TRIUMF

Progress in Ab Initio Techniques in Nuclear Physics
February 23-26, 2016
TRIUMF, Vancouver, BC, Canada

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

Precision predictions of pionless EFT and fine tuning in chiral EFT

Doron Gazit
Racah Institute of Physics
Hebrew University of Jerusalem

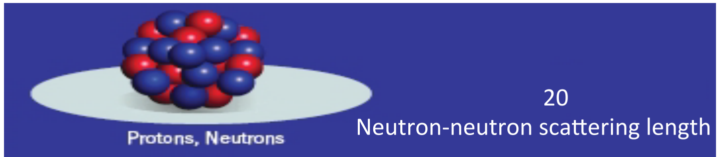
In collaboration with: ***Hilla De-Leon,*** *Johannes Kirscher, Sergiu Lupu*, Nir Barnea (HUJI).

Thanks: Lucas Platter, Bira van Kolck, Francesco Pederiva, Bezalel Bazak, Sebastian König.

Two QCD EFTs

$\not{\pi}$EFT

- <u>Large scattering length:</u> *Nucleons interacting via contact interactions* -- Efimov dominates 3-body problem, and power counting
- <u>Origin</u>: *low-energy QCD accidentally close to unitarity.*
- Very low energies ➔ very light nuclei & low-energy reactions.
- **allows a different approach to assess theoretical uncertainty:**
  - **Renormalizable QFT at LO and NLO – showing cutoff independence, with almost no power counting issues**
  - **Can be expanded about different momenta – few variations of the EFT**
  - **Few LECs, i.e., $\not{\pi}$EFT is not a statistical optimization problem.**

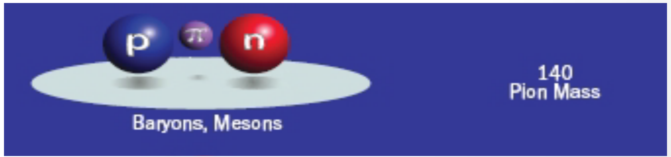


χEFT

- <u>Pion dominated theory:</u> *Nucleons interacting via pion exchanges and contacts.*
- <u>Origin</u>: *Standard Model broken chiral symmetry* $SU(2)_R xSU(2)_L$
- Wide range of applications.
- <u>A main challenge</u>:

multivariable systematic uncertainty quantifications in a non-renormalizable theory:

  - Statistical optimization
  - Bayesian
  - Order by order



$\not{\pi}$EFT and χEFT are both EFTs of the nuclear regime at low energy

a) Can we learn something useful from $\not{\pi}$EFT and apply it to χEFT?

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

b) Can one observe regulator/space dependence in $\not{\pi}$EFT, as in χEFT?

Kirscher, DG, Phys Lett B **755**, 253 (2016)

c) Use $\not{\pi}$EFT to calculate reactions and compare with χEFT, to get improved uncertainty estimate: **first $\not{\pi}$EFT calculation of ^{3}H beta decay** (@NLO), and a precision calculation of **proton-proton fusion in the Sun**.

De-Leon, DG, in prep., **see Hilla De-Leon's poster.**

d) A very interesting confirmation of Lattice QCD as well as $\not{\pi}$EFT consistency check:
first $\not{\pi}$EFT calculation of ^{3}H, ^{3}He, ^{2}H magnetic moments and n+p→d+γ (@NLO), and comparison to the **NPLQCD calculation of 2 nucleons in a magnetic field (Beane et al PRL** 115, 132001 (2015))

De-Leon, DG, in prep..

$\not\pi$EFT and χEFT are both EFTs of the nuclear regime at low energy

a) Can we learn something useful from $\not\pi$EFT and apply it to χEFT?

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

b) Can one observe regulator/space dependence in $\not\pi$EFT, as in χEFT?

Kirscher, DG, Phys Lett B **755**, 253 (2016)

c) Use $\not\pi$EFT to calculate reactions and compare with χEFT, to get improved uncertainty estimate: **first $\not\pi$EFT calculation of ^{3}H beta decay** (@NLO), and a precision calculation of **proton-proton fusion in the Sun**.

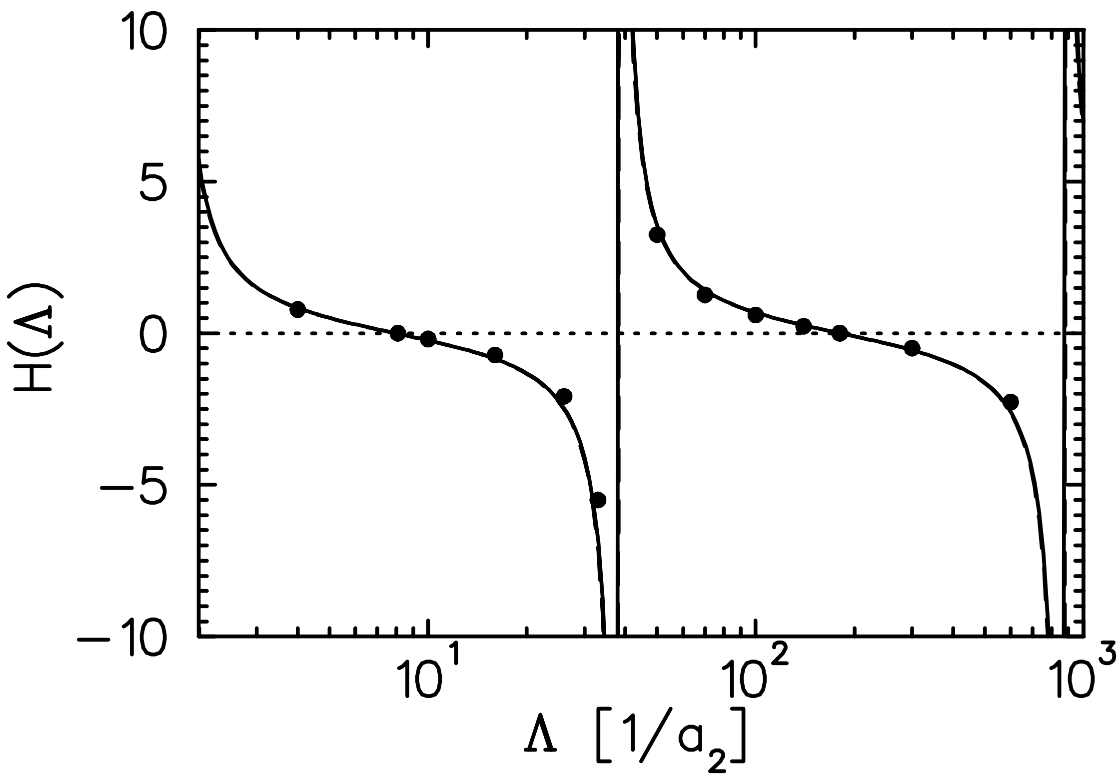
De-Leon, DG, in prep., **see Hilla De-Leon's poster.**

d) A very interesting confirmation of Lattice QCD as well as $\not\pi$EFT consistency check:
first $\not\pi$EFT calculation of ^{3}H, ^{3}He, ^{2}H magnetic moments and n+p→d+γ (@NLO), and comparison to the **NPLQCD calculation of 2 nucleons in a magnetic field (Beane et al PRL** 115, 132001 (2015))

De-Leon, DG, in prep..

π̸EFT @ LO

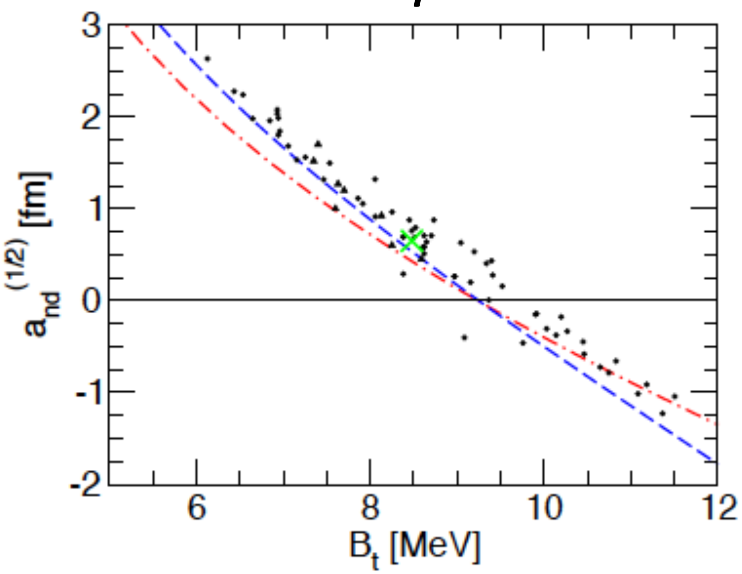
Bedaque, Hammer, van-Kolck: (1999)
triton B.E. at LO has strong cutoff dependence → add 3-body contact at LO



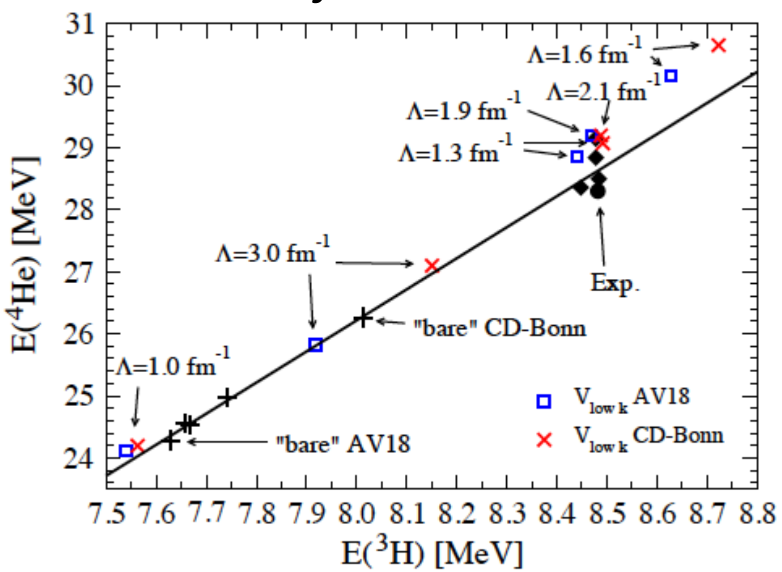
$\not\pi$EFT – and Correlations in light nuclei

- No 4 body parameter at LO.
- One 3b force – one line!
- Tjon/Phillips correlation originate in Efimov physics.

Phillips line



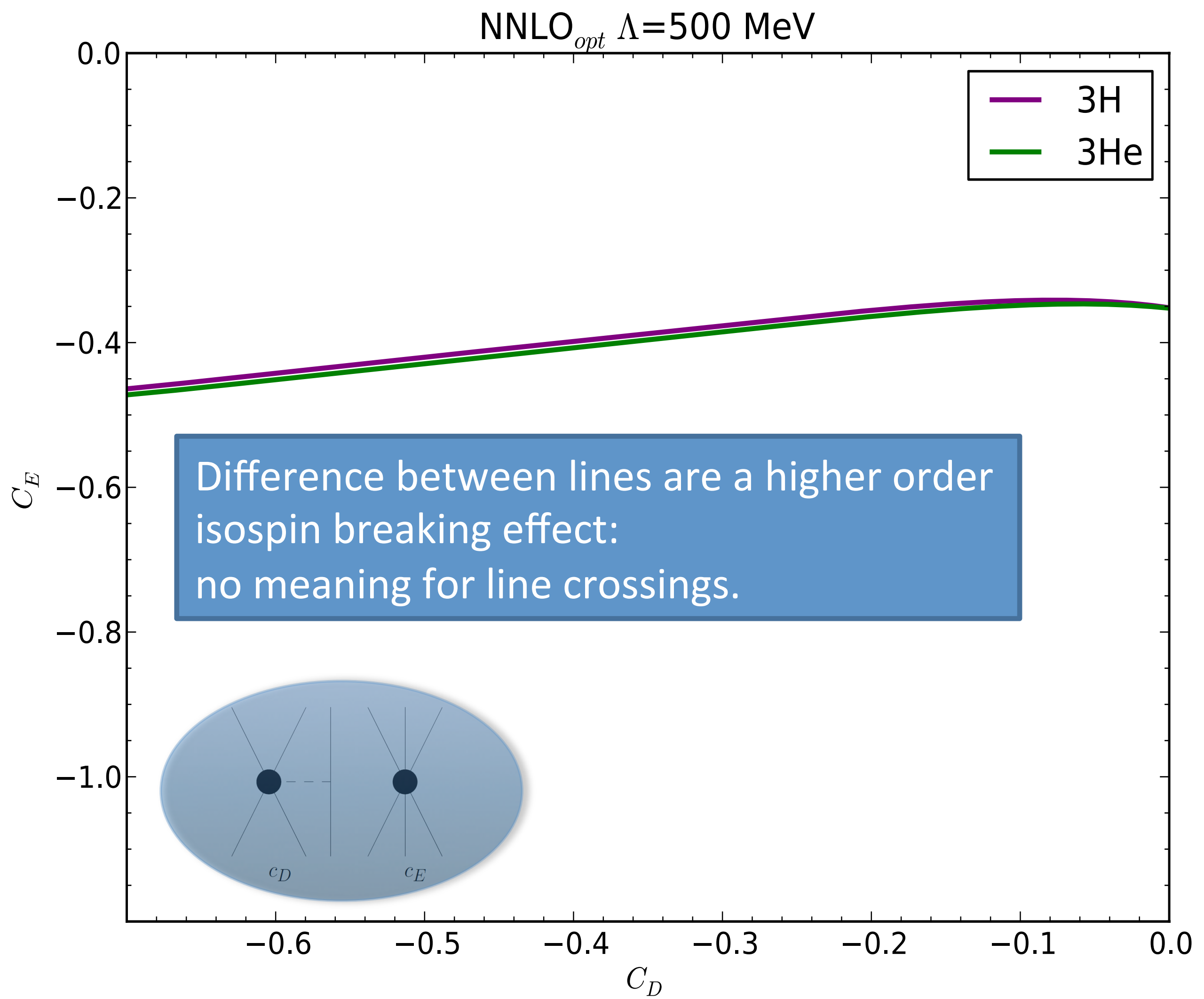
Tjon line



Platter (2006), Platter, Hammer, Meissner (2005), Kirscher, Griesshammer, Hofmann (2007)

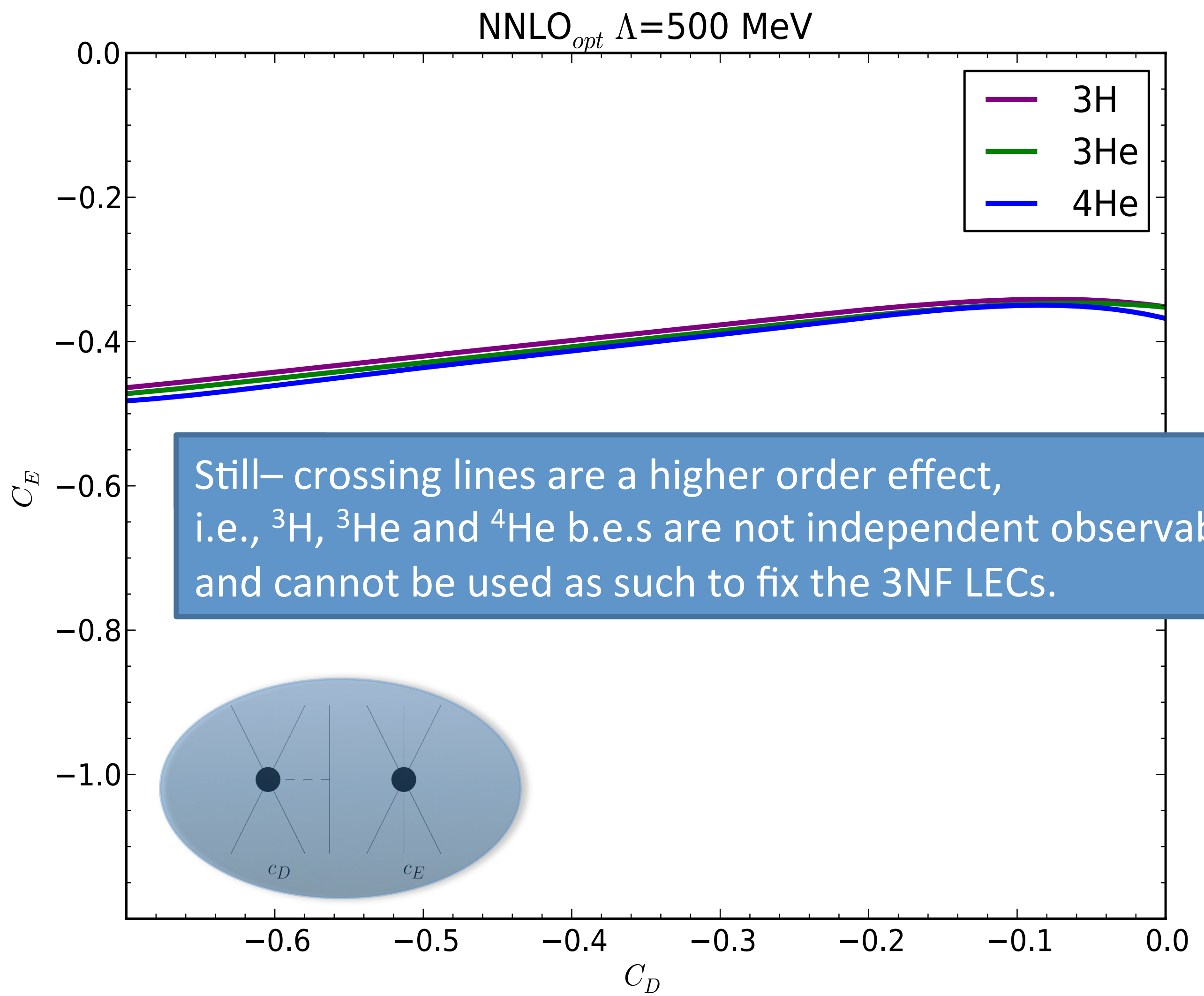
Nogga, Bogner, Schwenk (2005)

χEFT – three body problem in the (c_D, c_E) plane.



Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

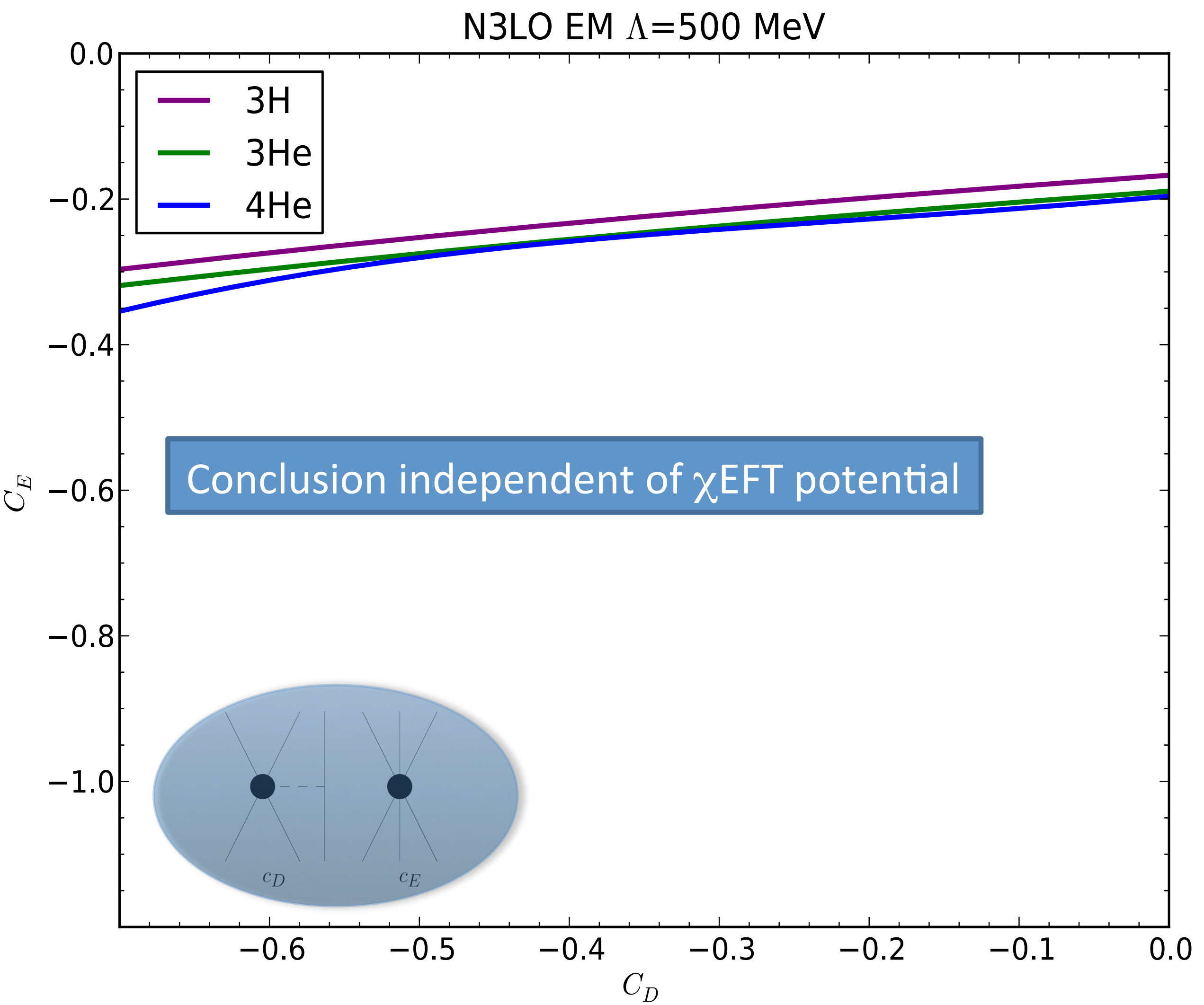
χEFT – a Tjon line representation



Still– crossing lines are a higher order effect,
i.e., ^{3}H, ^{3}He and ^{4}He b.e.s are not independent observables,
and cannot be used as such to fix the 3NF LECs.

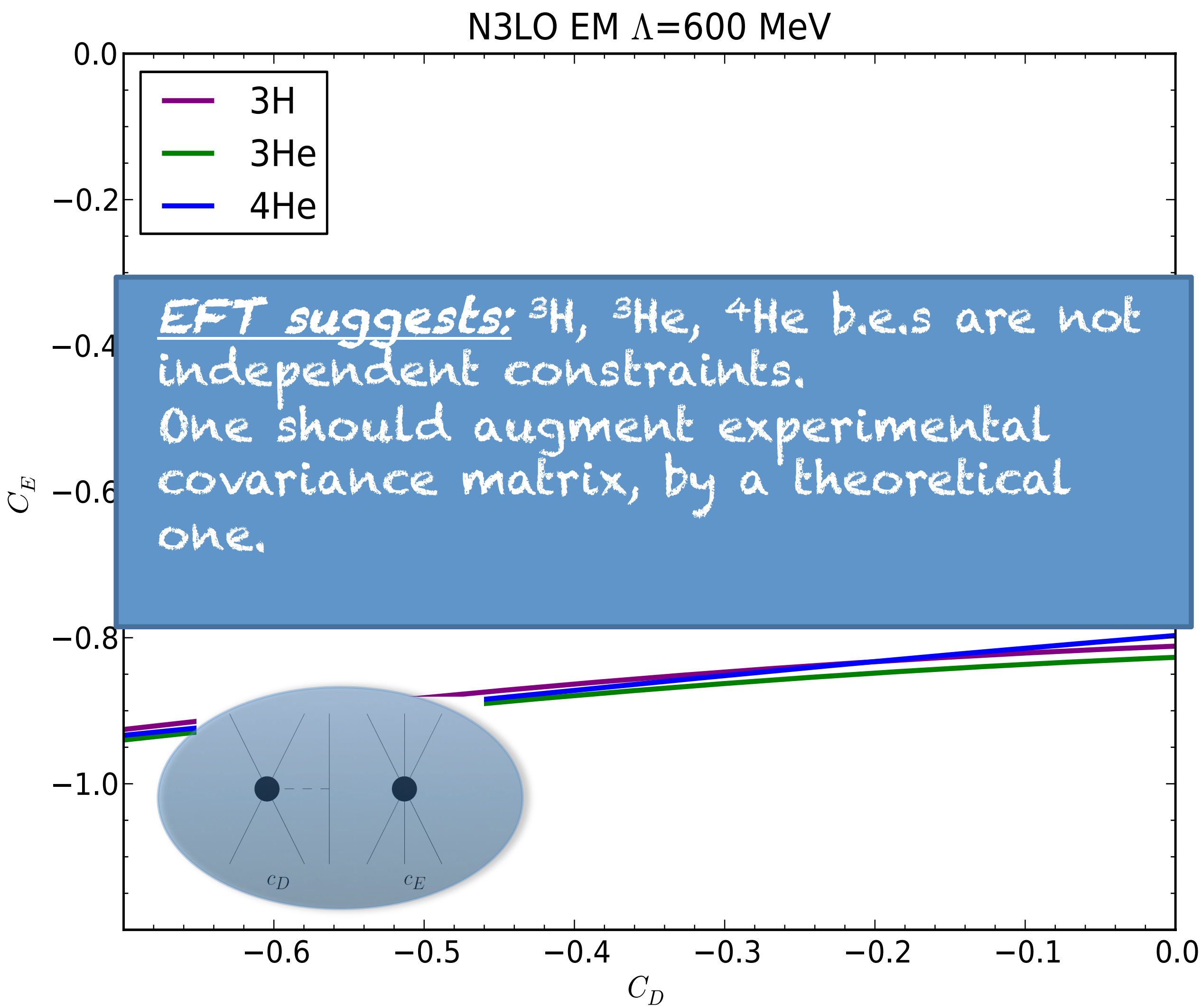
Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – a Tjon line representation



Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – a Tjon line representation

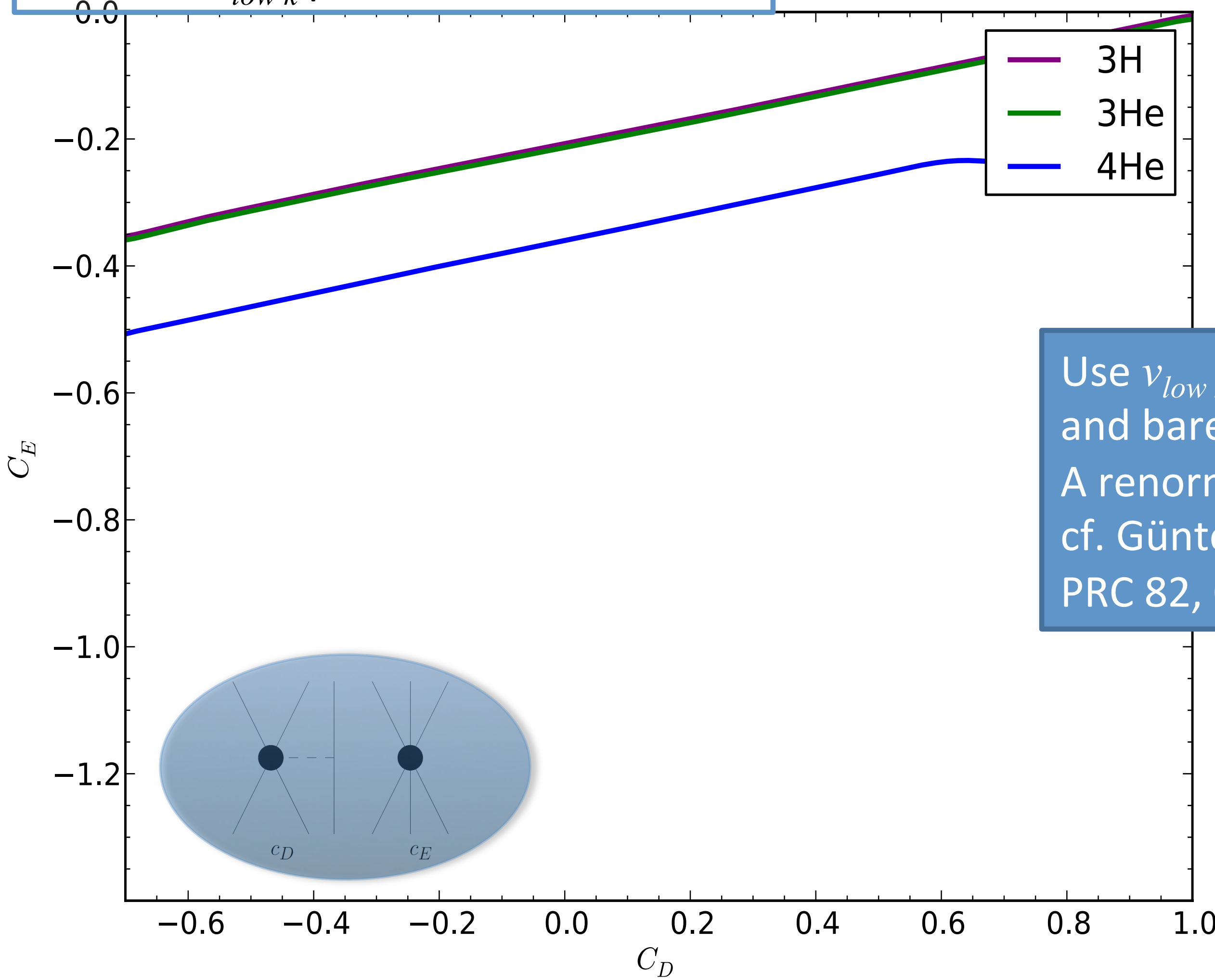


EFT suggests: ^{3}H, ^{3}He, ^{4}He b.e.s are not independent constraints.
One should augment experimental covariance matrix, by a theoretical one.

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – RG evolved potential

Different $v_{low\,k}$ potentials: Λ=1.6 fm^{-1}

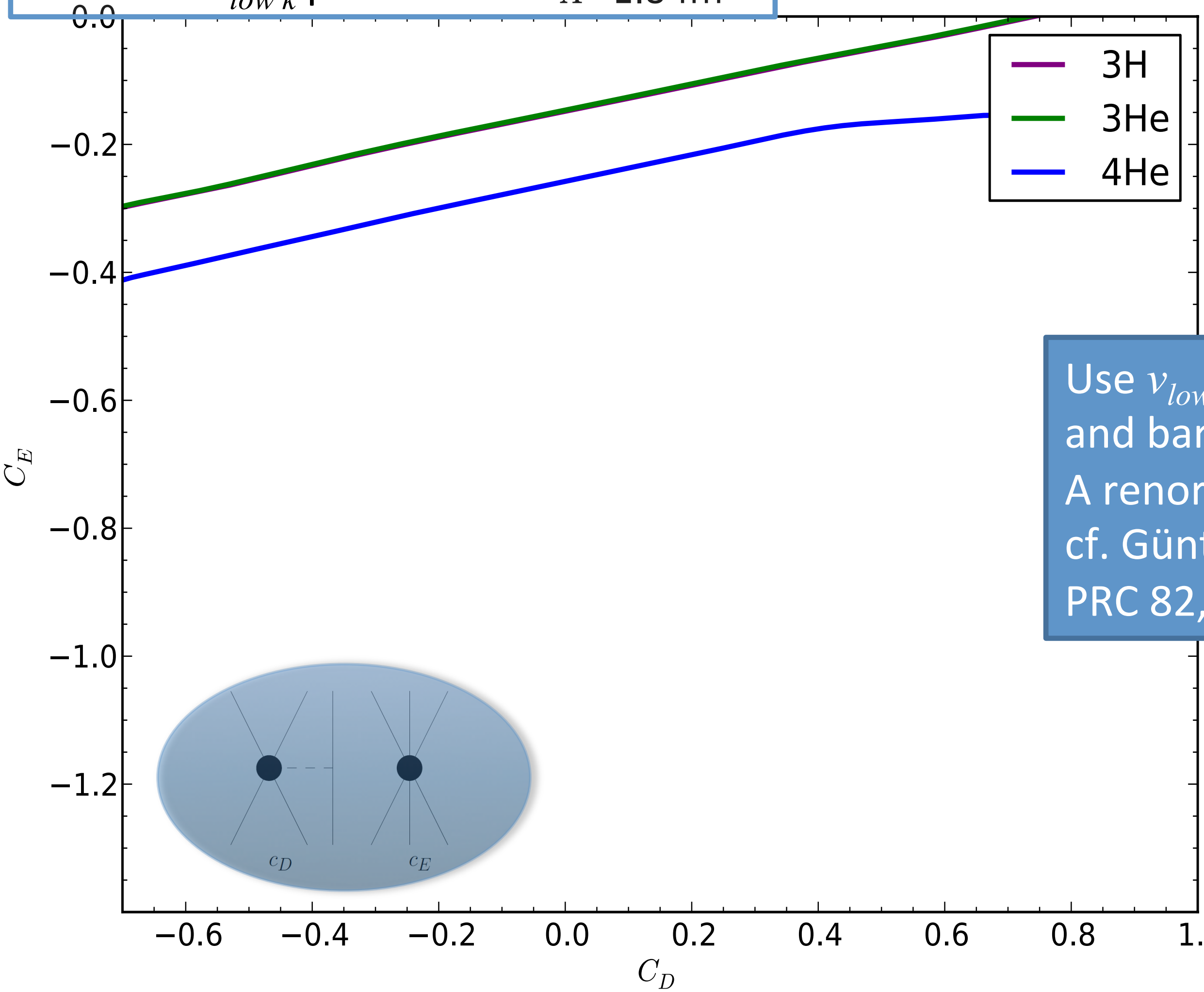


Use $v_{low\,k}$ for 2-body, and bare for 3NF –
A renormalization of cE?
cf. Günter et al
PRC 82, 024319 (2010)

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – RG evolved potential

Different $v_{low\ k}$ potentials: Λ=1.8 fm^{-1}

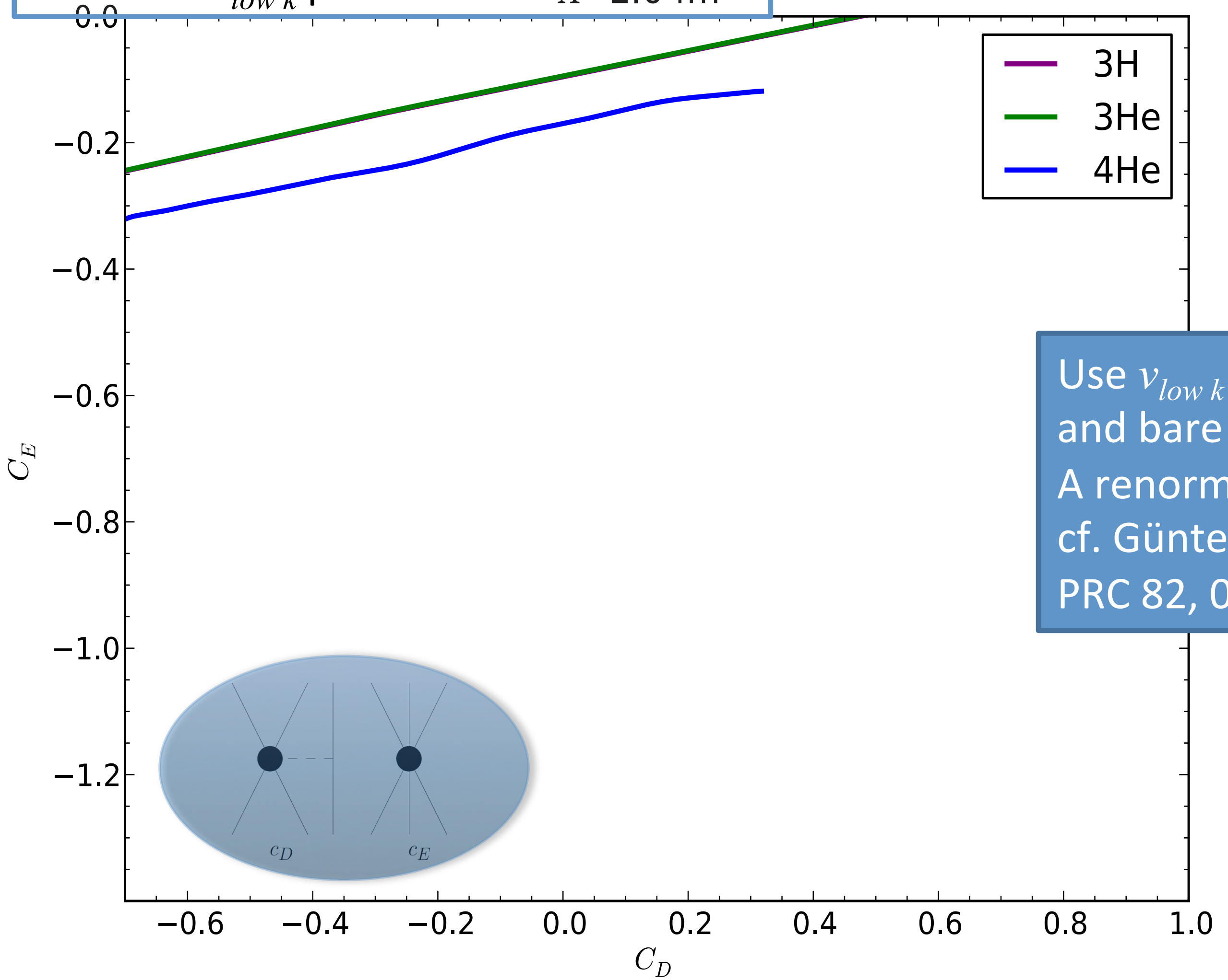


Use $v_{low\ k}$ for 2-body, and bare for 3NF –
A renormalization of cE?
cf. Günter et al
PRC 82, 024319 (2010)

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – RG evolved potential

Different $v_{low\ k}$ potentials: Λ=2.0 fm^{-1}

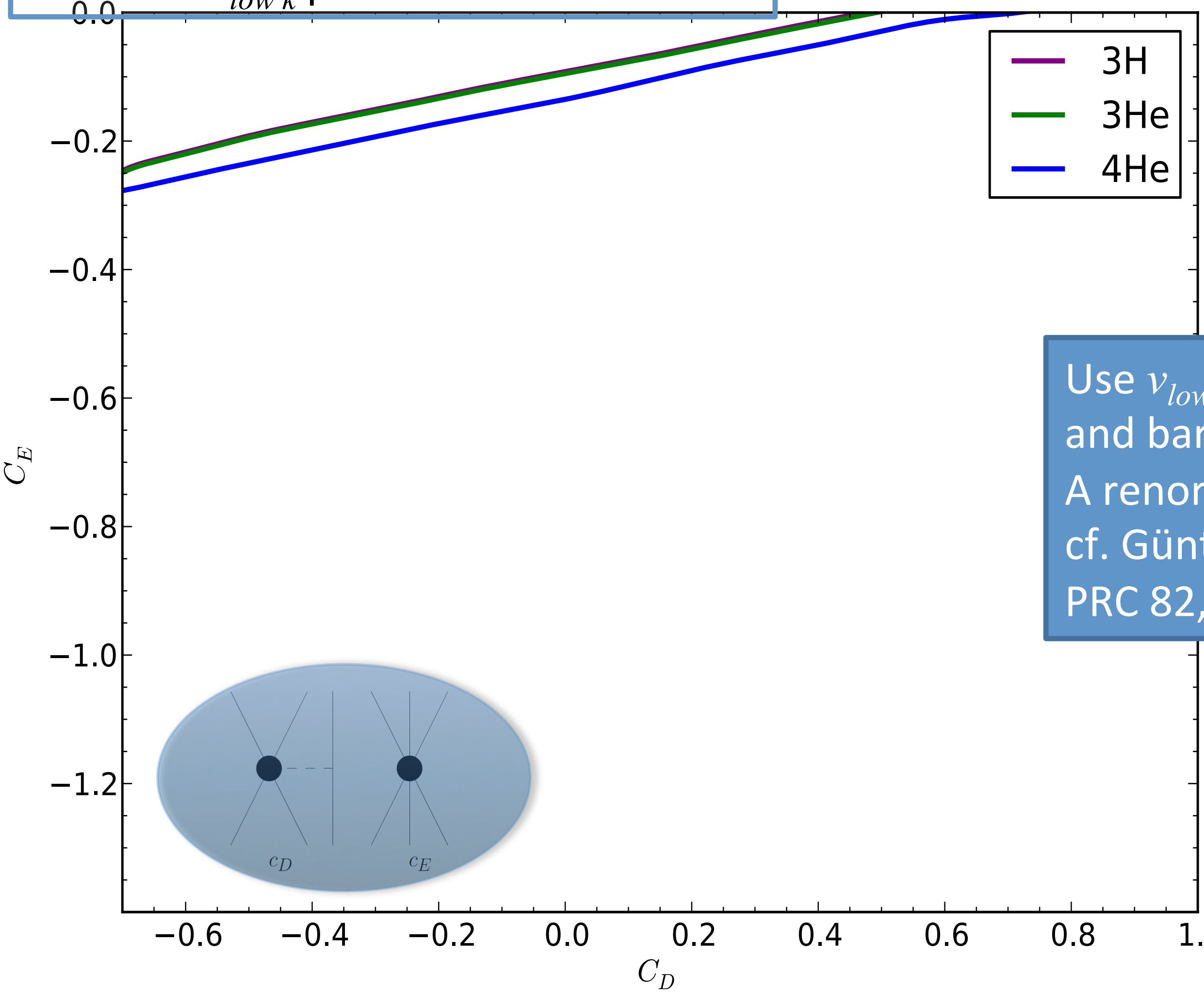


Use $v_{low\ k}$ for 2-body, and bare for 3NF –
A renormalization of cE?
cf. Günter et al
PRC 82, 024319 (2010)

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – RG evolved potential

Different $v_{low\ k}$ potentials: Λ=2.2 fm^{-1}

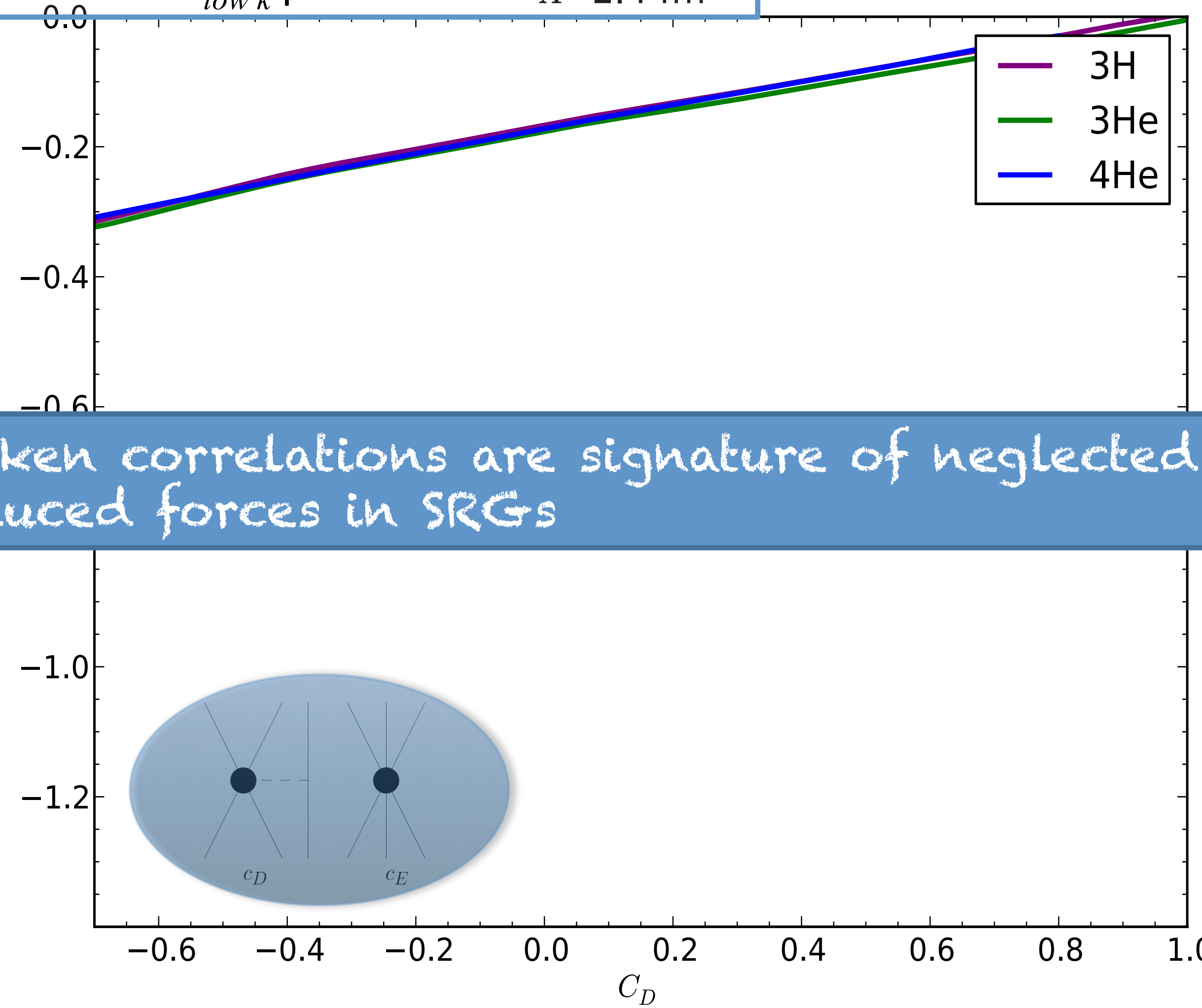


Use $v_{low\ k}$ for 2-body, and bare for 3NF –
A renormalization of cE?
cf. Günter et al
PRC 82, 024319 (2010)

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

χEFT – RG evolved potential

Different $v_{low\,k}$ potentials: Λ=2.4 fm^{-1}



broken correlations are signature of neglected induced forces in SRGs

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

$\not\pi$EFT and χEFT are both EFTs of the nuclear regime at low energy

a) Can we learn something useful from $\not\pi$EFT and apply it to χEFT?

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

b) Can one observe regulator/space dependence in $\not\pi$EFT, as in χEFT?

Kirscher, DG, Phys Lett B **755**, 253 (2016)

c) Use $\not\pi$EFT to calculate reactions and compare with χEFT, to get improved uncertainty estimate: **first $\not\pi$EFT calculation of ^{3}H beta decay** (@NLO), and a precision calculation of **proton-proton fusion in the Sun**.

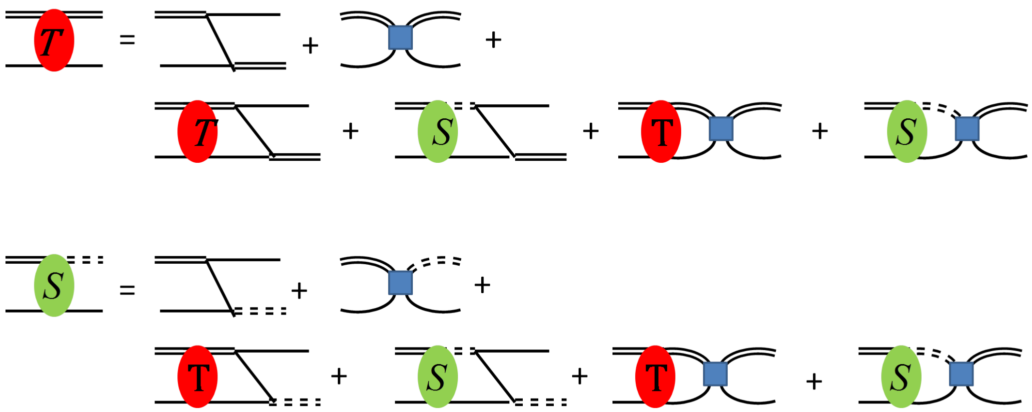
De-Leon, DG, in prep., **see Hilla De-Leon's poster.**

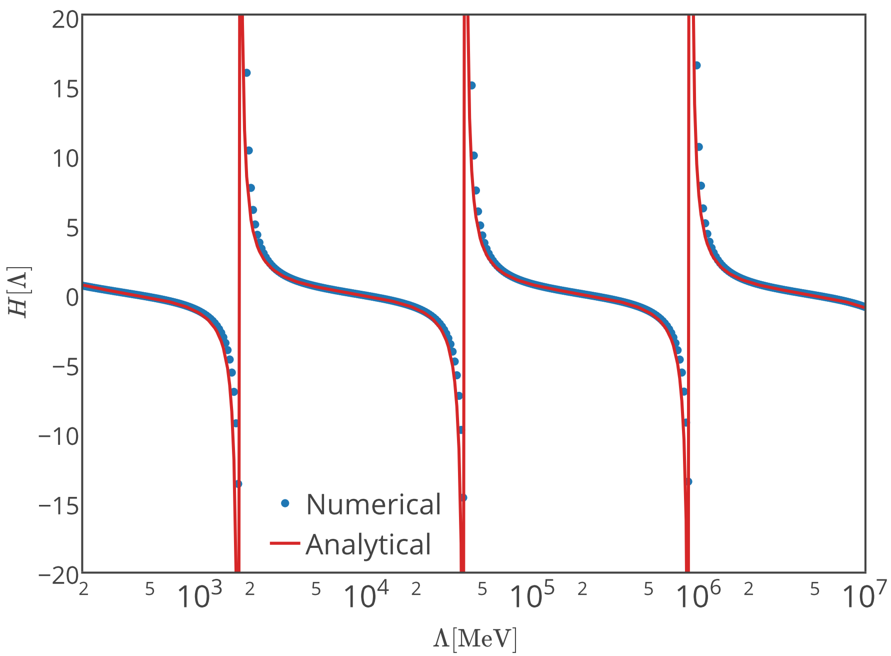
d) A very interesting confirmation of Lattice QCD as well as $\not\pi$EFT consistency check:
first $\not\pi$EFT calculation of ^{3}H, ^{3}He, ^{2}H magnetic moments and n+p→d+γ (@NLO), and comparison to the **NPLQCD calculation of 2 nucleons in a magnetic field (Beane et al PRL** 115, 132001 (2015))

De-Leon, DG, in prep..

³H:

- A=3 Efimov effect: *triton at LO has strong cutoff dependence ➔add 3-body contact at LO.*





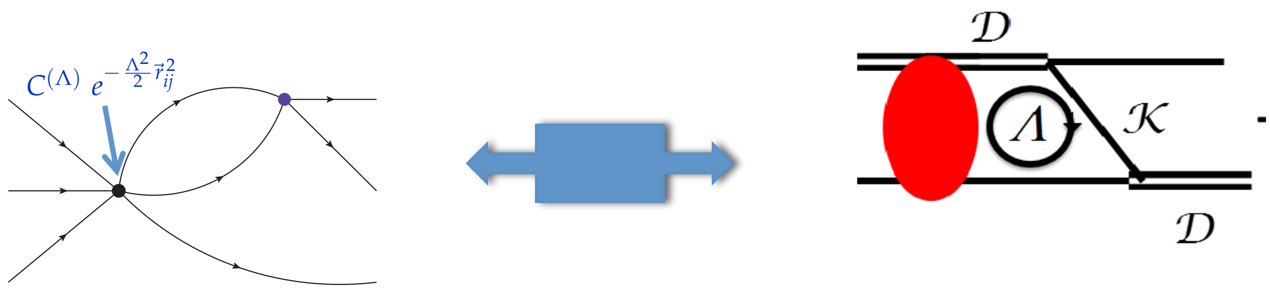
Regularization:
-- integrals cutoff at finite Λ.
-- each cycle is characterized by the appearance of a new bound state.

How does this look if using:
-- local regulator?
-- Schrödinger formalism?

Bedaque, Hammer, van Kolck

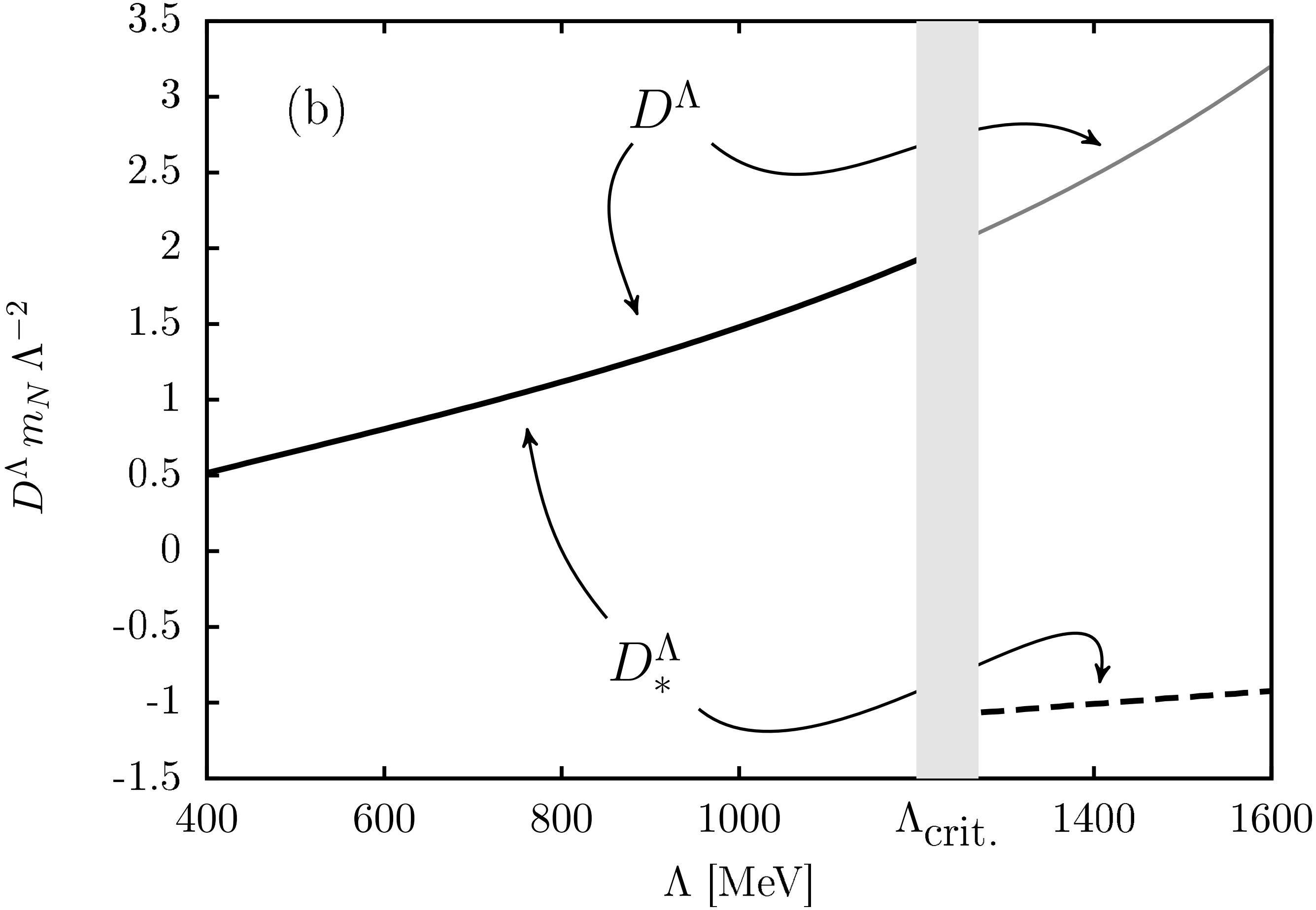
^{3}H: Schrödinger formalism, local regulator

- We have utilized a Schrödinger formalism for pionless EFT, with the same counting scheme.
- Cutoff potentials using local gaussian regulators (*a-la* local-χEFT).
- LO potential is iterated using the Schrödinger equation.
- NLO is treated perturbatively, using first order perturbation theory, which is **found to be identical to the distorted wave born approximation**.



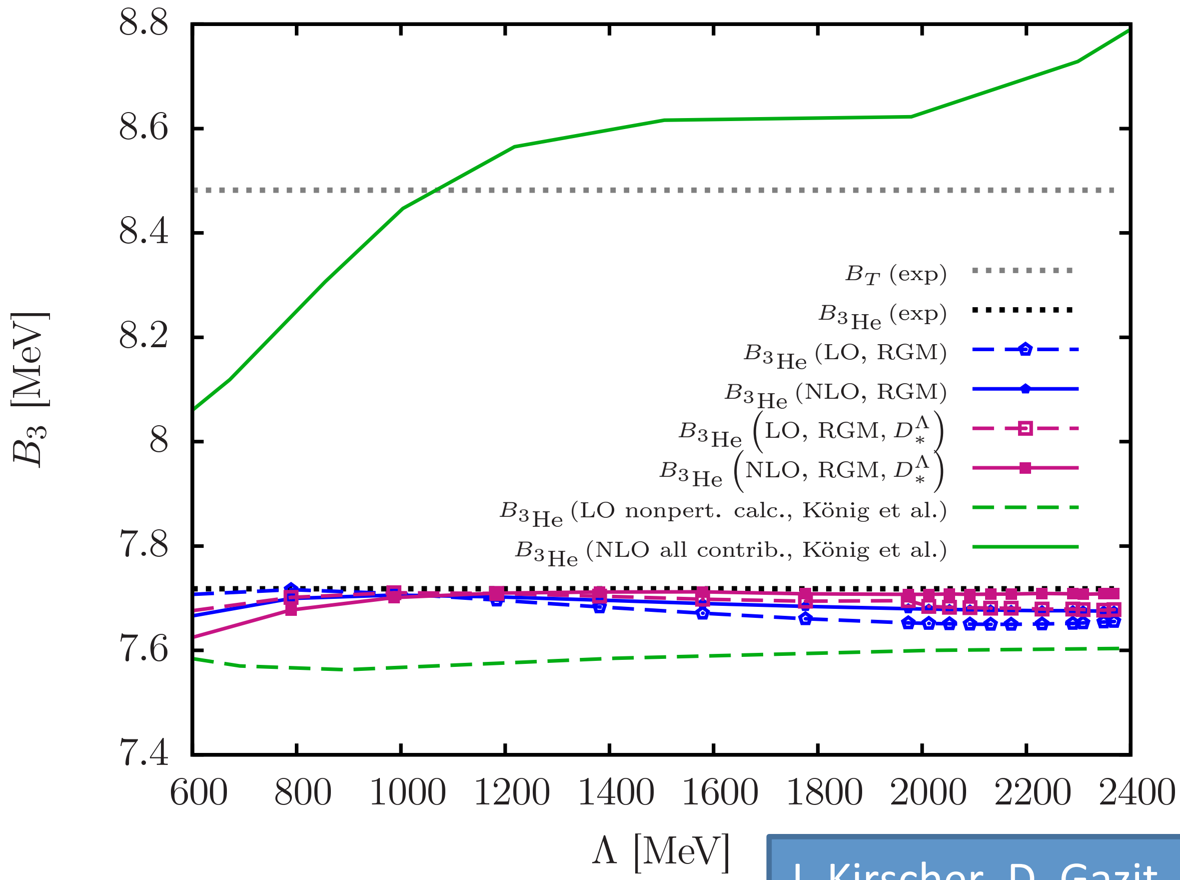
J. Kirscher, D. Gazit, PLB **755**, 253 (2016)

^{3}H: Schrödinger formalism, local regulator



J. Kirscher, D. Gazit, PLB **755**, 253 (2016)

^{3}He: one more difference between the two approaches

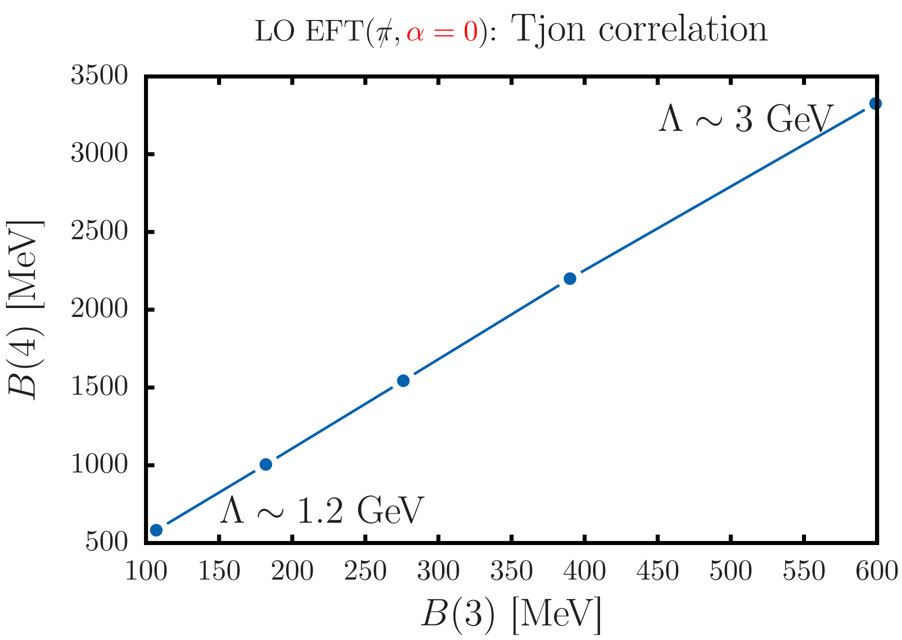


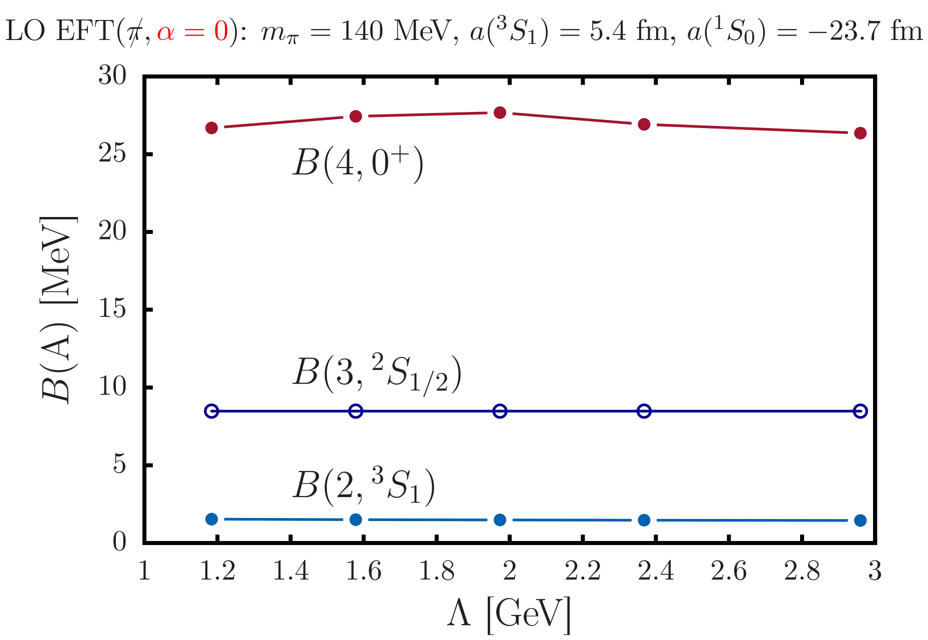
J. Kirscher, D. Gazit, PLB **755**, 253 (2016)

Compare with König et al (2011, 2013, 2014, 2015) in the dibaryon QFT formalism:
-- order of magnitude smaller cutoff dependence for non-pert. Coulomb calculation
-- ***Similar results in the perturbative Coulomb case***.

Kong, Ravndal (1999,2001), Rupak, Kong (2003), Ando, Birse (2010)

^{4}He – preliminary results@LO (no coulomb)





J. Kirscher et al, preliminary

$\not\pi$EFT and χEFT are both EFTs of the nuclear regime at low energy

a) Can we learn something useful from $\not\pi$EFT and apply it to χEFT?

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

b) Can one observe regulator/space dependence in $\not\pi$EFT, as in χEFT?

Kirscher, DG, Phys Lett B **755**, 253 (2016)

c) Use $\not\pi$EFT to calculate reactions and compare with χEFT, to get improved uncertainty estimate: **first $\not\pi$EFT calculation of ^{3}H beta decay** (@NLO), and a precision calculation of **proton-proton fusion in the Sun**.

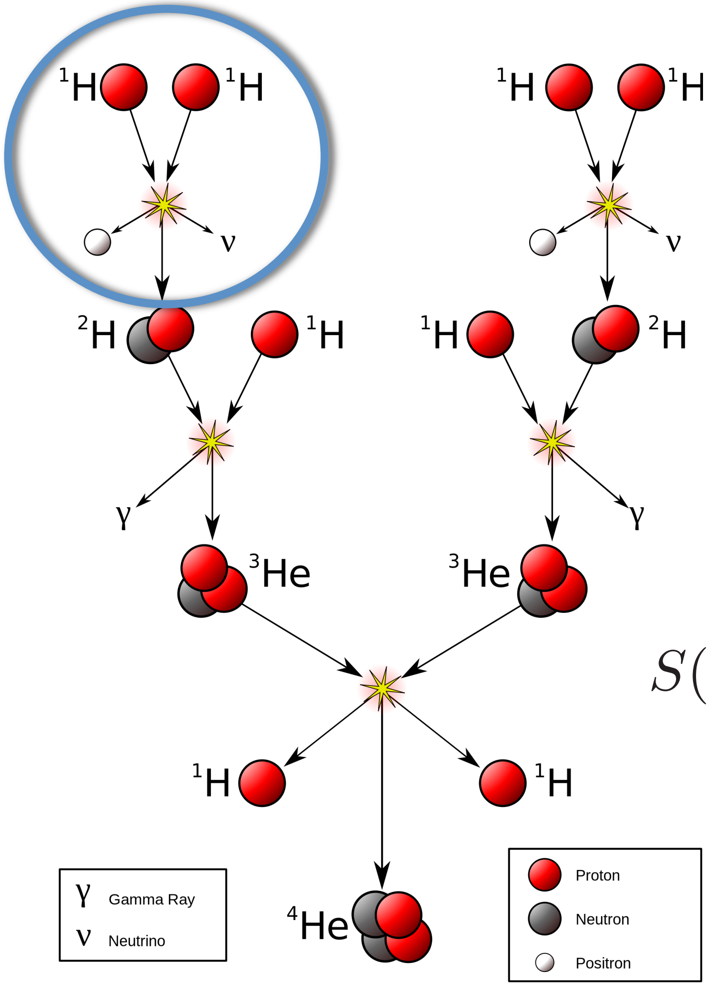
De-Leon, DG, in prep., **see Hilla De-Leon's poster.**

d) A very interesting confirmation of Lattice QCD as well as $\not\pi$EFT consistency check:
first $\not\pi$EFT calculation of ^{3}H, ^{3}He, ^{2}H magnetic moments and n+p→d+γ (@NLO), and comparison to the **NPLQCD calculation of 2 nucleons in a magnetic field (Beane et al PRL** 115, 132001 (2015))

De-Leon, DG, in prep..

Weak proton-proton fusion in the Sun

SFII – Adelberger et al., Rev. Mod. Phys. 83, 195 (2011)



- Cannot be measured terrestrially – depends on theory
- Very low proton-proton relative momentum (***E$_{rel}$~6 keV***).
- Needed accuracy: ~1%.

$$\sigma(E) = \frac{S(E)}{E} \exp[-2\pi\eta(E)]$$

$$S(E) = S(0) + S'(0)E + S''(0)E^2/2 + \cdots$$

Weak proton-proton fusion in the Sun – theory standards

SFII – Adelberger et al., Rev. Mod. Phys. 83, 195 (2011)

$$4.01(1 \pm 0.009) \times 10^{-25}\ \text{MeV b} \quad \text{potential models,}$$
$$4.01(1 \pm 0.009) \times 10^{-25}\ \text{MeV b} \quad \text{EFT}^*,$$
$$3.99(1 \pm 0.030) \times 10^{-25}\ \text{MeV b} \quad \text{pionless EFT.}$$

SFII recommended value (2011): $S_{11}(0) = 4.01(1 \pm 0.009) \times 10^{-25}\ \text{MeV b}.$

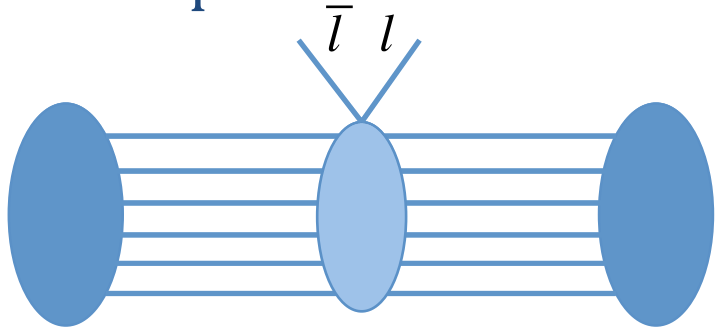
Modern χEFT calculation by Marcucci et al., Phys. Rev. Lett. (2013): Use consistent ^3H decay-rate to constrain consistently axial MEC (DG, Quaglioni, Navratil, PRL 2009), and predict pp-fusion rate.

$$S(0) = (4.030 \pm 0.006) \times 10^{-23}\ \text{MeV fm}^2$$

Including: p-wave contribution (+0.005%), full EM (-0.0025-(-0.0075)%), difference between 500 and 600 MeV cutoff and potential models.

Chen, Butler (2001-3), Ando et al (2005-8), Rupak (2014)

Pionless EFT description of weak interaction at low-energies



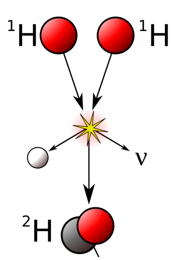
Initial amplitude

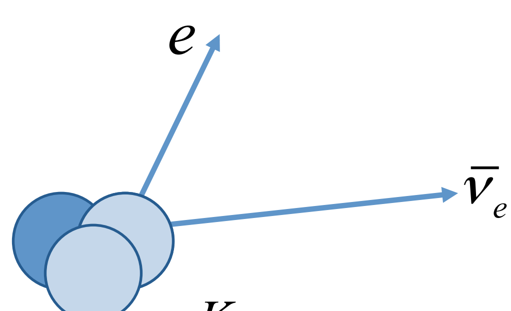
Weak Interaction

Final amplitude

$$\left\langle \psi_i \middle| \mathcal{J}_\mu \middle| \psi_f \right\rangle$$

$$\mathcal{J}_\mu^\pm = \frac{\tau_\pm}{2}\left(\mathcal{V}_\mu^\pm - \mathcal{A}_\mu^\pm\right)$$

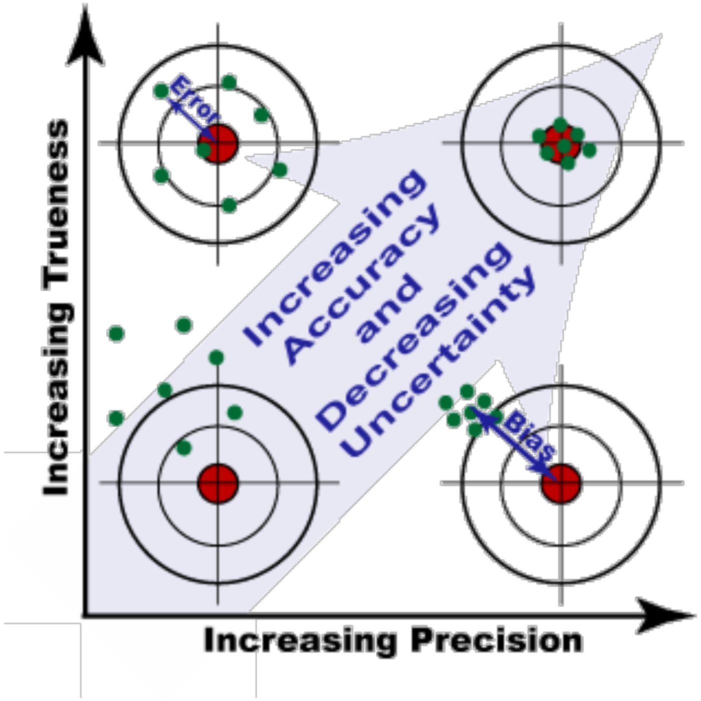




$$\left\langle pp \middle| \mathcal{A}_\mu^- \middle| {}^2\mathrm{H} \right\rangle$$

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \middle\| \mathcal{V}_\mu^+ \middle\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \middle\| \mathcal{A}_\mu^+ \middle\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$

Precision, Uncertainty, and predictions



Advantages of $\not{\pi}$EFT UQ for proton-proton fusion:

1. Small number of parameters.
2. Two $\not{\pi}$EFT expansions.
3. A "cheat-sheet" in the electromagnetic sector.
4. Cutoff independence up to infinity.

We revisit the pp-fusion problem within pionless EFT, fixing the unknown LEC using triton decay.

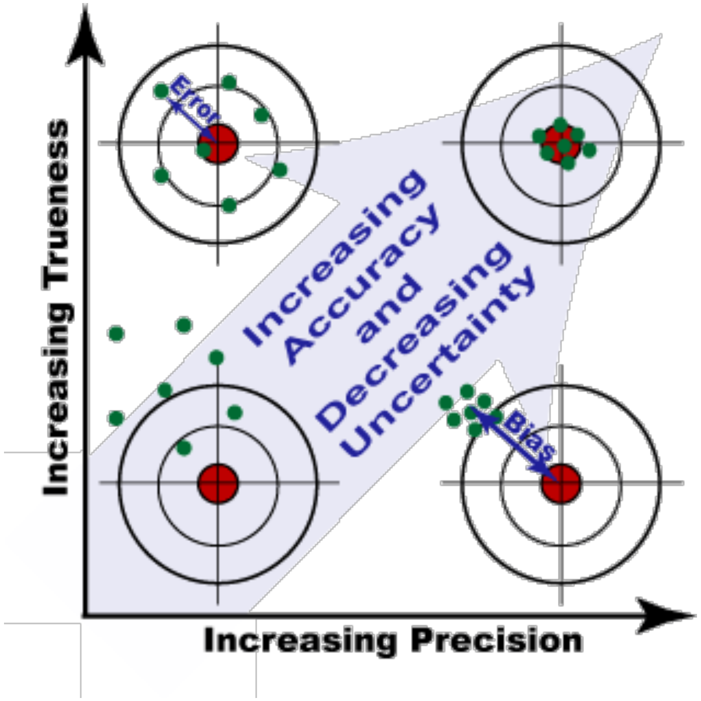
A fully perturbative pionless EFT A=2, 3 calculation @NLO

- LO Parameters:
  - nn and 2-np Scattering lengths: $^3S_1$, $^1S_0$.
  - pp scattering length.
  - Fine structure constant.
  - Three body force strength to prevent Thomas collapse.

- NLO parameters:
  - 2 effective ranges.
  - Renormalizations of pp and 3NF.
  - (isospin dependent 3NF to prevent logarithmic divergence in the binding energy of ^{3}He).

- ***Weak Interaction: LO (g_A – 1 body), NLO (L_{1A} – 2 body)***
- ***EM Interaction: LO (κ_S , κ_V) – 1 body), NLO (L_1 , L_2– 2 body)***

Precision, Uncertainty, and predictions



Advantages of $\not\pi$EFT UQ for proton-proton fusion:

1. Small number of parameters.
2. Two $\not\pi$EFT expansions.
3. A "cheat-sheet" in the electromagnetic sector.
4. Cutoff independence up to infinity.

We revisit the pp-fusion problem within pionless EFT, fixing the unknown LEC using triton decay.

The role of the deuteron tail

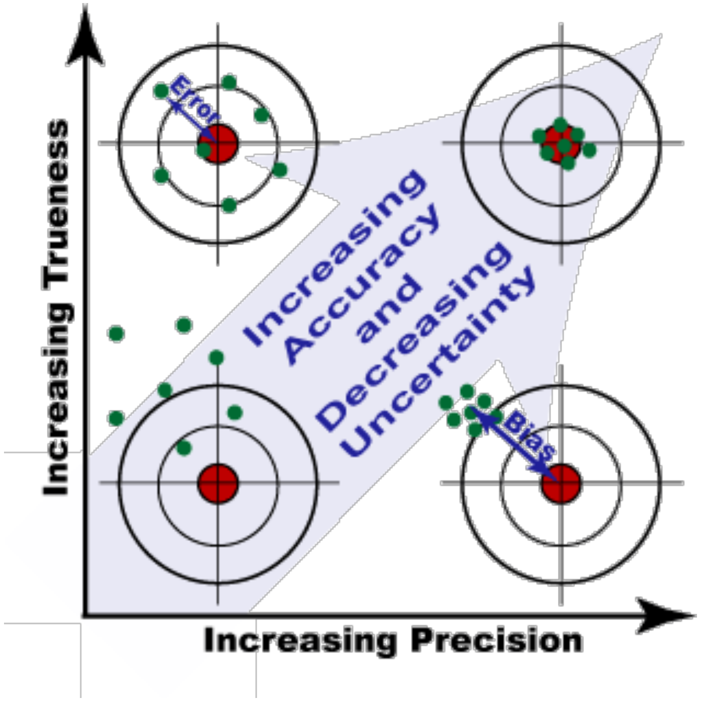
- Many low energy reactions depend on deuteron normalization.
- One has a choice of constructing pionless EFT:
  - rho-parameterization: $Z_d = \frac{1}{1-\gamma\rho} \approx 1 + \gamma\rho + (\gamma\rho)^2 + \ldots$
  - Z(ed)-parameterization: $Z_d = \frac{1}{1-\gamma\rho} \approx 1 + (Z_d - 1) + 0 + \ldots$

LO NLO N^{2}LO+…

Both theories are valid EFTs.
Z-parameterization sometimes has quicker convergence.

Phillips, Rupak, Savage, Phys. Lett. **B473**, 209 (2000)
Grießhammer, Nucl. Phys. **A744**, 192 (2004)

Precision, Uncertainty, and predictions



Advantages of $\not\pi$EFT UQ for proton-proton fusion:

1. Small number of parameters.
2. Two $\not\pi$EFT expansions.
3. A “cheat-sheet” in the electromagnetic sector.
4. Cutoff independence up to infinity.

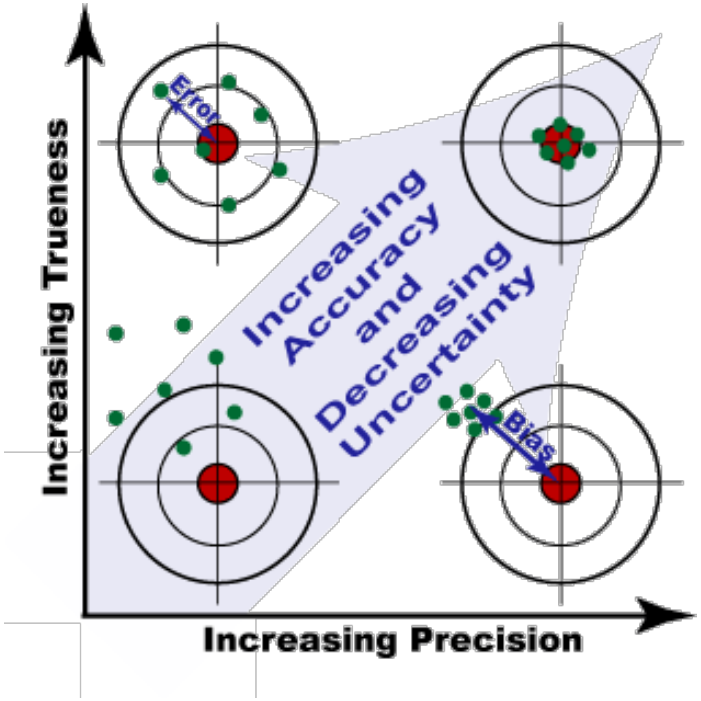
We revisit the pp-fusion problem within pionless EFT, fixing the unknown LEC using triton decay.

Analogy between weak and EM:

	EM	weak
1-body LEC	$\kappa_n,\ \kappa_p$	g_A
1-body operator	$\sigma, \sigma\tau^0$	$\sigma\tau^{+,-}, \tau^{+,-}$
2-body operator	$L_1 (d^i)^\dagger s^j,\ L_2 (d^i)^\dagger d^j$	$L_{1A} (d^i)^\dagger s^j$
$A = 2,\ q \approx 0$ observables	$\sigma_{np}: n + p \to d + \gamma$ d magnetic moment $\langle \mu_d \rangle$	pp fusion: $p + p \to d + e^+ + \nu_e$
$A = 3,\ q \approx 0$ observables	^{3}H, ^{3}He magnetic moments: $\langle \mu_{^3\mathrm{H}} \rangle,\ \langle \mu_{^3\mathrm{He}} \rangle$	^{3}H β-decay into ^{3}He: $^3\mathrm{H} \to ^3\mathrm{He} + e^- \bar{\nu}_e$

Use the same strategy in both cases: fix probe LECs at A=3 and predict A=2.

Precision, Uncertainty, and predictions



Advantages of $\not\pi$EFT UQ for proton-proton fusion:

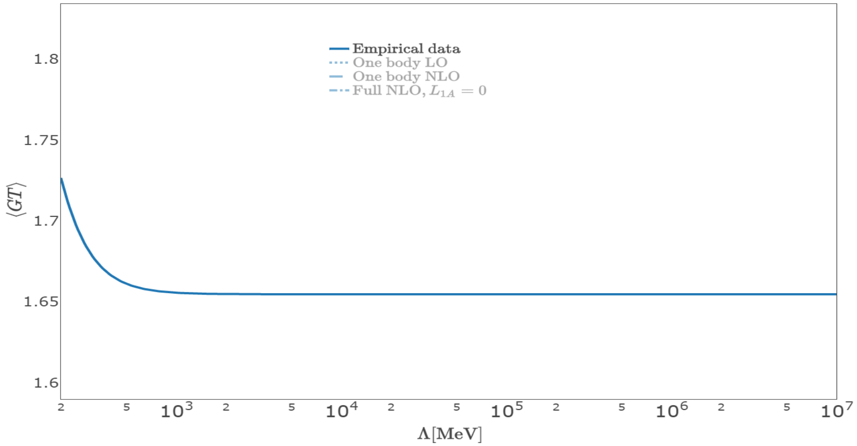
1. Small number of parameters.
2. Two $\not\pi$EFT expansions.
3. A "cheat-sheet" in the electromagnetic sector.
4. Cutoff independence up to infinity.

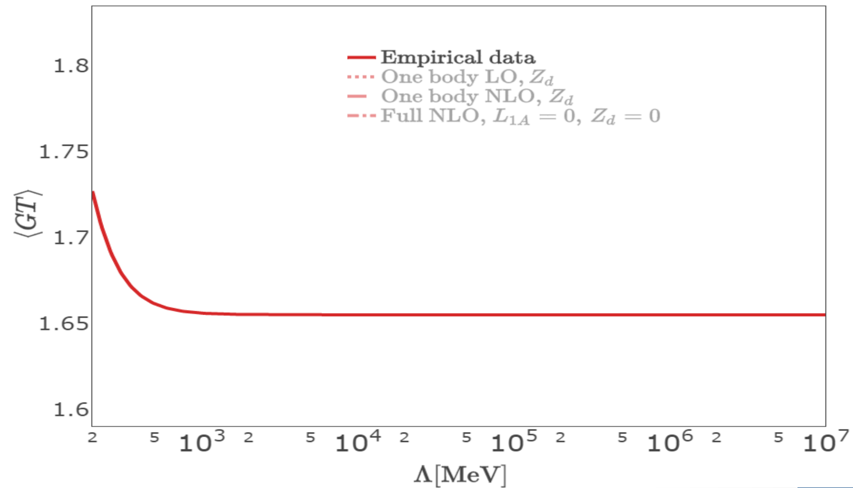
We revisit the pp-fusion problem within pionless EFT, fixing the unknown LEC using triton decay.

Triton decay – GT cutoff independence

Rho-parameterization | **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \left\| \mathcal{V}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \left\| \mathcal{A}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$



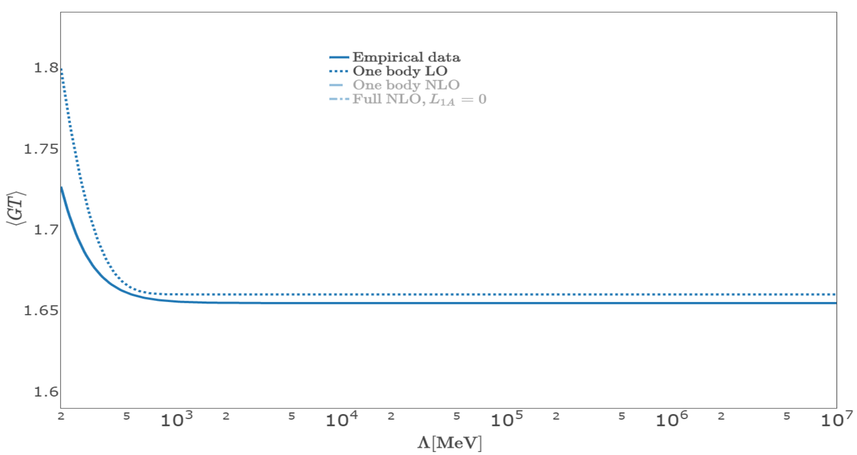


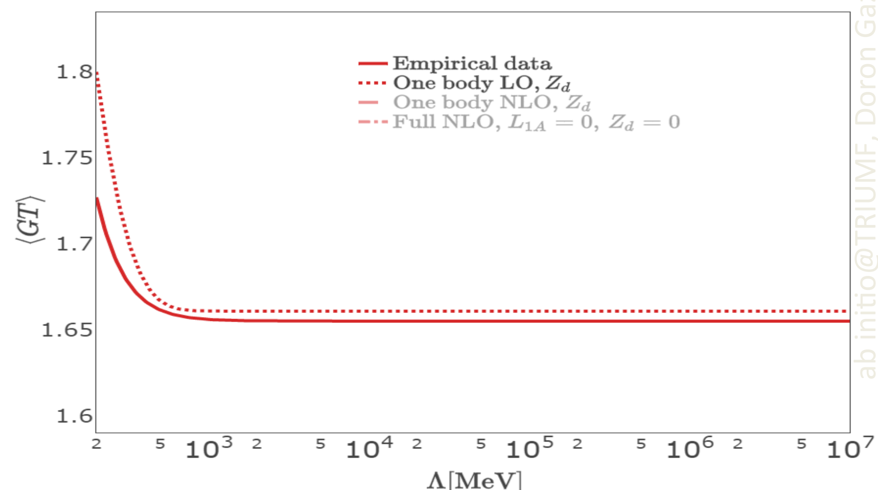
"Empirical" extraction of GT (using calculated F strength)

Triton decay – GT cutoff independence

Rho-parameterization | **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \left\| \mathcal{V}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \left\| \mathcal{A}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$



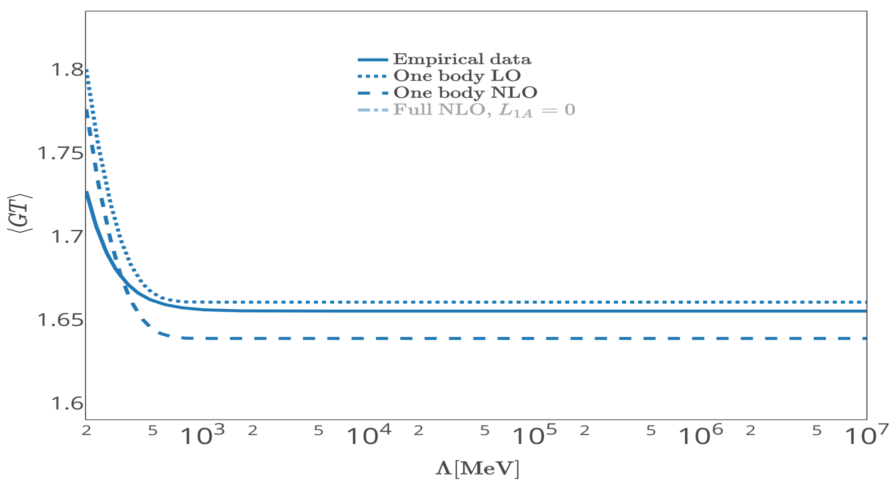


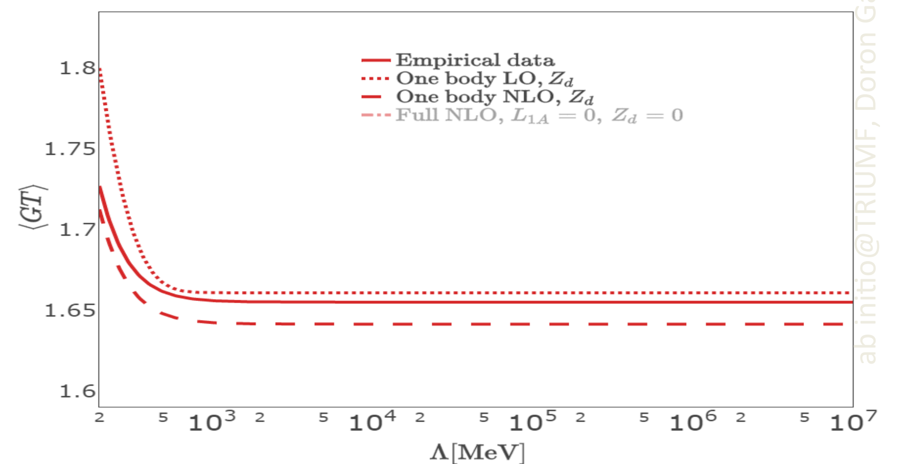
Adding the LO 1-body contribution

Triton decay – GT cutoff independence

Rho-parameterization **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \left\| \mathcal{V}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \left\| \mathcal{A}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$



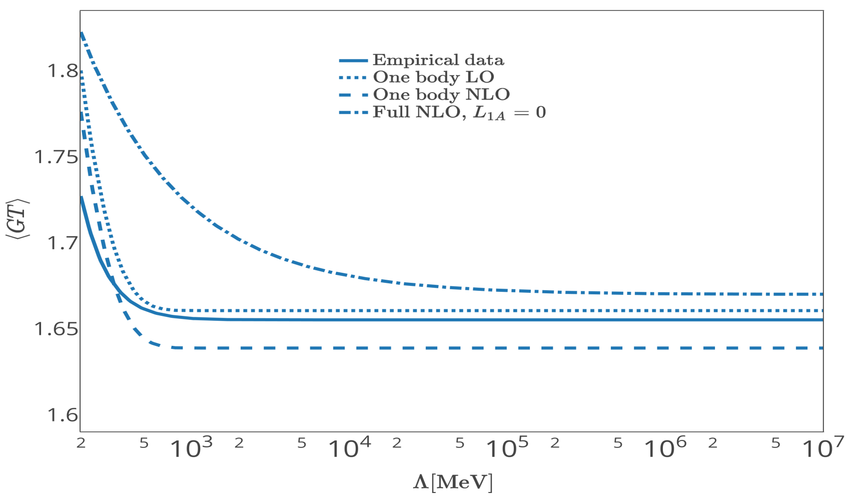


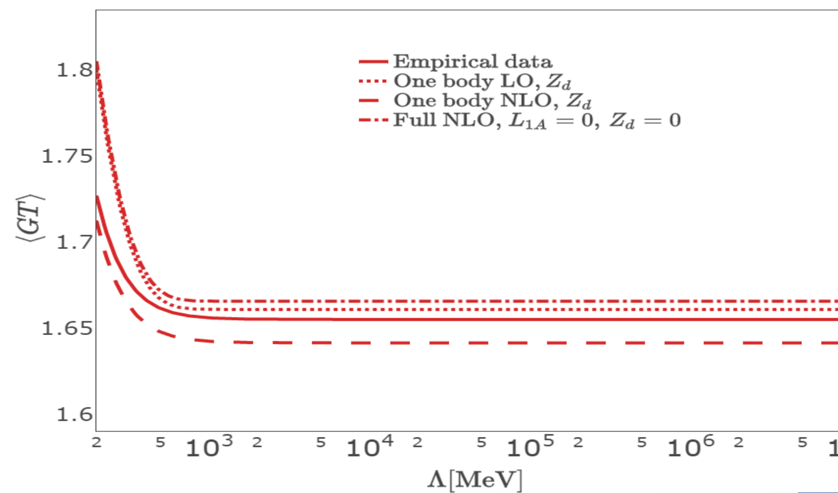
Adding the NLO 1-body contributions

Triton decay – GT cutoff independence

Rho-parameterization | **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \middle\| \mathcal{V}_\mu^+ \middle\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \middle\| \mathcal{A}_\mu^+ \middle\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$





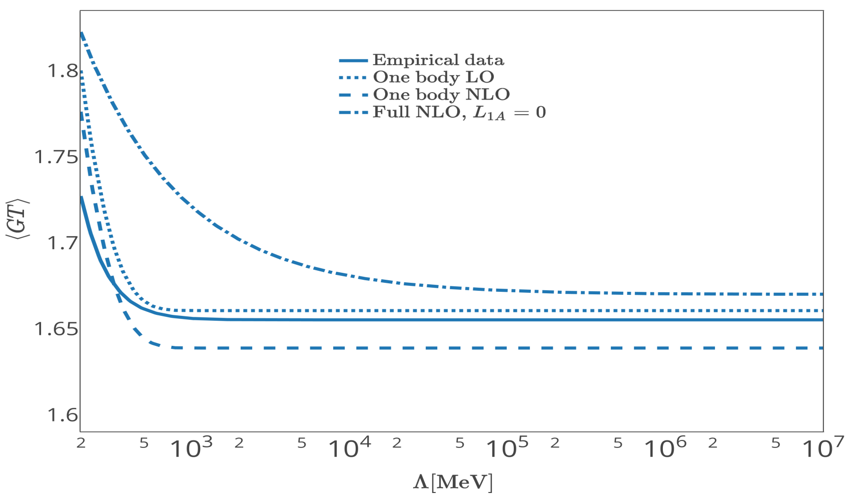
Adding all contribution, but L_{1A}

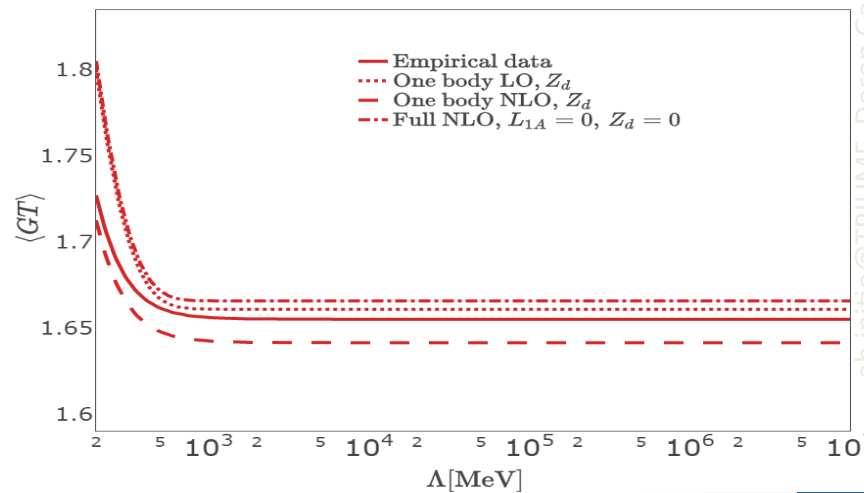
1st estimate of theoretical uncertainty:
All NLO contributions are of the same order,
one can estimate higher order effects as the NLO contribution.

Triton decay – GT cutoff independence

Rho-parameterization **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \langle {}^3\mathrm{H} \| \mathcal{V}_\mu^+ \| {}^3\mathrm{He} \rangle \right|^2 + \frac{f_A}{f_V} \left| \langle {}^3\mathrm{H} \| \mathcal{A}_\mu^+ \| {}^3\mathrm{He} \rangle \right|^2 \right]}$$





Adding all contributi

Translates to ±2% difference in pp fusion

1st estimate of theoretical uncertainty:
All NLO contributions are of the same order,
one can estimate higher order effects as the NLO contribution.

Triton decay – GT cutoff independence

Rho-parameterization | **Zed-parameterization**

$$ft = \frac{K}{G_F^2 V_{ud}^2 \left[\left| \left\langle {}^3\mathrm{H} \left\| \mathcal{V}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 + \frac{f_A}{f_V} \left| \left\langle {}^3\mathrm{H} \left\| \mathcal{A}_\mu^+ \right\| {}^3\mathrm{He} \right\rangle \right|^2 \right]}$$

Marcucci et al result (same assumptions)	$4.02 \cdot 10^{-23}\mathrm{MeV} \cdot fm^2 \pm 0.01$
$S_{pp}^{EFT(\not\pi)}(0)$	$3.90 \cdot 10^{-23}\mathrm{MeV} \cdot fm^2$
$S_{pp}^{EFT(\not\pi)}(0), Z_d$	$4.16 \cdot 10^{-23}\mathrm{MeV} \cdot fm^2$

±3% difference

Translates to ±2% difference in pp fusion

1^{st} estimate of theoretical uncertainty:
All NLO contributions are of the same order,
one can estimate higher order effects as the NLO contribution.

In the EM sector:

	$A=2$	
	σ_{np} [mb]	μ_d [μ_N]
LO	298.2	0.8798
LO, Z_d	298.2	0.8798
Full NLO	338.8	0.8592
Full NLO, Z_d	347.8	0.8547
Δ Z_d [%]	2.7	0.1
Exp data	334.2	0.8574
Δ Exp [%]	1-4	0.2-0.3

L1, L2 calibrated
in the A=3 sector
and A=2 is predicted

Capture reaction (n+p→d+γ) depends stronger on deuteron tail, same order of theoretical uncertainty again (a few percents).

In the EM sector:

PRL **115,** 132001 (2015) PHYSICAL REVIEW LETTERS week ending 25 SEPTEMBER 2015

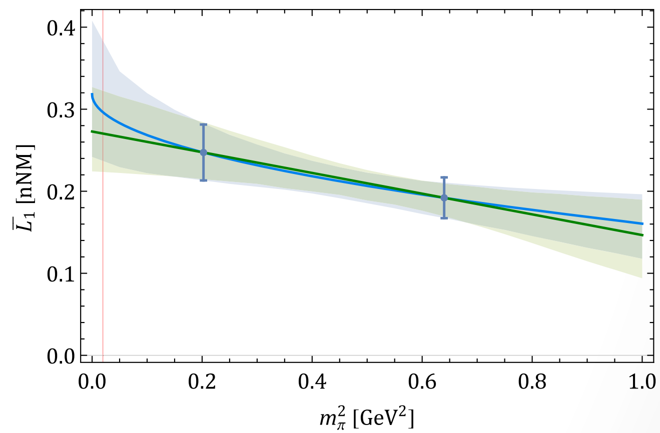
Ab initio Calculation of the $np \to d\gamma$ Radiative Capture Process

Silas R. Beane,[1] Emmanuel Chang,[2] William Detmold,[3] Kostas Orginos,[4,5] Assumpta Parreño,[6] Martin J. Savage,[2] and Brian C. Tiburzi[7,8,9]

(NPLQCD Collaboration)

$$\Delta E_{^3S_1,^1S_0}(\mathbf{B}) = 2(\kappa_1 + \gamma_0 Z_d^2 \tilde{l}_1)\frac{e}{M}|\mathbf{B}| + \mathcal{O}(|\mathbf{B}|^2),$$

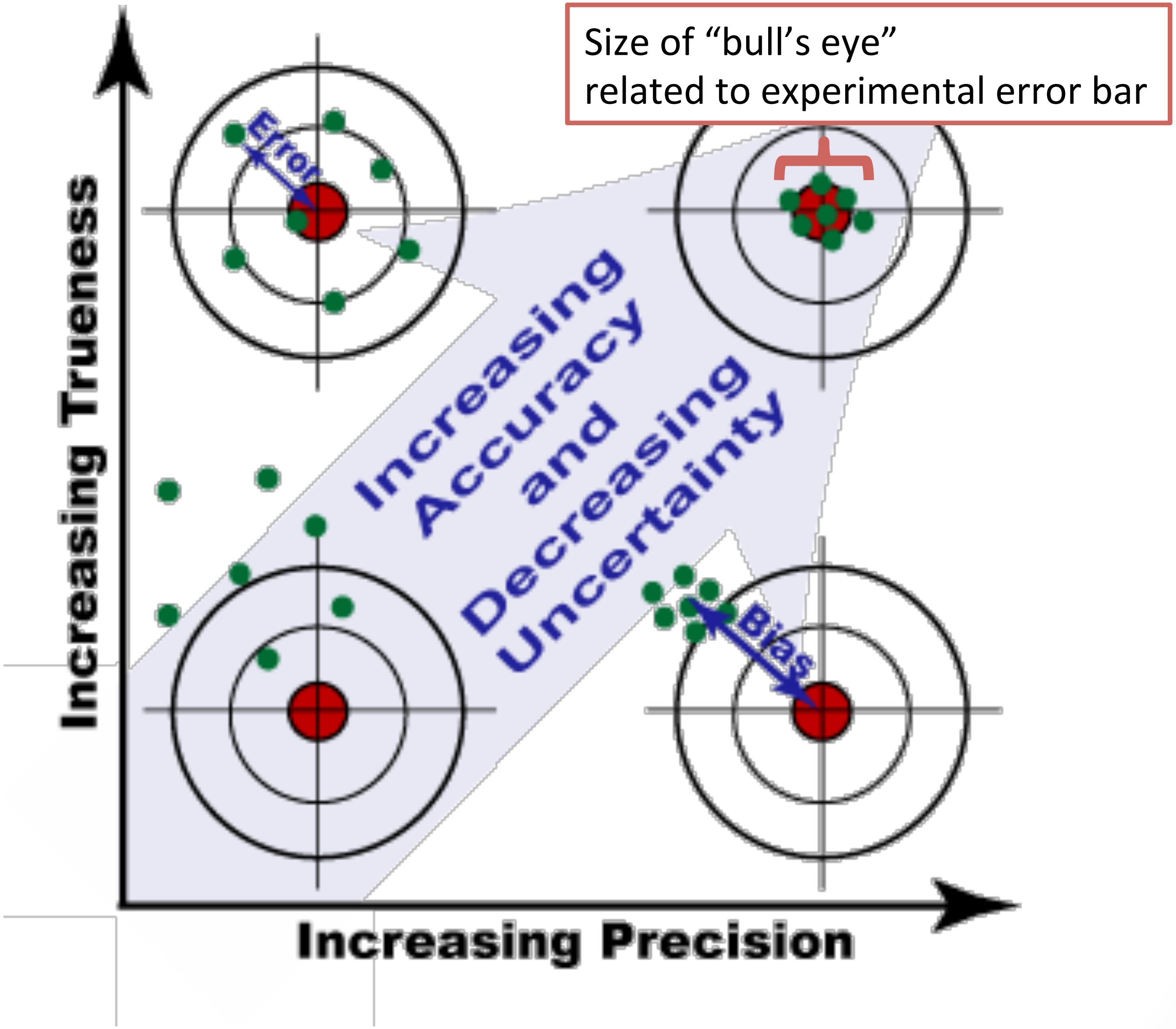
$$l_1^{\mathrm{lqcd}} = -4.41\left(\begin{smallmatrix}+15\\-16\end{smallmatrix}\right)\ \mathrm{fm}.$$



(they use different pionless EFT counting, comparison preliminary)

Our prediction for l_1=-3.3-(-5.7) fm

So… is 3% too big to be called precision physics?



So… is 3% too big to be called precision physics?

g_A systematic uncertainty

$$S_{pp}(g_A = 1.2695) = (3.90 - 4.16) \pm 0.07 \pm 0.04$$

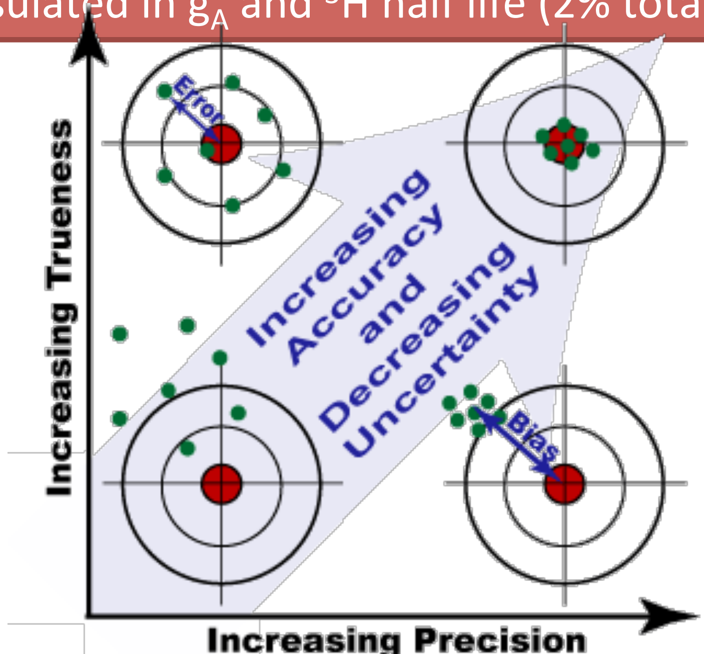
$$S_{pp}(g_A = 1.275) = (4.02 - 4.30) \pm 0.07 \pm 0.04$$

±3% theoretical uncertainty

g_A stat. unc.

^3H halflife syst. unc.

i.e., theoretical uncertainty (3%) of the same order of systematic experimental error encapsulated in g_A and ^3H half life (2% total).



Summary

a) We can learn something useful from $\not{\pi}$EFT and apply it to χEFT – disregarding correlations from $\not{\pi}$EFT would result in fine tuning!
One should augment covariance matrices.

Lupu, Barnea, DG, arXiv: arXiv: 1508.05654

b) One observes regulator/space dependence in $\not{\pi}$EFT just as in χEFT.

Kirscher, DG, Phys Lett B **755**, 253 (2016), Kirscher et al, in prep.

c) **First $\not{\pi}$EFT calculation of ^{3}H beta decay** (@NLO), and a precision calculation of **proton-proton fusion in the Sun**:
Improved and reliable theoretical uncertainty estimate.
Improvement in **g_A and ^{3}H decay** determination highly needed.
N2LO calculation should follow.
What can this do for SSM? A lot, mainly to CNO neutrinos flux

De-Leon, DG, in prep., **see Hilla De-Leon's poster.**

d) A very interesting confirmation of Lattice QCD as well as $\not{\pi}$EFT consistency check:
first $\not{\pi}$EFT calculation of ^{3}H, ^{3}He, ^{2}H magnetic moments and n+p→d+γ (@NLO), and good comparison to the **NPLQCD calculation of 2 nucleons in a magnetic field (Beane et al PRL** 115, 132001 (2015))

De-Leon, DG, in prep..