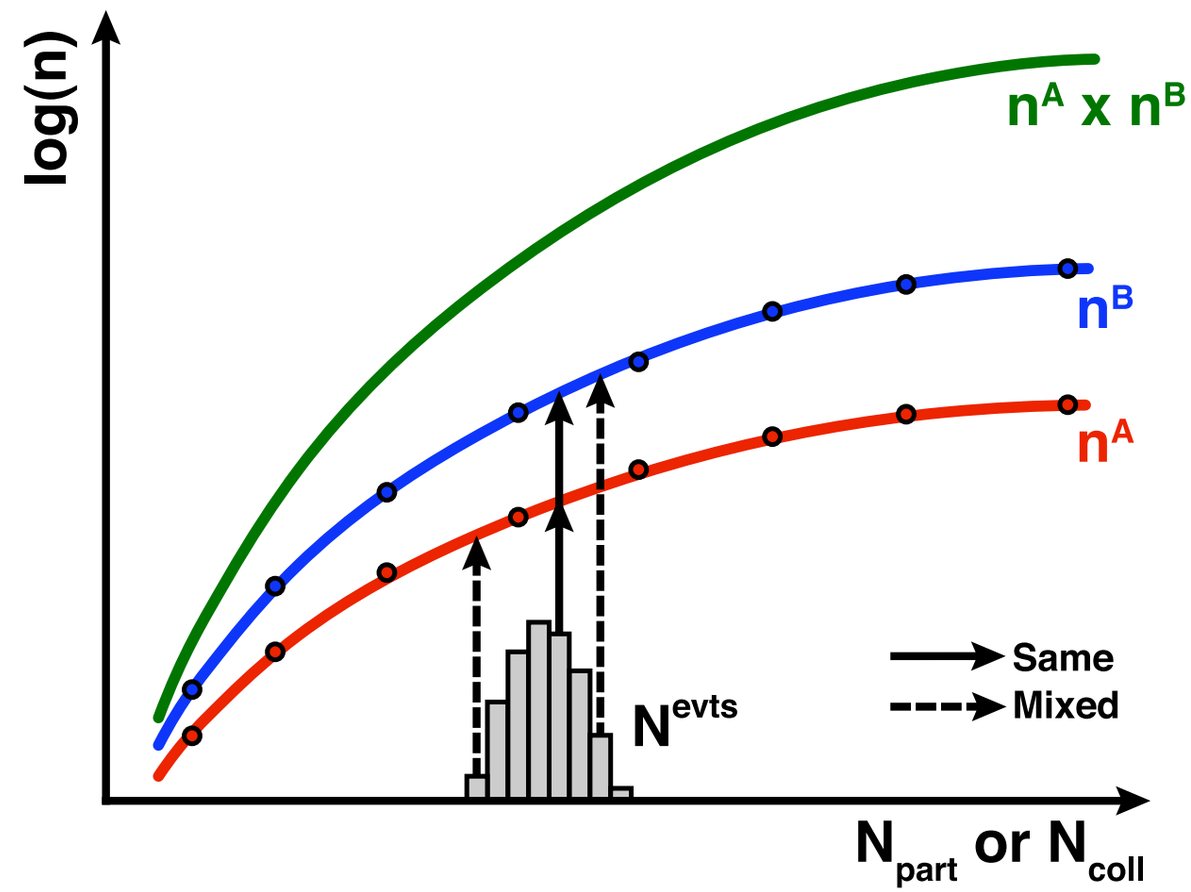

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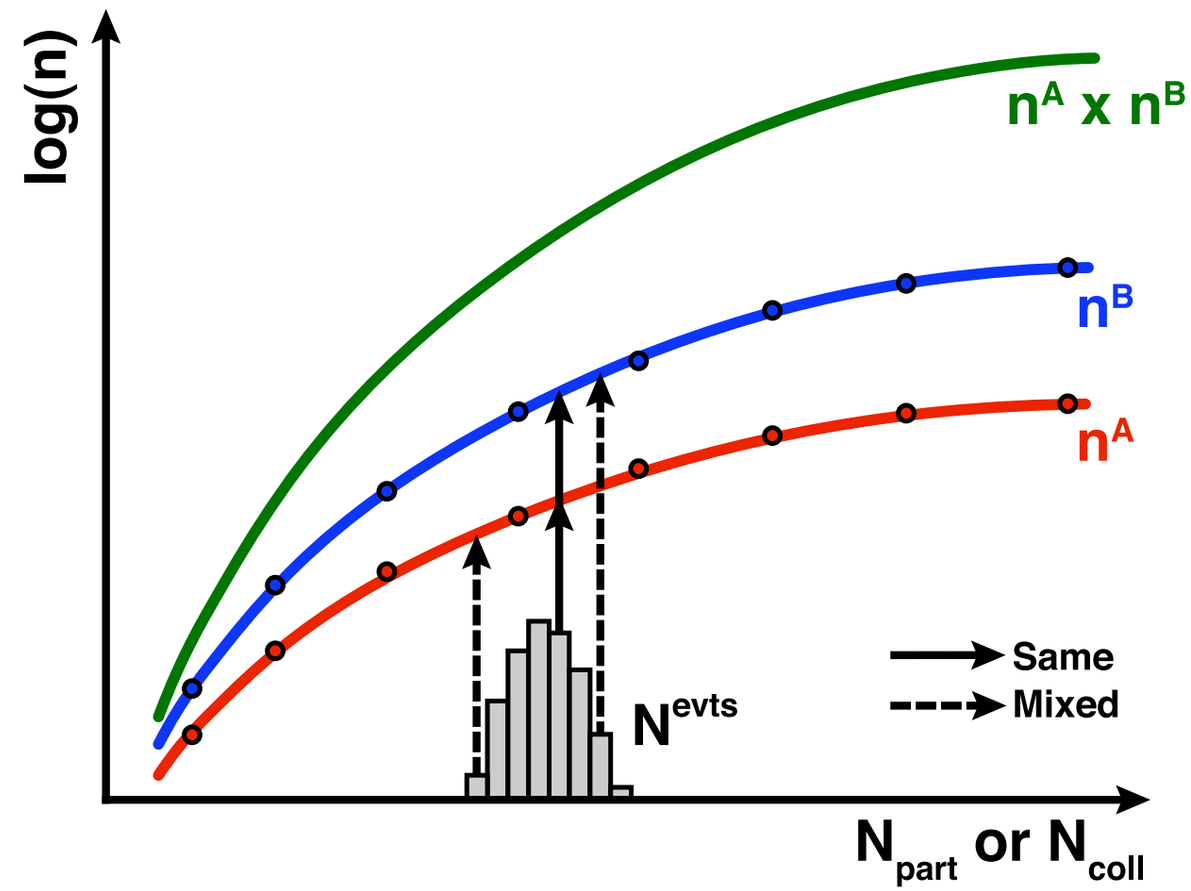

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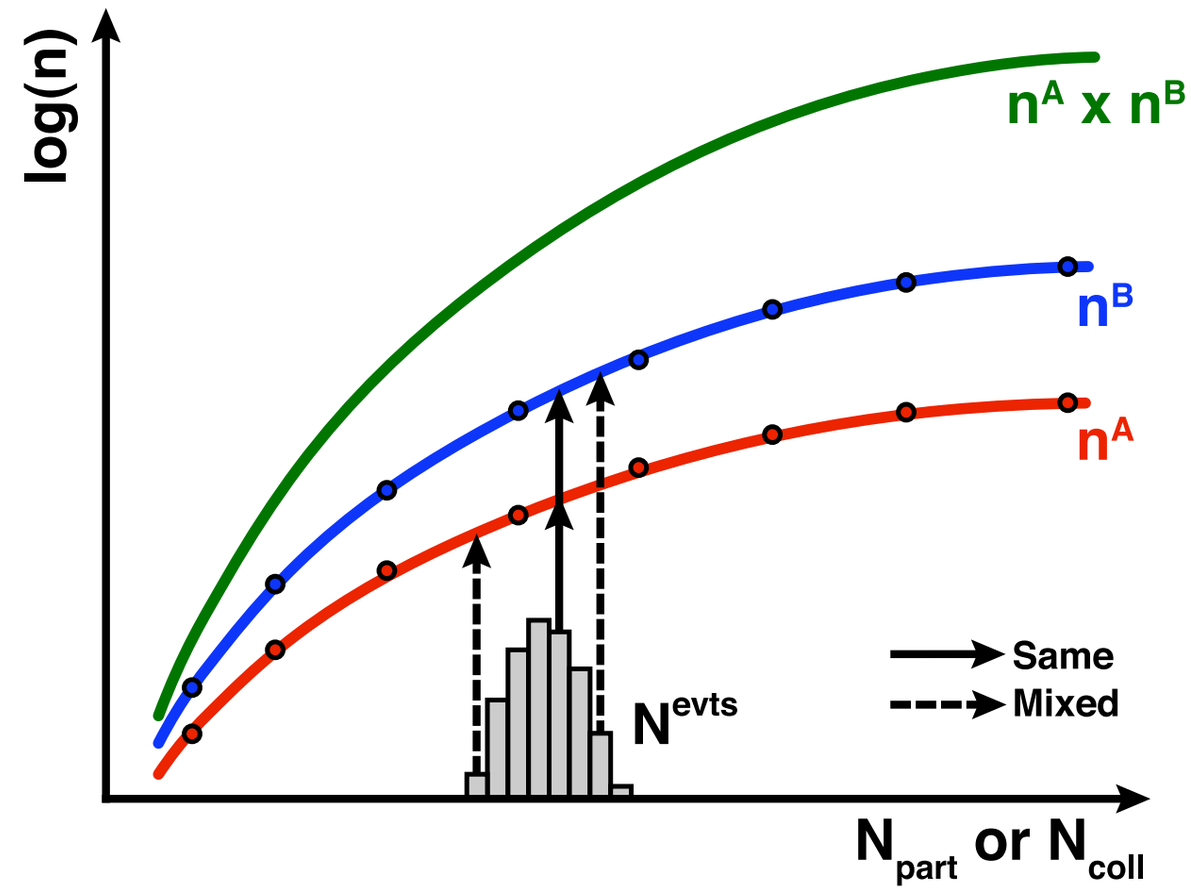

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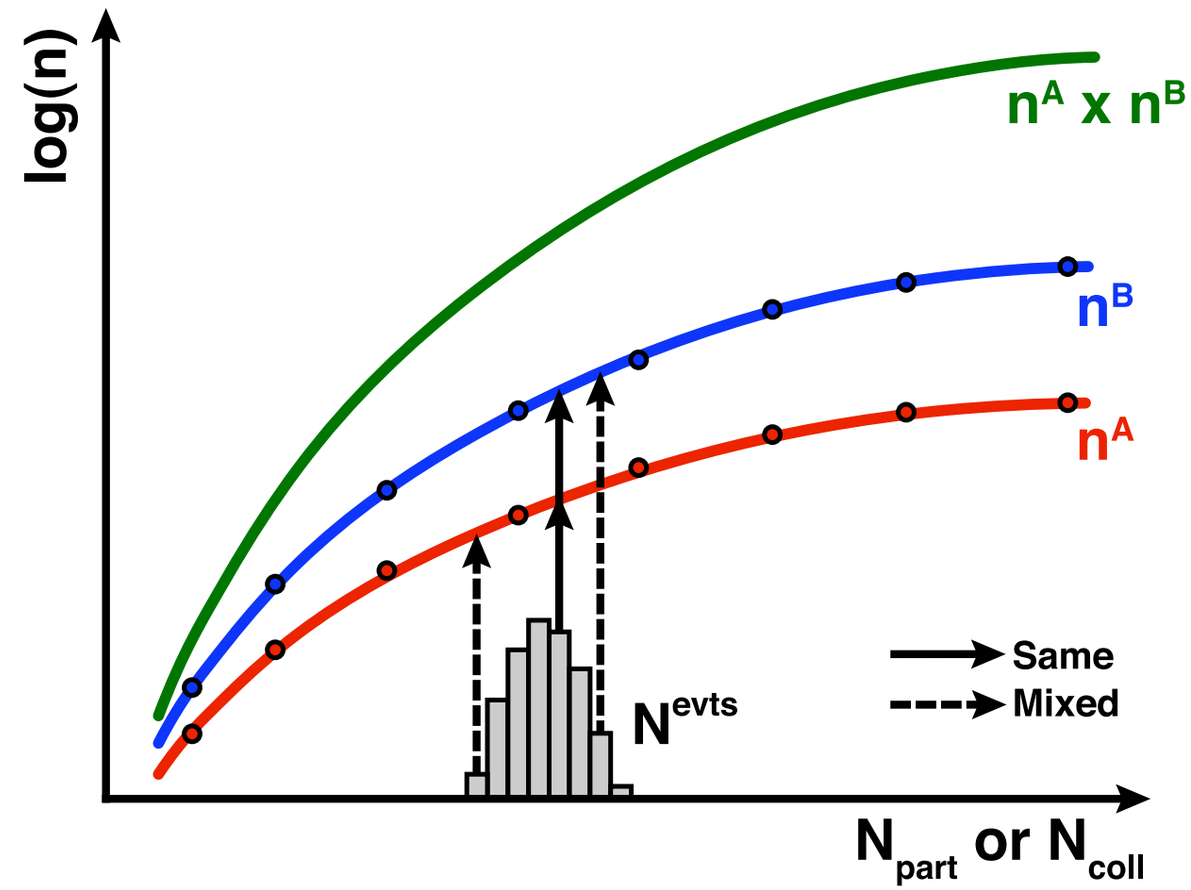

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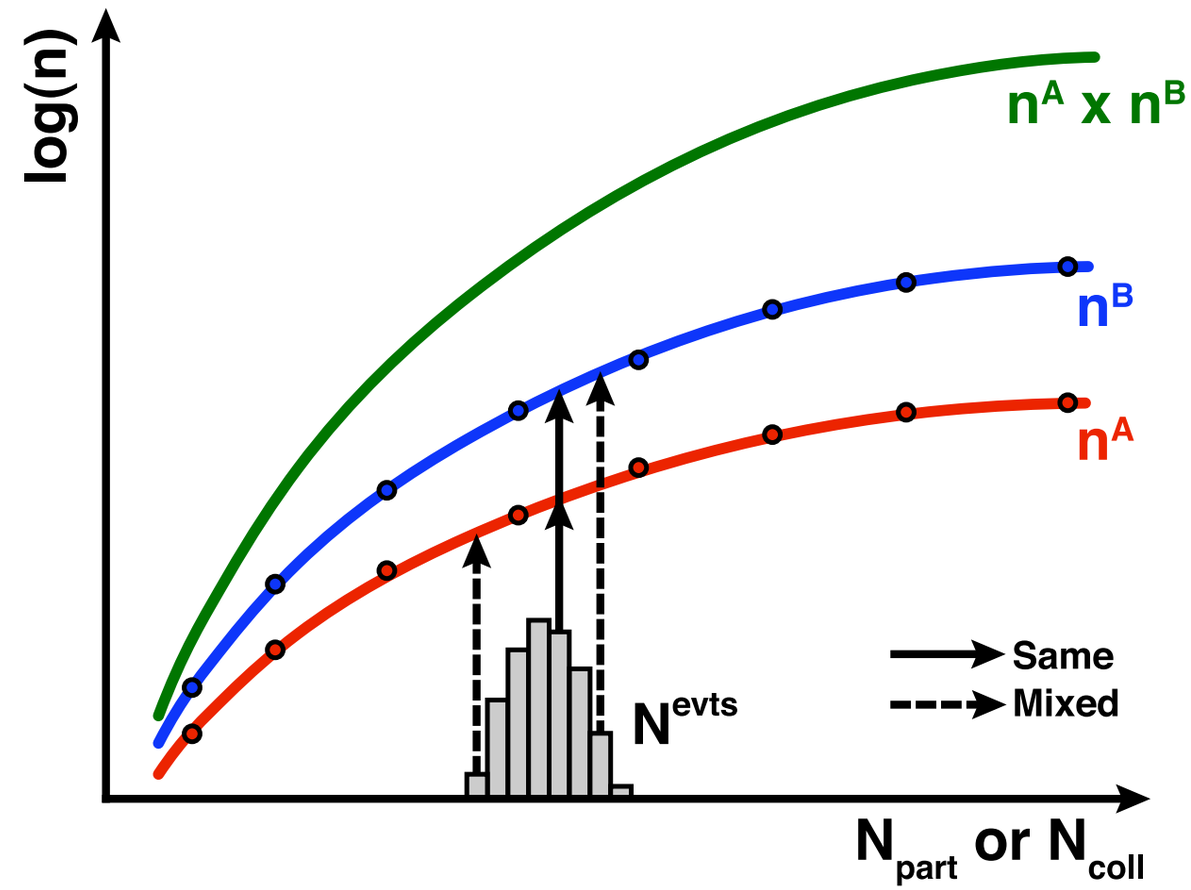
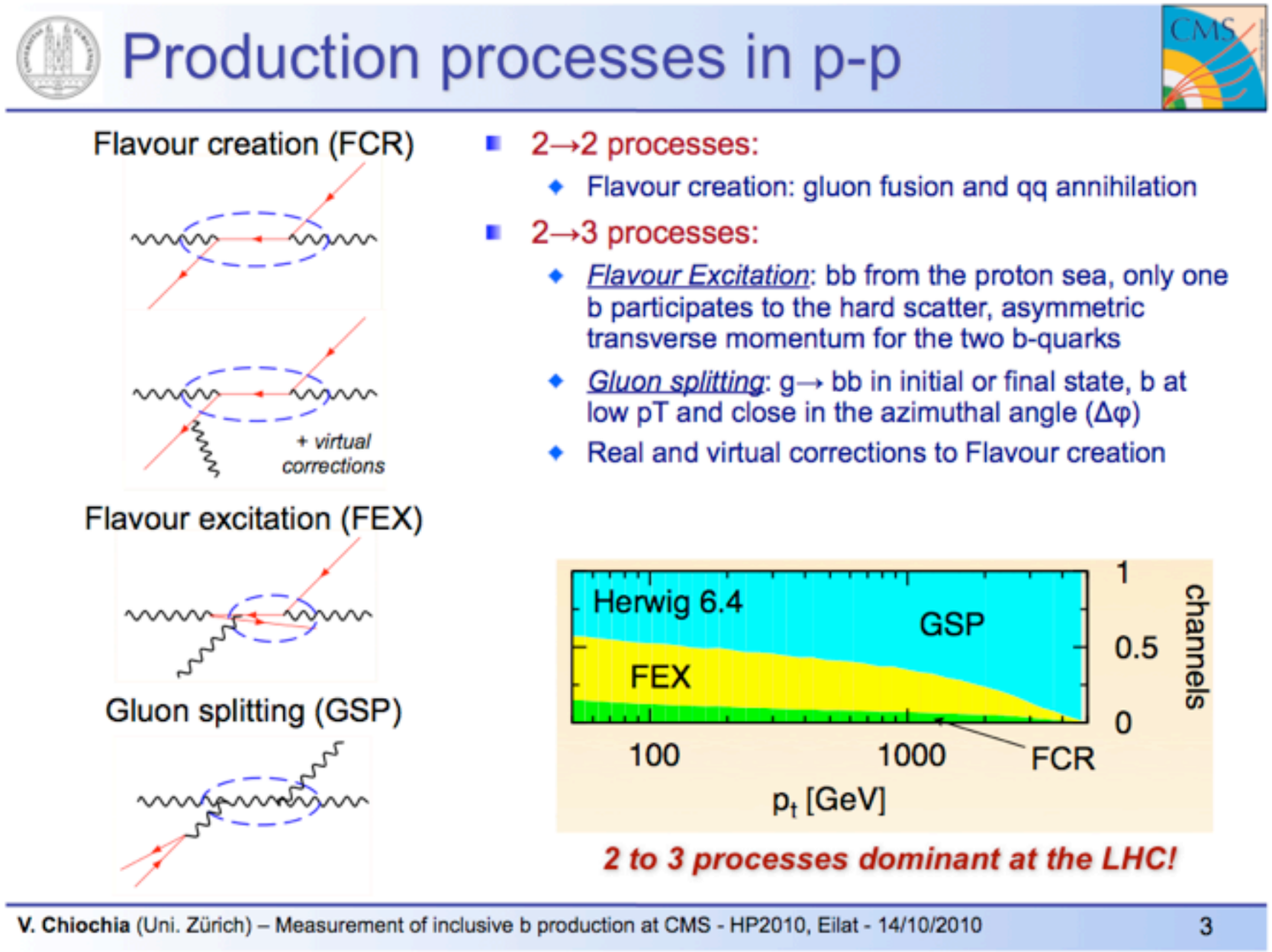


AMS, McCumber, Adare PRC 81 014908 (2010)

RHIC vs. LHC

- also different production mix



A Roadmap for Hard Probes

A Roadmap for Hard Probes

π^0 R_{AA}
π^0 I_{AA}

A Roadmap for Hard Probes

π^0 R_{AA}
π^0 I_{AA}

→ ***control geometry***

π^0 R_{AA} (ϕ)
π^0 I_{AA} (ϕ)

A Roadmap for Hard Probes

π^0 R_{AA}
π^0 I_{AA}

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π^0 R_{AA} (ϕ)
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↓ ***control parton***

$e^{\pm}$ R_{AA}
$e^{\pm}$ I_{AA}

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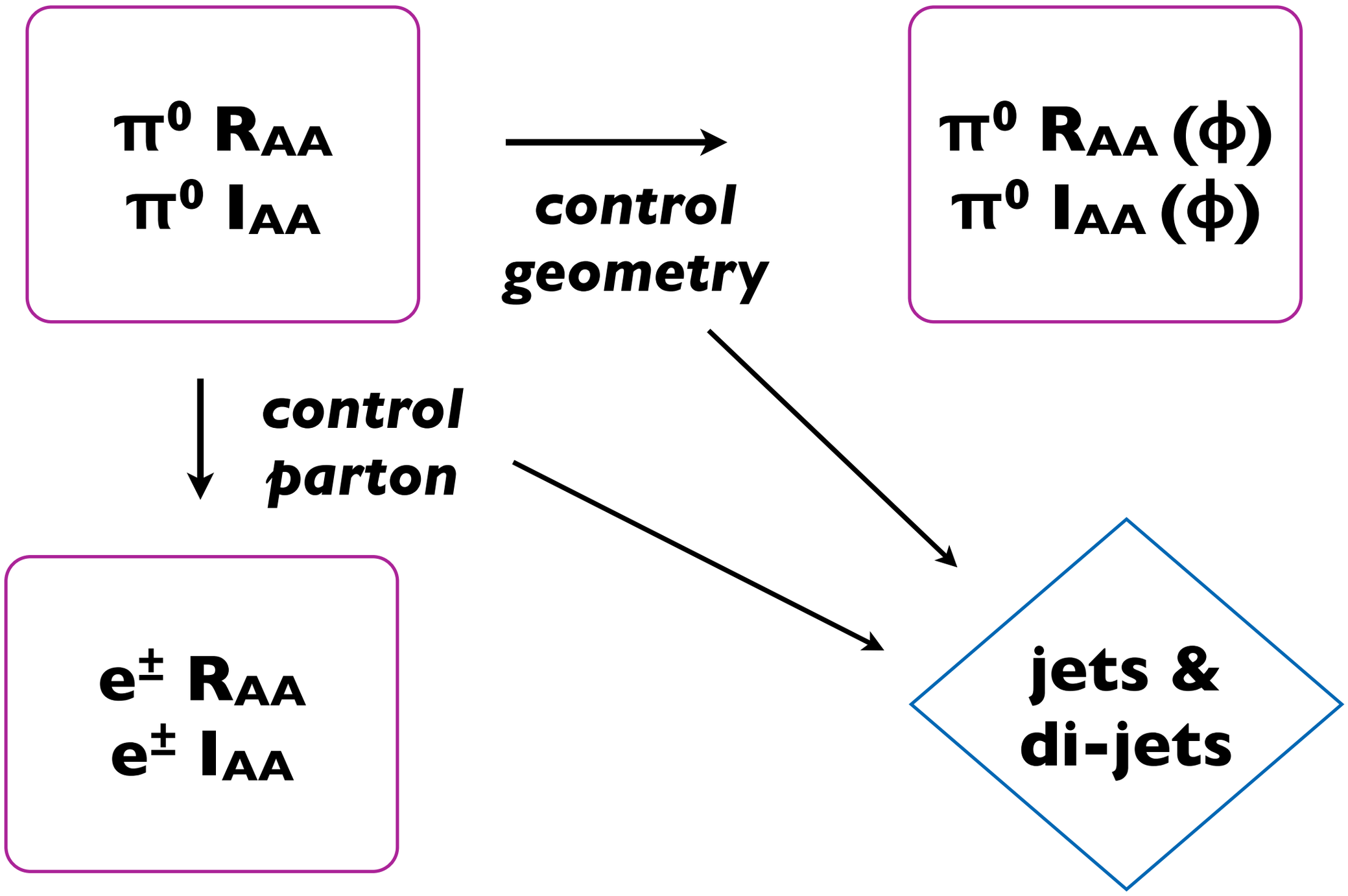

A Roadmap for Hard Probes

π^0 R_{AA}
π^0 I_{AA}

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π^0 R_{AA} (ϕ)
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$e^{\pm}$ R_{AA}
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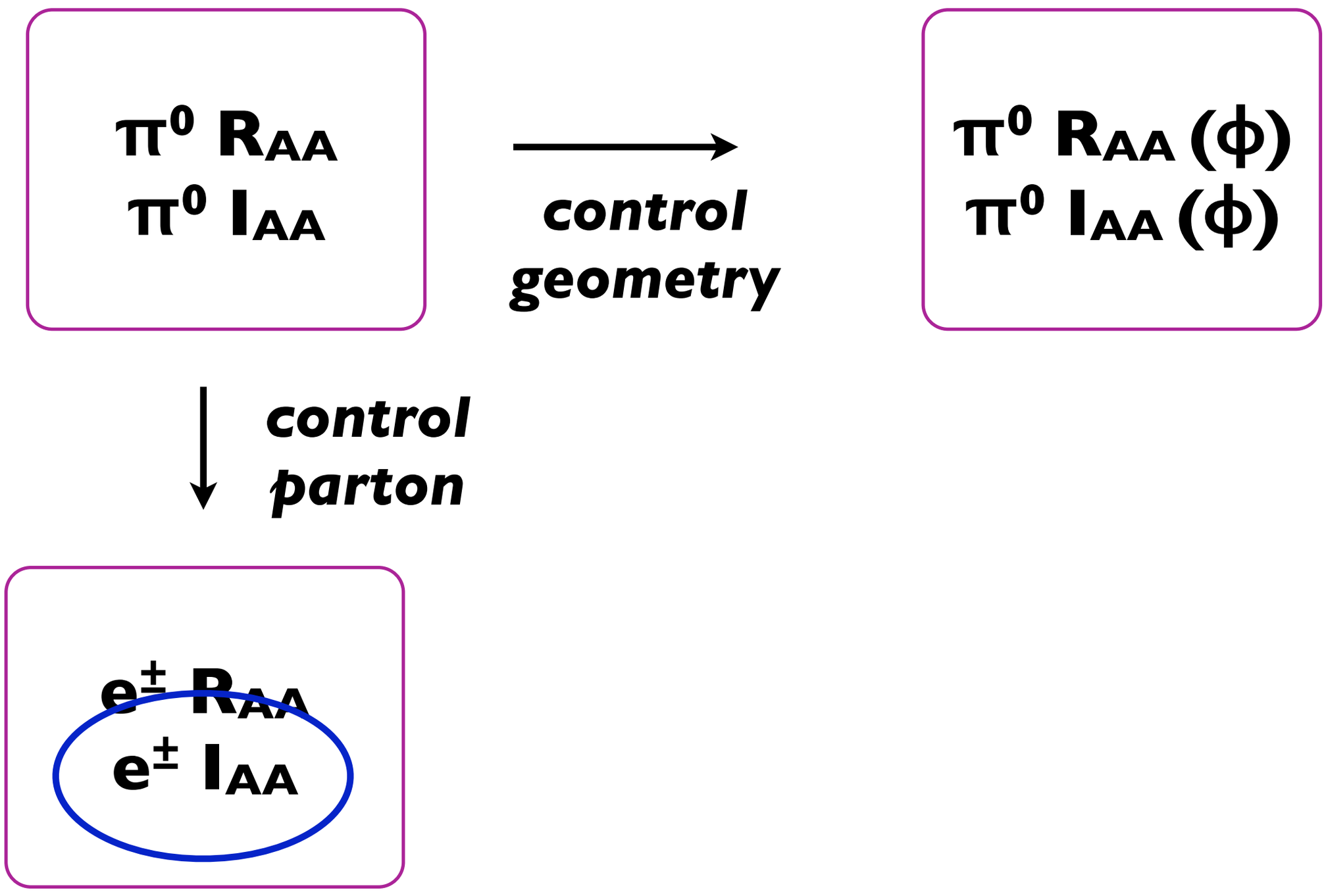
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