WISArD

Weak Interaction Studies with ^{32}Ar Decay

EAP S^3 LEB– DESIR 2025

P.Alfaurt, P.Ascher, D.Atanasov, B.Blank, L.Daudin, X.Fléchard, A.Garcia, M.Gerbaux, J.Giovinazzo, S.Grévy, J.Ha, L.Hayen, C.Knapen, S.Lecanuet, R.Lica, E.Liénard, D.Melconian, C.Mihai, C.Neacsu, M.Pomorski, M.Roche, N.Severijns, S.Vanlangendonck, **M. Versteegen**, D.Zakoucky

Exotic Weak Scalar and Tensor Couplings

- **Beta decay at the nucleon level : Lee & Yang (1956)**

$$-\mathcal{L}_{n\to pe^-\bar{\nu}_e} = g \sum_{i=S,V,T,A,P} \underbrace{\bar{p}\mathcal{O}_i n}_{\text{hadronic}} \underbrace{\bar{e}\mathcal{O}_i(C_i - C_i'\gamma_5)\nu}_{\text{leptonic}} + h.c.$$

$$\mathcal{O}_i = \begin{cases} 1 & \text{Scalar} \\ \gamma^\mu & \text{Vector} \\ \gamma^\mu\gamma_5 & \text{Axial} - \text{Vector} \\ \sigma^{\mu\nu} & \text{Tensor} \\ \gamma_5 & \text{Pseudoscalar} \end{cases}$$

Standard Model : "V-A" theory

$$C_V \equiv 1 \qquad C_A \simeq 1.27$$
$$C_V = C_V' \qquad C_A = C_A' \qquad \in \mathbb{R}$$

Beyond Standard Model : exotic couplings

$$C_S, C_S', C_T, C_T'$$

Extend the limit at the per mil level to compete with LHC bounds on New Physics at the 1-10 TeV scale

T. Lee, C-N. Yang Phys. Rev. 104 (1956)
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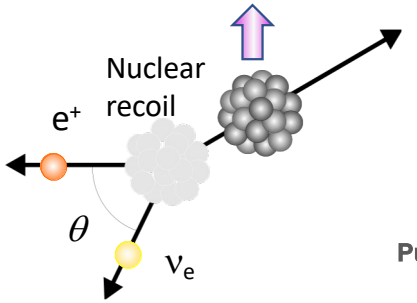
- **Nuclear beta decay probability for allowed transitions**



$$\frac{dW(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} = dW_0 \times \xi \left\{ 1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \frac{<\mathbf{J}>}{J}\cdot\left(A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_\nu}{E_\nu} + D\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_e E_\nu}\right)\right\}$$

Pure Fermi decay

$$a_F \cong 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2} \qquad b_F \approx \pm Re\left(\frac{C_S + C_S'}{C_V}\right)$$

Pure Gamow-Teller decay

$$a_{GT} \cong -\frac{1}{3}\left(1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right) \qquad b_{GT} \approx \pm Re\left(\frac{C_T + C_T'}{C_A}\right)$$

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The WISArD Project

- **Angular Correlation Measurement**

$$dW = dW_0 \times \xi \left(1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m}{E_e}\right)$$

$$a_F \cong 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2}$$

Objective: Measure a_F at a precision level of 0.1 - 0.2%
- state of the art is ~0.5% -

$$\tilde{a} = \frac{a}{1 + \alpha b}$$

- **Beta Spectrum Shape Measurements**

$$W(E_e) dE_e = dW_0 \times \xi \left(1 + b \frac{m}{E_e} \pm \frac{4}{3} \frac{E_e}{M} \frac{b_{\mathrm{WM}}}{Ac}\right)$$

$$b_{\mathrm{Fierz},GT} \simeq \pm \mathrm{Re}\left(\frac{C_T + C'_T}{C_A}\right)$$

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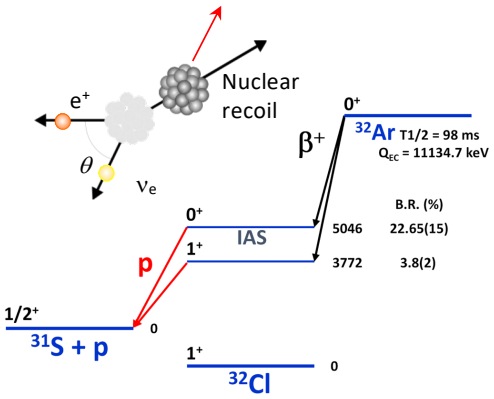
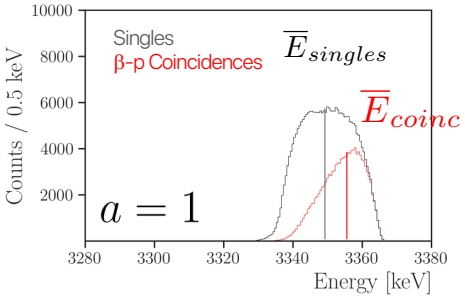
Kinematic shift measurement in ^{32}Ar





$$\overline{E}_{shift} = \left|\overline{E}_{singles} - \overline{E}_{coinc}\right| \propto \tilde{a}$$

- Pure Fermi transition : scalar currents
- Beta-delayed proton emitter

  IAS : $T_{1/2} \sim 10^{-17}$ s and p ~ 3.35 MeV

- Increased sensitivity
- Less sensitive to background
- Less sensitive to detector response functions

• Beta Spectrum Shape Measurements

$$W(E_e)dE_e = dW_0 \times \xi \left(1 + b \frac{m}{E_e} \pm \frac{4}{3} \frac{E_e}{M} \frac{b_{\mathrm{WM}}}{Ac}\right)$$

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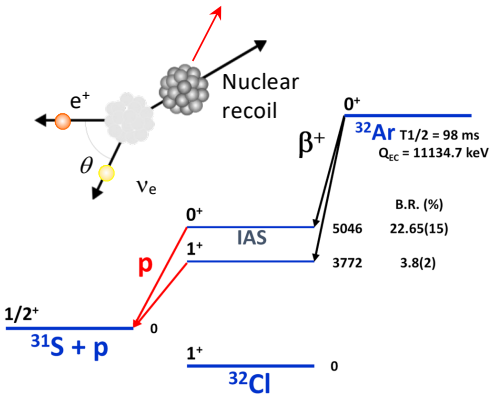

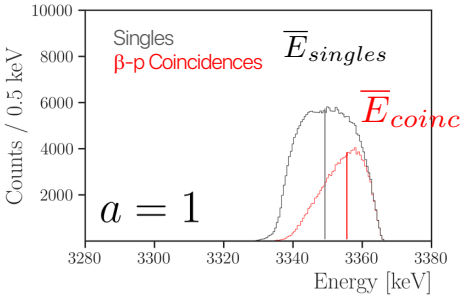

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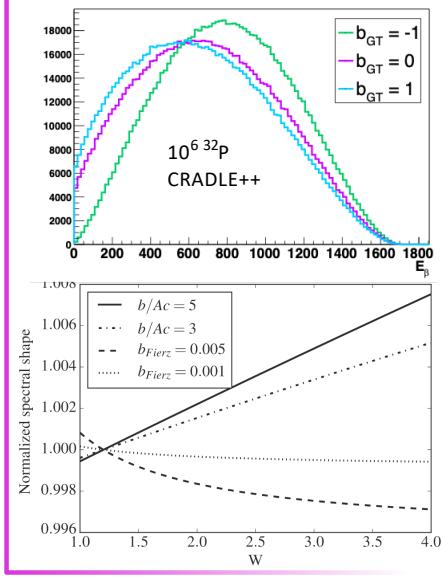
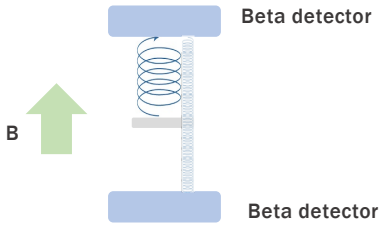
Spectrum Shape in a magnetic field



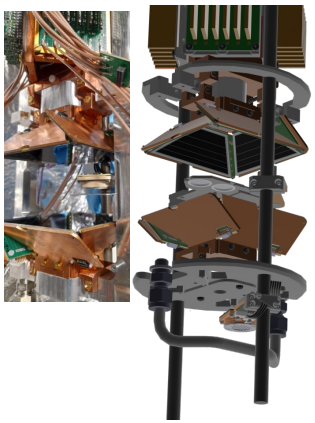
- Challenges
  - Partial energy deposit in detector due to backscattering, out-scattering, Bremsstrahlung
  - Energy loss in catcher and dead layer
- Confine beta particles in a magnetic field between 2 symmetrical detectors.

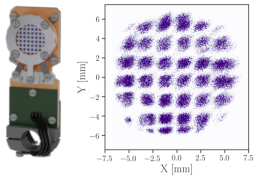


L. Hayen et al, Rev. Mod. Phys. 90 (2018)
N. Severijns et al Phys. Rev C 107, 015502 (2023)

Status

• Angular Correlation Measurement

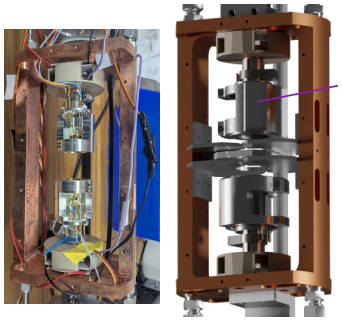




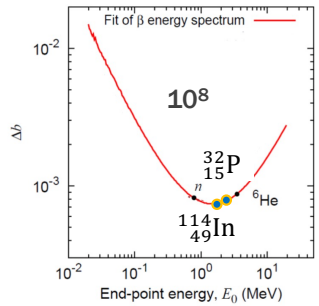
- **Fully operational detection tower as of 2024**
  - ▷ Eight 300 μm thick single-sided silicon strip detectors, resolution = 10 keV FWHM, 100 nm dead-layer for protons
  - ▷ 1 scintillator + 9 SiPM array for beta detection
  - ▷ 1 triple-stage MCP detector for beam characterisation
  - ▷ 1 tailor-made 3-position catcher to intercept the beam
  - ▷ Active glycol cooling
  - ▷ 9T superconducting magnet
- **Two ^{32}Ar physics campaigns @ CERN-ISOLDE**
  - ▷ 2024: ~ 11x10^6 events
    large beta rate due to contamination + beta backscattering on collimator
  - ▷ 2025: ~ 6x10^6 events
    with previously identified problems solved
- **Ongoing Data analysis :** Samuel LECANUET
- 1 paper in preparation : MCP operation in a magnetic field

- **Manpower**
  - ▷ **IN2P3 *permanent*:** B.Blank, X.Fléchard, M.Versteegen, P.Alfaurt, P.Ascher, L.Daudin, M.Gerbaux, J.Giovinazzo, S.Grévy, M.Roche
  - ▷ **IN2P3 PhD:** S. Lecanuet / A. Lépine
  - ▷ **KU Leuven:** N. Severjins, S. Vanlangendonck, C. Knapen, **UIF Rez**: D. Zakoucky, **SCK-CEN Mol:** D. Atanasov, **IBS Daejon:** J. Ha

• Beta Spectrum Shape Measurements



- **New detection tower under construction / tests**
  - ▷ two 5 mm thick Si(Li), 11 keV FWHM at -70 °C
  - ▷ 1 tailor-made 2-position catcher
  - ▷ 2 triple-stage Peltier elements + active glycol cooling
  - ▷ 9T superconducting magnet
- **Successful 1st test of installation @CERN-ISOLDE 09/25**
- **Upcoming calibration and data taking during LS3**
  - ▷ 2025: calibration with and without magnetic field
  - ▷ 2026: data taking
    - ➢ ^{114}In to constrain weak magnetism predictions and determine new limits on BSM physics
    - ➢ ^{32}P for BSM physics and weak-magnetism



M. González-Alonso, O. Naviliat-Cuncic Phys. Rev. C 94 (2016)
L. Hayen et al, Rev. Mod. Phys. 90 (2018)

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Prospectives

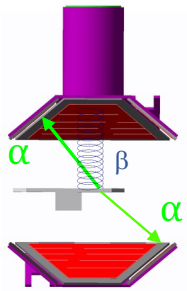
• Angular Correlation Measurements

CERN – ISOLDE: 2028 onwards

- **^{8}Li: β-delayed α break-up with existing set-up**
  - ▷ Gamow-Teller decay ➪ sensitive to BSM Tensor currents

$$a_{GT} \cong -\frac{1}{3}\left(1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right)$$

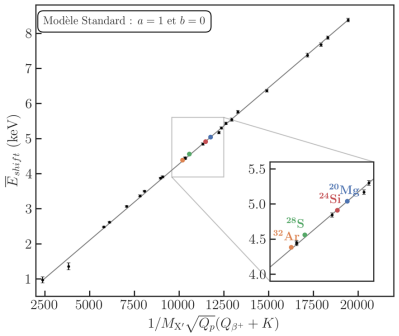
  - ▷ Measure a_{GT} at a precision level of 0.3% or better
  - ▷ Triple coincidence measurement: β–α–α
  - ▷ Existing detection tower and set-up
  - ▷ Improve Argonne National Lab result (~ 0.7%) with different technique



M.T. Burkey et al. Phys. Rev. Lett. 128 (2022)

GANIL – DESIR: 2030?

- **^{20}Mg: β-delayed p emission "à la ^{32}Ar"**
  - ▷ Increased sensitivity to BSM Scalar currents because larger kinematic shift
  - ▷ Need for ^{20}Na contaminant cleaning at DESIR with HRS or PIPERADE
  - ▷ **New magnet and new detection set-up needed!**

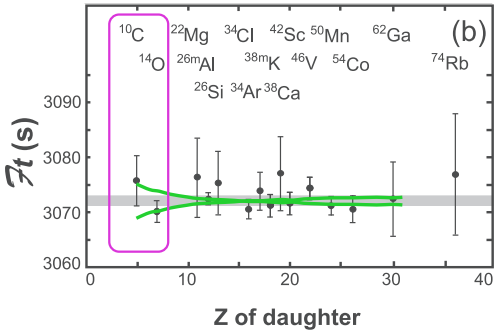


- **Manpower and Funding**
  - ▷ IN2P3 *permanent*: **need for support to continue this activity at same level**
  - ▷ 1 PhD and/or Post-Doc for ^{8}Li measurement
  - ▷ New ANR project to fund new set-up at DESIR

• Beta Spectrum Shape Measurements

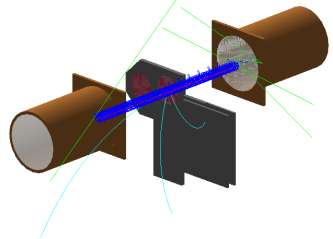
CERN – ISOLDE: 2028 onwards

- **^{14}O: super-allowed $0^+ \rightarrow 0^+$ branching ratio from spectrum shape**
  - ▷ Improve the constraint on BSM scalar currents from $0^+ \rightarrow 0^+$ Ft values
  - ▷ ^{14}O second lightest nucleus, very sensitive to new physics
  - ▷ Improve the uncertainty on ^{14}O super-allowed $0^+ \rightarrow 0^+$ BR by 2 to 3 to reduce total uncertainty budget



JC. Hardy & IS. Towner Phys.Rev.C 102 (2020)

- **New detection setup**
  - ▷ 2 plastic scintillators + SiPMs with one being automatically rotatable
  - ▷ Active cooling
  - ▷ 9T superconducting magnet from WITCH



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  - ▷ **Collaboration:** IBS South Korea
  - ▷ **2026**: ANR application for Post-doc, PhD and equipment

Conclusion

- The WISArD Project
  - ~ 20 collaborators from 8 institutions
  - ~ 1.1 M€ from ANR 2018-2024 and FWO
  - 2 PhDs and 1 post-doc fully or partially funded by IN2P3

  - Fully functional detection set-up for angular correlation measurements
  - New detection set-up for spectrum shape measurements mounted and being characterized

  - New limit on a_F at the ~0.2% level expected within the next year from 2024 and 2025 data

- Ready-to-go for new Physics cases @CERN-ISOLDE
  - Angular measurements : ^{8}Li
  - Spectrum shape measurements : ^{32}P, ^{114}In, ^{14}O, mirror nuclei…

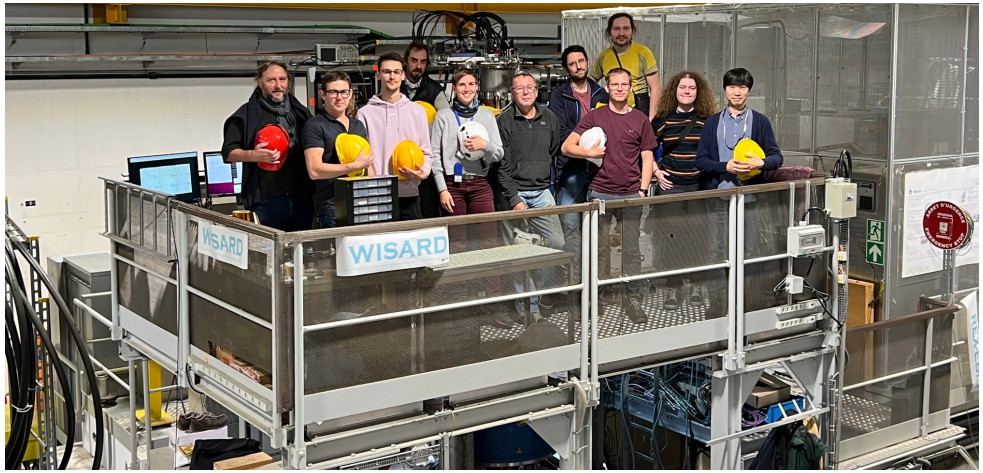
- Long term plan @DESIR
  - **New set-up** with smaller and horizontal superconducting magnet for ^{20}Mg and other spectrum shape measurements

Need for support :

- 20 k€/year for travels to CERN
- PhD grants

- **Long term** : 500k€ for new infrastructure

Thank you



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