LA-UR-16-22669

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Title: Establishing precision and accuracy in PDV results

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Intended for: document technical issue

Issued: 2016-04-19

Establishing precision and accuracy in PDV results

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Outline

- Why do we need to know uncertainties & systematic errors?
- Do we care about systematic and random errors separately?
- How to estimate precision and accuracy in PDV results.
- Sources of uncertainty and accuracy.
- Examples of characterizing a method.
- Discussion: what does the community need?

Why do we need to know uncertainties & systematic errors?

LANL, Sandia and LLNL Certify that our weapons will work.

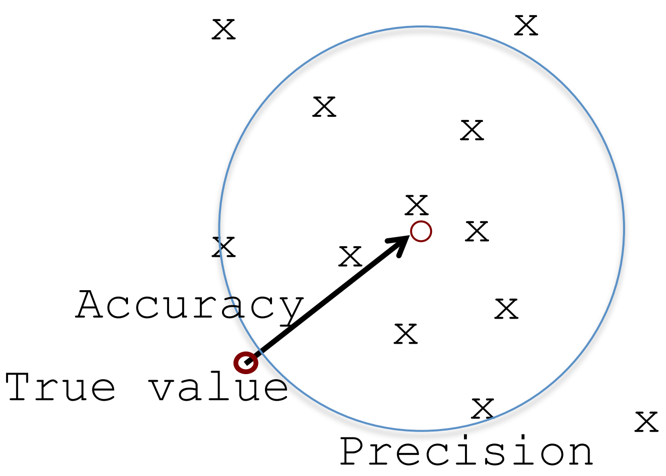
- We create and compare against archival weapons data; do we still get the *same* answer?
- We constrain the models: Is the model *consistent with* the data?
- We provide scientific results: Equations of state, material failure, ejecta…do new materials *match* the old? What range of parameters can a model justify using to match an experiment?

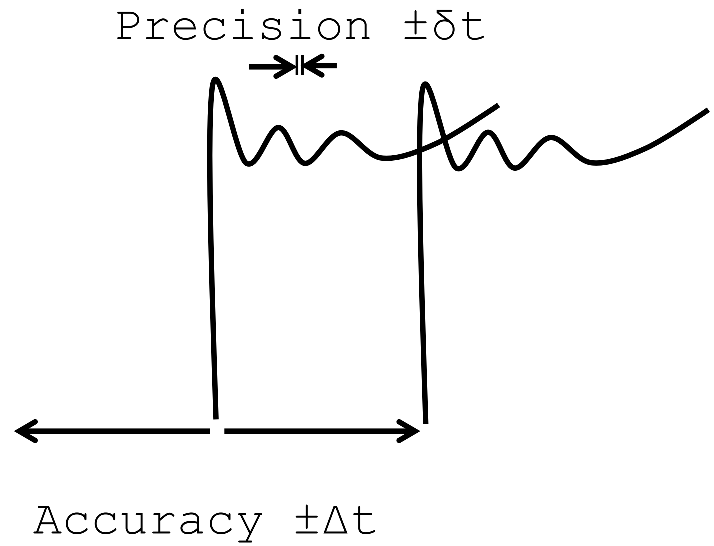
Example: Do new velocimetry results give the *same answer* as historical pin results?

$$\mathbf{v \pm \Delta v \rightarrow x_v \pm \Delta x_v \leftrightarrow x_p \pm \Delta x_p}$$

Complicated connection

Do we need to know our accuracy and precision separately, or will the largest suffice? We need to know both:

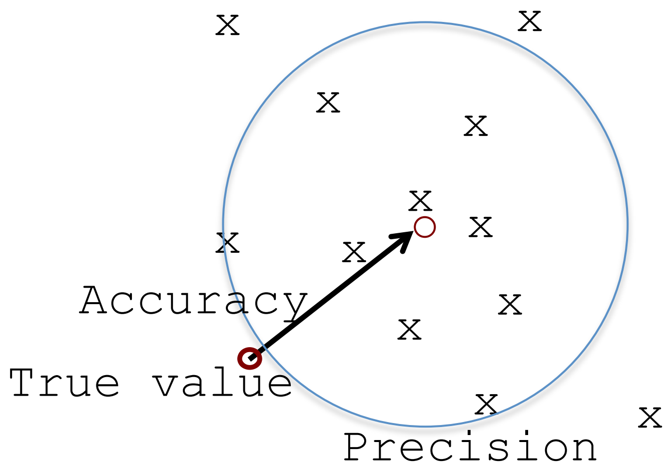


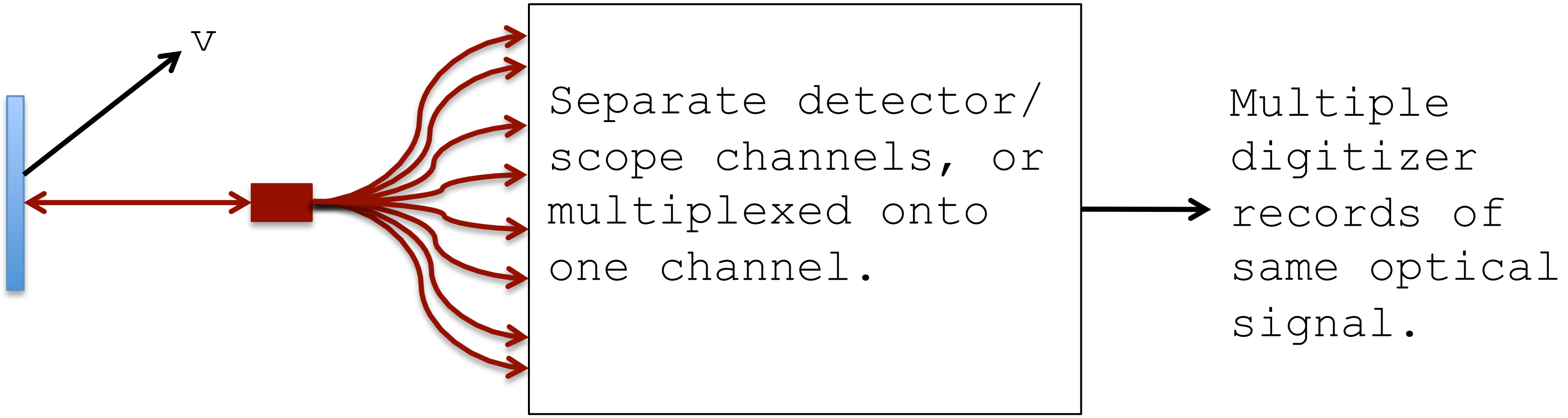


A systematic error is usually common to a group of data points, so that the whole group of data may be moved, but the relative changes must stay within the precision.

How do we find the accuracy and precision?

- Precision can be estimated from:
  - o Split signal experiments.
  - o Synthetic data.
- Accuracy can be estimated from:
  - o Independent measurement. Techniques.
  - o Synthetic data, but only for extraction, not recording.
  - o Systematic errors in recording are not revealed.

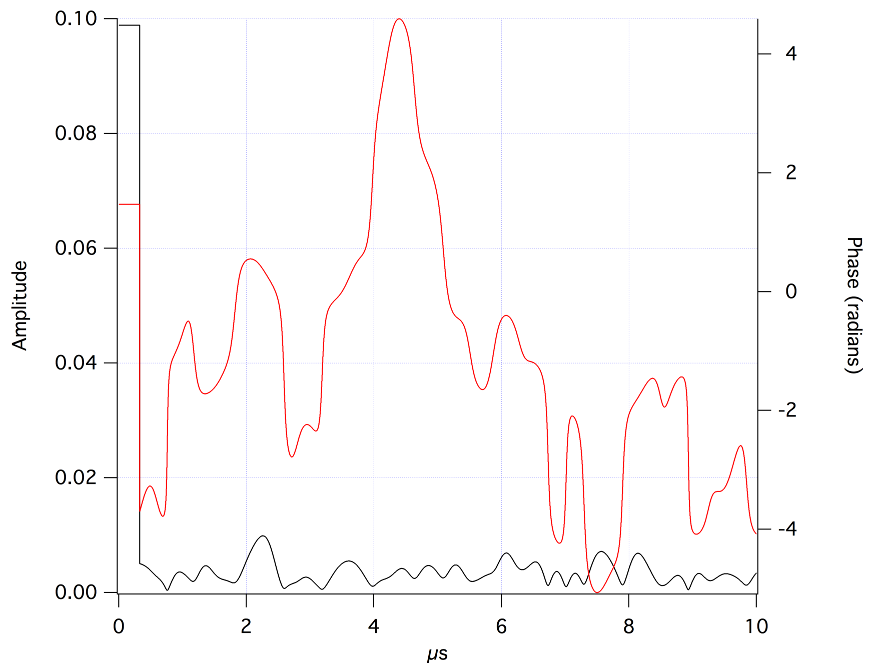




Assertion: we have or will soon have reliable estimates of precision available. We now need estimates of systematic errors.

Sources of systematic error in the optical signal

- Fast random amplitude variations
  - Shock break-out
  - Speckle
- Fast random phase variations
  - Laser phase drifts
  - Speckle
- Fast frequency variations not from motion (laser problems, harmonic distortion in recorder.)



Conjecture: Optical signal variations become systematic errors only if too sudden relative to the effective analysis window

- Amplitude conjecture: **Amplitude variations** become a problem if they are as fast or faster then the effective analysis window. Otherwise, they can be fit.
  - Limit (noiseless) is the bandwidth of the recording;

$$(1/A)\Delta A(\Delta t) << 1 \text{ for } \Delta t = \text{effective analysis window.}$$

  - In the absence of noise, the limit would be the system rise-time.

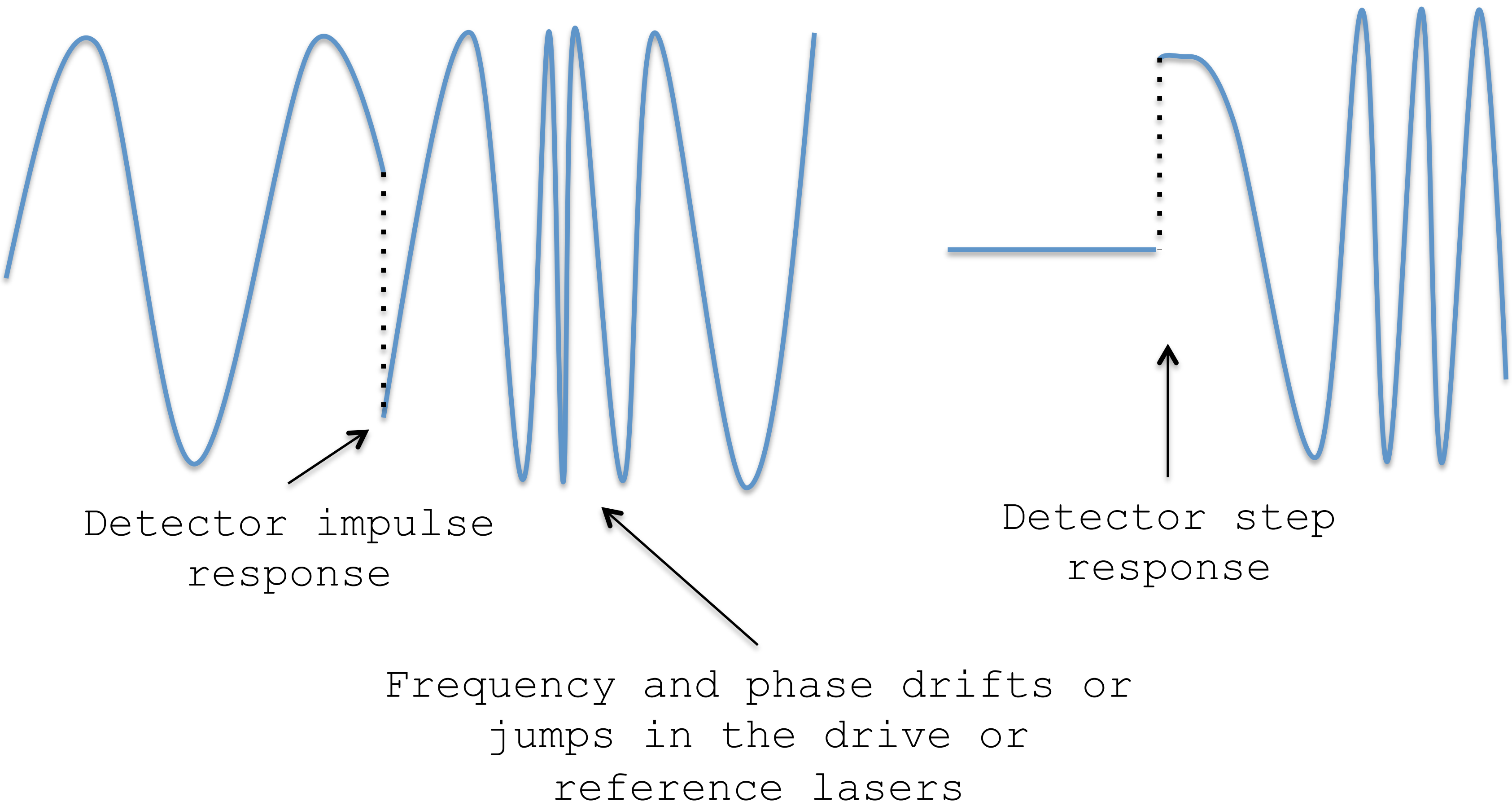
- Phase conjecture: **Phase variations** become a problem if they are comparable to the phase change from the beat frequency. Otherwise, they can be fit.

$$\Delta\Phi(\Delta t) << \omega_b \Delta t \text{ with } \Delta t \text{ the effective analysis window}$$

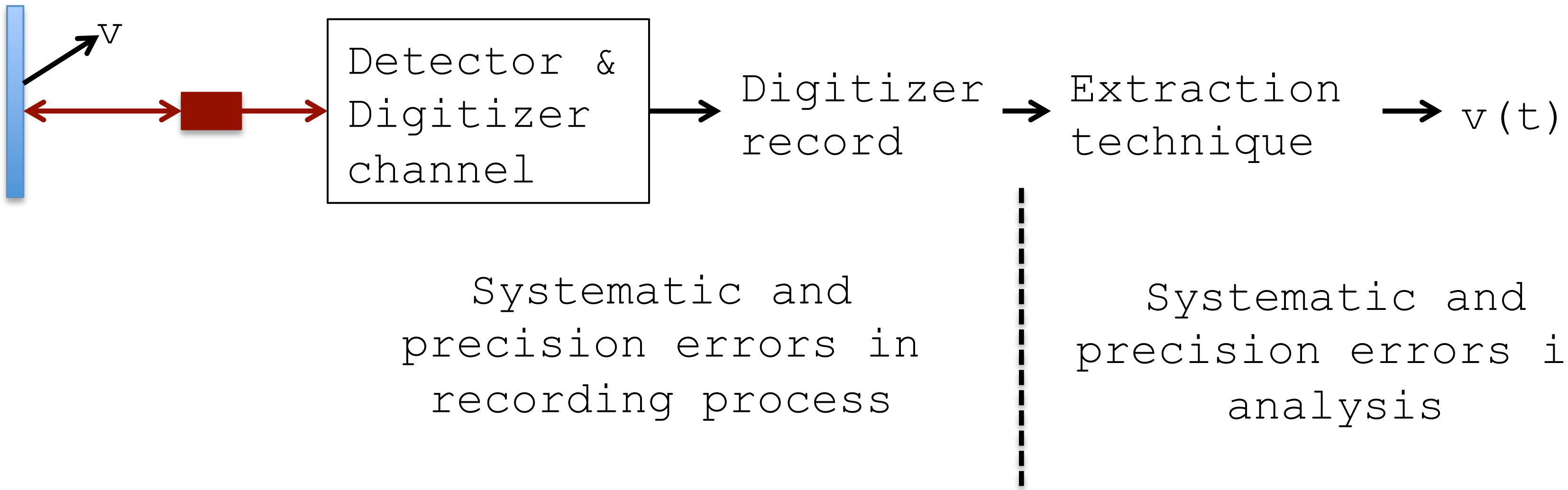
- Frequency conjecture: **Frequency variations** (not arising from motion) become a problem if they are comparable to the the beat frequency. They cannot be removed in analysis unless measured somehow.

$$\Delta\omega(\Delta t) << \omega_b \text{ with } \Delta t \text{ the effective analysis window}$$

Sources of systematic error from the detector & digitizer



Systematic errors from the detector response will not be measurable by either split-signal tests or synthetic data.



The error estimated from the analysis of the data can change with refinements in analysis technique. However, the accuracy and precision of the digitizer record are intrinsic to the measurement and will never change. The precision will reveal itself in split-signal experiments, but the systematic errors require a separate measurement of the detector response function.

Proposal for characterizing these errors

Impulse response data is now being gathered by Araceli Bender of NSTec for several combinations of detectors & digitizers. To find the systematic error that these would create, create a model of the impulse response and apply it to synthetic data.

Systematic Errors in Analysis

- Amplitude, frequency and phase variations mentioned earlier under systematic errors inherent in the signal.
- Presence of nearby frequencies.
- Analysis window position steps relative to data record.

Performance depends on specifics of signal

Extraction Method	Interpolated FFT	Extraction Method	Statistics-based Spline Fit
Extraction Description	After spectrogram creation, f_t, a first attempt at extracting the dominant frequency at each time step is to take the frequency at which the maximum signal strength occurs within the ROI. The interpolated fast Fourier transform (IpFFT) method, described by Schoukens (1992), advances this idea. For each t, the location of the maximum peak within the bounds of the ROI is determined, i, and the frequency, f(t), is given by f(t) = f_t(i) + ((2|f_t(i+1)/ f_t(i)|-1)/(|f_t(i+1)/f_t(i)|+1)).	Extraction Description	Two papers are attached giving more detail.
Error Bar Method	None currently implemented.	Error Bar Method	Statistical; produces fit errors and random errors.
Velocity Resolution limit	x	Velocity Resolution limit	x
Time Resolution	x	Time Resolution	x
BOT Resolution	x	BOT Resolution	x
Rise Time 20-80%	Done for Pollux, waiting to hear if this number is unclassified.	Rise Time 20-80%	Done for Pollux, waiting to hear if this number is unclassified.
Multiple Velocity Process	Only computes 1 velocity. It targets the velocity with greatest signal strength. To avoid unwanted velocities the ROI must be "squeezed" around the velocity of interest	Multiple Velocity Process	Only computes on velocity for one time point and oscillates (sine-like) about the stronger signal. If only one signal was present, that additional oscillation disappears.
Crossing Velocities Process	Only computes 1 velocity. It targets the velocity with greatest signal strength	Crossing Velocities Process	Has difficulty differentiating between two velocities in one ROI as they cross and favors the stronger velocity.
Zero frequency Process	FFT-based methods have high difficulty estimating zero frequency leading to noisier extractions near zero frequency (i.e errors are high near zero frequency). This leads to additional uncertainties in the BOT.	Zero frequency Process	Extremely noisy at zero frequency for non-upshifted velocities.
Removing Constant Velocities	x	Removing Constant Velocities	x
Resolving Surface within distribution	IpFFT follows peak center in unimodal symmetric distribution. In multimodal or nonsymmetric distributions this method follows the peak of greatest strength.	Resolving Surface within distribution	Tends to follow peak strength.
S/N Process	Does not output. Uses ROI to estimate noise about a region.	S/N Process	Does not output. Uses ROI to estimate noise about a region.

Summary of status of precision & accuracy in PDV

- Good estimates of precision from the data record are available and should be incorporated into existing results; reanalysis of valuable data is suggested.
- Estimates of systematic errors are largely absent. The original work by Jensen et al. using gun shots for window corrections, and the integrated velocity comparison with X-rays by Schultz are two examples where any systematic errors appear to be <1% level.
  - Do folks know of other examples?
  - Should we put in the resources to explore the sources identified above and try to determine their levels? Under what conditions?