Weak and rare nuclear processes

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Speak with Hilla Deleon
@ workshop

Outline

- The role of theory in calculating rare nuclear processes.
- Calculating weak reactions in chiral EFT.
- ***Gamow-Teller transitions within chiral EFT***: from ^{3}H through ^{6}He to medium-mass nuclei.
- $0\nu\beta\beta$ decay rates at medium-heavy nuclei.
- Spin-dependent WIMP scattering on nuclei.
- Summary.

Weak and rare nuclear processes

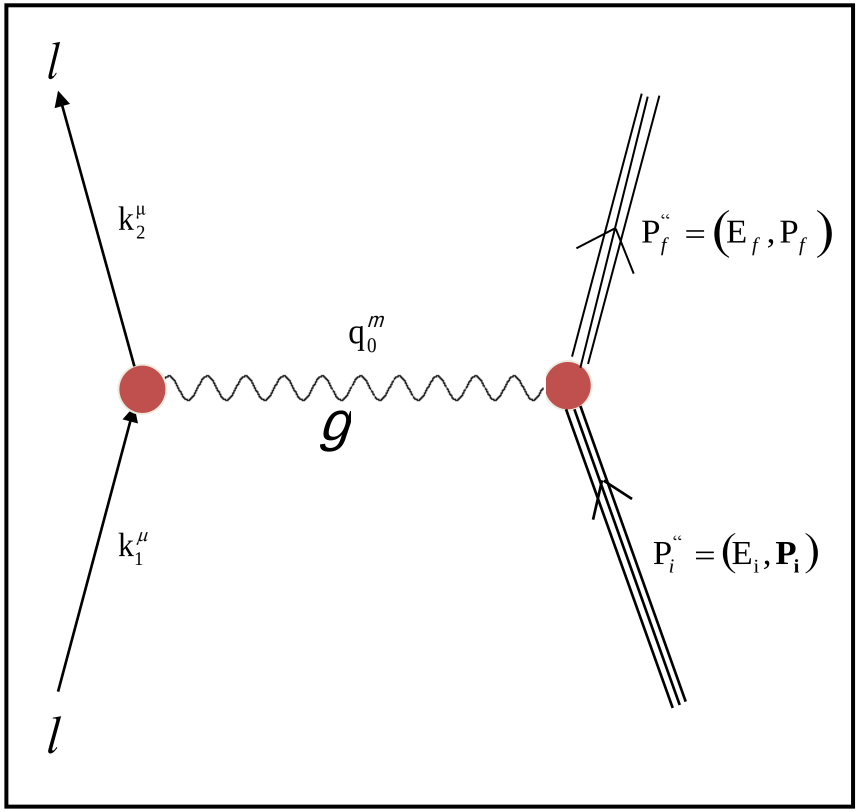
- Nuclear weak processes play a major role in:
  - Nuclear structure: Giant Gamow-Teller resonance, Fermi and GT Strength Functions.
  - Superallowed Fermi transitions: isospin symmetry breaking, CKM matrix unitarity.
  - ^{3}H single β-decay: measurement of the neutrino mass
  - $0\nu\beta\beta$ decay: Lepton Number Conservation, Majorana nature of neutrinos
  - Astrophysical phenomena.
- Dark matter as a weakly interacting massive particle.

The role of theory

- Rare processes are usually hard to measure. Accurate, parameter free predictions are needed to :
  - Constrain fundamental symmetries of QCD.
  - Quantify “beyond the standard model” effects for experiments and assessing the feasibility of experiments.
  - Describe the microscopic dynamics of astrophysical phenomena.
- Connecting reactions and structure in the nuclear domain.
- Understanding the nuclear regime from first principles is essential for a correct interpretation of natural phenomena and experiments.

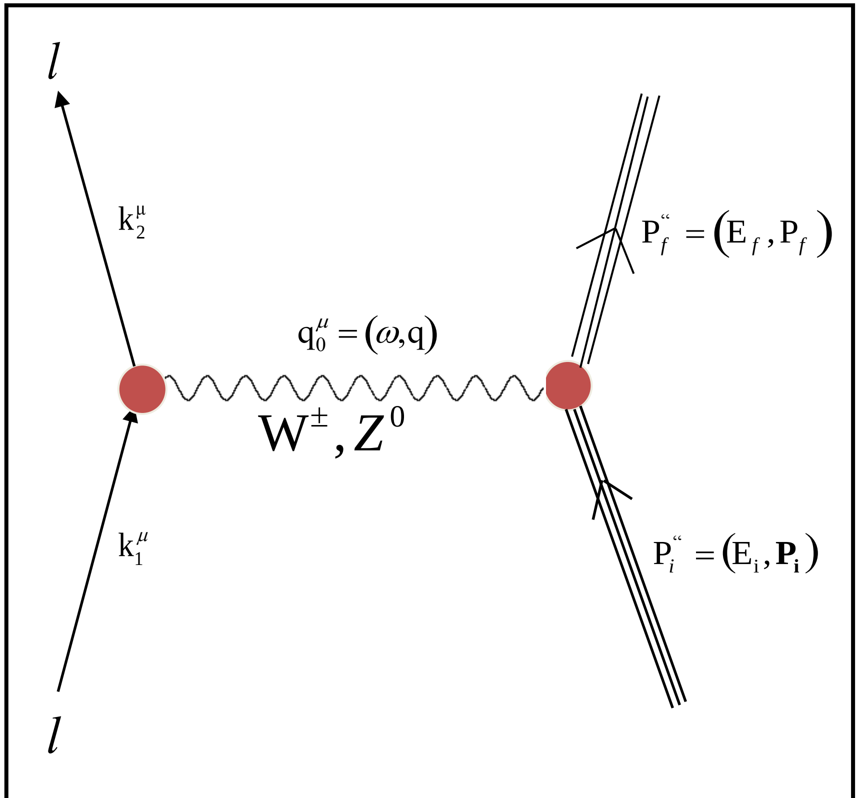
Introduction

- ***Low energy electromagnetic reaction***



Introduction

- ***Low energy weak reaction***



$$W,Z\ propagator = \frac{g_{mn} + \frac{q_m q_n}{M_W^2}}{q^2 + M_W^2}$$

Introduction

- ***Neutrino-less double beta-decay***

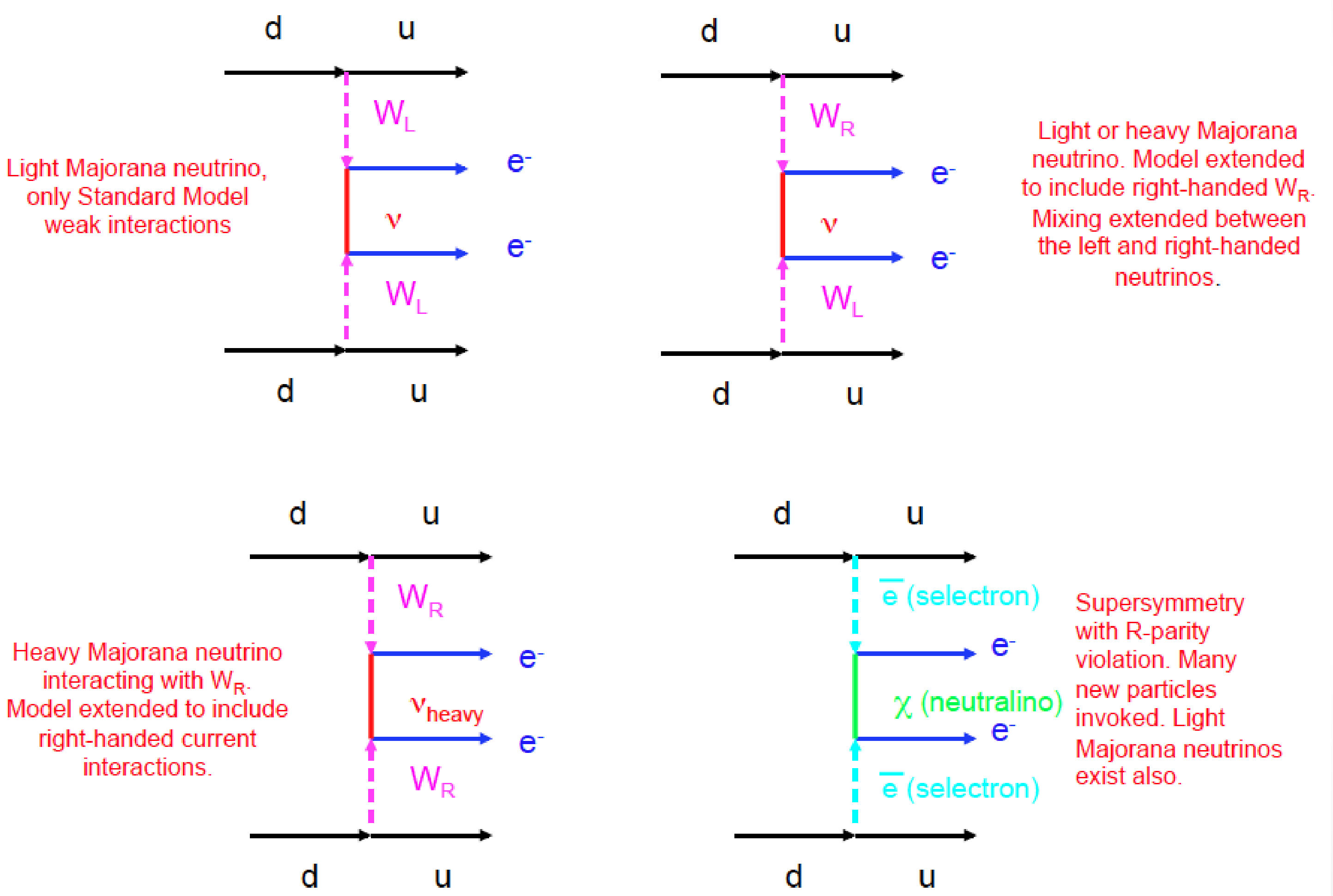
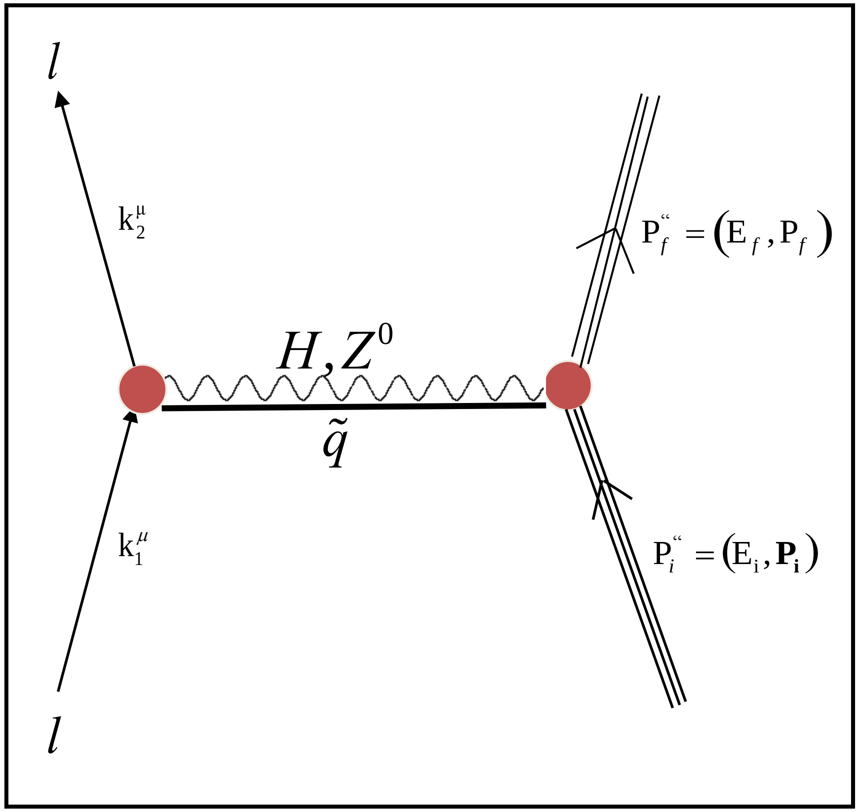


Figure taken from P. Vogel

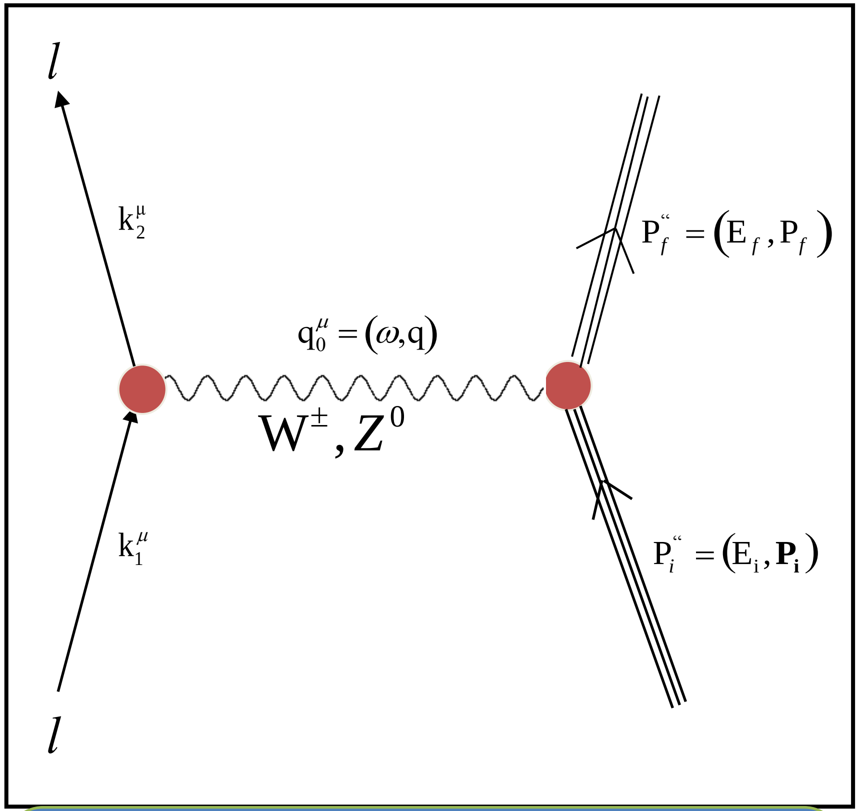
Introduction

- ***Neutralino scattering off a nucleus***



"All happy families are alike, every unhappy family is unhappy in its own way"

- ***Low energy weak reactions***



$$W,Z\ propagator = \frac{g_{mn} + \frac{q_m q_n}{M_W^2}}{q^2 + M_W^2}$$

Introduction

- ***Low energy reactions***

$$\hat{H}_W \sim \int d^3\vec{x}\, \hat{j}^+_\mu(\vec{x})\, \hat{J}^{\mu-}(\vec{x})$$

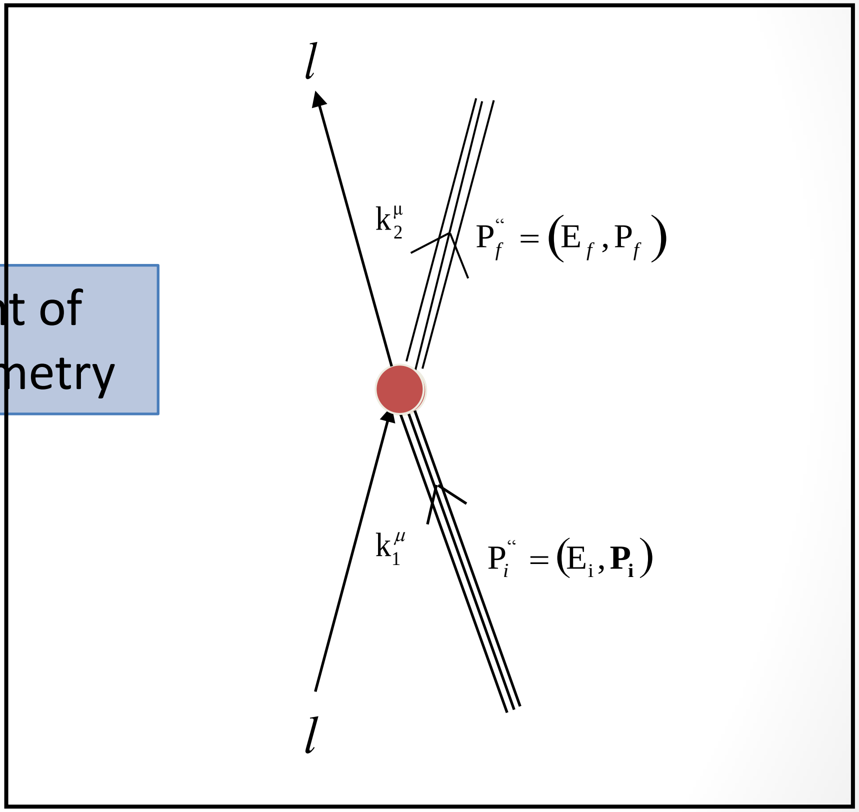
Probe current of known symmetry

Nuclear current of the same symmetry

$$\mathcal{O} \sim \langle \psi_i | \hat{J}^\mu | \psi_f \rangle$$

Scattering operator

Currents in the nucleus



Low energy nuclear reactions induced by an external probe

- ***Same symmetry*** will induce the ***same structure of the nuclear current***.
- Differences lie in ***coupling constants***.
- The currents are ***reflections*** of the ***symmetries*** and ***properties*** of the nuclear interaction, in particular can be used to characterize the elusive ***three nucleon force***.
- Thus, one can ***relate electro-weak properties and reaction rates*** with non-trivial properties not only of the ***target***, but also of the ***fundamental theory*** leading to its structure!

Chiral Effective Field Theory

- Symmetries are important ***NOT*** degrees of freedom.
- In QCD – an approximate chiral symmetry:
  - The *u* and *d* quarks are (almost) massless (~5-10 MeV).

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

  - The $SU(2)_V$ symmetry is the isospin symmetry.
  - The **pions** are the **Nambu-Goldstone bosons** of the spontaneous chiral symmetry breaking.
  - The order-parameter is the pion-decay constant:

$$\Lambda_{QCD} = 4\pi f_\pi$$

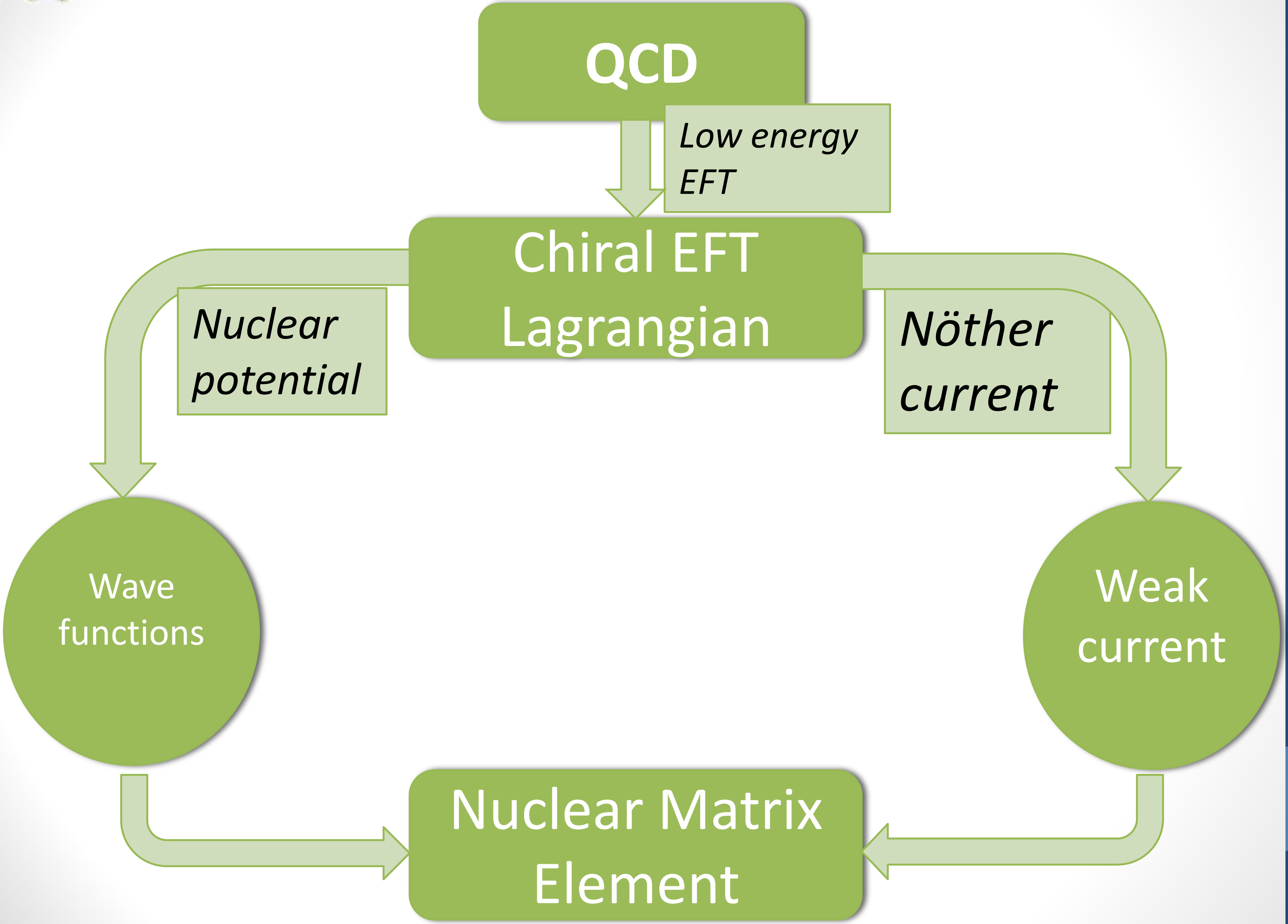
- Identify **Q** – the momentum scale of the process.
  - In view of Q-identify the effective degrees of freedom:
  - Write a Lagrangian composed of ALL possible operators invariant under symmetries of the underlying theory.

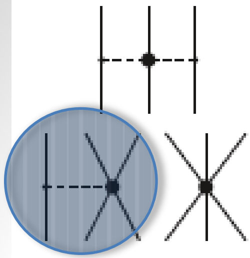
Chiral Effective Field Theory

- Find a ***systematic*** way to organize diagrams according to their contribution to the observable.
  - Expand in the inverse of the nucleon's mass (take Λ^{α}~M_N) ➔***Heavy Baryon χPT!***
  - ***Weinberg's Power Counting:*** Each Feynman diagram can be characterized by: $$\left(\frac{Q}{\Lambda}\right)^{\nu}$$
  - Weinberg showed that ν is bound from below.
- ***Issues!***

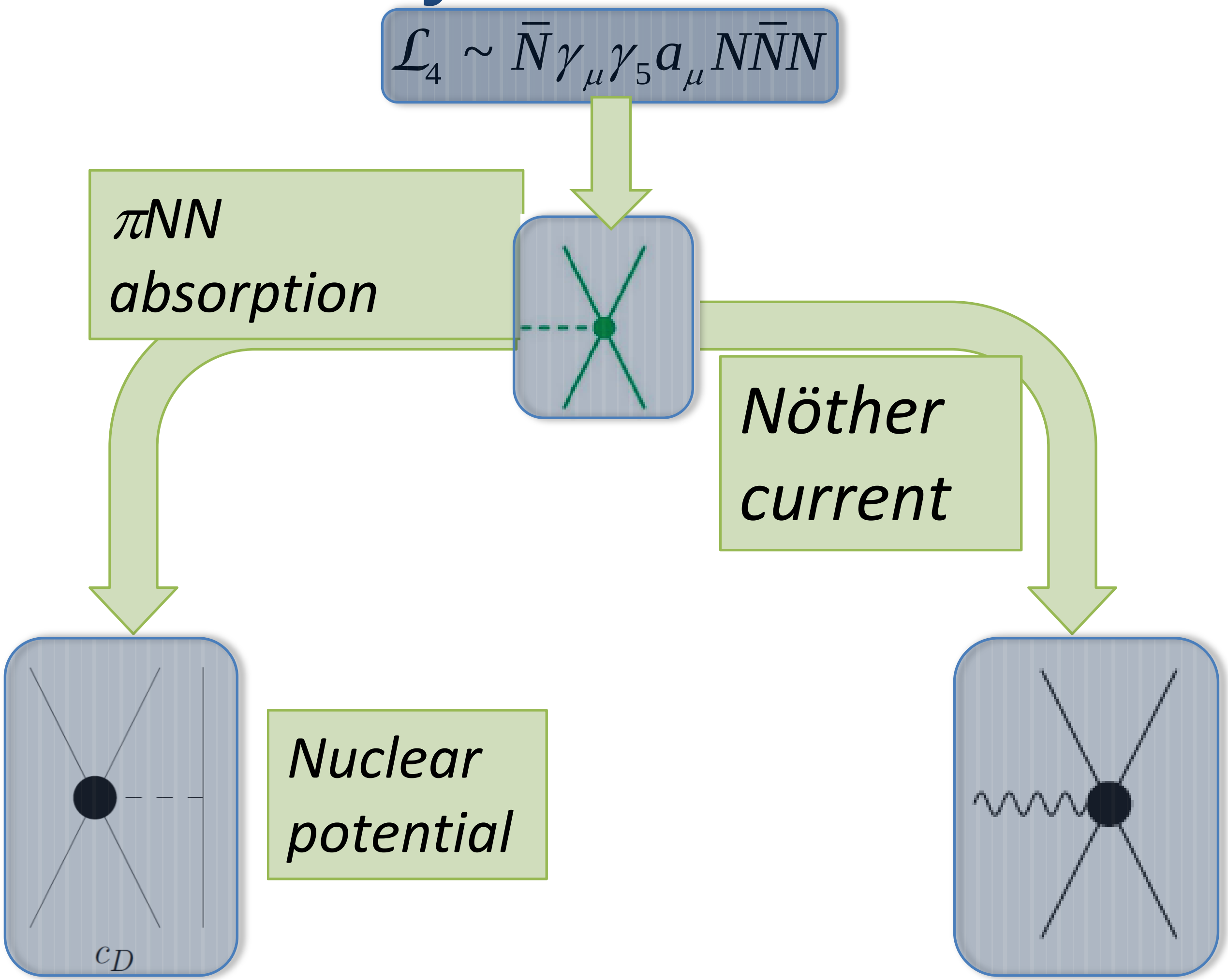
20 years of debate led by: Weinberg, Kaplan, Savage, Wise, van-Kolck, Nogga, Timmermans, Birse, Meissner, Epelbaum, Machleidt…

χPT approach for low-energy EW nuclear reactions:





Unites phenomena: 3 body forces and reactions

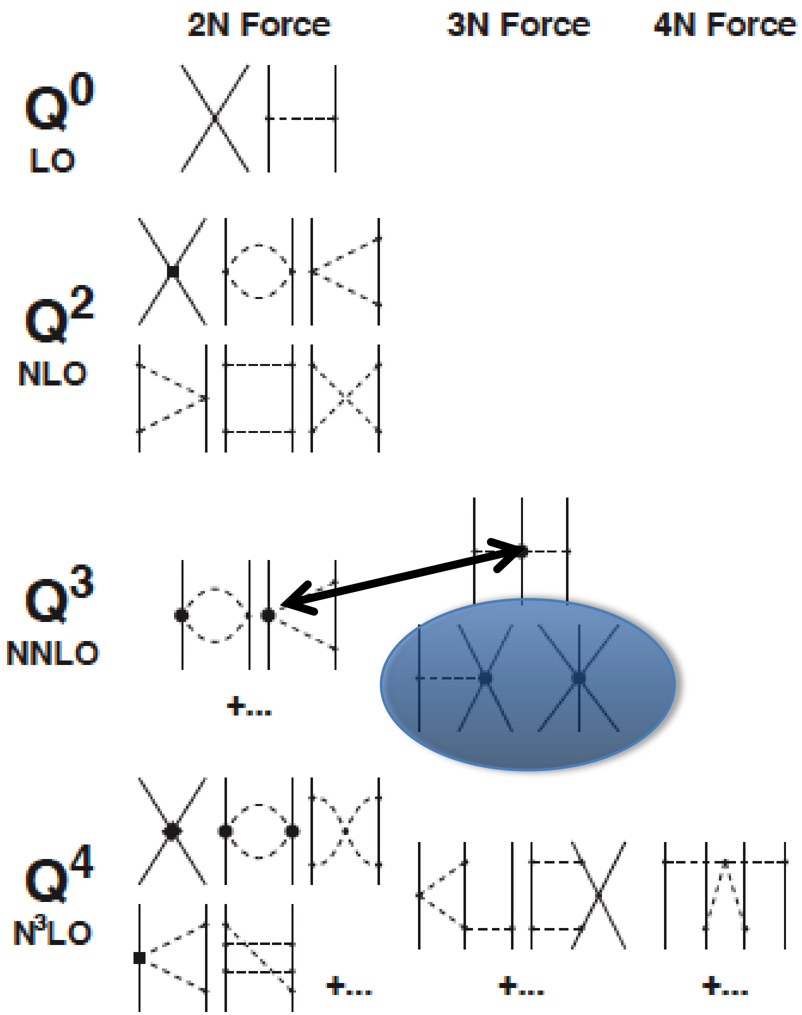


Same LEC appears in the potential and in the current!

van Kolck (1995); van Kolck, Ordonez (1995); Gårdestig, Phillips (2006); DG, Quaglioni, Navratil (2009)

Forces in pionfull χEFT

- The leading order NNN forces are at N²LO.
- They include 2 new contact parameters.
- No new parameters at N³LO.



Weinberg, van Kolck, Ordonez, Meissner, Epelbaum, Nogga, Bernard, Kaiser, Krebs, Machleidt, Entem…

Differences from Δ-full

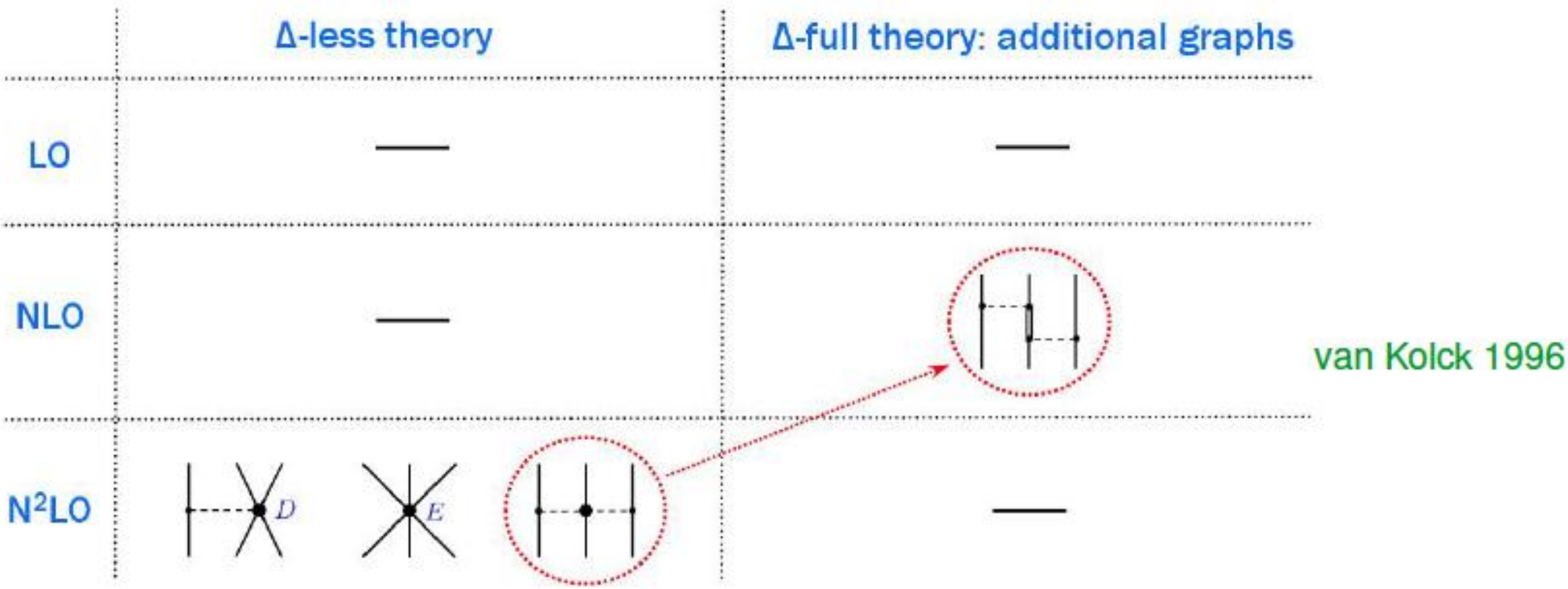


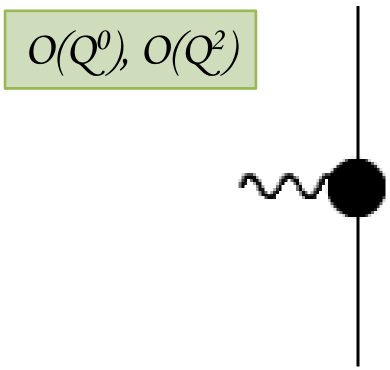
Figure adopted from Ulf Meissner.

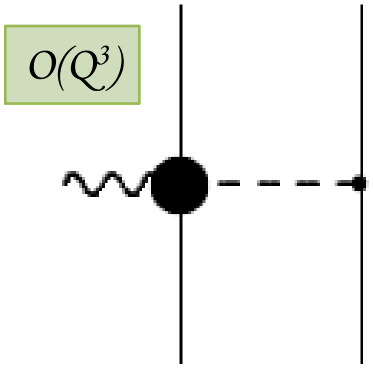
χEFT axial weak currents to $O(Q^3)$

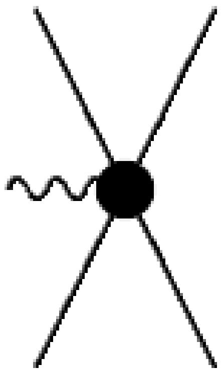
Single nucleon current

1 pion exchange

Contact term





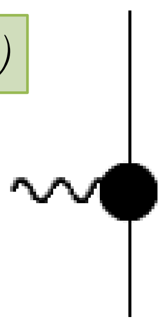


T.-S. Park *et al*, **Phys. Rev. C 67**, 055206 (2003); DG PhD thesis arXiv: 0807.0216

χEFT axial weak currents to $O(Q^3)$

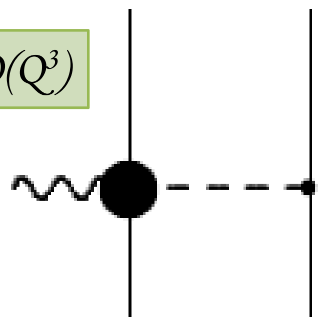
Single nucleon current

$O(Q^0)$, $O(Q^2)$

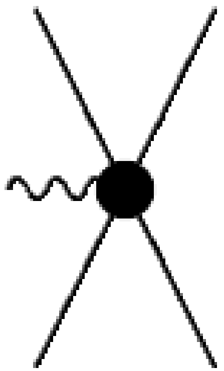


1 pion exchange

$O(Q^3)$



Contact term



$$J_n^0(p^2) = \tau_n^- \left[g_V(p^2) - g_A(p^2)\frac{\mathbf{P}\cdot\sigma_n}{2m_N} + g_P(p^2)\frac{E\,(\mathbf{p}\cdot\sigma_n)}{2m_N} \right]$$

$$\mathbf{J}_n^{1B}(p^2) = \tau_n^- \left[g_A(p^2)\sigma_n - g_P(p^2)\frac{\mathbf{p}\,(\mathbf{p}\cdot\sigma_n)}{2m_N} + \right.$$

$$\left. +i\,(g_M(p^2) + g_V(p^2))\,\frac{\sigma_n\times\mathbf{p}}{2m_N} - g_V(p^2)\frac{\mathbf{P}}{2m_N} \right]$$

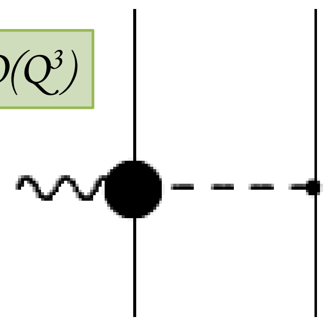
T.-S. Park *et al*, **Phys. Rev. C 67**, 055206 (2003); DG PhD thesis arXiv: 0807.0216

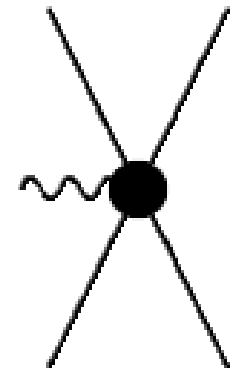
χEFT axial weak currents to $O(Q^3)$

Single nucleon current	1 pion exchange	Contact term

$O(Q^0)$, $O(Q^2)$

$O(Q^3)$





Fermi operator

$$J_n^0(p^2) = \tau_n^- \left[g_V(p^2) - g_A(p^2)\frac{\mathbf{P}\cdot\sigma_n}{2m_N} + g_P(p^2)\frac{E\,(\mathbf{p}\cdot\sigma_n)}{2m_N} \right]$$

$$\mathbf{J}_n^{1B}(p^2) = \tau_n^- \left[g_A(p^2)\sigma_n - g_P(p^2)\frac{\mathbf{p}\,(\mathbf{p}\cdot\sigma_n)}{\ldots} + \right.$$

$$\left. + i\,(g_M(p^2) + g_V(p^2)) \ldots (p^2)\frac{\mathbf{P}}{2m_N} \right]$$

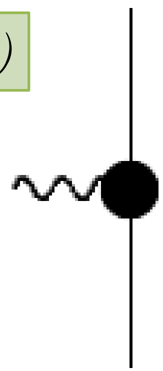
Gamow-Teller operator

T.-S. Park *et al*, **Phys. Rev. C 67**, 055206 (2003); DG PhD thesis arXiv: 0807.0216

χEFT axial weak currents to $O(Q^3)$

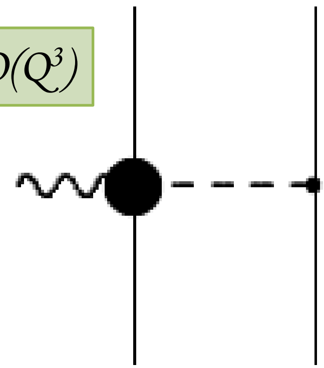
Single nucleon current

$O(Q^0)$, $O(Q^2)$



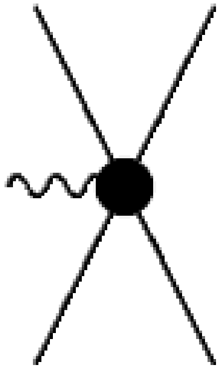
1 pion exchange

$O(Q^3)$



Nucleon-pion interaction,
NO new parameters

Contact term



$\hat{d}_R$

Contact term

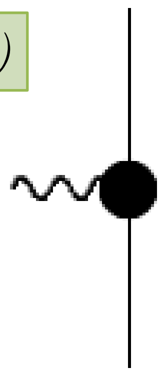
T.-S. Park *et al*, **Phys. Rev. C 67**, 055206 (2003); DG PhD thesis arXiv: 0807.0216

χEFT axial weak currents to $O(Q^3)$

$$\hat{d}_R \equiv \frac{M_N}{\Lambda_\chi g_A} c_D + \frac{1}{3} M_N (c_3 + 2c_4) + \frac{1}{6}$$

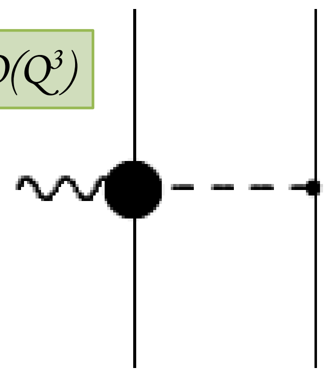
Single nucleon current

$O(Q^0)$, $O(Q^2)$



1 pion exchange

$O(Q^3)$



Nucleon-pion interaction,
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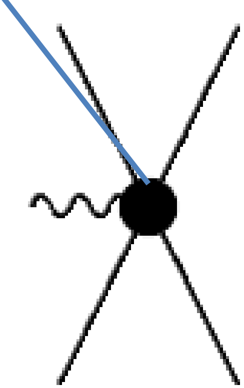
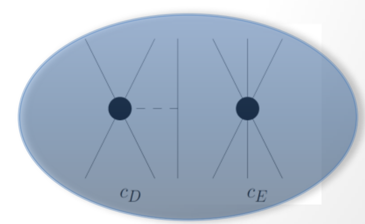
Contact term



$\hat{d}_R$

Contact term



Gårdestig, Phillips, **Phys. Rev. Lett. 98**, 232301 (2006); **DG**, Quaglioni, Navratil, **Phys. Rev. Lett. 103,** 102502 (2009).

Nuclear β decays

- Typically, a very low momentum transfer.

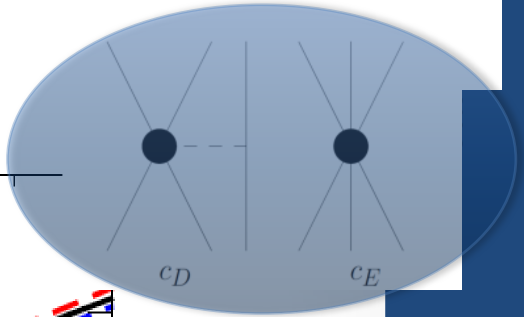
$$ft = \frac{2\pi^3 \ln 2 / m_e^3}{G_F^2 V_{ud}^2 \left[\left(1+\Delta_R^V\right) F_V^2 \left|M_V\right|^2 + \left(1+\Delta_R^A\right) g_A^2 \left|M_A\right|^2 \right]}$$

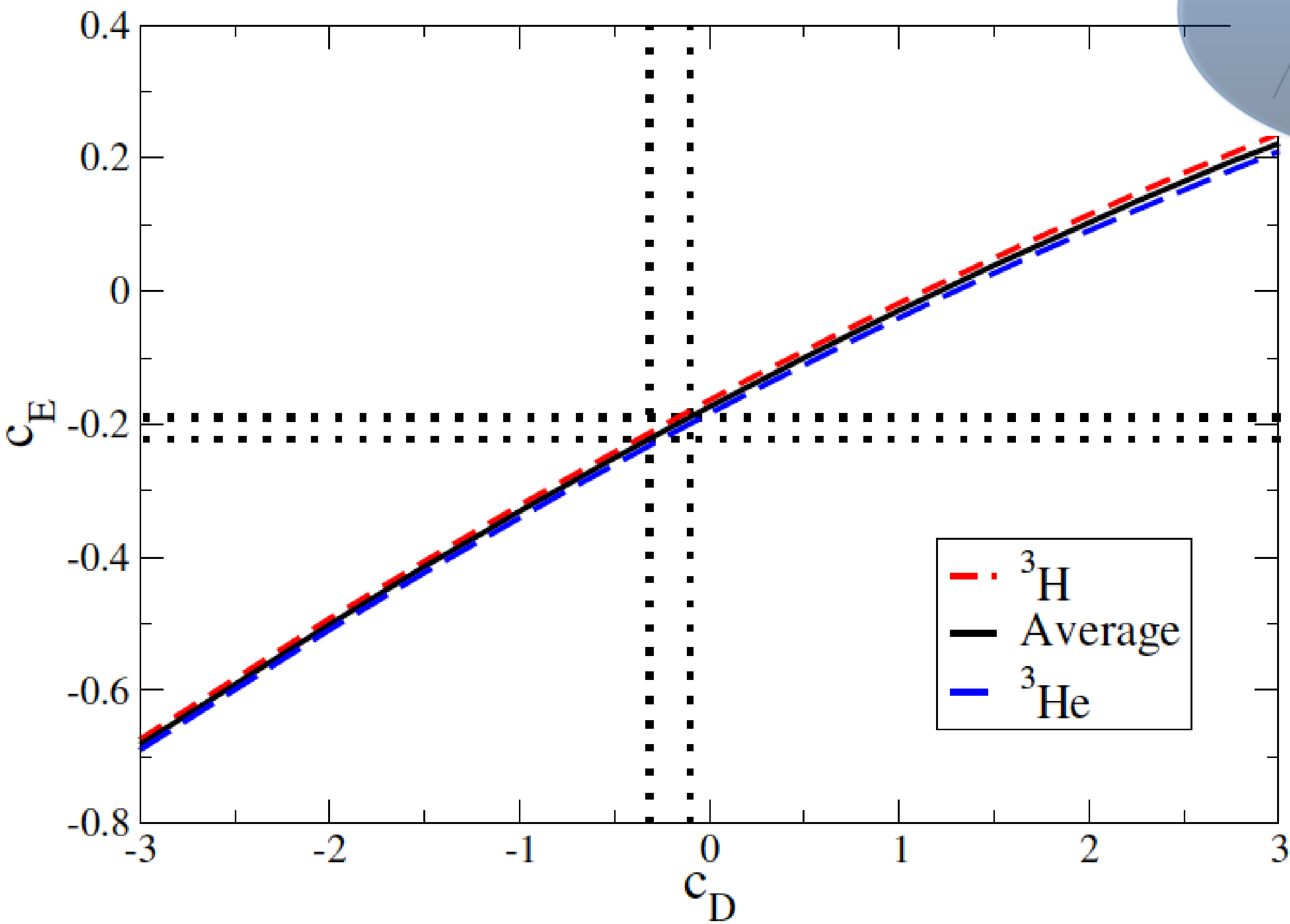
$$\left|M_V\right|^2 = \frac{1}{2J_i+1} \left| \left\langle \psi_i \left\| \sum_{k=1}^{A} t_k^{\pm} \right\| \psi_f \right\rangle \right|^2 =$$

$$= \left[T\left(T+1\right) - T_Z\left(T_z+1\right) \right] \left(1-\delta_C\right)$$

$$\left|M_A\right|^2 = \left| \left\langle \psi_i \left| E_1^A / g_A \right| \psi_f \right\rangle \right|^2 = \frac{1}{3\pi\left(2J_i+1\right)} \left| \left\langle \psi_i \left\| \sum_{k=1}^{A} \vec{\sigma}_k t_k^{\pm} \right\| \psi_f \right\rangle \right|^2 + corrections$$

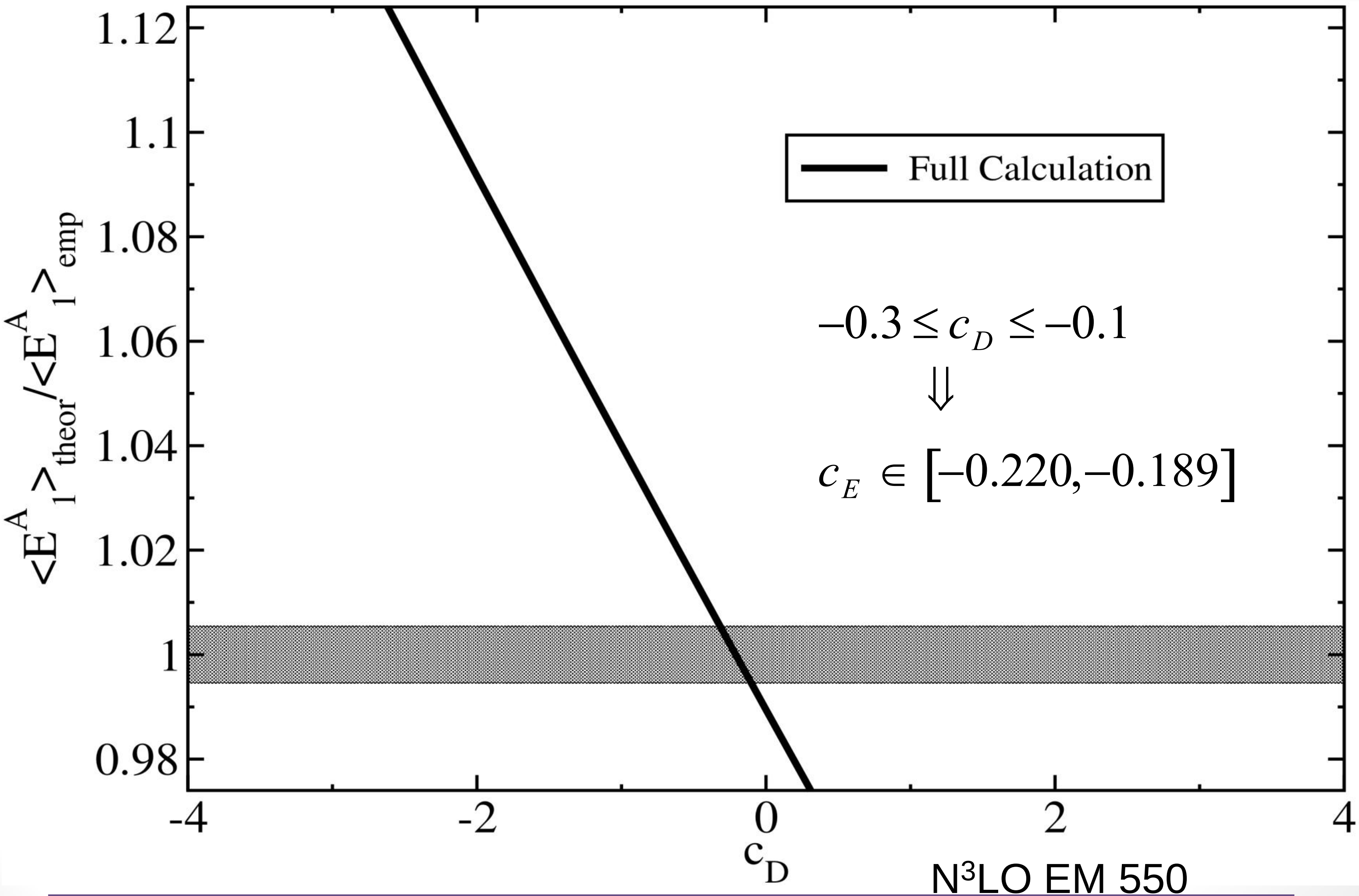
Step 1: use the trinuclei binding energies to find a c_D-c_E relation





Navratil *et al.*, Phys. Rev. Lett. **99**, 042501 (2007).

Step 2: calibrate c_D according to the triton half life.



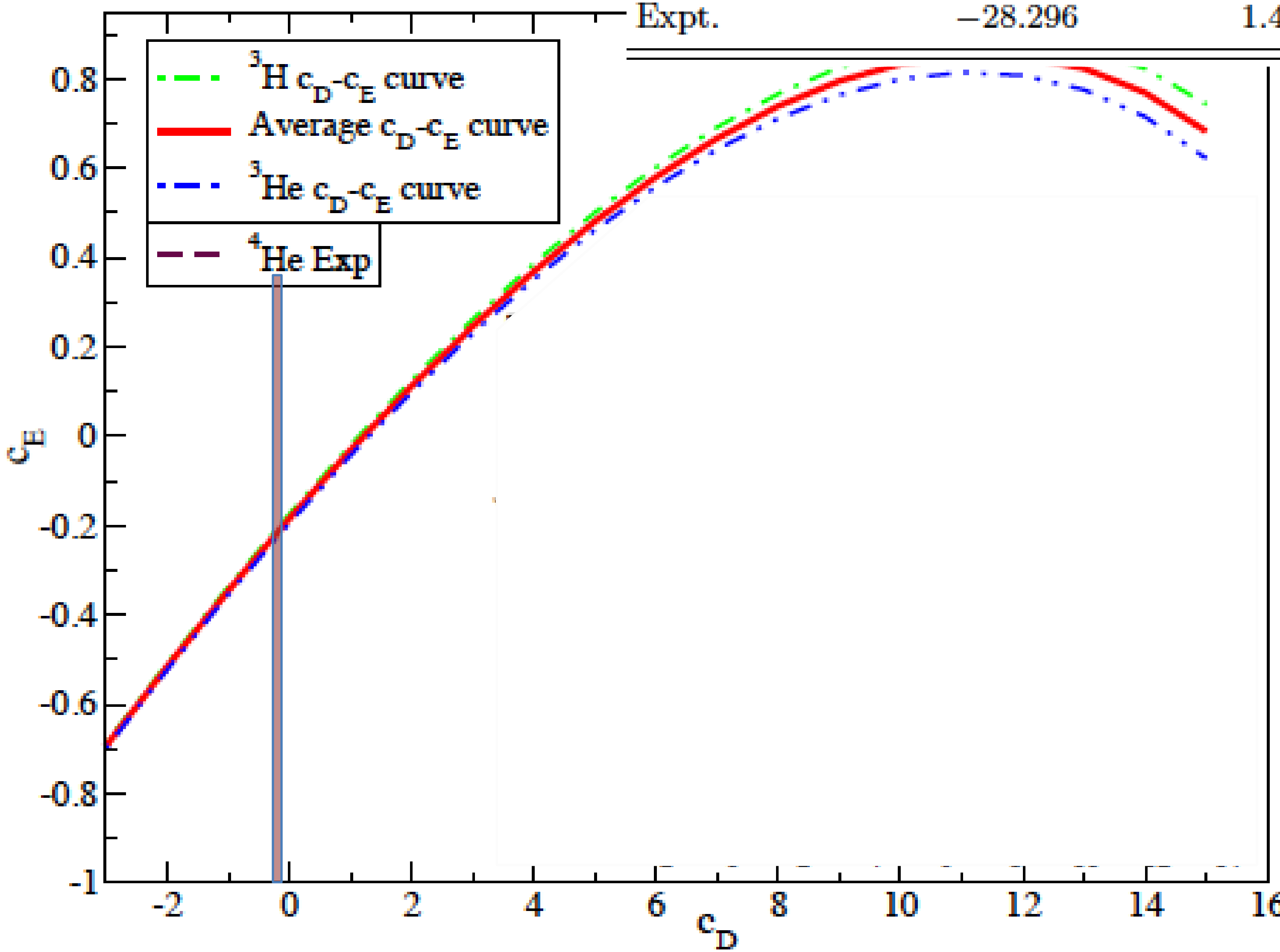
$$-0.3 \leq c_D \leq -0.1$$
$$\Downarrow$$
$$c_E \in [-0.220, -0.189]$$

N[3]LO EM 550

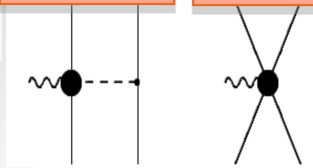
DG, Quaglioni, Navratil, Phys. Rev. Lett. 103, 102502 (2009)

A prediction of ^4He properties

	^{4}He	
	$E_{g.s.}$	$\langle r_p^2 \rangle^{1/2}$
NN	−25.39(1)	1.515(2)
$NN+NNN$	−28.50(2)	1.461(2)
Expt.	−28.296	1.467(13) [24]

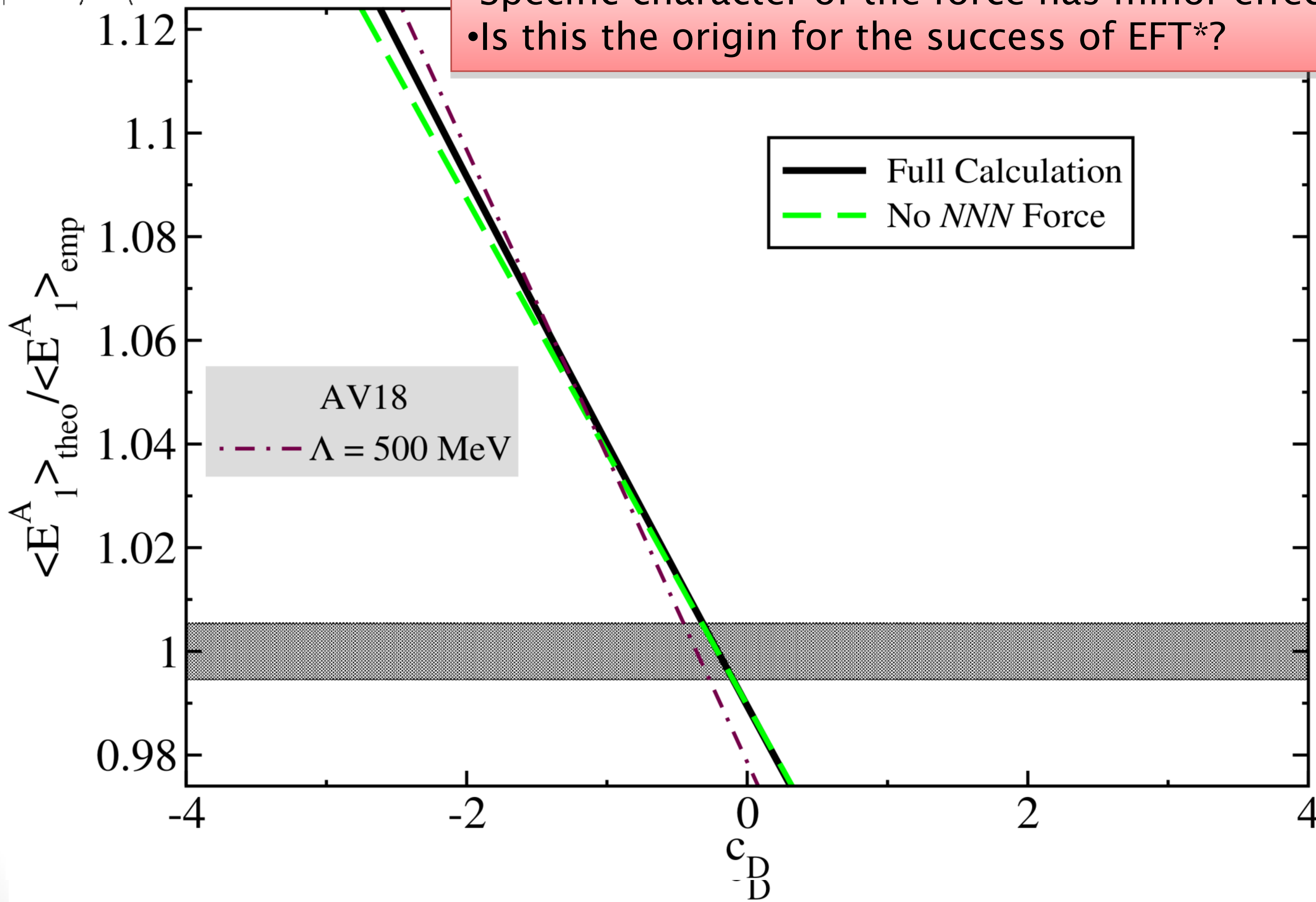


OPEC
Contact

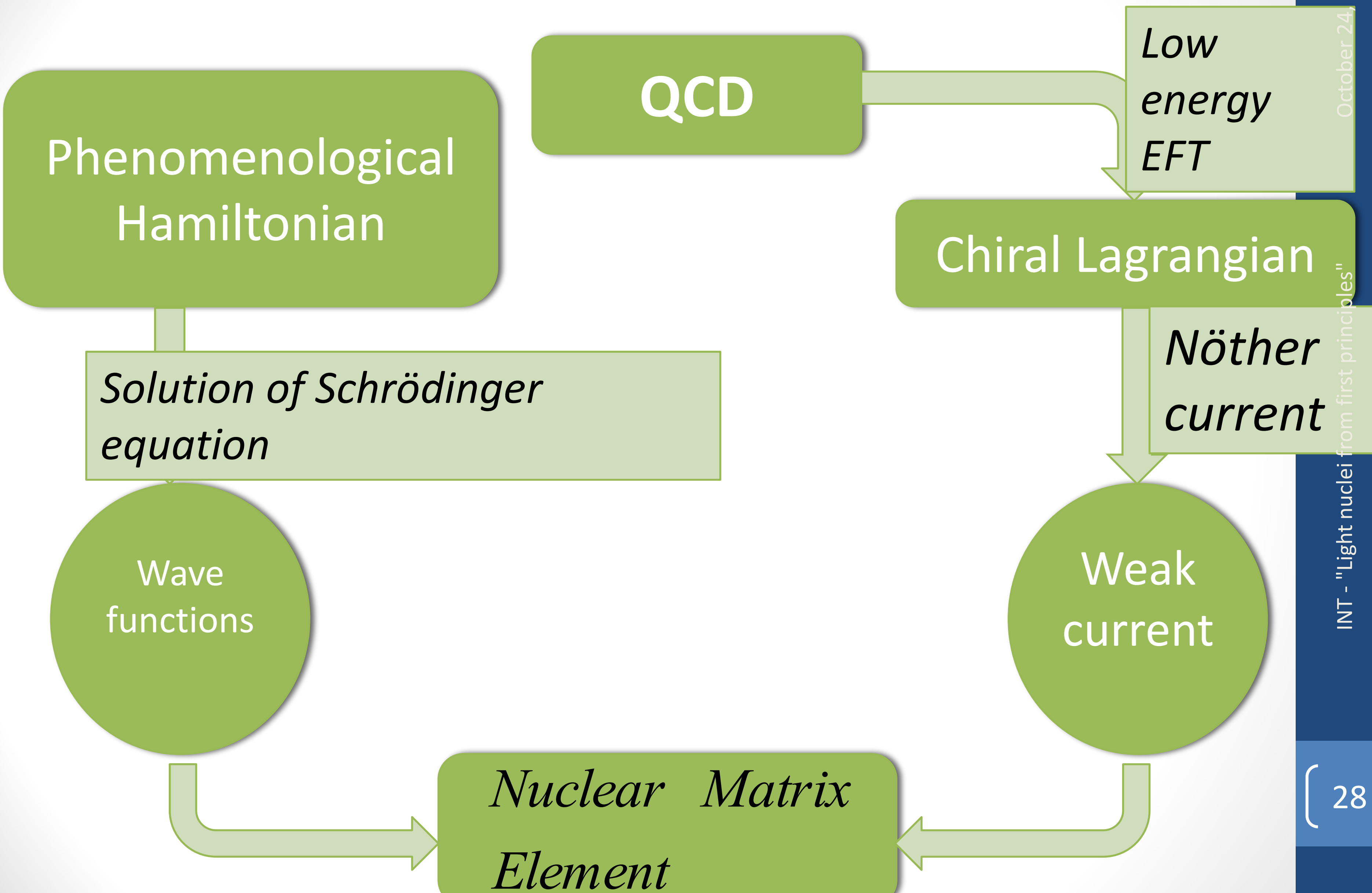


A closer look into the weak axial correlations in ^3H

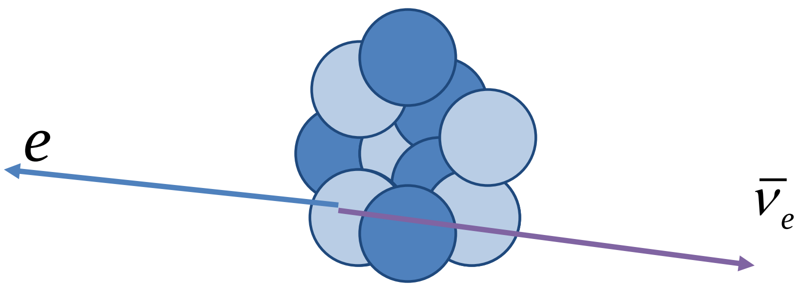
- Specific character of the force has minor effect
- Is this the origin for the success of EFT*?



EFT approach for low-energy weak reactions:*



T.-S. Park *et al*, **Phys. Rev. C 67**, 055206 (2003), M. Rho **arXiv:** nucl-th/061003.



$$M_A^2 = \left\langle \psi_i \middle| GT \middle| \psi_f \right\rangle^2$$

$$GT\Big|_{LO} = \sum_{i=1}^{A} \sigma_i \tau_i^{\pm}$$

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left(1+\Delta_R^V\right) F_V^2 \left|M_V\right|^2 + \left(1+\Delta_R^A\right) g_A^2 \left|M_A\right|^2 \right]}$$

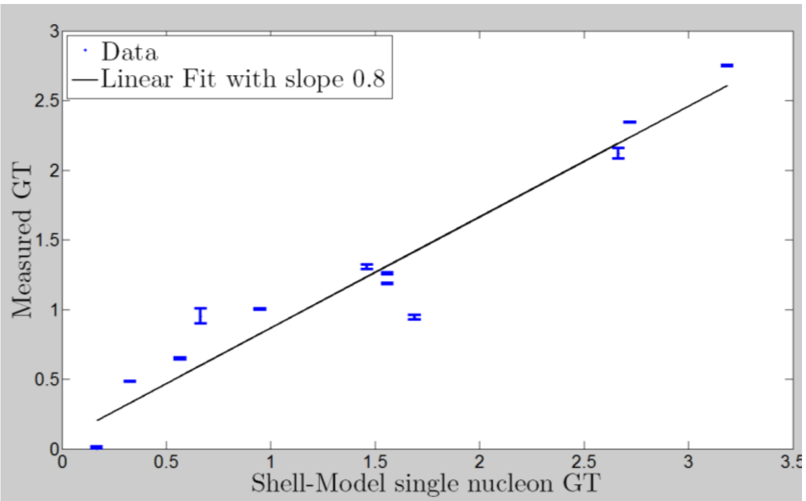
GAMOW-TELLER TRANSITIONS

Gamow-Teller Quenching

$\mathbf{J}_{n,1B} = g_A \sigma_n \boxtimes_n$, $g_A^{eff} = q g_A$, $q \uparrow 0.75$

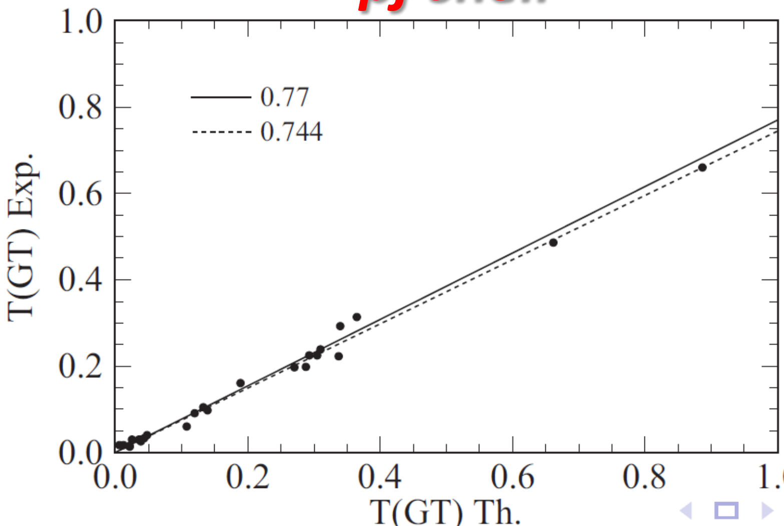
"Large quenching"

sd shell



Chou, Warburton, Brown, Phys. Rev. **C47,** 163 (1993)

pf shell



Martinez-Pinedo *et al*, Phys. Rev. **C53**, 2602 (1996)

- QRPA calculations reach similar results.

Alvarez-Rodriguez *et al*, Phys. Rev. **C70**, 064309 (2004)

- Energy Density Functional Methods

Bender *et al*, Phys. Rev. **C65**, 054322 (2002)
Rodriguez *et al*, Phys. Rev. Lett. **105**, 252503 (2010)

- Quenching needed in regions where spectroscopy is well reproduced.

Gamow-Teller Quenching

Sesano *et al*, Phys. Rev. **C79**, 024602 (2009); Yako *et al*, Phys. Lett. **B615**, 193 (2005)

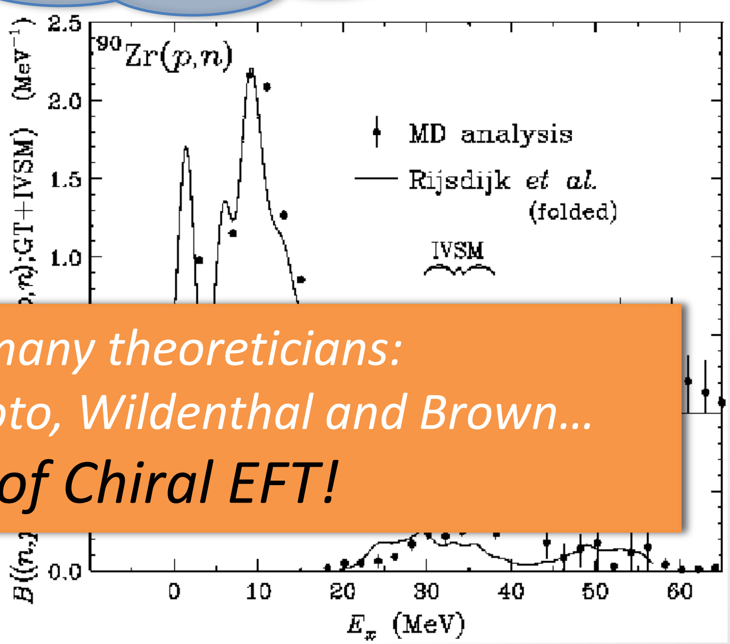
- (much debated) Measurements of Ikeda sum-rule in ^{90}Zr up to high energies, show very small quenching!

"Small quenching"

$$q^2 = \frac{S_{\beta-} - S_{\beta+}}{3(N-Z)} = 0.92 \pm 0.11 \Rightarrow q = 0.96 \pm 0.06$$

- Suggesting:

  many body approximations
  responsible for the discrepancy.



The quenching puzzle attracted many theoreticians:
Arima, Rho, Towner, Bertsch and Hamamoto, Wildenthal and Brown…
Revisit in the framework of Chiral EFT!

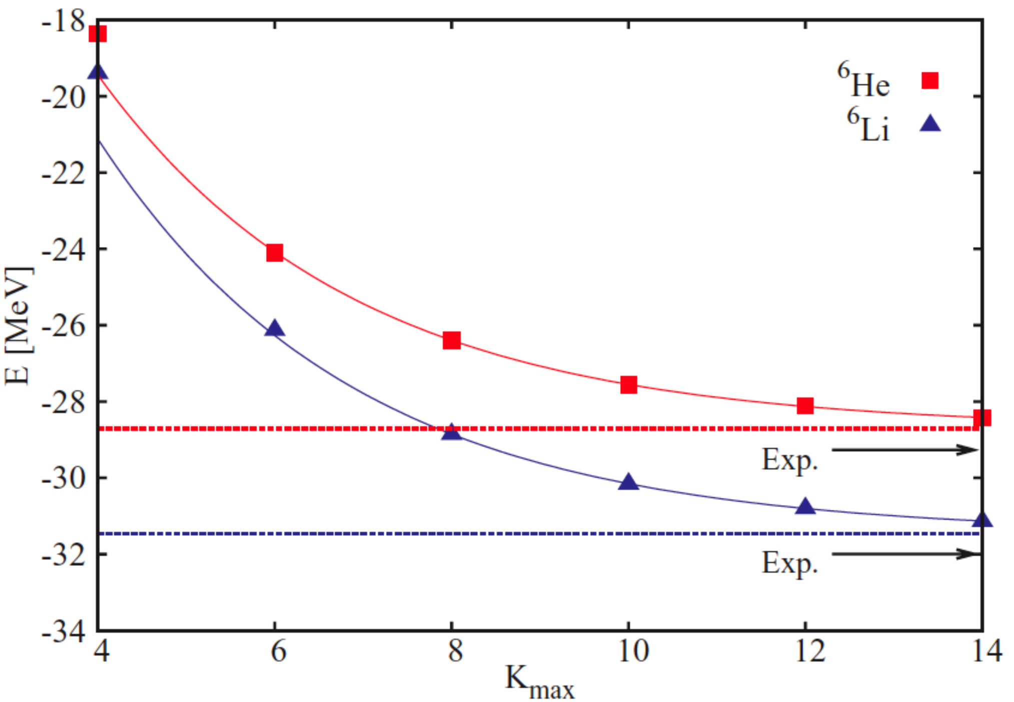
^{6}He β^- decay

- We use the HH method to solve the 6 body problem, with ***JISP16*** NN potential.
- We use χEFT axial MEC with c_D fixed using triton β decay
- Very rapid convergence:

$E_\infty(^6He)=28.70(13)$ MeV
$E_{exp}(^6He)=29.269$ MeV

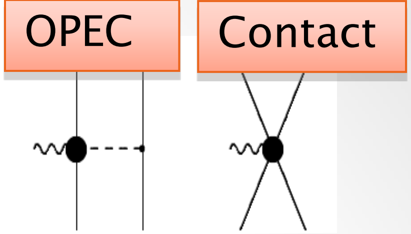
$E_\infty(^6Li)=31.46(5)$ MeV
$E_{exp}(^6Li)=31.995$ MeV

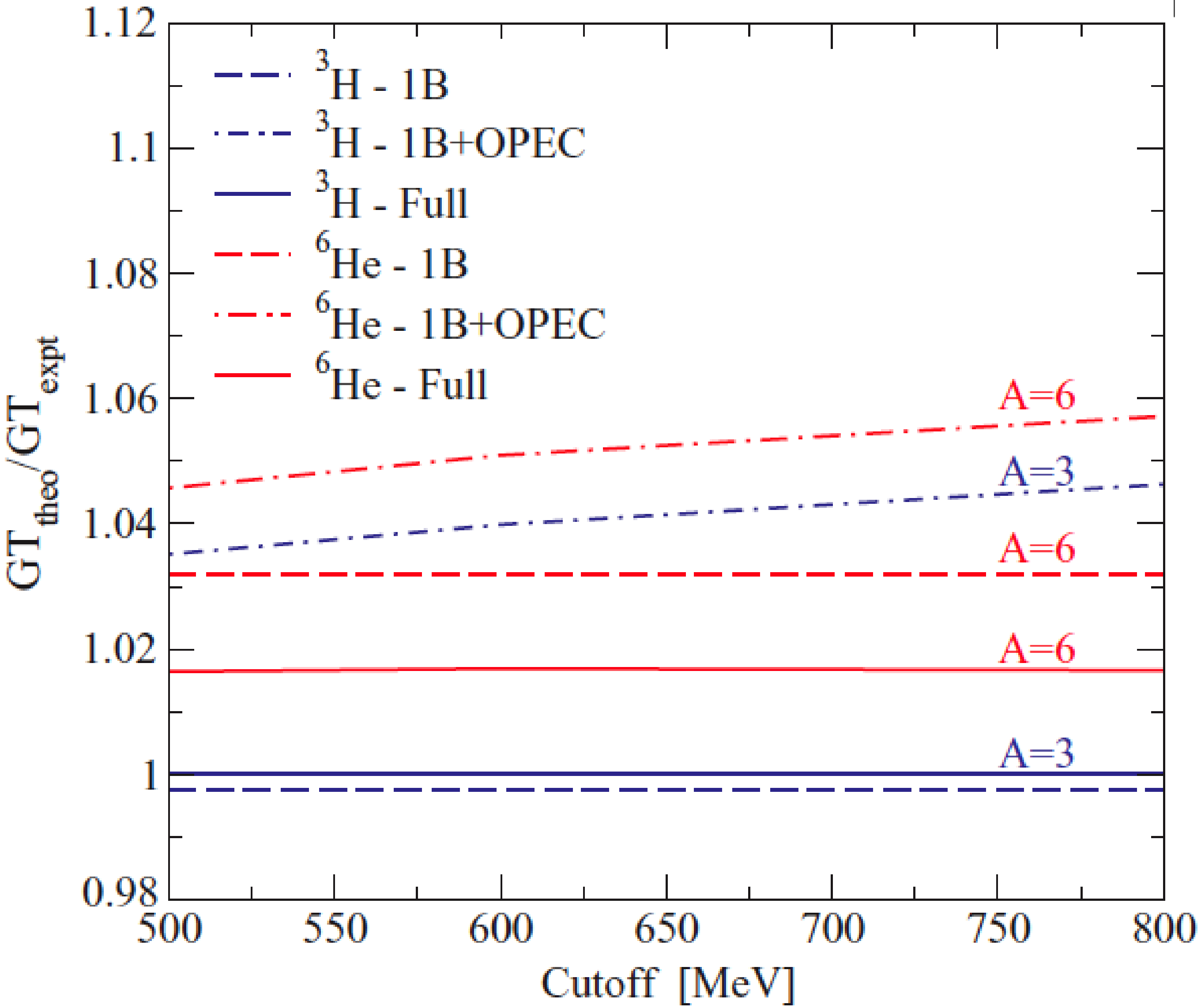
$GT|_{LO}=2.225(2)$
$GT=2.198(2)$



Vaintraub, Barnea, **DG**, Phys. Rev. C, **79** 065501 (2009); Lupo, Barnea, DG, work in progress

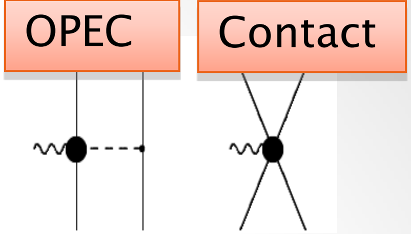
^{6}He β decay





Vaintraub, Barnea, **DG**, Phys. Rev. C, **79** 065501 (2009).

^{6}He β decay



- The contact interaction that does not exist in pheno. MEC, has an opposite sign with respect to the long range one.
- The final GT is just 1.7% away from the experimental one!
- MEC brings the theory closer to experiment!
- No dependence on the cutoff!

$|GT|^{JISP16}(^{6}He)=2.198(7)$
$|GT|^{exp}(^{6}He)=2.161(5)$

Vaintraub, Barnea, **DG**, Phys. Rev. C, **79** 065501 (2009).

^{6}He β decay and a hint to heavier nuclei

- The inclusion of χEFT based MEC is helpful, even when one uses phen. interaction.
- The need of χEFT based MEC is observed in μ capture on light nuclei.

  DG, Phys. Lett. **B666**, 472 (2008),
  Marcucci et al., Phys. Rev. C 83, 014002 (2011).

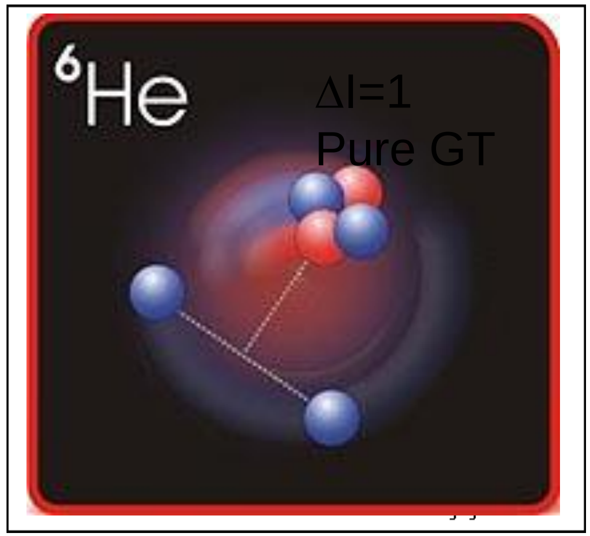
- The conclusion is that the weak correlations inside the nucleus can lead to (at least part of) the observed suppression.
- Going to heavier nuclei demands approximations.

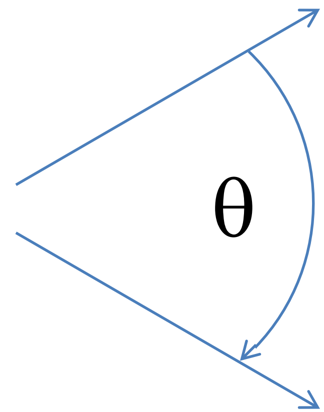
Intermission: β-decay and fundamental symmetries

^{6}Li
daughter nucleus

$$dW \propto a\xi\left(\frac{p_e}{E_e}\cos\theta\right)$$

$$dW_{SM}(^6He) \propto -\frac{1}{3}\left(\frac{p_e}{E_e}\cos\theta\right)$$





e⁻ Electron

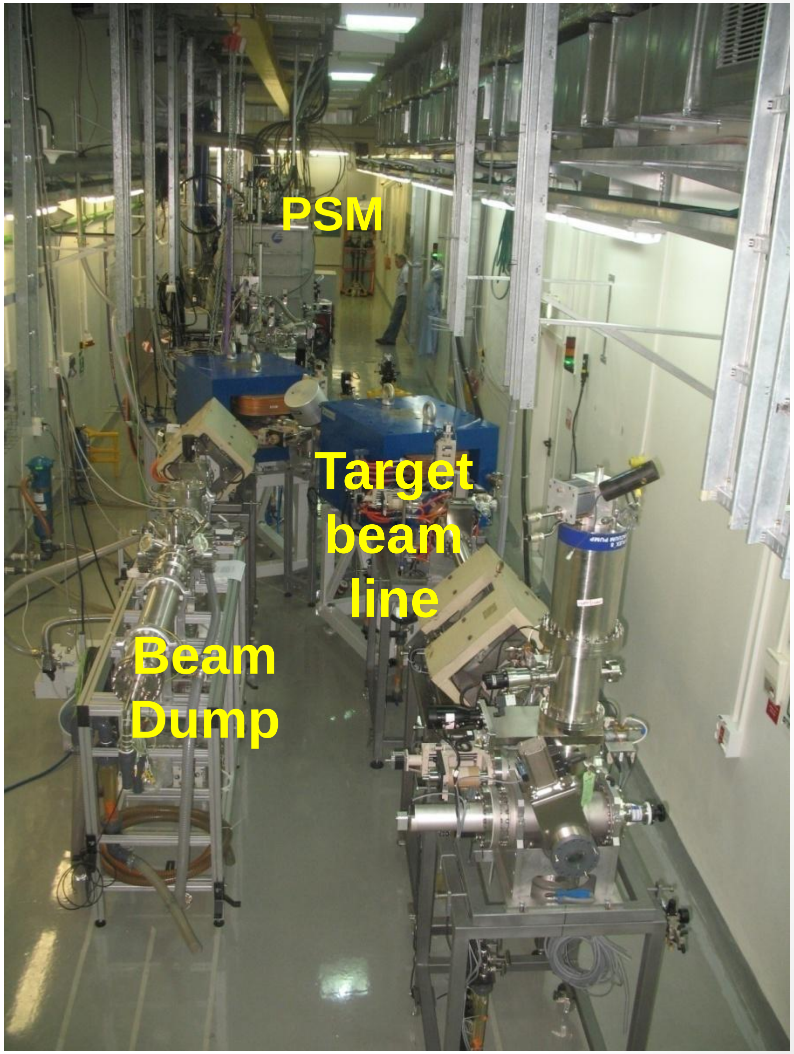
$\bar{\nu}_e$ Electron
anti-neutrino

$$^6He \rightarrow {}^6Li + e^- + \bar{\upsilon}_e$$

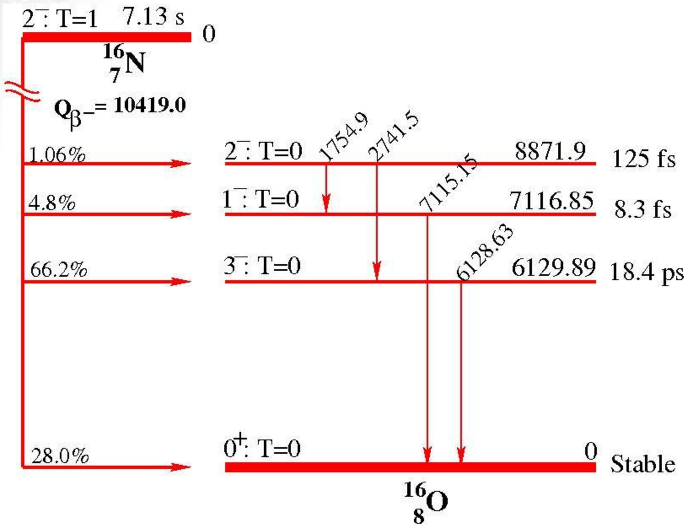
- Theoretical input needed!
- ^{6}He produced using a BeO target – enormous yield @ SARAF

SARAF Phase I
@
Soreq Center - Israel

- Commissioning of Phase-I is approaching finalization
- 1 mA CW proton beam has been accelerated up to an energy of 3.7 MeV
- Low duty cycle (~0.2 mA) deuteron beam has been accelerated up to an energy of 4.3 MeV
- Phase-II – up to 40 MeV (2015)



The case of ^{16}N



Pure E2 transition:

1. No MEC contribution – pinpointing suppression origin
2. Different β–ν correlation properties!

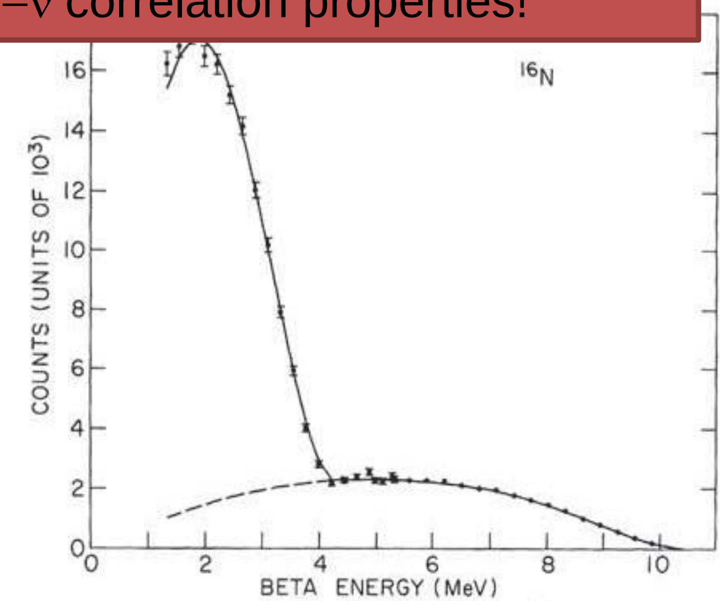
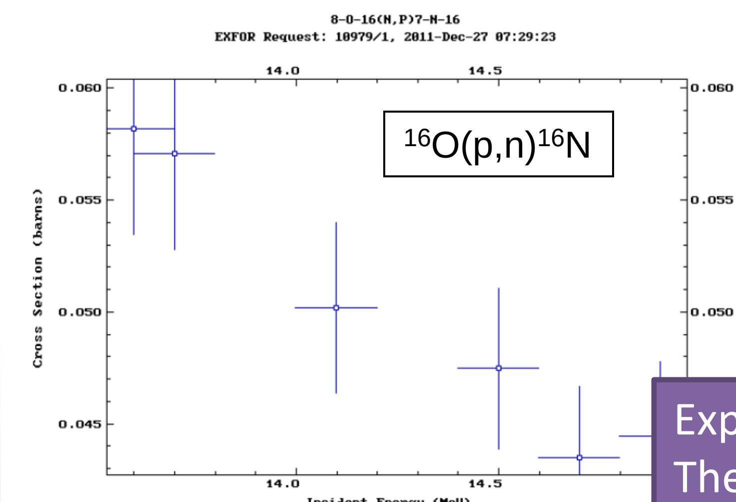


FIG. 1. Beta-ray spectrum for $^{16}N(\beta^-)^{16}O$. The data are from Ref. 1. The least squares fit assumed four branches to ^{16}O levels at 0, 6.13, 7.12, and 8.87 MeV and the intensities of the branches to these levels were varied. For the fit shown the uncertainties assigned to the data were adjusted so that the normalized χ^2 was unity. The shape factor for the g.s. branch was fixed at the unique value.

^{16}N is produced simultaneously with ^{6}He, and with a comparable yield, in the BeO target



Experiment: Hass, Vaintraub (2013)
Theory: DG (2012) in preparation.
Vary, DG, Maris, Schwenk, WIP

TO MEDIUM-HEAVY NUCLEI LAND

Effective 2-body current

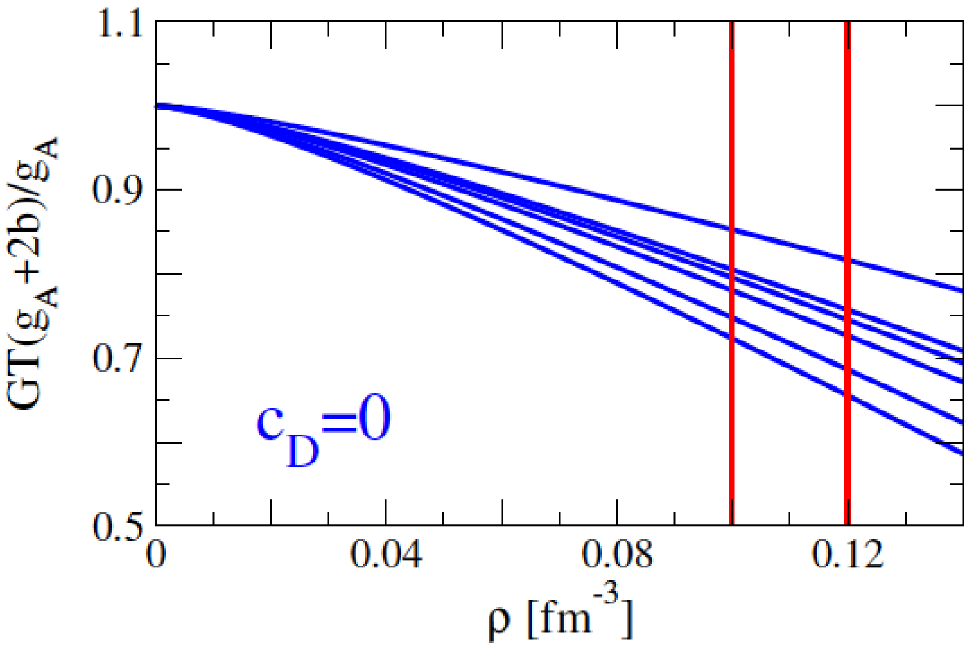
- The normal-ordered two-body currents are, neglecting (small) tensor-like terms

$$J^{eff}_{n,2b} = - g_A \sigma_n \tau_n^- \frac{\rho}{m_N f_\pi^2} F(\rho, c_3, c_4, c_D, p)$$

Menendez, DG, Schwenk, Phys. Rev. Lett. **107**, 062501 (2011)

Long range GT and quenching

At $p = 0$ and $c_D = 0$ (long-range part of the currents only)
2B currents suppress 1B currents by $q = 0.85 \ldots 0.66$



- For density ρ consider the general range $0.10 \ldots 0.12$ fm^{-3}
- Couplings c_3, c_4 taken from NN potentials

Entem et al. PRC68 041001(2003)
Epelbaum et al. NPA747 362(2005)
Rentmeester et al. PRC67 044001(2003)
$\delta c_3 = -\delta c_4 \approx 1$ GeV^{-1}

$\Rightarrow$ Long-range 2B currents predict g_A quenching

Menendez, DG, Schwenk, PRL **107**, 062501 (2011)

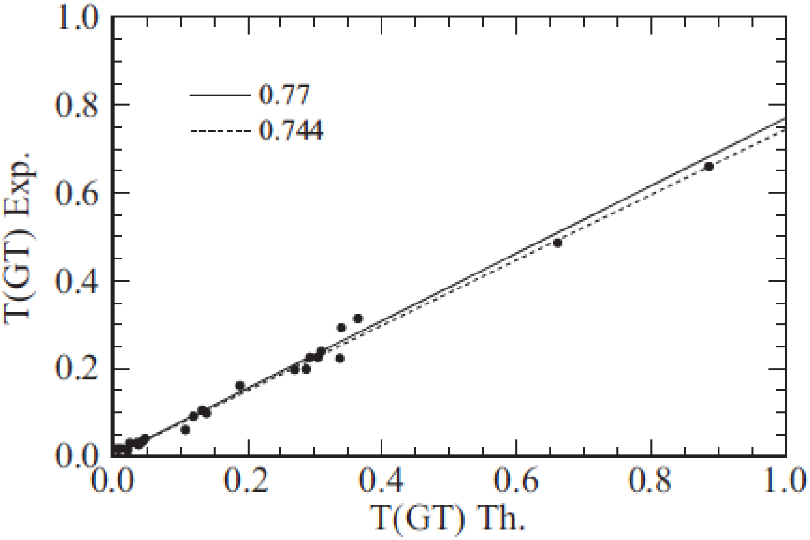
Short range contributions to GT and quenching

Short-range part (c_D) not so well-known
⇒ Adjust c_D according to the empirical quenching required in Gamow-Teller transitions
⇒ compare to c_D values obtained by 3N fits

Extreme scenario (big quenching)

2B currents cause all g_A quenching suggested by theoretical calculations $g_A^{\mathrm{eff}} = q g_A$ due to the operator

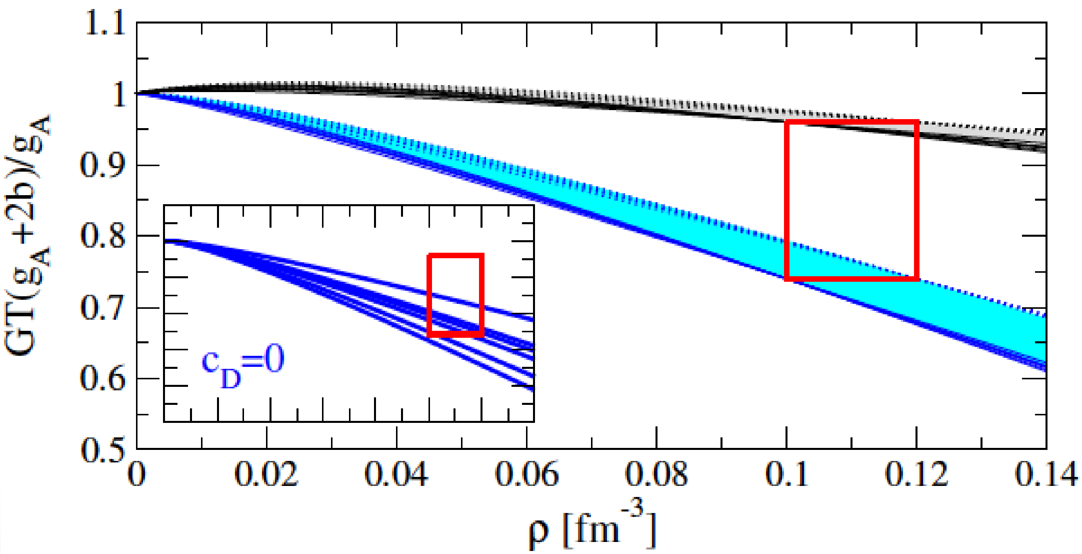
⇒ contribution of the 2B currents
$q = 0.74$



Short range contributions to GT and quenching

We use $q = 0.74$ and $q = 0.96$ to constrain c_D

Allowed c_D lead to q values that lie inside the box



Menendez, DG, Schwenk, PRL **107**, 062501 (2011)

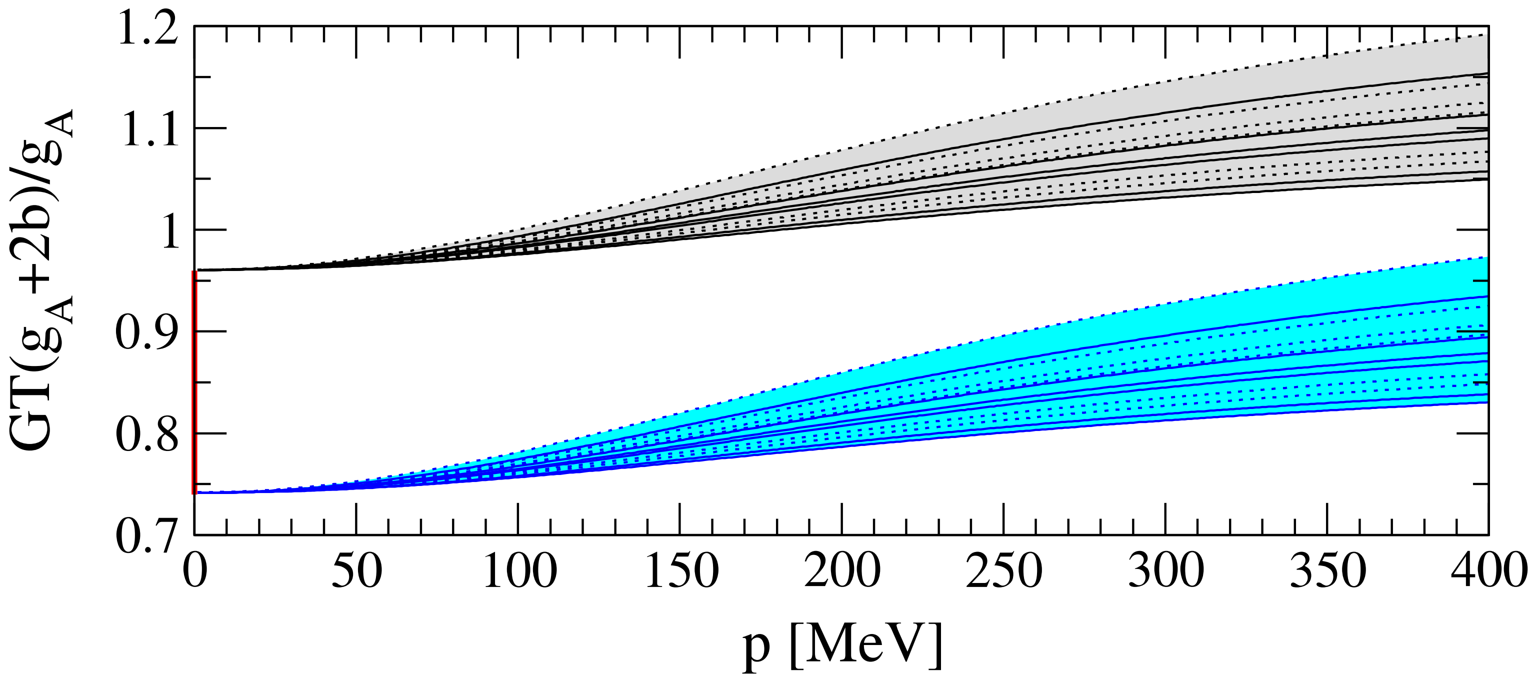
Using EM c_i's, $-0.3 \leq c_D \leq -0.1$ from ^{3}H BE and β decay fit favors empirical quenching

c_D values from fits to ^{3}H BE and ^{4}He radius also compatible with empirical quenching

Small quenching $q = 0.96$ cannot be ruled out compatible with ^{3}H BE, ^{4}He radius fits in some cases (not EM)

GT p dependence

The $\sigma\tau^-$ term, when two-body currents are included, depends on transferred momentum p through the $\frac{2}{3} c_3 \frac{\mathbf{p}^2}{4m_\pi^2+\mathbf{p}^2}$ term

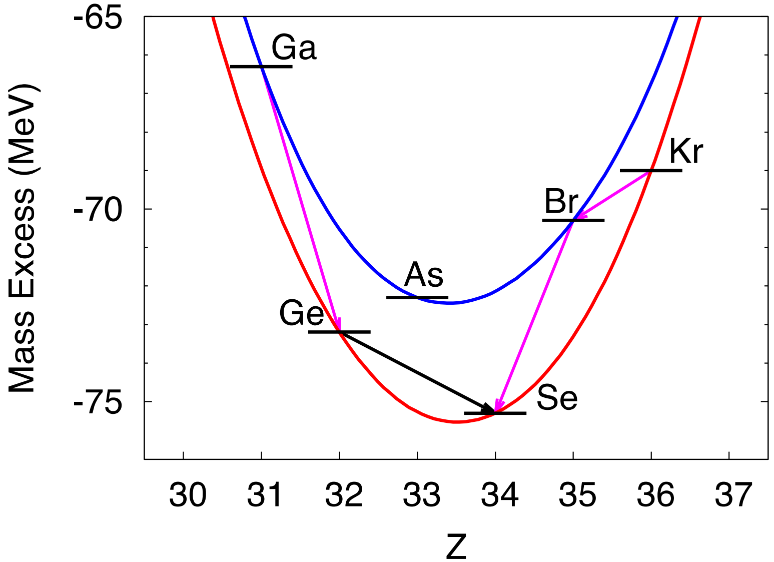


Quenching gets weaker at $p \neq 0$

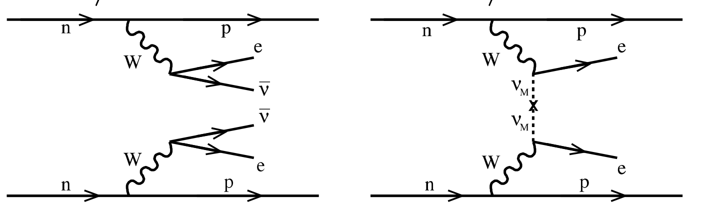
Menendez, DG, Schwenk, PRL **107**, 062501 (2011)

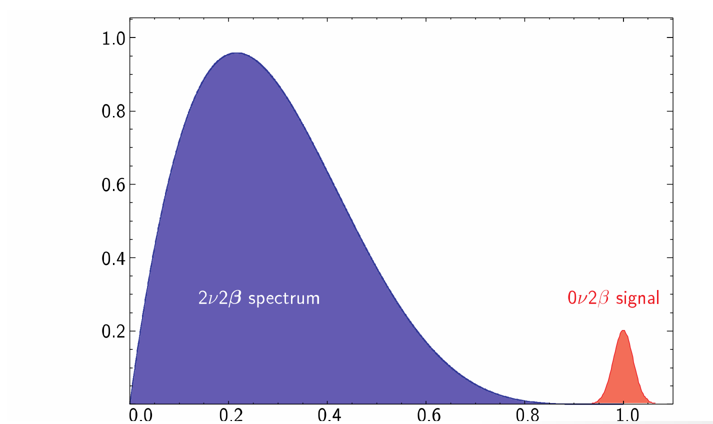
Neutrino-less double beta decay

- Double β-decay only appears when regular β-decay is energetically forbidden or hindered by large J difference.



$T_{1/2}^{2\nu\beta\beta} \gtrsim 10^{19}$ y $\qquad T_{1/2}^{0\nu\beta\beta} > 10^{25}$ y





Neutrino-less double beta decay

- *0νββ* decay needs also massive Majorana neutrinos ➔ detection would prove Majorana nature of neutrinos.

$$\left(T_{1/2}^{0\nu\beta\beta}\left(0^+ \rightarrow 0^+\right)\right)^{-1} = G_{01}\left|M^{0\nu\beta\beta}\right|^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

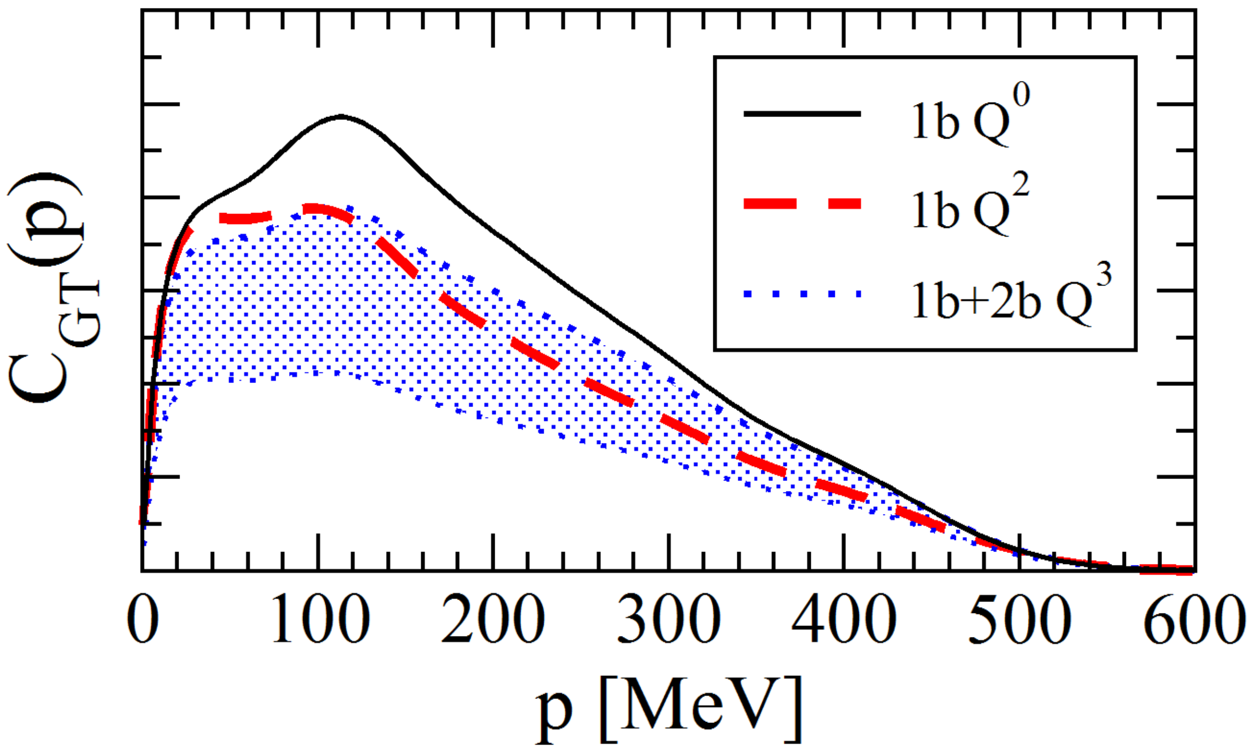
$$m_{bb} = \left| å_{k} U_{ek}^2 m_k \right|$$

Nuclear Matrix element, biggest uncertainty due to g_A: $T_{1/2}^{0nbb}$ µ g_A^{-4}
Relevant momentum transfer: $p \sim 100 MeV$.

Common debate:
Is g_A quenched at these momenta?

relevant *p* for *0νββ* ME

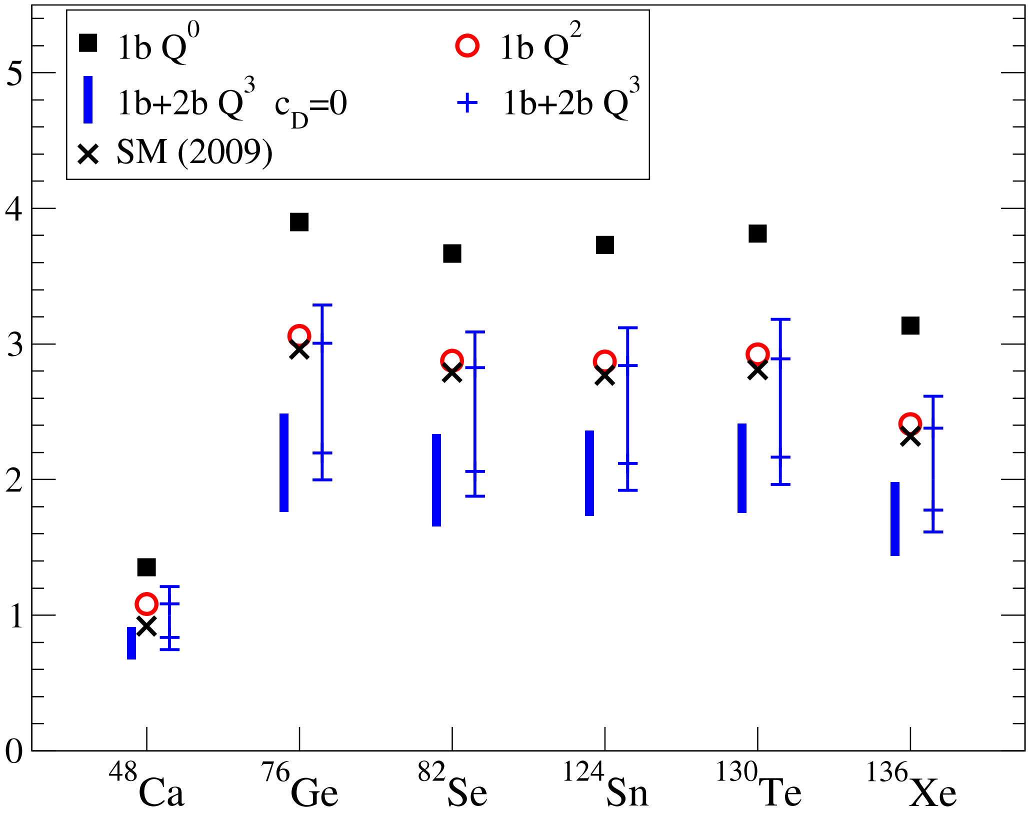
Check transferred momenta p □ $m_{□}$ dominate the NME,
true at different orders Q in the calculation



where $M^{0\square\beta\beta} = {}_{0}^{R_1} \; C(p)dp$

Menendez, DG, Schwenk, Phys. Rev. Lett. **107**, 062501 (2011)

ME predictions



Order Q^2 similar to phenomenological curren

Long-range Q^3 predicts NME $\sim$ 35% reduction
They are order Q^2 in Chir EFT with explicit Deltas

Effect of 2B currents Q^3 ranges from +10% to -35% of the NME
(Smaller than -45% expected by $q^2 = 0.74^2$ due to $p \neq 0$)

Menendez, DG, Schwenk, Phys. Rev. Lett. **107**, 062501 (2011)

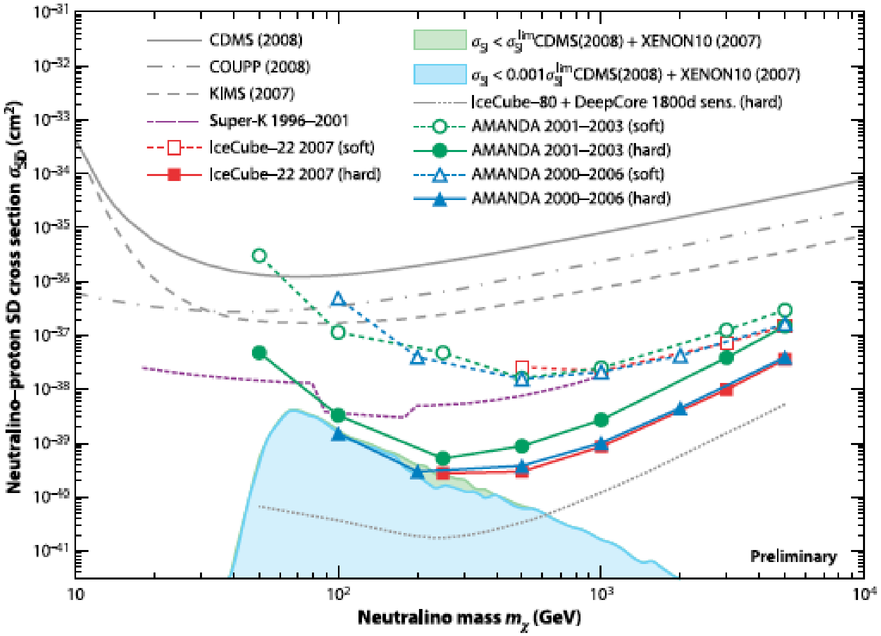
Conclusions for $0\nu\beta\beta$ ME

- 2B currents modify Gamow-Teller ($\sigma\tau^{-}$) term
  - The long range 2B currents predict g_A quenching
  - p dependence of the quenching is also predicted
- Nuclear Matrix Elements for $0\nu\beta\beta$ decay modified $-35\ldots10\%$ by chiral 2B currents

Spin-dependent WIMP scattering on nuclei

- More than 20% of the energy density of the Universe is understood as dark matter.
- Promising candidates are WIMPs, such as neutralinos.
- This has spurred direct detection of cold dark matter via elastic scattering off nuclei, requiring detailed knowledge of the response to WIMP induced currents in nuclei.
- This presents a challenging problem, because even if the coupling of to quarks is known, it needs to be evaluated at the nucleus level in the nonperturbative regime of quantum chromodynamics
- Chiral EFT provides an ideal theoretical framework since the typical momentum transfers in direct dark matter detection are of the order of 100 MeV/c.

Dark matter



Feng ARAA48 495 (2010)

Indirect evidence ⇒ challenge is direct detection of Dark Matter

Put big amount of material (like in $0\nu\beta\beta$ decay), search WIMP-matter signal WIMP-nucleus signal!

WIMP-nucleus scattering

- At low energies:

Spin dependent

$$\mathcal{L} = \chi\gamma_\mu\gamma_5\chi\mathcal{J}_5^\mu(x) + \chi\chi\mathcal{S}(x)$$

Spin independent

- Spin dependent:

$$\mathcal{L} = -\frac{G_F}{\sqrt{2}}\overline{\chi}\gamma\gamma_5\chi \cdot \sum_q A_q\overline{\psi}_q\gamma\gamma_5\psi_q$$

- When moving to the nucleon level:

$$\sum_q A_q\overline{\psi}_q\gamma\gamma_5\psi_q \longrightarrow \sum_{i=1}^{A} \mathbf{J}_{i,1\mathrm{b}} = \sum_{i=1}^{A}(\mathbf{J}^0_{i,1\mathrm{b}} + \mathbf{J}^3_{i,1\mathrm{b}})$$

$$= \sum_{i=1}^{A} \frac{1}{2}\left[a_0\,\boldsymbol{\sigma}_i + a_1\tau_i^3\left(\boldsymbol{\sigma}_i - \frac{g_P(p^2)}{2mg_A}(\mathrm{p}\cdot\boldsymbol{\sigma}_i)\mathrm{p}\right)\right],$$

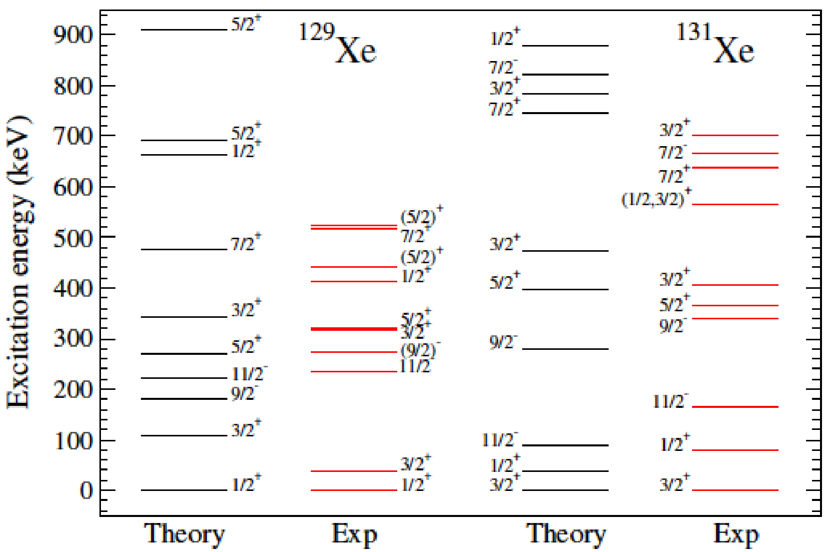
Isoscalar Isovector

- In the nucleus level the isovector part has 2b corrections – identical to the weak current!

Spin dependent WIMP scattering

For spin-dependent WIMP scattering off nuclei

$$\frac{d\sigma}{dp^2} = \frac{8G_F^2}{(2J+1)v^2} S_A(p), \quad S_A(p) = \sum_L \left(|\langle J || \mathcal{T}_L^{\mathrm{el}\,5}(p) || J \rangle|^2 + |\langle J || \mathcal{L}_L^5(p) || J \rangle|^2 \right)$$



Isotopes ^{129}Xe and ^{131}Xe for liquid Xenon detectors, which provide most stringent experimental limits

Calculations in the $0g_{7/2}$, $1d_{3/2}$, $1d_{5/2}$, $2s_{1/2}$ and $0h_{11/2}$ valence space using the gcn.5082 interaction

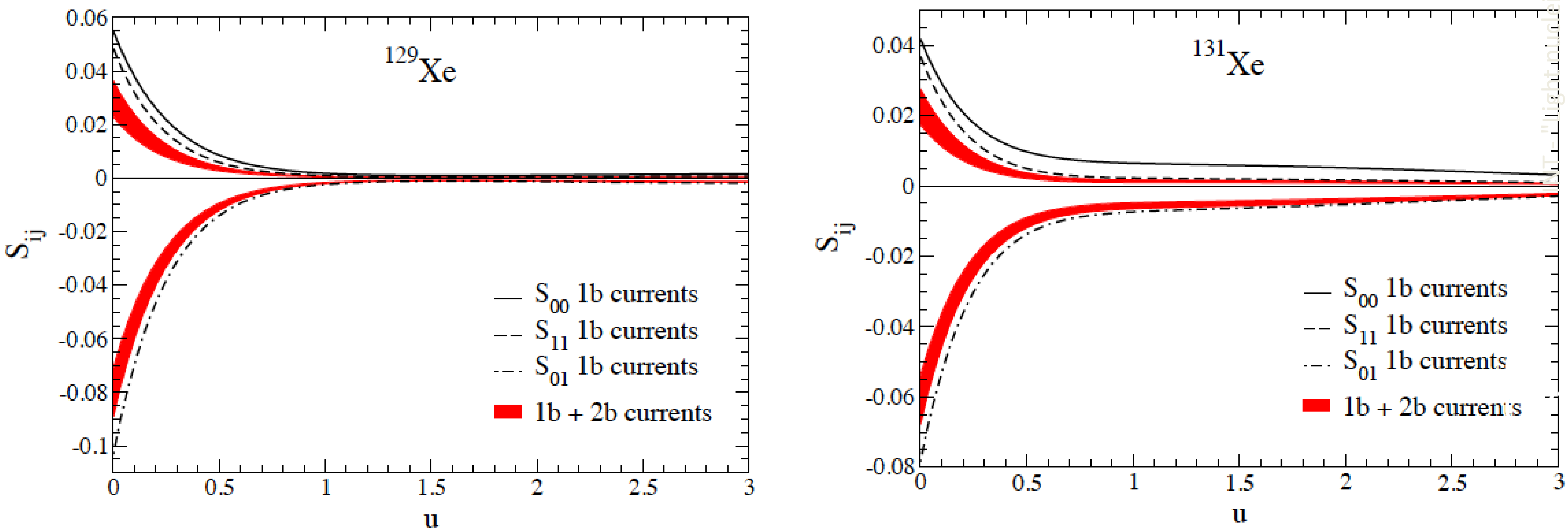
Menendez, DG, Schwenk, PRD (in press) **1012.1094** (2012)

Spin dependent WIMP scattering

$$S_A(p) = \sum_{L\,\mathrm{odd}} \left(\left| \langle J || \mathcal{T}_L^{\mathrm{el}\,5}(p) || J \rangle \right|^2 + \left| \langle J || \mathcal{L}_L^5(p) || J \rangle \right|^2 \right)$$

$$S_A(p) = a_0^2\, S_{00}(p) + a_0 a_1 S_{01}(p) + a_1^2\, S_{11}(p)$$

$$u = p^2 b^2 / 2$$



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- How to participate
- Info for Organizers
- Program archive

- Visitor Info
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- Jobs
- People
- About Us
- Friends of the INT
- NAC
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- Safety

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2012 Programs

Light Nuclei from First Principles (INT-12-3)
September 17 - November 16, 2012
N. Barnea, D. Lee, L. Platter

2013 Programs

Computational and Theoretical Advances for Exotic Isotopes in the Medium Mass Region (INT-13-1a)
March 25 - April 19, 2013
C. Barbieri, T. Duguet, G. Hagen, S. Bogner

Quantum Noise (INT-13-1b)
May 6 - May 31, 2013
A. Andreev, L. Glazman, D.B. Kaplan

Advances in Quantum Monte Carlo Techniques for Non-Relativistic Many-Body Systems (INT-13-2a)
June 24 - August 2, 2013
F. Pederiva, F. Arias de Saavedra, J. Drut, J. DuBois, S. Gandolfi

Nuclei and Fundamental Symmetries: Theory Needs of Next-Decade Experiments (INT-13-2b)
August 5 - August 30, 2013
D. Gazit, W. Haxton, A. Schwenk, N. Tolich

Quantitative Large Amplitude Shape Dynamics: Fission and Heavy Ion Fusion (INT-13-3)
September 23 - November 15, 2013
G.F. Bertsch, W. Nazarewicz, A.N. Andreyev, W. Loveland

INT "Light nuclei from first principles"

Summary

Constrain the Nuclear interaction and structure.

Extract microscopic information about the fundamental theory and its symmetries.

Using χPT to calculate weak reactions with nuclei can be useful to:

Predict in-medium evolution of nuclear properties.

Probe the limits of the standard model.

Nuclear theory is in the process of building a unified fundamental understanding of reactions and structure,
which can shed light on many physical mysteries.

Collaborators

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Sofia Quaglioni

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Michael Hass, Sergey Vaintraub

James Vary, Pieter Maris

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