Resolution of Several Puzzles at Intermediate p_T

and

Recent Developments in Correlation

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Quark Matter 05

Budapest, Hungary, August 2005

Puzzles at intermediate p_T

1. Proton/pion ratio
2. Azimuthal anisotropy

QM04

3. Cronin effect in pion and proton production
4. Forward-backward asymmetry in dAu collisions
5. Same-side associated particle distribution

Correlations

1. Correlation in jets: distributions in $\Delta\eta$ and $\Delta\phi$

2. Two-particle correlation without triggers

3. Autocorrelations

4. Away-side distribution (jet quenching)

Work done in collaboration with

Chunbin Yang (Hua-Zhong Normal University, Wuhan)

Rainer Fries (University of Minnesota)

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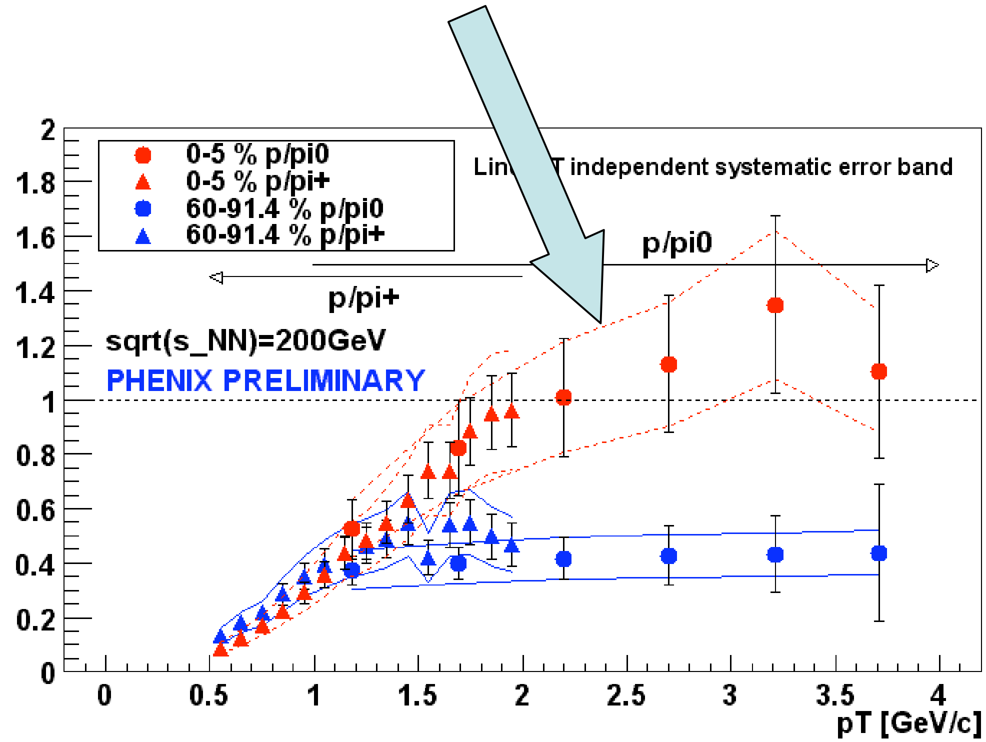
Zhiguang Tan (Hua-Zhong Normal University, Wuhan)

Charles Chiu (University of Texas, Austin)

Puzzle #1 $R_{p/\pi} > 1$

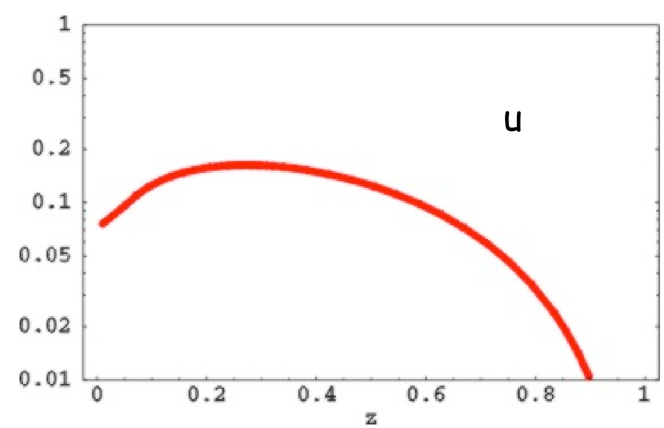
$R_{p/\pi}$



Not possible in fragmentation model:

$$D_{p/q} << D_{\pi/q}$$

$$\frac{D_{p/q}}{D_{\pi/q}}$$



In the recombination model

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

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

$$F_{q\bar{q}} = TT + TS + SS$$

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

Proton formation: uud distribution

$$F_{uud} = TTT + TTS + TSS + SSS$$

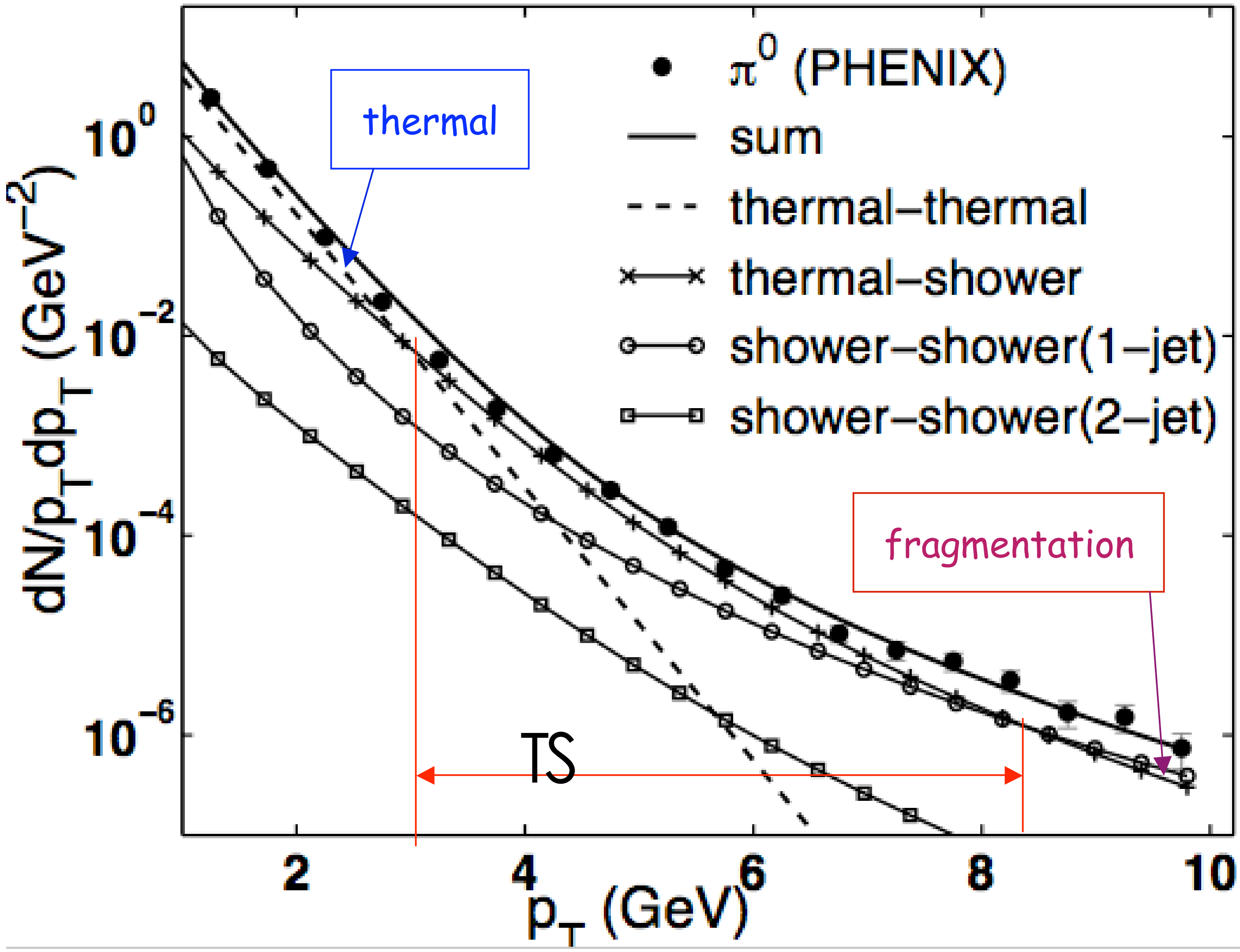
soft component

thermal-shower recombination

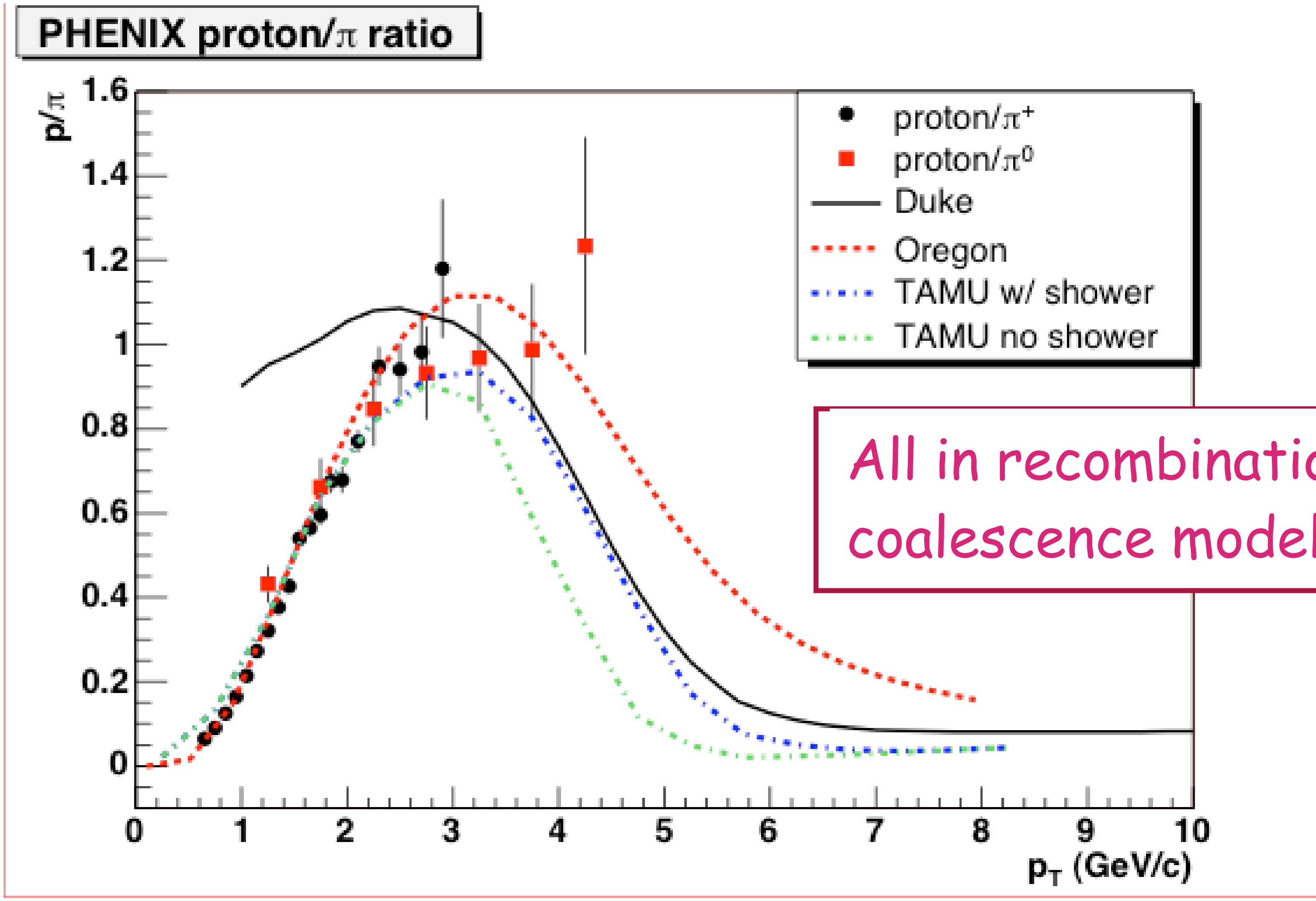
usual fragmentation

(by means of recombination)

π production in AuAu central collision at 200 GeV



Hwa & CB Yang, PRC70, 024905 (2004)



All in recombination/ coalescence model

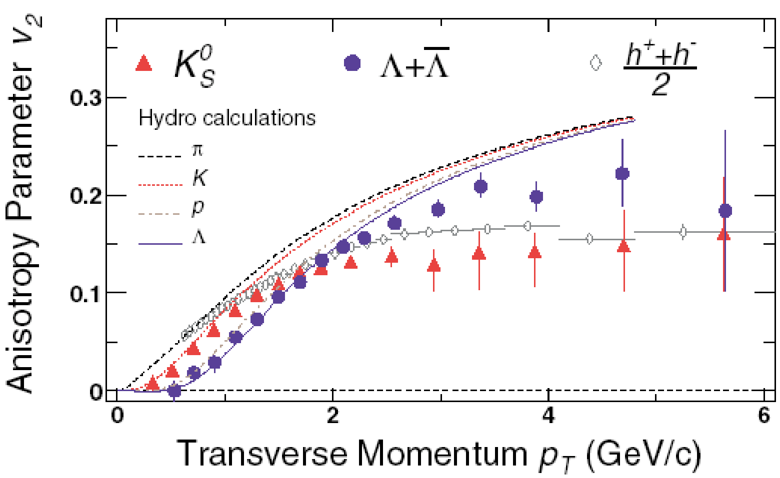
compilation by R.Seto (UCR)

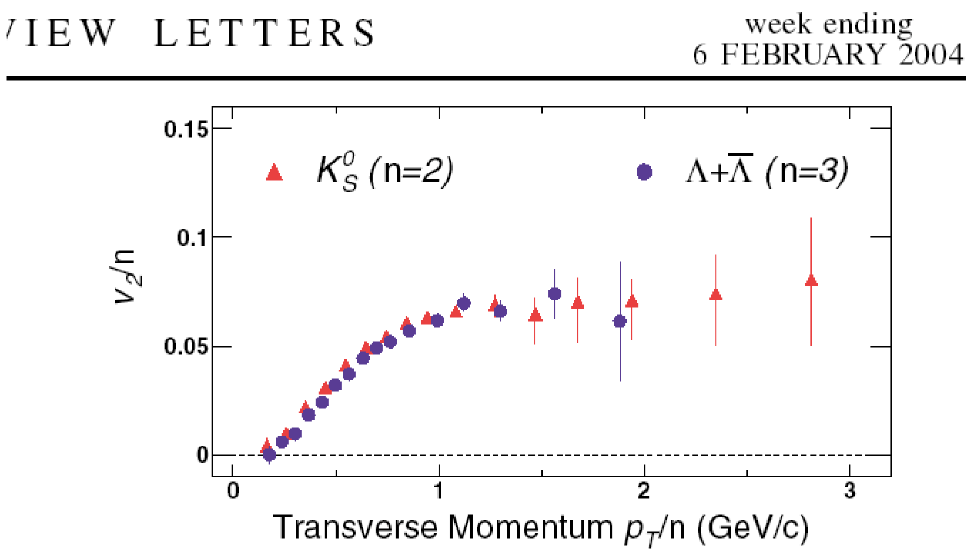
Puzzle #2 Azimuthal anisotropy

Molnar and Voloshin, PRL 91, 092301 (2003).

<u>Parton coalescence</u> implies that $v_2(p_T)$ scales with the number of constituents

STAR data

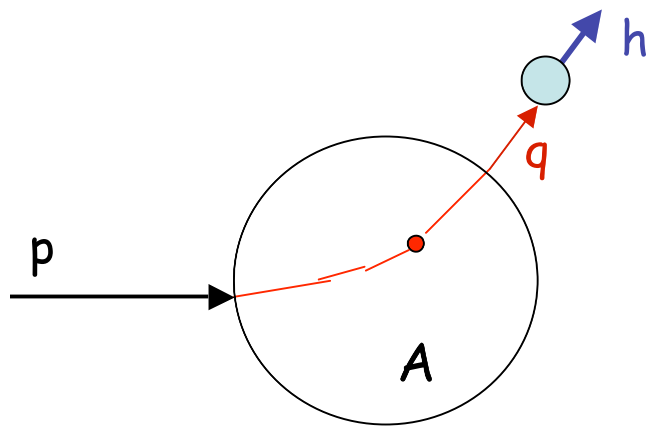




Puzzle #3 in pA or dA collisions

Cronin Effect

Cronin et al, Phys.Rev.D (1975)



$$\frac{dN}{dp_T}(pA \to \pi X) \propto A^{\alpha}, \qquad \alpha > 1$$

k_T broadening by multiple scattering in the initial state.

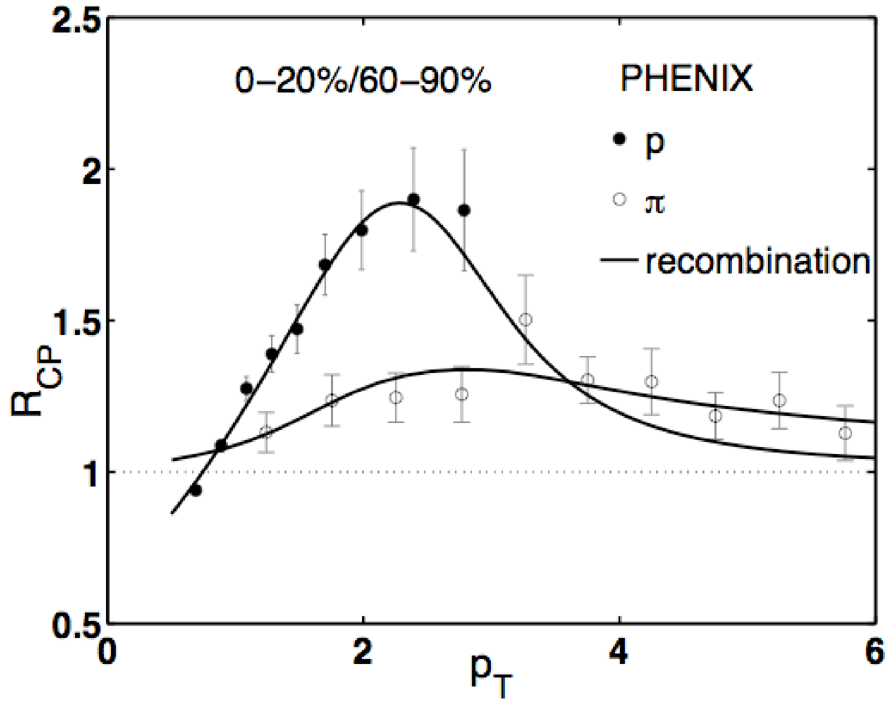
Unchallenged for ~30 years.

If the medium effect is before fragmentation, then α should be independent of h= π or p

$\alpha_p > \alpha_\pi$ Cronin et al, Phys.Rev.D (1975)

$R_{CP}^{p} > R_{CP}^{\pi}$ STAR, PHENIX (2003)

R_{CP} for d-Au collisions



Hwa & CB Yang,
PRL 93, 082302 (04).
PRC 70, 037901 (04).

$$\boxed{R_{CP}^{p} > R_{CP}^{\pi}}$$

because $3q \to p$, $2q \to \pi$

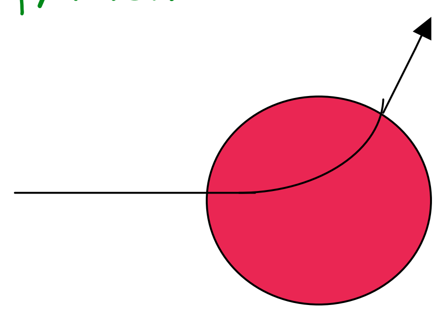
more partons at 1/3 than at 1/2

Argument does not extend to $5q \to \Theta$, $6q \to d$

nor to higher p_T because of ST and SS recombination.

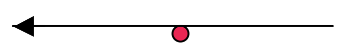
Puzzle #4 Forward-backward asymmetry in d+Au collisions

If initial transverse broadening of parton gives more hadrons at high p_T, then



- forward has more transverse broadening

Expects more forward particles at high p_T than backward particles

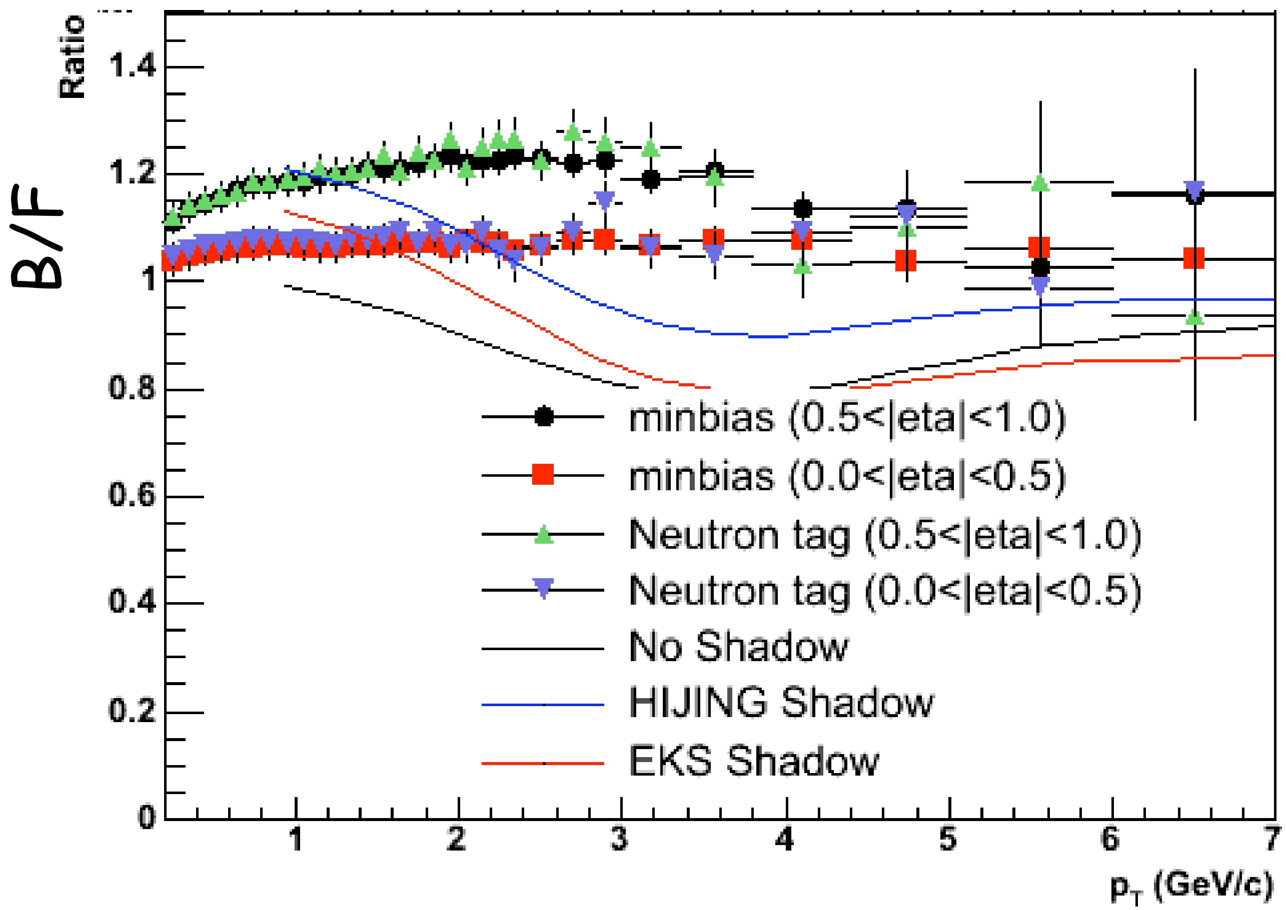


- backward has no broadening

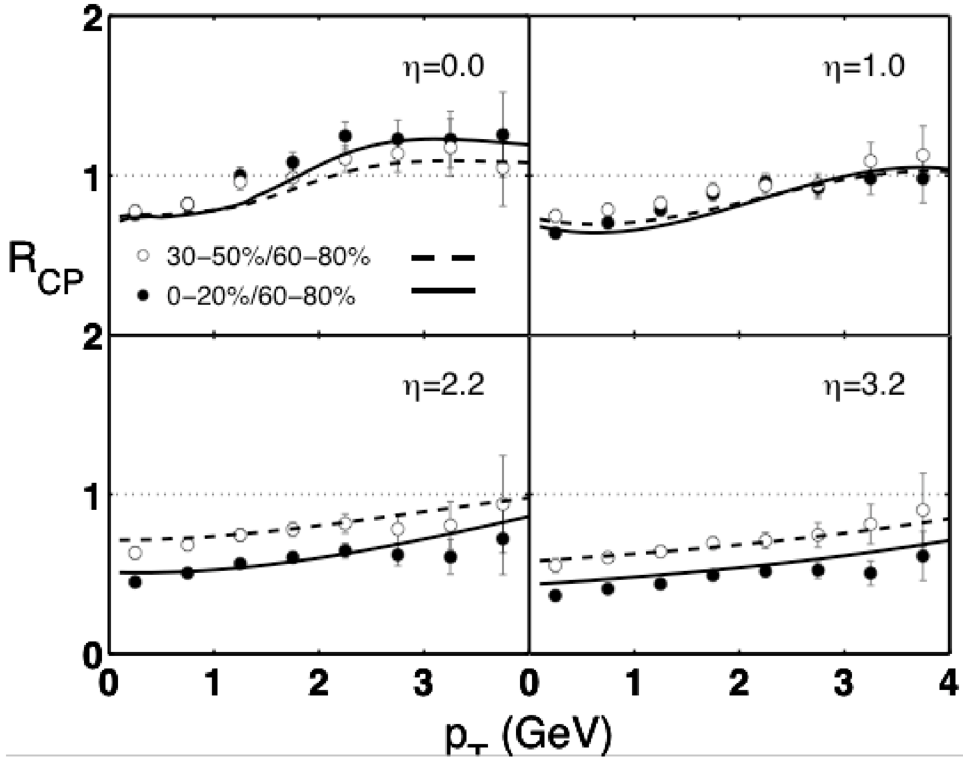
B/F < 1

Backward-forward ratio at intermed. p_T

in d+Au collisions (STAR)



Forward production in d+Au collisions



BRAHMS data

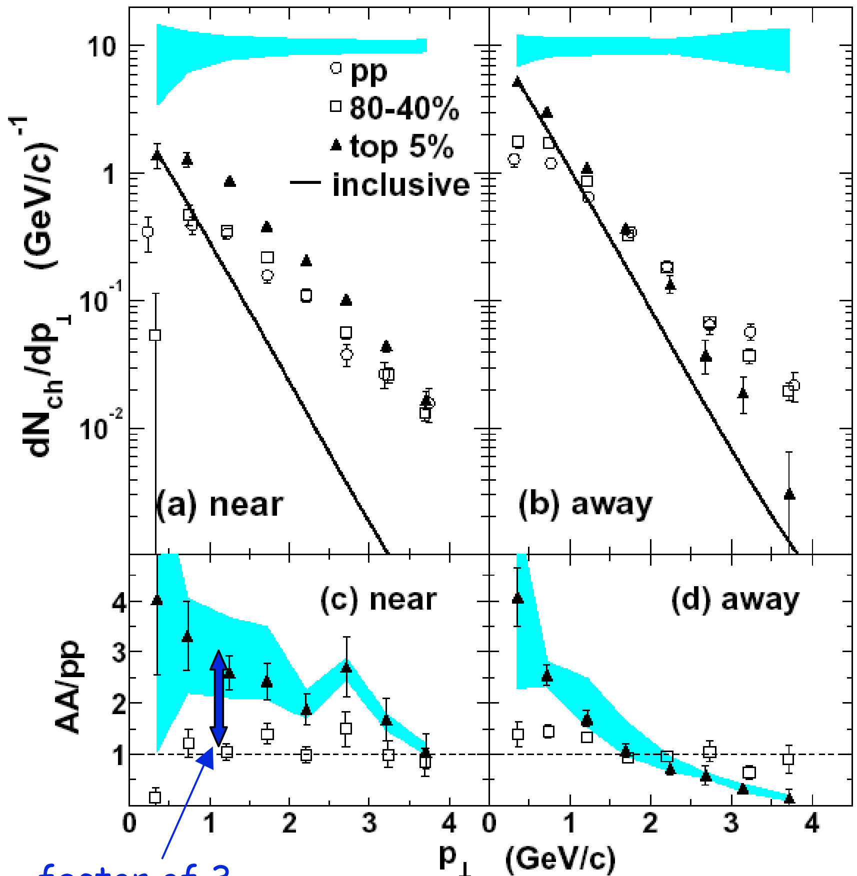
Hwa, Yang, Fries, PRC 71, 024902 (2005)

Underlying physics for hadron production is not changed from backward to forward rapidity.

Puzzle #5: Associated particle pT distribution (near side)

STAR : nucl-ex/0501016

Trigger 4 < p_T < 6 GeV/c

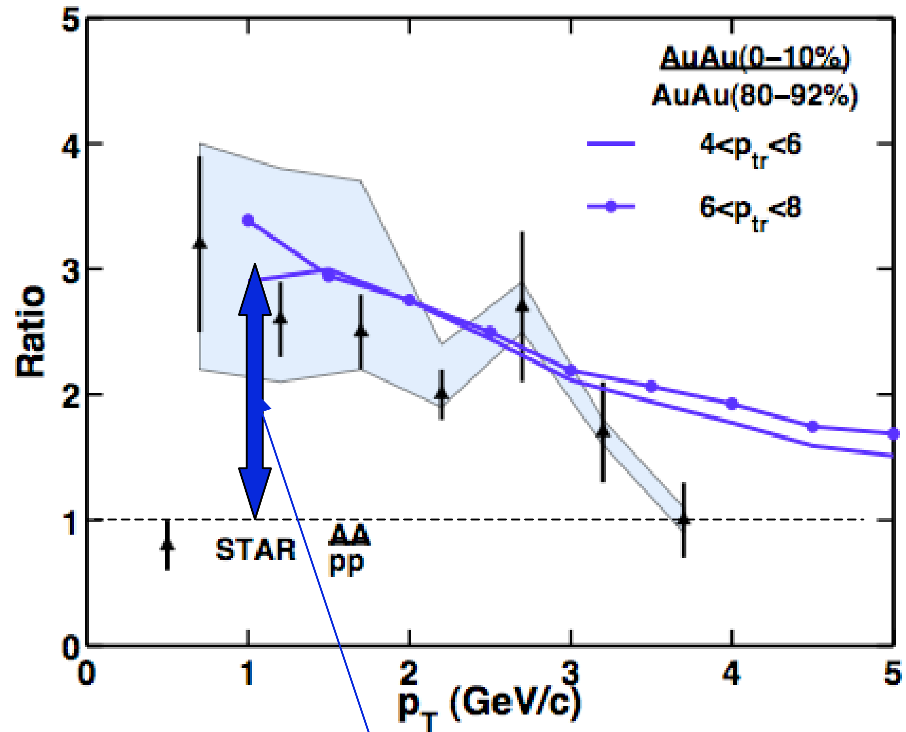


factor of 3

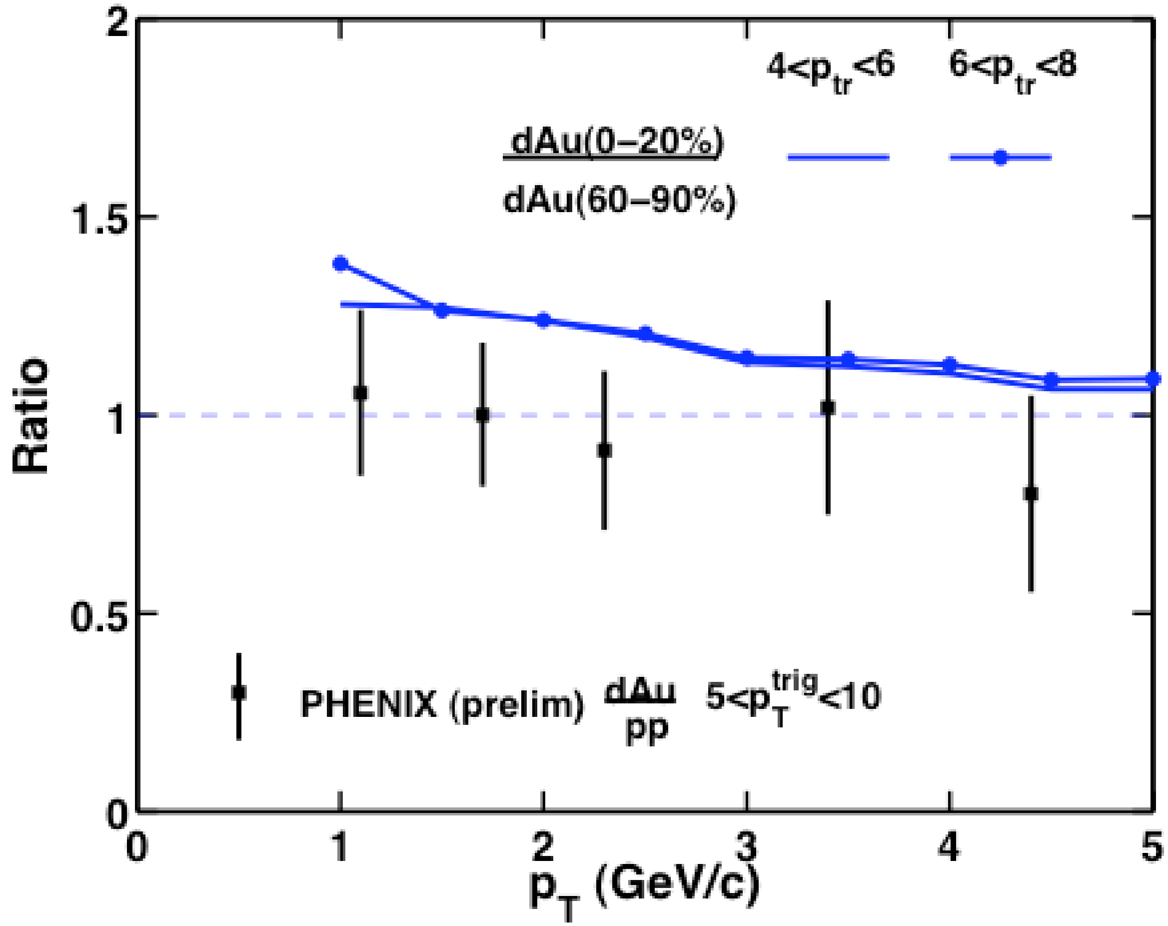
difficult for medium modification of fragmentation function to achieve

Hwa & Tan, nucl-th/0503060

Recombination model



because of T-S recombination



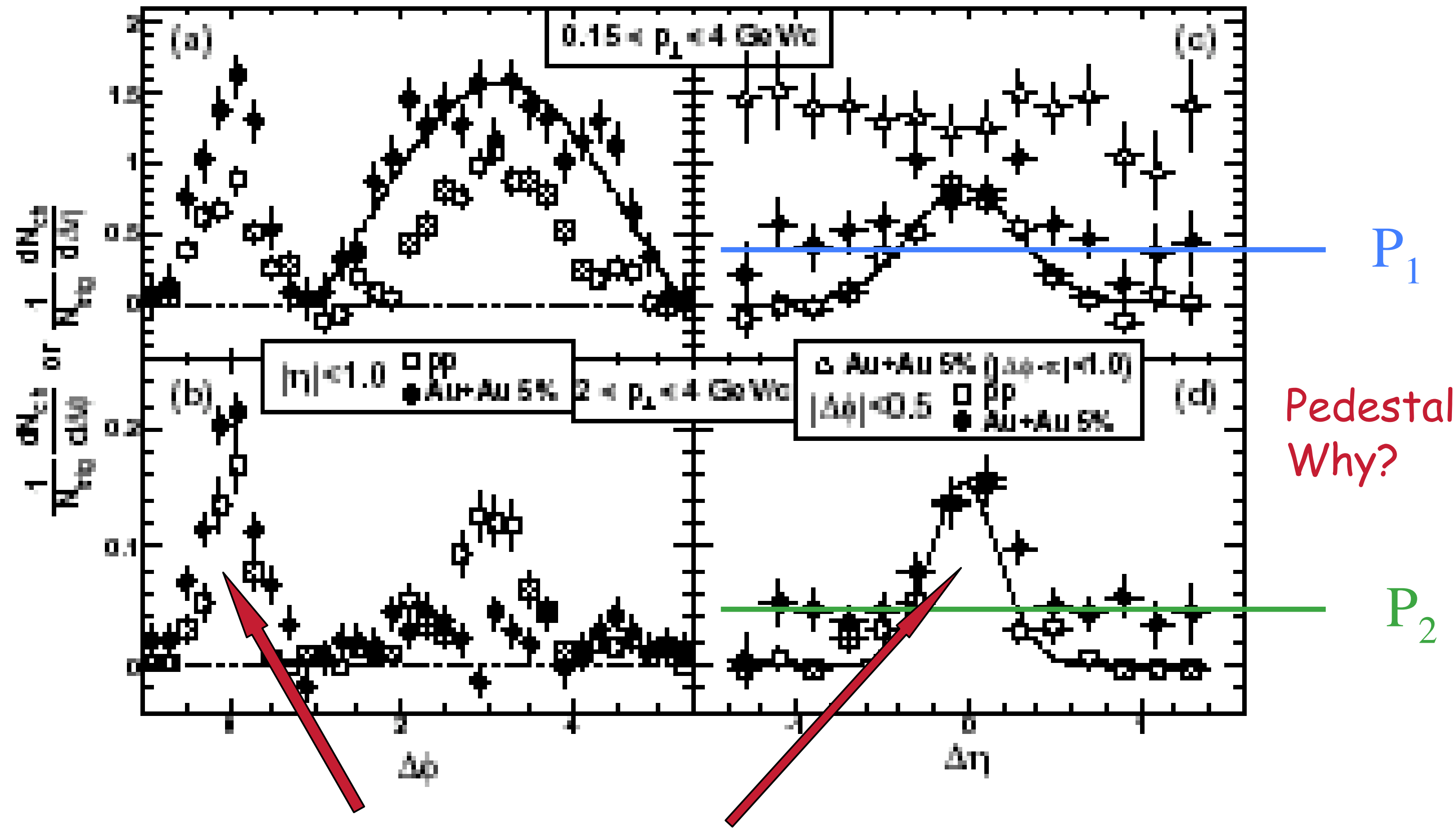
PHENIX (preliminary) $\frac{dAu(0-20\%)}{pp}$ N. Grau

STAR (preliminary) $\frac{\text{yield}(0-20\%)}{\text{yield}(40-100\%)} \approx 1$ J. Bielcikova

RIKEN/BNL Workshop 3/05

Correlations

Δφ and Δη distributions



Are these peaks related? How?

For STST recombination

$$F_4' = \xi \sum_i \int dk k f_i(k) \mathbf{T'}(q_3)\{\mathbf{S}(q_1), \mathbf{S}(q_2)\}\mathbf{T'}(q_4) e^{-\psi^2/2\sigma^2(q_2/k)} \Big|_{\psi = 2\tan^{-1} g(\eta, \eta_1)}$$

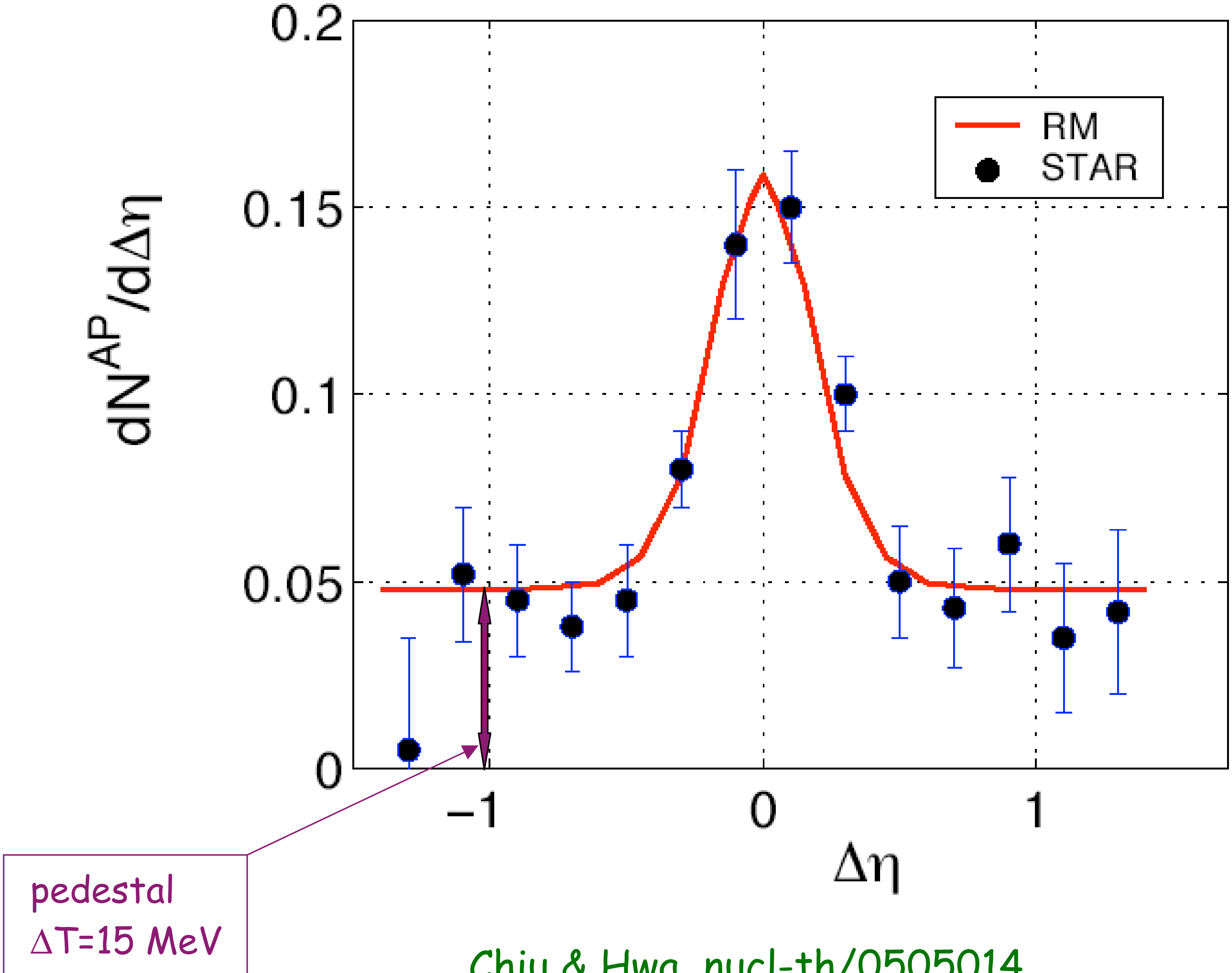
enhanced thermal

trigger

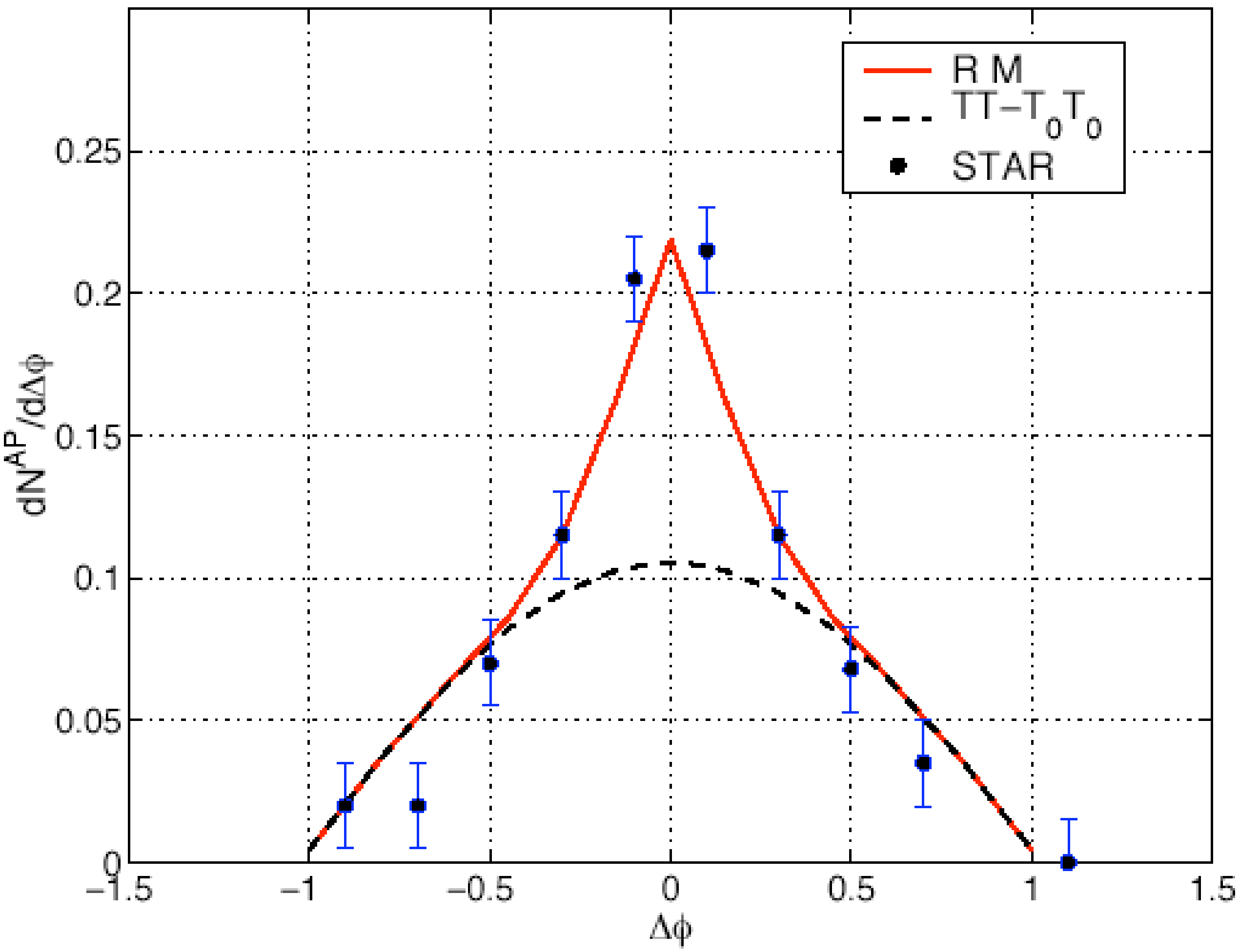
associated particle

with background subtracted

$$F_4^{tr-bg} = \sum \int \cdots (\mathbf{ST'})_{13} \underbrace{(\mathbf{T'T'} - \mathbf{TT})_{24}}_{\text{Pedestal}} + (\mathbf{ST'})_{13} \underbrace{(\mathbf{ST'})_{24}}_{\text{peak in } \Delta\eta \text{ \& } \Delta\phi}$$



Chiu & Hwa, nucl-th/0505014



Chiu & Hwa, nucl-th/0505014

Correlation without triggers

Correlation function

$$\boxed{C_2(1,2) = \rho_2(1,2) - \rho_1(1)\rho_1(2)}$$

$$\rho_2(1,2) = \frac{dN_{\pi_1\pi_2}}{p_1 dp_1 p_2 dp_2} \qquad \rho_1(1) = \frac{dN_{\pi_1}}{p_1 dp_1}$$

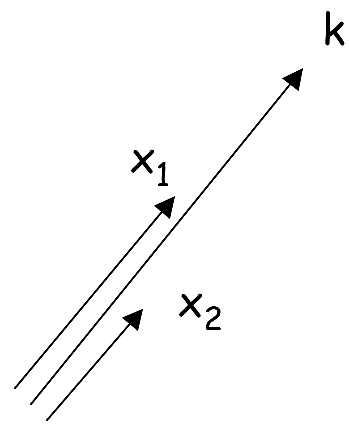
Normalized correlation function

$$\boxed{G_2(1,2) = \frac{C_2(1,2)}{\left[\rho_1(1)\rho_1(2)\right]^{1/2}}}$$

Correlation of partons in jets

Two shower partons in a jet in vacuum

Fixed hard parton momentum k
(as in e+e- annihilation)



$$\rho_1(1) = S_i^j(x_1)$$

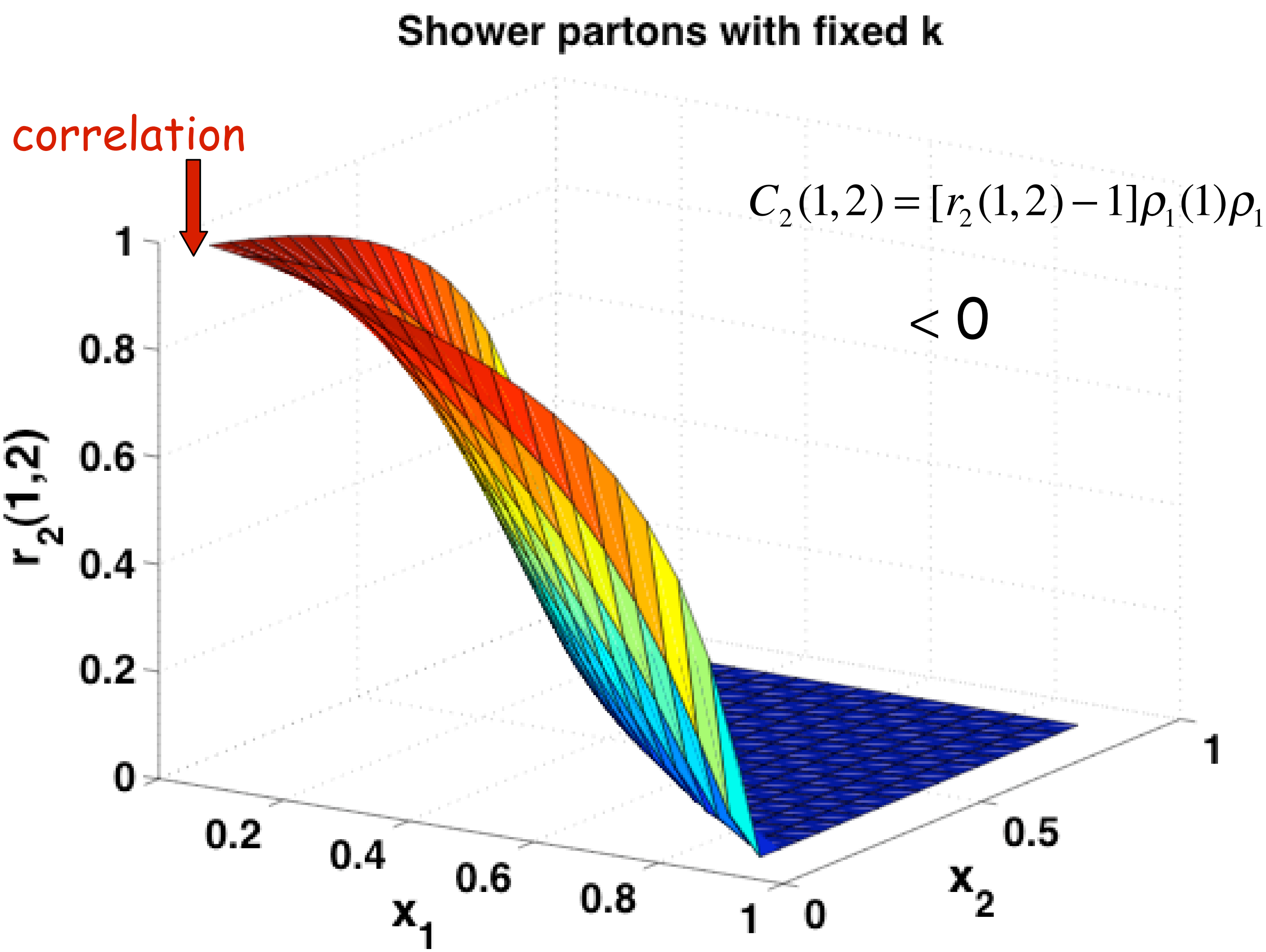
$$\rho_2(1,2) = \left\{ S_i^j(x_1),\, S_i^{j'}\left(\frac{x_2}{1-x_1}\right) \right\} = \frac{1}{2}\left\{ S_i^j(x_1) S_i^{j'}\left(\frac{x_2}{1-x_1}\right) + S_i^j\left(\frac{x_1}{1-x_2}\right) S_i^{j'}(x_2) \right\}$$

$$x_1 + x_2 \le 1$$

$$\boxed{r_2(1,2) = \frac{\rho_2(1,2)}{\rho_1(1)\rho_1(2)}}$$

kinematically constrained
dynamically uncorrelated

no correlation



$$C_2(1,2) = [r_2(1,2) - 1]\rho_1(1)\rho_1(2)$$

< 0

Hwa & Tan, nucl-th/0503052

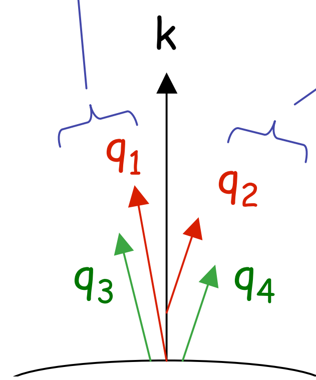
Correlation of pions in jets

Two-particle distribution

$$\frac{dN_{\pi\pi}}{p_1 dp_1 p_2 dp_2} = \frac{1}{(p_1 p_2)^2} \int \left[\prod_i \frac{dq_i}{q_i} \right] F_4(q_1, q_2, q_3, q_4) R(q_1, q_3, p_1) R(q_2, q_4, p_2)$$

$$F_4 = (TT + ST + SS)_{13} (TT + ST + SS)_{24}$$

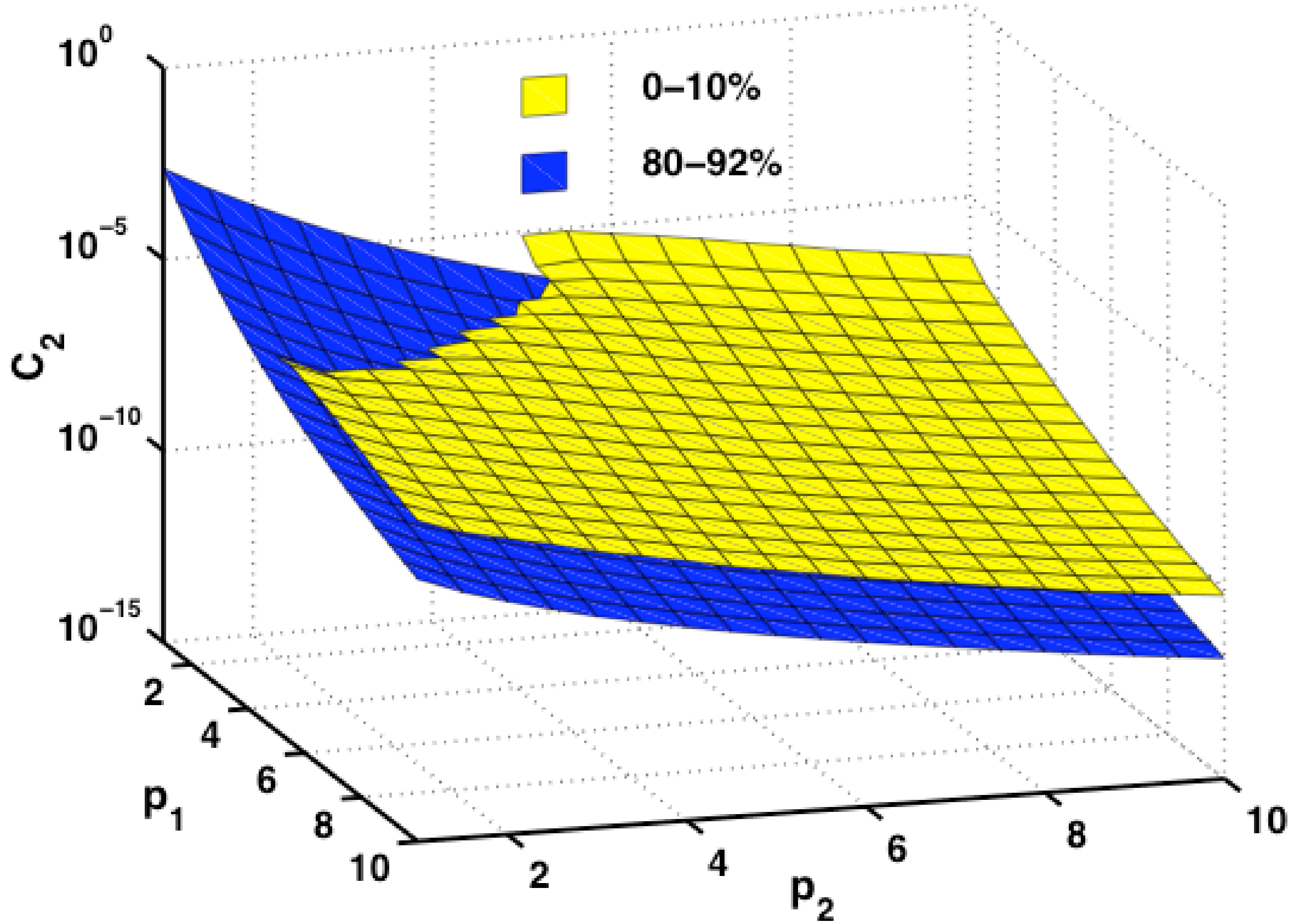
$$\sum_i \int dk k f_i(k)$$



The shower partons are anti-correlated

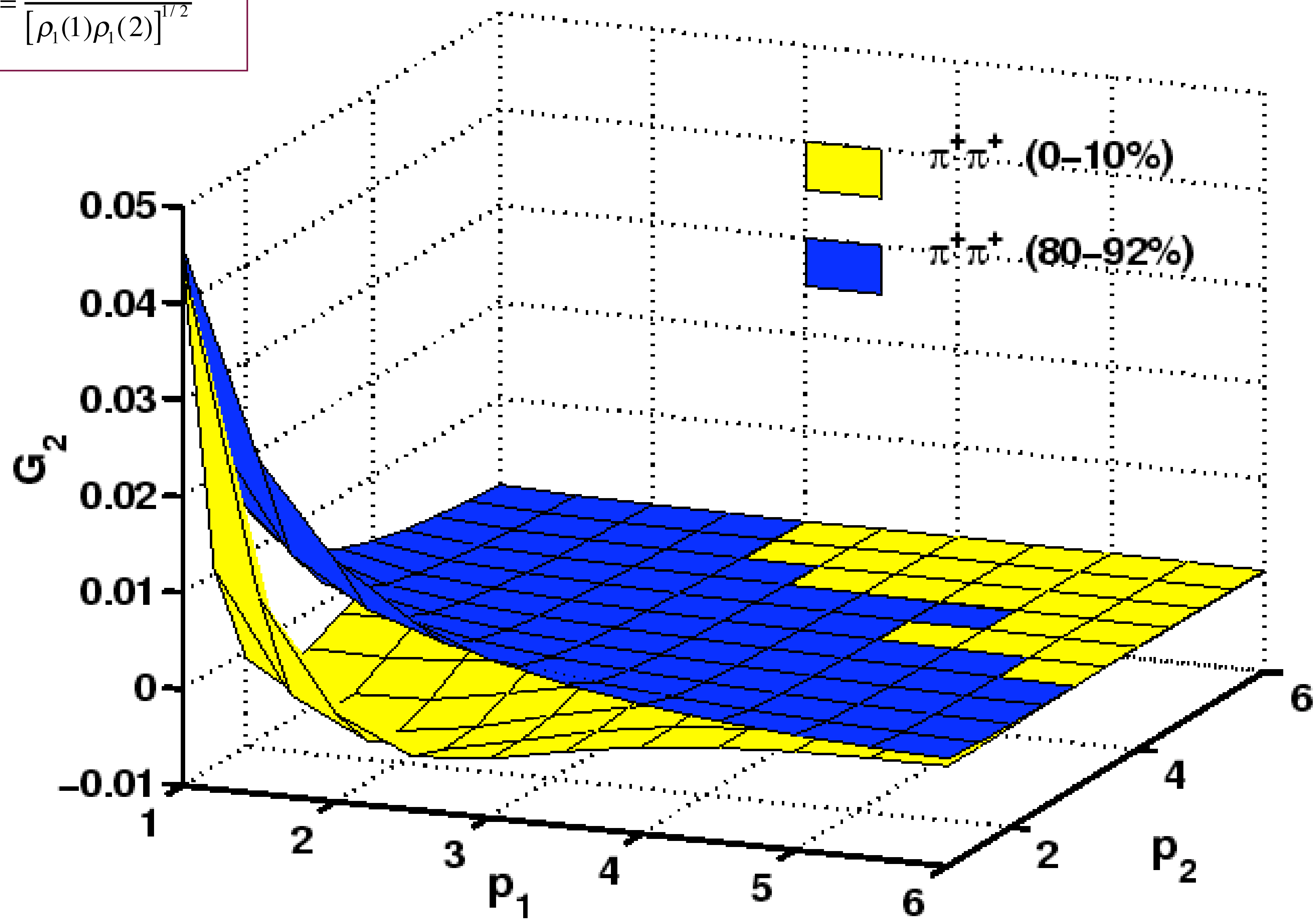
$$\boxed{C_2(1,2) = \rho_2(1,2) - \rho_1(1)\rho_1(2)}$$

$$\rho_2(1,2) = \frac{dN_{\pi_1\pi_2}}{p_1 dp_1 p_2 dp_2} \qquad \rho_1(1) = \frac{dN_{\pi_1}}{p_1 dp_1}$$

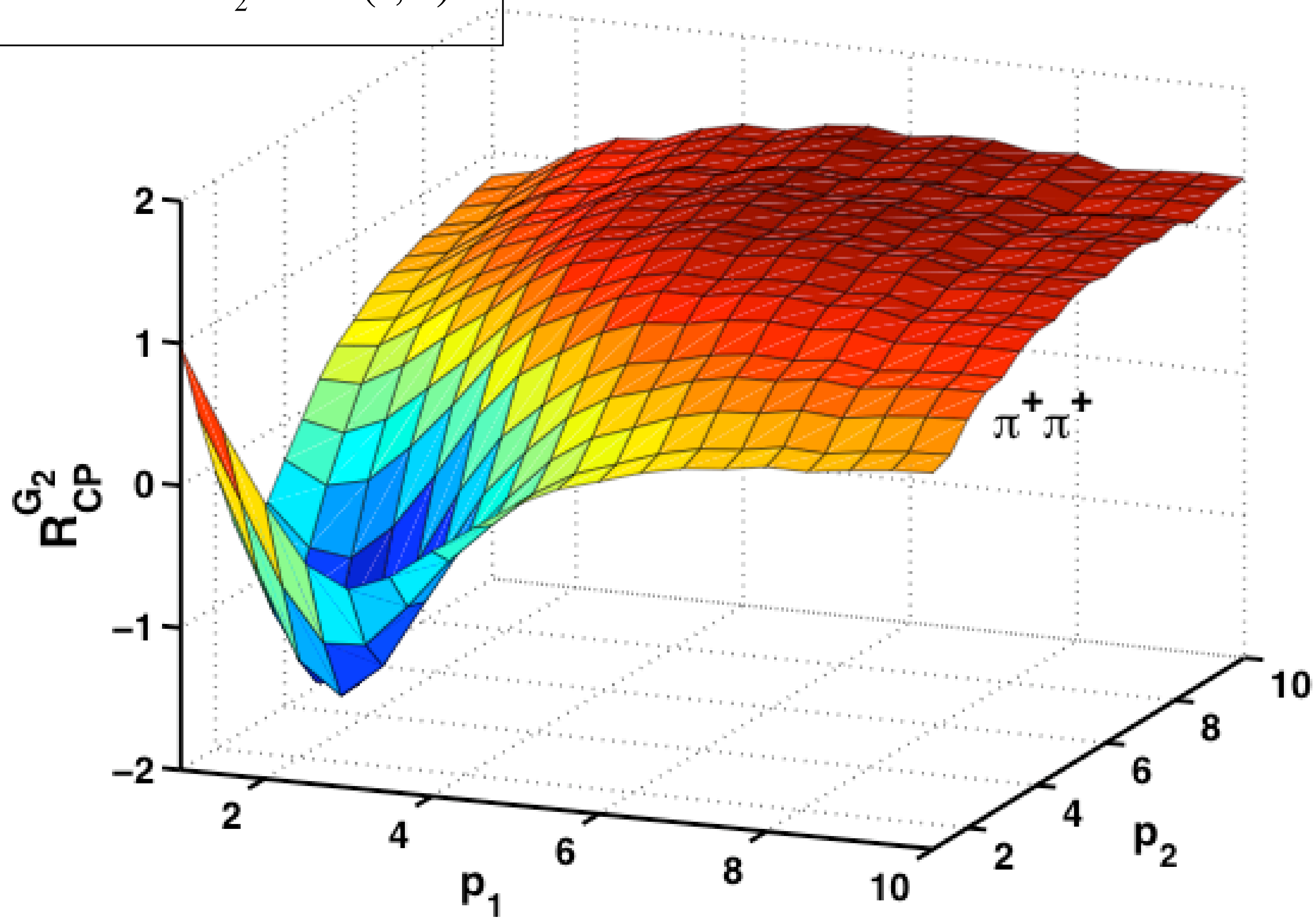


Hwa and Tan, nucl-th/0503052

$$G_2(1,2) = \frac{C_2(1,2)}{\left[\rho_1(1)\rho_1(2)\right]^{1/2}}$$



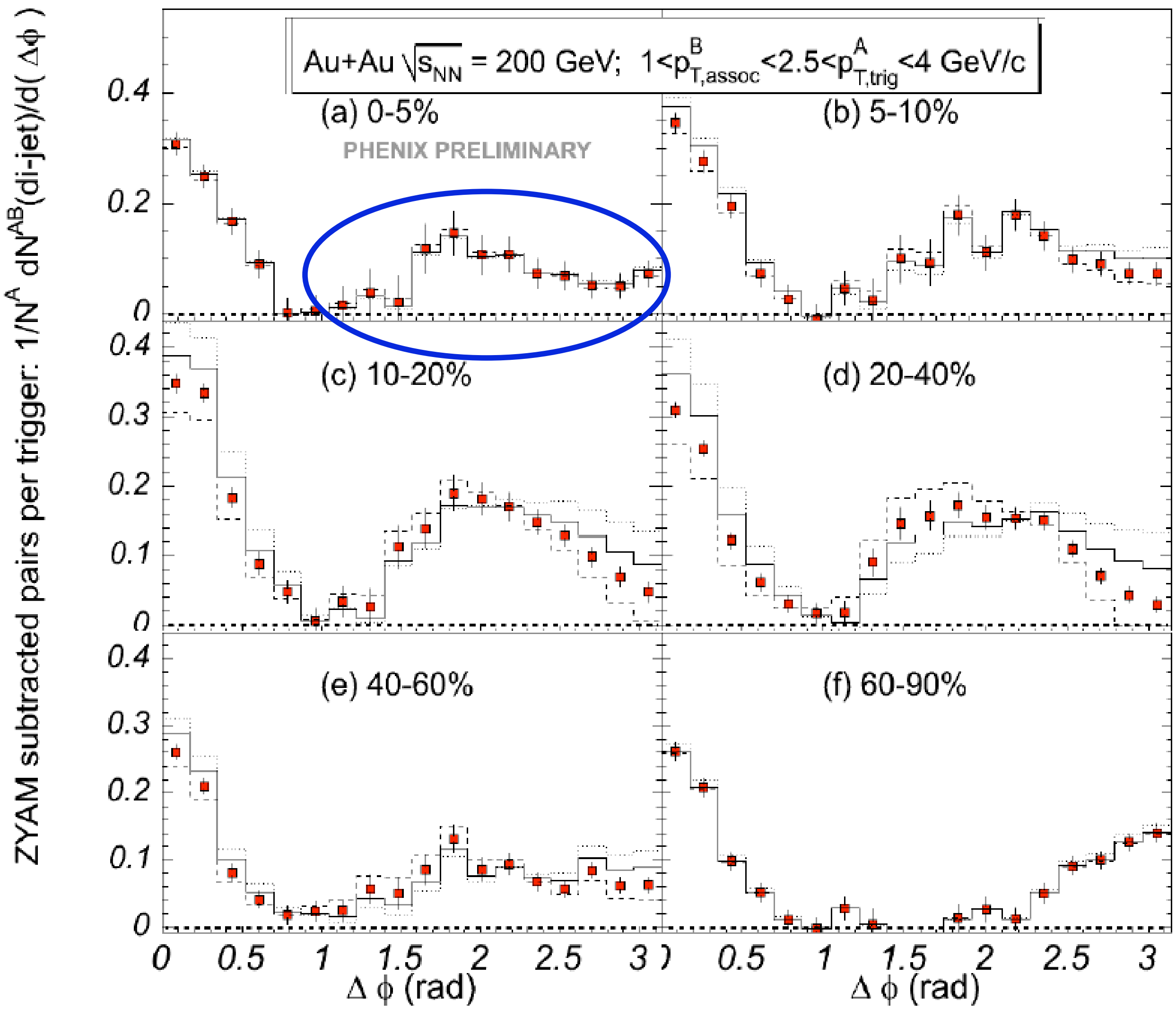
$$R_{CP}^{G_2}(1,2) = \frac{G_2^{(0-10\%)}(1,2)}{G_2^{(80-92\%)}(1,2)}$$



Hwa and Tan, nucl-th/0503052

Away-side $\Delta\phi$ distribution

PHENIX preliminary:



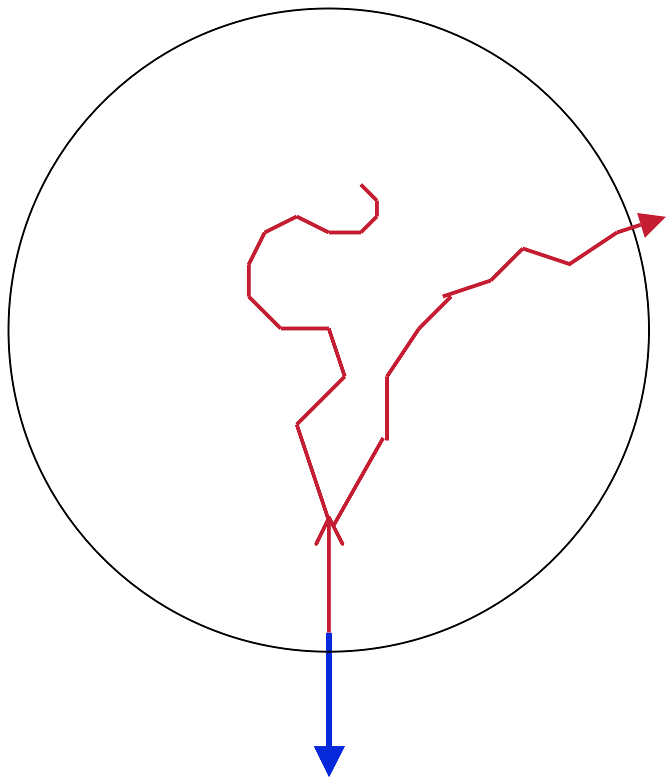
Simulation of parton rescattering

Random forward walker
on a circular mount

Direction of walk is
random within a
Gaussian peak

Step size depends
on local density

Most walks are absorbed
inside the medium

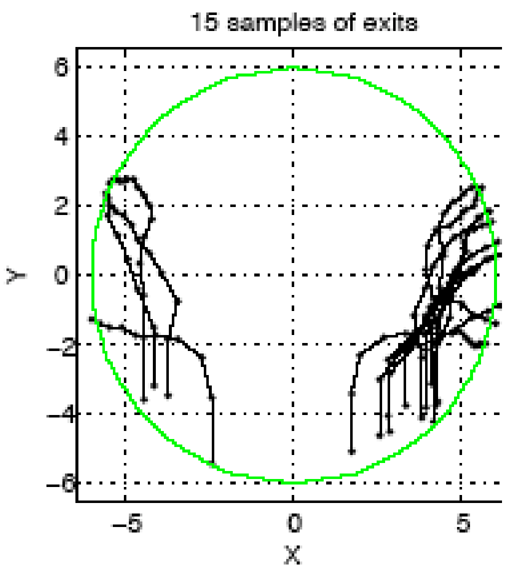


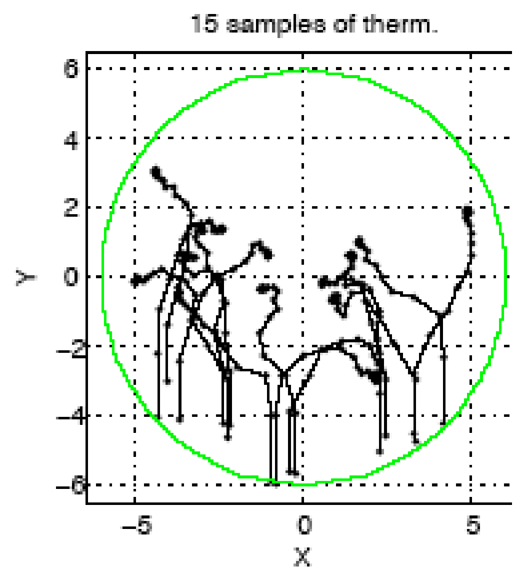
no conical flow

Sample tracks

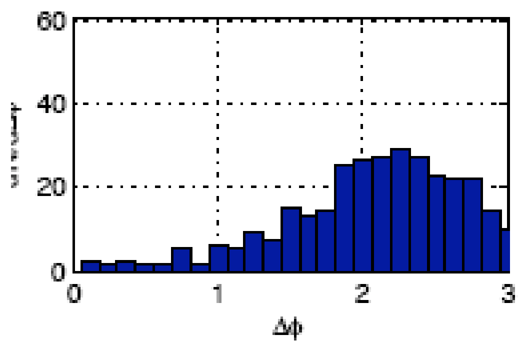
those that emerge

those that are absorbed





away-side distribution



Chiu & Hwa
(work in progress)

Autocorrelation

Correlation function $$C_2(1,2) = \rho_2(1,2) - \rho_1(1)\rho_1(2)$$

1,2 on equal footing --- no trigger

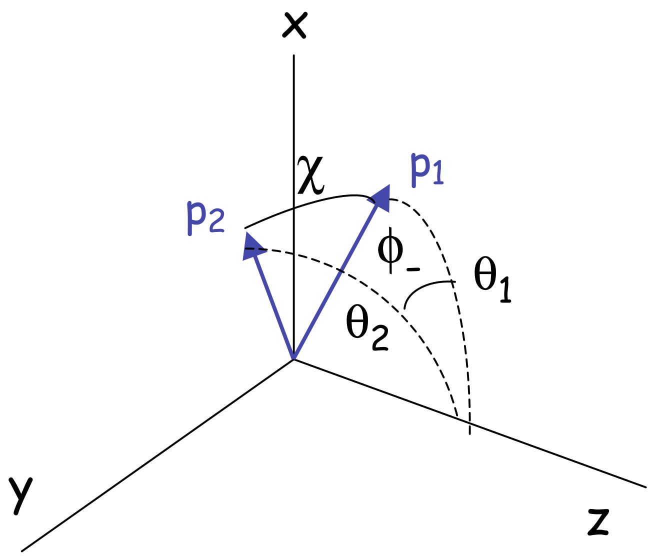
Define $\theta_- = \theta_2 - \theta_1$ $\phi_- = \phi_2 - \phi_1$

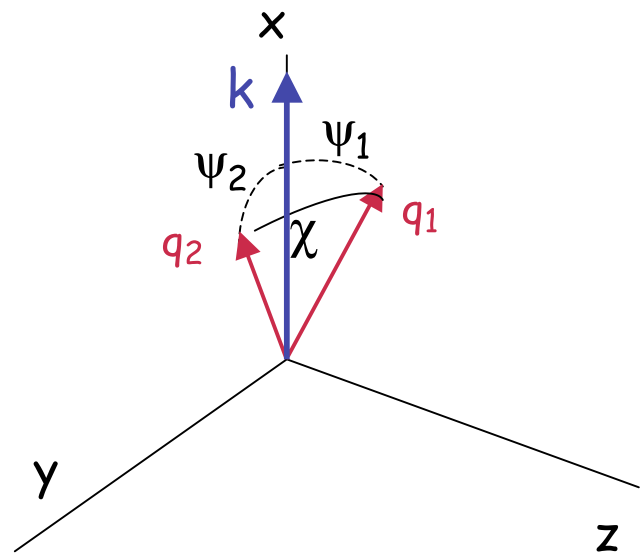
Autocorrelation: $$\boxed{A(\theta_-, \phi_-)}$$

Fix θ_- and ϕ_- , and integrate over all other variables in $C_2(1,2)$

The only non-trivial contribution to $A(\theta_-, \phi_-)$

near $\theta_- \sim 0$, $\phi_- \sim 0$ would come from jets





pion momentum space

parton momentum space

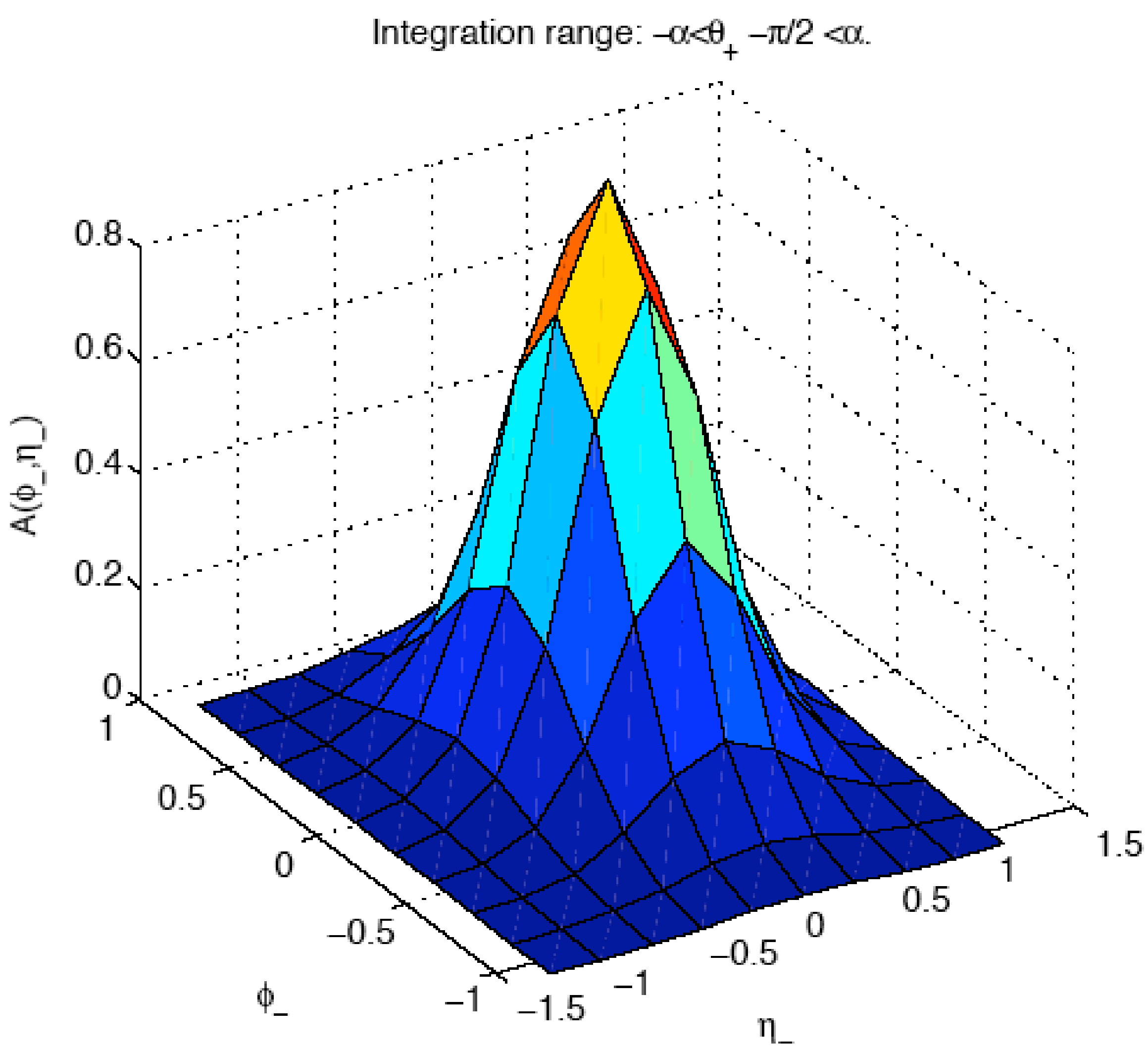
$P(\chi)$

$H(\theta_1, \theta_2, \phi_-)$ $\longleftarrow$ $G(\psi_1, \psi_2)$

Gaussian in jet cone

$\Downarrow$

$A(\eta_-, \phi_-)$



Chiu and Hwa (05)

Conclusion

- Hadronization by recombination resolves several puzzles at intermediate pT.
- The pedestal and peak structure in the near-side jets is due to enhanced thermal partons and to jet cone structure of shower partons.
- A dip is predicted in the correlation function due to anti-correlation among the shower partons.
- Promising start made in the $\Delta\phi$ distribution on the away-side by simulating parton rescattering and absorption.