



La MORA
Bayeux tapestry



THE MORA EXPERIMENT

Matter's Origin from RadioActivity

P. Delahaye, GANIL

ESNT / DPhN seminar, 26/06/2025

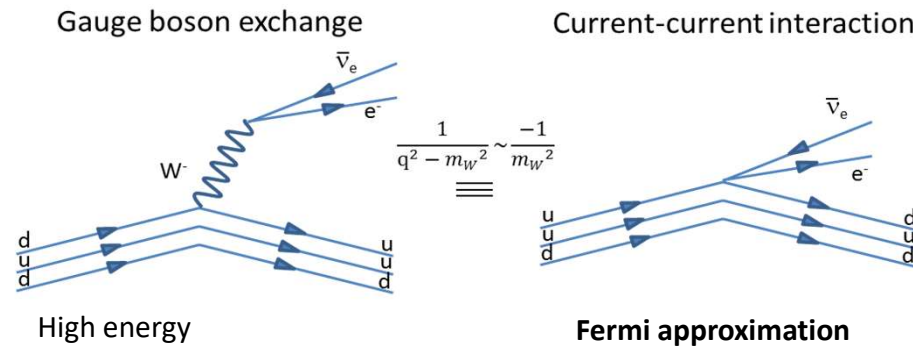


The MORA experiment: Radioactive nuclei to look for BSM Physics

- Nuclear beta decay as a laboratory for weak interaction
 - Reminder: correlations in nuclear beta decays
 - CP violation
- The MORA experiment
 - Overall description
 - Measurement principle
 - Status at JYFL
- Summary and perspectives

Nuclear β -decay as a laboratory for weak interaction

From high energy to
precision experiments



$$\mathcal{H} = \frac{G_F V_{ud}}{\sqrt{2}} \sum_{i=V,A,S,T,P} (\bar{\Psi}_p O_i \Psi_n) [\bar{\Psi}_e O^i (C_i + C'_i \gamma_5) \Psi_\nu] + h.c.$$

Accessible via **Ft-values**

$\sim 2 \cdot 10^{-4}$ thanks to $0^+ \rightarrow 0^+$ transitions

Hardy and Towner, arXiv:1807.01146v1

T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956).

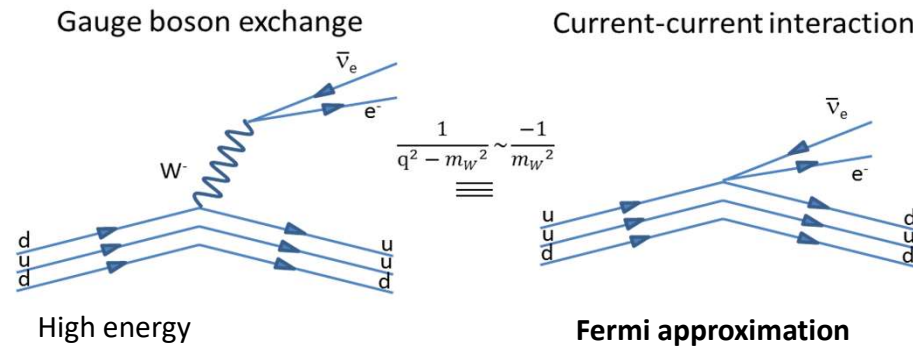
Explicit parity violation $C'_i \neq 0$

Sum of Lorentz invariants

V_{ud} from pion, neutron and nuclear beta decay: WS in GANIL, Nov. 24 <https://indico.in2p3.fr/event/33445/>

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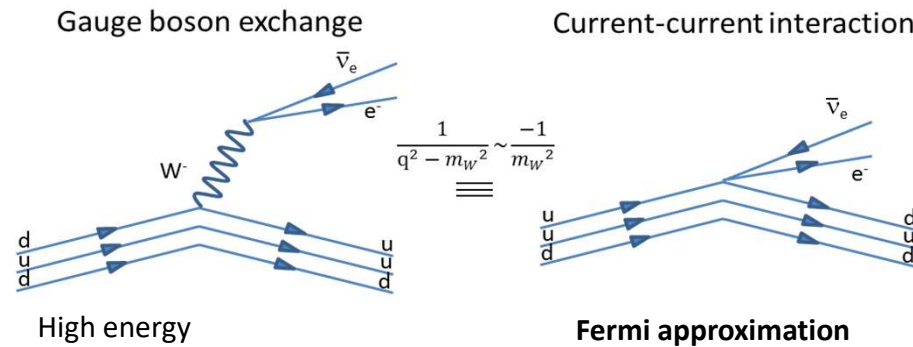
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Accessible via **correlation measurements**

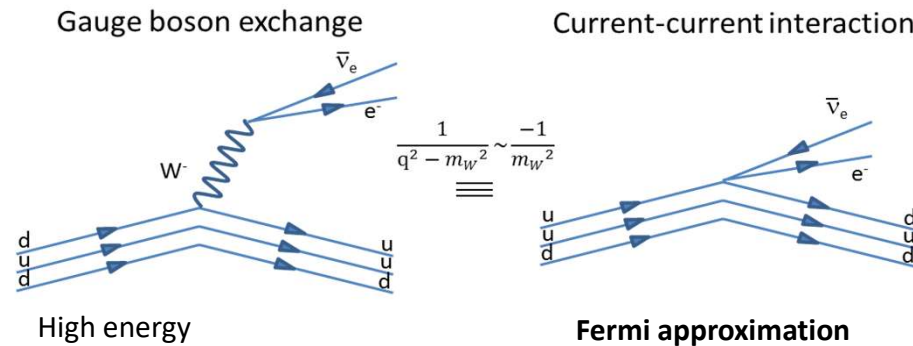
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T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956).

Explicit parity violation $C_i' \neq 0$

Sum of Lorentz invariants

Standard Model

At quark level: $C_V = -C_A = 1, C_S = C_T = 0$

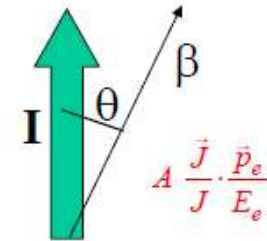
And $C_i = -C'_i$ for **maximal parity violation**

Real for T reversal/CP conserving interactions

Correlations in nuclear beta decay

$$\omega \langle \bar{J} \rangle | E_e, \Omega_e, \Omega_\nu \rangle dE_e d\Omega_e d\Omega_\nu$$

$$\propto \underbrace{F(\pm Z, E_e)}_{\text{Fermi function}} \underbrace{p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu}_{\text{phase space}}$$



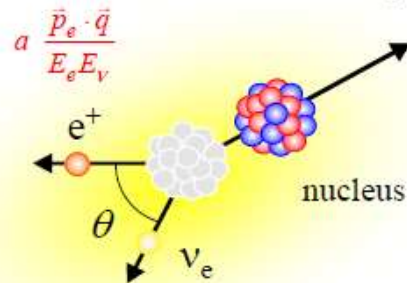
$$\times \xi \left\{ 1 + a \frac{\bar{p}_e \cdot \bar{q}}{E_e E_\nu} + b \frac{\gamma m_e}{E_e} + A \frac{\bar{J} \cdot \bar{p}_e}{J E_e} + D \frac{\langle \bar{J} \rangle}{J} \cdot \left(\frac{\bar{p}_e}{E_e} \times \frac{\bar{p}_\nu}{E_\nu} \right) \dots \right\}$$

β -v
correlation

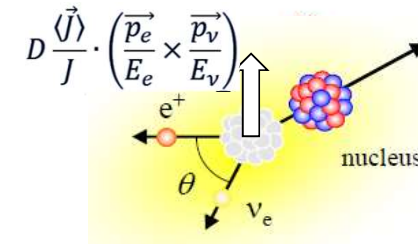
Fierz
interference term
($b \equiv 0$ in
standard model)

β -asymmetry

D-correlation



J.D, Jackson, S.B. Treiman, H.W. Wyld, Nucl. Phys. 4 (1957) 206



© N. Severijns, PSI, 2007

Access to the coupling constants of the β decay Hamiltonian: C_V , C_A and C_S , C_T

Reviews:

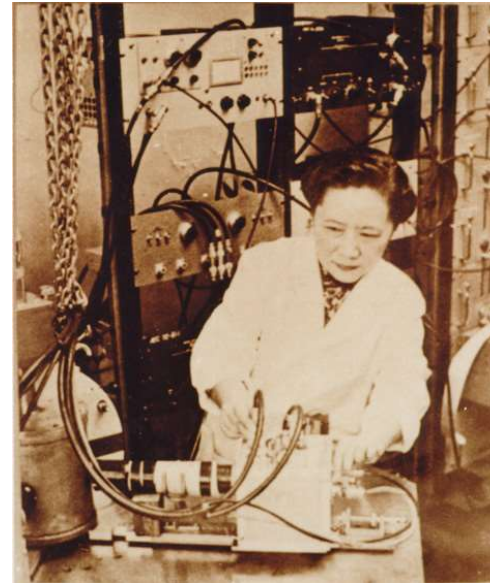
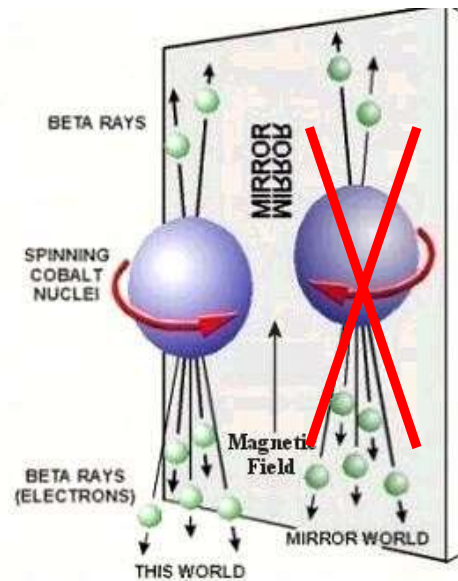
- Prog. Part. Nucl. Phys, M. Gonzalez Alonso, O. Naviliat Cuncic and N. Severijns, 2018
- JHEP04(2021)126, A. Falkowski, M. Gonzalez-Alonso, O. Naviliat-Cuncic

A famous *correlation* example!

- Probing intrinsic symmetries

Parity violation in ^{60}Co decay

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



$$A_{\beta}(C_A^2, C_V C_A)$$

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

P odd

Polarized nuclei

Searching for exotic S and T currents in nuclear beta decay

- **Direct – linear -constraints via Fierz interference term / beta shape measurement**
 - Ex. bSTILED experiment at GANIL – ${}^6\text{He}$ beta decay shape

$$b_F \propto \frac{C_S}{C_V}; b_{GT} \propto \frac{C_T}{C_A} \quad \mathbf{P, T \text{ even}}$$

- **Indirect constraints via β - ν angular correlation or beta-asymmetry**

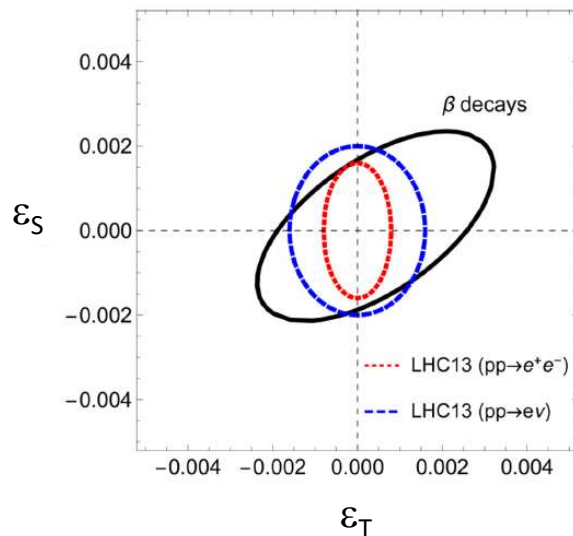
$$\tilde{X}_i \equiv \frac{X_i}{1 + b_i \langle m_e/E_e \rangle_i}, \quad \tilde{X}_i(E_e) \equiv \frac{X_i}{1 + b_i m_e/E_e}, \quad X = a, A, B$$

- Ex. WISArD experiment at ISOLDE
- Towards **per-mil precision**
 - New Physics [in the TeV regime](#), in competition with LHC
- Light nuclei
 - ${}^6\text{He}$, ${}^8\text{Li}$, ${}^{19}\text{Ne}$, ${}^{21}\text{Na}$, ${}^{32}\text{Ar}$, ${}^{35}\text{Ar}$, ${}^{37}\text{K}$, ${}^{38\text{m}}\text{K}$, ...
 - Role of light mirror nuclei has recently been underlined
 - Especially when right handed neutrinos allowed, see [JHEP04\(2021\)126](#)
 - **Nuclear facilities like TRIUMF, ISOLDE at CERN, JYFL in Finland, or GANIL / DESIR in France naturally suited - ISOL physics**

Review of constraints on S, T from beta decay

- Latest review: JHEP04(2021)126, A. Falkowski, M. Gonzalez-Alonso, O. Naviliat-Cuncic
 - EFT analysis gives direct comparison between high energy searches and beta decay
 - Sensitivity to NP: **Scalar** and **Tensor** current limits from LHC and beta decays

No right handed currents



ϵ_S and ϵ_T : Wilson coefficients / linear combination of couplings of scalar and tensor currents

$$\begin{cases} \bar{C}_S + \bar{C}'_S = 2 g_S \epsilon_S \\ \bar{C}_T + \bar{C}'_T = 8 g_T \epsilon_T \end{cases}$$

β-decay as a laboratory for weak interaction

$$\epsilon_{S,T} \sim \left(\frac{m_W}{\Lambda}\right)^2$$

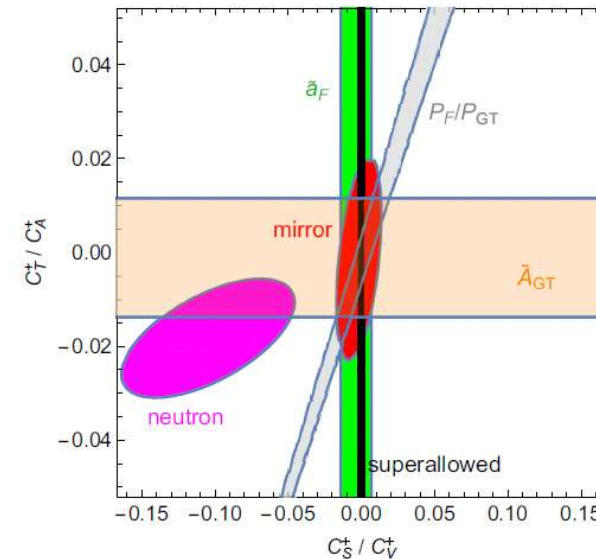
$$\epsilon_{S,T} \sim 10^{-3} \rightarrow \Lambda \sim \text{TeV}$$

Competition beyond the TeV scale!

LQ models under scrutiny!

b, a, A, B to the 10^{-3} level!

No right handed currents

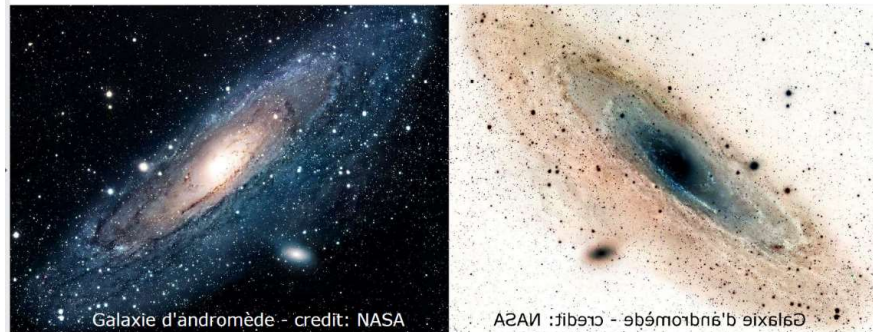


So far best constraints from:

- $0+ \rightarrow 0+$ corrected F_t value
- neutron A_{GT}

Matter-antimatter imbalance in the Universe

The big bang should have produced equal amounts of matter and antimatter



In 1967, Sakharov expresses the 3 conditions for Baryogenesis, the processus responsible for the matter antimatter assymetry observed in the universe:

- (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 asymetry of the universe,» *JETP Letters*, vol. 5, p. 24, 1967.

CP violation observed in the K, B and D - meson decays is not enough to account for the large matter – antimatter asymmetry

Physics beyond the Standard Model !

Searching for CP violation

- CPT theorem: CP violation equivalent to T violation

T-odd probes!

Electric dipole moments of particles and nuclei: $d \cdot \vec{\sigma}$

Correlations in nuclear β - decay

Sensitive probes to larger CP violations than predicted by the Standard Model, by 5 to 10 orders of magnitude [P. Herczeg, Prog. Part. Nucl. Phys. 46 \(2001\) 413.](#)

New physics beyond the TeV scale

Learn more from presentations at the International MORA Workshop at JYFL (past event May 2022) <https://indico.in2p3.fr/event/25986/>



See also les Houches School, CP 23 <https://indico.in2p3.fr/event/27893/>

P, T violation via the Schiff moment of radioactive molecules, extensively reviewed in this workshop

Searching for CP violation in nuclear beta decay

- CPT theorem: CP violation equivalent to T violation

T-odd probes!

Correlations in nuclear β - decay T - odd Triple correlations

D correlation

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

Jackson, Treiman and Wyld,
Nucl. Phys. 4, 206 (1957)

R correlation

$$R \cdot \vec{\sigma} \left(\frac{\langle \vec{J} \rangle}{J} \times \frac{\vec{p}_e}{E_e} \right)$$

Jackson, Treiman and Wyld,
Nucl. Phys. 4, 206 (1957)

New type of correlation In radiative β - decay

$$\propto (\vec{p}_e \times \vec{k}) \cdot \vec{p}_\nu$$

S. Gardner and He, Phys.
Rev. D 87, 116012 (2013)

D correlation in isospin hindered allowed decays

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

Barroso and Blin Stoye,
Physics Letters 45B, 178 (1973)

The MORA experiment at JYFL then GANIL

^{23}Mg , ^{39}Ca

$\sim \text{Im}(C_V C_A^*)$

P. Delahaye et al.

Hyp. Int. 240, 63 (2019)

The MTV experiment at TRIUMF

^8Li

$\sim \text{Im}(C_A C_T^*)$

J. Murata et al.

The TRINAT experiment at TRIUMF

^{92}Rb and $^{38\text{m}}\text{K}$

$\sim \text{Im}(C_T C_p^*)$

Other candidates ($^{37/38\text{m}}\text{K}$)

$\sim \text{Im}(c_5 C_V^*)$

Only prospects?

^{47}K

Sensitivity x100 to
internucleon P-even T
violating interactions
(Electromagnetic /
millistrong)

J. Behr et al.

Search for new physics via the D correlation measurement

A non-zero D can arise from CP violation

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

T reversal odd

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

Best measurement so far: $D_n = (-0.94 \pm 1.89 \pm 0.97) \cdot 10^{-4}$

emiT collaboration, PRL 107, 102301 (2011),

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

Calaprice, Hyp. Int. 22(1985)83

$\varphi_{AV} = 180.013^\circ \pm 0.028^\circ$ (68% CL)

Search for New Physics

- **Direct constraints** on CP-violating Wilson coefficients in the nucleon-level EFT
- Specific New Physics models
 - via **the L-R symmetric model**:
 - M. J. Ramsey-Musolf et J. C. Vasquez, «Left-right symmetry and electric dipole moments. A global analysis,» arXiv:2012.02799 [hep-ph], 2020.
 - via **the LQ model**
 - Thorough investigation undertaken at IJClab by Adam Falkowski and Antonio Rodriguez-Sanchez
 - «On the sensitivity of the D parameter to new physics », [Eur. Phys. J. C \(2022\) 82: 1134](#)
 - Presentation at MORA workshop <https://indico.in2p3.fr/event/25986/>
 - Severe constraints for CP violating terms from EDM, pion decay and high energy searches
 - But D is also sensitive **to exotic non-CP violating terms via recoil-order corrections**

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- Specific New Physics models ➡ Interest for $\sim 10^{-5}$ measurement
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Below 10^{-4} , measurement of Final State Interactions

Recoil order effect due to the weak magnetism (allowed in SM)

$$D_{FSI} \sim Z\alpha \frac{E_e}{M} \cdot A(\mu_f - \mu_i) \quad \text{Callan and Treiman, Phys. Rev. 162(1967)1494.}$$

Never accessed by a direct measurement in D

Search for new physics via the D correlation measurement

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A measurement of D to the 10^{-5} level: looking for New Physics and accessing for the first time FSI

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Edoardo Alviani and Adam Falkowski, IJCLab, revisiting FSI with Lorentz invariant description of nuclear beta decay amplitudes: ***On the Coulomb corrections in nuclear beta decay*** [arXiv:2412.17702](https://arxiv.org/abs/2412.17702) [hep-ph]

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MORA in a nutshell



D correlation measurement in ^{23}Mg , ^{39}Ca decays to the 10^{-5} level with some beam, laser and trapping R&D

State of the art techniques from ISOL facilities

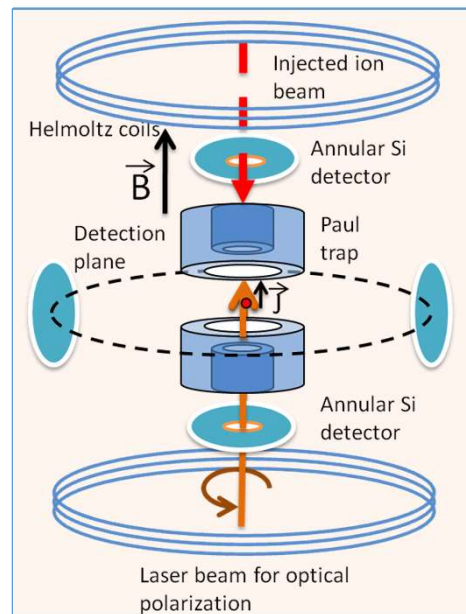
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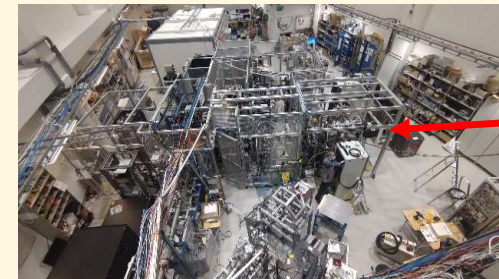
New trap and new detection setup:
off-line commissioning at

Completed in autumn 2021

- Theoretical studies with state-of-the-art EFTs



- Innovative laser polarisation techniques at



**MORA
installation at
JYFL/IGISOL
(completed!)**

Proof of principle of polarization
First D measurement $\sim 10^{-4}$

Started in Feb 2022

With experts from:



Back to GANIL / DESIR, making use of the intense and purified ISOL beams from SPIRAL 1/ S3-LEB: **2028**



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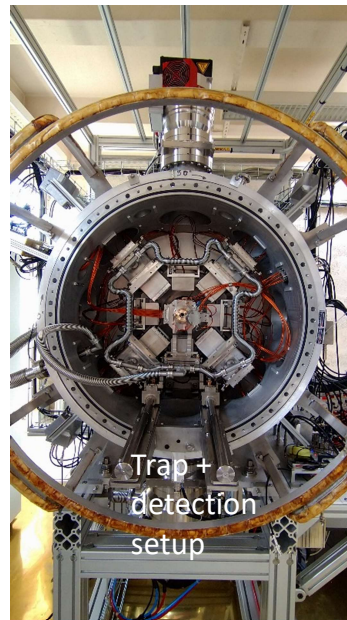
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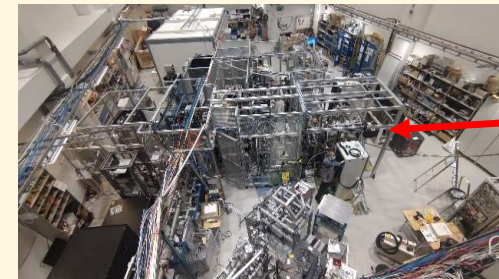
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Started in Feb 2022

With experts from:



Back to GANIL / DESIR, making use of the intense and purified ISOL beams from SPIRAL 1/ S3-LEB: **2028**

MORA: Best candidates for D measurement

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

Sensitivity to CP violating phase between V and A currents

Search for New Physics

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Neutron and mirror nuclei (N=Z-1): strong mixed (GT+ Fermi) transitions between analog states

	n	¹⁹ Ne	²³ Mg	³⁵ Ar	³⁹ Ca
Sensitivity $F(X)$	0,43	-0,52	-0,65	0,41	0,71
D_1 (x10⁻⁴)	0,11	2,31	2.64	0,43	-0,47
D_2 (x10⁻⁴)	0,02	0,17	0,16	0,01	-0,02

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

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.

MORA: Best candidates for D measurement

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MORA: Alkali earth elements for in trap laser ion polarization

1st candidate; 10^5 pps from JYFL 2nd candidate, R&D for ISOL
 $>10^8$ pps from SPIRAL 1 production required

	n	^{19}Ne	^{23}Mg	^{35}Ar	^{39}Ca
Sensitivity $F(X)$	0,43	-0,52	-0,65	0,41	0,71
D_1 ($\times 10^{-4}$)	0,11	2,31	2.64	0,43	-0,47
D_2 ($\times 10^{-4}$)	0,02	0,17	0,16	0,01	-0,02

10^7 pps requested

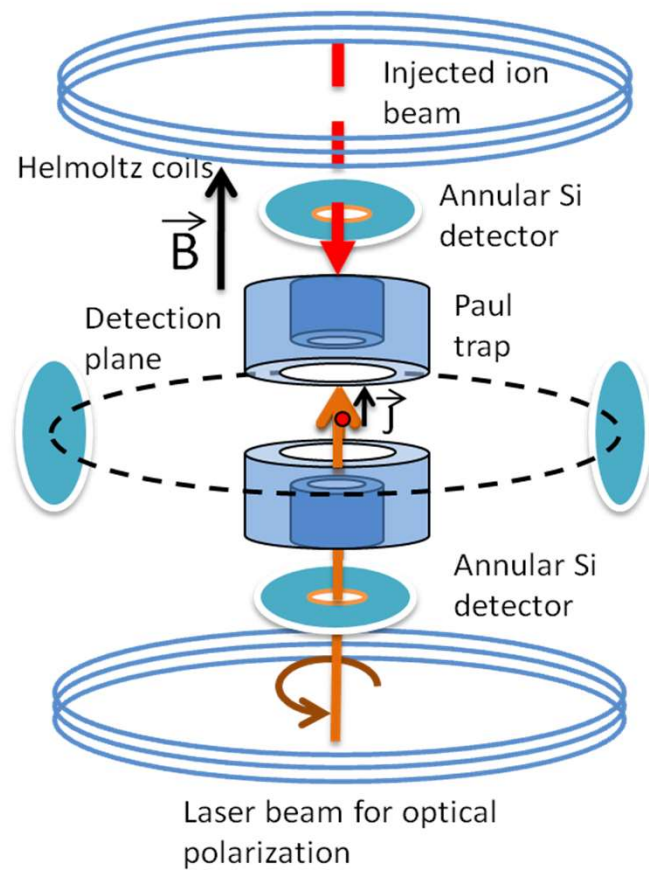
$$D_n = (-0.94 \pm 1.89 \pm 0.97) \cdot 10^{-4} \quad D_{^{19}\text{Ne}} = (1 \pm 6) \cdot 10^{-4}$$

Best measurement so far, *statistics limited*

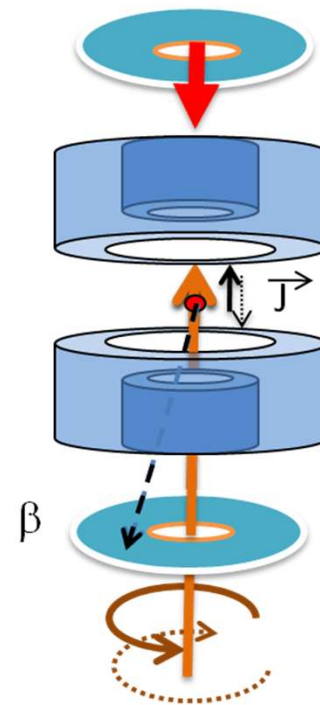
$$D_{FSI}(p_e) = \left(D_1 \cdot \frac{p_e}{p_{emax}} + D_2 \cdot \frac{p_{emax}}{p_e} \right) \times 10^{-4}$$

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

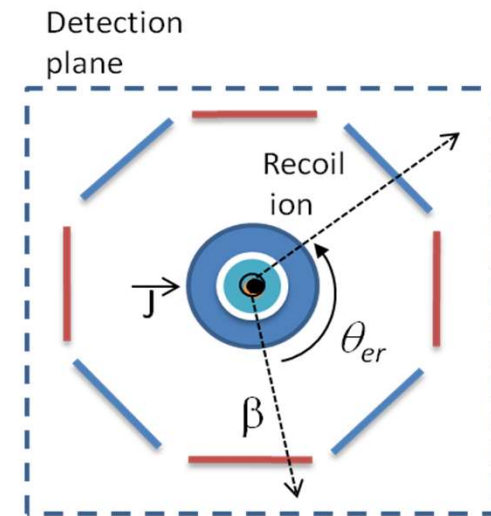
Precision measurement of the D correlation



Detection setups



P measurement

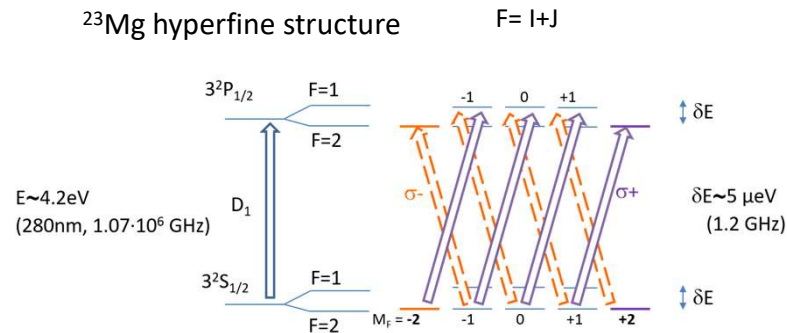


D correlation

MORA: in-trap laser polarization

Innovative technique! Proof of principle is the first objective at JYU

- The nuclear spin I interacts with the atomic one $J \rightarrow F=I+J$
- $\sigma+$ or $\sigma-$ light to scan the **hyperfine structure** forces ions in the $m_F=\pm F$ state



Transitions excited using tripped Ti:Sa laser pulses
 $\lambda \sim 280 \text{ nm}$ $\sigma+$ polarization, $\sim 4 \text{ GHz}$ width

Doppler shift/broadening due to ion motion $\sim 1.6 \text{ GHz}$

Collisions with He atoms (no spin) do not depolarize

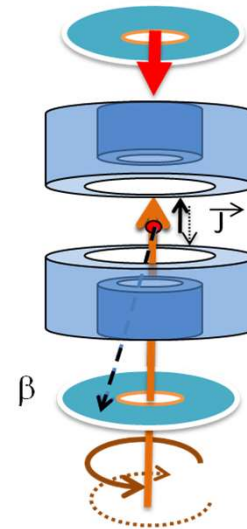
With the power available at JYFL
More than 99% achievable in 1 ms

Transition probabilities: numerical simulations
R. de Groote, X. Fléhard and W. Gins



Probable limitation: laser light polarization

Polarization monitoring thanks to β asymmetry: A_β



P measurement

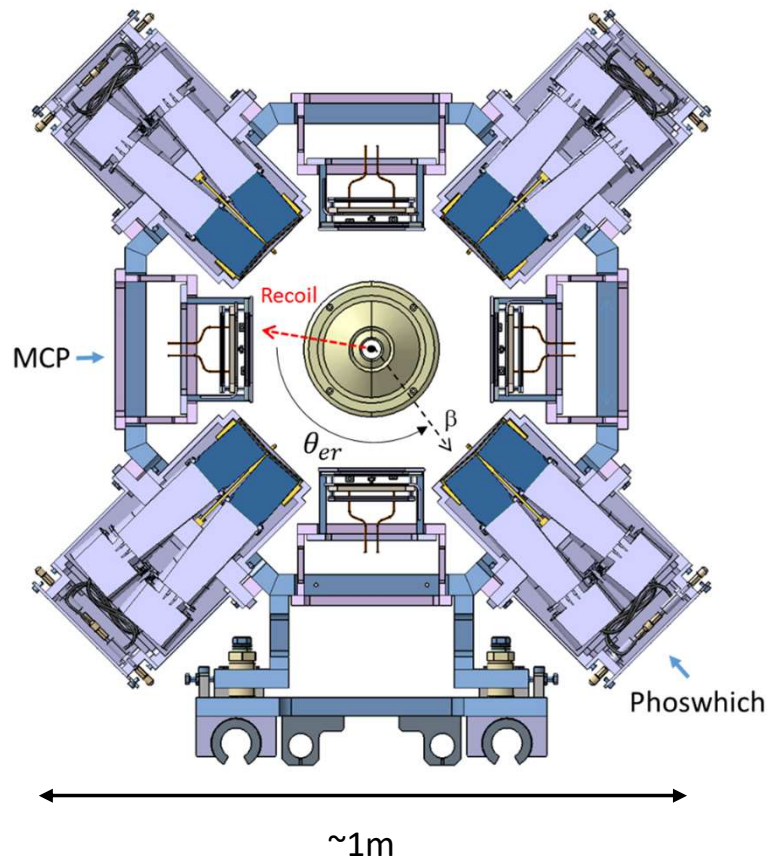
Remember: C. S. Wu et al.,
Phys Rev 105(1957)1413

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

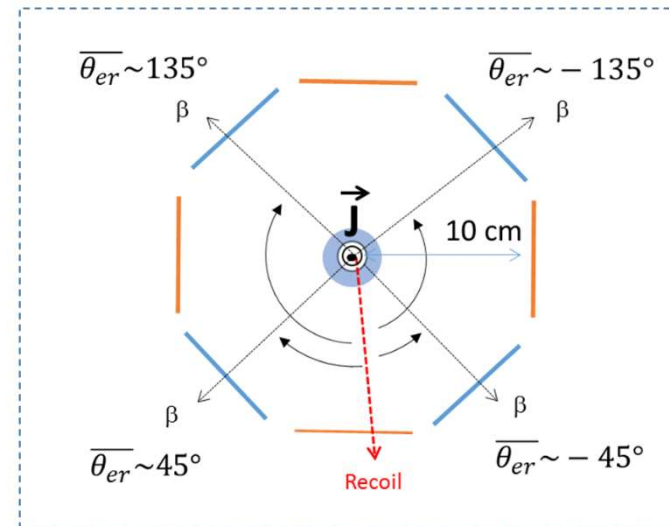
$$\frac{N_{\beta+}^{\uparrow} - N_{\beta+}^{\downarrow}}{N_{\beta+}^{\uparrow} + N_{\beta+}^{\downarrow}} \propto A_\beta \cdot P$$

MORA: measurement principle

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



In trap optical polarization

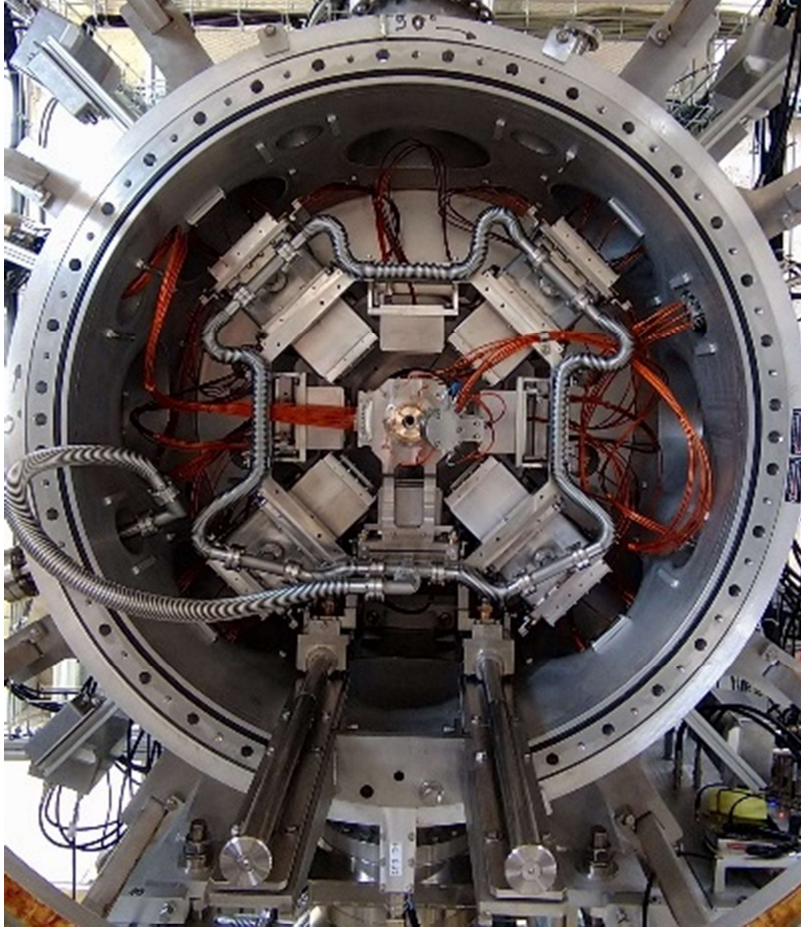


$$\frac{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} - N_{coinc}^{-45^\circ} - N_{coinc}^{-135^\circ}}{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} + N_{coinc}^{-45^\circ} + N_{coinc}^{-135^\circ}} = \delta \cdot D \cdot P$$

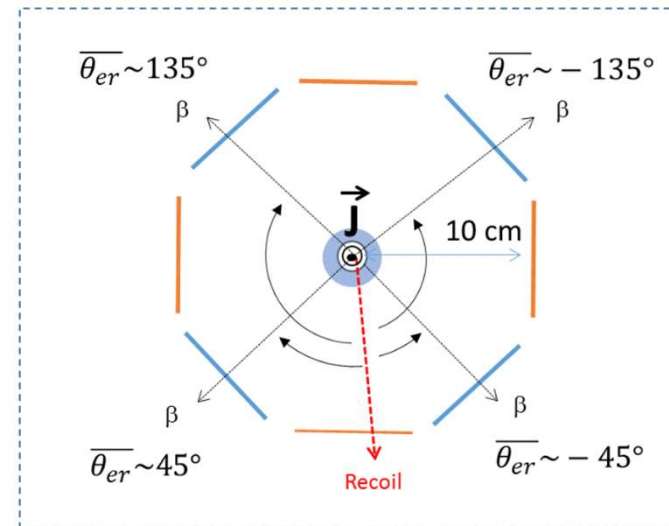
Where δ is depending on the phase space coverage

MORA: measurement principle

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In trap optical polarization

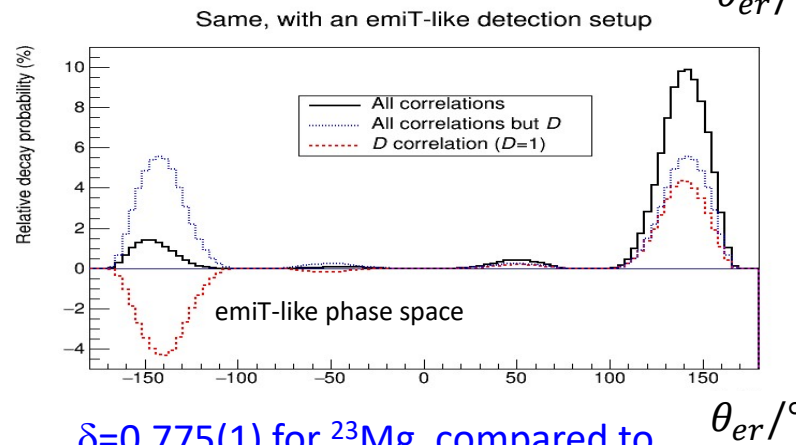
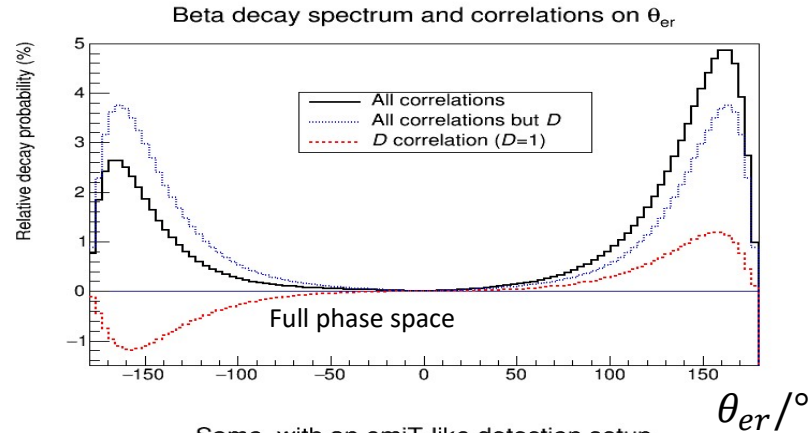


$$\frac{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} - N_{coinc}^{-45^\circ} - N_{coinc}^{-135^\circ}}{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} + N_{coinc}^{-45^\circ} + N_{coinc}^{-135^\circ}} = \delta \cdot D \cdot P$$

Where δ is depending on the phase space coverage

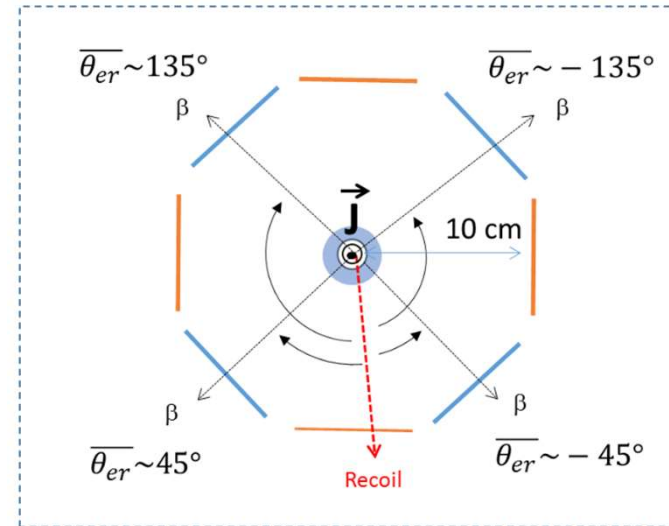
MORA: measurement principle

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$\delta=0.775(1)$ for ^{23}Mg , compared to
 $\delta \sim 0.3$ for the neutron

In trap optical polarization



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

Where δ is depending on the phase space coverage

MORA: sensitivity challenges

$$D \cong \left(\delta \cdot P \cdot \sqrt{N_{coinc}^{+45^\circ} + N_{coinc}^{+135^\circ} + N_{coinc}^{-45^\circ} + N_{coinc}^{-135^\circ}} \right)^{-1}$$

Place and type of measurement	Trapped ions /cycle	Decays/s	Meas. time (days)	Detected coincidences (P)	σ_p stat (%)	Detected coincidences (D)	σ_D
JYFL: P - 23Mg	2,00E+04	1,23E+03	8	1,7E+05	1,9E+00	1,5E+06	1,0E-03
JYFL: D - 23Mg	2,00E+04	1,23E+03	32	6,7E+05	9,4E-01	6,1E+06	5,2E-04
JYFL: D - 39Ca	2,00E+04	1,61E+04	32	9,2E+06	2,0E-02	8,1E+07	1,4E-04
DESIR: D - 23Mg	5,00E+06	3,07E+05	24	1,3E+08	6,9E-02	1,2E+09	3,8E-05
DESIR: D - 39Ca	5,00E+06	4,03E+06	24	1,7E+09	1,5E-03	1,5E+10	1,0E-05

So far statistical uncertainties have dominated, over systematic uncertainties

See for ex.: $D_n = (-0.94 \pm 1.89 \pm 0.97) \cdot 10^{-4}$

emiT collaboration, PRL 107, 102301 (2011), Phys. Rev. C 86 (2012) 035505

Provided that

- Trapping capacity is attained
- Efficient laser polarization is demonstrated
- Systematic effects are kept under control

→ Below $5 \cdot 10^{-5}$ is feasible

MORA: sensitivity challenges

Down to a few 10^{-5} sensitivity

- The emiT experiment gives a few hints

H. P. Mumm et al, Rev. Sci. Instrum. 75, 5343 (2004)

H. P. Mumm et al, PRL 107, 102301 (2011)

$$Dn = (-0.94 \pm 1.89 \pm 0.97) 10^{-4}$$

Systematic effects ($\times 10^{-4}$)

Source	Correction	Uncertainty
Background additive	-0.07	0.07
Multiplicative ^a	0.03	0.09
Electron backscattering additive	0.09	0.07
Multiplicative	0.11	0.03
Proton backscattering	0	0.03
Electron threshold nonuniformity	0.04	0.10
Proton-threshold effect	-0.29	0.41
Beam expansion	-1.50	0.40
Polarization nonuniformity	0	0.10
ATP-misalignment	-0.07	0.72
ATP-twist	0	0.24
Spin-correlated flux	0	<0.01
Spin-correlated polarization	0	<0.01
Polarization	^b	0.04 ^c
K_D	^b	0.04
Total corrections	-1.66	0.97

^aIn Ref. [11] this entry had a typographical error.

^bPolarization and K_D are included in the definition of \tilde{D} .

^cAssumes polarization uncertainty of 0.05.

- Investigations of systematic effects is ongoing by simulations
 - Initiated within postdoc **Abhilasha Singh**,
 - Continued within PhD **Luis Miguel Motilla and Marah Jbayli**
- Dominant effects highly reduced by the trap confinement

Measurements needed

$< 10^{-6}$

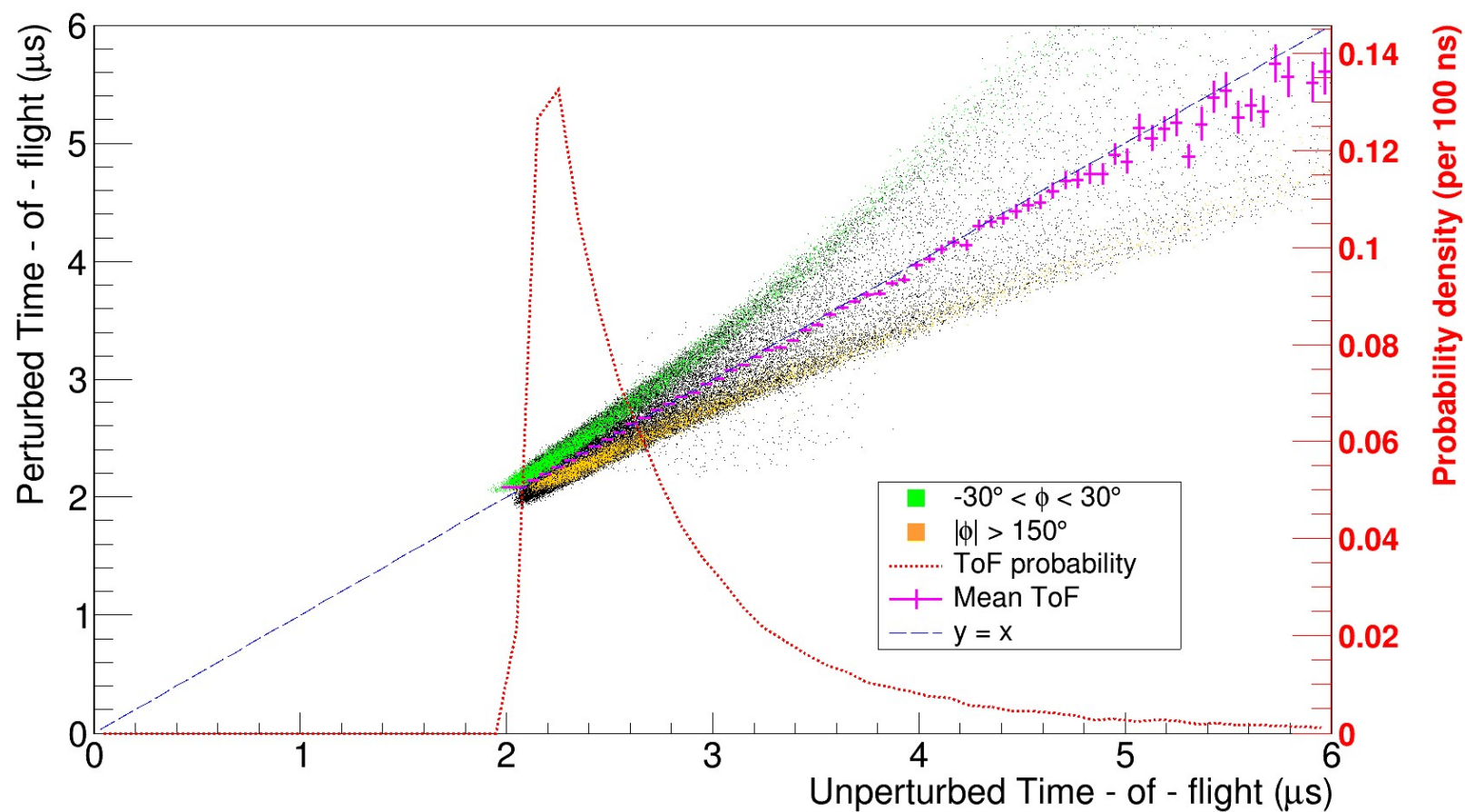
Under scrutiny, disturbance of recoil tof by RF look small

$< 10^{-6}$

$\sim 1 \times 10^{-6}$

$< 10^{-6}$

MORA: sensitivity challenges



The MORA experiment: Radioactive nuclei to look for BSM Physics

- Nuclear beta decay as a laboratory for weak interaction
 - Reminder: correlations in nuclear beta decays
 - CP violation
- **The MORA experiment**
 - Overall description
 - Measurement principle
 - Status at JYFL
- Summary and perspectives

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Installation at Jyväskylä 2021 - 2022

Off-line commissioning in LPC Caen
September 2021

^{23}Na trapped ions from alkali source



Shipping incident – trap chamber to be repaired - October 2021



Large involvement of LPC Caen technical resources

Installation in JYFL
November 2021 – injection line

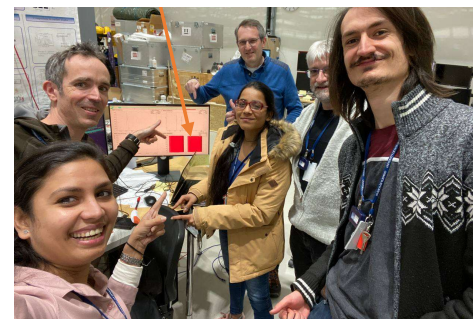


Installation in JYFL
January 2021 – trap and detectors

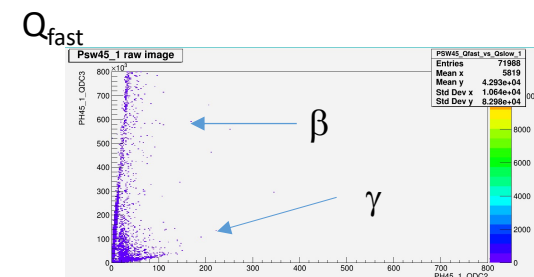


Commissioning in JYFL
Mid February – off-line

^{23}Na trapped ions from cooler buncher

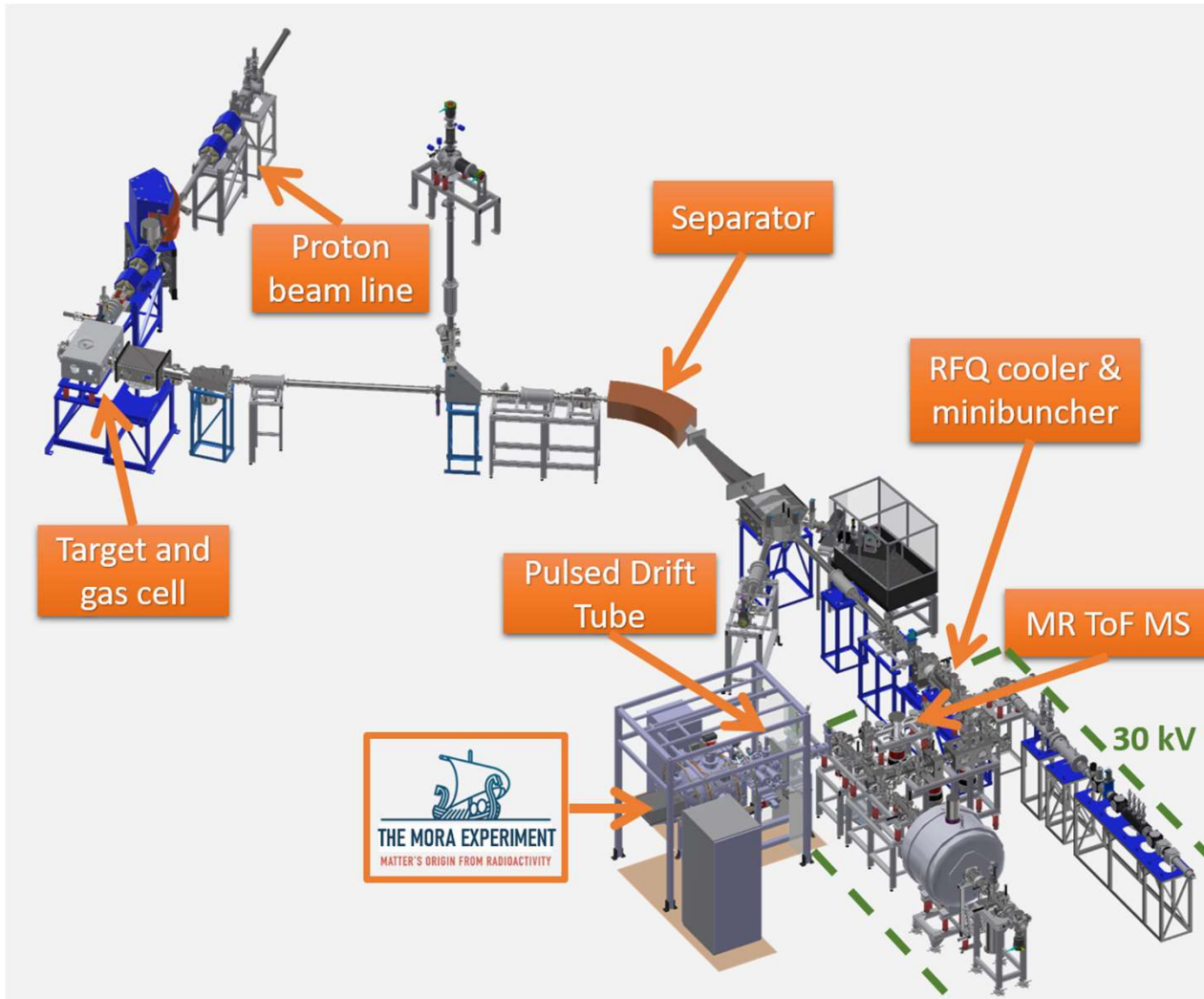


Commissioning in JYFL
18th - 20th February – on-line
27-31 May 2022 – on-line



First ^{23}Mg β activity is recorded

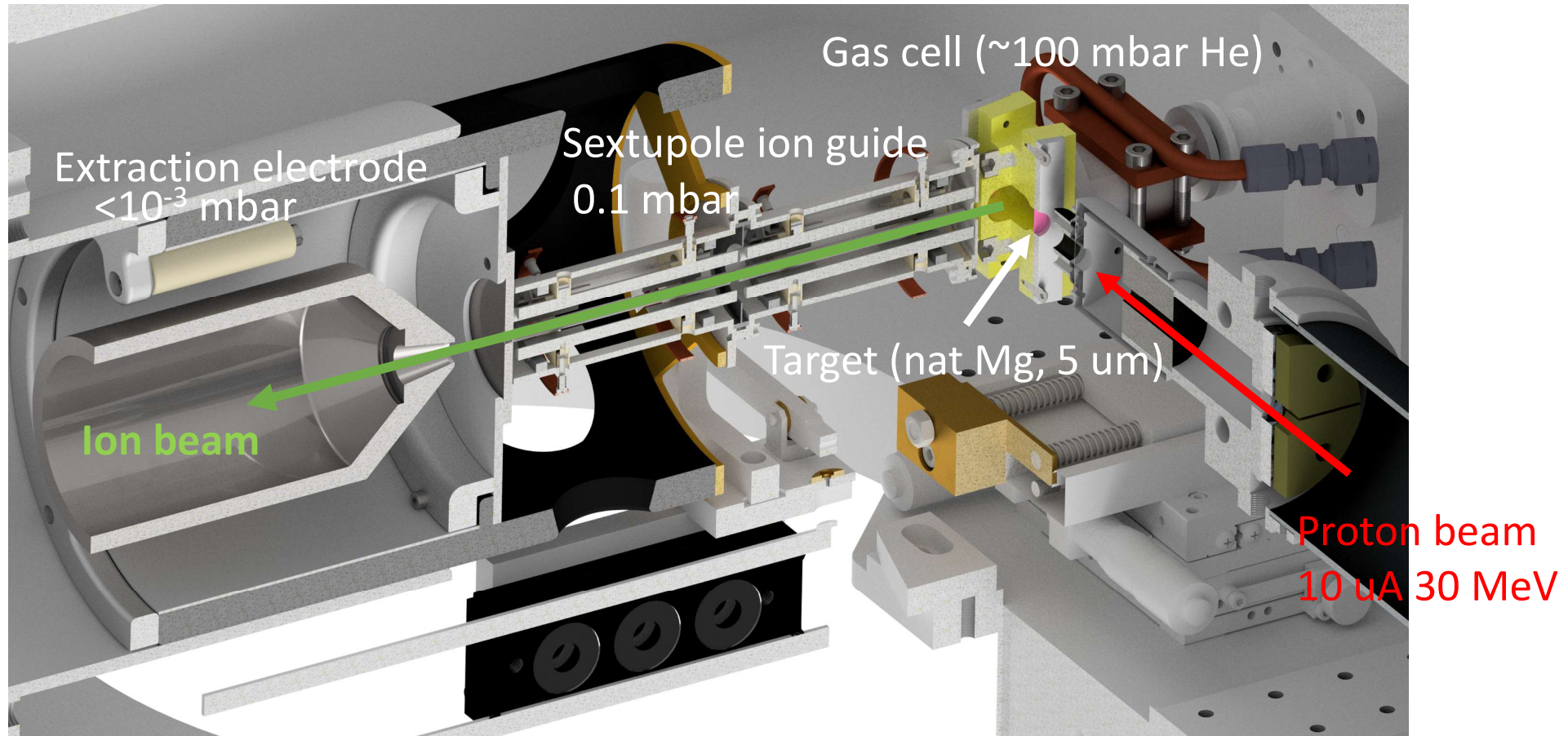
^{23}Mg Beam production and manipulation



- Up to 5×10^5 pps $^{23}\text{Mg}^+$ from gas cell
- Beam comes with $^{23}\text{Na}^+$ as isobaric contaminant after separator
 - Initially up to 10^4 more $^{23}\text{Na}^+$ than $^{23}\text{Mg}^+$ (TALYS gives a factor of 2)
- Beam is cooled and bunched in RFQ cooler and minibuncher
- Minibuncher saturates at $\sim 10^5$ ions per bunch
- Too little $^{23}\text{Mg}^+$ ions in MORA: < 10 bunch

^{23}Mg beam production in gas cell

Investigating the origin of the $^{23}\text{Na}^+$ contamination

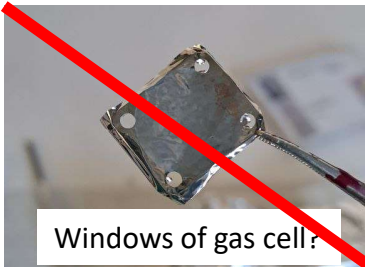
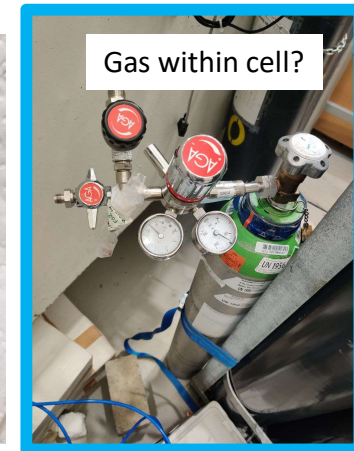
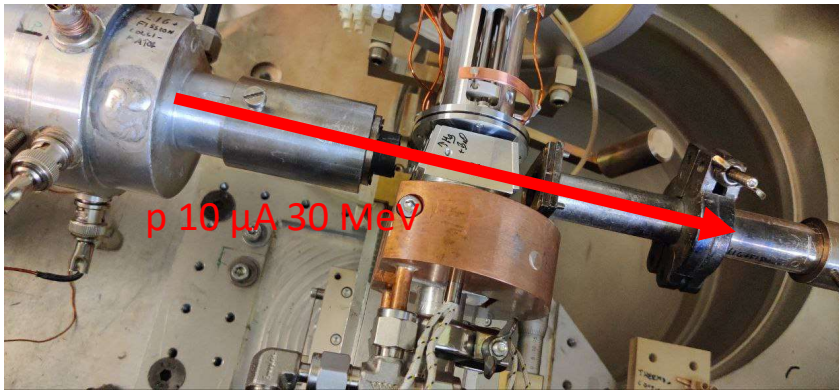


Struggling with contamination 2023 – 2024

Contamination makes progress difficult!

$^{23}\text{Na} : ^{23}\text{Mg} \gtrsim 1000$

Origin of the stable Na contamination?



Na⁺ beam only appears with p beam on

- Efforts focused first on targets and windows
- He gas was also discarded
- **Gas cell material is also discarded**

Culprit: zeolite filter in cold trap??

13X sieve: $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot m\text{SiO}_2 \cdot n\text{H}_2\text{O}$

Testing charcoal and SiO₂ filters instead of zeolite

➡ Same impurities

Cat litter!



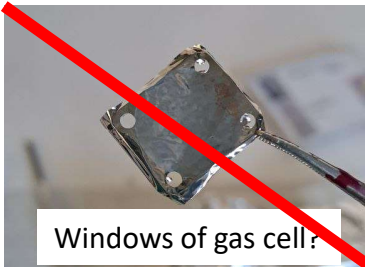
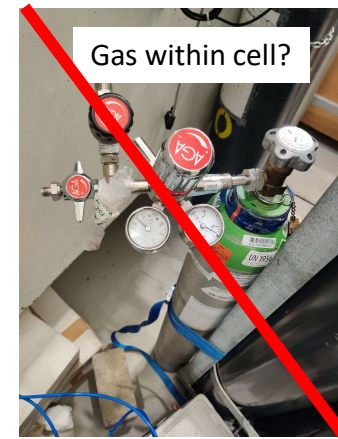
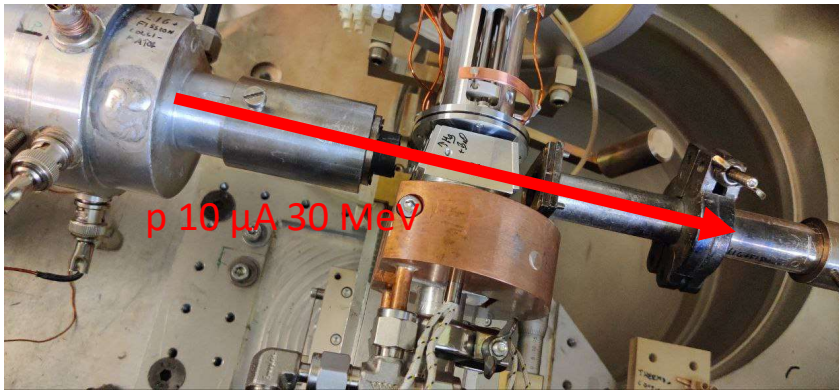
Dec. 2024

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No!

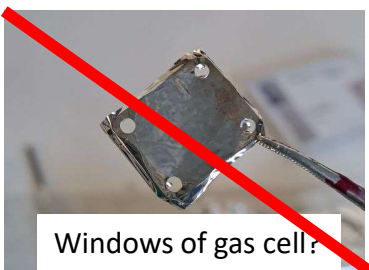
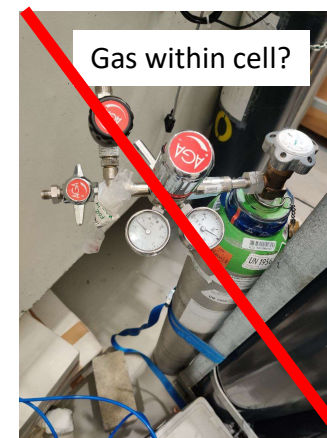
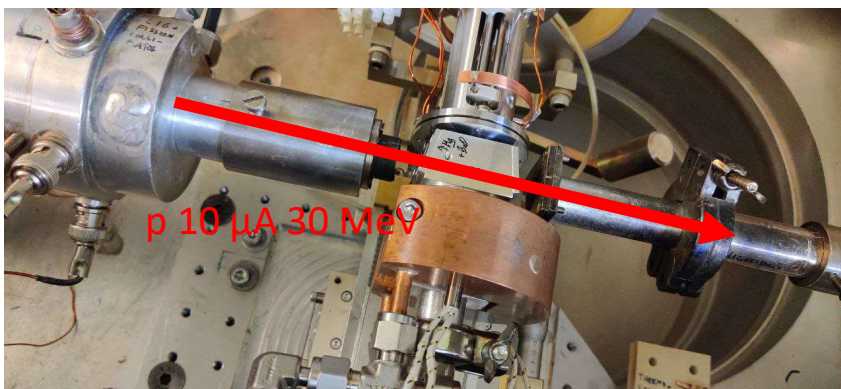
~~Culprit: zeolite filter in cold trap??
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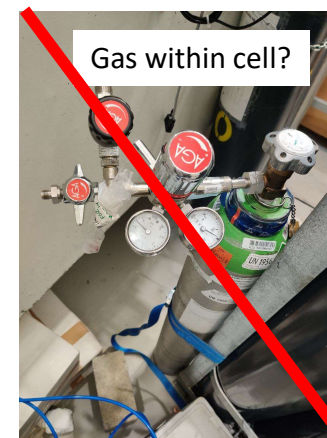
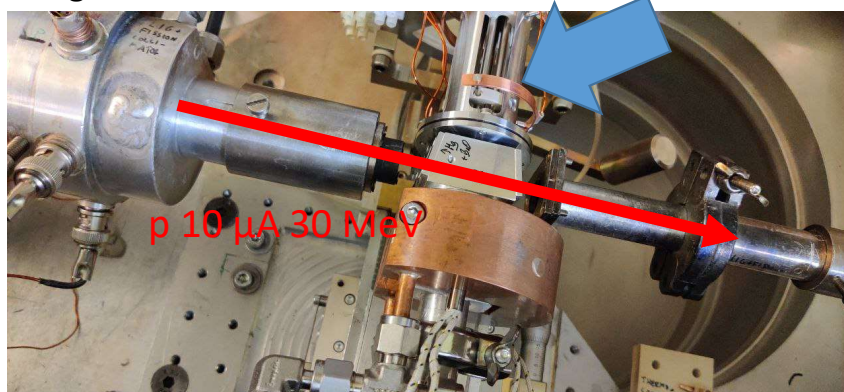
But then what is it?

Struggling with contamination 2023 – 2024

Contamination makes progress difficult!

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Origin of the stable Na contamination?



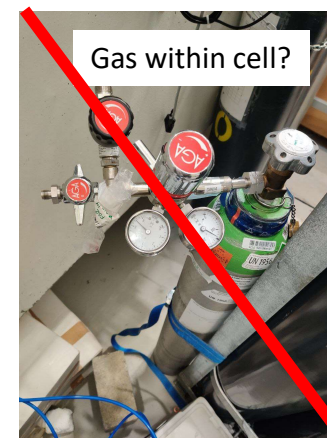
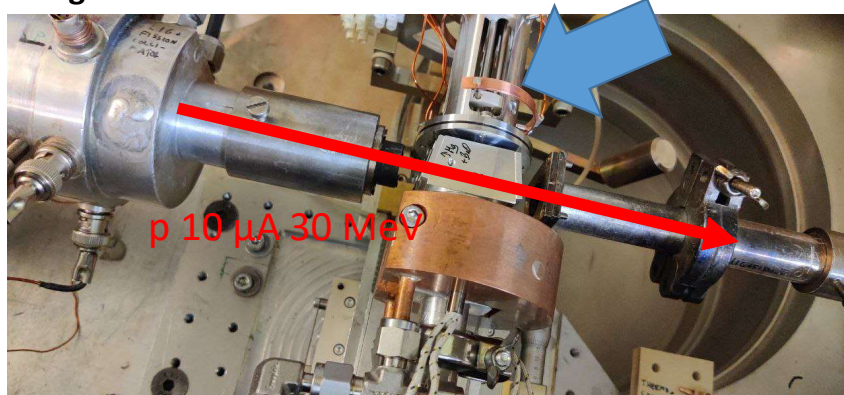
The SextuPole Ion Guide! SPIG

Struggling with contamination 2023 – 2024

Contamination makes progress difficult!

$^{23}\text{Na} : ^{23}\text{Mg} \gtrsim 1000$

Origin of the stable Na contamination?



The SextuPole Ion Guide! SPIG

Sputtering of electrodes by ionized He

Explains that:

- The gas purity matters
- The Na⁺ can be trapped in the SPIG
- The Na⁺ only comes when p beam on
- ...

SPIG deionized water cleaning



Experimental breakthrough

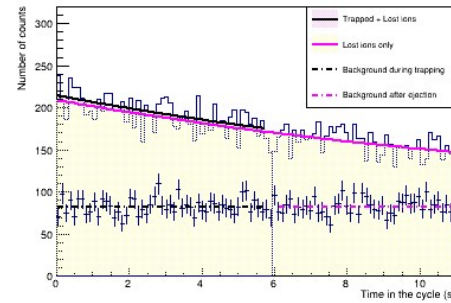
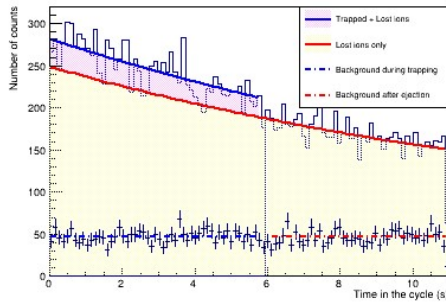
March 25

Si detectors to measure the polarisation

Si1

Si2

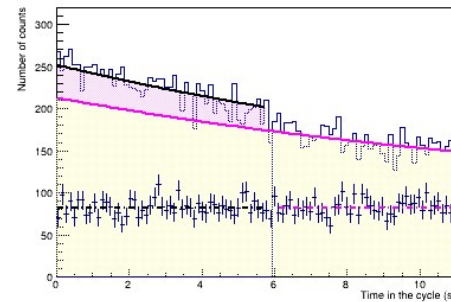
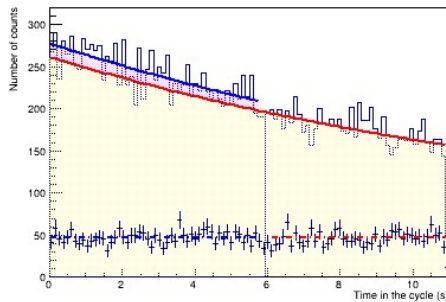
σ^-



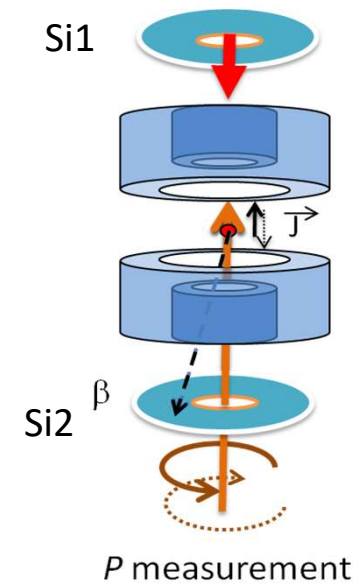
Si1 - σ^+

Si2 - σ^+

σ^+



Polarisation measurement



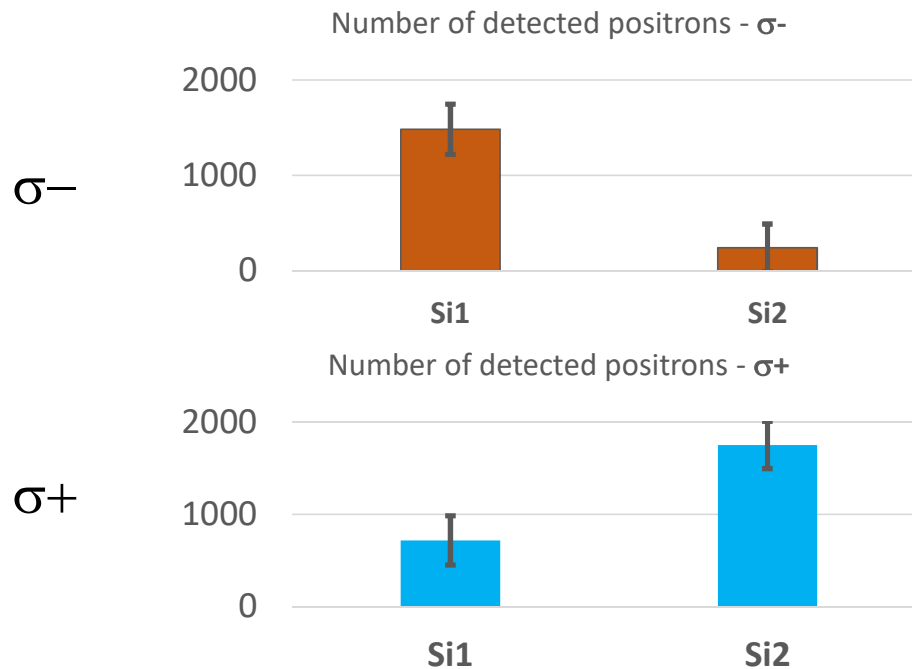
First polarization measurement

- Polarization σ^- : $A^- = \frac{nSi_1 - nSi_2}{nSi_1 + nSi_2} = 0.72 \pm 0.25$
- Polarization σ^+ : $A^+ = -0.42 \pm 0.16$
- Full polarization of the cloud (from simulations): $A^- = -A^+ = 0.51 \pm 0.01$

Experimental breakthrough

March 25

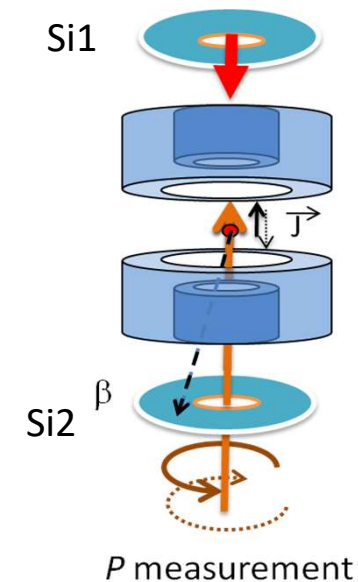
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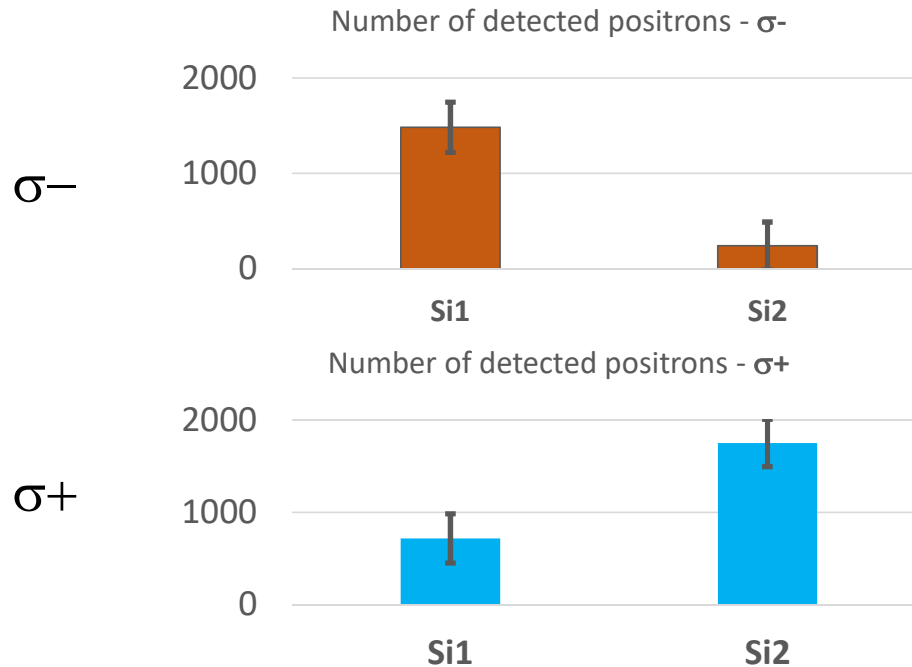
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Experimental breakthrough

March 25

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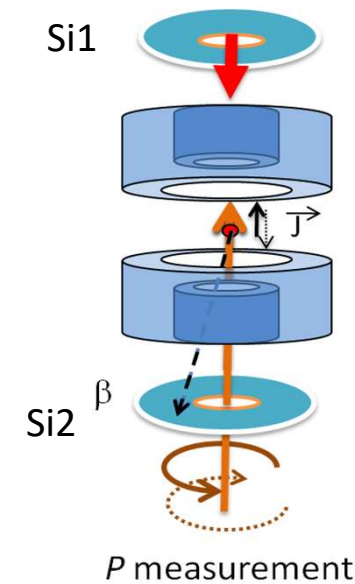
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$$|A| = 0.51 \pm 0.14$$

→ 55% < P < 100% at 90% C.L.

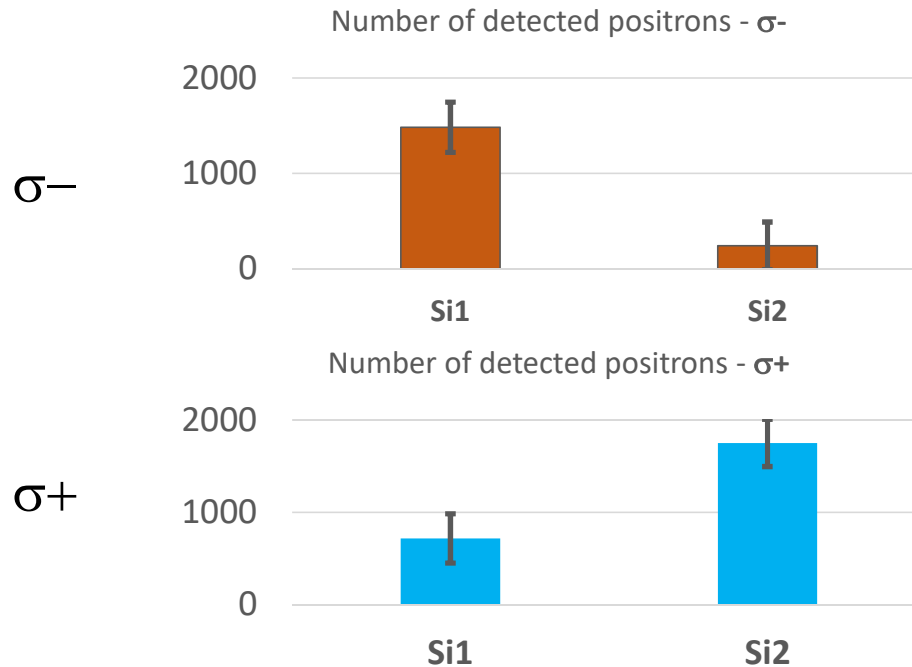
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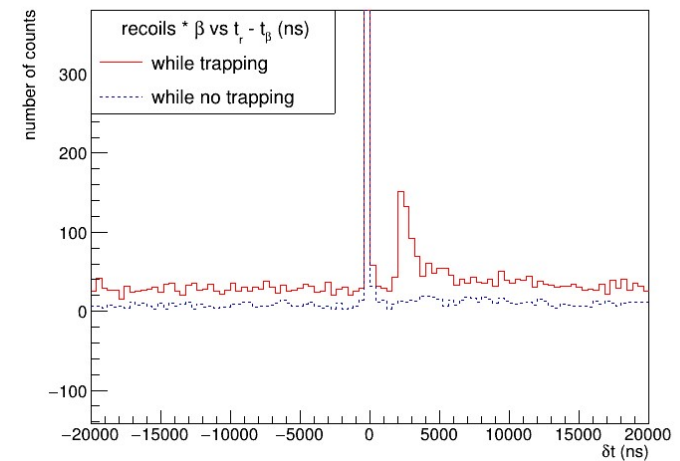
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First β -recoil coincidences



Trapped ions/cycle

90 ± 9 from Si detectors

145 ± 55 from coincidences

$$|A| = 0.51 \pm 0.14$$

→ **55% < P < 100% at 90% C.L.**

Conclusions

- **First major milestone attained!**
 - 55%<P<100% at 90 C.L.
 - More data to come
- **Progressing towards the *D* correlation measurement**
 - ^{23}Mg : 10^4 ions in the trap required
 - In March still 2 orders of magnitude of contamination to fight against
 - In June we tested baked and cleaned Nb rods for the SPIG
 - Proton beam tuning, SPIG RF & separator careful tuning
 - MR-ToF-MS to measure precisely the ^{23}Na : ^{23}Mg ratio
 - Likely less than 1 order of magnitude missing
 - **July 7th – 14th: initiating *D* correlation measurement ?** – stay tuned
- **Exploring $^{39}\text{Ca}^+$ at JYFL - IGISOL**
 - New ANR project: AvanCed CaLcium radioActive Isotopes Manipulation for MORA - **ACCLAIM MORA**
 - **Test foreseen in October**

Conclusions, outlook

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 - **Test foreseen in October**
- **Towards a $\sim 10^{-5}$ measurement of *D* at DESIR (2028-...)**
 - **High Resolution Separator (>20,000 Resolving power demonstrated!)**
 - Other purification tools: PIPERADE, MR ToF MS
 - $^{23}\text{Mg}^+$ **at required rate** > 10^8 pps from SPIRAL1 at GANIL
 - $^{39}\text{Ca}^+$ **beam development to reach > 10^7 pps** - part of the ACCLAIM project

• • • DESIR building

Courtesy: B. Blank



Laser cabin

Back side with
truck entrance



Front side



Roof



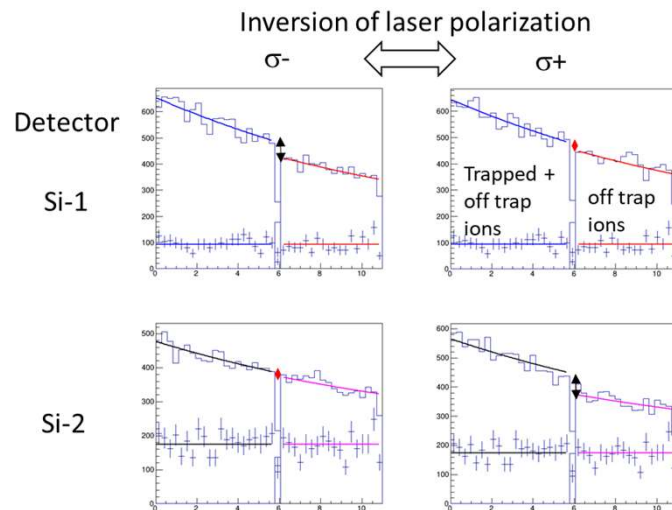
• • • **DESIR building**

Courtesy: B. Blank



**Building delivery:
05/09/2025**

Démonstration de la polarisation laser dans le piège de MORA Demonstration of the laser polarisation in the trap of MORA



Le degré de polarisation des ions $^{23}\text{Mg}^+$ dans le piège de MORA a été mesuré à IGISOL en Finlande. C'est une première expérimentale pour cette technique innovante. Les premières estimations montrent qu'il est supérieur à 55% avec un intervalle de confiance de 90%.

The degree of polarization of $^{23}\text{Mg}^+$ ions in the MORA trap has been measured at IGISOL in Finland. This is an experimental first for this innovative technique. Initial estimates show that it is greater than 55%, with a confidence interval of 90%.

MORA collaboration

Thanks a lot for your attention!



E. Liénard
M. Benali
V. Bosquet
S. Daumas-Tschopp
L. Hayen
Y. Merrer
X. Fléchar
G. Quéméner
A. De Roubin



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



M. Gonzalez-Alonso



P. Delahaye - **P.I.**
S. K. Chithakayala
F. De Oliveira
C. Fougères
G. Frémont
N. Goyal
M. JBayli
N. Lecesne
R. Leroy
L. M. Motilla
B.M. Retailleau
A. Singh
J. C. Thomas



A. Falkowski
A. Rodriguez – Sanchez



M.L. Bissel



I. Moore
T. Eronen
M. Reponen
Z. Ge
M. Mougeot
B. Kotte
W. Gins
V. Virtanen
J. Romero
A. Raggio
A. Jaries
A. Jokinen
A. Kankainen
S. Kujanpää
M. Stryczyk
S. Rinta-Antila



M. Kowalska

In **blue** PhD and Master students hired for MORA

Thanks a lot!

