J/ψ & Drell-Yan Production in p-A Collisions

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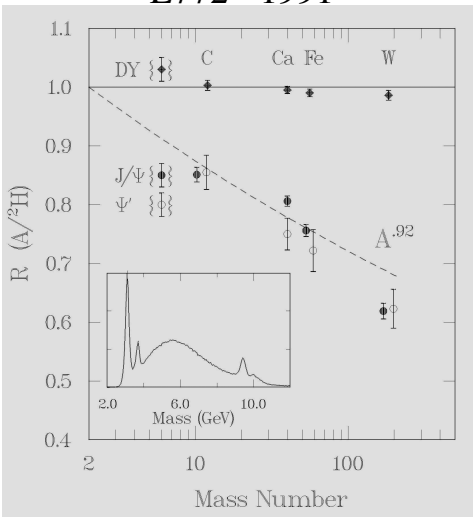
Workshop on High-p_T Phenomena at RHIC

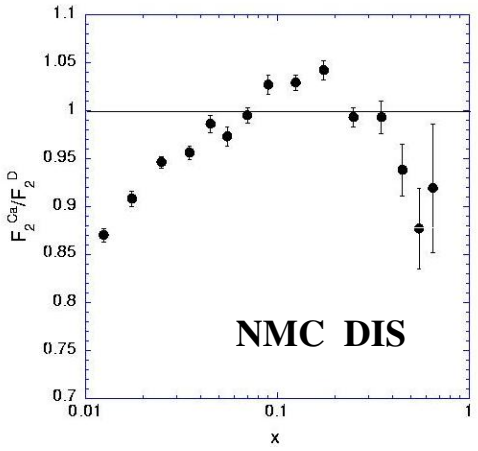
BNL, November 1-2, 2001

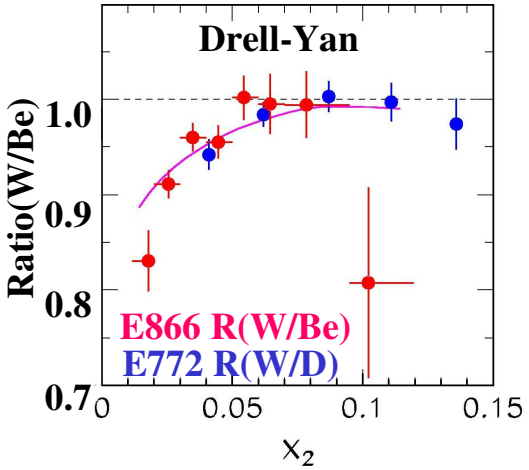
- **Introduction to Physics of Drell-Yan & Charmonium suppression in nuclei**
- **E866/NuSea & comparison to NA50**
- **Energy loss & shadowing**
- **Systemtics of p_T broadening**
- **Summary**

E772 - 1991

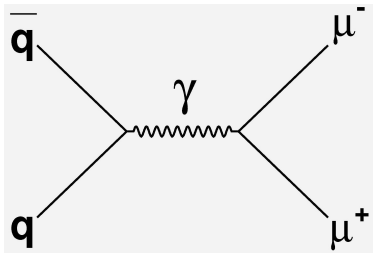


Nuclear modification of parton level structure & dynamics





Drell-Yan Process

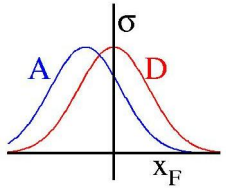


Modification of parton momentum distributions of nucleons embedded in nuclei

- e.g. shadowing – depletion of low-momentum partons. Process dependent?

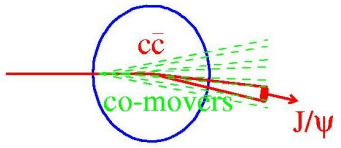
Nuclear effects on parton "dynamics"

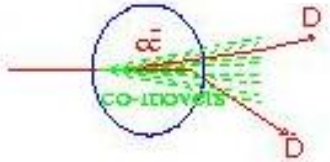
- energy loss of partons as they propagate through nuclei
- and (associated?) multiple scattering effects

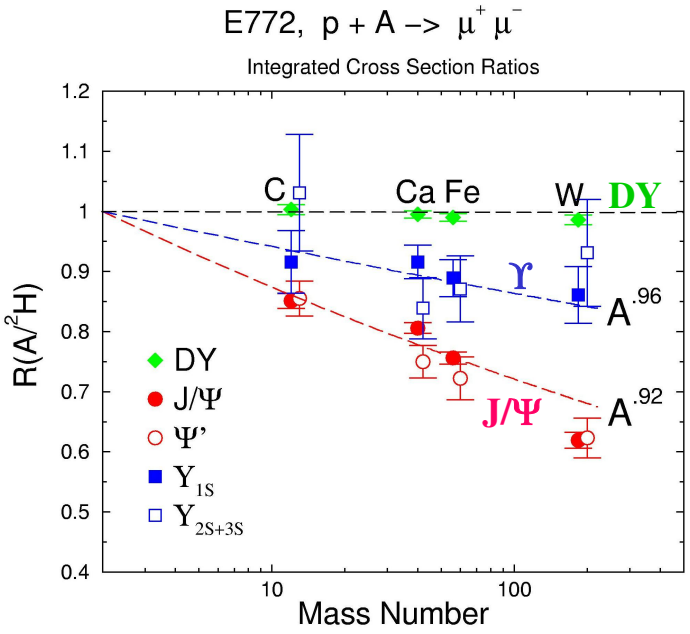


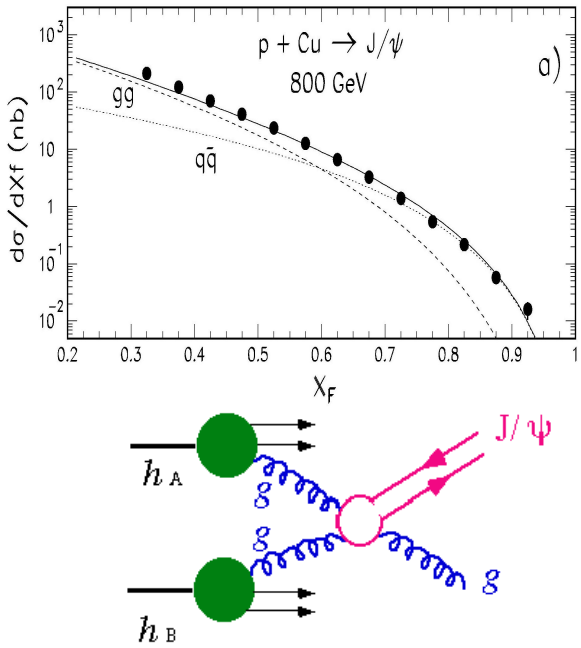
Production of heavy vector mesons, e.g. J/Ψ, Ψ ', ϒ

- production: color singlet or octet $c\bar{c}$ ($b\bar{b}$) and color neutralization timescale
- hadronization time: $l_H \approx 2E_{J/\Psi}/(m^2_{\Psi'} - m^2_{J/\Psi})$
- Coherence length for cc fluctuations: $l_C \approx 2E_{J/\Psi}/m^2_{J/\Psi}$
- absorption on nucleons or co-movers
- feed-down from higher mass resonances, e.g. χ_c







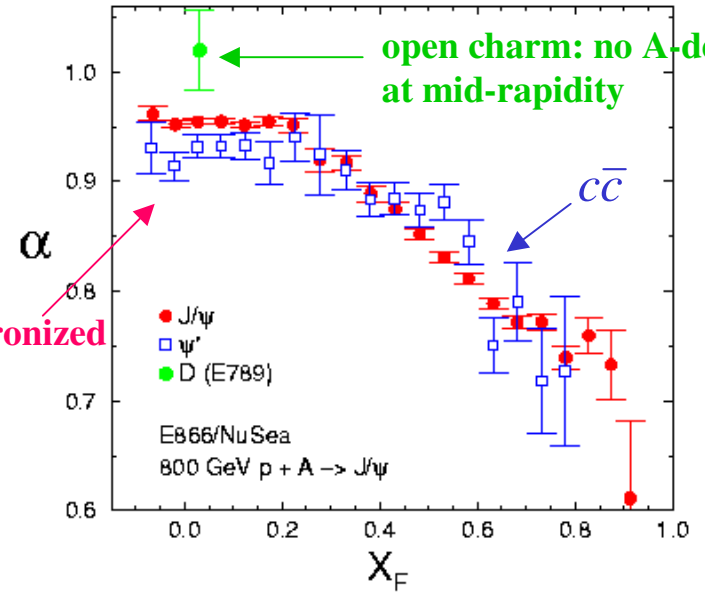


J/Ψ suppression – an effective signature of Quark-gluon plasma (QGP) formation?

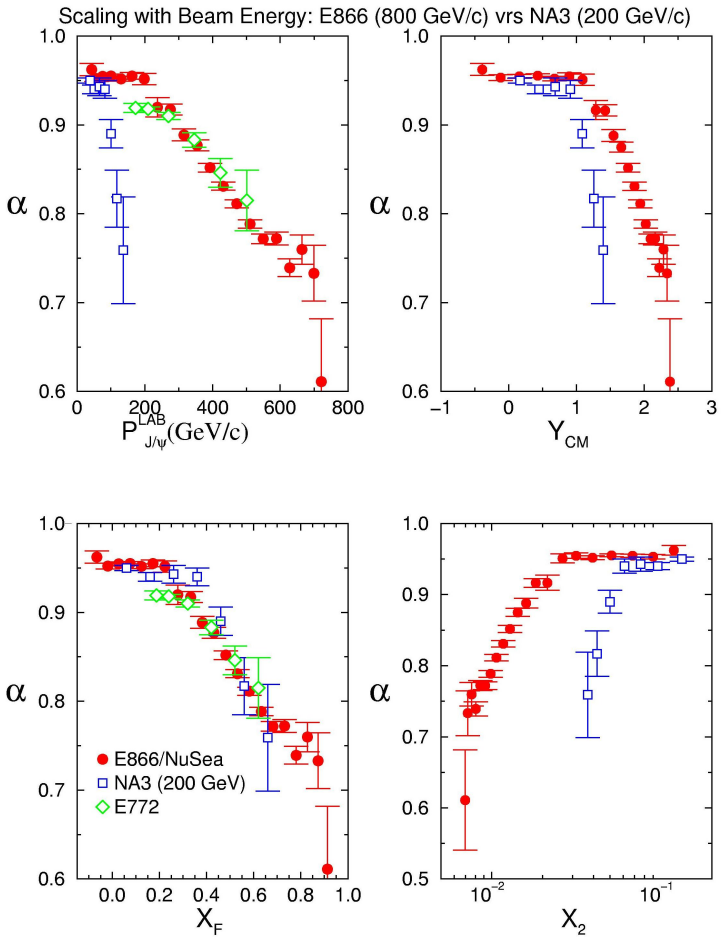
- **Color screening in a QGP would destroy $c\bar{c}$ pairs before they can hadronize into charmonium**
- **But ordinary nuclear effects also absorb or modify J/Ψ's**
- **We need a comprehensive understanding of charmonium production in nuclei**
- **Competing effects may be identified in p-A collisions by their strong kinematic dependencies, together with complementary studies of Drell-Yan scattering and open-charm production**

E866/NuSea: 800 GeV p-A (Fermilab)

PRL 84, 3256 (2000)



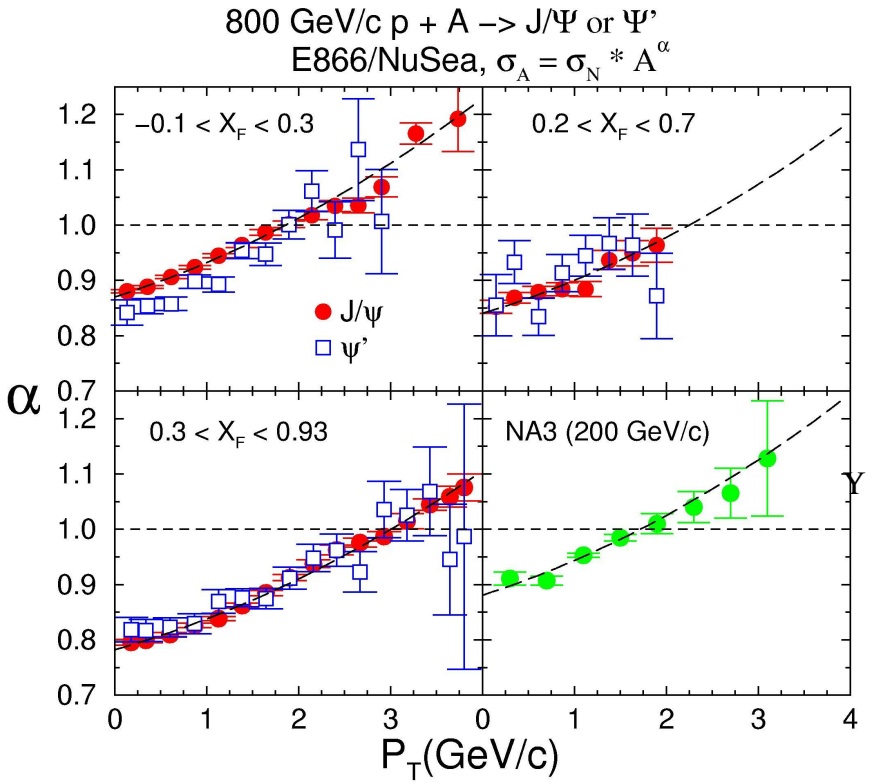
- J/Ψ and Ψ' similar at large x_F where they both correspond to a $c\bar{c}$ traversing the nucleus
- but Ψ' absorbed more strongly than J/Ψ near mid-rapidity ($x_F \sim 0$) where the resonances are beginning to be hadronized in nucleus.



Scaling of J/Ψ Suppression?

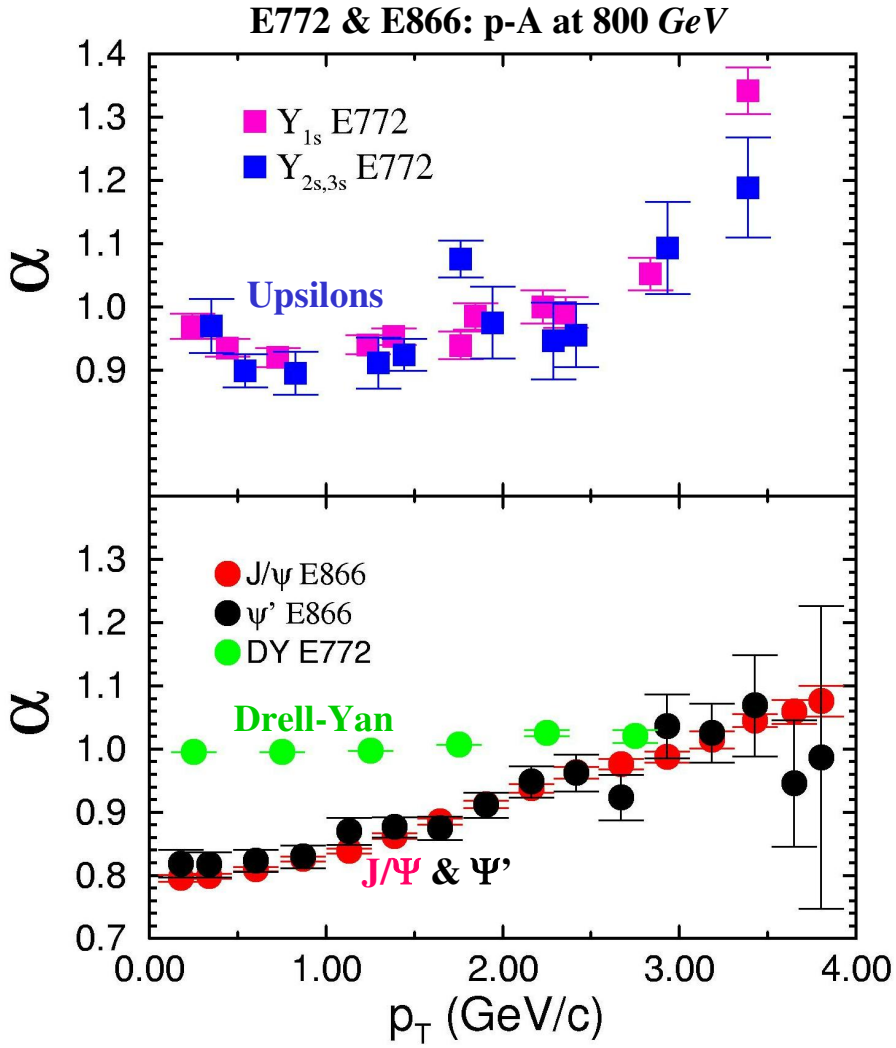
- Comparison of 800 GeV (E866) and 200 GeV (NA3) -appears to scale only with x_F

P_T Broadening at 800 GeV



$\alpha(p_T)$ shape is independent of x_F & same for NA3 at a lower energy

(curves are $\alpha(p_T) = A*(1+.06p_T+.011p_T^2)$ with A slightly different for each)



P_T Broadening in Drell-Yan and associated Energy Loss in Baier model

Baier et al. NP B484, 265 (1987)

$$-\frac{dE}{dz} = \frac{\alpha_S N_C}{4} \times \Delta < p_T^2 >$$

or

$$\Delta E = (0.24 \times slope \frac{GeV}{fm^2}) \times L^2$$

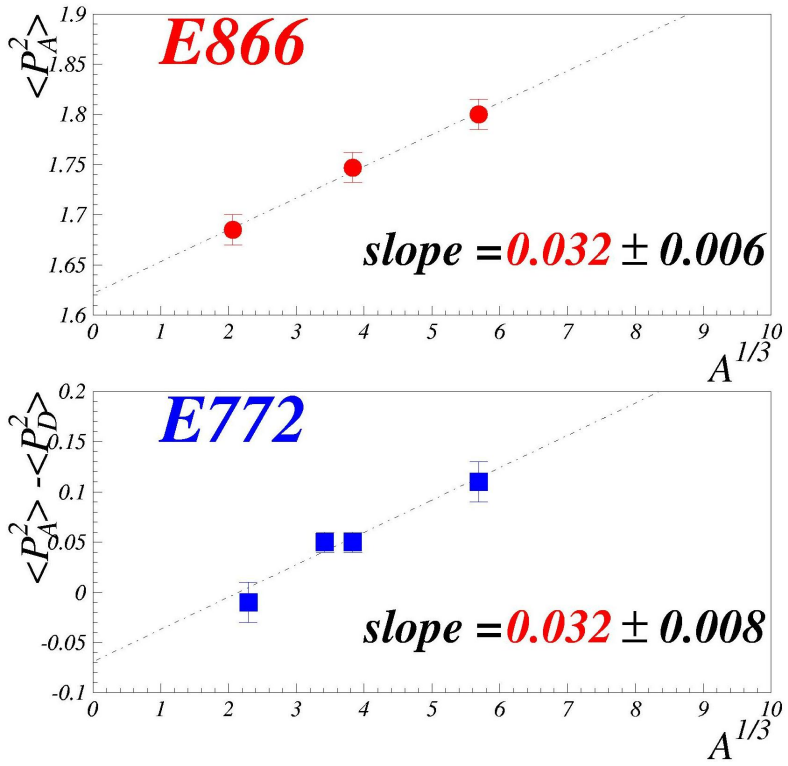
$$= (0.008 \frac{GeV}{fm^2}) \times L^2$$

So energy loss associated with observed p_T broadening is tiny, e.g. for W:

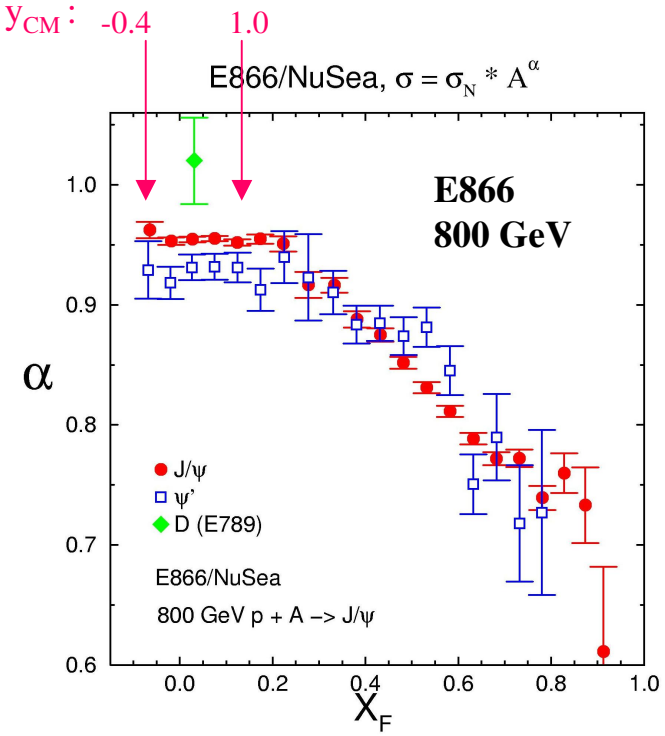
$$L \approx 3.94$$

$$\Delta E \approx 0.12 GeV$$

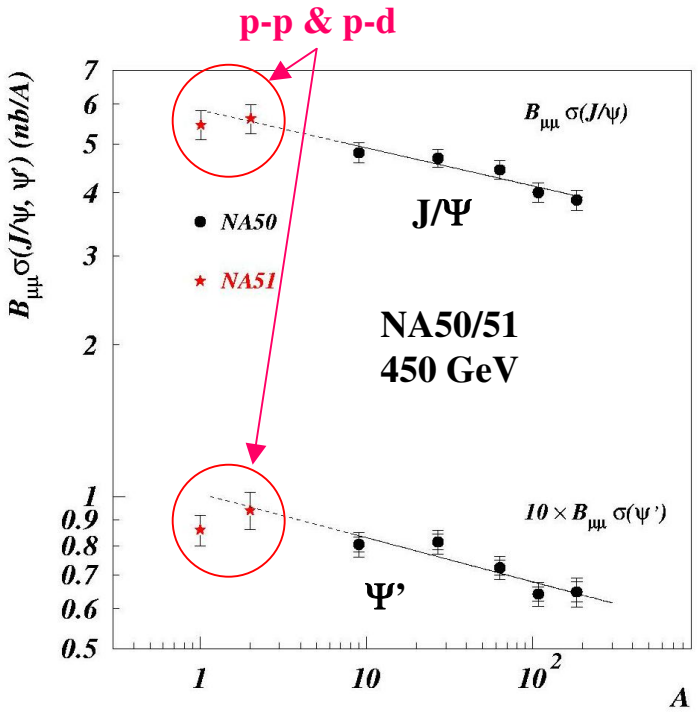
E866 – Preliminary (Maxim Vasiliev)



Comparison to NA50 J/Ψ Nuclear Dependence



$\sqrt{s}$



Charmonia cross sections from NA50/51 for p-A collisions at 450 GeV/c

$\alpha_{y\sim0}$ $\sqrt{s}$ dependence?

- **gluon shadowing?**
- **change in production, e.g. octet vrs singlet balance?**

(Both experiments have good p_T coverage, so strong p_T-dependence of α not the cause)

Expt.	E(GeV)	Y_{CM}	$\alpha_{J/\Psi}$	$\alpha_{J/\Psi} - \alpha_{\psi}$
E866	800	-0.4 to 1.0	.954 ± .001	.027 ± .006*
NA50	450	-0.4 to 0.6	.925 ± .018	.029 ± .014
NA38	200	0 to 1.0	.911 ± .034	

* mid-rapidity part of E866 data

Parton Energy Loss in Nuclei – Kopeliovich Model

Shadowing when coherence length,
$t_{coherence} = 2E_{J/\Psi} / 2M^2_{J/\Psi}$
is larger than nucleon separation

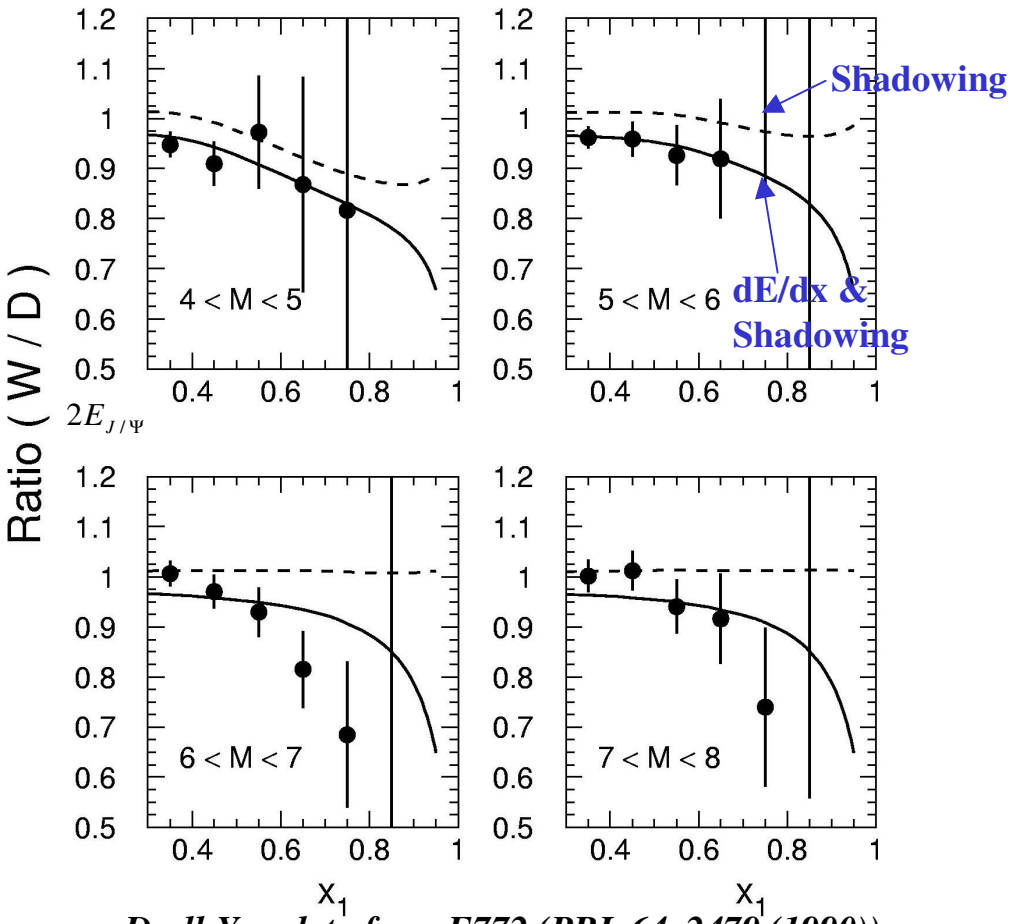
Three *dE/dx* mechanisms:

- **String breaking:** $dE/dz \sim K_s \sim 1$ GeV/fm
- **Multiple bremstrahlung (soft gluons):** $dE/dz \sim 3\alpha/\pi \langle k_T^2 \rangle \sim .8$ GeV/fm
- **Radiative gluon (BDMS) (hard gluons):** $\Delta E \sim 3\alpha/8\, \Delta \langle p_T^2 \rangle \langle L \rangle \sim .075$ GeV/fm (since $\langle p_T^2 \rangle \sim 0.1$ GeV^2 from E772)

Total $\Delta E \sim 2$ GeV/fm expected from above

From E866 DY data, with separation of shadowing & *dE/dx* via Mass dependence, $dE/dz \sim 3 \pm .6$ GeV/fm

Johnson, Kopeliovich et al., hep-ph/0105195



Drell-Yan data from E772 (PRL 64, 2479 (1990))

J.C.Peng, LANL

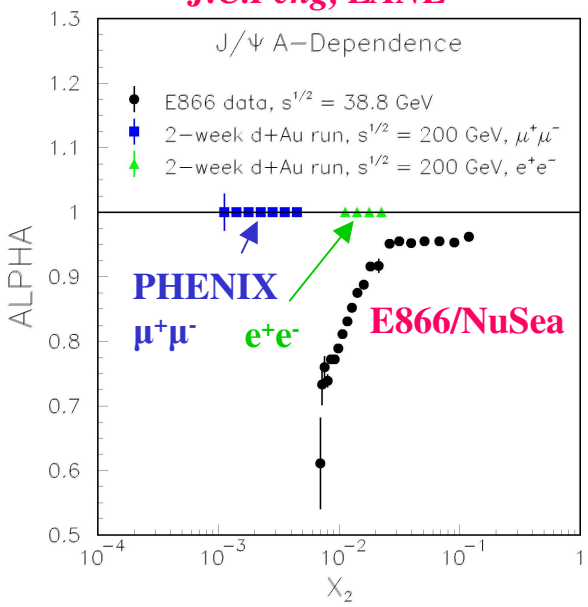
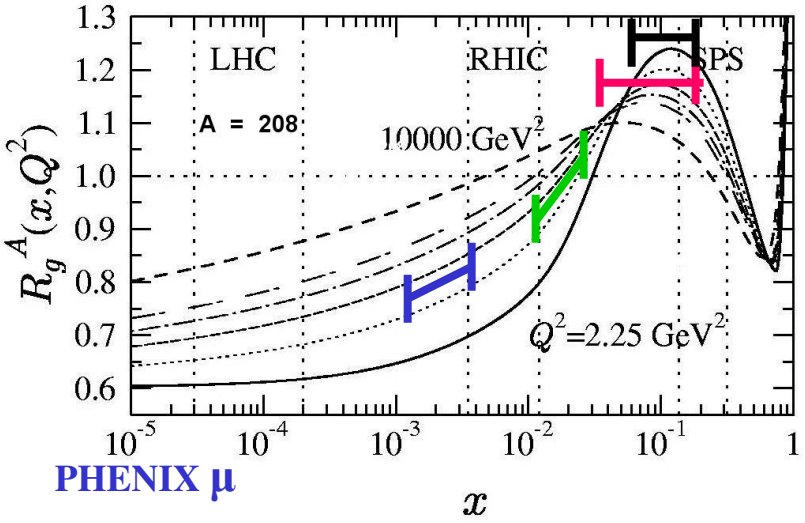


Figure 7: Expected statistical accuracy for measuring the nuclear dependence parameter α from a two-week d+Au run at PHENIX. Data from a fixed-target experiment [6] at $s^{1/2}$ = 38.8 GeV are also shown.

Eskola, Kolhinen, Vogt hep-ph/0104124



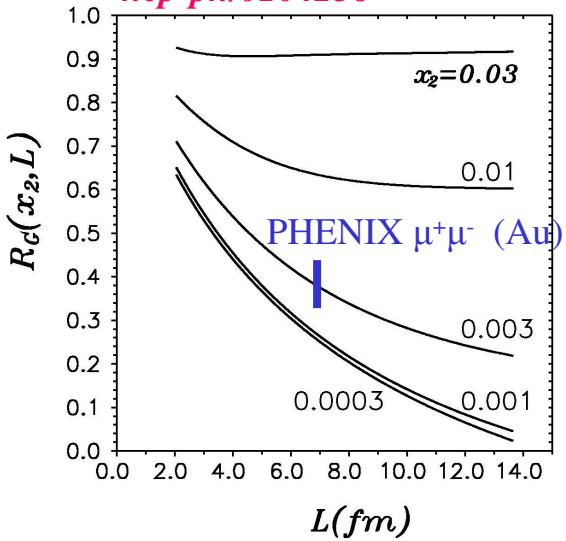
PHENIX μ

PHENIX e

E866 (mid-rapidity)

NA50

Kopeliovich, Tarasov, & Hufner hep-ph/0104256

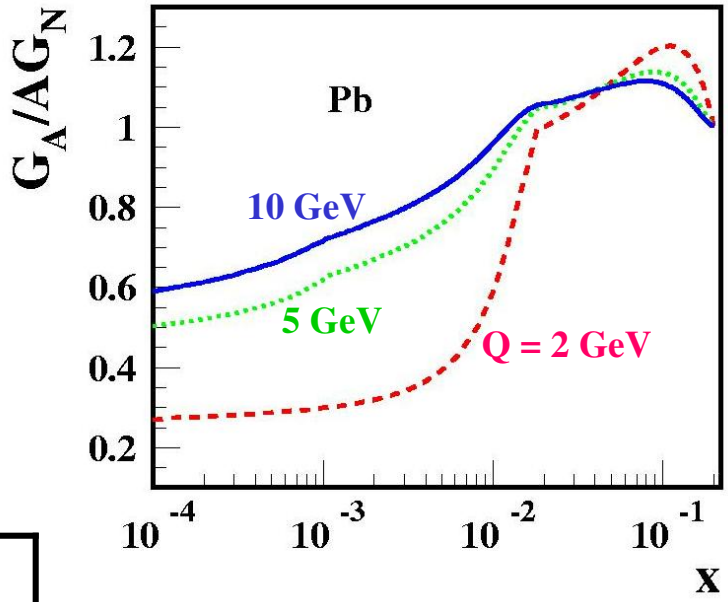


Gluon Shadowing for J/Ψ's

In PHENIX μ acceptance for Au-Au collisions?

- ***Eskola…* : ~ 0.8**
- ***Kopeliovich…* : ~ 0.4**
- ***Strikman… [hep-ph/9812322]* : ~ 0.4**

Gluon shadowing
Gerland, Frankfurt, Strikman, Stocker & Greiner (hep-ph/9812322)



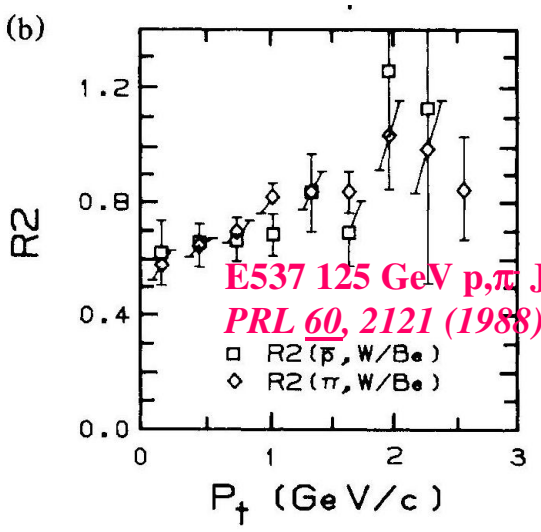
Change due to shadowing for PHENIX μ relative to NA50 for different models to the W/H ratio (*R*) and the resulting effective α.

"Model"	***R***	α
No shadowing difference from fixed-target expt.	1	.92
Eskola…	.66	.84
w/o anti-shadowing	.75	.87
Kopeliovich…	.4	.74

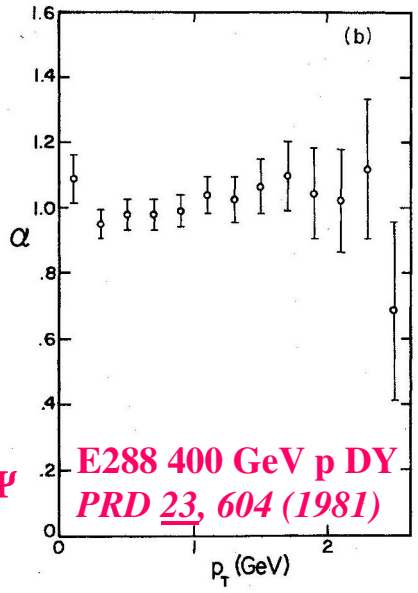
$$R \equiv \frac{R(W/H)_{PHENIX-\mu}}{R(W/H)_{NA50}}$$

(Ratios due to gluon shadowing alone)

P_T Broadening for different energies and probes – other data



E537 125 GeV p,π J/Ψ
PRL 60, 2121 (1988)



E288 400 GeV p DY
PRD 23, 604 (1981)

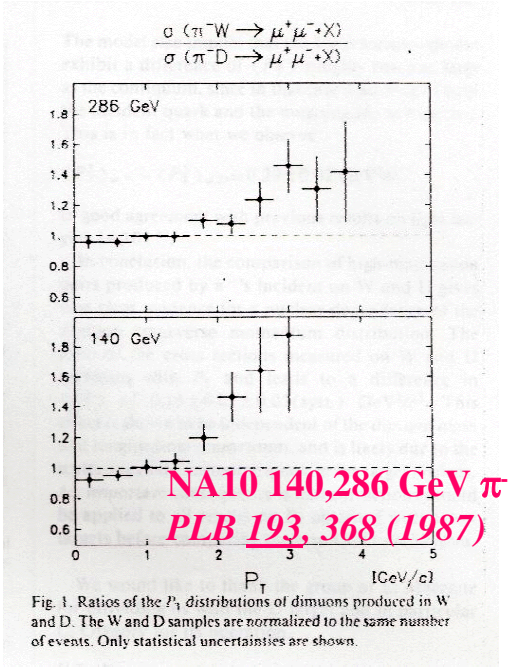
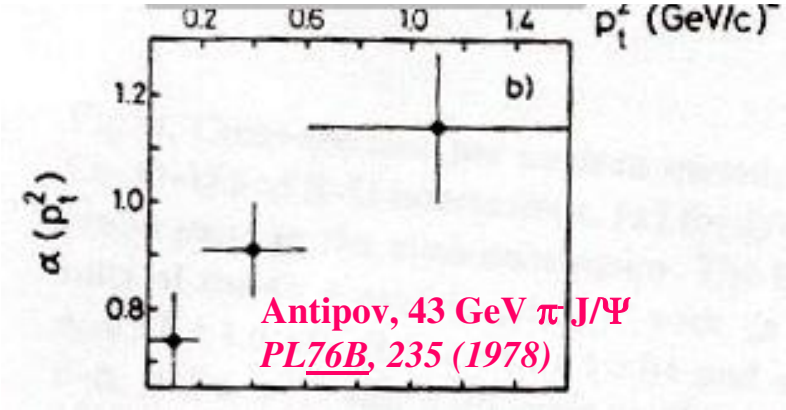
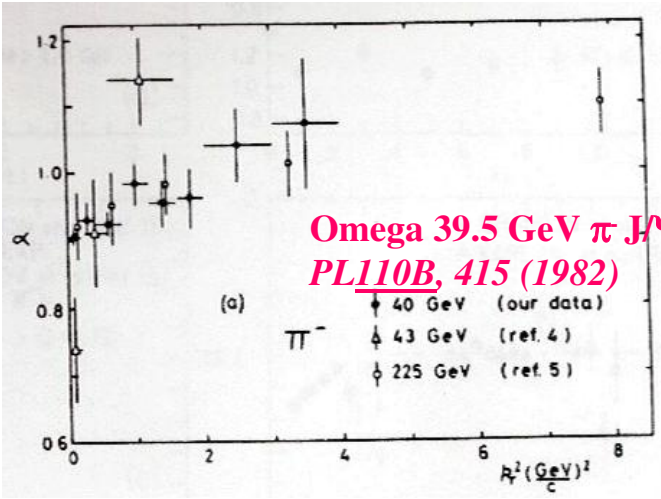


Fig. 1. Ratios of the P_T distributions of dimuons produced in W and D. The W and D samples are normalized to the same number of events. Only statistical uncertainties are shown.

NA10 140,286 GeV π^- DY
PLB 193, 368 (1987)

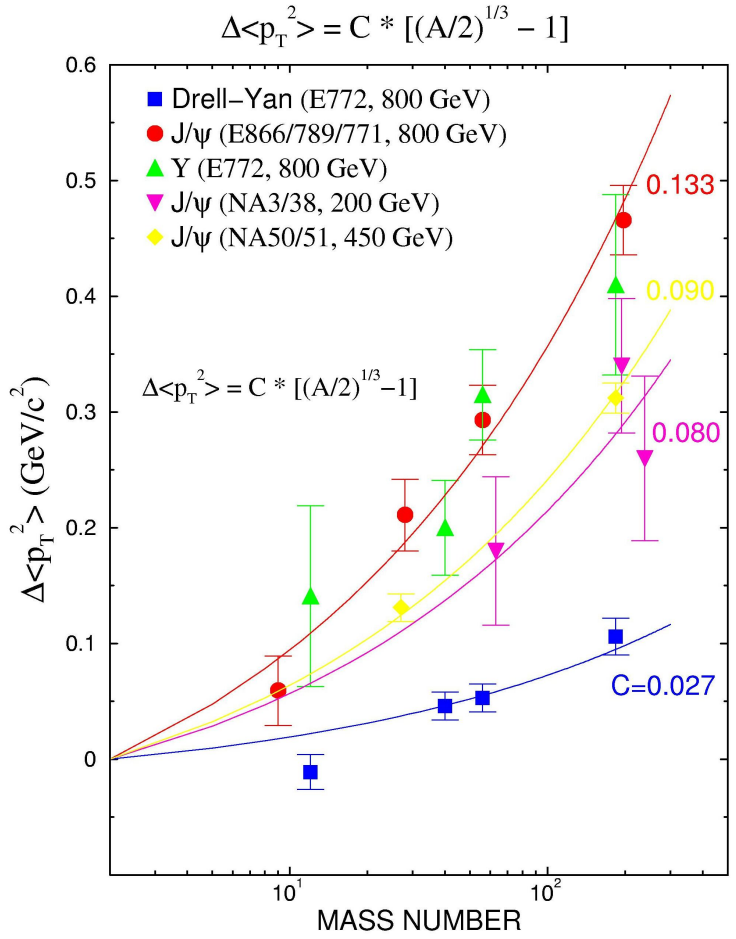


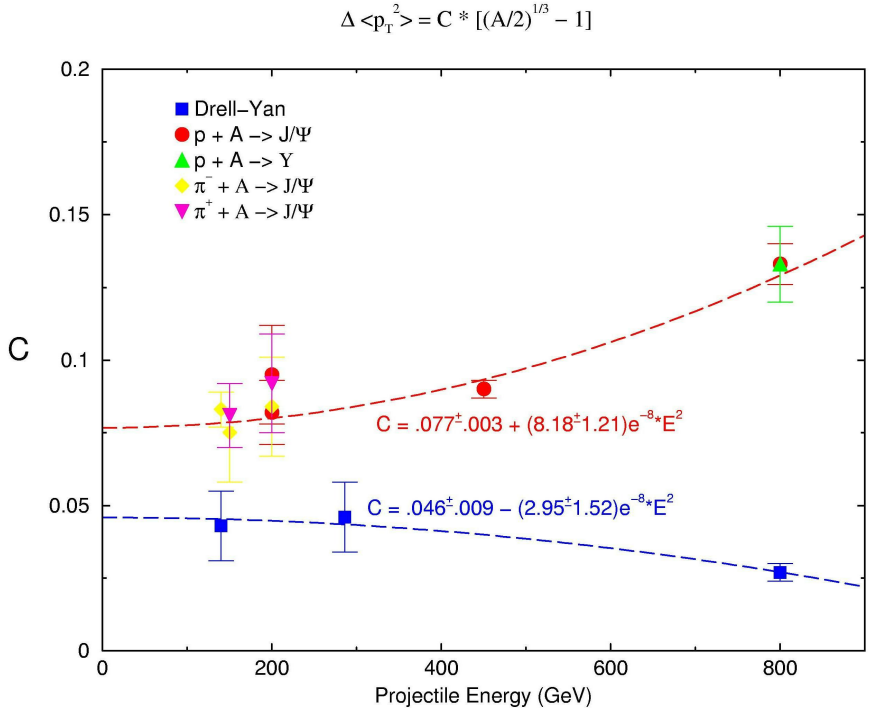
Antipov, 43 GeV π J/Ψ
PL76B, 235 (1978)



Omega 39.5 GeV π J/Ψ
PL110B, 415 (1982)

Systematics of P_T Broadening

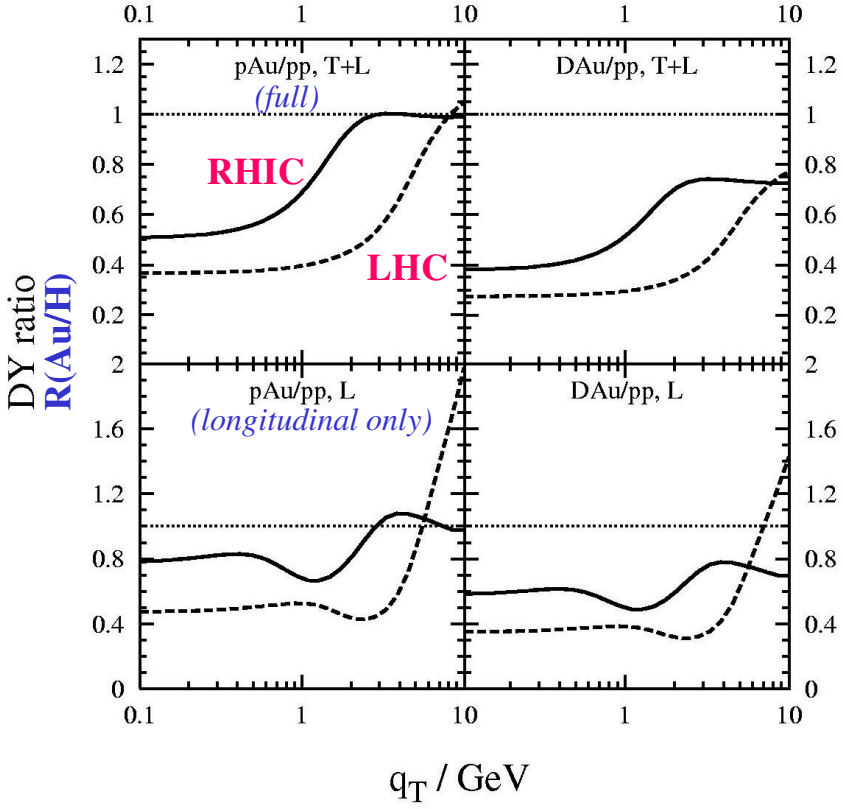




Theoretical Models for P_T Broadening

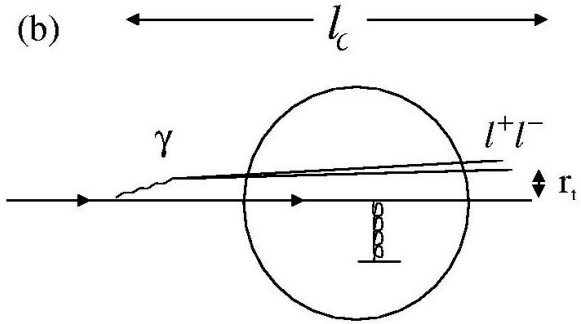
Kopeliovich et al, hep-ph/0110221

"Light Cone Dipole" approach



Predicts a different dominant mechanism for p_T broadening in DY at RHIC & LHC energies:

- **For lower energy fixed target measurements initial-state multiple scattering is most important**
- **But at RHIC & LHC color filtering preserves small $q\bar{q}$ dipole configurations which have high-p_T and therefore give larger p_T broadening**



DY as bremsstrahlung in the target rest frame

Theoretical Models for P_T Broadening

Gavin,Vogt hep-ph/9610432

$$\Delta < p_T^2 >= \lambda^2 (\overline{n}_A - 1)$$

$$\lambda = .18(DY)$$
$$= .36(J/\Psi)$$
$$= .46(\Upsilon)$$

Phenomenological approach: random walk proportional to the number of collisions, $\overline{n}_A$

Can also apply to A-A collisions:

$$\Delta < p_T^2 >= \lambda^2 (\overline{n}_A + \overline{n}_B - 2)$$

with $L = (\overline{n}_A + \overline{n}_B)/2\sigma_{NN}\rho_0 = \overline{n}/2\sigma_{NN}\rho_0$

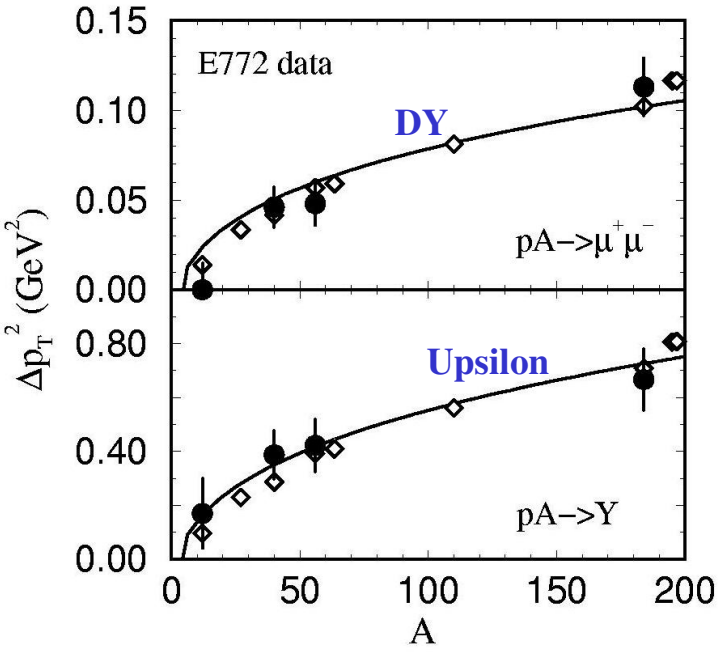


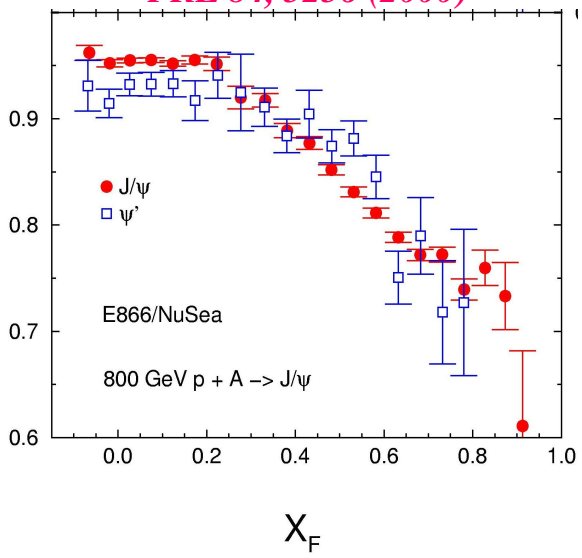
FIG. 2. Calculated Δp_T^2 from eq. (1) for $\overline{n}_A \approx 0.77\ A^{1/3}$ compared to FNAL E772 data on the Drell–Yan process and Υ production [13]. Diamonds are calculated using (4) and JVV nuclear densities from [3].

Summary:

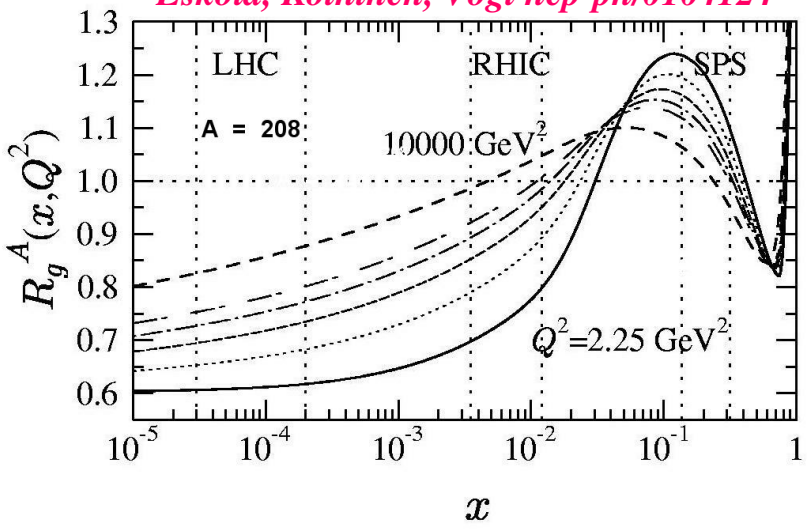
•Charmonium suppression involves a non-trivial interplay between different effects and involves several timescales including that for hadronizaton and for the coherence of a $c\bar{c}$ pair.

•It has large variations with x_F and p_T that help reveal the underlying mechanisms

PRL 84, 3256 (2000)



Eskola, Kolhinen, Vogt hep-ph/0104124

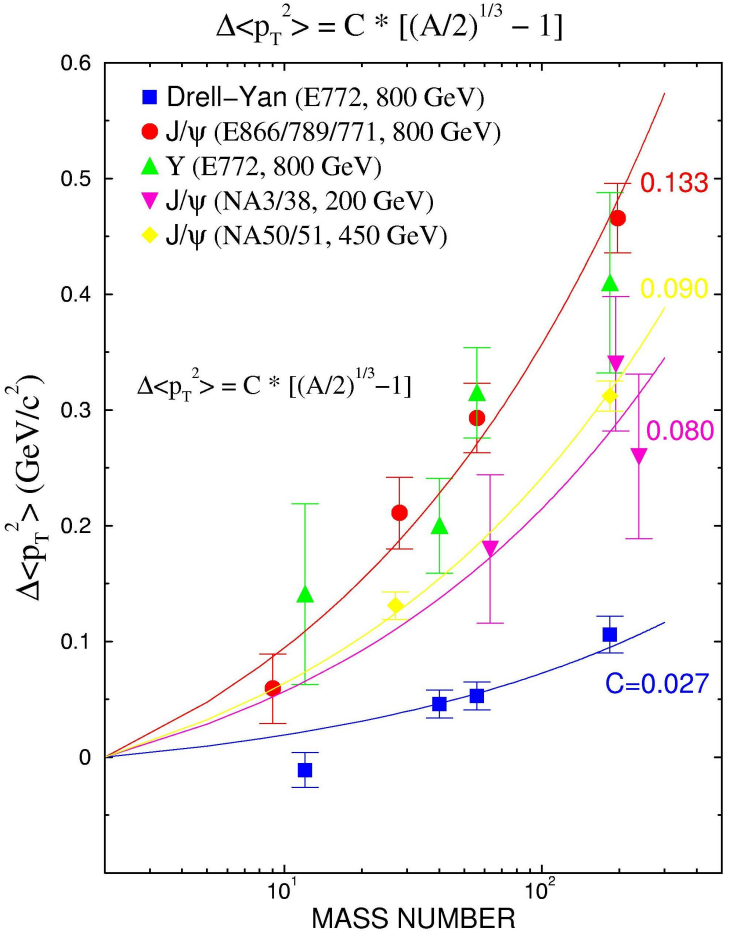


•p-A (or d-A) measurements serve as a basis for understanding what is seen in nucleus-nucleus collisions and are a must at RHIC.

•Shadowing is certainly very important at RHIC and must be measured in d-A collisions as soon as possible

Summary continued – P_T broadening:

- A universal phenomena seen with, e.g. π, p and $\bar{p}$ beams.
- $\Delta < p_T^2 >$ is ~5 times larger for J/Ψ than for Drell-Yan; cause?
  - gluons interact more strongly than quarks by 9/4 color factor
  - resonances can multiple scatter in final state
- J/Ψ $\Delta < p_T^2 >$ grows with $\sqrt{s}$
- Radiative energy loss associated with Drell-Yan p_T broadening in the BDMS model is tiny



Feeding of J/Ψ's from Decay of Higher Mass Resonances

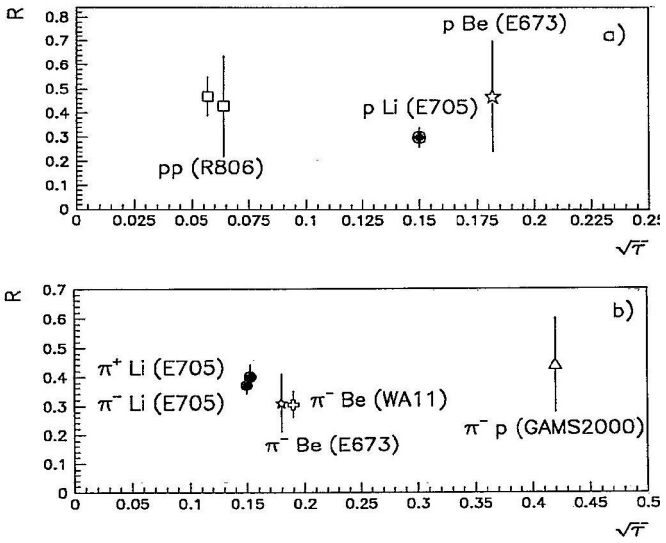


FIG. 3. Fraction of J/ψ produced via radiative χ in 300 GeV/c (a) proton and (b) $\pi^{\pm}$ ^{7}Li interactions.

E705 @ 300 GeV/c, PRL 70, 383 (1993)

- Large fraction of J/Ψ's are not produced directly

	Proton	Pion
$\chi_{,1,2} \rightarrow J/\Psi$	30%	37%
$\Psi' \rightarrow J/\Psi$	5.5%	7.6%

- Nuclear dependence of parent resonance, e.g. χ_C is probably different than that of the J/Ψ
- e.g. in proton production ~30% of J/Ψ's will have effectively stronger absorption because they were actually more strongly absorbed (larger size) χ_C's while in the nucleus

Meson	M(GeV)	R(Fm)	BE (MeV)
J/Ψ	3.1	.45	~640
Ψ′	3.7	.88	~52
χ_C	3.5	.70	

Open Charm Nuclear Dependence : x_F Dependence?

E769 250 GeV $\pi^{\pm}$ PRL 70,722 (1993)

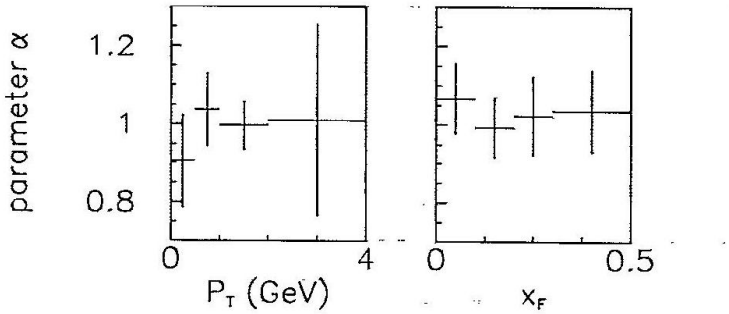


FIG. 4. Dependence of the parameter α on P_T and x_F for D^+ and D^0.

WA82 340 GeV π PRB 284,453 (1992)

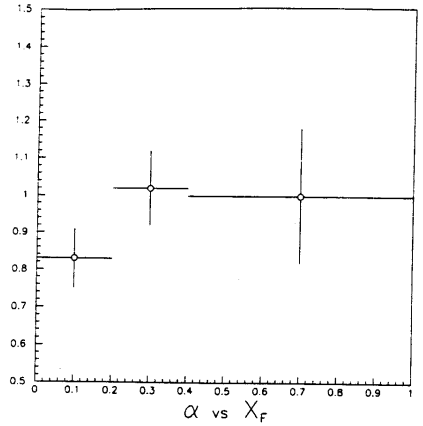
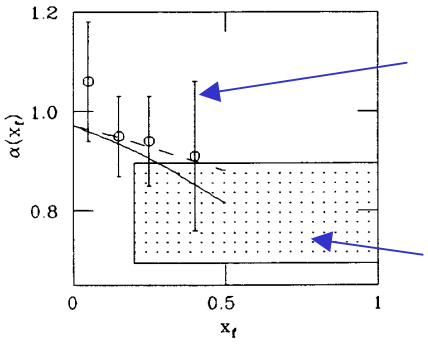


Fig. 4. The parameter α for charm production as measured in three x_F intervals.

Vogt et al., NP 383,643 (1992)



E769 250 GeV π

WA78 320 GeV π *(Beam dump)*

Fig. 14. We show $\alpha(x_f)$ for π^-A interactions at 300 GeV as calculated in our model. The dashed curve shows delta function fragmentation, the solid curve, the Peterson function. These results are compared to those for $D^{\pm}$ mesons produced by 250 GeV π^-A interactions [3] and the effective α found by the WA78 beam dump experiment [23], indicated by the band with $\langle x_f \rangle = 0.31$.