Gas Refueling for the PFRC-2

By Yosef Razin

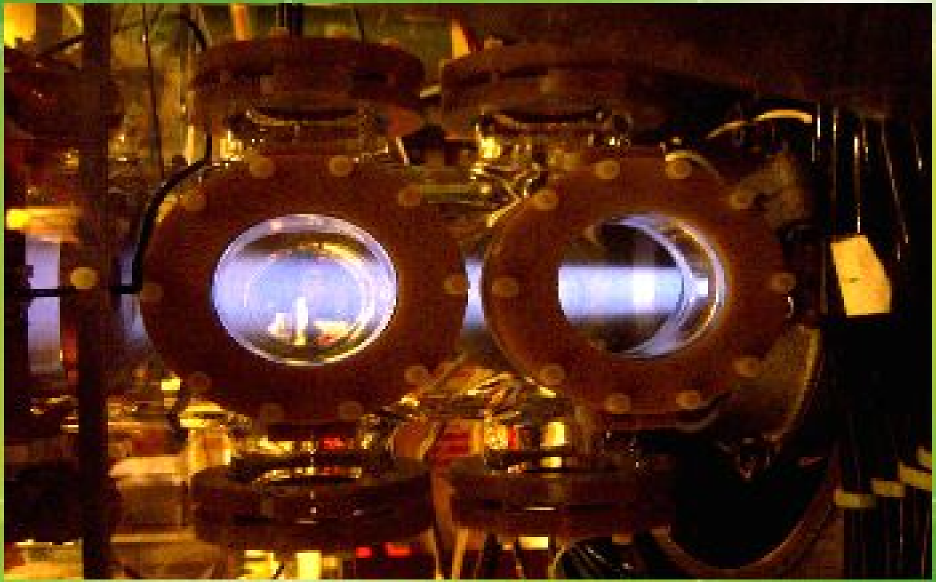
Princeton Plasma Physics Lab
Summer 2011

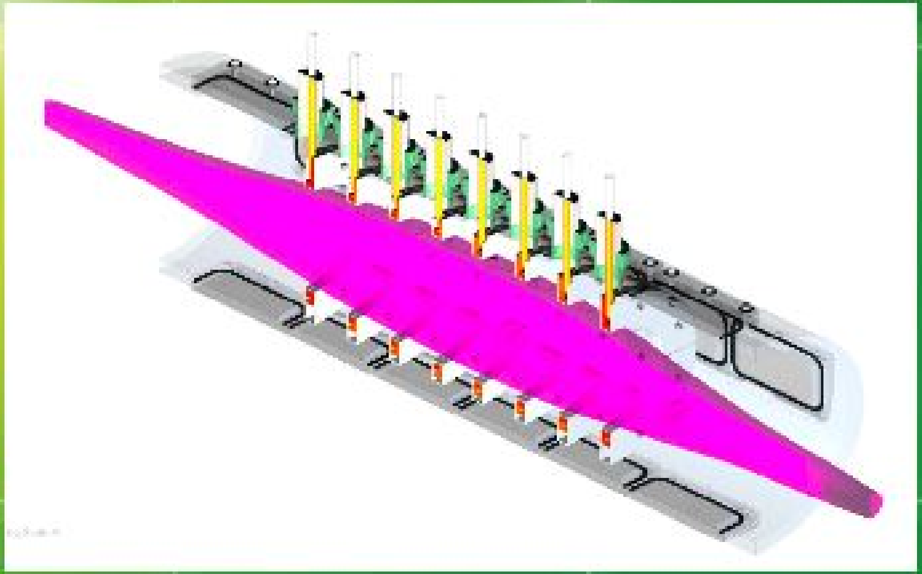
Outline

- Goals
- Methods
- Theoretical Underpinnings
  - Gas Conductance
  - Simulations
- Experimental Work
  - Setup
  - Calibration
  - Preliminary results
  - Models

Goals

- We wish to design a procedure which allows for precise control of the pressure in the PFRC-2





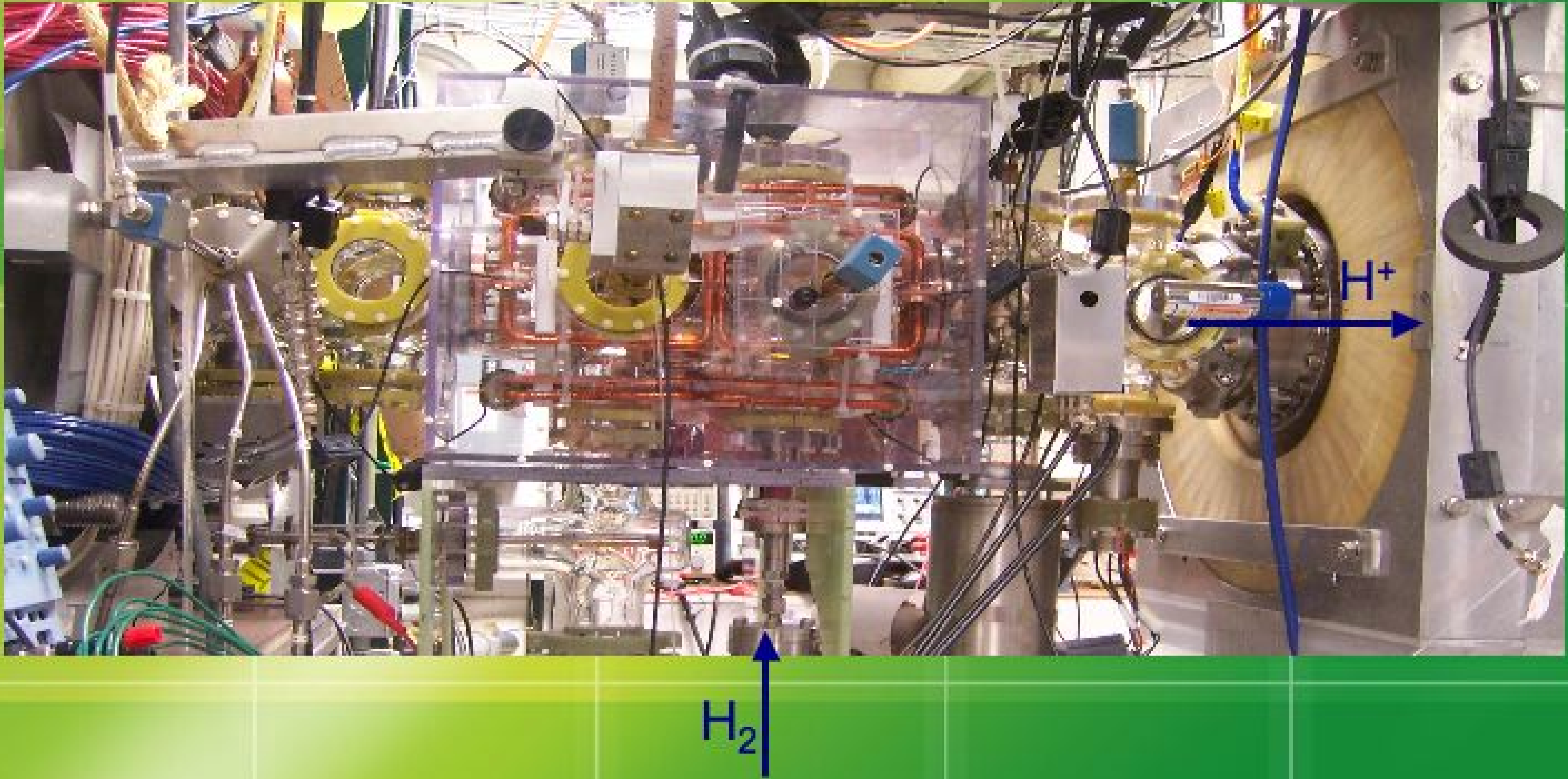
Theoretical Underpinnings
Gas Conductance

- We are interested in the pressure change, $\Delta p = p_{post\text{-}puff} - p_{base}$
- $R =: \frac{\Delta p}{q}$ which is analogous to $R = \frac{V}{I}$
- We define the conductance, C, as C=1/R
- In a high-vacuum, $C = \frac{\bar{c}}{4} AP$ where $\bar{c} = 1754.5$ m/s for H_2
- We can choose an area, A, and find the probability of transmission, P, through simulations

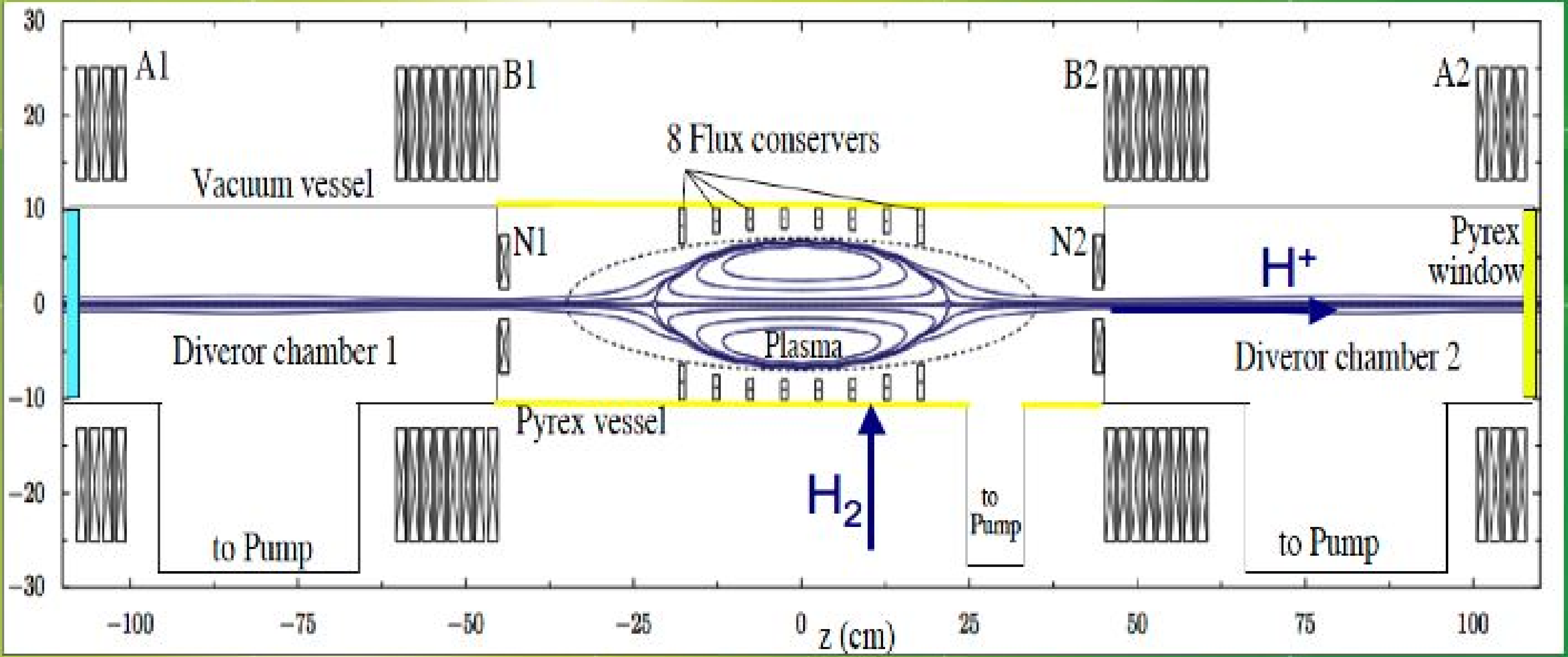
Methods

- Veeco PV-10 piezoelectric valve
- Control Parameters
  - Voltage
  - Pulse Width
  - Back Pressure
- Outputs
  - Peak Pressure
  - Lag
  - Rise time
  - Fall time

Methods



Methods


A1
B1
B2
A2
8 Flux conservers
Vacuum vessel
N1
N2
Pyrex window
H⁺
Diveror chamber 1
Plasma
Diveror chamber 2
Pyrex vessel
H₂
to Pump
to Pump
to Pump
30
20
10
0
−10
−20
−30
−100
−75
−50
−25
0
25
50
75
100
z (cm)

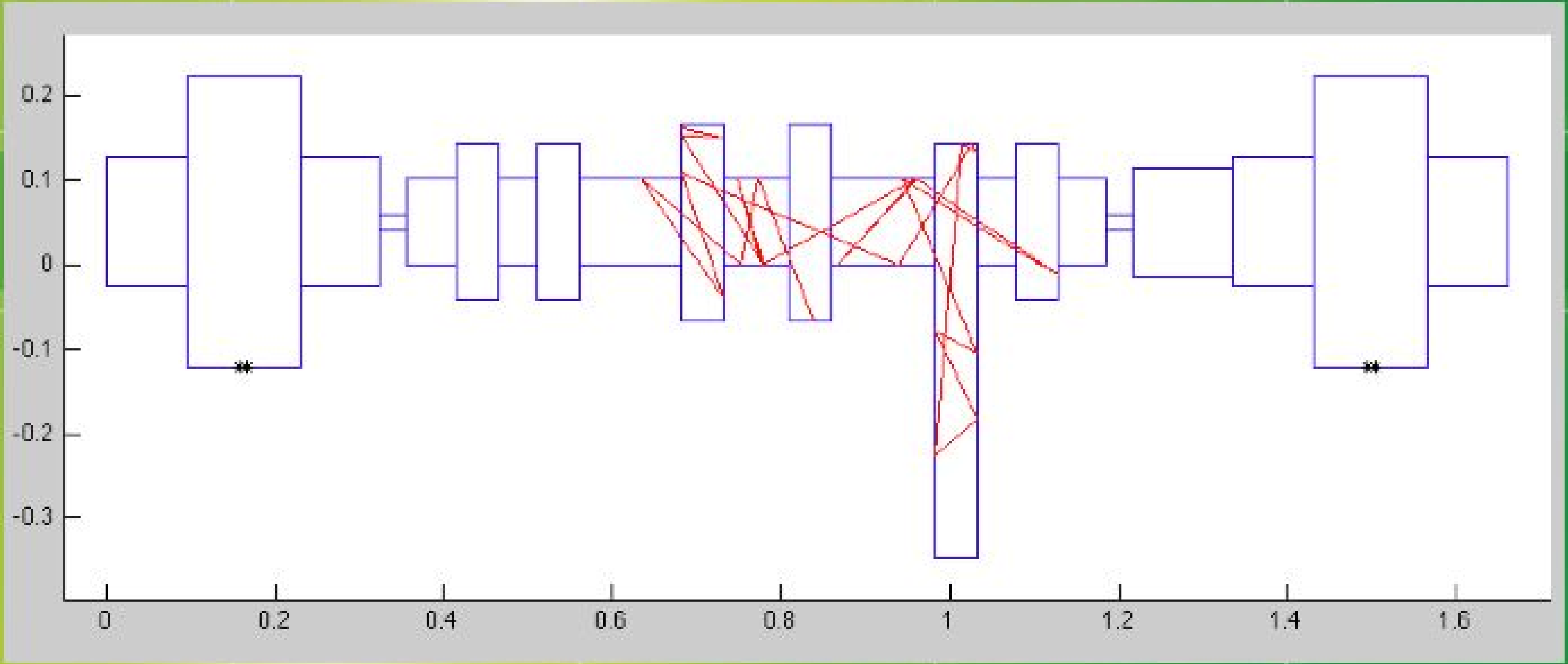
Goals

- Thus, we would like to achieve a fueling rate of $dN/dt=1.2\text{x}10^{17}/9\text{x}10^{-5}$
  $=1.3\text{x}10^{21}\ s^{-1}$
- Also, $dN/dt=nV/p$.
  - $V=1.1\text{x}10^{4}$cc
  - $n=P*3.5\text{x}10^{13}\ \text{mol}^{-1}$
  - Therefore, we need $P/p=3.4$ mT/ms

Goals

- Fuel needed, N=$n_e V$
  - *Electron density, n_e=$2x10^{13}$ particles/cm^3*
  - *Plasma volume, V=$4\pi r^2 Kr/3$*
    - With K=4, r=7 cm, we get V=5747 cm^3
  - Therefore, N=$1.2x10^{17}$ particles
- The fueling rate dN/dt=N/τ_p (τ_p=particle confinement time)
  - We guess that τ_p= τ_E, and we estimate that the τ_E needed for success is $9x10^{-5}$ s

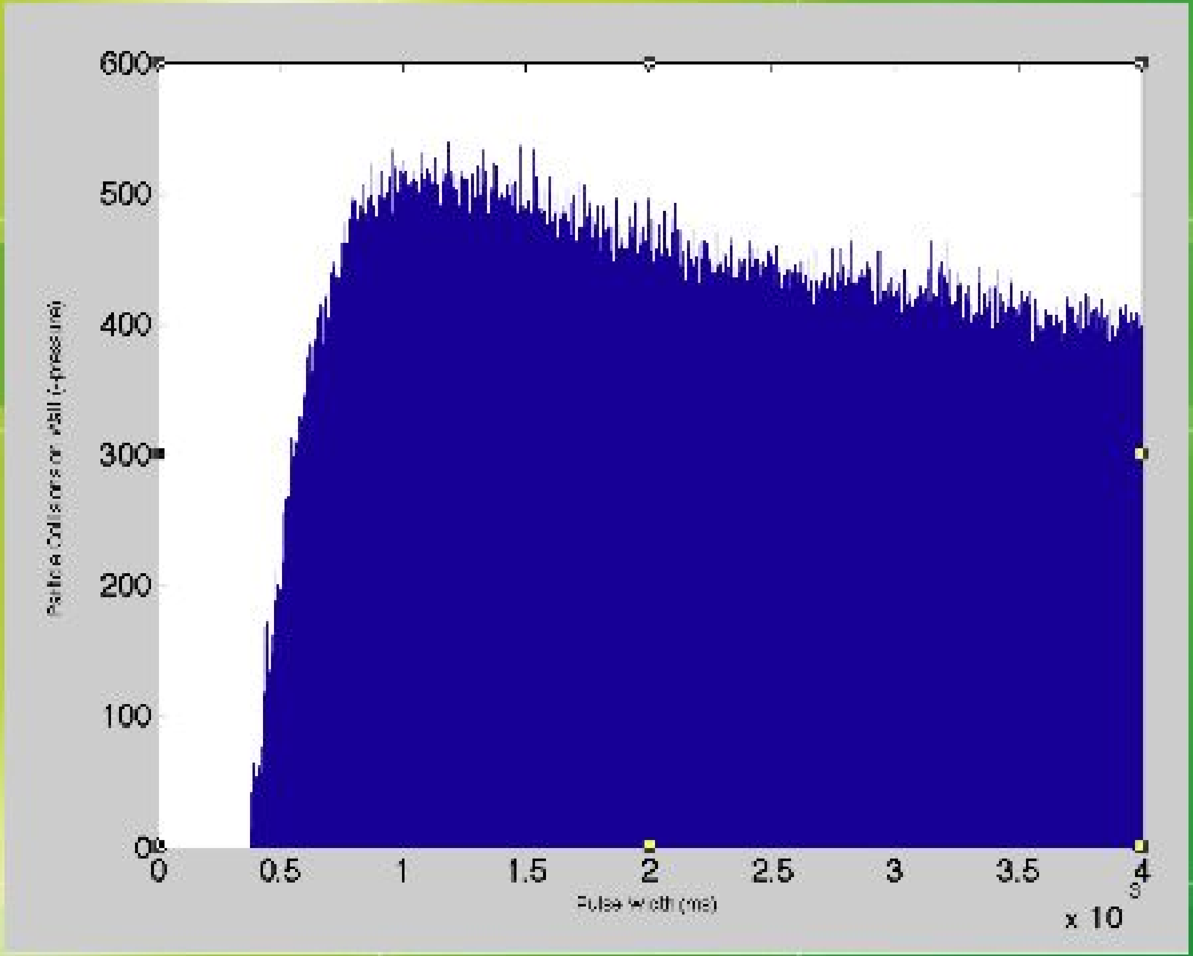
Theoretical Underpinnings
Simulation



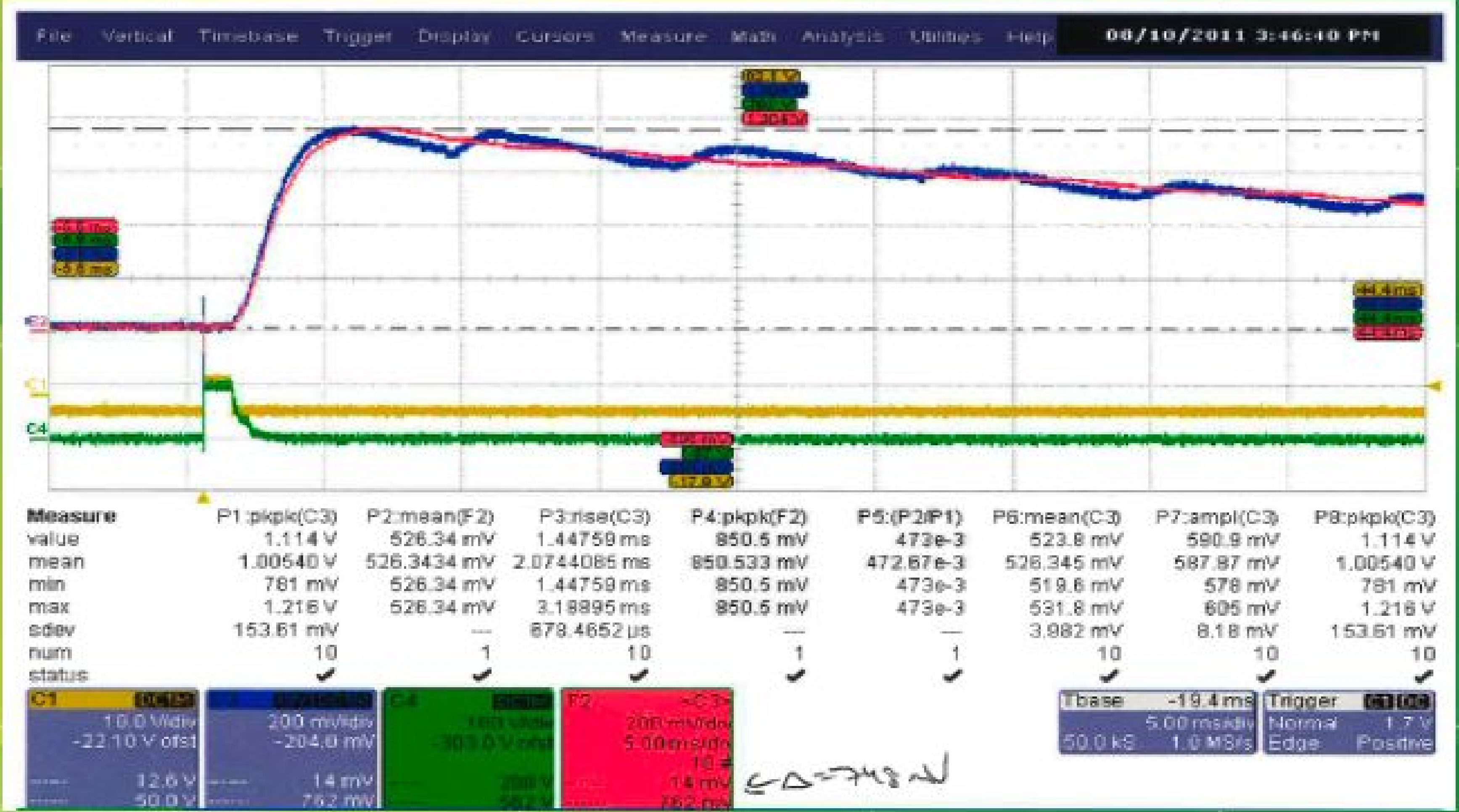
Theoretical Underpinnings
Simulation

- Model the vessel and pumps
- In a rarified gas and relatively small container, the particles are assumed to very quickly scatter off the walls, according to Knudsen's Cosine Law. This also implies that the gas particles quickly reach thermal equilibrium with the wall
- We use ray tracing and the mean thermal speed to calculate travel distances and times

Theoretical Underpinnings
Simulation



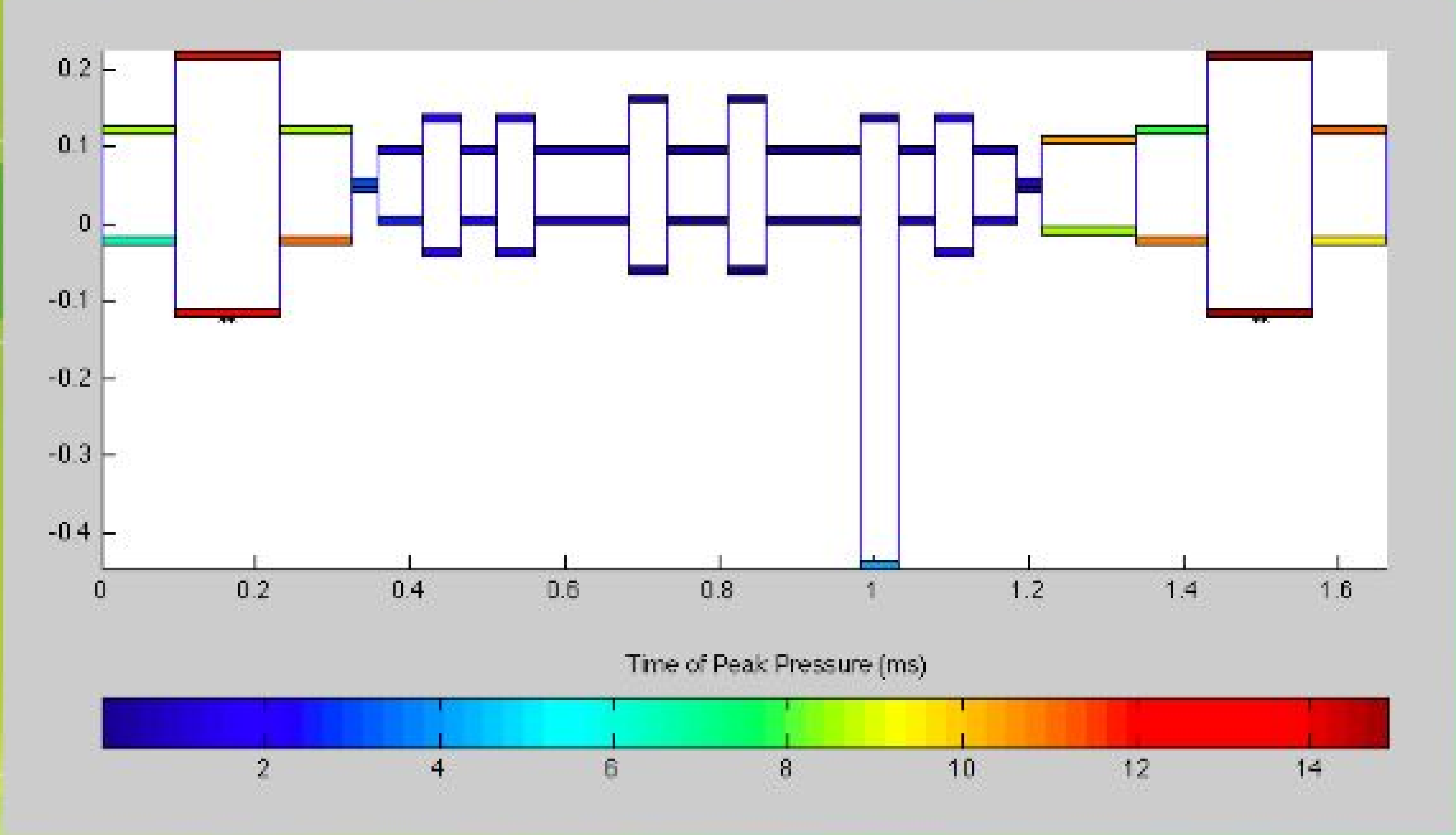
Theoretical Underpinnings
Simulation



Measure	P1:pkpk(C3)	P2:mean(F2)	P3:rise(C3)	P4:pkpk(F2)	P5:(P2/P1)	P6:mean(C3)	P7:ampl(C3)	P8:pkpk(C3)
value	1.114 V	526.34 mV	1.44759 ms	850.5 mV	473e-3	523.8 mV	590.9 mV	1.114 V
mean	1.00540 V	526.3434 mV	2.0744085 ms	850.533 mV	472.67e-3	526.345 mV	587.87 mV	1.00540 V
min	781 mV	526.34 mV	1.44759 ms	850.5 mV	473e-3	519.6 mV	578 mV	781 mV
max	1.216 V	526.34 mV	3.18895 ms	850.5 mV	473e-3	531.8 mV	605 mV	1.216 V
sdev	153.61 mV	---	678.4652 µs	---	---	3.982 mV	8.18 mV	153.61 mV
num	10	1	10	1	1	10	10	10
status	✓	✓	✓	✓	✓	✓	✓	✓

←Δ=748 mV

Theoretical Underpinnings
Simulation



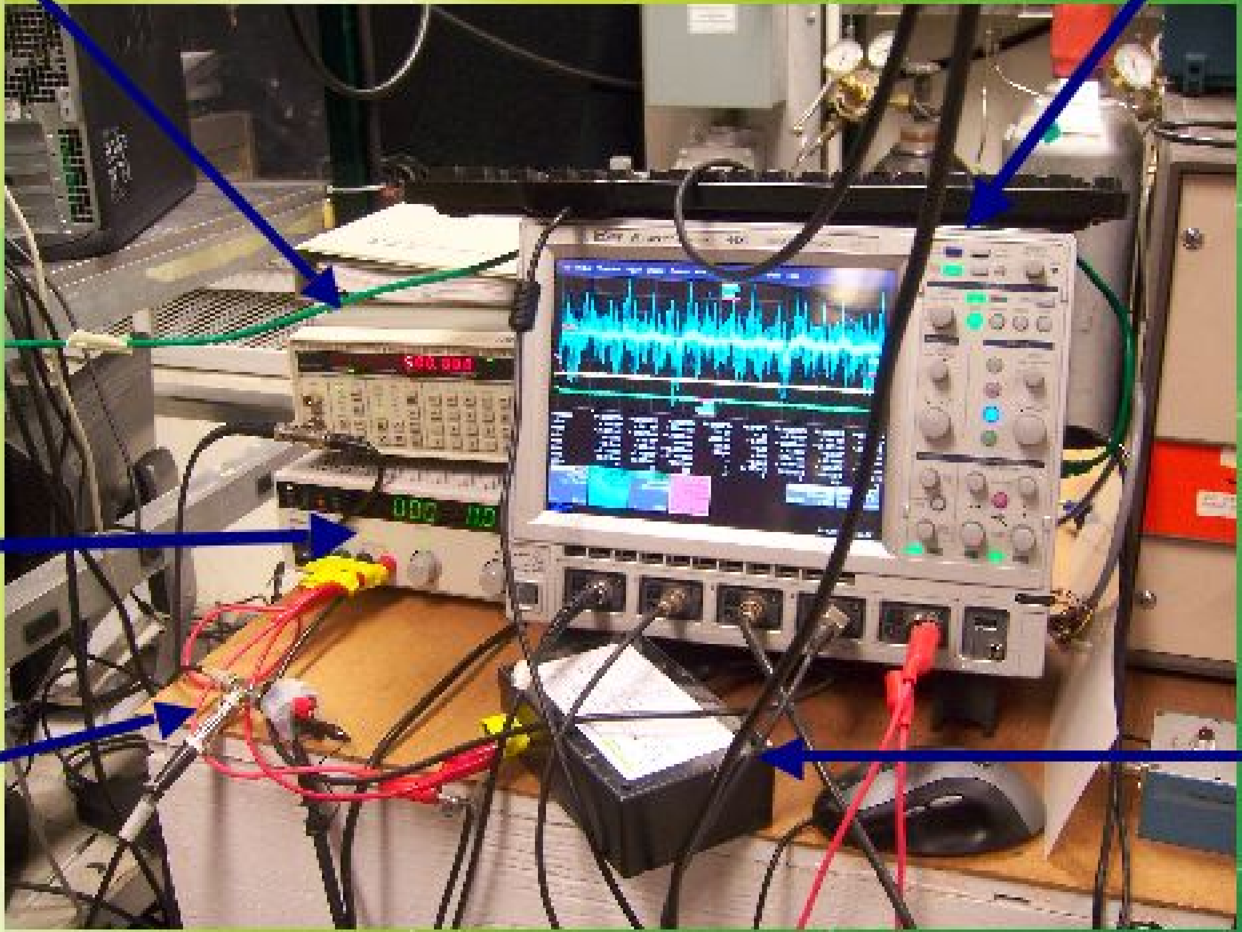
Theoretical Underpinnings
Simulation

- From the simulated data, we would expect the gas to rapidly expand, filling the expansion region in 3-4 ms
- The ion gauge should see a rise in pressure beginning around 0.4 ms and peaking at 1.1 ms
- While many particles are quickly evacuated (~70 ms) to the main and satellite chambers, some remain in the expansion region for a long time ~1 sec (not shown)

Experimental Work
Setup

- SRS345 wave generator sends a pulse to a MOSFET
- The MOSFET is also attached to a power source. It acts as a switch, such that when it gets a pulse from the SRS345 it outputs a pulse of the same width but with the amplitude of the voltage of the power source.
- This signal goes to the PV-10, opening the valve.

Experimental Work Setup



Experimental Work
Setup

- The SRS345 and the signal from the MOSFET are also attached to a LeCroy Digital Oscilloscope
- The valve is supplied by a gas line to a gas reservoir of H_2 whose back pressure can be adjusted from -1 atm to +1 atm. This can be read from an analog dial gauge as well as a digital read out.

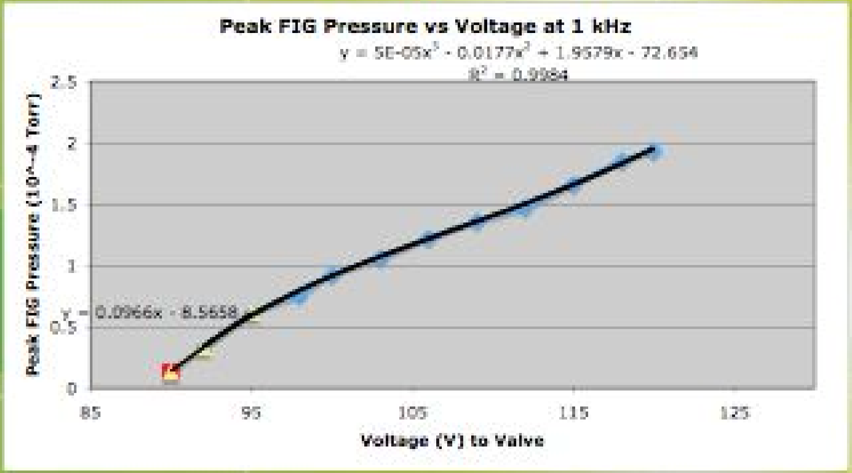
Experimental Work
Setup

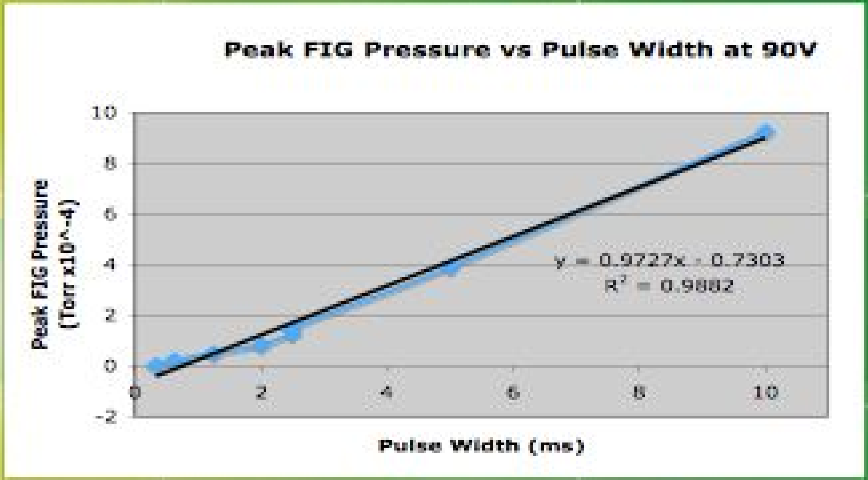
- Numerous pressure and temperature displays are available, all around the machine, including:
  - Baratron Gauges
  - Convectron Gauges
  - Thermocouples
  - The Fast Ion Gauge
    - This gauge and the convectron also have analog connections to the oscilloscope
  - Mass Spectrometer

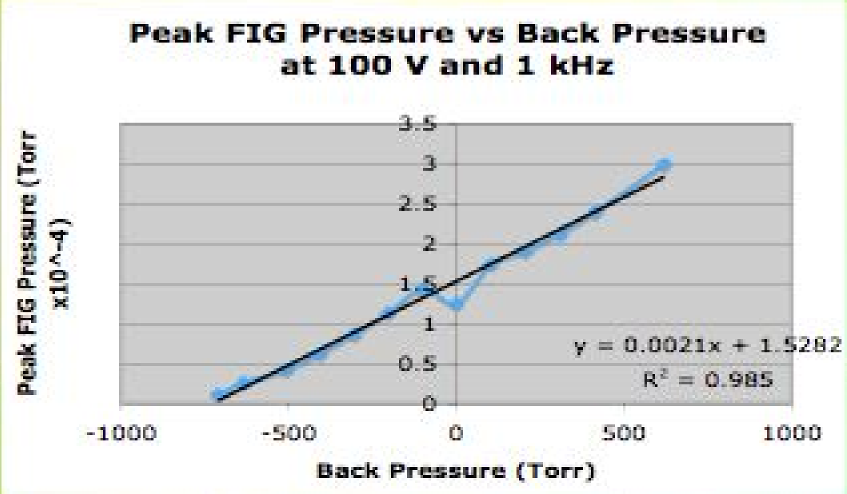
Experimental Work
Calibration

- Back pressure analog gauge (psi and inHg) to digital readout
- Convectron to Baratron
- Fast Ion Gauge
  - To Baratron
  - To analog out
  - Noise
  - Range Delays
  - B-Field Effect
- Navigator Pump effect

Experimental Work
Preliminary Results





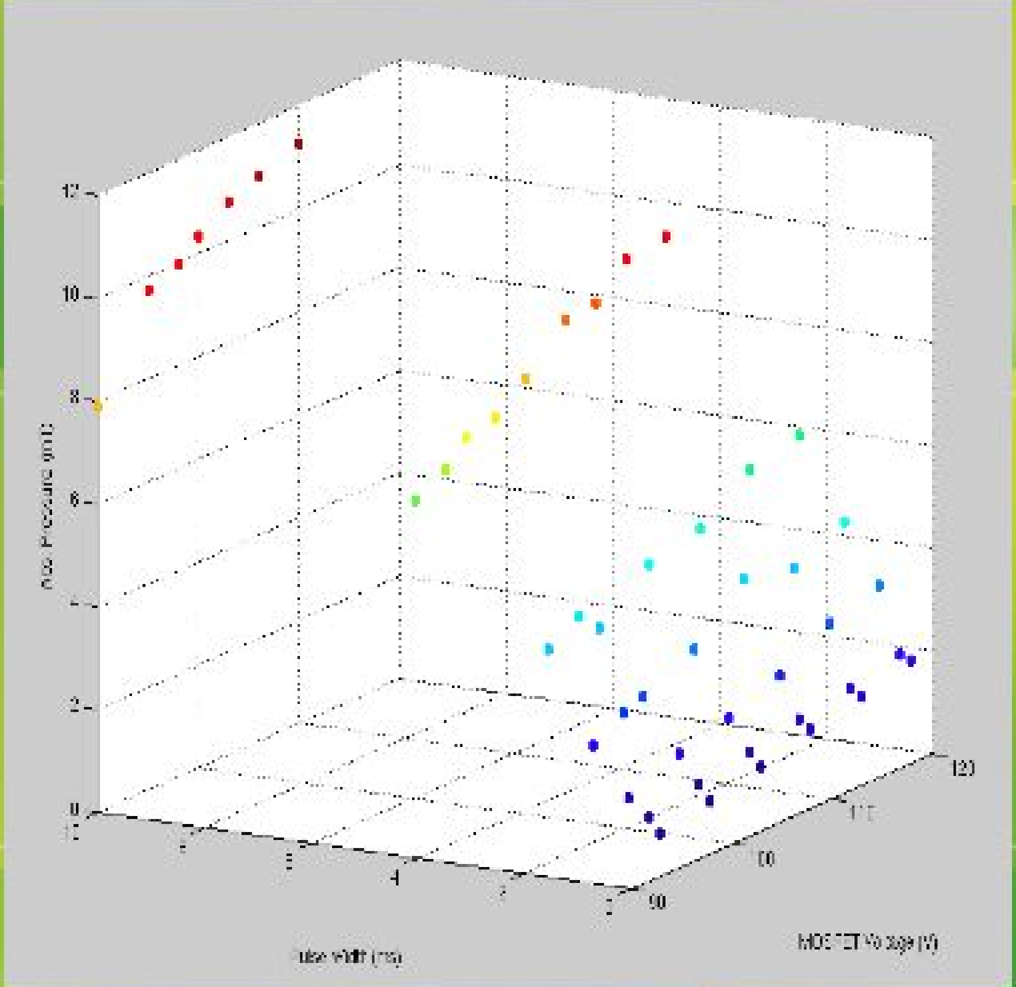


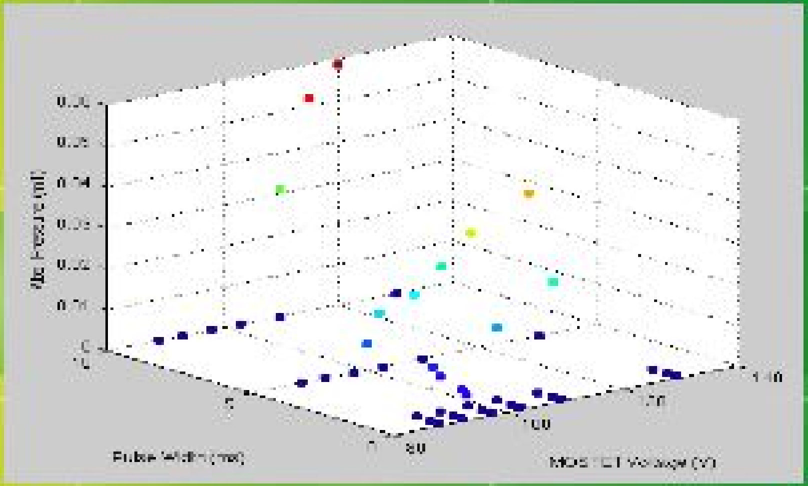
Experimental Work

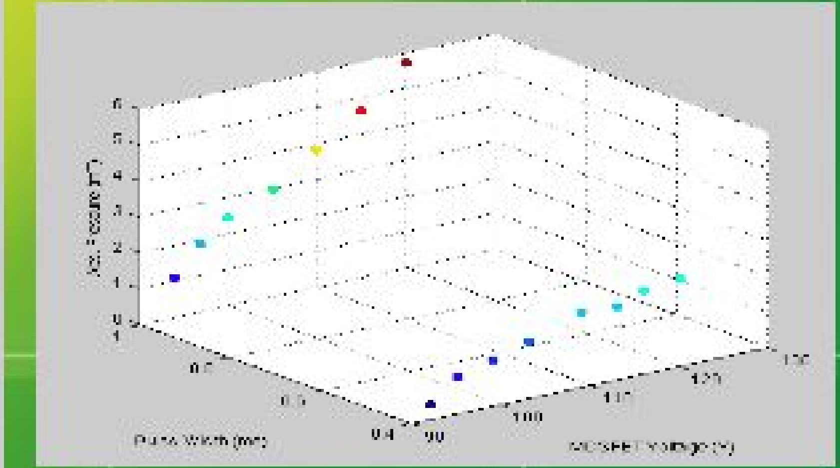
Model 1: Interpolation and Superposition

- We assume that each effect is independent
- We can calculate the individual gains from each parameter (interpolate) and added together (superposed)
- Major Issue
  - Gave massive residual errors for 30% of the data

Experimental Work
Further Results

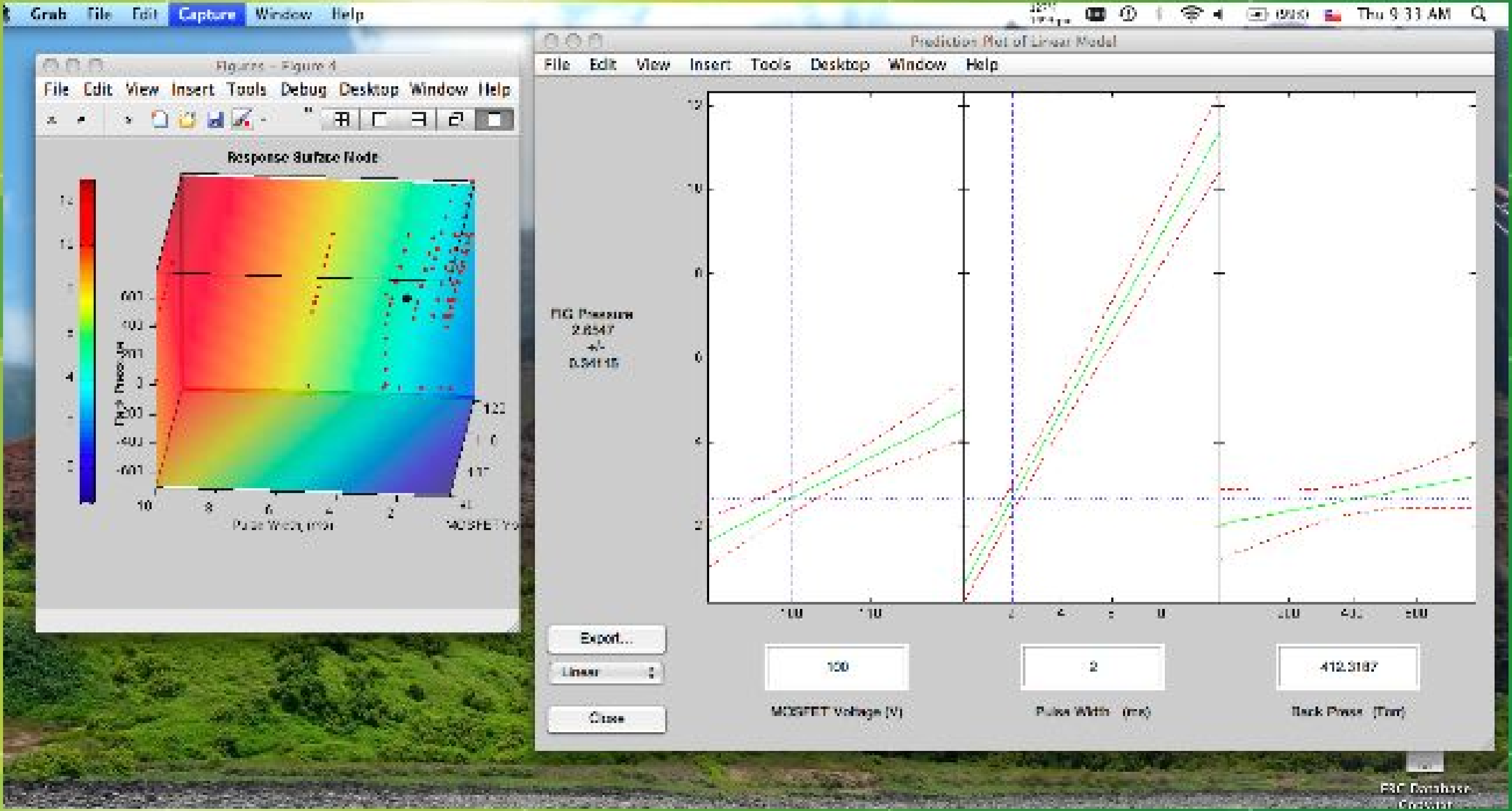






Experimental Work

Model 2: Regression



MOSFET Voltage (V): 100

Pulse Width (ms): 2

Back Press (Torr): 412.3187

Experimental Work
Model 2: Regression

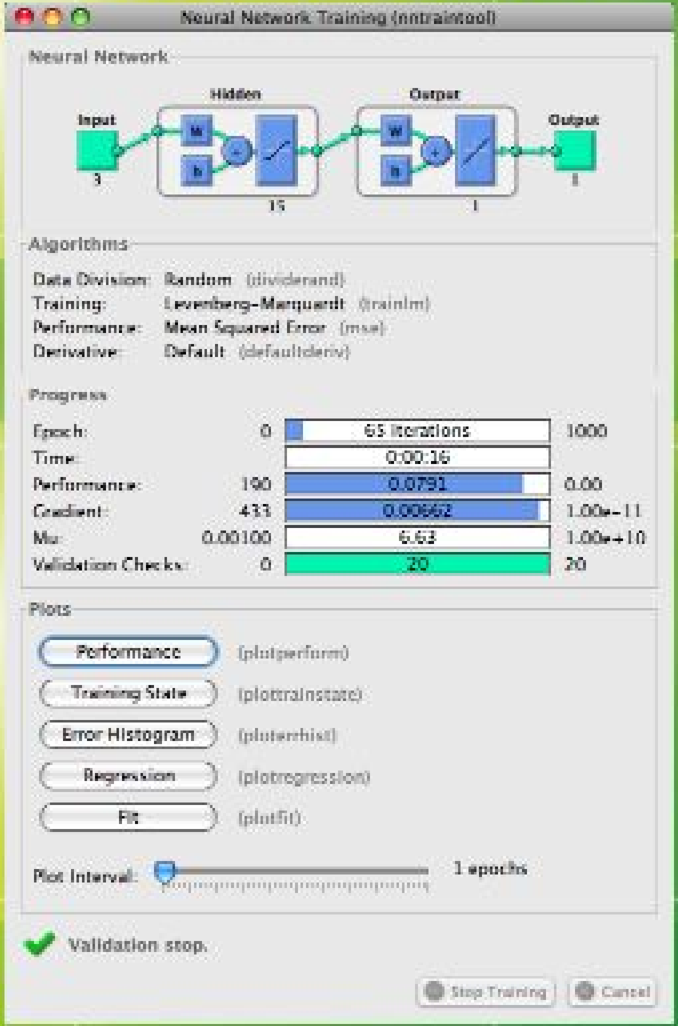
- Regression is an optimization technique used in linear algebra
- Using MATLAB’s Statistics Toolbox
  - Linear Regression (‘regress’/’regstats’)
    - R^2=72%
  - Robust Regression (‘robustfit’)
    - R^2=92%
- Major Issue
  - Predicts negative absolute pressures for very small back pressure and low voltage combinations

Experimental Work
Model 3: Neural Network

- A neural network is an algorithm that takes a given set of known data (inputs and outputs) and then is trained with it
- Upon receiving new data it attempts to process it using what it knows of the global or local environment

Experimental Work

Model 3: Neural Network



Algorithms

Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Derivative: Default (defaultderiv)

Progress

Epoch:	0	65 iterations	1000
Time:		0:00:16	
Performance:	190	0.0791	0.00
Gradient:	433	0.00662	1.00e-11
Mu:	0.00100	6.63	1.00e+10
Validation Checks:	0	20	20

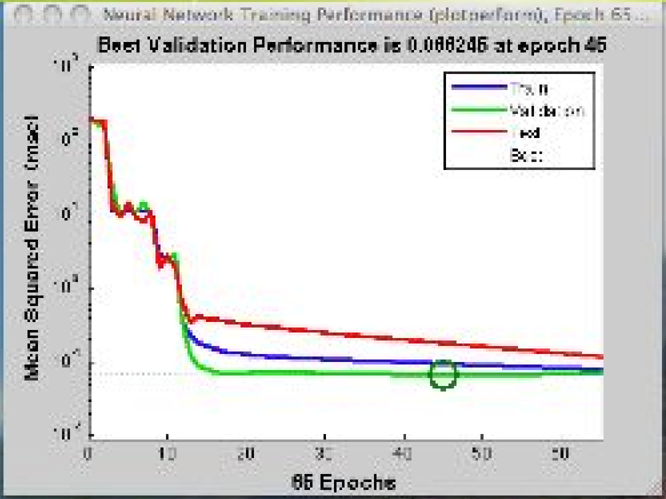
Plots

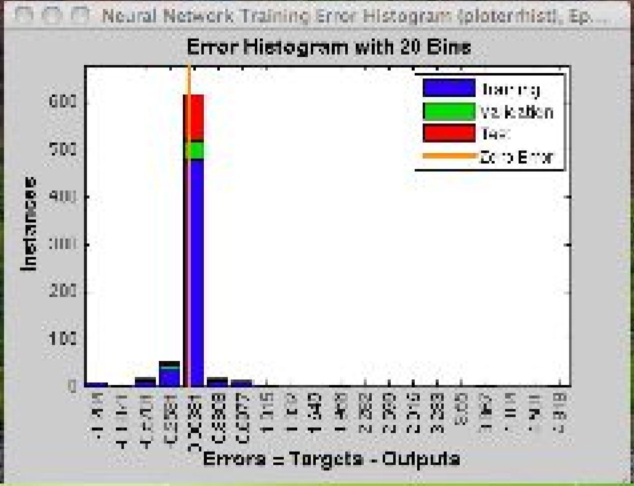
Plot Interval: 1 epochs

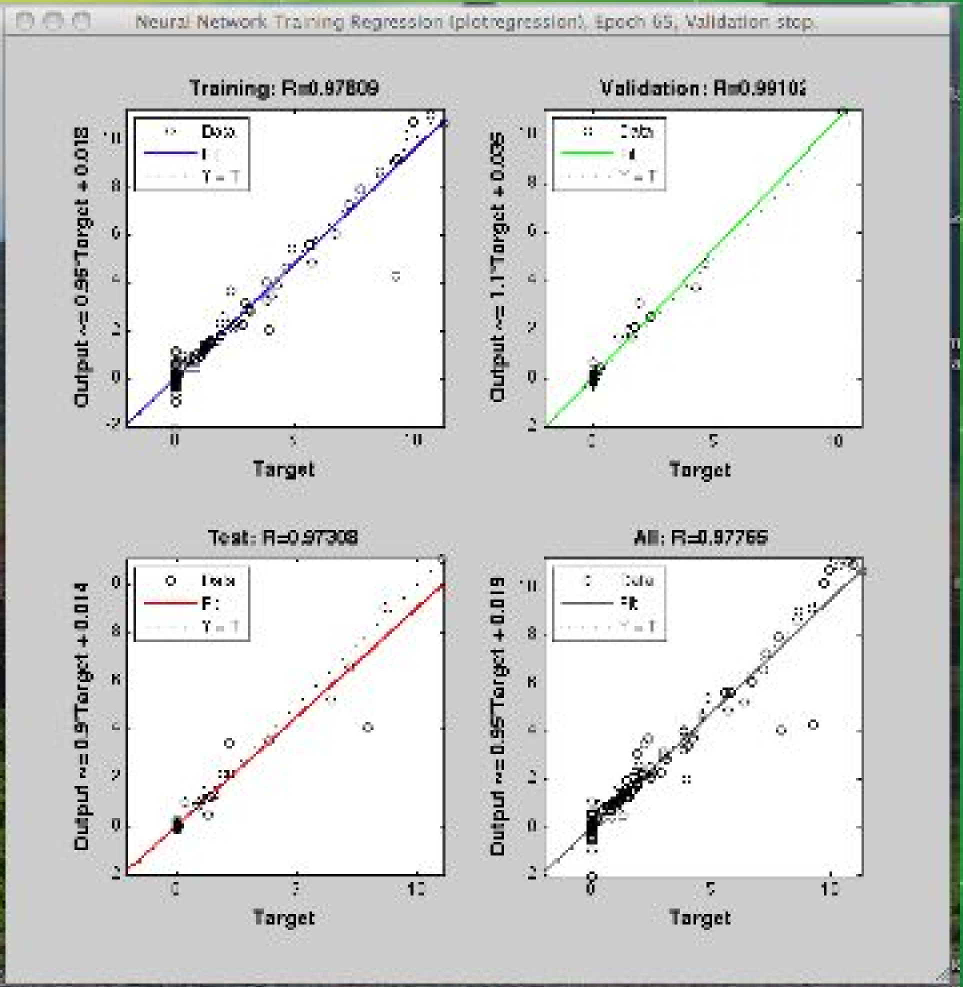
✓ Validation stop.

Experimental Work

Model 3: Neural Network







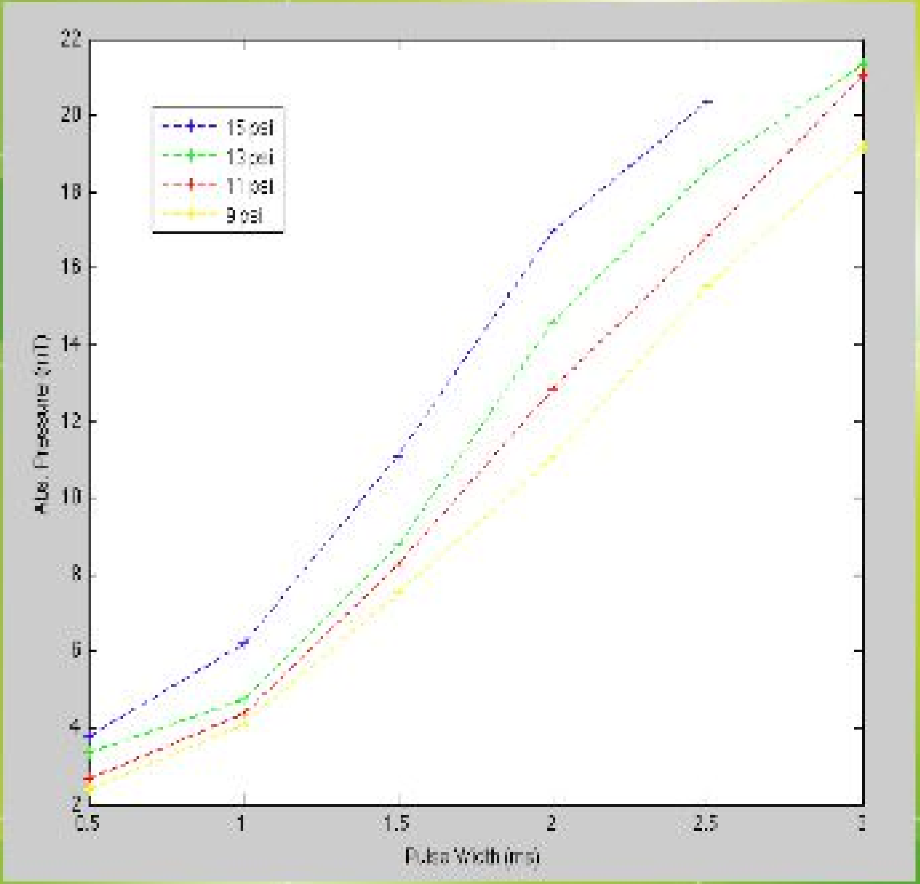
Experimental Work
Model 3: Neural Network

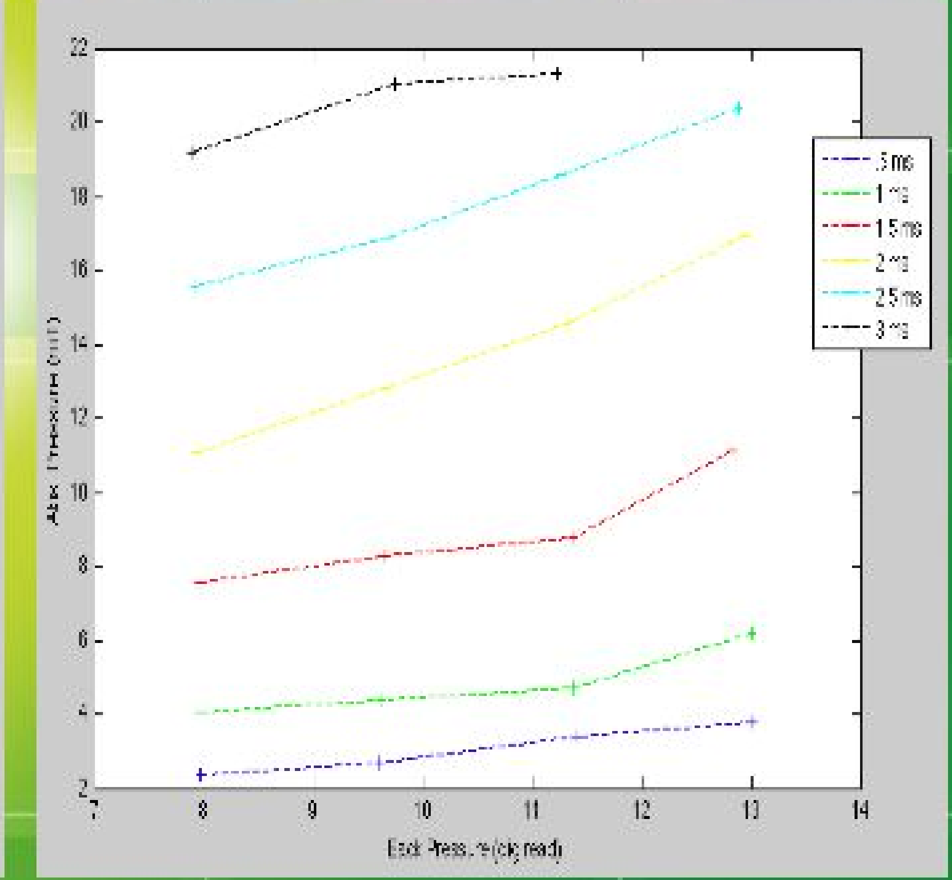
- While R^2 =97.7% for the whole set, there are a few large outliers and we still predict negative absolute pressures (though they tend to be very small)
- A variety of network architectures and training algorithms were tested, the above was the best result, I.e. ‘fitnet’ with the Levenberg-Marquardt training (‘trainlm’)

Experimental Work
Further Results 2

- Our results were giving us a fairly sparse set of data and our models continued to fail
- Therefore, we decided to explore a more limited region of interest and fixed the MOSFET voltage to the valve at 100V
- The first results were very promising…

Experimental Work
Further Results 2





Experimental Work
Current Issues

- While the new data looks good, when it was taken on multiple days, it was found that there was 10-20% variation.
- All data for the full range of back pressures and pulse widths up to 8 ms were taken over four days
- Mass spec and temperature readings were taken and showed almost no variation once the FIG warmed up

Experimental Work

Future Work

- Determine whether very slight fluctuations in temperature effect readings
- Determine if the current leak affects readings
- Narrow down possibilities for variation
- Reduce noise

Acknowledgments

- Professor Sam Cohen
- Bruce Berlinger
- Jeff Kollasch