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CHARACTERISTICS AND PERFORMANCE OF MONOLITHIC GaAs PREAMPLIFIERS FOR THE LAr BARREL CALORIMETER

The present note is a collection of two papers presented respectively at the 6th Pisa Meeting on Advanced Detectors, La Biodola 22-28 May 1994, (paper A) and at the V International Conference on Calorimetry in High Energy Physics, Brookhaven National Laboratory September 15 to October 1 1994, (paper B). We consider it useful to collect the two manuscripts in a single ATLAS Note that can immediately be made available for distribution.

Paper A discusses in detail technical aspects of a prototype chip, their dynamic and noise performance at the bench tests at LAr and also at higher temperatures, up to 220 K. The version of the manuscript included in this note contains the full information presented at the Meeting. For reasons of space limitations a shortest paper will actually be published in the volume of Nuclear Instruments and Methods devoted to the Proceedings.

Paper B focusses on the performance of a production run fabricated to readout more than 600 channels of the prototype Accordion Calorimeter and Integrated Preshower. Bench evaluation of a sample lot (198 channels) and pedestal fluctuations at the test beam set-up of a fully equipped calorimeter block are presented. In the last part of this paper data on radiation damage at LAr temperature for a ^{60}Co source are also presented.

It is unavoidable to have some superposition of data and related figures in A and B for which we apologize for the inconvenience.

presented in:"Frontier Detectors for Frontier Physics",
6th Pisa Meeting on Advanced Detectors,
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Paper A

MONOLITHIC CURRENT-SENSITIVE PREAMPLIFIER FOR THE ACCORDION LAr CALORIMETER

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Abstract:

Monolithic current-sensitive preamplifiers matching large detector capacitances, suitable for the Accordion LAr calorimeter prototype, have been designed and fabricated in an ion-implanted GaAs MESFET process. After pulse shaping with an CR-RC^2 filter, the equivalent noise charge is at least a factor of two lower than the value reached so far with existing hybrids circuits, without increasing the power dissipation. This preamplifier has a fast response and large dynamic range. Results show that it is still possible to further reduce the noise and extend the dynamic range; this is likely to be obtained in a new version presently being developed.

1. Introduction:

The use of current-sensitive preamplifiers for the readout of the Accordion LAr calorimeter has been considered as an efficient way to cope with the large dynamic range expected at LHC [1],[2].

Assuming that the search for a Z' extends up to 5 TeV, the maximum energy deposition in a single cell of the electromagnetic LAr calorimeter at LHC gives about 1.5 TeV [3]. As the sampling ratio is 0.23 and the drift time 400 ns, the maximum value of the triangular detector current is almost 4 mA. Reading out this large current with a charge-sensitive preamplifier would cause very large output voltage excursions, larger than 20 V even using a feedback capacitor larger than 30 pF. One solution to this problem of handling large dynamic range is to use non-linear charge preamplifiers [4]. Alternatively, a current-sensitive configuration would produce a voltage signal at the preamplifier output that, for the above-mentioned detector signal and for a feedback resistor of 1500 Ω, would be only 6 V.

Fast current-sensitive preamplifiers can be realized using dominant-pole amplifiers that have very large gain-bandwidth product (GBW). Large GBW is essential to assure that the pole determined by the feedback network is well separated from the second pole determined by the preamplifier's input resistance [5]. The cell's capacitances of the final detector for large rapidity may have values of a few nanofarads, from about 300-400 pF at zero rapidity. The input FET must match such values.

After designing GaAs MESFETs with 12000-μm gate width, which demonstrated very attractive noise performance with low power dissipation [6], we have designed a preamplifier chip for the readout of a 2-meter LAr calorimeter prototype with integrated preshower [7]. Many of those chips will soon be installed in the detector for a beam test foreseen for the end July 1994.

In this work we report the results obtained at the laboratory with the present monolithic version of the current-sensitive preamplifier. The chip was fabricated using an ion-implanted GaAs MESFET process, TriQuint's QED/A, already evaluated at cryogenic temperatures [8] and tested for radiation damage [9].

2. Configuration of the monolithic preamplifier:

Two channels have been accommodated in a single chip occupying an area of 2.5 x 1.5 mm^2, Fig 1. The circuit configuration, Fig 2, is basically similar to our previous designs: an input FET (B1) followed by a dual cascode (B2-B3) necessary to obtain a high impedance at the drain of B3, and a bootstrapped current source (B4-B5) acting as a dynamic load. The biasing current of B1 is supplied with a separate power supply V_{CO}, through a resistance of 500 Ω (R1). In this way the main power supply V_{CC} can be fixed at a suitable voltage depending on the desired dynamic range, while the power consumption, a large part of which takes place in the input FET B1 and resistor R1, is kept low. Diodes B11 to B19 fix, through the buffer B6, the drain voltage of B3. A large-value, 120 kΩ, feedback resistor (R_F) is internally connected to stabilize the loop at DC. Two buses ADJ and RTEM have been added to trim the output voltage when tests are performed at room temperature. Frequency compensation can be introduced by switching on FETs BW3 and/or BW2. Diode PD has been included to protect the input FET from large negative voltage excursions possibly resulting from high-voltage discharges in the detector.

In order to facilitate use of the preamplifier in different experimental conditions, the feedback components are external to the chip. However, the available process would allow stable NiCr resistors and capacitors to be incorporated on the chip.

3. Dynamic performance

The input transistor B1 dimensions are 3 x 24000 μm^2 (L x W), and it is biased at I_D = 8 mA and V_{DS} = 1 V. At these conditions its transconductance g_m is 180 mS at 77 K. The input capacitance is about 120-140 pF. These data have been determined in FETs with large gate-width that have been previously developed [6]. Measurements of noise have been performed at 77 K. Two devices of 3 x 12000 μm^2 put in parallel, with a total biasing current of 16 mA, gave a white noise term of 0.19 nV/√Hz and a corner frequency slightly lower than 1 MHz [6]. To substantially reduce the power dissipation of the whole preamplifier we decided for the present case to decrease the bias current by a factor 2 improving the ratio of g_m/I_D to 22 V^{-1} and dissipating only 8 mW in the FET. The series white noise increased, as expected, by $2^{0.25}$ up to 0.24 nV/√Hz.

SPICE simulations have been done to design the preamplifier. The parameters of the monolithic MESFETs had been previously extracted at 77 K. Simulations and measurements have been done for the following operating conditions: V_{CC} = 7 V, V_{CO} = 5 V, V_{EE} = - 2.5 V. Simulation of the open-loop voltage gain gives 60 dB at DC and a main pole at about 6 MHz with a compensating capacitor of 1 pF. Direct measurement of open-loop gain gave a low-frequency value close to the simulated one. Speed measurements have been done using a charge-sensitive feedback configuration and injecting a delta current excitation. Fig. 3 shows the preamplifier response when an external capacitor C_D = 390 pF is connected at the preamplifier's input and the feedback capacitor is C_F = 8.2 pF. The response exhibits a slight overshoot, therefore from the measured rise time t_r = 4.3 ns we can establish a limit of 5 GHz for the GBW product. The total power dissipation is 54 mW.

The feedback network consisted of a 1500 Ω resistor and a 1 nF decoupling capacitor connected in series from OUT to IN pins. A compensating capacitor C_F = 12 pF was connected in parallel to the 1500 Ω feedback resistor. The delta response for C_D = 390 pF can be observed in Fig. 4. The pulse shape was taken at the receiving end of a terminated 50 Ω coaxial cable. At the preamplifier output the pulse height is larger than 2 V, twice the value shown in Fig. 4, since the cable is also terminated at the sending end with a 50 Ω resistor. The rise time is slew-rate limited at 240 V/μs. The response to a much smaller signal after a CR-RC^2 shaper with 12 ns time constant is shown in Fig 5.

4. Noise Performance

The evaluation of the noise was done in three ways:

1) the equivalent noise charge (ENC) of a hybrid charge-sensitive preamplifier having at its input a MESFET from the monolithic process with the same dimensions and at the same biasing conditions as the input transistor B1, was determined. An RC^2-CR^2 shaper followed the preamplifier. The peaking time $t_{p\delta}$ was varied and the measurements were repeated for several external capacitances.

2) the ENC of the *whole* monolithic circuit fed back as a charge-sensitive preamplifier was determined in a similar way as in 1).

3) the ENC in the current-sensitive configuration was determined only for C_D = 390 pF and for $t_{p\delta}$ = 20 ns. An CR-RC^2 shaper was used in this case.

The results of 1) and 2) are shown in Figs. 6 and 7. It can be noted that :

a) At short peaking times the noise of the monolithic preamplifier is virtually the same as that of the input FET alone (case 1). A white noise density of 0.23 nV/√Hz can be extracted from the measurements.

b) There is a small dispersion between channels in the same chip.

c) In the monolithic preamplifier an additional noise source increases the ENC at long shaping times. This additional noise source has a 1/f series component and a parallel component. The 1/f component is attributed to noise coming from later stages, mainly transistors B2 and B4. The parallel noise originates in the feedback resistor which in this case is 120 kΩ instead of 1 MΩ as used in case 1.

The noise in the current-sensitive configuration (case 3) is about 10 % higher than the ENC determined in the charge-sensitive configuration. This noise increase is attributed to the slightly different weighting functions of the two systems and to some parallel noise contribution due to the small-valued feedback resistor.

In order to evaluate the effect on noise if the cryogenic liquid is different from LAr, measurements of the input FET series noise were done for several temperatures at I_D = 16 mA. The results show that there is no change in the white component from 87 K (minimum temperature used) up to 150 K, making these FETs useful for LAr, LKr and LXe applications, Fig 8. A slight increase of the low-frequency component can be observed in the same figure for the mentioned temperature range, whereas there is no difference at frequencies larger than 2 MHz. At temperatures higher than 150 K the corner frequency increases strongly, deteriorating the noise even at frequencies higher than 20 MHz. Still, the white noise is lower than 0.3 nV/√Hz. The ENC is virtually constant from 87 K up to 150 K even at $t_{p\delta}$ = 200 ns, Fig. 9.

5. Summary and conclusions

Monolithic current-sensitive preamplifiers suitable for detector capacitances of a few hundred picofarads have been designed and fabricated using an ion-implanted GaAs MESFET process. Two channels have been included in a single chip. The main characteristics of the preamplifer are sumarized in Table I.

The chips recently fabricated have shown high uniformity in static and dynamic parameters, but a larger dispersion (~ 20 % rms) in noise. The noise level is in any case a factor of two smaller than the hybrid circuits used up to now with the LAr Accordion calorimeter. However, the power dissipation is at the same level, i.e. 54 mW. An excess noise above the noise of the input FET was measured at long shaping times; it is attributed to later stages. A new version of the chip with reduced second stage noise contribution is under development. More than 300 chips of the present version will be installed in the 2-meter LAr Accordion calorimeter prototype which will be tested at CERN in summer 1994.

6. Acknowledgements

We thank F. Lanni and B.Maggi for their collaboration during the variable temperature noise measurements, F. Sabatini for the realization of high-frequency printed circuit boards used during tests, M. Perego for the systematic extraction of SPICE parameters, and our student M. Sironi for the large number of evaluation measurements. We also thank E.Johansen for the accurate layout realization and valuable technical advise.

7. References

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TABLE I

Main parameters of the Monolithic Current-sensitive Preamplifier

Gain Bandwidth Product (BW2, BW3 off)	~ 5 GHz
P_D per channel	54 mW @ ID = 8 mA with: V_{CC} = 7V; V_{EE} = -2.5V.
f_T/P_D	~ 92 MHz/ mW
Input Capacitance	140 pF
Maximum voltage swing	4.5 V on 100 Ω load.(V_{CC} = 9 V)
Noise at tp = 20ns (δ response) bipolar shaping.	ENC = 1700 el. + 12 el/pF
Integral nonlinearity at $t_{p\delta}$= 20 ns C_D = 390 pF and $V_{o\ max}$ = 4.5 V.	< 0.5 %

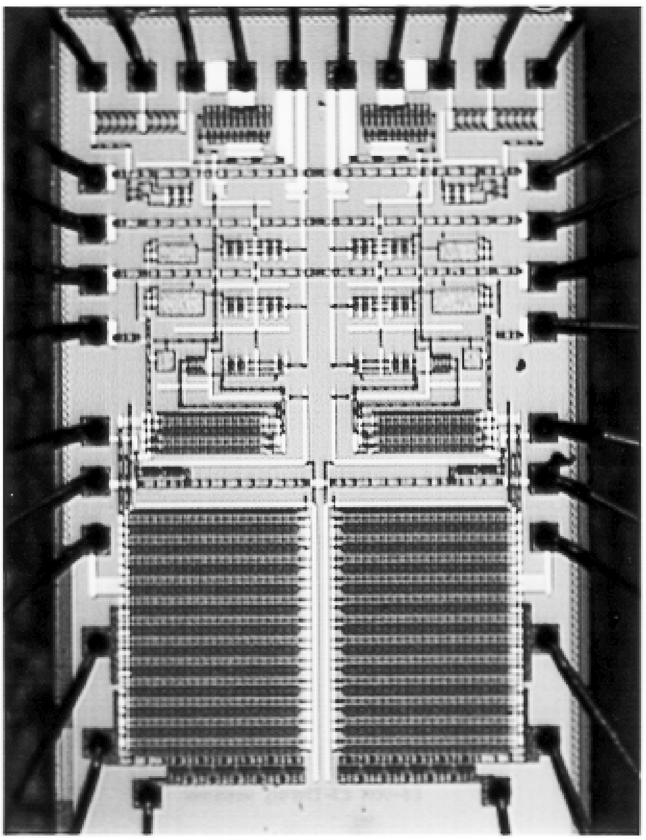

Fig 1 : The chip occupies 2.5 x 1.5 mm^2 and accomodates two channels. Note the large area of the input FETs.

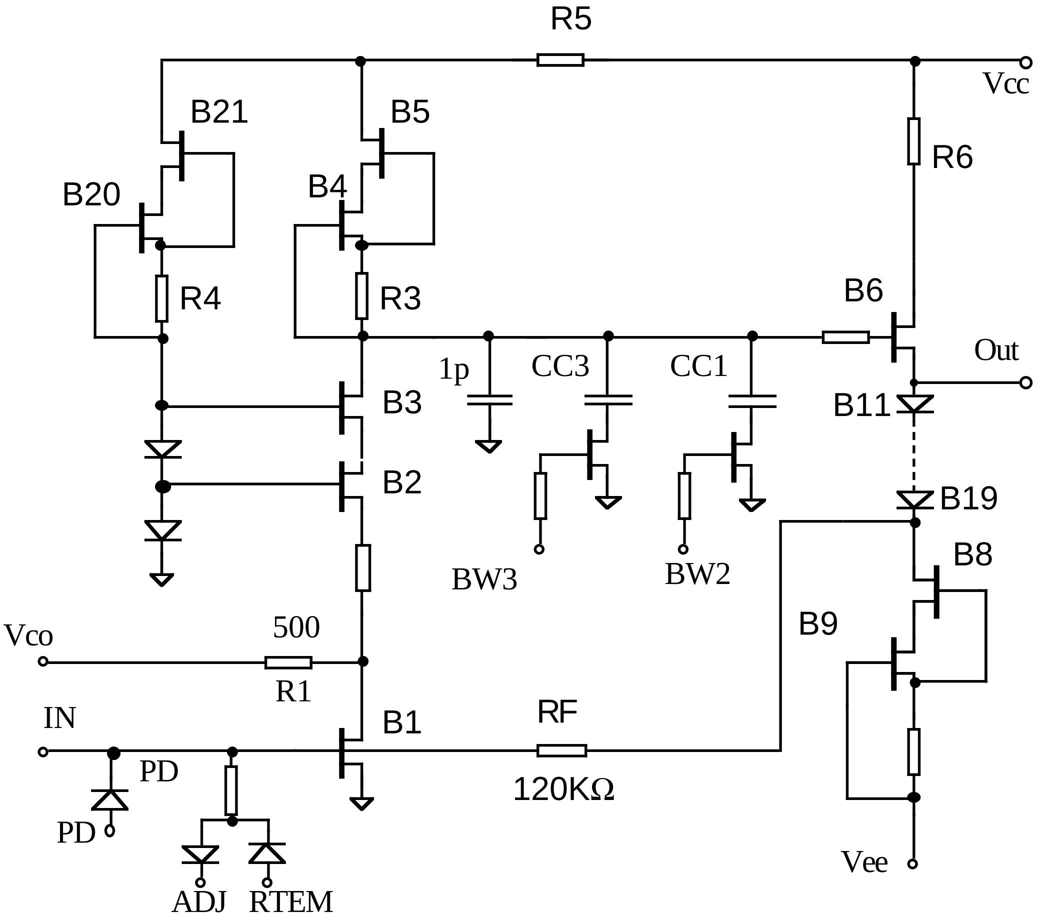

Fig 2: Circuit diagram of the monolithic GaAs preamplifier. The AC feedback network, not shown, is external to the chip.

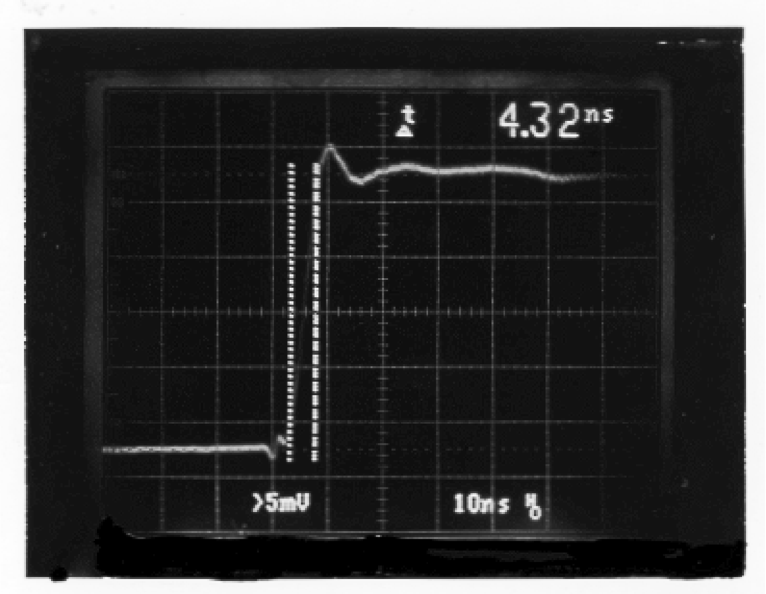

Fig 3: δ response of a charge-sensitive feedback configuration with C_D = 390 pF and C_F = 8.2 pF. Compensation control inputs BW2, BW3 off.

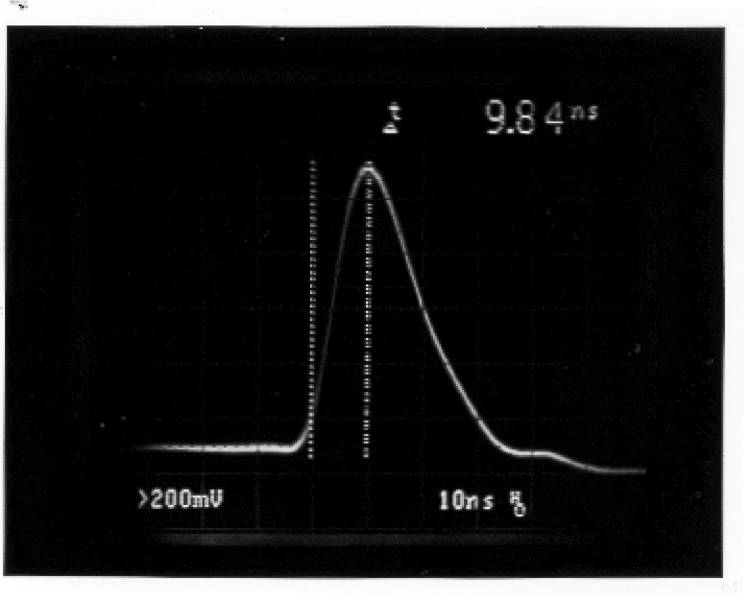

Fig 4: Large signal delta response of the current-sensitive configuration. The pulse was measured at the receiving end of a 50 Ω coaxial cable terminated also at the sending end. C_D = 390 pF, R_F = 1.5 KΩ and C_F = 12 pF. The slew rate is 240 V/µs.

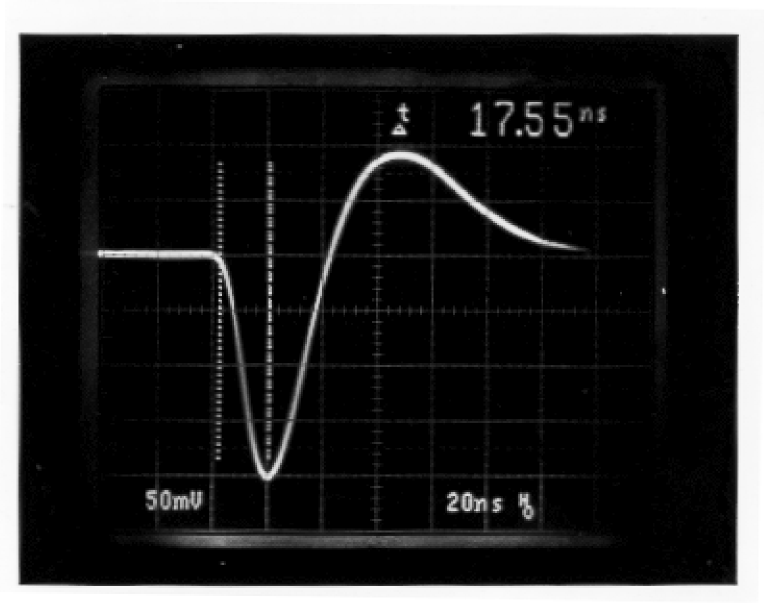

Fig 5: Small signal δ response after shaping with a CR-RC^2 filter with CR = 12 ns.

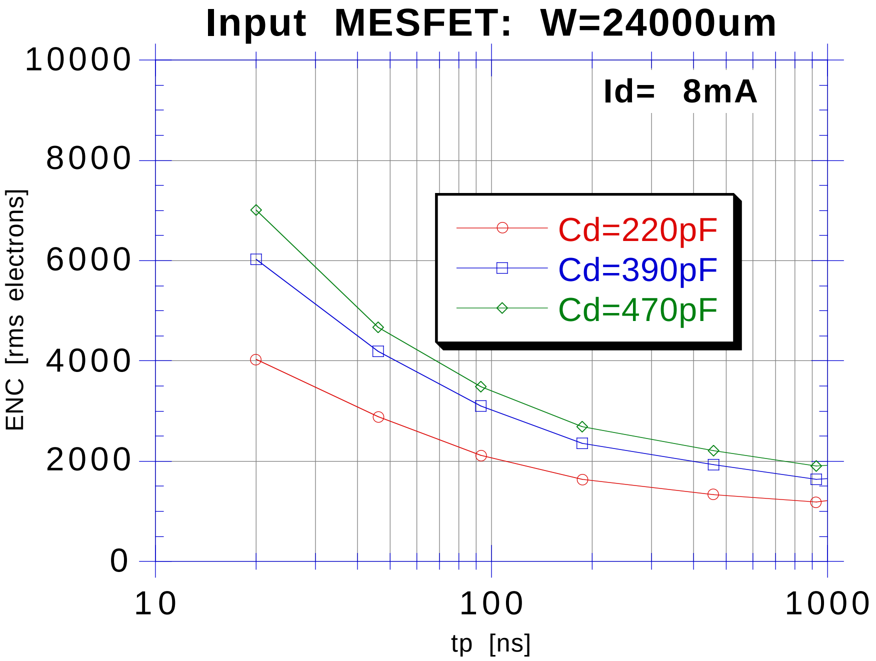

Fig 6: ENC as a function of peaking time of a hybrid charge-preamplifier having at its input a FET of 3 x 24000 μm^2 made with the monolithic process. The shaper is a CR^2-RC^2.

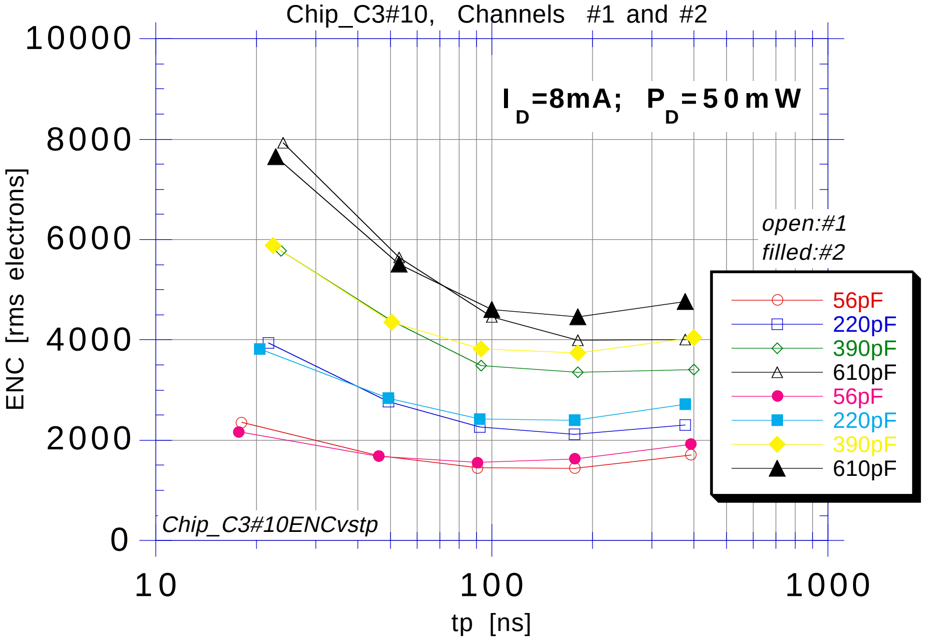

Fig 7: ENC as a function of peaking time of the monolithic preamplifier fed-back in a charge-sensitive configuration. Same shaper as in Fig. 6.

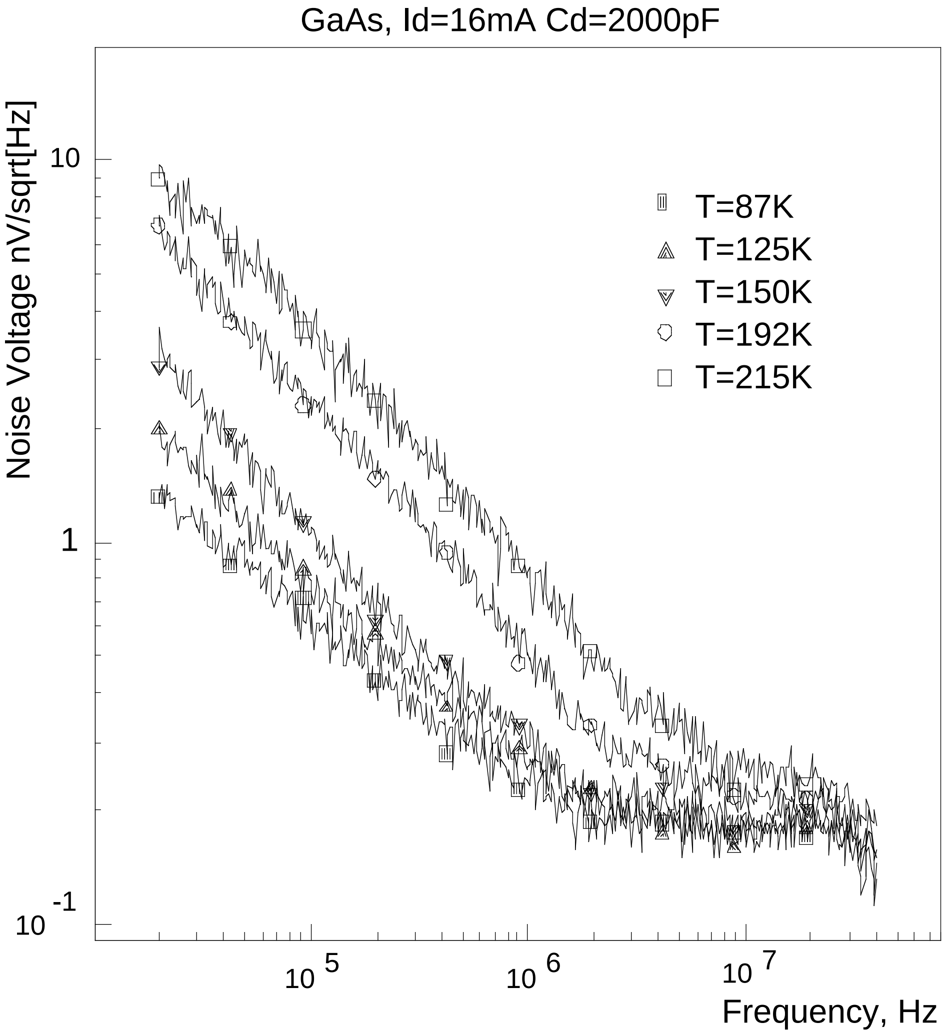

Fig 8: Series noise spectral density for different temperatures, of a 3 x 24000 μm^2 MESFET made with the monolithic process.

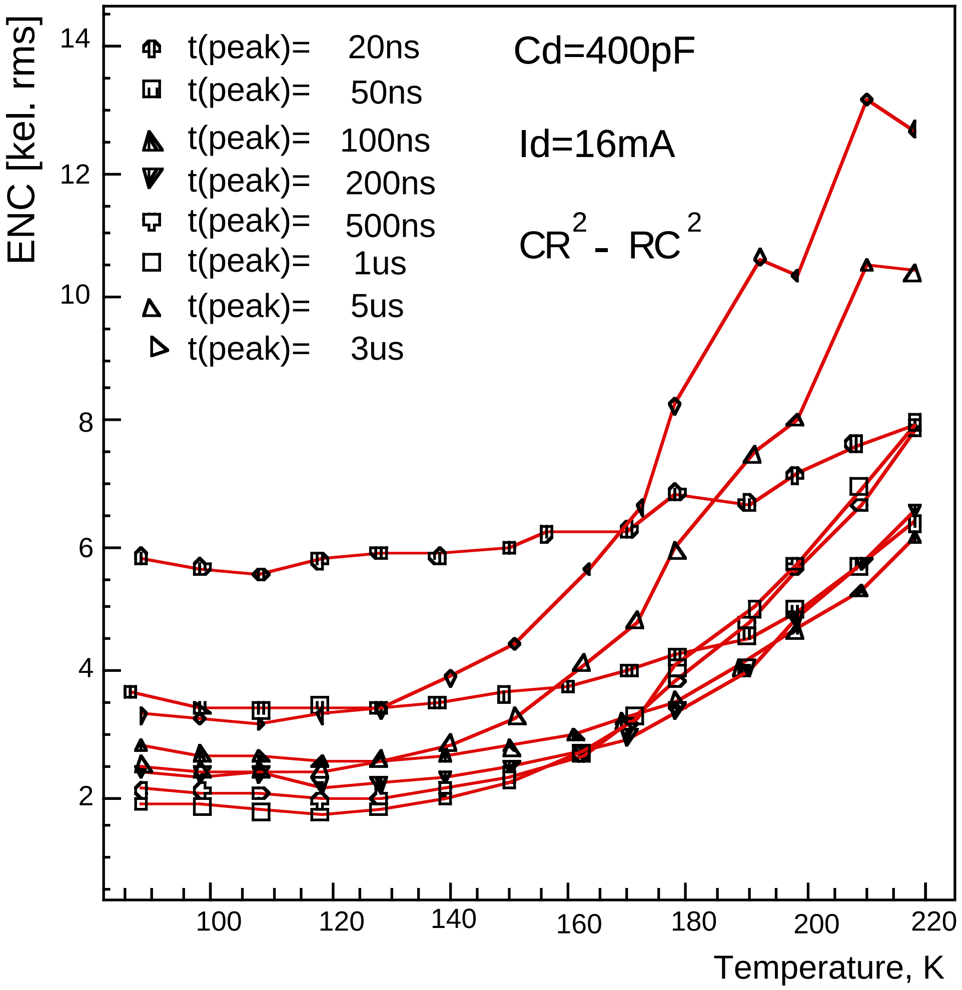

Fig 9: ENC as a function of temperature of an hybrid charge-preamplifier having at its input a FET of 3 x 24000 μm^2 made with the monolithic process. The shaper is a CR^2-RC^2.

V International Conference on Calorimetry in High Energy Physics.Brookhaven National Laboratory, September 15 to October 1, 1994.

PAPER B

PERFORMANCE OF MONOLITHIC CURRENT-SENSITIVE PREAMPLIFIERS WITH AN ACCORDION LAr CALORIMETER

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ABSTRACT

Monolithic current-sensitive preamplifiers have been used for the first time to read out more than 600 cells of a prototype Accordion LAr calorimeter with integrated preshower at CERN. These preamplifier chips, which have been fabricated using a GaAs MESFET process, improved the noise by a factor close to 2 compared to the noise level obtained with hybrid circuits based either on SiJFETs and/or discrete MESFETs. The noise improved without increasing the power dissipation; this was accomplished by using, at the preamplifier input, MESFETs with large gate width that better match the detector capacitance. The data presented in this paper was recently obtained at the beam test; further data is now being analyzed.

1. Introduction

The program of the RD3 collaboration includes the development and test of different options for the signal readout of the Accordion LAr calorimeter. The scope is to propose for the ATLAS detector, a solution which better fulfills the specifications for a particular detector region. The high radiation levels encountered at the end-cap region, for instance, makes it reasonable to adopt the so-called 0T preamplifier[1] which uses no transistors in the cryogenic liquid. For the barrel calorimeter two solutions have been proposed: one consists of hybrid charge preamplifiers using Si JFETs either in the form of discrete devices or grouped in arrays[2]. The other proposed solution consists of current-sensitive preamplifiers made in a monolithic GaAs MESFET process. This proposal was based on the fact that at cryogenic temperatures GaAs field-effect transistors have very good performance in terms of noise, speed and power dissipation that would make them ideal for fast noble-liquid calorimetry. A discussion of the applications of charge or current preamplifiers for the signal readout follows .

Assuming that the search for a Z' extends up to 5 TeV, the maximum energy deposition in a single cell of the barrel LAr calorimeter of the ATLAS detector will be about 1.5 TeV. In the LAr gap this energy corresponds to a peak detector current of almost 5 mA. The high luminosity expected at LHC makes it necessary to use fast bipolar shaping to limit the contribution of the pile-up noise. The weighting function will be bipolar (CR^2-RC^2) with a peaking time (5%-100%) of about 20 ns.

The signal of a detector cell will be read out by a low-noise preamplifier connected to the cell's end to reduce the transfer time of the collected charge[3]. Two feedback configurations may in principle be used: a charge-sensitive or a current-sensitive one.

A charge-sensitive configuration produces at the preamplifier output a voltage excursion proportional to the ratio of the charge deposited in the gap after the drift time and the feedback capacitance. For reasons of circuit stability and noise, the feedback capacitance can not be very large, therefore large voltage excursions are expected. A double-differentiator double-integrator shaper follows the charge preamplifier.

A current-sensitive configuration uses instead a resistive feedback making the maximum signal output proportional to the peak value of the triangular detector current. By fixing a sufficiently low-valued resistor the output voltage excursion can be kept limited. For a large detector capacitance, a low-valued resistor at the feedback can be tolerated as the parallel noise it generates will not give a significant contribution to the total noise. For stability reasons a compensating capacitor is required in parallel with the feedback resistor. The time constant of the feedback network can be made small, close to the one used at the shaper: a first differentiator is used at the preamplifier level. A single-differentiator double-integrator shaper follows the preamplifier .

A current-sensitive configuration is, therefore, the most convenient way to handle large detector signals [4]. But, as will be seen in section 2, the preamplifier must have a large gain-bandwidth product (GBW).

The present work reports on the results obtained with monolithic current-sensitive preamplifiers made in a GaAs process which has low noise and very large GBW at cryogenic temperatures[5].

In section 2, we recall the constrains determined by a fast current-sensitive feedback configuration. In section 3 the characteristics of the chip fabricated are summarized. In section 4 we discuss on the evaluation of a production run. In section 5 we report the results recently obtained at a beam test and finally in section 6 results on radiation damage are presented.

2. The monolithic current-sensitive preamplifer.

The circuit was realized using a dominant-pole amplifier fed back with a parallel combination of a resistor and a capacitor, as shown in Fig 1. In that figure C_D and C_A represent the detector and FET input capacitances respectively.

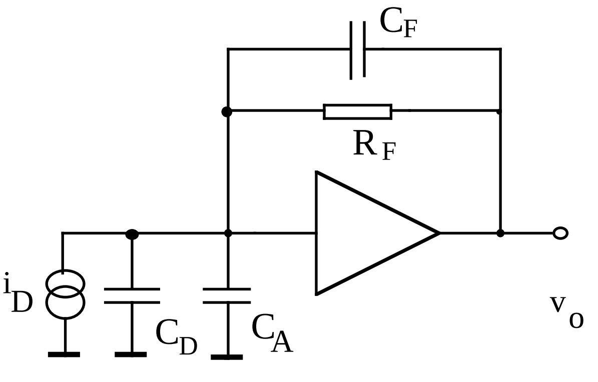

Fig 1: The dominant pole amplifier fed back with a parallel combination of a resistor and a capacitor. The time constant R_FC_F relative to the shaper time constant defines either a charge or a current-sensitive configuration.

The transfer function v_o/i_D of that circuit (providing that $1/\tau_i$ is higher than $4/\tau_F$) is

$$\frac{v_o(s)}{i_D(s)} = \frac{R_F}{(1+s\tau_F)(1+s\tau_i)} \tag{1}$$

where $\tau_F = R_F C_F$ is the feedback time constant, $\tau_i = C_T/2\pi f_T C_F$ is the time constant determined by the GBW f_T of the dominant-pole amplifier, and $C_T = C_D + C_A + C_F$ is the total capacitance seen at the preamplifier input.

The transfer function can be rewritten as:

$$\frac{v_o(s)}{i_D(s)} = \frac{1}{sC_F}\frac{s\tau_F}{(1+s\tau_F)}\frac{1}{(1+s\tau_i)} \tag{2}$$

which corresponds to the transfer function of a charge-sensitive configuration followed by a differentiator with time constant τ_F. This differentiator, located at the preamplifier, is the first CR network of the overall CR^2-RC^2 bipolar shaping.

For the present case $\tau_F = 18$ ns : a value very close to 12 ns used at the shaper was adopted[6]. To reduce the noise contribution of the shaper following the preamplifier, a large noise gain is required. If it is fixed to a reasonable value $C_T/C_F \sim 65$, then the GBW must be larger that 3 GHz. This value is easily obtained at LAr temperature with GaAs MESFET technology.

3. Characteristics of the chip fabricated

The monolithic preamplifier uses an input MESFET with a gate width W = 24000 µm[7]. Two channels have been accomodated in a die of 2.5 x 1.5 mm^2 mounted in a 28-pin ceramic package[6]. The circuit has internal input protection diodes and the frequency compensation can be selected by setting DC control voltages. The feedback network is connected externally to the chip, making it possible to use different combinations of resistors and capacitors to better adapt the different rapidity regions and longitudinal compartments of the final detector. In addition, the external feedback network allows for non-linear response if it would be required. The following measured parameters, valid in the temperature range 77 K to 150 K, define the main characteristics of the chips:

- Low frequency voltage gain: 900
- Main pole at: 6 MHz
- White series noise: 0.23 nV/√Hz
- Input capacitance: 140 pF.
- Output voltage excursion on 100 W: 4 V @ Vcc= 9 V; 2 V @ Vcc= 7 V
- Power dissipation: 54 mW @ Vcc= 7 V.

The series noise can be reduced to 0.19 nV/√Hz but at the expense of higher power dissipation, 150 mW. This can be done by simply increasing the value of a separate voltage supply used to bias the input transistor. Still, we consider the adopted values indicated above a good compromise of noise/power dissipation .

To evaluate the noise performance at different detector capacitances and shaping times, noise measurements in a charge-sensitive configuration have been performed at 77 K. The results are indicated in Fig. 2. From the measured data a white series noise density of 0.23 nV/√Hz was extracted. This noise level, obtained for the best chips, was verified by direct measurements of the preamplifier series noise spectral density.

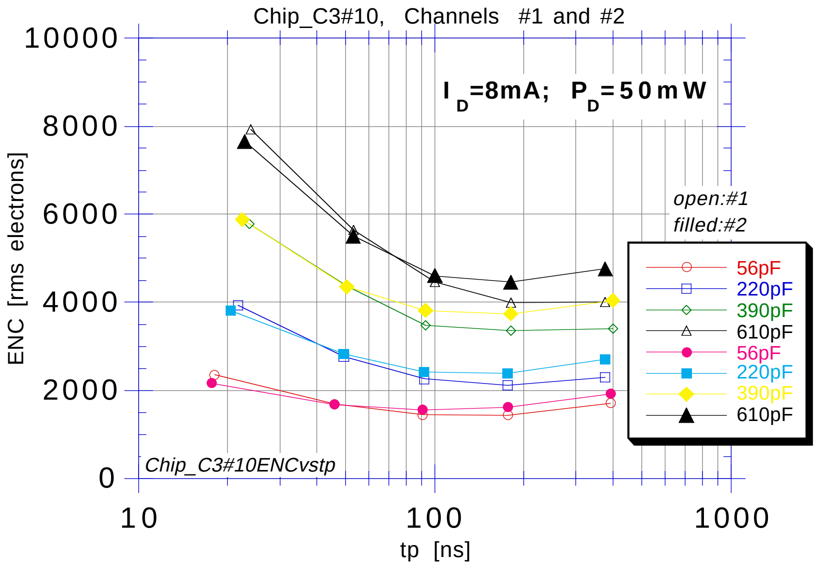

Fig 2: ENC as a function of peaking time for different detector capacitances of both channels of the monolithic preamplifier chip fed back in a charge-sensitive configuration.

To evaluate the effect of the temperature on the noise, measurements of ENC at different peaking times for a fixed detector capacitance have been performed (Fig 3). In that figure it can be observed that for 20 ns < tp(δ) < 200 ns the noise is virtually constant from 87 K to 160 K.

Regarding dynamic range, we point out that the present version of this current-preamplifier, although it was not optimized for large dynamic range, is able to read detector signals up to 3 mA with a +/- 1 % integral nonlinearity (Fig 4).

A detailed description of the chip is given in ref.[6].

4. Evaluation of a production run.

A number of chips exceeding the present needs of RD3 beam tests have been manufactured to have statistics of a production foundry run. Four wafers have been processed although not exclusively for the preamplifier chips, but sharing the area with other projects. A total of 1536 devices (3072 channels) have been manufactured.

Two screen tests have been performed on 892 devices randomly distributed in three wafers. A functional test was done at room temperature with a yield higher than 77 %. Later-on, dynamic and noise performance were verified at cold, for a small sample (160 units, i.e. 320 channels) of all chips manufactured.

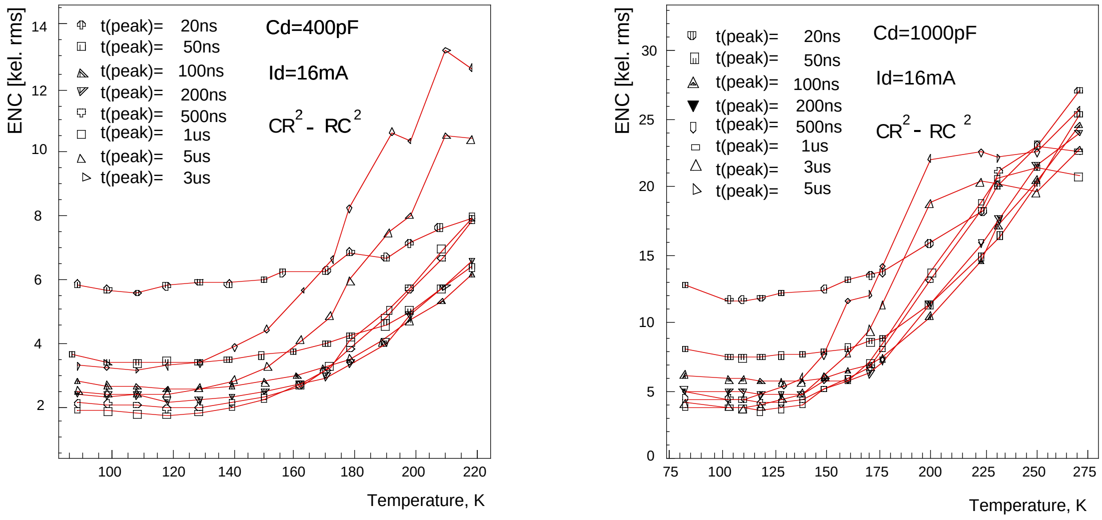

Fig 3: ENC as function of temperature for a) C_D = 400 pF and b) C_D = 1000 pF, at different peaking times (bipolar shaping). These measurements have been done at I_D = 16 mA.

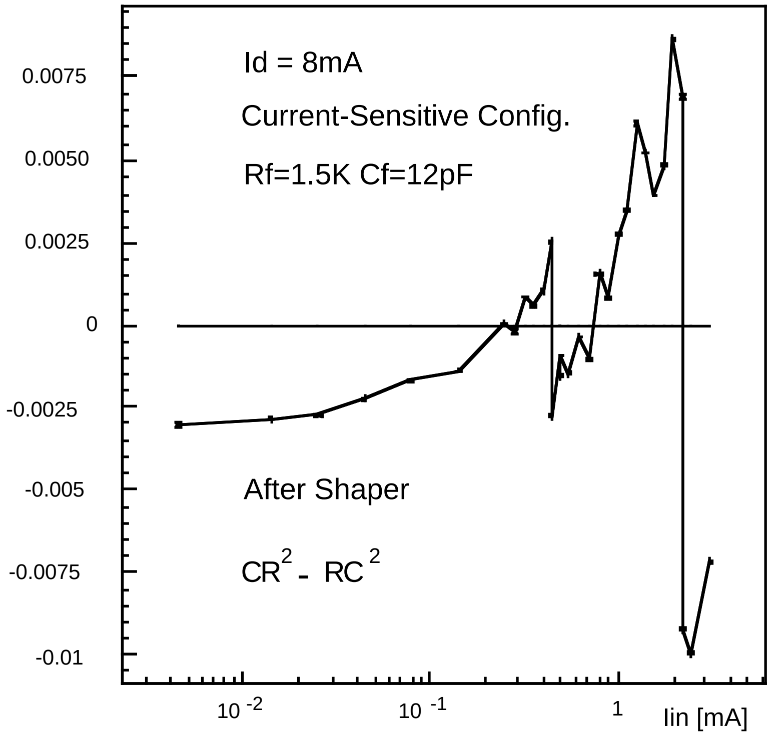

Fig 4: Residuals of output voltage linear fit for input current up to 3 mA.

In Fig 5 we show the ENC distribution at 77 K for tp(δ) = 20 ns (bipolar shaping) after cutting 47 more noisy and 14 of more slower chips out of 160 units that passed the room temperature test. The plot therefore shows the noise distribution of 62 % of the chips that passed the wafer test or, equivalently, 48 % of the chips fabricated randomly located in the three wafers. The average value is somewhat higher than the value expected from a series noise of 0.23 nV/√Hz. A contribution of noise coming from the second stage was identified as the cause of this excess noise. In Fig. 6, the peaking time distribution of the sample is shown.

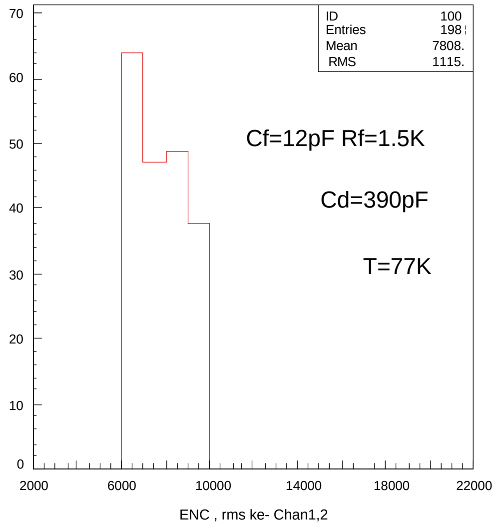

Fig. 5: Noise distribution of a 99 chips sample (198 channels). An CR-RC^2 filter was used.

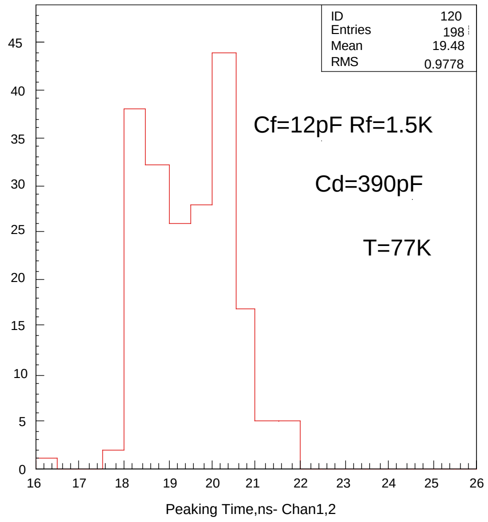

Fig 6: Peaking time after CR-RC^2 shaping of the same sample as Fig 5.

Most of the chips with very high noise were also slow. We plan to determine the correlation between parameters of the DC test and high noise or slow speed. Future screen tests will be more selective to filter those bad channels at the wafer test level.

In addition, it is expected to obtain lower noise contribution from the second stage in a new chip now being designed.

5. Results obtained at a beam test.

More than 600 channels of the prototype Accordion calorimeter and integrated preshower have been readout with GaAs monolithic current-sensitive preamplifiers. Pedestal fluctuations have been recorded in the region read out with these chips. The results, for the different detector compartments, are shown in Fig. 7. In the same figure, pedestal fluctuations of hybrid circuits are also indicated for comparison.

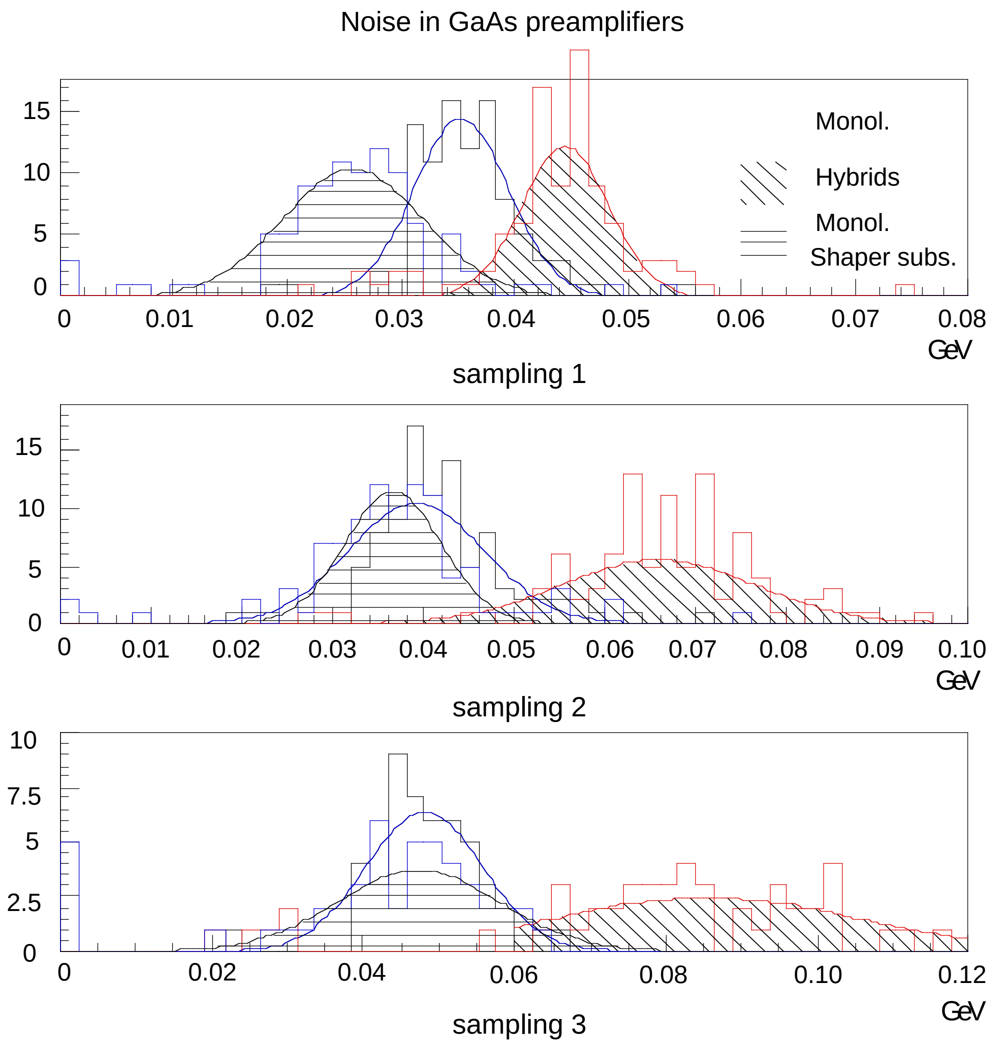

Fig 7 Pedestal fluctuations in the different calorimeter samplings, read out with monolithic current-sensitive GaAs preamplifiers and with charge-sensitive hybrid circuits.*Monol* and *Monol.Shaper*: see note 1.

It can be noted that in sampling 1, where the detector capacitance is smaller than in samplings 2 and 3 , the shaper/ADC readout system contributed to the total noise by the same amount (26 MeV) than the preamplifier itself.

The monolithic preamplifiers have also been used to read out the integrated (UV) preshower. The results have been reported in a separate paper[8].

Note 1: *Monol.* means noise measured by the system reading the monolithic preamplifiers. *Monol.Shaper substraction* distribution is obtained after quadratically substracting the pedestal fluctuation read out for every channel with the preamplifiers off.

6. Radiation damage.

We have evaluated the radiation damage at cold of monolithic preamplifiers fabricated with the same process used to make the present chips[9,10]. The results have shown a 15 % noise increase after a neutron fluence of 4.5 x 10^{14} n/cm^{2} (1 MeV equivalent) and 10 % noise increase after 0.5 MRad total dose. That indicated fluence and total dose values correspond, in the barrel region, to 10 years of LHC operation at a luminosity of 10^{34} /sec [11].

Just recently, we have performed an irradiation test at cold of the actual monolithic current-sensitive preamplifiers reported in this paper. Details of the irradiation tests follows.

Three chips containing four preamplifiers and a single FET have been installed in a cryostat in which the temperature could be varied from 77 K to 300 K [10]. Two channels, fed-back in a charge-sensitive configuration, had at their input a capacitance of 390 pF and 1000 pF respectively, simulating the detector. The circuits have been biased at the nominal conditions.

The cryostat was put in front of a ^{60}Co gamma source and has been irradiated at a rate of 100 KRad/ day. The Compton edge of the ^{60}Co source is at about 1 MeV, well above the threshold of 0.4 MeV below which electrons do not create displacement damage and vacancies in the lattice in GaAs[12,13]. After 500 KRad a Lorenztian spectrum can be observed in the series noise spectrum.

Measurements of ENC after shaping with an CR^{2}-RC^{2} filter, have been taken after each step of 100 KRad. The noise increased by about 10 %, Fig 8. Negligible change was observed in the peaking time after the shaper and in the DC biasing voltages or currents.

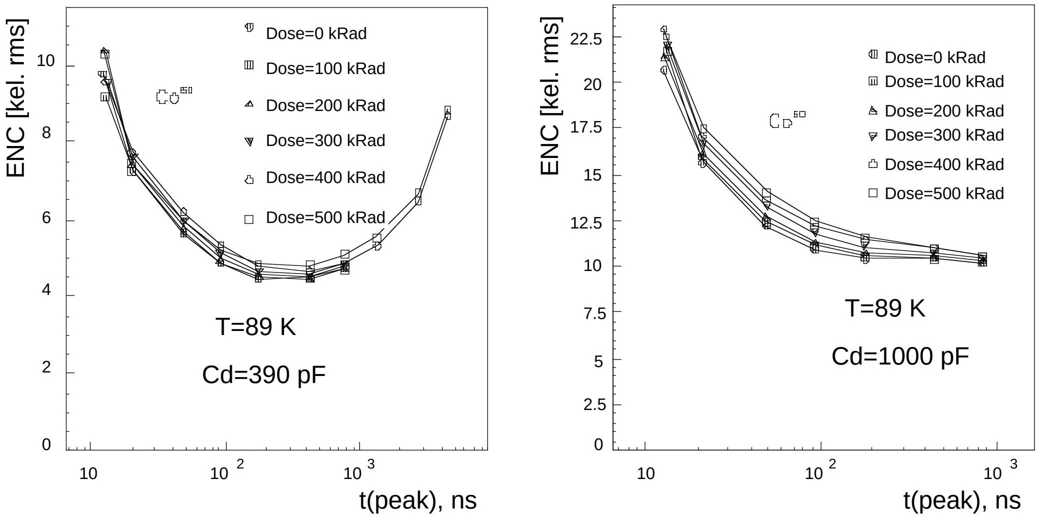

Fig 8: ENC as a function of peaking time before irradiation and after 5 steps of 100 KRad at 89 K for two different detector capacitances, C_D = 390 pF and C_D = 1000 pF.

7. Summary and conclusions.

Monolithic current-sensitive preamplifiers fabricated in a GaAs ion-implanted process, have been used to read out the signal of a prototype Accordion calorimeter and integrated preshower.

The evaluation of a production run have shown that 48 % of the chips fabricated have low noise and fast speed at LN temperature. Noise and speed change by a negligible amount in the temperature interval 77 K-160 K.

A noise reduction of about 50 % on the average, compared to hybrid preamplifiers also used with the detector, has been accomplished. The noise improvement was obtained with a power dissipation in the monolithic preamplifier equal or even lower than that of the hybrid circuits.

Radiation damage tests have shown that the preamplifier chips, designed for the barrel LAr calorimeter, are radiation hard to the levels expected after 10 years of LHC operation.

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