Valence quark distributions of spin-$\frac{1}{2}$ and spin-0 baryons.

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working under the supervision of

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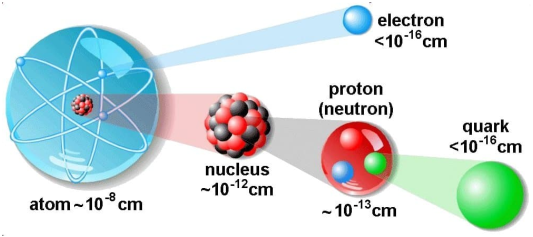
June 11, 2025

Outline

Introduction

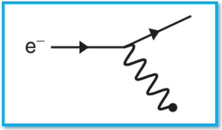
Quantum chromodynamics (QCD)

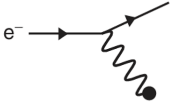
- an underlying theory for the strong interactions.
- describe the internal hadronic structure in terms of their constituent quarks and gluons degree of freedom.



Probing the structure of a hadron

Very low energy | Non-relativistic probe | $\lambda >> r_p$ | Elastic scattering of e^- in the static potential of an effectively point-like hadron





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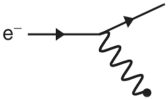
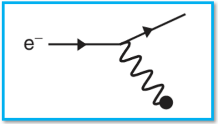
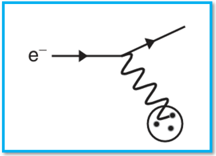


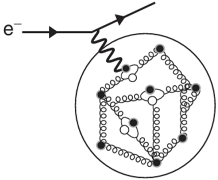


High energy | No longer purely electrostatic | $\lambda \approx r_p$ | Charge and magnetic distributions of hadron

Probing the structure of a hadron

Higher energy | Hadron subsequently breaks up | $\lambda < r_p$ | Dominant process: Inelastic scattering | γ^* interacts with constituent quark





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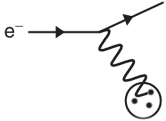
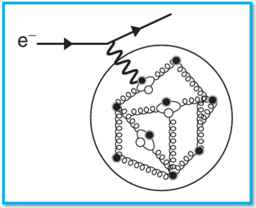


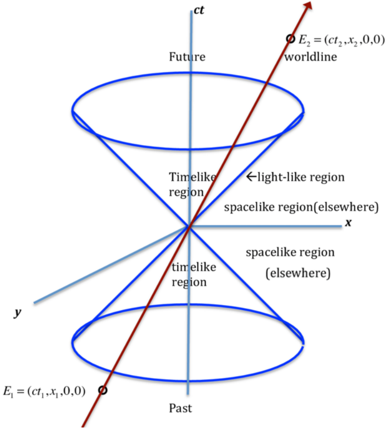


Very high energy | detailed dynamics of hadron | $\lambda << r_p$ | Appears to be a sea of partons

Highly preferable, Lorentz-invariant form.

- four-vectors.
- fundamental concept in special theory of relativity.

So, **Special theory of relativity becomes an important concept that must be follow**.



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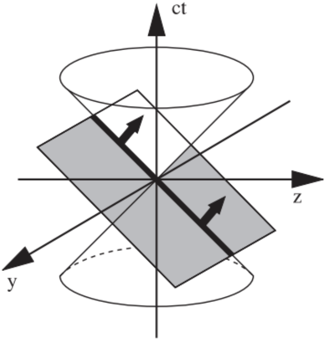


The front form

$$\tilde{x}^0 = ct + z$$
$$\tilde{x}^1 = x$$
$$\tilde{x}^2 = y$$
$$\tilde{x}^3 = ct - z$$

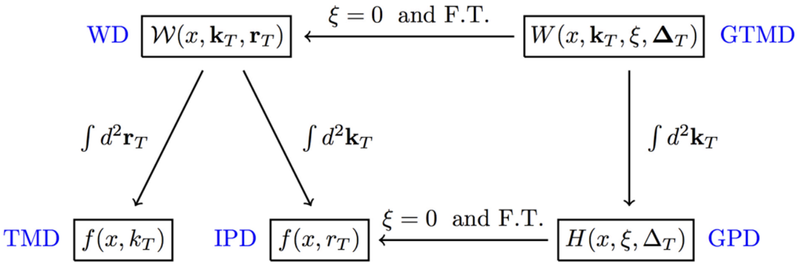
Distribution functions

$$\boxed{W(x, \mathbf{k}_T, \xi, \mathbf{\Delta}_T)}$$ GTMD

Distribution functions

$$\text{WD} \quad \boxed{\mathcal{W}(x, \mathbf{k}_T, \mathbf{r}_T)} \xleftarrow{\quad \xi = 0 \text{ and F.T.} \quad} \boxed{W(x, \mathbf{k}_T, \xi, \mathbf{\Delta}_T)} \quad \text{GTMD}$$

Distribution functions



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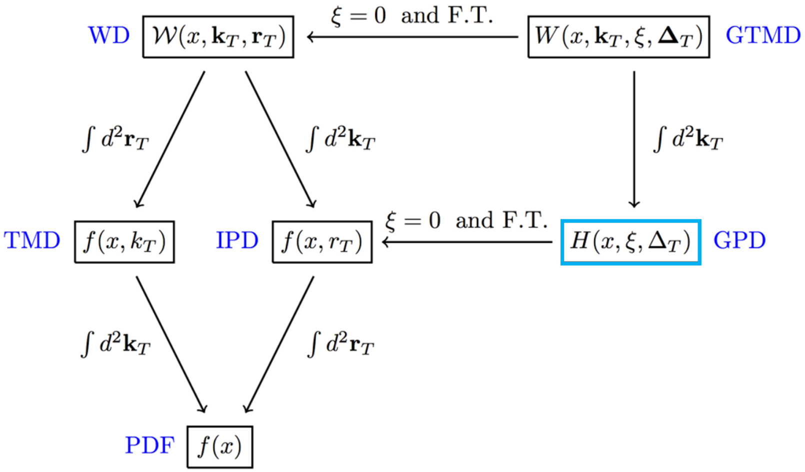


Outline

Generalized Parton Distributions

$$F^{[\Gamma]}_{\lambda\lambda'} = \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ik\cdot z} \left\langle p', \lambda' \middle| \bar{\psi}\left(\frac{-z}{2}\right) \Gamma\, \psi\left(\frac{z}{2}\right) \middle| p, \lambda \right\rangle \Big|_{z^+=0, \mathbf{z}_\perp = 0}$$

with

- $\lambda(\lambda')$: Initial (final) state helicity.
- $P = \frac{p+p'}{2}$, average momentum.
- $\Delta = p' - p$, momentum transfer.
- Impact parameter space, $\mathbf{\Delta}_\perp \leftrightarrow b_\perp$ via FT.
- Γ basis $[1, \gamma_5, \gamma^\mu, \gamma^\mu\gamma_5, \sigma^{\mu\nu}]$.

JHEP 08, 056 (2009)

Generalized Parton Distributions: spin-$\frac{1}{2}$

$$\frac{1}{2\bar{P}^+}\bar{u}(P')\Big[H^q_X(x,\zeta,\boldsymbol{\Delta}_\perp)\,\gamma^+ + E^q_X(x,\zeta,\boldsymbol{\Delta}_\perp)\,\frac{i\sigma^{+\alpha}(-\Delta_\alpha)}{2M}\Big]u(P)$$

Eur. Phys. J. A 52 (2016) 163.

quark pol. (columns) / nucleon pol. (rows)

	U	L	T	
U	$\boldsymbol{H}$		$E_T + 2\tilde{H}_T$	
L		$\boldsymbol{\tilde{H}}$	$\tilde{E}_T$	
T	E	$\tilde{E}$	$\boldsymbol{H_T}$	$\tilde{H}_T$

$\Gamma = \gamma^+$: H and E
unpolarized

$\Gamma = \gamma^+\gamma^5$: $\tilde{H}$ and $\tilde{E}$
longitudinal polarized

$\Gamma = i\sigma^{+i}\gamma^5$:
$H_T, E_T, \tilde{H}_T$ and $\tilde{E}_T$
transversely polarized

Generalized Parton Distributions: spin-1/2

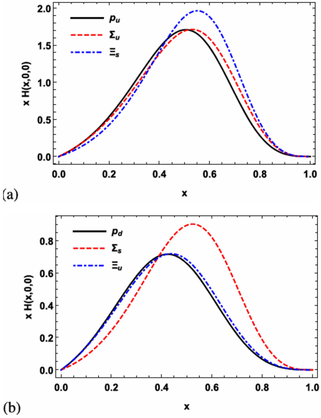
For $\Gamma = \gamma^+ : H$ | unpolarized parton distributions | Diquark spectator model

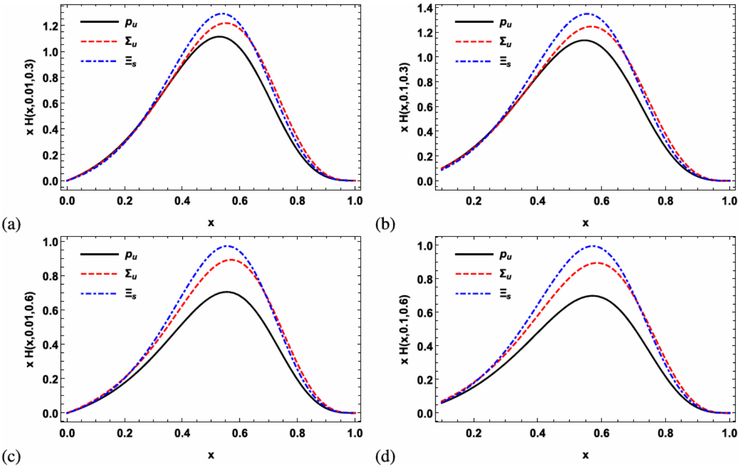
Light-cone wave functions for scalar and vector diquarks

$$\psi^{\lambda_X}_{\lambda_q}(x, \mathbf{k}_\perp) = \sqrt{\frac{k^+}{(P_X - k)^+}} \frac{\bar{u}(k, \lambda_q)}{k^2 - m_q^2} \mathcal{Y}_\mathfrak{s} \, U(P_X, \lambda_X),$$

$$\psi^{\lambda_X}_{\lambda_q \lambda_\mathfrak{a}}(x, \mathbf{k}_\perp) = \sqrt{\frac{k^+}{(P_X - k)^+}} \frac{\bar{u}(k, \lambda_q)}{k^2 - m_q^2} \epsilon^*_\mu \cdot \mathcal{Y}^\mu_\mathfrak{a} \, U(P_X, \lambda_X).$$

Observed: Heavier the quark, more is the probability to carry higher longitudinal momentum fraction x.





Left to right: Skewness parameter increases,
Top to bottom: invariant momentum transfer increases

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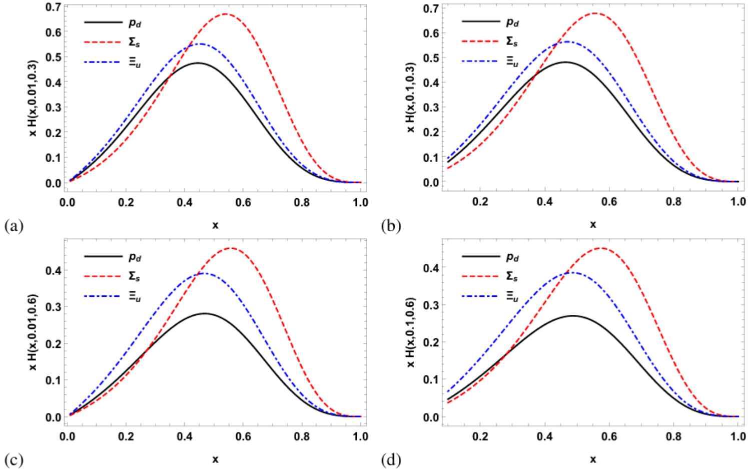

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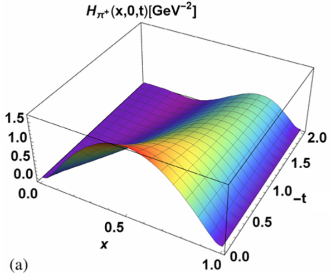
Generalized Parton Distributions: spin-0

For $\Gamma = \gamma^+ : H(x, \zeta, -t = \mathbf{\Delta}_\perp^2)$ | unpolarized parton distributions

LCWF for pseudoscalar meson

$$\psi(x, \mathbf{k}_\perp, \lambda_q, \lambda_{\bar{q}}) = \Psi(x, \mathbf{k}_\perp)\, \chi(x, \mathbf{k}_\perp, \lambda_q, \lambda_{\bar{q}})$$

- $\Psi(x, \mathbf{k}_\perp)$: momentum wave function
- $\chi(x, \mathbf{k}_\perp, \lambda_q, \lambda_{\bar{q}}$: spin wave function
- x: longitudinal momentum fraction
- $\mathbf{k}_\perp$: transverse momentum
- λ_q: quark helicity
- $\lambda_{\bar{q}}$: anti-quark helicity



(a)

Phys. Rev. D 111, 014008 (2025)

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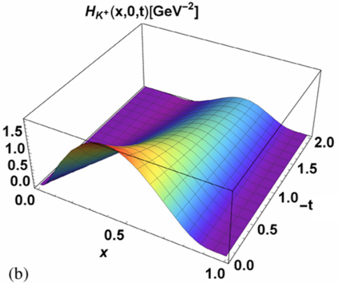


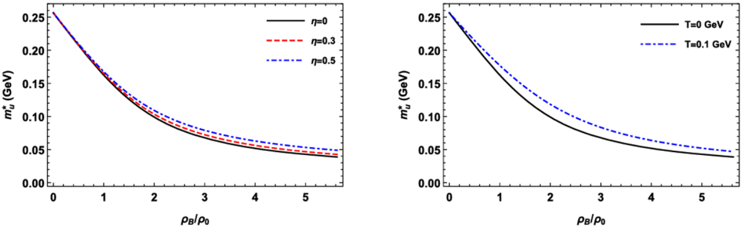
Phys. Rev. D 111, 014008 (2025)

Outline

Effective masses

Thermodynamic potential for isospin asymmetric nuclear matter at finite temperature and density

$$\Omega = \frac{-k_B T}{(2\pi)^3} \sum_i \gamma_i \int_0^\infty d^3k \Big\{ \ln\Big(1 + e^{-[E_i^*(k) - \nu_i^*]/k_B T}\Big) + \ln\Big(1 + e^{-[E_i^*(k) + \nu_i^*]/k_B T}\Big) \Big\} - \mathcal{L}_M - \mathcal{V}_{\text{vac}}$$



Left: Isospin asymmetry parameter dependence.
Right: Temperature dependence.

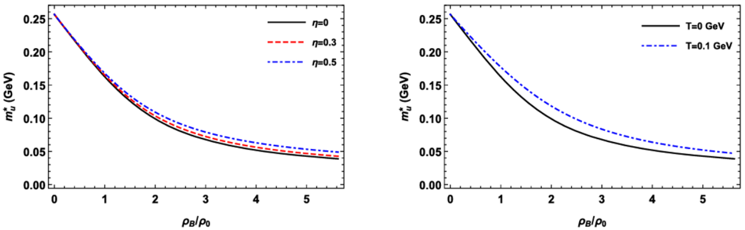
Effective masses

Dirac equation governing a quark field Ψ_{qi} is expressed as

$$\left[-i\vec{\alpha}\cdot\vec{\nabla}+\chi_c(r)+\beta m_q^*\right]\Psi_{qi}=e_q^*\Psi_{qi}$$

Quark effective mass

$$m_q^*=-g_\sigma^q\sigma-g_\zeta^q\zeta-g_\delta^q I_3^q\delta+\Delta m_q$$



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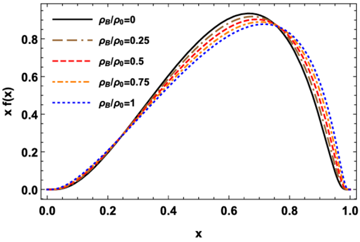
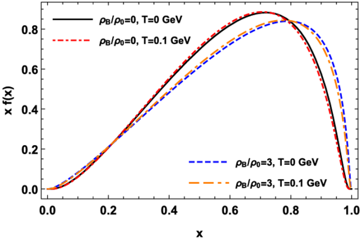
In-medium valence quark distributions

Valence quark of pion | Parton distribution function | dependence over baryonic density ratio and temperature





Left: Baryonic density ratio dependence.
Right: Temperature dependence.

Phys. Rev. D 110, 054042 (2024)

Summary

- GPDs provide 3D distribution in momentum space.
- Heavy quarks lead to carry higher longitudinal momentum fraction.
- As a function of momentum transfer, heavy quark falls slowly.
- The amplitude of PDFs decline as a function of baryonic density ratio: due to scaling down of effective quark masses.
- With increase in temperature, the amplitude raises.
- Temperature effect dominates at higher baryonic density ratio.

Thank you !