JAPW/IEF-Meeting / CERN

Achievements made at the Antiproton Decelerator / ELENA Facility in 2022

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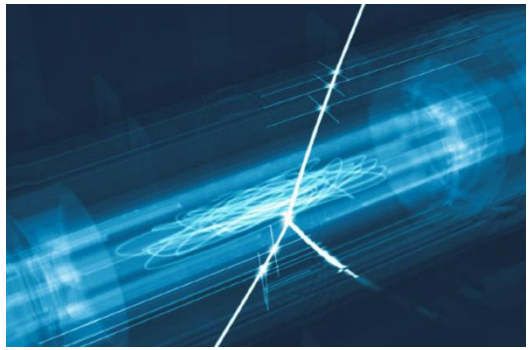
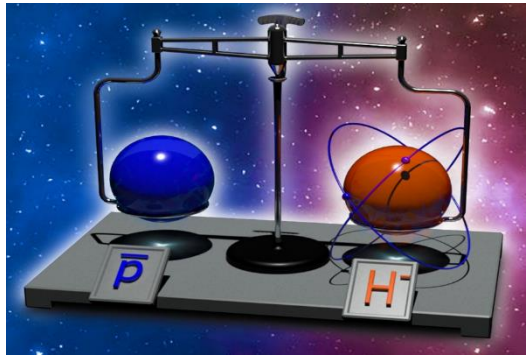
RIKEN / HHU Düsseldorf

On behalf of the AD/ELENA collaborations

2022 / 12 / 05



antihydrogen trap

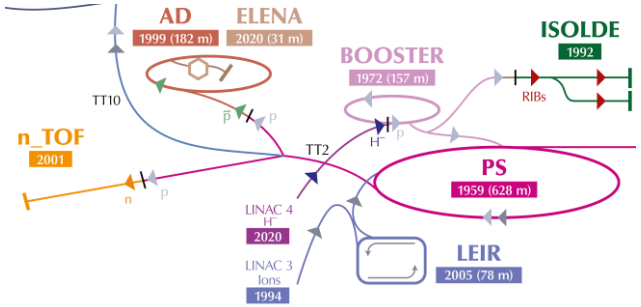


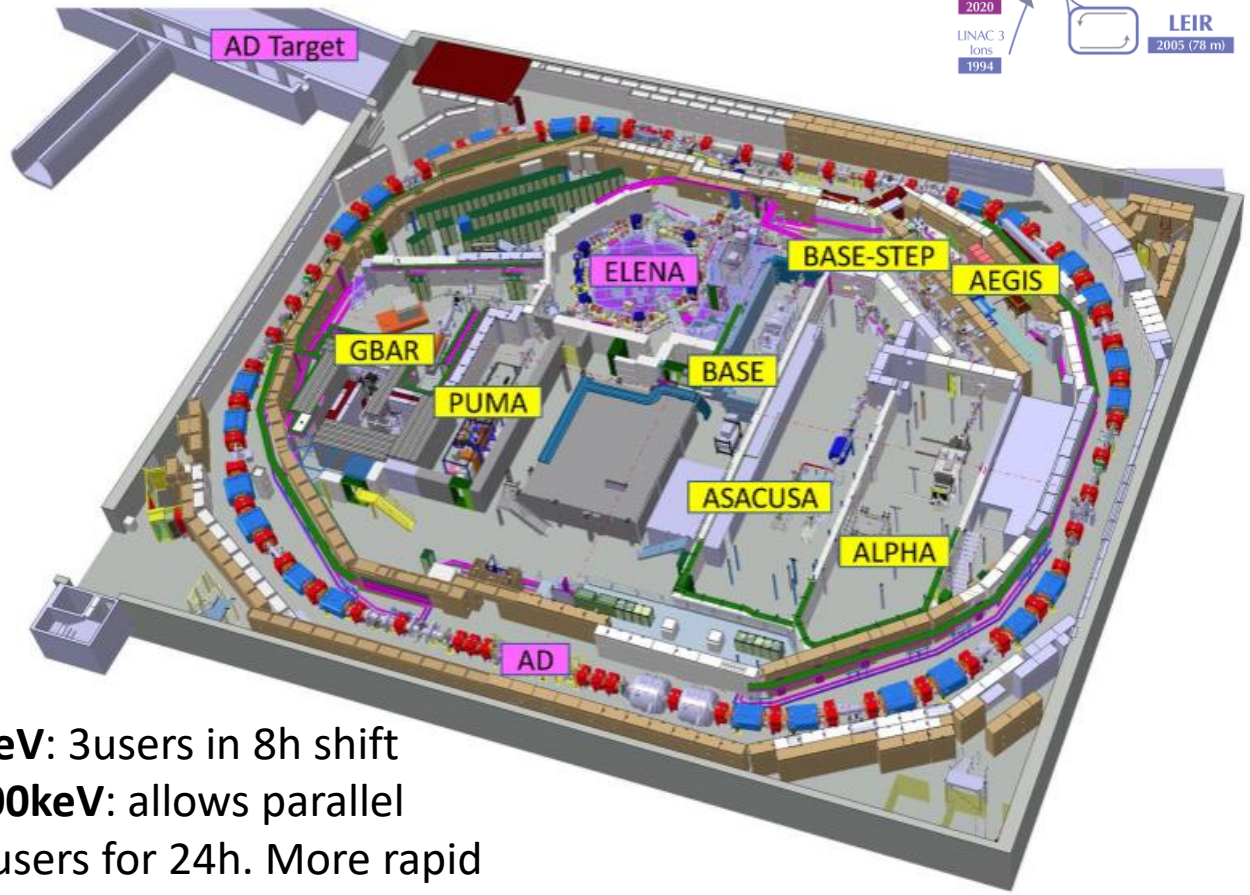
antiproton/proton balance

AD/ELENA Facility

- AD/ELENA Facility: Six user collaborations testing
  - CPT invariance (ALPHA / ASACUSA / BASE / BASE-STEP)
  - Weak Equivalence Principle (AEgIS (ff) / ALPHA (ff) / BASE (clock) / GBAR (ff))
  - Nuclear Structure (PUMA, joint AD / ISOLDE)

…using laboratory AMO **experiments** rather than particle detectors.





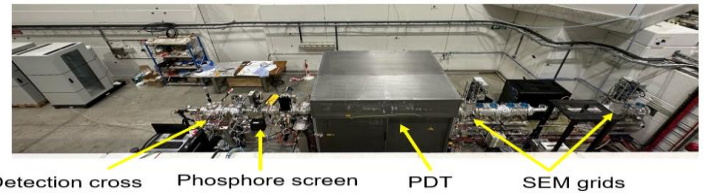
AD (2018) 5.6MeV: 3users in 8h shift
ELENA (2021) 100keV: allows parallel operation of all users for 24h. More rapid commissioning, more physics, more systematic studies,…etc…

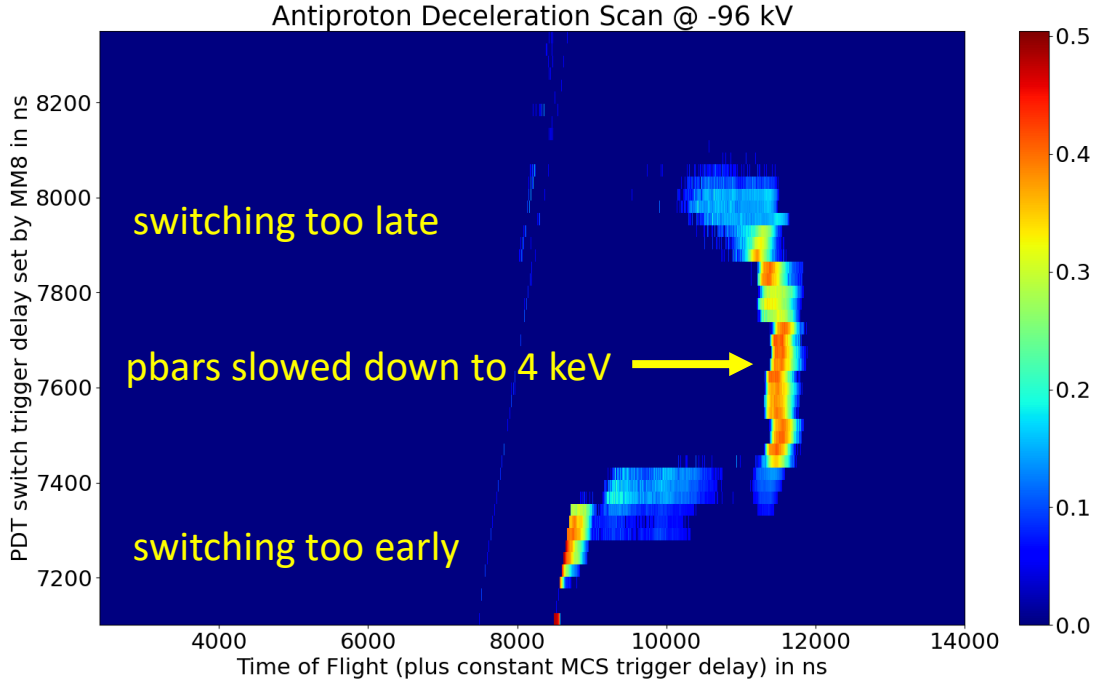
Community is still extremely excited about the new possibilities that come with 24h antiproton access for everyone

Highlights 2022: New Users – PUMA/BASE-STEP

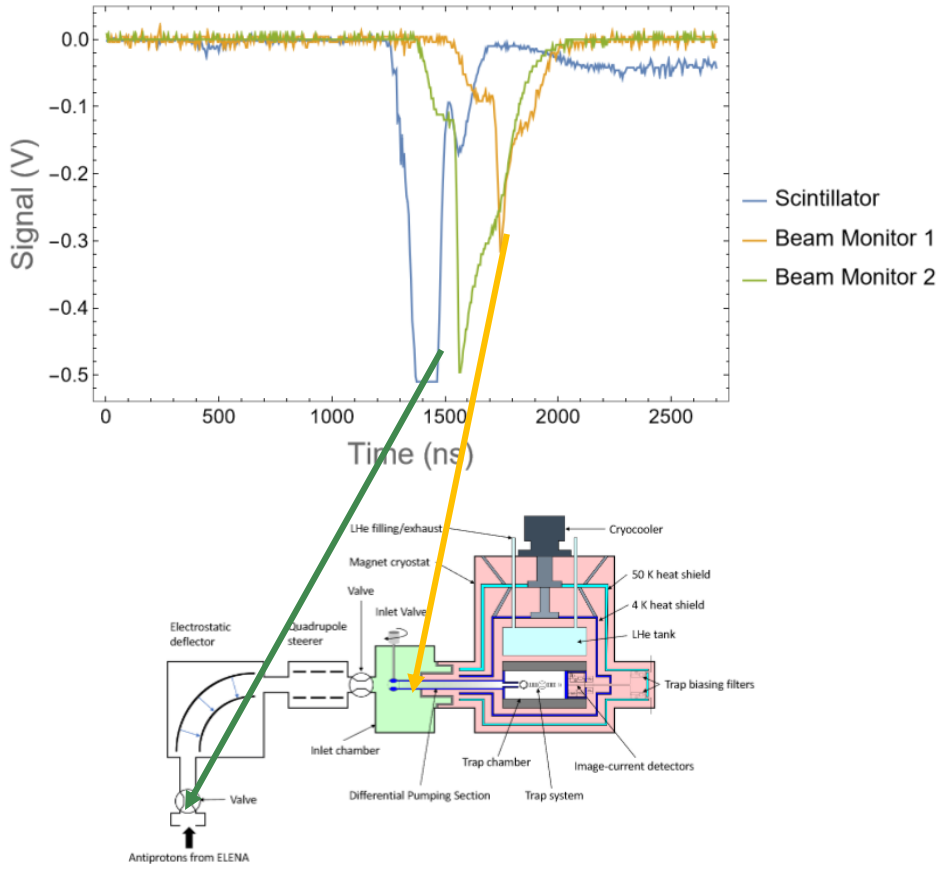
- In 2022 two new users took beam for the first time PUMA and BASE-STEP

- Deceleration of 100keV pbars to 4keV in **PUMA**



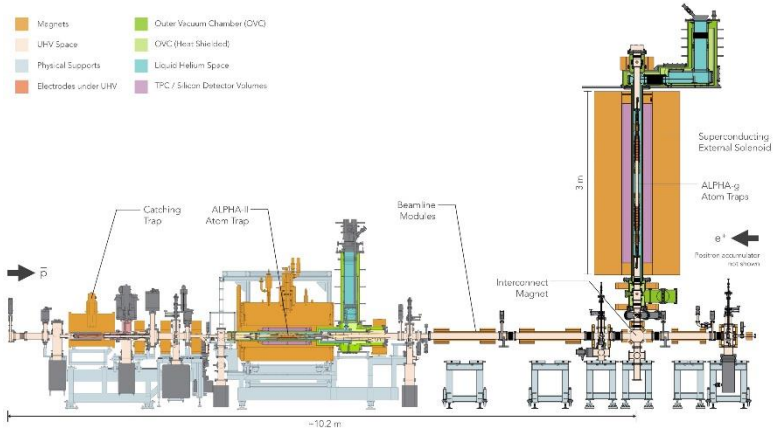


- Detection of 100keV pbars at entrance of the future **BASE-STEP** magnet

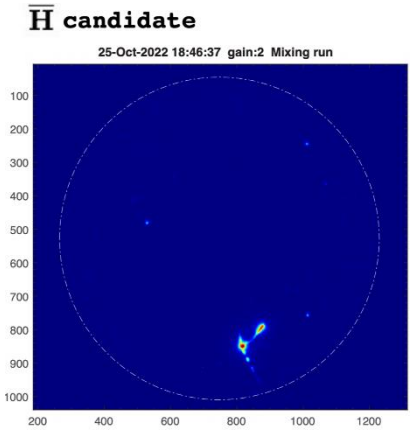


Highlights 2022: Old Users

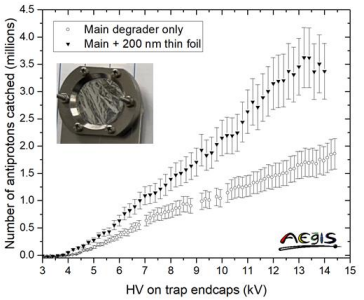
- ALPHA-g
  - After a lot of development work: **produces, traps and accumulates antihydrogen atoms**



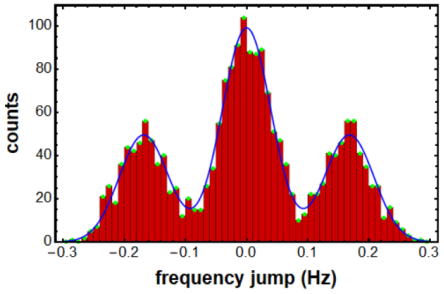
- GBAR
  - Several antihydrogen production candidate events were identified, detailed evaluation ongoing.



- AEGIS
  - **routinely catches ~50% of incoming ELENA antiprotons.**
  - **Essential for future evaporative cooling studies**

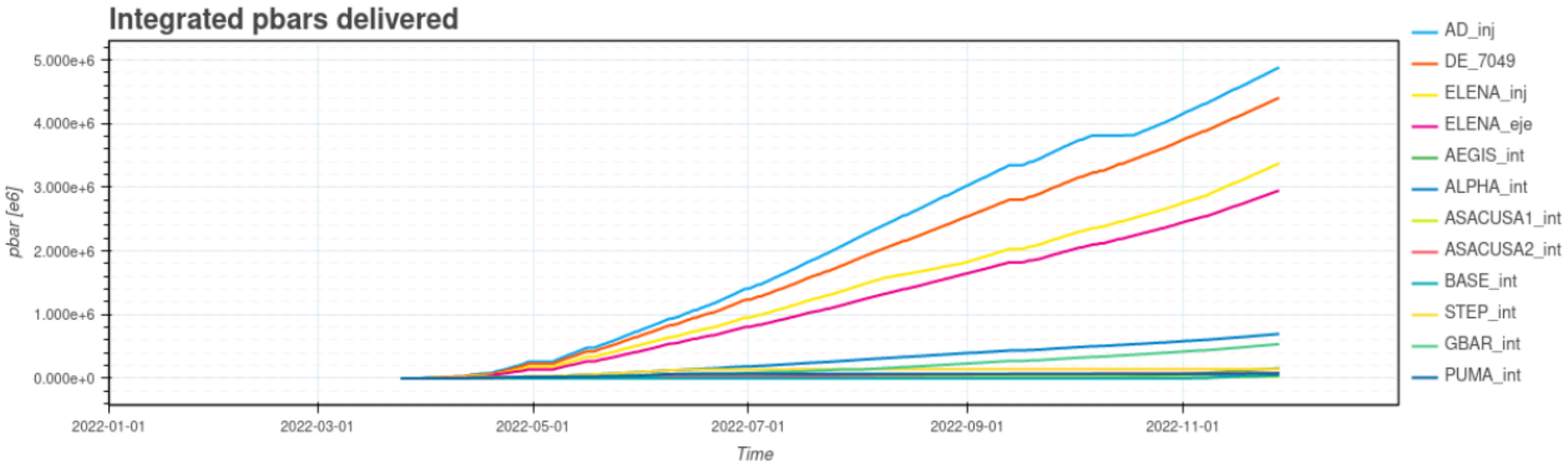


- BASE
  - Successful **non-destructive detection of single spin quantum transitions** at **60-fold improved preparation time.**



- ASACUSA
  - **Laser spectroscopy of infrared transition in antiprotonic helium atoms was successful and the hyperfine structure was resolved**

Beam Distribution and PBAR use

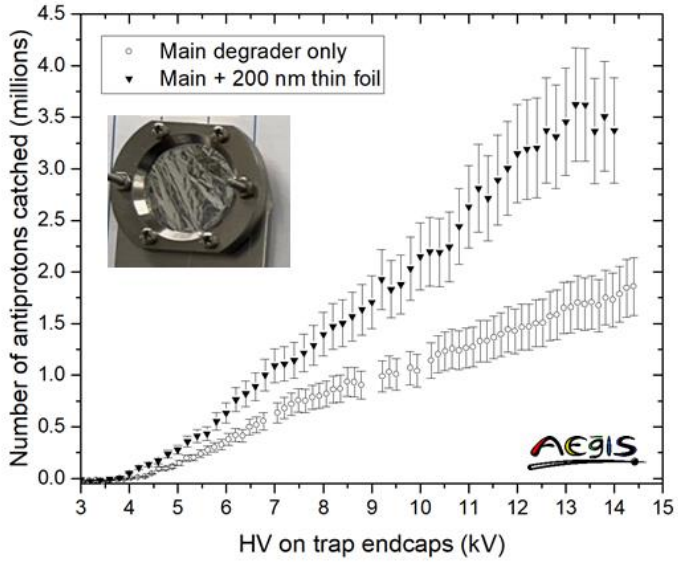


- **ALPHA** and **GBAR** continuously «on» - **antihydrogen physics run**
- **ASACUSA / AEGIS / BASE:** focus on technical developments
- **BASE-STEP and PUMA:** short **successful** beamline commissioning runs (since problems with magnet deliveries from Bilfinger Noell)

Feedback AEGIS-Collaboration - Summary

1.) Objectives of the 2022 run

Achieve nominal antiproton catching efficiency from ELENA and **commission the new Penning trap system for improved antihydrogen production**, installed during 2022, while progressing towards laser cooling of positronium.



2.) Achievements of the 2022 run

- Nominal antiproton catching efficiency was achieved by systematic study of degrading foils to determine best trapping configuration. **AEgIS now routinely catches ~50% of incoming ELENA antiprotons**.
- Successful commissioning of the new antihydrogen trap with electrons and antiprotons.
- Excellent progress towards establishing laser cooling of positronium atoms.

3.) Request for upgrades to be implemented / resources to be provided during the YETS

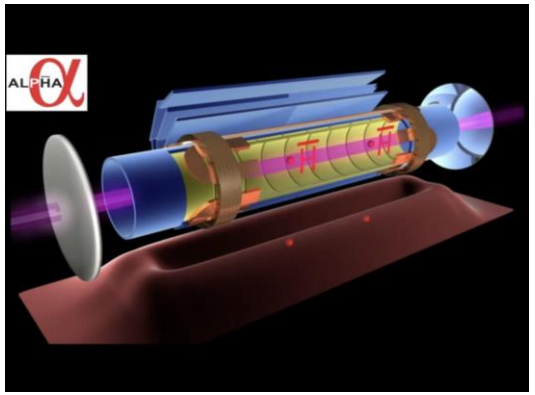
- AEgIS has switched the experiment to positron physics on Friday Dec. 2, 2022: **need power/cooling water during entire YETS.**
- Magnet switch-on planned in early 2023: **AEgIS requests its regular liquid helium share from February 15, 2023.**
- ***AEgIS requests to make steering to the other experiments independent of the status of magnetic field in AEGIS (a possibility is introducing magnetic field sensors to allow steering corrections to be readily applied)***

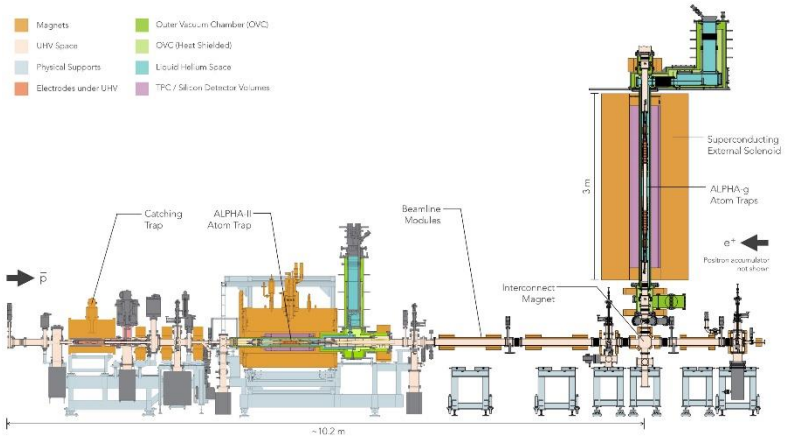
4.) Rough outline on the 2023 antiproton run

- **Main focus:** increase the yield of its pulsed antihydrogen source towards forming a forward-boosted pulsed beam.
- **Secondary focus:** excitation of Ps to high (n > 25) Rydberg states in a strong magnetic field for improved antihydrogen production.

Feedback ALPHA-Collaboration

- **ALPHA-2 – antihydrogen laser physics**
  - only four weeks dedicated to this
  - reproduced and perhaps improved the laser cooling from 2018
  - reproduced the 1S-2S line measurement (no attempt to improve)
  - received the Cs-fountain clock from NPL (UK); in process of commissioning (primary time standard; definition of SI second)





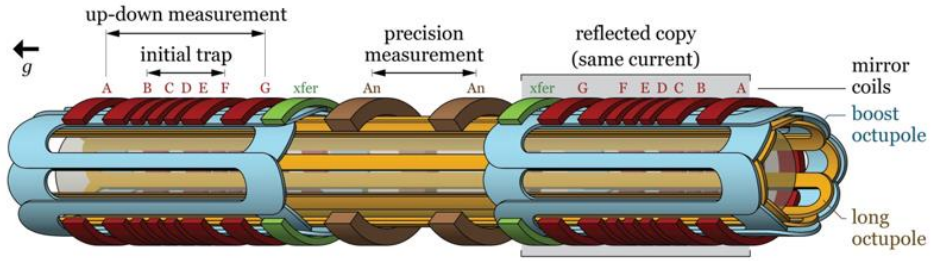
- **ALPHA-g – antihydrogen and gravity**
  - first full physics run with this machine – priority!
  - produces, traps and accumulates antihydrogen atoms
  - first attempts to do systematic release experiments – “up-down” determination
  - lots of data currently being analysed
  - **a very productive year in general**

Feedback ALPHA-Collaboration

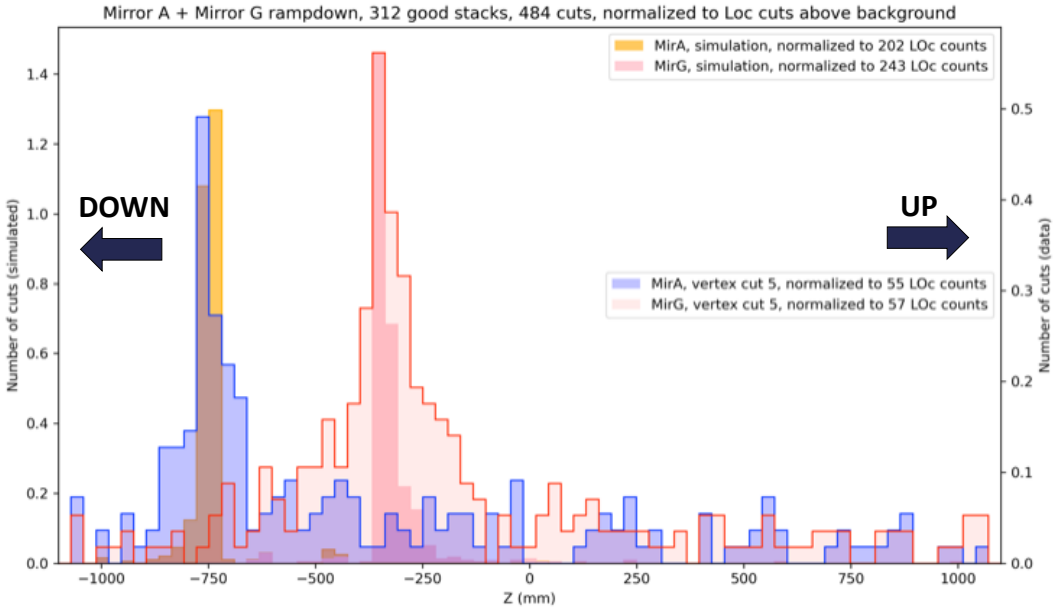
accumulated anti-atoms magnetically forced to escape either up or down

annihilation detected by TPC

NOT the gravity experiment



Signal of trapped antihydrogen released from ALPHA-g

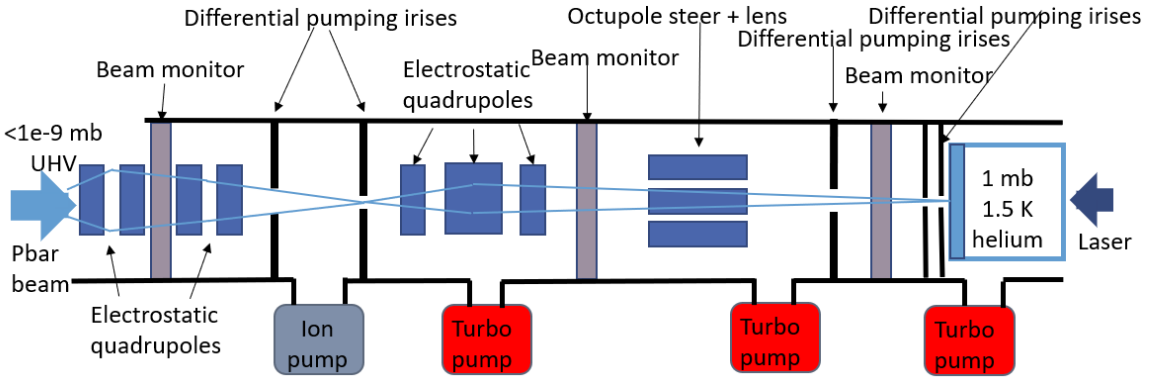


YETS 2022/2023 requests

- **Need liquid helium and water cooling for as much of YETS as possible.**
- Working with cryo-groups to reduce our helium transfer losses after the global distribution scheme has been abandoned.
- Fixed, return-gas-cooled transfer line being designed (L. Stewart); mid-2023

Feedback ASACUSA-Collaboration - pbarHe

- Objective and work done in 2022
  - ASACUSA modified the beamline compared to 2021 and achieved a beam size of 1.5 mm at the position of the experimental target with help from ELENA team. Highly improved compared to 2022.
  - Extensive differential pumping stages to separate the 1 mb / 1.5 K helium target, and the 1e-10 mb / 300 K vacuum of the ELENA beamlines: >11 orders of magnitude in terms of pressure at room temperature.



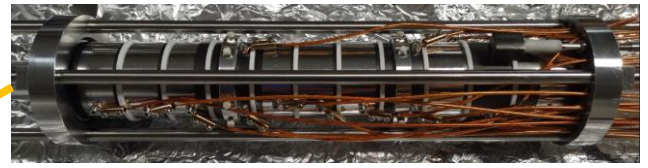
- Achievements made in the 2022 run
  - **Laser spectroscopy of infrared transition in antiprotonic helium atoms was successful and the hyperfine structure resolved. Demonstrated high signal stability of exotic atom signal compared to RFQD pre 2018.**

- Comments 2022 / 2023
  - Signal intensity will profit from induction deceleration of 100keV pbars to 80keV.
  - Helium gas from ASACUSA entered ELENA and resulted in 20% beam intensity losses, prevented prolonged operation of experiment. ELENA ion pump system is not designed to pump inert helium.

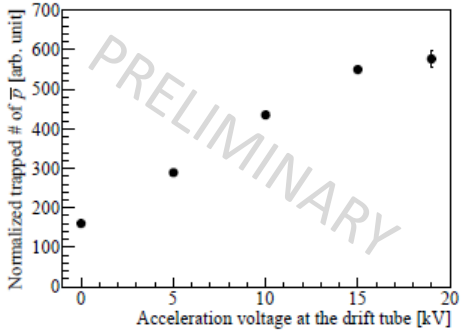
- Plans for 2023
  - ASACUSA will elongate the beamline to reduce gas going to ELENA, install 1 more lens, iris, pumps, steps toward induction decelerator at Mainz University Helmholtz-GSI Institute and KEK J-PARC.
  - **Request** urgent help in designing the beam optics for longer beamline.
  - **Request** help from cryogenic (helium pumping line) and vacuum brazing groups (new fused silica window) for modification of longer beamline.

Feedback ASACUSA-Collaboration: antihydrogen

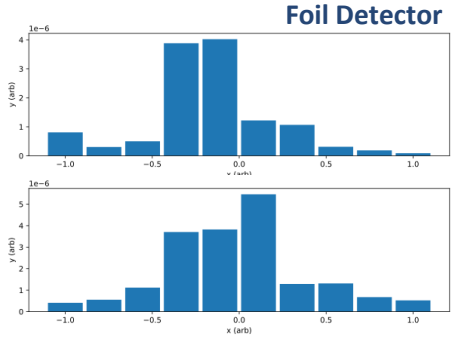
- **Install new positron system → no more LHe**
- **Upgrade antiproton trap DAQ and improve antiproton handling**



- **Antiproton catching working well with new drift tube**
- **Reduced antiproton prep. cycle time from 300s to 100s**
- **New positron system commissioned but still has a low trapping efficiency**



- **Beam spot was larger than expected at the MUSASHI trap entrance – many thanks to Yann Dutheil for his hard work trying to improve this during 2022**
- **In 2023 we will begin beam formation studies and look forward to more excellent stable beam as in 2022**



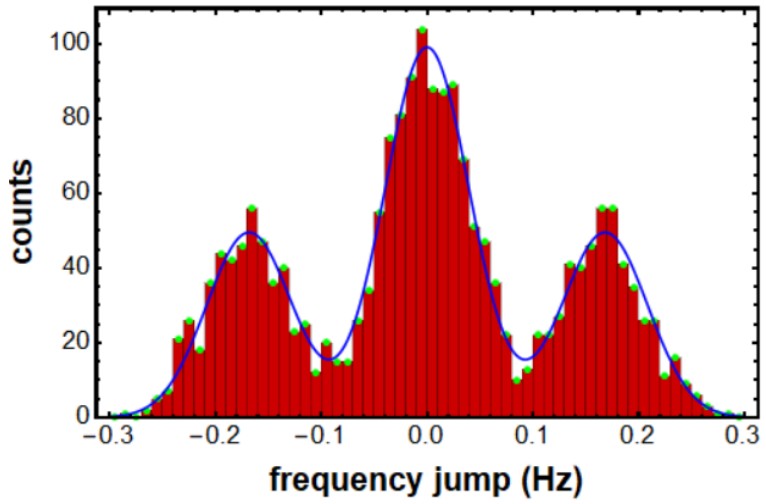
- **YETS (2022/2023) requests**
- **We need to keep developing the experiment running during YETS**
  - **Reliable cooling water**
  - **Uninterrupted power**
  - **Helium gas supply for compressor maintenance**

Feedback BASE-Collaboration

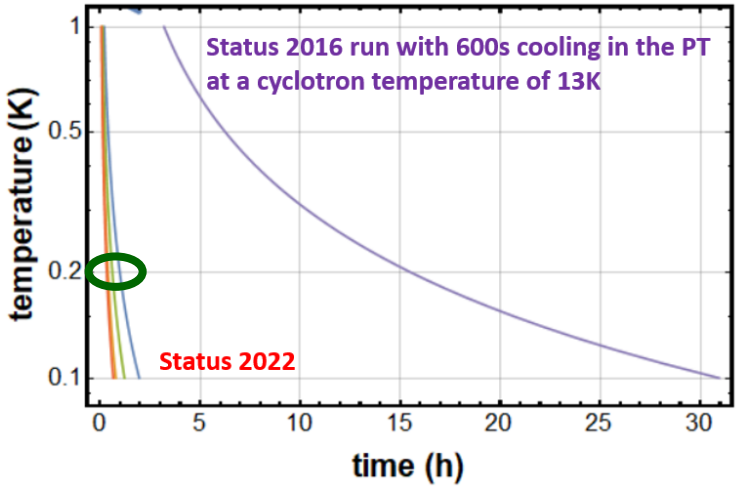
- **Goals of run**
  - Commissioning of a considerably upgraded multi Penning trap experiment to improve the precision in the antiproton magnetic moment by at least a factor of 10.
  - Vacuum (e-18) tests with newly developed 1.7um window
  - Re-commissioning of upgraded spin flip electronics and cryogenic filter system and **observation of single spin transitions in upgraded trap system.**
  - Implementation of quantum ground state transport.
  - Commissioning of newly implemented beam diagnostics tools.
  - Injection into the STEP magnet.
- **General Summary**
  - Excellent performance of the ELENA machine and fantastic support of the users by the ELENA OP team.
  - Moderately enthusiastic about experiment progress 2022.
- **Problems**
  - Antiproton injection problems through new degrader/catching/diagnosis system, additional upgrade of injection path required. New injection optics to be implemented.
- **Achievements**
  - **Successful** operation of considerably upgraded 4-trap system and local superconducting shimming system demonstrated.
  - **Successful** implementation of new cooling technology which **improves particle preparation time and experiment sampling rate by more than a factor of 60!**
  - Commissioning of trap homogeneity tuning **to reduce systematic shifts by factor of >1000 successful**.
  - BASE-STEP line successfully commissioned.
- **Requests for YETS 2022/2023**
  - Continuous delivery of cryoliquids during the entire YETS (1 dewar per week) to continue operation of BASE during the entire shutdown.
- **Plans / Requests for the 2023 (anti)proton run**
  - Finalize implementation of 4-trap control code.
  - Investigate implementation of coherent spin quantum transition spectroscopy.
  - Optimization of g-factor linewidth.
  - **Magnetic moment measurements (proton / antiproton / Hminus) and systematic studies.**
  - Antiproton transport with BASE-STEP

Progress BASE-Collaboration 2022

- Observation of single nuclear spin transitions with >90% quantum detection fidelity

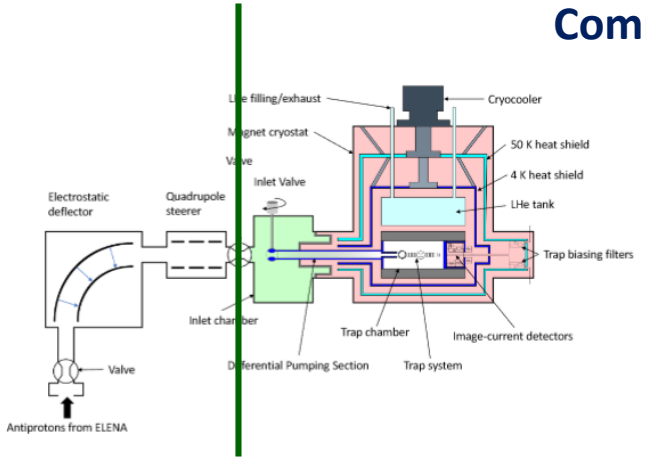


- New cooling technique improves time required for single particle preparation

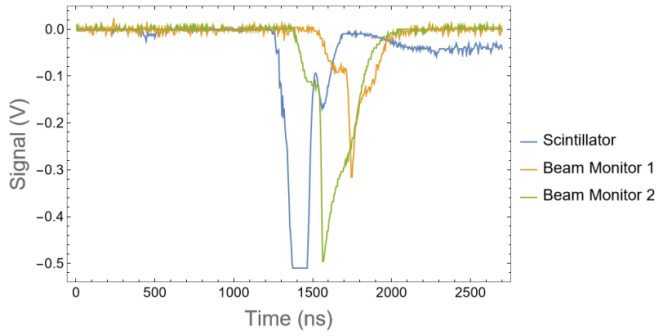


- 2017 antiproton run: 15h
- 2022 run: 10min.
- Considerable improvement of experiment sampling statistics

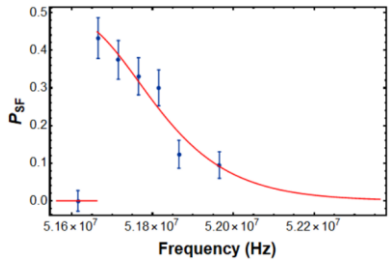
Commissioning of BASE STEP beamline



- Antiproton beam detected at the entrance of the future BASE-STEP magnet entrance.
- Magnet delivey problems (Bilfinger), scheduled delivery was March 2022, the Magnet has not been delivered yet.



ELENA is performing very well, **thanks to fantastic job of the AD/ELENA operators team and all related groups**



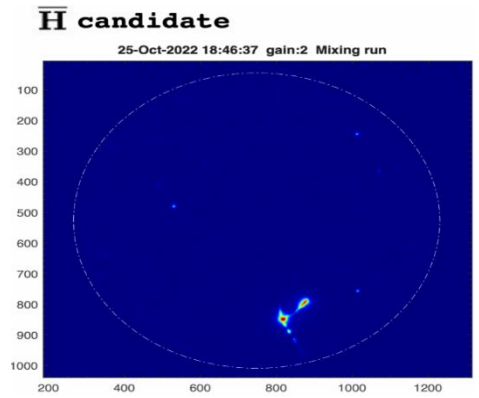
Feedback GBAR-Collaboration

- **AD/ELENA machine?**
  - Intensity, bunch length after rotation, steering, emittance measurement **—> very happy**
  - Would benefit from better emittance (without trap, we depend highly on beam quality), **present emittance is about factor 2 higher than in the initial proposal**.
  - H- beam has higher frequency (x8) —> more efficient steering, **but sensitive to AD magnet cycling**. Might be corrected in real time (ELENA team offered help, see talk by Davide Gamba).

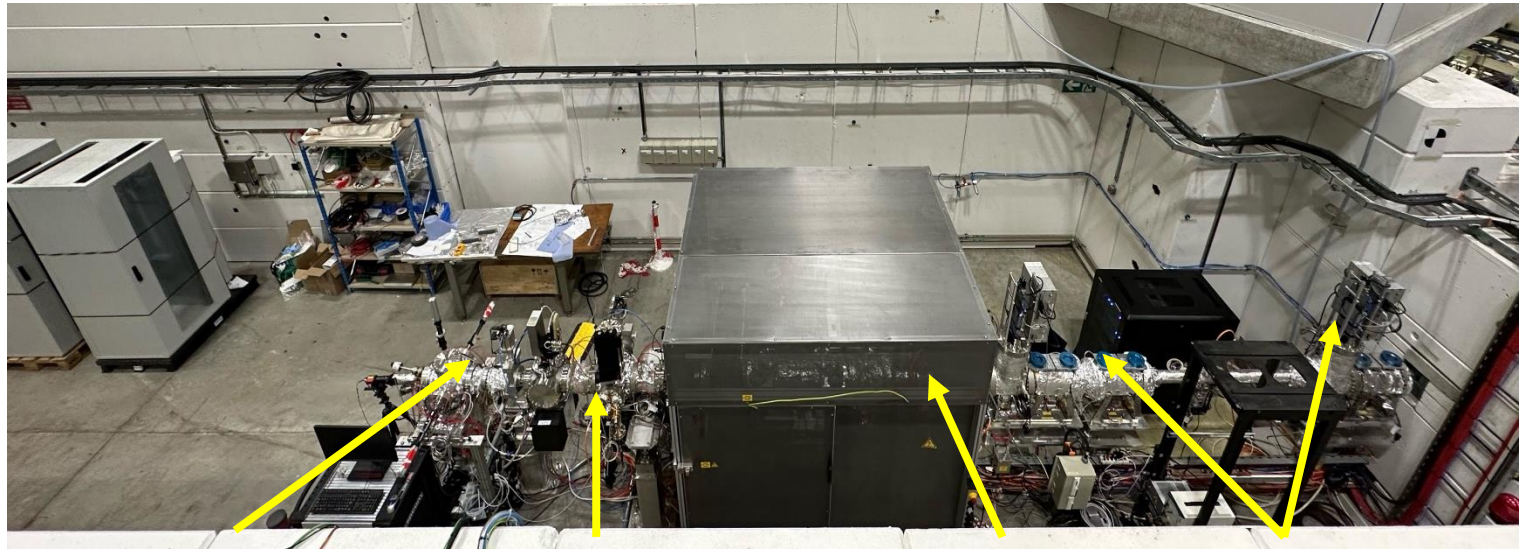
- **Experiment progress in 2022**
  1. Stable decelerator operation, **now at 6 keV, 100% efficiency**
  2. pbar beam steered to interaction point, beam spot ~2x larger than expected (incl. emittance) **—> 25% of beam interacts with Ps**
  3. Stable operation of e+ traps —> > 1.e8 e+/2 min. Efficiency of transport to interaction point is only 10% -> present bottleneck
  4. Hbar production analysis ongoing, first order evaluation **indicates evidence for antihydrogen production**.

- **Technical requests**
  - **YETS:** access to zone + water/power cuts, safety tests etc… are foreseen to happen at random times. This prevents us from organising efficiently to use this time to improve on positron trapping and transport. It seems each team determines when it is best for them to intervene. They may sometimes ask us when is best, but it would be more efficient for us if they would communicate more coherently among them to find a common period **-> better communication between CERN team and users requested**
  - Water flow —> makes high sound level in zone —> can this be improved?

- **Plans for 2023**
  - Hope to **implement antiproton trap in 2023**, which would alleviate the dependence on ELENA emittance.
  - Upgrade positron beamline to **increase the current 10% transport yield**.
  - Continued studies to **improve antihydrogen production yield**.
  - Progress towards production of the antihydrogen ion.



Feedback PUMA-Collaboration



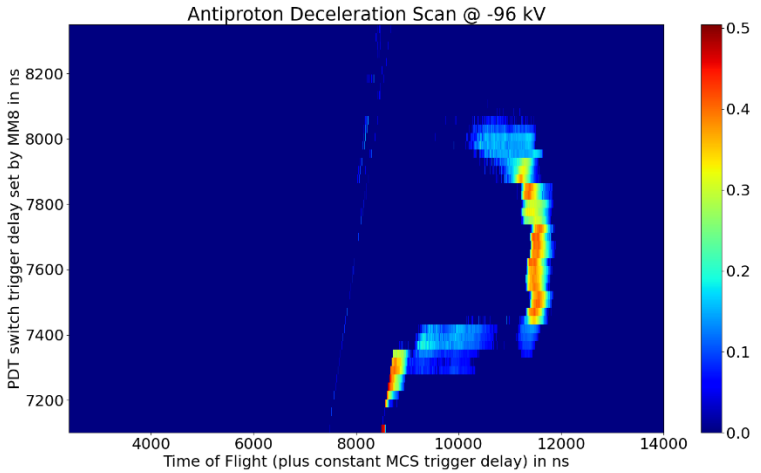
- **Progress 2022:**
  - Installation interlock of Pulsed Drift Tube (PDT) (June)
  - Safety visit for PDT (June)
  - Conditioning PDT (September - October)
  - PDT validation (November)
  - **Transmission of antiproton beam and slowing down to 4 keV successfully demonstrated**
- **Plans for 2023:**
  - modifications of PDT setup and final validation in-beam (May 2023)
  - construction of PUMA trap and assembly inside solenoid
  - validation with electrons
  - setup brought to ELENA and installed (summer 2023)
  - **first trapping of antiprotons**
  - **first attempt for transport (end 2023)**

PUMA trap:
- 90% of components received
- 4K cryostat in construction (CERN)
- Delays of procurement

Offline ion source:
- All equipments (source, Paul trap, MR-ToF) built
- Full assembly in December 22 – January 23

Time projection Chamber (pion detector):
- All parts built (CERN, November 22), electronics available and tested, cables received
- First test of detector in December 22

ISOLDE low-energy beam line:
- First design established



Summary

- **Overall Summary:** All collaborations made **excellent progress in 2022. Two new teams, PUMA and BASE-STEP successfully validated their beamlines and optics. Promising results in GBAR, very productive operation of ALPHA-g including the demonstration of antihydrogen trapping in this new experiment. Excellent progress in AEgIS towards evaporative cooling of antiprotons, excellent progress in BASE towards an improved measurement of the antiproton magnetic moment, hyperfine spectroscopy of antiprotonic helium demonstrated in ASACUSA.**

- **Communication:** All collaborations are **extremely happy about the professional, rapid, and pro-active support by the AD-operators team.**

- **Performance: Stability, reliability and reproducibility of the ELENA beam is excellent, congratulations and a big thank you to the awesome AD operators team and CERN!**

- **Experiment requirements:**
  - **All collaborations require support during the YETS,** since most experiments will continue shut-down experiments (cooling water / cryo-liquids / power), please communicate potential outages at least 14 days in advance.
  - Some collaborations **request better communication between CERN groups for more better synchronization and more efficient interfacing with the** collaborations.
  - Currently the AD program is mainly limited by LHe deliveries, no additional user could be accepted. **CERN may consider to upgrade LHe delivery system.**
  - Worries about the 2023/2024 YETS – old user side will be blocked by crane refurbishment. **For most collaborations technological progress during the YETS is essential for successful beamtime operation.**

Thank you very much for your attention

60 Research Institutes/Universities – 339 scientists – 6 Collaborations