AEgIS phase2

Work program

Ruggero Caravita (AEgIS Physics Coordinator)
Summary of the letter to the SPSC – addendum to the AEgIS proposal

Physics channels

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<td>Antihydrogen</td>
<td>beam</td>
<td>Pulsed extraction from 1T trap, Ps* via delayed e− injection</td>
<td>Multitarget beam detector</td>
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<td>Pulsed implantation, laser-cooled 2sPs in Ps test station</td>
<td>2s-3s hyperfine spectroscopy</td>
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Technical challenges

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<tr>
<th>#</th>
<th>Physics channel</th>
<th>source type</th>
<th>method</th>
<th>Challenge(s)</th>
<th>Electrode configuration</th>
<th>Minimal Bfield</th>
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<tr>
<td>1</td>
<td>Antihydrogen</td>
<td>4r</td>
<td>Ps* on static p in 1T trap</td>
<td>$\beta$ temperature</td>
<td>One $\beta$ well (harmonic) close to $Ps$ converter</td>
<td>IT</td>
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<td>Antihydrogen</td>
<td>4r</td>
<td>Cs excited to Cs* within e−; Ps* interacts with downstream p</td>
<td>$\beta$ temperature</td>
<td>2 opposite sign wells (harmonic)</td>
<td>IT</td>
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<td>Antihydrogen</td>
<td>beam</td>
<td>Cs− in upstream trap; p in middle trap; e− in downstream trap</td>
<td>$Cs^−$ formation; $\beta$ temperature</td>
<td>3 wells ↔ ↔</td>
<td>IT</td>
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<td>4</td>
<td>Antihydrogen</td>
<td>beam</td>
<td>Pulsed extraction from 1T trap, Ps* via delayed e− injection</td>
<td>$Cs^−$ formation; $\beta$ temperature</td>
<td>Decay (potential 0.17)</td>
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<td>Raze, Ps lifetime</td>
<td>1 well</td>
<td>IT</td>
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<td>Pulsed implantation</td>
<td>TPs (40 keV)</td>
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<td>12</td>
<td>Protonium</td>
<td>beam</td>
<td>2sPs</td>
<td>Laser cooling</td>
<td>Not in magnet</td>
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Prospects towards gravity

<table>
<thead>
<tr>
<th>System</th>
<th>Grating size</th>
<th>Goal</th>
<th>Statistics required</th>
<th>Expected beam time to reach sensitivity goal</th>
<th>Comment</th>
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<tr>
<td>$H^*$ or $H$</td>
<td>100 $\mu$m</td>
<td>5 g</td>
<td>5000 detected $H^*$</td>
<td>Integration time $\approx$ 5000 h at 0.1 Hz production rate</td>
<td>4r source at 10 K</td>
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<tr>
<td>$Pn^*$</td>
<td>6 $\mu$m</td>
<td>0.5 g</td>
<td>4000 detected $Pn^*$</td>
<td>Integration time $\approx$ 500 h</td>
<td>at 100 K</td>
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<tr>
<td>Cs($\beta^*$</td>
<td>6 $\mu$m</td>
<td>0.5 g</td>
<td>10 detected Cs$\beta^*$</td>
<td>Integration time $\approx$ 60 hours, assuming 100 s overall cycle for loading/mixing/cooling/mixing and 10$^7$ H− with p. Limited by H− availability.</td>
<td>at 100 K</td>
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<tr>
<td>Ps$^*$</td>
<td>6 $\mu$m</td>
<td>0.5 g</td>
<td>5000 detected Ps$^*$</td>
<td>$\approx$ 25 Cs$^+$ into 30 ms/100 s assuming 100 s cycles on 10$^5$ Ps$^*$ and stacking of 10 AD $\beta$ cycles.</td>
<td>at 100 K (10 K not better due to magnetron motion)</td>
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Summary of the letter to the SPSC – addendum to the AEgis proposal

Physics channels

Gravity on antihydrogen beam via pulsed charge exchange
- Installation and test of new trap electrodes
- Connection to the ELENA beamline
- Improvement of the Hbar source flux
- Development of pulsed Hbar beam via process #2 / #4
- Interaction of Hbar with gratings
- Proof-of-concept inertial sensing with pulsed Hbar

Complementary R&D and alternative methods
- Ps* cooling in B = 0
- Deflectometer development and test with Ps* development
- Development of 235 Ps beam
- Development of light grating interferometer and test with 235 Ps
- Installation and test of internal Cs source and Cs trapping
- Cs(pbar) and protonium formation
- Interaction of Pn* and Cs(pbar)* with gratings
- Inertial sensing with Pn* and Cs(pbar)*
- Fluorescence spectroscopy of Cs(pbar), Pn
- Transport/trapping of Pn* to downstream B=0 region

C2 - cooling in Paul trap
- C2 trapping and cooling in Penning trap
- Sympathetic cooling of pbar with C2
- Reduction of pbar plasma temperatures to O(10K)
- Demonstration of Hbar production via process #1 / #3
- De-excitation of Hbar
- Transport of Hbar/Hbar* in a B=0 magnetic field region
- Development of pulsed Hbar beam via process #1 / #3

| Cs(pbar)* | 6 µm | 0.5 g | 10 detected Cs | 10 minute C&D, 10 cycles, stacking of 10 A&D (pbar) cycles, Integration time ~ 10 minutes, Limited by Cs availability.
| Ps* |
Work program – proof-of-concept gravity measurement on an antihydrogen beam via pulsed charge-exchange

1. Setting up the stage for ELENA
   1. Positron system removal for beam line installation  Seba + Benji
   2. Development of the energy degrader for 100 keV antiprotons  TBD (*Nicola M.?)

   Goal/Milestone: getting x10 pbars from ELENA

2. New pbar trap design
   1. Simulation and optimization for scientific goals  Ruggero
   2. Design and build a new trap with high ideality  Stefan + Rob
   3. Proper RF noise filtering  TBD (*Leonardo R.?)
   4. Commissioning and optimization with electrons  TBD (Gianni?)

   Goal/Milestone: holding x10 pbars to state-of-the-art pbar temperature (T<15K)

3. New Ps target+holder for collinear charge-exchange (Ps* on-axis excitation)
   1. Simulation of through-plasma e+ implantation  TBD (Francesco G.?)
   2. Design and build a new small target and holder on-axis  Seba + Stefan
   3. Commission and optimization of Rydberg laser excitation efficiency  TBD

   Goal/Milestone: increase the Hbar formation probability by x10

4. Upgraded Hbar detection
   1. Design and installation of field-ionization grids  Rob + Stefan
   2. Compensation of FACT thermal drifts  Stefan
   3. FACT calibration system  Stefan
   4. Active MPPC veto  TBD (Oline)
   5. Maintainance/upgrade of scintillators  TBD (Pv group? Gianni?)
   6. Review/upgrade of DAQ system  Francesco P.
   7. Review/upgrade of data analysis tools  TBD (Bs group?)

   Goal/Milestone: unambiguous Hbar detection (possibly early-time)

5. Trap electronics work
   1. Repair of triggerable pulsers  TBD (Vittorio?)
   2. Consolidation of e-gun filament  TBD
   3. Consolidation of high voltage system  Luca P.

6. Control system work
   1. Definition of a language for automatic Excel files production  Ruggero + Michael
   2. Slicing of existing procedure in logical sub-blocks  Ruggero
   3. High-level user interface  Michael

   Goal/Milestone: easy hands-on experiment interface for common usage

7. Laser system work
   1. Recover EKSPLA beam energies  Antoine + Ruggero
   2. 1700nm automation and diagnostics (spectrum, imaging)  TBD
   3. Sharing of master clock to laser FPGA  TBD
   4. Fiber for inner region illumination  TBD

   Goal/Milestone: full automation and diagnostics of the laser

8. Active magnetic shimming (> 2021)
   1. Magnetic field homogeneity survey at room temperature (Hall probes)
   2. Design of the shimming coils and feedback (active magnetic shielding)
   3. Magnetic field homogeneity survey and compensation at cold (NMR probes)

   Goal/Milestone: demonstrate a magnetic field homogeneity for measuring gravity with Rydberg atoms

   1. Detector design for high spatial resolution  TBD (Hovard/Heidi?)
   2. Deflectometer design and build  TBD (PSI?)
   3. Design of the optical alignment system  TBD

   Goal/Milestone: demonstrate inertial sensitivity

First responsible people are all > PhD
* marks new people
Work program – complementary R&Ds and alternative methods

1. **R&D positronium**
   1. Ps cooling in B = 0
   2. Development of 2s5 Ps beam
   3. Deflectometer development and test with Ps/Ps*
      Long term goal: gravity on positronium
      TBD (Christian?)
      Ruggero
      Lisa

2. **R&D antiprotonic systems**
   1. Installation of internal Cs source and Cs- trapping
   2. Cs(pbar)* formation and Pn* formation
      Long term goal: gravity/spectroscopy with antiprotonic systems
      TBD (Saiva + Daniel?)
      TBD

3. **R&D sympathetic cooling with anions**
   1. C2- in the ground state
   2. C2- trapping and cooling in a Penning trap
      Long term goal: sympathetic cooling of pbars with anions
      Emmanuel?
      TBD

4. **R&D antihydrogen**
   1. Consolidation of TL cooling
   2. Reduction of pbar plasma temperature to o(10K)
   3. De-excitation of Rydberg hydrogen
   4. Antihydrogen production a la ATRAP
      Long term goal: improvement of hbar production
      TBD (Chloe? Tim/Lilli?)
      TBD

First responsible people can be PhD, and PhDs involved in the exp. are encouraged to take responsibility of a work package

LAC
- Lyman alpha
- Cesium oven

Still need input from:

*Krakow? *Warsaw
*India

INR?

*PSI

Oslo+Bergen?

INFN Brescia

INFN Pavia

SMI?
> request vote for approval <