Pion cloud contribution to parton densities and its spatial structure

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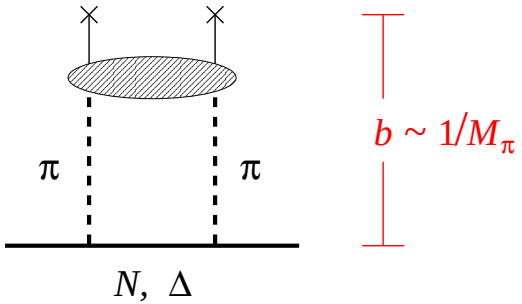
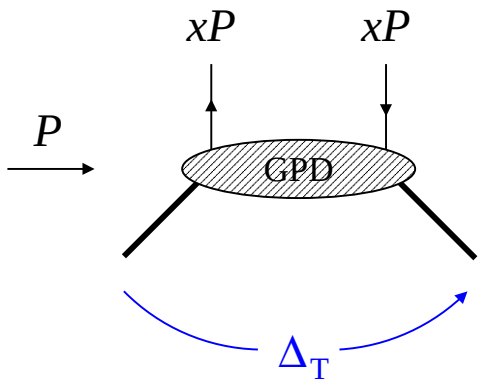
Parton density at transverse distances $b \sim 1/M_\pi$
due to chiral dynamics (soft–pion exchange)

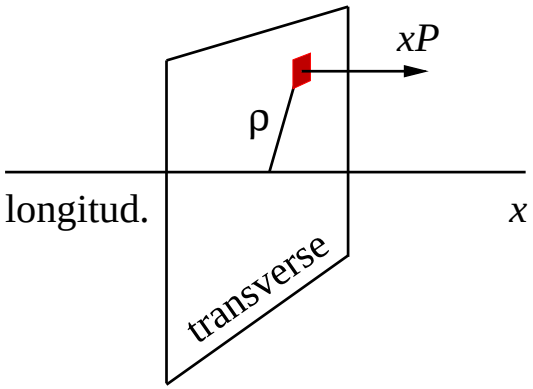


Isoscalar	Gluon, $\bar{u} + \bar{d}$	$N + 2\Delta$	Excl. J/ψ, DVCS at HERA, EIC
Isovector	$\bar{u} - \bar{d}$	$N - \Delta$	Drell–Yan at FNAL E866 Semi–incl. DIS at HERMES, JLab

- Model–independent analysis based on GPDs
- Relation to $N_c \to \infty$ limit of QCD

Transverse spatial distribution of partons





[Burkardt 02; Diehl 02]

- Transverse coordinate representation ($\xi = 0$)

$$H(x,t) \quad = \quad \int d^2\rho \; e^{-i\boldsymbol{\Delta}_T\cdot\boldsymbol{\rho}} \; f(x,\rho)$$

FF of partons with mom. xP

transverse spatial distribution

$$\int d^2\rho \, f(x,\rho) \; = \; f(x)$$

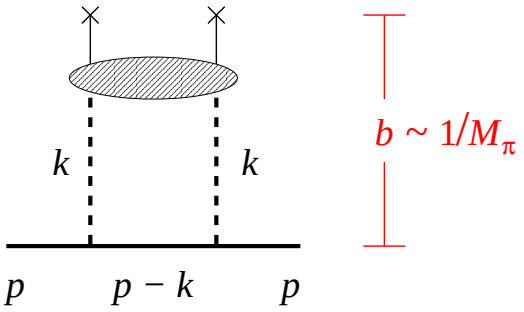
longitud. momentum density

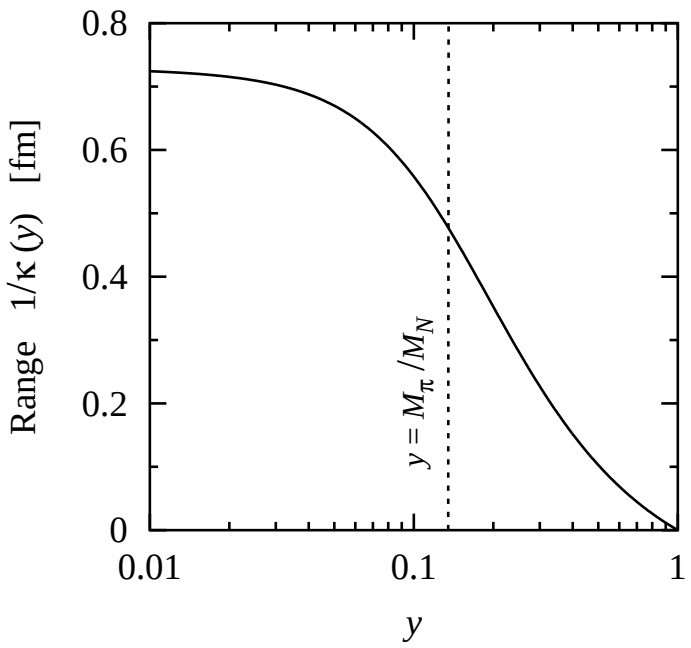
- Transverse size of nucleon (x–dep.)

$$\langle \rho^2 \rangle_f \; = \; 4 \, \frac{\partial}{\partial t} \; \frac{H(x,t)}{H(x,t=0)}$$

"Tomographic image" of nucleon at fixed x

Parton density at $b \sim 1/M_\pi$





[Strikman, CW, PRD **69**, 054012 (2004)]

- Parton density at $b \sim 1/M_\pi$ due to soft–pion exchange ($k^\mu \sim M_\pi$)

$$f_N^a(y,b) \;=\; \int_x^1 \frac{dy}{y}\, f_N^\pi(y,b)\; f_\pi^a(x/y)$$

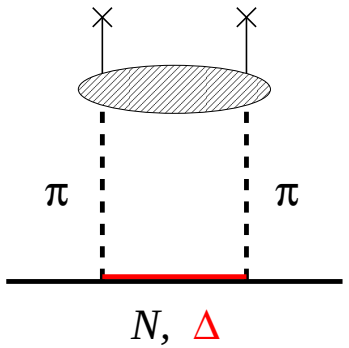
- Pion distribution in nucleon calculable in model–independent way
  - t–channel cut $\rightarrow$ Cutkosky rules
  - No πN formfactors!

- Yukawa tail with y–dep. range

$$f_N^\pi(y,b) \;\sim\; e^{-\kappa(y) b}$$

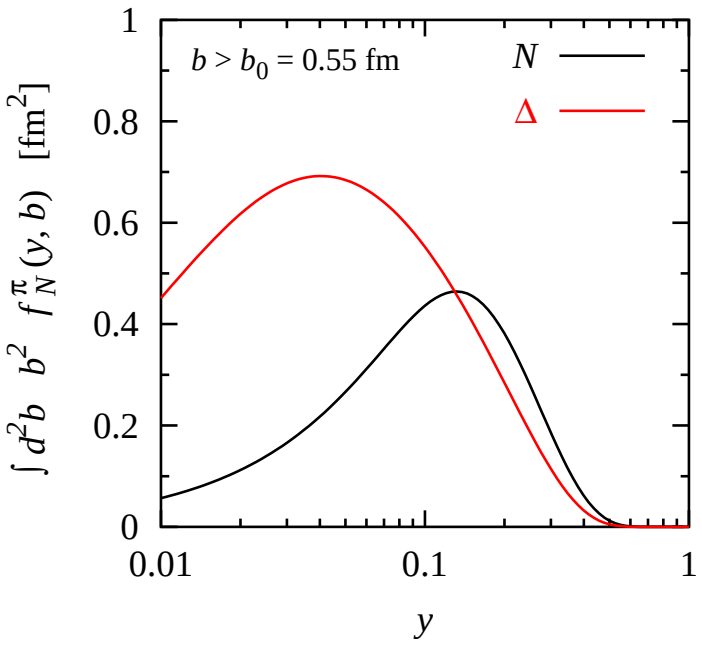
Chiral contribution only at $y < M_\pi/M_N$!

N and Δ intermediate states



- $N \to \Delta$ transitions phenomenologically important: $g_{\pi N\Delta} \approx (3/2)\, g_{\pi NN}$

- Computed using pointlike Δ (Rarita–Schwinger field)



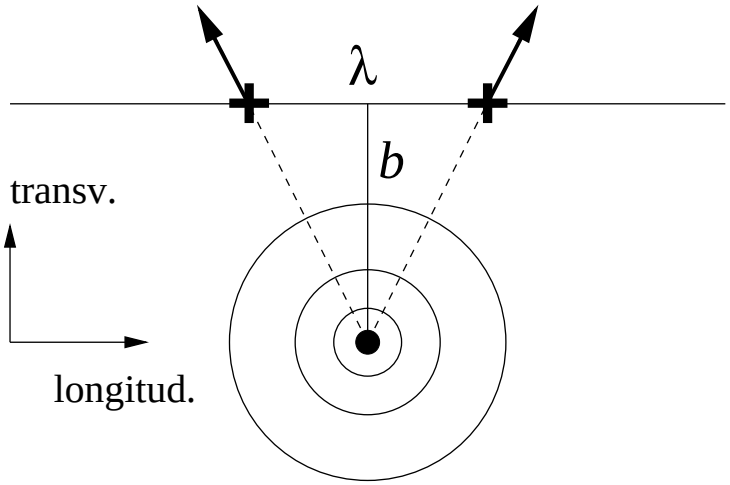
- Isospin dependence

I = 0	$g, \bar{u} + \bar{d}$	$N + 2\Delta$
I = 1	$\bar{u} - \bar{d}$	$N - \Delta$

Pion cloud contribution strongest in isoscalar channels: $g, \bar{u} + \bar{d}$

$N_c \to \infty$ limit of QCD

$$\begin{aligned} u+d,\, g &\sim N_c^2 \text{ fun}(N_c x) \\ u-d &\sim N_c \text{ fun}(N_c x) \end{aligned}$$



[Strikman, CW, 04]

- $N_c \to \infty$ limit: N, Δ degenerate

$$\begin{aligned} I=0 \quad N+2\Delta &\to 3N \\ 1 \quad N-\Delta &\to 0 \end{aligned}$$

- Restores general N_c counting of PDFs
  [Diakonov et al. 96]

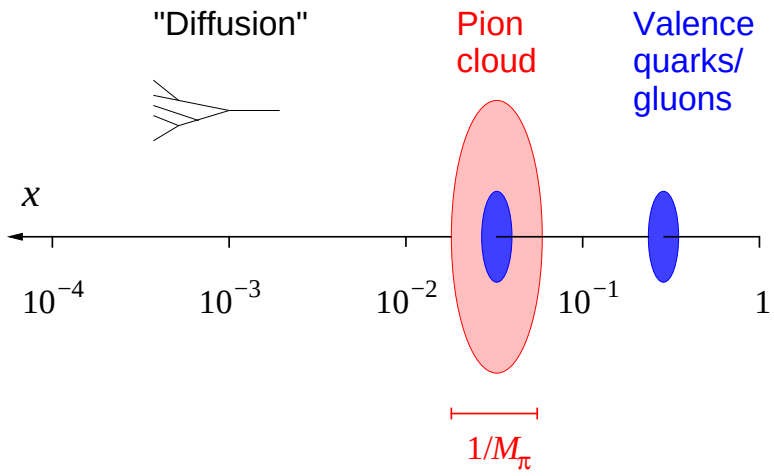
- Pion distribution calculable from classical soliton field at $b \sim 1/M_\pi$

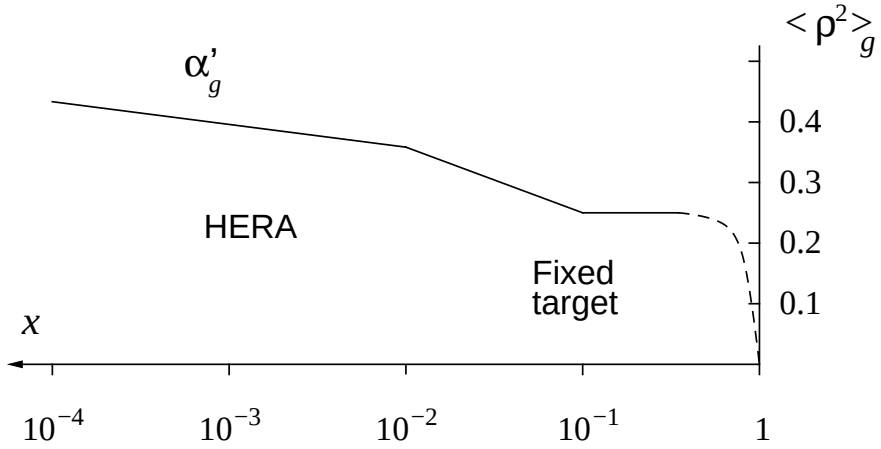
$$\langle N|\, \pi^a(-\lambda \boldsymbol{e}_z + \boldsymbol{b})\, \pi^a(\lambda \boldsymbol{e}_z + \boldsymbol{b})\, |N\rangle$$

$$\xrightarrow{\text{Fourier}} \quad f_N^\pi(y,b) \qquad (I=0)$$

"Pion cloud" consistent with $1/N_c$ expansion of PDFs in QCD

Phenomenology: Gluons





(Scale $Q^2 \approx 3\,\text{GeV}^2$)

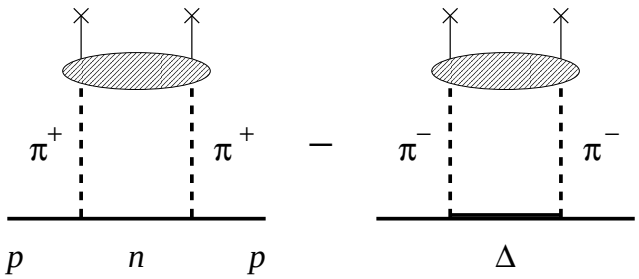
- Model–independent contribution to gluon density at $b > b_0 \sim 0.5$fm ("core radius")
- Produces finite increase in $\langle b^2 \rangle_g$ between $x \sim 0.3$ and $x \ll M_\pi/M_N$

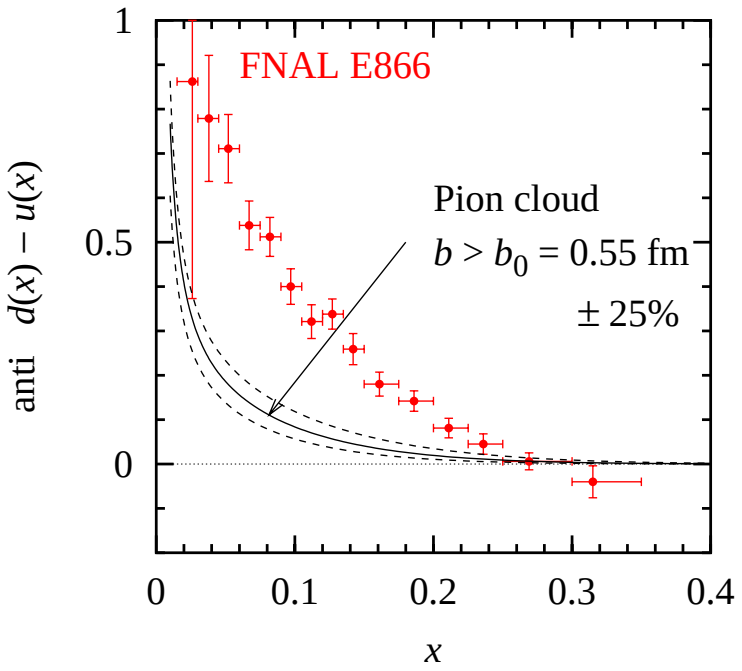
  cf. t–slope $B(J/\psi)$
- Gives $\langle b^2 \rangle_q > \langle b^2 \rangle_g$ at small x

  cf. $B(\text{DVCS})$ $>$ $B(J/\psi)$ HERA
  q, g g only

[Strikman, CW, in prep.]

Phenomenology: Flavor asymmetry $\bar{d} - \bar{u}$





[Strikman, CW; in prep.]

- "Pion cloud" early suggested to explain $\bar{d} > \bar{u}$ [Thomas 83]
- Coordinate space analysis shows that large–b chiral contribution
  - too small
  - concentrated at small x

  [same for $s, \bar{s}$ from $K\Lambda$: Brodsky et al.]
- Phen. models with πN formfactors: Virtualities $k^2 \sim 1\,\text{GeV}^2$ . . . unphysical!

Flavor asymmetry $\bar{d} - \bar{u} > 0$ due to quark core (Pauli blocking)

Summary

- Transverse coordinate representation (GPDs) allows for model–independent identification of "pion cloud" contribution: $b \sim 1/M_\pi, \;\; x < M_\pi/M_N$

- Chiral soliton picture for $N_c \to \infty$ coincides with phenomenological soft–pion exchange at large b

- Pion cloud strongest in isoscalar PDFs: $N + 2\Delta$, cf. large–N_c limit

- True "pion cloud" contribution to $\bar{d} - \bar{u}$ small: Observed asymmetry sits in quark core (Pauli blocking)

GPDs most useful for nucleon structure!