Updates on Various TPC Signal-Related Software

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Cold Electronics

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Outline

Improved Simulation

3D Field Calculation

protoDUNE Data Reduction

Some needed simulation improvements

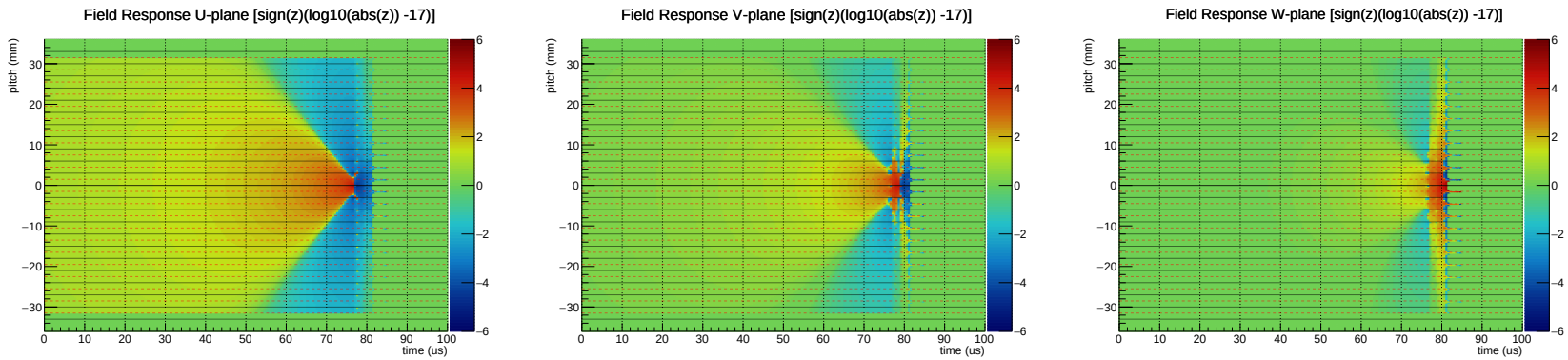
Current simulation (LArSoft) uses simplistic response model:

- Induces current on only nearest wire using single, average response function
  - (of course, one unique function for each plane).
- no long-range induction, no intra-wire variation as seen in MicroBooNE data.
- Some drift statistics also missing.

Improved 2D Field Response Calculation

New sim uses expanded Garfield 2D calculation (Yichen)

- Covers 21 wire-regions and 10 intra-wire "impact positions"
- Initial calculation uses MB's 3 mm pitch.
  - Will handle DUNE's mismatched planes by using average pitch.



Garfield 2D field response, 3 planes $\times$ 21 wires $\times$ 10 impact positions.
(color scale chosen to accentuate low fields)

$\longrightarrow$ Applied in Wire Cell Toolkit simulation package.
(`wire-cell-gen`)

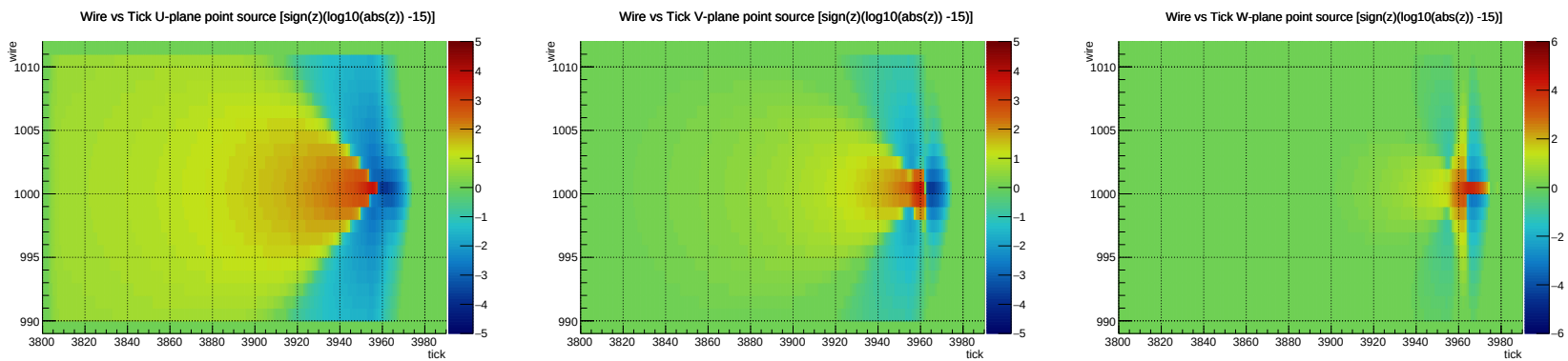
Simulation Challenges with Detailed Fields

Improved fields pose algorithm/memory challenges to sim.

- $21 \times 10 \times 3$ unique drift paths (instead of 3)
- Each Gaussian-diffused energy deposition must be binned to match: $5\,\mu s \times 0.3\,mm$ (MB)
- Naive convolution of charge distributions and detector response functions blows up RAM
  - optimization by Xiaoyue and Xin plus a just-in-time diffusion binning keeps RAM usage in check.
- And, one detail: even at the fine inter-impact-position scale, we still must interpolate each tiny element of drifting charge to the **two** nearby field-response drift paths in order to avoid causing fake peaks in induction-plane signal shapes due to binning/aliasing effects.

Wire Cell Simulation Status

- Uses the new **broad** and **detailed** 2D Garfield fields.
- The core convolution of diffuse charge and response functions is done.
- "Outer code edges" still under construction:
  - File I/O, configuration, LArSoft Module/Service/Tool integration.
- Need to add MicroBooNE's and Milind's noise models.
- Validation effort needed and just starting.



Digitized signals on wires from test-point source:
drifted, diffused and convoluted with field+electronics response functions.
(color scale chosen to accentuate low signals)

3D Field Calculation

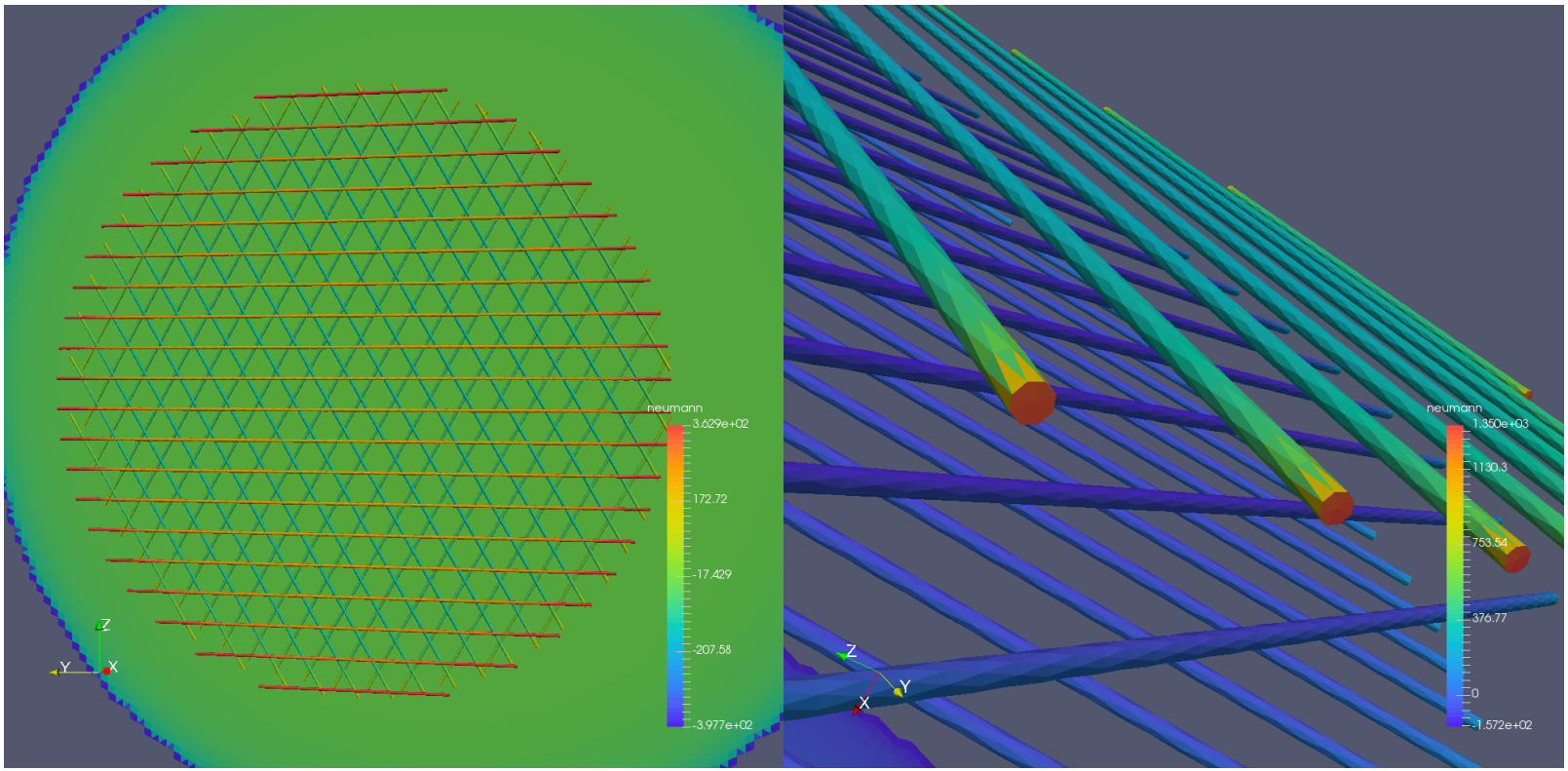
- Garfield uses FEM
  - FEM's CPU and RAM requirements scale with the "volume" of the problem.
  - Challenging but possible to scale 2D to few cm.
  - "Impossible"[1] to do 3D to at that scale.
  - Leon Rochester @ SLAC is braving this challenge with custom FEM code.
- Boundary Element Method (BEM) solves some problems
  - CPU/RAM requirements scale with **surface** instead of volume.
  - After surface boundary conditions calculated, can calculate fields at arbitrary locations.
  - Challenges: fewer software implementations (compared to FEM), DIY geometry/meshing, user exposed to difficult math/algorithm concepts.
- Applying it to LArTPC
  - LARF (using BEM++ library) handles wire geometry, applies BEM, pipeline job management and result data bookkeeping.
  - Able to calculate fields covering same 3D volume as new Garfield 2D.
  - Still requires substantial RAM+CPU (my new workstation will help!)
  - Newest BEM++ version supports MPI but yet to try this.

[1] Hearing this is what got me started to work on field calculations.

Some 3D Field Calculation Results

Now, flash through some slides from:
DUNE Collab mtg 2016-09-12

Boundary Conditions

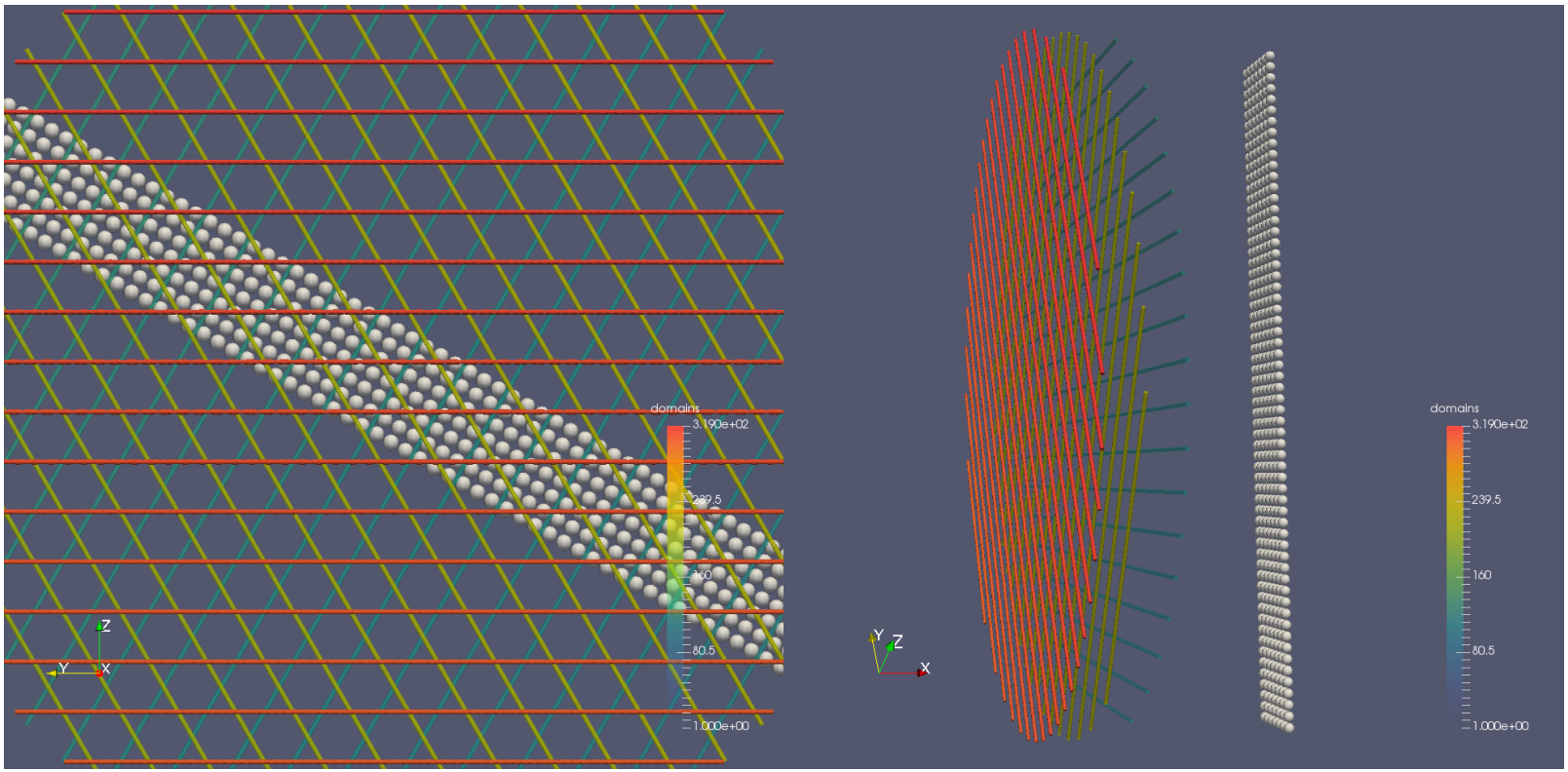


Color is Neumann b.c. Note, color scaled to show edge effects.

- Apply scalar potential (Dirichlet) boundary conditions.
- BEM solves for $|\hat{n} \cdot \vec{E}_{drift}|$ (Neumann) boundary conditions.
  - $\rightarrow$ once solved, can evaluate potential anywhere in space.

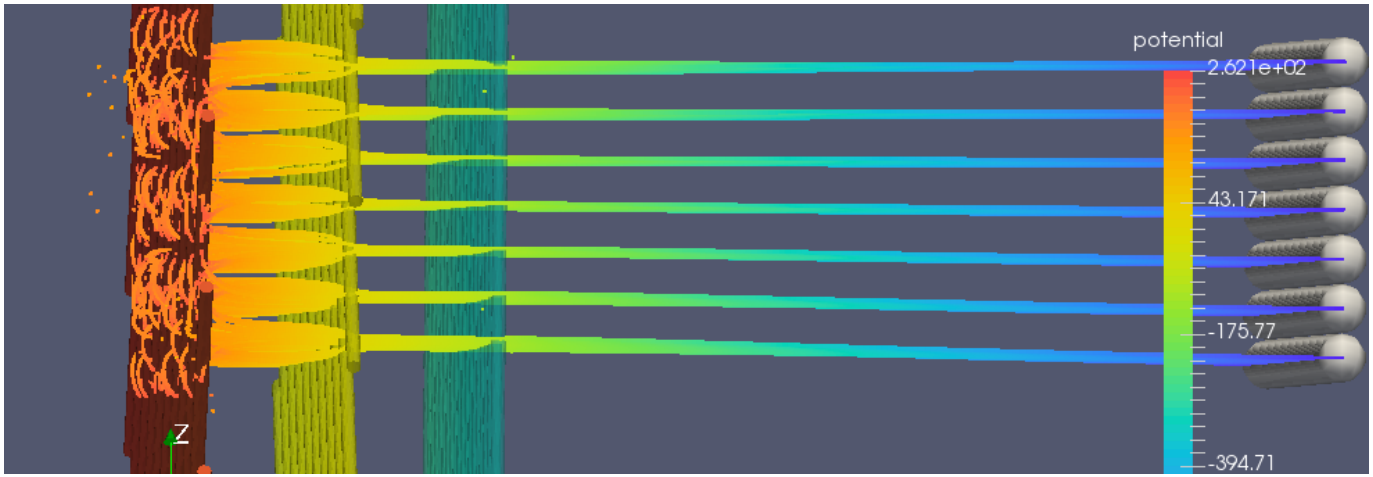
$\Rightarrow$ Finite sized geometry leads to **unwanted edge effects**. More on this later.

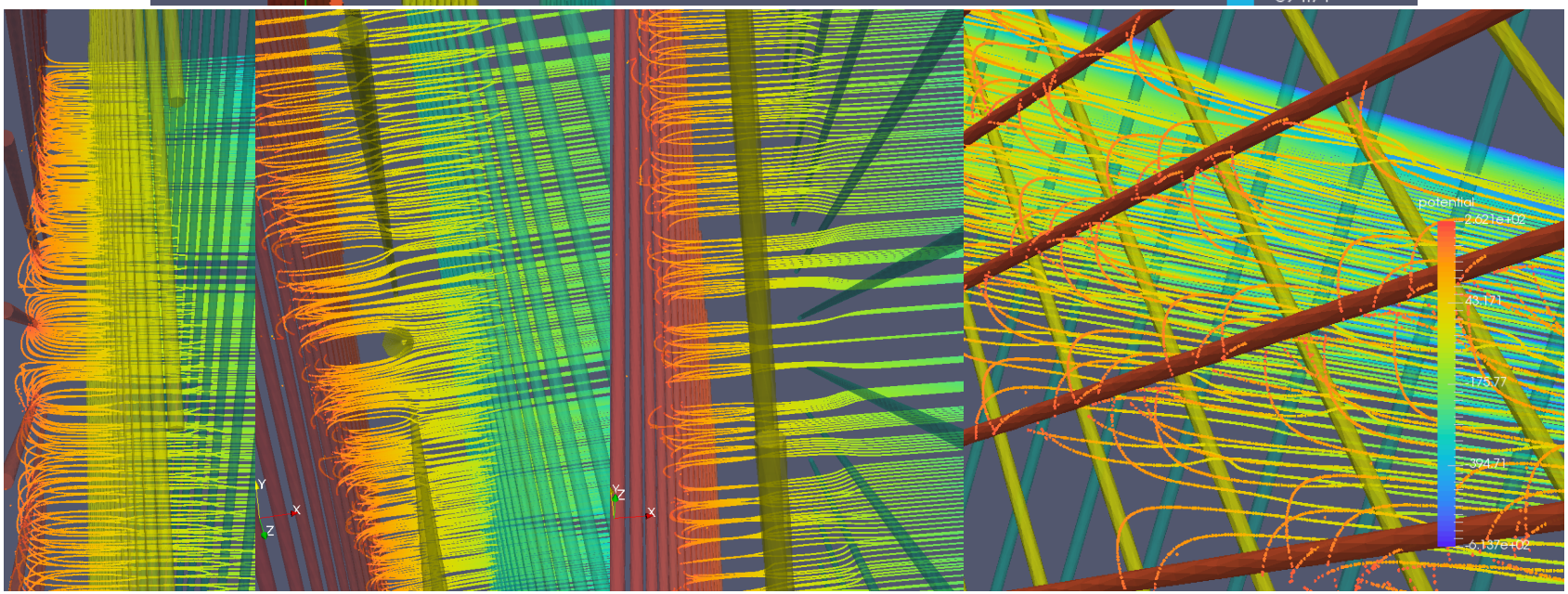
Path Starting Points



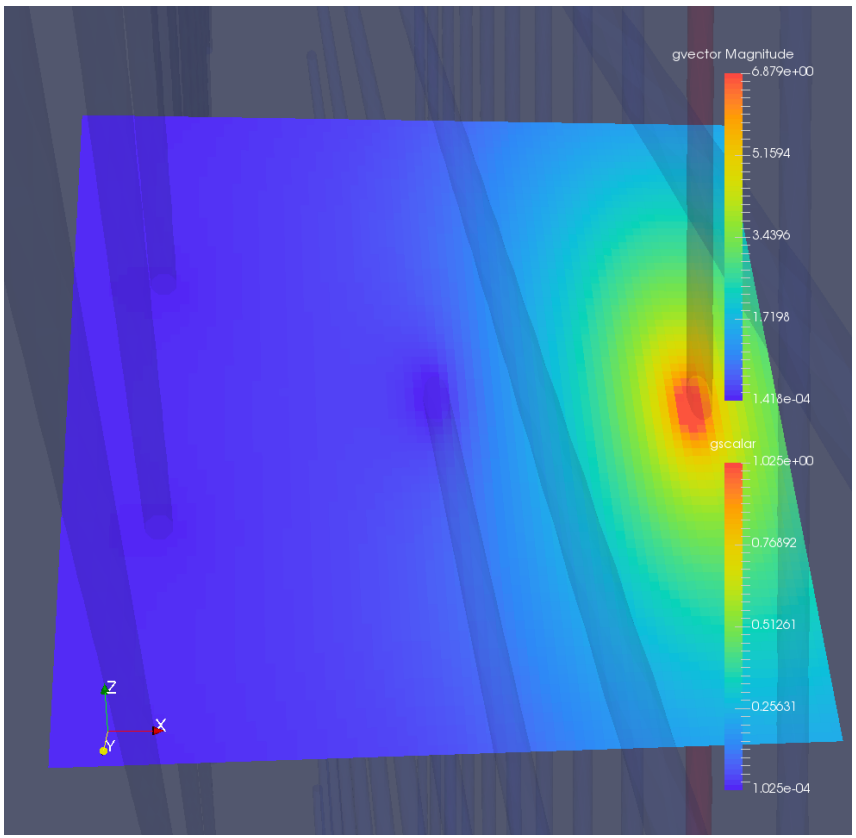
- Generate starting points for drift paths.
- Various possible schemes, this one aligns with central U-wire.
  - → spans ∼2 periods of crossing pattern in longitudinal direction.
  - → spans ±9 transverse wire regions in addition to central region.
    - Turns out, this is relatively coarse. More on this later.

Drift Path Visualizations

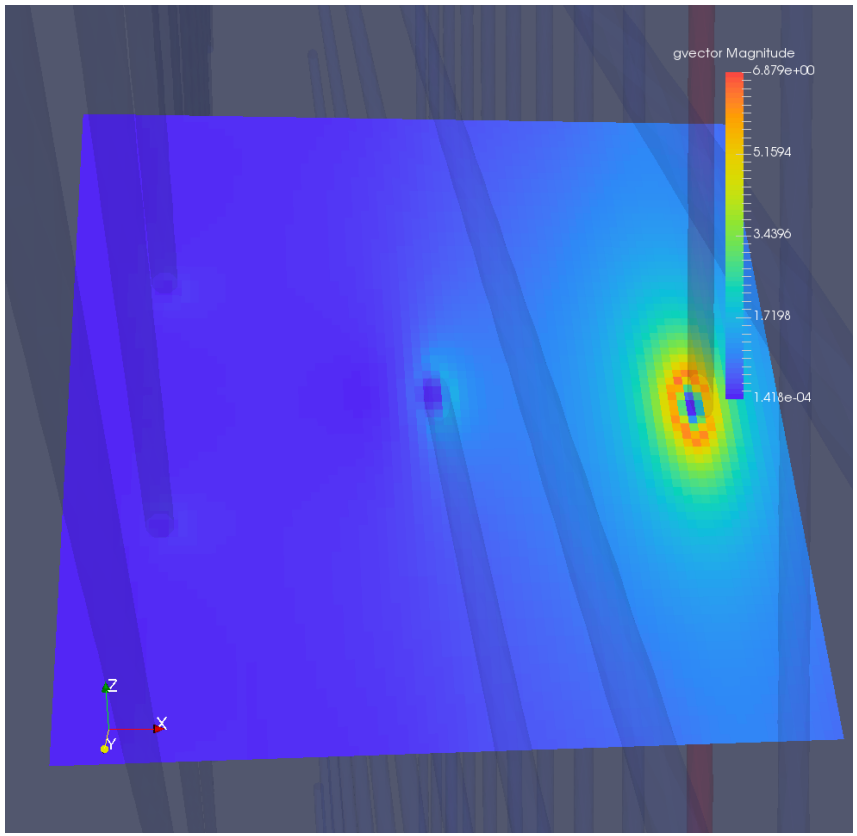




Weighting Field for U-wire



Weighting **potential**.

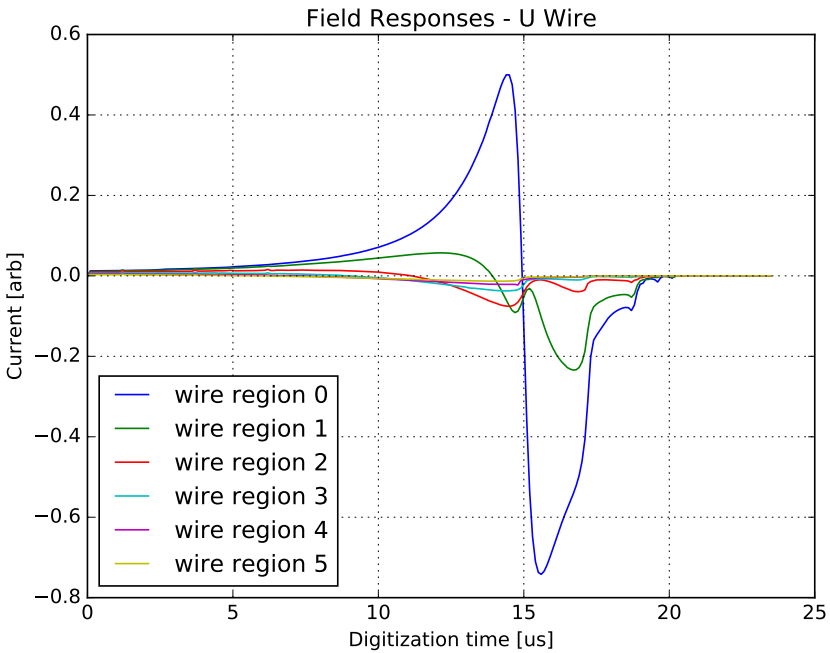


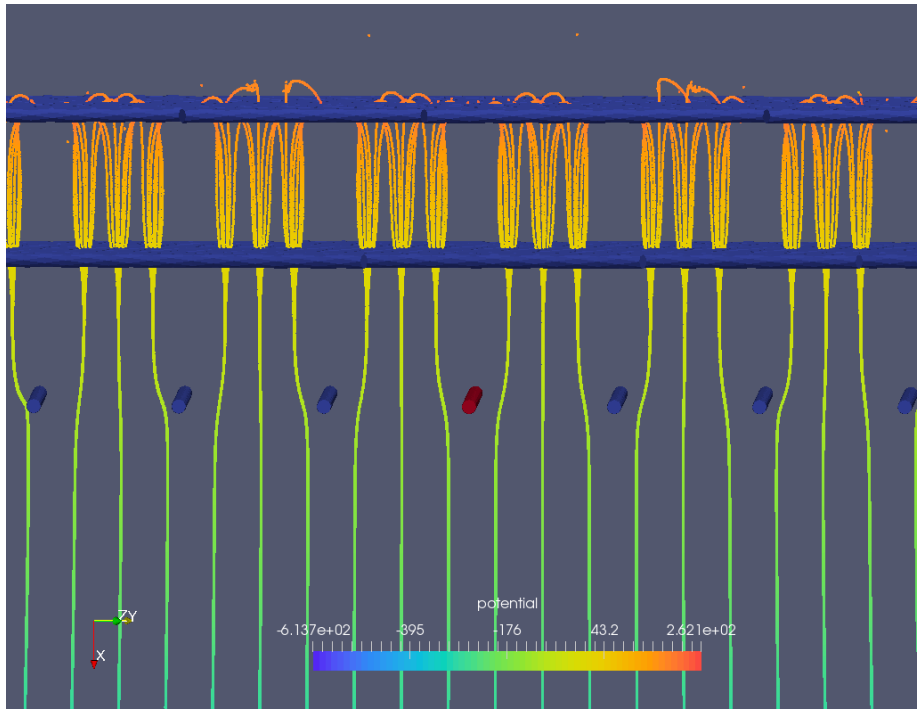
Weighting **field magnitude** ($|\vec{E}_{weight}|$).

- View is zoomed in to the inter-plane region, wires partially transparent.
- Reminder: this field is next sampled along drift paths to finally get current.

$$I_i = q * \vec{v} \cdot \vec{E}_{weight,i}$$

Response Functions - U-Wire

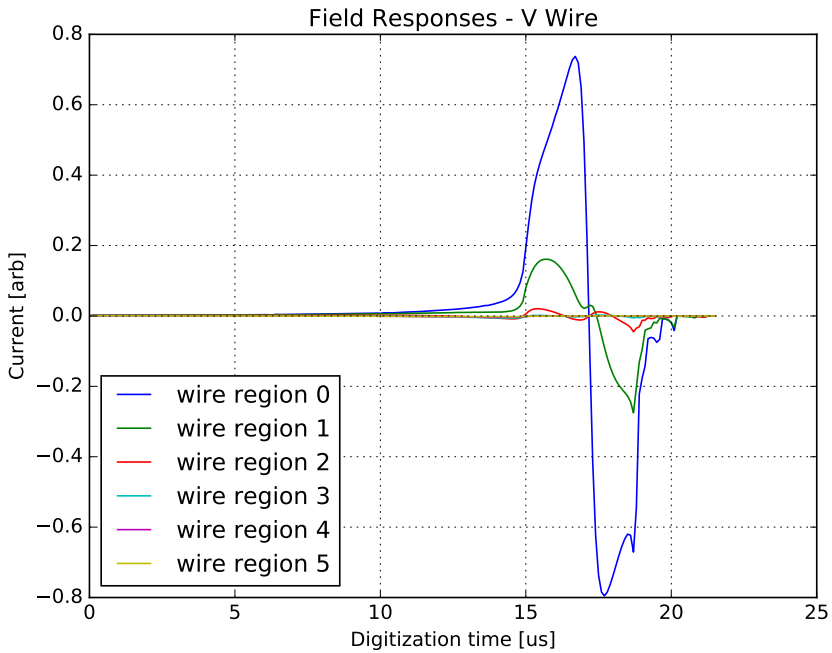


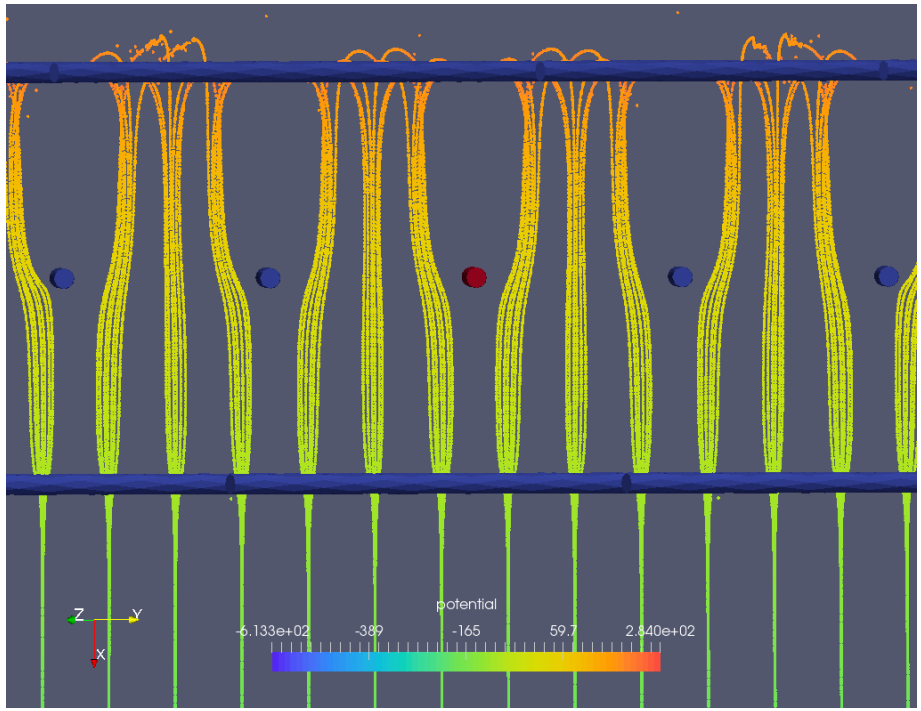


Average over 3mm in longitudinal direction and paths w/in $\pm$1.5mm of wire.

- Wire region 0 is $\pm$1.5mm around central U-wire.
- Wire regions 1-5 progressively further in transverse direction.
- Wire regions 6-9 not shown here.

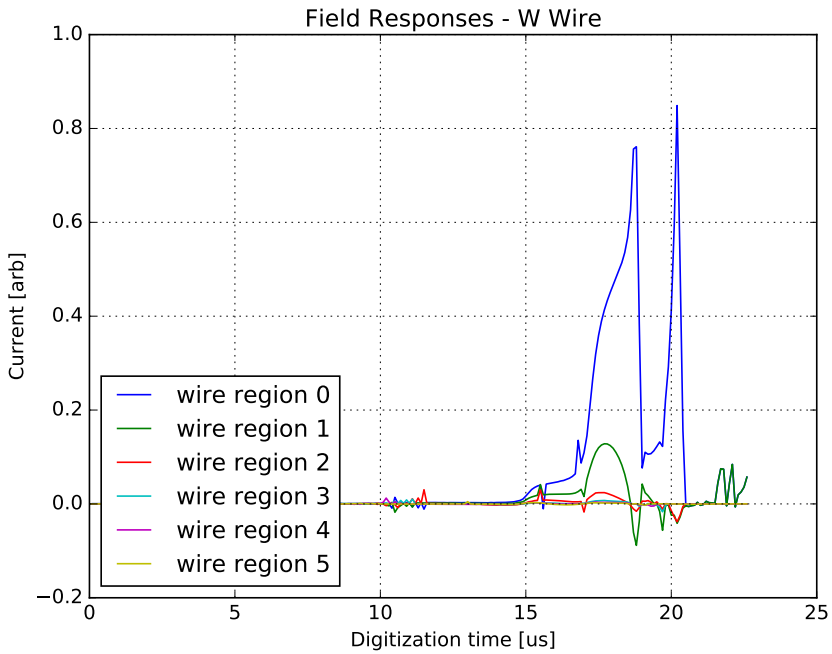
Response Functions - V-Wire

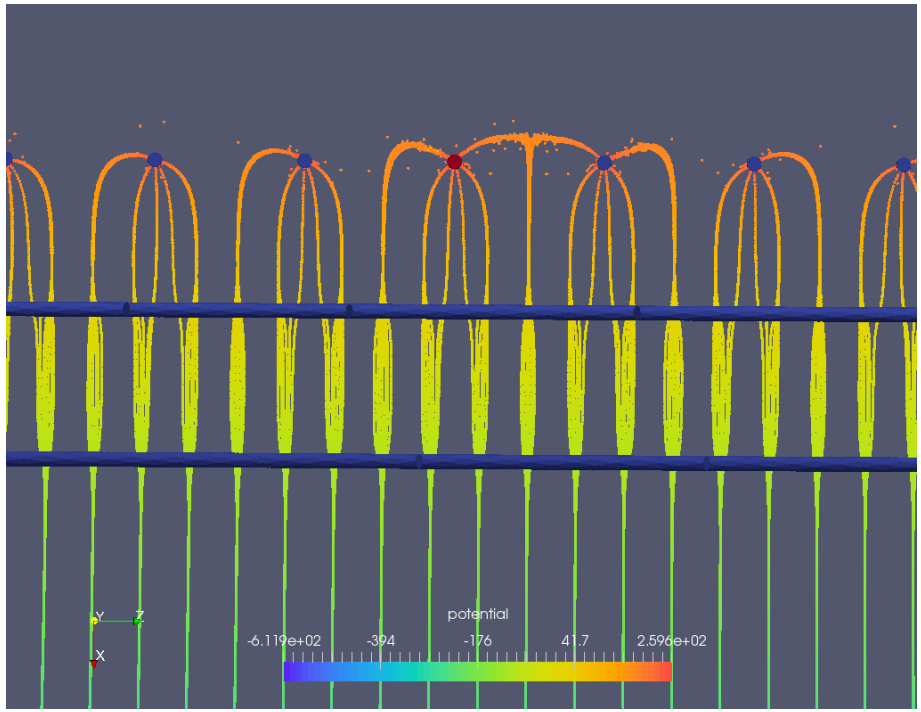




- Some end-of-track jaggies need checking,
  - maybe be due to paths on a "lucky" line of symmetry.
  - more severe example in W-wire.

Response Functions - W-Wire





- One set of paths precisely on line of symmetry take an extra-long time.
  - $\Rightarrow$ Need to fill in phase space with more intermediate paths.
- Non-unipolar signals from charge in wire region ≥ 1

Now, back to your regularly scheduled presentation already in progress.

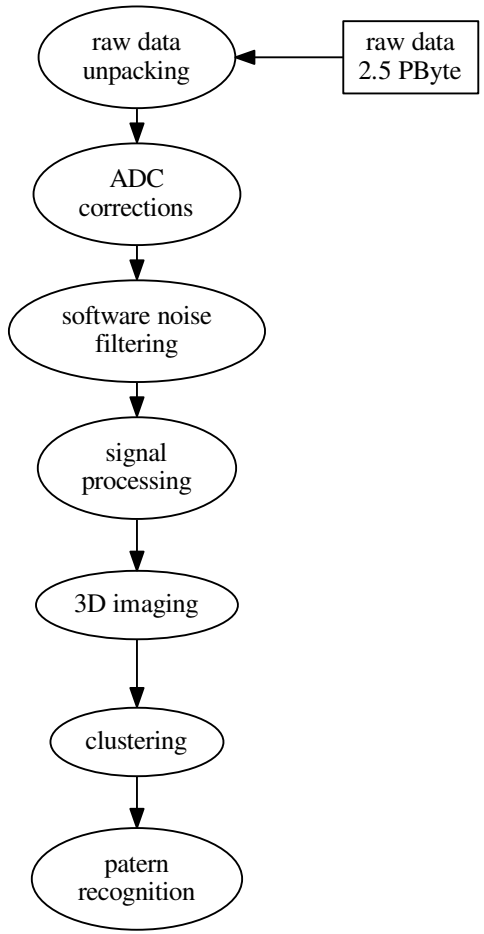
Future of 3D Field Calculations

Plans for and challenges with 3D Fields

- 3D field calculations on hold to finish WC Simulation work.
- Will use 3D fields as "next to leading order" validation of 2D field calculations.
  - Initial tests will be done w/out full simulation code.
  - If similar: will stick with 2D for simplicity, speed.
  - If different: must bite-the-bullet and implement full simulation code.
- Simulation w/3D fields is more challenging than w/2D:
  - Must define a replicatable "region of uniqueness" in which to calculate field drift paths:
    - $\rightarrow$ Triangle of $\sim$ 1 pitch for MicroBooNE,
    - $\rightarrow$ Polygon of $\sim$ 6 pitches for DUNE, 36$\times$ more!
  - The 630 2D field response functions $\rightarrow\sim 10^5$ for same impact distance!
    - Like 2D, some symmetries reduce this, but they are difficult to figure out.
  - Bookkeeping for convolution with diffused/drifted charge much more complex.

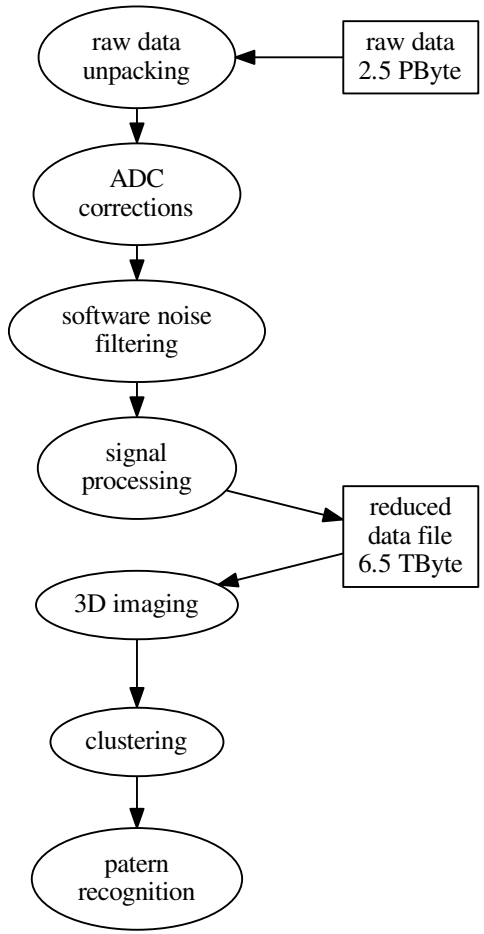
protoDUNE Data Reduction Concept

Basic idea:
Instead of shipping the full
2.5 PBytes to the grid for full,
CPU-heavy data processing.



protoDUNE Data Reduction Concept

Basic idea:
Run initial, CPU-light processing and save intermediate output of **6.5 TBytes** and ship that.



protoDUNE Data Reduction Details

Some details:

- protoDUNE/SP TPC is expected to produce 2.5 PByte of compressed raw data.
- Better than 400$\times$ reduction gives 6.5 TByte output.
- First 20% of the production processing CPU goes to:
  - ADC stuck code and nonlinearity corrections
  - Software noise filtering (if any is indeed needed)
  - Signal processing (detector response deconvolution, signal-ROI selection)
- It is signal processing that enables this reduction.
  - $\rightarrow$ All the FFTs require about 4000 CPU-cores to keep up with $\sim$ 1GByte/sec data stream.
- Note: data reduction is separate from "prompt processing".

Efficacy and Validation of Data Reduction

- Data reduction preserves all signal information.
  - Waveform segments consistent with **noise are removed** by signal-ROI selection. This step is to be done regardless.
  - Most of the oversampling is reclaimed by 3× rebinning, **stops short of Nyquist limit** (150× reduction w/out rebinning).
  - Remaining efficacy comes from packing and ROOT compression.
- Efficacy estimated using MicroBooNE data:
  - With MB excess noise: can achieve assumed 4× raw compression
  - Quiet protoDUNE should achieve 6× – 8× compression
  - Scale MB channel count to protoDUNE's
  - Use nominal protoDUNE 25 Hz spill-trigger + 1-for-1 out-of-spill cosmic triggers.
- Will redo estimates with new Wire Cell simulation.
  - Validate extrapolation from MicroBooNE data.
  - Look at efficacy as function of inherent and excess noise models.
  - Develop full-featured packing scheme.
  - Validate rebinning (although, I believe Nyquist).

Summary

- An improved drift and detector response simulation is being developed.
- It relies on broad and detailed 2D field response calculations.
- A plan to validate using 3D field response calculations exists.
- Saving protoDUNE data after signal processing produces a 400$\times$ data reduction factor which will enable efficient feeding of CPU-hungry reconstruction as well as general data sharing to the collaboration.