

Search for CP violation in nuclear beta decay:

The MORA project



THE MORA PROJECT

MATTER'S ORIGIN FROM RADIOACTIVITY

- Overview -

- Therorie and presentation of the experiment
- Detector set-up
- Trapping commississionning
- Results
- Futur schedule of the experiment

- Physics behind MORA -

Matter's Origin from RadioActivity of trapped and oriented ions

Goal: Looking for new CP violations

The probability rate function of beta decay:

$$\omega(\langle \mathbf{J} \rangle | E_e, \Omega_e, \Omega_\nu) dE_e d\Omega_e d\Omega_\nu = \underbrace{\frac{F(\pm Z, E_e)}{(2\pi)^5}}_{\text{Fermi function}} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu$$

$$\times \frac{1}{2} \xi \left\{ 1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m}{E_e} + \frac{\langle \mathbf{J} \rangle}{J} \cdot \left[A \frac{\mathbf{p}_e}{E_e} + B \frac{\mathbf{p}_\nu}{E_\nu} + D \frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu} \right] \right\}$$

nuclear transition matrix elements
Correlation parameters $a, b, A, B, \text{ and } D$
(correlation between spin & momenta of particles)

- Physics behind MORA -

Matter's Origin from RadioActivity of trapped and oriented ions

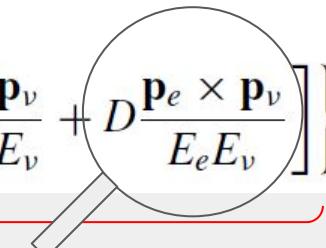
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Fermi function Phase space
 nuclear transition matrix elements Correlation parameters *a, b, A, B, and D*
(correlation between spin & momenta of particles)



- Physics behind MORA -

Matter's Origin from RadioActivity of trapped and oriented ions

Goal: Looking for new CP violations

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

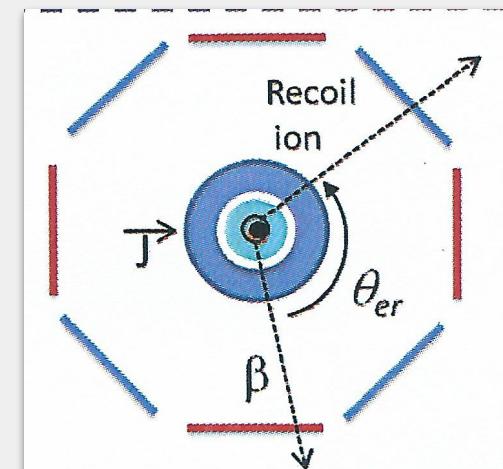
Laser polarisation to invert spin direction

Maximal correlation in the plane \perp to the spin direction = detection plan

Found by asymmetry in Beta - recoil ion counting \longrightarrow need trap
 If $D \neq 0$ then T violation (so of CP)

$N_{\text{coinc}}^{+45^\circ} + N_{\text{coinc}}^{+135^\circ} - N_{\text{coinc}}^{-45^\circ} - N_{\text{coinc}}^{-135^\circ}$	$\alpha \text{ D.P}$
<hr style="border-top: 1px solid black;"/>	
$N_{\text{coinc}}^{+45^\circ} + N_{\text{coinc}}^{+135^\circ} + N_{\text{coinc}}^{-45^\circ} + N_{\text{coinc}}^{-135^\circ}$	

Detection of Beta and recoil ion in coincidence



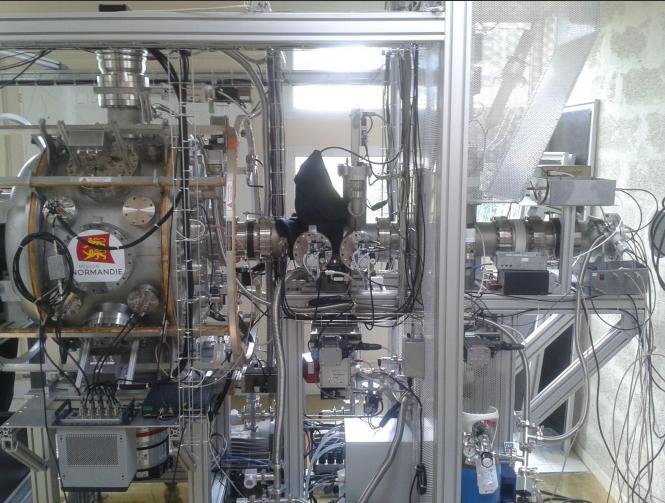
Delahaye et al, Hyp. Int., 2018

Polarisation P, monitored by Si detectors along beam direction

- General Status of the MORA experiment -

Trap and injection line:

All pieces have been built and installed (trap, line and electronics)
Almost all electronics monitored by the Slow Control



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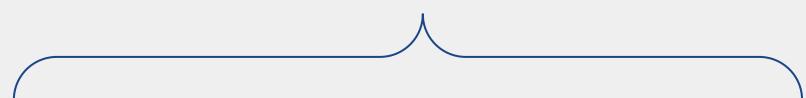
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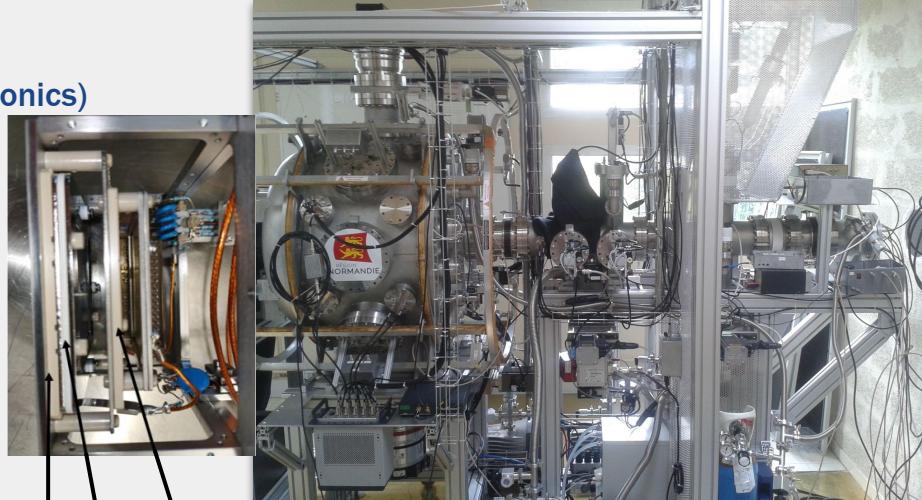
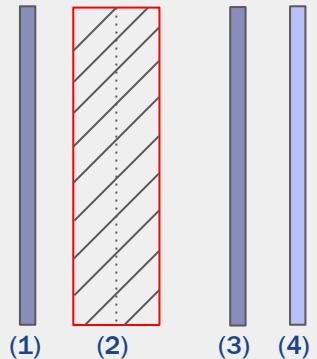
2 types of detectors:

4 RIDE for recoil ions



Four detectors @ cardinal positions

Micro Channel Plate (MCP)



- (1) = 90% transmission grid
- (2) = Micro channel plate
- (3) = Position sensitive resistive anode
- (4) = Reflection anode

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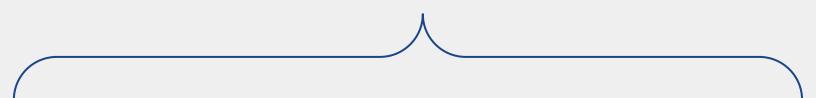
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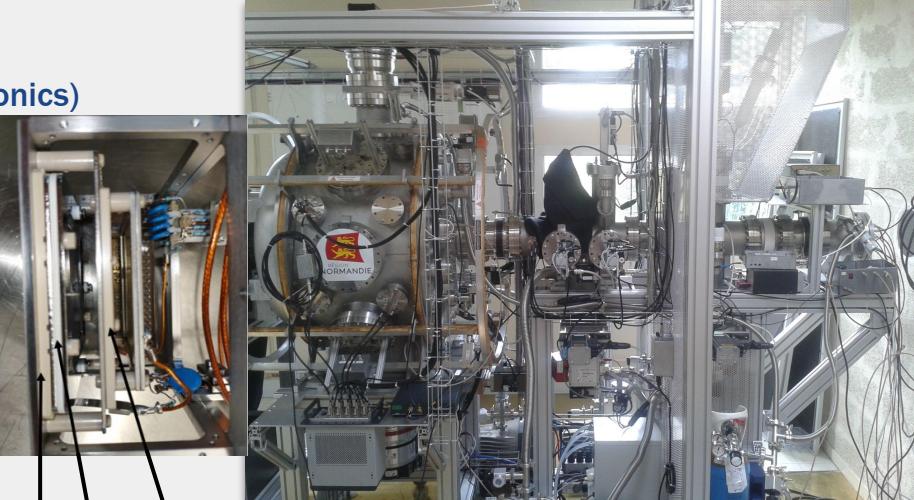
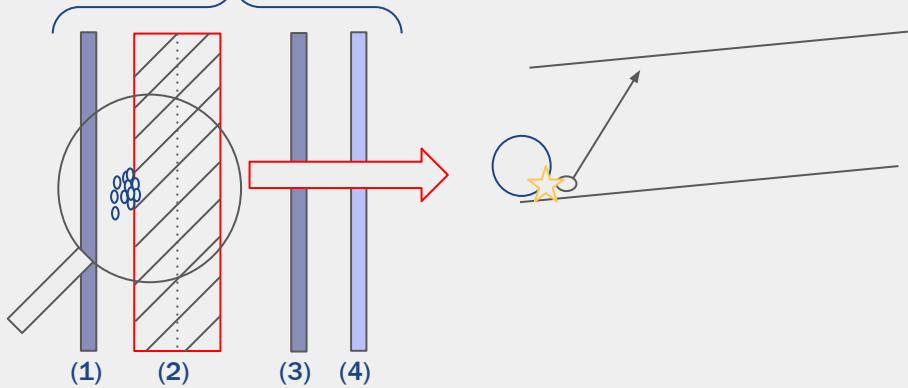
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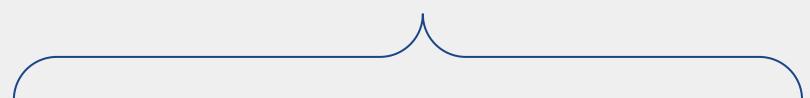
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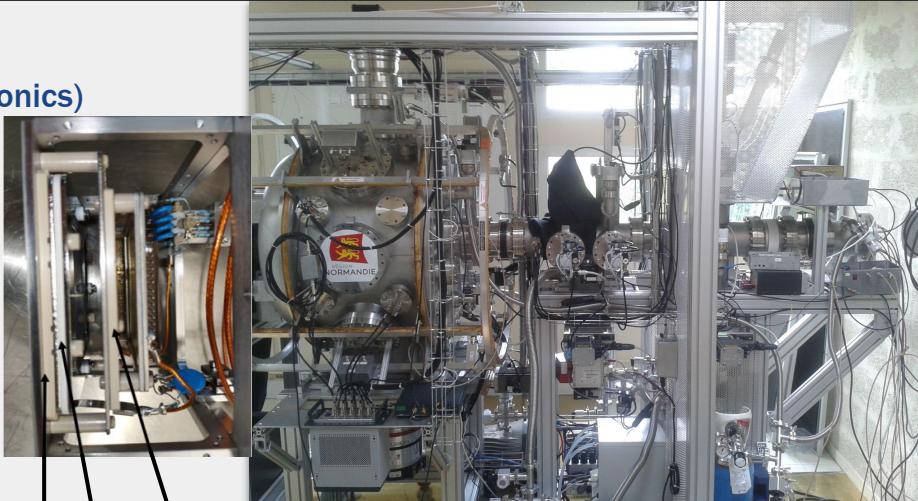
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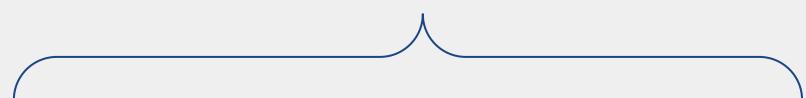
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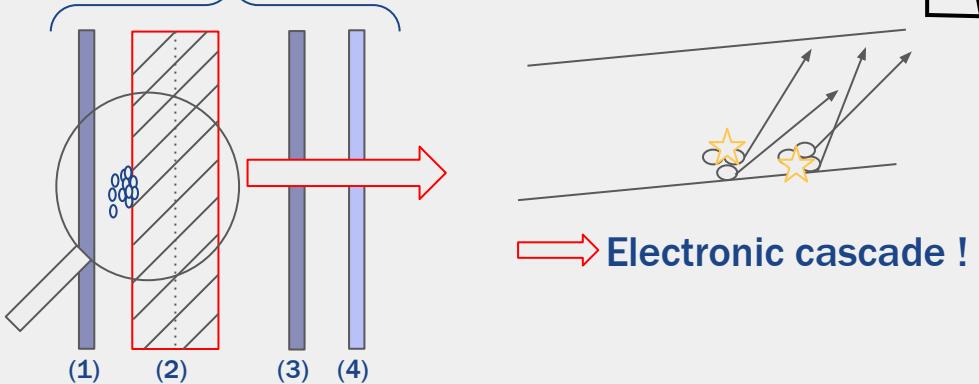
Almost all electronics monitored by the Slow Control

2 types of detectors:

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Four detectors @ cardinal positions
Micro Channel Plate (MCP)



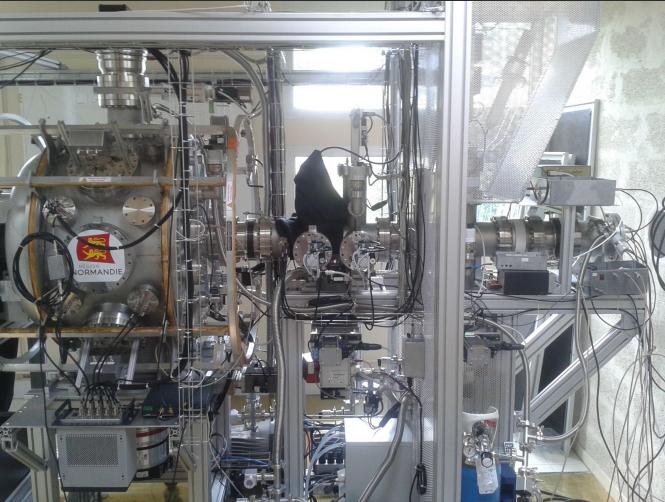
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→ Electronic cascade !

- General Status of the MORA experiment -

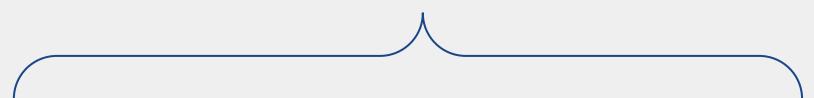
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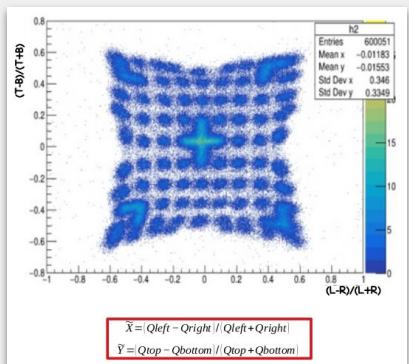
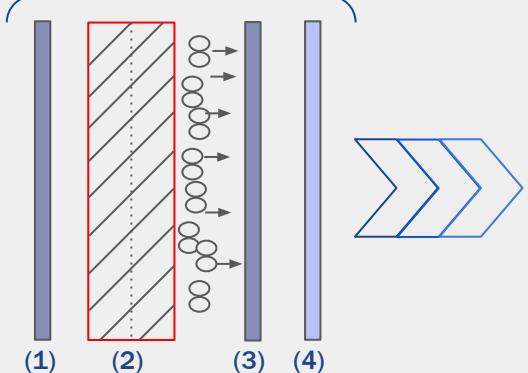
2 types of detectors:

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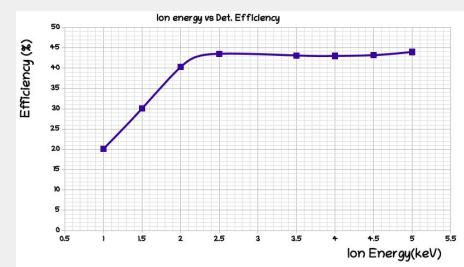


Four detectors @ cardinal positions

Micro Channel Plate (MCP) Electronic cascade



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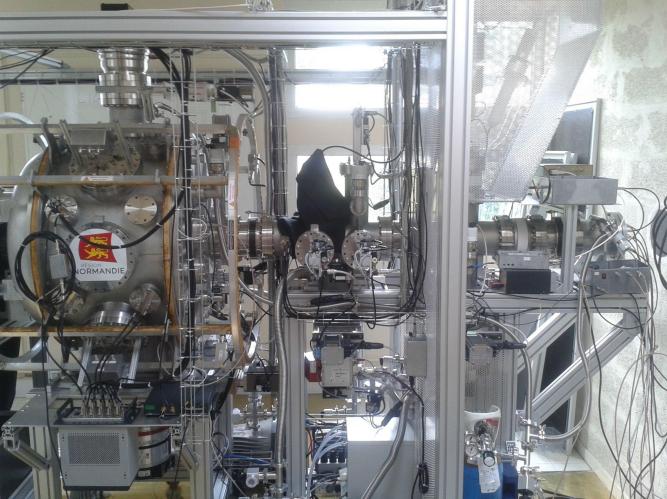


Reach 45% efficiency

- General Status of the MORA experiment -

Trap and injection line:

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2 types of detectors:

4 RIDE (Micro channel plates) for **recoil ions**

4 Phoswichs (Plastic Scintillators) for **Beta**

Four detectors @ intercardinal positions

↳ One detector = 4 independants phoswich

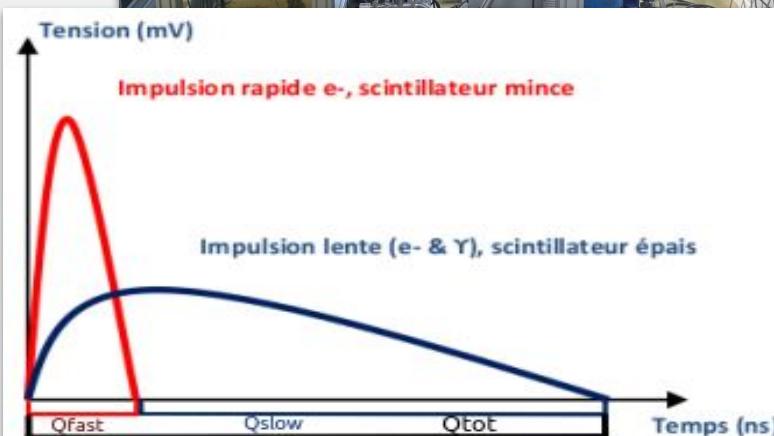
↳ One phoswich = 2 plastic scintillators (1 thin + 1 thick)

Different time responses:

1.8 ns for the thin $\Rightarrow Q_{\text{fast}}$

285 ns for the thick $\Rightarrow Q_{\text{slow}}$

3 time gates $\Rightarrow Q_{\text{tot}} = Q_{\text{fast}} + Q_{\text{slow}}$



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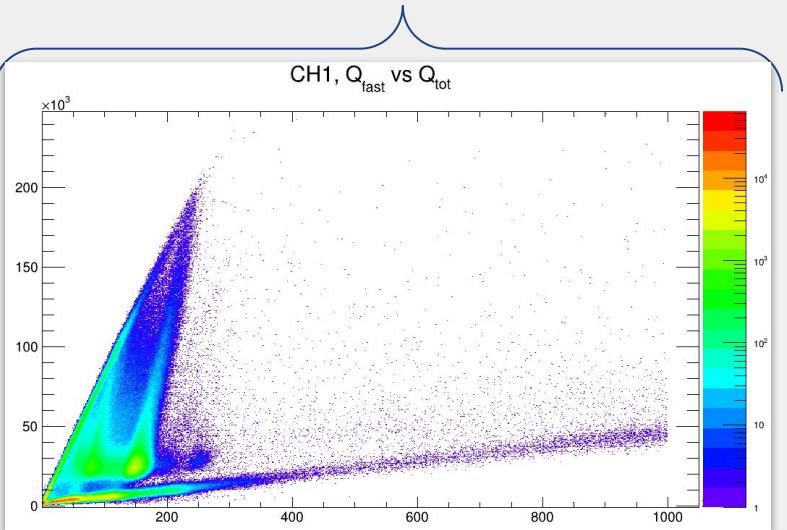
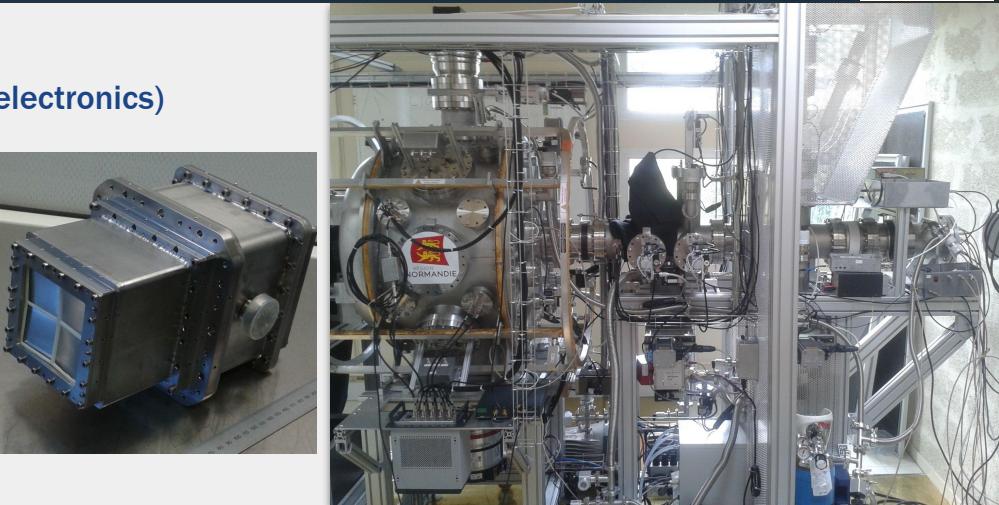
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Raw data collected by FASTER apparendus

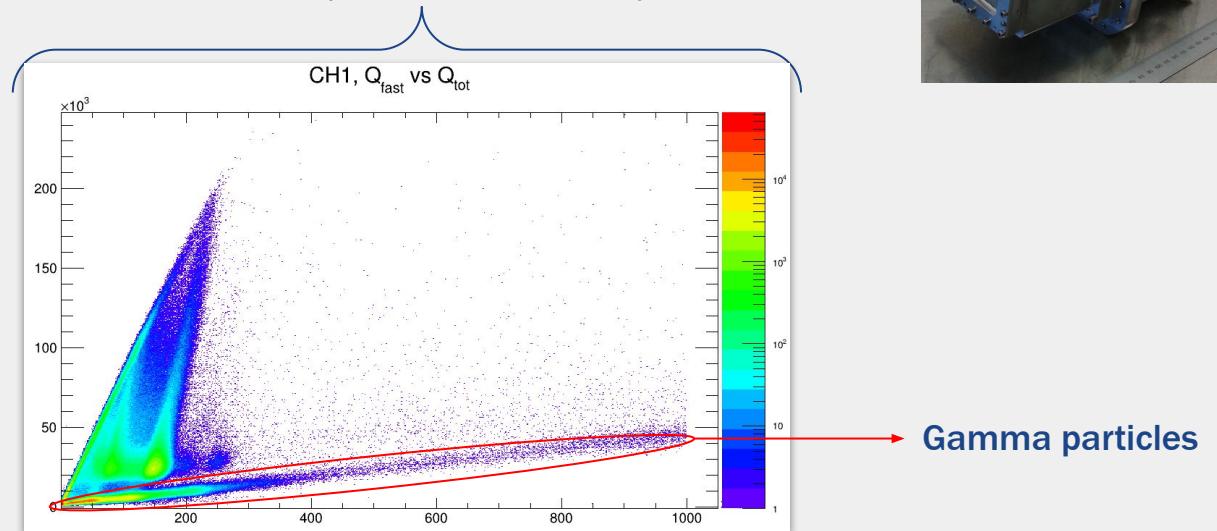
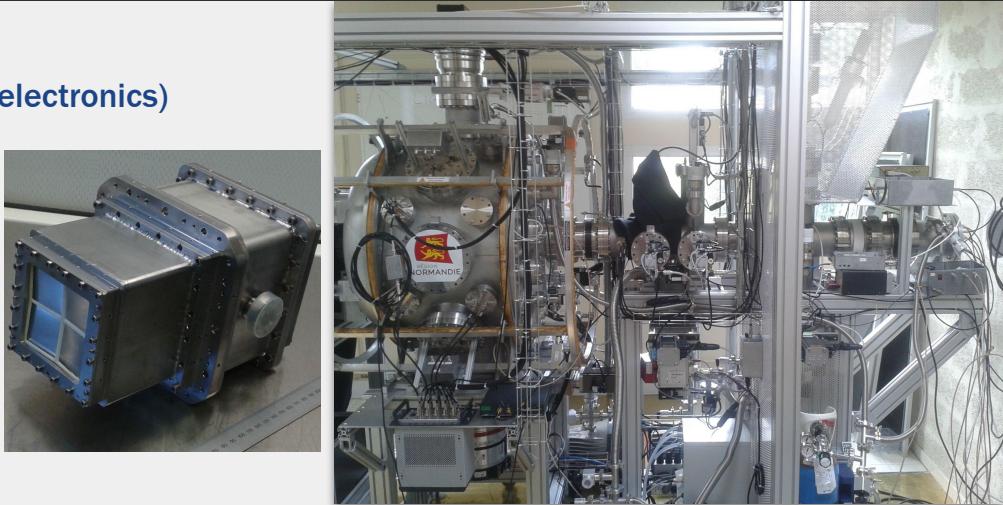
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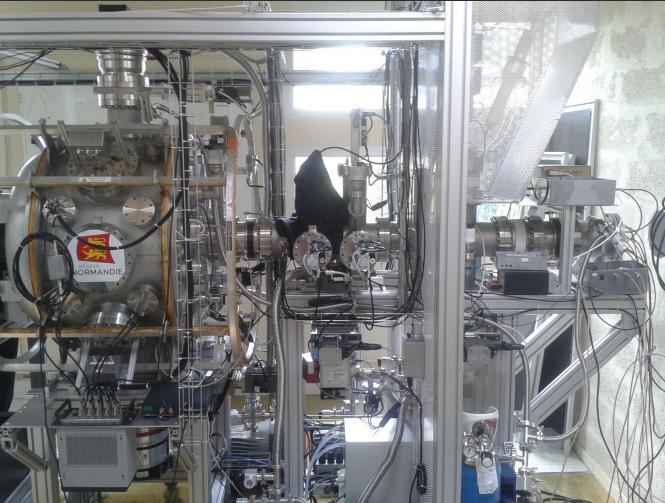


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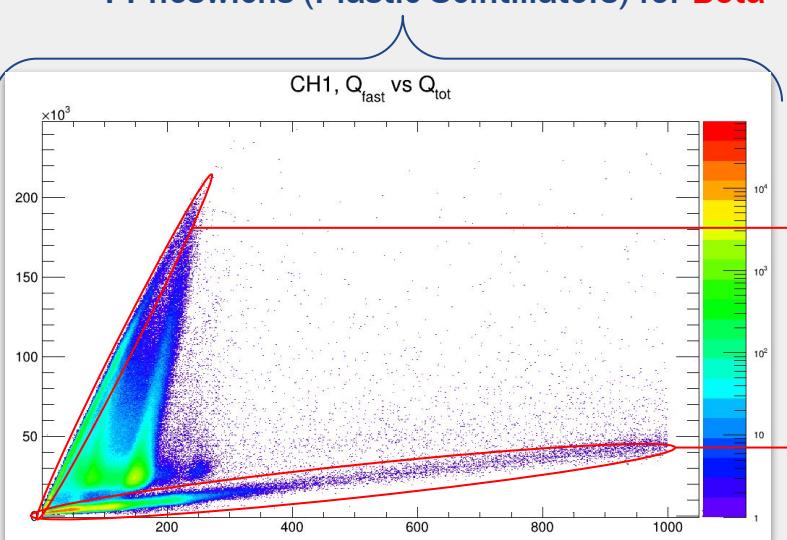
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Beta particles stopped by the thin scintillator

Gamma particles

Raw data collected by FASTER apparendus

Sacha Daumas-Tschopp - Journées Rencontre Jeunes Chercheurs, La Rochelle - 19/10/2021 -

- General Status of the MORA experiment -

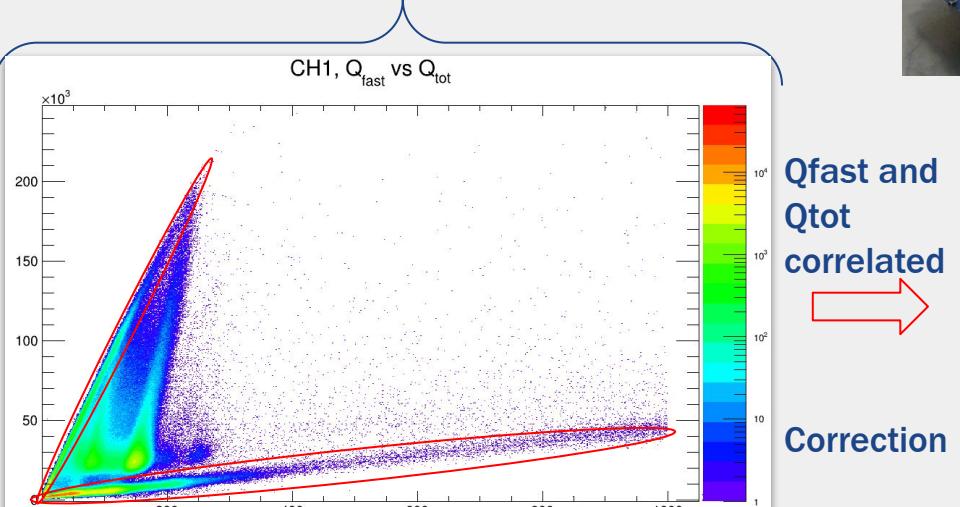
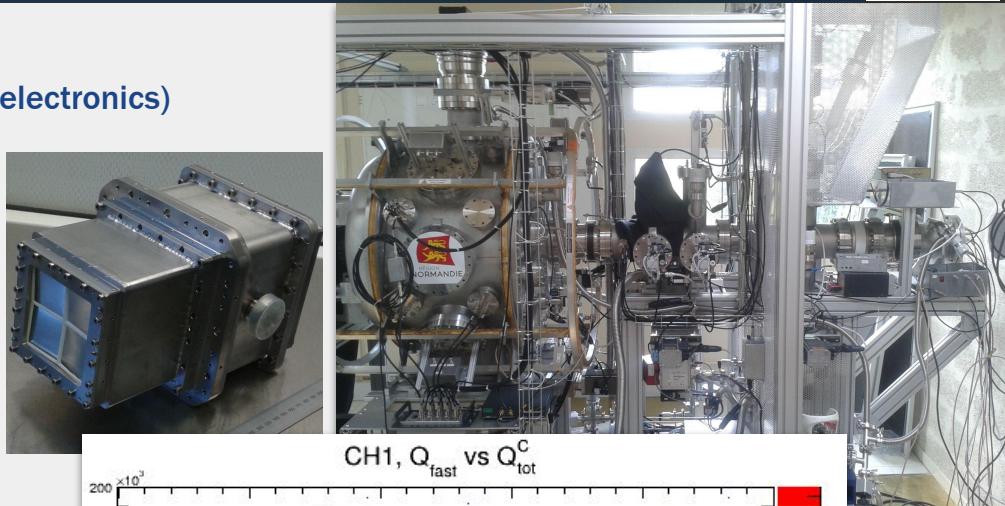
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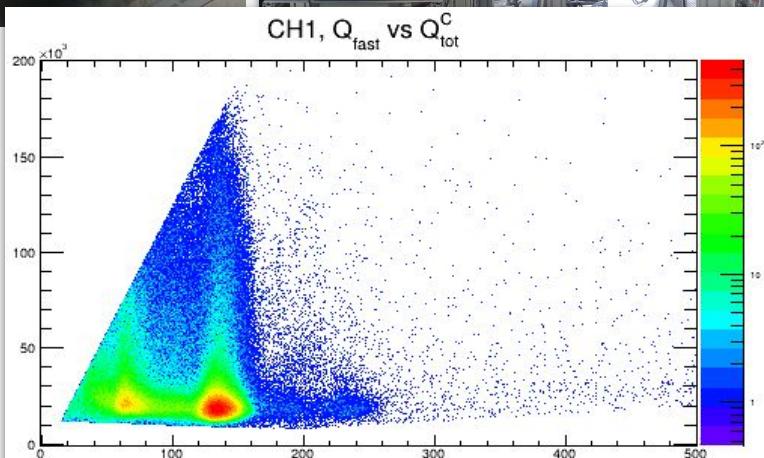
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Raw data collected by FASTER apparendus



Data after correction

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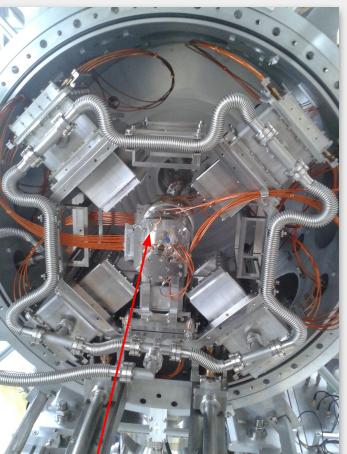
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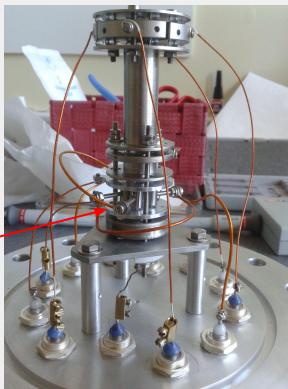
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Trapping in commissionning phase @ **LPC Caen**:

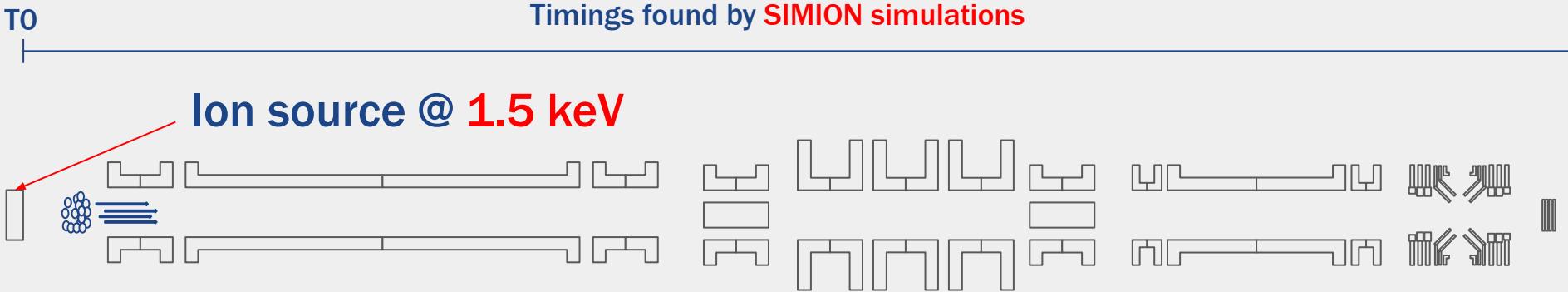
Use of a stable source(Surface ionization) of ^{23}Na
But not pure: contaminants = K + Rb



Add a RFQ on the source to bunch ions
(ex: every 10 ms for a 60 μs trap duration)

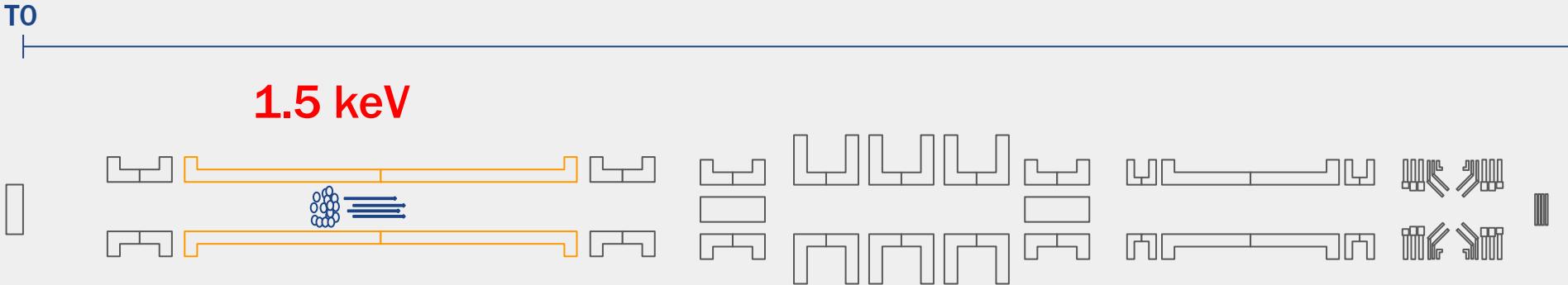
Trap (Benali et al,EPJA, 2020)

- Current set-up : Commissionning @ LPC CAEN -



Travelling through the line:

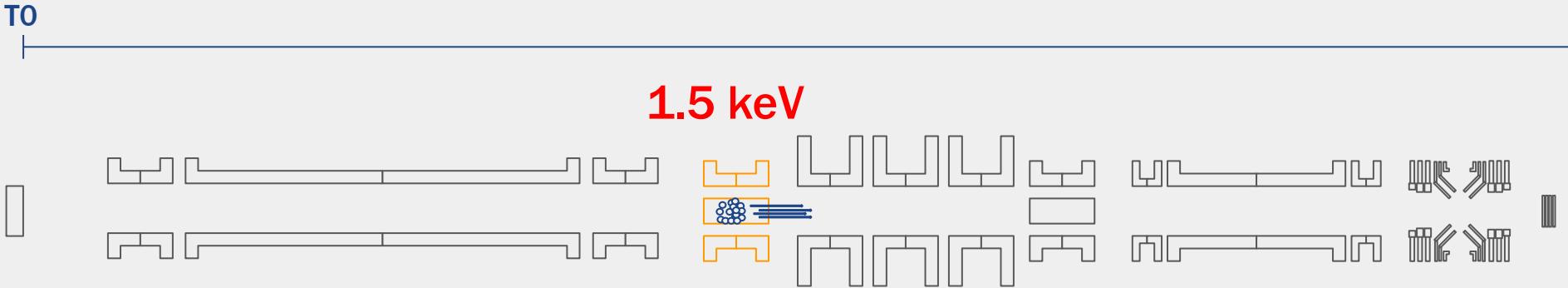
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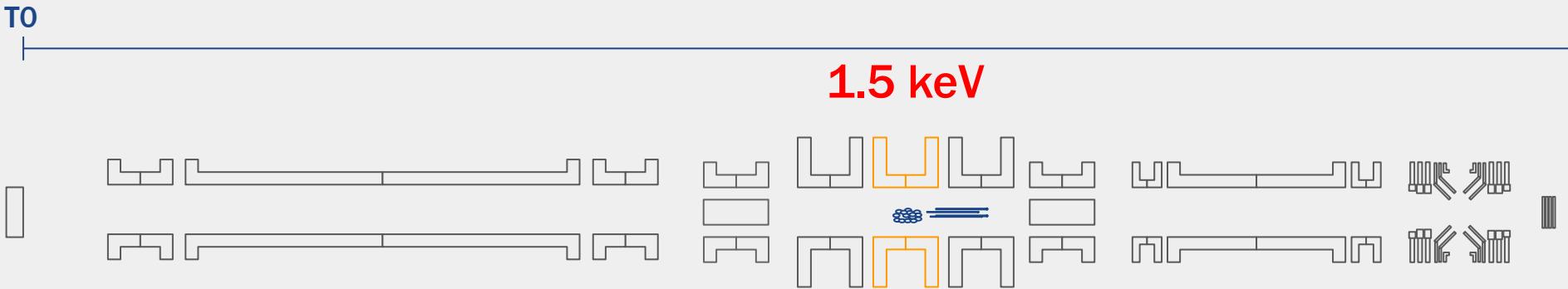
- Pulse Drift tube (act as a lens for now)

- Current set-up : Commissionning @ LPC CAEN -



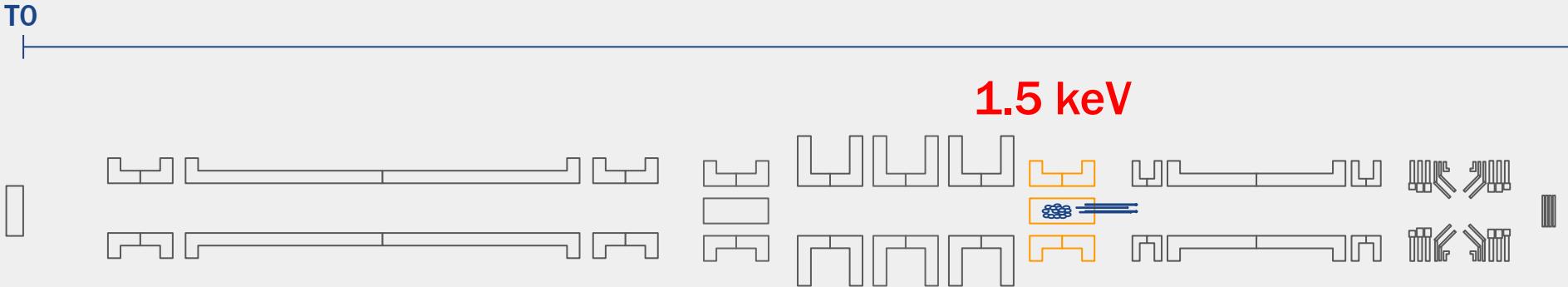
Travelling through the line:

- Pulse Drift tube (act as a lens for now)
- Steerer 1 to correct the beam direction



Travelling through the line:

- Pulse Drift tube (act as a lens for now)
- Steerer 1 to correct the beam direction
- **Lens 1** to refocalise the beam



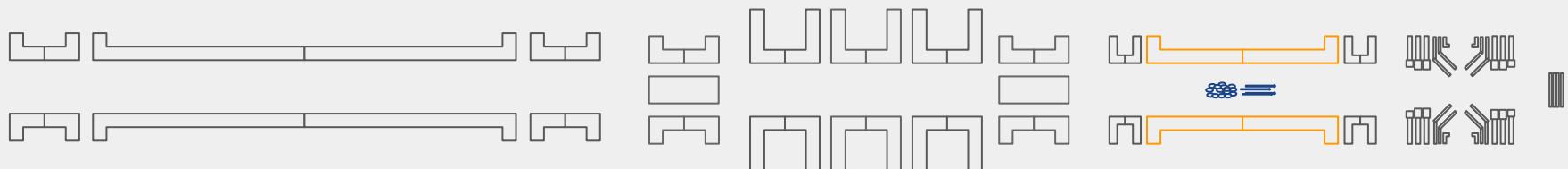
Travelling through the line:

- Pulse Drift tube (act as a lens for now)
- Steerer 1 to correct the beam direction
- Lens 1 to refocalise the beam
- Steerer 2 to adjust the beam

- Current set-up : Commissionning @ LPC CAEN -

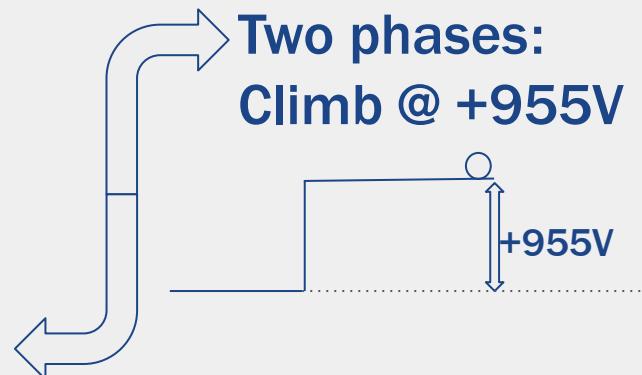
T0

$$1.5 - 0.955 = 545 \text{ eV}$$

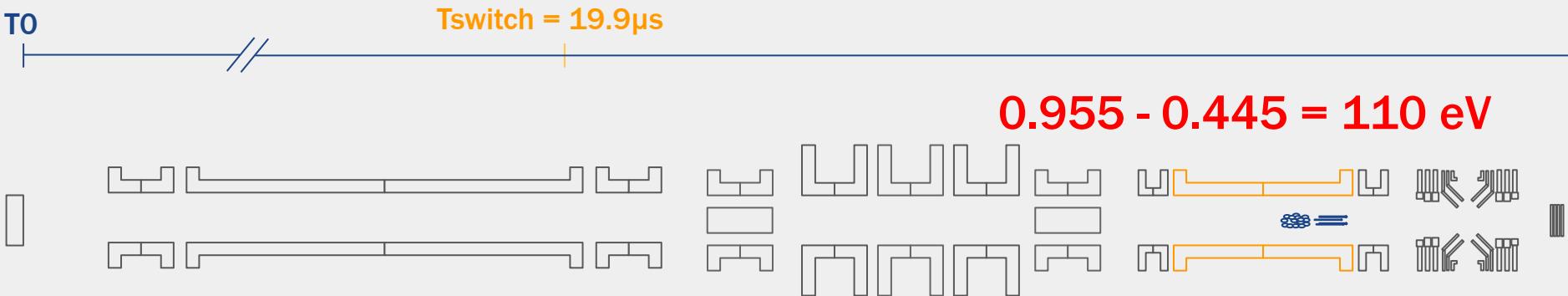


Travelling through the line:

- Pulse Drift tube (act as a lens for now)
- Steerer 1 to correct the beam direction
- Lens 1 to refocalise the beam
- Steerer 2 to adjust the beam
- Pulse Drift tube 2 to slow down the beam

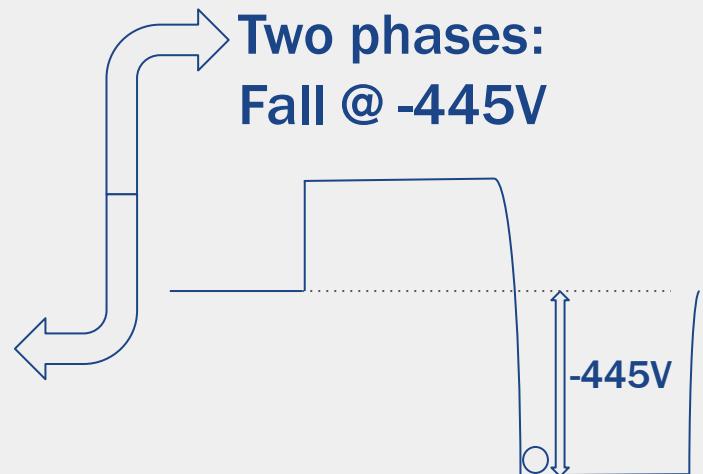


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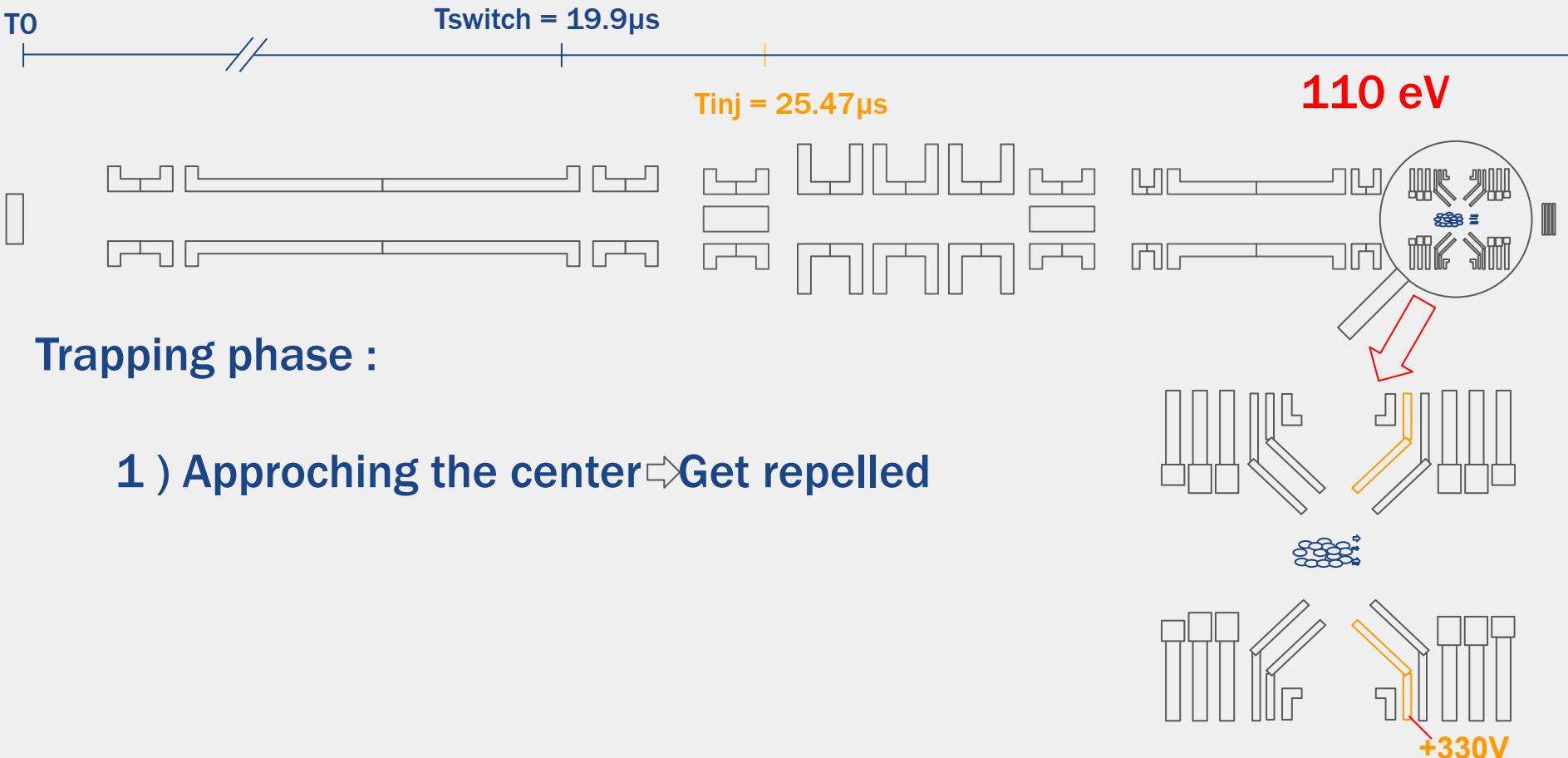
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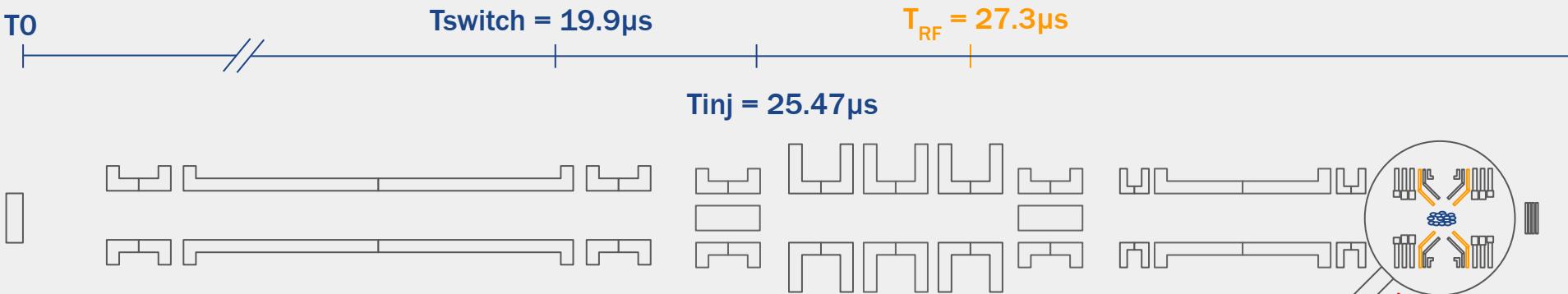


Two phases:
Fall @ $-445V$

- Current set-up : Commissionning @ LPC CAEN -



- Current set-up : Commissionning @ LPC CAEN -



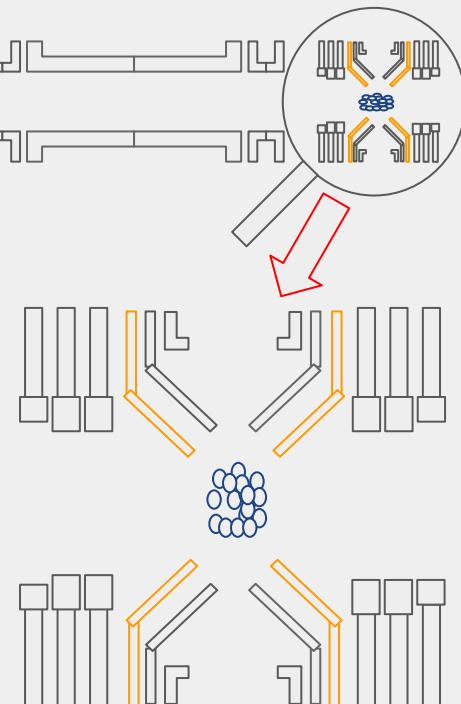
Trapping phase :

- 1) Approaching the center \Rightarrow Get repelled
- 2) Starting the RF when $E = \sim 0 \text{ eV}$

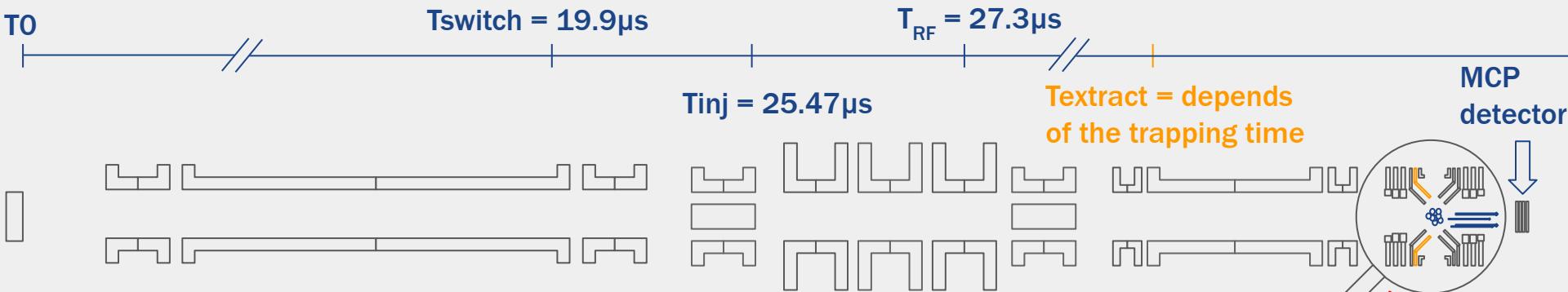
$$V_{\text{RF}} = \pm 76\text{V}$$

$$F = 333\text{kHz}$$

trapping time = ex: $60\mu\text{s}$; 90ms ; 450ms

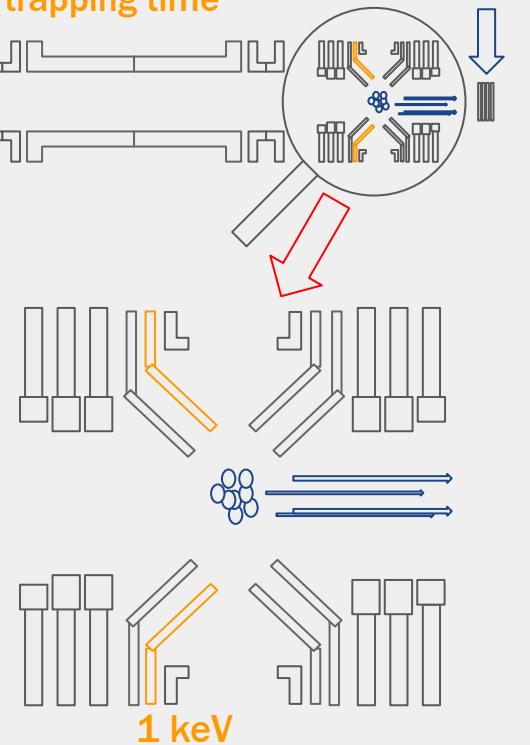


- Current set-up : Commissionning @ LPC CAEN -



Trapping phase :

- 1) Approaching the center \Rightarrow Get repelled
- 2) Starting the RF when $E_{\text{ions}} = \sim 0 \text{ eV}$
- 3) Extraction phase @ **1 keV**



- Latest data : Trapping and optimization -

Trapping efficiency evaluation:

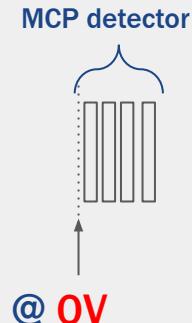
Three steps:

Collect data from the trapping process



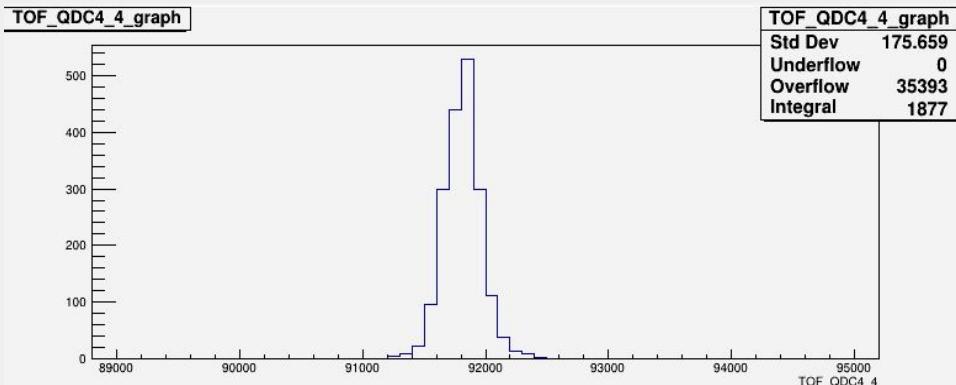
Single peak

Trapping process “on”



Grid @ 0V

Data collected **with trap**: only Na



- Latest data : Trapping and optimization -

Trapping efficiency evaluation:

Three steps:

Collect data from the trapping process

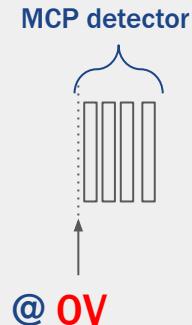
Disable the trap voltages and let ions passing through

Collecting data of the double peak (Na @ 112 eV + K @ 1.5 keV)

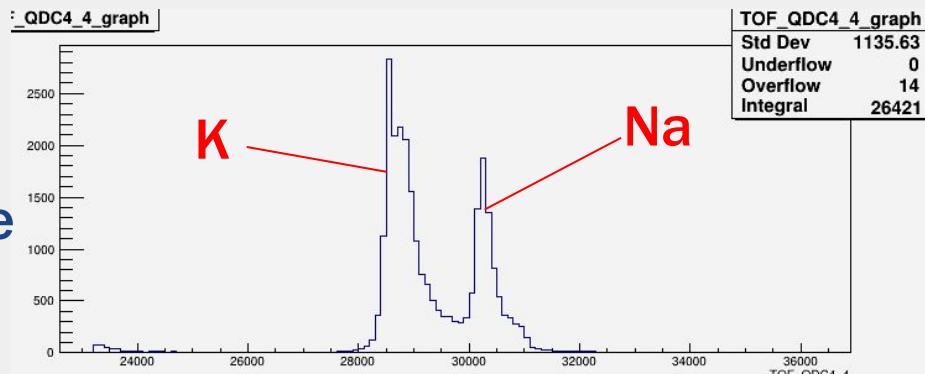


Double peak

Na slowed down by the
PDT2 while not K



Data collected w/o trap: Na + K



- Latest data : Trapping and optimization -

Trapping efficiency evaluation:

Four steps:

Collect data from the trapping process

Disable the trap and let ions passing through

Collecting data of the double peak (Na @ 112 eV + K @ 1.5 keV)

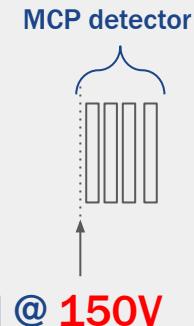
Filter the ion: only K and Rb will pass



$$\epsilon_{\text{trap}} = \frac{\text{Nb of trapped Na}}{\text{Nb of direct Na}}$$

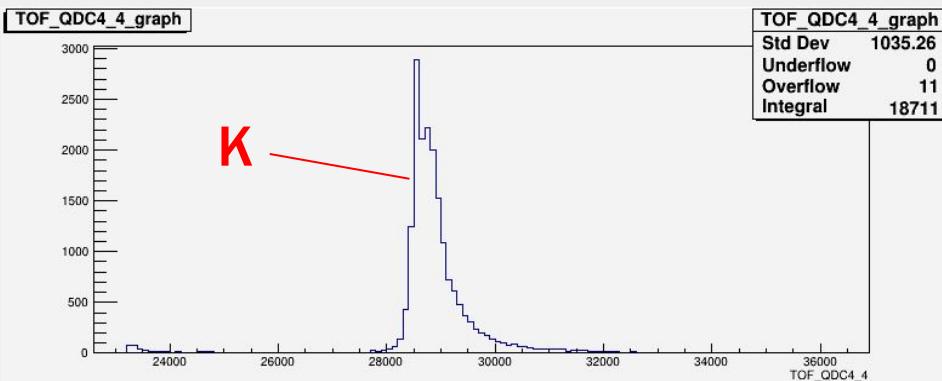
Single peak

Na disappears by selecting ions in energy



Grid @ 150V

Data collected w/o trap: only K



- Latest data : Trapping and optimization -

Currently:

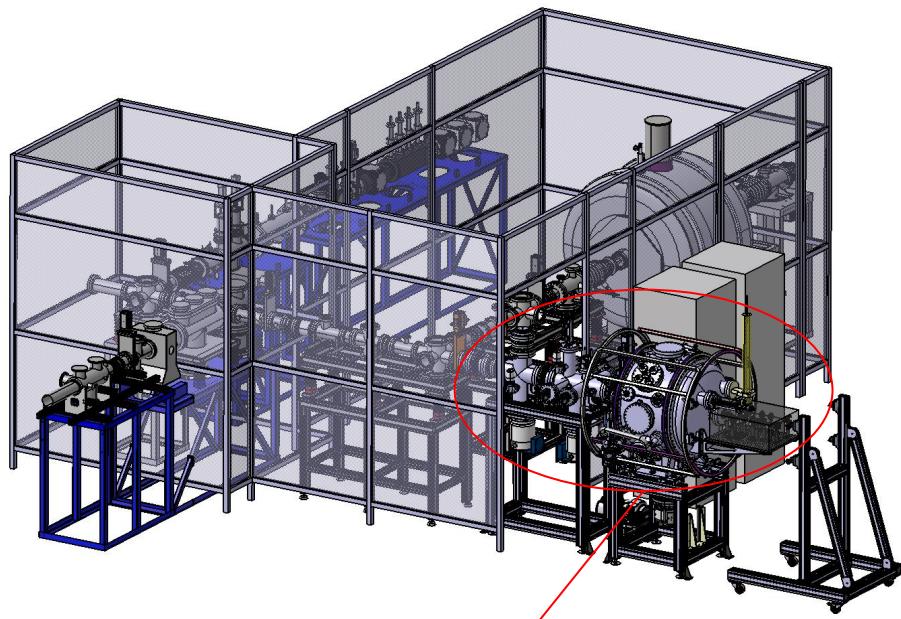
$$\left. \begin{array}{l} \varepsilon_{\text{trap}} = 56\% \text{ for } 60 \mu\text{s trapping time} \\ \varepsilon_{\text{trap}} = 22\% \text{ for } 90 \text{ ms trapping time} \\ \varepsilon_{\text{trap}} = 10\% \text{ for } 450 \text{ ms trapping time} \end{array} \right\} \begin{array}{l} \text{Evaporation phase (\sim 1 ms)} \\ \text{Half-life} \approx 350 \text{ ms} \end{array}$$

Conclusion:

The MORA line and trapping process are working very well and we are confident for future tests

Future schedule:

-  Move the experiment to JYFL at the end of October
- Installing MORA beginning/mid November
- Offline tests of the new experimental set-up
- Beam time: 18 - 20 December (TBC)



MORA set-up @ JYFL

→ **Test of online trapping and polarisation degree measurement**

- Future of MORA @ JYFL : Polarisation measurement -

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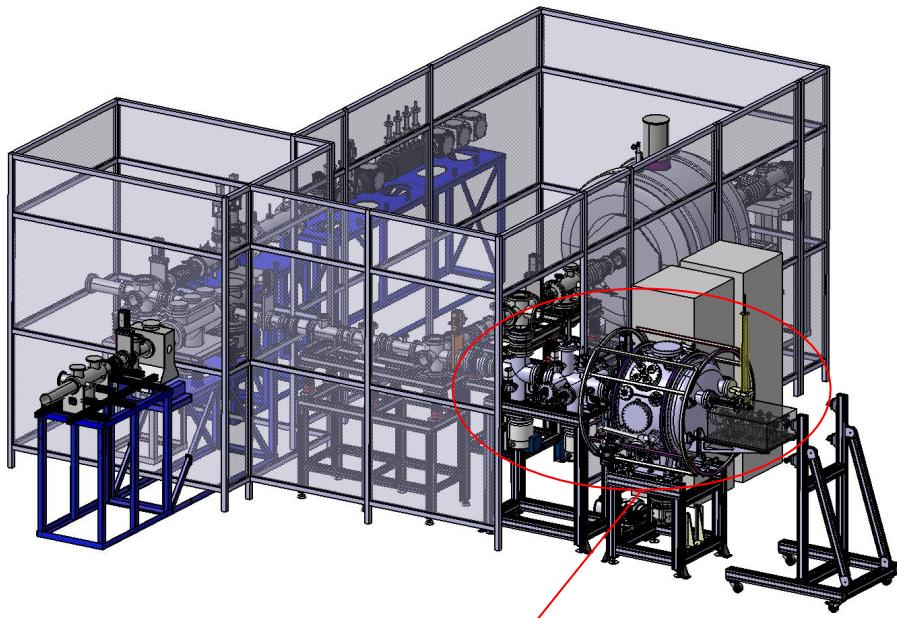
MORA set-up @ JYFL

Test of online trapping and polarisation degree measurement

- Future of MORA @ JYFL : Polarisation measurement -

Future schedule:

- Start over the test of the detectors
- Move the rest of the line to JYFL
- Beam time reschedule (TBC)



MORA set-up @ JYFL

→ **Test of online trapping and polarisation degree measurement if there are no oyster problems**

Thank you for your attention !

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■ The probability rate function of beta decay:

$$\omega(\langle \mathbf{J} \rangle | E_e, \Omega_e, \Omega_\nu) dE_e d\Omega_e d\Omega_\nu = \frac{F(\pm Z, E_e)}{(2\pi)^5} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu$$

$$\times \frac{1}{2} \xi \left\{ 1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m}{E_e} + \frac{\langle \mathbf{J} \rangle}{J} \cdot \left[A \frac{\mathbf{p}_e}{E_e} + B \frac{\mathbf{p}_\nu}{E_\nu} + D \frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu} \right] \right\}$$

nuclear transition matrix elements

with polarized nuclei

beta asymmetry neutrino asymmetry D triple correlation
Sensitive to CP violation