THE MORA PROJECT

# MORA, First Data Analysis

Polarization measurement analysis

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RÉGION NORMANDIE

- Physics Introduction
- MORA Setting
- Data acquisition
- Data analysis
- Beam purification
- Conclusions and Outlook

# Physics Introduction

# In search of CP Violation

Sakharov proposal for baryogenesis

In the **SM**, **CPV** occurs when we have a complex phase in the **CKM matrix**

There has been observed direct CPV in **K, B and D** mesons decay, **not enough** to account for the observable matter in the universe

We can search for more CPV **inside** the SM **or** search for CPV **outside the SM**

We use nuclear physics to study the **D correlation**

# Physics: β decay D-Correlation

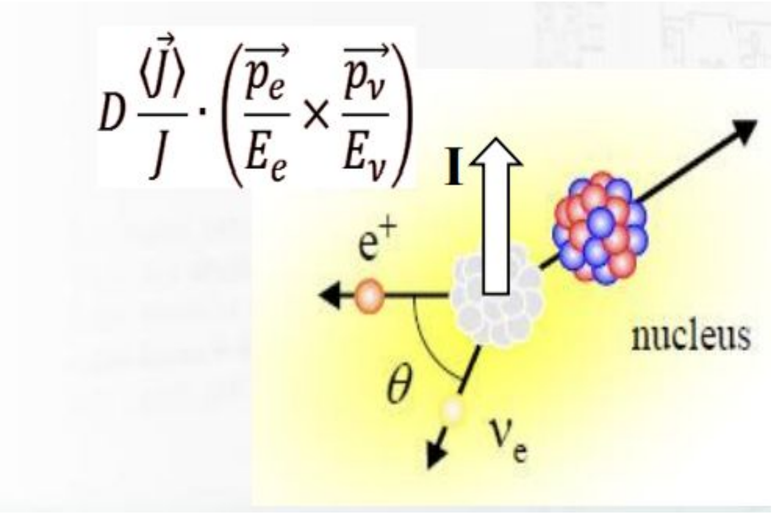
In a GT-F mixed β-decay the energy phase space can be written as *

$$\omega(\langle J\rangle | E_e,\Omega_e,\Omega_\nu)dE_e d\Omega_e d\Omega_\nu$$
$$= \frac{1}{(2\pi)^5} p_e E_e (E^0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu \xi \left\{ 1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} \right.$$
$$\left. + c\left[\frac{1}{3}\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} - \frac{(\mathbf{p}_e\cdot\mathbf{j})(\mathbf{p}_\nu\cdot\mathbf{j})}{E_e E_\nu}\right]\left[\frac{J(J+1)-3\langle(\mathbf{J}\cdot\mathbf{j})^2\rangle}{J(2J-1)}\right] + \frac{\langle\mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_\nu}{E_\nu} + D\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_e E_\nu}\right]\right\}$$

***A*** is the **parity-violation** term, ***b*** the **Fierz interference** shaping-term, ***a*** the **β-ν** correlation, and ***D*** the **triple correlation term.**

*D* is non-zero for **T** reversal violation

* Jackson, J. D.; Treiman, S. B.; Wyld, H. W. (1957) Phy Rev 106(3), 517−521



# Physics: Where to find the D-Correlation

As previously said: we need a GT-F mixed decay and polarization → **We to maximize the sensitivity factor F(X) and polarization degree to get the highest coupling**

$$D \equiv \sin(\varphi_{AV}) \cdot \overbrace{\frac{2\rho}{1+\rho^2} \cdot \left(\frac{J}{J+1}\right)^{1/2}}^{F(X)}$$

→ Proportional to mixture degree and axial vector-vector phase

$$\varphi_{AV} = 180.013° \pm 0.028° \text{ (68\% CL)}$$

Final state interactions (**FSI**), never measured using D-correlation

$$D_{FSI} \sim Z\alpha \frac{E_e}{M} \cdot A(\mu_f - \mu_i)$$

Callan and Treiman, Phys. Rev. 162(1967)1494.

# Physics: Selection of nuclei for D-Correlation

We want to maximize the **sensitivity F(X)**

We also need good **polarization**

| | n | $^{19}$Ne | $^{23}$Mg | $^{35}$Ar | $^{39}$Ca |
|---|---|---|---|---|---|
| **Sensitivity *F(X)*** | 0,43 | -0,52 | -0,65 | 0,41 | 0,71 |
| $D_1$ ($\times 10^{-4}$) | 0,108 | 2,326 | 1,904 | 0,386 | -0,489 |
| $D_2$ ($\times 10^{-4}$) | 0,023 | 0,169 | 0,099 | 0,010 | -0,024 |

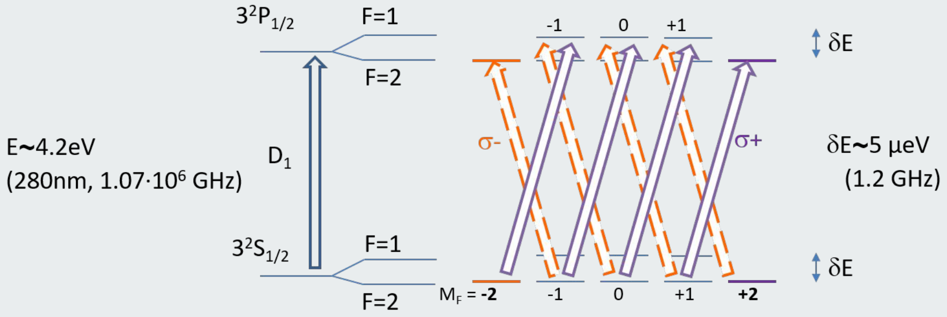
$D_n = (-0.94 \pm 1.89 \pm 0.97) \cdot 10^{-4}$  $D_{19Ne} = (1 \pm 6) \cdot 10^{-4}$

Best measurement so far, *statistics limited*

$$D_{FSI}(p_e) = \left( D_1 \cdot \frac{p_e}{p_{emax}} + D_2 \cdot \frac{p_{emax}}{p_e} \right) \times 10^{-4}$$

Callan and Treiman, Phys. Rev. 162(1967)1494.
Chen, Phys. Rev. 185(1969)2003.

# Physics: Laser polarization




The momentum (*J*) **polarization** is done with a **laser** setup.

The specifics of the polarization depend on the **hyperfine interaction of the isotopes,** originating from the coupling of the electrons and nucleus magnetic moments **of the nuclei**.

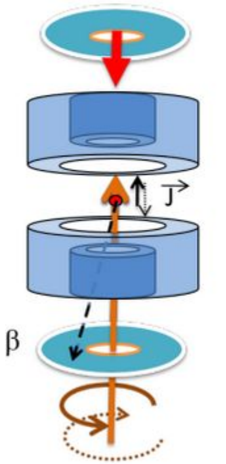
$^{39}$**Ca** has a harder structure to polarize than $^{23}$**Mg**

**Because all of this, we are using $^{23}$Mg for our first experiments**

# MORA Setup

# Experimental Setup

- 2 annular **Si detectors** in the line axis
- 4 **MCP detectors**, each 90° apart from each other
- 4 **phoswich detectors**, between the MCP detectors
- **Paul Trap** in the middle of the detections system
- Laser setup for polarization




*P* measurement

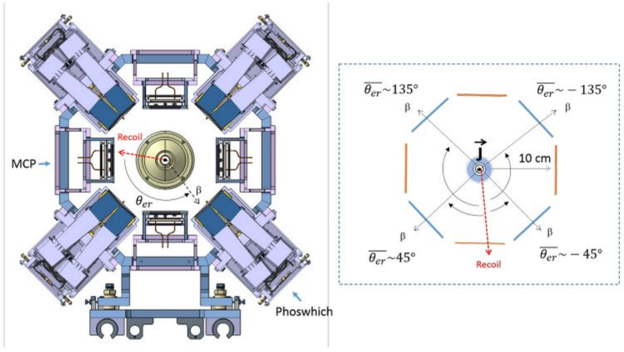


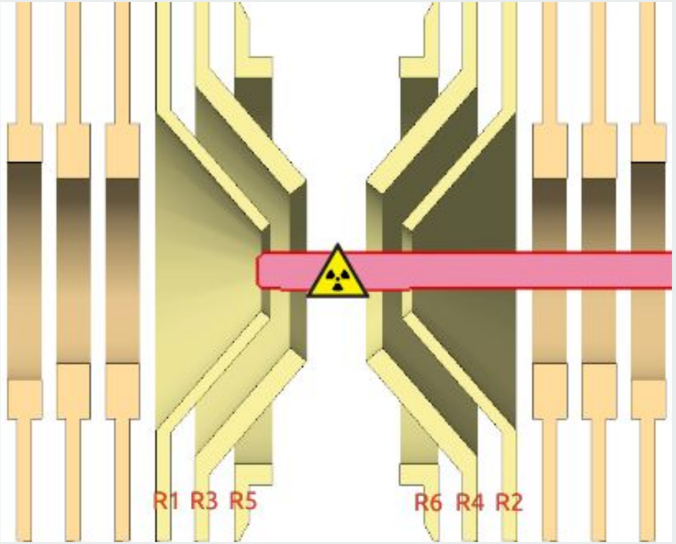

Figure 3: Left inset: cross section of the $D$ correlation detection setup. The trap electrodes are visible in the center of the detection setup. Right inset: sketch showing the different types of $\beta$-recoil coincidences which will be recorded by the detection setup.

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

$$\frac{N^{+45°}_{coinc} + N^{+135°}_{coinc} - N^{-45°}_{coinc} - N^{-135°}_{coinc}}{N^{+45°}_{coinc} + N^{+135°}_{coinc} + N^{-45°}_{coinc} + N^{-135°}_{coinc}} = \delta \cdot D \cdot P$$

# MORA Trap

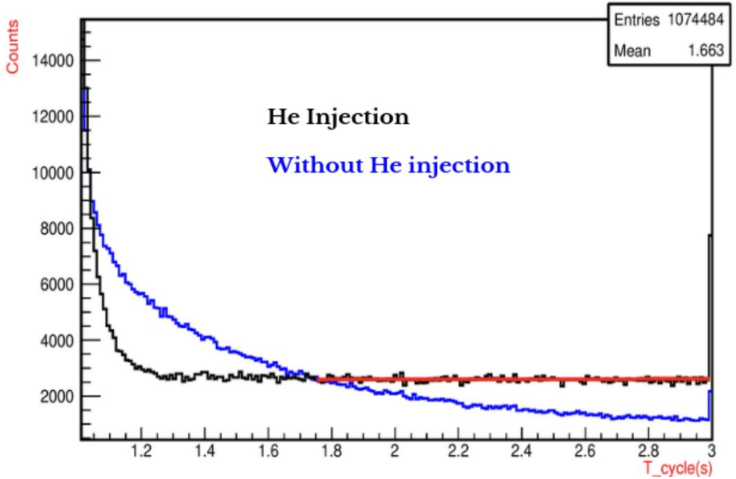
Paul Trap developed in LPC Caen




Paul Trap consisting on 3 pairs of **electrodes** (R1-R6) and 2 **Einzel lenses**

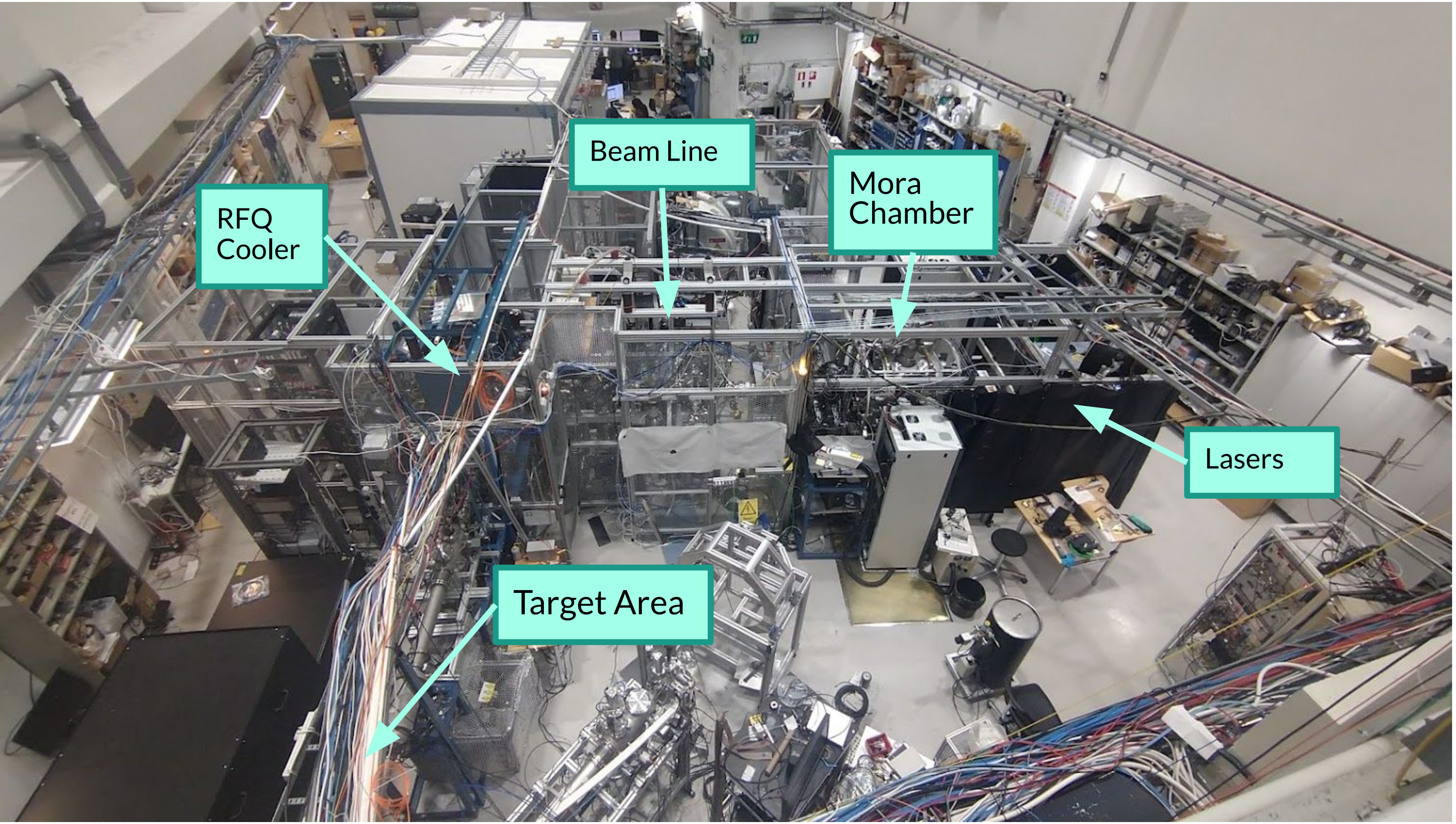
The electrodes (R1-R4) trap the ions

The einzel lenses focus the beam entering to the center of the trap and exiting, so they do not get deposited on Si detectors




The trapping ion cloud slowly evaporates. We use He gas to cool down the cloud and optimize the trapping half-life of ions in the trap

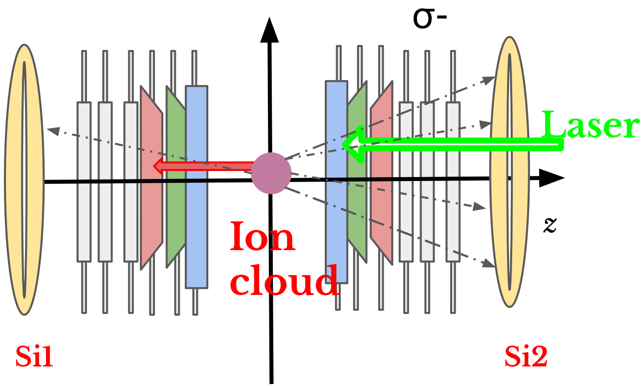
# MORA commissioning at IGISOL in JYFL

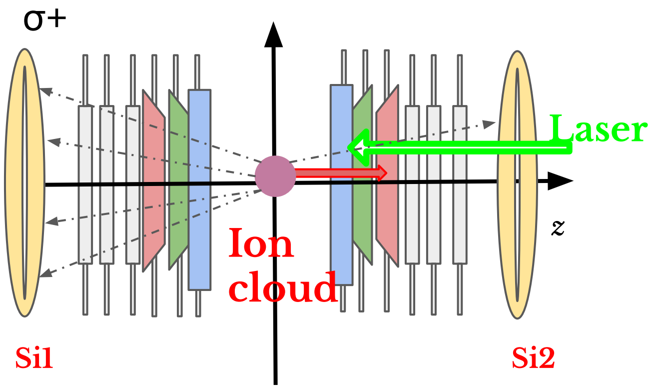


# Data Acquisition

# Data Acquisition

Nov 2022




June 2023

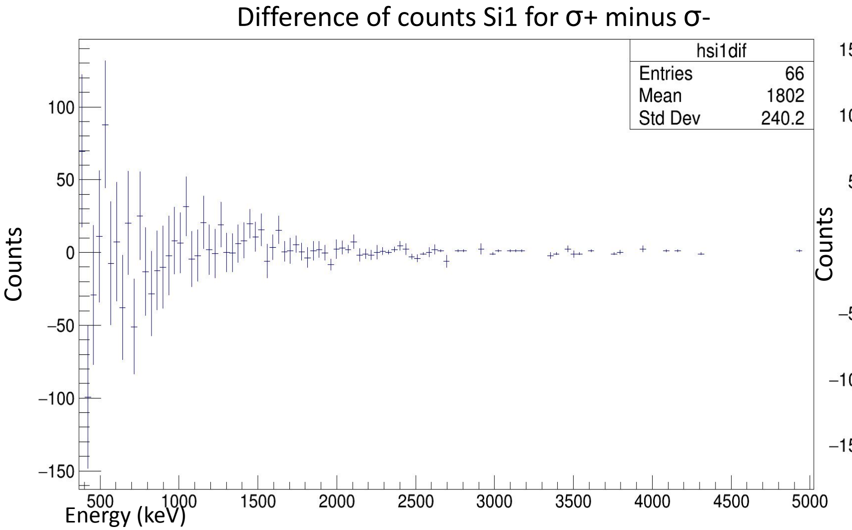
Target test ran with different targets: **MgO** coated with BaO, baked **Mg** and **pure Mg**

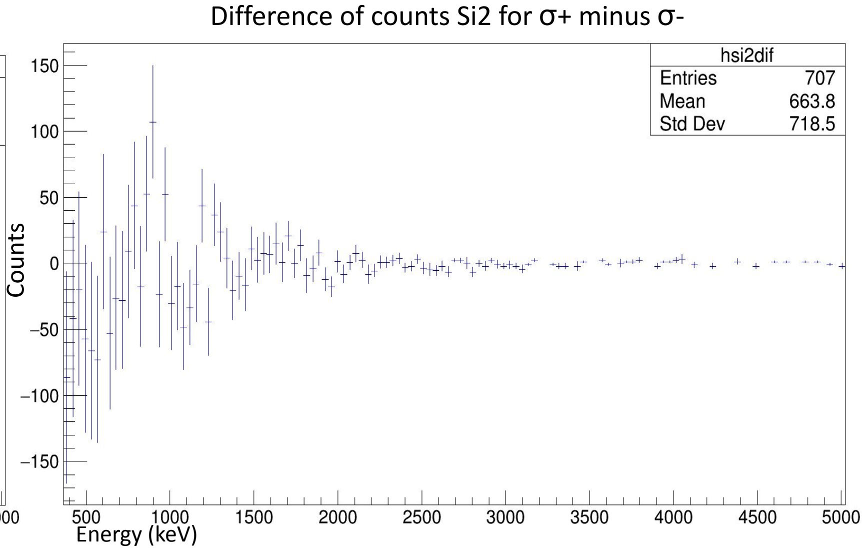
We also ran a test **injecting SF6** gas, in order to capture the ions in molecules

# Data Analysis: Polarization measurement

# Data Analysis: Polarization Measurement

Difference of **Si1+ and Si1-** (**Left**), and difference of **Si2+ and Si2-** (**Right**)



# Beam purification attempts

# Beam purification attempts, $^{23}Na$

We ran a test in June with different target heads ($^{24}Mg$) subjected to different treatments.

MgO coated with BaO, baked Mg and pure Mg

There was a double intention: **Baking** the targets to **evaporate** the residual **Na**, and **preventing** the **surface ionization** (or **capturing** the Na **before** escaping)

Unfortunately, the results were **not convincingly better**

**Same amount of Na**

This means that the contamination has to **come from other source**, future tests and analysis will say which

- Contamination in line
- Contamination of target head
- Contamination from the ion guide
- Ions and plasma ionizing Na (sputtering)

# Contamination Analysis

| Target | Na+ | Mg+ | Mg2+ | MgF+ |
|---|---|---|---|---|
| MgO | ~500pA at 1uA | ~9000 cnts/s at 1uA | up to ~500 cnts/s | X |
| Baked Mg | ~450pA at 1uA | ~21000 cnts/s at 1uA | up to ~600 cnts/s | X |
| Pure Mg (old) | ~150pA at 1uA | ~9000 cnts/s at 1uA | up to ~400 cnts/s | X |
| Pure Mg + SF6 | ~14pA at 16uA | ~900 cnts/s at 16uA | no measure | 1000cnt/s at 16uA |

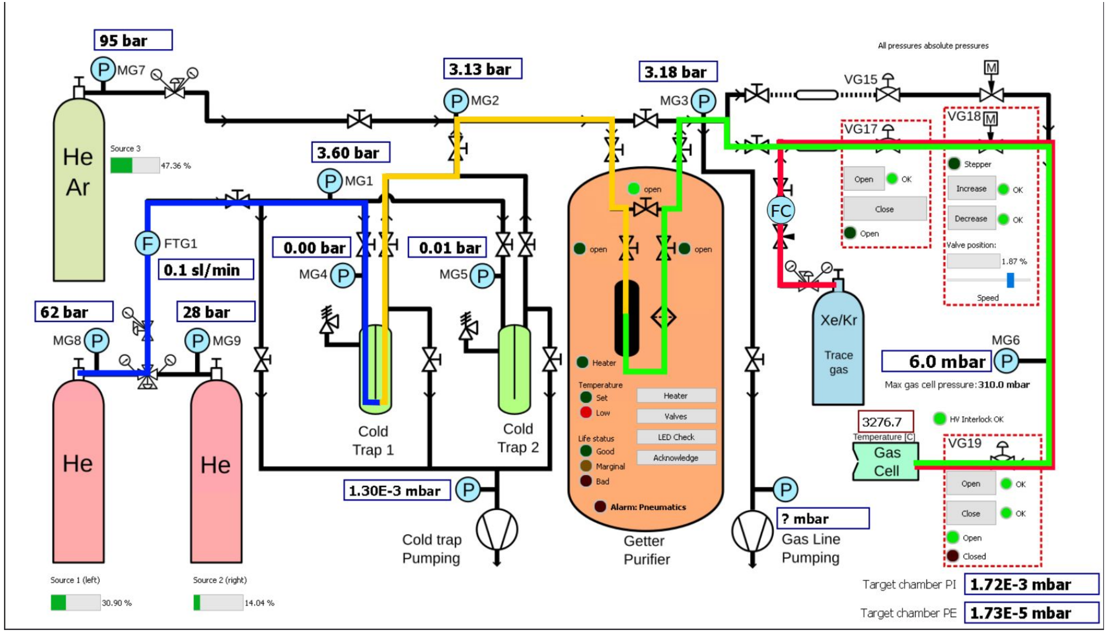
# Conclusions and Outlook

# Outlook

The polarization measurement did not work because of $^{23}Na$ **contamination**, the recent **target test did not improve** the results, we need **new ways to reduce the contamination**

- Using liquid **N** for cooling down the ion guide, preventing any surface ionization or sputtering
- Continue target tests with other materials(**Al, AlO** coating)
- Using gas injection to trap Mg or Na in molecules (**SF6, CF4**)
- Study other ions (Mg2+, MgF…)
- Hot cavity approach

# Gas Injection (CF$^4$): December test




Injection of He + CF4 gas (~10ppm), flow mass monitor

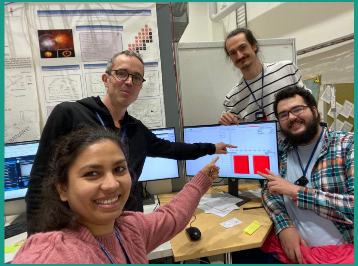
Natural Mg$^{24}$ spark source.

Creation of new molecules, contamination analysis.

Molecule breaking in RFQ Cooler

Pohjalainen, I., Moore, I., Eronen, T. et al. Hyperfine Interact 227, 169–180 (2014).

# Thank you for your attention!



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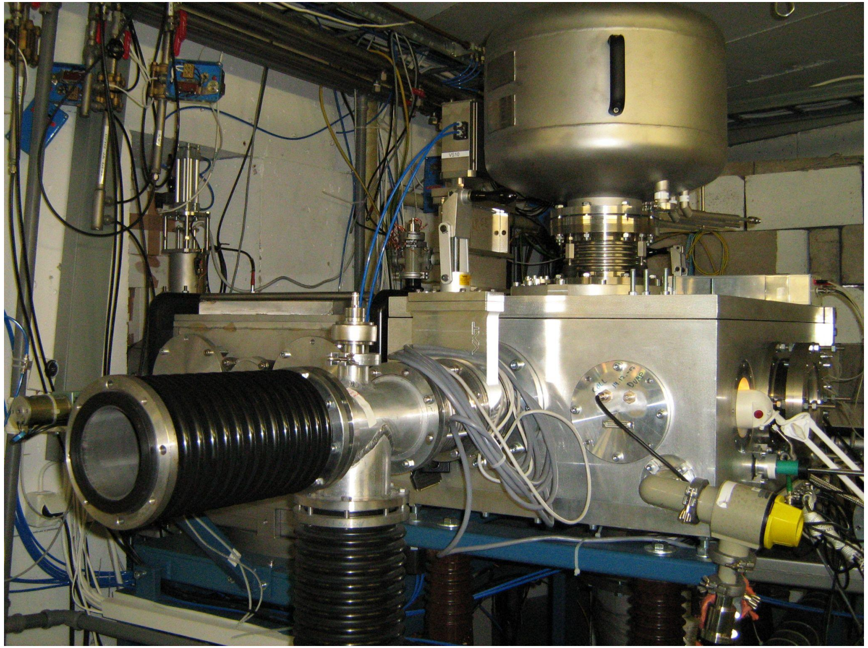
# Extra slides

# Cryogenics



Difficult to schedule: needs preparation for montage and test, also removal.

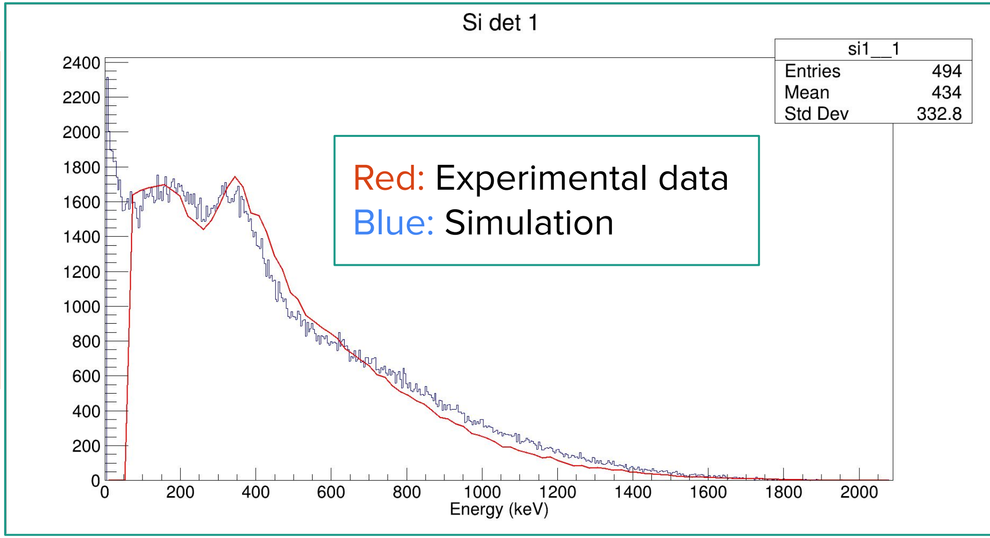
Eliminates heat induced surface ionization and sputtering.

# Data Analysis: Calibration

The calibration fit is done with a PENELOPE simulation

$Sr^{90}$ source for the Si detectors and 3 alpha sources for the RIDE detectors

Si calibration using 3 parameters



# Data Acquisition

72h of **Online** experience and many hours of **Offline** calibration and tests.

4h25' of **background** measurement

6h of **no polarization** without He cooling and 2h **with He cooling**

13h of **polarization**, one in **+z direction** and other in **-z direction**.

The **buncher** acts as a bottleneck → $4{\cdot}10^5$ ions/bunch max capacity

Data acquired with **faster**

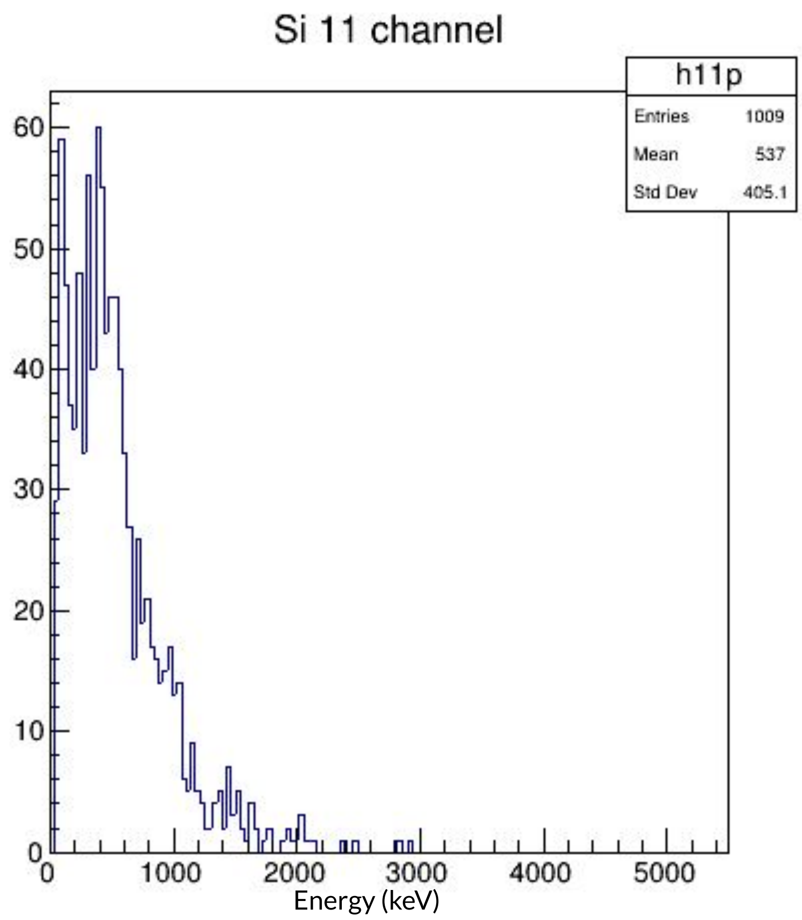
Calibration of the instruments during the **offline** experience, **Na**$^{23+}$ source, **Sr**$^{90}$ source for Si detector calibration

**+12h** of data for Si detector **calibration**

Data acquired with **cycles** of **3s** with **2s trapping**.

# Data Analysis: Polarization

Spectra of radioactive $^{23}Mg$



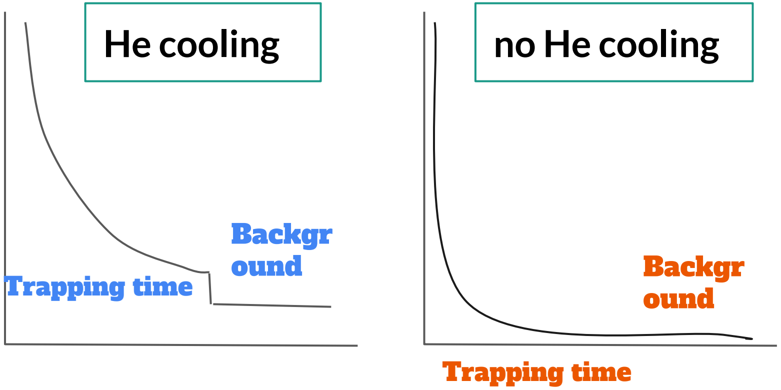
# Data Analysis: Polarization (Counts vs Time)

We are interested in the shape of the counts during the cycle running time

- It will tell us the source of the counts

Two distinct shapes:

- With He Cooling
- Without He Cooling

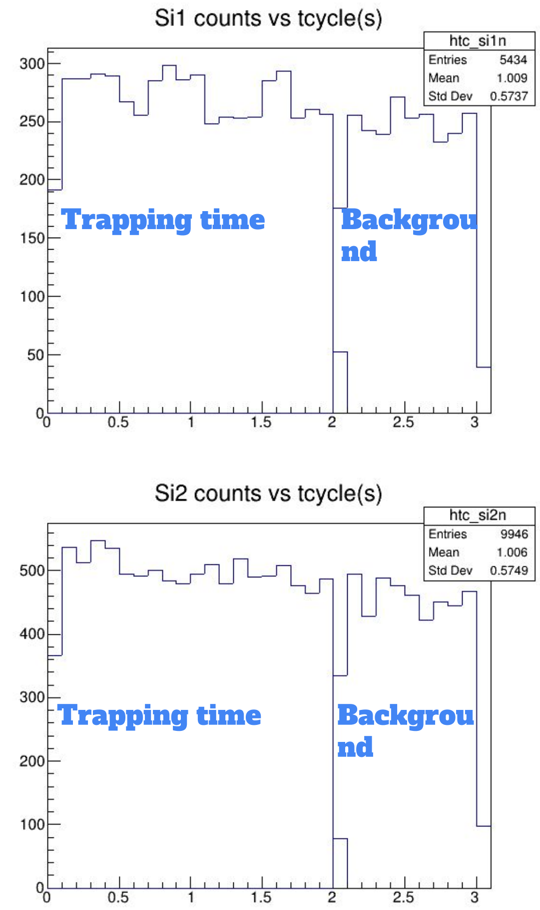



**Exaggerated** counts vs time for He cooling **(left)** and no He cooling **(right)** over a long enough cycle

**The left should permit a measurement of the $^{23}$Mg trapping half-life**

# Data Analysis: Polarization (Counts vs Time)

He cooling



# Data Analysis: Polarization (Counts vs Time)

no He cooling