Unintegrated parton distributions and pion production in pp collisions at SPS and RHIC energies

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Plan of the talk

- Introduction
- Kwieciński UPDF approach
- Applications to other processes
- Parton production at SPS
- From partons to hadrons
- Pion production at SPS
- From SPS to RHIC
- Conclusions

→

partially published:
M. Czech and A. Szczurek, Phys. Rev. **C72** (2005) 015202.

Introduction

Meson production in hadron-hadron collisions usually in collinear 2$\rightarrow$ 2 approach with phenomenological fragmentation functions

Sometimes corrected for internal transverse momenta:

- (a) on-shell approach (Owens, Wang, Levai)
- (b) off-shell approach (no corresponding cross sections available).

Recently new ideas:

- (a) Saturation in e p collisions (assumed not proven!, only total cross section)
- (b) Unintegrated gluon distributions (Kharzeev, Levin, McLerran, Gyulassy, etc.)

Introduction - continued

Shortcomings:

- Often form of UGD assumed (not derived from QCD)
- Instead of hadronization parton-hadron duality
- No quarks and antiquarks explicit

Recently:
A new method for unintegrated parton (gluons, quarks and antiquarks) distributions (Kwieciński)
Limitation: not too small x (not too large energies)

......Let us try to use them and combine with phenomenological fragmentation functions

Previous UGDF studies

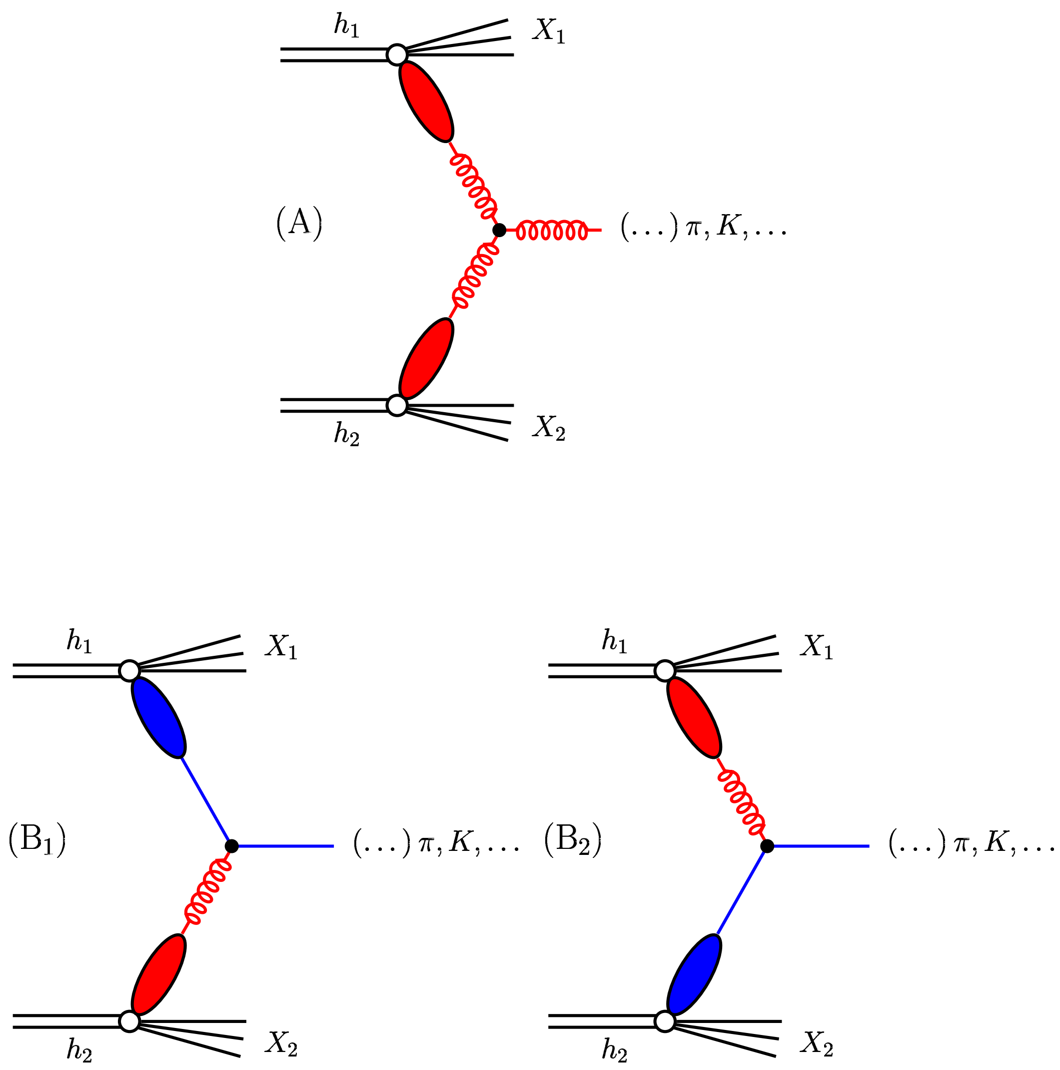
Concentrated on AA RHIC collisions only!

pp collisions - A. Szczurek,
Acta Phys. Pol. **B34** (2003) 3191

Different UGDF from the literature:

- Golec-Biernat-Wuesthoff – too small transverse momenta
- Kharzeev-Levin form adjusted to HERA data – only idea-inspired parametrization
- BFKL – too fast growth with energy
- Kimber-Martin-Ryskin ?

Processes included



Leading-order diagrams for inclusive parton production

g, q, $\bar{q}$ inclusive distributions

diagram A(gg→g)

$$\frac{d\sigma}{dy d^2p_t} = \frac{16N_c}{N_c^2-1}\frac{1}{p_t^2}$$

$$\int \alpha_s(\Omega^2)\, \mathcal{F}_{g/1}(x_1,\kappa_1^2)\, \mathcal{F}_{g/2}(x_2,\kappa_2^2)\delta(\vec{\kappa}_1+\vec{\kappa}_2-\vec{p}_t)\, d^2\kappa_1 d^2\kappa_2\ .$$

diagram B_1(q_f g → q_f)

$$\frac{d\sigma}{dy d^2p_t} = \frac{16N_c}{N_c^2-1}\left(\frac{4}{9}\right)\frac{1}{p_t^2}$$

$$\int \alpha_s(\Omega^2)\, \mathcal{F}_{q_f/1}(x_1,\kappa_1^2)\, \mathcal{F}_{g/2}(x_2,\kappa_2^2)\delta(\vec{\kappa}_1+\vec{\kappa}_2-\vec{p}_t)\, d^2\kappa_1 d^2\kappa_2\ .$$

diagram B_2(g q_f → q_f)

$$\frac{d\sigma}{dy d^2p_t} = \frac{16N_c}{N_c^2-1}\left(\frac{4}{9}\right)\frac{1}{p_t^2}$$

$$\int \alpha_s(\Omega^2)\, \mathcal{F}_{g/1}(x_1,\kappa_1^2)\, \mathcal{F}_{q_f/2}(x_2,\kappa_2^2)\delta(\vec{\kappa}_1+\vec{\kappa}_2-\vec{p}_t)\, d^2\kappa_1 d^2\kappa_2\ .$$

Kwiecinski parton distributions

QCD-most-consistent approach – CCFM.

In LO convenient to use a space conjugated to transverse momentum Kwieciński et al.)

$$\tilde{f}(x,b,\mu^2) = \frac{1}{2\pi} \int d^2\kappa \exp\left(-i\vec{\kappa}\cdot\vec{b}\right) \mathcal{F}(x,\kappa^2,\mu^2)$$

$$\mathcal{F}(x,\kappa^2,\mu^2) = \frac{1}{2\pi} \int d^2 b \exp\left(i\vec{\kappa}\cdot\vec{b}\right) \tilde{f}(x,b,\mu^2)$$

The relation between

Kwieciński UPDF and the collinear PDF:

$$xp_k(x,\mu^2) = \int_0^\infty d\kappa_t^2 f_k(x,\kappa_t^2,\mu^2)$$

Kwiecinski equations

for a given impact parameter
(Phys.Rev.**D68** (2003) 054001)

$$\frac{\partial f_{NS}(x,b,Q)}{\partial Q^2} = \frac{\alpha_s(Q^2)}{2\pi Q^2} \int_0^1 dz\, P_{qq}(z) \Big[\Theta(z-x)\, J_0((1-z)Qb)\, f_{NS}\left(\frac{x}{z}, b, Q\right) - f_{NS}(x,b,Q) \Big]$$

$$\frac{\partial f_{S}(x,b,Q)}{\partial Q^2} = \frac{\alpha_s(Q^2)}{2\pi Q^2} \int_0^1 dz \Big\{ \Theta(z-x)\, J_0((1-z)Qb) \Big[P_{qq}(z)\, f_S\left(\frac{x}{z}, b, Q\right) + P_{qg}(z)\, f_G\left(\frac{x}{z}, b, Q\right) \Big] - [zP_{qq}(z) + zP_{gq}(z)]\, f_S(x,b,Q) \Big\}$$

$$\frac{\partial f_{G}(x,b,Q)}{\partial Q^2} = \frac{\alpha_s(Q^2)}{2\pi Q^2} \int_0^1 dz \Big\{ \Theta(z-x)\, J_0((1-z)Qb) \Big[P_{gq}(z)\, f_S\left(\frac{x}{z}, b, Q\right) + P_{gg}(z)\, f_G\left(\frac{x}{z}, b, Q\right) \Big] - [zP_{gg}(z) + zP_{qg}(z)]\, f_G(x,b,Q) \Big\}$$

Nonperturbative effects

Transverse momenta of partons due to:

- perturbative effects
  (solution of the Kwieciński- CCFM equations),
- nonperturbative effects
  (intrinsic momentum distribution of partons)

Take factorized form:

$$\tilde{f}_q(x,b,\mu^2) = \tilde{f}_q^{CCFM}(x,b,\mu^2) \cdot F_q^{np}(b) \ .$$

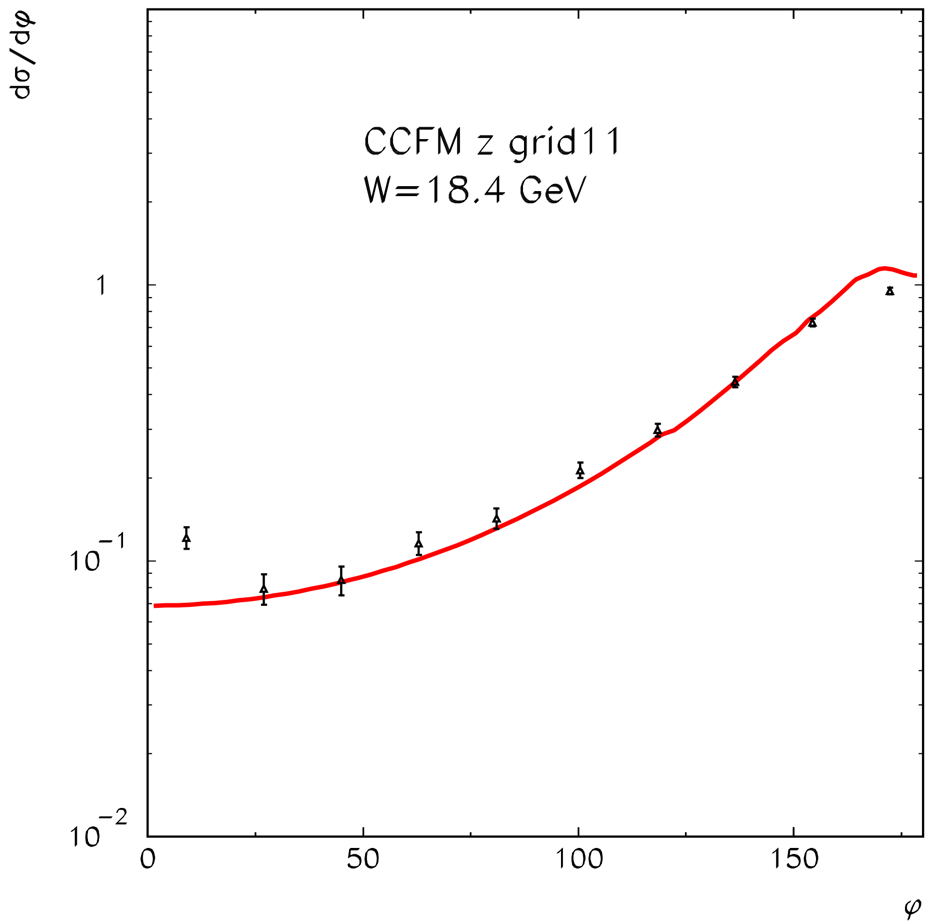
I shall try a flavour and x independent form factor

$$F_q^{np}(b) = F^{np}(b) = \exp\left(\frac{-b^2}{4b_0^2}\right)$$

May be too simplistic ?

$\gamma p \to c\bar{c}$ correlations

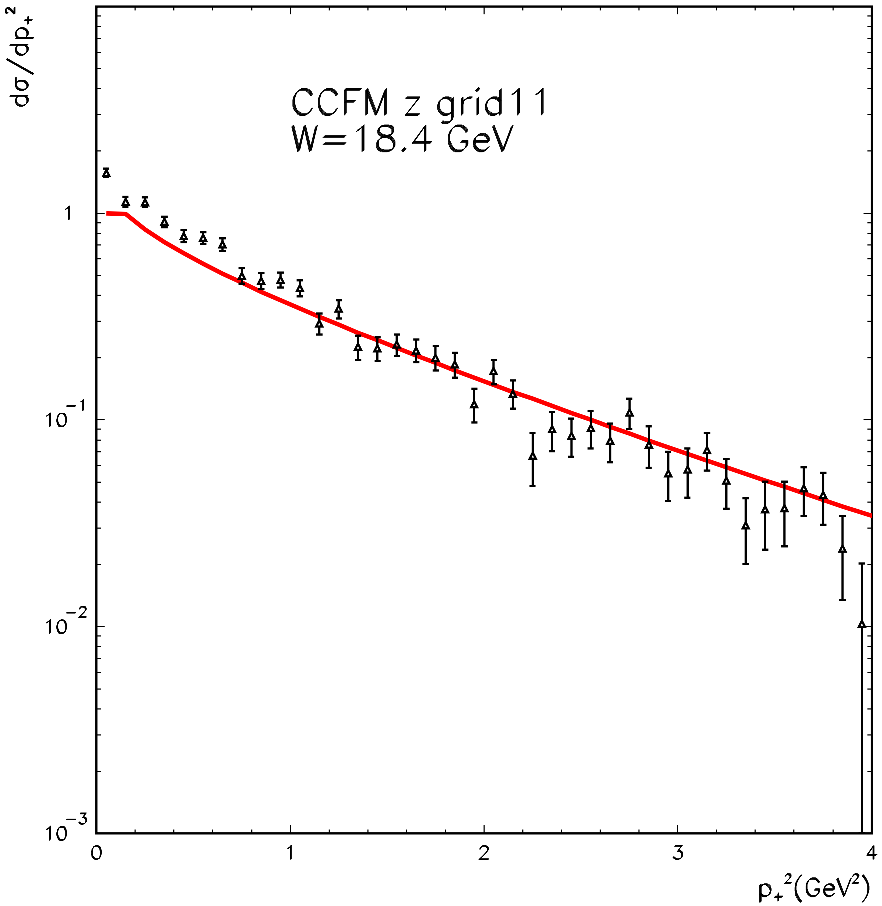
M. Łuszczak and A.Szczurek,
Phys. Lett. **B59** (2004) 291
azimuthal correlations



Gaussian form factor ($b_0 = 0.5 GeV^2$)
FOCUS collaboration data

$\gamma p \to c\bar{c}$ correlations

Define: $\vec{p}_+ = \vec{p}_{1,t} + \vec{p}_{2,t}$



Gaussian form factor ($b_0 = 0.5GeV^2$)
FOCUS collaboration data

From momentum space to b space

Assuming that $\alpha_s = \alpha_s(p_t)$ (not explicit function of κ_1^2 or κ_2^2) and taking

$$\delta^{(2)}(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t) = \frac{1}{(2\pi)^2} \int d^2 b \exp[(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t)\vec{b}]$$

The luminosity function

$$\begin{aligned} & \int \mathcal{F}_1 \left(x_1, \frac{\vec{p}_t + \vec{q}_t}{2} \right) \mathcal{F}_2 \left(x_2, \frac{\vec{p}_t - \vec{q}_t}{2} \right) d^2 q_t \\ = \;& 4 \int \tilde{f}_1(x_1, b, \mu^2) \tilde{f}_2(x_2, b, \mu^2) \exp\left(\vec{p}_t \cdot \vec{b} \right) d^2 b \\ = \;& 4 \int \tilde{f}_1(x_1, b, \mu^2) \tilde{f}_2(x_2, b, \mu^2) \; J_0(p_t b) \; 2\pi b db \end{aligned}$$

The scale for QCD evolution: $\mu^2 = p_t^2$?

b-space formulae

In terms of parton distributions in the conjugated space:

diagram A

$$\frac{d\sigma}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \frac{1}{p_t^2} \alpha_s(p_t^2) \int \widetilde{\mathfrak{F}}_{g/1}(x_1, b, \mu^2)\, \widetilde{\mathfrak{F}}_{g/2}(x_2, b, \mu^2) J_0(p_t b)\, 2\pi b\, db$$

diagram B_1

$$\frac{d\sigma}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \left(\frac{4}{9}\right) \frac{1}{p_t^2} \alpha_s(p_t^2) \int \widetilde{\mathfrak{F}}_{q_f/1}(x_1, b, \mu^2)\, \widetilde{\mathfrak{F}}_{g/2}(x_2, b, \mu^2) J_0(p_t b)\, 2\pi b\, db$$

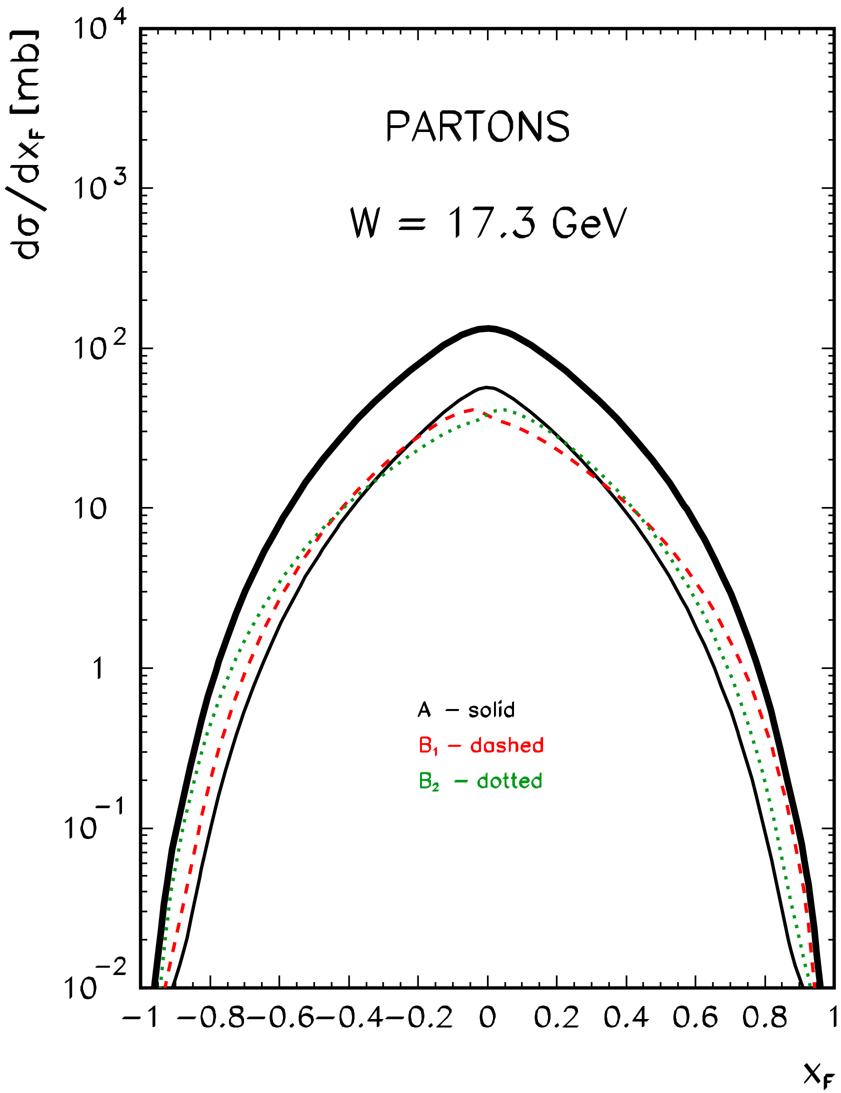
diagram B_2

$$\frac{d\sigma}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \left(\frac{4}{9}\right) \frac{1}{p_t^2} \alpha_s(p_t^2) \int \widetilde{\mathfrak{F}}_{g/1}(x_1, b, \mu^2)\, \widetilde{\mathfrak{F}}_{q_f/2}(x_2, b, \mu^2) J_0(p_t b)\, 2\pi b\, db$$

The scale for QCD evolution: $\mu^2 = p_t^2$?

PARTONS

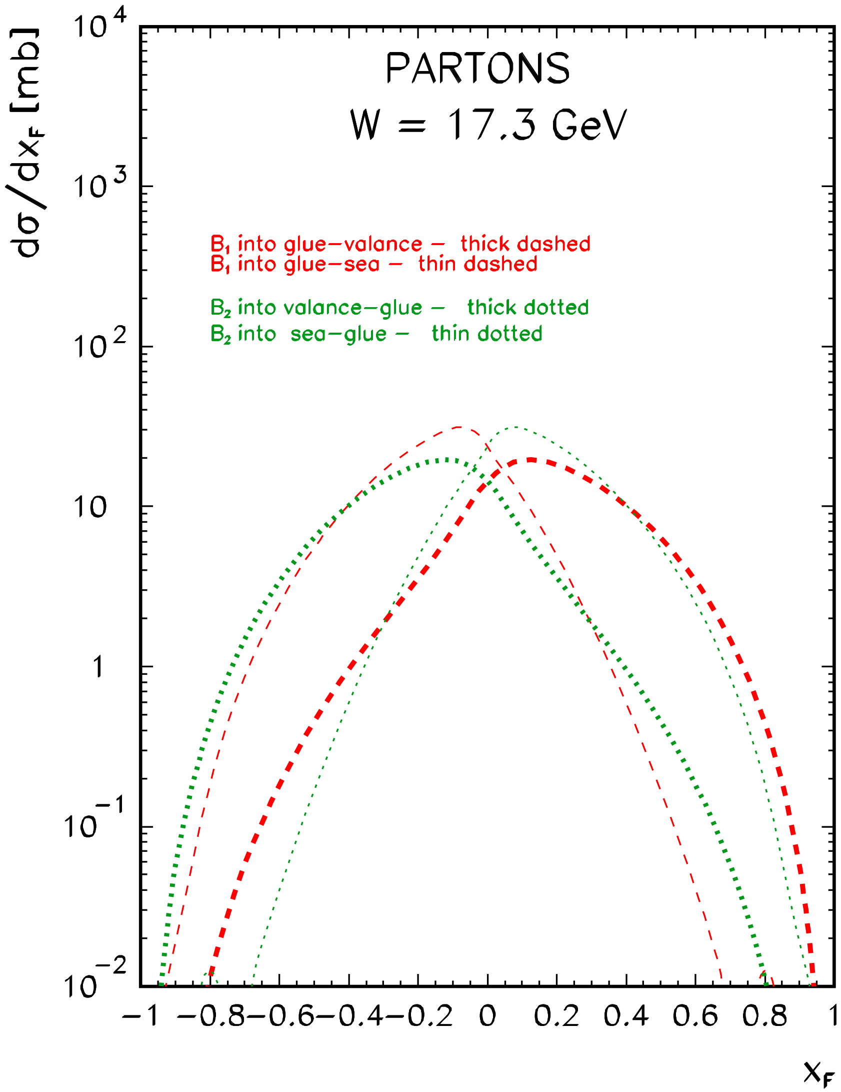
W = 17.3 GeV
Gaussian form factor
(b_0 = 1 GeV^{-1})
0.2 GeV $< p_t <$ 4 GeV.
diagram A – thin solid line,
diagram B_1 – dashed line
diagram B_2 – dotted line,
sum – thick solid line.



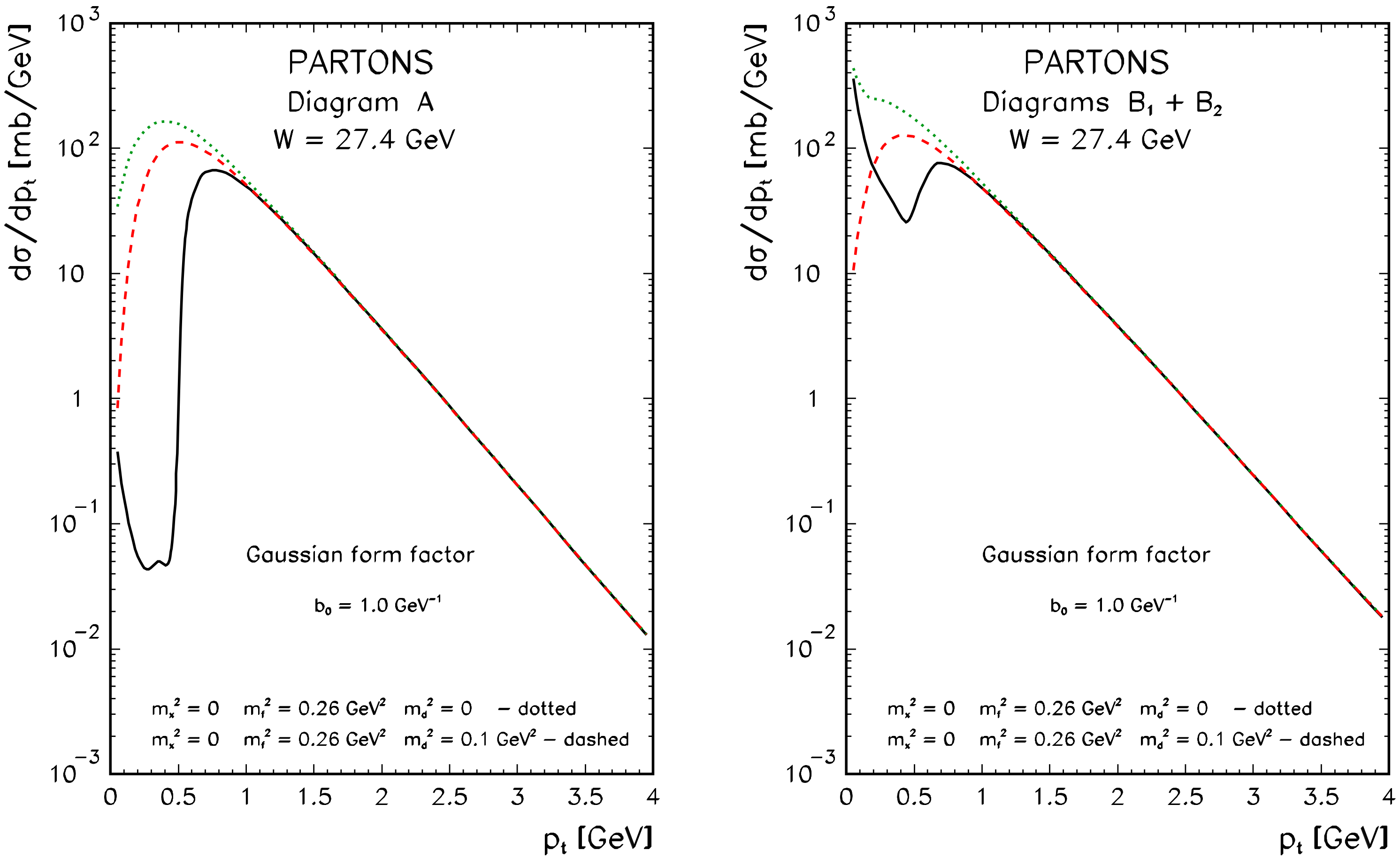
PARTONS, continued

diagram B_1:
glue-sea versus glue-valence
diagram B_2:
sea-glue and valence-glue

W = 17.3 GeV



PARTONS, continued



W = 27.4 GeV

-1 $< x_F <$ 1

Gaussian form factor b_0 = 1 GeV^{-1}

solid line: freezing prescription for μ_F^2

dotted line: shift prescription for μ_F^2

dashed line: shift of μ_F^2 and modification of denomina r

From partons to hadrons

In the case all diagrams (A+B_1+B_2) are included:

$$\frac{d\sigma(\eta_h, p_{t,h})}{d\eta_h d^2 p_{t,h}} = \int_{z_{min}}^{z_{max}} dz \frac{J^2}{z^2}$$

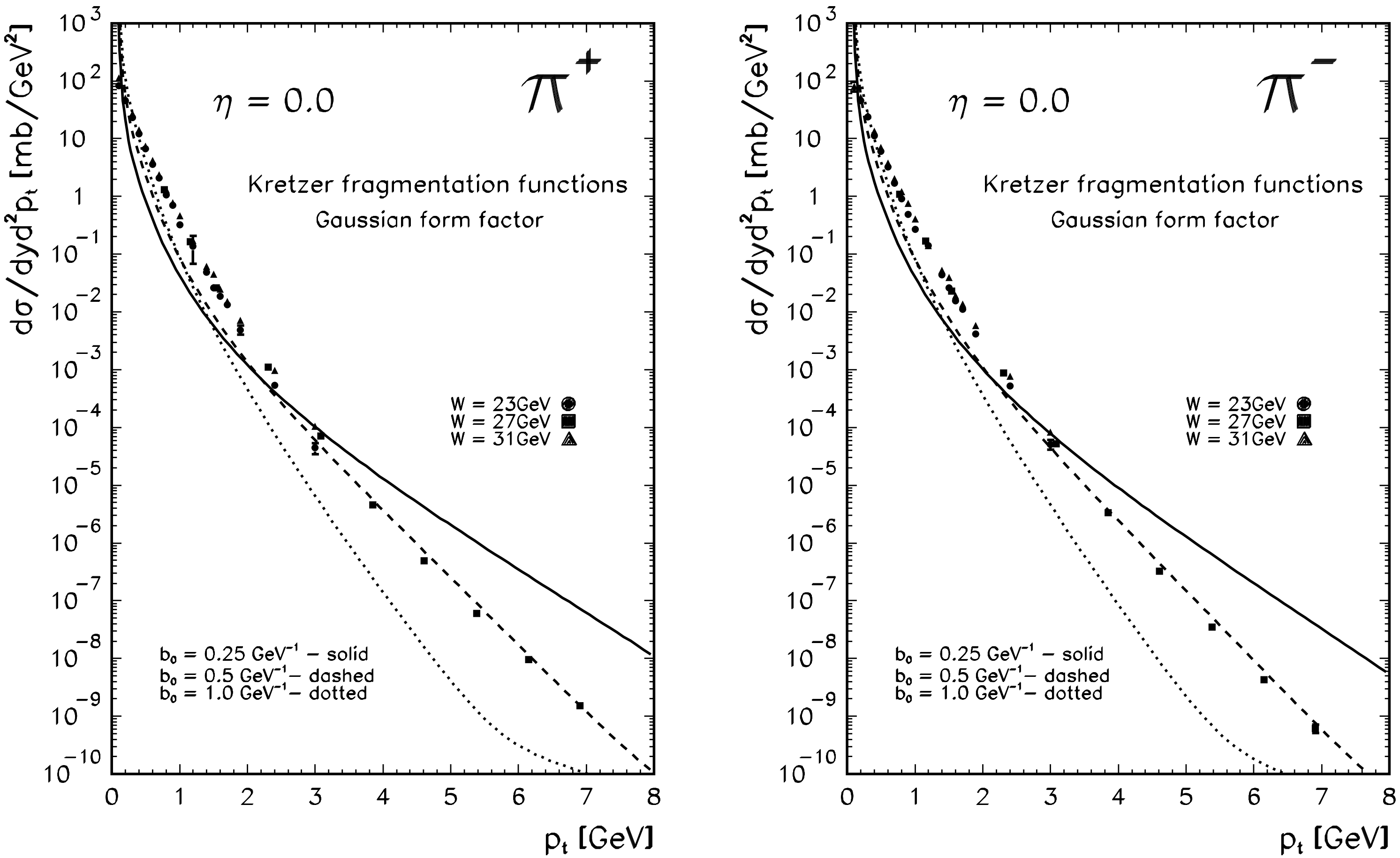
$$D_{g\to h}(z,\mu_D^2) \frac{d\sigma^A_{gg\to g}(y_g, p_{t,g})}{dy_g d^2 p_{t,g}}\Bigg|_{\substack{y_g=\eta_h \\ p_{t,g}=Jp_{t,h}/z}}$$

$$\sum_{f=-3}^{3} D_{q_f\to h}(z,\mu_D^2) \frac{d\sigma^{B_1}_{q_f g\to q_f}(y_{q_f}, p_{t,q_f})}{dy_{q_f} d^2 p_{t,q}}\Bigg|_{\substack{y_q=\eta_h \\ p_{t,q}=Jp_{t,h}/z}}$$

$$\sum_{f=-3}^{3} D_{q_f\to h}(z,\mu_D^2) \frac{d\sigma^{B_2}_{g q_f\to q_f}(y_{q_f}, p_{t,q_f})}{dy_{q_f} d^2 p_{t,q}}\Bigg|_{\substack{y_q=\eta_h \\ p_{t,q}=Jp_{t,h}/z}} .$$

Summing over flavours of quarks and antiquarks !

Pions



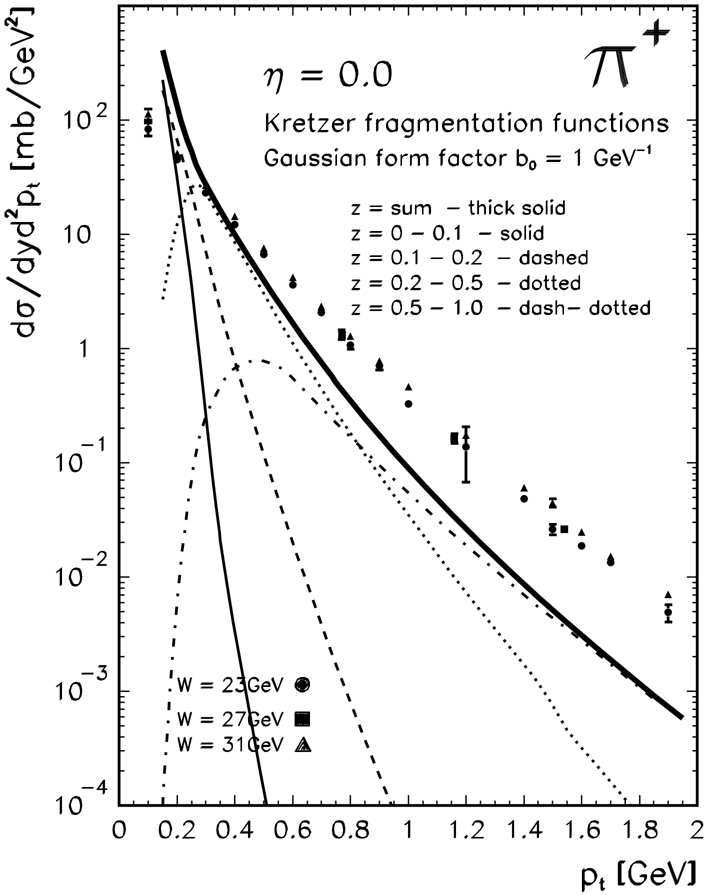
$\eta = 0$

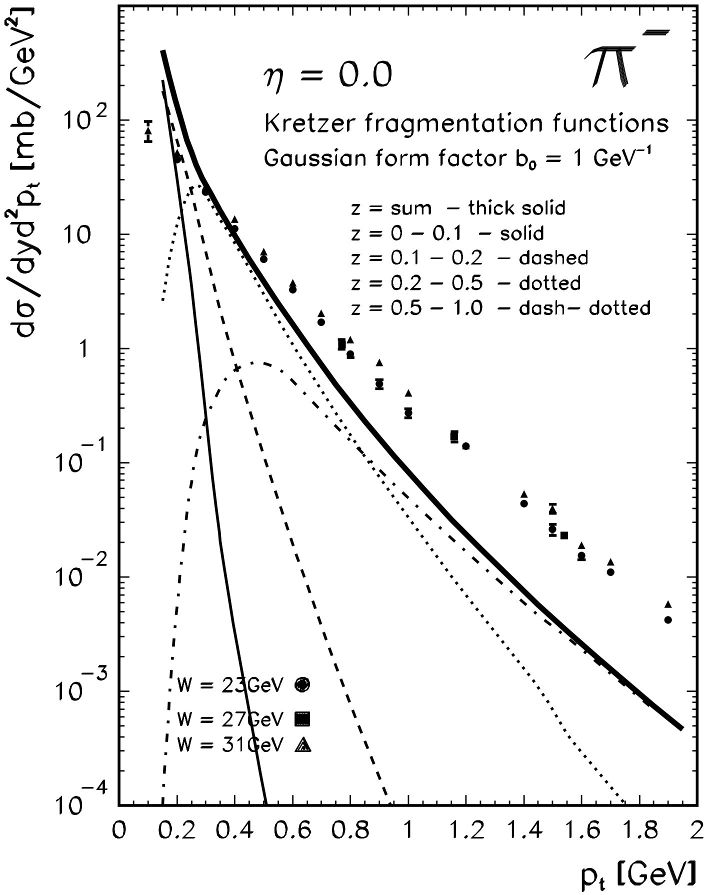
theory: W = 27.4 GeV

experiment: W = 23, 31 GeV (Alper)

experiment: W = 27.4 GeV (Antreasyan)

Pions, fragmentation function scan



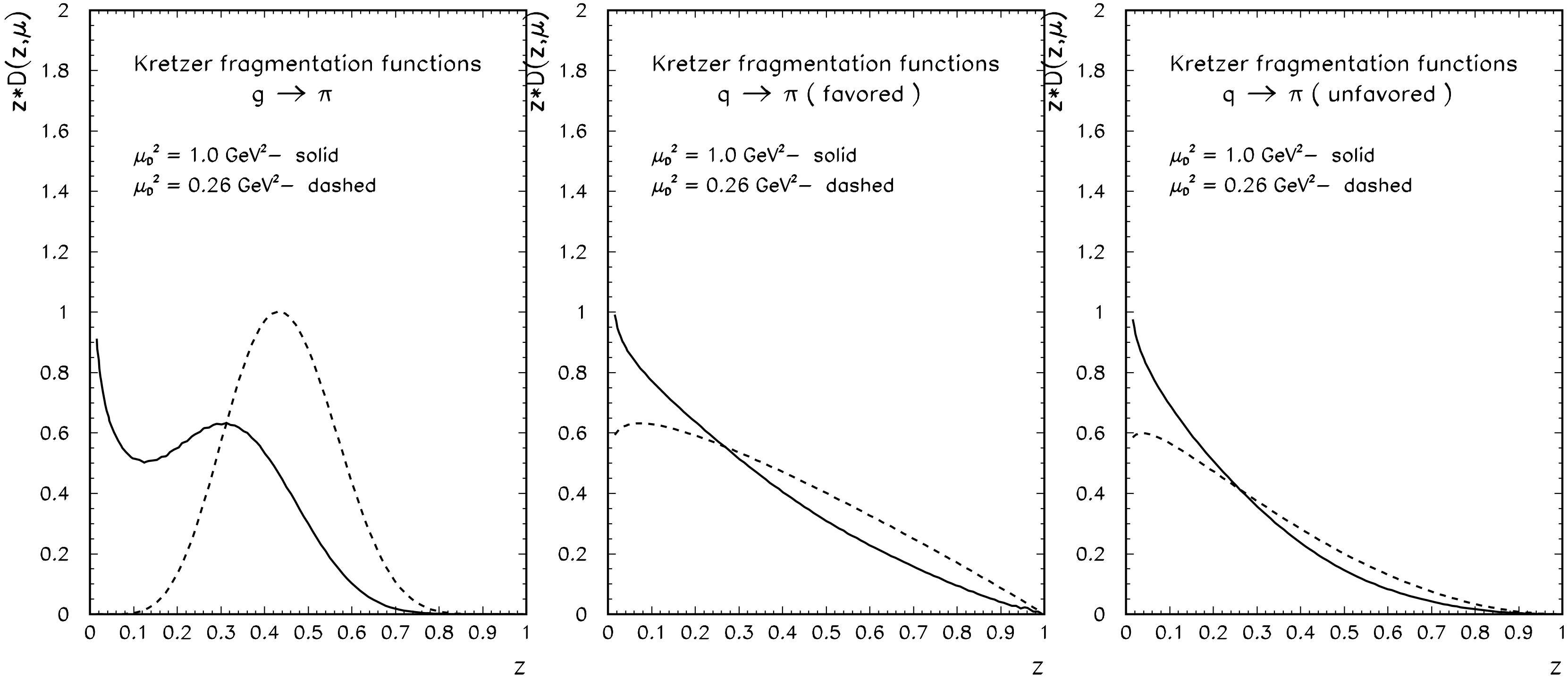


η = 0

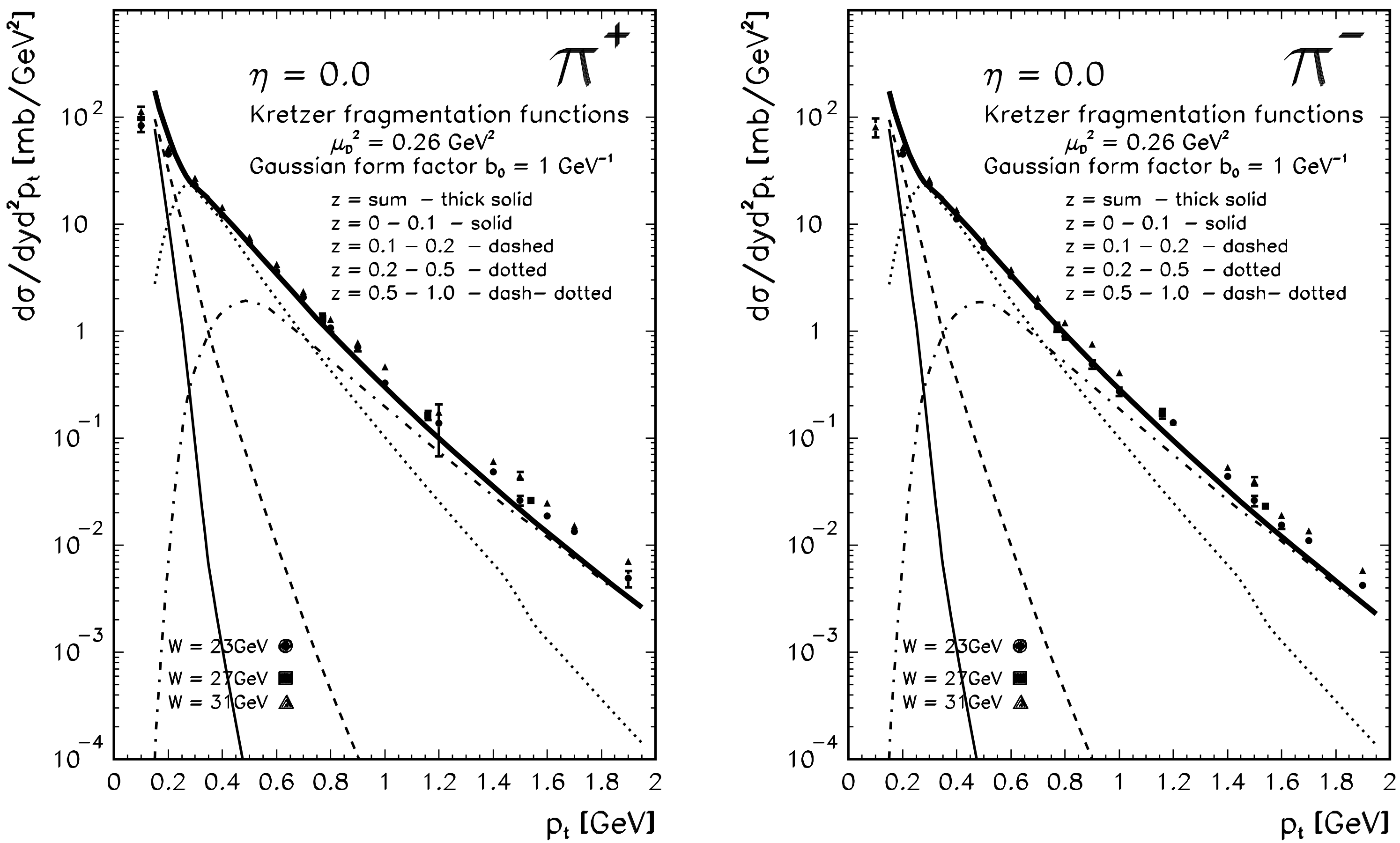
W = 27.4 GeV

b_0 = 1 GeV^{-1}

Fragmentation functions at low scales

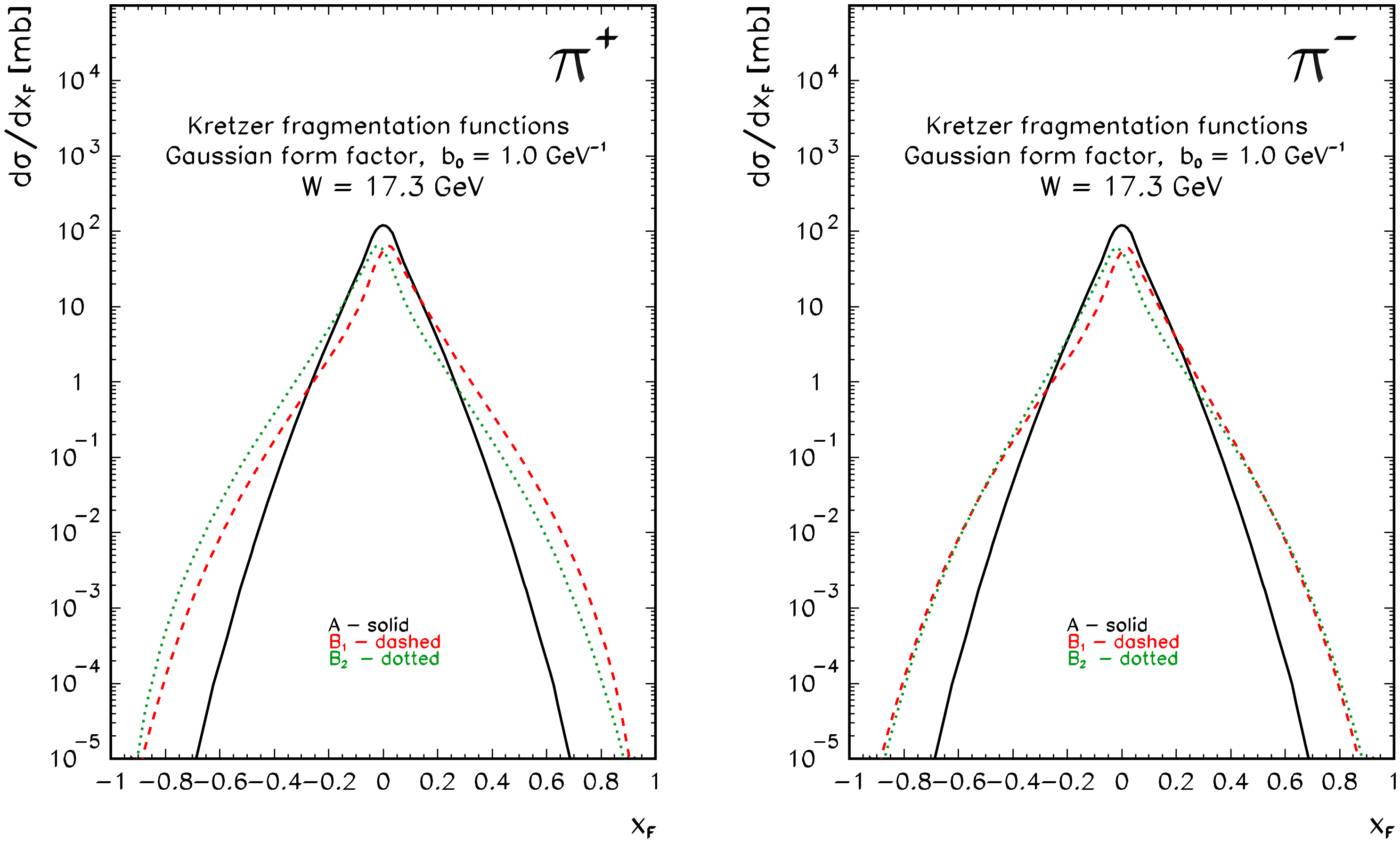


Pions, freezing scale for D(z) functions



η = 0
W = 27.4 GeV
b_0 = 1 GeV^{-1}

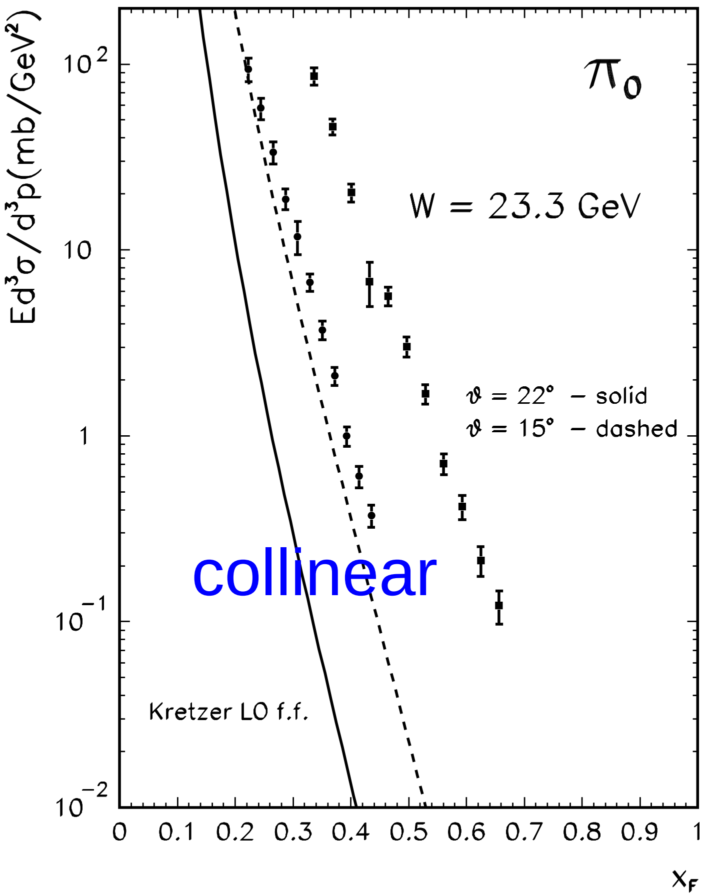
Pions, diagram decomposition

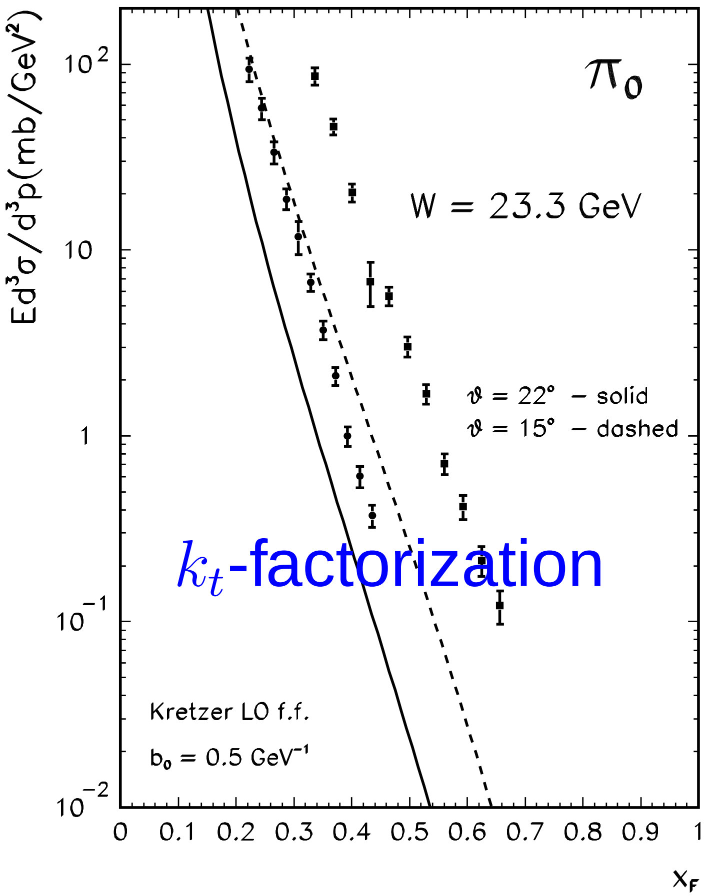


W = 17.3 GeV

b_0 = 1 GeV^{-1}

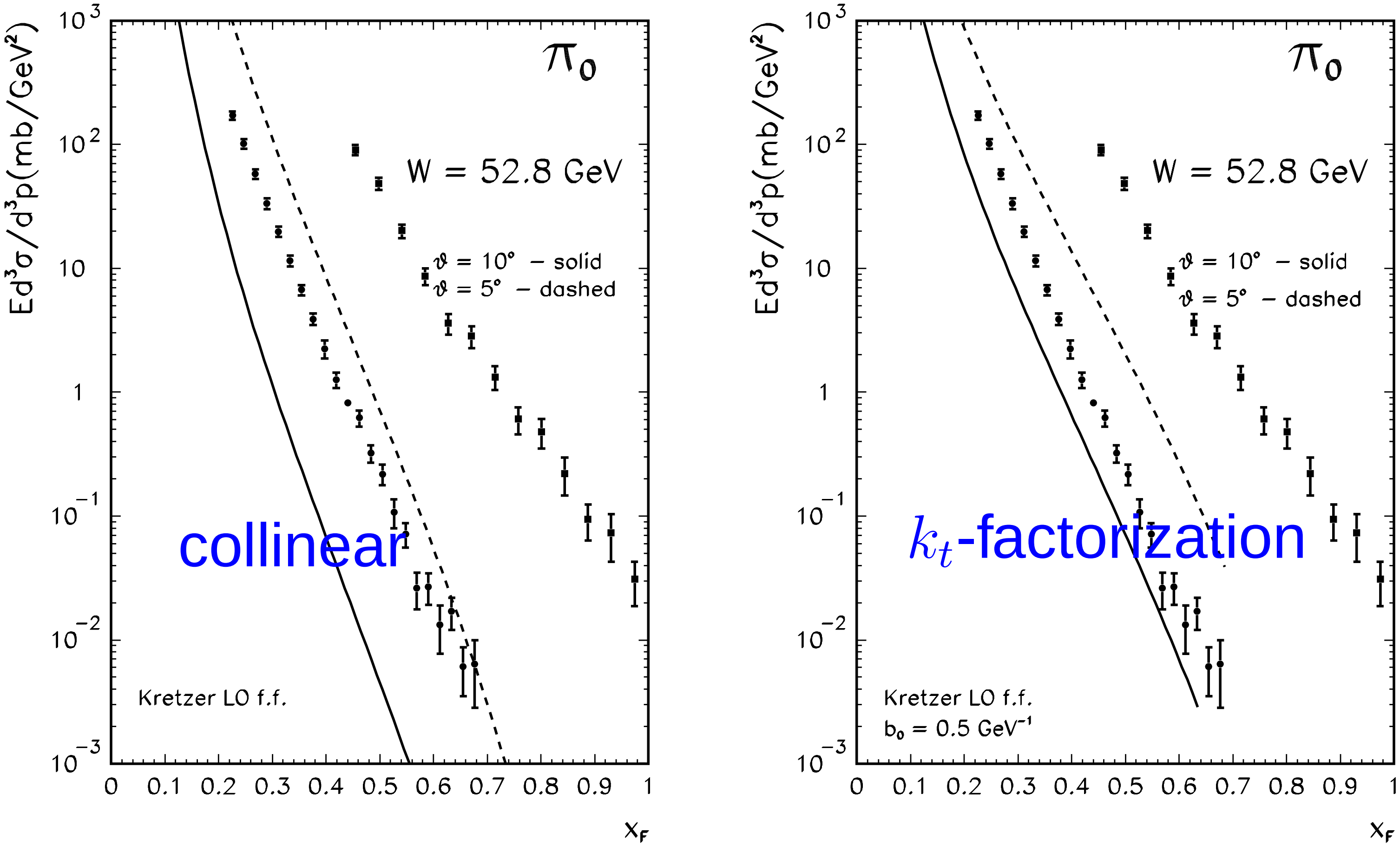
ISR forward rapidities





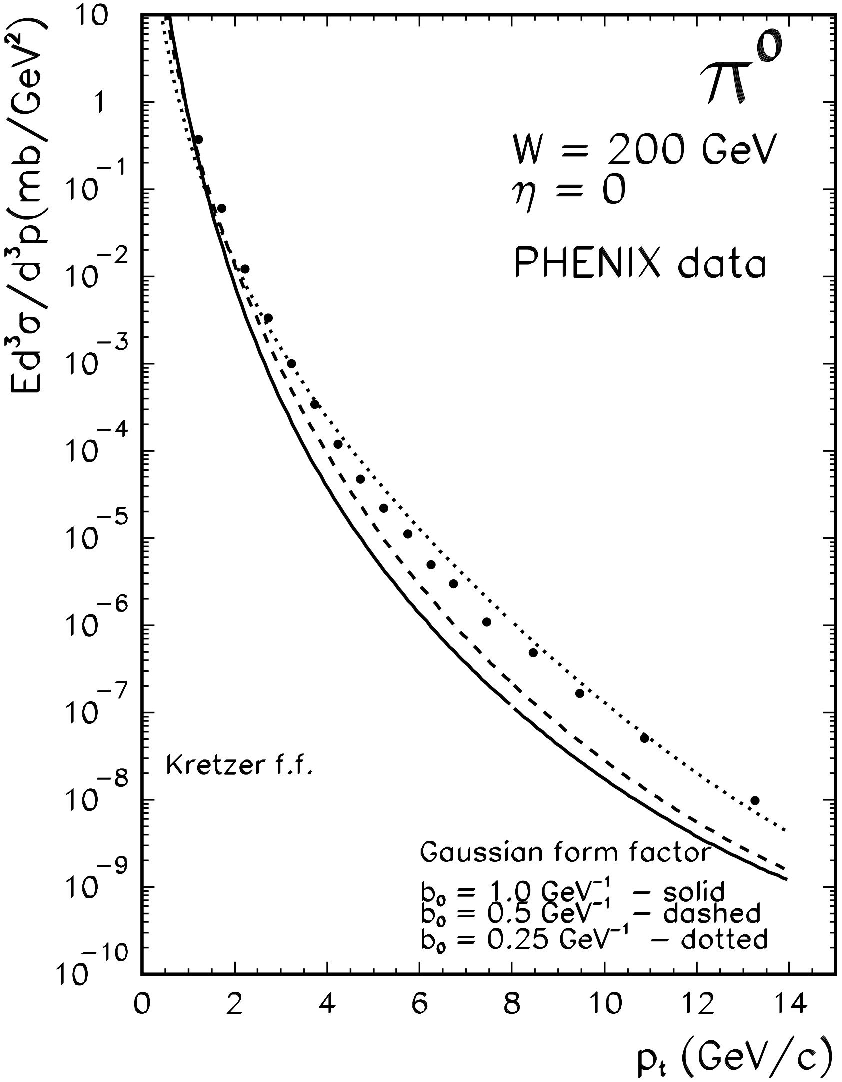
W = 23.3 GeV

ISR forward rapidities

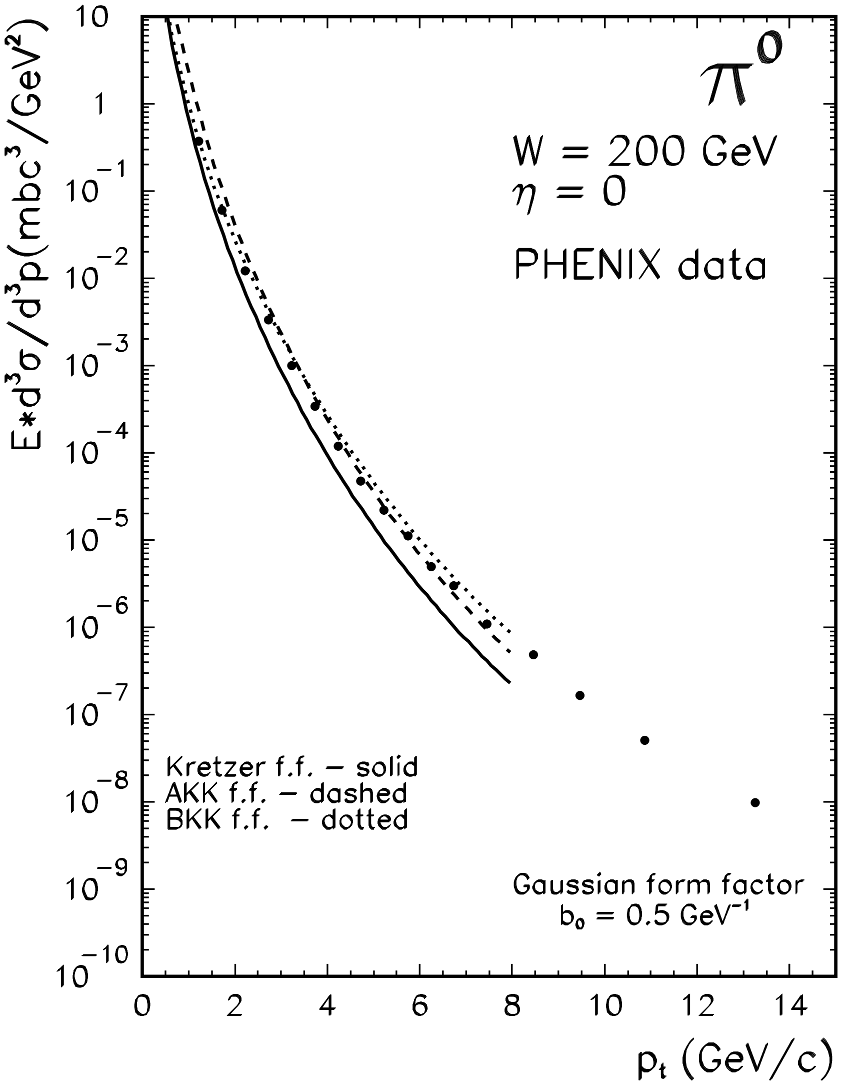


W = 52.8 GeV

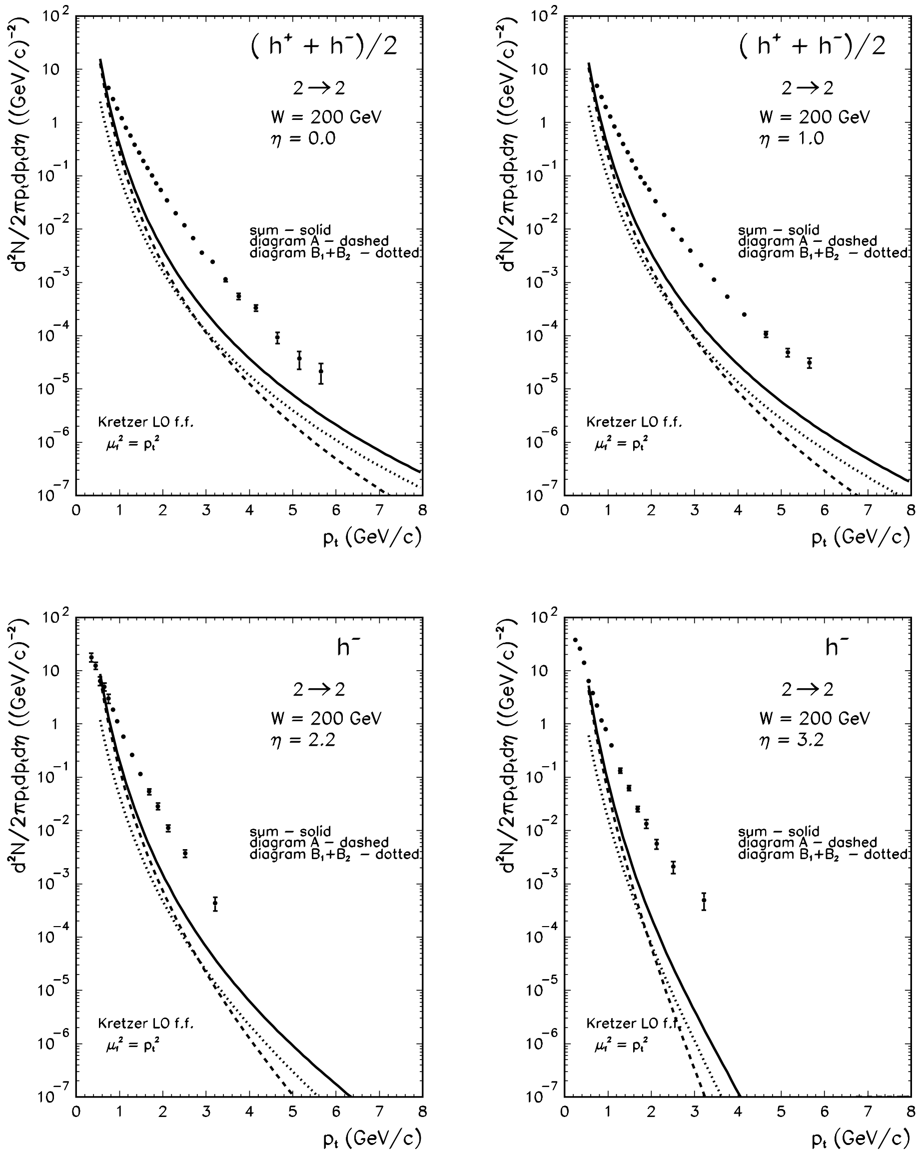
PHENIX π^0 data, b_0 dependence



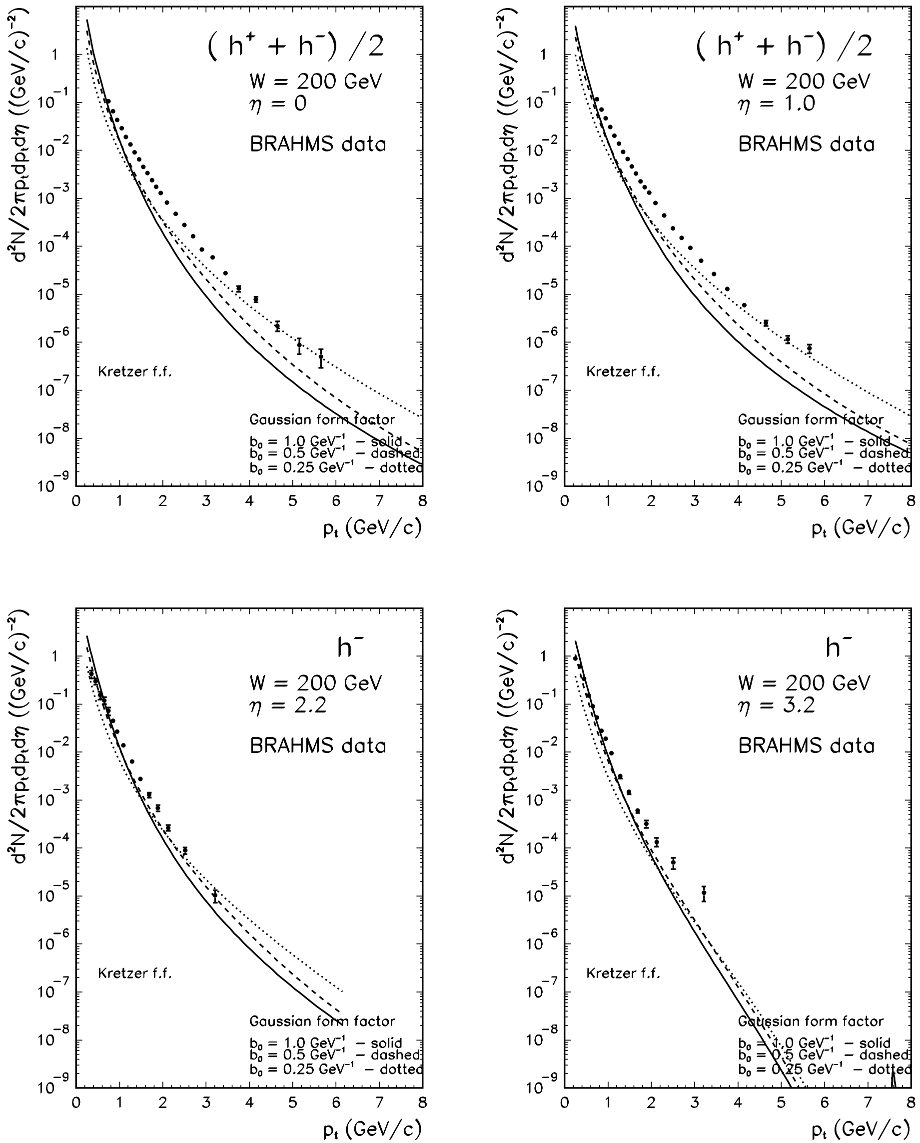
PHENIX π^0 data, fragmentation functions



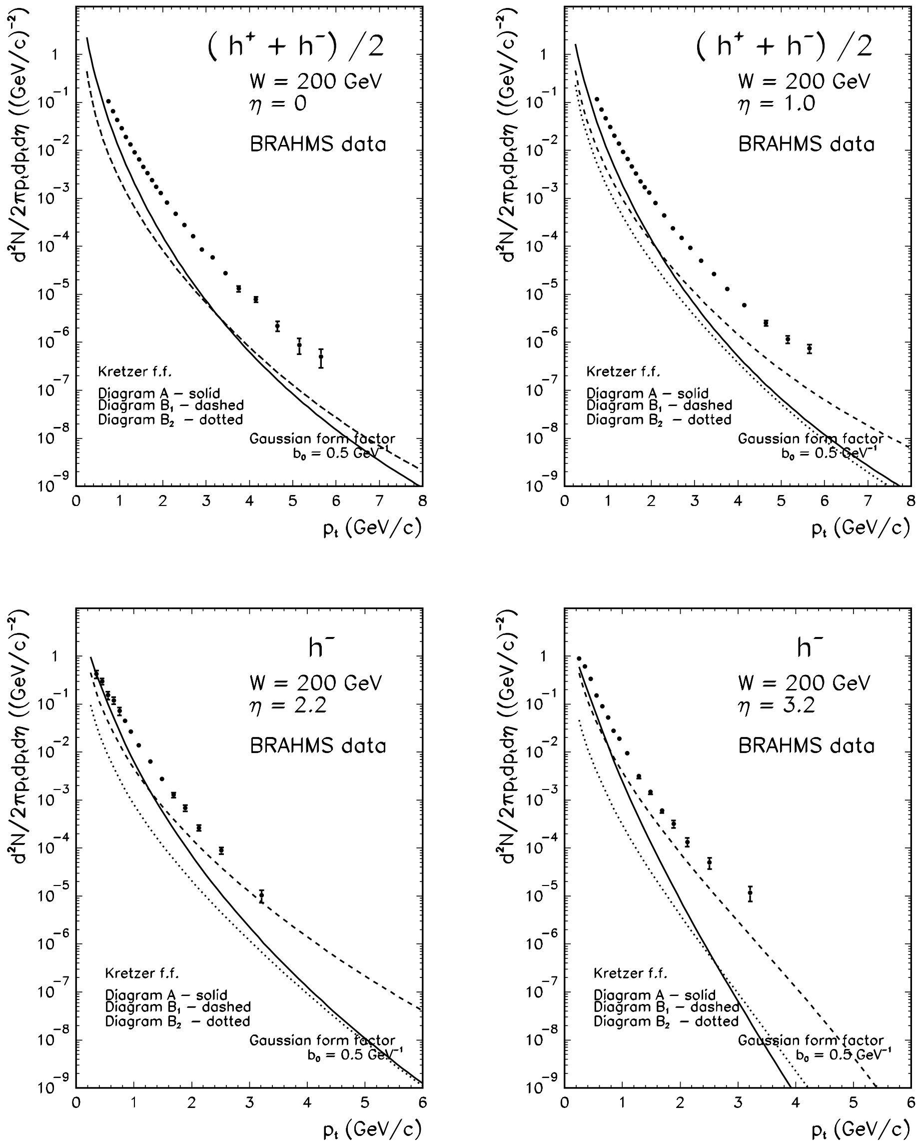
BRAHMS, collinear approach



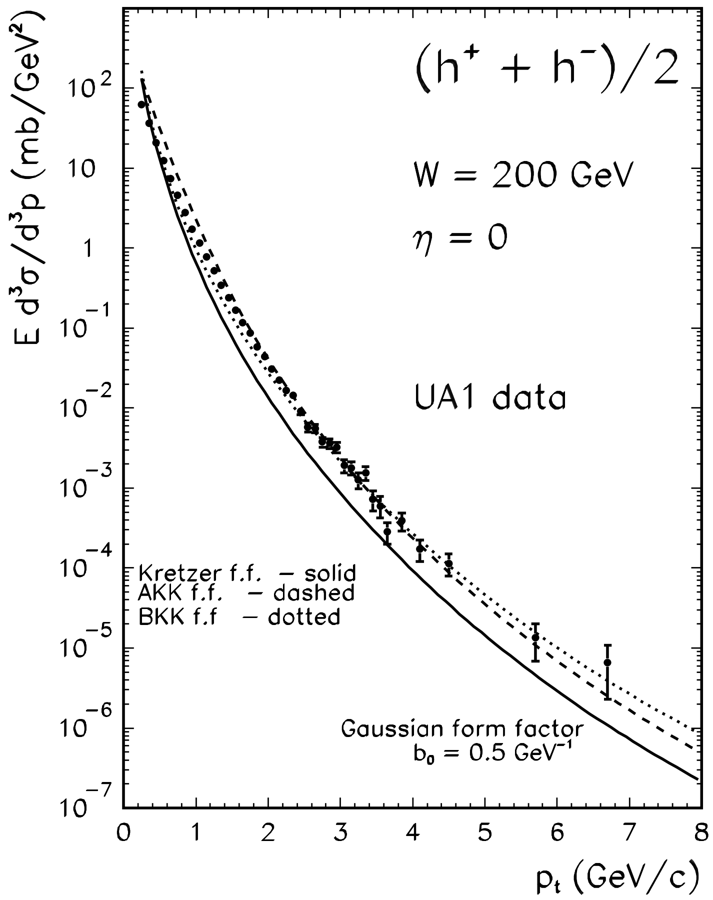
BRAHMS, k_t-factorization approach

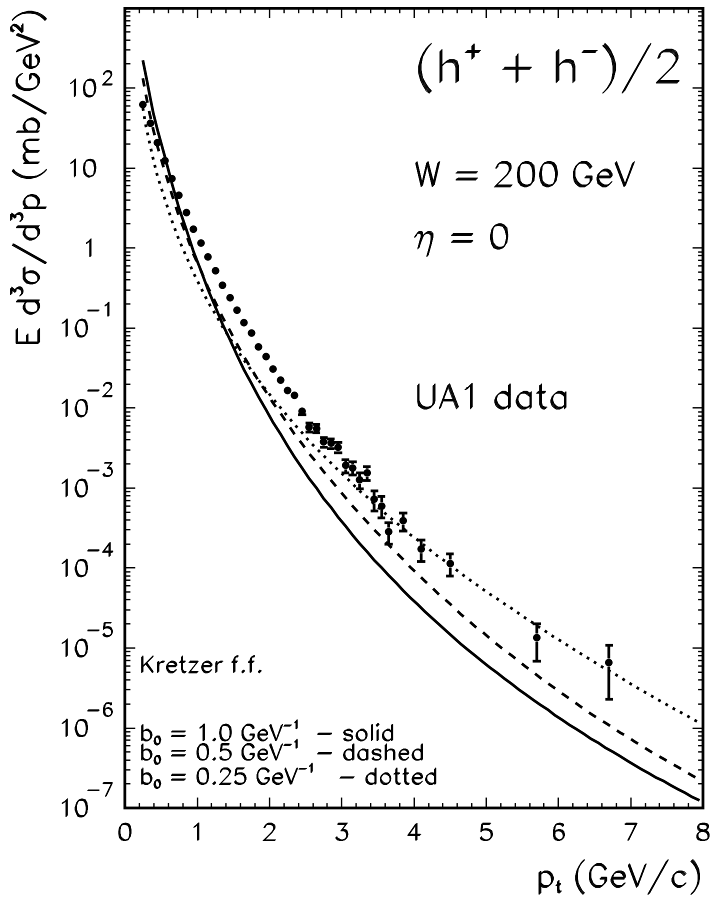


BRAHMS, k_t-factorization, diagrams

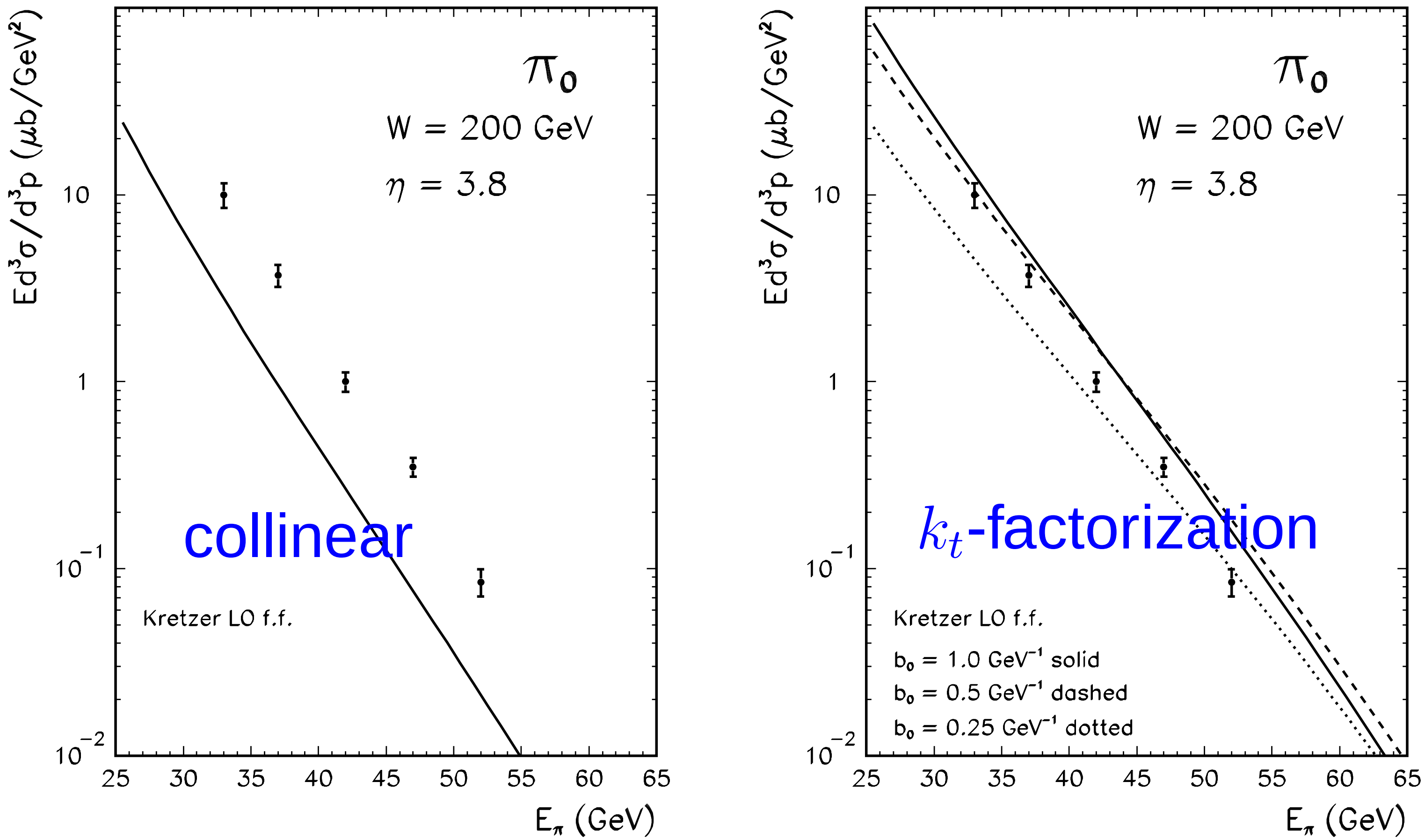


UA1, k_t-factorization



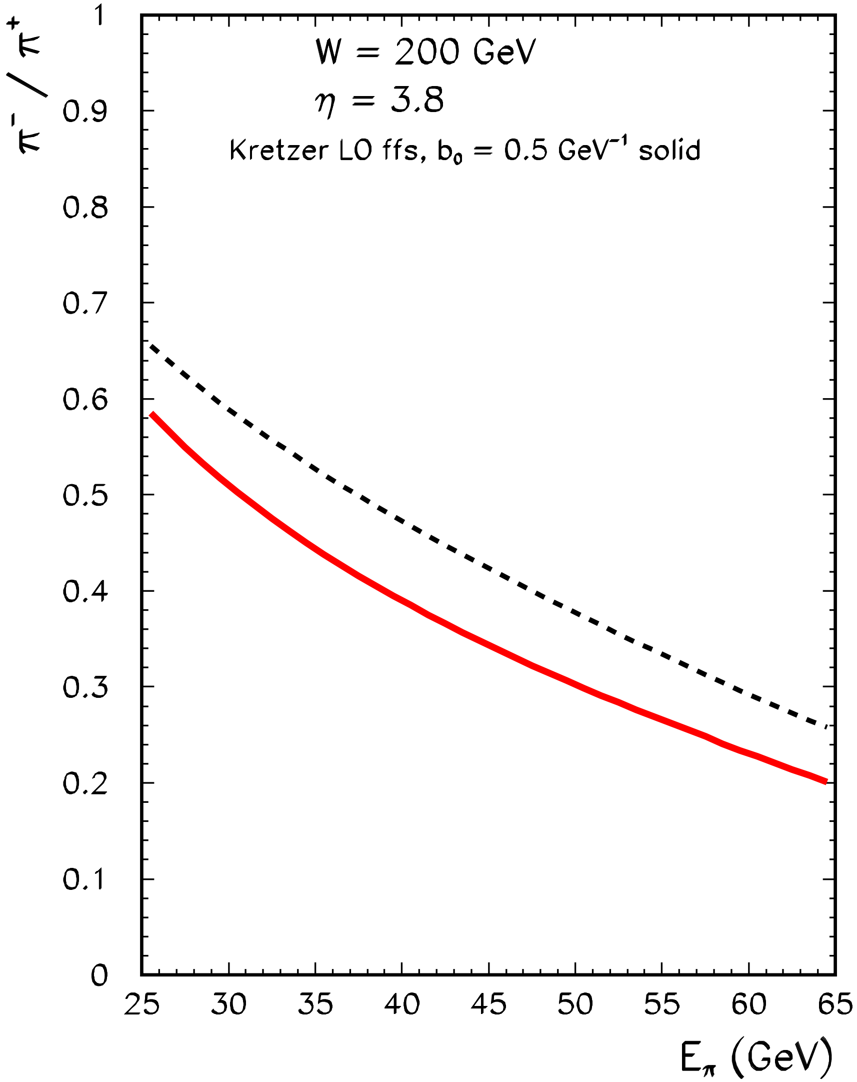


STAR, forward rapidities



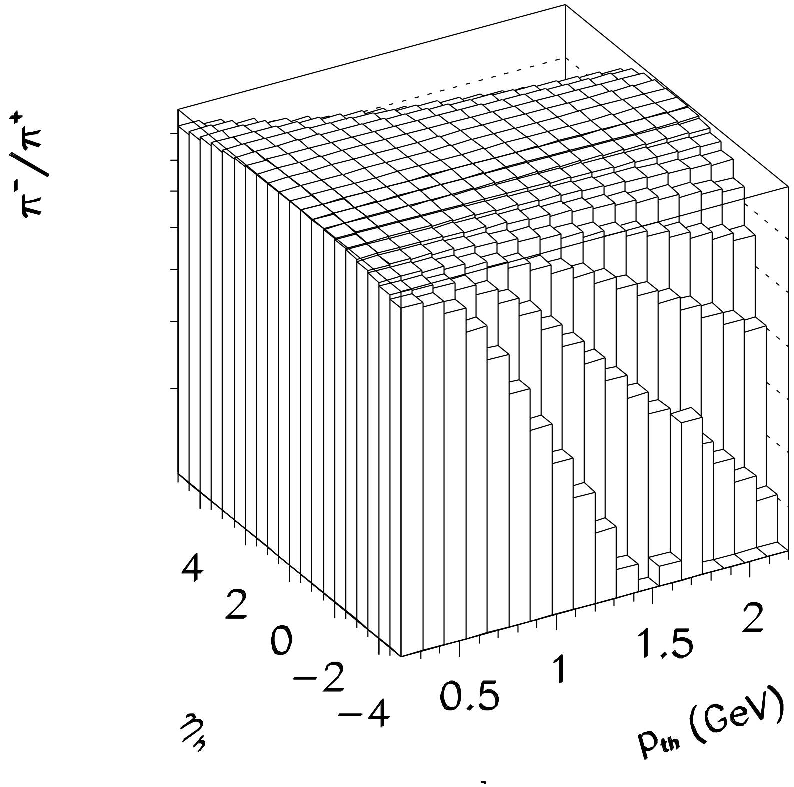
$\eta = 3.8$

π^- / π^+ ratio at forward rapidities



$\pi^+ - \pi^-$ asymmetry at RHIC

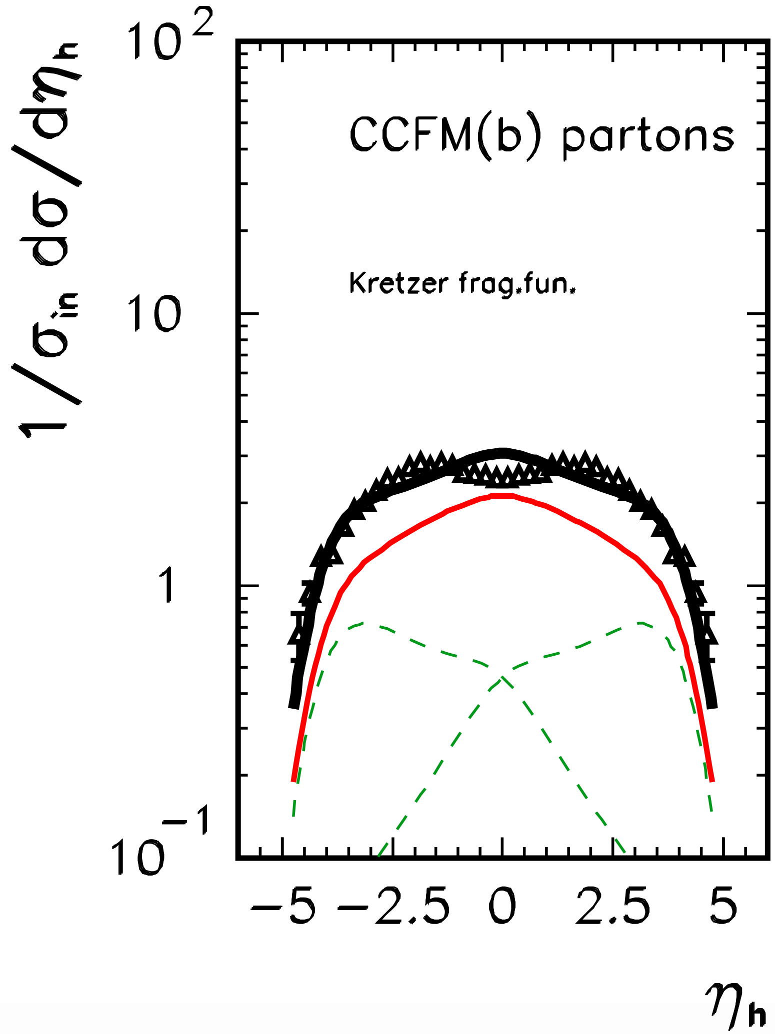
proton-proton collisions
gluons,(anti)quarks, W = 200 GeV



BRAHMS can measure !!!

Both gluons and (anti)quarks

gluons, (anti)quarks, W = 200 GeV
UA5 data



Homework to be done

- Testing uPDF's and/or $F^{np}(b, x, ..., ?, ...)$ in:
  - Drell-Yan dimuon production
  - Prompt photon production
  - Heavy quark production/correlations
  - Jet correlations
- Missing mechanisms of particle production:
  - $q\bar{q} \to g$ (low-energy problem?)
  - remnant frag. and/or leading baryons (fragmentation region?)
  - stripping of the pion cloud (camel-like shape?)
  - diffractive production (fragmentation region?)
- NLO for parton/particle production (important for larger p_t ?).
- Resonance decays explicitly ? (important at small p_t)