Spatial distributions of quarks / gluons in the nucleon at large N_c

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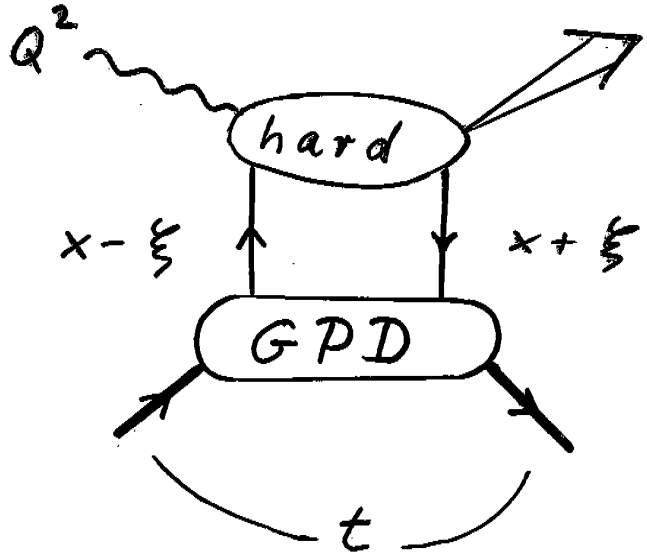
Hard exclusive processes in eN probe spatial distributions of quarks / gluons

$$q(x, \vec{b})$$

longit. momentum — transverse position

- Chiral dynamics: $b \sim 1/M_\pi$
- Large N_c: Nucleon as chiral soliton
- Application: Hard processes in pp at LHC

- Exclusive electroproduction at large Q^2

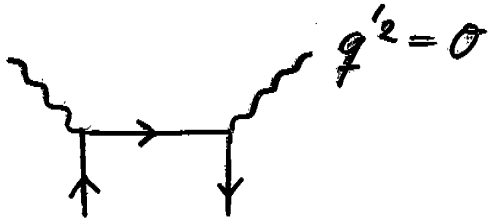


"Factorization"

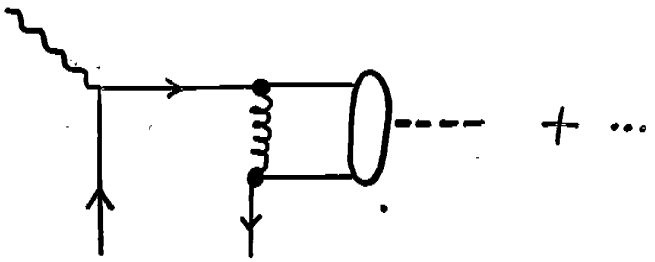
$H(x, \xi, t)$

$[E, \tilde{H}, \tilde{E}, \ldots]$

Examples:



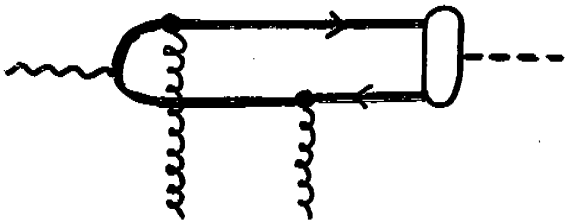
Deeply-virtual Compton scattering (DVCS)



Light meson production

π, K: $P_{intr} = -1$

ρ, ϕ $+1$



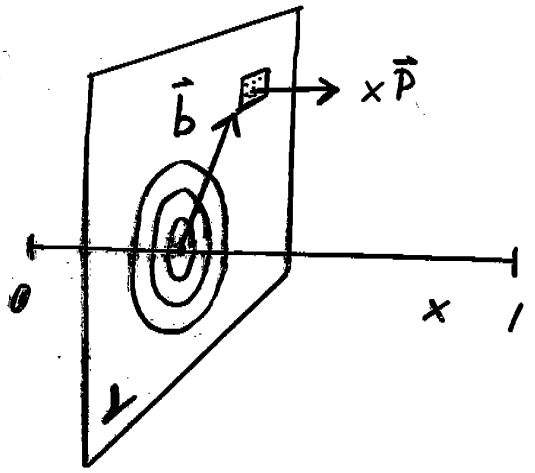
Heavy quarkonium photoproduction

$J/\psi, \Upsilon$

● GPDs: Impact parameter representation ($\xi = 0$)

... Frame $\Delta^\mu = (0, 0, \vec{\Delta}_\perp)$

$$H(x, t = -\vec{\Delta}_\perp^{\,2}) = \int d^2b \; e^{-i \vec{\Delta}_\perp \cdot \vec{b}} \; q(x, b) \qquad (x > 0)$$



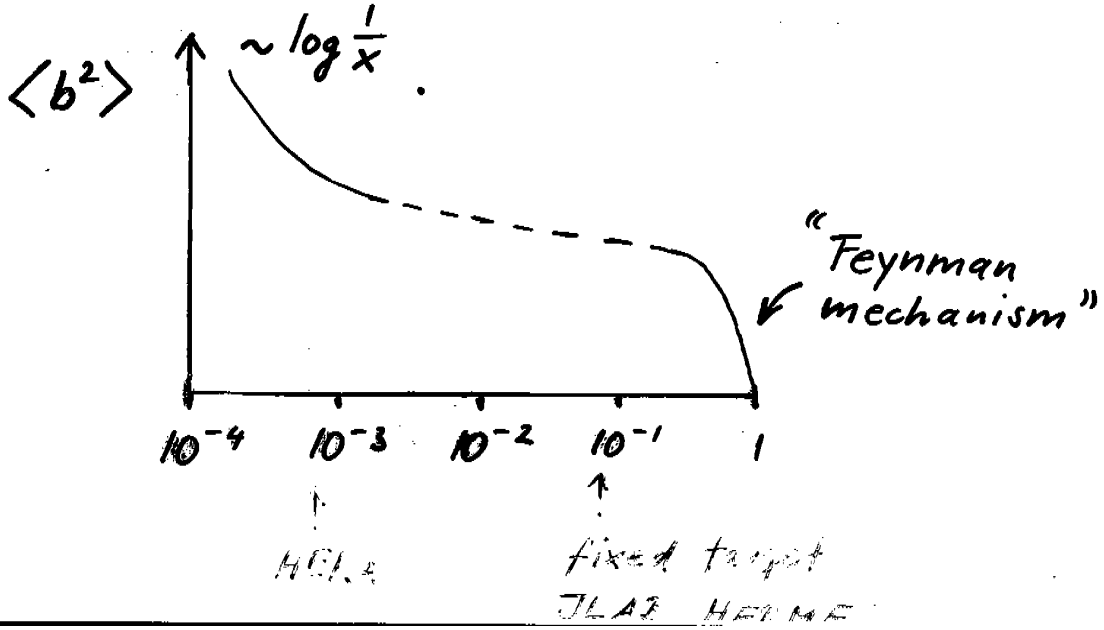
spatial distribution of partons w. given x in transverse plane

[Burkardt 02]

$$\int d^2b \; q(x, b) = q(x)$$ total density

$$\langle b^2 \rangle (x) = 4 \frac{\partial H}{\partial t}(x, t = 0)$$

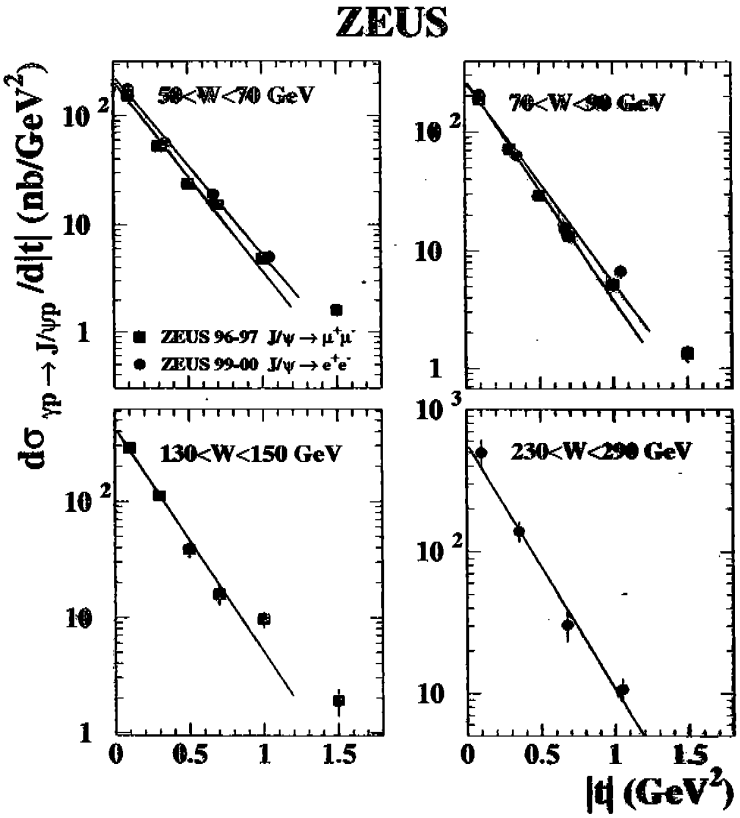
"transverse size" of nucleon (x-dependent!)



- J/ψ photoproduction: t–dependence of cross section

$x \sim \frac{M_{c\bar{c}}^2}{W^2}$

$\sim 10^{-2} \div 10^{-4}$



also: H1

... also fixed target data [SLAC, Cornell, Fermilab]

→ Transverse size of gluon distribution

$$\langle b^2 \rangle_x = 0.3\,\mathrm{fm}^2 \quad \text{at} \quad x \approx 10^{-1}$$
$$0.4 \qquad\qquad 10^{-3}$$

} Increase

[Frankfurt, Strikman, 02]

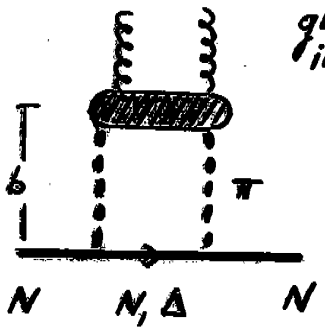
Large transverse distances: Chiral dynamics

cf. NN-interaction

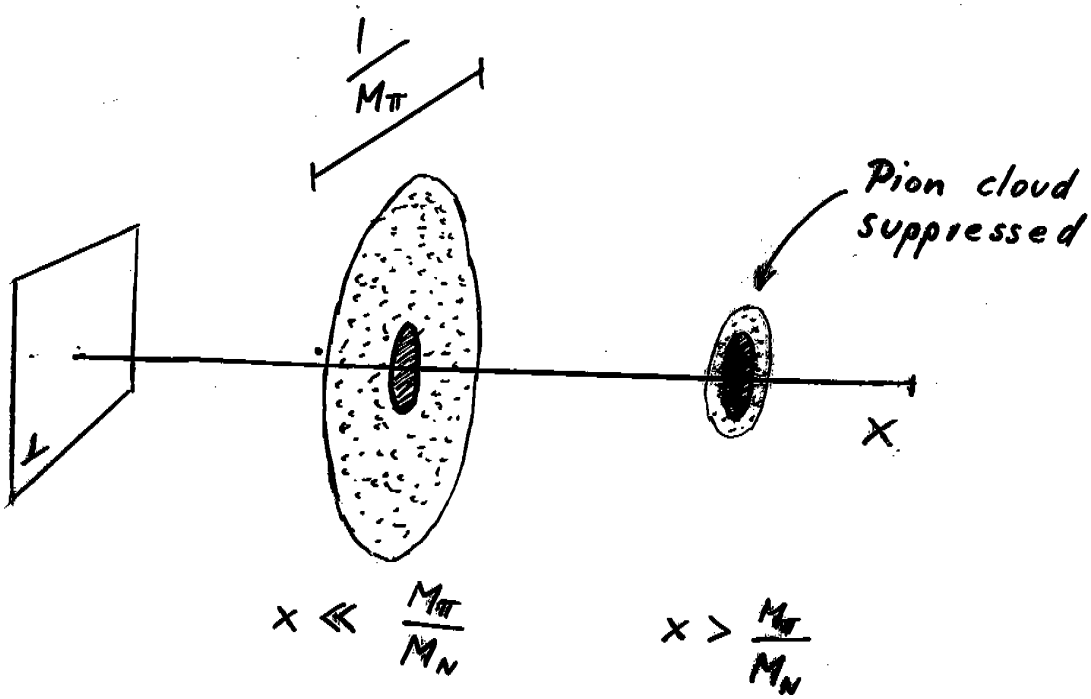
$\sim \dfrac{e^{-M_\pi r}}{r}$ Yukawa potential

- Gluon distribution at $b \sim 1/M_\pi$ [Strikman, CW 03]

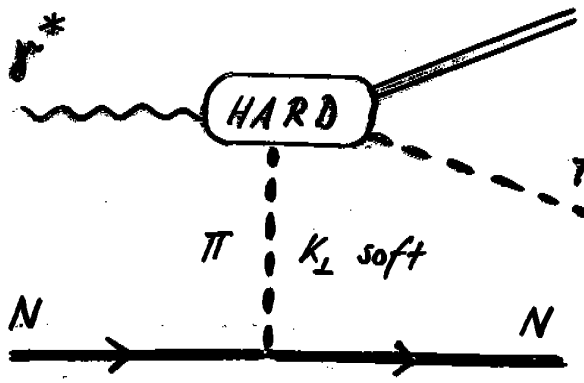
$g(x,b) \sim$



$\sim e^{-2M_\pi b} \times \text{function}(x)$



- Ultraperipheral hard exclusive processes with pion knockout

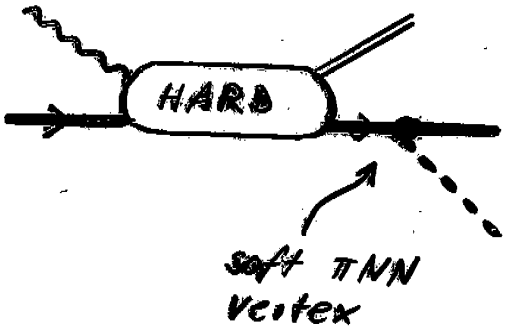


$K'_\perp$ large (≥ 2 GeV) !

$p'_\perp$ small (≤ 0.5 GeV)

[HERA, EIC]

vs.



suppressed !

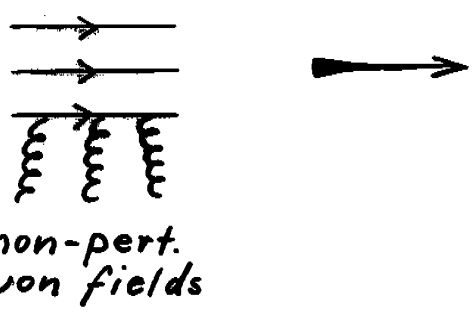
Impact parameter analysis: $\vec{K}_\perp \rightarrow \vec{b}$

... select large distances $b \sim 1/M_\pi$

Possible to measure gluon distribution in pion (including t - dependence)

Chiral quark-soliton model [Diakonov, Petrov, Polyakov 88]

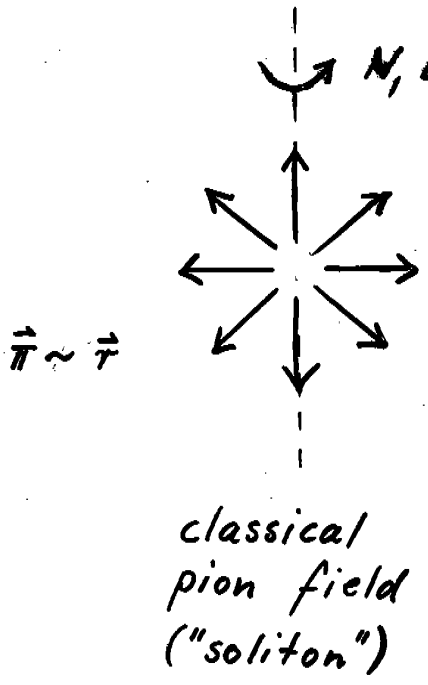
- Chiral constituent quarks

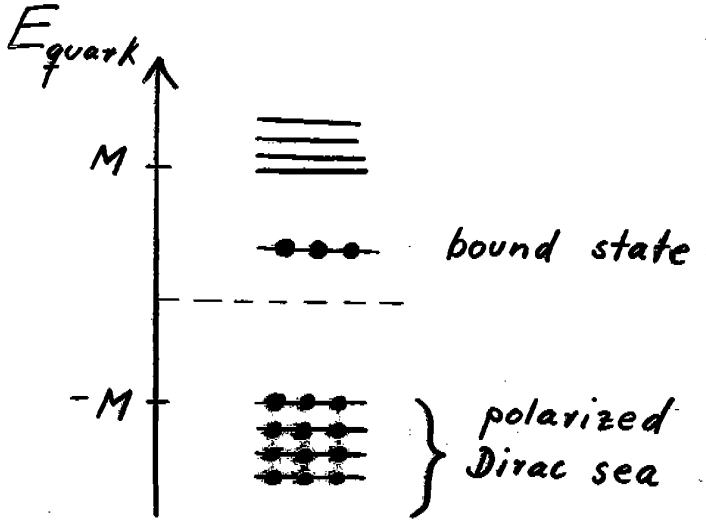


$M \approx 350$ MeV

("size" $\rho \ll M^{-1}$)

- Large N_c: Baryons semiclassical



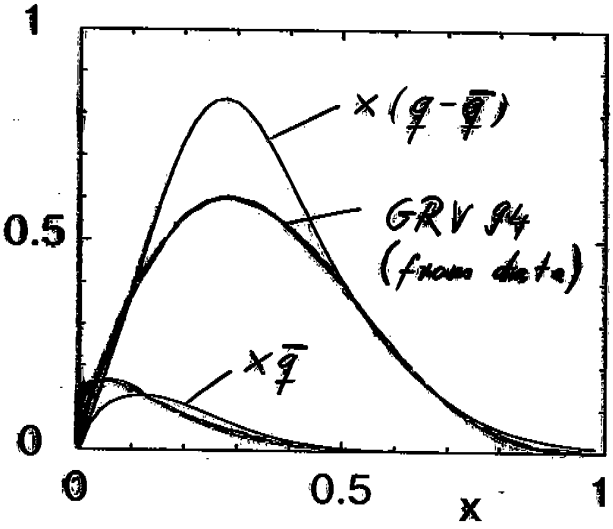


Field-theoretical description of nucleon

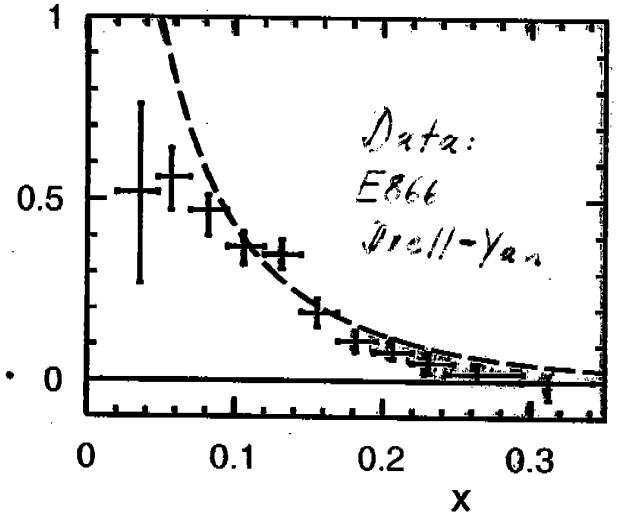
- Form factors [Goeke et al. '92-'98] $|t| \leq 16\,GeV^2$
- Parton distributions [Diakonov, Petrov, Pobylitsa, Polyakov, CW '96-'99]

$u+d$

Scale:
$\mu = \rho^{-1} = 600\,MeV$



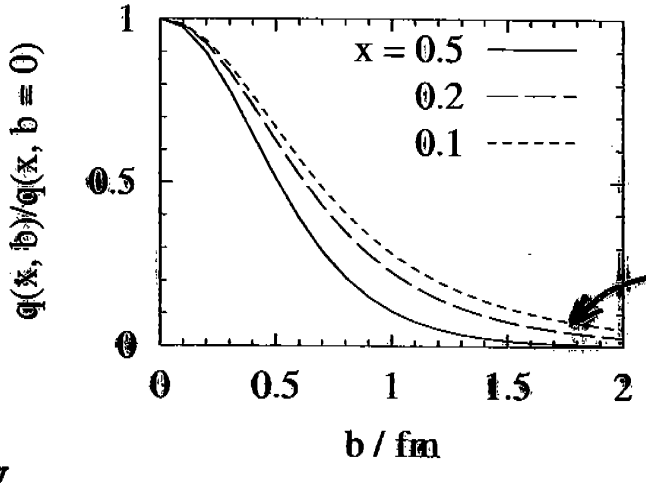
$\bar{d}-\bar{u}$



... Parameter-free predictions !

• Spatial distribution of quarks/antiquarks

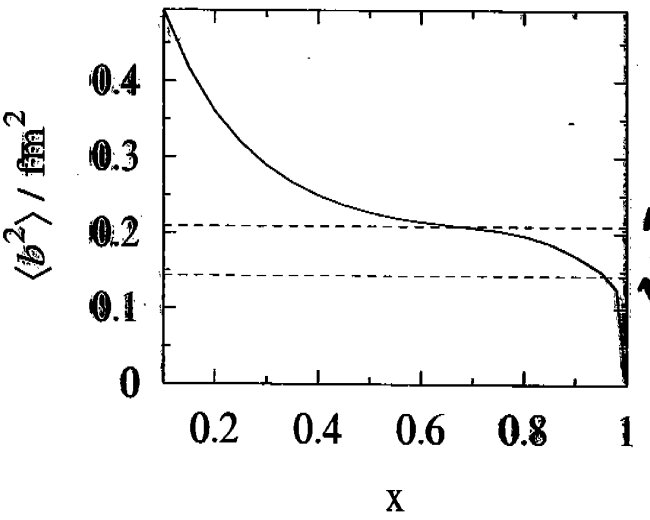
$u + d + \bar{u} + \bar{d}$



"generalized Yukawa tail"

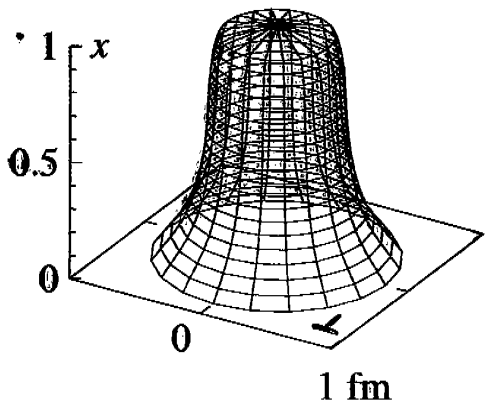
$\sim e^{-2M_\pi b} f(x)$

[Schäfer, Sölder, CW, in progress]



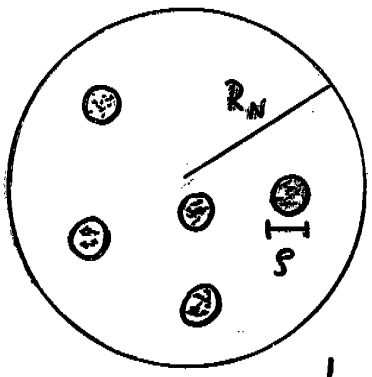
CLAS φ production

Visualization (3D)



Nucleon as seen by partonic observer...

● Gluonic transverse size



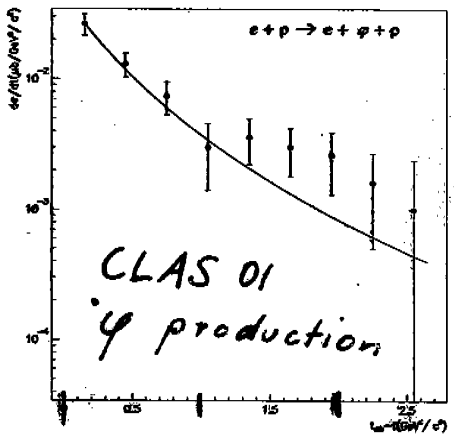
$\perp$ plane

Gluons "packaged" in constituent quarks/antiq. (size $s \ll R_N$)

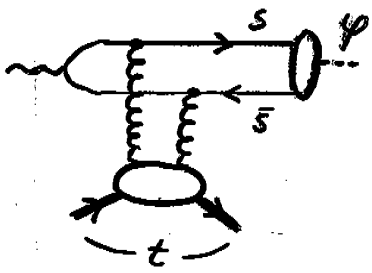
$\rightarrow \langle b^2 \rangle_{quark}(x) \longrightarrow \langle b^2 \rangle_{gluon}(\text{smaller } x)$

... roughly consistent with t-slope of gluon dist'n extracted from φ electroproduction [CLAS 01]

$\frac{d\sigma}{dt}$

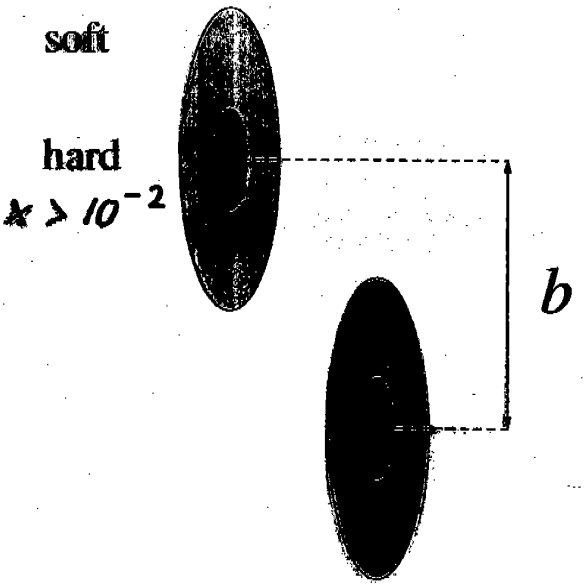


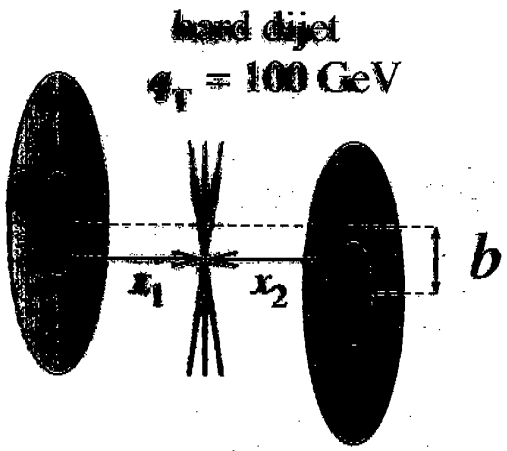
0 1 2 $t_{min} - t$ (GeV²)



Constituent quarks: Link between transverse distributions of quarks and gluons

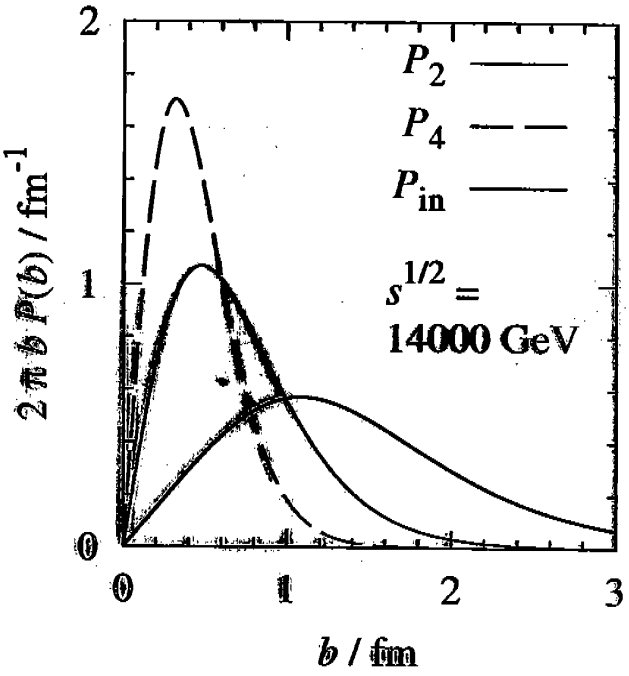
- Hard dijets in pp collisions at LHC [Frankfurt, Strikman, CW 03]





$x_{1,2} = 2q_T / W \sim 10^{-2}$

"peripheral" "central"



Distribution of pp impact parameters

Hard dijet production: "Centrality trigger"

Summary

EXPERIMENT:

- measure t-dependence over wide range
  $|t_{min}| \leq |t| \leq 2\ GeV^2$

- compare different channels

$$J/\psi \leftrightarrow S, \varphi \leftrightarrow \gamma\ (DVCS)$$
$$\updownarrow$$
$$\pi, K$$

THEORY:

- New arena for chiral dynamics

- Well-tested concepts

  $N_c \to \infty$ limit, constituent quarks

  help to develop comprehensive picture of spatial distribution of quarks / gluons

- ~~Need~~ to control power (subasymptotic) corrections !