Testing and Optimization of the 3-GEM Detector at Florida Institute of Technology

Georgia Karagiorgi

Undergraduate Research Report – Fall Semester 2004

Introduction

During this stage of the GEM detector development conducted by the High Energy Physics Group at Florida Institute of Technology, a 3-GEM detector setup was tested, which was designed and built during the spring and summer 2004 semesters in the Detector Development Laboratory (DDL), and the Machine Shop at Florida Institute of Technology. During the testing, some alterations and additions were been made to the original design for improvement purposes, such using a different amplifier (developed, manufactured and provided by the PHENIX Group, at BNL), as well as shielding of the circuit board, detector, and preamp setup employing coax cables and a Faraday box. The results showed relatively small improvement; no acceptable signal was observed, and leakage current measurements were inconclusive. Further changes need to be made to the detector design, and new GEM foils need to be used, as the ones that are currently being used do not seem to be working properly.

Method

The basic design of the 3-GEM detector assembly used is shown in Figures 1 and 2.

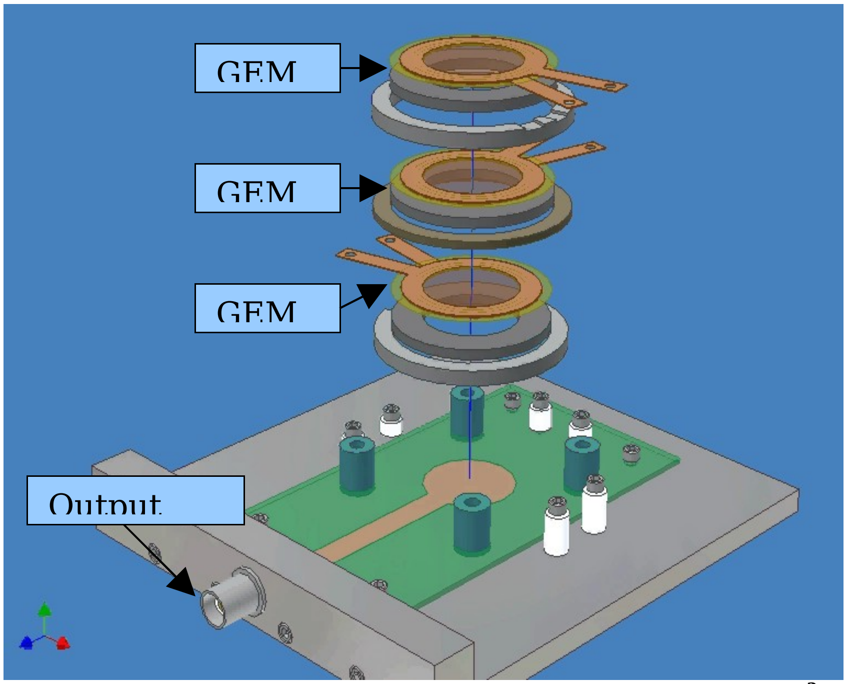


Figure 1: 3-GEM Detector Setup [Exploded view][2]

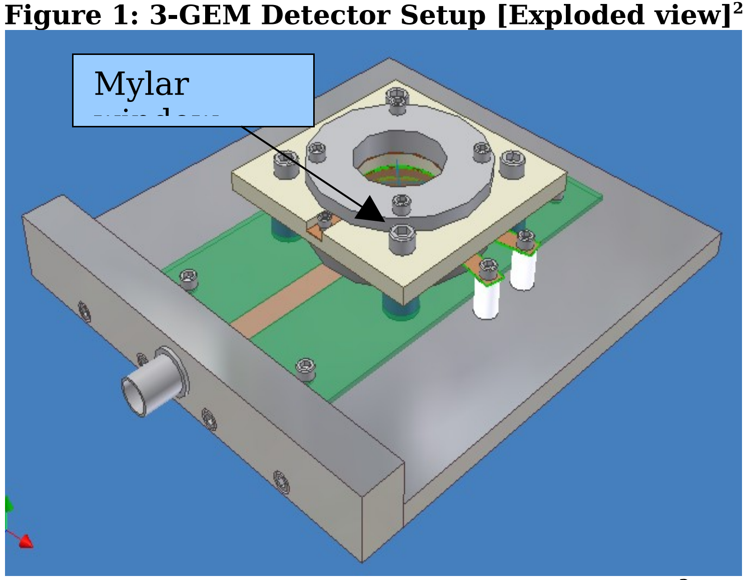


Figure 2: 3-GEM Detector Final Assembly[2]

The initial task was to verify that the setup was working properly, by observing output signals from a 5μCi Fe-55 γ-source, using three TechEtch, 1 inch-diameter GEM foils. Two series of trials were conducted; the first one using a Fujitsu preamp card that had previously been used during the single GEM testing, and the second one using a new preamp provided by the PHENIX Group, led by Dr. Craig Woody, at Brookhaven National Laboratory (BNL).

Both tests were run using the same basic experimental setup, displayed in Figures 3 and 4. The only variation was the different power supplies used to power up the two different preamps used. The Fujitsu preamp card required a single constant operating input voltage of 3.4V;

this voltage was provided by the same power supply used for powering the DC-DC converters in the HV circuit (see Figure 4): Power Designs Inc, Precision DC Source 0-20V. The BNL preamp required five separate constant input voltages (GND, +6V, -6V, +12V, and -12V) for its operation. It was powered using three separate power sources: Power Designs Inc, Power Supply 2005P (S.R. 108336); Power Designs Inc, Power Supply 2010 (S.R. E6652); and NIM Crate ORTEC 401A (S.R. 11745). Appendix A provides a reference for input connection specifications.

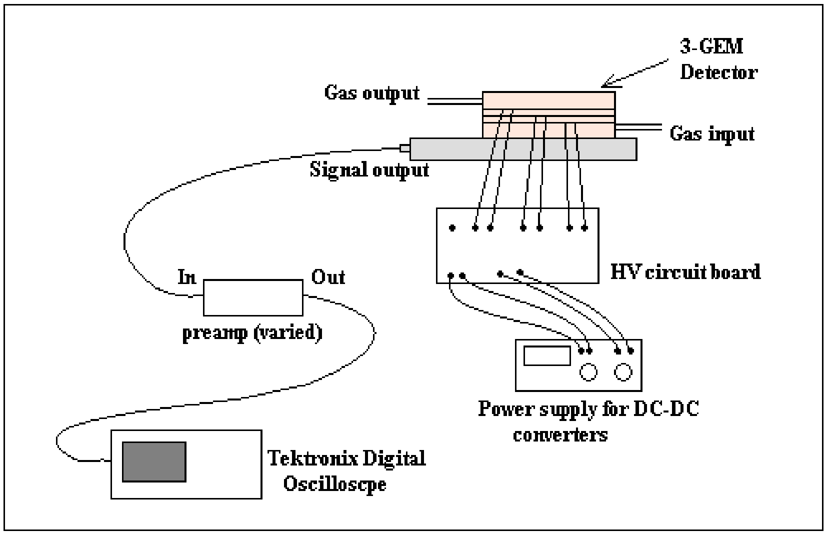


Figure 3: Experimental Setup for Signal Testing

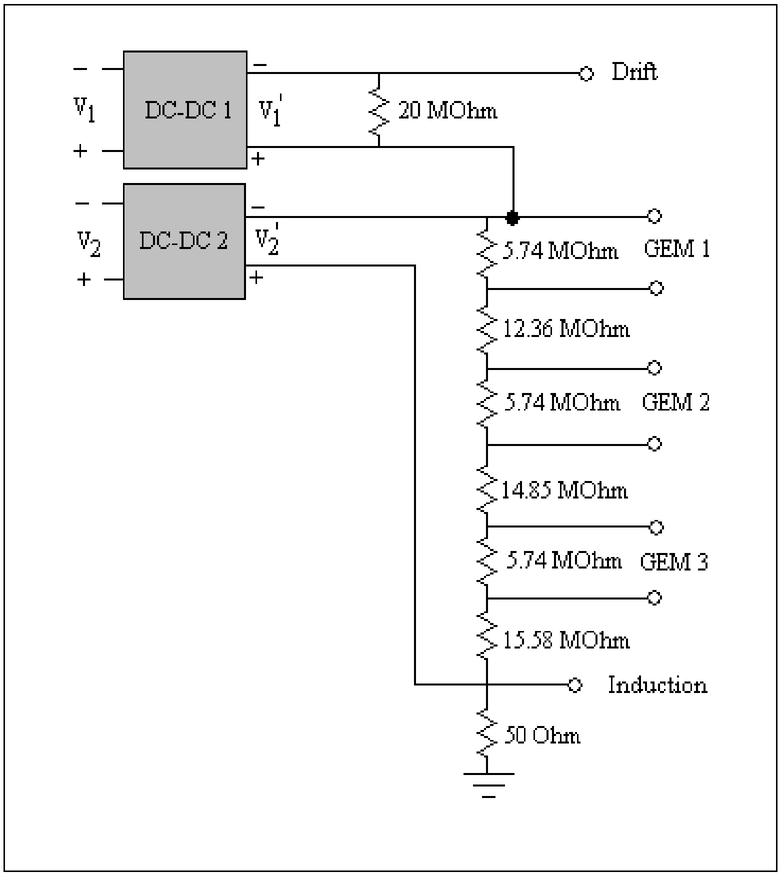


Figure 4: 3-GEM HV Circuit Board

The settings below were followed during the experimental setup that was used for signal testing:

DC-DC converters settings:

The voltage on the DC-DC converter 1 was set to:

V_1 = 2.7 V = constant during test

The voltage on DC-DC converter 2 was set to:

V_2 = 10-12 V = constant during (corresponding to V_{GEM} = ~300-330V)

[Note: Calibration measurements for DC-DC converter 2 were performed in a later stage, and the results are presented in Plots 1 and 2 of the Results section.] (See Appendix B for DC-DC converter specifications.)

Gas flow settings:

The Ar/CO_2 (70:30) flow was always set to ~75 kPa on the pressure gauge, and 80 scale units on the flowmeter scale (corresponding to 10 L/hr, according to flowmeter calibration data provided). Before any signal testing, gas was usually allowed to purge though the detector for 1-3 hrs.

[Note: An additional Ar/CO_2 (70:30) bottle was ordered and installed in September 2004. The name and address of company that provided the bottled gas is given in Appendix C.]

Data observation:

Data was observed using a Tektronix Digital Oscilloscope.

A second stage of investigation was the leakage current measurement for the GEM foils that were used. The experimental setup is shown in Figure 5.

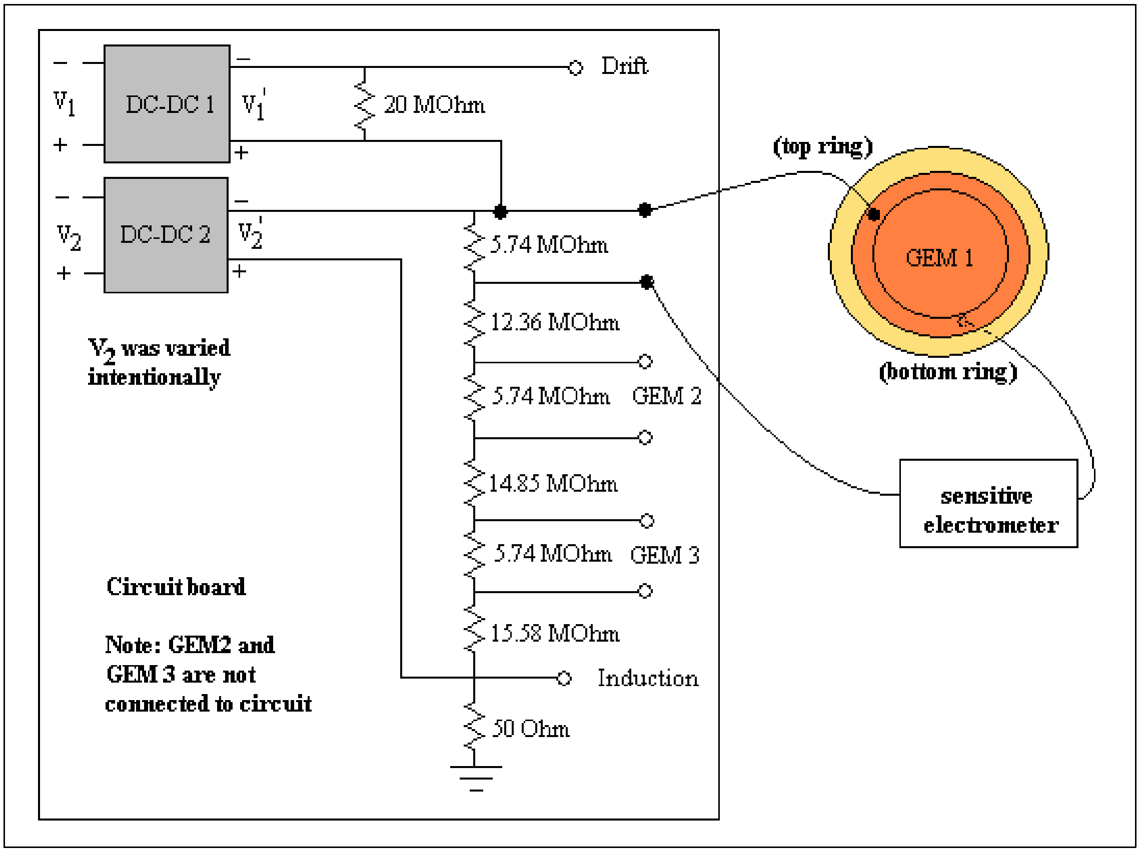


Figure 5: Experimental Setup for Leakage Current Measurements (Shown here: test for GEM 1)

The leakage current was measured using a Keithley 616 Digital Electrometer. The measurement was repeated after cleaning the GEM foils with isopropyl-alcohol. The test was conducted in order to determine the impedance of each GEM foil, as well as to investigate any charging up effects or strange behavior that the GEM foils showed. It was conducted both in Ar/CO_2 (70:30) and air, both inside and outside the detector. For the air test outside the detector, the GEM was supported in such a position that its plane was perpendicular to the horizontal plane, in order to prevent any particles from depositing on the active area while the test was running. It was supported using alligator clips, which also acted as electrodes, with one of their sides being insulated with mylar foil. The results of these tests are presented in Plots 3 to 5 of the Results section.

The basic procedure followed for cleaning GEM foils was suggested by Bob Azmoun, a researcher in the PHENIX Group at Brookhaven National Lab, via email correspondence. (See Appendix D.) The procedure, which is done under a laminar flow hood, is outlined below:

1. Spray down the foils (always at "grazing incidence") with dry N_2

2. Spray down the foils with ethyl-alcohol until foils are completely drenched, using a
   Windex-type dispenser spray
3. Before the ethanol has a chance to air dry (which could absorb particulate deposits from the
   air onto the GEM surface), quickly spray down the foils again with dry N_2 (again, always at
   "grazing incidence")

One should keep in mind that after this process the GEM impedance should drop dramatically, due to the conductivity of the remaining alcohol. However, usually after 5hrs of purging with dry gas, the impedance returns to its original value.

The procedure that was actually followed in the lab was slightly different: it was not done under a laminar flow hood, and pressured Ar/CO_2 (70:30) gas at 100 kPa was used instead of dry N_2, since the later was not available in the lab. In addition, isopropyl-alcohol was used instead of ethyl-alcohol, which is not as good a solvent as ethyl-alcohol. However, this was the only type of solvent available at the time. Methanol is an even better solvent than ethyl-alcohol that could have been used; however, it is much more dangerous, since it can cause blindness if ingested, so it was avoided.

Results

The tests performed with the first (Fujitsu) preamp in order to see whether a good signal could be obtained with the 3-GEM setup were unsuccessful; no expected results were obtained. Periodic signals, as well as random noise were observed on the oscilloscope; at specific occasions sparking was observed, both between the circuit board and the plexiglass box, and inside the GEM detector.

The tests performed with the second (BNL) preamp had the same results concerning the noise levels and sparking effects, even though this time the test was performed at a slightly lower V_{GEM} = 320V. The power supplies were tested to see if the noise signals were coming from those, but the noise levels remained unchanged. Another test was run with no HV supplied, but the noise signal persisted. In addition, during one of these tests, charge accumulation was observed on one of the four large, metal screws (shown in Figure 2) located on the top cover plate of the detector.

It is possible that sparking occurred due to bad contact between the O-rings (electrodes) and the GEM foils. Figure 6 shows how the detector electrodes were designed to fit inside the grooves of the spacer; however, in the actual design, the O-rings had a smaller outer diameter, therefore they could easily be displaced while or after assembling the detector as they were piled up, sometimes even covering a fraction of the active area of the GEM foil.

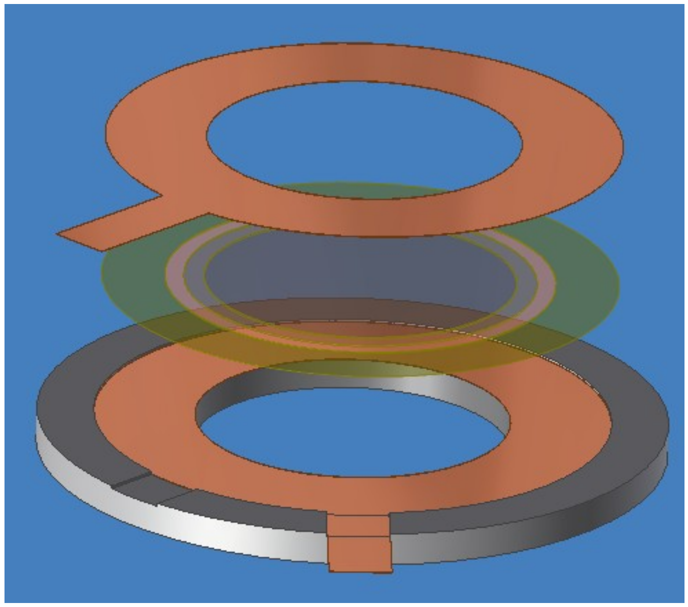
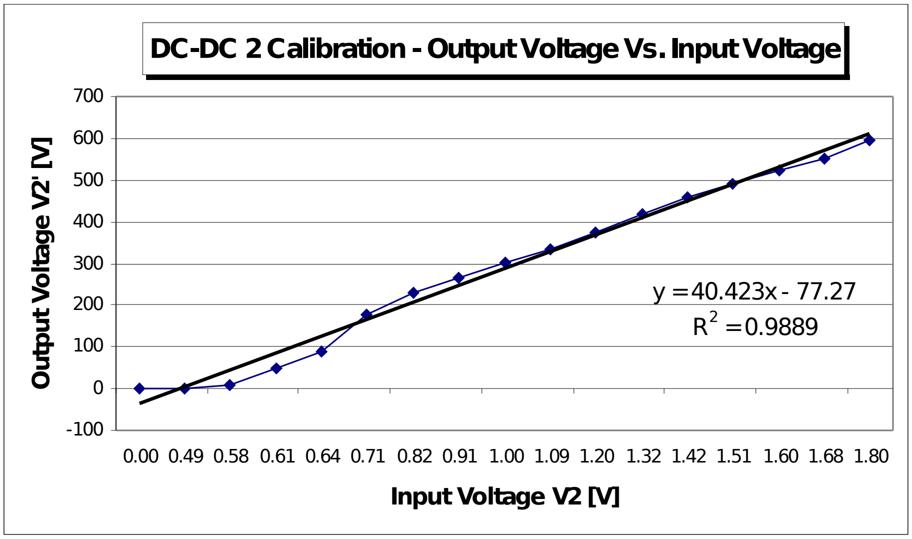


Figure 6: Placement of GEM Foil and Brass O-Rings (Electrodes) in the Detector[2]

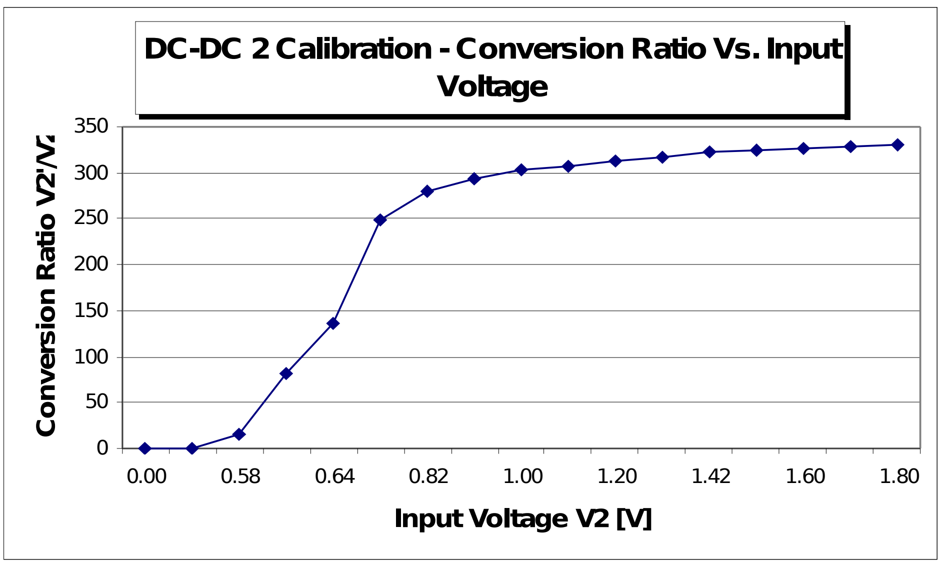
After this point, the GEM foils were cleaned using the procedure outlined above, in the Methods section. While assembling the detector component parts back together after the cleaning procedure, the gas input was found to be clogged, possibly with glue. This problem was solved using fishing wire sent through the gas tubes; this was double-checked by sensing the gas flow both in the gas input and gas output points of the detector setup.

One hour after cleaning the GEM foils, and after assembling the detector, the GEM foil impedances were measured directly between electrode points using the Keithley 616 Digital Electrometer, and they were all found to be above 10 GΩ.

After the cleaning procedure, the leakage current measurements were conducted. First, a calibration curve for the DC-DC converter 2 (used to provide V_{GEM}) was obtained to be used as a reference. Plots 1 and 2 show the behavior of the converter with respect to input voltage. (See Appendix E for raw data.)



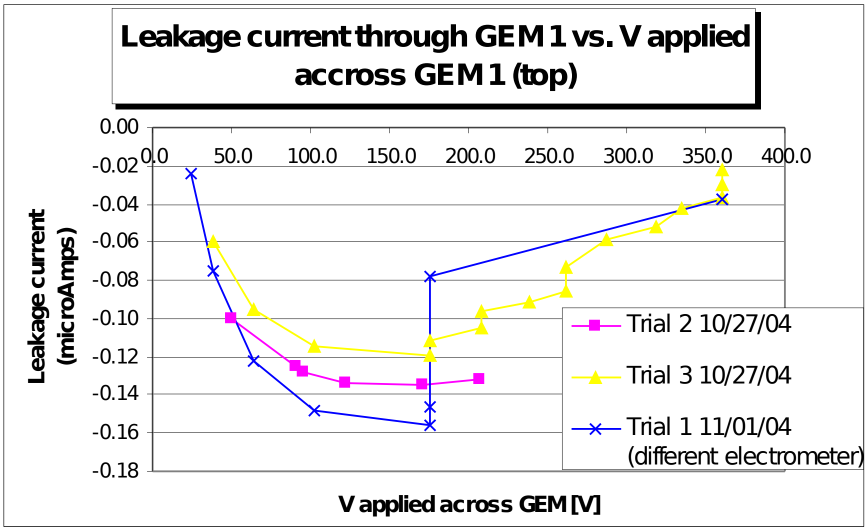
Plot 1: DC-DC Converter 2 Calibration – Output Vs. Input Voltage



Plot 2: DC-DC Converter 2 Calibration – Conversion Ratio Vs. Input Voltage

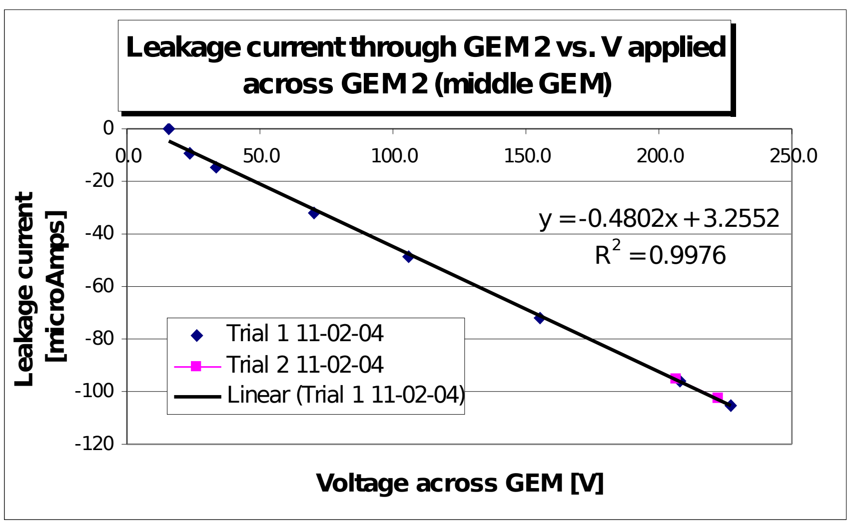
The leakage current measurements were first conducted in air, while the GEM foils were in the detector; however, sparking was observed at V_{GEM} = ~330V, possibly due to moisture accumulation after cleaning the GEM foils with alcohol (the detector had not been purged with Ar/CO_2 gas yet, since the cleaning).

When the procedure was repeated in Ar/CO_2 (after 1.5hrs of gas purging), higher potential differences were reached across the foils. Occasionally, as the potential increased, sparking was observed momentarily; as the potential was lowered soon after sparking was observed (in order to prevent foil damage) and then raised again (slowly), sparking was not disappeared. This was probably an effect due to tiny particles being sparked off of the GEM foil. In addition, the leakage currents observed to have some time dependence; their magnitude decreased with time. Also, for GEM 1, negative currents were obtained. This discrepancy might have been due to wrong polarity of the electrometer, or false grounding. The results for GEM 1 and GEM 2 are shown below, in Plots 3 and 4 (GEM 3 was not tested). (See Appendix E for raw data.)



Plot 3: Leakage Current Measurement in Ar/CO_2 (70:30) for GEM 1 (in the detector)

***Note: steep vertical line steps are due to time dependence shifts in current**

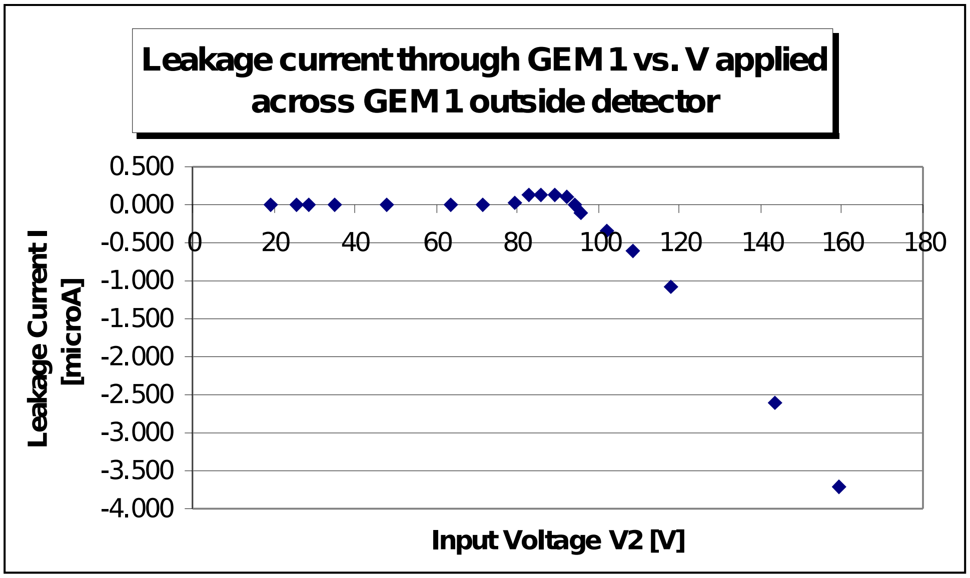


Plot 4: Leakage Current Measurement in Ar/CO_2 (70:30) for GEM 1 (in the detector)

Note that, even though GEM 2 showed stability with time, the leakage current values obtained were orders of magnitude greater than a few nA, which is what should be expected for this type of measurements[1]. In addition, the low impedances implied by the large currents were inconsistent with the previous leakage current measurement.

After this test, all the connections on the HV circuit board were soldered again, where the solder seemed to be fatigued. When GEM 1 was retested, it showed a similar behavior as before.

As a final test, GEM 1 was tested outside the detector, in air. The results are shown below, in Plot 5. (See Appendix E for raw data.)



Plot 4: Leakage Current Measurement in Ar/CO_2 (70:30) for GEM 1 (in the detector)

Conclusions

The experimental results were not satisfactory since they did not meet the expectations for a successfully operating 3-GEM detector. The leakage current measurement was inconclusive; the most probable scenario is that the GEM foils have been worn out, or permanently damaged during testing, which implies the need for their replacement. In addition, the initial design for the 3-GEM detector that was developed and tested was found to be impractical and flawed. A new 3-GEM detector setup needs to be developed, this time to employ 10x10cm^2 GEM foils. Improvements need to be made for better shielding the circuit board, the connection points between wires and electrodes on the 3-GEM detectors assembly, as well as for better gas sealing.

References

[1]B. Azmoun, G. Karagiorgi, C. Woody. A Comparative Study of GEM Foils from Different Manufacturers. <http://www.phenix.bnl.gov/WWW/TPCHBD/GEM_foil_comparison.pdf>

[2]J. Slanker, G. Karagiorgi, M. Hohlmann. Prototypes for Particle Detectors Employing Gas Electron Multipliers. FAS 68th Annual Meeting, Orlando, FL. March 12-13, 2004. < http://www.fit.edu/hep/FAS_2004_GEM_Julie.ppt>

Appendix A

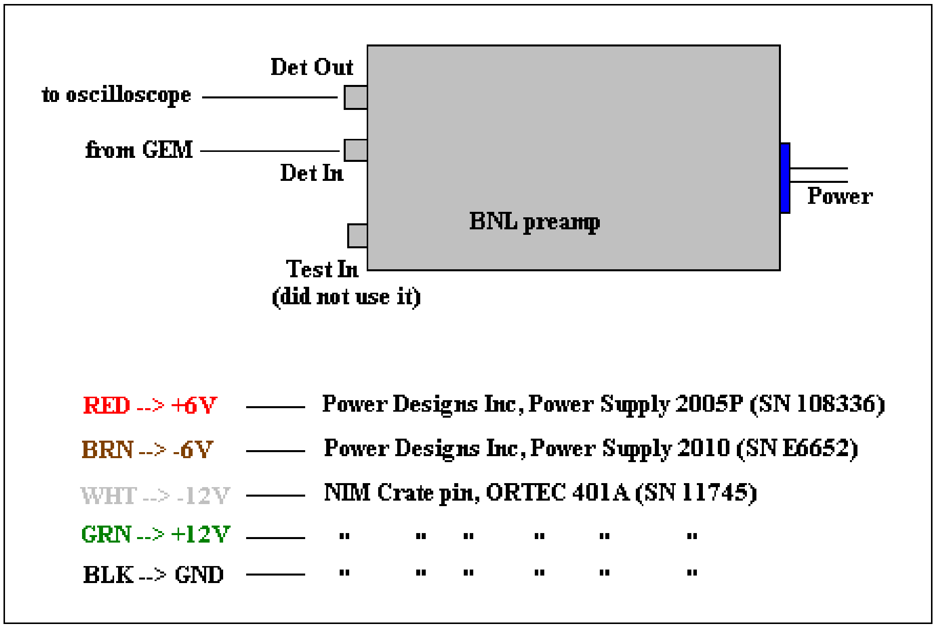


Figure 6: Reference for Connection Specifications for BNL Preamp

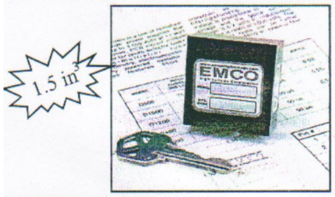
Appendix B-1

DC-DC Converter Specifications

Miniature DC to HV DC Converters

0 to + or -100 through 0 to + or -6,000 VDC @ 1.5 Watts
G Series

EMCO HIGH VOLTAGE CORPORATION



The G Series is a line of miniature, versatile component level building blocks that provide up to 6,000 VDC, positive or negative, in a compact PC mount package. The isolated output is directly proportional to the input, and is linear from approximately 0.7 volts in. Excellent filtering techniques and a low noise quasi-sinewave oscillator provide clean, reliable DC to HV DC conversion with low ripple, and low EMI/RFI. The isolated output allows for user selectable output polarity. An output center-tap option which, when grounded, provides both positive and negative outputs from one compact, low cost module. The pin pattern on the G Series allows for a direct drop-in replacement for many larger high voltage modules. The GPMT model has been specifically designed for biasing PMT's. Contact our Applications Department for immediate technical assistance.

FEATURES
- Low Ripple
- Miniature Case Size
- Low EMI/RFI Sinewave Oscillator
- Proportional Input/Output
- User-Selectable Output Polarity
- Low Cost/High Performance
- MTBF: >2.29 million hrs per Bellcore TR-332

OPTIONS
- Output Center Tap, See CT Series
- External Mounting Box, See AB Series
- Low Power Consumption, See GP Series
- 0 to 24 Volt Input (contact factory)

APPLICATIONS
- Non-impact Printers
- Sustaining Ion Pumps
- Piezo Devices
- Vacuum Gauges
- Photomultiplier Tubes
- Spectrometry
- Electrostatic Chucks
- Lamp Ignition and Drive
- Displays (see AC output option)

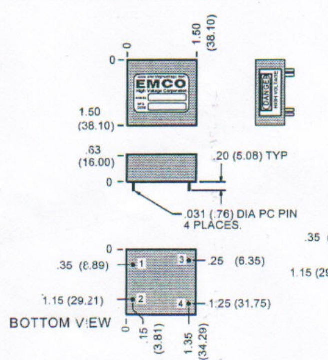
12V ⇒ 4000V

MODEL	INPUT CURRENT (NO LOAD)	INPUT CURRENT (FULL LOAD)	OUTPUT VOLTAGE	OUTPUT*[2] CURRENT	RIPPLE
G01	<100 mA	<250 mA	0 to +/-100V	0 to15 mA	<1.75%
G02	<100 mA	<250 mA	0 to +/-200V	0 to 7.5 mA	<0.75%
G03	<100 mA	<250 mA	0 to +/-300V	0 to 5 mA	<0.75%
G05	<100 mA	<250 mA	0 to +/-500V	0 to 3 mA	<0.02%
G06	<100 mA	<250 mA	0 to +/-600V	0 to 2.5 mA	<0.1%
G10	<100 mA	<250 mA	0 to +/-1,000V	0 to 1.5 mA	<0.1%
G12	<150 mA	<275 mA	0 to +/-1,200V	0 to 1.25 mA	<0.1%
G15	<125 mA	<275 mA	0 to +/-1,500V	0 to 1 mA	<0.5%
G20	<165 mA	<275 mA	0 to +/-2,000V	0 to 0.75 mA	<0.5%
G25	<125 mA	<275 mA	0 to +/-2,500V	0 to 0.6 mA	<1.0%
G30	<125 mA	<300 mA	0 to +/-3,000V	0 to 0.5 mA	<1.0%
G40*[1]	<125 mA	<300 mA	0 to +/-4,000V	0 to 0.37 mA	<1.0%
G50*[1]	<125 mA	<300 mA	0 to +/-5,000V	0 to 0.3 mA	<2.0%
G60*[1]	<125 mA	<300 mA	0 to +/-6,000V	0 to 0.25 mA	<2.0%
Photomultiplier Model					
GPMT	<30 mA	<75 mA	0 to +/-1,250	0 to 350 uA	<.05%

*Notes 1. Models G40, G50 & G60 do not have internal bleeder resistors on the output. Provisions must be made externally to discharge the output capacitors if this feature is desired.
2. At Maximum Rated Output Voltage.

PHYSICAL CHARACTERISTICS
SIZE: 1.5 x 1.5 x 0.63 (38.1 x 38.1 x 16.0)
WEIGHT: 1.5 Ounces (43 Grams) Approx.
PACKAGING: Fully Encapsulated
CASE MATERIAL: Glass-filled Epoxy
PINS: .031 (.79) Diameter, 0.2 (5.1) Long

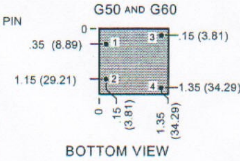
ELECTRICAL SPECIFICATIONS
INPUT VOLTAGE: 0 to 12 Volts
TYPICAL TURN-0N VOLTAGE: 0.7 Volts
OUTPUT VOLTAGE: *See Table*
OUTPUT CURRENT: *See Table*
RIPPLE: *See Table*
LOAD REGULATION: 10% (No Load to Full Load) Typical
ISOLATION: 3,500 Volts (Input to Output)
OPERATING TEMP: -10° to +60° C



Pin #	Function
1	(+) Input
2	(-) Input
3	(+) Output
4	(-) Output

Dimensions are in Inches
Dimensional Tolerances: ± .03 (.76)
(Metric Equivalents in Parenthesis)

G50 AND G60



us at: www.emcohighvoltage.com
l us at: sales@emcohighvoltage.com
Call us at: (209) 223-3626 Fax us at: (209) 223-2779
11126 Ridge Road, Sutter Creek CA 95685

Appendix B-2

Table 1: DC-DC 2 Calibration Raw Data

Input V (V2) [V]	Output V (V2') [V]	Conversion Ratio = V2'/V2
0.000	0.000	0.00
0.485	0.005	0.01
0.580	8.500	14.66
0.613	50.500	82.38
0.640	87.000	135.94
0.711	177.300	249.37
0.818	229.600	280.68
0.909	266.300	292.96
1.000	303.300	303.30
1.087	333.700	306.99
1.202	376.000	312.81
1.316	417.000	316.87
1.424	459.000	322.33
1.514	492.000	324.97
1.602	523.000	326.47
1.684	553.000	328.38
1.804	595.000	329.82

Appendix C

Type of gas ordered:
Compressed Ar/CO_2 (70:30)

Name and contact information of gas provider company:

Boggs Gases
620 Main St.
Titusville, FL 32796
Tel. (321) 267 4110

Appendix D

Email correspondence with Bob Azmoun, PHENIX Group, BNL – Regarding cleaning procedure for GEM foils.

From	"B. Azmoun" <azmoun@bnl.gov>
Subject	Re: Cleaning GEM foils
Date	Sat, November 6, 2004 4:54 pm
To	"Georgia Karagiorgi" <gkaragio@fit.edu>

Hi Georgia,
Nice to hear from you! All is well here, except very busy writing papers and such.

As far as cleaning is concerned, I can't remember whether you actually saw me clean any foils. In any case, I first spray down the foils with dry N2 at "grazing incidence" (as you saw), then I spray down the foils with Ethyl alc until the foils are completely drenched (I use a Windex-type dispenser spray). BTW, this is all done under the laminar flow hood that's in the lab. Before the alc has a chance to air-dry (which could adsorb particulate deposits from the air onto the GEM surface) I quickly spray down the foils again with dry N2 quite a bit, beyond the point where the foils are apparently dry--again at grazing incidence. One thing to keep in mind is that after this process, the impedance of the foils goes down dramatically due to the conductivity of the remaining alc on the foils. Usually after
5hrs of purging with dry gas, the impedance returns to its original value.
Hope this helps. Let me know if you have other questions.

Bob

----- Original Message -----
From: "Georgia Karagiorgi" <gkaragio@fit.edu>
To: "B. Azmoun" <azmoun@bnl.gov>
Sent: Thursday, October 07, 2004 3:21 PM
Subject: Cleaning GEM foils

> Hi Bob,
>
> How are you? I hope your research is going well.
>
> I have a question about the cleaning procedure of the GEM foils and I was wondering if you could help me. I am trying to clean the 3-GEM detector we have here in our lab, and Dr. Marcus Hohlmann has

mentioned to me that GEMs can be cleaned with alcohol; I couldn't remember if we did that for any of the GEM foils that we used during the summer (at BNL), so I don't know if this is actually true. If so, do you happen to know what exactly the process includes?
>
> Thank you.
>
> ~Georgia Karagiorgi
>

From	"B. Azmoun" <azmoun@bnl.gov>
Subject	Re: Cleaning GEM foils
Date	Mon, October 18, 2004 12:36 pm
To	"Georgia Karagiorgi" <gkaragio@fit.edu>

Hi Georgia,
Sorry for the late response, I was out of town the past week. I suppose isopropyl alc is Ok, but I don't think it's as good a solvent as ethyl alc. Methanol is even better than ethyl alc, but it's more dangerous--methanol is the alcohol that causes blindness if ingested...if possible, go with ethyl alc.

Regards,
Bob

----- Original Message -----
From: "Georgia Karagiorgi" <gkaragio@fit.edu>
To: "B. Azmoun" <azmoun@bnl.gov>
Sent: Wednesday, October 13, 2004 11:48 PM
Subject: Re: Cleaning GEM foils

> Hi Bob,
>
> I would like to ask you for one more thing about the cleaning of GEMs. Do you happen to know if there is or could be any reason why one could clean the GEMs using Ethyl-alcohol and not Iso-propanol?
>
> ~Georgia

Appendix E

*Note: For the following tests, the output voltage was approximated using a conversion factor of 333 for simplicity reasons, even though during the DC-DC converter 2 calibration it was found that at low input voltage this linearity breaks. Consult Plot 2 for more accurate values.

Table 2: Leakage Current Raw Data for GEM 1 in Ar/CO2 (70:30) - inside detector

10/27/2004	**V2 [V]**	**V2'=V2(333)(5.74/60) [V]**	**Leakage I [microA]**	
Trial 1	1.27	40.5	-6.26	
	2.28	72.6		sparking!
Trial 2	1.58	50.3	-0.100	
	2.85	90.8	-0.125	
	3.00	95.6	-0.128	
	3.84	122.3	-0.134	
	5.35	170.4	-0.135	
	6.50	207.1	-0.132	
	6.50	207.1	-0.114	2 min later
Trial 3	1.20	38.2	-0.060	
	2.00	63.7	-0.095	
	3.20	101.9	-0.115	
	5.50	175.2	-0.119	
	5.50	175.2	-0.112	2 min later
	6.54	208.3	-0.105	
	6.54	208.3	-0.096	2 min later
	7.50	238.9	-0.091	
	8.20	261.2	-0.086	
	8.20	261.2	-0.073	2 min later
	9.00	286.7	-0.059	
	10.0	318.6	-0.052	

	10.5	334.5	-0.042	
	11.3	360.0	-0.037	
	11.3	360.0	-0.030	2 min later
	11.3	360.0	-0.022	2 min later

Table 3: Leakage Current Raw Data for GEM 1 in Ar/CO2 (70:30) - inside detector

11/1/2004	V2 [V]	V2'=V2(333)(5.74/60) [V]	Leakage I [microA]	<u>*Using different electrometer</u>
Trial 1	0.75	23.9	-0.024	
	1.20	38.2	-0.075	
	2.00	63.7	-0.122	
	3.20	101.9	-0.148	
	5.50	175.2	-0.156	
	5.50	175.2	-0.146	2 min later
	5.50	175.2	-0.078	40 min later
	11.3	360.0	-0.038	after 10 min at 11.3V

Table 4: Leakage Current Raw Data for GEM 2 in Ar/CO2 (70:30) - inside detector

10/27/2004	V2 [V]	V2'=V2(333)(5.74/60) [V]	Leakage I [microA]	
Trial 1	0.50	15.9	-0.04	
	0.75	23.7	-9.37	
	1.06	33.8	-14.4	*values are stable after ~2min
	2.20	70.1	-32.0	
	3.32	105.8	-48.6	
	4.88	155.5	-71.7	
	6.53	208.0	-96.0	
	7.12	226.8	-105	sparking!
Trial 2	6.48	206.4	-95.3	
	6.98	222.4	-102.6	
	7.12	226.8		sparking!

Table 4: Leakage Current Raw Data for GEM 1 in Air - outside detector

11/16/2004 Trial 1	V2 [V]	V2'=V2(333)(5.74/60) [V]	Leakage I [microAmps]	
	0.6	19.1142	0.004	
	0.8	25.4856	0.0033	
	0.9	28.6713	0.002	
	1.1	35.0427	0.001	
	1.5	47.7855	0.0007	
	2	63.714	0.006	
	2.25	71.67825	0.0108	
	2.5	79.6425	0.017	
	2.6	82.8282	0.127	
	2.7	86.0139	0.132	
	2.8	89.1996	0.13	
	2.9	92.3853	0.1	
	2.95	93.97815	0.003	Fluctuates a lot between
	3	95.571	-0.1	-0.1 and 0.5 microAmps
	3.2	101.9424	-0.35	
	3.4	108.3138	-0.6	
	3.7	117.8709	-1.09	
	4.5	143.3565	-2.6	For V2=4.5V, high-f sound coming from DC-DC converter, but no
	5	159.285	-3.7	change in curent