On Detector Related Machine and Instrumentation Issues

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1. Introduction

The purpose of the Panel Discussion on Detector Related Machine and Instrumentation Issues was to evaluate the feasability of experiments and to discuss the assets and limitations of different experimental techniques at future large hadron colliders and also, to some extent, e^+e^- colliders. As the audience could be expected to already be convinced of the scientific merits of such experiments, the effort was directed towards formulating advice and making recommendations about how to design and realize the experiments.

A first important task was to evaluate what kind of development work on detectors and instrumentation, including computers, will be needed to meet the demanding requirements of the very high energies and luminosities considered. Development work of this type can in many cases be carried out at universities and national laboratories and advice in these matters should therefore be of interest to these institutions.

A second important question relates to the machine parameters. What requirements on bunch spacing, luminosity, machine background etc would come from the experiments? Conclusions on these matters should result in requests to the machine builders.

One of the primary purposes of ICFA is to promote interregional collaboration on future accelerators. Clearly, on detectors there is already very extended interregional collaboration as almost every large experiment nowadays comprises physicists participating from more than one region. Perhaps, however, some advice could be given on how to promote further interregional cooperation, including also industry, on the development of new detectors and instrumentation.

2. Panel presentations and discussions

Each of the panel members was asked to give an introductory presentation of the following topics:

G. Kane	The three most revealing future experiments
U. Amaldi	Calorimetry for jets and total energy
R. Schwitters	Tracking and momentum
G. Wolf	Identification of e, μ and other particles
M. Breidenbach	Trigger and data acquisition
S. Orito	Building large detectors in cooperation with industry.

Summaries of these presentations, prepared either by the speaker or myself, are given in appendices 1 to 6.

After these presentations followed a general discussion involving the udience.

V. Telegdi pointed out that the difficulty of precise alignment of track-chambers over large distances was an important point to be added to the list of problems concerning large track-chambers as reviewed by Schwitters. Telegdi furthermore asked Orito how the collaboration with industry was organized in practice, in particular with regard to how the cost of a certain type of development could be evaluated before the work was done. S. Orito and Takahashi answered by saying that usually industry did not take out any profit in the R & D stadge of the work, this often being balanced by the fact that the collaborating particle physics groups contributed to the development with test work on prototypes, e.g. radiation dose tests of BGO material and semiconductors.

B. Richter expressed doubts as to whether the future hadron colliders could be used to measure the rare decay-modes of the B as advertised by Kane, not due to lack of cross-section but because of the large background. He pointed out that the ISR had probably produced 10^6-10^8 times more charm than the present e^+e^- storage rings and yet charm had not been discovered at the ISR. As to microvertex detectors he underlined the necessity for such a detector to be close to the interaction point. The error in transverse position must be much less than 100 μm for the measurement to be of use for identification purposes, probably implying that such identification would only be possible in the central region at future colliders. With regard to collaboration with non-particle-physics groups, he pointed out the large potential of collaborating with other university departments like those for electronics, computation and material sciencies. With reference to the difficulties caused by the high rates, he asked whether for the production of a certain mass state, a decrease in luminosity could be compensated by an increase in energy. In answer to this question Kane said that well above the threshold for the mass state in question the increase in cross-section was only logarithimic with energy and therefore such a trade-off could not be made. Regarding the rare decays at colliders, Kane said that while some scepticism is appropriate, two studies at workshops have already concluded that the physics could probably be done. Wolf pointed out that at the highest luminosity and energy one would be looking for very large p_T jets which could be studied with detectors that would be blind for the low-energy back-ground. As such large p_T events could be expected to be very rare, the highest possible luminosity would be required.

C. Rubbia also expressed doubts with regards to the usefulness of luminosities as high as 10^{33} cm^{-2} s^{-1}. As basis for these doubts he referred to his own experience with the UA1 experiment at the SPS collider at much lower energy and luminosity and where at present a detector upgrade programme is under way to meet the planned increase in luminosity. As an example of the difficulties to be expected at the future colliders he pointed out that radiation-hardened electronics being able to stand 10^{33} cm^{-2} s^{-1} must be much more expensive than electronics that can stand 10^{32} cm^{-2} s^{-1}. He stated that the events at a hadron collider are far less clear than at an e^+e^- collider and that the requirements put on a detector for hadron-hadron collisions are much more demanding than those on an e^+e^- detector. In particular he expected the step from 10^{32} to 10^{33} cm^{-2} s^{-1} in luminosity at a hadron collider to represent a very substantial increase in experimental difficulty. From this point of view, if the physics that could be made at a 10^{32} cm^{-2} s^{-1} $p\bar{p}$ collider would be equivalent to that which could be made at a 10^{33} cm^{-2} s^{-1} pp collider, he would certainly choose the former. Quite generally he expected that from the point of view of luminosity the detectors will be the limiting element, not the accelerators. J. Ellis responded that the equivalence between $p\bar{p}$ collisions at 10^{32} cm^{-2} s^{-1}

luminosity and pp collisions at 10^{33} cm^{-2} s^{-1} was only valid when considering production of new strongly interacting particles but not when considering e.g. electroweak interactions. Schwitters commented that at a DPF workshop last year in Berkeley the increase in cost for the detector when going from 10^{32} to 10^{33} cm^{-2} s^{-1} in luminosity had been estimated to be a factor 3 to 4 for the detector hardware and an order of magnitude for the data handling. M. Koshiba remarked that the number of events quoted in the discussions were always valid for only one year of running. Since the investment cost of the future colliders is very high, the machine would certainly have to run for at least ten years. Taking this fact into account would imply that one could work at 10^{32} rather than at 10^{33} cm^{-2} s^{-1}. J. Sandweiss pointed out that not all experiments will aim at measuring the average event but rather be of the kind earlier indicated by Wolf, i.e. experiments that detect only large p_T jets and are blind for most of the events.

Sandweiss furthermore asked whether it would be useful to have polarized beams to discriminate against some of the background. Kane answered that for production of weak interaction particles like Z and W this is the case, but not in most other cases like e.g. for the production of the spin-zero Higgs.

Ellis remarked that the panel presentations had not at all discussed experiments at a future e^+e^- machine as had been advertised. The chairman asked the panel members to point out what in their conclusions would be different in the case of an e^+e^- experiment. Breidenbach said that all trigger and data acquisition questions became trivial at an e^+e^- machine as compared to a hadron machine. Wolf said that the demands on accuracy remained the same in the two cases but that due to the lower intensities, vertex detectors would have much less problems with radiation damage. Amaldi said that calibration would be easier at an e^+e^- machine, that there would be no problems to go to small angles, but that otherwise there was little difference. Orito pointed out that at a 1 TeV e^+e^- collider with a luminosity of 10^{32} cm^{-2} s^{-1} there would only be a few events per hour, a very comfortable rate from the point of data handling. Furthermore, to study objects of a few 100 GeV/c^2 mass certainly the detection conditions would be much cleaner at an e^+e^- machine than with a hadron machine. With a 10 TeV hadron collider, on the other hand, it should be possible to study objects of very high mass like 5 TeV/c^2.

H. Schopper said that earlier it had been argued that the great interest of hadron machines, as compared to e^+e^- machines, was that they provide gluon-gluon collisions at large rate. He noted that in the present discussion more had been said about W^+W^- collisions than about gluon-gluon collisions. Kane responded that for Higgs production up to a certain Higgs mass hadron colliders are much more efficient due to the gluon collisions. He also said that of the three experiments he had presented in his introduction, the first two would be possible at both e^+e^- and hadron colliders, whereas the third experiment could only be made at a hadron machine, again due to the presence of gluon-gluon collisions.

K. Tittel asked Schwitters if he thought that it was really possible or even desirable to measure the direction and momentum all 500 or so tracks in an event using a track chamber and magnet. Schwitters agreed that indeed the task seemed formidable and concluded that the kind of complete event reconstruction that is being made today would most probably not be possible at a future hadron collider.

J. Sacton asked if it would be important to determine the charge of the leptons and, if so, how to measure the charge of the electron. Schwitters answered that charge determination would be important but that it would be very difficult to measure the charge of electrons. Wolf said that charge determination would be useful for events which contain several leptons where as for events with single leptons charge determination would be less important.

3. Conclusions and recommendations

Below I will summarize what appears to me to be the essential conclusions of the panel discussion and formulate a few recommendations in the spirit given in the introduction.

In the discussion on detectors at the future large hadron colliders much emphasis was given to calorimetric measurements, muon measurements and micro-vertex detection. Calorimeters with the properties required are certainly feasible, although substantial development work will be needed. They represent the primary tool at any large future hadron collider. Also muon measurements are feasible, although by no means trivially, and of great importance. The value of a good minivertex detector is indisputable although here the technical problems that have to be solved are such that a solution cannot be guaranteed. Both the feasability and to some extent also the value of complete tracking and momentum measurement of all charged tracks seems questionable, at least at a luminosity of 10^{33} cm^{-2} s^{-1}.

It was suggested that at the very high energies under consideration a good calorimeter should have the same absorber material in the hadronic and electromagnetic parts, with as equal response to hadrons and electromagnetic particles as possible (e.g. Uranium), have no amplification of the primary charge (ionization chamber operation) and be provided with test beam calibration facilities (in situ if possible) up to the highest energies, all in order to optimise the energy-measurement accuracy. High granularity ($\sim 10^5$ channels) and small Molière radius ($\sim$1 cm) will be required for optimal localization of the jets and leptons. A good muon identification and measurement capability will require very thick magnetized iron walls (5 m) and large surface (several 1000 m^2), high precision (σ = 300 μm) drift chambers. A good microvertex detector should have high resolution (σ = 10 μm), good double track resolution (100 μm) and high radiation dose resistivity (10^4 Rads). An overriding requirement is that the detectors should be able to stand a bunch collision rate of one every 10 ns, which requires short pulses (clipping) and short drift distances in the detectors (less than 5 mm) and high redundancy in the measurements. There is a need for inexpensive and radiation-hardened front-end electronics for all detectors. As to data acquisition and analysis the use of a sequence of successive trigger levels with a large number of emulators (of the order of 100) in the last stage and the use of optical discs for data storage would be needed at the highest luminosities.

It is clear that the development of the instrumentation techniques mentioned here constitutes a prerequisite for the efficient use of a future large hadron collider. It will be an important task for the universities and national laboratories to carry out this development work, in particular because the laboratory that would host a large hadron collider probably would have to focus most of its efforts on machine development and construction and would have very limited resources available for detector development and construction. In view of the large scale and large numbers of many of the detector devices considered, collaboration with industry must be established for this work to a much larger extent than what has been the case till now. Collaboration with other departments at our universities, like those for electronics, computing and material sciences, should also be sought when working on specialized development problems.

It should be noted that when considering detectors for a future large e^+e^- collider, some of the technical problems mentioned are drastically simplifed, in particular those related to the high collision rate like signal pile-up, radiation damage and fast data processing. Many problems remain however, in particular those related to the large size of the detector and to the high measurement accuracy.

Although several reservations were made in the discussion and a number of technical questions remain unanswered, I believe that the large hadron collider should be built such that the highest possible luminosity, even above the value of 10^{33} cm^{-2} s^{-1}, could indeed be reached. Data taking at peak luminosity with specialized detectors would allow to search for rare events with very energetic jets that would stand out above the "noise" of minimum bias events, also when several of these would overlap with the trigger event. Exactly at what luminosity more complete measurements with full event reconstruction could be made seems difficult to say with confidence today, but it would probably fall somewhere between 10^{32} and 10^{33} cm^{-2} s^{-1}. For such measurement there should be only one interaction per bunch-crossing on average. As radiation damage caused by the bunch-crossing radiation already represents a precarious problem, it is crucial that the machine radiation at injection and abortion be kept at an absolute minimum.

All these perspectives are extremely challenging and very exciting from the physics point of view. I believe the pannel discussion showed that experimentation at the future colliders is indeed possible and also that the realization of experiments will be largely stimulated if a spirit of interregional cooperation will prevail in our work.

In conclusion I recommend that ICFA set up a more permanent working panel on Future Instrumentation Innovation and Development to give advice and stimulate interregional cooperation on these matters and to report progress at future ICFA meetings.