

ALICE in quarkland

The two main components of the ALICE detector for heavy ion beams at CERN's LHC collider are clearly visible in this cutaway drawing. The central detector will be built inside the existing solenoid of the L3 experiment at the LEP electron-positron collider. The forward muon spectrometer, on the right, will measure the spectrum of heavy-quark resonances.

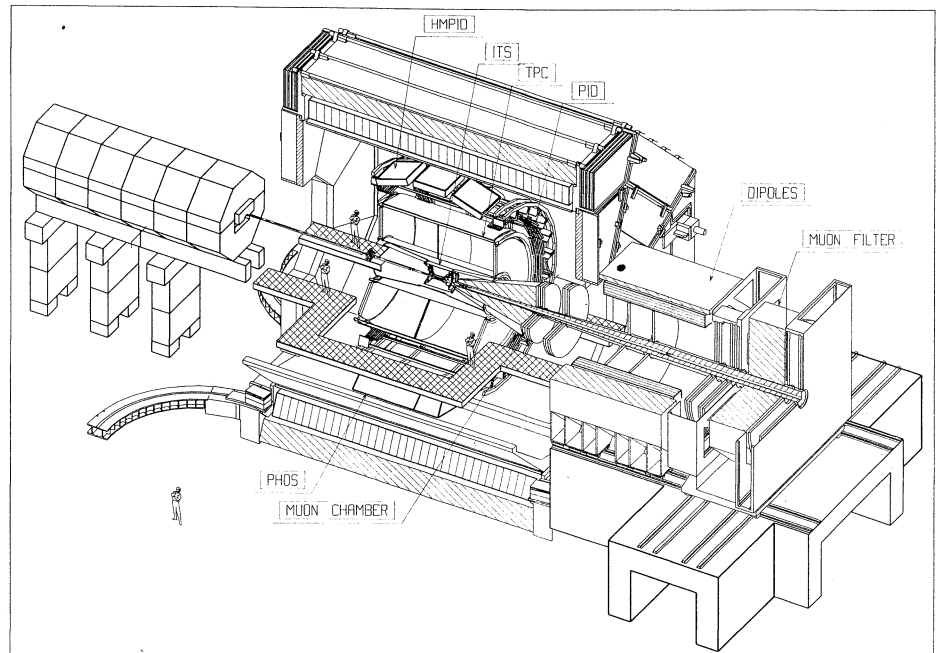
Another LHC experimental milestone

This month we publish the third in a series of articles marking the publication of full Technical Proposals for experiments at CERN's LHC collider.

The main thrust of LHC physics will be the study of proton-proton collisions, covered by two major experiments, ATLAS and CMS, who presented their Technical Proposals in December 1994 (June 1995, page 5). After recommendations from a specially-augmented CERN Research Board, both experiments have recently been approved. (However certain financial matters remain to be resolved.)

ALICE is designed to study heavy-ion collisions in the LHC, raising the energy stakes for this branch of physics from today's maximum of 17 GeV/nucleon collision energy at CERN's SPS to 5.5 TeV/nucleon. The intermediate ground will be studied at the Brookhaven National Laboratory near New York with the Relativistic Heavy Ion Collider, RHIC. RHIC will collide gold ions at 200 GeV/nucleon starting in 1999.

ALICE's Technical Proposal was submitted on 15 December 1995.



In the classic children's stories, Alice was the little girl who chased a white rabbit down a hole to find herself transported to a magical world. At the LHC, ALICE (A Large Ion Collider Experiment) will be pursuing new states of matter instead of white rabbits, but the wonderland to be found could be every bit as new and exciting as that of Lewis Carroll's invention.

ALICE is the third collaboration to submit a technical proposal for CERN's LHC collider after ATLAS and CMS, the big general purpose detectors which will spearhead the LHC physics thrust (June 1995, page 5). While the higgs boson search is high on the ATLAS/CMS agenda, ALICE, however, has different goals in mind. The LHC will continue CERN's tradition of diverse beams, being able to accelerate not only protons, but also the high energy beams of lead ions currently in use by SPS experiments. It is this capability which ALICE is designed to

exploit as the LHC's only dedicated heavy-ion experiment.

The idea of building a dedicated heavy-ion detector for the LHC was first aired at the historic Evian meeting, "Towards the LHC Experimental Programme", in March 1992. From the ideas presented there, the ALICE collaboration was formed, and in 1993, a Letter of Intent was submitted (July 1993, page 4).

High-energy heavy-ion collisions provide a unique laboratory for the study of strongly interacting particles. The field theory of quarks and gluons - quantum chromodynamics (QCD) - predicts that at sufficiently high energy densities there will be a phase transition from conventional hadronic matter, where quarks are locked inside nuclear particles, to a plasma of deconfined quarks and gluons. The reverse of this transition is believed to have taken place when the Universe was just 10^{-5} seconds old, and may still play a role today in

Prototype of a silicon drift detector developed by the DSI collaboration (supported by the Italian INFN), in the framework of development work for the ALICE Inner Tracking System. These detectors feature true two-dimensional readout with a small number of readout channels by measuring the drift time of the charge cloud produced by the crossing particle and its centroid at the array of readout anodes. Spatial resolution is of the order of 20 microns in both directions. The low anode capacitance allows excellent energy resolution. The drift field, parallel to the detector surface, is generated by on-board electrodes.

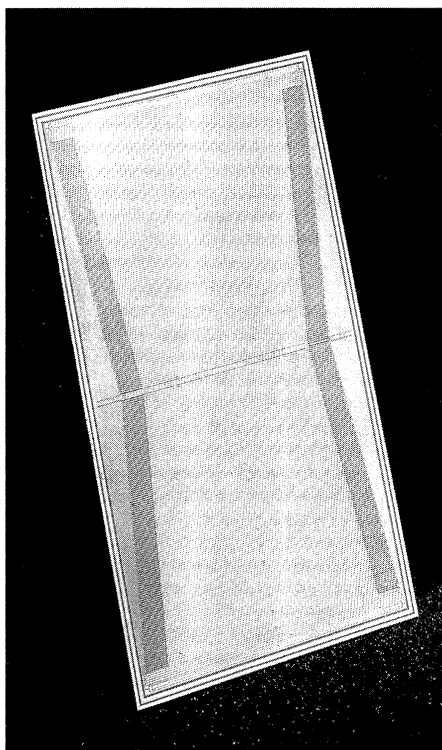
the hearts of collapsing neutron stars.

A similar phase transition is believed to have given rise to the higgs mechanism, responsible for particle masses. Although higgs particles should be produced at the LHC, the phase transition which created them is beyond the reach of experiments. The QCD phase transition which ALICE will study is the only one of this kind accessible in the laboratory.

The feasibility of this kind of research was clearly demonstrated at CERN and Brookhaven with lighter ions in the 1980s. Today's programme at these laboratories has moved on to heavy ions, and is just reaching the energy threshold at which the phase transition is expected to occur. This physics reach will be extended at the RHIC heavy ion collider at Brookhaven, scheduled to come into operation in 1999. The LHC, with a centre-of-mass energy around 5.5 TeV/nucleon, will push the energy reach even further, exceeding even the highest energy densities seen in cosmic ray nucleus-nucleus collisions.

ALICE is bringing members of CERN's existing heavy-ion community together with a number of groups new to the field drawn from both nuclear and high-energy physics. By LHC standards, the collaboration is modest, comparable in size to one of today's experiments at the Large Electron Positron collider, LEP. The ALICE collaboration has 565 members from 26 countries. Countries outside the CERN membership play an important role, with 245 physicists taking part.

By LHC standards, the detector is of moderate proportions, being based on the current magnet of LEP's L3 experiment. (The change in scale from LEP to LHC is reflected in the



fact that L3 is the largest detector in operation at LEP!) When LEP switches off, the L3 magnet will be left in place whilst ALICE is installed. LHC beams will pass through the magnet slightly off-centre, 30 cm higher than the current LEP beams. The total cost of the detector will be in the region of 120 MCHF.

Because the physics of the quark-gluon plasma could be very different from that of ordinary matter, the ALICE detector has been designed to cover the full range of possible signatures, whilst being flexible enough to allow future upgrades guided by early results.

The detector consists of two main parts, a central detector, embedded within the magnet, and a forward muon spectrometer included as an addendum to the Letter of Intent in 1995. The set-up is completed by zero-degree calorimeters located far

downstream in the machine tunnel, to intercept particles emerging very close to the colliding beams.

One feature of heavy-ion collisions which is well known is the large particle multiplicity arising from head-on collisions. At the LHC, such central collisions are expected to occur around 100 times per second, producing about 50,000 particles each time, several thousand of which will fall within ALICE's acceptance. The relatively low interaction rate allows the detector to be built with a simple trigger selecting only head-on collisions from the LHC's 40 MHz beam crossing rate.

One of the greatest challenges of heavy-ion physics is to pick out the individual tracks from the dense forest of emerging particles. ALICE's tracking system has been designed for safe and robust pattern recognition within a large volume solenoid producing a weak field. The L3 magnet with a field of 0.2 tesla is ideal for the purpose.

The Inner Tracking System, ITS, consists of six cylindrical layers of highly accurate position-sensitive detectors from radii of 3.9 cm to 45 cm extending to $\pm 45^\circ$. Its functions are secondary vertex recognition, particle identification, tracking, and improving the overall momentum resolution. The different layers are optimized for efficient pattern recognition. Because of the high particle density in the innermost regions, the first four layers provide position information in two dimensions. The first two layers are silicon pixel detectors, and the second two are silicon drift detectors. The two outermost layers will be composed of double sided silicon micro-strip detectors. The complexity and importance of this device is reflected in the number of institutions responsible for its production: Bari,

Under study for the ALICE particle identification system is the Pestov spark counter technique, single-gap gas filled parallel-plate devices giving a timing resolution of less than 50 picoseconds. Pestov counters will be the preferred choice if it can be demonstrated that reliable manufacture and operation are possible for the large-area system required.

(Photo Achim Zschau, GSI)

Catania, CERN, Heidelberg, Kharkov, Kiev, Nantes, NIKHEF, Padua, Rez, Rome, St. Petersburg, Salerno, Strasbourg, Turin, Trieste, and Utrecht.

Central tracking is completed by a Time Projection Chamber, TPC, being built by Bratislava, CERN, Cracow, Darmstadt, Frankfurt, and Lund. Proven technology has been chosen to guarantee reliable performance at extremely high multiplicity. The drawbacks of this technology are high data volumes and relatively low speed. The TPC occupies the radial region from 90 cm to 250 cm, and is designed to give a rate-of-energy-loss resolution of better than 7%. It will also serve to identify electrons with momenta up to 2.5 GeV/c.

Two different technologies are under study for the last sub-detector to cover the full azimuthal angle, the particle identification system, PID. Pestov spark counters, single-gap gas filled parallel-plate devices, are being investigated by Darmstadt, Dubna, Marburg, Moscow-ITEP, Moscow-MePHI, and Novosibirsk, whilst parallel plate chambers, PPCs, are being developed by CERN, Moscow-ITEP, Moscow-MePHI, and Novosibirsk. The final design is expected to be complete by the end of 1998. The PPCs are less demanding to construct and operate, but the Pestov counters give a timing resolution of less than 50 picoseconds, some four times better than PPCs. Pestov counters will therefore be the preferred choice if it can be demonstrated that reliable manufacture and operation are possible for the large-area system required.

A second particle identification device for higher momentum particles, the HMPID, is included in the design as a single arm device above the central PID. A ring-

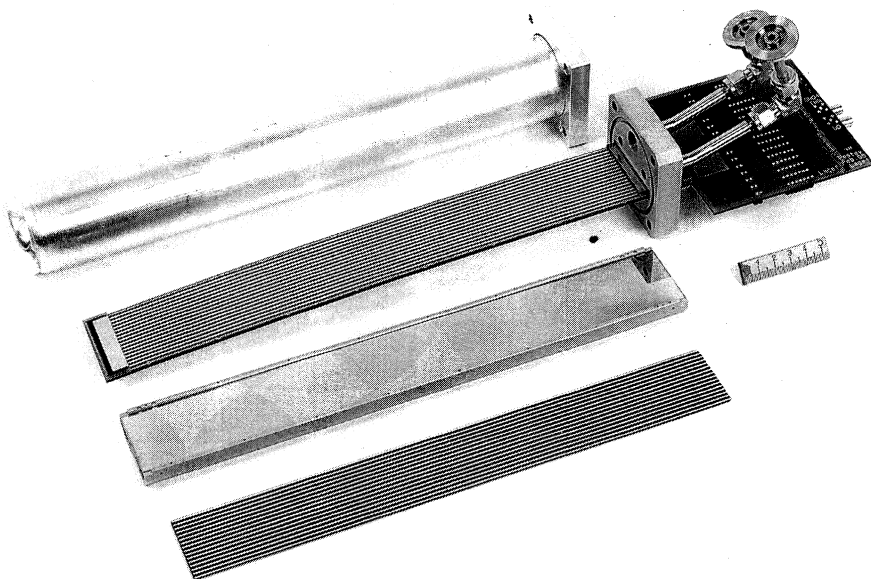
imaging Cerenkov (RICH) detector is the preferred option, being developed by Bari, CERN, Zagreb, and Moscow-INR. However, an organic scintillator approach being pursued by Catania, and Dubna has not yet been ruled out.

Below the central barrel region of the detector is another single-arm device, the photon spectrometer, PHOS, to measure prompt photons and neutral mesons. It is being prepared by Bergen, Heidelberg, Moscow-Kurchatov, Münster, Protvino, and Prague using scintillating lead tungstate crystals developed in the context of CERN's generic detector R&D effort.

Zero-degree calorimeters, ZDC, will be positioned 92 m from the interaction point to measure the energy carried away by non-interacting beam nucleons, a quantity directly related to the collision geometry. These are calorimeters of the spaghetti type, with quartz fibres as the active medium. Their construction is the responsibility of Turin.

Another forward detector, the forward multiplicity detector, FMD, will be embedded within the solenoid with the purpose of providing fast trigger signals and multiplicity information outside the central acceptance of the detector. Innovative micro-channel plate detectors are under consideration by Moscow-Kurchatov and St Petersburg, with conventional silicon multipad detectors as a back-up.

The forward muon spectrometer, FMS, is a major addition to the original design as specified in the Letter of Intent. It was included to measure the complete spectrum of heavy-quark resonances, which are expected to provide a sensitive signal for the production of a quark-gluon plasma. The first section of the spectrometer is an absorber placed inside the solenoid about 1m from the interaction point. This is followed by a large 3 tesla dipole magnet outside the solenoid containing 10 planes of tracking stations. A second absorber and two further tracking



planes provide muon identification and triggering. Teams from CERN, Clermont-Ferrand, Gatchina, Moscow-Kurchatov, Moscow-INR, Nantes, and Orsay are working on a more detailed design for the FMS, which is expected later this year.

Triggering is the responsibility of Birmingham and Kosice. Proton-proton mode and ion-ion mode have different trigger requirements. In proton-proton mode, a minimum bias trigger is required, whilst for ion-ion collisions, the trigger's function is to select on collision centrality. A level-zero trigger decision is made at around 1.2 microseconds based on centrality information from the FMD.

At level-one (2 microseconds) this is supplemented by the ZDC. A dimuon trigger from the FMD also contributes to level-one. The final level-two trigger decision is made after further processing at 100 microseconds.

The architecture of the ALICE data acquisition system is determined by the relatively short heavy-ion runs foreseen for the LHC, roughly 10% of each year's running. The collaboration will have ten times as long to analyse the data as they have to collect them, and so a high-bandwidth system is envisaged in order to collect as much data as possible in the time available. CPU-

intensive operations such as event filtering and reconstruction will be performed offline. Data acquisition is the responsibility of Budapest, CERN, and Oslo.

If all goes to plan, installation of ALICE should begin as soon as the L3 experiment is decommissioned and removed from the experimental area. According to the current LEP schedule, this should be around October 2001, leaving the ALICE collaboration two years to install and commission their detector, ready to set off in pursuit of a plasma wonderland with the first LHC beams in 2004.

CEBAF - on-line for physics

After a decade of design, R&D, construction, and commissioning, the Continuous Electron Beam Accelerator Facility (CEBAF) superconducting radiofrequency accelerator, Newport News, Virginia, is on-line for experiments to bridge the quark and hadronic descriptions of nuclear matter.

Following a commissioning period that included extended five-pass continuous wave (cw) operation at the 4 GeV design energy, the first of 76 presently approved experiments began on November 15 in Hall C. In the words of spokesman Don Geesaman of Argonne, "The accelerator is running better than any new accelerator I've ever seen, and

better than most mature accelerators I've seen."

Initial machine performance was indeed encouraging, with superconducting radiofrequency (SRF) performance the highlight. Before the holiday shutdown, cavity gradient averaged above 6 MeV/m, 20% over specification, and the average cavity Q of 5×10^9 was twice specification. The world's largest 2 K refrigerator - source of half the world's superfluid helium - supported superconducting operation with greater than 99% availability.

Emittance exceeded its 2×10^{-9} m design goal; energy spread at 2.8×10^{-5} exceeded its 10^{-4} baseline specification, nearly reaching its 2.5×10^{-5} design goal. Three interleaved,

independent-current bunch trains can be sent from the injector through the machine, and any one can be extracted from any pass. The adoption of EPICS (Experimental Physics and Industrial Control System) is clearly paying off. With two linacs, nine recirculation arc beamlines, and over 2200 magnets, machine complexity is comparable to that of CERN's LEP electron-positron collider. Up time was above 80%.

The presently approved experimental programme consists of 1282 days of beam time in the three experimental halls, or roughly three years of full simultaneous running. The spectrometers in halls A and B will become operational later this year. The programme represents the