Sensitivity of Neutron Beta Decay Observables to BSM Interactions

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Introduction

Part A: Neutron β–Decay

- Introduction
- Lifetime, Correlation Coefficients, Experimental Asymmetries
- SM next-to-leading order

Part B: Matrix Element V_{ud}

- Extraction from Neutron β–Decay
- Current Results

Part C: BSM

- Phenomenological Coupling Constants
- Access via Correlation Coefficients $\&$ CKM Unitarity

"Part A: Neutron β–Decay"

Different Kinds of Neutron Decays

Continuum State β^-- decay

$$n \longrightarrow p + e + \bar{\nu}_e$$

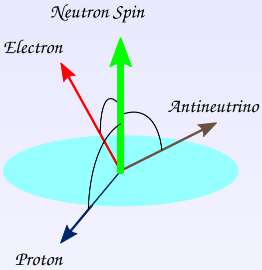
Bound State β^-- decay

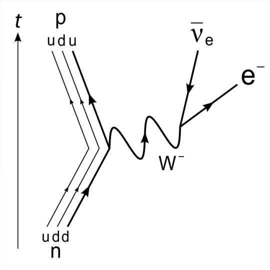
$$n \longrightarrow H + \bar{\nu}_e$$

Radiative β^-- decay

- $$n \longrightarrow p + e + \bar{\nu}_e + \gamma$$
- $$n \longrightarrow H + \bar{\nu}_e + \gamma$$

Kinematics of Continuum β^-- Decay





Conservation of four-momentum k^μ

$$m_n = E_p + E_e + E_\nu$$
$$\vec{0} = \vec{k}_p + \vec{k}_e + \vec{k}_\nu$$

Final state d.o.f.: 5

$$q = m_n - m_p - m_e = 0.782 \text{ MeV}$$

$$E_{max} = \frac{m_n^2 - m_p^2 + m_e^2}{2m_n} = 1.2927 \text{ MeV}$$

$$\begin{aligned} m_n &= 939.5654 \text{ MeV} \\ m_p &= 938.2720 \text{ MeV} \\ m_e &= 0.5110 \text{ MeV} \\ m_{\bar{\nu}_e} &= 0 \text{ MeV} \end{aligned}$$

Standard $V - A$ Theory of Weak Interactions

"Hadronic" Lagrangian of $V - A$ Weak Interactions

$$\mathcal{L}_W(x) = -\frac{G_F}{\sqrt{2}} V_{ud} \, [\bar{\psi}_p(x)\gamma_\mu(1 + \lambda\gamma^5)\psi_n(x)] \, [\bar{\psi}_e(x)\gamma^\mu(1 - \gamma^5)\psi_{\bar{\nu}_e}(x)]$$
$$= -\frac{1}{\sqrt{2}} \, [\bar{\psi}_p(x)\gamma_\mu(g_V + g_A\gamma^5)\psi_n(x)] \, [\bar{\psi}_e(x)\gamma^\mu(1 - \gamma^5)\psi_{\bar{\nu}_e}(x)]$$

with $g_V = G_F V_{ud}$ & $g_A = G_F V_{ud} \lambda$

Parameters of Weak Interactions

- Fermi Constant: $G_F = \dfrac{g_W^2}{8 m_W^2} = 1.1664 \times 10^{-11}\,\mathrm{MeV}^{-2}$
- CKM Matrix Element: $V_{ud} = 0.97425(22)$

  K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)
- Axial-to-Vector Coupling Ratio: $\lambda = -1.2723(23)$

  K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

"The Neutron Alphabet"

$$\frac{d^5\Gamma(\sigma_n)}{dE_e d^2\Omega_e d^2\Omega_\nu} = \xi(E_e)\left\{1 + a\,\frac{\vec{k}_e\cdot\vec{k}_\nu}{E_e E_\nu} + A\,\frac{\vec{\xi}_n\cdot\vec{k}_e}{E_e} + B\,\frac{\vec{\xi}_n\cdot\vec{k}_\nu}{E_\nu}\right\}$$

$$\xi(E_e) = \frac{G_F^2 V_{ud}^2}{32\pi^5}(E_0 - E_e)^2\sqrt{E_e^2 - m_e^2}\,E_e\,F(E_e, Z = 1)(1 + 3\lambda^2)$$

$$\frac{d^5\Gamma(\sigma_e)}{dE_e d^2\Omega_e d^2\Omega_\nu} = a, G, H, K$$

$$\frac{d^3\Gamma(\sigma_n, \sigma_e)}{dE_e d^2\Omega_e} = A, G, N, Q$$

- extensive literature (JTW '57, ...)
- many different notations

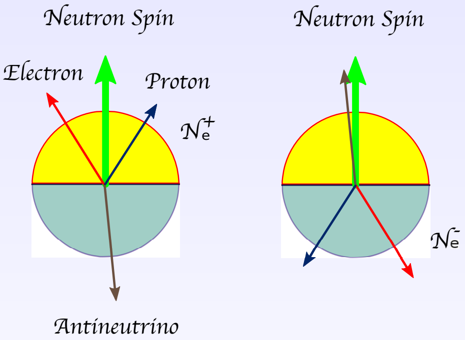
"The Neutron Alphabet"

The "Standard" Correlation Coefficients are

$$
\begin{aligned}
a &= \frac{1-\lambda^2}{1+3\lambda^2} \simeq -0.10 \\
A &= -2\lambda\,\frac{1+\lambda}{1+3\lambda^2} \simeq -0.12 \\
B &= -2\lambda\,\frac{1-\lambda}{1+3\lambda^2} \simeq 0.98 \\
&\ldots
\end{aligned}
$$

- Suppose we could *"switch off"* hadronic effects (perfect $V-A$ with "$\lambda=-1$" - compare to quark level)
- Deviation of a, A from 0 and B from 1 is due to hadronization

Experimental Asymmetries



$$A^{\beta}_{\text{exp}}(E_e) = \frac{N_e^+ - N_e^-}{N_e^+ + N_e^-}\,, \qquad \text{with} \qquad N_e^{\pm}(E_e) = \begin{cases} 2\pi \int_0^1 d(\cos\theta_e) \int_{[4\pi]} d\Omega_\nu \, d\Gamma \\ 2\pi \int_{-1}^0 d(\cos\theta_e) \int_{[4\pi]} d\Omega_\nu \, d\Gamma \end{cases}$$

$$A^{\nu}_{\text{exp}}(E_e) = \frac{N_\nu^+ - N_\nu^-}{N_\nu^+ + N_\nu^-}\,, \qquad \text{with} \qquad N_\nu^{\pm}(E_e) = \begin{cases} 2\pi \int_0^1 d(\cos\theta_\nu) \int_{[4\pi]} d\Omega_e \, d\Gamma \\ 2\pi \int_{-1}^0 d(\cos\theta_\nu) \int_{[4\pi]} d\Omega_e \, d\Gamma \end{cases}$$

The SM Leading Order Uncertainties

All *Correlation Coefficients* (a, A, B, G, H, K, N, Q) are only functions of λ (and m_e, E_e in the case H, N)

experimental uncertainty of λ $(\sim 10^{-3})$ leads to the only real *"theoretical" uncertainty*

A, N, Q have *highest sensitivity* with respect to λ

$\Longrightarrow$ A used for experimental determination

$\Longrightarrow$ *"theoretical" uncertainty* matches experimental one for A, N, Q and is even *higher* for the other correlation coefficients

Standard $V-A$ Theory of Weak Interactions

Inverse Lifetime of Free Neutron

$$
\begin{aligned}
\tau_n^{-1} &= \frac{1}{2} \sum_{\sigma_n=\pm} \int_{m_e}^{E_{max}} dE_e \int_{[4\pi]} d^2\Omega_e \int_{[4\pi]} d^2\Omega_{\bar{\nu}} \, \frac{d^5\Gamma(\sigma_n)}{dE_e d^2\Omega_e d^2\Omega_\nu} \\
&= (1+3\lambda^2)\, \frac{G_F^2 V_{ud}^2}{2\pi^3} f(E_{max}, Z=1)
\end{aligned}
$$

with the Fermi Integral

$$
\begin{aligned}
f(E_{max}, Z=1) &= \int_{m_e}^{E_{max}} dE_e \sqrt{E_e^2 - m_e^2}\,(E_{max}-E_e)^2 E_e\, F(E_e, Z=1) \\
&= 2\pi\alpha \int_{m_e}^{E_{max}} dE_e \, \frac{(E_{max}-E_e)^2 E_e^2}{1 - e^{-2\pi\alpha E_e/\sqrt{E_e^2-m_e^2}}} \\
&= 0.0588\,\mathrm{MeV}^5
\end{aligned}
$$

[1]Some experimental values for the Lifetime and λ

Lifetime τ [s]	Document ID	Year
880.3 ± 1.1	PDG Average Value	2014
$887.7 \pm 1.2 \pm 1.9$	YUE	2013
$881.6 \pm 0.8 \pm 1.9$	ARZUMANOV	2012
$882.5 \pm 1.4 \pm 1.5$	STEYERL	2012
$880.7 \pm 1.3 \pm 1.2$	PICHLMAIER	2010
$878.5 \pm 0.7 \pm 0.3$	SEREBROV	2005
$889.2 \pm 3.0 \pm 3.8$	BYRNE	1996
882.6 ± 2.7	MAMPE	1993

[1]taken from K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

[2]Some experimental values for the Lifetime and λ

$\lambda \equiv g_A/g_V$	**Document ID**	**Year**
-1.2723 ± 0.0023	PDG Average Value	2014
-1.2755 ± 0.0030	MENDENHALL	2013
$-1.2748 \pm 0.0008^{+0.0010}_{-0.0011}$	MUND	2013
$-1.275 \pm 0.006 \pm 0.015$	SCHUMANN	2008
$-1.2686 \pm 0.0046 \pm 0.0007$	MOSTOVOI	2001
-1.266 ± 0.004	LIAUD	1997
-1.2594 ± 0.0038	YEROZOLIMSKY	1997
-1.262 ± 0.005	BOPP	1986

[2]taken from K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

The SM Next-to-Leading Order Contributions

2 independent Expansion Parameters

1. $q/M \sim 10^{-3}$
2. $\alpha/2\pi \sim 10^{-3}$

Neglecting SM terms: $(q/M)^2, (q/M)\alpha/2\pi, (\alpha/2\pi)^2 \sim 10^{-6}$
BUT numerical factors can vary quite strong

New SM Physics Effects appearing in NLO

1. Proton Recoil
2. Weak Magnetism
3. Radiative Corrections

Additional Correlation Coefficients

- SM next-to-leading order
- new physics?

1. Proton Recoil

SM leading-order

$$\psi_p(x) \sim \begin{pmatrix} 1 \\ 0 \end{pmatrix} \otimes \sigma_p$$

$\Longrightarrow$ **no proton recoil** (i.e. neutron and proton are "static")

Next-to-leading-order

$$\psi_p(x) \sim \begin{pmatrix} 1 \\ \frac{\vec{\sigma}\cdot\vec{k}}{E+M} \end{pmatrix} \otimes \sigma_p$$

$\Longrightarrow$ **proton recoil** (recoil of the proton gives $\mathcal{O}(q/M)$ contribution)

Theoretical Uncertainty due to PR is completely negligible

2. Weak Magnetism

Effective Lagrangian

$$\mathcal{L}_{WM}(x) = -\frac{G_F V_{ud}}{\sqrt{2}} \frac{\mu}{2M} \partial^\nu [\bar{\psi}_p(x)\sigma_{\mu\nu}\psi_n(x)][\bar{\psi}_e(x)\gamma^\mu(1-\gamma^5)\psi_{\bar{\nu}_e}(x)]$$

with additional parameter

$$\mu = \mu_p - \mu_n = 1.7928 + 1.9130 = 3.7058$$

- $\mathcal{O}(q/M)$ effect
- experimental uncertainty of $\mu_{n,p} \sim 10^{-7} - 10^{-8}$

Theoretical Uncertainty due to WM is completely negligible

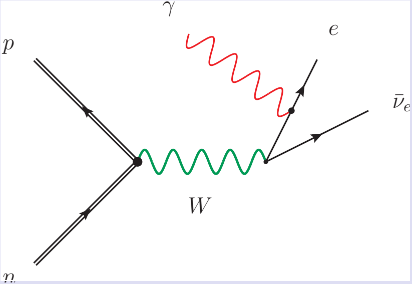
3. Radiative Corrections

All Observables (Lifetime, Correlation Coefficients) obtain Radiative Corrections due to the

- Emission of Real Photons *(Bremsstrahlung)*
- Exchange of Virtual Photons and Z-bosons

To leading order in α the principal graphs are

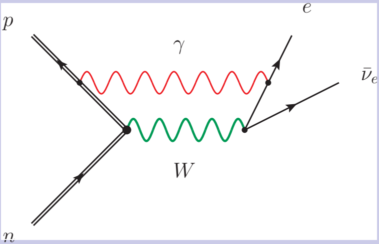
1. One γ *Bremsstrahlung* (mainly from the lepton)



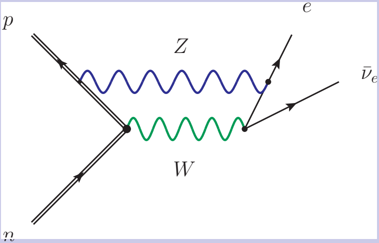
3. Radiative Corrections

To leading order in α the principal graphs are

2. γW-box



3. ZW-box graphs



3. Radiative Corrections

Following Marciano & Sirlin one splits $\sim$ 1 GeV into

1. Low-energy part

1. *Bremsstrahlung*
2. Low-energy part of γW

IR-divergences of 1 + 2 cancel
requires *model calculation* of the *hadronic structure*

2. High-energy part

1. ZW
2. High-energy part of γW

Using *free-quark Lagrangian* neglecting the *hadronic structure*

QCD corrections have to be added

3. Radiative Corrections

- *"bare values"* $G_F^0 V_{ud}^0$ and λ^0 are *per se unobservable*,
  - extraction hard due to the *"dirty" hadronic RC*
  (important only for comparison with other physical systems $\sim G_F^\mu$)
- *"bare" Correlation Coefficients* can be extracted easily due to *well-know RC* $\delta_\alpha^{(2)}$ (up to λ)
  $\Longrightarrow$ *Correlation Coefficients* well suited for search for **BSM**

$$\delta_\alpha^{(2)} = \frac{1-\beta^2}{\beta}\ln\left(\frac{1+\beta}{1-\beta}\right) + \left(\frac{E_0-E_e}{E_e}\right)\frac{4(1-\beta^2)}{3\beta^2}\left[\frac{1}{2\beta}\ln\left(\frac{1+\beta}{1-\beta}\right)-1\right]$$
$$+\left(\frac{E_0-E_e}{E_e}\right)^2\frac{1}{6\beta^2}\left[\frac{1-\beta^2}{2\beta}\ln\left(\frac{1+\beta}{1-\beta}\right)-1\right] \quad \text{with} \quad \beta = \frac{|\vec{k}_e|}{E_e}$$

1. model-independent
2. depends only on the *kinematics* of the electron
3. **uncertainties are completely negligible**

"Part B: Matrix Element V_{ud}"

CKM Matrix

Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix is *central pillar* of the *Electroweak Standard Model*

Any deviation from *unitarity* would signal presence of *"new physics" beyond the Standard Model*, i.e. non *$V-A$ interactions* or *fourth quark generation*

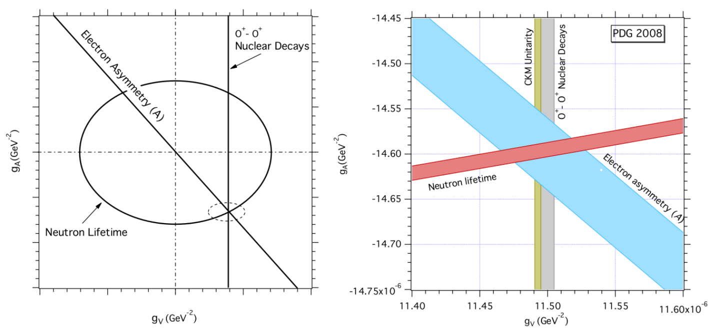
To date, best precision is obtained in the top-row test (with precision of 0.06%)

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

based on measurements of *superallowed* $0^+ \to 0^+$ *nuclear β–decay* and of *kaon semileptonic and leptonic decays*

[a]Lifetime, λ and super allowed $0^+ \to 0^+$ nuclear decays as functions from g_V and g_A

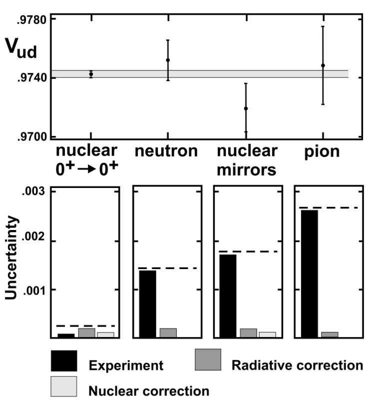
[a]taken from J S Nico, J. Phys. G: Nucl. Part. Phys. **36** (2009) 104001



$$\tau_n^{-1} = \frac{f}{K}\left(g_V^2 + 3g_A^2\right) \quad \& \quad \lambda \equiv \frac{g_A}{g_V} \quad \text{with} \quad K = \frac{2\pi^3\hbar^7}{m_e^5 c^4}$$

$$|V_{ud}|^2 = \frac{1}{f(1+\delta_R)\tau_n} \frac{K}{G_F^2(1+\Delta_R^V)(1+3\lambda^2)} = \frac{4908.7(1.9)\,s}{\tau_n(1+3\lambda^2)}$$

[3]Four Values for V_{ud}



<u>**Nuclear** $0^+ \rightarrow 0^+$</u>

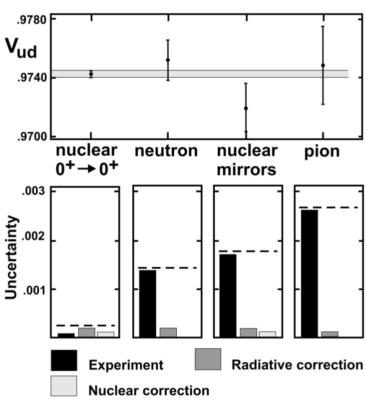
pro: only *vector current* involved - *CVC*, small exp. uncertainty

con: *isospin-symmetry breaking*, RC, nuclear structure

$\Rightarrow$ certainly the most precise current determination of V_{ud}

[3]taken from J. C. Hardy and I. S. Towner, Ann. Phys. (Berlin), No. 7 (2013)

[4]Four Values for V_{ud}



Neutron β–Decay

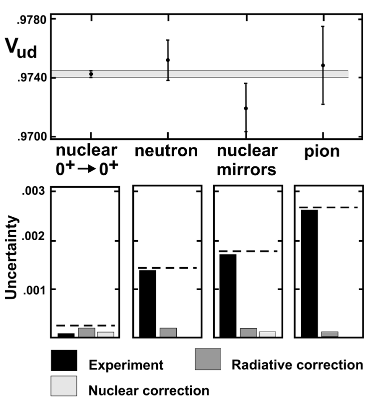
pro: no *isospin-symmetry breaking* $\&$ nuclear structure

con: difficult to confine, also *axial-vector current* involved $\Rightarrow$ need λ which introduces big *exp. uncertainties*

$\Rightarrow$ *uncertainty* still more than six times **nuclear** $0^+ \to 0^+$, intrinsically *small corrections* $\to$ promising future

[4]taken from J. C. Hardy and I. S. Towner, Ann. Phys. (Berlin), No. 7 (2013)

[5]Four Values for V_{ud}

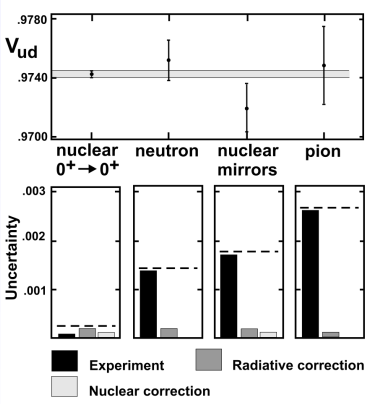


Nuclear $T = 1/2$ Mirror Decays

con: involves *axial vector current*
$\Rightarrow$ need λ, nuclear structure dependent corrections

[5]taken from J. C. Hardy and I. S. Towner, Ann. Phys. (Berlin), No. 7 (2013)

[6]Four Values for V_{ud}



Pion β–Decay

pro: only *vector decay current*, *uncontaminated* by nuclear-structure uncertainties

con: *branching ratio* is very small ($\sim 10^{-8}$) and *difficult to measure* with sufficient precision

$\Rightarrow$ *in principle* the best way to determine V_{ud}, but *insufficient precision*

[6]taken from J. C. Hardy and I. S. Towner, Ann. Phys. (Berlin), No. 7 (2013)

Current Status

Taken from K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

Currently (2014) there is *2 sigma disagreement* for V_{ud} obtained by

1. Superallowed $0^+ \rightarrow 0^+$ Nuclear β–Decay

$$V_{ud} = 0.97425(8)_{exp.}(10)_{nucl.dep.}(18)_{RC}$$

2. Neutron β–Decay

$$V_{ud} = 0.9774(5)_{\tau_n}(16)_{\lambda}(2)_{RC}$$

with $\tau_n^{ave} = 880.0(0.9) \quad \& \quad \lambda^{ave} = -1.2701(25)$

This points towards *higher values* of λ and/or τ_n

"Part C: BSM"

Effective Hamiltonian

Most general (hadronic) effective low-energy weak Hamiltonian

$$\mathcal{H}_W(x) = \frac{G_F}{\sqrt{2}} V_{ud} \Big\{ [\bar{\psi}_p(x)\gamma_\mu \psi_n(x)][\bar{\psi}_e(x)\gamma^\mu (C_V + \bar{C}_V\gamma^5)\psi_{\nu_e}(x)]$$
$$+ [\bar{\psi}_p(x)\gamma_\mu\gamma^5 \psi_n(x)][\bar{\psi}_e(x)\gamma^\mu (\bar{C}_A + C_A\gamma^5)\psi_{\nu_e}(x)]$$
$$+ [\bar{\psi}_p(x)\psi_n(x)][\bar{\psi}_e(x)(C_S + \bar{C}_S\gamma^5)\psi_{\nu_e}(x)]$$
$$+ \frac{1}{2}[\bar{\psi}_p(x)\sigma^{\mu\nu}\gamma^5 \psi_n(x)][\bar{\psi}_e(x)\sigma_{\mu\nu}(\bar{C}_T + C_T\gamma^5)\psi_{\nu_e}(x)] \Big\}$$

Possible *pseudo-scalar interactions* are *suppressed* ($\sim 10^{-6}$) and hence *neglected*

with

$$C_V = 1 + \delta C_V$$
$$\bar{C}_V = -1 + \bar{\delta} C_V$$
$$C_A = -\lambda + \delta C_A$$
$$\bar{C}_A = \lambda + \bar{\delta} C_A$$

Correlation Coefficients

Differential Decay Rate

$$\frac{d^5\Gamma(\sigma_n)}{dE_e d^2\Omega_e d^2\Omega_\nu} =$$

$$= \xi(E_e)\left\{1 + b\,\frac{m_e}{E_e} + a\,\frac{\vec{k}_e\cdot\vec{k}}{E_eE} + A\,\frac{\vec{\xi}_n\cdot\vec{k}_e}{E_e} + B\,\frac{\vec{\xi}_n\cdot\vec{k}}{E} + D\,\frac{\vec{\xi}_n\cdot(\vec{k}_e\times\vec{k})}{E_eE}\right\}$$

$$\xi(E_e) = \frac{G_F^2 V_{ud}^2}{32\pi^5}\,(E_0 - E_e)^2\sqrt{E_e^2 - m_e^2}\,E_e\,F(E_e, Z=1)(1+3\lambda^2)$$

$$\times\left\{1 + \frac{1}{1+3\lambda^2}\left(\mathrm{Re}(\delta C_V - \delta\bar{C}_V) - 3\lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\right)\right\}$$

$$a = a_{SM} + \frac{1}{1+3\lambda^2}\left\{\mathrm{Re}(\delta C_V - \delta\bar{C}_V) + \lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\right.$$

$$\left. - a_0\left(\mathrm{Re}(\delta C_V - \delta\bar{C}_V) - 3\lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\right)\right\}$$

$$b = \frac{1}{1+3\lambda^2}\left\{\mathrm{Re}(C_S - \bar{C}_S) + 3\lambda\,\mathrm{Re}(C_T - \bar{C}_T)\right\}$$

Correlation Coefficients

$$A = A_{SM} + \frac{1}{1+3\lambda^2}\Big\{-\lambda\,\mathrm{Re}(\delta C_V - \delta\bar{C}_V) + (1+2\lambda)\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)$$
$$- A_0\Big(\mathrm{Re}(\delta C_V - \delta\bar{C}_V) - 3\lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\Big)\Big\}$$

$$B = B_{SM} + \frac{1}{1+3\lambda^2}\Big\{-\lambda\,\mathrm{Re}(\delta C_V - \delta\bar{C}_V) + (1-2\lambda)\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)$$
$$- B_0\Big(\mathrm{Re}(\delta C_V - \delta\bar{C}_V) - 3\lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\Big)$$
$$- \Big(\lambda\,\mathrm{Re}(C_S - \bar{C}_S) + (1-2\lambda)\,\mathrm{Re}(C_T - \bar{C}_T)\Big)\frac{m_e}{E_e}\Big\}$$

$$D = -\frac{1}{1+3\lambda^2}\Big\{\lambda\,\mathrm{Im}(\delta C_V - \delta\bar{C}_V) + \mathrm{Im}(\delta C_A - \delta\bar{C}_A)\Big\}$$

Lifetime

$$\tau_n^{-1} = (\tau_n^{-1})_{SM}$$
$$\times\Big\{1 + \frac{1}{1+3\lambda^2}\Big(\mathrm{Re}(\delta C_V - \delta\bar{C}_V) - 3\lambda\,\mathrm{Re}(\delta C_A - \delta\bar{C}_A)\Big) + b\left\langle\frac{m_e}{E_e}\right\rangle\Big\}$$

Experimental Access

To *linear order* one can express the Hamiltonian in terms of the *effective couplings*

$$\lambda_{\text{eff}} = \lambda \left(1 - \frac{1}{2}\mathrm{Re}(\delta C_V - \delta \bar{C}_V)\right) - \frac{1}{2}\mathrm{Re}(\delta C_A - \delta \bar{C}_A)$$

$$(V_{ud})_{\text{eff}} = V_{ud} \left(1 + \frac{1}{2}\mathrm{Re}(\delta C_V - \delta \bar{C}_V)\right)$$

After this redefinition δC_V, $\delta \bar{C}_V$, δC_A, $\delta \bar{C}_A$ do **not appear** explicitly in the linearised Hamiltonian

This implies

1. $\mathrm{Re}(\delta C_V - \delta \bar{C}_V)$ only accessible via **CKM unitarity tests**
2. $\mathrm{Re}(\delta C_A - \delta \bar{C}_A)$ only accessible via **QCD calculation**

Experimental Access

Neutron β–Decay

provides to *leading order*

- **partial access** to *scalar interactions* (only "$C_S - \bar{C}_S$" for ν_L)
- **no access** to *pseudo-scalar interactions* (vs. pion decay. . .)
- **partial access** to *tensor interactions* (only "$C_T - \bar{C}_T$" for ν_L)

All *experimental asymmetries* can be expressed in terms of
$C_V, \bar{C}_V, C_A, \bar{C}_A, C_S, \bar{C}_S, C_T, \bar{C}_T$

for explicit expressions see

- *A.N. Ivanov, M.P., N.I. Troitskaya:* Phys. Rev. D **88**, 073002 (2013)
- *A.N. Ivanov, M.P., N.I. Troitskaya:* arXiv:1212.0332 [hep-ph]

Summary & Outlook

Summary

- The *SM Corrections* to leading order are well known (The theoretical uncertainties are *rather small*)
- **CKM unitarity** is crucial for the extraction of **BSM**

Outlook

- SM to *next-to-leading order* (proton recoil, weak magnetism, RC) for *"non-Standard" Correlation Coefficients* have still to be derived
- experimental improvements on λ and τ are most important to extract V_{ud} from Neutron β–Decay
- *hadronic couplings* C_V, $\bar{C}_V$, C_A, $\bar{C}_A$, C_S, $\bar{C}_S$, C_T, $\bar{C}_T$ have to be related to the corresponding *quark couplings (form factors)* in order to put bounds on *parameters* of *high-energy physics models* (MSSM, leptoquarks, . . .)

The results, expounded in this talk, are obtained in Collaboration with

- Hartmut Abele – TU Wien
- Andrei Ivanov – TU Wien

Thank You For Your Attention!