Strangeness Content of the Nucleon from Lattice QCD

Parikshit Junnarkar

Department of Physics, University of New Hampshire

Outline

The Basics

- Proton has quantum numbers of u,u,d ! → Valence or connected part

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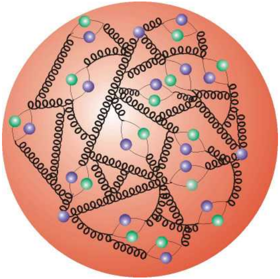


- 98 % nucleon mass is non-valence
- Strangeness in nucleon comes from sea effect !
- Contribution to $\langle N|\bar{s}s|N\rangle$, $\langle N|\bar{s}\gamma_\mu\gamma_5 s|N\rangle$, $\langle N|\bar{s}\gamma_\mu s|N\rangle$

Dark Matter Searches

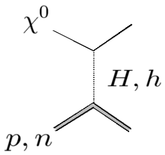


Figure: Scattering of a Neutralino from Nucleon

- In SUSY, Neutralino scatters off from a nucleon via Higgs exchange.
- Cross-section for scattering is given by,

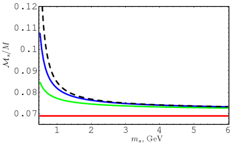
$$\sigma \sim f_{T_s}, \quad f_{T_s} = \frac{m_s \langle N | \bar{s}s | N \rangle}{M_N}$$

- Greatest source of uncertainty is $\langle N | \bar{s}s | N \rangle$

Lattice Motivation

Lattice calculation is the only solution to the problem !

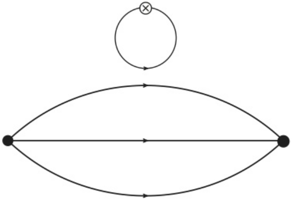
- No direct experiment possible.
- Analytical Calculation Fails.



- Since this calculation is inherently non-perturbative the only reliable from first principle calculation is a lattice computation.

Lattice Computation of $\langle N | \bar{s}s | N \rangle$

- Lattice Computation → (Direct and Indirect Method)



- $R(\Delta t, \Delta t_s) \equiv \frac{C_{3pt}(\Delta t, \Delta t_s)}{C_{2pt}(\Delta t)} \longrightarrow_{t \rightarrow \infty} \langle N | \bar{s}s | N \rangle$
- C_{3pt} → All-to-All propagator computation

Overview of Results - (Direct Method)

- Results by JLQCD
  - $N_f = 2+1$ on $16^3 \times 48$ & $24^3 \times 48$ Lattices
  - Iwasaki Gauge action with Overlap fermion
  - $m_s\langle N|\bar{s}s|N\rangle = \mathbf{12.37(8)(16)}$ MeV
- Results by M. Engelhardt
  - $N_f = 2+1$ on $20^3 \times 64$
  - Staggered sea quarks on Domain wall valence quarks
  - $m_s\langle N|\bar{s}s|N\rangle = \mathbf{39(12)}$ MeV
- Results by MILC
  - $N_f = 2+1$ on $20^3 \times 64$, $28^3 \times 96$, $32^3 \times 96$, $40^3 \times 96$,
  - Improved staggered sea quarks on Improved staggered valence quarks
  - $m_s\langle N|\bar{s}s|N\rangle = \mathbf{59(14)(6)}$ MeV
- Results by Young and Thomas
  - Analysis of LHPC and PACS-CS data
  - $m_s\langle N|\bar{s}s|N\rangle = \mathbf{31(15)(6)}$ MeV

Our Method

The Nucleon mass in the continuum chiral expansion is given by,

$$M_N = M_0 + (m_u + m_d)\sigma_{\pi N} + m_s\beta + \mathcal{O}(m_q^{3/2})$$

where,

$$\sigma_{\pi N} = \langle N|\bar{u}u + \bar{d}d|N\rangle \quad \& \quad \beta = \langle N|\bar{s}s|N\rangle$$

Hence, To compute β we have,

$$\beta = \frac{\partial M_N}{\partial m_s}|_{m_u=m_d=constant} = (\frac{M_{N1} - M_{N2}}{m_{s1} - m_{s2}}) + \dots.$$

Measure M_N on two ensembles with only different m_s.

Lattice Calculation

MILC has generated following gauge configurations:

Ensemble	bm_l	bm_s
`2064f21b676m010m030`	0.010	0.030
`2064f21b676m010m050`	0.010	0.050
`2064f21b676m030m030`	0.030	0.030
`2064f21b676m030m050`	0.030	0.050

NPLQCD has results on M_B:

`2064f21b676m010m050`	`2064f21b676m030m050`

I have computed M_B on:

`2064f21b676m010m030`	`2064f21b676m030m030`

Lattice Details

Computational details,

- By computing 55 (l&s) domain wall propagators on 328 `MILC_2064f21b676m010m030` configurations on a $20^3 \times 64$ lattice with a staggered sea quark mass $am_s = 0.01$ and valence domain wall quark mass $am_v = 0.03$.
- By computing 20 (l&s)domain wall propagators on 367 `MILC_2064f21b676m030m030` configurations on a $20^3 \times 64$ lattice with a staggered sea quark mass $am_s = 0.03$ and valence domain wall quark mass $am_v = 0.03$.

General Procedure

- Perform fermion matrix inversions to compute propagators
- Construct meson and baryon interpolating operators with appropriate quantum numbers.
- perform contractions over color, spin, lorentz indices to compute correlators
- We use the Chroma software system for LQCD (see Edwards, Joo; hep-lat/0409003), which is based on QDP++.

Data Analysis

- The correlators computed are not statistically independent as there is correlation between the monte-carlo of the gauge configs.
- We use the jackknife method to account for these correlations

$$\alpha_i = [\alpha_1, \alpha_2, \alpha_3, ...\alpha_N]$$

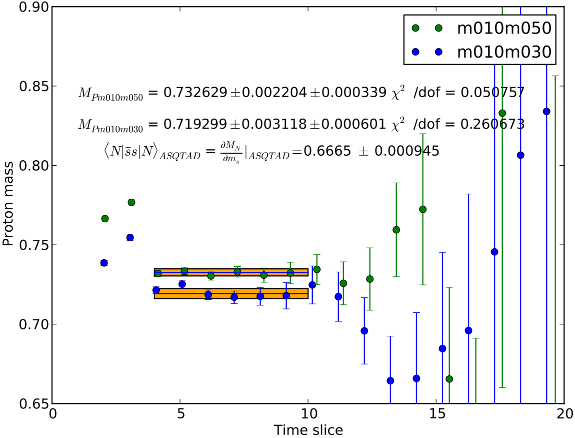
$$\alpha_i^{jackknife} = \frac{1}{N-1}\left[\sum_{i=1}^{N}\alpha_i - \alpha_1, \sum_{i=1}^{N}\alpha_i - \alpha_2, \sum_{i=1}^{N}\alpha_i - \alpha_3 ... \sum_{i=1}^{N}\alpha_i - \alpha_N\right]$$

- The ground state is extracted by fitting a effective mass as follows,

$$aM(t) \equiv \ln\left(\frac{C(t)}{C(t+1)}\right)$$

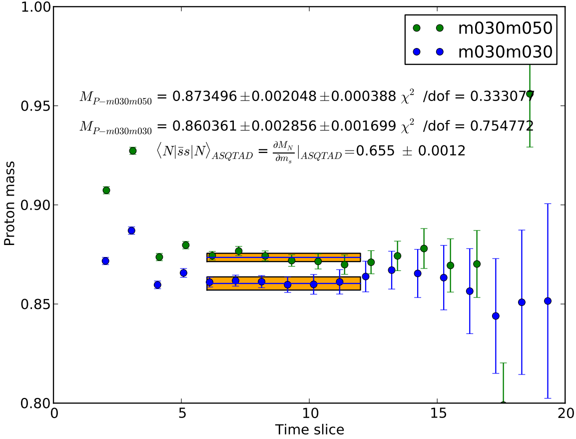
Results for Proton

Results on Proton at $m_\pi = 352\text{MeV}$



Results for Proton

Results on Proton at $m_\pi = 591\text{MeV}$



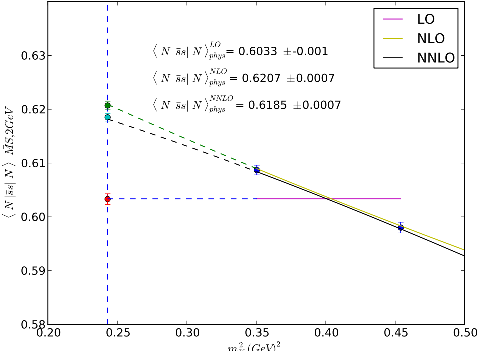
MA chiral extrapolation

With the available data, we try fits motivated from MAχPT

$$\langle B\,|\bar{s}s|B\rangle = a + b\tilde{m}_{ru} \quad \sim \text{ at NLO in MA}\chi\text{PT}$$

$$\langle B\,|\bar{s}s|B\rangle = a + b\tilde{m}_{ru} + c\tilde{m}_{ru}^2 \quad \sim \text{ at NNLO in MA}\chi\text{PT}$$

where, $m_{ru}^2 = m_K^2 + b^2\Delta_{mix}$



Comparison with Other computations

Table: Comparison of different $\frac{ms}{M_B}\langle B\,|\bar{s}s|B\rangle$ calculations

B	This work	MILC	Young & Thomas	Engelhardt	JLQCD
N	0.067(2)	0.074(10)	0.033(16)	0.041(12)	0.013(12)
Λ	0.0613(2)	-	0.144(15)	-	-
Σ	0.1082(16)	-	0.187(15)	-	-
Ξ	0.1036(21)	-	0.244(15)	-	-

$$m_s\langle N\,|\bar{s}s|N\rangle = 62.6(20)\text{ MeV}$$
$$m_s\langle \Lambda\,|\bar{s}s|\Lambda\rangle = 68.518(28)\text{ MeV}$$
$$m_s\langle \Sigma\,|\bar{s}s|\Sigma\rangle = 129.17(29)\text{ MeV}$$
$$m_s\langle \Xi\,|\bar{s}s|\Xi\rangle = 136.65(19)\text{ MeV}$$

Conclusions

- Indirect inclusion of loop effects
- We are able to compute strangeness in baryon octet
- We are able to bypass technical issues such as vacuum subtraction, renormalisation due to mixing of operators.

Acknowledgements

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