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**First results from a UA1 Uranium - TMP
calorimeter module.**

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Abstract

The UA1 detector is being upgraded for the high luminosity ACOL-era at the CERN $p\bar{p}$ collider. The upgrade is centered on the construction of a Uranium-TMP calorimeter. The design and construction of this novel warm-liquid calorimeter together with the first test results from a full scale module are reported.

1 - Introduction

Since 1981 the UA1 detector has collected data giving a wide range of physics results illustrated by the contributions to this conference. The calorimetry, unprecedented at the time of its conception, had a fundamental limitation in the jet energy and missing energy determinations. In fact there is a difference of response of ordinary calorimeters for hadronic and electromagnetic showers, which amounts to a 40 % enhancement factor for a purely electromagnetic deposition.

In order to take full advantage from the high luminosities to be achieved with the new antiproton accumulator ACOL a major upgrade of the UA1 detector was undertaken [1], the main component being the replacement of the old (Pb-scintillator) electromagnetic calorimeter by a fine-grained Uranium-tetramethylpentane (TMP) calorimeter [2].

2 - The choice for Uranium and TMP

The goal of the upgrade was the construction of a calorimeter with fine granularity, full containment of showers, improved energy resolution, and an absolute and stable calibration. Such a type of calorimeter will improve the jet energy and missing energy resolution and leads to a better determination of the W and Z masses, already dominated today by systematic errors. An obvious choice would have been Uranium and liquid Argon. In the case of Uranium one makes use of the fission amplification of the depleted Uranium in order to "boost" the hadronic response to the level of the electromagnetic response, improving also considerably the hadronic energy resolution. However our space constraints do not permit the inclusion of a cryogenic system. As an alternative we adopted the use of the warm liquid TMP.

A sampling calorimeter that uses, as active medium, a liquid ionisation chamber [3] has several advantages. The direct collection of the charge liberated by the passage of an ionizing particle is the most absolute and stable way of recording a signal, provided that the properties of the liquid remain constant. As thousands of ion pairs are typically created, their statistical fluctuations are negligible compared to sampling fluctuations. Furthermore, the calorimeter is spatially uniform, easy to segment in depth as well as surface, insensitive to magnetic fields and require little space for readout cables. Using TMP as liquid has the advantage, that due to its high hydrogen content, one expects, together with Uranium, to compensate for the difference in response between electrons and hadrons (e/π ratio) because recoil protons from the collisions of fission and spallation neutrons increase the hadron response.

The liquids which have been investigated so far and found to have suitable electronic properties are tetramethylsilane (TMS, $(\text{CH}_3)_4\text{Si}$), 2,2,4,4-tetramethylpentane (TMP, C_9H_{20}) and hexamethylenedisilane (HEDS), familiarly called double TMS. These liquids have a nonpolar molecular structure, an absence of reactive groups (Cl, O, OH, etc.), and support the existence of free electrons at room temperature. In addition, electrons produced through ionization can easily be drifted in them by applying an external electric field. Owing to the high flammability of TMS

preference is given to liquids with higher boiling and flash points. TMP and HEDS are therefore better candidates. We have chosen TMP because of the lower electron yield of HEDS .

All new calorimeters for UA1 are therefore made of Uranium plates as absorber intermixed with compact ionization boxes filled with TMP. The design guarantees the best possible granularity achieved using small detection elements arranged according to a tower structure.

3 - The new U-TMP calorimeter

All the central electromagnetic calorimetry in UA1, represented by the Gondolas and Bouchons, is being replaced with U-TMP versions. The original hadronic calorimeters, called "C's" and "I's" are preserved in the upgrade. By employing Uranium as passive material, the space occupied by the former electromagnetic calorimeter is sufficient to accomodate enough Uranium to make a hadronic compartment as well, effectively upgrading the hadronic calorimeter. Also a new forward calorimeter [4] located around the beam pipe in the "I's" and a very forward calorimeter behind a new compensating magnet are of the U-TMP version. They complete the angular coverage down to 3 mrad from the beam axis, which allows a separation of multiple interactions and improves the missing E_T resolution. Since the various U-TMP calorimeters are identical in conception, we restrict the description to the Super-Gondolas.

The most important part of such a calorimeter is the container for the TMP. Since the TMP must be extremely clean, also the containers which contain it must be free of e-capturing impurities, and must be tight such that none can leak in and poison the TMP. These requirements force us to rely solely on low carbon stainless steel, and considerable care must be taken in the construction and cleaning.

Fig. 1- Exploded view of a Super-Gondola box

The TMP is sealed in small but rigid boxes (Fig.1). Each of these boxes is made of a stainless steel picture frame, of $3 \times 3 \text{ mm}^2$ profile, where an additional intermediate bar increases its rigidity. Inside the box are 0.5 mm thick stainless steel electrodes, held in the middle of the gap by small ceramics. There are 8 such electrodes, roughly $10 \times 10 \text{ cm}^2$, separately insulated from each other and corresponding to the required segmentation of the detector. The high voltage, of the order of 1 to maximally 2.5 kV, is applied through a single feedthrough welded to one electrode. After the introduction of the electrodes and insulators the box is leak tight welded at each side with 0.15 mm thick stainless steel covers. Two tubes are welded in the frame for the TMP filling. Before assembly all components are washed ultra-sonically in a bath of hot deionized water and detergent, and then baked-out under vacuum ($p < 10^{-5}$) at 950°C . All welds are done by a YAG

laser under an inert gas atmosphere. This welding procedure was the only method found which satisfied our criteria of leak-tightness, thermal deformation and metal sputtering. A box must have a leak rate less than 10^{-8} mbar.liter/sec, and the feedthroughs must have a leakage current less than 1 nA to be accepted.

Construction of a full module starts with the assembly of a sandwich of 62 boxes and Aluminum spacer plates (simulating the Uranium). Once assembled to a stack, manifolds are welded on the two sets of TMP fill tubes. The boxes are then rinsed out with hot (80°C) ultra-pure water (specific resistivity = $18.2\text{ M}\Omega\cdot\text{cm}$), dried with pure Argon (O_2 content < 10 ppm), baked out at 300°C under vacuum, and then filled with pure Helium from a dewar. Two such stacks of contamination free boxes are placed side-by-side to form a full module. This is obtained by removing the Aluminium plates and replacing them by the Uranium plates. Steel straps are welded on the two outer supporting plates to form a rigid structure.

The next step is the TMP filling procedure in a large vacuum tank. It is essentially done by evacuating both the tank and the module. Once the boxes evacuated, the module is isolated from the pumps and by opening valves to the TMP container the liquid can flow into the boxes. The ultra pure TMP liquid is obtained by passing it in the vapor phase through silica gel and molecular filters and then condensing it into a collection barrel used in the filling system. The maximum lifetime achieved so far was approximately $280\text{ }\mu\text{sec}$. In the case of the present module the TMP lifetime was $> 100\text{ }\mu\text{sec}$. Once filled, the valves to the module are closed, the tank brought up to atmospheric pressure, and the module removed. After having "cold-welded" by crimping the Nickel tubes on the manifolds the module is cabled.

Fig. 2 - Cross-section of a Super-Gondola module

4 - The beam test results

The first full scale Super-Gondola module was placed in a test beam of the CERN SPS. The beam has a maximum momentum of $80\text{ GeV}/c$ and a $\Delta p/p$ of 0.3% after measurement with a beam spectrometer. Delay-line wire chambers were used to define the incident particle position and direction to better than 1 mm and 0.1 mrad respectively. The TMP module was followed by an

In Fig 2 is shown a cross section of a Super-Gondola module. It is composed of six samplings, four electromagnetic and two hadronic. The electromagnetic samples (2.9, 6.0, 9.9, $6.6 X_0$) consist of layers of 2 mm Uranium plates and 3.3 mm TMP boxes. The first box of sample 2 is a position detector box. This box, 6.8 mm thick, is a direct extension of the normal calorimeter boxes. In the extra space are inserted two orthogonal planes of strips on each side of the large central electrode which belongs to sample 2. The strips, 7.1 mm wide with a pitch of 9.1 mm , are read out to determine the shower position. The two hadronic samples have 5 mm Uranium plates ($0.6\lambda_I$ for each sampling). Fig.3 shows a full Super-Gondola module.

A Super-Gondola is composed of 16 such modules, arranged in a nonpointing geometry with respect to the beam crossing. Ten of these half-cylindrical Super-Gondolas, five on each side of the beam, are mounted in the old "C's" and enclose the central detector.

iron-scintillator calorimeter, a prototype of the present UA1 hadron calorimeter "C"-module, and 160 cm of iron. Data were taken with electrons, hadrons and muons from 5 to 70 GeV.

In this beam one obtained results [5] from earlier small prototypes, which indicated that the lifetime of the TMP was stable over a period of 2 years. In addition tests of position detectors showed a resolution of 1 mm for high energy showers [6].

Fig. 3 - A full Super-Gondola module

For the present beam test of the full scale module hybrid amplifiers with four low noise, high transconductance jFETs (75 pF each) in parallel were chosen in order to match the detector and amplifier capacitance. After a shaping amplifier with a shaping time of 2 μ sec the slope of the equivalent noise charge was measured to be ≈ 1.1 electrons per pF, which gives in the case of a 5-box sampling a signal-to-noise ratio of 3:1 for minimum ionizing particles at a field of 10 kV/cm. However the natural Uranium activity provides another noise, so that the muon signal-to-noise ratio is about 2:1.

Two important features of the calorimeter performance are the linearity of response and the energy resolution.

The measured charge of each sampling was individually weighted with an energy-independent calibration constant obtained by minimizing the resolution with respect to the electron momenta as measured by the beam spectrometer. From the measurements with electrons between 5 and 70 GeV the resulting deviation from linearity of the reconstructed energy compared to the beam momentum is less than 0.5 %. For 40 GeV electrons the uniformity between the 16 electrode towers is less than 2 % and the summed pulse height across the interelectrode gap is uniform. The measured resolution as function of the inverse square root of the electron energy is shown in Fig.4.

Fig. 4 - Energy resolution for electrons

Fig. 5 - Energy resolution for hadrons

Fig. 6 - Measured e/π ratio

By making now the ratio of electron response to hadronic response one obtains the result of the compensation shown in Fig. 6 compared to the old Gondola's and "C's", an Uranium scintillator calorimeter and the Monte Carlo prediction.

5 - Conclusion

The technique of warm liquid calorimetry developed by the UA1 Collaboration works. By using sophisticated technologies the requirements for purity and cleanliness are manageable. The test results of the first full scale U-TMP calorimeter confirm the previous prototype results. The energy resolution for electrons is $13.3\%/\sqrt{E}$ and $47.5\%/\sqrt{E}$ for hadrons, in agreement with expectations. The data show also evidence for a good $e-\pi$ compensation from Uranium.

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The result is $\sigma/E = 0.133/\sqrt{E} + 0.005$ in good agreement with a Monte Carlo prediction ($0.12/\sqrt{E}$) using the GEANT simulation.

The hadronic response of the calorimeter is of special interest since it is expected to increase relative to that for electrons because fission and spallation neutrons will produce recoil protons in the TMP liquid. By using pions from 5 to 70 GeV the measured hadron resolution, as shown in Fig.5, is $\sigma/E = 0.475/\sqrt{E} + 0.07$, in perfect agreement with the Monte Carlo prediction of $0.46/\sqrt{E} + 0.04$, where a Birk's constant of 0.014 was used. This measurement includes also the response from the "C" prototype behind the TMP-calorimeter. The result is a significant improvement to the resolution of $0.80/\sqrt{E}$ for the old "C's" and "I's".