The MORA experiment:

Search of CP violation through nuclear beta decay

THE MORA PROJECT

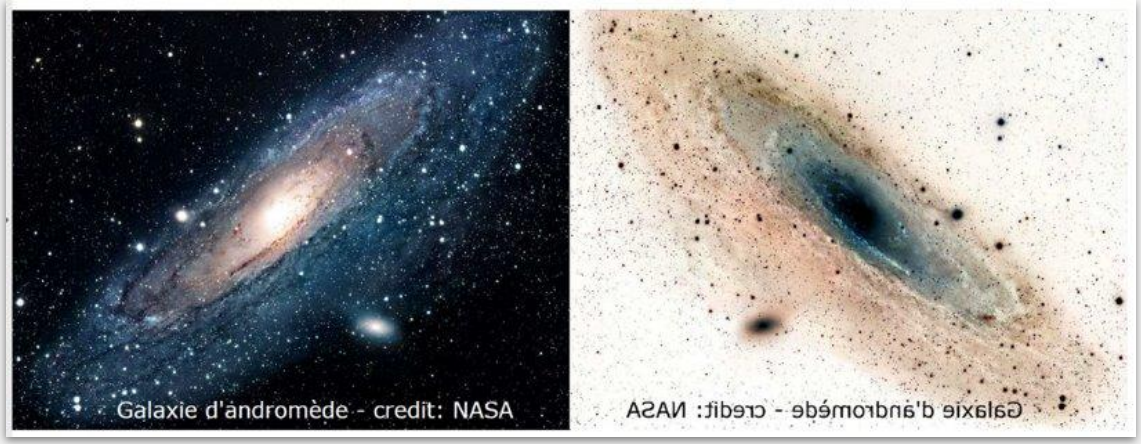
MATTER'S ORIGIN FROM RADIOACTIVITY

Sacha Daumas-Tschopp
- LPC Caen -

PhyNuBE 2023, Aussois - 30/03/2023

- Physics behind MORA: Matter anti-matter imbalance -

Big bang should have produced equal amounts of matter and antimatter



Sakharov expressed 3 conditions:

- Process out of the thermal equilibrium
- Violation of the baryonic number
- Large C and **CP violation**

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

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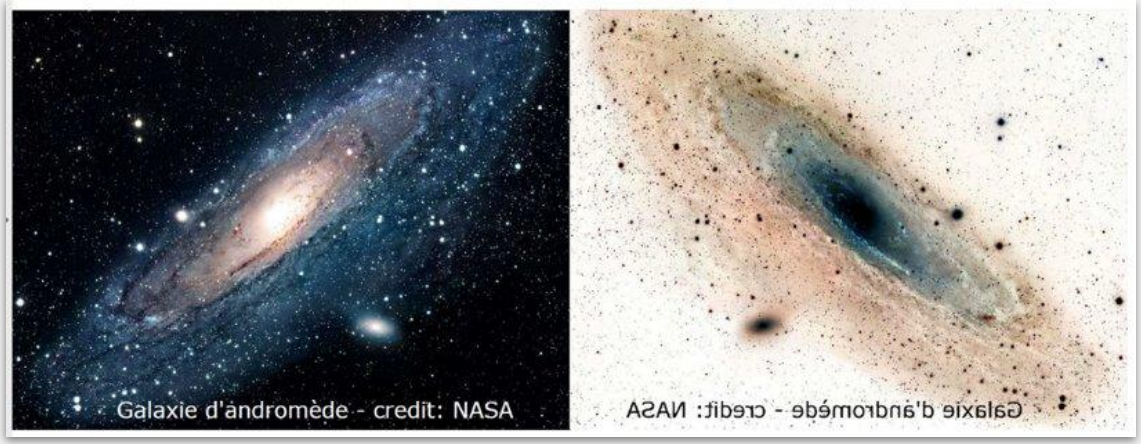

Sakharov expressed 3 conditions:

- Process out of the thermal equilibrium
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→ **Need CP probes**

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According to the CPT theorem, CP violations ≈ T violations

↳ Looking for **T-odds probes**

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Looking for T-odds probes

Fermi function

Phase space

$$\omega(\langle \mathbf{J} \rangle | E_e, \Omega_e, \Omega_\nu)\, \mathrm{d}E_e\, \mathrm{d}\Omega_e\, \mathrm{d}\Omega_\nu = \frac{F(\pm Z, E_e)}{(2\pi)^5} p_e E_e (E_0 - E_e)^2\, \mathrm{d}E_e\, \mathrm{d}\Omega_e\, \mathrm{d}\Omega_\nu \times \frac{1}{2}\xi \left\{ 1 + a\frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} + \frac{\langle \mathbf{J} \rangle}{J} \cdot \left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_\nu}{E_\nu} + D\frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu} \right] \right\}$$

nuclear transition matrix elements

Correlation parameters *a, b, A, B, and D*
(correlation between spin & momenta of particles)

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nuclear transition matrix elements

Correlation parameters *a, b, A, B, and D*
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$$D\frac{\langle \vec{J} \rangle}{J} \cdot \left(\frac{\overrightarrow{p_e}}{E_e} \times \frac{\overrightarrow{p_\nu}}{E_\nu} \right)$$

Scalar product maximum in the plan ⊥ to the spin direction (= maximum correlation)

↳ **Defines the detection plan**

Open Paul trap device to detect Beta and recoil ions

- Experimental set-up of MORA -

Looking for T-odds probes

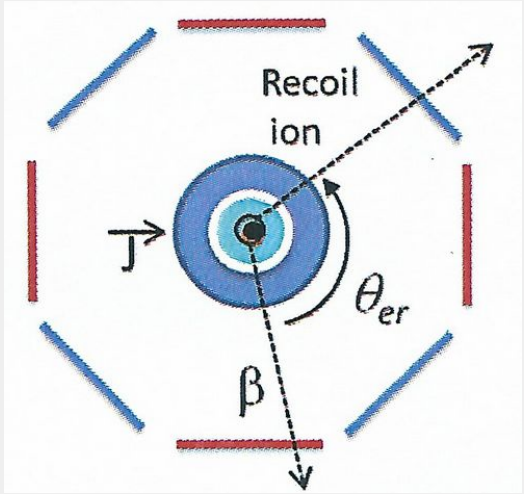
$$D\frac{\langle \vec{J} \rangle}{J} \cdot \left(\frac{\overrightarrow{p_e}}{E_e} \times \frac{\overrightarrow{p_\nu}}{E_\nu} \right)$$

Laser Beam used to oriented trapped ions

Reverting polarisation to revert the spin direction

Build **coincidences** between beta detector and recoil ions detectors

$$\frac{N_{coinc}^{+45°} + N_{coinc}^{+135°} - N_{coinc}^{-45°} - N_{coinc}^{-135°}}{N_{coinc}^{+45°} + N_{coinc}^{+135°} + N_{coinc}^{-45°} + N_{coinc}^{-135°}} \quad \alpha \quad D.P$$



Delahaye et al, Hyp. Int, 2018

First step: Proof of principle = Polarisation degree measurement thanks to beta asymmetry A_β

$$\frac{N_{\beta+}^{\uparrow} - N_{\beta+}^{\downarrow}}{N_{\beta+}^{\uparrow} + N_{\beta+}^{\downarrow}} \propto A_\beta \cdot P$$ ⇨ Alterning between Sigma+ and Sigma- configurations

- Experimental set-up of MORA -

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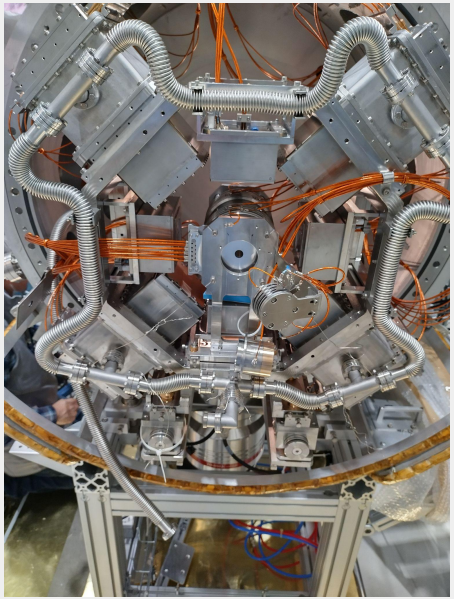

Trap out of the vacuum chamber

First step: Proof of principle = Polarisation degree measurement thanks to beta asymmetry A_β

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Looking for T-odds probes

$$D\,\frac{\langle \vec{J} \rangle}{J} \cdot \left(\frac{\vec{p_e}}{E_e} \times \frac{\vec{p_\nu}}{E_\nu} \right)$$

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

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

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

	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

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

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

Looking for T-odds probes

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Planned on the up-coming DESIR facility

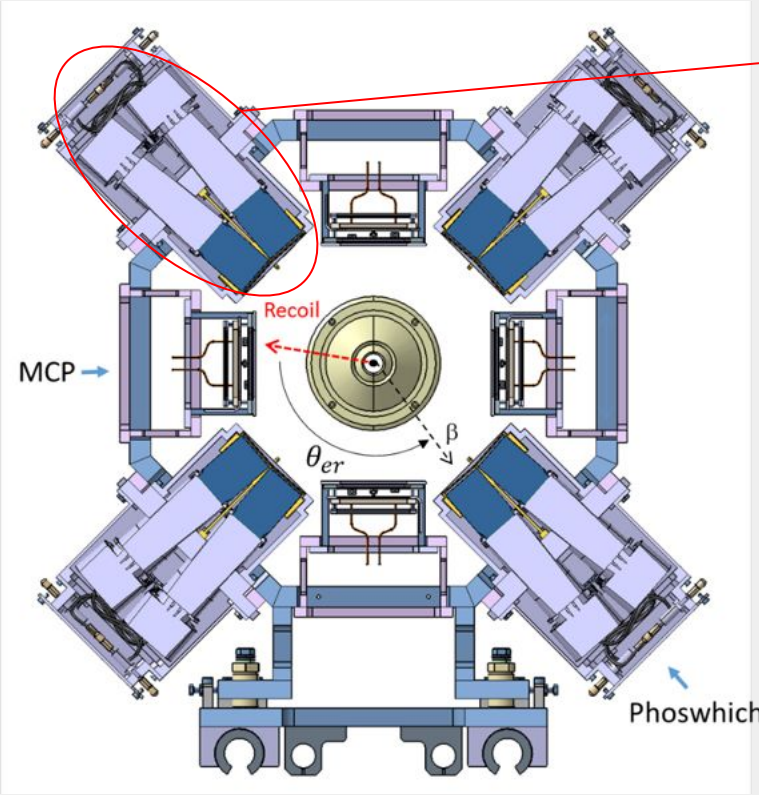
- Experimental set-up of MORA -

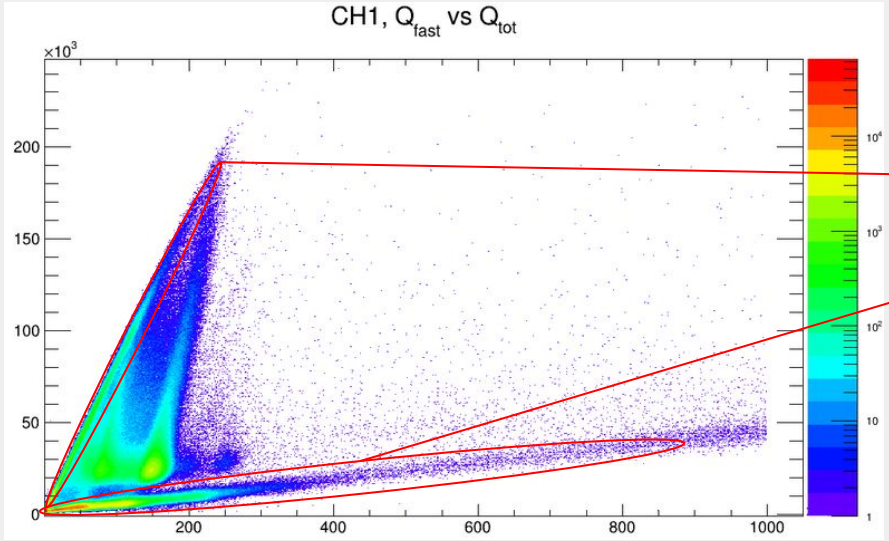
THE MORA PROJECT
MATTER'S ORIGIN FROM RADIOACTIVITY

Beta detectors: Phoswich configuration (x4)

↳ **4 channel per detector**

Allow discrimination between β and γ





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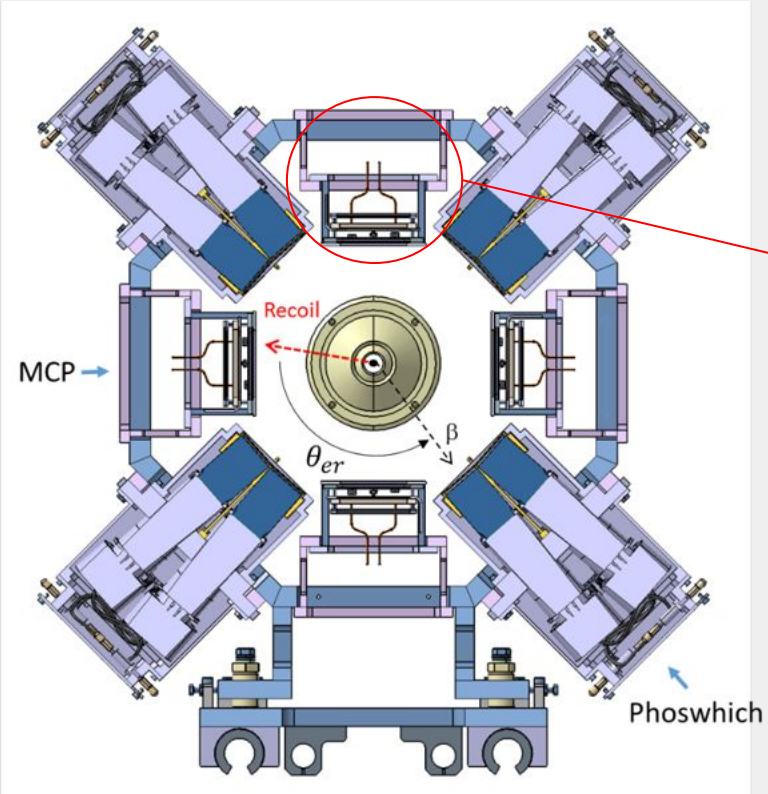

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Recoil Ion DEtector (RIDE) (x4)

↳ MCP + resistive anode

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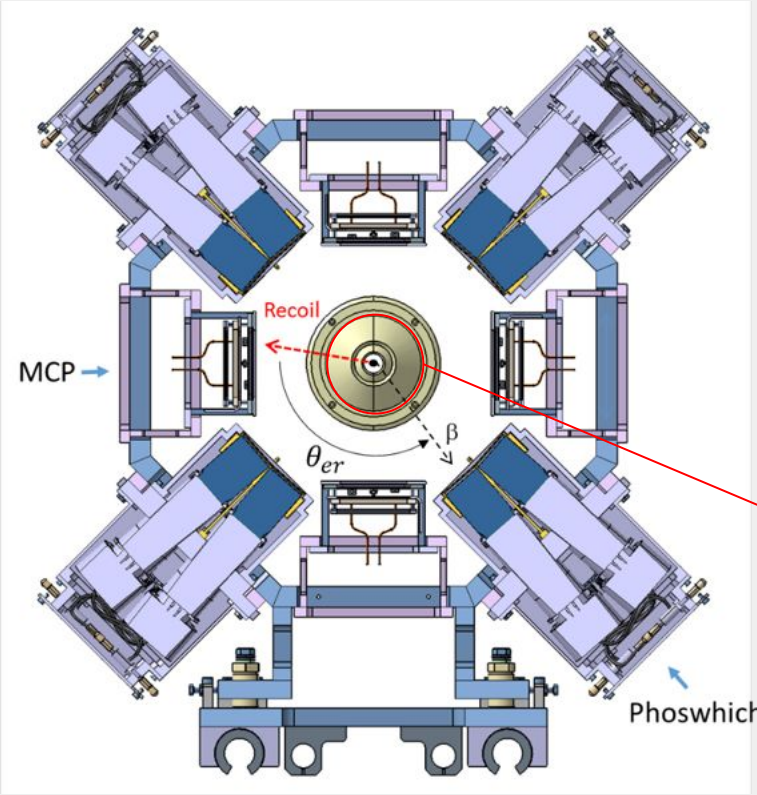

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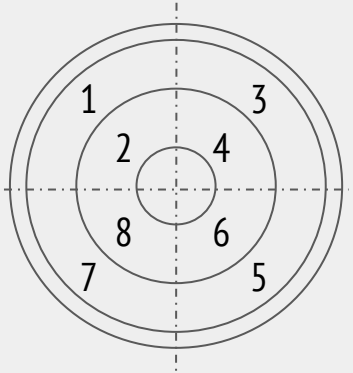
Recoil Ion DEtector (RIDE) (x4)

↳ MCP + resistive anode

Annular Si Detectors (x2)

↳ Segmented in 8 channels each



- MORA: Experimental summary -

THE MORA PROJECT
MATTER'S ORIGIN FROM RADIOACTIVITY

Off-line commissioning @LPC Caen
^{23}Na trapped ions

September 2021

- MORA: Experimental summary -

Off-line commissioning @LPC Caen
^{23}Na trapped ions

Shipping incident
Chamber to be repaired

Supposed to be on the vertical position

High dedication from the engineer team from LPC Caen

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Installation in JYFL
Injection line

September 2021 → October 2021 → November 2021 → January 2022

Installation in JYFL
Trap and detectors

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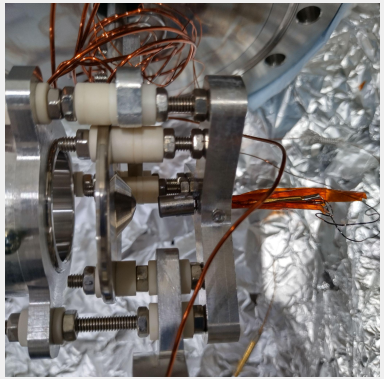
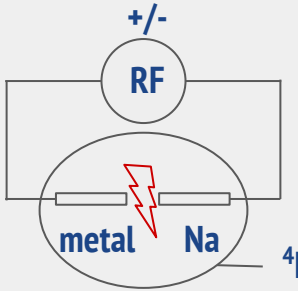
Commissioning in JYFL
off-line sources
^{23}Na trapped ions from
cooler buncher

September 2021 | October 2021 | November 2021 | January 2022 | Mid-February 2022

^{23}Na pellet for laser ablation source



^{23}Na pellet as surface ionisation source



^{23}Na sample for the spark source

- MORA: Experimental summary -

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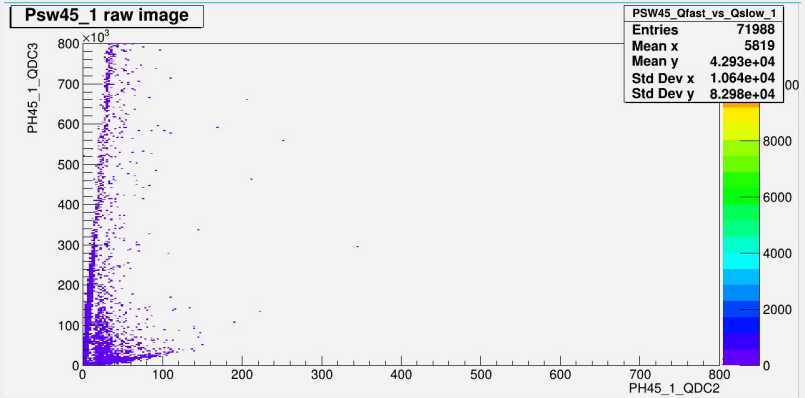
27-31 May



Installation in JYFL
Trap and detectors

Commissioning in JYFL
on-line ^{23}Mg beam

First radioactivity detected by the beta detectors

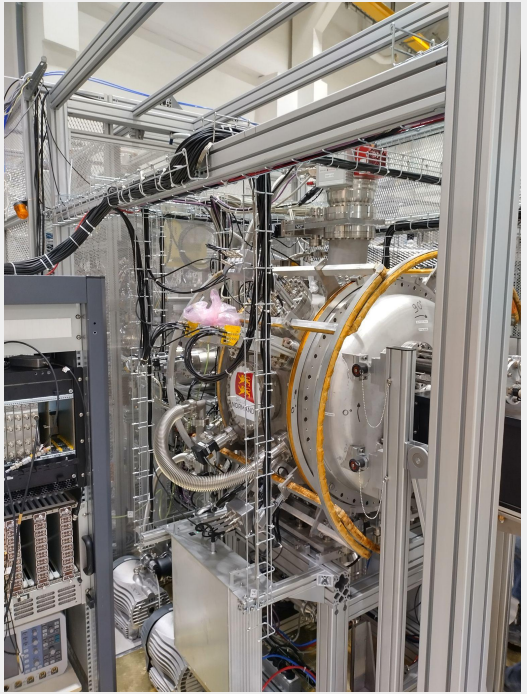
- MORA: Experimental summary -

THE MORA PROJECT
MATTER'S ORIGIN FROM RADIOACTIVITY

Three short beam times using ^{23}Mg (18-20th Feb, 27-31st May, 10-13rd Nov 2022)

Concerning the beam:

- nat Mg(p,d)^{23}Mg with 30 MeV p
- Large production of ^{23}Mg, 10^5 pps/μA, while 10μA
- Minibuncher @ IGISOL: space charged limited to $2\text{x}10^5$ ions/bunch
- Stable ^{23}Na contamination from IGISOL yields ⇨ 23Na:23Mg ≳ 1000



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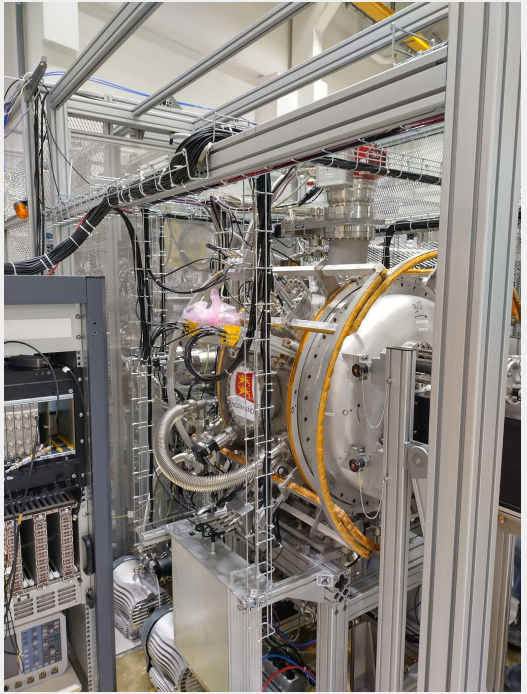
Concerning the trap:

- MORA apparatus is working with nominal performances
- Trapping efficiency ~10%, verified and optimized in November 2022
- Trapping half life > 11s measured in November

Concerning the Laser beam:

280 nm circularly polarized laser light produced at 260 mW



MORA apparatus is working with nominal performances

- MORA: Experimental summary -

Around 30h of data taking with a 3s trapping cycle:

Data:

8h σ^+, 8h σ^- and 8h with no laser

12h of calibration data

Background:

3h of environmental background (b_e)

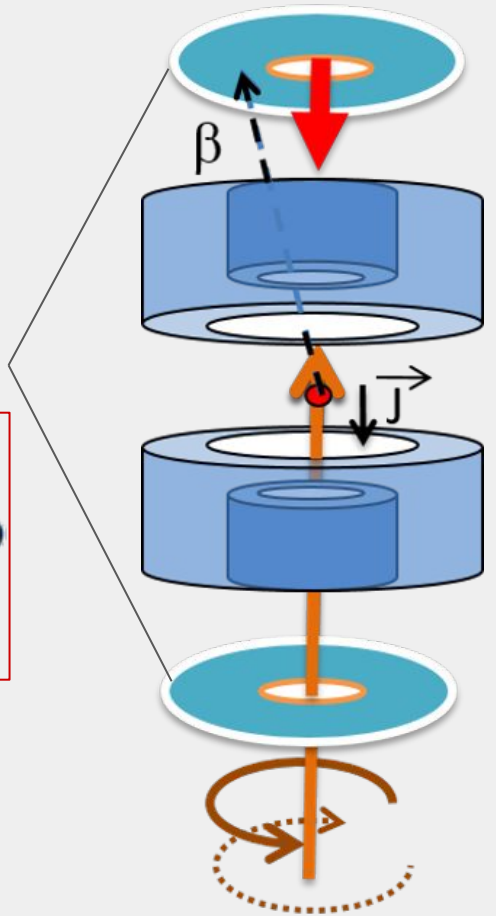
First step: Measure P

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

Need to remove backgrounds:

Environmental background (b_e)

Radioactive background (b_{rad})



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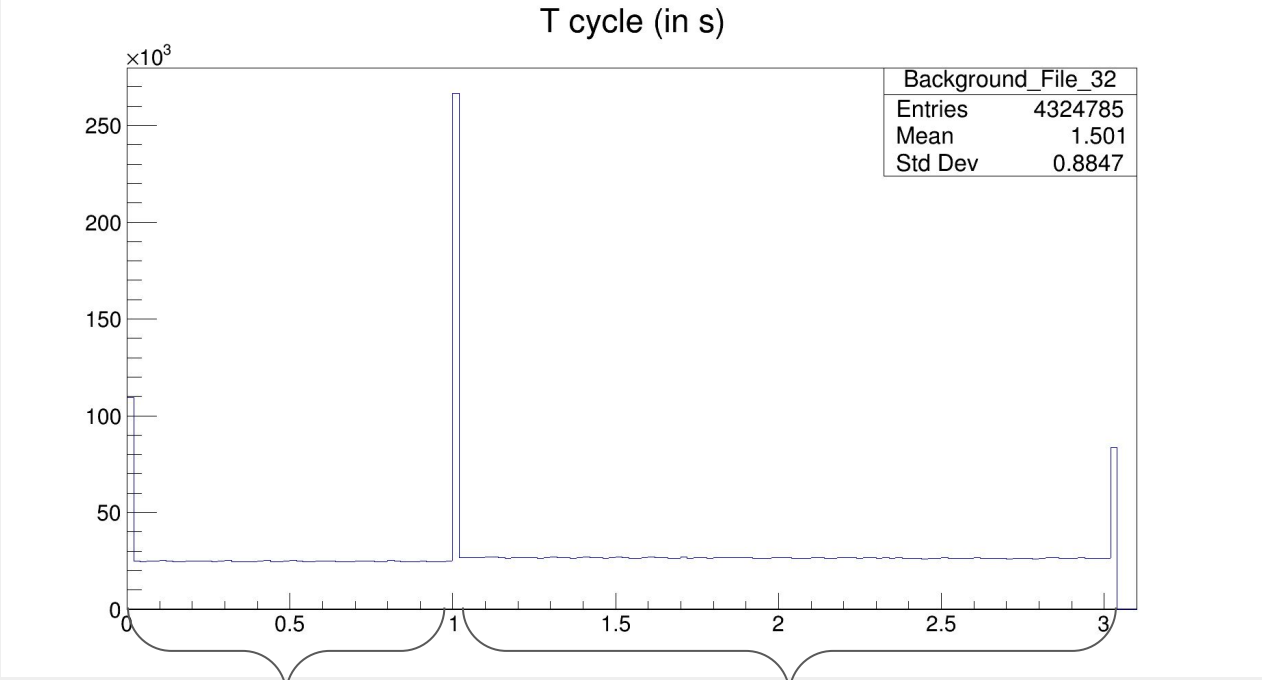
Trapping cycle = 2 + 1s ⟹ Same for environmental background

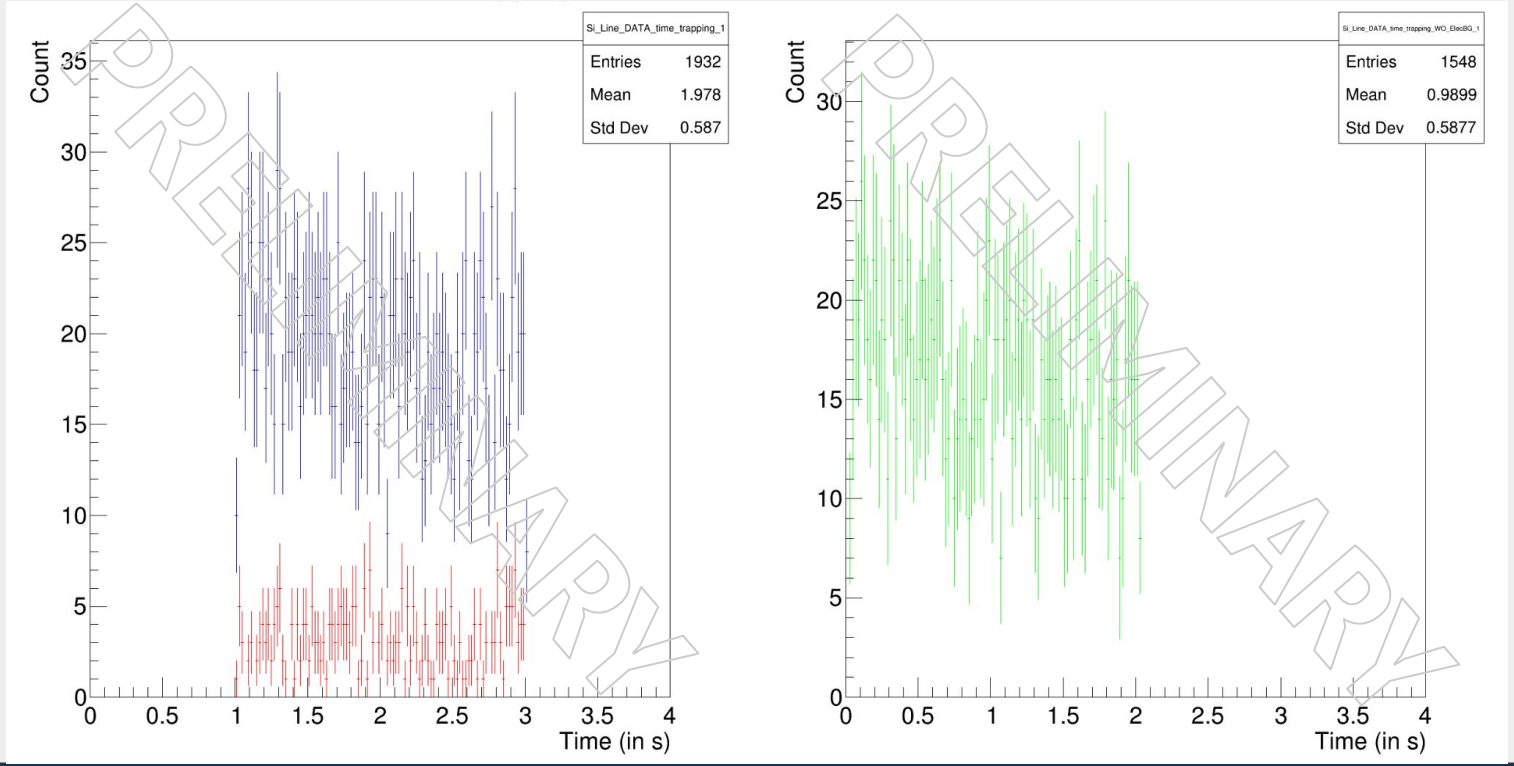


Removing b_e in the trapped data

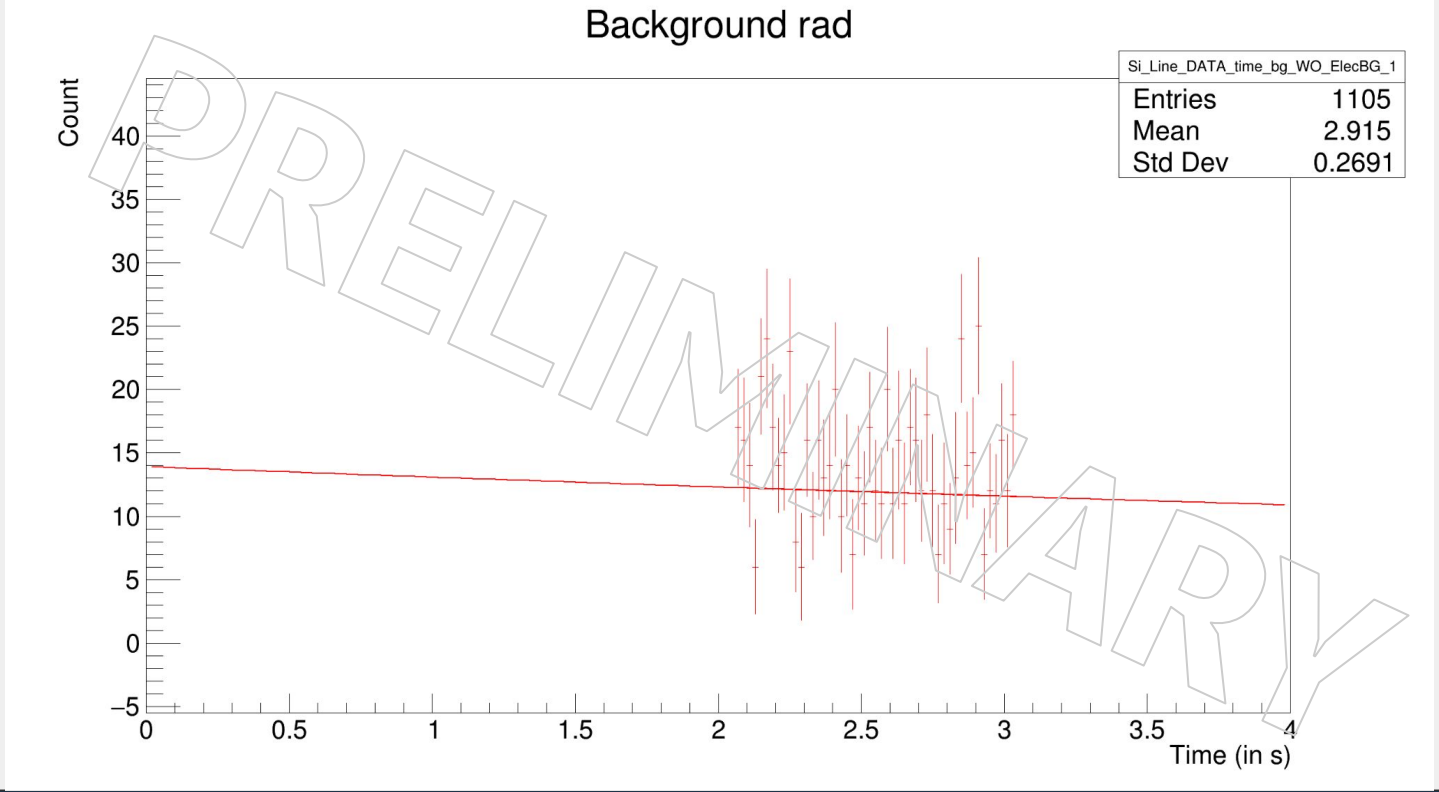
Data

b_e

Cleaned Data



Fitting b_{rad} with a negative exponential: λ is fixed

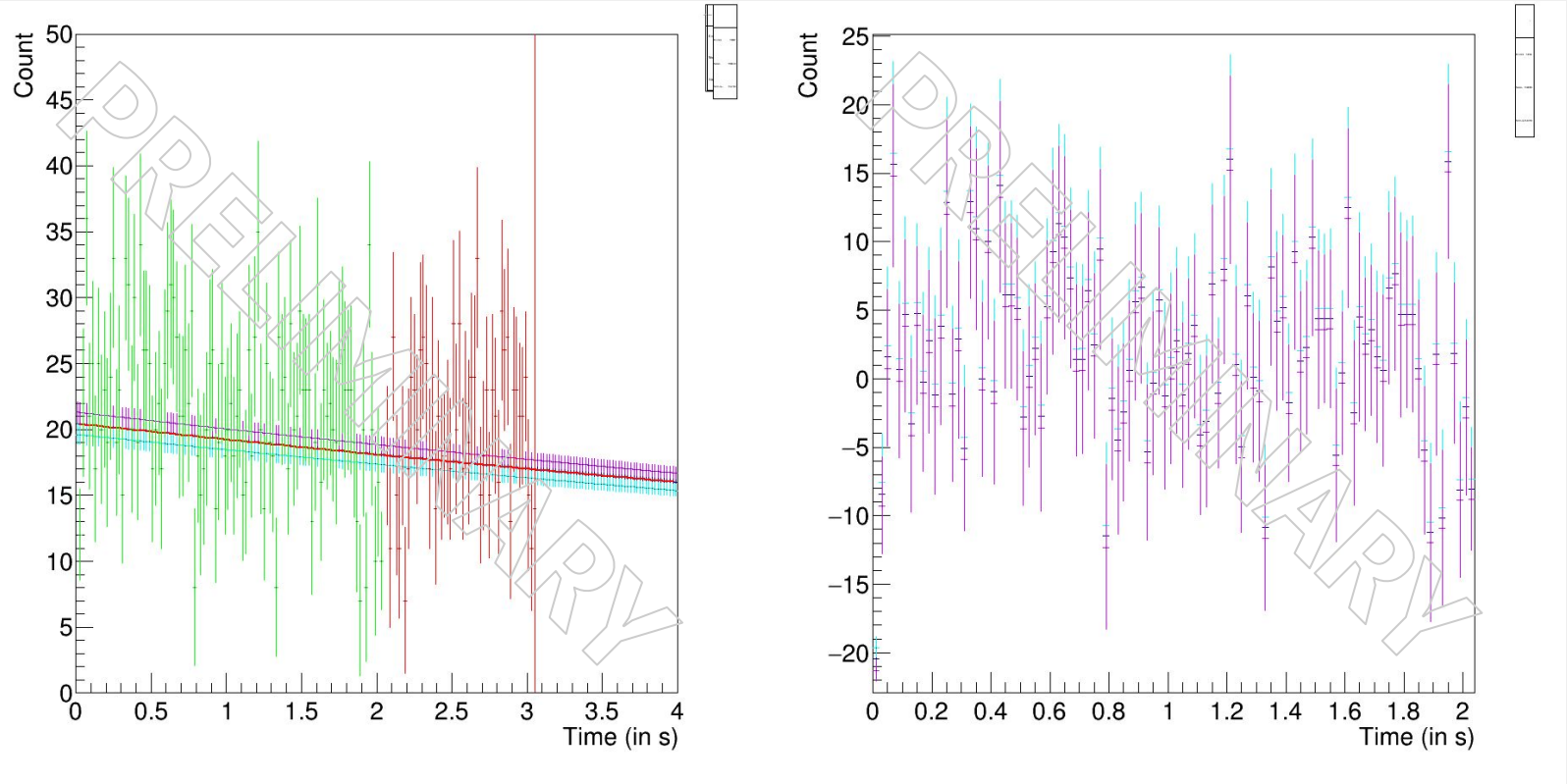


Reconstructing decaying events to remove b_{rad}

Data

b_{rad}

Cleaned Data



- MORA: Conclusions -

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Data analysis:

- Investigate of the asymmetry between Si detectors (on-going)
- Need good understanding of the background data

Experimental improvements:

- Need to get rid of the large contamination (Na:Mg = 100/1 max)

⇨ More statistics = more confident for the P determination

- Questions? -

Thank you for your attention!

MORA collaborators:

P.Delahaye
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G.Quéméner
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A. Rodriguez-Sanchez

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A.Jaries
A.Jokinen
A.Kankainen
A.Koszorus
S.Kujanpää
I.Moore
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S.Rinta-Antila
J.Romero
M.Stryjczyk
V.Virtanen

M.L.Bissel

G.Neyens
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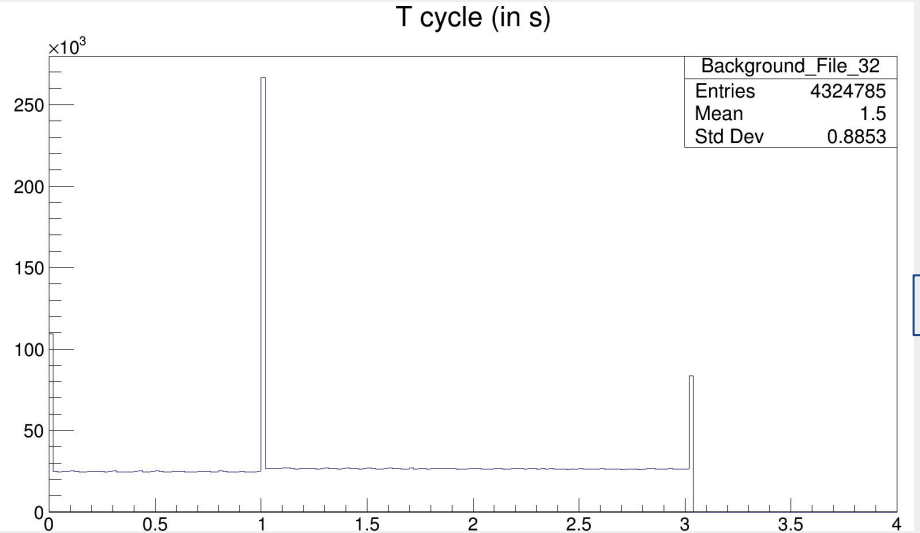
A.De Roubin

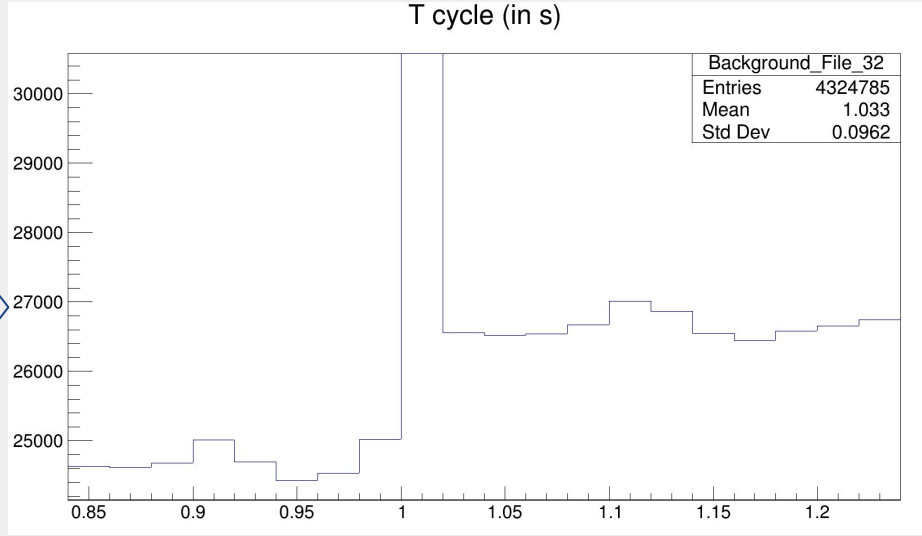
M.Kowalska
G. Neyens

M. Gonzáles-Alonso

Z.Ge

Background analysis

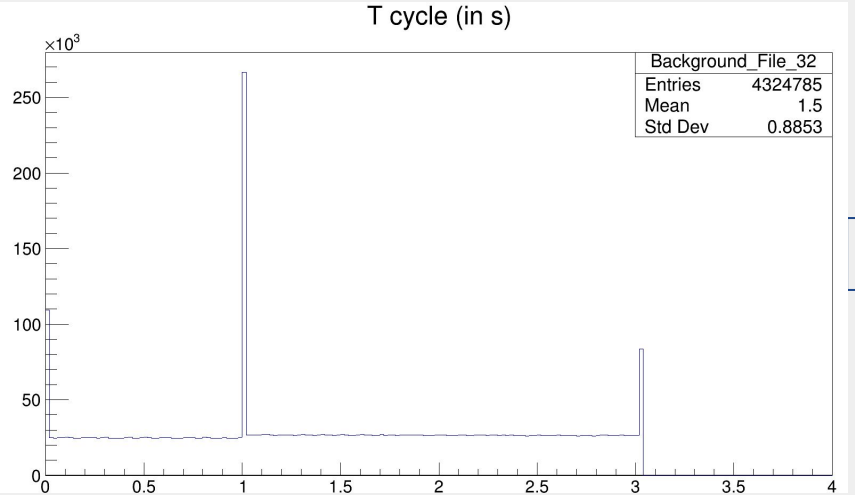


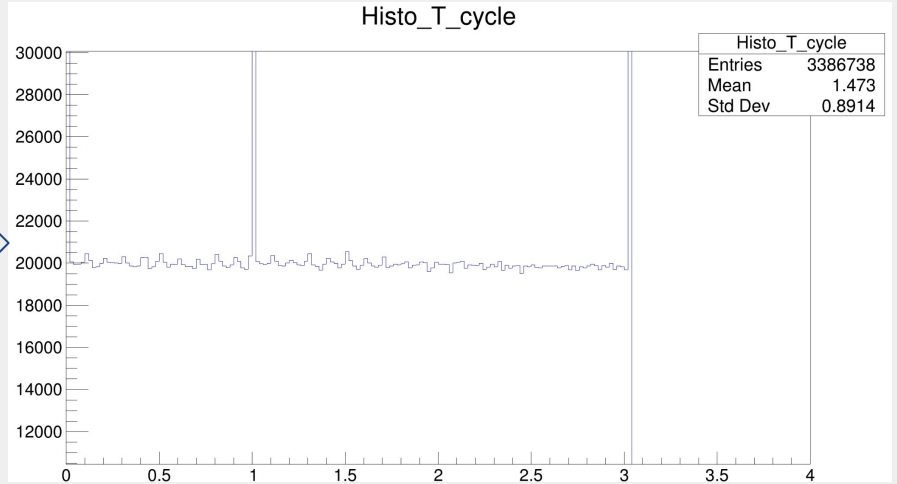


Difference of counts
RF contributions ?

Background analysis

Without the contributions of the RIDE detectors





No more extra contributions during the trapping

⇨ Trapping of some elements possibly buffer gas or ionized elements due to the pump gauges