Open Charm Physics at SPS and RHIC

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Production in pp

- Leading-Order Processes
- Higher-Order Results
- Fragmentation Functions
- Total Cross Section vs Data

Production in AA

- Scaling
- Observables at RHIC
- High-$p_\perp$ Suppression from Energy loss
- Mid-$p_\perp$ Enhancement from Radial Flow at SPS
- ? from Radial Flow at RHIC

Open Charm in pA at RHIC

Summary

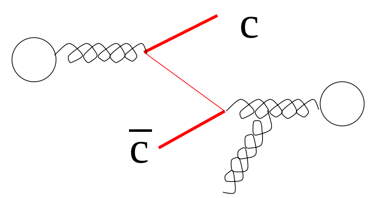
Why do we need open charm?

J/ψ suppression
suppression of total charm or only J/ψ

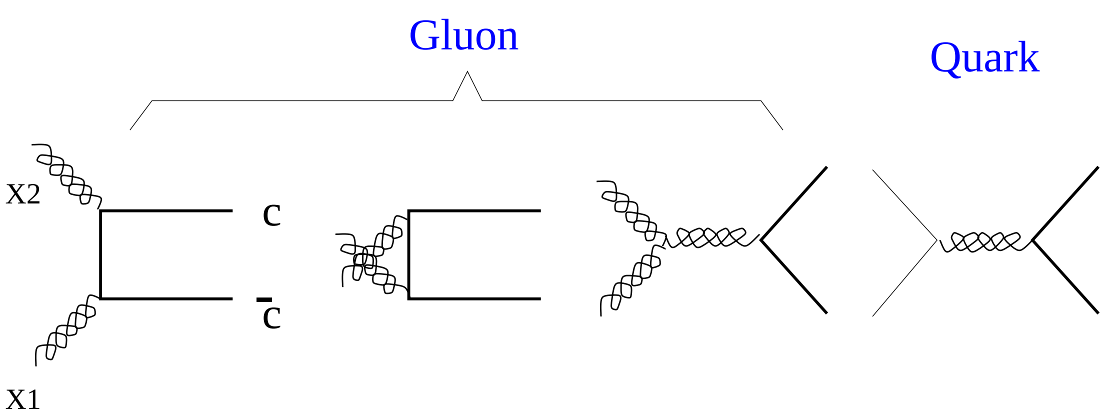
Thermal dileptons
needs good understanding of continuum dilepton spectra

Thermalization
sensitive to energy loss and thermalization effects

Open Charm Production in pp



Leading Order Diagrams



Combridge, NPB151,429(79)

Scale set by $m_c \simeq 1.3$ GeV

Perturbative QCD works reasonably well:

$$\frac{d\sigma}{d^3p} \propto \int dx_1 f(x_1) dx_2 f(x_2) \frac{d\hat{\sigma}}{d\hat{t}}$$

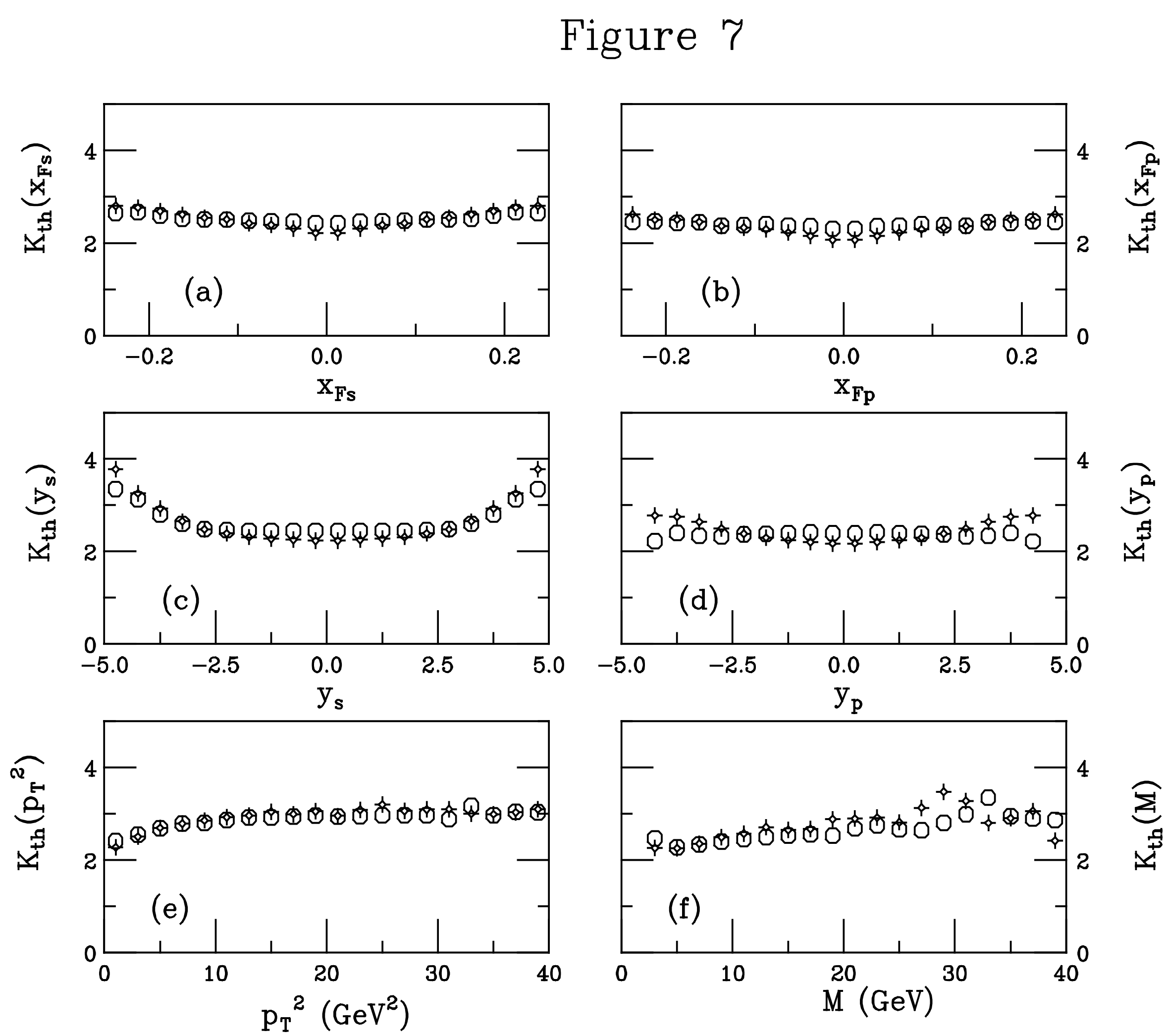
NLO charm production:

Heavy quark production at $O(\alpha^3)$:

Nason et al, NPB303,607(88); 327,49(89)
Beenakker et al, PRD40,54(89); NPB351,507(91)
see Nason hep-ph/9811468 for more

K-factor $\equiv \frac{LO+NLO}{LO}$

Almost constant over the whole phase space!



K far from 1: importance of higher order terms.

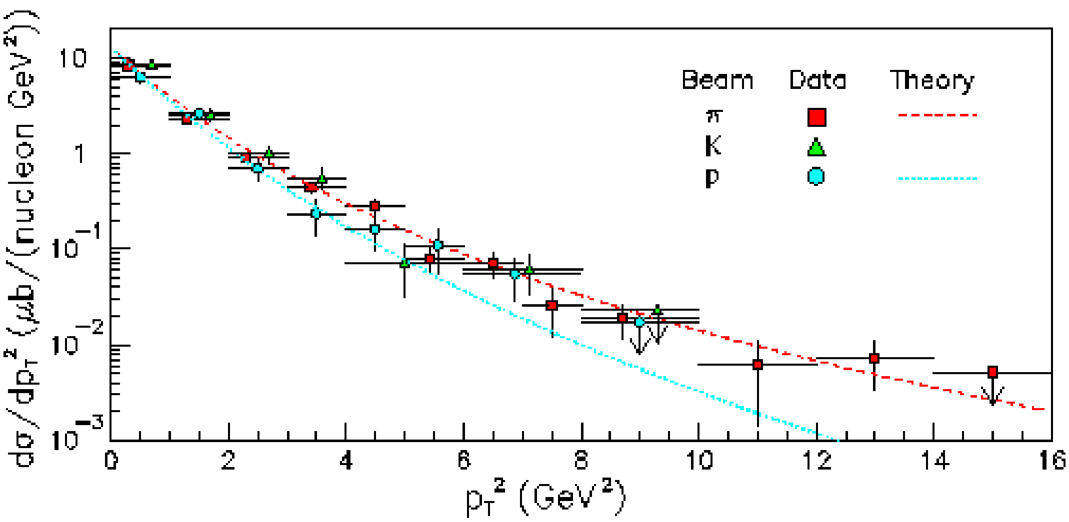
Vogt, ZPC71,475(96)

Charm Fragmentation in Hadroproductions

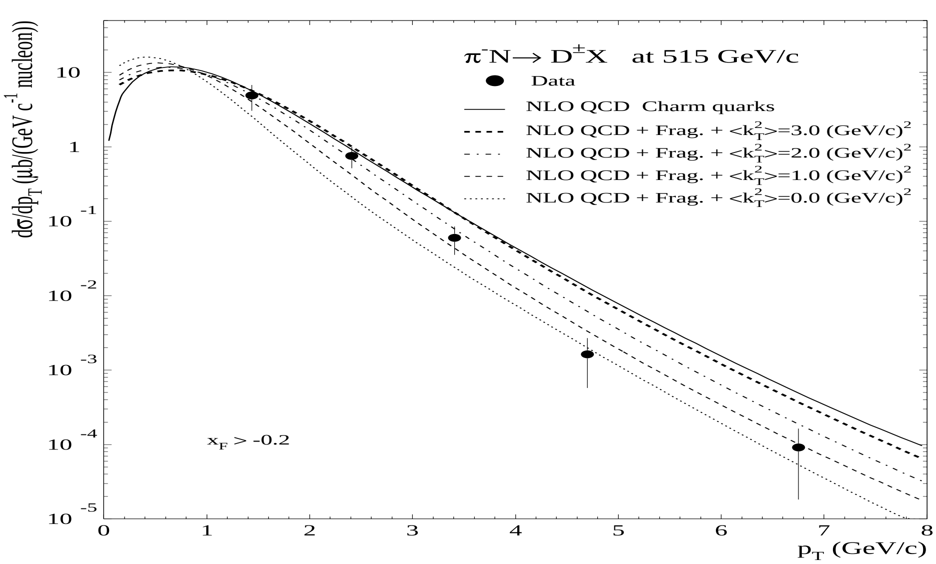
e^+e^- data suggests the Peterson form [a]:

$$D(z) \quad \propto \quad \frac{1}{z[1 - 1/z - \epsilon/(1-z)]^2}$$

E769, consistent with EITHER: bare charm quark spectra OR :Peterson plus intrinsic $< k_\perp^2 >$ of 2 GeV^2



E706, higher $p_\perp$ coverage,
consistent with Peterson plus intrinsic $< k_\perp^2 >$ of $1 - 2$ GeV^2



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[a] $z \equiv p_D/p_c$, $\epsilon = 0.06$(LO), 0.02 (NLO); $\epsilon \propto 1/m_Q^2$

$D\bar{D}$ correlation in hadroproductions [a]:

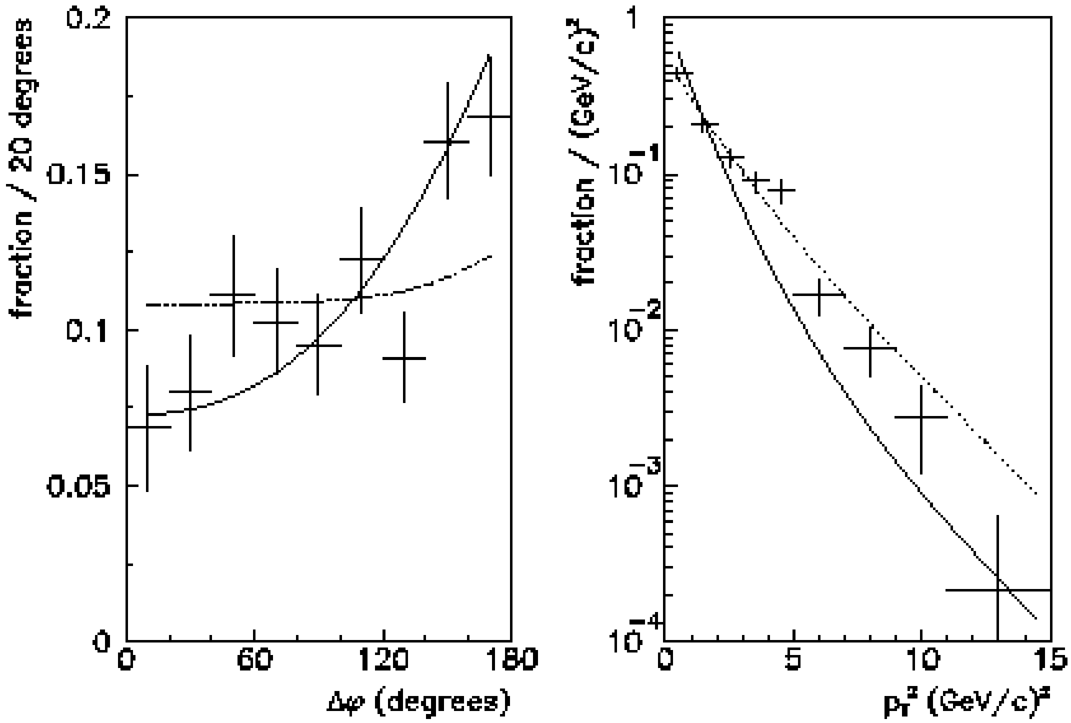


Figure 3: $\Delta\phi$ and $p_T^2(D\overline{D})$ distributions. The lines show for comparison the results of the NLO QCD calculation for $< k_T^2 >= 1\,GeV^2/c^2$ (solid) and $< k_T^2 >= 2\,GeV^2/c^2$ (dashed).

High-$p_\perp$ direct photon and π data suggests:

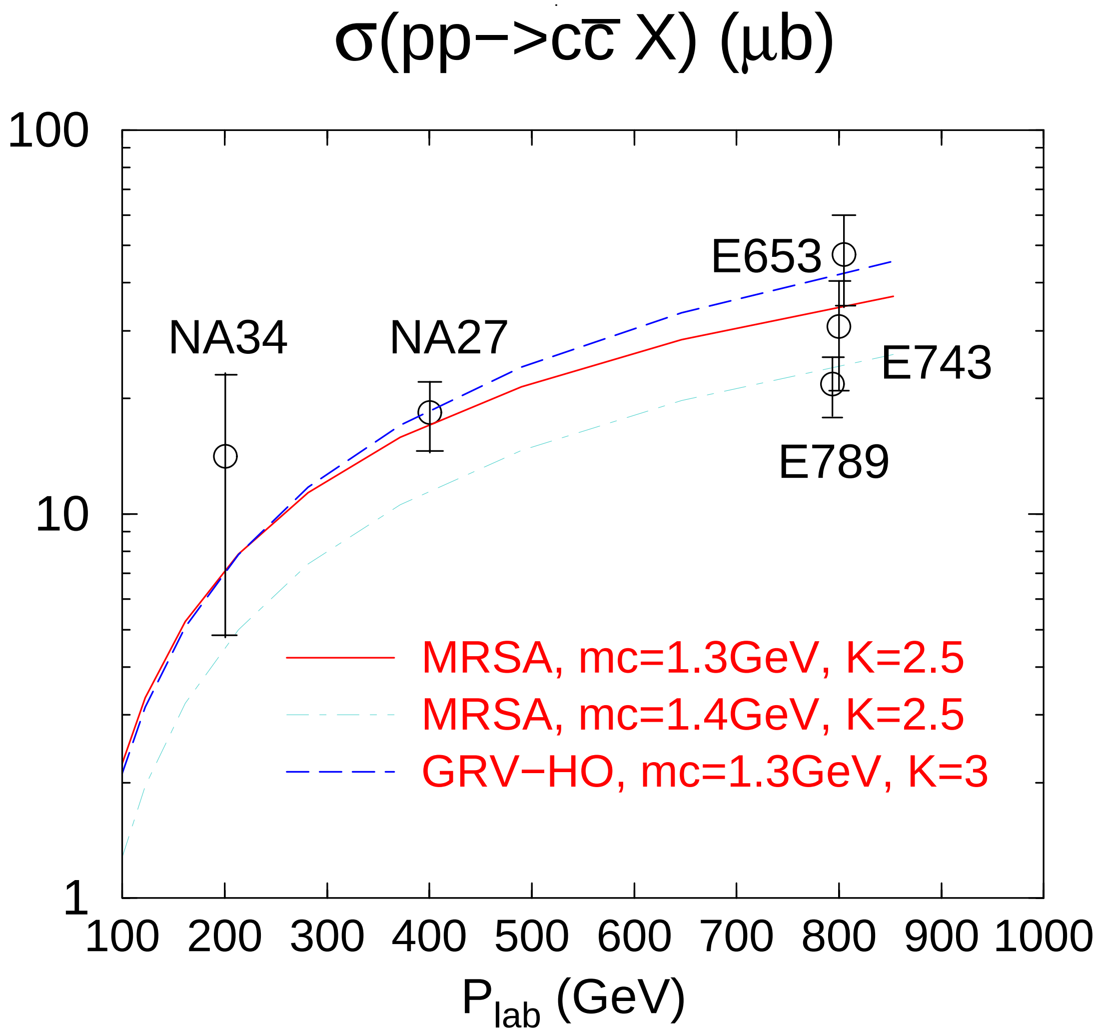
$< k_\perp^2 > \simeq 1$ GeV^2+C Q^2

$\Rightarrow$ Open charm hadroproduction most consistent with Peterson fragmentation+parton intrinsic $k_\perp$

[a] WA92, PLB385,487(96)

Total Cross Section vs Data

From leading-order calculation:



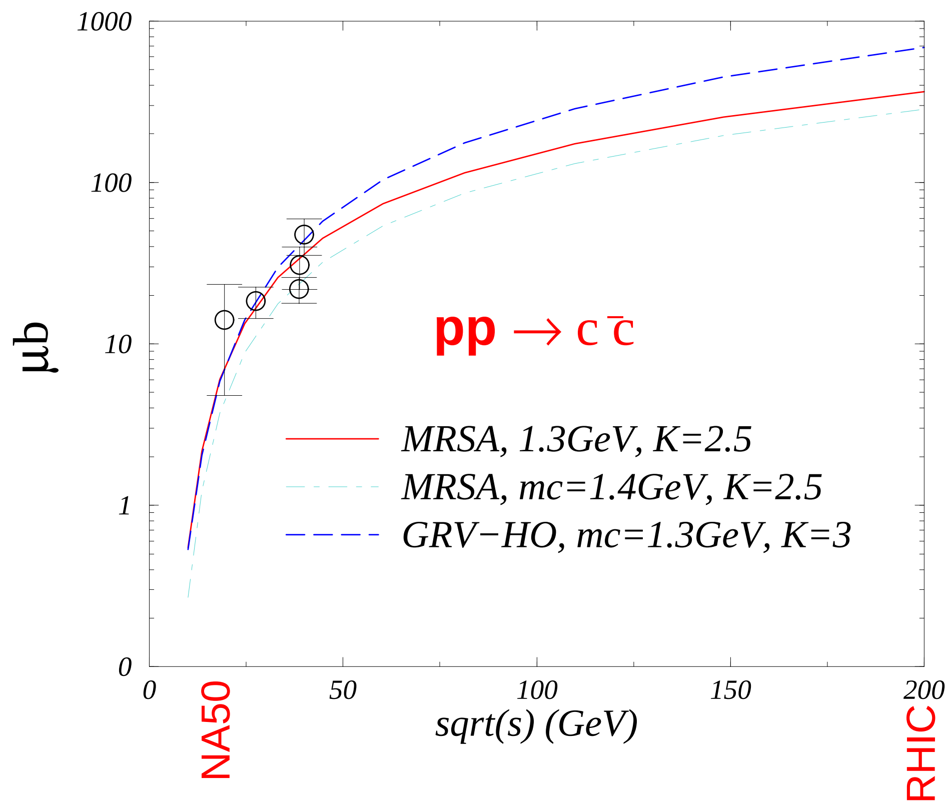
Large uncertainty from scale and quark mass.
However, data helps to constrain parameters,
NLO & resummation help,
making ratios helps(systematic studies)

Open Charm Production in AA

Scaling from pp to AA

(*shadowing* on nuclear structure function will be discussed later)

$$\frac{d\sigma^{c\bar{c}}_{AB}}{d^2b} \propto T_{AB}(b) * \sigma^{c\bar{c}}_{pp}$$



$$\sigma^{c\bar{c}}_{pp} \simeq 350\mu b \text{ (at 200GeV)}, \quad T_{AA}(0) \simeq 30/mb$$

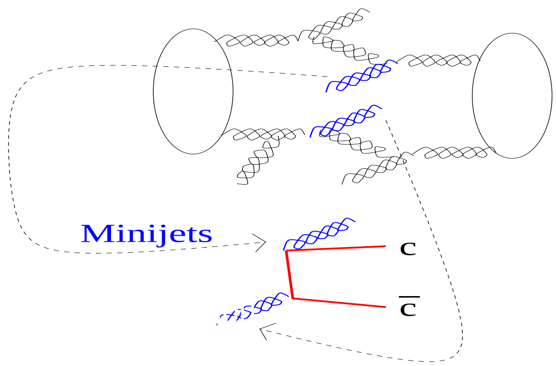
$\Rightarrow$ **large open charm production at RHIC!**

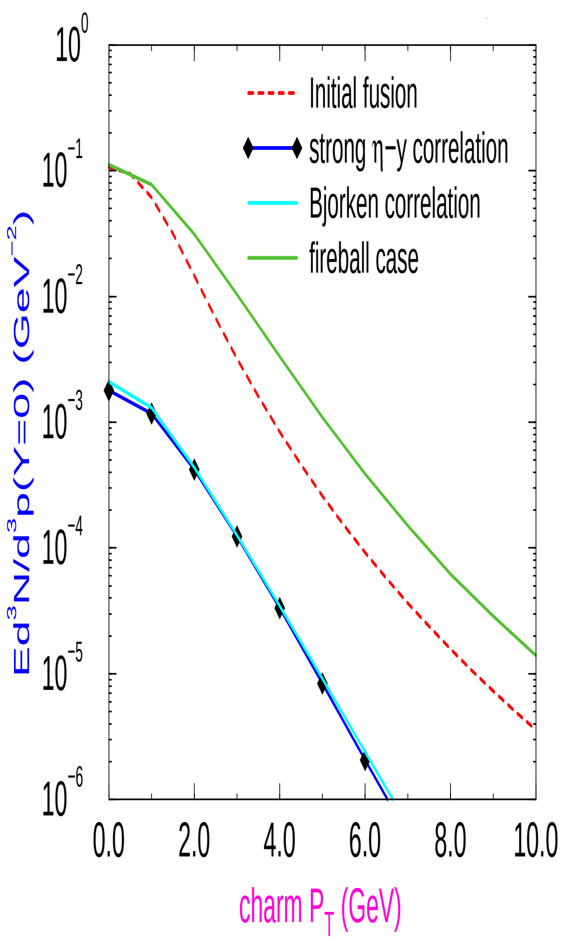
For an average central $Au + Au$ event:

$$N^{c\bar{c}}(\vec{b}=0) = T_{AA}(0) * \sigma^{c\bar{c}}_{pp} \simeq 10$$

Small secondary charm production

Pre-equilibrium charm production from minijets





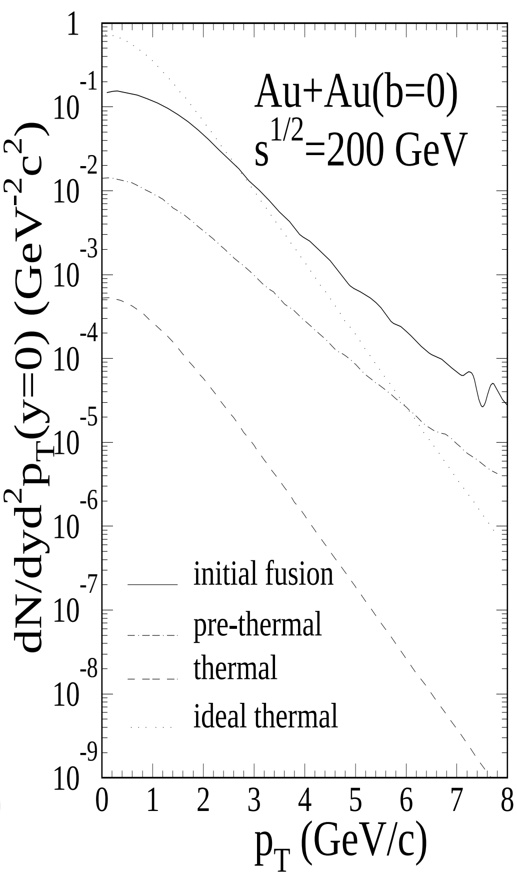


Fig. 5

Lin & Gyulassy, PRC51, 2177(95)   Lévai, Müller & Wang, PRC51, 3326(95)

Observables from open charm:

- D-mesons:
  $D \to K\pi\pi\cdots$
- leptons:
  $D \to e\cdots, \quad D \to \mu\cdots$
- dileptons from D/$\bar{D}$ pairs:
  $D \to e^+\cdots, \quad \bar{D} \to e^-\cdots$
  $\Rightarrow$
  - like-sign pairs: $e^+e^+,\ e^+\mu^+,\cdots$
  - opposite-sign pairs: $e^+e^-,\ e^+\mu^-,\cdots$
    - correlated pairs: from one D/$\bar{D}$ pair
    - uncorrelated pairs: from two D/$\bar{D}$ pairs

RHIC

STAR? PHENIX?

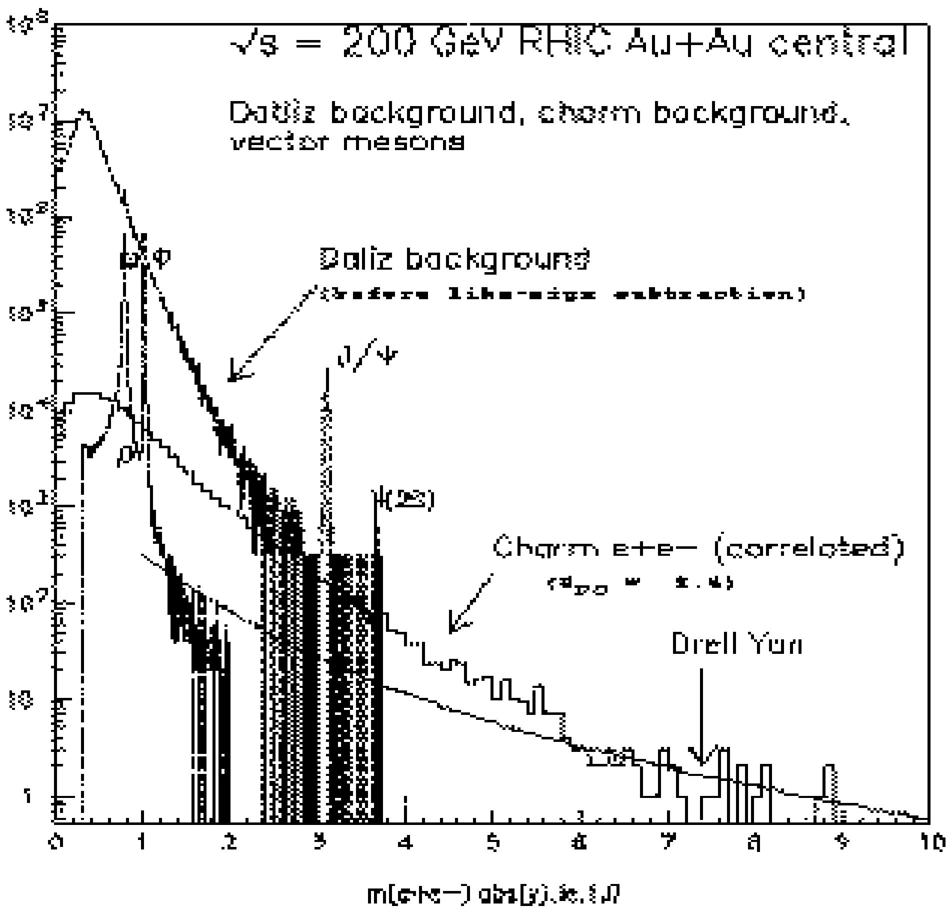
PHENIX, good

PHENIX,good

Large Dilepton Yield from Charm Decays

Larger than Drell-Yan,

PHENIX is able to see those:

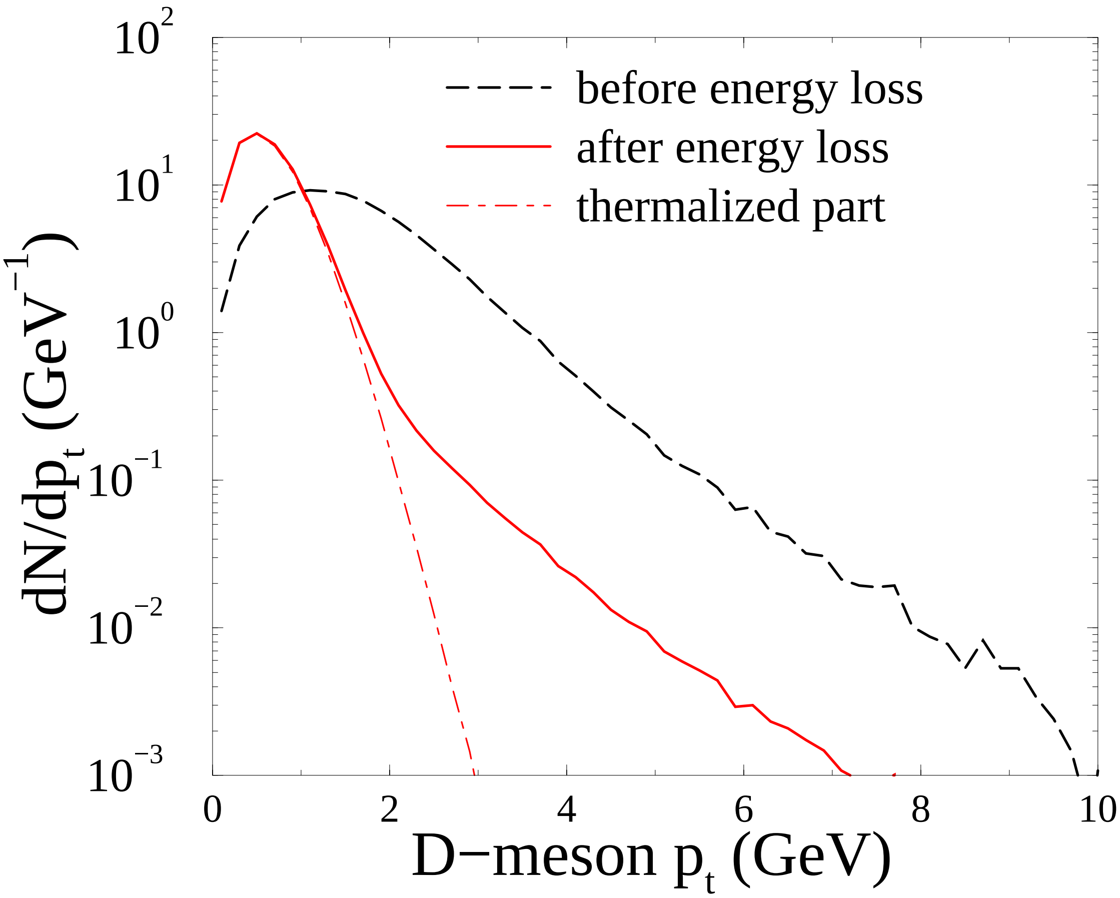


Mass spectrum of electron pair in central arms. The contribution of vector mesons, J/Psi, combinatorial background, correlated charm pair, and Drell Yan are shown. The statistic of the figure is roughly corresponds to 1 year of RHIC running

from Akiba

Heavy quark may have energy loss

Shuryak, PRC55,961(97); Lin, Vogt & Wang, PRC57,899(98)



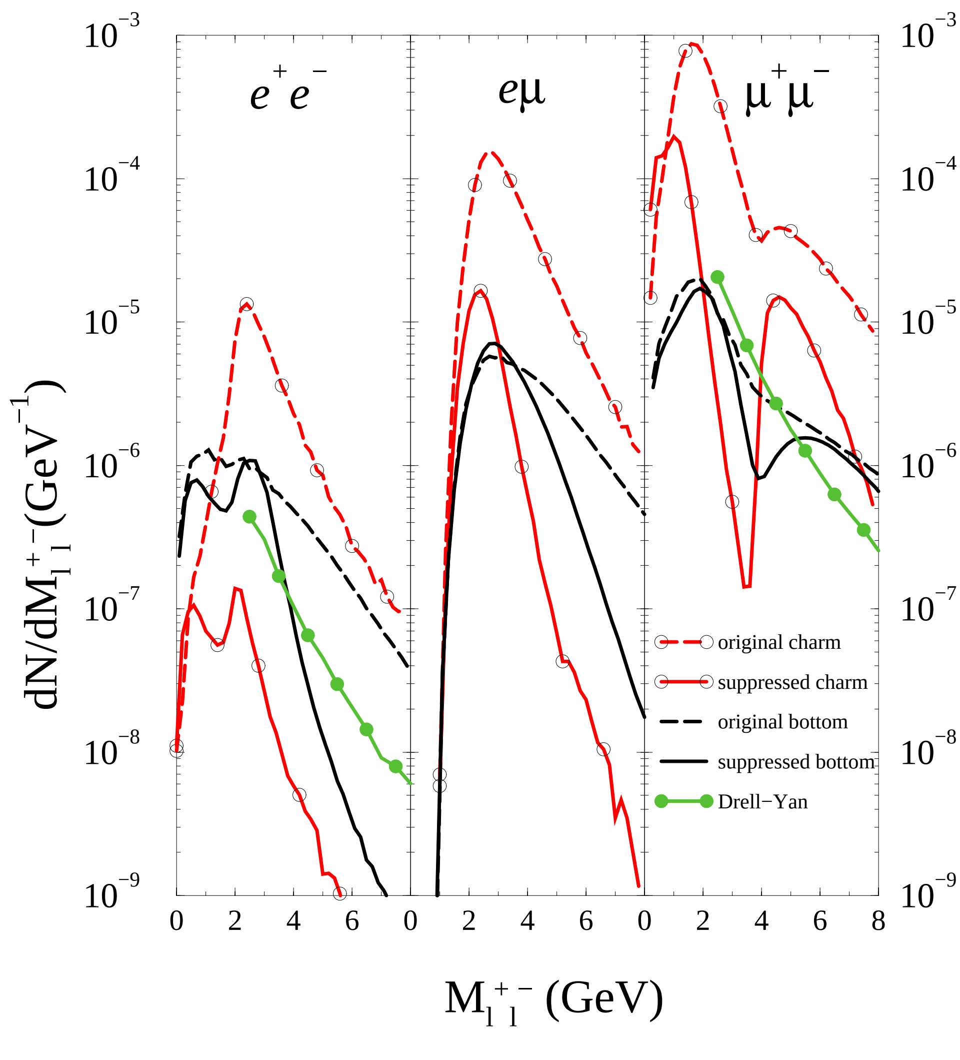
- Suppressions of high-$p_\perp$ D mesons, as well as high-$p_\perp$ leptons and high-M dileptons from charm decays.
- No evidence of jet quenching for pions At SPS [a] $\rightarrow$ large formation time for fast pions?
- heavy quarks might be the best probe of energy loss

Figure: assumed dE/dx=-1GeV/fm, Lin, Vogt & Wang, PRC57

[a] Wang, PRL81,2655(98)

PHENIX will then see a large suppression:

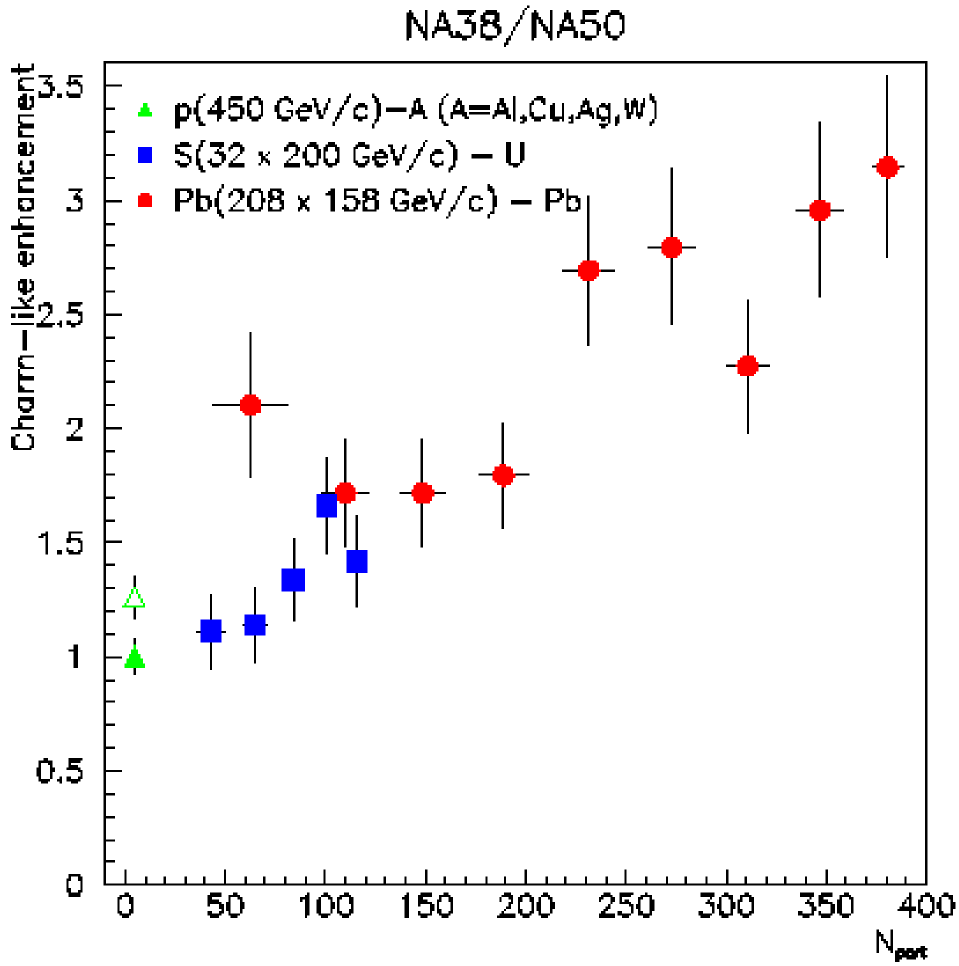
$E_e > 1$ GeV, $\eta_e \in (-0.35, 0.35)$; $E_\mu > 2$ GeV, $|\eta_\mu| \in (1.15, 2.44)$



Lin, Vogt & Wang, PRC57,899(98)

Enhancement of dileptons from NA50

Intermediate mass region: $M_{\mu^+\mu^-} > 1.5$ GeV



Charm–like enhancement:

a factor 3 in central Pb–Pb with respect to p–A

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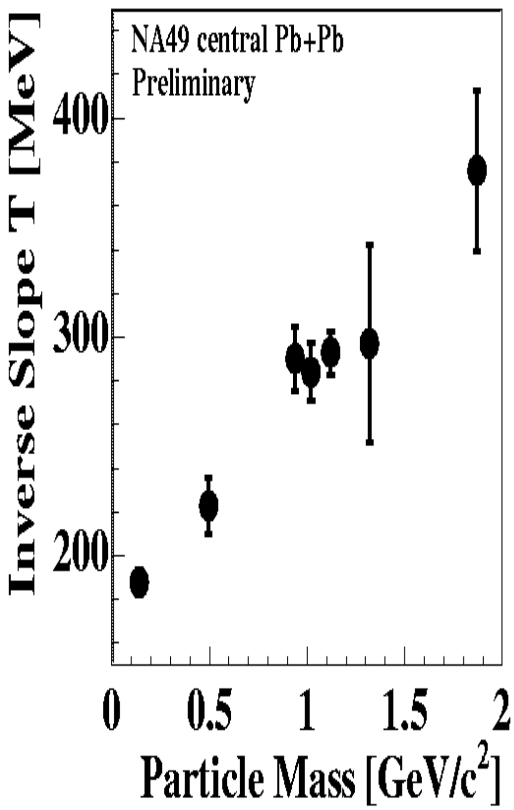
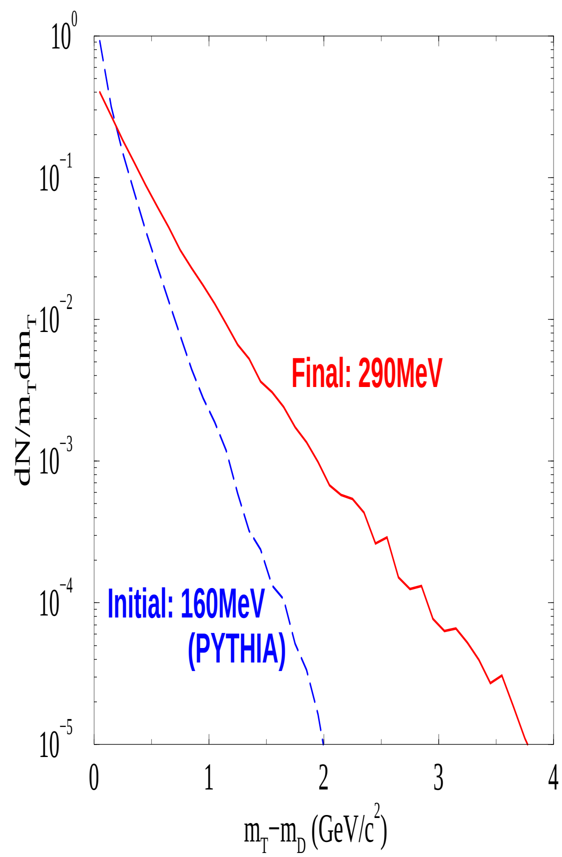
from Scomparin, SQM'98

Enhancement from Charm Radial Flow

Hadron m_T inverse slope $T_{eff} \propto$ mass:



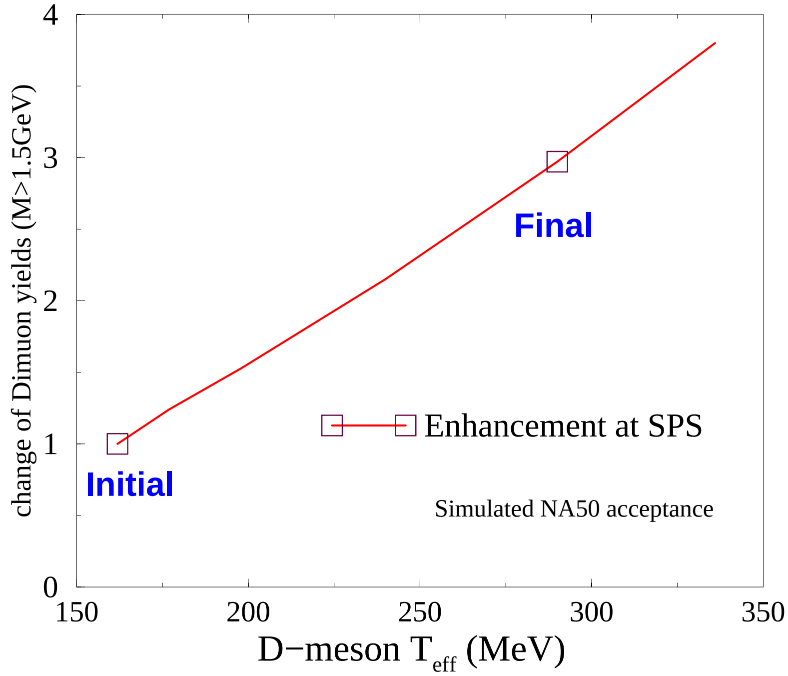


Then D-meson would be harder:

mid-$p_\perp$ D-mesons enhanced.

However, no change in the total number

Enhancement vs T_{eff}



Lin & Wang, PLB in press.
Detailed study can be done in a cascade model.

Will this enhancement happen at RHIC?

$\sqrt{s}$ (GeV)	Initial T_{eff}^{D} (MeV, PYTHIA)	Final T_{eff}^{D} (MeV)
17 (SPS)	160	290?
200 (RHIC)	430	
5500 (LHC)	500	

In addition to energy loss at RHIC, radial flow may soften D-meson spectrum & lead to a SUPPRESSION of dileptons from charm, instead of the enhancement at SPS.

Other Suggestions on IMR Dilepton Enhancement

- A)πa_1 annihilation [a]:
  - enhancement comes mainly from the πa_1 coupling to $\rho(1700)$;
  - however, this coupling is uncertain
- B) Secondary Drell-Yan processes [b]:
  - mainly from interactions between produced mesons and baryons
  - sensitive to hadron formation time τ_F
  - effect varies from 30% to 3 for $Pb + Pb$
- How to test these scenarios at RHIC?
  - A) scales with (pion number)^2
    $\Rightarrow$ bigger enhancement at higher energies
  - B) scales with (pion number)
    however, finite τ_F would probably kill the main contribution due to the huge γ factor
  - Suppression expected from the open charm scenario

[a] Li & Gale: Nucl.Phys.A638,491c(98)

[b] Spieles et al, Eur.Phys.J.C5,349(98)

Open Charm in pA at RHIC:

a unique place to measure gluon shadowing

$$\frac{d\sigma^{c\bar{c}}_{pA}}{d^3p} \propto \int dx\, f(x) \int dx_A \frac{d\hat{\sigma}}{d\hat{t}} f(x_A)\; S(x_A, Q^2)$$

Nuclear shadowing of
quark densities observed.
Gluon shadowing too(indirectly):

Large effects on
global observables at RHIC:
(Even Larger effects on
gluon-dominated processes)

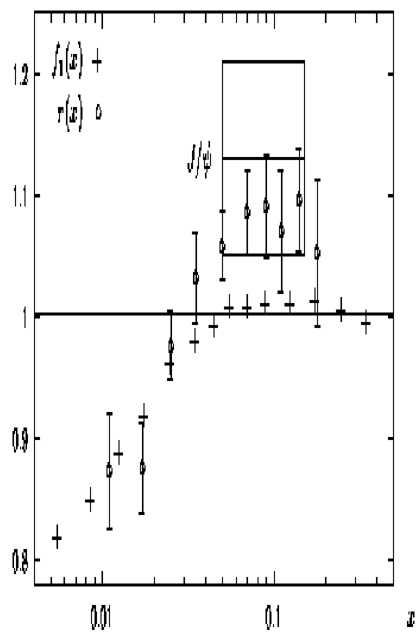
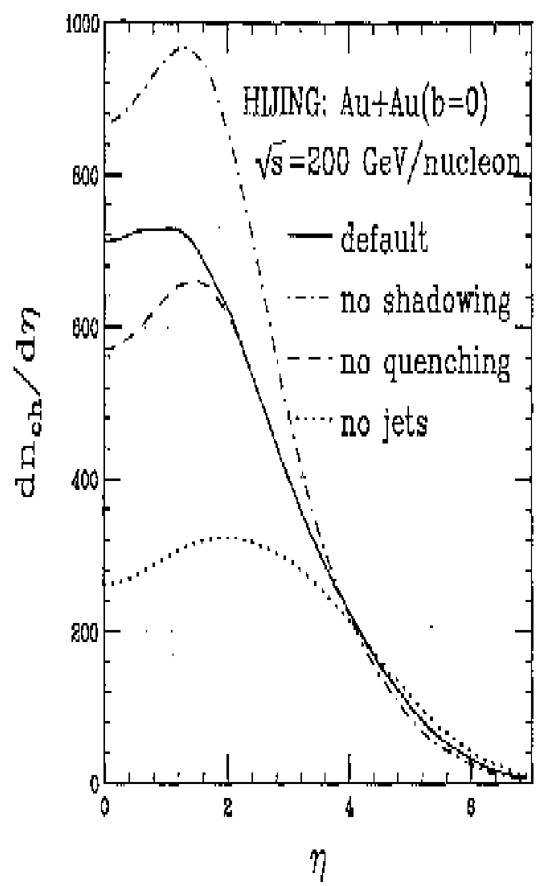


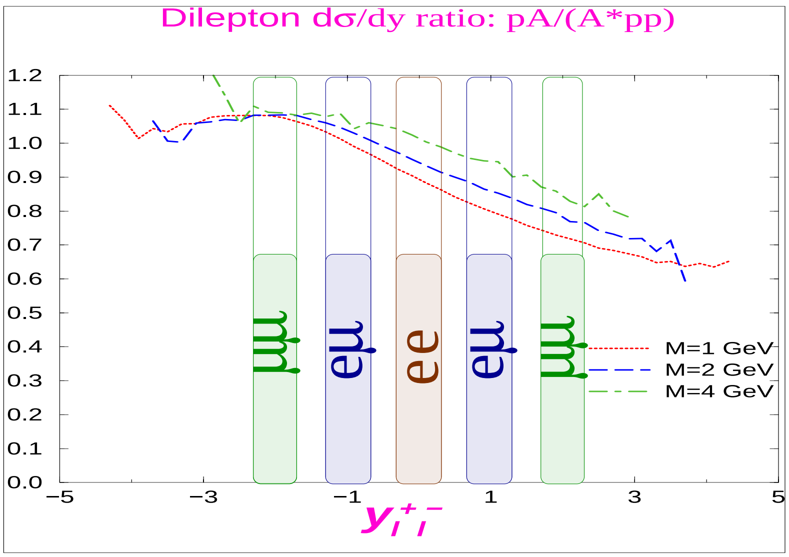
Figure 2: The ratio $r(x) = G^{Sn}(x)/G^{C}(x)$ of tin to carbon gluon density as a function of x together with the ratio of structure function, $f_1(x) = F_2^{Sn}(x)/F_2^{C}(x)$. The statistical error on f_1 is less than 1% in the whole range of x. The box represents the extraction of r from J/ψ electroproduction data [2] (see text).



Gousset & Pirner,PLB375,349(96).

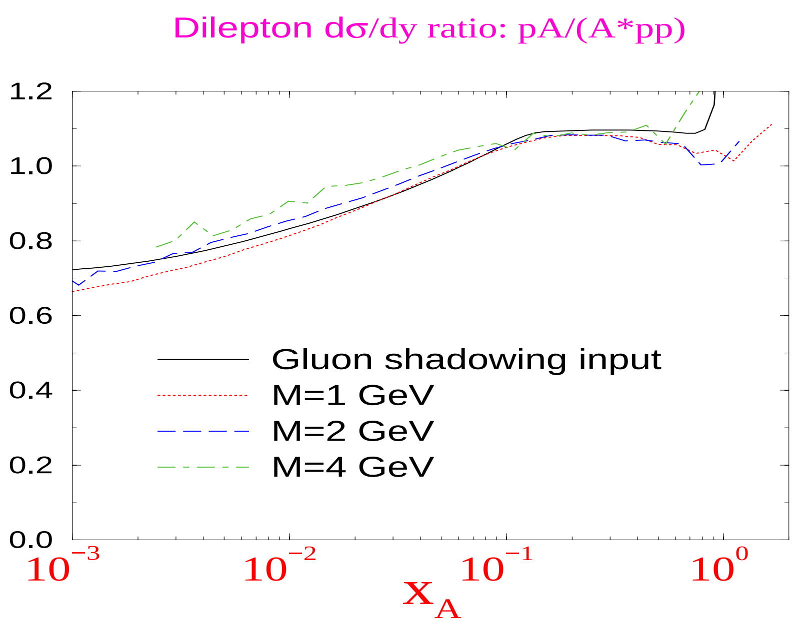
Wang & Gyulassy,PRD44,3501(91)

Mapping Gluon Shadowing in pA at RHIC:



Relate dileptons rapidity with Bjorken x_A:

$$\ln x_A \approx -y_{l^+l^-} + \ln(\alpha M + \beta)$$



Lin & Gyulassy, PRL77,1222(96)

α&β determined from charm fragmentation and decay kinematics

Summary

- Open charm production in pp
  - reasonably described by NLO pQCD
  - best fit with Peterson's fragmentation plus hadron intrinsic $k_\perp$
- Open charm production in AA at RHIC
  - large yield of open charm & dileptons from their decays
  - great coverage of open charm observables
  - high $p_\perp$ might be the best probe of energy loss
  - radial flow may change spectra at medium $p_\perp$
  - dilepton spectra from open charm decays in pA can map the gluon shadowing in nuclei
  - must be studied well before other issues can be addressed well, such as thermal dileptons and J/ψ suppression
- In 1/2 year RHIC will start to answer!