First Result of Wire-Cell Signal Processing in ProtoDUNE

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BNL

ProtoDUNE Sim/Reco Meeting, 11/28/2018

Outline

- Signal Processing in Wire-Cell toolkit
  - 2D deconvolution
  - Region of interest (ROI)

→ **Ionization Electron Signal Processing in Single Phase LArTPCs I.**
JINST 13 P07006 (2018)

- Software integration in LArSoft

- Performance of signal processing
  - Full TPC simulation sample
  - Data sample

Signal processing (SP): deconvolution & filter

$$M(t_0) = \int_t R(t - t_0) \cdot S(t) \cdot dt$$

↓ *Fourier transform*

$$M(\omega) = R(\omega) \cdot S(\omega)$$

↓ *Deconvolution + Filter*

$$S(\omega) = \frac{M(\omega)}{R(\omega)} \cdot F(\omega)$$

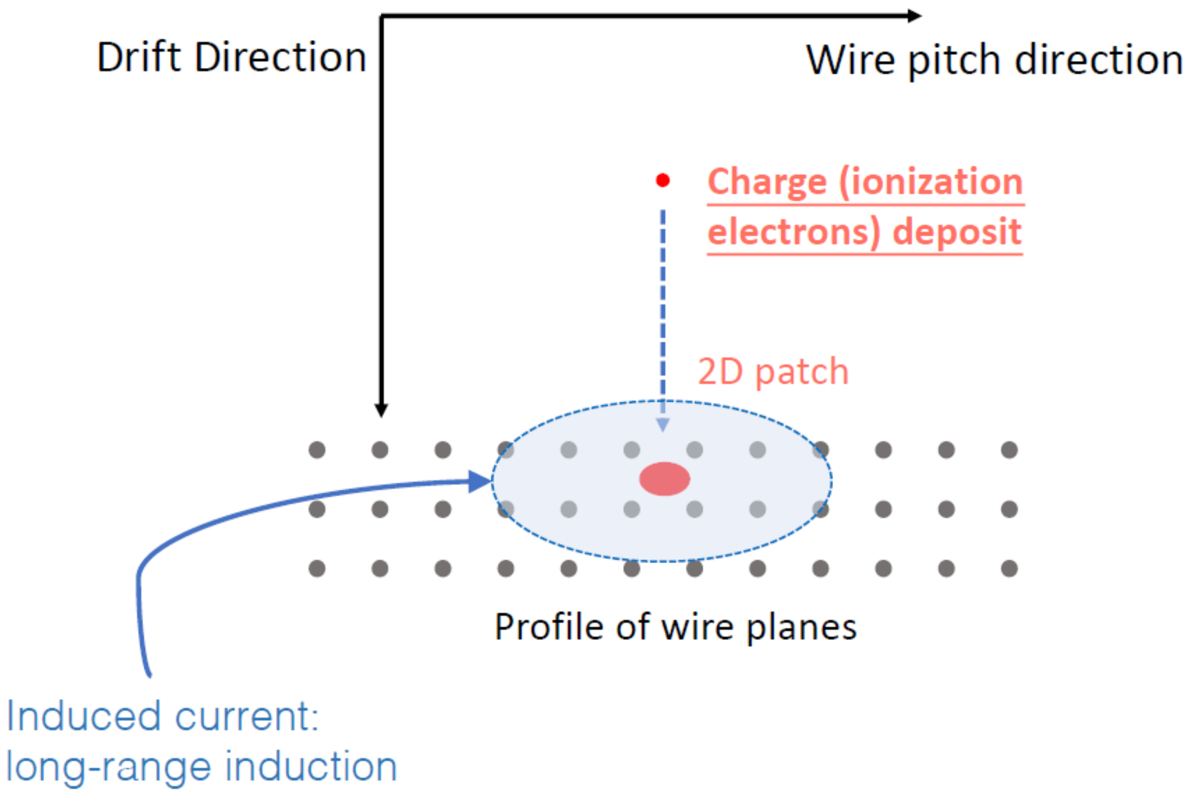
↓ *Inverse Fourier transform*

$$S(t)$$

- Principal method to extract wire charge S(t) is deconvolution
- By given a response function R(t), signal S(t) can be easily derived via Fourier transform
- A filter function $F(\omega)$ introduced to suppress the big fluctuation after deconvolution

Liquid Argon TPC Signal Formation, Signal Processing and Hit Reconstruction
Bruce Baller, *JINST 12 (2017) no.07, P07010*

Long-range induction → 2D deconvolution



- However, the induction from neighboring ionization electrons has to been considered

$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \\ \dots \\ M_{n-1}(\omega) \\ M_n(\omega) \end{pmatrix} = \begin{pmatrix} R_0(\omega) & R_1(\omega) & \dots & R_{n-1}(\omega) & R_n(\omega) \\ R_1(\omega) & R_0(\omega) & \dots & R_{n-2}(\omega) & R_{n-1}(\omega) \\ \dots & \dots & \dots & \dots & \dots \\ R_{n-1}(\omega) & R_{n-2}(\omega) & \dots & R_0(\omega) & R_1(\omega) \\ R_n(\omega) & R_{n-1}(\omega) & \dots & R_1(\omega) & R_0(\omega) \end{pmatrix} \cdot \begin{pmatrix} S_1(\omega) \\ S_2(\omega) \\ \dots \\ S_{n-1}(\omega) \\ S_n(\omega) \end{pmatrix}$$

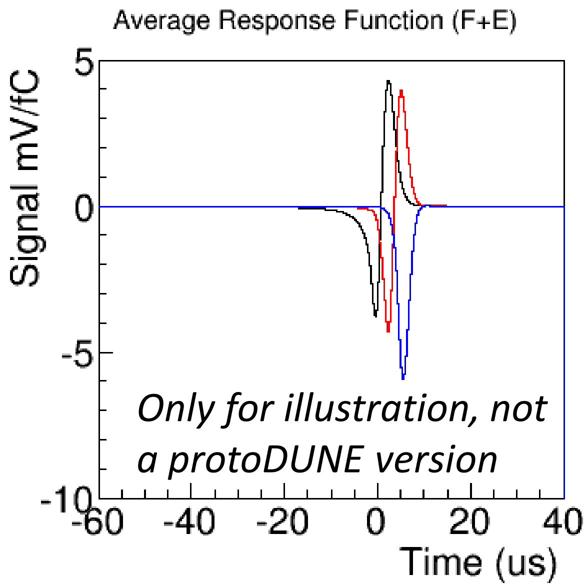
The inversion of matrix R can again be done with deconvolution through 2-D FFT

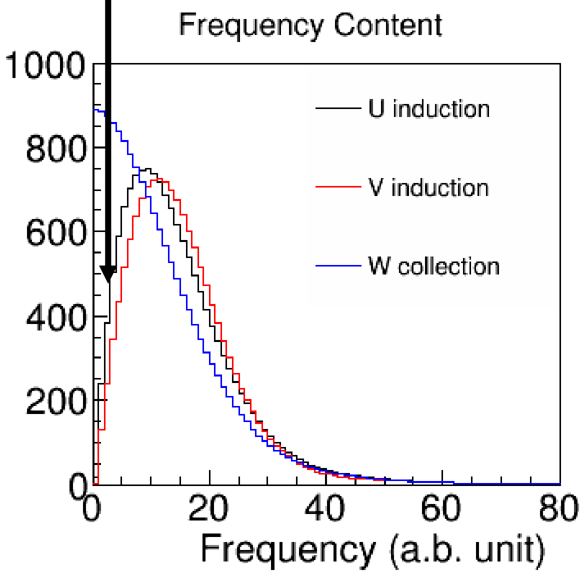
2D: both time and wires dimensions

Just 2D deconvolution will not be enough → ROI + Adaptive Baseline

$$S(\omega) = \frac{M(\omega)}{R(\omega)} \cdot F(\omega)$$

- The bi-polar nature of induction signal amplifies low-frequency noise during deconvolution
- Improved through region of interest (ROI) and the adaptive baseline technique

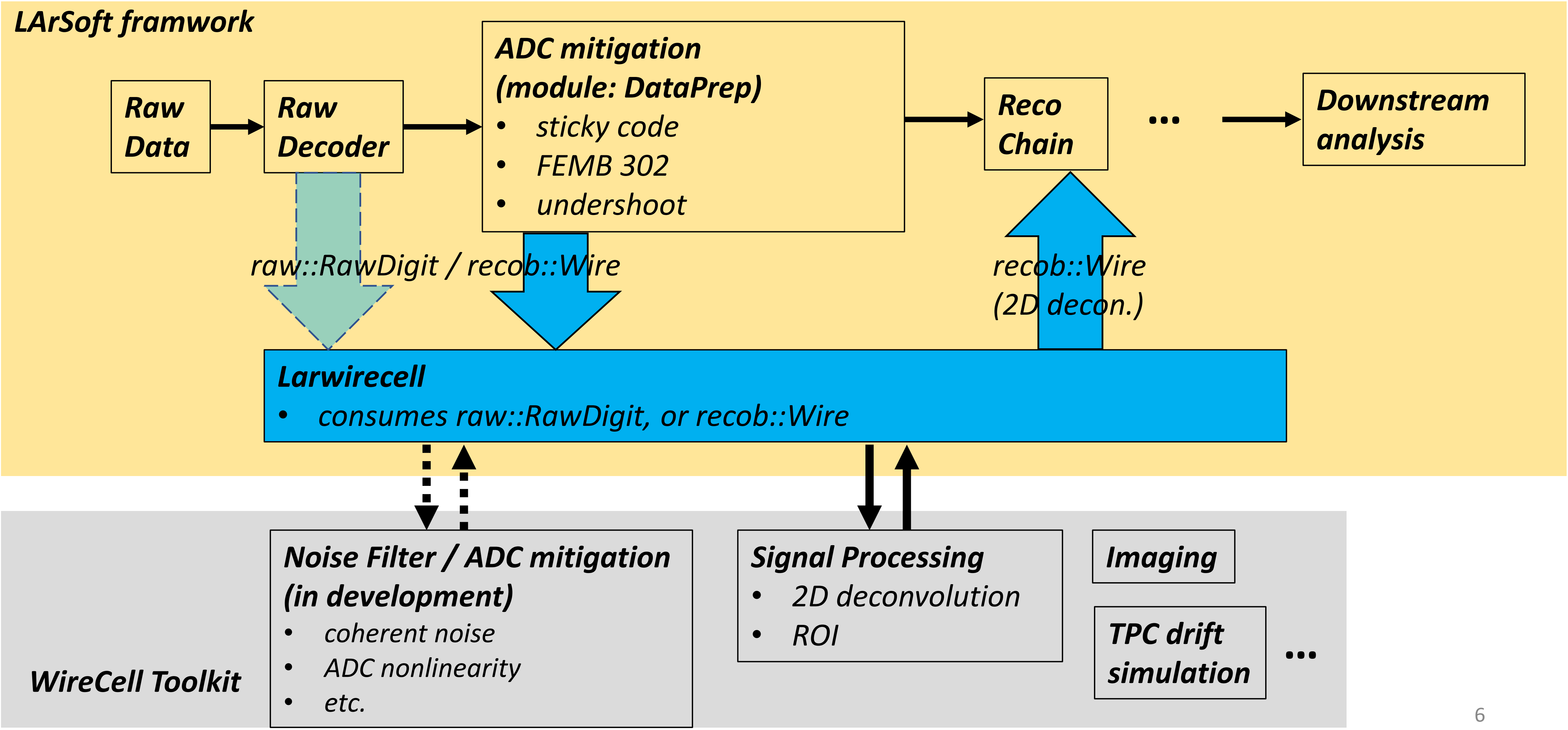




Given N time bins with 2 MHz digitization frequency,

- The highest freq is 1 MHz
- The lowest freq (above 0) is 2/N MHz
  e.g., 200 bins → 10 kHz
- Obviously not sensitive to noise < 2/N MHz
- Adaptive baseline → linear baseline correction instead of flat baseline correction

Software integration in LArSoft



Software integration in LArSoft (cont')

- ***Wire-Cell Toolkit***
  - Repository https://github.com/WireCell
  - Document https://wirecell.github.io/
- ***larwirecell*** (https://cdcvs.fnal.gov/redmine/projects/larwirecell)

--- usage example

$ lar -n 1 -c RunRawDecoder.fcl np04_raw_run005141_0017_dl1.root

$ lar -n 1 -c nfsp.fcl np04_raw_run005141_0017_dl1_decode.root

$ lar -n 1 -c wcls-nf-sp.fcl np04_raw_run005141_0017_dl1_decode_reco.root # get output.root

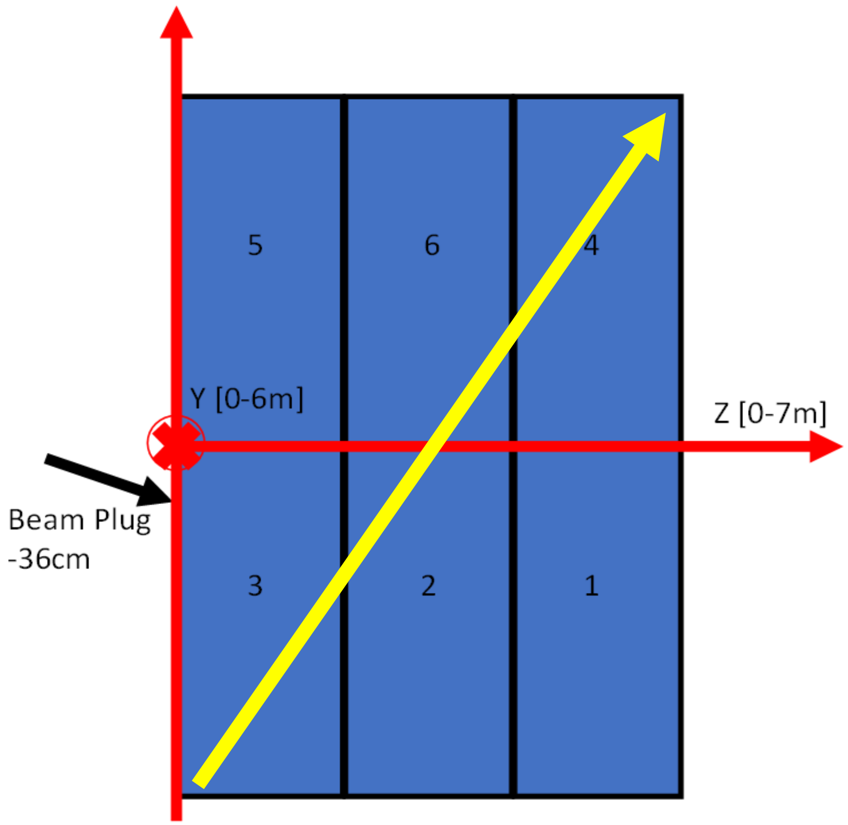
$ lar -n 1 -c eventdump.fcl output.root

nfsp.........	caldata.........	....	std::vector<recob::Wire>.......................	11648
nfsp.........	caldata.........	....	art::Assns<raw::RawDigit,recob::Wire,void>.....	11648
nfsp.........	TriggerResults..	....	art::TriggerResults............................	....-
wclsdatanfsp.	TriggerResults..	....	art::TriggerResults............................	....-
wclsdatanfsp.	nfspl1.........	wiener..............	std::vector<recob::Wire>.......................	15360
wclsdatanfsp.	nfspl1.........	gauss...............	std::vector<recob::Wire>.......................	15360

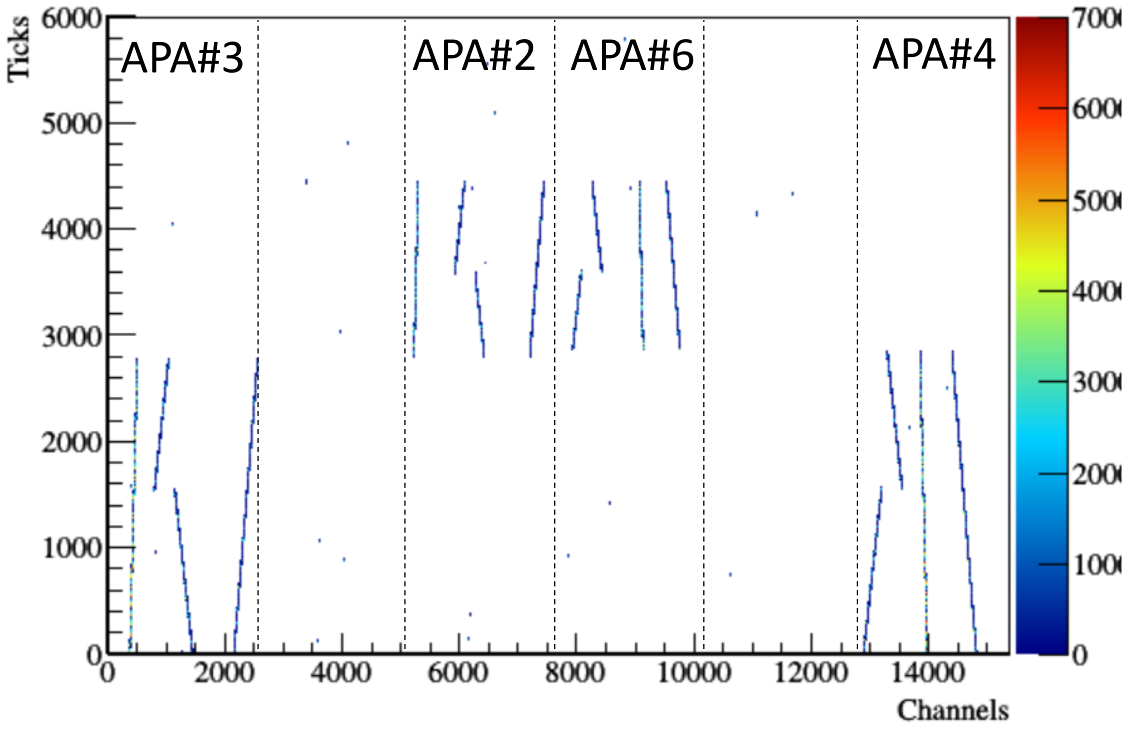
Two SP products with different software filters F(ω)

Upstream noise filtered raw waveforms from DataPrep module

SP performance test in a full TPC simulation



A MIP (~5000e/mm) track from bottom to top across the TPC



Full TPC includes:

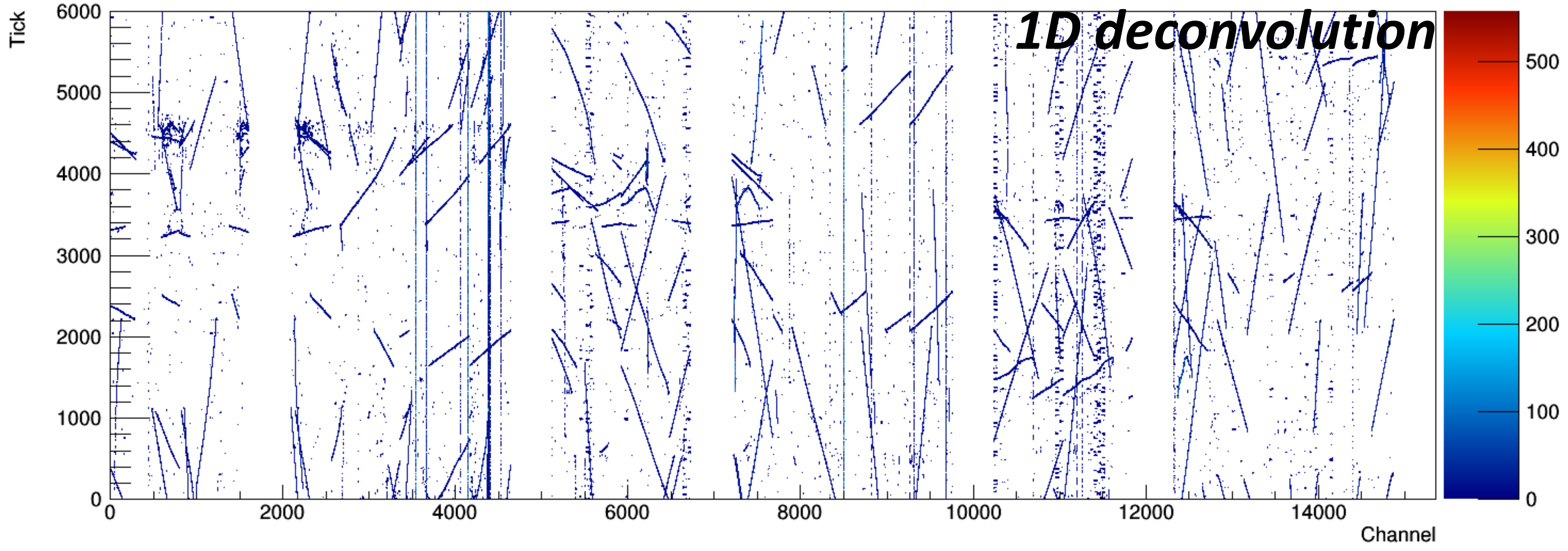
- Ionized electron absorption, diffusion, fluctuation
- Field response, electronics response, etc.
- Noise

Clear tracks from SP

Consistent with the channel map

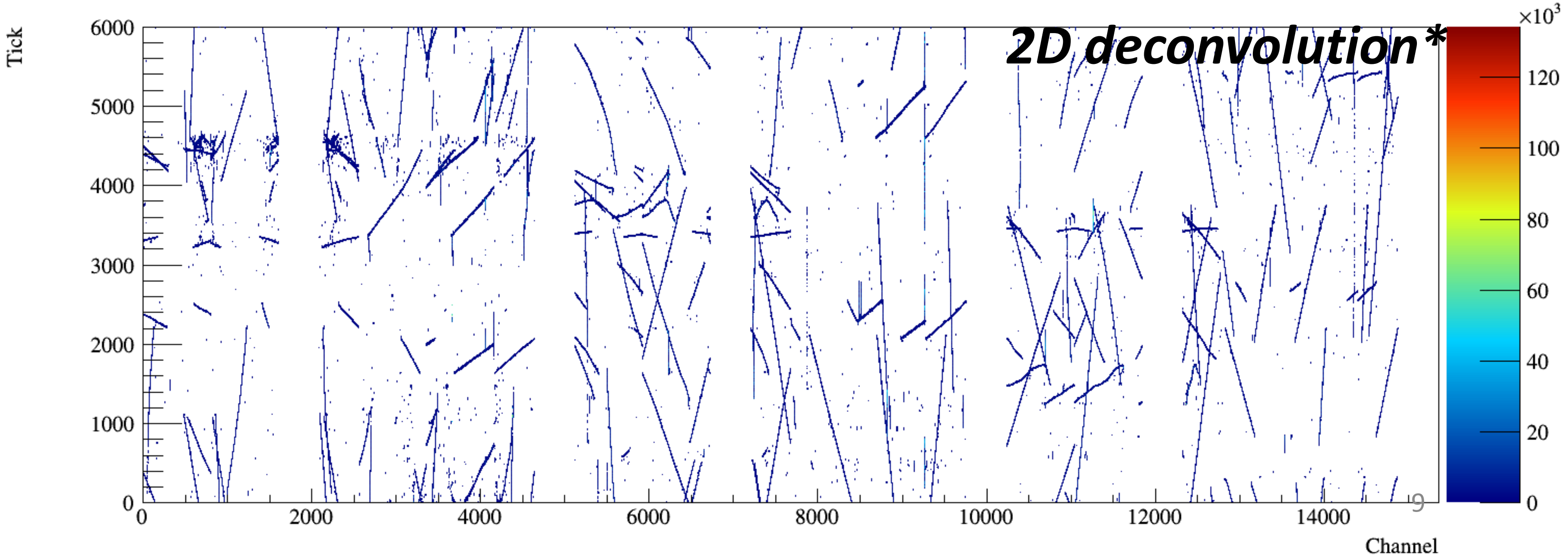
SP Performance in protoDUNE beam data

Run 5141, Event 23865
Threshold: 5
From the offline reco chain (protoDUNE_reco_data.fcl)

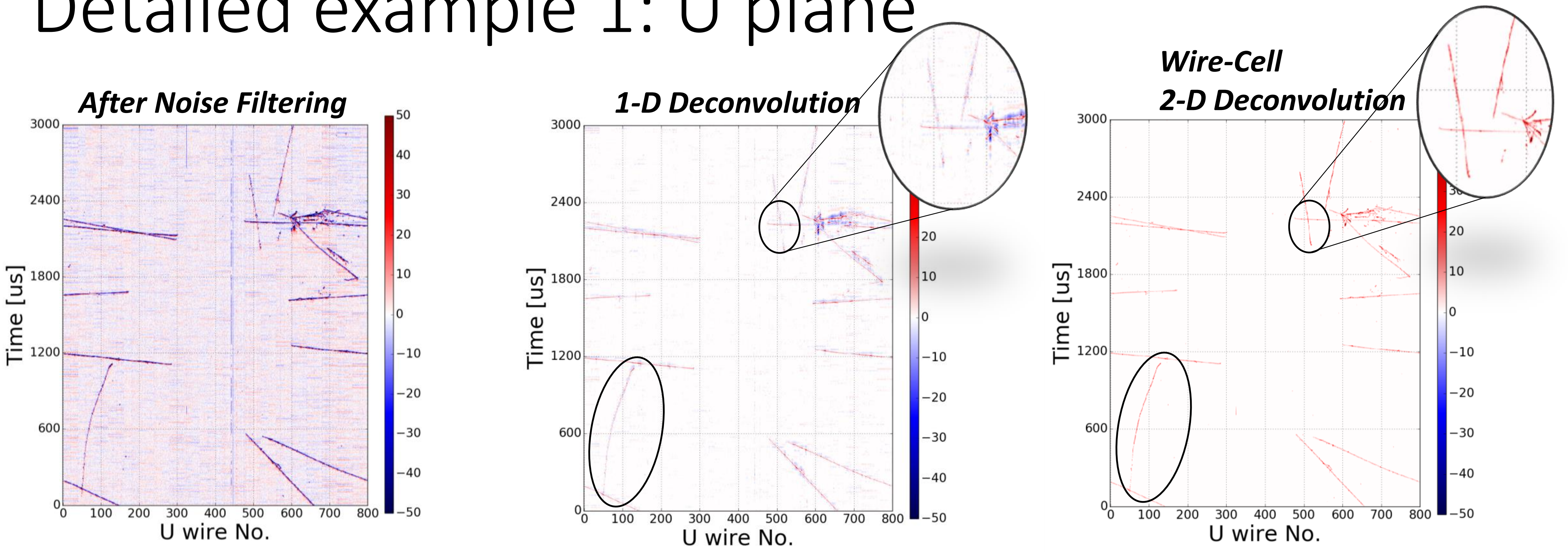


Run 5141, Event 23865
Threshold: 3σ noise
Unit: # of electrons
From Wire-Cell toolkit

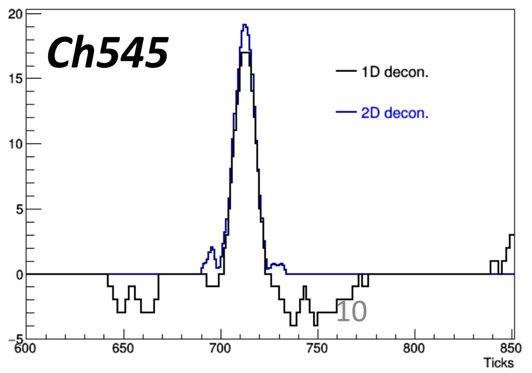
**: There is still room for improving the software filter and some thresholds, etc.*
***: Noise filtering has not been applied here for both 1D & 2D.*



Detailed example 1: U plane

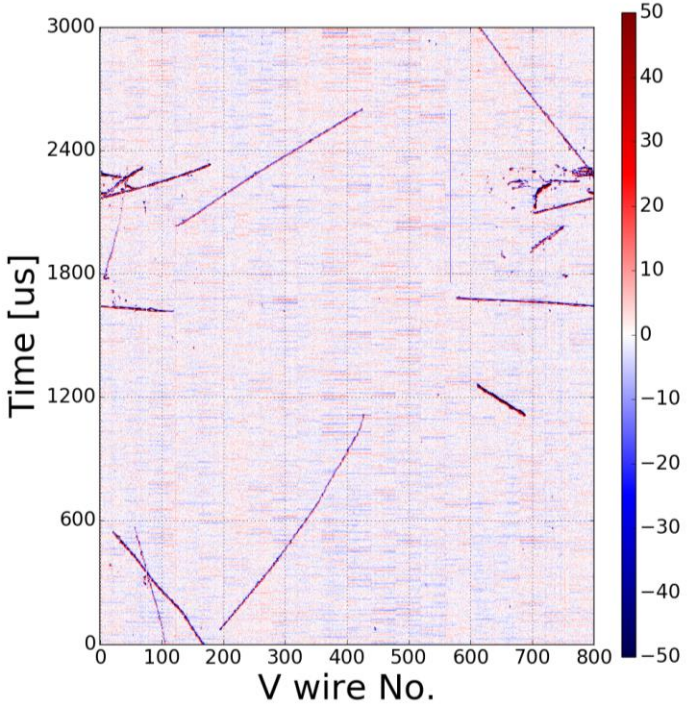


- Re-normalize 1D & 2D to the same scale
- No significant negative component after 2D deconvolution
- Long tracks (in time) are more visible in the 2D deconvolution

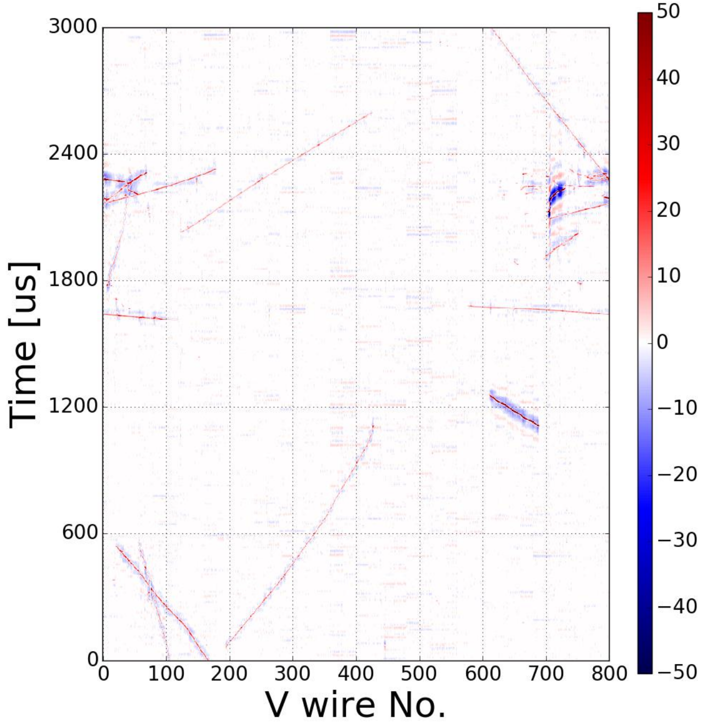


Example 2: V plane

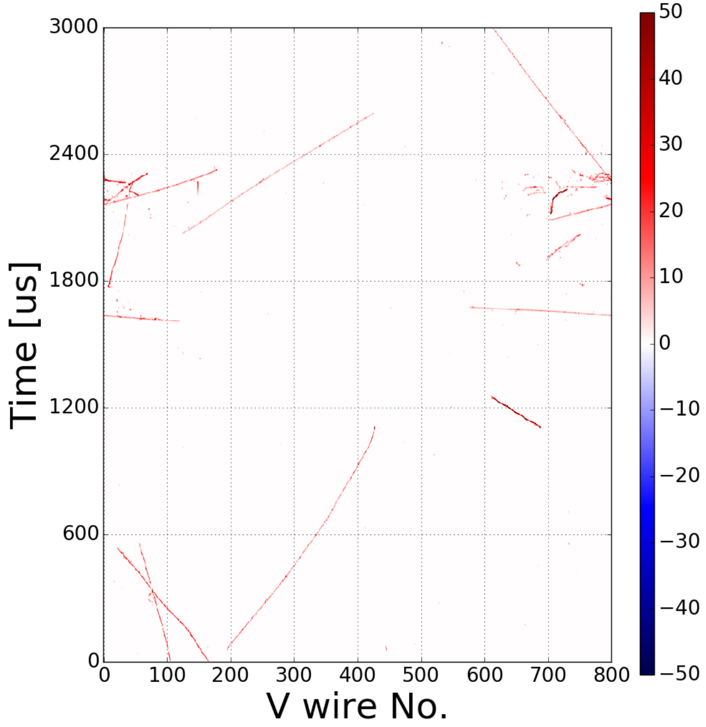
After Noise Filtering



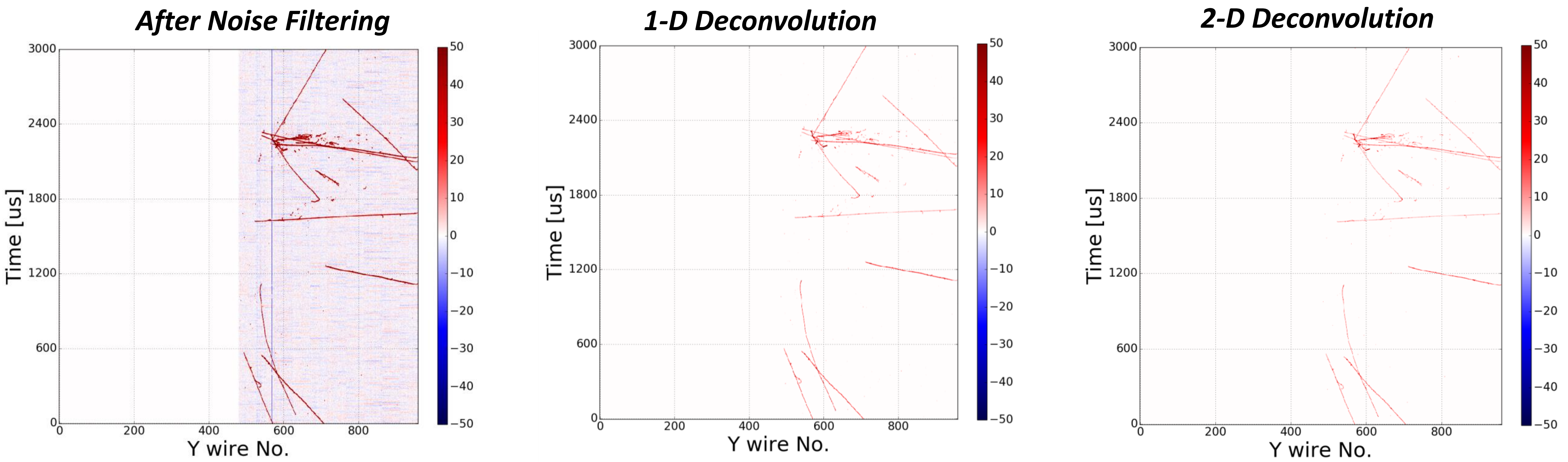
1-D Deconvolution



2-D Deconvolution

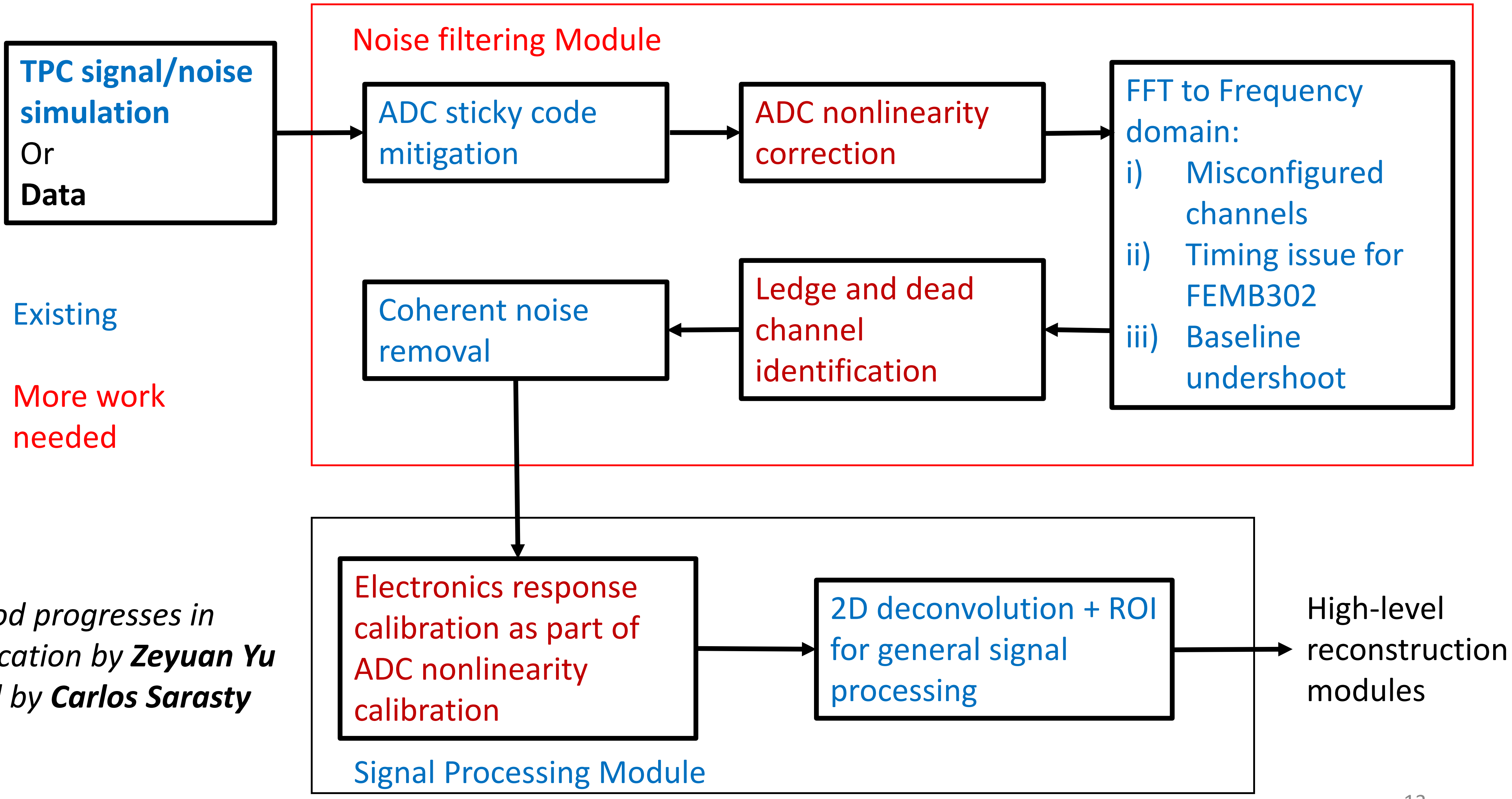


Example 3: W plane



- 1D & 2D deconvolution are consistent in collection plane

Other efforts from Wire-Cell team



Already have good progresses in

- *Ledge identification by **Zeyuan Yu***
- *Noisy channel by **Carlos Sarasty***

Summary

- With 2D deconvolution + ROI, Wire-Cell toolkit has successfully achieved the signal processing in protoDUNE
  - Still have some room for improving software filters, thresholds, etc.

- Wire-Cell toolkit has been integrated in the LArSoft via an interface module ***larwirecell***
  - Consumes the existing ADC mitigation in the reco chain for the December production

- More efforts will be made to improve the noise filtering and ADC problems in protoDUNE