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LBL

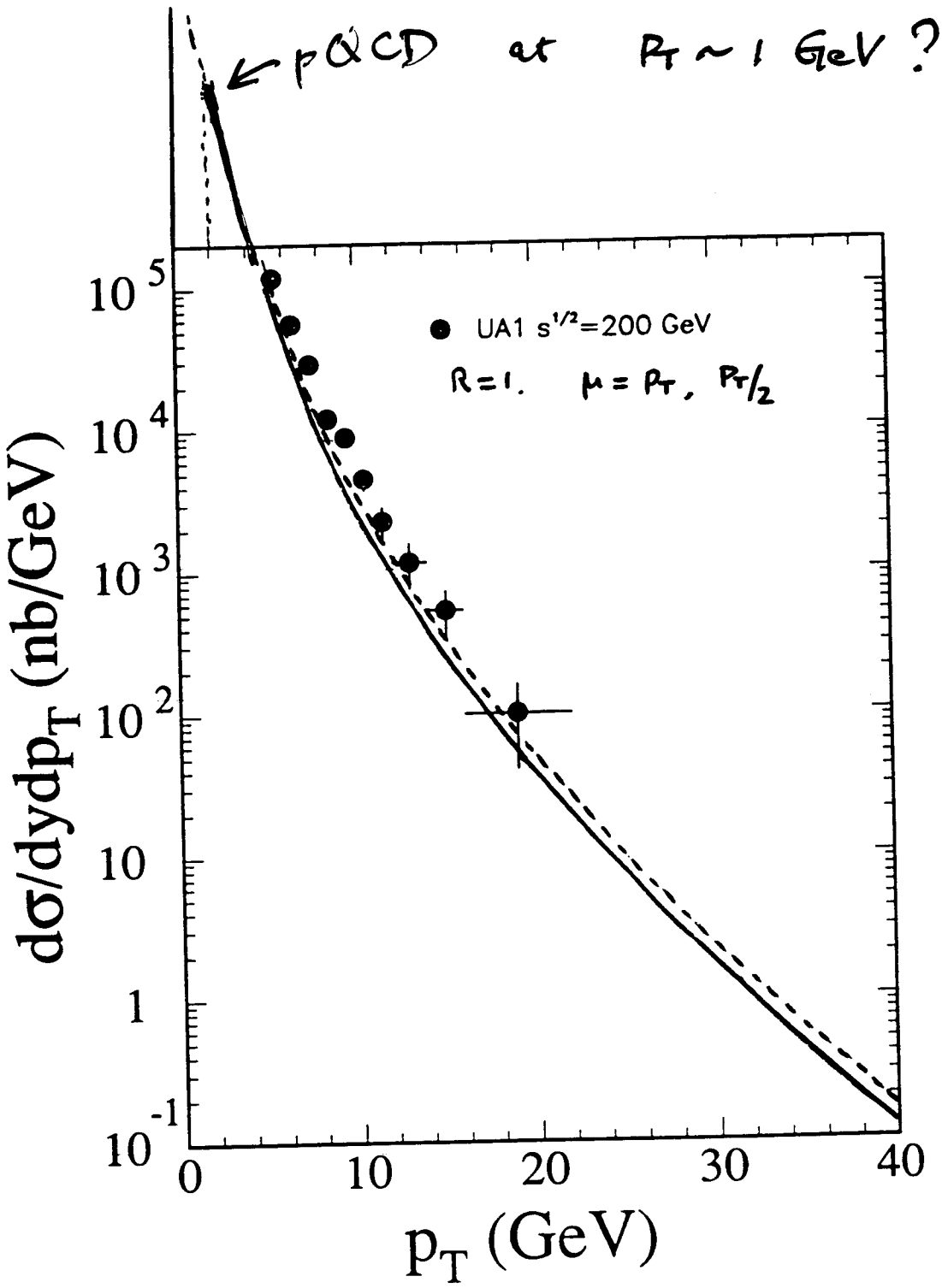
CTEQ Symposium
Fermilab 9/11/96

QCD Issues in A+A Collisions

1) What if pQCD valid at $p_T \sim$ few GeV?

2) Multiple Scatterings; Parton Energy Loss

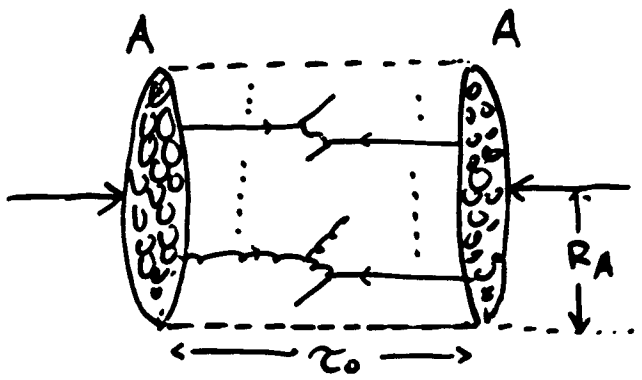
3) J/ψ Production & Suppression



Calculation using
Program by S. Ellis . D. Soper.

Minijets Production in A+A Collisions

$$\sigma_{jet}(s, p_0) = \int_{p_0^2}^{s/4} dp_T^2 dy_1 dy_2 \frac{K}{2} \sum_{ijkl} x_1 f_i(x_1, p_T^2)\, x_2 f_j(x_2, p_T^2) \frac{d\hat{\sigma}^{ij\to kl}}{d\hat{t}}$$



Blaizot & Mueller
Kajantie, Landshoff
Lindors.

$$\frac{dN_{jet}^{AA}}{dy}(b, p_0) = 2\, T_{AA}(b)\, \frac{d\sigma_{jet}}{dy}(s, p_0)$$

$p_0 = 2$ GeV	$\sqrt{s} = 200$ GeV	5.5 TeV
$\frac{dN_{jet}^{AA}}{dy}$	200	5980
N/V	13 fm^{-3}	388 fm^{-3}
E/V	35 GeV/fm^3	1 TeV/fm^3

$R_A \cong 7$ fm . $A = 200$. $\tau_0 \simeq \frac{1}{p_0} \simeq 0.1$ fm

Hard vs. Soft

$P_T > P_0$: Hard

$\sigma_{jet}(s, P_0) \leftarrow$ pQCD

$P_T < P_0$: Soft

$\sigma_{Soft}(s, P_0) \leftarrow$ nonpert.

$$\sigma_{tot}^{p\bar{p}}(s) \equiv 2\int d^2b \left[1 - e^{-(\sigma_{jet} + \sigma_{Soft})T(b)}\right]$$

A Simplest model:

$\sigma_{Soft} = const.$

$P_0 = const.$

(Wang & Gyulassy) Phys. Rev D45(92)

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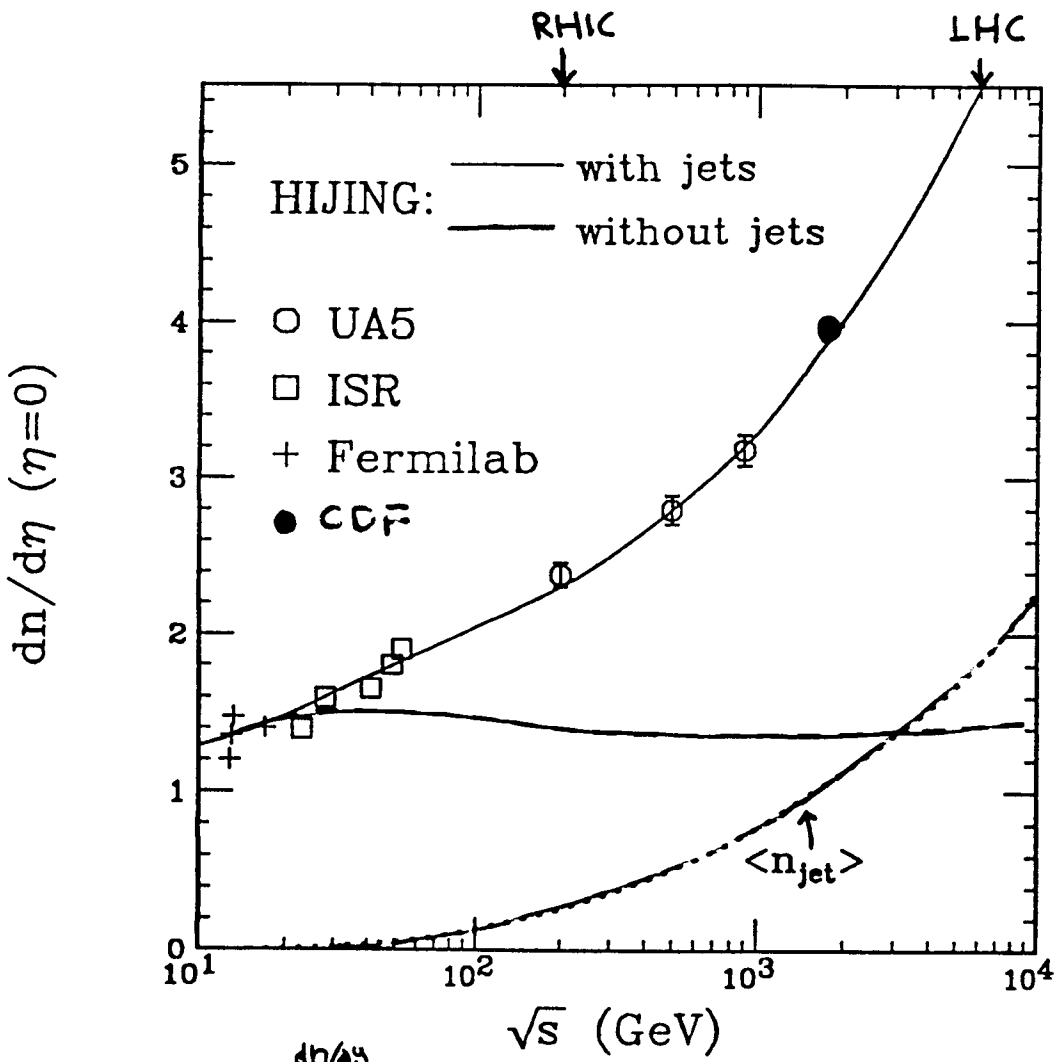


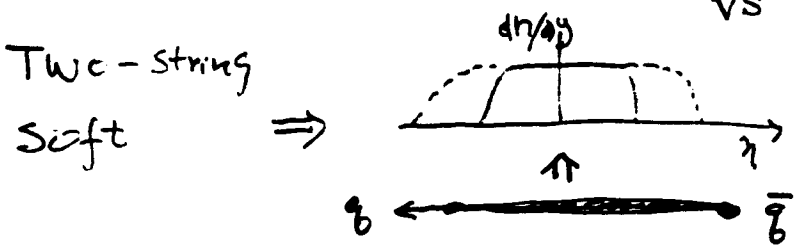
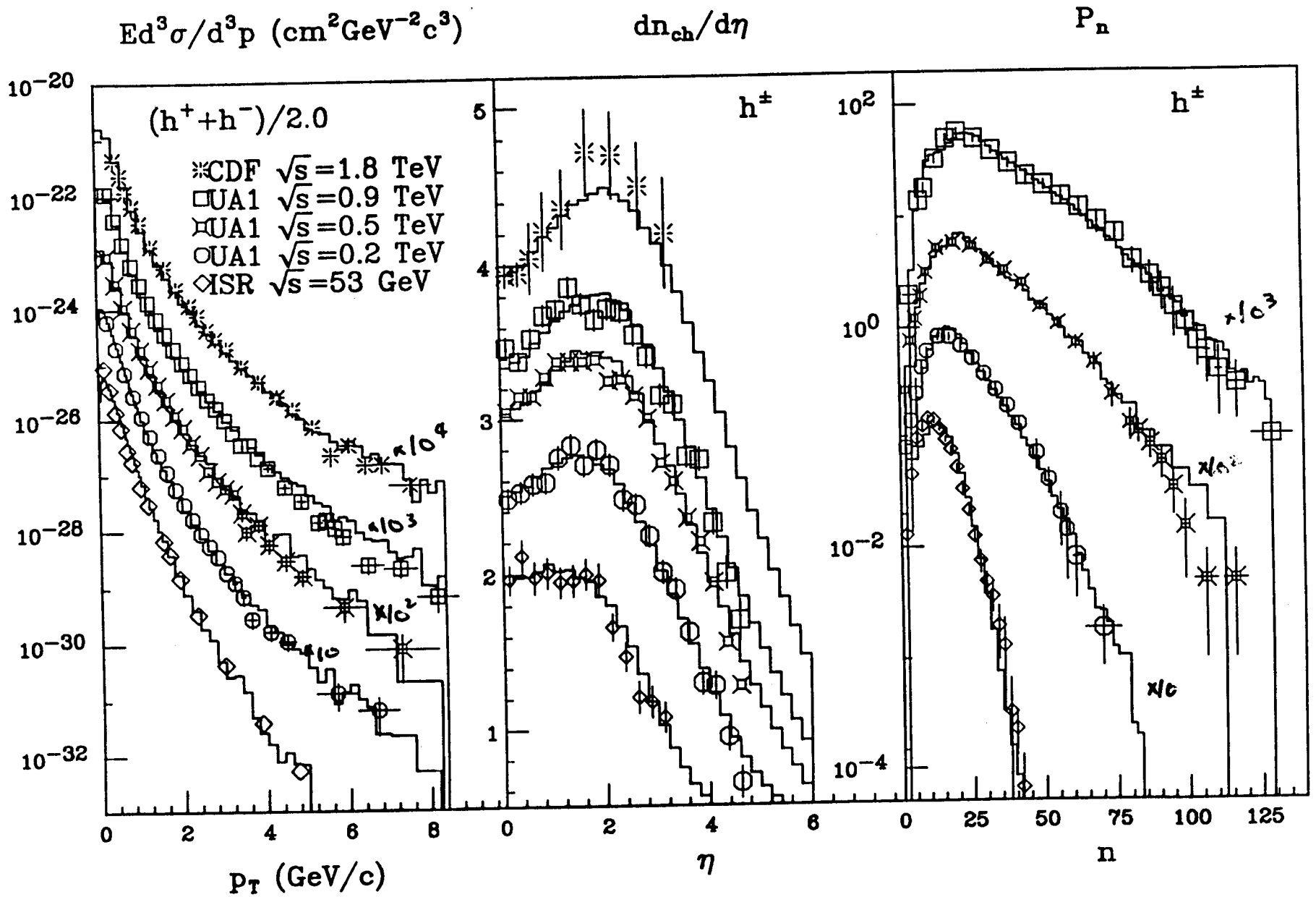


Fig. 5 Central pseudo-rapidity density at $\eta = 0$ of charged particles in inelastic pp and $p\bar{p}$ collisions as a function of $\sqrt{s}$. The solid line is HIJING calculation and the data are from Refs. [38, 40, 41]. The dashed line is for events without jet production in HIJING simulations. The dotted line is the calculated average number of jet production $\langle n_{jet} \rangle = \sigma_{jet}/\sigma_{in}$.

p+p(p) Collisions.

(Wang & Gyulassy) Phys. Rev. D45, 3501 (1992)



Phys. Rev. D47 2759(93)
D46 1900(92)

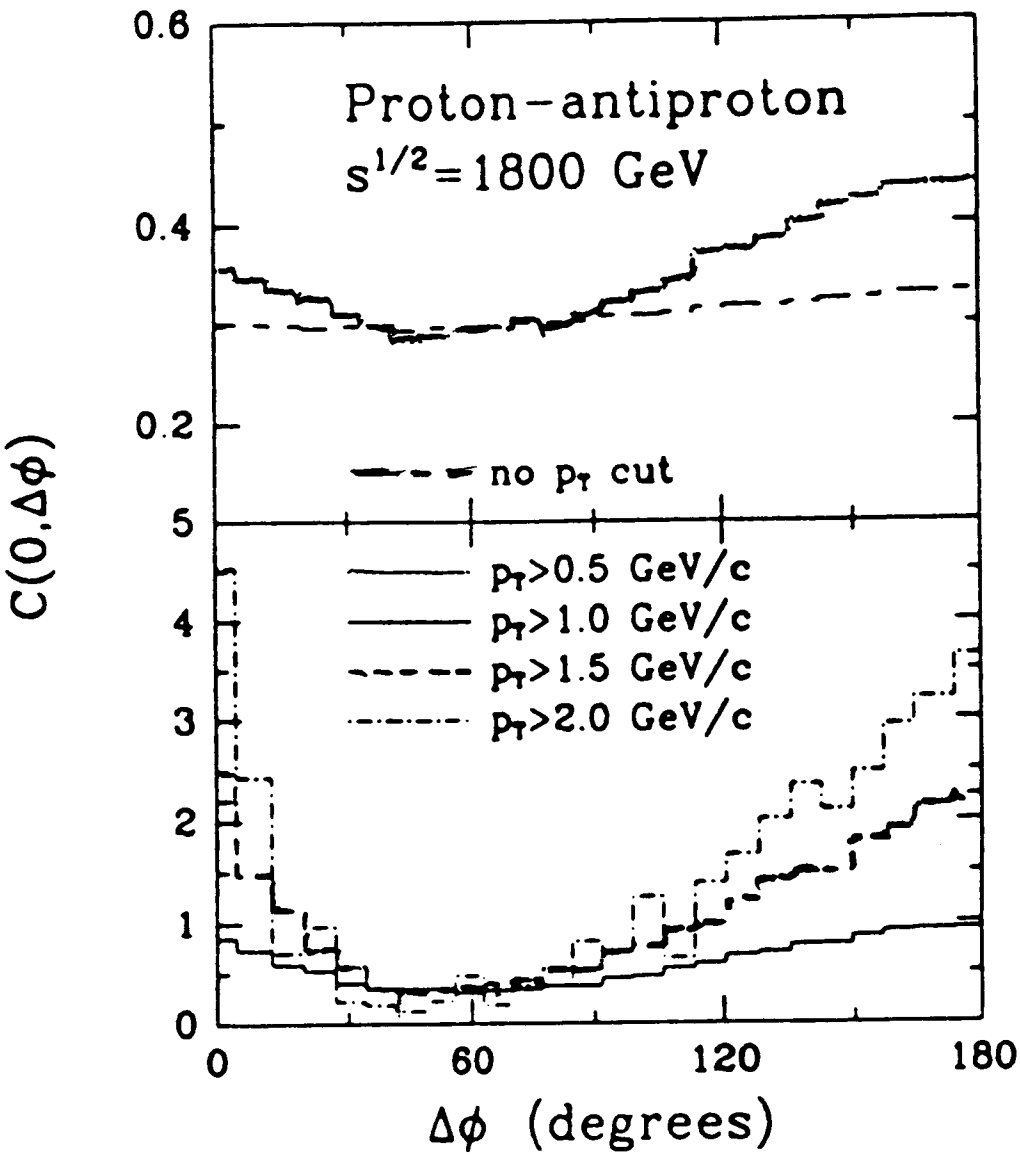
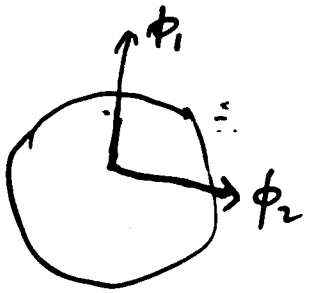


FIG. 4. The same as Fig. 2, except for $p\bar{p}$ collisions at $\sqrt{s}$ = 1.8 TeV.

$$C(\Delta\phi) = \frac{d^2n/d\phi_1 d\phi_2}{\frac{dn}{d\phi_1}\frac{dn}{d\phi_2}} - 1$$



Multiple Parton Scatterings

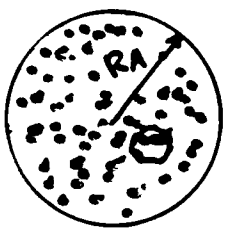
1) Initial multiple scatterings & Gluon fussion $\Rightarrow$ Saturation of $g(x)$ at small x.

[Should be there for p at smaller x]

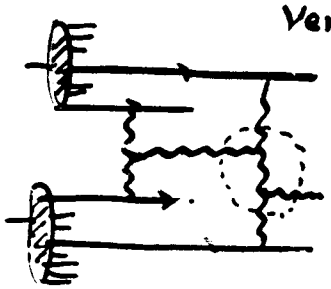
Mueller & Qiu.
Brodsky & Lu
Strikman et.al. ....

2) Multiple scatterings $\Rightarrow$ self-screening

Eskola. Müller. X.N.W.
Venugopalan. McLer



$$\frac{N_{jet}^{AA}}{\pi R_A^2} \gg \frac{1}{\pi/p_0^2}$$



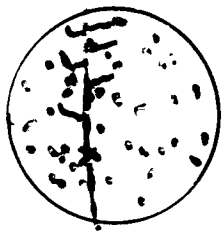
Screening mass : $\mu^2 \sim \alpha_s n/p_0$

3) Energy Loss of a fast parton

Thermalization

$\nwarrow$ Large E_T jet.

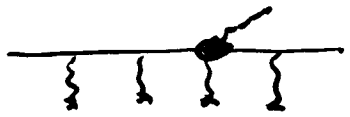
non-perturbative
non-equilibrium.



Energy Loss of a Fast Parton

Including Landau-Pomeranchuk-Migdal effect.

$$-\frac{dE}{dz} \simeq \frac{d_s N_c}{8} \frac{\mu^2}{\lambda} L$$

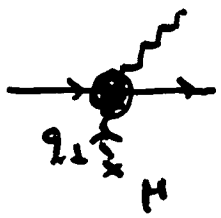


Baier, Dokshitzer
Mueller, Peigne & Schiff

Energy loss / scattering

X.N.W. Gyulassy.

$$\Delta E = \int d^2k_\perp dy \; \omega \frac{dn_g}{d^2k_\perp dy} \cdot \underline{\theta(\lambda - \tau(k))}.$$



$$\frac{dn_g}{d^2k_\perp dy} = \frac{C_A d_s}{\pi^2} \frac{q_\perp^2}{k_\perp^2 [(\vec{q}_\perp - \vec{k}_\perp)^2 + \mu^2]}$$

$$\frac{\Delta E}{\lambda} \simeq \frac{d_s N_c}{8} \langle q_\perp^2 \rangle \qquad \tau = \frac{2\omega}{k_\perp^2}$$

Full analysis: $\tau = \frac{2\omega}{k_{\perp max}^2}$ $\quad \langle q_\perp^2 \rangle \to \langle p_T^2 \rangle$

p_T broadening of jet $\langle p_T^2 \rangle \simeq \frac{\mu^2}{\lambda} L$

$\frac{\mu^2}{\lambda} \longleftrightarrow$ parton density

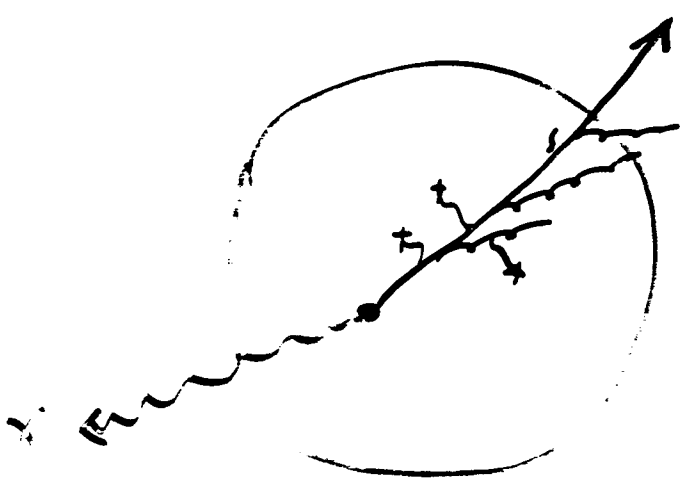
Measuring Parton Energy Loss in A+A.

—— modification of jet fragmentation fun.

1) Suppression of high-p_T particles.

$$R(p_T) = \frac{\frac{dN^{\pm}_{AA}}{dy\,d^2p_T}}{\sigma_{pp} T_{AA}(b)\,\frac{dN^{\pm}_{pp}}{dy\,d^2p_T}} < 1$$

2) Measuring effective Jet fragmentation function in γ + j'et events.



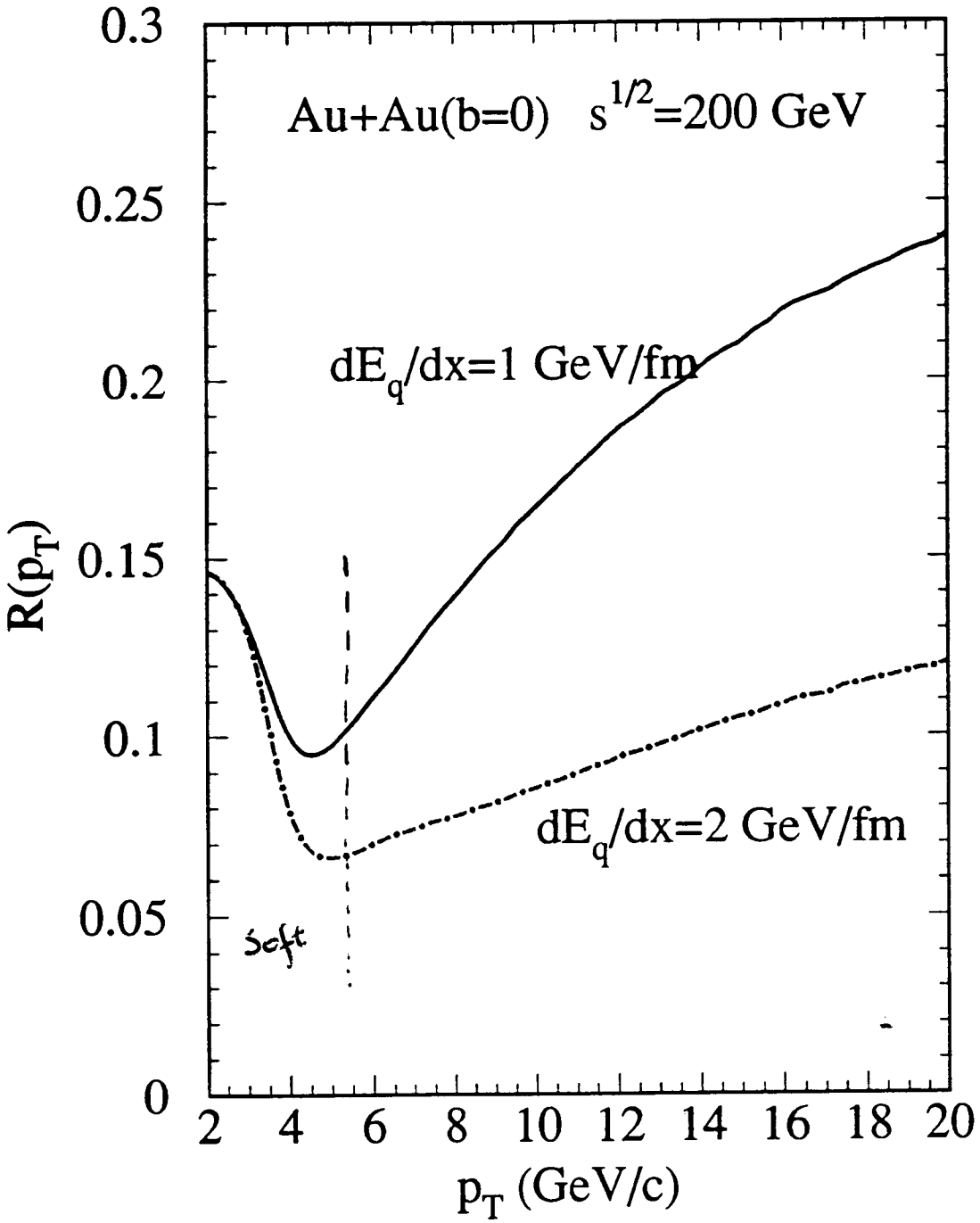
j'ets in AA?

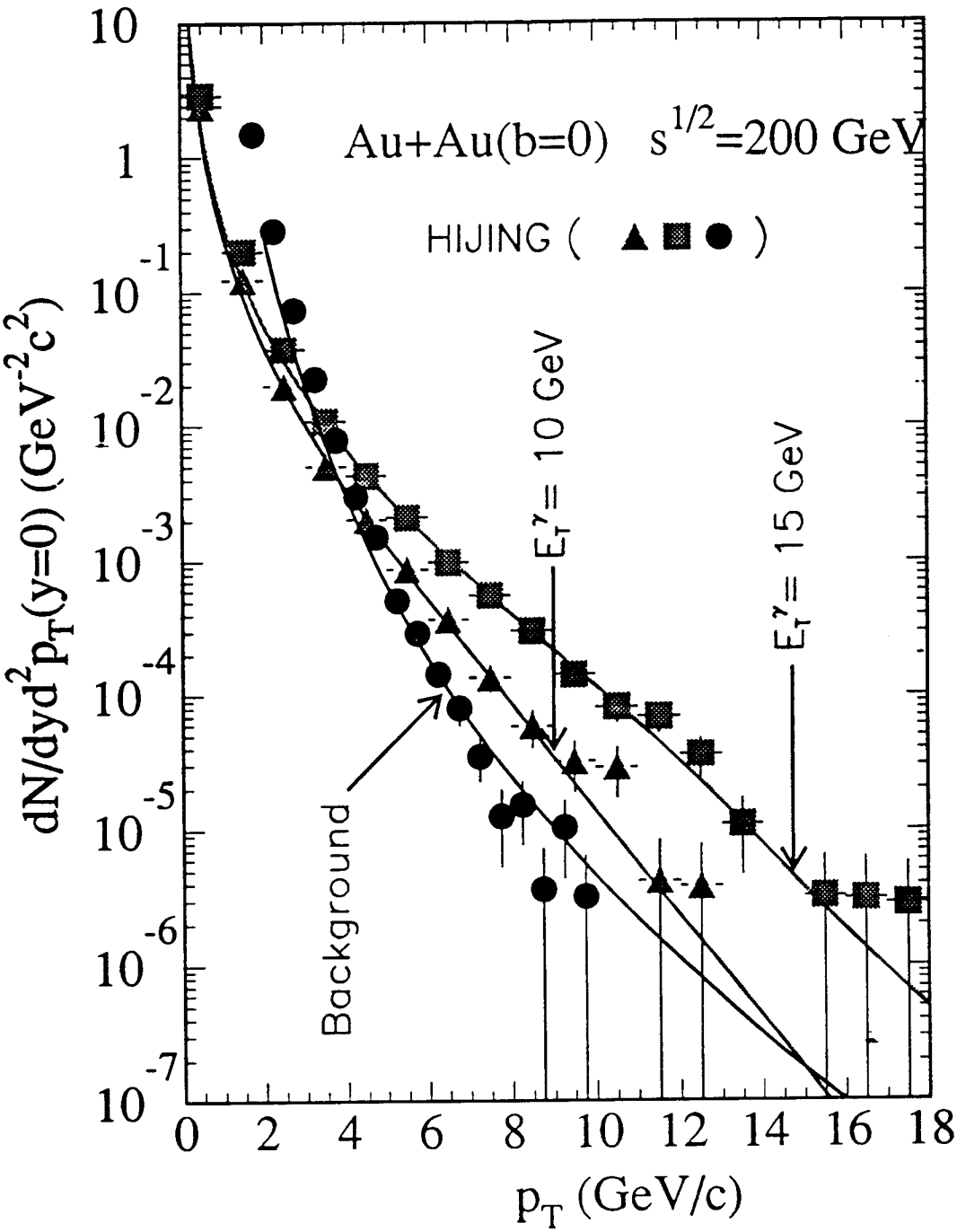
Large background.

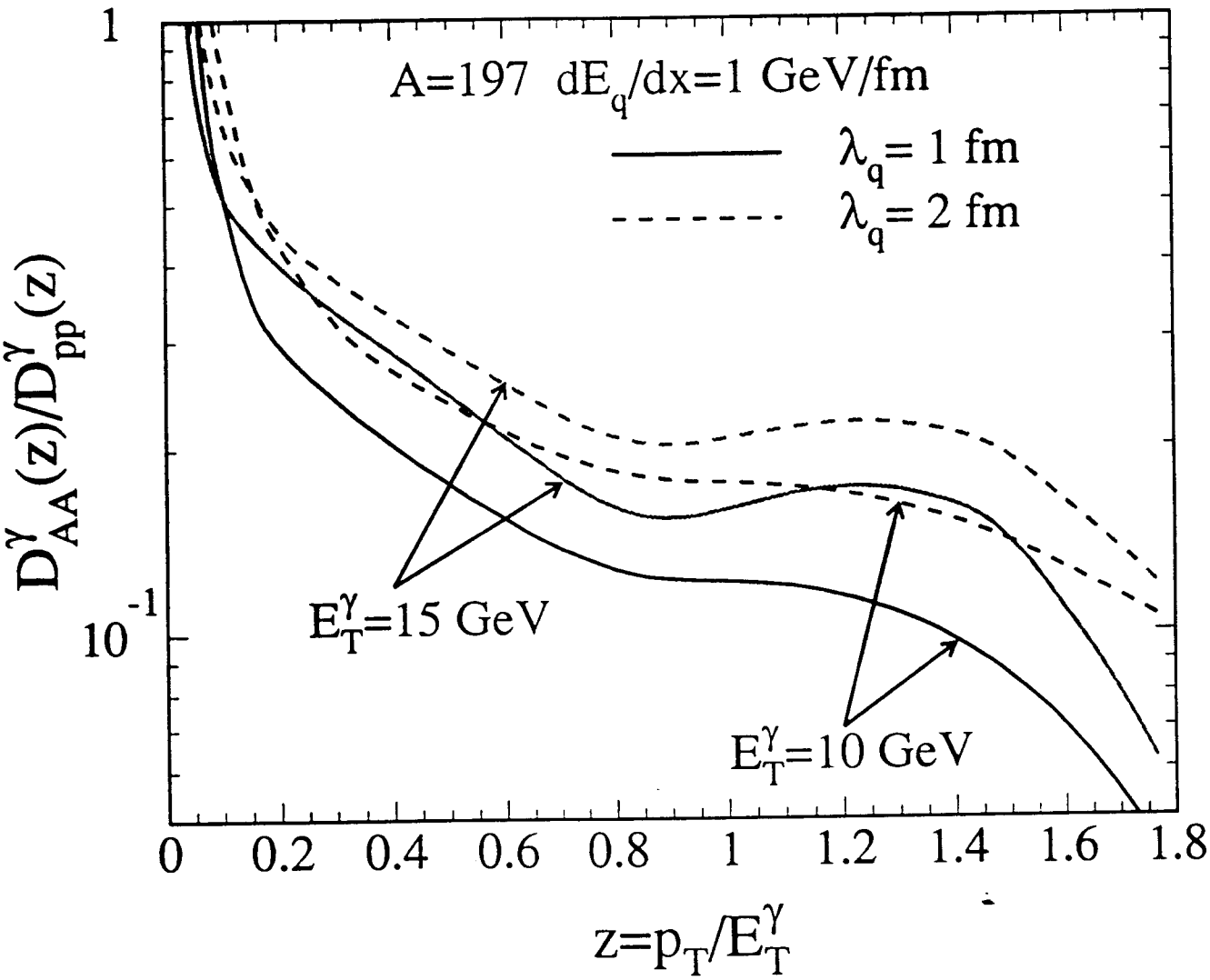
$\frac{dE_T}{dy\,d\varphi} \simeq 100$ GeV

($\sqrt{s} = 200$ GeV.

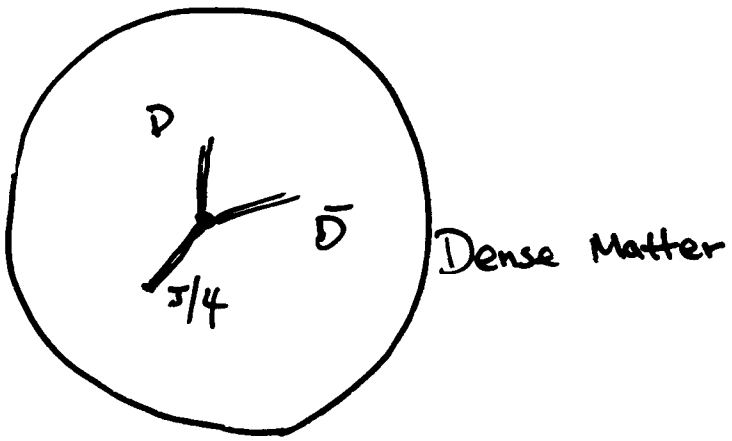
$$R(p_T) = \frac{dN/dy\,dp_T(A+A)}{\sigma_{pp}\,T_{AA}(c)\;\frac{dN}{dy\,dk_T}(p+p)}$$



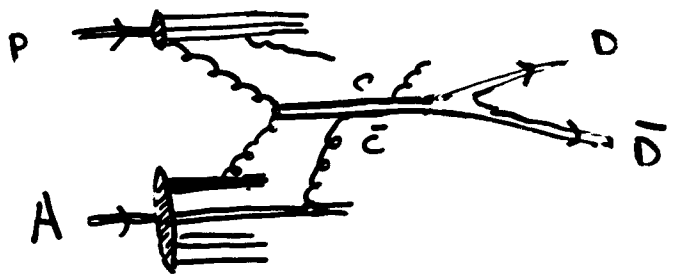

Au+Au(b=0) $s^{1/2}$=200 GeV
HIJING (▲ ■ ●)
E_T^γ= 10 GeV
E_T^γ= 15 GeV
Background
$dN/dyd^2p_T(y=0)$ ($GeV^{-2}c^2$)
p_T (GeV/c)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
2
4
6
8
10
12
14
16
18


1
10^{-1}
$D^{\gamma}_{AA}(z)/D^{\gamma}_{pp}(z)$
A=197 dE_q/dx=1 GeV/fm
λ_q= 1 fm
λ_q= 2 fm
E^{γ}_T=15 GeV
E^{γ}_T=10 GeV
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
$z=p_T/E^{\gamma}_T$

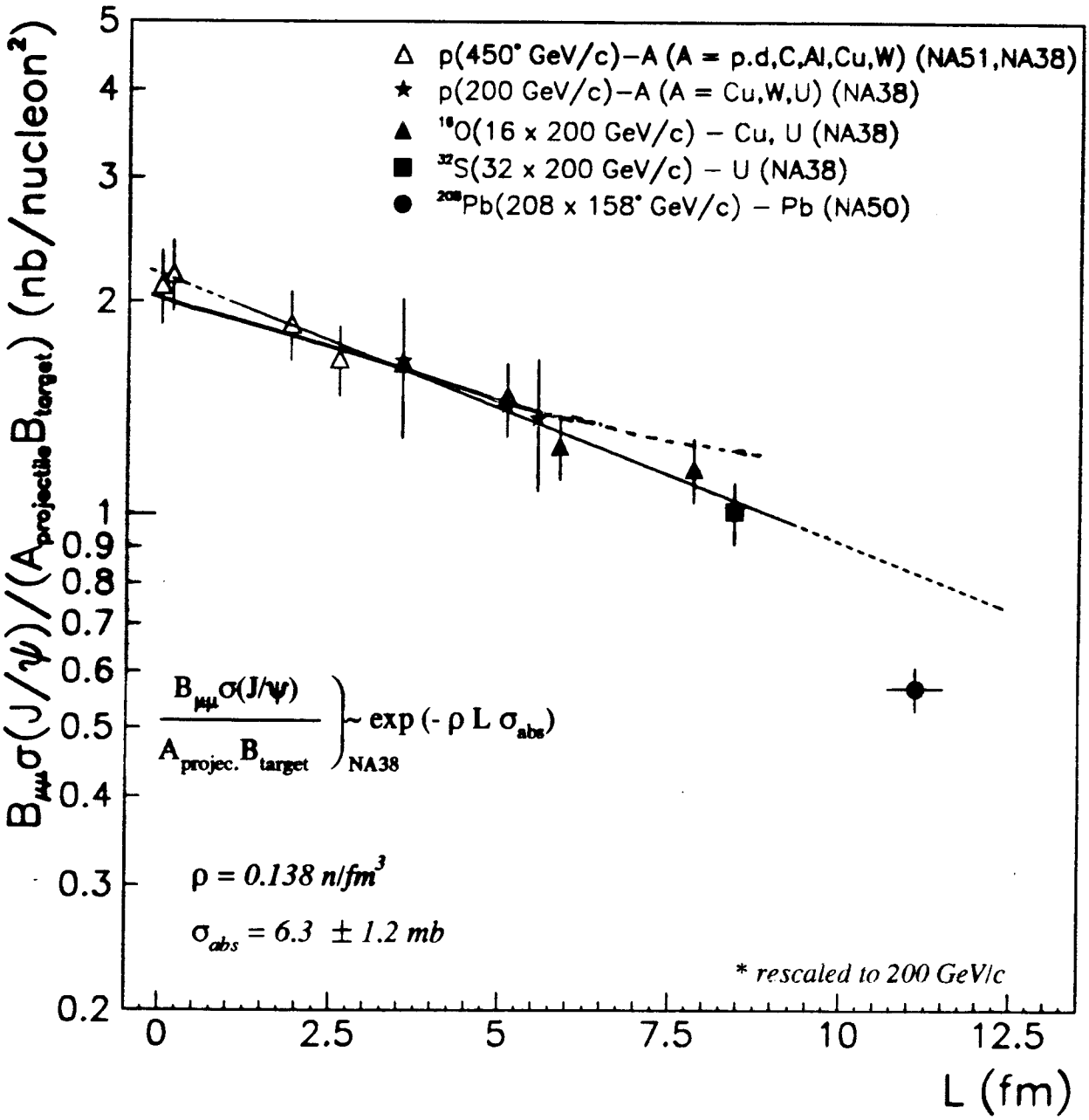
J/ψ Suppression



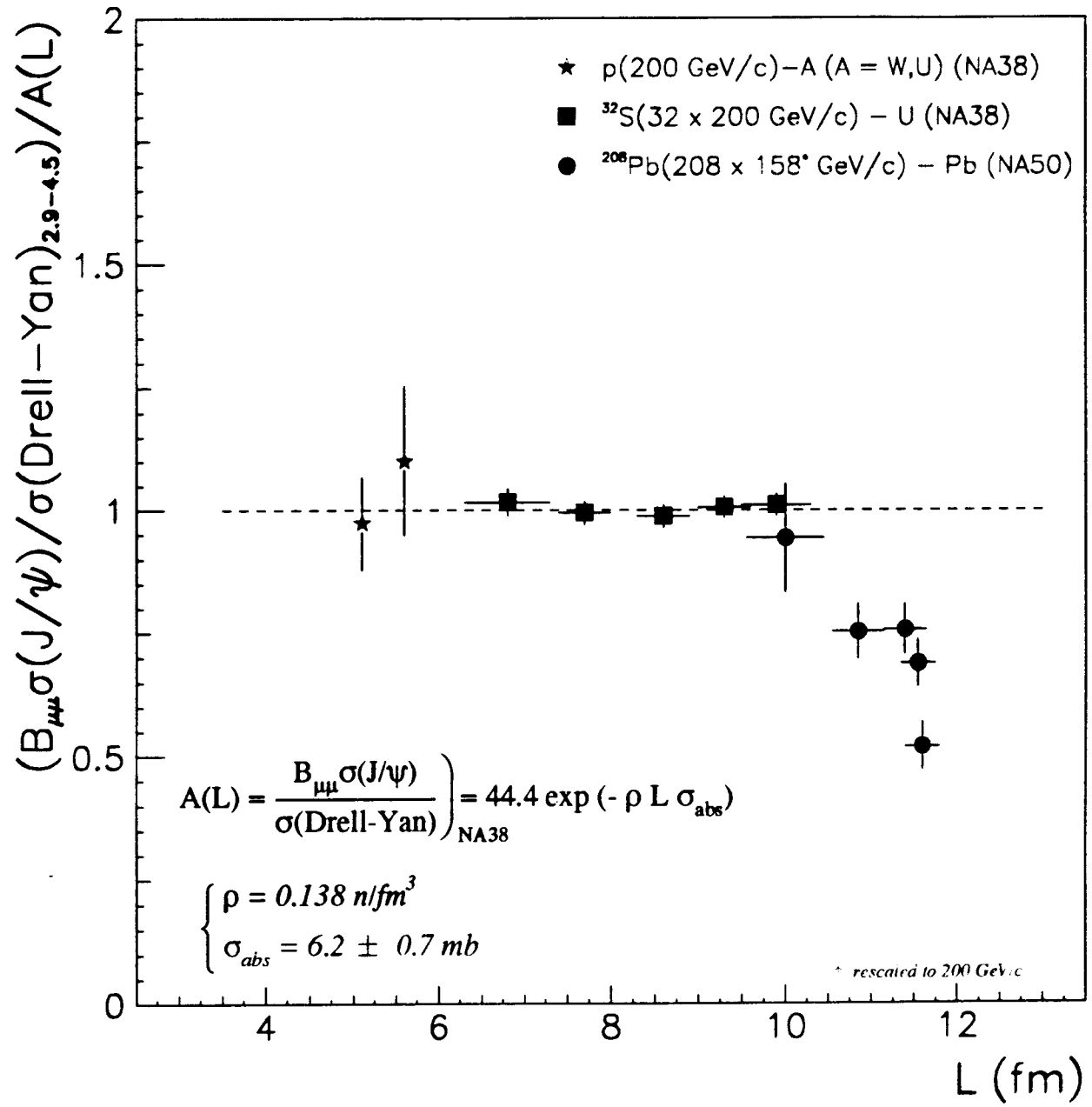
Nuclear absorption



J/ψ cross-sections versus L



Anomalous J/ψ suppression



Conclusions.

1) Energy density by mini-jets is very large in initial stage of AA Collisions

2) Study of $p\bar{p}$ collision could provide crucial information on initial condition of AuA Collision

3) Multiple scatterings essential energy loss of fast parton provides information of the dense system.