Fermi National Accelerator Laboratory

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SUMMARY SESSION OF THE GAS SAMPLING CALORIMETRY WORKSHOP

Jeffrey A. Appel

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Jeffrey A. Appel
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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ABSTRACT

The summary session of the Gas Sampling Calorimetry Workshop was a review and discussion session. A number of questions (Table I) were raised and briefly discussed. More extensive discussions of energy resolution (Tables II and III) formed the heart of the final session.

State of the Field

The convening of this Workshop has come at an auspicious time. A great deal of progress has been made recently in improving the performance of gas sampling calorimeters and extending their useful range to higher energy measurements. There was general agreement that we know today how to build the best gas sampling calorimeter to meet certain criteria of costs, relevant energy measurement range, and desired position and energy resolutions. As discussed below in the area of energy resolution, there is saturation of achievement. Most groups seem capable of achieving 27%/E electromagnetic energy resolution when their results are scaled to one radiation length sampling. Most groups also seem capable of achieving 70%/E hadronic energy resolution. Nevertheless, there was no true explanation of what limits these resolutions, except in regions where results were obviously worse than these limits.

While the uniformity across detectors is exceedingly good, the linearity of all devices is significantly limited. In all cases, the linearity is a matter of total charge collected, independent of the mode of operation of the calorimeter and gas. For 1 cm x 1 cm cell size for example, the charge limit is about 150 pC. This phenomena also suggests a fundamental limit on the performance of these devices. Yet no complete theory has been clearly demonstrated.

Thus, while great strides have been made in the technology of devices and the demonstrated achievements are impressive, a significant amount of work remains to be done in achieving basic understandings of the limitations of this technology. Only with an understanding of the apparently fundamental limitations will questions associated with extending the range or improving the performance of these devices be answered.

Energy Resolution

Tables II and III contain a summary of the achieved fractional energy resolution for devices reported at this Workshop. In each case, the linear response region (corresponding to the best test results) was selected. Table II contains results for electromagnetic showers initiated by incident electrons. Table III reports on hadronic showers in devices designed for that purpose. Aside from selecting the best results in each case, there have been no selections or corrections for shower containment, operating mode, or other factors.

The resolution tables also contain a column for sampling thickness, measured in radiation lengths for the electron initiated showers and in centimeters of iron equivalent for the hadron initiated showers. When one scales the best resolution achieved in the various devices by the square root of the sampling thickness, there is an evident uniformity (expressed in the final column of the tables).

The data in the tables allow one to check the dependence of the limiting resolution on three things: the energy, the sampling thickness, and the individual sample primary signal. Although the details of how the RMS resolutions are calculated may vary, the energy and sampling thickness scaled resolutions indicate agreement with the expected scaling in E and t over the rather signficant ranges reported. As we shall see below, the results for electromagnetic calorimetry with gas sampling devices are not as good as those available with scintillation sampling devices. The next natural question then is whether the individual sample primary statistics are the limiting feature.

For purposes of comparison, the CHARM collaboration result for scintillation sampling calorimeters is indicated in the tables. This value is typical of what has been achieved by a large number of groups for these types of devices. The gas sampling devices have poorer energy resolution for electromagnetic shower measurement.

In a similar attempt to understand fundamental resolution limitations, the table lists Battistoni's measurements of primary streamers in a gaseous device. For a total of n primary ionizations or streamers, one should not be able to do better than a fractional resolution of $\frac{1}{n}$. One sees that for the electromagnetic calorimeter, the observed resolution is two times this limiting value. Since one may imagine various effects adding in quadrature, it is clear that the fundamental limit is not the number of primary ionizations obtained in this particular device. The average number of primary streamers depends on the gas and the thickness of gas between layers, not on the sampling thickness, t. One can see from the distribution of the number of primary streamers that the width of the distribution is typical of the statistics associated with the mean number.

Also included in the hadron table is the California Institute of Technology-Fermilab iron scintillator active target with its very coarse sampling. Surely this device has a resolution dominated by sampling statistics, a fundamental limit. Battistoni also reported on the hadronic gas calorimeter for ALEPH. Here again, the number of primary streamers does not limit the achieved resolution. That is, the gas thickness was more than adequate for that device. On the other hand, if the sampling thickness was changed to 2.5 centimeters of iron, then the gas thickness would have had to increase as well. Of course, this would have been natural if the number of planes of gas had increased and the same individual gap gas thickness had been maintained.

In summary, the gas calorimeter energy resolution in the linear region scales as expected as a function of energy and sampling thickness. The primary signal generated at each sample has been found sufficient in the devices discussed. This leaves open the question of why the gas sampling electromagnetic calorimeters (at their best) are approximately 1/4 to 1/3 worse than scintillation sampling devices. In hadron calorimetry, the fundamental limitations caused by fluctuations in hadronic and electromagnetic shower components mask any benefits in scintillation sampling devices. Gas calorimetry is approximately equal in achievable hadronic energy resolution, at least within limited energy ranges.

Conclusion

Among the experts contributing to the Workshop, there was little doubt that with modest care a gas sampling calorimeter can be built to meet many experimental needs. Once resistive layers with resistivities of 100 Megohms/square are achieved, the details are not crucial. Similarly, whisker growth in the gas can be controlled either by gas selection (e.g., argon/CO^2) or by use of alcohol (as seems necessary for argon ethane mixtures). Most important of all, the details of gas sampling thickness and gas amplification need to be worked out with careful attention to the intended energy range and required resolutions. Virtually every detector shown at the Workshop had measured regions of saturation in which the device did not perform as would be expected from straight scaling of resolution in the best regions.

Given attention to the above problems, gas calorimetry has an obvious place in the calorimeters of the future. Uniformity of response, granularity and the ability to get signals out of tight places are their strengths. Because of the importance of these devices ahead, we should all thank Muzaffer Atac and the other organizers of this Workshop for a very instructive opportunity to review the technology behind these devices.

TABLE I

DO WE KNOW TODAY HOW TO BUILD THE BEST GAS SAMPLING CALORIMETER FOR GIVEN CRITERIA?

QUESTIONS FOR DISCUSSION

1. WHAT LIMITS ENERGY AND POSITION RESOLUTION?
   - SAMPLING
   - PRIMARY IONIZATION
   - OTHER
2. DOES MODE MATTER?
3. WHAT IS USEFUL ENERGY RANGE?
4. CAN LINEARITY BE IMPROVED?
5. CAN RATE LIMITS BE IMPROVED?
6. DOES RESISTIVE LAYER NEED SPECIAL CARE?

UNEXPLAINED RESULTS DESCRIBED HERE

RESOLUTION INDEPENDENT OF ANGLE UP TO 45°

WISKER GROWTH - HOW TO CONTROL?
ALCOHOL?

TABLE II

ENERGY RESOLUTION
ELECTRONS

		BEST % RESOL	t	SCALED % RESOL $\times\sqrt{\frac{E}{t}}$
GAS				
ATAC: MAC PROTO (S.A.)		$16.2/\sqrt{E}$	.5	23
		$19.7/\sqrt{E}$	.5	28
BATTISTONI: ELECTRA	TYPE 1	$28\%/\sqrt{E}$	1	28
	TYPE 2	$15\%/\sqrt{E}$	.35	25
MISHINA: CDF-EC	TYPE 1	-	-	30-40
	TYPE 2	$23\%/\sqrt{E}$	.5	29
LILLETHUN: HPC		$14.5\%/\sqrt{E}$	.26	28
		*$12.5\%/\sqrt{E}$	.26	24
VIDEAU: ALEPH		$16\%/\sqrt{E}$	.35	27
WENZEL: PEP4 (GEIGER)		$14\%/\sqrt{E}$	.25	28
SKUBIC: CLEO		$14.6\%/\sqrt{E}$	.2	33
BRANDENBERG: IT		$\frac{20\%}{\sqrt{E}} + 1\%)$ → @25 GEV	.8	28
FUESS: FLASH CH.		9.5% @5 GEV	.22	45
SCINT				
FLEGEL: CHARM		$20\%/\sqrt{E}$	1	20

PRIMARY STREAMERS (BETTER THAN STATISTICS OF PRIMARIES SHOULD BE IMPOSSIBLE

BATTISTONI: ELECTRA

700 @ 4 GEV	$7.6\%/\sqrt{E}$	.35	12.7

$$\sqrt{\frac{4\text{GeV}}{700}} = .076 \ \text{GeV}^{\frac{1}{2}}$$

TABLE III

ENERGY RESOLUTION
HADRONS

		BEST % RESOL	t (CM)	SCALED % RESOL $\times\sqrt{\frac{E}{t}}$
GAS				
ATAC: MAC PROTO		$72.8\%/\sqrt{E}$	2.7	70
		$102\%/\sqrt{E}$	5.4	70
BATTISTONI: ALEPH		$80\%/\sqrt{E}$	4.0	64
CARITHERS: CDF-EC		18.5% @ 25 GeV	5.1	65
		13.8% @ 50 GeV		69
FUESS: FLASH CH./PROP	PROP	$100\%/\sqrt{E}$	1.8	74
	FLASH	$75\%/\sqrt{E}$	.11	220
SCINT				
FLEGEL: CHARM		$47\%/\sqrt{E}$	1.5	70
CITF		$110\%/\sqrt{E}$	10.2	55

PRIMARY STREAMERS (BETTER THAN STATISTICS OF PRIMARIES SHOULD BE IMPOSSIBLE)

BATTISTONI: ALEPH			
300 @ 25 GeV →	$29\%/\sqrt{E}$	4	58

$$\sqrt{\frac{25\ \text{GeV}}{300}} = .29\ \text{GeV}^{\frac{1}{2}}$$