

Carlo Rubbia

Cronin for their discovery of CP violation, described Rubbia's contributions in this area of physics in the period 1966 to 1973. Fitch displayed a list of 20 physics papers and 4 instrumentation papers with Rubbia as an author, and which had helped to pin down vital parameters in these difficult measurements.

Klaus Winter of CERN looked at the neutrino sector. Rubbia was convinced that neutrino beams were the route to the discovery of the neutral currents – the key to electroweak unification. In the early 1970s, he and his colleagues convinced the new Fermilab to make a major commitment to this physics. The experiment's all-electronic detectors bore the unmistakable stamp of Rubbia ingenuity.

After a long period away from the neutrino stage, the excitement around neutrino oscillations tempted Rubbia back, this time with the ICARUS neutrino detector at the Italian Gran Sasso underground laboratory. The innovative liquid argon time-projection chamber again bears the trademark of Rubbia innovation.

Continual innovation

Turning away from the experimental side, Gerard 't Hooft of Utrecht sketched the development of the theoretical infrastructure that led to electroweak unification and the Standard Model, which Rubbia's 1983 discovery dramatically confirmed. 't Hooft remarked that new theoretical ideas in and around superstrings have predictions that are very difficult to verify by conventional experiments.

Alan Astbury of TRIUMF, Vancouver, a close collaborator of Carlo Rubbia for the UA1 experiment at CERN's proton-antiproton col-

lider, covered the historic period from the late 1970s that led to the 1983 discovery of the W and the Z particles. This physics was a continual close race between the UA1 and UA2 experiments. Astbury pointed out how UA1 had been galvanized into action in late 1982 by having lost the race to discover the tightly confined "jets" of particles, which signal quark-gluon interactions deep inside the proton-antiproton collisions.

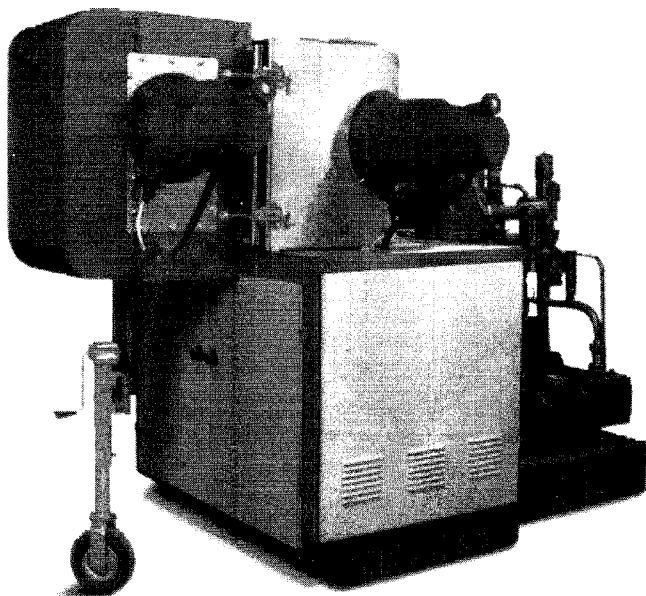
After his mandate as CERN director-general, Rubbia made a dramatic return to the physics stage, this time through his ideas for harnessing accelerators for energy production via nuclear fission with a minimum of nuclear waste and for the destruction of existing waste by transmutation.

Arthur Kerman was billed as covering this phase of Rubbia's career, but began by pointing out the initial role Rubbia had played in recommending the US Superconducting Supercollider. Kerman described the neutron behaviour that opens up the possibility of controlled fission reactions, whether by orthodox absorbers or via an accelerator in tandem with the reactor. The latter possibility had long been recognized, but only recently has accelerator performance begun to approach the necessary levels.

Carlo Rubbia characteristically used the occasion to look forward rather than back, underlining how little we know about the universe. With much of the world around us composed of invisible but all-pervading "dark matter", innovative instrumentation is still called for.

Finally director-general Luciano Maiani underlined the breadth of Carlo Rubbia's contributions, both to CERN and to physics.

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The RHIC heavy ion collider at Brookhaven. The Megascience nuclear physics working group recommends more co-ordination and collaboration to strengthen the worldwide effort in heavy ion collision physics.

national collaboration during the next 10 to 20 years.

Particular attention was given to the role of large facilities and programmes that would benefit from international co-operation:

- to examine the policies and practices that govern access to large facilities, and to assess the impact of current and future trends on the users and providers of international facilities;
- to explore specific opportunities for collaboration in research and development related to nuclear physics facilities, detectors and associated technologies.

Scientific objectives and applications

The fundamental challenges of nuclear physics are not the same as those of particle physics.

What are the constituents of matter, how do they interact and how do they form nuclei?

For nuclear physics, the aim is to understand the properties of nuclear particles from those of quarks and gluons, to solve the nuclear many-body problem and to predict the properties of large nuclei from the known interaction of protons and neutrons. These formidable theoretical problems may become tractable using high-power computers and results from new generations of electron and

hadron beam facilities.

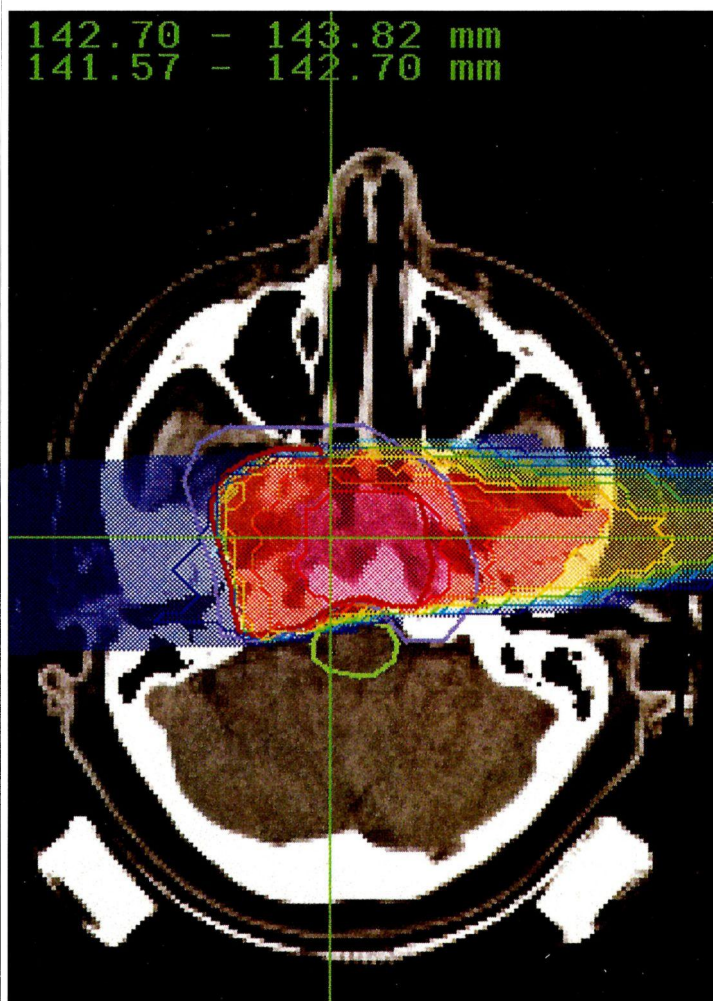
What are the limits of nuclear stability?

The early evolution of the universe was determined by the aggregation of quarks and gluons to form hadrons and nuclei, and the synthesis of heavier elements through nuclear reactions. The stability of nuclei arises from a delicate balance between the nuclear, electromagnetic and weak forces in the nuclear medium.

Some very neutron-rich nuclei have recently been found to have extended distributions of dilute, nearly pure neutron matter that are of much theoretical interest and thus a subject of intense investigation. The direct investigation of nuclear structure far from stability will be made possible through the production of intense beams of rare and short-lived isotopes (radioactive beams).

What happens to nuclear matter at extreme pressures and temperatures?

Nuclei can be compared to liquid drops of nuclear matter. In the collision between two nuclei at high energy, the pressure and temperature of nuclear matter are increased. Is there a transition in the nature of nuclear matter? Is there formation of a plasma of elementary constituents in ultrahigh-energy collisions of heavy nuclei? The search for these phase transitions via heavy-ion collision experi-



Cancer therapy using light ion beams at GSI, Darmstadt. New techniques permit the treatment of tumours in critical locations. In the wide-ranging applications sector, cancer therapy was one of the areas selected by the Megascience nuclear physics working group as worthy of special attention.

ments will be a subject of intense experimental and theoretical work during the next decade.

The liquid-gas phase transition is studied at existing energies. The "deconfinement" transition to a quark-gluon plasma will be investigated in new regimes at Brookhaven's RHIC and CERN's LHC colliders. The early universe presumably underwent this phase transition within the first few millionths of a second following the Big Bang. Such phenomena might have a bearing on important aspects of cosmology, such as nucleosynthesis, dark matter and the large-scale structure of the universe. In astrophysics, the dynamics of supernova explosions and the stability of neutron stars depend on the compressibility and thus the equation of state of nuclear matter.

What is the origin of the chemical elements in the cosmos?

Many elements are formed in stellar explosions via very neutron-rich or, under different circumstances, very proton-rich nuclei. The properties of both routes are largely unknown. While element formation inside stars can be sketched by extrapolating model calculations, there is a critical need for experimental data to provide benchmark

tests for these predictions or input to numerical simulations.

Nuclear methods are widely used in materials research and manufacturing. Some examples are non-destructive testing via computerized tomography or neutron radiography, the production of densely packed microchips by ion implantation and the sterilization of heat-sensitive materials by ionizing radiation.

Materials analysis using nuclear reactions and Rutherford scattering is a major research tool for surface analysis, catalysis, semiconductor manufacturing, archaeology, etc.

Particle beams from research accelerators are used to analyse the damage to microelectronic circuits that is caused by cosmic radiation or natural radioactivity – an issue of increasing importance for the further miniaturization of electronics.

Ultrasensitive accelerator mass spectrometry plays an increasing role in environmental research – the study of climatic change, global air and water circulation patterns, stratospheric ozone depletion, and the monitoring of air and water quality. Nuclear technology is indispensable in the monitoring of existing radioactive waste repositories.

For energy production, nuclear fission reactors currently provide about 17% of the world's electricity. Nuclear techniques have an impact on other forms of energy production, including the exploration and utilization of oil reserves. Neutron techniques are routinely used to monitor the chemical composition of coal, coal preparation plants and the determination of the sulphur, water, ash and energy content of coal. For the long term, thermonuclear fusion still holds the promise of a virtually inexhaustible supply of clean energy and is an area of active research and development.

Nuclear techniques are important in medicine and biology. Radioactive isotopes produced by accelerators and nuclear reactors are widely used for treatment and diagnosis, and also in biomedical research.

In the wide-ranging applications sector, the working group focused on three potentially promising topics: the accelerator-driven transmutation of nuclear wastes, medical imaging and cancer therapy.

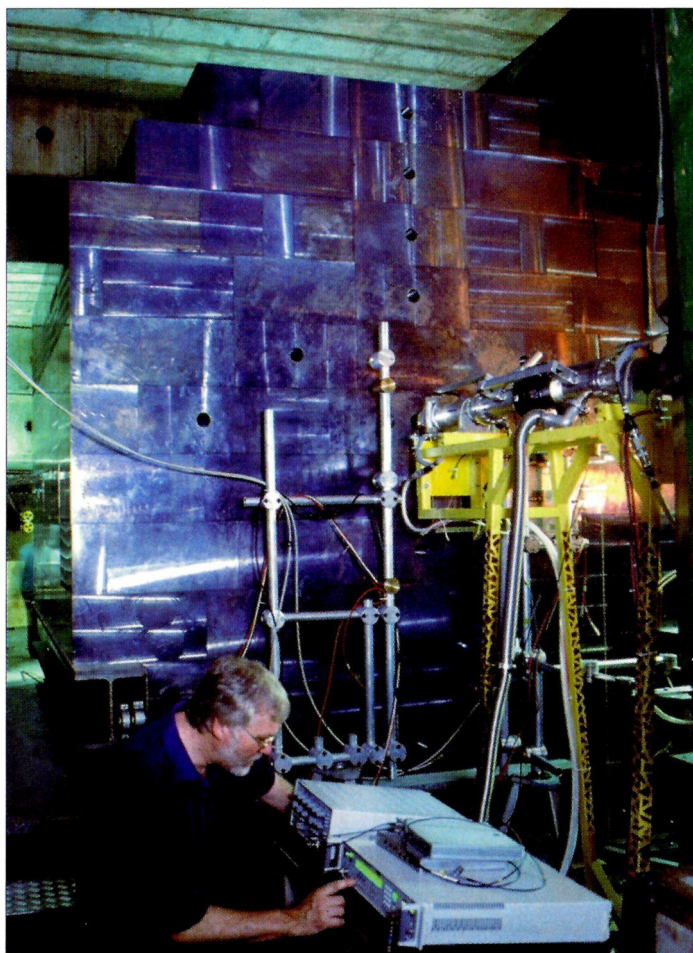
The recommendations

The working group believes that nuclear physics will continue to provide new and important direct benefits for society in the next century. It recognizes the need for

- high-intensity radioactive nuclear beam facilities;
- intense high-energy continuous electron beam facilities;
- multipurpose hadron facilities with a variety of secondary particle beams;
- facilities for heavy ion collisions at very high energies.

Radioactive nuclear beam facilities

Radioactive nuclear beam (RNB) facilities are seen as being important for a broad programme of research in fundamental nuclear physics and astrophysics, as well as in applications of nuclear science. A new generation of high-intensity RNB facilities of each of the two basic types – on-line and in-flight – should be built on a regional basis. Interested governments are encouraged to undertake the necessary decisions within the next few years, and the facilities should become operational in 5 to 10 years.



Carlo Rubbia's TARC (Transmutation by Adiabatic Resonance Crossing) experiment at CERN. Accelerator-driven transmutation has emerged as a potentially complementary technology for radioactive waste handling by transmuting the longest-lived radioactive isotopes into short-lived or stable ones.

A contact group should be established that consists of government-appointed programme managers and other scientific and technical experts from countries that are actively involved in planning and implementing new (or upgraded) RNB facilities. It should provide a venue for the accurate and timely exchange of information regarding decisions, priorities, schedules and progress being made in the three major regions of the world.

Electron facilities

High-energy continuous electron beams are important probes of nuclear and hadronic structures at the quark-gluon level.

The proposed upgrade of CEBAF at the Jefferson Laboratory to 12 GeV by 2005 would enter the high-intensity, high-energy domain at a reasonable cost and at the right time.

In Europe, attention has focused on the Electron Laboratory For Europe (ELFE). At the DESY laboratory in Hamburg, the 27 GeV pulsed injector of the proposed TESLA linear collider could be used with the existing HERA electron ring (operating in a "pulse stretcher" mode) to obtain an extracted continuous beam with a maximum intensity of 30 A.

The superconducting radiofrequency cavities from CERN's LEP collider (which will be removed to make way for the Large Hadron Collider) could be utilized for a new 3.5 GeV linac, which could provide a continuous 150 μ A beam at 25 GeV via the recirculation of the electrons.

The employment of heavy ions in the HERA electron-proton collider could be used to study electron-nucleus collisions at even smaller distances, where the gluon density is expected to increase strongly, leading to a completely new physics regime.

For a 25–30 GeV electron facility, the working group encourages international coordination and collaboration.

Hadron facilities

The Japan Hadron Facility (JHF) proposed by the KEK laboratory will attract a worldwide community. Interested parties are encouraged to form partnerships to develop instrumentation and detectors to take advantage of the facility. They should take note of the initiative to open the JHF to an international community.

Heavy-ion collisions

Given the challenges and the pre-eminent importance of heavy-ion collisions for quark matter physics, significant benefits would be realized from increased international collaboration.

Scientific and technical groups, in co-operation with the relevant funding agencies, should maintain the fruitful contacts initiated by the working group. Enhanced co-ordination and collaboration will strengthen the worldwide effort in this field, and, in particular, between the RHIC (Brookhaven) and ALICE (CERN) communities.

Applications

Accelerator-driven transmutation has emerged as a potentially complementary technology for radioactive waste handling by transmuting the longest-lived radioactive isotopes into short-lived or stable ones. This technology could have a significant synergy with other projects, like neutron sources and high-intensity accelerators.

To make optimum use of the available intellectual and financial resources, it may be necessary to strengthen existing co-operative mechanisms or to create new ones. The existing OECD Nuclear Energy Agency could be adapted to play a wider role. While recognizing the diversity of national policies, the working group nevertheless encourages coordination.

For cancer therapy, optimized medical synchrotrons for light-ion therapy have recently been designed by CERN and GSI Darmstadt. New techniques of more accurate beam delivery and precise control permit the treatment of tumours in critical locations, such as the brain or near the spinal cord.

For medical imaging, significant progress can be expected in terms of spatial resolution and sensitivity. Novel techniques will considerably improve the early detection of tumours.

For such a wide-ranging subject, the report is very compact and easy to digest, and it was well received by its parent Megascience Forum. It provides useful indications for scientists and their funding agencies. Even without its recommendations, it is a good summary of nuclear physics today. The full report is available at "http://www.oecd.org/dsti/sti/s_t/ms/prod/NUCLEAR2.pdf".

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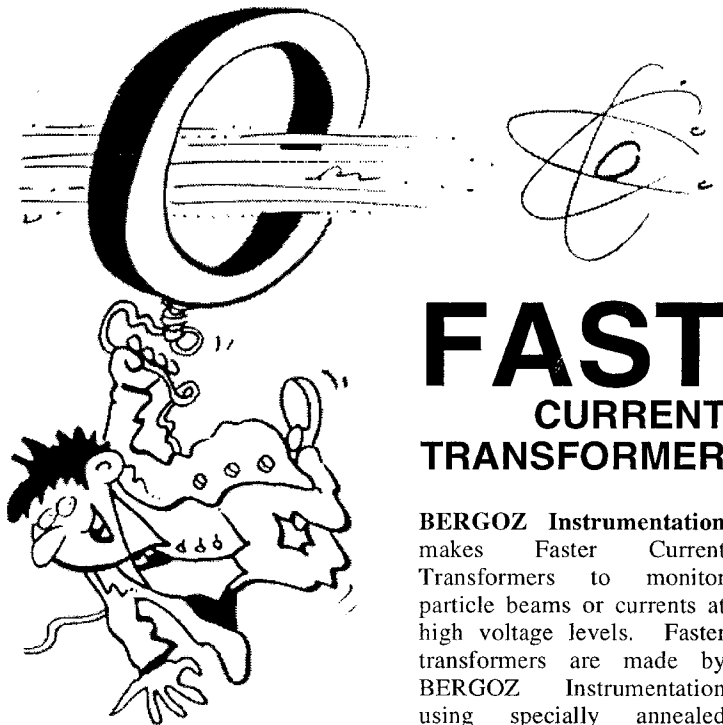
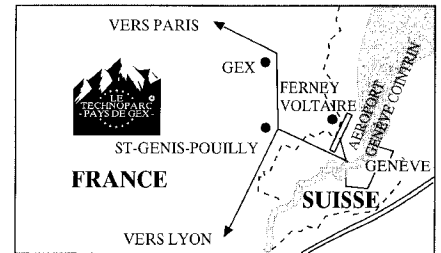
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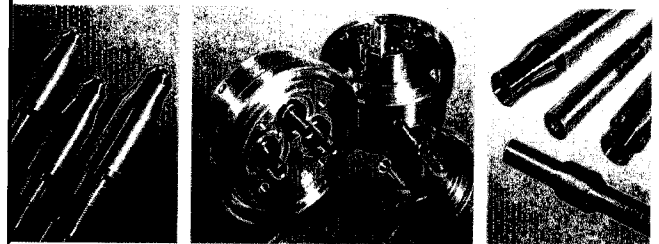
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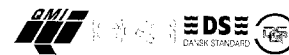
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