Investigation and Mitigation of Crosstalk Observed in the Prototype ME0 GEM Detector

Stephen D. Butalla\textsuperscript{1}, Elizabeth Starling\textsuperscript{2}, & Marcus Hohlmann\textsuperscript{1}

\textsuperscript{1}Florida Institute of Technology, \textsuperscript{2}Université libre de Bruxelles

on behalf of the CMS Muon Group

May 19, 2020

GEM Phase-2 Upgrade Workshop 2020
Introduction

- Cross-talk due to capacitive coupling has been observed in GE1/1, GE2/1, and ME0 chambers with double-segmented foils, as well as in $10 \times 10$ GEM detectors.
- Experimental setup at FIT and 904 with an ME0 chamber was used to characterize the crosstalk.
- This talk will present the results of our investigations into the crosstalk observed in an ME0 GEM detector with double-segmented GEM foils.
- We will also discuss mitigation strategies and the results of these interventions.
Motivation

- Crosstalk was first noticed and discussed by D. Fiorina [1, 2] during effective gain measurements on an ME0 chamber (the famous “double-polarity” signals).
- Scope traces below show an example of a good signal and a crosstalk signal.

![Good Signal](image1)

![Bad (crosstalk) Signal](image2)
Motivation

- VFAT3 analog amplifier circuit simulation by F. Licciulli shows that the XT signal can overshoot the ARM-discriminator threshold (and therefore register as a “real” signal)

Real signal (red) and crosstalk signal occurring ∼ 200 ns later (from F. Licciulli).

- This immediately presents an issue for the detector system to operate nominally
Goals

1. Quantify the magnitude of crosstalk and how it affects all of the readout (RO) sectors in the detector

2. Test mitigation strategies by reducing the impedance of GEM3B to ground, including bypass capacitors, and increasing the area of the HV partitions on GEM3B
Hypothesis

Proposed by M. Hohlmann [3, 4]: (see next talk)

- If we consider the capacitive coupling between RO sectors as a capacitor, and the 50 Ω impedance of a LEMO cable, we can approximate the behavior of this system as a high pass filter due to the fast, rising edge of the “real” signal [3].

![High-pass CR filter (differentiator): (a) basic circuit; (b) step input; (c) single (square) pulse (RC = T); (d) single pulse (RC ≫ T); (e) single pulse (RC ≪ T); (f) pulse train.](image)

Figure and caption reproduced from [5].
Confirmation of Hypothesis

- We observe very similar behavior when comparing the output of the (theoretical) CR differentiator circuit and the crosstalk pulses we observe.

Comparison between the scope trace and the output of a CR differentiator using a square pulse with a time constant equal to the circuit’s time constant. From M. Hohlmann [3] and D. Fiorina [2].
Hypothesis

- The “real” signal pulse induced on the readout strips is approximately a square pulse with a width on the order of 10 ns
- To experimentally test crosstalk under more controlled conditions, we can apply a square voltage pulse to a RO sector, and read the crosstalk signal out of other sectors

Good Signal [2].
Experimental Setup at FIT

- Tektronix TDS1012B 2 Channel, 100 MHz Oscilloscope (connections terminated with 50 Ω terminators)
- Siglent SDG2015 25 MHz Signal Generator
- Siglent SDG5162 160 MHz Signal Generator
- All Panasonic-to-LEMO adapters connected to shielding plate on GND pad, plate connected to common ground
Experimental Setup at FIT

Pulsing into a readout sector and reading out of a readout sector:
The following mapping convention \((i_\eta, i_\phi)\) partition scheme is used
Main Results: Injection into RO Sector

Input: $i_\eta = 8$, $i_\phi = 1$ RO connector
Output: $i_\eta = 8$, $i_\phi = 2$ RO connector
Channel 1: Pulse Generator
Channel 2: $i_\eta = 8$, $i_\phi = 2$ RO connector

We see XT between $i_\eta$ and $i_\phi$ partitions

$\tau \approx 60$ ns
Pulse Profile Comparison

Width = 20 ns

Approximately equal areas

Width = 100 ns

Almost fully exponential

Width = 1 \mu s

Figure on left from [5].

S. Butalla, E. Starling, & M. Hohlmann – “ME0 Crosstalk Investigation and Mitigation Studies” – May 19, 2020
Quantifying the Crosstalk

- To quantify the magnitude of the crosstalk, we take the ratio of $V_{\text{out}}/V_{\text{in}}$, as measured on the scope:

$$XT\% = \frac{V_{\text{out}}}{V_{\text{in}}} \cdot 100\%$$

with error given by:

$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{V_{\text{out}}}\right)^2} \cdot 100\%$$

- If the XT amplitude was indistinguishable from the baseline noise, the XT was recorded as zero.
- For zero XT, the error is not quoted because it is undefined, i.e., if the output pulse amplitude is 0 mV:

$$XT\% = \frac{0}{V_{\text{in}}} \cdot 100\% = 0$$

$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{0}\right)^2} \cdot 100\% = \text{undefined}$$

- Crosstalk maps were made for pulsing into each $i\phi$ partition of $i\eta = 1, 5, 8$ [6]

Example measurement for crosstalk magnitude
XT Map: Pulsing into (8,2)

<table>
<thead>
<tr>
<th>Eta Sector</th>
<th>0</th>
<th>1.8 ± 0.11</th>
<th>Pulse Input</th>
<th>2 ± 0.11</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0</td>
<td>0.8 ± 0.04</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

XT (%)

Pulse Input
XT Map: Pulsing into (5,2)
### XT Map: Pulsing into (1,1)

#### 2D Heatmap

<table>
<thead>
<tr>
<th>Eta Sector</th>
<th>Phi Sector 1</th>
<th>Phi Sector 2</th>
<th>Phi Sector 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>7</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>6</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>5</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>4</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>3</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>2</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>1</td>
<td>0.68 ± 0.04</td>
<td>0.36 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
</tbody>
</table>

#### 3D Graph

- **Pulse Input**
  - Phi Sector 1: 3.6 ± 0.21
  - Phi Sector 2: 2.5 ± 0.11
From the XT maps, we extracted the minimum and maximum XT observed (the first column is the sector being pulsed)

**Table 1: Crosstalk Range**

<table>
<thead>
<tr>
<th>$i\eta$ Sector</th>
<th>Minimum XT (%)</th>
<th>Maximum XT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.24±0.04</td>
<td>3.80±0.21</td>
</tr>
<tr>
<td>5</td>
<td>0.20±0.04</td>
<td>6.40±0.42</td>
</tr>
<tr>
<td>8</td>
<td>0.16±0.04</td>
<td>4.00±0.22</td>
</tr>
</tbody>
</table>
XT Seen in \((i\eta = 8, i\phi = 3)\)

- To get a better idea of how the XT scales with input pulse amplitude, the (measured) input pulse amplitude was varied over [10 mV, 600 mV] range
- The results indicate that crosstalk scales proportionally with input pulse amplitude, down to a level where it is unable to be differentiated from the baseline
Experimental Setup at 904

- Experimental setup and procedure of measurement/data analysis replicated at 904 with an unmodified ME0 chamber
- 5 MΩ protection resistor foils used
- Wavetek 395 100 MHz synthesized arbitrary waveform generator
- Tektronix TDS 2024C four channel digital storage oscilloscope, signal terminated with a 50Ω resistor
- Pulses injected into ($i_\eta = 8$, $i_\phi = 3$)
Example Scope Traces of Crosstalk

Average Normalized Cross-Talk Amplitudes in ME0

Pulse Input
Results at 904

- Similar results obtained to the setup at FIT
- Crosstalk ranges from 0.89% to 7.4%
- Crosstalk seen in sectors more than one $i\eta$ partition away could be a result of the lack of grounding (pulse pickup was observed at the FIT setup when no shielding plate/grounding was used)
- Due to the COVID-19 lockdown, comprehensive measurements and grounding have not yet been implemented
Mitigation Strategies

- We considered three mitigation strategies:
  - Reducing the impedance of GEM3B to ground (see backup)
  - Increasing the size of the HV segments on GEM3B
  - Bypass capacitors

- XT maps using the same experimental technique/data analysis were repeated
Modifying GEM3B

- The following modifications made to GEM3B:
  - 5 330±5% pF bypass capacitors ([https://www.digikey.com/product-detail/en/yageo/CC1206JRN0BBN331/311-4435-1-ND/8025524](https://www.digikey.com/product-detail/en/yageo/CC1206JRN0BBN331/311-4435-1-ND/8025524)) were soldered to the HV segments on GEM3B in $i\eta = 8$ and covered with Kapton tape (without the Kapton tape, there was a short between GEM3B and the $i\eta = 6-8$ RO sectors)
  - Three protection resistors on the HV segments in $i\eta = 5$ on GEM3B were removed and connected together with solder
  - Square pulse with 500 mV amplitude and 1 $\mu$s width was used for all XT maps [except for the baseline configuration in (5,1)]
  - We will present the “unmodified” baseline XT map, the modified XT map, and a map that shows the change in XT for 6 RO sectors
New Sectors Exhibiting XT

- From previous studies [7, 8, 9], the observed XT was localized to the same $i\eta$ sector being pulsed, and extended 1 $i\eta$ sector in either direction.
- After performing the modifications to the chamber, we observed XT in $i\eta$ sectors up to 4 away from the sector being pulsed:
- This XT typically has a small magnitude ($\lesssim 0.4\%$).
- Note also that many of these sectors do not have the enlarged HV segmentation or bypass capacitors on GEM3B (e.g., $i\eta$ sectors 1-4,6,7).

**Pulsing into (5,3), reading out of (1,1)**

Before modification

After modification
XT Maps: Pulsing into (8,2)
XT Map: Pulsing into (5,2)
Summary of Interventions to Mitigate the Crosstalk

- The addition of bypass capacitors in $i_\eta = 8$ and increasing the area of the HV segments in $i_\eta = 5$ on GEM3B have increased the XT in $(i_\eta, i_\phi)$ sectors where it was previously not detected.
- The modifications in $i_\eta = 8$ lead to reductions in crosstalk in $i_\eta = 7, 8$, which is expected from the addition of the bypass capacitors.
- Unexpected behavior of XT when pulsing into (5,1) and (5,3), but expected behavior when pulsing into (5,2).

Observations:

- Adding bypass capacitors to the HV segments on GEM3B in $i_\eta = 8$ have:
  - **Reduced** the XT in $i_\eta = 8$ (across $i_\phi$ partitions) by an average of $\sim 26\%$.
  - **Reduced** the XT in the adjacent $i_\phi$ sector in $i_\eta = 7$ by an average of $\sim 36\%$.
- Increasing the total area of the HV segments on GEM3B in $i_\eta = 5$ has:
  - **Increased** the XT in $i_\eta = 5$ (across $i_\phi$ partitions) by an average of $\sim 15\%$.
  - **Increased** the XT in the adjacent $i_\phi$ sector in $i_\eta = 4, 6$ by an average of $\sim 250\%$ (one outlier of $+1400\%$).
Current Status of the ME0 Setup at FIT

- COVID-19 restrictions have been relaxed in Florida ⇒ work is ongoing at Florida Tech with adherence to CDC guidelines
- Bypass capacitors and all protection resistors have been removed from GEM3B, and all HV segments are connected in parallel with solder (where the protection resistor was)
- After these modifications were completed, GEM2 experienced a short
- After attempting flushing with CO2 for several days and then sparking, we disassembled the stack and are currently trying to find the shorted sectors and resurrect the foil
- If this intervention fails, we will replace GEM2 with a 5 MΩ protection resistor foil from our other ME0 kit
Remaining R&D Work at FIT and 904

At FIT:

- Retake XT maps with all HV sectors on GEM3B connected in parallel
- Before assembly of this ME0, we drilled three ~3mm holes were drilled in the drift (to allow for $\alpha/\beta$ to enter the gas volume)
- Perform QC steps (leak test, HV test, effective gain and gain uniformity test)
- Perform HV discharge and discharge probability studies

At 904:

- Improve grounding of the chamber and retake comprehensive XT maps
Summary and Conclusions

- Capacitive coupling between RO sectors causes the observed crosstalk
- We see XT between RO sectors and between HV segments on the GEM foil
- Crosstalk ranges between 0.16% and 6.40% for the original configuration of the ME0 at FIT
- Crosstalk ranges between 0.89% and 7.40% for the ME0 studies at 904
- Bypass capacitors in parallel to the protection resistors reduced the XT by an average of 31%
- Increasing the area of the HV segments on GEM3B showed inconclusive results; XT reduced when pulsing into (5,2), but increased when pulsing into (5,1) and (5,3)
Acknowledgements

- We would like to thank M. Rahmani, B. Steffens (graduate students at FIT), D. Roy, C. Gettel, and J. Weatherwax (undergraduate students at FIT), and T. Elkafrawy (postdoctoral researcher) for their help with constructing the ME0.

- We would also like to thank M. Rahmani, B. Steffens, and T. Elkafrawy for their help with the crosstalk studies.
References


Backup
Experimental Setup at FIT

Pulsing into the GEM foil and reading out of a GEM foil:

- Pulse into HV segment of GEM foil
- Reading out of GEM foil to scope
Experimental Setup at FIT

- To quantify and characterize the crosstalk, we injected a square voltage pulse into HV segments on GEM3B and various RO sectors.
- Before assembly of an ME0, we modified a 10 MΩ, double-segmented ME0 foil with four LEMO cables (outer insulation and outer conductor removed to accommodate the wires inside of the chamber).
- Cables were soldered to three HV sectors on the protection resistor pad, with an additional cable on the opposite side of an HV sector (see next slide for a diagram and image), and insulated further with Kapton tape.
Experimental Setup at FIT

- Modified GEM3 bottom:

GEM3 Bottom

LEMO soldered to edge of active area

Convention:
1. Narrow
2. Middle
3. Wide

LEMO soldered to protection resistor pad
Main Results: Injection into HV Segment

Input: (1) GEM3 bottom, Narrow HV segment input
Output: GEM3 bottom, Middle HV segment
Channel 1: Pulse Generator
Channel 2: Middle HV segment output

We see cross-talk between HV segments of the GEM foil when a pulse is applied to one segment
Main Results: Injection into HV Segment

Input: (1) GEM3 bottom, Narrow HV segment input
Output: $i_\eta = 8$, $i_\phi = 1$ RO connector
Channel 1: Pulse Generator
Channel 2: $i_\eta = 8$, $i_\phi = 1$ RO connector

We see an induced pulse on the RO connector; very similar across $i_\eta$ partitions
Varying the width of the input pulse confirms the CR differentiator hypothesis.

Note that under 1 µs square pulse width, the impedance mismatch of the detector/scope system distorts the shape of the input pulse.

Width = 20 ns  Width = 100 ns  Width = 250 ns  Width = 1 µs
Pulse Pickup from Hirose-to-Panasonic Adapters

- We discovered that the vias on the bottom of the FlexPCB adapters (left image) were picking up a signal when contacting the grounding plate (right image).
- Similar signals are seen when no grounding configuration is used.
Pulse Pickup from Hirose-to-Panasonic Adapters

- To insulate the bottom of the adapter, we added a 1 mm FR4 spacer held in place with Kapton tape (left).
- With this insulation, there is no pulse pickup, just what is read out of the sector (right).

*Note that in \((i_\eta = 7, \ i_\phi = 2)\) there was no spacer added; no measurements were made here and the bottom of the FlexPCB adapter did not contact the grounding plate.*
### XT Map: Pulsing into (1,2)

<table>
<thead>
<tr>
<th>Eta Sector</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.24 ± 0.04</td>
<td>0.72 ± 0.04</td>
<td>0.24 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.6 ± 0.21</td>
<td>Pulse Input</td>
<td>3.8 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>Phi Sector</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

#### 3D View

- Pulse Input
- XT (%)

---

S. Butalla, E. Starling, & M. Hohlmann – “ME0 Crosstalk Investigation and Mitigation Studies” – May 19, 2020
**XT Map: Pulsing into (5,1)**

*200 mV input pulse amplitude*
### XT Map: Pulsing into (5,2)

#### Table:

<table>
<thead>
<tr>
<th>Eta Sector</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.2(\pm 0.1)</td>
<td>6.4(\pm 0.42)</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.2(\pm 0.11)</td>
<td>5.6(\pm 0.42)</td>
<td>0.4(\pm 0.04)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Diagram:

- **Pulse Input**
- **XT (%)**

---

S. Butalla, E. Starling, & M. Hohlmann – “ME0 Crosstalk Investigation and Mitigation Studies” – May 19, 2020
XT Map: Pulsing into (5,3)

XT Map: Pulsing Into (5,3)

Pulse Input

S. Butalla, E. Starling, & M. Hohlmann – “ME0 Crosstalk Investigation and Mitigation Studies” – May 19, 2020
*The baseline noise for this XT map was higher than usual*
### XT Map: Pulsing into (8,2)

<table>
<thead>
<tr>
<th>Eta Sector</th>
<th>Phi Sector</th>
<th>XT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1</td>
<td>0.8 ± 0.04</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Pulse Input**

** ediary Data: 1.8 ± 0.11**
XT Seen in \((i\eta = 8, i\phi = 2)\)

**XT vs. Measured Input Pulse Amplitude**

Input: RO Connector \((i\eta = 8, i\phi = 1)\)
Output: RO Connector \((i\eta = 8, i\phi = 2)\)

Least Squares Fit

\[ f(x) = p_0 x + p_1 \]

Coefficients (with 95% confidence bounds)

\[ p_0 = 0.0003406 (-0.001057, 0.001738) \]
\[ p_1 = 2.471 (1.996, 2.947) \]

\[ R^2 = 0.02 \]

\[ \chi^2/\text{NDF} \text{ of dataset: 2.44} \]
Example Scope Traces of Crosstalk at 904

Pulsing into (8,3)

Reading out of (5,1)  Reading out of (3,1)
To determine the effect of decreasing the impedance of GEM3B to ground, the wire soldered to the other side of the narrow HV strip was connected to the common ground of the grounding plate on the MEO:

- HP 8012B pulse generator used with inverted square pulse (20 ns pulse width)
Effect of Decreasing the Impedance of GEM3B to GND

Pulsing into \((i_\eta = 8, i_\phi = 1)\), reading out of \((i_\eta = 8, i_\phi = 2)\)

- **200 mV Measured Input Pulse Amplitude**
- **400 mV Measured Input Pulse Amplitude**
- **600 mV Measured Input Pulse Amplitude**

Note the different voltage scales on channel 2
Effect of Decreasing the Impedance of GEM3B to GND

Pulsing into \((i\eta = 8, i\phi = 1)\), reading out of \((i\eta = 8, i\phi = 2)\)

**XT vs. Measured Input Pulse Amplitude**

- Narrow HV Segment Grounded
- Narrow HV Segment Not Grounded

Measured Input Pulse Amplitude (mV)
New Sectors Exhibiting XT

- Another example
- Scope trace on left had a probe connected to GEM3B on channel 1, and channel 2 was output from (7,1)

**Pulsing into (5,2), reading out of (7,1)**

![Scope traces before and after modification](image)

Before modification

After modification
XT Maps: Pulsing into (8,1)
XT Map: Pulsing into (5,1)
XT Map: Pulsing into (5,3)