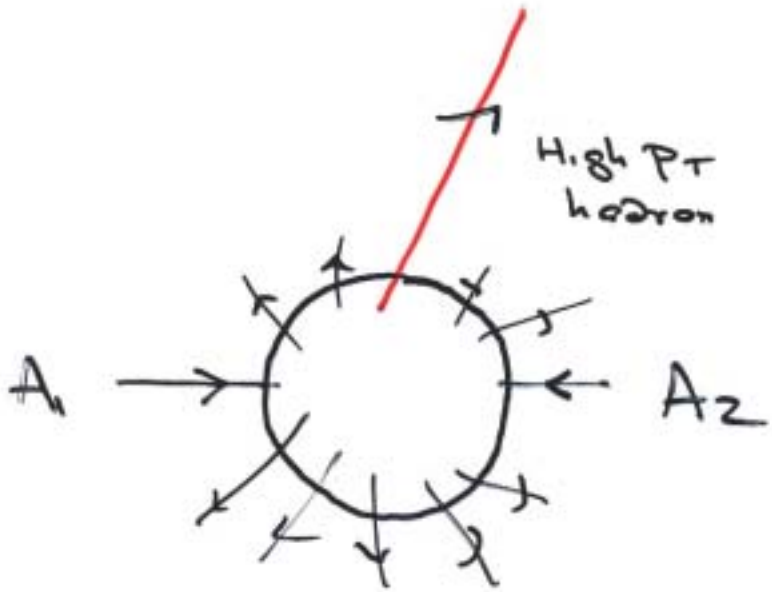
Riken BNL Research Center Workshop



$\sqrt{s_{A_1 A_2}} = 200$ GeV $A_1 A_2$

High p_T Physics at RHIC

"Outlook"

Stan Brodsky
SLAC

High p_T program at RHIC

$\vec{p}\vec{p} \to hX$ $\quad A_{LL} \quad A_N$

dAu collisions

$AuAu$ collisions

$\sqrt{s_{pp}} = 200$ GeV

* $pp \to \pi^0 X$ agrees with PQCD

* $pp \to pX$ exceeds PQCD

Away side jet quenched in AA !

$pp \to \pi^0 X$ decreased in AA !

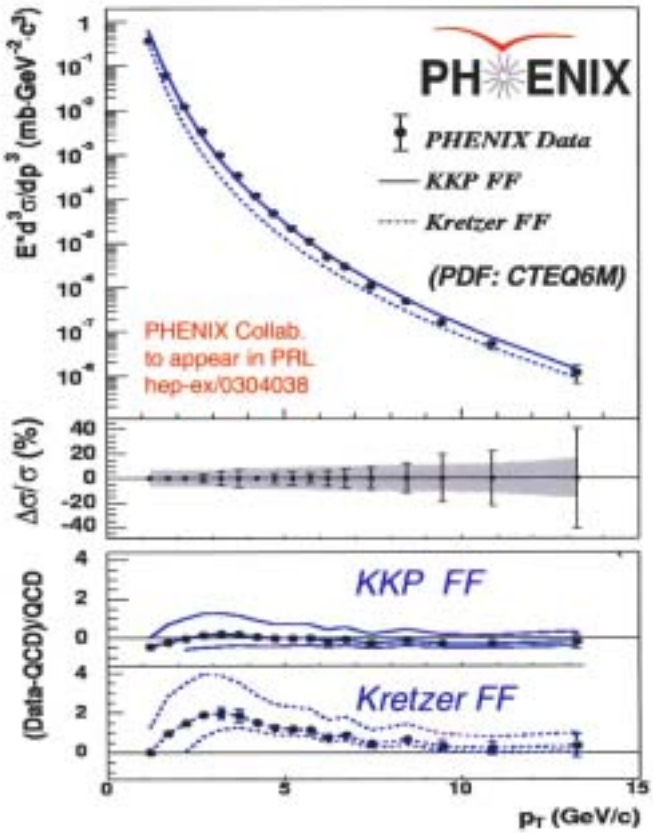
$pp \to pX$ less absorption !!

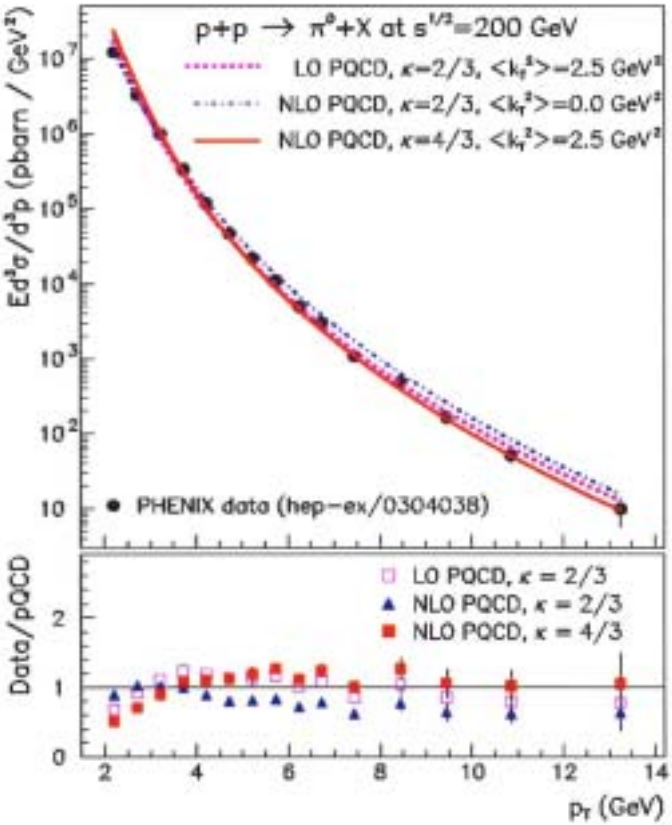
$$\frac{dE}{dx} \sim 0.5 \frac{\text{GeV}}{\text{fm}} \Rightarrow 15 \frac{\text{GeV}}{\text{fm}}$$

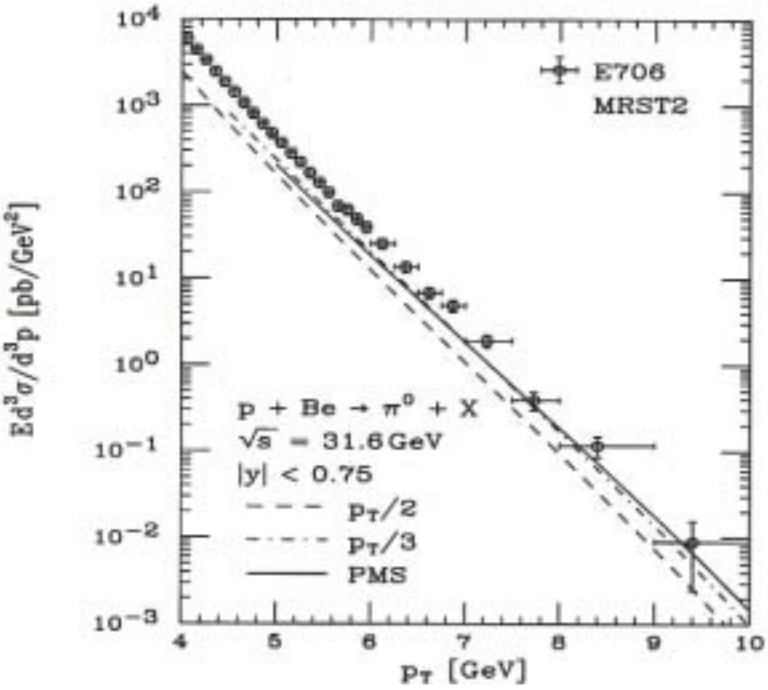
central A-A collisions

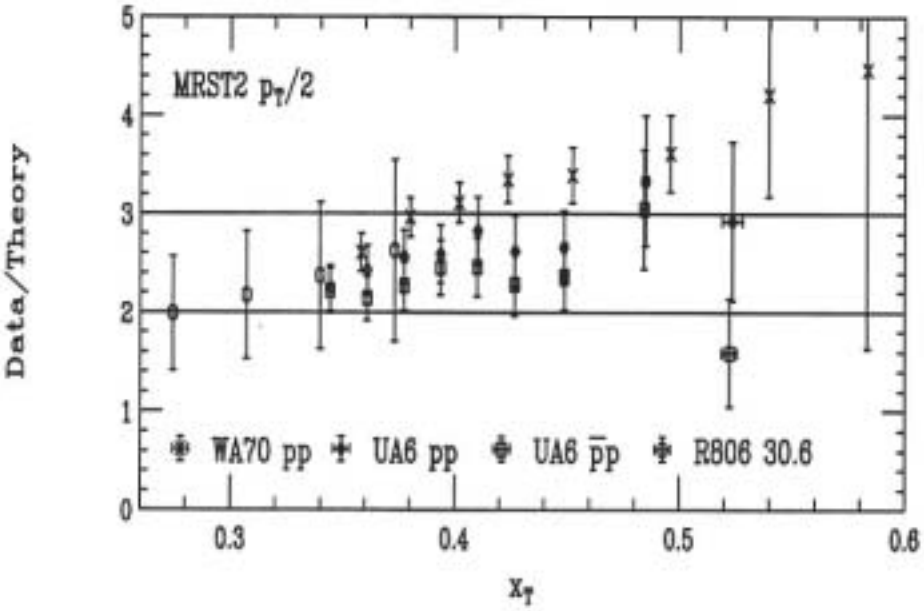
$p+p \to \pi^0 X$

Apparent agreement with PQCD





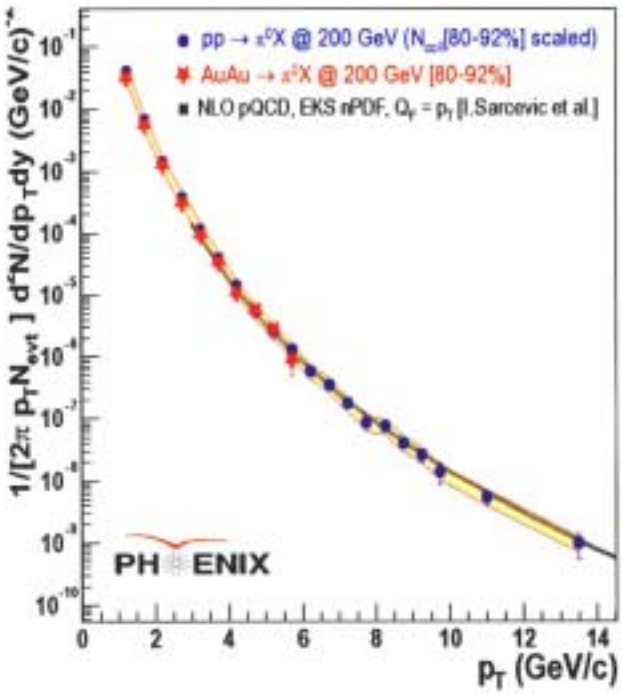




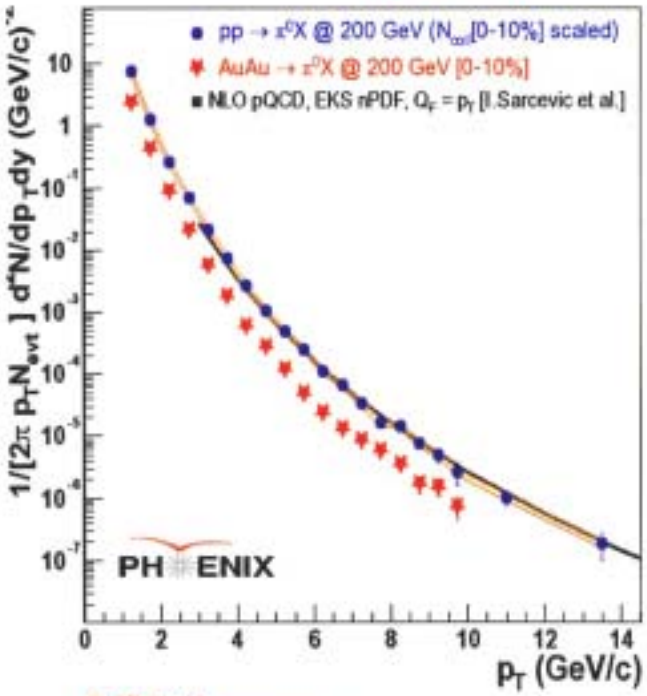
Aurenche et al hep-ph/9910252 Eur. J. Phys.

Sterman

Au+Au→ π^0 X (peripheral)



Au+Au→ π^0 X (central)

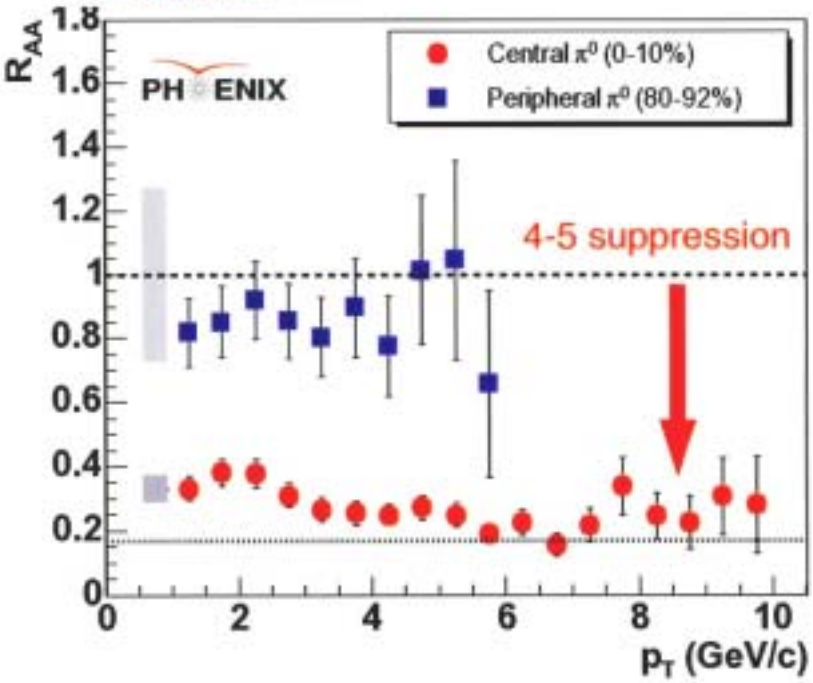


D.d'Enterria
(PHENIX Collaboration)
nucl-ex/0309015

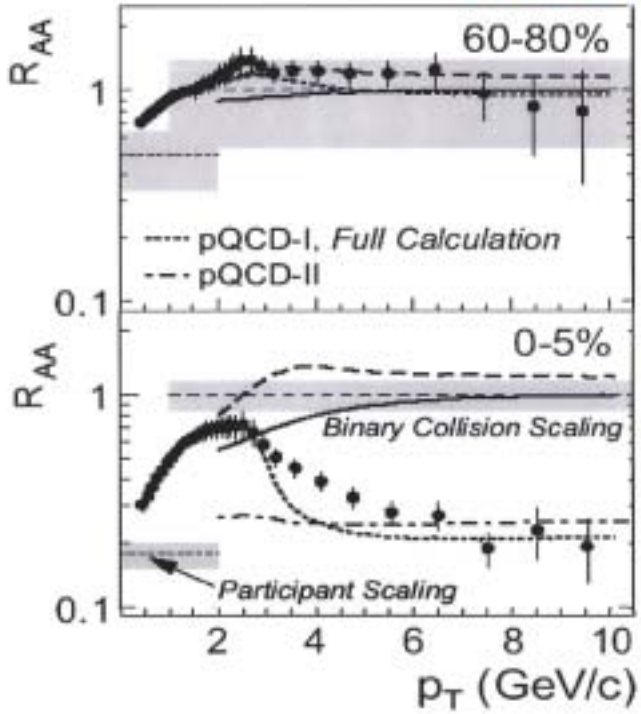
Absorption
Energy Loss
of quark in medium

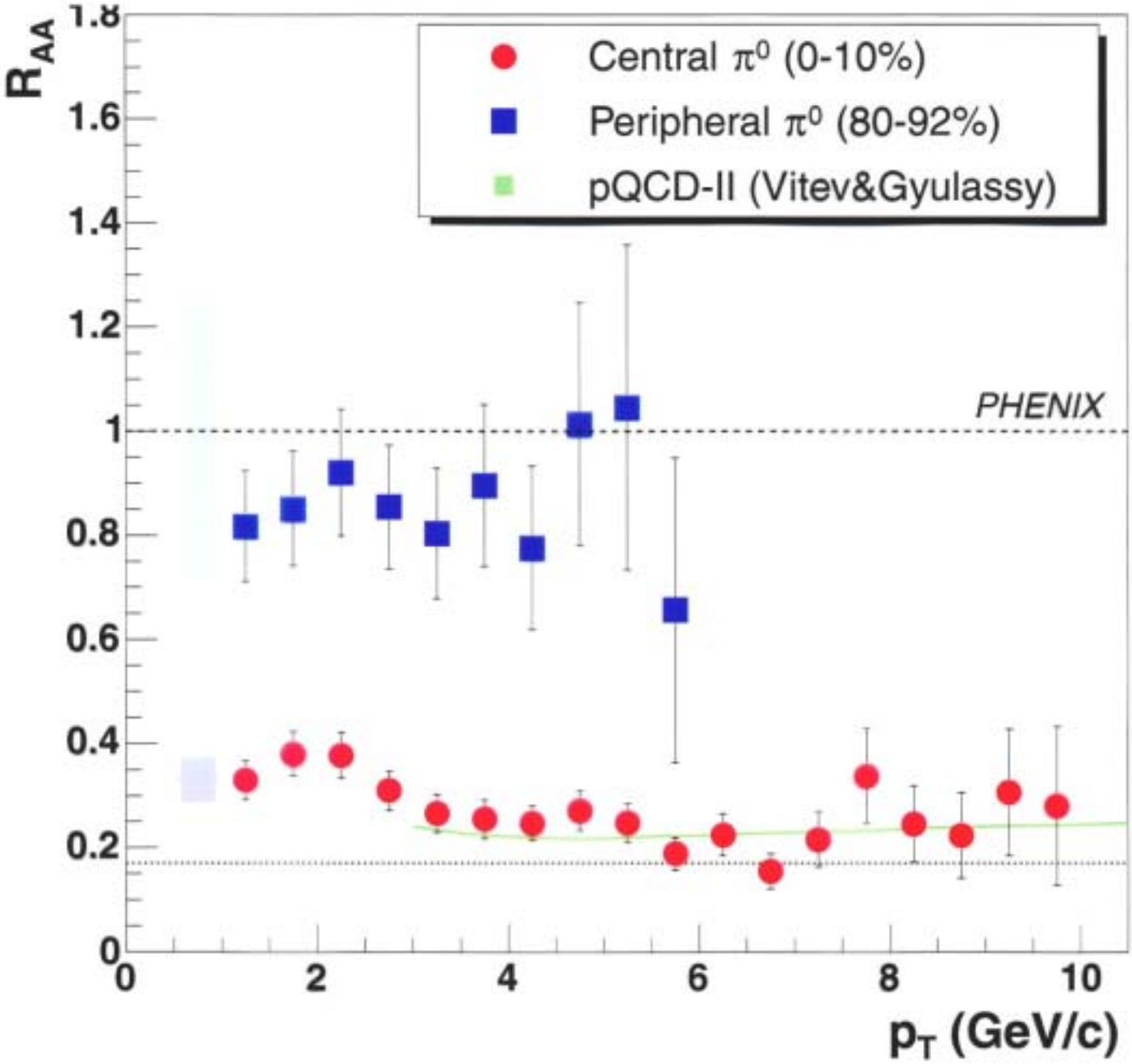
$$R_{AA}(p_T) = \frac{d^2 N_{AA}/d\eta dp_T}{\langle N_{coll}\rangle\, d^2 N_{pp}/d\eta dp_T}$$

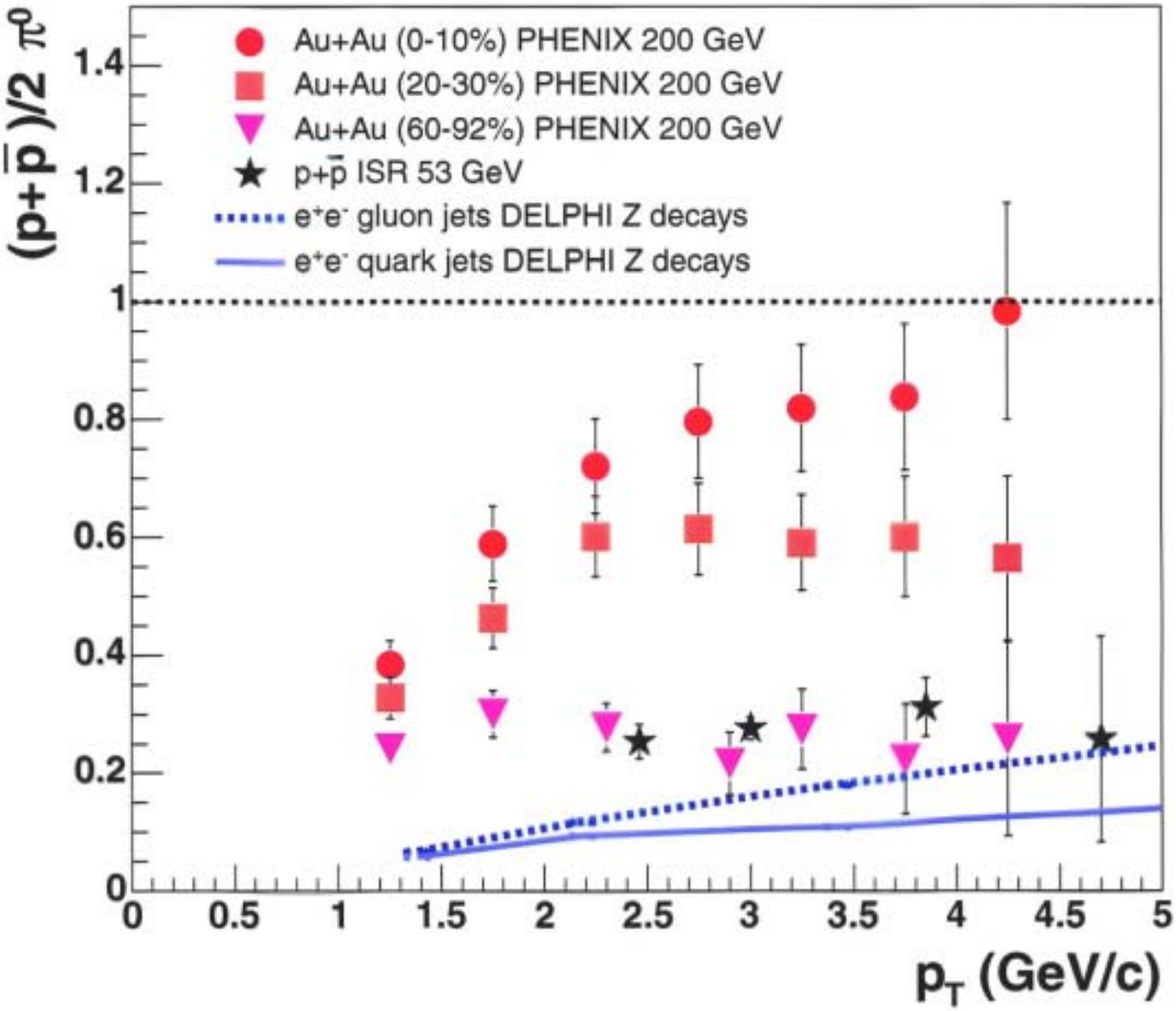
PHENIX Collab.
PRL 91, 072303 (2003)
nucl-ex/0304022

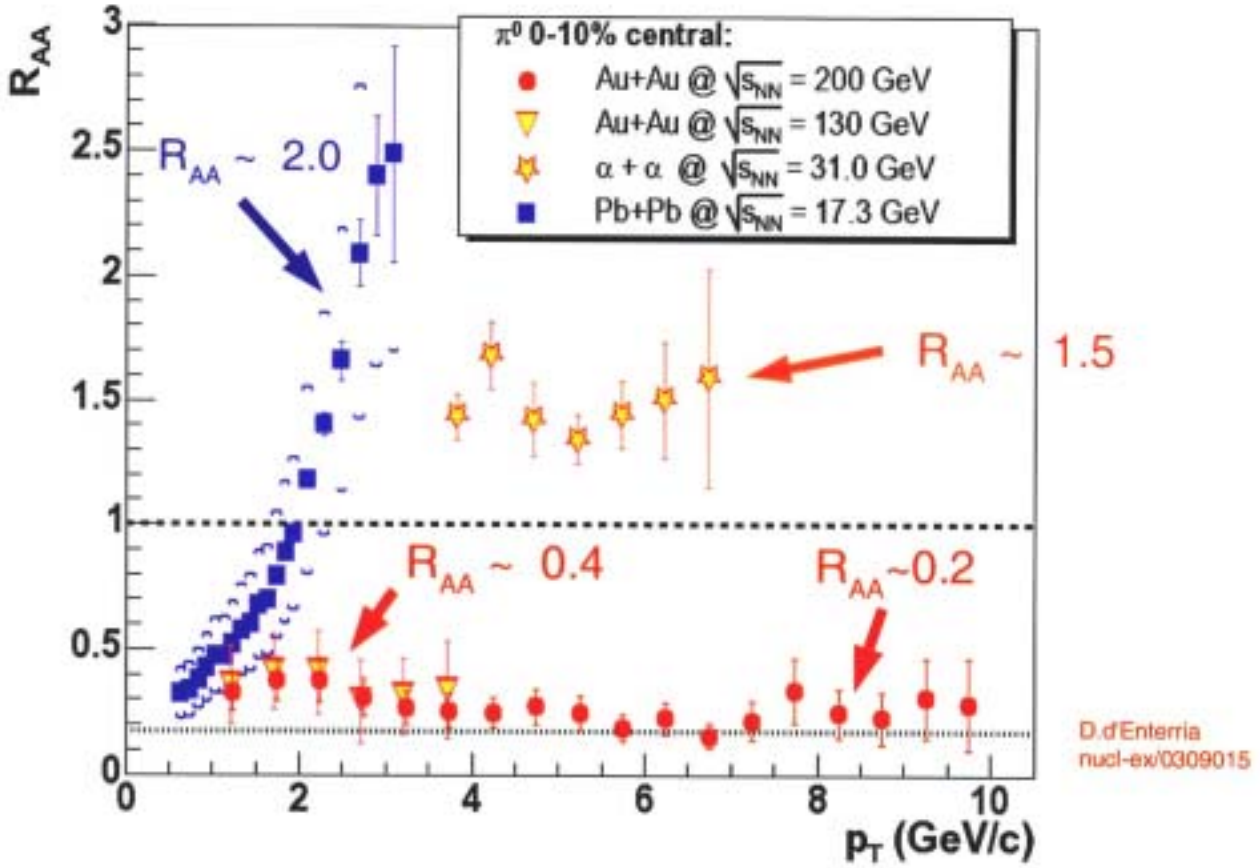


STAR Collab.
PRL91, 172302
nucl-ex/0305015

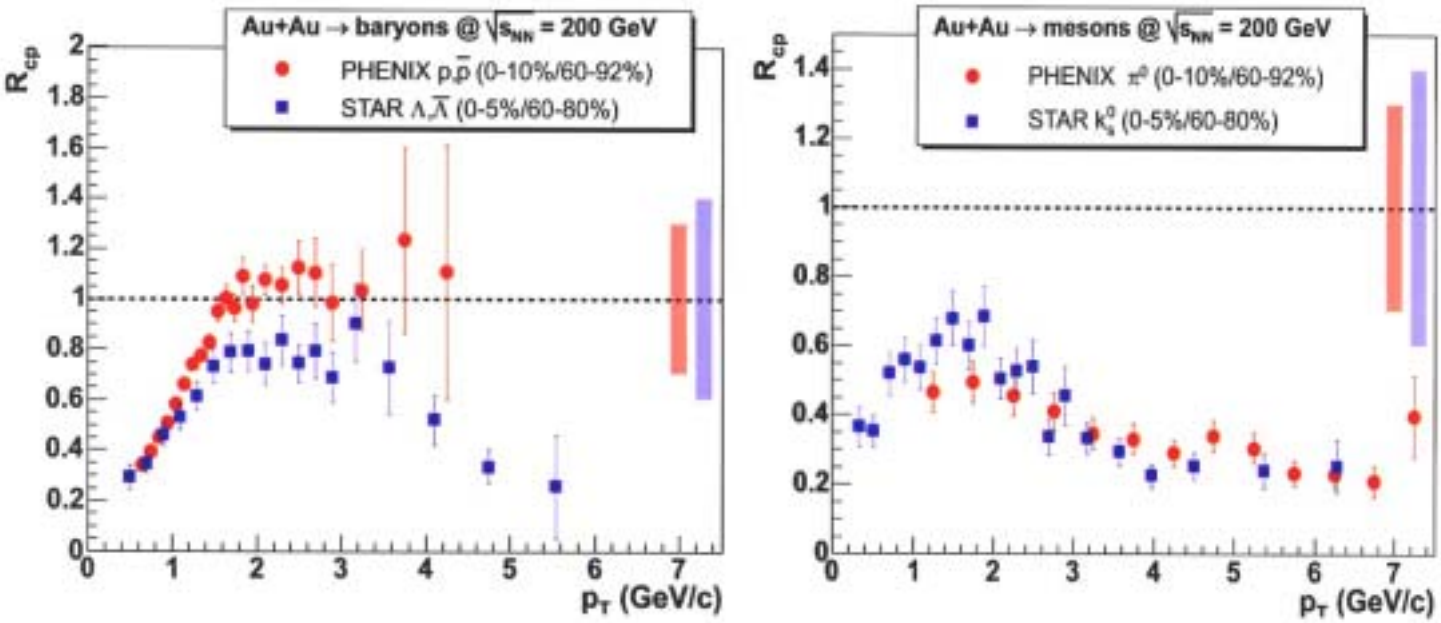



Central π^0 (0-10%)
Peripheral π^0 (80-92%)
pQCD-II (Vitev&Gyulassy)
PHENIX
R_{AA}
p_T (GeV/c)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
2
4
6
8
10


Au+Au (0-10%) PHENIX 200 GeV
Au+Au (20-30%) PHENIX 200 GeV
Au+Au (60-92%) PHENIX 200 GeV
p+p̄ ISR 53 GeV
e+e- gluon jets DELPHI Z decays
e+e- quark jets DELPHI Z decays
(p+p̄)/2 π0
pT (GeV/c)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.5
1.5
2
2.5
3
3.5
4
4.5
5

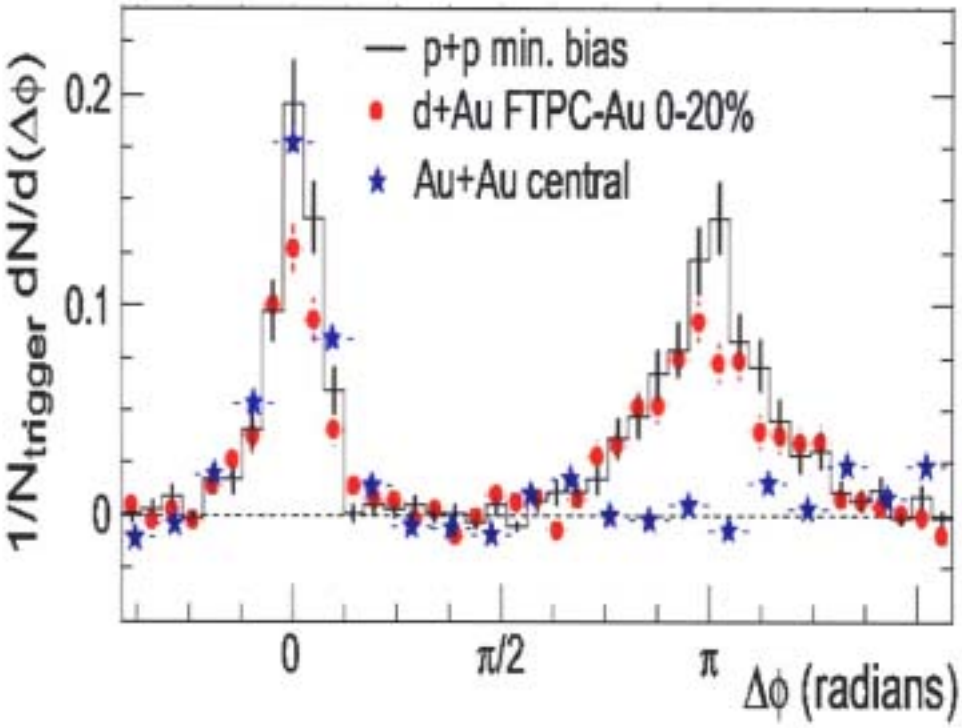

R_{AA}
π^0 0-10% central:
Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV
Au+Au @ $\sqrt{s_{NN}}$ = 130 GeV
α + α @ $\sqrt{s_{NN}}$ = 31.0 GeV
Pb+Pb @ $\sqrt{s_{NN}}$ = 17.3 GeV
R_{AA} ~ 2.0
R_{AA} ~ 1.5
R_{AA} ~ 0.4
R_{AA}~0.2
p_T (GeV/c)
D.d'Enterria
nucl-ex/0309015

- R_{cp} (ratio central/peripheral) at intermediate p_T = 2. – 4. GeV/c:
  (i) (anti)baryons: p, pbar, Λ, Λbar **NOT** suppressed in central Au+Au.
  (ii) mesons: π^0, k^0_s equally suppressed.



PHENIX Collab.
PRL91:172301(2003)

STAR Collab.
subm. to PRL, nucl-ex/0306007

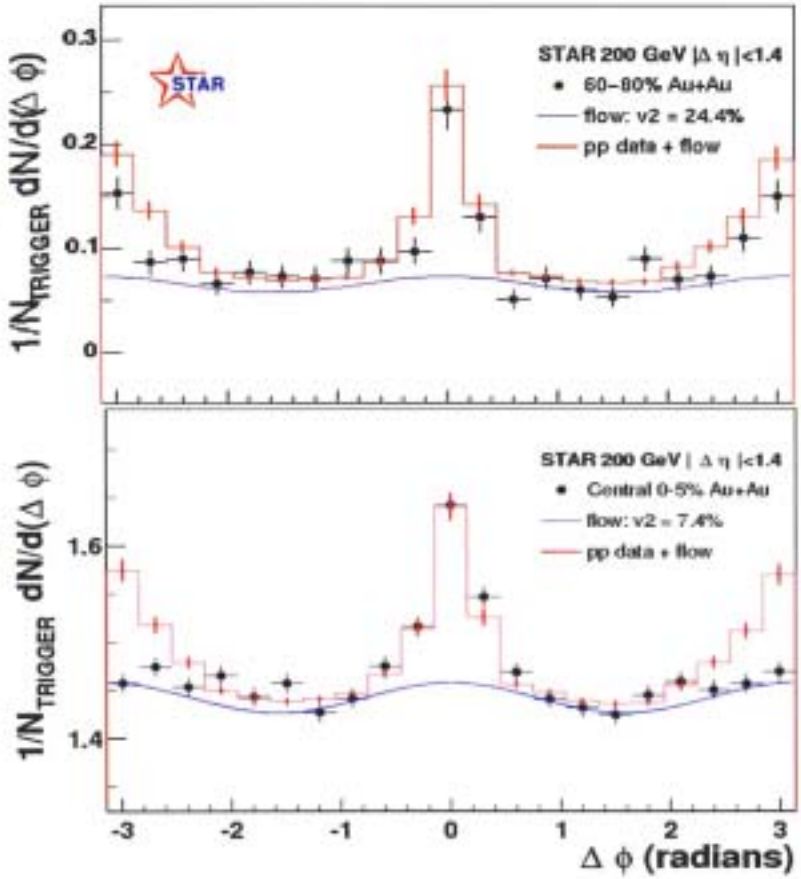


Remarkable suppression of away side particles

STAR Collab.
PRL91, 072304 (2003)

Periph.:

Central:

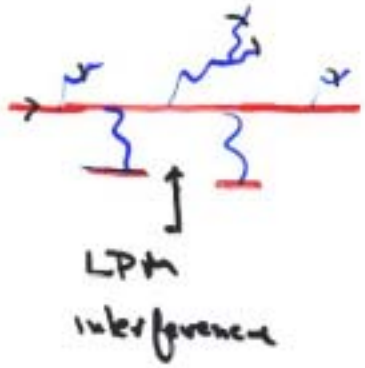


Trigger particle aligns with event plane

Red histogram: p+p (+flow)
Black points: Au+Au
Blue curve: flow contribution

P. Jacobs, J. Klay
(STAR Collab.)
nucl-ex/0308023

Energy Loss of Quarks



$$\frac{dE}{dx} \sim 0.5 \ \frac{\text{GeV}}{\text{fm}}$$ in cold matter

(including elastic collisions)

Away side suppression in $A_u A_u$ central collisions

$$\frac{dE}{dx} \sim 15 \ \frac{\text{GeV}}{\text{fm}}$$

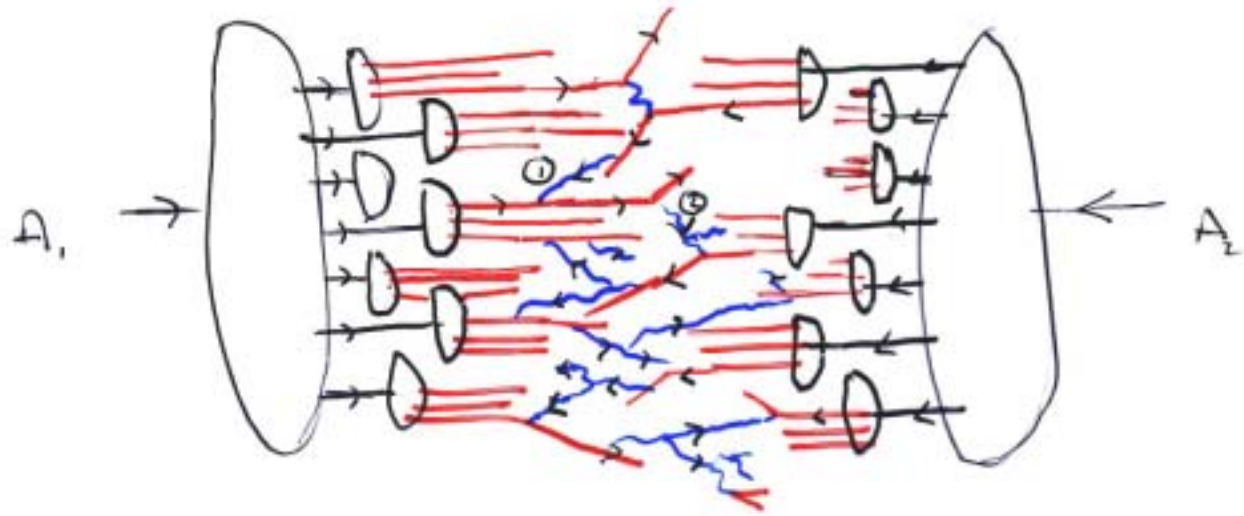
Increase by factor of ~30 !

X. N. Wang
M. Gyulassy

Strong evidence for q-g plasma

SJB

Model for formation of ε, δ plasma



Analog of back-scattered laser !

* Compton produces high energy polarised photon beam.

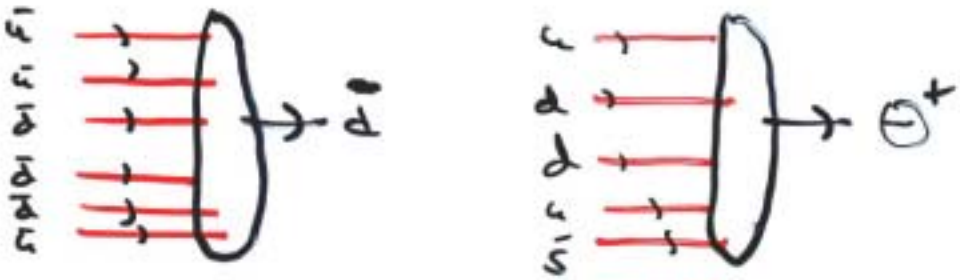
* In heavy ions : converts quark energy to gluonic energy — Gluon Avalanche!

* "Colliding mirrors": Cascading gluons

  { converts heavy ion energy to high density gluons, $q\bar{q}$

q, g plasma

multiquark condensation



look for exotic hadrons, glueballs

cascading fluxes ⇒ multiquark systems

What are critical parameters

A_1, A_2

$\sqrt{\sigma_{A_1 A_2}}$

Are we observing leading twist hard QCD subprocesses at RHIC ?

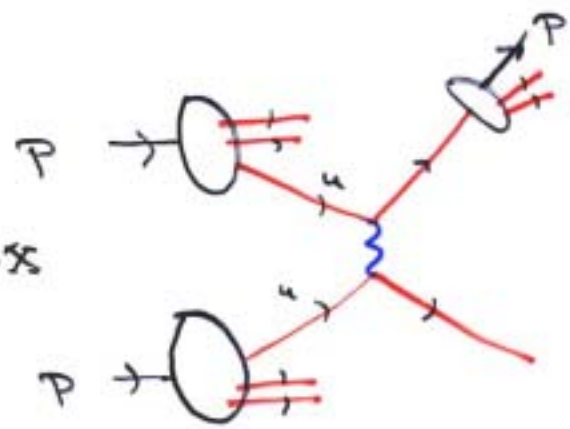
modulo $\log^2 p_T^2$ from DGLAP

$$\frac{d\sigma}{d^3p/E}(pp \to HX) = \frac{\alpha_s^2(p_T^2)}{p_T^4} F(x_T, \theta_{cm})$$

$$F(x_T, \tfrac{\pi}{2}) = (1-x_T)^{2n_{spect}-1}$$

$x_T \sim 1$

Farrar SJB
Blankenbecker Gunn SJB
Borkert, Schmidt SJB

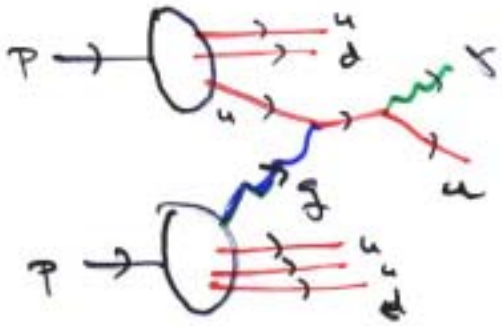


$pp \to pX$

$n_{spec} = 2+2+2$

$F(x_T) \sim (1-x_T)^{11}$

ADS/CFT: Polchinski-Strassler
de Teramond SJB



$pp \to \gamma X$

$n_{spec} = 2+3$

$F(x_T) \sim (1-x_T)^9$

corrections from spin $2|\Delta S_z|$

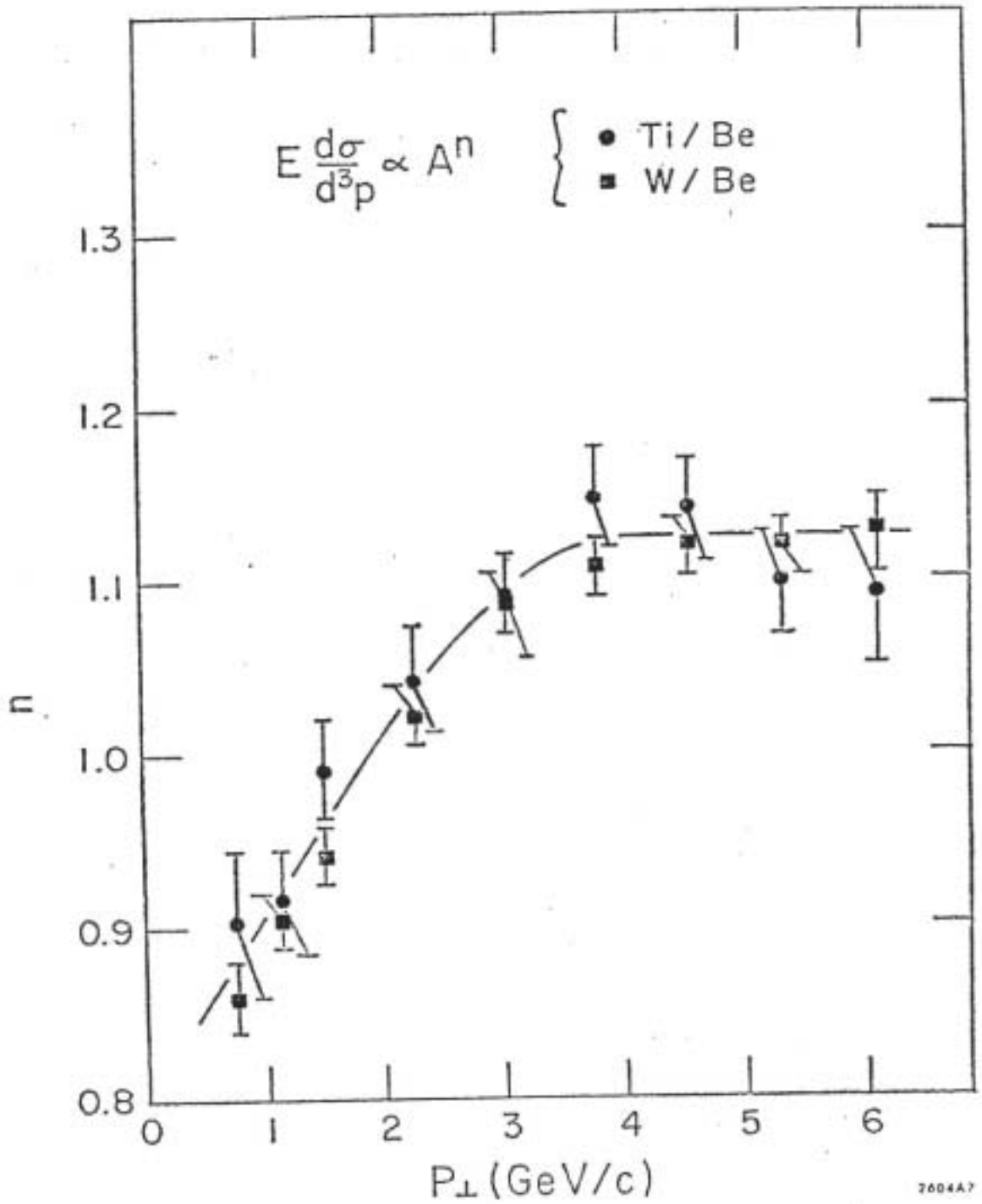
$q \to q + \delta$

and evolution $\log\log p_T^2$

TABLE I

Scaling Predictions for $E\, d\sigma/d^3p = C\, p_T^{-n}(1-x_T)^F$

Large p_T Process	Leading CIM Subprocess	Predicted	Observed (CP)[3]
		n//F	n//F
$pp \to \pi^+X$	$qM \to q\pi^+$	8//9	8.5//8.8
π^-	$qM \to q\pi^-$	8//9	8.9//9.7
K^+	$qM \to qK^+$	8//9	8.4//8.8
K^-	$qM \to qK^-$	8//13	8.9//11.7
	$q\bar{q} \to K^+K^-$	8//11	
$pp \to pX$	$q(qq) \to Mp$	12//5	11.7//6.8
	$qB \to qp$	12//7	
$pp \to \bar{p}X$	$q\bar{q} \to B\bar{p}$	12//11	8.8//14.2
	$qM \to qM$	8//15	
$\pi p \to \pi X$	$q\bar{q} \to M\pi$	8//5	
	$qM \to q\pi$	8//7	
	$q(qq) \to B\pi$	12//3	
	$\pi q \to \pi q$	8//3	


$E \frac{d\sigma}{d^3p} \propto A^n$
Ti / Be
W / Be
1.3
1.2
1.1
1.0
0.9
0.8
n
0
1
2
3
4
5
6
$P_\perp$ (GeV/c)
7604A7

ISR, Fermi Lab Fixed Target

$\sqrt{s} < 63$ GeV $\qquad\qquad$ $\sqrt{s} \lesssim 30$ GeV

Fit data to

$$\boxed{\frac{d\sigma}{d^3p/E}(pp \to HX) = A\,\frac{(1-x_T)^p}{p_T^{\,N}}}$$

$\theta_{cm} = \pi/2$

Examples:

$pp \to pX$: $\quad \frac{1}{p_T^{11.7}}(1-x_T)^7$ $\qquad$ need to vary s

$pp \to \pi^+ X$: $\quad \frac{1}{p_T^{8}}(1-x_T)^9$

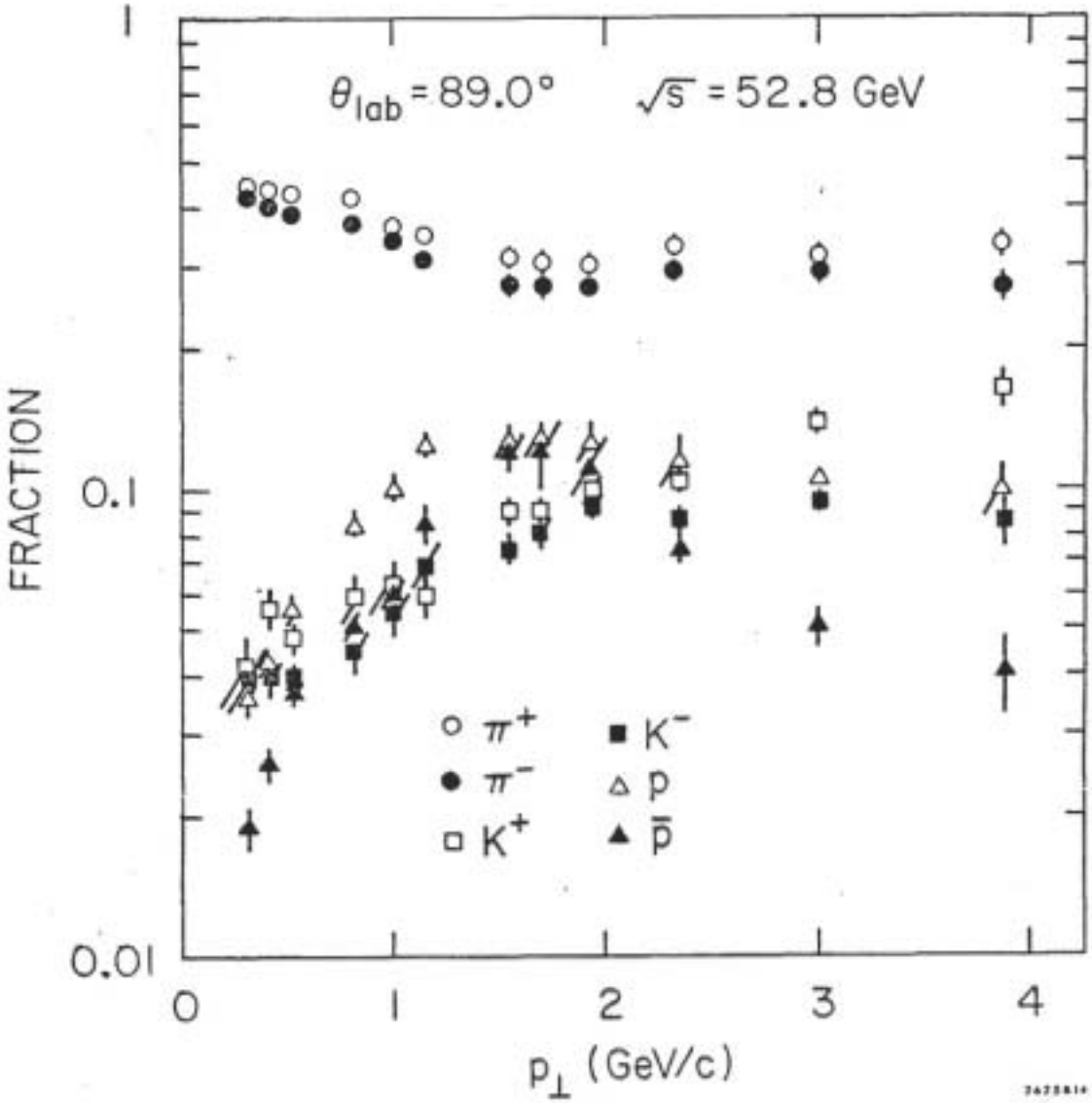
Far from $\frac{1}{p_T^4}(1-x_T)^{11+3}$, $\frac{1}{p_T^4}(1-x_T)^{9+3}$

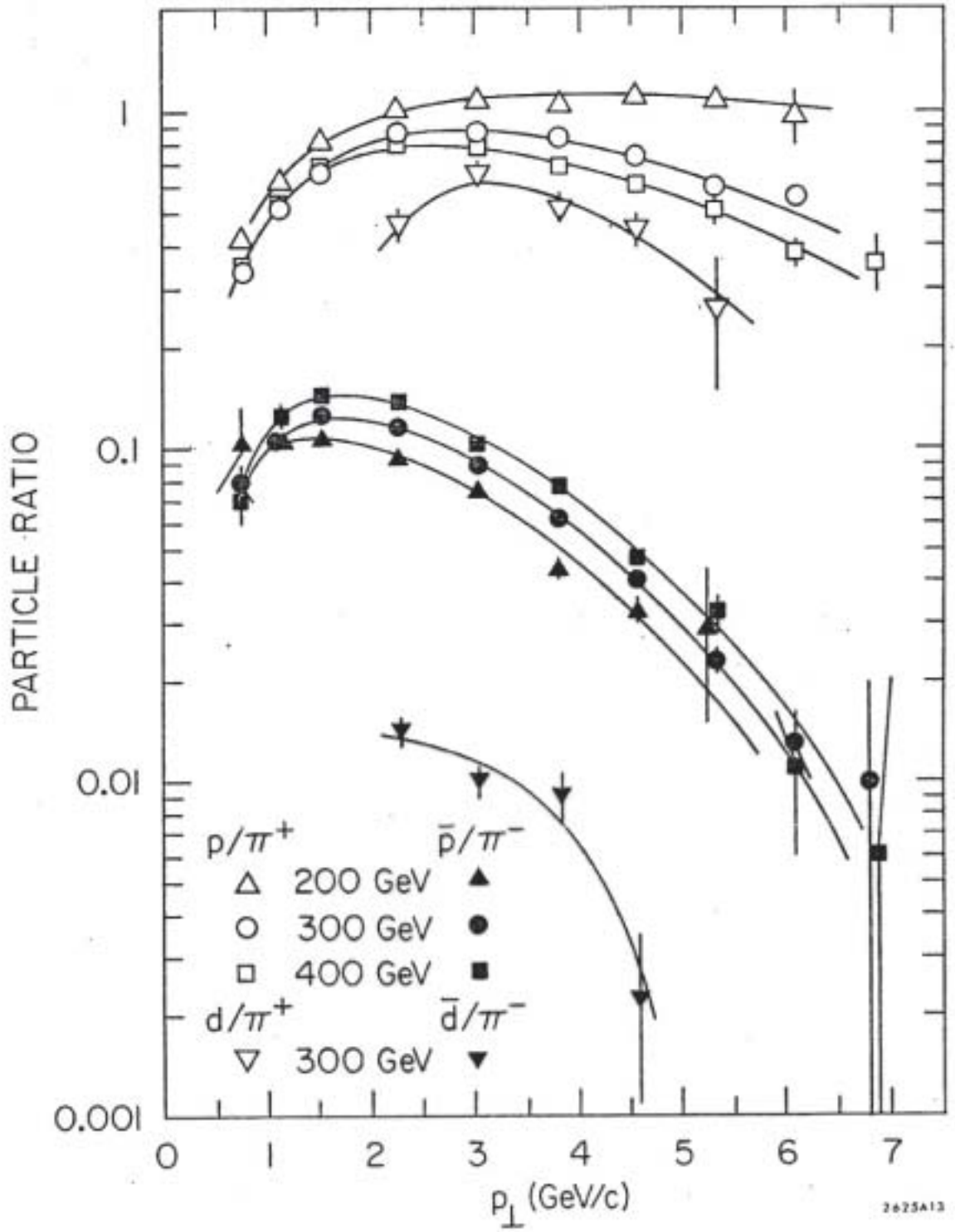
The different powers of p_T for $pp \to pX$, $pp \to \pi X$

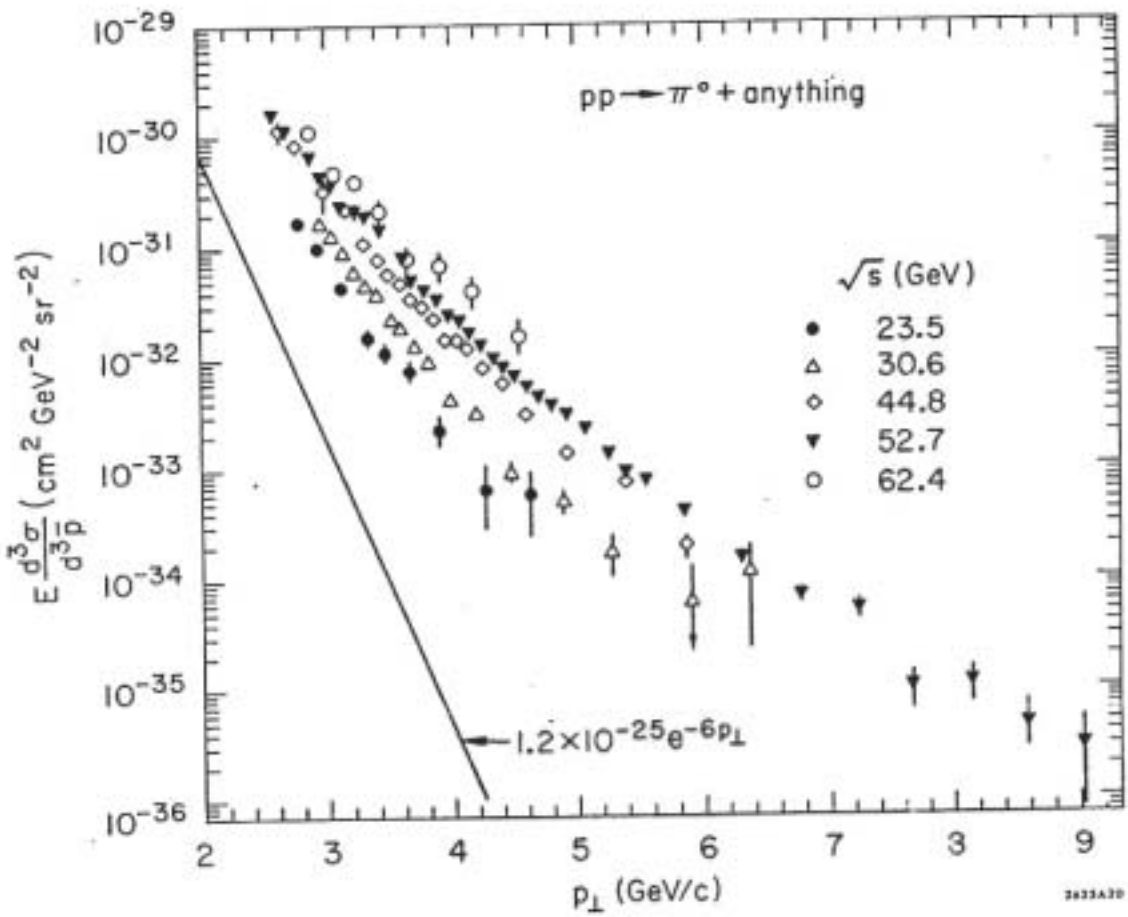
cannot be explained by evolution!

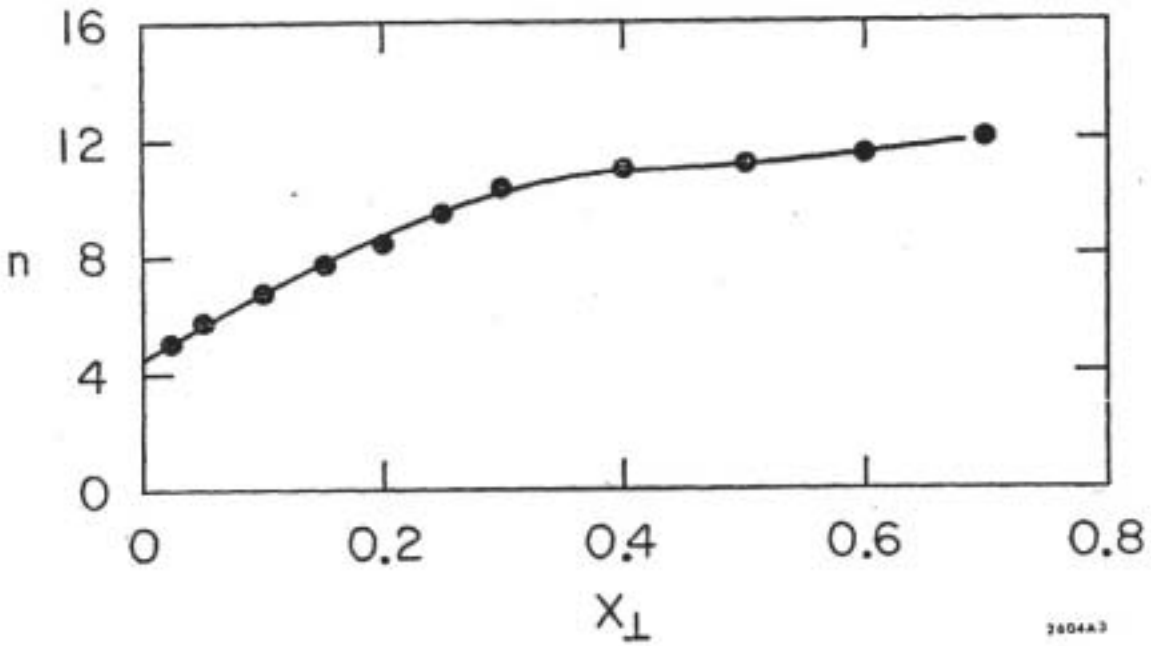
Indicative of higher twist terms

may effect RHIC data $\sqrt{s}_{pp} \sim 200$ GeV


$\theta_{lab} = 89.0°$
$\sqrt{s} = 52.8$ GeV
FRACTION
1
0.1
0.01
0
1
2
3
4
$p_\perp$ (GeV/c)
π^+
π^-
K^+
K^-
p
$\bar{p}$


PARTICLE RATIO
1
0.1
0.01
0.001
0
1
2
3
4
5
6
7
$p_\perp$ (GeV/c)
p/π^+
$\bar{p}/\pi^-$
200 GeV
300 GeV
400 GeV
d/π^+
$\bar{d}/\pi^-$
300 GeV
2625A13


pp → π° + anything
√s (GeV)
23.5
30.6
44.8
52.7
62.4
1.2×10⁻²⁵e⁻⁶ᵖ⊥
E d³σ/d³p (cm² GeV⁻² sr⁻²)
p⊥ (GeV/c)
10⁻²⁹
10⁻³⁰
10⁻³¹
10⁻³²
10⁻³³
10⁻³⁴
10⁻³⁵
10⁻³⁶
2
3
4
5
6
7
3
9


16
12
n 8
4
0
0
0.2
0.4
0.6
0.8
X⊥
2604A3