Search for physics beyond the Standard Model with radioactive beams

Dinko Atanasov
dinko.atanasov@cern.ch
CERN, Experimental Physics department

on behalf of
the WISArD collaboration
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- The WISArD experiment at ISOLDE/CERN
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Standard Model and New Physics

Standard Model (SM)

Image Credits: Philippe Mouche (https://cds.cern.ch/record/1708847), ESA and the Planck Collaboration
Standard Model and New Physics

Standard Model (SM) + New Physics (beyond SM)

Energy frontier
- LHC…

Precision frontier
- Nuclear beta decay

Cosmic frontier
- Planck…

Julia Woithe, Gerfried J Wiener and Frederik F Van der Veken Phys. Educ. 52 (2017) 034001

Image Credits: Philippe Mouche (https://cds.cern.ch/record/1708847), ESA and the Planck Collaboration
Weak interaction in the Standard Model

Present structure:

* Vector-Axial Vector interaction  \( C_V = 1; \quad C_A = -1.27 \) (\( C_A/C_V \) from n-decay)
* maximal parity violation  \( C_V' = C_V \quad \& \quad C_A' = C_A \)
* no Scalar (S) or Tensor (T) components  \( C_S = C_S' = C_T = C_T' = C_P = C_P' = 0 \)
* no time reversal violation \\

all C’s are real

(Except for the CP-violation included in the CKM matrix)

New Physics:

* experimental upper limits for  \( \left| \frac{C_S}{C_V} \right| \) and  \( \left| \frac{C_T}{C_A} \right| \) at few % level

(neutron and nuclear \( \beta \)-decay)

* Extending the limits to per mille level allows setting lower limits on new boson (mass \( \sim 2.5 \) TeV)

\[ C_i \propto \frac{M_W^2}{M_{\text{new}}^2} \]
Observables in the nuclear beta decay

Decay rate
\[ d\Gamma \sim d\Gamma_0 (1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \ldots) \]

- phase-space factor
- beta-neutrino angular correlation coefficient
- Fierz interference term
Observables in the nuclear beta decay

Decay rate
\[ d\Gamma \sim d\Gamma_0 (1 + a \frac{p_e \cdot p_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + ... ) \]

- **Phase-space factor**
- **Beta-neutrino angular correlation coefficient**
- **Fierz interference term**

**Pure Fermi transitions**
- **S=0**: Spin of leptons antiparallel

\[ a_F \approx 1 - \frac{|c_S|^2 + |c'_S|^2}{|c_V|^2} \]

**SM: vector current:**
- Preferred emission angle: \( \theta = 0^\circ \)
- Maximum recoil energy

**NP: scalar current:**
- Preferred emission angle: \( \theta = 180^\circ \)
- Minimum recoil energy

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### Observables in the nuclear beta decay

**Decay rate**

\[ d\Gamma \sim d\Gamma_0 \left( 1 + a \frac{p_e \cdot p_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \ldots \right) \]

- **Phase-space factor**
- **Beta-neutrino angular correlation coefficient**
- **Fierz interference term**

### Pure Fermi transitions

- **S=0**: Spin of leptons antiparallel
  - **Preferred emission angle**: \( \theta = 0^\circ \)
  - **Maximum recoil energy**

### Pure Gamow-Teller transitions

- **S=1**: Spin of leptons parallel
  - **Preferred emission angle**: \( \theta = 180^\circ \)
  - **Minimum recoil energy**

**SM**: vector current:
- Preferred emission angle: \( \theta = 0^\circ \)
- Maximum recoil energy

**NP**: scalar current:
- Preferred emission angle: \( \theta = 180^\circ \)
- Minimum recoil energy

**SM**: axial-vector current:
- Preferred emission angle: \( \theta = 180^\circ \)
- Minimum recoil energy

**NP**: tensor current:
- Preferred emission angle: \( \theta = 0^\circ \)
- Maximum recoil energy

**NOTE**

\[ \tilde{X} = \frac{X}{1 + b \left( \frac{m_e}{E_e} \right)} \]
Indirect correlation measurements

- Max recoil energy $\sim$ keV

\[ ^{32}\text{Ar} \xrightarrow{\beta} ^{32}\text{Cl} \]

\[ e^+ \quad \theta \quad \nu_e \quad \text{nucleus} \]
Indirect correlation measurements

- Max recoil energy $\sim$ keV

- $^{32}$Ar decays by $\beta$-decay to $^{32}$Cl which subsequently decays by proton emission to $^{31}$S

- Protons energies $\sim$ several MeV

- The energy of the emitted protons is subject to kinematic shift due to the recoiling daughter nucleus

$L. Hayen and N. Severijns / Computer Physics Communications 240 (2019) 152–164$
ISOLDE Experimental Hall

HRS
High Resolution Separator

Target area
Proof-of-principle: detection setup

**Beta detector** + SiPM

**Proton detectors planes**

**Catcher**

GEANT4 Simulation

**B = 4T**

* Plastic scintillator;
** Silicon surface-barrier (thickness = 300 μm);
*** Aluminized Mylar (thickness = 6.7 μm)

Proof-of-principle: detection setup

Energy shifts observed in the dominant vector contribution

![Energy shifts graph](image)

GEANT4 Simulation

B. Blanck et al. CERN-INTC-2016-050 (INTC-I-172); D. Atanasov et al in preparation.
Proof-of-principle: Results

Proton Spectra in SINGLES November 2018

- Lower plate detectors
  - Energy shifts observed in all detectors due to the dead layer

- Upper plate detectors
  - Proton energies shifted due to Catcher thickness ($\delta E \sim 100$ keV for the IAS)

Gamow-Teller

IAS: Fermi transition

V. Araujo-Escalona et al submitted.
Proof-of-principle: Results

Weighted average energy shifts:

\[ \Delta E = |\bar{E}_{\text{coinc}} - \bar{E}_{\text{single}}| \]

\[ \Delta E_F = 4.49(3) \text{ keV} \]
\[ \Delta E_{GT} = 3.05(9) \text{ keV} \]

By means of Monte Carlo simulations:

\[ \tilde{\alpha}_F = 1.01(3)_{\text{stat}}(2)_{\text{syst}} \]
\[ \tilde{\alpha}_{GT} = -0.22(9)_{\text{stat}}(2)_{\text{syst}} \]

V. Araujo-Escalona et al submitted.
Outlook

Ongoing Upgrades (2019-2021):

- Proton detectors to reach 10 keV (FWHM) (8 segmented quadrants with 5 strips each)
- DAQ extension to match detector requirements
- WISArD beamline instrumentation and diagnostics
- Backscattering of beta particles (detection threshold as function of $E$ and $\theta$ and validation + constraints for GEANT4)

Complete work beginning of 2021:

- WISArD experiment with precision goal of 1‰ on $a_F = 1$

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Prospects for:
- 0.1 s on neutron lifetime
- 0.1 % for $A_n$, $a_n$, $a_F$ and $a_{GT}$
- abs.unc. of 0.001 on $b_{GT}$
- LHC: 14 TeV, 300 fb$^{-1}$.

O. Naviliat-Cuncic and M. Gonzalez-Alonso, Annalen der Physik 525 (2013) 600
Thank you!


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