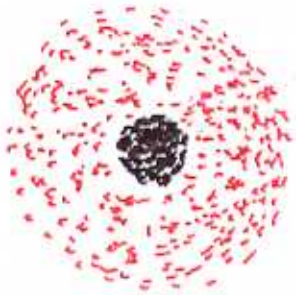
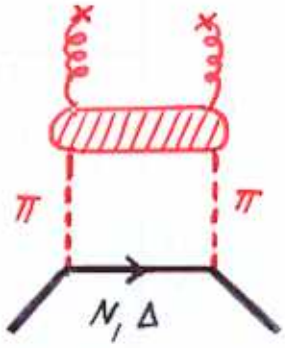
Chiral dynamics and the transverse size of the gluon distribution at small x

M. Strikman, C. Weiss, hep-ph/0308191



$b \sim \frac{1}{M_\pi}$

$g(x, b)$ $(x \sim 10^{-2} \ldots 10^{-3})$



"pion cloud"

Gluon distribution in nucleon at $b \sim \frac{1}{M_\pi}$ governed by chiral dynamics!

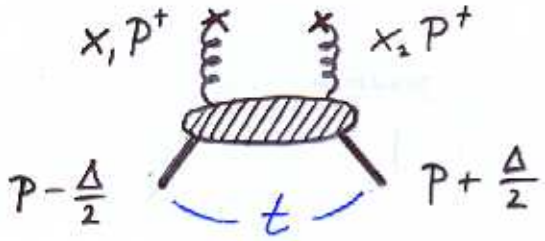
→ Increase of transverse size $\langle b^2 \rangle$ for $x \ll \frac{M_\pi}{M_N}$

→ Ultraperipheral hard exclusive processes
$\gamma + N \to J/\psi + N + \pi$ [HERA, EIC]

→ Implications for $\bar{p}p$ at Tevatron
pp at LHC, RHIC

[→ M. Strikman, this meeting]

- Spatial distribution of gluons in transverse plane



$g(x_1, x_2; t)$ "generalized" gluon distribution

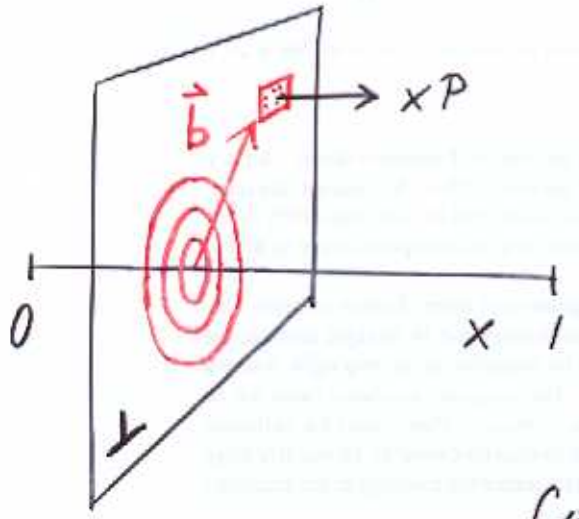
(here: $x_1 \approx x_2 \equiv x$)

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

$$g(x, t = -\vec{\Delta}_\perp^2) = \int d^2b \, e^{-i\vec{\Delta}_\perp \cdot \vec{b}} \, g(x, b)$$

"impact parameter-dependent" gluon distribution

[M. Burkardt 01]



Spatial distribution of gluons w. given x in $\perp$ plane

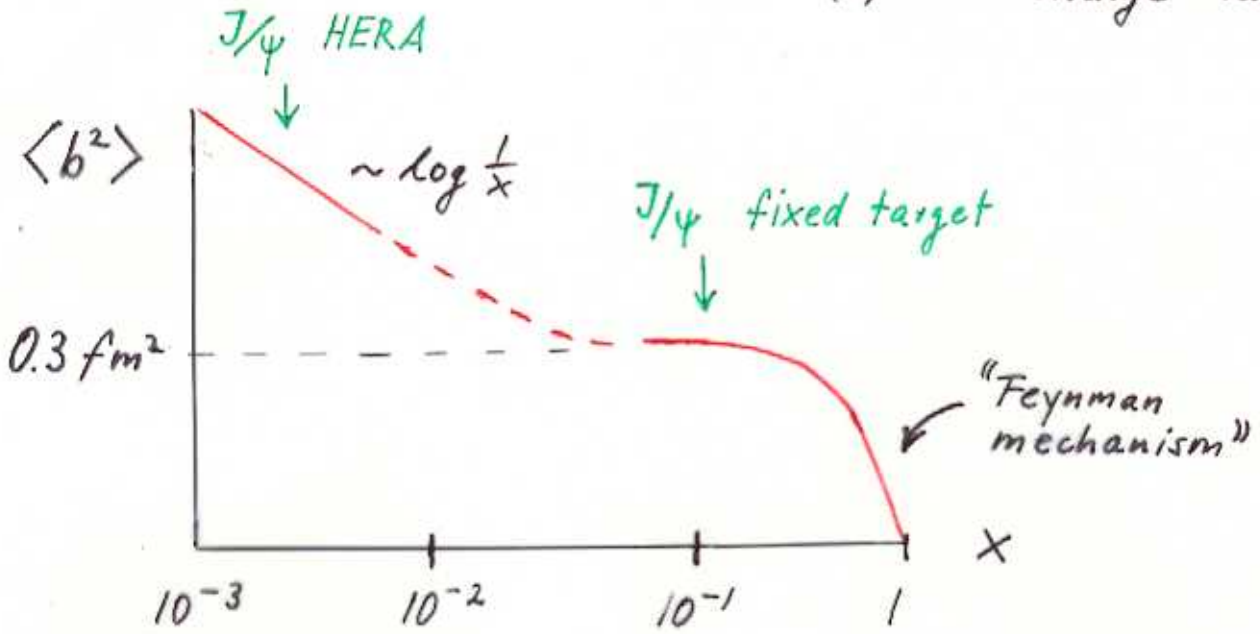
$$\int d^2b \, g(x, b) = g(x)$$ total gluon density

Positivity: $g(x, b) > 0$ [Pobylitsa 02]

- Transverse gluonic size of nucleon

$$\langle b^2 \rangle \equiv \frac{\int d^2b \; g(x,b) \; b^2}{\int d^2b \; g(x,b)} = 4 \left. \frac{\frac{\partial g}{\partial t}(x,t)}{g(x,t)} \right|_{t=0}$$

(cf. em charge radius)



Note: 1) $\langle b^2 \rangle \; (x \approx 10^{-1}) < \frac{2}{3} \langle r^2 \rangle_{em}$

$0.3 \; fm^2$ $\qquad$ $0.5 \; fm^2$

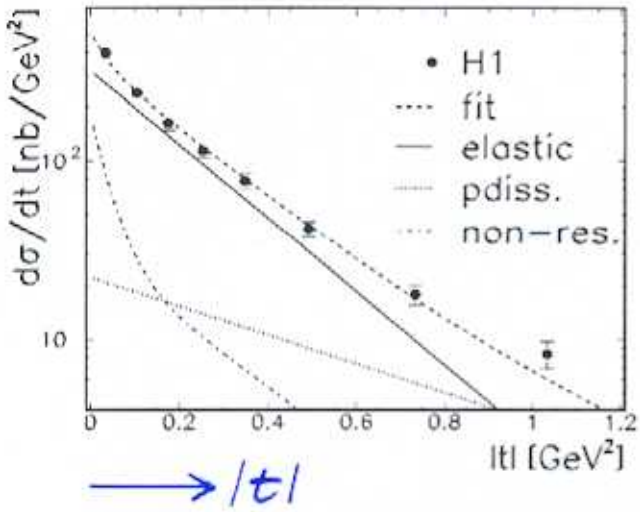
2) $$\frac{d\langle b^2 \rangle}{d(\log \frac{1}{x})} \approx \frac{1}{2} \alpha'_{soft}$$

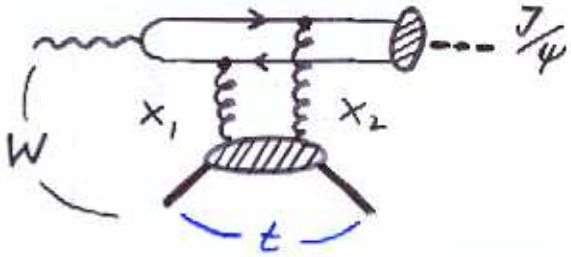
slow rise with $\log \frac{1}{x}$!

• J/ψ photoproduction at HERA energies

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

H1

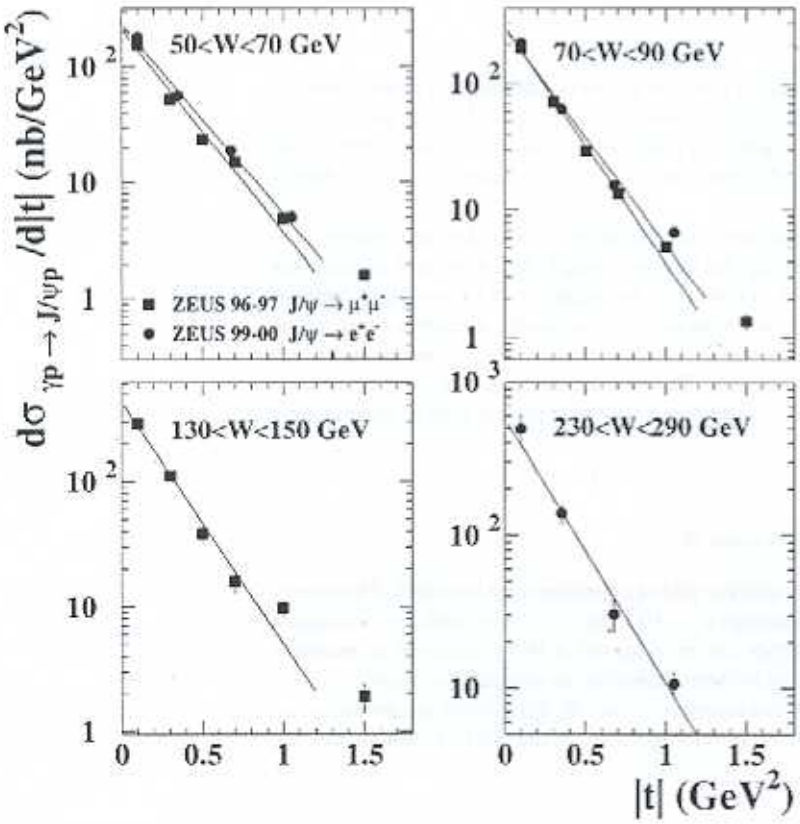




$x_1, x_2 \sim 10^{-2} \ldots 10^{-4}$

$x_1/x_2 \sim 2$

ZEUS



Fit: $\frac{d\sigma}{dt} \sim e^{-Bt}$

$B = B(W)$

- J/ψ photoproduction at fixed-target energies

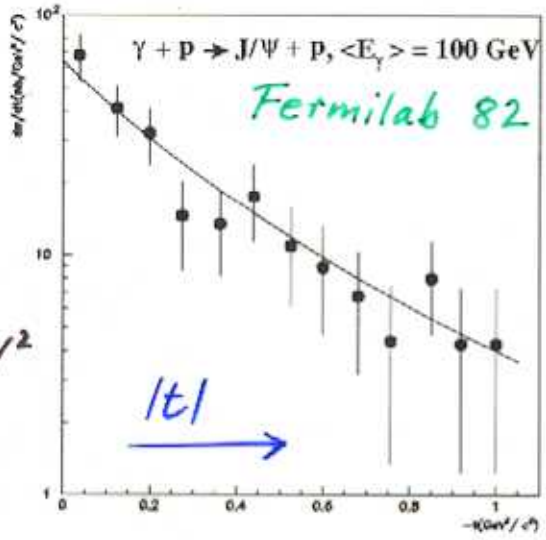
$\frac{d\sigma}{dt}$

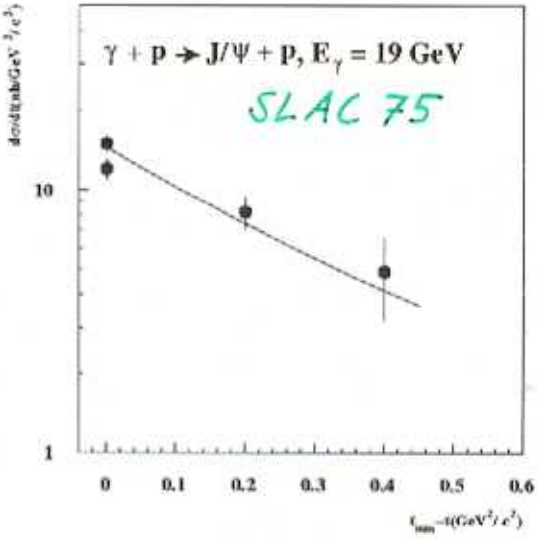
Fit:

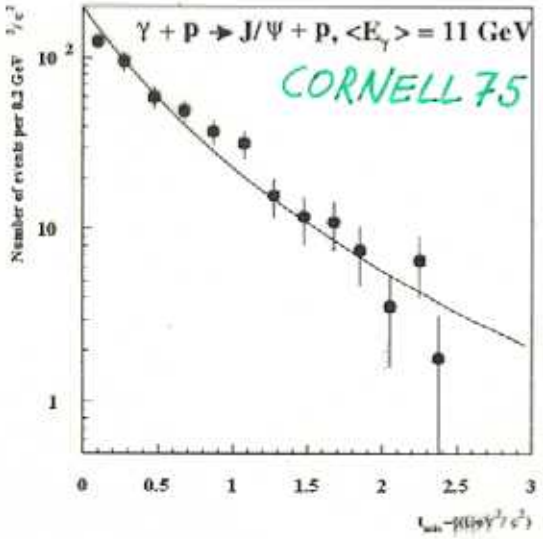
Dipole,

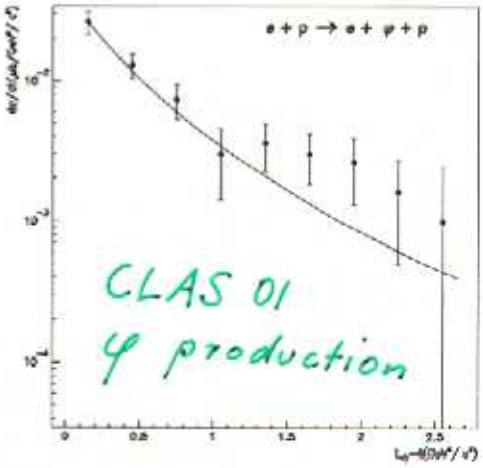
$m_g^2 = 1.1\ GeV^2$

[Frankfurt, Strikman 02]

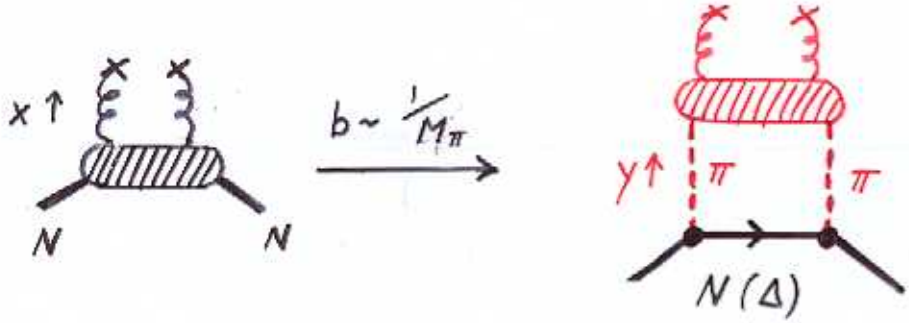








- Gluon distribution at $b \gtrsim \frac{1}{M_\pi}$: Chiral dynamics



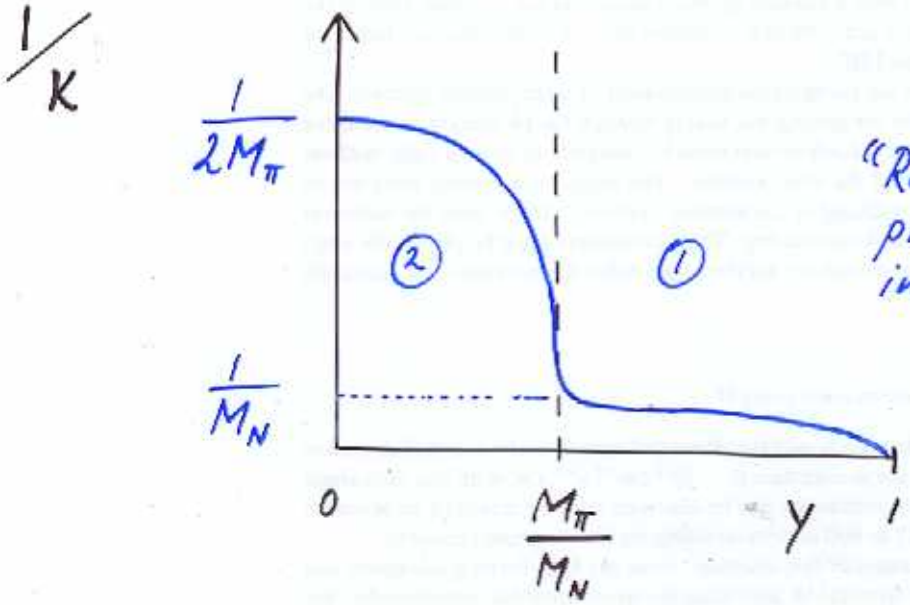
$g_\pi\left(\frac{x}{y}\right)$ gluon distribution in pion

$f_\pi(y,b)$ "pion distribution" in nucleon (calculable!)

$$g(x,b) \sim \int_x^1 \frac{dy}{y}\, g_\pi\left(\frac{x}{y}\right) f_\pi(y,b)$$

[Neglect "intrinsic" transverse size of pion ($\ll b$)]

$$f_\pi(y,b) \overset{b\to\infty}{\sim} \frac{e^{-kb}}{b} \quad \text{"Yukawa tail"}$$



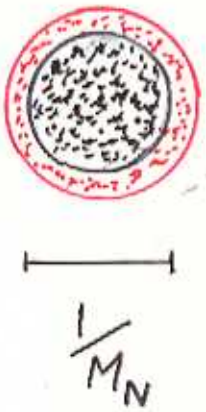
"Range" of pion distribution in nucleon

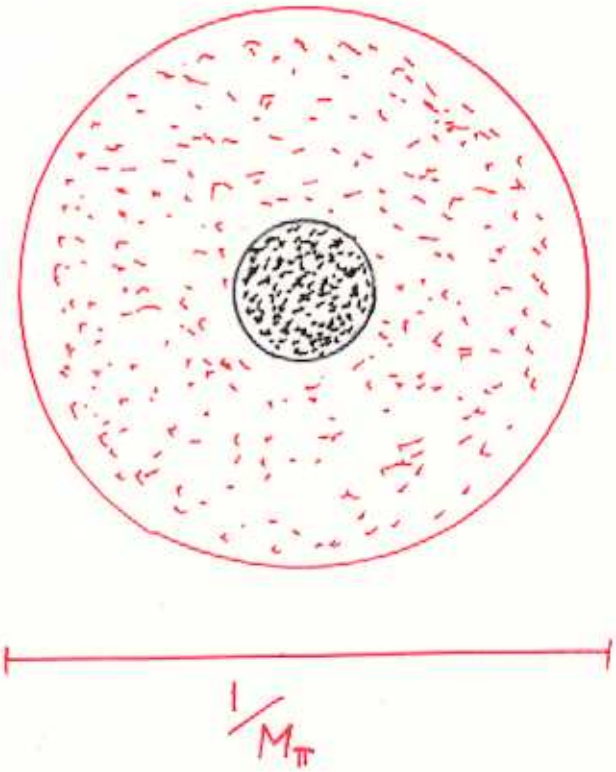
... Two regimes!

→ Gluon density in nucleon $(y \geq x!)$

$$\boxed{x \gtrsim \frac{M_\pi}{M_N}}$$

$$\boxed{x \ll \frac{M_\pi}{M_N}}$$





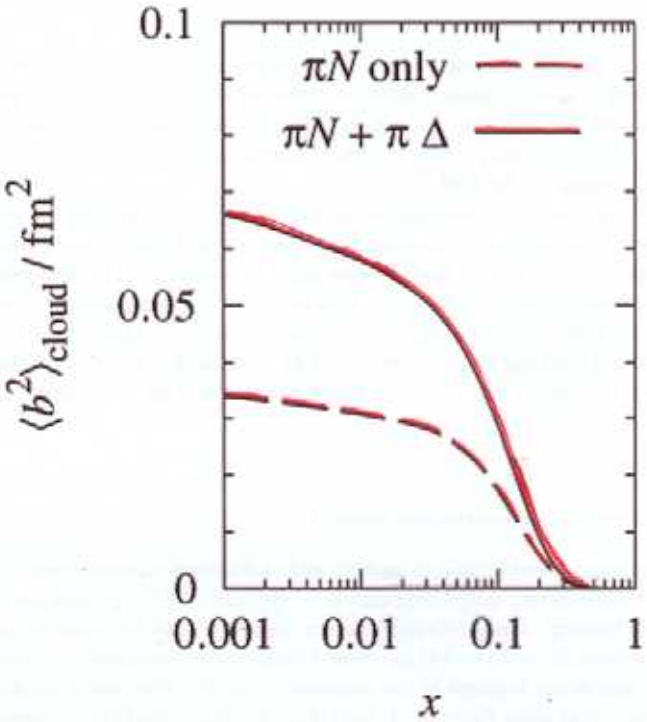
pion cloud
"hidden" in
average configurations

pion cloud
"visible"

Pion cloud distinct from average configurations only for $x \ll M_\pi / M_N$

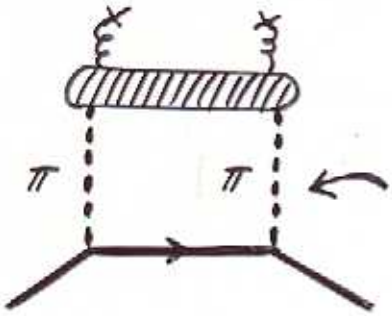
- Effect on "overall" transverse size of nucleon

$$\langle b^2 \rangle = \underbrace{\langle b^2 \rangle_{bulk}}_{\approx\, 0.3\ fm^2} + \underbrace{\langle b^2 \rangle_{cloud}}_{\text{Integrate Yukawa tail } (b > b_0)\,!}$$



"Freeing" of pion cloud causes ~20% increase of transverse size of nucleon for $x \ll M_\pi / M_N$

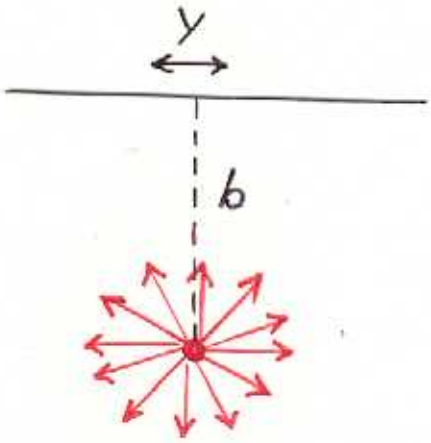
- $b \gtrsim \frac{1}{M_\pi}$: Pions soft!



$\leftarrow K^2 \sim M_\pi^2$ pion virtuality

$\leftrightarrow$ Meson cloud model for $\bar{d}(x) - \bar{u}(x)$:
No restriction to large b! [Sullivan 77, Thomas 83]

- Alt. approach to chiral dynamics: $N_c \to \infty$ limit



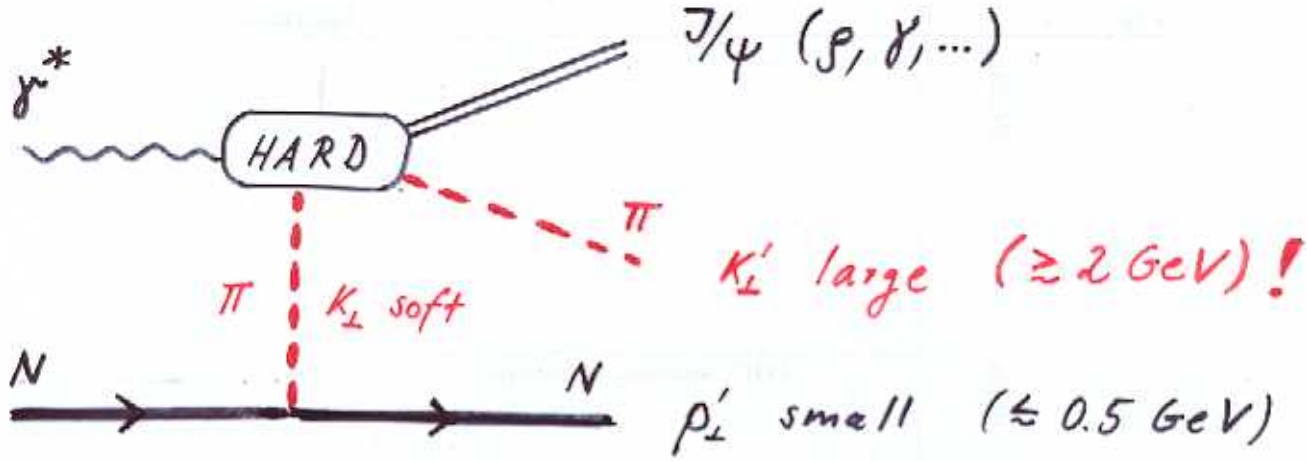
classical pion field in nucleon rest frame ("hedgehog")

$f_\pi(y, b)$

$\sim$ classical pion field at transverse distance $b \sim \frac{1}{M_\pi}$

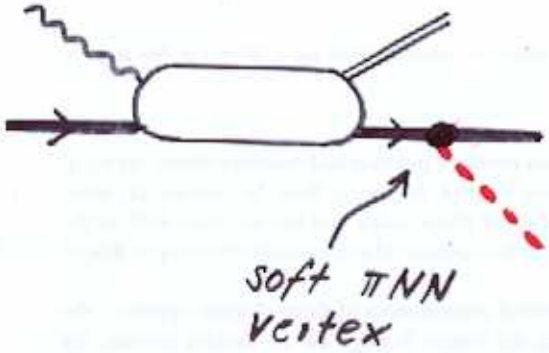
... model-independent!

- Ultraperipheral hard exclusive processes with pion knockout



[HERA, EIC]

vs.



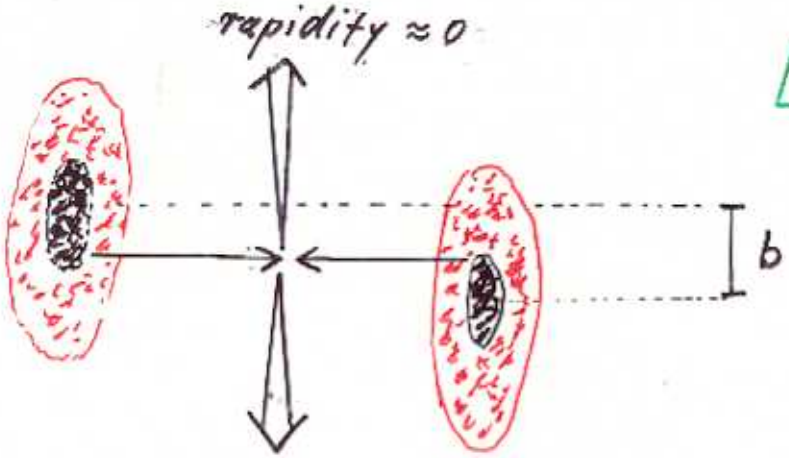
suppressed!

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

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

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

- Centrality trigger for pp collisions at LHC
  $p\bar{p}$ " Tevatron



[→ M. Strikman]

... Enforce overlap of hard partons in "core"
→ Restricts effective values of b !

- Spatial structure of gluon distribution should be incorporated in studies of non-linear QCD evolution (→ saturation) !

[Rummukainen, Weigert 03]

Summary

"Chiral fringe" of gluon distribution:
Important model-independent feature!

- Pion cloud "visible" only for $x \ll \frac{M_\pi}{M_N}$

- Causes ~20% rise in $\langle b^2 \rangle_{gluon}$ for $x \ll \frac{M_\pi}{M_N}$

  cf. J/ψ production at HERA $\longleftrightarrow$ fixed target

- Can be probed in "ultraperipheral" hard exclusive electro-/photoproduction with pion "knockout"