# THE MORA PROJECT

## MATTER'S ORIGIN FROM RADIOACTIVITY

GDR-InF Annual Workshop 2022
2–4 Nov 2022
Domaine Lyon Saint-Joseph

Nishu GOYAl
Grand Accélérateur National d'Ions Lourds

*On behalf of* MORA collaboration

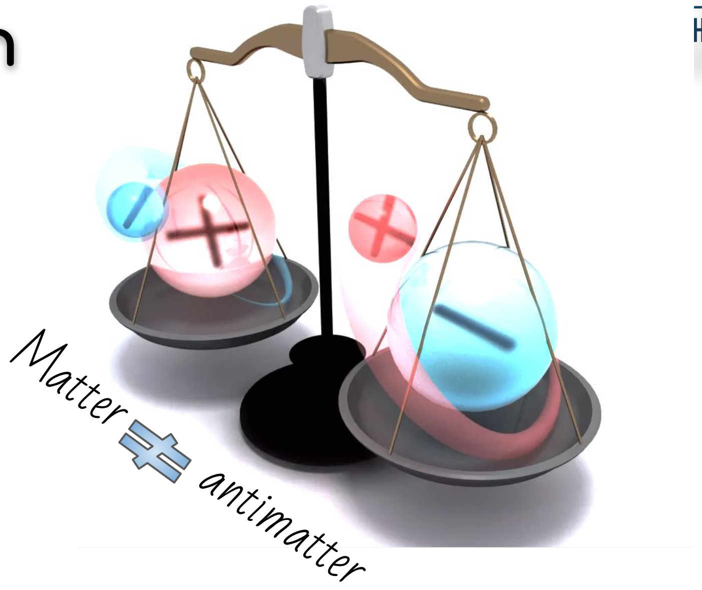
AGENCE NATIONALE DE LA RECHERCHE ANR
Normandie Université
RÉGION NORMANDIE

HE MORA PROJECT

# The mystery of CP violation

(i) a large C and CP violation
(ii) a violation of the baryonic number
(iii) a process out of thermal equilibrium

*A. D. Sakharov, «Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe,» JETP Letters, vol. 5, p. 24, 1967*




CP violation observed in the K, B and D - meson decays....Not enough!!!

Physics beyond the standard Model...NEW PHYSICS!

# β decay- laboratory for Weak interactions

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Probability rate function of beta decay

$$\omega(\langle\vec{J}\rangle|E_e,\Omega_e,\Omega_\nu)dE_e\, d\Omega_e\, d \propto F(\pm Z,E_e)\, p_e E_e (E_0 - E_e)^2 dE_e\, d\Omega_e\, d\Omega_\nu$$

$$\times\ \xi \left\{1 + a\frac{\vec{p_e}\cdot\vec{q}}{E_e\,E_\nu} + b\frac{\gamma\, m_e}{E_e} + A\frac{\vec{J}}{J}\cdot\frac{\vec{p_e}}{E_e} + D\frac{\langle\vec{J}\rangle}{J}\cdot\left(\frac{\vec{p_e}}{E_e}\times\frac{\vec{p_\nu}}{E_\nu}\right)\right\}$$

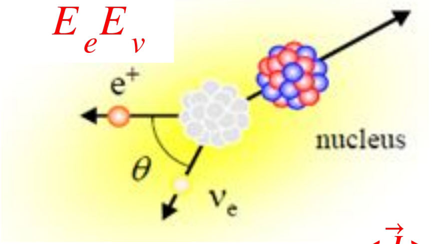
β-neutrino angular correlation

Fierz interference term

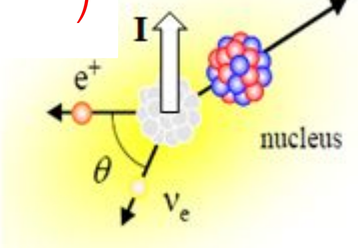
β asymmetry

D-correlation

$$a\frac{\vec{p}_e\cdot\vec{q}}{E_e E_\nu}$$




$$D\frac{<\vec{J}>}{J}\cdot\left(\frac{\vec{p}_e}{E_e}\times\frac{\vec{p}_\nu}{E_\nu}\right)$$




A non zero D can arise from CP violation!

*Jackson, Treiman and Wyld, Nucl. Phys. 4 (1957)*

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$$\times\,\xi\left\{1+a\frac{\vec{p_e}\cdot\vec{q}}{E_e\,E_\nu}+b\frac{\gamma\,m_e}{E_e}+A\frac{\vec{J}}{J}\cdot\frac{\vec{p_e}}{E_e}+D\frac{\langle\vec{J}\rangle}{J}\cdot\left(\frac{\vec{p_e}}{E_e}\times\frac{\vec{p_\nu}}{E_\nu}\right)\right\}$$

β-neutrino angular correlation

Fierz interference term

β asymmetry

D-correlation

strong mixed (GT+FERMI ) transitions

Neutron and Mirror Nuclei (N=Z-1)

$D_n = (-0.94 \pm 2.1)\cdot 10^{-4}$

$D^{19}Ne = (1 \pm 6)\cdot 10^{-4}$

*emiT collaboration, PRL 107, 102301 (2011)*

*Calaprice, Hyp. Int. 22(1985)83*

# β decay- laboratory for Weak interactions

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Probability rate function of beta decay

$$\omega(\langle \vec{J} \rangle | E_e, \Omega_e, \Omega_\nu) dE_e \, d\Omega_e \, d \;\propto F(\pm Z, E_e)\, p_e E_e (E_0 - E_e)^2 dE_e \, d\Omega_e \, d\Omega_\nu$$

$$\times \, \xi \left\{ 1 + a \frac{\vec{p_e} \cdot \vec{q}}{E_e E_\nu} + b \frac{\gamma m_e}{E_e} + A \frac{\vec{J}}{J} \cdot \frac{\vec{p_e}}{E_e} + D \frac{\langle \vec{J} \rangle}{J} \cdot \left( \frac{\vec{p_e}}{E_e} \times \frac{\vec{p_\nu}}{E_\nu} \right) \right\}$$

β-neutrino angular correlation

Fierz interference term

β asymmetry

D-correlation

$^{23}$Mg, $^{39}$Ca - Candidates in the Framework of MORA

Goal : Reaching a sensitivity close to $10^{-5}$

# in a Nutshell…

Laser Polarization Techniques + Beam Cooling and Bunching + Trapping Techniques

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# General Overview of the setup

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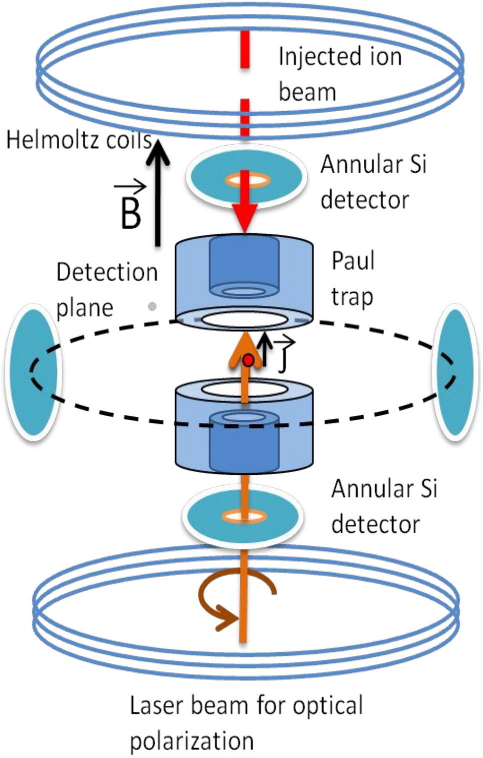
D1 hyperfine transition used to orient the spin of $^{23}Mg^{+}$ ions
*(~280 nm)*

Laser circular polarization
*( σ+ to σ−)*



# General Overview of the setup

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

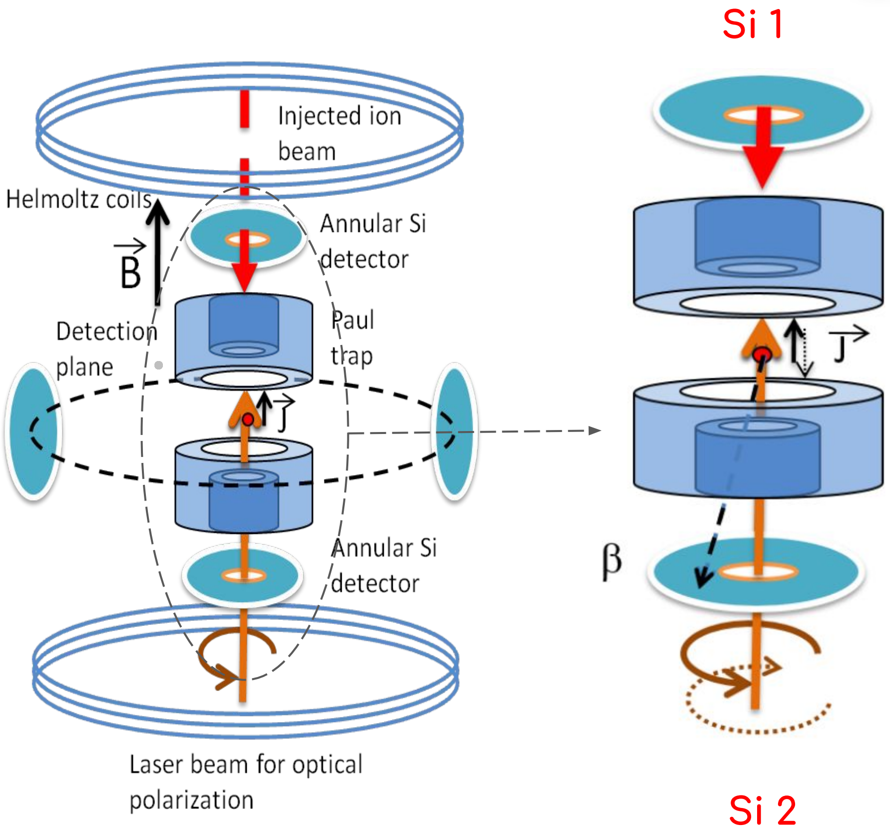
Polarization Degree

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

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

$$A_\beta = -0.5584 \pm 0.0017$$

*N.Severijns et al., PRC 78*



# D measurement Setup

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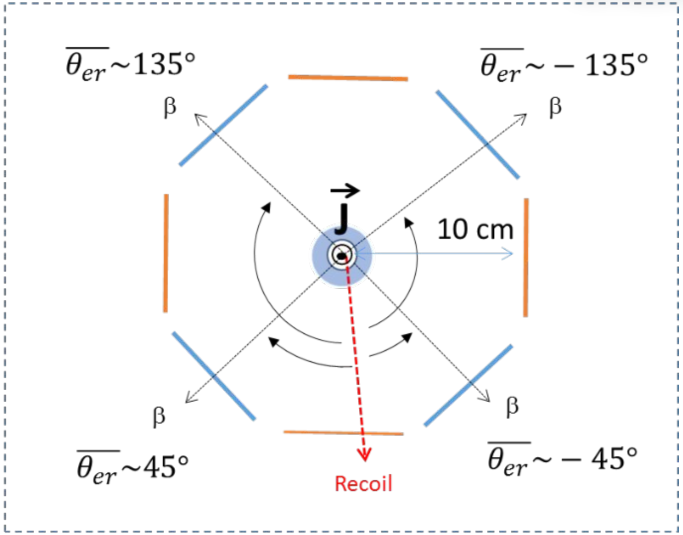
$$D \propto \left( \frac{N_{(\beta r)coin}^{(\theta_{er}\in[0,\pi])} - N_{(\beta r)coin}^{(\theta_{er}\in[0,-\pi])}}{N_{(\beta r)coin}^{(\theta_{er}\in[0,\pi])} + N_{(\beta r)coin}^{(\theta_{er}\in[0,-\pi])}} \right)$$

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

Sensitivity parameter ($\delta$) — D-correlation ($D$) — Polarisation Degree ($P$)

$D_n \leq 2.10^{-4}$

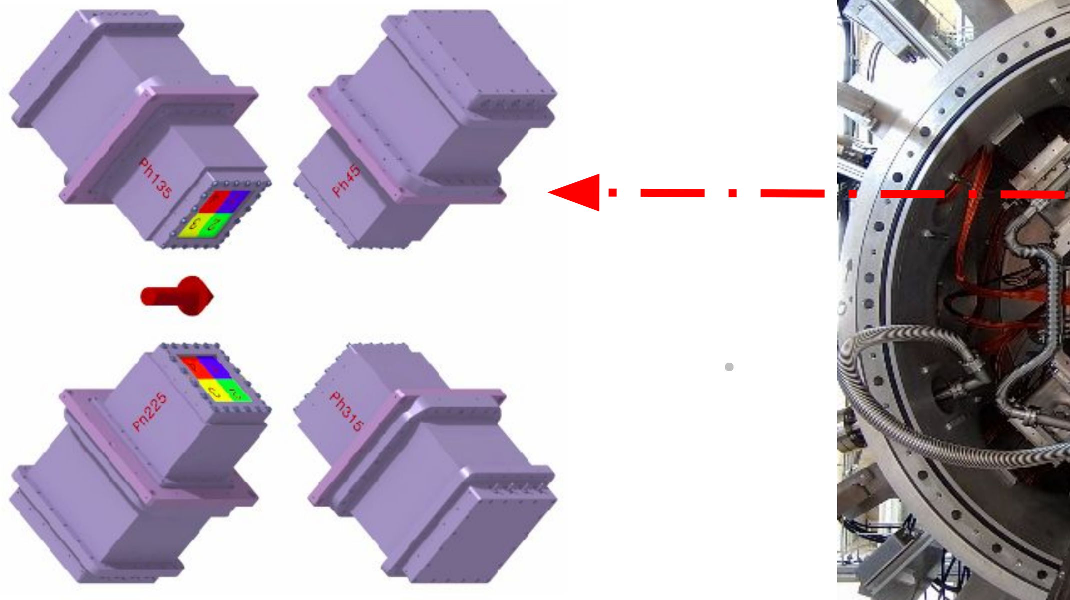
*emiT collaboration, PRL 107, 102301 (2011)*



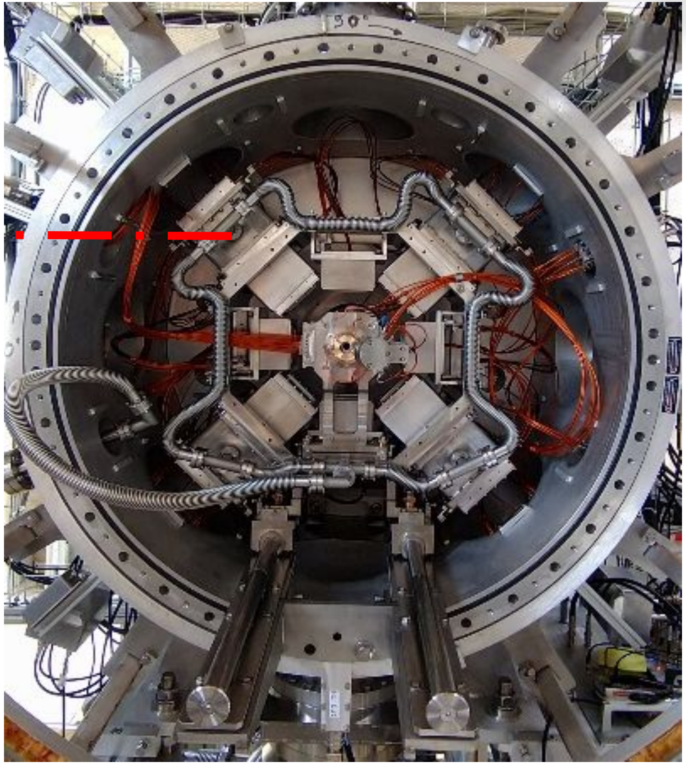

Magnified view of the D correlation detection setup, showing the different types of β-recoil coincidences

*P. Delahaye et al, The MORA project, Hyp. Int. (2019) 240:63*

# β- recoil coincidences

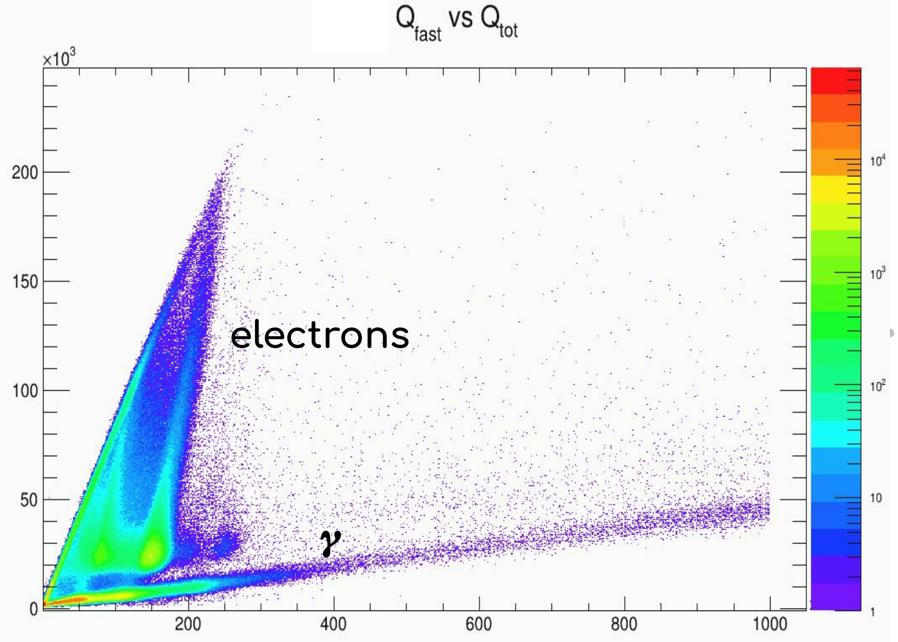



PHOSWICH Detectors
Thick (5cm)& Thin(0.5mm) Scintillator
+ Photomultiplier Tube

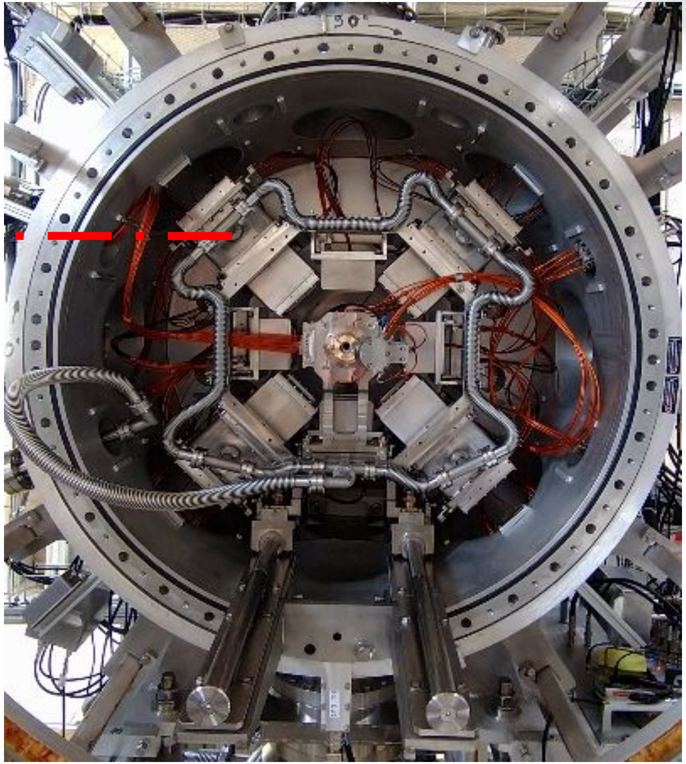


First installation of experimental setup
@IGISOL facility of Jyvaskyla, FINLAND

# β- recoil coincidences

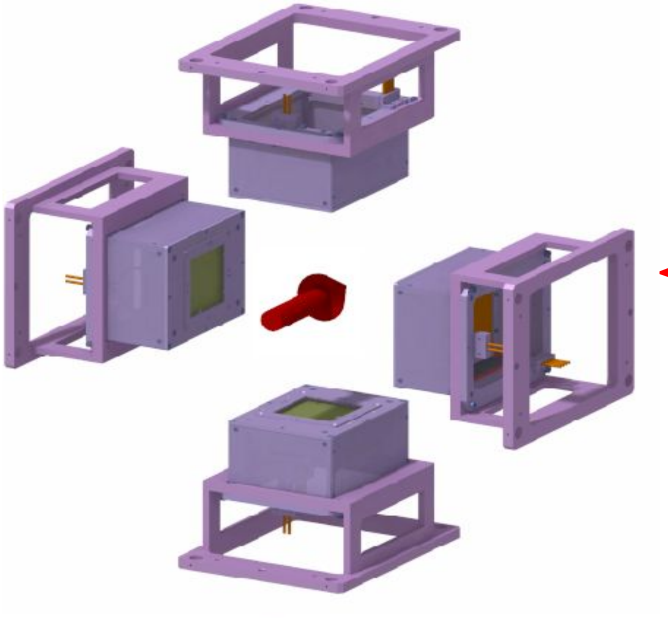



Slow and Fast Response from scintillators
(Precise discrimination of electrons and gammas)

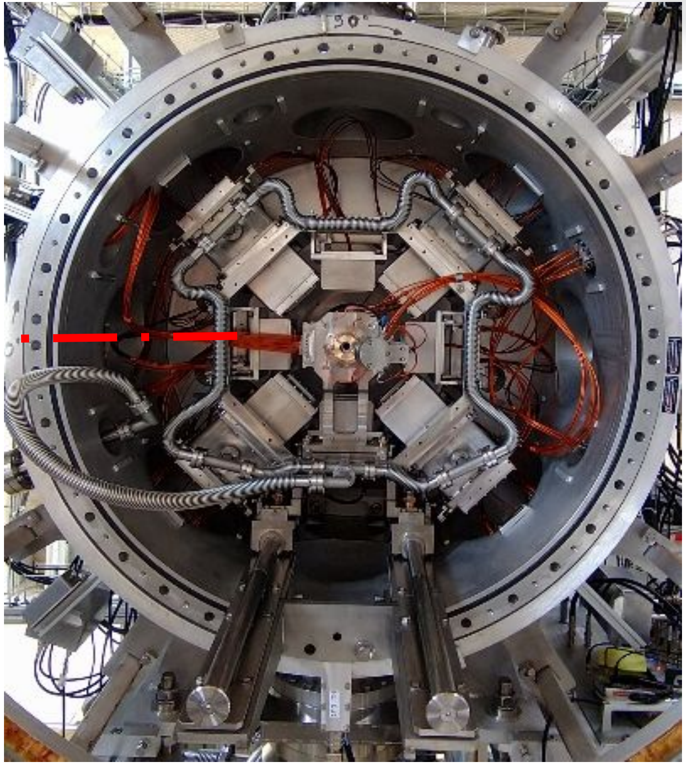


First installation of experimental setup @IGISOL facility of Jyvaskyla, FINLAND

# β- recoil coincidences

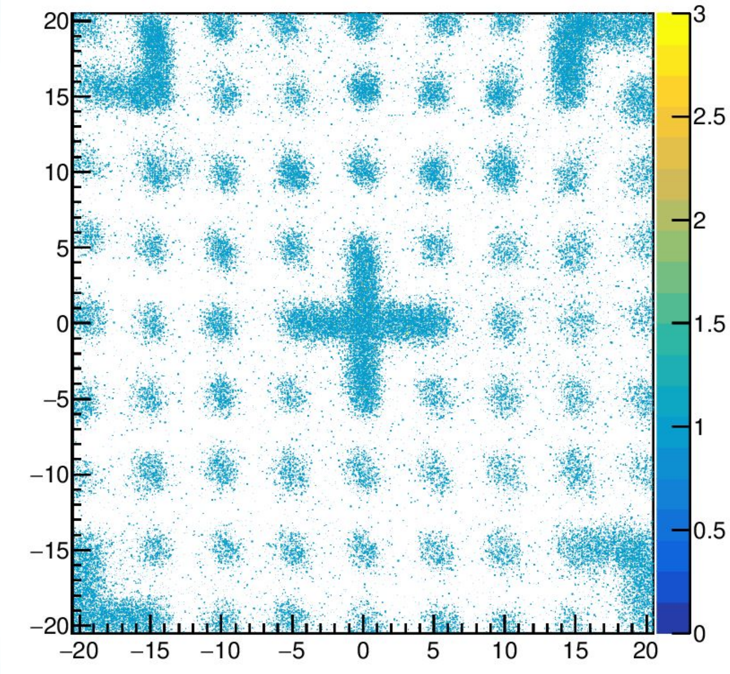


RIDE Detectors
Acceleration Grid+ MCP's(CHEVRON)+ Position sensitive flex

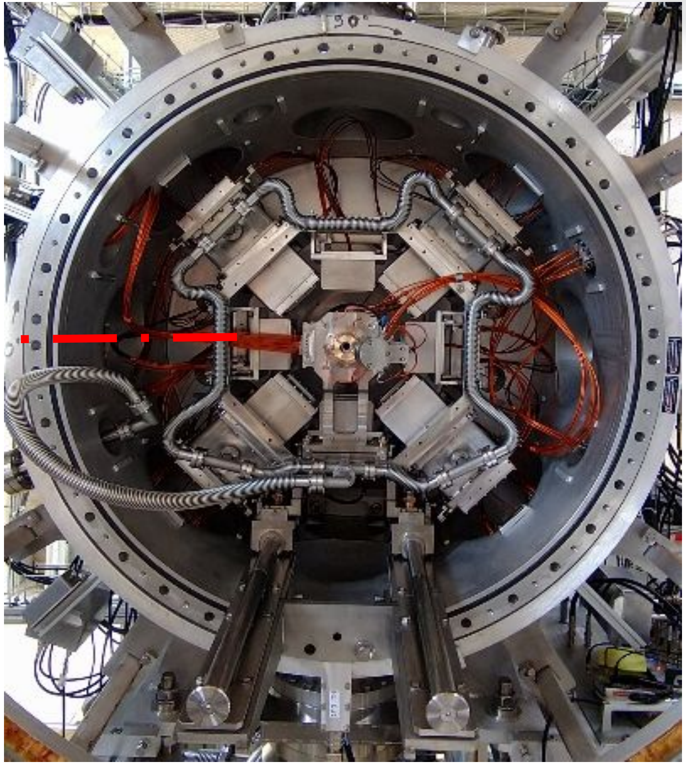


First installation of experimental setup @IGISOL facility of Jyvaskyla, FINLAND

# β- recoil coincidences




Detector Image for Position Response
using Resistive Position Sensitive Flex



First installation of experimental setup
@IGISOL facility of Jyvaskyla, FINLAND

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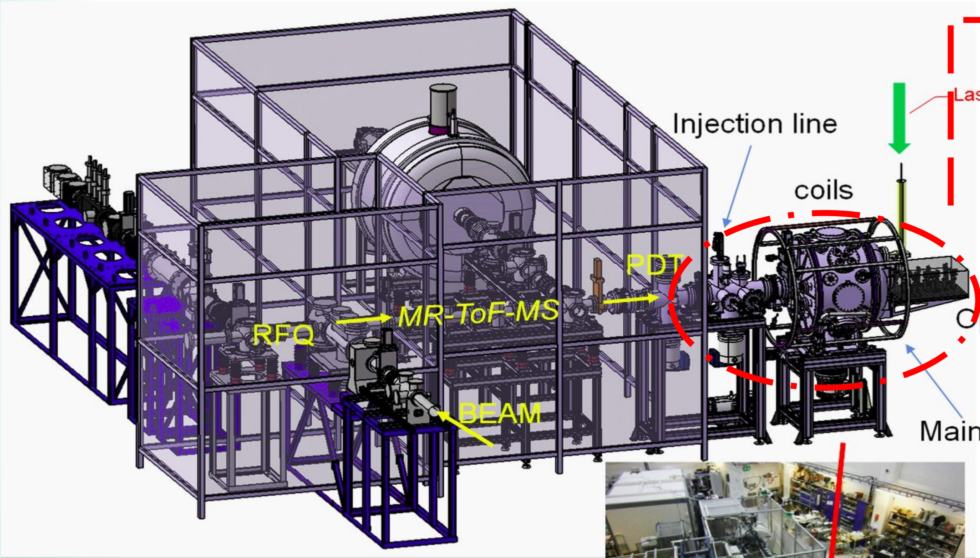
# Beam Manipulation in IGISOL

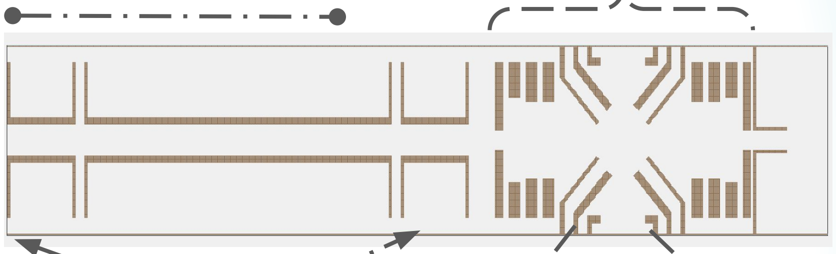
Ions starts @2keV before PDT1

Ions @subeV energies




PDT2

MoraTrap

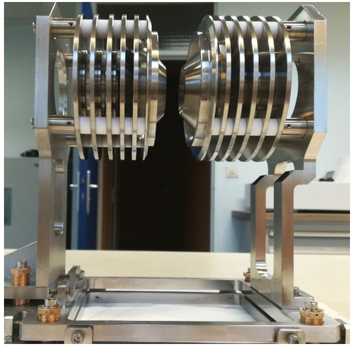


Steerers

R3

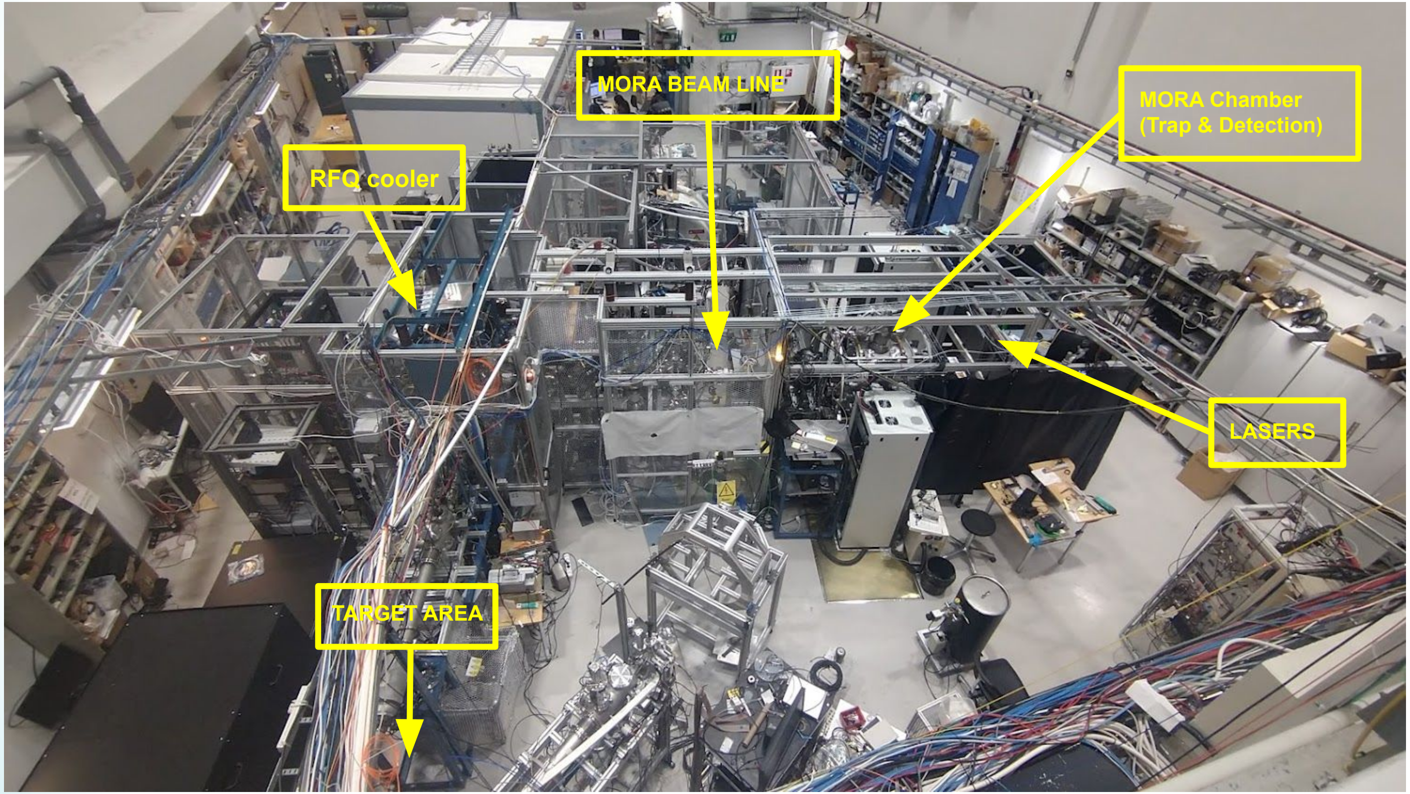
R4

IGISOL LINE (INSIDE CAGE) @30kV



The MoraTrap (Optimized version)

# MORA Commissioning @ IGISOL




Experimental conduct in two Phases so far..

Beamline Preparation Period:
Jan 16 - Feb 13, 2022

1st Beamtime:
Feb 13-15$^{th}$, 2022

2nd Beamtime:
May 27-31$^{st}$, 2022

# Progresses @ IGISOL

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## Feb, 2022

Primary beam

7 $\mu$-Amps proton beam
($10^5$ ions/$\mu$A)

**Beam Purity**

Na contamination

Na:Mg
-reduced from 20,000 to 2000

## May, 2022

Primary beam

7 $\mu$-Amps proton beam
($10^5$ ions/$\mu$A)

Na:Mg
-reduced from 2000 to 500

(cleaning of target heads and beam optics helped)

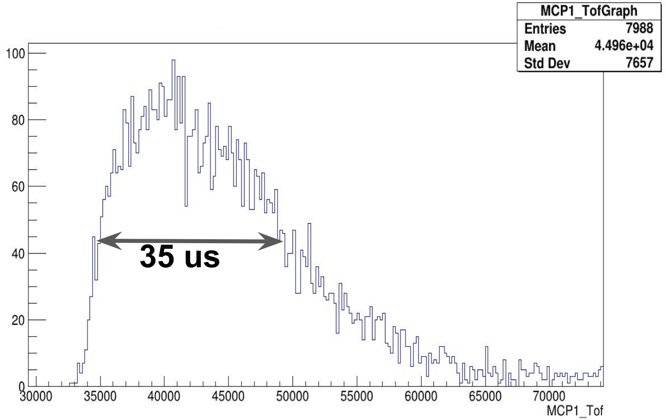
# Progresses @ IGISOL

## Feb, 2022

Bunching

500ms (endplate Bunching)

(20-100us)Bunches

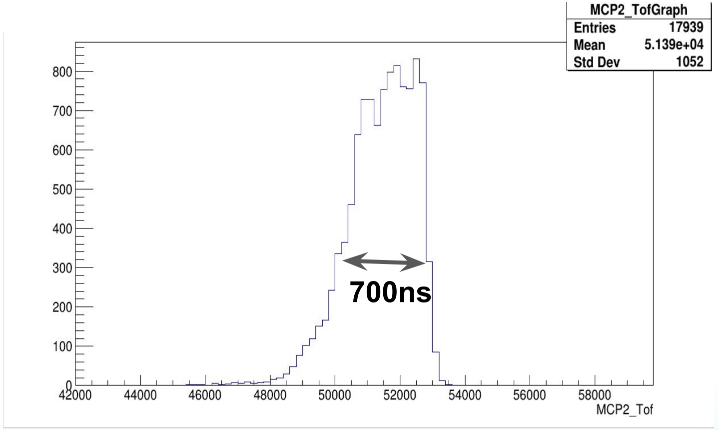



## May, 2022

Bunching

130ms (Mini Buncher)

(500ns-1us)Bunches further optimized to <500ns



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# Progresses @ IGISOL

## Trapping Progress (approximate statistics)

MR-TOF

| | From IGISOL target (pps) | cooler efficiency | Efficiency due to space charge limit | PDT efficiency | Trapping Efficiency | Number of trapped ions per cycle |
|---|---|---|---|---|---|---|
| Feb, 2022 | 1000000 | 0.1 | 1 | 0.01 | 0.01 | 10 |
| May, 2022 | 1000000 | 0.1 | 0.01 | 1 | 0.1 | 100 |

With Minibuncher

Can be improved!!

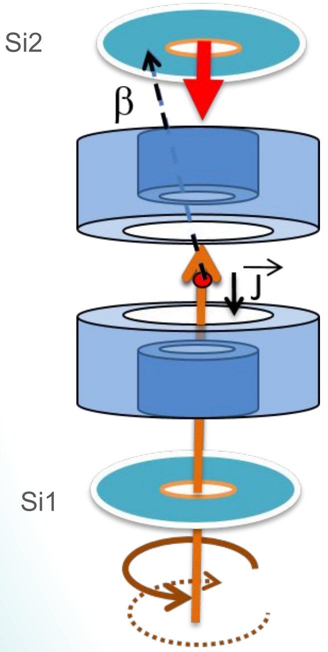
- By increasing space charge capacity - from $10^5$ to $10^7$ /bunch
- By reducing contamination: Na:Mg from 500 to 10

Goal: $10^4$ ions/bunch

# Very preliminary estimates from on-line measurements

Last beam time
(May,2022)

$^{23}$Mg: $T_{1/2}$=11.3s, 43 min ~1600 decays in 4π
**σ+** polarized light



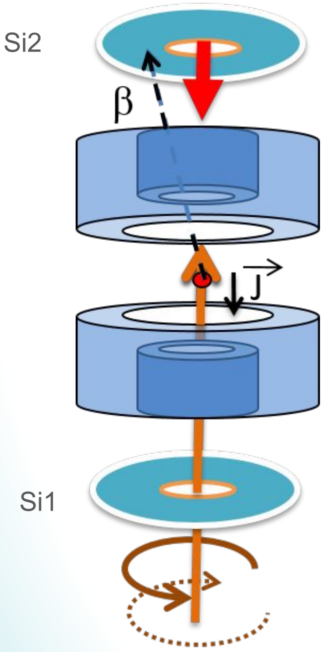

| Experiment | Theoretical | |
|---|---|---|
| | Hypothesis: P=1 | Hypothesis: P=0 |
| 97 counts 6 sectors (2 are noisy) | ~2.4% of betas = 67 β<br>Background: 30 β | ~1.5% of betas = 43 β<br>Background: 54 β |
| | about 17 ions per bunch | about 17 ions per bunch |
| 48 counts 5 sectors (3 are noisy) | ~0.64% of betas = 18 β<br>Background: 30 β | ~1.5% of betas = 43 β<br>Background: 5 β |

Both situations are possible...

# Very preliminary estimates from on-line measurements

Next beam time

$^{23}$Mg: $T_{1/2}$=11.3s, about 17 ions per bunch, 8 hours ~31300 decays in **σ+** and **σ-** polarized light & Background Measurement




| σ+ | σ- | Bkgd |
|---|---|---|
| 1330 β | 657 β | 335 β |
| 657 β | 1330 β | 335 β |

$$\alpha P = (Si2 - Si1) / (Si1 + Si2 - 2Si0)$$

$\alpha$= 0.5

is the background, assuming about 1 count/min

$$\frac{\sigma P}{P} = \frac{1}{(S2 - S1)} * \sqrt{(1-\alpha^2)\sigma^2_{S1} + (1+\alpha^2)\sigma^2_{S2} + 4\alpha^2\sigma^2_{S0}}$$

$$\frac{\sigma P}{P} = 0.07$$

<10% measurement is possible,
If we achieve high Polarization!!

# Summary & Future perspectives

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## Beam Purity and Trapping

Less contamination from $^{23}Na$ to trap more $^{23}Mg$ ions

Smaller Bunches <500ns (with Mini Buncher)

Transmission Improved from RFQ to MORAbeamline

## Detection

High background has been mitigated

Pulsed electrode noise was filtered with time cycle information

RIDE detectors position recalibration (in progress..)

Simulations (Geant4/PENELOPE) for beta detector's final calibration (in progress..)

## Foreseeable Improvements/ modifications

Optimization of minibuncher RF( inc. space charge capacity)

Hot Cavity for the production of Pure $^{23}Mg$ beams (operating Temp 2000°C)

New reaction Mechanism (C+C, 10mbarn, 5-10 MeV/A)

Possible use of MR-TOF-MS for preventing space charge issues in MORATrap.

Next Beam time , we expect to reach **10%** accuracy on P measurement.

**Next beam time : November 11-14th,2022**

*Sincere thanks to the Organizers*

*&*

*MORA collaborators*

# Thank you for your attention!

**MORA collaborators:**

P.Delahaye
F.De Oliveira
C.Fougères
N.Goyal
N.Lecesne
A.Singh

G.Ban
M.Benali
S.Daumas-Tschopp
X.Fléchard
E.Liénard
G.Quéméner

A.Falkowski
A. Rodriguez-Sanchez

T.Eronen
W.Gins
A.Jaries
A.Jokinen
A.Kankainen
A.Koszorus
S.Kujanpää
I.Moore
A.Raggio
M.Reponen
S.Rinta-Antila
J.Romero
M.Stryjczyk
V.Virtanen

M.L.Bissel

G.Neyens
N.Severijns
R.P.De Groote
A.De Roubin

M.Kowalska
G. Neyens

M. Gonzáles-Alonso

Z.Ge