

Wire-Cell 3D Imaging in wirecell 0.25.1

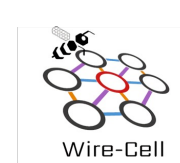
Haiwang Yu



Executive summary

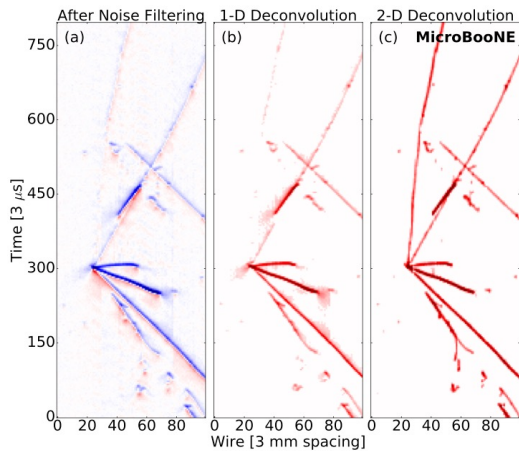
- All Wire-Cell 3D imaging functions from Prototype (used in uboone, wcp) are available in Wire-Cell Toolkit (wirecell)
 - can be configured for DUNE and other experiments
 - available in larsoft v09_80_00rc2, with larwirecell v09_80_00rc2 and wirecell v0_25_1.
 - <https://cdcvs.fnal.gov/redmine/issues/28242>
 - Thanks to Lynn and the LArSoft team!
- The Wire-Cell 3D imaging result will be used in downstream reconstructions of Wire-Cell or other reconstruction paradigms, e.g., AI/ML.
- Currently only standalone output for WireCell::ICluster. Which can be used for BEE event display. We are figuring out the proper data object in LArSoft.
 - Different principle compared to current other algorithms in LArSoft.
- Planning the imaging results in artROOT IO discussions in a dedicated Wire-Cell workshop/topic for LArTPC Algorithm Workshops

Wire-Cell Event Reconstruction



available in WCT

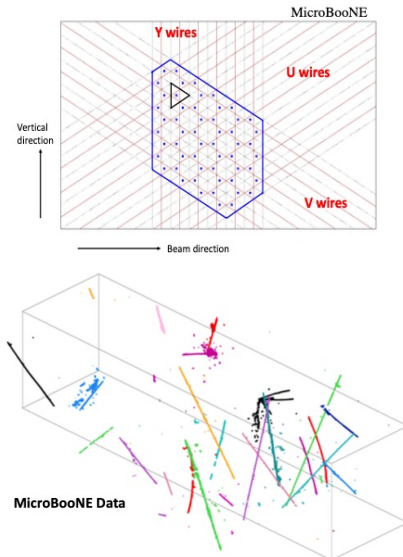
TPC simulation
noise filtering
signal processing



[JINST 12 P08003 \(2017\)](#)
[JINST 13 P07006 \(2018\)](#)
[JINST 13 P07007 \(2018\)](#)
[JINST 16 P01036 \(2020\)](#)

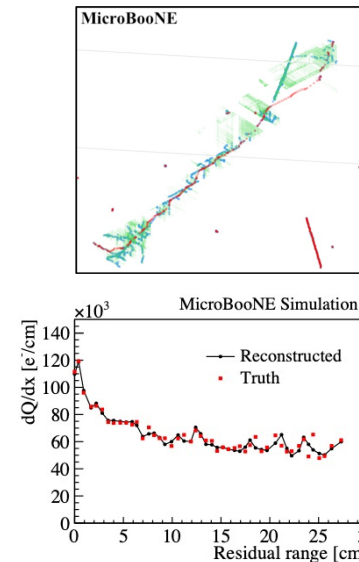
Porting in progress

3D imaging
clustering
charge-light matching



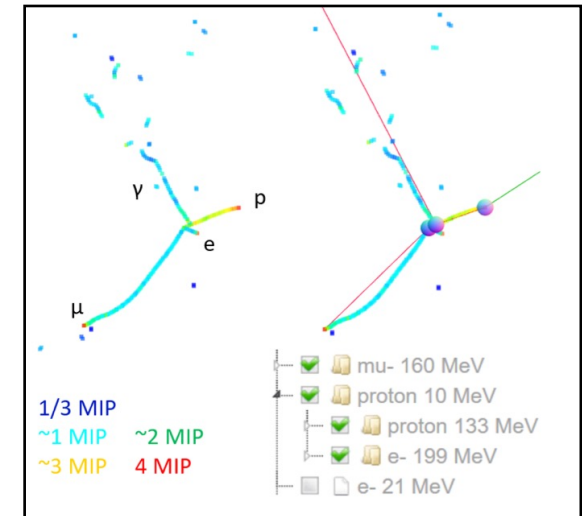
[JINST 13 P05032 \(2018\)](#)
[JINST 16 P06043 \(2021\)](#)

3D trajectory & dQ/dx fitting
cosmic muon tagger



[Phys. Rev. Applied 15, 064071 \(2021\)](#)

multi-track fitting
DL-3D vertexing
particle identification



[JINST 17 P01037 \(2022\)](#)

Wire-Cell 3D Imaging Principle

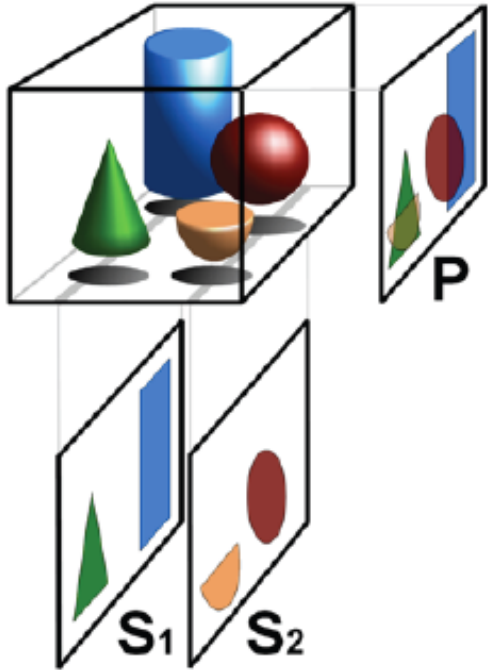
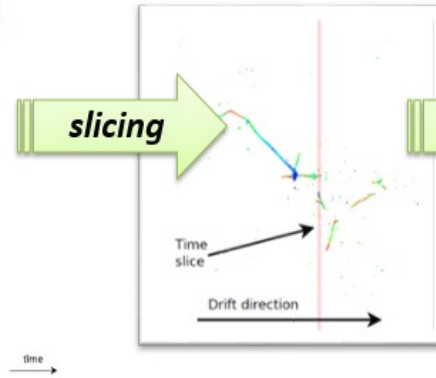
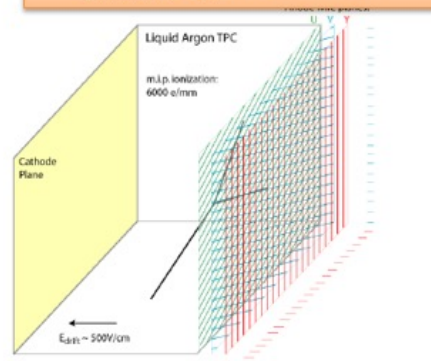


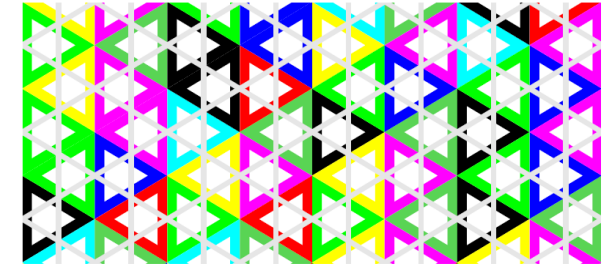
Fig.1: Basic principle of **tomography**: superposition free tomographic cross sections S1 and S2 compared with the projected image P

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

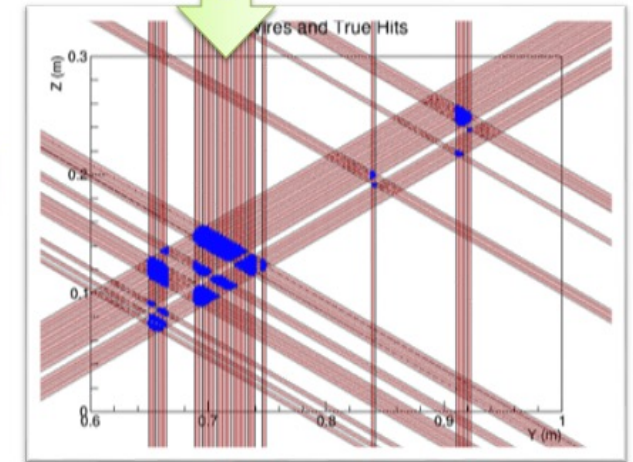
LArTPC Signal Formation



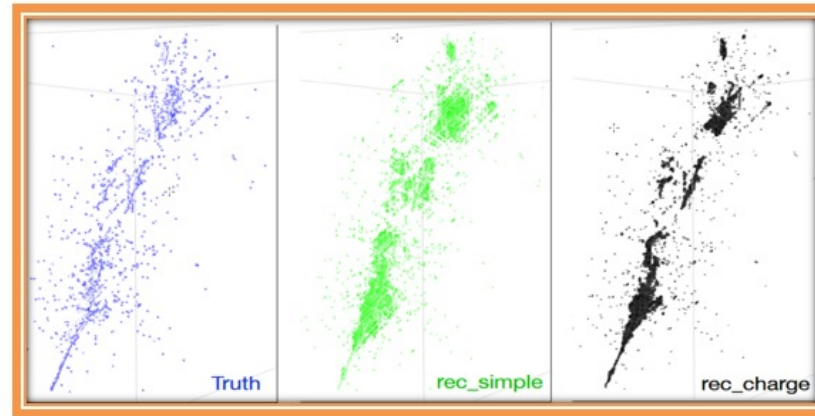
tiling



merging



solving



“Three-dimensional Imaging for Large LArTPCs”,
[JINST 13, P05032 \(2018\)](#)

Wire-Cell 3D Imaging Principle

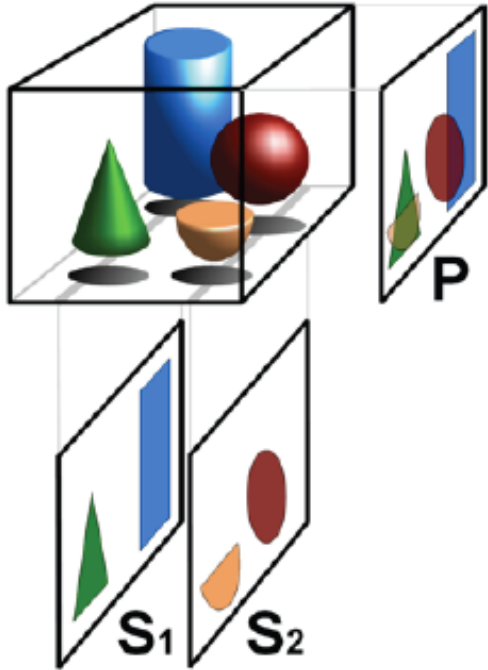
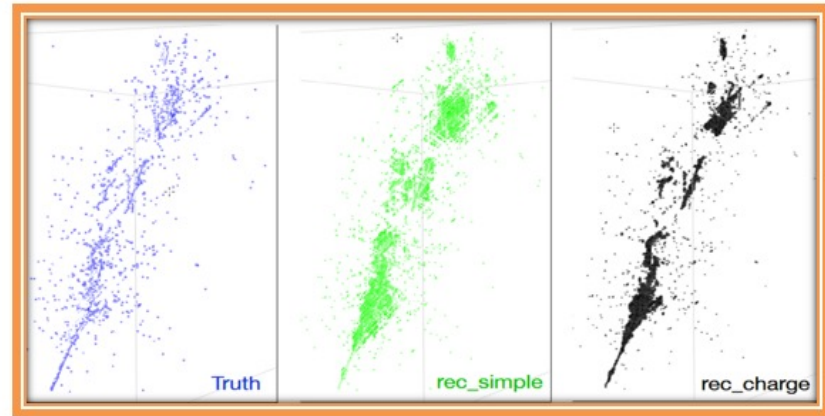
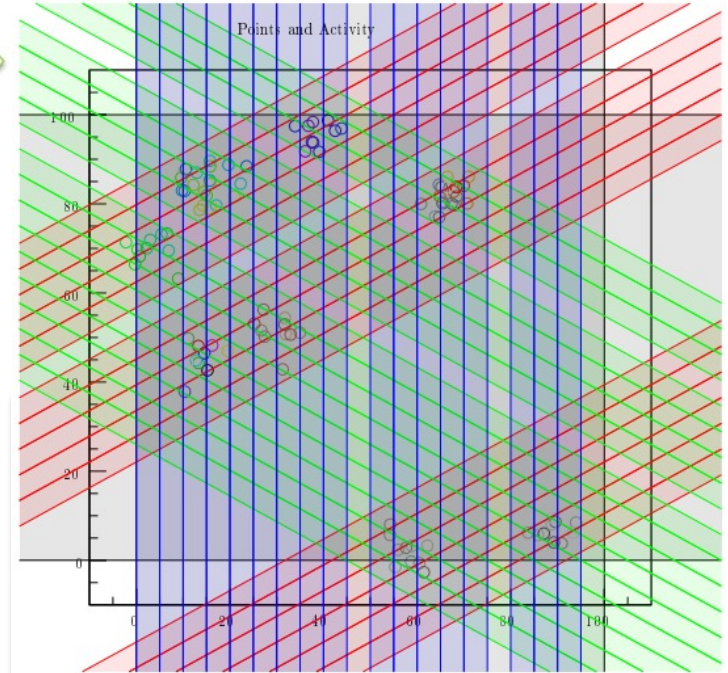
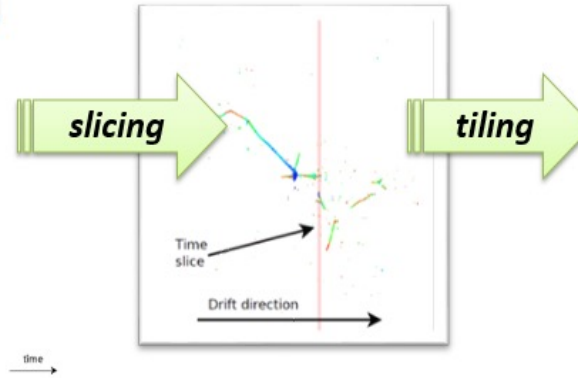
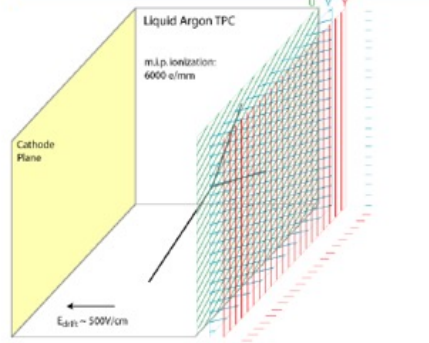


Fig.1: Basic principle of **tomography**: superposition free tomographic cross sections S1 and S2 compared with the projected image P

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

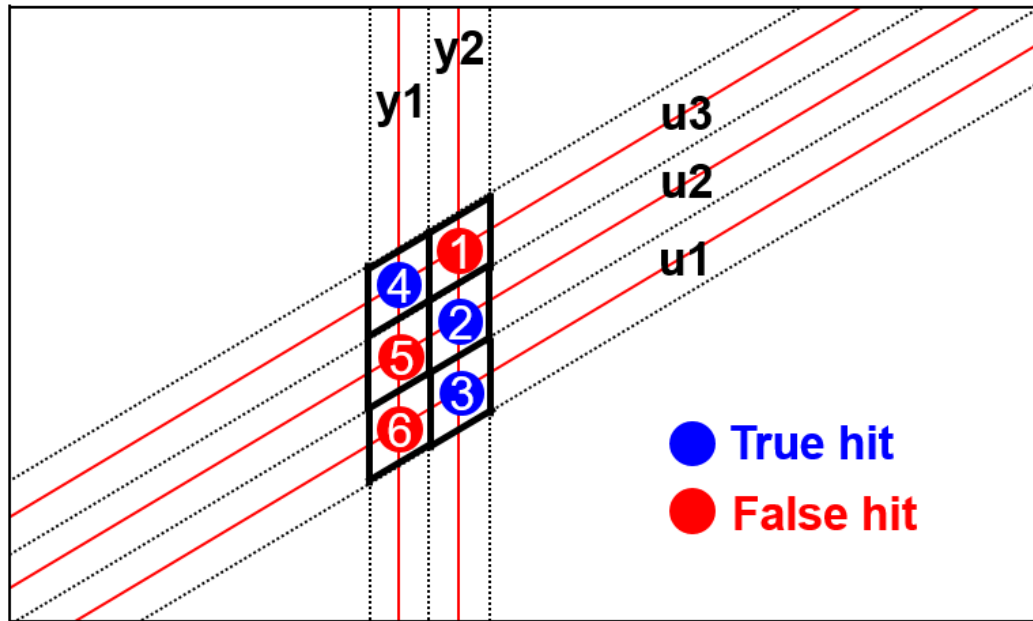
LArTPC Signal Formation



solving

“Three-dimensional Imaging for Large LArTPCs”,
[JINST 13, P05032 \(2018\)](#)

Solving: usage of Charge, Sparsity, Positivity, Proximity



measured charges on Wires $y = A \cdot X$ true charge to be resolved

$$\begin{pmatrix} y_1 \\ y_2 \\ u_1 \\ u_2 \\ u_3 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & a & a & a \\ a & a & a & 0 & 0 & 0 \\ 0 & 0 & a & 0 & 0 & a \\ 0 & a & 0 & 0 & a & 0 \\ a & 0 & 0 & a & 0 & 0 \end{pmatrix} \begin{pmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \\ H_5 \\ H_6 \end{pmatrix}$$

matrix determined by geometry, $a=1$

- The goal is to differentiate the true hits from fake ones by using the charge information
 - \sim large charge \rightarrow true hits
 - \sim zero charge \rightarrow fake hits
- Sparsity, positivity, and proximity information are added through compressed sensing (L1 regularization)

L1 reg. $O(N!) \rightarrow O(m \times N)$

$$\chi^2 = (y - A \cdot x)^2 + \lambda \cdot \sum_i |x_i|$$

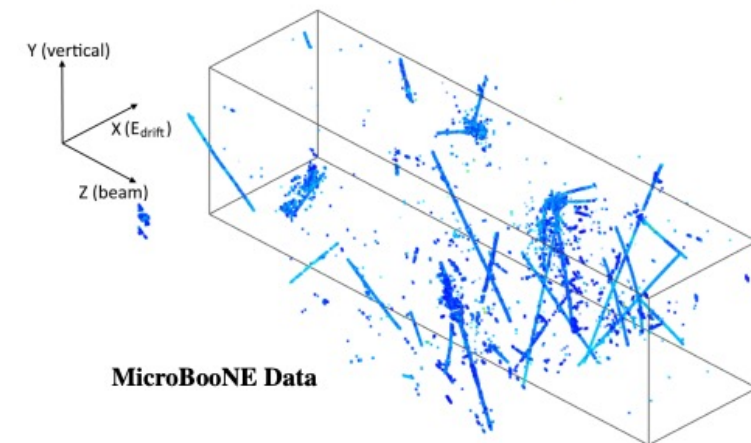
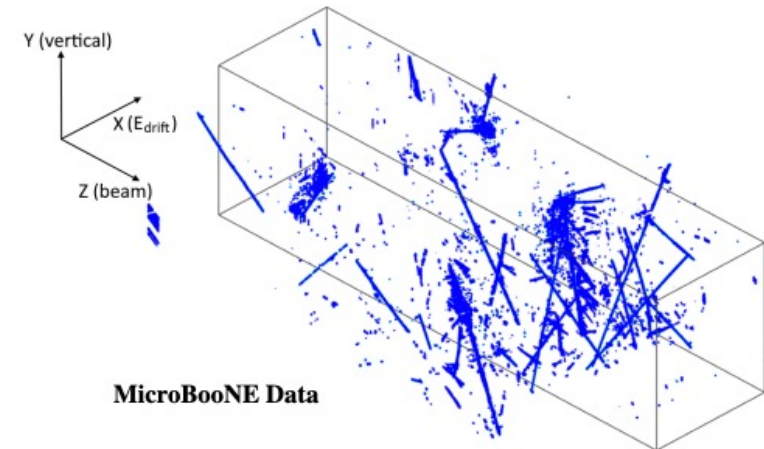
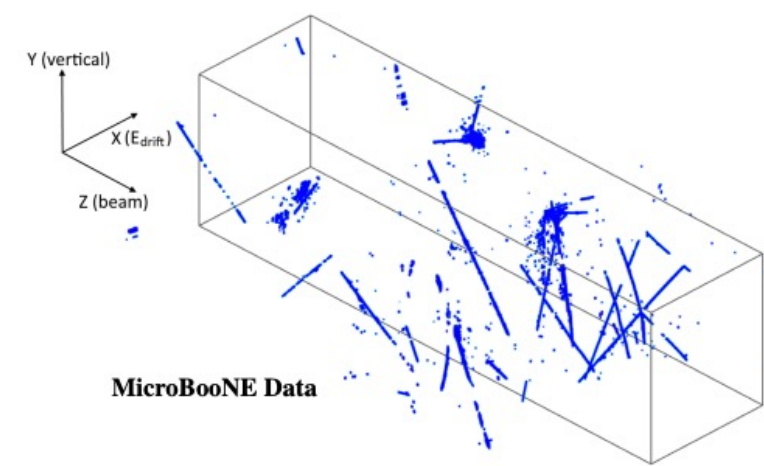
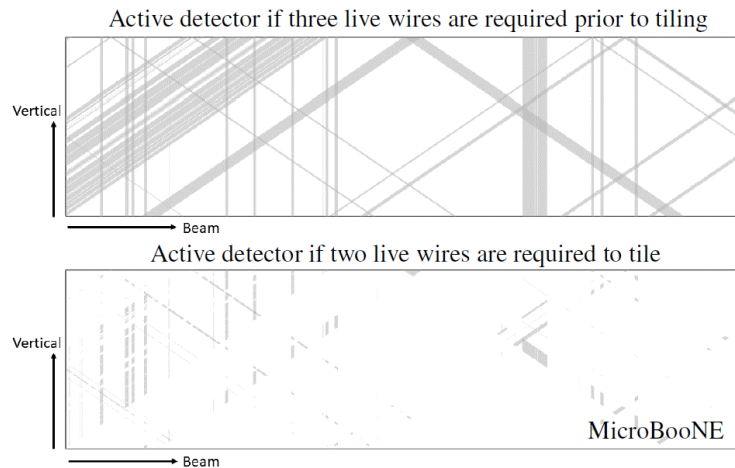
E. Candes, J. Romberg, T. Taoⁱ
arXiv-math/0503066

uboone Implementation

Implementation:

- <https://arxiv.org/abs/2011.01375>
- dead regions
- deghosting
- code: [link](#)

dead regions

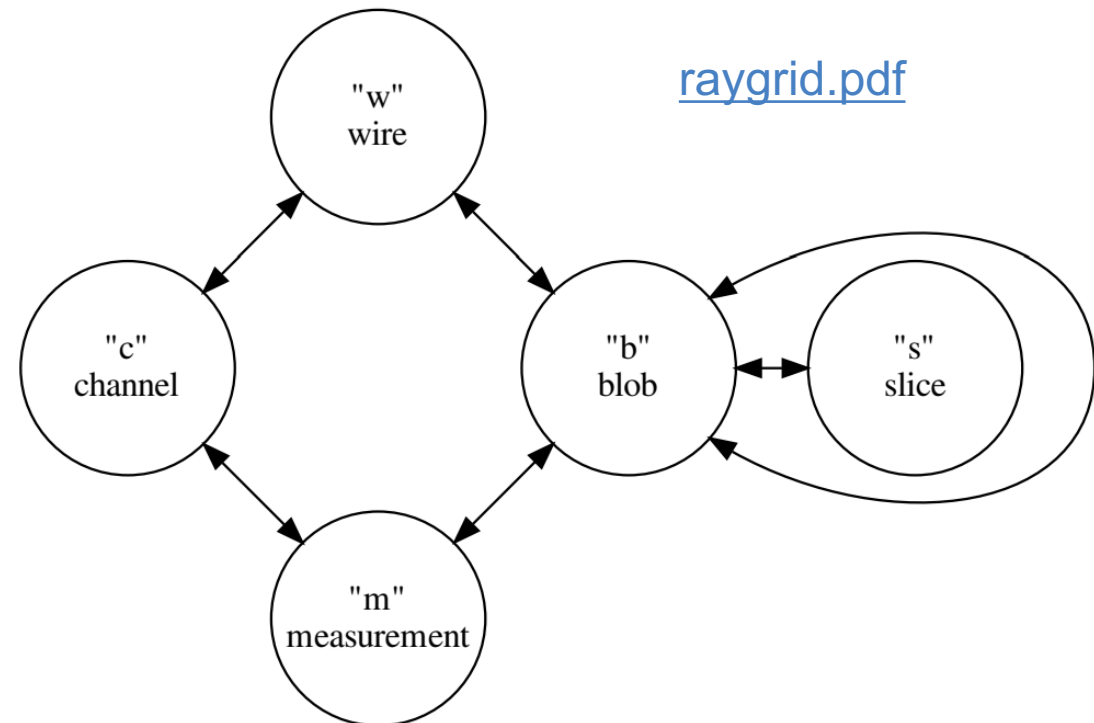


Prototype → Toolkit

- **Generalization** → **deploy to multiple experiments with only configuration change**
- Optimization → performance↑ and computing resources↓
- Working better with LArSoft → data flow through memory not disk
- Easier to maintain → modularized code, fewer interface objects, more functional

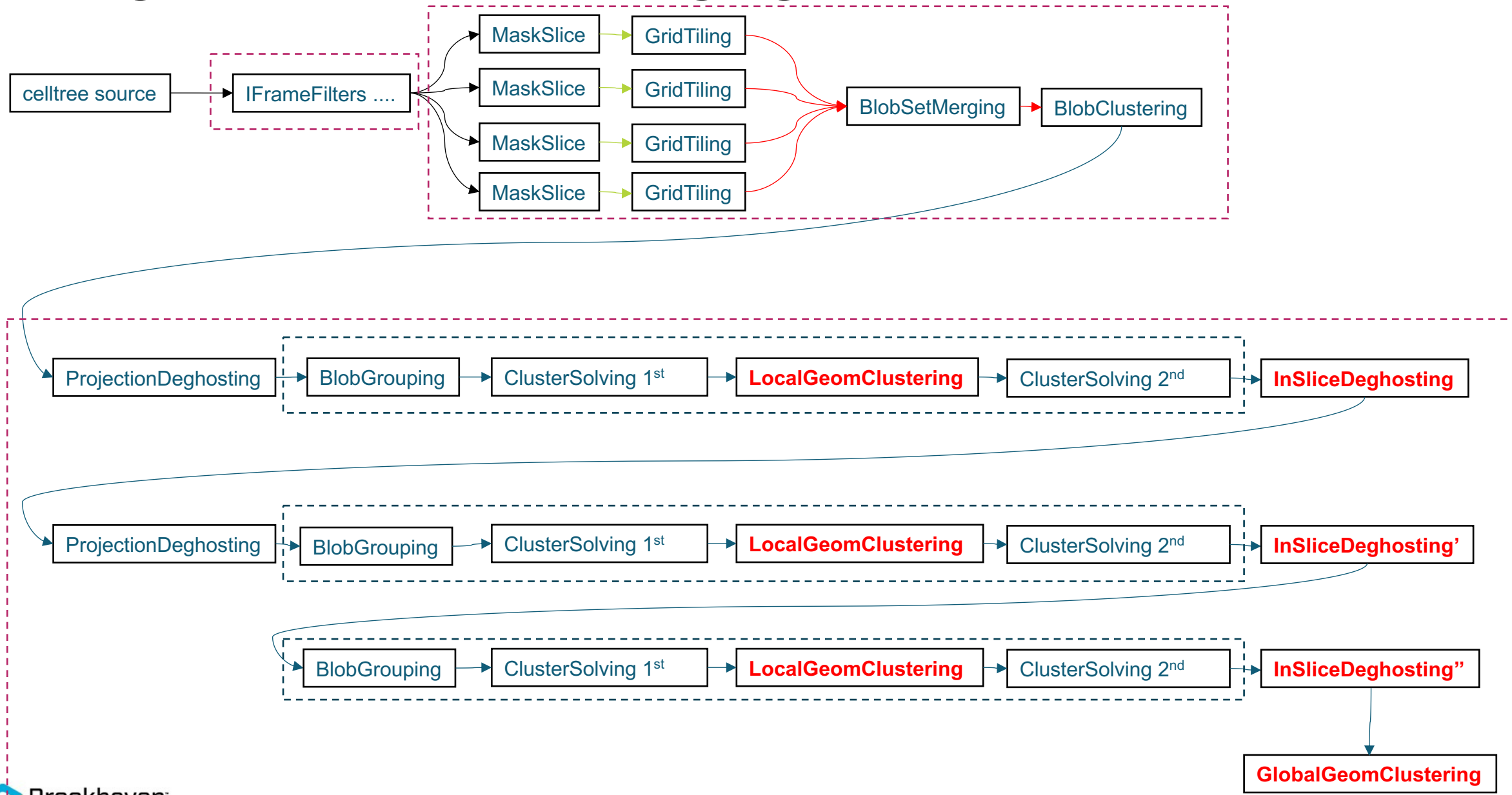
<https://github.com/BNLIF/wire-cell-data/blob/master/inc/WCPData/SlimMergeGeomCell.h>

```
Blob {  
  charge_map;  
  time;  
  wires;  
  ...  
}  
  
connectivity_map;
```



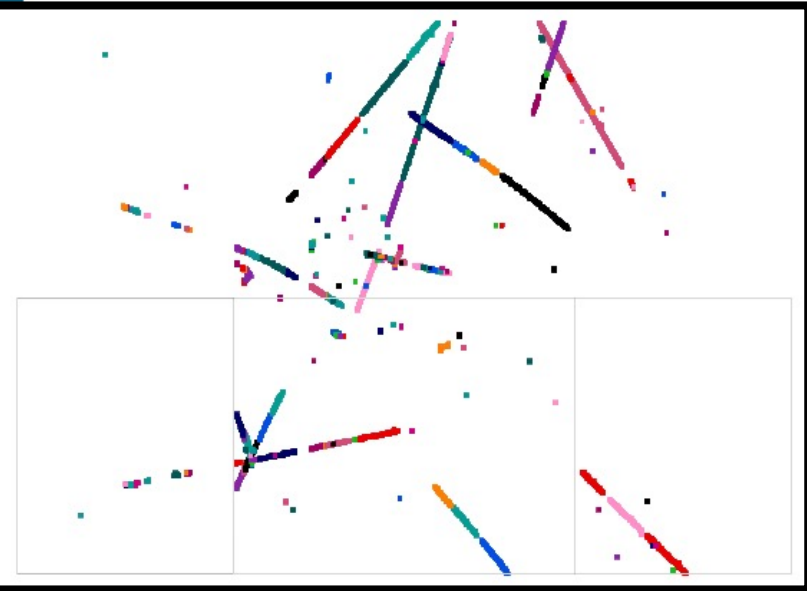
<https://github.com/WireCell/wire-cell-toolkit/blob/master/iface/inc/WireCellIface/ICluster.h>

Configuration: uboone imaging pipeline in WCT

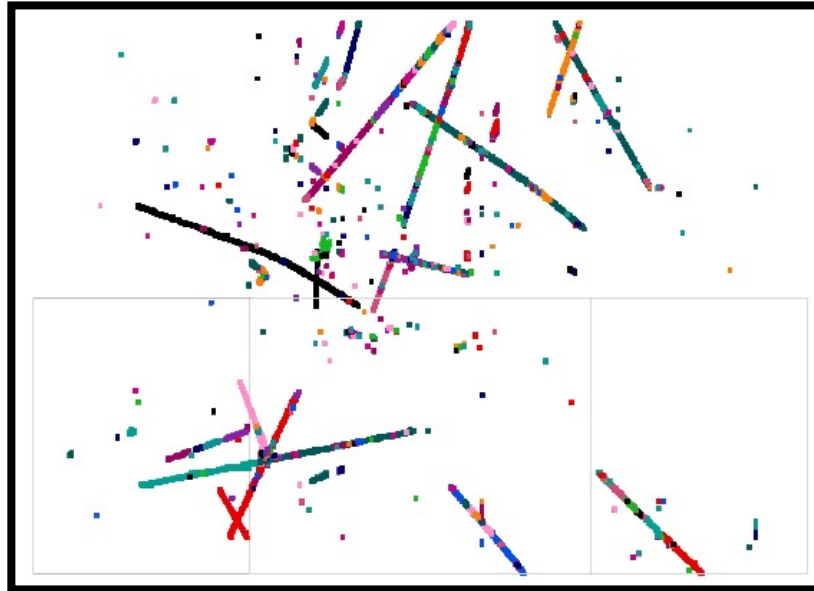


BEE Event display

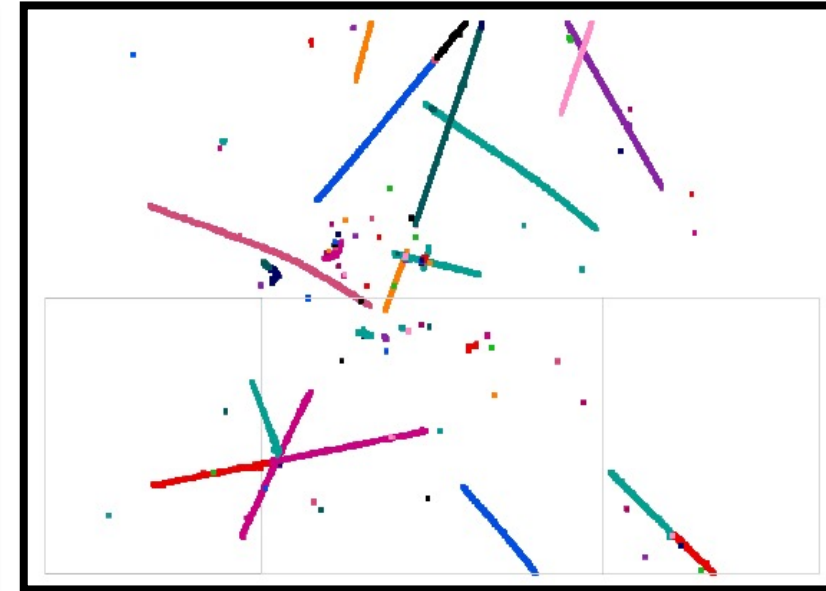
3-view only



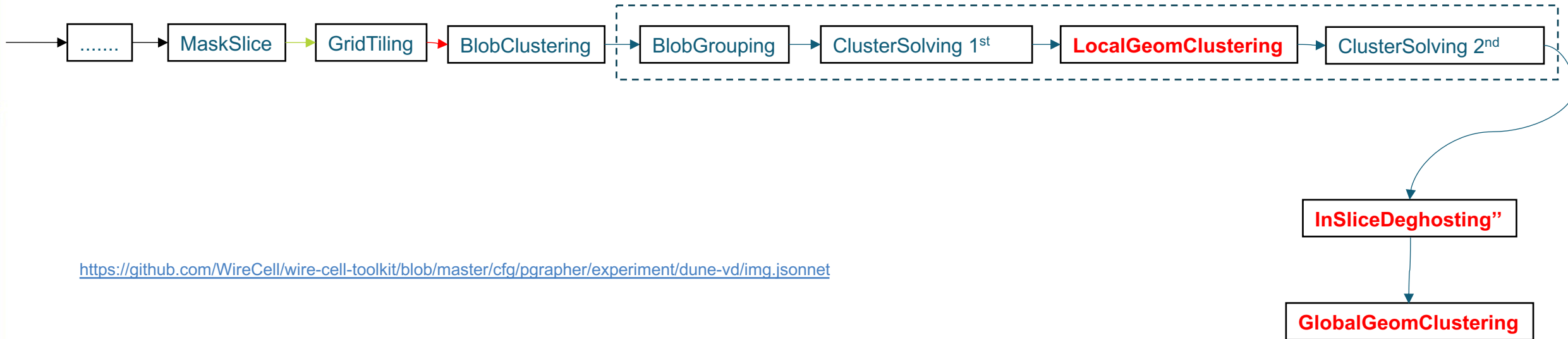
2-view w/o deghosting



2-view w deghosting



DUNE-FD-VD: Simplified version for now



<https://github.com/WireCell/wire-cell-toolkit/blob/master/cfg/pgrapher/experiment/dune-vd/img.jsonnet>

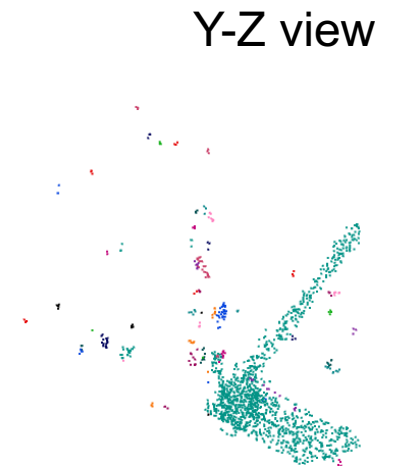
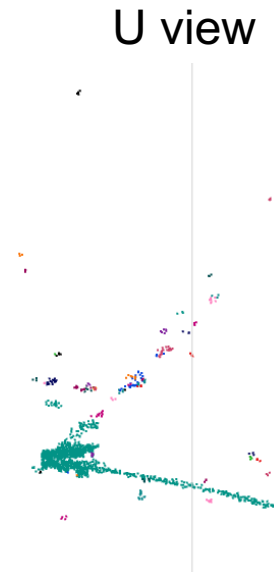
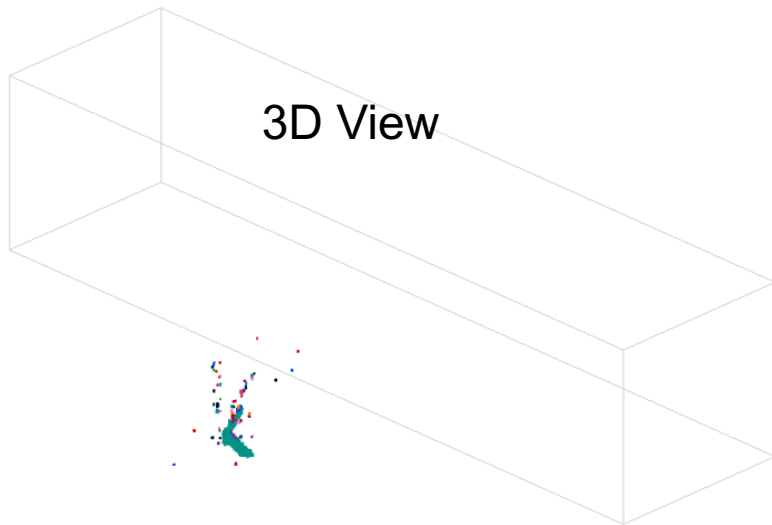
```
98 local sp_maker = import 'pgrapher/experiment/dune-vd/sp.jsonnet';
99 local sp = sp_maker(params, tools, {sparse: false, use_roi_debug_mode: false});
100 local sp_pipes = [sp.make_sigproc(a) for a in tools.anodes];
101
102 local img = import 'pgrapher/experiment/dune-vd/img.jsonnet';
103 local img_maker = img();
104 local img_pipes = [img_maker.per_anode(a) for a in tools.anodes];
```

- The parameters of `img()` could be similar like `sp`.

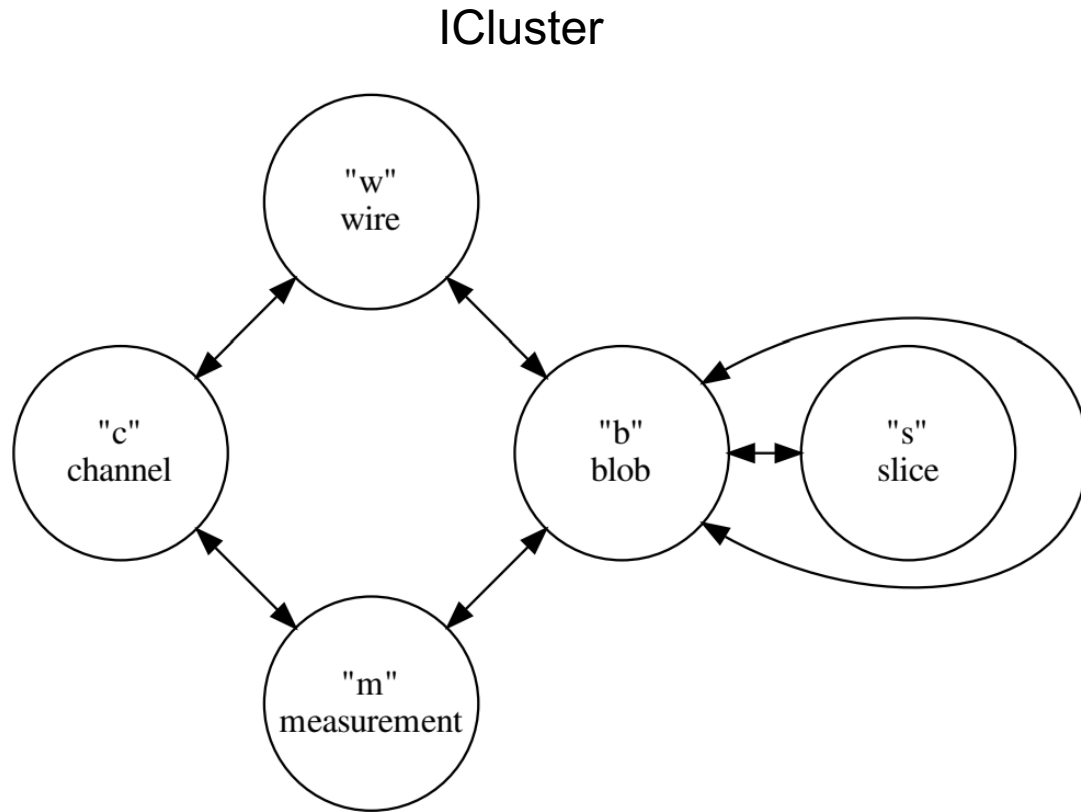
BEE Event display (using uboone boundary for now)

<https://www.phy.bnl.gov/twister/bee/set/6105426a-8b4c-40a5-97bb-c6cbdd43463a/event/0/>

Points for BEE are randomly sampled from the reconstructed 3D "blob"s

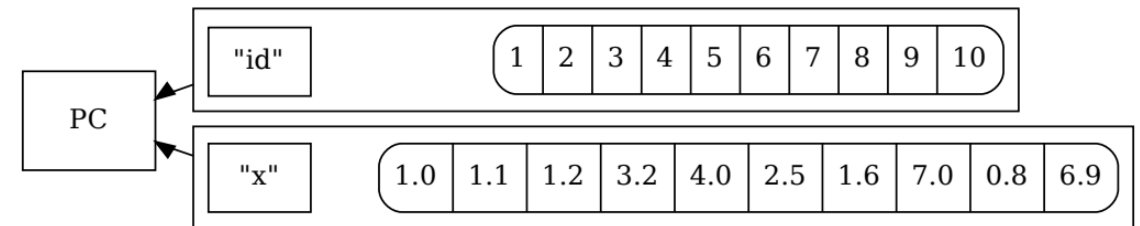


Current Wire-Cell interface objects



- ICluster contains full SigProc waveforms and reconstructed 3D “blob”s and auxiliary information with minimum redundancy.
- PointCloud is based on WireCell::ITensor for persistency and can utilize KDTree for spacial information.

PointCloud/PointCloudTree



Testing

Configuration (jsonnet) compatibility for various experiments

CPU/Memory usage

Optimizations

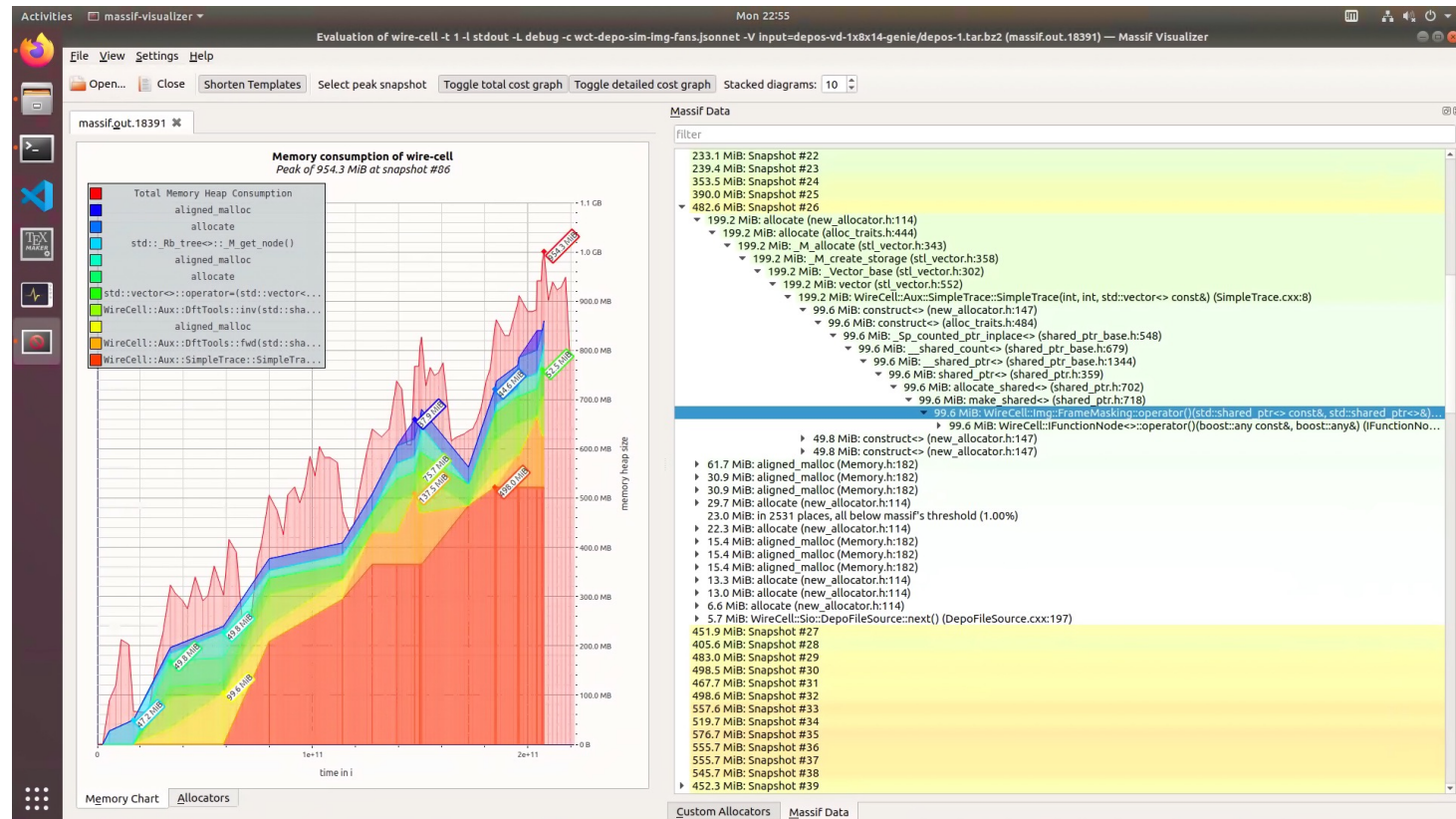
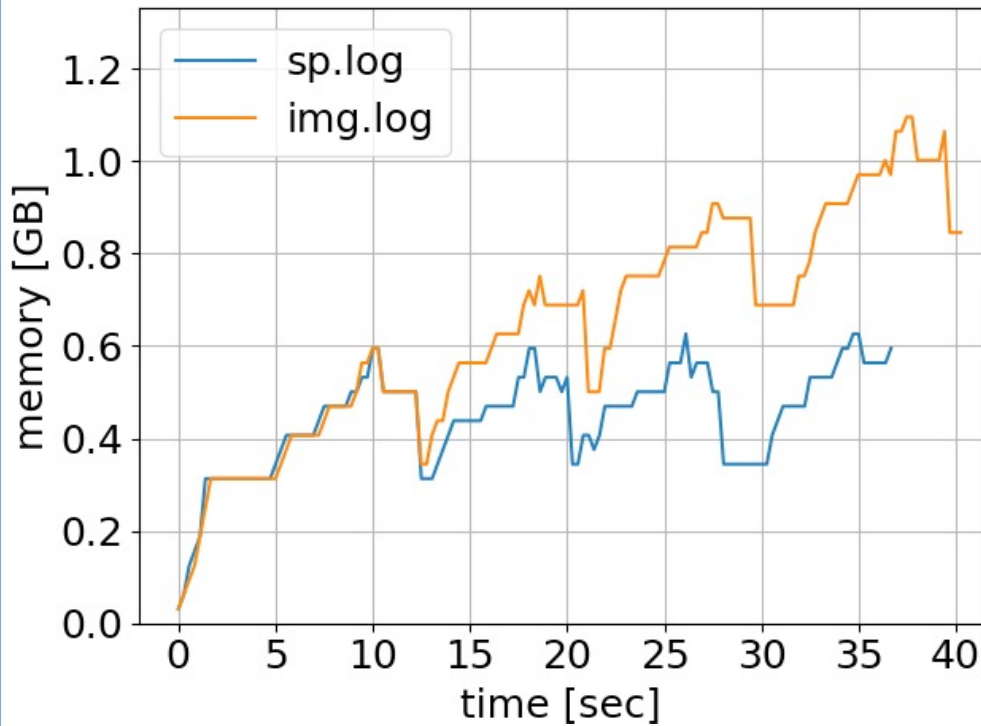
<https://github.com/WireCell/wire-cell-toolkit/commit/fcd9999c839a7f1481218ed6b26a8180acf0495d>

```
@@ -333,7 +266,7 @@ WireCell::Configuration OmnibusSigProc::default_configuration() const
333     cfg["charge_ch_offset"] = m_charge_ch_offset;
334
335     cfg["wiener_tag"] = m_wiener_tag;
336 -   cfg["wiener_threshold_tag"] = m_wiener_threshold_tag;
337     cfg["decon_charge_tag"] = m_decon_charge_tag;
338     cfg["gauss_tag"] = m_gauss_tag;
339     cfg["frame_tag"] = m_frame_tag;

266     cfg["charge_ch_offset"] = m_charge_ch_offset;
267
268     cfg["wiener_tag"] = m_wiener_tag;
269 +   // cfg["wiener_threshold_tag"] = m_wiener_threshold_tag;
270     cfg["decon_charge_tag"] = m_decon_charge_tag;
271     cfg["gauss_tag"] = m_gauss_tag;
272     cfg["frame_tag"] = m_frame_tag;
```

Testing

4 CRUs processed with 1 CRU has a neutrino interaction



massif-visualizer

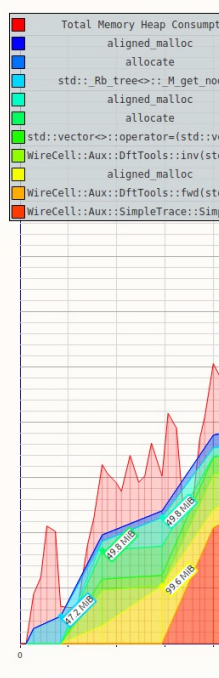
Mon 22:56

Evaluation of wire-cell -t 1 -l stdout -L debug -c wct-depo-sim-img-fans.jsonnet -V Input=depos-vd-1x8x14-genie/depot-1.tar.bz2 (massif.out.18391) — Massif Visualizer

File View Settings Help

Open... Close Shorten Templates Select peak snapshot Toggle total cost graph Toggle detailed cost graph Stacked diagrams: 10

massif.out.18391



Total Memory Heap Consumption

- aligned_malloc
- allocate
- std::Rb_tree<::M_get_no
- aligned_malloc
- allocate
- std::vector<::operator=(std::v
- WireCell::Aux::DftTools::inv(st
- aligned_malloc
- WireCell::Aux::DftTools::fwd(st
- WireCell::Aux::SimpleTrace::Sim

Memory Chart Allocators

Code File Edit Selection View Go Run Terminal Window Help

SEARCH

frame()

Replace

files to include

files to exclude

12 results in 12 files - Open in editor

- SimpleSlice.h aux/inc/WireCellAux
- ClusterArrays.cxx aux/src
- ClusterHelpers.cxx aux/src
- ClusterHelpersJsonify.cxx aux/src
- ClusterHelpersLoader.cxx aux/src
- test_blobshadow.cxx aux/test
- ISlice.h iface/inc/WireCelliface
- ImgData.h img/inc/WireCellimg
- BlobClustering.cxx img/src
- BlobReframer.cxx img/src
- BlobSetMerge.cxx img/src
- JsonBlobSetSink.cxx img/src

wct-sim-fans.jsonnet 1 wct-depo-sim-fans.jsonnet 1 wct-depo-sim-img-fans.jsonnet 1, U FrameMasking.cxx 2 ISlice.h x EmpiricalNoiseModel.h EmpiricalNc

```

iface > inc > WireCelliface > C ISlice.h > {} WireCell > ISlice > frame() const
35 ..... // A sample is a channels value in the time slice.
36 ..... struct IdentHash {
37 .....     size_t operator()(const IChannel::pointer p) const {
38 .....         return std::hash<int>()(p->ident());
39 .....     }
40 ..... };
41 ..... struct IdentEq {
42 .....     size_t operator()(const IChannel::pointer p1, const IChannel::pointer p2) const {
43 .....         return p1->ident() == p2->ident();
44 .....     }
45 ..... };
46 ..... struct IdentLess {
47 .....     size_t operator()(const IChannel::pointer p1, const IChannel::pointer p2) const {
48 .....         return p1->ident() < p2->ident();
49 .....     }
50 ..... };
51 ..... typedef std::pair<IChannel::pointer, value_t> pair_t;
52 ..... typedef std::unordered_map<IChannel::pointer, value_t> map_t;
53 ..... typedef std::unordered_map<IChannel::pointer, value_t, IdentHash, IdentEq> map_t;
54 ..... typedef std::map<IChannel::pointer, value_t> map_t;
55 ..... typedef std::map<IChannel::pointer, value_t, IdentLess> map_t;
56 ..... };
57 ..... // Pointer back to IFrame from which this ISlice was created.
58 ..... virtual IFrame::pointer frame() const = 0;
59 ..... };
60 ..... // Return a opaque numerical identifier of this time slice
61 ..... // unique in some broader context.
62 ..... virtual int ident() const = 0;
63 ..... };
64 ..... // Return the start time of this time slice relative to frame's time
65 ..... virtual double start() const = 0;
66 ..... };
67 ..... // Return the time span of this slice
68 ..... virtual double span() const = 0;
69 ..... };
70 ..... // The activity in the form of a channel/value map;
71 ..... virtual map_t activity() const = 0;
72 ..... };
73 ..... }; // namespace WireCell
74 ..... };
75 #endif
76

```

PROBLEMS 9 PORTS OUTPUT DEBUG CONSOLE TERMINAL

```

commit 71c86d5b1e903c78bd453d4ebab3394c28e1dcfc
Author: HaiwangYu <yuhw.pku@gmail.com>
Date: Sun Sep 17 22:55:14 2023 -0400

    add dnn roi

commit 052091682b0a932fac968ecda97e06ee9876da53
Author: HaiwangYu <yuhw.pku@gmail.com>
Date: Fri Sep 15 13:50:53 2023 -0400
:[]

```

SSH: kratos.phy.bnl.gov mp-memory-fix* 6 3 1

Ln 58, Col 40 (7 selected) Spaces: 4 UTF-8 LF C++ Linux esbonio: Sphinx build error