STAR

Open Charm Production IN STAR

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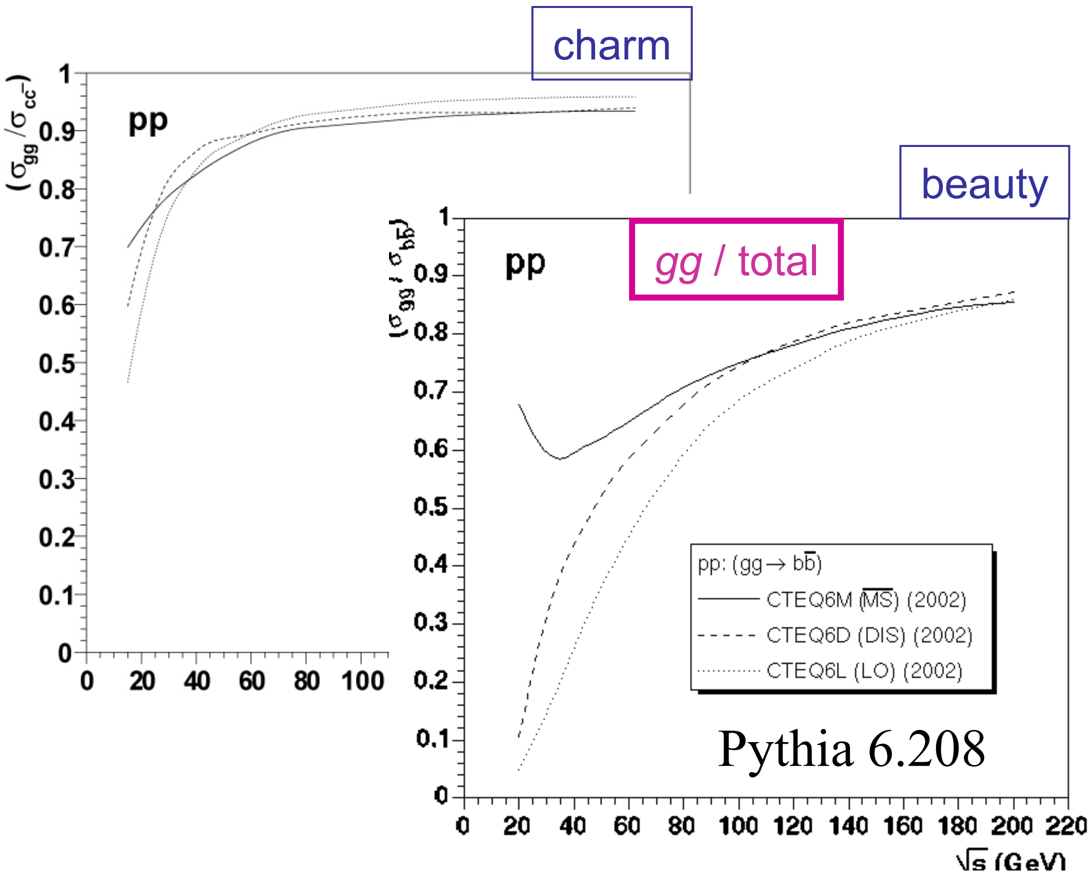
STAR Collaboration

Hard Probes,
November 6, 2004

Outline

- ★ Open Charm: what we know / would like to know
- ★ D0, D*±, D± open charm measurement in d+Au collisions
- ★ Combination with single electron spectra in p+p and d+Au collisions
- ★ Charm cross sections
- ★ Open charm pT spectrum and theoretical comparisons

$Q\overline{Q}$ in pp…



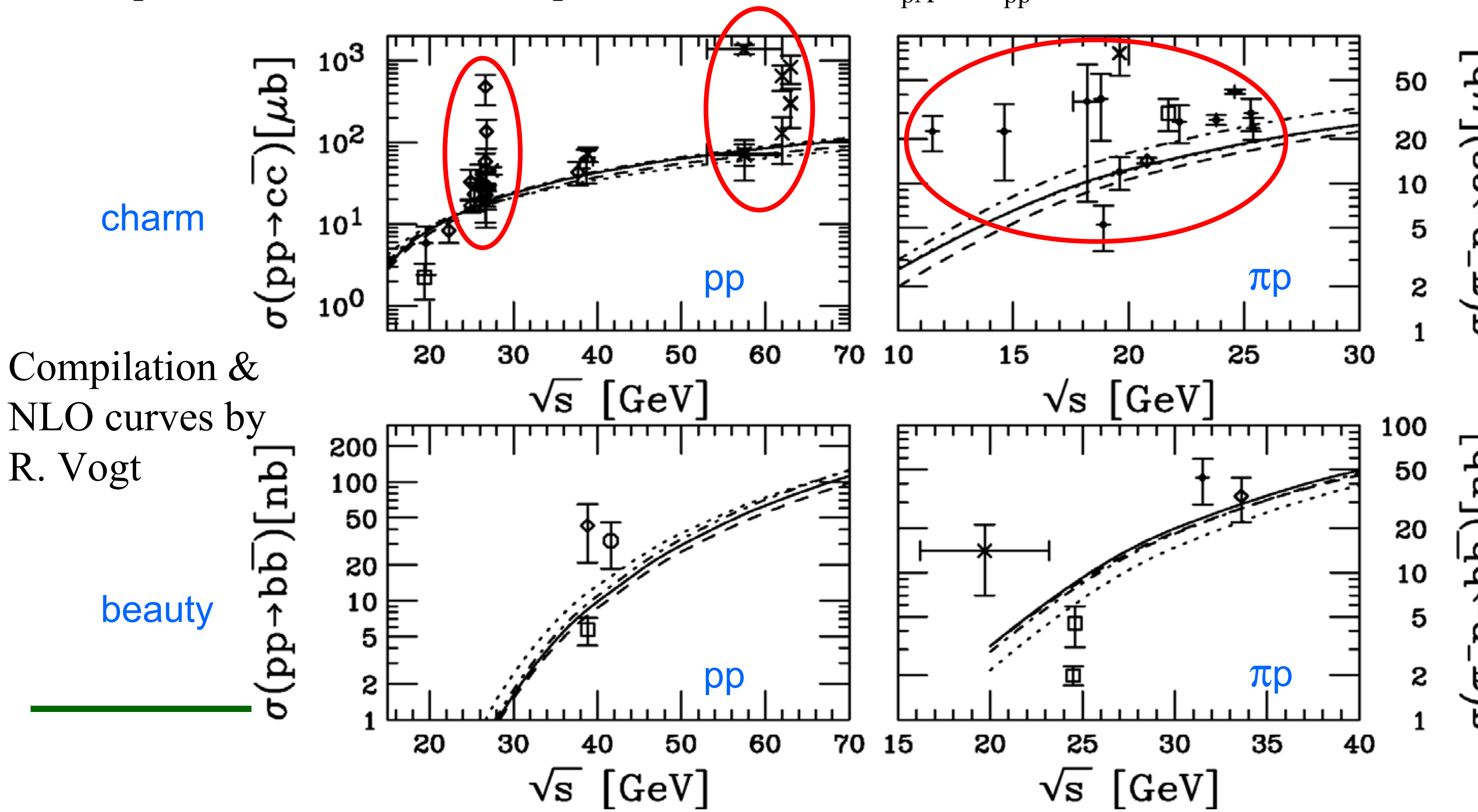
At high energies, gluon fusion dominates the production cross-section ⇒ Heavy Flavor production directly probes gluon distributions of colliding particles

General: Heavy-flavor and quarkonia production is theoretically not fully understood … even in p+p collisions.

Open Charm is hard…to measure

Data mostly from fixed target experiments at SPS and Fermilab, but also CDF

- energy range : 200–800 AGeV ($\sqrt{s}$ = 19 – 38 GeV), $\sqrt{s}$=1.8 TeV
- p+A: linear nuclear A-dependence assumed $\sigma_{pA} = \sigma_{pp} A^{\alpha}$, $\alpha = 1$



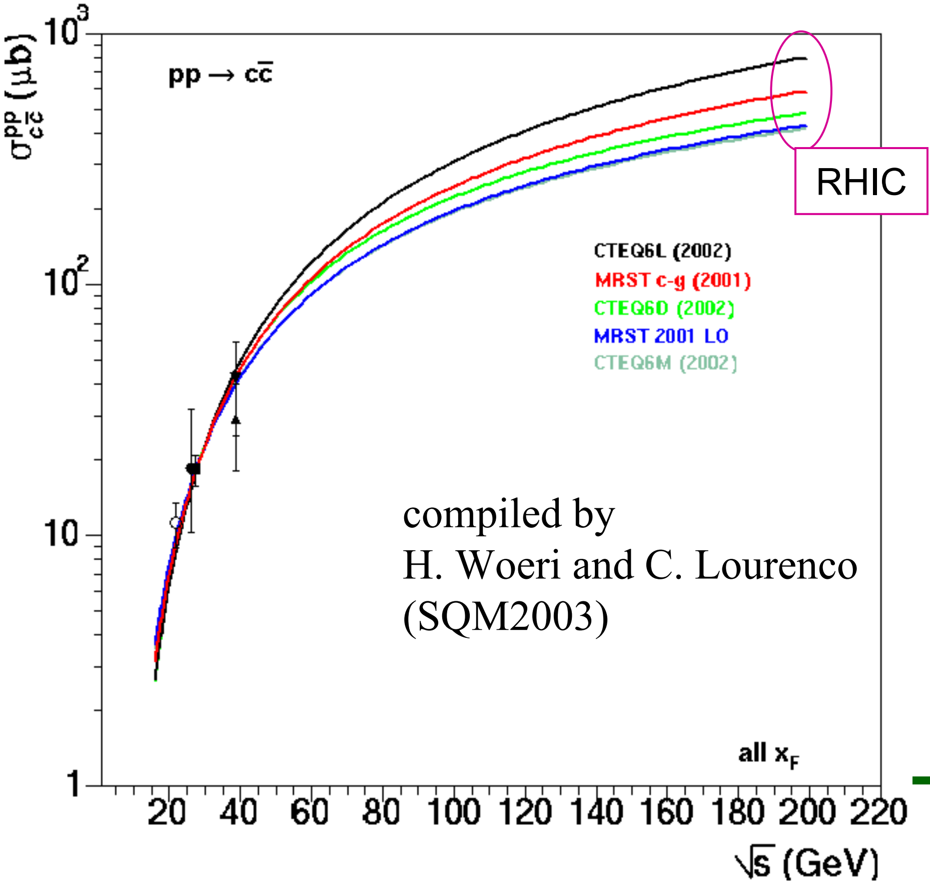
Extrapolations to RHIC energies

- Different PDF sets or quark masses lead to different energy dependences
- All the curves are normalized at low energies

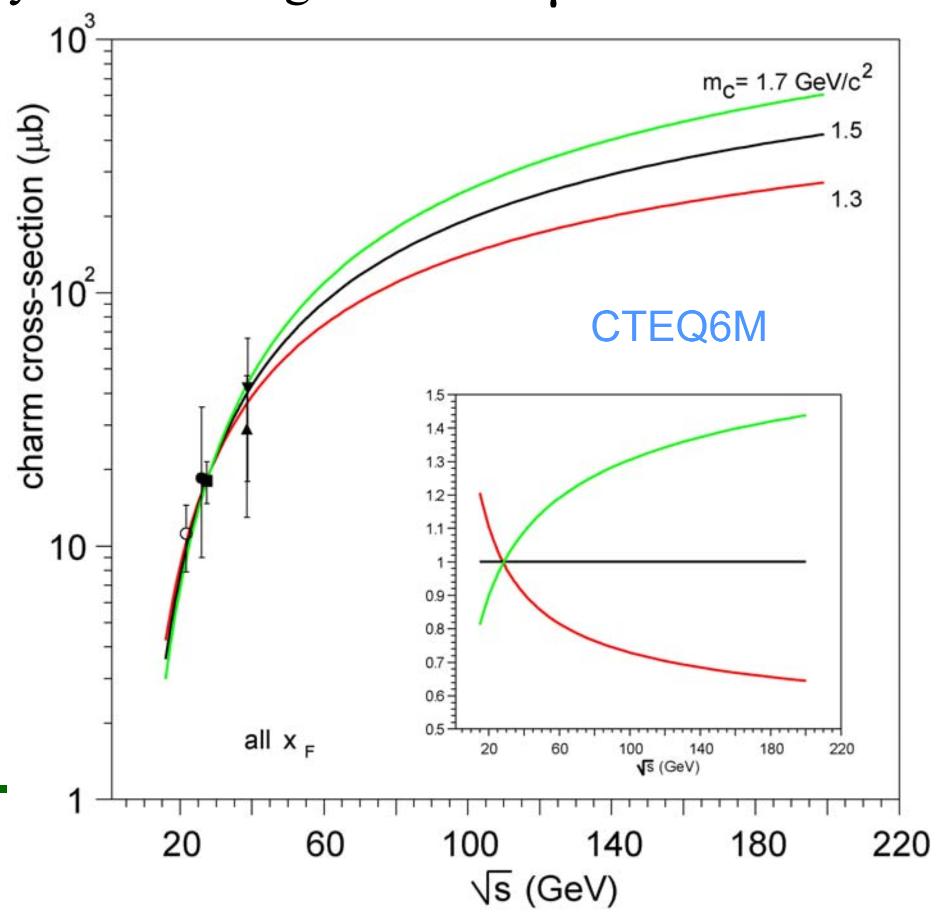
  → the 'predictions' for higher energies have a certain spread :

  ① changing PDF sets : range 400–800 μb at RHIC energies

  ② changing c quark mass by ±15% : range 300–700 μb



compiled by
H. Woeri and C. Lourenco
(SQM2003)

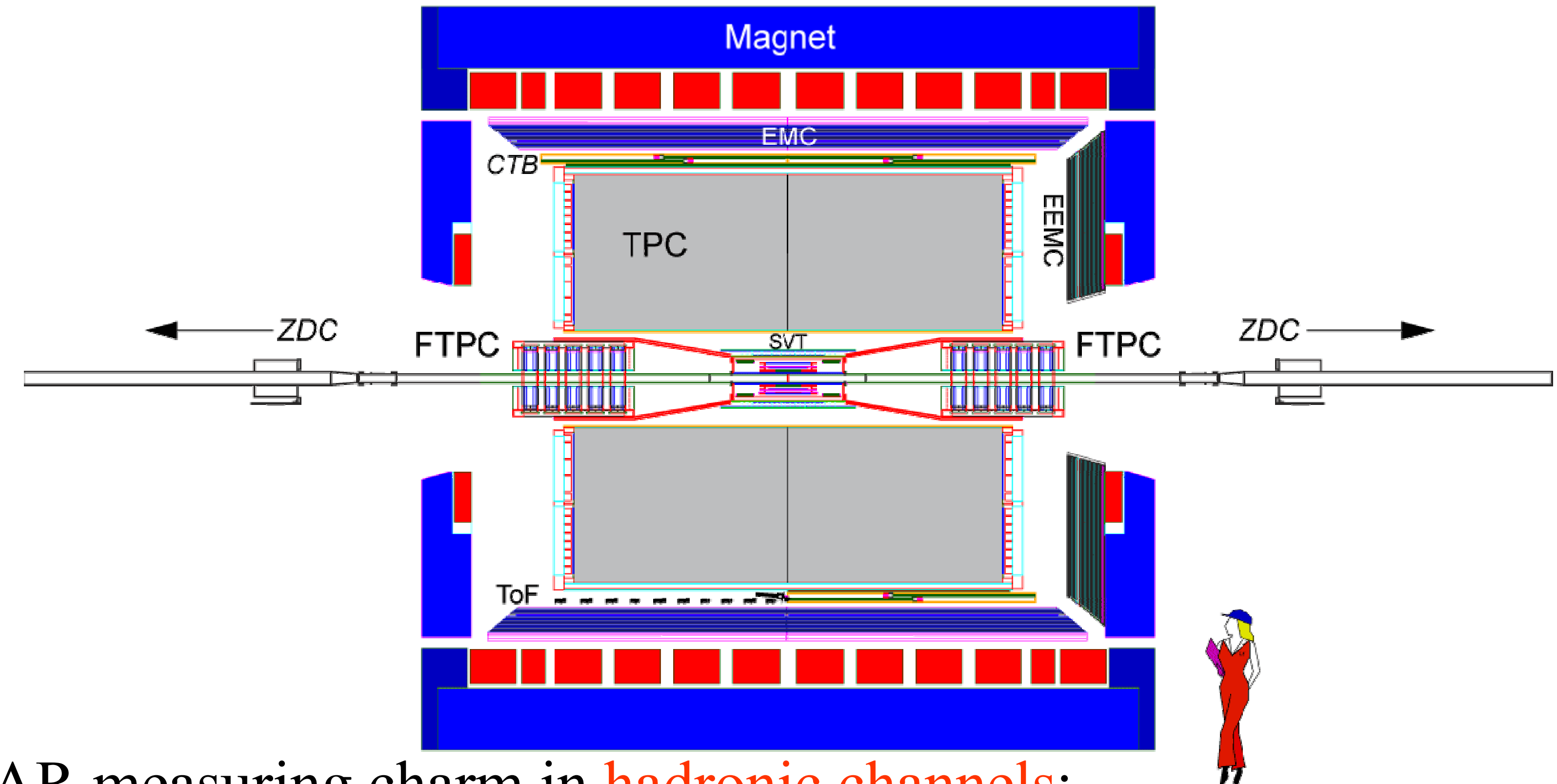


Open charm at RHIC

- Part of fundamental understanding of charm production in pp
- J/Ψ suppression, of course!
  - Needed for normalization (can't do Drell-Yan)
  - Goal: $\sigma_{J/\psi} / \sigma_{c\bar{c}}$ in pp, d+A, A+A (that's a long term program!)
- More recent questions:
  - Thermalization of charm quarks?
    - Charm quarks interact with evolving QGP (light quarks, g) makes early thermalization a possibility
    - Production rate (J/Ψ recombination), pt spectra (flow? Thermal?), azimuthal anisotropy (v_2)
  - Heavy quark energy loss
    - Vacuum radiation is suppressed in the dead cone,
    - but maybe filled by medium induced radiation…
    - Maybe an observable D/π enhancement at pt 5-10 GeV

Arnesto, Salgado, Wiedemann, hep-ph/0312106

Heavy Flavor and the STAR Experiment

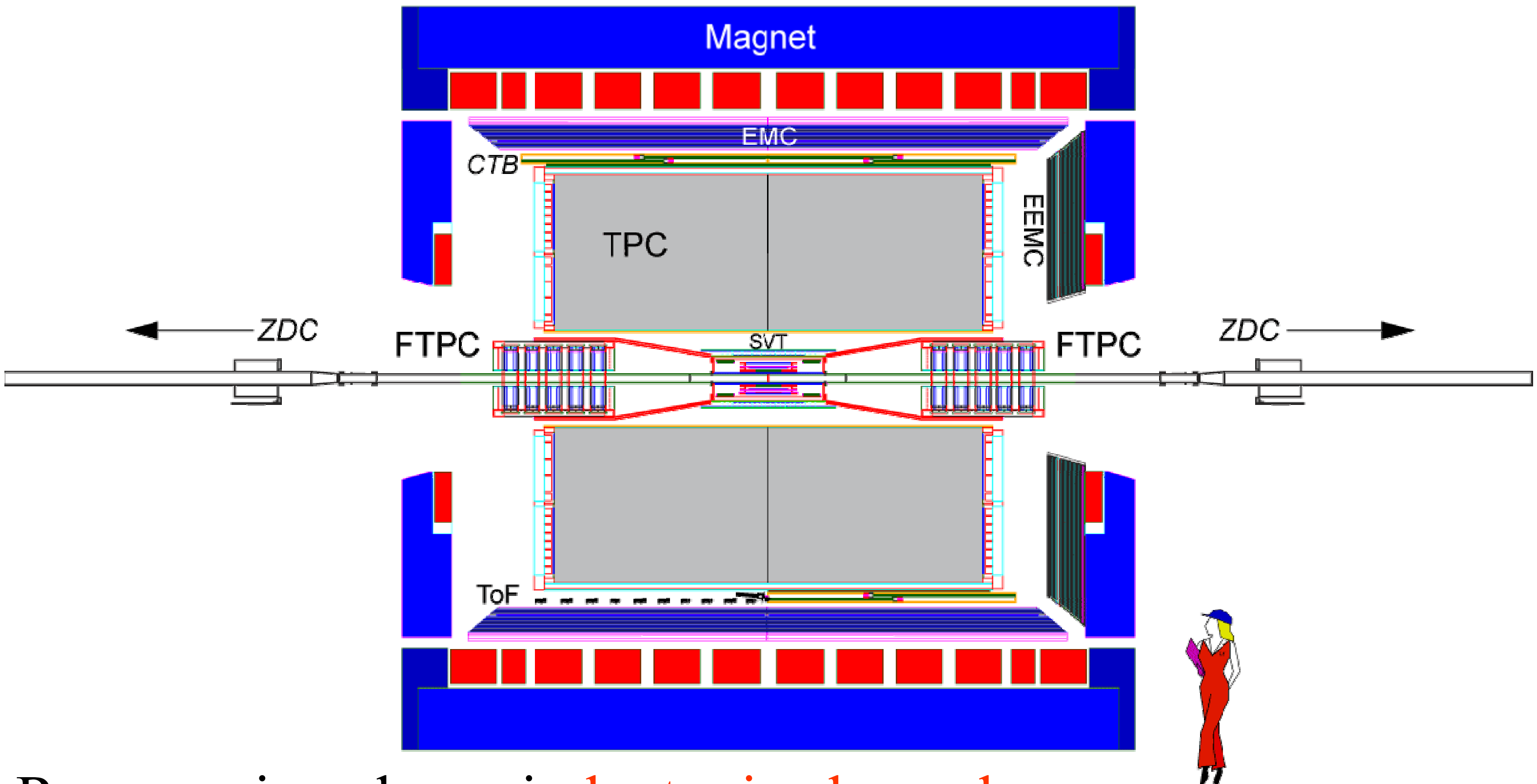


STAR measuring charm in hadronic channels:

- $D^0 \rightarrow K\pi$ (B.R. 3.8%) and $K\pi\rho$ (B.R. 6.2%)
- $D^\pm \rightarrow K\pi\pi$ (B.R. 9.2%)
- $D^{*\pm} \rightarrow D^0\pi$ (B.R. 68%)
- $\Lambda_c \rightarrow p K \pi$ (B.R. 5%)

all with TPC only

Heavy Flavor and the STAR Experiment

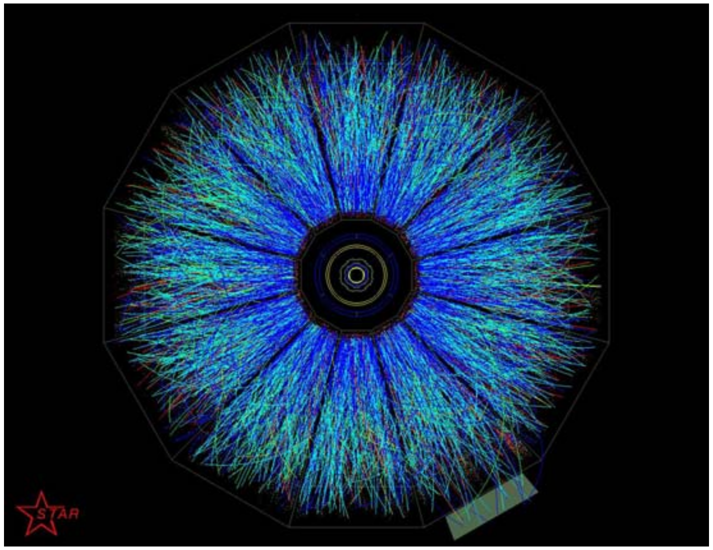


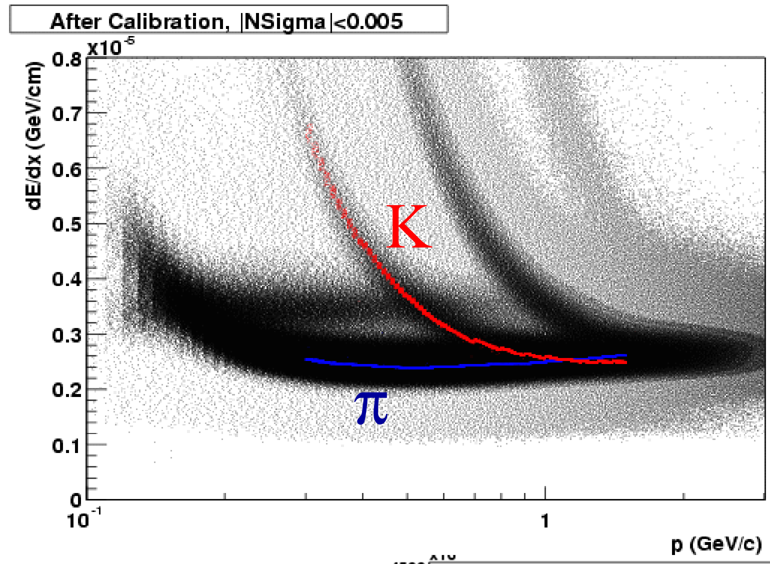
STAR measuring charm in leptonic channels:

b, c → e + X

- TPC (tracking → p_T)
- ToF (PID < 3 GeV/c)
- EMC (PID > 1 GeV/c)

D^0 in STAR: Analysis Methods

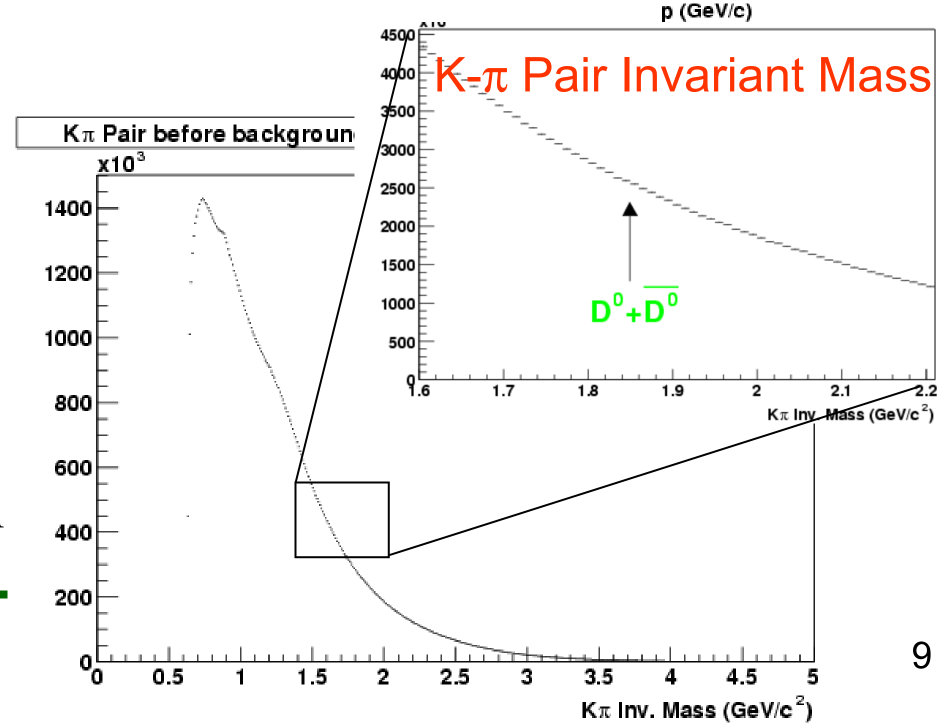




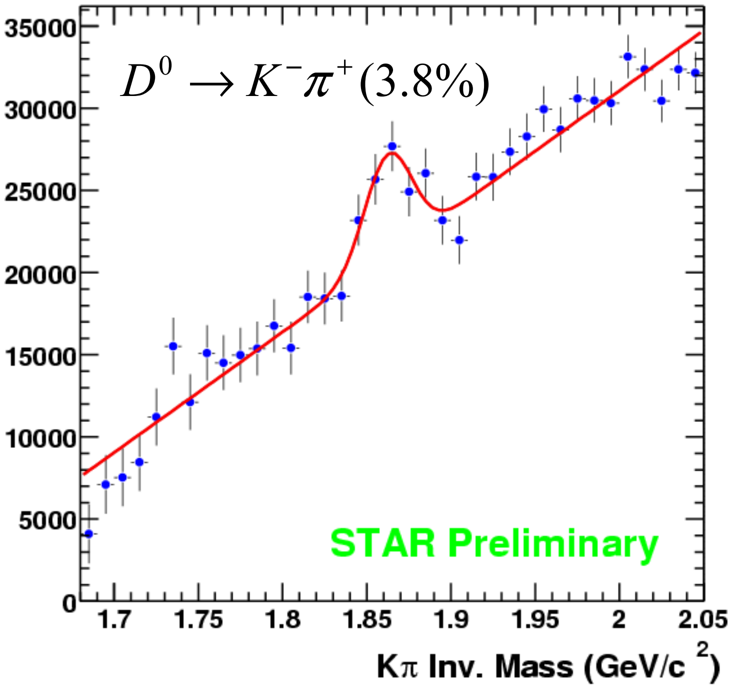
Event-Mixing Technique

- Identify charged Kaon and Pion tracks through energy loss in TPC
- Produce oppositely charged K-π pair invariant mass spectrum in same event
- Obtain background spectrum through mixed event
- Subtract background and get D^0 spectrum

d+Au: 15.7 M events



D^0 in d+Au Collisions

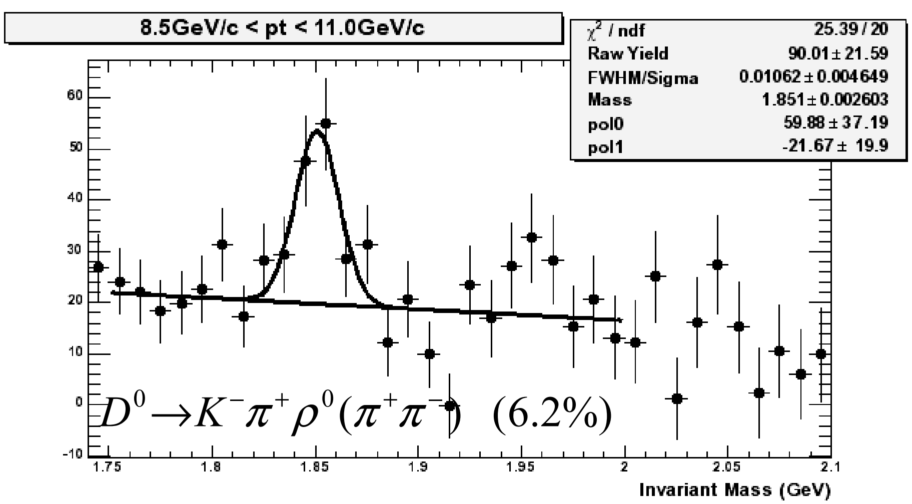


D^0+$\overline{D^0}$ to increase statistics

$0 < p_T < 3$ GeV/c, $|y| < 1.0$

Gaussian function + linear

Residual background



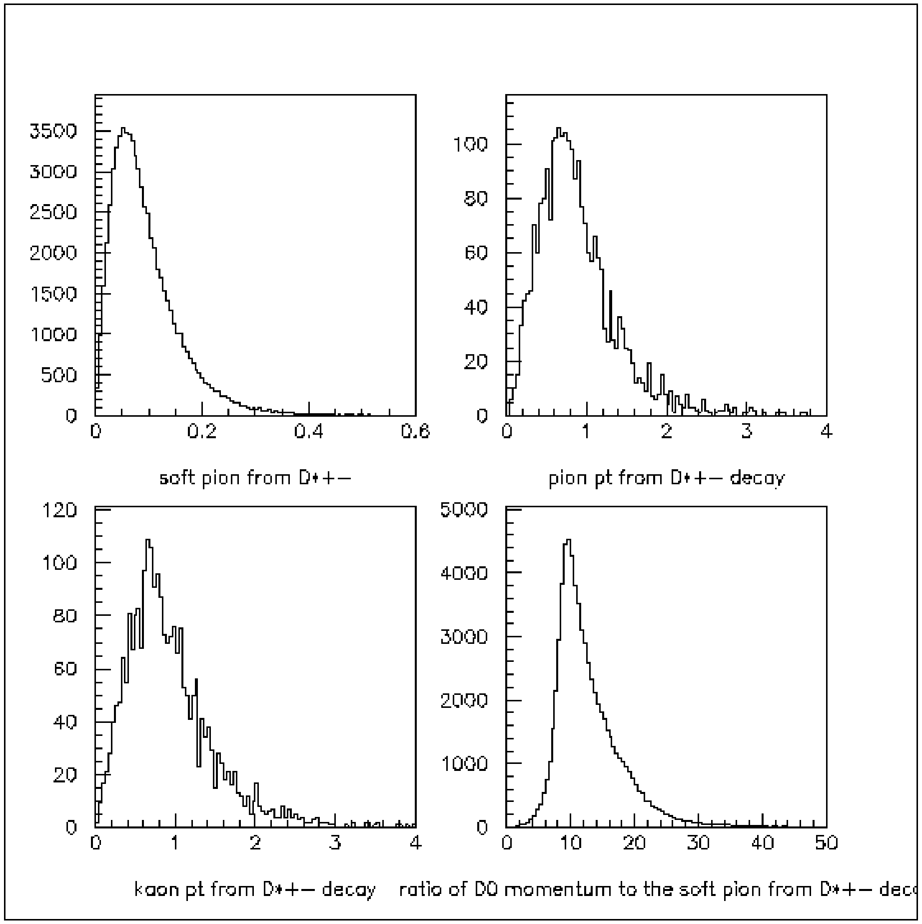
Mass and Width consistent with PDG values considering detector effects

- mass=1.867±0.006 GeV/c^2;
- mass(PDG)=1.8645±0.005 GeV/c^2
- mass(MC)=1.865 GeV/c^2
- width=13.7±6.8 MeV
- width(MC)=14.5 MeV

D*± Mesons in d+Au Collisions

$D^{*\pm} \rightarrow D^0\pi$ (B.R. 68%)

Decay Kinematics (Pythia)



"Golden channel" for open charm study

Standard method:

$M(D^{*\pm}) - M(D0)$=145.421 MeV

Width~1 MeV

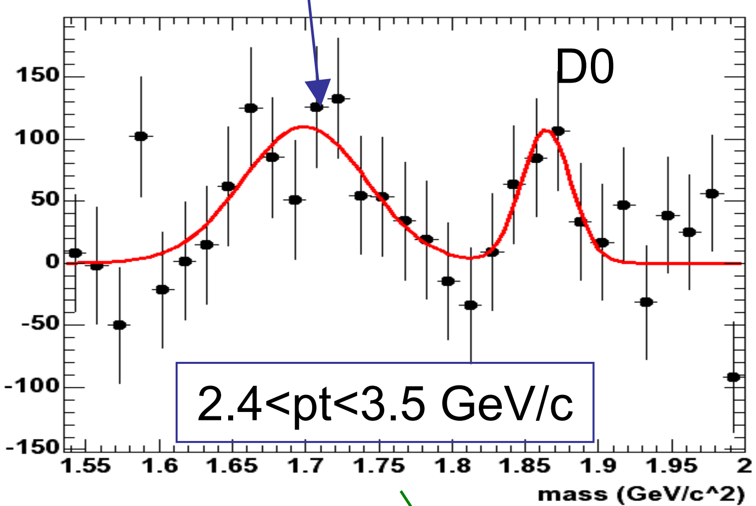
Difficulty: the low efficiency of the soft pion reconstruction

STAR full field:

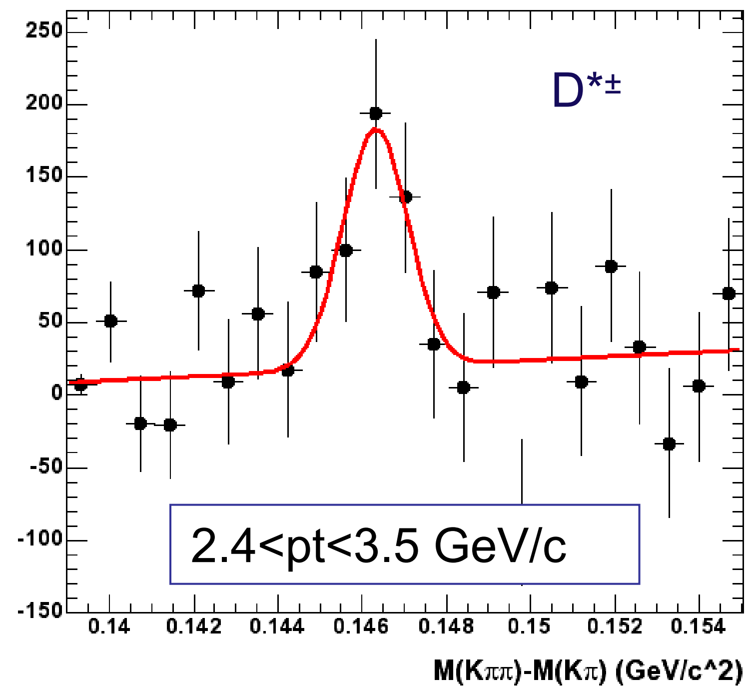
tracks curl up for p_T < 100 MeV/c

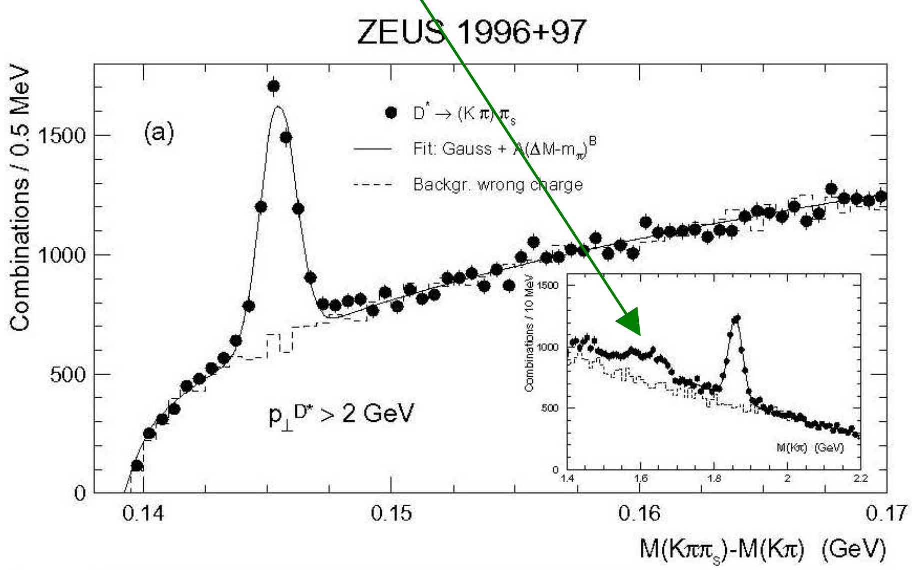
D*± Mesons in d+Au Collisions

D0 → K⁻π⁺π⁰ (B.R. 13.1%)



D0 from D* decays





Masses and Widths OK:

$m(D^*)-m(D^0) = 0.1467 \pm 0.00016$ GeV/c²

$m(D^*)-m(D0)(PDG) = 0.1454$ GeV/c²

$m(D^*)-m(D0)(MC) = 0.1451$ GeV/c²

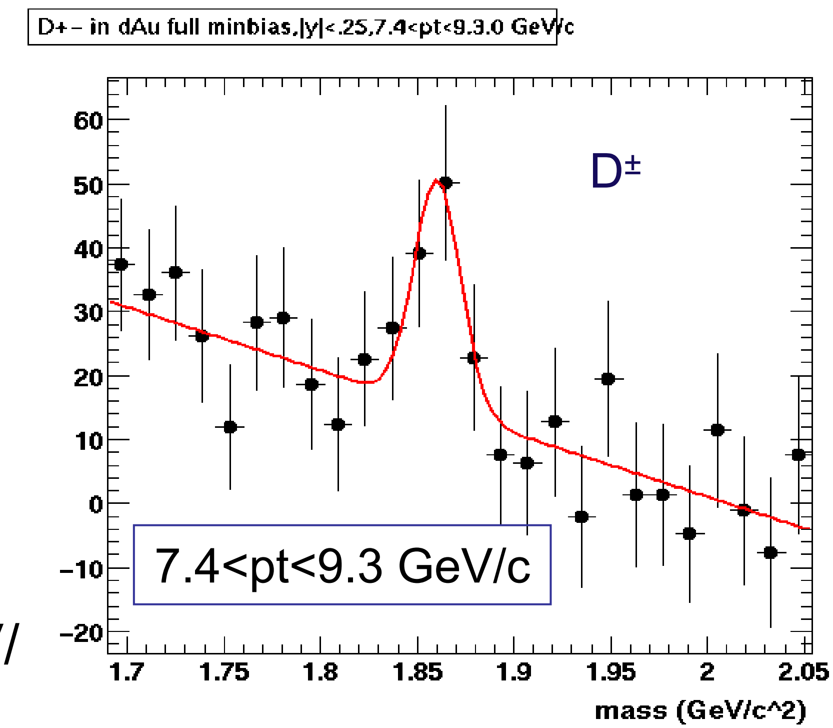
width=0.43±0.14 MeV

width(MC)=0.67 MeV

$D^{\pm}$ Mesons in d+Au Collisions

$D^{\pm} \rightarrow K\pi\pi$ (B.R. 9.1%)

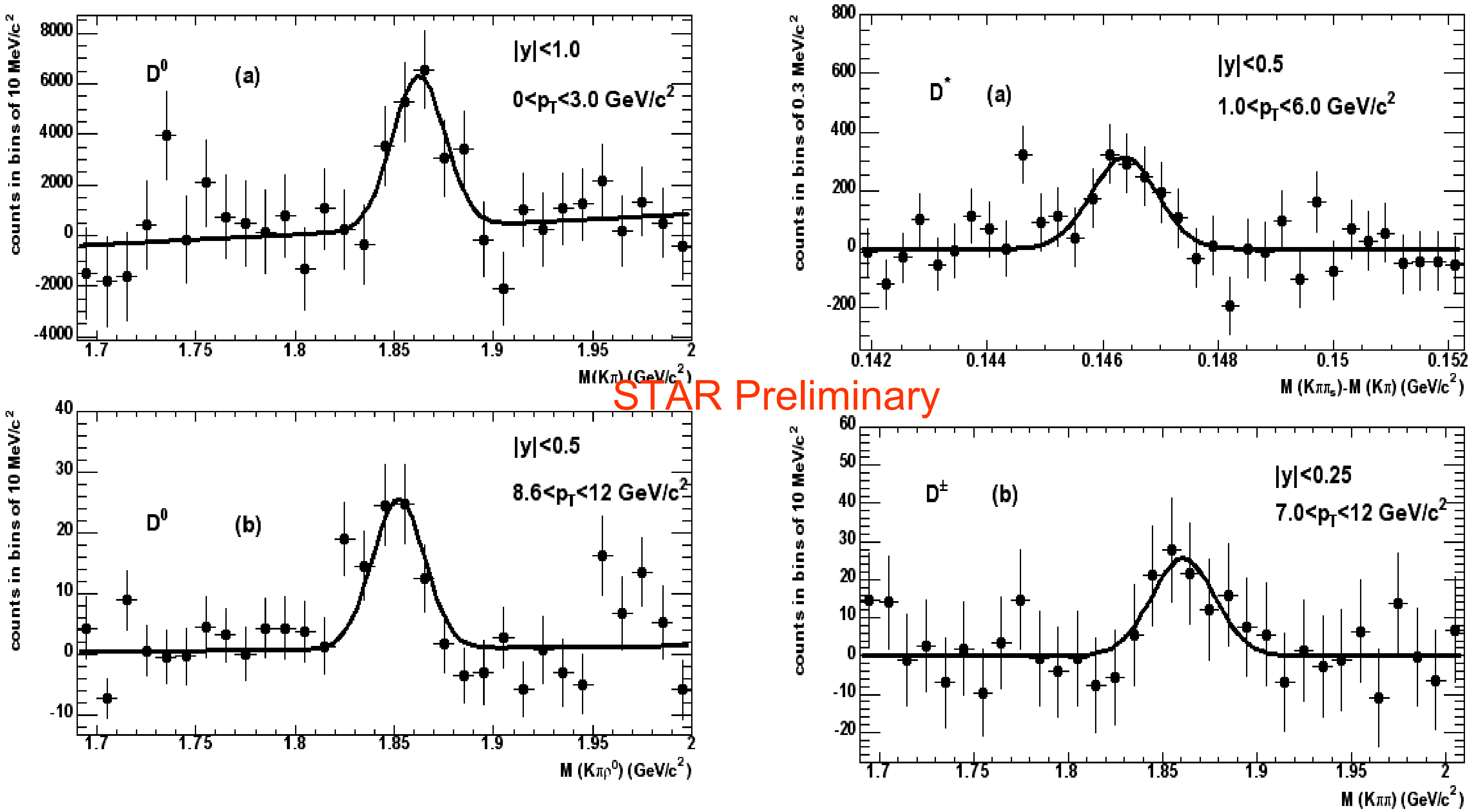
- 3-body decay ⇒ more background
- high-p_T reach



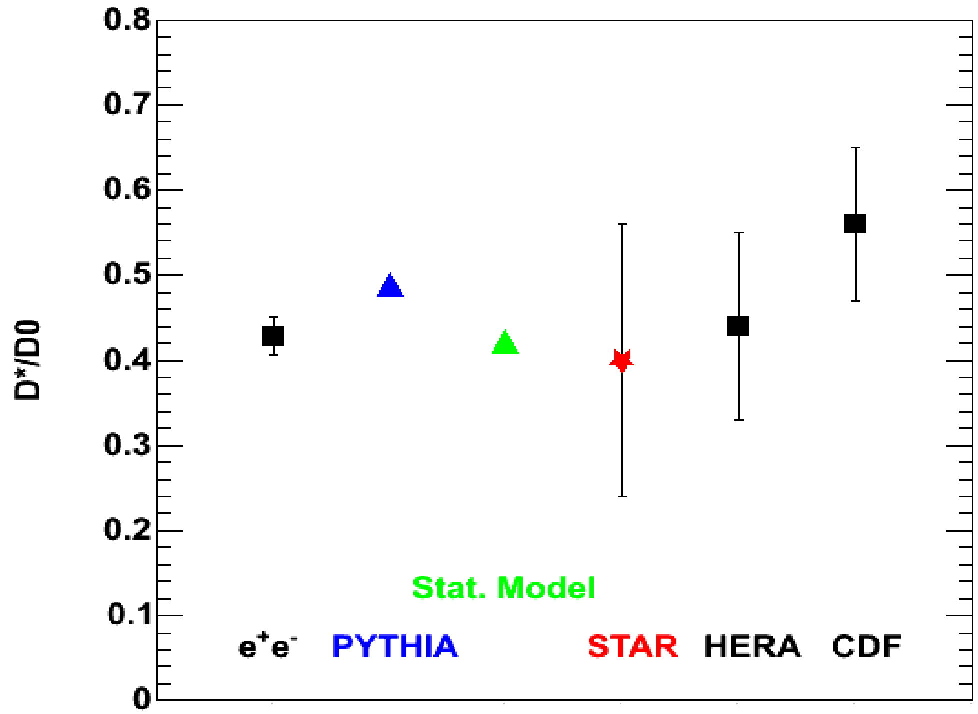
- ★ $D^{\pm}$ mass=1.864±0.0052 GeV/c^2
- ★ $D^{\pm}$ mass(PDG)=1.869 GeV/c^2
- ★ $D^{\pm}$ mass(MC)=1.868±0.002 GeV/
- ★ width = 13.83±3.7 MeV
- ★ width (MC)=14.9±1.6 MeV

D Mesons, putting it all together

d+Au minbias collisions @ 200GeV



D^*/D^0 Ratio



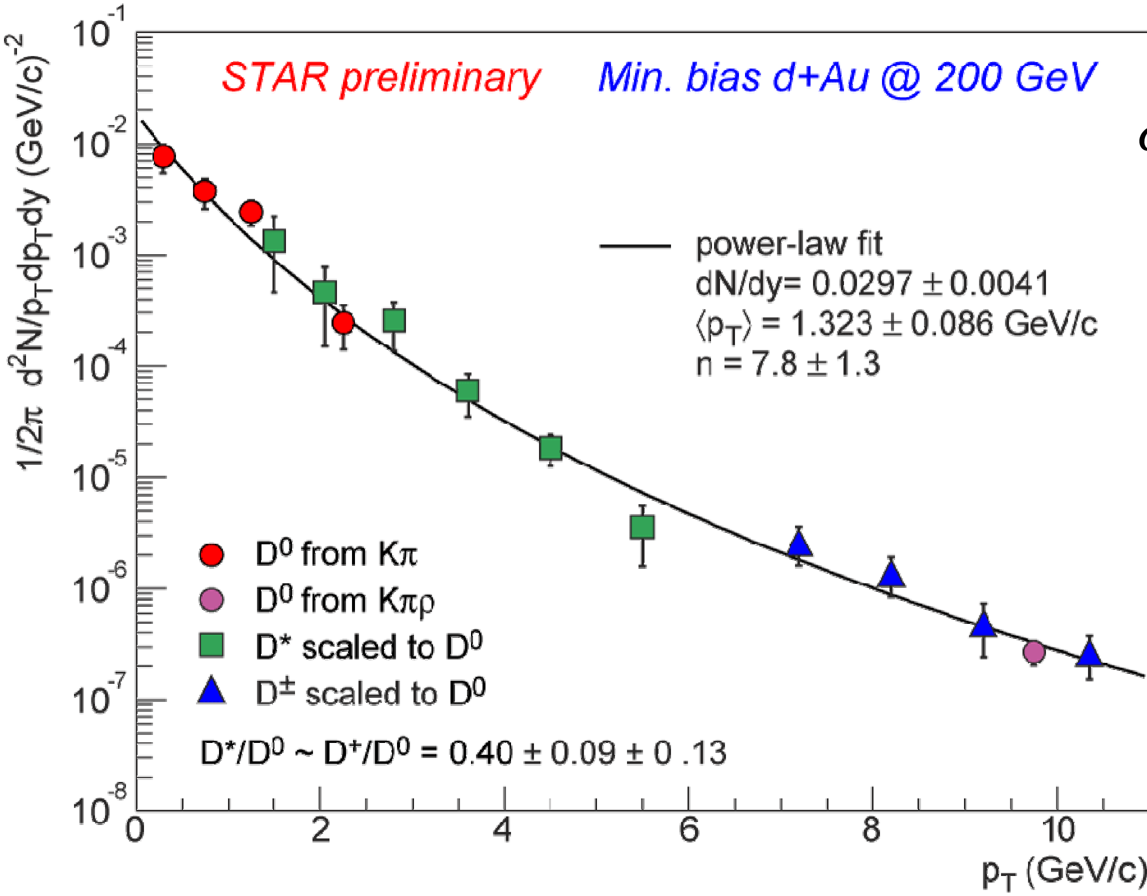
- CDF: hep-ex/0307080
- HERA: www-h1.de/h1/www/publications/conf_list.html
- e^+e^-: hep-ph/0312054
- Statistical model: Andronic et al. nucl-th/0209035

Good agreement with other experiments:

$D^+/D^0 \approx D^*/D^0 = 0.40 \pm 0.09$ (stat) ± 0.13 (sys)

D-Meson Spectra in d+Au

Assuming σ(D*) = σ(D±) and scale σ(D*) and σ(D±) to match D^0 by D^*/D^0=0.40



$$\sigma_{c\bar{c}}^{NN} = \frac{(dn/dy)\ \ \sigma_{inel}}{N_{bin}} \times \left(\frac{n}{dn/dy|_{|y|<1}}\right)\left(\frac{1}{N_{D^0}/N_{c\bar{c}}}\right)$$

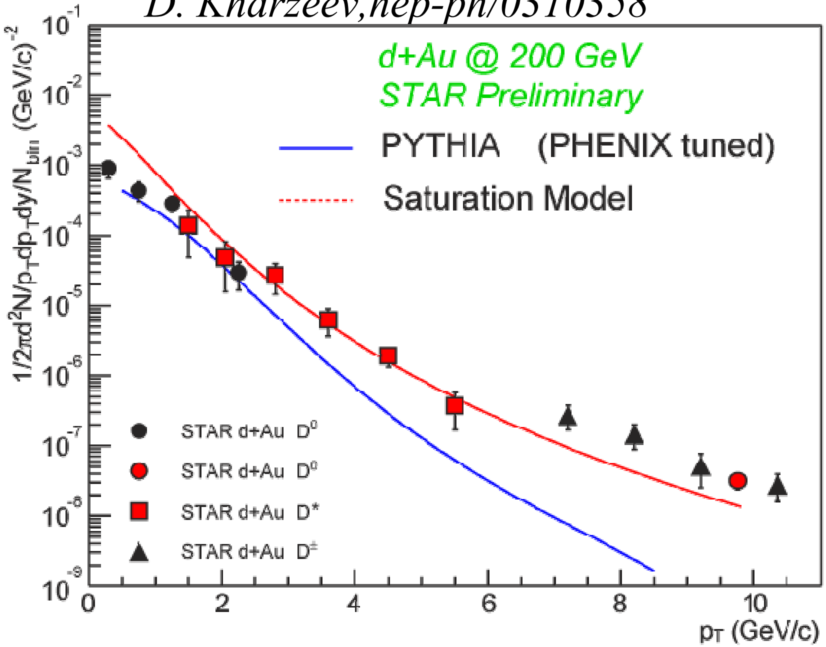
$$= \frac{(dn/dy)\ \ 42\text{ mb}}{7.5 \pm 0.4} \times (4.7 \pm 0.7)\left(\frac{1}{0.54 \pm 0.05}\right)$$

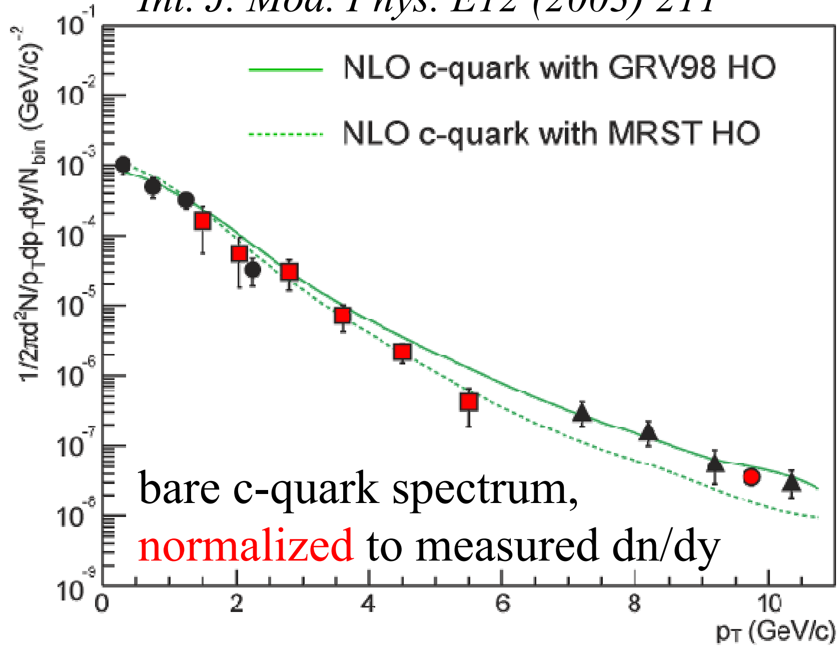
$$\sigma_{c\bar{c}}^{NN} = 1.3 \pm 0.2(stat) \pm 0.4(sys)\text{ mb}$$

Charm Quark Hadronization at RHIC

Phenix: PRL 88, 192303(2002)
D. Kharzeev,hep-ph/0310358

NLO pQCD predictions by R. Vogt,
Int. J. Mod. Phys. E12 (2003) 211

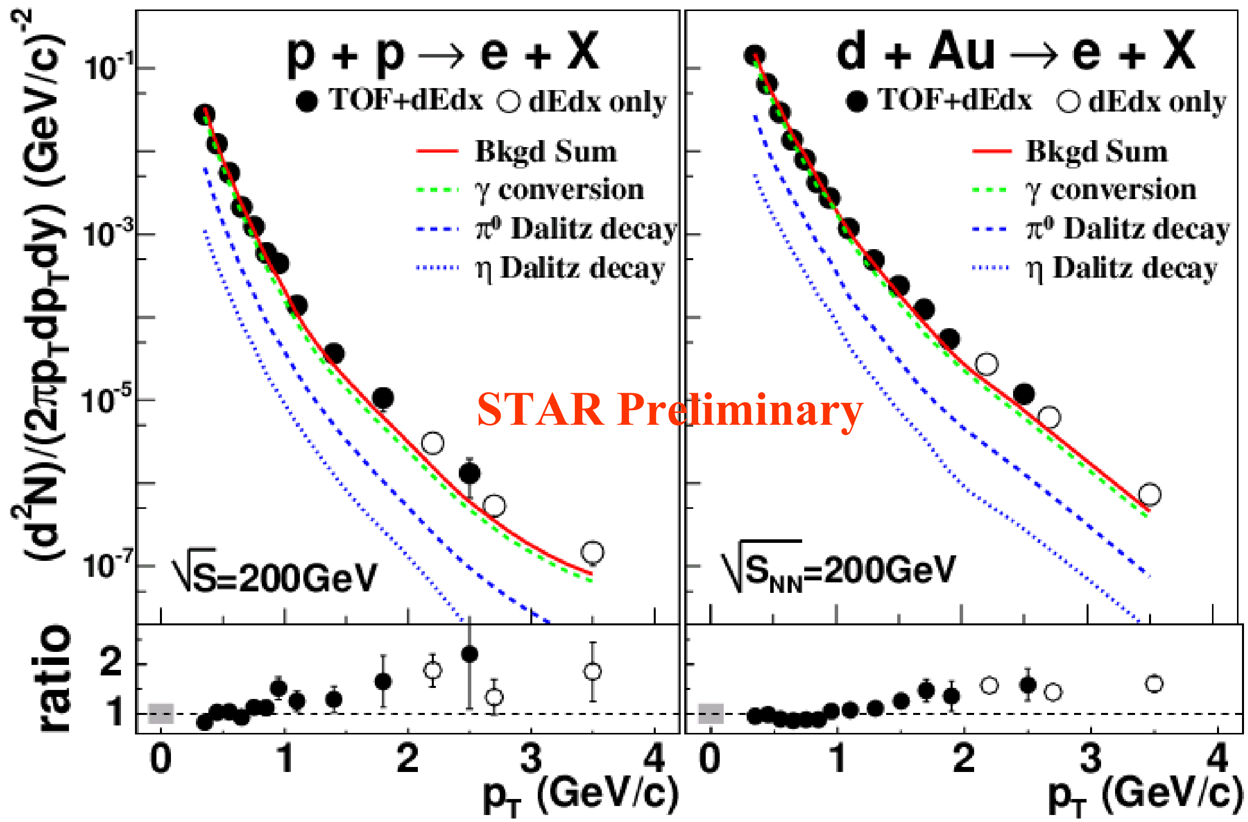




Open charm spectra is hard: NLO c-quark spectrum = D spectrum

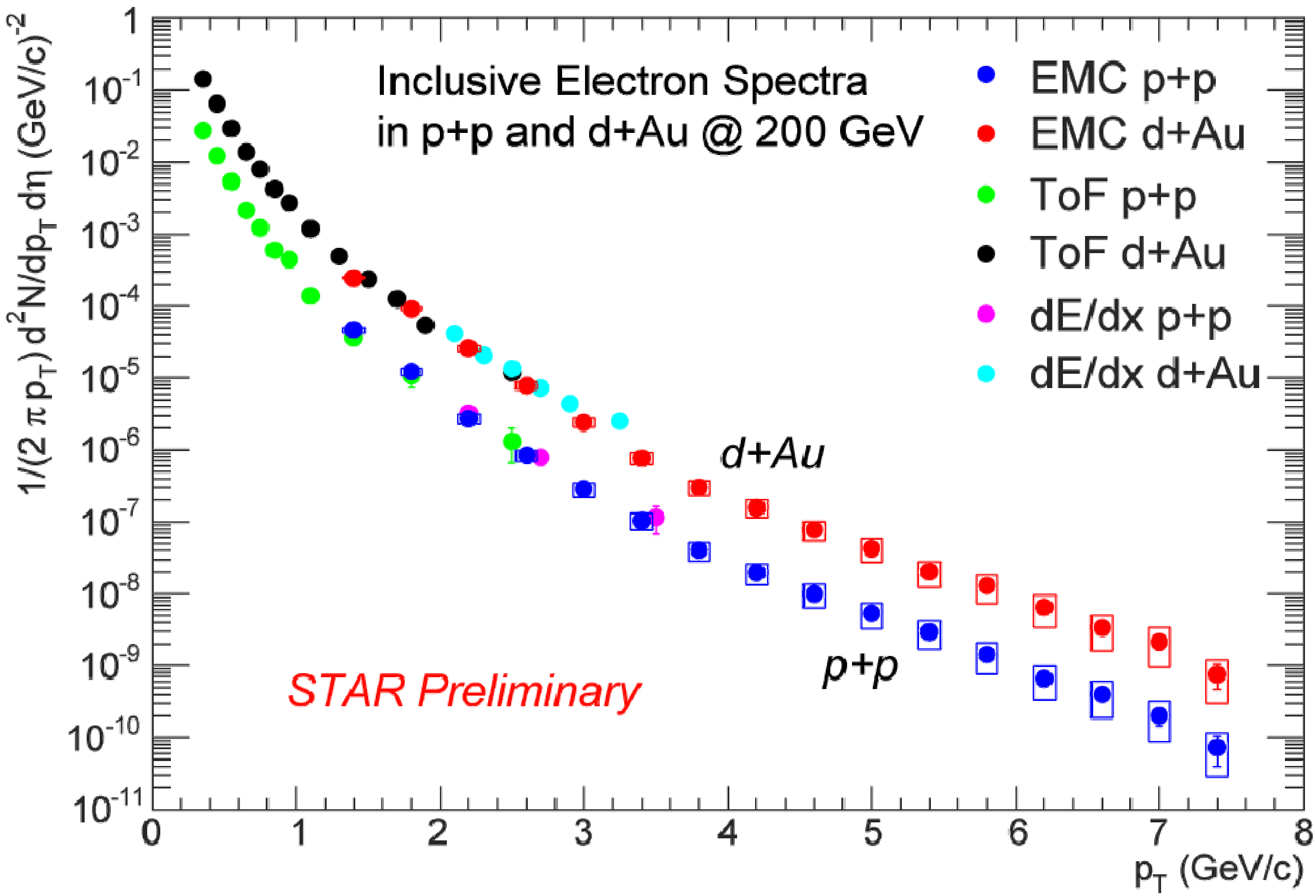
- data favor a fragmentation function peaked at z~1.
- observed in fixed target exp. at lower energies
- solved by intrinsic k_T model to counter-balance effect of c-quark hadronization
- doesn't work at RHIC because spectrum is too broad
- Note: Choice of PDF can change yield at high p_t by factor of 3…

Combining with Electron Analysis

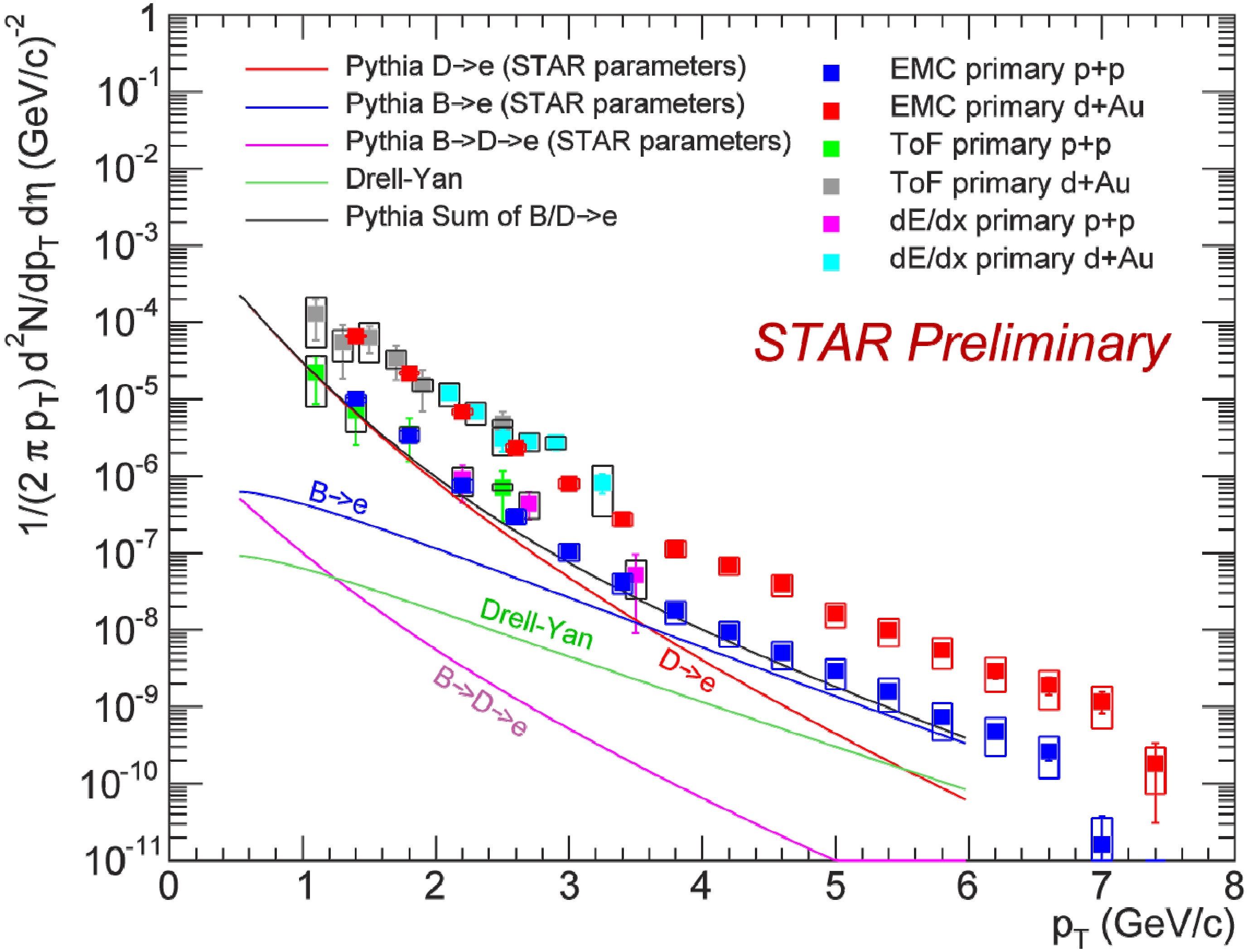


An increasing excess found at higher pT region, $p_T > 1.0$ GeV/c,
→as expected to be contribution of semi-leptonic decay from heavy flavor hadrons

Inclusive Electron Spectra in p+p and d+Au



Background Subtracted Spectra in p+p & d+Au



Semantics: "background subtracted" in STAR = "non-photonic" in PHENIX

Nuclear Effects (Cronin) ?

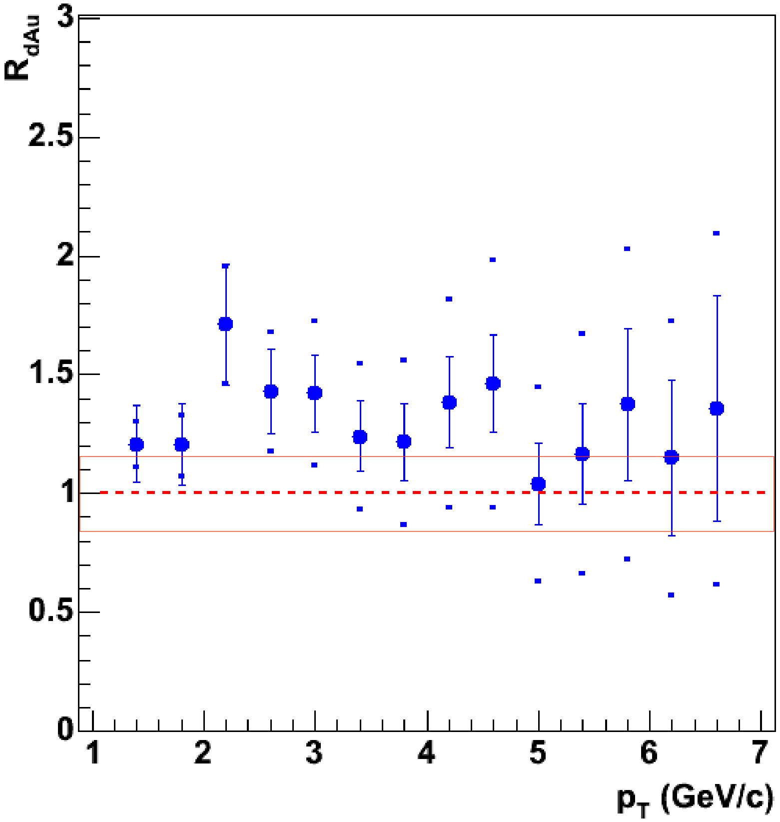
min bias: $\sigma_{\mathrm{pA}} = \sigma_{\mathrm{pp}}\ \mathrm{A}^{\alpha}$

Nuclear Modification Factor:

$$R_{\mathrm{dAu}}(p_T) = \frac{d^2 N_{\mathrm{dAu}}/dp_T d\eta}{T_{\mathrm{dAu}} d^2\sigma_{\mathrm{pp}}/dp_T d\eta}$$

where:

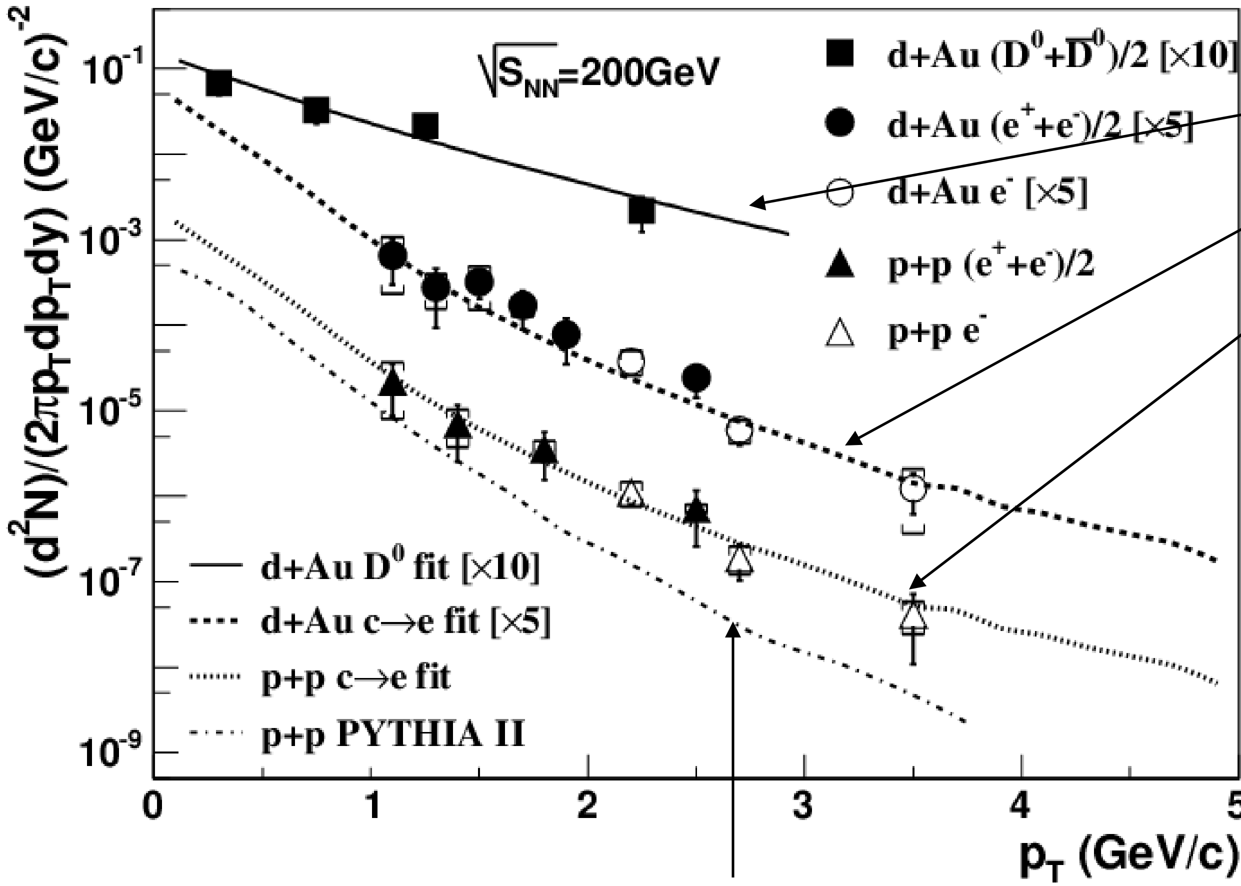
$$T_{\mathrm{dAu}} = \langle N_{\mathrm{binary}} \rangle / \sigma_{\mathrm{pp}}^{inel}$$



- Within the errors consistent with binary scaling ...
- *NOTE:* R_{dAu} for a given p_T comes from heavy quarks from a wide p_T range

Spectra

STAR Preliminary



Combining fit for D0 and electrons

PYTHIA: MSEL = 1, CTEQ5M1

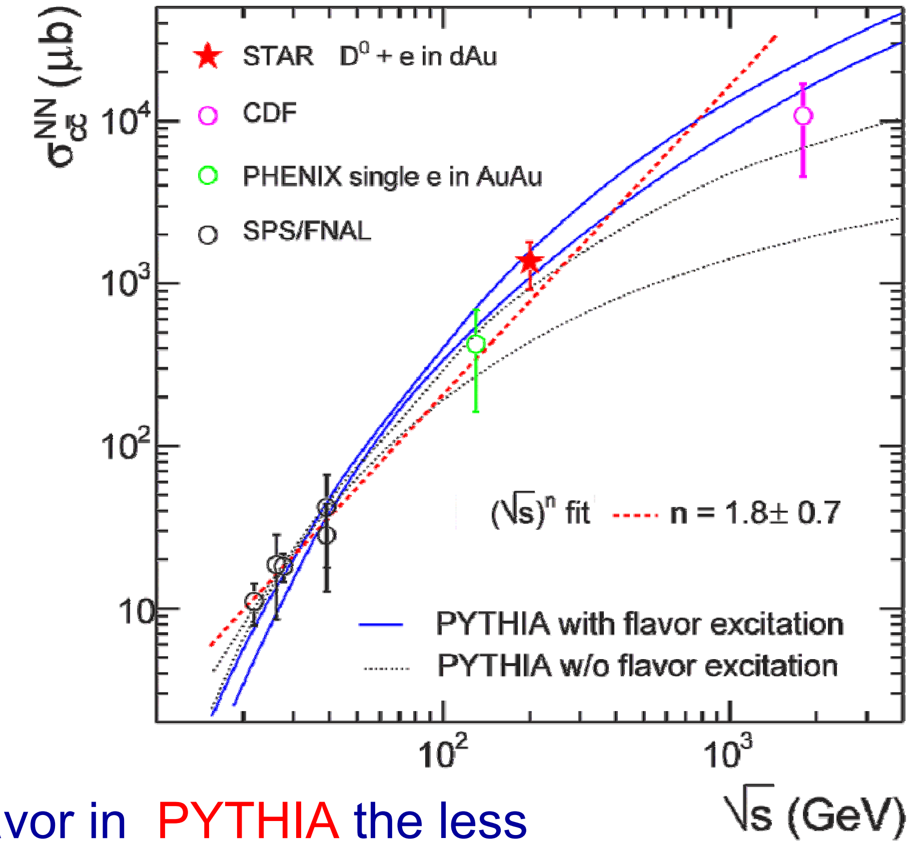
- Good agreement between D^0 and electrons spectra!
- d+Au and p+p do not show significant nuclear effect

Charm Cross-Section and PYTHIA

Measured D combined with measured electron spectra

$\Rightarrow$better σ_{cc}

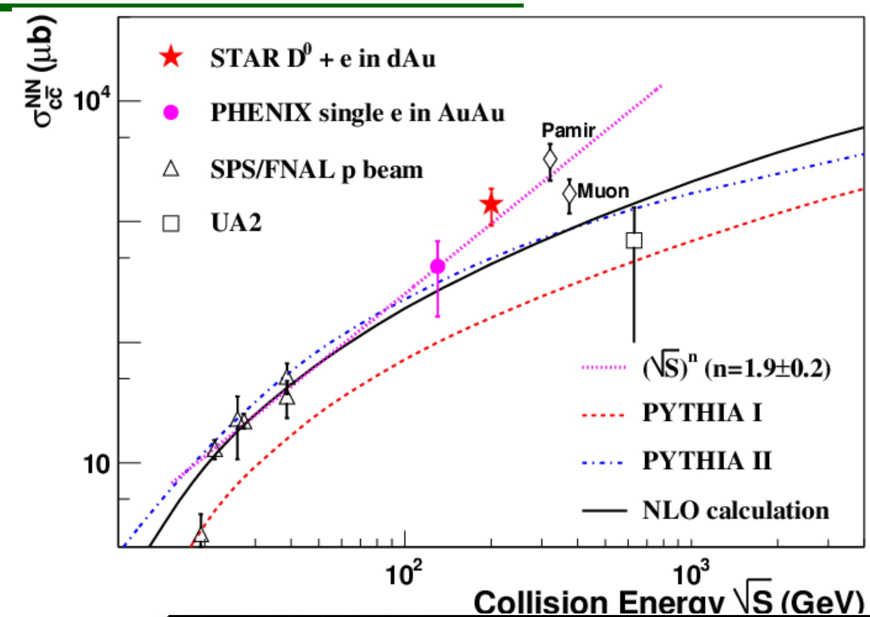
$$\sigma_{c\bar{c}}^{NN} = 1.4 \pm 0.2(stat) \pm 0.4(sys)\ \mathrm{mb}$$

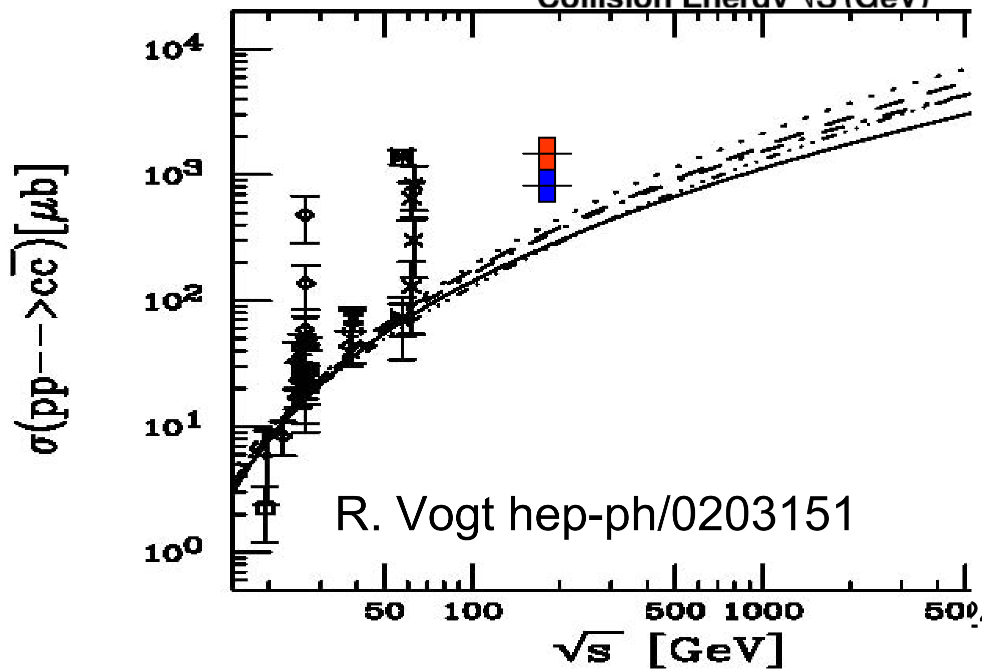


- The more we learn about heavy flavor in PYTHIA the less
- we believe to learn something from it.
- Vary parameters (K, k_T, processes, PDF, m_C, etc.) within reasonable limits
- $\Rightarrow$ σ changes up to factor 2
- $\Rightarrow$ $d\sigma/dp_T$ at high p_T up to a factor of 10

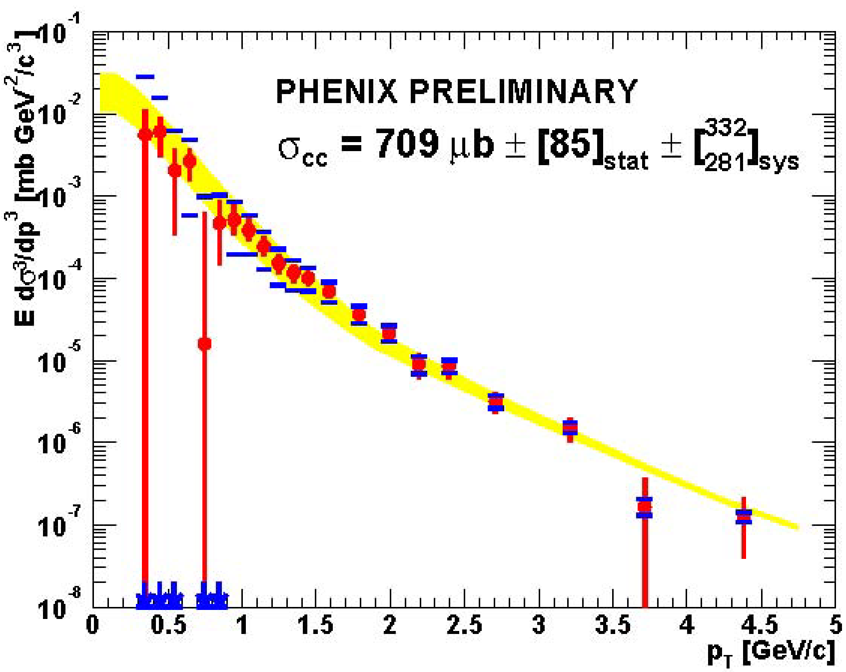
Cross Section Comparisons II

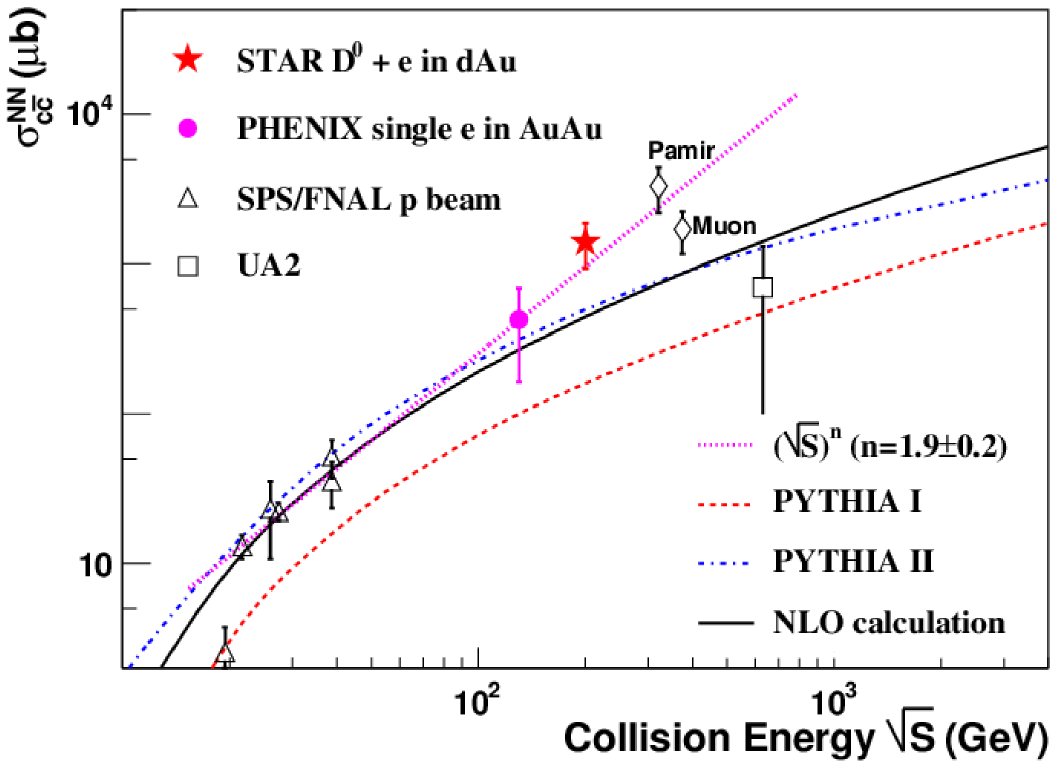
- NLO Calculations are better suited
- …but, extrapolation has large uncertainties, >50% (R. Vogt)
  - lower energy data differ by factors of 10 or more
  - Choice of PDF
  - Choice of m_c
- Measurements at RHIC might be in better agreement





Among RHIC experiments…



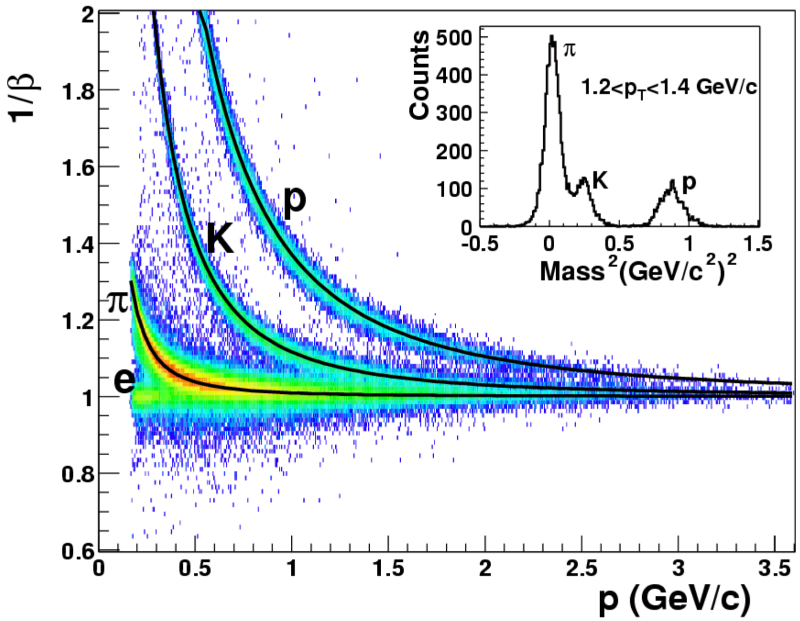


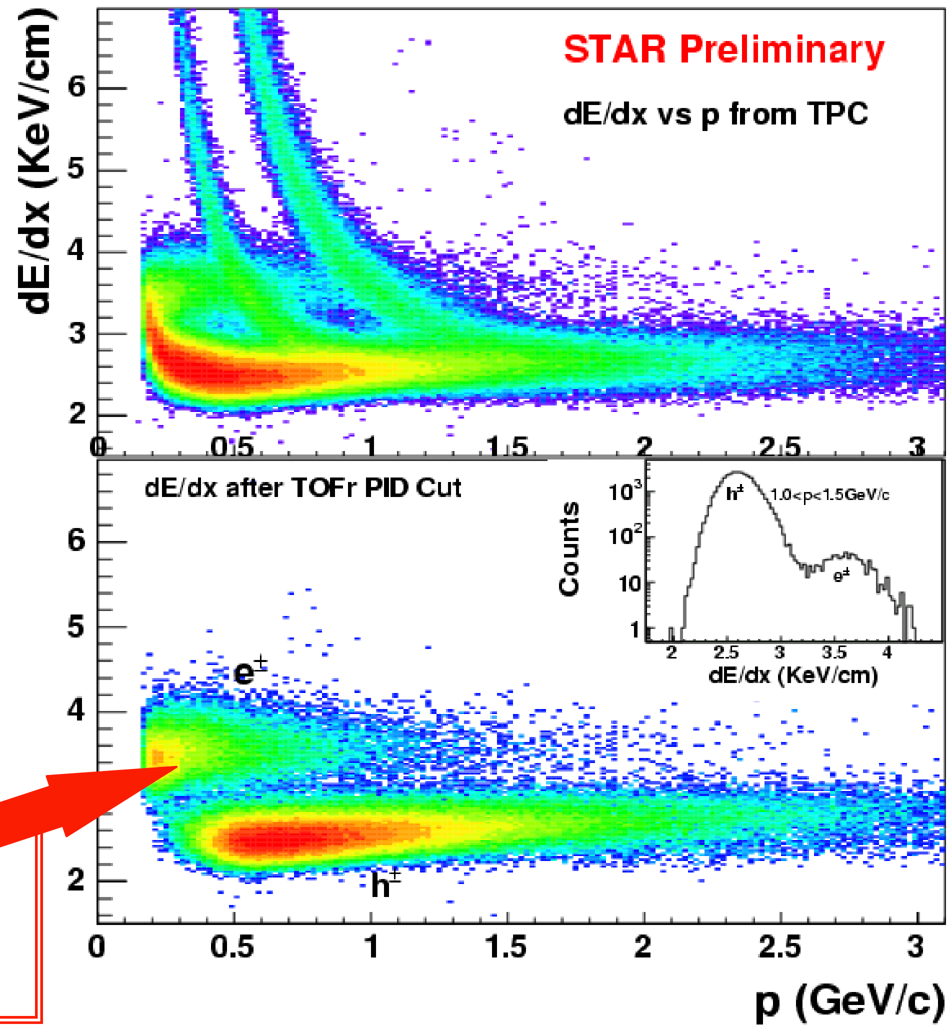
- ⋆ Both experiments are consistent with $\sigma_{c\bar{c}} \approx 1\ \text{mb}$

The work has just begun…

- Direct open Charm D0, D* and D± were measured in d+Au collisions
- Single electron measurements agree with direct D measurements well.
- The D p_T spectral shape is about the same as the bare-quark distribution from the NLO calculation
  - Very peaked fragmentation function?
- Cross section (glass half empty/half full):
  - PHENIX e in p+p : $\sigma \sim 700$ μb
  - STAR D in d+Au: $\sigma \sim 1.3$ mb
  - Actually, only 1.6σ away… (not factors of >10)
  - Maybe RHIC can become a better reference…

Time of Flight





Hadron identification:
STAR Collaboration, nucl-ex/0309012

Electron identification:

TOFr |1/ß-1| < 0.03

TPC dE/dx electron ID p<1.5

Electron Background

Single Electrons Spectra:

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

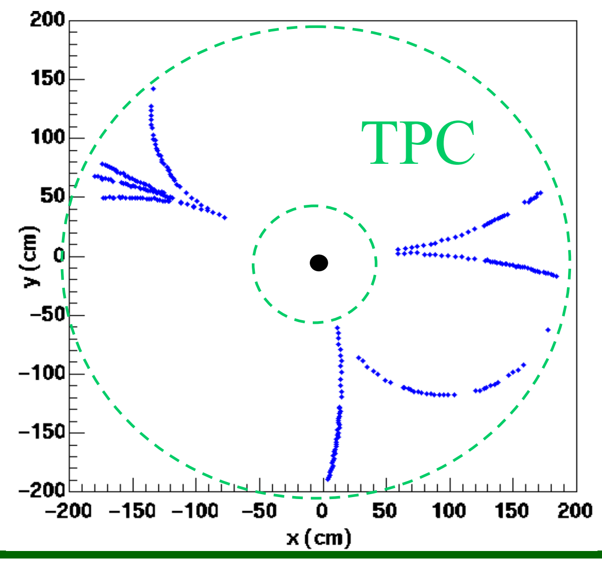
} background

- heavy quark semi-leptonic decay
- others

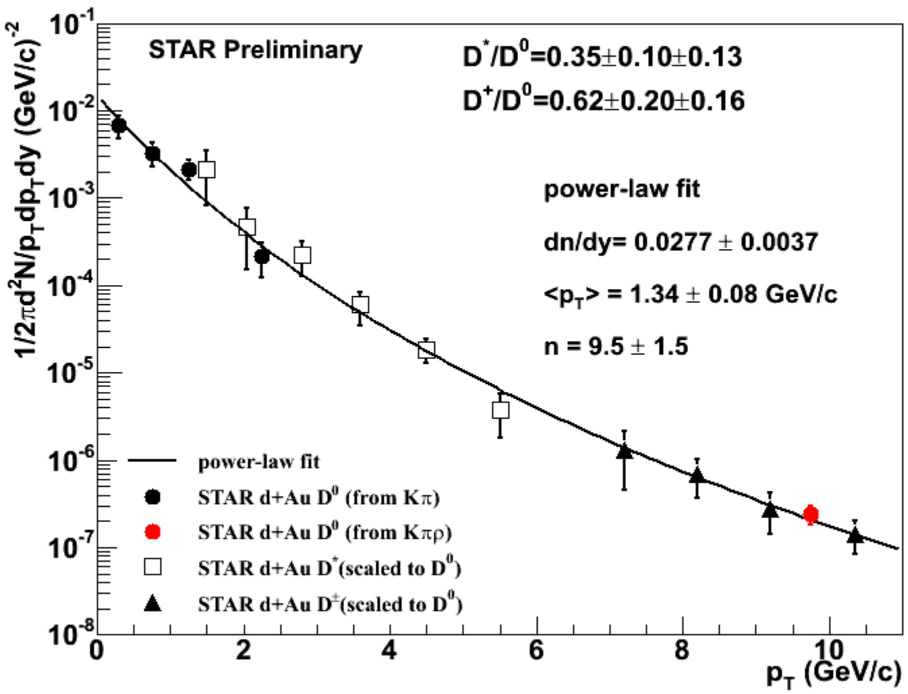
} **signal**

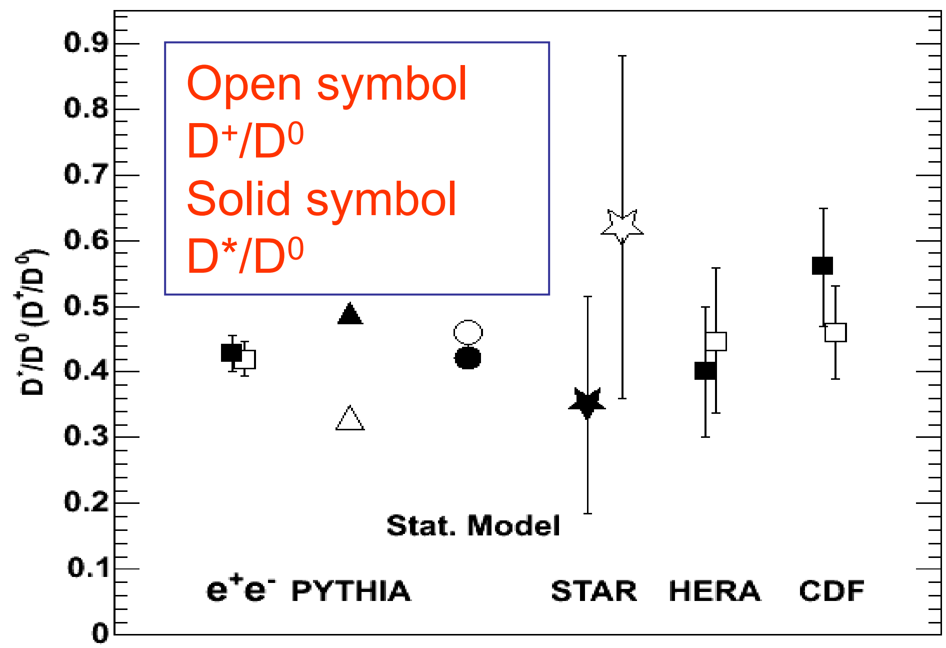
γ conversion and π^0 Dalitz decays are the dominant sources at low pt region.

For the γ conversion and π^0 Dalitz decay, background spectra are obtained from data using kinematical selection of the pairs in TPC



Charm p_T Spectrum



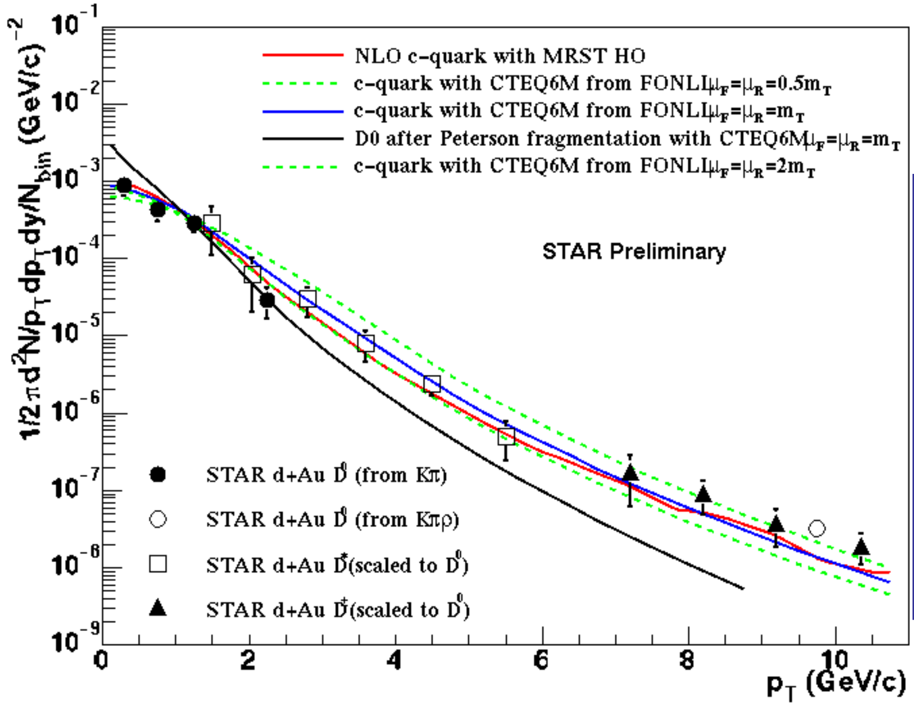


Charm pT spectrum can be fit well by the power-law function

Charm meson ratios consistent with models and previous measurements

Charm p_T Spectrum

Scaled to STAR measured cross section



The measured D pt spectrum shape coincides with the bare-quark distribution from the NLO calculation.

Data favor a fragmentation function peaked at *z*~ 1

NLO order calculation was done by R. Vogt and FONLL code (fixed order NLO and resummations of next-to-leading logs) was obtained from M. Cacciaria and P. Nason, hep-ph0306212