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**PERSPECTIVES FOR A NEW DETECTOR AT A FUTURE
SUPERCOLLIDER: THE LAA PROJECT**

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1. INTRODUCTION.

The present *status of accelerators and detectors* is as follows (see Fig. 1).

No one knows, at present, how to design an (e^+e^-) collider in the TeV energy range, while a conceptual design of ELOISATRON^[1] (the 100 TeV (pp) collider) has shown that there are no basic difficulties for the machine to be designed in all details.

The situation is reversed for the case of detectors.

If a multi-TeV (e^+e^-) collider would be operative, we could immediately design an experimental set-up. The reason being that, due to the electroweak photon propagator dumping, the cross-section left over is very small.

But, if a multi-TeV hadron collider would be operating, no physicist in the planet would know how to perform a meaningful experiment, apart from the trivial «full screened» systems. The basic motivations being the high rate of events and the strong radiation doses which the detectors are exposed to.

As discussed later on, for the first time in the field of High Energy Physics, there are basic reasons to justify a jump in energy as big as possible. The multi-TeV energy domain is - at present - exclusive privilege of proton machines, in spite of the gluon and quark structure of the colliding particles. The 100 TeV level is off-limits for (e^+e^-) colliders. This is why the choice emerging from Fig. 1 is R&D for detectors, in proton colliders.

A multi-TeV Collider opens up a new series of problems. These problems are of great general interest for all those who want to do Physics in the next generation of Accelerators.

Fig. 1 - The present situation of Accelerators and Detectors.

The urgency of undertaking a series of studies where new ideas and new instruments could be investigated, has brought us to the present status of the CERN LAA Project^[2,3,4,5,6].

The LAA Project consists of ten sub-projects which are open to all physicists and engineers who are interested in participating. The ultimate goal is to prove, on the basis of prototypes, the feasibility of essential components for a detector to operate in a future multi-TeV hadron Collider. Special attention is paid to radiation hardness, rate capability, momentum resolution and hermeticity of such a detector assembly.

In what follows, the motivations, the requirements, the choices of the LAA Project and the results achieved after one year of operation, are reported.

2. THE MOTIVATIONS.

Is this large R&D programme justified in terms of Physics goals?

Back in 1979 it was clear to some of us that we were entering a new *Era* in Physics.

In spite of the great development of our Physics, little was done to promote the necessary support required by these *new frontiers of advanced research*. Why? Probably because the physics community was not convinced that this new *Era* was really there.

This new *Era* indicated that a big jump was needed in the *energy level*.

The strong feeling that we were entering a new *Era* in Physics initiated the ELOISATRON Project, and LAA is part of this programme.

New ideas, new concepts and new phenomena make physics of just twenty years ago seem as old as millenia. Einstein's quadri-dimensional space-time seemed to be a conquest beyond which no one would be able to go. This, however, seems to be an incredibly narrow outlook for two reasons, both fundamental: the number of dimensions and the property of those dimensions.

No one had thought, before the sixties, that there could exist space-time dimensions with *fermionic* properties. Those of Einstein are *bosonic*. This is how the new concept of *superspace* was born, and with it, *superparticles* and *supermatter*.

The world in which we live and the matter which we are made of, could have their roots in a *bosonic* superspace with ten dimensions, plus the 32 *fermionic* ones. And this is not all.

The concept of «point» that has held its position for centuries and centuries, falls by the wayside. In its place is the «superstring»^[7]: a unidimensional entity with a pointless structure in a 42-dimensional Superspace. More recently, the p-brane^[8] (a membrane with p-dimensions) has taken the leading role over the string.

In this extraordinary progress of our knowledge, the winning parameter has so far been and will certainly remain the **energy**. The final goal is the unification of all the fundamental forces of Nature. Figure 2 shows the unification scale, and where the ELOISATRON hadron collider stands. The straight lines and the unification point are just to show the conceptual game. For example, the point at 10^{15} GeV is more like an ellipse. And the straight lines should not be taken as if no basic problems were there.

Fig. 2 - All the fundamental forces of nature should be generated by a unique force. The convergence of the three fundamental constants g_1 , g_2 , g_3 , is the basis for GUT.

There are four basic theoretical problems to be solved in the multi-TeV (1+100 TeV) energy domain:

- The **family** problem.
- The **hierarchy** problem.
- The **proliferation** problem.
- The **compositeness** problem.

The questions which raise when translating these theoretical problems into physically observable phenomena are the following:

- i) Do **new**, heavier, **quarks** and **leptons** exist?
- ii) Are there **other intermediate vector bosons**?
- iii) How many **Higgs bosons** exist?
- iv) Do **supersymmetric partners** exist?
- v) Are **quarks** and **leptons composite**?
- vi) Would some **unexpected exotic process** occur?

In order to go from theory to down-to-earth physics the detectors should be able to observe and measure in the multi-TeV range:

- i) electrons and photons;
- ii) muons and other lepton-like long-lived particles;
- iii) neutrinos and other non-interacting particles (i.e. missing objects);
- iv) leading protons (for hermeticity and new physics);
- v) hadrons and jets, with and without leptons inside.

In addition to all these new effects, there is an impressive series of «expected» phenomena to be studied. The multi-TeV range is overcrowded with the Physics of long and short lived hadrons.

3. THE BASIC DATA.

Let me discuss the *basic data* for a new detector at a future *SUPER-COLLIDER*.

The first and main requirement is that a Luminosity as high as possible ($10^{33}+10^{34}+10^{35} \text{ cm}^{-2}\text{s}^{-1}$) should be aimed at. This imposes severe conditions on new detectors. Among them, a vital one is radiation hardness.

A basic feature of new physics is to produce undetectable events. Hermeticity will be essential for the discovery of new phenomena. Therefore the average number of events per bunch crossing ($\langle n \rangle$) must be ONE if the missing energy is to be used as a signature in event selection and analysis*)

The limiting Luminosity is:

$$L_{pp} = \frac{\langle n \rangle}{\Delta t_b \times \sigma_{pp}}$$

where:

- $\langle n \rangle$ = average number of events per bunch crossing,
- Δt_b = time between bunch crossings,
- σ_{pp} = total (pp) cross-section.

*) It must be remembered, however, that $\langle n \rangle = 1$ means that in 37% of the cases the number of events per crossing is 0, in 37% of the cases it is equal to 1, and in 26% of the cases it is greater than 1.

Figure 3 shows the cross-section limit for the detection of rare events (fixed at 10 events per year), and the total minimum bias rate, as a function of Luminosity. Note that a total running time of 10^7 seconds per year, and a total (pp) cross-section of 100 mb are assumed. The «magic» limit of observability, at the 10^{-40} cm² level in the cross-section for new physics, is reached if a Luminosity at the level of 10^{34} cm⁻²s⁻¹ can be achieved.

At present, the following machine parameters:

$$\Delta t_b \sim 100 \text{ ns, and}$$

$$L_{pp} \sim 10^{32} \text{ cm}^{-2} \text{ s}^{-1},$$

are well within reach from a technological point of view.

On the other hand, the total (pp) cross-section is expected to be:

$$\sigma_{pp} \cong 100 \text{ mb} = 10^{-25} \text{ cm}^2.$$

These three values together produce $\langle n \rangle \sim 1$. Figure 4 summarizes the present status, including the radiation level.

But what is wanted is $\langle n \rangle = 1$ at higher luminosities. And therefore the corresponding Δt_b reaches prohibitive figures:

$$\begin{array}{ccccccc}
 L = & 10^{33} & \rightarrow & 10^{34} & \rightarrow & 10^{35} & \text{cm}^{-2} \text{ s}^{-1}, \\
 & \downarrow & & \downarrow & & \downarrow & \\
 \Delta t_b = & 10 & \rightarrow & 1 & \rightarrow & 0.1 & \text{ns.}
 \end{array}$$

High values of Luminosity, such as $10^{34}+10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, must be the aim to be reached in future SuperColliders, and Detectors must be ready to cope with this high Luminosity, in order to study the existence of rare phenomena. Conclusion: machine builders^[1] and physicists have to solve very difficult problems. This is a great challenge for all of us.

At present, no detector is able to make full use of a (pp) collider working with $L > 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, thus a strong R&D effort on Detectors must be pursued. **This is the aim of the LAA Project.**

4. THE MAJOR REQUIREMENTS.

In this section, the major requirements on multi-TeV detectors are outlined, and the R&D necessary to obtain the wanted performances are indicated.

Vertex detector technologies.

Requirements :

- Unambiguous and precise determination of primary and secondary vertices;
- Tracking back to the vertex, measuring the charged multiplicities and defining the topology of the event;

- Very high spatial accuracy, double-track resolution and redundancy, because of :
 - large multiplicities (~ 100),
 - high particle densities in jets,
 - high momenta.
- Particle identification.

Superconducting, very high field magnets should be used in association with very high precision vertex detectors.

The above requirements imply R & D on :

- Multidrift gas proportional tubes.
- High resolution scintillating fibres.
- GaAs and Silicon microstrips.
- Superconducting magnets (≈ 10 T).
- Current-carrying beam pipe^[9]: iron-free space with high toroidal field (~ 10 T).

Calorimetry.

Requirements :

- Large coverage and hermeticity:
 - full detection of showering particles and jets;
 - study of missing p_T (neutrinos, photinos and other "inos").
- High granularity:
 - for electron identification inside jets,
 - increasing when going to more forward regions.
- High rate capability:
 - to cope with the high Luminosity and short time interval between bunch crossings (≤ 100 ns).
- Optimum energy resolution.
It depends on :
 - response to electromagnetic and hadron showers (compensation),
 - choice of absorbers and sampling medium,
 - longitudinal segmentation and depth,
 - control of systematics, which become crucial at very high energies.

The above requirements imply R & D on :

- Lead/scintillating fibres;
- BaF_2 scintillators and photosensitive wire chambers;
- Liquid Xenon calorimeters with electrical and optical read-out.

Muon detection.

Requirements :

- Good rejection against hadron decays and hadron punch-through.
- Maximum angular coverage for detector hermeticity.
- Good momentum analysis over very large volumes, i.e. high resolution and precision alignment.

- Easy and economic construction.
- Minimum number of electronic channels.

The above requirements imply R & D on :

- Very large area detectors :
 - Limited streamer tubes;
 - Large toroidal and solenoidal magnets (air/iron);
 - Very large, high-precision drift chambers.
- Alignment.

Leading particle detectors.

Requirements :

- Large coverage down to the smallest polar angles, needed for :
 - exploring the leading effect and the forward physics domain;
 - studying the longitudinal momentum balance;
 - tagging multiple interactions in the same crossing.
- Capability of facing serious background problems.
- Very high precision in measuring the space points (some μm).
- Stability in position (survey) and response (calibration) over large distances and long periods of time.

Particularly relevant for new heavy flavour research and other expected and unexpected phenomena.

The above requirements imply R & D on :

- GaAs microstrip detectors;
- Silicon microstrip detectors;
- Compact calorimeters;
- Ring Imaging Cherenkov counters (RICH);
- Completely new detectors.

Data acquisition and analysis.

This is the possible scenario for the trigger and data acquisition system:

- First Level trigger:
 - Reduction in rate from 10^7 to $\sim 10^5$ Hz;
 - Decision time : some hundreds of nanoseconds;
 - Simple cuts on energy and p_T ;
 - Each detector element provides an independent trigger;
 - Pipelined with the bunch crossing frequency to avoid completely the problem of dead time;
 - Massive use of custom-programmable processors, realized in close connection with industry.
- Second Level trigger:
 - Reduction in rate from 10^5 to $\sim 10^3$ Hz;
 - Decision time : $\sim 10 \mu\text{s}$;

- Refines the first level trigger results using the digitized signals;
- Massive use of custom-programmable processors.
- Third Level trigger:
 - Most important part of the whole trigger and data acquisition system;
 - Reduction in rate from $\sim 10^3$ to 1 Hz;
 - Capable of handling event sizes of about 1 Mbyte;
 - Analysis of the full event in a multiprocessor stack of about 1'000 CPUs linked by fast data buses;
 - Flexible to explore new energy domains;
 - Implemented in strong connection with off-line (by using the same analysis programmes) to allow a fast implementation of algorithms, coping with new and interesting event topologies.

The above requirements imply R & D on :

- Microelectronics;
- Radiation hardness on the relevant components of the detector;
- Real-time data processing with ultra-high event rates;
- Dedicated Supercomputers.

Theory (QCD lattice calculations for dynamics) and Monte Carlo Simulations.
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Requirements: Event simulation must be based on QCD calculations.

This implies R & D on :

- Dedicated Supercomputers for lattice QCD (dynamics) calculations.
- QCD perturbative models.

5. THE CHOICE.

The previous analysis in terms of physics goals and machine parameters, have brought us to the following choices for the LAA Project: ten basic components (see Fig. 5).

1. HIGH PRECISION TRACKING.

Here three parts are needed. The closest to the vertex uses gaseous detectors consisting of multidrift tubes. The surrounding one, uses the technology of scintillating fibres. The third one, along the beam, is based on microstrips made of a new type of detector material: Gallium Arsenide (GaAs).

2. CALORIMETRY.

Here we follow two lines. One is for the «fixed-target» mode of operation, and it is based on BaF₂ scintillators coupled to photosensitive wire chambers. The other, for a «collider» mode is based on the so-called "Spaghetti Calorimeter" (lead-plastic fibre calorimeter). Of course, no one can exclude that the first approach becomes so successful to be extended also to the collider mode.

THE LAA PROJECT

- 5 - SUBNUCLEAR MULTICHANNEL INTEGRATED DETECTOR TECHNOLOGIES
- 6 - DATA ACQUISITION AND ANALYSIS

Fig. 5 - The ten components of the LAA Project.

3. LARGE AREA DEVICES.

Here there are two basic parts. The first studies the problem of constructing large area devices sensitive to charged particles and with high precision. The other part of the R&D refers to the problem of positioning and monitoring the alignment of these large area devices. There is, in fact, no point in constructing a large area device if we do not know how to position it with great accuracy.

4. LEADING PARTICLE DETECTION.

This is a crucial component of the LAA project. All, in fact, started with the discovery of the «leading» effect at the ISR^[10,11,12,13,14,15]. To work near the beam of a high energy collider presents a series of very difficult, and therefore extremely exciting, problems to be solved. From fast removal of the detectors, to high precision positioning, to high radiation resistance.

5. SUBNUCLEAR MULTICHANNEL INTEGRATED DETECTOR TECHNOLOGIES.

The very high number of channels needed in the detectors for high Luminosity colliders, and, consequently, the problem of compactification of the very many elements, the electric power consumption, etc., lead naturally to the development of integrated electronics. Moreover, the problem of producing radiation resistant electronic components, must be solved if these have to be operated very close to the detector. Therefore, this component of the LAA Project consists of two parts, one dedicated to the design of general-purpose integrated circuits with standard technologies (silicon), and the other which will concentrate mostly on new, radiation-hard, technologies.

6. DATA ACQUISITION AND ANALYSIS.

Here, the objective is the real-time processing of the detector signals. Solutions have to be found to the triggering and data compaction problems, filling the gap which exists today between the custom-made electronics and the programmable devices. Specific solutions have to be found for each of the trigger levels, with particular emphasis on the communication between the various components.

7. SUPERCOMPUTERS AND MONTE CARLO SIMULATIONS.

A full understanding of the theoretical predictions on high energy hadron collisions would be absolutely necessary, in order, both to design the detector, and to analyze in a meaningful way the data. QCD non-perturbative calculations (QCD lattice) have never been applied to the dynamics of the hadronic interactions. Powerful supercomputers are needed to perform the calculations in a reasonable time. Moreover, the theoretical understanding of the algorithms is not yet complete. Therefore, a strong effort is needed in this direction. Meanwhile, a unification of the various Monte Carlo programs, based on QCD perturbative models, is necessary. The goal is to produce a single, QCD «Super - Monte Carlo» program, which eliminates all the uncertainties and contradictions still present today in this field.

8. VERY HIGH MAGNETIC FIELDS.

Here the aim is to design a magnet to produce an extremely high magnetic field in the interaction region. Coupled to very precise tracking detectors, this magnetic field will allow the measurement of the momentum and of the charge sign of the particles produced in multi-TeV interactions. The higher is the magnetic field, the more compact the full detector will be.

9. SUPERCONDUCTIVITY AT HIGH TEMPERATURE.

The recent discovery of superconductivity at high temperatures, opens up a very large range of possibilities in High Energy Physics. Here, most of the problems to be solved concern the technology of materials: for example, how to produce reliable cables, capable of sufficiently high current density to be of practical use. The LAA Project will follow the developments in this field through a series of contacts with the various research centres in the World.

10. RADIATION HARDNESS.

Here, all the studies on the radiation hardness of the various materials and electronics, developed by the different LAA components, are co-ordinated.

6. SUMMARY OF THE RESULTS AFTER ONE YEAR.

The present status of the LAA Project, after one year of activity, is fully reported in Ref. 6.

Here I will limit myself to a very telegraphic summary.

A new plastic scintillator, PMP, has been found: it will allow to produce 50 μm diameter scintillating fibres.

A new wire, radiation resistant at the MRad level has been found.

A new substance, EF, has been found which is better in time resolution and mechanical operation than TMAE. This will allow the construction of the so much needed Solid Scintillator Proportional Counters (SSPC).

It has been proved that GaAs competes very well with the so far dominating Si.

It has been discovered that intrinsic fluctuations in Pb nuclei are lower than in U. This means that future calorimeters will be free from the complex of Uranium.

A new microelectronic circuit - 4 channels amplifier and multiplexer - has been built and shown to work in spite of its 1 cm^2 surface and 100 μm thickness.

7. CONCLUSIONS.

There is no doubt that the feasibility of future experiments will totally rely upon intensive R&D studies on detectors carried out by a large community of researchers. The first results of the LAA Project make us confident that the ambitious goal of operating a detector at the next SuperCollider, which we hope will be the 10% ELOISATRON, is not out of reach.

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