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UNINTEGRATED PARTON DISTRIBUTIONS AND PARTICLE PRODUCTION IN HADRONIC COLLISIONS

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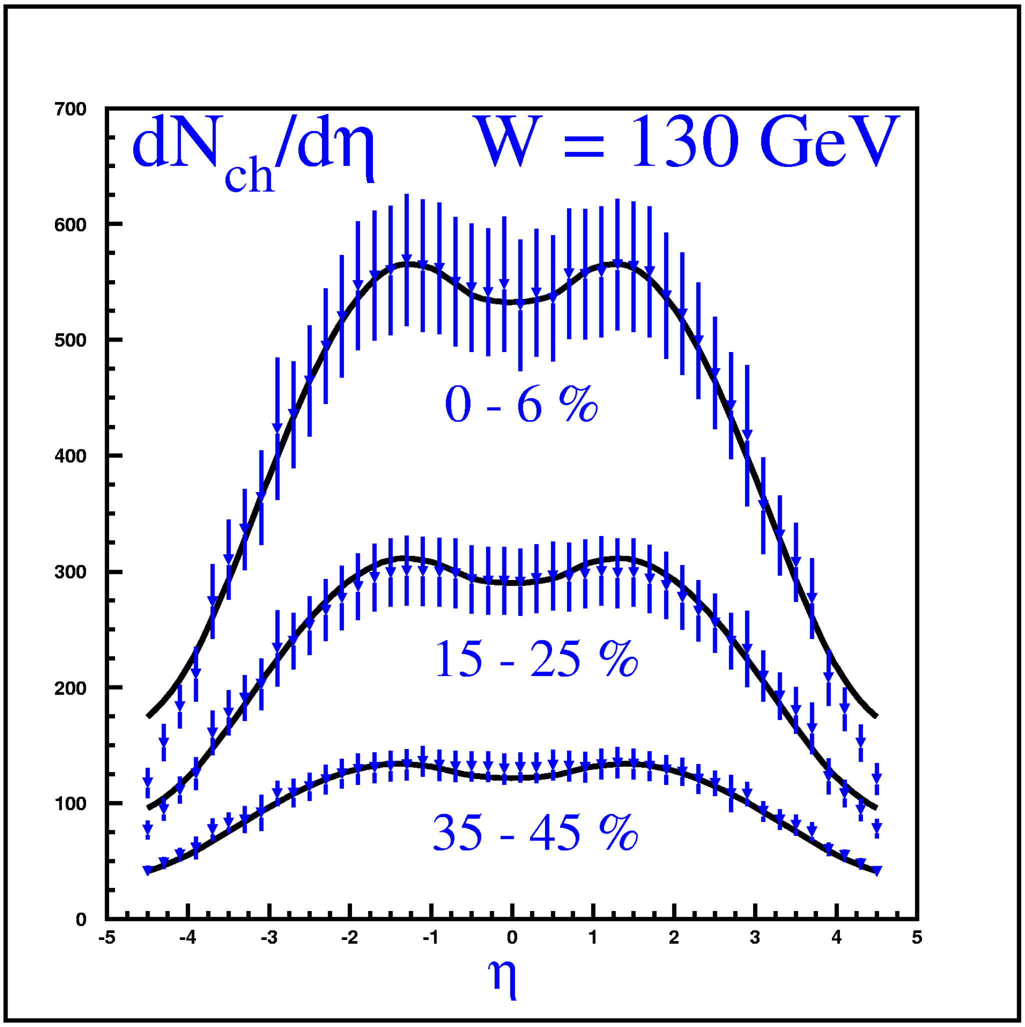
Motivation

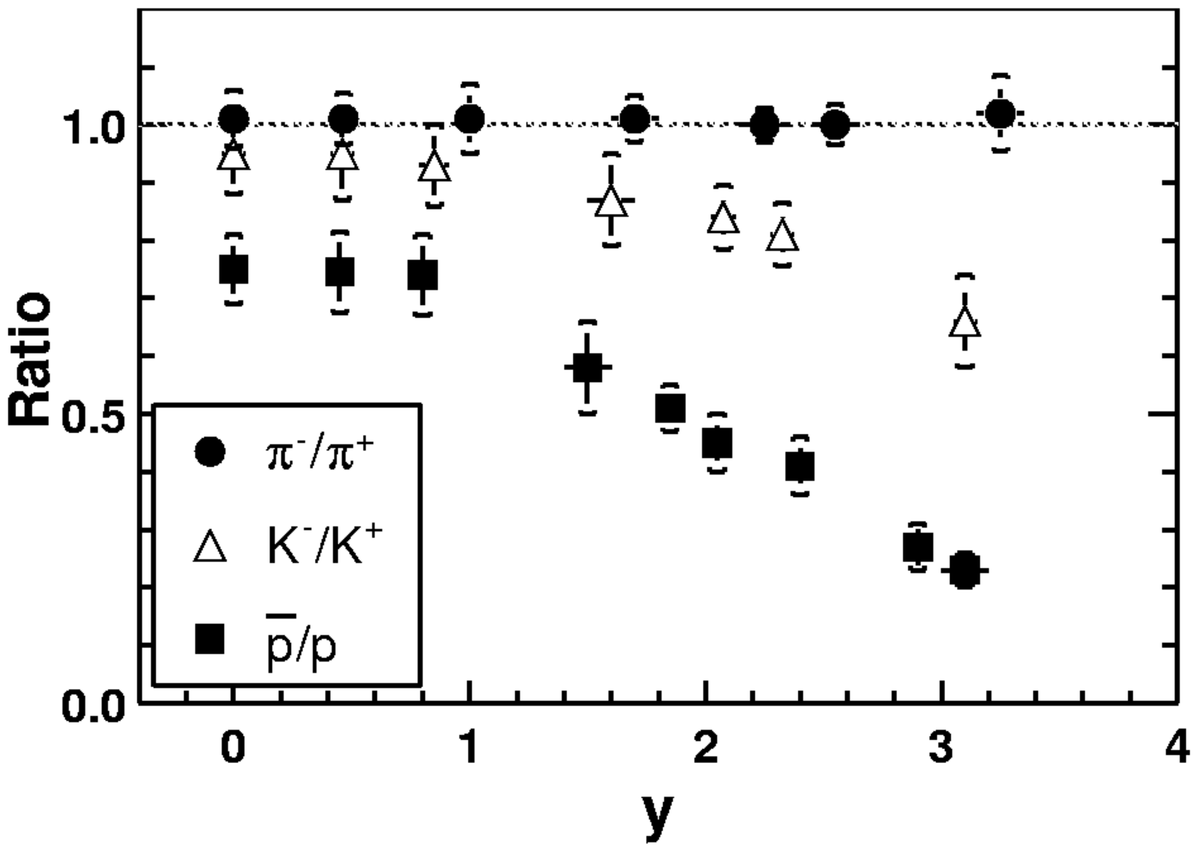
Charged particle pseudorapitity spectra in relativistic heavy ion collisions at RHIC (Karzeev-Levin)



Gluon-gluon fusion
($\rightarrow$ unintegrated gluon distribution)

Motivation

Particle ratios at RHIC
(BRAHMS collaboration)



$K^-/K^+ \neq 1$!!!

and (pseudo)rapidity dependent

THESE RESULTS ARE INCONSISTENT !

Karzeev-Levin gluon distr.

Let's take the most simplified functional form:

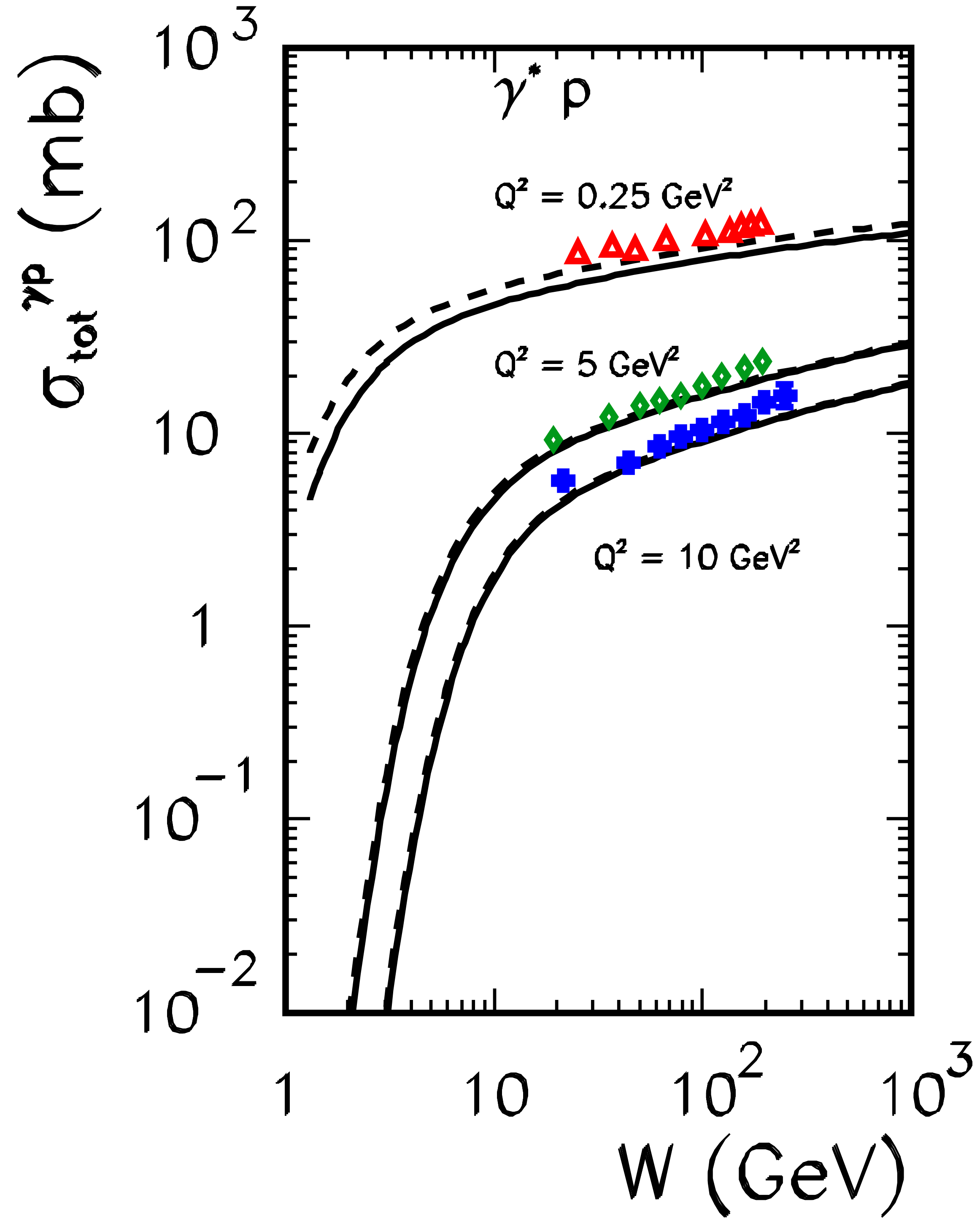
$$\mathcal{F}(x,\kappa^2) = \begin{cases} f_0 & \text{if } \kappa^2 < Q_s^2, \\ f_0 \cdot \frac{Q_s^2}{\kappa^2} & \text{if } \kappa^2 > Q_s^2. \end{cases} \quad (1)$$

Saturation momentum from Golec-Biernat-Wüsthoff model $Q_s^2(x) = 1 \text{ GeV}^2 \cdot \left(\frac{x_0}{x}\right)^{\lambda}$.

Let's fit f_0 to the HERA data

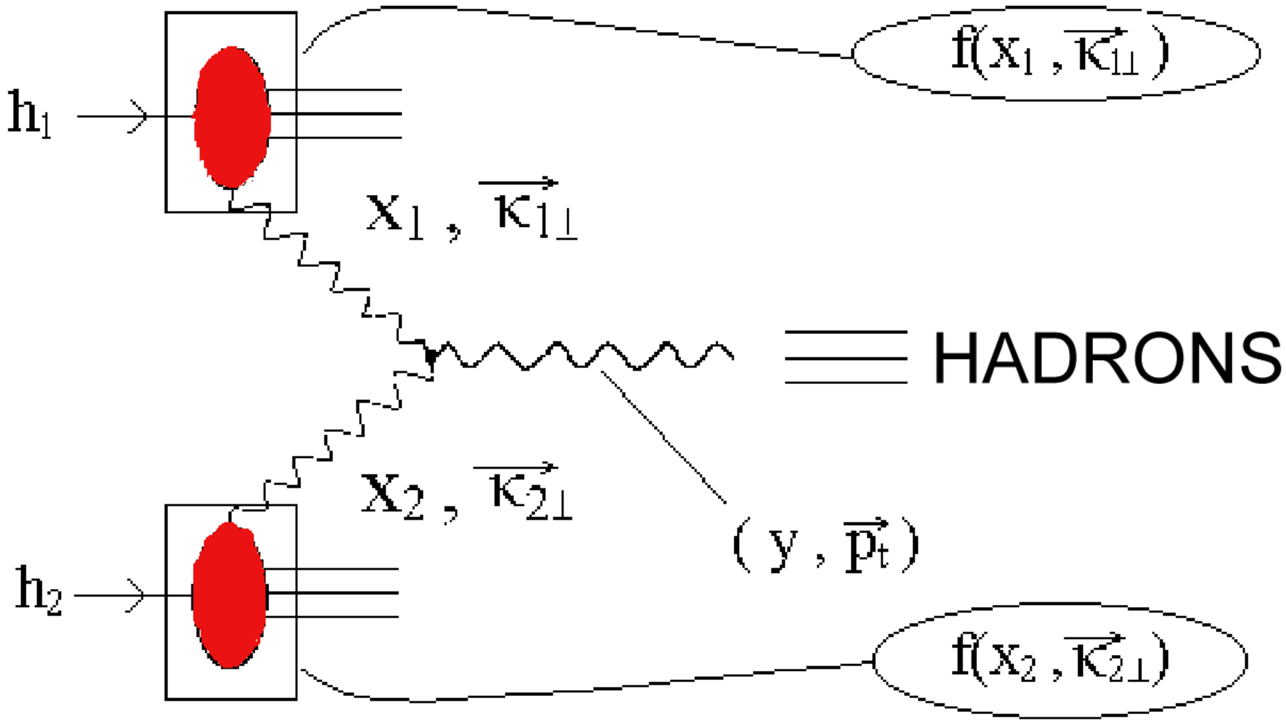
(→ see next page)

$\sigma_{tot}^{\gamma^* p}$



Inclusive gluon production

consider reaction: $h_1 + h_2 \to g$



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

$$\int \alpha_s(\Omega^2)\mathcal{F}_1(x_1,\kappa_1^2)\mathcal{F}_2(x_2,\kappa_2^2)$$

$$\delta(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t)\; d^2\kappa_1 d^2\kappa_2 \; . \qquad (2)$$

(Gribov-Levin-Ryskin, Gyulassy-McLerran)

$\mathcal{F}_1$, $\mathcal{F}_2$ - unintegr. gluon distr. in h_1, h_2,

$x_{1/2} = \frac{p_t}{\sqrt{s}} \cdot \exp(\pm y)$.

$\Omega^2 = \max(\kappa_1^2, \kappa_2^2, p_t^2)$.

Let introduce: $\vec{q}_t = \vec{\kappa}_1 - \vec{\kappa}_2$

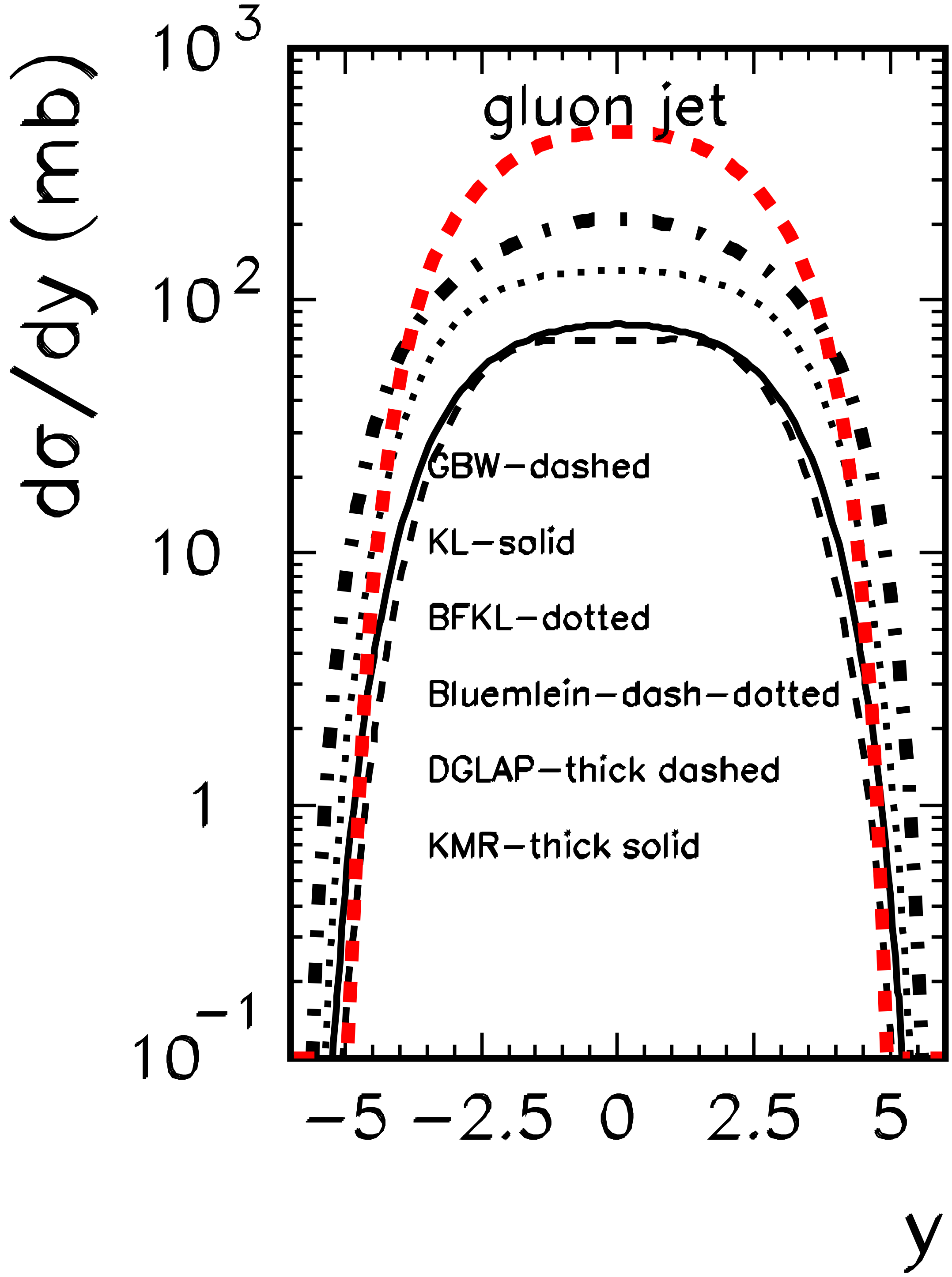
$$\frac{d\sigma}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \frac{1}{p_t^2} \frac{1}{4} \int \alpha_s(\Omega^2)$$
$$\mathcal{F}_1\left(x_1, \left(\frac{\vec{p}_t + \vec{q}_t}{2}\right)\right) \mathcal{F}_2\left(x_2, \left(\frac{\vec{p}_t - \vec{q}_t}{2}\right)\right) d^2 q_t$$

$$\frac{d\sigma}{dy d^2 p_t} = \int I(\phi) \, d\phi \,, \tag{3}$$

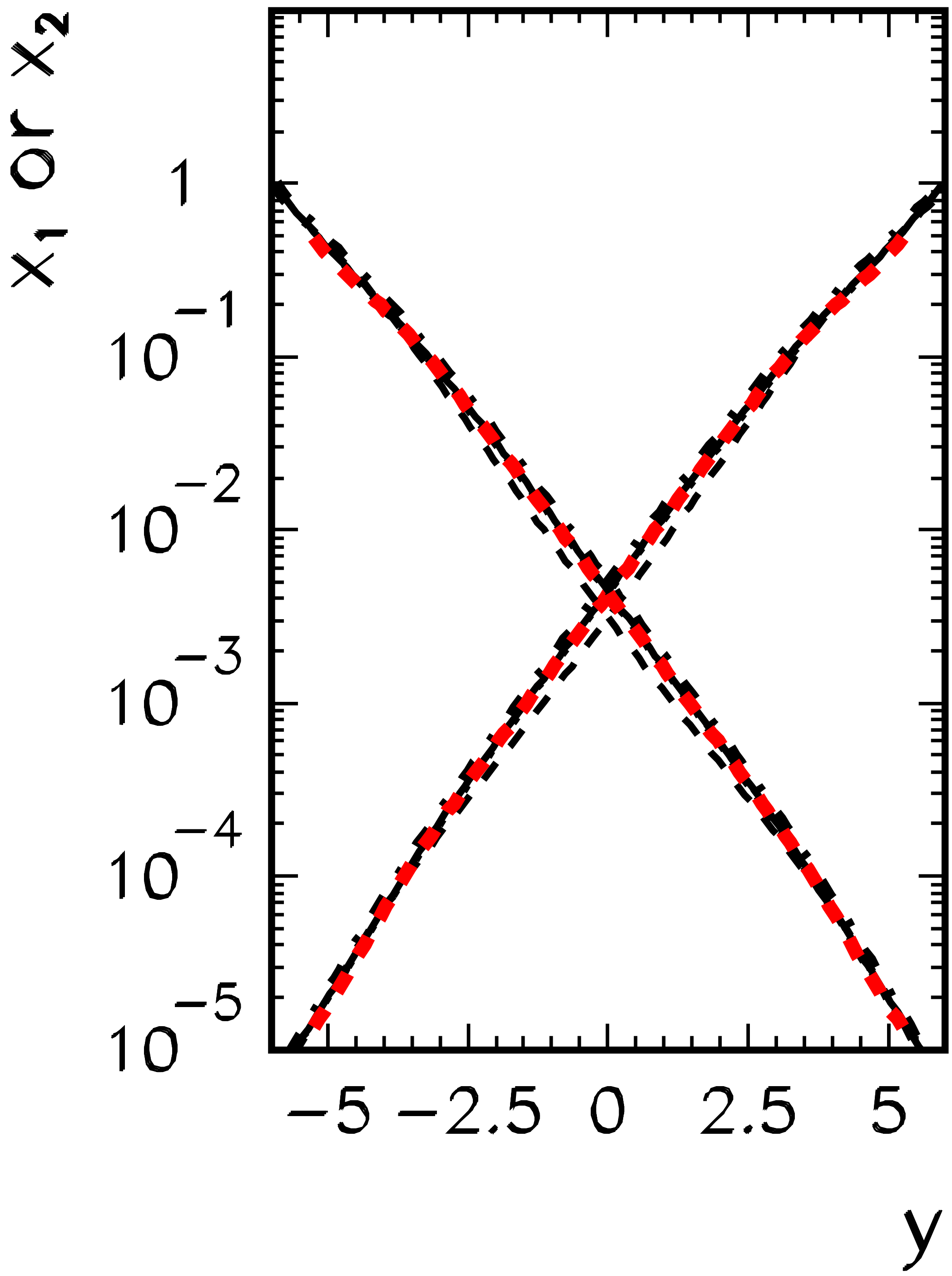
where

$$I(\phi) = \frac{4 N_c}{N_c^2 - 1} \frac{1}{p_t^2}$$
$$\int \alpha_s(\Omega^2) \mathcal{F}_1\left(x_1, \kappa_1^2\right) \mathcal{F}_2\left(x_2, \kappa_2^2\right) \; q_t dq_t \,. \tag{4}$$

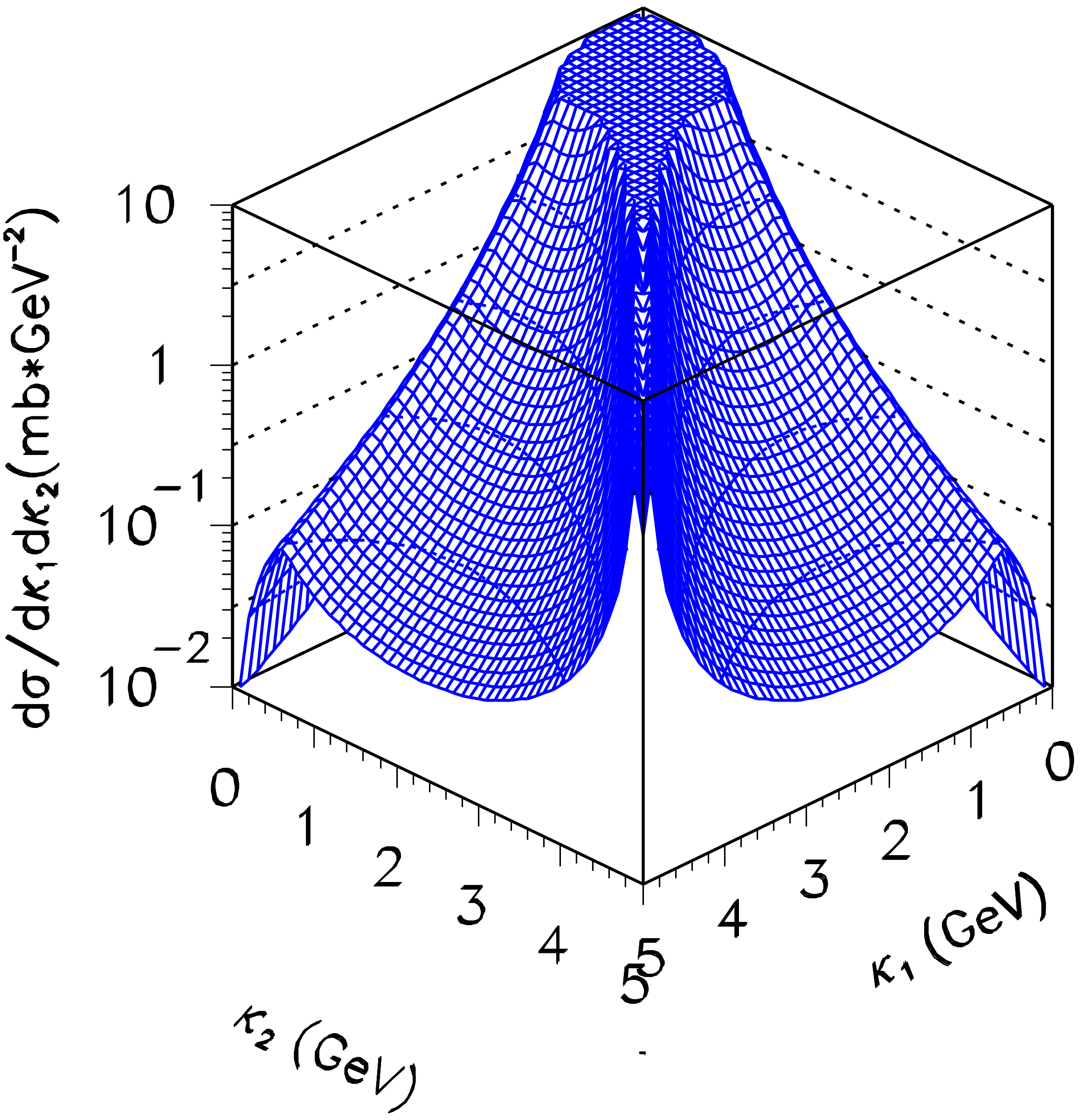
gluon rapidity distribution



$< x_1 >$ and $< x_2 >$



transverse momenta of uPDF



Kinematics of fragmentation

$$y_h = \frac{1}{2}\left[\frac{\sqrt{\frac{m_h^2+p_{t,h}^2}{p_{t,h}^2}+\sinh^2\eta_h}+\sinh\eta_h}{\sqrt{\frac{m_h^2+p_{t,h}^2}{p_{t,h}^2}+\sinh^2\eta_h}-\sinh\eta_h}\right] . \tag{5}$$

Collinearity of gluons and hadrons

$$y_g = \operatorname{arsinh}\left(\frac{m_{t,h}}{p_{t,h}}\sinh y_h\right) . \tag{6}$$

Let's define z: $E_h = zE_g$, then

$$p_{t,g} = \frac{p_{t,h}}{z} J(m_{t,h}, y_h) , \tag{7}$$

$$J(m_{t,h}, y_h) = \left(1 - \frac{m_h^2}{m_{t,h}^2 \cosh^2 y_h}\right)^{-1/2} . \tag{8}$$

From gluons to hadrons

$$\frac{d\sigma(\eta_h, p_{t,h})}{d\eta_h d^2 p_{t,h}} = \int dy_g d^2 p_{t,g} \int dz\, D_{g\to h}(z, \mu_D^2) \tag{9}$$

$$\delta(y_g - \eta_h)\, \delta^2\left(\vec{p}_{t,h} - \frac{z\vec{p}_{t,g}}{J}\right) \cdot \frac{d\sigma(y_g, p_{t,g})}{dy_g d^2 p_{t,g}} \,.$$

$$\frac{d\sigma(\eta_h, p_{t,h})}{d\eta_h d^2 p_{t,h}} = \int_{z_{min}}^{z_{max}} dz \frac{J^2 D_{g\to h}(z, \mu_D^2)}{z^2} \tag{10}$$

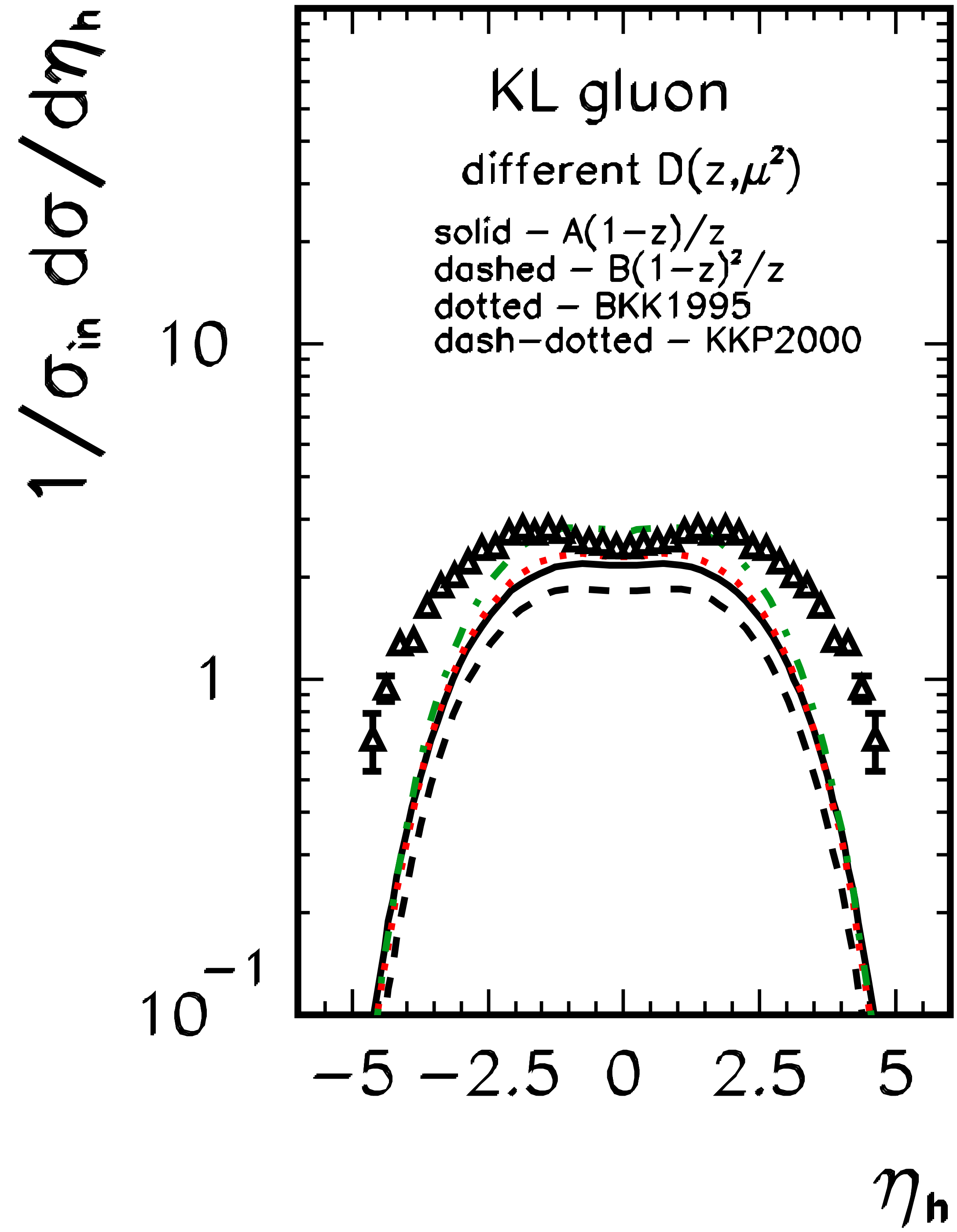
$$\left.\frac{d\sigma(y_g, p_{t,g})}{dy_g d^2 p_{t,g}}\right|_{\substack{y_g = \eta_h \\ p_{t,g} = J p_{t,h}/z}} \,.$$

Fragmentation functions from e^+e^- collisions:

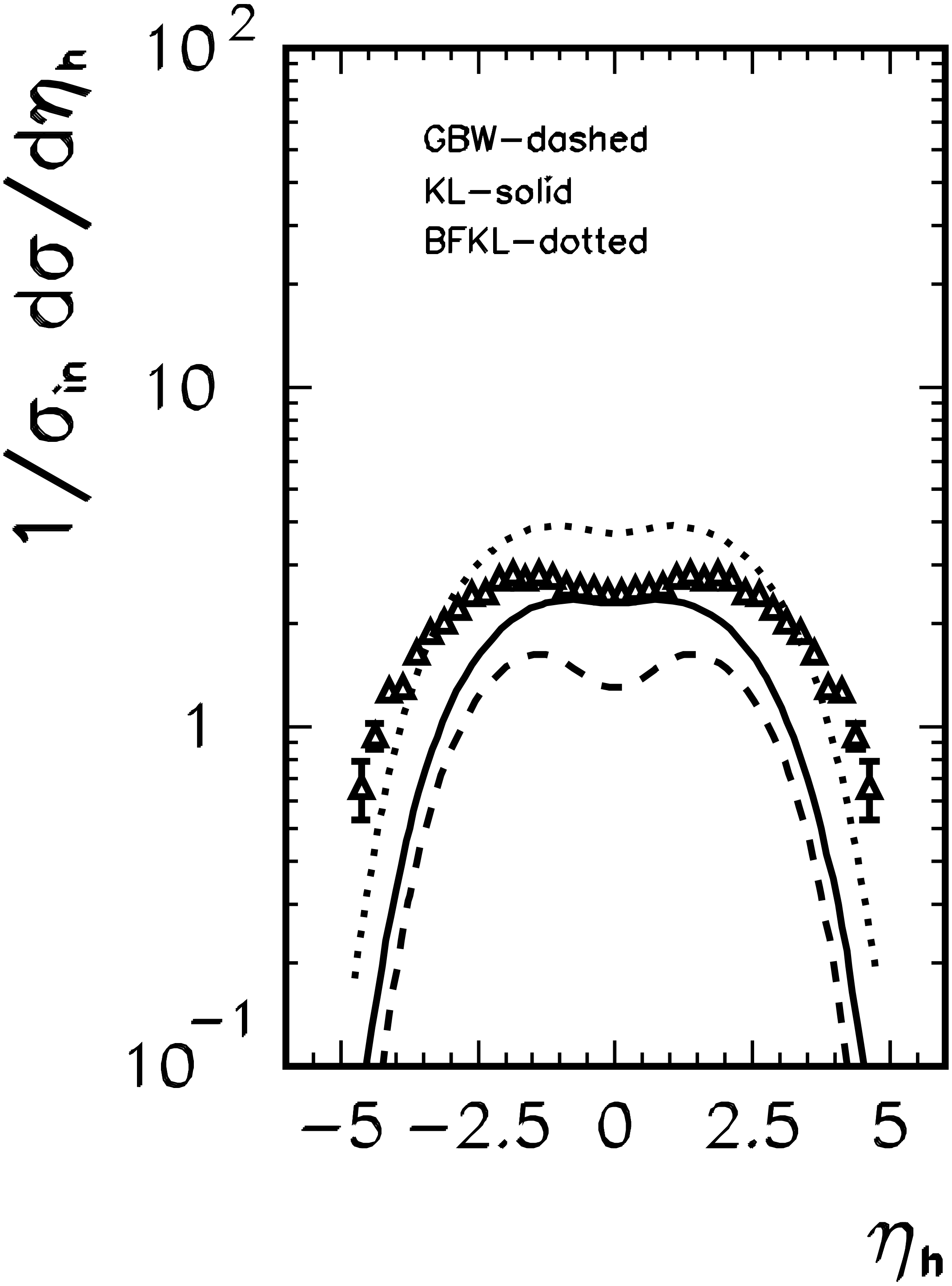
(a) Binnewies-Kniehl-Kramer (BKK95)

(b) Kniehl-Kramer-Pötter (KKP00)

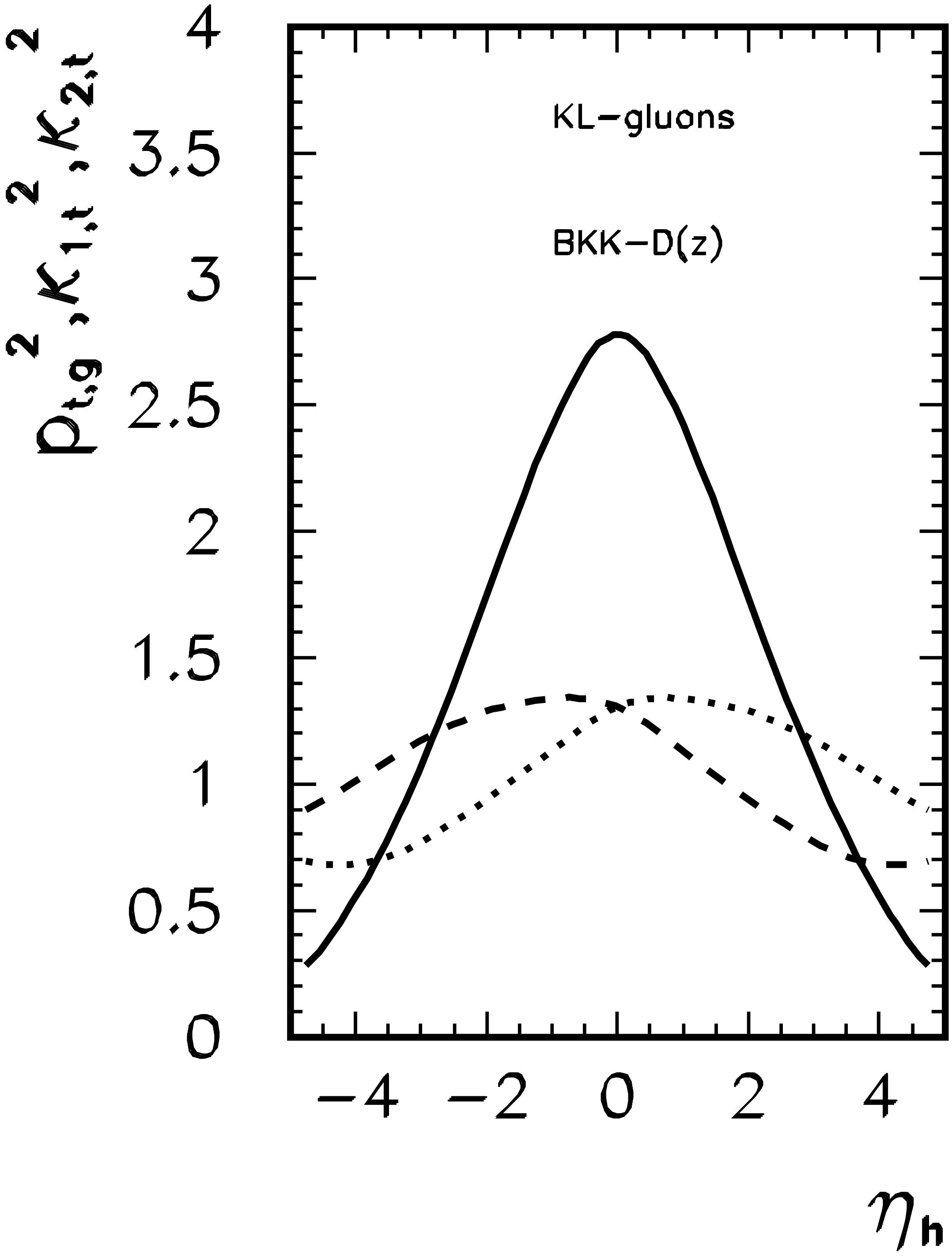
pseudorapidity dist. of particles



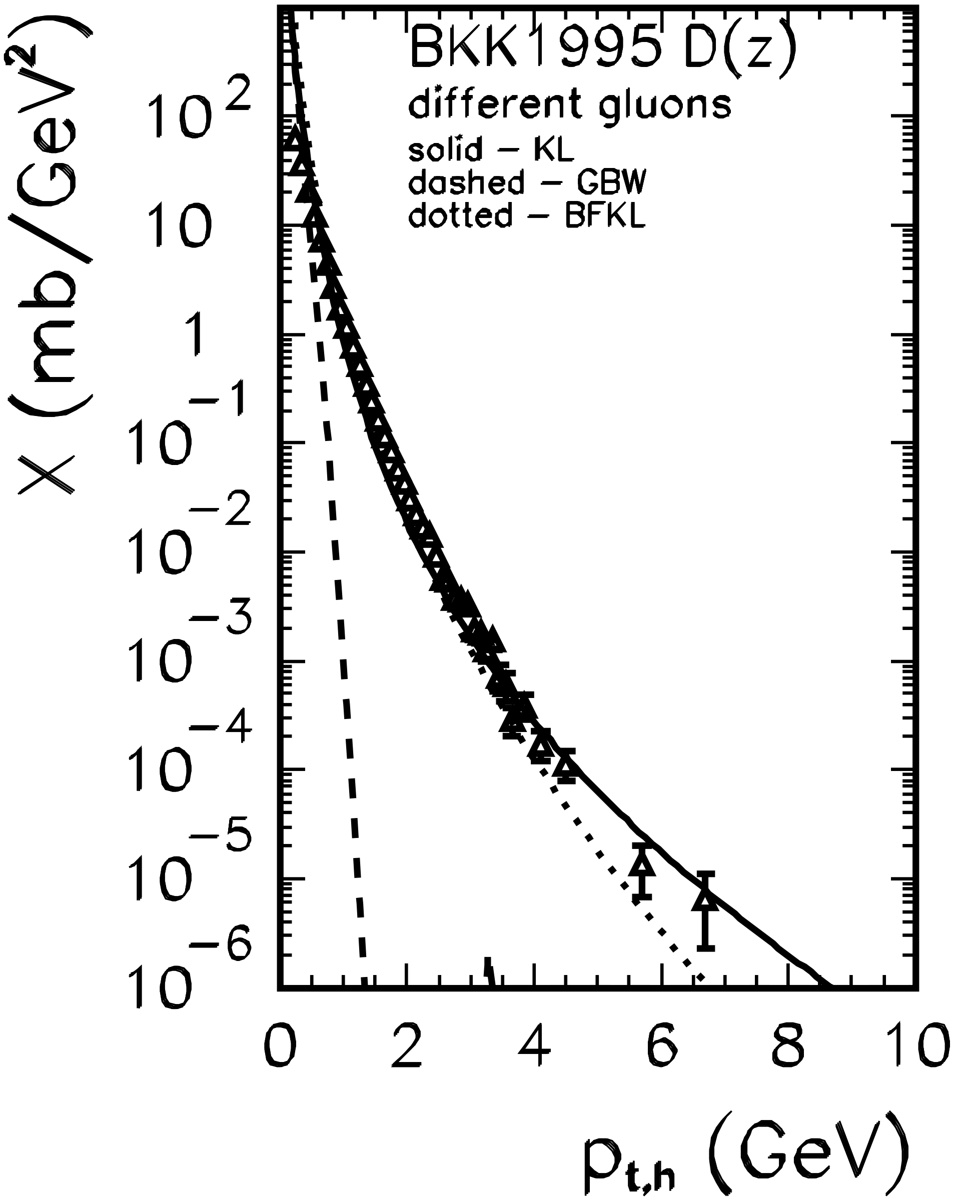
pseudorapidity dist. of particles



average trans. mom.

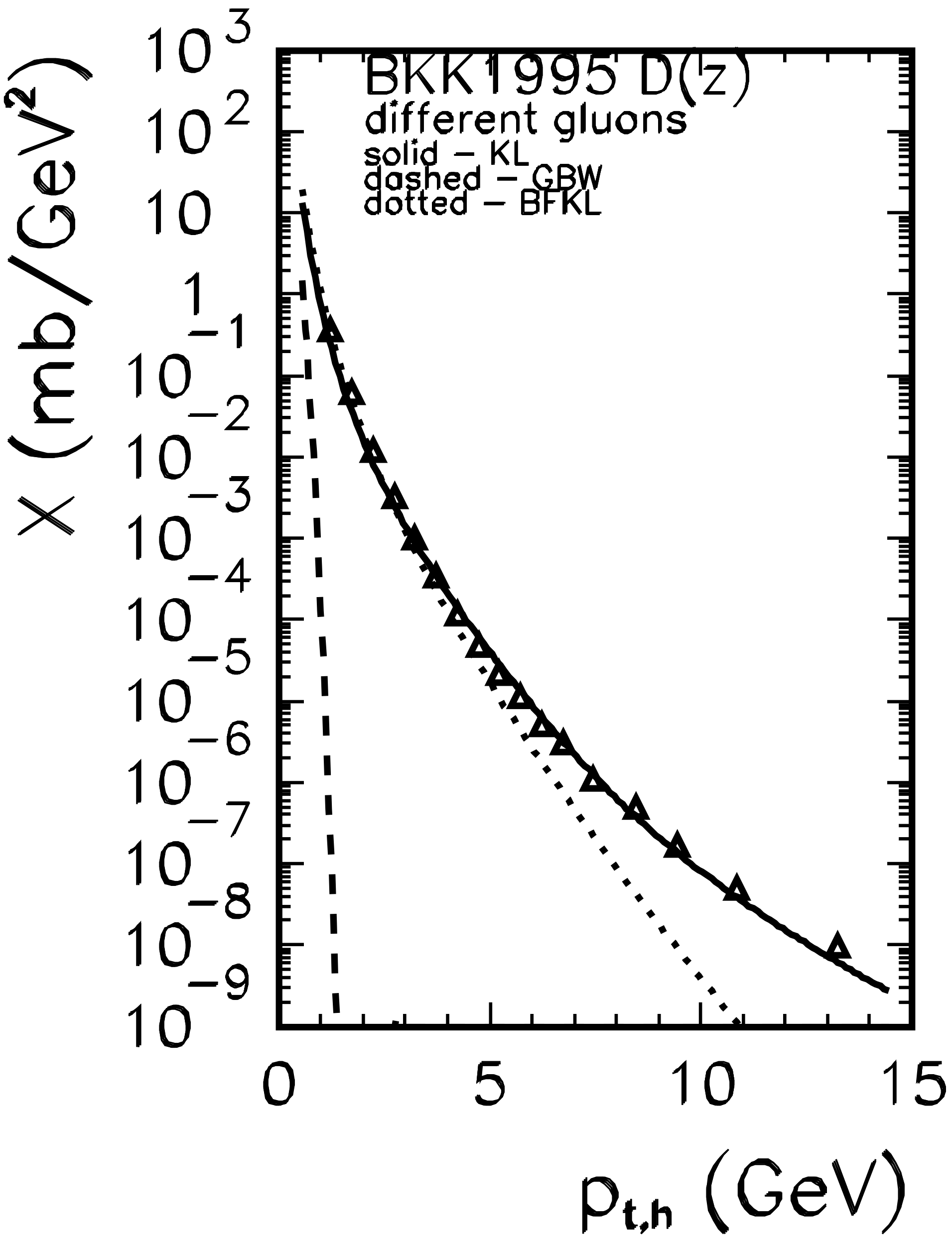


Trans. mom. distribution



W = 200 GeV, $\eta_h \in$ (-2.5,2.5)

PHENIX, new data



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

W $=$ 200 GeV, $\eta_h \in$ (-0.35,0.35)

CCFM parton distributions

A special formulation in the transverse-coordinate or impact factor representation
due to Jan Kwieciński et al.

$$f_k(x,\kappa_t^2,\mu^2) = \int_0^\infty db b J_0(\kappa_t b) \tilde{f}_k(x,b,\mu^2)$$

$$\tilde{f}_k(x,b,\mu^2) = \int_0^\infty d\kappa_t \kappa_t J_0(\kappa_t b) f_k(x,\kappa_t^2,\mu^2)$$

The new objects:

$$\tilde{f}_k(x,b,\mu^2)$$

fulfil integro-differential equations
(see Kwieciński et al.)

k numerates gluons (k=0),
quarks (k$>$ 0) and antiquarks (k$<$ 0) !!!

CCFM parton distributions

Transverse momenta of partons due to:

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

Take factorized form:

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

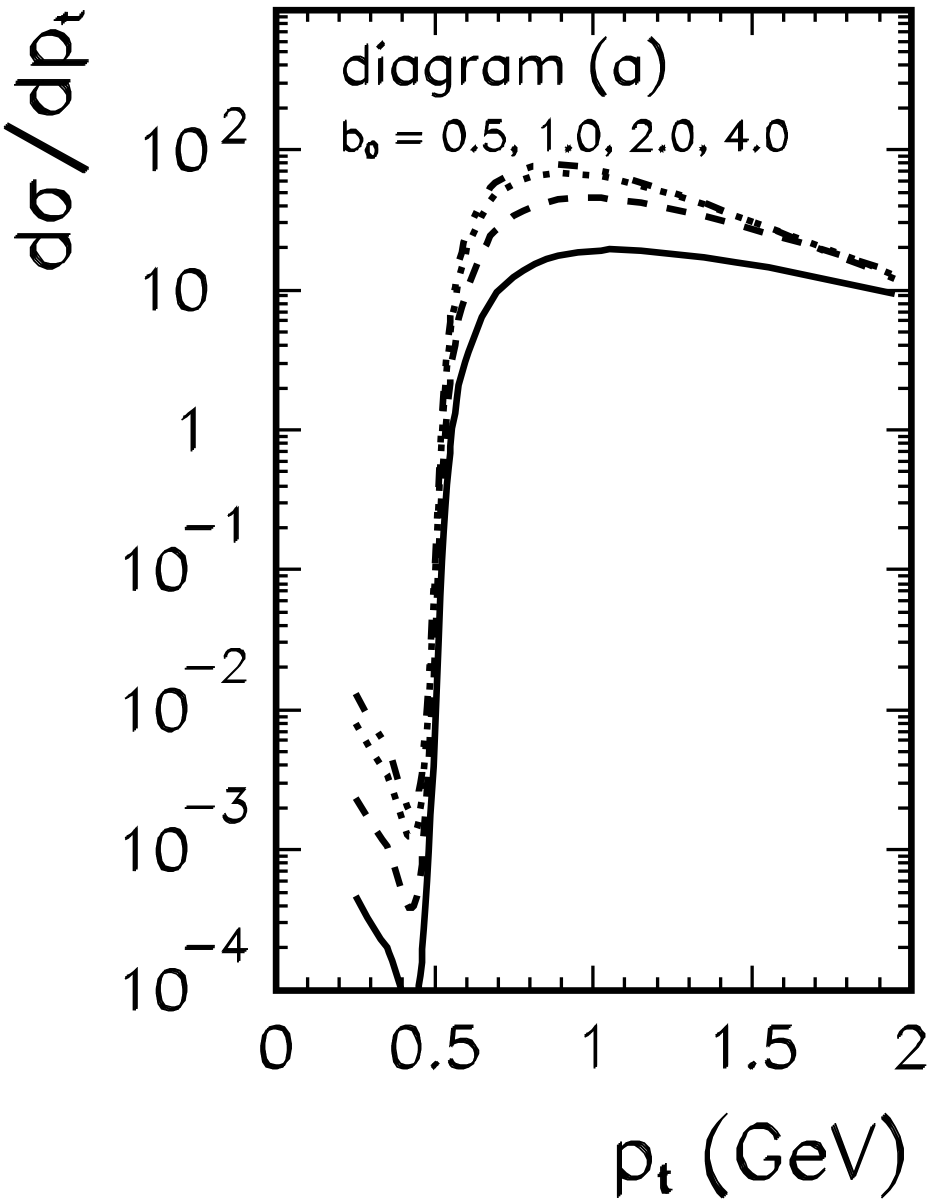
I shall try a flavour and x independent form factor

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

May be too simplistic ?

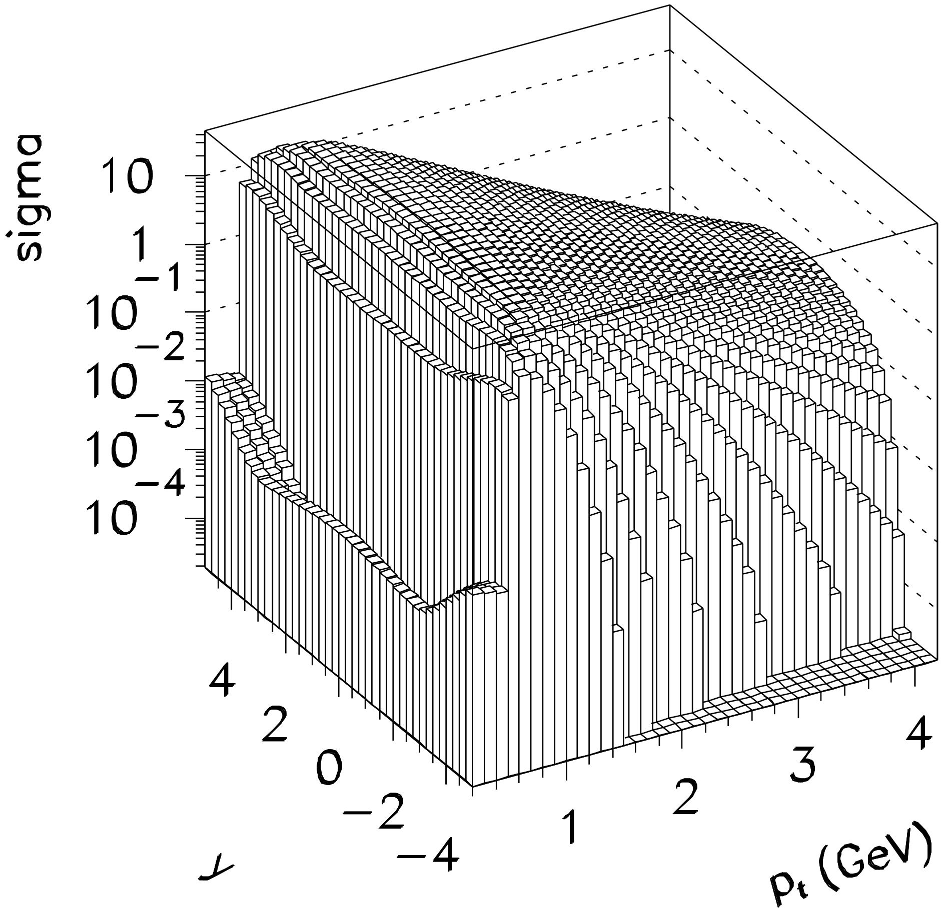
b-dependence of jets

only gluons, W = 200 GeV

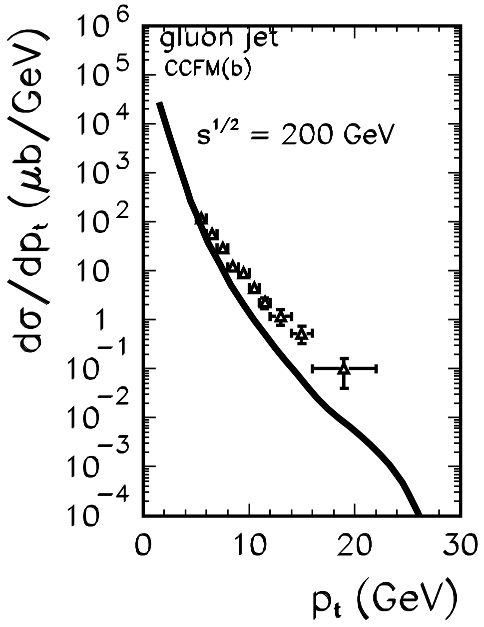


two-dimensional map

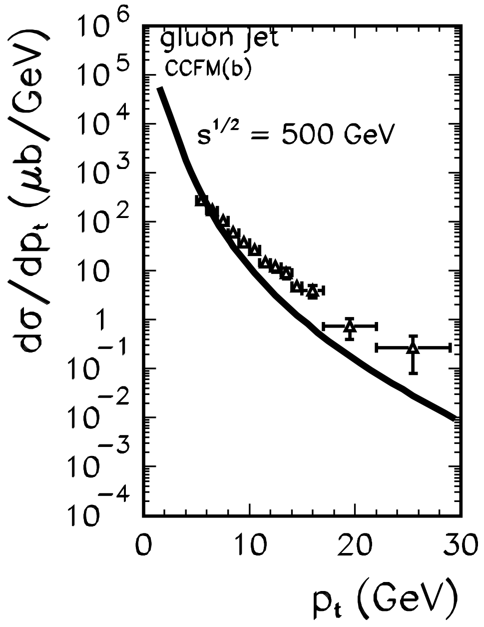
only gluons, W = 200 GeV, $b_0 = 1\ \mathrm{GeV}^{-1}$



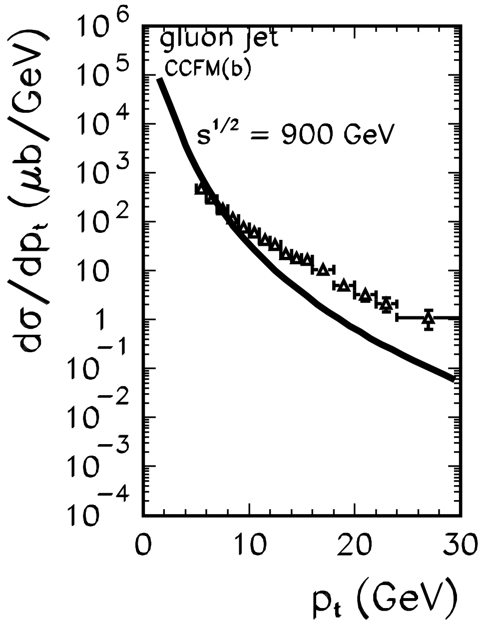
gluonic jets



(a)



(b)

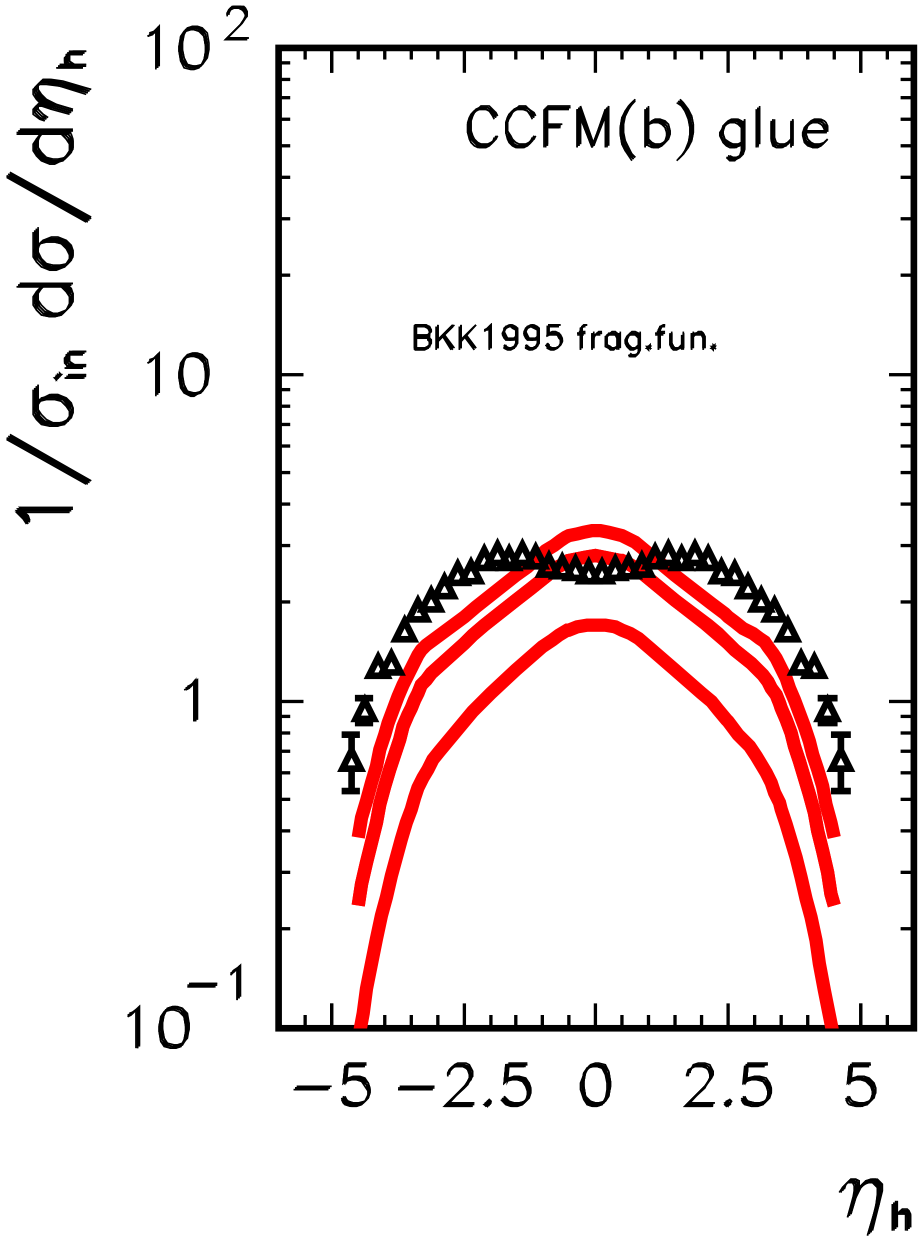


(c)

η_h distribution – b_0 dependence

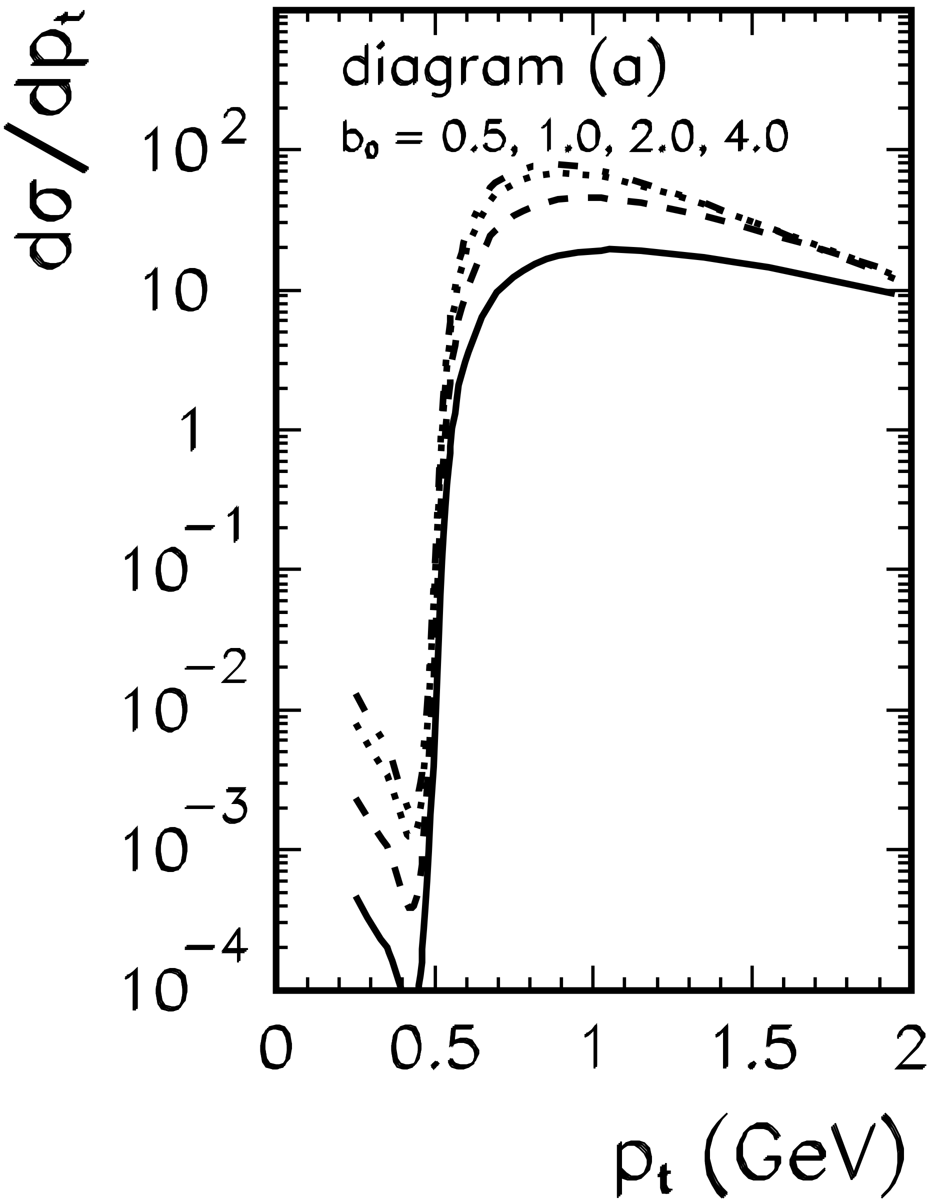
only gluons, W = 200 GeV

b_0 = 0.5, 1, 2 GeV^{-1}



b-dependence of jets

only gluons, W = 200 GeV



missing terms

B_1 – type	B_2 – type
$p_1 p_2 \to p_f$	$p_1 p_2 \to p_f$
$ug \to u$	$gu \to u$
$dg \to d$	$gd \to d$
$\bar{u}g \to \bar{u}$	$g\bar{u} \to \bar{u}$
$\bar{d}g \to \bar{d}$	$g\bar{d} \to \bar{d}$
......	......

$u_{val} > d_{val}$ $\quad N(\pi^+) > N(\pi^-)$

$\bar{d} > \bar{u}$ $\quad$ asymmetry !

CONCLUSION

One needs:

unintegrated quark/antiquark distributions

CCFM, in b-space

QCD-most-consistent approach – CCFM.
In LO convenient to use a space conjugated to transverse momentum (Kwieciński et al.)

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

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

Then the luminosity function

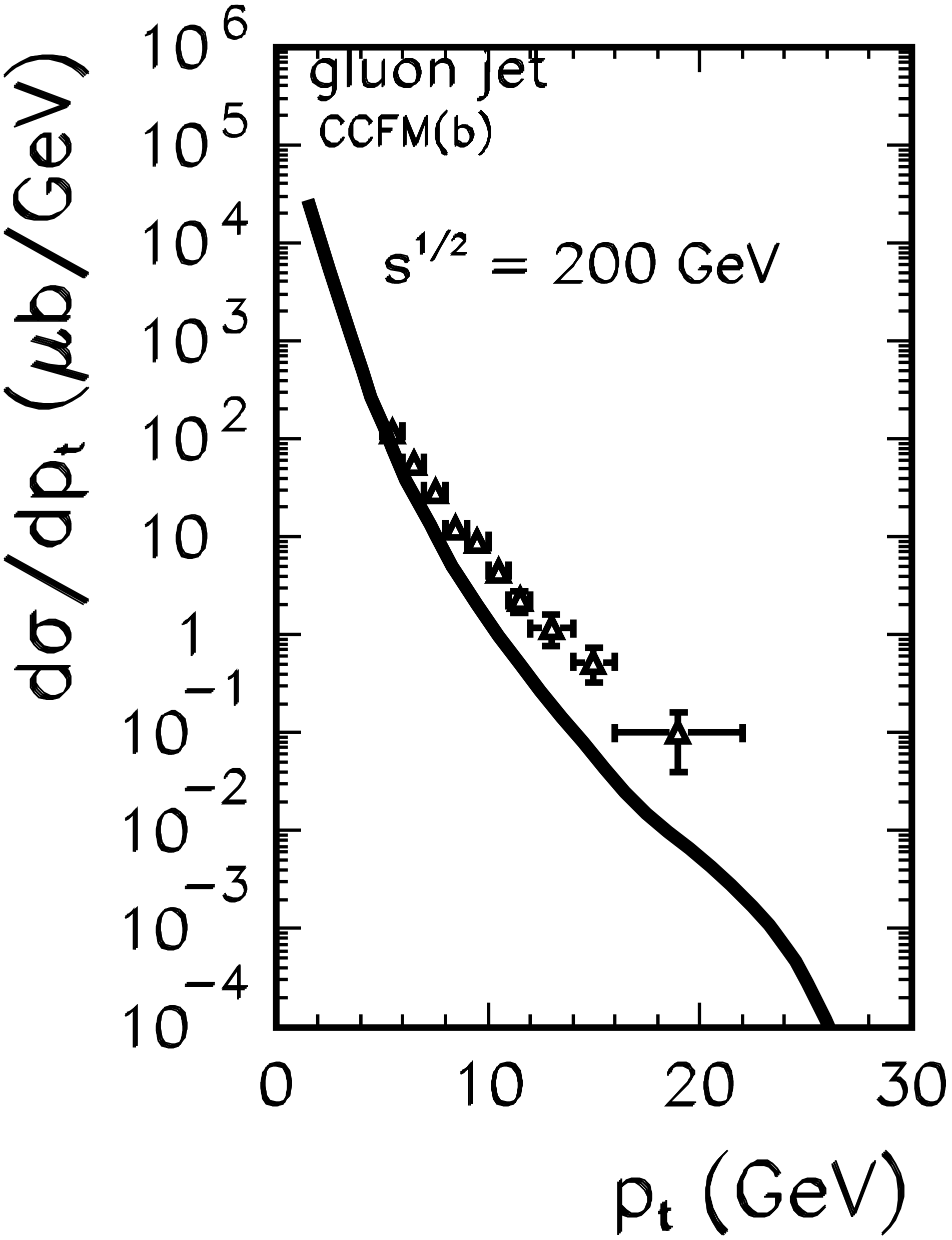
$$\int \mathcal{F}_1\left(x_1, \frac{\vec{p}_t + \vec{q}_t}{2}\right) \mathcal{F}_2\left(x_2, \frac{\vec{p}_t - \vec{q}_t}{2}\right) d^2 q_t$$

$$= 4 \int \tilde{f}_1(x_1, b, \mu^2) \tilde{f}_2(x_2, b, \mu^2) \exp\left(\vec{p}_t \cdot \vec{b}\right) d^2 b$$

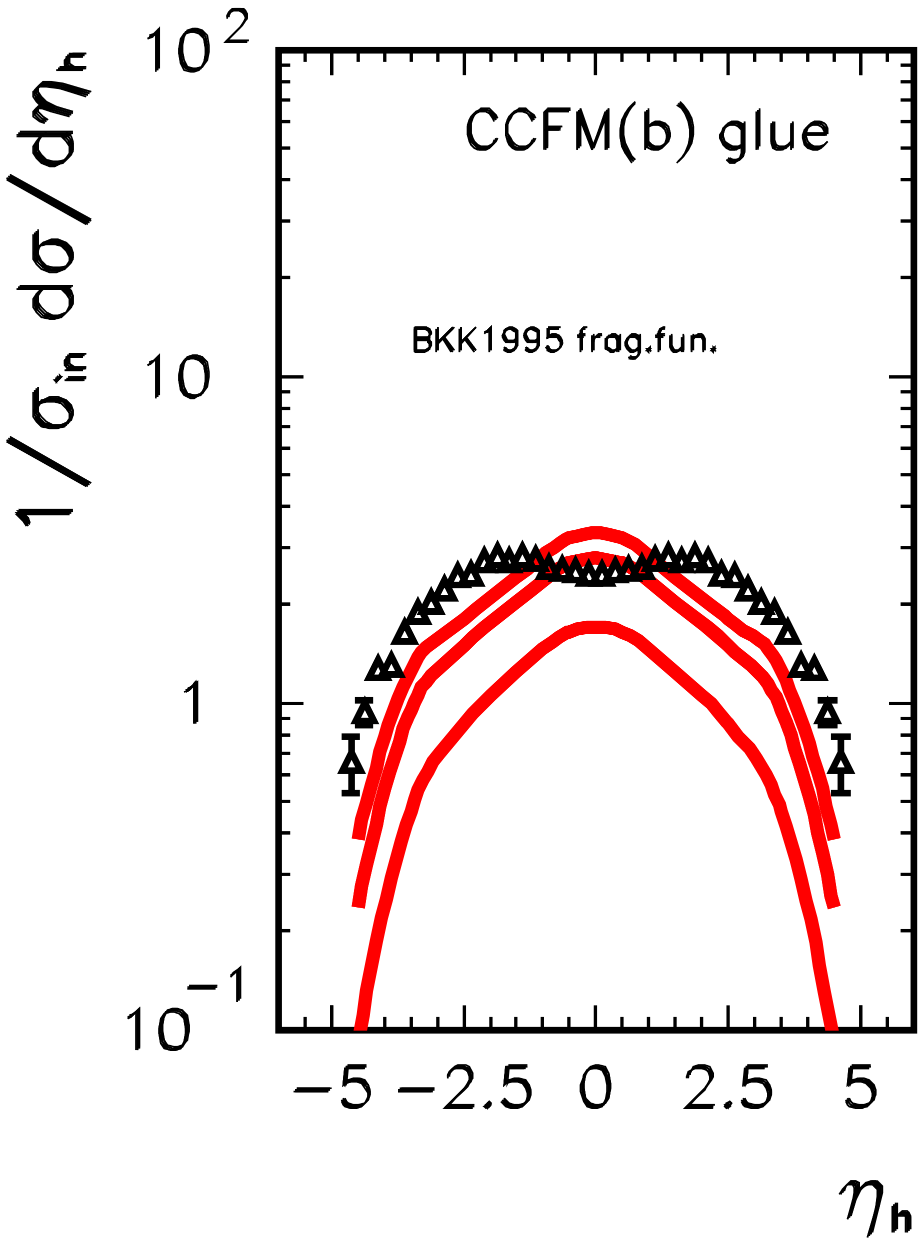
$$= 4 \int \tilde{f}_1(x_1, b, \mu^2) \tilde{f}_2(x_2, b, \mu^2)\; J_0(p_t b)\; 2\pi b db$$

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

CCFM, jets


gluon jet
CCFM(b)
$s^{1/2}$ = 200 GeV
$d\sigma/dp_t$ (μb/GeV)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
10
20
30
p_t (GeV)

CCFM, pseudorapidity dist.



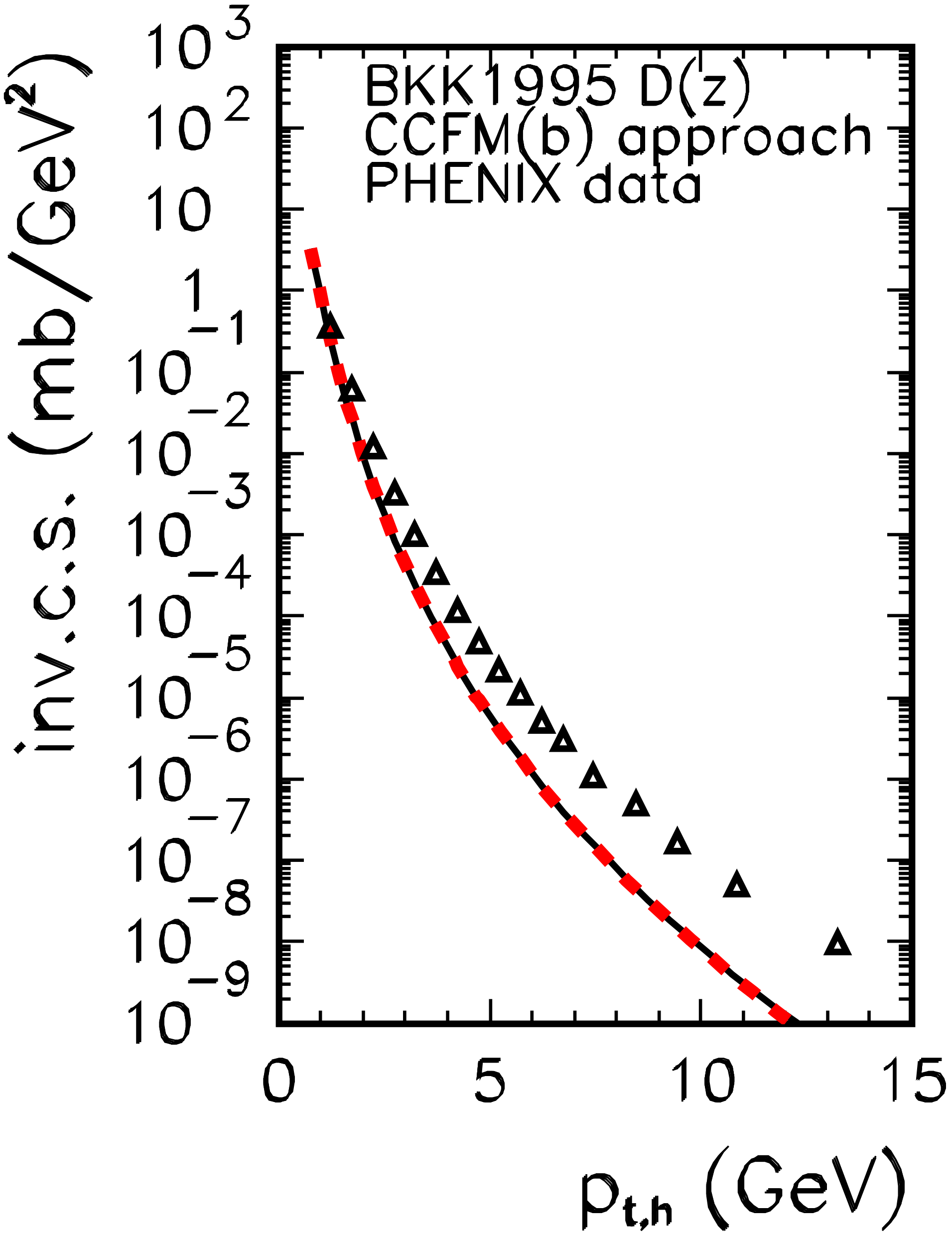
Observation:

room for other processes

(anti)quark gluon → (anti)quark (?)

gluon (anti)quark → (anti)quark (?)

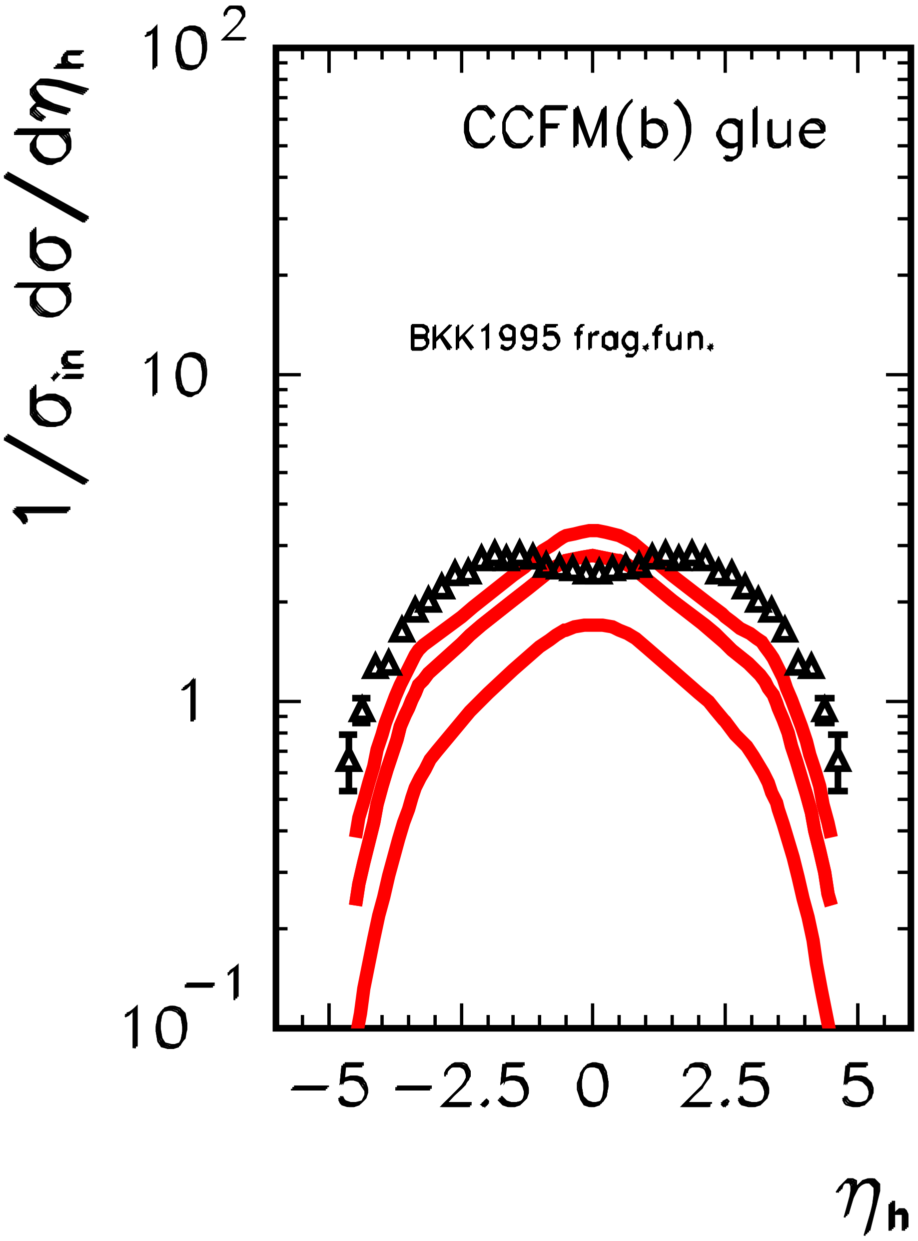
CCFM, transv.mom. dist.



η_h distribution – b_0 dependence

only gluons, W = 200 GeV

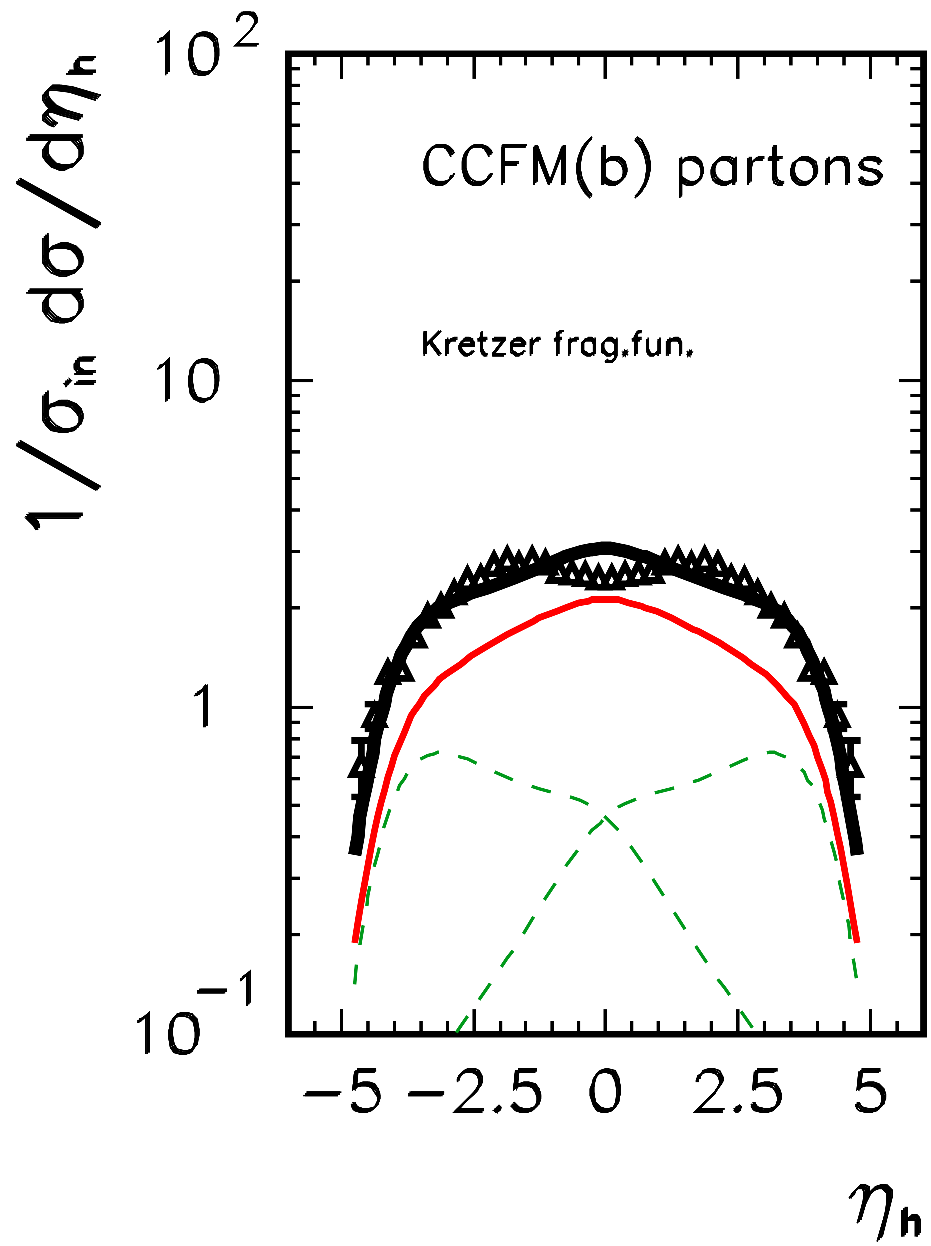
b_0 = 0.5, 1, 2 GeV^{-1}



Both gluons and (anti)quarks

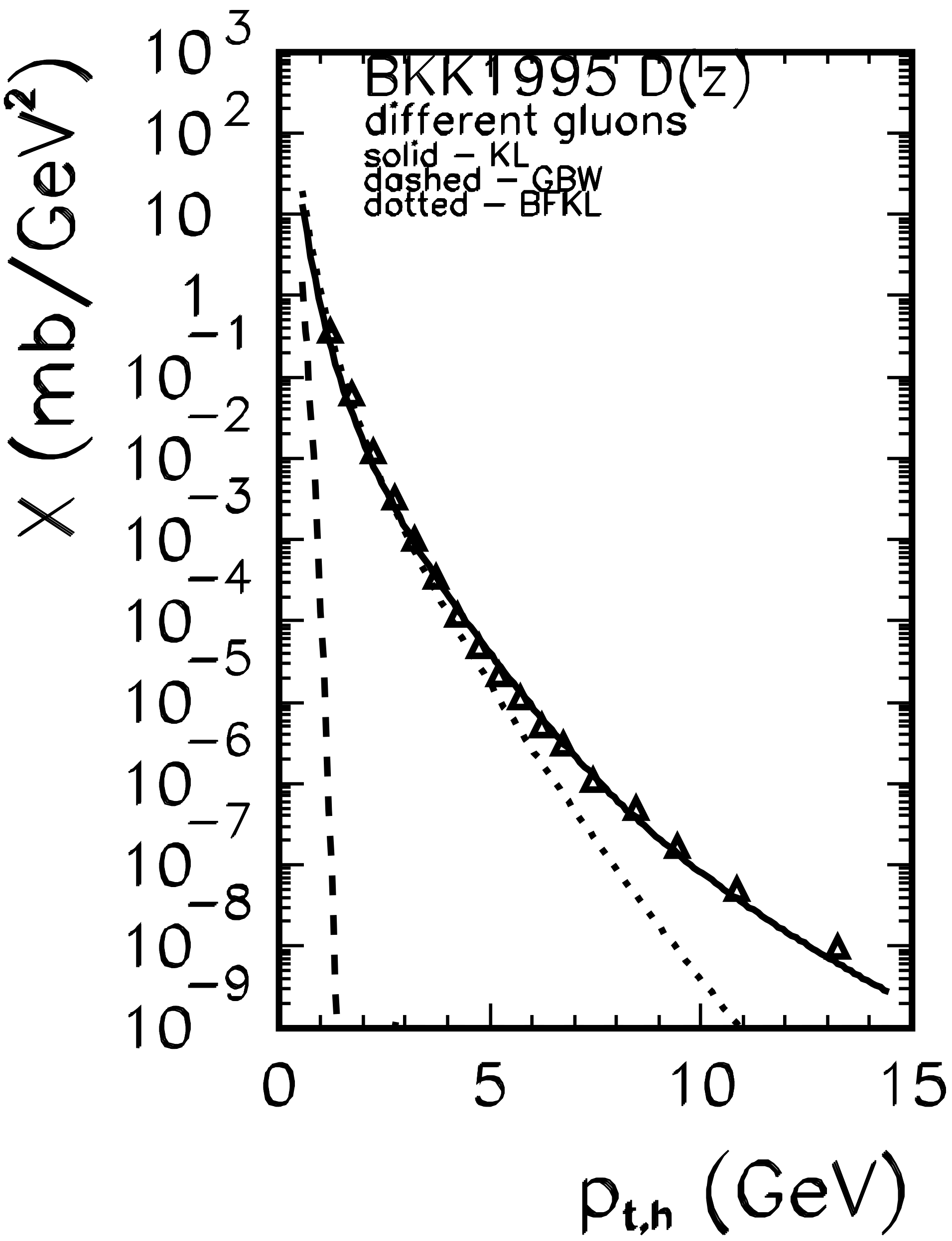
gluons, (anti)quarks, W = 200 GeV

UA5 data



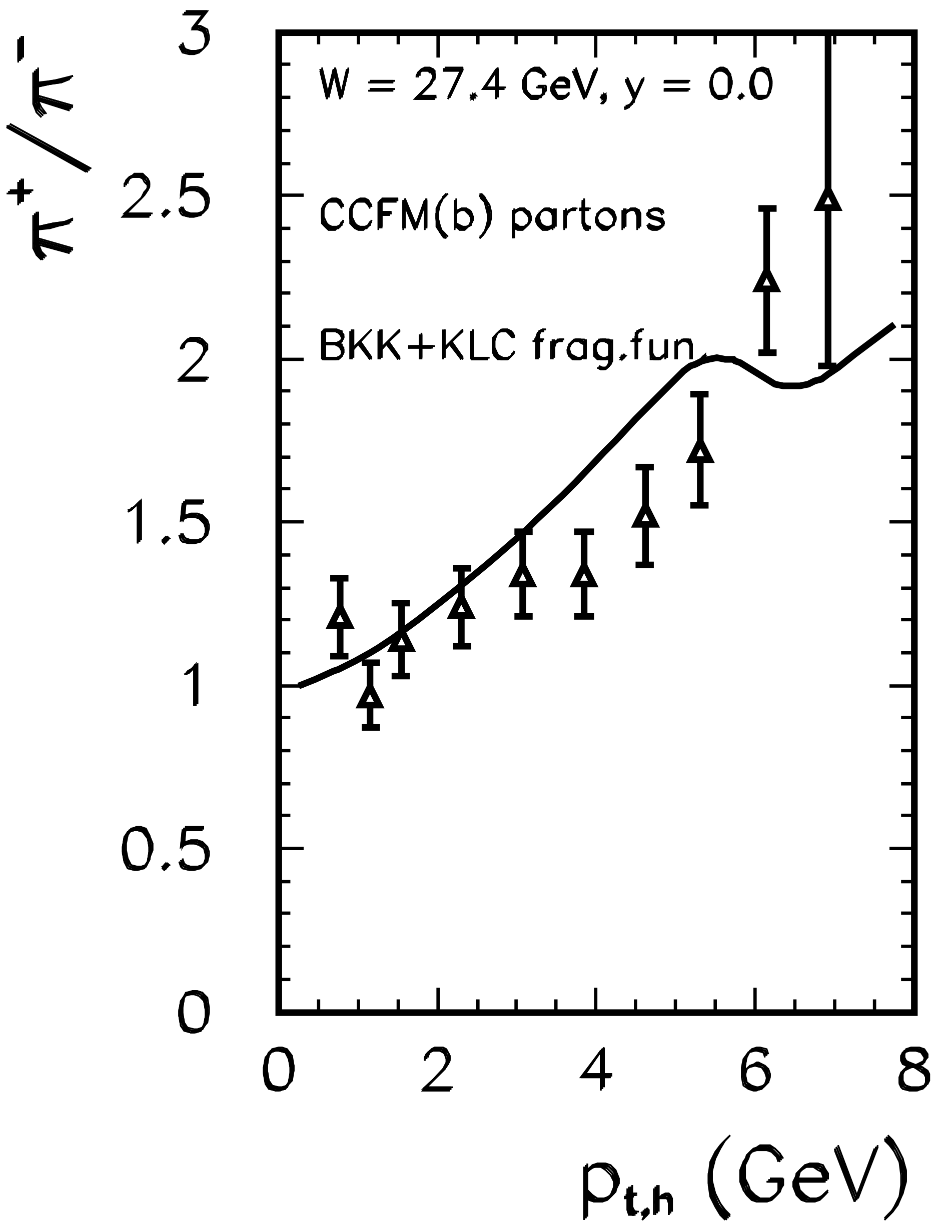
PHENIX data

gluons,(anti)quarks, W = 200 GeV



$\pi^+ - \pi^-$ asymmetry

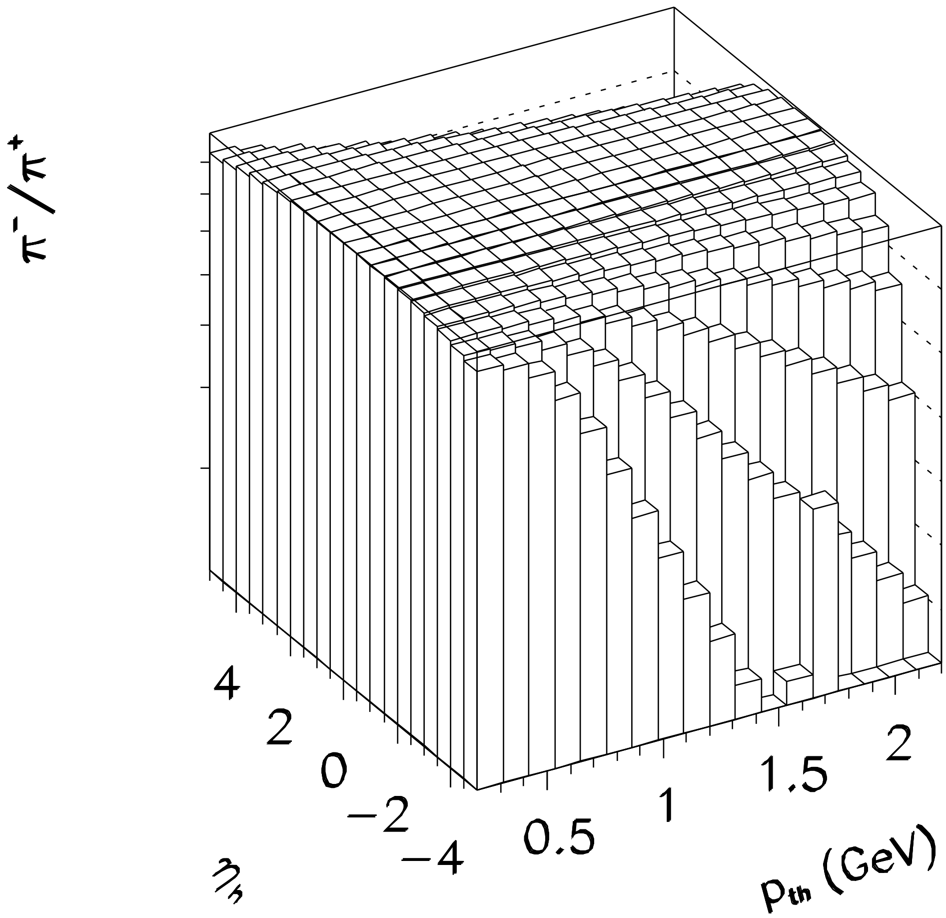
proton-proton collisions
gluons,(anti)quarks, W = 27.4 GeV, y=0



$\pi^+ - \pi^-$ asymmetry

proton-proton collisions

gluons,(anti)quarks, W = 200 GeV



BRAHMS can measure !!!

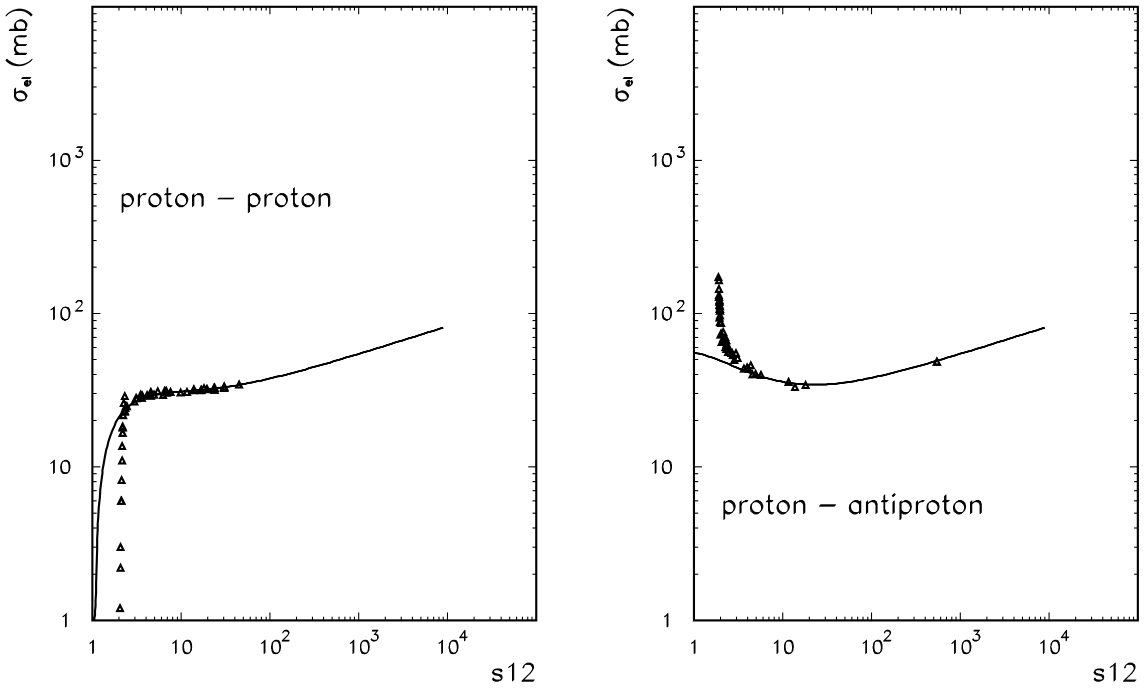
Particle multiplicities

($\sigma \to$ multiplicities)

$\to$ we need a parametrization of $\sigma_{ine}(W)$

$$\sigma_{ine}(W) = \sigma_{tot}(W) - \sigma_{ela}(W)$$

We use Regge-type parametrization of $\sigma_{tot}(W)$ and $\sigma_{ela}(W)$ for pp and $p\bar{p}$ scattering



A smooth parametrization
valid for 4 GeV < W < 10000 GeV

Summary/Conclusions

- Distribution of gluons and charged pions in nucleon-nucleon collisions calculated from different $\mathcal{F}(x_g, \kappa^2)$: GBW, BFKL, KL, KMR, etc.
- KL distribution tested against ep DIS data from HERA (GBW and BFKL also describe HERA data)
- GBW, KL, BFKL almost exhaust $\frac{d\sigma}{d\eta_h}(0)$
- KL, BFKL well describe transverse momentum distribution of $\pi^\pm$ if $D_{g\to\pi}$ taken from e^+e^-.
- missing strength in the fragmentation region due to missing mechanisms.

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 ?).