Report of the joint MIPP/PPD RICH Panel [1] on the RICH Accident of March 14,2004

(Dated: April 14, 2004)

Abstract

We analyze the circumstances surrounding the accident of March 14, 2004 in the MIPP experiment. We show conclusively that the event was due to a fire in the photomultiplier box of the Ring Imaging Cherenkov (RICH) detector. We analyze the probable causes and recommend remedial steps designed to prevent similar recurrences in the detector.

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I. DESCRIPTION OF THE EVENT

On Sunday, March 14, 2004, during the commissioning phase of the MIPP experiment, a controlled access was made at approximately 11:30AM. During the access, a strong smell of smoke was noticed in the area surrounding the RICH. In the portakamp, the APACS [2] system computer had registered three smoke alarms [3], from smoke detectors placed in relay rack 18, relay rack 20 and on top of the RICH detector. The relay rack smoke detectors were wired to turn the power off to the downstream portion of the experiment, and this they had done. The RICH blower and cooler were at that time on a separate power circuit and they were still running. They were turned off. It was not clear at this time which detector or rack was responsible for the smoke. Subsequent investigation clearly pointed to the RICH as the source of the smoke, since all the other electronics came back on without problems.

II. DESCRIPTION OF THE APPARATUS

The MIPP RICH detector is inherited from the SELEX [4] experiment and refurbished by MIPP. It is filled with CO_2 as the radiator. The Cerenkov rings are imaged on to an array of $\frac{1}{2}''$ photomultiplier (pmt) tubes that have 89 columns and 32 rows. Each column decouples into two strings of 16 tubes. There are 70 columns of FEU-60 tubes (made in Russia) and 19 columns of Hamamatsu R-760 (made in Japan) tubes, making a total of 2848 tubes. The FEU-60 tubes ($\approx$ \$45 each) are considerably cheaper than the R-760 tubes ($\approx$ \$350 each) but less efficient at detecting photoelectrons. All tubes in the same column have the same high voltage. The high voltage is distributed to the columns by means of a zener chain powered by 6 Glassman EK3R200 HV power supplies. Each supply thus was connected to approximately 475 tubes. Four of these supplies were set to trip if the current exceeded 100mA and the remaining two were set to trip if the current exceeded 140 mA. The stored energy in each supply is 0.2 Joules. The photocathode of each photomultiplier tube is at negative high voltage. The anode signal wire is at 0V. The only power source in the base is the High Voltage. MIPP has discarded the SELEX readout system and custom-built its own. Figure 1 shows observation of rings in the MIPP RICH detector during commissioning.

The amount of power dissipated in the pmt box is estimated to be of the order of 900 Watts. This heat is dissipated entirely in the resistive chain providing high voltage to the pmt dynodes. This power is removed by the circulation of cooled air which is blown into the pmt box through a plenum placed at the bottom of the box. The air exiting the top of the box is recirculated after the heat from it is removed by means of a heat-exchanger using chilled water.

There are also a set of fans that mix up the air inside the pmt box to reduce the temperature gradients.

There is an interlock system that shuts off the HV if either the pmt box is opened (by means of 4 switches placed at the corners of the lid)or the temperature of the air inside the pmt box gets too large. This is achieved by including in the interlock daisy-chain three temperature klixons placed close to the pmt bases that are designed to spring open when the temperature exceeds 50^oC. Once the interlock is broken, the HV is switched off and can only be manually reset at the HV rack.

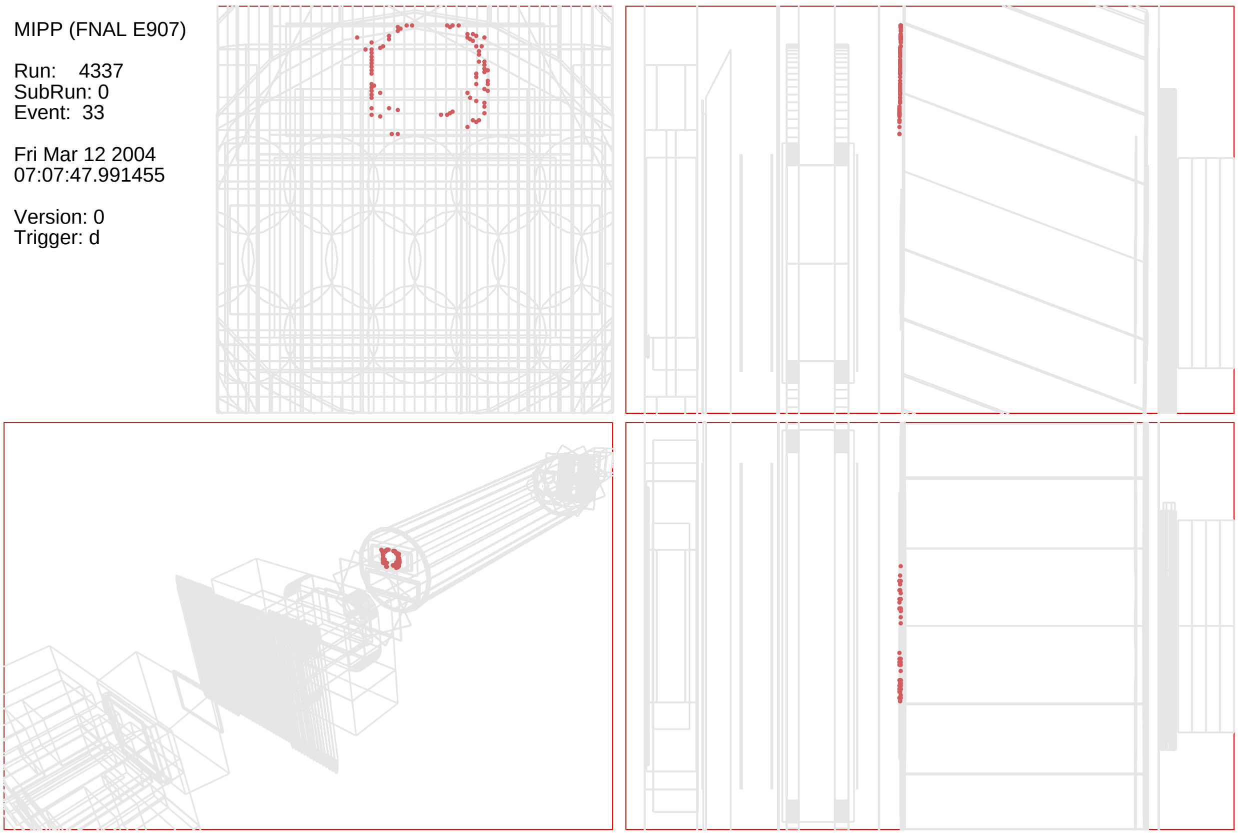

FIG. 1: Rings observed in the MIPP RICH detector prior to the accident of March 14, 2004. The four views show the RICH from four perspectives. The top left hand view shows the photomultiplier array hits looked head on. They show two rings for this event corresponding to two tracks from the event that entered the RICH.

III. ANALYSIS OF THE ACCIDENT

The readout cards were first checked and all were found to be functional. This implied that the source of the smoke was very likely in the pmt box. The RICH was pulled back from its nominal position in the experiment and the pmt box was opened up. It was discovered at this time that the cooling ducts that supply the cooled air into the pmt box were hooked up in reverse order [5] such that the airflow was from top to bottom and that the mixing fans were not hooked up. It was discovered that there was a bunch of cables in the pmt box that looked melted at the surface(see Figure 2).

The initial hypothesis was that the air inside had got too hot due to the cooling being hooked up backwards. The temperature klixons should have cut the HV if the air temper-

FIG. 2: The appearance of the photomultiplier box after opening up revealed a singed area to the right.

ature had exceeded 50^{o}C. The klixons were removed from the box. Two out of the three klixons seemed in good shape and were tested to open correctly in a temperature controlled environment [6]. The third was found to be burned. Also the temperature at which the insulating wrapping of the cable bundles (said to be a form of Teflon) began to melt and emit fumes was measured to be 266^{o}C. At this point it was evident that we were dealing with a fire inside the pmt box and that the protection afforded by the klixons tripping the HV was largely irrelevant in preventing the fire.

The average number of phototubes hit per event is plotted as a function of time for the run that ended at 11:13:17 CST on March 14, 2004. This curve is flat until about 20 minutes before the end when a large number of hits are observed in the RICH. This behavior lent further support to the fire hypothesis. We then proceeded to call some arson experts from the Fermilab fire department, who [7] concluded

"Our examination of the wiring and subject area was as complete as could be. There were portions of the effected wiring and material already removed to aid access to the area and assess the damage. Our examination started at row 81 and went from there. A significant amount of damage to the insulation and wiring was noted. It is our opinion that the damage is consistent with a fire condition...".

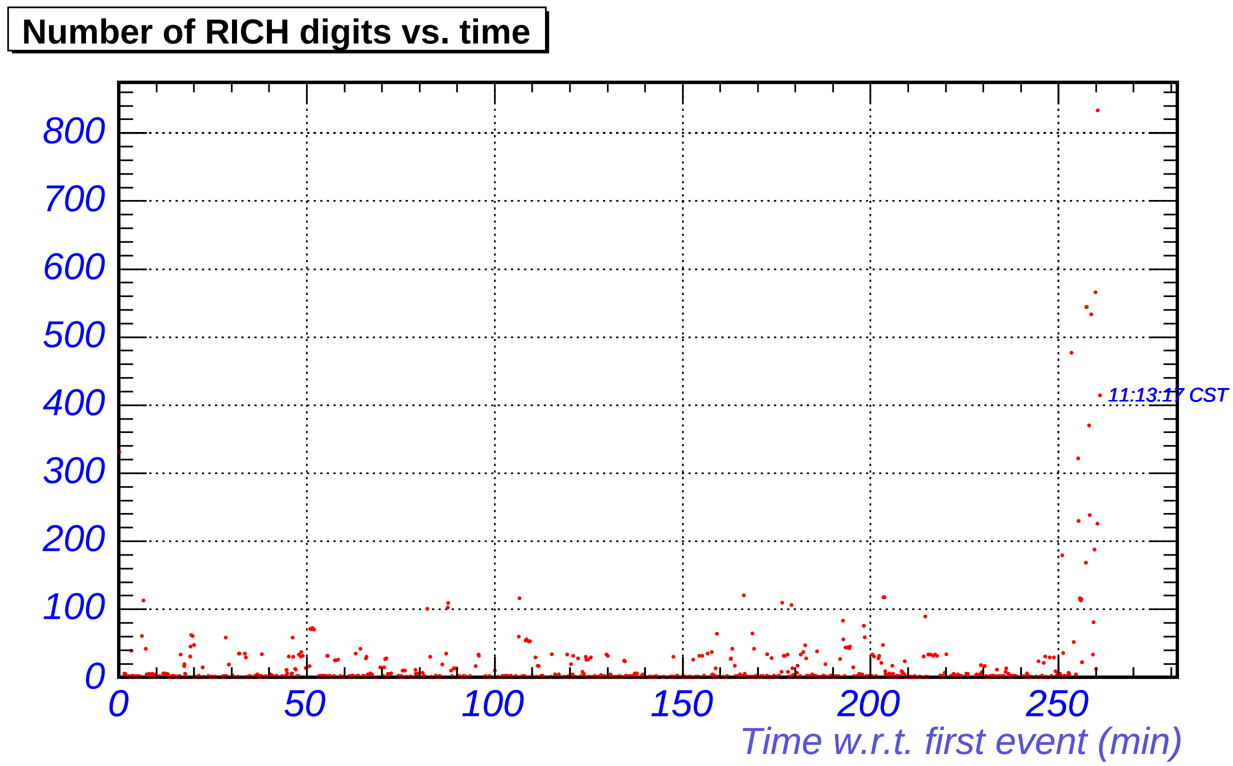

FIG. 3: Average RICH hit multiplicity as a function of time for 250 minutes prior to the accident

Further removing the cables from the affected area revealed the picture in Figure 4 that left no question as to whether there was a fire or not. A large number of phototube bases ($\approx$ 500) were fused together and melted as a result of the fire. The condition of the tubes in this region is unknown and awaits further testing. The HV interlock was indeed found to be broken upon examination. So at least one of the klixons (clearly the burnt out one) exceeded 50^{o}C.

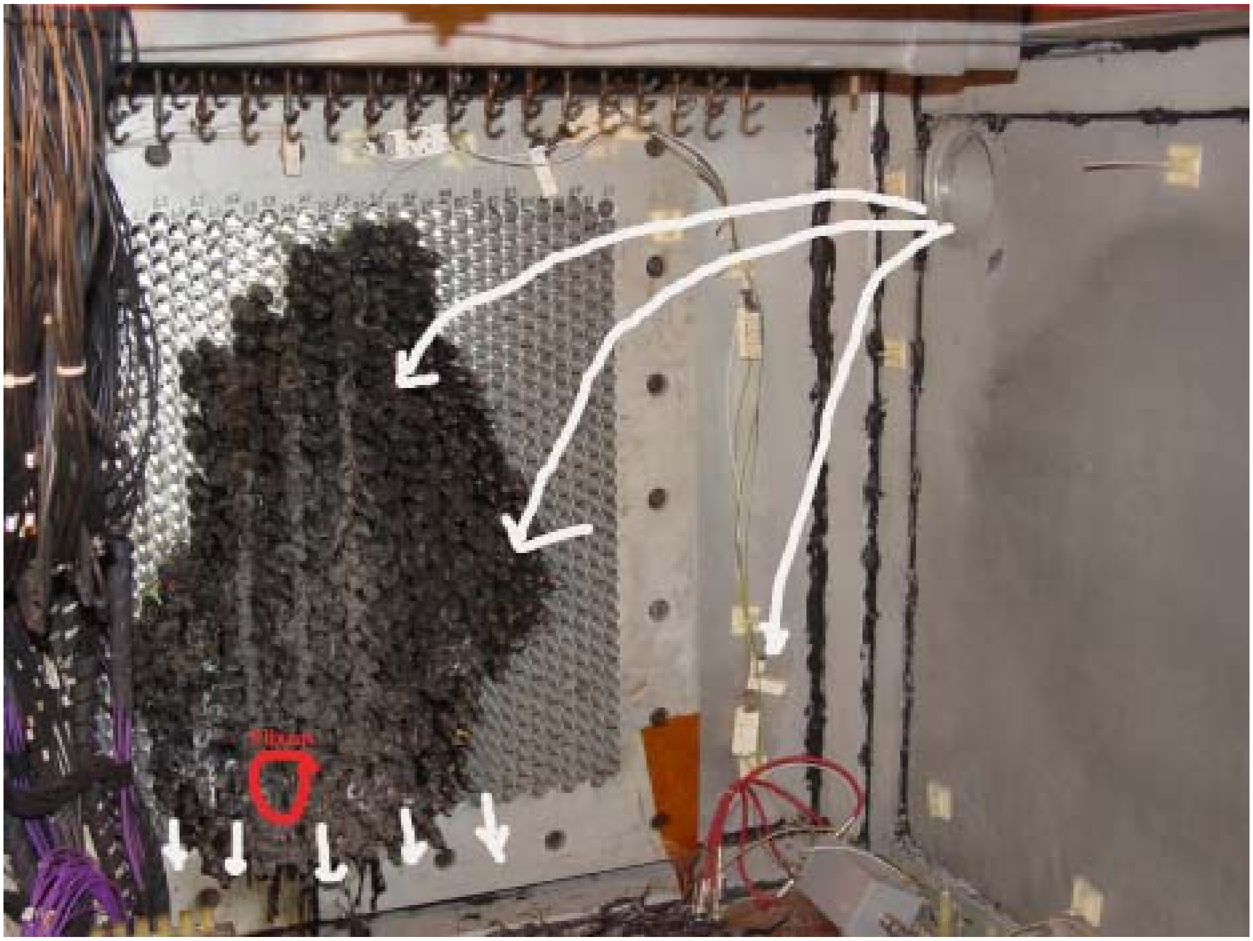

FIG. 4: Appearance of the array after the removal of the burned cables. The bases of phototubes that fused together under the heat are shown. The approximate direction of the airflow at the time of the fire is shown by the arrows. The position of the temperature klixon that was burned is shown.

IV. FLAMMABILITY TESTS

Jim Priest then conducted a series of flammability tests on pairs of bases, one FEU-60 and the other Hamamatsu R-760. He conducted three tests, during the first one a flame (equivalent of a candle) was applied to the bases, the second one used a piezo-electric spark generator with 4 joules per spark going “continuously” and during the third one only the unconsumed portion of the Hamamatsu base was tested. The details of his tests can be found at [8]. His conclusions can be summarized as

- Enough energy was present in some form to ignite the FEU-60 base and have selfsustained burning without the need for additional energy input.

- The FEU-60 base burned rapidly to consumption in 2 to 3 minutes.
- The FEU-60 base dripped its burning material down spreading the fire and produced enough flame and energy vertically and horizontally, to rapidly spread the fire to adjacent units.
- The Hamamatsu R-760 base does not burn if left to itself. It needs the flame provided by the burning FEU-60 base to show evidence of charring.
- The less flammable Hamamatsu bases and the gap between the grates and the backward airflow most likely limited the fire because the FEU-60 bases were consumed rapidly in 2 to 3 minutes. The fire duration was most likely between 3 and 10 minutes.

Figure 5 shows the FEU-60 base in flames after the first test.

A visual examination of the fire region showed that the fire was most intense in column 73 a few rows from the bottom. This is probably the origin of the fire. It is worth noting that column 73 is a FEU-60 tube column.

A. Possible causes of ignition

We have considered two possible causes of ignition. The first is due to sparks in the pmt base caused by High Voltage leads coming in close proximity and producing arcing. We have isolated a FEU-60 tube that exhibited this behavior. The tube was seen to spark at about 5Hz very close to where the wires went into the phototube. The spark was between one of the HV dynode wires and the anode signal wire that is at 0V. There was an accompanying spark in the readout pin (to complete the circuit). We have made movies (with sound) of the sparking which can be seen at the link in reference [9]. This behavior has been observed periodically in the past, where one of the tubes would spark sporadically and kill its readout card. We pthen proceeded to measure the current associated with the spark and found that at the start of the spark it exceeded an ampere. We have verified that sparks produce surges in the HV current output which do NOT trip the supply. So it is possible for repeated sparking to occur.

FIG. 5: The FEU-60 base is at the bottom and has caught fire as a result of a candle-like flame being applied for approximately 10 seconds. This picture is taken 25 seconds into the burn.

The second mechanism is provided by a short in the resistor chain in the base. There are 10 stages to the FEU-60 tube and the total power dissipated per tube is approximately 0.3W. If the resistive chain is shorted so that the total resistance is only 1/10 of the original, then the power consumed is 3W. The current in this base would jump from 0.2mA to 2mA, that is barely noticeable. It then behooves us to ask what would happen if the tube produced

3W excess energy that does not get removed efficiently by the cooling. Does the base get hotter and hotter over time causing it to go into ignition? We need to conduct further tests on this.

V. RECOMMENDATIONS

Based on what has been discovered so far, it is possible to recommend preventive measures to avoid such accidents in the future. Our recommendations are aimed first at preventing the recurrence of fires and second at monitoring and shutting down the system upon the detection of any abnormal behavior.

A. Fire Prevention

- Reconstitute the klixon interlock. Replace the burnt-out klixon. This will prevent accidents due to overheated air.
- Inert the atmosphere in the pmt box by replacing the air with nitrogen. Monitor the oxygen content and report it to APACS.
- Detect current surges in the HV due to sparks and abort the HV supply output if sparks occur.
- Replace the flammable shrink-wrap around the FEU-60 tubes by a flame-retarded variety . In the process, reduce the risk of sparking and shorting in the base by applying a layer of insulating coating to the base (such as an acrylic conformal coating that can be sprayed on).

B. Monitor and abort

- Monitor the temperature in the pmt box at various locations as well as in the zener box and report it to APACS.
- Install a compact Very Early Smoke Detection and Alarm (VESDA) system in the pmt box. Feed its output to APACS.

- Have APACS abort power to the HV if either the temperature, or the VESDA system or the oxygen monitor is off limits.

VI. CONCLUSIONS

We conclude that the fire of March 14, 2004 in the MIPP RICH detector was most likely caused by the ignition of the flammable wrapping around one of the FEU-60 bases most likely situated in column 73. The ignition mechanism was very likely related to the High Voltage power supplies.

It is worth noting that MIPP followed all the existing safety regulations to obtain Operational Readiness Clearance for the RICH. The measures we propose here can be implemented swiftly and will go a long way to reduce the chance of recurrence of such incidents to negligible proportions.

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[1] The panel was jointly appointed by the heads of the Fermilab Particle Physics Division PPD and the MIPP experiment. Its membership is as follows W. Baker (MIPP/SAFETY/FNAL) P. D. Barnes,Jr. (MIPP/LLNL), P. Cooper (SELEX/FNAL), G. Feldman (MIPP/Harvard) N. Graf (MIPP/Indiana) J. Kilmer (SELEX/MIPP/FNAL) A. Lebedev (MIPP/Harvard) M. Messier (MIPP/Indiana) S. Orr (SAFETY/FNAL) J. Priest (SAFETY/FNAL) R. Raja (MIPP/FNAL) E. Ramberg (SELEX/FNAL) K. Schuh (SAFETY/FNAL) S. Seun (MIPP/Harvard)
The Main Injector Particle Production Experiment (MIPP/FNAL-E907) is located in the Meson Center beamline at Fermilab in area MC7. More information on MIPP can be found at http://ppd.fnal.gov/experiments/e907

[2] APACS or Advanced Process Automation and Control Series system is a monitoring and control system employed widely by experiments at Fermilab for the purpose of ensuring that the parameters of the system under observation are within limits.

[3] These alarms were not noticed by the person on shift, since they were visual and were not on the page being displayed on the APACS computer. We have since made such alarms into audible alarms.

[4] The SELEX experiment (FNAL-E781) finished data taking in 1997. More information on SELEX can be found at
http://fn781a.fnal.gov/

[5] This reversing of the cooling ducts probably occured at the time the old ducts were changed to new ones during commissioning.

[6] For details of the klixon and insulation melting tests, see R. Raja
http://ppd.fnal.gov/experiments/e907/RICH/accident/klixons.pdf

[7] Lieut. Russ Wood and Firefighter Brian Schopp, private communication

[8] J.Priest,
http://ppd.fnal.gov/experiments/e907/RICH/accident/ MIPP%20base%20test%20Burnr1.pdf

[9] Two movies on the sparking can be found at
http://ppd.fnal.gov/experiments/e907/RICH/accident/