GBAR plans from 2020 to 2024

(This is a draft to be discussed with our referees at the SPSC in order to check that the format is what the committee expects. It is presently limited to the minimum since I heard they wanted one or two pages. To be checked. Patrice)

The specificity of GBAR is to produce anti ions that will allow obtaining ultra-cold $\overline{\mathrm{H}}$. Thus, the first priority is toward producing $\overline{\mathrm{H}}^+$ ions in a reproducible way. Next is to cool these to μK temperature. An interesting by product is to measure the Lamb shift of hydrogen and anti-hydrogen with the same apparatus and very similar beam conditions [1]. Then the first application with the cold ions is the gravity experiment. The classical free fall measurement will be followed with quantum interference of the states produced from quantum reflection on a mirror that should allow improving the precision on $\bar{g}$ by three orders of magnitude [2].

We have started to discuss possible applications that the GBAR setup could host. The study of quantum reflection on the Casimir Polder effect is a subject in itself, which can be best studied with antimatter since each event can be detected. For instance, when the falling anti atom hits the inner surface of the vacuum chamber, it will have 5% probability to be reflected. Such events will be distinguishable provided the surfaces are well polished. *(this depends on the velocity wrt the wall and might be studied as a function of height).* Another application of having $\overline{\mathrm{H}}^+$ ions is to study the production of molecular anti H_2^+ ions, for instance by their interaction with antiprotons. If anti H_2^+ ions can be cooled, they would allow a higher precision on CPT tests than with $\overline{\mathrm{H}}$, up to three orders of magnitude in certain conditions [3]. Although a test on the production of those ions can be carried during run 3, the CPT experiment, if feasible, could only take place after LS3. A further extension is to add a neutral atom chip to the Paul traps in order to catch a neutral $\overline{\mathrm{H}}$ atom before it starts its free fall, opening the possibility to trap it at μK temperature, thus allowing for very high precision spectroscopy of $\overline{\mathrm{H}}$. Antiprotonic atoms could be created in the GBAR beam line that was originally dedicated for their dump, by interaction with a gas jet. Their spectroscopy using state of the art calorimeters would give new insight on Bound State QED.

The list of milestones below is thus more detailed about the steps toward the production of the anti-ions. We are still in the construction phase and will attempt at obtaining intermediate results during this phase. The production of anti-ions scales linearly with the flux of antiprotons, but as the square of the positronium density. Hence progress in the production and accumulation of positrons is of utmost importance and will be pursued steadily. The antiprotons will also be accumulated in a Penning-Malmberg trap. First simulations show that the beam of unused antiprotons can be reflected back into the trap with high efficiency instead of being dumped. Such scheme would allow increasing the flux of antiprotons and is considered as an upgrade for the short term. The capture and cooling of the anti-ions is being tested at Mainz and Paris.

The periods when antiprotons are not available will be used to improve processes using our proton source as well as the H- source from ELENA, if these can be delivered during these periods.

In the list of milestones below, I added months in red for internal scrutiny. For the SPSC, the time granularity would only be described in semesters or years. Maybe there are too many milestones for the SPSC, but I left them for collaborators to check that they agree on the roadmap. Then, depending on the request from our referees, elaborate the text, or not.

2020

First half

- Linac commissioning with new positron moderator → 10^8 e^+/s **March**
- Accumulation and storage of 10^9 e^+ in 500 s, formation of 3×10^8 Ps **March**
- Demonstrate H production using our proton gun **April**

- Demonstrate capture and cooling of protons (instead of $\overline{\mathrm{H}}^+$, same mass/sign) in capture trap by Be^+ or mix of Be^+ with HD^+ at Mainz **June**
- Receive H^- beam from ELENA → tune beam line, decelerate H^- to 1 keV **June**

2^{nd} half

- If 10^{10} e^+ accumulated in 500 s → demonstrate H^- production **July**
- Measure H Lamb shift
- Install antiproton trap **August**
- Demonstrate shuttling of cold protons from capture to precision trap in Mainz **September**
- Trap 10^7 protons in the antiproton trap and produce a usable beam **October**
- Study 2^{nd} reaction at high statistics with H from H^- stripped from ELENA **November**

2021

First half

- Install Free Fall Chamber, Tracker and TOF, cooling lasers
- Tests with cosmic rays, protons and H^-
- Possibly recycle protons into antiproton trap
- Study of capture of $^9Be^+$ by $^{88}Sr^+$ at Paris (same mass ratio as $\overline{\mathrm{H}}^+$/ Be^+, visible fluorescence of Be^+) [4]

2^{nd} half

- Demonstrate production of $\overline{\mathrm{H}}$ and $\overline{\mathrm{H}}^+$
- Measure Lambshift with $\overline{\mathrm{H}}$
- Attempt at observing free fall

2022

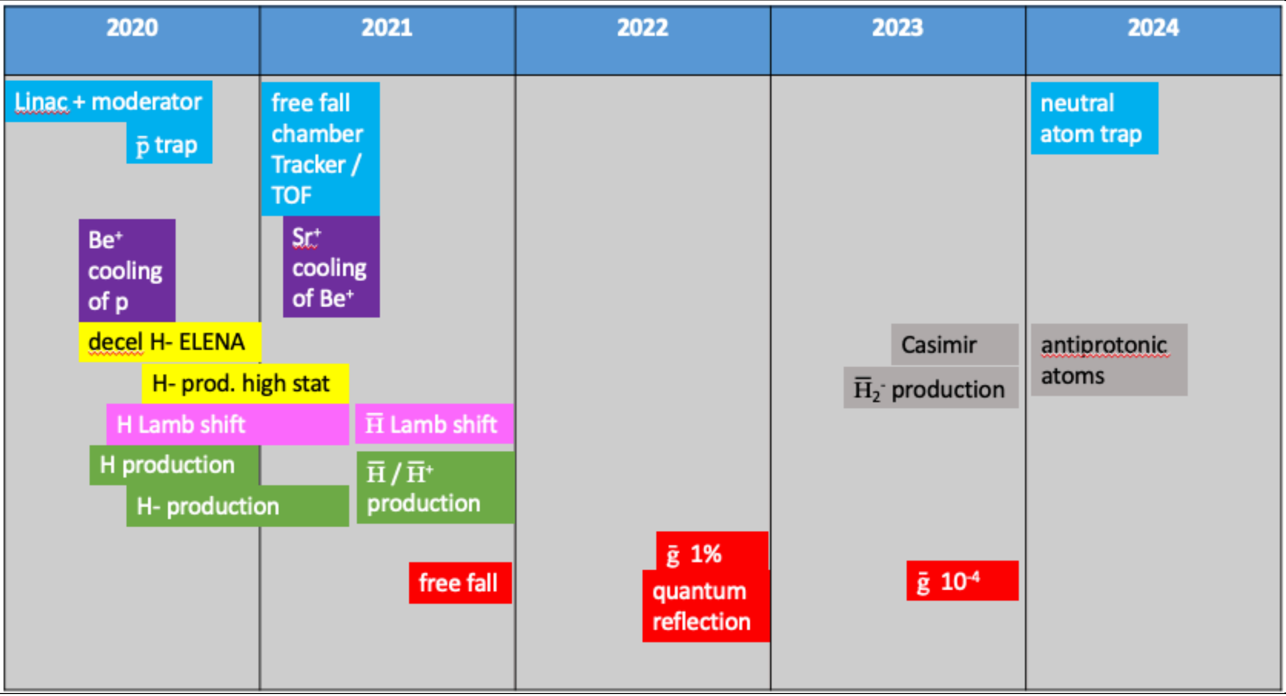
- Aim at 1% precision on $\bar{g}$
- Insert mirror for quantum reflection and observe interference pattern → improve precision

2023

- Improve precision on $\bar{g}$
- Study of Casimir effect
- Test production of anti $\overline{\mathrm{H}}_2^+$

2024

- Insert neutral atom chip → ultracold μK temperature → spectroscopy



References

[1] P. Crivelli, D. Cooke and M. W. Heiss, Phys. Rev. D 94, 052008 (2016)

[2] P.-P. Crépin et al., Phys. Rev. **A 99**, 042119 (2019)

[3] E. G. Myers, Phys. Rev. **A 98**, 010101 (R) (2018)

[4] *Sympathetic cooling of $^{9}Be^{+}$ by $^{88}Sr^{+}$ Doppler cooled ions in large Coulomb crystals: an experimental study.* A. Douillet et al., NACTI, Boulder/CO : s.n., 2017