

# 2S-4P Spectroscopy of Antihydrogen and Centrifugal Separation of $\text{Be}^+/\text{e}^+$ Plasma

ALPHA Collaboration

Cheng Chiu

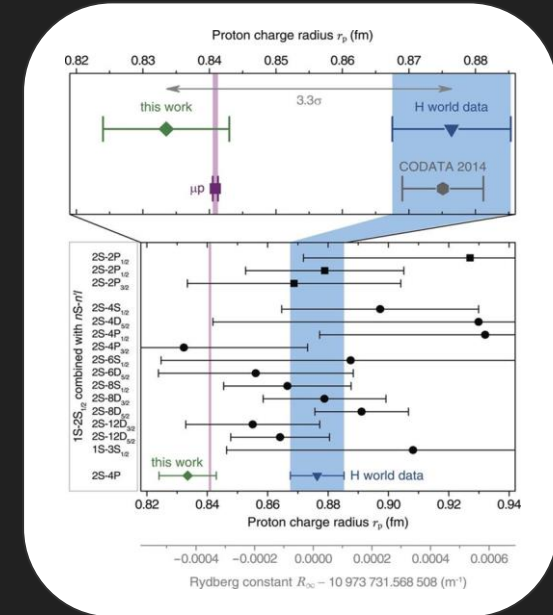
ALPHA

# Motivation

- ❖ Test of CPT symmetry with trapped antihydrogen atoms
- ❖ The matter-antimatter asymmetry problem
  - Why do we exist?
- ❖ Measure proton/antiproton charge radius

Axel Beyer et al.

$$E_{nlj} = R_{\infty} \left( -\frac{1}{n^2} + f_{nlj} \left( \alpha, \frac{m_e}{m_p}, \dots \right) + \delta_{\ell 0} \frac{C_{NS}}{n^3} r_P^2 \right)$$



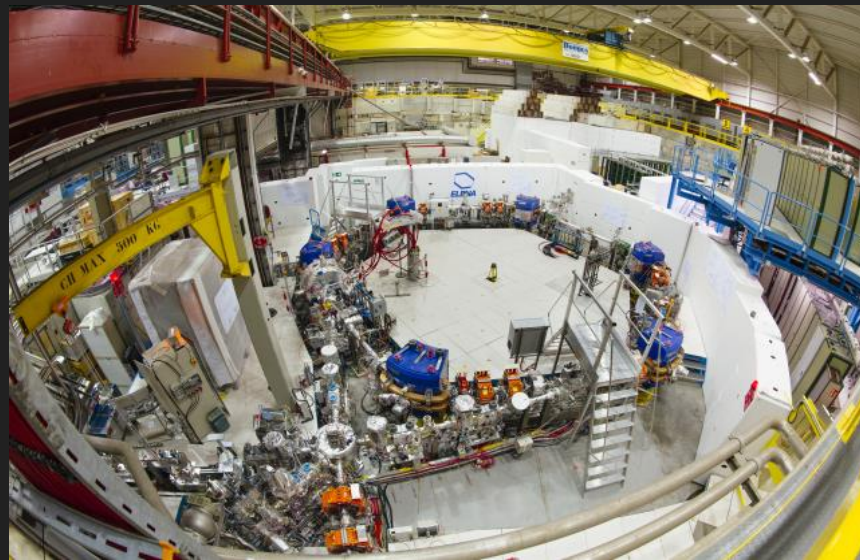
# Apparatus

Antiproton Decelerator (AD)



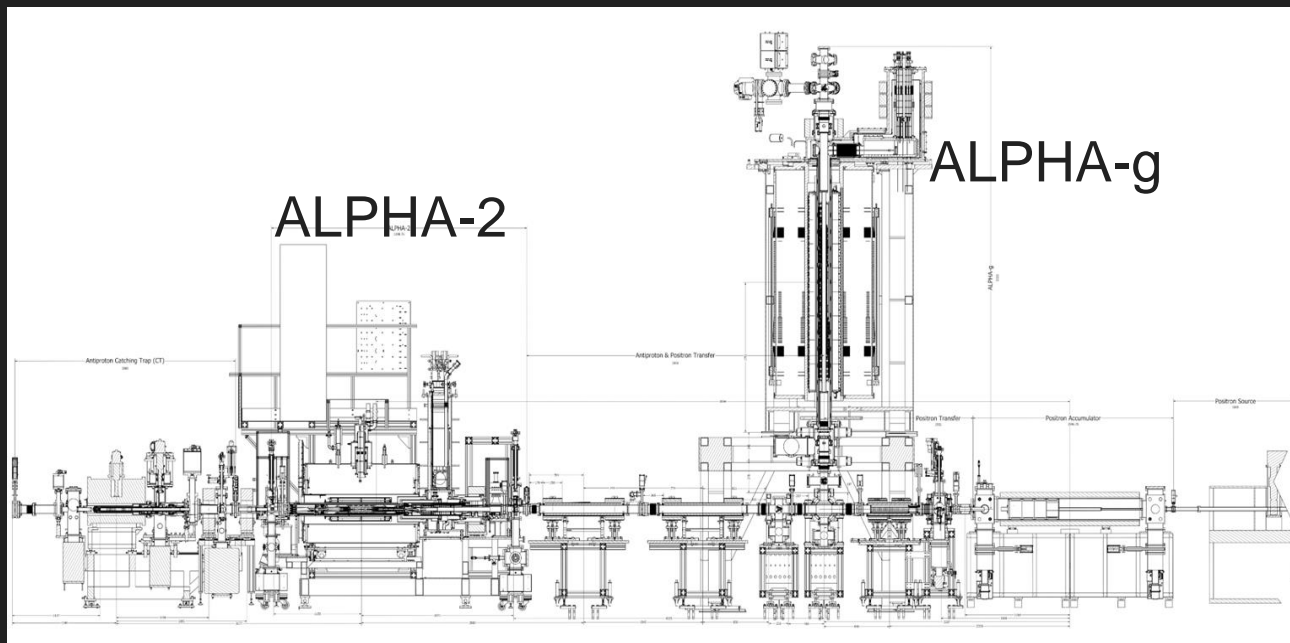
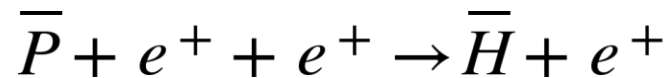
<https://cds.cern.ch/record/39385>

Extra Low ENergy Antiproton ring (ELENA)



<https://home.cern/fr/node/4325>

# Experiment Logistics

 $\bar{p}$  $e^+$ 

# Experiment Logistics Cont.

## Produce and Store Antihydrogen

- ❖ Slow down antiproton beam
- ❖ Cool positron with beryllium
- ❖ Cool antiproton with electron
- ❖ Laser cool Antihydrogen

## Do Measurement with it

- ❖ ALPHA-2
  - Spectroscopy (1S-2S, 2S-4P,...)
- ❖ ALPHA-G
  - Gravitational measurement

## Detector

- ❖ Reconstruct annihilation vertex

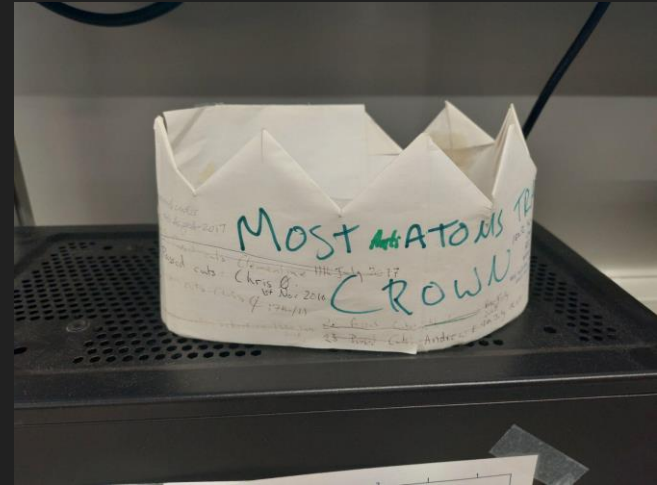
# Shift Work

## → Regular work:

- ◆ Stacking
- ◆ Data-logging
- ◆ Cryogenics
- ◆ Thermal cycle (every ~2 weeks)
- ◆ ... anything that needs to be done

## → Currently Happening:

- ◆ 2S-4P Measurement
- ◆ Lyman-Alpha Measurement (1S-2P)
- ◆ Energy mixing experiment
- ◆ ALPHA-G upgrade installation



New pass cut record: 182 (X)  
Now 186

# 2S-4P Measurement with 486nm Laser

2S-4Pa ( $\sim 1 \mu W$ ) :

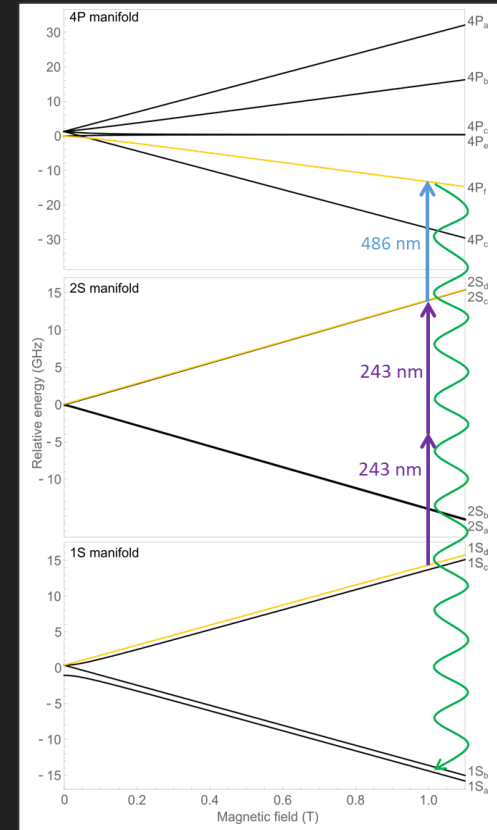
100% decay back to 1Sd trappable state

=> signal suppression on resonance

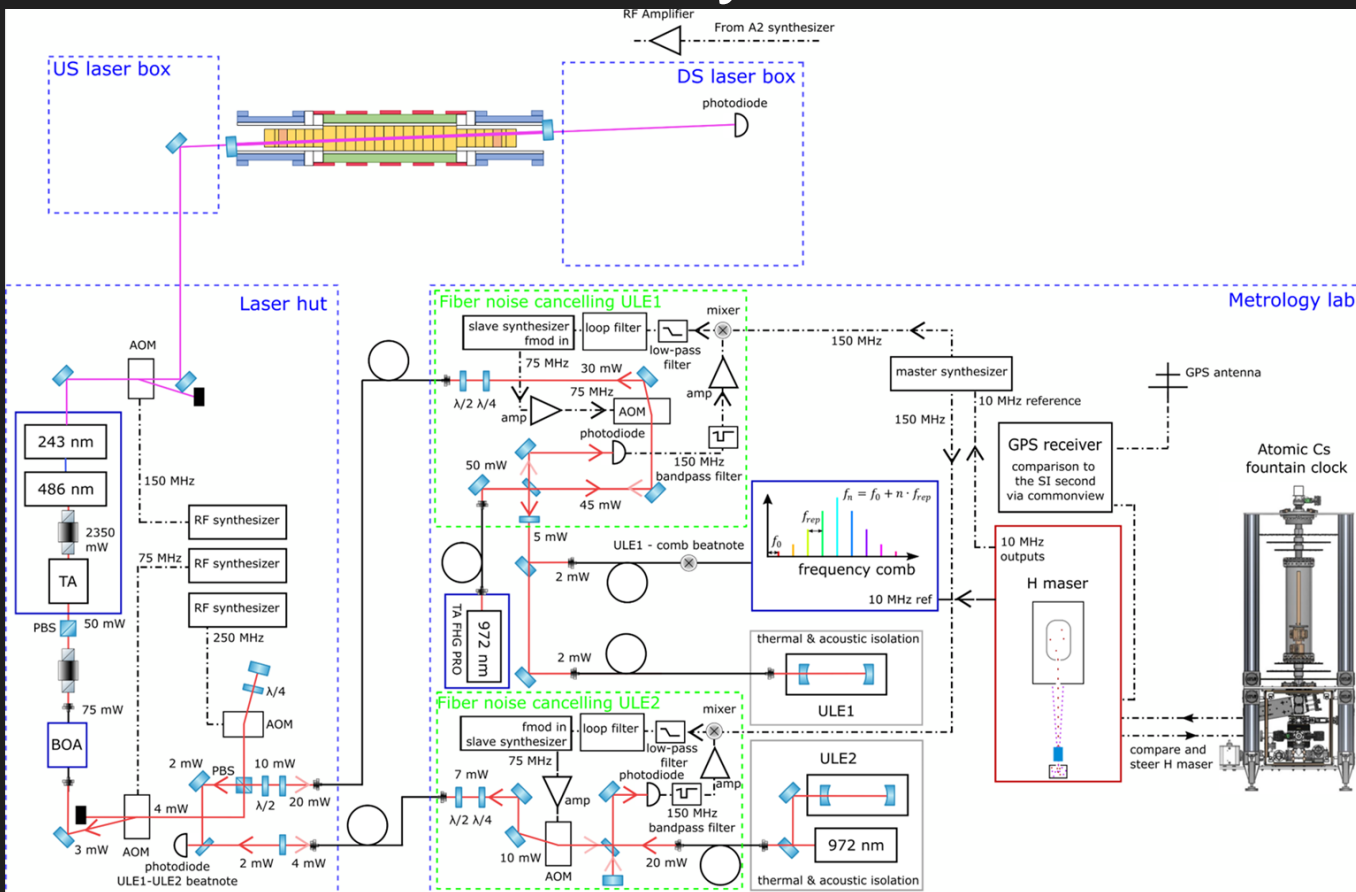
2S-4Pf ( $\sim 100 \mu W$ ) :

$\sim 100\%$  decay into 1Sa untrappable state

=> signal enhancement on resonance

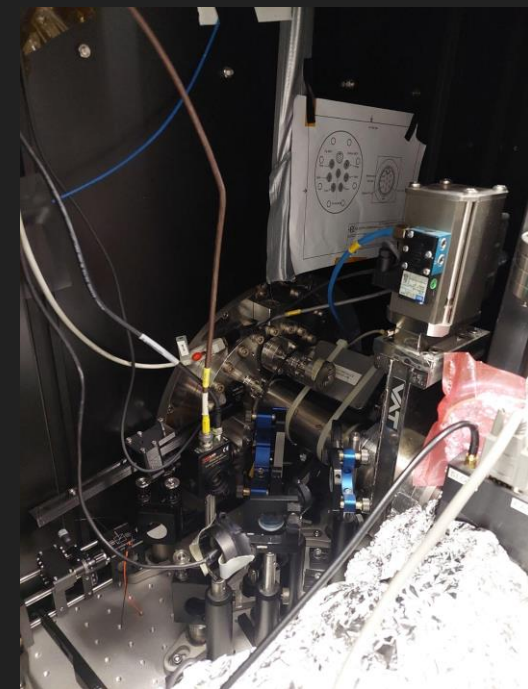


# Laser System

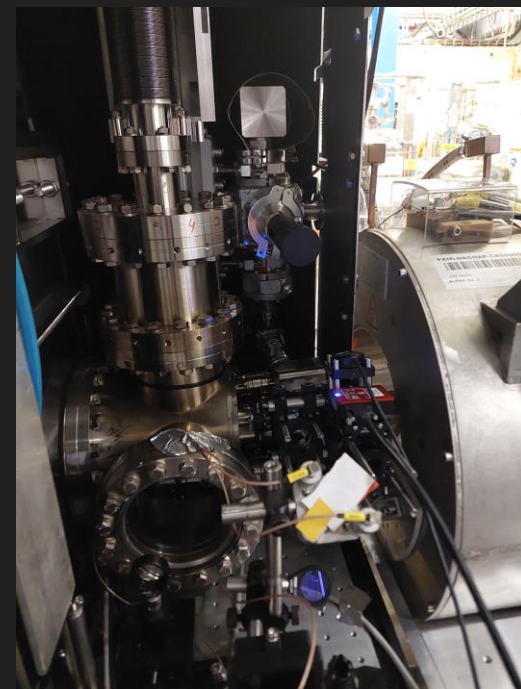
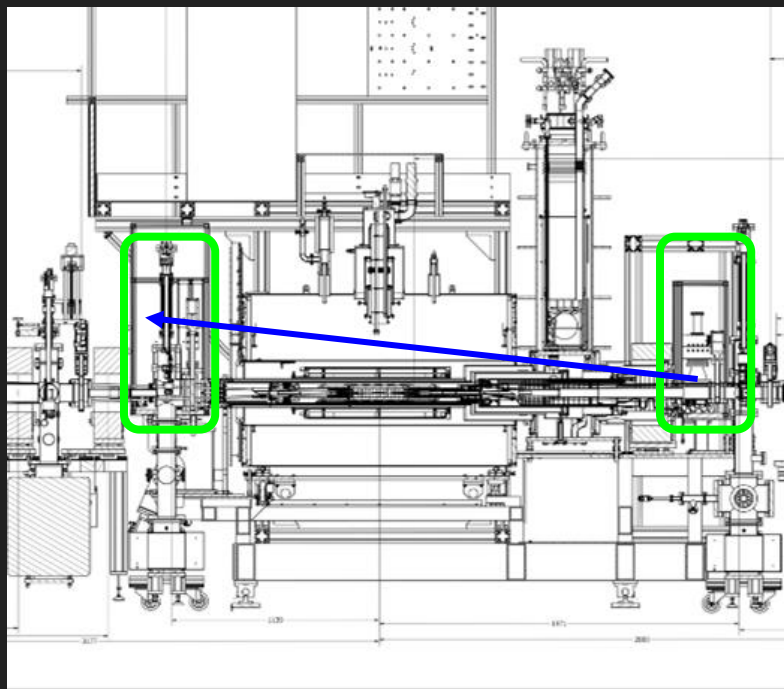




# 486 nm Laser



Upstream

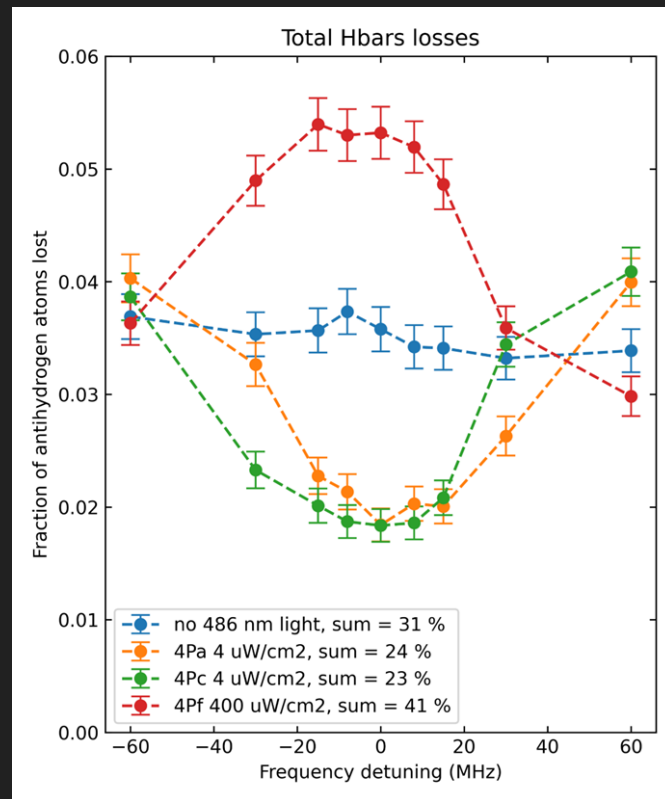


Downstream

# 2S-4P Summary

## ❖ Procedures:

- Optical design & alignment
- Labview control
- Connect to sequencer
- Cooperation with Laser Cooling Team & Microwave Team
- Run experiment (of course)

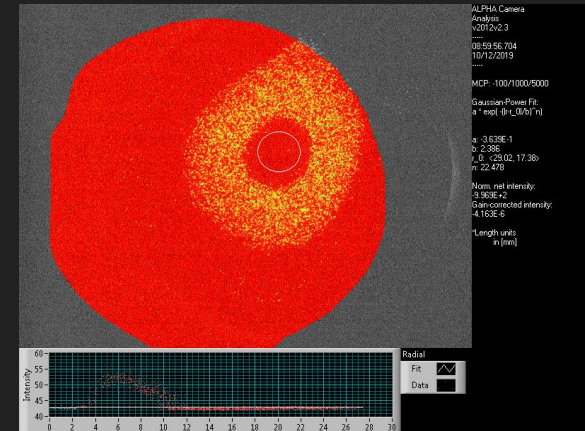


# Centrifugal Separation of $\text{Be}^+/\text{e}^+$

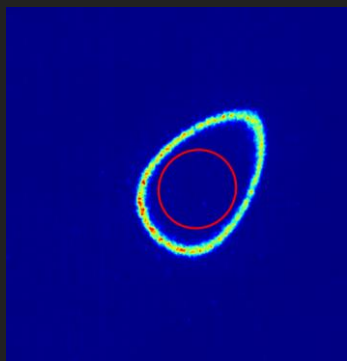
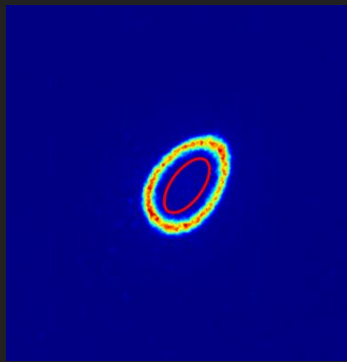
- ❑ Why: Cold position  $\Rightarrow$  more trappable antihydrogen
- ❑ How: sympathetic cooling of  $\text{e}^+$  with laser-cooled  $\text{Be}^+$
- ❑ Lower temperature  $\Rightarrow$  more centrifugal separation
- ❑ Implies no further cooling of  $\text{e}^+$

## Goal:

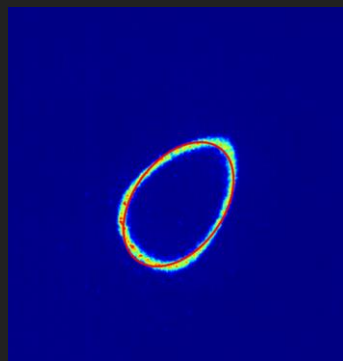
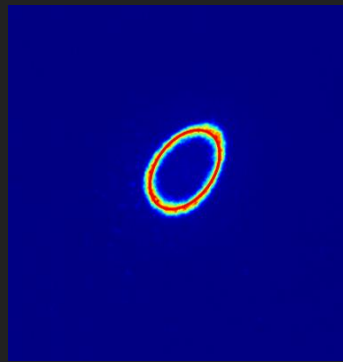
1. Model-to-Data Comparison
2. Feasibility Test of New Species for Cooling



# Centrifugal Separation of Be<sup>+</sup>/e<sup>+</sup> Analysis

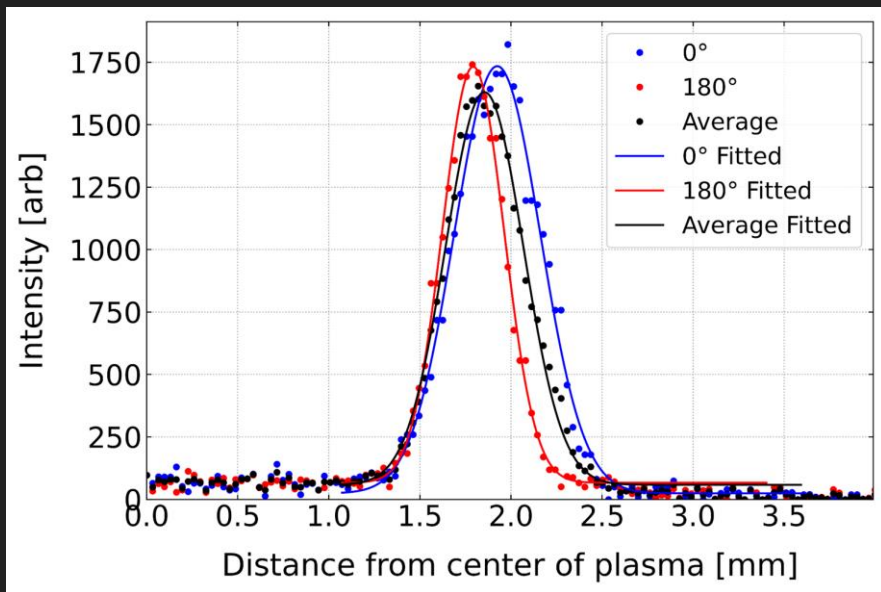


Old Fitting

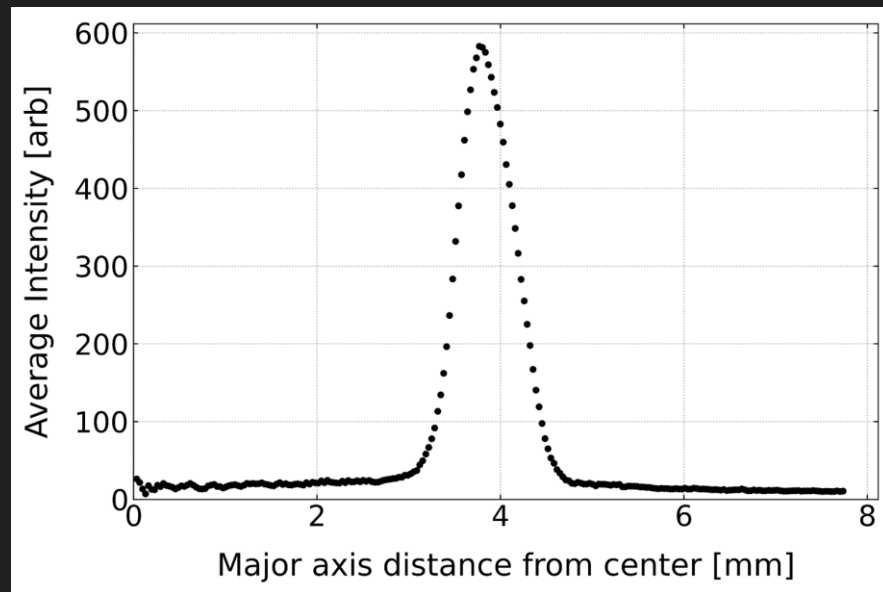


New Elliptical Fitting

# Centrifugal Separation of Be<sup>+</sup>/e<sup>+</sup> Analysis

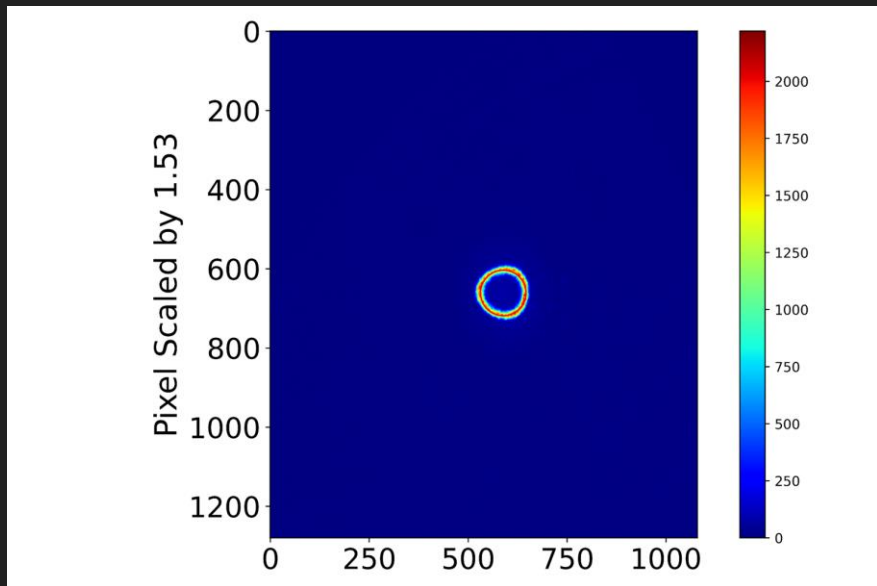


Along Major Axis

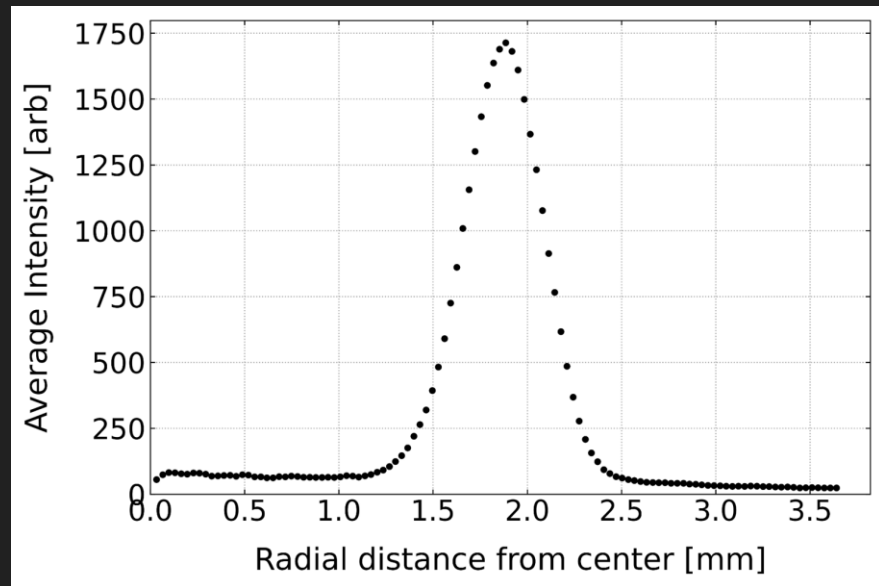


Elliptical Average

# Centrifugal Separation of Be<sup>+</sup>/e<sup>+</sup> Analysis

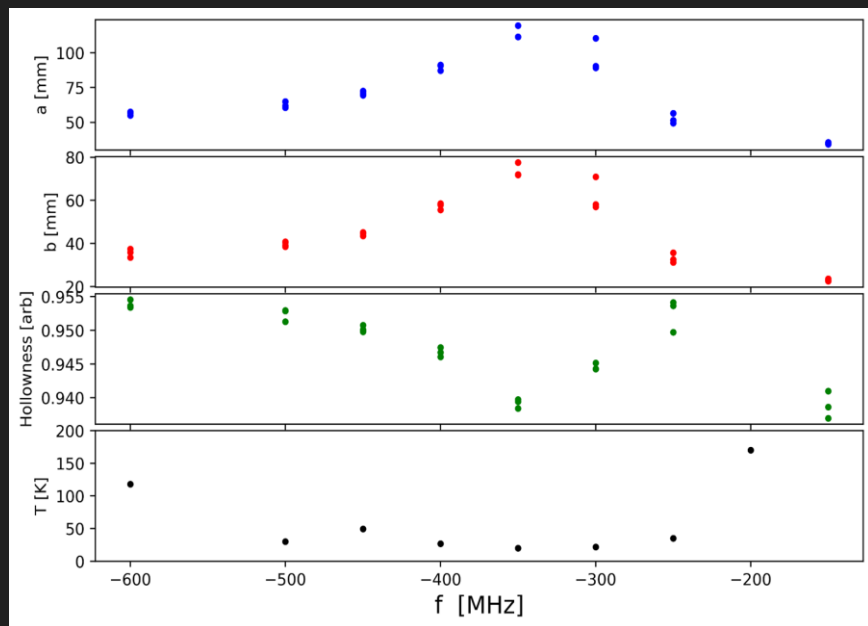


Circular Fitting after Transformation

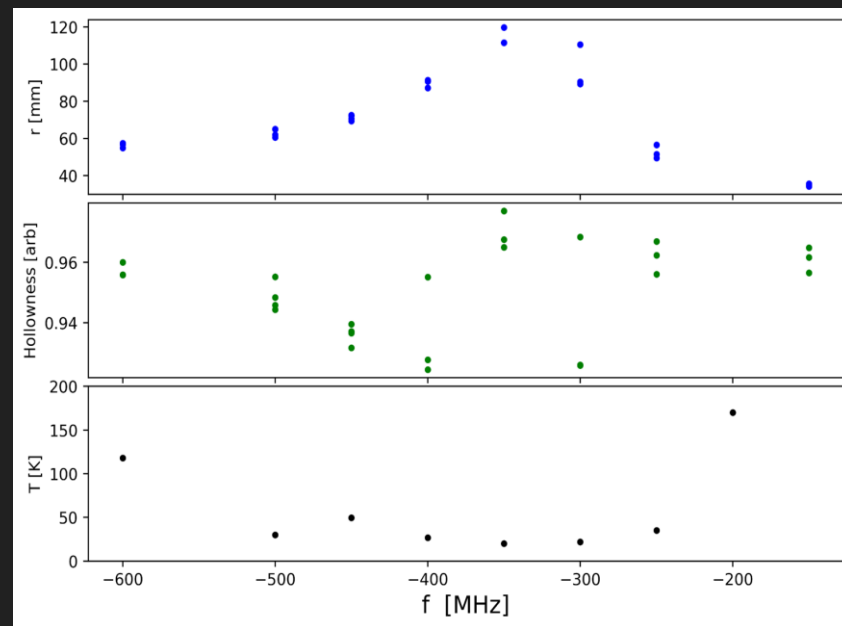


Circular Average

# Centrifugal Separation of Be<sup>+</sup>/e<sup>+</sup> Analysis

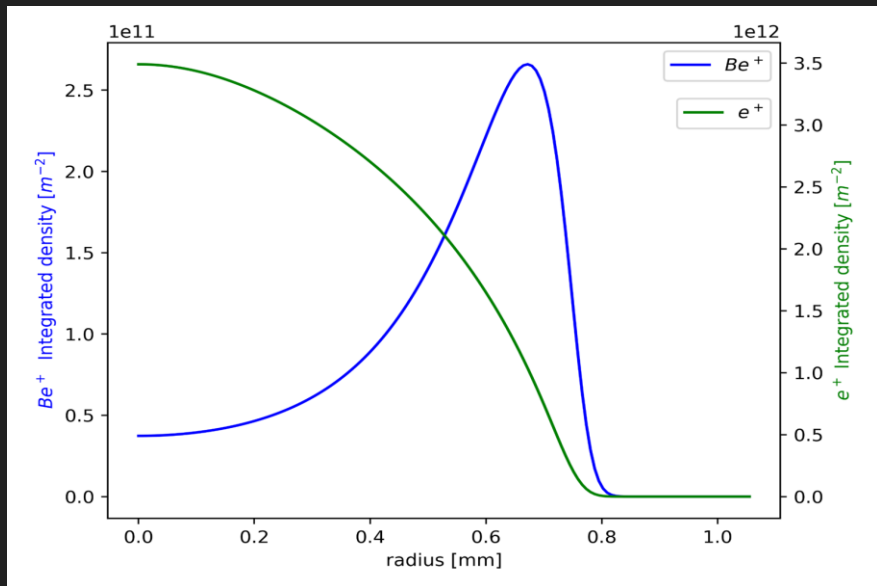


Elliptical Profile

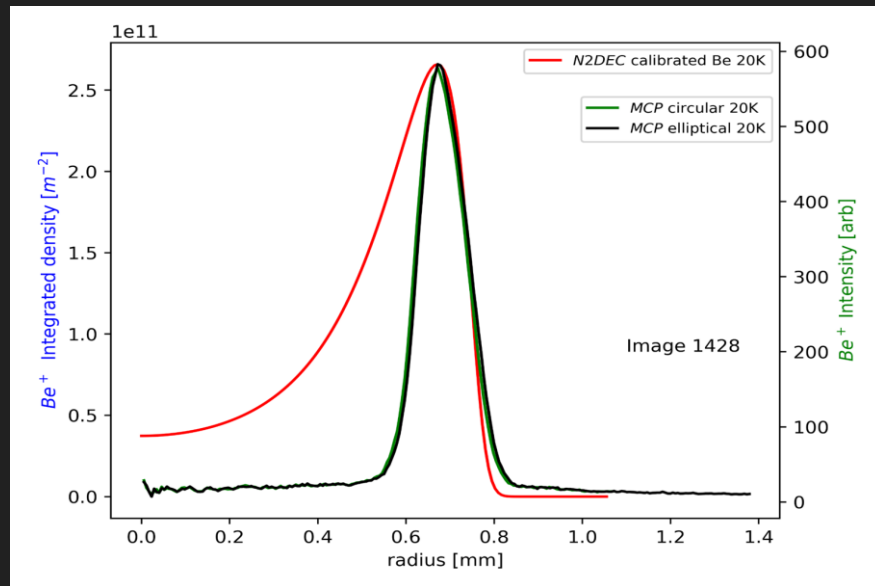


Circular Profile

# Centrifugal Separation of Be<sup>+</sup>/e<sup>+</sup> Simulation



Simulation



Comparison with data



# Mentors



Prof. Niels Madsen



Dr. Kurt Thompson

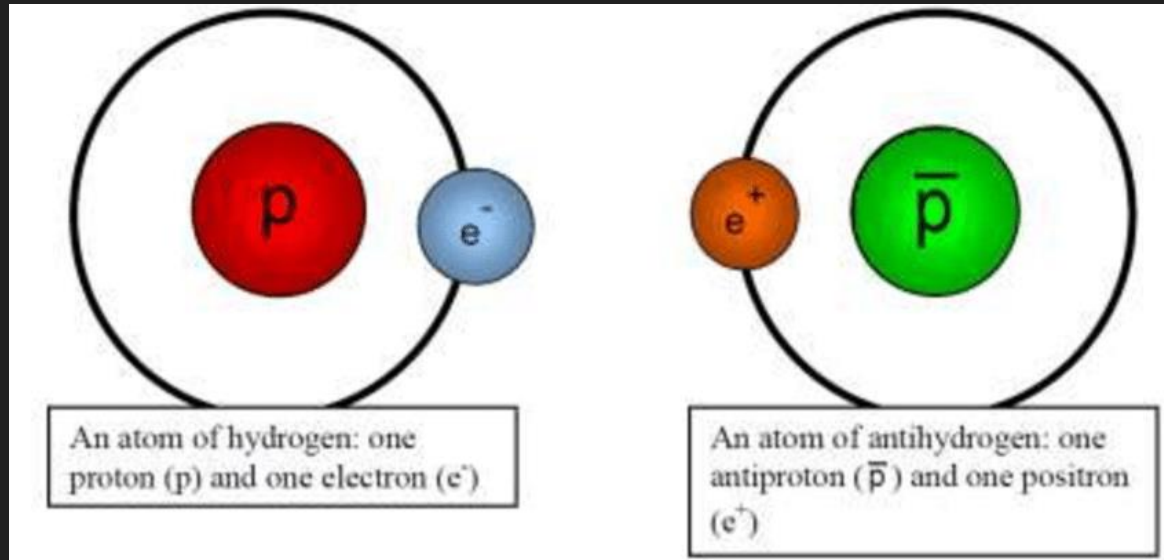


Dr. Janko  
Nauta



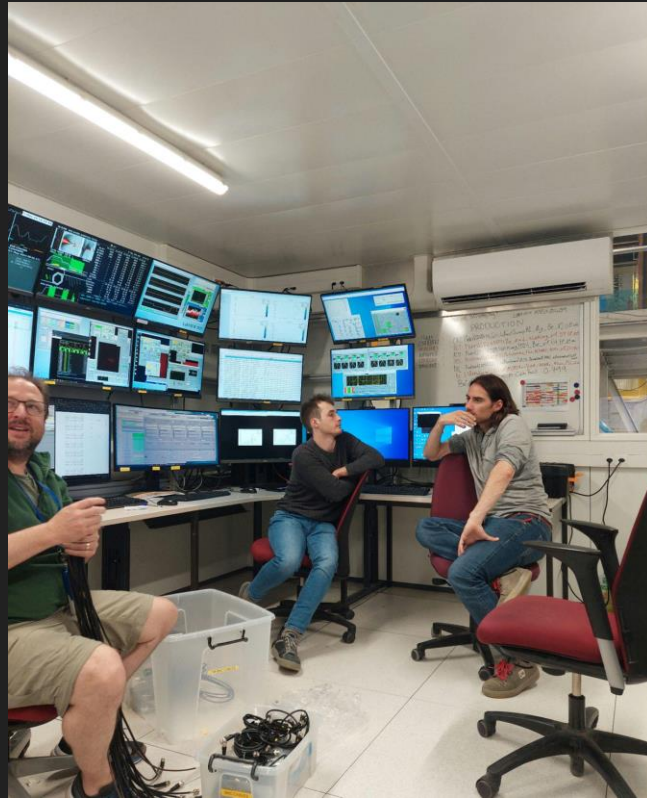
# Purpose

Investigate any asymmetry between matter and antimatter, with antihydrogen



[https://www.researchgate.net/figure/Description-of-hydrogen-and-antihydrogen-atom-2\\_fig1\\_343695668](https://www.researchgate.net/figure/Description-of-hydrogen-and-antihydrogen-atom-2_fig1_343695668)

# Control Room



# Shift Work



- Cryogenic Operation:  
Liquid Helium / Nitrogen Transfer

# Culture

