to the 60s, was described by H. Leutwyler. Among many solid results in this sector, the combination of chiral perturbation and lattice techniques looks a promising way to get low energy hadron physics parameters.

The transition from QCD confinement to deconfinement is still more accessible on the lattice than in laboratory heavy ions collisions. F. Karsch showed exciting hints from lattice simulations for a complicated non-perturbative structure of the quark-gluon plasma near the critical temperature.

Progress in heavy ion collisions was reviewed by H. Satz. Good probes for monitoring the QCD phase transition have now been devised by theorists, and the 'smoking gun' may be provided by the production of the J/psi and related particles.

The future will bring new challenges for QCD. G. Wolf summarized the status of HERA, where a new chapter in deep inelastic scattering is about to begin, with the nucleon structure being explored down to $2x10^{-16}$ cm.

The long awaited sixth (top) quark, where indirect evidence points to a mass around 130 GeV, should soon show up at the Fermilab Tevatron. Startling new QCD effects are predicted for top physics (J. Kühn) due to the interplay between electromagnetic and strong interactions at these energies. Weak decays of hadrons containing heavy quarks (C. Sachrajda and A. Buras) is another frontier.

John Ellis looked at how QCD could fit eventually into a larger Theory of Everything, and Harald Fritzsch summarized. While QCD has some remarkable achievements to its credit after 20 years, there are still challenging problems to be solved in the next 20 years.

By O. Nachtmann

Looking at the antiworld

A popular pastime among amateur scientific historians is tracing key concepts in twentieth century physics back to their origins. Participants at the Antihydrogen Workshop in Munich on July 30-31 were astonished to hear 1989 Nobel prizewinner Wolfgang Paul mention in his introductory remarks that W. Nernst referred to antimatter as far back as 1897.

Nernst thus 'beat' Dirac by some 30 years, (breaking by a matter of months the previous record, held by A. Schuster's 1898 letter to *Nature*). These historical footnotes enhance Dirac's achievement in demonstrating the existence of antimatter as the price paid for combining quantum mechanics and special relativity.

As every physicist knows, Dirac turned the embarrassing 'redundant' solutions of his relativistic wave equation for electrons to good effect, hypothesising that they corresponded to '...a new kind of particle, unknown to experimental physics, having the same mass and opposite charge to the electron...'. The positron obligingly appeared in 1932, but the discovery of the antiproton had to wait a further quarter of a century, and it was only at that time that the relationship of matter and antimatter was finally seen in terms of the CPT (charge conjugation/parity/time reversal) theorem.

In 1981, CERN began to mass-produce antiprotons, stacking millions of millions of them at a time for physics experiments. A few years later Fermilab too built an antiproton factory.

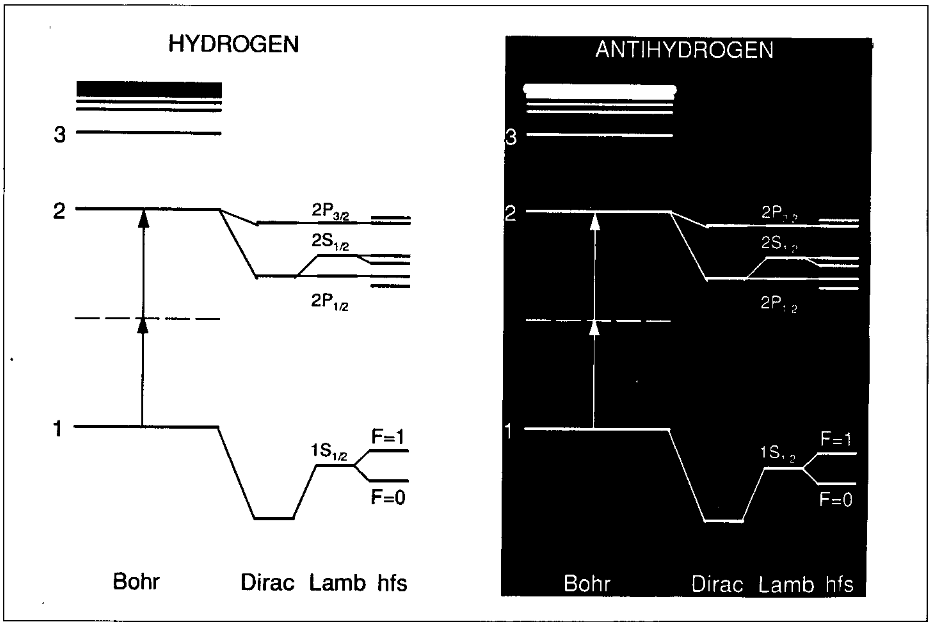
In spite of all this work with antiparticles, not one atom of antihydrogen has yet been synthesized for study in the laboratory. The enormous strides now being made in cooling, trapping, storing and manipulating charged and neutral particles, as well as in ultra high precision laser spectroscopy should soon change this.

The aims of the workshop were to review progress in these areas, assess the potential of antihydrogen as a test bench for answering fundamental questions of physics, and guide current deliberations on the future of the antiproton programme at CERN.

The workshop attracted some 100 participants from all over the world. The unifying nature of anihydrogen studies was evident in the diversity of their research backgrounds, which ranged from atomic to nuclear and particle physics, from laser spectroscopy to permanent magnet design, and from accelerator physics to cosmology. There were some eleven hours of oral presentations and discussions, as well as 23 posters.

Wolfgang Paul's introduction was followed by R.J. Hughes (Los Alamos) who reviewed the physics potential of high precision atomic spectroscopy of antihydrogen. Seen simply as a probe of CPT, such measurements are capable of reaching with atomic matter the four parts in10^{18} precision given by the neutral kaon system.

If sacred physics laws hold good, the atomic spectra of hydrogen and antihydrogen should be identical. Any difference matter and antimatter spectroscopy would signal would signal some profound physics. (Diagram by R.J. Hughes, Los Alamos.)



At this level of precision, the gravitational properties of antimatter play a role. Any anomalous gravitation of antimatter would reveal itself as an annual or daily variation of any difference observed in the behaviour of hydrogen and antihydrogen. The gravitational weak equivalence principle could then be tested on antimatter to about one part in 10^8, a precision approaching that of Eotvos-type measurements on bulk matter. Paradoxically, direct empirical tests at the cosmic scale 'Planck energy' (10^{19} GeV) seem to be achievable by experiments done at the ultra low antiproton and positron energies conducive to antihydrogen formation.

Continuing in cosmic vein, A.D. Dolgov (Moscow) reviewed cosmologies which permit or require overall matter-antimatter symmetry in a Universe which, CPT notwithstanding, appears to contain only one kind of matter, at least up to the galactic cluster scale. In a talk on the astonishingly high precisions now achieved in atomic spectroscopy, workshop chairman T.W. Haensch (Munich), described techniques which push spectroscopy measurements of (ordinary) hydrogen to one part in 10^{12} - like comparing a human hair to the size of the earth. Even this impressive limit could be pushed further with laser techniques rapidly advancing towards an ultimate precision of one part in 10^{18}!

Production of antihydrogen from its antiproton and positron constituents was the topic of a session entitled 'Routes to Antihydrogen'. A third body is required to conserve energy-momentum in such syntheses. For high precision work the most fruitful route seems to be via chemical recombination reactions at meV (milli-eV) energies, in which the third body is either an electron (initially bound with the positron in a positronium atom), or a second positron.

In the first case, being investigated in Aarhus, the positronium atoms would be produced by positrons in the wall of a trap containing cold antiprotons, while the second possibility, under study at Harvard, would use a 'nested trap' to hold particles of different charge at the same time.

The recombination reaction was the most thorny of all the problems addressed in the workshop, and further studies will be needed before either of the two techniques can be favoured. A third 'chemical' possibility was presented by E. Widmann (Tokyo) exploiting the recently discovered metastable antiprotonic helium states (June, page 14), and a 'high energy' method was discussed by C. Munger (SLAC), involving electron-positron pair production by a GeV antiproton beam in the E760 gas jet target at Fermilab. Finally, laser-induced recombination was discussed by A. Wolf (Heidelberg). Although any one of these three possibilities might conceivably produce antihydrogen first, none of them seems to offer the physics potential of the two main experimental approaches.

A further paradox now becomes clear: since antiprotons and positrons are not produced at meV, but at MeV (or GeV) energies, accelerator physicists have to aim for deceleration instead. The CERN team (represented by P. Lefèvre) summarized the progress and perspectives for low energy beams from the LEAR low energy antiproton ring, in which 10^9 antiprotons can now be stored down to 2 MeV.

H. Kalinowsky (Mainz) then reported on the next stage of deceleration, from MeV to keV energies. Degrading by foils is easiest, the foil serving as a window into the high vacuum region needed for long term survival of antimatter. While the overall efficiency is small compared with that of more elaborate post-decelerators such as radiofrequency quadrupoles or

inverse cyclotrons, the simplicity of the method makes it the clear favourite.

G. Gabrielse discussed recent progress in trapping keV antiprotons emerging from deceleration foils and their 'cooling' to meV energies. Electron cooling in such traps works extremely well, and has permitted his PS 196 experiment at CERN to accumulate more than 10^5 antiprotons at 4.2 K (0.3 meV) in their attempt to reach a one part in 10^9 comparison of the charge/mass ratios of protons and antiprotons.

The same group recently demonstrated the feasibility of transporting trapped particles by moving a trap filled with electrons across the United States. 'You can regard this as serious work or as a cheap stunt!', said Gabrielse. If a stunt, it is still necessary since ultra high precision measurements must be done far from the electromagnetically noisy environments near particle accelerators.

Several routes to the production of cold low energy positrons were discussed by M. Charlton (London), including the use of beta emitters produced at CERN's ISOLDE on-line isotope separator and positrons from electromagnetic showers produced either in a special purpose electron accelerator or in the LIL LEP injector linac.

After production, antihydrogen must itself be confined or trapped to prevent it from annihilating on the walls of its container. This can be done using the 'restoring' force produced by a magnetic quadrupole field on the positron's magnetic moment. J.T.M. Walraven described how this technique has been perfected with atomic hydrogen at MIT and Amsterdam and reviewed the prospects for further cooling within such traps from K to mK temperatures using Lyman alpha lasers which are now close to reality.

Summarizing, D. Kleppner of MIT, himself a pioneer in the trapping of spin polarized atomic hydrogen, said that comparison of normal and antihydrogen will be of tremendous interest. The probability of violating sacred physics laws like CPT and the equivalence principle may be low, but these laws have to be tested to the limit.

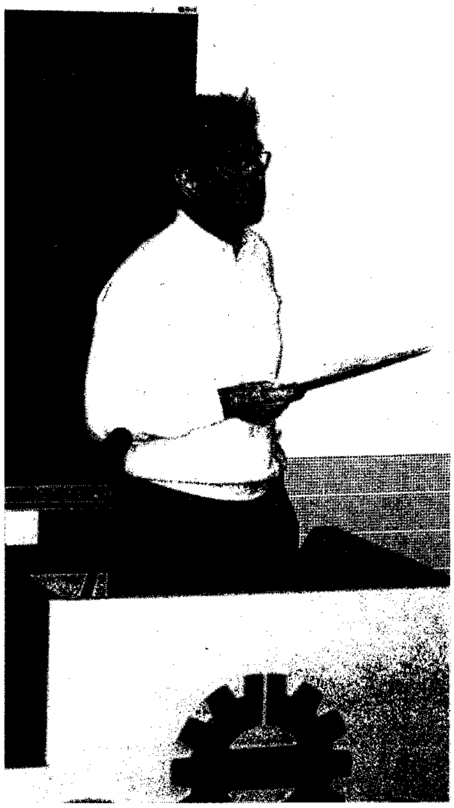
Comparing the present situation with that of the 1987 Karlsruhe symposium on atomic antimatter, Kleppner added that progress in hydrogen spectroscopy 'exceeds our wildest dreams of five years ago', while trapping and cooling of charged particles to temperatures of a few K and of neutral atoms to millikelvin levels (both of which looked 'wild' in 1987), are now demonstrated facts.

In hydrogen spectroscopy, the attainable resolution is now kHz instead of MHz in 1987 and will soon be reduced to Hz. The challenge in antihydrogen formation is to combine these techniques. Even if deep underlying symmetries withstand the attack, we will learn a lot about both fundamental symmetries and new technology.

From John Eades

Signal Processing

New technology for physics. Y. Neuvo reviewing median based filters during the recent Signal Processing for LHC workshop in Tampere (Finland).



Signal processing techniques, extensively used nowadays to maximize the performance of audio and video equipment, have been a key part in the design of hardware and software for high energy physics detectors since pioneering applications in the UA1 experiment at CERN in 1979.

In addition to the problem of disentangling the signal produced by the particles in the detectors from noise, advanced image processing algorithms will be needed in future experiments to pattern recognize events of interest. Thus a topical Signal Processing Workshop was jointly organized by CERN, the Finnish Research Institute of High Energy Physics (SEFT) and the Tampere University of Technology (TUT), from 2 to 4 July in Finland.

Specifically in the context of applications for the LHC proton-proton collider to be built in CERN's LEP tunnel, the workshop aimed at triggering cross-fertilization between