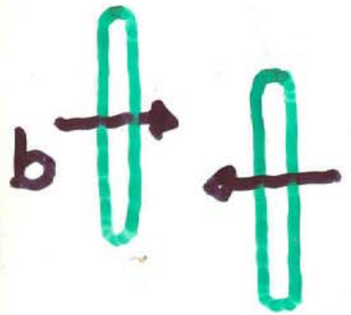
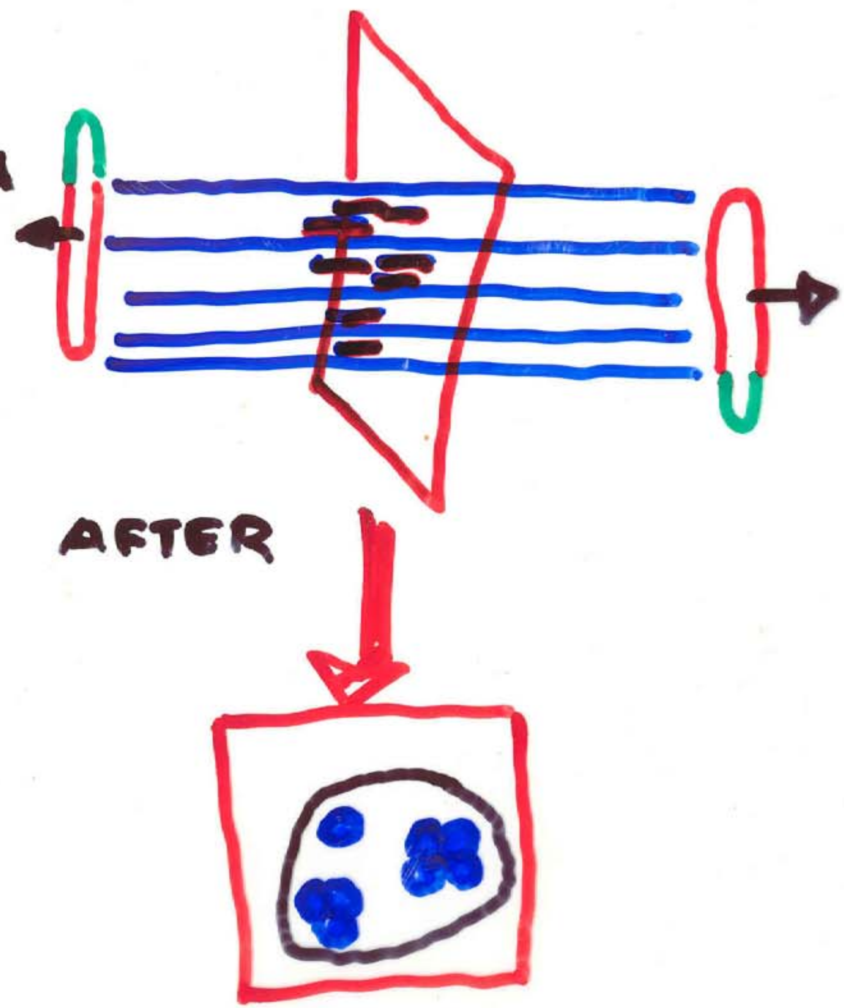
PERCOLATION AND P_T DISTRIBUTIONS

ROBERTO U.
CARLOS P.
ELENA F.
J. DD

1. DSM AND PERCOLATION
2. SCHWINGER MODEL
3. AA COLLISIONS AT RHIC AND LHC
4. AWAY FROM $y=0$
5. CONCLUSIONS

1- DSM with PERCOLATION





$N_{part.} = 2 N_A$

IMPACT PARAMETER PERCOLATION - 2D

DENSITY : $\eta \equiv \left(\frac{r}{R}\right)^2 \bar{N}_s$

r : STRING TANSVERSE RADIUS $r \simeq 0.2\,fm$

R : INTERACTION RADIUS

$\bar{N}_s$: AVERAGE NUMBER OF STRINGS

APPROXIMATIONS : $R \simeq R^p N_A^{1/3}$ (Nuclear Phys.) $R^p \simeq 1\,fm$

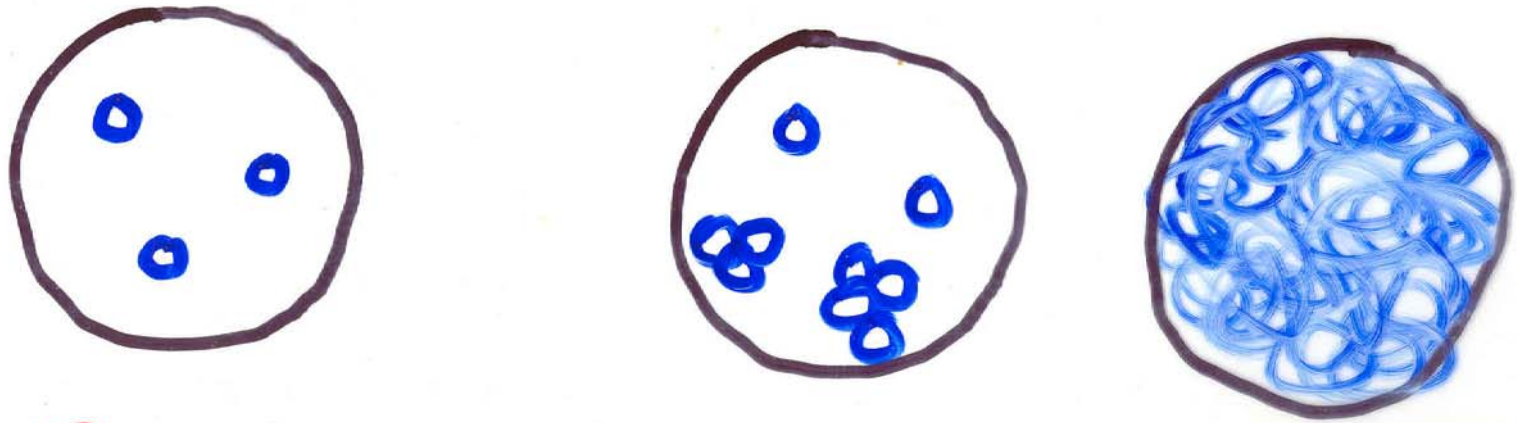
$\bar{N}_s \simeq N_s^p N_A^{4/3}$ (Multiple Scatt.)

$N_s^p(\sqrt{s})$: pp case

$$\eta = \left(\frac{r}{R^p}\right)^2 N_s^p \, N_A^{2/3}$$

Increases with Energy

Increases with Centrality



$\eta \ll 1$ $\quad$ $\eta \simeq 1$ $\quad$ $\eta \gg 1$

OVERCROWDING?

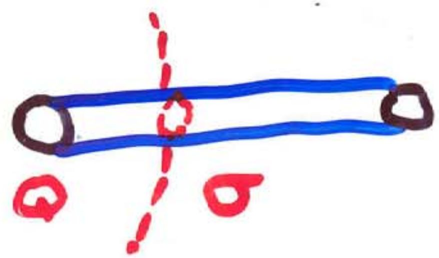
OBJECTS $\sim \sqrt{s}$

AREA OF INTERACTION $\sim (\ln s)^2$

OBJECTS/AREA $\longrightarrow \infty$

2 - SCHWINGER MODEL

$$\begin{cases} dn/dy \sim Q \\ \langle p_T^2 \rangle \sim \sigma \end{cases}$$



GAUSS: $Q = S\,\sigma$

$$Q \to dn/dy \qquad \sigma \to \langle p_T^2 \rangle$$

CLUSTER OF N-STRINGS

$$Q_N = \sqrt{\frac{S_N}{N S_1}}\, N\, Q_1 \qquad N S_1 \geq S_N \geq S_1$$

$$\begin{cases} \left.\dfrac{dn}{dy}\right|_N = \sqrt{\dfrac{S_N}{NS_1}}\, N\, \bar{n} \\[2ex] \langle p_T^2 \rangle_N = \sqrt{\dfrac{NS_1}{S_N}}\, \overline{p^2} \end{cases}$$

($\bar{n}$, $\overline{p^2}$: single string)

P_T- DISTRIBUTION OF A N-STRING $\exp(-a\, p_T^2)$

SUM OVER ALL N-STRINGS

$$\exp\left(-p_T^2/\overline{p^2}\right) \longrightarrow \frac{1}{\left(1 + \frac{1}{n}\frac{p_T^2}{\overline{p^2}}\right)^n}$$

7

$1/R$: NORMALIZED WIDTH OF N-CLUSTER DISTRIBUT.

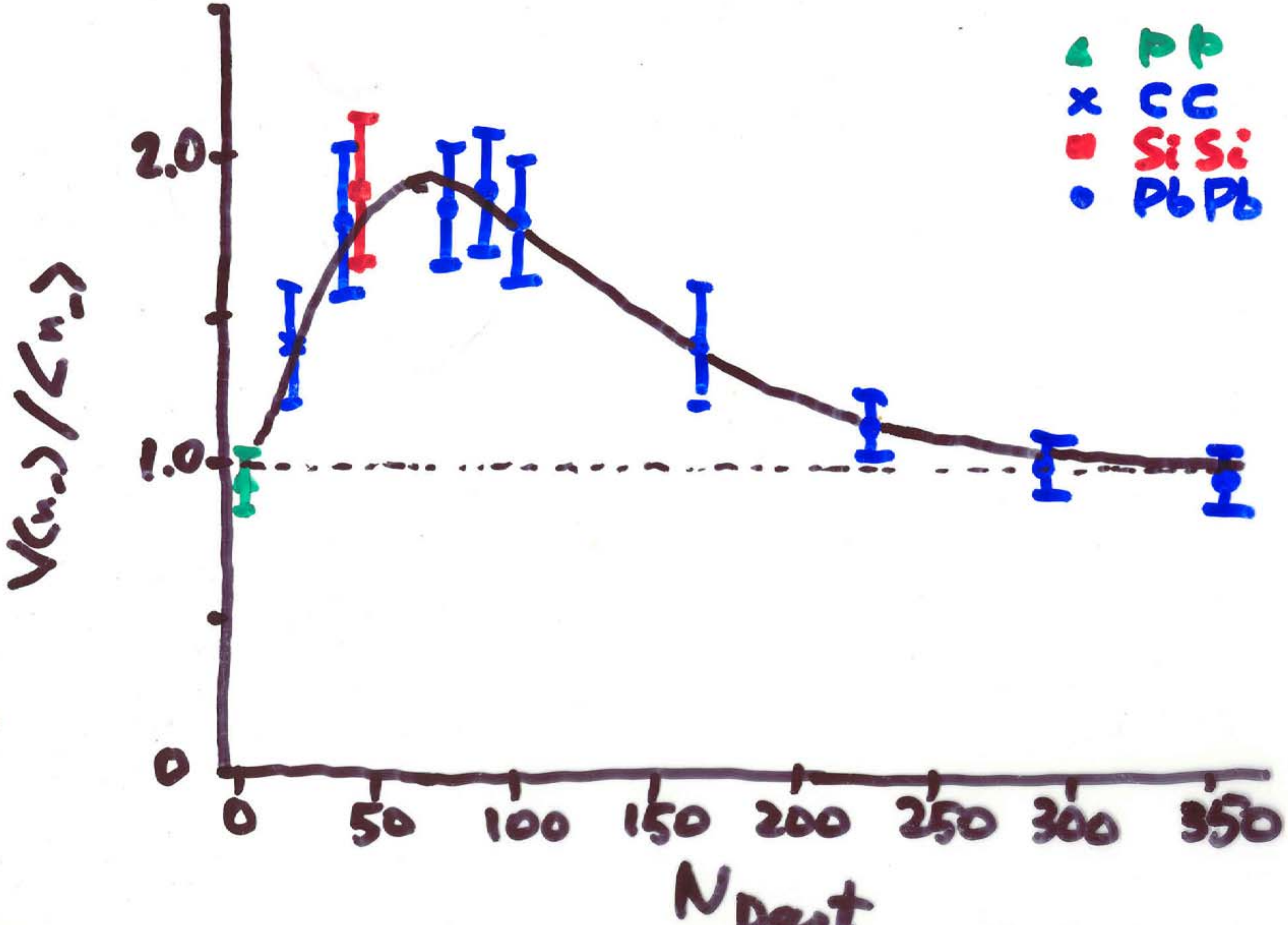
$$\frac{1}{R} \equiv \frac{\langle N^2\rangle - \langle N\rangle^2}{\langle N\rangle^2}$$

NAIVELY:

$\eta \ll 1$, $N=1$, $1/R \rightarrow 0$

$\eta \gg 1$, $N=N_s$, $1/R \rightarrow 0$

2
18



pp
CC
SiSi
PbPb
2.0
1.0
0
$V(n_-)/\langle n_-\rangle$
0
50
100
150
200
250
300
350
N_{part}

RANDOM DISTRIBUTION

$$\langle Q \rangle = \sqrt{\frac{\langle A \rangle}{\langle N \rangle}} \left(\bar{N}_s Q_1 \right)$$

$\langle A \rangle$: Average Cluster Area (in units of S_1)

$\langle N \rangle$: Average Number of strings per cluster

BUT :

$$\begin{cases} \bar{N}_c \langle N \rangle = \bar{N}_s \\ \bar{N}_c \langle A \rangle = \left(\frac{R}{r}\right)^2 \left(1 - e^{-\eta}\right) \end{cases} \rightarrow \frac{\langle A \rangle}{\langle N \rangle} = \frac{\left(1 - e^{-\eta}\right)}{\eta}$$

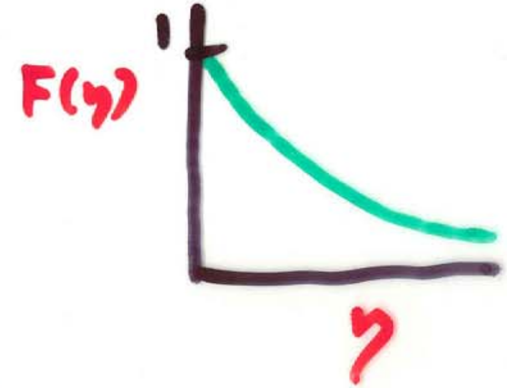
FINALLY:

$$\begin{cases} dn/dy = F(\eta)\,\bar{N}_s\,\bar{n} \\[2ex] \langle p_T^2 \rangle = \dfrac{k(\eta)}{k(\eta)-2}\,\dfrac{1}{F(\eta)}\,\bar{p}^2 \end{cases}$$

$$\left[\bar{N}_s = N_s^p N_A^{4/3}\right]$$

WITH

$$F(\eta) \equiv \sqrt{\frac{1-e^{-\eta}}{\eta}}$$



CONSEQUENCES:

SLOW INCREASE OF dn/dy (with $\sqrt{s}$ and N_A)

INCREASE OF $\langle p_T^2 \rangle$ (with $\sqrt{s}$ and N_A)

UNIVERSALITY : η IS UNIVERSAL

$\langle p_T^2 \rangle$: UNIVERSAL FUNCTION OF η

dn/dy : NOT UNIVERSAL ! $\left[\eta = \left(\frac{r}{R}\right)^2 \bar{N}_s\right]$

But: $\bar{N}_s = \left(\frac{R}{r}\right)^2 \eta \Rightarrow \frac{dn}{dy} = F(\eta)\,\eta \left(\frac{R}{r}\right)^2 \bar{n}$

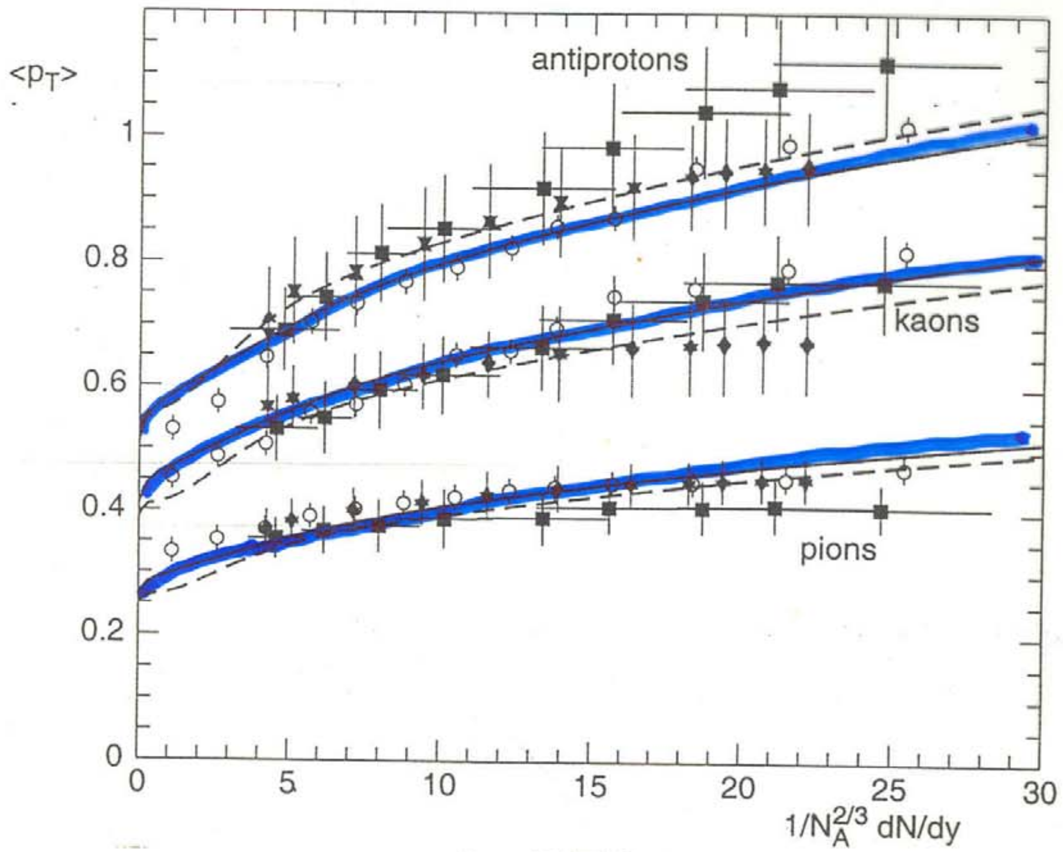
$\left[R = R_p N_A^{1/3}\right]$

$$\Rightarrow \frac{1}{N_A^{2/3}} \frac{dn}{dy} = F(\eta)\,\eta \left(\frac{R_p}{r}\right)^2 \bar{n}$$

UNIVERSAL FUNCTION OF η

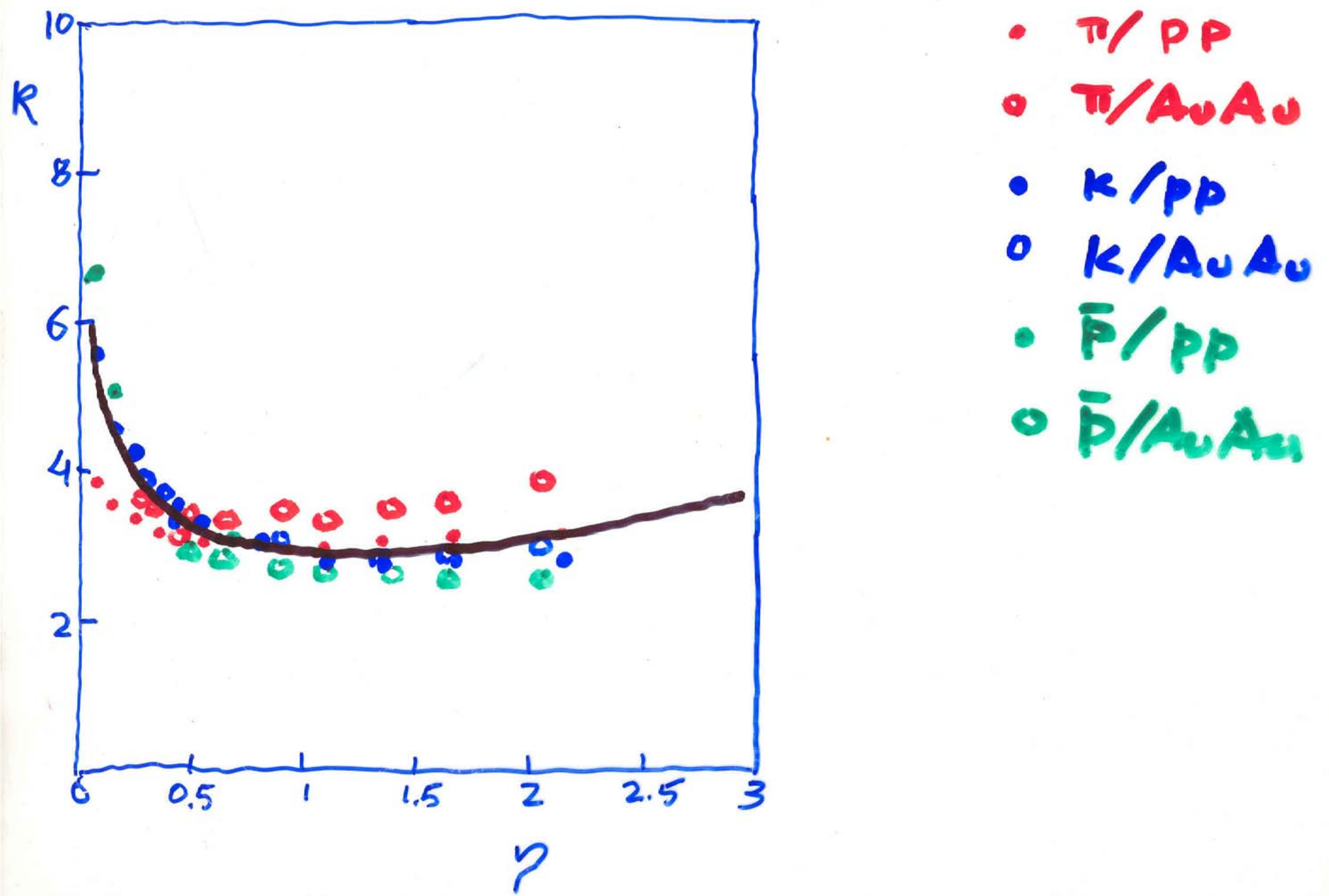
$i = \pi, K, \bar{p}$

$$\boxed{\langle p_T \rangle_i = \bar{p}_i\, \phi(x)} \qquad x \equiv \frac{1}{N_A^{2/3}} \frac{dn}{dy}$$

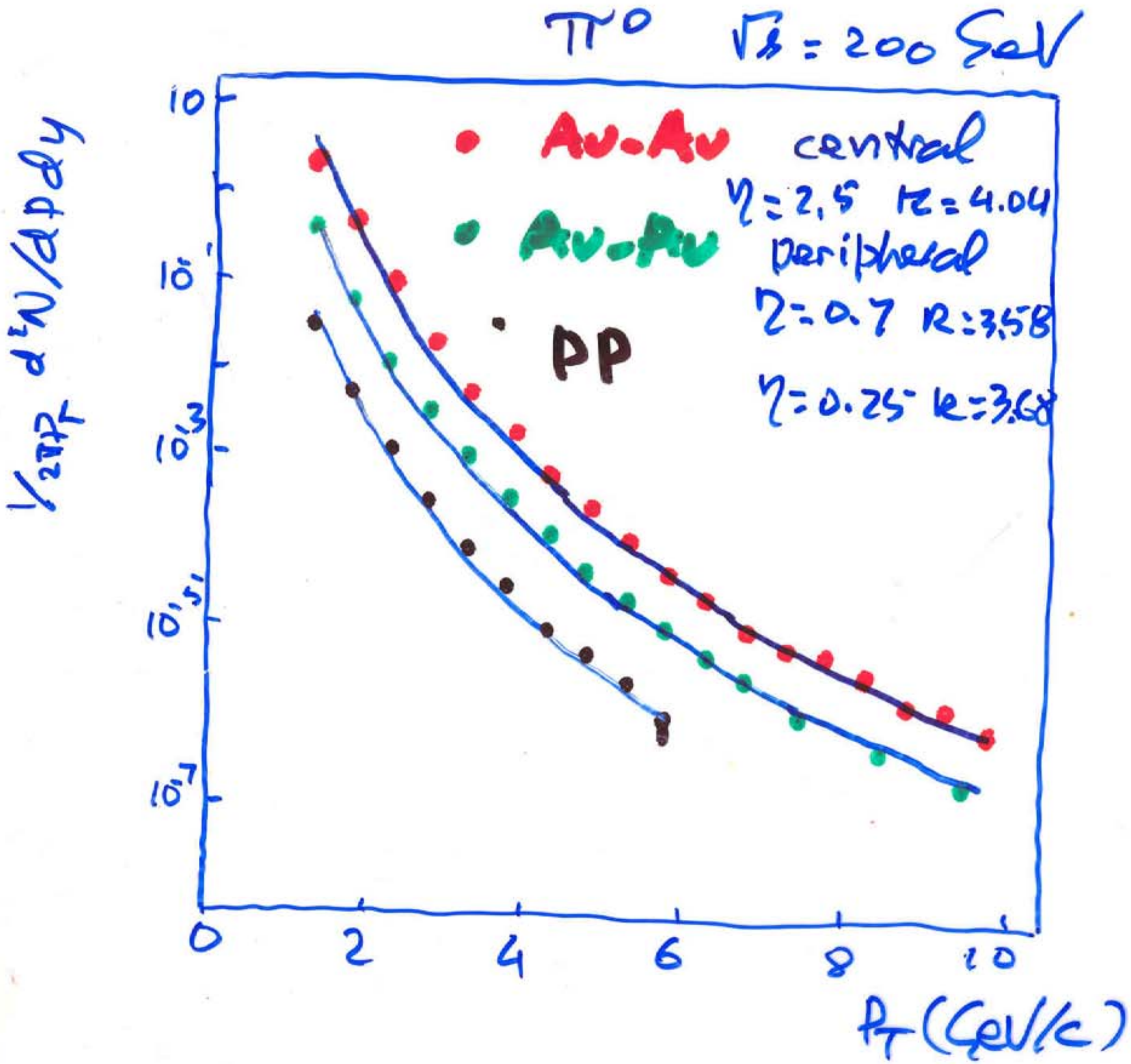


pp̄ : $\sqrt{s}$ = 1.8 TeV

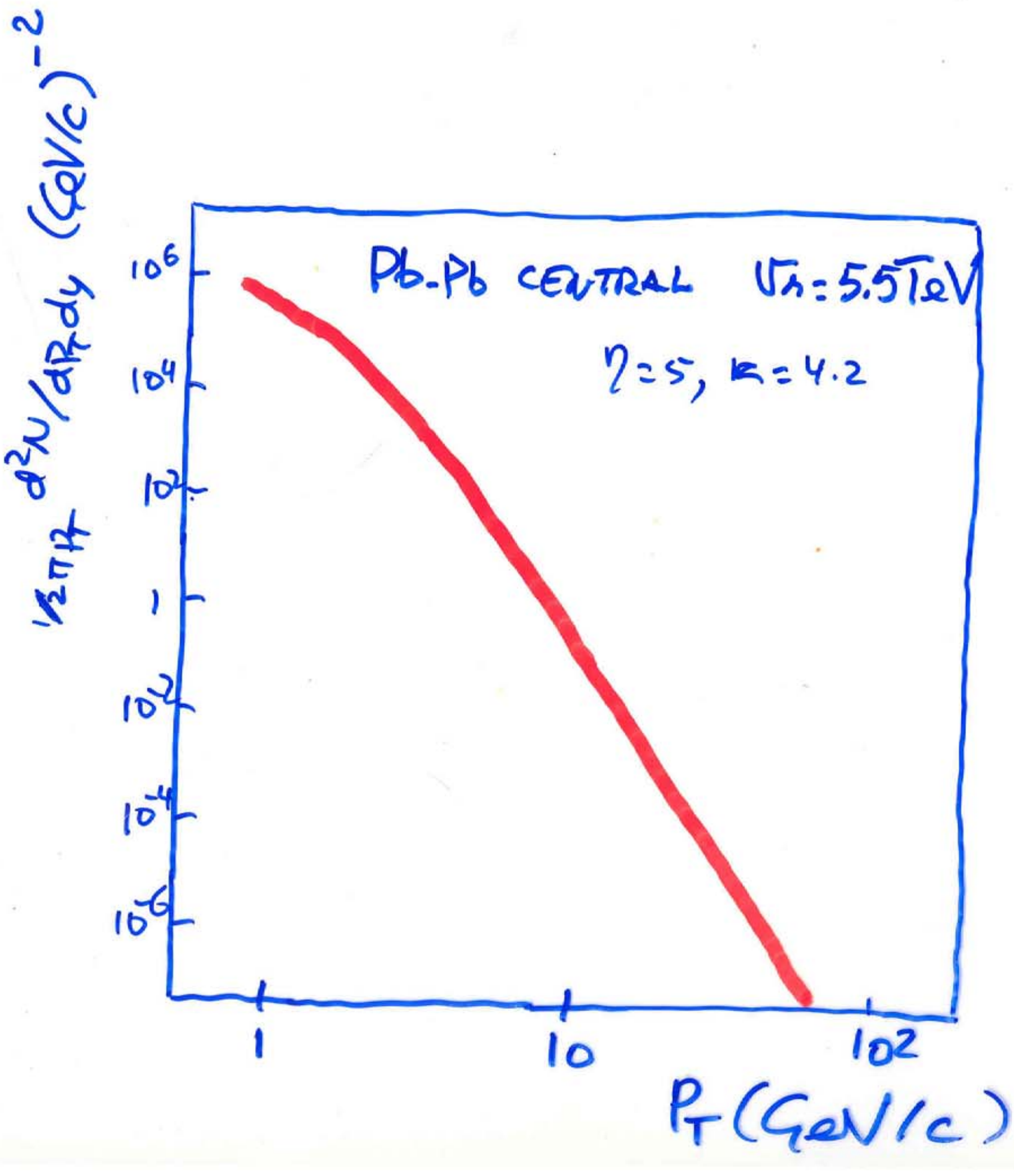
PHOBOS + PHENIX AuAu : $\sqrt{s}$ = 200 GeV



R
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
γ
π/pp
π/AuAu
K/pp
K/AuAu
p̄/pp
p̄/AuAu


π⁰ √s = 200 GeV
Au-Au central
η = 2.5 R = 4.04
Au-Au peripheral
η = 0.7 R = 3.58
pp
η = 0.25 R = 3.68
1/2πpT d²N/dpTdy
10
10⁻¹
10⁻³
10⁻⁵
10⁻⁷
0
2
4
6
8
10
pT (GeV/c)

ph/0304068



Pb-Pb CENTRAL $\sqrt{s} = 5.5$ TeV
$\eta = 5$, $K = 4.2$
$1/2\pi p_T \; d^2N/dp_T dy \; (GeV/c)^{-2}$
10^6
10^4
10^2
1
10^{-2}
10^{-4}
10^{-6}
1
10
10^2
p_T (GeV/c)

3 - AA Collisions at RHIC (PHENIX) AND LHC.

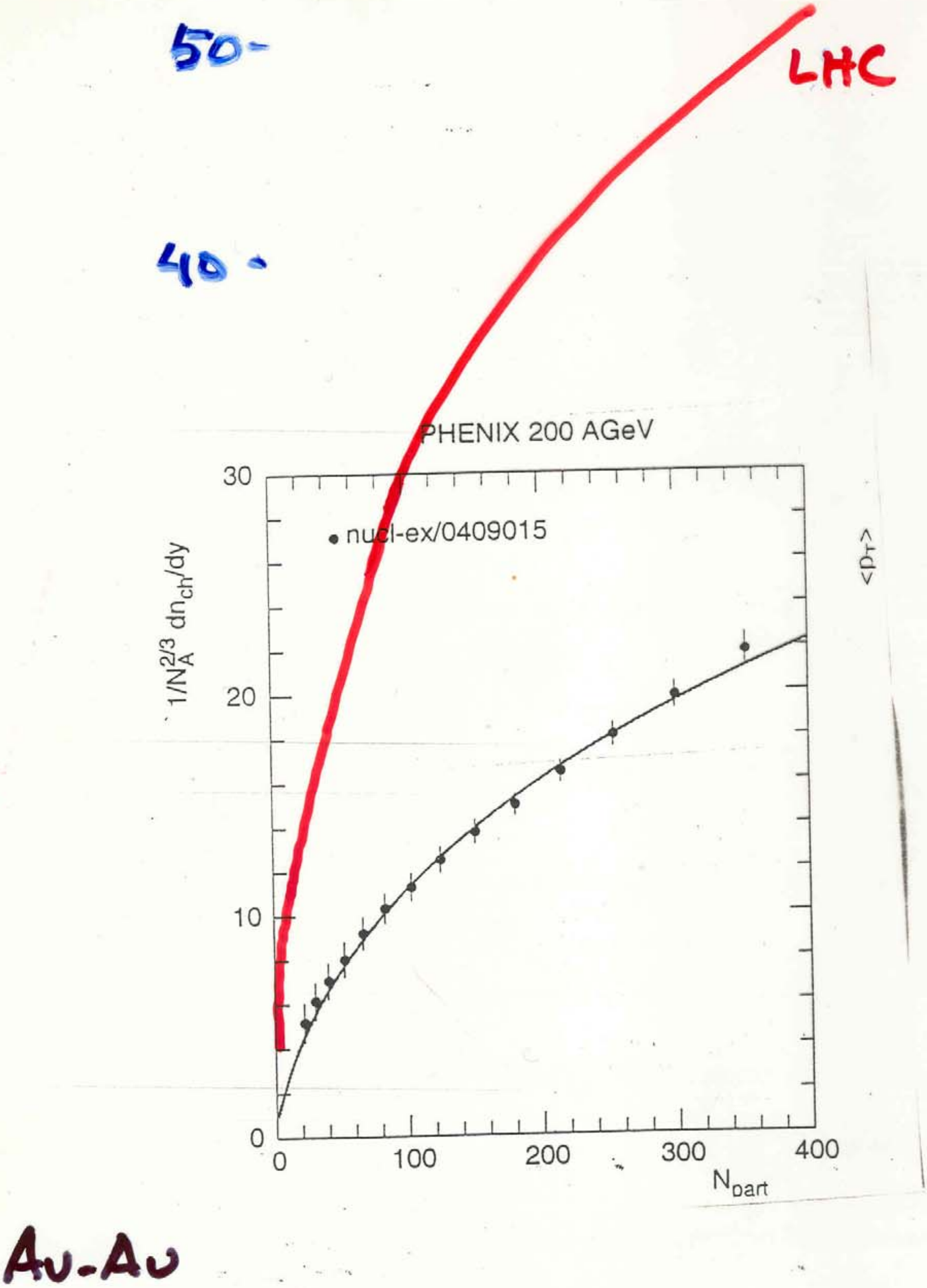
1) $\dfrac{1}{N_A^{2/3}} \dfrac{dn}{dy} = F(\eta)\, \eta \left(\dfrac{R_p}{r}\right)^2 \bar{n}$

2) $\langle p_T \rangle_i = \dfrac{r(\eta)}{r(\eta)-2} \, \dfrac{\bar{p}_i}{F(\eta)}$ $\qquad \eta = \left(\dfrac{r}{R_p}\right)^2 N_s^p N_A^{2/3}$

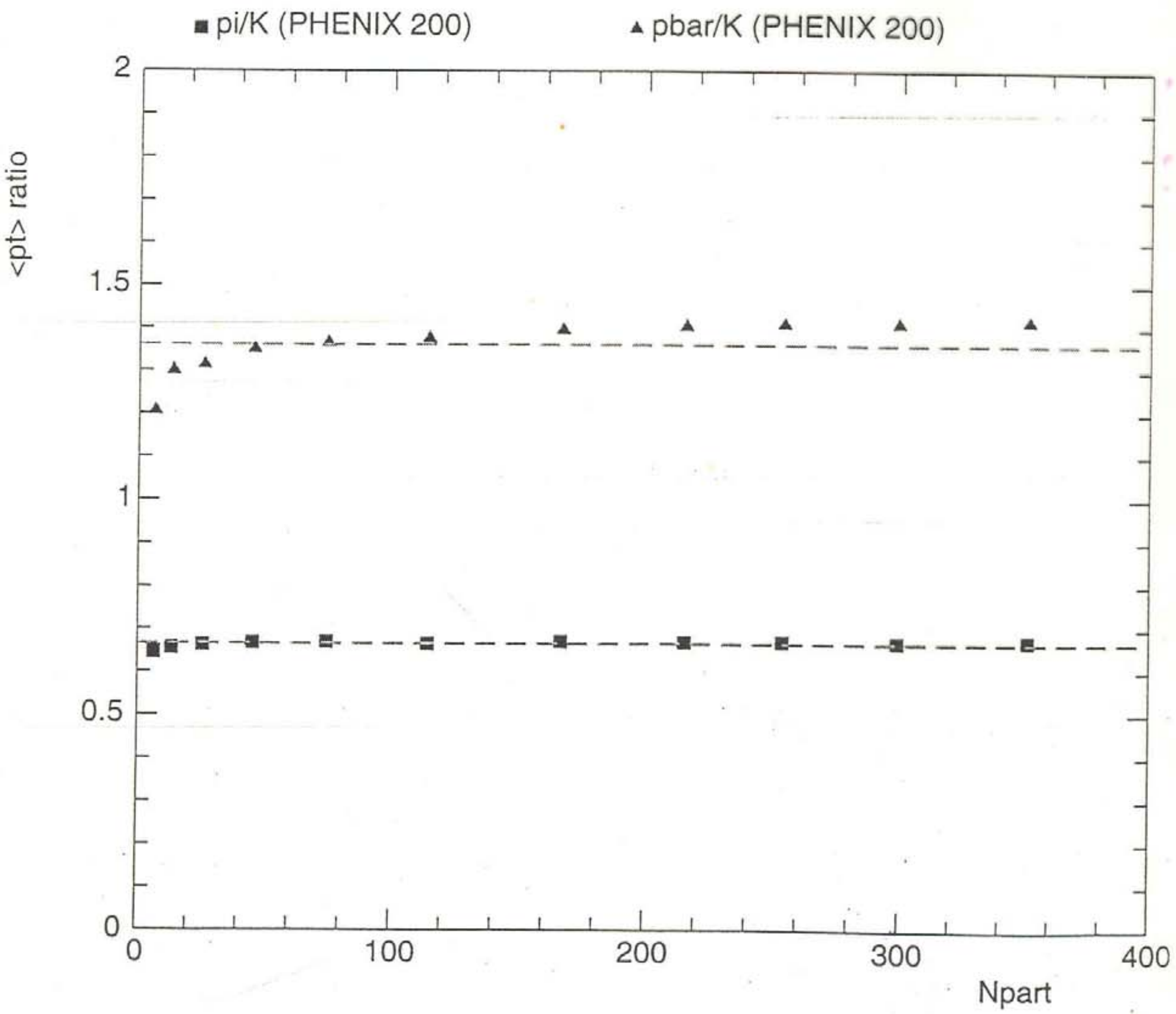
3) $\langle p_T \rangle_i \simeq \bar{p}_i \, \phi \left[\dfrac{1}{N_A^{2/3}} \dfrac{dn}{dy} \right]$ $\qquad i = \pi, K, p$

PARAMETERS: $r/R_p \simeq 0.2$, $\bar{n} \simeq 0.12$, $N_s^p(\sqrt{s} = 200) = 8.0$,

$\bar{p}_i$: $\bar{p}_\pi = 0.21$ GeV/c, $\bar{p}_K = 0.33$, $\bar{p}_p = 0.45$

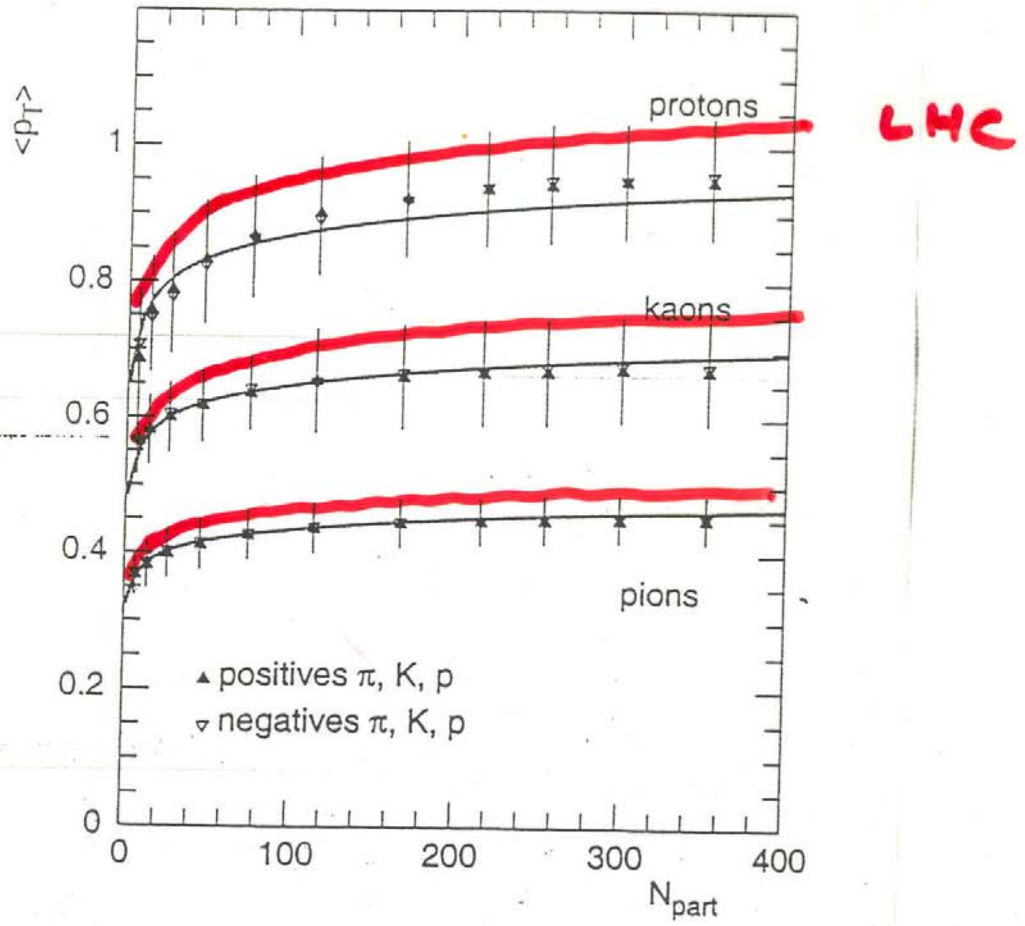


50
40
LHC
PHENIX 200 AGeV
nucl-ex/0409015
$1/N_A^{2/3}\, dn_{ch}/dy$
30
20
10
0
0
100
200
300
400
N_{part}
$\langle p_T \rangle$
Au-Au



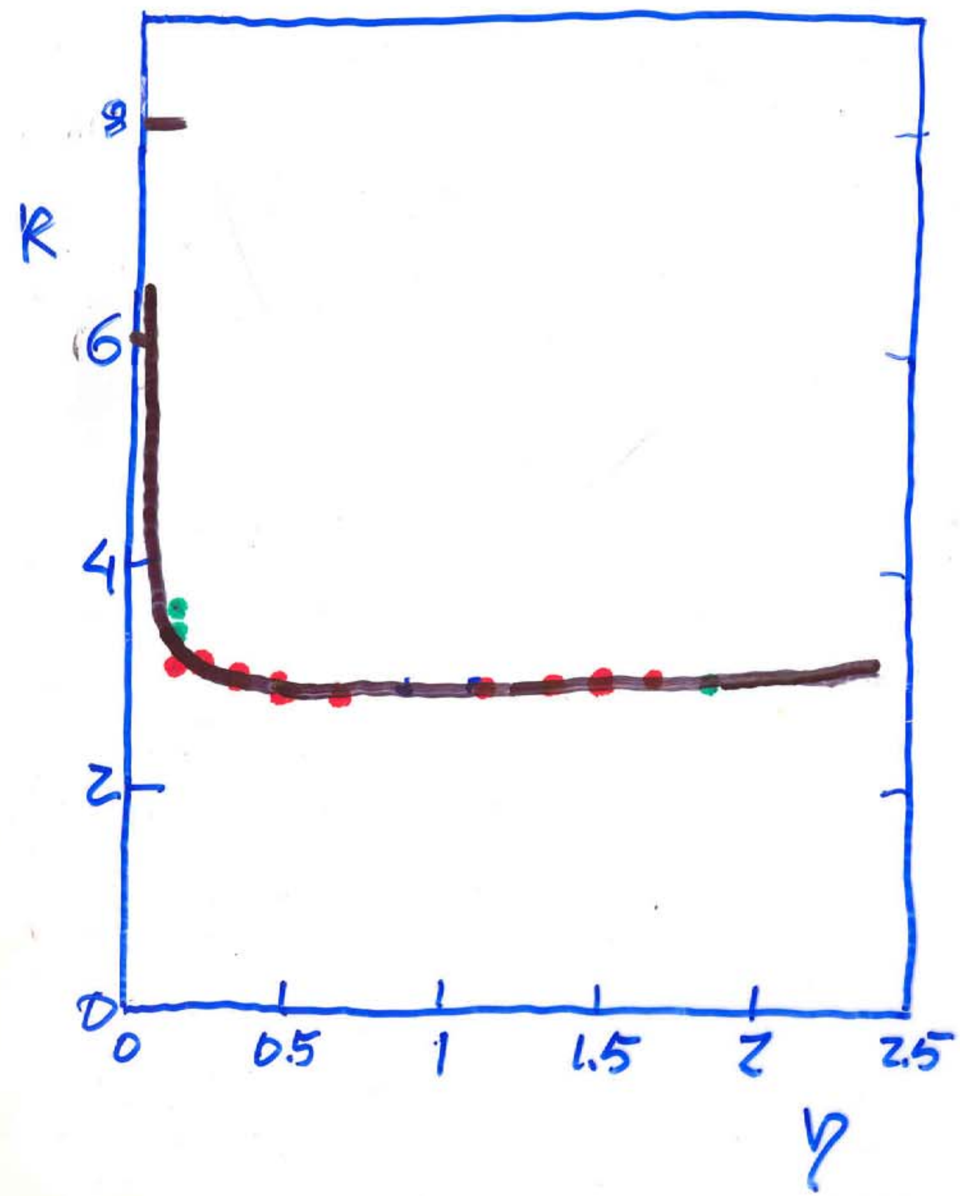
pi/K (PHENIX 200)
pbar/K (PHENIX 200)
2
1.5
1
0.5
0
<pt> ratio
0
100
200
300
400
Npart

15


$\langle p_T \rangle$
protons
LHC
kaons
pions
▲ positives π, K, p
▽ negatives π, K, p
N_{part}
0
0.2
0.4
0.6
0.8
1
0
100
200
300
400

Au-Au

PHENIX



$$f_i(y,p_T) = \frac{dn}{dy}\frac{1}{\bar{p}_i^2} F(\eta)\,\frac{k-1}{k}\,\frac{1}{\left(1+\frac{F(\eta)}{k}\frac{p_T^2}{\bar{p}_i^2}\right)^k}$$

$$\frac{dn}{dy} = F(\eta)\,\bar{N}_s\,\bar{n}$$

$$\begin{cases} y=0 & \bar{N}_s \sim N_A^{4/3} \\ |y|>0 & \bar{N}_s \sim N_A \end{cases}$$

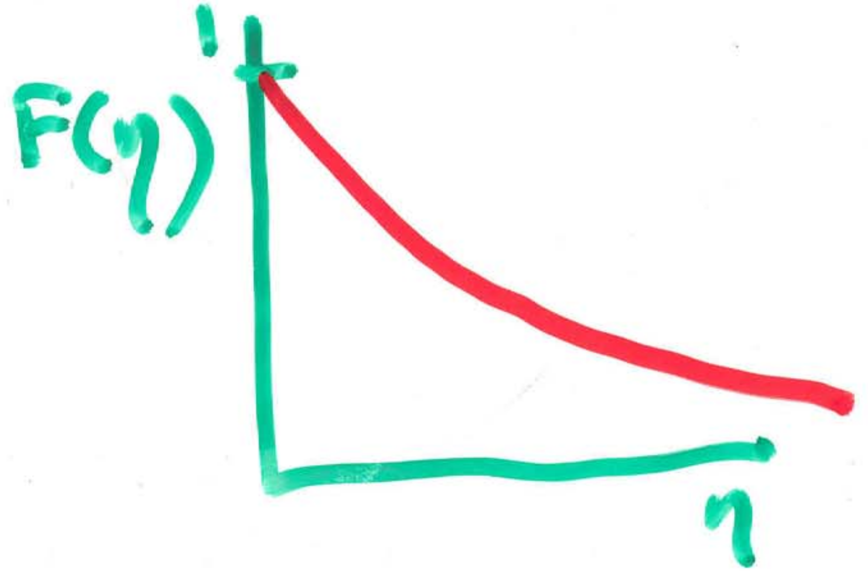
$$R_{CP}(y=0) = \frac{(k'-1)/k'}{(k-1)/k} \left(\frac{F(y')}{F(y)}\right)^2 \frac{\left(1+\frac{F(y)}{k}\frac{p_T^2}{\bar{p}_i^2}\right)^{k}}{\left(1+\frac{F(y')}{k'}\frac{p_T^2}{\bar{p}_i^2}\right)^{k'}}$$

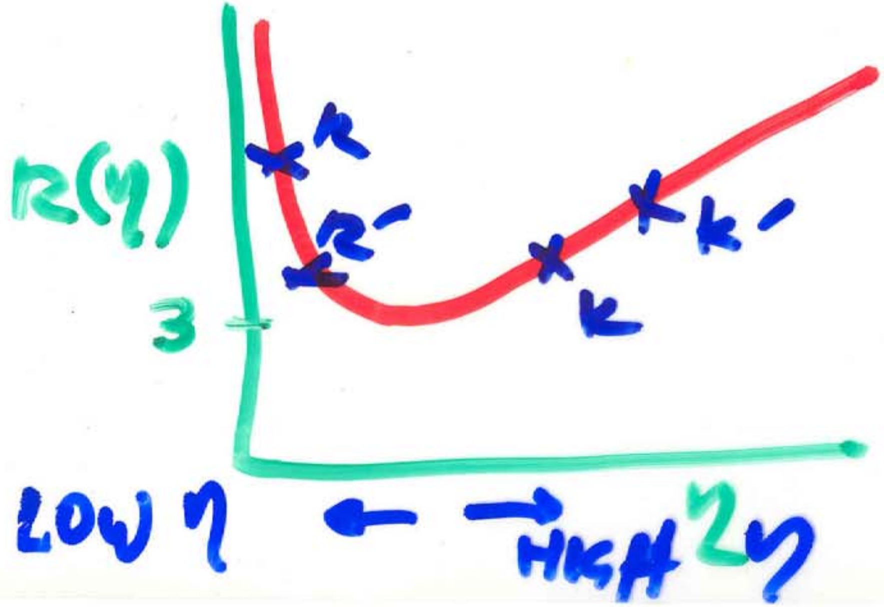
→ $p_T = 0$ $\quad R_{CP} = \frac{(k'-1)/k'}{(k-1)/k} \left(\frac{F(y')}{F(y)}\right)^2 < 1$

→ p_T small

$$R_{CP} \sim 1 + \left(F(y) - F(y')\right)\frac{p_T^2}{\bar{p}_i^2} \quad \nearrow$$

TO REMIND YOU...





→ Is there a Maximum?

$$\frac{d R_{cp}}{d P_T^2} = 0 \longrightarrow [F(\eta).F(\eta')] - F(\eta)F(\eta')\left[\frac{1}{\kappa} - \frac{1}{\kappa'}\right] P_T^2 = 0$$

HIGH η : $\kappa' > \kappa$ YES : R_{cp} decreases

LOW η : $\kappa > \kappa'$ NO : R_{cp} increases (>1)

→ P_T very large

$$R_{cp} \sim (P_T^2)^{\kappa - \kappa'} \begin{cases} \searrow & \kappa' > \kappa \\ \nearrow & \kappa > \kappa' \end{cases}$$

WHAT ABOUT pp COLLISIONS? $(N_{Part.} = 2)$

$R_{CP} \longrightarrow R_{HL}$

(Central - Peripheral) (High - Low Energy)

$$R_{HL} \equiv \frac{f(p_T, y, N_A, \sqrt{s'}) / \frac{dn}{dy}(y, N_A, \sqrt{s'})}{f(p_T, y, N_A, \sqrt{s}) / \frac{dn}{dy}(y, N_A, \sqrt{s})}$$

Low Density

CRONIN

High Density

LHC ?

4) AWAY FROM $y \simeq 0$

$y = 0$ $\quad\quad\quad\quad$ $|y| > 0$

$$\eta = \left(\frac{r}{R}\right)^2 \bar{N}_s$$

$\bar{N}_s \sim N_A^{4/3}$ $\quad\quad\quad\quad$ $\bar{N}_s \sim N_A$

$$R_{CP} \sim \frac{N_s}{N_{coll}} \sim 1 \quad\quad\quad\quad \sim \frac{1}{N_A^{1/3}}$$

$$\frac{R_{CP}(y>0)}{R_{CP}(y=0)} \sim \left(\frac{N_A}{N'_A}\right)^{1/3}$$

IN GENERAL $\sim$ $\boxed{\dfrac{(N'_{coll.}/N'_A)}{(N_{coll}/N_A)}}$

EX:

BRAHMS d-Au

$$\frac{R_{CP}(p_T, y=3.2)}{R_{CP}(p_T, y=0)} \simeq \frac{0.45}{1.25} = 0.36$$

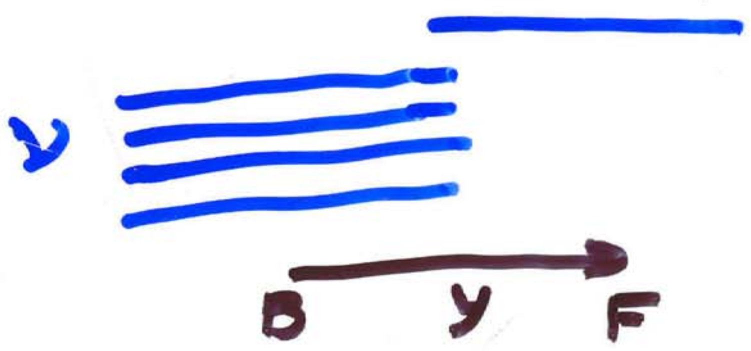
$N'_d = 1.96$, $N'_{coll.} = 13.6$

$N_d = 1.39$, $N_{coll.} = 3.3$

$$\frac{R_{CP}(y=3.2)}{R_{CP}(y=0)} = \frac{(1.96/13.6)}{(1.39/3.3)}$$

$$= 0.35$$

SIMPLE VERSION FOR pAu (dAu)



$N_{coll.} \sim \nu$

$$R_{cp}(y=0) \sim \frac{(1+\nu')/\nu'}{(1+\nu)/\nu} = \frac{\nu}{\nu'}\,\frac{1+\nu'}{1+\nu}$$

$$R_{cp}(y>0) \sim \frac{(1/\nu')}{(1/\nu)} = \frac{\nu}{\nu'} \quad < R_{cp}(0)$$

$$R_{cp}(y<0) \sim \frac{\nu'/\nu'}{\nu/\nu} = 1 \quad > R_{cp}(0)$$

$$R_{pA} = f_{pA}(p_T) / \langle \nu \rangle f_{pp}(p_T) \qquad \text{MB}$$

$$R_{pA}(y=0) \sim \frac{1+\langle \nu \rangle}{\langle \nu \rangle}$$

$$R_{pA}(y>0) \sim \frac{1}{\langle \nu \rangle} < R_{pA}^{(0)}$$

$$R_{pA}(y<0) \sim \frac{\langle \nu \rangle}{\langle \nu \rangle} < R_{pA}^{(0)}$$

$$\left\{ \begin{array}{l} \dfrac{dn}{dy} = F(y)\,\bar{N}_s\,\bar{n} \\[2ex] \langle p_T^2 \rangle = \bar{p}_i^2 \dfrac{n(y)}{n(y)-2} \dfrac{1}{F(y)} \end{array} \right.$$

$$\bar{N}_s = \eta \left(\frac{R}{r}\right)^2 = \eta \left(\frac{R_p}{r}\right)^2 N_A^{2/3}$$

• REL. dn/dy vs. $\langle p_T \rangle$ is the same

$y = 0$	$\lvert y \rvert > 0$
$\frac{1}{N_A^{2/3}} dn/dy \sim N_A^{1/3}$	$\sim N_A^{1/6}$
$\langle p_T \rangle \sim N_A^{1/6}$ (N_A LARGE)	$\sim N_A^{1/12}$

JET QUENCHING

$y > 0$ EFFECT $\searrow$

CONCLUSIONS

- IN THE TRANSITION TO QGP PERCOLATION EFFECTS SHOULD OCCUR
- GENERAL UNDERSTANDING OF dn/dy, $\langle p_T \rangle$, $f(p_T, y)$, R_{CP}, R_{PA}
- WE EXPECT THE p_T DISTRIBUTION IN PP COLLISIONS TO BECOME NARROWER AT HIGHER ENERGY (LHC?)