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APPLIED R&D IN THE CERN RESEARCH DIVISIONS

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Introductory note:

This is far from being a complete survey; the present version is a first draft based on information collected during the Summer months and not yet checked with all those involved. Where possible the names of contacts are given (in bold); this is done on an informal basis as a help in obtaining further information. Most of the R&D mentioned is done in collaboration with other institutes and with industry. Much of it has been carried out as part of the LAA project, and full details are available in the reports of the Project Leader **Prof.A.Zichichi** [1].

Part 1

R&D Projects in PPE Division

A. Calorimetry

A1. Warm liquid calorimetry

(G.Maurin)

Status: in progress

A2. Liquid Argon calorimetry with LHC performance characteristics

(Ch.Fabjan, D.Fournier, P.Jenni)

Status: in progress

Study and improve certain aspects of a LAr calorimeter to meet the performance required by the LHC discovery potential. Specifically:

- evaluation of a novel fast readout technique (Accordion)
- comprehensive design study of a LAr calorimeter with large acceptance
- development of fast preamplifiers (Si JFET and GaAs) and evaluate their radiation hardness
- extensive simulation programme to study compensation and system performance as a function of calorimeter parameters
- evaluation of the radiation resistance of calorimeter components.

A3. Liquid Argon dopants for LHC hadron calorimetry

(**V.Vuillemin**)

Status: in progress

The effect of dopants to liquid argon to improve on drift speed and on its response to densely ionising particles is studied in a systematic way. The measurement and monitoring of the critical parameters, including the use of infrared absorption spectroscopy are part of the project.

A4. Scintillating fibre calorimetry at the LHC (SPACAL)

(**G.Goggi, P.Jenni, R.Wigmans**)

Status: in progress

Based on the very good performance of a 20-ton prototype calorimeter recently achieved by the SPACAL Collaboration, the technique of scintillating fibre calorimetry is now believed to have the potential of meeting the difficult requirements of calorimetry at LHC. The aim of the proposal is to develop an integrated electromagnetic-hadronic calorimeter having an optimal combination of essential parameters, such as speed, compensation, energy resolution, granularity and hermeticity. The proposal covers the construction and tests of a large-scale projective prototype, as well as parallel investigations in the related fields of high dynamic range photodetectors, front-end electronics, triggering, data acquisition, radiation damage and overall system design of a calorimetric detector.

A5. Photosensitive pad chamber for BaF_2 calorimetry

(**F.Sauli**)

Status: in progress

Following the development of an electromagnetic calorimeter based on the use of barium fluoride as scintillating medium and a photosensitive gaseous chamber as detector, a segment of the calorimeter has been realised with a matrix of pads on the sensitive element, fully equipped with amplifiers and read-out electronics. The gas system under construction will allow to form in the chamber the condensed photocathodes detecting with good efficiency the UV photons emitted by the fast scintillation of BaF_2. Both energy resolution and localization accuracy are being studied.

A6. Heavy Fluoride glasses

(**P.Lecoq**)

Status: letter of intent

Heavy Fluoride Glasses like BaF_2, CeF_3, LaF_3, PbF_2, offer interesting possibilities for electron detection at the LHC. They have the advantage of high density, are fast and are relatively radiation resistant at reduced production cost. Light collection and read-out techniques as well as engineering solutions have already been developed. In a four-year R&D project the first two years are planned for procurement of raw materials, sample production and development of test equipment. After these preliminary studies one or two candidate glasses should be selected for the construction of prototypes of reasonable size, for systematic work in test beams as well as large scale production studies and cost evaluations.

B. Tracking and Preshower Detectors

B1. Double sided read-out Silicon detectors

(P.Weilhammer)

Status: in progress

Small double-sided read-out detectors, including detectors with parallel strips on p- and n-side for keV energy X-ray detection; optimisation w.r.t. spatial resolution, gettering and yield. Prototype double-sided read-out detector, similar to above, with additional double metal layer read-out for n-side strips; on-detector multiplexing of several n-side strips into one amplifier channel.

B2. Silicon Tracking/Preshower detector for the LHC

(A.G.Clark, C.Gössling)

Status: in preparation

Programme of studies aimed at determining whether the track stub/ preshower technique of electron identification, such as the one provided by a silicon pad detector, can be used at the highest operating luminosities of the proposed LHC Collider. The proposal covers detector and electronics developments required for the construction of a track-stub and preshower detector preceding the electromagnetic calorimeter of an LHC experiment.

B3. Proportional chamber pad detectors

(Ch.Fabjan, F.Piuz)

Status: in progress

B4. Microstrip proportional detectors

(F.Sauli)

Status: in progress

This gaseous detector is based on the idea of reproducing strength and structure of the electric field typical of Multiwire Proportional Chambers but on a scale reduced by a factor of 10. This is possible by using electron microelectronics technology to etch on an insulating glass substrate thin metal strips, 100 micrometers apart, connected alternatively as anodes and cathodes. With attainable gains in excess of 10^4 and a very good energy resolution (12% FWHM for 6 keV X-rays), the prototype chambers have shown also excellent localization accuracy (35μ rms) and high rate capability. To a large extent, the microstrip gas chamber appears as a valuable alternative to the solid state silicon strip detectors, at a fraction of the cost. The structure described can also be realized on a thin plastic support. The advantages are reduced thickness (less multiple scattering and the possibility to realize cylindrical geometries. Studies on engraving the strips by ion implantation are under way (electron beam lithography cannot be used on plastics).

B5. Multidrift chamber modules

(F.Sauli)

Status: in progress

A vertex detector is being developed designed to operate at the very high particle rates and radiation levels expected at future high energy colliders. The detector is made of an array of hexagonal multidrift modules, each independently providing local re constructed track segments in space, with very good angular resolution (0.5 mrad or better in the radial direction) and two-particle separation (500 micrometer). In the final design, each module has 132 drift cells of 1.4 mm radius, defined by six cathode wires. The completed tubes are 30 mm in diameter and 80 cm long. Signals are read out from both sides.

B6. Scintillating fibre detectors

(J.Kirkby, J.P.Fabre)

Status: letter of intent

Plastic scintillating fibres are proposed as detectors for LHC/SSC on the following merits:

- fast response (signal integration time about 20 ns)
- granularity which results in a compact device, low occupancy, high measurement accuracy and good two-track resolution
- hydrogenous medium,which results in compensated Pb calorimetry
- radiation hardness

A systematic study of the use of SCIFI for central tracking and for imaging preshower counters is proposed. Read-out is proposed via highly granular optoelectronic devices, such as multianode phototubes, image intensifiers and CCDs.

B7. Scintillating fibre central tracking detector

(H.Leutz)

Status: in progress

Scintillating fibres form a reasonable compromise for central tracking detectors in terms of price, resolution, response time, occupancy and heat production. New fluorescents with large Stokes' shifts have been produced, capable of working without wavelength shifters. Coherent multibundles have been developed to achieve high packing fractions. Small segments of tracker shell have been assembled, and beam tests have confirmed expectations on spatial resolution. An opto-electronic delay line has been designed to delay the track patterns and enable coincidences with a first-level trigger.

The aim of the proposal is to improve hit densities for small diameter fibres by increasing the fraction of trapped light, reducing absorption and reflection losses, reflecting light at the free fibre end, and increasing the quantum efficiency for photon conversion. Further development of the delay tube is also planned.

B8. Scintillating fibre/capillaries target

(K.Winter)

Status: in progress

A scintillating fibre detector (target mass about 400 kg) is being developed to detect tau lepton production and decay in neutrino interactions. Two different techniques are being investigated:

- glass capillaries (external diameter 27 microns) filled with liquid scintillator;
- Terbium doped glass fibres of 20 x 20 microns**2

Light output, attenuation lengths and production techniques for bundles of fibres are being investigated.

B9. Muon triggers and reconstruction at the LHC

(M.Della Negra, K.Eggert)

Status: in preparation

A small solid angle of a muon detector in a large magnetic field, foreseen for LHC, will be constructed and tested in a test beam containing hadrons and muons. Hadron punch-through, i.e. angle, momentum and timing distributions of the outgoing particles will be measured for various absorber thicknesses, including the effect of a strong magnetisation of the absorber. The efficiency of different muon triggers and the rejection against hadron punch-through and decay muons will be studied. Reconstruction of muons and their momentum measurement in magnetised iron will be investigated with special emphasis on the effect of catastrophic energy losses of high momentum muons.

C. Other Detectors

C1. Integrated high-rate transition radiation detector and tracking chamber for the LHC

(T.Akesson, B.Dolgoshein, Ch.Fabjan)

Status: in preparation

Development of an integrated transition radiation detector (TRD) and charged particle tracker for use at LHC, aimed at discriminating between electrons and hadrons and at identifying rare high energy charged particles. Such detector consists of a low mass structure of radiator materials and proportional straws to generate and detect radiation X-rays and track charged particles. The development would include the readout of the straw signals and trigger processors correlating the TRD signal to other detectors. Parts of the program are also the test of a small prototype, followed by a fine-grained calorimeter and sufficient to contain a high energy jet, and the construction of an engineering prototype to verify the design for a large detector. Parts of the program are also the test of a small prototype, followed by a fine-grained calorimeter and sufficient to contain a high energy jet, and the construction of an engineering prototype to verify the design for a large detector.

Part 2

Related R&D in ECP Division

Introduction

The following is a summary of development work on detectors, readout, triggering, data acquisition and control in which the ECP Division participates, and which is potentially relevant to future high rate experiments. An ECFA Working Group on signal processing, triggering and data acquisition (**S.Cittolin**) is considering a range of problems in this field, and related work is going on in the trigger and data acquisition working group (**L.Mapelli**)

Detector studies and developments

Solid-state detectors

The programme of silicon detector technology development (**E.Heijne, P.Jarron**) includes silicon pad detectors and pixel detectors. The design study for a tracker/preshower pad detector addresses the questions of granularity, mechanical mounting, interconnect structure, heat management and radiation damage. Pixel detector development will proceed via applications in fixed-target heavy ion experiments and in LEP. The approach will be based on hybrid systems in the first instance, and several new devices will be manufactured to try out the bump bonding technology involved.

The first phase of a study of GaAs as a base material for solid state detectors has been completed (**C.del Papa**). Many diodes of different sizes and shapes have been built and tested. The goal is to build a prototype microstrip detector on a semi-insulating GaAs substrate.

In addition, ECP has participated in work on double-sided readout Silicon detectors (**P.Weilhammer**), leading particle detection, muon detectors, and radiation damage studies (**H.Schönbacher**). Physics generators have been set up and GEANT support given to physicists in the Study Group for high luminosity detectors at LHC (**C.Onions**).

Readout electronics

Analog front-end electronics

Several circuits have been developed (**E.Heijne, P.Jarron**), which can serve as functional building blocks for system-on-chip detector signal processing. The AMPLEX continuous feedback front-end amplifier with shaping and multiplexing is finding numerous applications: work has started on several schemes to implement front-end amplifier blocks with better performance. The FASTPLEX experimental chip implements a low-noise high-speed regenerative comparator. The SAPE analog pipeline chip with simultaneous read and write operation and the 12-bit pipelined A/D converter PIPAD lay the groundwork for the HARP (Hierarchical Analog Readout Pipeline) processor. This offers a low-power alternative to FADC-based systems for detectors with many densely-packed elements which need local intelligence, such as fine-grained Silicon detectors.

Digital front-end electronics

A digital front-end system is under study for calorimetry (**B.Löfstedt**). It involves ADCs with stringent dynamic range and resolution requirements, a digital pipeline with programmable trigger filter/summing functions, and a CPU for data identification and reduction, and overall control. The components, including several ASICS, would be combined either on a microsystem module or on a PCB using chip-on-board technology. Other developments under study include two-dimensional readout for MWPC using VLSI (**E.Chesi**), and possible applications of Sigma Delta ADCs (**B.Hallgren**)

Optoelectronic delay line

A Vacuum Image Pipeline is under development as a delay tube for use with a scintillating fibre fast tracking detector (**J.P.Fabre**). This allows the track images to be stored during the time taken for the trigger decision (around 1μsec). The small fraction selected are then transmitted to later stages, whilst others are discarded.

Trigger processor architectures

A second level trigger will probably need to take events at around 10^5/sec and reduce them to a rate at which conventional programmable systems can undertake further processing. A number of architectures are under consideration; they usually depend on pipelining or fine-grained parallelism to achieve the necessary speed. In one study (**R.Bock**), a set of algorithms has been selected covering applications such as peak and track finding, calorimeter cluster analysis and RICH pattern recognition. These have been used to benchmark several alternative architectures, including the MaxVideo, GAPP, ASP and FDPP as well as conventional processors.

Image processing systems

The MaxVideo commercial modular image-processing system is configurable and programmable. It has been evaluated for a number of detector pattern recognition tasks (**W.Krischer**), and the benchmarks have been run on it. A study of cluster analysis algorithms for electron-pion shower discrimination using spaghetti calorimeter test data has given encouraging results

Fine-grained parallel processors

Several efforts are based on the ASP (Associative String Processor), a SIMD architecture available as VLSI building blocks. The TRAX-I system, incorporating 16k such processors, is intended for the offline analysis of NA35 streamer chamber data (**A.Sandoval**). A number of algorithms has been developed for it, along with a library of software for basic operations. The MPPC project (**R.Bock, F.Rohrbach**) plans to set up the necessary hardware infrastructure and computing environment for a system with 65k processors, and to use these in a pilot project with a fast intelligent image-intensified CCD camera. This aims to demonstrate real-time data-acquisition and online analysis of images with 1Mbyte of information per event. Algorithms will be developed for track reconstruction and RICH pattern recognition. The application of ASP-base architectures to TRD tracking is also under study.

Signal processing

The Fast Digital Parallel Processor FDPP (**D.Crosetto**) is a modular system integrating the computing power of a DSP with the communication facilities of a Transputer. Preliminary benchmarking on cluster analysis with spaghetti calorimeter data has given encouraging results, and an architecture with a number of FDPPs operating in parallel is proposed for further study in this type of application.

Other activities

Tracking, vertex finding and event selection in the UA6 experiment are carried out by an array of some 50 Transputers, which allows the potential of this device for triggering to be assessed (**R.Dobinson**) A number of studies of Level-1 triggering and Level-1 to Level-2 connection have been made by the Study Group for high luminosity detectors at LHC, using modelling and simulation techniques (**L.Mapelli**). Studies of algorithms and architectures for track and vertex finding in beauty triggers have also explored several approaches such as associative memories, neural nets and data-driven processors (**R.Amendolia, P.Schlein**).

Data-flow organisation, interconnection, event-builders

Evolution of backplane systems and interconnects

The ECFA working subgroup on buses and standards (**H.Müller**) is undertaking a comparative study of buses and interconnects to assess their suitability for applications in future high-rate experiments. They include FASTBUS, V-buses, Futurebus+, SCI, SCSI, Transputer links and Turbochannel. A related subgroup on data links and event builders (**R.McLaren**) is looking into the potential for our field of HIPPI, FDDI, optical links and crossbar switch technology.

Current activities related to HIPPI, the High-Performance Parallel Interface, (**R.McLaren**) include the design of a VMEbus interface and test box as well as the use of optical links. Transputers and their links have been used in a pilot project for data transport and event building in the JETSET experiment (**R.Dobinson**) Several types of event-builder based on crossbar-style switches are currently the subject of simulation studies to assess their suitability for high-rate data-acquisition systems (**A.Fucci, R.McLaren, L.Romero**).

Another approach to event building involves embedding commercial programmable RISC processors in backplane architectures (**A.Marchioro**). A pilot project consists of a FASTBUS board with four SPARC processors interfaced via coprocessors to FASTBUS. The open SPARC architecture in principle allows it to be extended to offer direct addressing of FASTBUS. Such custom-designed interfacing of high-performance commercial processors offers a way to put conventional processing power close to the detectors. An important element of this work is the acquisition of experience in modern digital design tools.

Higher levels of data-acquisition

System modelling and investigation

A number of system modelling studies are under way using the description of existing data-acquisition systems such as UA1 and UA2 as a starting point for further work, and as a means of evaluating various simulation and modelling techniques (**L.Mapelli**).

Evolving test and data-acquisition system

Design studies have begun on an evolving data-acquisition system which could be used in test beams for detector development. This would permit the testing of new hardware and software directly on real data from modern detectors. The conceptual design must be flexible enough to allow alternative approaches to be tried out in various parts of the system (**L.Mapelli, E.Rimmer**). A test bench for hardware developments is also under study which will allow the experience gained in existing systems to be applied in the more demanding regimes of high-rate readout electronics (**S.Cittolin**).

Parallel processing etc

Farm-style approach to on and offline processing

The higher levels of event selection and processing rely on parallelism at the event level. Several approaches to processor farms are currently in existence, including the use of conventional commercial processors of various kinds as well as emulators such as the 3081/E. The PPCS project offers a new attempt to provide computing power of this kind (**A.Fucci**). Involvement in the APE and Super-APE supercomputer projects has been mainly in packaging and in design studies for high-rate data communications between processors and memories (**A.Fucci**).

Transputers

Several features of the Transputer architecture, in particular its interconnection possibilities, make it attractive in various roles in the experiment. Its use in data transmission, triggering and event building have already been mentioned. In addition, a current ESPRIT project (**R.Dobinson**) aims to provide a standard architecture and software environment for a system scalable up to 10^4 Transputer nodes. An experimental machine at CERN will have 64 nodes of the new H1 Transputer. It is planned to test it in an online application, and also to port GEANT to it. The project also includes a VME interface and a fibre-optic link extender.

Monte Carlo, Analysis and data presentation

The ECFA working group on simulation and software engineering (**R.Brun**) is tackling a range of software problems including structures for the event database and geometry database, parametrisation techniques, and a number of software engineering issues.

QCD simulation and Monte Carlo

The software tools for a full Monte Carlo chain have been developed (**L.Cifarelli**). These are built around data structures using the ADAMO system based on the Entity-Relationship model. Various event generators and tracking programmes such as GEANT are interfaced to these structures, and in addition physics analysis and presentation packages can be incorporated. Studies and tests have been carried out using various QCD event generators. The COSMOS project aims to take this work further.

Interactive object-oriented simulation package

The GISMO project (**M.Storr**) aims to develop a detector design, simulation and reconstruction package using object-oriented methods. It will serve to investigate the applicability of these methods to HEP computing problems.

Methods and infrastructure

A Software Technology Interest Group has been set up (**M.Sendall**) to allow people using new software technologies to exchange information and experience on methods and products. This is aimed to help spread awareness of modern methods which will be essential to solving the software problems of the next generation of experiments.

Evaluation of methods and tools is under way in several of the areas already mentioned. They include data modelling with ADAMO etc, logic programming, system modelling and simulation, structured analysis and design, object-oriented programming.

Part 3

R&D in CN Division and in TIS

Related work in CN Division

Whilst it is true to say that no detector development per se is carried out in CN division, it is worth drawing attention to two areas of research that are relevant to CERN's future physics programme in general and LHC in particular.

The Applications Software group is actively involved with simulation techniques for LHC experiments. (**R.Brun**) runs the ECFA sub-group on "Simulation tools and software tools" which will report at the Aachen workshop in October. A particular emphasis is on calorimetric simulation – Lead/PbSc, Liquid Xenon, Liquid Argon with the accordion geometry, Spacal, Ypsilantis group,etc, with a view to reducing the potentially enormous CPU requirements for shower simulation at LHC energies.

The distributed computing section of the software group, led by (**L.Robertson**), are investigating the use of CPU and magnetic disk technologies as developed for high performance workstations together with very high speed networks to construct scalable computing systems (of up to of the order of 500 MIPs) that will exhibit a price/performance typical of modern RISC workstations. Whilst this effort is currently aimed at solving the offline computing requirements of modern high

energy physics experiments, it has direct relevance to the problems of higher level triggering for LHC experiments.

Radiation damage studies in TIS

An extensive programme of radiation damage studies is under way (**H.Schönbacher**). It mainly covers scintillating materials, both organic and inorganic, and semiconductor materials for detectors and electronics.

Part 4

References

[1] A.Zichichi, The LAA Project, CERN – LAA/89 – 1