Overall status of the GBAR experiment

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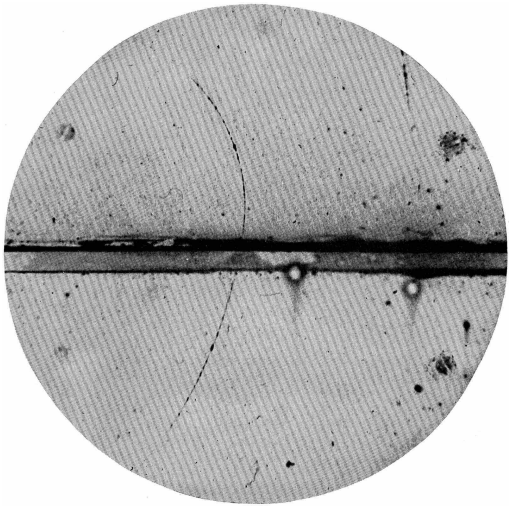
What is antimatter?

Dirac (1928), Quantum physics + Spin + Special relativity $(i\hbar\gamma^{\mu}\partial_{\mu} - mc)\,\psi = 0$



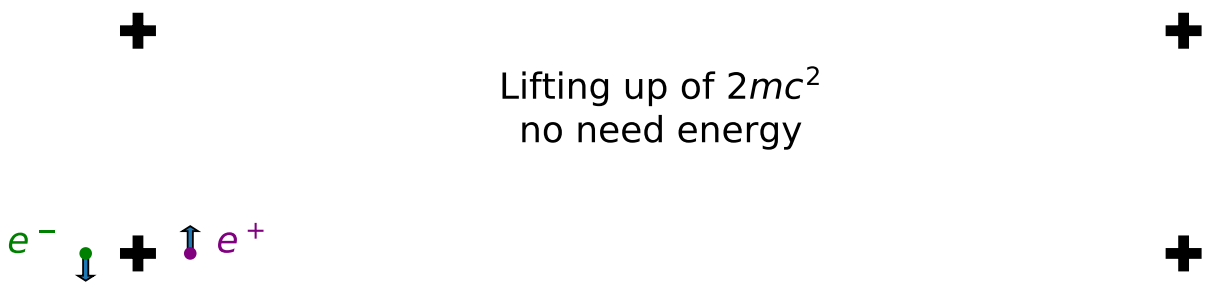
Experimental evidence of e^{+} (1933, Anderson)

- Antimatter has been studied in many ways
- Gravity has not been unified with quantum physics and antimatter is absolutely quantum $\rightarrow$ GBAR experiment

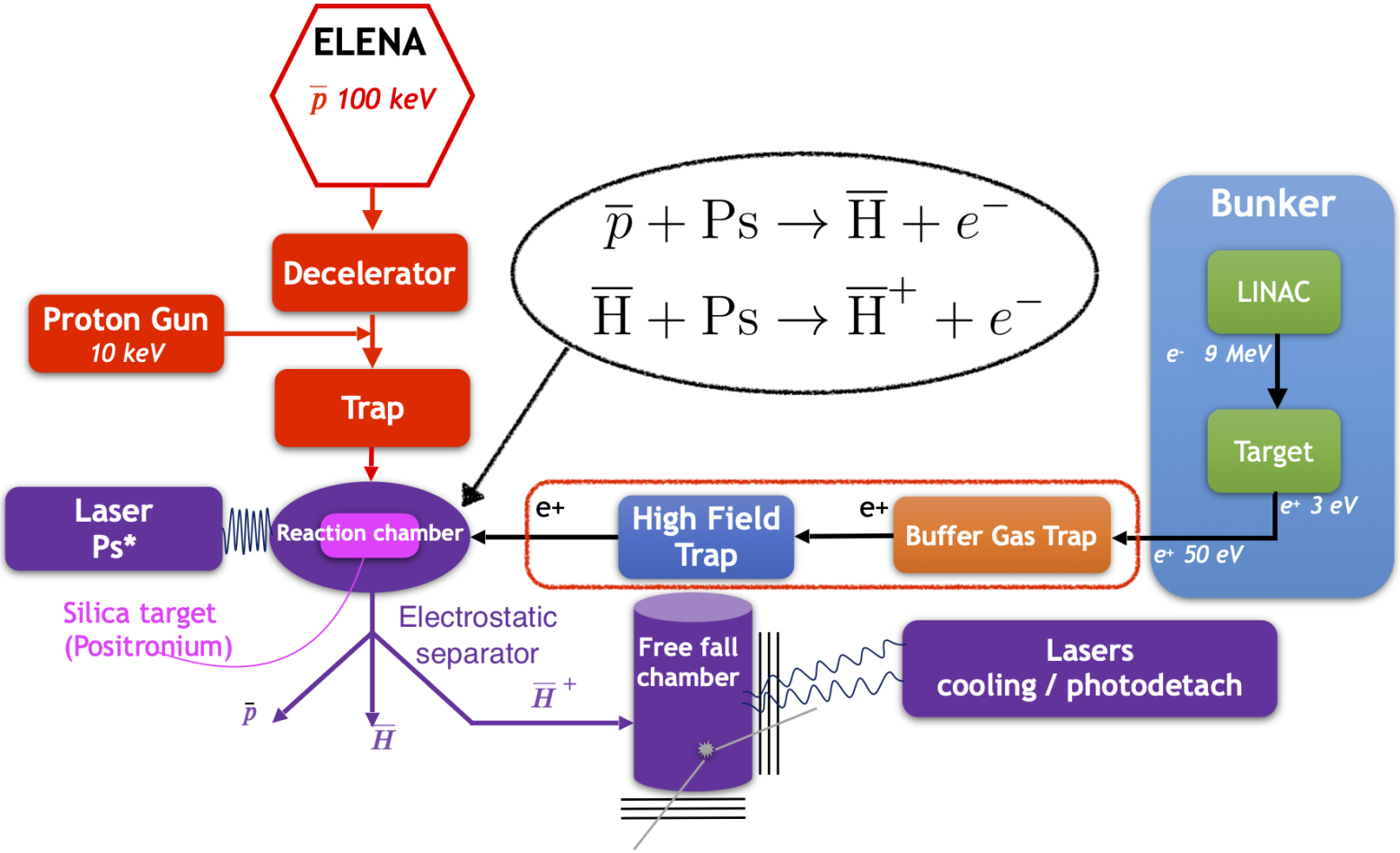
"Antimatter Factory", where GBAR, PUMA, ASACUSA, BASE, AEGIS and ALPHA are located.

Context of the GBAR experiment → Antigravity

- Analogy EM and gravitation $\nabla \cdot E = \rho/\epsilon_0 \leftrightarrow \nabla \cdot g = -4\pi G\rho$
- 2 opposite charges are attracted $\leftrightarrow$ 2 positive masses
- Gravity: $m_I a = m_G g$ and $m_I = m_G$, CPT: $m_I = \bar{m}_I$ but $\bar{m}_I = \bar{m}_G$?
- Morrison's argument: Antigravity $\leftrightarrow$ no energy conservation.
- A γ falls in a gravity field, but $\bar{\gamma} = \gamma$.
- Just a variation of $\left|\frac{\bar{m}_I - \bar{m}_g}{m_I}\right| \sim 1\%$ is already important.

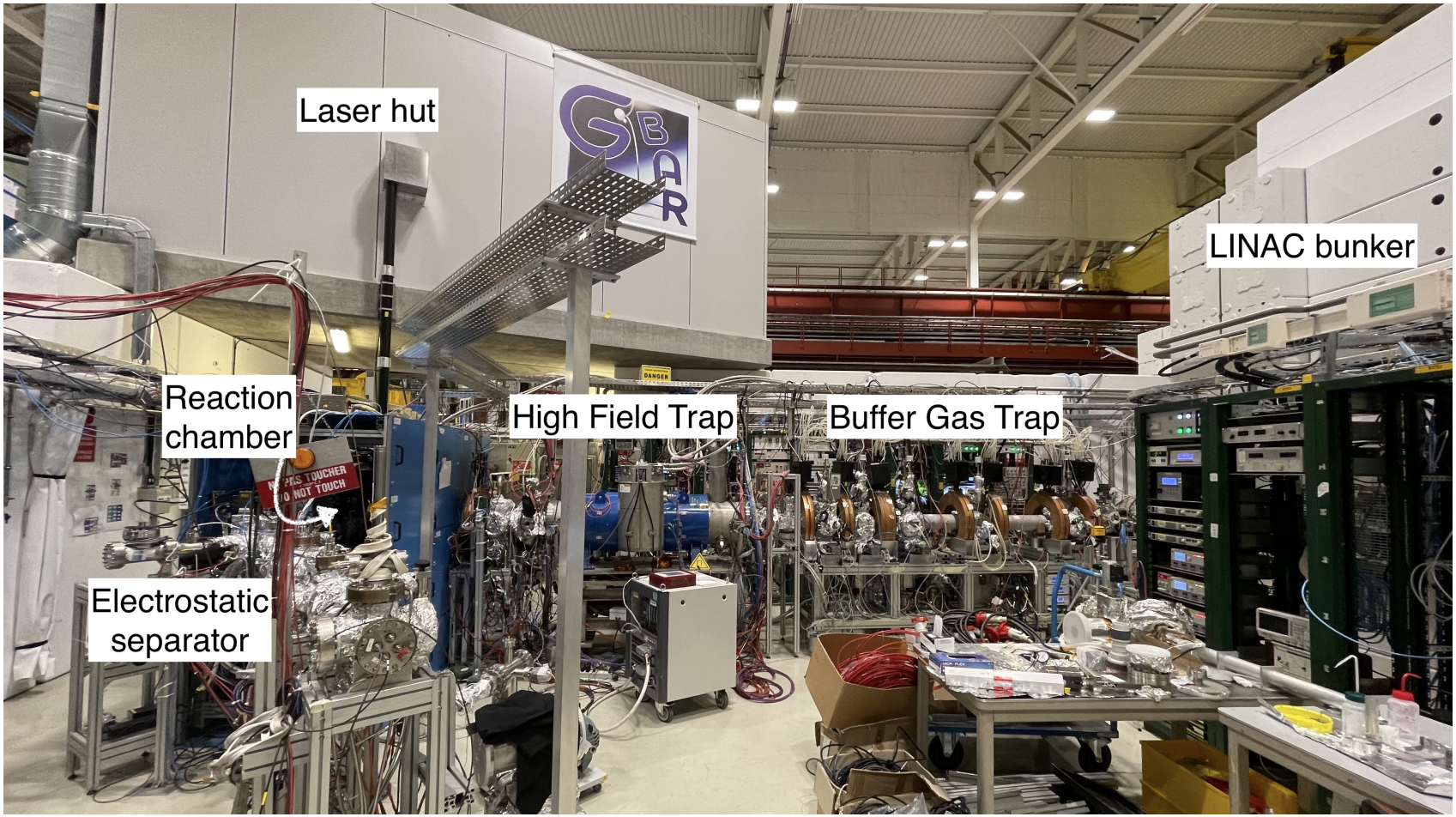


General overview



Overall scheme of the GBAR experiment.

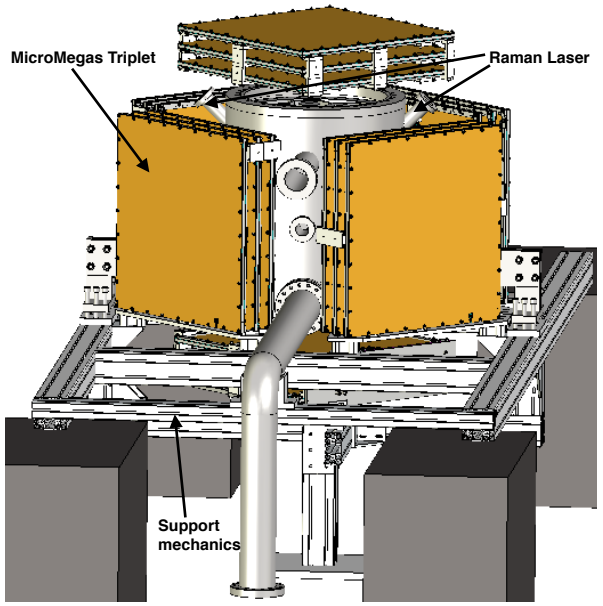
General overview



Picture of the GBAR experiment at CERN.

Almost in the final settings

- $\overline{p}$ trap capable of trapping e^-
- End of 2021 run: $\overline{p}$ trap at the end of the line
- $\overline{p}$ trap need to be placed between the drift tube and the reaction chamber
- The free fall chamber still need to be built



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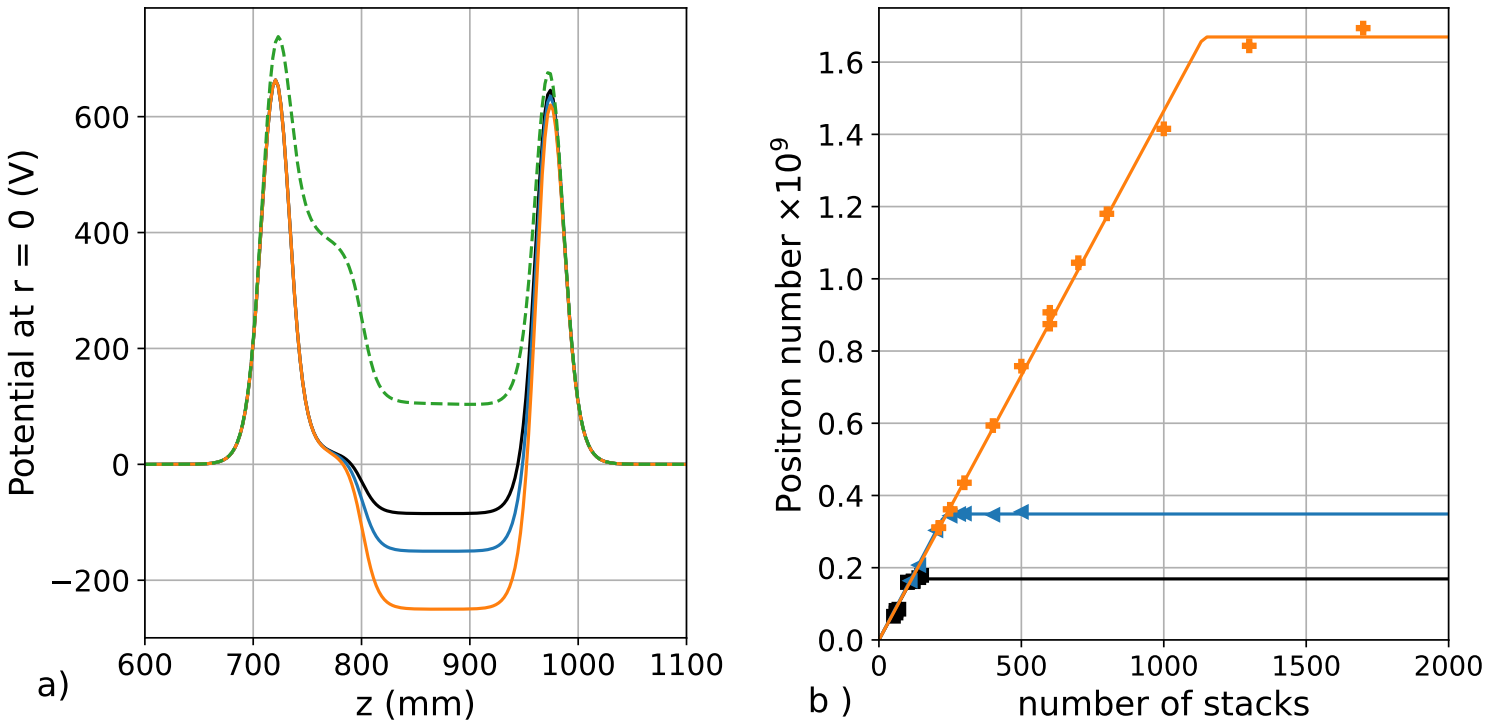
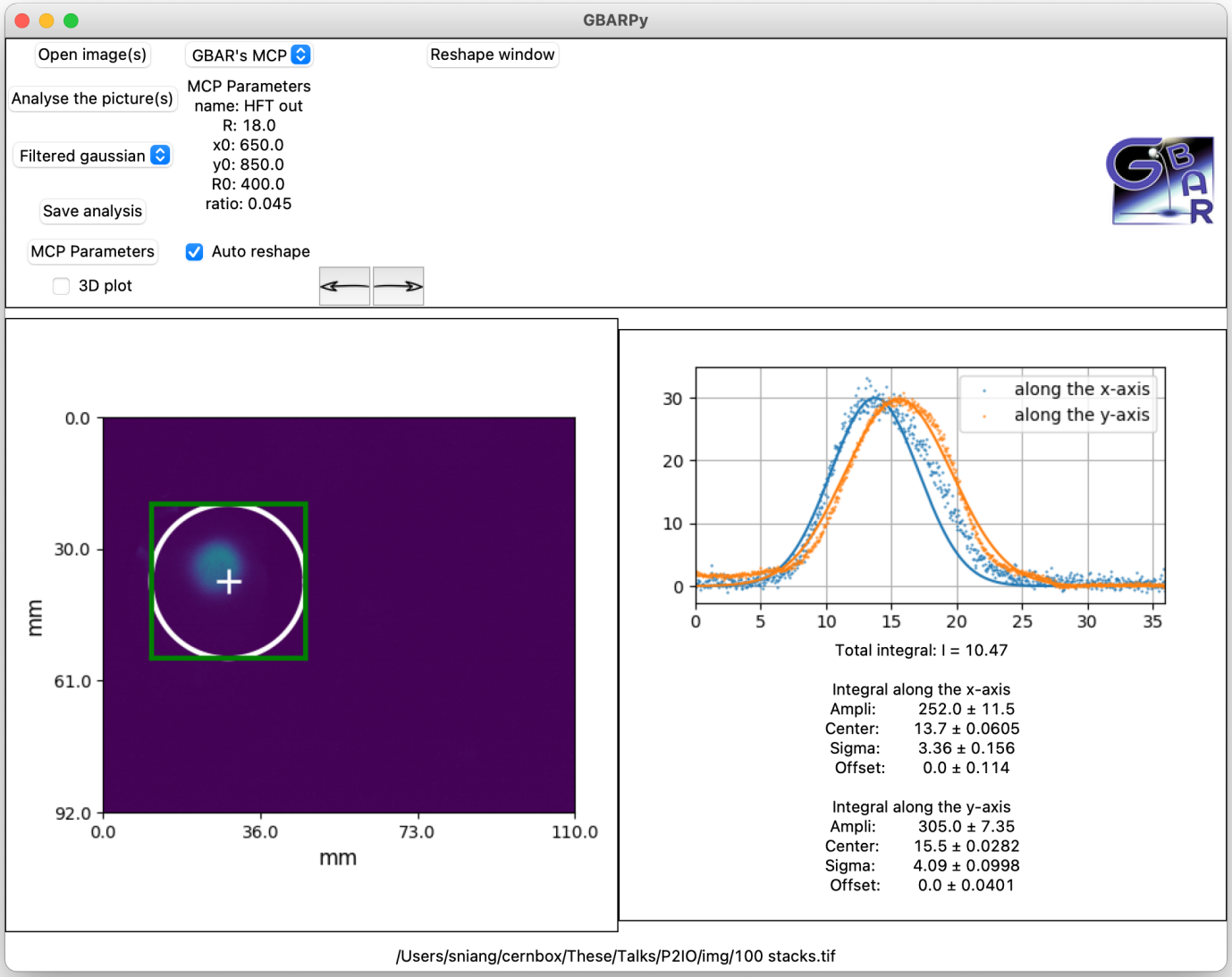
$1.7 \times 10^9 e^+$ trapped in 1100 seconds

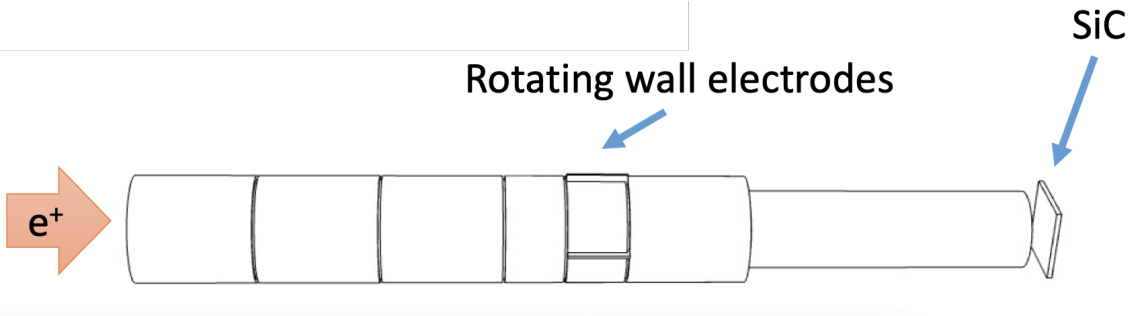


a) Potential profiles used for the stacking (solid lines) and the ejection (broken line) procedure. b) Positron number as a function of the number of stack for the successive potential wells. **A world wide record**.

$10^8 e^+$ accumulated between 2 ELENA bunches (115 s)



- trapping rate too slow: SiC re-moderator inserted in the BGT. It lead → 40% efficiency instead of 10%. Not fully implemented yet because of mechanical issues



- LINAC at 200 Hz needs to go to 300 Hz. Another technical challenge: cooling of the target.
- The final bunch is too large → still looking for solutions

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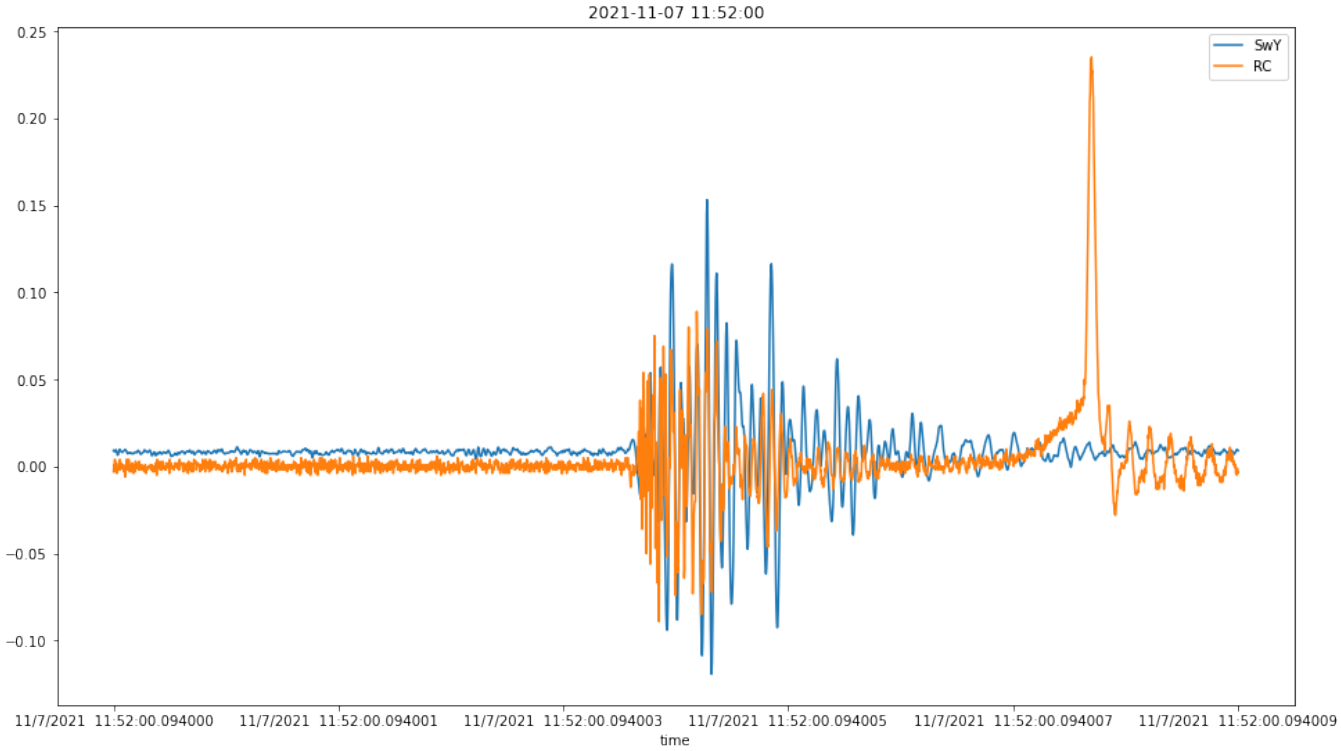
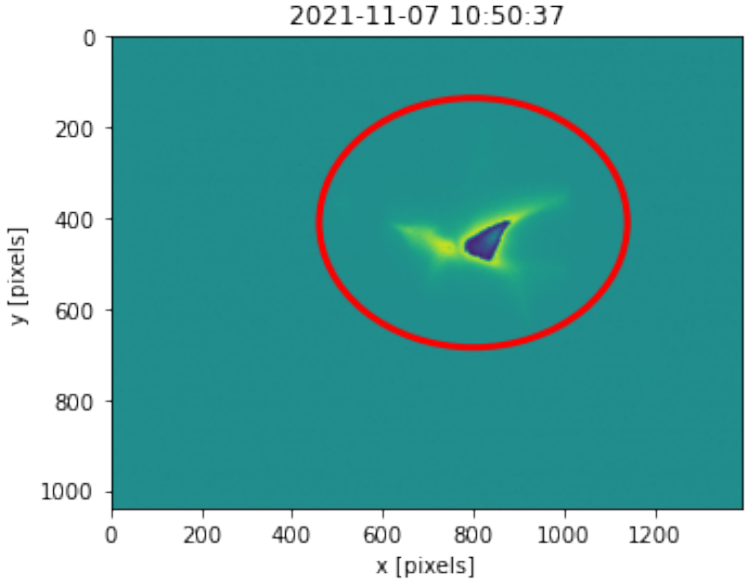
Antiprotons can reach their target after the final deceleration (10-20 keV)

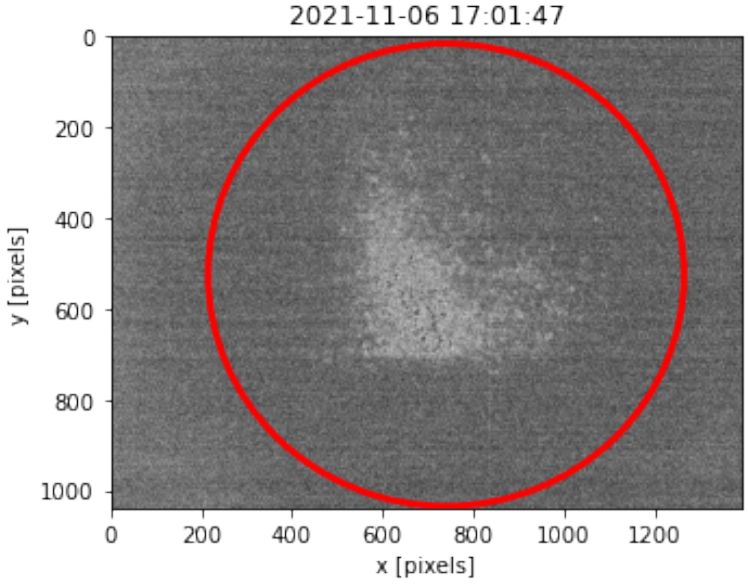


Signal of the antiprotons in the reaction chamber after a pulse of a drift tube.

Antiprotons can reach their target after the final deceleration (10-20 keV)

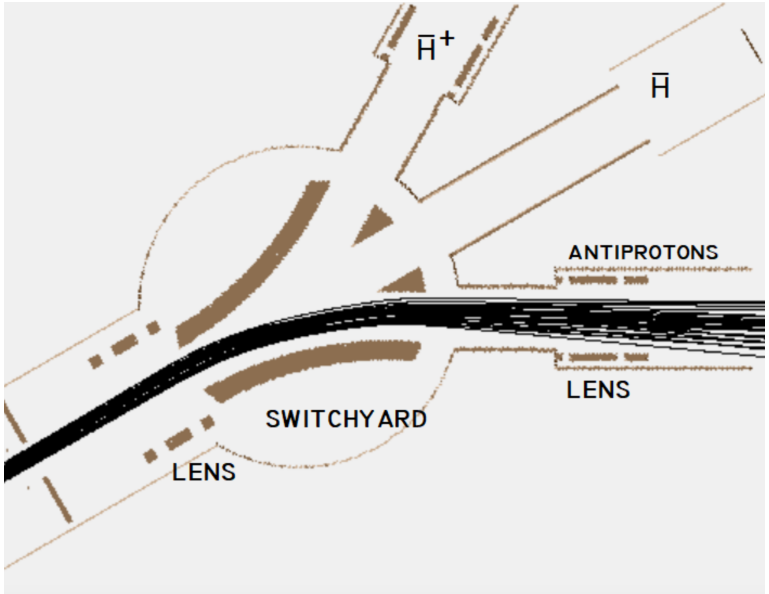


MCP picture of the $\overline{p}$ bunch in the Reaction Chamber.

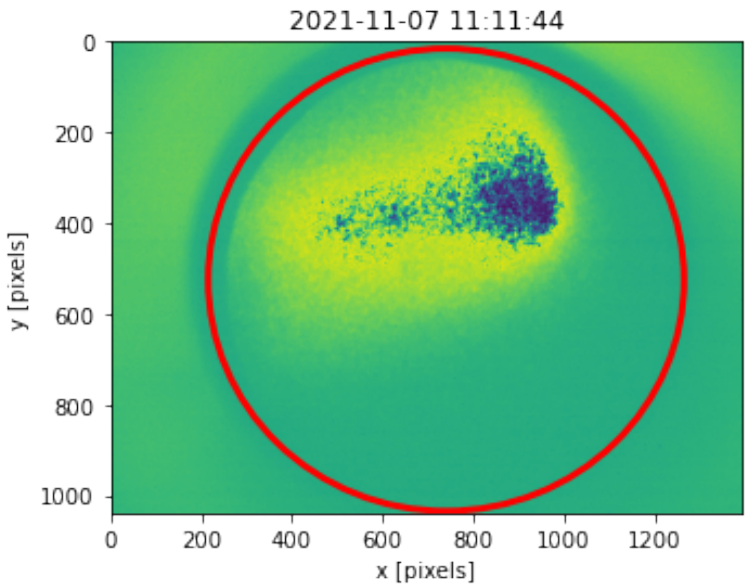


$\overline{p}$ after the switchyard when they went through the cavity.

Antiprotons can reach their target after the final deceleration (10-20 keV)

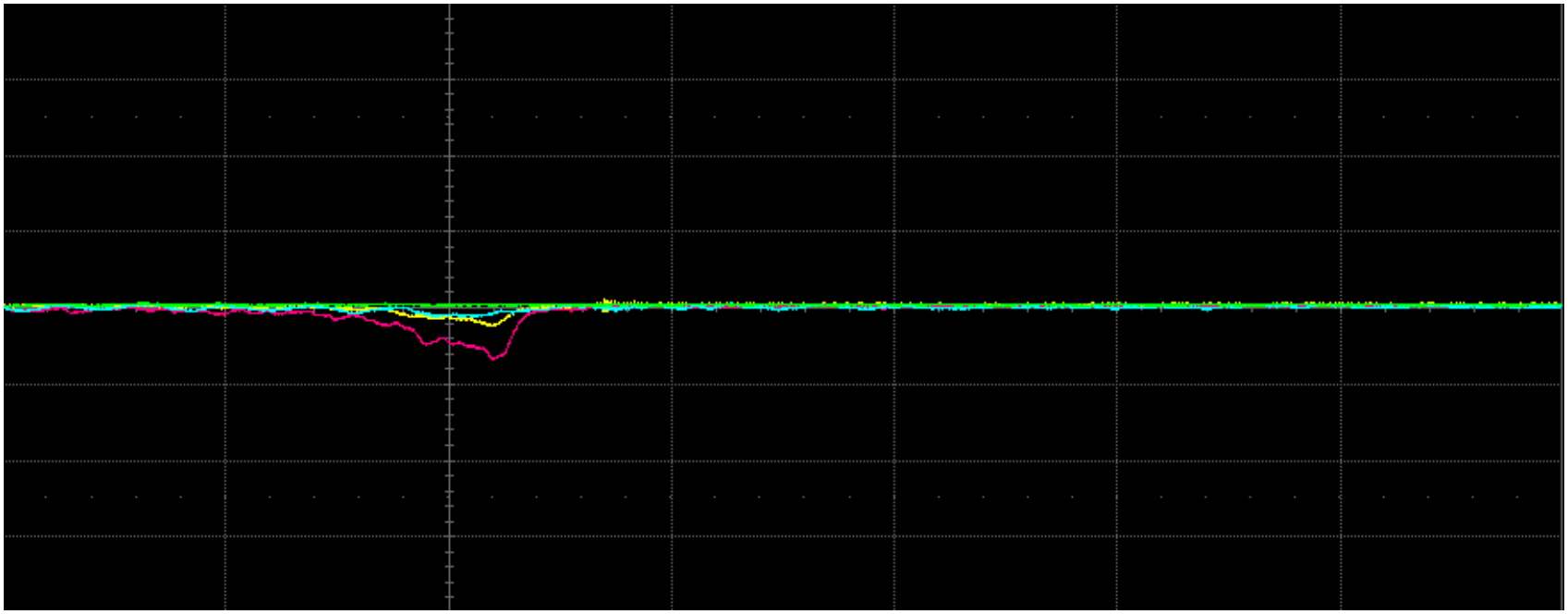


Scheme of the switchyard. In the end the $\overline{p}$ will be "recycled".



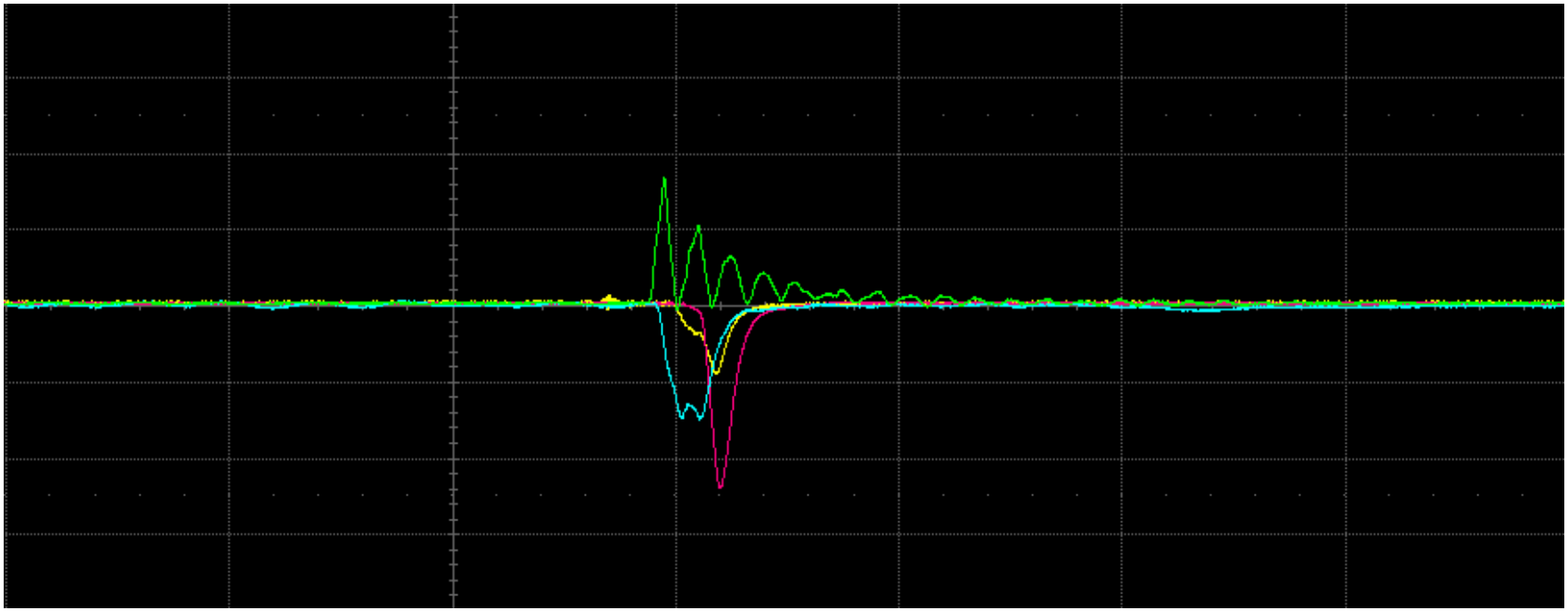
MCP picture of the $\overline{p}$ bunch after the switchyard.

Synchronisation between e^+ and $\overline{p}$



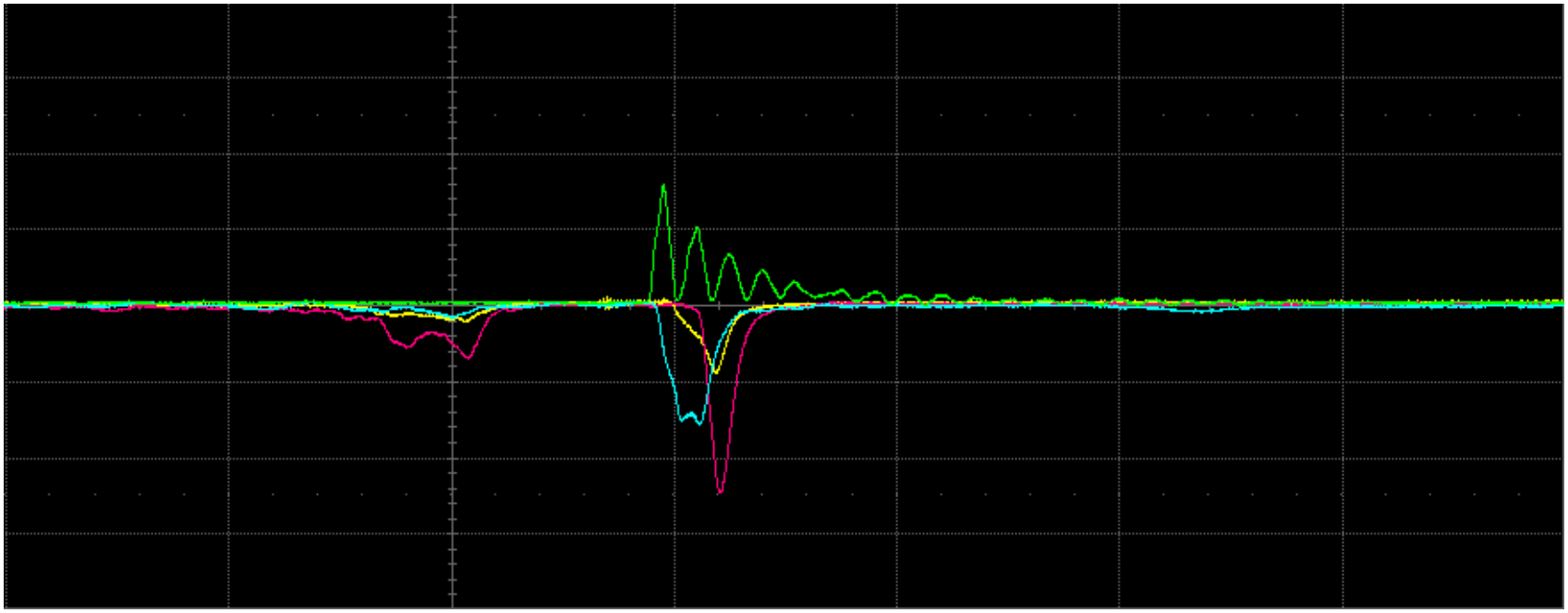
$\overline{p}$ only in the reaction chamber cavity.

Synchronisation between e^+ and $\overline{p}$



$e^+(\mathrm{Ps})$ annihilation only in the reaction chamber cavity.

Synchronisation between e^+ and $\overline{p}$



$\overline{p}$ and Ps in the reaction chamber cavity. It is then possible to mix them!

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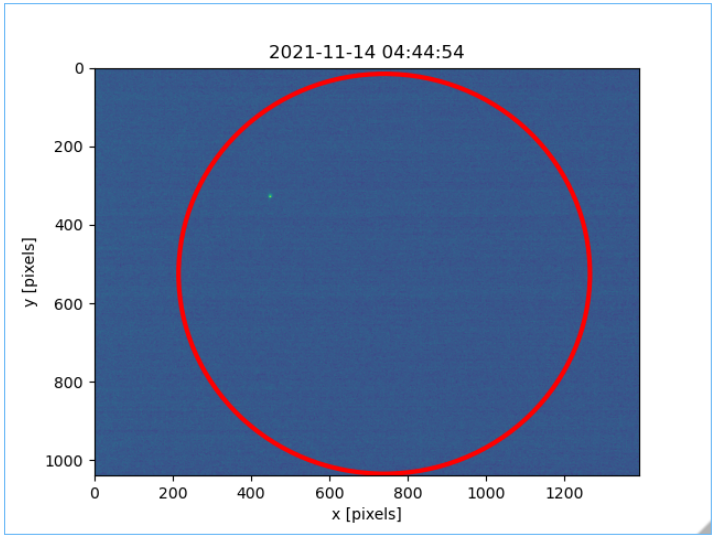
Conclusion of the 2021 run and outcomes

What have done:

- antiprotons slowed with the pulsed drift tube
- antiprotons lead to the reaction chamber and the switchyard
- first calibrations of the detectors with $\overline{p}$
- background measurement $\overline{p}$, e^+, AD.
- $\mathrm{Ps} - \overline{p}$ mixing. $\overline{\mathrm{H}}$?



For the next run:

- $\overline{p}$ accumulation
- $\overline{\mathrm{H}}$ production
- $\overline{\mathrm{H}}^+$?