The Response of Residential Smoke Alarms at Low Flow Velocities

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Objective

To develop time response model correlations for residential-style smoke alarms as a function of flow and approach angle

Background

- Heskestad's first-order response model
  - one parameter, characteristic length
  - inadequate low-velocity predictions
- Critical velocity concept (Brozovski, 1991)
  - Below ~ 0.15 m/s no alarms
- Cleary *et al*. first-order response with lag
  - 4 parameters, function of flow velocity
- Ierardi's flow measurements (2005)
  - Detector internal velocity can be a small fraction of the approach velocity

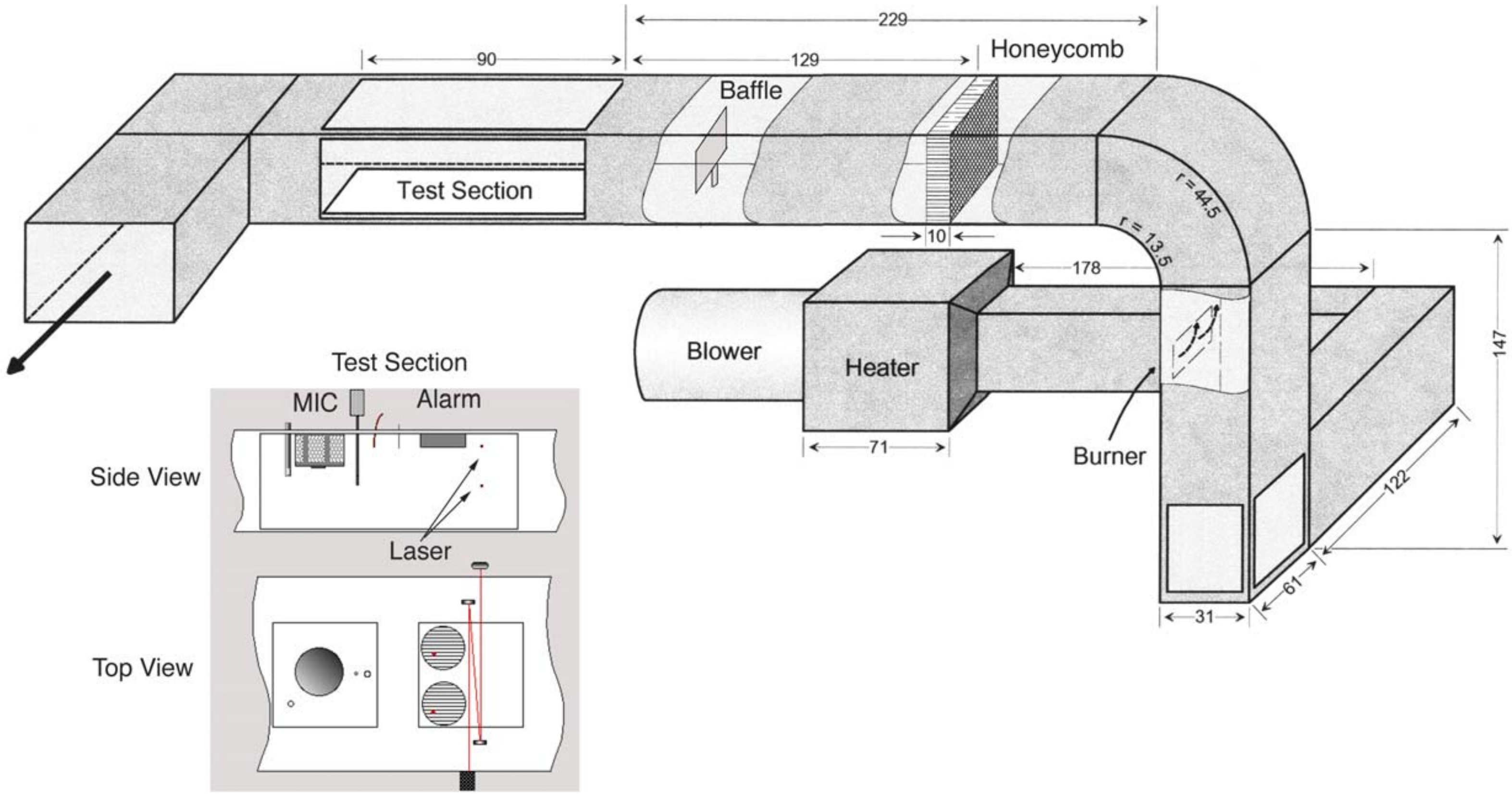
Background Cont.

- Gockel overall model (AUBE ’01)
  - Sensor housing acts as a particle filter
  - bandpass filter concept for particle losses inside detector
- Rexfort coagulation model in FDS
  - Models coagulation from source to alarm location
- FDS implemented smoke alarm algorithm
  - User can choose between L number and 4-parameter model

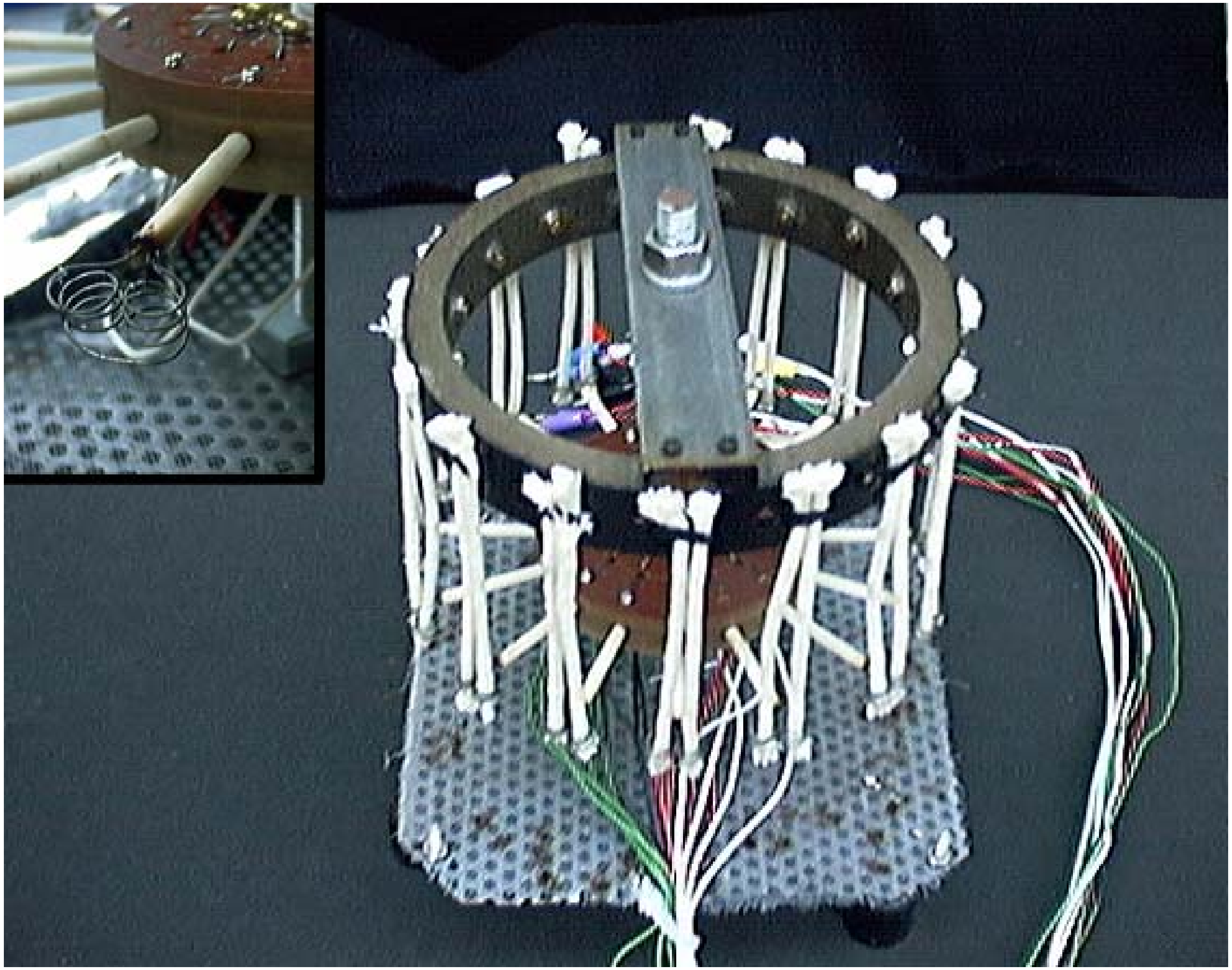
Experimental Approach

- Use FE/DE and cotton smolder smoke
- Examine 3 alarms (2 ion, 1 photo) from HSAT series and 1 battery-powered ion model – Record sensor response voltage
- Vary flow from 0.02 m/s to over 0.2 m/s
- Examine 3 approach angles (0^o,90^o,180^o) relative to the sensing chamber location

The Fire Emulator/Detector Evaluator



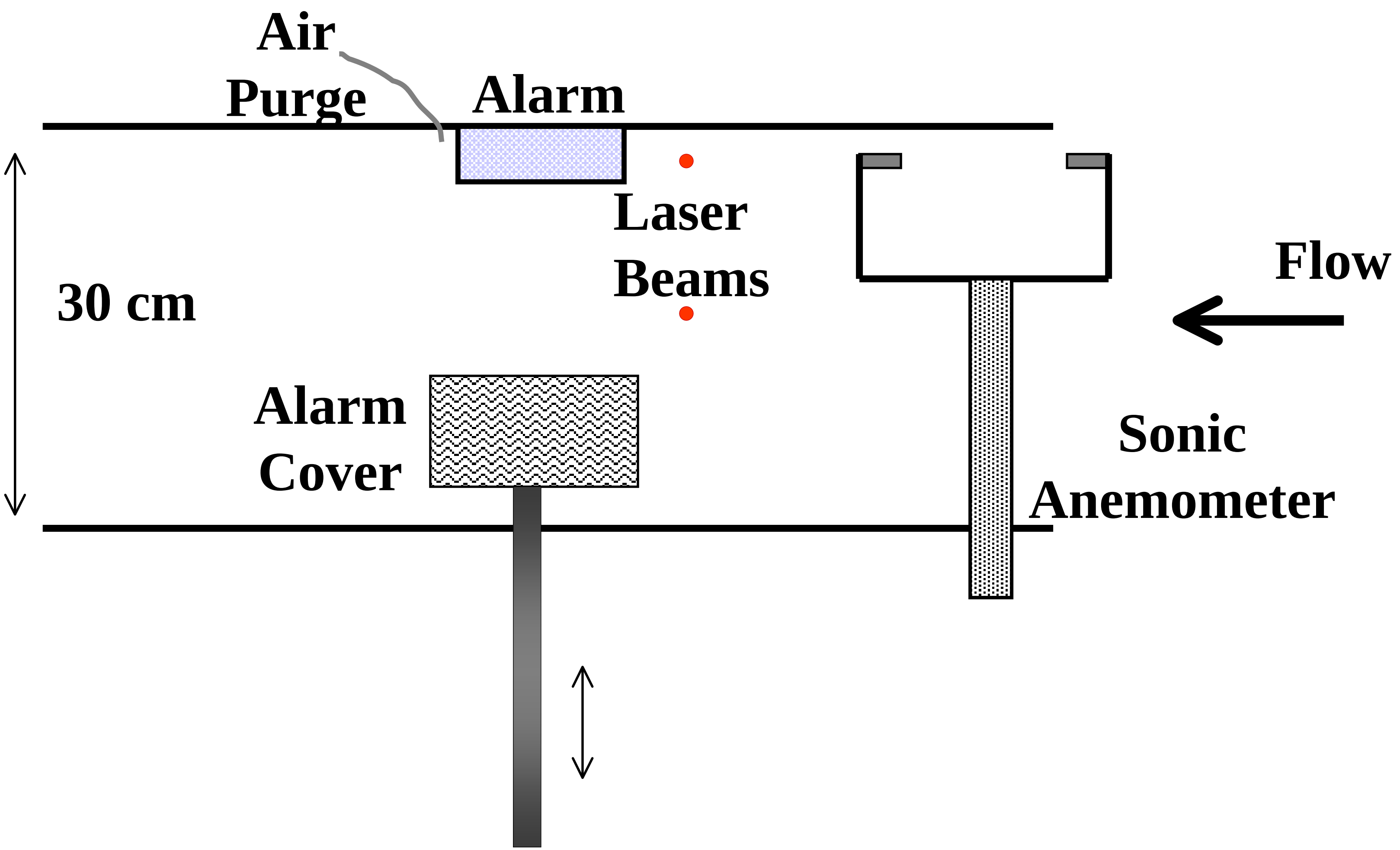
Cotton Smolder Smoke Generator
Staged Wick Ignition



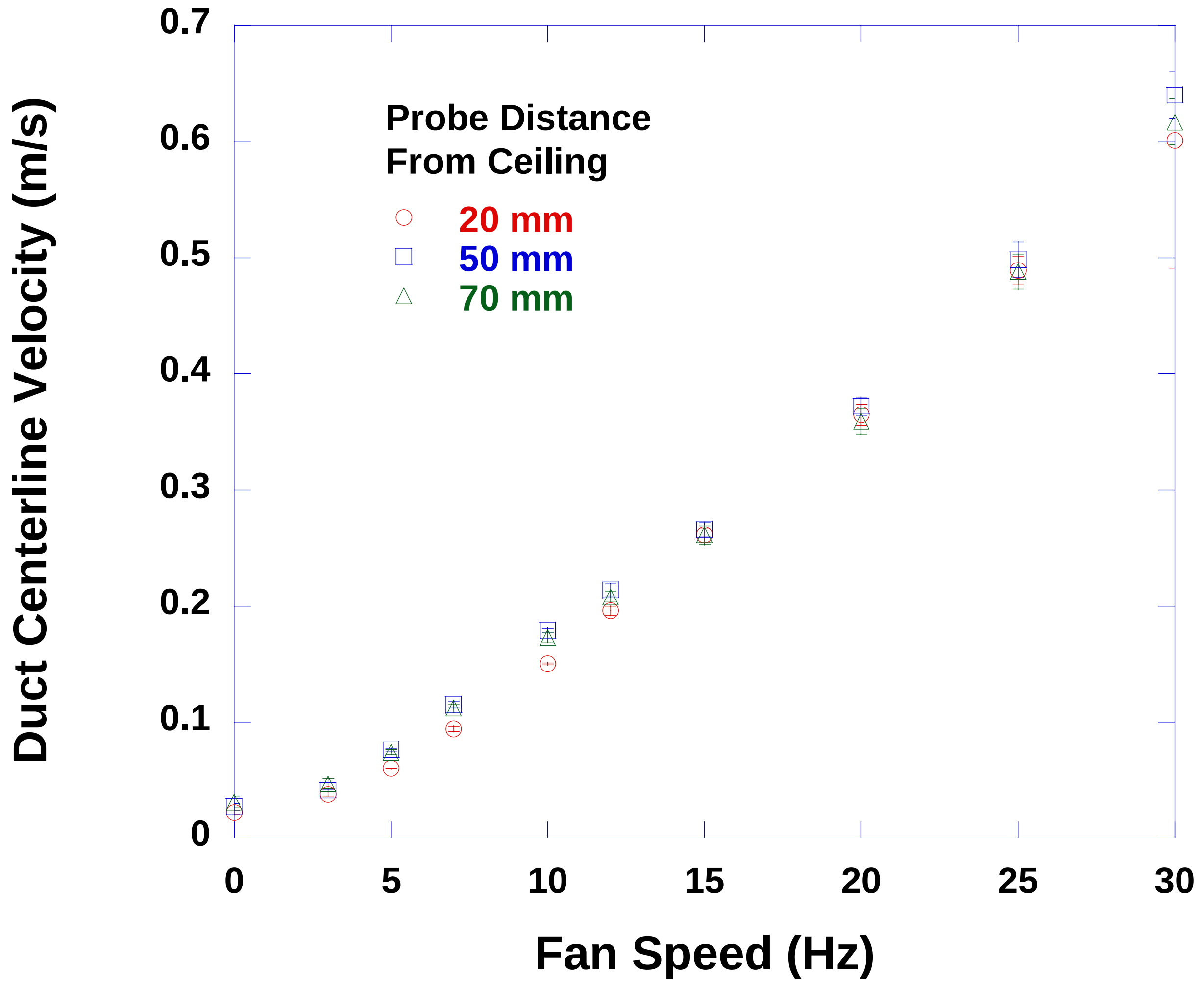
Test Procedure

- Ignite a number of wicks
- Set fan speed to establish flow velocity
- Cover and purge alarm
- At steady laser transmittance start data recording, and at a fixed time period drop alarm cover
- After alarm reaches steady-state, cover and purge alarm and repeat.

Cross-section of Test Section

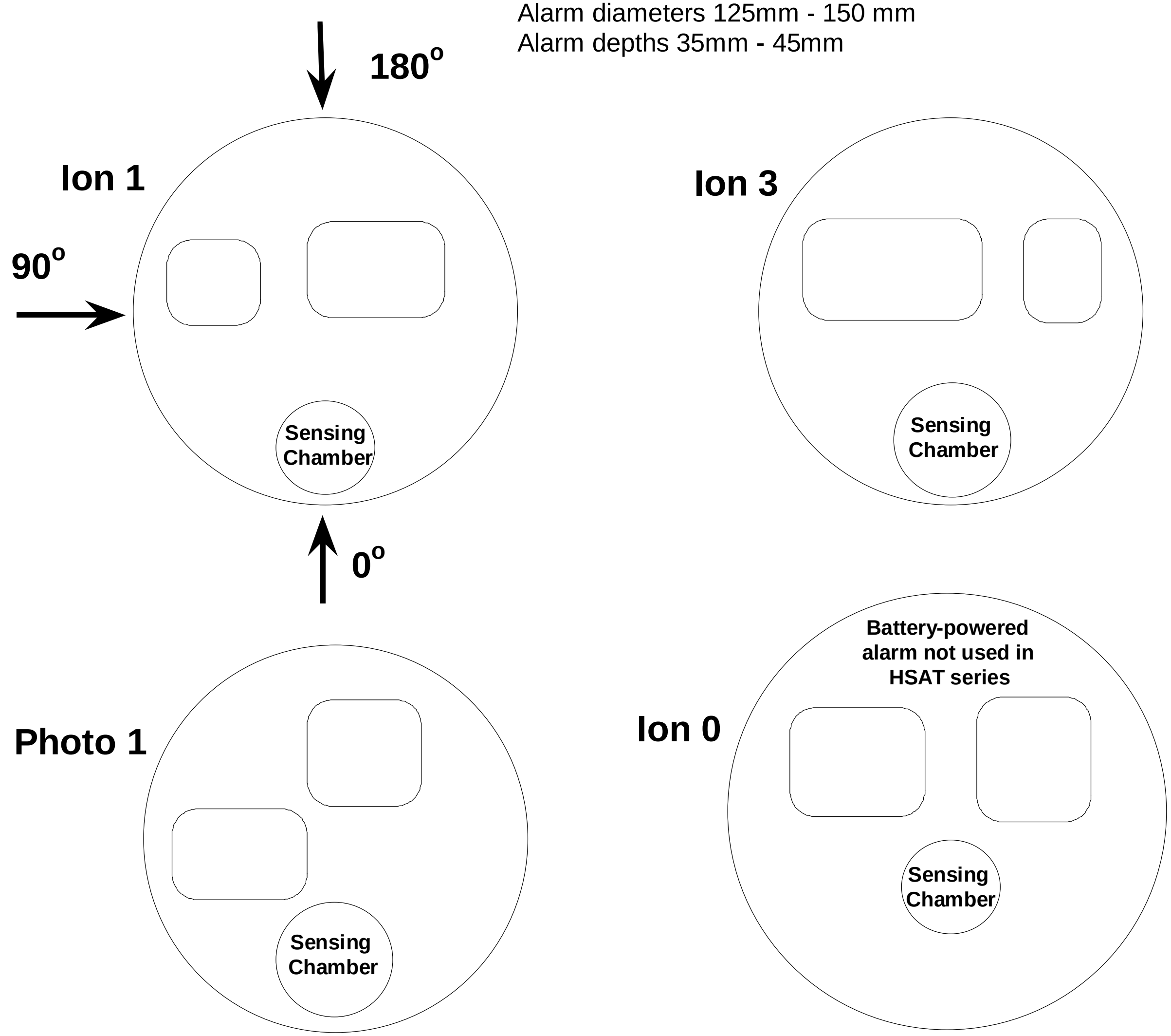


Duct Velocity



Alarm sensor locations and approximate locations of flow obstructing components

Alarm diameters 125mm - 150 mm
Alarm depths 35mm - 45mm



Fitting Equation

$$Y = Y_{end}\left(1 - e^{\left(t-td/\tau\right)}\right)$$

$Y = x(2-x)/(1-x)$, where

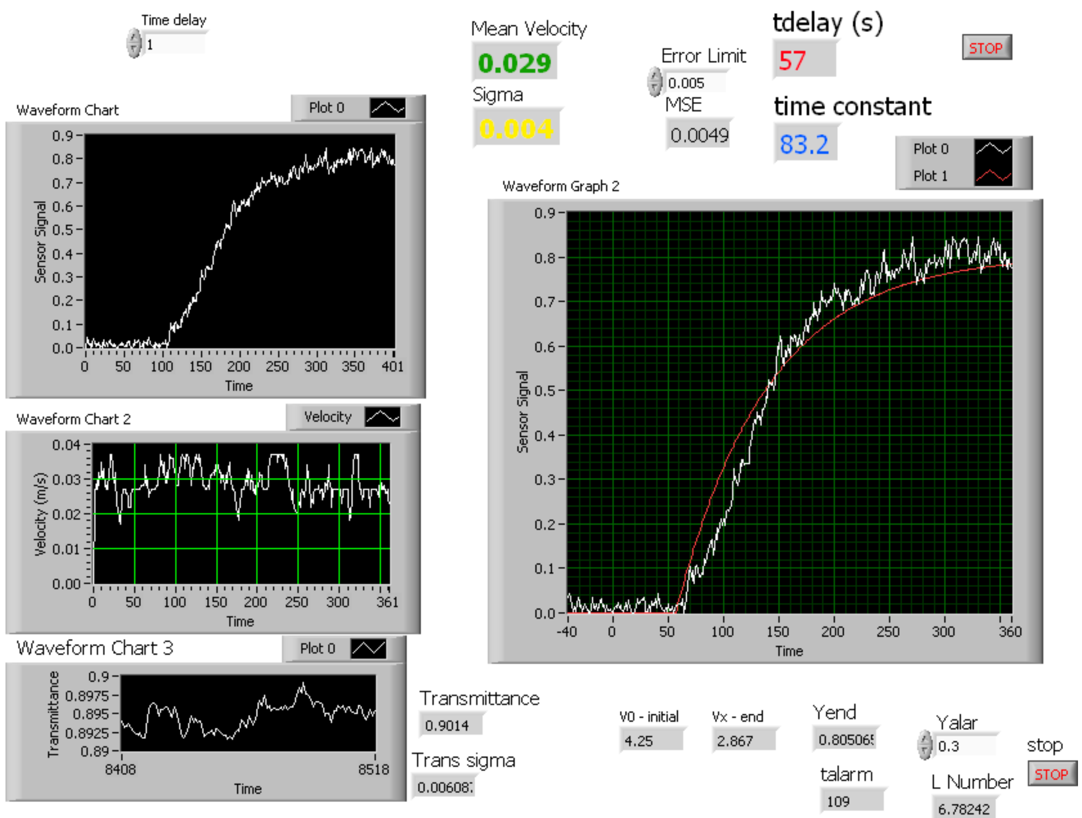
$x = (v_0-v)/v_0$ ion chamber voltage

or

$Y = v-v_0$ photoelectric chamber voltage

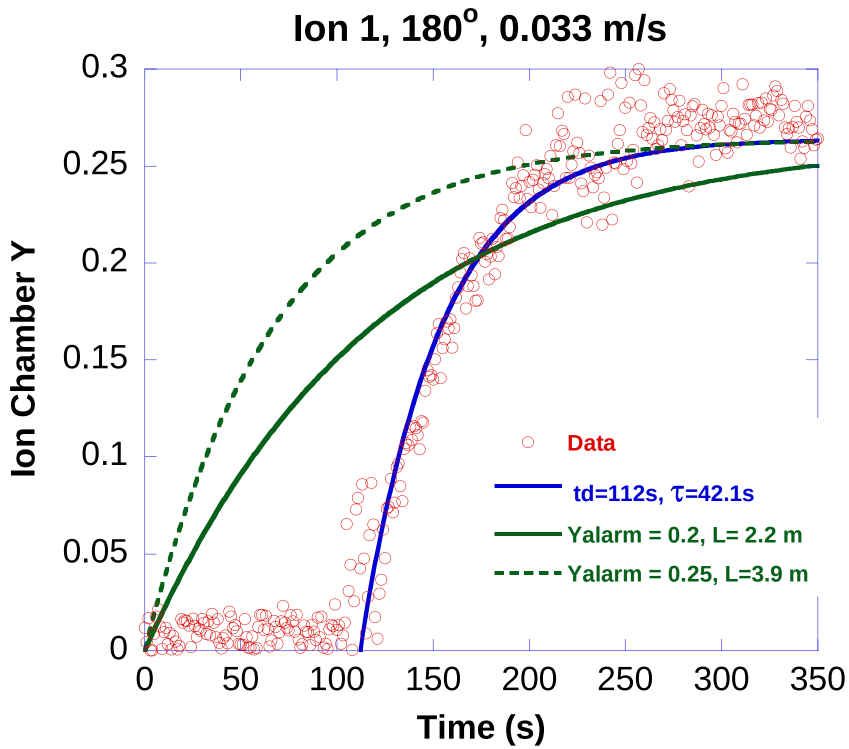
Y_{end} is the steady-state value achieved

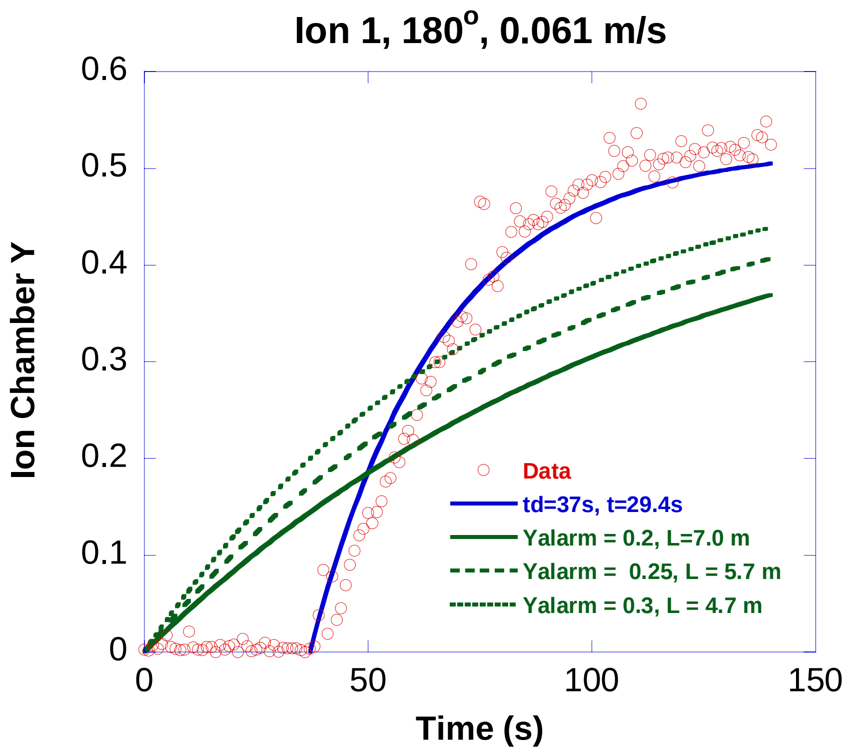
Data Reduction



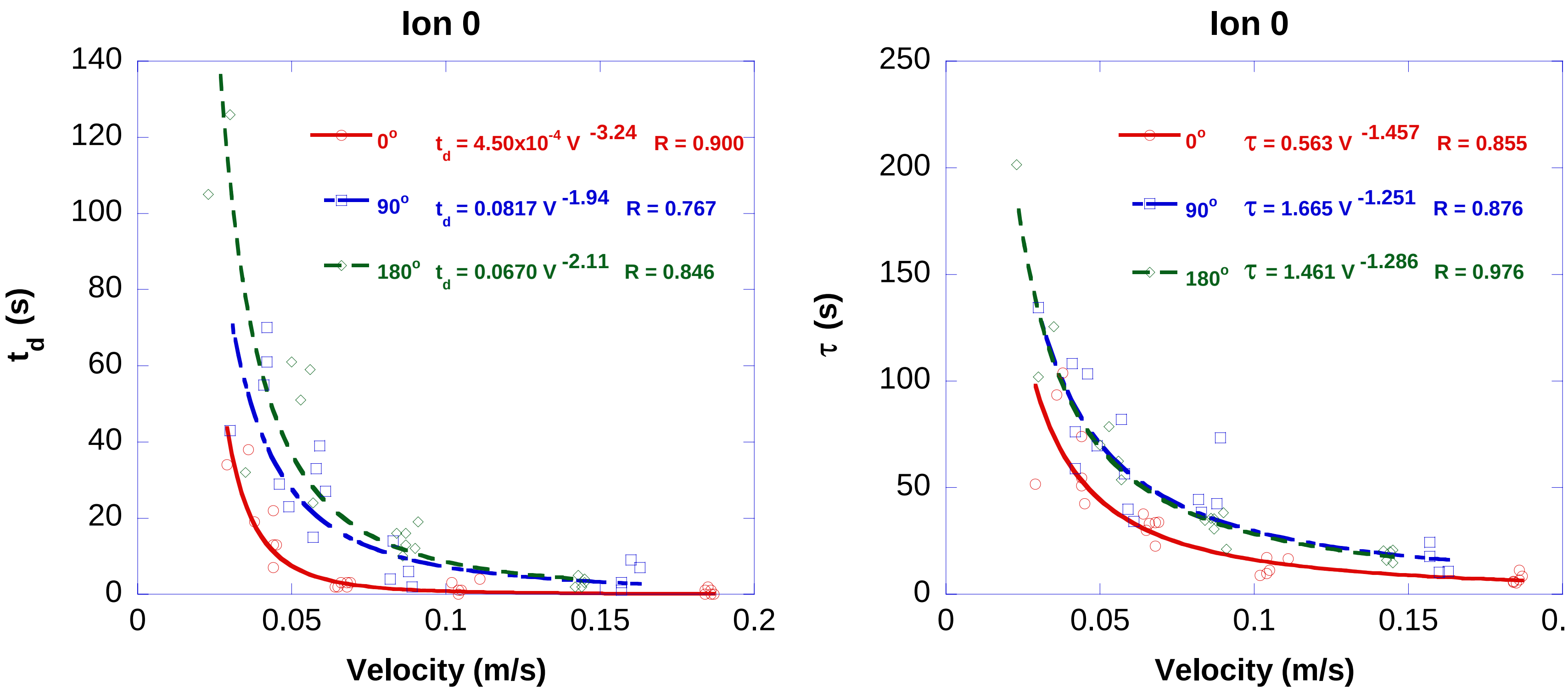
Test Data Fitting Examples

Cleary and Heskestad models





4-parameter Model Fits



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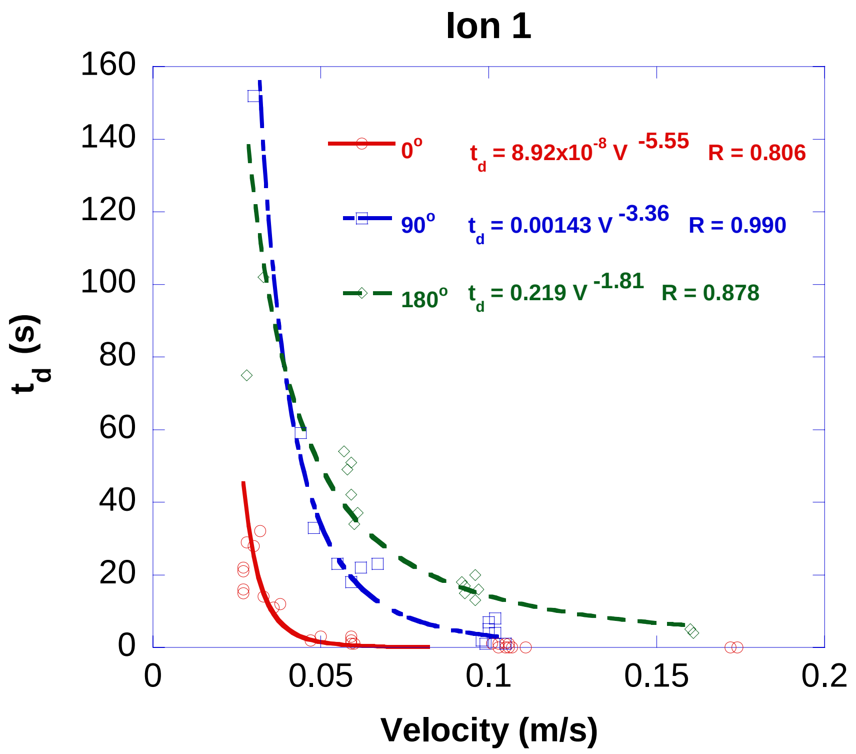

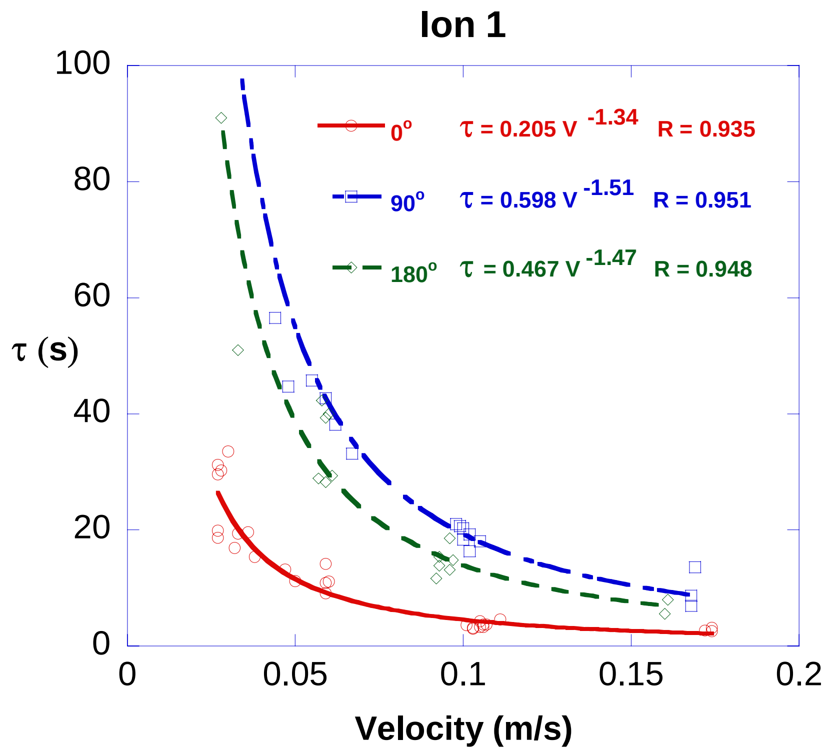

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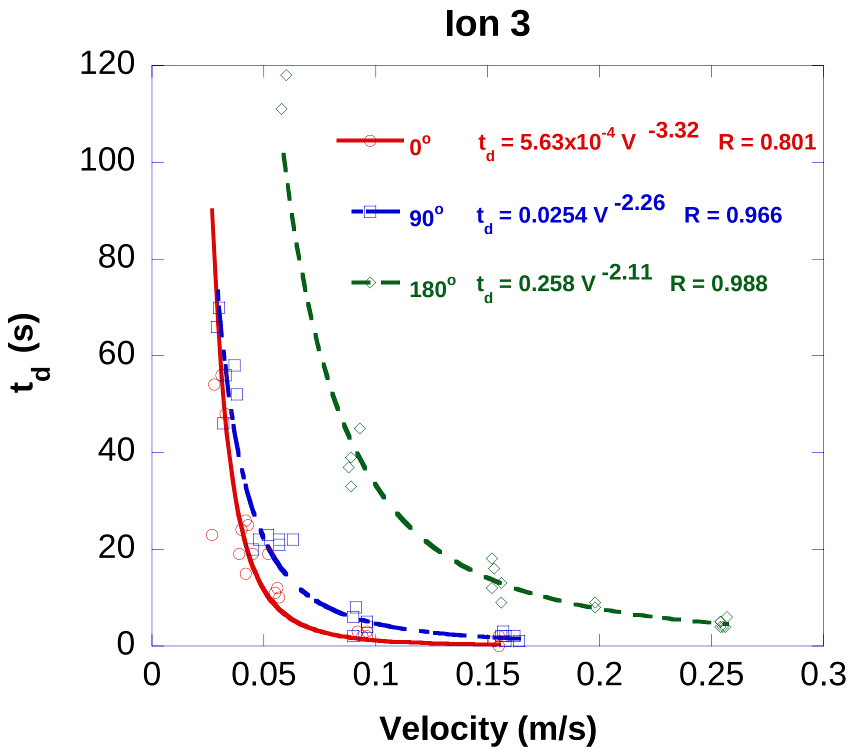

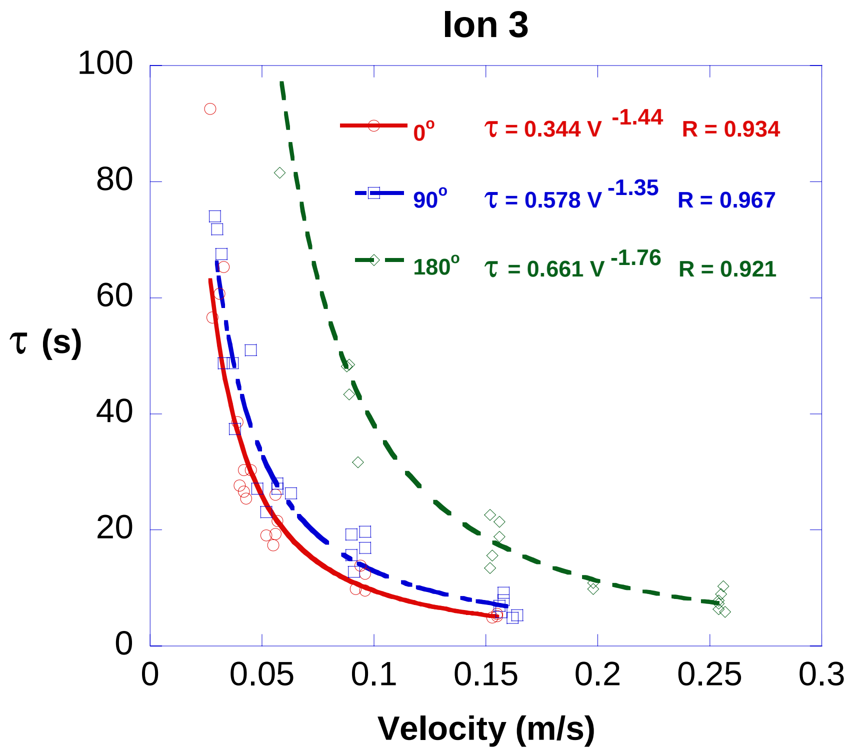

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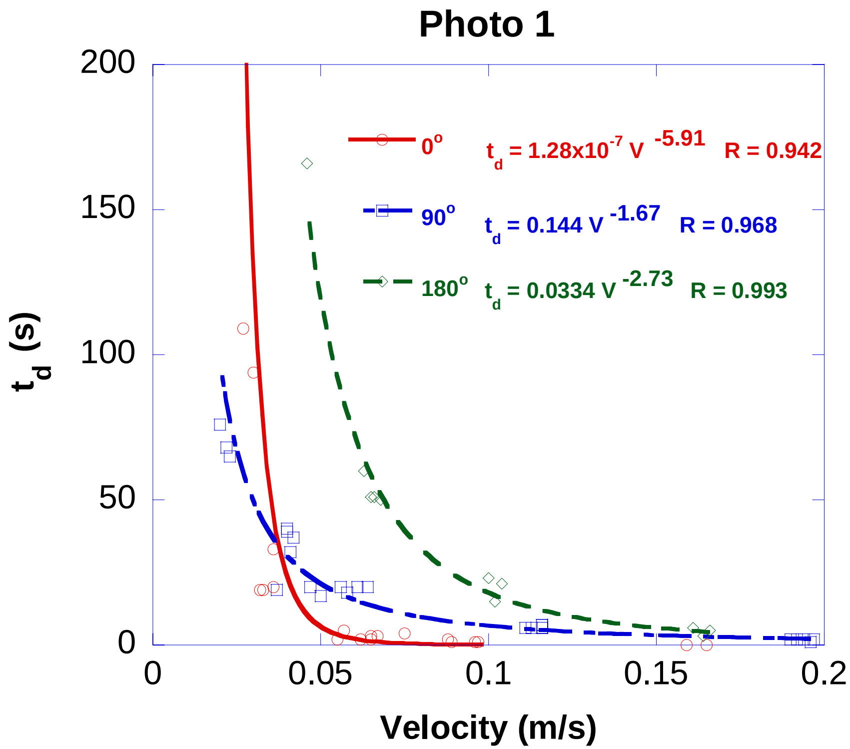

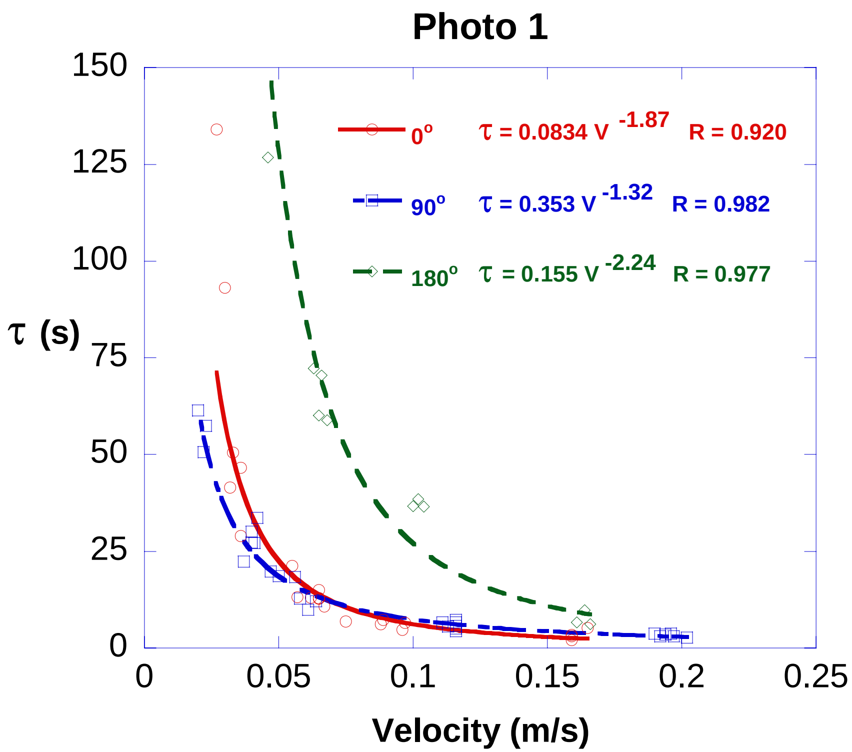

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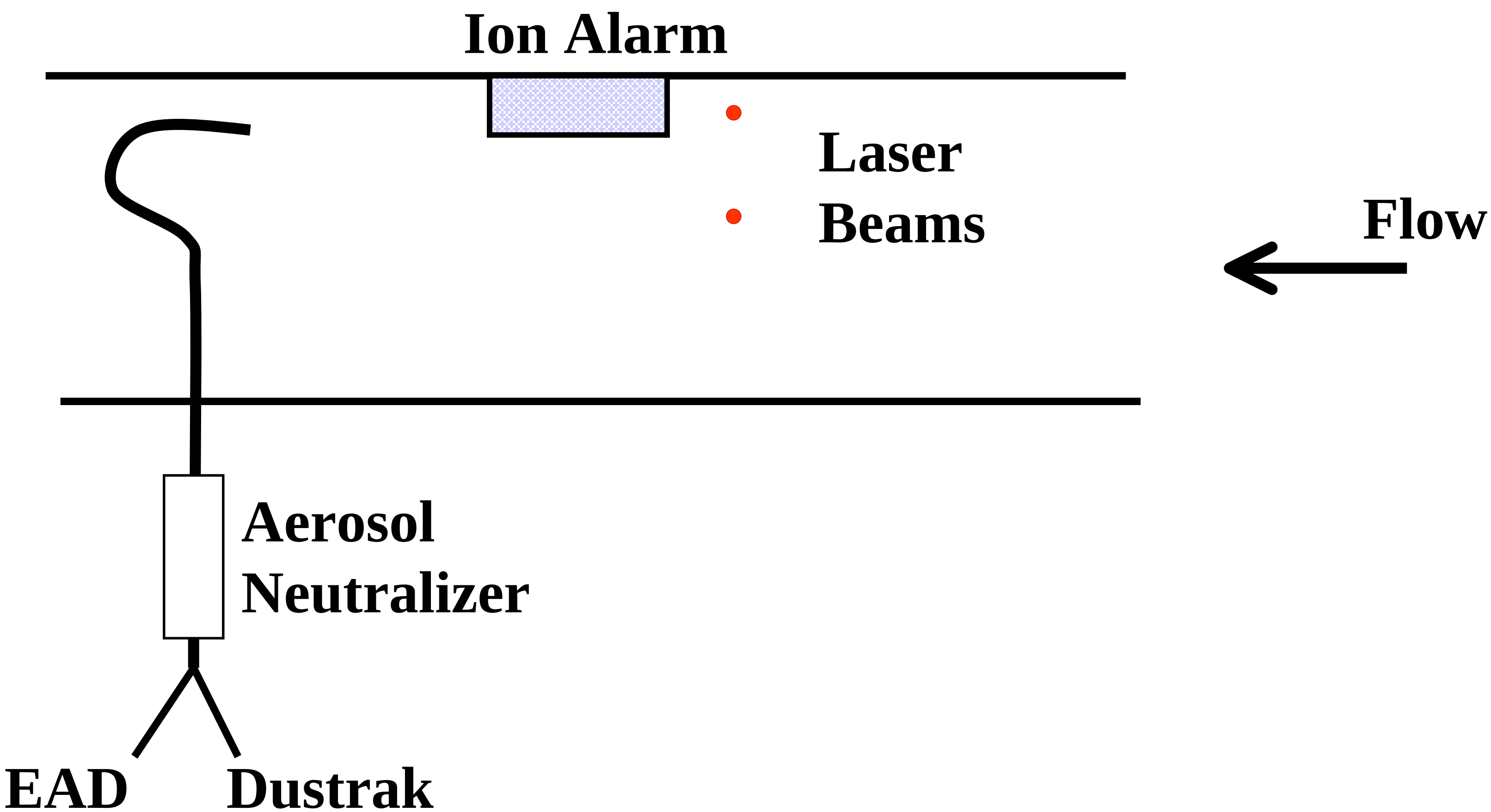
Sensor Response Observations

- Ultimate steady sensor response depends on velocity, alarm orientation, and extinction (concentration)
- Cotton smolder smoke changes as it is transported from the generator to the test section, and as it enters an alarm
- Extinction is a poor predictor of ion alarm response

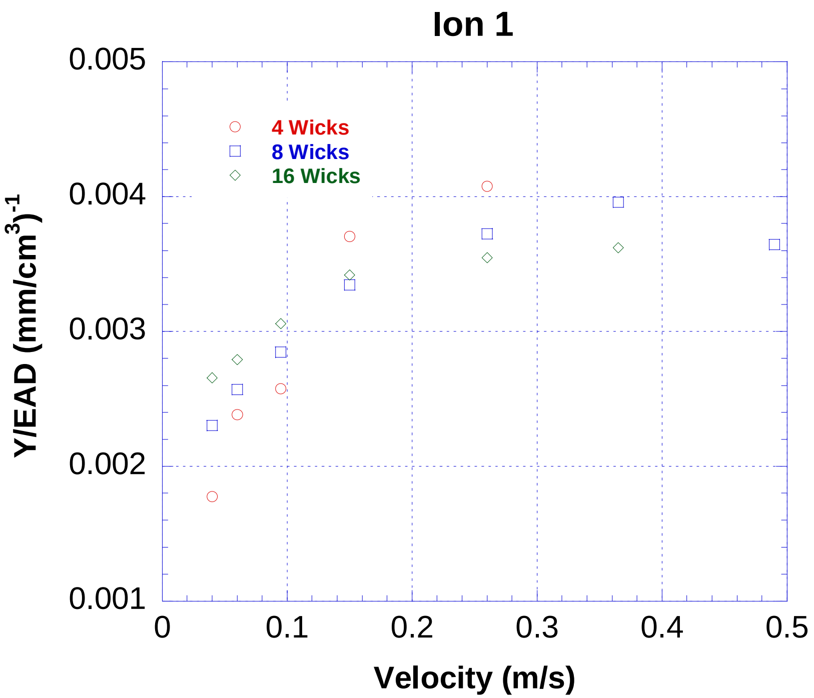
Cotton Smoke Measurements

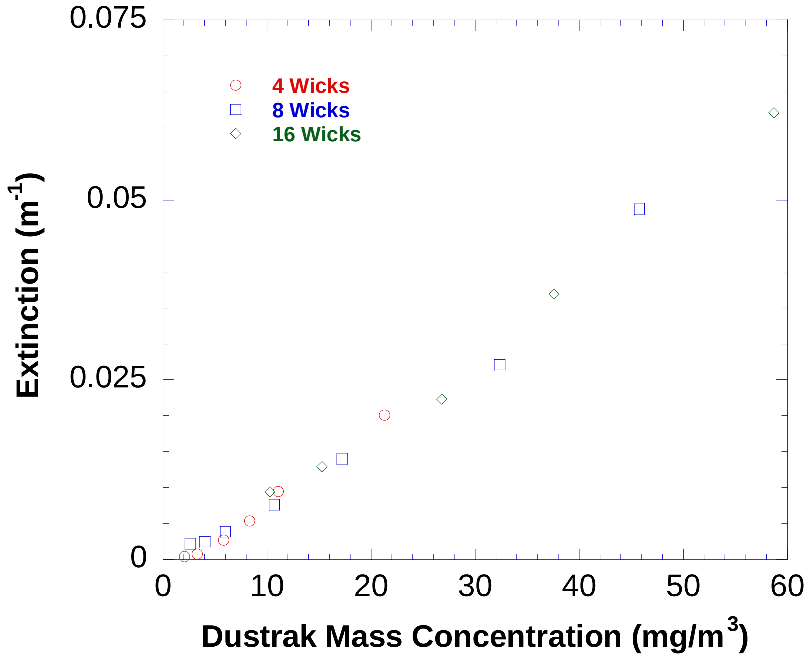
- Used an electrical aerosol detector (EAD) to measure the aerosol total diameter (correlates to MIC Y value)
- Used a 90^{o} light scattering aerosol monitor (Dustrak) to record an “instantaneous” scatter signal

Aerosol measurements



Cotton Smoke

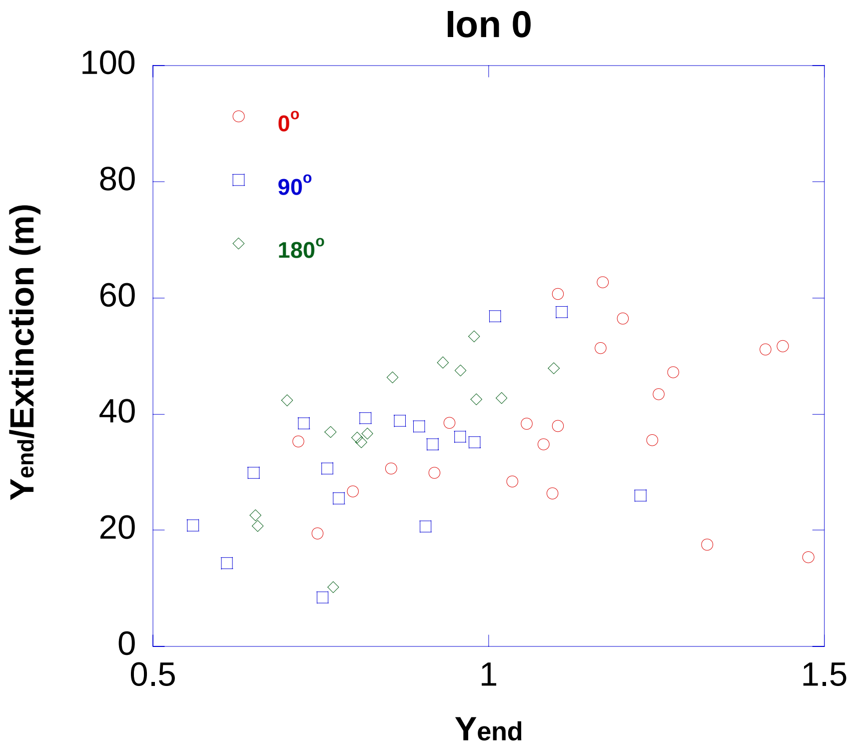




Sensor Response

- Need a relationship between smoke outside the alarm and inside the alarm
  - estimate particle losses and size distribution changes as smoke is transported into alarm, then compute response from a sensor specific model
  - explore simpler approach, an empirical filter function

Steady Sensor Response



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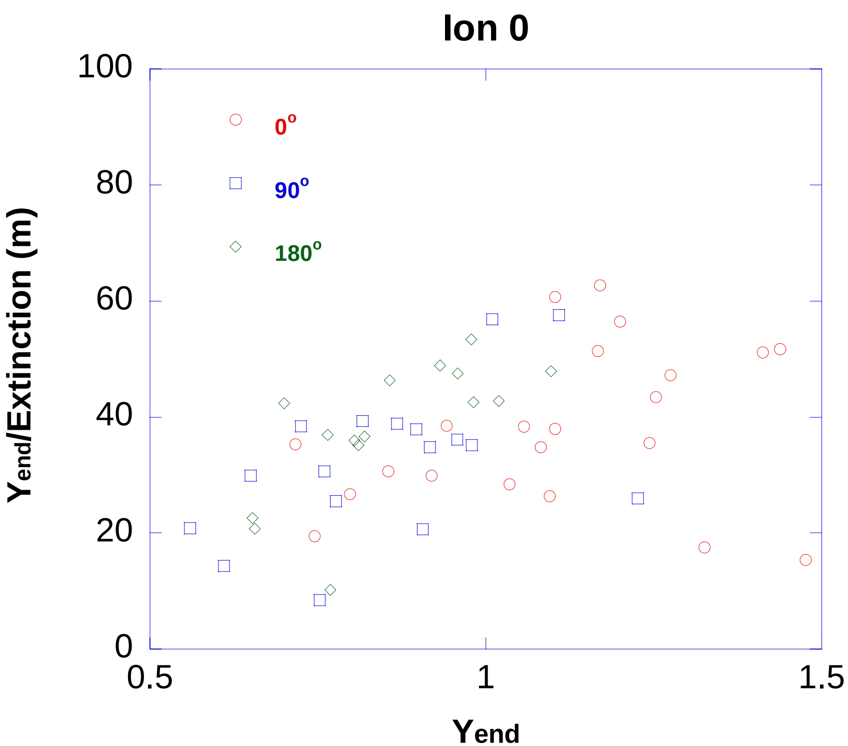

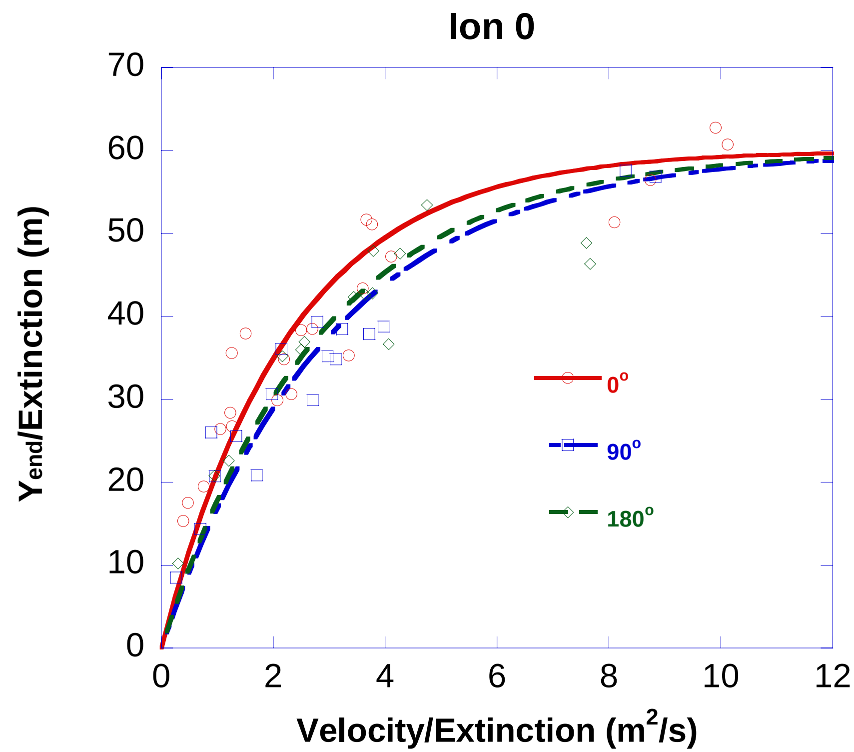

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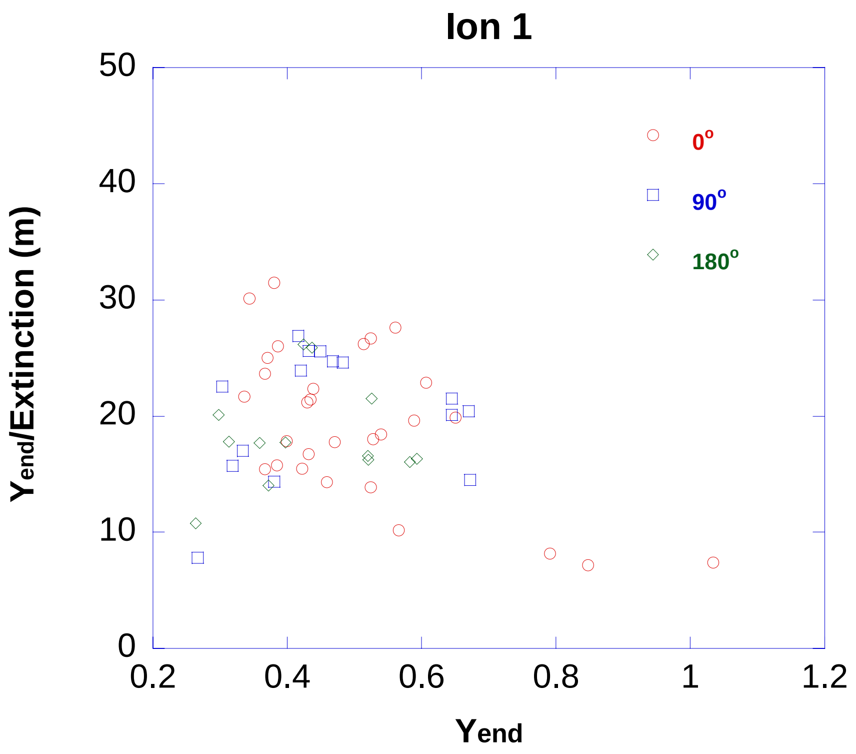

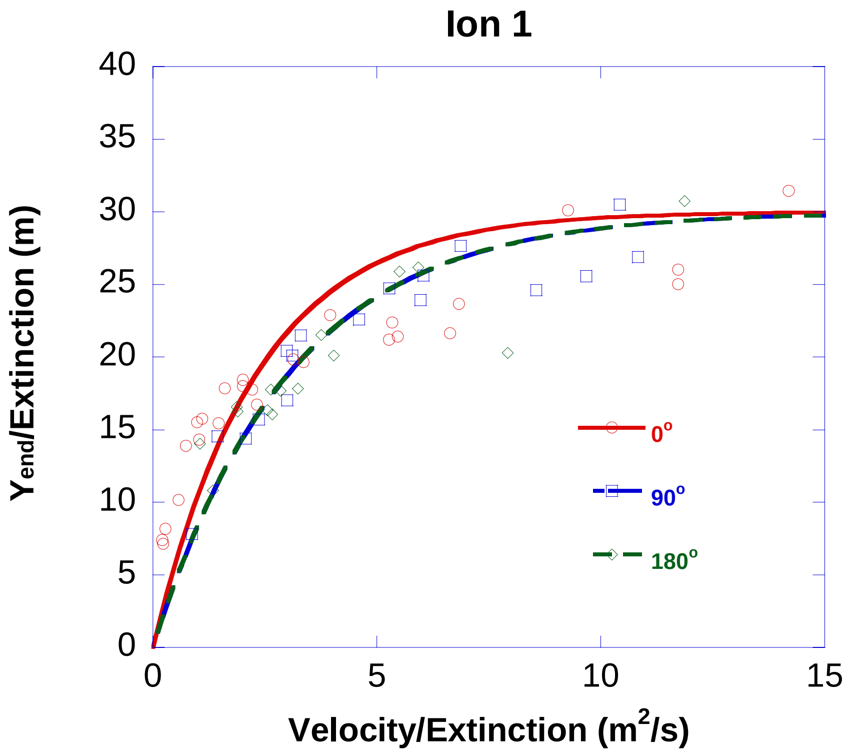

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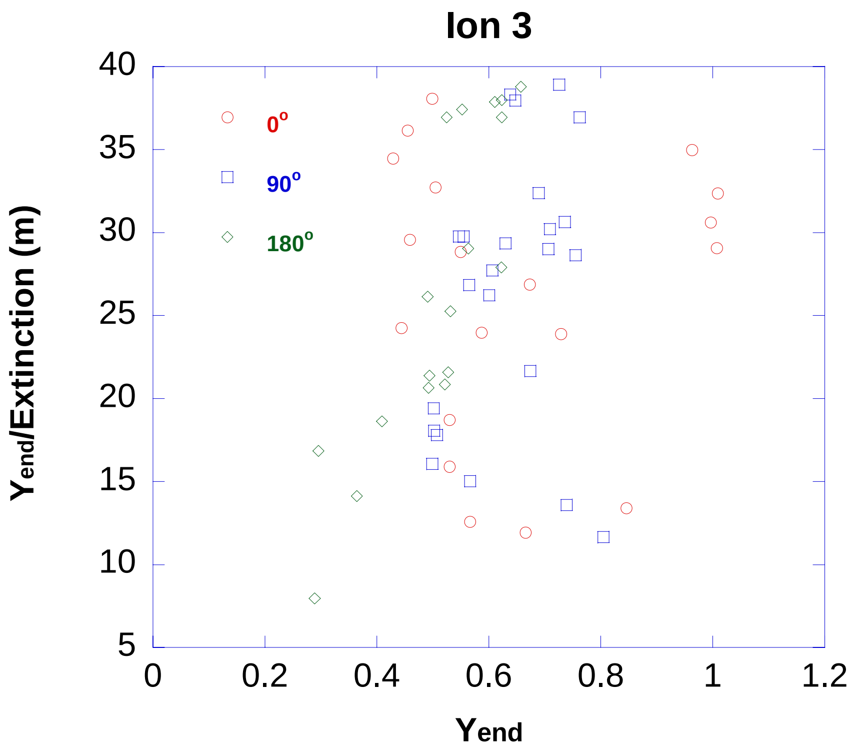

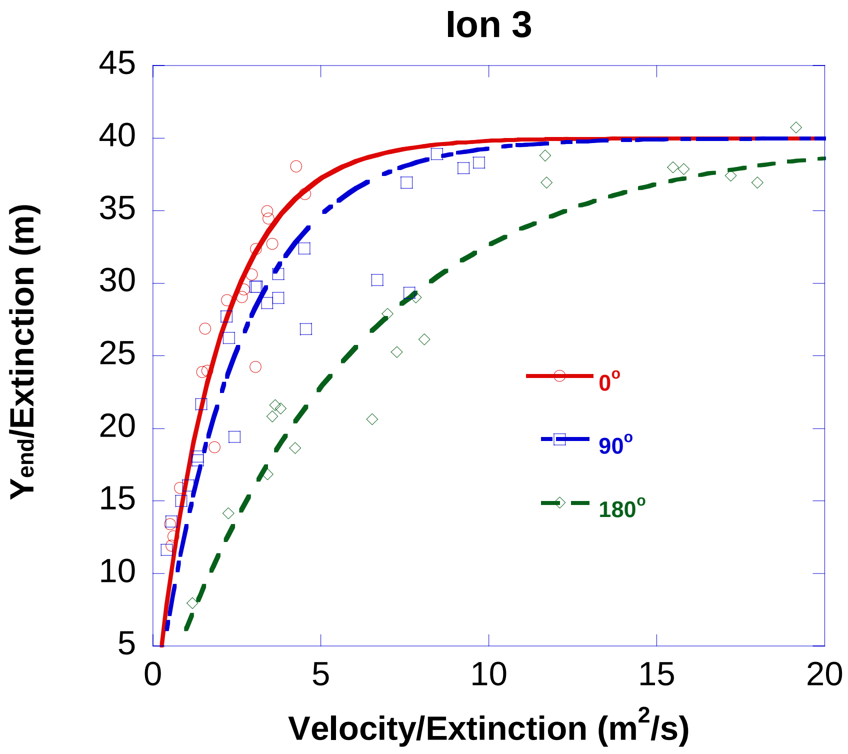

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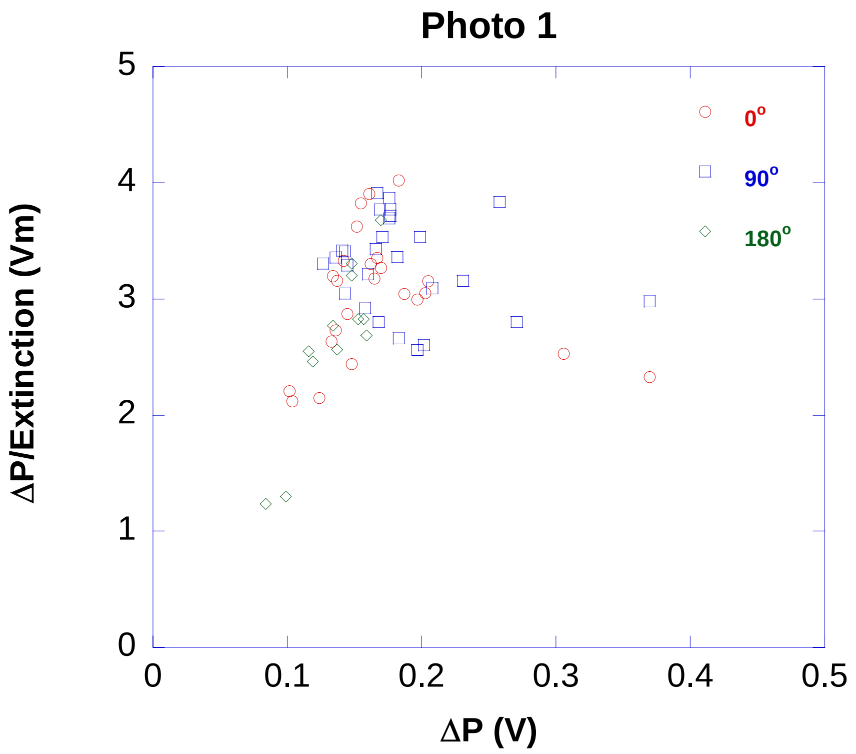
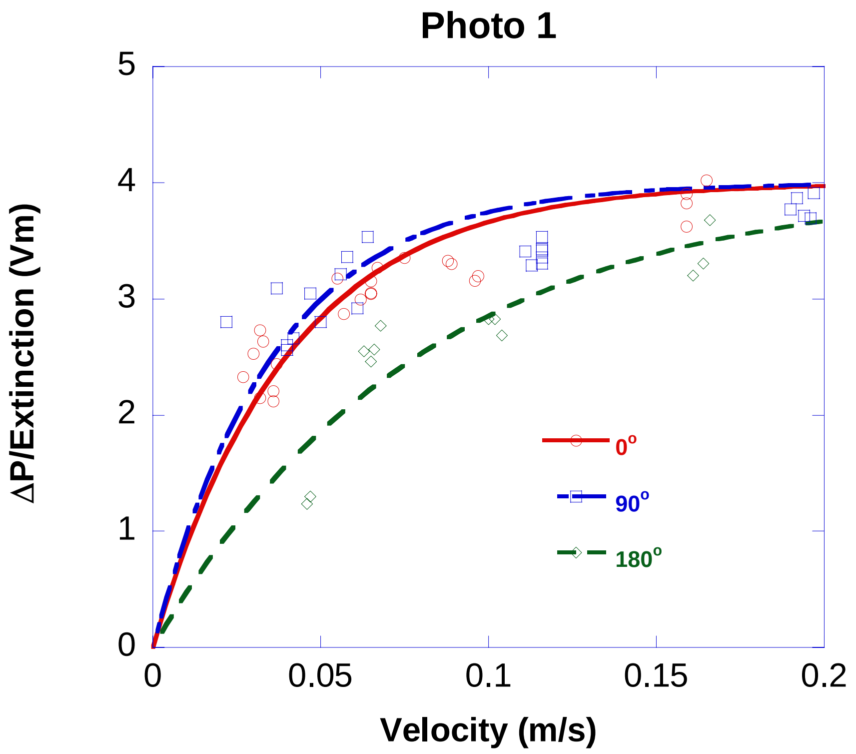




Filter Functions

- Simple functions that captures the steady-state sensor signal reduction of an alarm as a function of flow velocity, alarm orientation, smoke concentration, and smoke type
- Previous results only apply to FE/DE cotton wick smoke
- Need to examine other smokes (soot, other smolder smokes) and variables

Predicted Alarm Times from Un-modified Alarms

Expose alarms to steady smoke and velocity, and record time to alarm

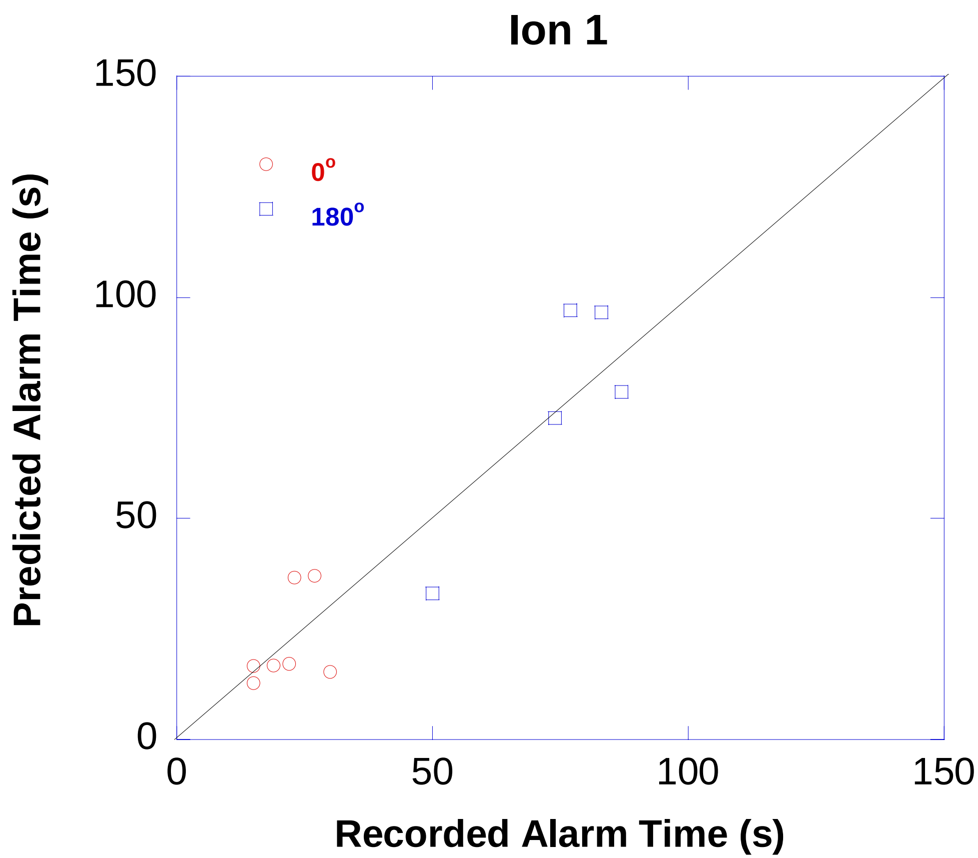
$$t_{alarm} = -\ln(1 - Y_{alarm}/Y_{end})\tau + t_d$$

$$\tau = aV^b$$

$$t_d = a'Vb'$$

Y_{end} obtained from filter curve

Predicted Alarm Times



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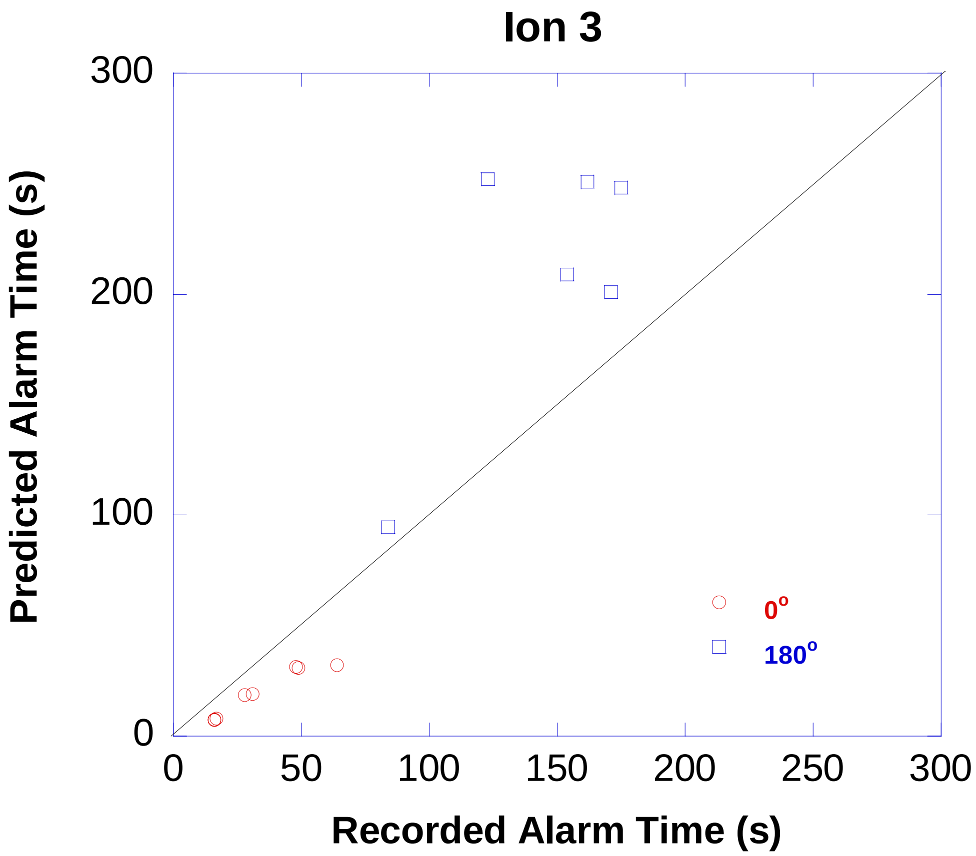

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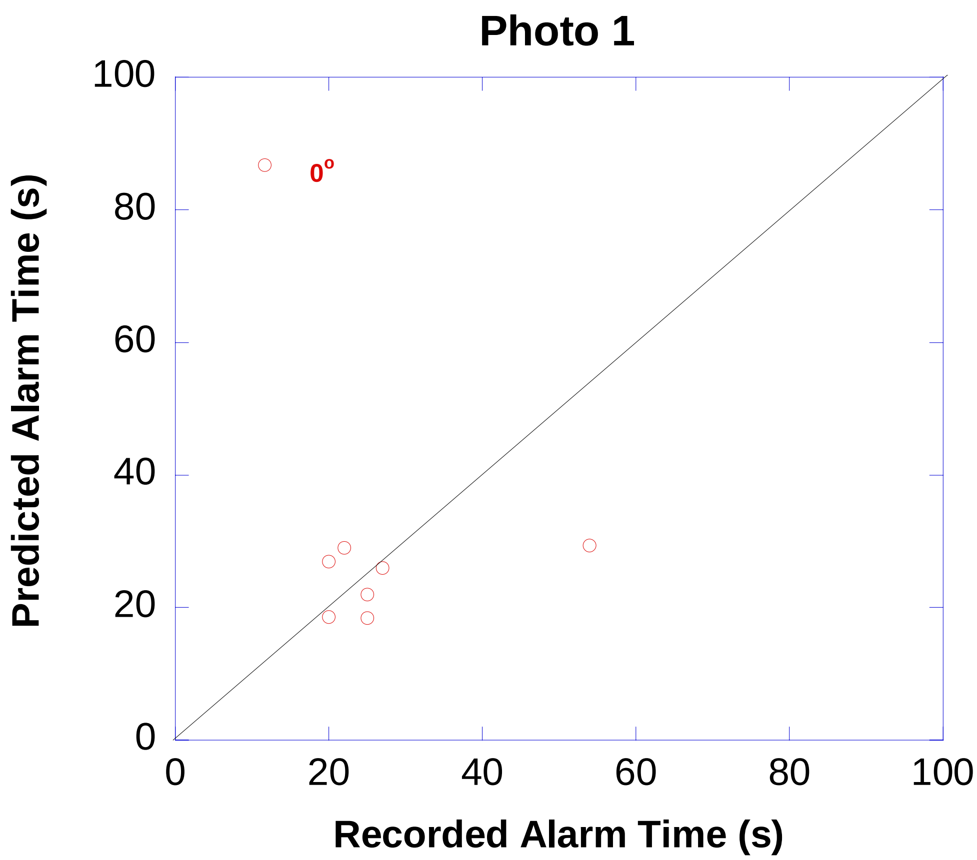

Summary

- Developed response time correlations for 4 residential smoke alarms
- Implemented a simple filter function to account for particle losses and size changes
- Predicted alarm times for un-modified residential smoke alarms

Conclusions

- Residential alarm response time correlations are sensitive to alarm orientation
- Particle losses inside the detector at low flow need to be accounted for
- Predictions follow trends, but uncertainties can be large