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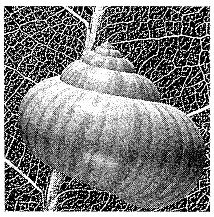

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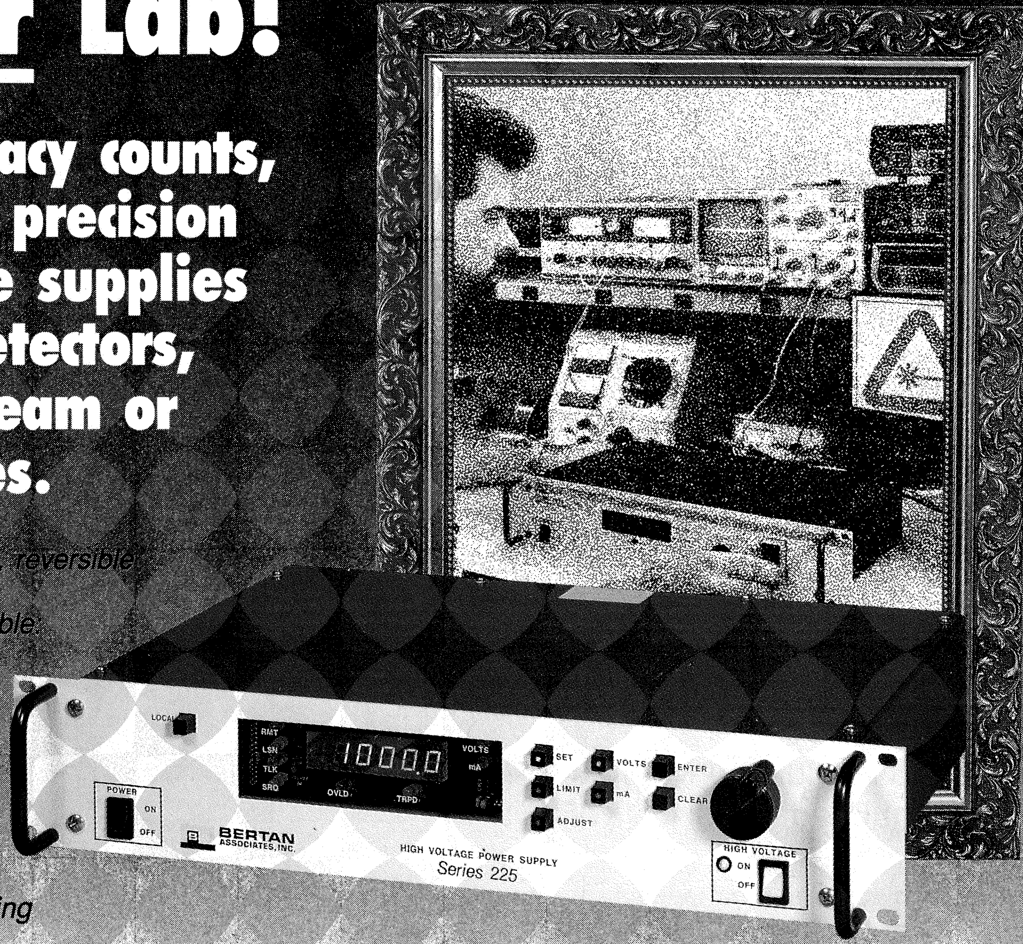

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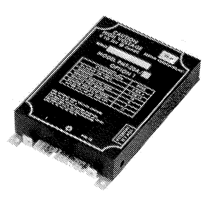

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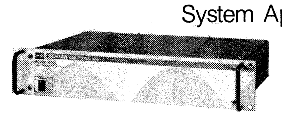

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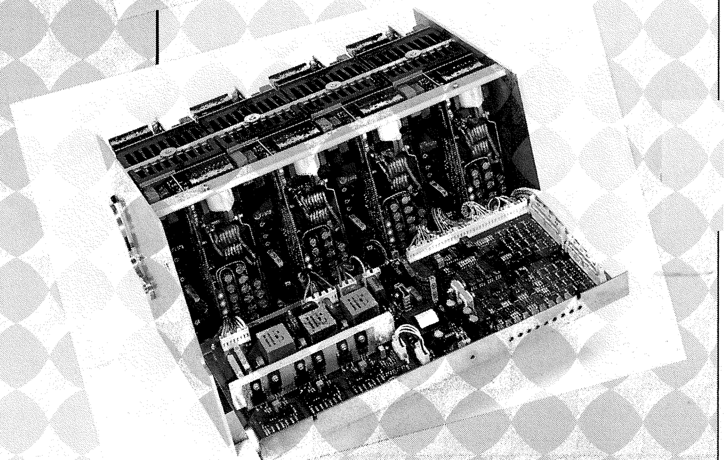

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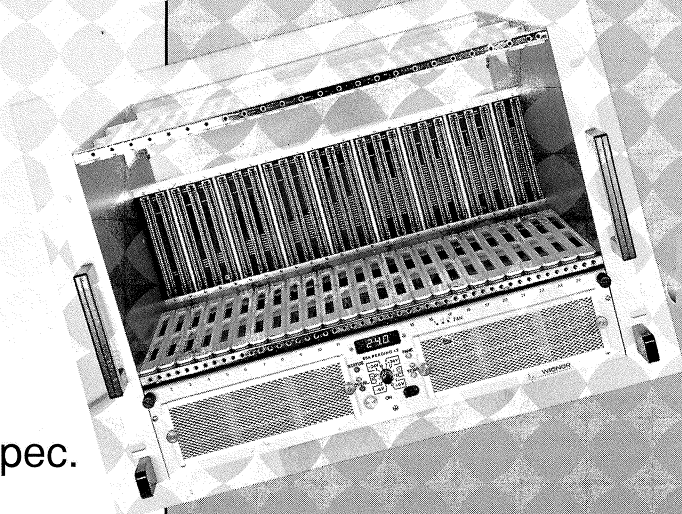

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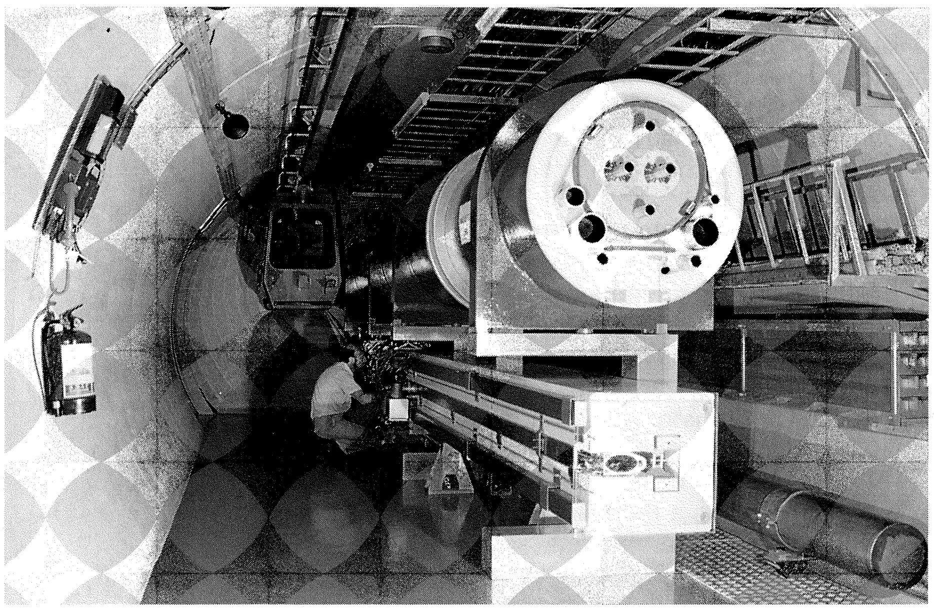
Meeting the demands of future colliders

A mock-up of how CERN's big 27 kilometre tunnel could look towards the end of the decade. Above the low field magnets for the LEP electron-positron collider (which came into action last summer) are the powerful superconducting 'two-in-one' magnets for the high energy proton beams of the proposed LHC collider. With the LHC and US Superconducting Supercollider (SSC) projects posing technological challenges for detectors, electronics and data processing as well as machine design and construction, research and development work is pushing ahead across a wide front, providing a foundation for the physics of the next millenium.

(Photo CERN 337.5.90)



The challenge

Physicists are very aware of the challenge of developing and building detectors and instrumentation for the next generation of proton colliders – the US Superconducting Supercollider (SSC) and CERN's LHC. The accompanying articles highlight special problems in electronics and in computing, but the effort underway extends over a wider front.

For LHC at CERN, physics and detector working groups continue to investigate the opportunities, and an LHC Workshop on Physics and Instrumentation, sponsored by the European Committee for Future Accelerators (ECFA) and held in Aachen from 4-9 October, will review thinking so far and point the way ahead (May issue, page 27; for further information bitnet reithler at dacth 51).

At CERN, the Italian-funded LAA project led by Antonino Zichichi continues to blaze a new technological trail on the detector front.

For the SSC, ongoing detector research and development will be highlighted in a symposium at Fort Worth, Texas, from 15-18 October. For further information bitnet detrd at sscvx1.

Electronics

The need for electronics in elementary particle physics has grown exponentially as higher energies and higher beam intensities have rapidly increased the number of data acquisition channels and support functions required by experimenters. While research has always required state-of-the-art instrumentation, the demands of the next generation of hadron colliders surpasses all precedents.

How we got here

In contrast to user demands, budgets for particle physics have not expanded exponentially, and the increased need for instrumentation had to be counterbalanced by reducing the electronics price per channel. So far this has been achieved by using industry standards and new technologies.

Standards bring economies of scale and common utilities (crates, power supplies, interfaces, software libraries, etc). Thus the same Fastbus IEEE-960 multi-hit drift chamber time to digital converter is used by a Brookhaven heavy ion experiment, a Fermilab hadron collider group, and electron-positron collider groups at Stanford and at CERN.

Technologies have evolved from discrete components and TTL integrated circuits, to hybridized circuits, to simple semi-custom application specific integrated circuits (ASICs), and finally to fully customized ASICs, the latter development following from the expanding size and contracting price syndrome. In addition, the problems of testing a semi-custom design as well as migrating the design from an engineering run to production were often more difficult than developing the original idea!

Future hadron colliders – a new environment

The requirements of running at the proposed US Superconducting Supercollider (SSC) and CERN's LHC

A promising candidate for the next generation of particle detectors is the 'spaghetti calorimeter' developed at CERN by the Italian-funded LAA project. Using a compact construction of scintillating fibres embedded in a lead matrix, the technique aims for rapid electron/pion discrimination, together with high resolution measurements of electronic and hadronic showers and the 'missing energy' signal of neutrinos and other possible invisible particles. This 20-ton detector is now being tested at CERN.

(Photo CERN 322.5.90)

will dwarf those of today's experiments. These requirements include:

- bunch spacings measured in nanoseconds rather than microseconds
- 30 nanosecond flight times for a relativistic particle
- half nanosecond timing accuracies for multi-hit drift chamber electronics
- analog-digital converters to measure calorimeter data with 20 bits dynamic range and up to 14 bits resolution
- interaction times a thousand times higher than at present, and
- ten times more data per event.

Additional restrictions and problems include:

Pipelines : to provide a time delay to form the first level trigger all data must be stored in analog or digital pipelines for a few microseconds. Analog storage components such as switch capacitor arrays or CCDs and digital techniques such as flash ADCs with fast digital memory arranged as FIFO are possible solutions. Power, cost, clock noise and simplicity of operation will eventually determine the best solution. Currently switch capacitor arrays are preferred but much work is underway on CCD and flash ADC technologies.

Trigger : Trigger information will follow its own pipelined routing through the first level trigger logic. Data from a particular beam crossing arrives at the ends of its storage pipeline at the same time as the first trigger is completed. The data is then either discarded as it falls out of the pipes or retained for the next level of trigger decision.

The second level trigger uses primary data (rather than trigger signals), so that if the original storage pipelines were analog, the data has to be converted first. Dedicated or reduced instruction set processors will compute track segments or more detailed energy depositions from this data and the events either passed to a processing 'farm' for complete reconstruction or else suppressed.

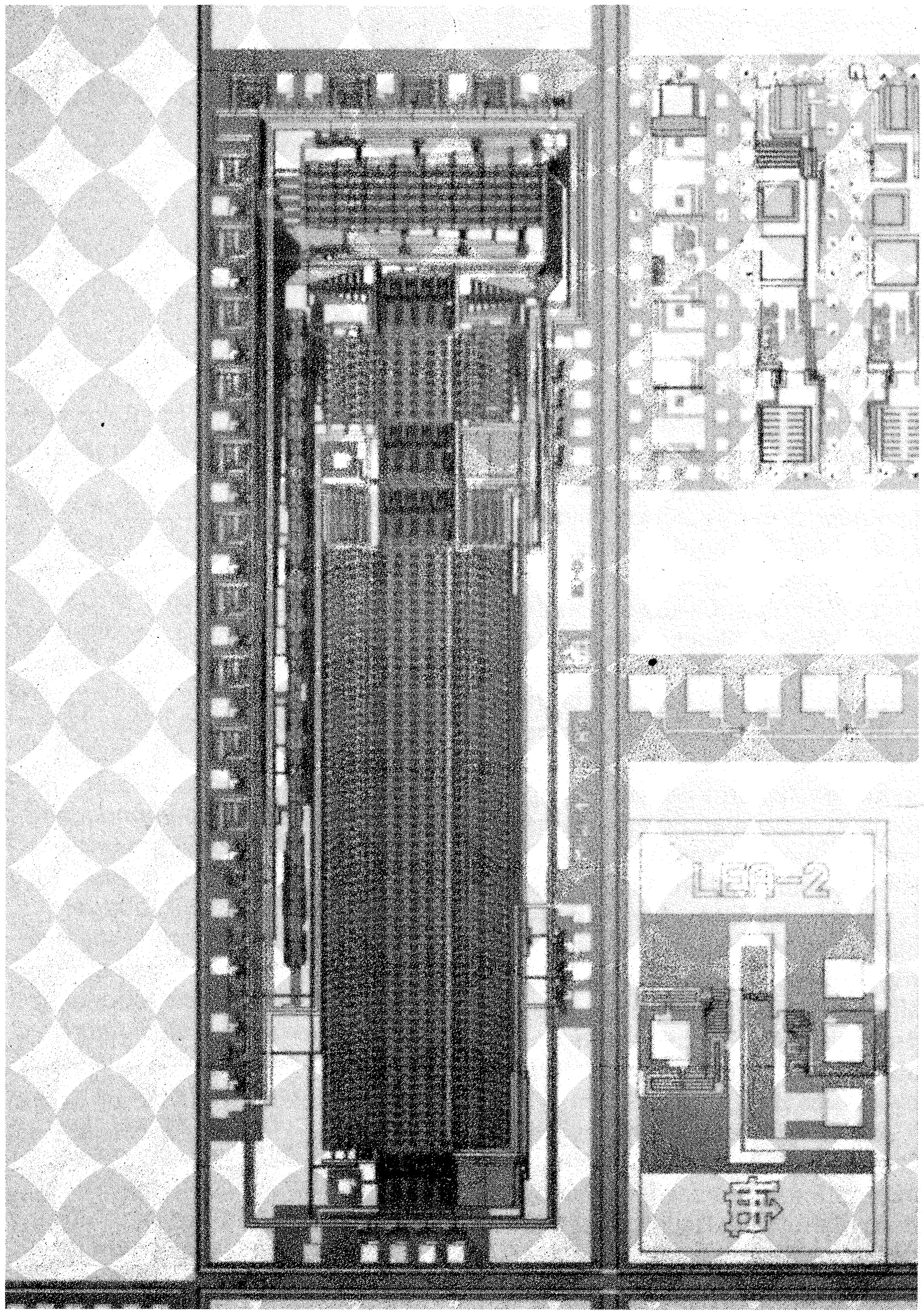
Radiation hardness : while awaiting the outcome of reliable estimates, one thing is sure – the conditions will be hotter than anything instrumented in particle physics to date. Even the stringent demands of defence applications may not be relevant. Several semiconductor processes, including simple bipolar, MOS and others may have to be excluded. CMOS, special bipolar and GaAs are among the better candidates.

Power : requirements will have to be cut by a factor of 20. As an example, simple fibre optic transmission with the LED transmitters on the chambers would not be acceptable because of too much heat generated in too small a volume. Appropriate technologies (CMOS) and separate power lines will help. An interesting new idea from ETH Zurich uses remote light sources, individual 'modulators' on each chamber channel and off-chamber receivers.

Space : with proposals calling for hermetic detectors, each detector layer should have as close to full solid angle coverage as possible. Little room is left for electronics, much less the cabling or heat removal plumbing. A recent suggestion incorporated integrated signal/control paths in the detector using cable harness technology from medical applications.

Reliability : new levels of reliability and fault tolerance will demand both revised architectures for capturing data and new electronics design rules. Space, avionics and defence experience may help.

Another LAA development is HARP (Hierarchical Analog Readout Pipeline Processor) – a general purpose electronics design aimed at high rate hadron colliders, of which an experimental 64-cell pipeline is shown here. The design is the result of a collaboration between CERN and the Norwegian Centre for Industrial Research, Oslo, and is produced in Belgium by Mietec N.V.



Density : space, power, noise sensitivity and reliability restrictions will continue the trend of designing multi-channel ASICs. Sixteen to 64-channel designs are now being discussed.

Detector-mounted electronics

The next generation of hadron colliders presents us with a critical dilemma. They will need several hundred thousand channels per detector subsystem at a cost of less than $10 per channel. With an overhead for cooling, power, support, etc, of about $10 per channel, branch/crate/module-type electronics of the CAMAC, VME, Fastbus or VXI genre won't work.

Despite contradictions imposed by radiation hardness, power and space, the economics of data acquisition are overwhelming. Most designs being considered mount a substantial portion of the front-end electronics directly on the instrument and integrate the entire electronic chain into the logical and physical structure of the detector.

Electronics will have to use new techniques like flexible circuit boards. Signal processing and multiplexing of the data on the detector will help minimize cabling. Fibre links could then get the data out of the detector and into a computer 'farm' for further in-line processing and higher level trigger decisions.

Aware of the problems, commercial, laboratory and research groups are now working together. They are meeting the challenges today so that by the end of this decade the next generation of experiments will be ready to make their contributions to physics.

By George Blanar, LeCroy Corporation

New computing techniques

Motivated by the increasing complexity of high energy and nuclear physics experiments now entering an accelerating phase with CERN's LEP electron-positron collider and continuing with plans for LHC and SSC experiments, the first international workshop on Software Engineering, Artificial Intelligence and Expert Systems in High Energy and Nuclear Physics was held in Lyon (France) earlier this year.

Physics simulations, equipment designs, detector and accelerator control, on-line data taking and data analysis, all computing related activities absorb a huge part of the financial and manpower resources of these experiments. However software support and performance are lagging behind the huge increase in power of computer hardware.

Recently developed techniques of software management and expert systems may bridge the gap and become an essential ingredient of the success of these projects, but these techniques and methods still have to be integrated and accepted by the research community.

Software engineering covers the tools and methods needed to attack large applications in an efficient, reliable and well-documented way. Various approaches from the LEP experiments showed the need for a multi-version, multi-system, multi-developer package. Software quality validation, project management, intelligent editors, data management, and interactive physics analysis were also discussed.

Languages such as Ada, C, Fortran 90, Prolog, C++, and Eiffel, with built-in facilities for large package development or for object representation, are blooming in the quest to replace the obsolete but omnipresent Fortran-77.

Expert systems are not only used to control and diagnose hardware, but also to manage an off-line production chain or user interfaces. Neural networks are being applied to triggers, pattern and feature recognition, and event classification. First results look very promising. Genetic algorithms seem to offer new possibilities for event analysis.

As collision energy increases, the number of contributing processes for theoretical calculations rises alarmingly. Daughter of the artificial intelligence gold rush, symbolic manipulation languages help solve this computing problem, and were also shown to be useful for handling super-algebra calculus.

Due to the increasing interest in these evolving techniques and the urgent need for solutions, the organizing committee proposed a new workshop on these topics within 18 months. Tutorials, extended demonstrations and hands-on experience will be added to the regular workshop activities. To be on the mailing list for future information, send address and e-mail to Michele Jouhet, CERN, 1211 Geneva 23, Switzerland, bitnet jouhet at cernvm

Fermilab Main Injector plan

Panel recommendations

The US High Energy Physics Advisory Panel – HEPAP – which counsels the Department of Energy, major paymaster of US high energy physics, recently set up a subpanel, chaired by Frank Sciulli of Columbia, to ensure an orderly transition in US activities between now and the next decade, when experiments at the proposed SSC Superconducting Supercollider would get underway in earnest (March, page 5).

Under a 'constant' budget scenario (interpreted by the subpanel as cumulative spending over the decade corresponding to ten times the annual figure currently envisaged, but allowing for considerable annual variations around this figure) the subpanel 'strongly recommends the immediate commencement and speedy completion of the Tevatron Main Injector at Fermilab'. Existing US facilities should be meanwhile strongly exploited, and a B factory project pursued, with hopefully additional funds becoming available for its construction.

The subpanel also recommends increased support for university groups, in technical infrastructure, scientific manpower and funding. Stanford (SLAC) is singled out for its R and D effort for very high energy electron-positron linear colliders. During SSC construction, SSC Laboratory physicists should have an opportunity to participate in active research, the subpanel advocates. For all US researchers, the possibilities of collaborating in non-accelerator studies and in experiments in other countries should continue, while detector R and D should be pushed to assure timely exploitation of new machines.

For a rising budget (one per cent per year), the proposed B factory slips into the funding envelope.

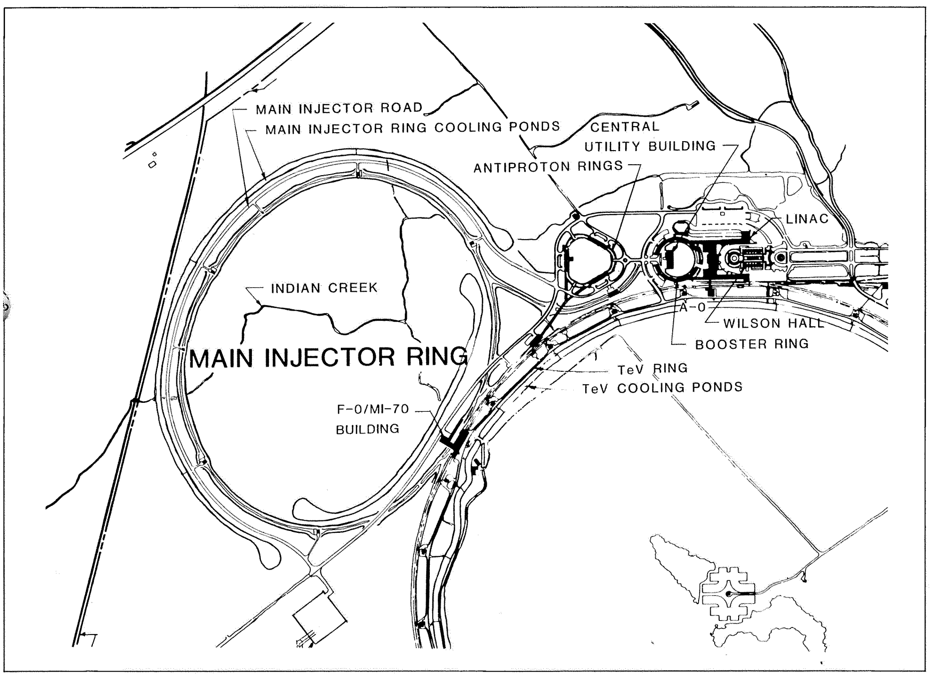
For a lower budget, averaging over the decade five per cent below the 1991 level, did not find much support. This would give 'an accumulated loss in vitality by the end of the decade that would leave the field poorly positioned to pursue research at the SSC or elsewhere'.

The Fermilab Main Injector is the centrepiece of the 'Fermilab III' scheme to significantly upgrade the Laboratory's existing accelerator complex. The new accelerator is designed to provide increased particle beam levels to boost the collision rate in the Tevatron proton-antiproton collider (luminosity in excess of 5 x 10^{31} per sq cm per s) and, if approved, would provide increased flexibility in all areas of high energy physics research.

The concept of the Main Injector (June 1989, page 15) has been developed over the last two years and a Conceptual Design Report has been submitted to the US Department of Energy accompanied by a request for a Fiscal Year 1992 construction start. Total project cost is estimated at $194 million with construction extending over 38 months from October 1991, implying a seven month disruption of Fermilab operations from April 1994.

Development work on a new dipole magnet design for the Main Injector was initiated last October

Layout of Fermilab's proposed 3.3 km circumference Main Injection ring, supplying beam to the adjoining superconducting Tevatron.



and two full-scale prototypes will be produced this year.

The Tevatron is the world's highest energy particle collider and will remain in this preeminent position until the advent of either the SSC Superconducting Supercollider in the United States or the LHC at CERN. The Tevatron collider supplied a total energy of 1800 GeV, with a total delivered luminosity of 10 inverse picobarns, during the run from June 1988 – June 1989. The data accumulated by the CDF detector during this period have been used to measure the Z mass, to measure the difference between the masses of the Z and W particles, to set a lower limit of 90 GeV on the top quark mass, and to rule out production of several types of new particles below a few hundred GeV.

The Fermilab III programme is designed to look for the top quark in the mass range 90-200 GeV suggested by current knowledge, and to search for life beyond the Standard Model. Fermilab III includes electrostatic separators in the Tevatron, antiproton supply improvements, a doubling of the linac energy (September 1988, page 16), an increase of the collider energy to 2000 GeV, and replacing the existing four-mile Main Ring with the new Main Injector. Tevatron collision rate should rise fivefold following the implementation of separators and the linac upgrade, and by a similar amount with the Main Injector in operation.

The Main Injector is designed to carry out in a much more efficient way the support functions currently provided by the Main Ring, Fermilab's original 400 GeV accelerator. In the 1970s this was the Laboratory's primary research tool, however with the construction of the Tevatron superconducting ring in the early 1980s, the Main Ring took on a new role, feeding the Tevatron. The consequent reconfiguration included overpasses around the Tevatron interaction regions, and several new extraction areas for antiprotons. These modifications had an adverse effect on Main Ring performance (reducing the available aperture) so that today the Main Ring is a bottleneck in the particle supply. The Main Injector is designed to remove this bottleneck once and for all.

The new machine, to take beams normally to 120 GeV, will be constructed tangentially to the Tevatron in a separate tunnel on the southwest corner of the site. Roughly half the size of the existing Main Ring, the Main Injector will boost the antiproton supply sevenfold (to 1.5 x 10^{11} per hour) and proton supply fivefold.

As well as extending research horizons at the Tevatron, the Main Injector will optimize operations and supply new beams for test and calibration studies, important for both Fermilab and SSC detector development and preparation. Delivery of Main Injector beam to all experimental areas will be compatible with collider running.

The plan is for many Main Ring components, including radiofrequency, quadrupole magnet power supply, and correction element systems to be taken over and reused.

Most performance improvements stem from the ring optics. The stronger focussing means that the beam is more compact and better behaved. The Main Injector will be seven times the circumference of the Booster and slightly more than half the circumference of the existing Main Ring and Tevatron. Six Booster cycles will be required to fill the MI and two MI cycles to fill the Tevatron. A single Booster batch will be accelerated for antiproton production while six such batches are required to fill the MI. MI yields for a full ring are expected to lie in the range 3-4 x 10^{13} protons (6-8 x 10^{13} delivered

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to the Tevatron.) By way of contrast the existing Main Ring accelerates 1.8 x 10^{13} protons in twelve batches for delivery to the Tevatron.

The power supply and magnet system is designed to allow a significant increase in the number of 120 GeV acceleration cycles for antiproton production, as well as permitting a 120 GeV slow spill. The cycle time at 120 GeV can be as low as 1.5 seconds, believed to be the maximum rate at which the Antiproton Source can ultimately stack antiprotons, and is to be compared to the current Main Ring figure of 2.6 seconds.

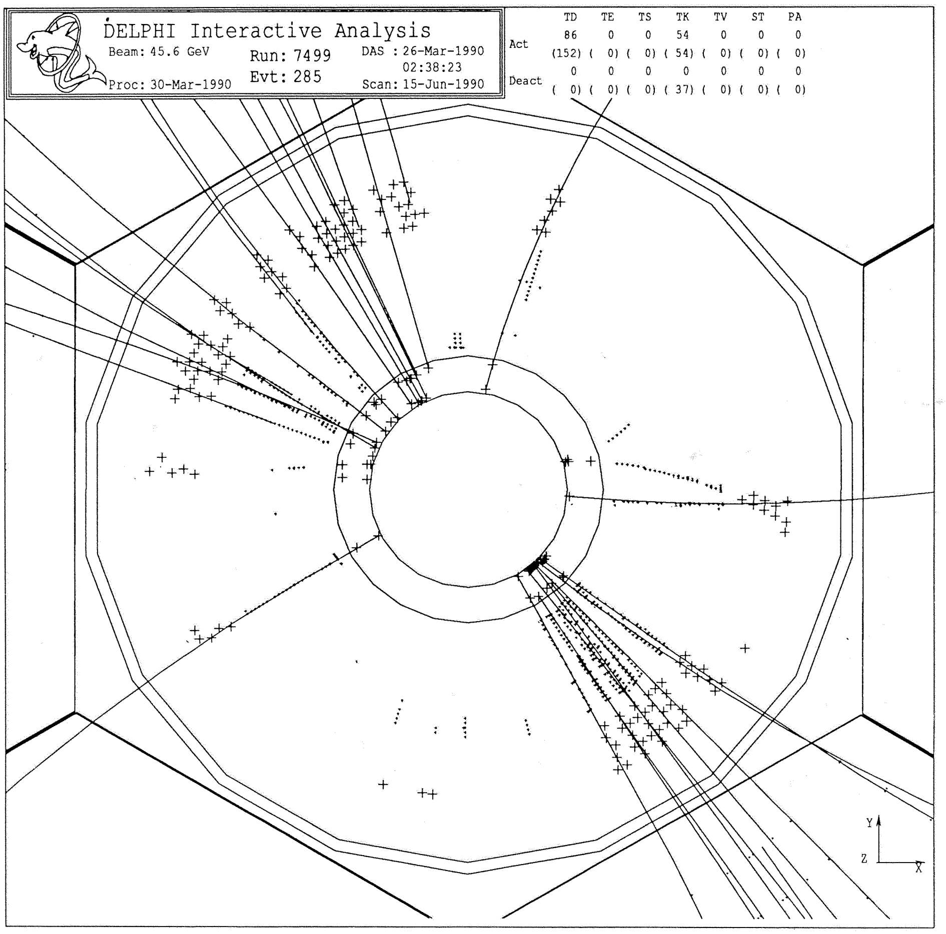
Fermilab's latest project could play a significant role in US high energy plans for the 1990s.

Fermilab Main Injector Parameter List

Circumference – 3319.419 metres
Injection Momentum – 8.9 GeV/c
Peak momentum – 150 GeV/c
Minimum cycle time (at 120 GeV) – 1.5 sec
Number of protons – 3 x 10^{13}
Number of bunches – 498
Protons/bunch – 6 x 10^{10}
Number of straight sections – 8
Length of standard cell – 34.3 metres
RF frequency (injection) – 52.8 MHz
RF frequency (extraction) – 53.1 MHz
RF voltage – 4 MV
Number of dipoles – 300
Dipole length – 6.1 metres
Dipole field (at 150 GeV) – 1.73 tesla
Dipole Field (at 8.9 GeV) – 0.1 tesla
Number of quadrupoles – 202
Quadrupole gradient – 19.6 tesla/m

Around the Laboratories

The decay of a Z particle as seen by the Delphi experiment at CERN's LEP electron-positron collider. The innermost tracking region shows the hits recorded in the microvertex detector (inner and outer radii 90 and 109 mm) surrounding the beam pipe. The tracking continues outwards in the next layer of the inner detector before entering the time projection chamber. First results from the Delphi microvertex detector show resolutions in each plane of better than 7.5 microns.



CERN Microvertices

When beams of high energy electrons and positrons collide, some rare and highly unstable (and therefore very interesting) particles can be formed. To pick up the tiny decay path of these transient particles, which live for only a millionth of a millionth of a second (or even less) before they decay, needs 'microvertex detectors' – precision tracking very close to the beam pipe.

One technique developed with this in mind uses arrays of closely-packed semiconductor diodes, the so-called 'silicon microstrips'. The first such detectors emerged about a decade ago, and from these initial devices with hundreds of strips and 200 micron pitch, the technology progressed to thousands of strips with 20-50 micron spacing.

In the 1980s their use was confined to fixed target experiments searching for particles containing heavy quarks, pioneered by the NA11 and NA32 groups at CERN. Another notable early success was the 1985 B meson sighting by the WA75 experiment at CERN, which discerned track stubs only a fraction of a millimetre long.

Silicon microvertex detectors are now in use at the Delphi and Aleph experiments at CERN's LEP electron-positron collider, and initial results are promising. Z events in

LEP progress

With CERN's new LEP electron-positron collider about half-way through its three-month run for this year, good progress continues to be made, with production coasts for physics alternating with machine development studies to bring the complex machine towards its design performance levels.

In its debut last year, LEP supplied its four big experiments – Aleph, L3, Delphi and Opal – with a total of over 100,000 Z particles, boosting the world supply about a hundredfold.

Optimism rose in April when a new tune value was found to give better beam accumulation. Towards the end of May, careful optimization of the injection procedures paid off, with long coasts of 12 hours or more and with beam intensity (electrons and positrons combined) attaining 4 mA after accumulation at the 20 GeV injection level and with 3.5 mA ramped to around 45 GeV per beam for physics, an encouraging increase over last year's performance. At these levels LEP is really in business.

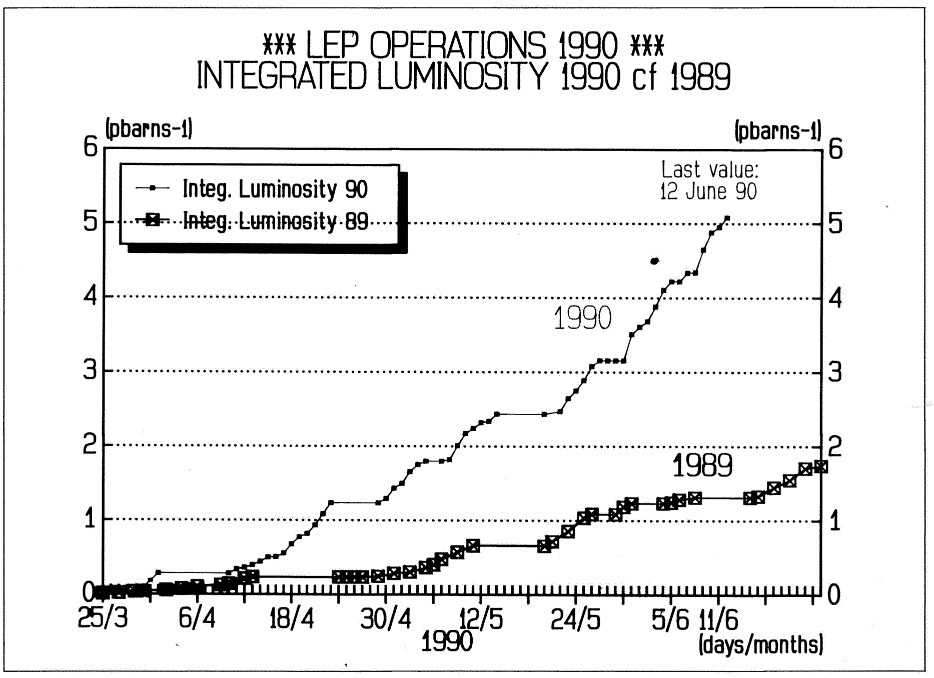
*Underlining this progress, in a subsequent development run the machine attained its design level of 0.75 mA in one bunch (2.88 mA for four bunches) in single beam operation.**

Superconducting 'low-beta' magnets squeeze the beams in the experimental areas and boost the collision rate, but the luminosities (a measure of the collision rate) seen by the experiments have been unpredictable if the squeeze is pushed hard (to 4 cm). Squeezing to the design value of 5 cm has been adopted for routine physics while machine experts study how best to squeeze significantly below design.

Meanwhile the experiments are getting plenty of Zs, with the lowest-beta card and its potential 60 per cent luminosity increase still to be played. Pushing the injection energy from the SPS from 20 to 21.8 GeV should also help.

**** LEP's positron current has subsequently exceeded 2.9 mA***

Steady increase in performance (integrated luminosity) by CERN's new LEP electron-positron collider this year (compared to the initial run last year), with production runs for physics alternating with machine development periods (the plateaux where no luminosity score is kept). The luminosity figures do not take into account perturbations due to beam-beam effects which have yet to be accurately estimated.



Delphi show that the spatial resolution of each microvertex detector plane is better than 7.5 microns. A similar detector is planned for the Opal experiment. A silicon strip microvertex detector is also used at the heart of the Mark II experiment at Stanford's SLC linear collider (May, page 9), while the SLD detector being prepared in the wings for SLC will use instead CCD technology (November 1988, page 37).

Delphi uses two concentric cylinders (actually 24-sided polygons as the constituent microstrip modules are flat) at 90 and 109 mm from the beam axis, fitting between the existing beampipe (radius 80 mm) and the innermost layer of the main detector (118 mm). With an active length of 240 mm, it gives substantial angular coverage around the collision point.

The microstrips themselves, five microns across set at 25 micron pitch, incorporate integrated coupling capacitors to facilitate readout, a technique specially developed in CERN's silicon detector development group in collaboration with the Norwegian Centre for Industrial Research, Oslo. Each detector unit contains more than a thousand strips, and there are more than 50,000 readout channels in total. New readout MXIII chips using CMOS technology and with reduced power consumption were developed by the UK Rutherford Appleton Laboratory's microelectronics group, based on the original Microplex design.

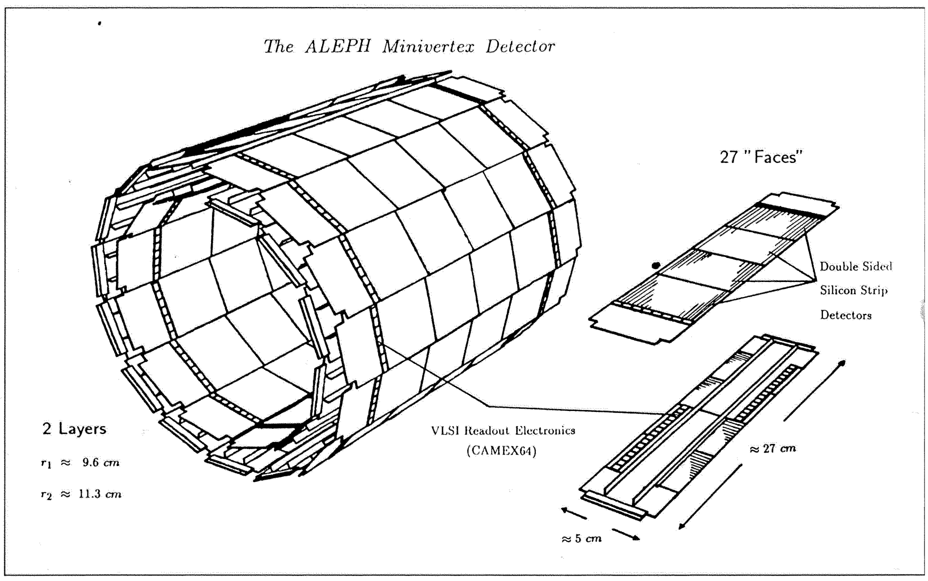
Two concentric barrels are also used in Aleph – 12 faces at 96mm radius inside 15 faces at 113 mm. The detector modules are wafers with strip patterns on both sides, one side measuring parallel to the beam and the other perpendicular, with strip pitch 25 and 50 microns respectively. This scheme reduces both the number of strip modules needed and the amount of scattering material attenuating secondary particles, and improves three-dimensional reconstruction.

A 64-channel CMOS VLSI analog amplifier chip (CAMEX64) giving high gain, low noise amplification with low power consumption and fast power switching was specially developed at the Max Planck Institute Munich and the Fraunhofer Microelectronics Institute, Duisburg.

For Opal, the strip devices will be mounted in two concentric barrels with 11 faces in the inside and 14 on the outside. Double-sided wafers are the preferred option, but a fallback solution with single-sided units mounted back-to-back to give orthogonal coordinate readout is also being prepared. The detector would be installed during the major LEP shutdown beginning in August and extending into next year.

All experiments will benefit from a smaller LEP beam pipe in the experimental areas, to be installed in the next shutdown so as to be ready for running next year. This will allow the inner strip arrays to be mounted closer to the beam collision point.

The microvertex detector for the Aleph experiment at CERN's LEP electron-positron collider uses double sided silicon strip modules to assist three dimensional reconstruction.



UPPSALA
Warm reception for cold beams

The The (for Theodor) Svedberg Laboratory (commemorating the 1926 Nobel prizewinner and pioneer of Sweden's particle accelerator effort) groups all Uppsala accelerator-based science. With a tandem machine, the rebuilt Gustaf Werner cyclotron and the CELSIUS cooler/storage ring, the centre caters for some 50 experiments by 200 scientists from all over Sweden and further afield.

Pride of place at the Laboratory goes to the 82-metre CELSIUS ring, equipped with magnets previously used at CERN, first in the g-2 ring to measure the anomalous magnetic moment of the muon, and then in the late 1970s in the ICE ring which explored the then new techniques for beam cooling.

After initial operation last year (June 1989, page 24), CELSIUS research is getting into its stride. Installed in one 9.6 metre straight section, the electron cooler, built by Miroslav Sedlacek of Stockholm's Royal Institute of Technology and Lars Hermansson of TSL, went into preliminary operation in May. It has cooled protons at the 48 MeV injection energy, and with only 150 mA of electron beam current has achieved a cooling time of about one second. The momentum width in a 10^{10} proton beam appears to be a hundred times smaller than that of the injected beam.

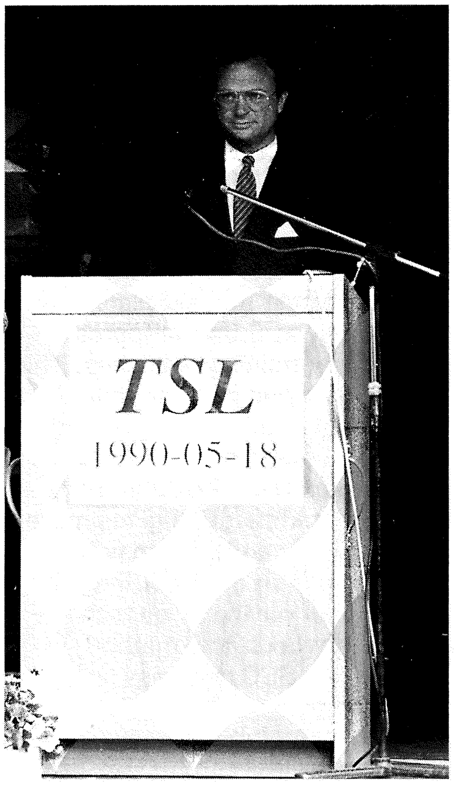
The electron cooler's gun provides a 2 cm-diameter circular beam at up to 3 A. In a homogeneous longitudinal magnetic field of up to 0.18 tesla, the electrons can be taken to between 10 and 300 keV.

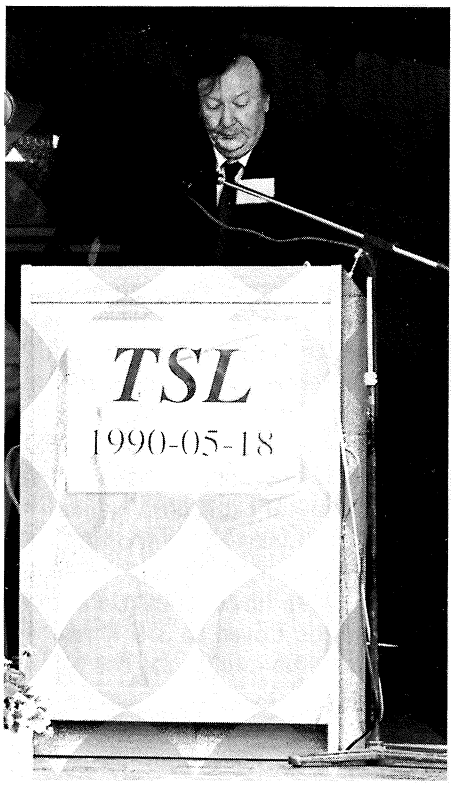
CELSIUS is filled from the adjacent Gustaf Werner cyclotron (substantially rebuilt since it was commissioned as a 185 MeV synchrocyclotron, Europe's highest energy machine, in 1949), using multi-turn injection and two time-dependent 'bumping' magnets, together with a septum magnet and electrostatic deflectors for small angular corrections. As well as providing magnets, CERN has also assisted in the development of the CELSIUS injection and acceleration scheme.

For CELSIUS, the cyclotron in fact supplies hydrogen-2+ ions (two protons bound with one electron). This beam is moved by the bumper magnets onto a stripping foil, the resulting proton beam becoming separated from the parent ion beam. This technique gives beams a hundred times more intense than with protons alone, with about 7 mA (4 x 10^{10} protons) having been stored.

Maximum proton energy in CELSIUS is currently 1.3 GeV, dictated by the power available. The magnet lattice could handle 2 GeV protons.

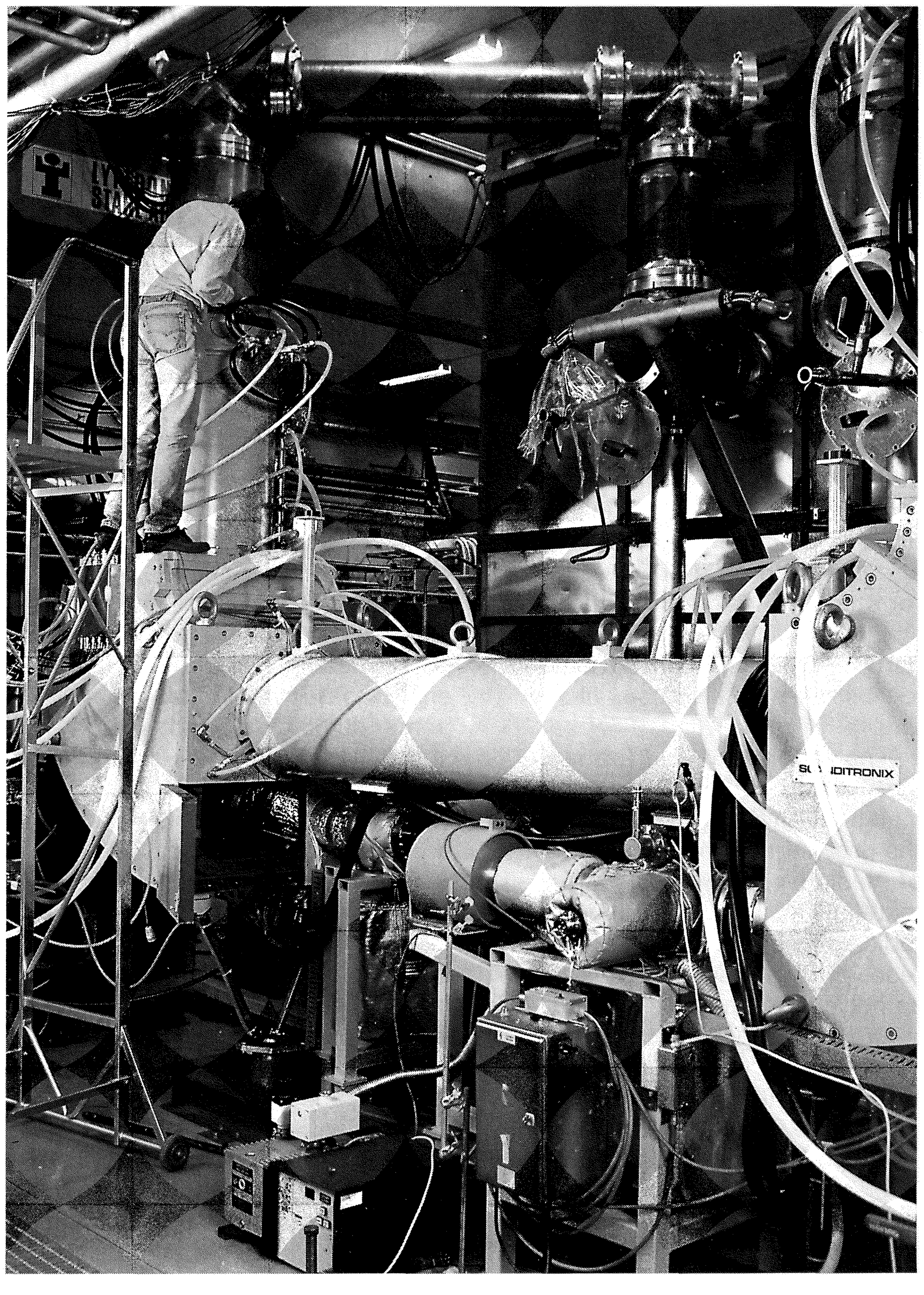
Another straight section con-





Left, at the inauguration on 18 May of the The Svedberg Laboratory at Uppsala – top, King Carl XVI Gustaf of Sweden; below, CERN Director General Carlo Rubbia.

Below: the Svedberg Laboratory is the home of the Celsius cooler/storage ring, using magnets inherited from the historic g-2 and ICE experiments at CERN. Seen here is the Celsius electron cooling equipment, which has already operated on 48 MeV protons, giving a cooling time of about one second with an electron current of 150 mA. The momentum spread of a 10^{10} proton beam is reduced by a factor of a hundred.



tains a 'cluster-jet' internal target supplying effective thicknesses of the order of nanograms per sq cm, enough to supply substantial reaction rates, but not so large as to destroy the carefully prepared beam. Fibre targets are also available. In operation, the stored beams are used up by target interactions during 10-100 seconds, the machine then being prepared for a subsequent injection.

Early physics objectives include precision studies of pion effects, light meson production, and the search for rare decays to cast more light on the mechanisms underlying today's Standard Model of physics.

Upstream of CELSIUS, the substantially rebuilt Gustav Werner machine can operate both as an isochronous cyclotron and as a synchrocyclotron feeding a range of experiments as well as CELSIUS. Biomedical research has a long tradition at Uppsala and the reconstructed cyclotron provides additional impetus for this work. Wide and narrow proton beams are used for studies and for actual radiotherapy, 70 MeV protons being standard for eye melanomas. Radiobiological research also uses heavy ions.

The Laboratory was formally inaugurated on 17-18 May. An Inauguration Symposium covered the growing range of applications of medium energy accelerators – materials analysis and treatment, radioisotope dating, and biomedical research and radiotherapy as well as nuclear and particle physics.

During the inauguration ceremony on 18 May CERN Director General Carlo Rubbia sketched the history of the CELSIUS hardware in its previous g-2 and ICE incarnations at CERN, explaining how the muon magnetic moment results had dramatically confirmed the accuracy of quantum electrodynamics, underlining the richness and complexity of the vacuum. ICE and cooling techniques had opened the door to a new field of physics, and the precision experiments possible in the new generation of cooler rings provides an additional physics frontier complementary to the high energy regime of the big machines. Finally King Carl Gustaf, who had been his country's representative at the inauguration of CERN's LEP ring in November, reflected his country's pride in the new Uppsala accelerator research centre and formally opened the new Laboratory.

SUPERCOLLIDER Magnet update

The heart of the proposed US Superconducting Supercollider (SSC) is the set of superconducting magnets to hold its beams in orbit. Approximately 8,000 dipoles and 2,000 quadrupoles are needed, as well as many other special magnets. In addition the 2 TeV high energy booster would also be a superconducting machine, using about 1,200 magnets. In all, some 12,000 superconducting magnets would need to be precision built at the lowest possible cost.

SSC magnet research and development has been underway since 1985 at Brookhaven, Berkeley and Fermilab. The new SSC Laboratory in Ellis County, Texas, is beginning its in-house R&D effort and preparations are underway to involve industry as soon as possible.

A series of nine full-length (17 metre) magnets were built in 1989, drawing on the first four years of research. The quench performance of these magnets was greatly improved over that of their predecessors. After at most one or two training quenches, they plateau at the critical current, about 6,800 amperes at the operating temperature of 4.35 K, corresponding to a magnetic field about 5% above the design level.

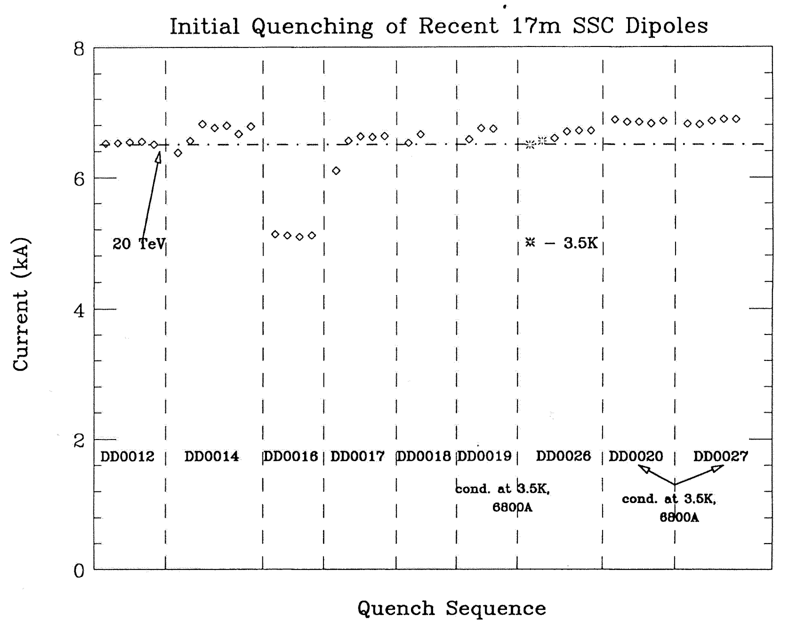
In tests at Brookhaven in mid-April, the latest magnet plateaued immediately at 6,840 amperes without any training quenches. This magnet was one of three that had first been 'conditioned' – cooled to 3.5K and powered at higher than operating current (6,500 amps). The lower temperature gives more critical current and so it may be possible to train magnets in this way without having to quench them. If it works, this method would make SSC commissioning much easier.

For manufacturers of superconducting wire, the current carrying capacity has been defined, at standard conditions of 4.2K and 5 tesla, as 2,750 A/sq mm. This is an ambitious goal for the superconductor industry and has been the focus of a four year R&D programme. The community is very close to achieving it, the conductor used in the latest magnets carrying essentially this current density.

Variation around this figure should be minimal, and uniform diameter (about 6 microns) and spacing (1-2 microns) of the superconducting filaments inside the wire are also important. Such uniformity will simplify correction of the so-called 'persistent currents' which induce potentially troublesome multipole fields.

The dipoles have been run at temperatures down to 3.5 K to test their behaviour under the higher currents and correspondingly higher forces. The increase in critical current and magnetic field at

Performance of superconducting dipoles for the proposed US Superconducting Supercollider (SSC). Starting with DD0019, an attempt was made to 'condition' the magnets by powering them to 6800 amps at 3.5K, hopefully without quenching. If this works, then magnet commissioning becomes simpler. However DD0026 did not cooperate, and 'trained' in the normal way, by quenching.



lower temperatures agrees with measurements of short samples of cable, and the magnets are structurally sound at currents up to 7,500 amperes.

Earlier this year (April, page 12) it was decided to increase the collider dipole aperture from 40 to 50 mm to enlarge the good field region for more reliable operation and easier commissioning.

This design change also opens the door to other modifications to increase the dipole field operating margin to about 10%. Thus the amount of superconductor in the cable will be increased from 23 to 30 strands per cable in the inner layer and from 30 to 36 in the outer layer, increasing the cable width by about 25%. The copper to superconductor ratio will also be increased from 1.3 to 1.5 in the inner cable.

The new 50 mm dipole development programme is following a dual path. At Brookhaven six short 50 mm magnets will be built as soon as possible, paced by the acquisition of new curing presses and tooling for making collar and yoke laminations. Winding for the first 1.8 metre magnet is to begin in October. At Fermilab, six short 50 mm magnets will explore design variations prior to assembly of the first long 50 mm magnets at Fermilab, leading in turn to industrial assembly. A task force headed by Bob Palmer, with representatives from all four labs, is studying the 50 mm dipole development.

In parallel with the 50 mm development, work on the original 40 mm dipoles is continuing. These magnets are well understood and serve as a valuable test bed for studying basic design questions.

Berkeley has spearheaded the development of SSC quadrupoles. The present design uses a 40 mm aperture, and after model studies the first full length quads are scheduled for tests late this year. Preliminary studies of a thin collar version suggest that the current field gradient could be maintained with a 50 mm aperture.

The selection of a principal industrial contractor for the dipole magnets is given high priority, and it is hoped to have the contractor on board soon, using existing Fermilab facilities until his own can be set up. If all goes well, the first industrially assembled full length collider dipoles could be put together by the contractor at Fermilab starting next spring. A series of twelve such demo magnets is planned, ten to be used in 1992 SSC on-site string tests, five in a half cell above ground, and five below ground in the first section of SSC tunnel.

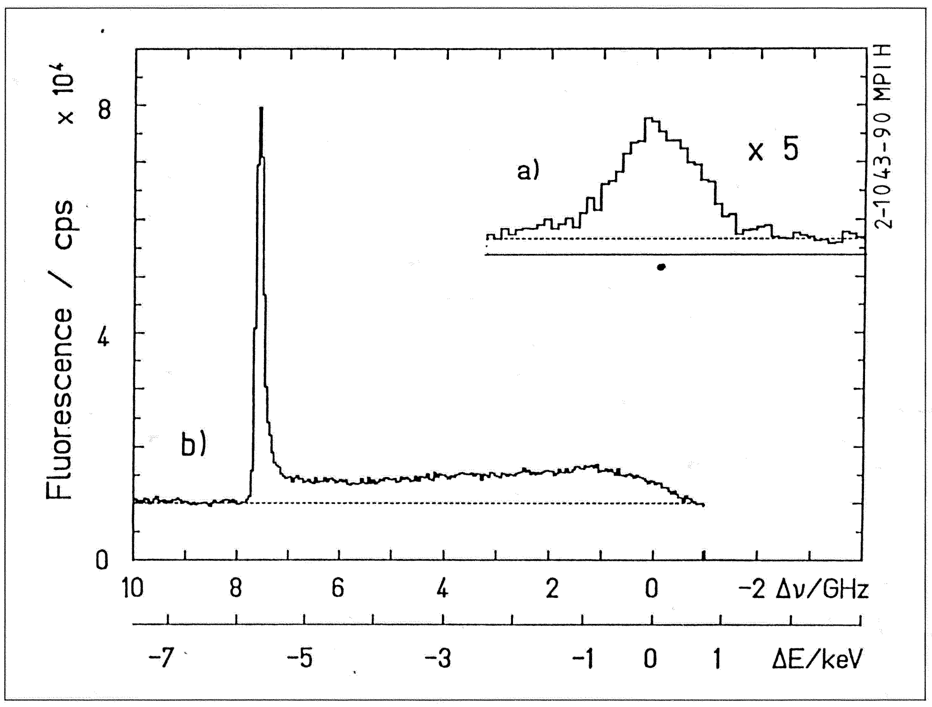
In parallel the contractor will begin building 15 prototype dipoles in his own plant leading eventually to full production at a rate of ten magnets per day for several years. After the principal or 'leader' firm has magnet work well underway, it is expected to transfer the technology and subcontract part of the production to a 'follower' firm. A separate contractor is to be selected for the quadrupoles.

Another machine design change made this year was to decrease the half-cell length (quad-to-quad spacing) from 114 to 90 metres and the dipole length from 17.4 to 15.8 meters. With these changes, the total number of superconducting magnets increases from about 10,000 to a little over 12,000.

Three magnet laboratories are planned on site. The first, called the Magnet Evaluation Laboratory (MEL), has been set up in one of the leased buildings in Dallas. It will be used to gain local expertise through hands-on experience and for preliminary engineering studies. Two magnets from Brookhaven and Fermilab will be autopsied and used for vibration tests.

A second facility, the Magnet

Laser cooling in action at the Heidelberg Test Storage Ring (TSR). Top (a) – initial velocity distribution with a longitudinal beam temperature of 260 K. After laser cooling, the velocity spread is highly compressed – below (b) is the fluorescence spectrum of stored lithium-7+ ions. After a 2-second sweep of the dye laser the temperature drops to about 3 K.



Test Laboratory (MTL), is to be built as soon as possible, probably near the E1 area where the first section of tunnel is to be excavated and the string tests conducted. It should be available by mid-1992 and will be used for cold testing all magnets built on-site and some fraction of those built by industry during its production run. Ten test stands are planned initially, which could be increased to twenty.

The third, called the Magnet Development Laboratory (MDL), would follow, providing in-house capability to build magnets of any type.

AARHUS/ HEIDELBERG Laser cooling in action

First successful laser cooling of accumulated ion beams has been accomplished at the new storage rings ASTRID at Aarhus in Denmark and TSR (Test Storage Ring) at Heidelberg's Max Planck Institute.

The researchers hope that by extending the laser cooling power, final beam temperatures in the mK region might be attained, when the beam could show 'solid' or even 'crystalline' behaviour.

TSR Heidelberg

The TSR heavy ion cooler/storage ring (September 1988, page 17) was built in collaboration with groups from GSI Darmstadt, Heidelberg, Giessen and Marburg. The 55m ring is able to handle a wide range of ions.

In the latest experiment, a coasting lithium-7 beam of 25 mm diameter containing about 10^{7-8} ions was accumulated at 13.3 MeV and stored in the TSR with a lifetime of 8 sec. During the stripping process in the tandem accelerator supplying the ions, about 10% of the ions were excited to a long-lived metastable state (1s2s $^3S_1$). The $^3S_1$ and $^3P_2$ states, connected by an optical electric dipole transition of wavelength 548.5 nm, form a closed two-level system, well suited for laser cooling.

The ion beam was merged in one of the TSR straight sections with a copropagating laser beam from a single-mode argon ion laser (wavelength 514.5 nm) and a counterpropagating beam from a single-mode dye laser (wavelength 584.8 nm). The energy of the ion beam was tuned so that the Doppler-shifted frequencies of both laser beams in the rest frame of the ions corresponded to the 548.5 nm transition.

For laser cooling the frequency of the argon ion laser was set in resonance with ions at the low energy side of the beam velocity profile and kept constant. The frequency of the counterpropagating dye laser was set at the corresponding high energy side and swept towards lower energies. Ions coming into resonance with the dye laser were decelerated by the laser light pressure during the absorption/emission process and the combined action of sweeping the laser frequency and transferring photon momenta pushed the ions into a narrow velocity band.

The initial and compressed velocity distributions were measured by detecting the fluorescent light perpendicular to the ion beam. The initial distribution was obtained by reverse sweeping the dye laser to avoid any cooling compression. The metastable ions were accumulated during the initial stage of the scanning process and then emitted fluorescent light of approximately constant intensity while being further decelerated. The narrow velocity distribution became visible as the ions were finally shifted across the resonant frequency of the intense copropagating argon laser beam. At this stage the cooled ions were simultaneously interacting with both laser fields, giving a bright fluorescence.

In these experiments – similar results have been obtained for beryllium-9+ – the initial longitudinal velocity distribution, corresponding to a temperature of 260 K in the rest frame of the ions, could be compressed up to a factor of 100 and final temperatures of less than 3 K have been observed.

In the transverse direction, however, the ion beam temperature remained at the initial level of about 10^6 K because under these conditions the longitudinal-transverse coupling is small.

In addition ion beams have been improved by electron cooling - beam diameters of less than 2 mm having been obtained after 3 sec. Combined electron and laser cooling experiments are underway to investigate the possibility of indirect laser cooling in the transverse direction by intrabeam scattering. This method should be particularly effective for beryllium-9 as, in contrast to lithium-7, all ions are directly accessible by laser cooling.

Simultaneous storage of deuteron and oxygen beams

With beam accumulation by electron cooling, deuteron and oxygen ions (kinetic energy 6.1 MeV/nucleon) have been stored at the same time in the TSR Test Storage Ring at the Max Planck Institute, Heidelberg. The electron cooling simultaneously improved beam behaviour (reduced emittance) and transferred the first stored beam to a stack position. Successive injection of the second ion species allowed 10^9 deuterons (100 microamps) and 10^8 oxygen ions (80 microamps) of the same velocity and nearly equal magnetic rigidity to be stored simultaneously. The two beams could be discerned as well-separated peaks in the Schottky noise because of the different nuclear binding energies of the two ions.

The ASTRID ring at Aarhus in Denmark – synchrotron radiation and ion beams.

Aarhus results

ASTRID at Aarhus is a new storage ring for ions and electrons modelled on CERN's LEAR low energy antiproton ring. The project went ahead with help also from synchrotron radiation centres MAX (Lund, Sweden) and BESSY (Berlin) as well as CERN.

Electrons are injected into the 'ring' (four eight-metre straights connected by 90° bends) from a race-track microtron, and ions from a specially built ion separator.

For synchrotron radiation, electrons are injected at 100 MeV and accelerated to 600 MeV. Radiation is taken from the bending magnets, but future plans include addition of wiggler/undulator magnets in a straight section to boost intensity and photon energy.

For heavy ions, the objective is to store particles for a long time. Injection is at 100 keV from an ultra-stable isotope separator, and so far beams of helium, neon, argon and lithium ions have been stored, typically at the 10^8 level.

The isotope separator's energy spreads are already very small, of the order of 10^{-5}, but this has been reduced at least tenfold along the beam direction by laser cooling, using contra-firing dye lasers and a lithium-7 beam.

Future studies will investigate the possibility of cooling also in the transverse direction, relying on intra-beam scattering. Also lined up is a study using beams of erbium ions, where the cooling mechanism acts on ground state ions, rather than the metastable lithium states.

At the moment an electron cooling system is used on the nearby tandem accelerator, but in time this will be transferred to the ASTRID ring to boost the cooling possibilities.

DESY European cryogenics

Built to provide cryogenics for the superconducting proton ring of the HERA electron-proton collider now nearing completion at the DESY Laboratory in Hamburg, the biggest liquid helium refrigeration plant ever built in Europe has just completed its first three years of operation.

Performance is of great interest for specialists contemplating the next generation of proton colliders – LHC at CERN and the US Superconducting Supercollider, SSC.

Technical details were specified by DESY experts. The plant has to cool down and keep cold all HERA superconducting devices, including about 650 magnets of the proton ring, several detector magnets, the superconducting accelerating cavities for the electron ring and the seven-kilometre helium transfer line.

In normal operation the plant should supply supercritical helium at 4.4 K and 3.5 bar (up to 13.5 kW) , cold helium at 40 K (up to 40 kW, mainly for the radiation shields) and 41 g/sec of liquid helium for the magnet current leads. Liquid nitrogen is only used in the cooling down phase.

HERA is divided into two cooling circuits, and a third line supplies cold helium to the large superconducting magnet test hall.

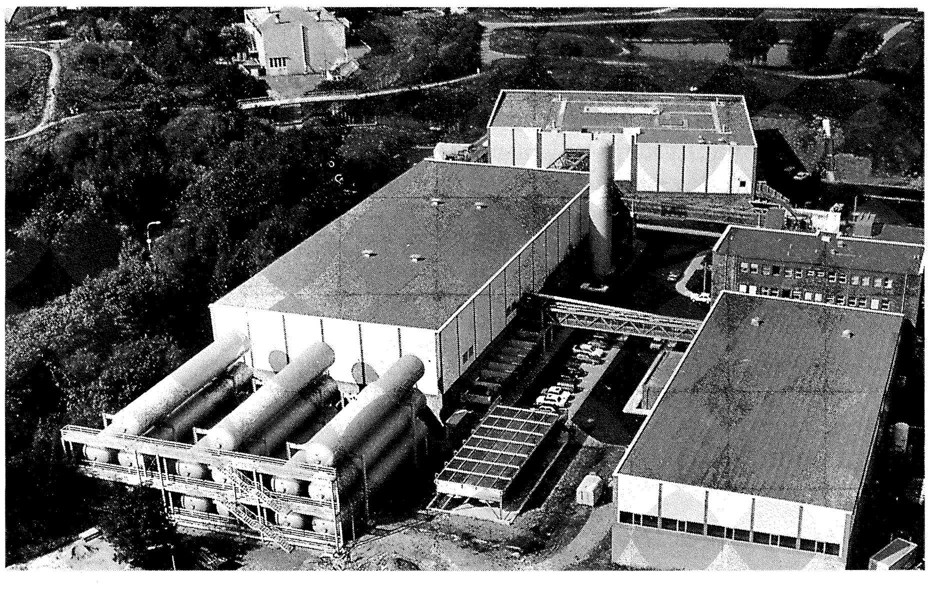
The cryogenic plant, 33 x 72 metres, consists of three almost independent units, each capable of providing half the required cooling power, with compressors, purifiers and cold-boxes (with seven gas suspended expansion turbines each) feeding cold helium to a big distribution box. The north and south segments of HERA are served by one refrigeration unit each, selected by the distribution box, leaving in general the third unit free for backup.

About 13 tons of helium circulate in the system. Still cold returned helium is used in heat exchangers in the cold-boxes to cool the gas coming from the compressors.

All the helium can be stored at room temperature (18 atm) in 15 special tanks. Two dewars for another 1.25 ton of helium are also available.

Particular care was given to reliability of the most important components, the compressors and the expansion turbines. In three years of operation, no serious problems have been encountered.

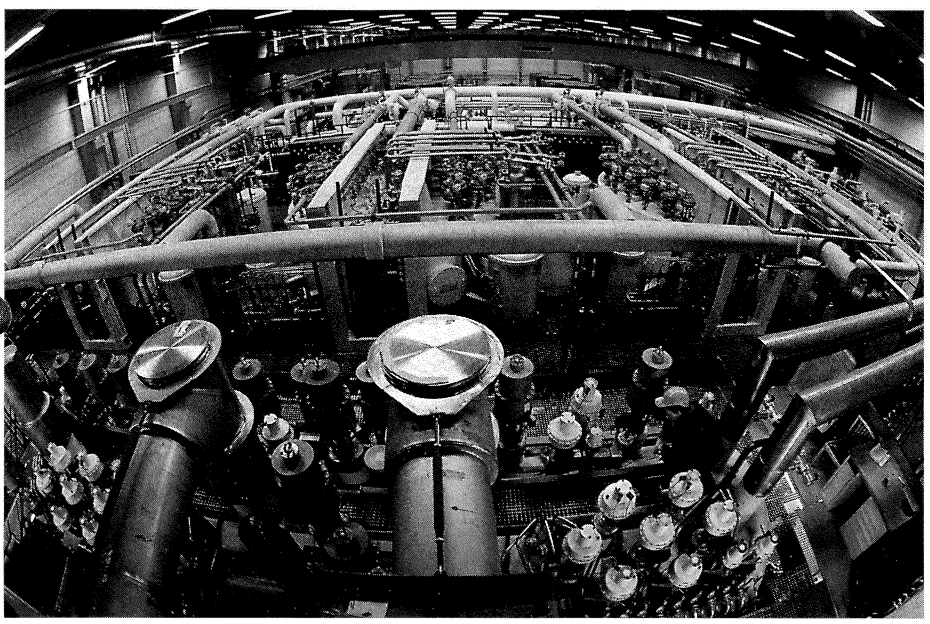
Helium purification has been shown to be extremely important. After compression to about 18 bar, each kilogram of helium includes 18 kgs of oil, which must be reduced to less than 10 parts per billion. Other impurities must be kept under 5 parts per million.



Left, the cryo-hall for the HERA electron-proton collider at the DESY Laboratory in Hamburg, with, top, the HERA West Hall and, right, the superconducting magnet test hall.

Inside the big HERA cryo-hall

(Photo P. Waloschek).



The efficiency of the system is remarkable, 281 Watt at 300 K (power consumption) per Watt at 4.3 K. Construction was handled by Sulzer-Escher-Wyss (Lindau), manufacturers of the three big cold-boxes, and who since June 1987 have also handled operation. The main helium distribution box and the low temperature purifier were made by the Linde company. The screw compressors are from Aerzener (Hanover) and the vacuum system from Balzers and Leybold.

In April, a complete octant of the HERA proton ring was successfully cooled down and results are eagerly awaited.

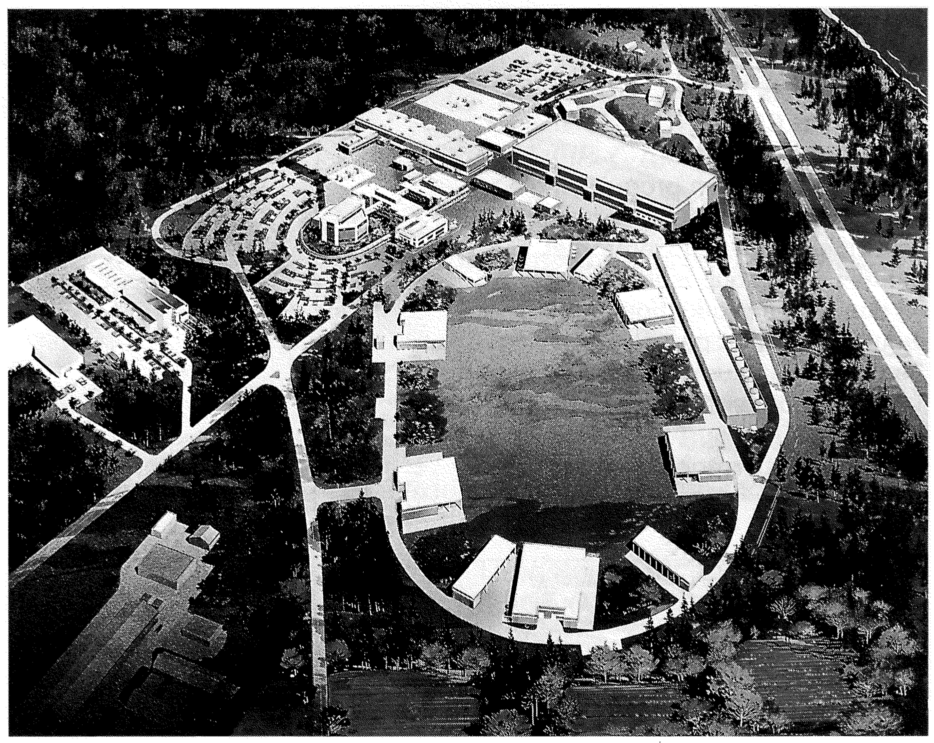
TRIUMF KAON impact study

Funded by an 11 million Canadian dollar agreement between the Canadian government and the regional British Columbia administration, an impact study for the proposed KAON particle beam factory at the TRIUMF Laboratory in Vancouver (October 1989 issue, page 9) is very positive, providing valuable impetus for the final decision-making process in Ottawa.

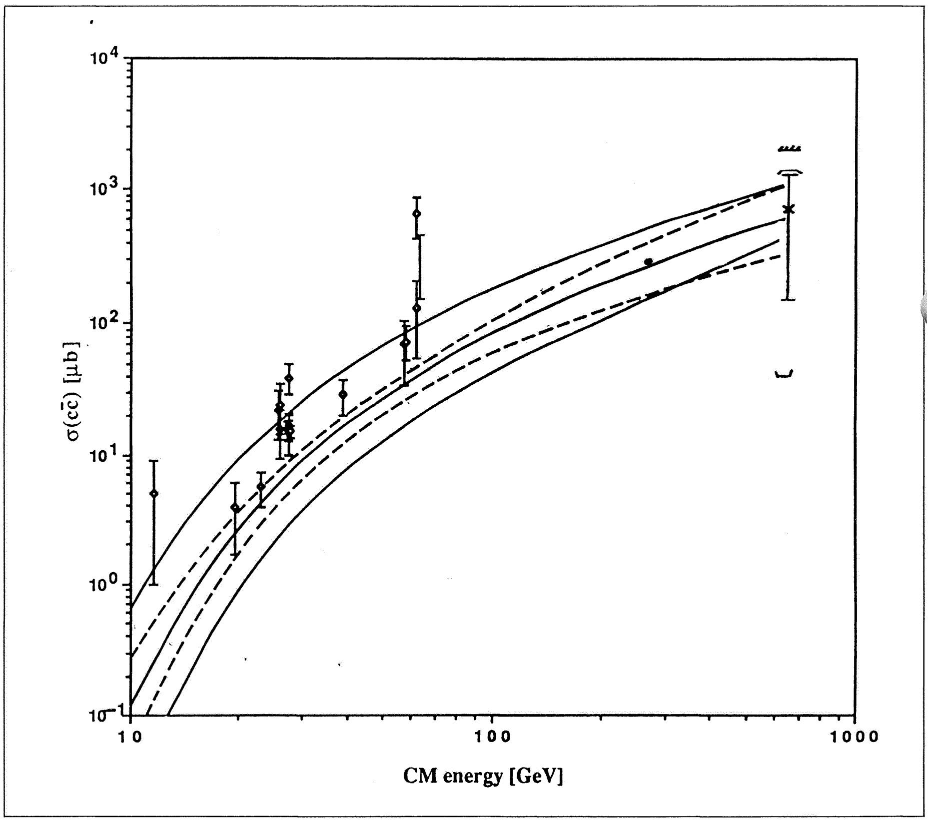
The study reaffirms the scientific value of the project, and the design has been approved by a panel under Lee Teng of Fermilab (and including the late Eifion Jones of CERN). International consultations indicate that foreign participation (mainly component equipment) for the $693 million scheme could be close to the $200 million target. Construction would be of high priority to Canadian industry, with $316 million of high technology equipment involved. Estimates indicate that direct benefits alone can cover 80 per cent of the project costs.

The Canadian government decision is expected later this year.

Below – model of the KAON particle beam factory proposed for the Canadian TRIUMF Laboratory in Vancouver. The main 1070-metre tunnel would house three rings – Collector, Driver and Extender.



The production rate for charmed particles (vertical axis) increases slowly at higher energy. The right-hand point at 630 GeV collision energy, measured by a group using a ring-imaging Cherenkov detector (RICH) in the UA2 experiment at CERN's proton-antiproton collider, provides a valuable extrapolation beyond previously measured levels. The curves are recent (higher order) theoretical calculations.



CERN RICH dividends

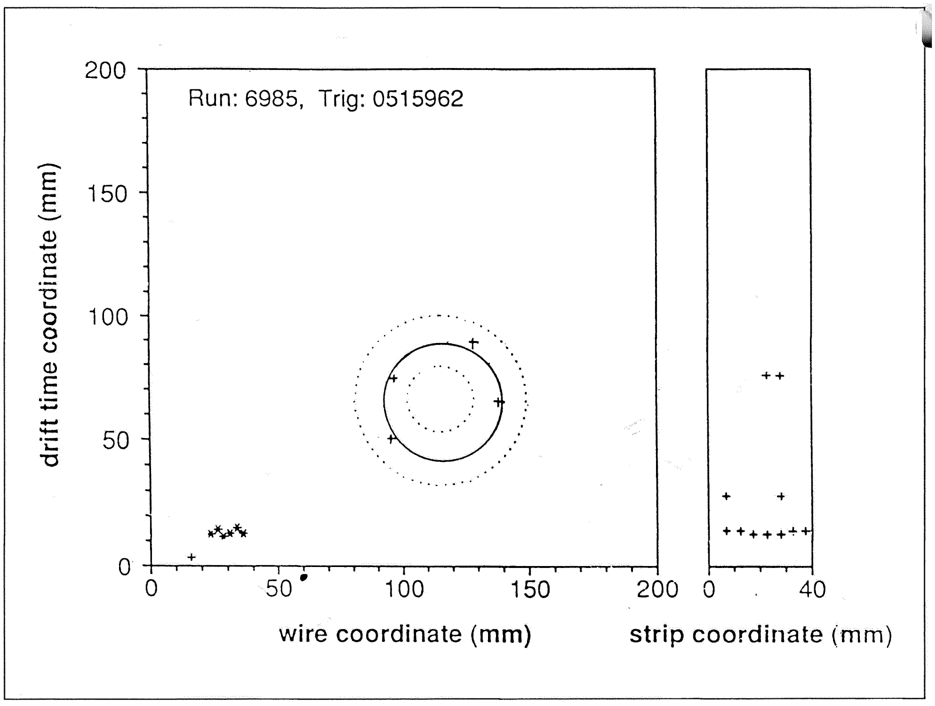
Back in 1985, when the hunt was on at CERN's proton-antiproton collider for as many W and Z particles as possible, an Athens/CERN/Uppsala/Wuppertal group had an unique chance to install a ring-imaging Cherenkov counter (RICH) in one of the twelve end-cap sectors of the big UA2 experiment and squeeze in a short run.

In a RICH, the photons radiated by a traversing charged particle are focused by a special mirror to form a ring image. With the ring size related to the mass and momentum of the charged particle, this provides a means of particle identification.

RICH counters had appeared in fixed target experiments before, but the project at UA2 was the first time the technique had been used in a collider, where the available space is very restricted. This also blazed a trail for the use of RICH counters in the big Delphi experiment at CERN's new LEP electron-positron collider.

Concentrating on prompt single electrons, and carefully eliminating electrons emanating from other sources, the group isolated the signal due to the production and subsequent decay of particles carrying the charm quantum number.

While such particles are produced fairly copiously in high energy proton-antiproton collisions,

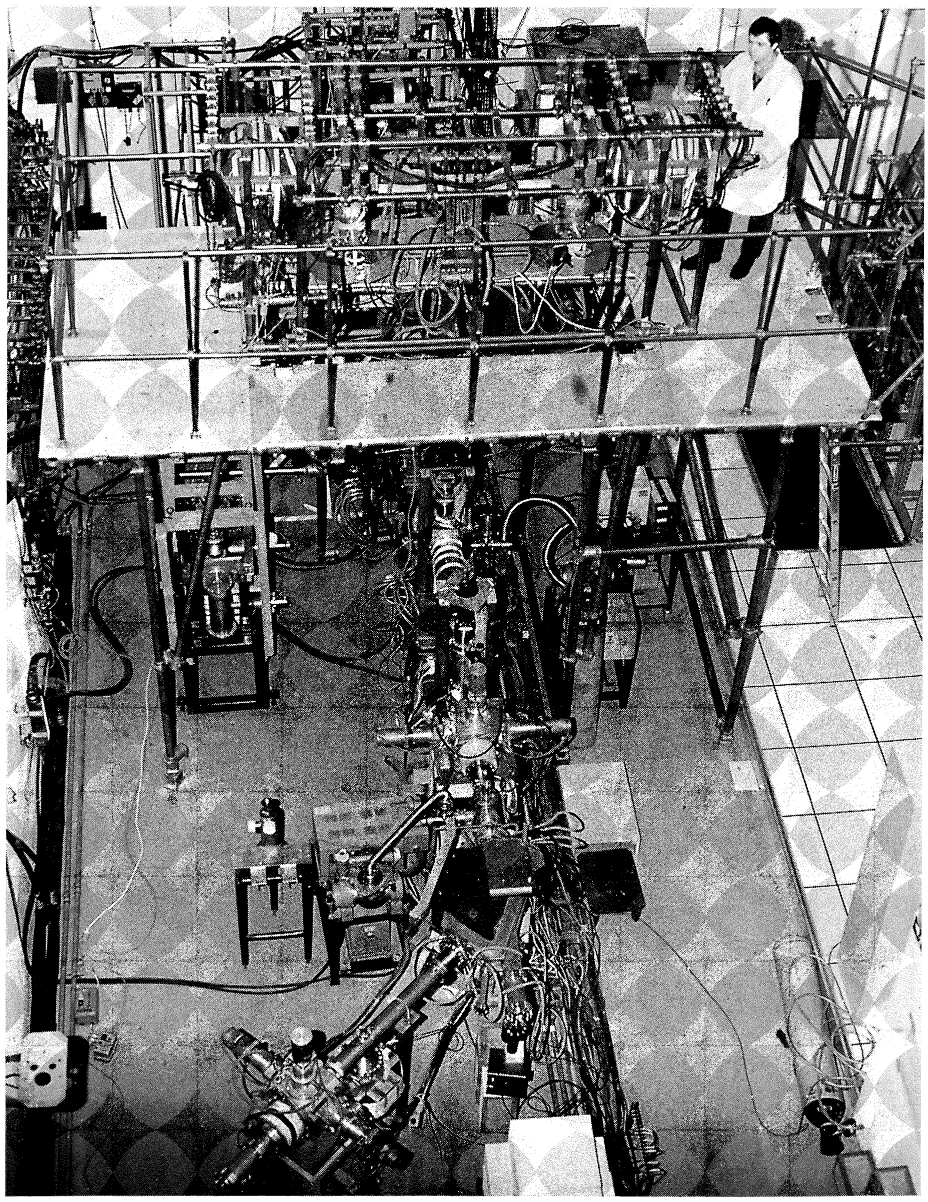


A Cherenkov ring fitted round the four photons (shown as crosses) given off by particle traversing the RICH detector inside the UA2 setup at CERN's proton-antiproton collider. (The dotted lines delimit the expected ring position.) The ring radius fixes the particle as an electron. Its track ionization is seen in the lower left corner.

their decay electrons are not kicked away strongly from the beam direction, and are swamped by pions unless the detector has good angular resolution.

Measuring the charm production level at the collider energy of 630 GeV is an order of magnitude energy step beyond the previous measurements at CERN's Intersecting Storage Rings (ISR – where proton beams gave collision energies of up to 62 GeV). At the time these ISR measurements led to speculation that the charm production rate would take off at higher energies.

However the production rate seen in the rapid but valuable RICH exposure at the proton-antiproton collider shows only moderate growth, shooting down the earlier speculations. Moreover the measurements are in good agreement with recent (higher order) calculations in the underlying field theory of quark interactions (QCD – quantum chromodynamics), adding additional confidence in our understanding of fundamental processes.



The NEPAL test station at the French Orsay Laboratory.

ORSAY
High-gradient experiment

Maintaining the tradition of its contribution to the LEP Injector Linac (LIL), Orsay's Linear Accelerator Laboratory (LAL) is carrying out an R&D programme entitled 'New accelerator physics experiments at LAL' (NEPAL). The aim is to contribute to the long-term development of high energy electron-positron linear colliders, where progress can be of short-term benefit both to conventional accelerators and to injectors in rings or free-electron lasers.

The high-gradient experiment, part of the NEPAL programme, is an examination of accelerating structures in high accelerating fields. So far two structures have been investigated – a short 0.8 m LIL type, with conventional electric coupling and maximum energy density per unit length; and a longer structure, 1.3 m, manufactured by General Electric/CGR-MeV in collaboration with LAL, with magnetic coupling (inverse wave) to optimize shunt impedance and propagation time separately, and the field reinforced by the cell's 'nose' structure.

The NEPAL test station is a complete small accelerator comprising: a 3 GHz r.f. power source pulsed to 100 Hz with a klystron used either directly or after a

(LIPS/SLED-type) pulse compressor system; a 4 MeV electron source with a SLAC-type triode gun, a pre-bunching cavity and a high field buncher; space for accelerating sections up to 1.8 m long; and instrumentation, including a spectrometer which can be used up to 75 MeV/c.

The aim is to quantify the two main phenomena limiting the energy gain per unit length: the breakdown threshold, where the corresponding field is measured from the r.f. power or directly via the energy gain of the accelerated electrons; and the current of field emitted electrons well before breakdown and bunched into a coherent beam, characterized by the overall accelerated charge at the end of the section, the time structure, the transverse profile and the energy spectrum. This phenomenon can be simulated using a mathematical model designed and developed at the University of Genoa.

There is reason to believe that parasitic currents will be a severe limitation at very high energies. Cumulative effects could absorb a substantial fraction of the r.f. power and produce wake fields with consequent damaging transverse effects.

The LIL structure gave long pulses of maximum surface fields of 80 MV/m corresponding to accelerating fields of 40 MV/m. SLED mode with 170 MW gave axial fields of 88 and 68 MV/m on the LIL and CGR structures respectively, corresponding in the latter case to a surface field of 180 MV/m. Under these conditions, the peak current from the LIL section was 60 mA per metre.

The properties of accelerating structures improve if the r.f. frequency is increased or the pulse is shortened. The efficiency (shunt impedance/unit length) also increases with frequency, leading to a reduction in the individual lengths of sections and the filling times. This is borne in mind in designs for future large colliders, but awaiting availability of the higher frequencies proposed for some of these machines (e.g. 29 GHz for CERN's CLIC idea) studies have to make do with what is available.

Extrapolating the 3 GHz results suggests that breakdown thresholds can be pushed beyond the 100 MV/m envisaged by designers for frequencies over 10 GHz. The increase in frequency should also help reduce parasitic currents.

Progress is also being made at other electron centres (January/February, page 15). Together these efforts build a foundation for a next generation of electron-positron colliders.

Physics monitor

DESY
Hot spots in the nucleon?

The HERA electron-proton collider nearing completion at the DESY Laboratory in Hamburg and scheduled to come on-line next spring will provide unusual collision conditions (protons of almost 1000 GeV slamming into 30 GeV electrons). This physics will probe the deep structure of the proton under new conditions, particularly the kinematic area, known in the trade as small x, where a constituent quark carries only a small fraction of the total proton momentum.

To prepare the way, DESY was the venue for a topical meeting on the behaviour of nucleon structure (structure functions) at small x, with x-values as small as 10^{-4} expected at HERA.

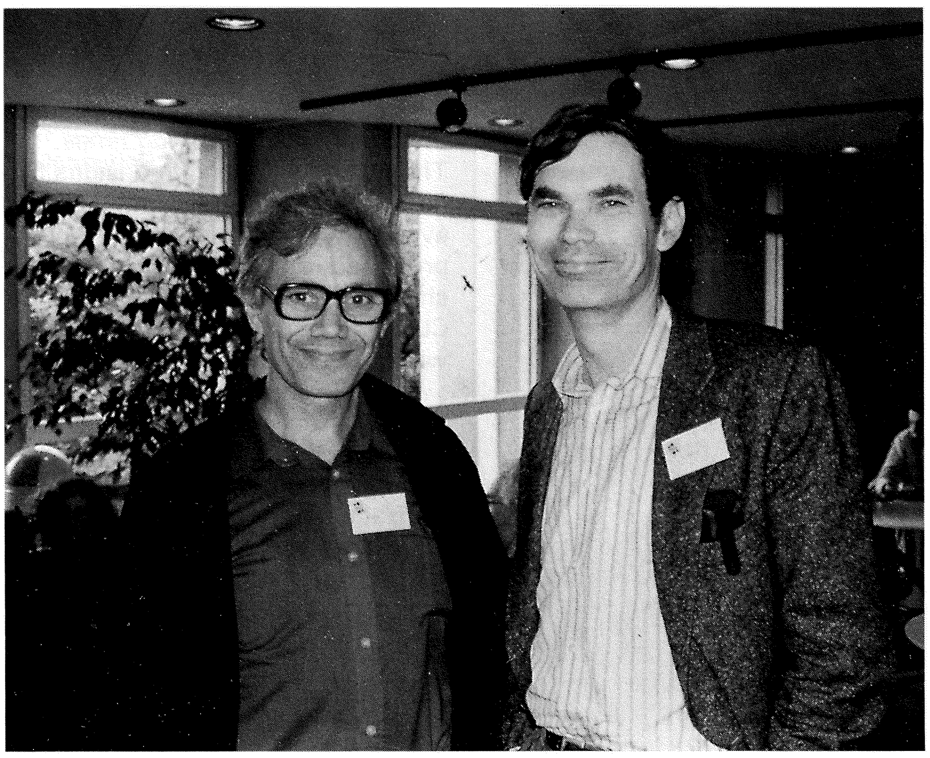
A quantitative description of the physics in this region will require an improved theoretical framework, going beyond the standard vogue of QCD quark-gluon field theory techniques. Recent developments, pioneered by the Leningrad group (L. Lipatov, E. Levin and M. Ryskin) and by A. Mueller from Columbia provided a focus at the meeting.

Assessing the experimental possibilities of structure function measurements at HERA, Franz Eisele of the H1 collaboration showed how extrapolations of present structure functions to HERA energies indicate that as well as going to x values one hundred times smaller, experiments should also be able to probe correspondingly larger values of Q^2 (a measure of the distance that a highly virtual photon is able to probe inside a nucleon). The availability of deuteron beams in HERA would open up additional structure function measurements.

The status of the standard QCD

Al Mueller (right, Columbia) and E. Levin (Leningrad) – new trends in quark-gluon field theory.

(Photo P. Waloschek)



evolution of structure functions was reviewed by J. Stirling, Wu-Ki Tung, M. Glueck, D.McKay, M. Krawczyk and D. Strozik-Kotlorz. Particular emphasis was given to the dependence upon input distributions and to the predictions for the low-x region, using data culled from current experiments. An improved theoretical treatment of gluon radiation at small x which allows simulations of deep inelastic processes was the subject of talks by G. Marchesini and B.Webber.

The property of QCD factorization, separating structure functions and the contributing hard scattering probabilities, was discussed by J. Collins. D. Treleani emphasized the importance of multiple quark/gluon collisions inside two colliding hadrons, especially at high energies such as those envisaged for the next generation of proton colliders.

P. Landshoff and S.Brodsky emphasized how non-perturbative aspects of strong interactions have to be carefully estimated before any quantitative analysis based on a perturbative approach.

L. Lipatov summarized the status of the Pomeron (responsible for elastic scattering) in (perturbative) QCD, making clear that the small-x region is a transition between the moderate-x perturbative QCD regime and the nonperturbative limit of the time-honoured Regge approach. A complete understanding of this transition will naturally take care of the small-x region.

One of the most interesting new ideas and which may very well become one of the central issues at HERA is the concept of saturation of quark and gluon densities at very small x. Stated simply, QCD predicts a rapid rise in the number of constituents as x becomes very small. At sufficiently large quark/gluon densities, one can no longer ignore their mutual interactions, including intra-nucleon scatterings and annihilations. Under these conditions a nucleon struck by a penetrating electron would resemble a dense gas of quarks and gluons, very different from anything studied so far. Its main feature would be saturation of quark and gluon densities. E. Levin M. Ryskin and A. Mueller outlined the theoretical ideas, and J. Kwiecinski and G. Schuler speculated on the kinematical regions where such effects could show up, with Al Mueller suggesting that already at HERA energies first hints might be seen of such proton 'hot spots'.

Summarizer Stan Brodsky emphasized the unique nature of experiments at HERA in providing a trustworthy description of the nucleon, exceedingly important for accurate estimations of the potential of proposed proton-proton colliders (the SSC in the US and LHC at CERN), as well as revealing new facets of the nucleon structure.

From A.Ali and J.Bartels

Phi factories

Plans for 'phi factories' gathered momentum with a recent workshop at UCLA. These machines, high luminosity electron-positron colliders working near the phi resonance at 1020 MeV, have been proposed at Laboratories in Europe, the US, Japan and the USSR (July/August 1989, page 26).

Physics interest centres around symmetry breaking effects, particularly CP violation, the delicate particle/antiparticle left/right asymmetry seen in the decays of neutral kaons.

One of the major decay modes of the phi is a pair of neutral kaons, one of the long-lived type, the other short-lived. This is potentially a valuable source of neutral kaons.

Current designs for phi factories fall into two classes – compact machines with superconducting elements (e.g. Novosibirsk and UCLA) and larger conventional rings (Frascati, KEK, Mainz). Synchrotron damping time is shorter in the former at the expense of more complicated filling procedures. Room-size compact machines could also be considered as candidates for compact synchrotron light sources or for other types of particle factory. However the detectors for use at these compact rings would not be correspondingly scaled down.

Luminosity should reach 10^{33} per sq cm per s, providing some 10^{10} phis per year decaying into neutral kaons and opening up a useful range of physics. At the UCLA meeting, detector and machine specialists felt that the special requirements of a phi factory were within reach.

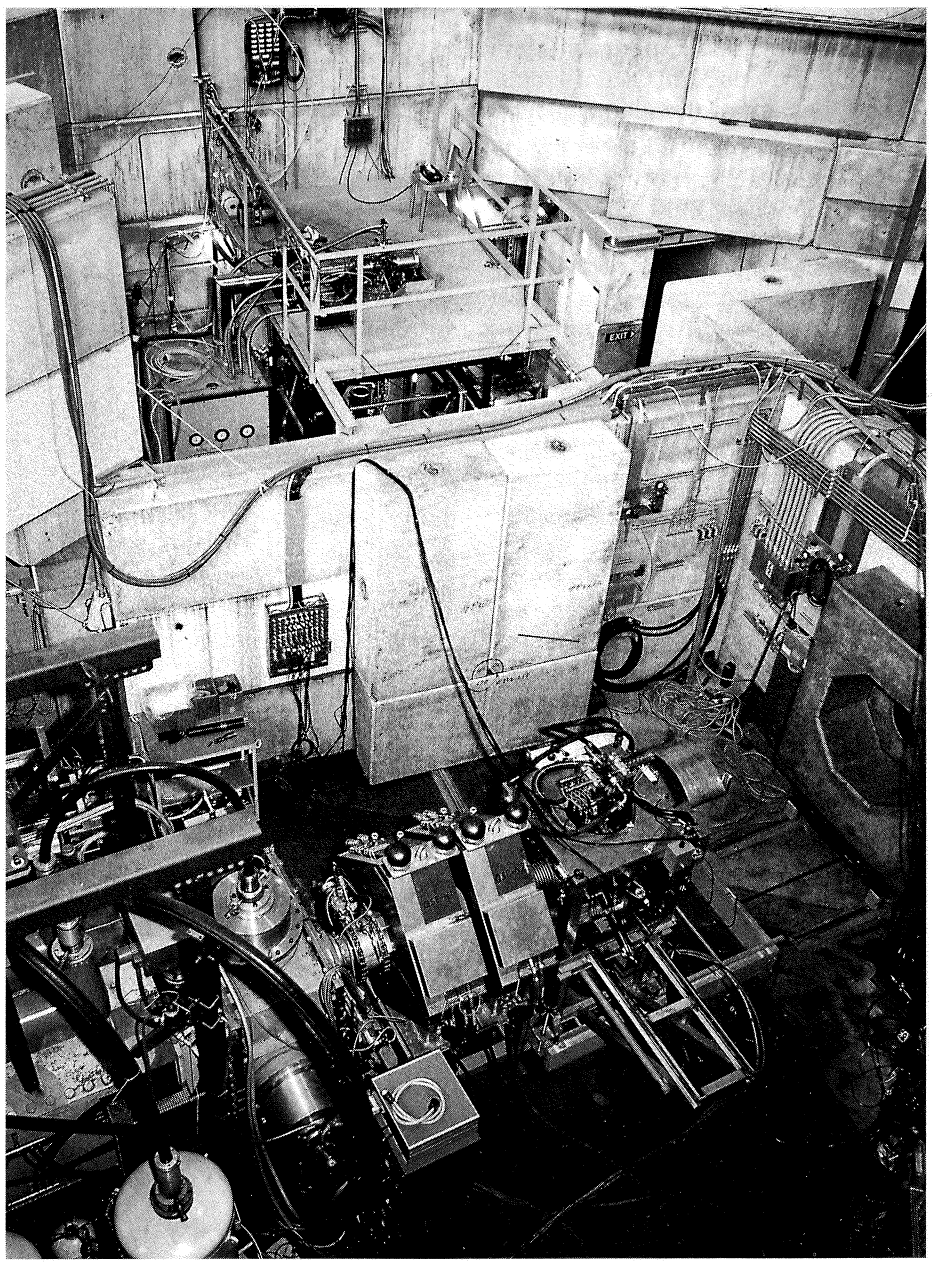
Musing over muons

The Standard Model of modern physics looks simple – six types of quark grouped pairwise into three families, each associated with a different type of weakly interacting particle, or lepton – the electron, the muon and the tau.

Despite its many successes, this picture cannot be the end of the road. Why is the muon about two hundred times heavier than the electron? The answer is hidden by the Standard Model's price tag.

The physicists attending a workshop on Low Energy Muon Science in the 1990s, held at the Swiss Paul Scherrer Institute (PSI) in April, were looking for ways to learn more about the muon and uncover what lies behind the Standard Model.

Muons in action – the muon spin rotation station at the Swiss Paul Scherrer Institute.



Experiments searching for new muon decay modes probe down to one decay per hundred million and in some cases even much less, but even this close no cracks show up in the Standard Model facade. Convinced there has to be a deeper message, the physicists prepare for new rounds of experiments to subject the model to even closer scrutiny.

A related issue is the masses of the three neutrinos which accompany the trio of leptons. Again there are as yet no theoretical guidelines, but neutrino masses play an important role in basic processes, such as those of interest to astrophysicists. Experiments at PSI have provided important limits on the masses of the electron-type and muon-type neutrinos.

When the muon does decay, it goes most of the time into an electron and a pair of suitably labelled neutrinos. The strength of this decay is one of the basic input parameters of the electroweak picture within the Standard Model. Careful analysis of the spins of the muon and the electron in these decays, together with studies of the scattering of muon-type neutrinos off electrons, could help look beyond the Standard Model.

Other insights could come from tiny violations of basic symmetries (mirror reflection, time reversal) in muonic atoms and in muon capture by nuclei. These and other muon studies are now so sensitive that any positive effects would signal mechanisms comparable to those produced by particles with masses around 15 TeV (15,000 GeV), heavier than anything discovered so far and heavy even by the standards of the giant proton colliders of tomorrow.

Another theme at the meeting was nuclear muon capture, when an orbital atomic muon disappears into the nucleus, giving a muon neutrino and possibly an excited nuclear state. (Because the muon is so heavy, muonic atoms are much more compact then their electronic counterparts and nuclear interactions correspondingly more important.) Pooling together information from several sectors, experimental tools are now emerging for the systematic exploitation of nuclear muon capture as a probe of nuclear structure and weak nuclear interactions.

When the nucleus is just a single proton, muon capture can help explore the low energy regime of quantum chromodynamics (QCD), the candidate field theory of quark interactions and, with the electroweak picture, one of the twin facets of Standard Model formalism. Muon capture on hydrogen has been a challenge to experimentalists; the process is rare and is masked by atomic and molecular effects, but a new generation of studies is planned at meson factories.

Atomic and molecular physics again emerges as a dominant theme in the interaction of muons with hydrogen isotopes – deuterium and tritium. Compact muonic atoms have long been advocated as a possible catalyst for controlled thermonuclear fusion, but the various possible paths are difficult to calculate theoretically and unravel experimentally. Low energy muons slowed down by a layer of frozen deuterium are currently being looked at, and the discovery last year of muonic deuterium by stopping muons in a layer of frozen hydrogen with a small concentration of deuterium provides a new ingredient.

One sector which has really taken off is muon spin rotation – the electron from muon decay points to the spin direction of the muon, itself a gauge of the local electromagnetic fields. With this technique, custom-built muon beams provide a precision tool for condensed matter physics, a good example being recent investigations of the structure of the new generation of high temperature superconductors. New sources of low energy beams would benefit surface physics.

For a particle not yet understood, the muon is pretty useful.

From Jack Missimer, PSI

People and things

20 Tesla for sale

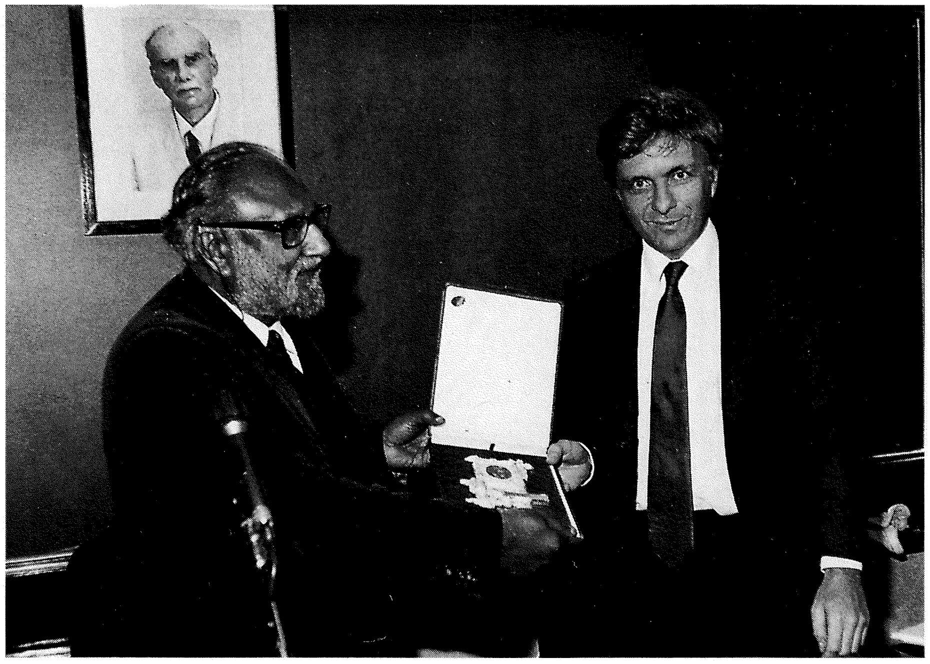
An Oxford Instruments superconducting solenoid magnet which has exceeded 20 Tesla is now available commercially. Although higher fields have been achieved with laboratory magnets, this is said to be the most powerful such magnet on the market.

Operating at 2.15 K, the 32 mm diameter coil uses niobium-titanium wire for the outer windings with the inner sections of niobium-tin optimized for high field use. Oxford Instruments is at Eynsham, Oxford, OX8 1TL, UK, telephone (+44)865 882855, fax (+44)865 881567.

Boost for Dubna

To provide a foundation for future physics at the Joint Institute for Nuclear Research (JINR), at Dubna, near Moscow, an international commission recently pledged their support for a new electron-positron storage ring to extend the centre's physics activities. As well as synchrotron radiation-based studies, such a machine would open up the physics of charm particles and tau leptons. An ion option for the ring is also foreseen.

The physics programme of the 11 Member State JINR Organization has so far centred on its 10 GeV Synchrophasotron, operational since 1957.



Michael Green (right) of London's Queen Mary College receives from Abdus Salam, Director of the International Centre for Theoretical Physics, Trieste, one of the two 1989 Dirac Medals awarded by ICTP. The other medal went to John H. Schwartz of Caltech. Both recipients have made fundamental contributions to superstring theory.

Meetings

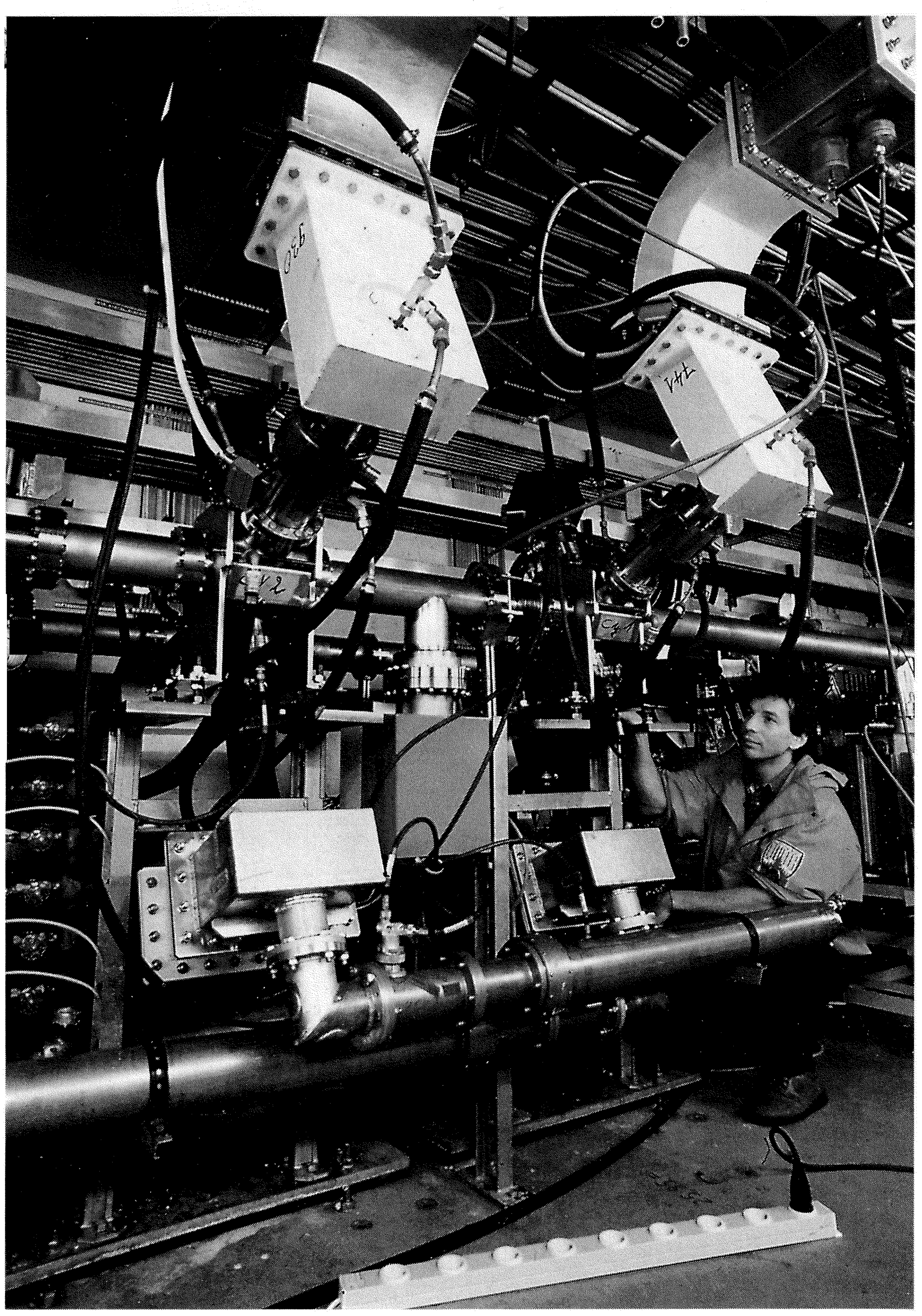
The Pittsburgh Workshop on Soft Lepton Pair and Photon Production will be held from 6-8 September. Contact Julia A. Thompson, Dept. of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, phone (412) 624 9060 or bitnet jth at pittvms

An International Conference on Calorimetry in High Energy Physics at Fermilab from 29 October – 1 November will consist of invited reviews, followed by contributed papers. Information from A. Para at Fermilab, bitnet ICCHEP at FNAL.

Following the first such meeting held at SLAC in summer 1989, the Second International Workshop on Accelerator alignment, looking at objectives for the next generation of machines, will be held at DESY from 10-12 September. Information from Franz Loeffler at DESY, bitnet meabit at dhhdesy3

US-CERN Accelerator School

This year's Joint US-CERN School on Particle Accelerators, organized jointly by the CERN Accelerator School and the US Particle Accelerator School, is from 7-14 November and will be hosted by CEBAF. The topical course on frontiers of particle beams will concen-



A view of the two 1 GHz cavities (with wave guides and additional equipment) of the longitudinal feedback system successfully tested at the PETRA ring at the DESY Laboratory in Hamburg in May and destined for the electron ring of the HERA electron-proton collider now nearing completion at DESY. This feedback system (together with vertical and radial ones already tested) aims for high currents in multibunch operation.

(Photo P. Waloschek)

Heavy ion experimenters Reinhard Stock (left) of the NA35 experiment at CERN and Emanuele Quercigh of WA85 check the programme at the 'Quark Matter 90' meeting held in Menton, France, from 7-11 May. Highlights included results on enhanced strangeness yields in reactions producing many secondary particles, principally from the NA35 and WA85 experiments.

(Photo Maurice Jacob)

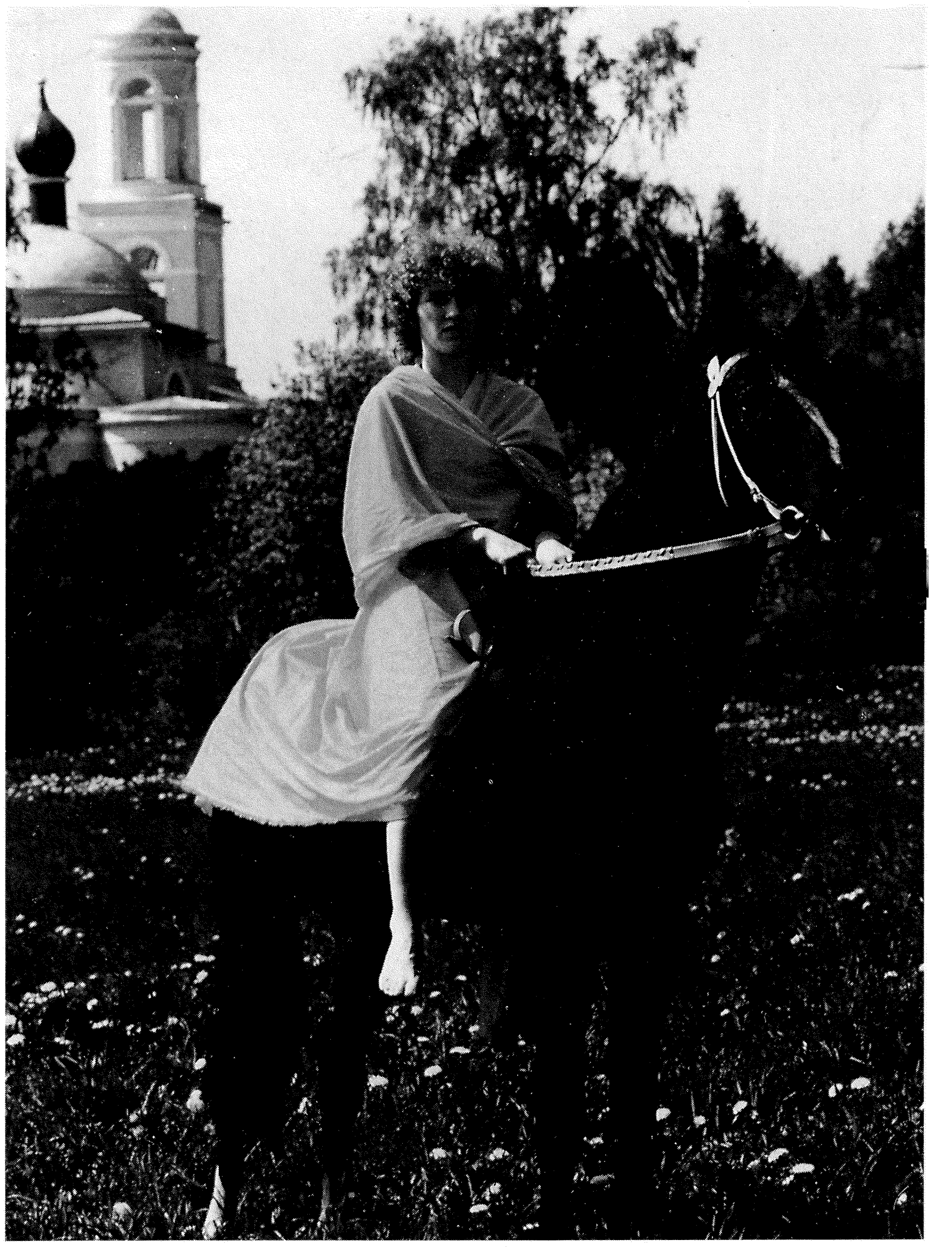
trate on intensity limitations. Information from US Particle Accelerator School, Fermilab MS 125, PO Box 500, Batavia, Illinois 60510, USA.

Texas/ESO-CERN Symposium

The 4th Symposium on Cosmology, Astronomy and Fundamental Physics, organized jointly by CERN and the European Southern Observatory (ESO), and the 15th Texas Symposium on Relativistic Astrophysics are being combined in a joint Texas/ESO-CERN Symposium to be held in Brighton, UK, from 16-21 December.

The plenary sessions (early universe, quantum cosmology, high energy physics, nucleosynthesis, galaxy formation, large-scale structure, dark matter, X-ray and gamma-ray astronomy, pulsars, gravitational lensing, background radiation, solar oscillations, neutrinos, gravitation theory) will be complemented by afternoon mini-symposia on neutron stars and black holes, underground physics, and large scale structure and galaxy formation.

Further information from the Chairman of the Local Organizing Committee; L. Mestel, Astronomy Centre, Division of Physics and Astronomy, University of Sussex, Falmer, Brighton BN1 9QH, UK, or from the Theory Division Secretariat, CERN, 1211 Geneva 23, Switzerland.



An Akhal-teke horse and rider in the shadow of the recently-reopened Orthodox church in Dubna, near Moscow. A flourishing cooperative breeding these rare animals is headed by Tito Pontecorvo, son of Dubna physicist Bruno Pontecorvo.

European Southern Observatory (ESO) Director General Harry van der Laan (left) with CERN Research Director Pierre Darriulat at the opening of the ESO 'Discoveries in the Southern Sky' feature at CERN's 'Microcosm' exhibition centre. Forthcoming Microcosm guest themes include DESY's HERA collider (September 1990 – February 1991), followed later next year by the European Space Agency's scientific programme.

(Photo CERN 380.5.90)

Meeting

A workshop on tau (not tau neutrino) physics to be held at Orsay from 24–27 September, organized jointly by the French IN2P3 (CNRS) and CEA, will cover experiment, theory, and ideas for the future. Attendance (about 100) is by invitation only. Contact Tau workshop, c/o Nicole Mathieu, Université Paris-Sud, LAL Bat 200, 91405 Orsay Cedex, France, bitnet orsaytau at frcpn11

UK Honour

UK Science and Engineering Research Council Chairman E.W.J. Mitchell becomes Sir William. His successor will be Sir Mark Richmond.

This year's winners of the 'Open' category of the traditional relay race round the CERN Meyrin site were the Security Service from nearby Geneva Airport, followed by a CERN 'Pigs in the Wind' selection (left), with the International Labour Organization runners in third place. The event attracted over 50 teams, traditionally drawn from distinct organizational units. 'Elite' combinations compete in the Open category, but only the Airport Security lineup finished clear of the rest of the field.

(Photo CERN 450.5.90)