Antimatter Source

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High Intensity Hadron Facility and Nuclear and Particle Physics Experiments
June 19, 2003, CHEP, Daegu, Korea
Outline

- Antimatter Physics
- Anti-matter Factories
- Antiproton Source
- Anti-Hydrogen
- Summary
Antimatter Physics?
(LEAP03 ๔ ๔)

- Symmetry and Antihydrogen
  - Theoretical aspects of CPT violation
  - CP,T and CPT Violations in the $K^0 - \bar{K}^0$ System - Present Status -

- Anti-hydrogen Atoms
  - First Production and Detection of Cold Antihydrogen Atoms
  - Temperature dependence of antihydrogen production in ATHENA
  - Background-free Observation and Driven Production of Cold Antihydrogen
  - Positron Cooling of Antiprotons in a Nested Penning Trap

- Future AD experiments
  - Progress Toward Two-stage Charge Exchange Production of Anti-hydrogen Atoms
  - Lasers and Antihydrogen
  - A Cusp Trap - a possible new technique to synthesize a polarized antihydrogen beam for HFS measurements
  - Measurement of the Hyperfine Structure of Antihydrogen
  - Future experiments with ATHENA
QCD and Hadron Physics
- Testing QCD - from LEAR to GSI
- Hadron Physics with Antiprotons
- Study of charmonium states formed in antiproton-proton annihilations: results from Fermilab E835
- Charmed Hybrids in Proton-Antiproton Annihilations
- Open problems in low energy antineutron interactions
- New types of nuclear systems containing antibaryons

Antiprotonic helium atoms
- High precision laser spectroscopy of antiprotonic helium atoms
- Precise study of Auger dominant metastable states in antiprotonic helium atoms
- High-accuracy calculation of metastable states of the antiprotonic helium atom: Characterization of the atoms
- Laser-induced antiproton-positron recombination in traps
- State selective (n,l) capture distributions in low energy antiproton-helium collisions
- Measurement of the hyperfine structure of antiprotonic helium by a laser-microwave spectroscopy technique
- Collisional Effects on HFS transitions of Antiprotonic Helium
- Auger Decay Rates of Antiprotonic Helium Atom States
Antiprotons in the universe and antihydrogen
- AMS - Alpha Magnetic Spectrometer
- BESS- Polar
- The balloon- borne and PAMELA Experiments for the Study of the Antimatter Component in Cosmic Rays
- A novel antideuteron detector for space- based indirect dark matter searches
- Does the World of the Antimatter exist in the Universe?
- Antihydrogen formation in antiproton- positronium collisions
- Effects of impurity molecules on the lifetime of antiprotonic helium atoms

Atomic collisions
- The slowing down of antiprotons in matter
- Theory of the ionization of Helium by protons and antiprotons
- Collinear study of protonium formation in collisions of antiprotons with hydrogen molecular ions
- Ionization cross sections of helium and hydrogenic ions by antiproton impact
- Hydrogen- Antihydrogen interaction at sub Kelvin temperatures
- Double- to single- ionization ratio of helium atoms by proton and antiproton impacts
- Double- ionization by fast proton and antiproton impact
Nuclear Physics

- Future Experiments on Hypernuclei and Hyperatoms
- Theoretical Prediction to Double $\Lambda$ Hypernuclear Spectroscopy with Antiprotons
- Information on the nuclear periphery deduced from the properties of heavy antiprotonic atoms
- Antiprotonic Potentials from Global Fits to the PS209 Data
- The pbar- Atoms, Optical Potential and Nuclear Surface Studies
- Depolarization and spin transfer in p+pbar - $\to$ Lambda+Lambdabar with a polarized target
- Correlations among spin observables in the reaction antiproton-proton - $\to$ AntiLambda- Lambda
Summary for Antimatter Physics

- Tests of Symmetry: CPT, CP, T invariance
  - Anti-hydrogen Atoms
  - Anti-hydrogen Cooling, atomic collisions
- Antimatter in the Universe: CP violation, Baryon Genesis
- Antiprotonic Helium
- QCD and Hadron Physics
- Nuclear Physics
1964, CP violation was observed in K mesons, or kaons.

1967, Andrei Sakharov: 3 conditions for dominance of matter in the universe:
   1) CP violation
   2) Baryon number nonconservation
   3) Early universe cannot always have been in thermal equilibrium

2001, CP violation in B system was observed by BaBar at SLAC and Belle at KEK.

CP violation in SM (K and B: weak interactions) is not enough
→ beyond the SM

Supersymmetry may be a modification: SUSY allows stronger CP violation

CP violation in Strong interactions (not so, so far) but why not?

New Physics?

Need Detailed studies in direct measurements of
   Antimatter/matter ratio in the universe
   Precision tests of CPT, CP, T
Why antimatter?

Why do physicists want to get a very good look at antimatter?

- One reason is that no one, so far, has been able to figure out why our universe is made of matter instead of antimatter.
  - According to all our best theories about the beginning of the universe, the amounts of matter and antimatter should have been exactly equal.
  - This would have been very bad for any future prospects of life, or indeed, any structure in our universe. For each particle created by the Big Bang, a similar antiparticle came into existence. Mix this together in the tiny spaces of the new universe, and all matter and antimatter should have annihilated in a fraction of the first second of time.
- In truth, we think this very nearly happened. Matter and antimatter were created in almost exactly the same amounts, and did fill the early universe with an intense bath of radiation created by their annihilation. But for some unknown reason, the universe was slightly off balance. For every billion, trillion (who knows, maybe far more than that) particles of antimatter, a billion or trillion or whatever plus one particles of matter were created. We, our galaxy, and all the matter in the universe are just the tiny bit of ash that was left over after almost all of the universe annihilated itself.

What caused this tiny imbalance that we owe our existence to?

- We don't know, but the folks at CERN and the world's other particle laboratories are hoping to find some kind of clue in the behavior of antimatter. Now that antiatoms can be created in abundance, they'll be poked and prodded for any clues to the intrinsic differences between matter and antimatter.
- Maybe, in hundreds of years, we'll end up with warp drives and starship Enterprises. Maybe terrible weapons. Or maybe just a better understanding of how our entire universe came into being in the first place.
Beyond the Standard Model

"we might find a flaw in the Standard Model, since the dominance of matter in the universe strongly suggests that there are other forms of CP violation in nature that are not included in the theory."

In 1967 the late Andrei Sakharov showed that, in addition to CP violation, two criteria must be met for matter to dominate the universe: the universe cannot be in thermal equilibrium, and there must exist certain processes that can change "baryon number". However, reactions that change baryon number have never been observed, although they are allowed by certain extensions of the Standard Model.

"It is possible that the theory of how the matter-antimatter asymmetry in the universe built up may need modification," adds Harrison. "But either way we win because there is something that we don't fully understand about the universe and, therefore, there is something new to be found."

Indeed, most extensions of the Standard Model introduce other parameters that violate CP symmetry. "It is a puzzle," says Matthias Neubert, "that these effects are not seen in the vast data sets collected by the B factories at Cornell, Stanford, KEK and Fermilab." Another mystery, he adds, is the fact that CP violation has not be observed in strong interactions, where the effect should be orders of magnitude larger than in weak decays.

"We are sure that the Standard Model must fail at some level and are stunned by the fact that no such failure is observed at the current level of experimental precision. Searches for new physics at the B factories will complement direct searches for new physics in experiments at the energy frontier."
Where is all the Antimatter?
(AMS exp. will look for antiprotons, antiheliums, anti-carbons etc.)

- ...
- The new AMS02 is scheduled to be placed aboard the International Space Station sometime in 2005 (NASA).
- Still, some scientists think that there might be large sections of universe made from antimatter. To try and settle this matter, NASA will use the new Alpha Magnetic Spectrometer (AMS) scheduled to be installed on the International Space Station in 2005. This AMS is designed to look for relatively heavy antimatter -- anti- helium nuclei or particles even more massive, such as anti- carbon, that may come zipping through our solar system from far away antimatter galaxies.
- Finding massive antimatter particles would be important because normal high-energy particle interactions involving regular matter don’t usually produce heavyweight antimatter such as anti- helium or anti- carbon. Such heavy antimatter would most likely have been left over from the creation of the universe, suggesting that somewhere out there is a mass of antimatter that has so far gone undetected.
The Antimatter Factory at CERN

- The first "self-contained antiproton factory", the Antiproton Decelerator (or AD), is operational at CERN. It will produce the low energy antiprotons needed for a range of studies, including the synthesis of antihydrogen atoms - the creation of antimatter.

- **16 Sept 2002**
  
  **Anti-atoms produced at CERN**
  
  The ATHENA collaboration, one of the 3 international teams of physicists working at the Antiproton Decelerator (AD), has announced the first controlled production of large numbers of antihydrogen atoms at low energies!

- "The controlled production of antihydrogen observed in ATHENA is a great technological and scientific event - says Professor Luciano Maiani, Director General of CERN - even more so because ATHENA has produced antihydrogen in unexpectedly abundant quantities..."

- **ATHENA, ATRAP, ASACUSA**
LEAR (Low Energy Antiproton Ring)

Proton anti-proton annihilation event
- The AD ring:
  - an approximate circle with a circumference of 188 m

- It consists of a vacuum pipe surrounded by a long sequence of vacuum pumps, magnets, radio-frequency cavities, high voltage instruments and electronic circuits. Each of these pieces has its specific function:
  - Antiprotons circulate inside the vacuum pipe in order to avoid contact with normal matter (like air molecules), and annihilate. The vacuum must be optimal, therefore several vacuum pumps, which extract air, are placed around the pipe.
  - Magnets as well are placed all around. There are two types of magnets: the dipoles (which have a North and a South pole, like the well-known horseshoe magnet) serve to change the direction of movement and make sure the particles stay within their circular track. They are also called "bending magnets". Quadrupoles (which have four poles) are used as 'lenses'. These "focussing magnets" make sure that the size of the beam is smaller than the size of the vacuum pipe.
  - Magnetic fields can change the direction and size of the beam, but not its energy. To do this you need an electric field: this is provided by radio-frequency cavities that produce high voltages in synchronicity with the rotation of particles around the ring.
  - Several other instruments are needed to perform more specific tasks: two cooling systems "squeeze" the beam in size and energy; one injection and one ejection system let the beam in and out of the machine.
Example of a Radio-Frequency (RF) accelerating cavities. Here the ones installed for the first phase of LEP 1989-95.
Technician installing a magnet in CERN’s new Antiproton Decelerator (AD) ring.
The new AD, begun in 1997, is actually optimized to slow antiprotons rather than to let them coast or speed up in the manner the other storage rings in the world. Based upon TRAP’s demonstration that antiprotons could be accumulated in tiny ion trap much more inexpensively than in a large storage rings, CERN was able to open the way to the new, low energy frontier, and at the same time save resources by replacing three storage rings with the new AD.

Two experiments, ATRAP (the offspring of TRAP) and ATHENA, seek to make cold antiprotons interact with cold positrons (the antimatter counterpart of electrons) in a way intended to form cold antihydrogen atoms for the first time. A third experiment, ASACUSA, creates and studies exotic helium atoms in which an electron is replaced with an antiproton. With the first AD antiprotons, ATRAP has already trapped and electron-cooled antiprotons, and ASACUSA has begun its spectroscopy of exotic helium.

An antihydrogen atom, a positron orbiting an antiproton, is the simplest atom formed entirely of antimatter. Several very rapidly moving antihydrogen atoms were first observed at CERN in 1995, demonstrating that these atoms can be formed. With CERN’s new dedicated facility the quest begins to make antihydrogen atoms that are cold enough to be trapped, whereupon lasers directed at them can probe for tiny differences between antihydrogen and hydrogen.
The History of Antimatter

From 1928 to 1995

• 1928: the Beginning: P.A.M. Dirac electron and positron
• 1930: nature's helping hand: In 1932 Carl Anderson, a young professor at the California Institute of Technology, was studying showers of cosmic particles in a cloud chamber and saw a track left by "something positively charged, and with the same mass as an electron". After nearly one year of effort and observation, he decided the tracks were actually antielectrons, each produced alongside an electron from the impact of cosmic rays in the cloud chamber. He called the antielectron a "positron", for its positive charge. Confirmed soon after by Occhialini and Blackett, the discovery gave Anderson the Nobel Prize in 1936
• 1954: power tools: In October 1955 the big news hit the front page of the New York Times: "New Atom Particle Found; Termed a Negative Proton". With the discovery of the antiproton, Segre' and his group of collaborators (O. Chamberlain, C. Wiegand and T. Ypsilantis) had succeeded in a further proof of the essential symmetry of nature, between matter and antimatter. (Berkeley’s Bevatron: 6.2 GeV)
• 1965: antinuclei: The answer to the antinuclei question was found in 1965 with the observation of the antideuteron, a nucleus of antimatter made out of an antiproton plus an antineutron (while a deuteron, the nucleus of the deuterium atom, is made of a proton plus a neutron). The goal was simultaneously achieved by two teams of physicists, one led by Antonino Zichichi, using the Proton Synchrotron at CERN, and the other led by Leon Lederman, using the Alternating Gradient Synchrotron (AGS) accelerator at the Brookhaven National Laboratory, New York.
• 1995: from antiparticles to antimatter

The Accelerator Era

Pioneer machines
Colliders
High energy frontier
Low energy frontier

Antimatter in Cosmology
AMS

Antimatter Everyday

PET scan
Cosmic rays
Science Fiction
Star Trek
Antimatter propulsion
The Anti-Proton Source consists of three major components:

- The **Target Station**: 120 GeV p → ~20 pbar (8 GeV) out of 1 M protons on Nickel every 1.5 sec
- The **Debuncher**, an 8 GeV synchrotron
- The **Accumulator**, an 8 GeV synchrotron

The key to accumulating a large number of antiprotons is **Stochastic Cooling**.
Fermilab: The Target Station

- A beam of 120 GeV protons from the Main Injector is smashed on to a Nickel Target every 1.5 sec. In the collisions many particles are created.
- For every 1 million protons that hit the target, only about twenty 8 GeV pbars survive to make it into the Accumulator. The pbars come off the target at many different angles. They are focused into a beam line with a Lithium lens. The beam after the Lithium lens contains many different particles besides antiprotons. Many of these particles are filtered away by sending the beam through a pulsed magnet which acts as a charge-mass spectrometer.
Fermilab: The Debuncher

- The 120 GeV protons that arrive at the target station are **bunched**. Because of the details of the collision process the antiprotons coming off the target will have a very large spread in energy. This large spread in energy of the pbars will be difficult for downstream accelerators to accept. **The Debuncher accelerator is used to exchange the large energy spread and narrow time spread into a narrow energy spread and time spread.**

- The antiprotons have velocity very close to the velocity of light independent of their energy. The antiprotons with more energy have more mass so they travel on the outside of the Debuncher ring. The lower energy (lighter) ones will travel on the inside of the ring. Thus the lower energy antiprotons arrive at the RF cavity before the higher energy ones because of the difference in path lengths around the accelerator.

The low energy antiprotons will see a different phase of the RF than the high energy ones. This different RF phase will cause the low energy particles to be accelerated and the high energy particles to be decelerated. As this process happens over and over, eventually the energy spread will be reduced. The energy spread has been traded for a large time spread. The debunching process takes about 100 milliseconds.

- Antiprotons right after the target
- Antiprotons arriving at the RF cavity
- Antiprotons after many turns through the RF cavity
- Antiprotons at the end of debunching

- The Main Injector ramp rate is limited to once every 1.5 seconds. Therefore, the debunched beam can "hang around" in the Debuncher for almost 1.5 seconds before it needs to be transfered to the Accumulator and make room for a new batch of bunched antiprotons.
Fermilab: The Accumulator

- The purpose of the Accumulator, as its name implies, is to accumulate antiprotons. This is accomplished by momentum stacking successive pulses of antiprotons from the Debuncher over several hours or days. Both RF and stochastic cooling systems are used in the momentum stacking process. The RF decelerates the recently injected pulses of antiprotons from the injection energy to the edge of the "stack tail." The stack tail momentum cooling system sweeps the beam deposited by the RF away from the edge of the tail and decelerates it towards the dense portion of the stack, known as the core.

- Additional cooling systems keep the antiprotons in the core at the desired momentum and minimize the transverse beam size.

- The Accumulator "ring" resembles a triangle with flattened corners. The lattice (arrangement of bending and focusing magnets) has been designed to accommodate the requirements of the different stochastic cooling systems. The Accumulator must be capable of storing an antiproton beam over many hours.
Stochastic Cooling

- The antiprotons leave the target at a wide range of energies, positions and angles. This randomness is equivalent to temperature so we say that the beam coming off the target is “hot.” This “hot” beam will have a difficult time fitting into a beam pipe of reasonable dimensions. Also, this hot beam is very diffuse and not very “bright”. Bright beams are needed in the collider in order to increase the probability that a rare particle might be created.

Stochastic cooling is a technique that is used to remove the randomness of the “hot” beam on a particle by particle basis. Simone van der Meer won the Nobel prize for its invention.

- Stochastic Cooling systems are used in both the Debuncher and the Accumulator.
- Stochastic cooling uses feedback. A pickup electrode measures an “error” signal for a given particle. This “error” signal could be that particle's position or energy. The pickup signal can be extremely small, on the order of 2 trillionths of a Watt.

- Many of the pickups are cooled to liquid Nitrogen temperatures to reduce the effect of thermal noise. In the future, the temperature of some of the pickups will be reduced to liquid Helium temperatures. This signal is processed and amplified. The gain of some systems is about 150 dB (a factor of $10^{15}$)

The opposite of the “error” signal is applied to the antiproton at the kicker. The kicker signal can be as large as 1500 Watts.
Stochastic Cooling
- Fermilab: old experiment with pbars, now used for Tevatrons

- CERN: AC + LEAR by 1999
  - AD · Îº¯È¯, CERNÀÇÁֿ俬±¸°úÁ¦·Î¼±Á¤µÇ¾îÁö¿ø¹Þ°íÀÖÀ½

- J - Parc
  - 2008 Ï³ , Ï³ Ï³
  - 600 MeV → 3 GeV Synchrotron → 50 GeV PS → Antiproton Ê Ê

- GSI
  - Ï³ Ï³ Ï³ Ï³ Ï³ Ï³
  - 100/200 GeV
- CPT, CP, T tests
  - AMS
    - anti-proton, anti-\( \mu \), anti-\( \bar{\mu} \)
    - Dark Matter Source?
  - Belle
    - CP violation in Weak decays
  - Hadron (K system, QCD test\( \rightarrow \) CP viol in Strong interaction, etc.)

- New Physics (SUSY, anything else)?
- $2.5 \times 10^{13}$ protons (1~30 GeV)
- 3~30 GeV anti-protons on targets
- Pbar cooled

**Hadron Structure and Quark-Gluon Dynamics - Antiprotons**

Non-pertubative QCD
Quark-gluon degrees of freedom
Confinement and chiral symmetry
Concept for Staged Construction of the International Facility for Beams of Ions and Antiprotons
J-PARC Facility

Materials and Life Science Experimental Facility

Nuclear and Particle Experimental Facility

Nuclear Transmutation

Neutrino to Kamiokande

Linac (350m)

3 GeV Synchrotron (25 Hz, 1MW)

50 GeV Synchrotron (0.75 MW)

J-PARC = Japan Proton Accelerator Research Complex

Center for High Energy Physics
Three Goals at J-PARC

- **Muon Science**: \( \mu_SFL, \) high-Tc superconductor, Muonium, \( \muCF \)
- **Nuclear/Particle Physics**: Hypernuclei, Mesons in Nuclear Matter, Neutrino Oscillation, K Rare Decays
- **R&D toward Transmutation**: Antimatter

**Materials & Life Sciences at 3 GeV**

**Nuclear & Particle Physics at 50 GeV**

**R&D toward Transmutation at 0.6 GeV**
## Construction Schedule & Commissioning

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- **Power**: 0.1%, 1%, 10% ~ 100%
- **Beam Test**
- **Installation**
- **Construction**
- **Test Period**
- **Open to Users**
- **Start Usage**
- **Now**
- 8 GeV PS
- 40~200 GeV PS

Center for High Energy Physics
250 MeV Linac
- 60 Hz, $10^{13}$ ppp for 0.1 mA, 0.025 MW
- ~10 pbar per million protons $\Rightarrow$ $10^8$ antiprotons per pulse
- For 120 seconds, $\Rightarrow$ $10^{10}$ antiprotons for every 2 min.

0.25~8 GeV PS
- $R=60$ m, $\theta = 400$ m (leakage), $f = 750$ kHz
- $B_{\text{max}} = 0.5$ T $\sim 1$ T ($R=27$ m) $\leftarrow$ $? 750$ kHz
- RF Cavity: 7750 MeV/750 kHz $\Rightarrow$ 10.5 kV/kick
- Current: $10^{13} \times 1.6 \times 10^{-19} \times 750$ k $= 1.2$ A
  $\Rightarrow$ 0.0105 MV/1.2 A = 0.012 MW

40~200 GeV Synchrotron
- $R=500$ m, $\theta = 3$ km, $f=100$ kHz
- $B_{\text{max}} = 0.6$ T $\sim 3.3$ T ($R=200$ m)
- RF = 192 GV/100 kHz = 1.9 MV/kick or $\frac{1}{2}$ for two RF’s
- Current = $10^{13}$ protons/pulse * 100 k pulses/s = 0.16 A
  $\Rightarrow$ 1.9 MV/0.16 A = 0.30 MW

Beam Extraction for Antiproton Study
- Ramping at 40 GeV or 26 GeV or 120 GeV to target section?
- Debuncher, Decelerator+Accumulator to Detector, Electron Cooling?
Neutron Facility

8 GeV PS

40~200 GeV PS

Meson/Hyperon Lab

Proton Linac for Application

1 GeV Linac (superconducting)

Antimatter Lab

250 MeV Linac for HEP

Neutrino Lab

Neutron Facility
경북대학교·고에너지물리연구소·Center for High Energy Physics
Detector & Anti-hydrogen Production

- Detector $\rightarrow$ Physics Dependent $\rightarrow$ needs discussion and studies
  - Hadron spectroscopy?

- Anti-hydrogen production and study
  - needs collaboration with Atomic Physics People
  - Electron Cooling and usage of High Power Laser for Anti- Hydrogen Production?
  - Methods of pickup of positron to form anti-hydrogen atoms? To what energy ($\sim$keV region)?
  - Atomic Spectroscopy studies
Summary

- Tests of Fundamental Symmetries
- Anti-Hydrogen
- Nuclear Physics and Hadron spectroscopy

- CERN/AD, GSI, J - PARC

- NASA:
Where is all the Antimatter?

(AMS exp. will look for antiprotons, antiheliums, anti-carbons etc.)

- While scientists have produced tiny amounts of antimatter in laboratories, it doesn't seem to exist in large quantities anywhere in the universe. When matter and antimatter come into contact they "annihilate" each other and turn into a burst of energy (gamma rays to be exact). Because of this, it is easy for scientists to tell that no significant mass of antimatter exists in our solar system. If the sun were made of antimatter, the solar wind (particles shot off from the sun) would generate gamma rays when they hit the Earth. The same is true for all the planets. If Mars were made of antimatter the gamma rays from annihilation as the solar wind hit would be easily detectable.

- Using the same logic, scientists can infer that no significant amount of antimatter exists in our galaxy, or our local cluster of galaxies or even our supercluster of galaxies. (A supercluster of galaxies is a group of galaxies about 100 million light years wide.) Yet, it should be there. When matter is created from energy, as scientists believe happened in the very early universe, antimatter is also created. A proton cannot be created without also getting an oppositely-charged antiproton.

- The universe is a big place, and perhaps there is a chance that the antimatter exists somewhere out beyond our local galactic supercluster (perhaps there are whole galaxies and galactic superclusters made of nothing but antimatter) but there are no good theories about how it could get so far separated from the matter. Some scientists and NASA tried to resolve this riddle by using an experiment aboard a space shuttle in 1998 to try and detect the cosmic rays (atoms and parts of atoms traveling through space) that may have originated in an antimatter portion of the universe. No significant amount of these were found. The few sources of antimatter that were detected seemed to come from the core of energetic galaxies or quasars (which are probably black holes that generate small amounts of antimatter as they suck regular matter into themselves). None of the sources detected was antimatter left over from the creation of the universe.

- How can this be possible given that when matter is created, so an equal portion of antimatter should also be created? Some experiments have suggested that antimatter may behave slightly differently than matter. In the very hot and energetic early universe where energy was coalescing into matter and antimatter and then annihilating back into energy, a tiny portion of the antimatter may have decayed before it could annihilate with matter. The tiny portion of matter (perhaps as few as 1 particle out of 100 million) left over would account for the entire universe we now see - planets, moon, stars, and galaxies.

- The new AMS is scheduled to be placed aboard the International Space Station sometime in 2005 (NASA).

- Still, some scientists think that there might be large sections of universe made from antimatter. To try and settle this matter, NASA will use the new Alpha Magnetic Spectrometer (AMS) scheduled to be installed on the International Space Station in 2005. This AMS is designed to look for relatively heavy antimatter -- anti-helium nuclei or particles even more massive, such as anti-carbon, that may come zipping through our solar system from far away antimatter galaxies.

- Finding massive antimatter particles would be important because normal high-energy particle interactions involving regular matter don't usually produce heavyweight antimatter such as anti-helium or anti-carbon. Such heavy antimatter would most likely have been left over from the creation of the universe, suggesting that somewhere out there is a mass of antimatter that has so far gone undetected.
CERN AD history

- 7 May 2001 AD physics has started on schedule in the new millenium, with an antiproton beam more intense than ever (5x10^7 particles injected every second minute).
- 9 April 2001 The AD starts the new millenium with 4 weeks of machine development.
- 12 March 2001 The AD machine is currently shut down. The vacuum leak on the ejection kicker magnet has been repaired and a new DC current transformer, able to read a low number of antiprotons, has been installed. The bakeout of the sectors 1 and 2 has been completed; it is going on in sector 4 and is expected to end next week. From week 12 on, during the day, experts will work on the machine inside the tunnel and in the evenings other experts will tests the power supplies, in which case the tunnel will be closed. We shall work in these conditions until the 9th of April, date of the AD start-up.
- 30 November 2000 at 8.00 starts the AD shutdown, which will end in Spring 2001
- 10 October 2000 While the foreseen number of antiprotons the AD was supposed to decelerate did not exceed 12 million, the engineers in charge of the machine have succeeded to decelerate more than twice this figure: 27 million.
- 6 October 2000 The Decelerating Radio Frequency Quadrupole (RFQD), constructed at CERN for the ASACUSA collaboration is ready: its aim is to slow down antiprotons leaving the AD to about 50 KeV in energy.
- 29 August 2000 The ATRAP Collaboration has accumulated the first cold positrons at CERN's AD. ATRAP now has both of the ingredients of cold antihydrogen in the same trap structure at the same time.
- 23 August 2000 Another new resonance, (36,34)-(37,33) was discovered at 616 nm by the ASACUSA Collaboration.
- 11 August 2000 Antiprotons have been captured and stored for up to one minute by the ATHENA experiment.
- 1 August 2000 A few thousand antiprotons captured by the ATHENA collaboration
- 24-25 July 2000 ASACUSA did a lifetime and initial population measurement of the (35,34) state of the antiprotonic helium, using the newly discovered resonance at 372 nm.
- 18 July 2000 The ASACUSA experiment found the first new physics result at the AD: a new antiprotonic helium laser resonance at 372.583 nm.
- 29 June 2000 The AD team produced today CERN's first antiproton beam for the year 2000. With the beam now ready, the three experiments can begin running, as scheduled, during the next few weeks.
- 10 May 2000 During the live webcast, the AD team did the first antiproton injection to the AD, which began just before the program started.
- 2 December 1999 The heroic efforts of the AD team (led by Stephan Maury of PS division) paid off: antiprotons were at last delivered to the ASACUSA collaboration's cold helium gas target and produced a familiar sight on their computer screens.
- 29 November 1999 Physicists at the AD have succeeded in slowing down antiprotons, proving for the first time that the AD works well with antiprotons.
- 9 August 1999 For the first time at the AD, a proton beam has been decelerated from its initial momentum of 3.5 GeV/c to the target momentum of 100 MeV/c.
- 9 November 1998 A major milestone has been reached when the first beam of protons has been injected into the new AD machine.