Open Charm Cross Section and Cronin Effect of Electrons and Identified Hadrons

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for the **STAR** Collaboration

- **Motivation**
- **Analysis techniques**
  - → event-mixing technique for D^0 analysis
  - → MRPC-TOFr detector for hadron and electron identification
  - → single electron spectrum: background subtraction
- **Physics Results**
  - → open charm total cross section:
    direct (D^0) and indirect (single electron)
  - → Cronin effect of identified hadrons and electrons
- **Conclusions**

Motivations

(I) Study heavy quark (charm) production

1) A unique probe to partonic matter
2) Sensitive to initial **gluon density** and possible **medium effects**

Important reference to understand **possible quarkonium suppression**

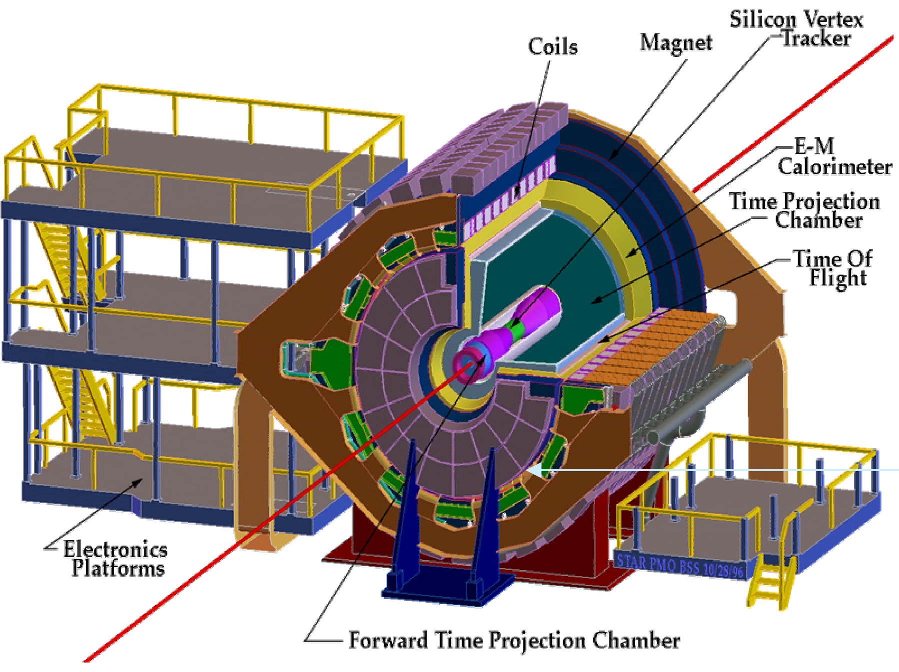
Parton energy loss
--- heavy quark "**dead cone**" effect

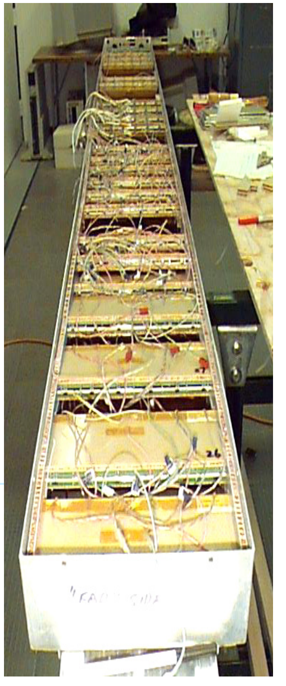
(II) Nuclear Modification Effects at RHIC

Measure $\mathbf{R_{dAu}}$ of π, K, p, e at 200 GeV.

$$R_{AB} = \frac{d^2N/(2\pi p_T dp_T dy)}{T_{AB} d^2\sigma_{inel}^{pp}/(2\pi p_T dp_T dy)}, T_{AB} = \langle N_{bin} \rangle / \sigma_{inel}^{pp}$$

STAR Detector: TPC & MRPC-TOFr





A new technology ----
Multigap Resistive Plate Chamber (MRPC)
adopted from CERN-Alice.
Advantages:
low cost,
high timing resolution (<100ps)

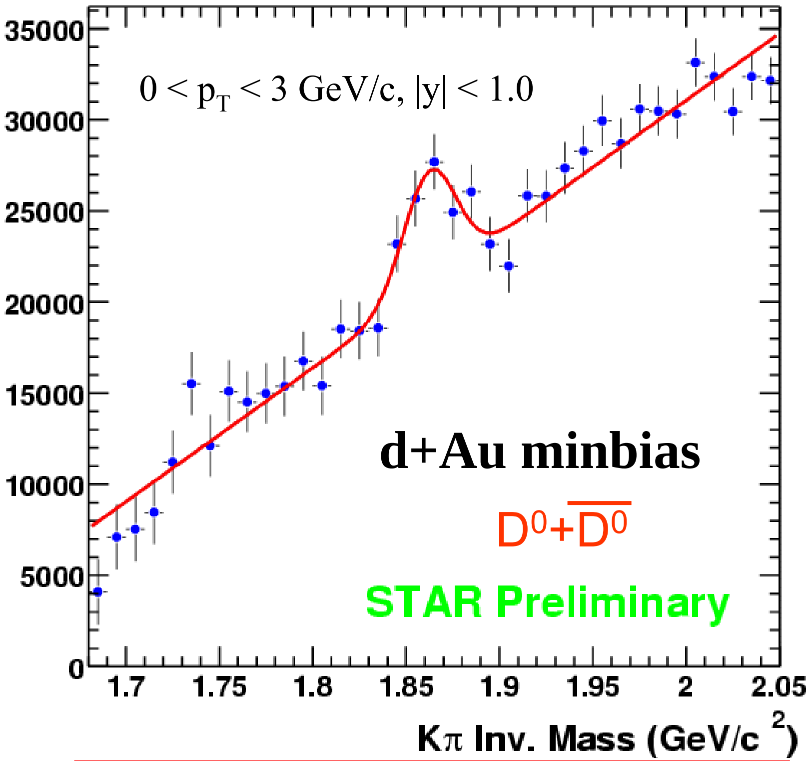
TPC dE/dx PID:
pion/kaon ~ 0.6 GeV/c, proton ~ 1GeV/c

MinBias Trigger:
ZDC-Au in d+Au, BBCs in p+p

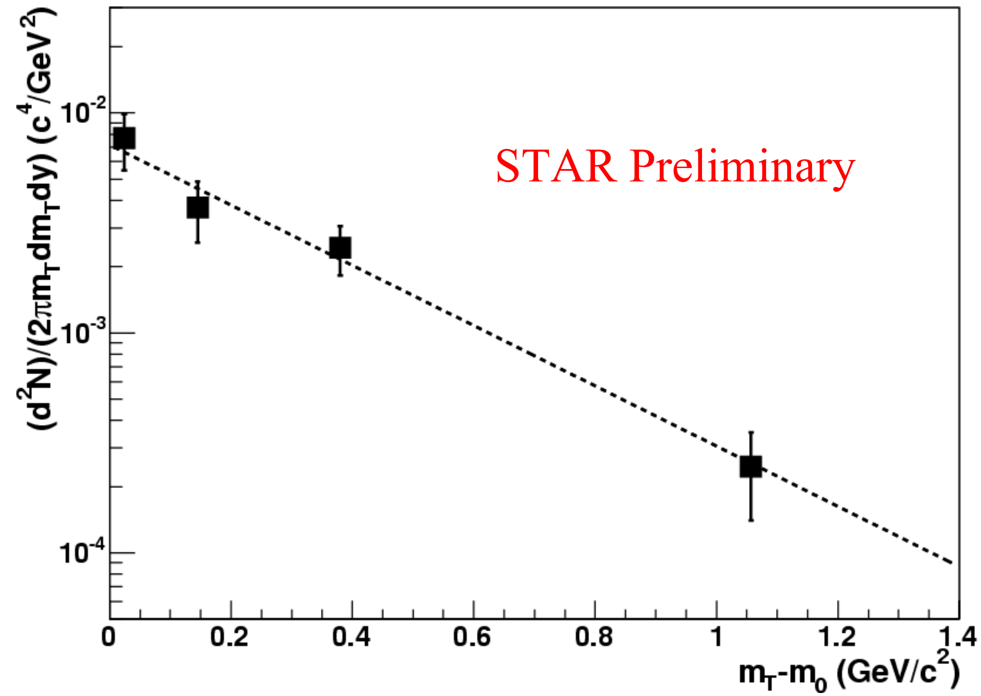
- A prototype detector of time-of-flight (**TOFr**) was installed in year3
- Just one tray: ~0.3% of TPC coverage (eta coverage (-1.0, 0.0), phi coverage 1/60 of 2π, in the forward Au beam outgoing direction)
- Intrinsic timing resolution: 85 ps in year3

Open charm reconstruction in STAR

hadronic channel: $D^0 \rightarrow K^- \pi^+$
(B.R. 3.80% ± 0.09%)



First direct open charm measurement at RHIC!



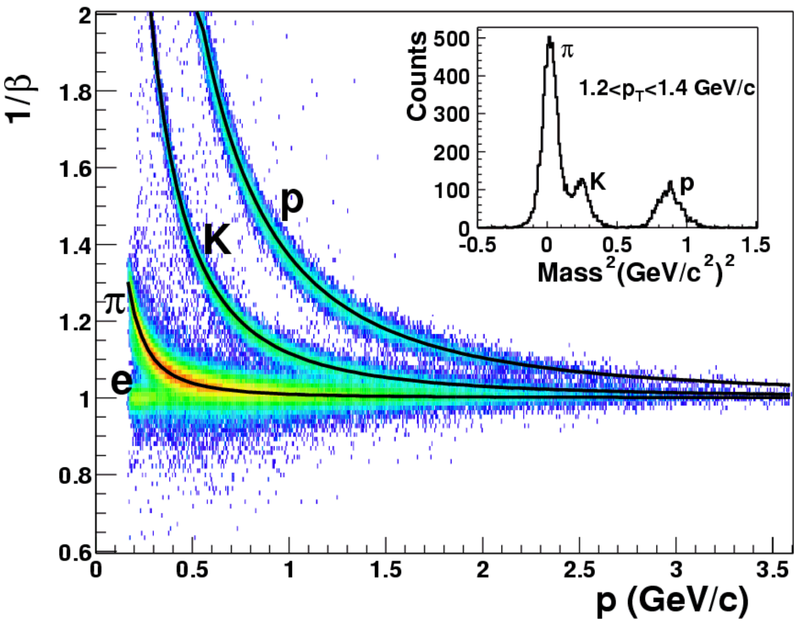
Exponential Fit

$$\frac{1}{2\pi m_T}\frac{d^2N}{dm_T dy} = \frac{dN/dy}{2\pi T(m_0+T)} e^{-(m_T-m_0)/T}$$

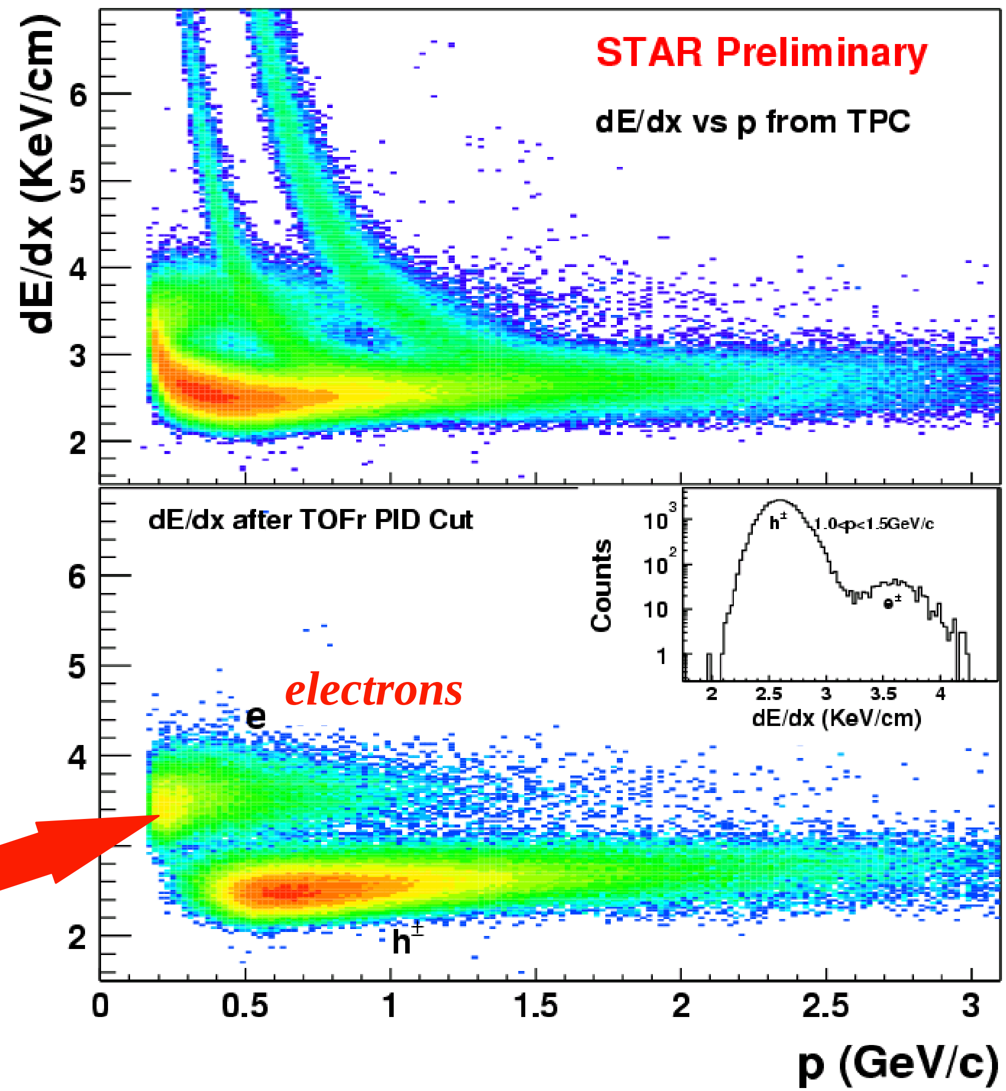
dN/dy = 0.0312 ± 0.0048 ± 0.007

T = 317 ± 47 ± 29 MeV

STAR MRPC-TOFr PID



Hadron identification:
STAR Collaboration, nucl-ex/0309012



Electron identification:

TOFr |1/ß-1| < 0.03

TPC dE/dx electrons!!!

Measurements of electron background

Single Electrons Spectra

- γ conversion
- π^0 , η Dalitz decays
- Kaon decays
- ρ ω Φ vector meson decays

background

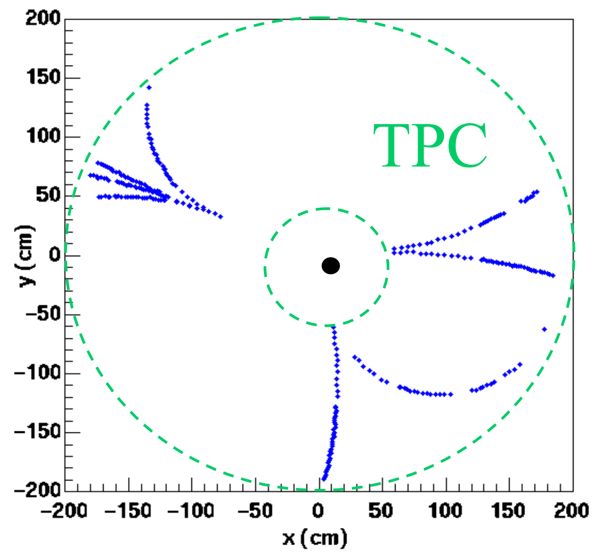
- heavy quark semi-leptonic decay
- others

signal

γ conversion and π^0 Dalitz decays are the dominant sources at low pt region.

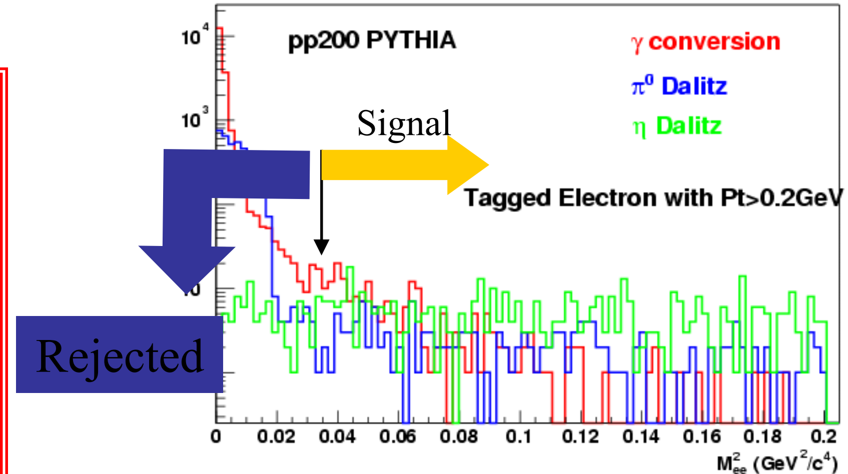
Electron Pair Topology:

- TOFr tagged e^+/e^-
- Large TPC acceptance
- High efficiency of reconstructing electron pair



Background subtraction

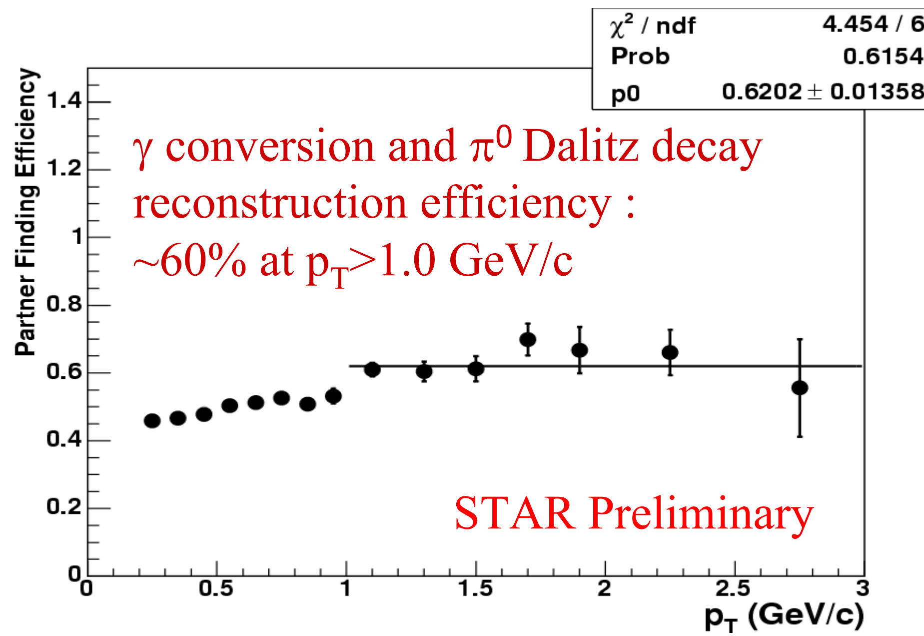
Invariant Mass Square



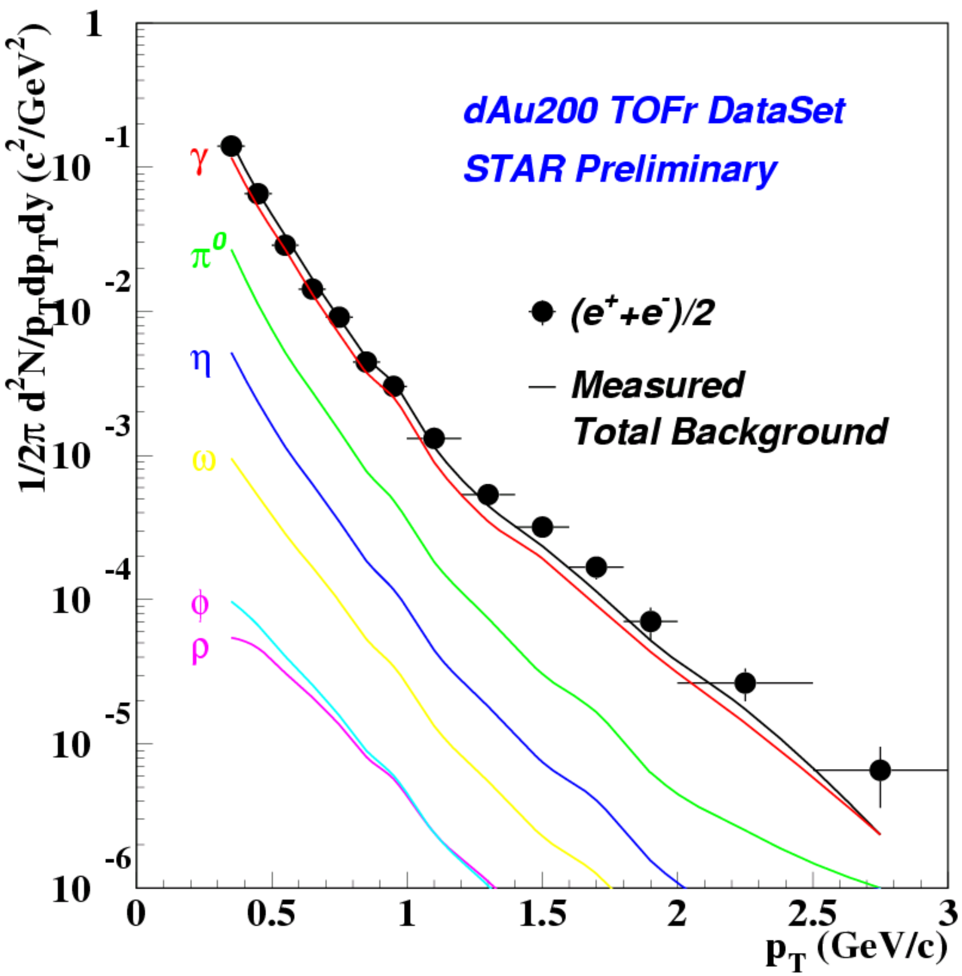
a) Data: background spectra
kinematical selection of the γ conversion and π^0 Dalitz decay pairs in TPC

b) MC: γ conversion and π^0 Dalitz decay reconstruction efficiency
~60%

c) MC: relative contributions of different sources:
determined from PYTHIA/HIJING + detector simulations



Contributions of different sources



p_T (1.0-3.0) GeV/c

Bg Sources	Contribution (%)
π^0 Dalitz decay	13 ± 1
γ conversion	82 ± 7
Total measured bkgd	~ 95
η	3.2
ω	1.0
ϕ	0.22
ρ	0.19
K	0.21
Total simulated bkgd	~ 5

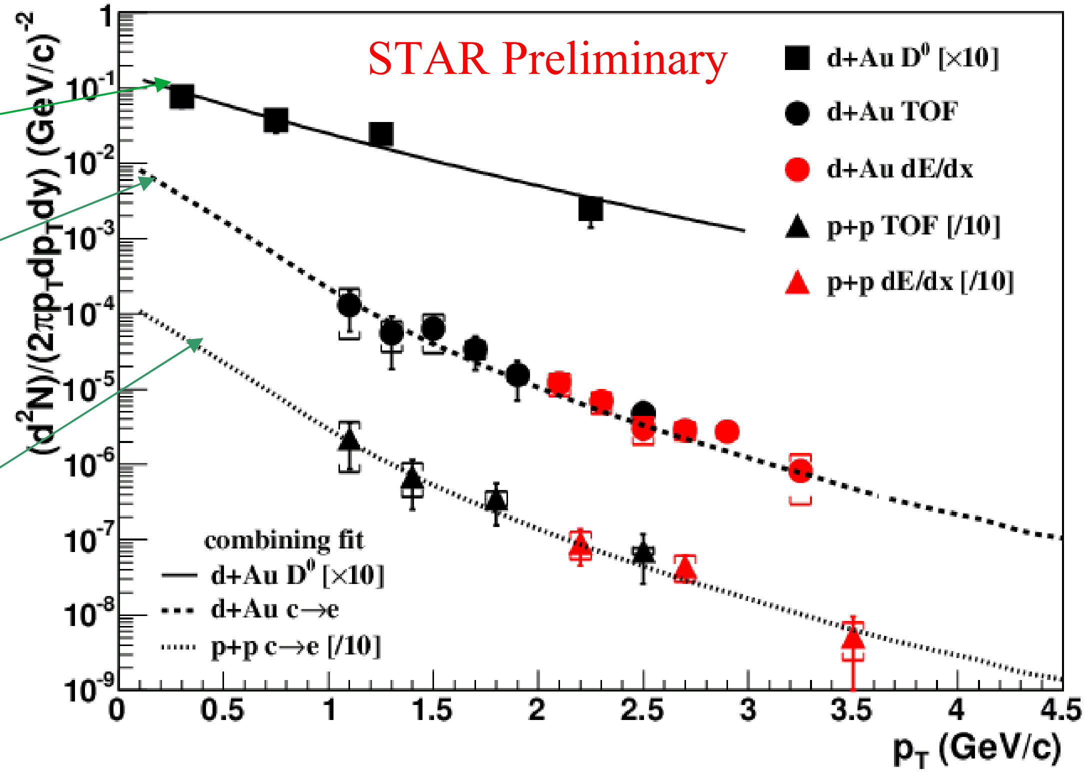
An increasing excess found in higher pt region, $p_T > 1.0$ GeV/c,
→as expected to be contribution of semi-leptonic decay from heavy flavor hadrons

D^0 meson and electron spectra from d+Au and p+p

Reconstructed D^0
(d+Au at 200 GeV)

From combined-fit
D decay
(d+Au at 200 GeV)

From combined-fit
D decay
(p+p at 200 GeV)



Combine D^0 and single electron,
p_T coverage for open charm mesons:

D^0 : $0<P_T<3$ GeV/c

Single electron for D^0 : $\sim2<P_T<\sim5$ GeV/c

$dN/dy = 0.033 \pm 0.005 \pm 0.009$

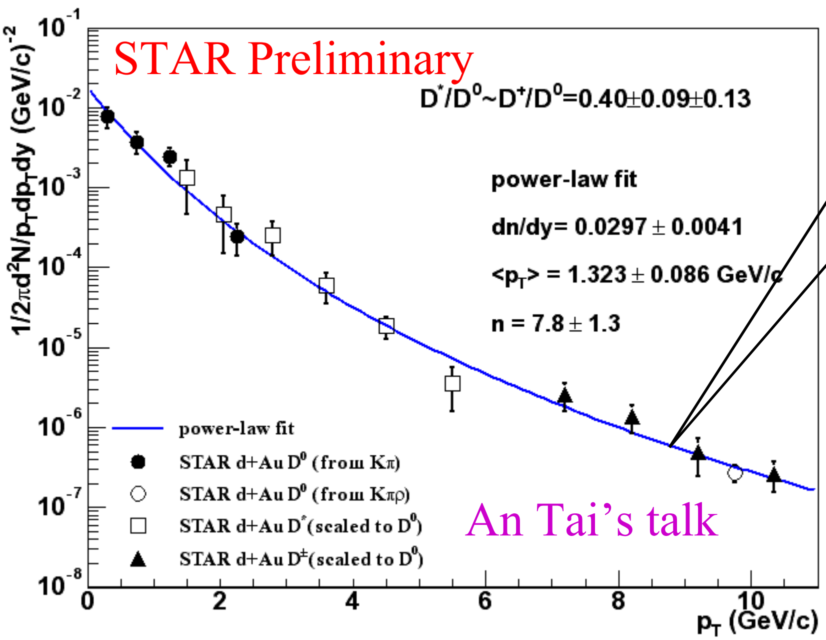
Assuming N_{bin} scaling

$$\sigma_{c\bar{c}}^{NN} = 0.033/54\%/7.5\times42\text{mb}\times4.0$$

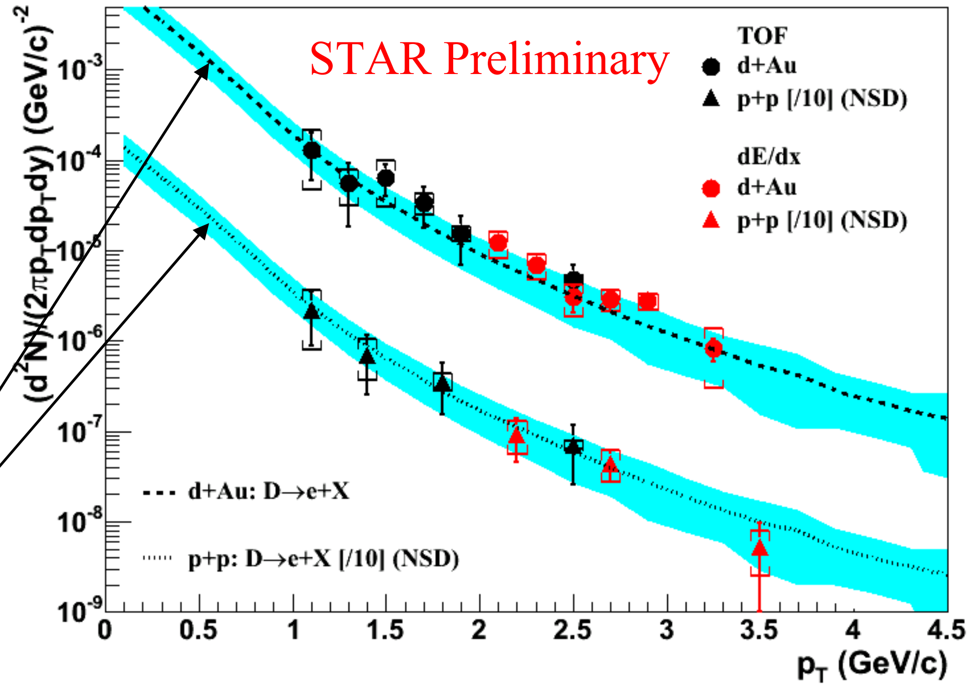
$$\mathbf{= 1.36 \pm 0.20 \pm 0.39\ mb}$$

D meson and electron spectra from STAR

Directly reconstructed D-mesons!



1.12 ± 0.20(stat) ± 0.37(syst) mb

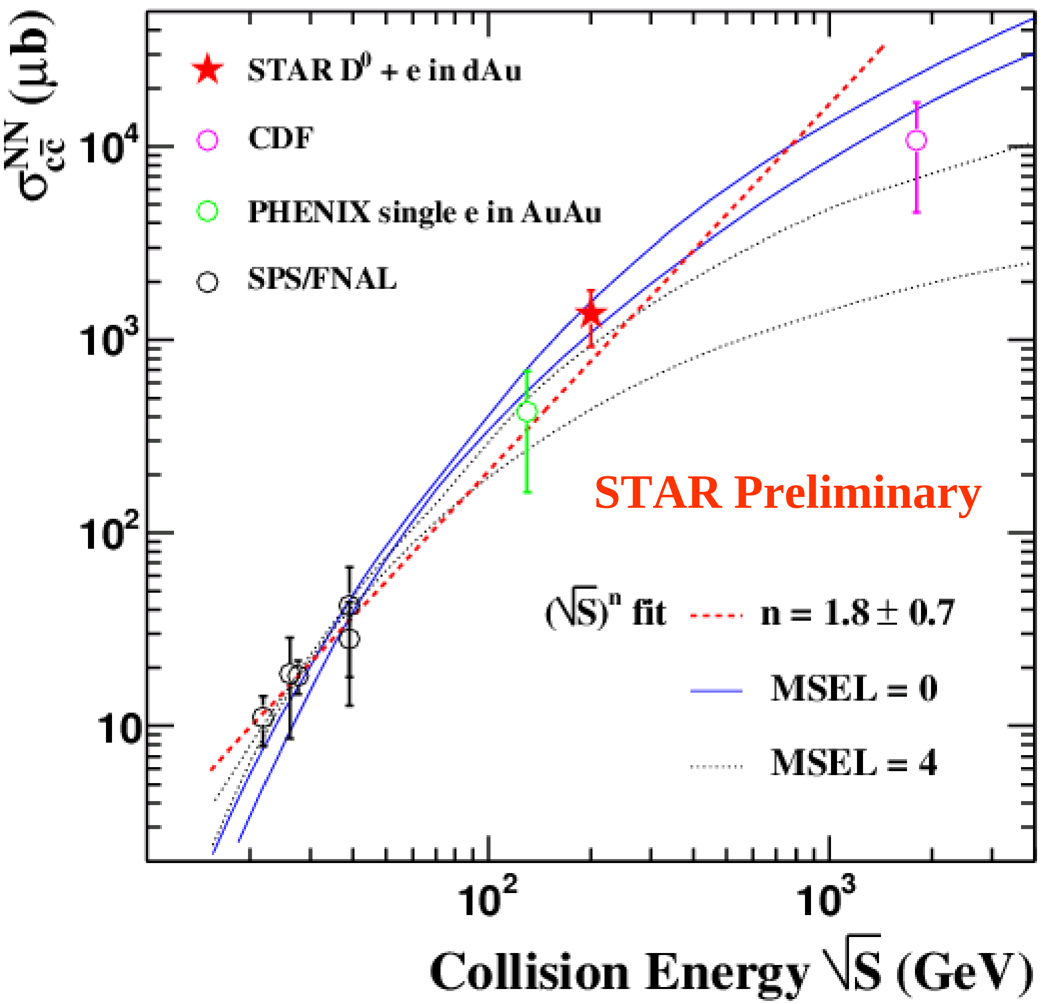


Data Points: Measured electron spectra

Lines: D-meson decayed electron spectra!

D and electron spectra are consistent!

Total charm production X-section

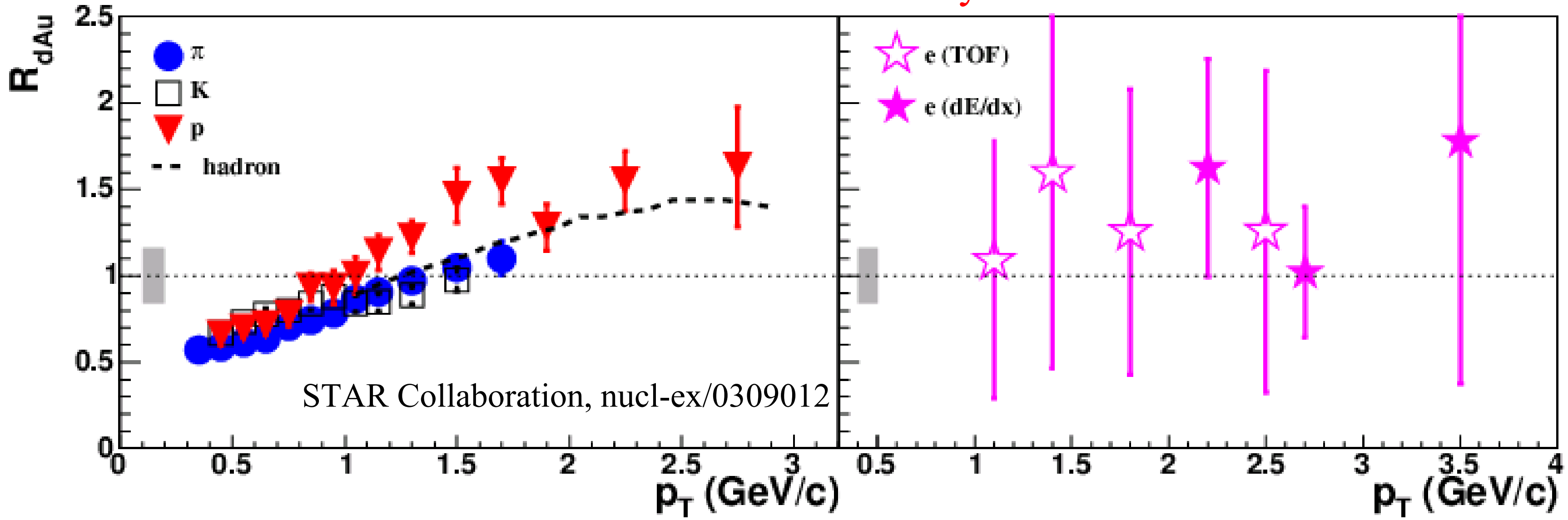


--- Curves from H. Wörhi, CIPANP03

- Total charm production cross section has been measured at 200 GeV
- Default Pythia calculations failed to reproduce data
- Higher order processes like ***flavor excitation, gluon splitting, parton showers*** et al. are needed for charm production at RHIC.

R_{dAu} of π, K, p, e --- Cronin Effect

STAR Preliminary



1. R_{dAu}(π,K,p): increase with transverse momentum
2. R_{dAu} (p) > R_{dAu} (π, K)
3. R_{dAu} (e) : ~ 1 **R_{dAu}(e) = 1.23 ± 0.26(stat) ± 0.31(sys)**
4. R_{dAu}(p) rises faster than R_{dAu}(π, K) and becomes larger than N_{bin} scaling within $1.5<p_T<3.0$ GeV/c.

Needs more data to address Open Charm Cronin effect!

Conclusions

- First results on **direct measurement** of D production ($0.1<P_T<11.0$ GeV/c) at RHIC.

- STAR MRPC TOF / TPC provide clean electron spectrum measurement up to $p_T \sim 3$ GeV/c in both 200 GeV p+p and d+Au collisions.

- Open charm from d+Au collisions: the directly measured open charm and single electron (from D decay) spectra are consistent!

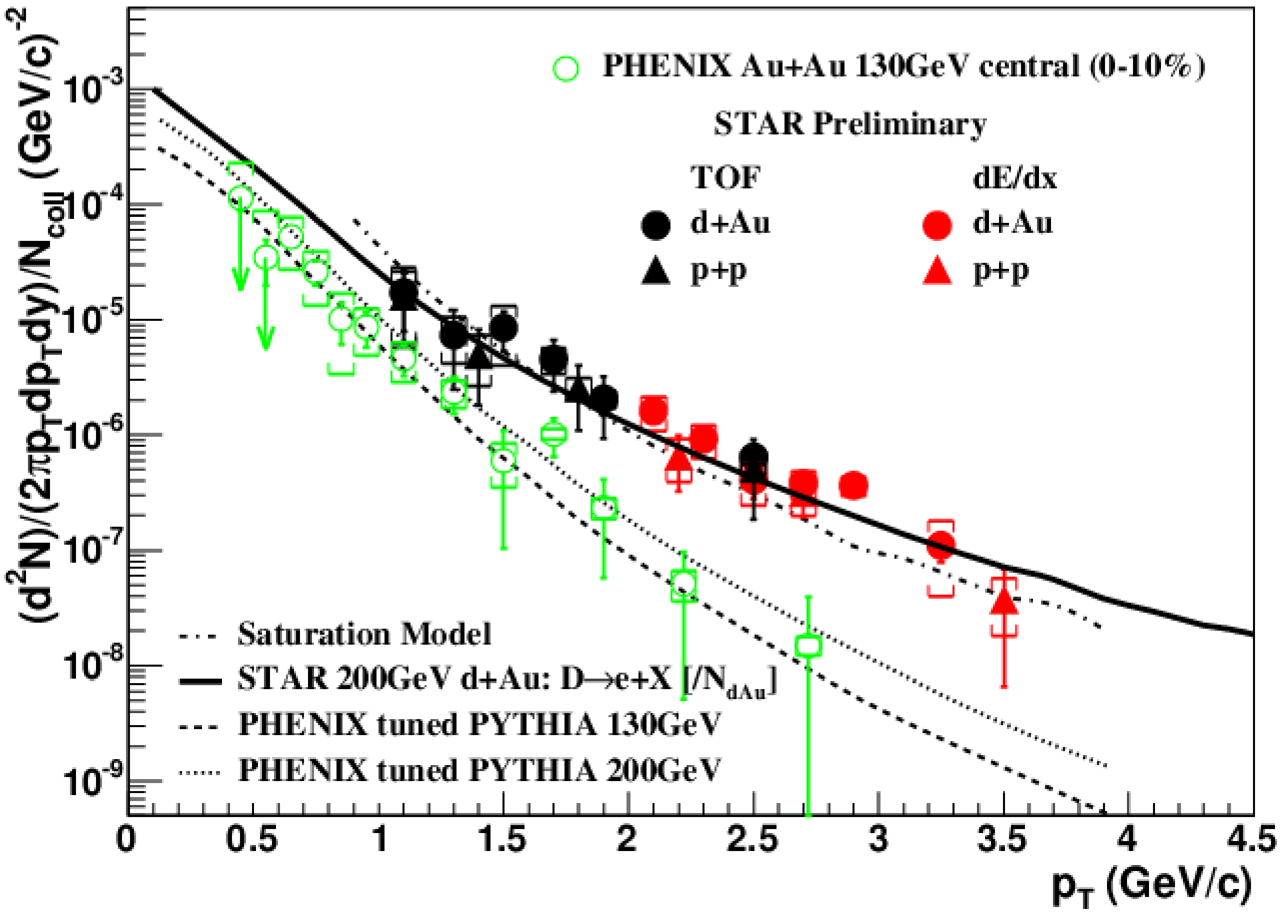
- Open charm total cross section measurements:

$$\begin{array}{ll} D^0\text{+e:} & \\ \text{All D:} & \end{array} \quad \sigma_{c\bar{c}}^{NN} = \begin{array}{l} 1.36 \pm 0.20(\text{stat}) \pm 0.39(\text{syst})\ \text{mb} \\ 1.12 \pm 0.20(\text{stat}) \pm 0.37(\text{syst})\ \text{mb} \end{array}$$

- R_{dAu} of e from charm production is consistent with $\boldsymbol{N_{bin}}$ scaling within the errors.

  This is an important physics and more data are needed to confirm this!

Outlook



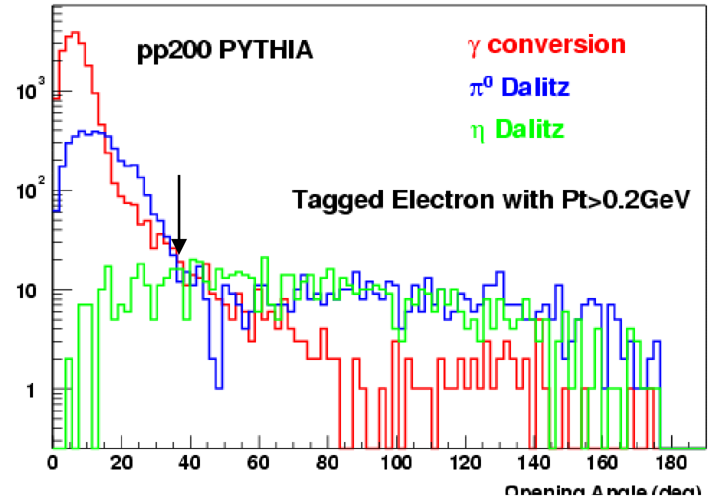
PHENIX data: Phys. Rev. Lett. 88, 192303 (2002)

Look forward to the electron spectra from Run 4 Au+Au collisions.

Backup Slides

Background Subtraction

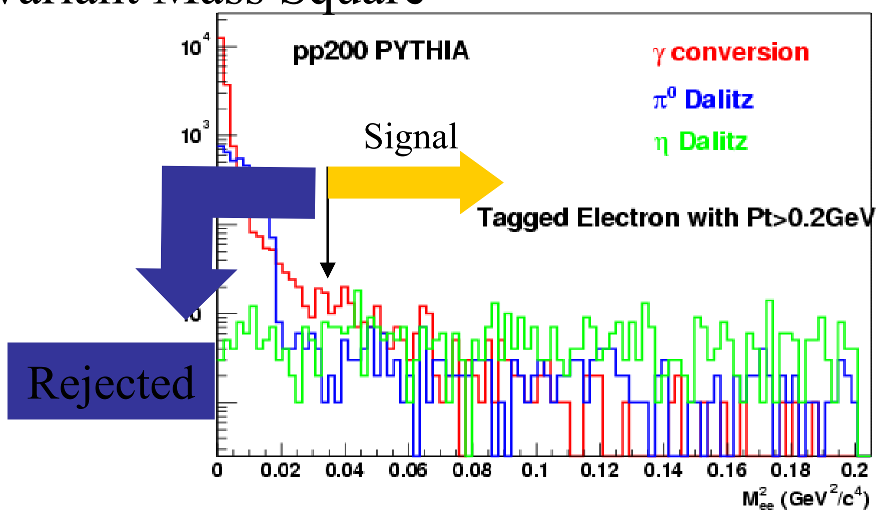
Opening Angle



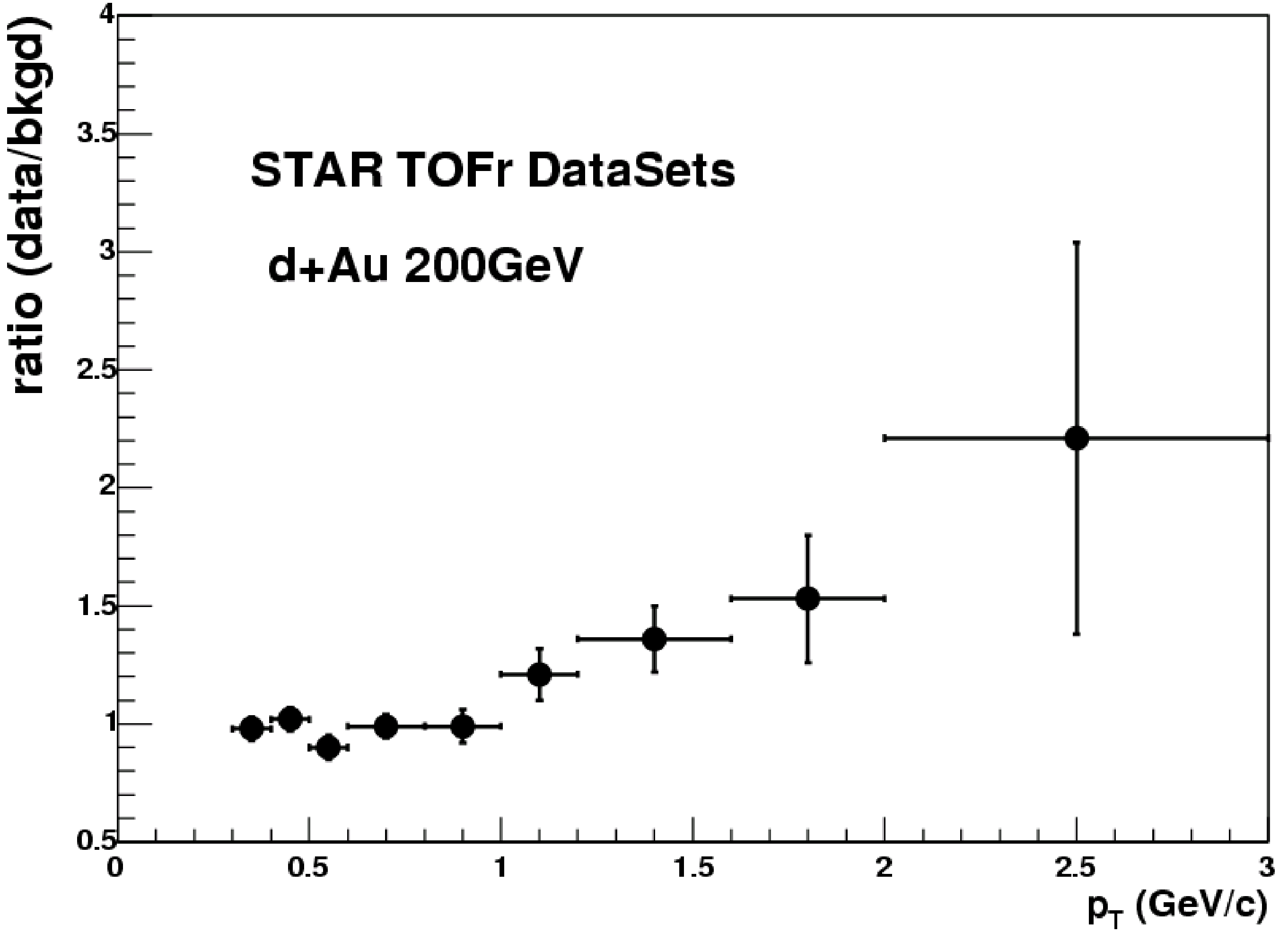
Main background subtraction

Using TOFr cut select an primary electron/position
--- Tag

Invariant Mass Square



Data/background ratio



Subtract background: step by step

a) Use MC Simulation to get the efficiency (~**60%** at P_T>1GeV/c) of our background subtraction under the kinematical cuts (for π^0 Dalitz decay and γ conversion).

b) Apply the same cuts on data, get the cutout background, scaled by the efficiency from simulation, and get the total background (π^0 Dalitz decay and γ conversion) from data.

c) Some other background (η,ρ,ω,Φ) as well as the signals which fall into the cuts and are randomly rejected are also corrected.

d) Use decay generators to get the single electrons spectra according to the assumed (p_t, y) distributions for η,ρ,ω,Φ, π^0 $\rightarrow$
get the background from η,ρ,ω,Φ by comparing through the background from π^0 Dalitz decay in data.

e) Background from Kaon decays is also studied from simulation and found to be negligible

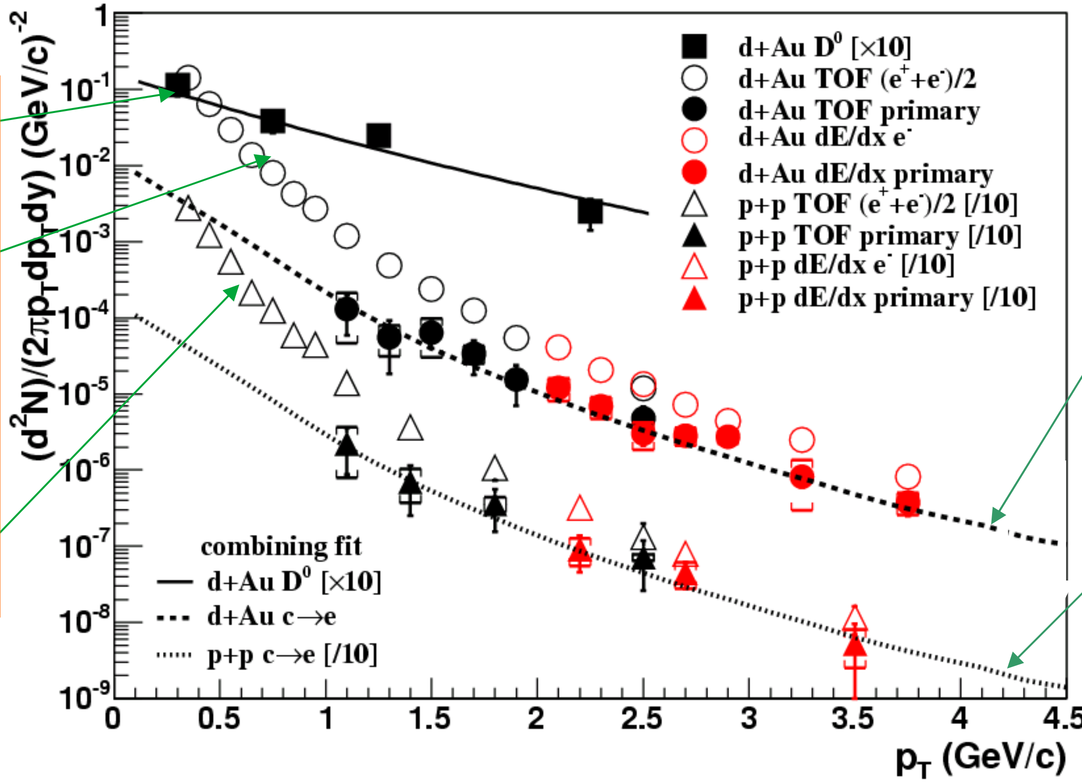
f) Extract the signal and estimate the heavy quark production

D^0 meson and electron spectra from d+Au and p+p

Reconstructed D^0
(d+Au at 200 GeV)

Inclusive electrons
(d+Au at 200 GeV)

Inclusive electrons
(p+p at 200 GeV)



From combined-fit D decay
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From combined-fit D decay
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Assuming N_{bin} scaling:

$$\sigma_{c\bar{c}}^{NN} =$$

1.36± 0.20 ± 0.39 mb

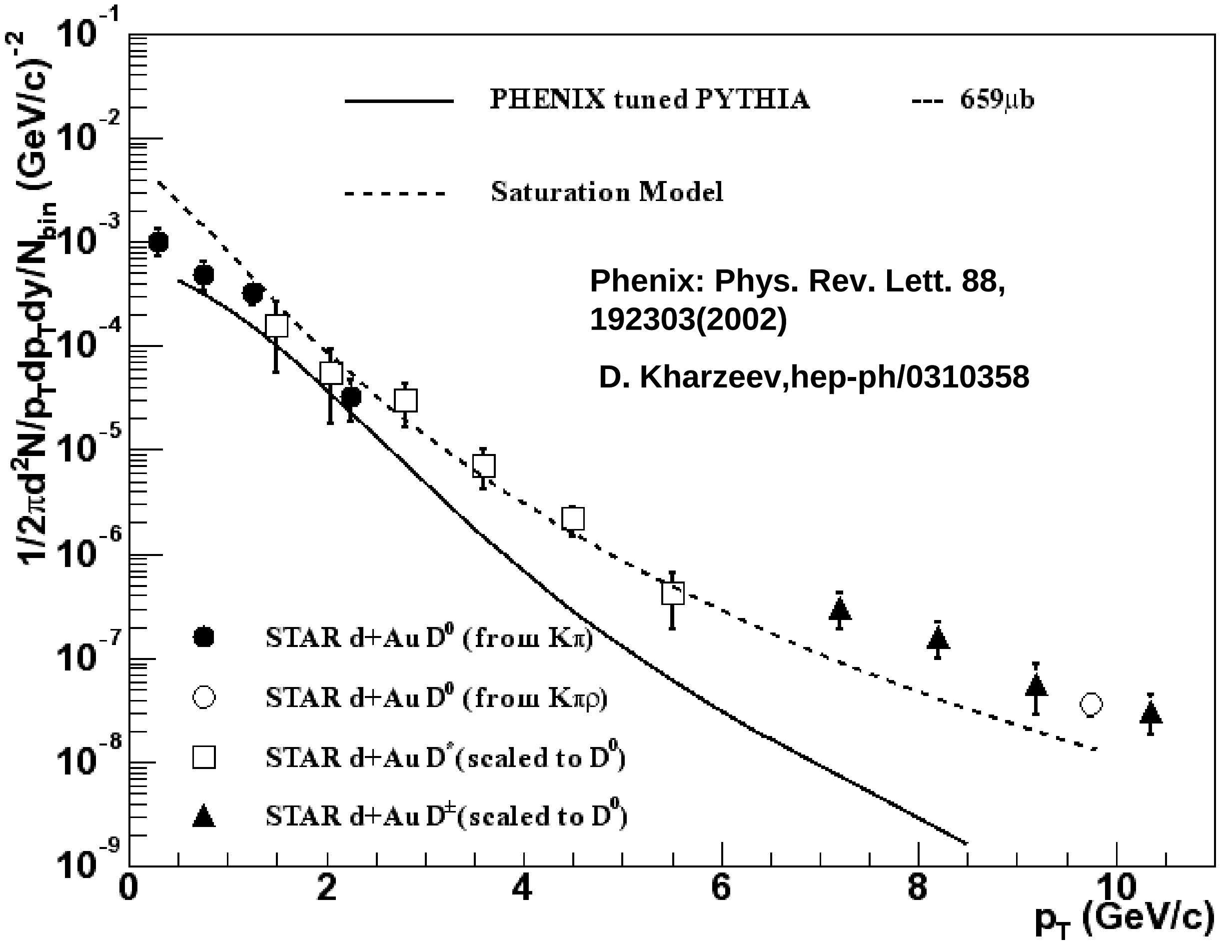
Charm total cross section

Table 1. Charm and bottom total cross sections per nucleon for the extrapolated calculations shown previously. The heavy quark mass and factorization/renormalization scales are given, along with the cross sections at 40 GeV (HERA-B), 200 GeV (Au+Au at RHIC), and 5.5 TeV (Pb+Pb at LHC).

			40 GeV	200 GeV	5.5 TeV
			$c\overline{c}$		
PDF	m_c (GeV)	μ/m_c	σ (μb)	σ (μb)	σ (mb)
MRST HO	1.4	1	37.8	298	3.18
MRST HO	1.2	2	43.0	382	5.83
CTEQ 5M	1.4	1	40.3	366	4.52
CTEQ 5M	1.2	2	44.5	445	7.39
GRV 98 HO	1.3	1	34.9	289	4.59
			$b\overline{b}$		
PDF	m_b (GeV)	μ/m_b	σ (nb)	σ (μb)	σ (μb)
MRST HO	4.75	1	9.82	1.90	185.2
MRST HO	4.5	2	8.73	1.72	193.2
MRST HO	5.0	0.5	10.96	2.16	184.8
GRV 98 HO	4.75	1	13.40	1.65	177.6
GRV 98 HO	4.5	2	12.10	1.64	199.0
GRV 98 HO	5.0	0.5	14.80	1.73	166.0

R. Vogt: hep-ph/0203151

Saturation model prediction



Nuclear Shadowing Effect

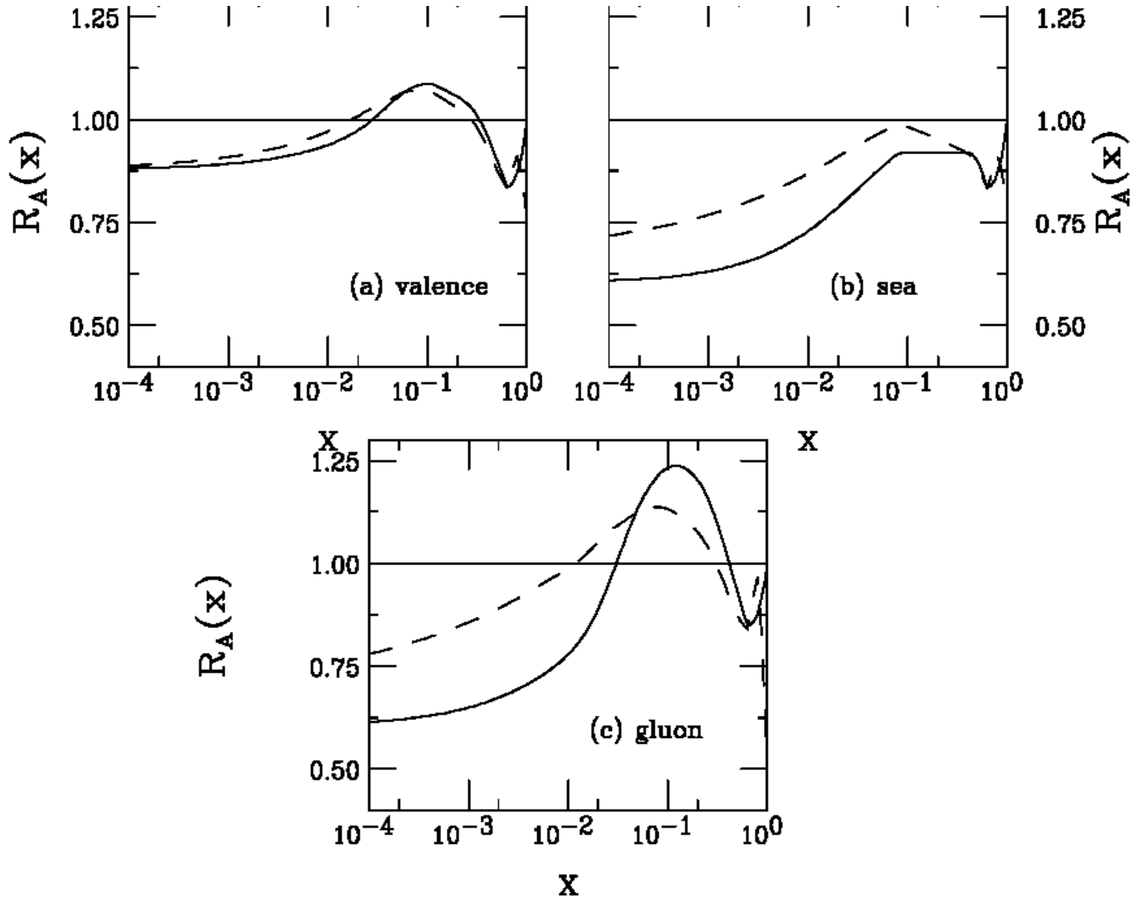


Figure 4: The shadowing parameterizations for $A = 200$ for (a) u_V valence quarks, (b) $\overline{u}$ sea quarks, and (c) gluons. The solid curves show the ratios at $\mu = \mu_0$ while the dashed curves are at $\mu = 10$ GeV.

R. Vogt: hep-ph/0111271

Charm: the ratio of pA to pp

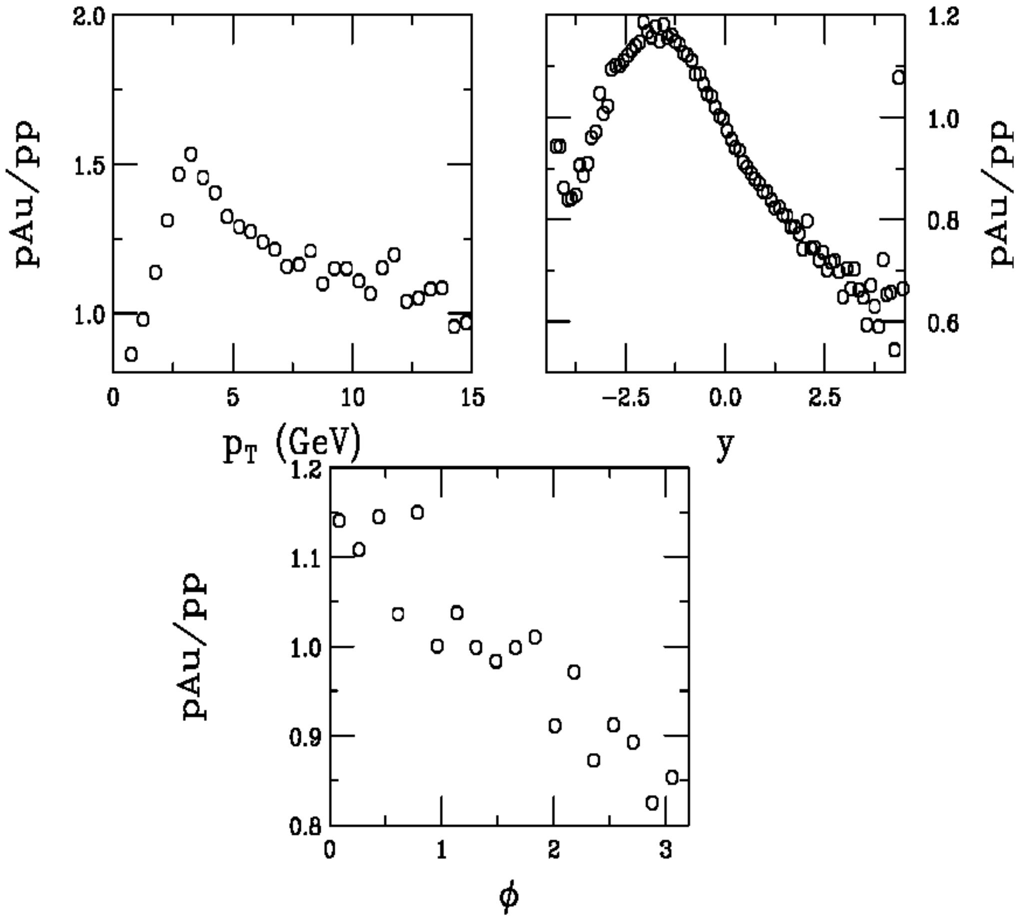
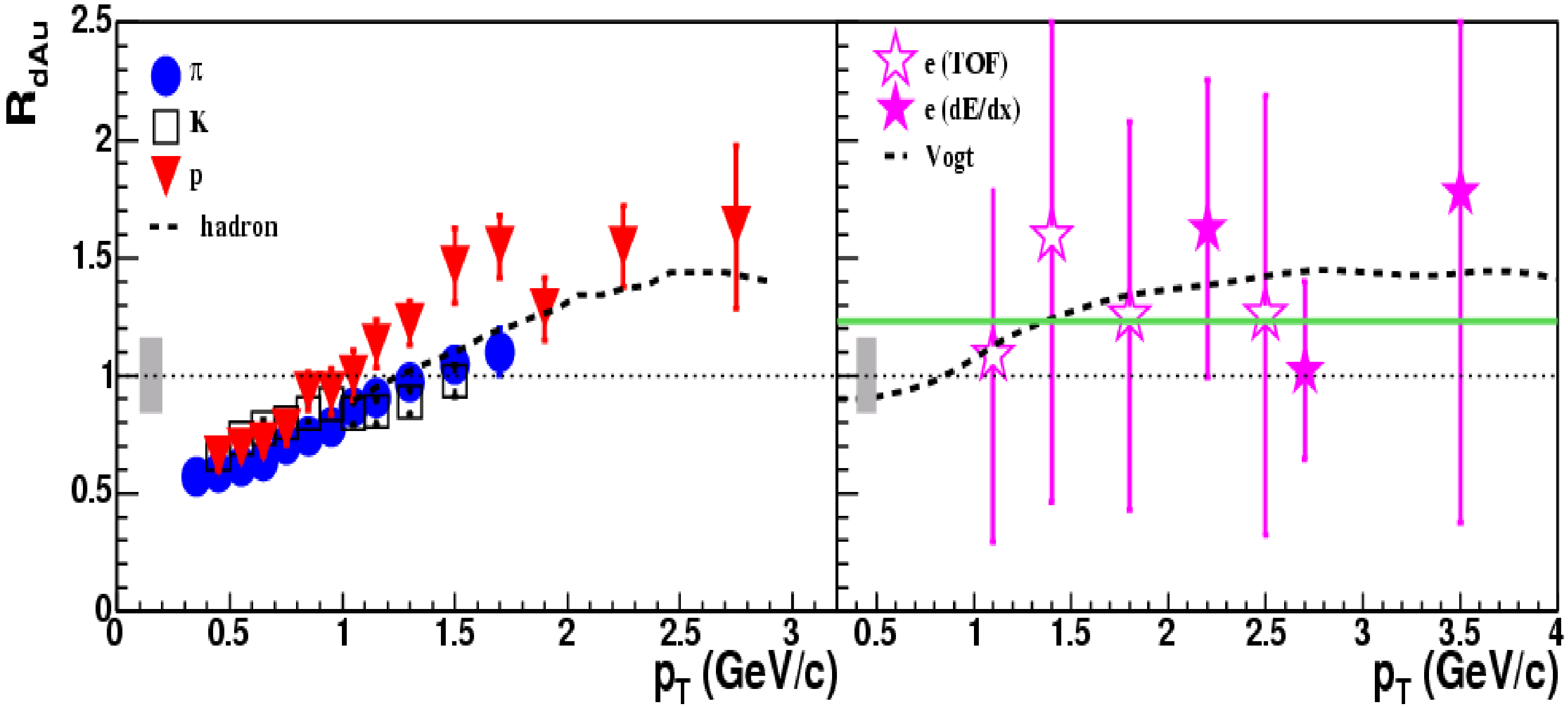


Figure 27: The ratio of pA to pp exclusive NLO $c\overline{c}$ pair production at $\sqrt{s} = 200$ GeV as a function of p_T, y, and ϕ.

R. Vogt: hep-ph/0111271

R_{dAu} comparison



- ccbar R_{dAu} curve from R. Vogt: hep-ph/0111271
- decay into electrons in d+Au and p+p collisions assuming D spectrum as STAR measured

Systematic errors

Source	d+Au	p+p
Ratios between diff. D mesons	10%	11%
D spectrum shape†	13%	13%
Decay modes (CERNLIB general and PYTHIA)	12%	12%
NFitHits 15->25	18%	14%
Rapidity distribution	~15%	~15%
Nbin in dAu	5%	-
Total sys. errors	31%	29%

† not needed in the combining fit