Brief Introduction to Wire-Cell

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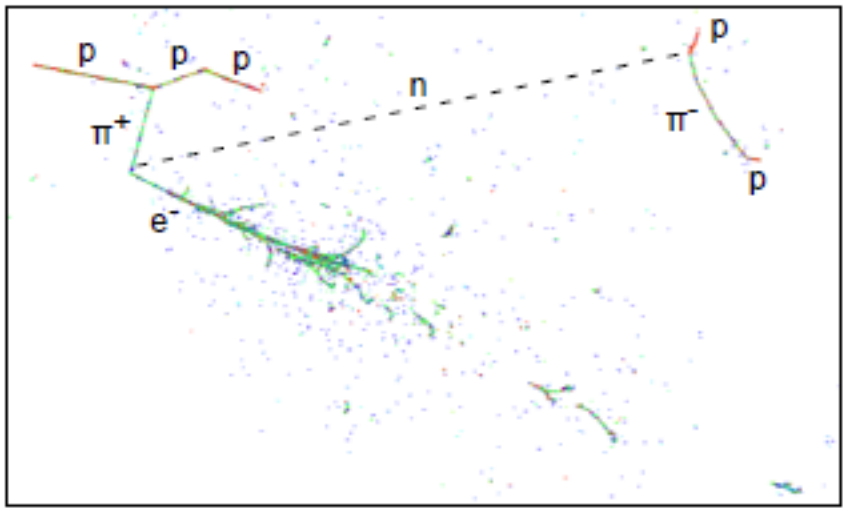
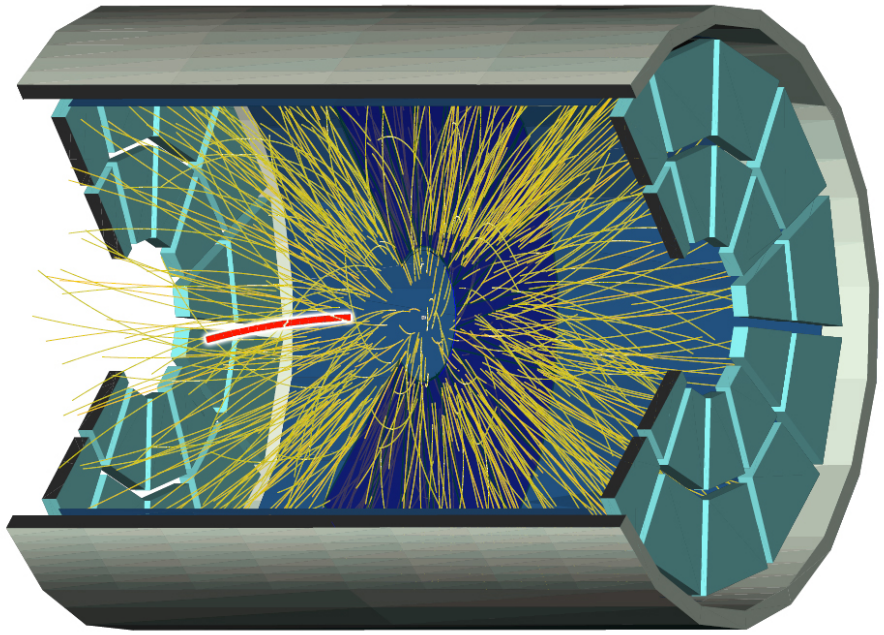
http://www.phy.bnl.gov/wire-cell/

Challenges of Event Reconstruction in LArTPCs

- Event topology:
  - Tracks, showers, unknown vertex in LArTPCs
  - Simple tracks in collider's gas TPCs

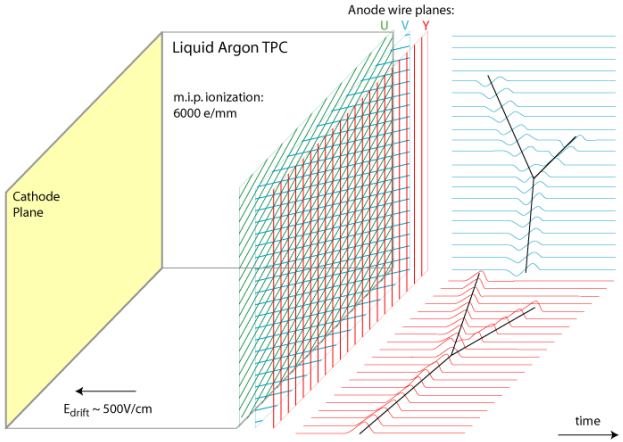


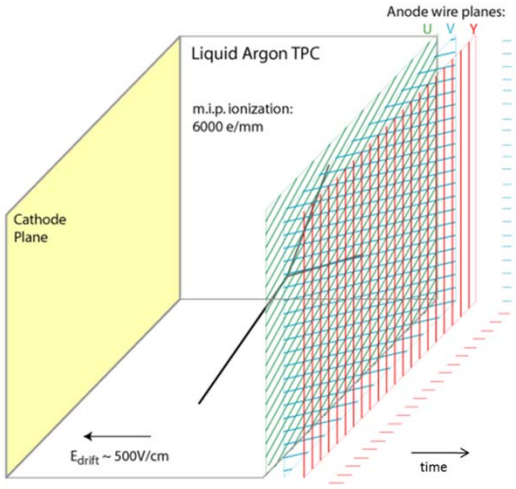


- Wire vs. Pixel readout
  - Large LArTPCs has to use wire readout due to **power consumption** of electronics and **costs**
  - Puedo-3D detector

Review of Existing Approaches

2D matching → 3D





Wire-Cell Approach

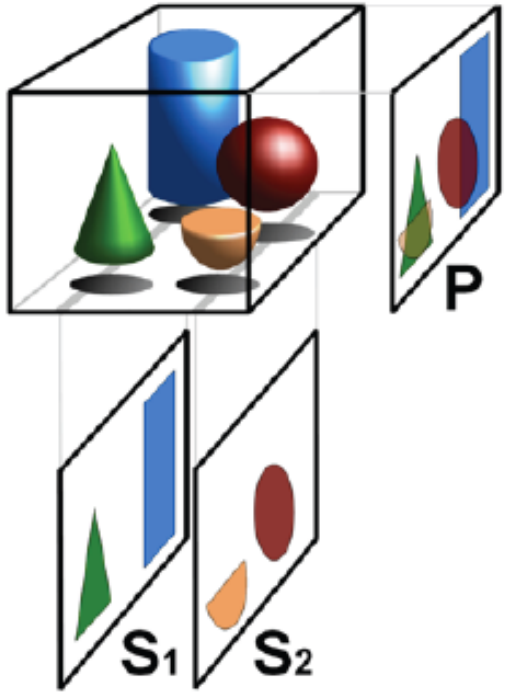
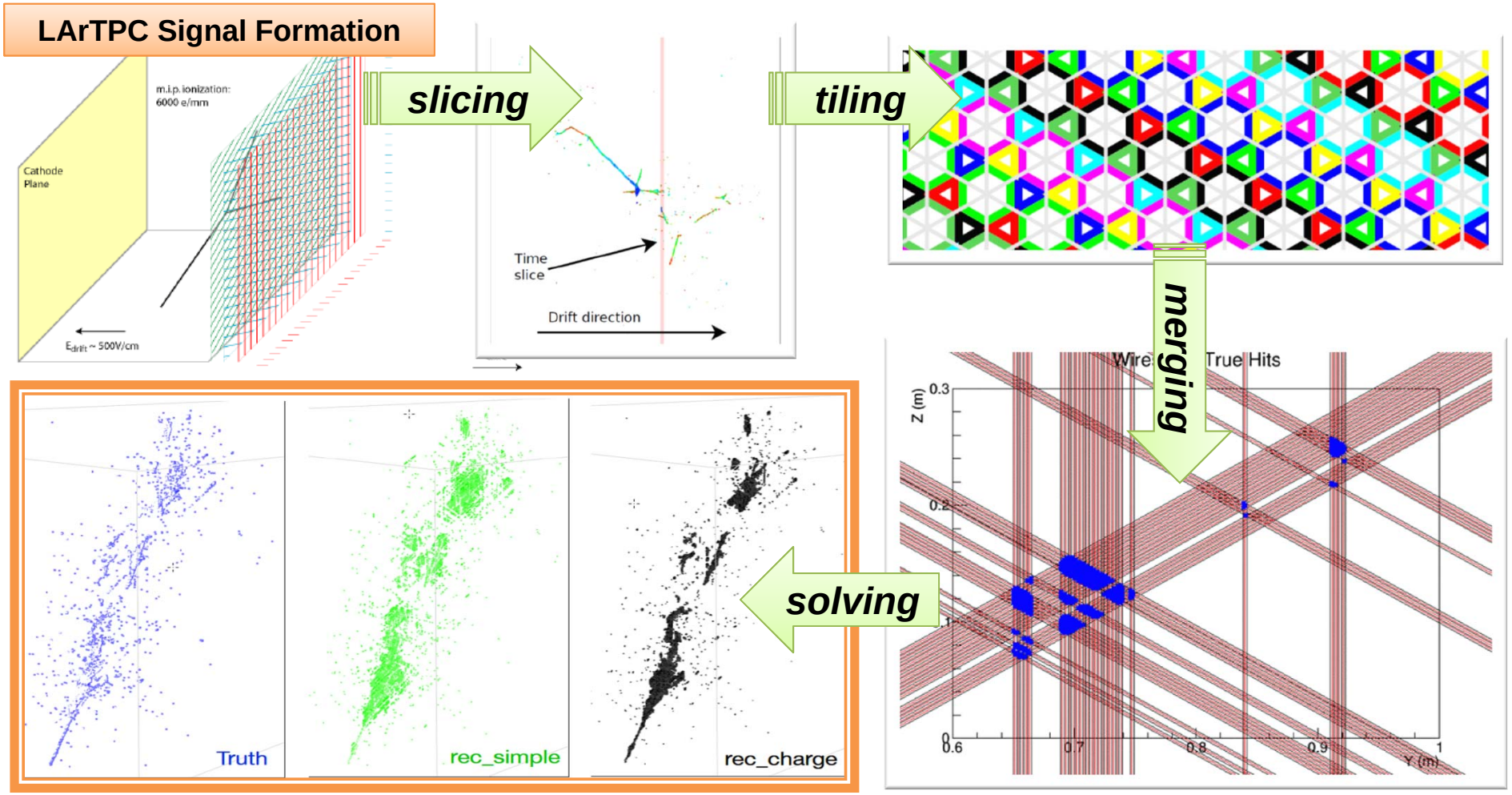


Fig.1:Basic principle of tomography: superposition free tomographic cross sections S1 and S2 compared with the projected image P

https://en.wikipedia.org/wiki/Tomography

Wire-Cell Imaging

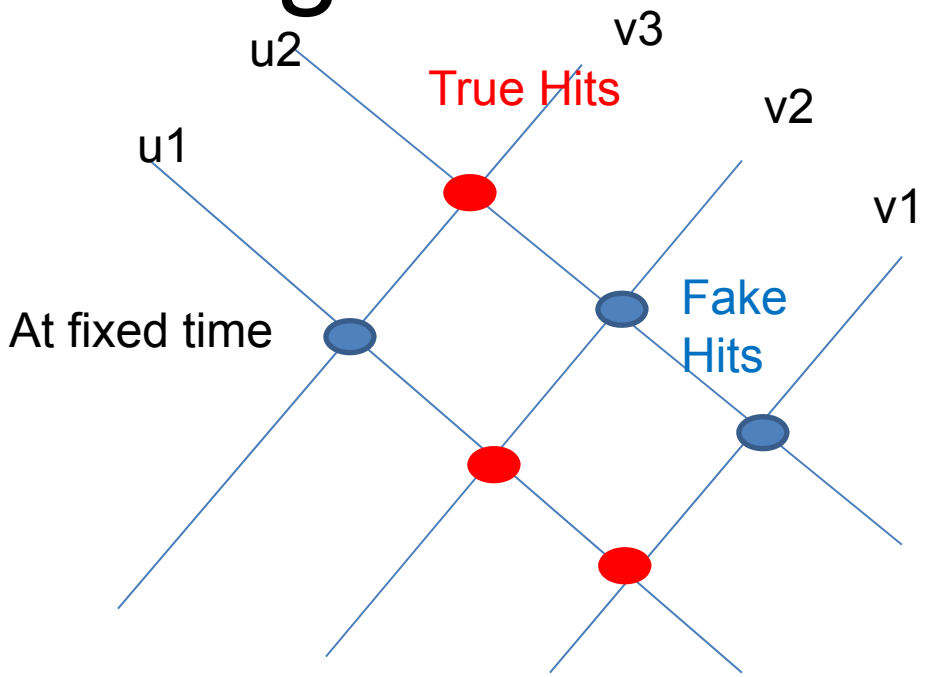


Solving for Images

$$\chi^2 = (\mathrm{B}\cdot \mathrm{W} - G\cdot C)^T V_{BW}^{-1} (\mathrm{B}\cdot \mathrm{W} - G\cdot C)$$

$$\frac{\partial \chi^2}{\partial C} = 0 \rightarrow C = (\mathrm{G}^T V_{BW}^{-1} \mathrm{G})^{-1} G^T V_{BW}^{-1} BW$$

- C: charge in each (merged) cell
- G: Geometry matrix connecting cells and wires
- W: charge in each single wire
- B: Geometry matrix connecting merged wires and single wires
- V_{BW}: Covariance matrix describing uncertainty in wire charge



- Use two-plane as an example
- Red points are true hits
- Blue ones are fake hits

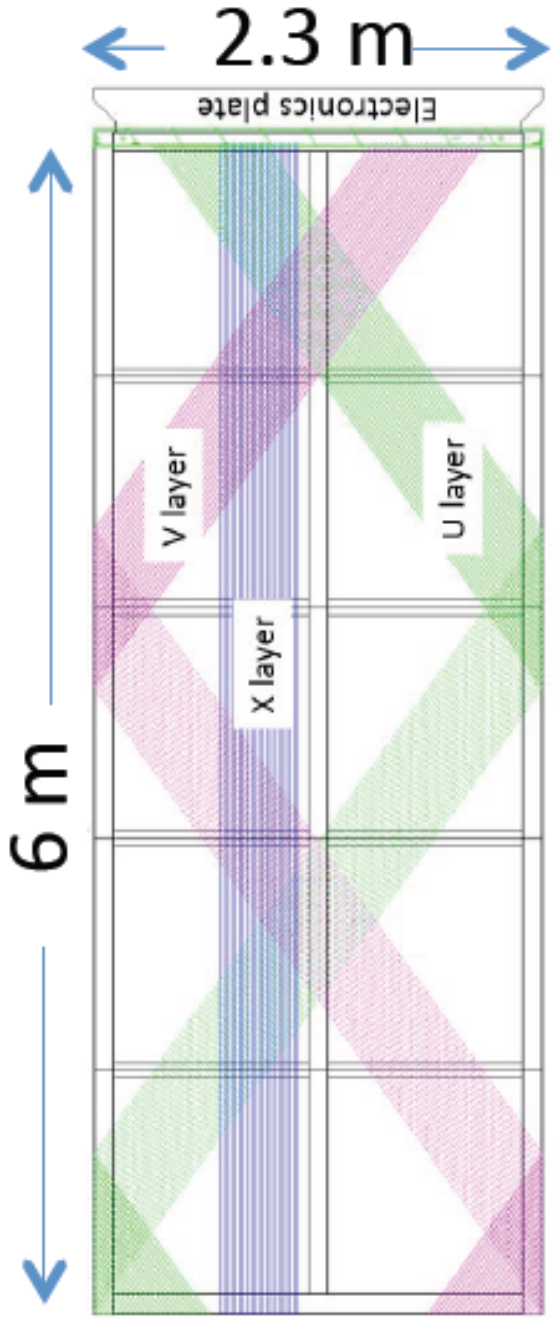
$$W = G\cdot C$$

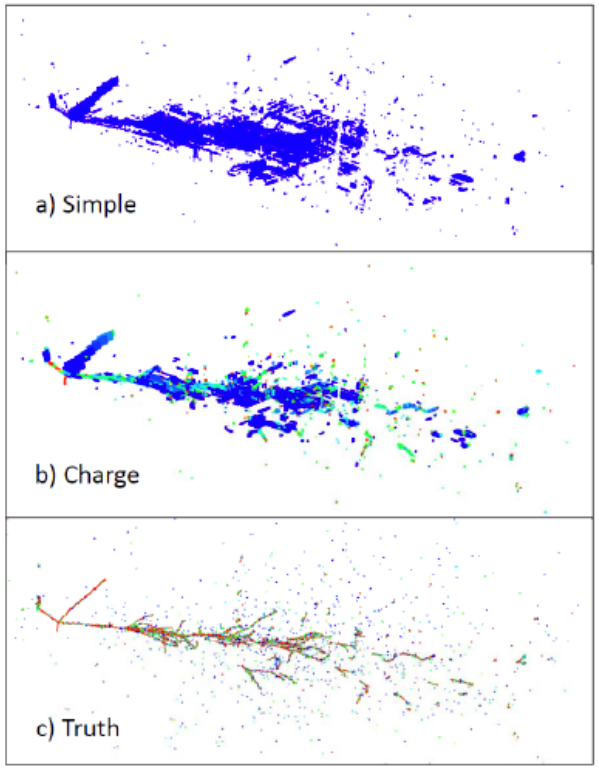
Same formulism for DUNE Wrapped Wire

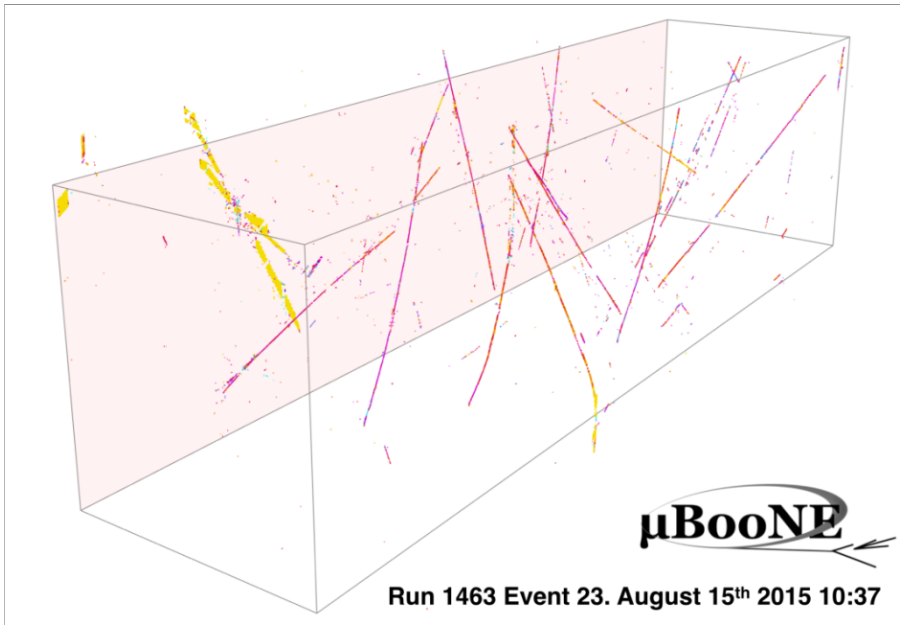
$$\chi^2 = (\mathrm{B}\cdot\mathrm{W} - G\cdot C)^T V_{BW}^{-1} (\mathrm{B}\cdot\mathrm{W} - G\cdot C)$$

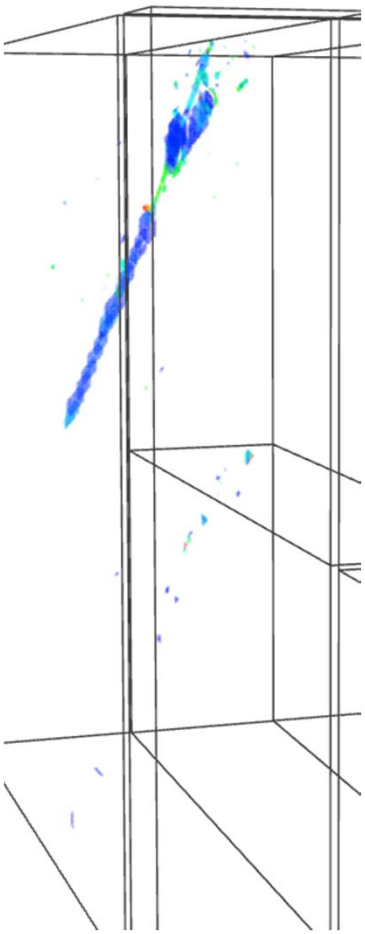
$$C = (\mathrm{G}^T V_{BW}^{-1} \mathrm{G})^{-1} G^T V_{BW}^{-1} BW$$

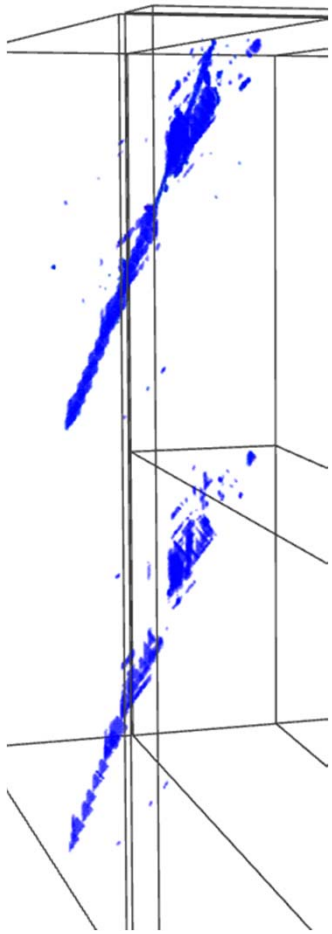
- C: charge in each (merged) cell
- G: Geometry matrix connecting cells and **channels**
- W: charge in each single **channel**
- B: Geometry matrix connecting merged **channels** and single **channels**
- V_{BW}: Covariance matrix describing uncertainty in **channel** charge











With Charge Without Charge

More 3D events can be found at http://www.phy.bnl.gov/wire-cell/bee/
Bee: interactive 3D display (Chao Zhang)

The Usage of Connectivity

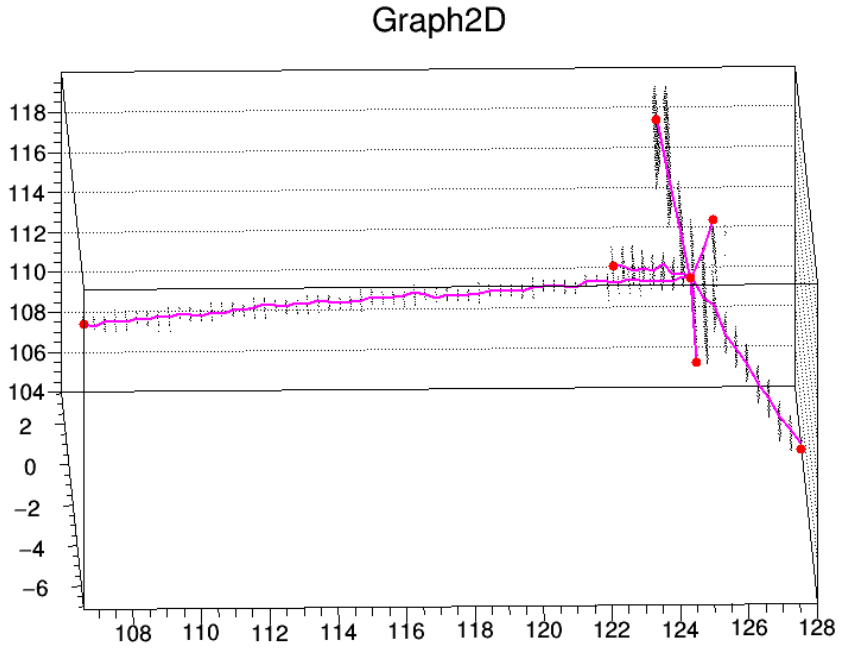
- We can add penalty to χ^2 based on connectivity and single channel assumption
  - For example, if we remove a merged cell that are connected to good cells in the adjacent time slice, we can add penalty in χ^2 to increase the chi-square value → less chance to be chosen as the optimal solution

- For later pattern recognition, we can also cluster with all merged cell, and then remove bad ones taking into account connectivity

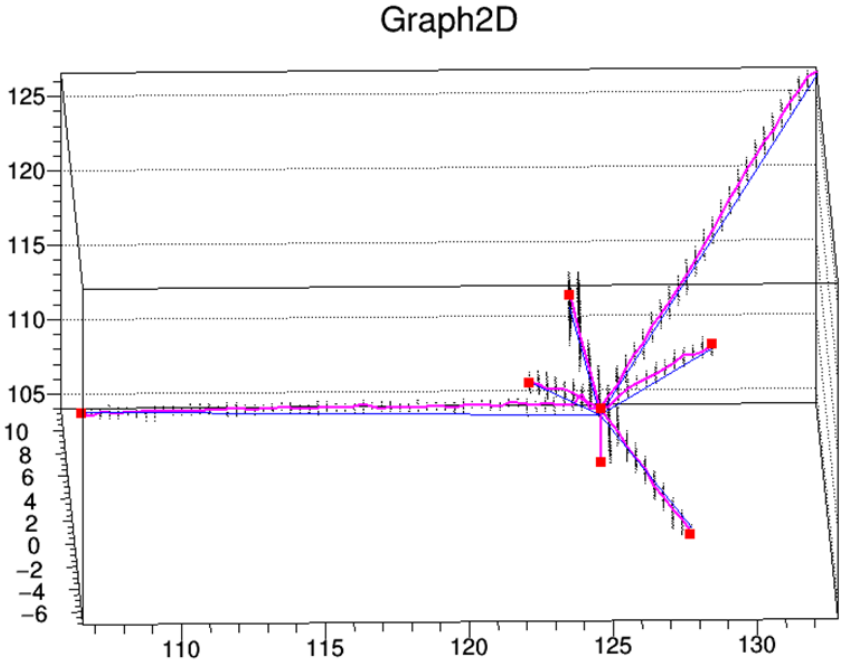
Connectivity information

- Use the connectivity information to choose the optimal imaging solution
  - Penalty term added in chisquare

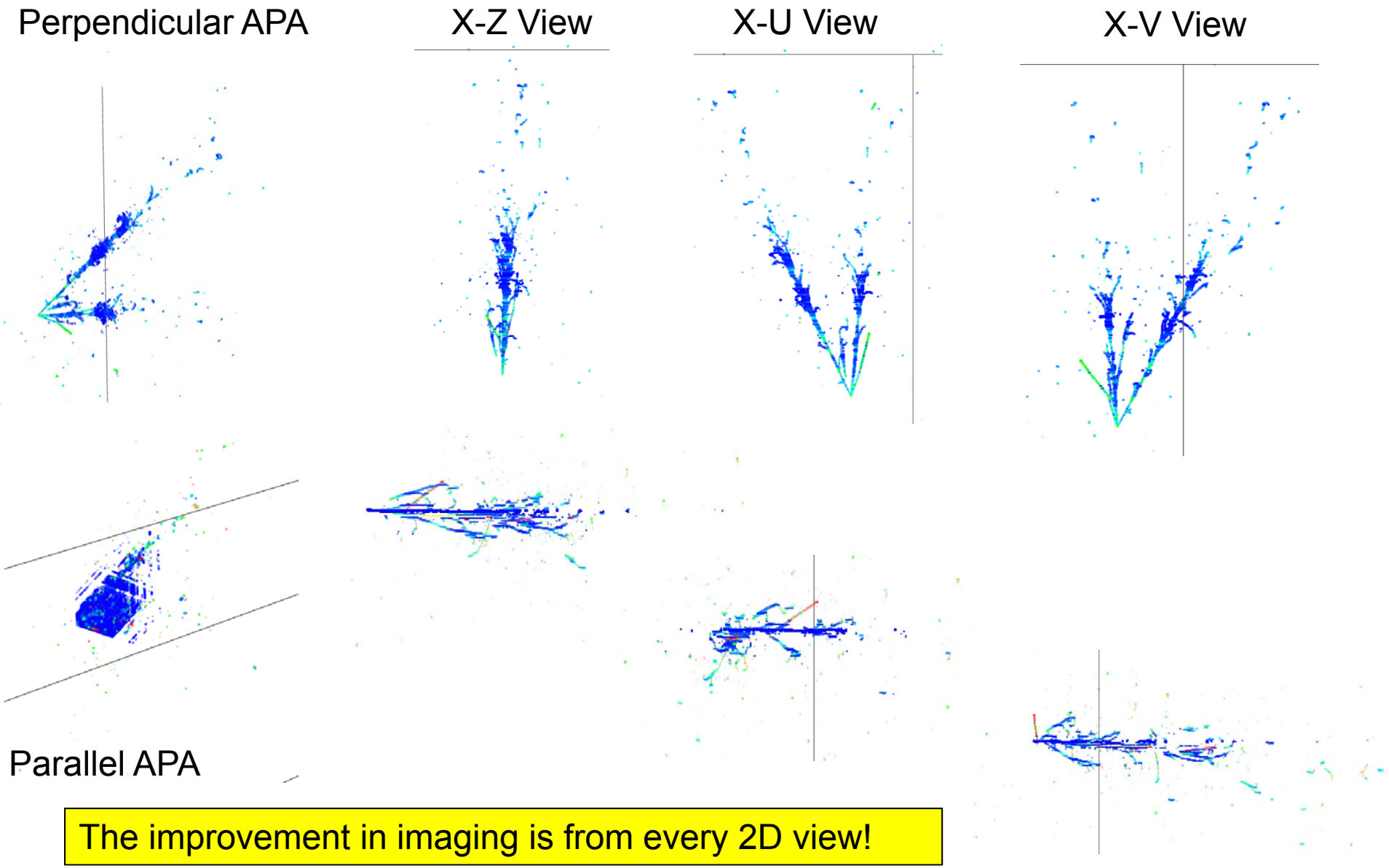
Without Connectivity



With Connectivity



Parallel vs. Perpendicular APA



The improvement in imaging is from every 2D view!

Strategy Comparison

2D Matching

- Start with 2D (time+wire x 3)
- 2D pattern recognition
  - Particle track/cluster information
- Matching 2D patterns into 3D objects
  - **Time** information (start/end of clusters)
  - **Geometry** information
  - Some **charge** information to remove ambiguities in matching

3D Tomography

- Start with 2D (wire+wire+wire at fixed time slice)
- 2D image reconstruction
  - **Explicit Time + Geometry + Charge** information
  - Some connectivity information can be used
- 3D image reconstruction
  - Straight forward
- 3D pattern recognition
  - Particle track/cluster information (tracks, showers)

Each approach uses the same set information in different order!

Discussion (Pros)

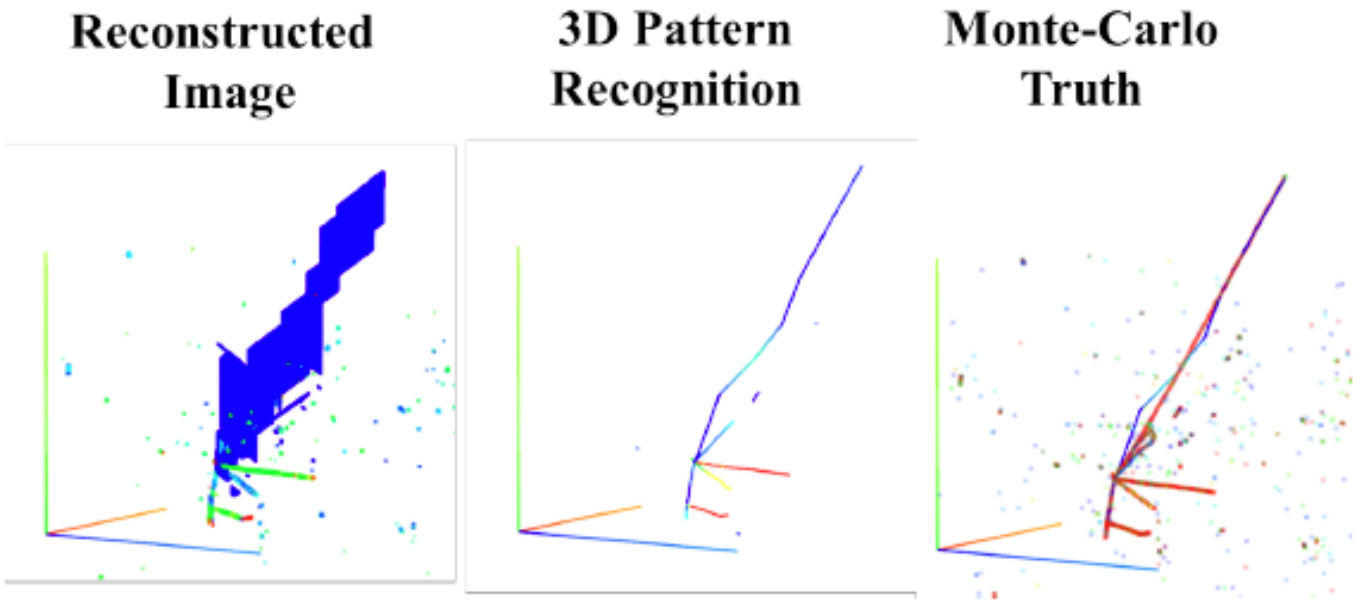
- Wire-Cell Imaging tells us **which hits CANNOT be associated together**
  - Hits from different time slice CANNOT be associated together (**time information**)
  - Hits from wires that are not crossing each other CANNOT be associated together (**geometry information**)
  - Hits with "different" charge is UNLIKELY to be associated together (**charge information**)
- Advantages:
  - Utilize full TPC information (time/geometry/charge)
  - Natural way to suppress electronics noise
  - Track/shower hypothesis not used, delay the pattern recognition process → better automated
  - Expected to be better for complicated topologies

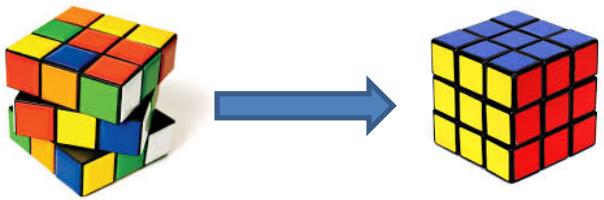
Discussions (Cons)

- Likely worse performance for 2-plane configuration
  - With 2-plane configuration, the power of the geometry information is strongly reduced
  - It is important to use track/shower hypothesis early to reduce ambiguities
- Stringent requirements on TPC performances
  - Relative time among hits from different planes
  - Charge reconstruction from induction plane
    - Use this feature for calibration purpose
  - Also dead channels (more sensitive to inefficiency)
- High resources requirement on the memory and speed

Wire-Cell Pattern Recognition

- Given the 3D images, pattern recognition is performed with the track and shower hypotheses





- Operations are all “local” i.e. Hough transformation, Crawler, Vertex fitting/merging …
- Too many different topologies → many corner cases

Wire-Cell Solve the Reconstruction Problem?

- No!
  - The 3D pattern recognition is still an open question → Pandora 3D pattern recognition, PMA, LineCluster …
  - With recognized pattern, how to do the fine tracking? → Projection Matching Algorithm
  - Energy calculation, angle determination, PID …

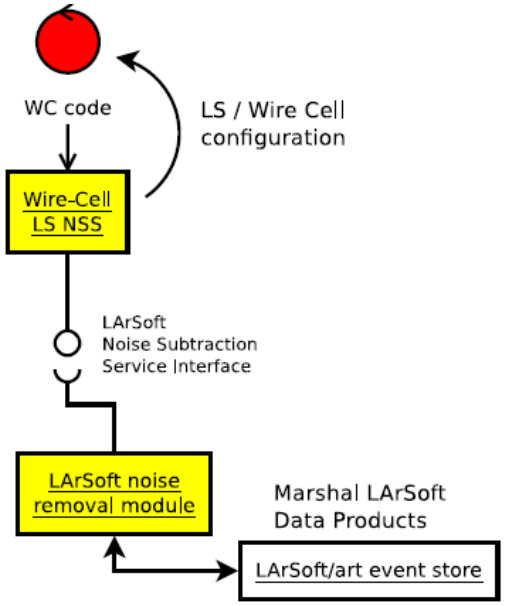
- What's the ultimate solution for pattern recognition?
  - Human-directed pattern correction is being developed with modern web-based tools → Bee 2.0
  - Deep learning?

Related Technical Progress

Brett Viren
Chao Zhang
David Adam

- Bee:
  - Improved on memory usage and UI responsiveness and added object picking.
  - Further performance improvements and a UI redesign coming.
- Wire Cell:
  - Excellent results from prototype noise removal on MicroBooNE data.
  - Porting to Wire Cell Toolkit is underway.
  - LArSoft Noise Subtraction Service Interface developed.
  - WCT NSS implementation will provide first LS/WC integration.
  - Will adopt service-based model for future WC imaging, etc, integration.

http://www.phy.bnl.gov/wire-cell/bee/



Summary

- Advantages and disadvantages of Wire-Cell approach are discussed
- Wire-Cell imaging is in a good shape
- More work is needed for the 3D pattern recognition
- Bee 2.0 is under development
- Integration with LarSoft is in progress