DETECTOR R & D PROPOSAL

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DEVELOPMENT OF A LARGE AREA ADVANCED FAST RICH DETECTOR FOR PARTICLE IDENTIFICATION AT THE LARGE HADRON COLLIDER OPERATED WITH HEAVY IONS.

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Abstract

A proposal is made for R&D support to investigate the feasibility of a fast RICH detector with pad readout for low interaction rate applications (10-100 kHz). Such conditions are met specifically at the Large Hadron Collider when used in heavy ion mode as well as at a number of other applications (tau-Charm, Phi and B factories, SIS and others).

The main objectives are:

- to develop a complete chain of adequate techniques for deposition of photosensitive materials (CsI and similar) on pad electrodes
- to optimize the detector for photon detection efficiency, noise contributions, and radiation thickness
- to develop a specific VLSI front end electronics matched to pad readout of MWPC's with a large number of channels.

Special attention will be paid to the operation of the detector in a high multiplicity environment (≥ 40 m^{-2}), testing a 50x50 cm^2 prototype in the beam.

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1. INTRODUCTION

A large number of collider experiments planned at the Large Hadron Collider Heavy Ion Facility (HI-LHC), Phi, B, τ-Charm factories etc... will require particle identification as a basic tool. The identification requirements will vary from experiment to experiment (in particle species and/or momentum range) but the methods to achieve them are few so that one detector type may, with minor changes, satisfy a large number of applications.

At present, the planned heavy ion experiment [1] at HI-LHC is the most demanding task for a particle identification that should cover a momentum range 0.1 to 4 GeV/c. The striking feature of the planned Lead-Lead collisions at the HI-LHC is a multiplicity of about 6000 particles emitted in a unit of rapidity at mid-rapidity for central collisions. The collisions are expected at a rate of a few 10^4 Hz. These numbers hint at the complexity but also at fundamental differences with the p-p collision experiments that run at much higher rate and much lower multiplicities.

For the sake of clarity, we shall refer in the text to the requirements of a detector for heavy ions collisions although clearly several groups participating in this proposal may have other applications.

2. PARTICLE IDENTIFICATION METHODS

So far, the particle identification (PID) requirements can be met with only three identified detector arrangements:

- Detectors based on dE/dx measurements in gaseous or solid media (low momentum region)
- Time of Flight (TOF) detectors
- Ring Imaging Cherenkov detectors (RICH)

Of these three detectors, the one with dE/dx capability covers the largest range of energies, with however a notable deficiency in the range $0.8 < p < 2.5$ GeV/c in the π/K separation as illustrated in Fig. 1. A similar gap applies also to K/p separation. A similar situation occurs at lower energies for electron-hadron identification.

For the above reasons, it is accepted that to cover the whole range of momenta, one has to supplement the dE/dx device with a TOF or RICH device.

At present, both methods cannot, for various reasons, satisfy the specifications required from such a detector, imposing us to pursue intensive R&D on them, incorporating the technological advances achieved in the past few years. We do not intend to discuss here the comparative merits of these two detectors because it depends on the specific applications in view and on the evolution of their performance in terms of capability and price.

3. AIM OF THE PROPOSAL

We shall, in the present document, propose the development of an advanced RICH detector, adequate to cover the momentum range 0.8-2.5 GeV/c for π/K separation in an environment of particle densities evaluated at the moment at 40 particles /m^2, with emphasis on radical improvements in the price and performance of this type of detector based on recent developments.

To master the problem of pattern recognition in the high multiplicity environment, it will be crucial to optimize:

- the signal to noise ratio associated to the detection of the Cherenkov photoelectrons and the charged particles
- the signal to noise ratio associated to the environmental background by minimizing the amount of material involved in the detector
- the accuracy in measuring Cherenkov ring patterns and localizing the charged particles.

The knowledge of these parameters will ultimately determine the particle density acceptable by the detector. Namely, the maximum allowed density for satisfactory separation determines the distance from the collision point, i.e. the surface of the detector.

As the size is expected to be as large as several tens of square meters, the emphasis will be immediatly put on the realisation of final size detector elements of as simple and as reliable mechanical and electronical conception as possible. We shall assume, in a first step, that the detector will be implemented in a "barrel" configuration.

4. THE FAST RICH DETECTOR APPROACH

In order to satisfy the requirements of HI-LHC physics, we intend to use the Ring Imaging Cherenkov technique in a mode known as "fast RICH" configuration [2].

This approach has the essential feature to make possible a two dimensionnal event localization by reading out a cathode segmented into pads and therefore, allows for unambiguous pattern reconstruction. In addition, the sensitive part of the detector represents a very thin layer of gas (a few mm).

In the past few years, several groups investigated various approaches to the fast RICH problems, with special emphasis to high event rates.

In fig. 2, we show a typical detector configuration that operates in a "proximity focusing geometry" mode.

It is composed of a radiator array separated from the photo detector by a proximity gap of depth L.

4.1 The Radiator

The momentum range of interest, imposes the choice of solid or liquid radiator, media of high refractive index. The solid ones are: sodium fluoride, lithium fluoride, calcium fluoride, quartz, the liquid: freon C_6F_{14} (requiring an additionnal quartz window for containement).

Typically, 10 mm of radiator thickness provides enough Cherenkov photons in the photoconversion band set by the use of TEA or TMAE and the associated absorbing media.

It is important to keep this thickness at a minimum since it implies a proportional error term in the Cherenkov radius determination , due to the lack of focusing.

For identical ring characteristics, the depth of the proximity gap can be made smaller the higher the refractive index is, allowing for more compact arrays. However, total internal reflexion mechanism introduces cut-offs on the particle velocity above which no photons are emitted within some range of particle incidence. Among the solid radiators, only sodium fluoride does not show this inconvenience as its index is smaller than $\sqrt{2}$.

Solid radiators are attractive by their simple implementation. Unfortunately, at the present time, the investement for large area seems still prohibitive, for which reason the cheaper liquid Freon is still being used. A low index (1.28) and a small chromatic dispersion render it attractive to the expense of non trivial circulating and purifying system. It is evident that the thinnest quartz window necessary for containement would have to be implemented to keep the number of photons radiated simultaneously by the quartz at a minimum. Possibly, care should be taken that incidence angles are such that a large fraction of particles are in a total reflexion situation for the quartz Cherenkov emission.

4.2 The Photon Detector And The Electronics

A simple solution consists of a thin symmetric MWPC with cathode pad read out. The chamber gap acts as photoconverting and detecting medium. The Cherenkov light penetrates through a UV transparent window and a mesh cathode pressed against it, then follow the sense wire plane and the pad segmented cathode.

If TMAE is chosen as a photo converting vapor, a quartz window can be used. A small MWPC gap is desirable for larger induced signals but the photo absorption mean free path in TMAE of several mm will demand for higher temperature operating point in order to get enough converted photons in the gap. Chamber gain has to be limited in order to avoid photon feedback problems expected in such an opened geometry. It is thus essential to have a front end pad electronics of very high sensitivity.

If TEA is chosen, the photon feedback problem is relaxed, room temperature operation possible but expensive CaF_2 window is necessary to match the TEA quantum efficiency curve.

As every pad is read out, its size has to be carefully optimized, being immediatly reflected on the number of channels and the difficulty of achieving implementation and connection of the front end pad electronics with a minimum amount of material.

5. PRESENT STATUS OF DEVELOPMENT

We shall briefly describe two examples of recent development work on fast RICH detector and illustrate how the configuration of the detector can be influenced by the event rate expected in their application.

Let us first mention a work [3] foreseen at a high luminosity Beauty factory where 10 MHz interaction rate is anticipated. In such a situation, the realisation of a fast digital readout of a large number of pads is a key issue. It imposes a solution where fast digital signals are generated at every pad. To match a feasible VLSI electronics scheme, the detector choice was to use a MWPC of small gap (0.4 mm distance between sense wire and pads), a pad size of 5x7 mm^2 and the use of TEA as photoconverting agent and its associated CaF_2 window. A devoted VLSI electronics was developped [4], achieving the wanted fast digital response in less than 20 nsec and an event read out cycle in less than a few microseconds.

We give now more details on an other work [5,6,7], closer to the low luminosity application treated in this proposal. It is based on the use of an analog multiplexed readout of the pad signal performed with a VLSI electronics (Amplex [8]). The integrating time of its preamplifier stage is 500 nsec, a value matching applications where interaction rates are limited to a 10-100 kHz range.

In this case, very good results were obtained with a 2 mm gap MWPC, a pad size of 8x8 mm^2, using TMAE from 30 to 50°C with a quartz window, and a NaF or Freon radiator, 10 mm thick. TEA was giving equally satisfactory results.

In fig. 3, the measured mean number of photoelectrons per ring is represented as a function of the particle velocity for 50°C TMAE operation and a NaF radiator 10 mm thick. Fig. 4 gives an example of the ring radius distribution and the r.m.s errors on the radii measured as a function of the particle velocity with NaF or liquid freon radiators.

Based on these results, Fig. 4 shows the particle separation expected with this detector. It largely satisfies our requirement for π/K separation in the 0.8-2.5 GeV/c momentum range for single track at normal incidence.

A first conclusion is that the behaviour of a fast RICH detector with pad readout is satisfactory and well understood in the case when conventional photoconverting agents, such as TEA or TMAE in their vapor phase are used.

Let us finally emphasize that the charged particle impact can be localized with an accuracy of 0.5 mm r.m.s along the wire direction by centroid calculation, a very important feature in case of multi particle pattern reconstruction and matching with tracks in the previous detectors.

Pad electrodes of large size have already been realized in a composite structure, representing 3% X_0 (radiation length) with the complete pad electronics implemented at the back [9].

At present time, a detector representing a mass equivalent to about 20% of a radiation length is achievable.

A prototype of size 50x50 cm^2 with a liquid Freon radiator of equivalent area will be tested in a Sulphur-Sulphur run at the Omega Facility in April 1992 to study multi hit pattern condition.

Some experience on the operation of a RICH detector in high multiplicity environment has been collected also by the NA35 collaboration [10].

6. LINES OF RESEARCH AND DEVELOPMENT

The present status shows promising performance and potentiality of the fast RICH for a possible use at the HI-LHC. However, we are confronted with a series of problems which will clearly hinder satisfactory operation of a large detector and keep its cost at a prohibitive level.

These problems are:

- the use of the agressive TMAE vapor, necessitating high temperature operation
- the use of several expensive UV windows
- the price and size of solid radiators
- the liquid radiator containement
- the lack of a specific front end pad electronics, limiting the detector performance.

Therefore, we propose an R&D programme which aims at designing and constructing a new generation fast RICH detector .

The specific points that we shall address are:

- the substitution of the TEA/TMAE vapors by the newly developed solid photocathodes.

It has been recently demonstrated [11], that photocathodes realised with a thin deposit of Cesium Iodide, with or without TMAE doping, can achieve a quantum efficiency equivalent or better than the TMAE vapour itself (see fig. 6). A pad detector equipped with such photocathodes covering an area of about 20 cm^2 has shown satisfactory behaviour [12].

These results, if scalable to large area cathode, are very attractive since:

- the detector can thus be operated at room temperature without adding TMAE to the chamber gas

- it allows to suppress the MWPC quartz window if the ionization deposited in the proximity gap is prevented to be collected in the MWPC by implementing an extra electrode close to the radiator

- the ring accuracy will improve as the photo electrons, now issued from a plane, will not suffer from the fluctuation in the depth of their absorption in the MWPC. A schematic drawing of the foreseen solid photocathode RICH is shown in Fig. 7.

- design of a new front end pad VLSI chip.

An optimum ring accuracy is essential to achieve the expected particle separation performance. That requires a maximum number of Cherenkov photons to be detected at a low chamber gain with a good spatial resolution. The ring accuracy is inversely proportional to the square root of the number of photoelectrons.

Therefore, we need to develop a new VLSI chip, whose input block is adapted to the specific signals developed at a pad in a MWPC. In addition, the very large number of channels requires the achievement of very high rate of analog multiplexing, possibly in the 5-10 MHz range.

- the search of an optimum radiator material and design.

On the liquid freon radiator problem, the possibility to build a radiator with minimum quartz thickness for containement and possibly without permanent freon circulation will be investigated.

The possibility to use large size solid radiators will also be studied.

- specific construction problems.

The minimization of the mass of the detector and the optimization of its acceptance will require specific solutions and materials in designing the detector (frames, mesh electrode, etc..).

7. OBJECTIVES, MILESTONES

Our main objectives are:

- to demonstrate that a fast RICH with pad readout can be operated at its best performance for particle separation with large size solid photocathodes (50x50 cm^2) in high multiplicity hadron environment

- to develop an overall manufacturing procedure making such a detector safe and affordable in large area for application around the HI-LHC (modules of size ≥ 1 m^2).

We propose to fulfil this long term programme, going through the following steps:

Milestone 1: mastering of the technologies for producing solid photocathodes and their assembly in a pad detector.

Milestone 2 : testing a fast RICH with its solid photocathode with particles and multihit event using the existing Amplex electronics in the first phase.

Milestone 3 : testing the new pad front end VLSI with the same implementation on the pad electrodes.

Milestone 4 : defining design and technologies adapted to LHC module size, including the radiator.

We want to emphazise that for the successful production of large size modules, it is crucial to prove that the sequence of production and testing, including the new electronics, can be made respecting all the constraints imposed by the final detector under consideration.

We describe the activities foreseen and the basic equipment needed to achieve them.

i) Laboratory evaluation of Solid Photocathode.

We want to evaluate the physical properties of the photocathode at a reduced scale, for different kinds of deposit, doping, substrates as a function of their manufacturing processes.

We intend to try various photosensitive materials in different structural states of the thin layer. For this reason, we shall need to perform some structural analysis of the deposits, in/out situ (resistivity, reflectivity, Xrays, scanning electron microscopy, etc..).

The radiation hardness and ageing characteristics of the photosensitive elements will be tested.

This part of the work will lead to a definition of the optimum photocathode candidate and the most adequate production process. In addition, it will define monitoring standards for routine production.

ii) Production of photocathodes for pad detectors.

The realisation of a large size pad electrode with incorporated electronics and solid photocathode requires a sequence of complex operations, and it is of importance to operate in the most integrated and controlled way.

Therefore, it seems justified to plan the building of a versatile dedicated facility where the whole sequence of procedures to produce photosensitive pad electrodes can be carried out. This facility would have capabilities for the analysis of the pad electrode substrate, evaporation of the photocathode material, possibly doping, protection before mounting and transfer in the detector assembly.

It is understood that the above facility would treat detectors which surfaces do not exceed the size 50x50 cm^2. It is clear in our mind that the production of modules of $1m^2$ or larger that might represent the optimal size for a collider detector would not be economically justified at CERN.

iii) Testing a fast RICH.

The performance of the fast RICH equipped with a photocathode will be evaluated at a test beam in terms of factor of merit, response to multi particle events and charged particle localization.

The test setup that we intend to use on a 200 GeV/c beam line is shown in fig. 8. It is composed of a set of Microstrip Silicon detectors surrounding the detector under test and of two tracking pad chambers (30x30 cm^2), achieving a 150 μm resolution by centroid finding. A target and a multiplicity trigger can be implemented in order to generate multiparticle events. It will be assumed that the velocities of the secondaries can be considered as having a value of beta of 1 Single particle as well as multiparticles events will be characterized by this reference in relation with the patterns observed in the fast RICH.

We already have a large fraction of the necessary equipment: detectors, pad electronics, DAQ etc...

We propose that this reference setup can be used for similar tests related to other type of pad detectors necessitating to be evaluated in a multiparticle environment [13].

iv) Testing the new front end pad VLSI.

This new chip will have an input block with filtering characteristics carefully optimized to the pad detector. Due to the very large number of channels expected in our application, a highly multiplexed operation mode is necessary. In addition, solutions for local data compression will be necessarily implemented in such a system.

In addition to our application, such a chip might be useful for other applications dealing with data rates in the same low range (10-100 kHz). For example, the next generation fixed target experiments with heavy ions will make use of tracking pad detectors [14].

We are aware that other R&D works are in preparation in the field of solid photocathodes, having different applications in view. One of us (F.P.) is involved in such a proposal. It is evident that common facilities, equipment, pad electronics or test beam facilities will be shared among us.

We intend to keep close scientific contacts with the groups where already a large expertise on the photosensitive cathode is existing, namely the College de France group (J. Seguinot, T. Ypsilantis) and the Strasbourg group (R. Arnold, J.L. Guyonnet).

8. BUDGET, MANPOWER

We estimate that this R&D programme should cover a period of three years with our available manpower capability. By experience, that is also a reasonable time scale to complete a VLSI electronics development,known for its long iterative procedure.

We therefore present a proposal of budget covering a period of three years.

- Laboratory tests
- Development of dedicated tools and techniques necessary for the production of large size deposits (substrate conditioning, masking, etc)
- Prototype electrodes construction
  test cells, handling equipment
- study and analysis of photosensitive deposits
  (UV sources, Neodym Yag quintupler, radiactive sources, electronics etc..).

We estimate that a sum of 150 kSF will cover these expenses during the first year (including usual laboratoriy consumables). An amount of 75 kSF/year will be necessary for the following two years.

- station for photocathode production	
- evaporating station	100 kSF
- conditioning, doping, assembling under clean conditions	100 kSF
- control, monitoring	50 kSF

- fast RICH test at the beam	
- construction of a fast RICH detector, including pad electronics, radiator, gas/liquid circulation	100 kSF
- installation in beam, mechanics	50 kSF
- completion/replacement of elements of the beam set up	50 kSF
- DAQ	50 kSF

- radiator study and others	
- sealed freon radiator elements	
- solid radiator evaluation	
- mesh cathodes	100 kSF

- pad front end VLSI chip	
- analog building block with fast MPX (2 chips)	150 kSF
- readout blocks (2 chips)	150 kSF

At the present time, and submitted to approval of their respective authorities, the following financial participations have been proposed:

Bari INFN and University	:	100 kSF/year
Giessen and Munich Universities	:	100 kSF/year
Padova University	:	50 kSF/year
Zagreb	:	20 kSF/year

We request from CERN:

- an allocation of 130 kSF/year
- the allocation of a beam station of several meters (SPS) for use in parasitic and main user (2 periods of 2 weeks/year) modes
- the access to the electronics pool for a total amount of 500 kSF (20kSF/year)
- the access to the central computing facility
- 1 technician/year or equivalent
- 1 physicicst/engineer/year or 1 applied physicist fellowship position or equivalent (doctorant technical student)
- a collaboration with the Microelectronics Group at ECP division will be essential.

References

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[6] F. Piuz et al., 4th San Miniato Topical Seminar, Experimental Apparatus for High Energy Particle Physics and Astronomy, eds P. Giusti et al, 1990, World Scientific, 121-142.
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[8] E. de Beuville et al., Nucl. Instrm. Methods, A288 (1990) 157.

[9] F. Piuz et al., Internal Note CERN/PPE/WA94/ 1991.

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[11] J. Seguinot et al., Nucl. Instrm. Methods, A297 (1990) 133.

[12] R. Arnold et al., CRN/HE 91-06, Centre de Recherches Nucléaires, Strasbourg.

[13] Proposal DRDC G. Charpak et al.
Y. Giomataris et al., CERN-PPE/91-106.

[14] Proposal WA97.

Figure Captions

Fig. 1 : Typical curves for dE/dx hadron-hadron separation.
From J. Va'vra et al., Nucl. Instr. and Meth. 203, 109 (1982).
J. Va'vra, Contribution to Proceedings of the Tau-Charm factory Workshop, 1989, SLAC-343.

Fig. 2 : a) Schematic of a fast RICH configuration with indicative dimensions.
b) Example of a Cherenkov ring event on a pad cathode (pad size: 8×8 mm^2).
The square area is proportional to the pulse height at the pad.
The charge particle impact can be seen at the centre of the ring.

Fig. 3 : Measurement of the mean number of photoelectrons detected per Cherenkov ring as a function of the particle velocity.
Radiator: 10 mm of sodium fluoride. TMAE at 50 °C, 1750 V.
Simulation results of this number is shown at three TMAE temperatures.

Fig. 4 : a) Example of a measured distribution of Cherenkov ring radii (TMAE at 40 °C, b = 0.966).
b) Measurement of the r.m.s. errors on the Cherenkov radii measured as a function of the particle velocity for a NaF radiator.
Comparison with calculated values in case of a liquid freon radiator.

Fig. 5 : Separating power with a) NaF, b) liquid freon radiators at normal incidence. The error bars are taken as the measured (NaF) or calculated (freon) ring resolutions (one standard deviation).

Fig. 6 : Quantum efficiency of various solid photocathodes and TMAE.
From J. Seguinot et al., Nucl. Instrm. Methods, A297 (1990) 133.

Fig. 7 : Schematic of a fast RICH configuration using a solid photocathode pad readout.

Fig. 8 : Schematic of the test beam setup.

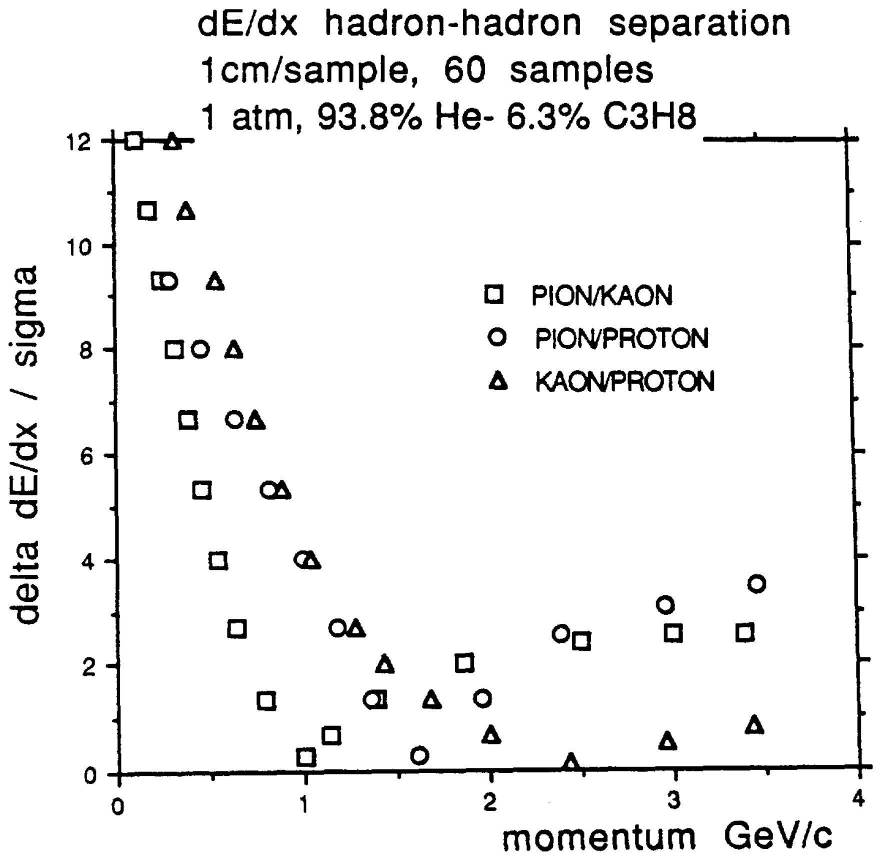
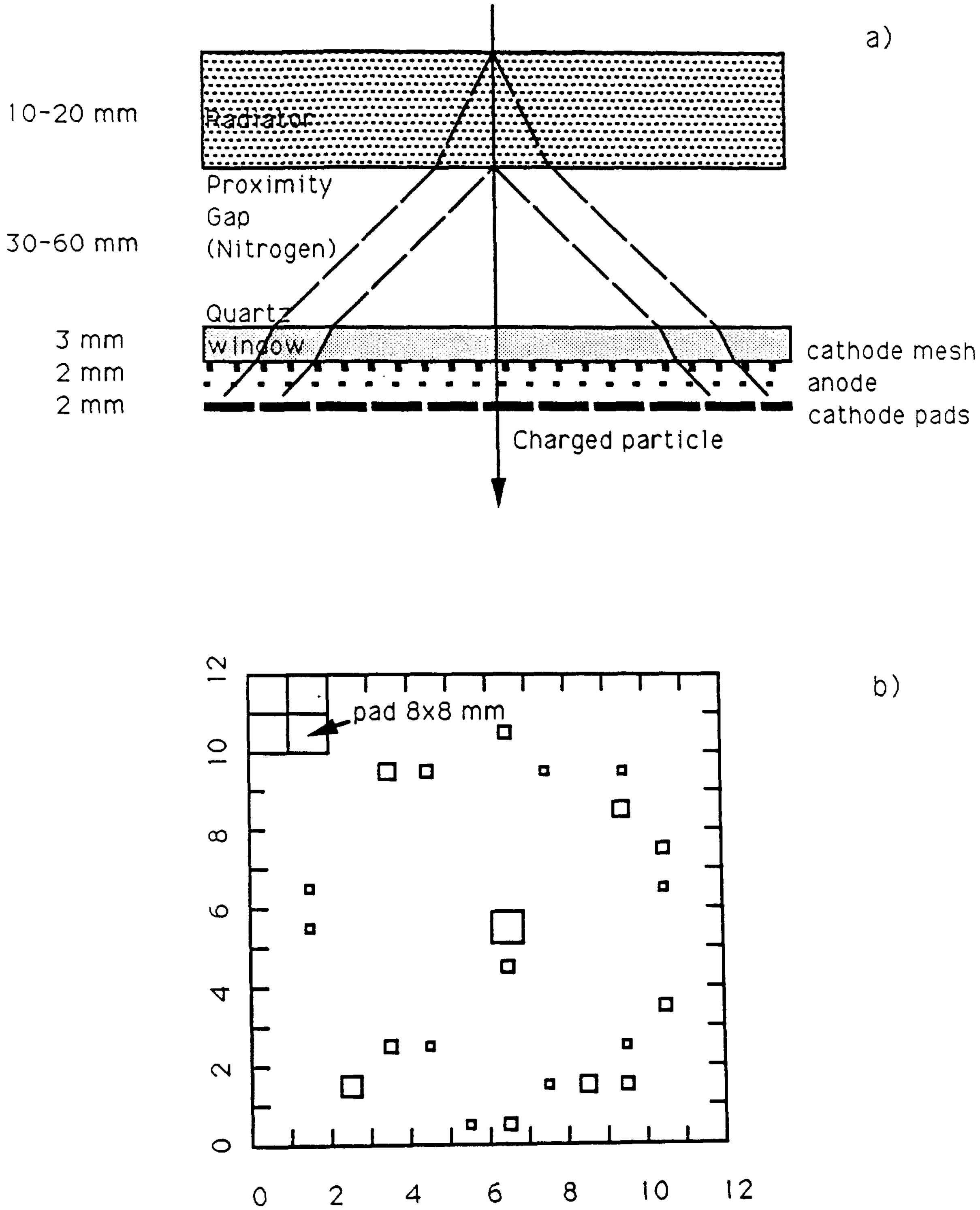
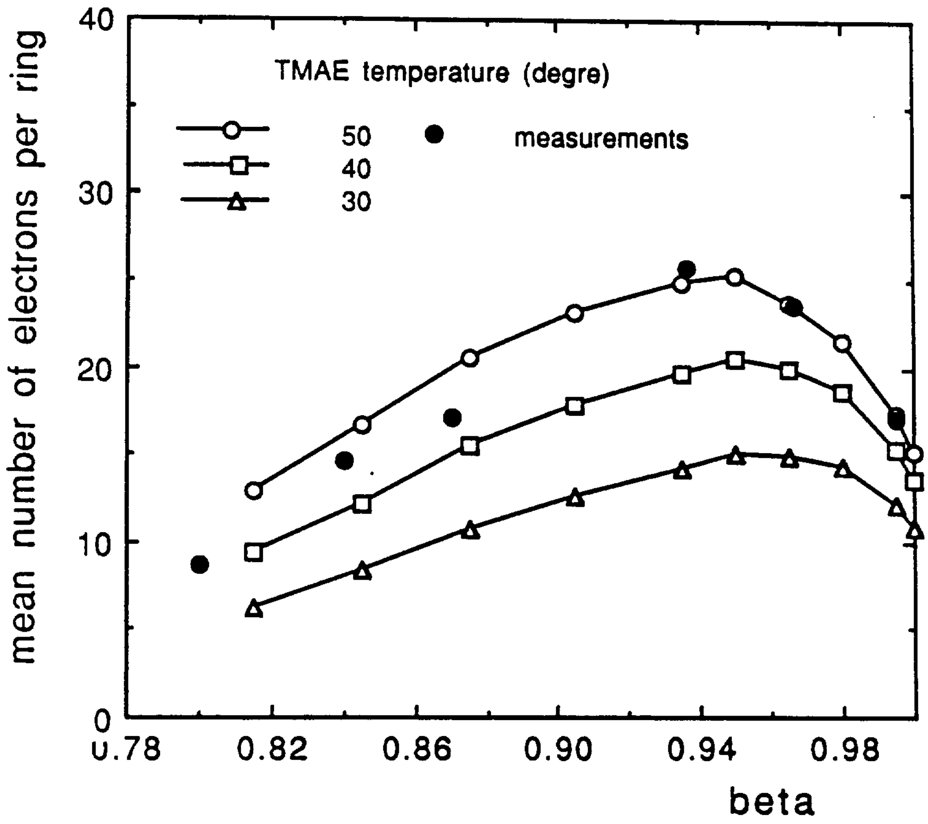

dE/dx hadron-hadron separation
1cm/sample, 60 samples
1 atm, 93.8% He- 6.3% C3H8
delta dE/dx / sigma
momentum GeV/c
PION/KAON
PION/PROTON
KAON/PROTON
0
2
4
6
8
10
12
0
1
2
3
4

Fig. 1



a)
10-20 mm
Radiator
Proximity
Gap
(Nitrogen)
30-60 mm
Quartz
window
3 mm
2 mm
2 mm
cathode mesh
anode
cathode pads
Charged particle
b)
pad 8x8 mm
0
2
4
6
8
10
12

FIG. 2



TMAE temperature (degre)
50
40
30
measurements
mean number of electrons per ring
beta
0
10
20
30
40
0.78
0.82
0.86
0.90
0.94
0.98

Fig. 3

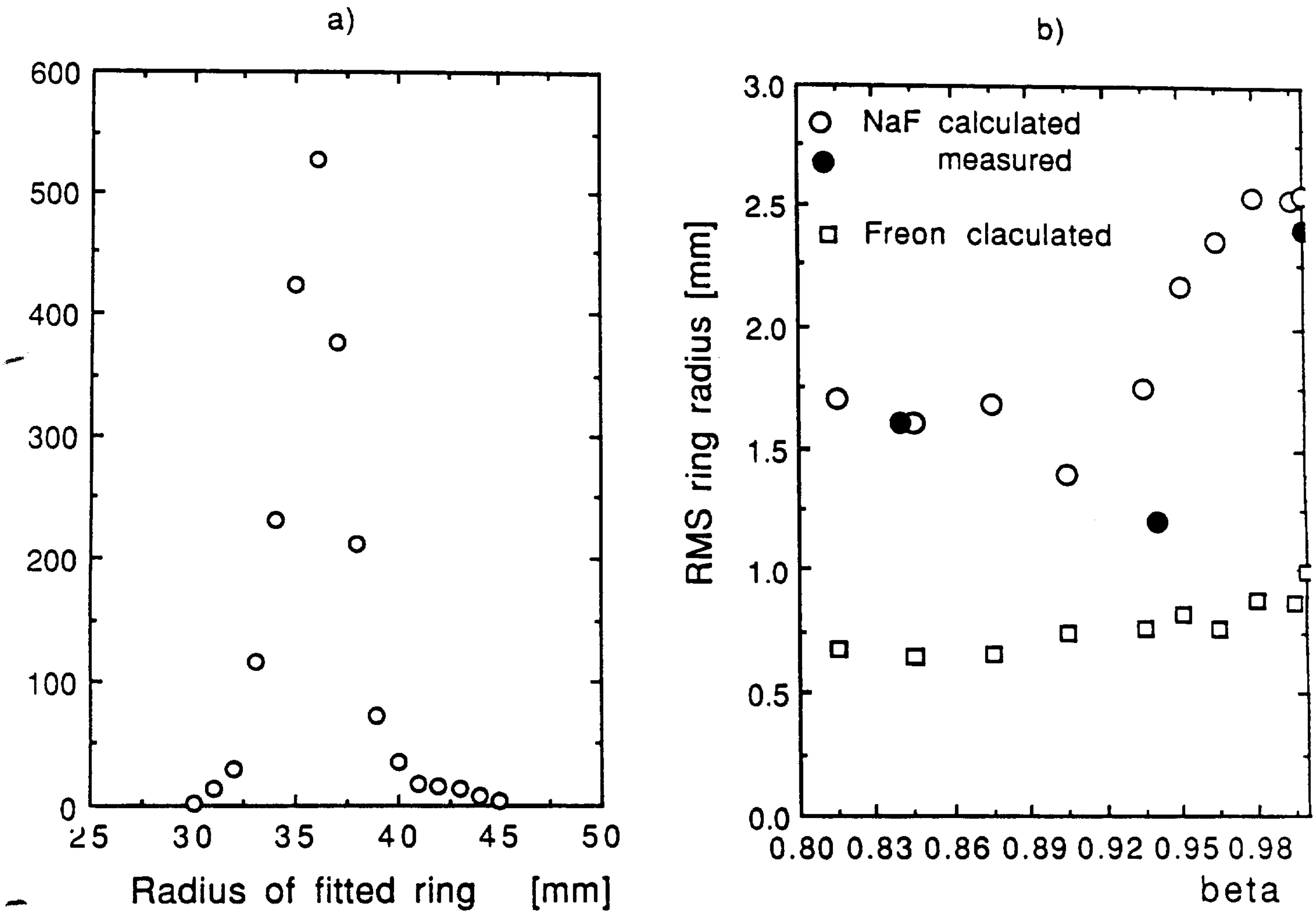

a)
600
500
400
300
200
100
0
25
30
35
40
45
50
Radius of fitted ring [mm]
b)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
RMS ring radius [mm]
NaF calculated
measured
Freon claculated
0.80 0.83 0.86 0.89 0.92 0.95 0.98
beta

Fig. 4

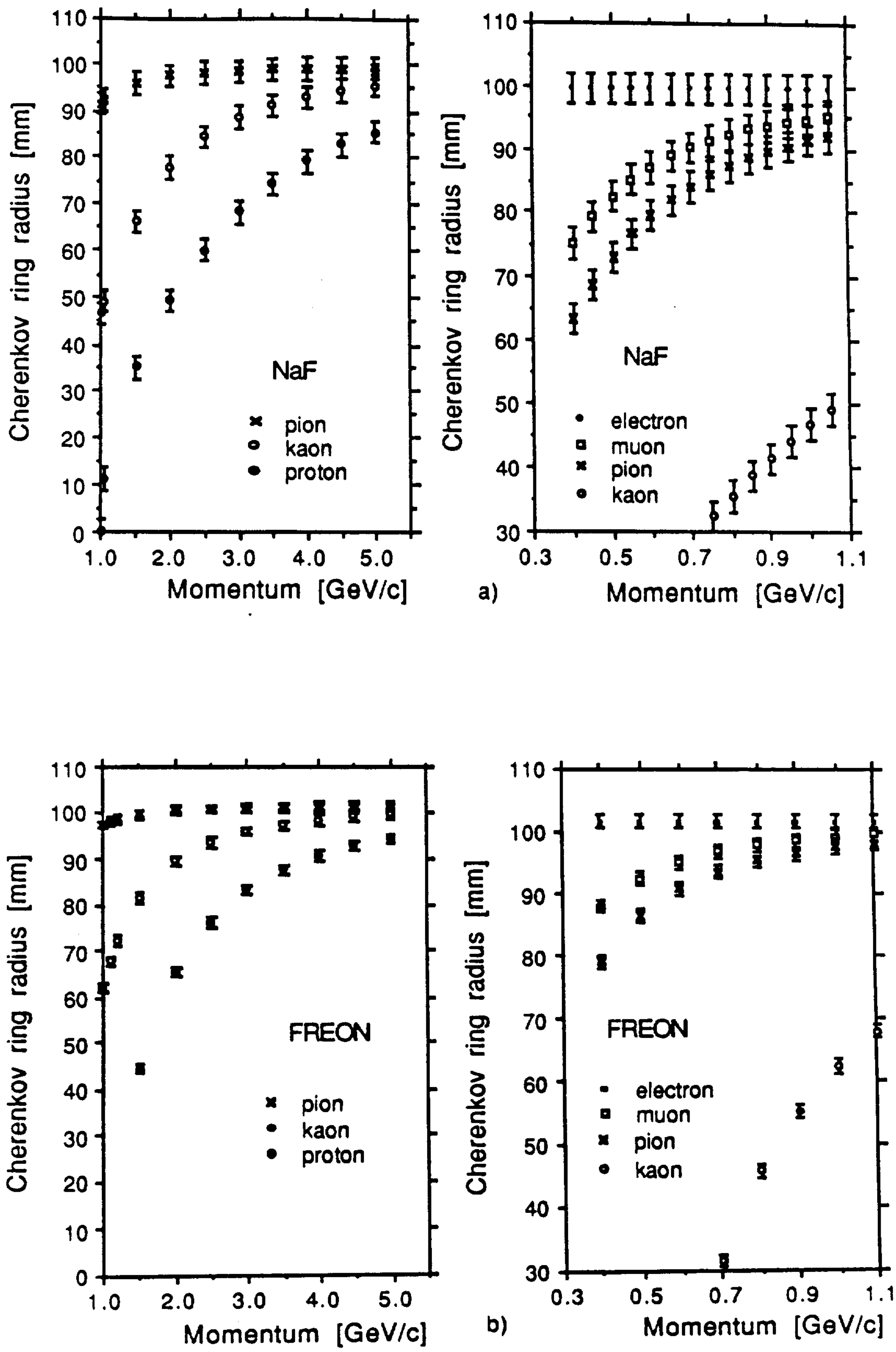

Cherenkov ring radius [mm]
Momentum [GeV/c]
NaF
pion
kaon
proton
a)
Cherenkov ring radius [mm]
Momentum [GeV/c]
NaF
electron
muon
pion
kaon
Cherenkov ring radius [mm]
Momentum [GeV/c]
FREON
pion
kaon
proton
b)
Cherenkov ring radius [mm]
Momentum [GeV/c]
FREON
electron
muon
pion
kaon

Fig. 5

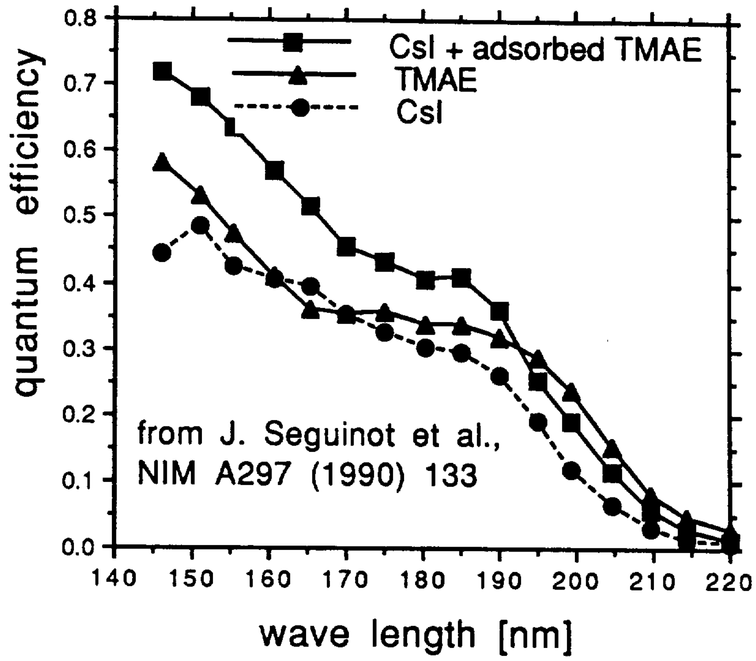

CsI + adsorbed TMAE
TMAE
CsI
from J. Seguinot et al.,
NIM A297 (1990) 133
quantum efficiency
wave length [nm]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
140
150
160
170
180
190
200
210
220

fig. 6

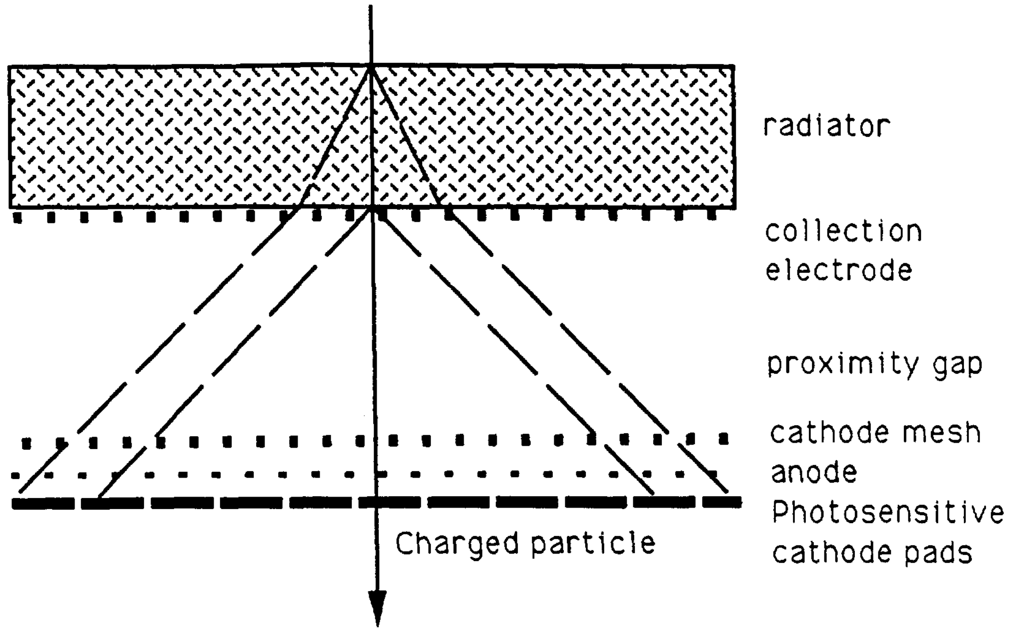
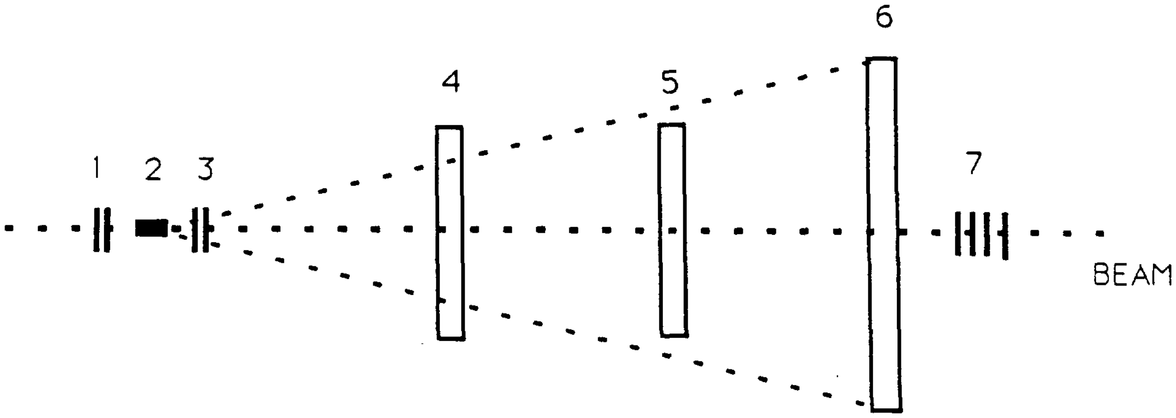

radiator
collection
electrode
proximity gap
cathode mesh
anode
Photosensitive
cathode pads
Charged particle

Fig. 7



1- MICROSTRIP SILICON DETECTOR X/Y 100 micron pitch, 40x40 mm2
2- TARGET AND MULTIPLICITY TRIGGER
3- MICROSTRIP SILICON DETECTOR X/Y/U/V 100/200 micron pitch, 40x40 mm2
4- MWPC PAD READOUT 30X30 cm2
5- MWPC PAD READ QUT 30X30 cm2
6- FAST RICH 50X50 cm2
7- MICROSTRIP SILICON DETECTOR U/V 200 micron pitch, 40x40 mm2

Fig. 8