Sea-quark content of octet baryons

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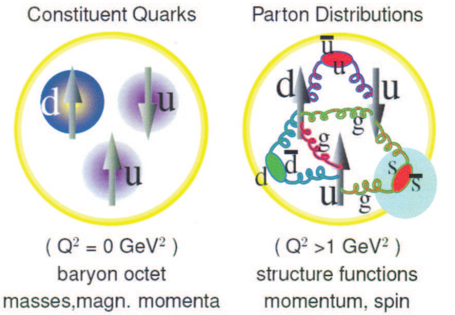
Outline :

- Nucleon sea
- Origins of the sea-quark flavor asymmetry in the nucleon
  - * Virtual meson-baryon states
  - * Higher Fock components
- Extended chiral constituent quark model
  - * Five-quark components in the N, Λ, Σ and Ξ
- Summary & Outlook

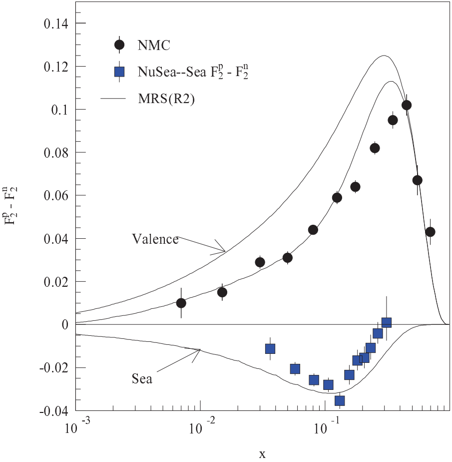
Baryon structure

Valence quark distribution : flavor asymmetric ; sea quark : symmetric or asymmetric ?



Credit: Bing-Song Zou (IHEP)

Nucleon structure functions



$F_2^p - F_2^n$ as measured by NMC at Q^2=4 (GeV/c)^2 and the E866 results evolved to the same Q^2, for the sea contribution. Curves from a global fit parameterizing the nucleon sea (Martin, Roberts, Stirling, PL B387, 1996 ; Towell, PhD Thesis, Univ. of Texas, 2008).

breaking of the Gottfried sum rule :

$$\mathcal{S}_G = \int_0^1 \left[F_2^p(x) - F_2^n(x) \right] dx/x,$$

Assuming charge sym. ($u_p(x) = d_n(x)$...) & ignoring heavier quarks

$$\mathcal{S}_G = \frac{1}{3} \int_0^1 \left[u + \bar{u} - d - \bar{d} \right] dx,$$

$$\mathcal{S}_G = \frac{1}{3} \Big[\int_0^1 (u - \bar{u}) dx - \int_0^1 (d - \bar{d}) dx \Big] - \frac{2}{3} \int_0^1 \left[\bar{d} - \bar{u} \right] dx,$$

with the proper number of up and down quarks

$$\mathcal{S}_G = \frac{1}{3} - \frac{2}{3} \int_0^1 \left[\bar{d} - \bar{u} \right] dx.$$

$$\int_0^1 [\bar{d}_p(x) - \bar{u}_p(x)] dx = \mathcal{P}_5^{d\bar{d}} - \mathcal{P}_5^{u\bar{u}} \equiv \bar{d} - \bar{u}$$

Determined from Deep Inelastic Scatt. (DIS), Semi-Inclusive DIS & Drell-Yan (DY) experiments

Experiment [Year]	Q^2	x range	$\bar{d} - \bar{u}$
NMC [1994]	4.0	0.004-0.80	0.147 ± 0.039
HERMES [1998]	2.3	0.020-0.30	0.16 ± 0.03
FNAL [2001]	54.0	0.015-0.35	$\mathbf{0.118 \pm 0.012}$

Origins of the baryon sea

- Perturbative : $g \to q\bar{q}$; *but* produced a mostly symmetric sea.
- Nonperturbative : meson cloud, genuine higher Fock components

Meson cloud

$$|p\rangle \to \sqrt{1-\alpha-\beta}\;|p_o\rangle \quad + \quad \sqrt{\alpha}\left(-\sqrt{\frac{1}{3}}\;|p_o\pi^\circ\rangle + \sqrt{\frac{2}{3}}\;|n_o\pi^+\rangle\right)$$

$$+ \quad \sqrt{\beta}\left(\sqrt{\frac{1}{2}}\;|\Delta_o^{++}\pi^-\rangle - \sqrt{\frac{1}{3}}\;|\Delta_o^{+}\pi^\circ\rangle + \sqrt{\frac{1}{6}}\;|\Delta_o^{\circ}\pi^+\rangle\right)$$

B_o : bare baryon $\equiv$ only valence quarks involved

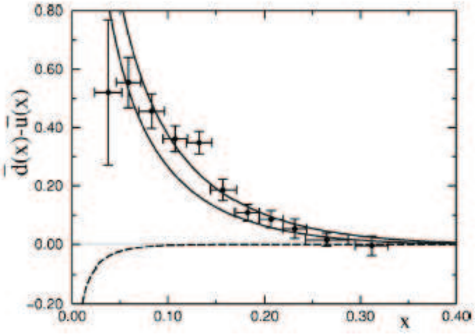
α (β) : probability that the proton is in a virtual $|N\pi\rangle$ ($|\Delta\pi\rangle$) state.

$$2\alpha - \beta = 3(\bar{d} - \bar{u})\;;\; \alpha > 0\;,\; \beta > 0\;,\; \alpha + \beta < 1$$

Other BM states : $B \equiv N,\ \Delta,\ \Lambda,\ \Sigma...$, $M \equiv \rho,\ \omega\ , K,\ K^*...$

$\rightarrow$ *increasing number of degrees of freedom !*

Reggeized virtual mesons



E866 data at Q^2=54 (GeV/c)^2 ; solid (dashed) curves : $\pi N-$ ($\pi\Delta-$) Fock states.

Nikolaev et al., PRD 60, 014004 (1999).

BHPS & G-BHPS models

BHPS : Early study on intrinsic $uudc\bar{c}$ components in the proton, interpreting the charm production data ; light-con model of energetically-favored meson-baryon fluctuations

Brodsky, Hoyer, Peterson, Sakai, PL 93B, (1980) ; Brodsky, Ma, ibid B 381, (1996)...

G-BHPS : Extension to the light-quark sector

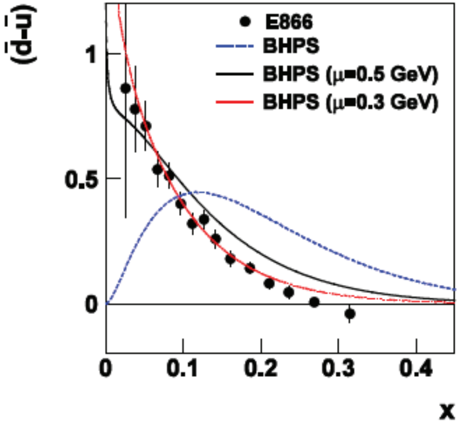
Chang, Peng, PRL 106, 252002 (2011) ; PL B 704, 197 (2011).

Probability for quark i to carry a momentum fraction x_i :

$$P(x_1, ..., x_5) = N_5 \delta\left(1 - \sum_{i=1}^{5} x_i\right)\left[m_p^2 - \sum_{i=1}^{5} \frac{\hat{m}_i^2}{x_i}\right]^{-2}.$$

Calculations performed analytically [BHPS] in the limit of $m_{4,5} >> m_p, m_{1,2,3}$ for $c\bar{c}$ and numerically [G-BHPS] for lighter quarks, using Monte-Carlo techniques.

Results from the G-BHPS model



Dashed curve : from the probability expression above, solid and dotted curves obtained by evolving the BHPS result to Q2=54 (GeV/c)2, for two different scale (μ) values .

Peng & Chang, PoS QNP2012, 012 (2012).

Extended chiral constituent quark model (EχCQM)

An-Saghai-Yuan-He, PRC 81 (2010) ; An-Saghai *ibid* 84 (2011) ; *ibid* 85(2012).

Baryon Wave function

$$|\psi\rangle_B = \frac{1}{\sqrt{\mathcal{N}}}\left[|QQQ\rangle + \sum_{n,l,i} C_{nli}|QQQ(Q\bar{Q}), n, l, i\rangle\right],$$

n (l) : inner radial (orbital) quantum number,

i : Number of five-quark configurations.

$$C_{nli} = \frac{\langle QQQ(Q\bar{Q}), n, l, i|\hat{T}|QQQ\rangle}{M_B - E_{nli}},$$

$\hat{T}$: Transition coupling operator, model-dependent.

Transition coupling operator

Matrix elements of $\hat{T}$ btw the 3- & 5-quark configs derived using a $^3P_0$ version for the transition coupling operator

$$\hat{T} = -\gamma \sum_j \mathcal{F}^{00}_{j,5}\ \mathcal{C}^{00}_{j,5}\ \mathcal{C}_{OFSC}\ \left[\sum_m \langle 1, m; 1, -m|00\rangle \chi^{1,m}_{j,5} \mathcal{Y}^{1,-m}_{j,5}(\vec{p}_j - \vec{p}_5) b^\dagger(\vec{p}_j) d^\dagger(\vec{p}_5)\right],$$

$\mathcal{F}^{00}_{j,5}$ and $\mathcal{C}^{00}_{i,5}$: flavor and color singlet of the $Q_i\bar{Q}$ pair in the 5-quark system,

$\mathcal{C}_{OFSC}$: orbital-flavor-spin-color overlap between the residual 3-quark config. in the 5-quark system and the valence 3-quark system.

Probability of the sea quark

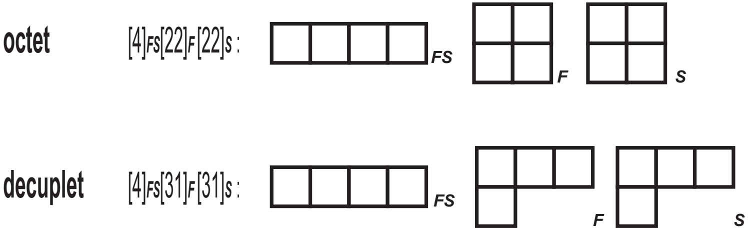
$$P^{Q\bar{Q}}_B = \frac{1}{\mathcal{N}} \sum_{i=1}^{17} \left[\left(\frac{T^{Q\bar{Q}}_i}{M_B - E^{Q\bar{Q}}_i}\right)^2\right].$$

The formalism leads to a model with only one adjustable parameter (the energy contributed by the inharmonic part of the potential for the five-quark system), fixed using the measured $\bar{d} - \bar{u}$.

Configurations

All possible 34 five-quark configurations were examined in baryon octet and shown that only 17 of them, corresponding to the orbital quantum number $l = 1$ and radial quantum number $n = 0$, are relevant to the higher Fock components in the ground state octet baryons.

For example, the lowest energy mixed symmetry configuration in shorthand notation for the Young tableaux decomposition :



Predictions for the sea-quark content of the octet baryons

Baryon	$\bar{u}$	$\bar{d}$	$\bar{s}$	$\bar{d}-\bar{u}$	$\bar{u}+\bar{d}$	$\bar{u}+\bar{d}+\bar{s}$	Ref.
p	0.098	0.216	0.057	0.118	0.314	0.371	*a*
	0.228	0.358	-	0.130	**0.586**	-	*b*
	0.122	0.240	0.024	0.118	0.362	0.386	*c*
Λ	0.139	0.139	0.057	0	0.279	0.336	*a*
Σ^+	0.100	0.163	0.063	0.063	0.263	0.326	*a*
Σ^0	0.132	0.132	0.063	0	0.263	0.326	*a*
Ξ^0	0.131	0.121	0.057	-0.009	0.252	0.309	*a*

a) E-χCQM : An-Saghai, PRC 85, 055203 (2012).

b) χCQM : Shao-Zhang-Ma, PL B686, 136 (2010).

c) G-BHPS : Chang-Peng, PL B704, 197 (2011).

Baryon properties

Strong decay widths (in MeV) for the $S_{11}(1535)$ and $S_{11}(1650)$

N^*	πN	ηN	$K\Lambda$	Ref.
$S_{11}(1535)$	68 ± 15	79 ± 11		PDG
	58 ± 5	79 ± 11		E-χCQM
$S_{11}(1650)$	128 ± 29	3.8 ± 3.6	4.8 ± 0.7	PDG
	143 ± 5	4.5 ± 3.0	4.8 ± 0.7	E-χCQM

An, Saghai, PRC 84, 045204 (2011).

Also reproduced : $\Gamma_{\Lambda(1405)\to(\Sigma\pi)^\circ} = 50 \pm 2$ MeV

An, Saghai, Yuan, He, PRC 81, 045203 (2010).

Meson-Baryon σ terms

Meson-baryon sigma terms, σ_{MB}, a test of QCD, provide a measure of chiral-symmetry breaking.

$$
\begin{aligned}
\sigma_{\pi N} &= \frac{\hat{\sigma}}{1 - 2y_N}, \\
\sigma_{KN}^{I=0} &= \frac{\hat{m} + m_s}{4\hat{m}}(1 + 2y_N)\sigma_{\pi N}, \\
\sigma_{\eta N} &= \frac{\hat{m} + 2y_N m_s}{3\hat{m}}\sigma_{\pi N},
\end{aligned}
$$

where

$$
\begin{aligned}
y_N &= \frac{2\langle p|s\bar{s}|p\rangle}{\langle p|u\bar{u} + d\bar{d}|p\rangle} = \frac{2P_{s\bar{s}}}{3 + 2(P_{u\bar{u}} + P_{d\bar{d}})}, \\
\hat{\sigma} &= \hat{m}\langle p|u\bar{u} + d\bar{d} - 2s\bar{s}|p\rangle.
\end{aligned}
$$

Predictions for the meson-nucleon σ-terms (in MeV)

with $\hat{\sigma}$=35 MeV (Gasser, Leutwyler, Sainio, PL B253, 252 (1991)) and

$m_s/\hat{m}$=25 (Leutwyler, PL B378, 313 (1996)).

Reference	Approach	$\sigma_{\pi N}$	σ_{KN}	$\sigma_{\eta N}$
An & Saghai PoS QNP2012, 077 (2012)	$E\chi CQM$	37	256	32
Alarcon *et al.* PRD 85, 051503 (2012)	χPT	43±5		
Bali *et al.* PRD 85, 054502 (2012)	$LQCD$	38±12		

Summary & Outlook I :

- Intrinsic light-quark sea allows interpreting data on the sea-quark distribution.
- Determination of the sea quark content of the proton :

  $\mathcal{P}^{u\bar{u}} \approx 10\%\,;\ \mathcal{P}^{d\bar{d}} \approx 20\%\,;\ \mathcal{P}^{s\bar{s}} \approx 5\%\,;\ \mathcal{P}^{c\bar{c}} \approx 1\%.$

- Predictions also for the percentage per flavor, of the sea quark content for Λ, Σ and Ξ.
- The W-boson production at the RHIC and LHC proton-proton colliders, would provide a unique opportunity in extracting the $\bar{d}/\bar{u}$ flavor asymmetry in the proton.

  Yang, Peng, Grosse-Perdekamp, PL B680, 231 (2009).

Summary & Outlook (II) :

- The suppression factor (κ) of the nucleon strange quark content with respect to the non-strange sea quarks

$$\kappa = \frac{\int_0^1 [xs(x) + x\bar{s}(x)]\, dx}{\int_0^1 \left[x\bar{u}(x) + x\bar{d}(x)\right]\, dx} \approx \frac{2P_{s\bar{s}}}{P_{u\bar{u}} + P_{d\bar{d}}},$$

$\kappa = 1$ would indicate a flavor $SU(3)$ symmetric sea ; the CCFR result κ=0.48$\pm$0.05 ; $E - \chi CQM$: κ=0.4.

- Neutrino Scattering On Glass (NuSOnG), can allow measuring the strange sea in the nucleon through charged current opposite sign dimuon production *via* the following two step reactions :

$$\begin{aligned} \nu_\mu + N &\rightarrow \mu^- + c + X \;;\; c \rightarrow s + \mu^+ + \nu_\mu, \\ \bar{\nu}_\mu + N &\rightarrow \mu^+ + \bar{c} + X \;;\; \bar{c} \rightarrow \bar{s} + \mu^- + \bar{\nu}_\mu, \end{aligned} \tag{1}$$

improving significantly the data accuracy compared to that released by the NuTeV Collaboration.

Adams *et al.* [NuSOnG Collaboration], IJMP A25, 909 (2010)

Summary & Outlook (III) :

- Strange content of the nucleon is an important ingredient in the dark matter search : the WIMP coupling to the nucleon would proceed through coupling of the Higgs boson to the scalar quark content of the nucleon. The dark matter cross section has been found dominated by the strange quark content of the proton.
  Dinter & Jansen, IJMP E20, 110 (2011).

- Access to rich information on the intrinsic sea quark content of the proton, expected thanks to AFTER@LHC...
  Brodsky, Fleuret, Hadjidakis, Lansberg , Phys. Rept. 522, 239 (2013).

Good luck to the AFTER Collaboration

&

Thank you for your attention !