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

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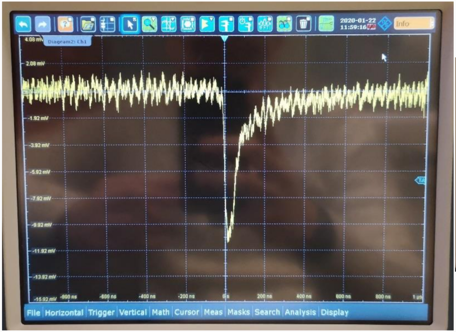
Introduction

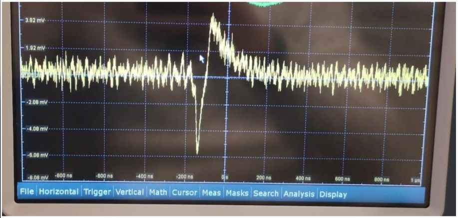
- Crosstalk due to capacitive coupling has been observed in GE1/1, GE2/1, and ME0 chambers **with double-segmented foils**, as well as in 10×10 GEM detectors Note that crosstalk has **not** been observed in single segmented foils (i.e., in GE1/1 chambers)
- Experimental setup at FIT and CERN with an ME0 chamber was used to characterize the crosstalk
- We built a model in `OrCAD PSPICE` to simulate and investigate the physical process of the crosstalk in the detector and also to test mitigation strategies
- 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 experimental 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 (direct readout to scope)



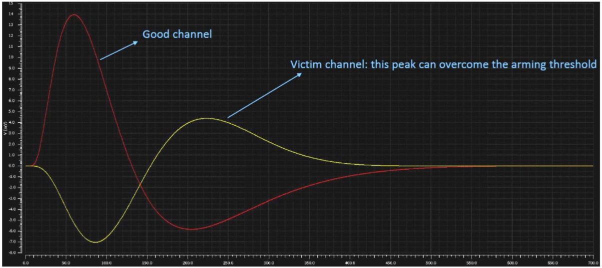
Good Signal [2].



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)

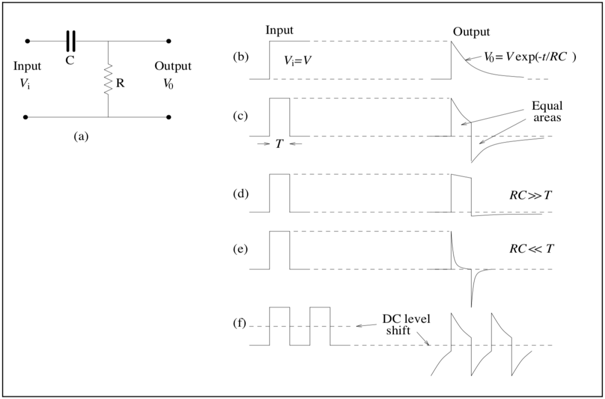


Real signal (red) and crosstalk signal occurring ∼ 200 ns later (from F. Licciulli).

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

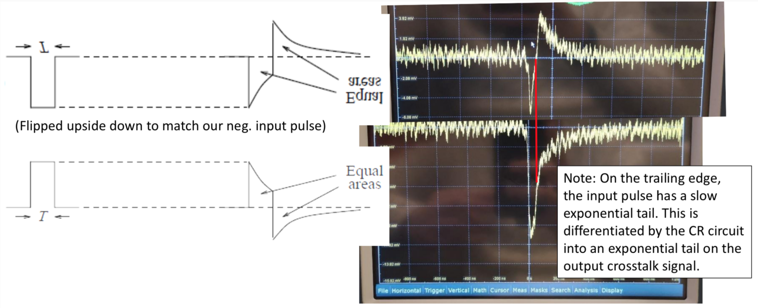
Hypothesis

- 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, 4]



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].

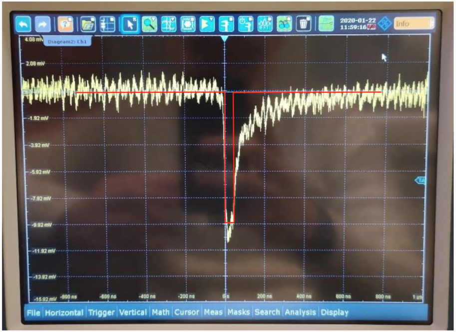
- We observe very similar behavior when comparing the output of the (theoretical) CR differentiator circuit and the crosstalk pulses we observe



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].

Experimental Motivation

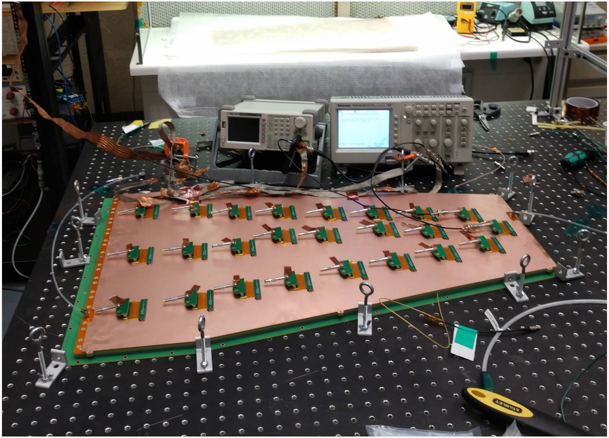
- The "real" signal pulse induced on the readout strips is approximately a square pulse with a width on the order of 10 ns
- To experimentally test crosstalk under more controlled conditions, we can apply a square voltage pulse to a RO sector, and read the crosstalk signal out of other sectors



Good Signal [2].

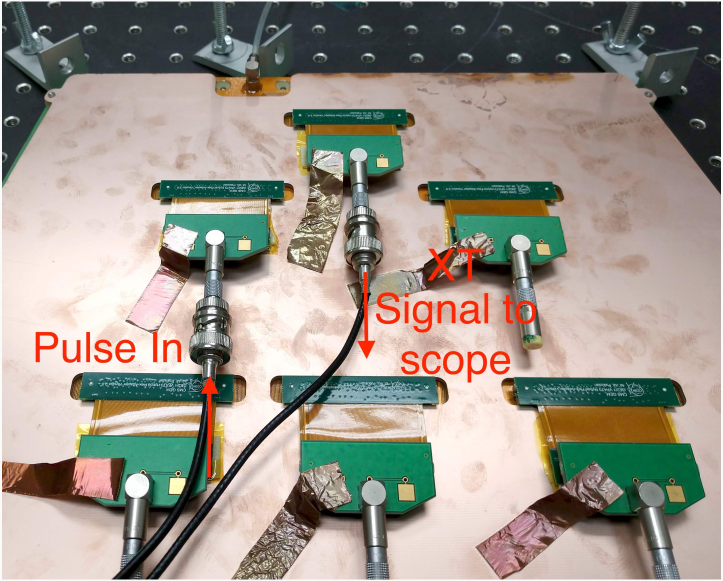
Experimental Setup at FIT

- 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



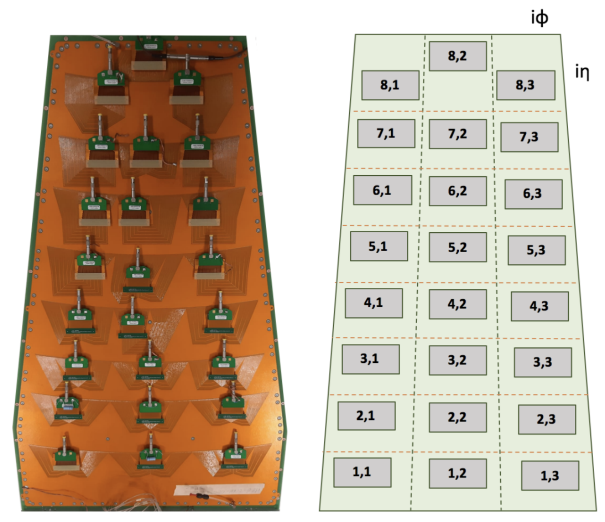
Experimental Setup at FIT

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



Experimental Setup at FIT

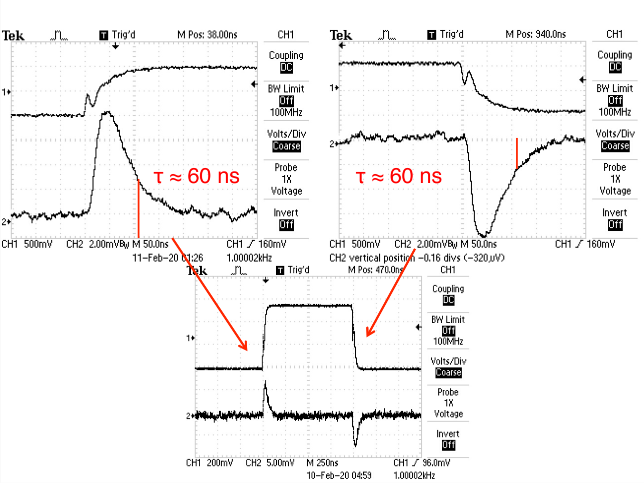
The following mapping convention ($(i\eta, i\phi)$ partition scheme) is used



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

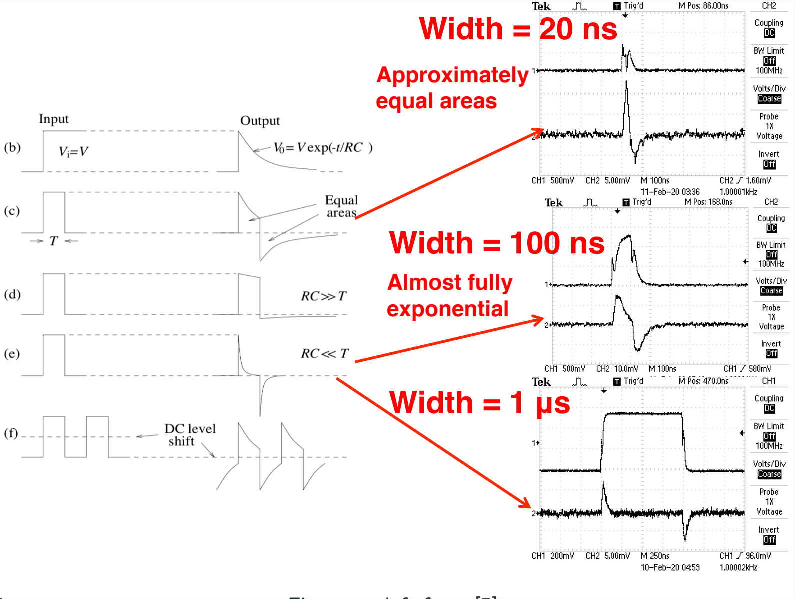
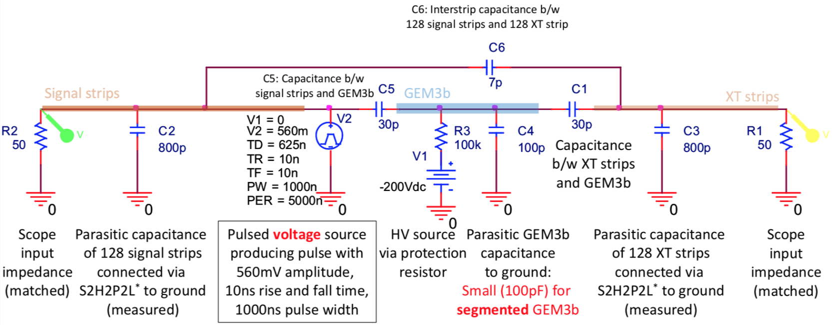


Figure on left from [5].

PSpice Model of a Circuit for Voltage Pulser Studies

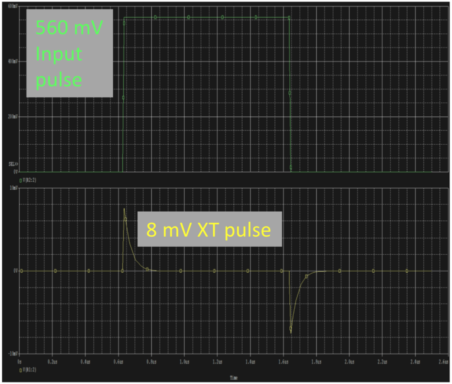
- The model below was constructed to simulate the experimental setup of using a signal generator to apply a square **voltage** pulse to 128 strips in one readout sector

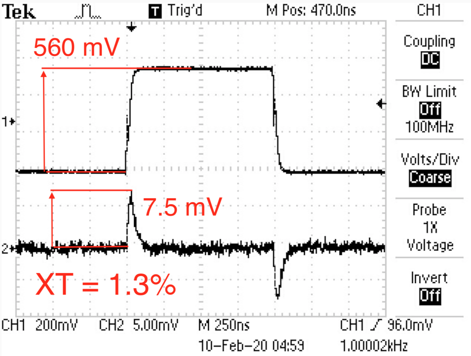


* "Strip to Hirose to Panasonic to LEMO" adapter

Results of Voltage Pulser Circuit Model

- Simulation and measurement agree with respect to crosstalk amplitude, CR time constant, and polarity

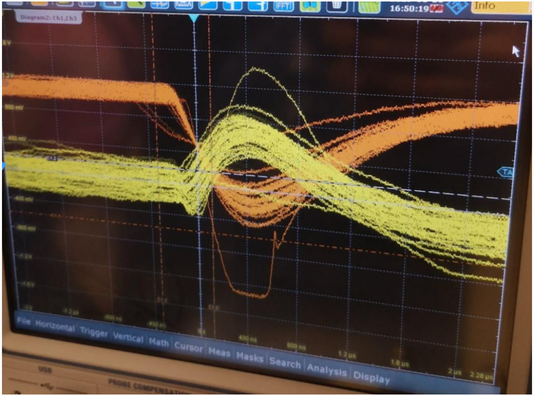




FLORIDA TECH

Unexplained Results

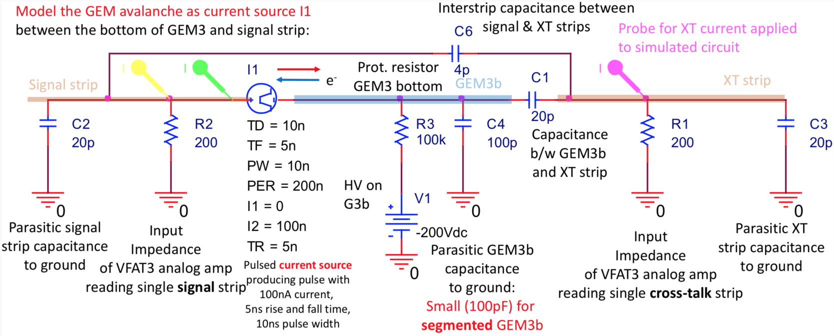
- Why is the crosstalk observed in GEM detectors of **opposite** polarity of the input pulse (good signal) after shaping by a preamplifier?
- Why are opposite polarity signals not observed with the voltage pulser studies?
- Why is crosstalk not observed in chambers with single-segmented foils?



Good signal (orange) and opposite polarity, crosstalk signal (yellow) seen after shaping. From [2].

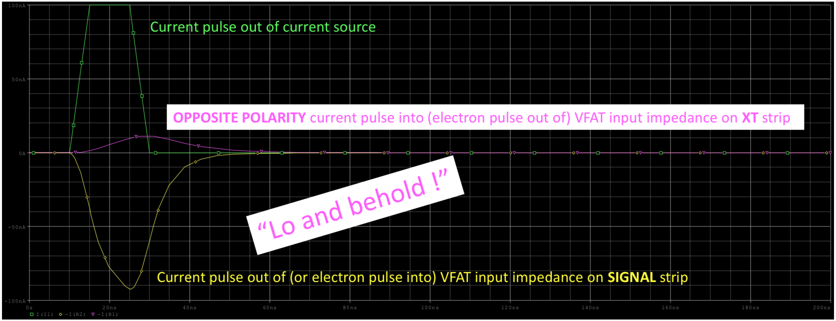
PSpice Model of a Circuit for Normal GEM Operation

- The model below was constructed to simulate the actual operation of a GEM detector (simulating the current source produced by GEM avalanches)
- Current source is 10k primary e^- (1.6 fC) over 15 ns (100 nA)
  Note that this **doesn't** take gas gain into account



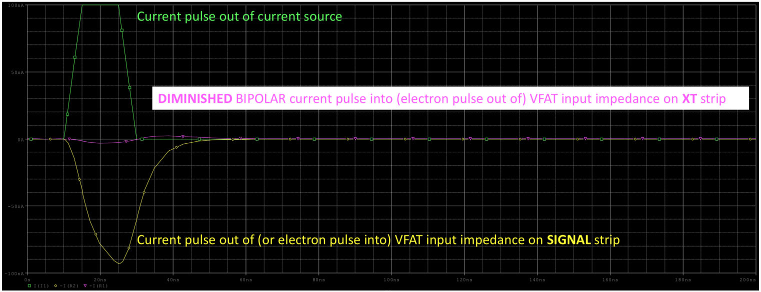
PSpice Analyisis of Normal GEM Operation (current source

- The positive polarity crosstalk pulse is seen on the output channel of a crosstalk strip as seen in experimental setups at CERN
  ⇒ **current is flowing from the crosstalk readout strip to the signal strip, which is why the polarity is flipped on the crosstalk pulse!** Whereas the voltage pulser just changes the potential on the strips ⇒ the polarity is in the same direction
  Current sources and voltage sources are physically different



PSpice Model of a Circuit for Normal GEM Operation with a Single-Segmented Foil

- To simulate a single-segmented foil, the protection resistors were decreased from 100 kΩ to 10 Ω (see backup slides for circuit)
- With this configuration, the reduced resistance of the protection resistor provides a much reduced impedance for sinking the current from the current source to ground and therefore limits the current that can flow to the neighboring readout strips/GEM3B capacitor system
  ⇒ This is why crosstalk is **not** observed in single-segmented foils



PSpice Models of Mitigation Strategies

- Simulation results show that reducing the impedance from GEM3B to ground allows for less resistance of the AC current of the crosstalk signal to go to ground instead of to neighboring strips
- Additional PSpice models considered:
  - Increasing the capacitance of GEM3B to ground (increasing the HV segmentation size) ($Z_C = (\omega C)^{-1}$)
  - Bypass capacitors in parallel with the protection resistors on the HV segments on GEM3B (provides an additional path for the AC current to flow to ground)
  - Blocking capacitor on GEM3B (provides an additional path for the AC current to flow to ground)

PSpice Simulation of Mitigation Strategies: Results

- Increasing the capacitance of GEM3B to ground **reduces the crosstalk amplitude by a factor of ∼four** (tested experimentally)
- Placing a 1 nF bypass capacitor in parallel with the 100 kΩ protection resistor **reduces the crosstalk amplitude by a factor of ∼four** (tested experimentally)
- Placing a 1 nF blocking capacitor in series with GEM3B **reduces the crosstalk amplitude by a factor of ∼four**
- See backup slides for circuit diagrams

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:

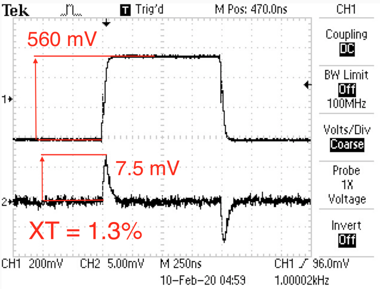
$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{V_{\text{out}}}\right)^2} \cdot 100\%$$

- 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:

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

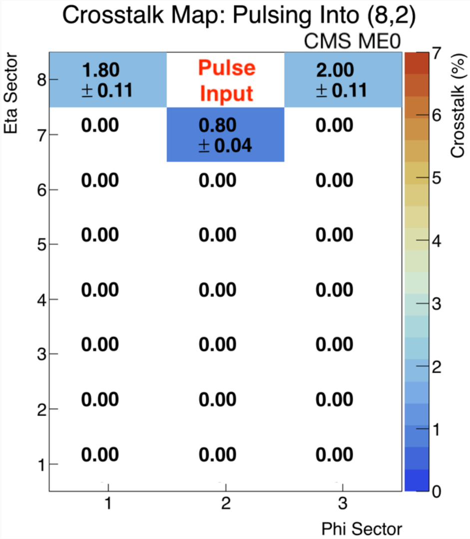
$$\delta(XT\%) = |XT|\sqrt{\left(\frac{\delta V_{\text{in}}}{V_{\text{in}}}\right)^2 + \left(\frac{\delta V_{\text{out}}}{0}\right)^2} \cdot 100\% = \text{undefined}$$

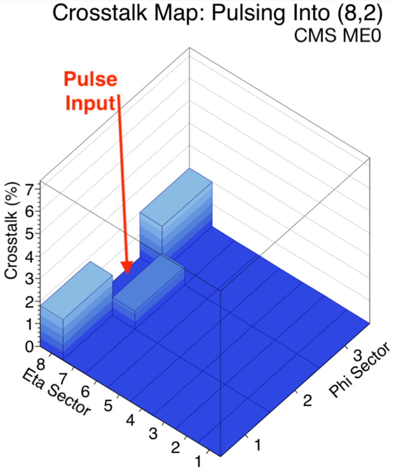
- Crosstalk maps were made for pulsing into each $i\phi$ partition of $i\eta$ =1, 5, 8 [6]



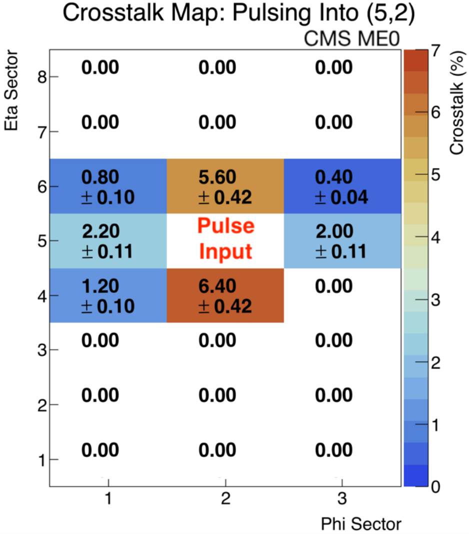
Example measurement for crosstalk magnitude

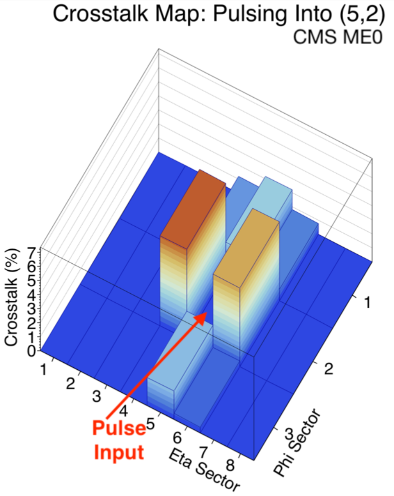
XT Map: Pulsing into (8,2)





XT Map: Pulsing into (5,2)





XT Characterization

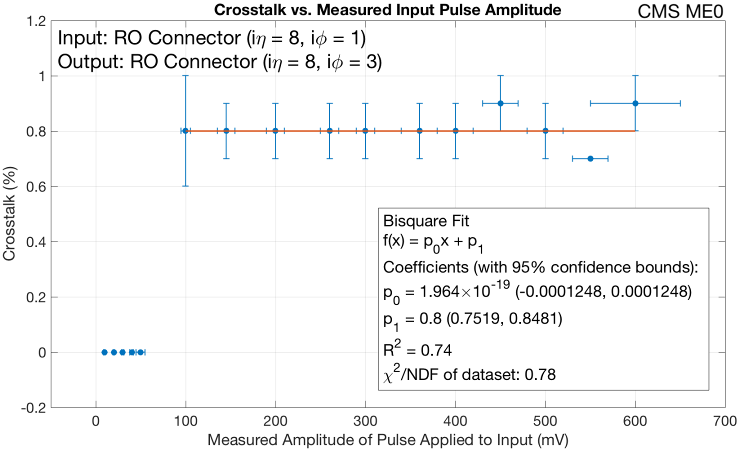
- Crosstalk in the unmodified configuration of the chamber is localized to the immediately adjacent $i\eta$ sectors and the $i\phi$ partitions in the sector being pulsed
- From the XT maps, we extracted the minimum and maximum XT observed (the first column is the sector being pulsed)

Table 1: Range of Crosstalk for Adjacent Sectors Experiencing Crosstalk

$i\eta$ Sector	Minimum Crosstalk (%)	Maximum Crosstalk (%)
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

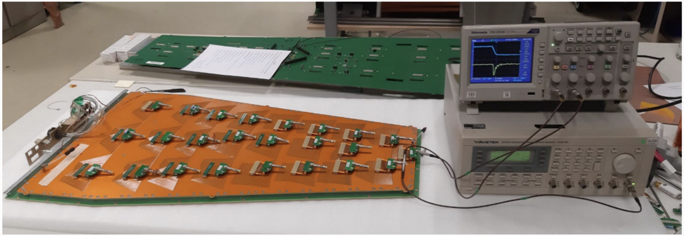
Crosstalk Seen in $(i\eta = 8, i\phi = 3)$

- 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**



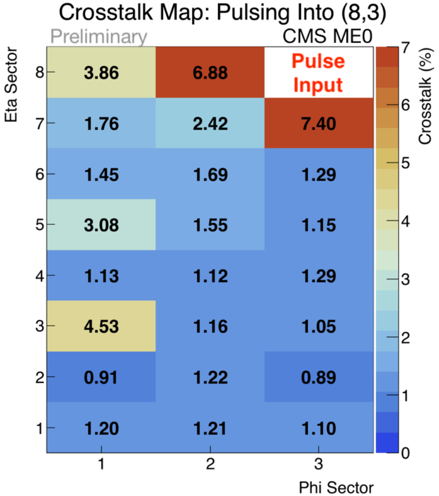
Experimental Setup at CERN

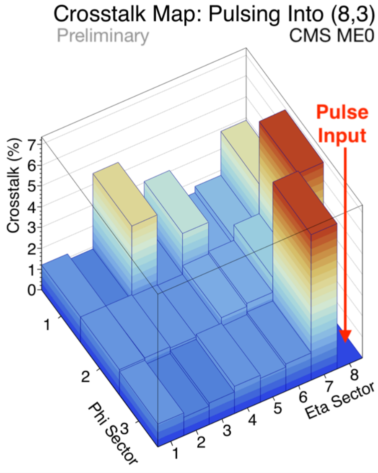
- Experimental setup and procedure of measurement/data analysis replicated at CERN with an unmodified ME0 chamber
- 5 MΩ protection resistor foils used
- Wavetek 395 100 MHz synthesized arbitrary waveform generator
- Tektronix TDS 2024C four channel digital storage oscilloscope, signal terminated with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



From [10].

Example Scope Traces of Crosstalk CERN





Note that the crosstalk is larger in magnitude and extends to all readout sectors in the detector due to a lack of grounding. Data from [10].

Results at 904

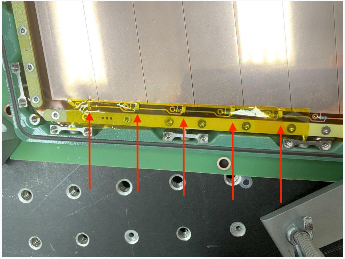
- Similar results obtained to the setup at FIT
- Crosstalk ranges from 0.89% to 7.4%
- Crosstalk seen in sectors more than one $i\eta$ partition away could be a result of the lack of grounding (pulse pickup was observed at the FIT setup when no shielding plate/grounding was used)
- Due to the COVID-19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

Mitigation Strategies

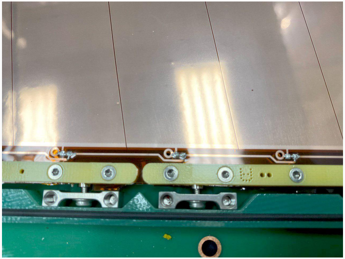
- From the simulation results, we know that we can reduce the crosstalk by decreasing the impedance of GEM3B
- We considered three mitigation strategies:
    - Directly reducing the impedance of GEM3B to ground (see backup slides)
    - Increasing the size of the HV segments on GEM3B
    - Bypass capacitors
    - Making GEM3B "continuous" by removing all protection resistors and connecting the HV segments in parallel
- Crosstalk maps using the same experimental technique/data analysis were repeated
- In the interest of time, we will discuss only the results; all maps are included in the backup slides

Modifying GEM3B with Bypass Capacitors and Connecting HV Segments

- The following modifications made to GEM3B:
  - 5 330±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)] (see backup slides for maps)



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

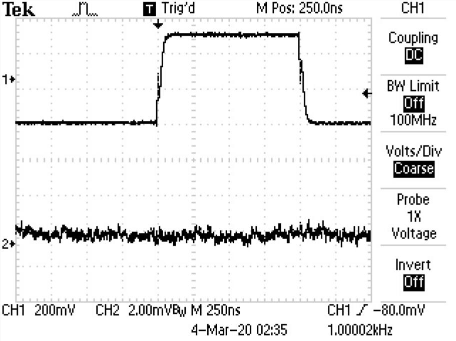


HV segments in $i\eta = 5$ connected

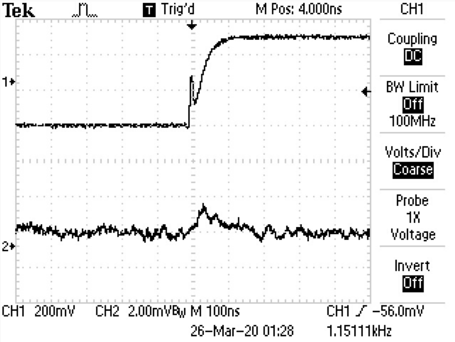
New Sectors Exhibiting XT

- 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)



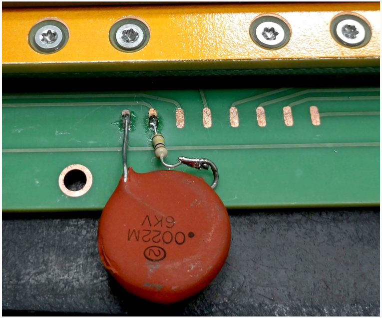
Before modification



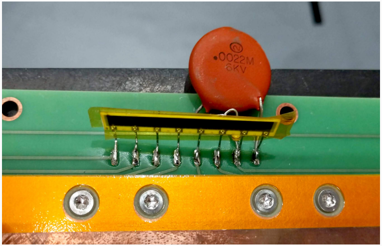
After modification

Other Configurations Considered

- We removed all 37 protection resistors on GEM3B and connected all HV segments in parallel (making GEM3B "continuous")
- Two additional configurations were considered:
  1. GEM3B continuous with a lowpass filter (100 kΩ resistor and 2.2.nF capacitor in series to ground) on GEM3B
  2. GEM3B continuous with the lowpass filter on GEM3B and a 4.7 MΩ (3/1/2/1 gap mm) HV divider on the HV circuit



Lowpass filter on GEM3B.



Lowpass filter and HV divider.

Summary of Interventions to Mitigate Crosstalk

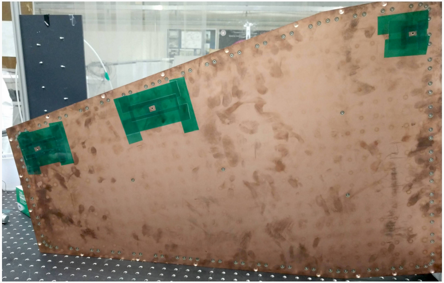
- Crosstalk is reduced by the addition of bypass capacitors and connecting HV segments
- Crosstalk is also **reduced** by making GEM3B continuous and adding a lowpass filter to GEM3B
- Crosstalk is further **reduced** by the addition of the HV divider
- Sectors that previously did not experience XT now see a small level of crosstalk ($\sim 0.18 - 0.8\%$) after the modifications
- Unexpected behavior of XT is seen when pulsing into (5,1) and (5,3), but expected behavior when pulsing into (5,2)

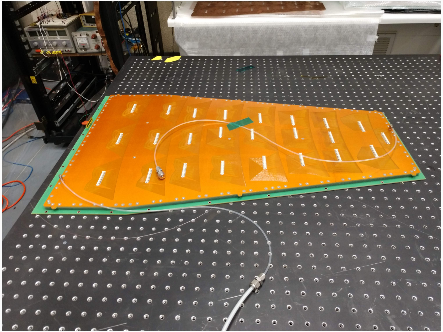
Table 2: Average Change in Crosstalk for each Pulsed Sector (average change of all sectors previously experiencing Crosstalk) With GEM3 Bottom Continuous and HV Filter

Pulsing Into	$\Delta(Crosstalk)$		
	Bypass Cap. & HV segments connected in $i\eta = 5$	GEM3B Continuous, HV Filter (w/o Divider)	GEM3B Continuous, HV Filter (w/ Divider)
$i\eta = 8$	-0.47±0.04%	-0.50±0.04%	-0.53±0.03%
$i\eta = 5$	+0.03±0.04%	-0.05±0.05%	-0.36±0.07%
$i\eta = 1$	N/A	-0.17±0.04%	-0.39±0.05%
Grand Average	-0.22±0.03%	-0.24±0.03%	-0.43±0.03%

Current Status of the ME0 Setup at FIT

- COVID-19 restrictions have been relaxed in Florida $\Rightarrow$ work is ongoing at Florida Tech
- Previously, 3 $\sim$3mm holes were drilled in the drift of the ME0 to allow for αs to enter the gas volume (for later use with HV discharge/probability studies)
- We have sealed the chamber with tape and cling film, and have proceeded to qualify the chamber with the CMS GEM QC chain
- Currently, the ME0 is undergoing the gas-tightness test





Remaining R&D Work at FIT and CERN

At FIT:

- Perform all QC steps (leak test, HV test, effective gain and gain uniformity test)
- Perform HV discharge and discharge probability studies

At CERN:

- Improve grounding of the chamber and retake comprehensive XT maps

Summary and Conclusions

- **Capacitive coupling between RO sectors causes the observed crosstalk**
- This capacitive coupling and the reading out of the signal form the capacitor and resistor of a CR differentiator circuit, respectively, which explains the crosstalk pulse profile
- Simulation agrees well with experimental measurement
- Simulation shows that **decreasing the impedance of GEM3B to ground reduces crosstalk** (in the form of blocking/bypass capacitors, increasing HV segmentation size on GEM3B, etc.)
- Experimentally, we see crosstalk 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
- **All experimental interventions have successfully reduced the crosstalk**, and making GEM3B continuous and adding an HV divider reduce the crosstalk the most (by $\sim$0.43$\pm$0.03%)

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.

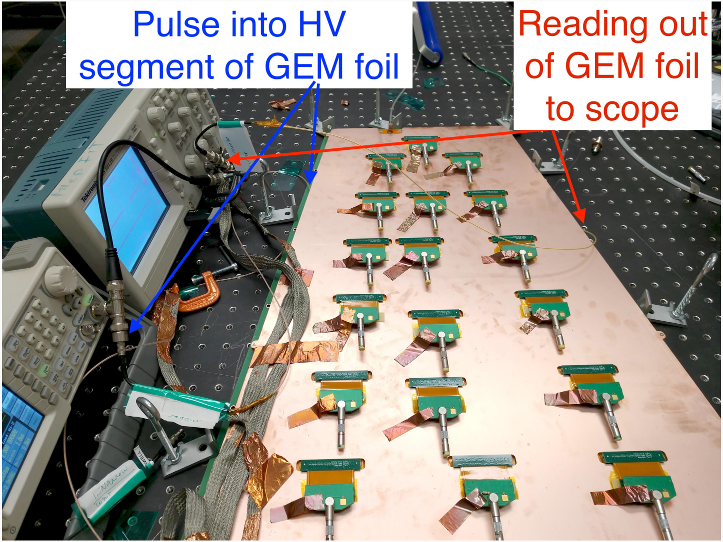
[9] S. Butalla & M. Hohlmann, "ME0 Crosstalk Study Update," Presented at the *GEM Phase-2 R&D Meeting*, Feb. 25, 2020, https://indico.cern.ch/event/891682/contributions/3760827/attachments/1993420/3324696/ME0CrosstalkUpdate_20200225.pdf.

[10] S. Butalla, E. Starling, & M. Hohlmann, "Investigation and Mitigation of Crosstalk Observed in the Prototype ME0 GEM Detector," Presented at the *GEM Phase-2 Upgrade Workshop*, May 19, 2020, https://indico.cern.ch/event/918611/contributions/3864584/.

Backup

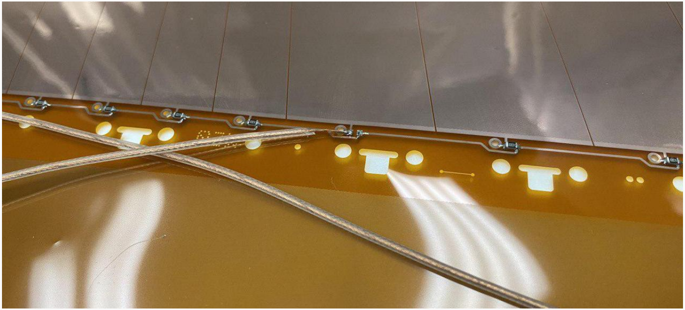
Experimental Setup at FIT

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



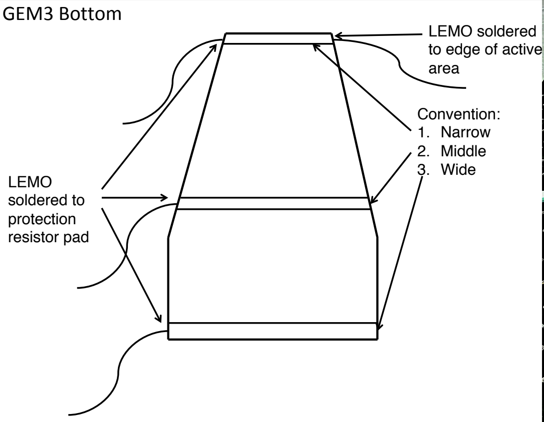
Experimental Setup at FIT

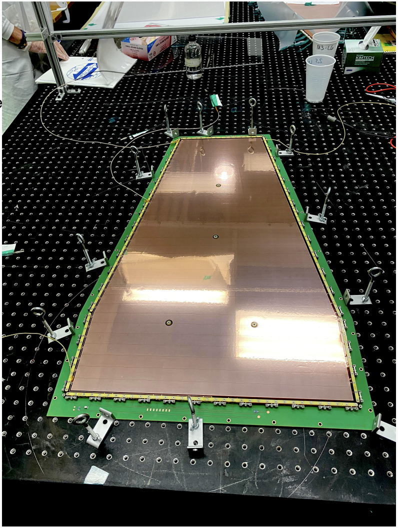
- To quantify and characterize the crosstalk, we injected a square voltage pulse into HV segments on GEM3B and various RO sectors
- Before assembly of an ME0, we modified a 10 MΩ, double-segmented ME0 foil with four LEMO cables (outer insulation and outer conductor removed to accommodate the wires inside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





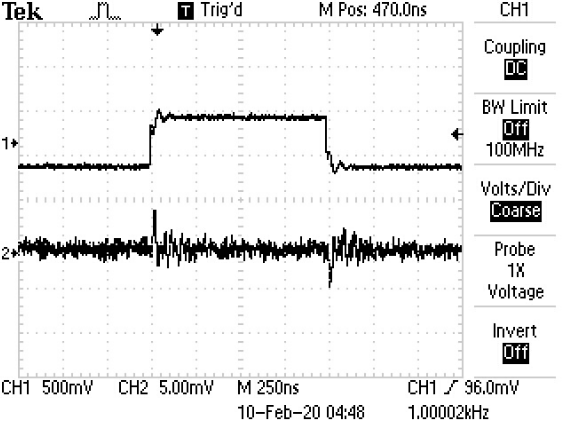
Main Results: Injection into HV Segment

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

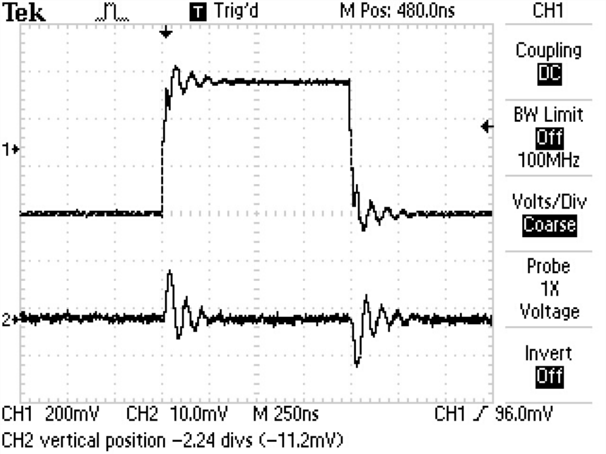
Main Results: Injection into HV Segment

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

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

Channel 1: Pulse Generator

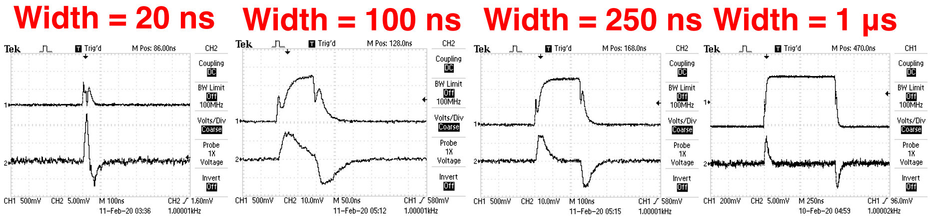
Channel 2: $i\eta = 8,\ i\phi = 1$ RO connector



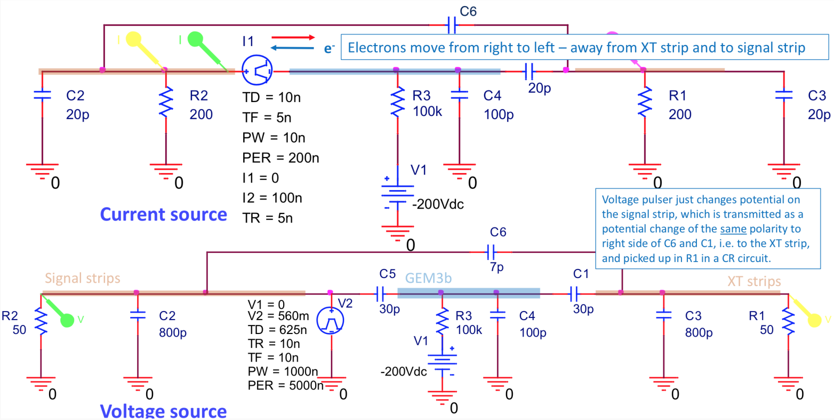
We see an induced pulse on the RO connector; very similar across $i\eta$ partitions

Pulse Profile Comparison

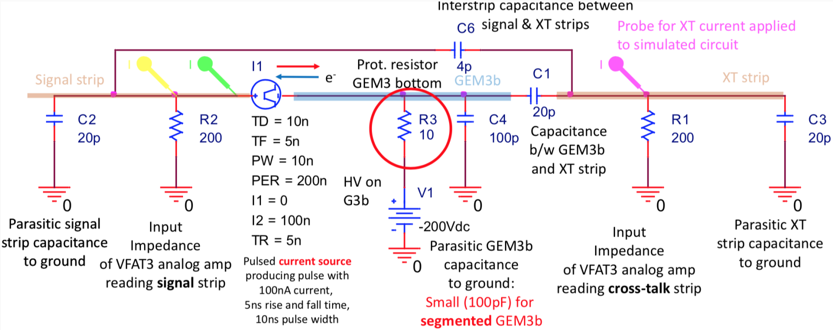
- Varying the width of the input pulse confirms the CR differentiator hypothesis
- Note that under 1 μs square pulse width, the impedance mismatch of the detector/scope system distorts the shape of the input pulse



Difference Between a Current and Voltage Source



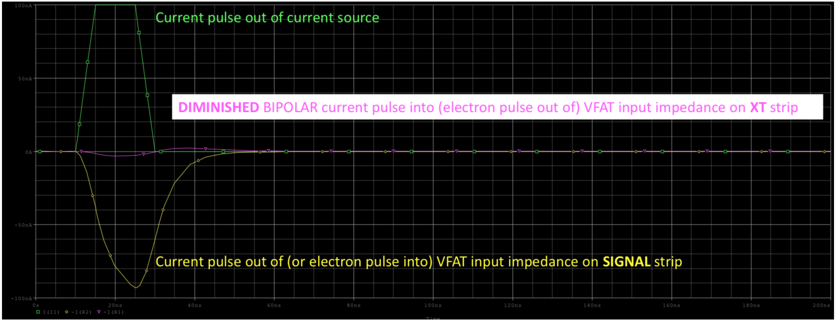
PSpice Circuit for Single-Segmented Foil Simulation



Current source: 10,000 primary electrons (1.6fc) over 15 ns: $i = 10^4\ 1.6\ 10^{-19}\ C / 15\ 10^{-9}\ s = 10^{4-1-19+9} = 10^{-7}\ A = 100nA$
(note that this doesn't even take gas gain into account)

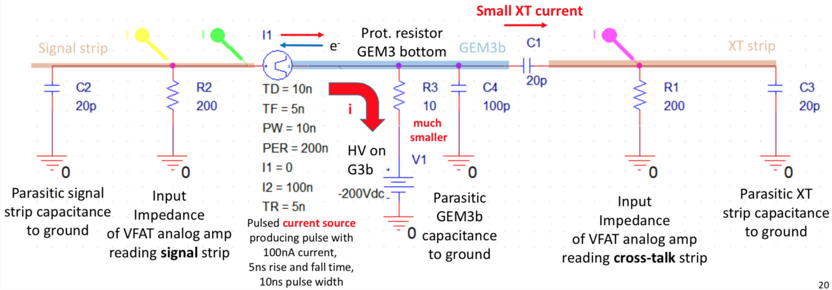
PSpice Circuit for Single-Segmented Foil Simulation

The crosstalk pulse is diminished by ∼4 times



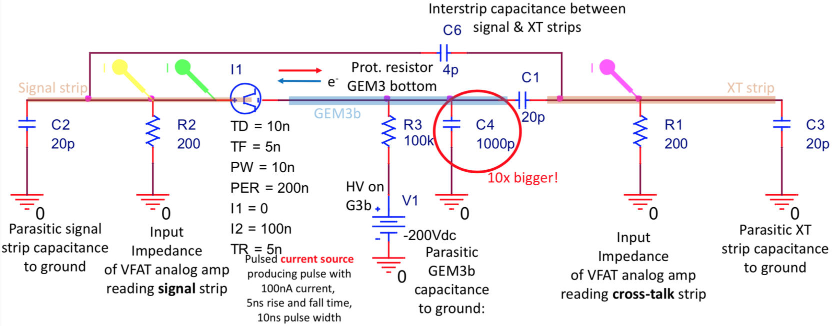
PSpice Circuit for Single-Segmented Foil Simulation

When the resistance (impedance) from GEM3B to ground is decreased, more crosstalk current can flow to ground and not to the GEM3B/readout strip capacitor system (C4)



CMS

When the resistance (impedance) from GEM3B to ground is decreased, more crosstalk current can flow to ground and not to the GEM3B/readout strip capacitor system (C4)

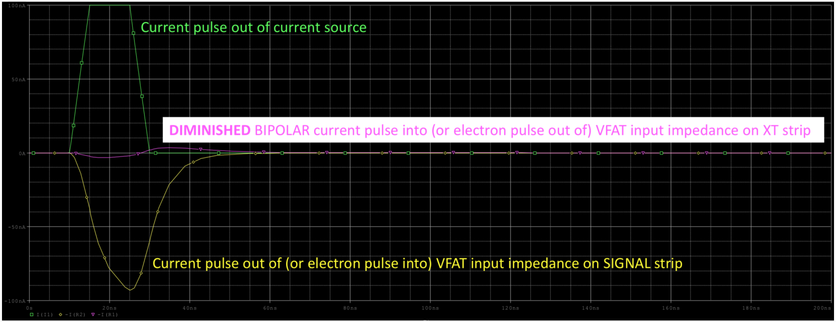


Current source: 10,000 primary electrons (1.6 nF) over 15 ns: i = 10^4 1.6 10^{-19} C / 15 10^{-9} s = $10^{4-1-19+9}$ = 10^{-7} A = 100nA
(note that this doesn't even take gas gain into account)

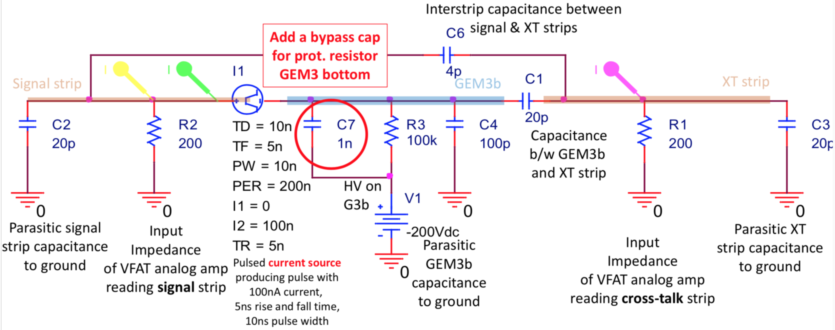
FLORIDA TECH

PSpice **Analysis for Increasing Capacitance to Ground Simulation**

The crosstalk pulse is diminished by ∼4 times



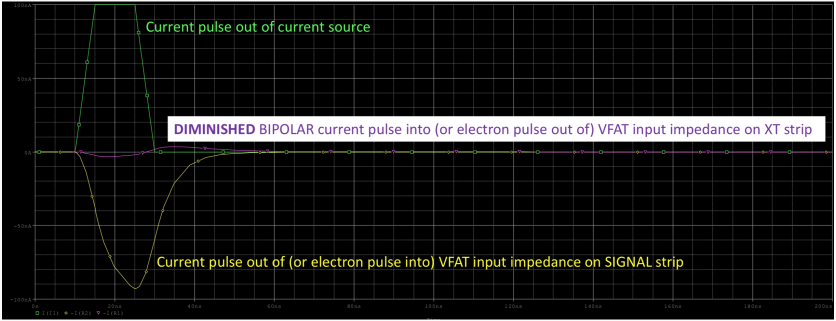
PSpice Circuit for Implementing a Bypass Capacitor



Current source: 10,000 primary electrons (1.6 fC) over 15 ns: $i = 10^4\ 1.6\ 10^{-19}$ C / 15 10^{-9} s = $10^{4-1-19+9}$ = 10^{-7} A = 100nA
(note that this doesn't even take gas gain into account)

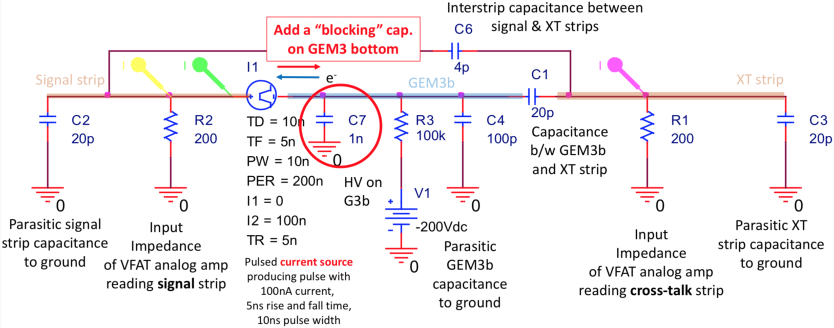
PSpice **Analysis for Implementing a Bypass Capacitor**

The crosstalk pulse is diminished by ∼4 times



FLORIDA TECH

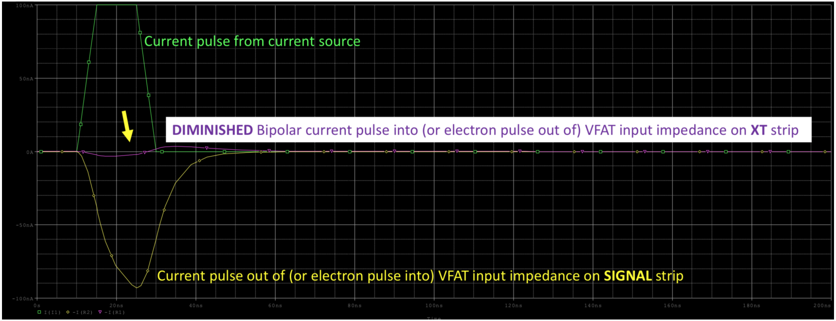
PSpice Circuit for Implementing a Blocking Capacitor



Current source: 10,000 primary electrons (1.6 fC) over 15 ns: $i = 10^4\ 1.6\ 10^{-19}\ C / 15\ 10^{-9}\ s = 10^{4-1-19+9} = 10^{-7}\ A = 100nA$
(note that this doesn't even take gas gain into account)

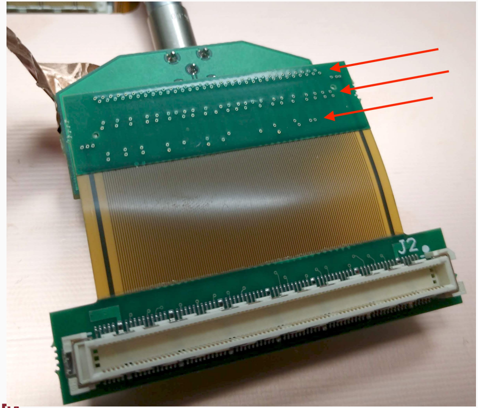
PSpice Analysis for Implementing a Blocking Capacitor

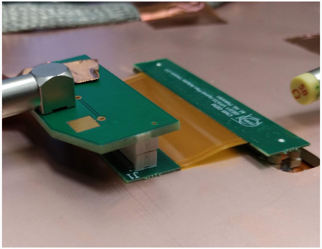
The crosstalk pulse is diminished by ∼4 times

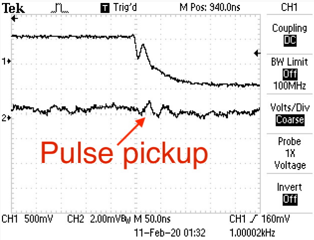


Pulse Pickup from Hirose-to-Panasonic Adapters

- 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

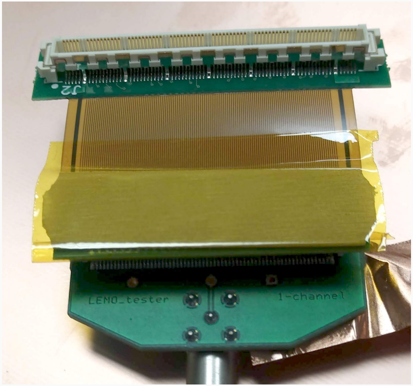


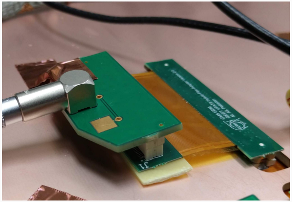


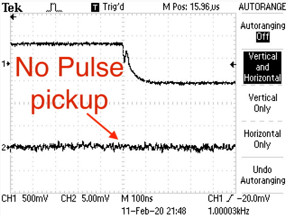


Pulse Pickup from Hirose-to-Panasonic Adapters

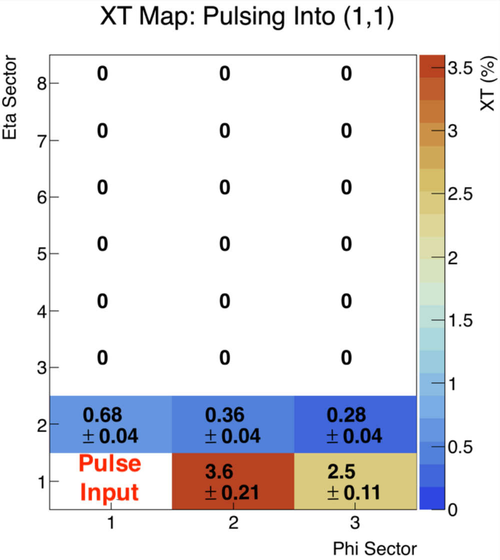
- To insulate the bottom of the adapter, we added a 1 mm FR4 spacer held in place with Kapton tape (left)
- With this insulation, there is no pulse pickup, just what is read out of the sector (right)
  *Note that in ($i\eta = 7,\ i\phi = 2$) there was no spacer added; no measurements were made here and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

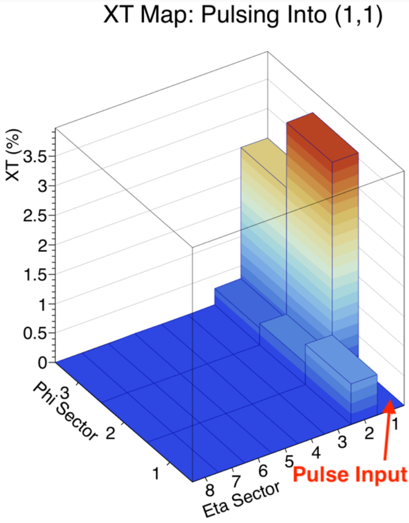




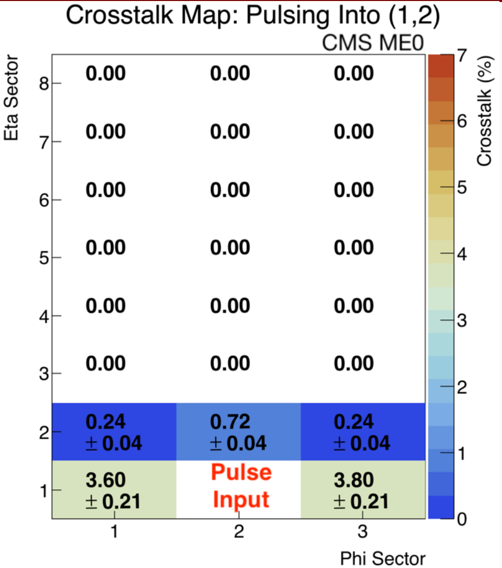


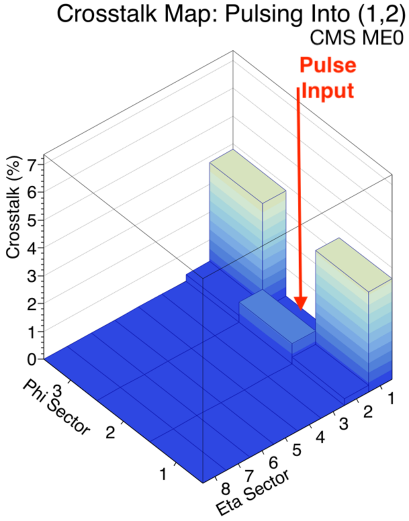
XT Map: Pulsing into (1,1)



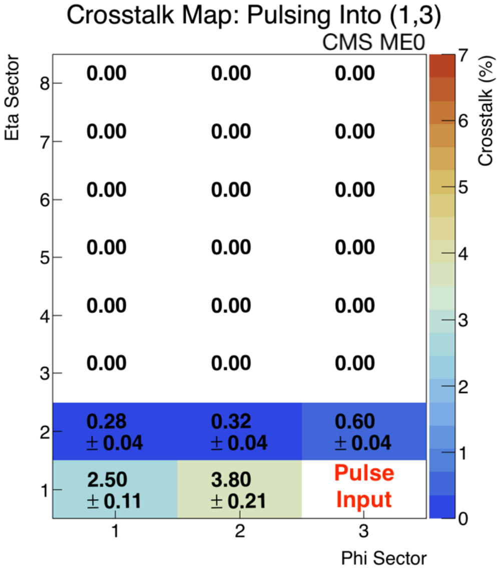


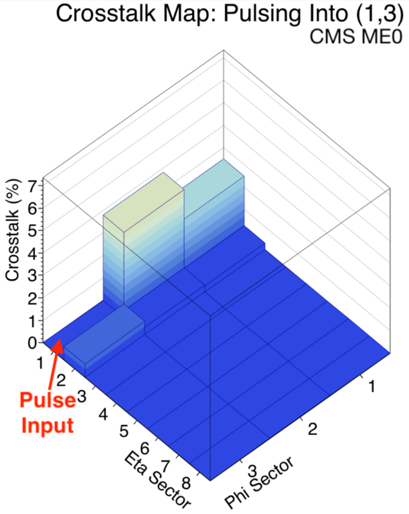
XT Map: Pulsing into (1,2)



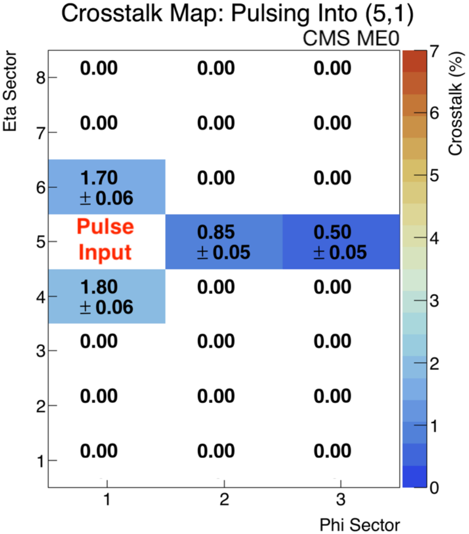


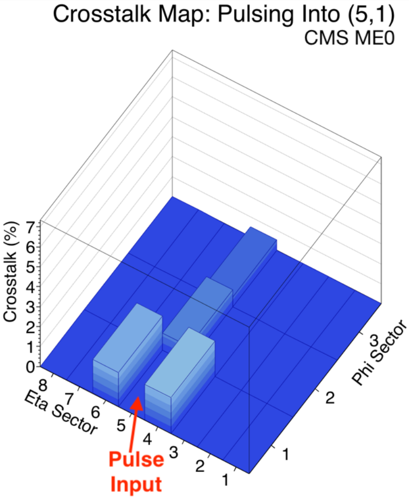
XT Map: Pulsing into (1,3)





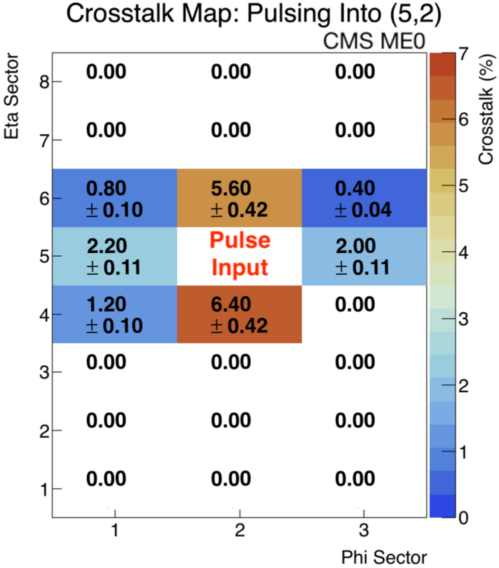
XT Map: Pulsing into (5,1)

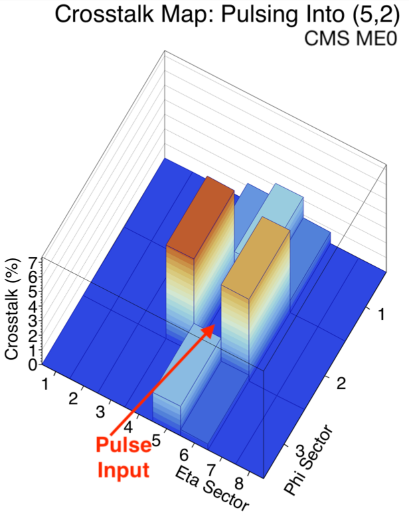




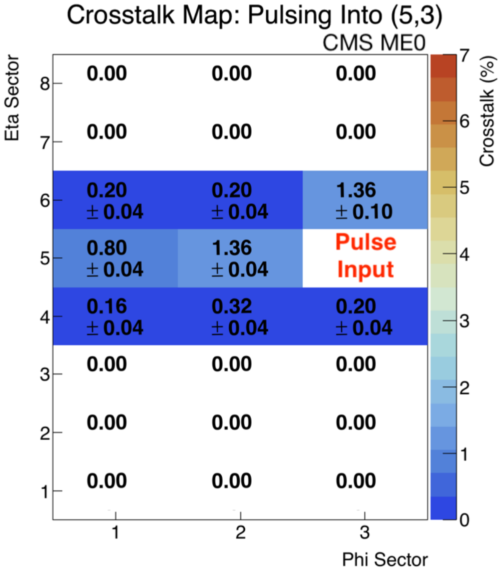
*200 mV input pulse amplitude

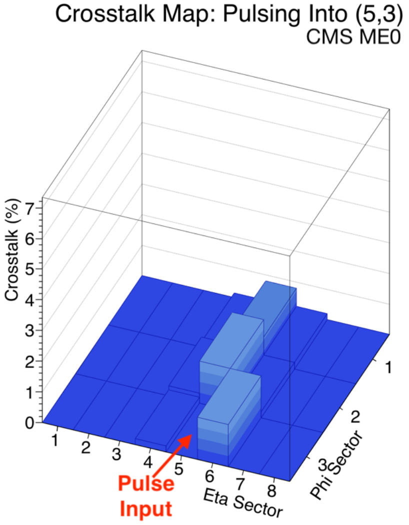
XT Map: Pulsing into (5,2)



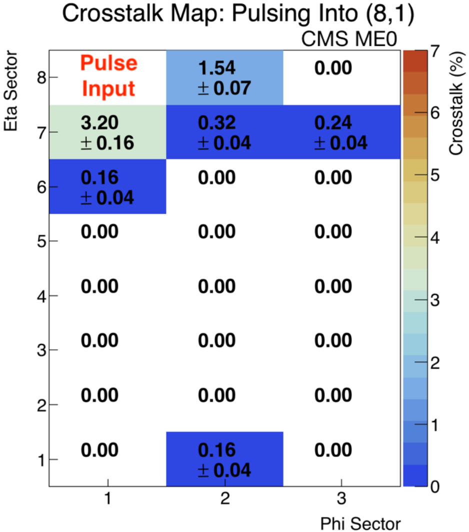


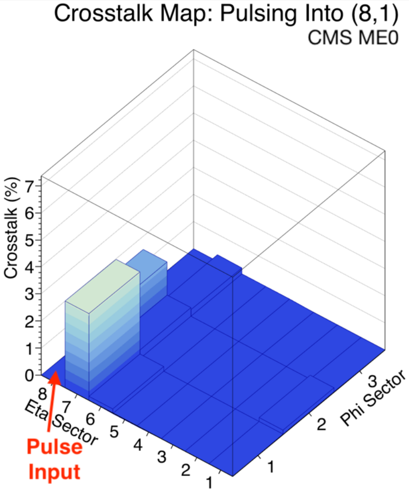
XT Map: Pulsing into (5,3)





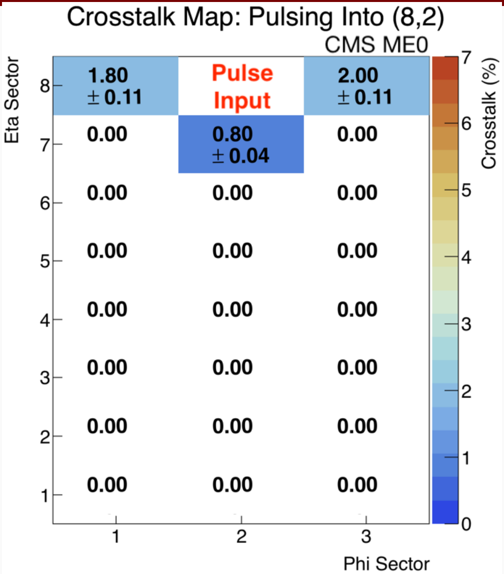
XT Map: Pulsing into (8,1)

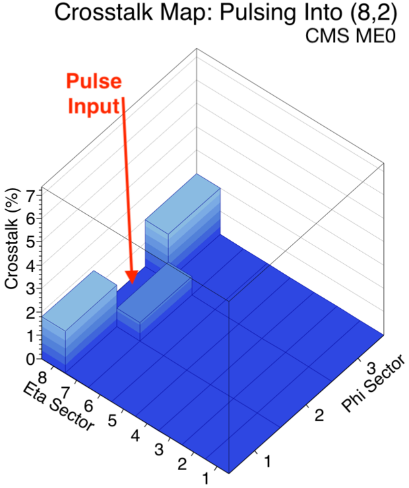




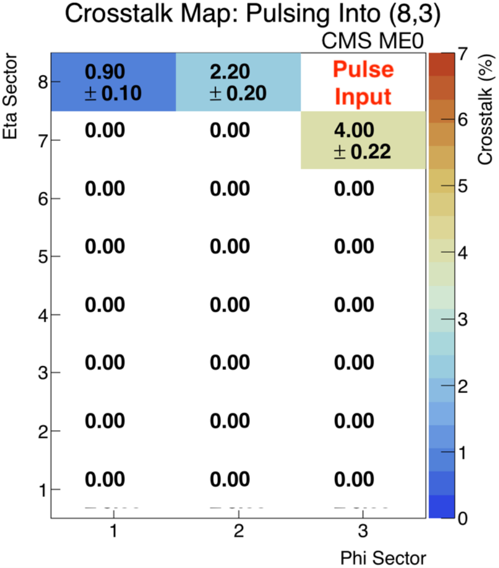
*The baseline noise for this XT map was higher than usual

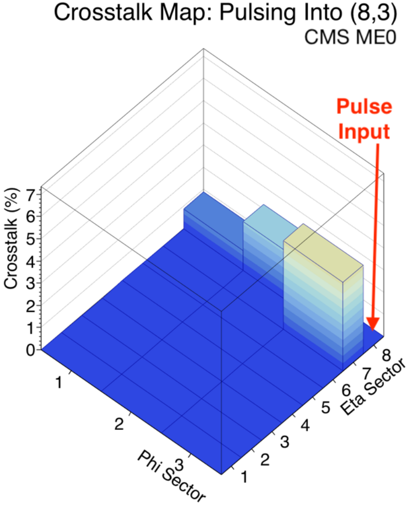
XT Map: Pulsing into (8,2)



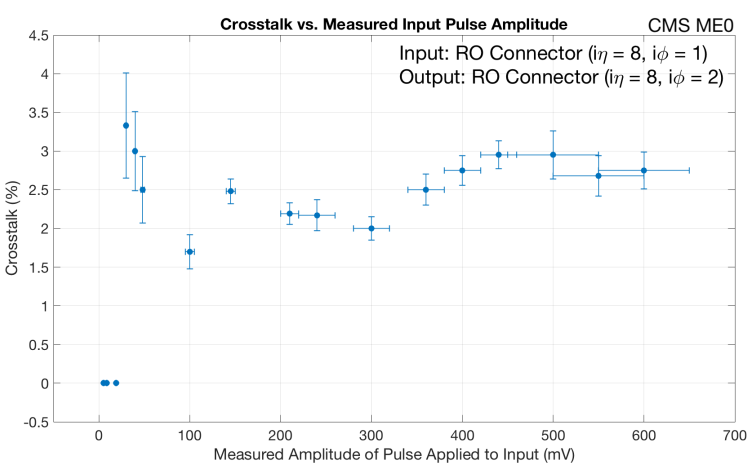


XT Map: Pulsing into (8,3)



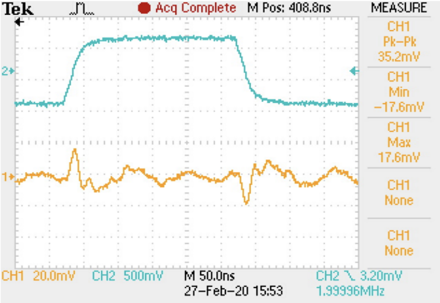


XT Seen in $(i\eta = 8, i\phi = 2)$

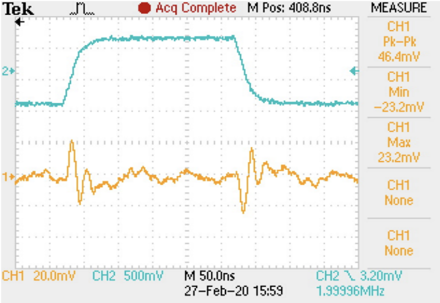


Example Scope Traces of Crosstalk at 904

Pulsing into (8,3)



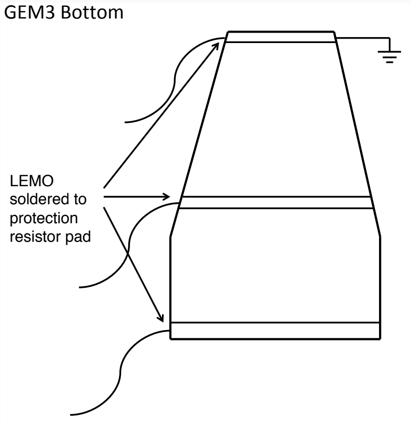
Reading out of (5,1)

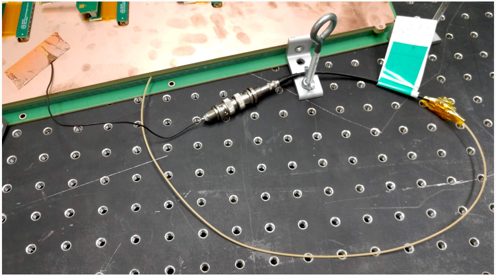


Reading out of (3,1)

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:



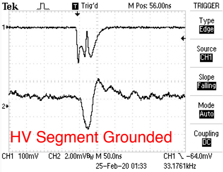


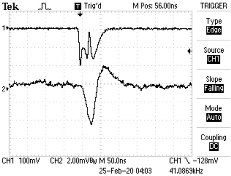
- HP 8012B pulse generator used with inverted square pulse (20 ns pulse width)

Effect of Decreasing the Impedance of GEM3B to GND

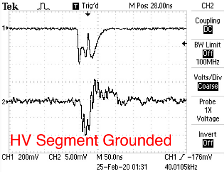
Pulsing into $(i\eta = 8, i\phi = 1)$, reading out of $(i\eta = 8, i\phi = 2)$

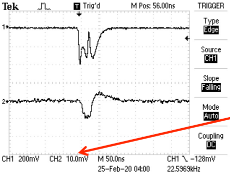
200 mV Measured Input Pulse Amplitude





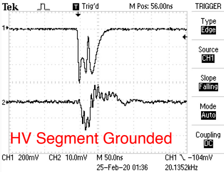
400 mV Measured Input Pulse Amplitude

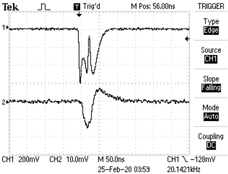




Note the different voltage scales on channel 2

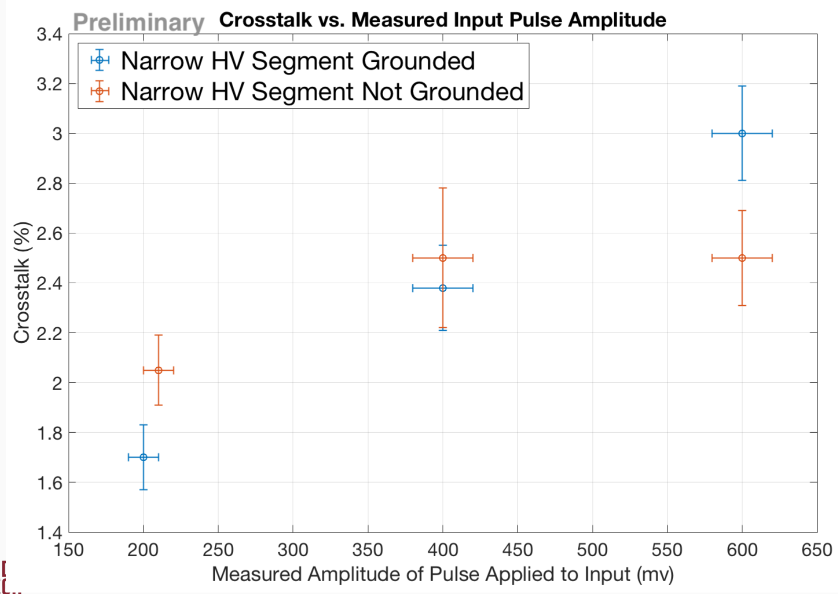
600 mV Measured Input Pulse Amplitude





Effect of Decreasing the Impedance of GEM3B to GND

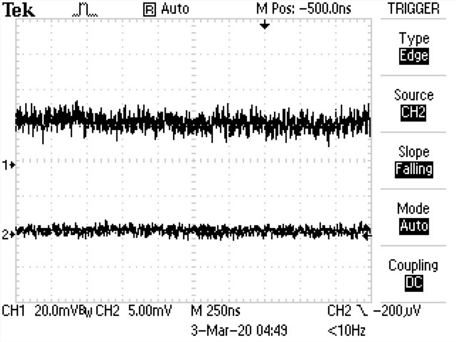
Pulsing into $(i\eta = 8, i\phi = 1)$, reading out of $(i\eta = 8, i\phi = 2)$



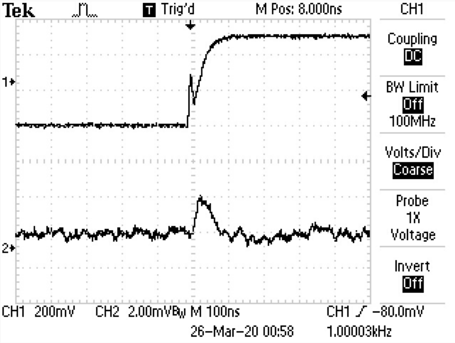
New Sectors Exhibiting XT

- Another example after adding the bypass capacitors in $i\eta = 8$ and connecting the HV segments in $i\eta = 5$
- 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)



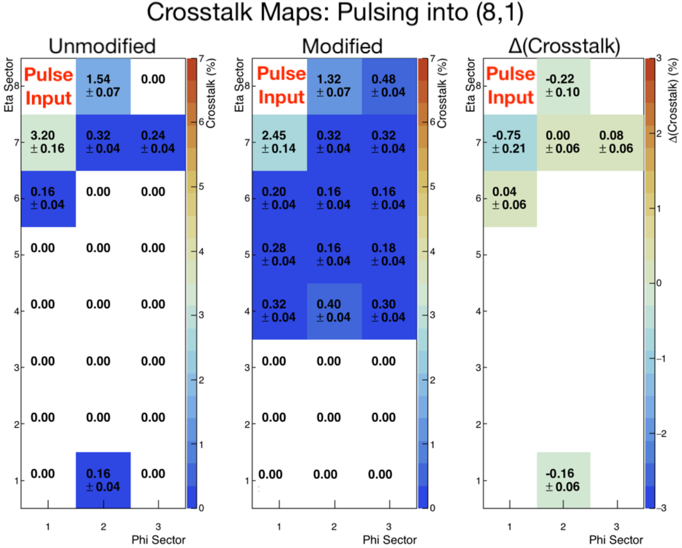
Before modification



After modification

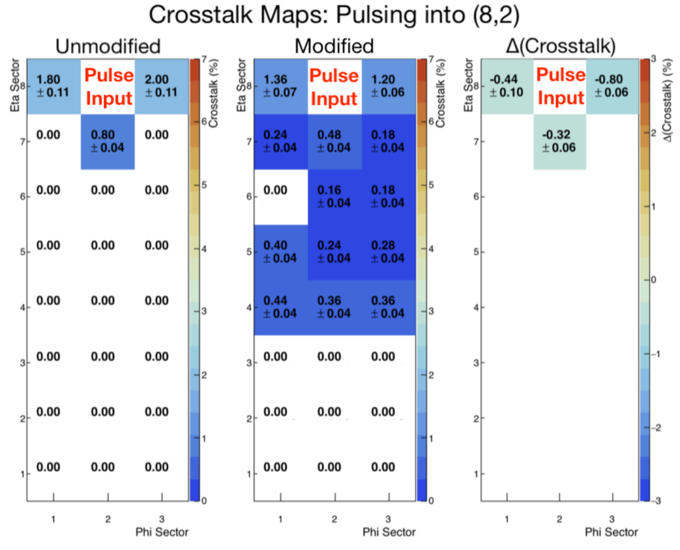
XT Maps: Pulsing into (8,1)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$



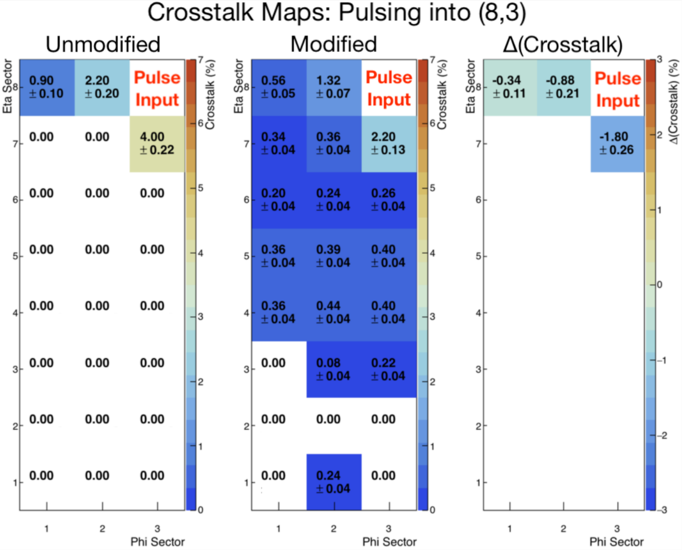
XT Maps: Pulsing into (8,2)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$



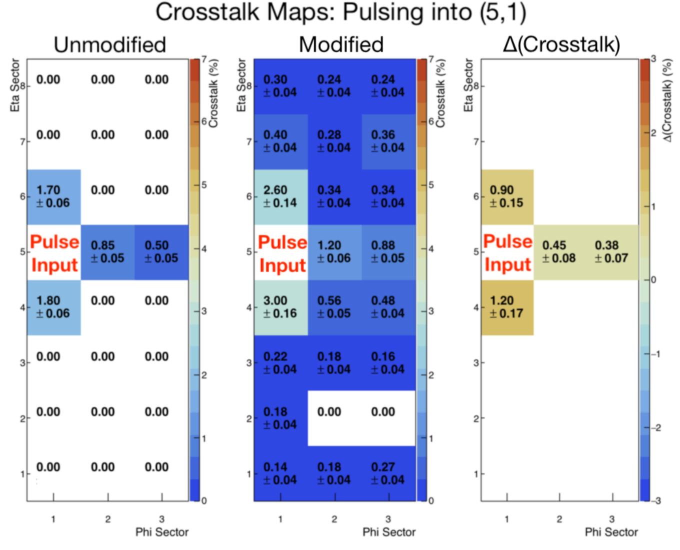
XT Map: Pulsing into (8,3)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$



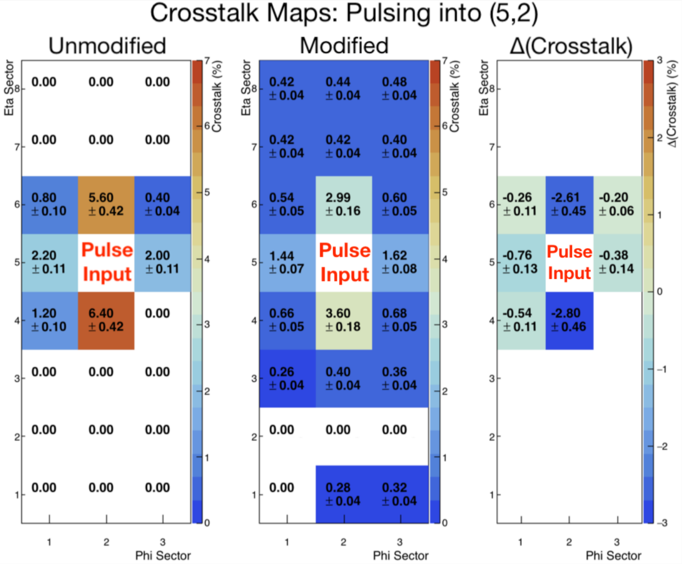
XT Map: Pulsing into (5,1)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$



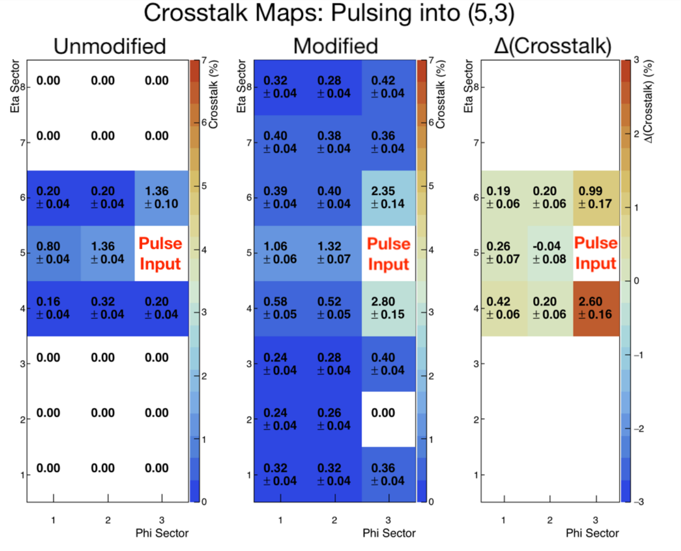
XT Map: Pulsing into (5,2)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$

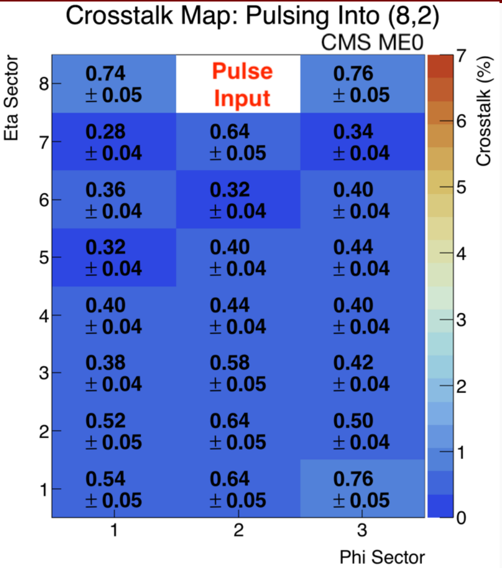


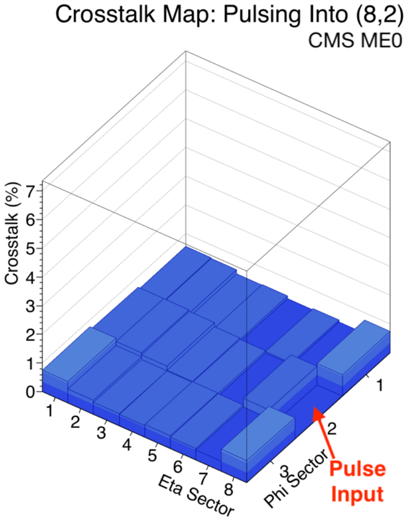
XT Map: Pulsing into (5,3)

With bypass capacitors in $i\eta = 8$ and HV segments connected in $i\eta = 5$



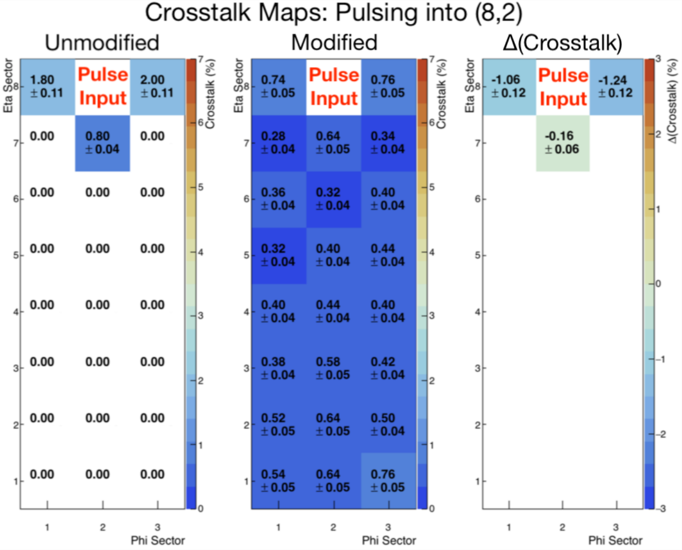
XT Map: Pulsing into (8,2), With HV Filter Circuit



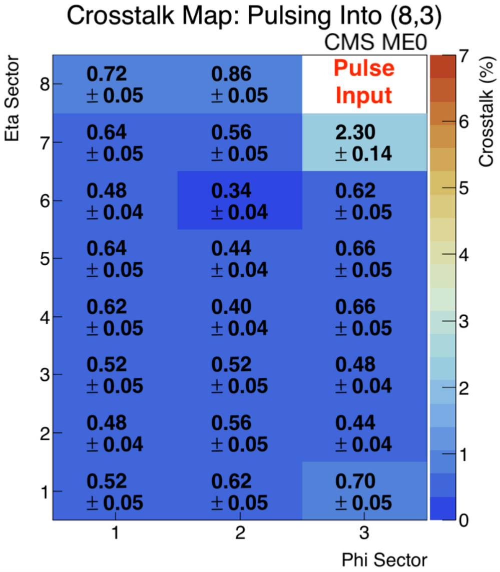


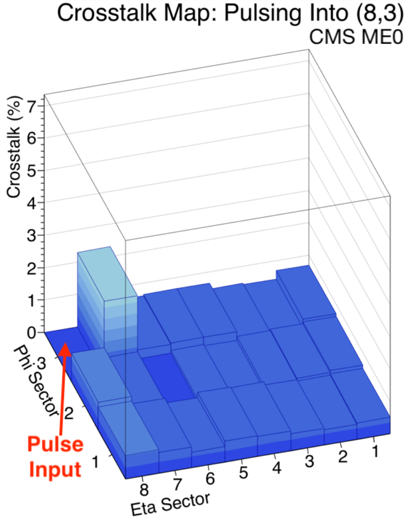
XT Map Comparison: Pulsing into (8,2)

With GEM3B continuous and a lowpass filter on GEM3B.



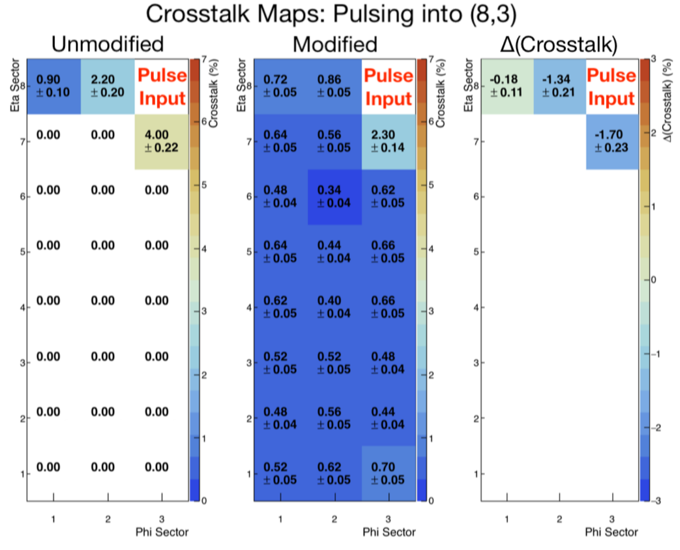
XT Map: Pulsing into (8,3), With HV Filter Circuit



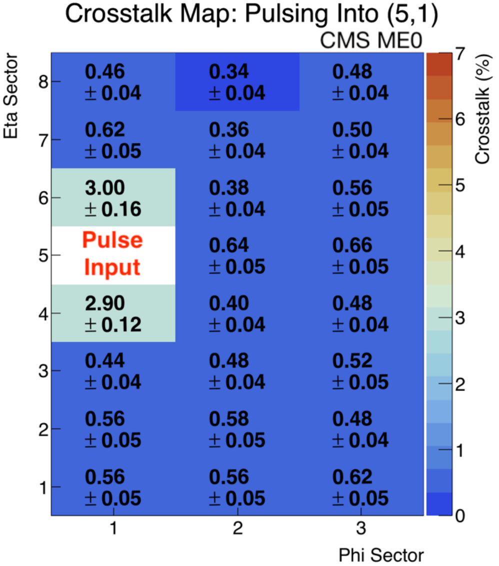


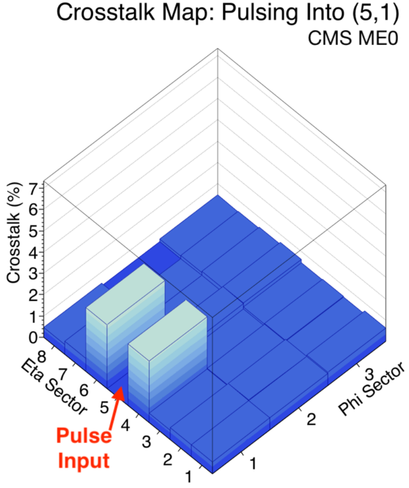
XT Map Comparison: Pulsing into (8,3)

With GEM3B continuous and a lowpass filter on GEM3B.

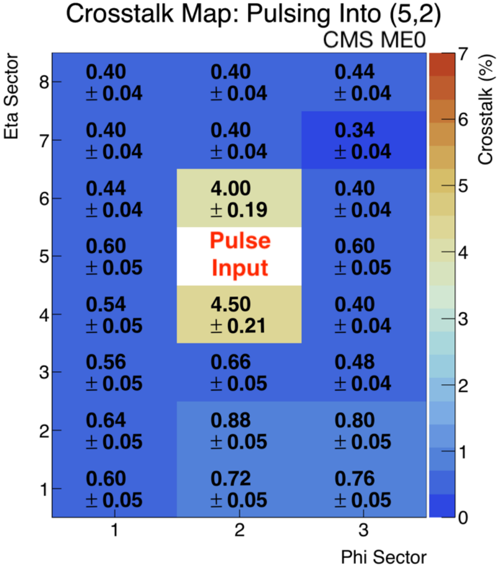


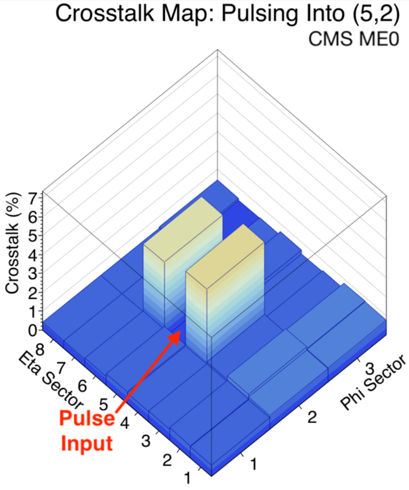
XT Map: Pulsing into (5,1), With HV Filter Circuit



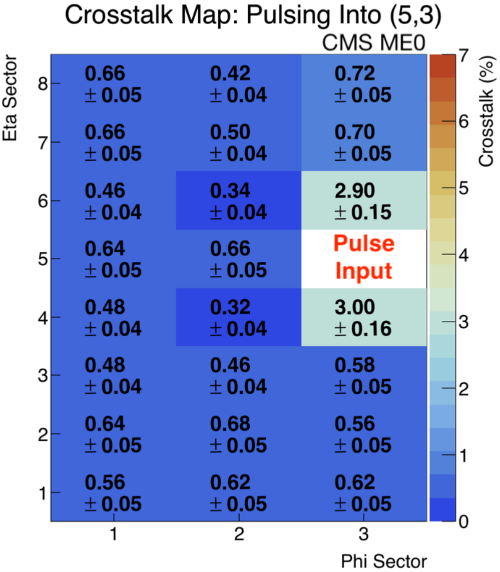


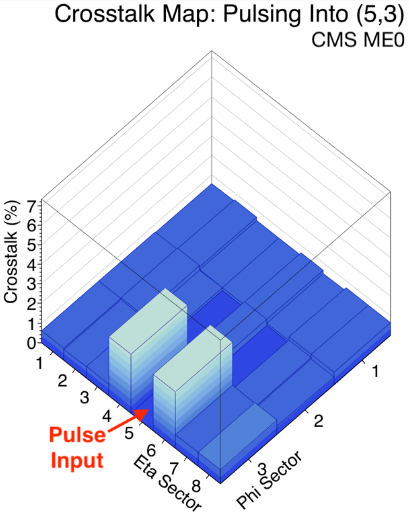
XT Map: Pulsing into (5,2), With HV Filter Circuit





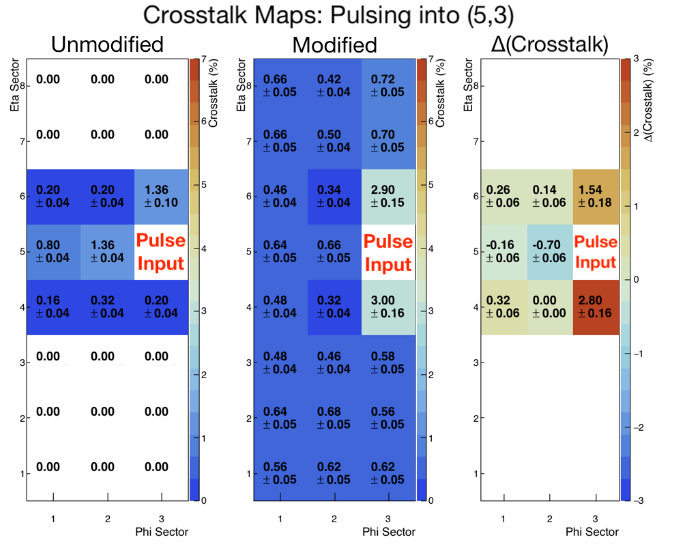
XT Map: Pulsing into (5,3), With HV Filter Circuit



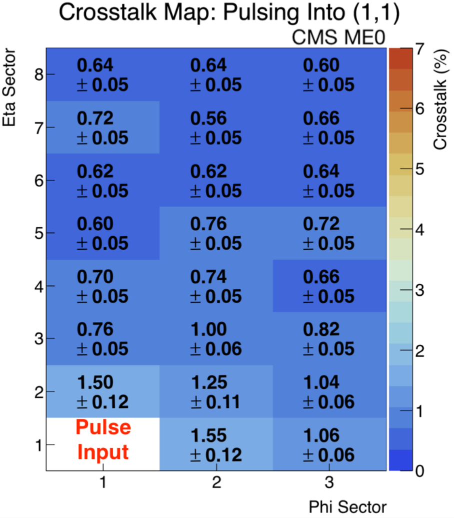


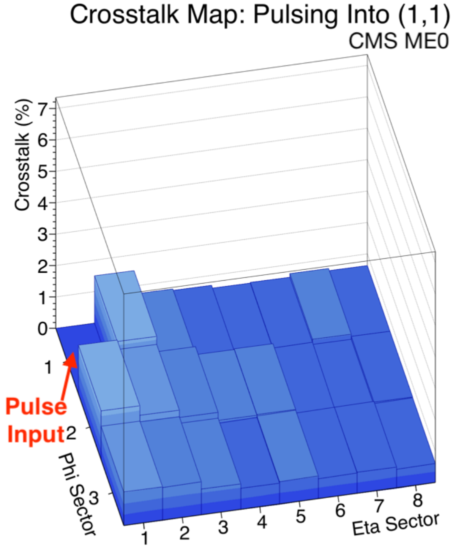
XT Map Comparison: Pulsing into (5,3)

With GEM3B continuous and a lowpass filter on GEM3B.

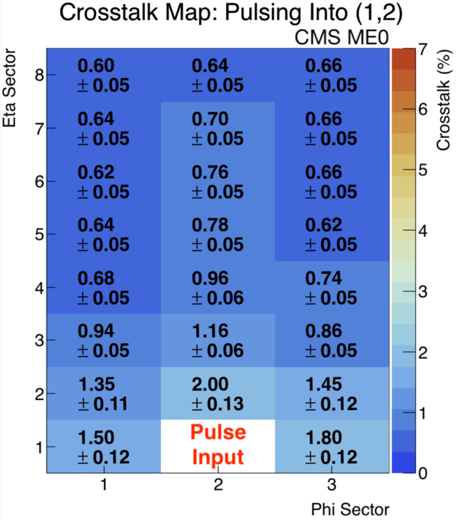


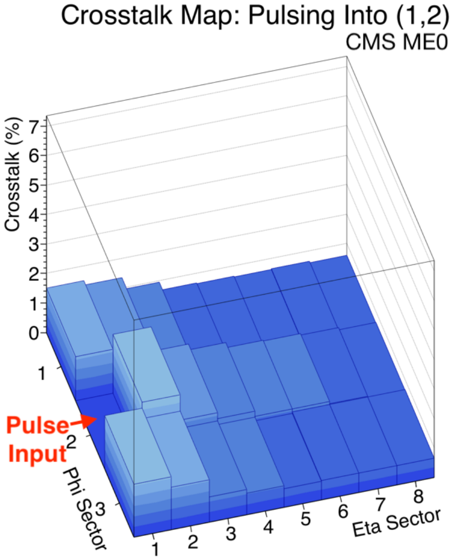
Pulsing into (1,1), With HV Filter Circuit





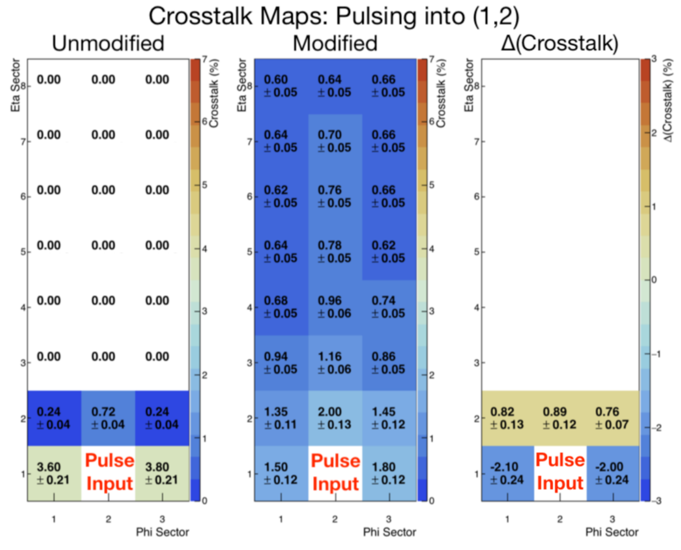
Pulsing into (1,2), With HV Filter Circuit



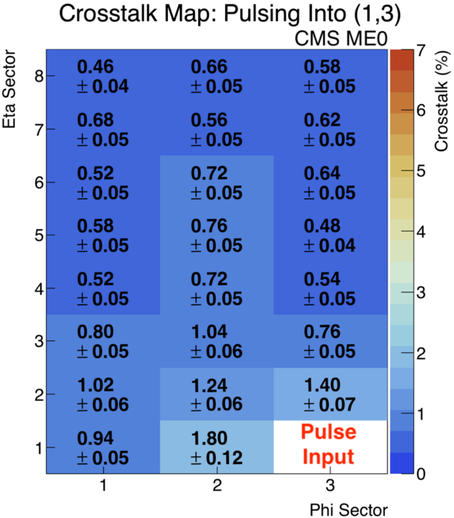


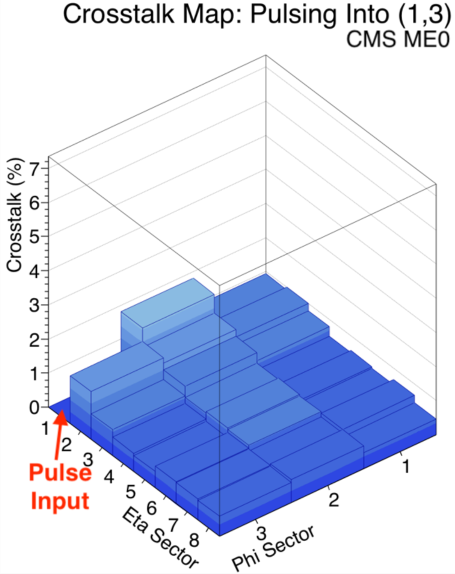
XT Map Comparison: Pulsing into (1,2)

With GEM3B continuous and a lowpass filter on GEM3B.



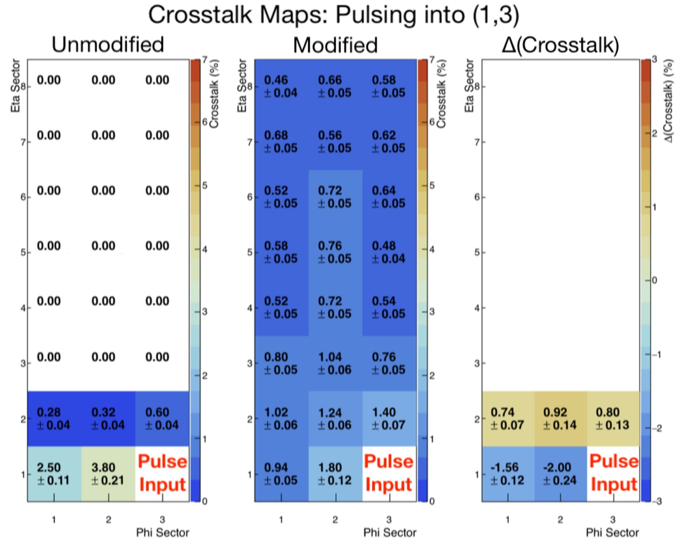
Pulsing into (1,3), With HV Filter Circuit



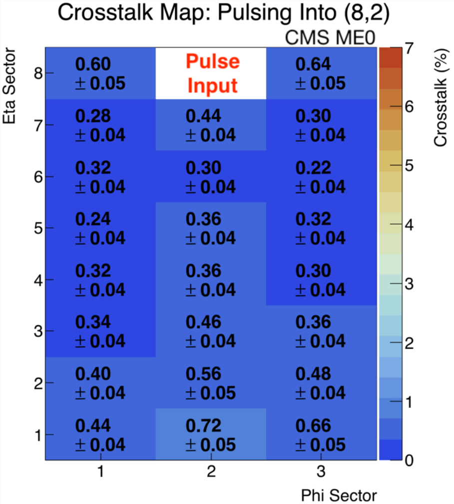


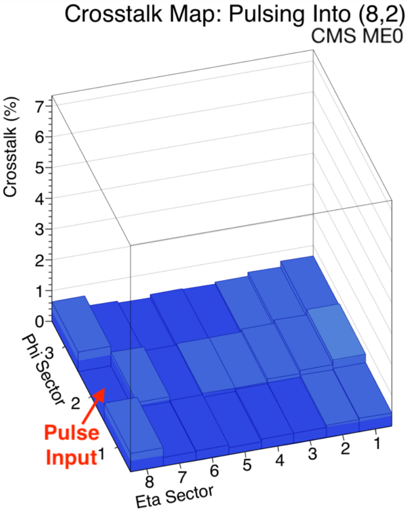
XT Map Comparison: Pulsing into (1,3)

With GEM3B continuous and a lowpass filter on GEM3B.

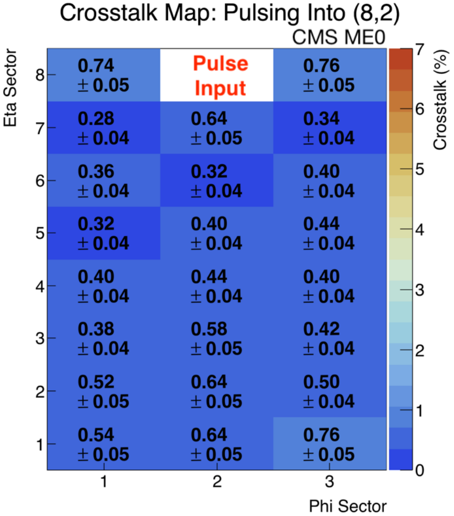


XT Map: Pulsing into (8,2), With HV Filter Circuit and Divider

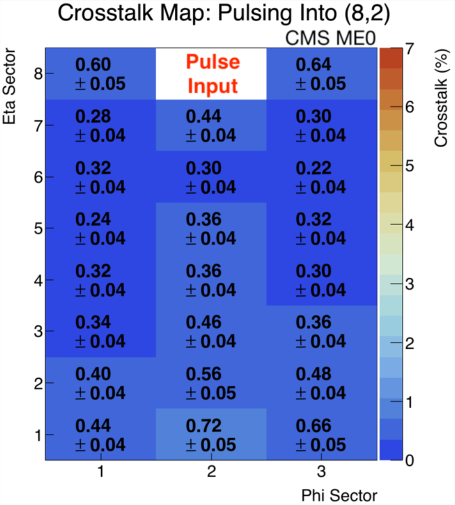




Comparison: Pulsing into (8,2), With and Without HV Divider



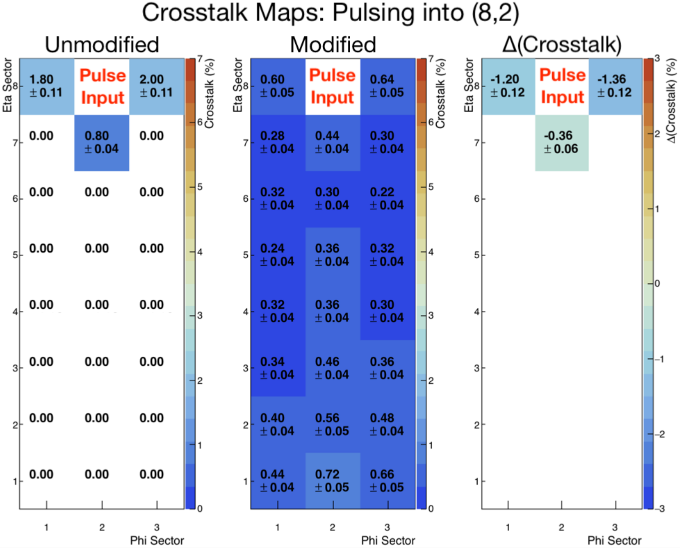
Without divider



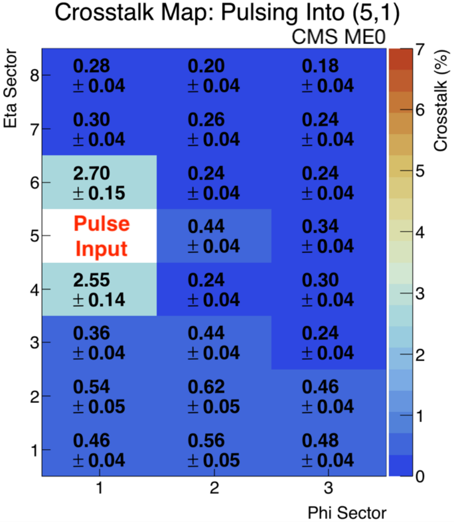
With divider

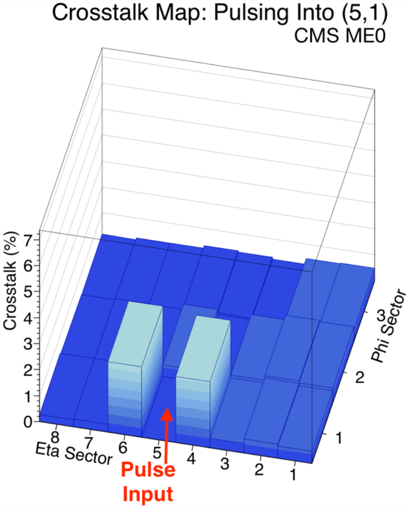
XT Map Comparison: Pulsing into (8,2)

With GEM3B continuous, a lowpass filter on GEM3B, and the HV divider.

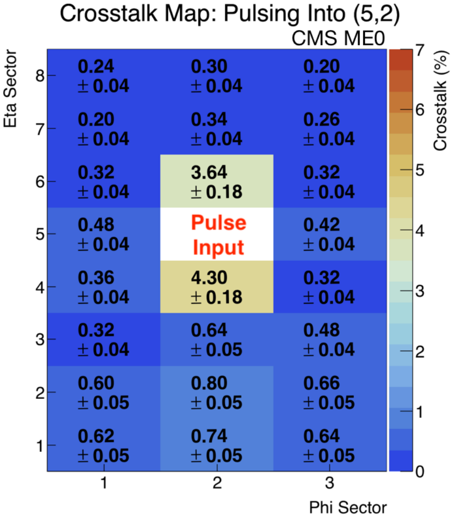


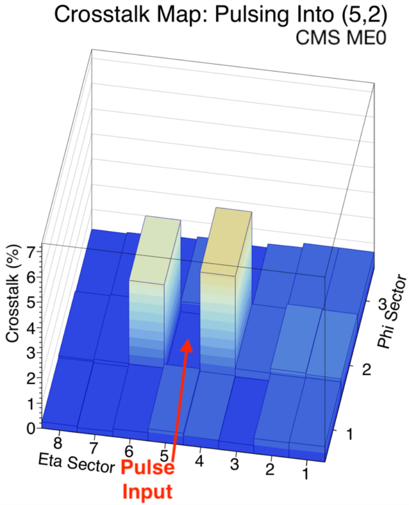
XT Map: Pulsing into (5,1), With HV Filter Circuit and Divider



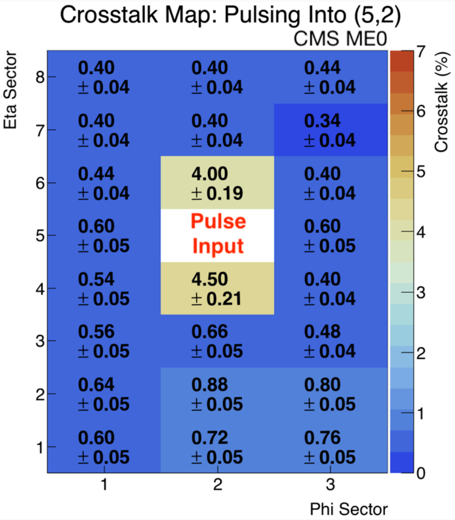


XT Map: Pulsing into (5,2), With HV Filter Circuit and Divider

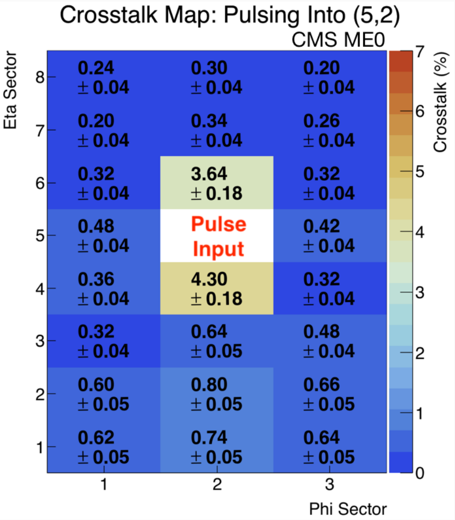




Comparison: Pulsing into (5,2), With and Without HV Divider



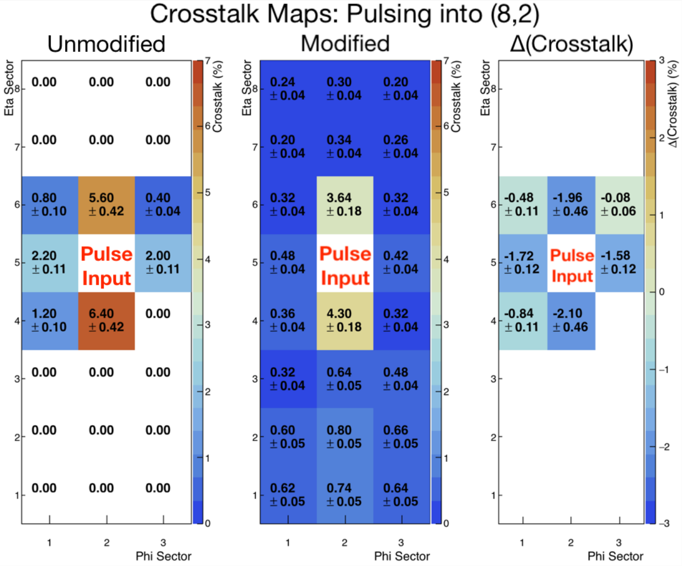
Without divider



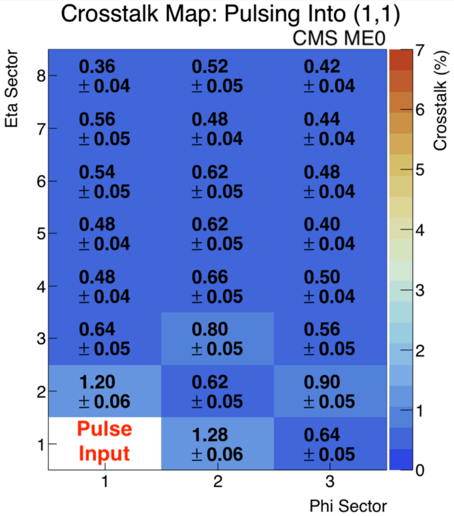
With divider

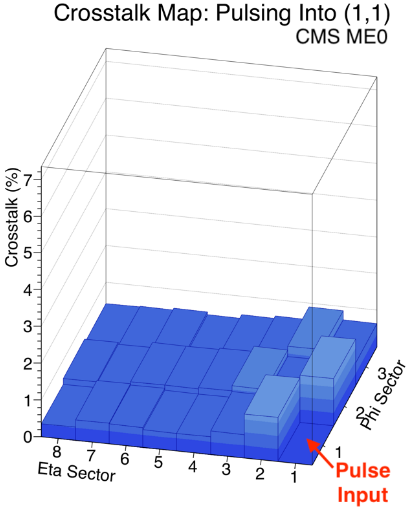
XT Map Comparison: Pulsing into (5,2)

With GEM3B continuous, a lowpass filter on GEM3B, and the HV divider.

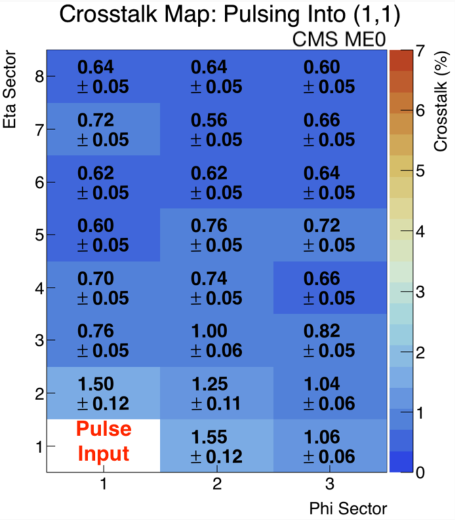


XT Map: Pulsing into (1,1), With HV Filter Circuit and Divider

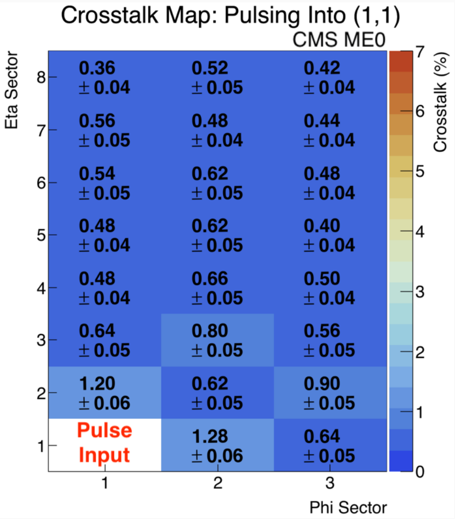




Comparison: Pulsing into (1,1), With and Without HV Divider

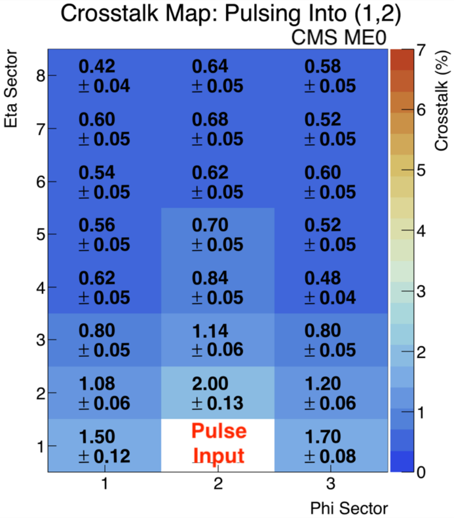


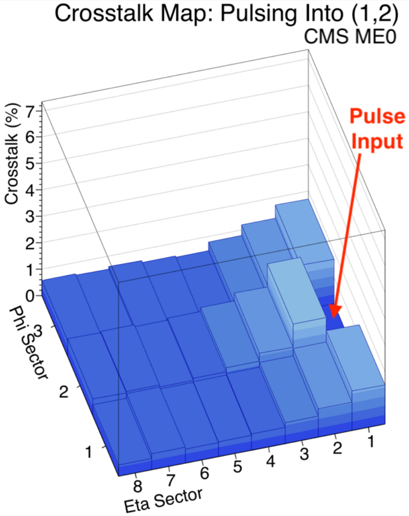
Without divider



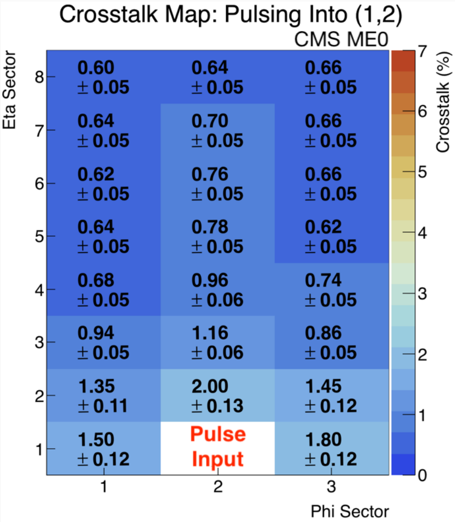
With divider

XT Map: Pulsing into (1,2), With HV Filter Circuit and Divider

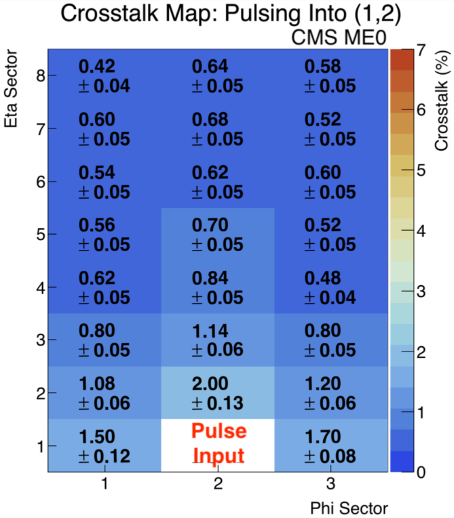




Comparison: Pulsing into (1,2), With and Without HV Divider



Without divider



With divider

XT Map Comparison: Pulsing into (1,2)

With GEM3B continuous, a lowpass filter on GEM3B, and the HV divider.