

## Sensors for the Hall C Neutral Particle Spectrometer

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September 30, 2020

This note presents the Detector Support Group's (DSG) research on the sensors required to measure the environment and operating conditions within the Neutral Particle Spectrometer (NPS) [1].

The sensors implemented in NPS will have a cable run of ~140 feet [1] to the readout instrumentation and will be exposed to radiation [2–4]. Table I lists the types of sensors needed for NPS.

| Sensor type  | Qty | Locations  |
|--------------|-----|--|
| Temperature  | 136 | crystal array, detector internal, electronics, ambient |
| Humidity     | 10  | Detector internal, ambient                             |
| Fan speed    | 4   | electronics zone, heat exchanger                       |
| Light        | 2   | crystal array  |
| Coolant leak | 2   | NPS crystal and electronics zone                       |

TABLE I. List of different types of sensors needed for NPS.

It is important to control and monitor the temperature of the  $\text{PbWO}_4$  crystals [5] at an optimum level because even though the light yield of the crystals increases at lower temperatures, their resistance to radiation effects decreases [1]. Also, it is important to control and monitor the heat generated by the internal electronics, ~550 W [3], to preclude temperature gradients in the calorimeter [1].

The most common types of temperature sensors used are resistance temperature devices (RTDs), thermistors, and thermocouples. All three types are radiation hard and are used in harsh environments such as nuclear power, spacecraft, and medical applications. [6–10].

There are many guides [11–22] describing temperature sensor construction, theory of operation, and instrumentation requirements to aid in the selection of these types of sensors. Table II summarizes the findings.

DSG has investigated the use of digital integrated circuits for measuring temperature and humidity of detectors [26–31]. Digital sensing has many advantages, however, the radiation tolerance of integrated circuits is unknown and therefore they are not recommended for use in NPS.

For NPS, RTDs are the prime candidates for temperature sensing. RTDs are stable, accurate, and with a four-wire configuration, the resistive effects of a long cable run between detector and the readout instrumentation is minimized. DSG has used RTDs in many temperature sensing applications and can attest to their reliability.

Typically, in control systems developed for physics detectors that are subject to radiation, either a commercial humidity sensor that meets the radiation tolerance, or one that was known to be used in another experiment, is implemented.

For example, during the development of the tracker for the Compact Muon Solenoid (CMS) experiment, CERN and INFN developed an experimental setup to test tracker components, to aid in the development of the thermal and hygrometric control system, and to evaluate humidity sensor candidates for use in the construction of the tracker [32].

For the detector control system [24] of the CMS Electromagnetic Calorimeter (ECAL) [33] at the CERN Large Had-

|   | RTD                                | Thermistor                           | Thermocouple                       |
|---|------------------------------------|--------------------------------------|------------------------------------|
| Accuracy                                | $\pm 0.1$ to $\pm 1^\circ\text{C}$ | $\pm 0.5$ to $\pm 1.5^\circ\text{C}$ | $\pm 1$ to $\pm 2.2^\circ\text{C}$ |
| Stability                               | $0.05^\circ\text{C}/\text{year}$   | $0.2^\circ\text{C}/\text{year}$      | $1.5^\circ\text{C}/\text{year}$    |
| Excitation                              | required                           | required                             | none                               |
| Output                                  | resistance                         | resistance                           | voltage                            |
| Output linearity                        | linear                             | non-linear                           | non-linear                         |
| Response time                           | 1 to 10 s                          | 0.12 to 10 s                         | 0.5 to 10 s                        |
| Range                                   | -200 to $650^\circ\text{C}$        | -100 to $325^\circ\text{C}$          | -270 to $1800^\circ\text{C}$       |
| Relative cost                           | high                               | low to moderate                      | low                                |
| Signal conditioning needed (long leads) | no                                 | no                                   | yes                                |
| Self-heating                            | yes, minimal                       | yes, highly                          | no                                 |
| Detector example                        | Hall D Comcal [23]                 | CMS ECAL [24P]                       | Primex HYCAL [25]                  |
| Overall advantages                      | stable, accurate, linear           | fast, accurate, low cost             | high temperatures, low cost        |

TABLE II. List of features for different types of temperature sensors.

ron Collider, all components inside ECAL were required to tolerate up to 5 kGy (0.5 Mrad) and neutron fluence of up to  $10^{12}$  neutrons/cm<sup>2</sup> [34]. For ECAL's humidity monitoring system, which has 176 sensors, the UPS-600 humidity sensors manufactured by Ohmic Instruments [35] were tested to determine if they would work at the CMS radiation levels. Testing showed that the sensors would be able to meet specifications during the expected running lifetime of ECAL.

The temperature and humidity monitoring systems for detectors for Belle II at KEK [36–37] included the Ohmic Instruments sensors because CMS had used them. As the Belle II development continued, additional radiation testing performed on the Ohmic Instruments sensor indicated that the radiation tolerance was 2 Mrad [38].

Based on the above information, the UPS-600 humidity sensors manufactured by Ohmic Instruments are prime candidates for measuring humidity.

In conclusion, research is ongoing into the different types of sensors that will meet the requirements of NPS.

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