GBAR principle: cool $\bar{H}^+$ to get ultra-slow $\bar{H}$

- $\bar{H}^+ = \bar{p} \ e^+ e^+$
- Sympathetic cooling with Be$^+ \rightarrow 10 \ \mu K$
- Photodetachment of e$^+$
- Time of flight

$h = \frac{1}{2} \ g (t_1 - t_0)^2$

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$m_i \ddot{a} = m_g \ddot{g}$

$h = v^0_z t + \frac{1}{2} \frac{m_g}{m_i} g t^2$

L 0.1 m
h 10 cm
$\Delta t$ 143 ms
$v_h$ 0.5 m/s
$T_H$ 20 $\mu K \sim 7$ neV

Goal

$\frac{\Delta g}{g} \leq 1\%$
A recipe to produce anti ions

Standard $\bar{H}$ production via 3-body process

$\bar{p} + e^+ + e^+ \rightarrow \bar{H}^* + e^+$

Demonstrated by ATRAP (2004)

Idea for GBAR:
2$^{nd}$ charge exchange reaction

$\bar{p} + Ps \rightarrow \bar{H} + e^-$

$\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$

Binding energy of $\bar{H}^+ = 0.75$ eV = energy level of $Ps (n=3)$

Expect cross-section enhancement if $Ps$ excited to $n=3$
CERN provides per bunch every 110 s

\[ \sim 0.5 \times 10^7 \bar{p} \]
\[ 10^{12} \text{Ps/cm}^2 \]
\[ \rightarrow 10^4 \bar{H} \]
\[ \rightarrow 1 \bar{H}^+ \]

\[ \text{threshold for Ps}(1s) \]

\[ 20\% \text{Ps}(2p) \]
\[ 100\% \text{Ps}(1s) \]
\[ 40\% \text{Ps}(3d) \]

\[ \sigma^2 (\pi a_0^2)^2 \]

\[ \text{Impact energy (keV)} \]

P. Comini, P-A. Hervieux and F. Biraben, LEAP 2013
synoptic view

- LASER 1.64 µm
- LINAC $e^- 10 \text{ MeV}$
- W TARGET & MODERATOR $e^+ 3 \text{ eV}$
- Buffer Gas $e^+ 1 \text{ keV}$
- MR TRAP
- ELENA CERN-AD $\bar{p} 100 \text{ keV}$
- DECELERATOR $\bar{p} \text{ keV}$
- FOCUS

**DETECTION**
1 Be$^+$
1 $\bar{H}^+$
$\sim \text{ neV}$

**CAPTURE & COOLING**
$\bar{H}^+ - \text{Be}^+$

**LASERS**
313 nm

**LASER**
410 or 243 nm

Ps

keV $\bar{H}$
keV $\bar{H}^+$
keV $\bar{p}$
Tested and ready for 100 kV switching

Vacuum 5 $10^{-9}$ mbar  OK for passage of $\bar{p}$ but too high for ELENA

Chamber will be changed before April 2018  $\rightarrow$ $10^{-10}$ mbar

Proton gun for tests
• 7 T superconducting magnet with active shielding
• will be operated at 3 T
• being equipped → trap
• now at Korea University Seoul
• to be tested with electrons in Korea
• then transport to CERN in 2018?
Electron Linac

- installation started in February 2017
- temporary accelerating cavity structure
- destruction of heat exchangers due to > 20 bar water pressure bursts
- leaks in wave guide → procurement delay
- extensive safety documentation
- two operation modes depend on repetition rate:
  - < 3 Hz allow working in exp. zone
  - 3-300 Hz zone patrolled, work in remote control
- radiation shield tested with RP
  → OK after few adjustments
- beam permit approved for October 2017
• first beam in October 2017
• beam energy measured with magnetic spectrometer
• set operating point at 8.3 MeV / 100 mA to keep safety margin
  (activation threshold ~10 MeV)
• repetition rate limited to 100 Hz due to target outgassing
• final accelerating structure completed at NCBJ
• new gun $\rightarrow$ 1 A/4 $\mu$s pulses
• tests OK at 300 mA peak / 7.5 MeV $\rightarrow$ 10 MeV
• installation starts Feb. 12 (3 weeks)
- Tungsten target is water cooled
- Tungsten mesh moderator
- slow positrons are guided outside the bunker using 8 mT solenoids and coils
• slow positrons hit a target outside the bunker and produce 2 gammas of 511 keV
• gamma detection with NaI or plastic scintillator
• energy measured with retarding potential grid
• $3.7 \times 10^4\ e^+ / \text{pulse}$
• outgassing limited in 2017, ready to proceed to higher linac power
• energy spread $1.3\ \text{eV (std dev.)}$ suitable for buffer gas trapping
Positron trapping

- Buffer Gas Trap built & tested at Saclay
- High field Trap from RIKEN repaired (cryoheads)
- aligned in exp. zone
- being commissioned for trapping

reaction chamber ready for installation
switchyard to distribute $\bar{p}$, $H$ and $H^+$

free fall chamber

Ps excitation laser
Be$^+$ cooling towards H$_2^+$ cooling

Be$^+$ crystal

Hollow crystal

LKB team

LKB Paris-Jussieu
Mixed crystals

*fluorescent Be\(^+\) crystal*

*Ca\(^+\) crystal with dark Be\(^+\) ion*

Rabi-flops on axial COM mode of a mixed crystal

Mainz – JGUM lab

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23/01/2018

P. Pérez - SPSC CERN
Detection

First plane of TOF counters operational
time resolution 80 ps

- can distinguish particles going up from down,
i.e. annihilations occurring at top or bottom of
free-fall vessel or cosmic rays

Five double planes of MicroMegas chambers made
Increase of gap from 5 mm to 10 mm
Change gas mixture → Ar/CF4/Isobutane (96/2/2)
→ better than 96 % efficiency per X/Y plane
Outlook

- final linac
- drift tube decelerator with 10 kV protons, then ~100 keV H\(^-\) from ELENA
- e\(^+\) traps
- Ps in reaction chamber
- Ps* laser
- first \(\bar{p}\) for physics (June-July?)
- antihydrogen beam in 2018?
GBAR Collaboration