Forward production in d+Au collisions by parton recombination

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Overview

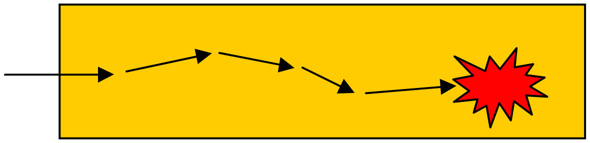
- Cronin Effect
- Recombination Models
- d+Au at midrapidity
- d+Au in forward direction*

*Work in collaboration with R.C. Hwa and C.B. Yang

Cronin Effect

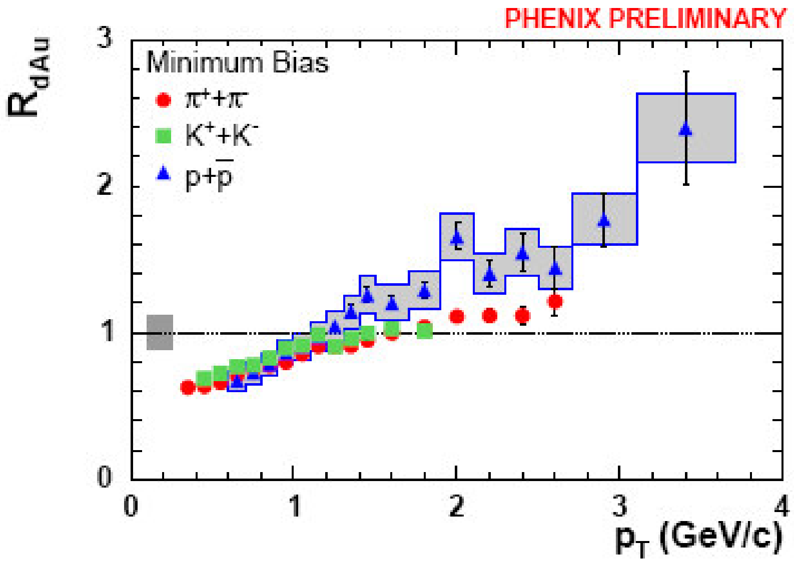
- Cronin et al. (1975): enhancement of production cross sections at moderate P_T in proton-nucleus interactions
- Standard explanation: initial state multiple scattering leads to additional P_T

$$d\sigma_{pA} = A^{\alpha} d\sigma_{pN}$$
$$\alpha > 1 \text{ for } P_T > 2\,\mathrm{GeV}/c$$



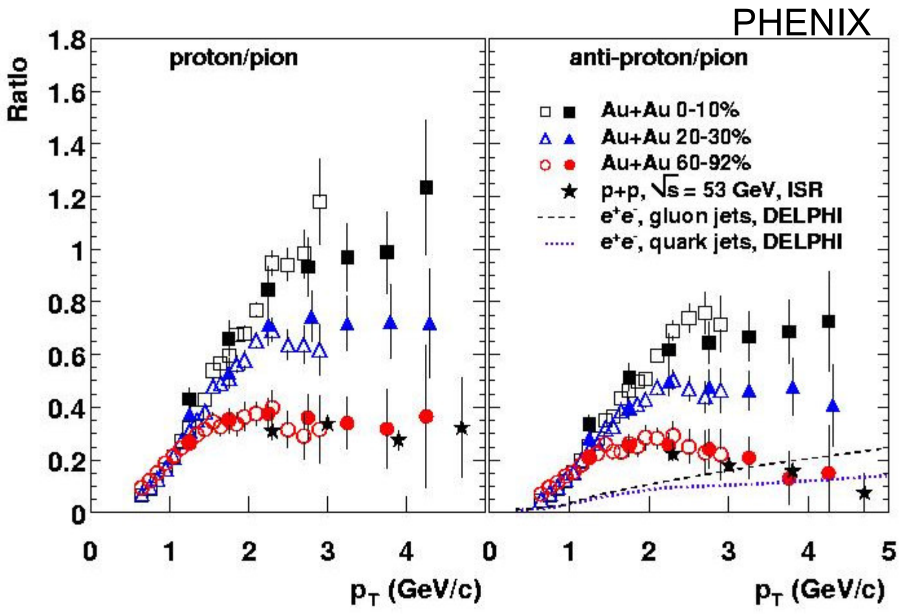
$$\left\langle \Delta P_T^2 \right\rangle \sim A^{1/3}$$

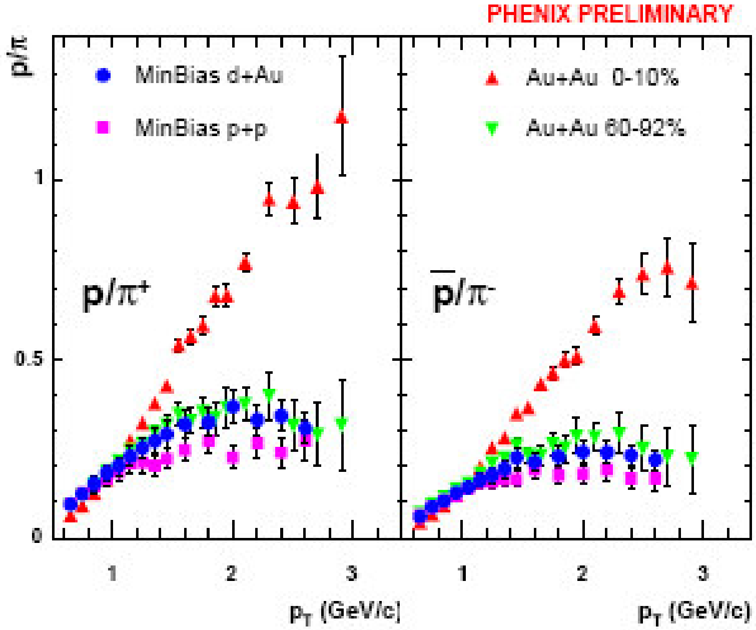
- However: significant dependence on hadron species
  - ☐ at odds with pure initial state effec
  - ☐ similar to Au+Au at RHIC



Hadron Chemistry at high P_T

- Enhanced baryon yield in nuclear systems found at RHIC
  - ☐ $p/\pi \sim 1$ in Au+Au (for $P_T > 2 \ldots 4.5$ GeV/c)
  - ☐ $p/\pi \sim 0.3$ in p+p,



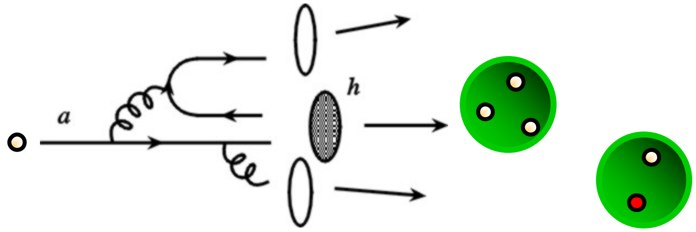


- General meson vs baryon pattern in observables in A+A

Hadronization

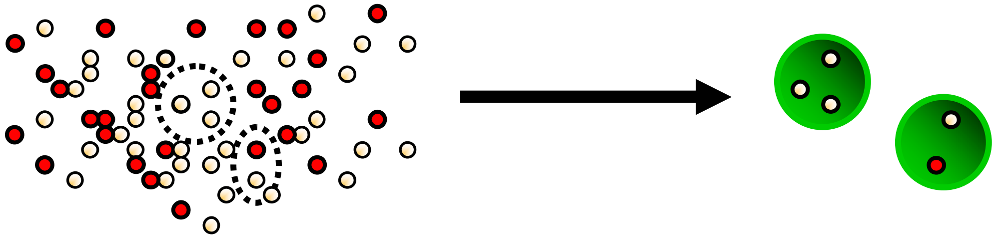
- Usual picture of parton fragmentation at large P_T:
  - ☐ Gluon radiation ⇨ additional quark/antiquark pairs ⇨ hadrons
  - ☐ Then p/π ≈ 0.1 … 0.2

Dilute parton systems
High virtualities



- Different hadronization at intermediate P_T in A+A
  - ☐ Phase space already filled with partons!
  - ☐ Recombine quarks into hadrons

Dense parton systems
Low virtualities



Recombination Model

- Meson M made of quarks α and β:

$$\frac{d^3N_M}{d^3P} = C_M \int_\Sigma \underbrace{w_\alpha \otimes w_\beta}_{\text{Product of quark distributions}} \otimes \overbrace{\Phi_M}^{\text{Meson Wigner function}}$$

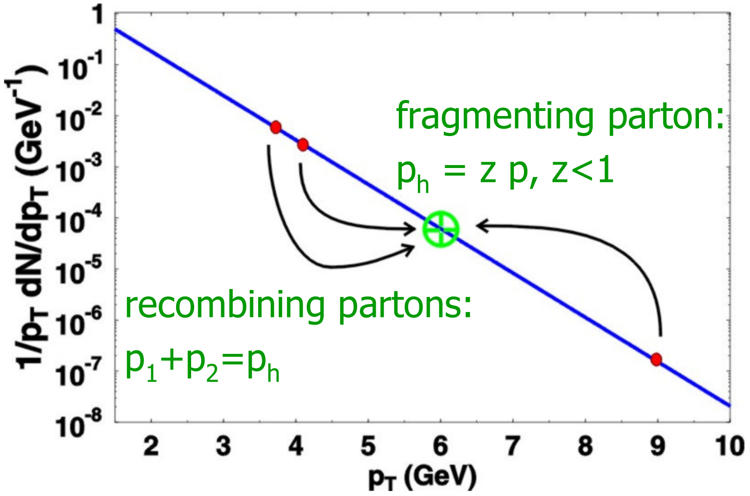
$q\bar{q} \rightarrow M$ $\qquad$ $qqq \rightarrow B$

- For $P_T >> M, k_T$: collinear kinematics, small mass corrections
- Thermal parton distribution ⇨ meson ~ baryon

$$w \sim e^{-p/T} \Rightarrow \begin{cases} N_M \sim w_\alpha w_\beta \sim e^{-xP/T} e^{-(1-x)P/T} = \boxed{e^{-P/T}} \\ N_B \sim w_\alpha w_\beta w_\gamma \sim e^{-x_\alpha P/T} e^{-x_\beta P/T} e^{-(1-x_\alpha - x_\beta)P/T} = \boxed{e^{-P/T}} \end{cases}$$

Recombination & Fragmentation

- Competition of hadronization mechanisms



fragmenting parton:
$p_h = z\ p,\ z<1$

recombining partons:
$p_1+p_2=p_h$

  ☐ Fragmentation dominates for power law spectra in the limit $P_T \to \infty$

  ☐ Recombination dominates for exponential spectra

Power law: $w \sim p_T^{-\alpha}$

$$N_{\rm frag} \sim P_T^{-\alpha}$$

$$N_{\rm reco} \sim P_T^{-2\alpha}$$

for mesons

Exponential: $w \sim A e^{-p_T/T}$

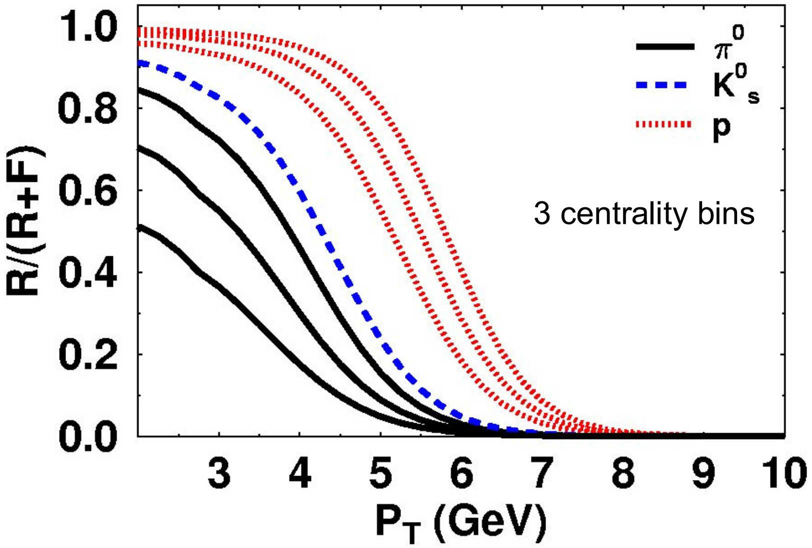
$$N_{\rm frag} = w \otimes D \sim A e^{-P_T/\langle z \rangle T} \langle D \rangle$$

$$N_{\rm reco} = w \otimes \Phi \otimes w \sim A^2 e^{-P_T/T}$$

Recombination Effects in d+Au

- Recombination very effective for baryons

- Centrality scaling in Au+Au:
  - ☐ Large recombination contribution for protons even in periperal Au+Au



- Idea: recombination still important in d+Au, at least for baryons
- Expect larger enhancement for protons

Hwa & Yang Formalism

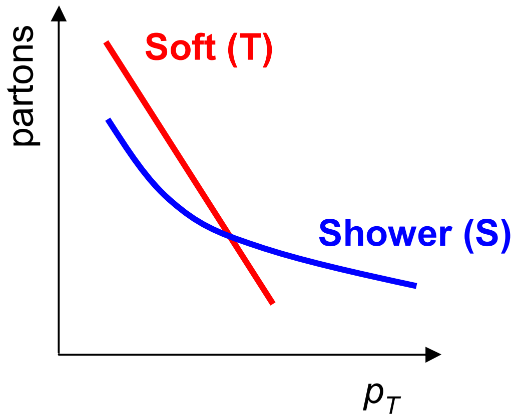
- Recombination a la Hwa and Yang

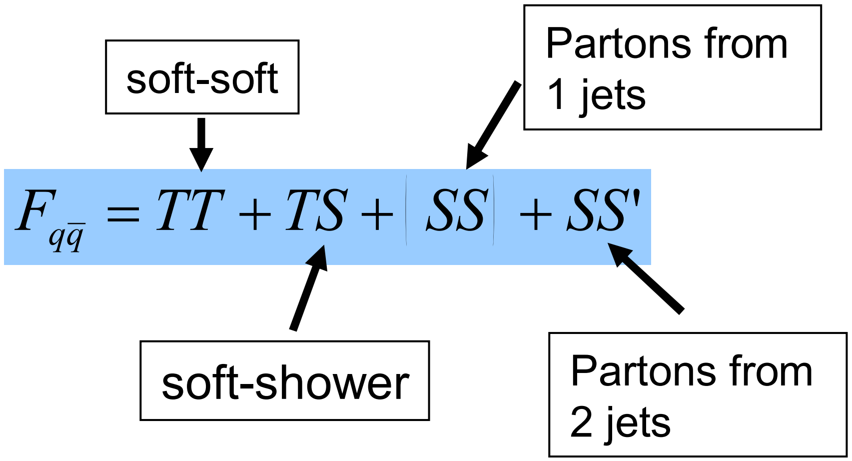
  R.C. Hwa and C.B. Yang, PRC 70, 024904 (2004); 024905 (2004)

  - ☐ Hadron spectrum

    $$\frac{dN_\pi}{p_T dp_T} = \frac{1}{p_T^2} \int \frac{dq_1}{q_1} \frac{dq_2}{q_2} F_{q\bar{q}}(q_1, q_2) R_\pi(q_1, q_2; p_T)$$

  - ☐ Partons before hadronization: soft/thermal + showers from jets





soft-soft

Partons from 1 jets

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

soft-shower

Partons from 2 jets

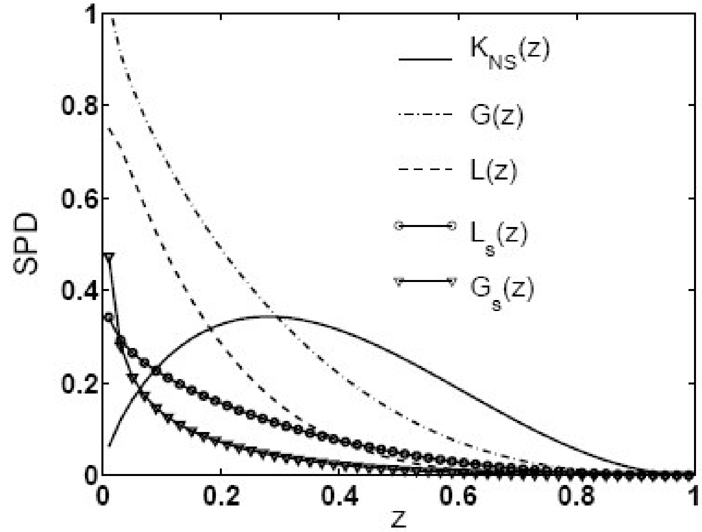
  - ☐ Recombination functions

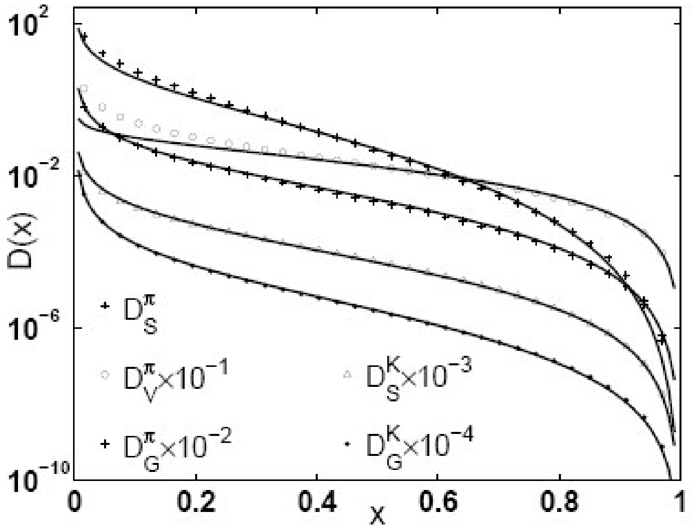
    $$R_\pi(q_1, q_2; p) = \frac{q_1 q_2}{p} \delta(q_1 + q_2 - p)$$

Parton Showers I

- Shower parton distribution
  - ☐ Hard parton *i* $\xrightarrow{S_i^j(z)}$ shower parton *j*, momentum zp_i
  - ☐ Determined by fits to fragmentation functions

$$xD_{i\to\pi}(x)=\sum_{j,k}\int\frac{dx_1}{x_1}\frac{dx_2}{x_2}S_i^j\,|\,x_1\,|\,S_i^k\left(\frac{x_2}{1-x_1}\right)R_\pi^{jk}\,|\,x_1,x_2;x\,|$$





Parton Showers II

- Single parton in a shower from a jet

$$S_j | p_T | = \sum_i \int dk S_i^j | p_T / k | \frac{dN_i}{dk}$$

- Double parton distribution in one shower

$$| S_j S_k | | p_1, p_2 | = \sum_i \int dk \left\{ S_i^j \left(\frac{p_1}{k} \right) S_i^k \left(\frac{p_2}{k - p_1} \right) \right\} \frac{dN_i}{dk}$$

- By definition: Recombination in one jet (SS) = fragmentation
  - ☐ Following earlier work: Migneron et al., Hwa et al.

Model Parameters

- d+Au Jets from pQCD calculation including EKS shadowing
- Distribution of shower partons $S(p_T)$ parameter-free prediction for d+Au

$$T\left(p_T\right) = Cp_T e^{-\beta p_T}$$

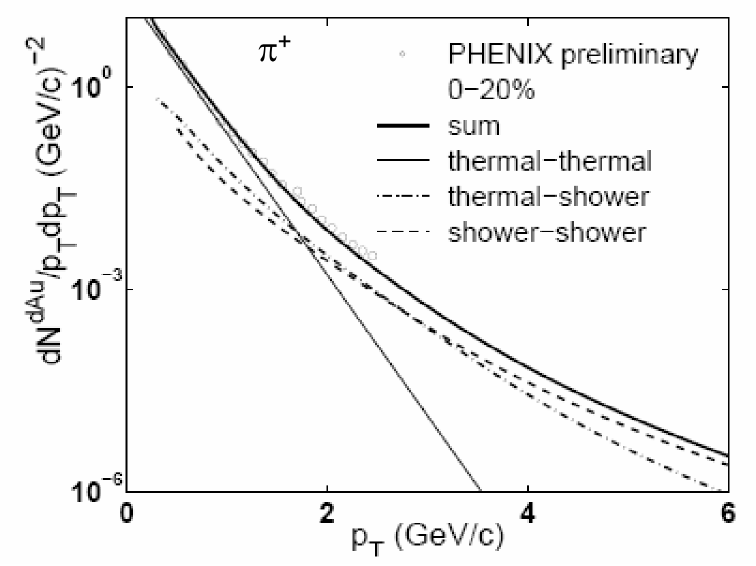
- Ansatz for distribution of soft partons
  - ☐ Parameters C, β fitted to hadron spectrum at low P_T
- Recombination of baryons

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

Numerical Results @ η=0

- Results for d+Au midrapidity

R.C. Hwa and C.B. Yang, PRL 93, 082302 (2004); PRC 70, 037901 (2004)

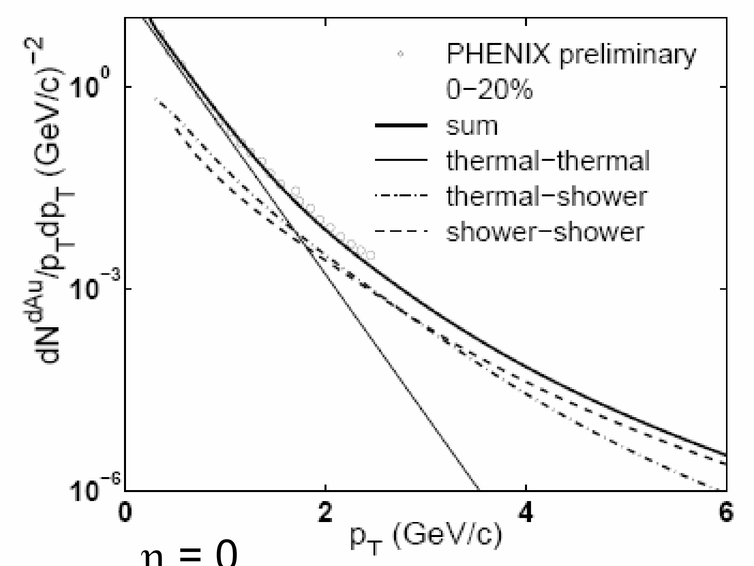


☐ TS + TT dominant below P_T = 3 GeV

☐ Proton enhancement

Forward Rapidities

- Fix normalization of T by scaling $C \sim dN_{ch}/d\eta$
- For central d+Au: $C(\eta=0)/C(\eta=3.2) \approx 3$
- 2 scenarios for slope β:
  - ☐ Extrapolate from mid rapidity $\beta(\eta) = \beta(\eta=0) = 1/(0.21\ \text{GeV}) \approx 1/\Lambda_{QCD}$
  - ☐ Permit to adjust β for better fit



$\eta = 0$

Large suppression of jet contributions at forward rapidity

Forward Jet Suppression

- Running out of phase space

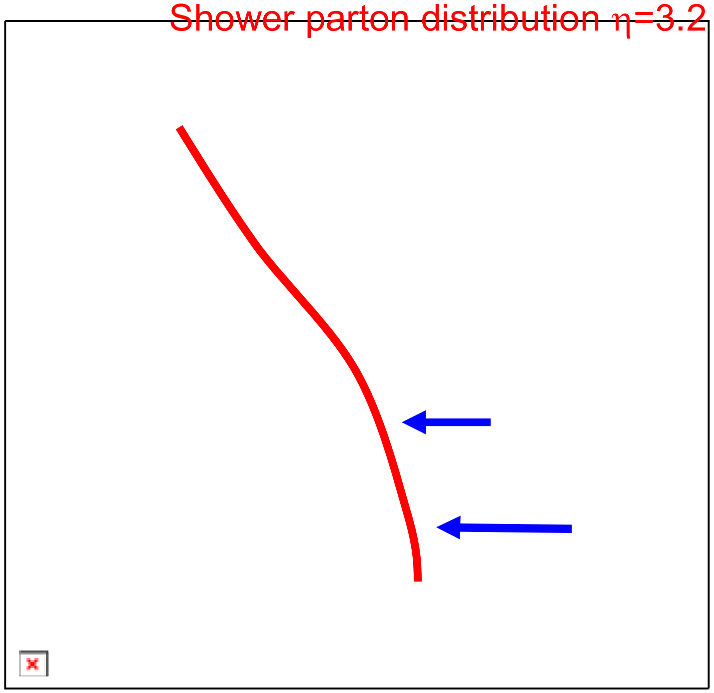
Max P_T

100 GeV/c

22 GeV/c

8.1 GeV/c

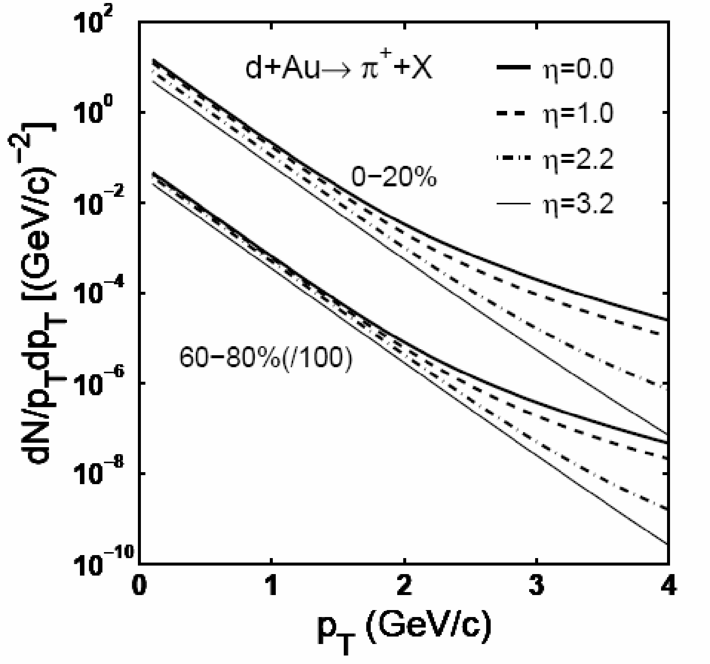
Shower parton distribution η=3.2



- η~3 dominated by soft physics

Central vs Peripheral

- Pion spectrum for different rapidities



- Central vs peripheral for β fixed;
  - ☐ Data: BRAHMS charged hadrons

Remarks

- Additional Cronin enhancement by initial state multiple scattering not taken into account here.
- Recombination does not predict the origin of the soft parton distribution: use your favorite model!
- To test our picture at forward rapidity: measure identified pions and protons!
  - ⇨ Better constrain slope β
- Connection to leading particle effect?
  - ☐ Recombination of beam remnants observed in very forward direction in fixed target experiments (WA82, E791)

Outlook

- Hadronization in parton-filled phase space proceeds by recombination
- Recombination in d+Au explains $R_{dAu}(\mathrm{p}) > R_{dAu}(\pi)$ at midrapidity
- Suppression of shower partons suggests recombination of soft partons dominates for $\eta > 3$
- To come: confirmation by measuring identified particles
- Origin of soft partons?