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AXIAL PROPERTIES OF NUCLEI FROM LATTICE QCD AND EFT

INT WORKSHOP ON FUNDAMENTAL PHYSICS WITH ELECTROWEAK PROBES OF IGHT NUCLEI, JUNE 2018

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le.

A DOUBLY-WEAK PROCESS The *nuclear matrix* element of $\mathbf p$ **determining the** *pp* $\mathbf p$ function $\mathbf p$ matrix element contributing to tritium $\mathcal{L} = \mathcal{L} = \mathcal{L}$

 $n+m\rightarrow n+m+e$ the short-distance correlation correlations to the matrix element of \mathbb{R}^n . The matrix element of the mat $n + n \rightarrow p + p + e^{-} + e^{-} + \overline{\nu}_{e} + \overline{\nu}_{e}$

n

p

 $\overline{\nu}_e$

e

p

 $\overline{\nu}_e$

e

n

PACS numbers: 11.15.Ha, 12.38.Gc, 13.40.Gp

Tiburzi et al (NPLQCD), Phys.Rev.D96,054505(2017), Shanahan et al (NPLQCD), Phys.Rev.Lett.119,062003(2017). ics of core-collapse supernova. In this work, the results of the Standard model and plays an important role in Proton-proton fusion and tritium -decay from lattice quantum chromodynamics $\frac{1}{2}$ Beand Chang, $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$

ENERGIES FROM TWO-NUCLEON CORRELATION FUNCTIONS \vert barding brom two-nitcular correlation finctions the two-barse tensor three-momentum, enables the two-baryon \vert interpolators at the sink to have either zero or non-zero CM momentum, with various possibilities for

in blocks of three quarks to assemble a baryon field with given α baryon field with given α

the momentum of each baryon. As the next step, a fully-antistic step, and the next step, and level wavefunction

ENERGIES FROM TWO-BARYON CORRELATION FUNCTIONS

 $N_f = 3, m_\pi = 0.806 \text{ GeV}, a = 0.145(2) \text{ fm}$

ENERGIES FROM TWO-BARYON CORRELATION FUNCTIONS

 $n_{\pi} = 0.806 \text{ GeV}, a = 0.145(2) \text{ fm}$

TRADITIONAL MATRIX ELEMENT CALCULATIONS: 3-POINT FUNCTIONS

MATRIX ELEMENTS FROM A COMPOUND PROPAGATOR/BACKGROUND FIELD

$$
S^{(q)}_{\lambda_q;\Gamma}(x,y) = S^{(q)}(x,y) + \lambda_q \int dz \ S^{(q)}(x,z) \Gamma S^{(q)}(z,y)
$$

$$
\begin{array}{|l|}\n\hline\n\end{array}
$$

Savage et al (NPLQCD), Phys. Rev. Lett. 119,062002(2017).

Buochard et al (CALLATT), Phys.Rev.D96,014504(2017).

MATRIX ELEMENTS FROM A COMPOUND PROPAGATOR/BACKGROUND FIELD

1514 <u>144</u> $\overline{1}$ MATRIX ELEMENTS FROM A COMPOUND PROPAGATOR/BACKGROUND FIELD

14

(c) (d)

 $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (d) $\overline{}$ (FIG. 2. The field-strength dependence of sample correlation functions constructed from compound prop-**Tiburzi et al (NPLQCD), Phys. Rev. D 96, 054505 (2017).**

PRIMARY REACTION IN THE *pp* CHAIN THAT POWERS SUN. UNCERTAINTIES LARGE AT LOW INCIDENT VELOCITIES RELEVANT TO ENERGY PRODUCTION IN SUN. T_{min} is a function of T_{min} function p INCERTAIN FIES LAKUTE AT LUW \blacksquare , \blacksquare -symmetric value of the \blacksquare symmetric value of the quark masses, corresponding of the quark masses, corresponding \blacksquare $t_{\rm{max}}$ short-distance correlations to the matrix element (meson-exchange cur-

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). re et al (NPLQCD), Phys.R the *pp* ! *de*⁺⌫*^e* fusion process and tritium -decay. The the search for new physics. The super-allowed process v.Lett.119,062002(2017). semileptonic weak decay of a nuclear system. In con-

FIRST-ORDER RESPONSE TO AN AXIAL BACKGROUND FIELD

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017).

FIRST-ORDER RESPONSE TO AN AXIAL BACKGROUND FIELD $\overline{\text{X}}$

2. ^I = 1 *two-nucleon axial transitions: pp* ! *de*⁺⌫*^e*

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). is *E*^l decarry et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). of two-nucleon systems. Additionally, = *Enn E^d* as defined previously. The terms

corrections. Separating ground-state contributions in the initial and or final states leads to initial and or final states leads to initial and or final states leads to include the initial states leads to include the initi

$\begin{array}{|c|c|}\n\hline\n\multicolumn{1}{|c|}{\text{MATRIX ELEMENT FROM QCD}}\n\end{array}$

(lower-left panel), and the quantity = *Enn E^d* (lower-right panel). Blue circles and orange diamonds

$$
N_f = 3, \, m_\pi = 0.806 \text{ GeV}, \, a = 0.145(2) \text{ fm}
$$
 Savage et al (NPLQCD), arXiv:1610.04545.

MATRIX ELEMENT FROM QCD

$$
\boxed{N_f=3, m_\pi=0.806~{\rm GeV},~a=0.145(2)~{\rm fm}}
$$

Savage et al (NPLQCD), arXiv:1610.04545.

MATRIX ELEMENT FROM EFT \vert

where the first uncertainties are statistical and the second statistical and the second statistical and the second

TWO-NUCLEON SHORT-DISTANCE COUPLING

FROM TRITON LIFETIME:

$$
L_{1,A} \approx 2.0(2.4) \text{ fm}^3 \text{ } \text{ } \text{ } \text{ } \text{ } \mu = m_\pi^{\text{phys.}} = 140 \text{ MeV}
$$

De-Leon, Platter and Gazit, arXiv:1611.10004 (2016).

THIS WORK:

$$
L_{1,A} \approx 3.9(0.2)(1.0)(0.4)(0.9) \text{ fm}^3 \text{ @ } \mu = m_{\pi}^{\text{phys.}} = 140 \text{ MeV}
$$

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017).

A SUPER-ALLOWED PROCESS, PROVIDES CONSTRAINTS ON THE ANTI-NEUTRINO MASS. THEORETICAL UNCERTAINTIES ARISE FROM GAMOV-TELLER MATRIX ELEMENTS (POOR CONSTRAINTS ON L_1A OF PIONLESS EFT). SUPER-ALLOWED PROCESS P \sim \sim \sim \sim \sim \overline{P} ice edgma G amov/Telised M to a pion of the Game Western with the Game of α ² with in the Game in the second to be a pion in the second to be a pion to be a pion of the second to be a pion to be a pion to be a pion of the second to be a pion to Ω NICTD AINTS ON L Ω A OF DIONI rents) depend only mildly on the quark masses, as seen for the analogous magnetic interactions, the calculated *pp* ! *de*⁺⌫ transition matrix element leads to a fusion cross section at the physical quark

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). re et al (NPLQCD), Phys.R the *pp* ! *de*⁺⌫*^e* fusion process and tritium -decay. The the search for new physics. The super-allowed process v.Lett.119,062002(2017). semileptonic weak decay of a nuclear system. In con-

unrenormalized isovector and matrix element in \mathbf{M} Δ TRIX ELEMENT ERON panel), and the ratio of the isovector axial matrix element MATRIX ELEMENT FROM QCD

band corresponds to the plateau interval of \mathbf{A} $m = 0.006 \text{ C} \cdot \text{N}$ $N_f = 3, m_\pi = 0.806 \text{ GeV}, a = 0.145(2) \text{ fm}$

FIG. 2. The ratios of correlation functions that determine the

in 3H to that in the proton (lower panel). The proton (lower panel). The orange dia-base dia-base dia-base dia-

fective correlator ratios, *Rp*(*t*), defined in Eq. (4), and the

A DOUBLY-WEAK PROCESS **Tiburzi et al (NPLQCD),Phys.Rev.D96,054505(2017),** Shanahan et al (NPLQCD),Phys.Rev.Lett.119,062003(2017). Proton-proton fusion and tritium -decay from lattice quantum chromodynamics $\frac{1}{2}$ silas R. Beang,1 $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ $n + n \rightarrow p + p + e^- + e^- + \overline{\nu}_e + \overline{\nu}_e$ *n n p p e e* $\overline{\nu}_e$ $\overline{\nu}_e$

SECOND-ORDER RESPONSE TO AN AXIAL BACKGROUND FIELD

Tiburzi et al (NPLQCD),Phys.Rev.D96,054505(2017), Shanahan et al (NPLQCD),Phys.Rev.Lett.119,062003(2017).

SECOND-ORDER RESPONSE TO AN AXIAL BACKGROUND FIELD \Box compared with the inverse of the inverse of the source \Box the matrix elements while the energy splitting between ground and exited states in both splittings in section axial-field strength.⁶ The correlation function for the *nn* ! *pp* transition can be formed utilizing introduce any linear dependence in time with *a* ⌧ 1.

Eq. (22). To arrive at Eq. (32), the deuteron-dineutron energy splitting is assumed to be modest

determined exactly, given calculations at a such a su

³*S*1*,*¹ *S*⁰ contamination from broken Wigner symmetry. Note that the term proportional to *c*⁺ does not

3. Second-order matrix elements in the dinucleon system

channels are assumed to be large, so that *^e*l0*^t* ! 0 and *^e*n*^t* ! 0. If this is not the situation,

$$
C_{nn\to pp}(t) = 2 C_{\lambda_u;\lambda_d=0}^{(np(^{1S_0)})(t)}(t) \Big|_{\mathcal{O}(\lambda_u^2)} - C_{\lambda_u;\lambda_d=0}^{(nn)}(t) \Big|_{\mathcal{O}(\lambda_u^2)} - C_{\lambda_u=0;\lambda_d}^{(nn)}(t) \Big|_{\mathcal{O}(\lambda_d^2)}
$$

$$
C_{\lambda_u;\lambda_d=0}^{(np(^{1S_0)})(t)}(t) = \sum_{x} \langle 0 | \chi_{np}(x,t) \chi_{np}^{\dagger}(0) | 0 \rangle + \lambda_u \sum_{x,y} \sum_{t_1=0}^{t} \langle 0 | \chi_{np}(x,t) J_3^{(u)}(y,t_1) J_3^{(u)}(z,t_2) \chi_{np}^{\dagger}(0) | 0 \rangle + g_{3} \lambda_u^3
$$

$$
+ \frac{\lambda_u^2}{2} \sum_{x,y,z} \sum_{t_1=0}^{t} \sum_{t_2=0}^{t} \langle 0 | \chi_{np}(x,t) J_3^{(u)}(y,t_1) J_3^{(u)}(z,t_2) \chi_{np}^{\dagger}(0) | 0 \rangle + g_{3} \lambda_u^3
$$

$$
\alpha^2 \mathcal{R}_{nn\to pp}(t) = \left[-t + \frac{e^{\Delta t} - 1}{\Delta} \right] \frac{\langle pp | \tilde{J}_3^+ | d \rangle \langle d | \tilde{J}_3^+ | nn \rangle}{\Delta} + t \sum_{\substack{t' \neq d \\ \text{SVDIF THAT DEPEND} \\ \text{ON EXCTTED STATES}}} \frac{\langle pp | \tilde{J}_3^+ | t' \rangle \langle t' | \tilde{J}_3^+ | nn \rangle}{\delta_{t'}}
$$

$$
\text{HERE THE FACT THAT } \Delta \neq 0 \text{ RESCUES US!}
$$

Savage et al (NPLQCD), Phys.Rev.Lett.119,062002(2017). \overline{a} and \overline{a} \overline{b} (NPI OCD) and \overline{a} elements, as can be read from Eq. (30), but have no time dependence. The critical aspect of Eq. (34) is that both the short-distance and the short-distance and the long-distance contributions of \mathcal{L}_max Sayage et al (NPLOCD) phys Rey Lett 119 062002(2017) second-order weak correlation function function function function $\mathcal{L}_{\mathcal{A}}$

 $E_{\rm eff}$

³*S*1*,*¹

*^S*⁰ (*t*), defined analogously using *R*

SHORT-DISTANCE PIECE

ˆ*Rnn* !*pp* ˆ*Rnn* !*pp* MATRIX ELEMENT FROM QCD

t

t

(a) (b) (a) (b) $N_f = 3$, $m_\pi = 0.806$ GeV, $a = 0.145(2)$ fm

SHORT-DISTANCE CONTRIBUTION

FULL CONTRIBUTION

\overline{D} EFT VERTICES AND CORRELATION FUNCTIONS USING DIBARYONS

to incorporate the e↵ect of channel-changing contact interactions on the bare dibaryon propagators.

EFT CONSTRAINED WITH LQCD.

LESSON FROM 800 MEV WORLD:

AXIAL POLARIZABILITY COULD BE IMPORTANT. CANNOT BE CONSTRAINED BY SINGLE-BETA DECAY PROCESSES.

MATCHING HIGH SCALE TO LOW SCALE

?

?

MATCHING HIGH SCALE TO LOW SCALE

?

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THANK YOU