Probing the structure of weak interactions

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Experimental project **WISArD**
(**W**eak-**I**nteraction **S**tudies with ^{32}**Ar D**ecay)
online at ISOLDE/CERN

Study structure of weak interactions : search for 'forbidden' Scalar & Tensor components by precise measurements of sensitive correlations in low-energy beta-decays

CENBG Bordeaux   KU Leuven   ISOLDE,CERN   LPC Caen   NPI Rez

Motivation, sensitive variables

Standard model of electro-weak interactions: **V-A character of interaction**

C_V=1, C_A=-1.27, C_V'=C_V & C_A'=C_A, C_S=C_S'=C_T=C_T'=C_P=C_P'=0   No Scalar or Tensor

But experimental limits for $|C_T^{(\prime)}/C_A|$ and $|C_S^{(\prime)}/C_V|$ only at the % level (After 60 years of efforts !!!)

β-ν correlations in β-decay - **a** parameter (sensitive to both **Scalar**, **Tensor** interaction)
can simultaneously study both "forbidden interactions" – Scalar in Fermi decays, Tensor in Gamow-Teller decays
study **recoil nuclei** instead of **neutrinos -** measurement of the shape of p-spectrum from **β-delayed proton decay** (WISArD)

High-energy and low-energy experiments are complementary :
experimental upper limits for $|C_S/C_V|$ & $|C_T/C_A|$ are currently at the % level (*n* & nuclear β-decay)
- extending the limit to ‰ level allows to increase lower limits on possible new bosons whose exchange could create possible Scalar or Tensor-type interactions (mass ~ 2.5 TeV)

$$C_i \propto \frac{M_W^2}{M_{new}^2}$$

Decay rate for non polarized nuclei

$$dW = dW_0\left(1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu} + b\frac{m_e}{E_e}\right)$$

$$a_F \cong 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2} \quad \text{=1 SM}$$

$$a_{GT} \cong -\frac{1}{3}\left[1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right] \quad \text{= -1/3 SM}$$

β-ν correlation coefficient

$$b_F \cong Re\,\frac{C_S + C_S'}{C_V}$$

$$b_{GT} \cong Re\,\frac{C_T + C_T'}{C_A} \quad \text{= 0 SM}$$

Fierz interference term

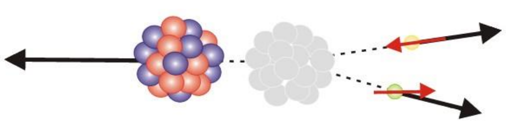
Best measurements:
a_F ~ 0.45%,
a_{GT} ~1%

WISArD: measuring $\tilde{a}$, sensitive to both *a & b*

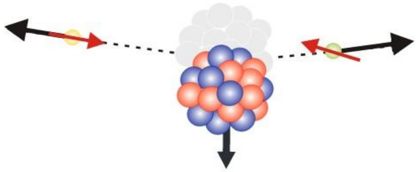
$$\tilde{a} \approx \frac{a}{1 + b\langle m_e / E_e\rangle}$$

measuring **recoil nucleus energy**⇒ ratio Scalar/Vector
F decay $\tilde{a}_F$ limits Scalar, GT $\tilde{a}_{GT}$ limits Tensor

Vector interaction (SM)
High energy of recoil nucleus,
moving opposite to emitted particles

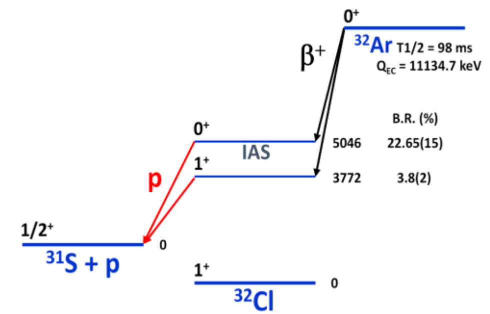


Scalar interaction (beyondSM)
Very small energy of recoil nucleus



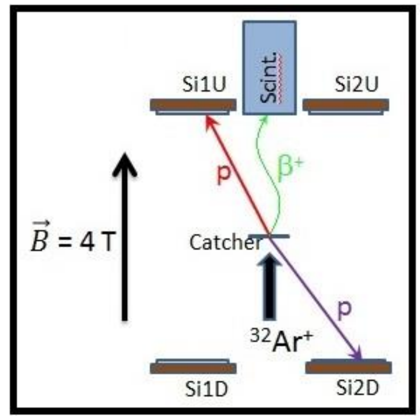
WISArD (Weak-Interaction Studies with ^{32}Ar Decay) experiment

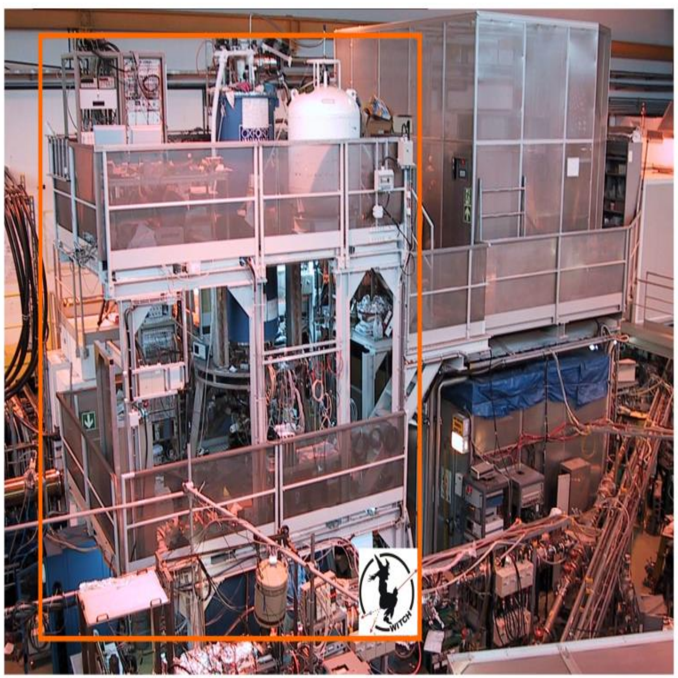
WISArD – measuring β-delayed proton decay of ^{32}Ar
in β-p coincidence measurement we measure the proton energy shift for same & opposite β emission directions which is a linear function of $\tilde{a}$

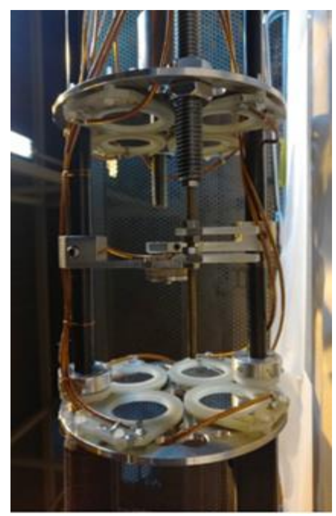


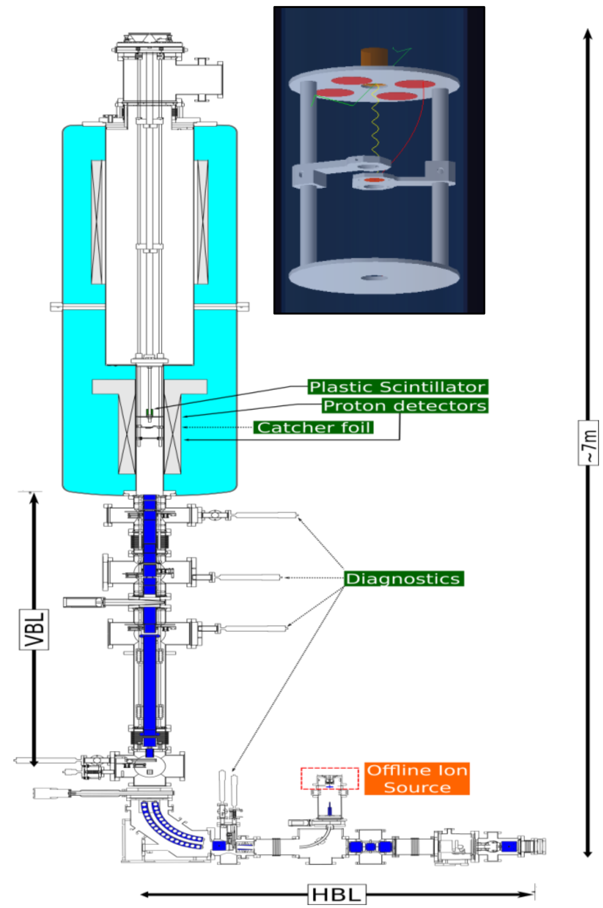
- Super-allowed Fermi β-decay ^{32}Ar→ ^{32}Cl to Isobaric Analog State is promptly followed (Γ~20eV ⇔ $T_{1/2}$~10^{-17}s) by the proton decay ^{32}Cl → ^{31}Si
- Protons are emitted from the moving nucleus ^{32}Cl recoiling after previous β-decay ⇒ proton energy is Doppler shifted: high recoil energy, Vector interaction, *a* = 1 ; low recoil energy, Scalar, *a* = -1

- ^{32}Ar ions implanted into the catcher mylar foil
- Positrons from the β-decay detected by the narrow forward detector placed on axis
- Protons from the subsequent p-decay of ^{32}Cl detected by arrays of Si detectors in forward (UP) and backward (DOWN) direction off axis
- Whole setup in the **magnetic field 4T** (up to 9T)) → spiraling positrons cannot reach the proton detectors placed off axis ⇒ **no summing p+e, no distortions of p-peaks**





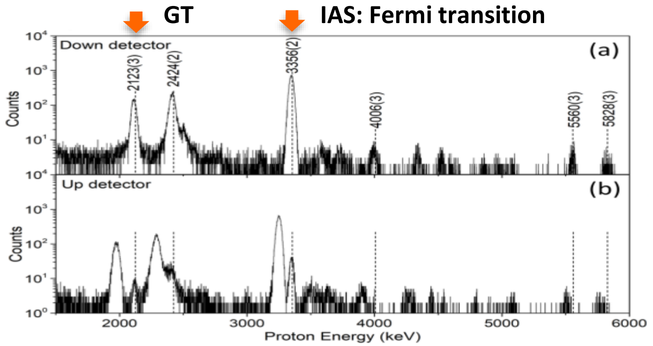




Results, outlook

WISArD online proof-of-principle experiment

Nov 2018, latest run before the CERN shutdown
- readily available beta and proton detectors
- ~ 1700 pps of ^{32}Ar instead of 3000 nominal
- ~ 35h of beamtime



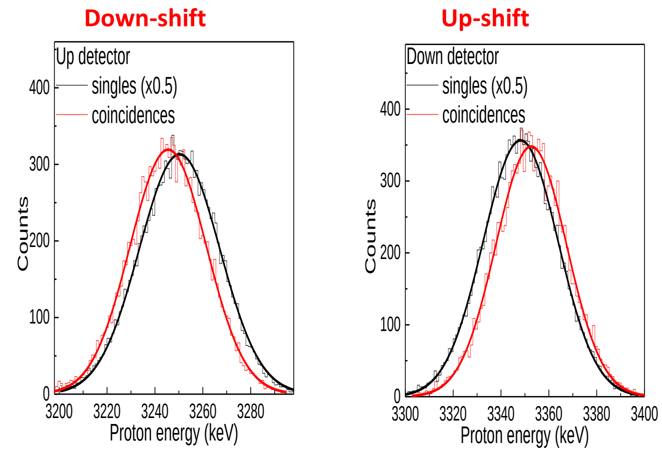
Current precision, outlook:

Systematic error budget (in ‰) :

	Source	Uncertainty	$\Delta\tilde{a}_{\beta\nu}(10^{-3})$
background	false coinc.	8%	< 1
proton	detector calibration	0.2%	2
	detector position	1 mm	< 1
	source position	3 mm	3
	source radius	3 mm	1
	B field homogeneity	1%	< 1
	silicon dead layer	0.3 μm	5
	mylar thickness	0.15 μm	3
positron	detector backscattering	15%	2
	catcher backscattering	15%	21
	threshold	12 keV	8
total			24

-unknown detectors DL
-source profile poorly known
→upgrade of p-detectors
can be easily reduced by factor *x ~10*

→Must be reduced by factor >20
thinner catcher → *x ~10 improvement*
dedicated BS measurements→ *x ~3-5 improvement*



Typical resolution ~35 keV FWHM

$\Delta E_F = 4.49(3)$keV, $\Delta E_{GT} = 3.05(9)$keV

$$\tilde{a}_F = 1.01(3)_{\rm stat}(2)_{\rm syst}$$

$$\tilde{a}_{GT} = -0.22(9)_{\rm stat}(2)_{\rm syst}$$

Statistical error reduction below 1 ‰
- production + transmission + time (ISOLDE, beamlines upgrade, 2weeks beamtime)
  → x ~50 in decay statistics
- dedicated detection setup (higher p-resolution, higher solid angle, lower beta threshold)
  → x ~5 in sensitivity

⇒ achievable **~0.9 ‰ (F), ~1.4 ‰ (GT)**

V. Araujo-Escalona et al, PRC 101 055501 (2020)