
# AEgIS status report 2022

**148th meeting of the SPSC**
February 7th, 2023

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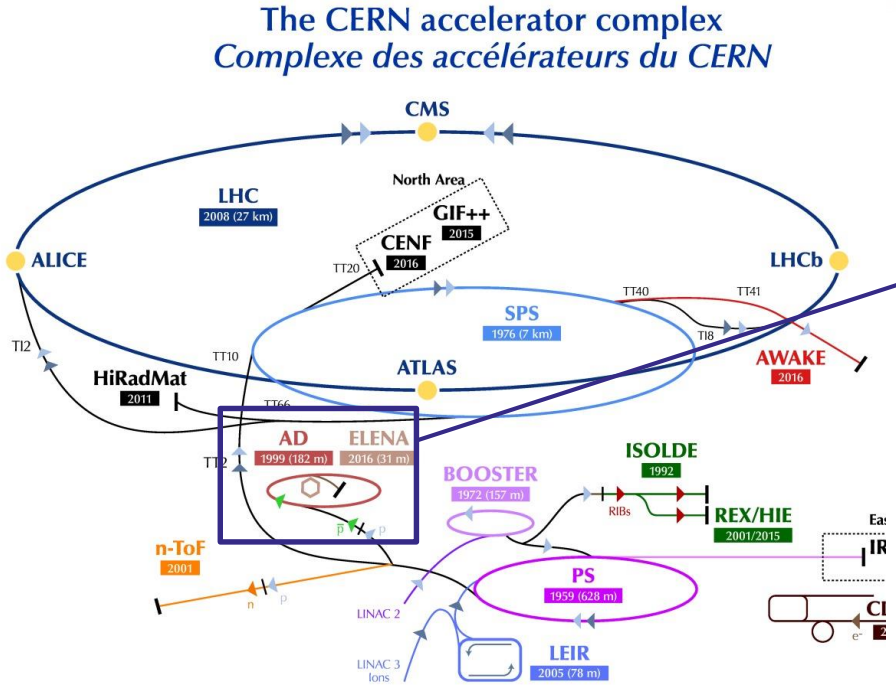
on behalf of the **AEgIS Collaboration**

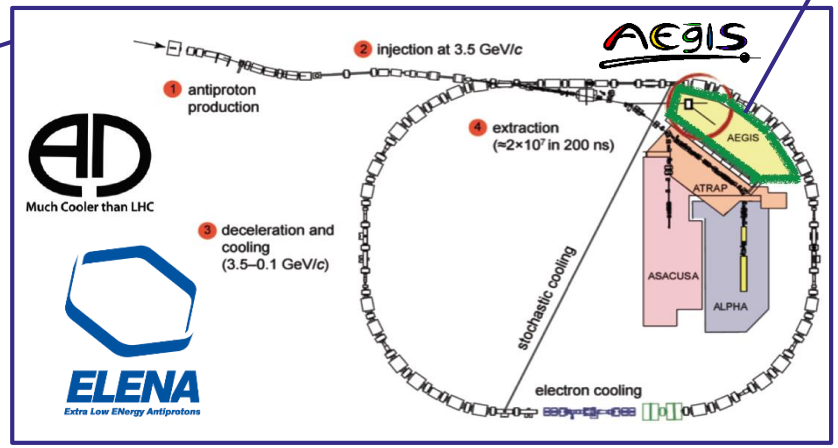
# The AEgIS collaboration

The Antimatter Experiment: Gravity, Interferometry, Spectroscopy (**AEgIS**) collaboration aims at performing direct experimental tests of the Weak Equivalence Principle (**WEP**) using **anti-atoms**.

The chosen method is the **direct detection of the free-fall trajectory** of antihydrogen atoms, produced in a **pulsed** way



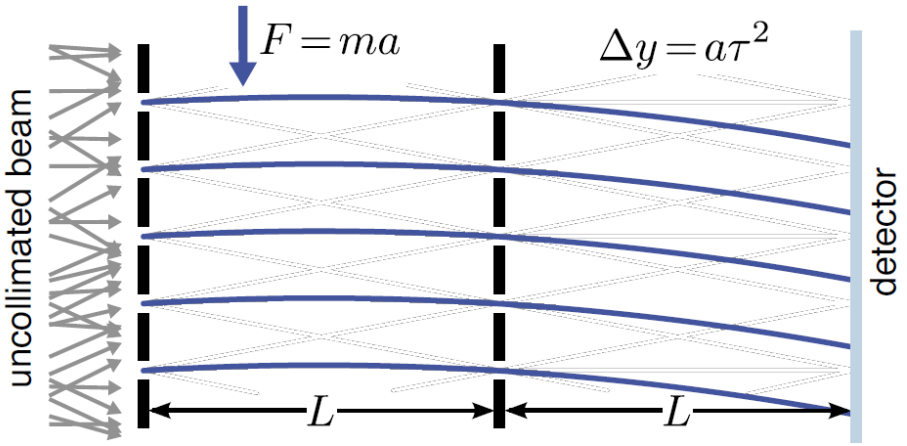


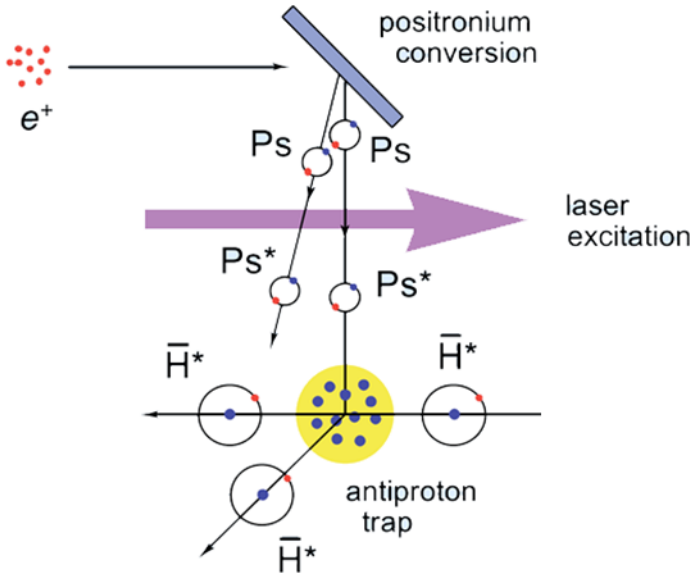


# Conceptual experimental scheme

## Inertial sensing with a deflectometer

1) A set of two gratings selects the trajectories
2) A position- and timing-sensitive detector
3) Anti-atoms from an incoherent, uncollimated source



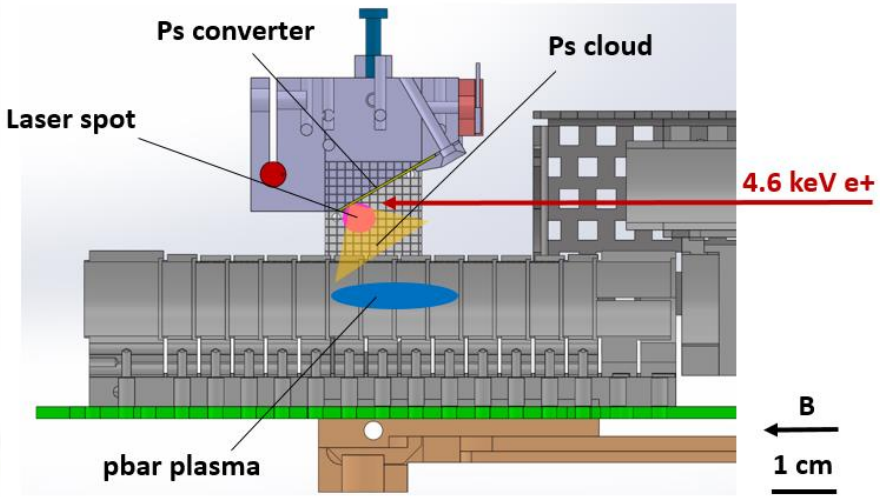

## Pulsed antihydrogen source

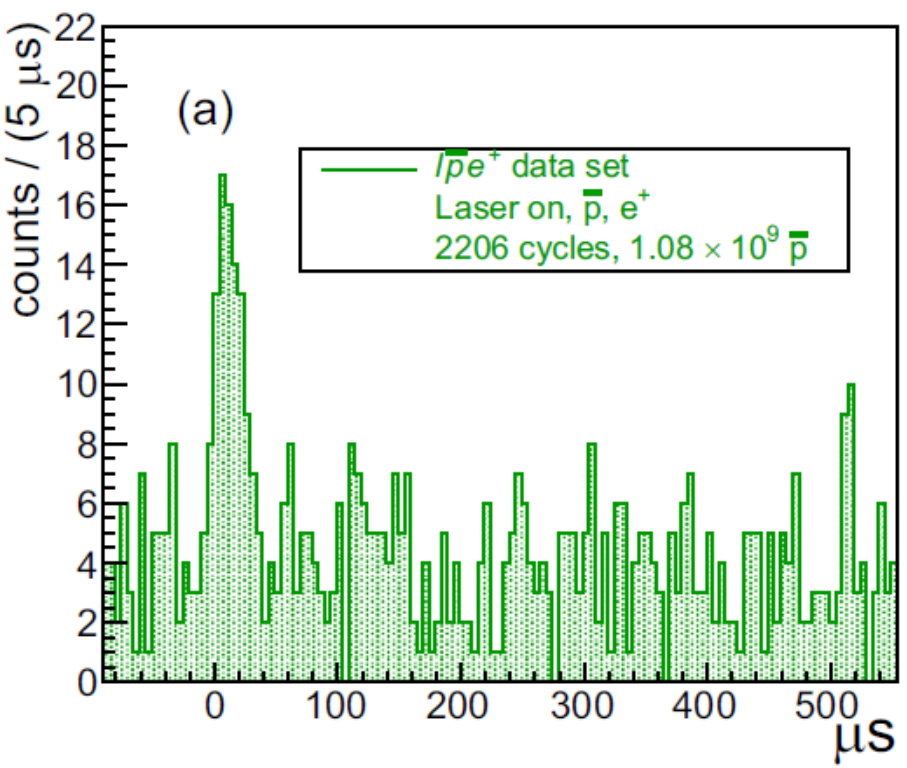
1) Cold antiproton ($\bar{p}$) plasma in a Malmberg-Penning trap
2) Pulsed positronium (Ps) from positron ($e^+$) conversion
3) Two-step laser excitation of Ps to Rydberg levels (Ps*)
4) Rydberg antihydrogen ($\bar{H}^*$) via charge-exchange, $\sigma \propto n_{Ps}^4$
5) Beam formation

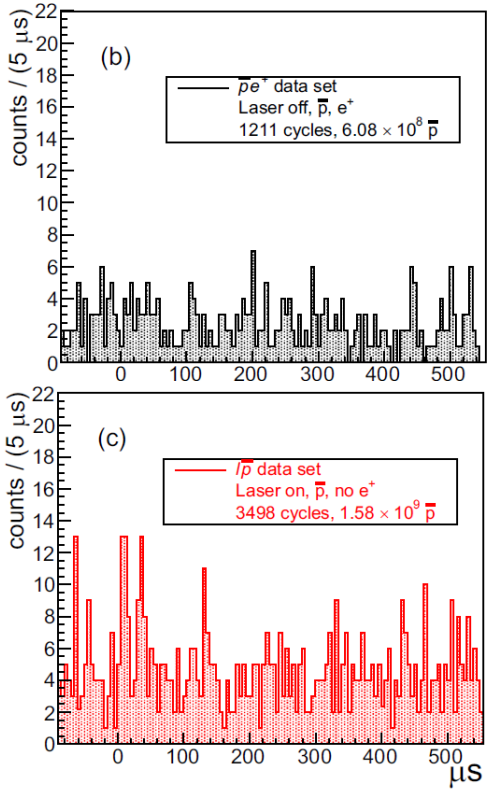
# A first pulsed source of Rydberg antihydrogen

https://doi.org/10.1038/s42005-020-00494-z OPEN

## Pulsed production of antihydrogen

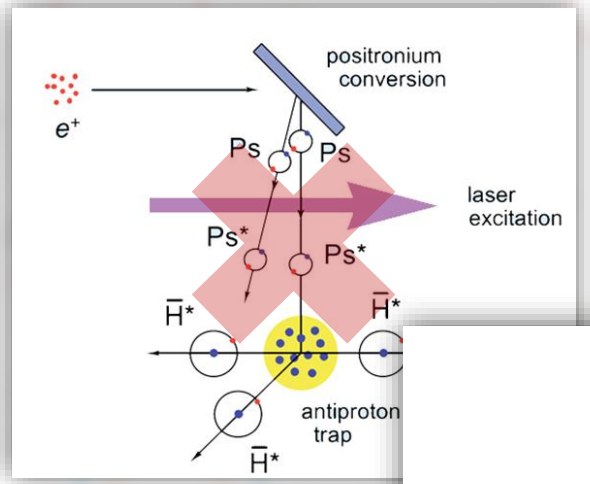


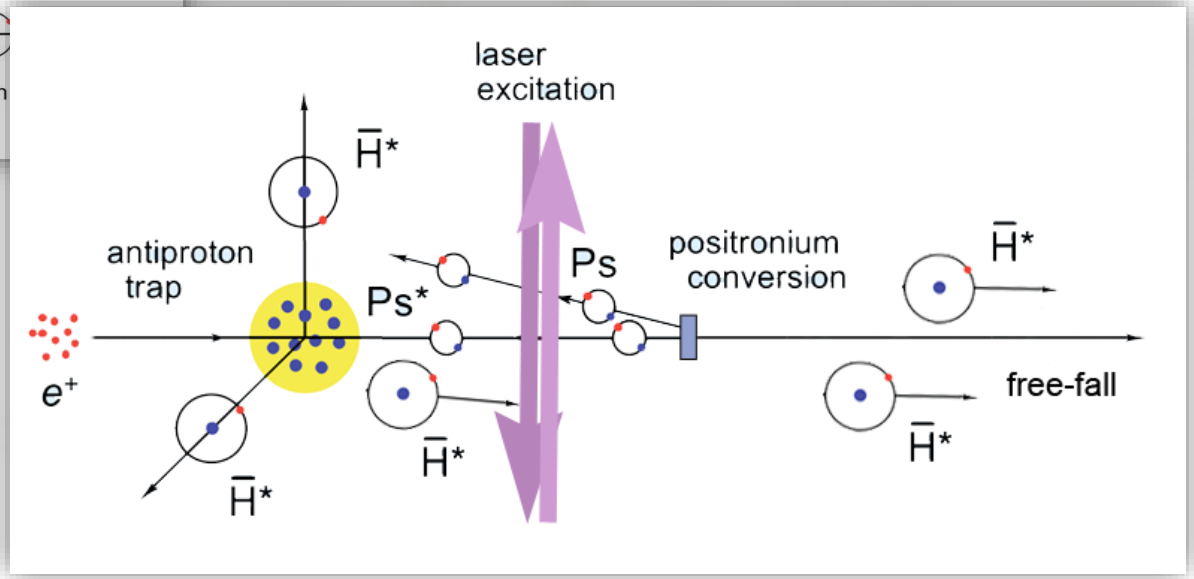

**Key finding:** 0.05 $\bar{H}^*$ produced every 2 mins (with $1.0 \cdot 10^6$ antiprotons)

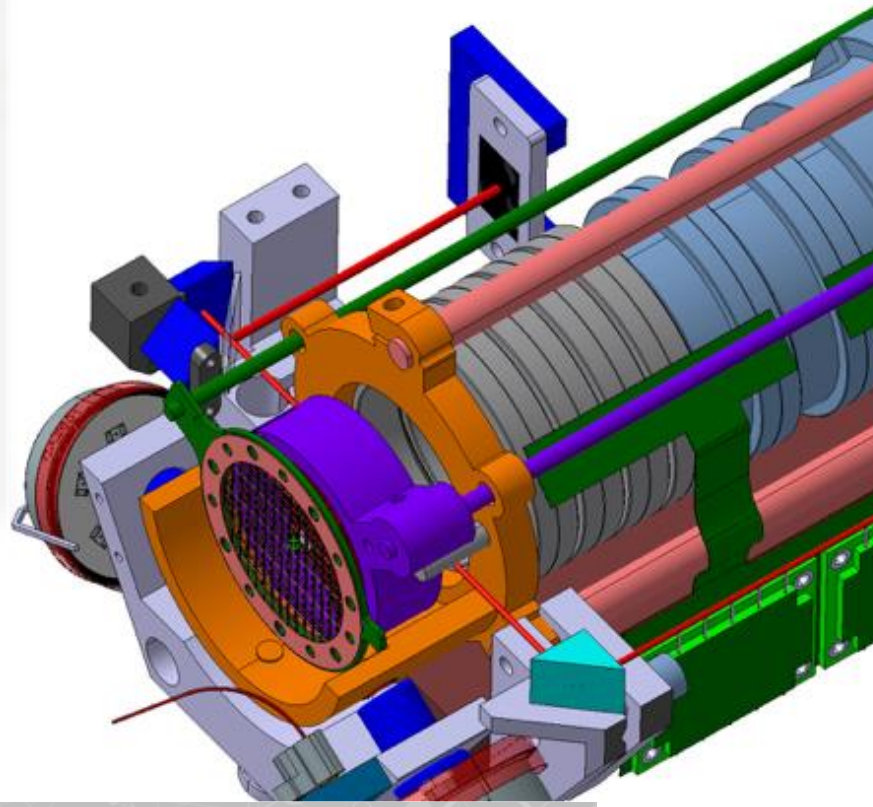
# Collinear antihydrogen production




## Redesigned antihydrogen production region

- Positronium conversion target on-axis: cross-section enhancement
- Antiprotons can be brought much closer to the Ps source
- Laser excitation in a Doppler-free scheme



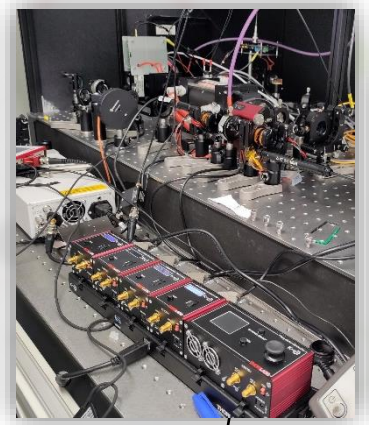



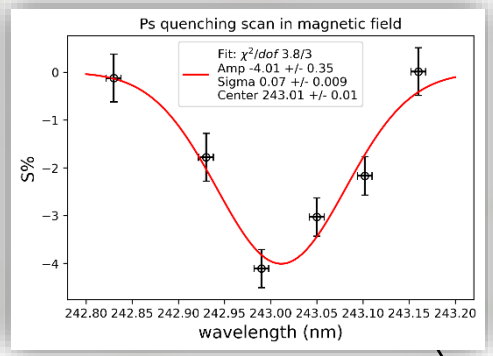
## Expected improvements to the antihydrogen flux

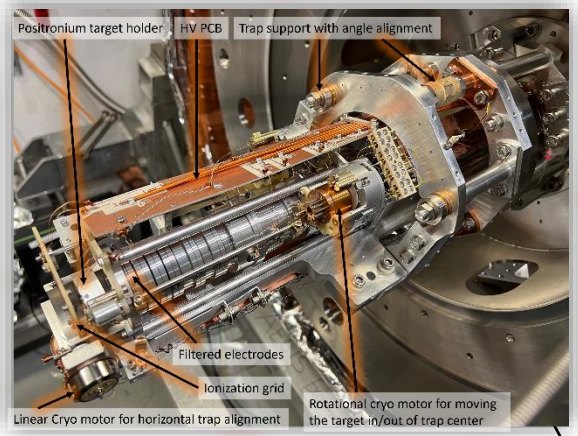
x20 from the ELENA antiproton flux

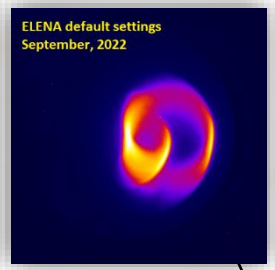
x10 from Ps/collinear scheme

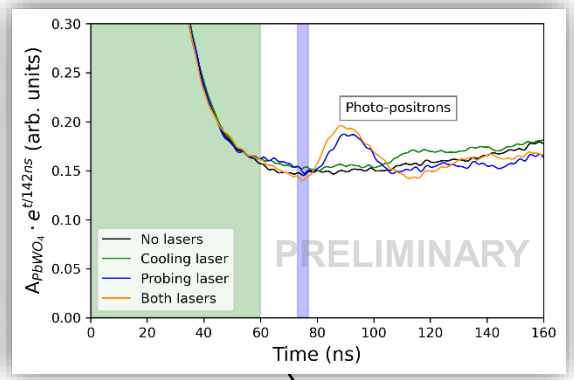
# Activity timeline of AEgIS in 2022





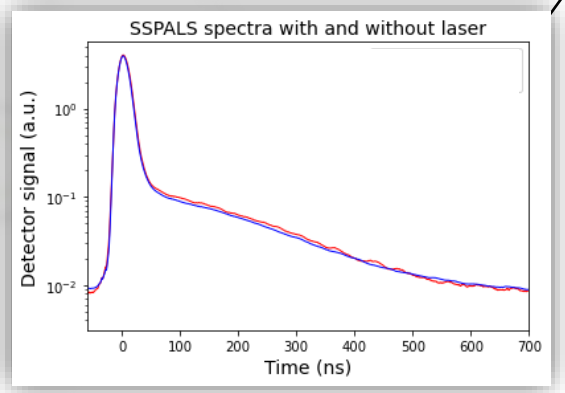

**Antihydrogen production trap upgrade**

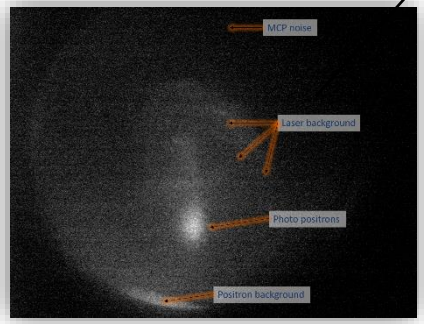
**Cooldown**

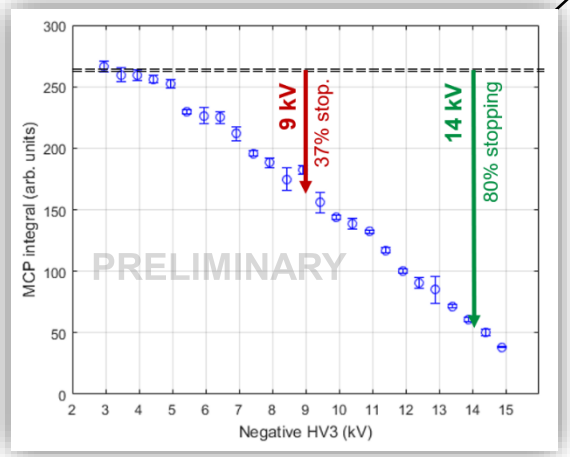
**Antiproton physics**

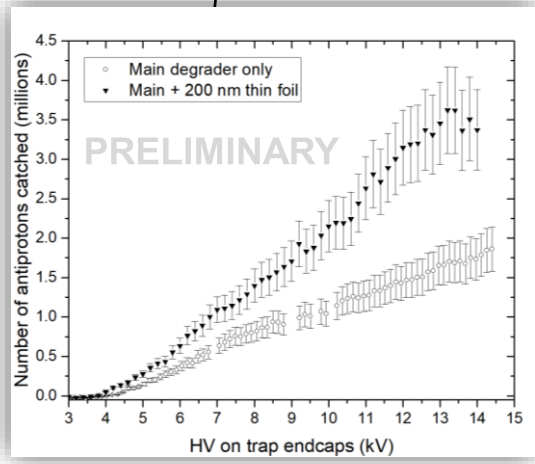
Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec

**Ps physics**



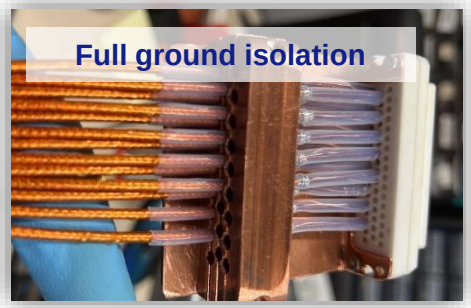



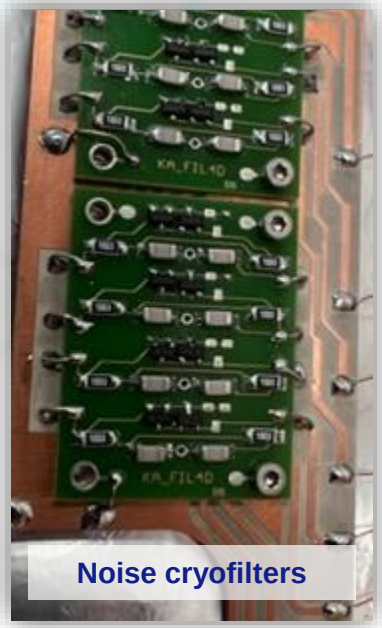



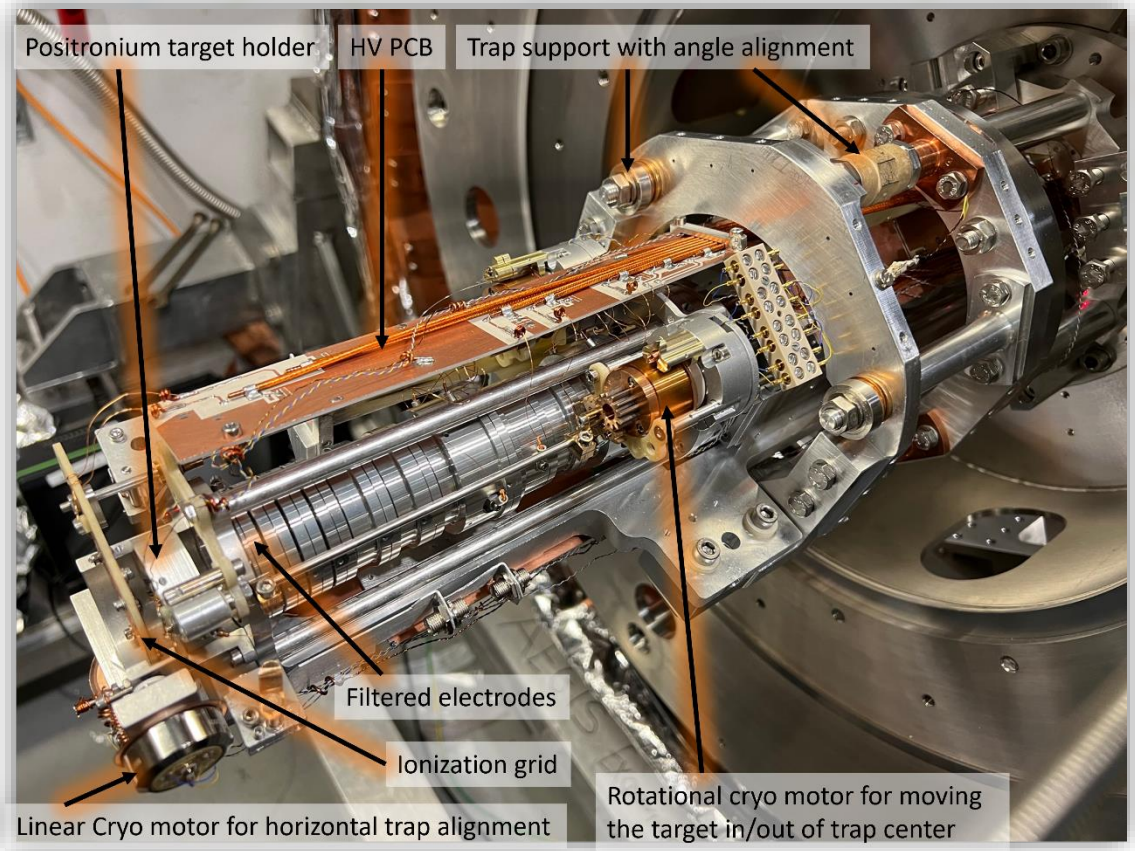
# Construction, installation and test of the new antihydrogen production trap

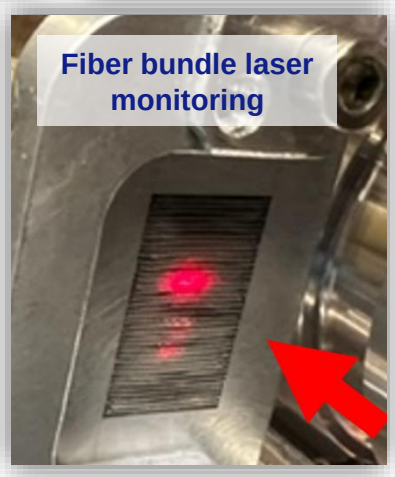


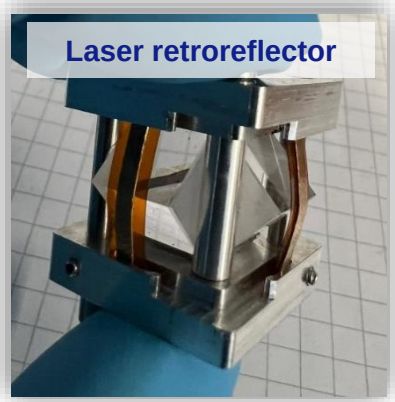




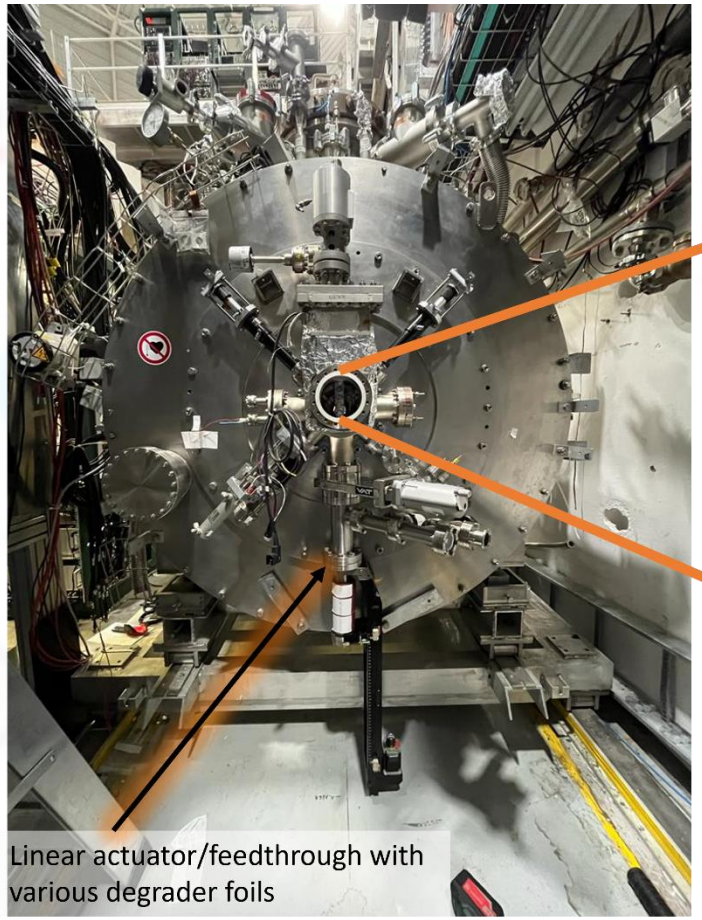



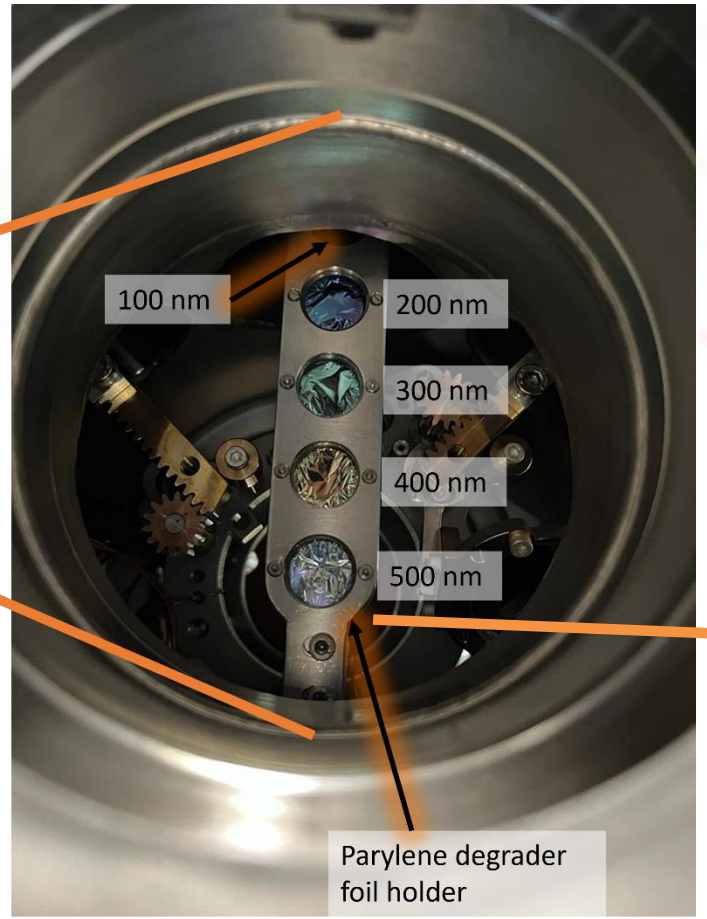



# Upgraded degrading structure

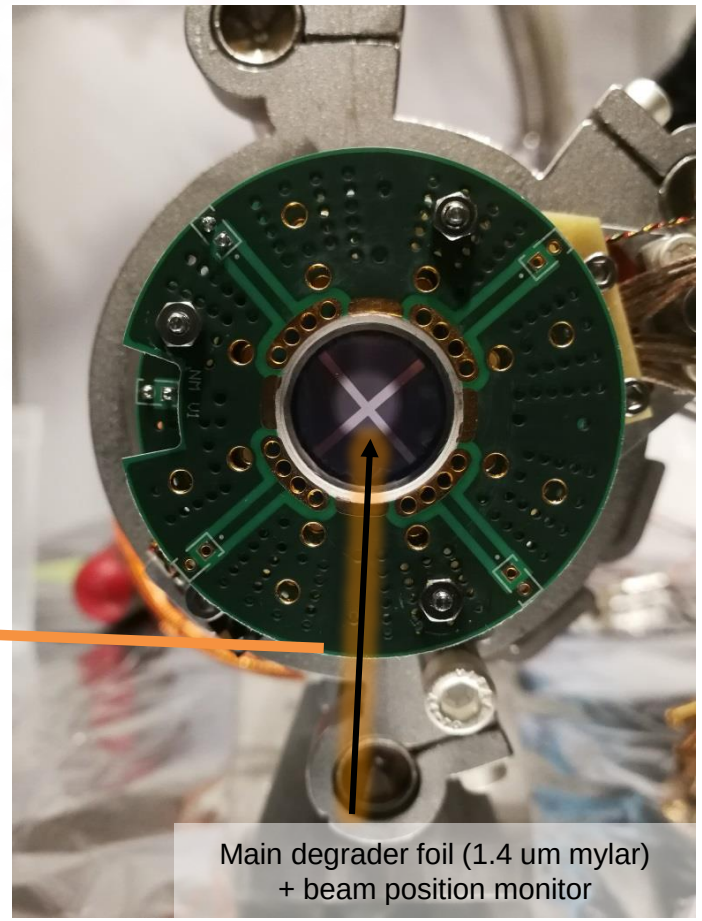
## Separate vacuum chamber




## Tunable foils actuator

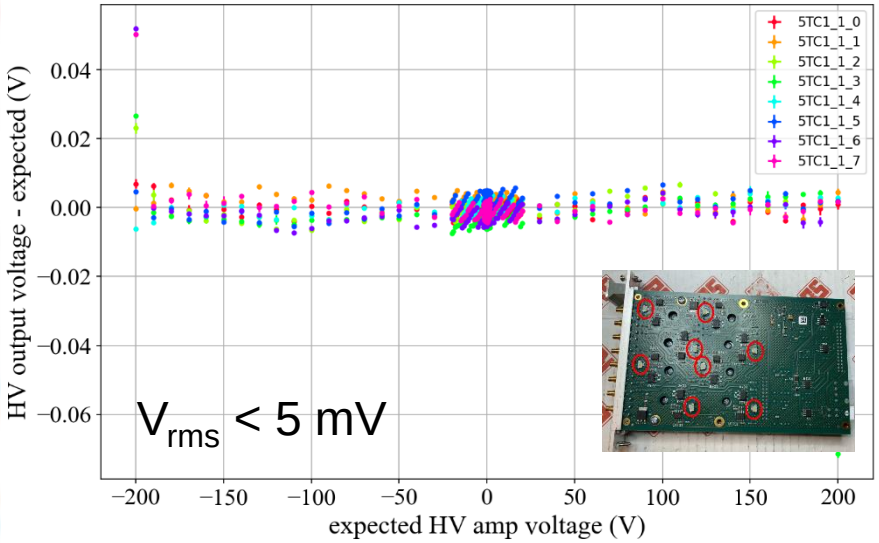



## Mylar foil degrader

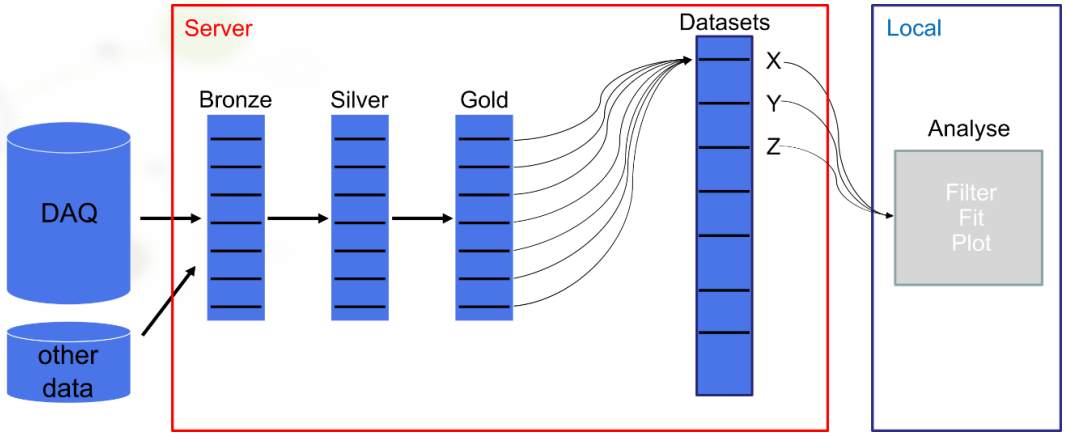


# Improvements to the control system

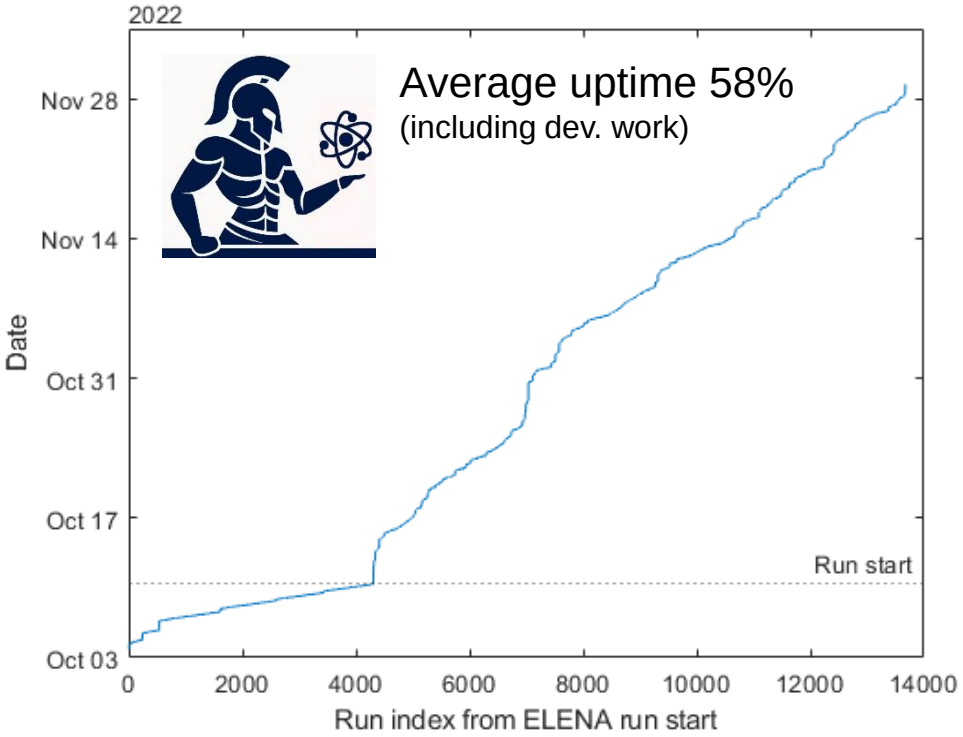
## SINARA amplifiers reached design noise level



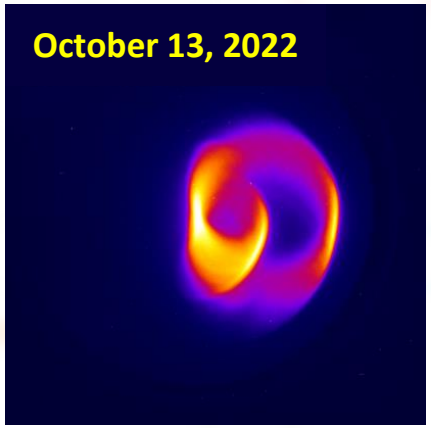

## Developing of an automated analysis pipeline




## Full deployment of the TALOS control system

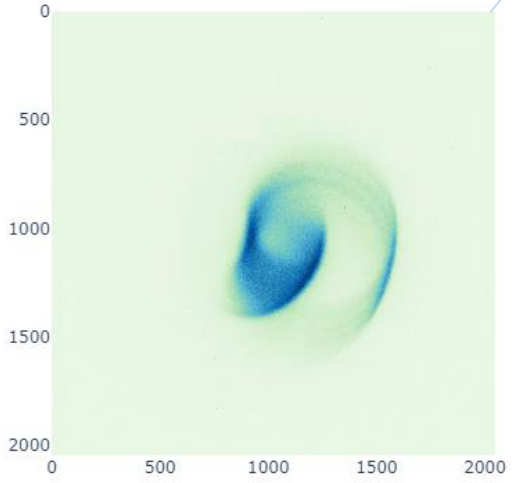


# Reworking to optimize ELENA steering settings

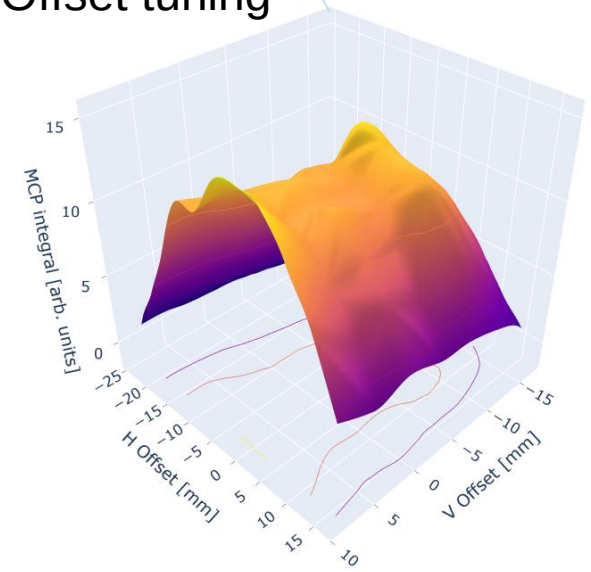



**ELENA beam optimization**

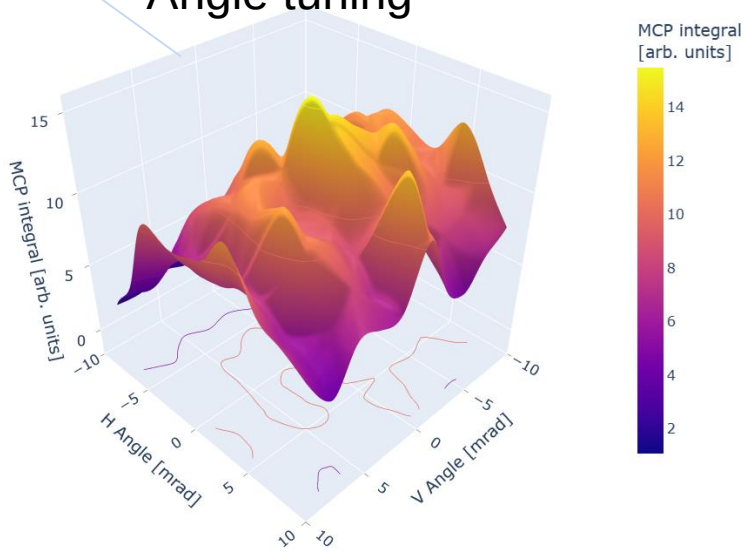

## Coarse 4D scan



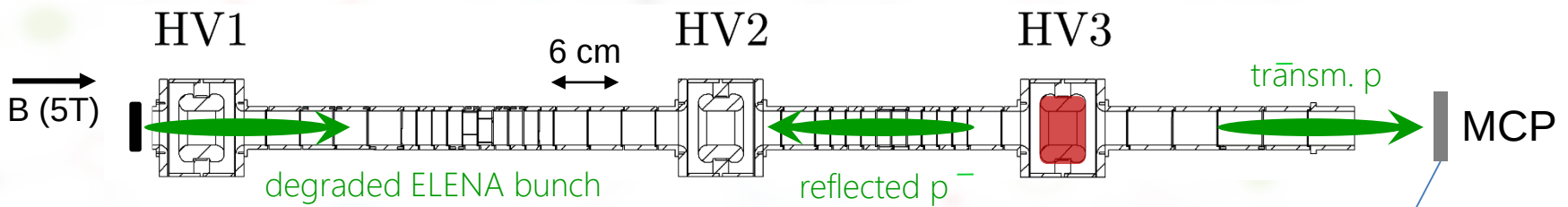

## Offset tuning

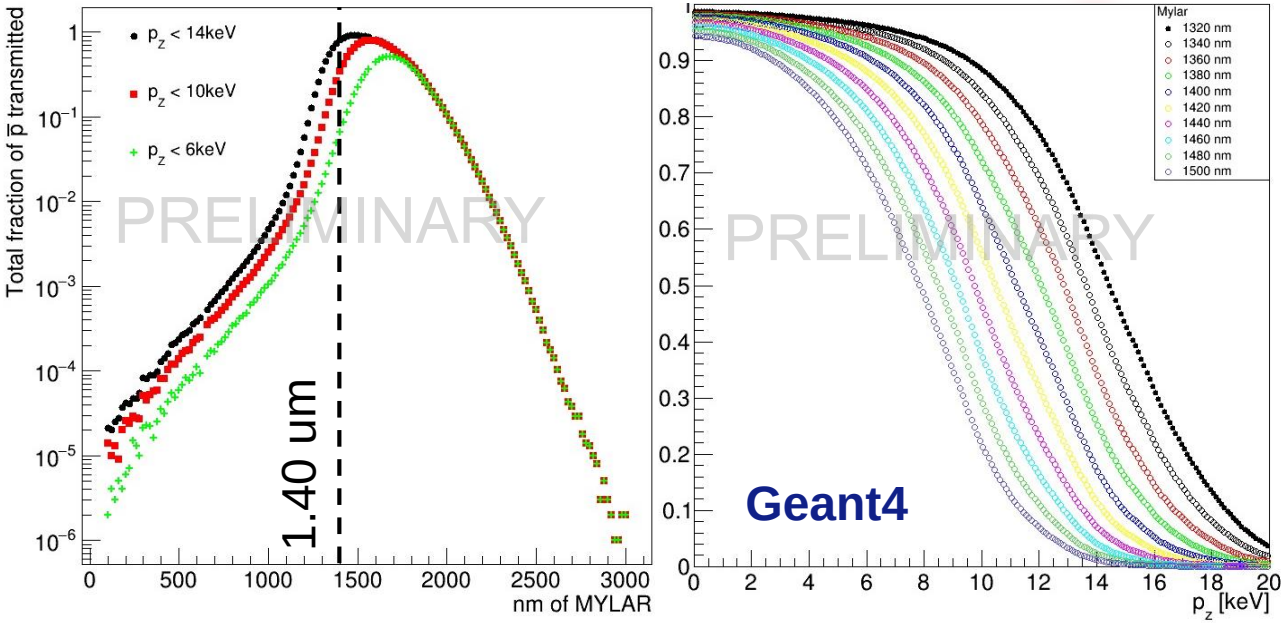


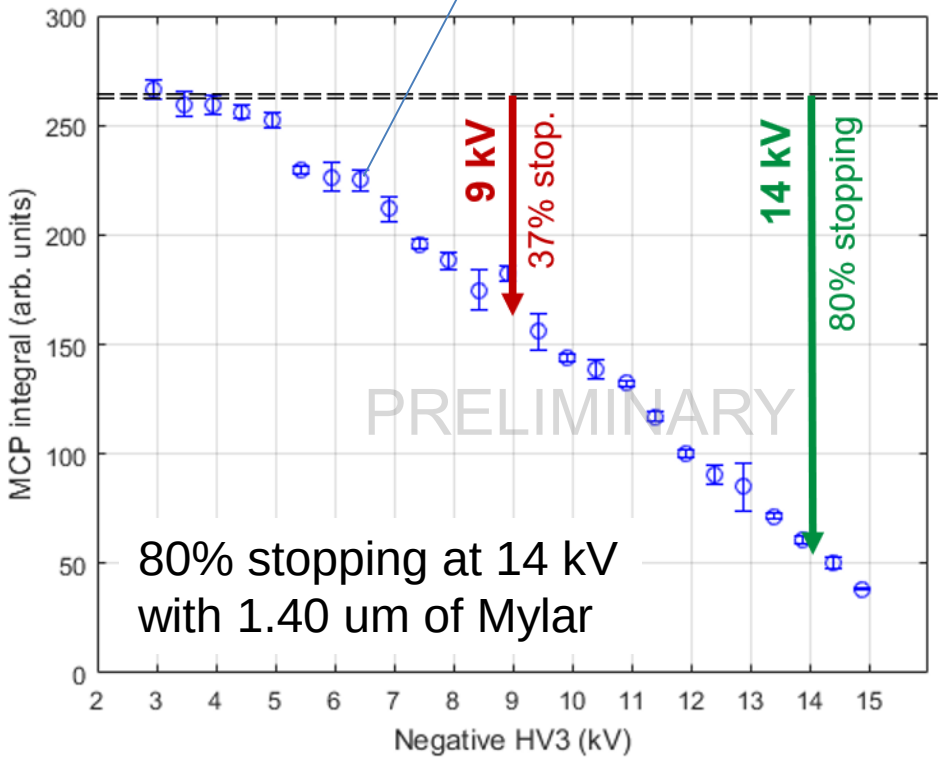

## Angle tuning



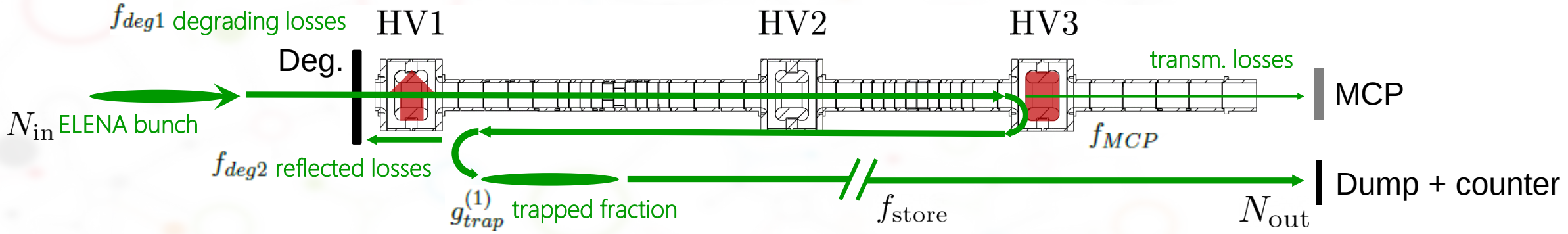
# Degrading efficiency of the main degrader



# Efficient antiproton trapping from ELENA

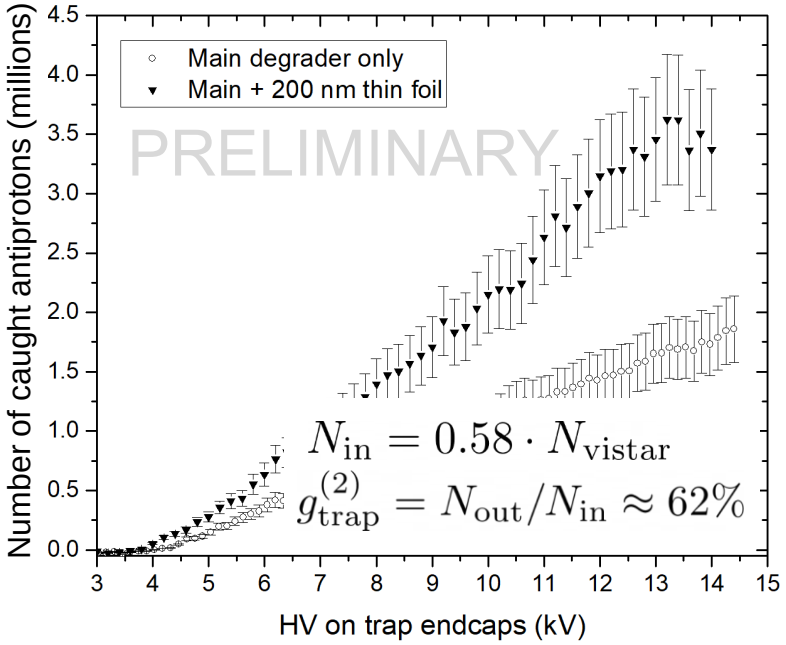



## Validation 1) measuring losses

$$1 = f_{deg1} + g_{mod}$$
$$g_{mod} = f_{MCP} + g_{refl}$$
$$g_{refl} = f_{deg2} + g_{trap} \quad ,$$

$$f_{deg1} \approx 0.5 \div 1.5\,\%$$
$$f_{MCP} \approx 16 \div 21\,\%$$
$$f_{deg2} \approx 4 \div 6\,\%$$
$$f_{\mathrm{store}} \approx 10\%$$
$$g^{(1)}_{trap} \approx 71 \div 79\,\%$$

## Validation 2) absolute pbar counting




In 2022, AEgIS has **achieved efficient antiproton trapping from ELENA**, routinely trapping 3.7 million pbars per bunch

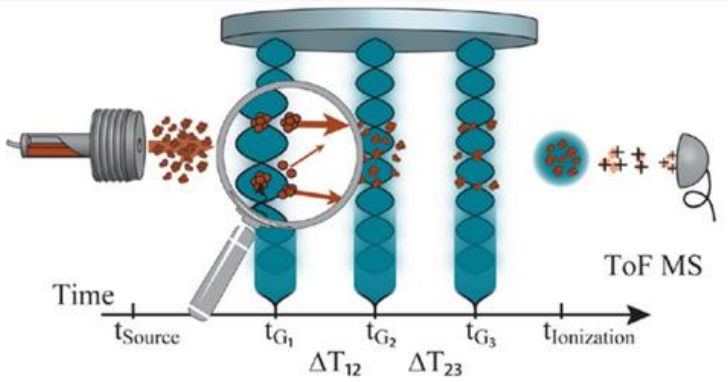
**Improving the antihydrogen flux**

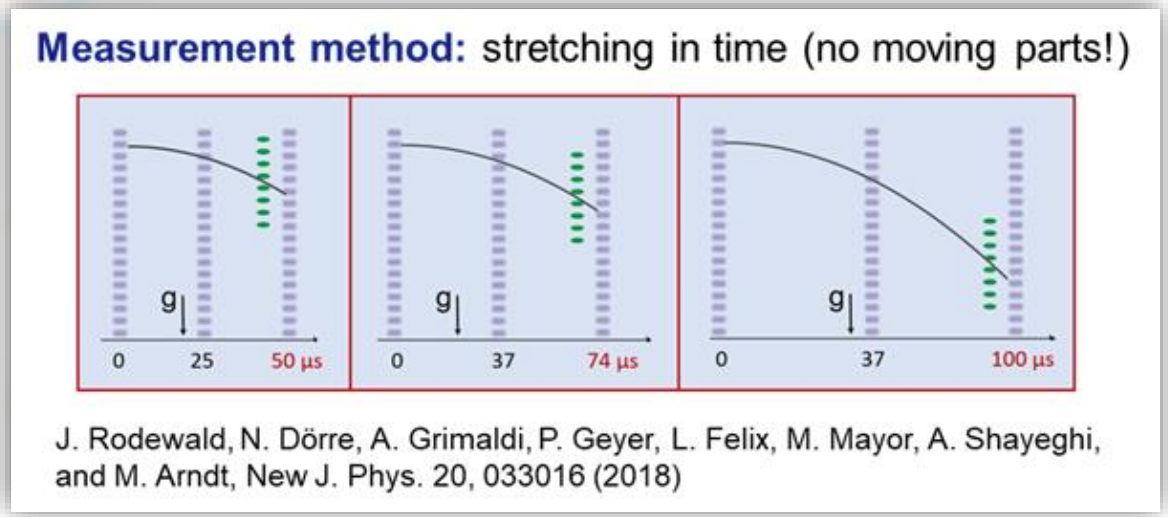
- x20 from ELENA
- x10 Hbar from Ps/collinear scheme

Main goal for 2023

## Potential advantages of Optical Time-domain Matter-wave (OTIMA) Interferometry

- Nanometric periodicity $\lambda/2 \approx 500\,nm$
- Alignment in y by construction (optical flat)
- No strict alignment in z, only laser pulses synchronization
- Only timing/counting detector



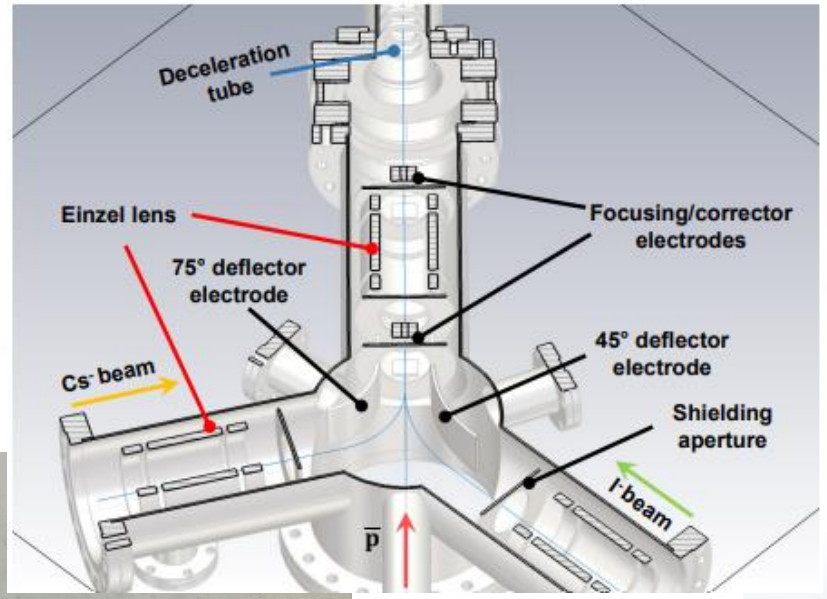

In contact with the Arndt group

High contrast is possible with commercial Nd:YAG systems

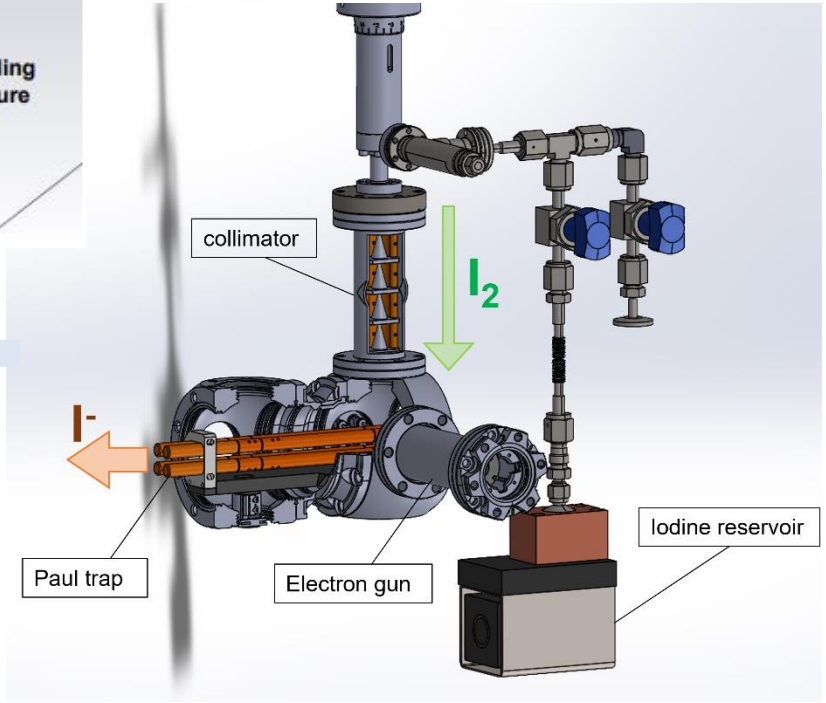
# R&D – setup of an ion injection beamline

**Goal of the R&D**: establish the techniques to form antiprotonic bound states.

On track for 2023

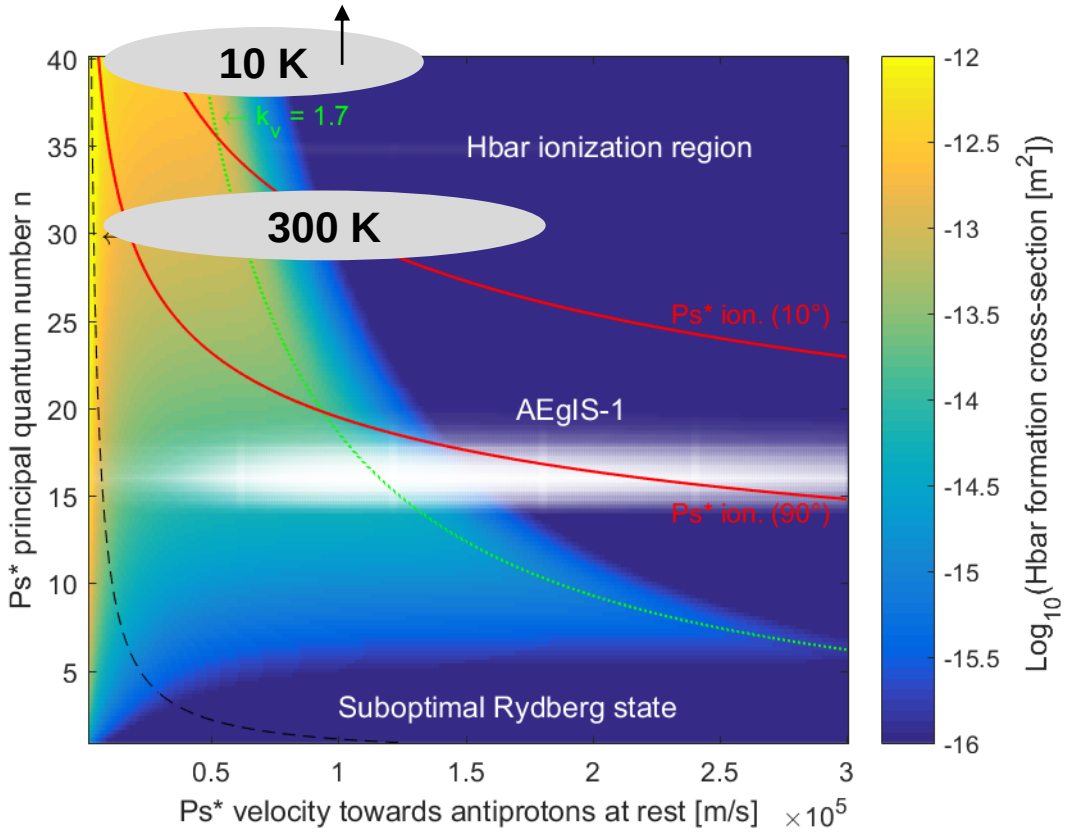



Our Polish collaborators won a grant to finance this R&D activity from the Polish Ministry of Education of about ~700 k€.



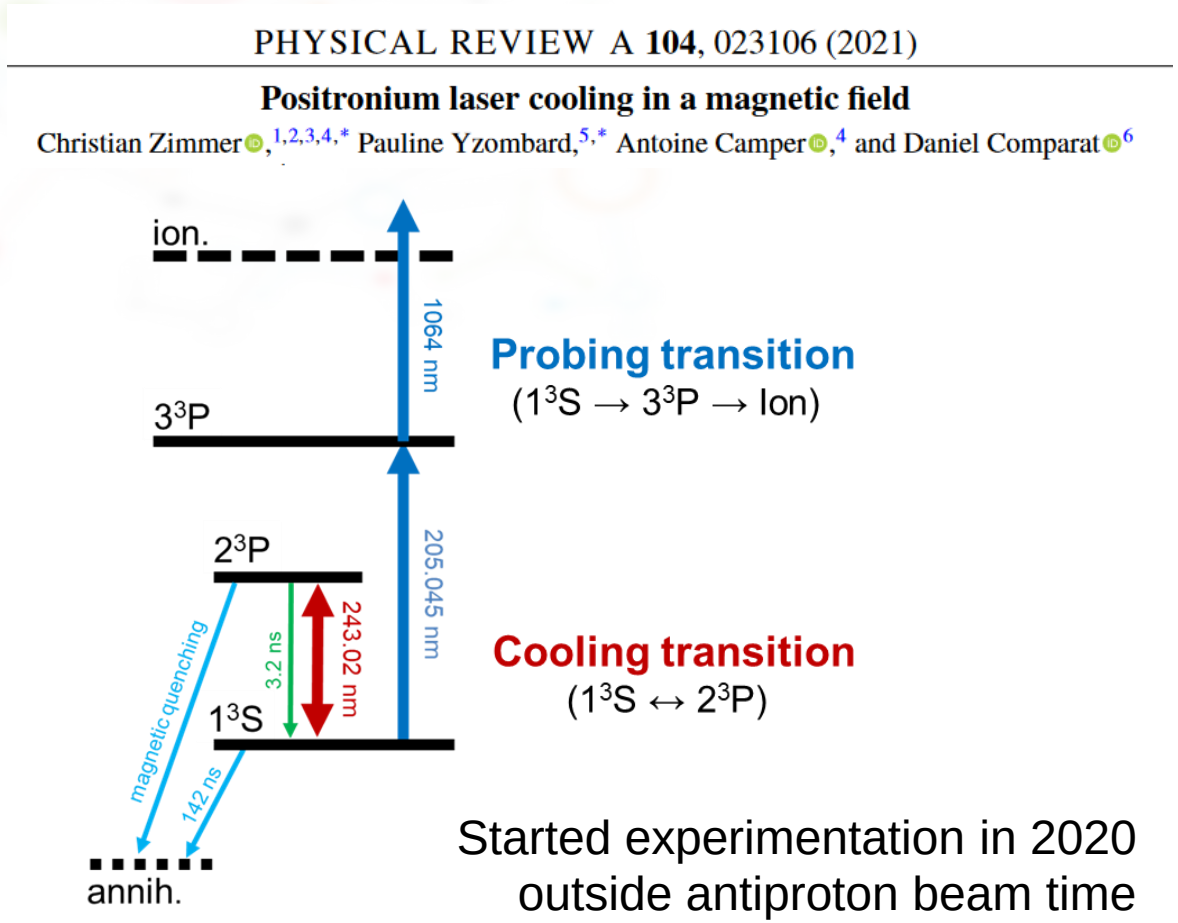
# R&D – Laser cooling of Ps

The interaction cross-section between pbar and Ps* can be enhanced by targeting higher Rydberg levels, only by first **lowering the temperature/improving the collimation** of the Ps beam.




collinear + 300 K → cross-section ×10

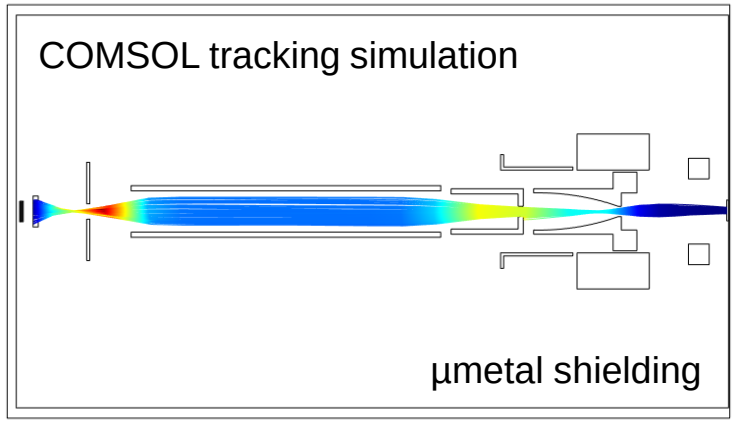
collinear + 100 K + Ps cooling to 10 K → cross-section ×70



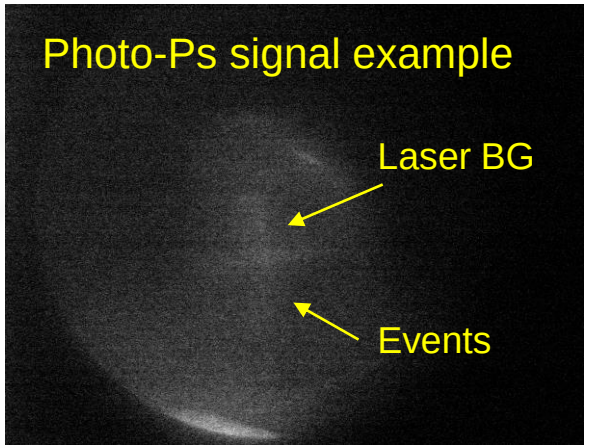

Started experimentation in 2020 outside antiproton beam time

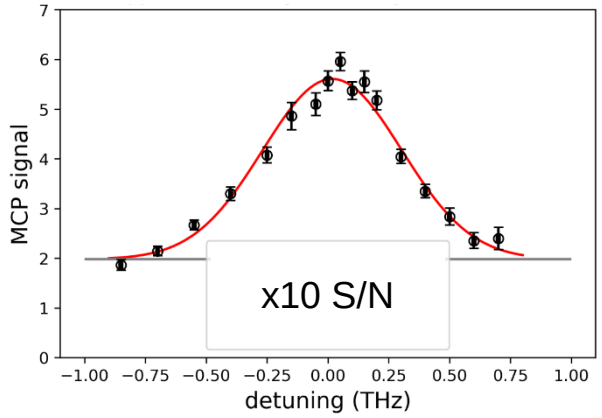
# Three non-trivial upgrades of the laser cooling setup in 2022

## 1. Fully field-free Ps beamline

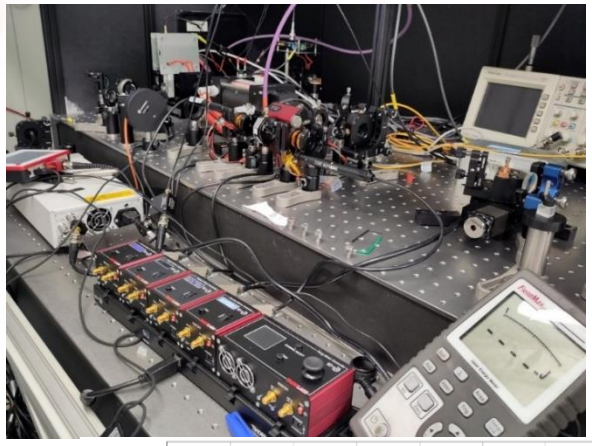


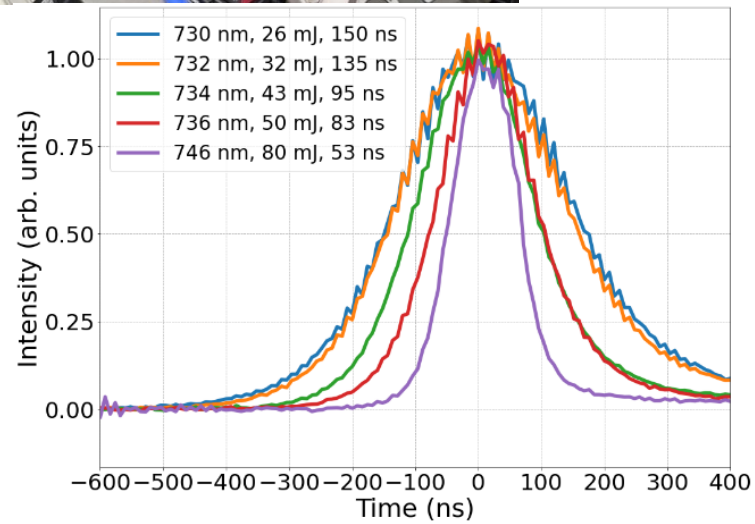

## 2. Faster diagnostics based on a MCP in B=0




## 3. New 100ns 243nm cooling laser





# Deploy of the pump-and-probe measurement technique

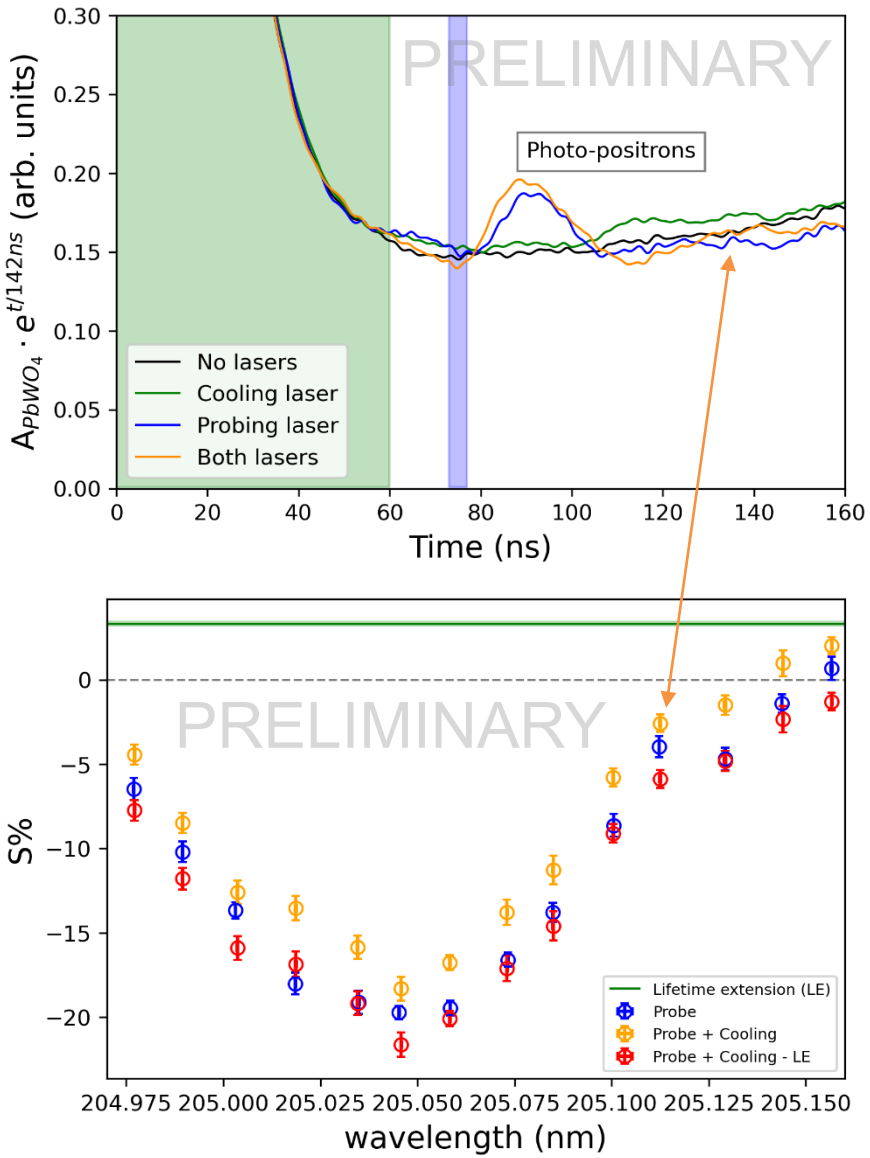
## Synchronization challenges solved

- Three devices to be synchronized with ns accuracy
  - Nd:YAG pulsing at 10 Hz
  - Alexandrite pulsing at 4 Hz
  - Positron system pulsing at 0.01 Hz
  - ... plus all detector ns triggers
- The ARTIQ/Sinara electronics was crucial

## First Doppler broadening studies

- A lot of consolidation was required: temperature/energy stabilization, humidity ...
- Successful first experiments employing the two laser scanning at the same time
- The effect of the cooling laser on Ps (Doppler) velocity distribution is under study

One of our young CERN-based Liverpool colleagues is part of a 1M£ grant awarded to Liverpool by EPSRC in 2023, PI: CP Welsch.




End of slides