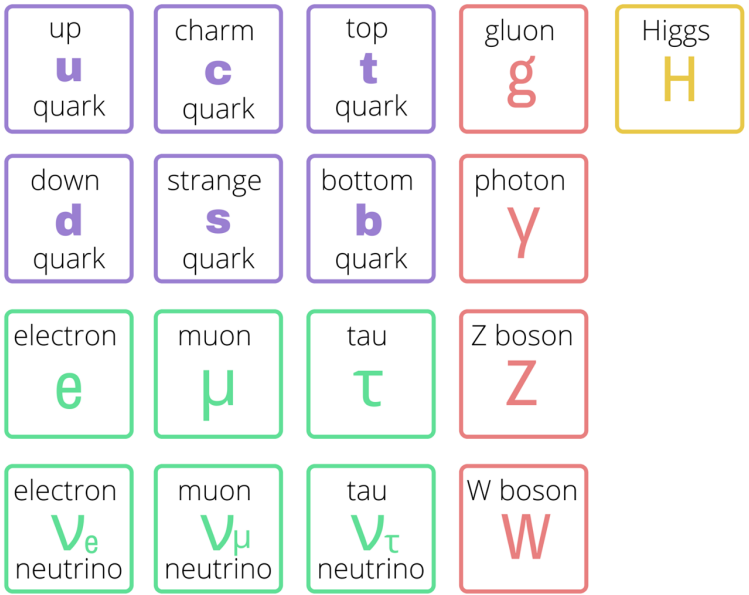
Searching for hidden matter with milliQan

Emily Pottebaum - Iowa State University

Faculty advisor: Dr. David Stuart

Graduate mentor: Ryan Schmitz

The Standard Model



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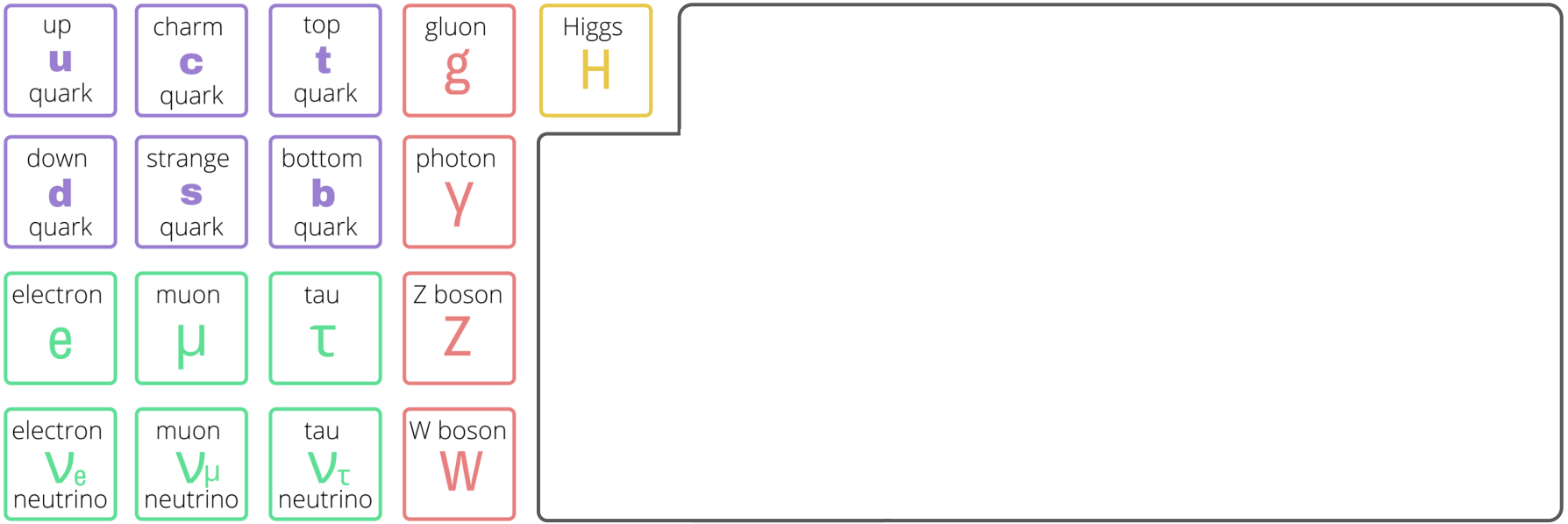
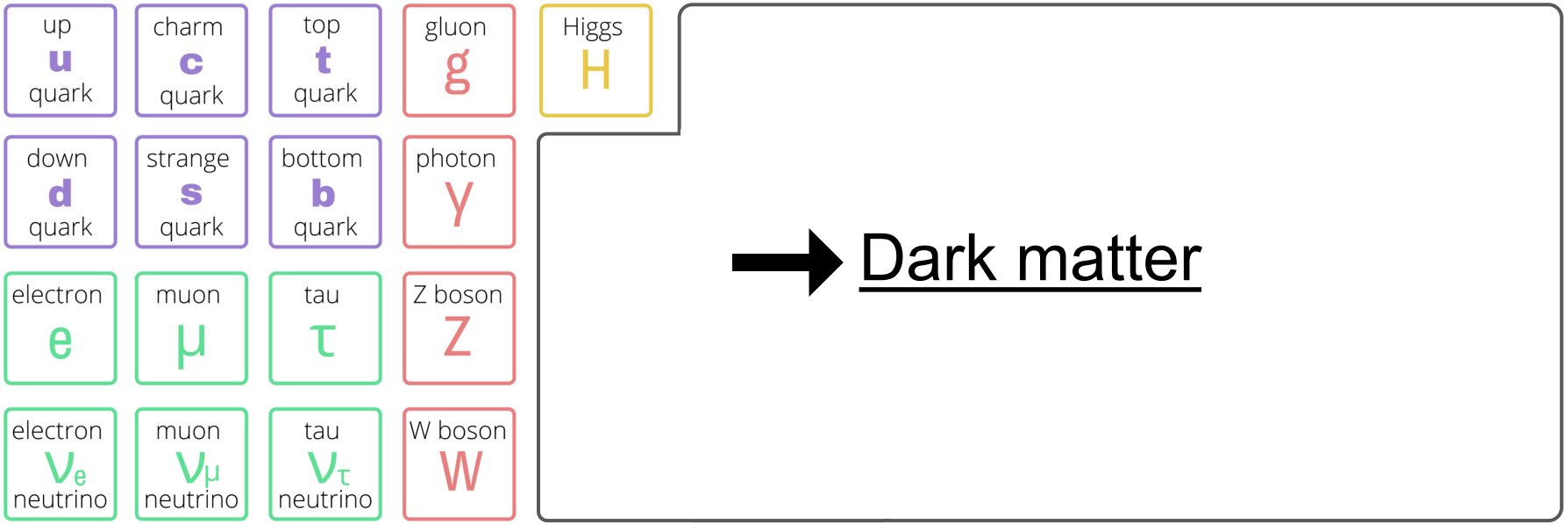


...and beyond

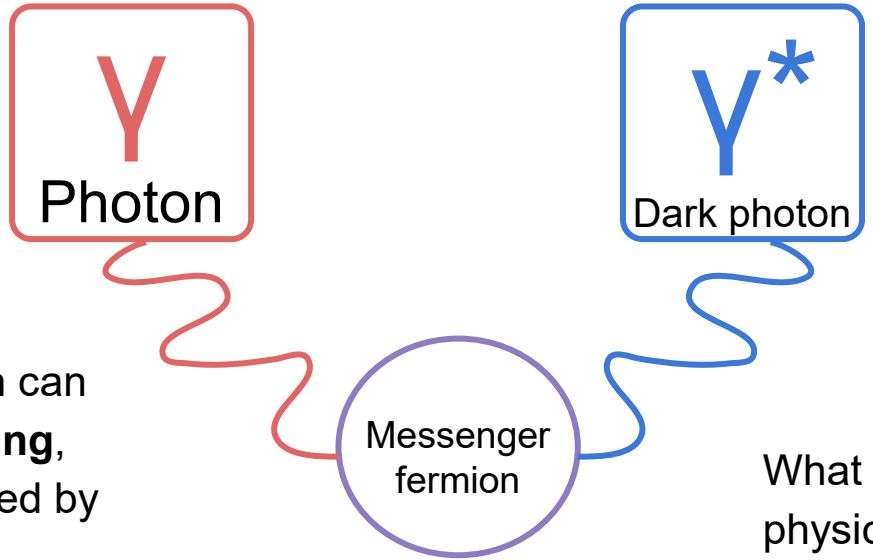
The Standard Model



...and beyond

Detecting dark matter

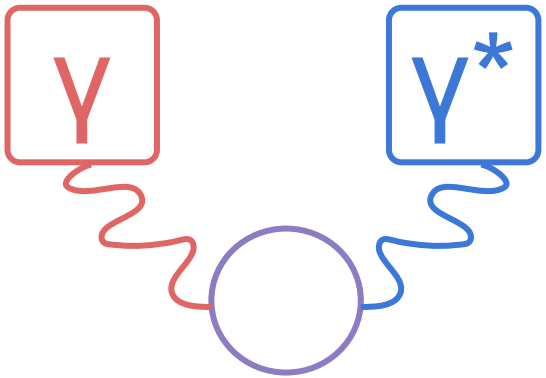
Detecting dark matter



Photon and dark photon can interact via **kinetic mixing**, where they are connected by a messenger fermion

What does this look like physically?

Detecting dark matter



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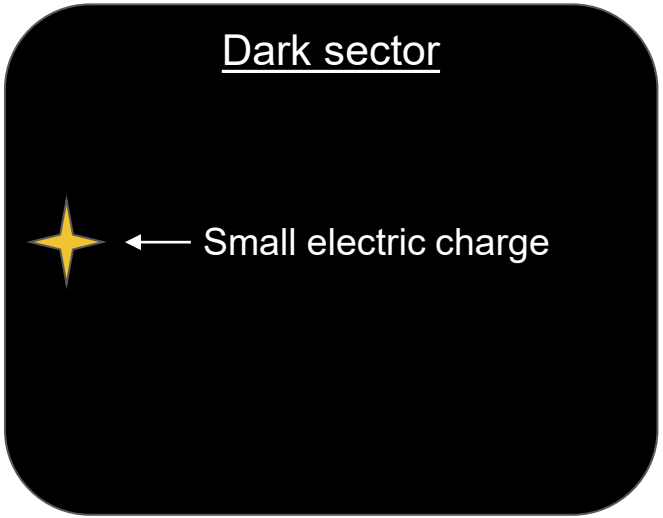
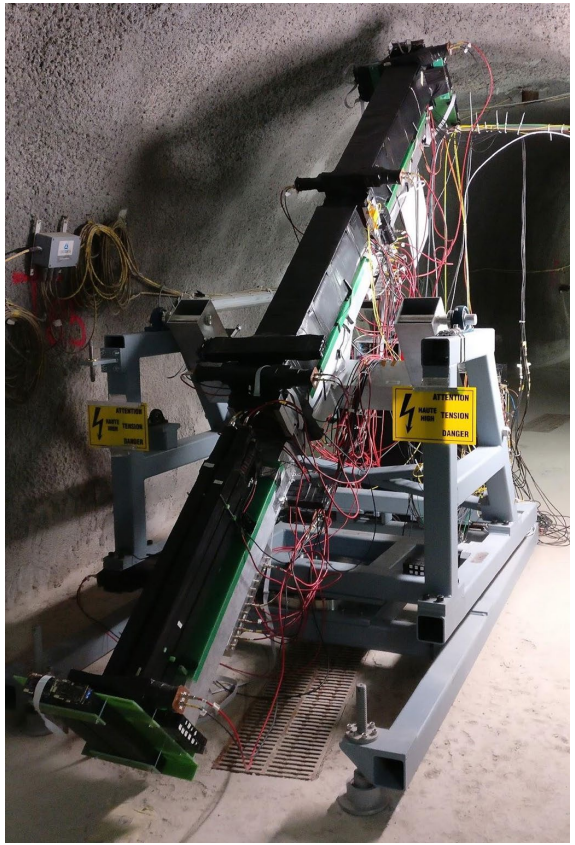


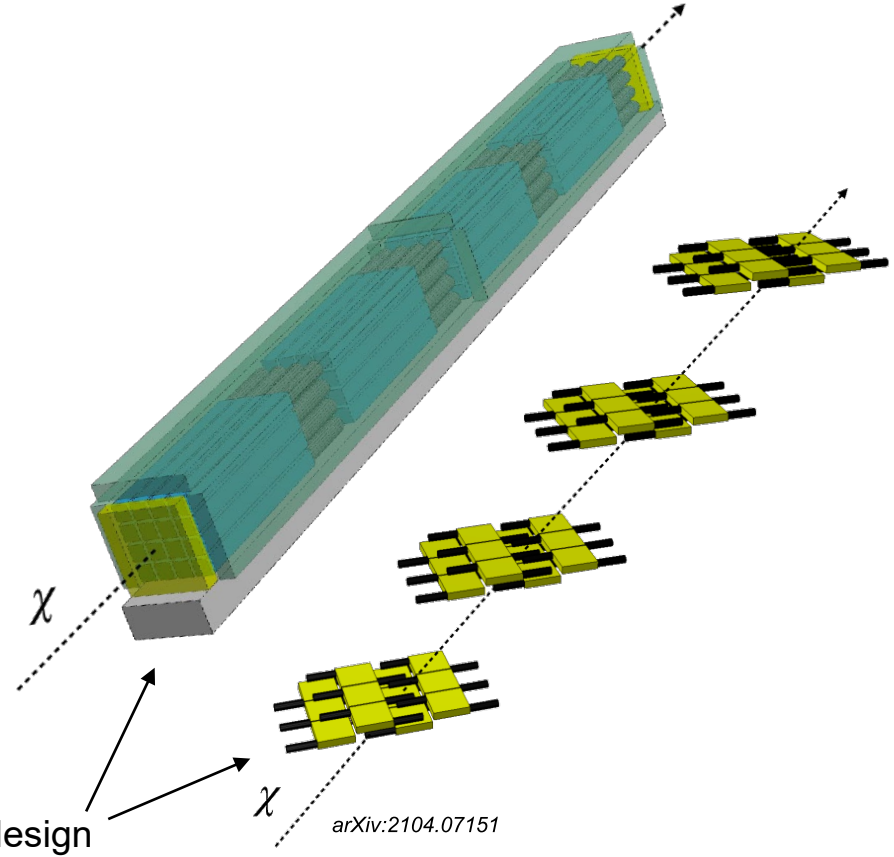
When the photon and dark photon are connected, we can see a small electric charge coming from the dark sector. This is a **milli-charged particle (mCP)**!

The milliQan detector



arXiv:2005.06518

Demonstrator

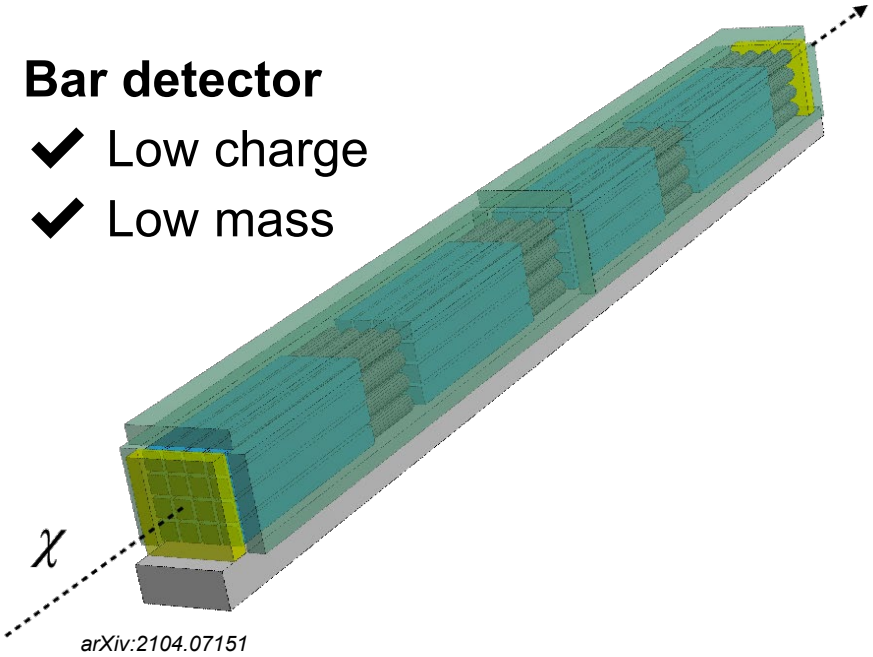


arXiv:2104.07151

The milliQan detector

Bar detector

- ✔ Low charge
- ✔ Low mass



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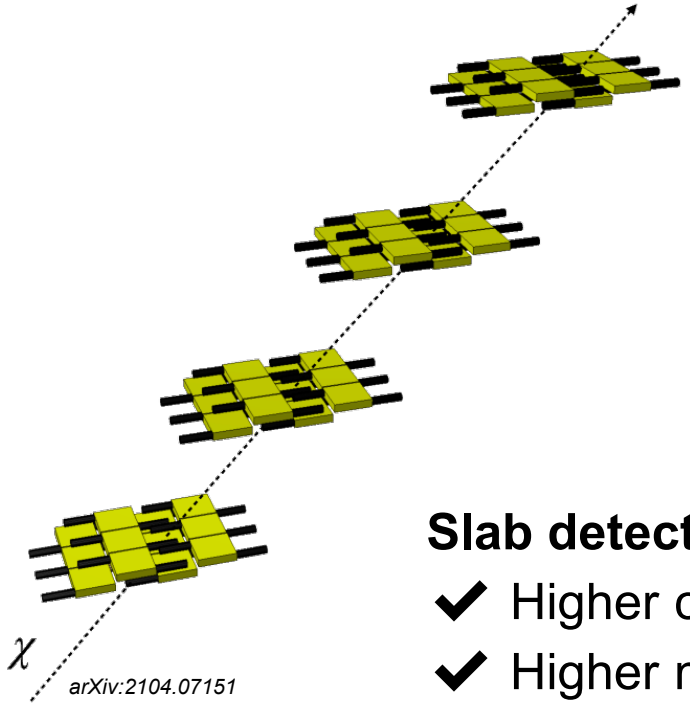


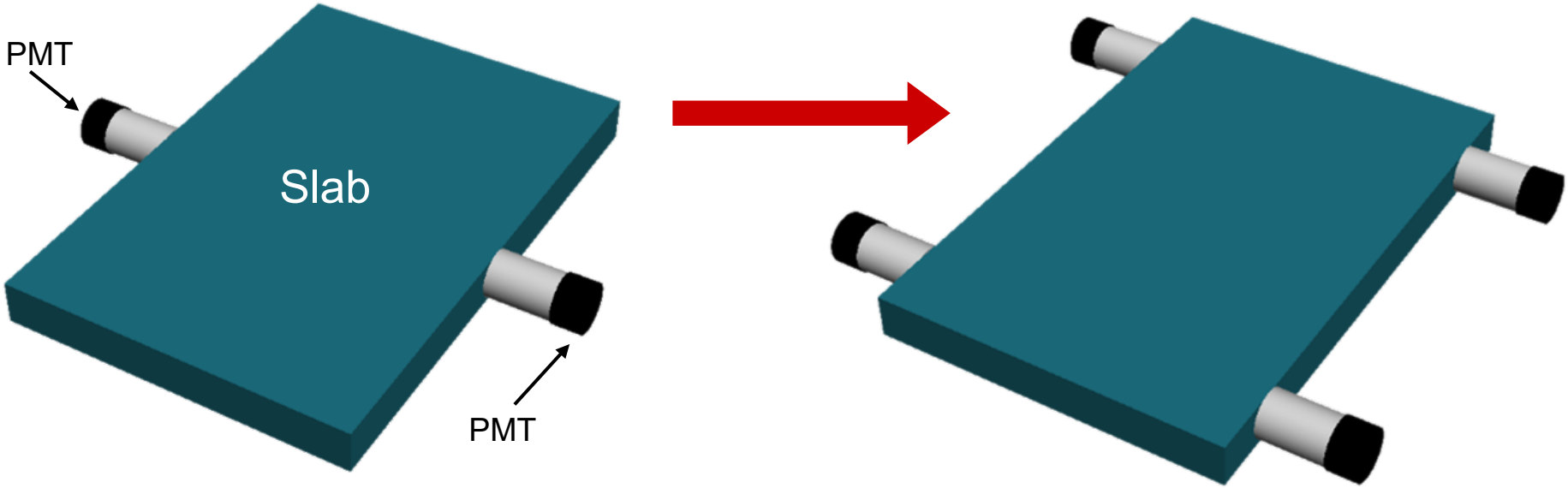
arXiv:2104.07151

Slab detector

- ✔ Higher charge
- ✔ Higher mass

Increasing slab charge sensitivity

Double the number of photomultiplier tubes (PMTs) on each slab

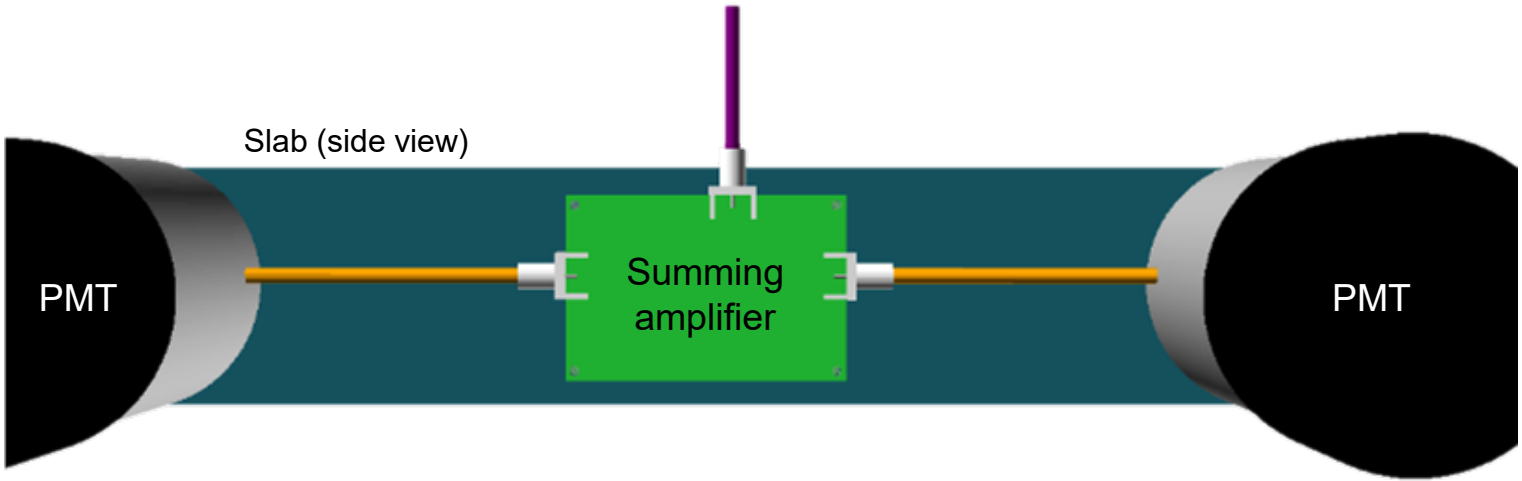


(simplified models)

Increasing slab charge sensitivity

Double the number of photomultiplier tubes (PMTs) on each slab

Design a summing amplifier to add PMT outputs



(simplified model)

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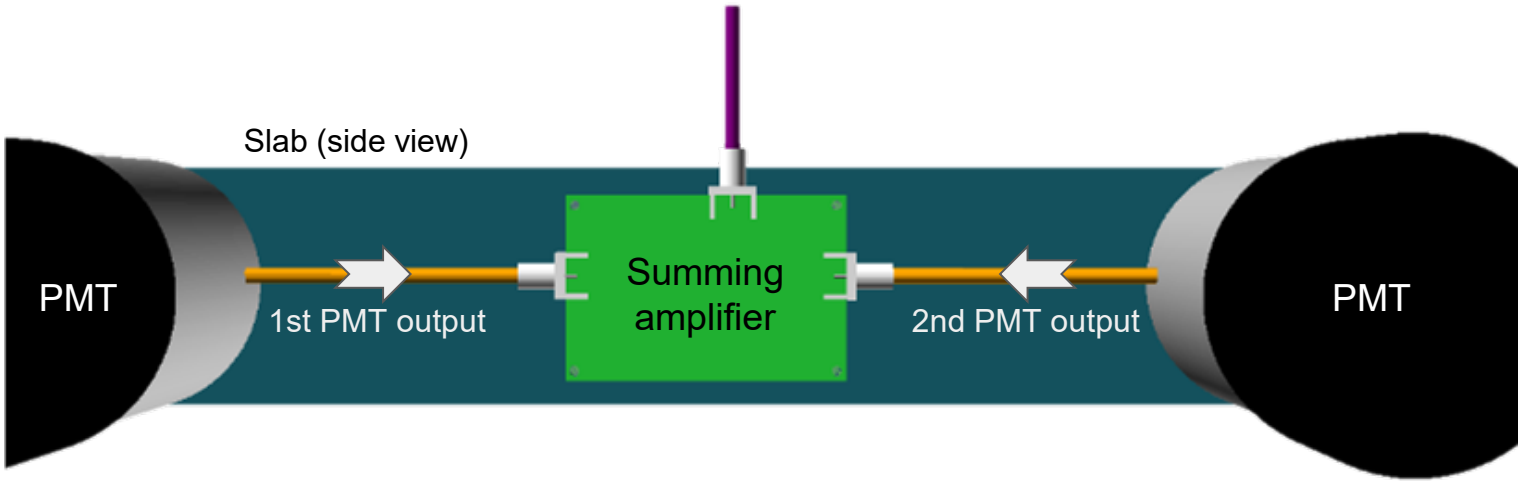

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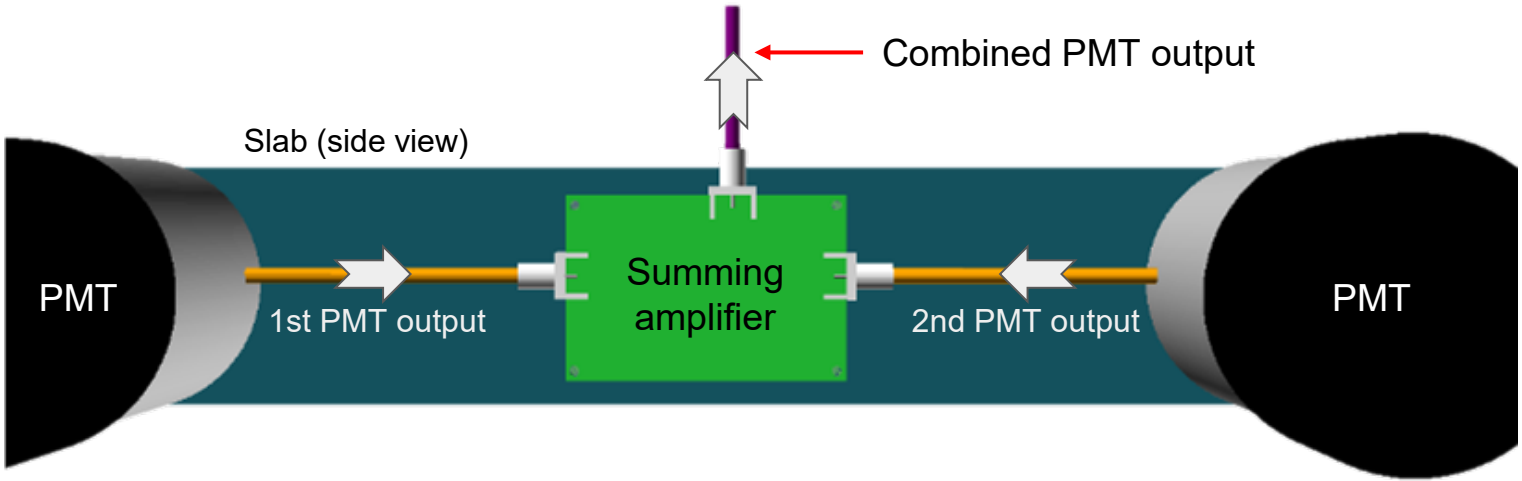
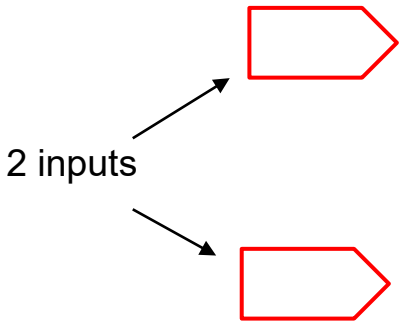


(simplified model)

Designing the summing amplifier

Step 1: Draw the circuit



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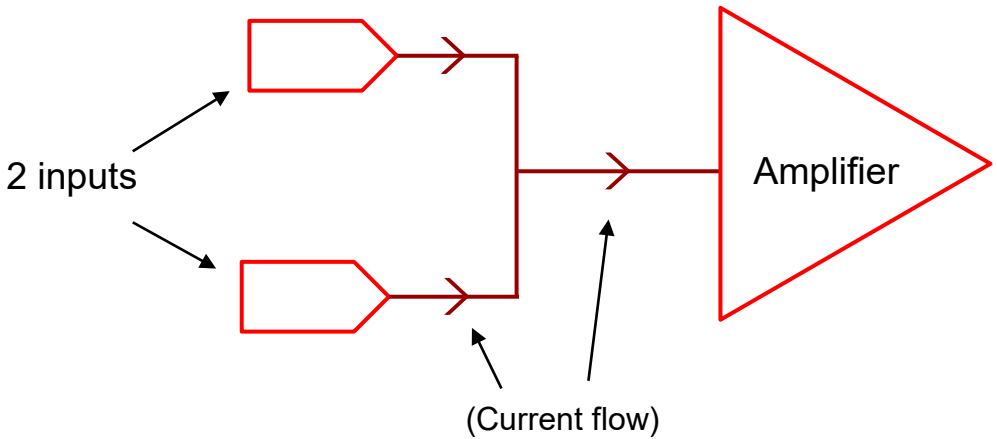

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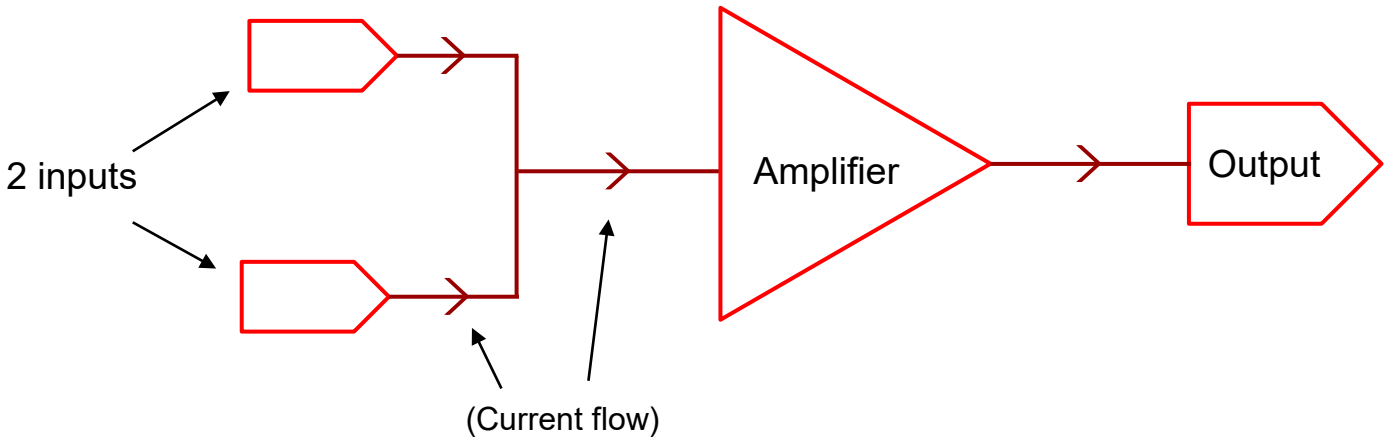
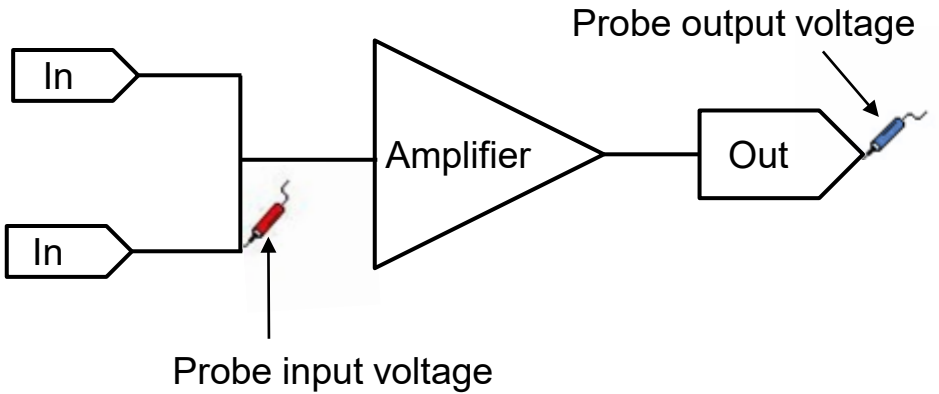


Designing the summing amplifier

Step 1: Draw the circuit

Step 2: Simulation

Does the circuit do what it's supposed to do?



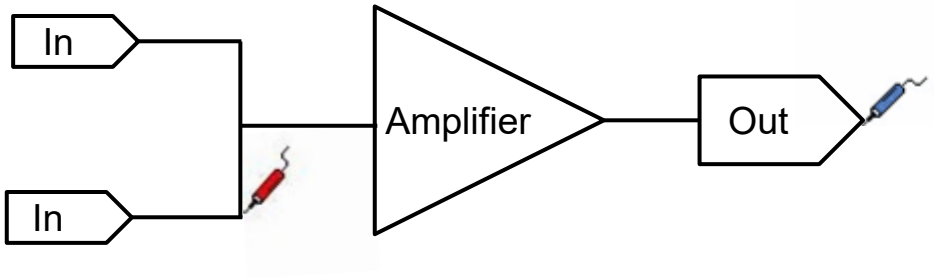
Designing the summing amplifier

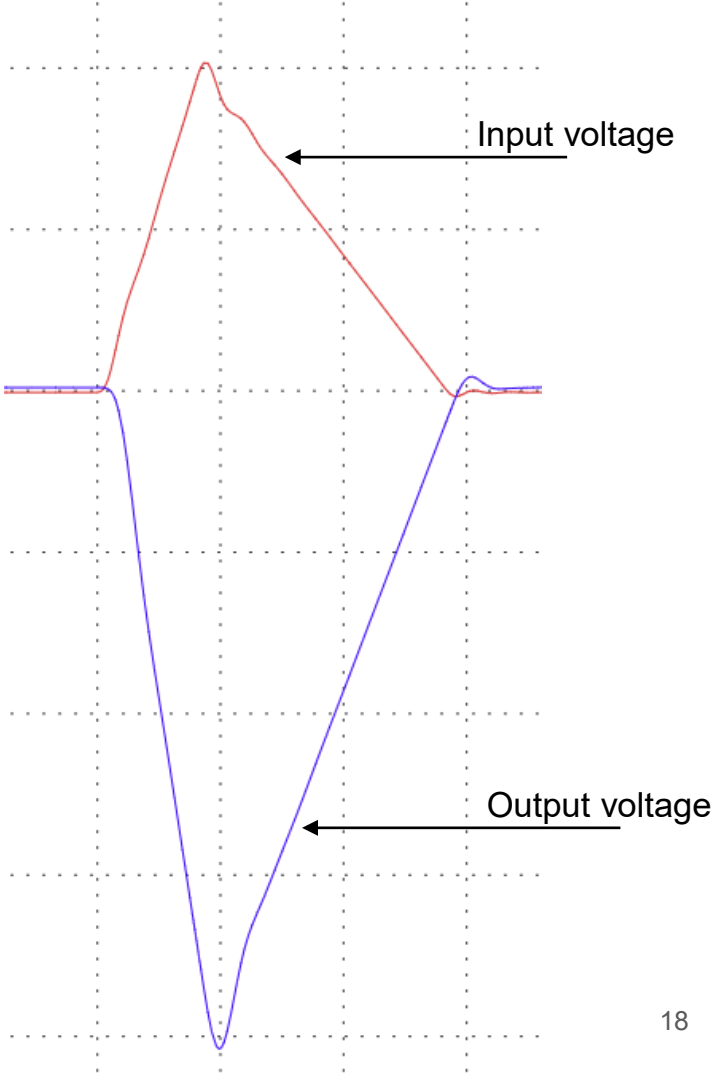
Step 1: Draw the circuit

Step 2: Simulation

Does the circuit do what it's supposed to do?

- ✔ Amplifies signal
- ✔ Inverts signal



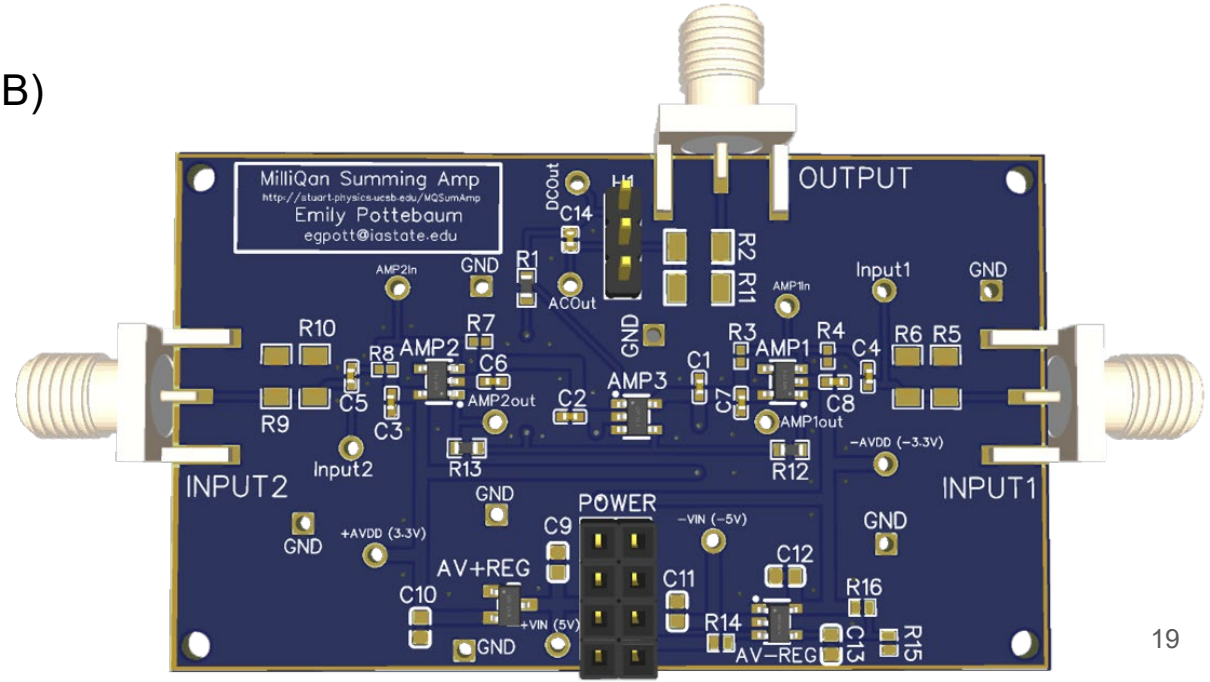


Designing the summing amplifier

Step 1: Draw the circuit

Step 2: Simulation

Step 3: Printed circuit board (PCB)



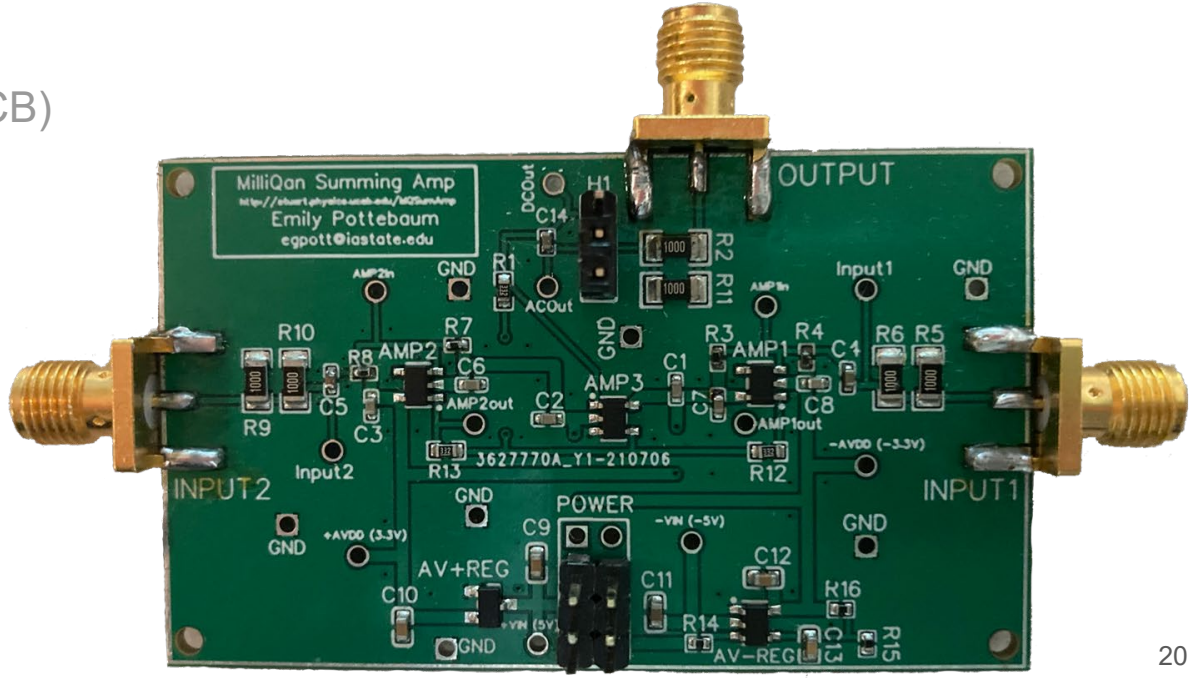
Designing the summing amplifier

Step 1: Draw the circuit

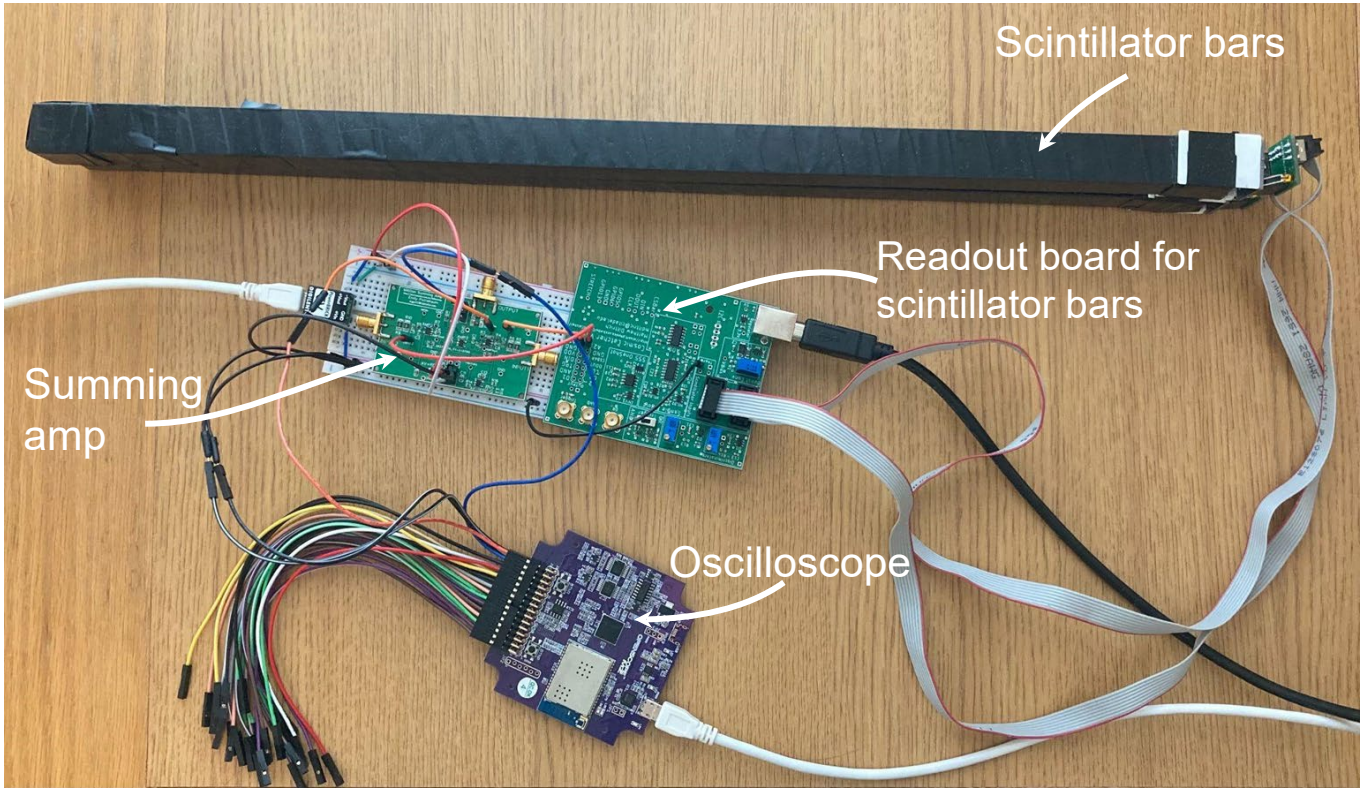
Step 2: Simulation

Step 3: Printed circuit board (PCB)

Next step: physical testing!

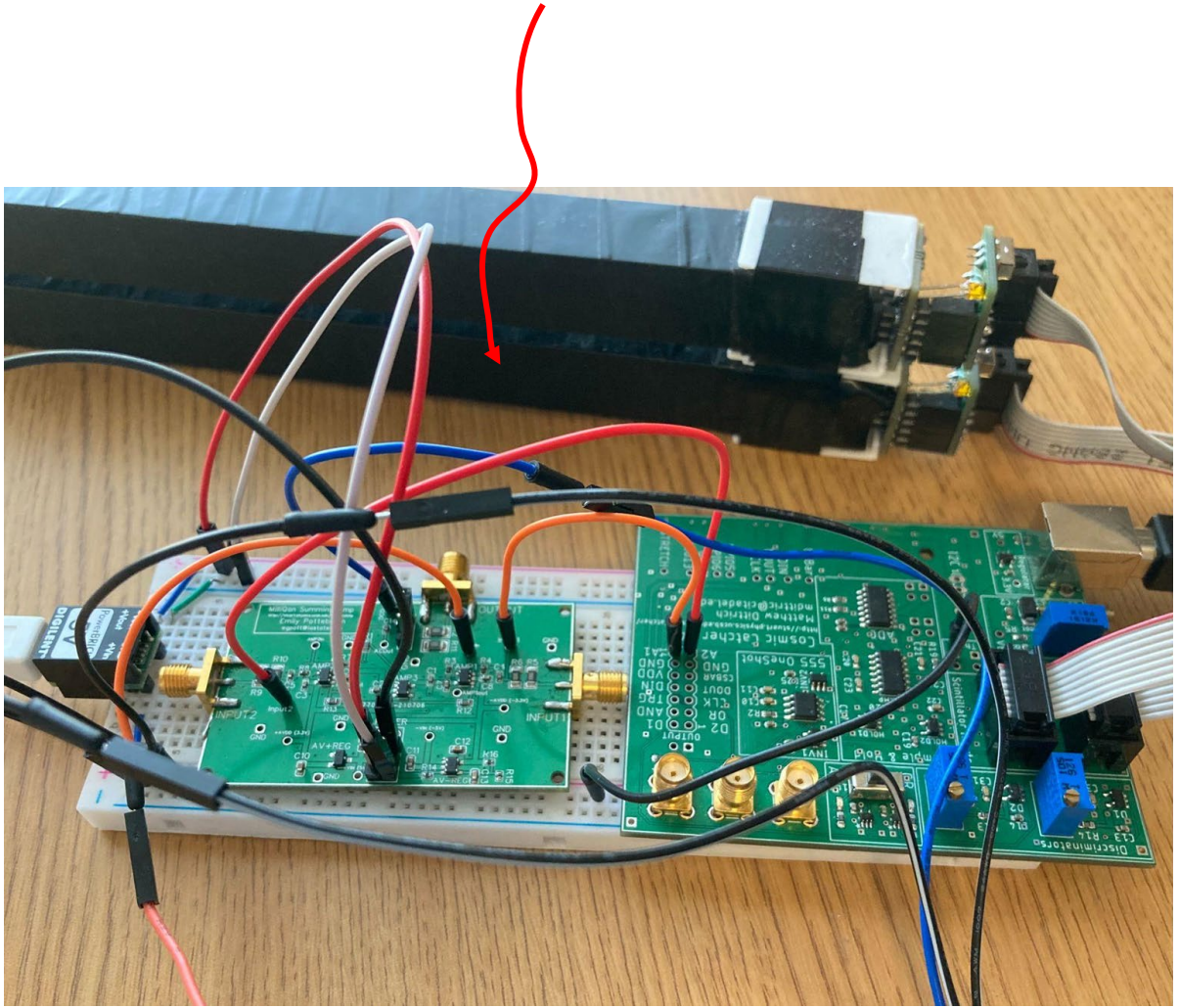


Testing the board: setup



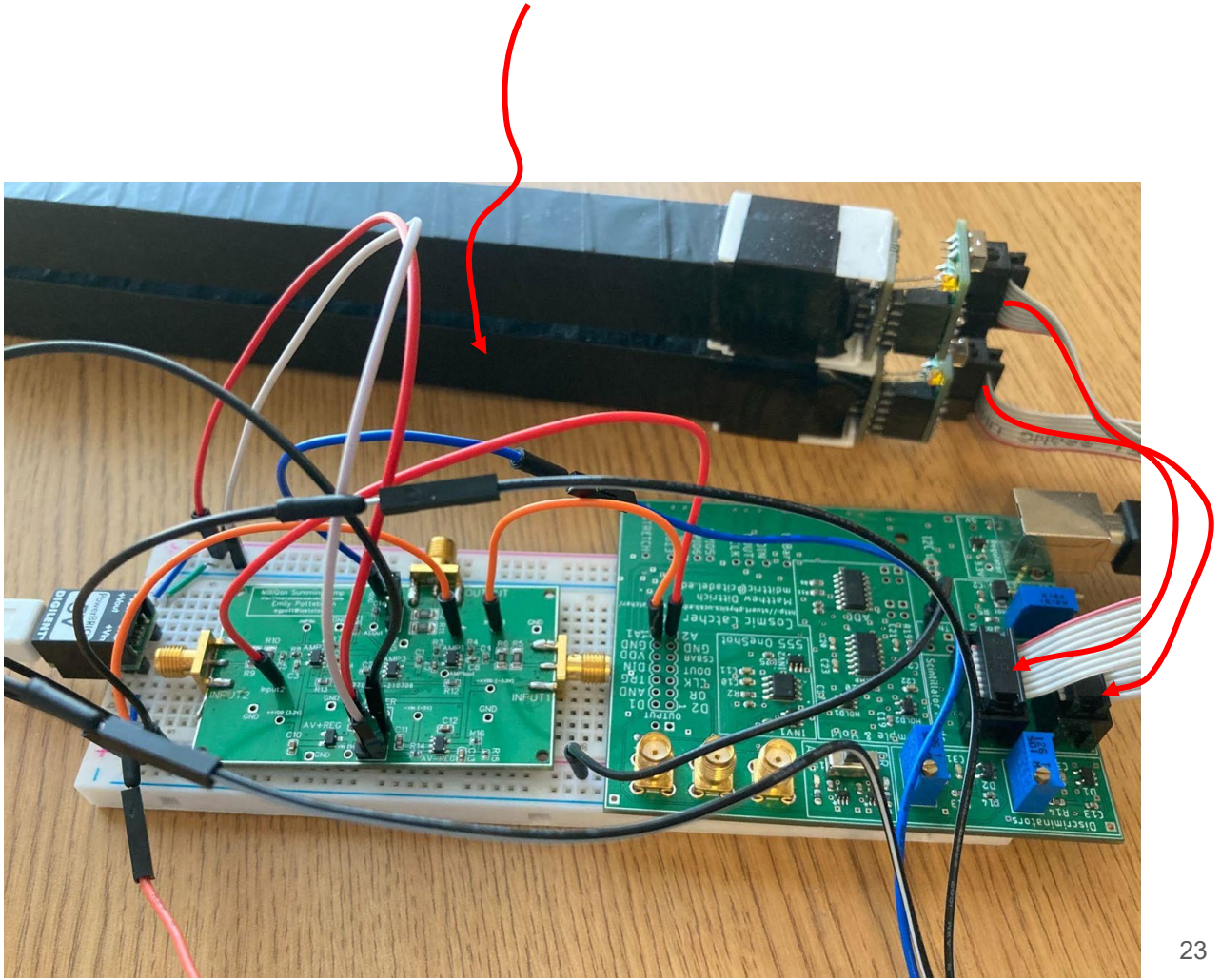
Testing the board

1. Cosmic ray hits bars



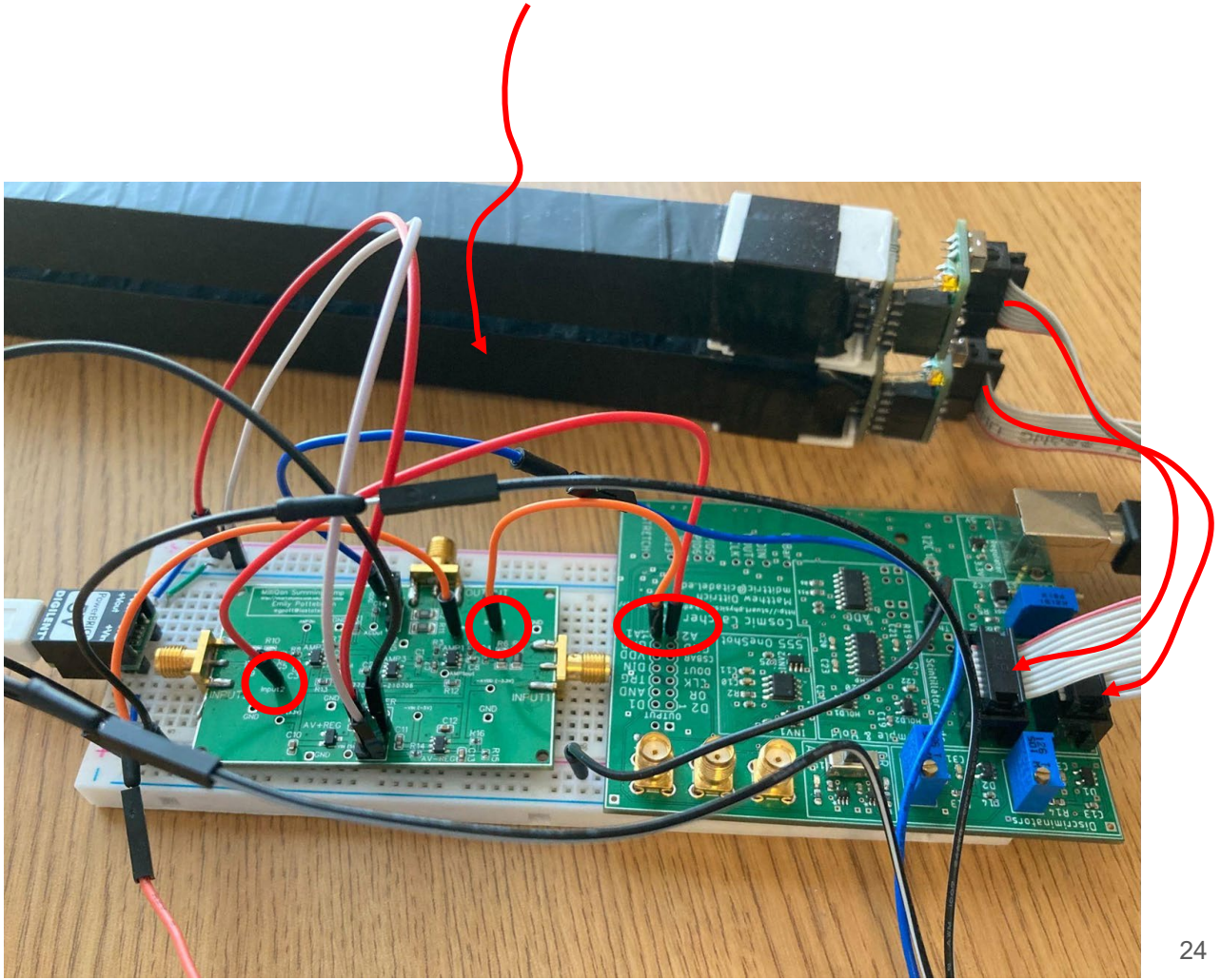
Testing the board

1. Cosmic ray hits bars
2. Signals sent to readout board

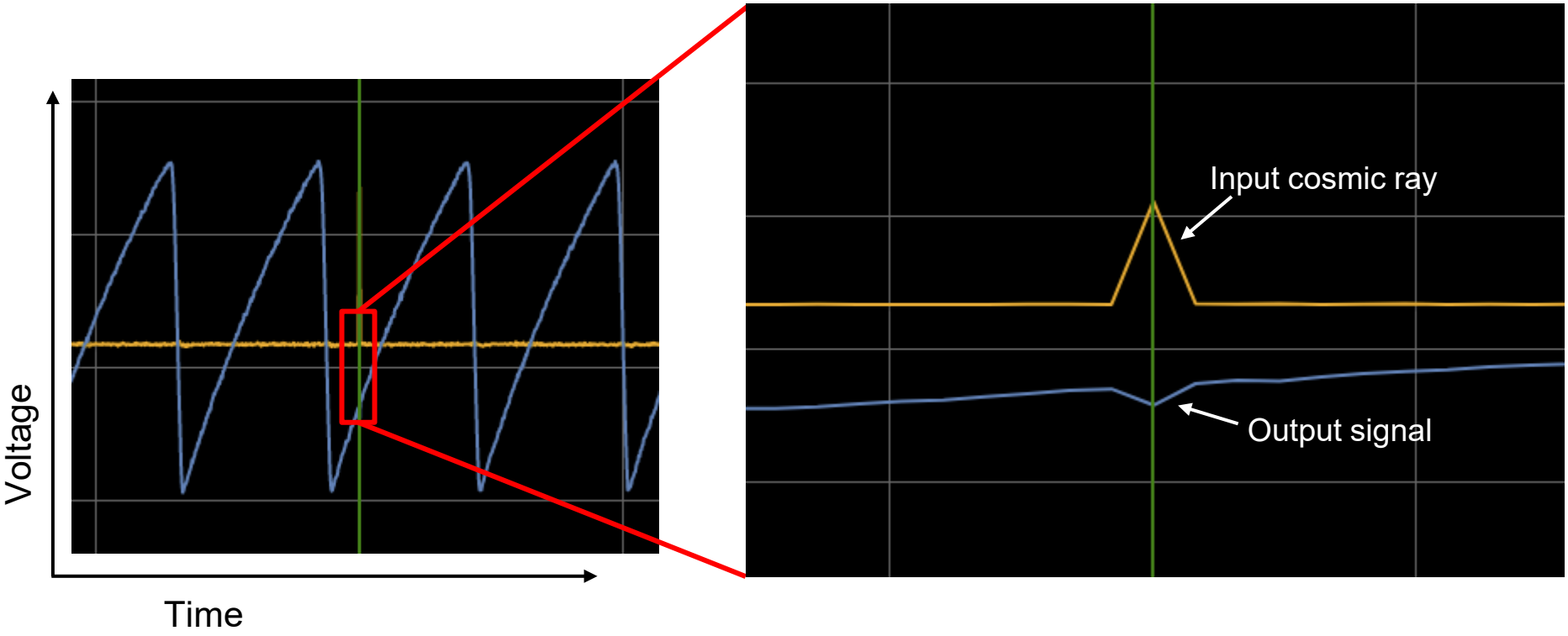


Testing the board

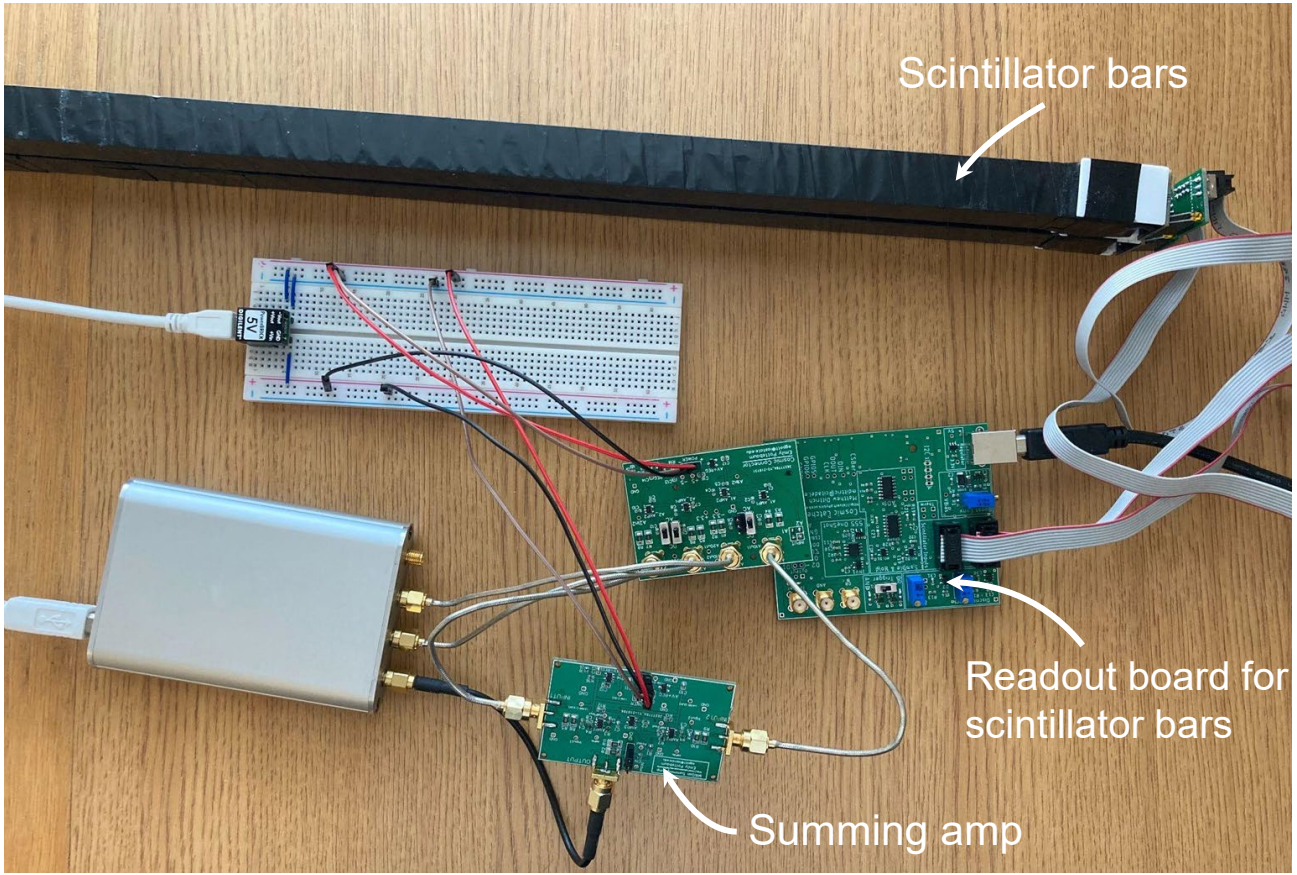
1. Cosmic ray hits bars
2. Signals sent to readout board
3. Summing amp receives the 2 signals as inputs



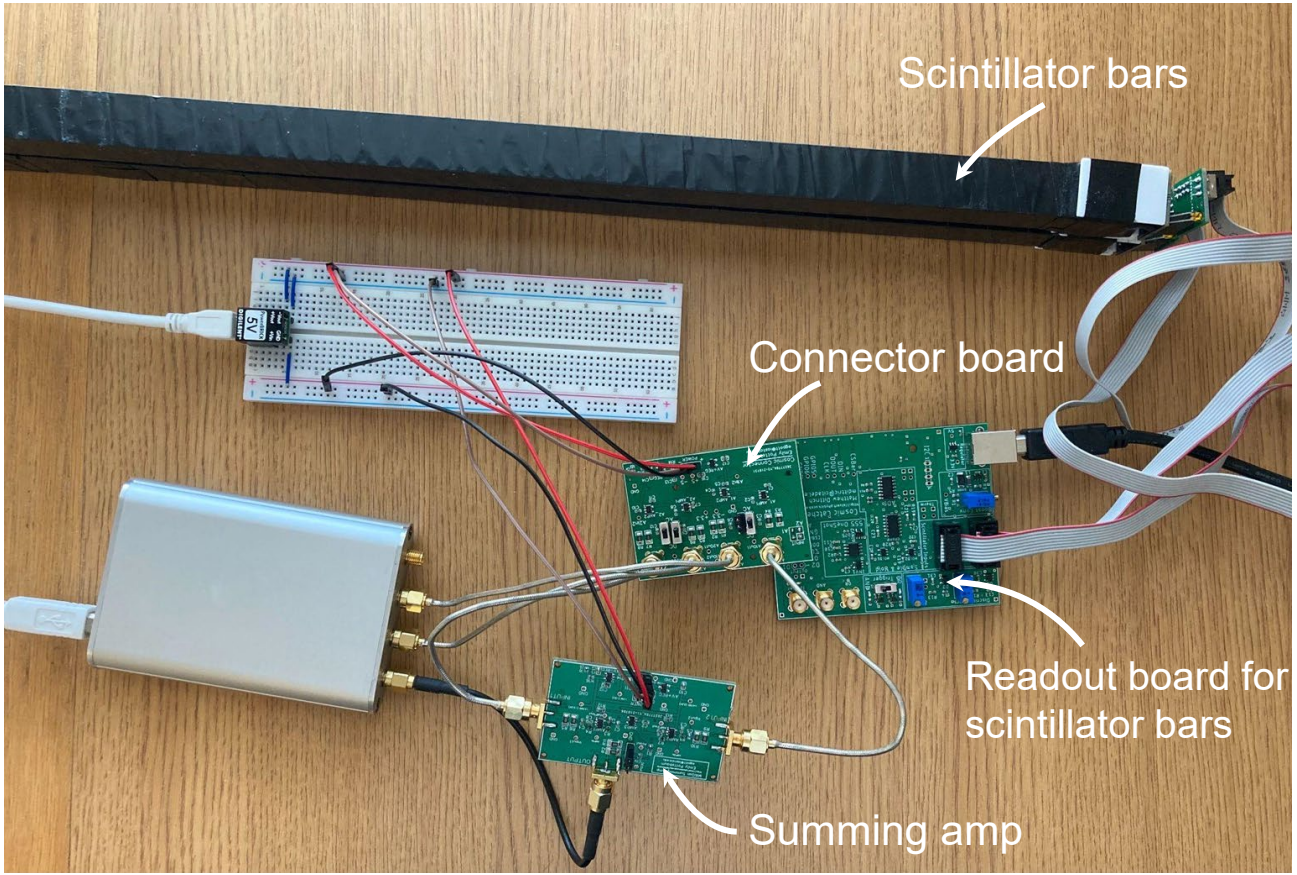
Breadboard wires pick up too much noise



Modified testing setup



Modified testing setup



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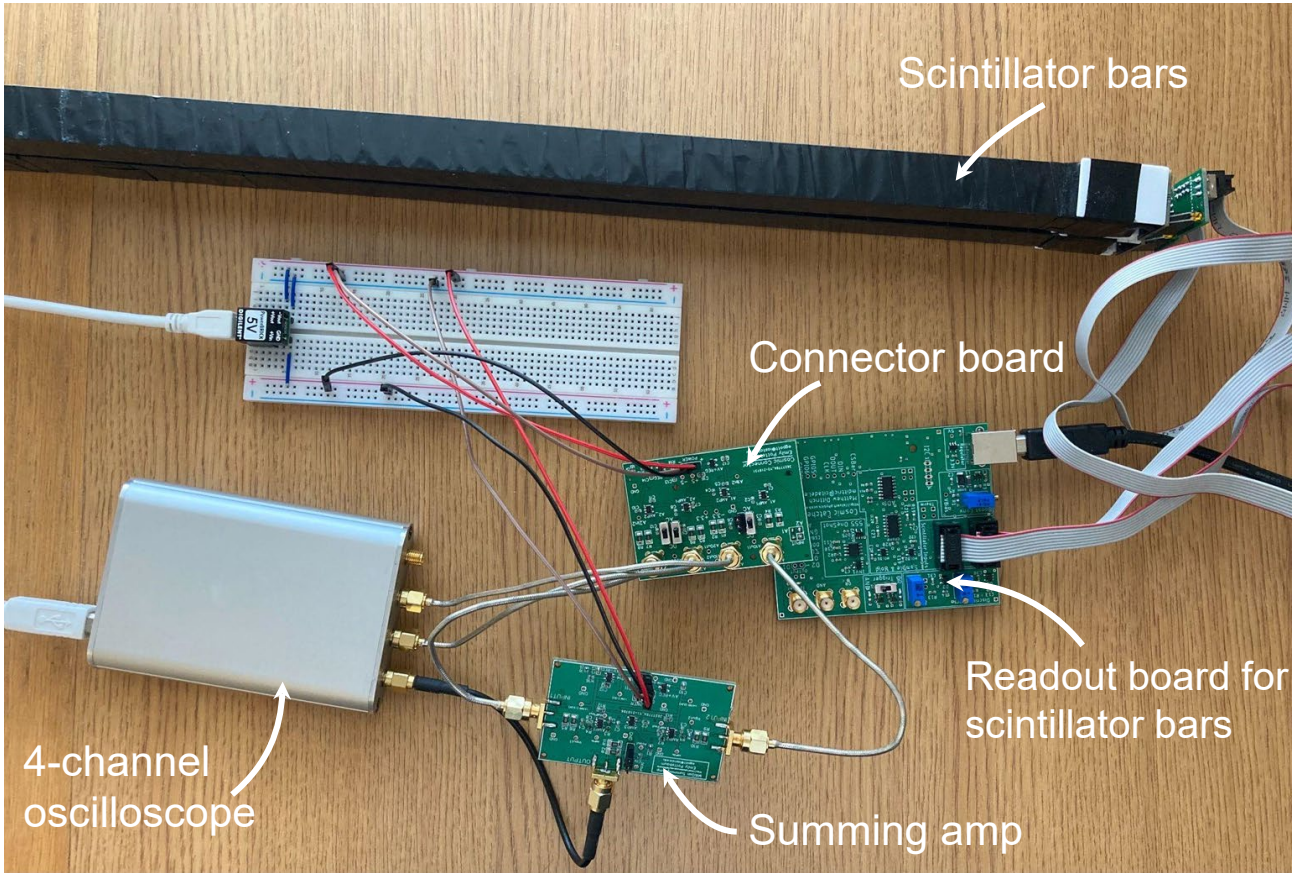

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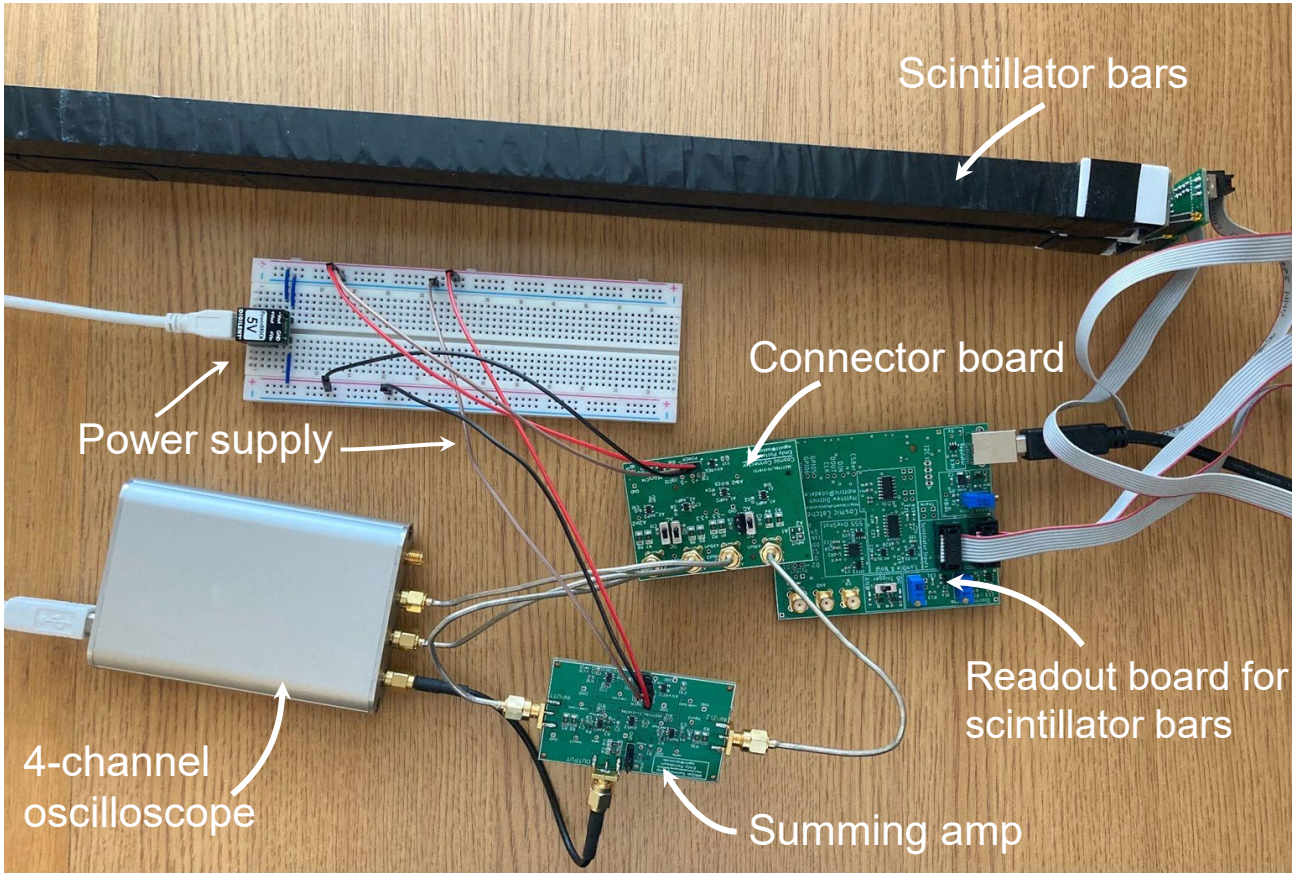
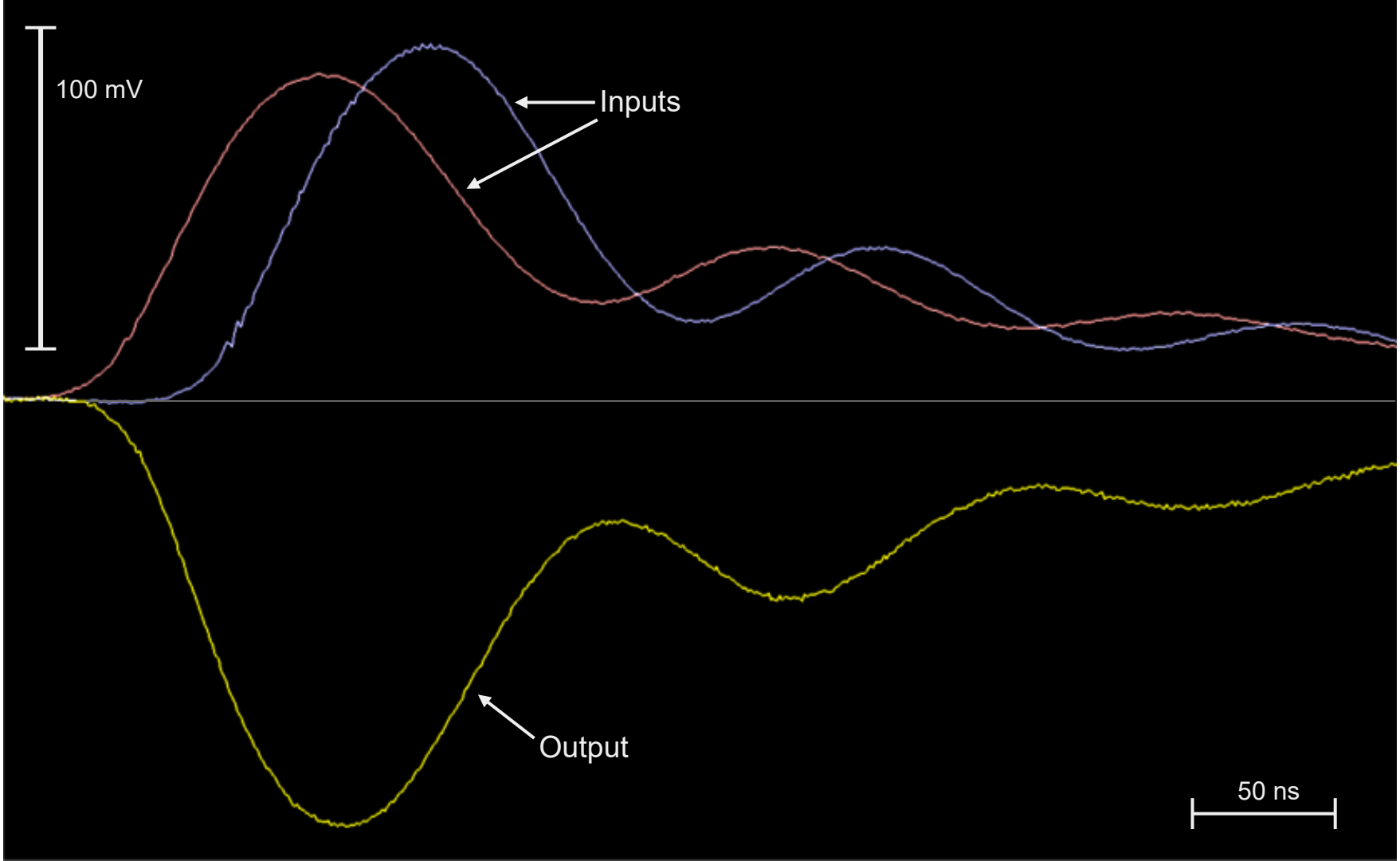


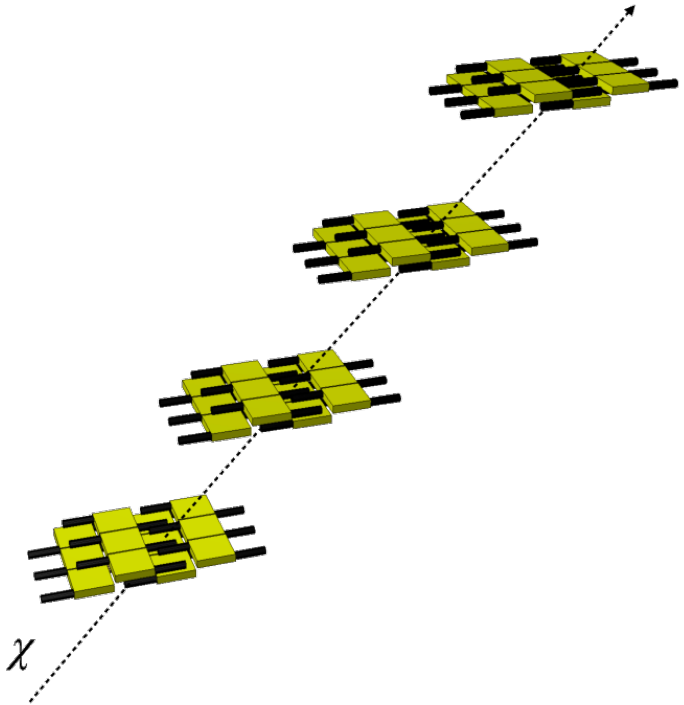

100 mV
Inputs
Output
50 ns

Next Steps

- Test summing amplifier with PMTs
- Calibration
- Look into uses of summing amplifier on other parts of detector

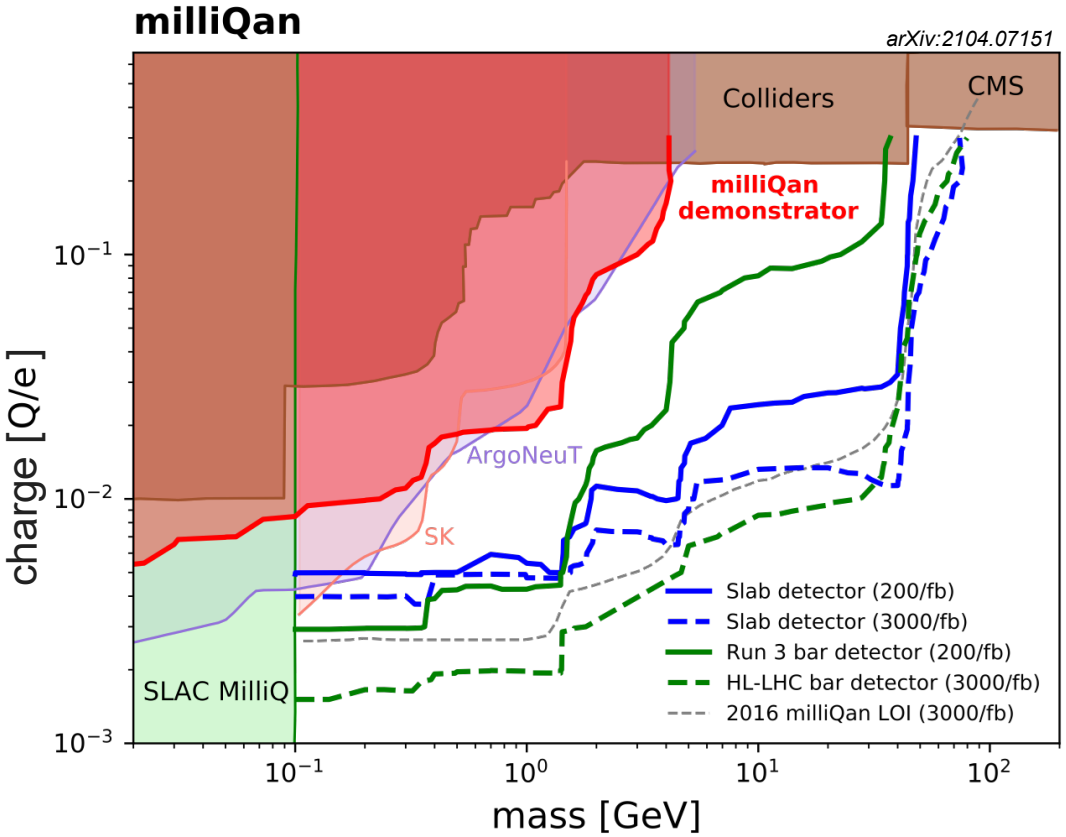
What does this mean for milliQan?

- 4 PMTs per slab instead of 2



What does this mean for milliQan?

- 4 PMTs per slab instead of 2
- Slab detector should see significant increase in charge sensitivity



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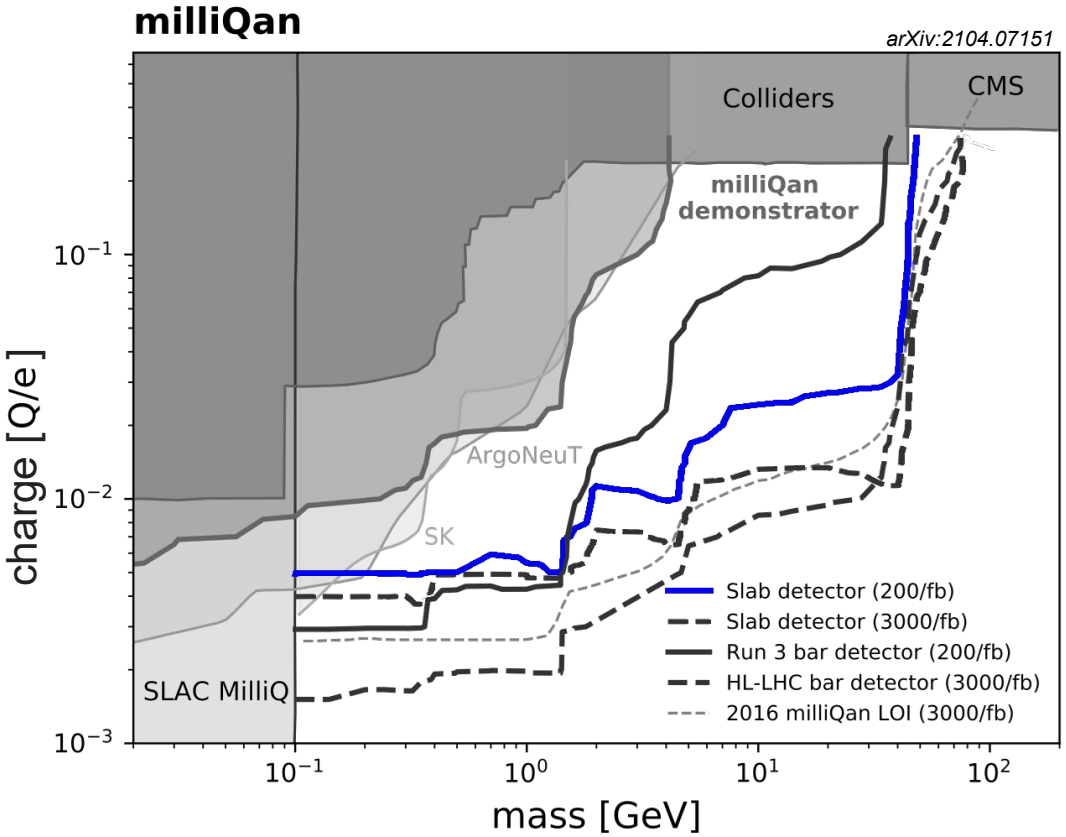

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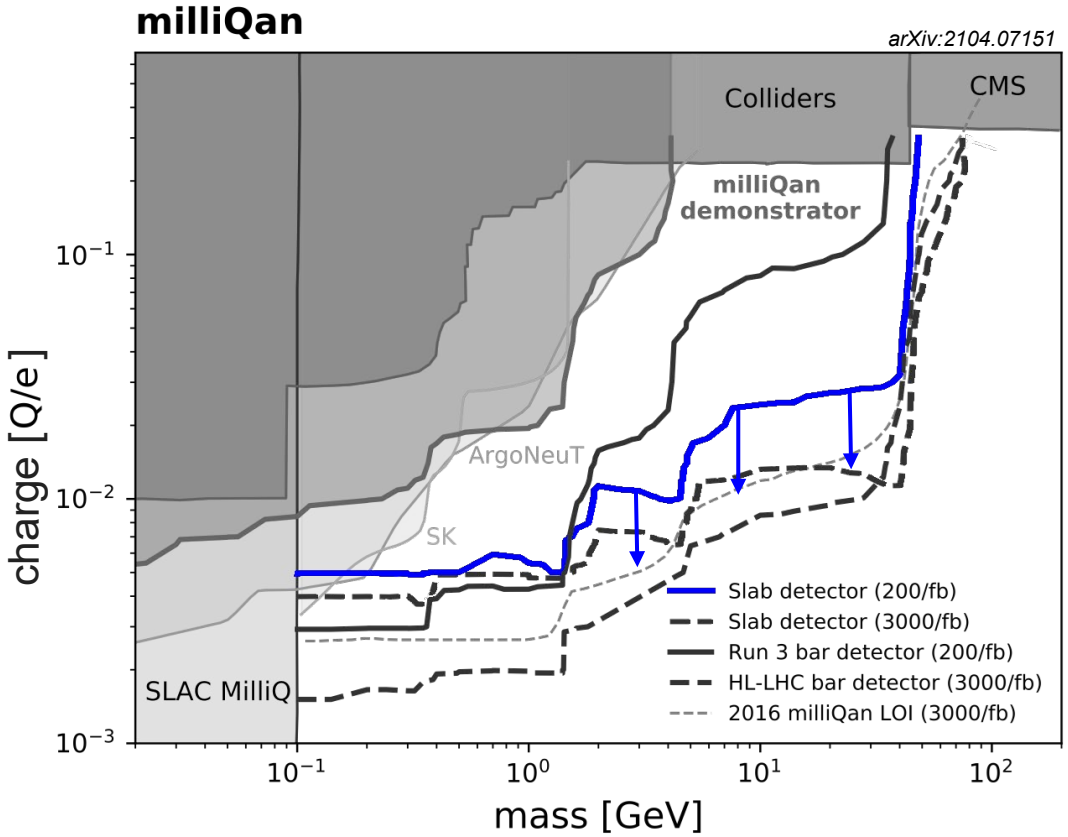


Acknowledgements

Special thanks to:

Dr. Sathya Guruswamy, UCSB Physics REU site director

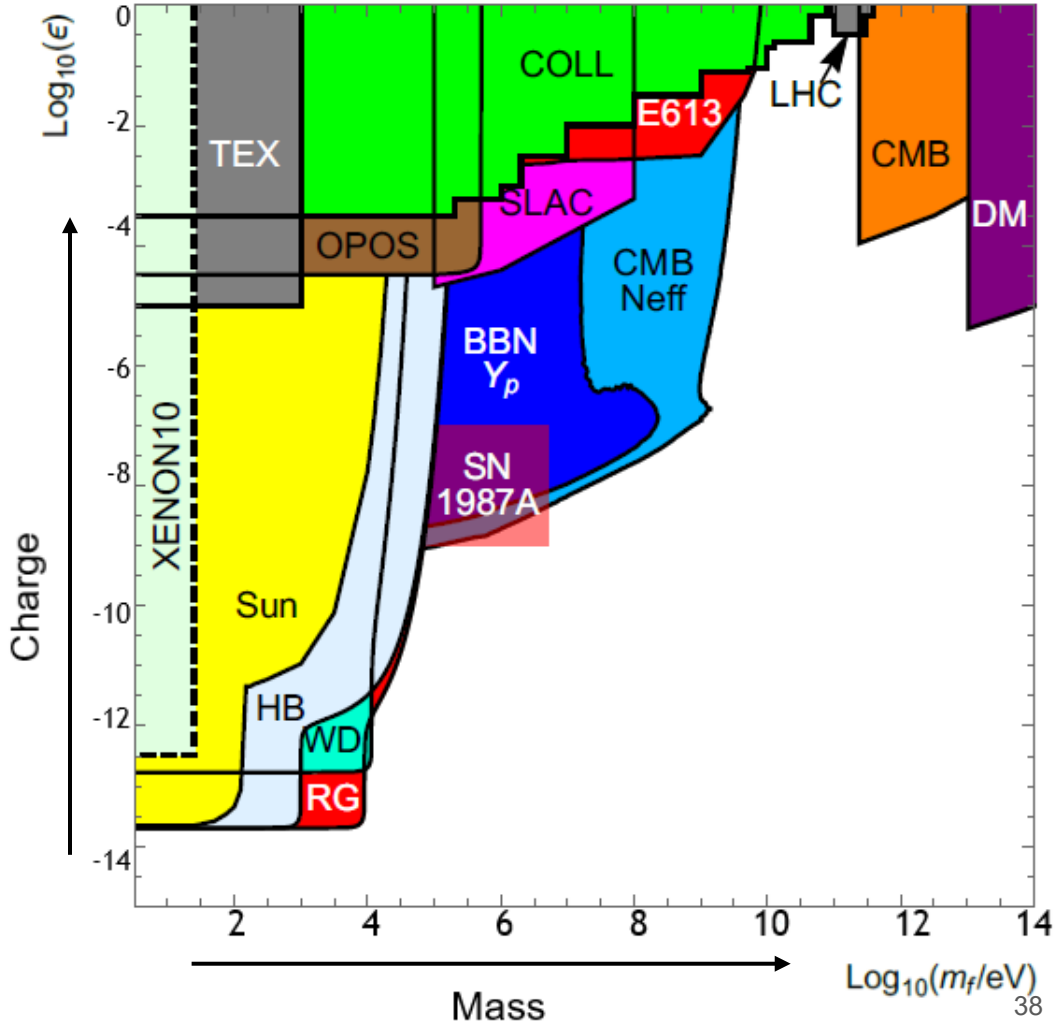
Dr. David Stuart, faculty advisor

Ryan Schmitz, graduate mentor

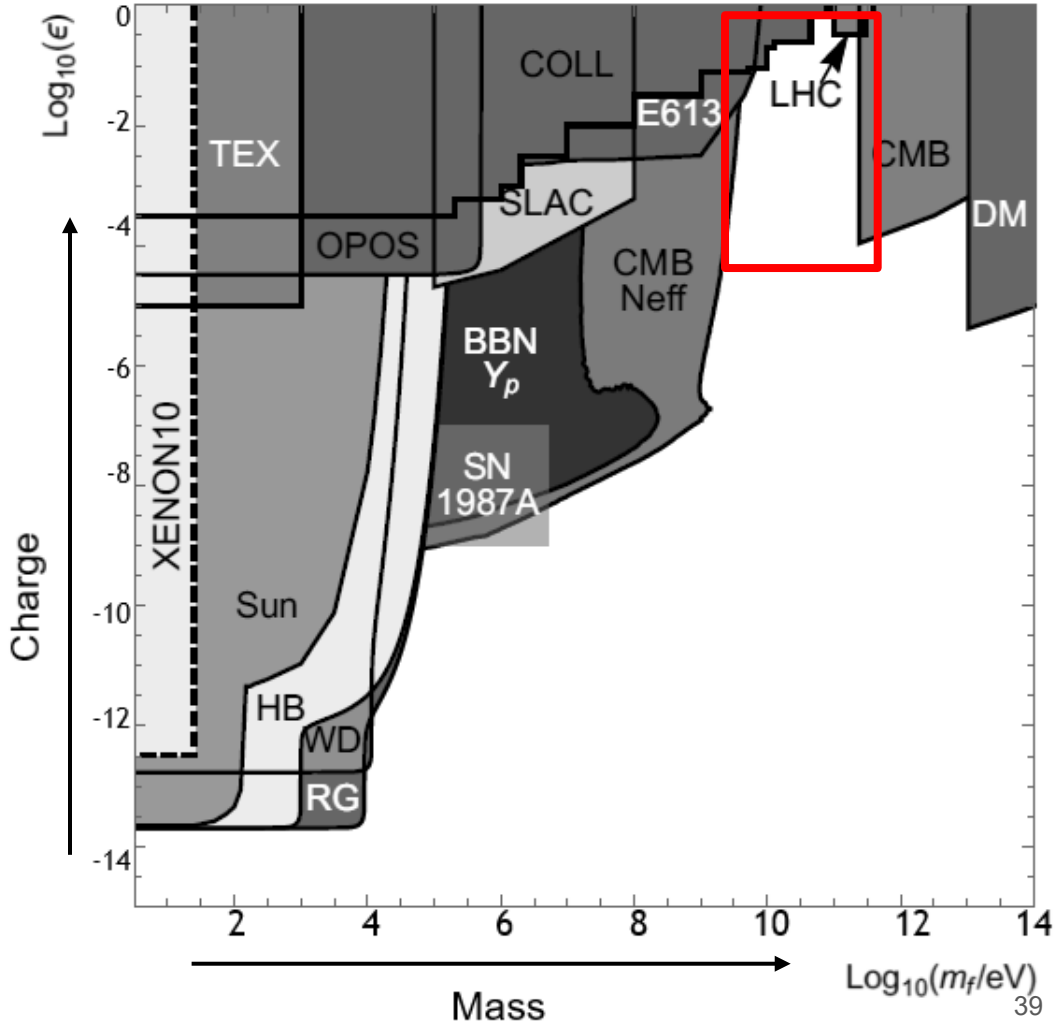
National Science Foundation REU grant PHY-185257

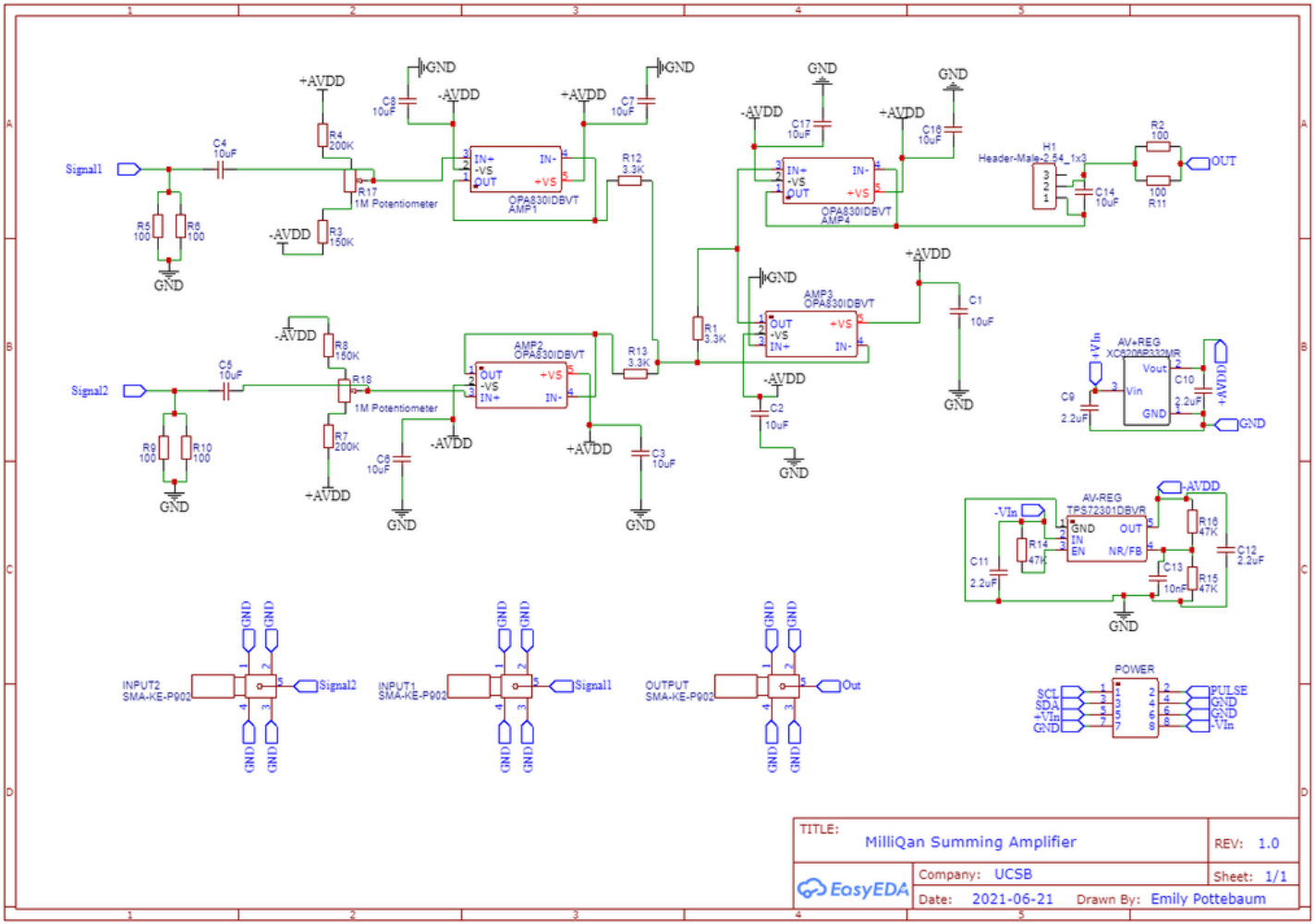
Backup slides

mCP phase space

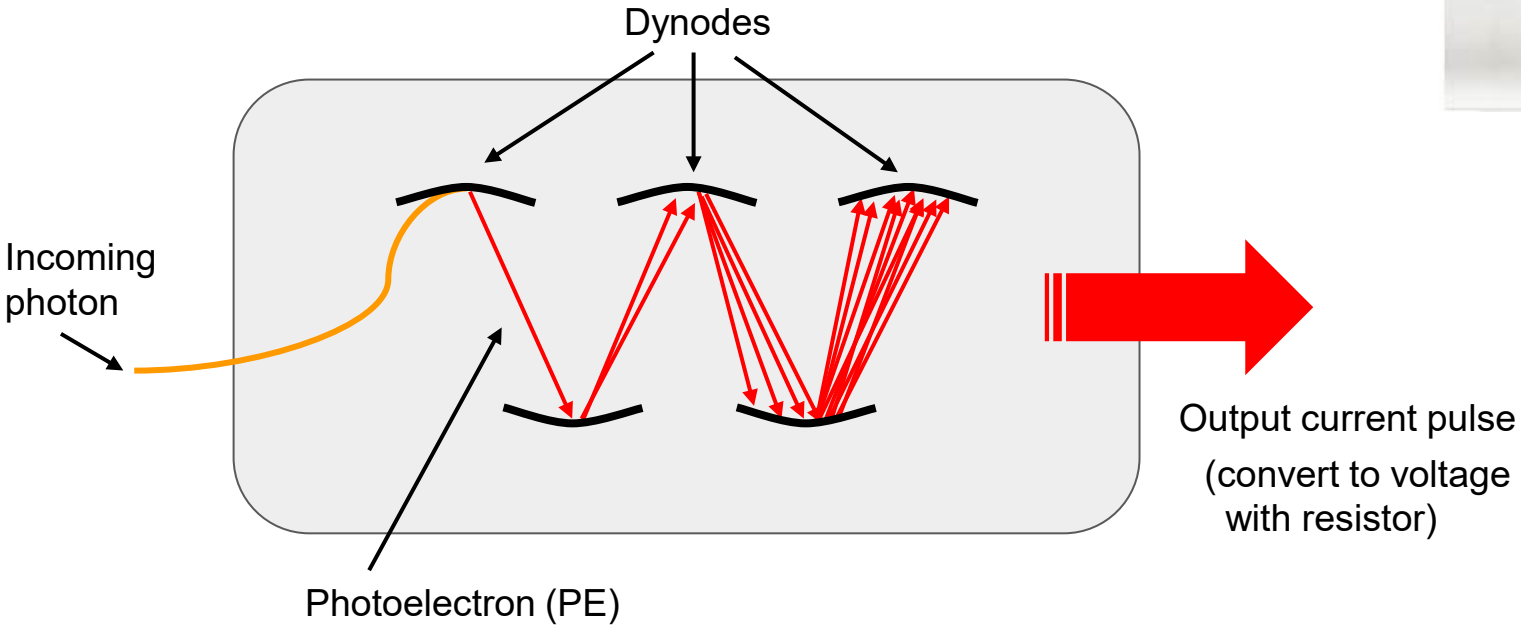


mCP phase space

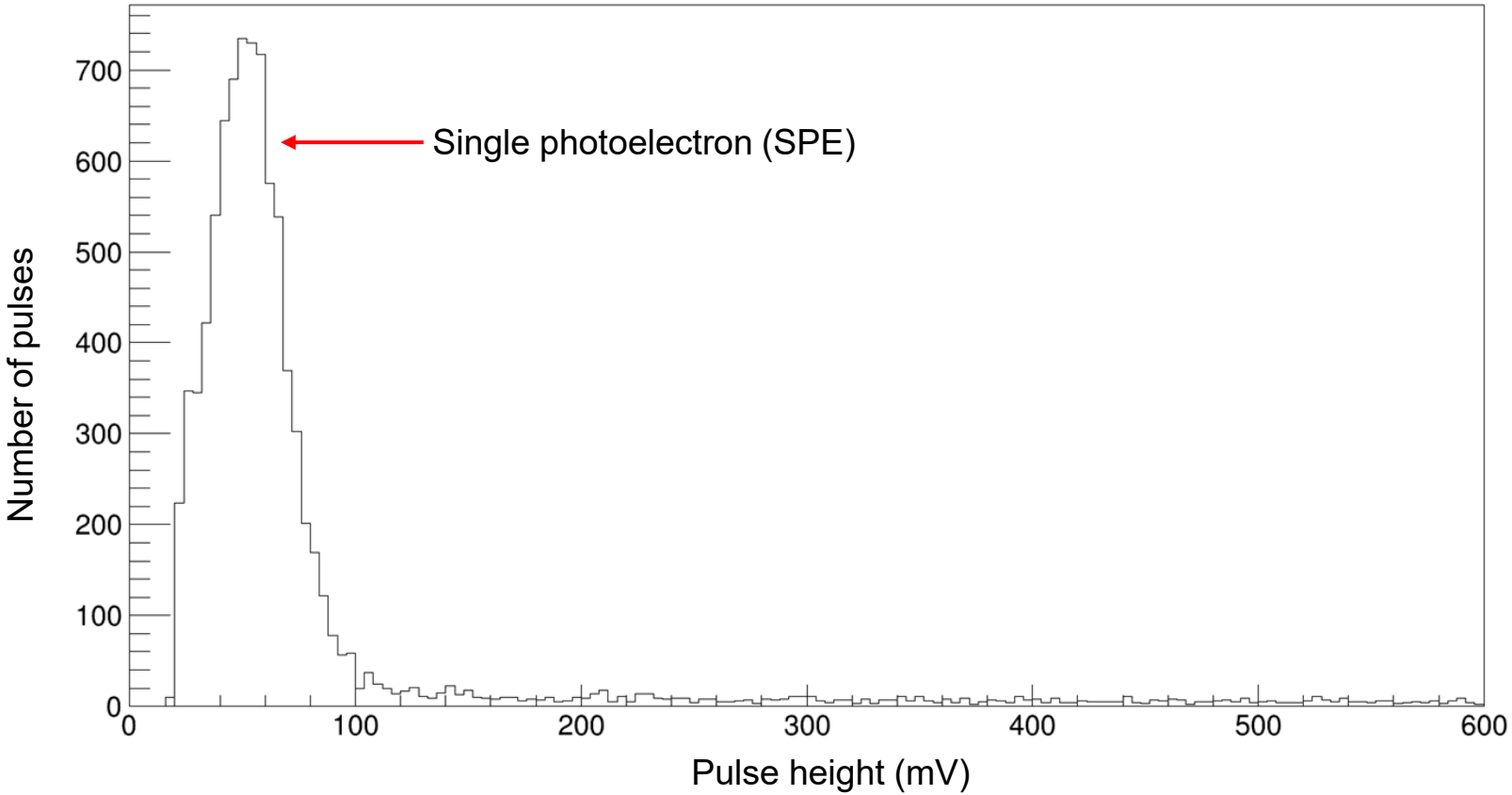



Signal1
Signal2
+AVDD
-AVDD
GND
C4 10uF
C5 10uF
C8 10uF
C7 10uF
C6 10uF
C3 10uF
C2 10uF
C1 10uF
C17 10uF
C16 10uF
C14 10uF
C9 2.2uF
C10 2.2uF
C11 2.2uF
C12 2.2uF
C13 10nF
R4 200K
R3 150K
R8 150K
R7 200K
R17 1M Potentiometer
R18 1M Potentiometer
R5 100
R6 100
R9 100
R10 100
R12 3.3K
R13 3.3K
R1 3.3K
R2 100
R11 100
R14 47K
R15 47K
R16 47K
AMP1 OPA830IDBVT
AMP2 OPA830IDBVT
AMP3 OPA830IDBVT
AMP4 OPA830IDBVT
H1 Header-Male-2.54_1x3
AV+REG XC6206P332MR
AV-REG TPS72301DBVR
POWER
INPUT2 SMA-KE-P902
INPUT1 SMA-KE-P902
OUTPUT SMA-KE-P902
OUT
PULSE
SCL
SDA
+VIn
-VIn
TITLE: MilliQan Summing Amplifier
REV: 1.0
Company: UCSB
Sheet: 1/1
Date: 2021-06-21
Drawn By: Emily Pottebaum
EasyEDA

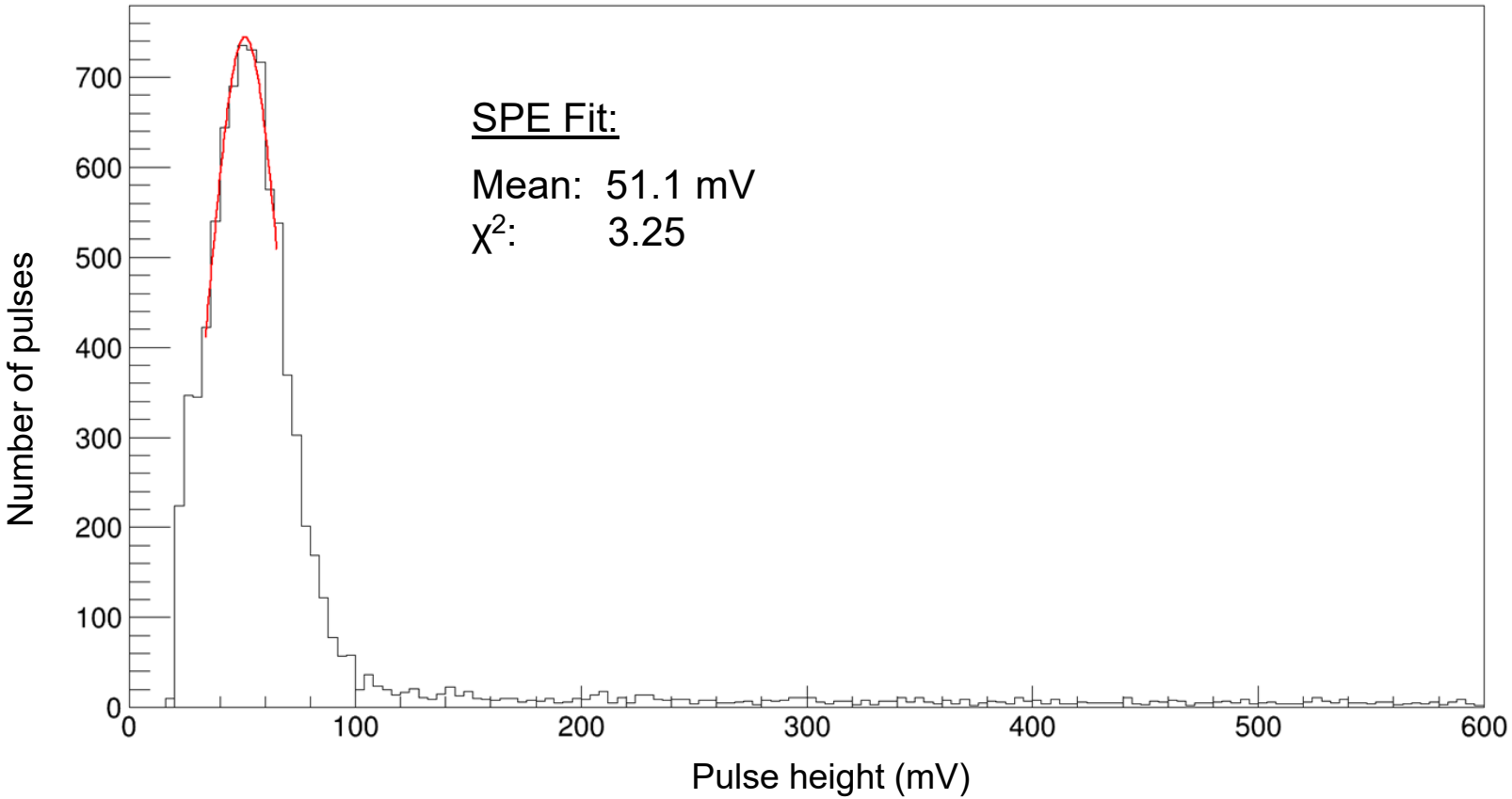
Photomultiplier Tubes 101



PMT output


Single photoelectron (SPE)
Number of pulses
Pulse height (mV)
0
100
200
300
400
500
600
700

PMT output


SPE Fit:
Mean: 51.1 mV
χ2: 3.25
Number of pulses
Pulse height (mV)
0
100
200
300
400
500
600
700