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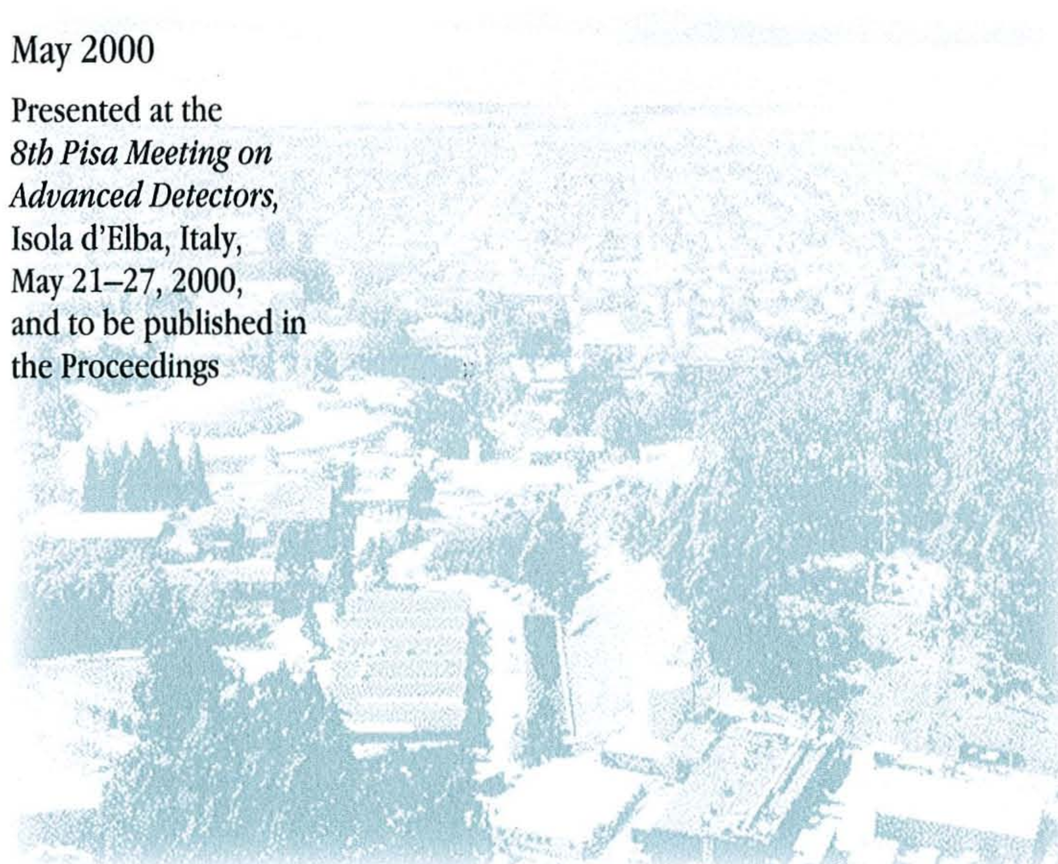

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Abstract

The front IR quadrupole absorbers (TAS) and the IR neutral particle absorbers (TAN) in the high luminosity insertions of the LHC each absorb approximately 1.8TeV of forward collision products on average per pp interaction (~235W at design luminosity $10^{34}cm^{-2}s^{-1}$). This secondary particle flux can be exploited to provide a useful storage ring operations tool for optimization of luminosity. Novel segmented, multi-gap, pressurized gas ionization chambers are proposed for sampling the energy deposited near the maxima of the hadronic/ electromagnetic showers in these absorbers. The system design choices have been strongly influenced by optimization of signal to noise ratio and by the very high radiation environment. The ionization chambers are instrumented with state of the art low noise, fast, pulse shaping electronics capable of resolving individual bunch crossings at 40 MHz. Data on each bunch are separately accumulated over multiple bunch crossings until the desired statistical accuracy is obtained. At design luminosity approximately $2x10^3$ bunch crossings suffice for a 1% luminosity measurement.

1 INTRODUCTION - REQUIREMENTS

The IR absorbers in the LHC and the concept of instrumenting them to provide a machine operations tool for optimization of luminosity are described in previous reports.[1,2] The requirements of an LHC luminosity monitor for machine operations purposes were established at a mini workshop held at CERN on 15-16 Apr. 1999.[3] The requirements that are relevant for this report are:

- Dynamic luminosity range 10^{28} to 10^{34} cm^{-2} s^{-1} with "reasonable" integration time
- Bandwidth 40 MHz to resolve luminosity of individual bunches.

The practical consequence of these two requirements is that the luminosity instrumentation must be designed to have a dynamic range capable of measuring the signal from one to ~ 100 pp interactions per bunch crossing at 40 MHz. The signal to noise ratio should be large enough to clearly separate the signal from one pp interaction from noise.

Aside from bandwidth and sensitivity requirements, an IR absorber luminosity monitor must be able to withstand very high radiation doses. The peak flux of particles of various types at the shower maximum in the TAN is given in Table 1 for design luminosity 10^{34} $cm^{-2}s^{-1}$. Fluxes in the TAS are similar. The cutoff energy for neutrons is .002 eV so the neutron flux includes thermal neutrons. For all other particles the cutoff energy in 0.1 MeV. The flux of neutrons with energy above 0.1 MeV is approximately $2.1x10^9$ $cm^{-2}s^{-1}$.

Table 1: The peak flux of particles of various types at the shower maximum in the TAN at design luminosity 10^{34} $cm^{-2}s^{-1}$.

Particle type	Flux($cm^{-2}s^{-1}$)
Charged hadrons	$4.7x10^8$
Electron/positron	$7.5x10^{10}$
Photons	$1.1x10^{12}$
Neutrons	$4.6x10^9$

Additional requirements dealing with backgrounds and correlation of the apparent luminosity signal with

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crossing angle transverse position of the IP have been discussed in previous reports.[1,4,5] The device described in this report is intended to provide a relative luminosity measurement, calibrated against a particle detector (ATLAS, CMS or TOTEM) or by use of simultaneous measurements of bunch intensity and rms beam radius.

2 CHOICE OF DETECTOR

The following detectors have been considered for the application described in this paper: CVD diamond, water Cerenkov, transition radiation, liquid Ar ionization and gas ionization.[6] CVD diamond begins to degrade at 2-5x10^{15} hadrons/cm^2 which, for the fluxes given in Table 1, leads to impractically short operation times.[7] Water Cerenkov and transition radiation detectors are very fast but awkward to implement because of the requirement of transporting photons out of the IR absorbers to a region where photomultipliers could withstand the radiation. A liquid Ar detector could perhaps meet the radiation tolerance requirement but the 85K cryogenics required is difficult to deal with in the IR absorbers and low ion mobility leads to space charge problems at high luminosity. We have therefore chosen a gas ionization chamber filled with a mizture of Ar and N_2 as the simplest detector that can meet the requirements.

3 OPTIMIZATION

The design of the ionization chamber and front end electronics have been optimized for meeting the noise, bandwidth and radiation requirements. A 3-m radiation hard cable between the ionization chamber and front end electronics is needed in order to locate the solid state devices in a low radiation zone (< 100 Gy/yr). The bipolar transistor was chosen as the device for the front end amplifier on the basis of low noise and the possibility of utilizing a cold cable termination.[8] The front end amplifier is followed by a pulse shaper to restore the signal to the baseline before the arrival of the next bunch. Neglecting the presence of a cable connecting the ionization chamber to the front end amplifier, the maximum signal to noise ratio for such devices may be expressed as

$$\left(\frac{S}{N}\right)^2 = \frac{N_{gap}Q_{gap}^2}{2kTC_{gap}\left(\frac{a_1 a_3}{\beta}\right)^{1/2} * \sigma^2} . \quad (1)$$

where N_{gap} is the number of gaps in the ionization chamber, Q_{gap} is the charge collected in a single gap, C_{gap} is the capacitance of a single gap.[9] The transistor current gain is β (~100); a_1 and a_3 are additional dimensionless transistor parameters with values near unity. The ballistic deficit σ ~ 2.8 describes the loss of signal due to the ratio of the transit time of electrons (~ 20ns) to the shaping time (τ ~ 2ns). One notes from Eqn. 1 that the most sensitive parameter for controlling the signal to noise ratio is Q_{gap}. Since the area, width and therefore the capacitance and volume of a gap are fixed by transit time and geometrical constraints the primary means for changing Q_{gap} is the pressure of the gas.

The signal to noise ratio in the presence of a cable connecting the detector and electronics is controlled by two parameters, the cable delay time θ and the shaping time τ, each normalized to the rise time of the chamber capacitance C_d connected to the cable impedance R_0.

$$\gamma = \frac{\theta}{R_0 C_d} , \qquad \delta = \frac{\tau}{R_0 C_d} \quad (2)$$

The detector capacitance $C_d = (N_p/N_s)C_{gap}$ is the capacitance of a single gap multiplied by the number of gaps in parallel (N_p) and divided by the number in series (N_s). The total number of gaps $N_{gap} = N_p*N_s$. In order that the ratio of signal to noise not be degraded by the cable with $\gamma > 1$, we must choose δ ~ 1.

4 IONIZATION CHAMBER PARAMETERS

The parameters of the ionization chamber have been determined by specifying S/N ~ 6 for 1 pp interaction, δ ~ 1 and a equivalent noise charge ~ 4.4x10^3e for 1 pp interaction. Parameters of the ionization chamber are given in Table 2. An illustration of the ionization chamber is given in Fig. 1. The total area of the detector is constrained to 80mmx80mm by the distance between the beams in the TAN and further divided into quadrants to allow measurement of the beam crossing angle at the IP. The parameters in Table 2 refer to a single quadrant 40mmx40mm. The chamber operating pressure is 4 atmospheres with gap voltage 150V to achieve saturation electron drift velocity 2.3cm/μs in Ar+1%N_2. The plate gap is chosen to be 0.5mm so the electron transit time 21.7ns plus 2ns shaping time is less than the 25ns between bunches. The total number of gaps is 60 with six series groups of ten in parallel. The MARS code has been used to simulate hadronic/electromagnetic shower production at the position of the detectors.[10] To good approximation a single pp interaction produces 268 minimum ionizing particles which in ten gaps produce 5.2x10^4 ionization pairs. The corresponding induced electron charge collected is 2.6x10^4e. At design luminosity 10^{34} cm^{-2}s^{-1} the average number of pp interactions is 20 per bunch crossing and the average signal is twenty times larger.

Table 2: Properties of the ionization chamber.

Property	Value	
Active Area (1 quadrant)	40mm x 40mm	
Plate gap	0.5mm	
No. of gaps	60(electrically 10 parallel x 6 series)	
Capacitance per gap	28.3pF	
Gas	Ar+1%N_2, 4x760 Torr	
Gap voltage	150V	
Electron gap transit time	21.7ns	
Bunch freq/Rev freq	40.079MHz/11.2455kHz	
Bunch structure	12x(3x81+2x8+38)=3564	
Inel pp int/bunch xing @ $10^{34}cm^{-2}s^{-1}$	20	
mip per pp int	268	
mip per bunch xing @ $10^{34}cm^{-2}s^{-1}$	$5.35x10^3$	
Electron-ion pairs/cm-mip	388	
Ioniz e^-/pp int	$5.2x10^3$ (1 gap)	$5.2x10^4$ (10 gaps)
Ioniz e-/bunch xing @ $10^{34}cm^{-2}s^{-1}$	$1.04x10^5$ (1 gap)	$1.04x10^6$ (10 gaps)

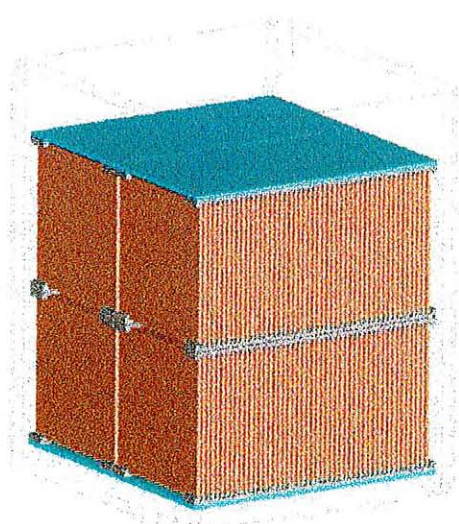

Fig. 1: Illustration of the multi-plate ionization chamber.

A prototype ionization chamber and front end electronics package have been fabricated. The equivalent noise charge has been measured to be ~ $4.4x10^3$e per pulse thus achieving the desired S/N ~ 6 for a signal corresponding to 1pp interation. The prototype will be tested in the Summer of 2000 in showers produced by 450 GeV protons extracted from the SPS and incident on a SS absorber. Provisions have been made for collecting the ion charge as well as electrons.

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