Open heavy flavor with the STAR detector

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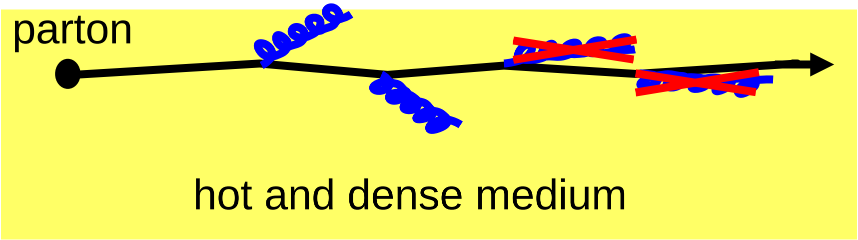
Yale

for STAR collaboration

Heavy Flavor and Quarkonia Production Workshop
RHIC&AGS User's meeting 2007

Heavy quarks as a probe

- Studying energy loss of heavy quarks → independent way to extract properties of the medium

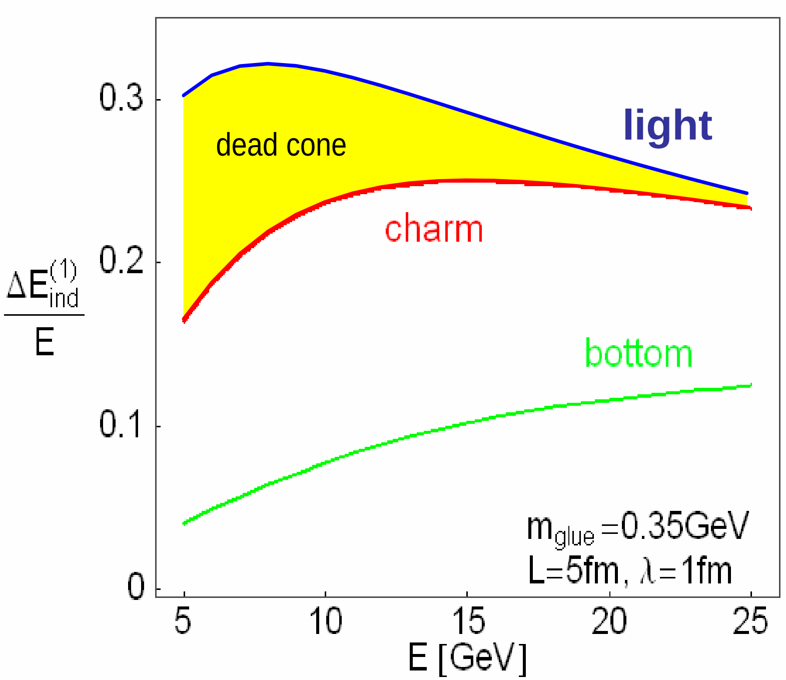


- Due to their large mass heavy quarks are primarily produced by gluon fusion
→ production rates calculable by pQCD
→ sensitive to initial gluon distribution
M. Gyulassy and Z. Lin, PRC 51, 2177 (1995)

- Heavy quarks lose less energy due to suppression of small angle gluon radiation (dead-cone effect)
Dokshitzer and Kharzeev, PLB 519, 199 (2001)

- Amount of collisional and radiative energy losses seems to be similar
M.G. Mustafa, PRC72, 014905

ENERGY LOSS



M.Djordjevic PRL 94 (2004)

Open heavy flavor

Direct: reconstruction of all decay products

$$D^0 \to K^-\pi^+, \overline{D}^0 \to K^+\pi^-,$$

$$B.R. = 3.80 \pm 0.07\%$$

$$D_s^+ \to \phi\pi^+ \to K^+K^-\pi^+$$

$$B.R. = 2.16 \pm 0.28\%$$

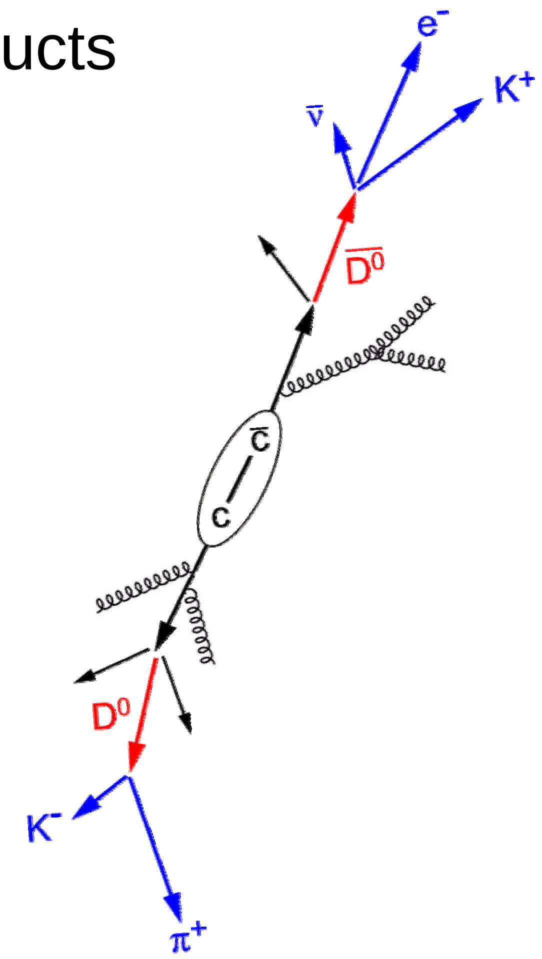
Indirect: charm and beauty electrons

c $\to$ e^+ + anything (B.R.: 9.6%)
b $\to$ e^+ + anything (B.R.: 10.9%)

charm (and beauty) muons

c $\to$ μ+ + anything (B.R.: 9.5%)

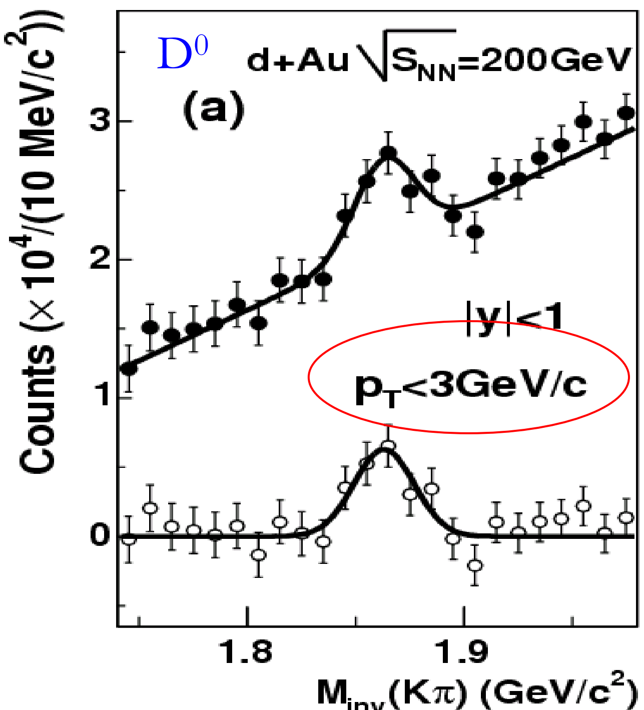
Azimuthal Correlations: **e-h, e-D**



Charm via hadronic decays

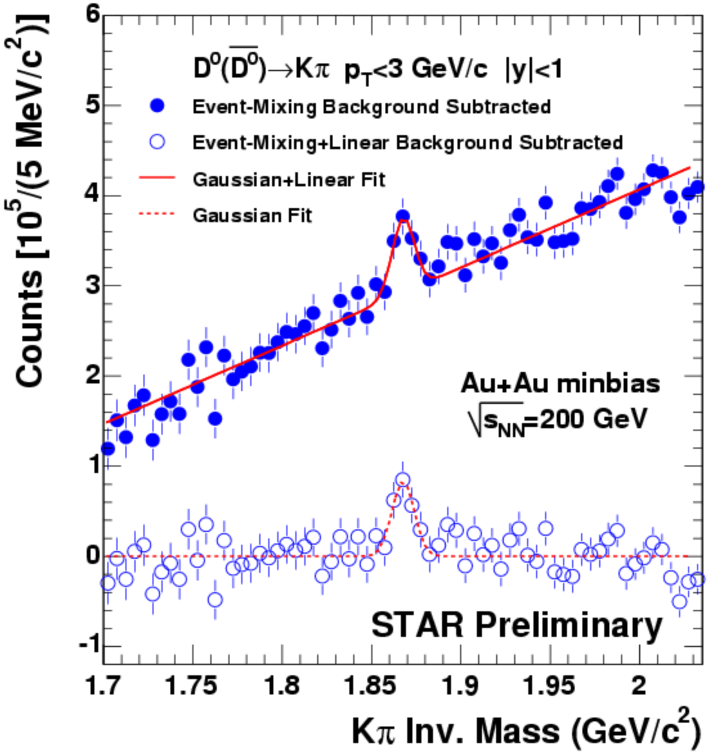
d+Au

Au+Au



$S/\sqrt{N} \sim 6$

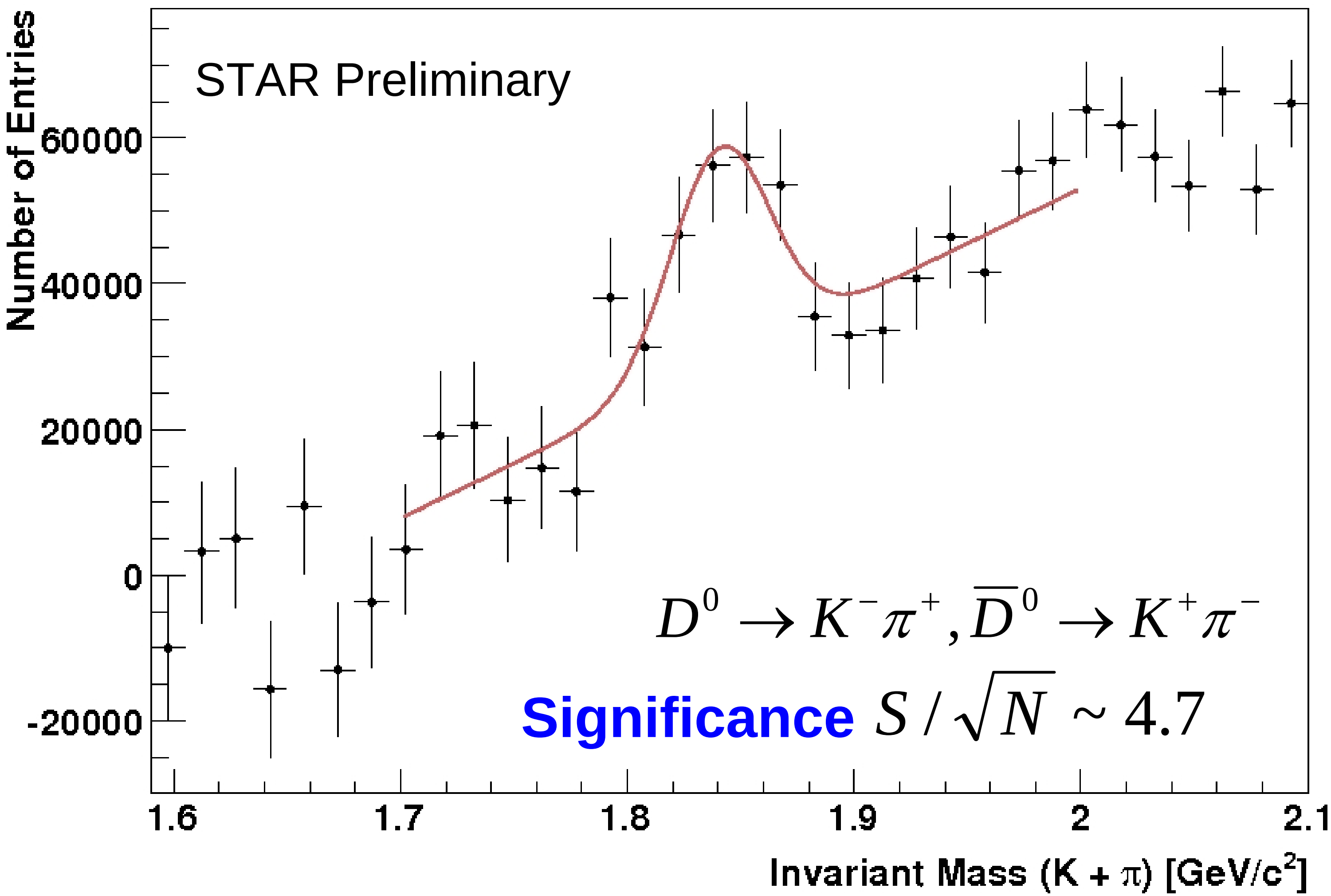
STAR Phys. Rev. Lett. 94 (2005)



TPC only

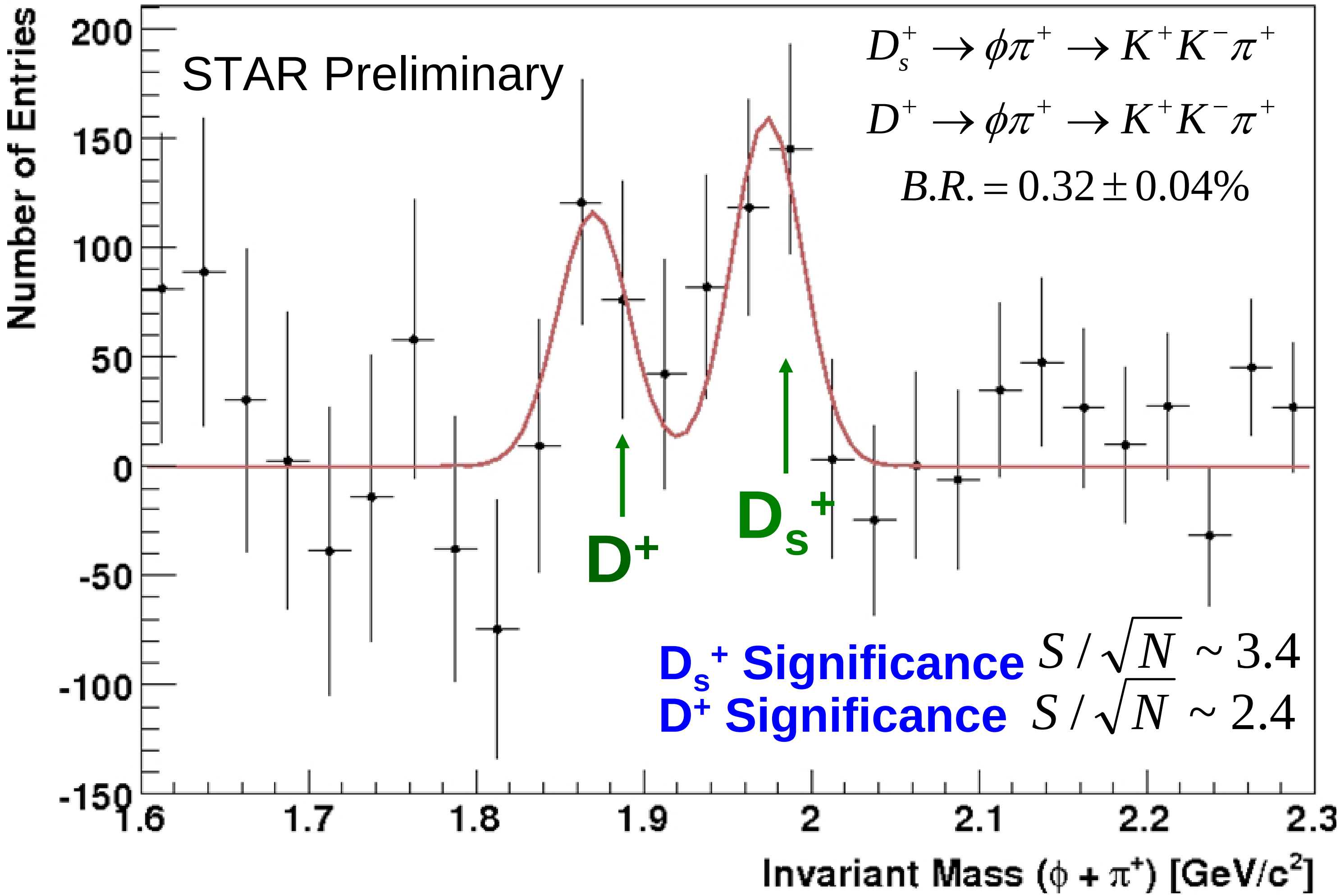
- D^0 in d+Au and Au+Au at 200GeV (p_T 0.1- 3.0 GeV/c)

$D^0 + \overline{D}^0$ in Cu+Cu at 200GeV



TPC only

D/D_s Peak in d+Au



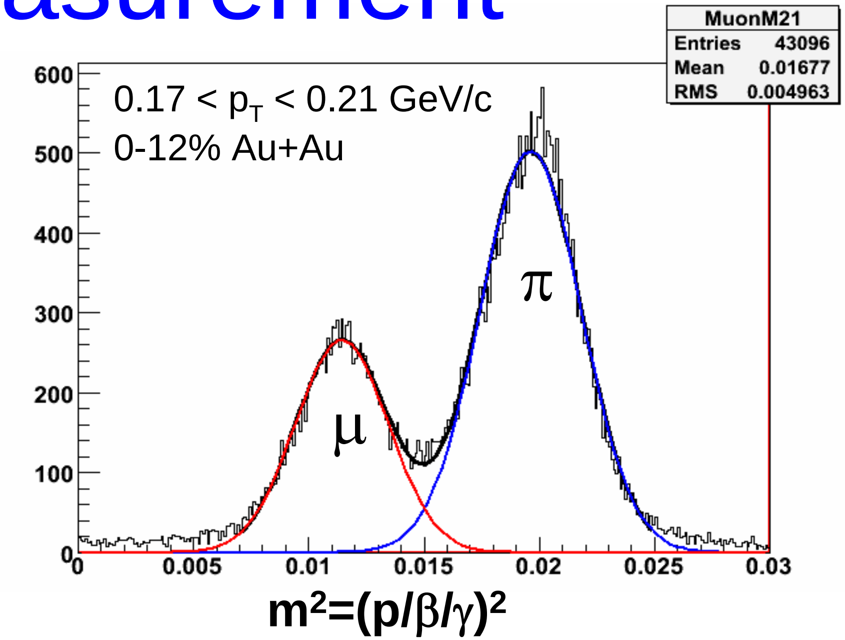
TPC only

- No negatively charged D or D_s found yet

Muon measurement

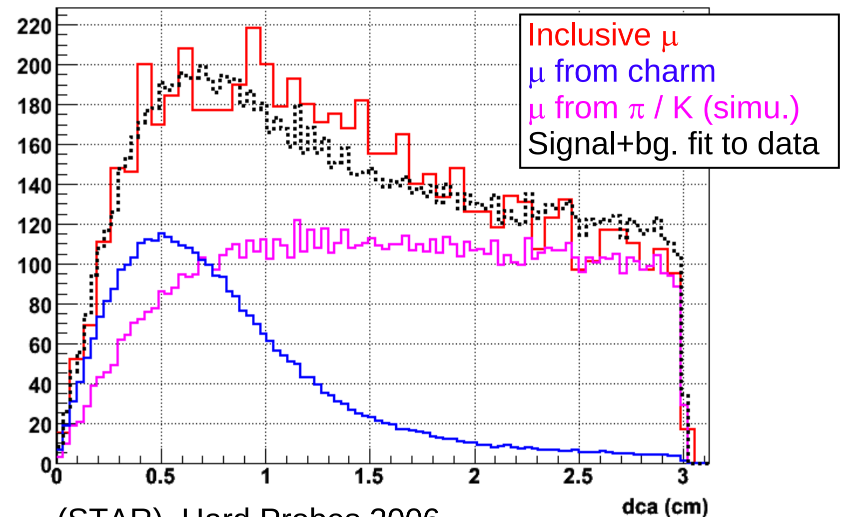
- Low-p_T (p_T < 0.25 GeV/c) muons can be measured with TPC + ToF

  - this helps to constrain charm cross-section



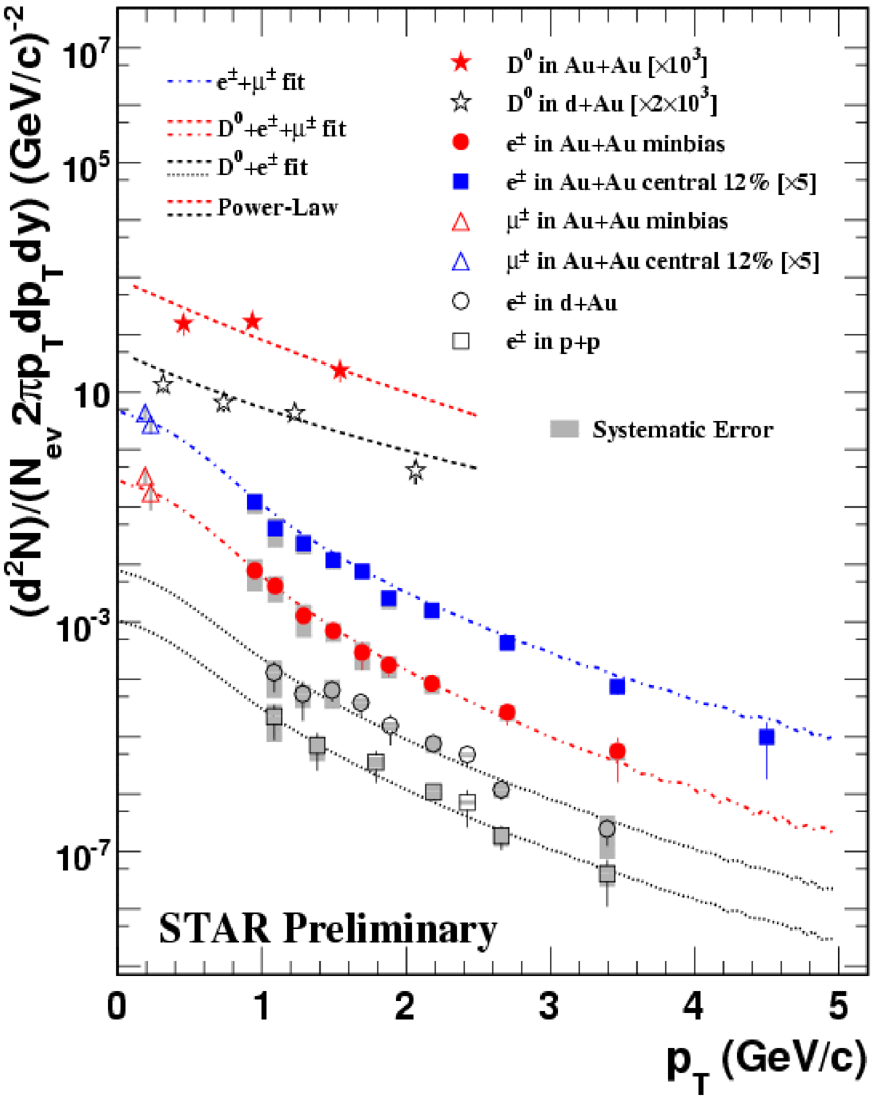
TPC+TOF

- Separate different muon contributions using MC simulations:
  - K and π decay
  - charm decay
  - DCA (distance of closest approach) distribution is very different



(STAR), Hard Probes 2006

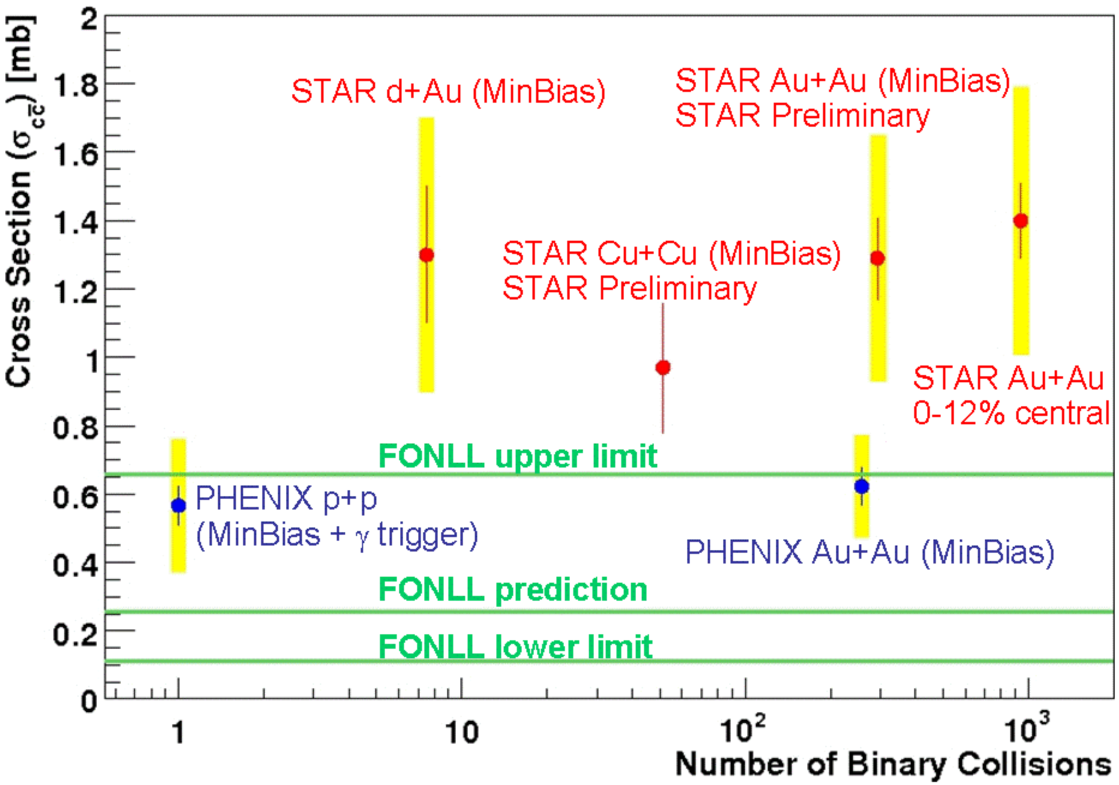
Non-photonic electrons (part I)



- Photonic background must be reconstructed and subtracted
- only TOF patch $\Delta\phi=\pi/30$ instrumented
- **non-photonic electrons:** **p_T 0.9-5.0 GeV/c**
- D^0+electrons+muons 90% of total kinematic range covered

TPC+TOF

Charm total cross sections



number of binary collisions N_{bin}

- 1.4 ± 0.2(stat.) ± 0.4(sys.) mb
  in 200GeV minbias d+Au
- 1.29 ± 0.12 ± 0.36 mb
  in 200GeV minbias Au+Au
- 1.40 ± 0.11 ± 0.39 mb
  in 200GeV central 12% Au+Au

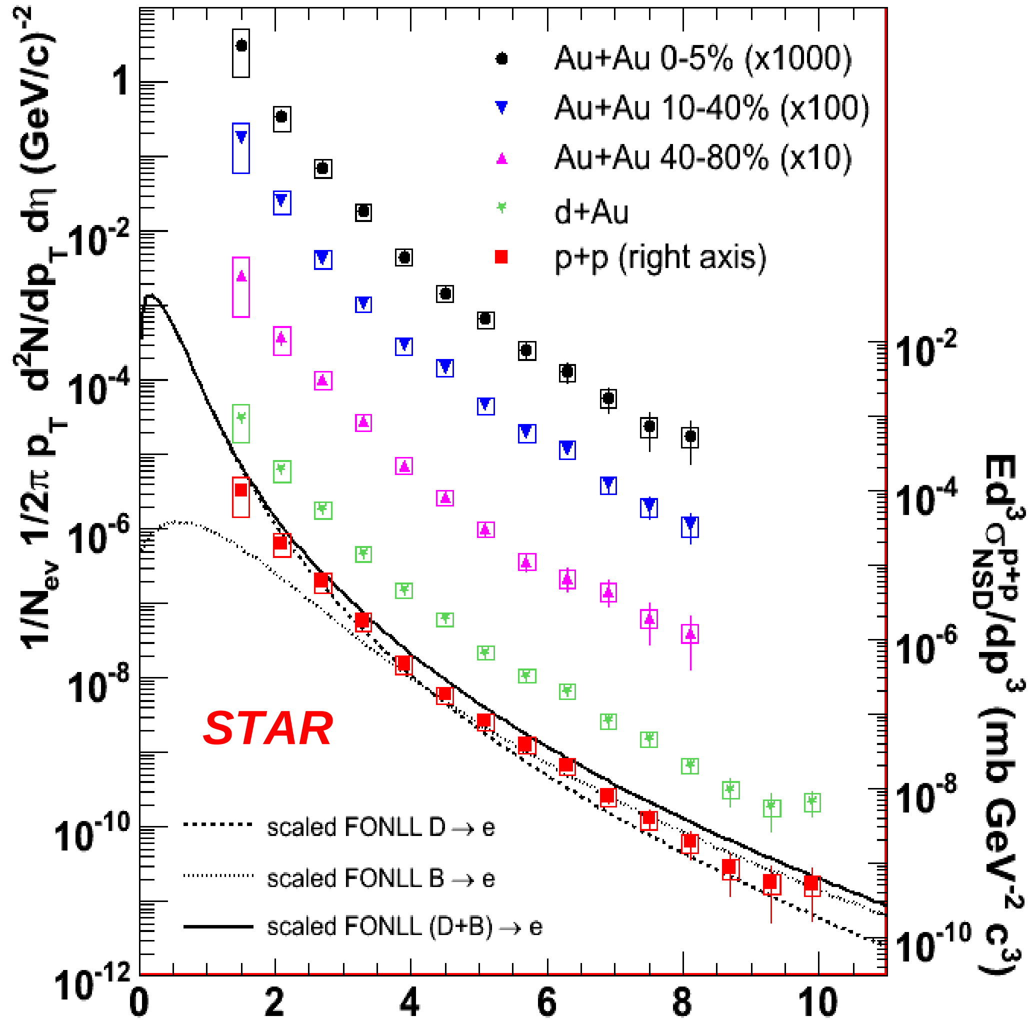
oss sections follow binary scaling,
ure of charm production
ively at the initial impact.

NLL underestimates measured cross-section by factor ~5

$$\sigma^{NN}_{c\bar{c}} =$$

- 0.94 ± 0.18(stat.) mb
  in 200GeV minbias Cu+Cu

Non-photonic electrons (part II)

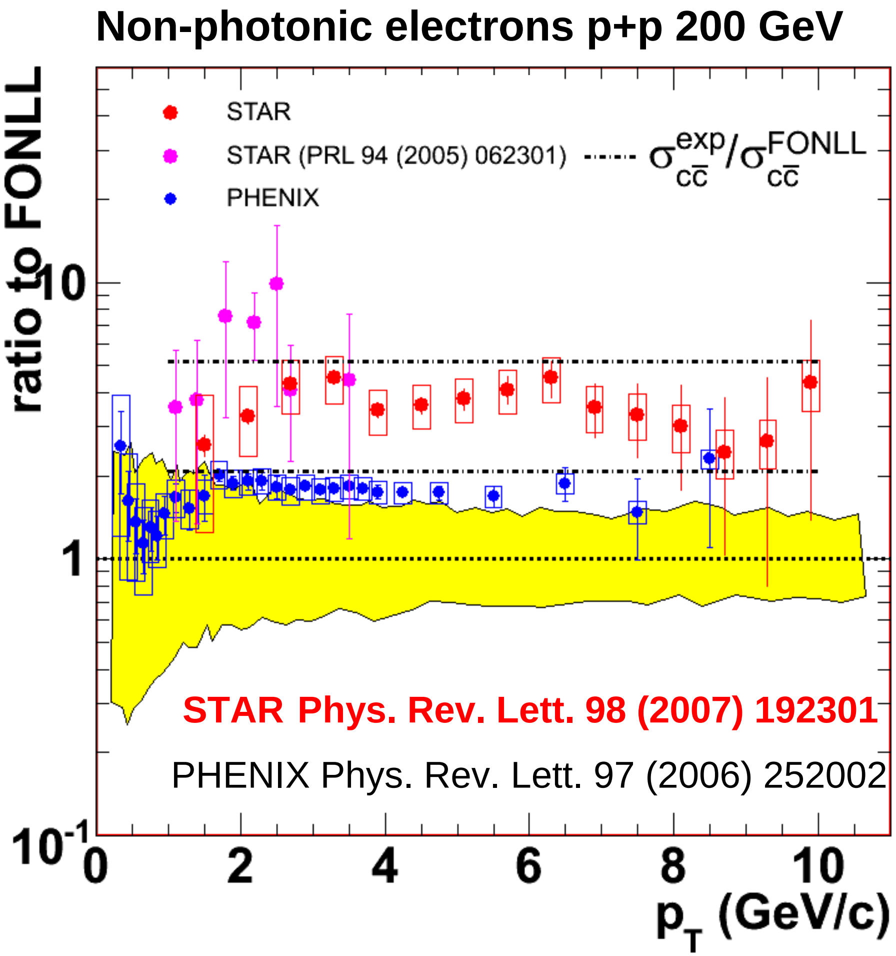


Phys. Rev. Lett. 98 (2007) 192301

- High-tower EMC trigger => high p_T electrons
- Photonic electrons reconstructed and subtracted
- FONLL scaled by ~5,, describes shape of p+p spectra well suggesting bottom contribution

TPC+EMC

Non-photonic electrons vs. FONLL



- FONLL underestimates measured electrons by factor 4-5
- PHENIX high-p_T data differs from STAR by factor 2
  - not understood yet
  - STAR low material run planned

R_{AA} from d+Au to central Au+Au

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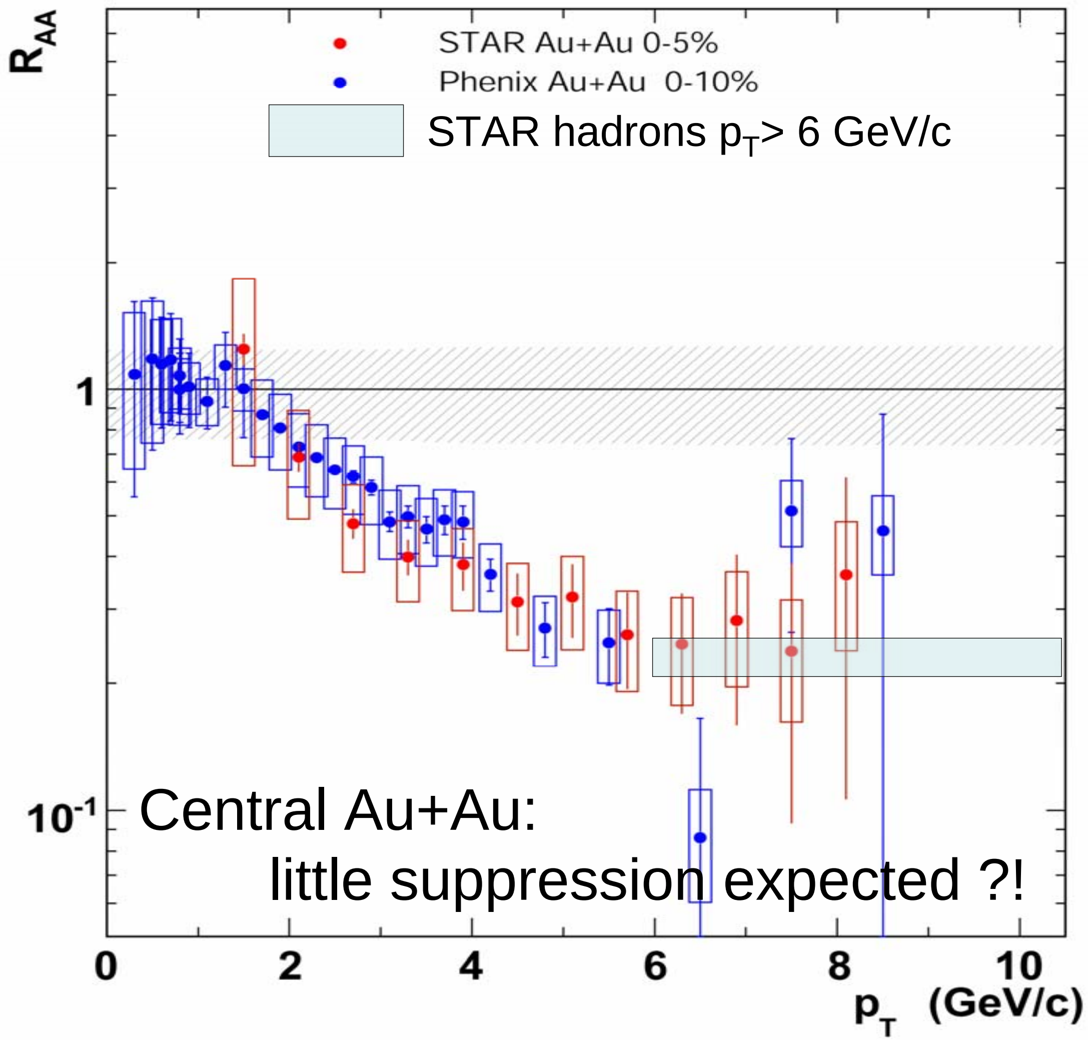
PHENIX Phys.Rev.Lett.98 (2007) 172301



Nuclear modification factor

$$R_{AA}(p_t) = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

Electron R_{AA} Radiative energy loss (c+b)

- parameters of medium in models extracted from hadron data
- **Radiative energy** loss alone in medium with reasonable parameters **does not describe** the data
- **What are the other sources of energy loss ?**

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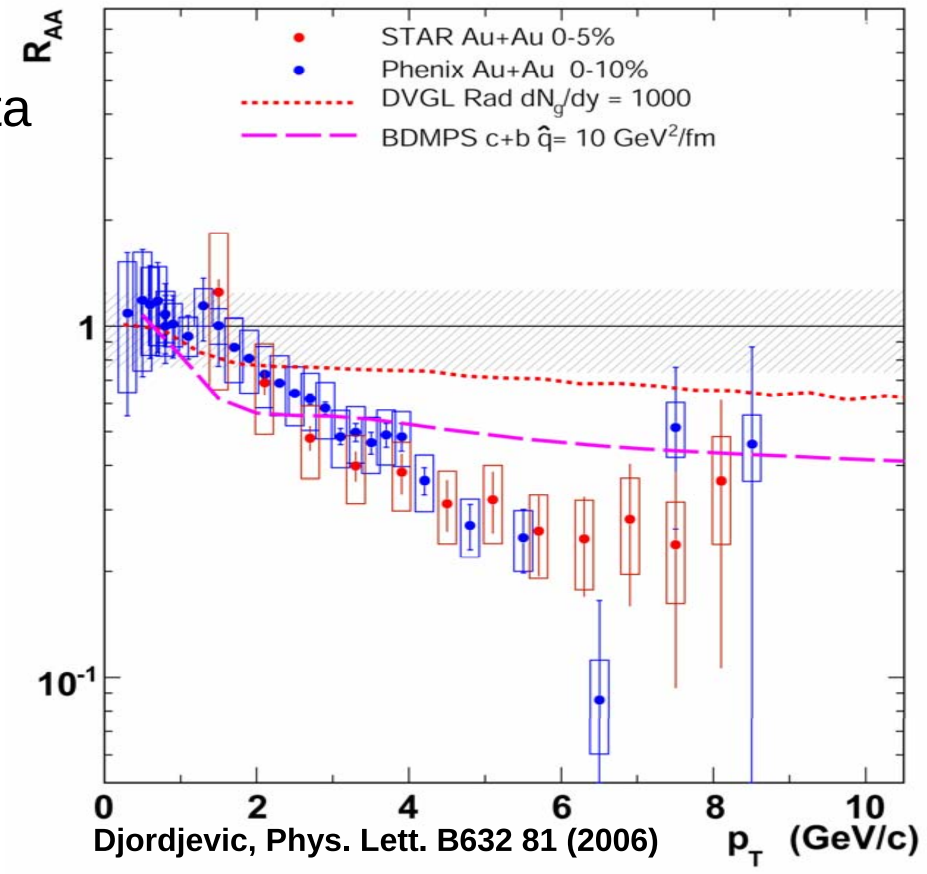

Djordjevic, Phys. Lett. B632 81 (2006)

Armesto, Phys. Lett. B637 362 (2006)

Role of collisional energy loss

- **Collisional**/elastic **energy loss** may be **important** for heavy quarks
- Still not good agreement at high-pT

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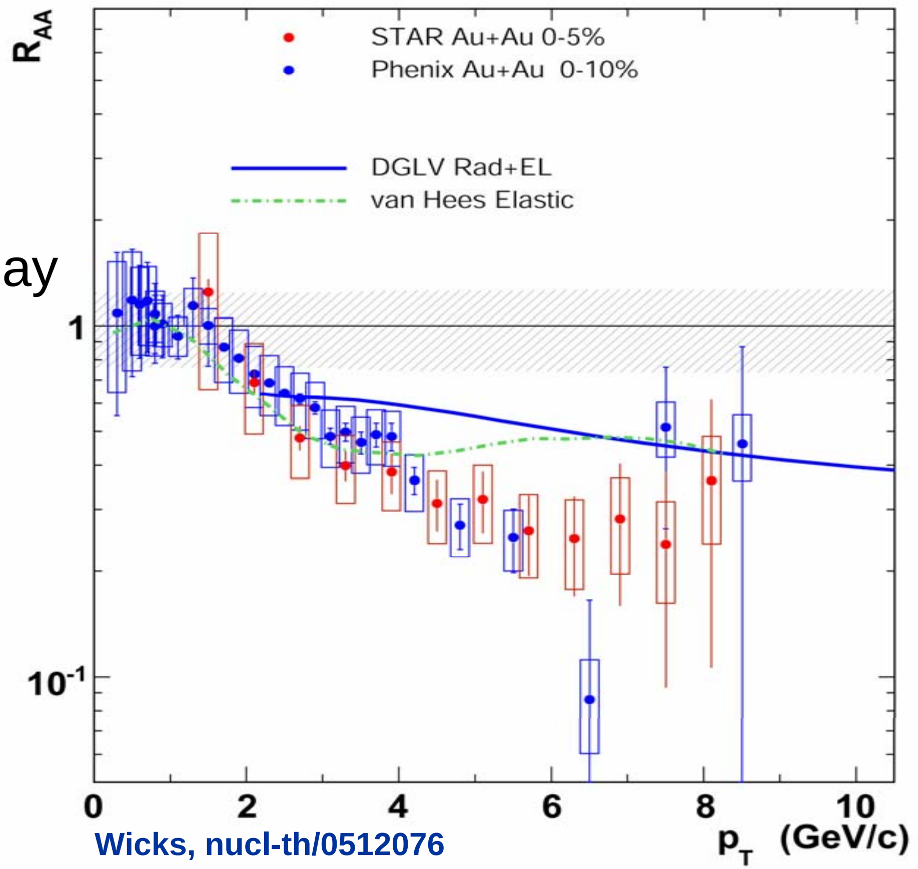

Wicks, nucl-th/0512076
van Hess, Phys. Rev. C73 034913 (2006)

Charm alone?

- Since the suppression of b quark electrons is smaller
  - **charm alone agrees better**
- **What is b contribution?**

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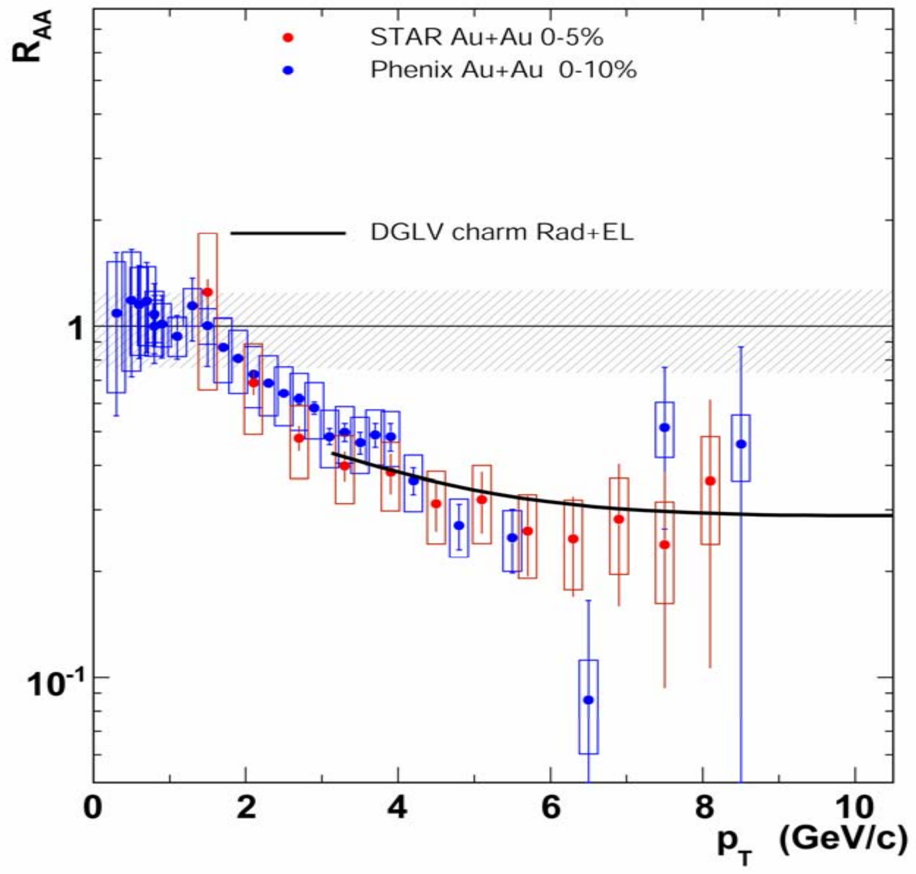

In medium fragmentation

- **Other effects** may contribute to the observed suppression
  - – heavy quarks can **fragment inside the medium** and can be suppressed by **dissociation**
- both **b+c** taken into account

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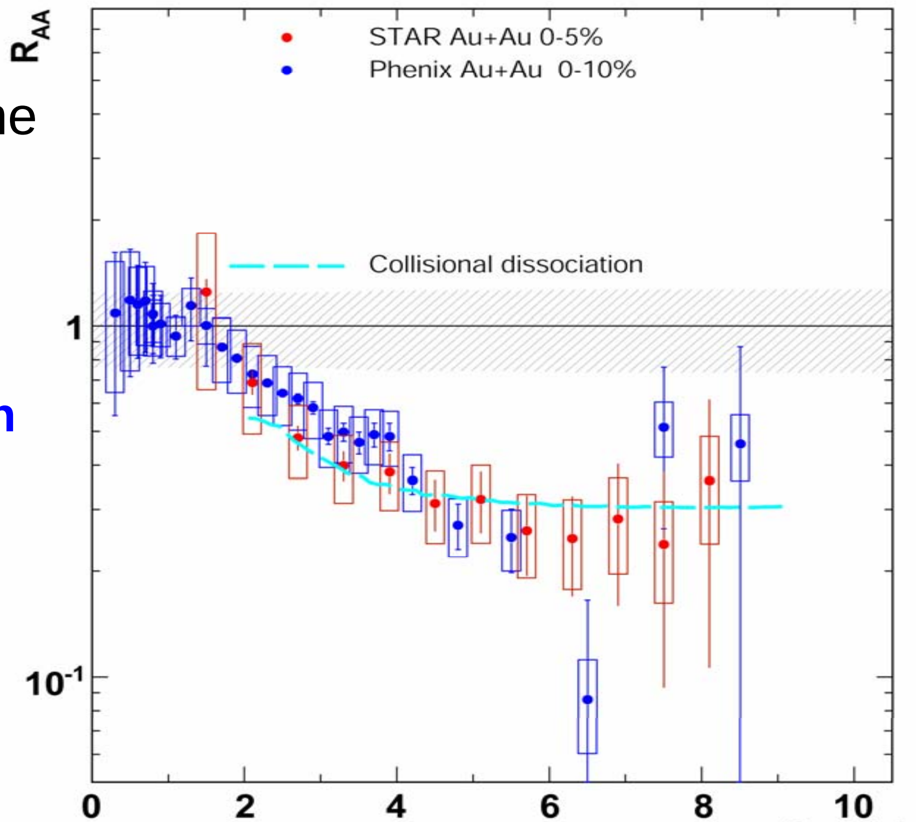
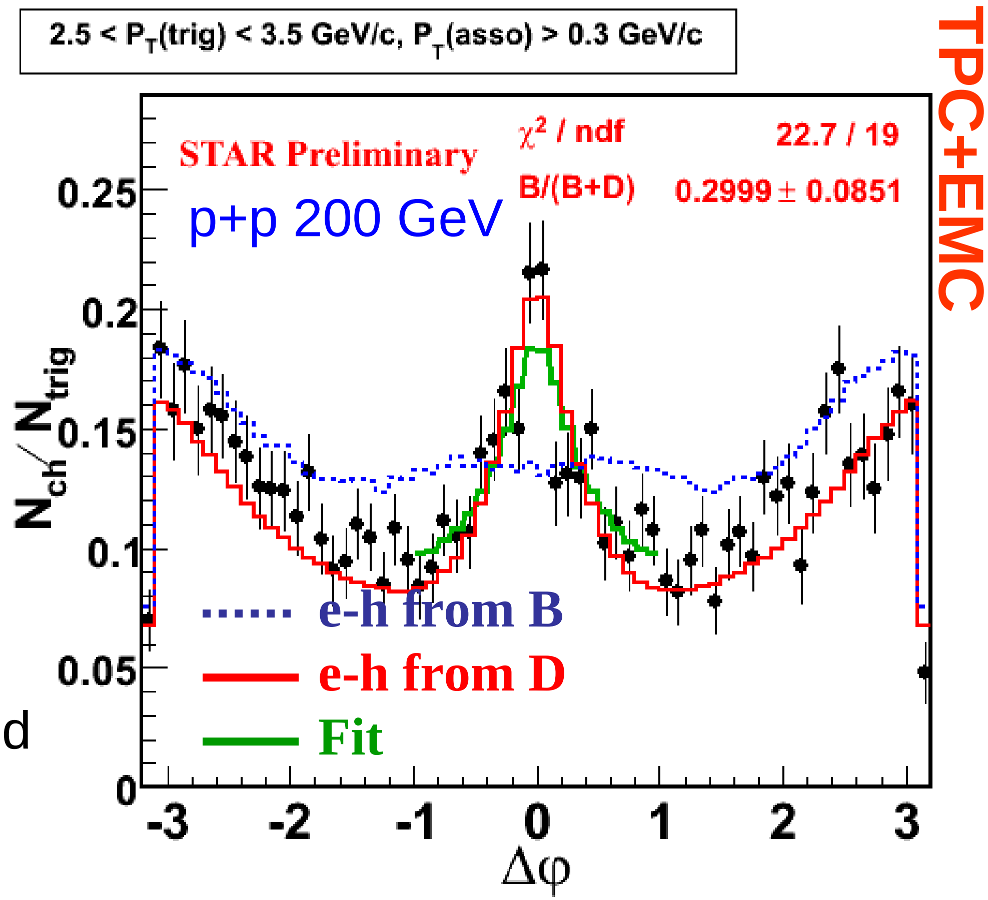


Adil and Vitev, Phys.Lett.B649 (2007) 139

Can we tell how much beauty?

- Use e-h Correlation
  - Large B mass compared to D
  - Semileptonic decay:
    e gets larger kick from B
  - Broadened e-h correlation on near-side.
- **Extract B contribution**
  - Use PYTHIA shapes
    - Con: Model dependent
    - Pro: Depends on decay kinematics →well described
  - Fit ratio **B/(B+D)**

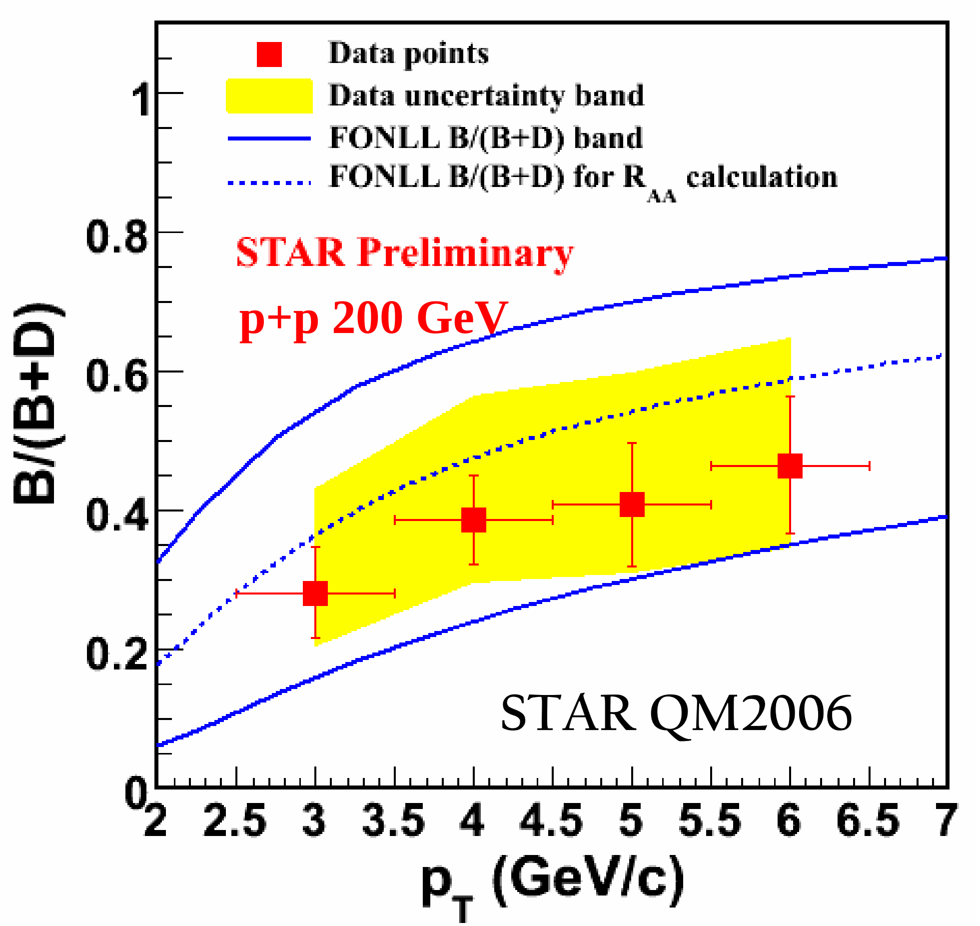


STAR QM2006 nucl-ex/0701050

Relative bottom contribution to nonphotonic electrons vs. p_T

Bottom !

- Fit **e-h** correlation with **PYTHIA** D and B
- **Data** shows non-zero **B contribution**
- Contribution **consistent** with FONLL
  - **Model dependent (PYTHIA)**
  - **Depends mainly on kinematics of D/B decay (not on Fragmentation)**
- Dominant systematic uncertainty:
  - photonic background rejection efficiency
  - Additional uncertainties under study



Heavy flavor tagged correlations

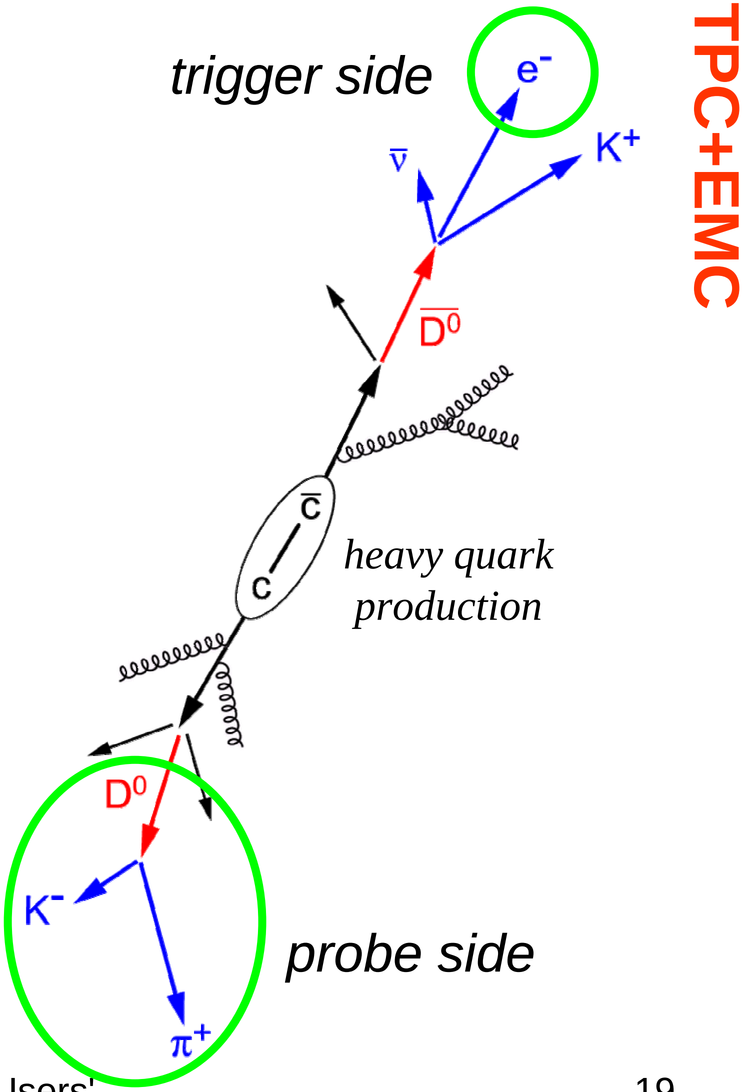
- Advantage: STAR has large acceptance (|η| < 1 and full azimuth)

- **Underlying production mechanism** can be identified using second charm/bottom particle

- **Experimental approach**

  - **non-photonic electrons** from semi-leptonic c/b decays are used to **trigger** on **c-cbar** or **b-bbar** pairs

  - **associate D^0** mesons are reconstructed via their **hadronic decay** channel (probe)



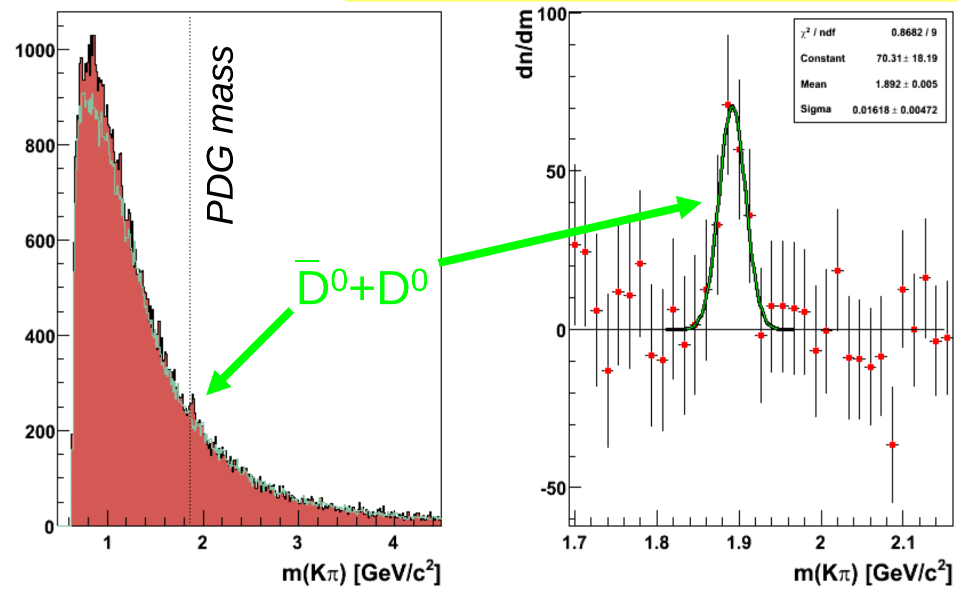
electron-D^0 azimuthal correlations

- Clear **D^0 signal**
  - S/B ratio factor ~100 better than signal w/o electron trigger
- Near- and away-side correlation peak with similar yields observed

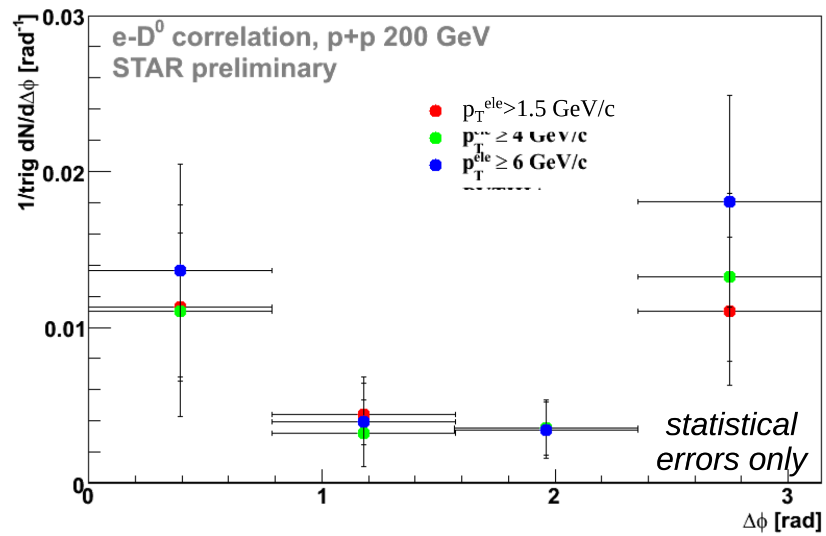
→ Evidence for heavy flavor correlations

- Next: Separate charm and bottom contribution as well as sub-processes (e.g. gluon splitting) using
  - dedicated simulations
  - charge-sign requirement on (e, D^0) pairs

p+p $\sqrt{s_{NN}}$ = 200 GeV, ∫Ldt = 9 pb^{-1}



STAR nucl-exp 0705.2089



Mid-Term Upgrades at RHIC

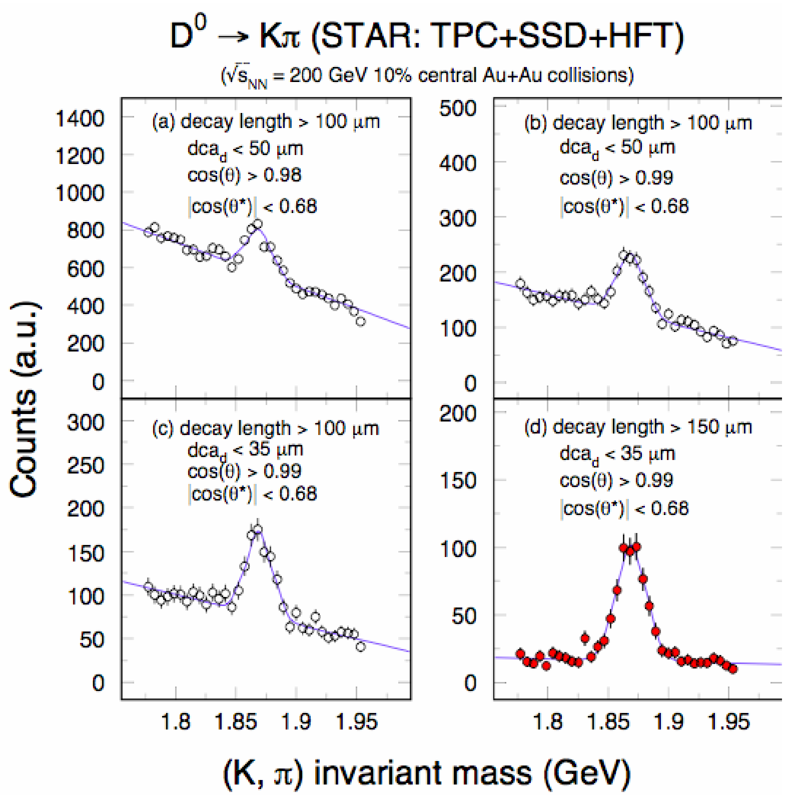
- **Detector Upgrades** relevant for heavy flavor physics

Particle identification	– improved electron PID – improved PID range for charm decay daughters	STAR – Full barrel ToF – Barrel μ Detector
Displaced vertex detection	direct open charm and bottom measurements	STAR high precision vertex tracking HFT (Silicon pixel & strip layers)
Increased rate and acceptance	larger open heavy flavor yields	STAR: – New TPC Readout Electronics – DAQ upgrade

Machine Upgrade (RHIC-II):Increased luminosity (x 40) via electron cooling

See Z.Xu talk on STAR upgrades

HFT Direct Charm Measurements



Current data rate:
100×10^6 per run
DAQ1000: x10 rate

Spectra vs p_T at 10% error

p_T (GeV/c)	Δp_T (GeV/c)	# of Events (p + p)	# of Events 0-10% Au + Au (N_{bin} = 950)	# of Events 0-80% Au + Au (N_{bin} = 290)
1.0	0.5	44×10^6	0.45×10^6	1.75×10^6
2.0	0.5	70×10^6	0.45×10^6	1.75×10^6
3.5	1.0	70×10^6	0.45×10^6	1.75×10^6
5.5	1.0	350×10^6	0.75×10^6	3×10^6
7.5	1.0	1200×10^6	3.5×10^6	11×10^6
10.5	1.5	7500×10^6	9×10^6	30×10^6

Elliptic flow v_2 vs p_T at 10% error

p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Open bottom

B-> J/psi+X

- possible with displaced vertex measurement and RHIC II luminosity
- enough for measurement of cross section and $R_{AA} \sim p_T, y$
- not enough for v_2 measurement

Species	signal	$\|\eta\|$	To Date	Projected RHIC I	Projected RHIC II
pp	$J/\psi \to e^+e^-$	< 1.0	–	1,260,000	1,600,000
	$\psi' \to e^+e^-$		–	23,000	29,000
	$\Upsilon \to e^+e^-$		–	6,600	8,300
	$B \to J/\psi \to e^+e^-$		–	15,000	19,000
Au+Au	$J/\psi \to e^+e^-$	< 1.0	?	16,000	220,000
	$\psi' \to e^+e^-$		–	300	4,000
	$\Upsilon \to e^+e^-$		?	830	11,200
	$B \to J/\psi X \to e^+e^- X'$		–	190	2,500
	$D \to K\pi$		–	30,000	30,000

12 weeks run; HFT in; D assumes 100Hz min.bias rate

Conclusions and considerations

- **Heavy flavor** is an **important** tool to understand HI physics **at RHIC**
- First RHIC results are **interesting** and challenging
  - Large **differences** in cross section between **Phenix** and **STAR**
  - **Binary scaling** in charm production
  - Why so much **suppression** at high-p_T?
  - Charm and bottom **relative production**. Where bottom starts dominating?
    - First attempts from STAR indicates a non-zero **contribution of bottom** to the non-photonic electron spectra
    - First observation of **heavy flavor correlations**
    - Very first step on the understanding of **heavy quark energy loss**
- **RHIC II** higher-luminosities and detector upgrades
  - more **precise** measurements of **charm**
  - direct **access** to **bottom** physics

Conversion from dN/dy to Cross-Section

$$\sigma_{c\bar{c}}^{NN} = dN_{D^0}^{Cu+Cu} / dy \times \sigma_{inel}^{pp} / N_{bin}^{Cu+Cu} \times f / R$$

$$dN_{D^0} / dy = 0.132 + / - 0.025\,(\text{stat.})$$

p+p inelastic cross section $\sigma_{inel}^{pp} = 42\, mb$

number of binary collisions $N_{binary}^{Cu+Cu} = 51.52 + 1.04 - 2.87$

conversion to full rapidity $f = 4.7 \pm 0.7$

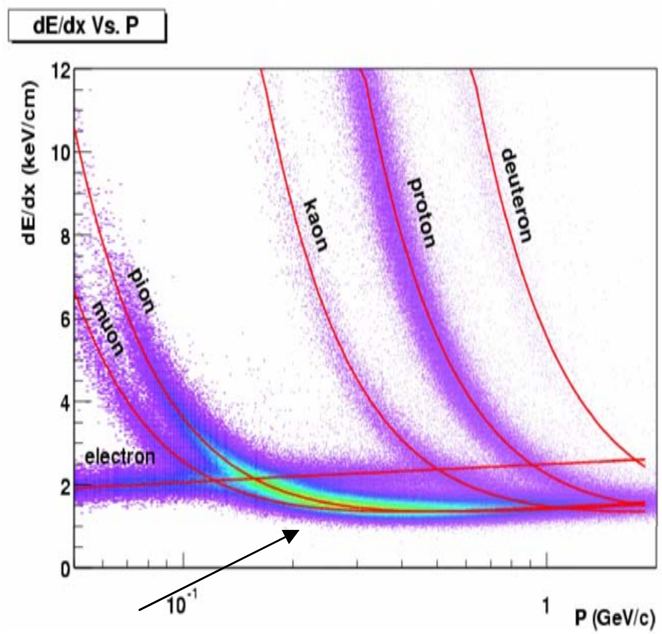
ratio from e+e- collider data $R = N_{D^0} / N_{c\bar{c}} = 0.54 \pm 0.05$

$$\Rightarrow \sigma_{c\bar{c}}^{NN} = 0.94 \pm 0.18(stat.)\, mb$$

$$\text{sys. error from dN/dy to } \sigma \text{ conversion} = +0.17 - 0.18\, mb$$

***Systematic error measurement for dN/dy in progress.**

Muon measurement

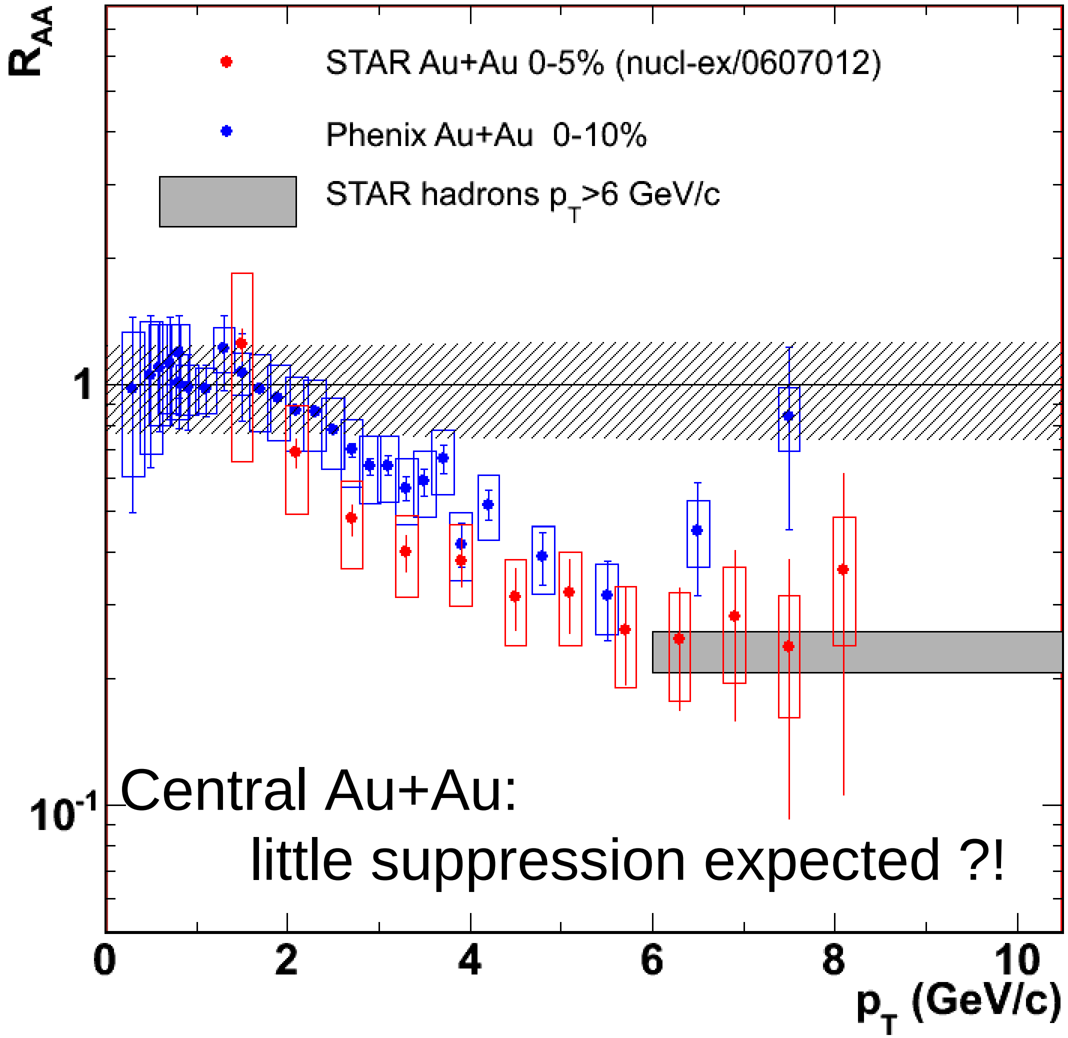


- There are no photonic muons !!!
- **p_T 0.16-0.26 GeV/c**
- it is good that it is so low p_T

TPC+TOF

R_{AA} from d+Au to central Au+Au

Phys. Rev. Lett. **98** (2007) 192301



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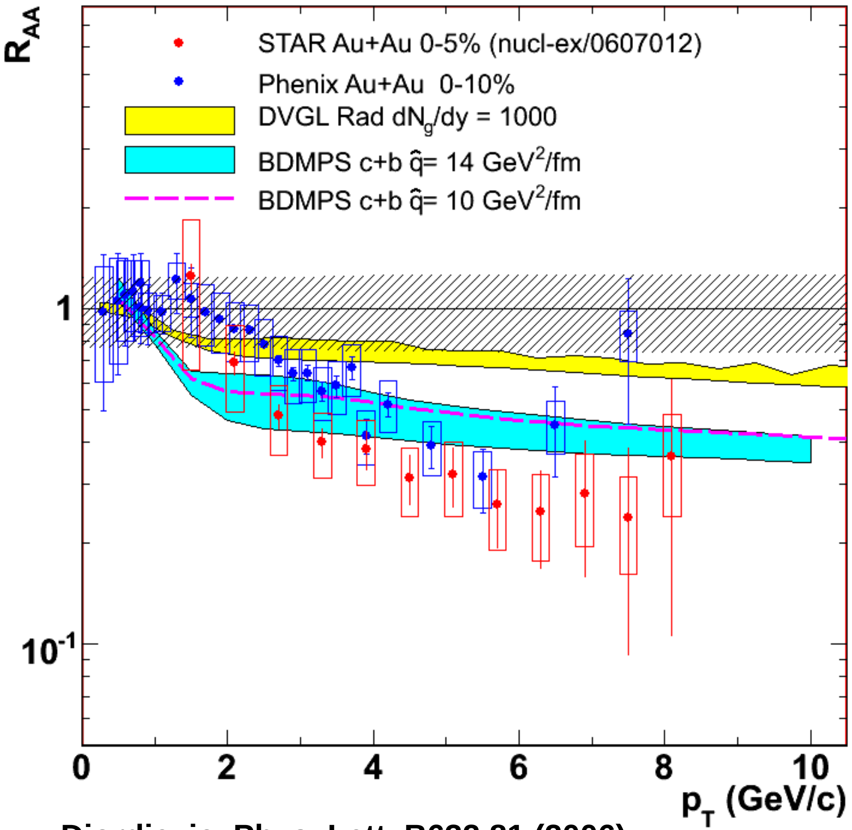

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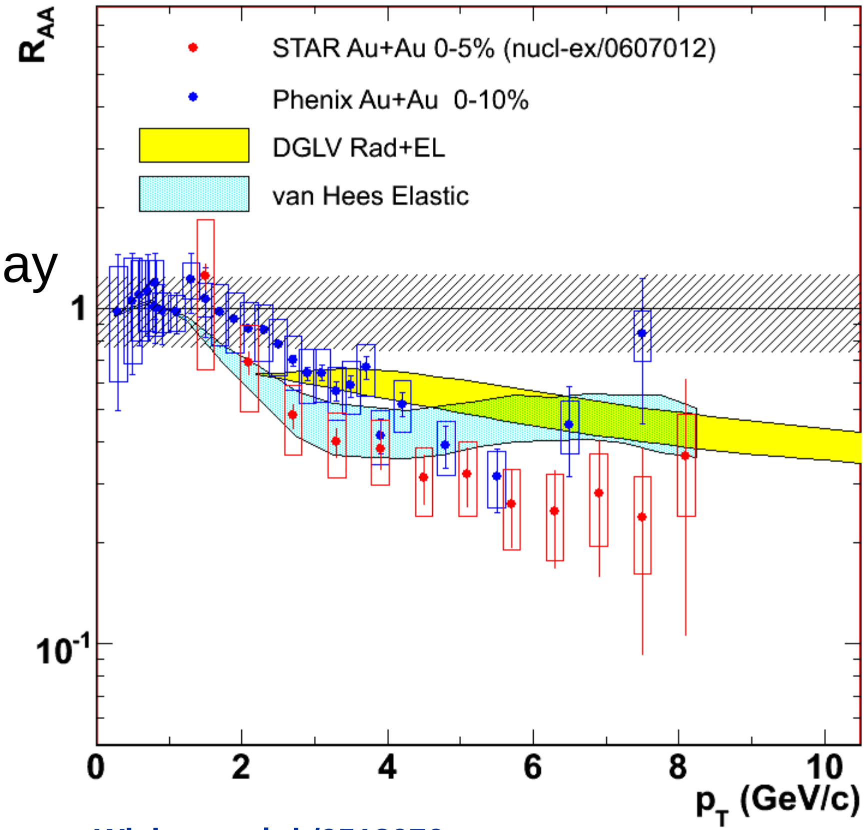

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van Hess, Phys. Rev. C73 034913 (2006)

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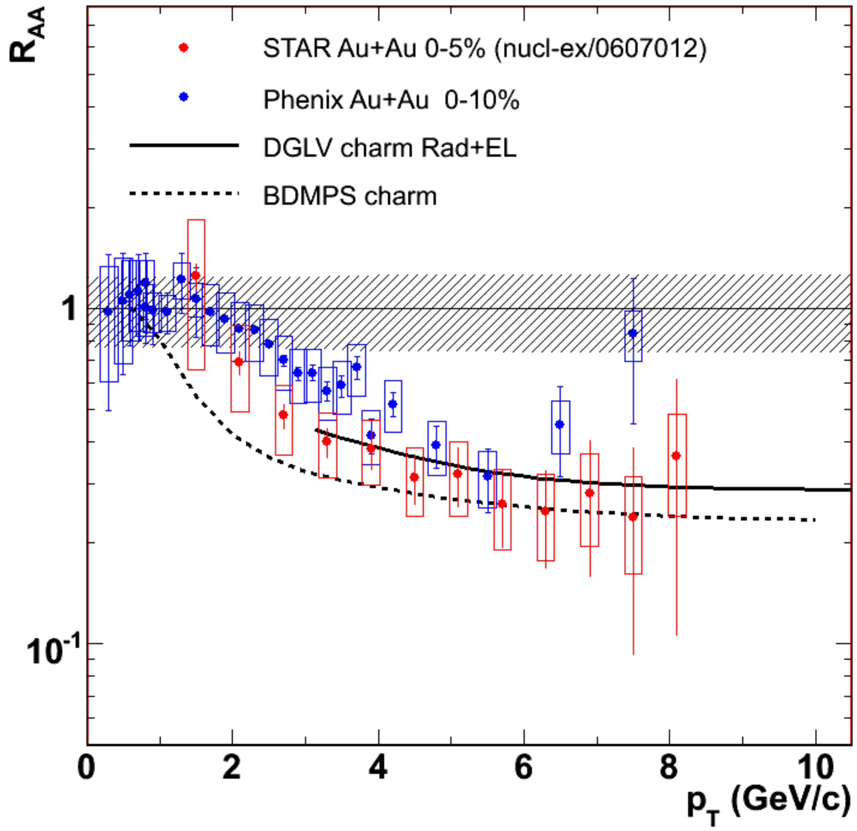

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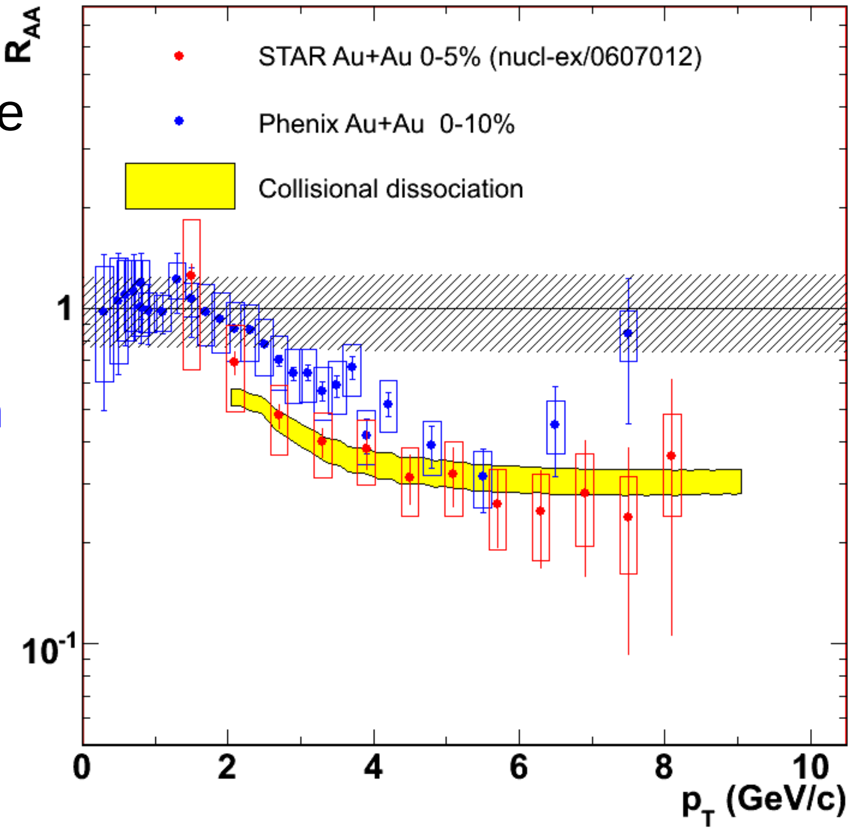
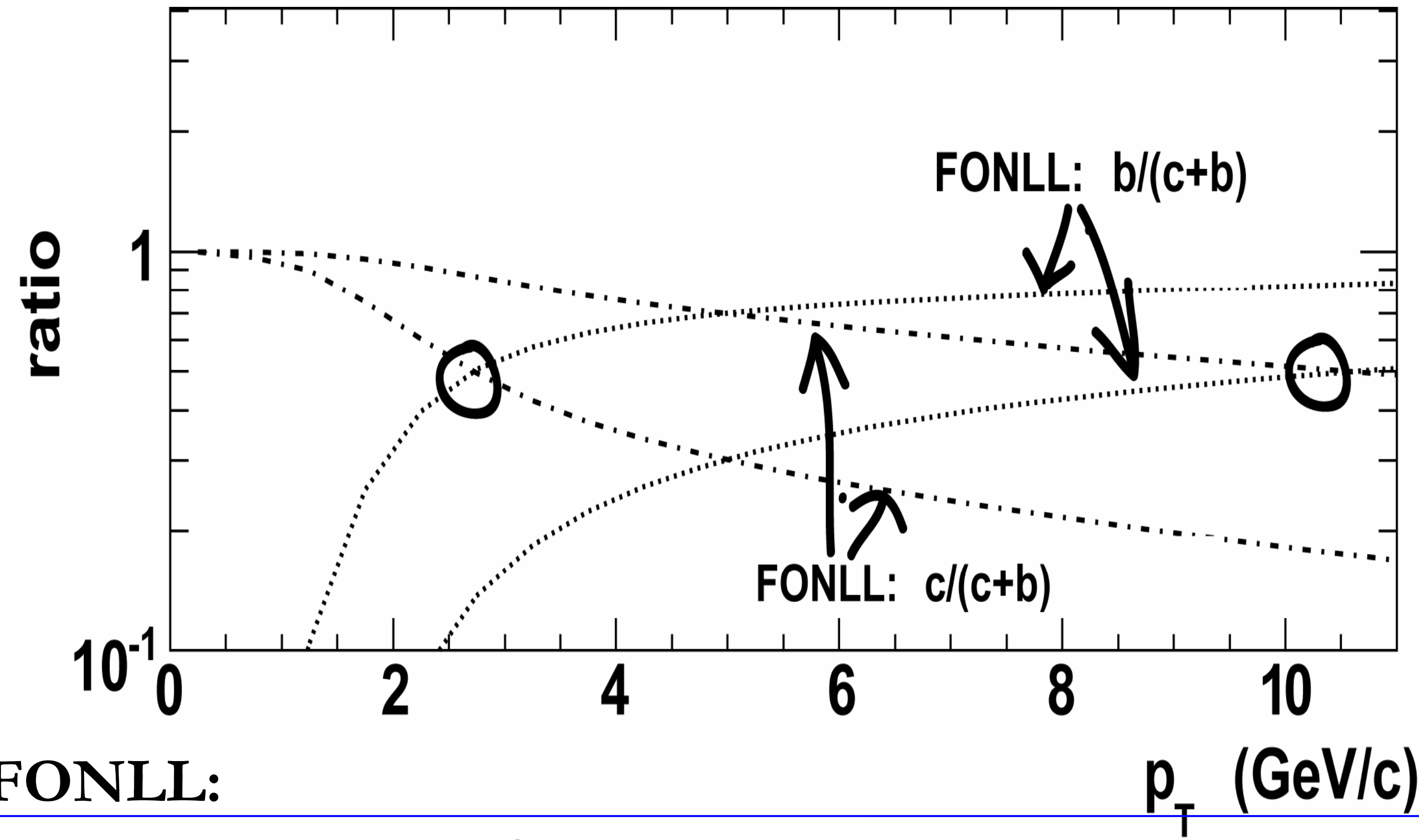


Adil and Vitev, Phys.Lett.B649 (2007) 139

Uncertainty of c/b relative contribution



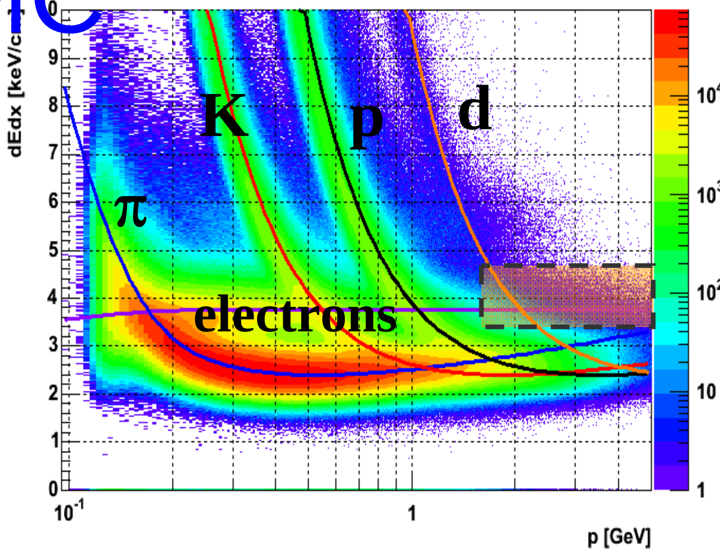
- FONLL:

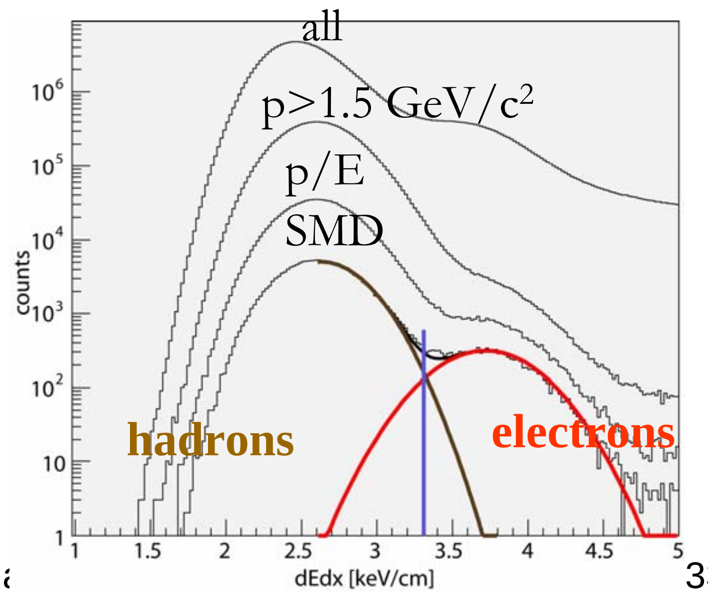
Large uncertainty on c/b crossing 3 to 9 GeV/c

Beauty predicted to be significant above 4-5 GeV/c

Electron ID in STAR – EMC

1. TPC: dE/dx for p > 1.5 GeV/c
   - Only primary tracks (reduces effective radiation length)
   - Electrons can be discriminated well from hadrons up to 8 GeV/c
   - Allows to determine the remaining hadron contamination after EMC
2. EMC:
   a) Tower E p/E~1 for e^-
   b) Shower Max Detector
      - Hadrons/Electron shower develop different shape





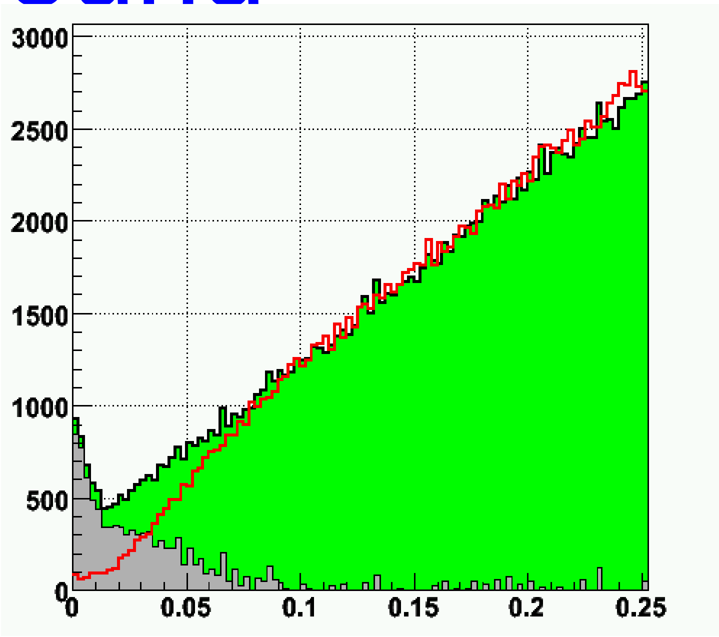
85-90% purity of electrons (p_T dependent)

Photonic electrons background

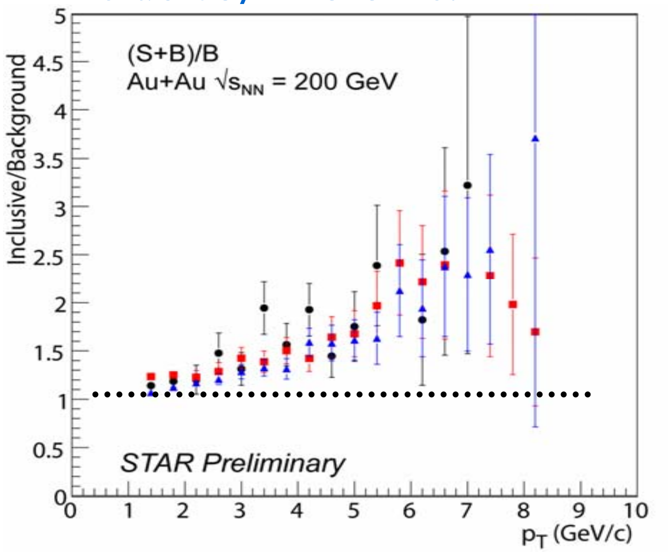
- **Background: Mainly from γ conv and π^0,η Dalitz**
- **Rejection strategy:**

For every electron candidate

- Combinations with all TPC electron candidates
- M_{e+e-}<0.14 GeV/c^2 flagged *photonic*
- Correct for primary electrons misidentified as background
- Correct for background rejection efficiency ~50-60% for central Au+Au



Inclusive/Photonic:



- **Excess over photonic electrons observed for all system and centralities**

  => non-photonic signal