Search for CP violation in nuclear beta decay
The Matter's Origin from the RadioActivity (MORA)

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Introduction

Why is there a strong asymmetry between matter and antimatter in the universe?

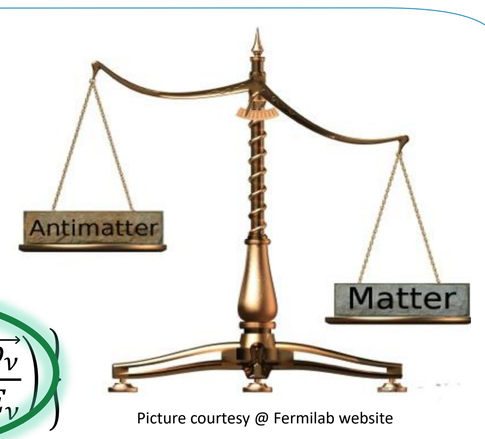
- MORA aims for possible hints via the *D* correlation measurement offering the possibility to search for new CP-violating interactions
- CP violation observed in the K, B, and D - meson decays is not enough to account for the matter-antimatter asymmetry

How?

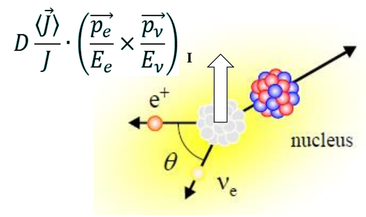
- By accessing coupling constants via correlations in beta decay spectrum
- The probability rate function of beta decay is:

$$\omega\left(\langle\vec{J}\rangle \middle| E_e, \Omega_e, \Omega_\nu\right) dE_e\, d\Omega_e\, d\Omega_\nu \propto F(\pm Z, E_e)\, p_e E_e (E_0 - E_e)^2 dE_e\, d\Omega_e\, d\Omega_\nu \times \xi \left\{1 + a\frac{\overrightarrow{p_e}\cdot\vec{q}}{E_e E_\nu} + b\frac{\gamma m_e}{E_e} + A\frac{\vec{J}}{J}\cdot\frac{\overrightarrow{p_e}}{E_e} + D\frac{\langle\vec{J}\rangle}{J}\cdot\left(\frac{\overrightarrow{p_e}}{E_e}\times\frac{\overrightarrow{p_\nu}}{E_\nu}\right)\right\}$$

Fermi function | Phase-space | β-ν Correlation | Fierz interference | β-asymmetry | D-correlation



Picture courtesy @ Fermilab website



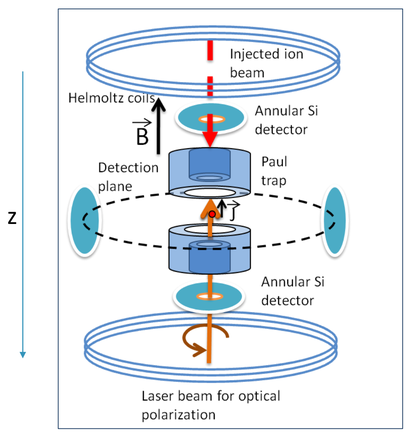
D correlation occurs in strong mixed (GT+FERMI) transitions → Neutron and Mirror Nuclei (N=Z-1)

Best measurements available so far: $D_n = (-0.94 \pm 1.89 \pm 0.97)\cdot 10^{-4}$ | $D_{^{19}Ne} = (1 \pm 6)\cdot 10^{-4}$

Final sensitivity goal in MORA is 10^{-5} and the best candidates are ^{23}Mg – IGISOL, JYFL and GANIL - SPIRAL2 & ^{39}Ca - GANIL SPIRAL2

Measurement scheme

1. Trapping of ions using a transparent Paul trap
2. Polarization of trapped ions by optical pumping method: hyperfine transition used to orient the spin of $^{23}Mg^{+}$ ions *(~280 nm* laser circular polarization *(σ+ to σ−)*
3. *M*easurement of polarization P in the Z-axis and D correlation in the azimuthal plane



In trap optical polarization

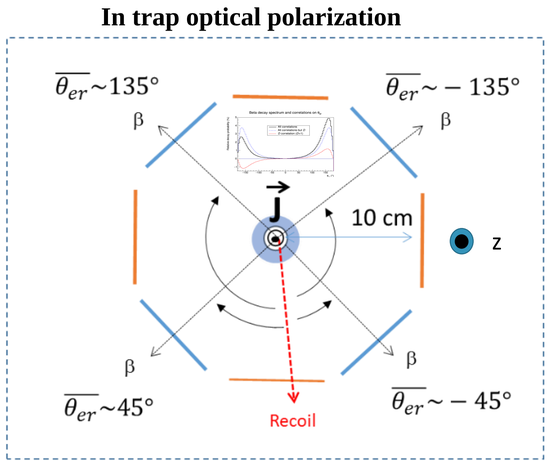


Figure 1: Left: Polarization measurement scheme. Right: D-correlation in the azimuthal plane of the trap

$$\frac{N_{\beta+}^{\uparrow} - N_{\beta+}^{\downarrow}}{N_{\beta+}^{\uparrow} + N_{\beta+}^{\downarrow}} \propto A_\beta \cdot P$$

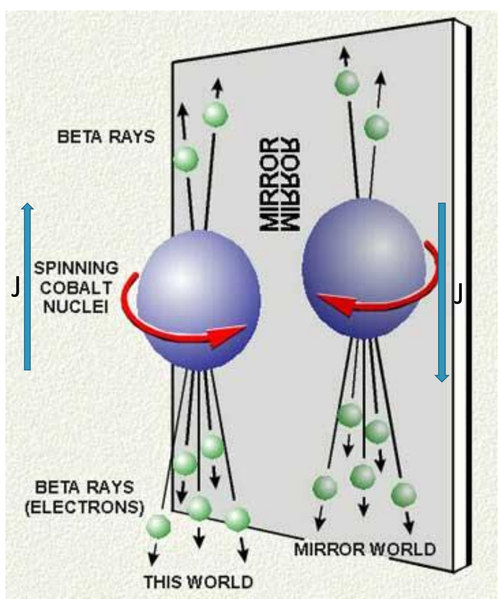
$N_{\beta+}^{\uparrow}$, $N_{\beta+}^{\downarrow}$ are the number of betas detected parallel and antiparallel to the spin

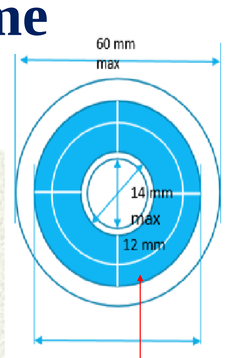
$$\frac{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} - N_{coinc}^{-45^\circ} - N_{coinc}^{-135^\circ}}{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} + N_{coinc}^{-45^\circ} + N_{coinc}^{-135^\circ}} = \delta \cdot D \cdot P$$

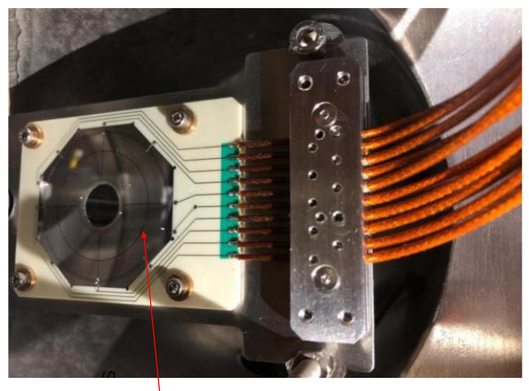
Sensitivity factor | Polarization

δ = 0.765(1) – Monte Carlo simulations

Polarization measurement scheme







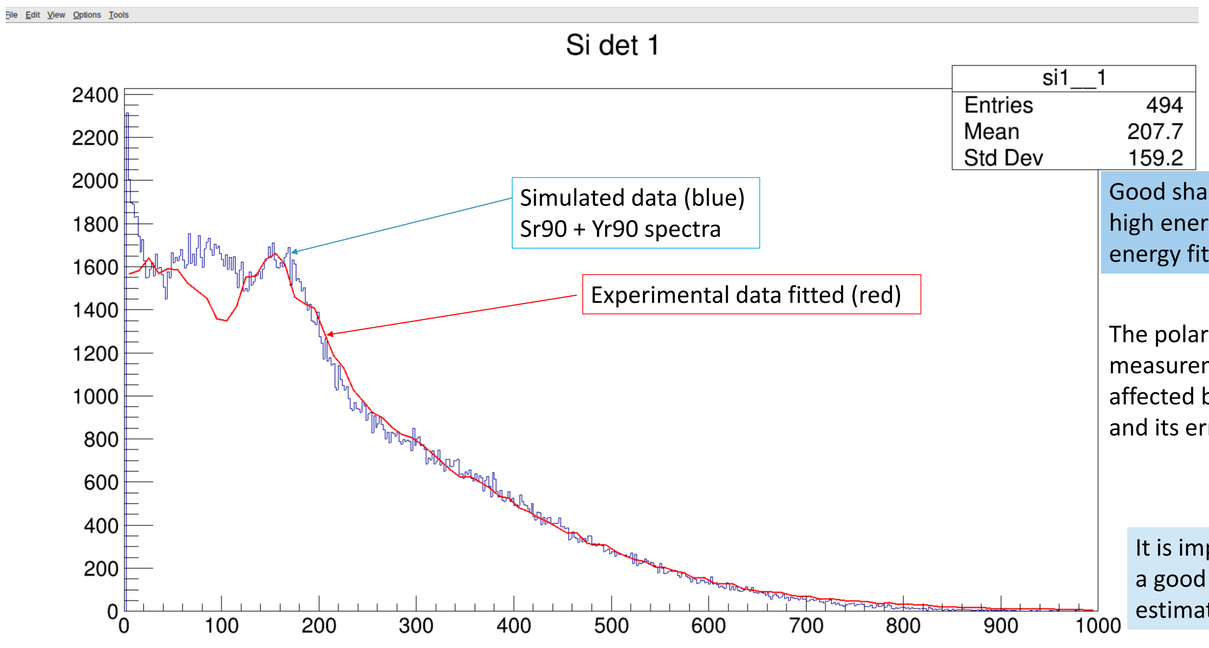
8 Sectors in 2 annular rings. For the calibration we use a Sr90 source, while for the polarization measurement we use $Mg^{+}23$

Figure 2: Left: Co beta decay (Wu experiment) if parity was conserved by weak force. Right: Si detector schematics and photography.

Si detectors are be covered by an Al plate of 100 µm for laser protection

Calibration progress

- Last experiment done in Nov 2022, 72 h of beam time.



Good shape fit, specially at high energies, but not real energy fit yet.

The polarization measurement is indirectly affected by the calibration and its errors

It is important to have a good calibration and estimation of errors

Simulation and Calibration still on progress.

Systematic effects

- The emiT experiment already provides hints about the main systematic effects as MORA detection geometry in similar to the emiT
- The four main systematic effects are studied at the first order and second order
- Monte Simulations are used to study them: PENELOPE – electrons & SIMION – recoil ions

First and second order effects - Preliminary

Source	Effect, D_{fake}	Effect, P_{fake}
Expansion of ion cloud size	0	To be quantified
Transverse Polarization (towards X-axis instead of Z)	0	Cos(Ω)
Asymmetric transverse polarization (towards X-axis + displacement of ion cloud)	~ 1 X 10^{-6}	To be quantified + Cos(Ω)
Electron backscattering	< 10^{-6}	To be quantified
Recoil ion threshold (Disturbance of recoil ions with RF)	To be quantified (~ negligible so far)	No effect

Conclusion: Mostly single effects are canceled out and combined effects are more prominent to be studied in detail

Summary and Outlook

Achievements

- On path of a good channel-energy calibration
- First real data acquisition in JYFL, 72h of beam time
- First attempt at polarization possible

New things in the horizon

- Finish the calibration and estimate the errors
- Polarization degree measurement. Estimation of systematic effects
- Continue the data analysis and systematic errors, build better models and prepare for the next experiment and the measurement of the D correlation

Next experiment: TBA

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