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Yu.A.Budagov, N.D.Giocaris[1], G.A.Ivanov[2],
A.I.Kalinin, D.M.Khazins, A.A.Kuritchin,
N.O.Poroshin[3], S.Tokar

FORWARD CALORIMETRY FOR TeV-COLLIDERS

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[1] Rockfeller University, New York
[2] GSU, Gomel
[3] MEFI, Moscow

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Here a version of the compressed gas ionisation calorimeter based on stacks of stainless steel tubes immersed into lead and disposed at small angle to the incident particle direction, for the forward calorimetry in the SDC detector/1/ is presented.

We suppose the next list of the <u>forward calorimeter parameters.</u>

- Energy resolution......... - $\delta E/E = 0.7/E^{1/2} \oplus 0.05 \oplus 0.7/E$, E in GeV; the last term is caused by electronics noises.
- Minimal registered transverse energy, E_{Tmin}...- 0.1 GeV.
Segmentation transversal.. .- 10 * 10 cm^2,
longitudinal..- 0.4 m - electromagnetical part,
- 2 * 1.3 m - hadron part.
- Shower position accuracy...- 1 cm.
- Time resolution...........- 60 ns (full width of the signal).
- Electron/hadron separation - Is possible due to the longitudinal segmentation.
- Radiation hardness.........- > 100Mrad.
- Stability..................- high.
- Linearity..................- high.
- Passive material...........- lead + stainless steel (or cooper).
- Gas........................- Ar + $10\%CH_4$, P = 100 atm.
- High voltage supply........- ≃ 10 KV.
- Total number of tubes......- ≃ 1.5 million, for both calorimeters.
- Electronics channel number - ≃ 7000.

The design of one hadron calorimeter cell is shown in fig. 1 - 3. It consists of 200 stainless steel (or cooper) tubes with 4 mm inner diameter. In the center of each tube 50 μm diameter wires are stretched. The tubes are sealed with insulator made plugs, which support the wires. At one cell end the gas collector plate is soldered to the tubes, while the plate at the second end forms a divergend tube stock to satisfy the forward calorimeter projective geometry. The volume between the tubes is filled with molded lead plates.

The hadron cells are packed into the forward calorimeters at a small angle (α) to the incident particle directions (~ 1^0 both in the polar and azimuthal directions). The EM cells must have some bigger inclination (up to 5^0, as it will be discussed below). The only disadvantage of the inclination is a some worsening of the shower position resolution, but it would not be meaningful, as we believe.

The gas ionisation calorimeter, based on tubes, has some attractive <u>advantages</u> over the multiplate sandwich structure/2,3/, as follows.

1. There are <u>no problems with the high pressure gas containment</u> in the tubes.

2. The construction technology based on the commercially available tubes is much simpler and cheaper than that for the multiplate calorimeter.

3. The capacitance of the tube structure is twice less the multiplate one than that of adequate multiplate one, which is crucial for the electronics noise problem.

4. The output signal charge from wire ionisation detector is very close to the summary charge of all electrons liberated in the gas, whereas in the parallel plate case the signal is twice as less.

5. The signal spreading in multiplate structure is very intricate, which leads to the signal expansion and cross-talks between neighbor calorimeter cells if they are placed in a common volume. There are no such problems with the tubes, which are practically ideal waveguides with the wave resistance ρ = 262 Ω.

The main <u>problem</u> with the tube option is the energy resolution. There are no investigation of such calorimeter structure. (The most similar is the "spaghetti" one, but it differs very much in the structure scale and active substance.). Our Monte Carlo simulation with the GEANT[4] program are shown in fig. 4-7, where the statistical term coefficient ($\delta E/E*root(E)$)and constant term (A) of the calorimeter energy resolution function for protons and electrons are presented versus to the geometrical calorimeter parameters (inner tube diameter (d), volume ratio of passive to active materials (v) and angle(α). The base set of the parameters in these calculations were as follow. The passive material (including the tube walls) - lead or copper, the active material - argon with 9% of methane admixture at 100 atm pressure, $v = 3$, $d = 4$ mm, $\alpha = 5^0$.

As it follow from fig.4 the statistical term for hadrons is ~ 70%/root(E) and satisfied the forward calorimetry needs in the wide range of the geometrical parameters rather well. The real problem we have with the constant term. There are two reasons for its origin.

The first one is caused by narrowness of the EM showers which leads to the strong dependence of the EM shower signal to the shower axis position between the tubes. As a result the constant term for incident EM particles is large and badly depend on the calorimeter parameters (fig.6). The hadron shower, being much wider than EM one, realises part of its energy through the electromagnetic form. So the formula for hadron energy resolution contains the constant term as well. But in the last case it is much smaller and smoothly depend on the calorimeter parameters (fig.7).

The second reason for the hadron constant term is inequality of the calorimeter response to the hadron and EM showers (e/h-ratio). Our simulations show the ratio $e/h = 1.2$ for the cooper/(argon + 9% methane) calorimeter and $e/h = 0.93$ for the lead/(argon + 9% methane) one independently of the calorimeter geometrical parameters. The e/h-ratio dependence on the methane concentration is shown in fig.8 for both the cases.

As it follows from these calculations the hadron calorimeter, consisting from lead mainly with 4 mm inner diameter tubes inclined at the angle $\alpha = 1.5^0$ and with the passive to active volume ratio $v = 3$, will be characterized by the constant term $a = 5\%$ which meets the forward calorimeter demands[1]. (The lead may be replaced by steel or copper but for calorimeter compensation more methane percentage (30 - 40%) would be needed which leads to a higher anode voltage.)

But such a calorimeter structure would give the extremely large constant term for gammas and electrons which are presented inside the jets together with hadrons. So the front part of the forward calorimeter must have different geometrical parameters. One of possibilities is to use such calorimeter structure as is shown in fig. 1 - 3, but without lead plates and with angle $\alpha = 5^0$.

The <u>time resolution</u> of the gas calorimeter is defined by the time needed to collect the electrons liberated in the gas. The electron drift velocity in argon with small percentage of methane at 100 atm pressure was measured by N. Giokaris et al[5]. The calculations made by G.Niculescu[6] coincide with the measurements very well (fig. 9). So we expect the collection time ~ 40 ns for tubes with inner diameter $d = 4$ mm. The full signal width at the amplifier output would not exceed 60 ns.

The possibility of the freon CF_4 admixture to the gas have to be examined.

The scheme of the <u>signal collection</u> from one calorimeter cell is shown in fig. 10. It profits by the excellent waveguide properties of the tubes. The tubes are connected in sequence by 4 (the number is limited by the disperse of the signal spreading time along the tube chain) and united at the input of the cable with the wave resistance $\rho^1 = \rho/N$, where ρ is the tube wave resistance and N is a number of parallel

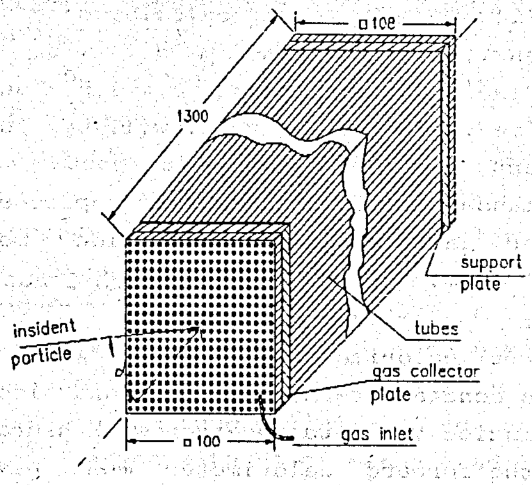

FIG. 1. Hadron calorimeter module.

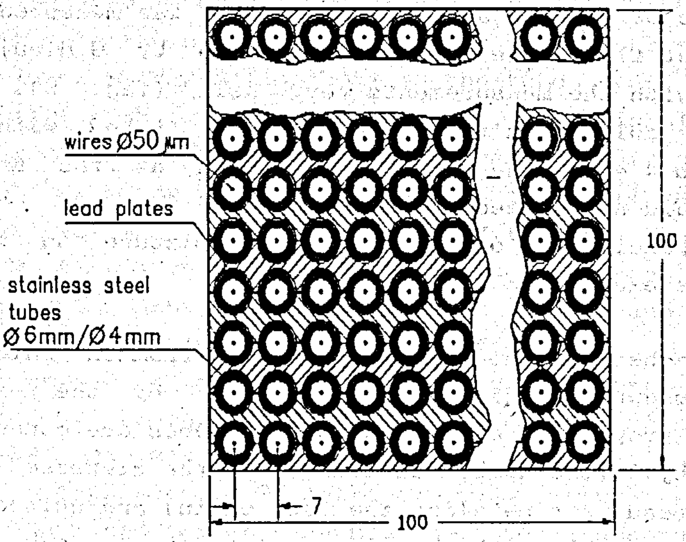

FIG. 2. Cross section of the module.

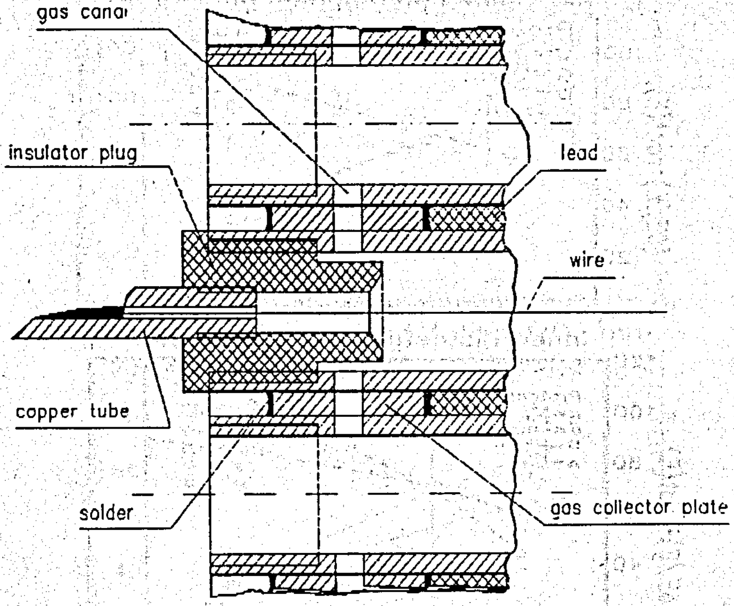

FIG. 3. Front end of the module.

connected tube chains. (In our case $\rho = 260\ \Omega$, $N = 40$, $\rho^1 = 6.5\ \Omega$.) The cable is necessary to remove the preamplifiers from highly irradiated zone inside the forward calorimeter. (It may consist of 8 standard 50 Ω cables.) The transformer is used to match the preamplifier input impedance with the cable wave resistance.

The calculations show that the electronics noises of such a scheme are equivalent to the calorimeter charge amplitude fluctuations:

$$Q^2 = \frac{kT * t_c^2 * N * [1 + \exp(-2t_s/\tau_f) + 2R_s/R_{in}]}{2 * \rho * \tau_f * [1 - \exp(-t_c/\tau_f)]^2},$$

where k – the Boltzman constant, T – the absolute temperature, t_c – the charge collection time, $\tau_f \cong 2t_c$ – the filter constant, t_s – the time of signal spreading along the cable, R_s – the effective noise resistance of the preamplifier and R_{in} – its effective input resistance.

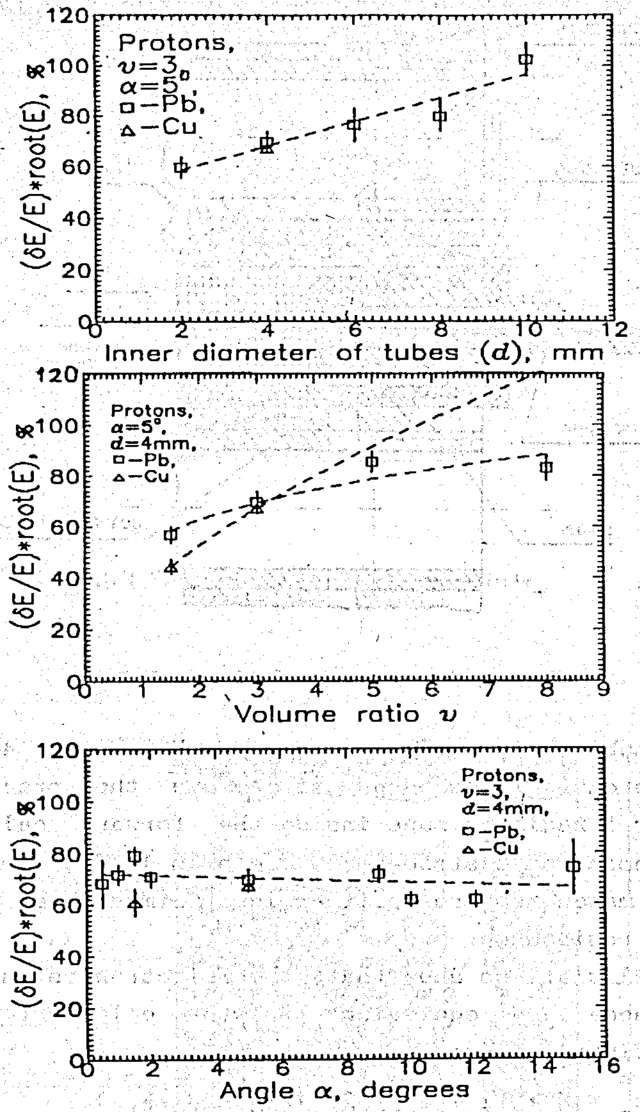

FIG. 4. Dependence of the statistical term coefficient of the calorimeter hadron energy resolution on inner diameter of tubes (d), active to passive material volume ratio (v), and angle between the incident particle and tube directions.

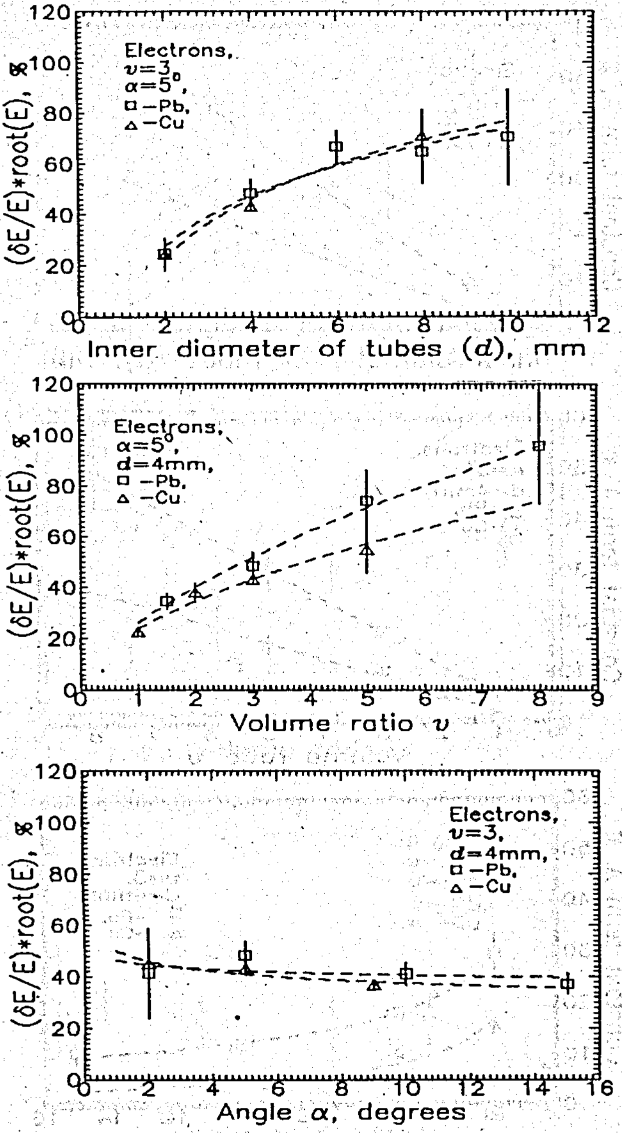

FIG. 5. Dependence of the statistical term coefficient of the calorimeter EM energy resolution on inner diameter of tubes (d), active to passive material volume ratio (v), and angle between the incident particle and tube directions.

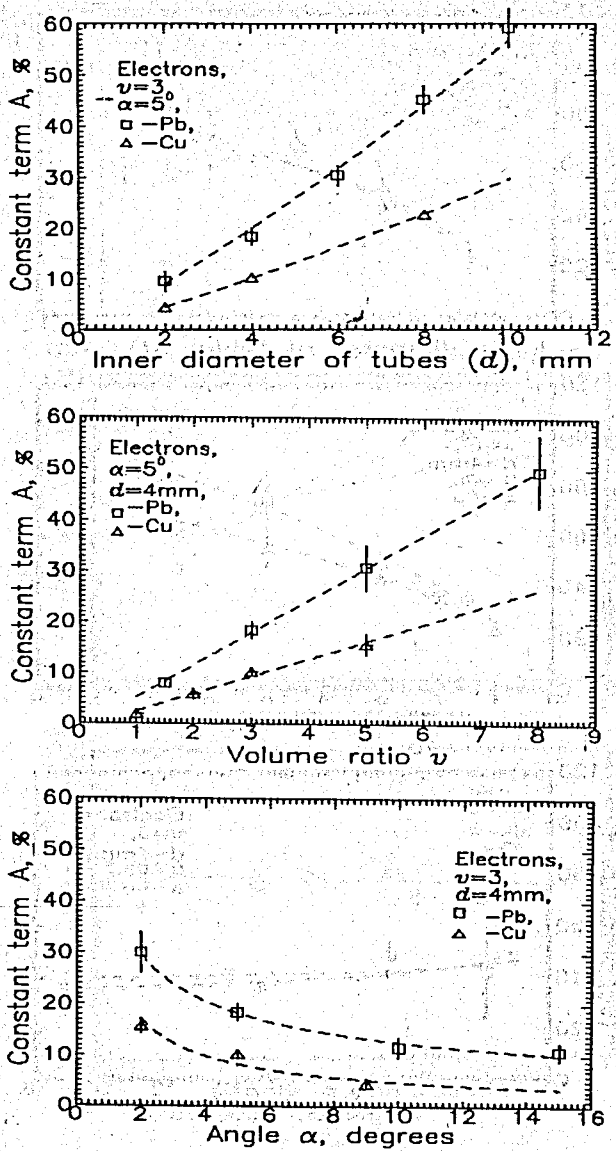

FIG.6.Dependence of the constant term of the calorimeter EM energy resolution on inner diameter of tubes (d),active to passive material volume ratio (v),and angle between the incident particle and tube directions.

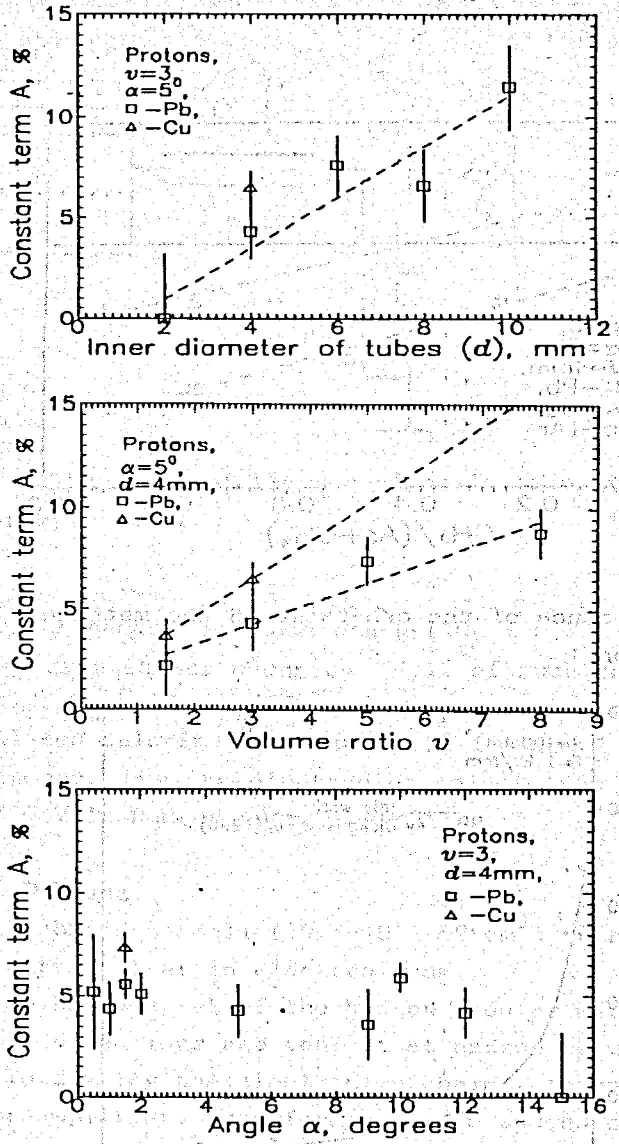

FIG. 7. Dependence of the constant term of the calorimeter hadron energy resolution on inner diameter of tubes (d),active to passive material volume ratio (v),and angle between the incident particle and tube directions.

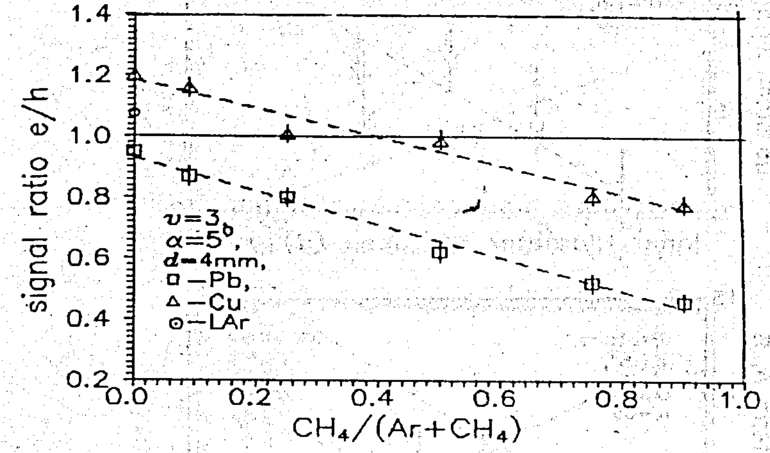

FIG.8.Dependence of the e/h-ratio on the methane concentration.

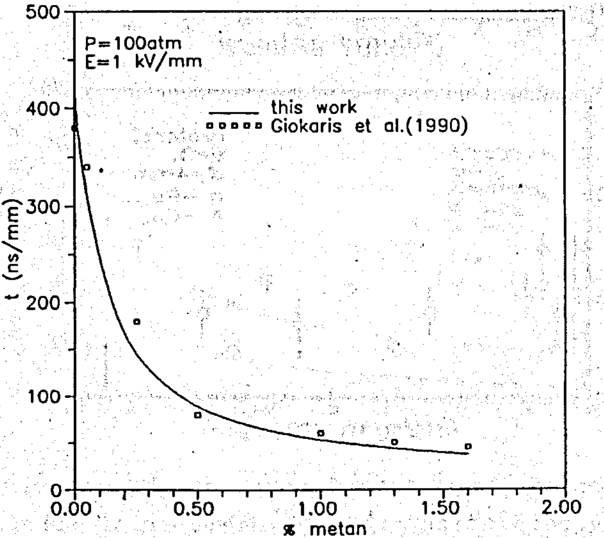

FIG.9.Dependence of the electron drift velocity in argon on the methan concentration.

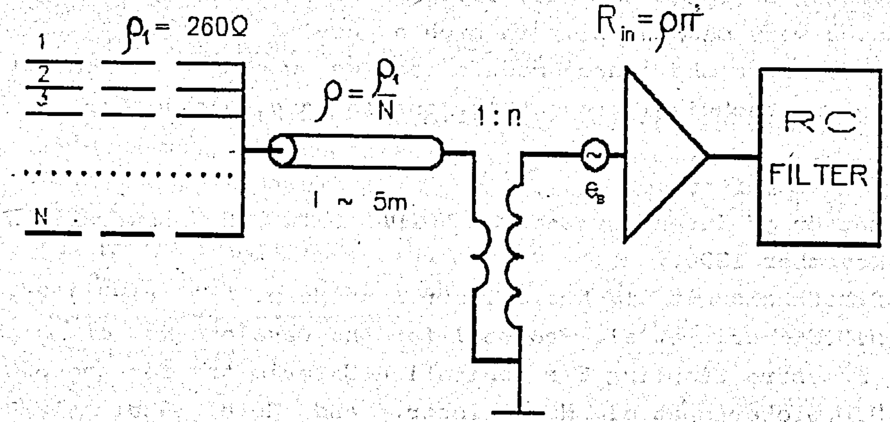

FIG.10.The sheme of the signal collection from one calorimeter cell.

For our hadron cell one can get Q_c = 0.7 * root(N) =5 fC. But the hadron shower occupies ~ 12 of such cells with the total noise Q_s = 17 fC. This value has to be compared with the simulated calorimeter response 22 fC to 1 GeV of the shower energy. Thus the electronics noise gives an uncertainty δE = 0.7 GeV in hadron energy measuring.

R & D Plans.

1. To build a small (10 * 10 * 50 cm^3) tube calorimeter module to test it at an electron beam.

2. To build a set of the hadron modules with 0.4 * 0.4 * 3 m^3 total dimensions and test it at hadron beam.

3. To develop the electronics chain (to choose the type of the preamplifier, transformer, cable and so on).

4. To continue the calorimeter investigation by Monte Carlo simulations.

By the way we plan to simulate the tube calorimeter with the wires replaced by roads. It leads to decreasing of the signal to noise ratio by factor ~ 3 (see items 3 and 4 of the "advantages"), but the calorimeter construction cost may be reduced very meaningfully in such a case.

5. After the hadron module test we would be ready to write the technical project for the forward calorimeter.

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