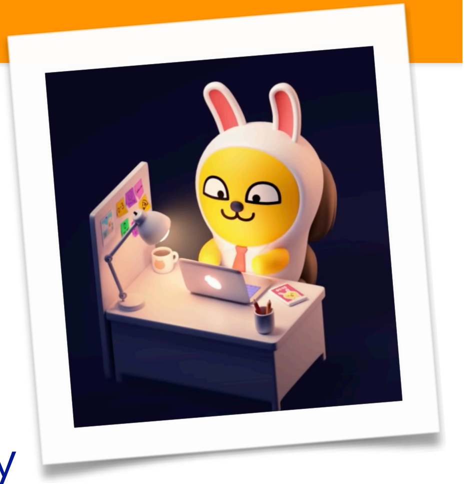
Gluon and valence quark distributions for the pion and kaon in nuclear matter



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Contents based on
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Introduction

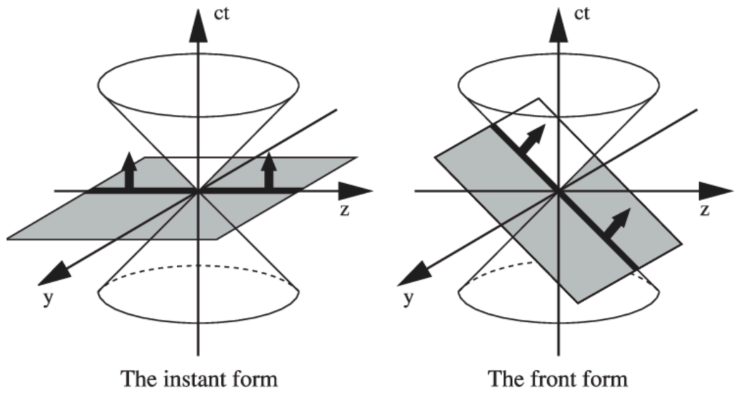
- Feynman's partonic interpretations of high-E scattering: Bjorken scaling etc.
- Partonic interpretations of (bound state) hadron

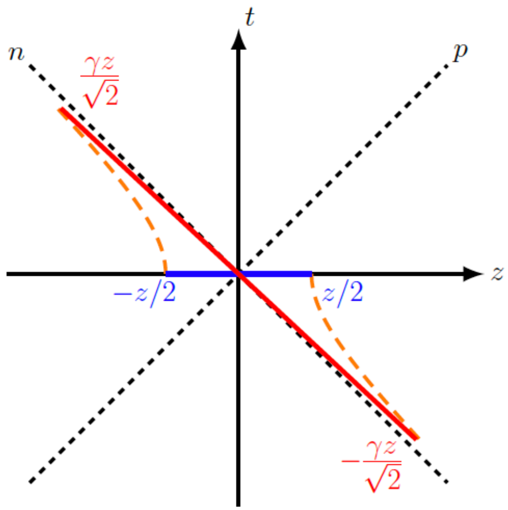
  ~ light-front quantization (LFQ)
- Well-defined Fock space and frame-independent

  for hadron wave function
- Difficult in covariant Euclidean space time:

  Moments calculation in LQCD
- Recent development from LFQ

  to Large-momentum (LaM) frame for LQCD





Introduction

- What are partonic structure functions??

1) Local operators or bilocal? 2) Momentum transferred or not? 3) Matter or vacuum?

⟨ H(k+q) | O(x,y)| H(k) ⟩ : Generalized parton distribution (GPD)

⟨ H(k) | O(x,y) | H(k) ⟩ : Parton distribution function (PDF)

⟨ H(k+q) | O(x) | H(k) ⟩ : Form factor (FF)

⟨ H(k) | O(x) | H(k) ⟩ : Coupling constant (CC)

⟨ 0 | O(x,y) | H(k) ⟩ : Light-cone wave function (LCWF)

And more…

Introduction

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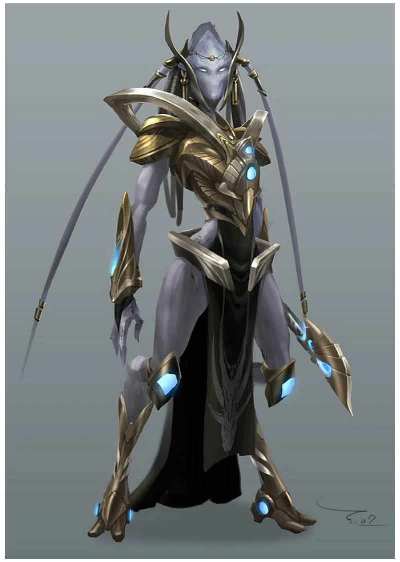
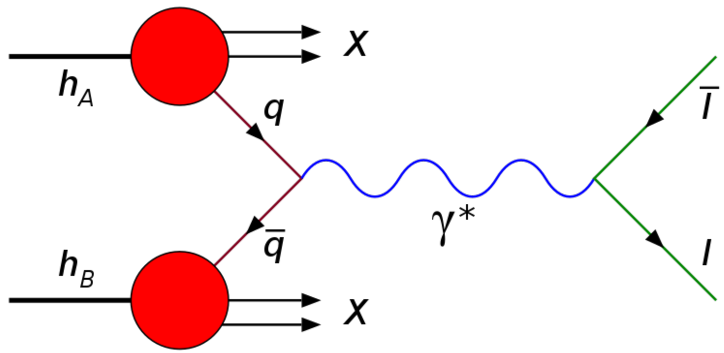


And more… with the Great prototype "Parton correlation function"

Introduction

- PDF is UNIVERSAL for processes depending on several scales (factorization & renormalization)
- Non-perturbative nature of QCD
- Effective models, LQCD, Global fit with Neural network (CTEQ)

Can we survive this? orz



- Momentum distribution of partons inside hadrons $x = k^+/P^+$
- Pseudo-scalar meson PDF defined in LFQ by

$$q_m(x) = \frac{p^+}{2\pi} \int d\xi^- \exp(ixp^+\xi^-) \langle m|\bar{q}(0)\gamma^+ q(\xi^-)|m\rangle_c,$$

- Two quarks on LF "coordinate (-)" with separation ξ evolving with LF "time (+)"
- What happens for PDF in medium? ⇒ Extension to nuclear PDF!?!

Theoretical framework

- NJL Lagrangian density

$$\mathcal{L}_{\mathrm{NJL}} = \bar{q}(i\partial\!\!\!/ - \hat{m}_q)q + G_\pi[(\bar{q}\lambda_a q)^2 - (\bar{q}\lambda_a\gamma_5 q)^2] - G_\rho[(\bar{q}\lambda_a\gamma^\mu)^2 + (\bar{q}\lambda_a\gamma^\mu\gamma_5 q)^2].$$

- Constituent-quark mass via the gap equation with proper-time regularization (PTR)

$$M_q = m_q + \frac{3G_\pi M_q}{\pi^2}\int_{\tau_{\mathrm{UV}}^2}^{\tau_{\mathrm{IR}}^2}\frac{d\tau}{\tau^2}\exp(-\tau M_q^2),$$

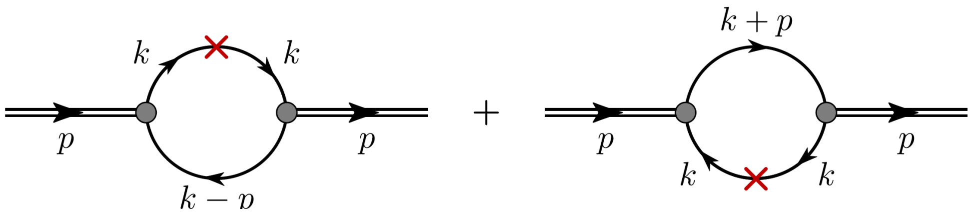
- Pseudo-scalar meson dressed propagators via Dyson-Schwinger Eq.

$$t_{\pi,K} = \frac{-2iG_\pi}{1 + 2G_\pi\Pi_{\pi,K}(p^2)} \qquad \Pi_\pi(p^2) = 6i\int\frac{d^4k}{(2\pi)^4}[\gamma_5 S_l(k)\gamma_5 S_l(k+p)]$$

- Pseudo-scalar meson mass and coupling are the pole and residue of t

Theoretical framework

- PDF in vacuum NJL



$$q_{\pi,K}(x) = ig^2_{mq\bar{q}} \int \frac{d^4k}{(2\pi)^4} \delta(k^+ - xp^+)\,\mathrm{Tr}_{c,f,\gamma}[\gamma_5 \lambda_a^\dagger S_l(k)\gamma^+ \hat{P}_{u/d} S_l(k)\gamma_5 \lambda_a S_l(k-p)]$$

- Quarks are charged fermion ⇒ Gluon Bremsstrahlung ⇒ Energy loss
- How about inverse process?: PDF at low Λ ⇒ higher Λ: DGLAP at larger Q^2
- Gluon radiation at local point described by Splitting function *P*
- Flavor-singlet quark PDF (qPDF) and gluon PDF (gPDF) are inter-related

$$\frac{\partial}{\partial \ln Q^2}\begin{bmatrix} q_S(x,Q^2) \\ g(x,Q^2) \end{bmatrix} = \begin{bmatrix} \mathcal{P}_{qq} & \mathcal{P}_{qg} \\ \mathcal{P}_{gq} & \mathcal{P}_{gg} \end{bmatrix} \otimes \begin{bmatrix} q_S(x,Q^2) \\ g(x,Q^2) \end{bmatrix}.$$

- Once we know qPDF, by solving differential eq. At certain Q^2, we have gPDF

Theoretical framework

- NJL modified in medium with iso-scalar vector potential (SNM)

$$\mathcal{L}_{\text{SNM-NJL}} = \bar{q}(i\partial\!\!\!/ - M_q - V\!\!\!/)q - \frac{(M_q - m_q)^2}{4G_\pi} + \frac{V_\mu V^\mu}{2G_\omega}$$

- Compute medium quark mass and iso-scalar potential V (not field)

$$M_q = m_q - 2G_\pi \langle \rho | \bar{q}q | \rho \rangle,$$

$$V^\mu = 2G_\omega \langle \rho | \bar{q}\gamma^\mu q | \rho \rangle = 2\delta^{0\mu} G_\omega \langle q^\dagger q \rangle,$$

- Effective potential by solving Faddeev eq. With quark-diquark bound state

$$\mathcal{E} = \mathcal{E}_V - \frac{V_0^2}{4G_\omega} + 4\int \frac{d^3p}{(2\pi)^3}\theta(p_F - |\mathbf{p}|)\epsilon_p,$$

Integration up to Fermi momentum

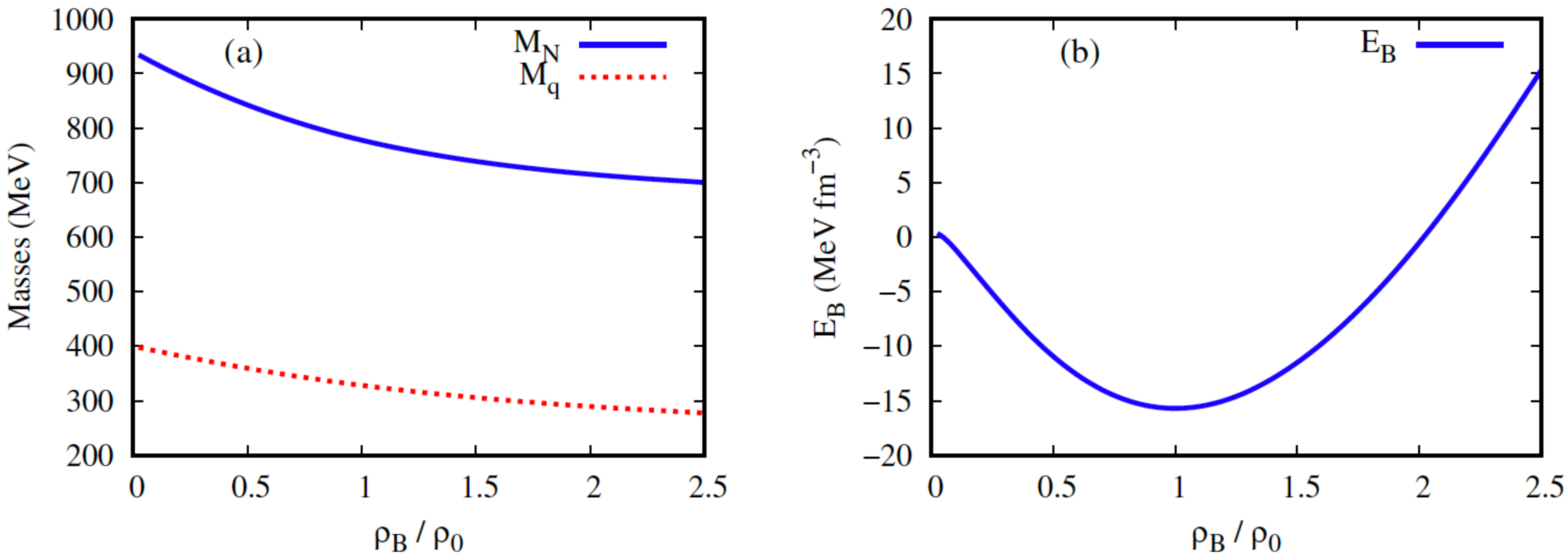
$$\epsilon_p = \sqrt{M_N^{*2} + \mathbf{p}^2} + 3V_0 \equiv E_p + 3V_0.$$

Theoretical framework

- Variation or potential wrt V and Mq

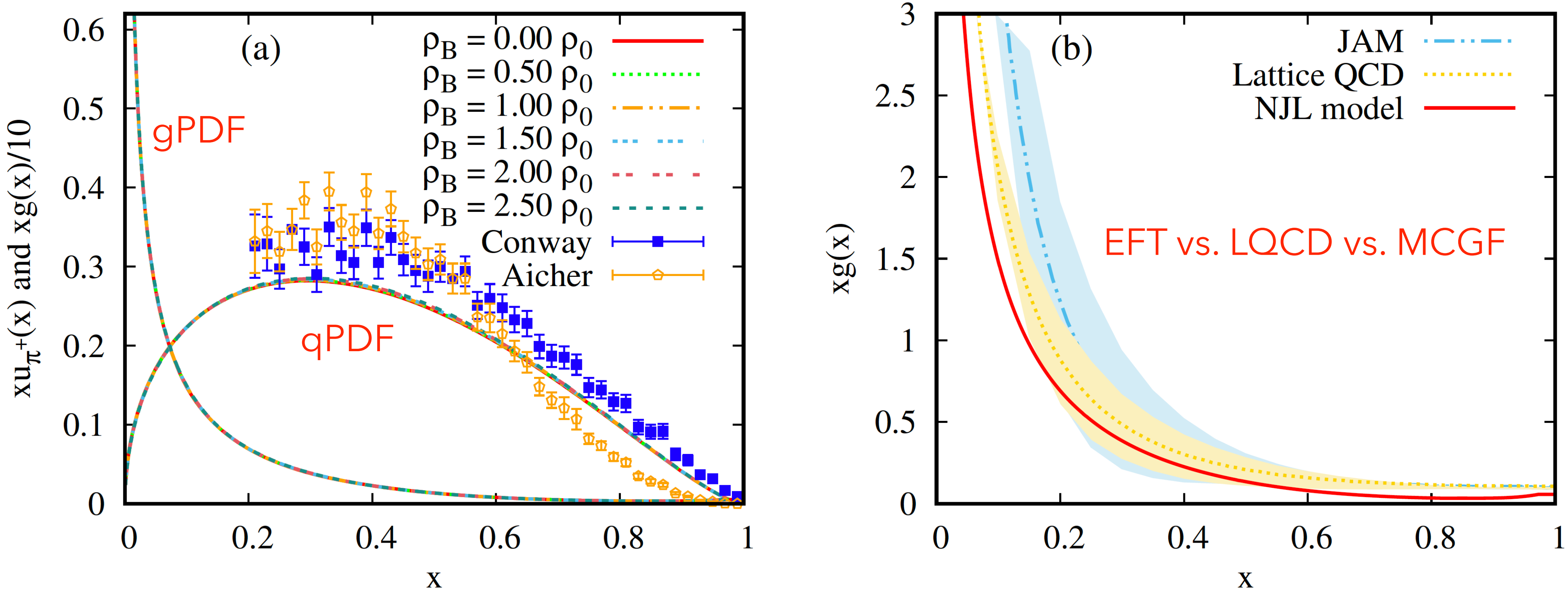
$$\partial\mathcal{E}/\partial V_0 = 0,\ V_0 = 6G_\omega\rho_B,\quad \rho_B = 2p_F^3/3\pi^2 \qquad \frac{\partial\mathcal{E}}{\partial M_q} = 0$$

- By combining them, we obtain Mq as a function of density!!!!!



Numerical results

- qPDF and gPDF for pion (u-d) in symmetric nuclear matter

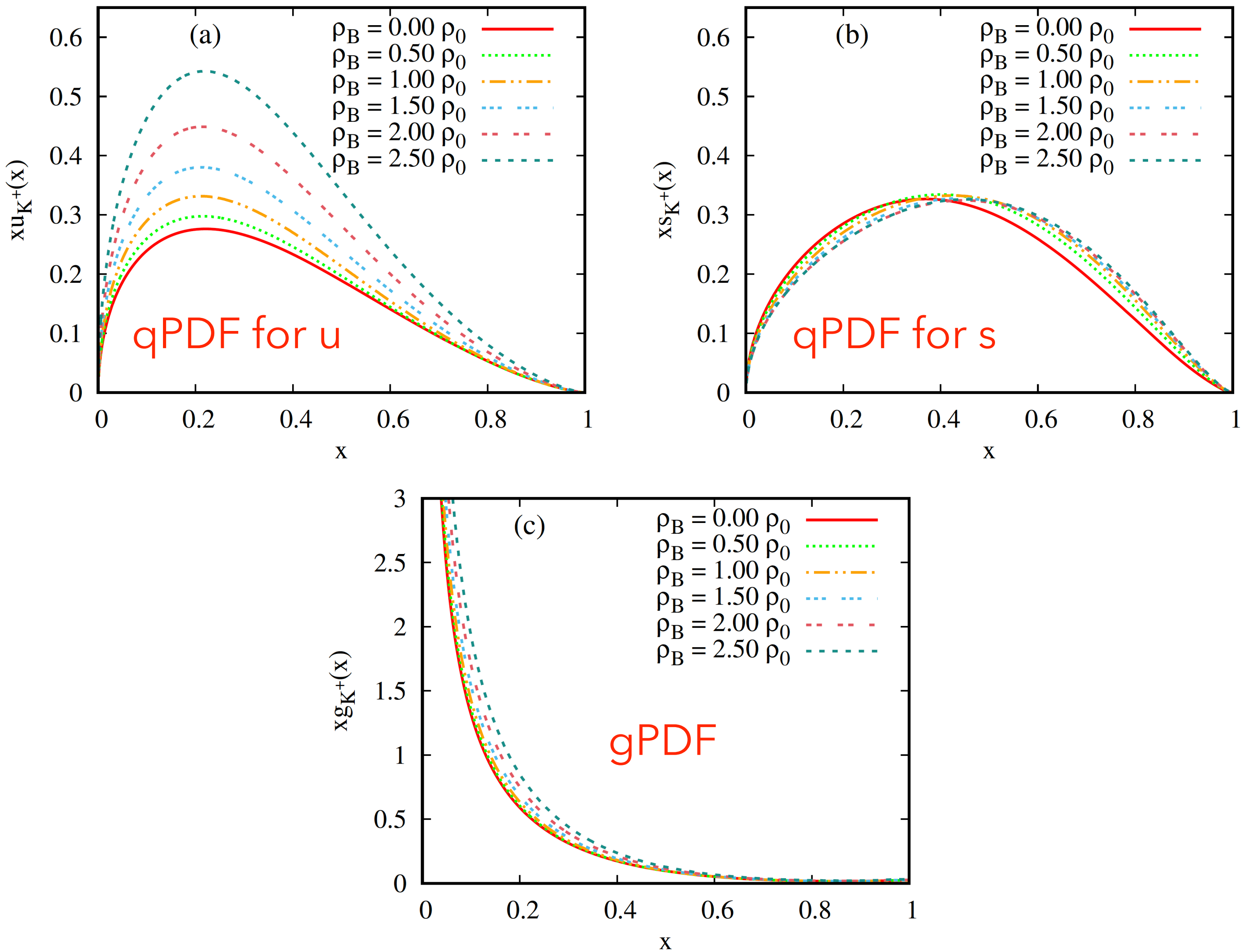


- DGLAP evolution up to |Q| =4 GeV

- Density effects are almost negligible: Why?

Numerical results

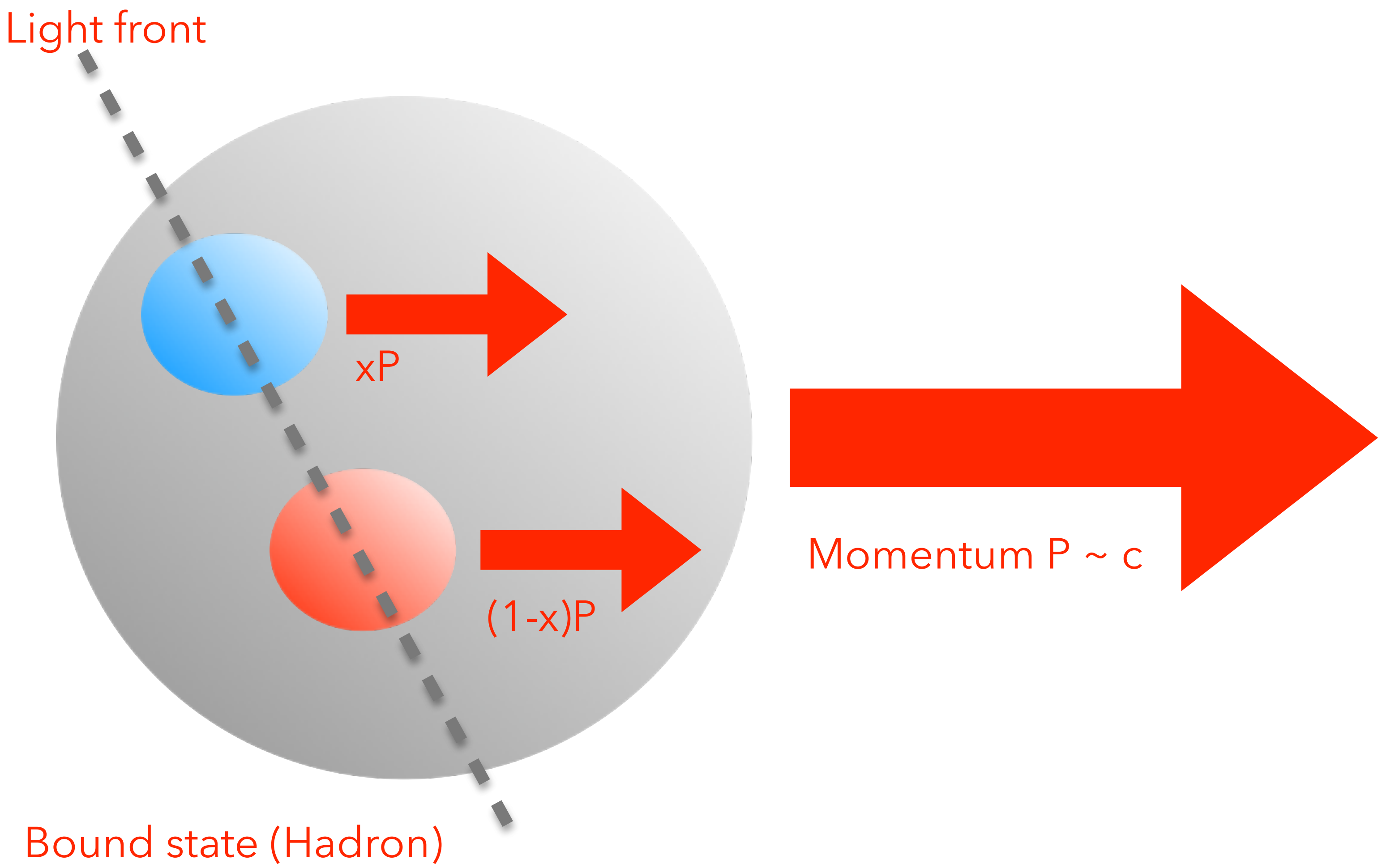
- What about Kaon (u-s)???: Considerable changes in light quark u, not s!!!



- Density effects are obvious: Why?

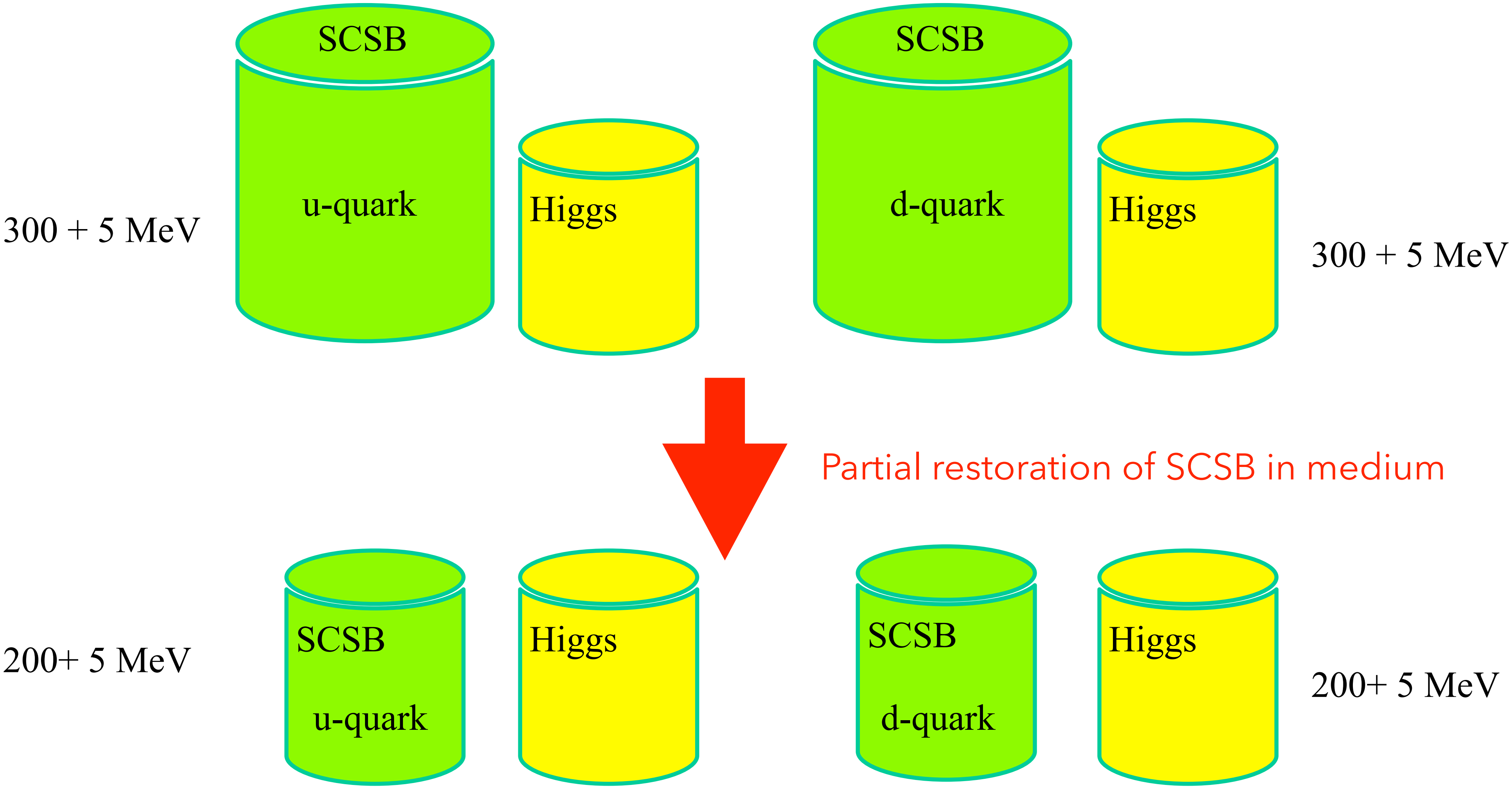
Numerical results

- PDF describes fractional longitudinal momentum (x) distribution of patron



Numerical results

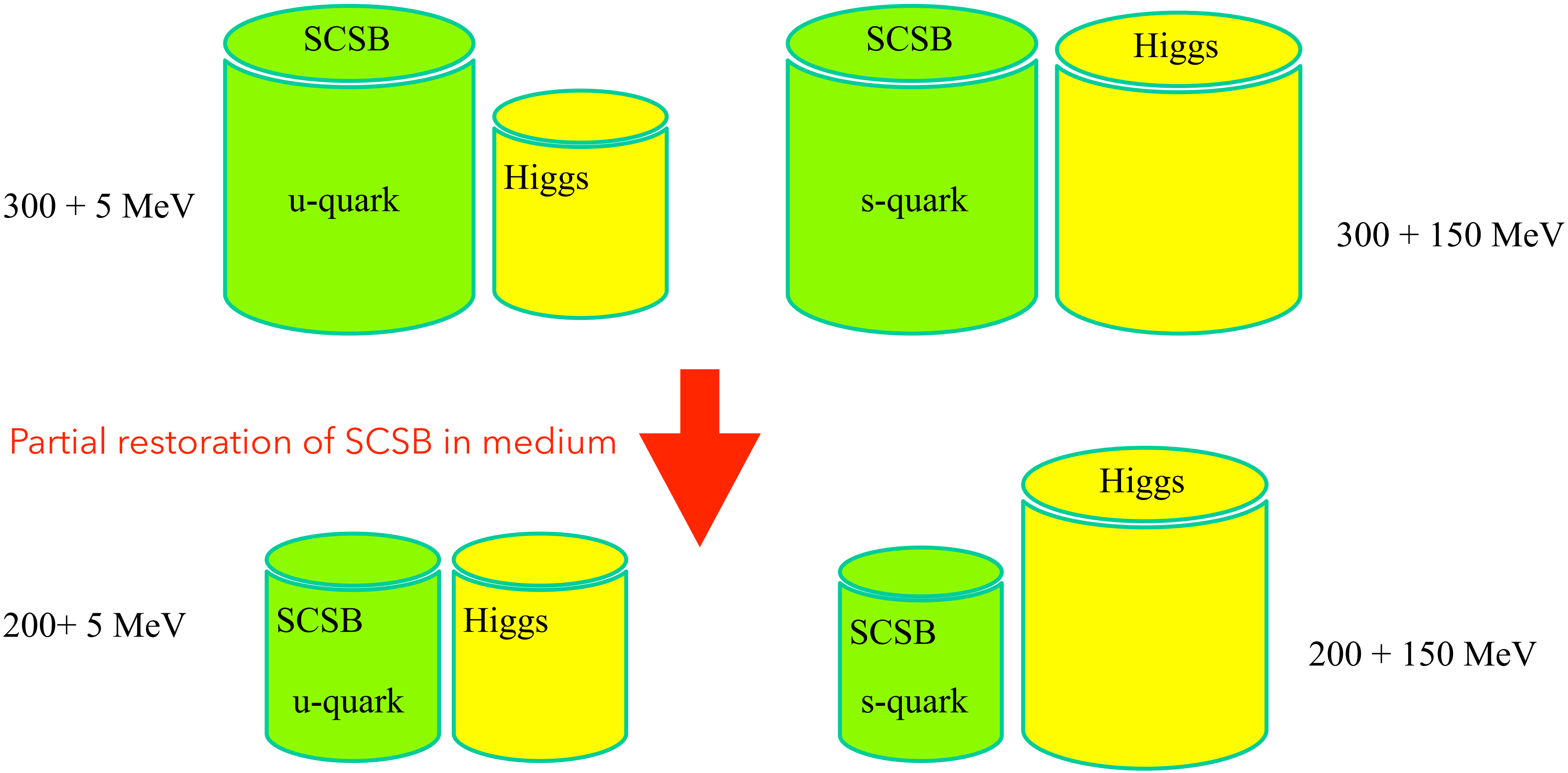
- Intuitive explnation: Pion



Same total mass-reduction rate for u (33%) and d (33%)

Numerical results

- Intuitive explnation: Kaon



Different total mass-reduction rate for u (33%) and s (22%)

Numerical results

- Intuitive explnation: Kaon

Different total mass-reduction rate for u (33%) and s (22%)

Summary and outlook

- qPDF and gPDF for pseudo-scalar meson investigated in medium
- Medium-modified NJL model employed: NJL-SNM in LFQ
- gPDF from NS qPDF ⊗ gPDF combined diff. Eq.
- (u,d)PDF-SNM and gPDF-SNM ~ vacuum ones for pion
- For kaon, sPDF-SNM and gPDF-SNM ~ vacuum ones, not uPDF-SNM
- Same and different mass reduction via SCSB for pion and kaon
- Competition between Higgs and SCSB mechanisms in PDF
- Important implications in heavy-light bound state: More obvious for $B^{(*)}$,$D^{(*)}$?

More works on the way, please, stay tuned!!!

Thank you for your attention!!

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