Institute for Particle Physics
and Astrophysics

Increased Antihydrogen Production in GBAR towards a first Lamb-Shift Measurement in Antihydrogen

Laurin Koller
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Contents

1. Setup of the GBAR Experiment

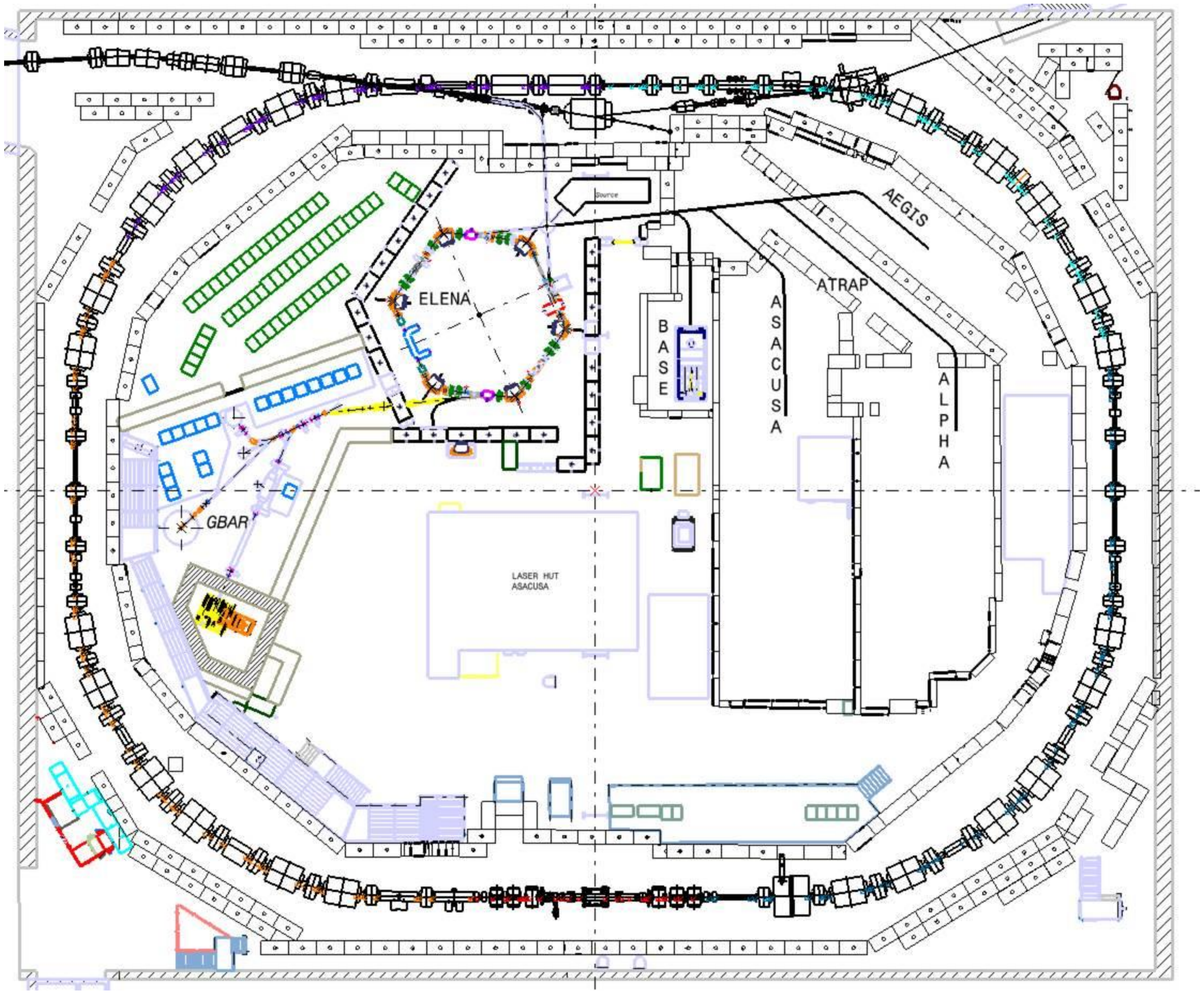


Image from [Oelert, 2015]

GBAR – Gravitational Behavior of Antimatter at Rest

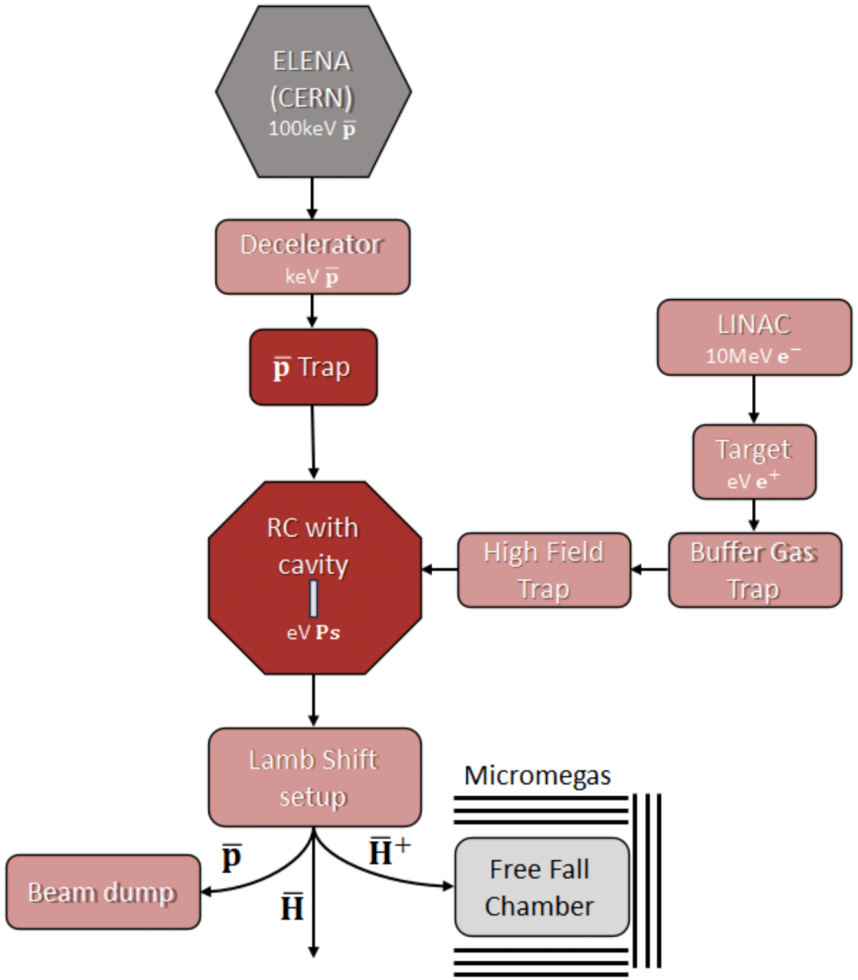
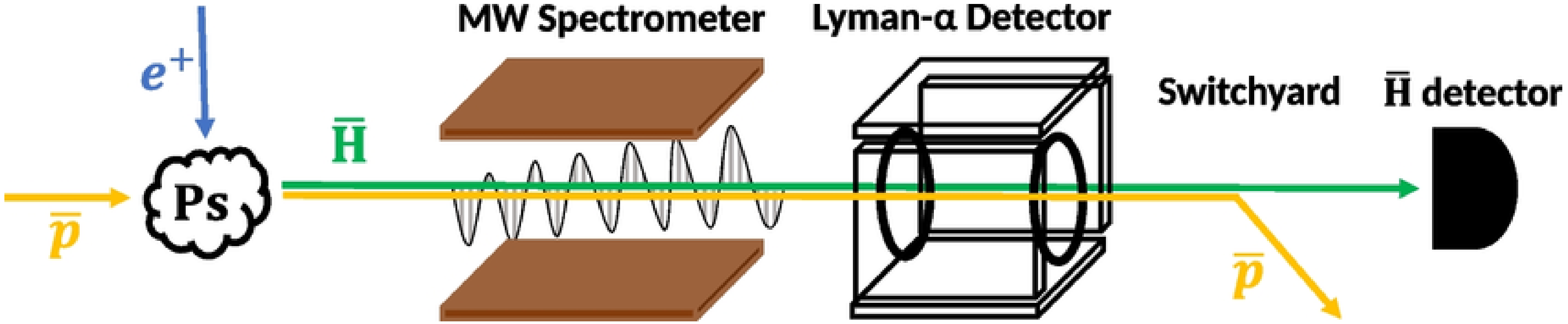


Image from [Blumer, 2024]

- $100\ \mathrm{keV}\ \bar{\mathrm{p}}$ beam from ELENA
- Cooling in drift tube
- $\bar{\mathrm{p}}$ Trap to reduce beam emittance and compress beam radially
  - Beam leaves trap with $6\ \mathrm{keV}$
- Beam enters cavity in reaction chamber with positronium
  - $\bar{\mathrm{p}} + \mathrm{Ps} \rightarrow \bar{\mathrm{H}} + \mathrm{e}^-$
  - $\bar{\mathrm{H}} + \mathrm{Ps} \rightarrow \bar{\mathrm{H}}^+ + \mathrm{e}^-$
- $\bar{\mathrm{H}}$ and $\bar{\mathrm{H}}^+$ pass through Lamb shift setup
- $\bar{\mathrm{H}}^+$ gets separated and enter free fall chamber
  - Cool $\bar{\mathrm{H}}^+$ with laser cooled Be^+ to ~$10\ \mu\mathrm{K}$
  - Strip positron from $\bar{\mathrm{H}}^+$ with laser
  - $\bar{\mathrm{H}}$ falls $30\ \mathrm{cm}$

Lamb Shift Setup



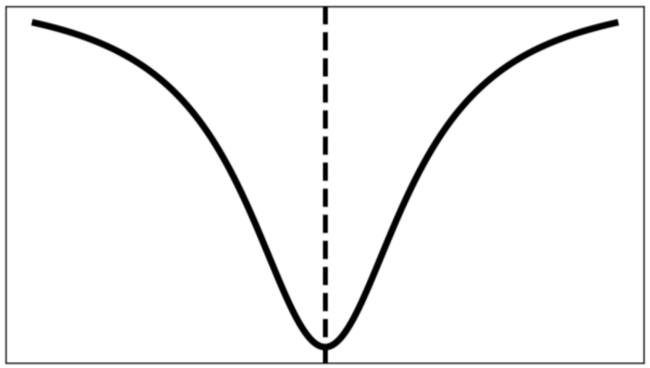


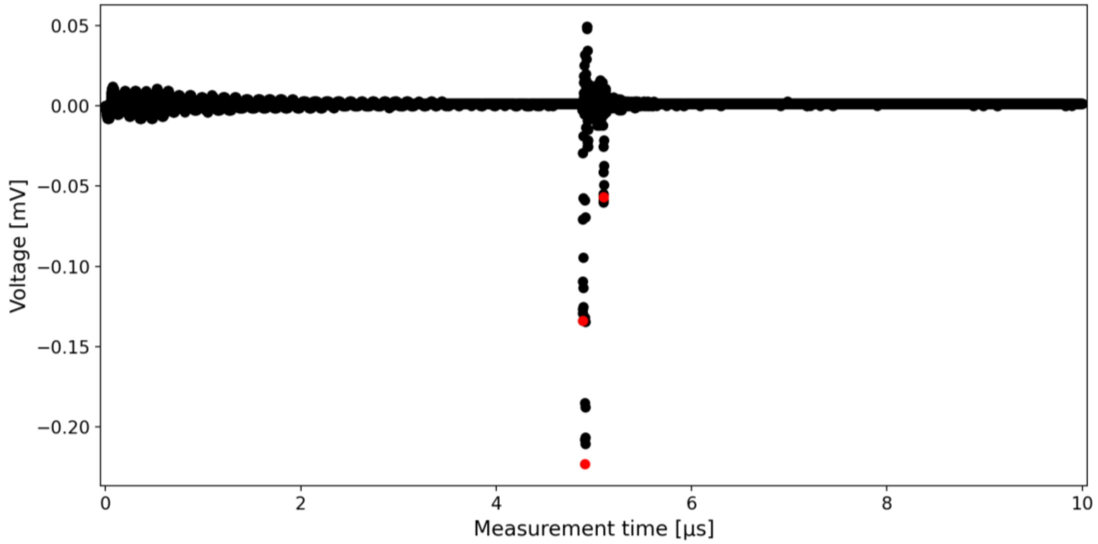
Image from [Tanaka, 2024]

- Microwave Spectrometer generating E-field to test different frequencies
  - If $2S \rightarrow 2P$ transition is induced, $2P$ state decays to ground state with emission of Lyman-α photon
- Quenching field in the Lyman-α detector induces remaining $2S \rightarrow 2P$ transitions
- Four MCPs on the sides of the detector are used to detect the emitted Lyman-α photons
- Charged particles get deflected in the switchyard, neutral particles can be seen on the $\bar{\mathrm{H}}$ detector (MCP5)
  - $\bar{\mathrm{H}}$ production is determined using MCP5

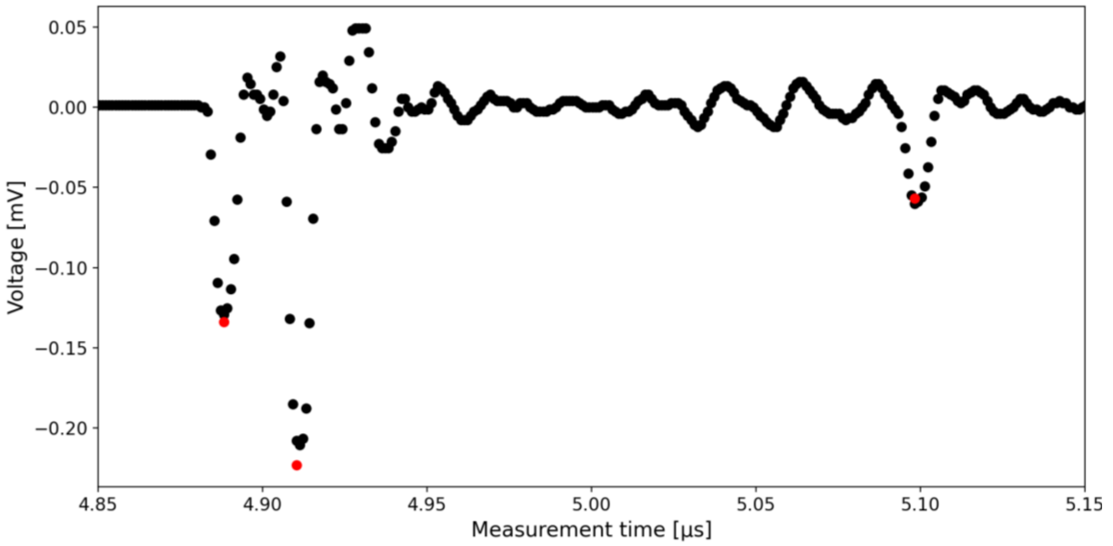
2. Lamb Shift Setup Test using a H^- Beam

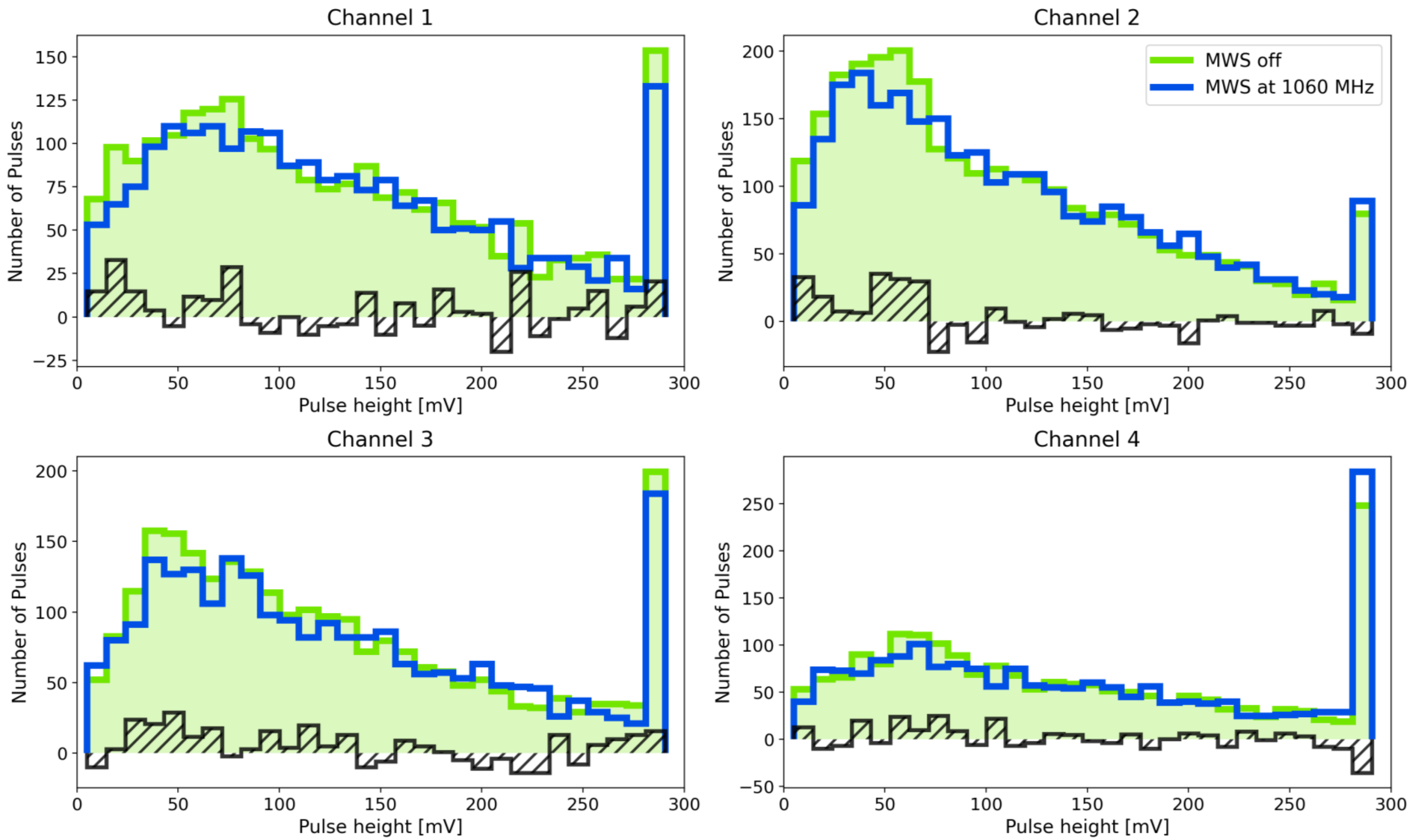
Microwave Scanner on/off Measurement

MWS Frequency	0 MHz	1060 MHz
Number of events	1169	1170
Average beam intensity	8.85×10^6	8.78×10^6
Average pulses per spill	8.70	8.38

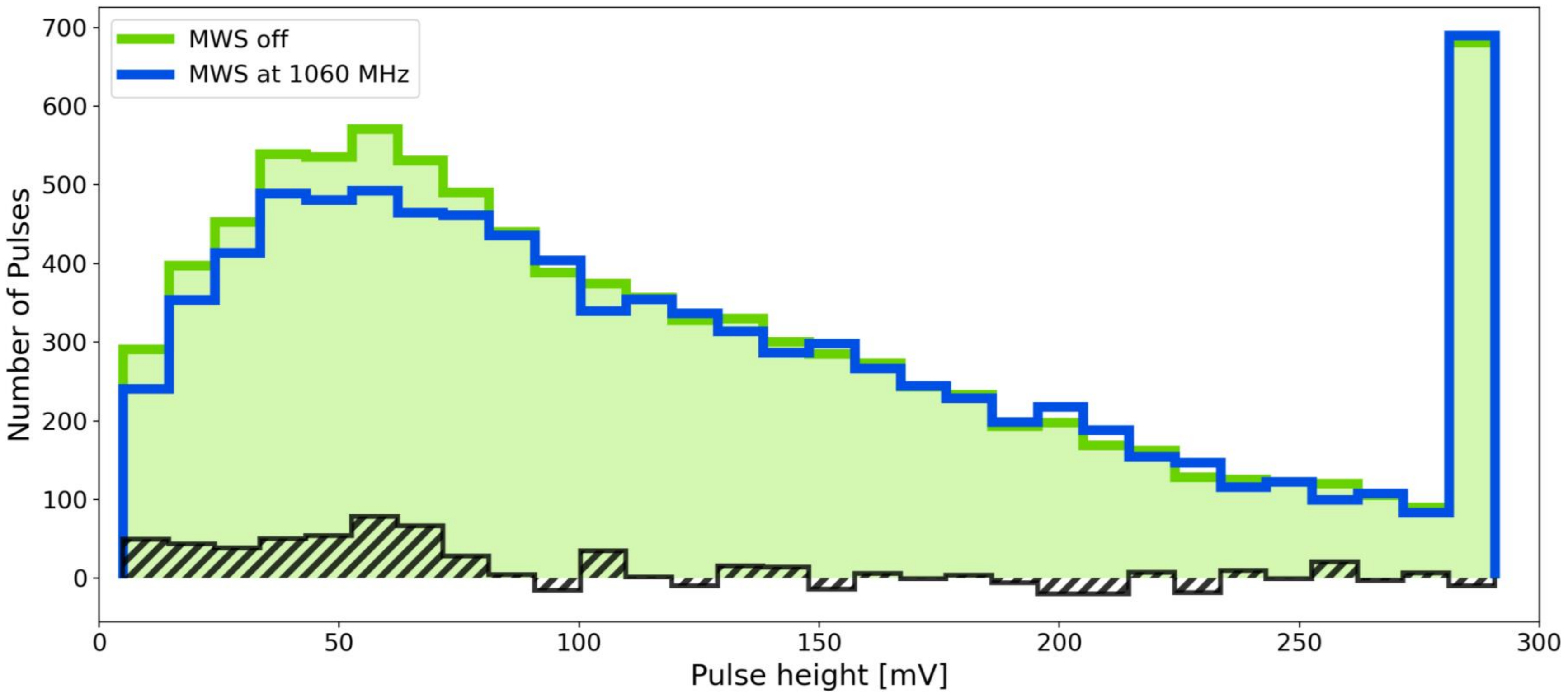


- Images from one H^- spill with the MW scanner off
  - Voltage for one of the four MCPs
- Ringing in the voltage after each pulses
  - Scales with height of pulse





- Pulse height histograms for each MCP in the Lyman-α detector separately
  - Each pair of histograms is scaled using the total beam intensities

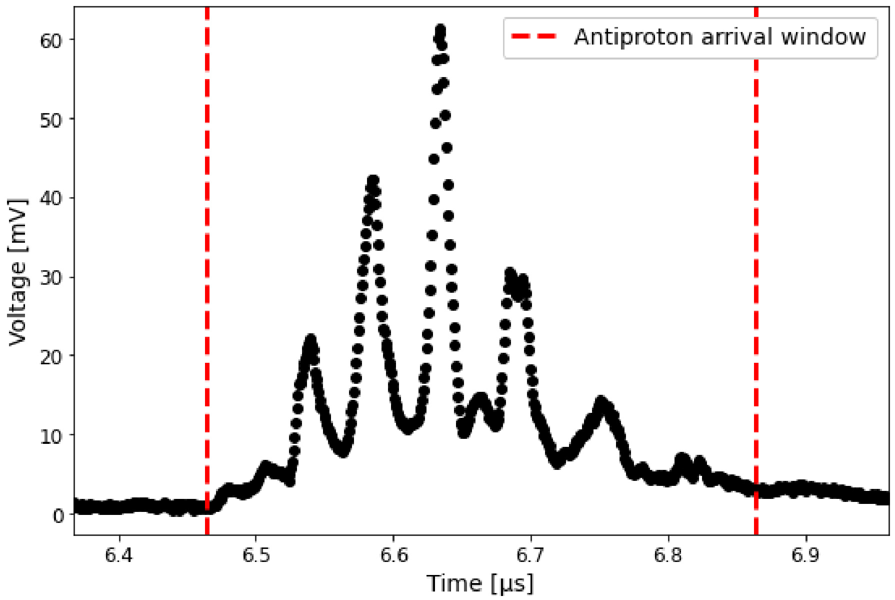


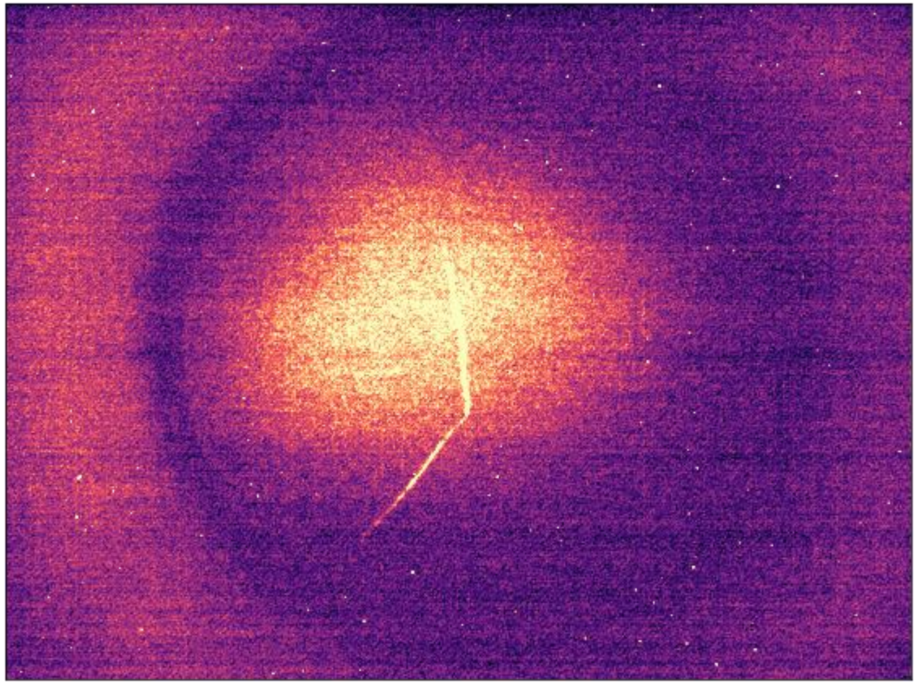
- Pulse height histogram summed over the four MCPs
  - The two histograms for the MW Scanner off and on are scaled using the total beam intensities
- 511 ± 92 more Lyman-α photons detected in the MW Scanner off events
- Rough estimate for detection efficiency: 0.0041
  - Efficiency of detector was measured around 0.16 when it was new

3. First $\overline{\mathrm{H}}$ Production Measurements in 2024

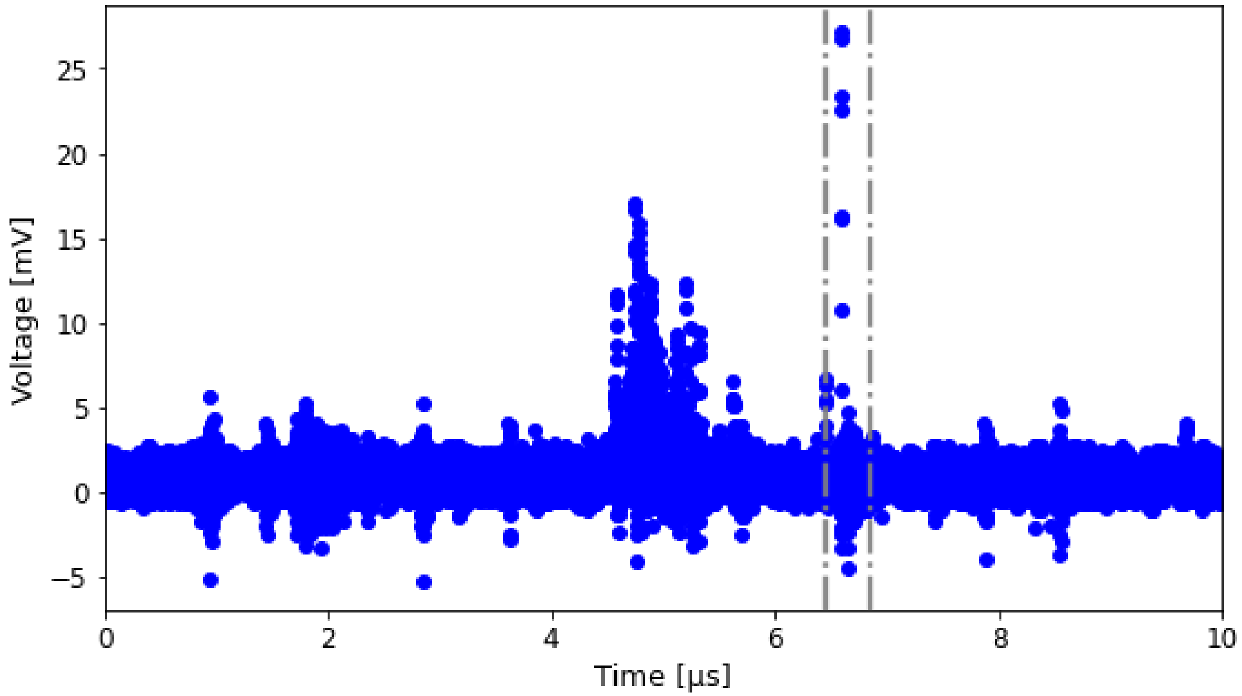
Data taken for the 2024 $\overline{\mathrm{H}}$ Production

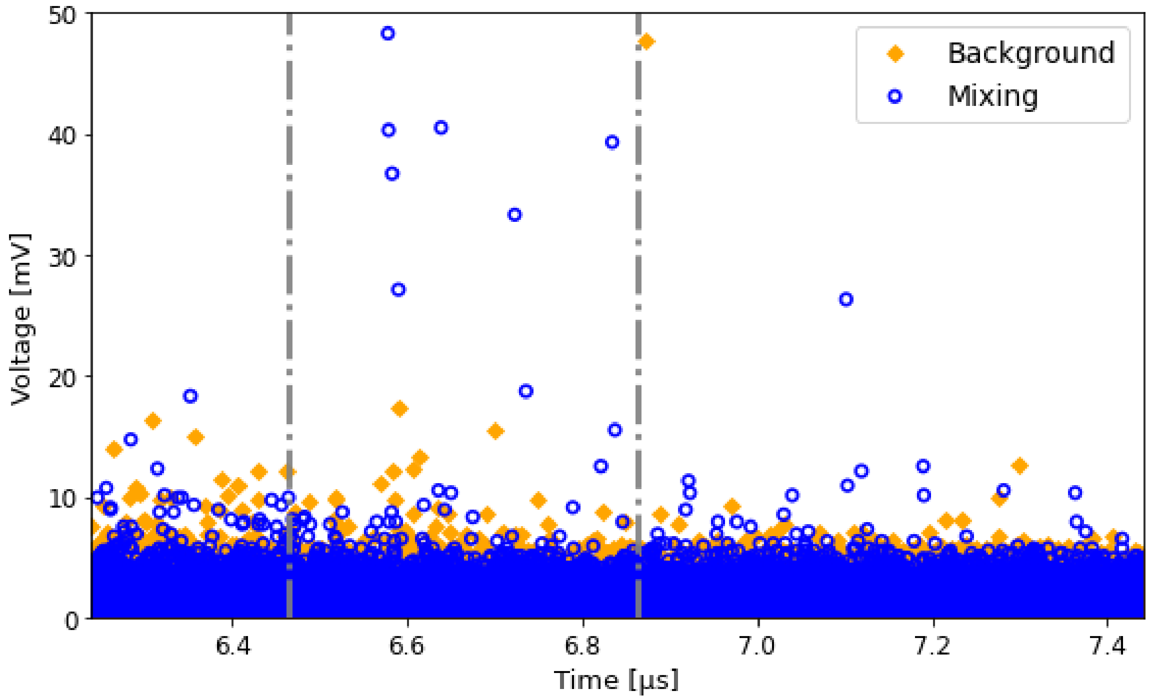
- Take mixing and background measurements with identical beam steering and $\overline{\mathrm{p}}$ trap setup
  - For background events no positronium is in the cavity
  - 468 mixing events, 776 background events
- To get arrival window of $\overline{\mathrm{H}}$ take background events with the switchyard off
  - 11 such events were taken
  - Voltage is averaged over the 11 events
  - Use time window from $6.46\ \mu s$ to $6.86\ \mu s$
- Image of MCP5 are taken for each spill with a phosphor screen behind the MCP and a CCD camera
  - Images are generated over $1\ \mu s$





Antihydrogen Production from Voltage Pulses in MCP5





- Voltage of MCP5 for one $\bar{p}$ spill
  - The vertical lines show the $\bar{p}$ arrival on MCP5
  - The pulse is a $\bar{H}$ candidate
- All pulses found in the voltage of MCP5 around the $\bar{p}$ arrival window for the mixing (blue) and background (orange) events

Works cited:

- Oelert, W. (2015). “The ELENA project at CERN”. https://doi.org/10.48550/arXiv.1501.05728
- Tanaka, T. (2024). “Design of a microwave spectrometer for high-precision Lamb shift spectroscopy of antihydrogen atoms”. https://doi.org/10.1007/s10751-024-01876-3
- Blumer, P. (2024). “Production of a 6keV antihydrogen beam in the GBAR experiment”. PSAS 2024. https://indi.to/QpJ8j