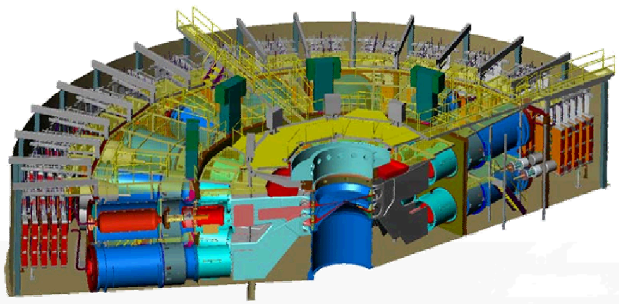
SAND2012-1617C

High-Pressure Strength Determination via Quasi-Elastic Optimization



Z Machine

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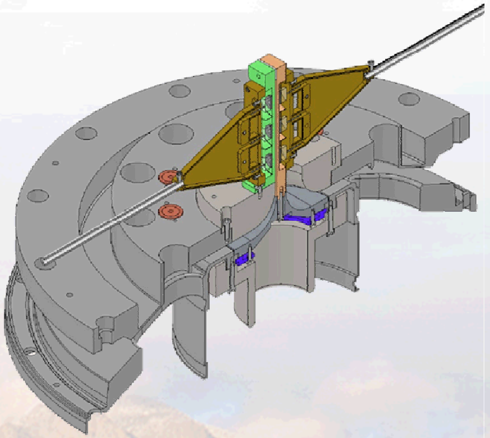
APS March Meeting

Boston, MA

February 28, 2012



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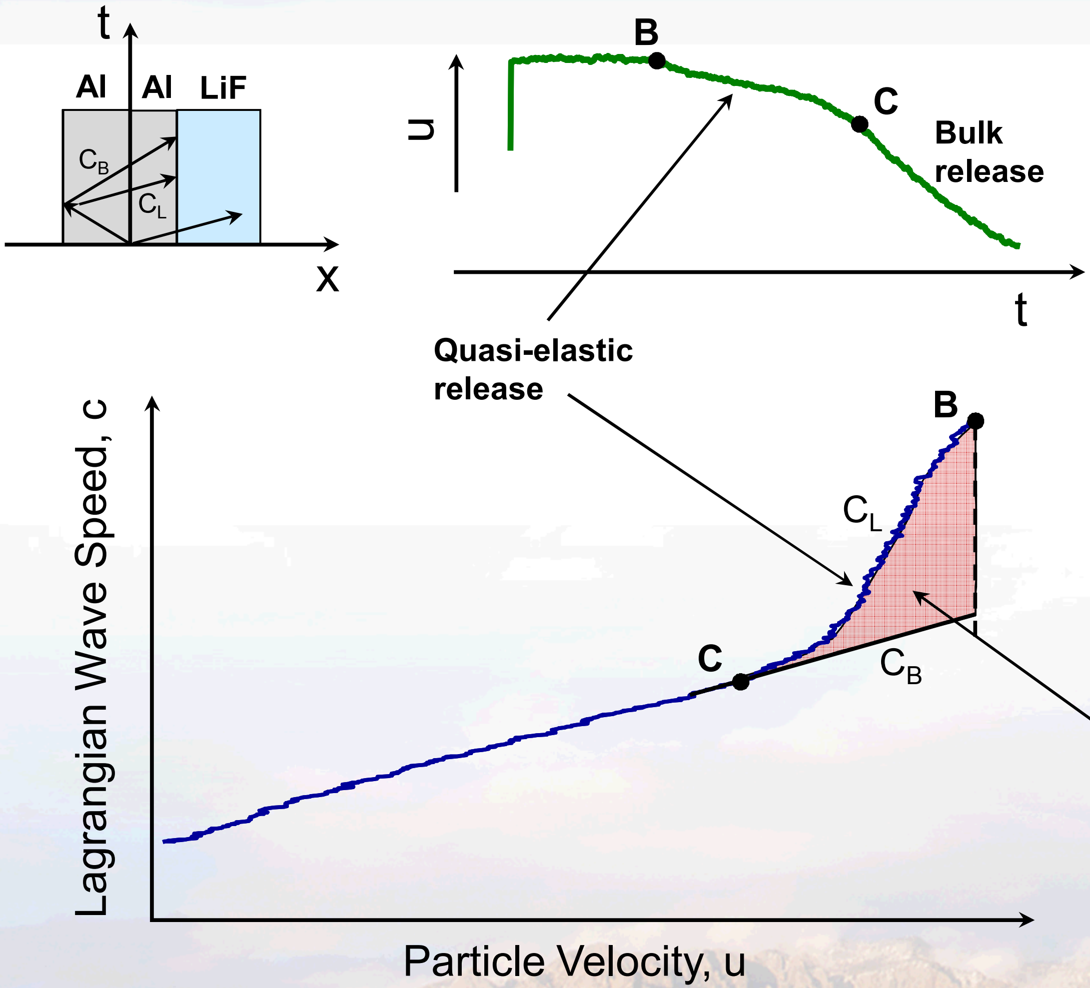
Measured unloading wave velocities may *be used to* estimate the strength



Assumptions

- Uniaxial strain, elastic-plastic

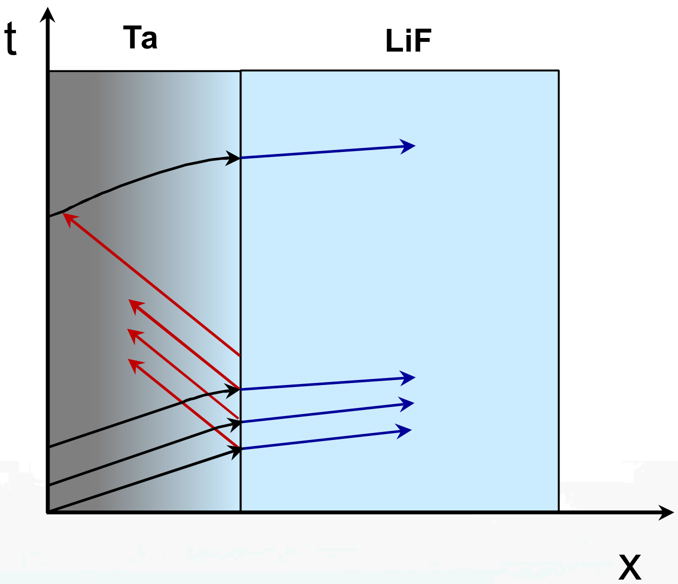
$$\sigma(\varepsilon) = P(\varepsilon) + \frac{4}{3}\tau(\varepsilon)$$

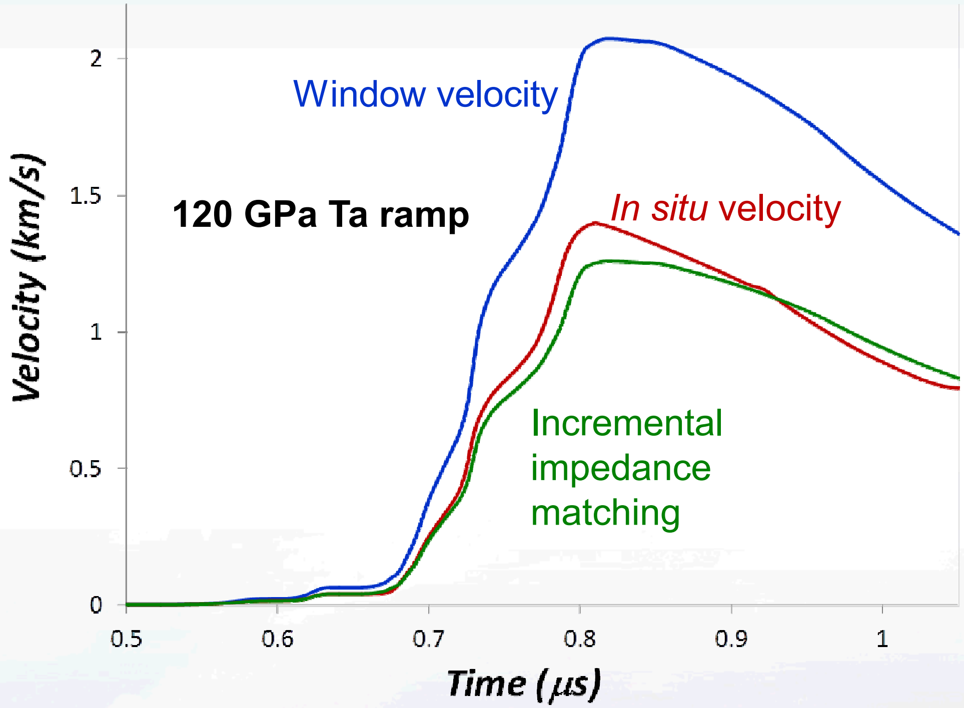
$$\frac{d\tau}{d\varepsilon} = \frac{3}{4}\rho_0\left[c_{\exp}^2 - c_B^2\right]$$

- Rate independent response
- Von-Mises yield surface
- Flow strength determined from quasi-elastic unloading

$$Y = 2\tau = \frac{3}{4}\rho_0\int\left[c^2 - c_B^2\right]\frac{du}{c}$$

Window effects on ramp loading





- **Poor impedance match is difficult to account for**
  - Release waves are constantly generated at the window interface which interact with the incoming ramp
    - Non-simple waves
  - Produces a non-uniform stress state in the sample
  - Incremental impedance matching can be a poor approximation (for ramp waves), particularly at higher stresses

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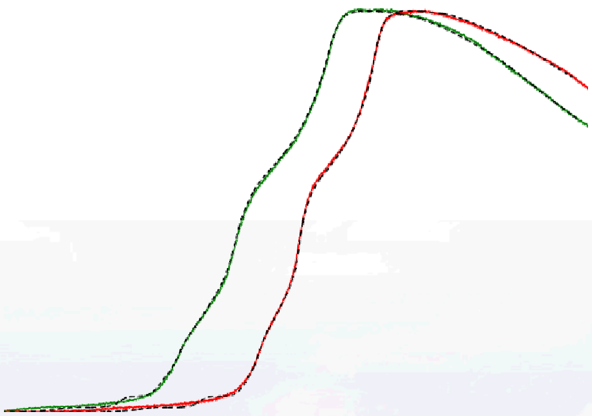
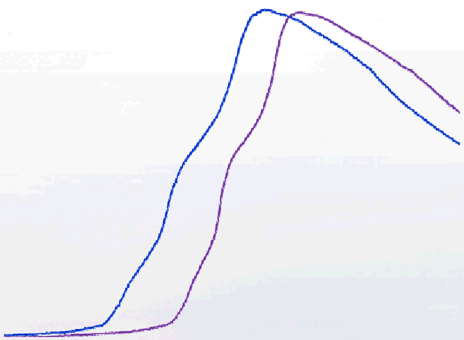
Strategy for removing window effects

Perform optimized simulations until a good match of the experiment is obtained: Laslo (1-D wave dynamics with MHD) + Dakota (optimization package)

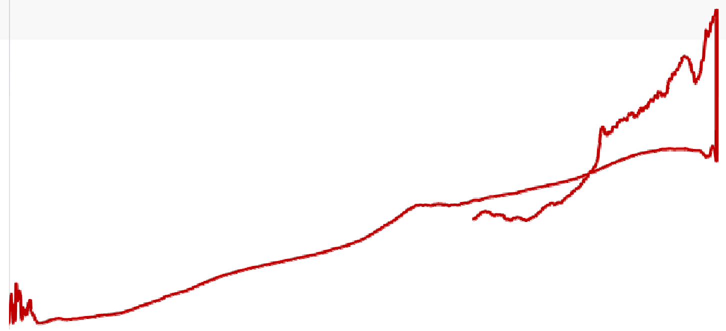


Calculate the *in situ* response: what the waveform at each location would have looked like if the window was replaced by the sample

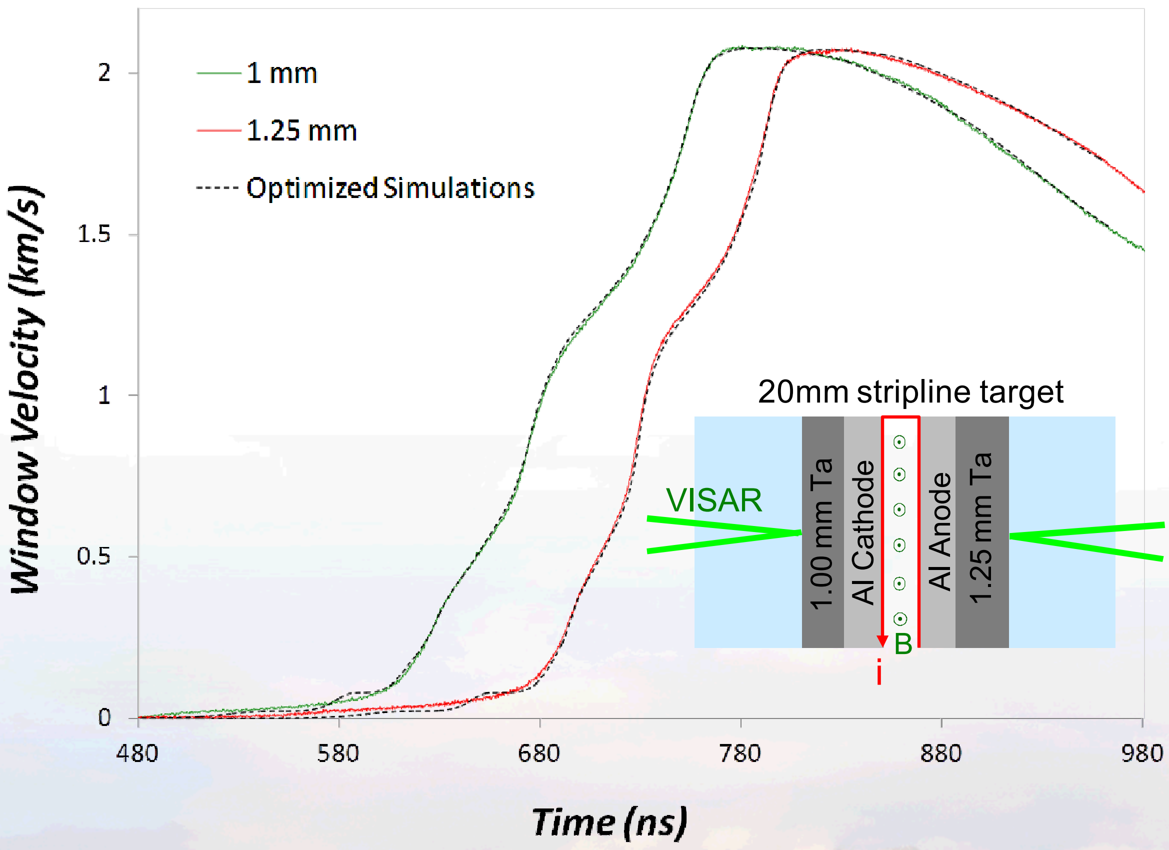
Calculate a transfer function (mapping) and apply to experimental data



Perform Lagrangian analysis and calculate the strength



1) Optimized simulations

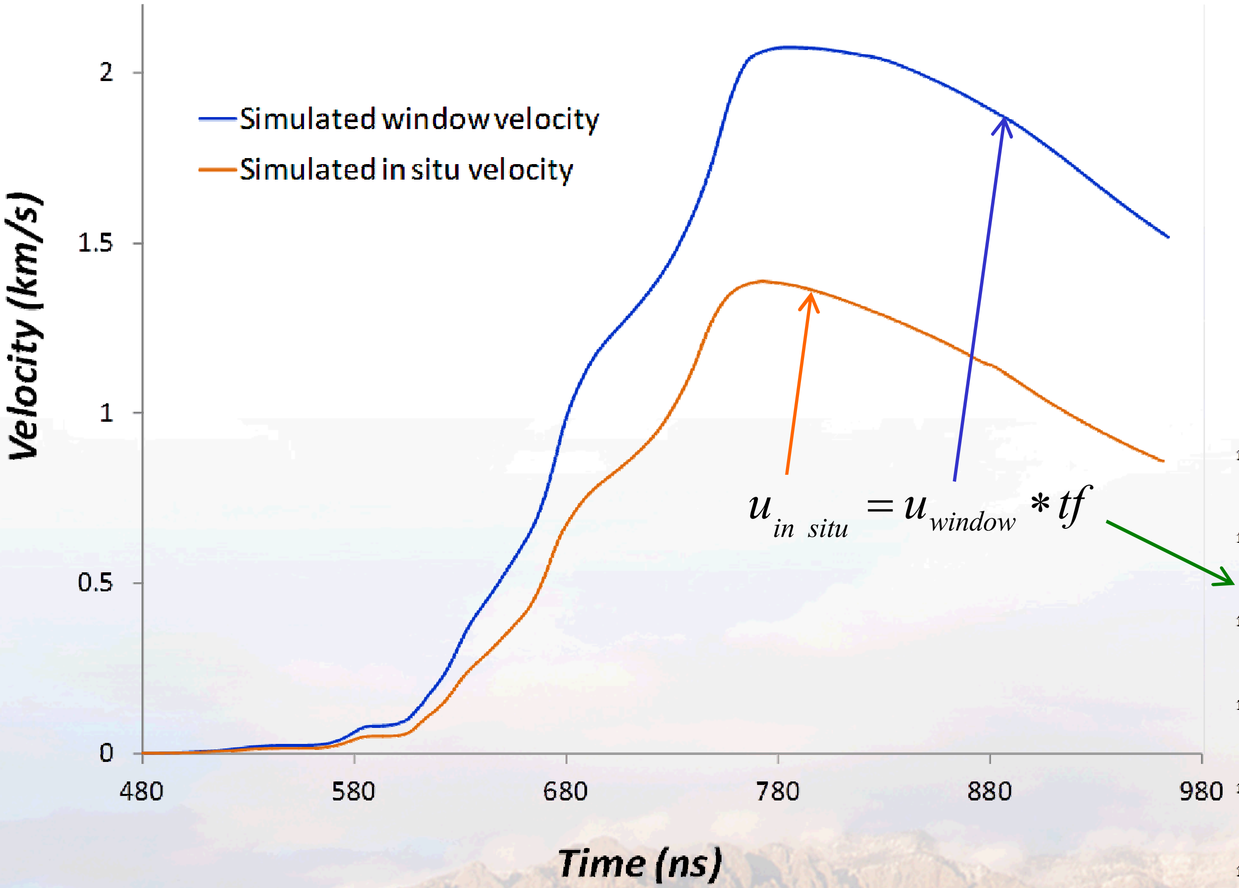


- **50 control points to define the 1-D current**
  - Interpolation scheme coupled with low pass filter
- **Independent time shifts of up to 0.5 ns**
- **Mie-Gruneisen EOS**
  - Small changes to c_0 and s
- **Quasi-elastic strength model**
  - Rate-independent Steinberg-Guinan with linear decay of the shear modulus

$$Y = Y_0\left[1+\beta\left(\varepsilon+\varepsilon_i\right)\right]^n\left[1+A\frac{P}{\eta^{1/3}}+B\left(T-300\right)\right]$$

$$G_{eff} = G\left(1-\frac{\varepsilon-\varepsilon_m}{\varepsilon_m-\varepsilon_t}\right)$$

2) Run *in situ* simulation and 3) determine the transfer function



$$u_{in\ situ} = u_{window} * tf$$

$$U_{in\ situ} = fft\left(u_{in\ situ}\right)$$

$$TF = \frac{U_{in\ situ}}{U_{window}}$$

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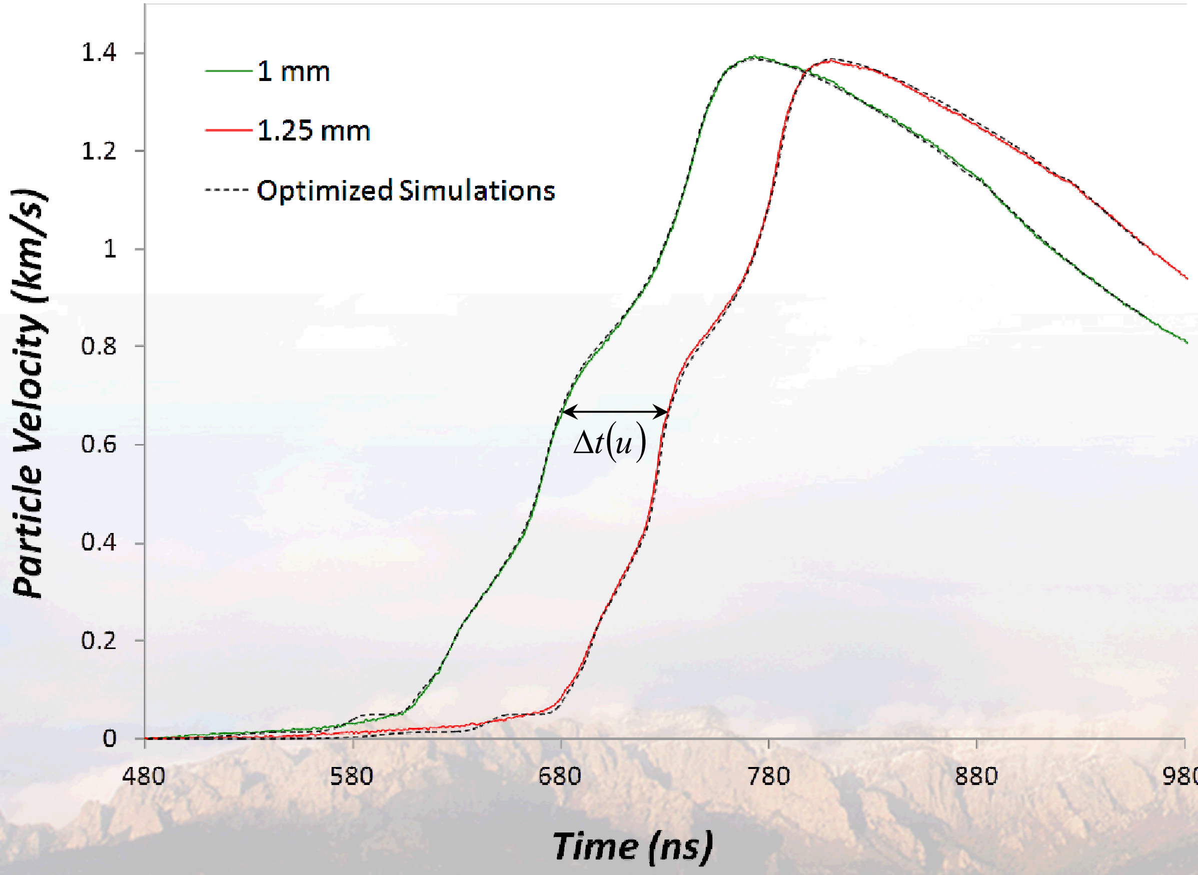
4) Use the transfer function to determine the *in situ* experimental profiles

- **Features not captured in the optimized simulations are transferred through to the *in situ* profiles**
  - Can now perform standard Lagrangian analysis



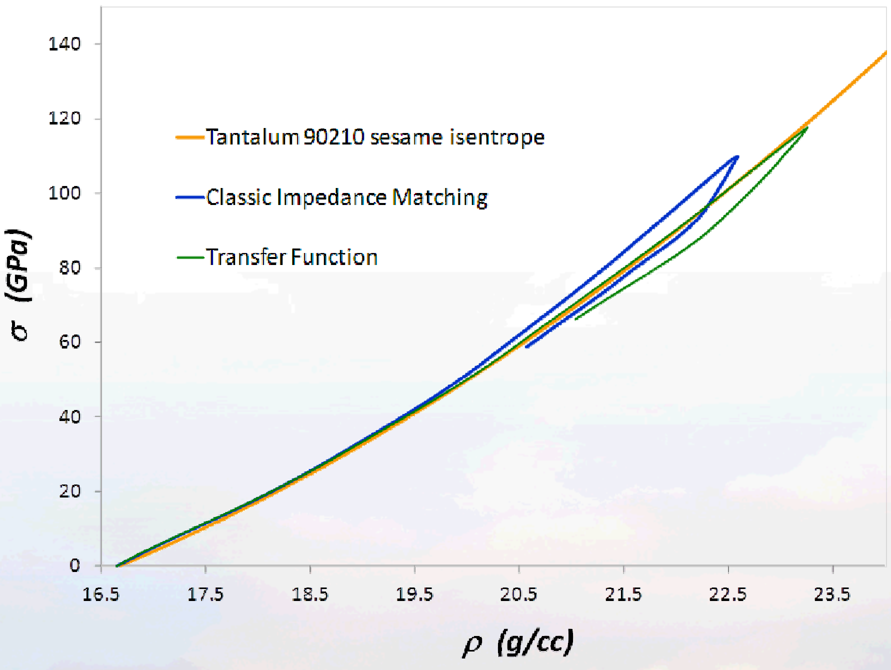
$$c(u) = \frac{\Delta x}{\Delta t(u)}$$

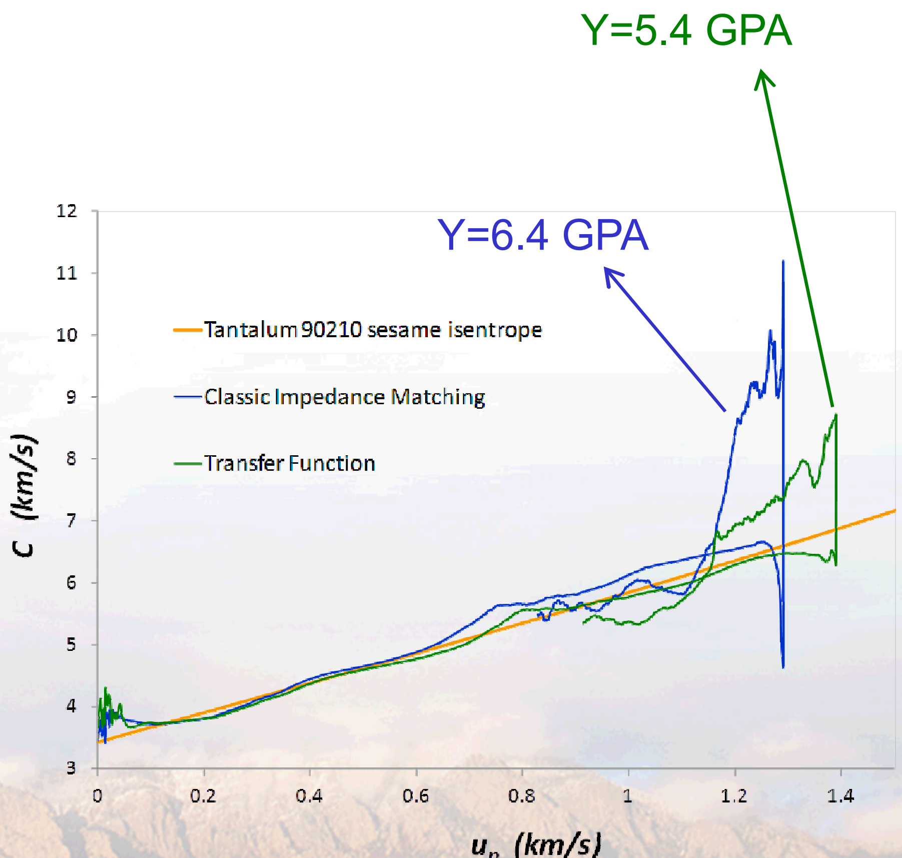
$$d\sigma_x = \rho_0 c du_p$$

$$d\varepsilon_x = \frac{c}{du_p}$$

Z1904 Results

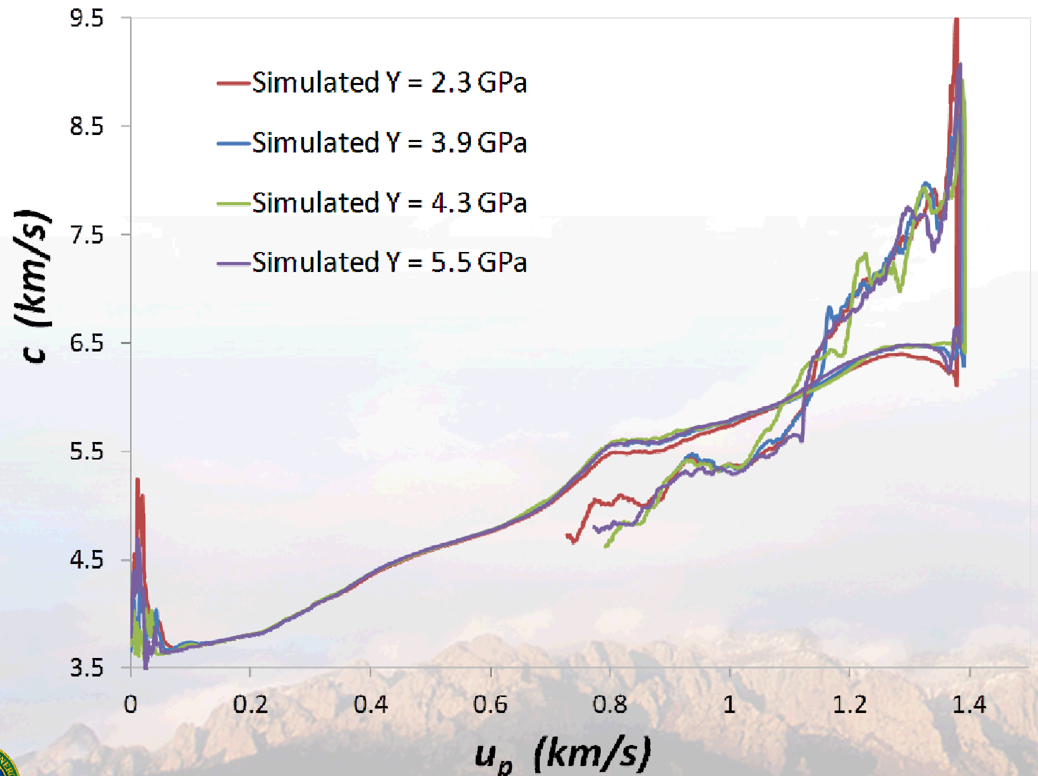
- **Results are in good agreement with the tabular isentrope**
  - Classic impedance matching diverges at ~ 50 GPa





Analysis is model independent

- **As long as the optimized simulations are "close", the experimental data dictates the response**
  - Varying the strength used in the optimizations results in fits which are not as good, but the end result is nominally the same



Mean Y:
5.3 GPa

Standard Deviation:
0.2 GPa (4%)

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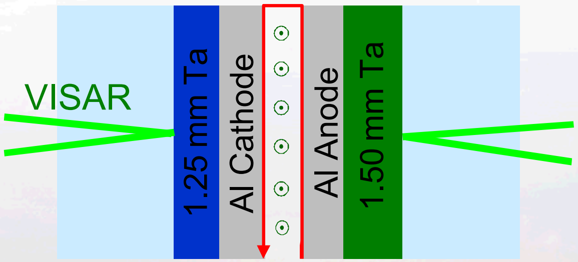
Conclusions and future work

- **Transfer function approach appears to be a robust methodology for accurately accounting for window effects in ramp experiments**
  - Should provide high fidelity strength estimates (5%?)

- **Next generation of experiments on tantalum**
  - Generate flat top pulses to eliminate attenuation
  - Experiments between 50 – 200 GPa
    - Avoid corruption of the unload from the initial reflection off of the window interface (reverberation)

- **Quantify uncertainties**
  - Monte Carlo simulations



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Additional Slides

Quasi-elastic strength model

- **Rate-independent Steinberg-Guinan quasi-elastic strength model**

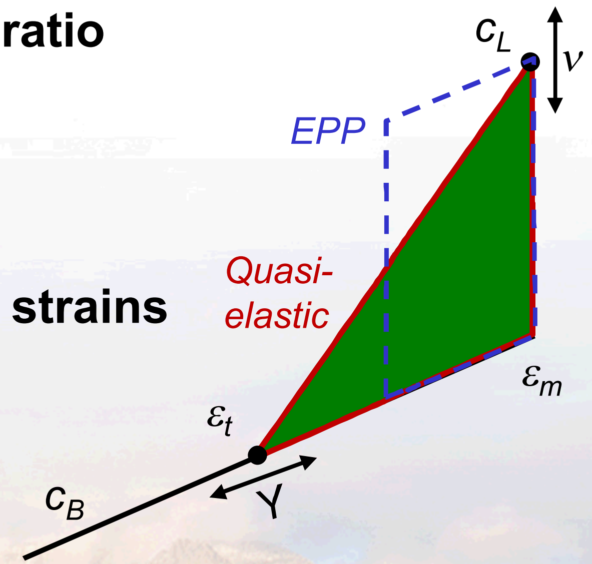
$$Y = Y_0\left[1+\beta(\varepsilon+\varepsilon_i)\right]^n \left[1 + A\frac{P}{\eta^{1/3}} + B(T-300)\right]$$

- **Determine shear modulus from EOS and Poisson's ratio**

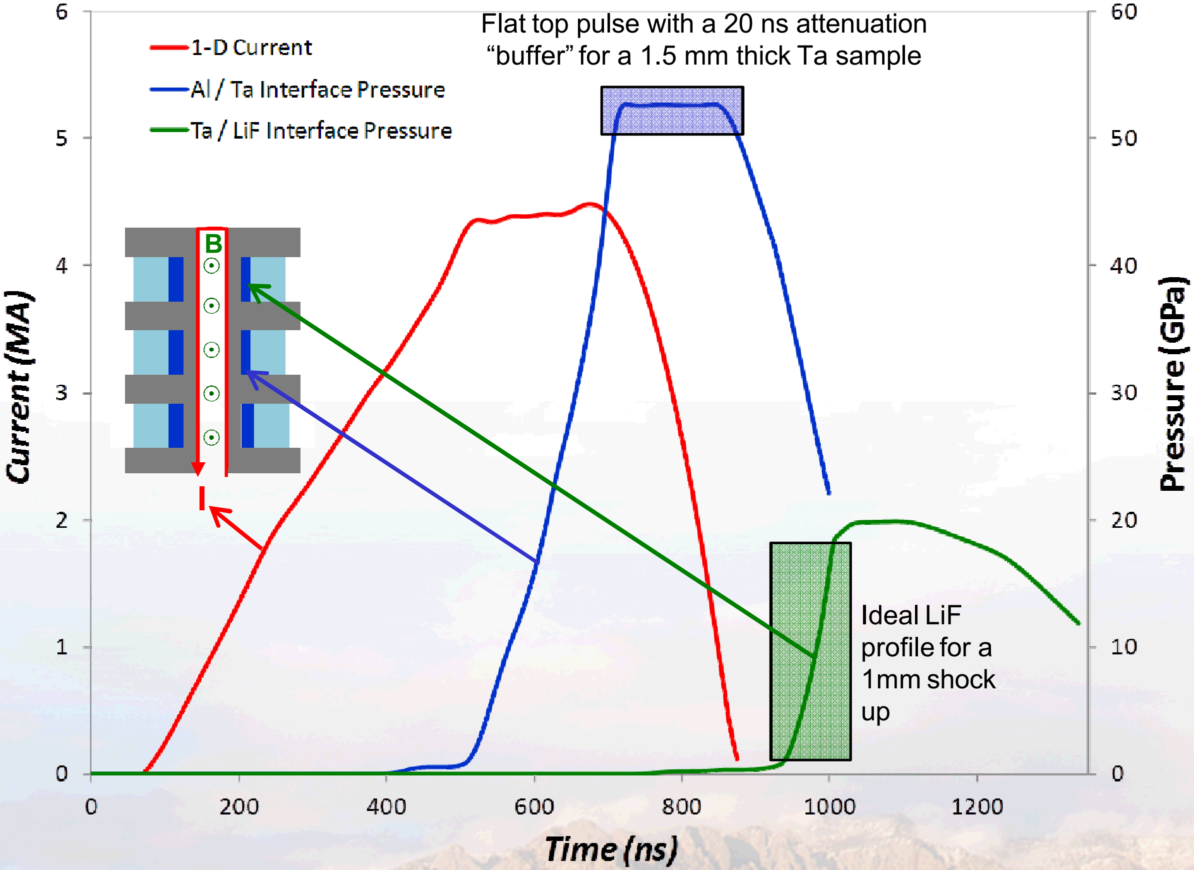
$$G = \frac{3K(1-2\nu)}{2(1+\nu)}$$

- **Vary shear modulus linearly from peak to transition strains**

$$G_{eff} = G\left(1 - \frac{\varepsilon-\varepsilon_m}{\varepsilon_m-\varepsilon_t}\right)$$



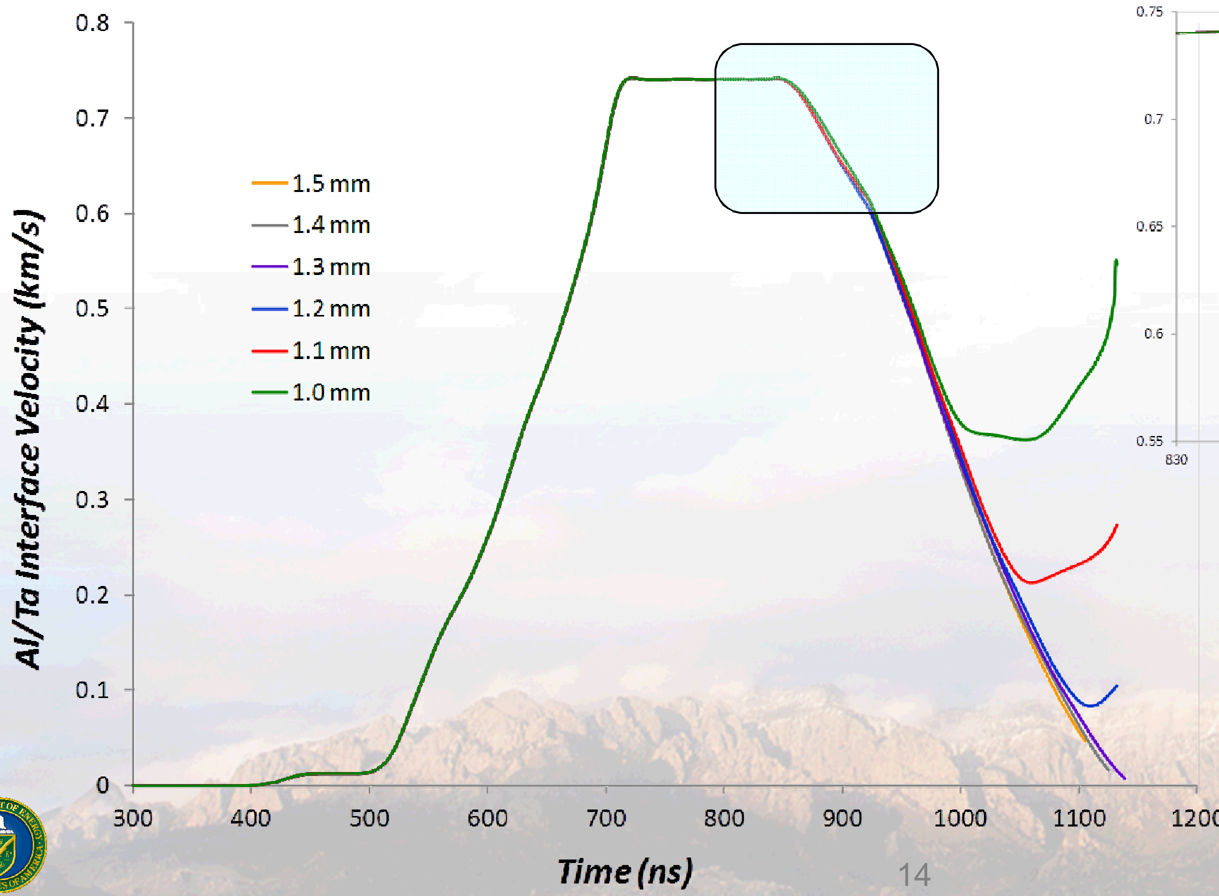
Design of new experiments

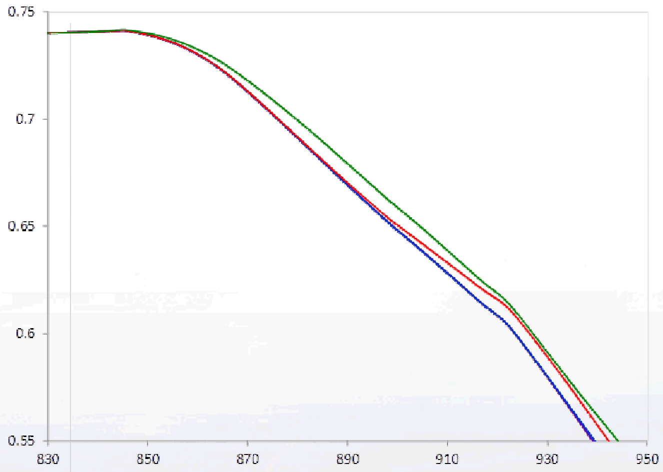


- **50 GPa peak stress in 1.5 mm thick Ta**
- **Used optimized simulations to generate a drive current such that:**
  - Flat top pulse such that there is 0 attenuation in the in-situ case
  - 1 mm shock up distance in the window
  - Tried to pick a realistic tail current fall off

Reverberation is taken into account

- **Sample thicknesses can then be chosen to avoid corruption of the unloading wave (reverberation)**
  - 1.2 mm is the minimum thickness to maintain consistency through the quasi-elastic unload





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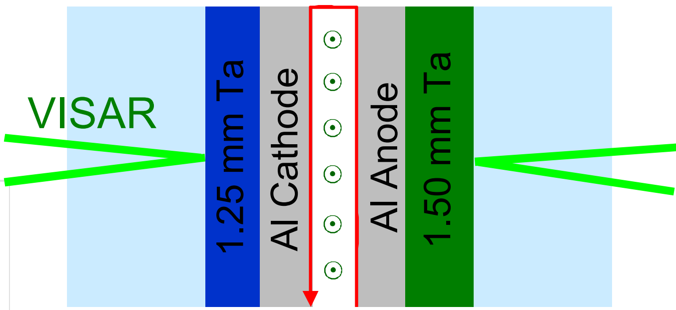
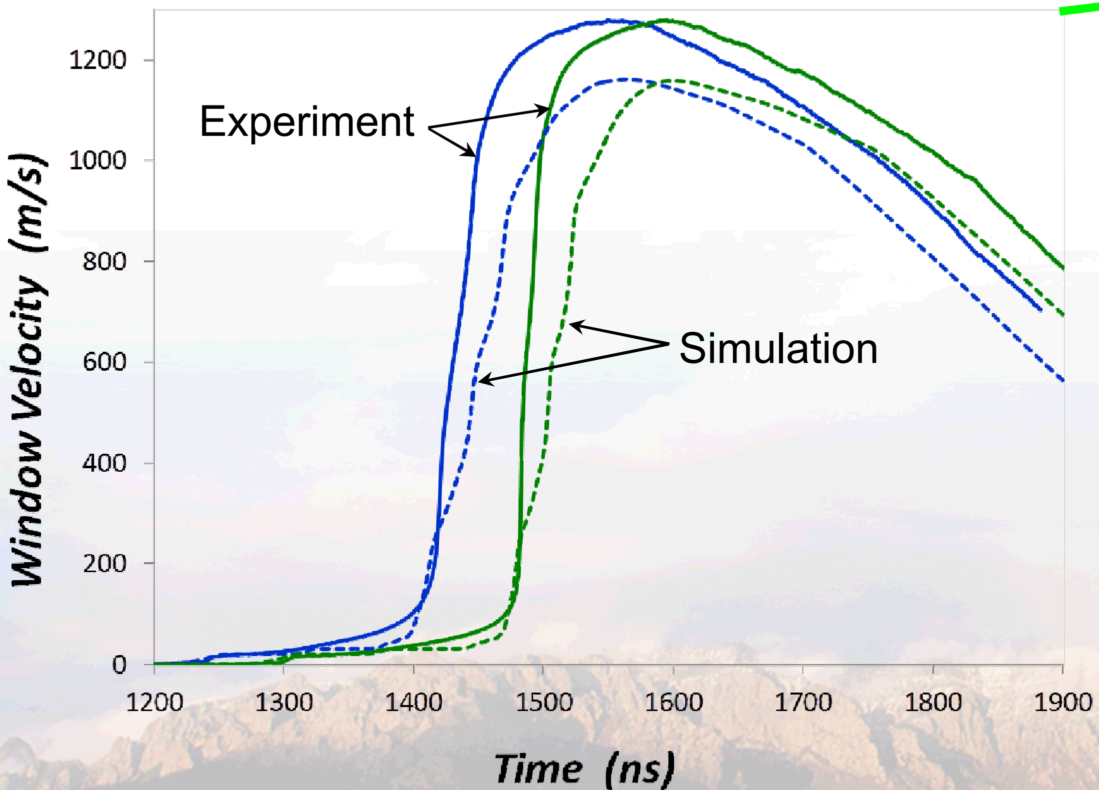
Preliminary Z2296 shot results

- **Current was higher than predicted**
  - Steeper waveforms
  - Attenuation is negligible





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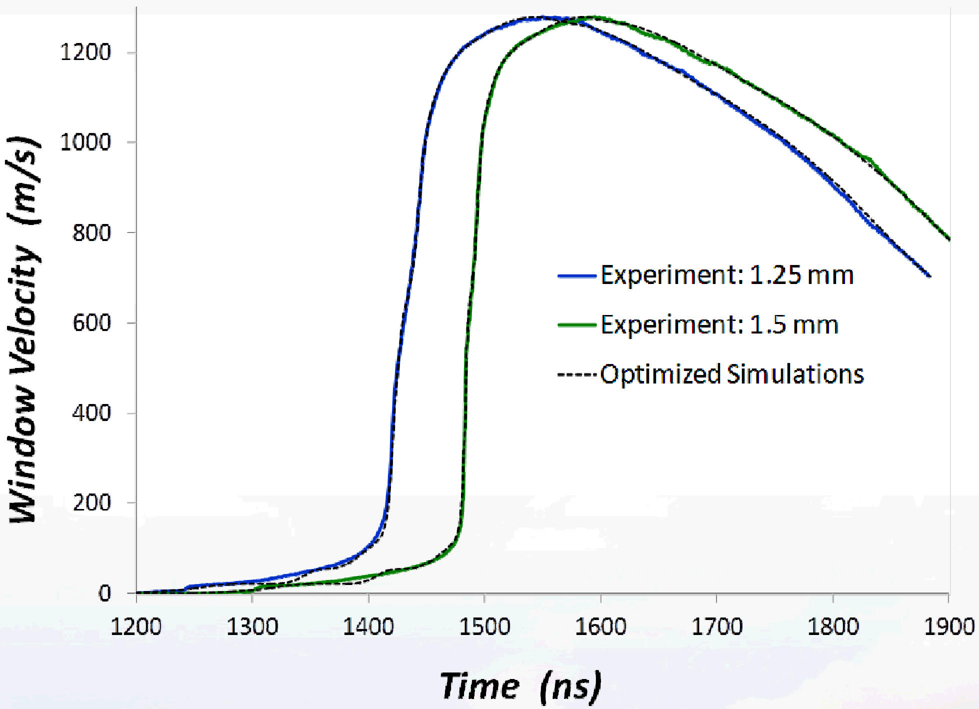
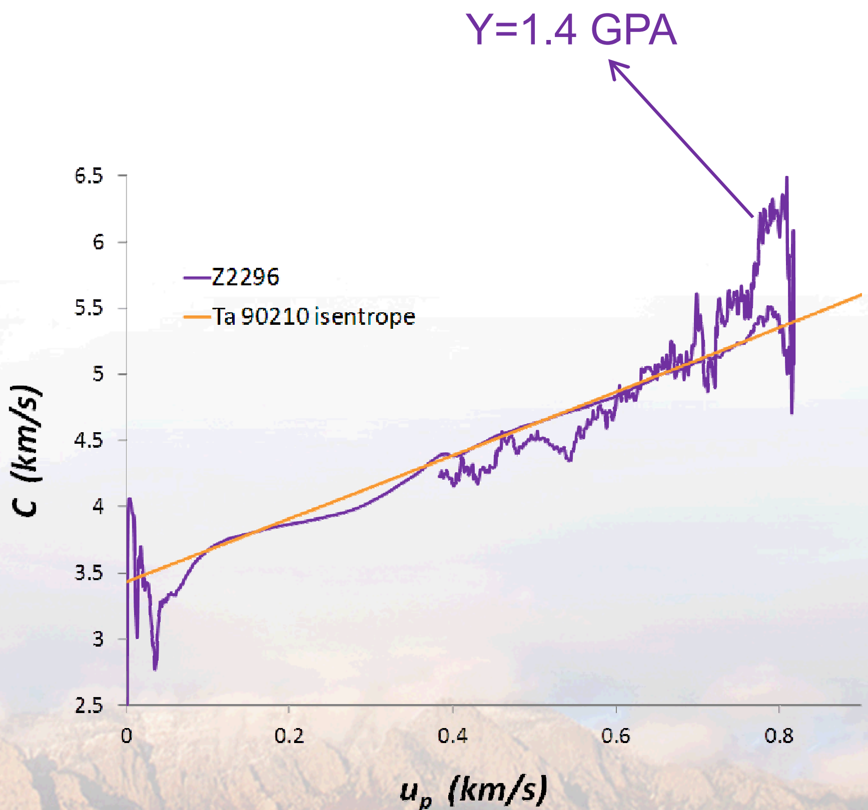
Optimization and Lagrangian analysis





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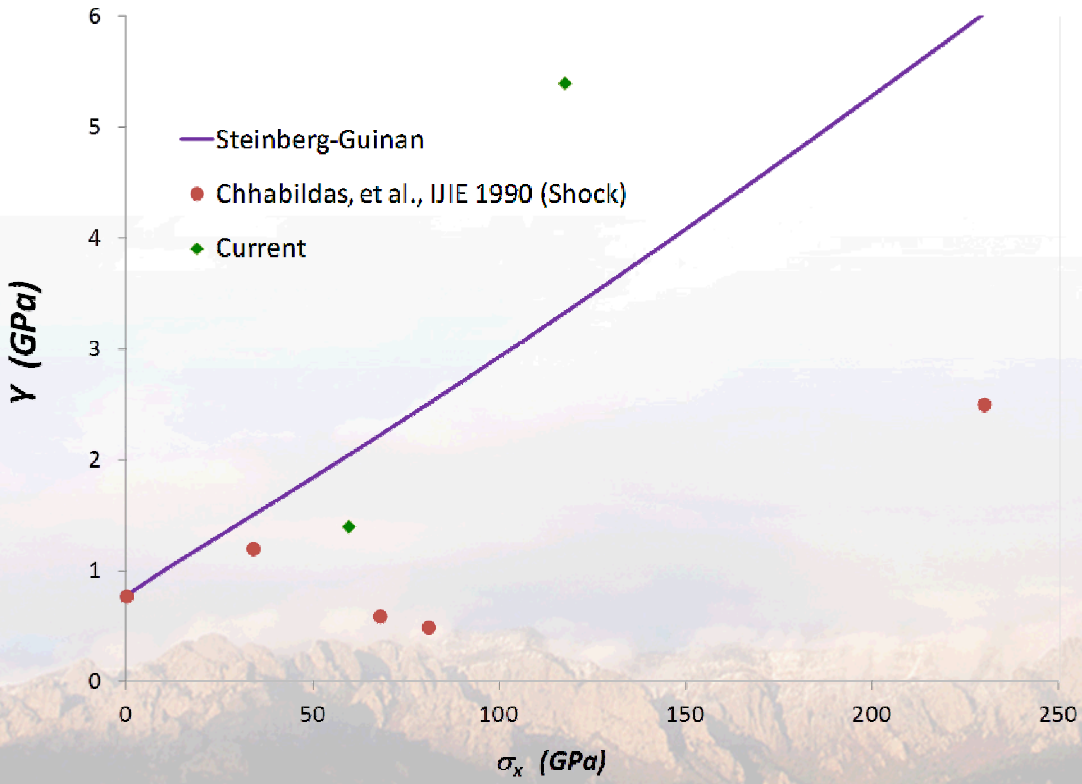
Measured strength

- Lower pressure point (60 GPa) is in reasonable agreement with shock data
- Higher pressure point (120 GPa) suggests tantalum is significantly stronger under ramp compression



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