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

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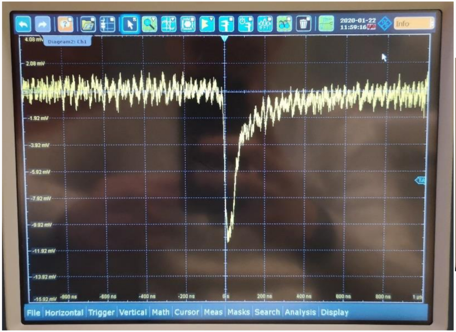
Introduction

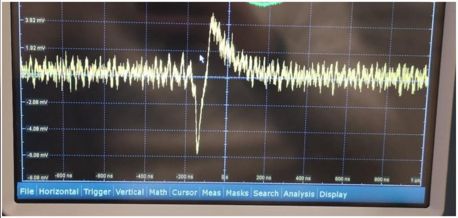
- Cross-talk due to capacitive coupling has been observed in GE1/1, GE2/1, and ME0 chambers **with double-segmented foils**, as well as in 10×10 GEM detectors
- Experimental setup at FIT and 904 with an ME0 chamber was used to characterize the crosstalk
- This talk will present the results of our investigations 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



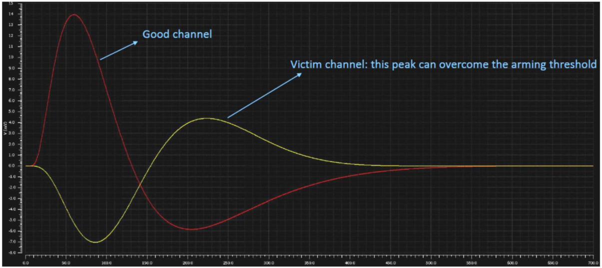
Good Signal [2].



Bad (crosstalk) Signal [2].

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).

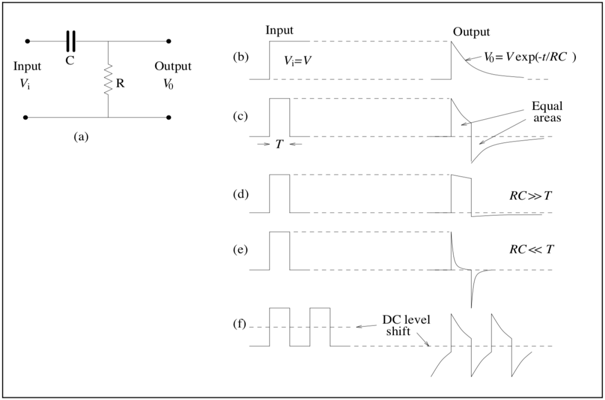
- This immediately presents an issue for the detector system to operate nominally

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

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

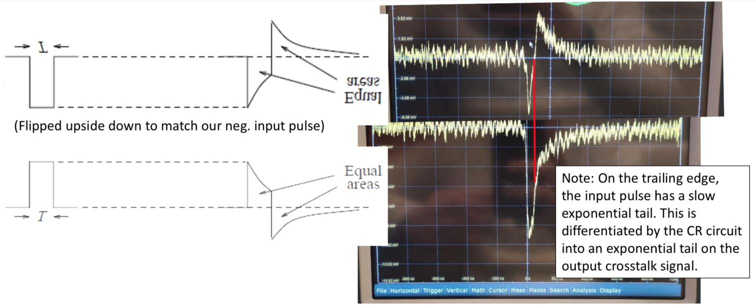
- If we consider the capacitive coupling between RO sectors as a capacitor, and the 50 Ω impedance of a LEMO cable, we can approximate the behavior of this system as a high pass filter due to the fast, rising edge of the "real" signal [3]



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. Figure and caption reproduced from [5].

Confirmation of Hypothesis

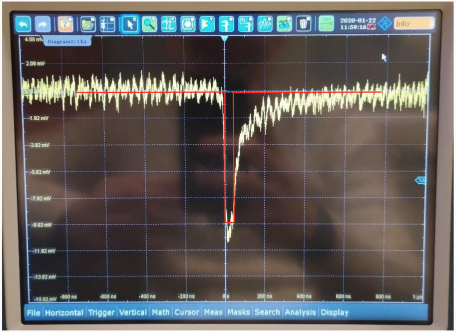
- We observe very similar behavior when comparing the output of the (theoretical) CR differentiator circuit and the crosstalk pulses we observe



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

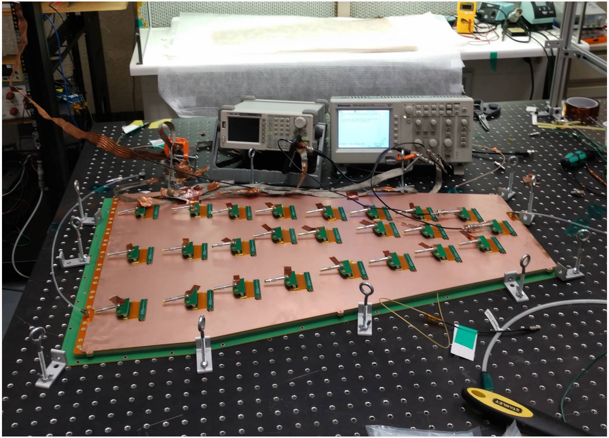
- The "real" signal pulse induced on the readout strips is approximately a square pulse with a width on the order of 10 ns
- To experimentally test crosstalk under more controlled conditions, we can apply a square voltage pulse to a RO sector, and read the crosstalk signal out of other sectors



Good Signal [2].

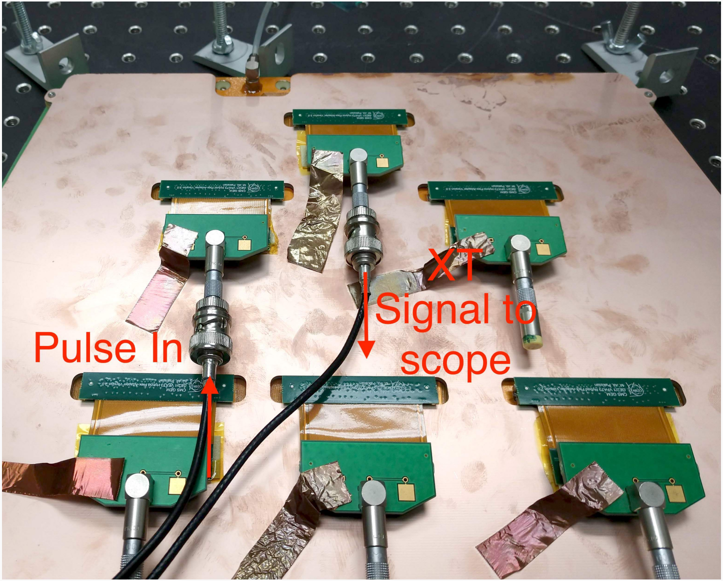
Experimental Setup at FIT

- 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



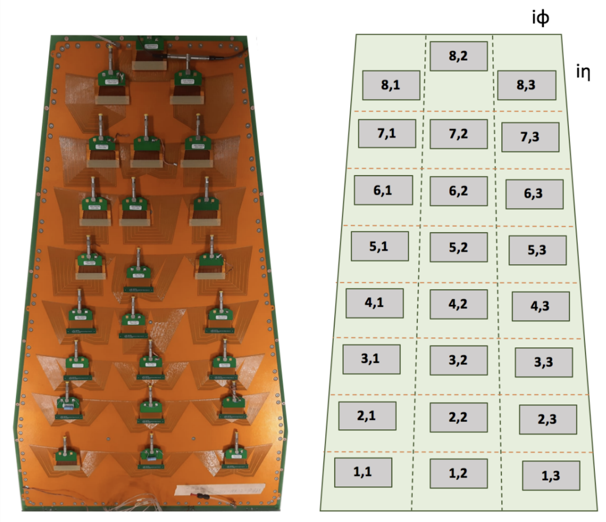
Experimental Setup at FIT

Pulsing into a readout sector and reading out of a readout sector:



Experimental Setup at FIT

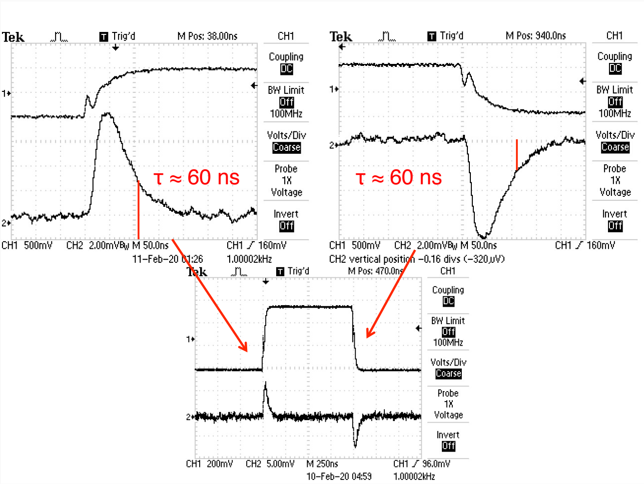
The following mapping convention (($i\eta, i\phi$) partition scheme) is used



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 iη and $i\phi$ partitions



Pulse Profile Comparison

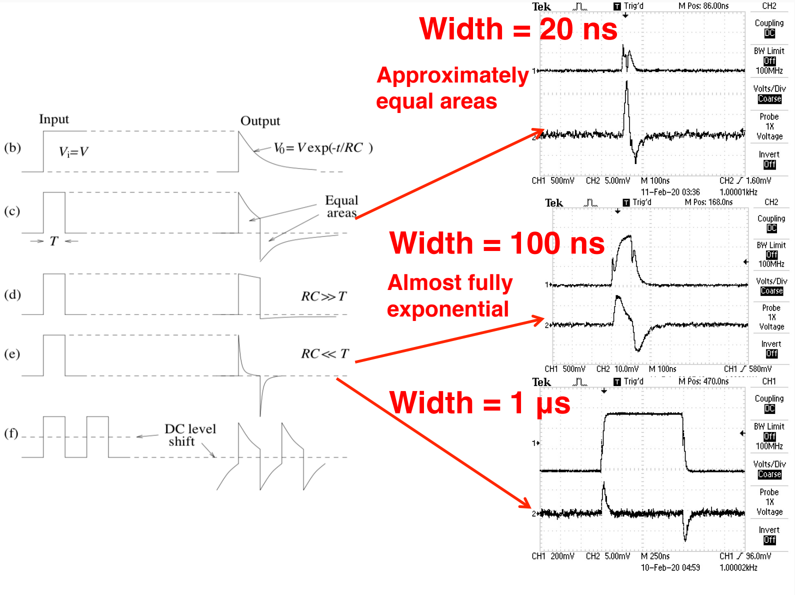


Figure on left from [5].

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:

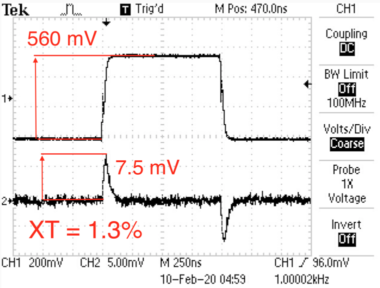
$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{V_{\text{out}}}\right)^2} \cdot 100\%$$

- 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:

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

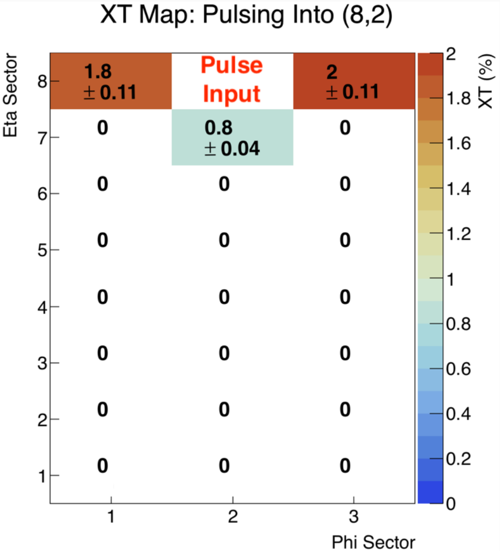
$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{0}\right)^2} \cdot 100\% = \text{undefined}$$

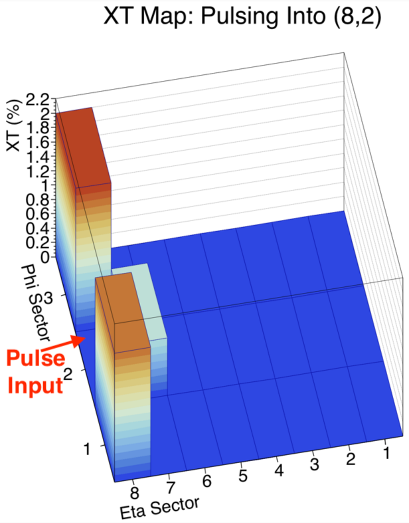
- Crosstalk maps were made for pulsing into each $i\phi$ partition of $i\eta$ =1, 5, 8 [6]



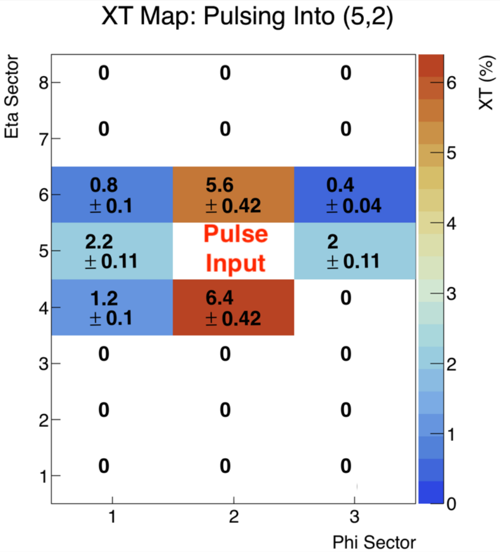
Example measurement for crosstalk magnitude

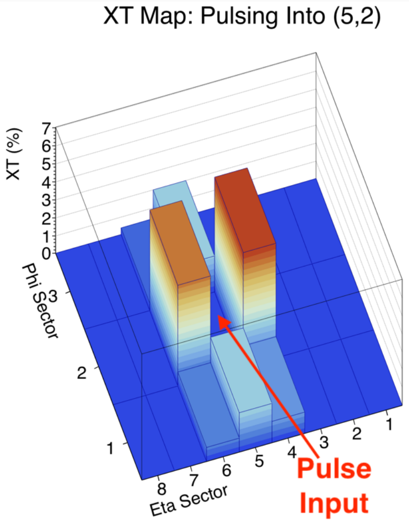
XT Map: Pulsing into (8,2)



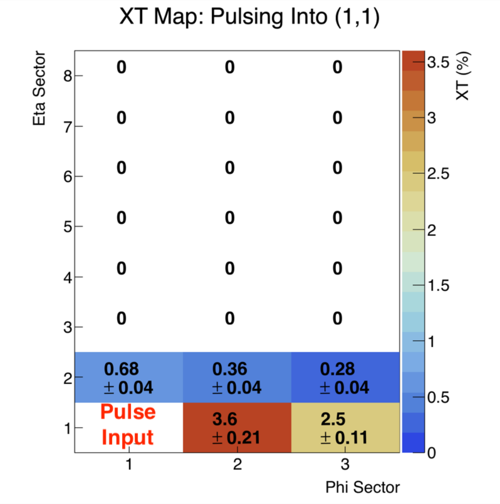


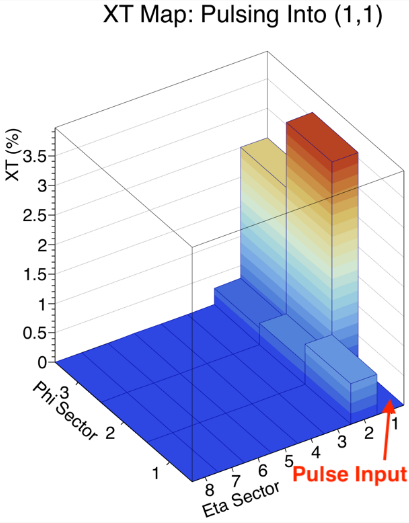
XT Map: Pulsing into (5,2)





XT Map: Pulsing into (1,1)





XT Characterization

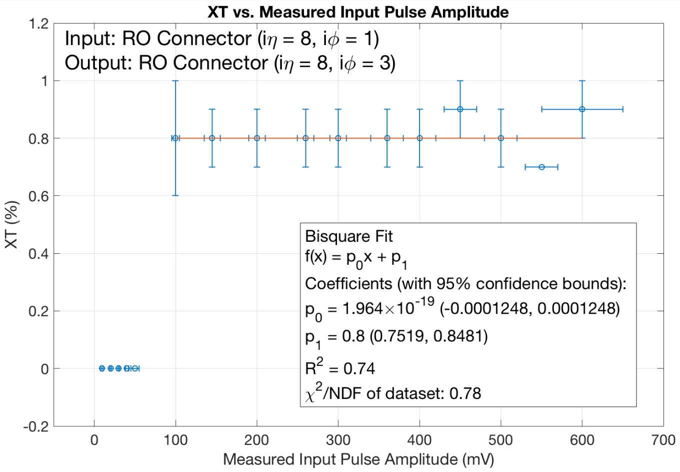
- From the XT maps, we extracted the minimum and maximum XT observed (the first column is the sector being pulsed)

Table 1: Crosstalk Range

$i\eta$ Sector	Minimum XT (%)	Maximum XT (%)
1	0.24±0.04	3.80±0.21
5	0.20±0.04	6.40±0.42
8	0.16±0.04	4.00±0.22

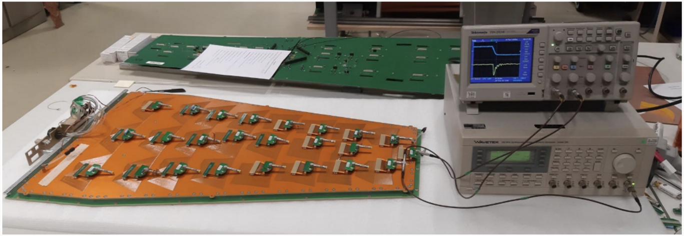
XT Seen in $(i\eta = 8, i\phi = 3)$

- 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**

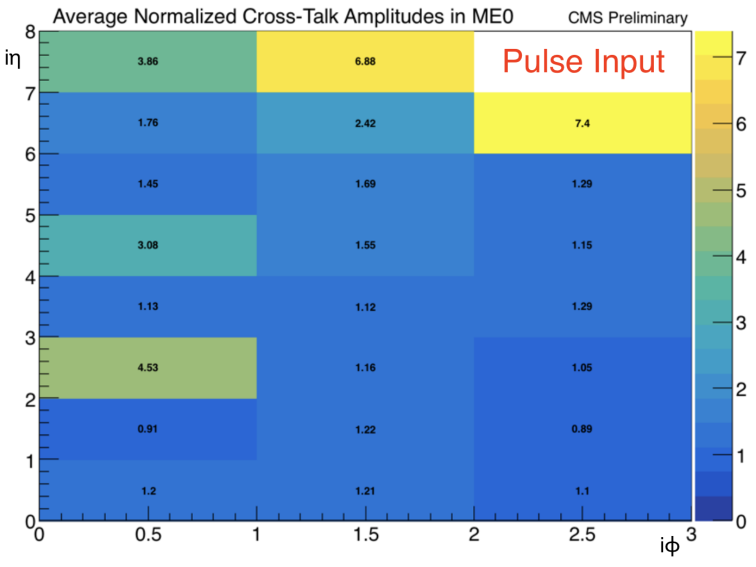


Experimental Setup at 904

- 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



Results at 904

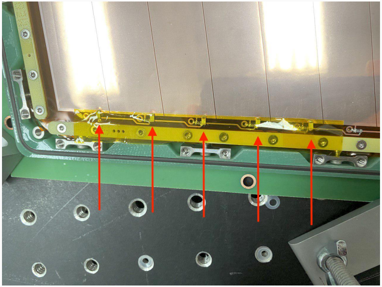
- Similar results obtained to the setup at FIT
- Crosstalk ranges from 0.89% to 7.4%
- Crosstalk seen in sectors more than one $i\eta$ partition away could be a result of the lack of grounding (pulse pickup was observed at the FIT setup when no shielding plate/grounding was used)
- Due to the COVID-19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

Mitigation Strategies

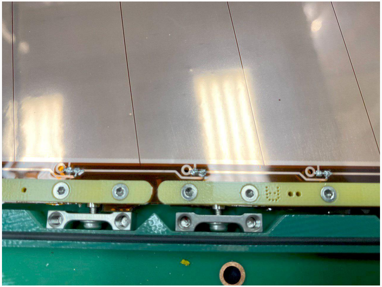
- We considered three mitigation strategies:
  - Reducing the impedance of GEM3B to ground (see backup)
  - Increasing the size of the HV segments on GEM3B
  - Bypass capacitors
- XT maps using the same experimental technique/data analysis were repeated

Modifying GEM3B

- The following modifications made to GEM3B:
  - 5 330$\pm$5% pF bypass capacitors (`https://www.digikey.com/product-detail/en/yageo/CC1206JRNPOBBN331/311-4435-1-ND/8025524`) were soldered to the 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 μs 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



Bypass capacitors on the HV segments in $i\eta = 8$

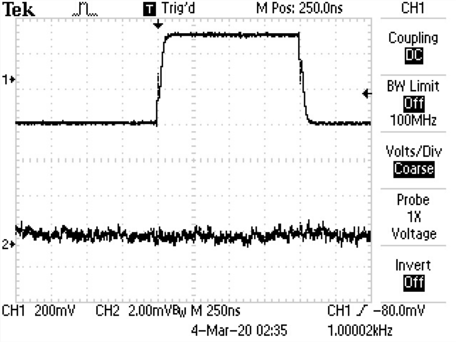


HV segments in $i\eta = 5$ connected

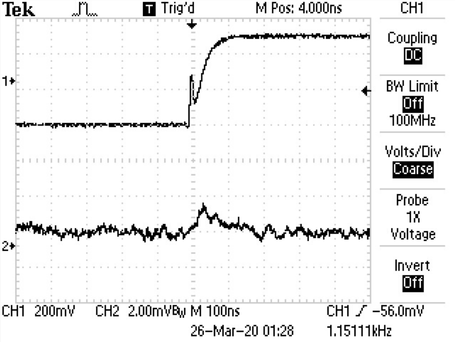
New Sectors Exhibiting XT

- 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)

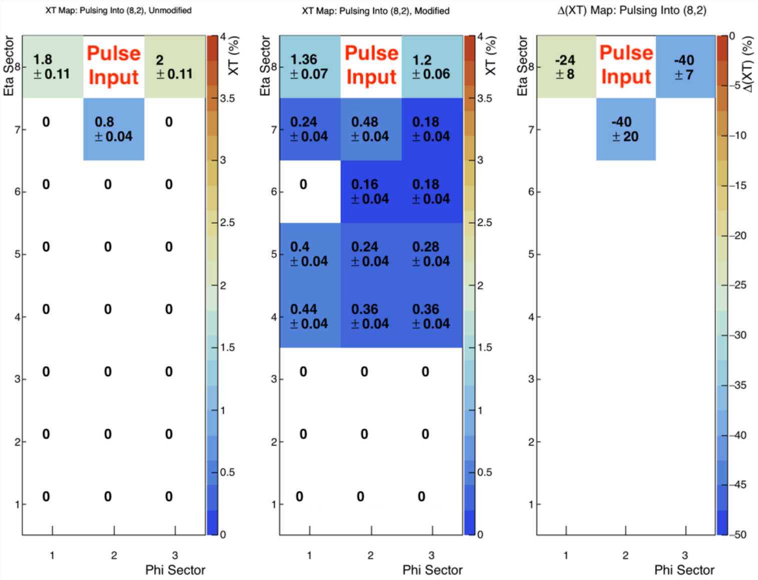


Before modification

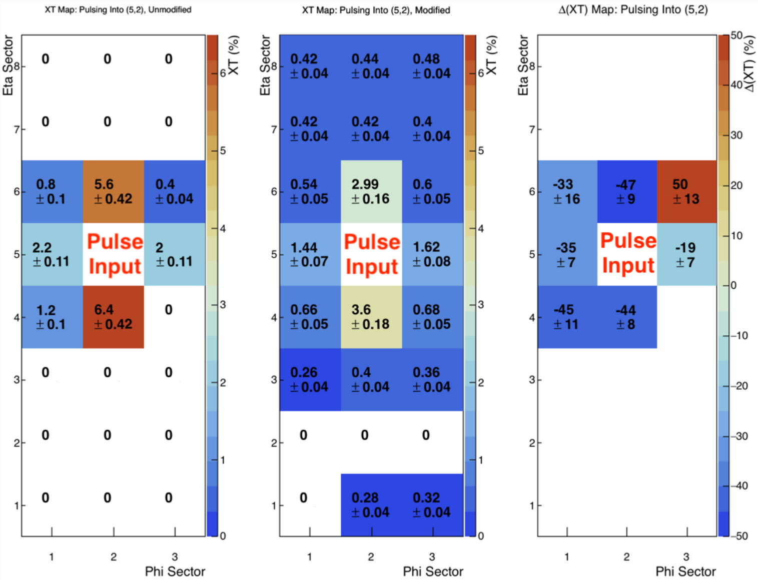


After modification

XT Maps: Pulsing into (8,2)



XT Map: Pulsing into (5,2)



Summary of Interventions to Mitigate the Crosstalk

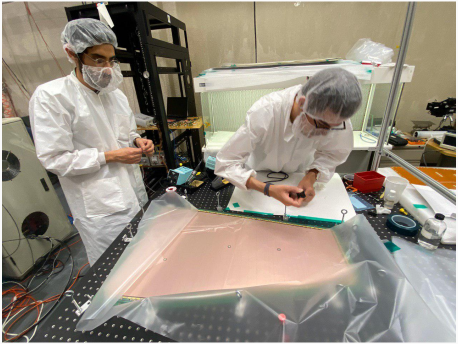
- The addition of bypass capacitors in $i\eta = 8$ and increasing the area of the HV segments in $i\eta = 5$ on GEM3B have increased the XT in ($i\eta$, $i\phi$) sectors where it was previously not detected
- The modifications in $i\eta = 8$ lead to reductions in crosstalk in $i\eta = 7, 8.$ which is 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 $\Rightarrow$ 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 says 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 $\sim$3mm holes were drilled in the drift (to allow for α/β 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

[1] D. Fiorina, "Double polarity signals in Double segmented chambers: R&D studies report," Presented at the *GEM Phase 2 R&D Meeting*, Jan. 14, 2020, `https://indico.cern.ch/event/878543/contributions/3701069/attachments/1968941/3274755/Double_Polarity_signals_II.pdf`.

[2] D. Fiorina, "Double polarity signals in Double segmented chambers: R&D Update," Presented at the *Bi-weekly GEM Detector Production Meeting*, Jan. 29, 2020,`https://indico.cern.ch/event/880071/contributions/3707941/attachments/1977597/3291978/DFiorina-DoublePolarity-Updates.pdf`.

[3] M. Hohlmann, "Understanding GEM Crosstalk Pulses Due to Capacitive Coupling," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 11, 2020, `https://indico.cern.ch/event/887407/`.

[4] M. Hohlmann, "PSPICE Simulation of Crosstalk on GEM Strips," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 25, 2020, `https://indico.cern.ch/event/891682/`.

[5] "Pulse Processing: Pulse Shaping," `http://ns.ph.liv.ac.uk/~ajb/ukgs_nis/pre-course-material/lec2-03.pdf`.

[6] S. Butalla, T. Elkafrawy, M. Hohlmann, "ME0 Crosstalk Study Update," Presented at the *GEM Phase-2 R&D Meeting*, March 24, 2020, `https://indico.cern.ch/event/902359/`.

[7] S. Butalla, B. Steffens, T. Elkafrawy, & M. Hohlmann, "ME0 Cross-talk Studies," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 11, 2020, `https://indico.cern.ch/event/887407/contributions/3741571/attachments/1985459/3308526/ME0PulseStudies_20200211.pdf`.

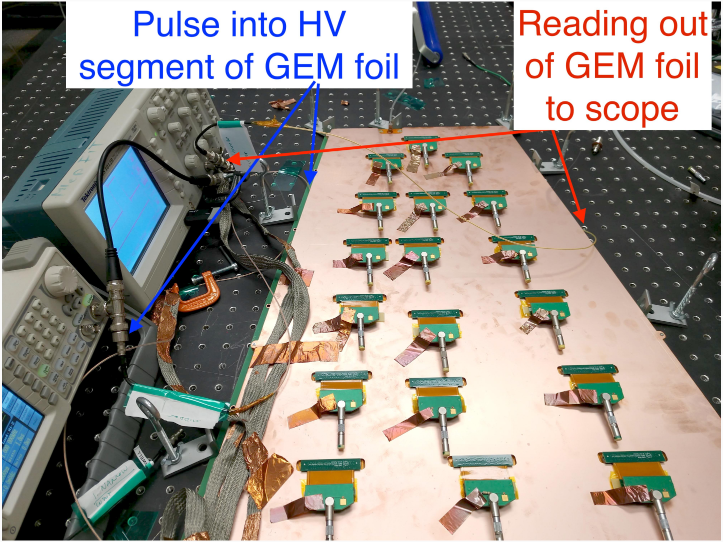
[8] S. Butalla, B. Steffens, T. Elkafrawy, & M. Hohlmann, "ME0 Cross-talk Studies," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 11, 2020, `https://indico.cern.ch/event/889831/contributions/3752411/attachments/1989676/3316709/ME0CrossTalkUpdate.pdf`.

[9] S. Butalla & M. Hohlmann, "ME0 Crosstalk Study Update," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 25, 2020, `https://indico.cern.ch/event/891682/contributions/3760827/attachments/1993420/3324696/ME0CrosstalkUpdate_20200225.pdf`.

Backup

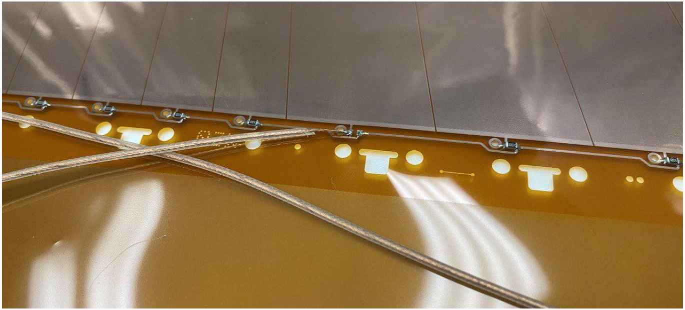
Experimental Setup at FIT

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



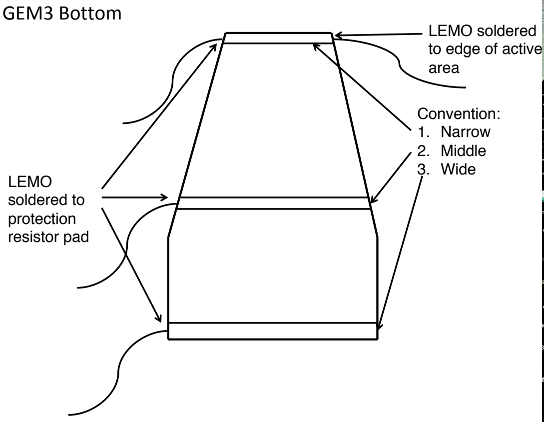
Experimental Setup at FIT

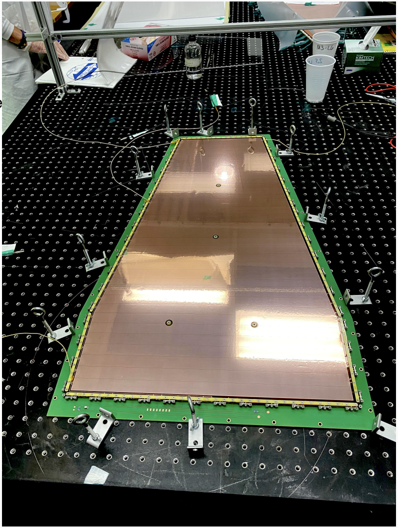
- To quantify and characterize the crosstalk, we injected a square voltage pulse into HV segments on GEM3B and various RO sectors
- Before assembly of an ME0, we modified a 10 MΩ, double-segmented ME0 foil with four LEMO cables (outer insulation and outer conductor removed to accommodate the wires inside 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:





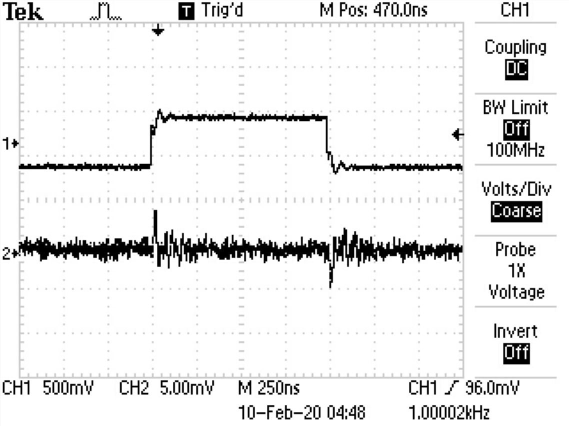
Main Results: Injection into HV Segment

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

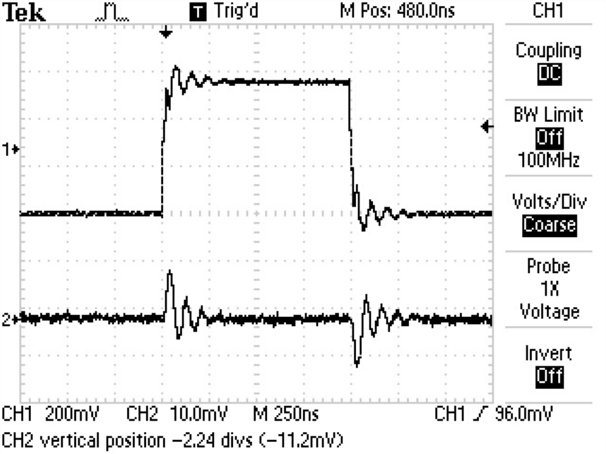
Main Results: Injection into HV Segment

Input: (1) GEM3 bottom, Narrow HV segment input

Output: $i\eta = 8,\ i\phi = 1$ RO connector

Channel 1: Pulse Generator

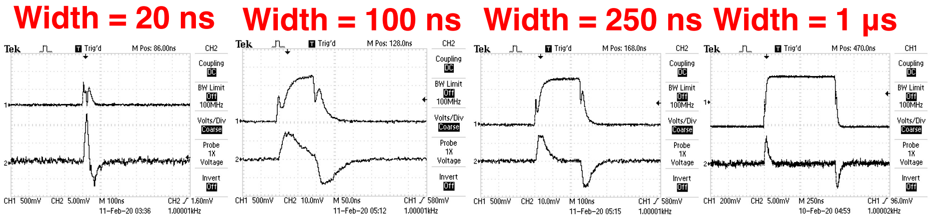
Channel 2: $i\eta = 8,\ i\phi = 1$ RO connector



We see an induced pulse on the RO connector; very similar across $i\eta$ partitions

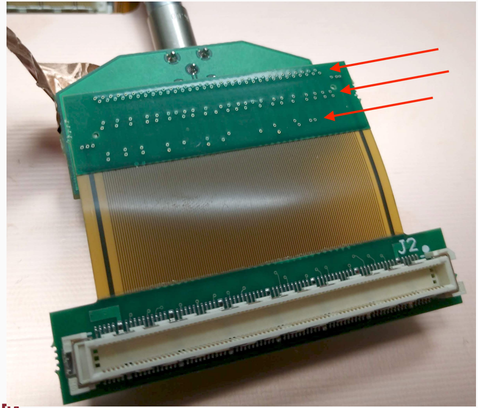
Pulse Profile Comparison

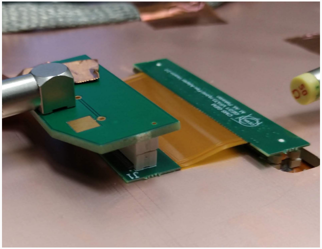
- Varying the width of the input pulse confirms the CR differentiator hypothesis
- Note that under 1 μs square pulse width, the impedance mismatch of the detector/scope system distorts the shape of the input pulse

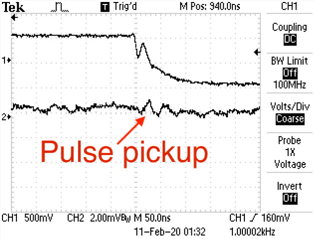


Pulse Pickup from Hirose-to-Panasonic Adapters

- 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

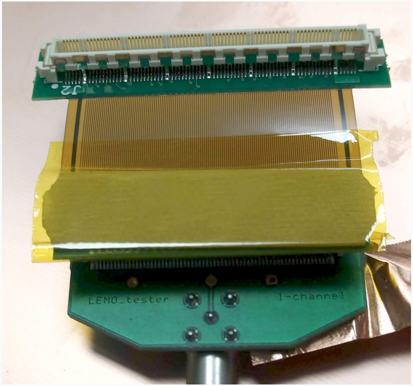


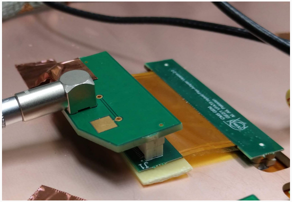


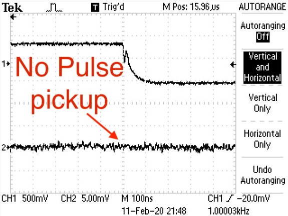


Pulse Pickup from Hirose-to-Panasonic Adapters

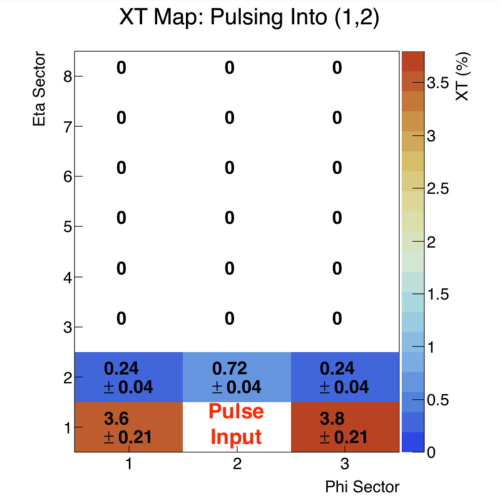
- To insulate the bottom of the adapter, we added a 1 mm FR4 spacer held in place with Kapton tape (left)
- With this insulation, there is no pulse pickup, just what is read out of the sector (right)
  *Note that in ($i\eta = 7,\ i\phi = 2$) there was no spacer added; no measurements were made here and the bottom of the FlexPCB adapter did not contact the grounding plate

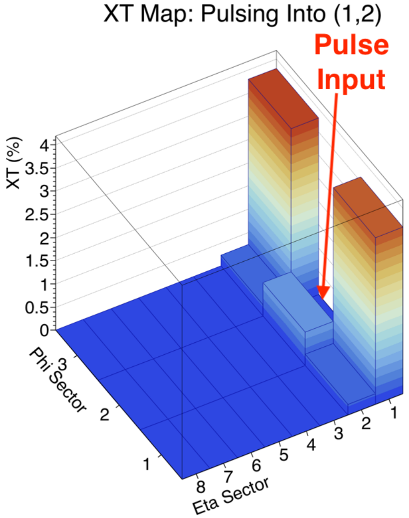




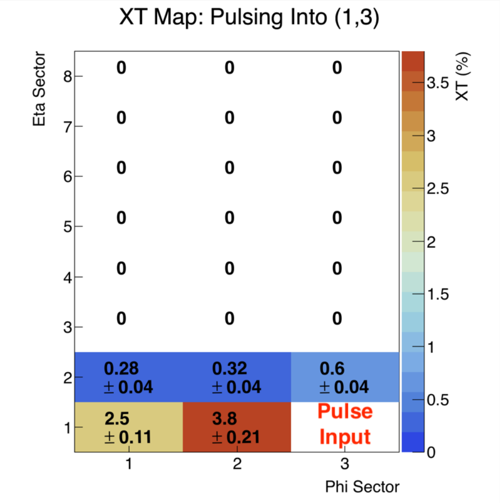


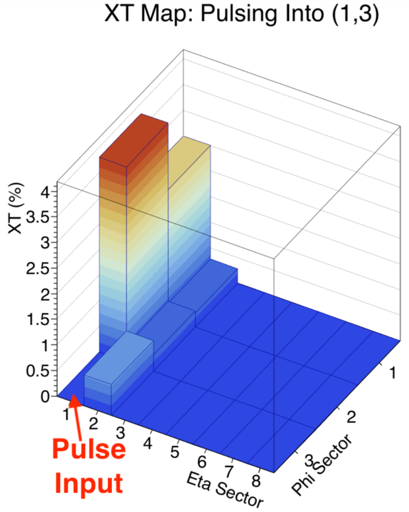
XT Map: Pulsing into (1,2)





XT Map: Pulsing into (1,3)





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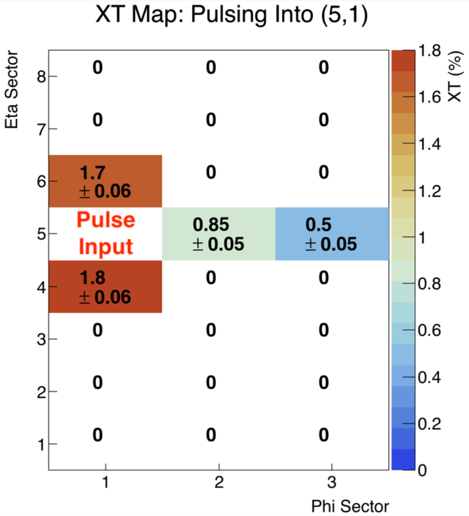
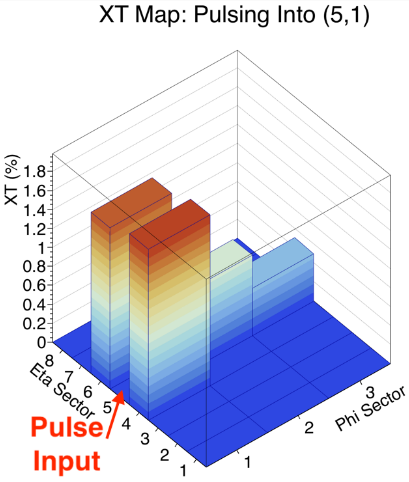
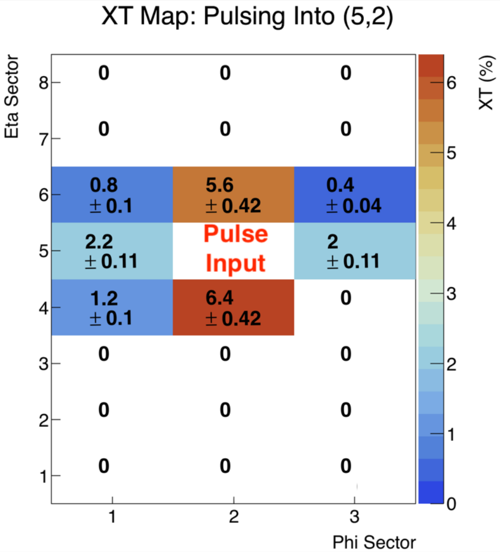
XT Map: Pulsing into (5,1)

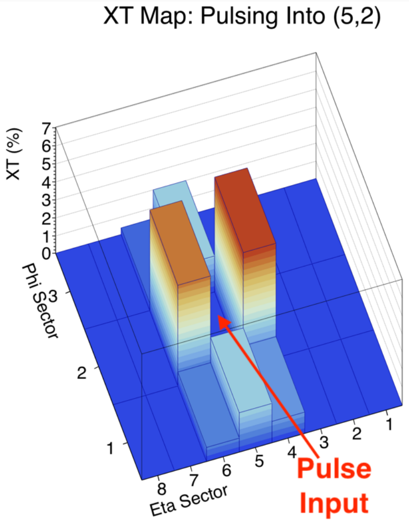




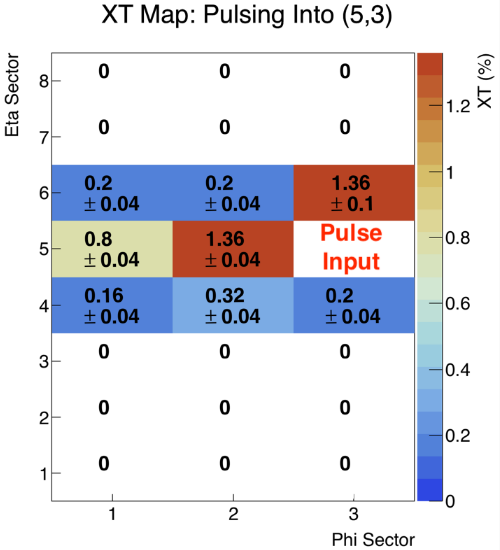
*200 mV input pulse amplitude

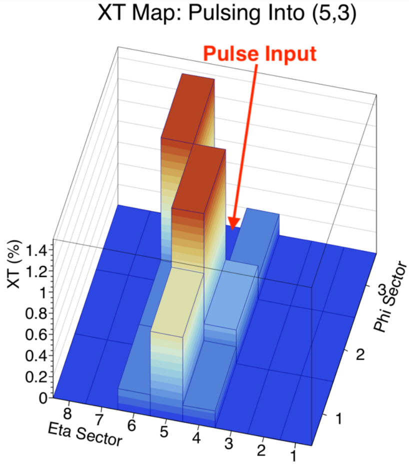
XT Map: Pulsing into (5,2)



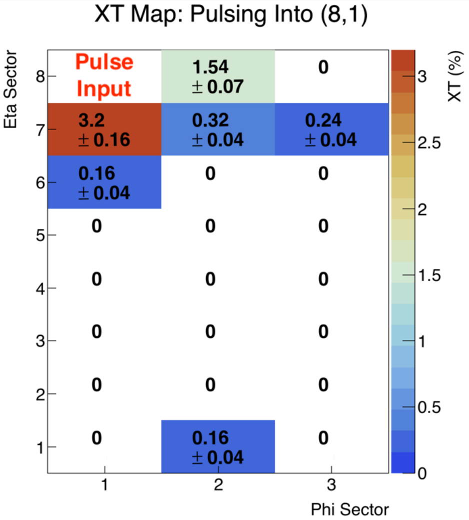


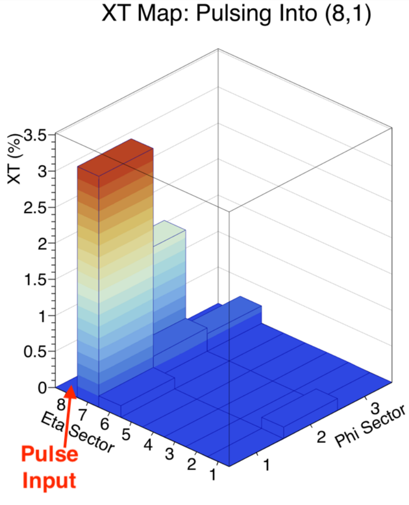
XT Map: Pulsing into (5,3)





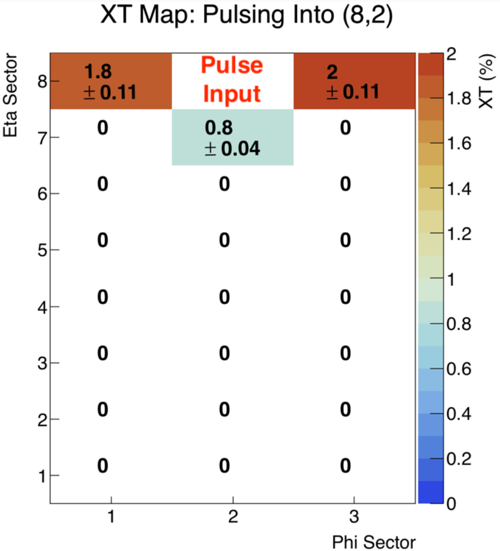
XT Map: Pulsing into (8,1)

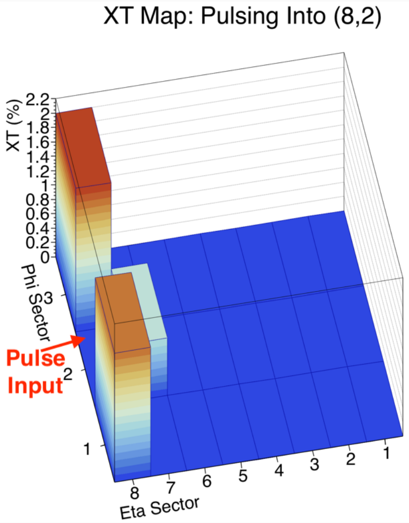




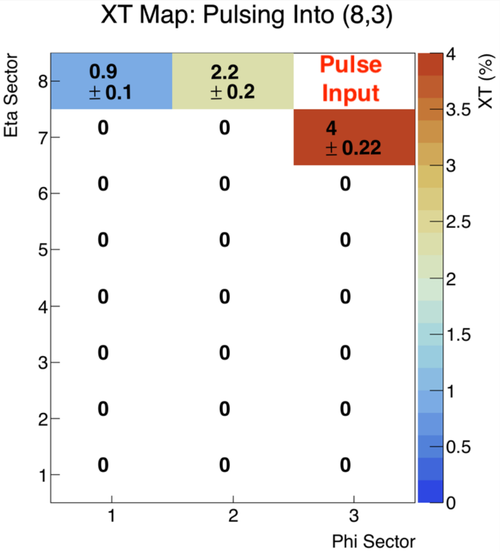
*The baseline noise for this XT map was higher than usual

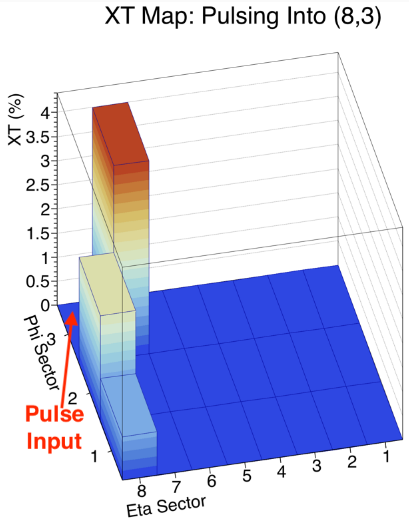
XT Map: Pulsing into (8,2)





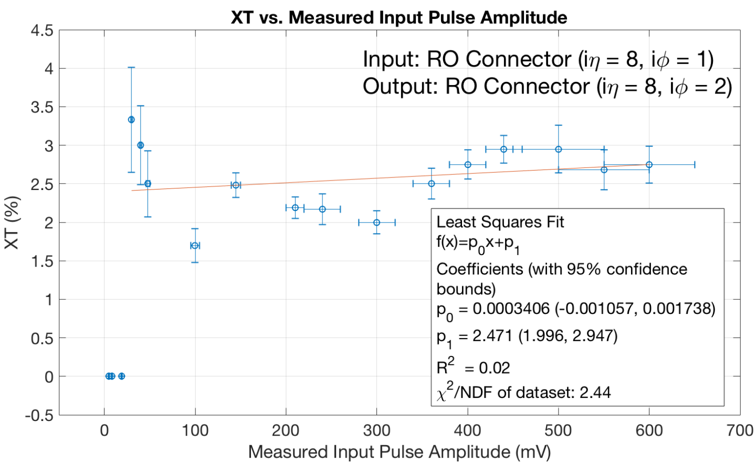
XT Map: Pulsing into (8,3)





XT Seen in $(i\eta = 8, i\phi = 2)$

CMS



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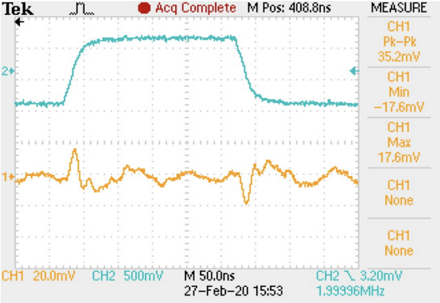
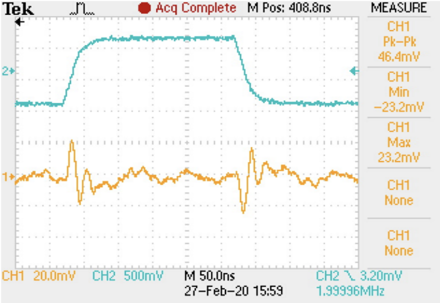
Example Scope Traces of Crosstalk at 904

Pulsing into (8,3)



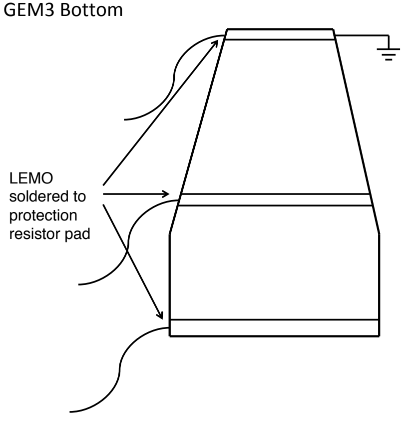
Reading out of (5,1)

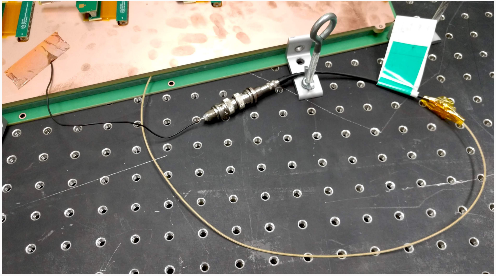


Reading out of (3,1)

Effect of Decreasing the Impedance of GEM3B to GND

- 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:



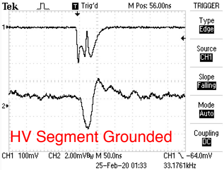


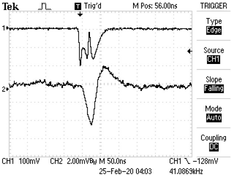
- HP 8012B pulse generator used with inverted square pulse (20 ns pulse width)

Effect of Decreasing the Impedance of GEM3B to GND

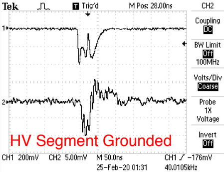
Pulsing into $(i\eta = 8, i\phi = 1)$, reading out of $(i\eta = 8, i\phi = 2)$

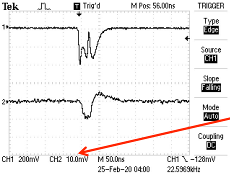
200 mV Measured Input Pulse Amplitude





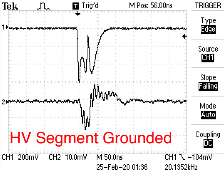
400 mV Measured Input Pulse Amplitude

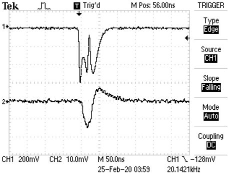




Note the different voltage scales on channel 2

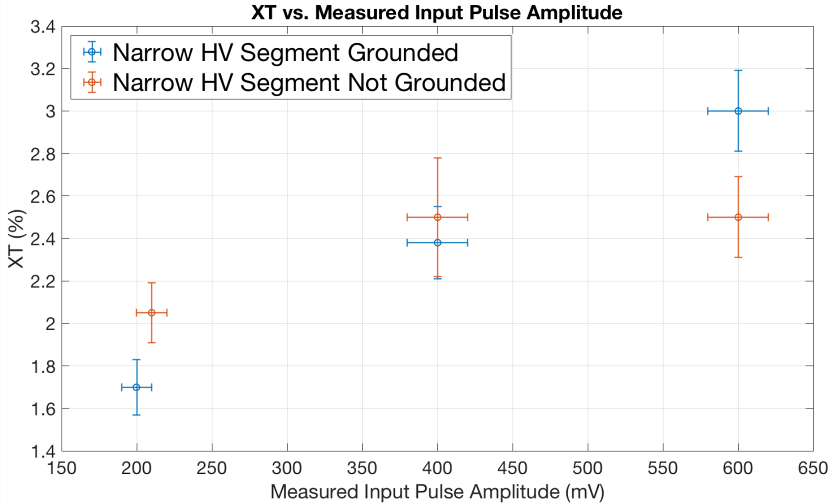
600 mV Measured Input Pulse Amplitude





Effect of Decreasing the Impedance of GEM3B to GND

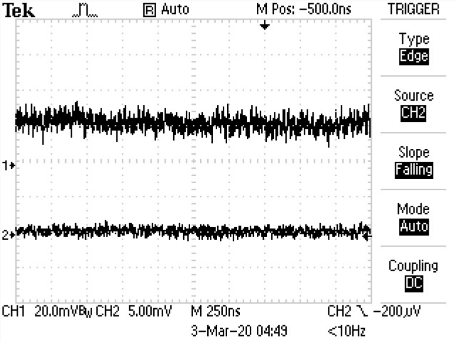
Pulsing into $(i\eta = 8, i\phi = 1)$, reading out of $(i\eta = 8, i\phi = 2)$



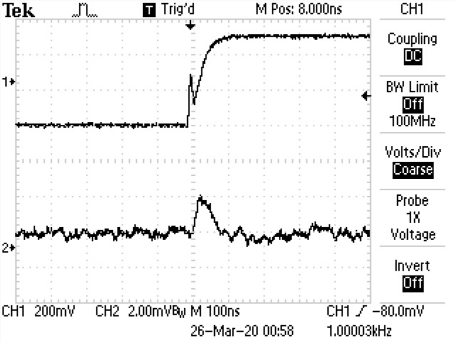
New Sectors Exhibiting XT

- 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)

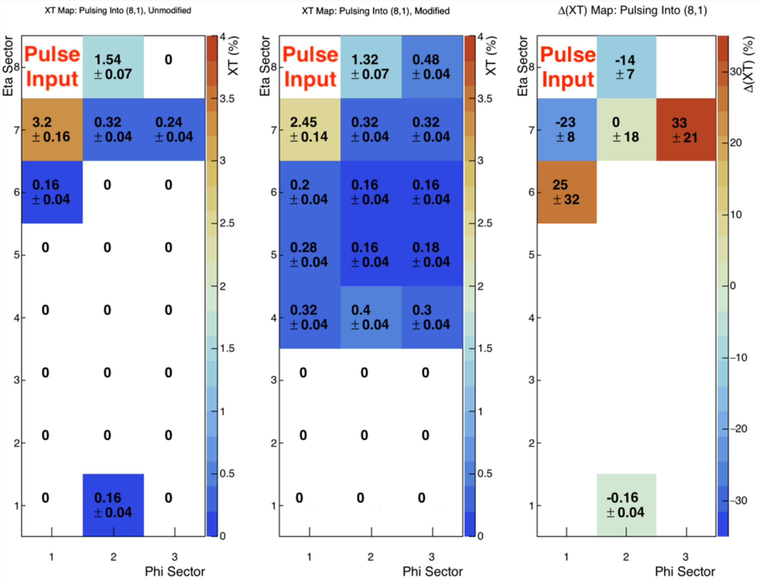


Before modification

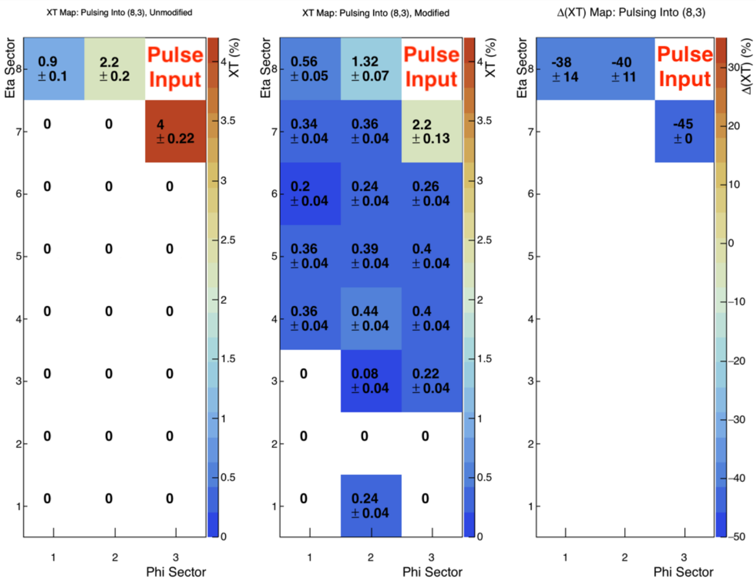


After modification

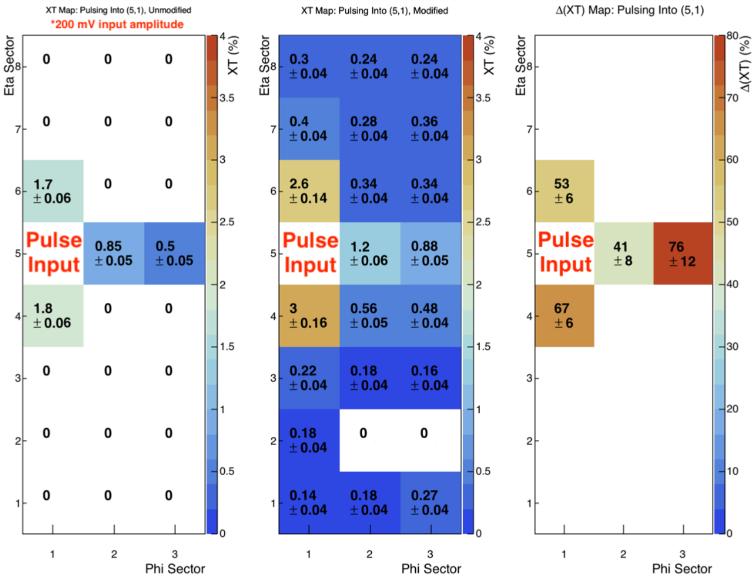
XT Maps: Pulsing into (8,1)



XT Map: Pulsing into (8,3)



XT Map: Pulsing into (5,1)



XT Map: Pulsing into (5,3)