The quark contents of the nucleon and their implications for dark matter search

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Outline

Introduction

Motivations

- Experimental direct detection of dark matter put bounds on the WIMP-Nucleon cross section
- Results are interpreted using various models (including SUSY) : systematic uncertainty due to $\langle N(p)|\bar{q}q|N(p)\rangle$
  $\longrightarrow$ non-perturbative computation is required

- sigma terms : $\sigma_{\pi N} \equiv m_l \langle N(p)|\bar{u}u + \bar{d}d|N(p)\rangle$ and $\sigma_s = m_s \langle N(p)|\bar{s}s|N(p)\rangle$
- dimensionless ratio : $y_N \equiv \frac{2\langle N(p)|\bar{s}s|N(p)\rangle}{\langle N(p)|\bar{u}u+\bar{d}d|N(p)\rangle}$
- Twisted mass fermions offer two main advantages :
  - efficient noise reduction technique
  - multiplicative renormalization

see [arXiv:1202.1480] for details

Lattice setup

$N_f = 2+1+1$ dynamical simulations

- $N_f = 2+1+1$ configurations generated by ETMC
- two lattice spacing $a \sim 0.085$ fm and $a \sim 0.062$ fm
- pion masses : $[210, 450]$ MeV
- $L \geq 2.$ fm, $m_{\mathrm{PS}}L > 3.4$
- One run with a very large statistic used to quantify excited states contamination

Mixed action setup

- Mixed action setup : introduce a doublet of degenerate twisted mass fermions (χ_q, μ_q)
- $a\mu_s$ and $a\mu_c$ can be tuned to reproduce the K, D meson masses in the unitary setup
- Noise reduction techniques based on an exact property of the valence action see also talk of [A. Vaquero]

Correlators

J : (smeared) nucleon interpolating field

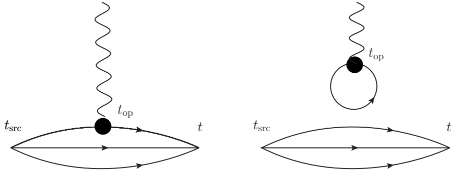
$$R_l(t_{\rm op}, t_s) = \frac{\sum_{\vec{x},\vec{y}} \langle J(t_s, \vec{x}) O_l(t_{\rm op}, \vec{y}) J^\dagger(0)\rangle}{C^X_{\rm 2pts}(t_s)} \xrightarrow[t_{\rm op}, t_s \to \infty]{} \langle N|\bar{u}u + \bar{d}d|N\rangle^{\rm bare}$$

(receive both a connected and disconnected contribution illustrated below)

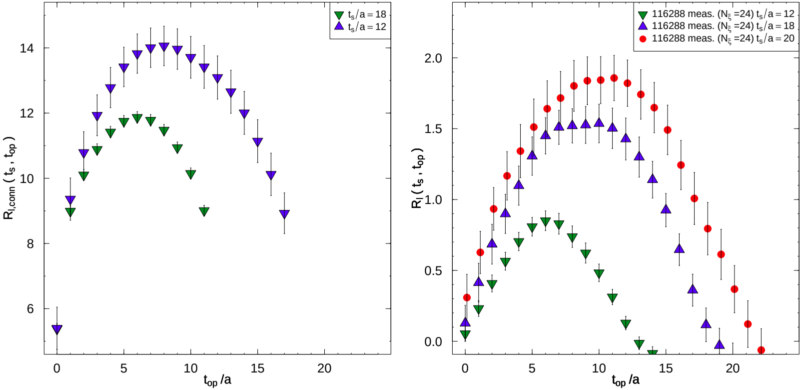
$$R_s(t_{\rm op}, t_s) = \frac{\sum_{\vec{x},\vec{y}} \langle J(t_s, \vec{x}) O_s(t_{\rm op}, \vec{y}) J^\dagger(0)\rangle}{C^X_{\rm 2pts}(t_s)} \xrightarrow[t_{\rm op}, t_s \to \infty]{} \langle N|\bar{s}s|N\rangle^{\rm bare}$$

$$R_y(t_{\rm op}, t_s) = 2\frac{\sum_{\vec{x},\vec{y}} \langle J(t_s, \vec{x}) O_s(t_{\rm op}, \vec{y}) J^\dagger(0)\rangle}{\sum_{\vec{x},\vec{y}} \langle J(t_s, \vec{x}) O_l(t, \vec{y}) J^\dagger(0)\rangle} \xrightarrow[t_{\rm op}, t_s \to \infty]{} y_N$$

Precise definitions and techniques can be found in [arXiv:1202.1480]



Excited states contamination



- Plateaux in the light sector for source-sink separation up to 1.7 fm (1.5 fm for the connected part)
- Large excited states contamination : $\sim$ 15% (conn.) and $\sim$ 100% (disc.)
- Similar behaviour is observed for $R_s(t_s, t_{\mathrm{op}})$

Strategy for the analysis of systematical errors

Perform several extrapolations to $t_s = \infty$ using several fitting functions and fitting ranges and estimate systematical error.

Defining $f^{t_{\rm op}}(t_s) \equiv A^{t_{\rm op}}(t_s) + B^{t_{\rm op}}(t_s)e^{-\delta m t_s}$

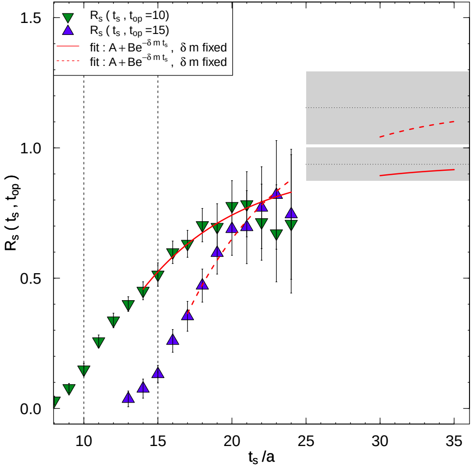
Disconnected part

- type I : $\left(t_{\rm op}^1, t_s^{1,min}, t_s^{1,max}, \delta m^1\right)$
- type II : $\left(t_{\rm op}^2, t_s^{2,min}, t_s^{2,max}, \delta m^1\right)$
- type III : $\left(t_{\rm op}^1, t_s^{1,min}, t_s^{1,max}, \delta m^2\right)$
- type IV : $\left(t_{\rm op}^2, t_s^{2,min}, t_s^{2,max}, \delta m^2\right)$

Connected part

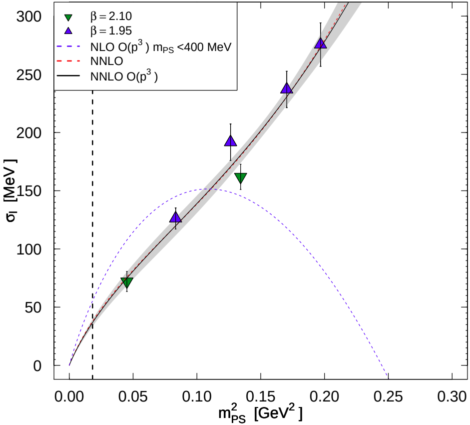
- case A : fixed source-sink separation results with $t_s = 1$ fm
- case B : estimate data at $t_s = 1.5$ fm using only one ensemble and assuming that the excited states contamination does not depend on $m_{\rm PS}$ ($\sim$ 15% shift)

Exemple of extrapolation of the disconnected piece (type I& II)



- $R_s(t_s, t_{\rm op})$ as a function of t_s for two different $t_{\rm op}$
- Extrapolated value depends on the fit : Largest source of systematic errors
- No clear evidence of that we reach the asymptotic regime

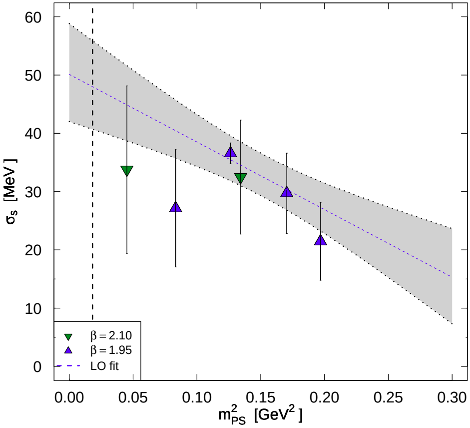
σ_l chiral behaviour : case A-I



- $\sigma_l^{NLO} = m_{\rm PS}^2 \,(A + B m_{\rm PS})$, $\sigma_l^{NNLO} = m_{\rm PS}^2 \left(A + B m_{\rm PS} + C m_{\rm PS}^2\right)$
- $O(p^3)$ denotes $B \equiv -(3/2) g_A^2/(32\pi f_\pi^2)$, determined by $HB\chi pt$
- NLO $O(p^3)$ does not describe well the data.
- Using $(A, B) \otimes (I, II, III, IV)$ and various type of chiral fits we get :

  PRELEMINARY : $\sigma_{\pi N} = 37.0(2.6)(24.7)$ MeV

σ_s chiral behaviour : case A-I



- $\sigma_s^{LO} = A + Bm_{\mathrm{PS}}^2$ and $\sigma_s^{NLO} = A + Bm_{\mathrm{PS}}^2 + Cm_{\mathrm{PS}}^4$
- Fitting the data (I, II, III, IV) with various type of chiral fits we get :

  PRELEMINARY : $\sigma_s = 47.9(8.0)(16.0)$ MeV

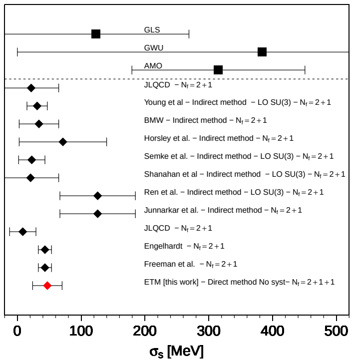
Comparison

Preliminary results :

- $\sigma_{\pi l}^{ETM} = 37.0(2.6)(24.7)$ MeV, $\sigma_s^{ETM} = 47.9(8.0)(16.0)$ MeV

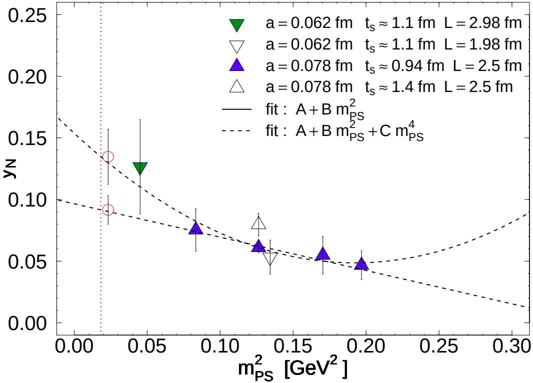
Estimates based on EFT :

$\sigma_{\pi L}^{AMO} = 59(7)$ MeV, $\sigma_{\pi L}^{GWU} = 64(7)$ MeV,$\sigma_{\pi L}^{GLS} = 45(8)$ MeV



general agreement with recent lattice determinations

Strangeness of the nucleon



- Cancelation of the excited states contamination in the ratio $R_y(t_s, t_{\mathrm{op}})$
- different analysis strategy : empty points are excluded of the fits and used to estimate systematics
- PRELEMINARY : $y_N = 0.099(16)(39)$
- EFT determination : $y_N = 0.44(13)$ [Pavan et al,2002]

Conclusion

Twisted mass fermions

- Efficient noise reduction techniques (no eigenmode preconditionning)
- Multiplicative renormalization both in the unitary (light) and mixed action (strange) setup

Results

- Large dependence in the source-sink separation indicates excited states contamination :
  $\rightsquigarrow$ large systematic error that needs to be improved in the future
- Preliminary analysis of the systematics gives :

$$\sigma_{\pi N}^{ETM} = 37.0(2.6)(24.7) \text{ MeV}, \quad \sigma_s^{ETM} = 47.9(8.0)(16.0) \text{ MeV}, \; y_N^{ETM} = 0.099(16)(39) \text{ MeV}$$

- Compatible results with indirect determinations using the Feynman-Hellmann theorem:
  $\rightsquigarrow$Recent lattice QCD results suggest that the constraints on Dark Matter models are less stringent