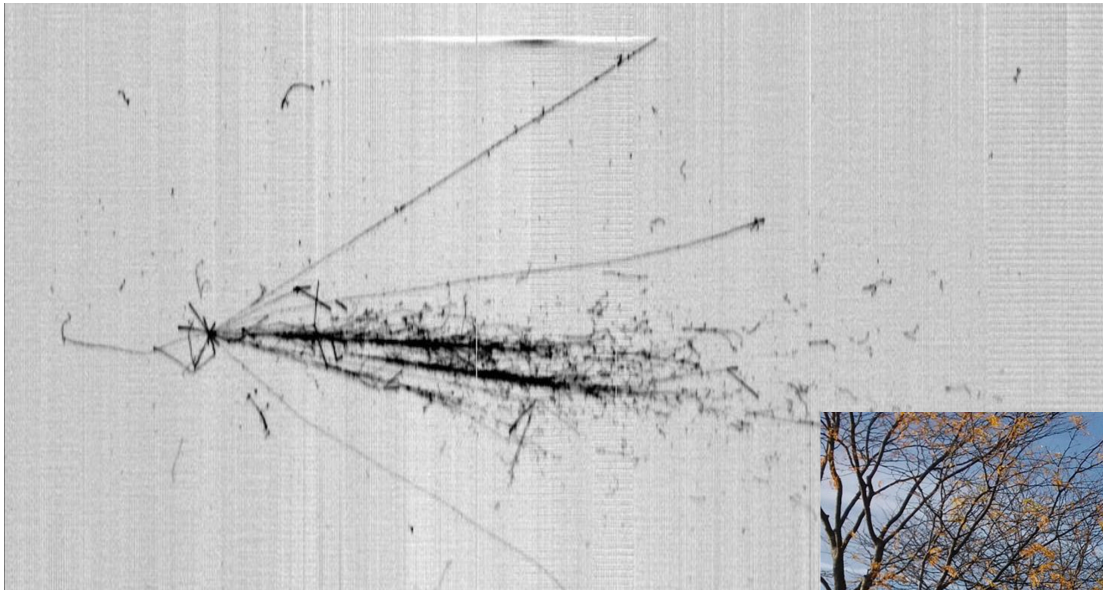
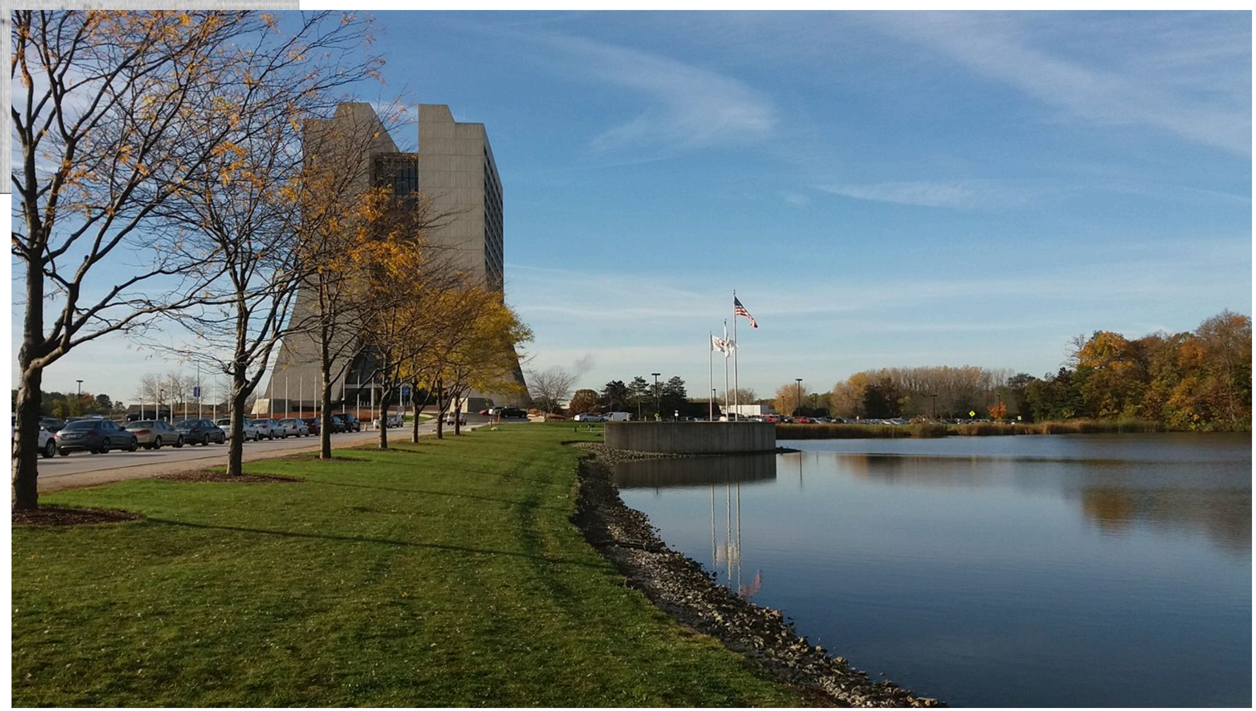
Signal processing and hit-finding in ICARUS at SBN



F. Varanini
INFN Padova

T. Usher
SLAC



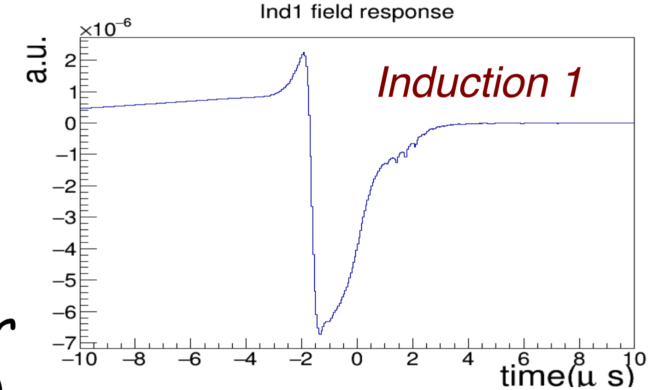
FNAL
September 20th 2018

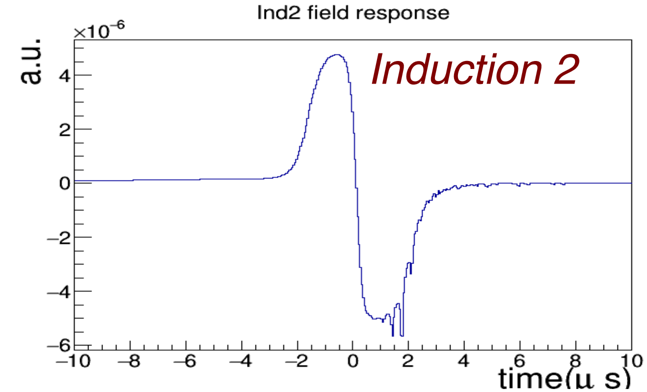
Outline

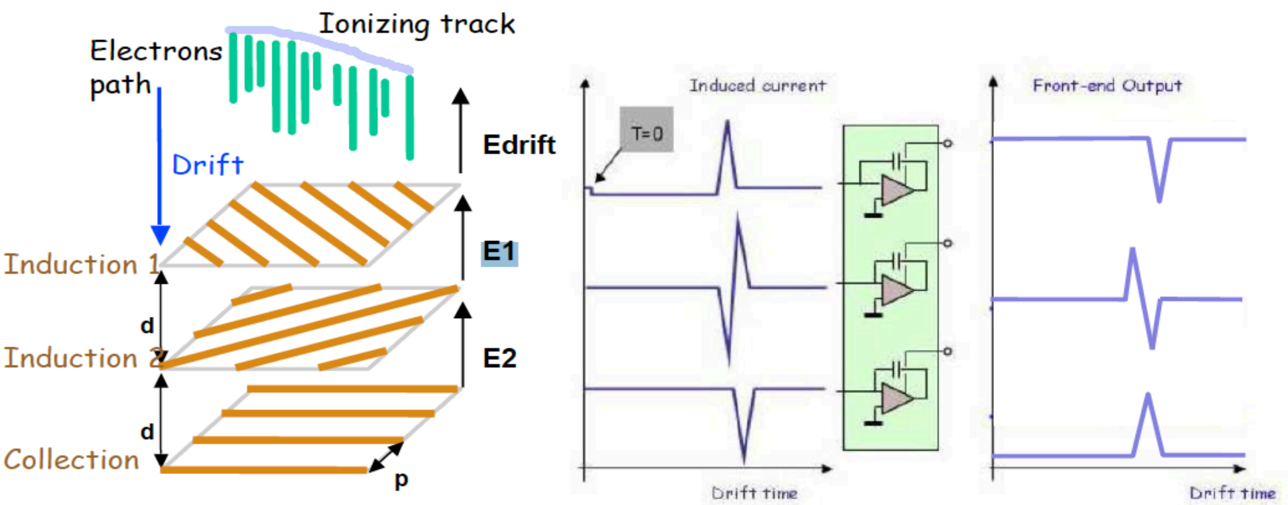
- Simulation ingredients: field/electronics response and noise model
- The "deconvoluted" signal processing path: deconvolution, filtering, Gaussian hit-finding
- The "raw" signal processing path: ICARUS-like hit-finding and fitting
- Some preliminary results: efficiency and fake rate

Electrostatic field response

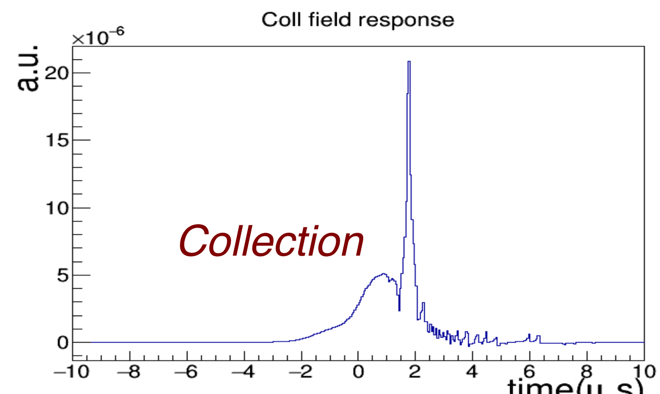
- The recorded signal produced by the read-out electronics depends on the electrostatic field between the wireplanes and the read-out electronics response
- The effect of the electrostatic field is different for the 3 wire planes (Induction1, Induction2, Collection)





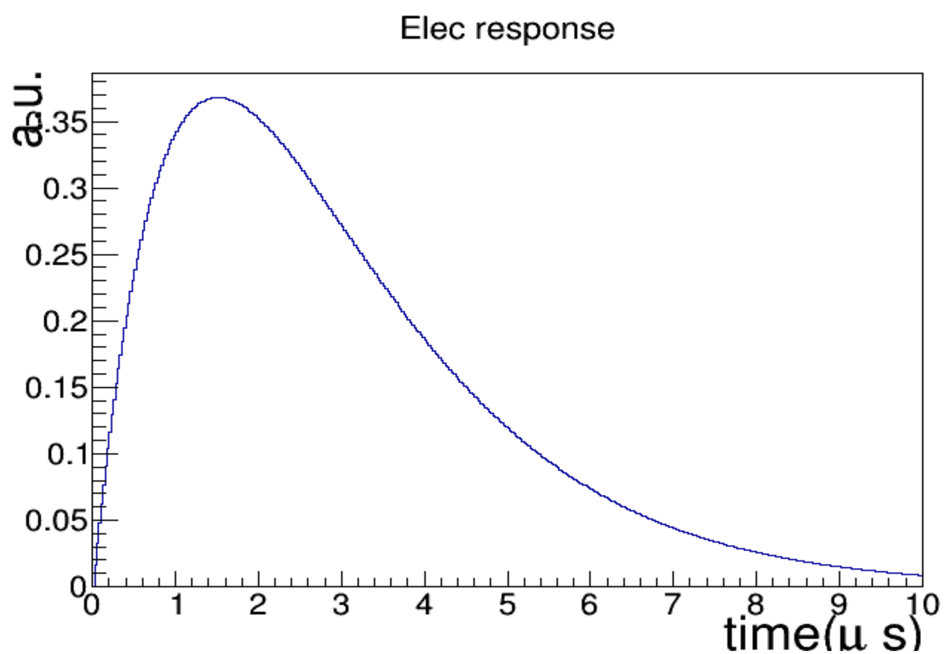


- To first order, it can be considered as uniform between adjacent wire-planes ("box approximation")
- More detailed responses were computed by L.Rochester with Garfield electrostatic simulation program



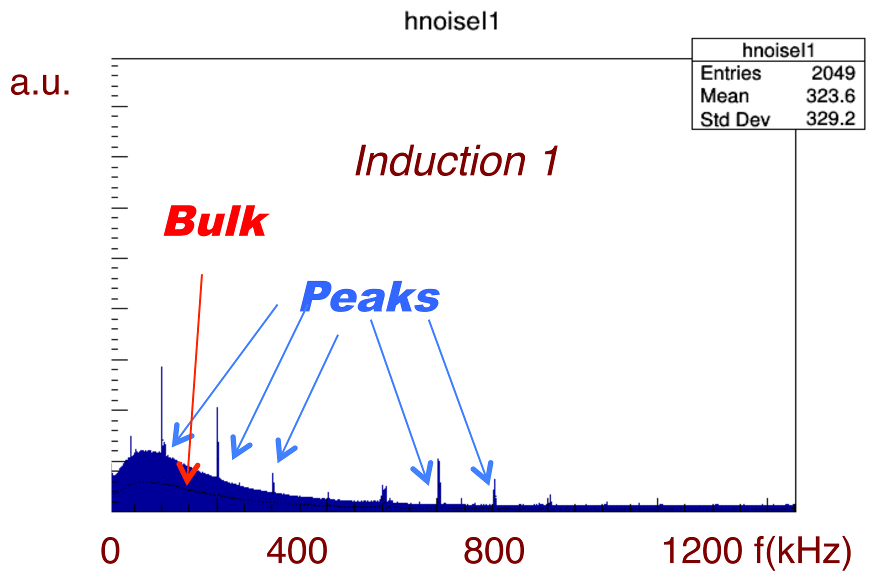
Electronics response

- The new ICARUS read-out electronics provides the same fast response for all planes
- The time response to a δ input current $q\delta(t)$ is $V_{out}(t)=q/C*t/\tau*e^{-t/\tau}$ (τ=1.5μs)
- A more accurate description can be implemented in the future, taking into account the Bessel filter in the electronics (see *JINST_027P_0518*)
- The fast response (of the same order of the intrinsical incoming signal width) allows to preserve signal shape and reduce undershoots
- The absolute normalization of the digitized signal is determined by measurement with small TPC at CERN: 0.027 fC per (ADC*μs)



SBN simulated noise model: uncorrelated noise

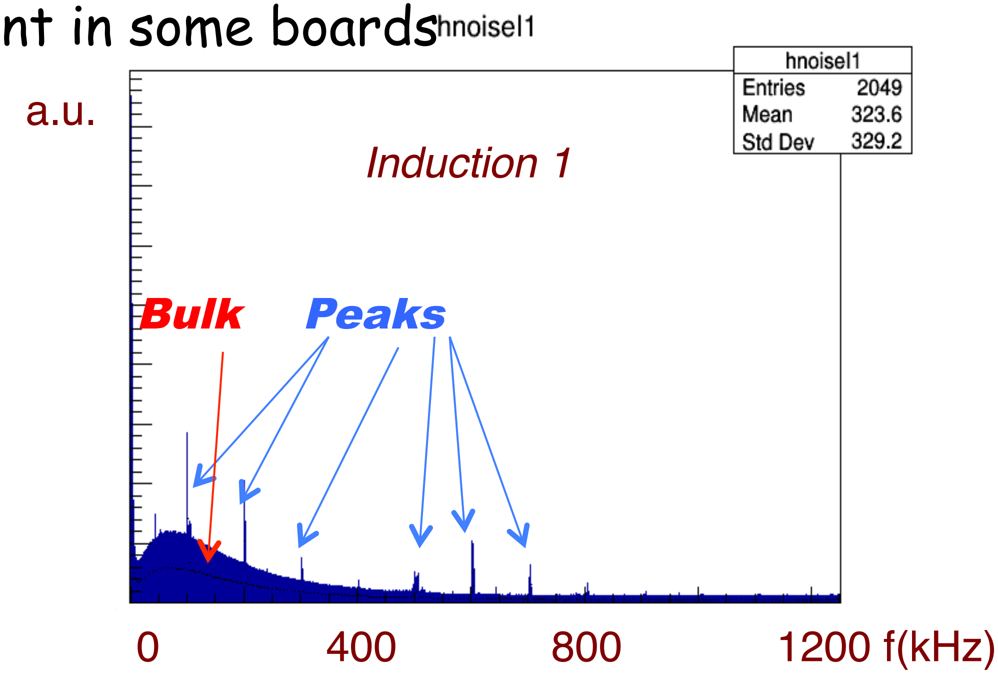
- As a realistic first approximation, the frequency spectrum of the SBN simulated noise was assumed to be the same as measured in ICARUS at LNGS
- The measured noise spectrum from Induction1 (shaping time=3 μs, not so different from the current one) was used



- Only the "bulk" of the spectrum was considered; peaks are associated to correlated noise (see next slide)
- Absolute RMS normalization was taken from tests with 50-liter chamber at CERN: ~2.4 ADC#
- More flexible noise filtering tools must be ready to face possibly different conditions on the SBN setup

SBN simulated noise model: correlated noise

- Data from ICARUS-T600 and 50-liter exhibit also a noise component, highly correlated on a board (32 adjacent wires)
- Usually associated with sharp frequency peaks (~100 kHz and harmonics)
- Amplitude of this noise is highly variable; usually negligible w.r.t. uncorrelated one, but can be dominant in some boards



- For SBN simulation, these peaks are identified in T600 spectrum. The corresponding noise is (approximately) simulated in a fully correlated way in each board
- Amplitude, for each board, extracted ramdomly from amplitude distribution of correlated noise extracted at T600

MC event for ICARUS at SBN

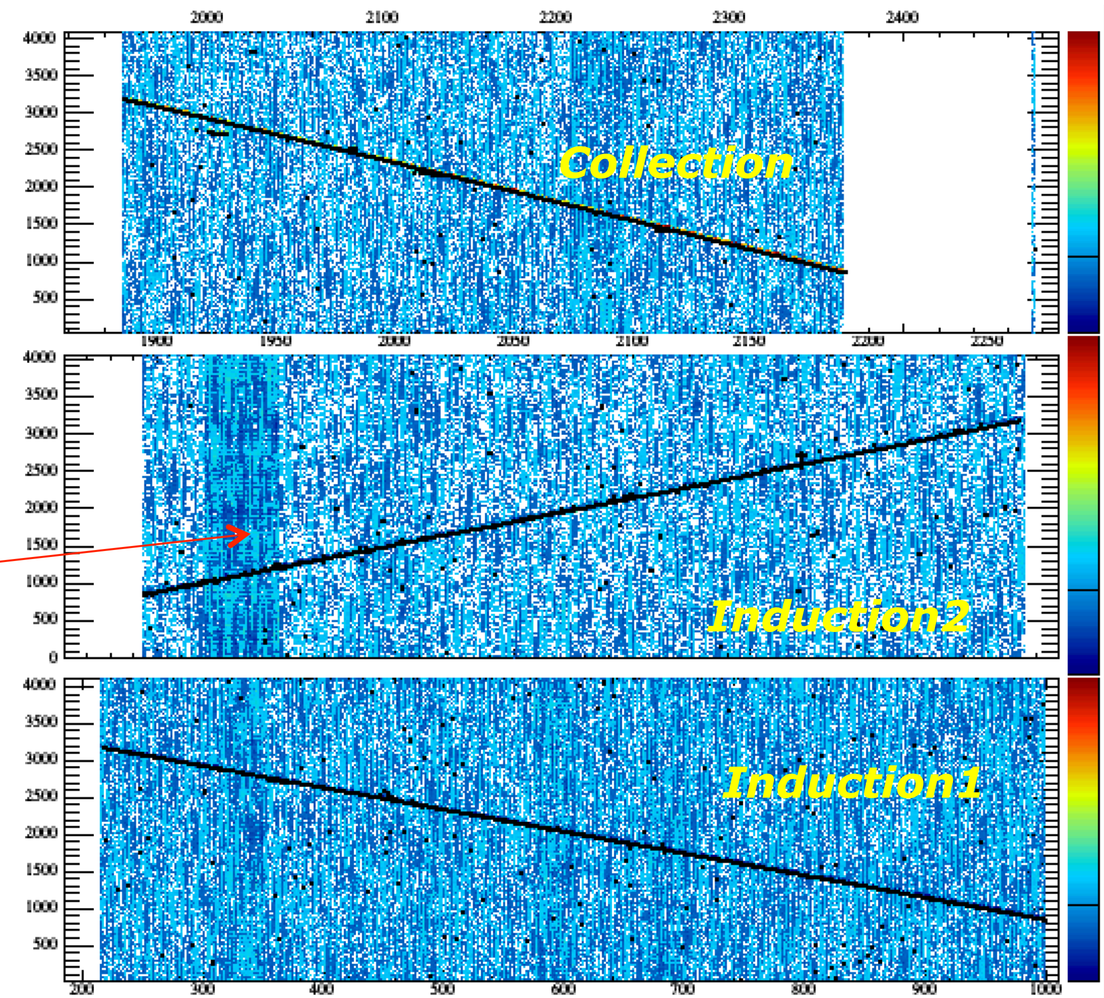
COSMIC MUON:

E~5GeV,l~3m,θ~30°, f~0° (not far from minimal energy deposition per wire)

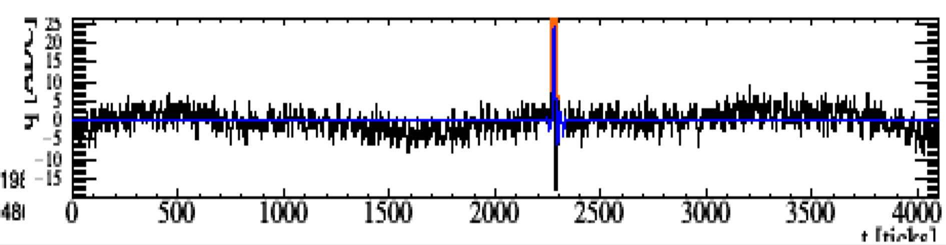
"raw" S/N: ~15 in Collection, ~10 in Induction 1.

Similar to S/N measured in CERN 50-litre TPC with new electronics (see *JINST_027P_0518*)

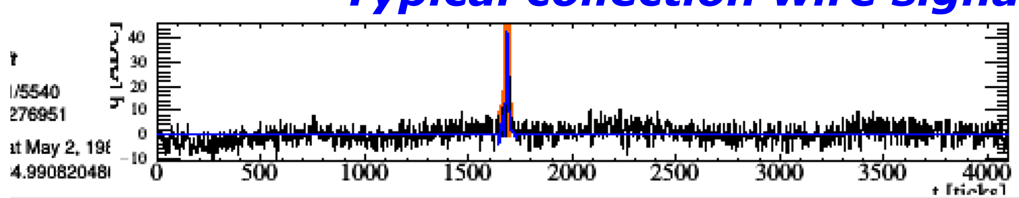
Noisy board



Typical Induction1 wire signal



Typical collection wire signal



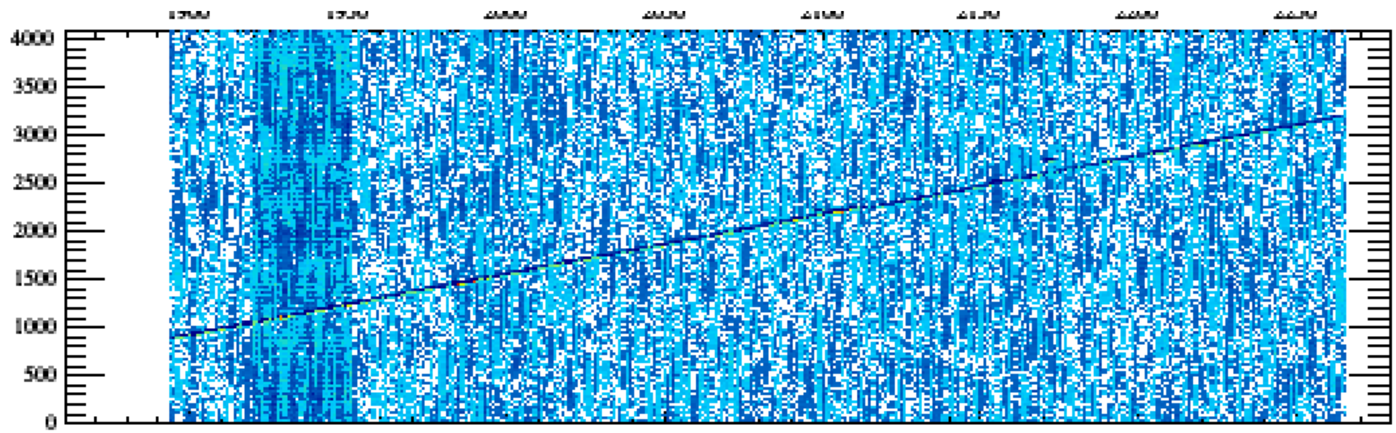
Signal processing and hit-finding approaches

- Two different approaches to raw signal processing and hit-finding can be considered and implemented:
  - "RAW" hit-finding applied directly to signals recorded by electronics.
  - "DECONVOLUTION" of the field/electronics response signal to recover (in principle) the upstream intrinsical signal
- In the raw approach (used in ICARUS@LNGS), a threshold-based hit-finding algorithm is applied on the raw signals for Collection and Induction1 (with different parameters to match the different shapes).
- Given the new fast-response electronics in Induction, the raw signal is intrinsically bipolar. An offline integration procedure (running sum+baseline restoring) is needed to transform it into unipolar, allowing calorimetric measurement in this plane
- Deconvolution (used for instance by MicroBooNE) inverts the effect of field/electronic responses, allowing to reduce all signals on a wire to approximately Gaussian shapes – equal for all wire planes. It requires a good a-priori knowledge of detector effects and noise; noise filtering is mandatory

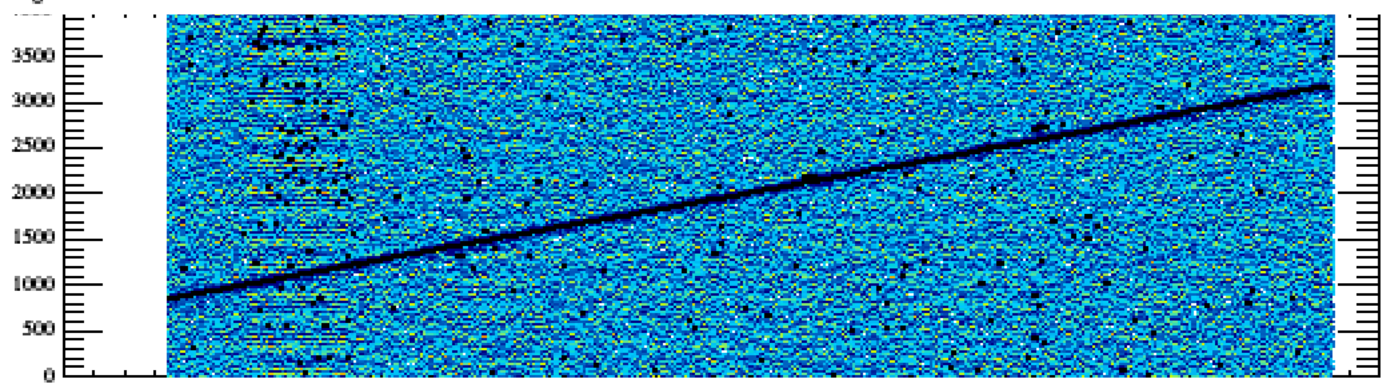
Raw path: Induction2 offline integration

Same cosmic muon as in Slide 7

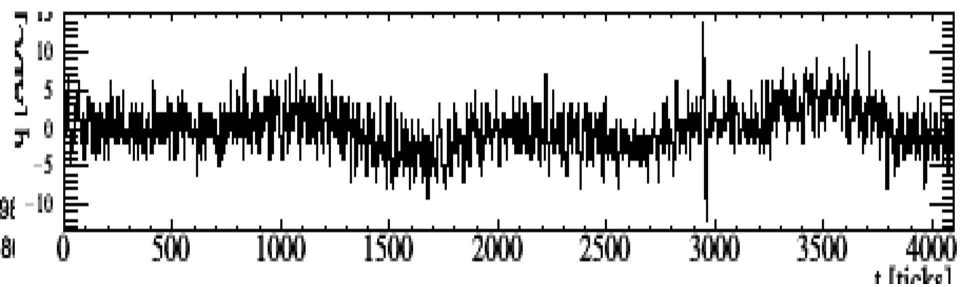
raw event image



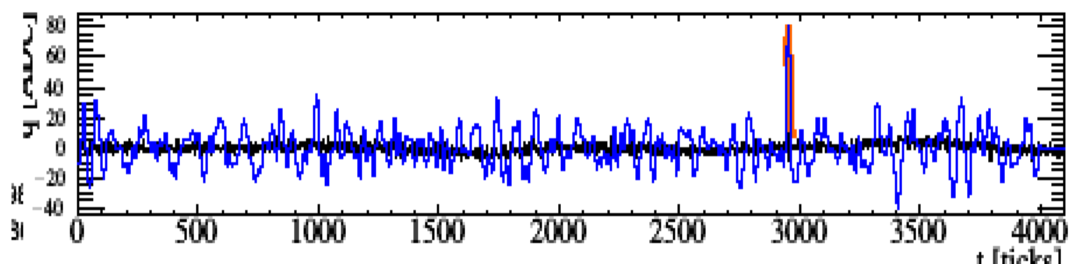
Integrated event image



Typical raw wire signal



Typical integrated wire signal

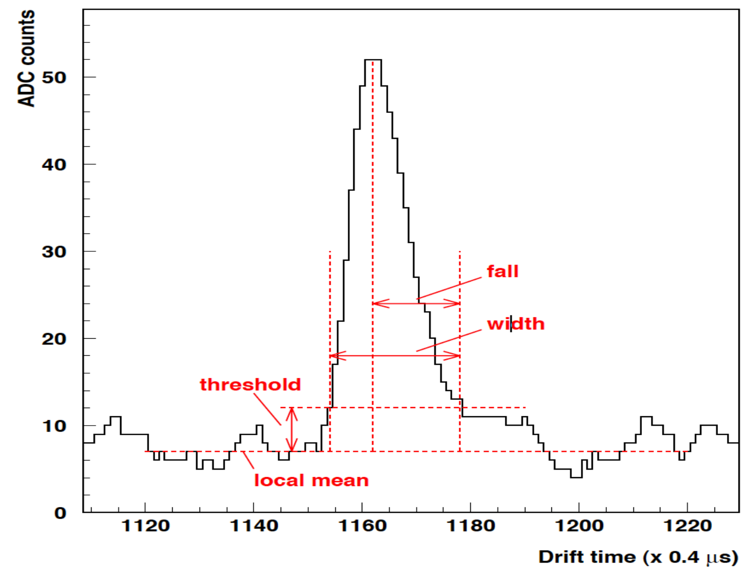


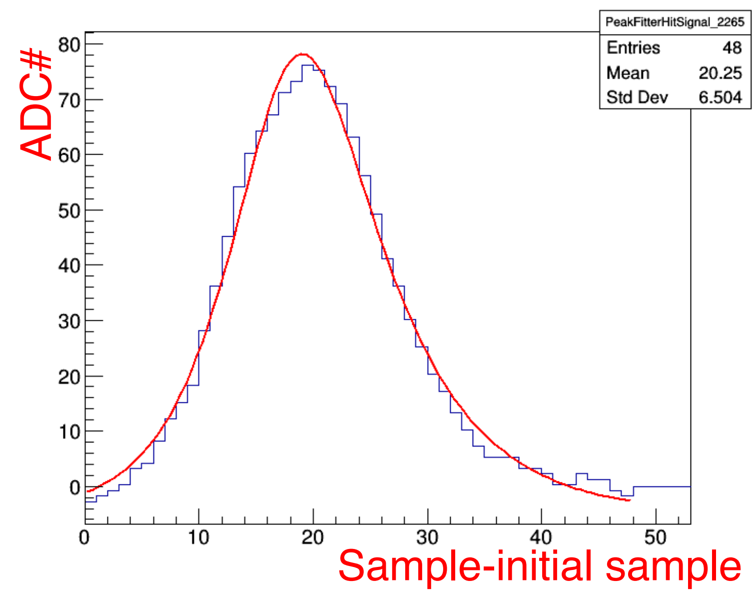
Raw hit-finding algorithm

- Algorithm is inherited from ICARUS software, ported into *larsoft*
- Based on "time over threshold", with minimum width and falling time
- Hit-finding parameters are plane-dependent
- Hit is then fitted, based on double exponential:
- Fitting function is generally asymmetrical, unlike in deconvoluted case

$$f(t) = B + A\,\frac{e^{\frac{-(t-t_0)}{\tau_1}}}{1 + e^{\frac{-(t-t_0)}{\tau_2}}}$$

- Cannot be shown in usual display since shape is asymmetrical (needs larsoft generalization)
- Special fitting function for multiple hits or "long" hits in drift coordinate (due to track inclination): expressed as superposition of standard MIP hits, shifted in time



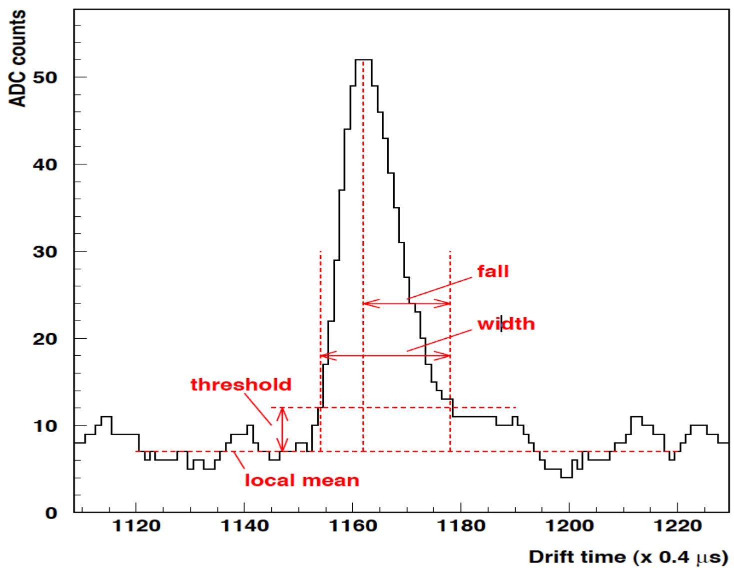


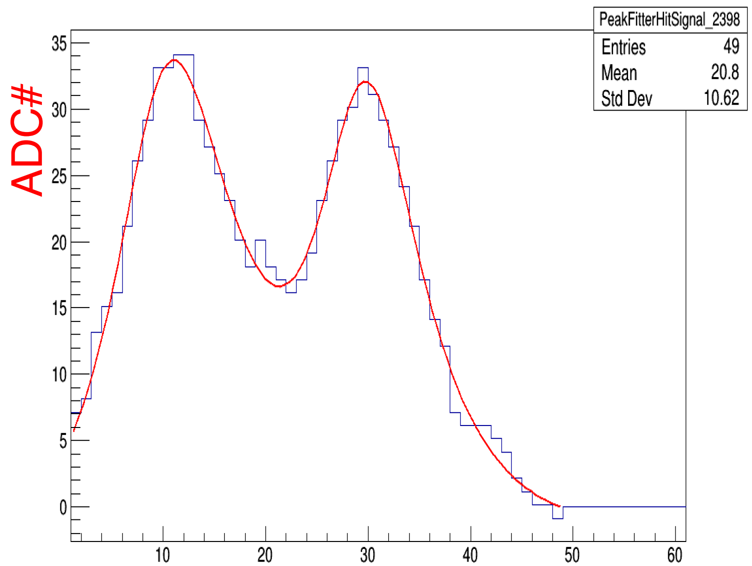
Raw hit-finding algorithm

- Algorithm is inherited from ICARUS software, ported into *larsoft*
- Based on "time over threshold", with minimum width and falling time
- Hit-finding parameters are plane-dependent
- Hit is then fitted, based on double exponential:
- Fitting function is generally asymmetrical, unlike in deconvoluted case

$$f(t) = B + A\,\frac{e^{\frac{-(t-t_0)}{\tau_1}}}{1 + e^{\frac{-(t-t_0)}{\tau_2}}}$$

- Cannot be shown in usual display since shape is asymmetrical (needs larsoft generalization)
- Special fitting function for multiple hits or "long" hits in drift coordinate (due to track inclination): expressed as superposition of standard MIP hits, shifted in time





Sample-initial sample

Deconvolution: the RawDigit Filter Stage

- Simulated waveforms from the detector simulated are stored in "RawDigit" data products.
- The first step in the signal processing is to pass these RawDigits into a filter module
  - This provides an interface to a suite of tools first developed in MicroBooNE to address various forms of electronics noise
    - Coherent noise, low frequency oscillations, other special problems
  - Also characterizes the waveforms
    - Pedestals and rms useful in next steps
- For current production the filter is running a high pass filter (via FFT) to filter out the low frequency oscillation and running the characterization stage
  - We are not using the coherent noise removal since we do not currently output waveforms for channels with no simulated activity
- Eventual plan to look at replacing the current filter module with the noise filtering suite from the BNL wirecell group
  - Looking at a timeline of early next year for this move

Deconvolution definitions

- For a given wire the signal we measure will be a convolution of the "real" signal with the field and electronics responses and the noise in the system:

$$s(t) = \int_{-\infty}^{\infty} r(t-\tau)u(\tau)d\tau + n(t)$$

$u(\tau)$ is the input signal we want to measure
$r(t-\tau)$ is the response function
$n(t)$ is the noise in the system
$s(t)$ is the signal we measure

- The "real" signal can be obtained by taking the Fourier Transform of the above:

$$S(\omega) = R(\omega)U(\omega) + N(\omega)$$

where: S, R, U and N are the Fourier transforms of s, r, t and n respectively

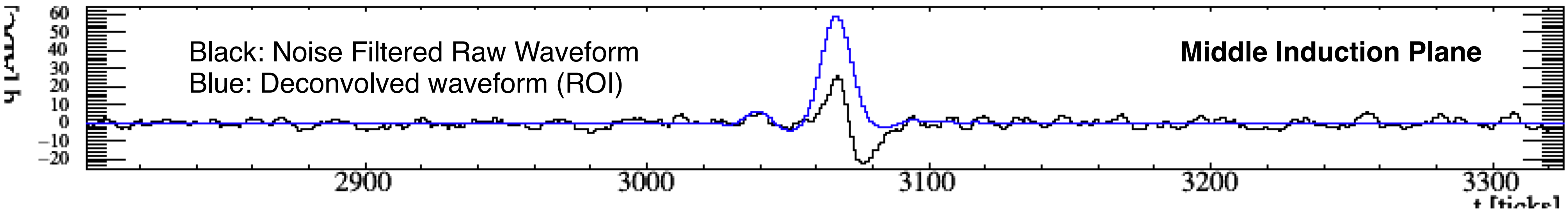
- From which one obtains the "deconvolution" giving an estimate of the "real" signal by taking the inverse Fourier Transform of:

$$\tilde{U}(\omega) = \frac{S(\omega)\Phi(\omega)}{R(\omega)}$$

where: $\tilde{U}(\omega)$ is the estimate of the true signal
$\Phi(\omega)$ is a "filter" function to accommodate the noise

Deconvolution

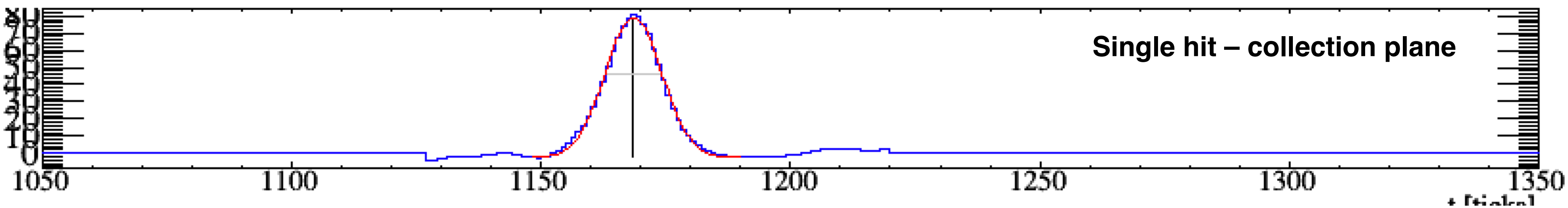
- Generally, the deconvolution will recover a gaussian shaped signal representing the "real" charge deposited in the TPC
  - Not including the effects of recombination and diffusion

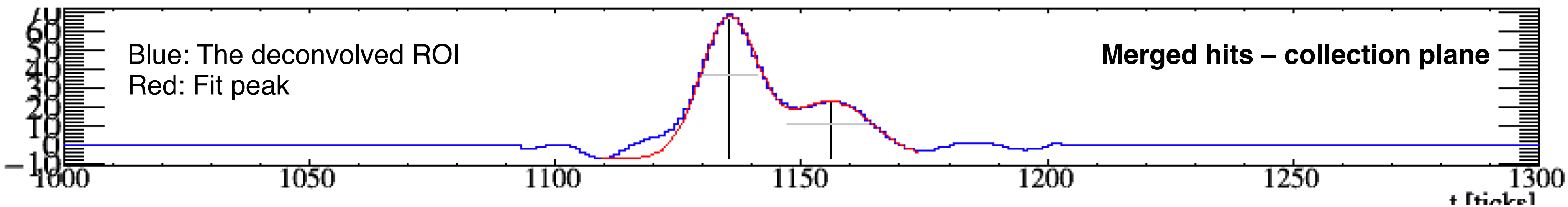


- Generally this approach gives good results for charge deposits from most tracks and showers
  - Best for relatively shallow angle tracks which match the generated field response functions
  - Best for localized charge deposits (vs long pulse trains)
- Starts to break down for more steeply inclined tracks where drift path length differences and induced charge effects become important
  - This can be solved with the 2D Deconvolution that we hope to introduce early next year

Deconvolution Hit Finding with the "gaushit" Finder

- The "gaushit" finder takes as input "Wire" data
  - These are deconvolved waveform snippets which represent "Regions of Interest" (ROI's) for a given wire's waveform
- The first step is to search the snippets for candidate peaks
  - Allow for multiple peaks, perhaps merged together, which can happen near event vertices, delta ray start points, etc.
- Candidate peaks are then fit to one or more gaussian peak shapes





Preliminary efficiency measurement

- Efficiency of hit-finding algorithms measured on production samples, by comparing reconstructed hits with wire-by-wire simulated energy depositions (SimChannels)
- Efficiency defined as (n.of wires with >=1 reco hits)/(n.of wires with >=1 sim hits)
- Pseudo-cosmic muons (E~5 GeV) checked so far, only 1 file (50 events~10000 wires)
- Efficiency >95% in Induction 2 and Collection for both algorithms
- Efficiency>90% in Induction 1 for both algorithms
- No significant efficiency differences between algorithms within the available statistics
- Fake rate roughly ~1 fake hit/wire for Induction1, <~0.1 fake hit/wire for the other two planes

Perspectives and conclusions

- A first-order simulation of wire signal and noise is complete. Tools to handle both correlated/uncorrelated noise are in place, and ready to handle real data.
- Hit-finding performance is generally adequate in both deconvoluted and raw paths and allows adequate following pattern recognisition/reconstruction stages. Performance for large showers/energy depositions, large angle tracks and crowded events must be studied in more detail.
- Offline integration of induction 2 raw signal is available and guarantees adequate hit-finding efficiency. Fitting and calorimetry still to be implemented
- 2D deconvolution will be also tested and introduced by the BNL group, it is expected (as in MicroBooNE) to improve performance for inclined tracks