Optimal Filtering in the Atlas Testbeam

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The Algorithm and
Software Infrastructure

Crosstalk

Results

Status and Plans

Optimal Filtering: The Big Picture

Waveform Modeling

Calibration Delay Runs from Test Beam

Algebraic representation of Calibration and Electron Waveforms

INPUTS

Master Waveforms are a measure of the gain of the system (ADC/uA) at each point in time [effectively a derivative of several DAC settings].

Fit of the Calibration Waveform to the Master Waveform from delay runs

The calculation of the calibration and electron waveforms uses calculated (or measured where available) parameters and the circuit model for L−Ar electronics. The only fitted parameters are the amplitudes of the basis functions.

OUTPUTS

Calibration Waveform (Fit)

Electron Waveform (Prediction)

The Model and Optimal Filtering are completely independent.

Calibration Optimal Filtering Coefficients

Electron Optimal Filtering Coefficients

Optimal Filtering

The Calibration Delay Runs

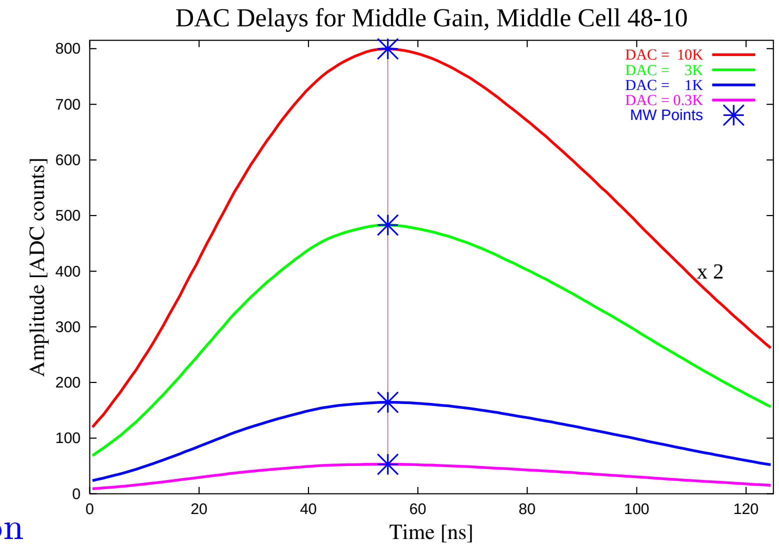
Input data

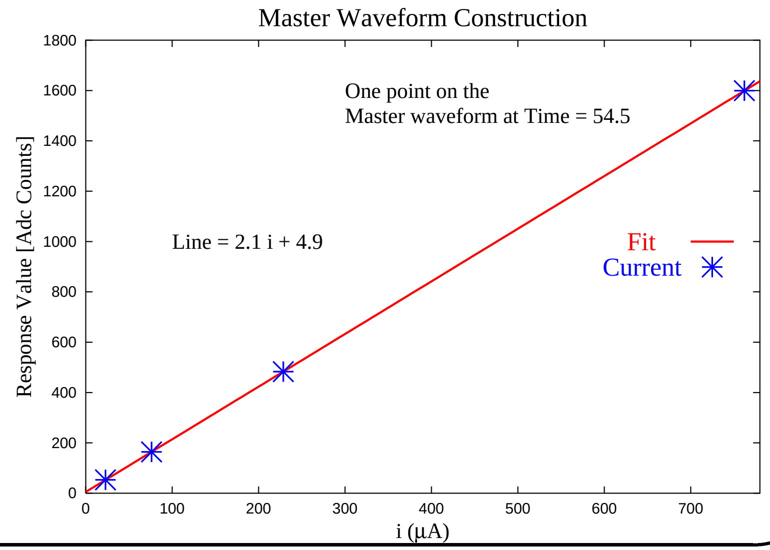
- Use only the test beam delay runs at different DAC values
- A Master waveform is determined by the linear response of the system for several values of DAC in a given time bin, from which the input current is calculated,

$$y = m \times i + b,$$

where y is the response in ADC counts, i is the calculated current for this DAC setting and m, b are fit parameters to the delay data at each time. The master waveform is the component of the calibration response proportional to the DAC.

- Several DACs settings are used to map the response of the system to obtain a response averaged over the DAC value, and independent of the clock feedthrough and DAC offset.
- The peak value of the master waveform is the calibration constant (ADC/μA) for the channel.

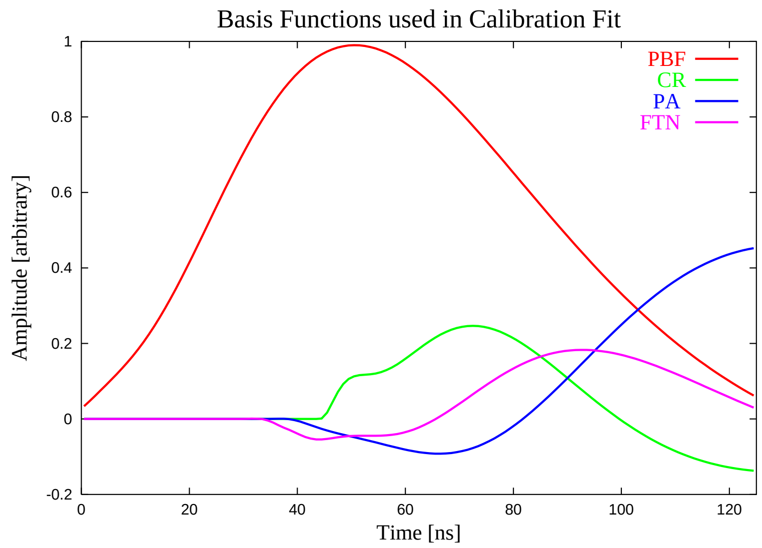


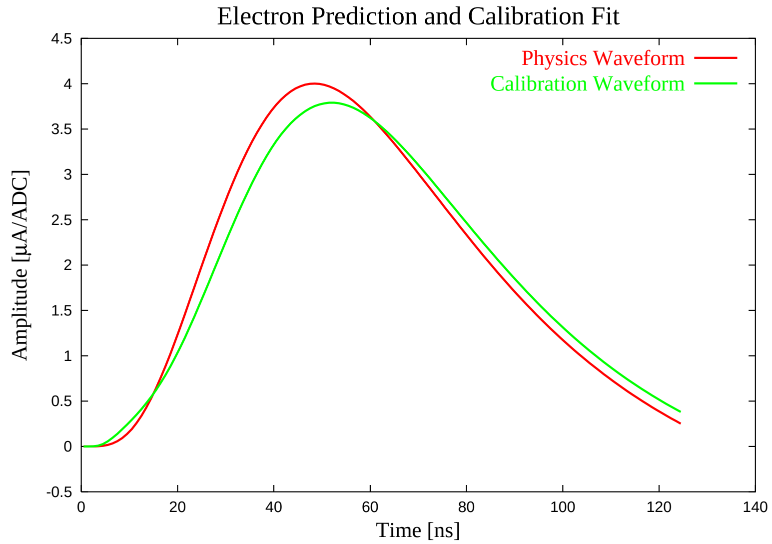


The Waveform Calculation

Calibration/Electron Waveforms

- We use the standard form (two-pole pre-amp, RC^2CR shaping) for the response function with all of the known values of the circuit components.
- Detector inductances, capacitances use nominal measured or calculated values. Effects of reflections are important.
- One additional pole is added to to simulate the skin effect
- The amplitude of the electron curve is calculated for the same value of input current as the calibration master waveform. (note the difference in peaking time and amplitude)





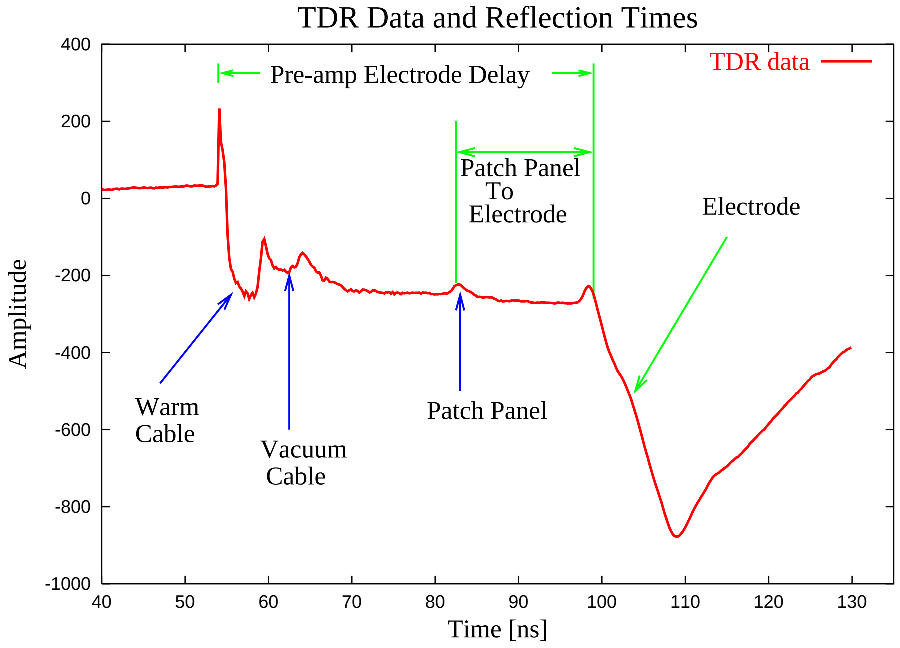
Calculation Details

- The calibration curve is a sum of one or more of the primary waveforms plus reflection terms. All curves used to describe the calibration are a linear combination of these functions:
  (1) Primary basis function (PBF), (2) Reflection
  from the pre-amp (PA) (3) Reflection from the Feedthrough Network (FTN), (4) Reflection from the Patch Panel (PP), and (5) Reflection of the calibration signal from the termination resistor (CR)

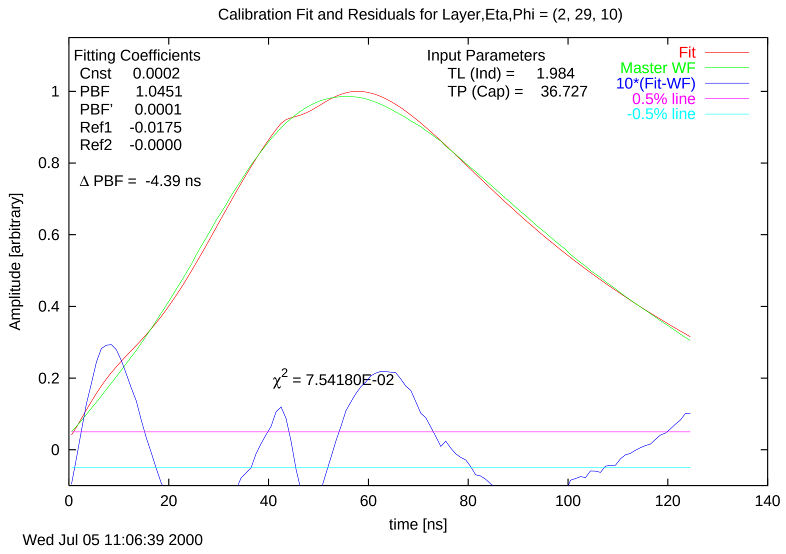
Mon Dieu, Mon Dieu, Reflections, Reflections....

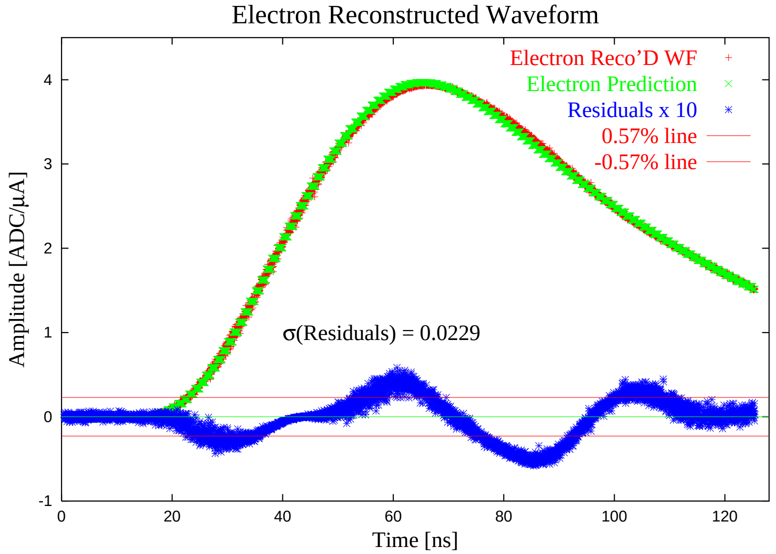
Reflections Notes

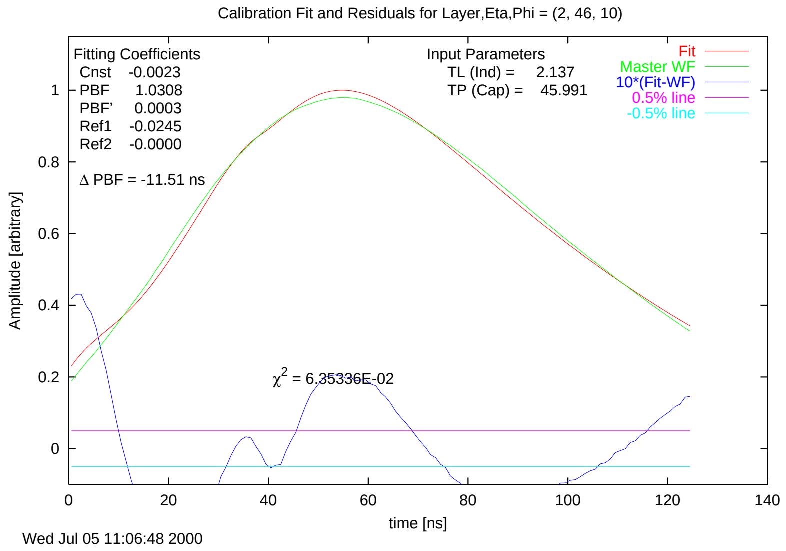
- In order to achieve the desired accuracy in the calibration fit, one must consider reflections.
- Reflections can mimic incorrect values for capacitances and inductances.
- The reflections typically contribute between 1% and 3%.
- The reflections are due to several "features" of the circuit:
  - cold cable termination at the preamp
  - feedthrough network (including warm and vacuum cables)
  - patch panel
  - calibration cable termination (affects calibration signal only)
- TDR measurements are crucial in determining the timing of the reflections.
- See W. Cleland's talk on Reflections (Test Beam meeting, 27/2/00)

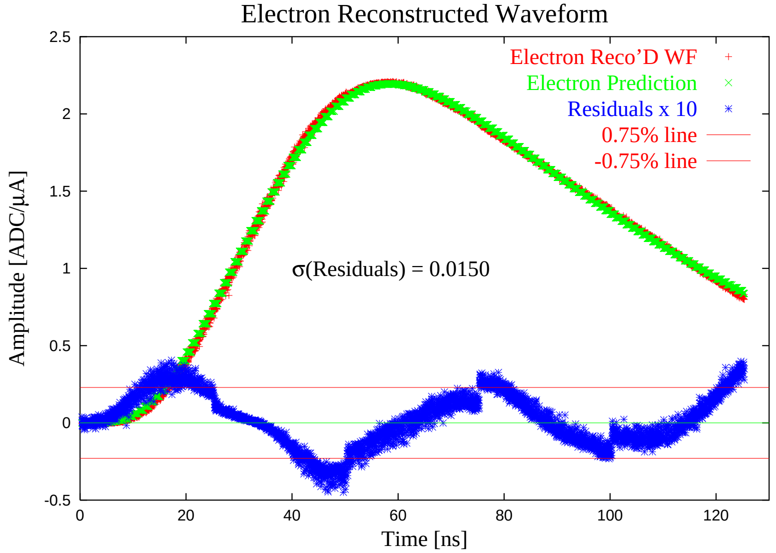


Example of Reflection Problems









Calculation Notes

The circuit model

- The electron current is triangular; the calibration is exponential and has a step-function component
- The inductor/capacitor are in series in the electron; parallel in the calibration
- Nominal drift time is used is for the electron pulse

Frequency Domain Calculation

- All calculations are performed in the Laplace Frequency domain and transformed back to the time domain.
- Partial Fraction Expansion is used to calculate time domain

$$\frac{F(s)}{\Pi G_i(s) L^n(s)} = \sum_i \frac{M_i}{G_i(s)} + \sum_{p=1}^{n} \frac{K_p}{L^p(s)},$$

  $G_i(s)$ are simple roots and $L(s)$ are n repeated roots. The time-domain is trivial on the right hand side of this equation,

$$\frac{1}{(1+s\tau)^n} \rightarrow \frac{t^{n-1} e^{-t/\tau}}{\tau^n (n-1)!}.$$

- This expansion is calculated in maple and exported as c-code with circuit parameters as arguments.
- Reflection waveforms are calculated exactly, using frequency dependent reflection coefficients.

Optimal Filtering

Quick Overview

- A given sample (S_i) is a point on a known waveform, $g(t)$. For any time, we can write the expected value of S_i as $y_i = Ag(t_i - \tau)$. We can expand this in a Taylor series using the function g and its derivative g',

$$y_i = Ag(t_i) - A\tau g'(t_i)$$

- The Amplitude (A) of a waveform is given by: $A = \sum_i a_i S_i$, where the a_i are the amplitude optimal filtering coefficients and the S_i are the sample points (typically five). The normalization of the a_i are such that the units of A are μA with S_i given in ADC counts.
- An independent quantity ($A\tau$) is also determined by $A\tau = \sum_i b_i S_i$, where the b_i are the timing optimal filter coefficients for the set of sample points. Fitting for τ makes the amplitude A insensitive to timing shifts to first order, which also renders A insensitive to capacitative crosstalk.

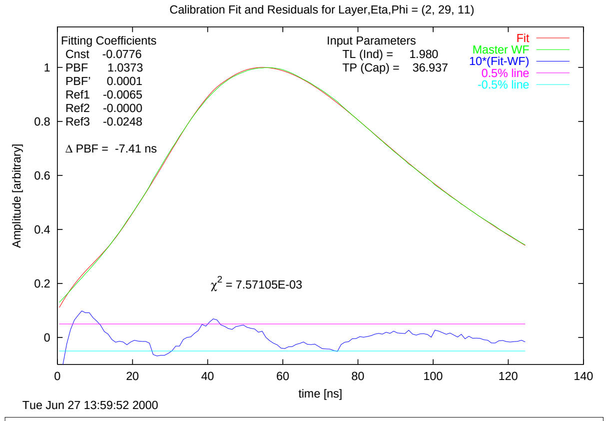
Details.....

- The optimal filtering coefficients are determined by minimizing the variance of the amplitude and time measurements. The autocorrelation function is needed for this minimization.
- Four additional constraints are used as Lagrange multipliers in determining the optimal filtering coefficients, $\sum_i a_i g_i(t) - 1 = 0$, $\sum_i b_i g\prime_i(t) + 1 = 0$, and $\sum_i b_i g_i(t) = \sum_i a_i g\prime_i(t) = 0$.

Using Optimal Filtering

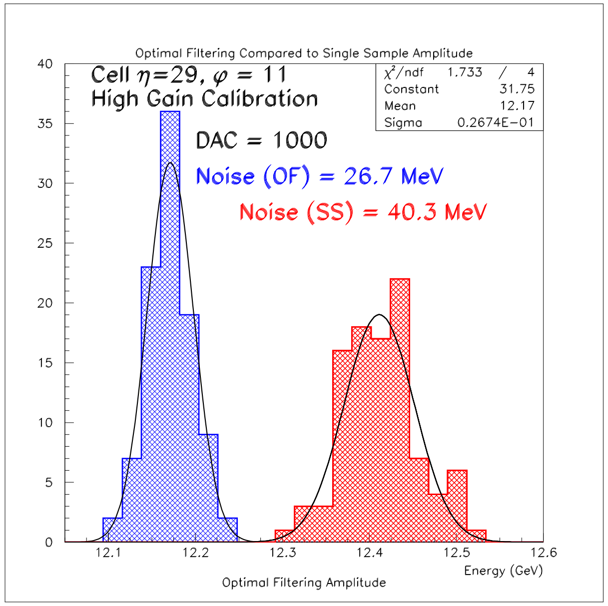
Fitting the Calibration Signal

- We fit the calibration waveform to the PBF plus reflections.
- In the fit on the right, there are three reflections: one from the pre-amp, one from the patch panel and one from the calibration cable. The residuals, multiplied by a factor of 10 and shown as the lower curve, are typically below 0.5%.



Reconstructing a Calibration Waveform

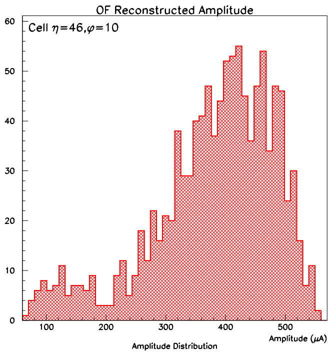
- Using calibration runs as events, we compare the optimal filtering to the "single sample" measurement selected at the peak
- The optimal filtering distribution is narrower and peaked at a slightly different value due to effects like clock feedthrough and DAC offset.

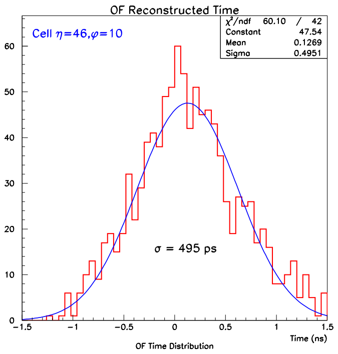


Optimal Filtering for Electrons

Global Reconstruction Quantities

- With the prediction of the electron waveform, we obtain optimal filtering coefficients for all electron cells.
- We measure the amplitude *directly* in μA.
- We reconstruct global quantities like amplitude and time distributions. (For the testbeam data, the timing resolution is limited by the beam scintillator counters.)





Waveform Distributions

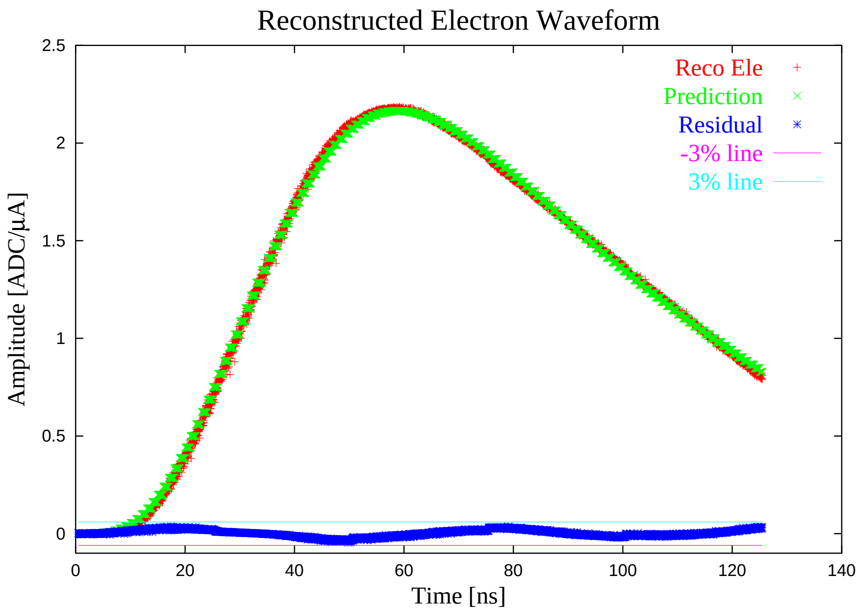
- Electron waveforms can be reconstructed using the amplitude per event and the timing per event. For a set of samples S_i and sample timing t_i,

$$S'_i \rightarrow S_i/A$$

and

$$t'_i \rightarrow t_i + \tau$$

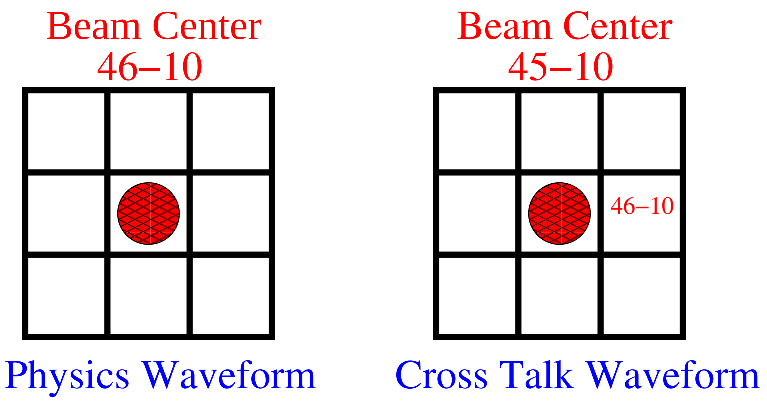
- Optimal filtering is an extremely powerful analysis tool!



The Crosstalk Waveform

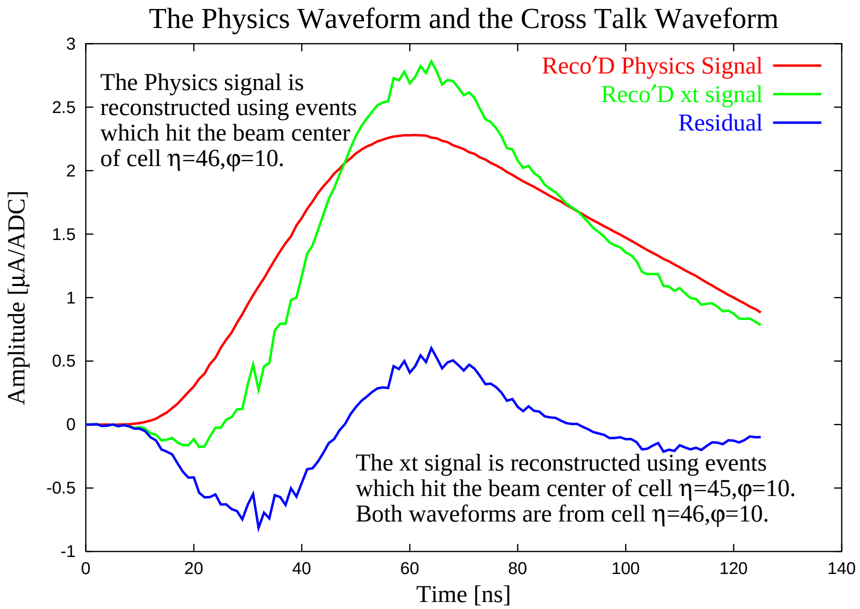
Electron Reconstruction

- Optimal filtering allows one to reconstruct both the amplitude and the time of an electron signal.
- We can construct a "master" electron waveform from this reconstruction using the asynchronous data.



The Physics and the Crosstalk signal

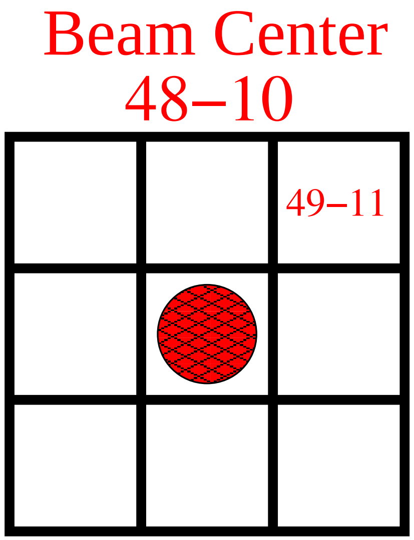
- The physics signal for a given cell can be reconstructed from TB data when the beam is in that cell. The signal is primarily due to the electron current.
- The crosstalk signal is reconstructed when the cell is the "spectator cell." The resulting waveform is a composite of the physics signal and a crosstalk signal.



Crosstalk

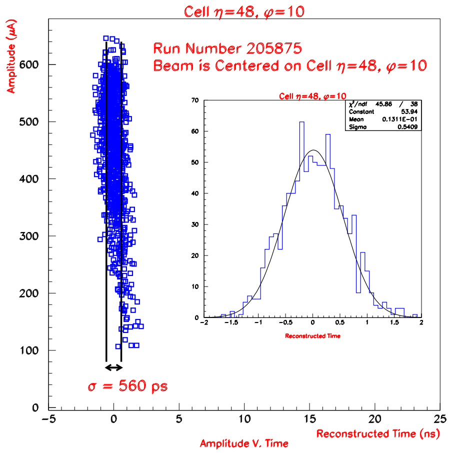
Event-by-event study of crosstalk

- When we plot reconstructed amplitude vs. the time for cells which are neighbors ("spectator cells") to the one hit by the beam, we observe an unexpected distribution.
- By viewing raw data for events which have low amplitude and large τ (see following slide), we conclude that the waveform is not given by our model, but rather similar to the one shown on the previous slide.

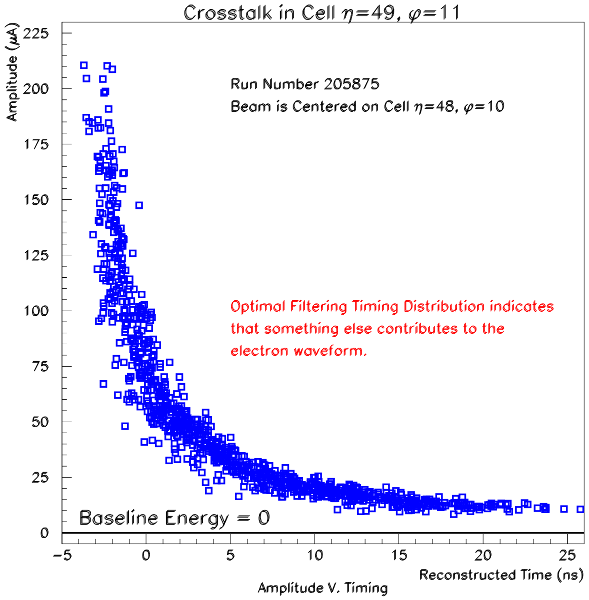


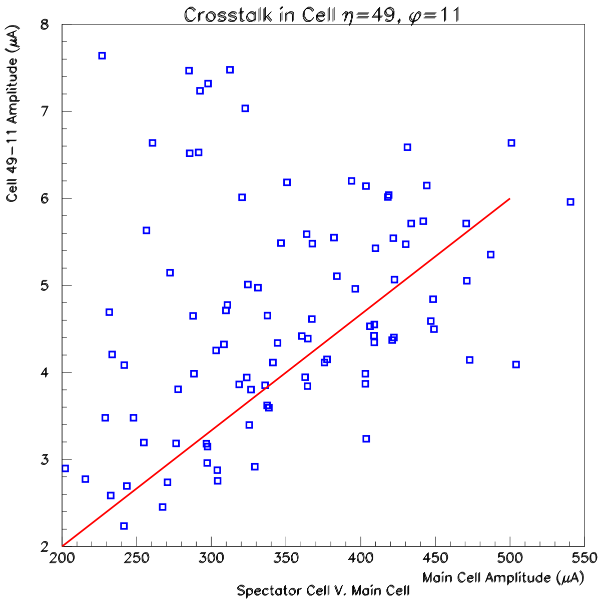
Analysis

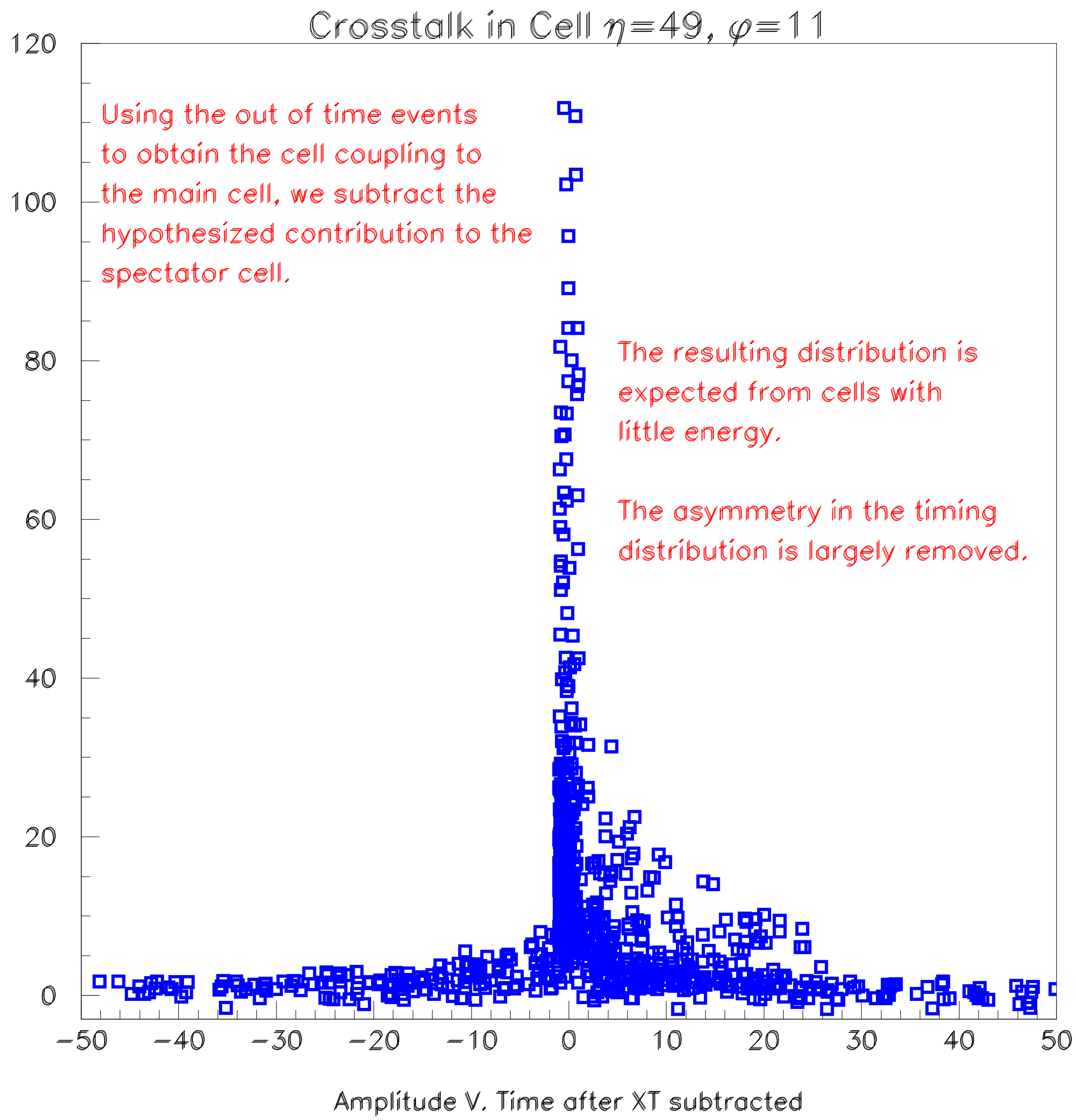
- We look for correlations between the energy deposition in the main cell and the amplitude found in the "spectator cell"
- We determined a coupling based on the energy of the main cell and the amplitude of the out of time "spectator" events
- We subtract the crosstalk, using this coupling constant and an approximate "crosstalk waveform" and compare the amplitude vs. time in this crosstalk subtracted sample.



Crosstalk Can Be Removed Event-by-Event







Software Notes

Dependencies and Inputs

- Fitting package and optimal filtering package are independent C++ routines which depend on the *Standard Template Library* and *CLHEP*.
- The input data uses waveform profiles from an averaging procedure over test beam data events. A profile is an average of delay runs for a given value of the DAC.

Outputs

- *Optimal filtering coefficients for the electron and calibration waveforms*
- Performance parameters: χ^2, reflection amplitudes, calibration constants
- Graphics interface to *gnuplot* with fitting waveforms and electron waveforms

Software Plans

- Calculate the autocorrelation function calculation based on fit waveform (cell by cell)
- Make any additional systematic corrections to the optimal filtering coefficients (for example, to account for nonuniformities in the calibration system).

Status and Plans

Current status

- Optimal filtering coefficients have been obtained for the back, front and middle sections for any middle gain cell with delay runs
- Very good χ^2s for all of the calibration fits
- See http://www-atlas.phyast.pitt.edu/optfilt for more information and plots of the calibration fits
- Software is freely available at http://www-atlas.phyast.pitt.edu/optfilt

Things to do...

- We must analyze TDR data from the front layer to obtain reflection times (Pittsburgh)
- Obtain optimal filter coefficients for the presampler layer (Pittsburgh)
- Re-analyze data including OFCs for the presampler layer (BNL)
- Apply analysis to Test Beam 2000 (BNL, Milano ...)
- Document! (Pittsburgh)