

# PDFs from non-local chiral SU(3) effective theory

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## Outline

- Introduction
- Meson cloud model
- Splitting functions with differen regularization methods
- Results

# Introduction

## 1.NMC anomaly & Proton flavour asymmetry

$$\text{Gottfried Sum Rule : } S_G = \int_0^1 \frac{dx}{x} [\bar{F}_p^2(x) - \bar{F}_n^2(x)] = \frac{1}{3} + \frac{2}{3} \int_0^1 dx [\bar{u}_p(x) - \bar{d}_p(x)], u_p = d_n, d_p = u_n, \bar{u}_p = \bar{d}_n, \bar{d}_p = \bar{u}_n$$

under the assumptions of  $\bar{d}(x) = \bar{u}(x)$ (flavor symmetric),  $S_G = \frac{1}{3}$

The New Muon Collaboration (NMC) determined the Gottfried sum to be  $0.235 \pm 0.026$  at  $Q^2 = 4 \text{ GeV}^2$ , which is smaller than  $1/3$ , this is called NMC anomaly.

$\langle Q^2 \rangle$	CT10	MSTW2008	NNPDF2.3	Experiment
$2.3 \text{ GeV}^2$	$I_G = 0.129(1)$	$I_G = 0.079(1)$	$I_G = 0.137(3)$	$I_G = 0.16(3)$ (HERMES)
$4 \text{ GeV}^2$	$I_G = 0.129(1)$	$I_G = 0.079(1)$	$I_G = 0.138(3)$	$I_G = 0.148(39)$ (NMC)
$54 \text{ GeV}^2$	$I_G = 0.130(1)$	$I_G = 0.080(1)$	$I_G = 0.139(3)$	$I_G = 0.118(12)$ (E866)

with  $I_G = \int_0^1 dx [\bar{d}_p(x) - \bar{u}_p(x)]$

Chang & Peng Prog.Part.Nucl.Phys.79(2014)

## 2. NuTeV anomaly & strange quark asymmetry

Under the assumptions of  $\bar{s}(x) = s(x), \bar{c}(x) = c(x)$ , Paschos-Wolfenstein relation:

$$R^- = \frac{\sigma_{NC}^{vN} - \sigma_{NC}^{\bar{v}N}}{\sigma_{CC}^{vN} - \sigma_{CC}^{\bar{v}N}} = \frac{1}{2} - \sin^2(\theta_W)$$

# Introduction

NuTeV result:  $\sin^2(\theta_W) = 0.2277 \pm 0.0013 \pm 0.0006 \pm 0.0006$

Global fit:  $\sin^2(\theta_W) = 0.2226 \pm 0.0004$ , This result about  $3\sigma$  away from the NuTeV data.

Strange quark asymmetry  $\bar{s}(x) \neq s(x)$

$$R_N^- = \frac{\sigma_{NC}^{vN} - \sigma_{NC}^{\bar{v}N}}{\sigma_{CC}^{vN} - \sigma_{CC}^{\bar{v}N}} = R^- - \delta R_S^-$$

Asymmetric term is related to the Strange quark asymmetry  $S^-$

$$\delta R_S^- = (1 - \frac{7}{3} \sin^2(\theta_W)) \frac{S^-}{S^- + Q_v}, S^- = \int dx x [s - \bar{s}], Q_v = \int dx x [u_v + d_v].$$

PDF Analysis	$S^-(Q^2) \cdot 10^3$	$Q^2 [\text{GeV}^2]$	$S^-(Q_{\text{ref}}^2 = 20) \text{ GeV}^2 \cdot 10^3$
NNPDF1.2	$0.5 \pm 8.6$	20	$0.5 \pm 8.6$
MSTW08	$2.4 \pm 2.0$	1	$1.7 \pm 1.4$
CTEQ6.5s	$2.0 \pm 1.8$	1.69	$1.6 \pm 1.4$
CTEQ6.1s	$1.5 \pm 1.5$	1.69	$1.2 \pm 1.2$
AKP08	$1.0 \pm 1.3$	20	$1.0 \pm 1.3$
NuTeV07	$2.2 \pm 1.3$	16	$2.2 \pm 1.3$
BPPZ03	$1.8 \pm 3.8$	20	$1.8 \pm 3.8$

Large uncertainty for the Strange quark asymmetry  $-0.001 < S^- < 0.004$ , R. D. Ball et al, Nucl. Phys. B823, 195 (2009), PRL.93(2004) 152003

⇒ Where are they from? Perturbative or Non-perturbative?

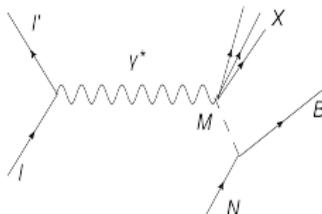
# Meson cloud model

## 1.Theoretical explanation

- Experimental data shows that proton flavor asymmetry weakly depends on  $Q^2$ . This indicates that perturbative contributions to the flavor asymmetry is very small and main part of flavor asymmetry comes from non-perturbative origin.
- Non-perturbative quark distribution is more like valence quark distributions than sea quark distribution. Valence quark distributions peaked at intermediate  $x$  while sea quark distributions peaked at low  $x$ .

Combine these two factors it can be confirmed that flavour and strange quark asymmetry of proton only can be explained within non-perturbative scenario. Meson cloud model was suggested in order to explain proton flavour asymmetry. The core idea of meson cloud model is that during the scattering process, the proton splits into a meson and a baryon, and the virtual photon interacts with the meson and baryon. Antiquark distributions in the pion contribute to the corresponding antiquark distributions in the proton.

- It should be reminded that during the QCD evaluation sea quark density increase, but perturbative contributions to flavour and strange quark asymmetry of proton are still suppressed.



## Meson cloud model

Using mathematical language, the wave function of the physical proton can be expressed in terms of a series of baryon-meson Fock states:

$$|N\rangle_{phy} = \sqrt{Z}|N\rangle_{bare} + \sum_{MB} \int dy d^2\vec{k}_\perp \Phi_{BM} \left( y, k_\perp^2 \right); \left| B \left( 1-y, -\vec{k}_\perp \right), M \left( y, \vec{k}_\perp \right) \right\rangle$$

- $M, B \mapsto$  Fock states,
- $\Phi_{BM}(y, k_\perp^2) \mapsto$  Probability amplitude,
- $f_{BM}(y) \equiv \int d^2\vec{k}_\perp \left| \Phi_{BM} \left( y, k_\perp^2 \right) \right|^2 \mapsto$  Splitting function,
- $y \mapsto$  meson momentum fraction.  $y$  defined as  $y = \frac{k^+}{p^+}, k^+ = k^0 + k^3, k^- = k^0 - k^3,$
- $\vec{k}_\perp \mapsto$  transverse momentum.

# Meson cloud model

At non-perturbative low energy region, baryon-meson interaction is described by Chiral effective theory.

$$\begin{aligned}\mathcal{L} = & \text{Tr} \left[ \bar{B} (i \not{D} - m_B) B \right] + D \text{Tr} \left[ \bar{B} \gamma^\mu \gamma_5 [u_\mu, B] \right] + F \text{Tr} \left[ \bar{B} \gamma^\mu \gamma_5 [u_\mu, B] \right] \\ & + \overline{T}_{\mu}^{ijk} (i \gamma^{\mu\nu\alpha} D_\alpha - m_T \gamma^{\mu\nu}) T_{\nu,ijk} + \mathcal{C} \left[ \epsilon^{ijk} \overline{T}_{\mu}^{ilm} \Theta^{\mu\nu} (u_\nu)^{lj} B^{mk} + \text{h.c.} \right] \\ & - \mathcal{H} \overline{T}_{\mu}^{ijk} \gamma^{\mu\nu\alpha} \gamma_5 (u_\alpha)^{kl} T_{\nu}^{ijl} + \frac{f^2}{4} \text{Tr} \left[ D_\mu U (D^\mu U)^\dagger \right],\end{aligned}$$

$$\Theta^{\mu\nu} = g^{\mu\nu} - Z \gamma^\mu \gamma^\nu, \gamma^{\mu\nu} = \frac{1}{2} [\gamma^\mu, \gamma^\nu], \gamma^{\mu\nu\alpha} = \frac{1}{2} [\gamma^{\mu\nu}, \gamma^\alpha]$$

The currents for a given quark flavor are then expressed as combinations of the SU(3) singlet, triplet and octet currents,

$$\begin{aligned}J_u^\mu &= \frac{1}{3} J_0^\mu + \frac{1}{2} J_3^\mu + \frac{1}{2\sqrt{3}} J_8^\mu, \\ J_d^\mu &= \frac{1}{3} J_0^\mu - \frac{1}{2} J_3^\mu + \frac{1}{2\sqrt{3}} J_8^\mu, \\ J_s^\mu &= \frac{1}{3} J_0^\mu - \frac{1}{\sqrt{3}} J_8^\mu.\end{aligned}$$

For example, strange quark currents can be expressed in terms of hadronic current

$$\begin{aligned}J_s^\mu = & \bar{\Sigma}^+ \gamma^\mu \Sigma^+ + \bar{\Sigma}^0 \gamma^\mu \Sigma^0 + \bar{\Lambda} \gamma^\mu \Lambda + \frac{1}{2f^2} (2 \bar{p} \gamma^\mu p K^+ K^- + \bar{p} \gamma^\mu p \bar{K}^0 K^0) \\ & + \bar{\Sigma}_\alpha^{*+} \gamma^\alpha \beta^\mu \Sigma_\beta^{*+} + \bar{\Sigma}_\alpha^{*0} \gamma^\alpha \beta^\mu \Sigma_\beta^{*0} - i(K^- \partial^\mu K^+ - K^+ \partial^\mu K^-) \\ & - i(\bar{K}^0 \partial^\mu K^0 - K^0 \partial^\mu \bar{K}^0) + [\frac{i(D-F)}{\sqrt{2}f} \bar{p} \gamma^\mu \gamma^5 \Sigma^+ K^0 \\ & + \frac{i(D-F)}{2f} \bar{p} \gamma^\mu \gamma^5 \Sigma^0 K^+ - \frac{i(D+3F)}{\sqrt{12}f} \bar{p} \gamma^\mu \gamma^5 \Lambda K^+ + \text{h.c.}] \\ & + \frac{\mathcal{C}}{\sqrt{12}f} (-i \bar{p} \Theta^{\mu\nu} \Sigma_\nu^{*0} K^+ + i\sqrt{2} \bar{p} \Theta^{\mu\nu} \Sigma_\nu^{*+} K^0 + \text{h.c.})\end{aligned}$$

# Splitting functions with Pauli-Villars regularization

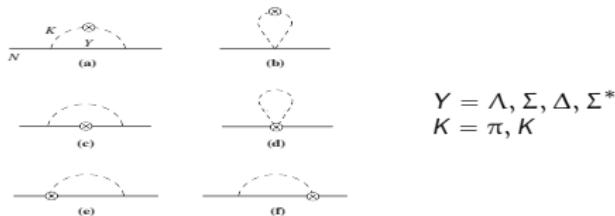
Electromagnetic vertex operator  $\Gamma_i^\mu$

$$\Gamma_i^\mu (2\pi)^4 \delta^4(0) = \langle p | i^2 \int d^4x d^4y d^4z \mathcal{L}_{nl}^{int}(x) J_i^{\mu,q}(y) \mathcal{L}_{nl}^{int}(z) | p \rangle \equiv \int \frac{d^4k}{(2\pi)^4} \tilde{\Gamma}_i^\mu(k)$$

The splitting functions then can be expressed as

$$f_i(y) = \frac{m}{p^+} \int \frac{dk^+ dk^- d\vec{k}_\perp}{(2\pi)^4} \tilde{\Gamma}_i^+(k^+, k^-, \vec{k}_\perp, p^+, p^-, \vec{p}_\perp = 0) \delta(y - \frac{k^+}{p^+})$$

In order to cancel ultraviolet divergence, different regularization scheme will be used in meson loop integral . As a comparison, we will illustrate two different methods.



## 1.Pauli-Villars regularization

Meson propagator is replaced by  $\frac{1}{D_K} \rightarrow \frac{1}{D_K} - \frac{a_1}{D_{\mu_1}} - \frac{a_2}{D_{\mu_2}}$ .

With this method splitting function of Kaon rainbow diagram (a) can be calculated as

$$f_{KY}^a(y) = \frac{C_K^2 \bar{M}^2}{(4\pi f_K)^2} \int dk_\perp^2 \left\{ \frac{1}{M^2} [\log \Omega_K - a_1 \log \Omega_{\mu_1} + a_2 \log \Omega_{\mu_2}] \delta(y) \right. \\ \left. + \frac{y[k_\perp^2 + (my + \Delta)^2][2(k_\perp^2 + yM^2 - y\bar{y}m^2)\bar{y}(\mu_1^2 - m_K^2) + \bar{y}^2(\mu_1^4 - m_K^4)]}{L_M^2 L_{\mu_1}^2} \right\}$$

# Splitting functions with Pauli-Villars regularization

The main idea of the convolution approach is that there are no interactions among the particles in a multi-particle Fock state during the interaction with the hard photon in deep-inelastic scattering. In this way, proton quark distributions can be expressed in terms of convolution integral of splitting function and Fock state quark distribution.

Proton flavour asymmetry

$$\bar{d}(x) - \bar{u}(x) = [f_{\pi^+ n}(y) + f_{bub, \pi^+}(y) + f_{\pi^+ \Delta^0}(y) - f_{\pi^- \Delta^{++}}(y)] \otimes \bar{q}_\pi(x),$$

Strange quark distribution in the proton

$$s(x) = \sum_{YK} \left( \bar{f}_{YK}^{(\text{rbw})} \otimes s_Y + \bar{f}_{YK}^{(\text{KR})} \otimes s_Y^{(\text{KR})} \right) + \sum_K \bar{f}_K^{(\text{tad})} \otimes s_K^{(\text{tad})}$$

Anti-strange quark distribution in the proton

$$\bar{s}(x) = \left( \sum_{KY} f_{KY}^{(\text{rbw})} + \sum_K f_K^{(\text{bub})} \right) \otimes \bar{s}_K.$$

First moment of unpolarized quark distributions of octet baryon

	$p$	$n$	$\Sigma^+$	$\Sigma^0$	$\Sigma^-$	$\Lambda$	$\Xi^-$	$\Xi^0$
$\langle x \rangle_u$	$a + b + c$	$c$	$a + b + c$	$b + c$	$-a + b + c$	$\frac{b}{3} + c$	$-a + b + c$	$c$
$\langle x \rangle_d$	$c$	$a + b + c$	$-a + b + c$	$b + c$	$a + b + c$	$\frac{b}{3} + c$	$c$	$-a + b + c$
$\langle x \rangle_s$	$-a + b + c$	$-a + b + c$	$c$	$c$	$c$	$\frac{4b + 3c}{3}$	$a + b + c$	$a + b + c$

Unknown constants are related to the first moment of quark distribution of proton,

$$c = \langle x \rangle_d^p, \quad a = \frac{1}{2} \langle x \rangle_u^p, \quad b = \frac{1}{2} \langle x \rangle_u^p - \langle x \rangle_d^p.$$

Hyperon quark strange quark distribution  $s_\Lambda = \frac{2u_p - d_p}{3}$ ,  $s_{\Sigma^+} = s_{\Sigma^0} = d_p$ .

# Splitting functions with Pauli-Villars regularization

First moment of quark distributions of tadpole vertex.

	$(\bar{s})_K$	$K^0 \bar{K}^0$	$K^+ K^-$	$(\bar{s})_{\bar{K}}$	$K^+ \bar{K}^0$	$K^+ K^-$	$(\bar{s})_m$	$\bar{K}^0 \bar{K}^0$	$K^+ K^-$
$p$	$-\frac{3}{2}\frac{3}{2}$	0	$-a$	$\frac{3}{2}\frac{3}{2}$	$-\frac{3}{2}\frac{3}{2}$	0	0	$\frac{3}{2}\frac{3}{2}$	$a$
$n$	$\frac{3}{2}\frac{3}{2}$	0	$-\frac{3}{2}\frac{3}{2}$	$-\frac{3}{2}\frac{3}{2}$	$-a$	0	0	$a$	$-\frac{3}{2}\frac{3}{2}$
$\Sigma^-$	$a$	0	$\frac{3}{2}\frac{3}{2}$	$-a$	$-\frac{3}{2}\frac{3}{2}$	0	0	$\frac{3}{2}\frac{3}{2}$	$-\frac{3}{2}\frac{3}{2}$
$\Sigma^0$	0	0	$\frac{3}{2}\frac{3}{2}$	0	$\frac{3}{2}\frac{3}{2}$	0	0	$\frac{3}{2}\frac{3}{2}$	$\frac{3}{2}\frac{3}{2}$
$\Lambda$	$-a$	0	$-\frac{3}{2}\frac{3}{2}$	$a$	$\frac{3}{2}\frac{3}{2}$	0	0	$-\frac{3}{2}\frac{3}{2}$	$\frac{3}{2}\frac{3}{2}$
$\Xi^-$	0	0	$\frac{3}{2}\frac{3}{2}$	0	$-\frac{3}{2}\frac{3}{2}$	0	0	$-\frac{3}{2}\frac{3}{2}$	$\frac{3}{2}\frac{3}{2}$
$\Xi^0$	$\frac{3}{2}\frac{3}{2}$	0	$a$	$-\frac{3}{2}\frac{3}{2}$	$\frac{3}{2}\frac{3}{2}$	0	0	$\frac{3}{2}\frac{3}{2}$	$-a$
$\Xi^+$	$-\frac{3}{2}\frac{3}{2}$	0	$\frac{3}{2}\frac{3}{2}$	$a$	0	0	0	$-a$	$-\frac{3}{2}\frac{3}{2}$

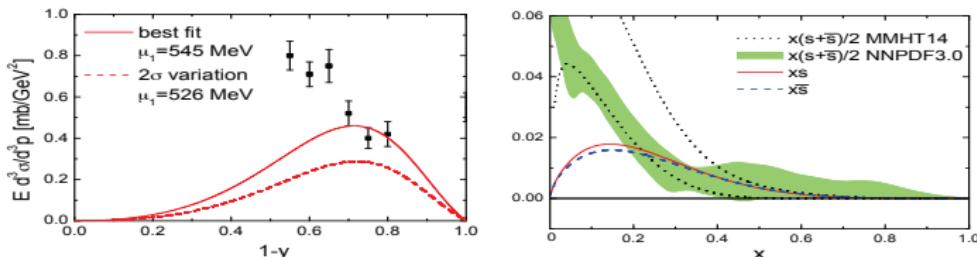
The cut-off parameter  $\mu_1$  can be obtained from the cross section data . The differential cross section for  $pp \rightarrow \Lambda X$  with K exchange is expressed as

$$E \frac{d^3 \sigma (pp \rightarrow \Lambda X)}{d^3 p} = \frac{1-y}{\pi} f_{\Lambda K^+}^{(on)}(y) \sigma_{total}^{pK^+} (s(1-y)t)$$

Meson quark distribution

$$\bar{d}_{\pi^+}(x) = \bar{u}_{\pi^-}(x) = \bar{s}_{K^+} = \bar{s}_{K^0} = \bar{q}_\pi$$

Strange quark distribution in the proton



Using the cut-off palmettes, Strange quark asymmetry of proton with P-V regularization is  $-0.07 \times 10^{-3} \leq S^- \leq 1.12 \times 10^{-3}$ . X.G.Wang et al. PLB 762, 52 (2016), PRD 94, 094035 (2016)

# Splitting functions with covariant form factor

Conclusion: Splitting functions with P-V regularization depend on two parameters  $\mu_1$  and  $\mu_2$ . In order to decrease the number of parameters we will consider the covariant vertex form factor.

## 2. Splitting functions with covariant form factor

Non-local Lagrangian

$$\begin{aligned} \mathcal{L}_{nl}(x) = & \bar{B}(x)(i\gamma^\mu \mathcal{D}_{\mu,x} - m_B)B(x) + \bar{T}_\mu(x)(i\gamma^{\mu\nu\alpha} \mathcal{D}_{\alpha,x} - m_T \gamma^{\mu\nu})T_\nu(x) \\ & + \frac{C_B \phi}{f} \int d^4a \text{Exp} \left[ -ie_{\phi}^q \int_x^{x+a} dz^\mu \mathcal{A}^\mu(z) \right] F(a) \bar{p}(x) \gamma^\mu \gamma^5 B(x) \mathcal{D}_{\mu,x+a} \phi(x+a) + \text{h.c.} \\ & + \frac{C_T \phi}{f} \int d^4a \text{Exp} \left[ -ie_{\phi}^q \int_x^{x+a} dz^\mu \mathcal{A}^\mu(z) \right] F(a) \bar{p}(x) \Theta^{\mu\nu} T_\nu(x) \mathcal{D}_{\mu,x+a} \phi(x+a) + \text{h.c.} \\ & + \frac{iC_{\phi\phi} \phi^\dagger}{2f^2} \int d^4a \int d^4b F(a) F(b) \text{Exp} \left[ -ie_{\phi}^q \int_{x+b}^{x+a} dz^\mu \mathcal{A}^\mu(z) \right] \bar{p}(x) \gamma^\mu p(x) \times \\ & [\phi(x+a) (\mathcal{D}_{\mu,x+b} \phi)^\dagger(x+b) - \mathcal{D}_{\mu,x+a} \phi(x+a) \phi^\dagger(x+b)] + \mathcal{D}_{\mu,x} \phi(x) (\mathcal{D}_{\mu,x} \phi)^\dagger(x), \end{aligned}$$

To evaluate the splitting functions derived in the previous section requires a specific choice for the meson baryon vertex form factor. In momentum space covariant form factor can be parameterized. Consistency with Lorentz invariance restricts the form factor to in general be a function of the meson virtuality  $k^2$  and the baryon virtuality  $(p-k)^2$ . For convenience, we choose the regulator to have a simple dipole shape

$$F(k) = \left( \frac{m_M^2 - \Lambda^2}{k^2 - \Lambda^2 + i\varepsilon} \right)^2$$

# Splitting functions with covariant form factor

Then the normal quark current in nonlocal case is expressed as

$$\begin{aligned}
 J_{min}^{\mu, q}(x) &= \frac{\delta \int d^4 y \mathcal{L}_{nl}^{min}(y)}{\delta A_\mu(x)} \\
 &= e_B^q \bar{B}(x) \gamma^\mu B(x) + e_T^q \bar{T}_\alpha(x) \gamma^{\alpha \nu \mu} T_\nu(x) + ie_\phi^q [\partial^\mu \phi(x) \phi^\dagger(x) - \phi(x) \partial^\mu \phi^\dagger(x)] \\
 &\quad - e_\phi^q \frac{iC_B \phi}{f} \int d^4 a F(a) \int d^4 y \bar{p}(y) \gamma^\mu \gamma^5 B(y) \phi(y+a) \delta(x-y-a) + \text{h.c.} \\
 &\quad - e_\phi^q \frac{iC_T \phi}{f} \int d^4 a F(a) \int d^4 y \bar{p}(y) \Theta^{\mu \nu} T_\nu(y) \phi(y+a) \delta(x-y-a) + \text{h.c.} \\
 &\quad - e_\phi^q \frac{C}{2f^2} \int d^4 a F(a) \int d^4 b F(b) \int d^4 y [\bar{p}(y) \gamma^\mu p(y) \phi(y+a) \phi^\dagger(y+b) \delta(x-y-a) \\
 &\quad + \bar{p}(y) \gamma^\mu p(y) \phi(y+a) \phi^\dagger(y+b) \delta(x-y-b)]
 \end{aligned}$$

Additional current

$$\begin{aligned}
 J_{Ad}^{\mu, q}(x) &= - \frac{ie_\phi^q C_B \phi}{f} \int_0^1 dt \int d^4 a F(a) a^\mu \bar{p}(x-at) \gamma^\rho \gamma^5 B(x-at) \partial_\rho \phi(x-at+a) + \text{h.c.} \\
 &\quad - \frac{ie_\phi^q C_T \phi}{f} \int_0^1 dt \int d^4 a F(a) a^\mu \bar{p}(x-at) \Theta^{\rho \nu} T_\nu(x-at) \partial_\rho \phi(x+a-at) + \text{h.c.} \\
 &\quad + \frac{e_\phi^q C}{2f^2} \int_0^1 dt \int d^4 a F(a) \int d^4 b F(b) (a-b)^\mu \bar{p}[x-ta-(1-t)b] \gamma^\rho \\
 &\quad \times p[x-ta-(1-t)b] \left\{ \phi[x-ta-(1-t)b+a] \partial_\rho \phi^\dagger[x-ta-(1-t)b+b] \right. \\
 &\quad \left. - \partial_\rho \phi[x-ta-(1-t)b+a] \phi^\dagger[x-ta-(1-t)b+b] \right\}
 \end{aligned}$$

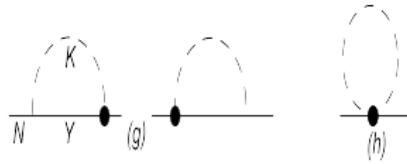
# Splitting functions with covariant form factor

$$f_{KY}^a(y) = \frac{C_{YM}^2 \overline{\Lambda}^4}{(4\pi f_M)^2} \int dk_\perp^2 \left\{ \frac{[(ym + \Delta)^2 + k_\perp^2] \bar{M}^2 \bar{y}^4 y}{L_M^2 L_\Lambda^4} - \int_0^1 dz \frac{(1-z) z^3 \delta(y)}{\Omega^4} \right\}, \Omega = k_\perp^2 + (1-z)m_K^2 + z\Lambda^2$$

Decuplet meson rainbow diagram.

$$f_{KY^*}^a(y) = \frac{C_{TM}^2 \bar{\Lambda}^4}{6(4\pi f)^2 m_T^2} \int dk_\perp^2 \left\{ \frac{y \bar{y}^2 [(ym - \bar{M})^2 + k_\perp^2]^2 [(ym + \Delta)^2 + k_\perp^2]}{L_\Lambda^4 L_M^2} \right. \\ \left. + \int_0^1 dz \left[ \frac{4z^3 \bar{Z}(\bar{Z}-1) \delta(y)}{3\Omega^3} - \frac{z^3(1-z)[\bar{M}^2 + 4\bar{Z}(\bar{Z}-1)m_M^2] \delta(y)}{\Omega^4} \right] \right\}, \bar{Z} = -\frac{1}{2} + Z$$

Additional diagrams are generated from additional quark current  $j^\mu \propto \frac{\partial F(k)}{\partial k^\mu}$ .



$$f_{Ad}^g(y) = \frac{C_{YM}^2 \overline{\Lambda}^4}{(4\pi f_M)^2} \int dk_\perp^2 \left\{ - \frac{4[(ym + \Delta)^2 + k_\perp^2] \bar{M}^2 \bar{y}^4 y}{L_\Lambda^5 L_M} + \int_0^1 dz \frac{z^4}{\Omega^4} \delta(y) \right\}.$$

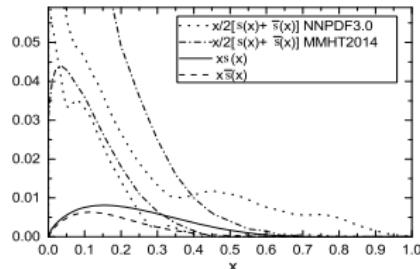
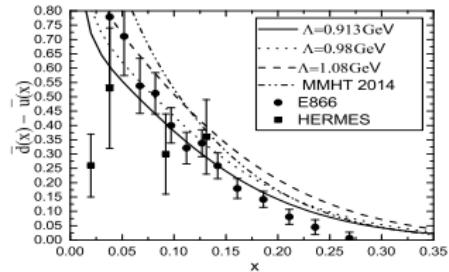
Together with the additional contributions splitting functions satisfy the identity

$$f_{YK}(y) + f_{KR,Y}(y) + f_{Ad,Y}(y) - f_{KY}(y) = 0.$$

Using this identity, net strangeness in the proton is zero, ie

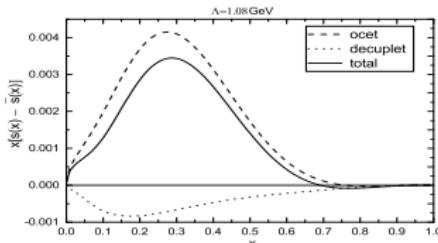
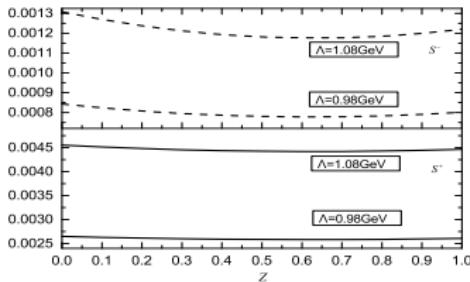
$$\int_0^1 dx [s_p(x) - \bar{s}_p(x)] = 0$$

## Results



- Proton flavour asymmetry and strange quark asymmetry found to be  $0.1153 \leq \int_0^1 dx [\bar{d}(x) - \bar{u}(x)] \leq 0.16$  at  $0.913 \text{ GeV} \leq \Lambda \leq 1.08$
- Model result shows that the strange quark asymmetry of proton is  $0.00056 \leq S_{Ex}^- \leq 0.0012$  which consistent with the experimental constrain  $-0.001 < S_{Ex}^- < 0.004$  and consistently positive.

# Results



- Total strange quark content of proton is  $0.0017 \leq S^+ \leq 0.0045$ .
- This result is almost equal to  $\frac{1}{10}$  of the experimental data  $0.018 \leq S_{Ex}^+ \leq 0.04$ . The total strange quark content of proton include perturbative and non-perturbative contributions  $S_{Ex}^+ = S_P^+ + S_{NP}^+$ .
- The perturbative contributions to the strange and anti-strange quarks in the proton arising from gluons splitting into quark-antiquark pairs can be taken into account using perturbative evolution in QCD, while the non-perturbative strange and anti-strange quark contents of the proton can be calculated in the low energy effective field theory.
- Perturbative  $S_P^-$  has small contribution to the  $S^-$  because strange and anti-strange quarks are generated equally during the QCD evaluation..
- Octet contribution is comparatively larger than decuplet contribution. .
- Total result does not strongly depends on decuplet off-shell parameter  $Z$ .