The MORA Project

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Matter's Origin from the Radioactivity of Trapped and Laser Oriented ions

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(on behalf of MORA collaboration)

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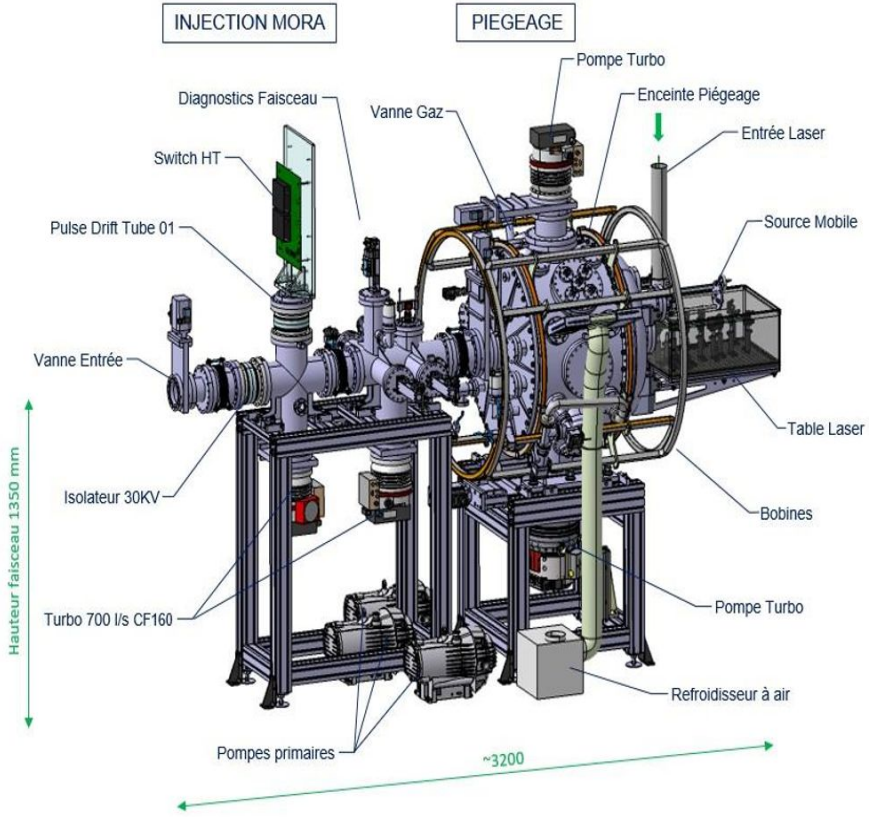
KU LEUVEN NUCLEAR AND RADIATION PHYSICS

ISOLDE

AGENCE NATIONALE DE LA RECHERCHE ANR



Physics Hypothesis-

- The MORA project focuses on the searches for new sources of CP violation
- Searches of New Physics in nuclear beta decay.
- D correlation parameter measurement with unprecedented precision.
- Use of an Innovative in-trap orientation method ***(high trapping efficiency of transparent Paul trap with laser orientation techniques)***
- First time possibility to probe FSI (Final state interaction) effects.

Objectives & Project Focus-

- Proof-of-principle of in-trap laser orientation techniques.
- D- correlation measurement in the decay of $^{23}Mg^{+}$ ions at **JYFL (2021-2023)**
- D- correlation measurement at the future DESIR facility. ***Highest accuracy for measurements incl. neutron decay.*****(2024-..)**

THE MORA PROJECT

Sensitivity to New Physics:

➔ *D* correlation measurements in neutrons and nuclei

Best limits on T-violating phase $Im(C_V/C_A)$

Neutron decay, $D_n = (-0.94 \pm 1.89 \pm 0.97)\ 10^{-4}$ $Im(C_V/C_A) < (1.6 \pm 6.3) \times 10^{-4}$

^{19}Ne decay, $D = 0.0001 \pm 0.0006$, limited by statistics

➔ Sensitivity depends on the transition $D_X = F(X) \times Im(C_V/C_A)$

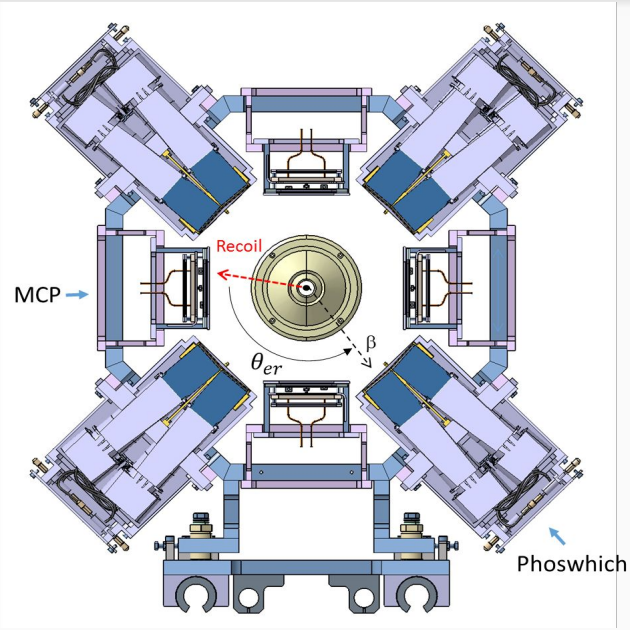
➔ **Strong mixed (GT+fermi) transitions between analog states Alkali earth elements for in trap laser ion polarization.**

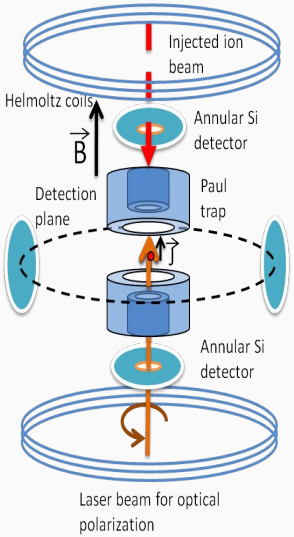
	n	^{19}Ne	^{23}Mg	^{39}Ca
F(X)	-0.55	0.66	**0.82**	**-0.90**
D_{FSI}	1.2×10^{-5}	1.5×10^{-4}	$\mathbf{1.2\times10^{-4}}$	$\mathbf{-3\times10^{-5}}$

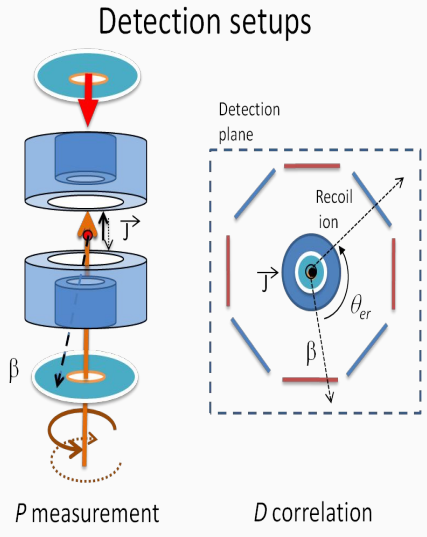
^{23}Mg and ^{39}Ca can be laser polarized as ions.

✔ **^{23}Mg** well produced and laser polarized.

Measurement of D Correlation Parameter:





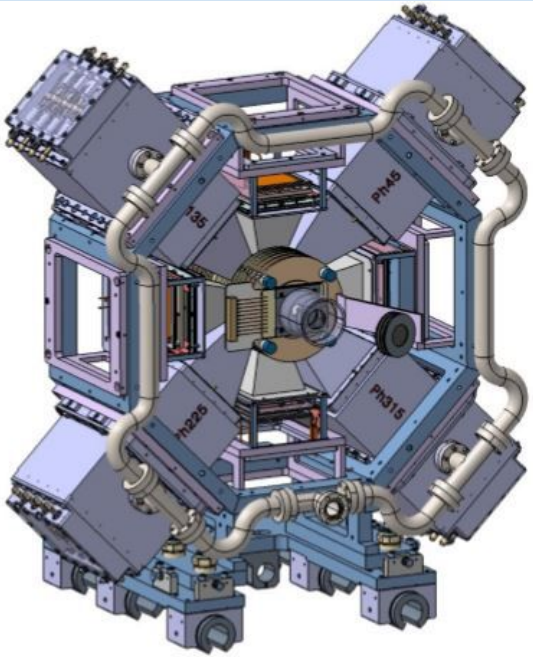


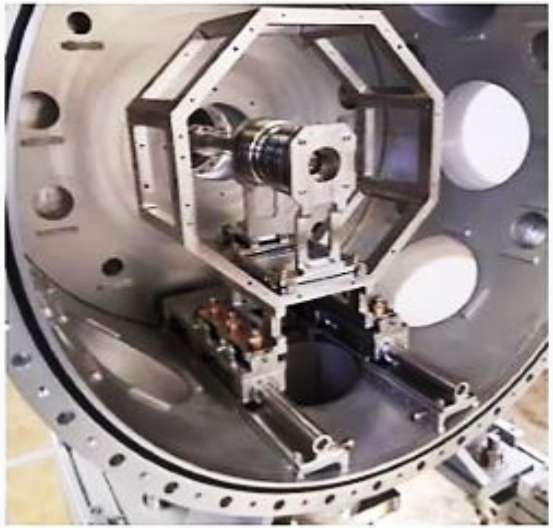
- The polarization along the trap axis by superimposing a circularly polarized laser beam with the injected ion beam.
- B-field alignment with helmholtz coil. The polarization is monitored by a difference of count rates in the two annular Si detectors.
- The *D* correlation is measured in the azimuthal plane of the trap by an emiT – like arrangement of beta and recoil ion detectors.

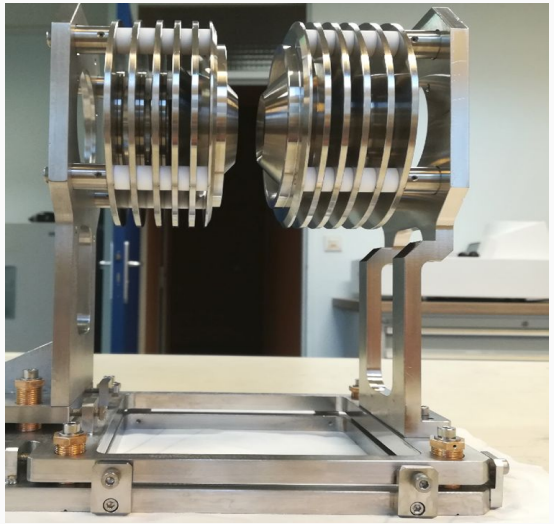
$$D \propto \left(\frac{N^{(\theta_{er}\in[0,\pi])}_{(\beta r)coin} - N^{(\theta_{er}\in[0,-\pi])}_{(\beta r)coin}}{N^{(\theta_{er}\in[0,\pi])}_{(\beta r)coin} + N^{(\theta_{er}\in[0,-\pi])}_{(\beta r)coin}} \right)$$

$N_{(\beta r)coin}$: number of recorded (electron-recoil ion)

Trapping and detection setup of MORA







MORA Trap:

3-D transparent Paul trap fixed in the centre of MORA chamber, characterized by a large potential depth and wide trapping region which leads to an increase of the storage time and better trapping efficiency

Place and type of measurement	Trapped ions /s	Decays/s	Meas. time (d)	Detected coinc. (P)	σ_P/P stat (%)	Detected coinc. (D)	Sensitivity on *D*
JYFL: polarization degree	1.00E+04	6.13E+02	8	1.7E+05	1.9E+00	1.5E+06	1.0E-03
JYFL: *D* correlation	1.00E+04	6.13E+02	32	6.7E+05	9.4E-01	6.1E+06	5.2E-04
DESIR: *D* correlation*	5.00E+05	3.07E+04	24	2.5E+07	1.5E-01	2.3E+08	8.5E-05
DESIR: *D* correlation**	5.00E+06	3.07E+05	24	2.5E+08	5E-02	2.3E+09	2.5E-05

Expected number of trapped ions per cycle & sensitivity on D & P at JYFL and GANIL

Detection setup of MORA

- (β-recoil coincidences)

Phoswich for betas:

Combination of 2 plastic scintillators

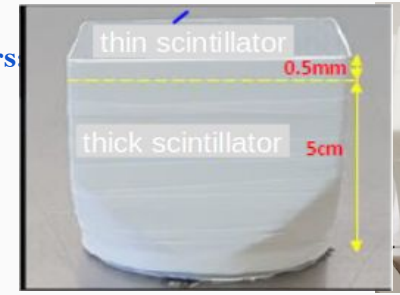
ΔE: thin (0.5 mm) & fast (t = 1.8 ns)

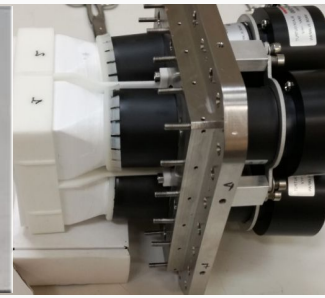
"Q_fast"

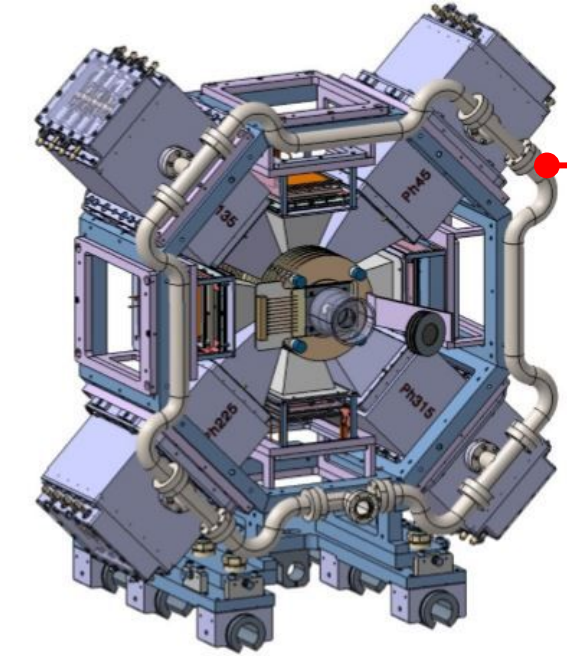
(connected to a common PMT)

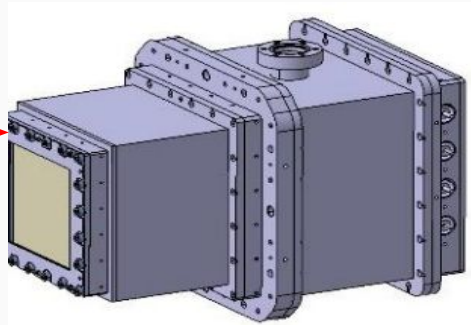
E: thick (5 cm) & slow (t = 285 ns)

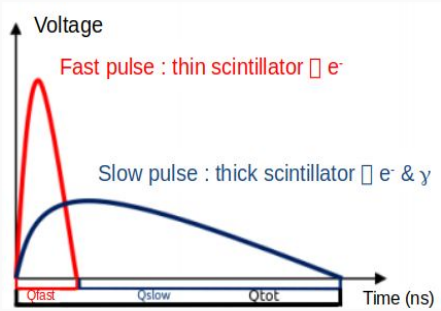
"Q_slow"



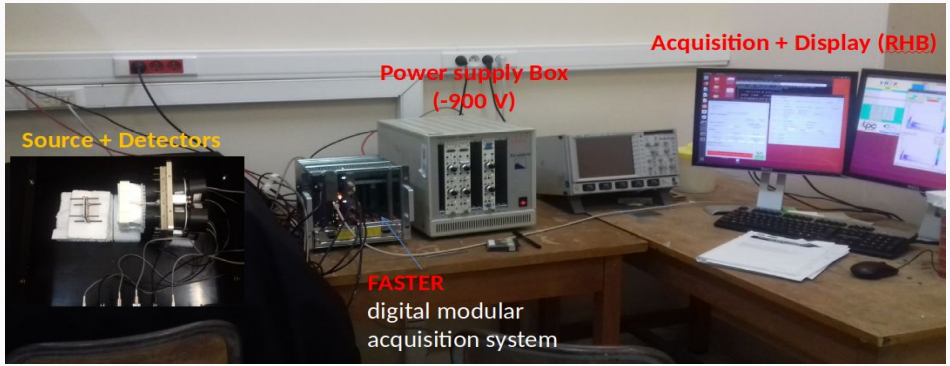




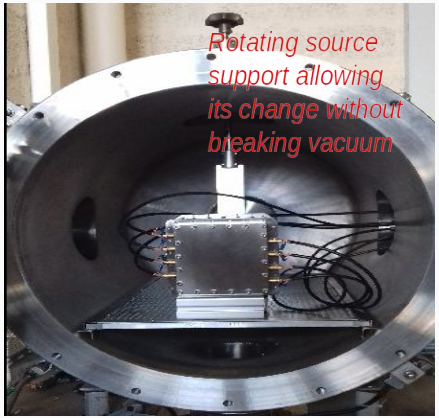


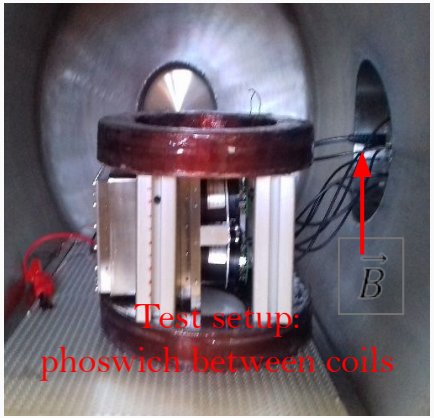


Test bench @LPC,Caen
dedicated for phoswich testing



Phoswich Response Function:

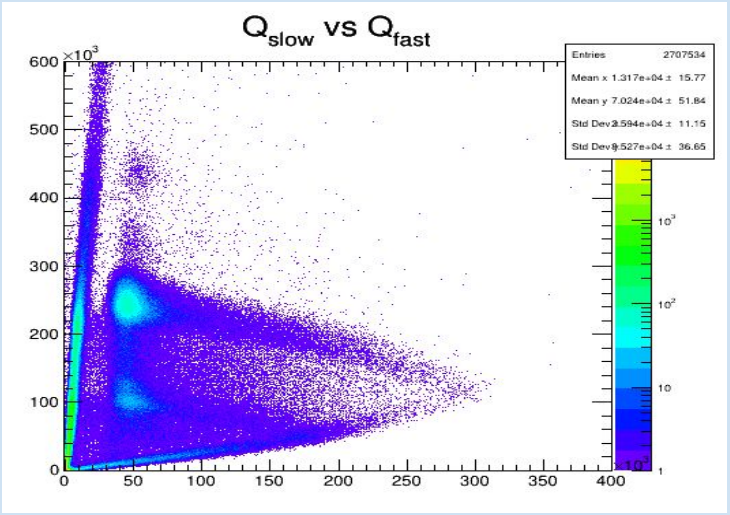




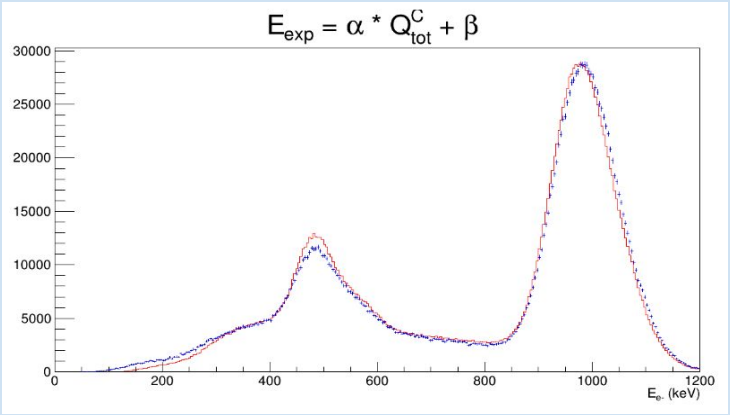
Various IC electrons :
481.7 keV (1.5%), 556.9 keV (0.6%), 994.6 keV (9.4%)
1682.2 keV (0.02%)

Some gamma rays:
570 keV (97.76%), 1063 keV (74.5%), 1770 keV (6.87%)

207Bi source in geant4 database



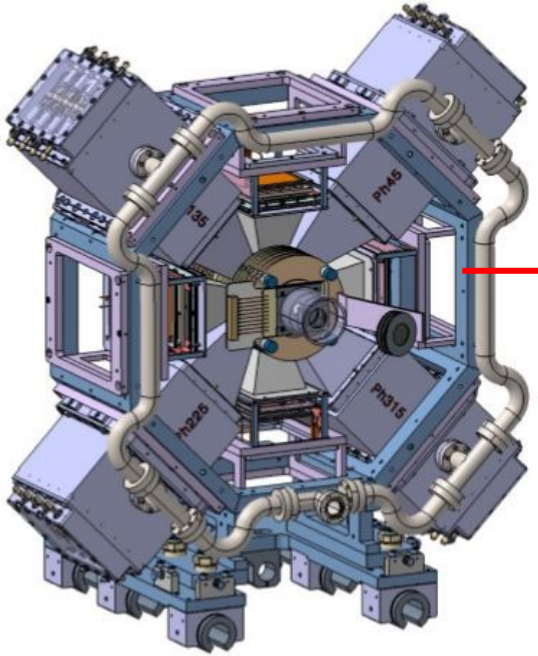
$$E_{tot} = \Delta E_{fast} + \Delta E_{slow} = \alpha Q_{fast} + \beta Q_{slow} = \beta Q_{tot} + (\alpha - \beta) Q_{fast}$$



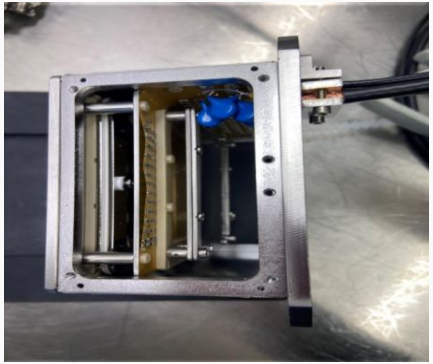
Simulation vs Data

Detection setup of MORA

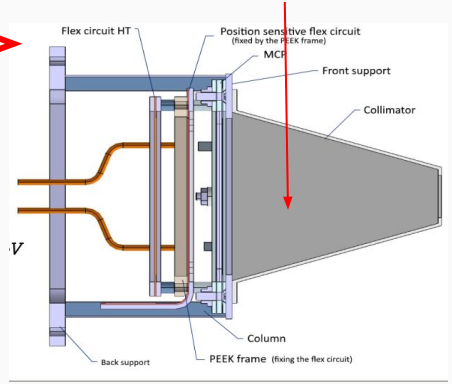
- (β-recoil coincidences)



Recoil-ion Detectors (RIDE):



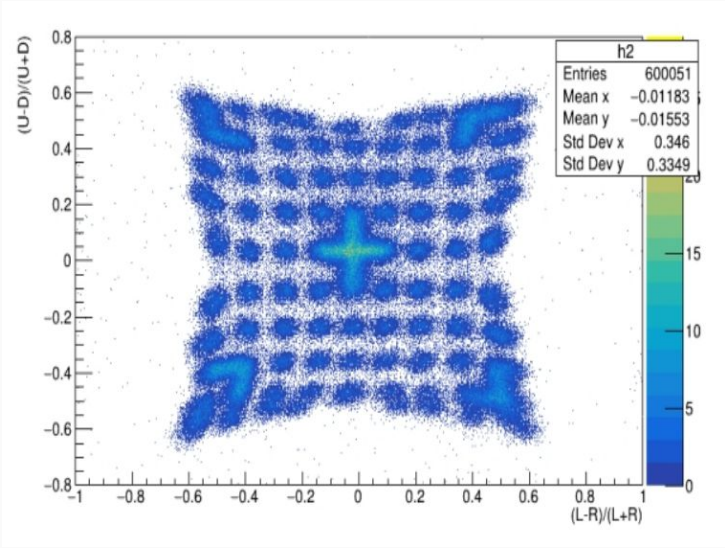
WITHOUT COLLIMATOR IN THE CURRENT CONFIGURATION



- **5 signals:** charge emitted by MCPs, charge collected on anodes (z1,z2,y1,y2)
- **3 Polarization Voltages:** front MCP, back MCP=reflection electrode, anode

MCP detectors equipped with-

- ❏ 90% transmission grid
- ❏ 4 KeV acceleration from Grid tO MCP to reach the efficiency plateau.
- ❏ Resistive PSA (Position Sensitive Anode) collecting electrons from the MCP.

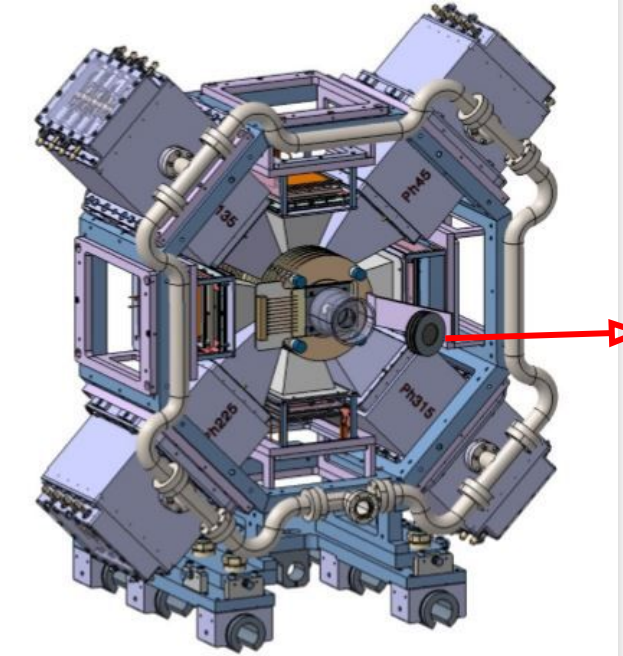


RIDE Raw Image Construction:

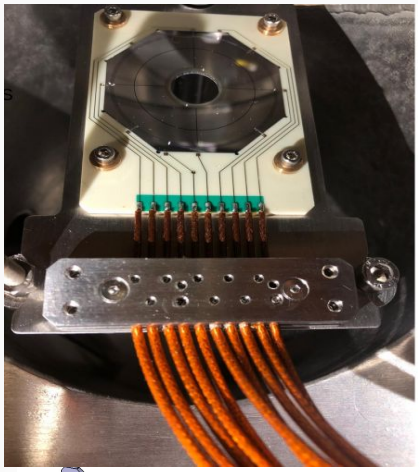
$$\tilde{X} = \frac{Qleft - Qright}{Qleft + Qright} \qquad \tilde{Y} = \frac{Qleft - Qright}{Qleft + Qright}$$

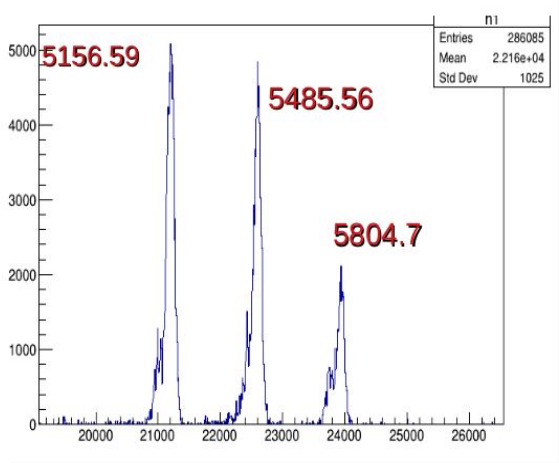
Detection setup of MORA

- Polarization degree Measurement

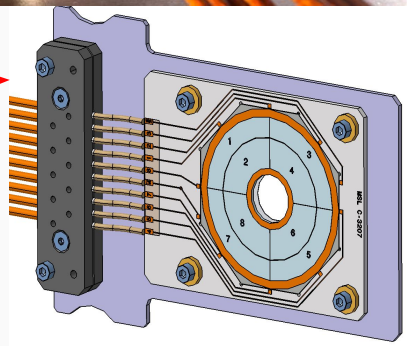


SI Detectors for polarisation Degree Monitoring:

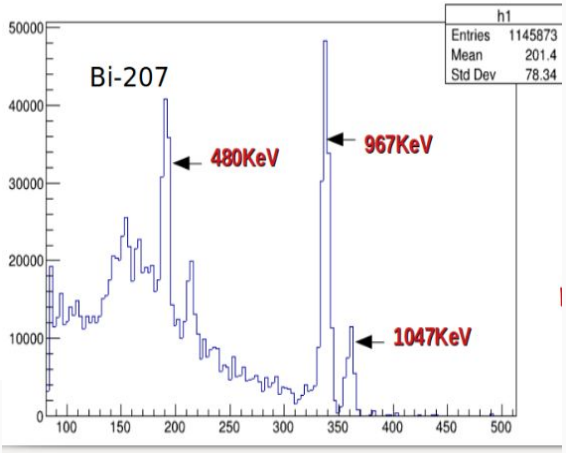




Testing with Alpha source(Am, Pu,Cm).-Resolution with alphas – (18-20KeV) FOR 5.5MeV particles

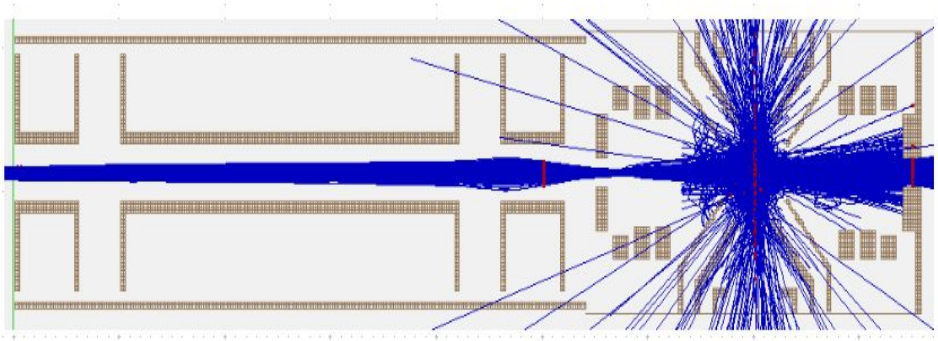


Detectors mounted on the axip of MORATrap,for the measurement of degree of Polarization(P).



Resolution of 22 KeV achieved for 1 MeV energy peak in the preliminary testing with electron source.

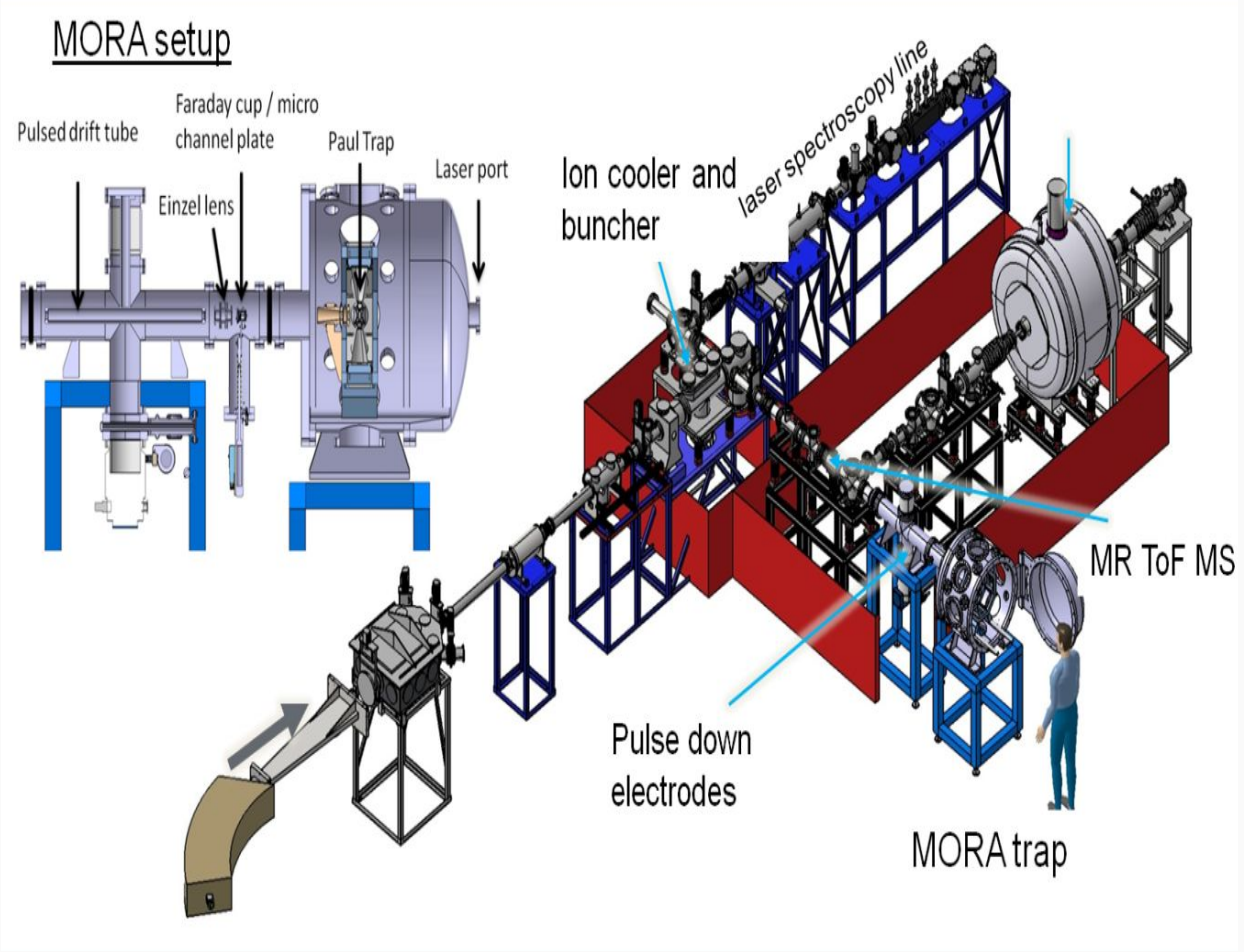
Beam line testing and Simulation (Preparation for the move to JYFL)



- SIMION simulations for MORA beamline are currently in progress.
- Testing yet to be done.. (We expect to start the beam line testing by the beginning of month May..)

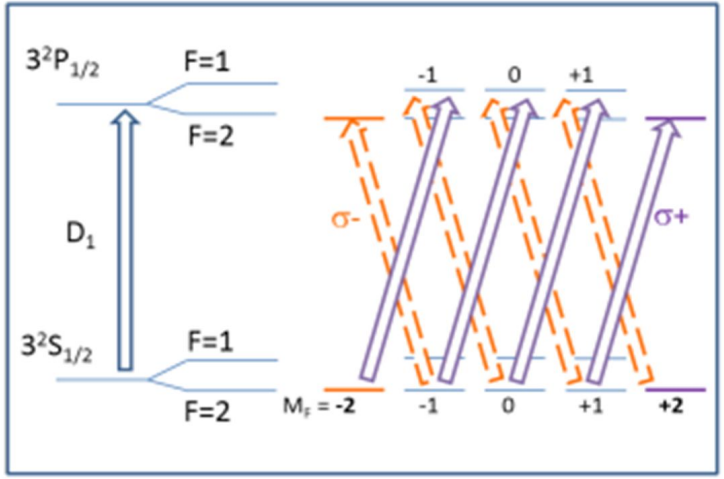
New Perspectives with MORA Project:

- Finishing the tests of the detectors and the beamline at LPC,Caen & GANIL. *(June,2021)*
- Moving to JYFL *(July,2021)*
- Proof of Principle of Polarization and first Measurement of D correlation parameter at JYFL.*(Dec,2021-2023)*
- Higher Accuracy approach with D correlation measurement in future DESIR facility,
  - Expected improvement of 1 order of magnitude on the sensitivity to Im(Cv/CA).
  - Probing new Physics beyond the level predicted in Standard Model in TeV scale,
  - Probing of Final state Interaction effects in the case of 23Mg.



Backup

Optical Polarization:



D1 hyperfine transition used to orient the spin of 23Mg+ ions (~280 nm)

Extended interaction time with laser light
Very high polarization degree
>90%: enough for the measurement of D!

Degree of polarization estimated to more than 99% after 0.2 ms of trapping time

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

$$A_\beta \frac{\langle \vec{J} \rangle}{J} \cdot \frac{\overrightarrow{p_e}}{E_e}$$

C. S. Wu et al., Phys Rev 105(1957)1413