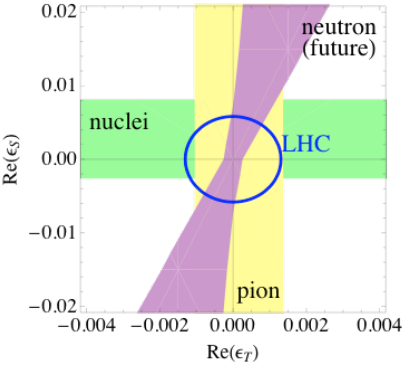
BSM effects in semileptonic CC decays of light quarks

LIO Conference

Nov 24th, 2015



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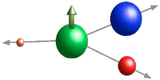
Outline



($d_i \rightarrow u_i\, l_k\, \nu_l$)

- Introduction and motivation;
- Matching of low- and high-E EFT;
- $U(3)^5$ flavor symmetry;
- General flavor structure;

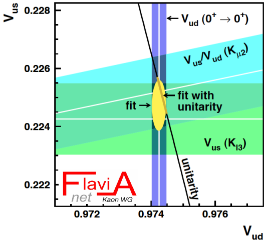
Motivation

Precise data

+

Precise SM predictions

[Remember… $V_{ud} = 0.97425(22)$]



$\pi^+ \to \pi^0 e^+ \nu_e$

$\pi^+ \to l^+ \nu_l$

$K \to \pi l \nu_l$

$K^+ \to l^+ \nu_l$

n decay

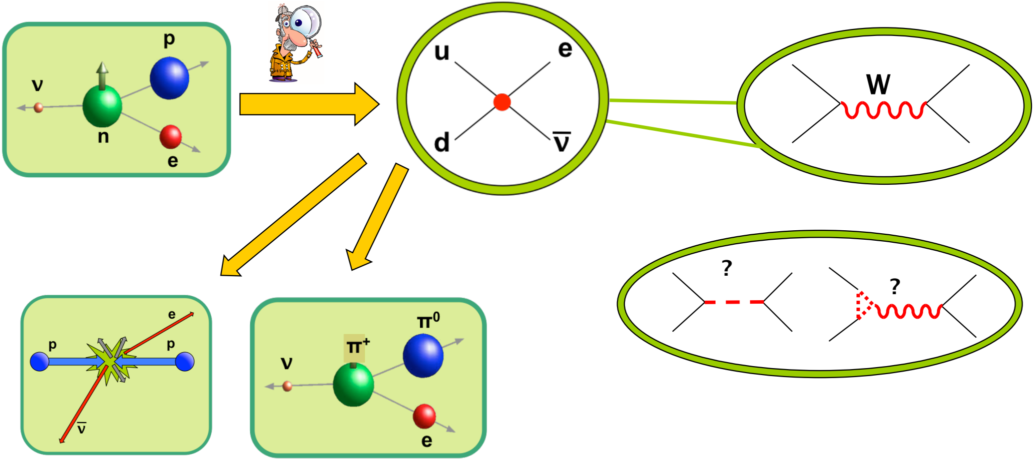
$0^+ \to 0^+$

$\left(\mu \to e \bar{\nu}_e \nu_\mu\right)$

- EFT analysis not available;
  (particularly interesting in the LHC era…)
  [Nucleon-level language for β decays]

- We were interested in d→ueν & s→ueν,
  but most of the results are valid for any flavor structure.

Motivation



Low-energy EFT for d → u e ν

$$\mathcal{L} \sim (1+\epsilon_L)(V-A)(V-A) + \epsilon_R(V-A)(V+A) + \cancel{\tilde{\epsilon}_L(V+A)(V-A)} + \cancel{\tilde{\epsilon}_R(V+A)(V+A)}$$
$$+ \epsilon_S (S-P)\, S - \epsilon_P (S-P)\, P + \cancel{\tilde{\epsilon}_S (S+P)\, S} - \cancel{\tilde{\epsilon}_P (S+P)\, P}$$
$$+ \epsilon_T (T - T\gamma_5)(T + T\gamma_5) + \cancel{\tilde{\epsilon}_T (T + T\gamma_5)(T - T\gamma_5)}$$

Linear approximation: SM + small perturbation

$$\mathcal{L}_{d\to ue^-\bar{\nu}_e} = -\sqrt{2} G_F V_{ud} \left(1 + \mathrm{Re}\,(\epsilon_L + \epsilon_R)\right) \Big[\bar{e}_L \gamma_\mu \nu_L \cdot \bar{u}\left(\gamma^\mu - (1-2\epsilon_R)\gamma^\mu\gamma_5\right) d$$
$$+ \epsilon_S\, \bar{e}_R \nu_L \cdot \bar{u} d - \epsilon_P\, \bar{e}_R \nu_L \cdot \bar{u}\gamma_5 d + 2\, \epsilon_T\, \bar{e}_R \sigma_{\mu\nu} \nu_L \cdot \bar{u} \sigma^{\mu\nu} d_L \Big]$$

V & A gets "hidden" inside V_{ud}

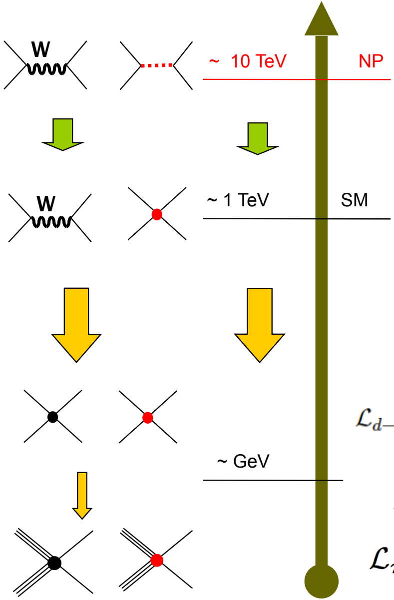
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \neq 1$$

(The real part) gets hidden in the corresponding axial-vector FF
(precise LQCD needed)

Diff. distr. altered;
SM analysis not valid;
New Form factors;
Channel dep. effects;

==> Comparison between low-E processes possible.

Matching high- & low- EFT



$$\mathcal{L}(x) = \mathcal{L}\,(\text{SM fields, bSM fields})$$

[Buchmüller-Wyler'1986, Leung et al.'1986, Grzadkowski et al'2010]

$$\mathcal{L}_{eff.} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum \alpha_i\, \mathcal{O}_i$$

[Cirigliano, MGA, Jenkins'2010, Cirigliano, MGA, Graesser'2012]

$$\mathcal{L}_{d\to u\ell^-\bar{\nu}_\ell} = -\frac{4G_F V_{ij}}{\sqrt{2}}\left[\bar{\ell}_L\gamma_\mu\nu\cdot\bar{u}\gamma^\mu d_L \;+\; \sum_{\rho\delta\Gamma}\epsilon^{\Gamma}_{\rho\delta}\;\bar{\ell}_\rho\Gamma\nu\cdot\bar{u}\Gamma d_\delta\right]$$

$$\mathcal{L}_{\pi,N,\ldots} = \ldots$$

$$\varepsilon_i = f(\alpha_j)$$

Matching high- & low- EFT

[Cirigliano, MGA, Jenkins'2010, Cirigliano, MGA, Graesser'2012]

$$\epsilon_L = \epsilon_L^{(v)} + \epsilon_L^{(c)} \qquad \tilde{\epsilon}_L = -\hat{\alpha}'^{*}_{\varphi\varphi}$$

$$\epsilon_L^{(v)} = 2\hat{\alpha}^{(3)}_{\varphi l} + 2\frac{[V\,(\hat{\alpha}^{(3)}_{\varphi q})^{\dagger}]_{11}}{V_{ud}} + 4\hat{\alpha}^{(3)}_{\varphi l}\,\delta_{el}\,\frac{[V\,(\hat{\alpha}^{(3)}_{\varphi q})^{\dagger}]_{11}}{V_{ud}}$$

$$\epsilon_L^{(c)} = -2\frac{[V\,\hat{\alpha}^{(3)}_{lq}]_{11}}{V_{ud}}$$

$$\epsilon_R = -\delta_{el}\frac{[\hat{\alpha}_{\varphi\varphi}]_{11}}{V_{ud}} \qquad \tilde{\epsilon}_R = -\frac{[\hat{\alpha}_{e\nu ud}]_{11}}{V_{ud}}$$

$$\epsilon_S - \epsilon_P = -2\frac{[V\,\hat{\alpha}^{\dagger}_{qde}]_{11}}{V_{ud}} \qquad \tilde{\epsilon}_S - \tilde{\epsilon}_P = 2\frac{[V\,\hat{\alpha}'_{lq}]_{11}}{V_{ud}}$$

$$\epsilon_S + \epsilon_P = -2\frac{[\hat{\alpha}^{\dagger}_{lq}]_{11}}{V_{ud}} \qquad \tilde{\epsilon}_S + \tilde{\epsilon}_P = -2\frac{[\hat{\alpha}_{qu\nu}]_{11}}{V_{ud}}$$

$$\epsilon_T = -\frac{[\hat{\alpha}^{t\,\dagger}_{lq}]_{11}}{V_{ud}} \qquad \tilde{\epsilon}_T = \frac{[V\,\hat{\alpha}^{t\,\prime}_{lq}]_{11}}{V_{ud}}\,.$$

Vertex corrections:

$$O_{\varphi\varphi} = i(\varphi^T \epsilon D_\mu \varphi)(\overline{u}\gamma^\mu d) + \text{h.c.}$$
$$O^{(3)}_{\varphi q} = i(\varphi^\dagger D^\mu \sigma^a \varphi)(\overline{q}\gamma_\mu \sigma^a q) + \text{h.c.}$$
$$O^{(3)}_{\varphi l} = i(\varphi^\dagger D^\mu \sigma^a \varphi)(\overline{l}\gamma_\mu \sigma^a l) + \text{h.c.}$$
$$O'_{\varphi\varphi} = i(\varphi^T \epsilon D_\mu \varphi)(\overline{\nu}\gamma^\mu e) + \text{h.c.}$$

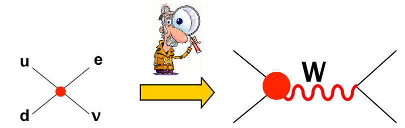
Four-fermion operators:

$$O^{(3)}_{lq} = (\bar{l}\gamma^\mu \sigma^a l)(\bar{q}\gamma_\mu \sigma^a q) \qquad O_{e\nu ud} = (\bar{e}\gamma^\mu \nu)(\overline{u}\gamma_\mu d) + \text{h.c.}$$
$$O_{qde} = (\bar{l}e)(\bar{d}q) + \text{h.c.} \qquad O_{qu\nu} = (\bar{l}\nu)(\overline{u}q) + \text{h.c.}$$
$$O_{lq} = (\bar{l}_a e)\epsilon^{ab}(\bar{q}_b u) + \text{h.c.} \qquad O'_{lq} = (\bar{l}_a \nu)\epsilon^{ab}(\bar{q}_b d) + \text{h.c.}$$
$$O^{t}_{lq} = (\bar{l}_a \sigma^{\mu\nu} e)\epsilon^{ab}(\bar{q}_b \sigma_{\mu\nu} u) + \text{h.c.} \qquad O^{t\prime}_{lq} = (\bar{l}_a \sigma^{\mu\nu} \nu)\epsilon^{ab}(\bar{q}_b \sigma_{\mu\nu} d) + \text{h.c.}$$

Matching high- & low- EFT

What are the consequences of assuming the (d → u e ν) low-E Lagrangian comes from the EW Effective Lagrangian (SMEFT)?

- ϵ_R is lepton independent:



$$\bar{e}_L \gamma_\mu \nu_L \cdot \bar{u}_R \gamma^\mu d_R \qquad i(\varphi^T \epsilon D_\mu \varphi)(\overline{u}\gamma^\mu d)$$

  → Irrelevant for β decays, but not for e.g. π/K/hyperon decays, μ capture…

  → Very different in b → s e^+e^-, where some structures are forbidden! *[Alonso, Grinstein & Martin Camalich'2014]*

  → Not true in the non-linear EFT! *[Cata & Jung'2015]* (Flavor probing the Higgs sector!)

Matching high- & low- EFT

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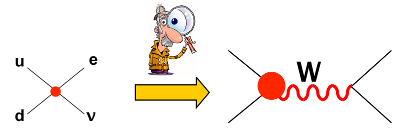
- ε_R is lepton independent;



$\bar{e}_L \gamma_\mu \nu_L \cdot \bar{u}_R \gamma^\mu d_R$ $\quad$ $i(\varphi^T \epsilon D_\mu \varphi)(\overline{u}\gamma^\mu d)$

- It relates beta decays with a plethora of other experiments:
  - ➔ LEP physics;
  - ➔ LHC physics:
    - ➔ p p → e MET (+X)
    - ➔ p p → $e^+ e^-$ (+X)
    - ➔ Higgs decays
    - ➔ …

- EFT flavor structure?
  - *$U(3)^5$ flavor symmetry;*
  - *General flavor structure;*

Matching high- & low- EFT: U(3)^5

What are the consequences of assuming the (d → u e ν) low-E Lagrangian comes from the EW Effective Lagrangian (SMEFT)?

- If U(3)^5 is an approx. flavor symmetry (e.g. MFV), only the (V-A)x(V-A) structure survives!

[Cirigliano, MGA & Jenkins, Nucl. Phys B830 (2010)]

$\mu^- \to e^- \nu_\mu \bar{\nu}_e$

$$\mathcal{L}^{eff}_{\mu\to e\nu\bar{\nu}}(x) = \frac{-g^2}{2m_W^2}\left[(1+\tilde{v}_L)(\bar{e}_L\gamma_\mu \nu_{eL})(\bar{\nu}_{\mu L}\gamma_\mu \mu_L) + \tilde{s}_L(\bar{e}_R \nu_{eL})(\bar{\nu}_{\mu L}\mu_R)\right] + h.c.$$

where… $\tilde{v}_L = 4\bar{\alpha}^{(3)}_{\varphi l} - 2\bar{\alpha}^{(3)}_{ll}$

$$G_F^{pheno(\mu)} = G_F^{(0)}(1+\tilde{v}_L)$$

$d^j \to u^i l \bar{\nu}_l$

$$\mathcal{L}^{eff}_{d^j\to u^i l\bar{\nu}_l}(x) = \frac{-g^2}{2m_W^2}V_{ij}\left[\begin{array}{l}(1+v_L)(\bar{u}^i_L\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL}) + v_R(\bar{u}^i_R\gamma^\mu d^j_R)(\bar{l}_L\gamma_\mu \nu_{lL}) \\ + s_L(\bar{u}^i_R d^j_L)(\bar{l}_R \nu_{lL}) + s_R(\bar{u}^i_L d^j_R)(\bar{l}_R \nu_{lL}) \\ + t_L(\bar{u}^i_R\sigma^{\mu\nu} d^j_L)(\bar{l}_R\sigma_{\mu\nu} \nu_{lL})\end{array}\right] + h.c.$$

$$G_F^{pheno(SL)} = G_F^{(0)}(1+v_L)$$

where… $[v_L]_{llij} = 2\bar{\alpha}^{(3)}_{\varphi l} + 2\bar{\alpha}^{(3)}_{\varphi q} - 2\bar{\alpha}^{(3)}_{lq}$

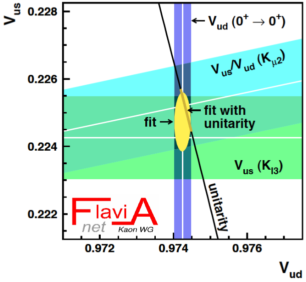
Matching high- & low- EFT: $U(3)^5$

What are the consequences of assuming the ($d \to u\, e\, \nu$) low-E Lagrangian comes from the EW Effective Lagrangian (SMEFT)?

- If $U(3)^5$ is an approx. flavor symmetry (e.g. MFV), only the (V-A)x(V-A) structure survives!
  - Only NP effect: G_F & V_{ud} shifts; (channel-indep.!)
  - SM analyses are OK;
  - No new FF;

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = (0.1 \pm 0.6)\cdot 10^{-3} \;=\; \mathbf{2\,\varepsilon_L} \;= 4\left(-\bar{\alpha}^{(3)}_{\varphi l} + \bar{\alpha}^{(3)}_{\varphi q} - \bar{\alpha}^{(3)}_{lq} + \bar{\alpha}^{(3)}_{ll}\right)$$

$$\Lambda_{NP} > 11\ \text{TeV}$$



Better than LEP & LHC bounds!

It should be part of any global EFT analysis.

[Cirigliano, MGA, Jenkins'2010]
[Cirigliano, MGA, Graesser'2012]

PS: Numbers have changed, but not much…

Flavor sym. considerations make CKM unitarity test special wrt the other NP searches.

CKM tests vs. HEP

[Cirigliano, MGA & Jenkins, Nucl. Phys B830 (2010)]

$$\Delta_{CKM} = 4\left(-\hat{\alpha}_{\varphi l}^{(3)} + \hat{\alpha}_{\varphi q}^{(3)} - \hat{\alpha}_{lq}^{(3)} + \hat{\alpha}_{ll}^{(3)}\right) = -(1 \pm 6)\cdot 10^{-4}$$

$$O_{ll}^{(3)} = \frac{1}{2}(\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{l}\gamma_{\mu}\sigma^{a}l)$$

$$O_{lq}^{(3)} = (\bar{l}\gamma^{\mu}\sigma^{a}l)(\bar{q}\gamma_{\mu}\sigma^{a}q)$$

$$O_{\varphi l}^{(3)} = i(h^{\dagger}D^{\mu}\sigma^{a}\varphi)(\bar{l}\gamma_{\mu}\sigma^{a}l) + \text{h.c.},$$

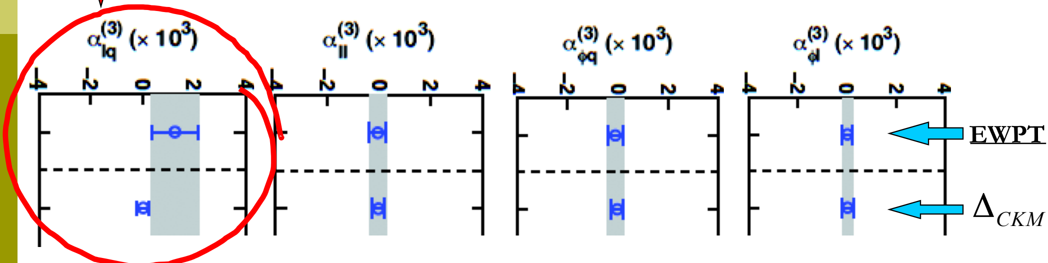
$$O_{\varphi q}^{(3)} = i(\varphi^{\dagger}D^{\mu}\sigma^{a}\varphi)(\bar{q}\gamma_{\mu}\sigma^{a}q) + \text{h.c.}$$

What did we know about them from LEP and other EWPT?

Han & Skiba, PRD71, 2005:

$$4\left(-\bar{\alpha}_{\varphi l}^{(3)} + \bar{\alpha}_{\varphi q}^{(3)} - \bar{\alpha}_{lq}^{(3)} + \bar{\alpha}_{ll}^{(3)}\right) = -(4.7 \pm 2.9)\cdot 10^{-3}$$

5 times less precise!



M. González-Alonso

NP effects in u→d l ν

Outline

- Introduction and motivation;
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- General flavor structure;

General flavor structure

$$\mathcal{L}_{d\to ue^-\bar{\nu}_e} = -\sqrt{2}G_F V_{ud}\left(1+\mathrm{Re}\left(\epsilon_L+\epsilon_R\right)\right)\left[\bar{e}_L\gamma_\mu\nu_L\cdot\bar{u}\left(\gamma^\mu - (1-2\epsilon_R)\gamma^\mu\gamma_5\right)d\right.$$
$$\left. + \ \epsilon_S\ \bar{e}_R\nu_L\cdot\bar{u}d - \ \epsilon_P\ \bar{e}_R\nu_L\cdot\bar{u}\gamma_5 d + 2\ \epsilon_T\ \bar{e}_R\sigma_{\mu\nu}\nu_L\cdot\bar{u}\sigma^{\mu\nu}d_L\right]$$

V & A gets "hidden" inside V_{ud}

$$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2-1=(0.1\pm0.6)\cdot 10^{-3}$$

(The real part) gets hidden in the corresponding axial-vector FF
(precise LQCD needed)

Diff. distr. altered;
SM analysis not valid;
New Form factors;
Channel dep. effects;

PS: All these low-E searches for non (V-A) effects are nothing but searches of $U(3)^5$ breaking effects!
These are probes of the NP flavor structure!

General flavor structure

$$\mathcal{L}_{d\to ue^-\bar\nu_e} = -\sqrt{2}G_F V_{ud}\Big(1+\mathrm{Re}\,(\epsilon_L+\epsilon_R)\Big)\Big[\bar e_L\gamma_\mu\nu_L\cdot\bar u\Big(\gamma^\mu - (1-2\epsilon_R)\gamma^\mu\gamma_5\Big)d$$
$$+\epsilon_S\ \bar e_R\nu_L\cdot\bar u d - \epsilon_P\ \bar e_R\nu_L\cdot\bar u\gamma_5 d + 2\ \epsilon_T\ \bar e_R\sigma_{\mu\nu}\nu_L\cdot\bar u\sigma^{\mu\nu}d_L\Big]$$

Example: searches of S & T interactions with beta decays;

$$\epsilon_S = -\frac{[V\,\hat\alpha^\dagger_{qde}]_{11}}{V_{ud}} - \frac{[\hat\alpha^\dagger_{lq}]_{11}}{V_{ud}}$$
$$\epsilon_T = -\frac{[\hat\alpha^{t\,\dagger}_{lq}]_{11}}{V_{ud}}$$

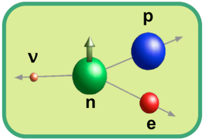
←

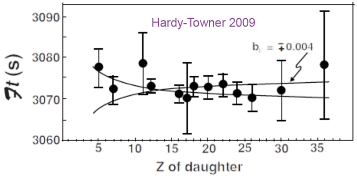
$$O_{qde} = (\bar l e)(\bar d q) + \text{h.c.}$$
$$O_{lq} = (\bar l_a e)\epsilon^{ab}(\bar q_b u) + \text{h.c.}$$
$$O^t_{lq} = (\bar l_a \sigma^{\mu\nu} e)\epsilon^{ab}(\bar q_b\sigma_{\mu\nu} u) + \text{h.c.}$$

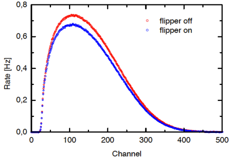
Searches of low-E (udeν) S & T interactions

$$\frac{d\Gamma(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} \sim \xi(E)\left\{1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + A\frac{\mathbf{p}_e}{E_e}\frac{\mathbf{J}}{J} + \left(B + b_B\frac{m_e}{E_e}\right)\frac{\mathbf{p}_\nu}{E_\nu}\frac{\mathbf{J}}{J}\right\}$$

$$\mathbf{b} = \#\, g_S\, \varepsilon_S + \#\, g_T\, \varepsilon_T$$







Clean powerful tree-level probes!

$\langle p|\bar{u}d|n\rangle \Rightarrow g_S$

$\langle p|\bar{u}\sigma_{\mu\nu}d|n\rangle \Rightarrow g_T$

How well do we know them?

Neutron

LANSCE (Los Alamos), ILL (Grenoble), J-PARC (Tokai), PNPI (Gatchina), FRM-II (Munich), SNS (Oak Ridge), NIST (Gaithersburg), PSI (Villigen), ...

Nuclei

TRIUMF (^{38m}K, ^{37}K), CERN (^{32}Ar), GANIL (^{35}Ar, ^{6}He), PSI (^{8}Li), Louvain-la-Neuve (^{14}O/^{10}C, ^{114}In, ^{60}Co), Groningen (^{26m}Al/^{30}K), Oak Ridge (^{6}He), Seattle (^{6}He), Princeton (^{19}Ne), ...

Searches of low-E (udeν) S & T

$b \sim g \times \varepsilon$

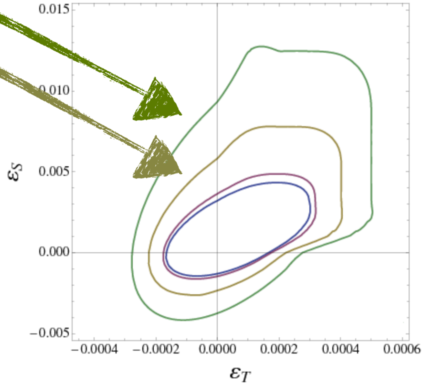
How well do we know g_S and g_T?

Is this precision OK?
How well do we need to know them?
(assuming $b_n < 0.001$)

	g_S	g_T
Adler et al.'1975 (quark model)	0.60(40)	1.45(85)
PNDME 2011	0.80(40)	1.05(35) *[average]*
÷2.5	*20%*	*13%*
÷5.0	*10%*	*7%*

$\delta g_S/g_S \sim 20\%$

$\delta g_T/g_T \sim 10\%$



[Bhattacharya, Cirigliano, Cohen, Filipuzzi, MGA, Graesser, Gupta, Lin, PRD85 (2012)]

Searches of low-E (udeν) S & T

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LHPC 2012	1.08(32)	1.04(02)
RQCD 2014	1.02(35)	1.01(02)
PNDME 2013/15	0.72(32)	1.02(08)
ETMC 2015	1.21(42)	1.03(06)
χQCD *2015*	$0.66(03)_{stat}$	-

$\delta g_S/g_S \sim 20\%$

$\delta g_T/g_T \sim 10\%$ ✓

"We quantify all syst. errors, including for the 1st time a simultaneous extrapolation in a, V & m_q"

PS: (Less precise) gT pheno det are also possible:
Active field, with more data in the near future…
[Gao et al., 2011, Goldstein et al, 2014, Courtoy et al, 2015]

$$g_T = \int \left(h_1^u(x) - h_1^d(x)\right) dx$$

Searches of low-E (udeν) S & T

b ~ g x ε

How well do we know g_S and g_T?

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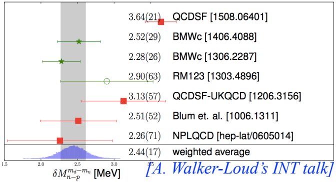
ETMC 2015	1.21(42)	1.03(06)
χQCD *2015*	$0.66(03)_{stat}$	-
CVC	0.97(10)	

Is this precision OK?
How well do we need to know them?
(assuming b_n < 0.001)

$\delta g_S/g_S \sim 20\%$ ✓

$\delta g_T/g_T \sim 10\%$ ✓



[A. Walker-Loud's INT talk]

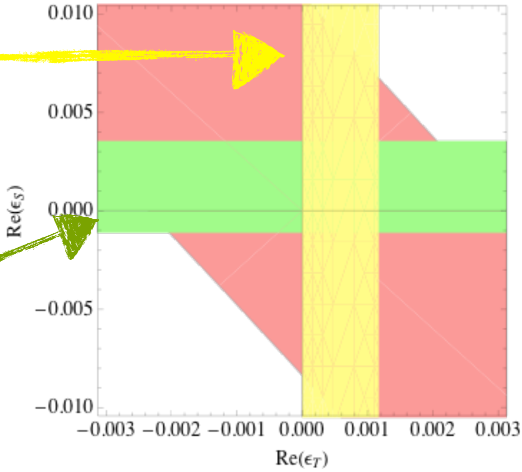
$$\partial_\mu \left(\bar{u}\gamma^\mu d\right) = -i(m_d - m_u)\bar{u}d$$

$$g_S = \frac{\left(M_n - M_p\right)_{QCD}}{m_d - m_u}\, g_V$$

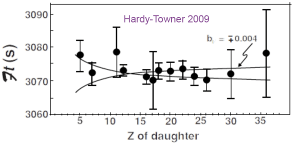
[MGA & Martin Camalich, Phys. Rev. Lett. 112 (2014)]

Current limits on S & T from low-E:

Global fit of nuclear & neutron β decay data.
[Wauters, Garcia & Hong, 2013]
[Pattie, Hickerson & Young, 2013]

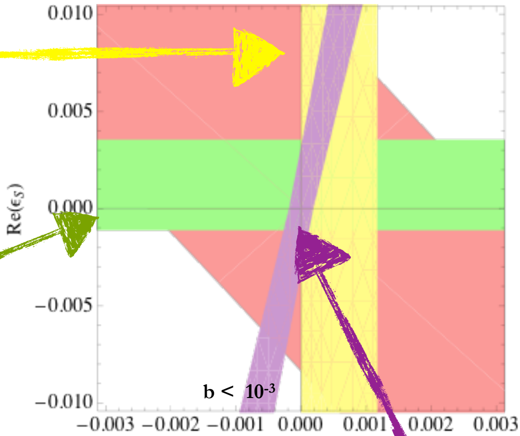


Superallowed nuclear β decays (b_{0+})

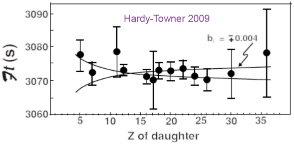


~~Current~~ Future limits on S & T from low-E:

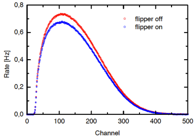
Global fit of nuclear & neutron β decay data.
[Wauters, Garcia & Hong, 2013]
[Pattie, Hickerson & Young, 2013]



Superallowed nuclear β decays (b_{0+})

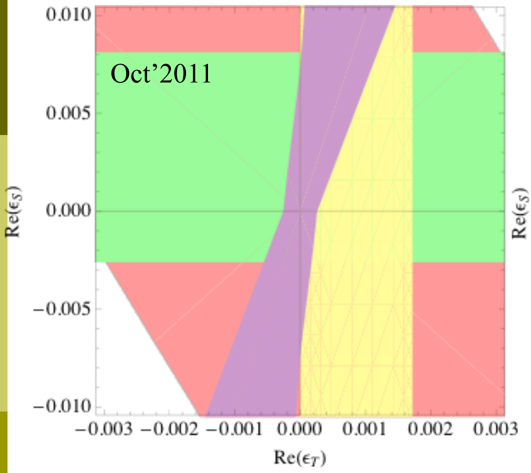


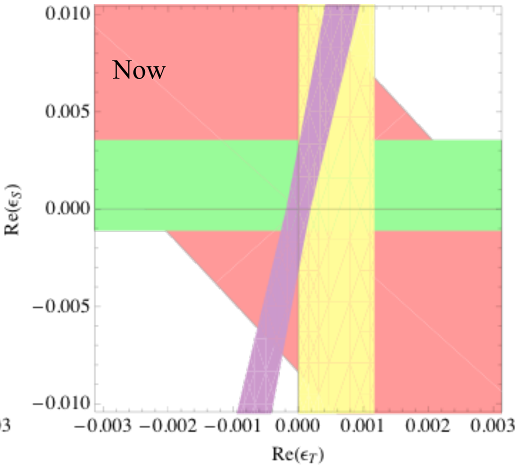
Future neutron decay exp.



$b \approx 0.3\, g_S\, \varepsilon_S - 5.0\, g_T\, \varepsilon_T$

~~Current~~ Future limits on S & T from low-E:



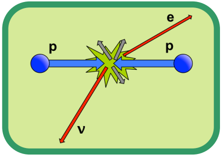


- We are benefiting here from the advance in the FF determinations!
- Conclusion: S,T are at least ~1000x weaker than the V-A Fermi interaction.

$$\varepsilon_i \sim \frac{M_W^2}{M_{NP}^2} \rightarrow M_{NP} \sim 2\text{ TeV}$$

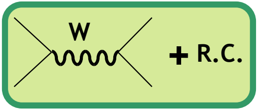
LHC limits on $\varepsilon_{S,T}$

[Bhattacharya et al'2012, Cirigliano, MGA, Graesser'2012]



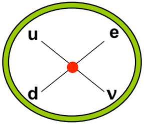
=

SM background



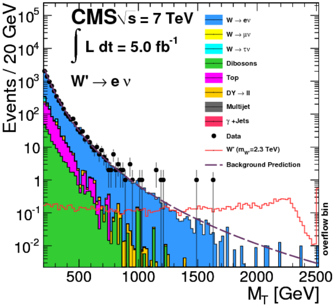
+

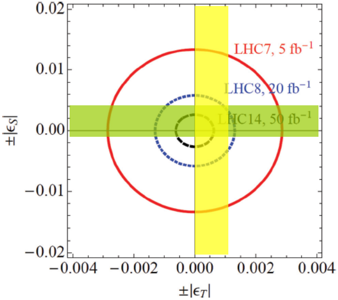
NP (EFT)



$$N_{pp\to e\nu X} = \varepsilon \times L \times \sigma_{pp\to e\nu X} \,|\!= \varepsilon \times L \times \left(\sigma_W + \sigma_S\, \varepsilon_S^2 + \sigma_T\, \varepsilon_T^2\right)$$

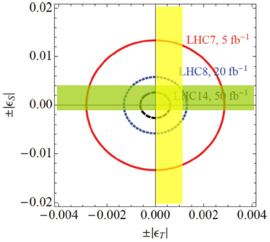
- Sensitive to many eff. operators; (good & bad… cancellations)
- Interference with SM ~ m/E (D=8 effects?)



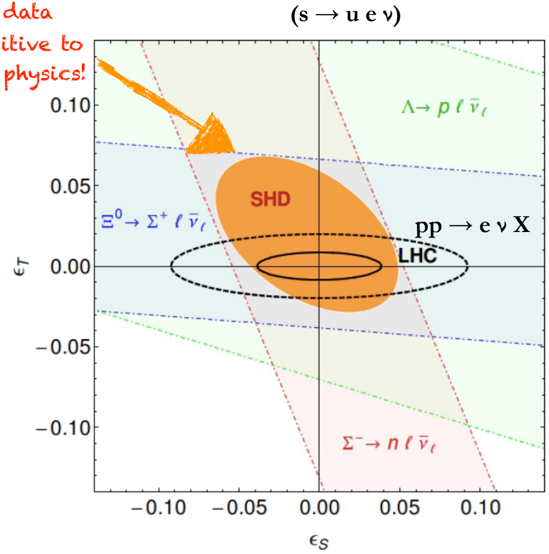


[MGA & Naviliat-Cuncic, 2013]

What about SL hyperon decays? (s → u e ν)



Old data sensitive to TeV physics!



δBR/BR

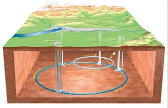
	e	μ
$\Lambda \to p\, \ell\, \nu$	*2 %*	*20 %*
$\Sigma^- \to n\, \ell\, \nu$	*3 %*	*10 %*
$\Xi^0 \to \Sigma^+ \ell\, \nu$	*4 %*	*15 %*
$\Xi^- \to \Lambda\, \ell\, \nu$	*6 %*	*100 %*

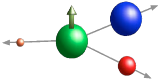
…

$$R^{\mu e} = \frac{\Gamma(B_1 \to B_2\, \mu^- \bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\, e^- \bar{\nu}_e)}$$

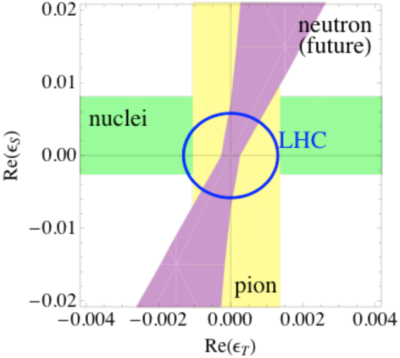
[Chang, MGA & Martin Camalich, PRL114 (2015)*]*

Conclusions





- EFT analysis of $d_i \to u_i\, l_k\, \nu_l$
  - $U(3)^5$: CKM unitarity tests as a unique TeV probe;
  - Beyond $U(3)^5$:
    - Diff. distributions (channel dep.);
    - New FF;
    - Examples:
      - Beta decays;
      - Hyperon decays;



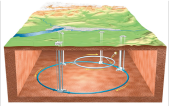
- This interplay becomes much more interesting if we see a NP signal!

Backup slides

Eff. Lagrangians

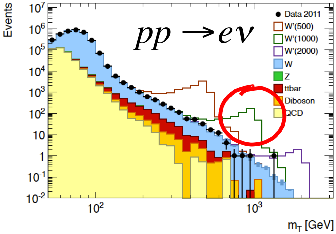
$$
\begin{aligned}
\mathcal{L}_{\rm CC} = -\frac{G_F^{(0)} V_{ud}}{\sqrt{2}} \Big[& \Big(\delta_{e\ell} + \epsilon_L\Big) \bar{e}\gamma_\mu (1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu (1-\gamma_5) d \\
& + \tilde{\epsilon}_L \bar{e}\gamma_\mu (1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu (1-\gamma_5) d \\
& + \epsilon_R \bar{e}\gamma_\mu (1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu (1+\gamma_5) d + \tilde{\epsilon}_R \bar{e}\gamma_\mu (1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma^\mu (1+\gamma_5) d \\
& + \epsilon_S \bar{e}(1-\gamma_5)\nu_\ell \cdot \bar{u} d + \tilde{\epsilon}_S \bar{e}(1+\gamma_5)\nu_\ell \cdot \bar{u} d \\
& - \epsilon_P \bar{e}(1-\gamma_5)\nu_\ell \cdot \bar{u}\gamma_5 d - \tilde{\epsilon}_P \bar{e}(1+\gamma_5)\nu_\ell \cdot \bar{u}\gamma_5 d \\
& + \epsilon_T \bar{e}\sigma_{\mu\nu} (1-\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu} (1-\gamma_5) d + \tilde{\epsilon}_T \bar{e}\sigma_{\mu\nu} (1+\gamma_5)\nu_\ell \cdot \bar{u}\sigma^{\mu\nu} (1+\gamma_5) d \Big]
\end{aligned}
$$

Scalar resonance



- What if we see a bump? EFT breaks down…
  TOY model: scalar resonance:

$$\mathcal{L} = \lambda_S V_{ud} \phi^+ \overline{u} d + \lambda_l \phi^- \overline{e} P_L \nu_e$$



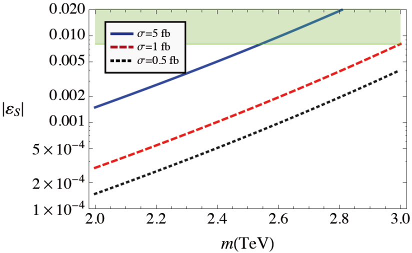
- Then we have a lower-limit value for ε_S:

$$\sigma \cdot \mathrm{BR} \leq \frac{|V_{ud}|}{12 v^2} \frac{\pi}{\sqrt{2N_c}} |\epsilon_S| \tau L(\tau)$$

$$L(\tau) = \int_\tau^1 dx f_q(x) f_q'(\tau/x)/x$$

$$\tau = m^2/s$$

$$\epsilon_S = 2\lambda_S \lambda_l \frac{v^2}{m^2}$$



Nice interplay of two experiments separated for so many orders of magnitudes!!!!

[T. Battacharya et al., 2012]

What about SL hyperon decays? ($s \to u\, e\, \nu$)

Differences with neutron decay

- Completely different exp. facility;
- BR are tiny (hadronic modes open);
- (Mainly) data from 70s-80s;
- SU(2) → SU(3)
  $\delta = \Delta M/M \sim 0.001 \to$ 10-20%
- Muon channel open!
- 12 different channels (with diff. NP dependencies)
- New FFs (even in the SU(3) limit);
- S,P,T term $\sim m_\ell/q \to$ Tiny effects in the e-modes (useful for SM)

⇒ Theory at NLO is also OK here!
Error ~ NNLO ~ δ^2 ~ 1-5%

$\delta BR/BR$

	e	μ
$\Lambda \to p\, \ell\, \nu$	*2 %*	*20 %*
$\Sigma^- \to n\, \ell\, \nu$	*3 %*	*10 %*
$\Xi^0 \to \Sigma^+\, \ell\, \nu$	*4 %*	*15 %*
$\Xi^- \to \Lambda\, \ell\, \nu$	*6 %*	*100 %*
…		

NOTE:
Let's forget for now about kaons…

[*Chang, MGA & Martin Camalich*, PRL114 (2015)]

What about SL hyperon decays? (s → u e ν)

$$R^{\mu e} = \frac{\Gamma(B_1 \to B_2\,\mu^-\,\bar{\nu}_\mu)}{\Gamma(B_1 \to B_2\,e^-\,\bar{\nu}_e)}$$

Illustrative & very simple observable:

$$R^{\mu e}_{\rm SM} = \sqrt{1-\frac{m_\mu^2}{\Delta^2}}\left(1-\frac{9}{2}\frac{m_\mu^2}{\Delta^2}-4\frac{m_\mu^4}{\Delta^4}\right)+\frac{15}{2}\frac{m_\mu^4}{\Delta^4}\,\mathrm{arctanh}\left(\sqrt{1-\frac{m_\mu^2}{\Delta^2}}\right)$$

No FFs! (at NLO)

$$R^{\mu e}_{\rm NP} \simeq \frac{\left(\epsilon_S\frac{f_S(0)}{f_1(0)}+12\,\epsilon_T\,\frac{g_1(0)}{f_1(0)}\frac{f_T(0)}{f_1(0)}\right)}{\left(1-\frac{3}{2}\delta\right)\left(1+3\frac{g_1(0)^2}{f_1(0)^2}\right)}\,\Pi(\Delta, m_\mu)$$

Scalar charges: CVC!

Tensor charges?

In the SU(3) limit you only need two:

- g_T (n→p)
- One more!

Only model calculations available, LQCD desirable!

Future?

- Better measurements (mu-modes); NA62? PANDA? …
- Theory: include next SU(3) corrections;
- Lattice: g_T
- Use more observables!

[Chang, MGA & Martin Camalich, PRL114 (2015)]

What about SL hyperon decays? $(s \to u\, e\, \nu)$

& what about SL kaon decays?

Strong limits on BSM($s \to u\, e\, \nu$)… 1-0.1% level, but SL hyperon decays are complementary because…

- Limits using old hyperon data are fairly strong…
- Phase space in K is huge ($q \not\ll M$)… no expansion, but parameterizations; Notice that the only effect of tensor interaction is a distortion of the shape!
- Scalar gets hidden in the f(0)… ways out: LQCD.
- No global analysis available? Complementarity looks probable…

[Chang, MGA & Martin Camalich, PRL114 (2015)*]*