

# Wire-Cell Simulation for Point-like Energy Depos

Wenqiang Gu

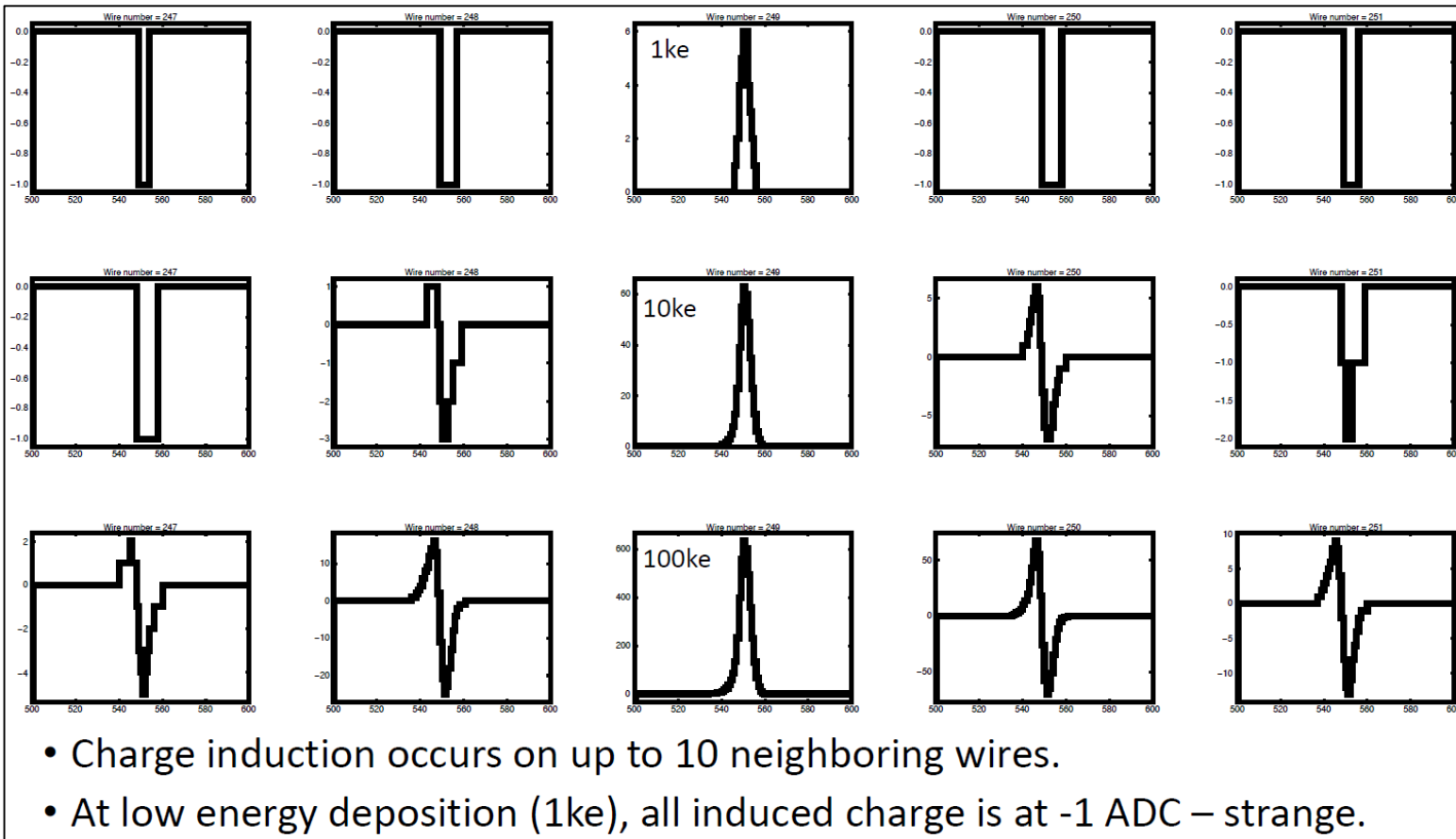
BNL

# Outline

- Point source simulation using the WireCell
  - Question 1: Can we reproduce Tingjun's observation on the collection wire?
  - Question 2: Do we understand the biases at high charge and low charge?
- Validation of the deconvolved charge from signal processing
  - Impact from the diffusion

# Tingjun's point-source simulation

@ Tingjun

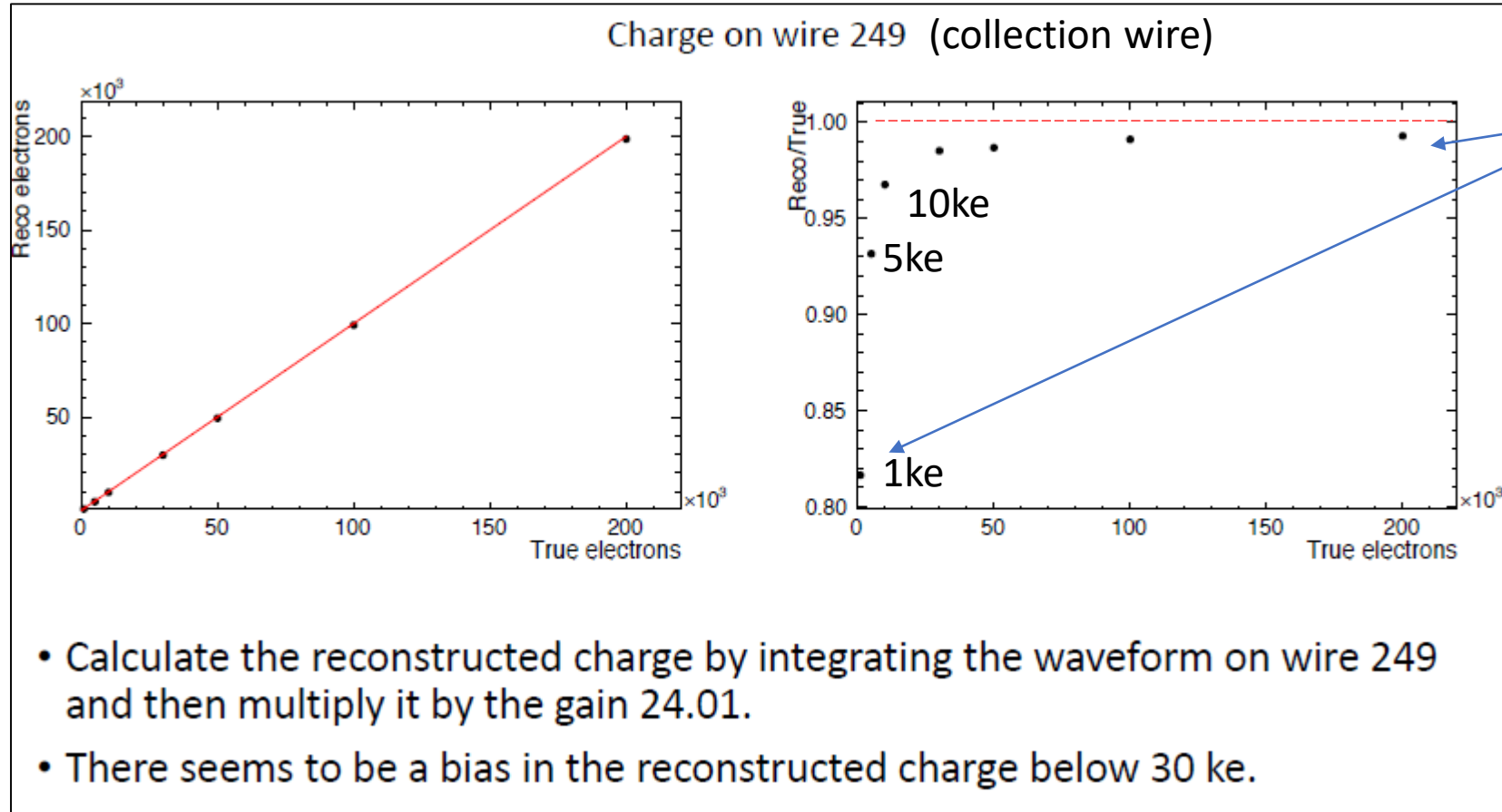


- Point-like energy deposition injected at (-355, 300, 120) cm
- Close to anode
- Largest signal on wire 249, plane 2 of TPC1
- Diffusion OFF
- Noise OFF
- Infinite electron lifetime

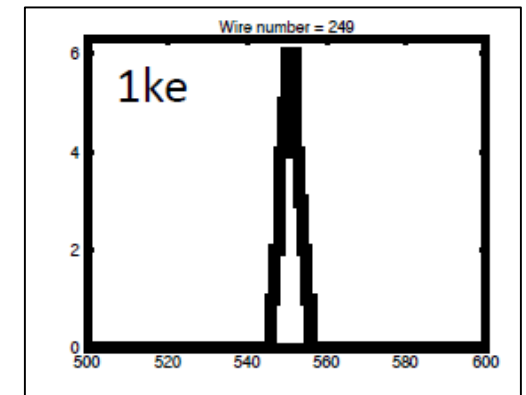
Not surprising! Small induction signal loses precision when it is floored to int during the digitization  
e.g. `std::floor(0.5) = 0`, `std::floor(-0.5) = -1`

# Charge bias in the raw waveform simulation

@Tingjun



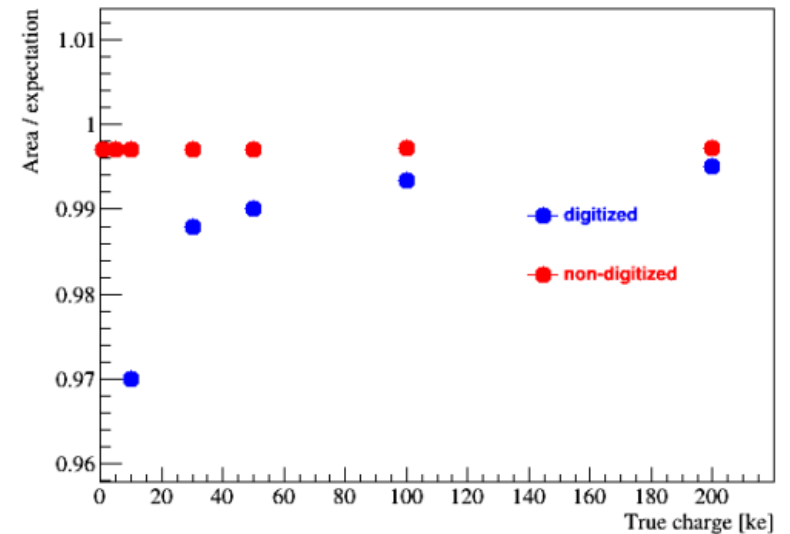
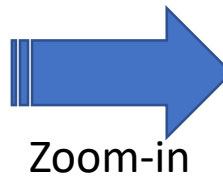
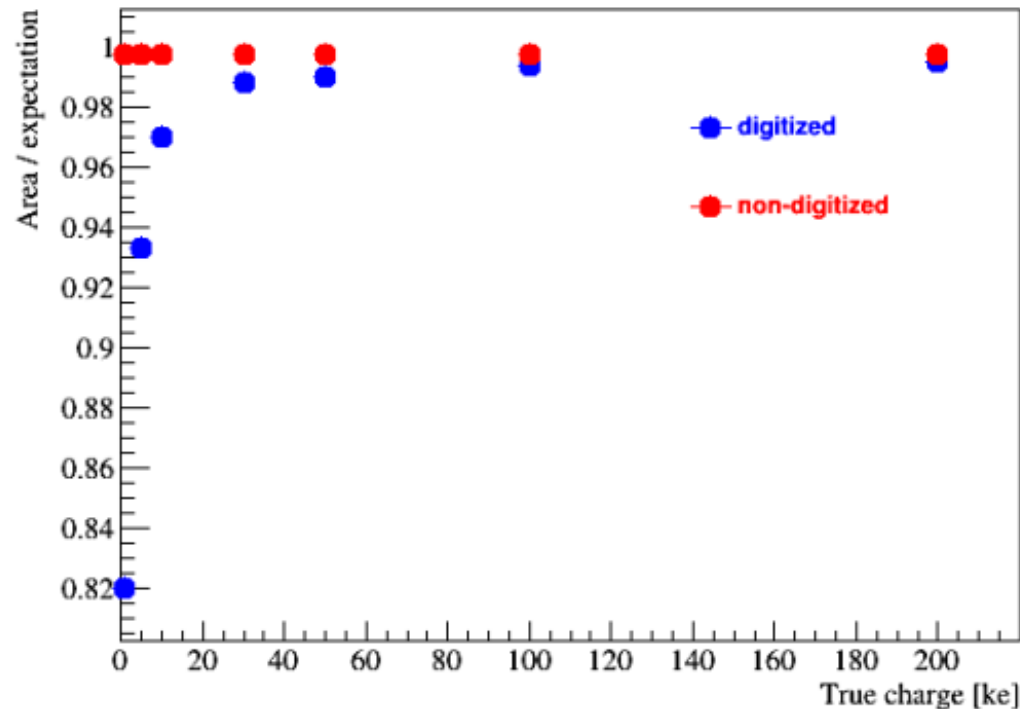
Are the biases because of the digitization?



- The bias can be up to -18% for 1ke simulation
- It seems to be very sensitive to the digitization, can we reproduce the result?

# Reproducing Tingjun's result

- Our result (more details in the later slides) is consistent with Tingjun's simulation result
  - The -18% bias is indeed caused by the digitization process
  - No charge-dependent bias



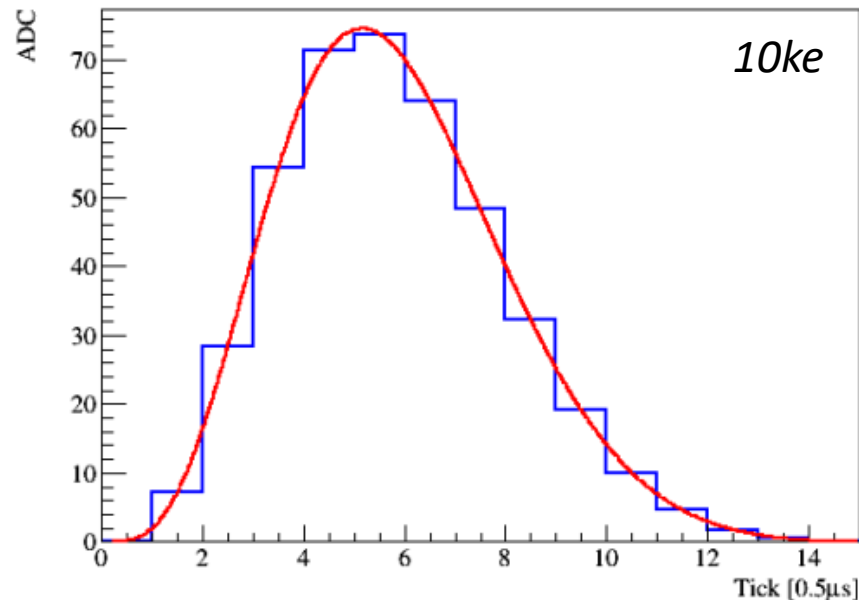
- Bias due to digitization is less than 1% for 30ke ( $\sim 1\text{MIP}$ )
- A global -0.3% bias could be from the accuracy in calculating the expectation

# Basic parameters for our simulation study

- Electronics response setting
  - 14mV/fC + post gain 1.1365, shaping 2.2us
- ADC gain: 1.4V/4096ADC
- RC: 1.1ms, turned OFF in this simulation study
- Diffusion: disabled at the beginning, turned ON when study the impact
- Electron lifetime: 35 seconds, sufficient to avoid charge attenuation
- Noise: disabled at the beginning, turned ON when study the impact

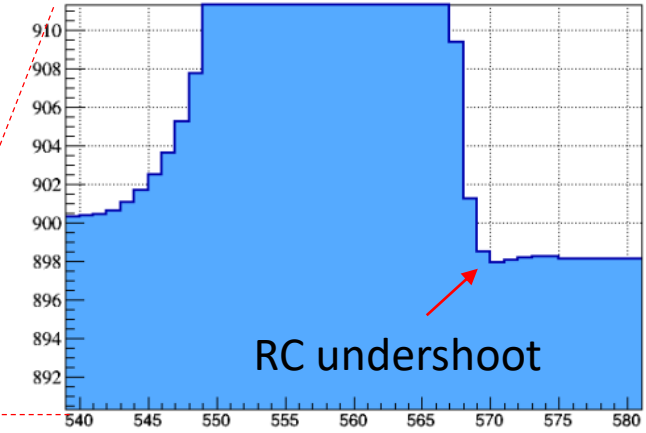
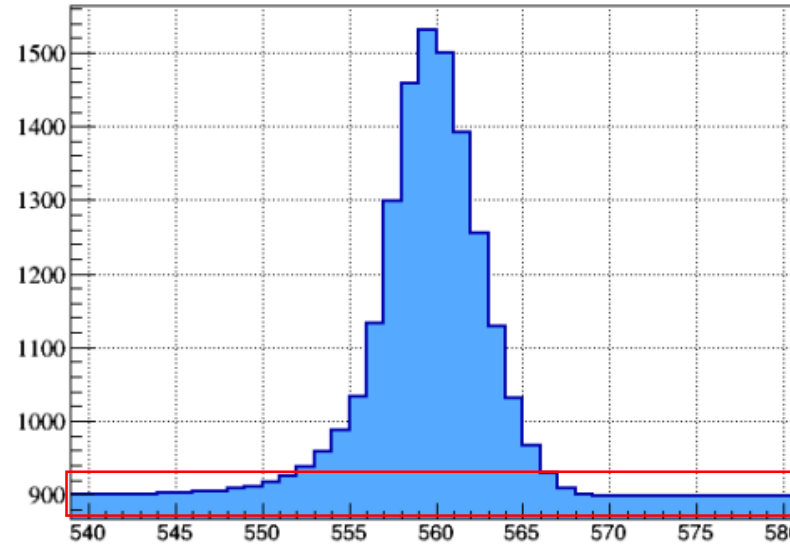
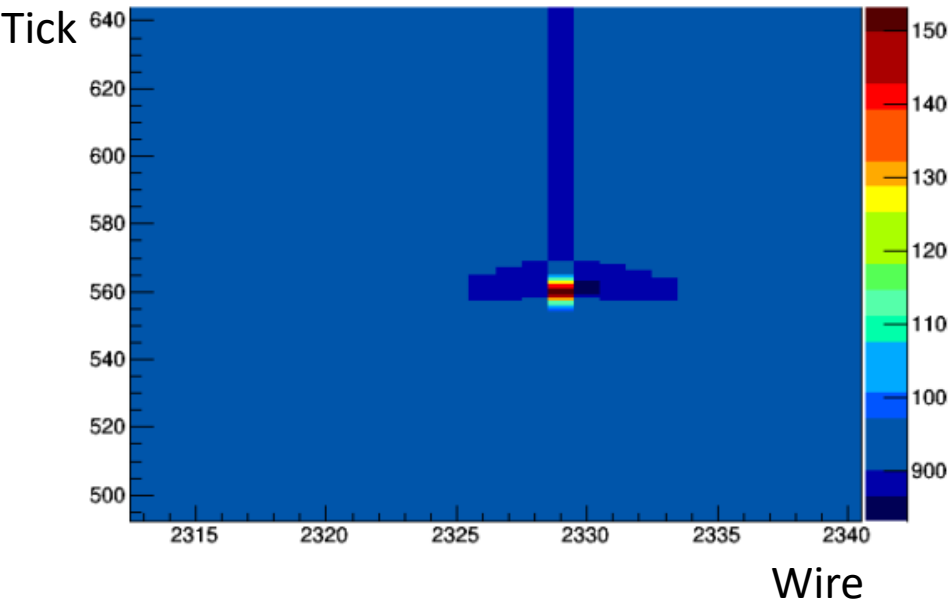
# Calculating the electronics response

- Shaping function: <https://github.com/WireCell/wire-cell-toolkit/blob/6976891db6db4165b992b3ec77c20925fa95a803/util/src/Response.cxx#L316>
- 14mV/fC + post gain 1.1365, shaping 2.2us



- $10\text{ke} \approx 415.762 \text{ ADC}\cdot\text{tick}$
- The result is not sensitive to
  - Sampling rate (0.5us vs 0.1us)
  - Time offset in each tick (0us vs 0.25us)
  - Details in backup slides

# Impact from RC



- Expectation: 4157.6 ADC\*tick on a wire from 100ke point-like depo
- (w/ RC) Integral over a 60-tick window: 4091.02 “ADC”
- (w/o RC) 4145.88 “ADC”
- A -1.6% bias from RC undershoot, so we disable RC in the simulation

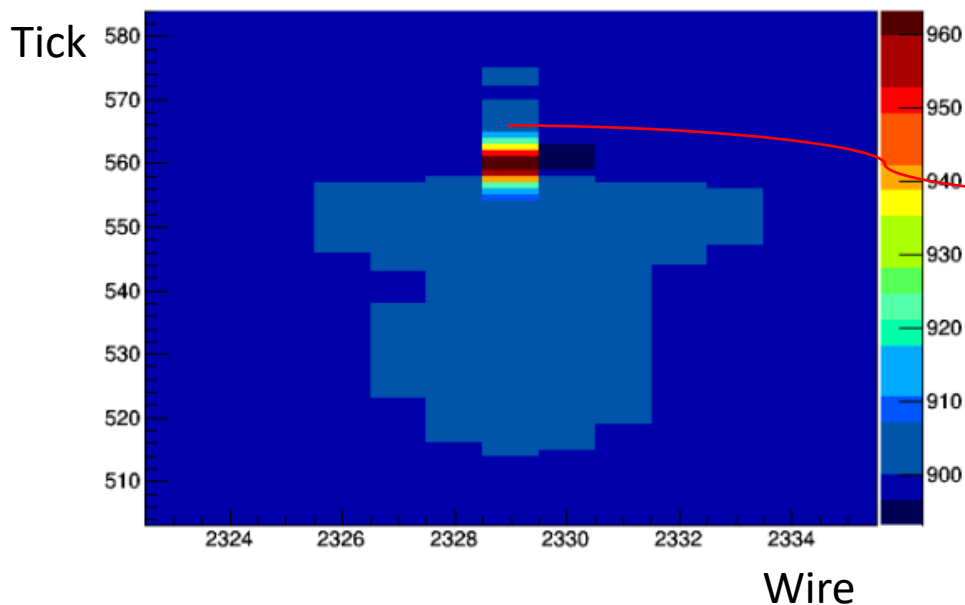


# 10ke point-source simulation

- (-355, 300, 120)cm, 10k electrons

- Expectation: 415.76 ADC\*tick on central wire for 10k electrons
- (int ADC) 403/415.76 ~ -3% bias
- (float ADC) 414.587 / 415.76 ~ -0.3% bias, could be from the variation of the filed response within one wire pitch, or from the calculation precision

Integrate ADC charge on +/- 10 collection wires  
- WireCell saves both the float ADC value and the int ADC value after digitization



“Int ADC”

```
channel: -10 ADCxtick: 0 decon: 0
channel: -9 ADCxtick: 0 decon: 0
channel: -8 ADCxtick: 0 decon: 0
channel: -7 ADCxtick: 0 decon: 0
channel: -6 ADCxtick: 0 decon: 0
channel: -5 ADCxtick: 0 decon: 0
channel: -4 ADCxtick: 0 decon: 0
channel: -3 ADCxtick: -6 decon: 0
channel: -2 ADCxtick: -10 decon: 0
channel: -1 ADCxtick: -14 decon: 330
channel: 0 ADCxtick: 403 decon: 9923
channel: 1 ADCxtick: -13 decon: 333
channel: 2 ADCxtick: -14 decon: 0
channel: 3 ADCxtick: -9 decon: 0
channel: 4 ADCxtick: -5 decon: 0
channel: 5 ADCxtick: 0 decon: 0
channel: 6 ADCxtick: 0 decon: 0
channel: 7 ADCxtick: 0 decon: 0
channel: 8 ADCxtick: 0 decon: 0
channel: 9 ADCxtick: 0 decon: 0
channel: 10 ADCxtick: 0 decon: 0
decon sum: 10586
```

“Float ADC”

```
channel: -10 ADCxtick: -0.0344849 decon: 0
channel: -9 ADCxtick: -0.0458984 decon: 0
channel: -8 ADCxtick: -0.0613403 decon: 0
channel: -7 ADCxtick: -0.0820312 decon: 0
channel: -6 ADCxtick: -0.108154 decon: 0
channel: -5 ADCxtick: -0.142761 decon: 0
channel: -4 ADCxtick: -0.187927 decon: 0
channel: -3 ADCxtick: -0.263245 decon: 0
channel: -2 ADCxtick: -0.503479 decon: 0
channel: -1 ADCxtick: -2.11865 decon: 330
channel: 0 ADCxtick: 414.587 decon: 9923
channel: 1 ADCxtick: -0.2724 decon: 333
channel: 2 ADCxtick: -0.293579 decon: 0
channel: 3 ADCxtick: -0.251648 decon: 0
channel: 4 ADCxtick: -0.205078 decon: 0
channel: 5 ADCxtick: -0.160889 decon: 0
channel: 6 ADCxtick: -0.123535 decon: 0
channel: 7 ADCxtick: -0.0940552 decon: 0
channel: 8 ADCxtick: -0.0706177 decon: 0
channel: 9 ADCxtick: -0.0527954 decon: 0
channel: 10 ADCxtick: -0.0397339 decon: 0
decon sum: 10586
```

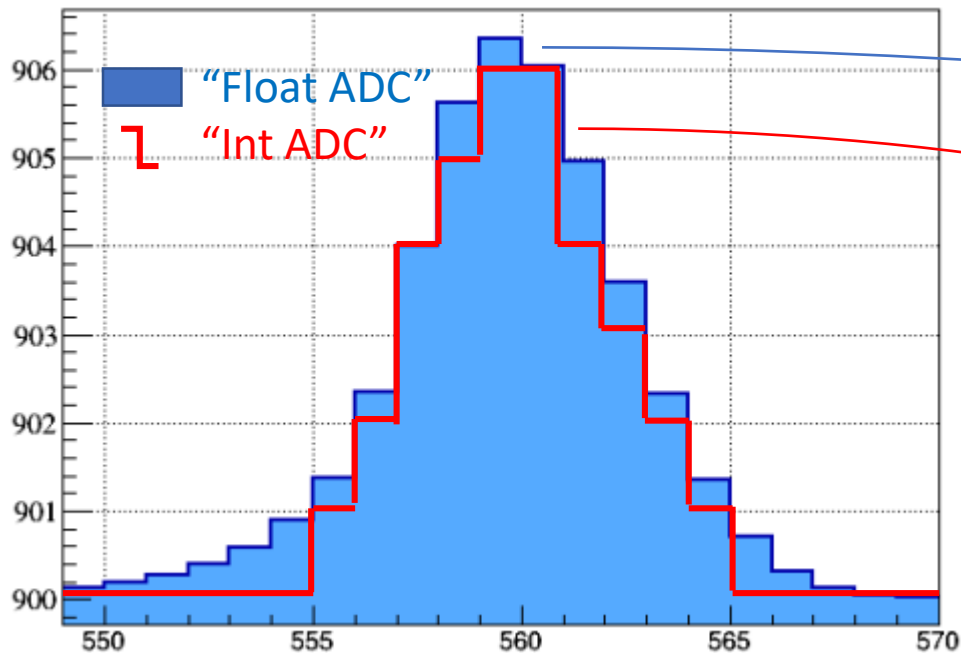
# 1ke point-source simulation

- (-355, 300, 120)cm, 1k electrons

- Expectation: 41.576 ADC\*tick on central wire
- **(int ADC) 34/41.576 ~ -18% bias**
- (float ADC) 41.4587 / 41.576 ~ -0.3% bias

Digitization to int ADC value significantly reduces small signals  
But this is how ADC digitizer works!

Central Wire for the point-like depo



```

channel: -10 ADCxtick: 0 decon: 0
channel: -9 ADCxtick: 0 decon: 0
channel: -8 ADCxtick: 0 decon: 0
channel: -7 ADCxtick: 0 decon: 0
channel: -6 ADCxtick: 0 decon: 0
channel: -5 ADCxtick: 0 decon: 0
channel: -4 ADCxtick: 0 decon: 0
channel: -3 ADCxtick: 0 decon: 0
channel: -2 ADCxtick: -5 decon: 0
channel: -1 ADCxtick: -8 decon: 0
channel: 0 ADCxtick: 34 decon: 0
channel: 1 ADCxtick: -9 decon: 0
channel: 2 ADCxtick: -7 decon: 0
channel: 3 ADCxtick: 0 decon: 0
channel: 4 ADCxtick: 0 decon: 0
channel: 5 ADCxtick: 0 decon: 0
channel: 6 ADCxtick: 0 decon: 0
channel: 7 ADCxtick: 0 decon: 0
channel: 8 ADCxtick: 0 decon: 0
channel: 9 ADCxtick: 0 decon: 0
channel: 10 ADCxtick: 0 decon: 0
decon sum: 0

channel: -10 ADCxtick: -0.00305176 decon: 0
channel: -9 ADCxtick: -0.00445557 decon: 0
channel: -8 ADCxtick: -0.00640869 decon: 0
channel: -7 ADCxtick: -0.00830078 decon: 0
channel: -6 ADCxtick: -0.0107422 decon: 0
channel: -5 ADCxtick: -0.0141602 decon: 0
channel: -4 ADCxtick: -0.0184937 decon: 0
channel: -3 ADCxtick: -0.0263062 decon: 0
channel: -2 ADCxtick: -0.0505981 decon: 0
channel: -1 ADCxtick: -0.211792 decon: 0
channel: 0 ADCxtick: 41.4587 decon: 0
channel: 1 ADCxtick: -0.0272827 decon: 0
channel: 2 ADCxtick: -0.0292969 decon: 0
channel: 3 ADCxtick: -0.0250854 decon: 0
channel: 4 ADCxtick: -0.0206909 decon: 0
channel: 5 ADCxtick: -0.0160522 decon: 0
channel: 6 ADCxtick: -0.0115967 decon: 0
channel: 7 ADCxtick: -0.00946045 decon: 0
channel: 8 ADCxtick: -0.00738525 decon: 0
channel: 9 ADCxtick: -0.00549316 decon: 0
channel: 10 ADCxtick: -0.00372314 decon: 0
    
```

# 5ke point-source simulation

```
channel: -10 ADCxtick: 0 decon: 0
channel: -9 ADCxtick: 0 decon: 0
channel: -8 ADCxtick: 0 decon: 0
channel: -7 ADCxtick: 0 decon: 0
channel: -6 ADCxtick: 0 decon: 0
channel: -5 ADCxtick: 0 decon: 0
channel: -4 ADCxtick: 0 decon: 0
channel: -3 ADCxtick: -5 decon: 0
channel: -2 ADCxtick: -8 decon: 0
channel: -1 ADCxtick: -13 decon: 162
channel: 0 ADCxtick: 194 decon: 4955
channel: 1 ADCxtick: -13 decon: 164
channel: 2 ADCxtick: -10 decon: 0
channel: 3 ADCxtick: -8 decon: 0
channel: 4 ADCxtick: 0 decon: 0
channel: 5 ADCxtick: 0 decon: 0
channel: 6 ADCxtick: 0 decon: 0
channel: 7 ADCxtick: 0 decon: 0
channel: 8 ADCxtick: 0 decon: 0
channel: 9 ADCxtick: 0 decon: 0
channel: 10 ADCxtick: 0 decon: 0
decon sum: 5281
```

```
channel: -10 ADCxtick: -0.0171509 decon: 0
channel: -9 ADCxtick: -0.0231934 decon: 0
channel: -8 ADCxtick: -0.0308228 decon: 0
channel: -7 ADCxtick: -0.0401001 decon: 0
channel: -6 ADCxtick: -0.0540771 decon: 0
channel: -5 ADCxtick: -0.0713501 decon: 0
channel: -4 ADCxtick: -0.0939941 decon: 0
channel: -3 ADCxtick: -0.131531 decon: 0
channel: -2 ADCxtick: -0.251953 decon: 0
channel: -1 ADCxtick: -1.05914 decon: 162
channel: 0 ADCxtick: 207.294 decon: 4955
channel: 1 ADCxtick: -0.136292 decon: 164
channel: 2 ADCxtick: -0.14679 decon: 0
channel: 3 ADCxtick: -0.12561 decon: 0
channel: 4 ADCxtick: -0.1026 decon: 0
channel: 5 ADCxtick: -0.0802612 decon: 0
channel: 6 ADCxtick: -0.0618896 decon: 0
channel: 7 ADCxtick: -0.0470581 decon: 0
channel: 8 ADCxtick: -0.0355225 decon: 0
channel: 9 ADCxtick: -0.0267334 decon: 0
channel: 10 ADCxtick: -0.0199585 decon: 0
decon sum: 5281
```

- Expectation: 207.88 ADC\*tick on central wire
- (int ADC) 194/207.88 ~ -6.7% bias
- (float ADC) 207.294/ 207.88 ~ -0.3% bias

# 30ke point-source simulation

- (-355, 300, 120)cm, 30k electrons

```
channel: -10 ADCxtick: 0 decon: 0      channel: -10 ADCxtick: -0.10376 decon: 0
channel: -9 ADCxtick: 0 decon: 0      channel: -9 ADCxtick: -0.137817 decon: 0
channel: -8 ADCxtick: 0 decon: 0      channel: -8 ADCxtick: -0.183838 decon: 0
channel: -7 ADCxtick: 0 decon: 0      channel: -7 ADCxtick: -0.244385 decon: 0
channel: -6 ADCxtick: 0 decon: 0      channel: -6 ADCxtick: -0.324646 decon: 0
channel: -5 ADCxtick: 0 decon: 0      channel: -5 ADCxtick: -0.427856 decon: 0
channel: -4 ADCxtick: -8 decon: 0      channel: -4 ADCxtick: -0.564331 decon: 0
channel: -3 ADCxtick: -10 decon: 0     channel: -3 ADCxtick: -0.78949 decon: 0
channel: -2 ADCxtick: -14 decon: 0     channel: -2 ADCxtick: -1.51117 decon: 0
channel: -1 ADCxtick: -22 decon: 999   channel: -1 ADCxtick: -6.35547 decon: 999
channel: 0 ADCxtick: 1232 decon: 29787 channel: 0 ADCxtick: 1243.76 decon: 29787
channel: 1 ADCxtick: -14 decon: 1015   channel: 1 ADCxtick: -0.817444 decon: 1015
channel: 2 ADCxtick: -13 decon: 0      channel: 2 ADCxtick: -0.881042 decon: 0
channel: 3 ADCxtick: -10 decon: 0      channel: 3 ADCxtick: -0.755127 decon: 0
channel: 4 ADCxtick: -8 decon: 0       channel: 4 ADCxtick: -0.615112 decon: 0
channel: 5 ADCxtick: 0 decon: 0        channel: 5 ADCxtick: -0.483398 decon: 0
channel: 6 ADCxtick: 0 decon: 0        channel: 6 ADCxtick: -0.371155 decon: 0
channel: 7 ADCxtick: 0 decon: 0        channel: 7 ADCxtick: -0.281433 decon: 0
channel: 8 ADCxtick: 0 decon: 0        channel: 8 ADCxtick: -0.211853 decon: 0
channel: 9 ADCxtick: 0 decon: 0        channel: 9 ADCxtick: -0.15918 decon: 0
channel: 10 ADCxtick: 0 decon: 0       channel: 10 ADCxtick: -0.119263 decon: 0
decon sum: 31801
```

- Expectation: 1247.28 ADC\*tick on central wire
- (int ADC) 1232/1247.28 ~ -1.2% bias
- (float ADC) 1243.76 / 1247.28 ~ -0.3% bias

# 50ke point-source simulation

- (-355, 300, 120)cm, 50k electrons

```
channel: -10 ADCxtick: 0 decon: 0
channel: -9 ADCxtick: 0 decon: 0
channel: -8 ADCxtick: 0 decon: 0
channel: -7 ADCxtick: 0 decon: 0
channel: -6 ADCxtick: -3 decon: 0
channel: -5 ADCxtick: -8 decon: 0
channel: -4 ADCxtick: -14 decon: 0
channel: -3 ADCxtick: -13 decon: 0
channel: -2 ADCxtick: -14 decon: 0
channel: -1 ADCxtick: -23 decon: 1667
channel: 0 ADCxtick: 2057 decon: 49652
channel: 1 ADCxtick: -14 decon: 1695
channel: 2 ADCxtick: -14 decon: 0
channel: 3 ADCxtick: -12 decon: 0
channel: 4 ADCxtick: -14 decon: 0
channel: 5 ADCxtick: -12 decon: 0
channel: 6 ADCxtick: -6 decon: 0
channel: 7 ADCxtick: 0 decon: 0
channel: 8 ADCxtick: 0 decon: 0
channel: 9 ADCxtick: 0 decon: 0
channel: 10 ADCxtick: 0 decon: 0
decon sum: 53014
```

```
channel: -10 ADCxtick: -0.172546 decon: 0
channel: -9 ADCxtick: -0.230103 decon: 0
channel: -8 ADCxtick: -0.306519 decon: 0
channel: -7 ADCxtick: -0.407837 decon: 0
channel: -6 ADCxtick: -0.541077 decon: 0
channel: -5 ADCxtick: -0.712646 decon: 0
channel: -4 ADCxtick: -0.940491 decon: 0
channel: -3 ADCxtick: -1.31506 decon: 0
channel: -2 ADCxtick: -2.51904 decon: 0
channel: -1 ADCxtick: -10.5925 decon: 1667
channel: 0 ADCxtick: 2072.94 decon: 49652
channel: 1 ADCxtick: -1.36224 decon: 1695
channel: 2 ADCxtick: -1.46802 decon: 0
channel: 3 ADCxtick: -1.25854 decon: 0
channel: 4 ADCxtick: -1.02496 decon: 0
channel: 5 ADCxtick: -0.805603 decon: 0
channel: 6 ADCxtick: -0.618896 decon: 0
channel: 7 ADCxtick: -0.469543 decon: 0
channel: 8 ADCxtick: -0.352966 decon: 0
channel: 9 ADCxtick: -0.265442 decon: 0
channel: 10 ADCxtick: -0.198975 decon: 0
```

- Expectation: 2078.8 ADC\*tick on central wire
- (int ADC) 2057/2078.8 ~ -1% bias
- (float ADC) 2072.94 / 2078.8 ~ -0.28% bias

# 100ke point-source simulation

- (-355, 300, 120)cm, 100k electrons

```
channel: -10 ADCxtick: 0 decon: 0
channel: -9 ADCxtick: 0 decon: 0
channel: -8 ADCxtick: -9 decon: 0
channel: -7 ADCxtick: -13 decon: 0
channel: -6 ADCxtick: -16 decon: 0
channel: -5 ADCxtick: -18 decon: 0
channel: -4 ADCxtick: -21 decon: 0
channel: -3 ADCxtick: -17 decon: 0
channel: -2 ADCxtick: -19 decon: 0
channel: -1 ADCxtick: -37 decon: 3342
channel: 0 ADCxtick: 4130 decon: 99314
channel: 1 ADCxtick: -15 decon: 3398
channel: 2 ADCxtick: -18 decon: 588
channel: 3 ADCxtick: -15 decon: 0
channel: 4 ADCxtick: -18 decon: 0
channel: 5 ADCxtick: -21 decon: 0
channel: 6 ADCxtick: -16 decon: 0
channel: 7 ADCxtick: -15 decon: 0
channel: 8 ADCxtick: -11 decon: 0
channel: 9 ADCxtick: -3 decon: 0
channel: 10 ADCxtick: 0 decon: 0
decon sum: 106642
```

```
channel: -10 ADCxtick: -0.345764 decon: 0
channel: -9 ADCxtick: -0.460144 decon: 0
channel: -8 ADCxtick: -0.612915 decon: 0
channel: -7 ADCxtick: -0.815857 decon: 0
channel: -6 ADCxtick: -1.08167 decon: 0
channel: -5 ADCxtick: -1.4259 decon: 0
channel: -4 ADCxtick: -1.88153 decon: 0
channel: -3 ADCxtick: -2.63068 decon: 0
channel: -2 ADCxtick: -5.03772 decon: 0
channel: -1 ADCxtick: -21.1857 decon: 3342
channel: 0 ADCxtick: 4145.88 decon: 99314
channel: 1 ADCxtick: -2.7254 decon: 3398
channel: 2 ADCxtick: -2.93604 decon: 588
channel: 3 ADCxtick: -2.51691 decon: 0
channel: 4 ADCxtick: -2.04999 decon: 0
channel: 5 ADCxtick: -1.61133 decon: 0
channel: 6 ADCxtick: -1.23761 decon: 0
channel: 7 ADCxtick: -0.937683 decon: 0
channel: 8 ADCxtick: -0.706421 decon: 0
channel: 9 ADCxtick: -0.530334 decon: 0
channel: 10 ADCxtick: -0.397644 decon: 0
decon sum: 106642
```

- Expectation: 4157.6 ADC\*tick on central wire
- (int ADC) 4130/4157.6 ~ -0.66% bias
- (float ADC) 4145.88 / 4157.6 ~ -0.28% bias

# 200ke point-source simulation

- (-355, 300, 120)cm, 200k electrons

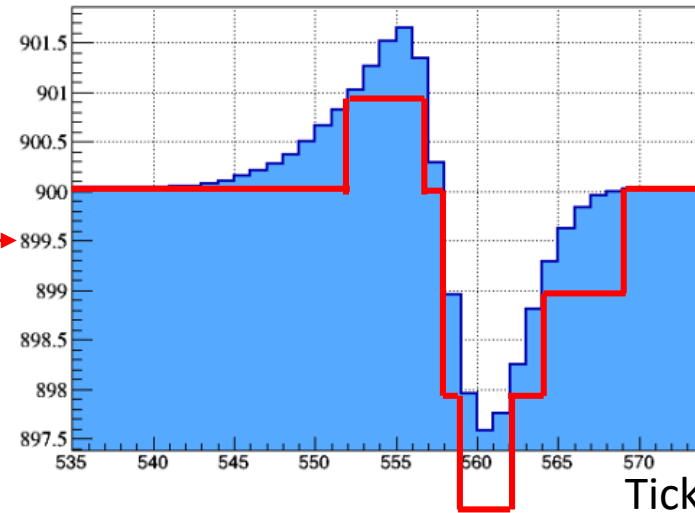
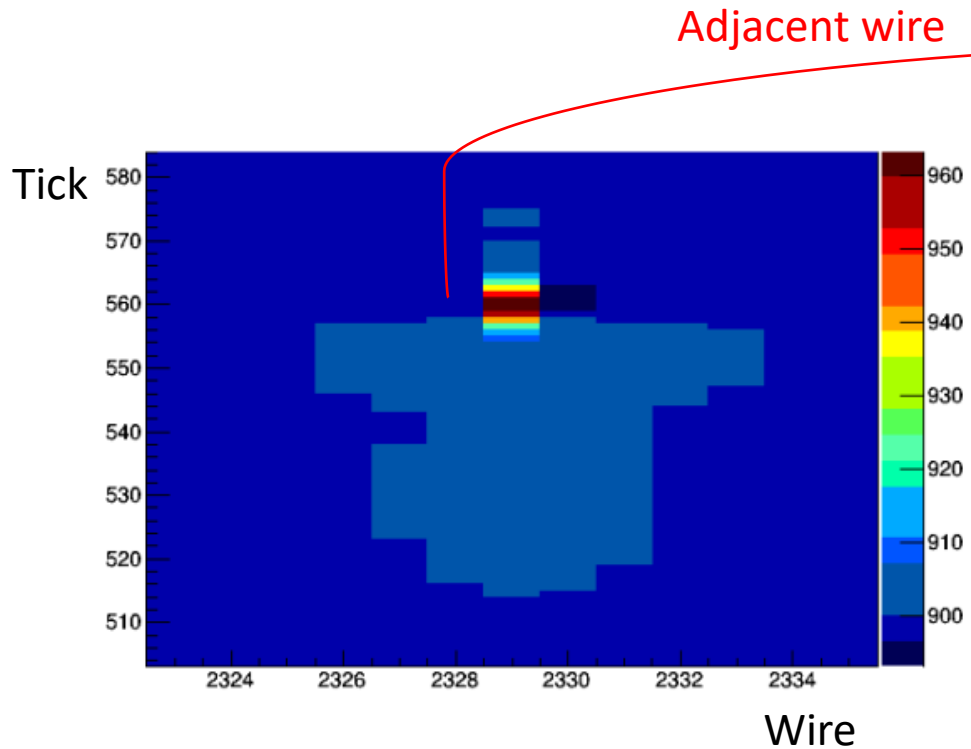
```
channel: -10 ADCxtick: -19 decon: 0
channel: -9 ADCxtick: -22 decon: 0
channel: -8 ADCxtick: -24 decon: 0
channel: -7 ADCxtick: -25 decon: 0
channel: -6 ADCxtick: -24 decon: 0
channel: -5 ADCxtick: -28 decon: 0
channel: -4 ADCxtick: -25 decon: 0
channel: -3 ADCxtick: -23 decon: 0
channel: -2 ADCxtick: -24 decon: 264
channel: -1 ADCxtick: -60 decon: 6693
channel: 0 ADCxtick: 8273 decon: 198646
channel: 1 ADCxtick: -23 decon: 6808
channel: 2 ADCxtick: -22 decon: 1177
channel: 3 ADCxtick: -20 decon: 0
channel: 4 ADCxtick: -22 decon: 0
channel: 5 ADCxtick: -27 decon: 0
channel: 6 ADCxtick: -26 decon: 0
channel: 7 ADCxtick: -25 decon: 0
channel: 8 ADCxtick: -25 decon: 0
channel: 9 ADCxtick: -24 decon: 0
channel: 10 ADCxtick: -20 decon: 0
decon sum: 213588
```

```
channel: -10 ADCxtick: -0.690918 decon: 0
channel: -9 ADCxtick: -0.920532 decon: 0
channel: -8 ADCxtick: -1.22632 decon: 0
channel: -7 ADCxtick: -1.63135 decon: 0
channel: -6 ADCxtick: -2.16327 decon: 0
channel: -5 ADCxtick: -2.8526 decon: 0
channel: -4 ADCxtick: -3.76312 decon: 0
channel: -3 ADCxtick: -5.26099 decon: 0
channel: -2 ADCxtick: -10.0759 decon: 264
channel: -1 ADCxtick: -42.3713 decon: 6693
channel: 0 ADCxtick: 8291.75 decon: 198646
channel: 1 ADCxtick: -5.45032 decon: 6808
channel: 2 ADCxtick: -5.8714 decon: 1177
channel: 3 ADCxtick: -5.03387 decon: 0
channel: 4 ADCxtick: -4.10114 decon: 0
channel: 5 ADCxtick: -3.22253 decon: 0
channel: 6 ADCxtick: -2.47498 decon: 0
channel: 7 ADCxtick: -1.87585 decon: 0
channel: 8 ADCxtick: -1.41248 decon: 0
channel: 9 ADCxtick: -1.06073 decon: 0
channel: 10 ADCxtick: -0.796265 decon: 0
decon sum: 213588
```

- Expectation: 8315.2 ADC\*tick on central wire
- (int ADC) 8273/ 8315.2 ~ -0.5% bias
- (float ADC) 8291.75 / 8315.2 ~ -0.28% bias

# How about integrate charges on all wires?

- 10ke point-like energy depo



■ “Float ADC”  
┌ “Int ADC”

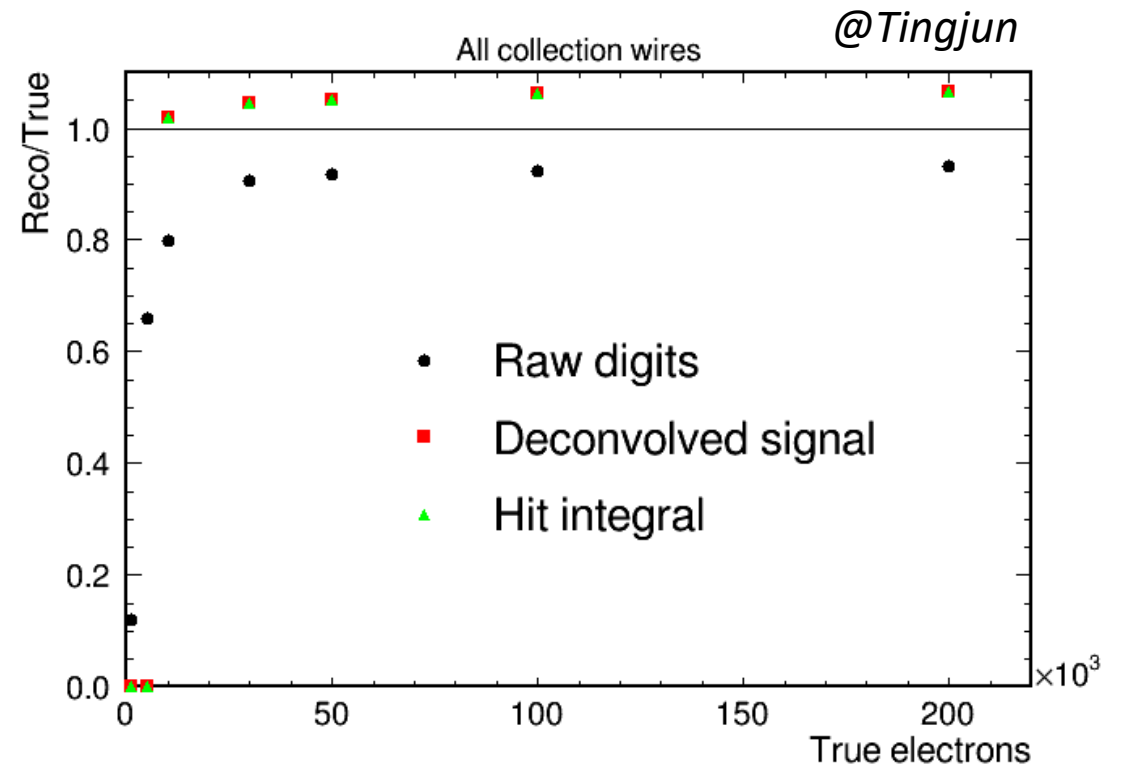
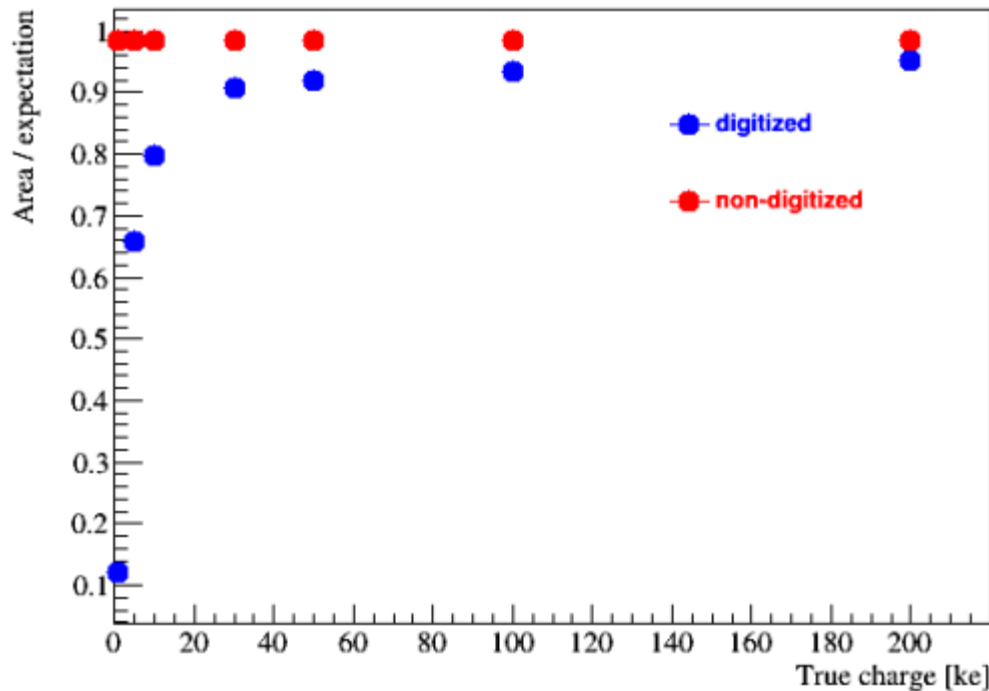
Integrated area  
• “Float ADC”: -2.11  
• “Int ADC”: -14

- The adjacent wires have induction signals, the digitization error also has impact on them
- For 10ke point source simulation, if integrate charges on all wires
  - (float ADC) 408.798 ADC\*tick
  - (int ADC) 332 ADC\*tick
- Compare with 415.76 ADC\*tick, it's a bias of 1.67% and 20.1%, respectively



# Reproducing Tingjun's result for integral of all wires

- For collection wires, the adjacent wires have bipolar shaped induction, which is more sensitive to the digitization error since the signal length is longer

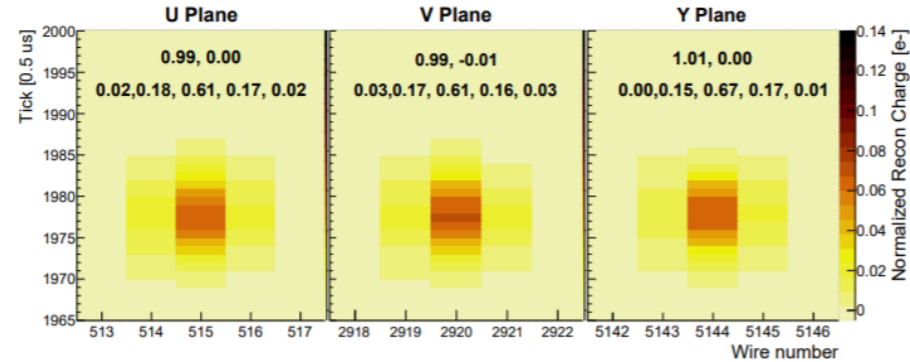
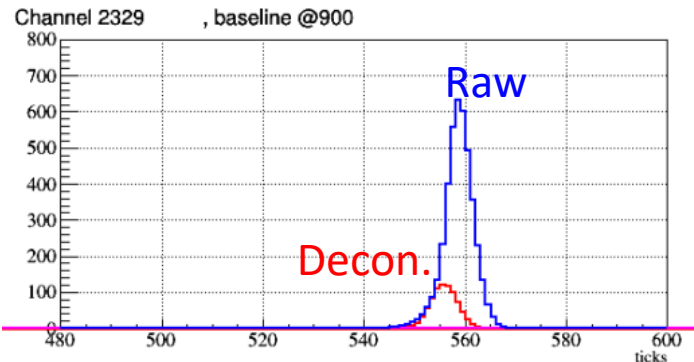
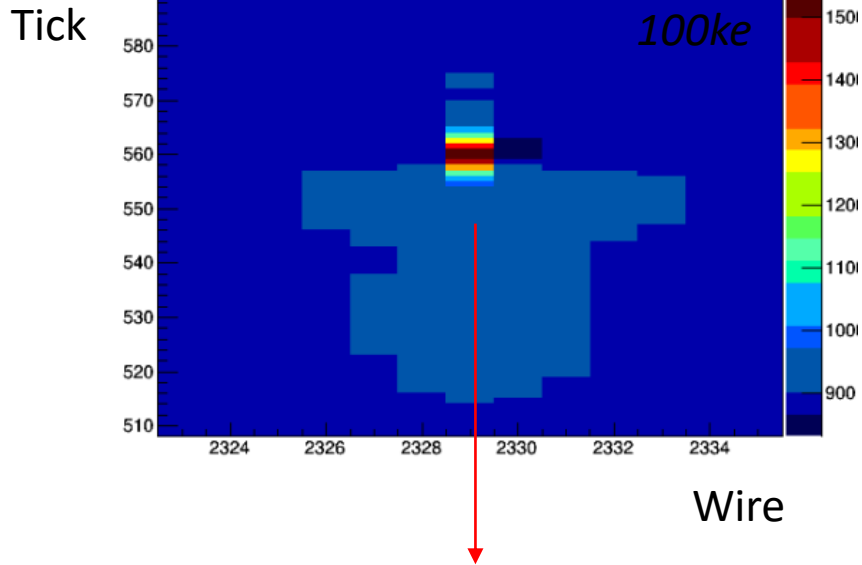


# Interim summary

- We can reproduce Tingjun's observation about the point-like energy depo simulation
- The bias at low charge ( $<30\text{ke}$ ) is mainly due to the nature of the digitizer about how the float is converted to integer
- No charge-dependent bias
- A tiny global bias ( $\sim 0.3\%$ ) could come from the accuracy in calculating the expectation

# Validation of the charge deconvolution

# 100ke point-like depo (without diffusion)

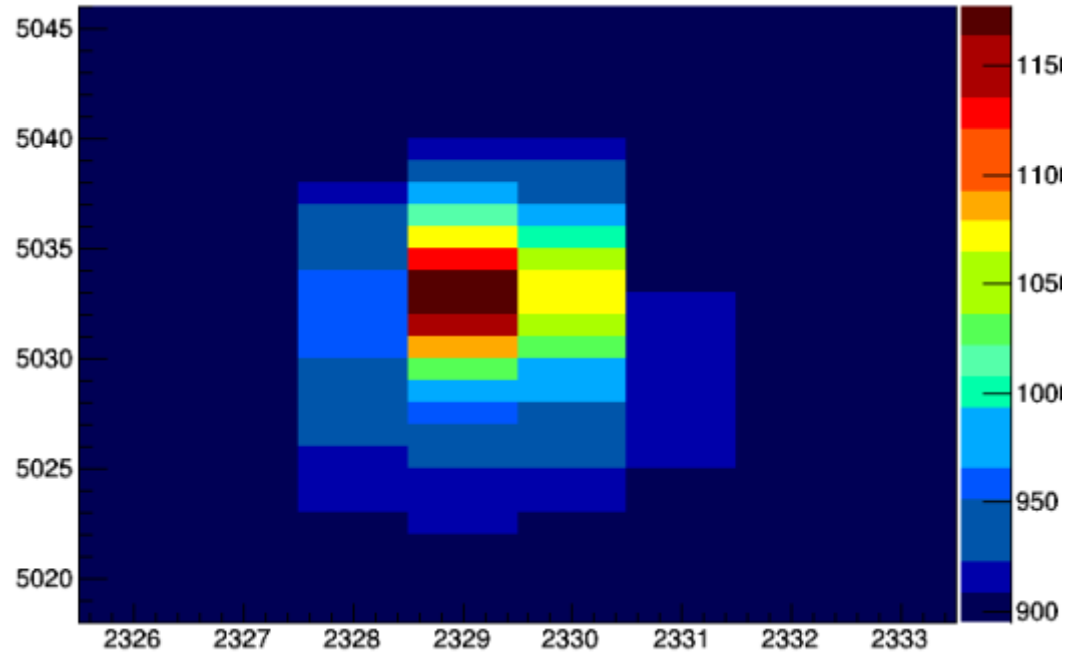


(a) Point source at the wire (0.0 mm transverse position relative to the closest wire).

[MicroBooNE Signal Processing Paper:](#)  
Figure 26

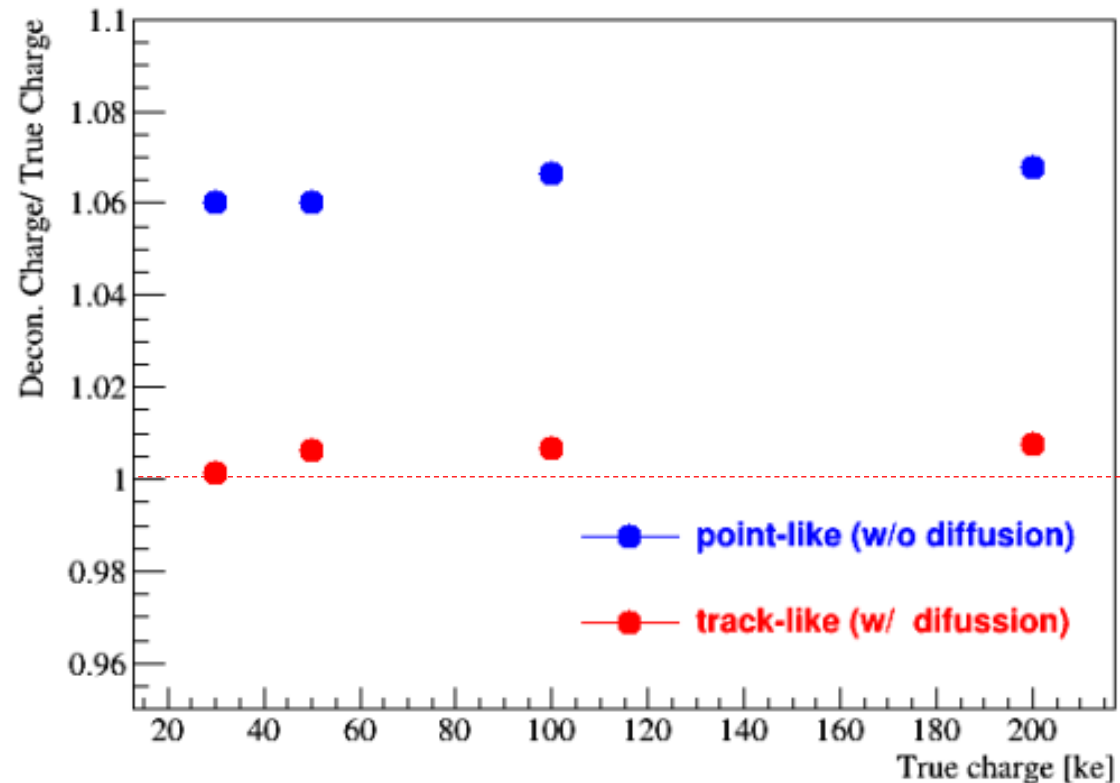
- MicroBooNE simulation study indicates 1~2% bias for point charge deconvolution
- Total decon charge on collection wires: 106642
  - $106642/100k \sim 6.6\%$  bias
- Fine-grained position dependence for the field response
  - The deconvolution kernel takes the averaged response
  - Adding diffusion should make the field response closer to the averaged response (next slide)

# 100ke, with diffusion



- With diffusion ( $DT=8.8 \times 3 \text{ cm}^2/\text{s}$ ), the point-like depo can be smeared over two wire regions, the averaged field response works better for the deconvolution
- Total charge on the collection wires: 100683
- $100683/100\text{k} \sim 0.68\%$  bias
- Consistent with the MicroBooNE simulation

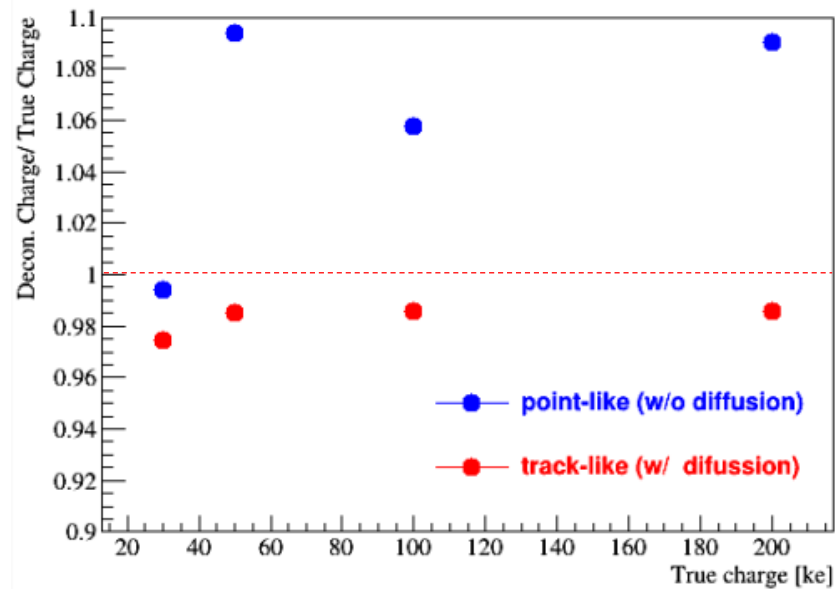
# Point charge decon (w/ diffusion): collection wires



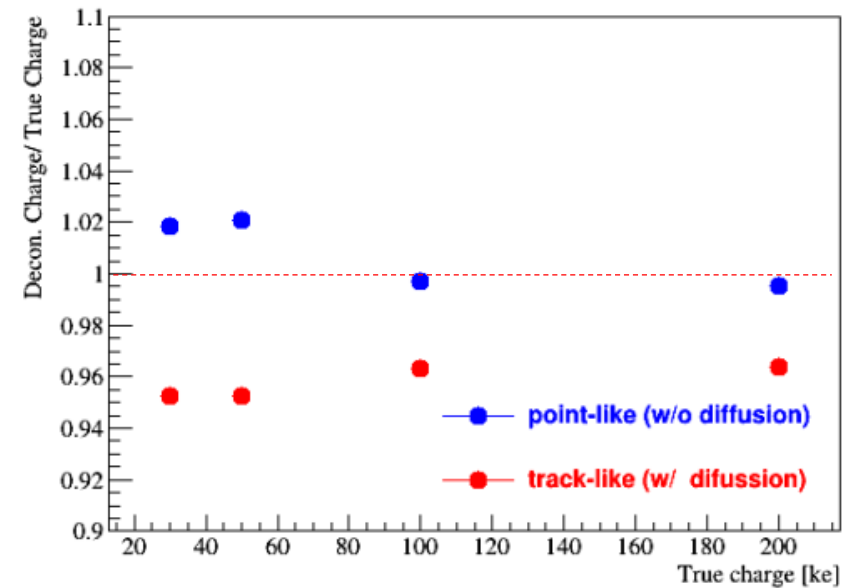
- With diffusion, the bias for point-like depo on collection wire is small (<1%)

# Induction planes

Induction U



Induction V



- This study is done without noise simulated
- While sometimes the result would be even better by adding noise because the WireCell ROI finding and thresholding is tuned based on the data

# Example of a 2cm track depo (with noise)

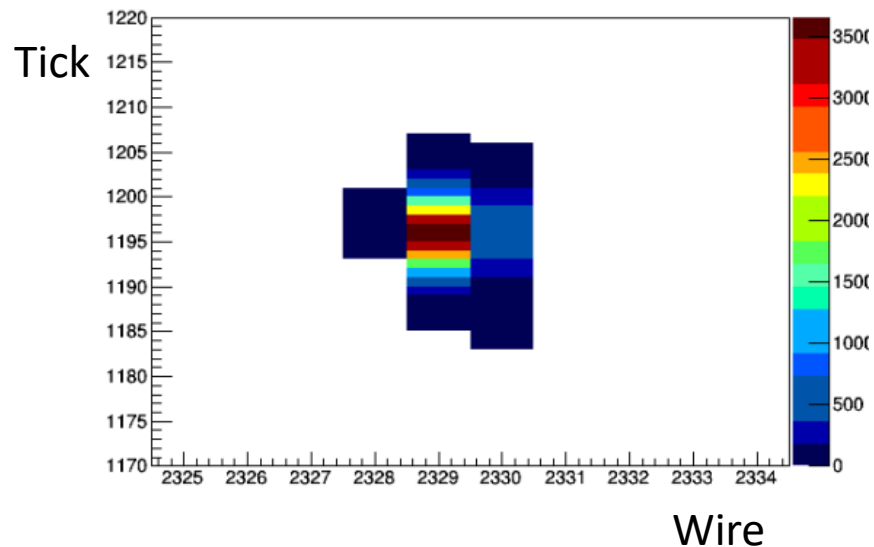
# of e / mm	Bias (%)	U	V	W
30ke		2.6	3.05	0.3
50ke		-0.3	-1.6	0.72
100ke		0.58	-1.6	0.8

- A track-like simulation with diffusion, with noise
  - $DL=0$ ,  $DT=8.8*5 \text{ cm}^2/\text{s}$
  - Start point (-5, 300, 120) cm
  - 2cm length, 1mm per depo step
  - Parallel to wire plane, perpendicular to collection wire
- Bias in the induction plane can be less than 1%, however, a reasonable statistics needs to be achieved to address the mean bias and resolution
  - See backup for the performance of MIP track



# Measuring electron lifetime (w/ diffusion, w/o noise)

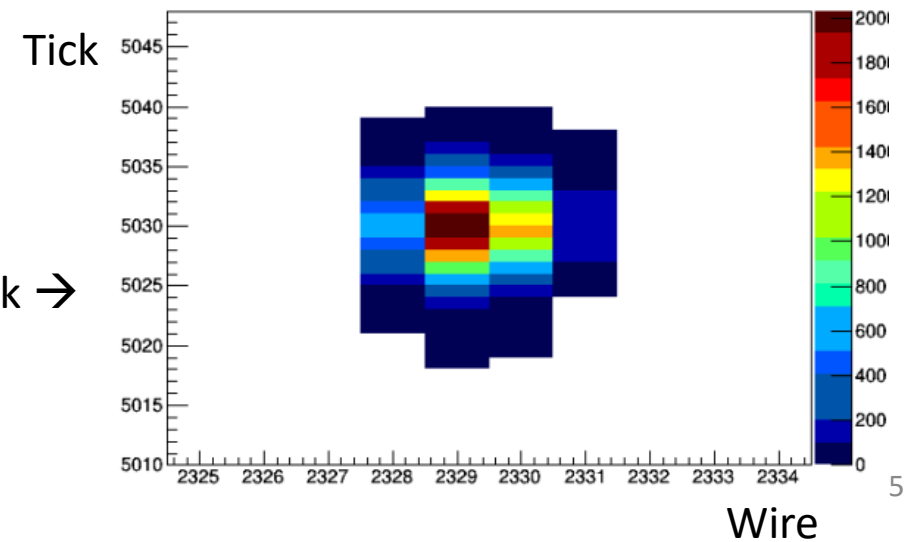
- Simulate two track-like depositions (2cm) with 30ke/mm each
  - Position: (-5, 300, 120)cm and (-305, 300, 120)cm
  - Typical protoDUNE diffusion, and 35ms lifetime
- Deconvolution charge on the collection wire: 567010 and 600567
  - **Measured lifetime =  $-1.917\text{ms}/\ln(567010/600567) = 33.3\text{ ms}$**



← t0 = 1195 tick

t1 = 5029 tick →

Drift time ~ 1.917ms



# Backup Slides

# Calculating the electronics response

- The electronics gain (ADC\*tick/1ke) is not sensitive to
  - Time offset in each tick
  - Sampling rate

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Electronics gain for 10ke (14mV/fC + post gain 1.1365, shaping 2.2us)

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integral (non-binning): 415.77

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integral (0.5us binning): 415.776      *Offset: 0*

integral (0.1us binning): 415.77

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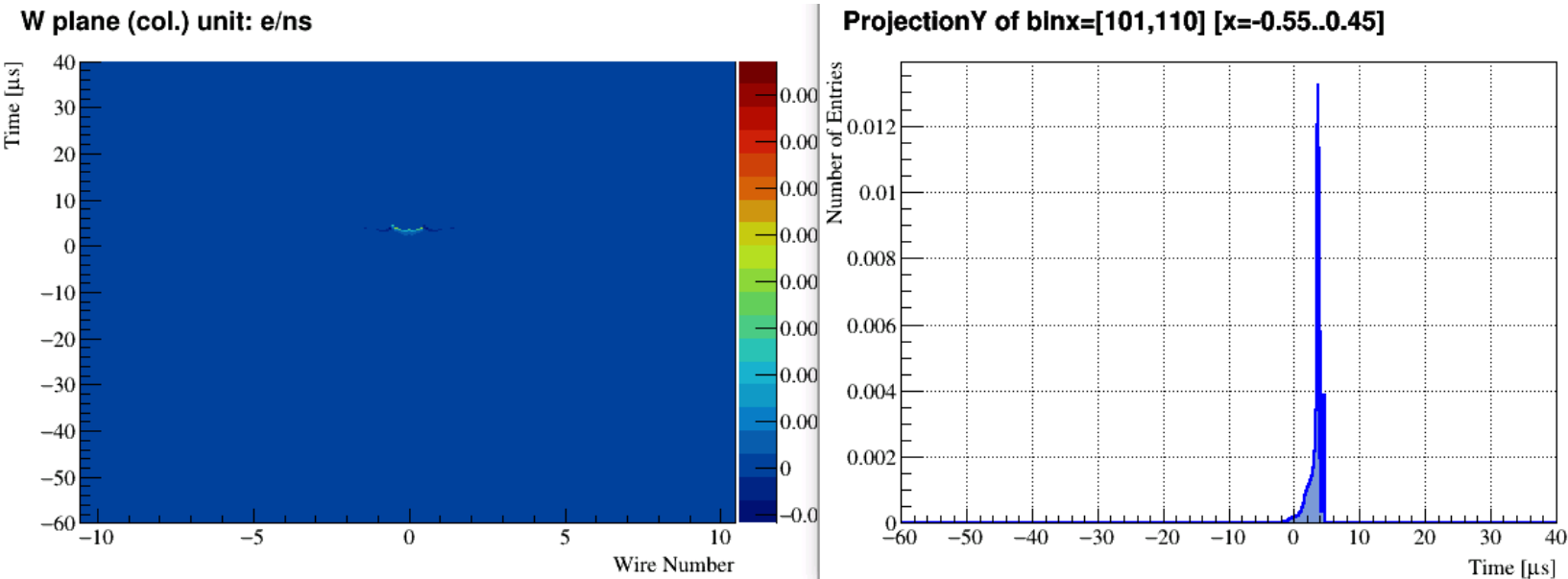
integral (0.5us binning): 415.762

integral (0.1us binning): 415.768      *Offset: 0.25 us*

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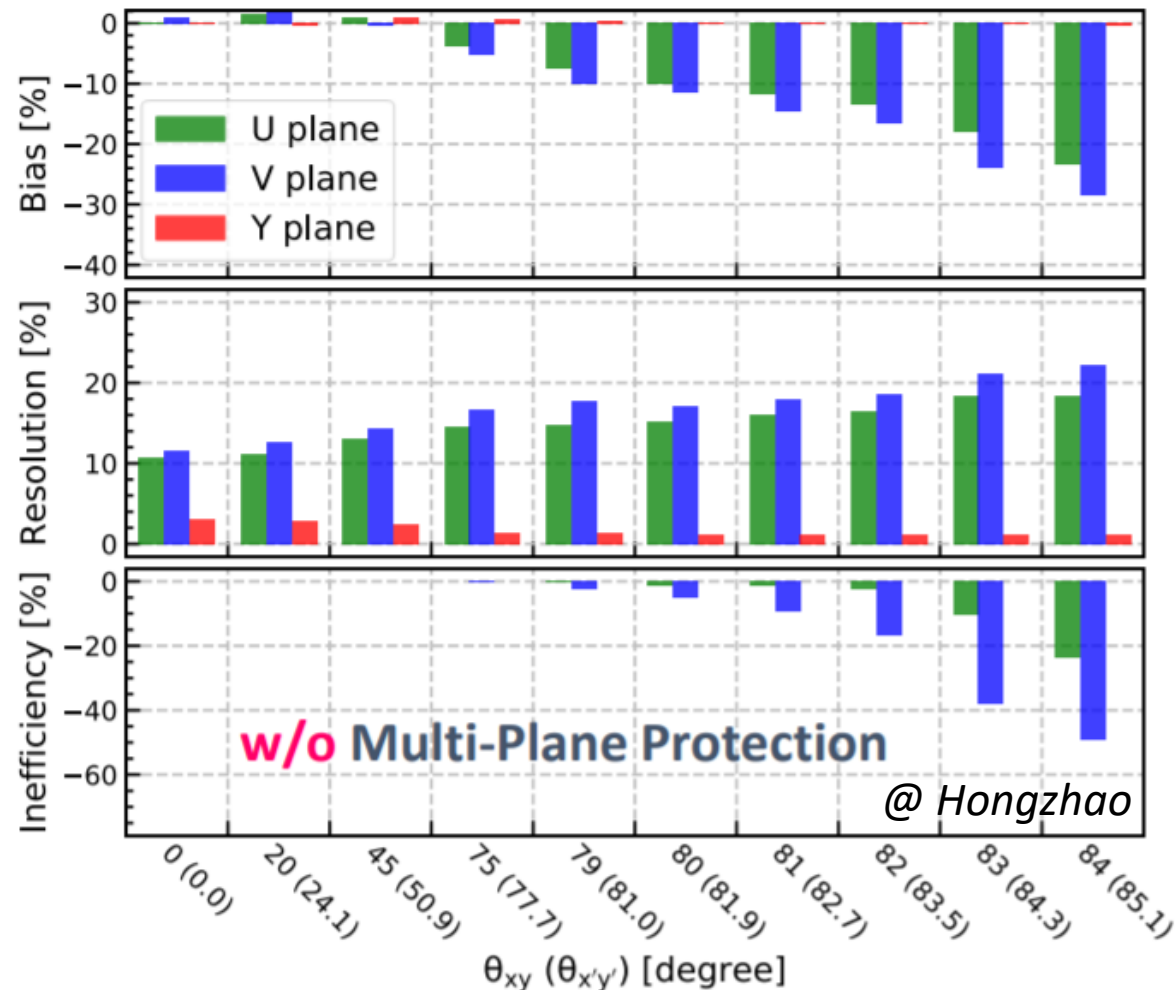
# Total Field Response



- Central 10 electron paths normalized to 0.01002 e/ns
- Integral with 0.1us binning yields 1.002 e

```
TFile**      dune-garfield-1d565.root
TFile*      dune-garfield-1d565.root
  OBJ: TH2F   FieldRes_W      W plane (col.) unit: e/ns : 0 at: 0x5613d2000e00
  OBJ: TH1D   slice_py_of_FieldRes_W ProjectionY of binx=[101,110] [x=-0.55..0.45] : 0 at: 0x5613d23f3040
  KEY: TH2F   FieldRes_U;1    U plane (1st ind.) unit: e/ns
  KEY: TH2F   FieldRes_V;1    V plane (2nd ind.) unit: e/ns
  KEY: TH2F   FieldRes_W;1    W plane (col.) unit: e/ns
root [5] slice_py_of_FieldRes_W->Integral()/10.0
(double) 0.010019683
```

# Performance for MIP line-track deconvolution



- Performance of WireCell signal processing in protoDUNE
- For small angle ( $<45^\circ$ ), bias is less than 2%
- Resolution for collection is not worse than  $\sim 3\%$
- Resolution for induction is about 10% for small angle