Fragmentation or Recombination at High p_T?

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Question: Fragmentation or Recombination ?

Answer: not even Fragmentation and Recombination,

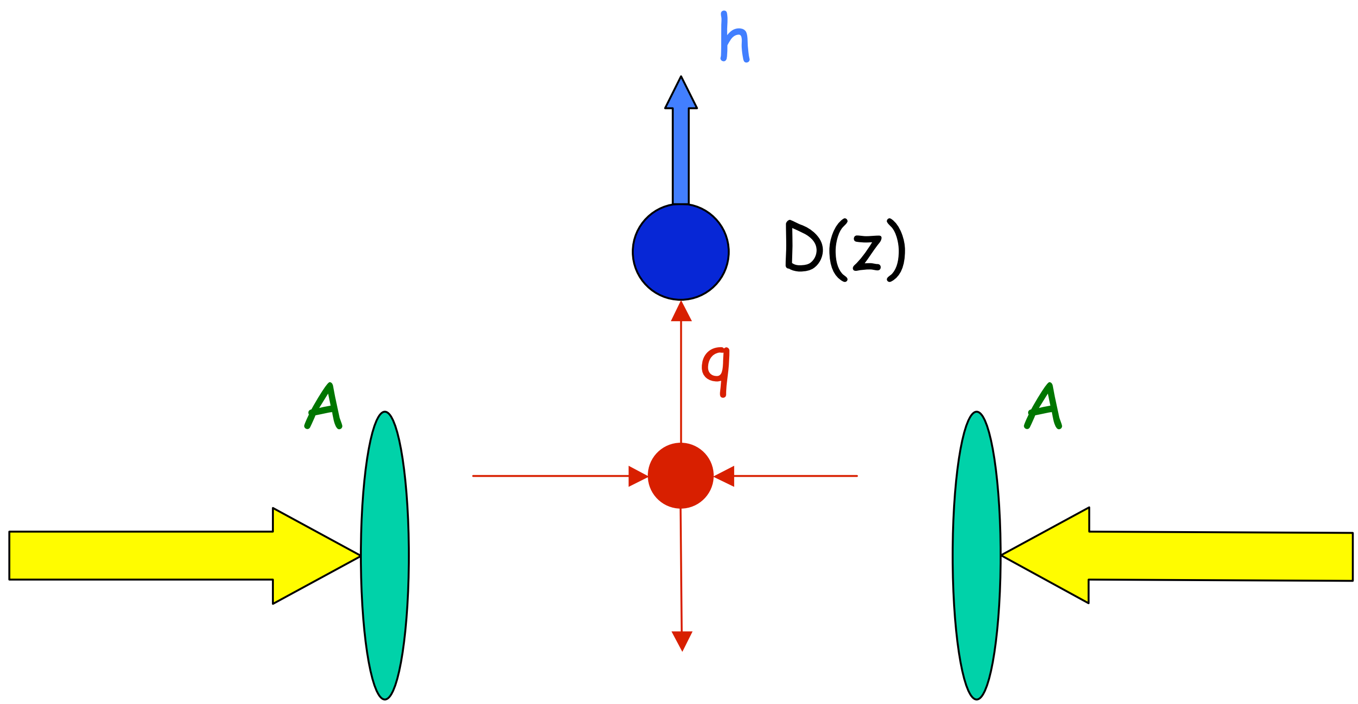
but Recombination only.

Fragmentation is not a description of the hadronization process.

It is represented by a phenomenological function D(z) that gives the momentum fraction z of a hadron in a parton jet.

We formulate fragmentation in terms of recombination.

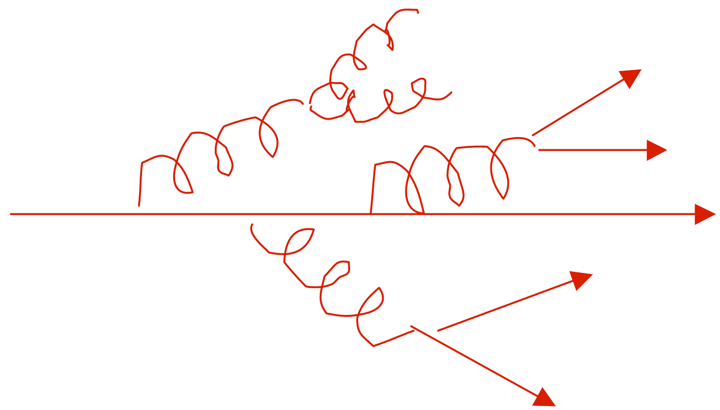
Conventional approach



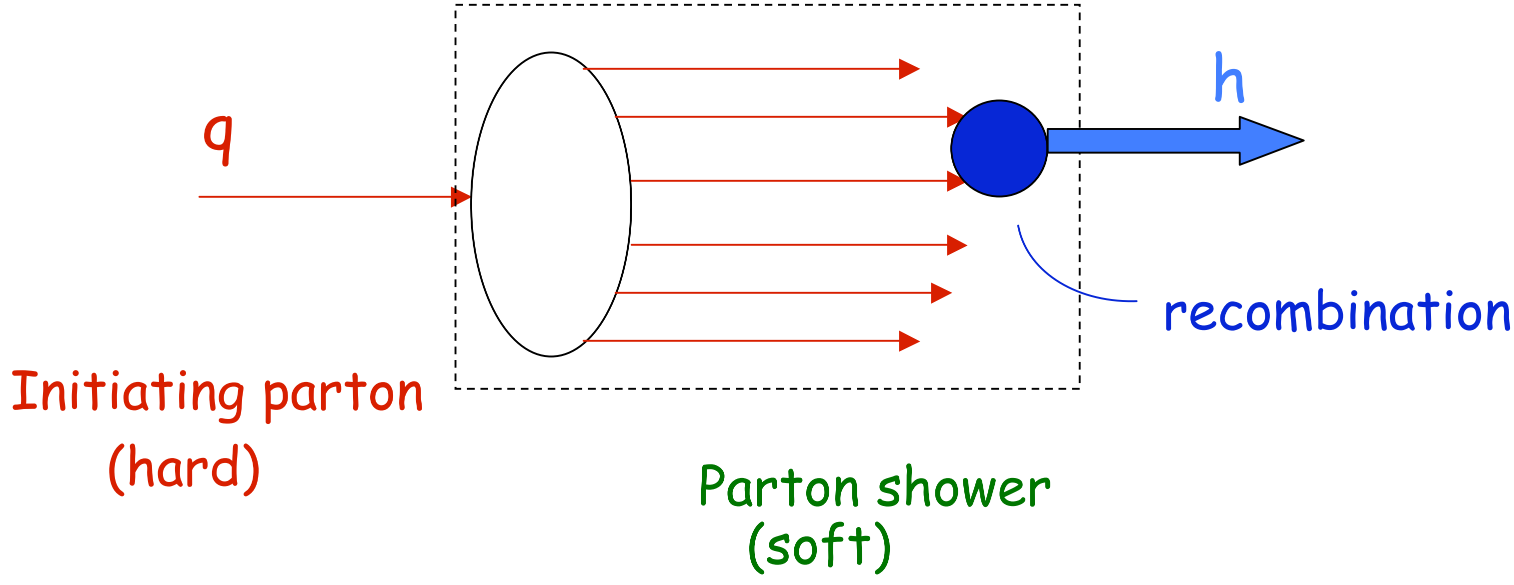
We present evidence that this is not important

until $p_T > 9$ GeV/c.

Parton shower



fragmentation



Recombination model for fragmentation

$$xD(x) = \int \frac{dx_1}{x_1}\frac{dx_2}{x_2} F_{q\bar{q}}(x_1, x_2) R(x_1, x_2, x)$$

Fragmentation function known from fitting e+e- annihilation data

S → □
V → □
G → □
S → K
G → K

Biennewies, Kniehl, Kramer
Kniehl, Kramer, Pötter

Recombination function known in the recombination model

Hwa, Phys. Rev. D (1980).

↓

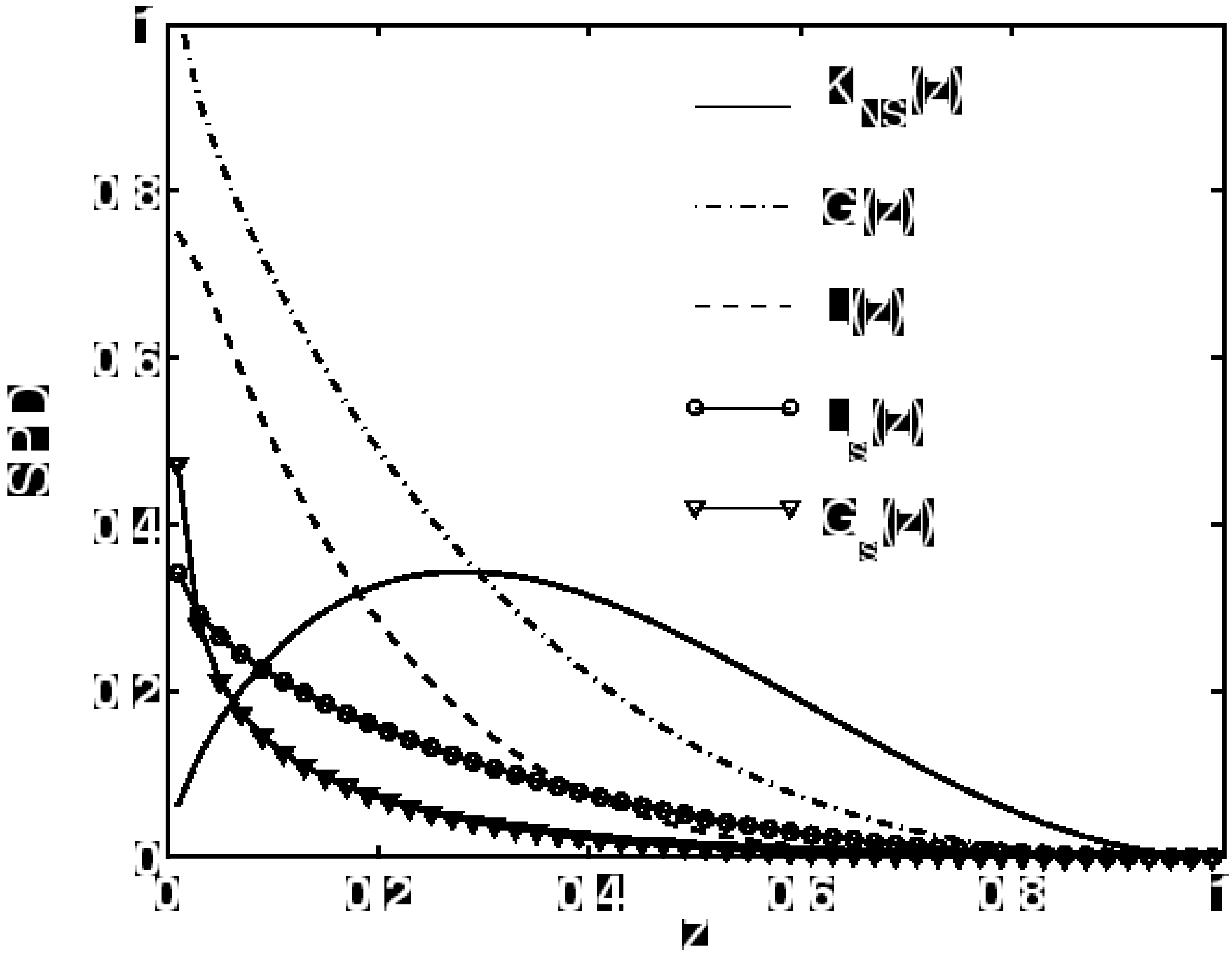
Shower parton distributions

$S_i^j(x_1)$ $\quad j = u, d, s, \bar{u}, \bar{d}, \bar{s}$

$\quad i = u, d, s, \bar{u}, \bar{d}, \bar{s}, g$

K, L, G, L_s, G_s

Hwa and Yang, hep-ph/0312271

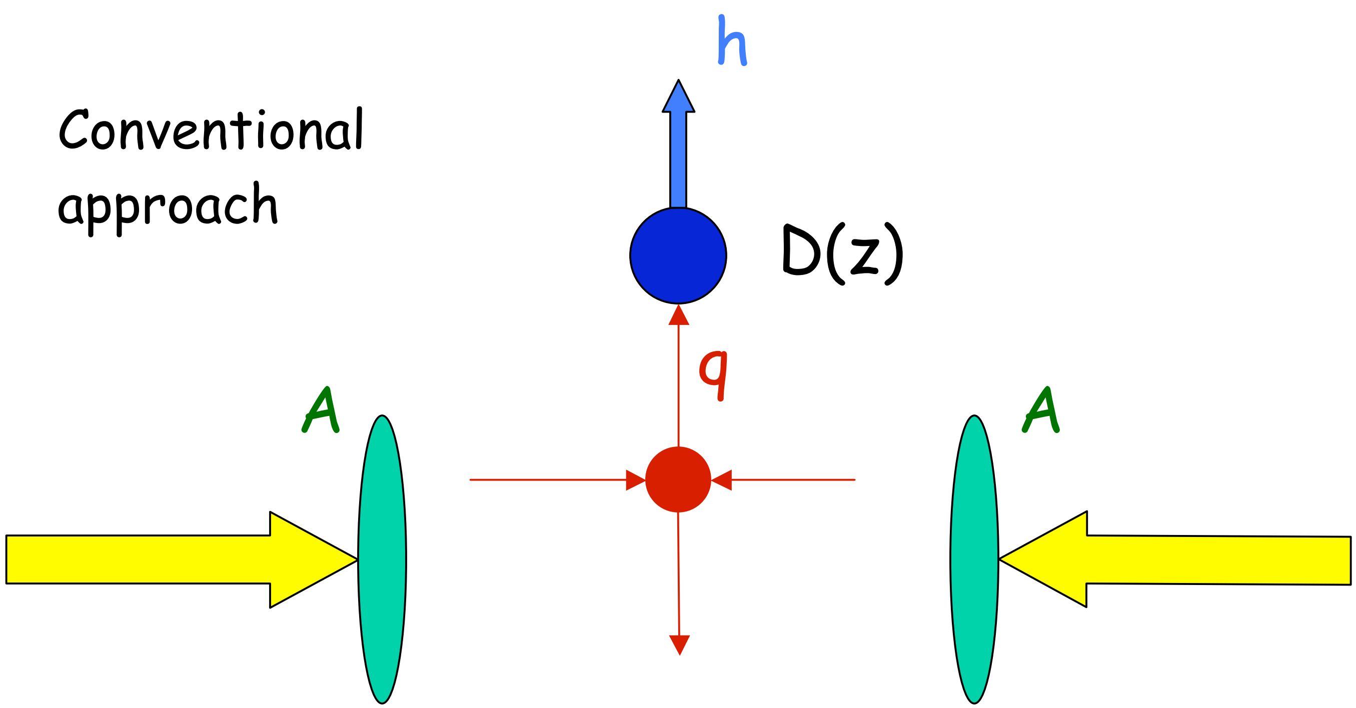


Hwa and Yang, hep-ph/0312271

Once the shower parton distributions are known, they can be applied to heavy-ion collisions.

The recombination of thermal partons with shower partons become conceptually unavoidable.

Conventional approach



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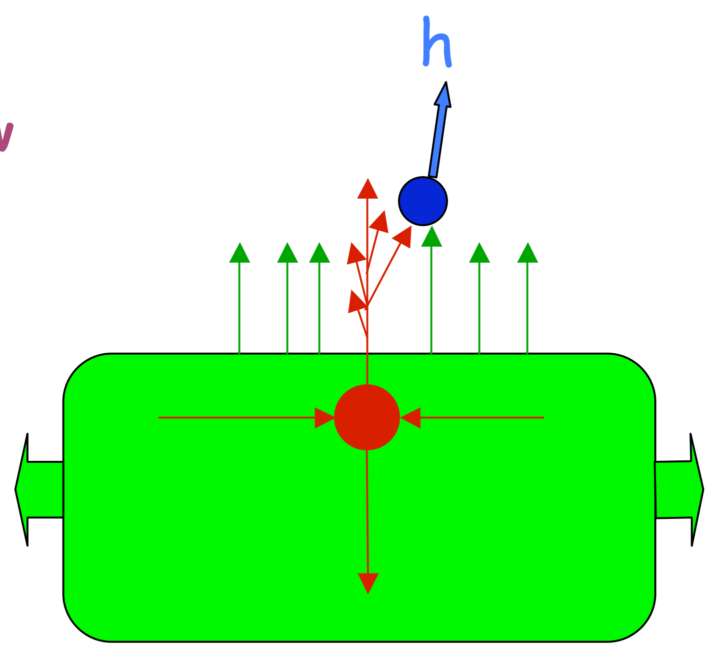
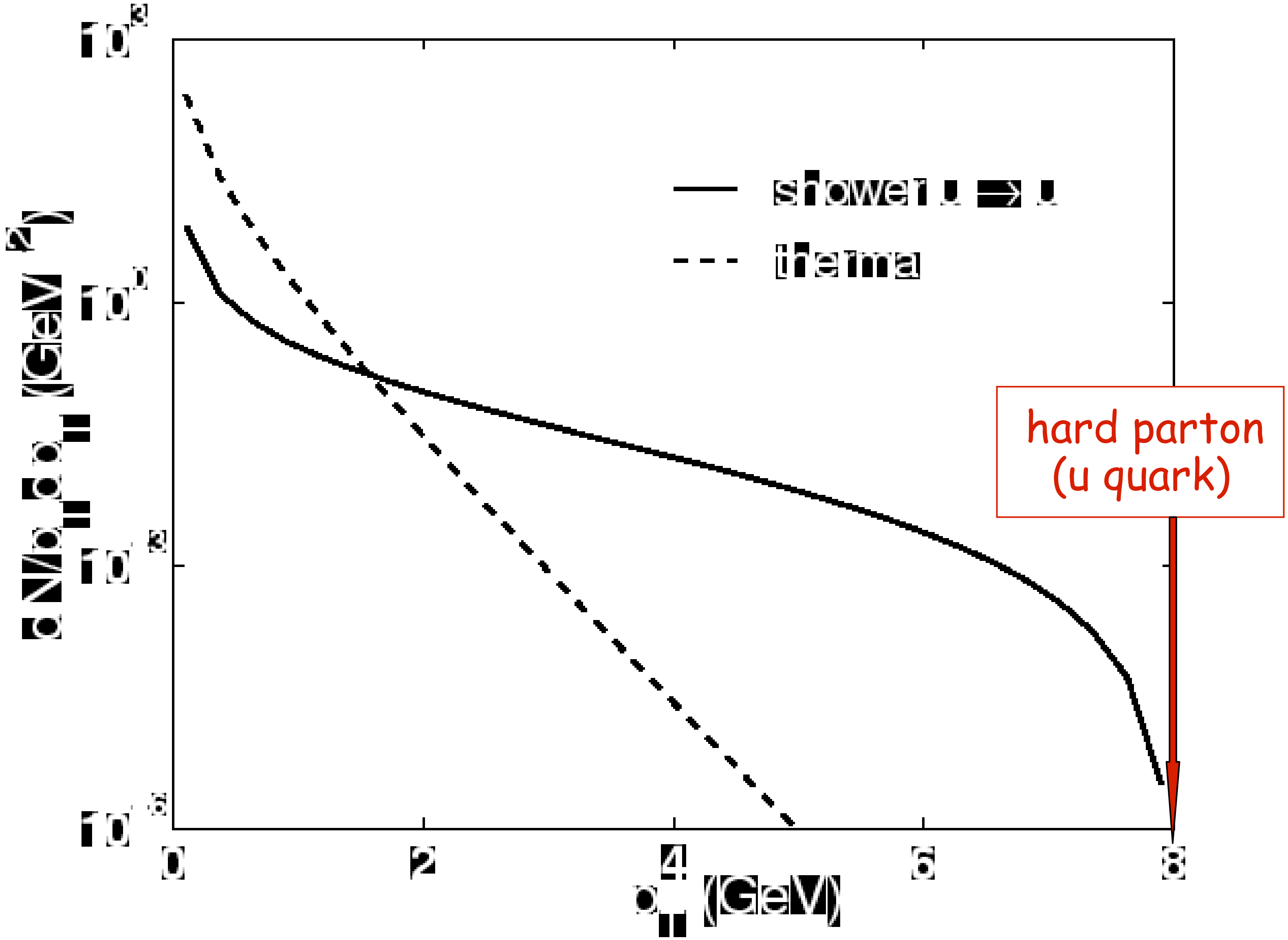
Now, a new component




hard parton
(u quark)
0
2
4
6
8
(GeV)

Inclusive distribution of pions in any direction $\vec{p}$

$$p\frac{dN_\pi}{dp} = \int \frac{dp_1}{p_1}\frac{dp_2}{p_2} F_{q\bar{q}}(p_1, p_2) R_\pi(p_1, p_2, p)$$

Take $\vec{p}$ to be in the transverse plane, and write

$$p_T \rightarrow p$$

$$\frac{p_1 p_2}{p^2}\delta(p_1 + p_2 - p)$$

Pion p_T Distribution

$$\frac{dN_\pi}{pdp} = \frac{1}{p^3}\int_0^p dp_1 F_{q\bar{q}}(p_1, p - p_1)$$

Quark-antiquark distribution

$$F_{q\bar{q}}(p_1, p_2) = TT + TS + S_2 + SS$$

Thermal partons: $T(p_1) \propto \exp(-p_1/T)$

Shower partons: $S(p_2) = \xi \sum_i \int dk\, k\, f_i(k) S_i^j(p_2/k)$

2-shower partons in 1 jet: $S_2(p_1, p_2) = \xi \sum_i \int dk\, k\, f_i(k) S_i^j\left(\frac{p_1}{k}\right) S_i^{j'}\left(\frac{p_2}{k - p_1}\right) \times R_\Gamma(p_1, p_2, p)$

$\downarrow$

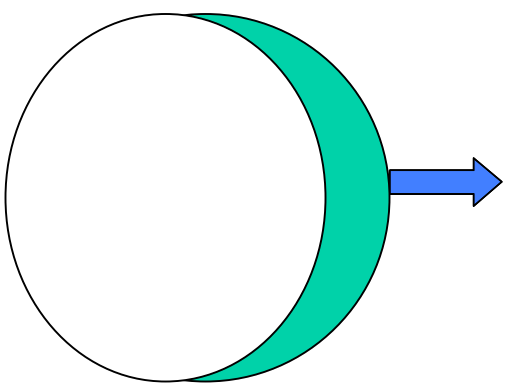
$D_i^\pi(p/k)$

2-shower partons in 2 jets: $S(p_1)S(p_2)$

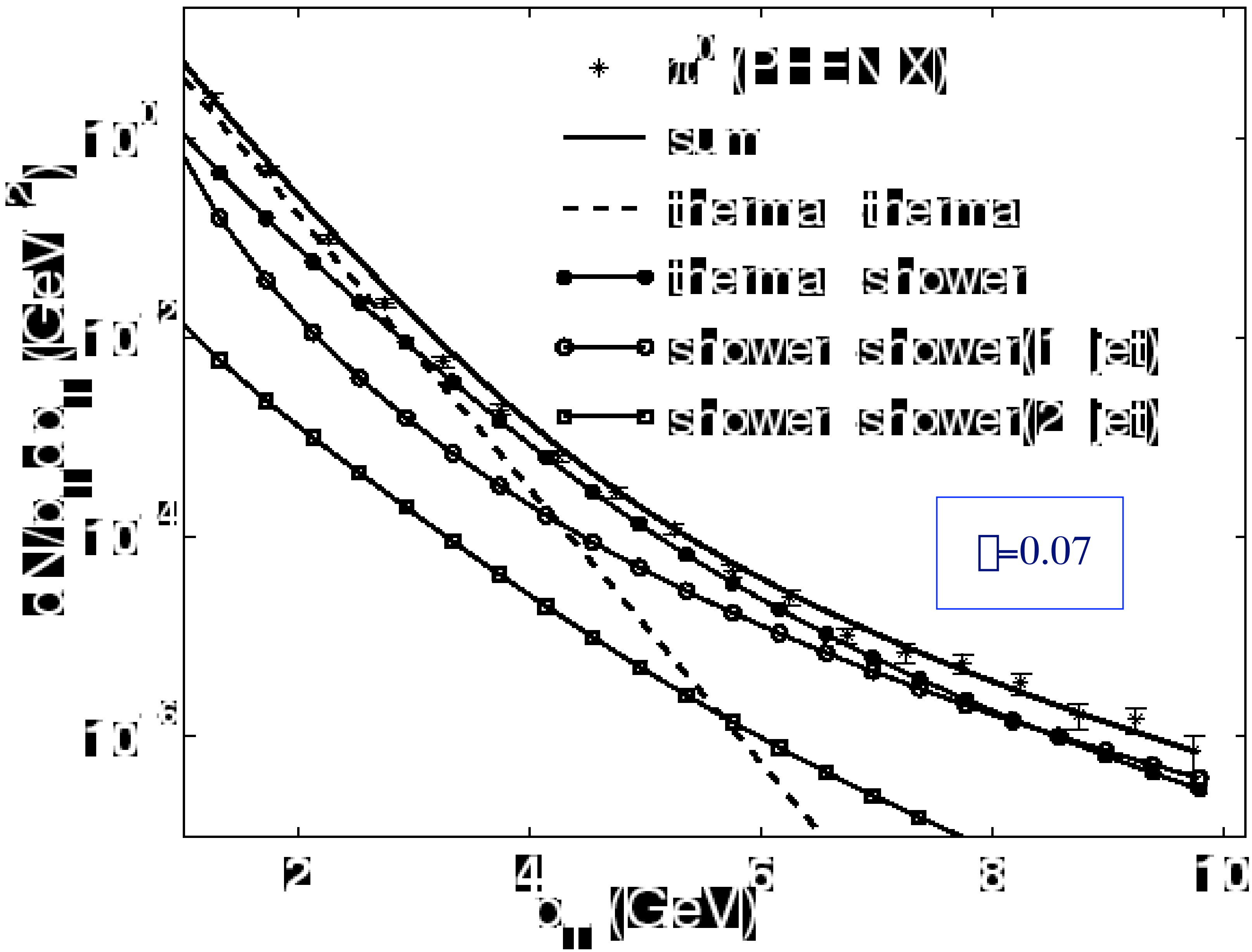
$$f_i(k) = \frac{dN_i^{\mathrm{hard}}}{kdkdy}\bigg|_{y=0}$$

density of hard partons with $p_T = k$

□ fraction of hard partons that can get out of the dense medium to produce shower



an average quantity to parameterize energy loss effect



Hwa and Yang, nucl-th/0401001

Energy loss

Nuclear modification factor

$$R_{AA}(p_T) = \frac{dN / p_T dp_T (AA)}{N_{coll} dN / p_T dp_T (pp)}$$

Average suppression factor

$$\square = \left\langle \frac{dN / p_T dp_T (AA)}{\square^{TS} R(AA)} \right\rangle \leftrightarrow \square S_2 R(AA)$$

$$R_{AA}(p_T) \square 0.2$$

for p_T>4 GeV/c

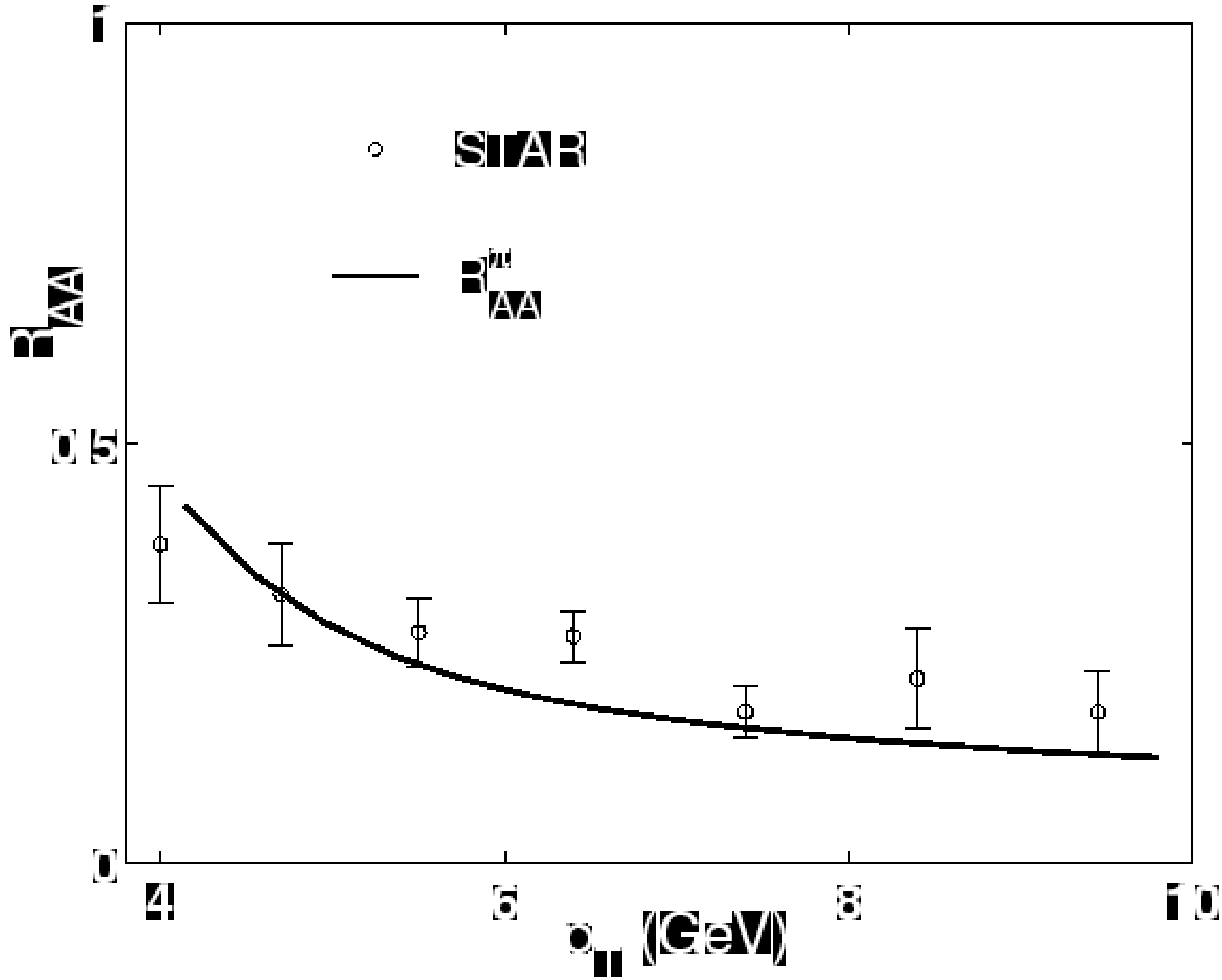
$$\square \square 0.07$$

Pion contribution to the nuclear modification factor

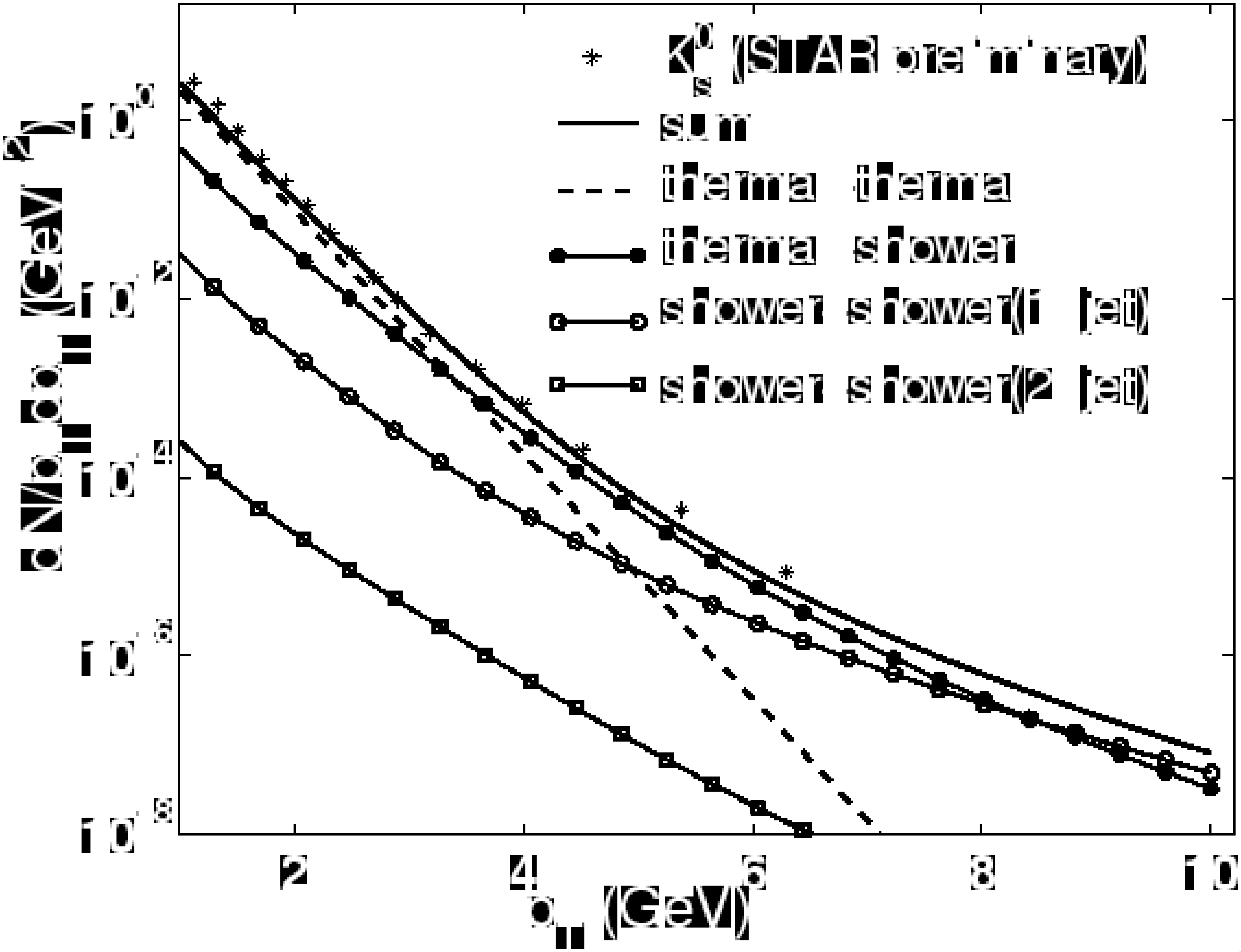
$$R^{\square}_{AA}(p_T) = \frac{dN_{\square} / p_T dp_T (AA)}{\square^{\square 1} dN^{S_2}_{\square} / p_T dp_T (AA)}$$

$$N_{coll} dN / p_T dp_T (pp)$$

Pion contribution to the scaled pp collisions



1
0.5
0
4
6
8
10
p_T (GeV)
R_{AA}
STAR
R^{π}_{AA}



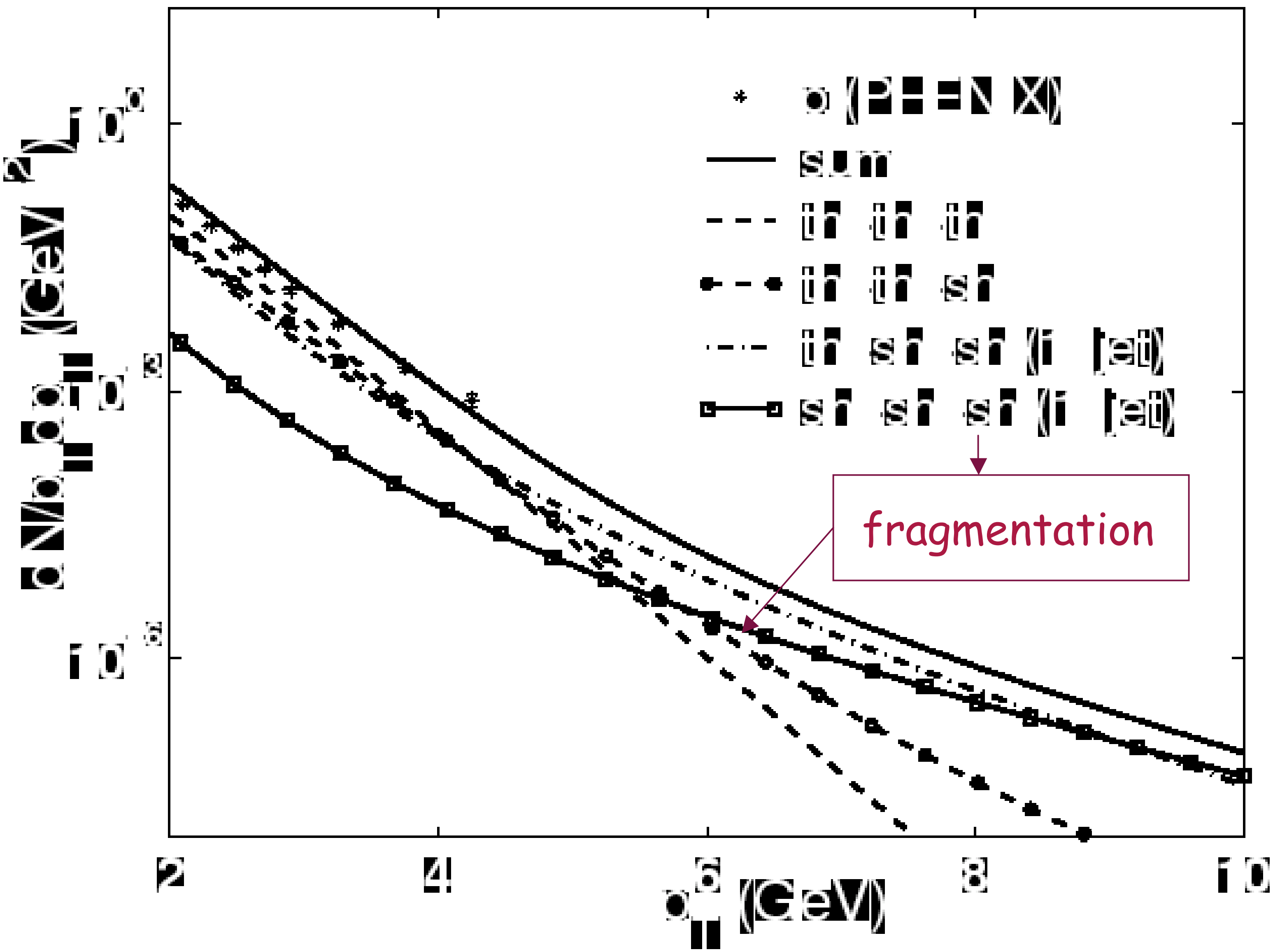
sum
(GeV)
2
4
6
8
10

Proton Spectrum

$$p\frac{dN_p}{dp} = \int \frac{dp_1}{p_1}\frac{dp_2}{p_2}\frac{dp_3}{p_3} F_{uud}(p_1, p_2, p_3) R_p(p_1, p_2, p_3, p)$$

$$F_{uud} = \mathcal{TTT} + \mathcal{TTS} + \mathcal{TS}_2 + \mathcal{S}_3 + \mathcal{TSS} + \mathcal{SS}_2 + \mathcal{SSS}$$

$$\boxed{\mathcal{S}_3 \; \prod R} \;\rightarrow\; \boxed{D_i^p}$$



Hwa and Yang, nucl-th/0401001

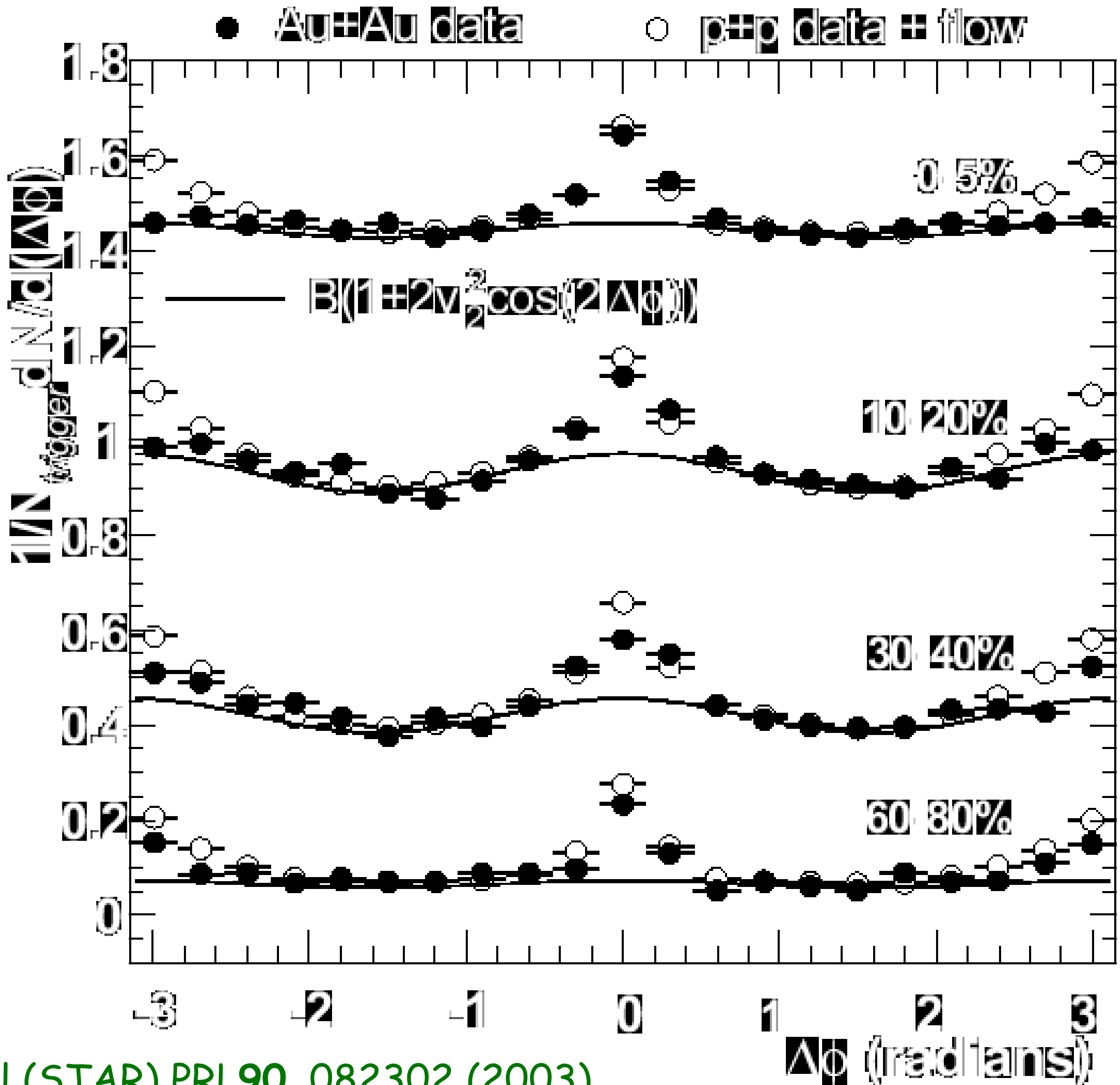
Same-side correlation

- Pions in AA collisions dominated by TS recombination
- Jets in pp collisions has only S_2 recombination: $D_i^p(z)$

□ Jet structure in AA collisions

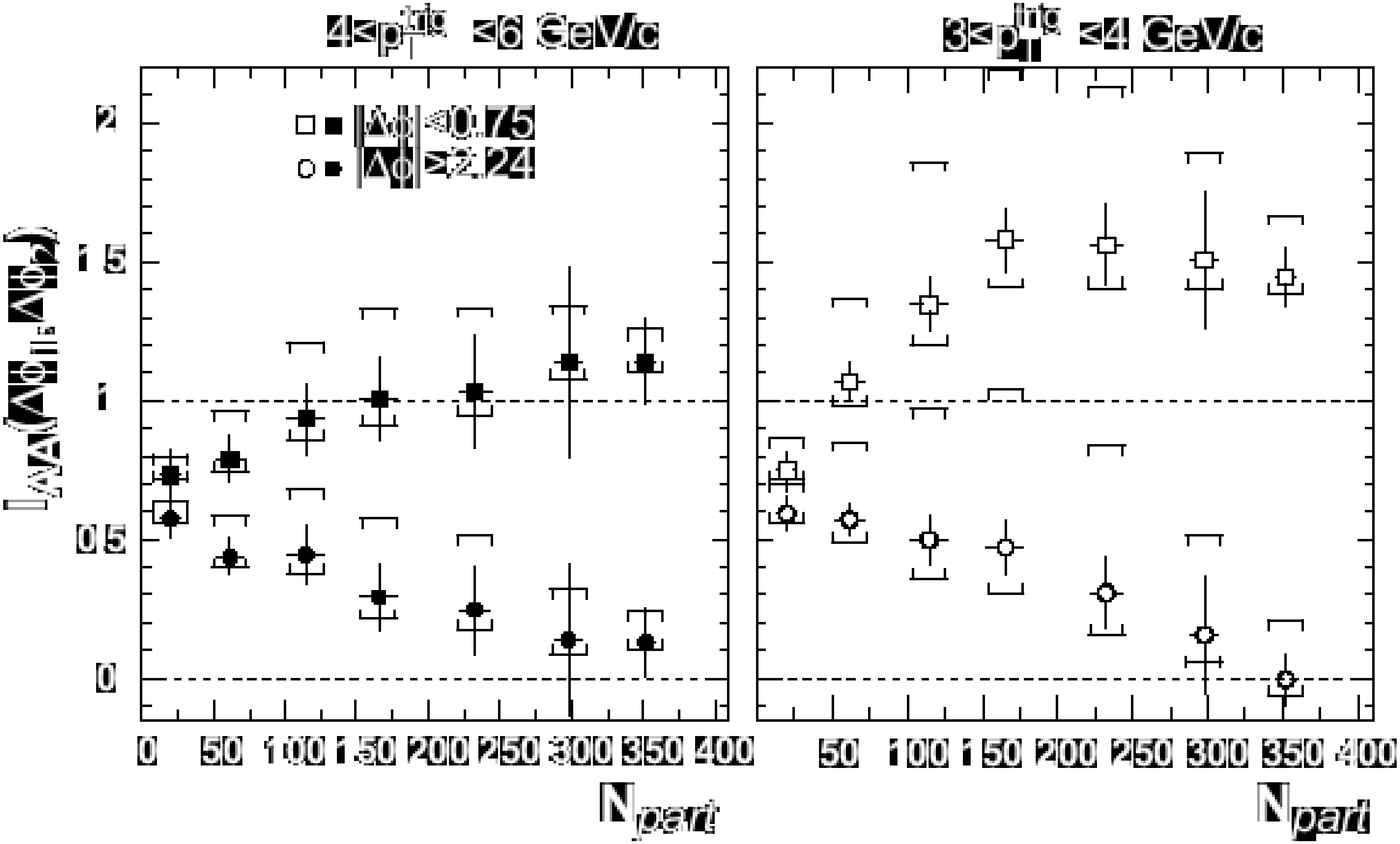
$\neq$ jet structure in pp collisions

There should be more particles associated with a trigger particle in AA collisions than in pp collisions.



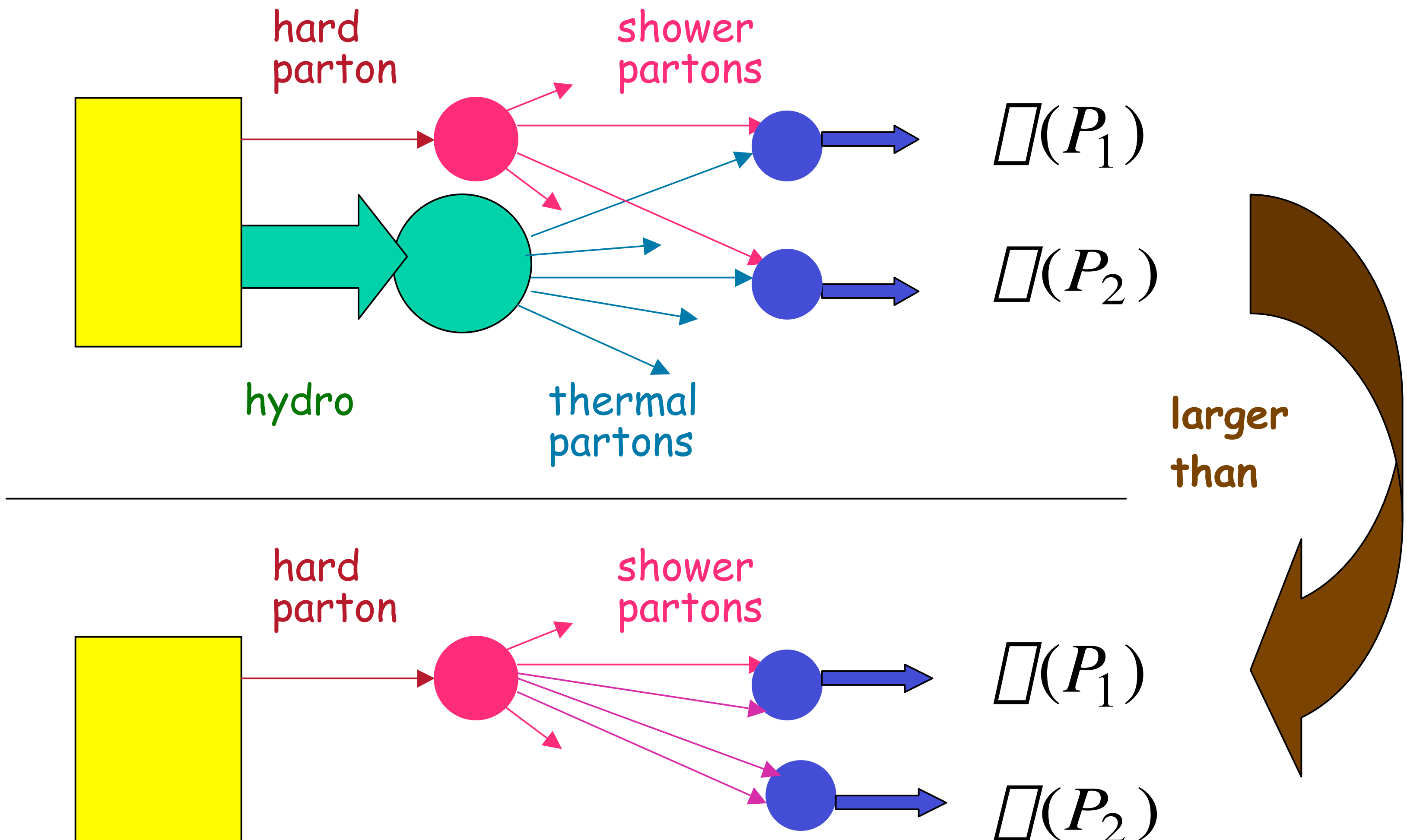
Adler et al (STAR) PRL**90**, 082302 (2003)

$$I_{AA}(\Delta\phi_1, \Delta\phi_2) = \frac{\int d(\Delta\phi)\{D^{AuAu} - B[1 + 2v_2^2 \cos(2\Delta\phi)]\}}{\int d(\Delta\phi) D^{pp}}$$



Adler et al (STAR) PRL**90**, 082302 (2003)

$$I_{AA} = \frac{\square dP_2 P_2 \,\text{TTS}_2\, R(p_1, p_1^{'}, P_1)\, R(p_2, p_2^{'}, P_2)}{\square dP_2 P_2 \,\text{S}_4\, R(p_1, p_1^{'}, P_1)\, R(p_2, p_2^{'}, P_2)}$$



□ $I_{AA} > 1$

STAR data: $I_{AA} \approx 1.5$ for $3 < p_T^{trig} < 4$ GeV/c

≈ 1.1 for $4 < p_T^{trig} < 6$ GeV/c

Higher p_T^{trig}

□ momenta of the associated partons (especially in S_4 for pp collisions) forced to be lower

□ the density of those partons higher

□ denominator of I_{AA} larger

□ I_{AA} is smaller

Integration over □□ is dominated by lower p_T particles.

It masks the difference in the jet structures.

We suggest the measurement of:

$$\mathbf{P}(P_{1_T}, P_{2_T}) = \frac{dN}{P_{1_T}\, dP_{1_T}\, P_{2_T}\, dP_{2_T}}$$

Fix P_{1_T} (trigger), show P_{2_T} dependence.

Conclusion

Hard parton shower partons
Hydrodynamics thermal partons
} recombine

- Thermal-shower recombination more important than shower-shower recombination in 1-jet (fragmentation)
- Jet structure is different in *AA* vs pp collisions: $I_{AA} > 1$
- a crude representation of the effects of energy loss, but good enough to fit all single-particle spectra:

pion, kaon, proton

and to give the correct $R_{AA}(p_T)$.

Hadronization of partons at any p_T

can be successfully described by

the recombination model ---

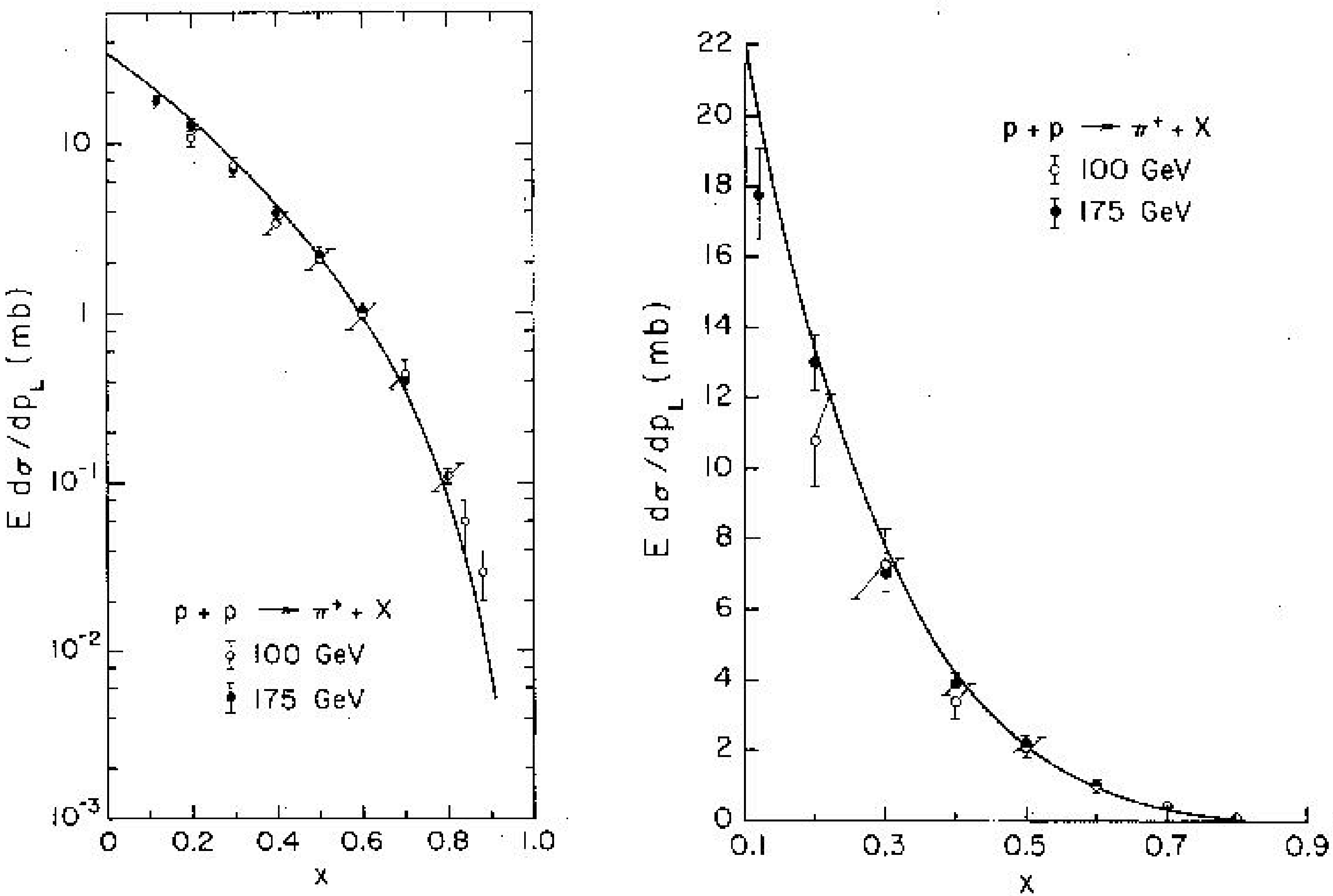
if care is exercised in determining

what partons are to recombine.

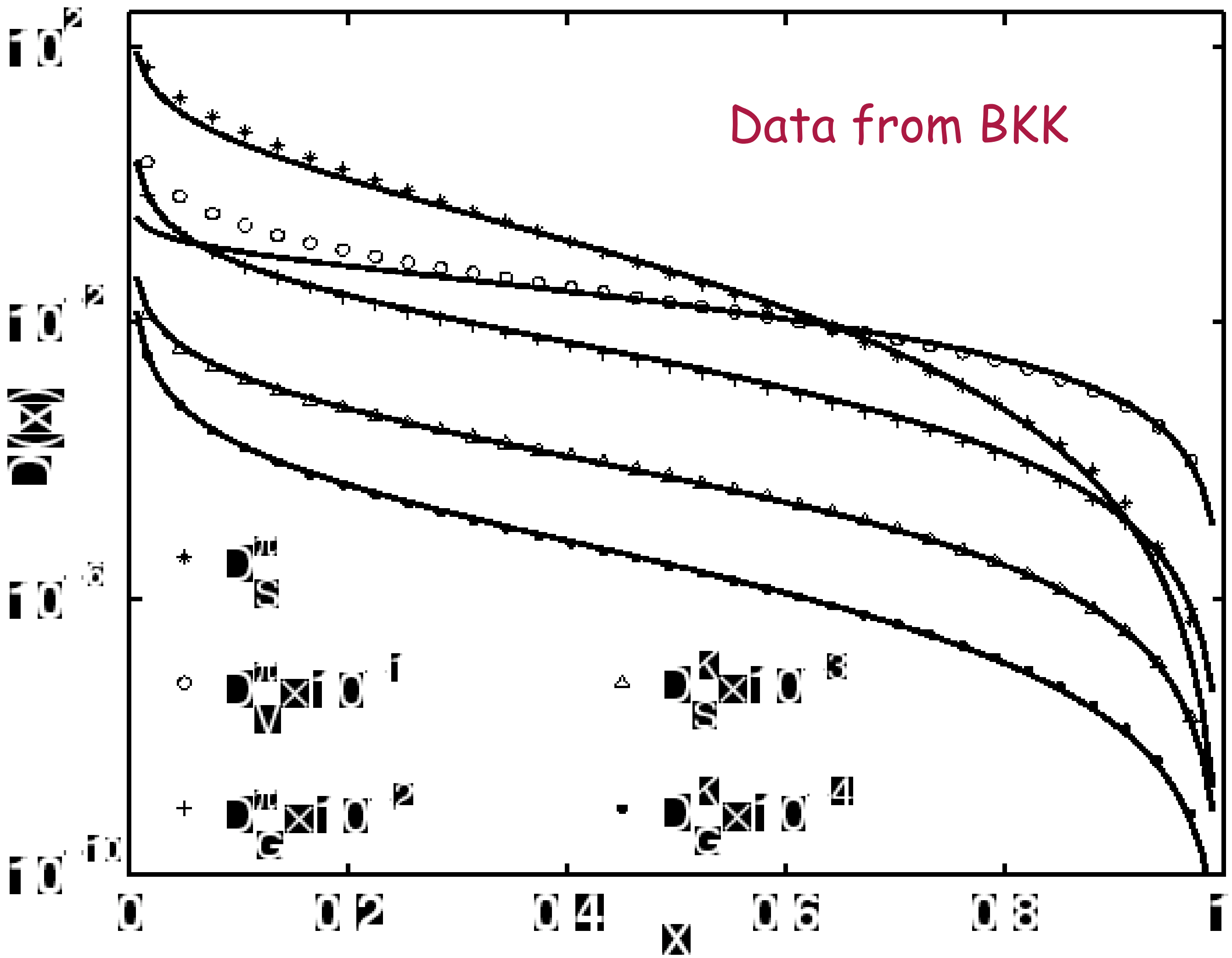
Gluon conversion

- Gluons carry half the momentum of a nucleon. They have to hadronize to conserve momentum.
- No glueball has ever been found. Thus gluons must hadronize through conversion to $q\bar{q}$ pairs.
- Gluon conversion □ saturated sea to satisfy momentum sum rule.
- When applied to p+p□ □+X at low p_T, recombination model gives the inclusive cross section with the correct p_L dependence and normalization.

Hwa, Phys. Rev. D**22**, 1593 (1980).



Hwa, Phys. Rev. D 22, 1593 (1980).



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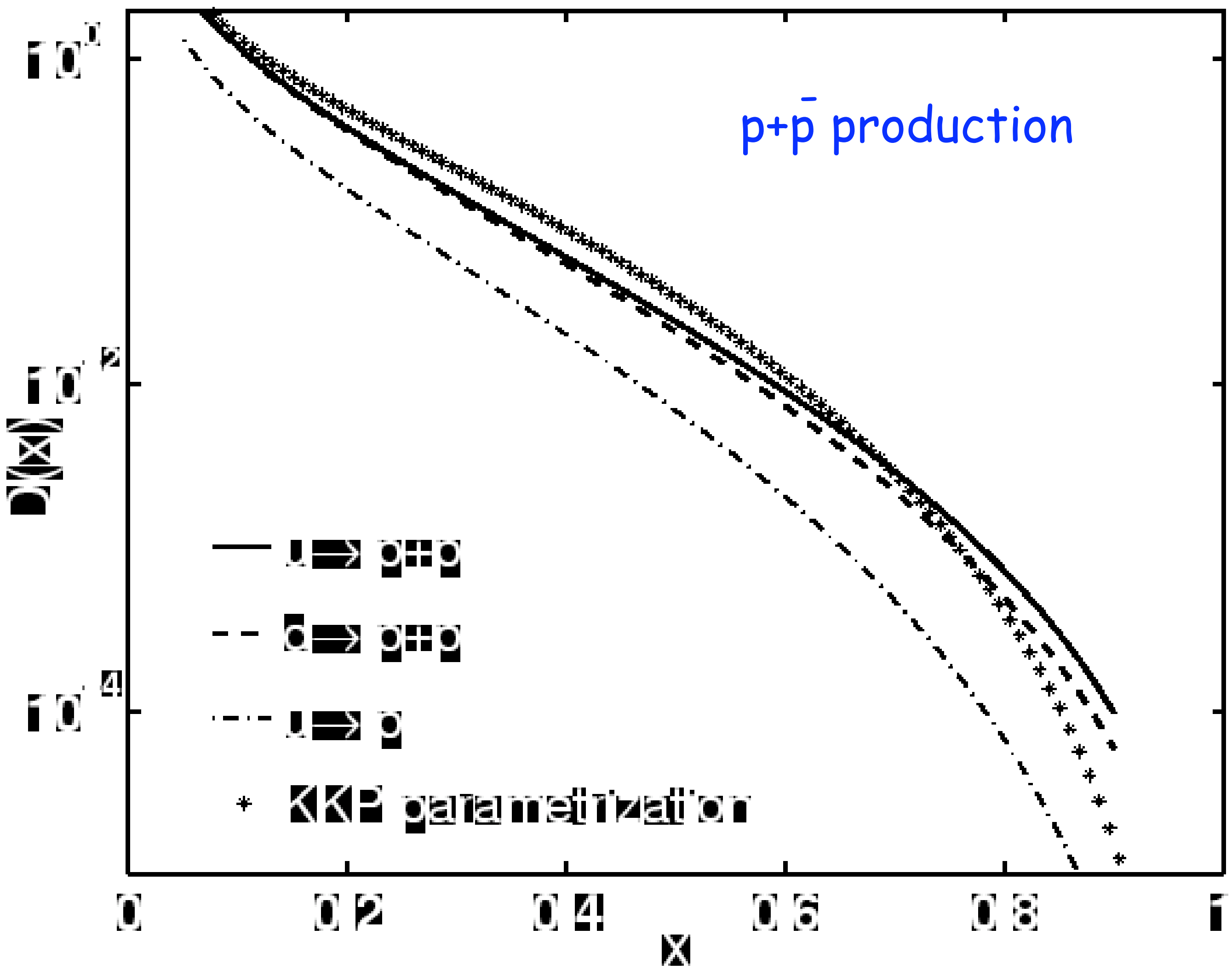

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