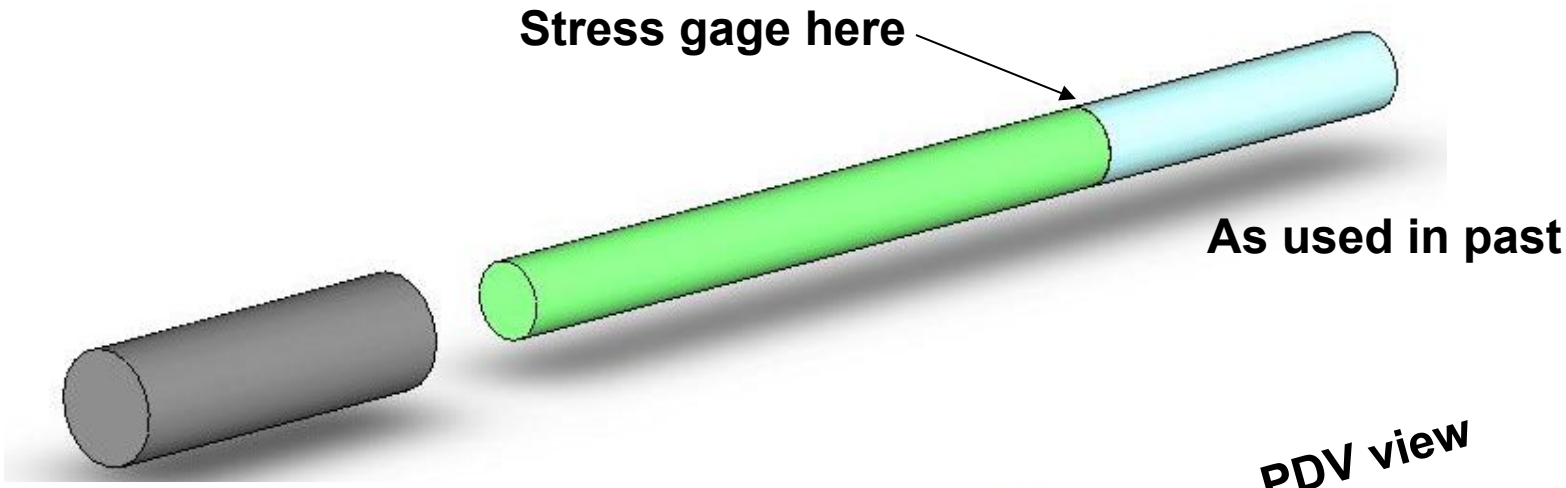
Dynamic strength of brittle materials using PDV Measurements of high speed bar impact

2008 PDV Conference & Workshop
Sandia National Laboratories, NM
September 3rd, 4th, 2008

Scott Levinson
John Tolman
Stephan Bless

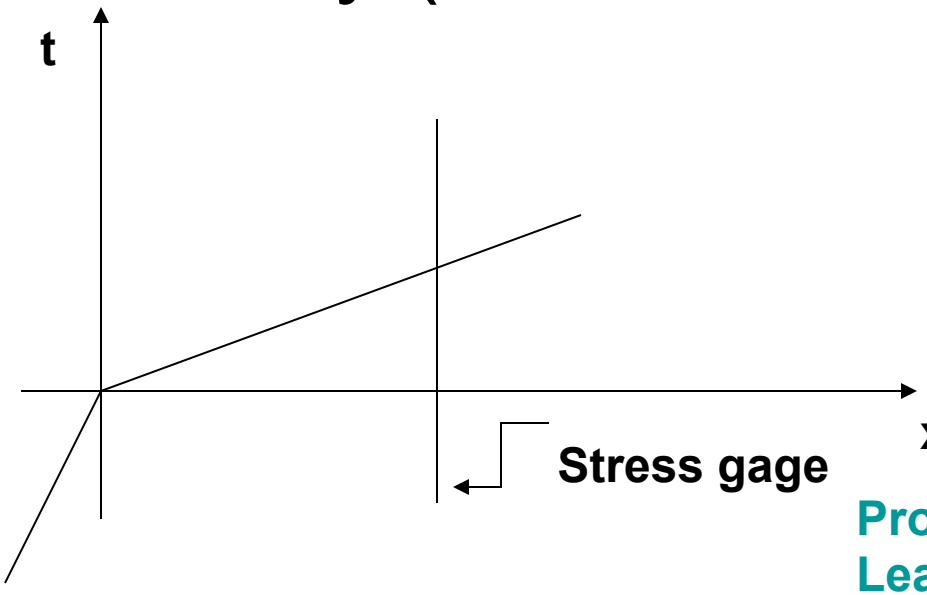
Improved Bar Impact Experiments

Goal: Develop technique to measure strength of glasses

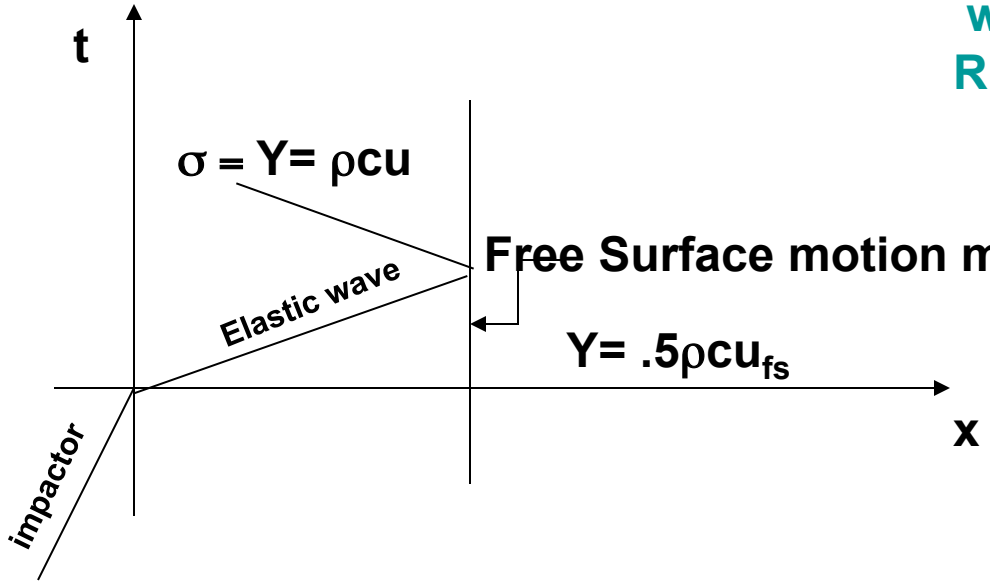


These experiments: observe free surface motion with hi speed camera and PDV.

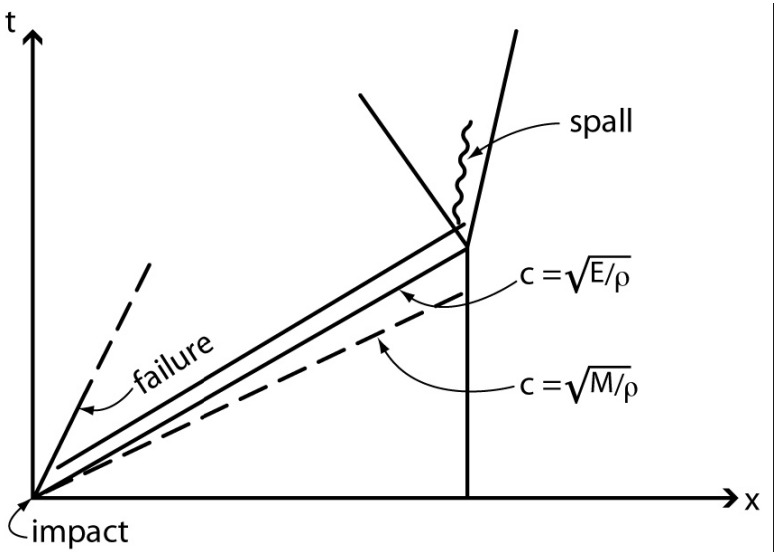
Theory (for ductile materials)

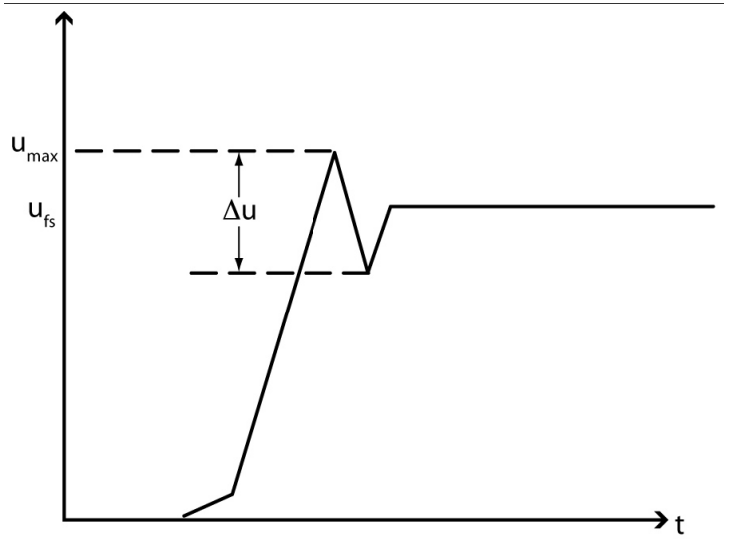


Problems with gauge –
Leads break
Very short lifetime
when used with brittle materials
Risetime limited



Theory for brittle materials



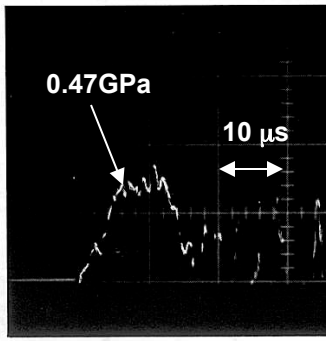


Failure causes release near impact, resulting in triangular instead of square pulse. For many brittle materials, spall strength is less than compressive strength, resulting in a "spall signal" at free surface.

(M=K+4G/3. K,G,E are elastic moduli)

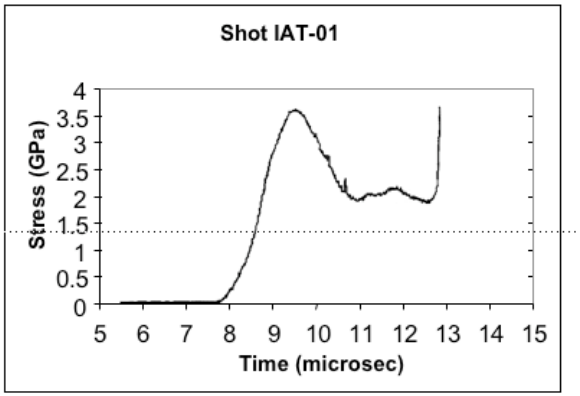
Examples of Previous work

Strength of a Mild Steel



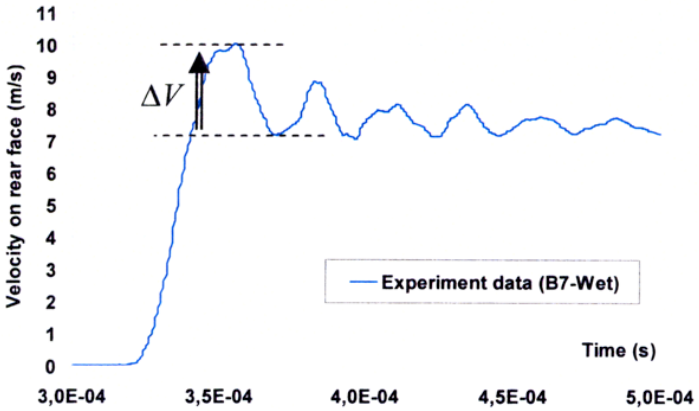
Rosenberg & Bless, 1986

Strength of Alumina



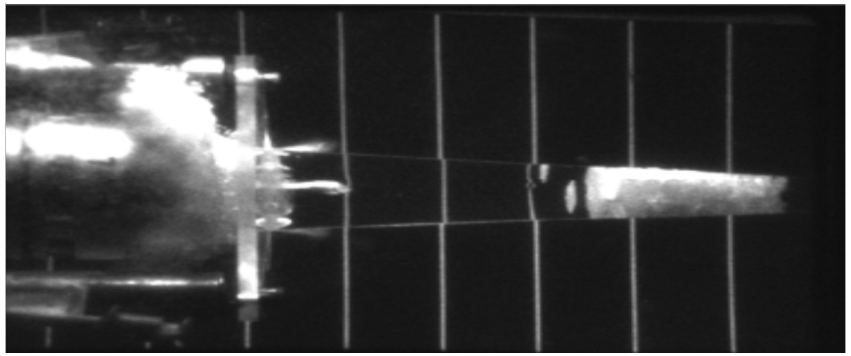
T. Beno at al, 2006, strength of alumina = 3.6 GPa

Spall in Concrete



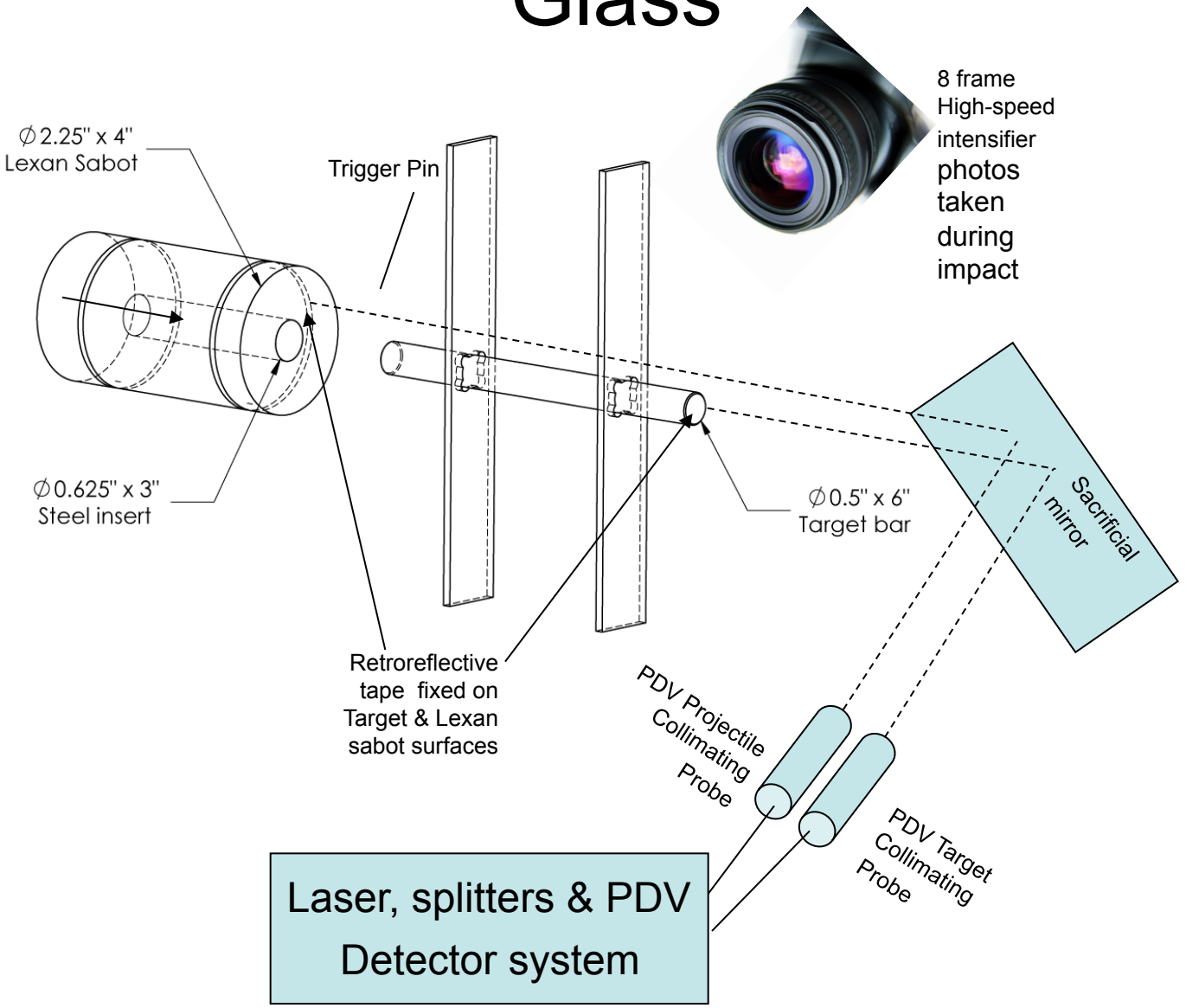
P. Forquin, & Erzan, 2008

Failure in tapered homalite bar

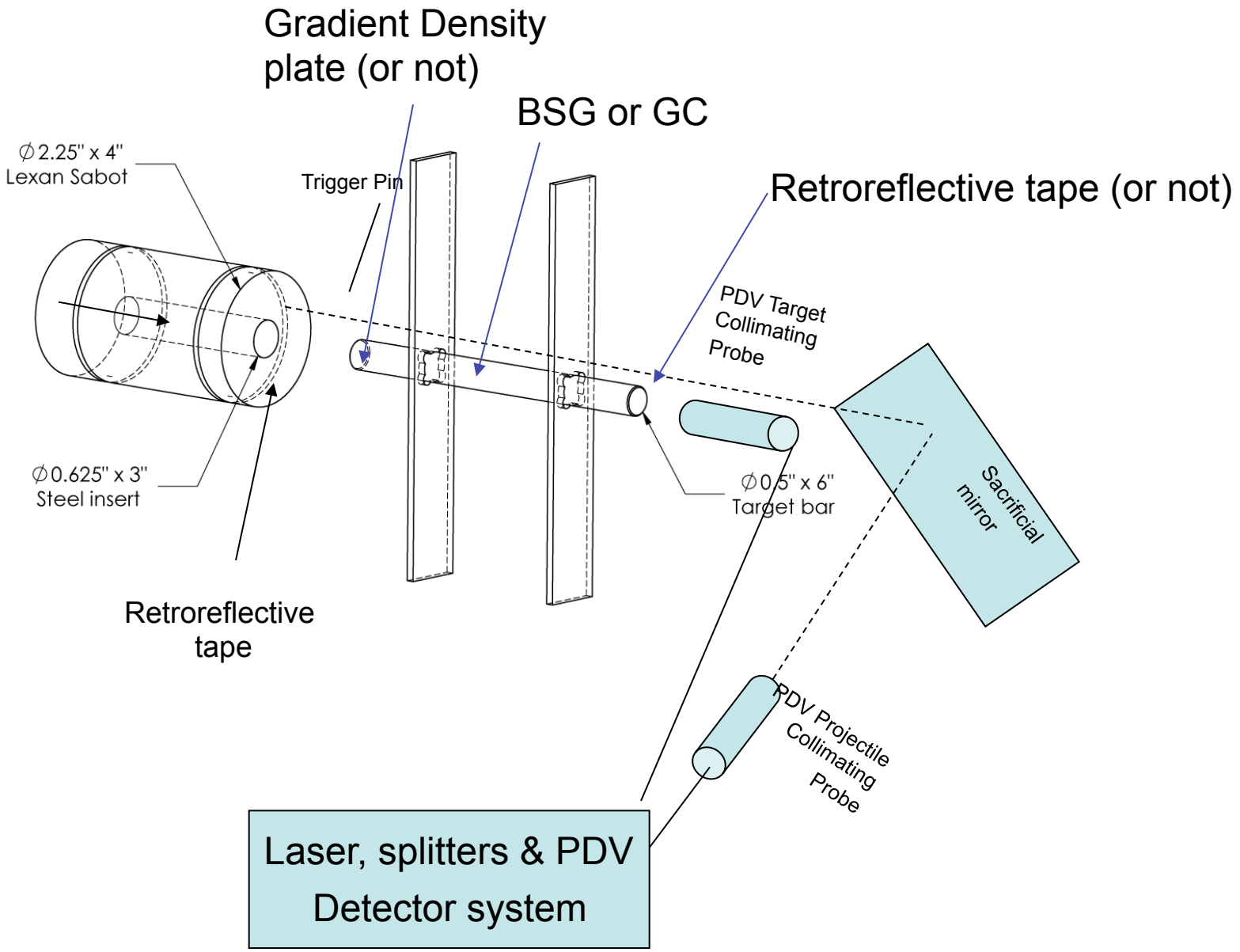


Bless, 2003

Experimental Setup for Glass



Test Variations



10 Tests conducted

All impact velocities between 250 and 310 m/s.

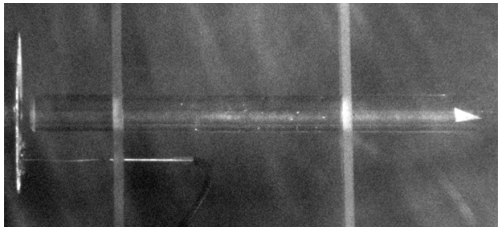
Test	Material	Impact Velocity (m/s)	Free Surface Velocity (m/s)	Stres (Gpa)
A1- 004	GC	260	287	1.84
A1- 007	GC	256	275	1.95
A1- 011	GC	262	280	1.99
A1- 013	GC+GDI	280	160	1.13
A1- 014	GC+GDI	253	118	0.84
A1- 015	BSG+GDI	255	160	0.93
A1- 003	BSG	266	247	1.44
A1- 008	BSG	250	223	1.30
A1- 012	BSG	265	235	1.37
A1- 017	BSG w/o Retro	310	374	2.18

GC = Glass Ceramic, BSG = Borosilicate glass
GDI=graded density impactor

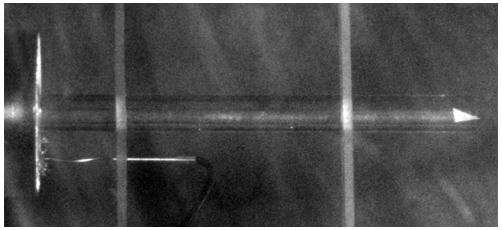
Results of bar impact on BSG

shot A1008
borosilicate glass

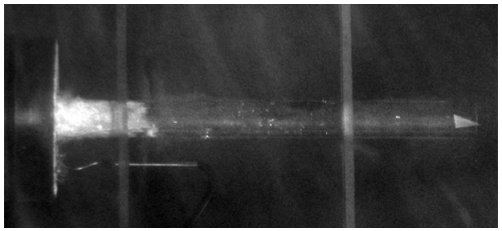
Direction of travel



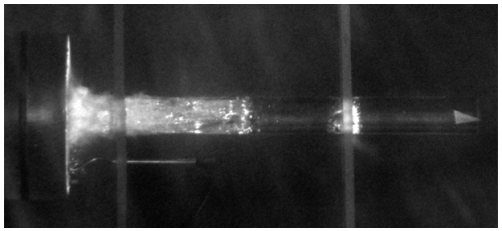
150 μs



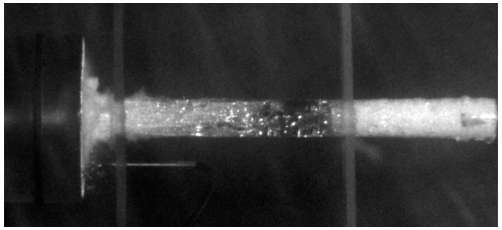
160 μs



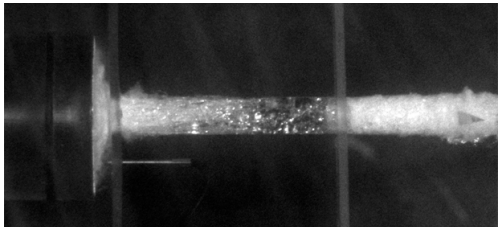
170 μs



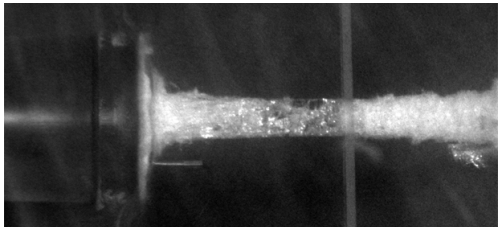
175 μs



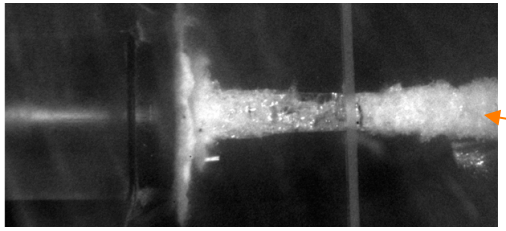
180 μs



200 μs



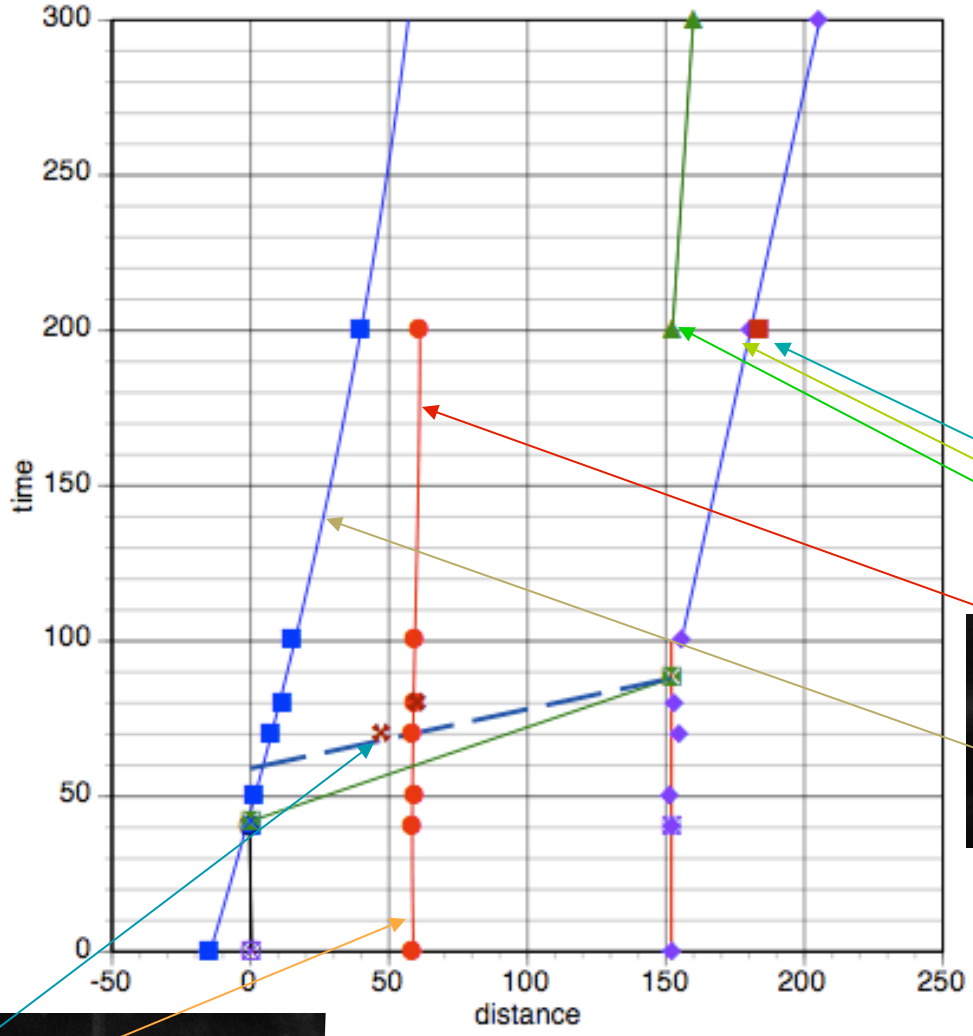
250 μs

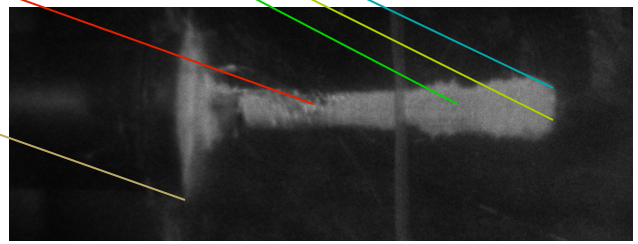


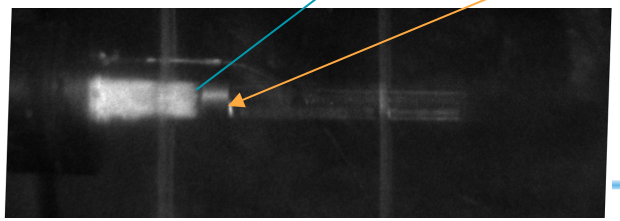
300 μs

explosive
tensile failure

X,t analysis of shot A1-003, BSG







$Y = 2\rho c u_{fs}$

uf_s=250m/s, implying 1.5GPa strength

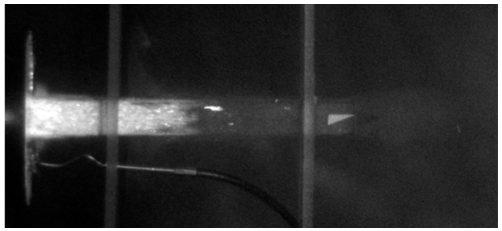
flyoff disk 275 m/s, implying 1.6 GPa

Results of bar impact on GC

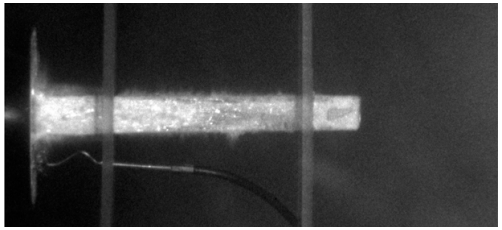
shot A1011
glass ceramic

Direction of travel

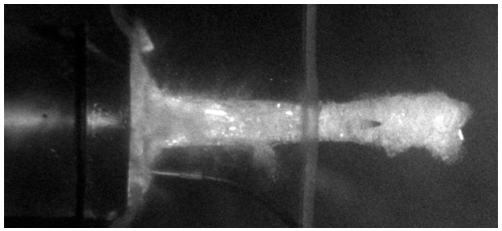
145 μs



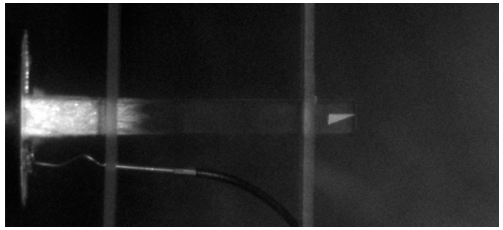
153 μs



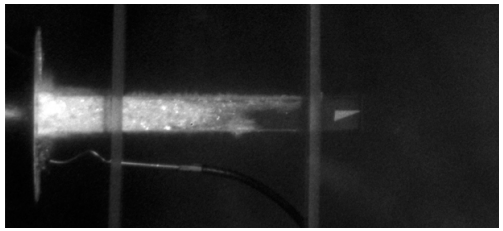
180 μs



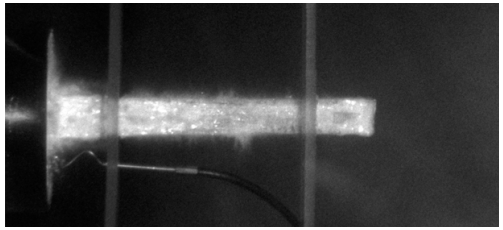
250 μs



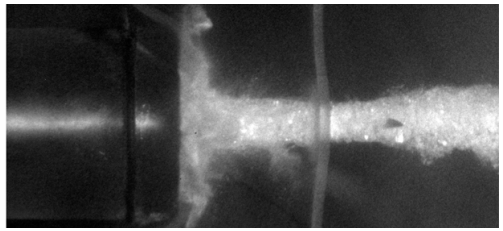
150 μs



175 μs



200 μs



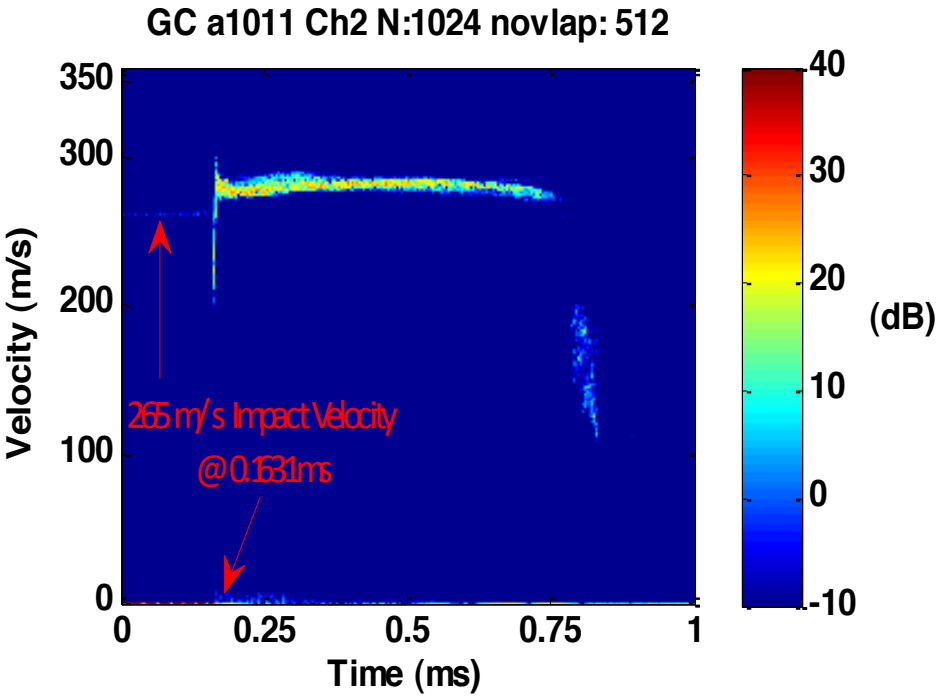
300 μs

Glass Cermamic Impact: A1-011 (GC)

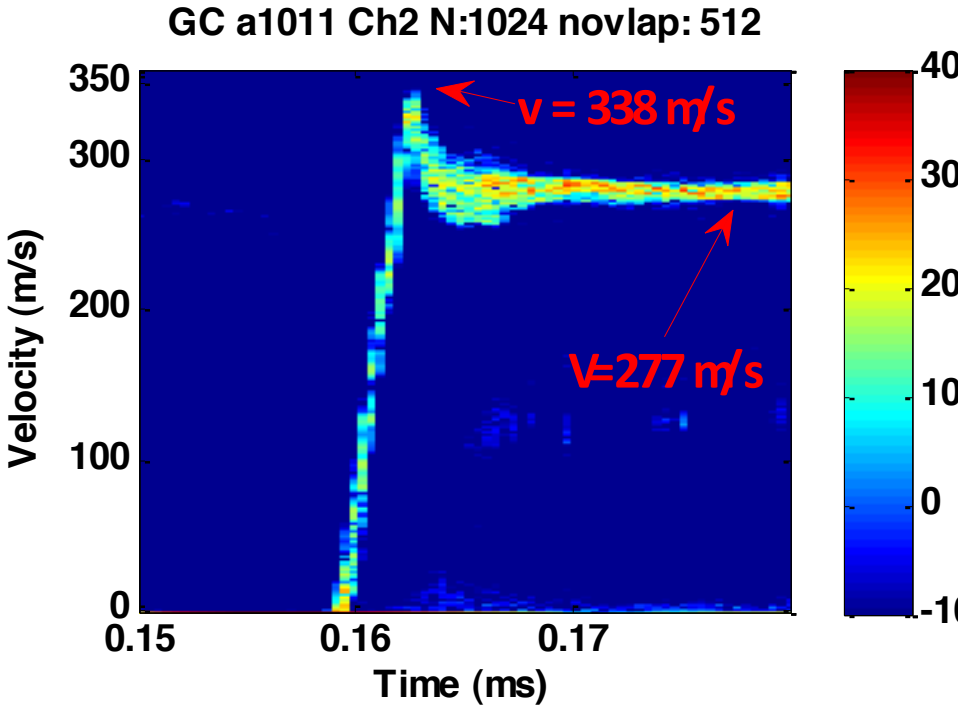
Velocity (m/s) ($\Delta v = \lambda \Delta f/2$ =1.22 MHz * $\lambda/2$) = 0.948 m/s)

GC : showing bar is decoupled from proj after impact

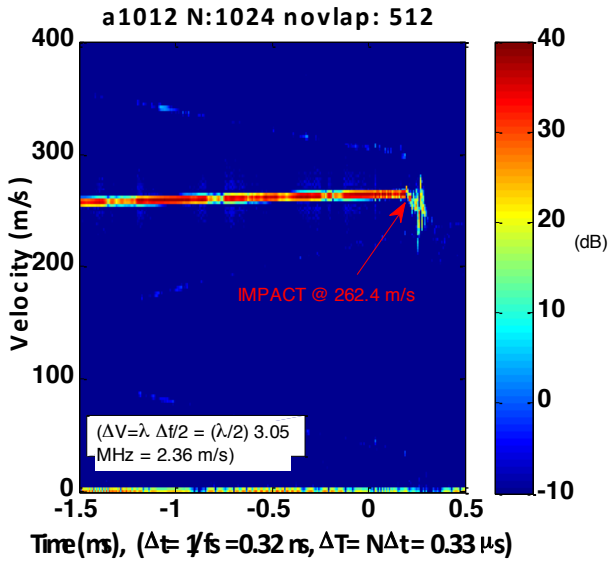
Time (ms), Δt= 1/fs =08 ns, N=1024, $\Delta T = N \Delta t$ = 0.8192 μs



GC : showing peak stress and spall

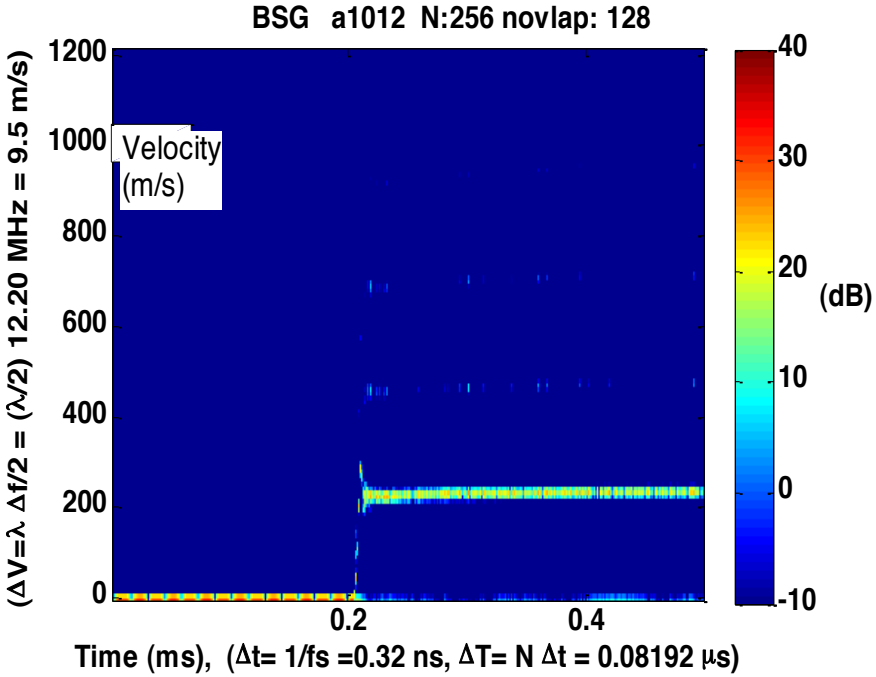


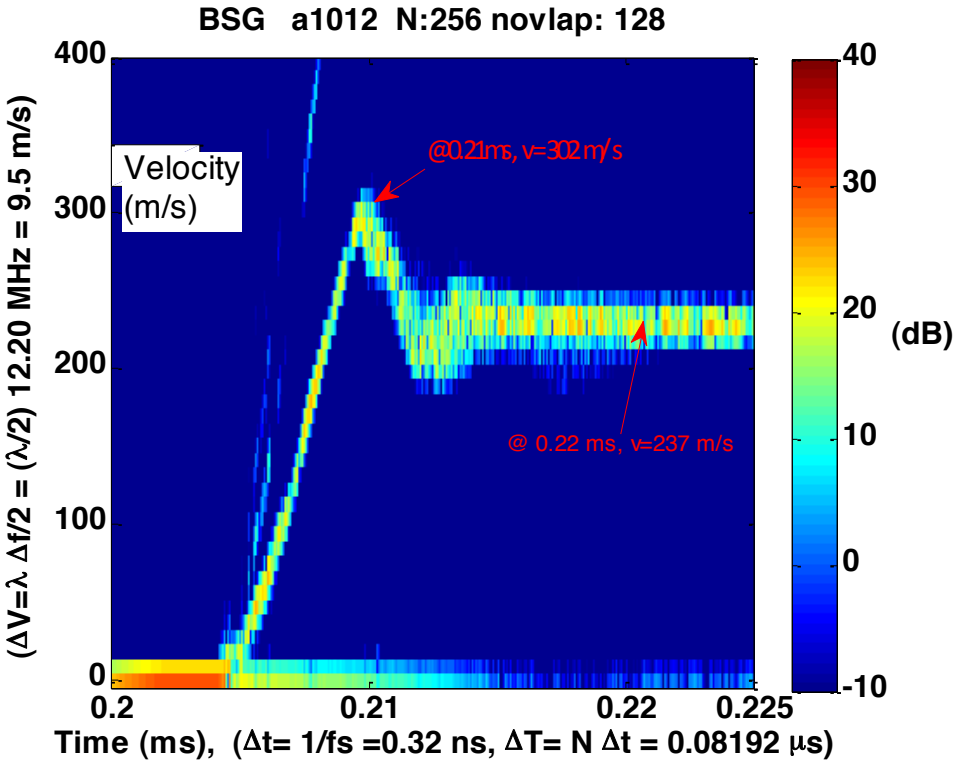
A1-012 Borosilicate glass (BSG)



Velocity (m/s) (Δv=λ Δf/2 = (λ/2) 12.2 MHz = 9.5 m/s)

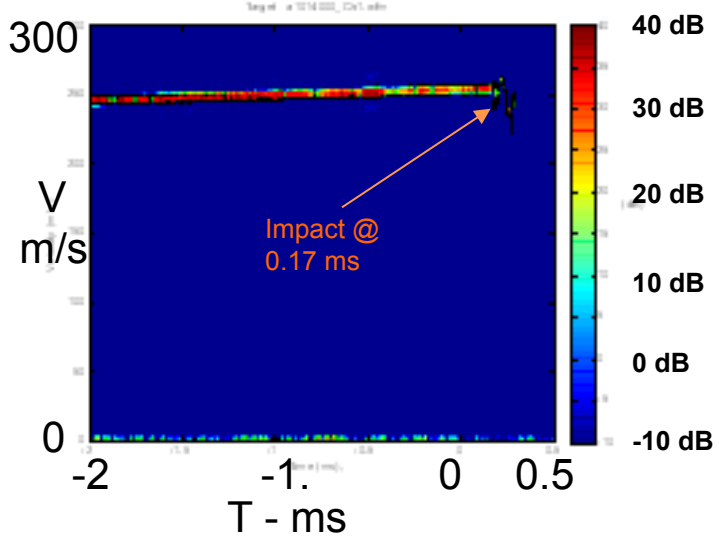
Time (ms), Δt= 1/fs =0.32 ns, N=256, ΔT= N Δt = 0.08192 μs





A1-014 (GC +GDI)

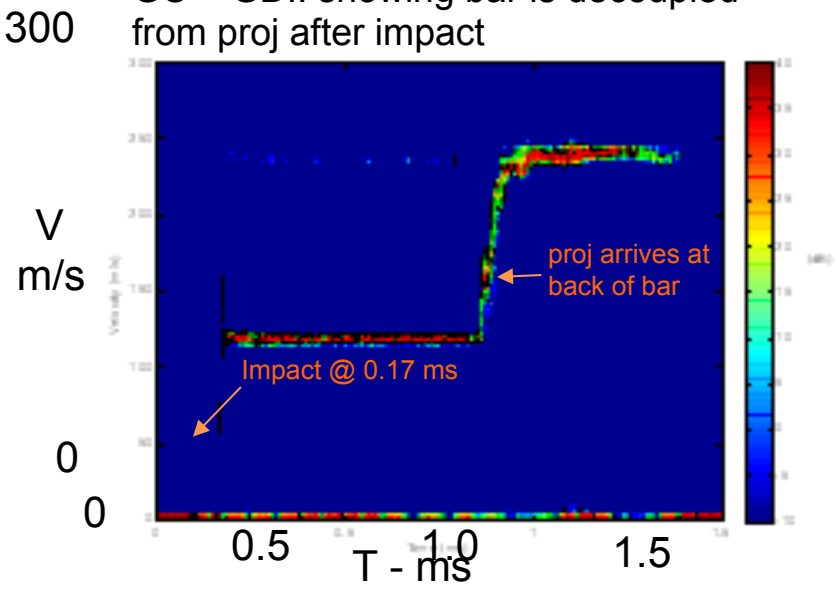
Projectile: showing acceleration in bore.



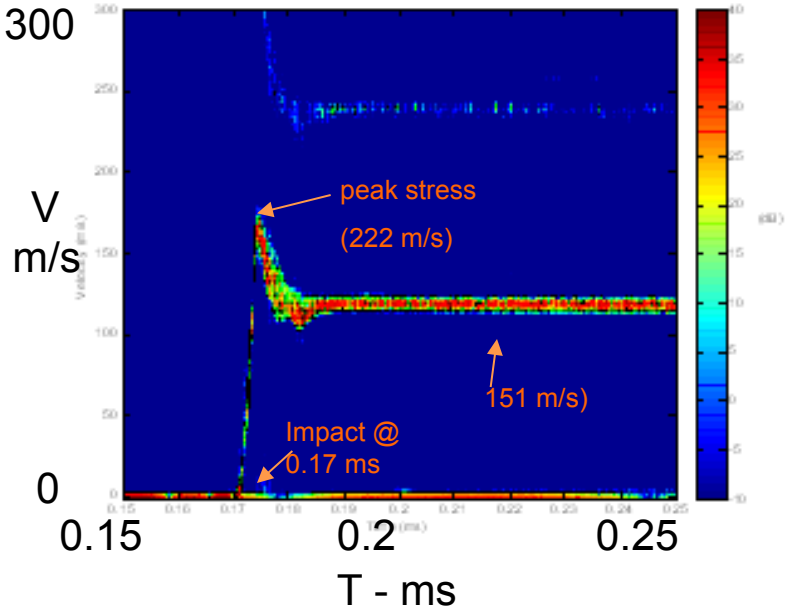
Velocity (m/s) ($\Delta v = \lambda \Delta f/2$ = (λ/2) 3.051 MHz = 2.3642 m/s)

Time (ms), $\Delta t = 1/fs$ =0.32 ns, N=1024, $\Delta T = N \Delta t$ = 0.32768 μs

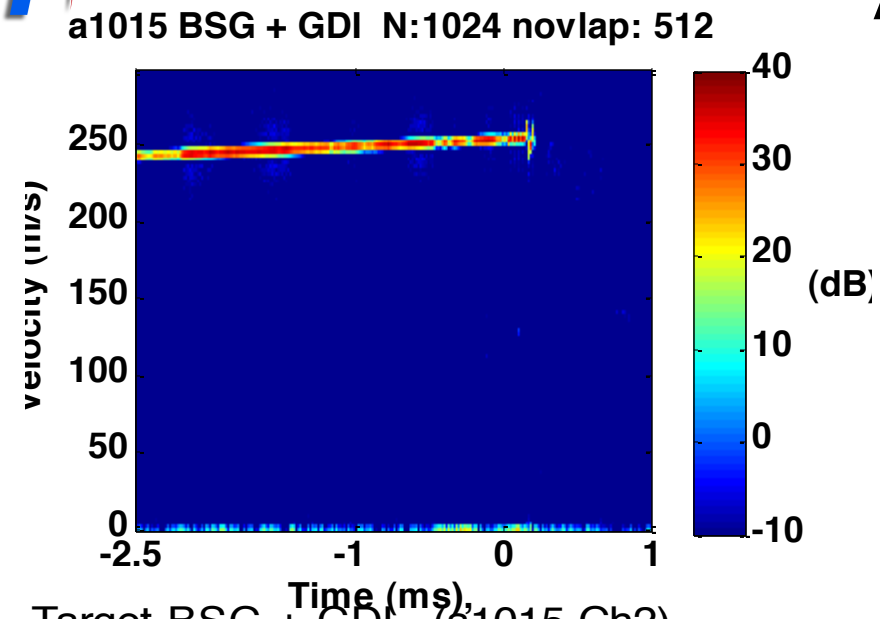
GC + GDI: showing bar is decoupled from proj after impact



GC + GDI: showing peak stress and spall

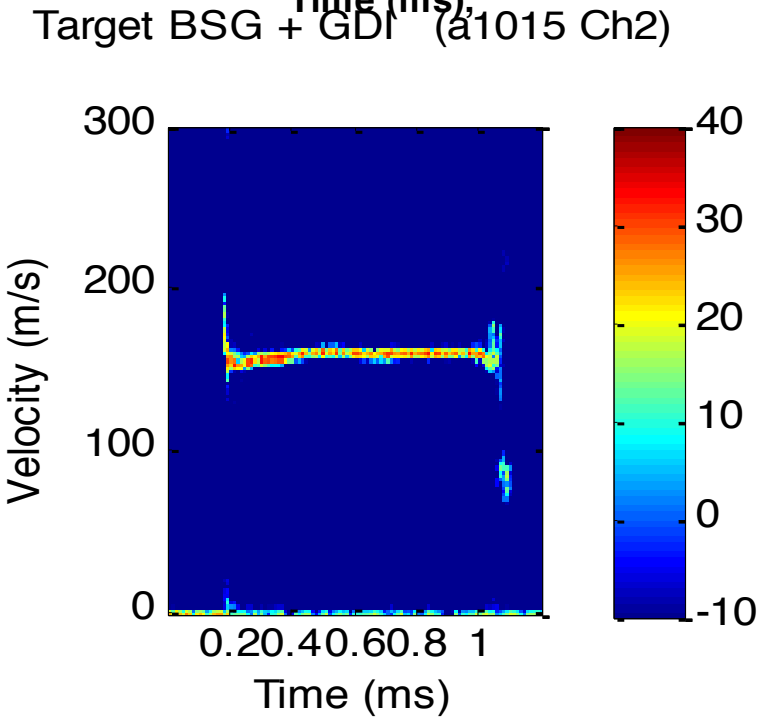


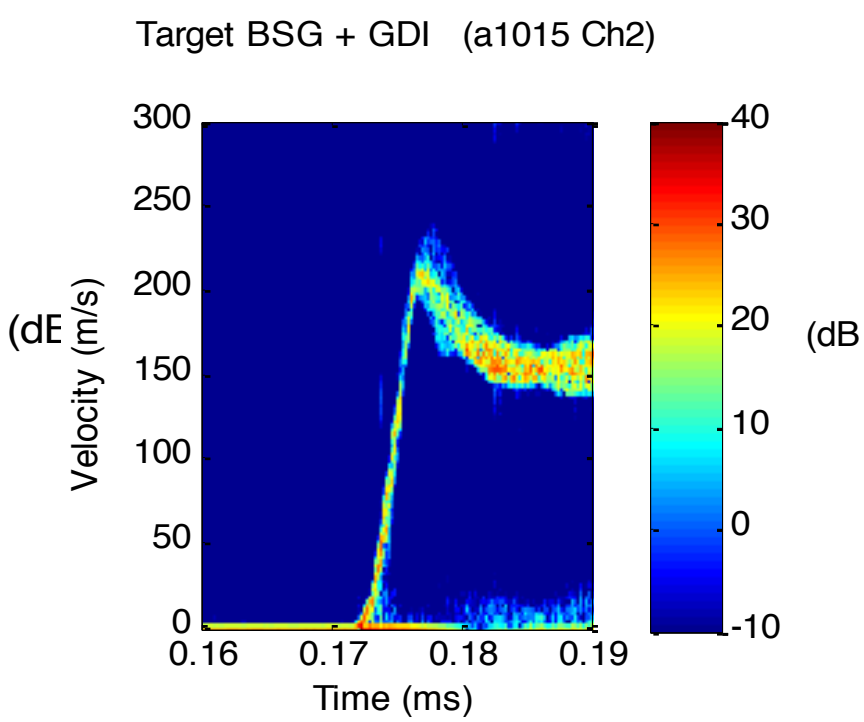
A1-015 (BSG +GDI)



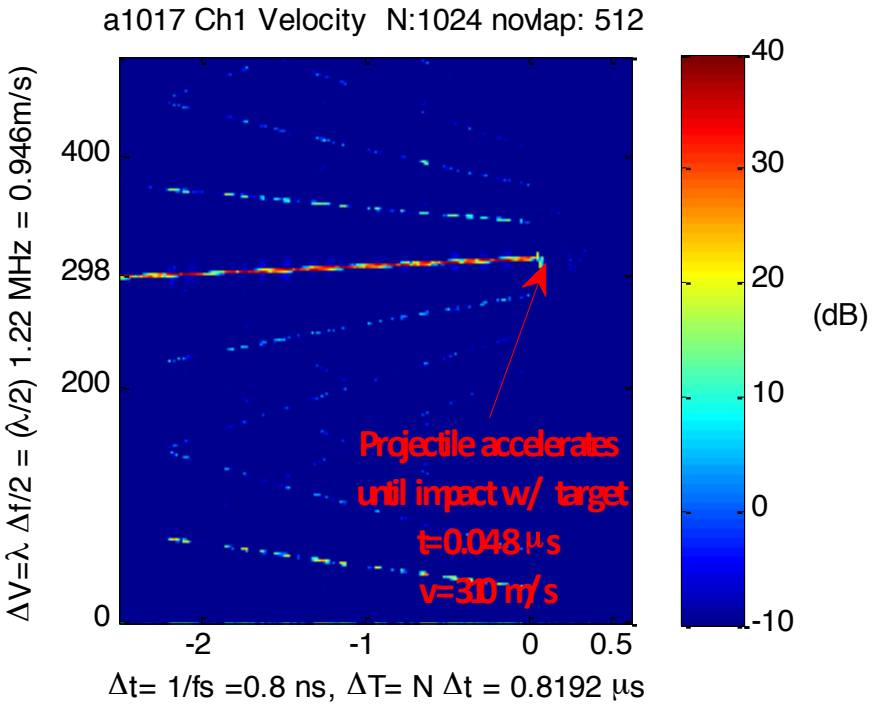
Velocity (m/s) ($\Delta v = \lambda\, \Delta f/2$
$= (\lambda/2)\ 3.051\ \text{MHz} = 2.3642\ \text{m/s}$)

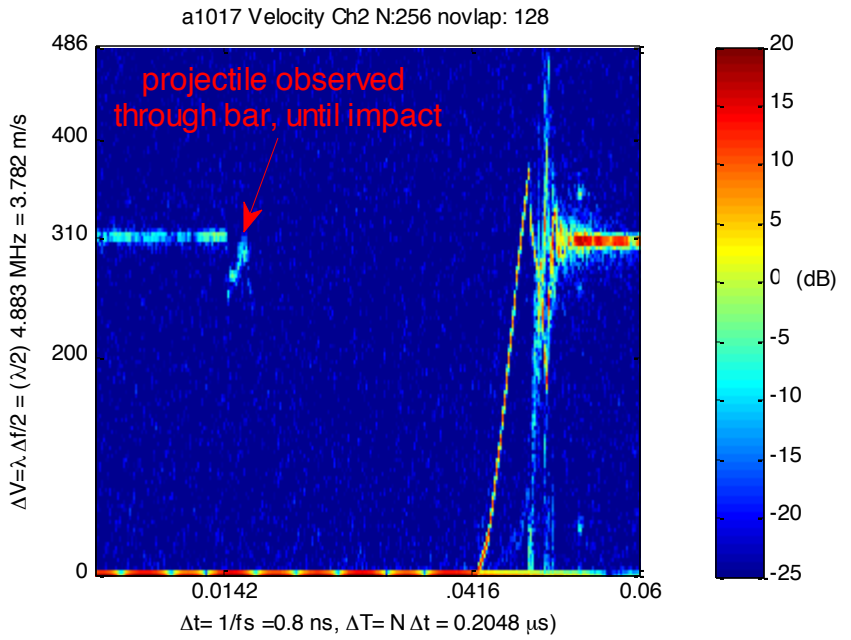
Time (ms), $\Delta t = 1/fs = 0.32\ \text{ns}$,
$N = 1024$, $\Delta T = N\, \Delta t = 0.32768\ \mu\text{s}$



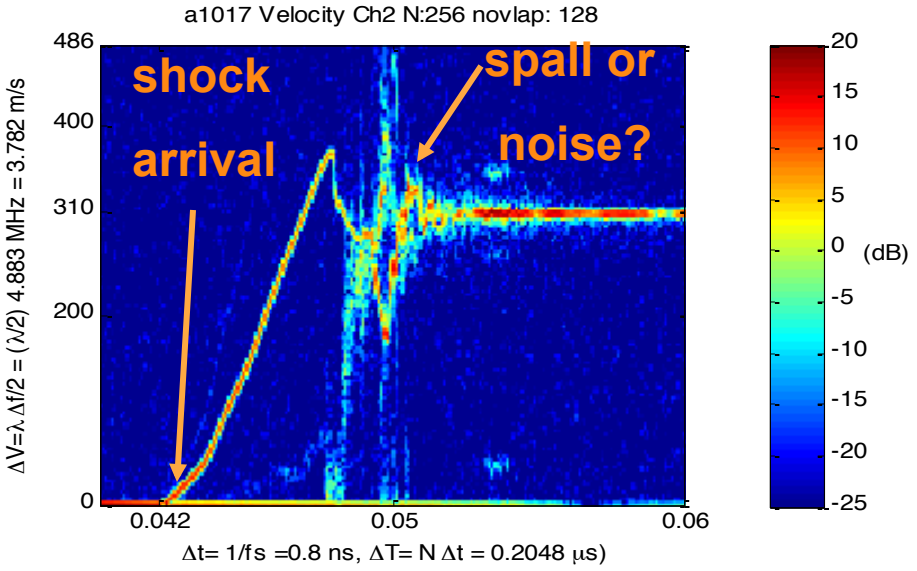


A1-017 Direct PDV BSG Target (no retro)

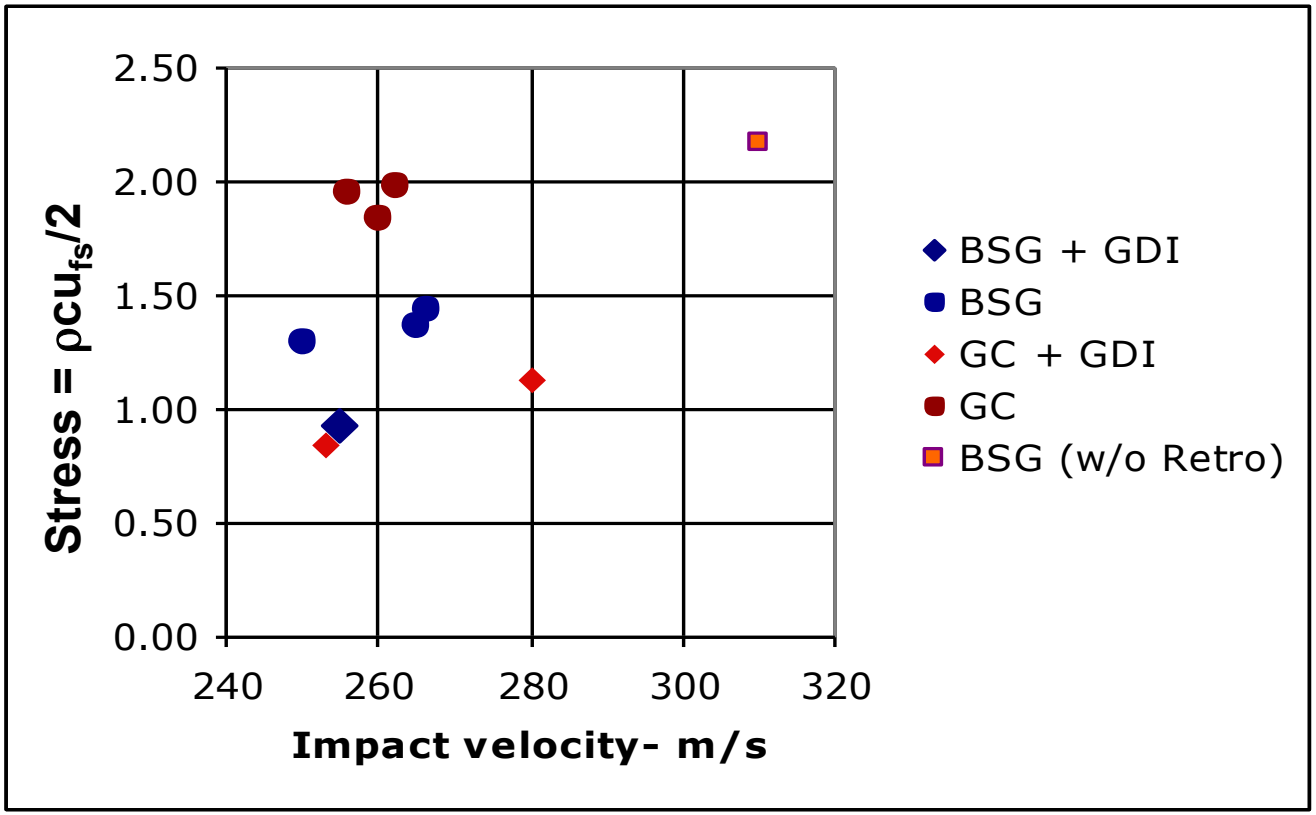




Much better time resolution resulted from direct observation of bar rear face.



Results of Experiments



Conclusion/Discussion

- The dynamic strength of BSG is about 1.4 GPa. Similar to recent SwRI static tests.
- The dynamic strength of glass ceramic is about 1.9 Gpa.
- Ramping the loading lowers the peak stress, presumably due to largest-flaw failures.
- Higher Stress observed w/o retro-tape – due to impact speed or did tape “smear out” the peak stress?
- Future experiments w/o retro-tape
- Technique has potential to measure dynamic tensile strength

… and on Sep 25 . . .

DoD Innovative Science and Technology EM Railgun
Sandia National Laboratories
Albuquerque, NM 87185

Photonic Doppler Velocimetry and Accelerometry in a Railgun

Scott Levinson*, Sikhanda Satapathy*, Dwight Landen*, David Holtkamp, and Adam Iverson*****

*Institute for Advanced Technology, Austin, TX
** Los Alamos National Laboratory, Los Alamos, NM
***National Security Technologies, Albuquerque, NM