Unconventional PDV applications: detecting plasma and radiation

D. H. Dolan, K. Bell, B. Fox, S. C. Jones, P. Knapp, M. R. Gomez, M. Martin, A. Porwitzky, and G. Laity

SAND2018-5286 C

PDV Workshop

May 16, 2018

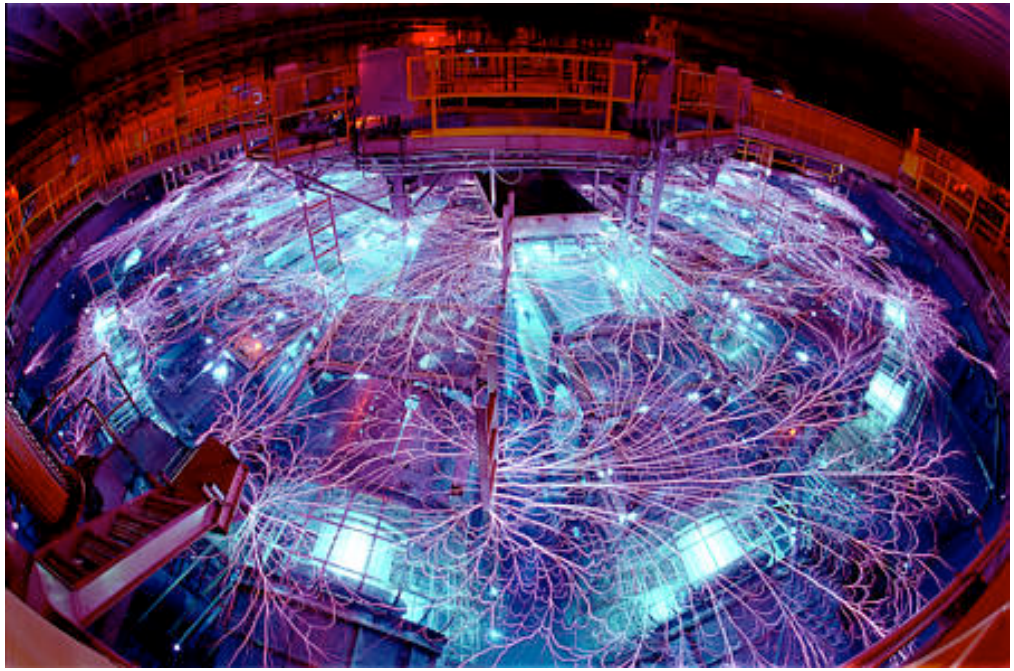
Sandia National Laboratories

Exceptional service in the national interest

Sandia National Laboratories is a multi- mission laboratory managed and operated by the National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under Contract No. DE-NA0003525.

The Sandia Z machine produces many things

- In less than 500 ns:
  - I > 20 mega amp
  - P > 1 million bar
  - T > 1000 to 10^5 K
- Radiation
  - Photons (usually)
  - Neutrons (sometimes)
- All sorts of plasma



PDV has been very successful for measuring pressure and in inferring current. Can we build on this success?

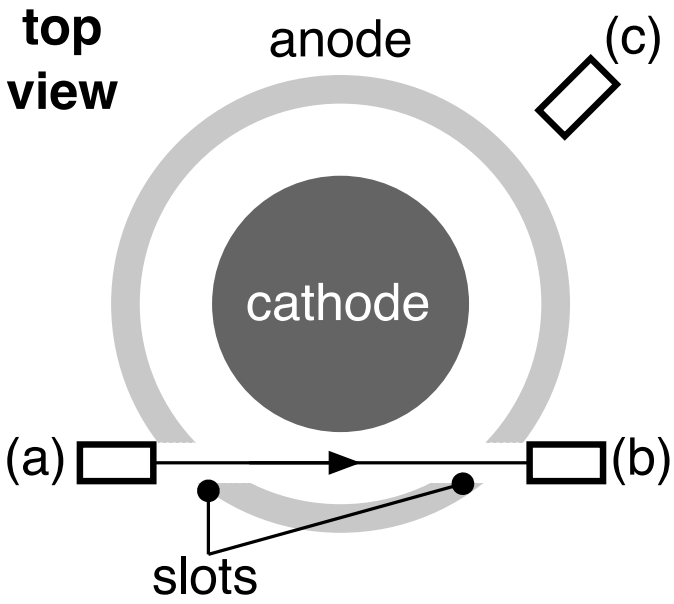
What does PDV measure?

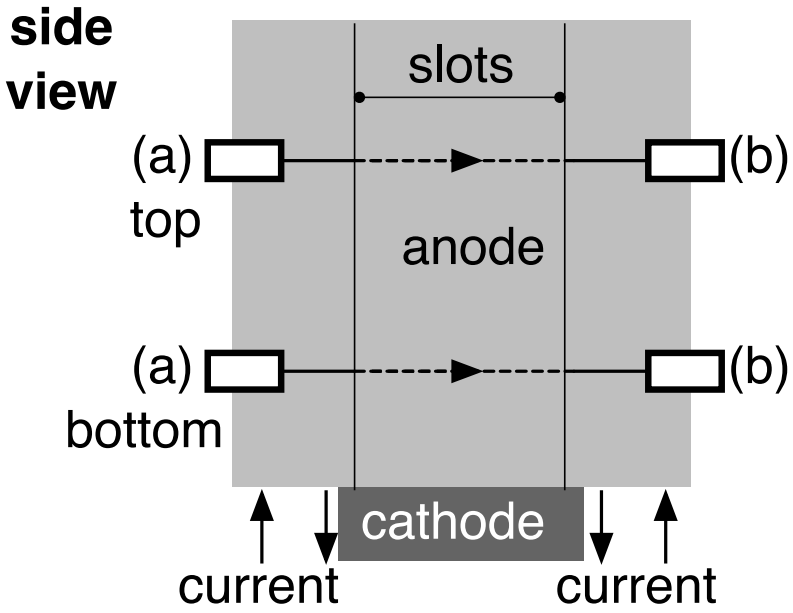
- Apparent velocity:

$$v^* = -\frac{d}{dt}\int n(x,t)\ dx \approx -L\frac{d\hat{n}}{dt}$$

- Apparent velocity comes from:
  - Actual motion
  - Dynamic compression of optical windows
  - **Other refractive index changes**

Plasma detection



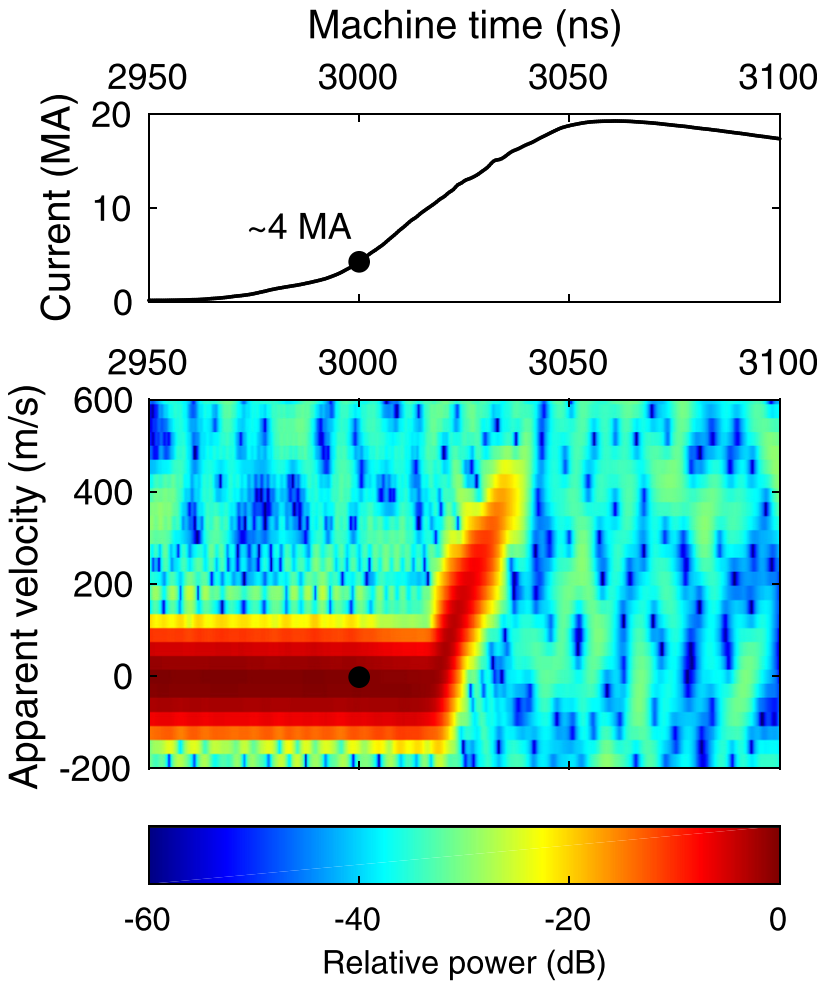


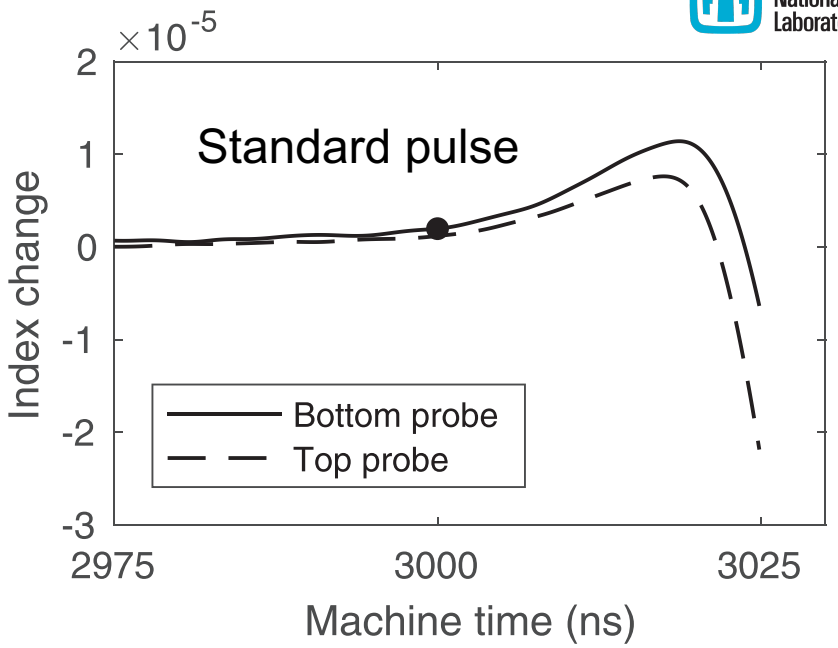
- Pass beam through vacuum
  - (a) to (b)
  - (a) to (b) to (a)
- Free electrons cause n < 1
  - N_c=4.6x10^{20} electrons/cc

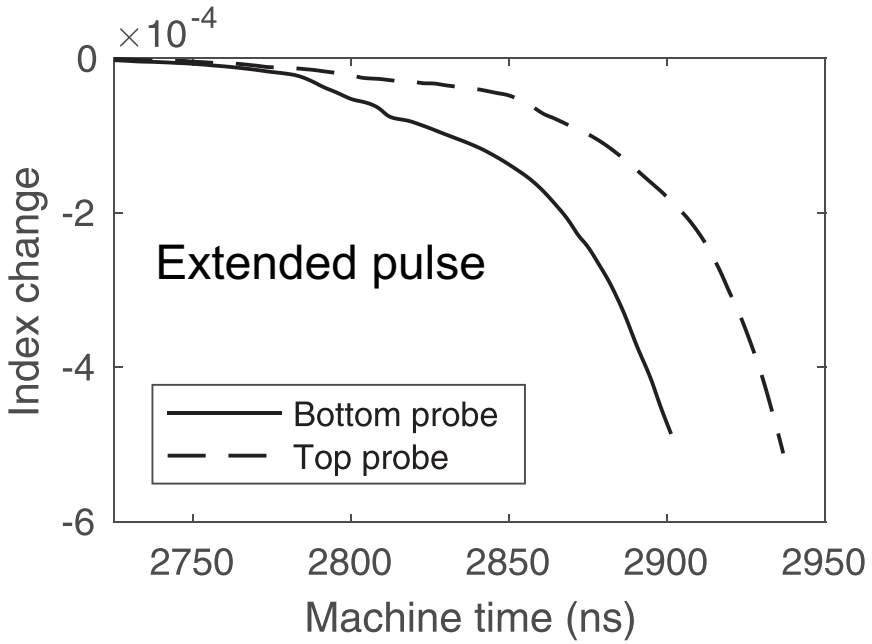
$$n = \sqrt{1 - \frac{N}{N_c}}$$

$$N_c = \frac{m_e \epsilon_0}{e^2} \left(\frac{2\pi c}{\lambda} \right)^2$$

Z Power Flow experiments







Signal loss at 10^{16}-10^{17} electrons/cc

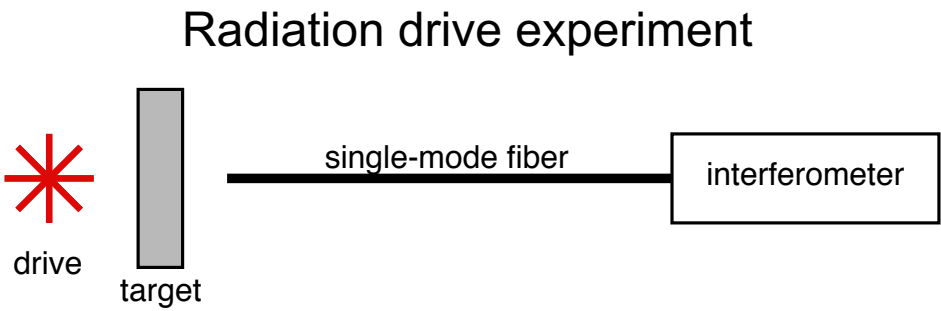
Several interpretations

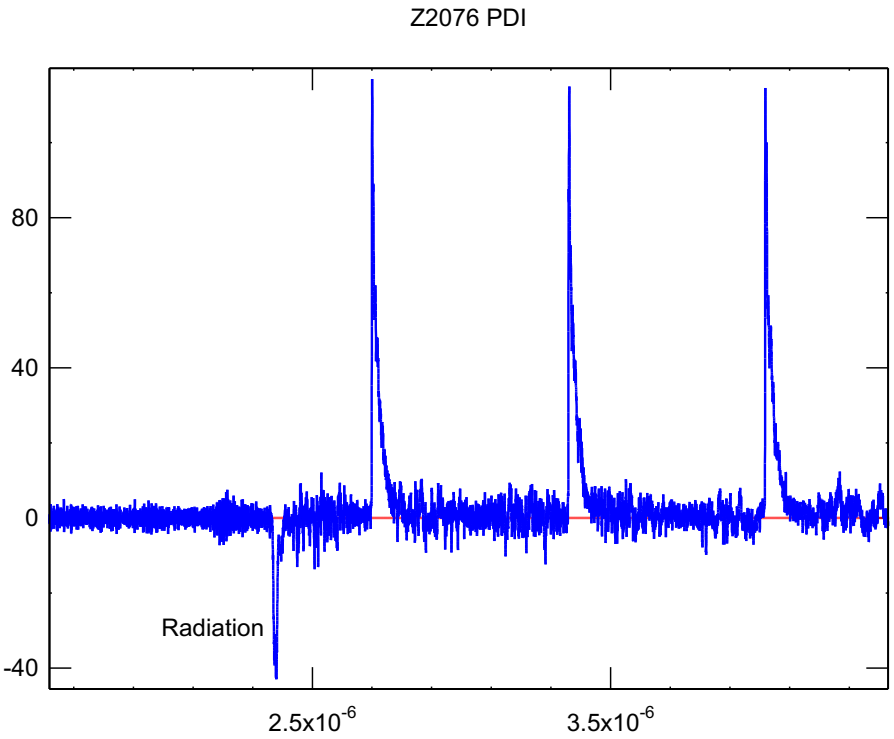
- Local density gradients may deflect the beam
  - Less likely with retroreflective tape
- Local density may reach/exceed critical value
  - We can only measure path average
- Ions and neutral atoms may also play a role
  - Precise materials and ionization states unknown
- Fast density increases may exceed the measurement bandwidth

In any event, PDV senses something that should not be there (according to most simulations)

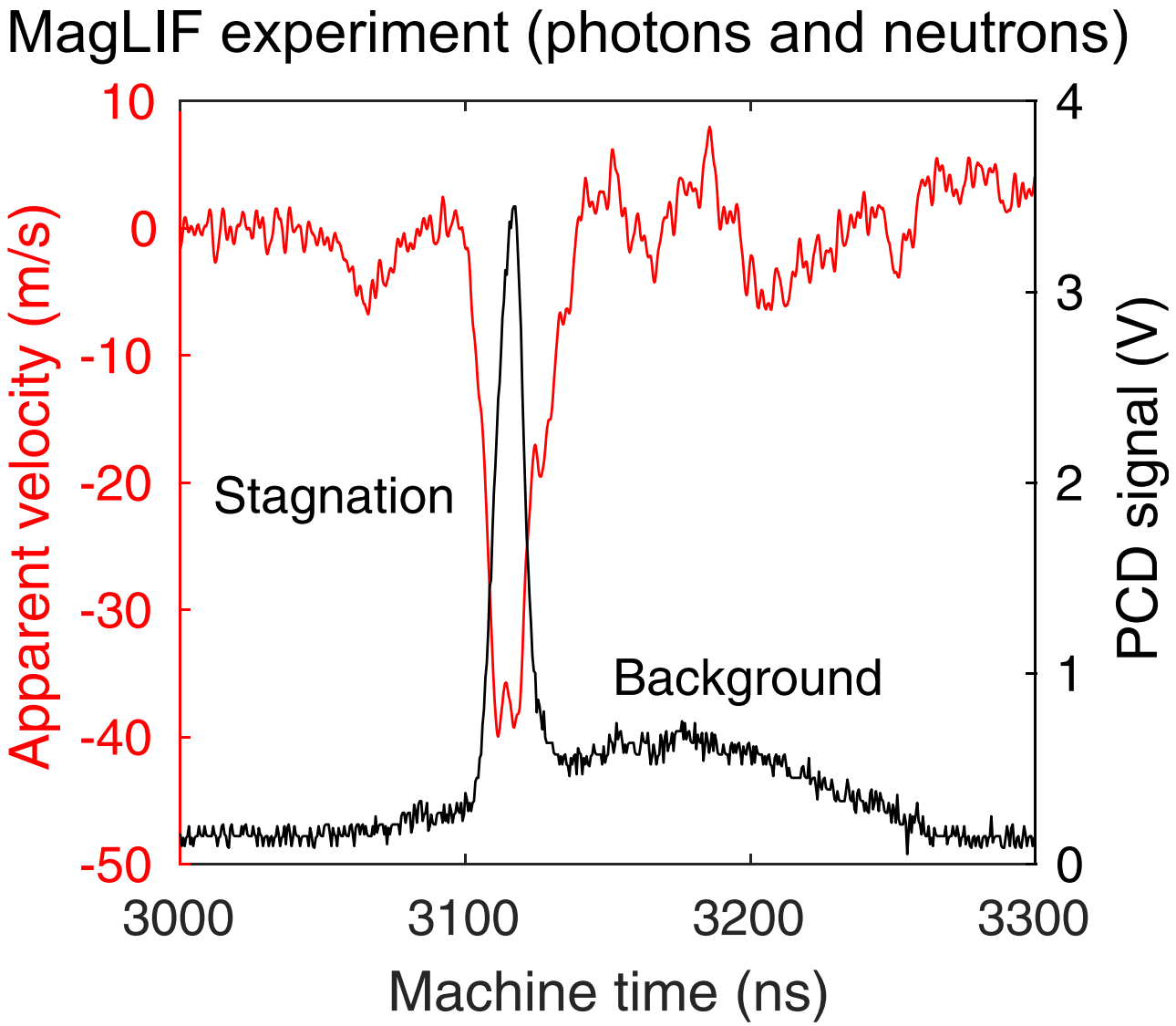
Detecting radiation

- Negative velocity occurs too soon to be actual motion
- Effect only observed when radiation is produced





Feature shows up in shielded/capped probes

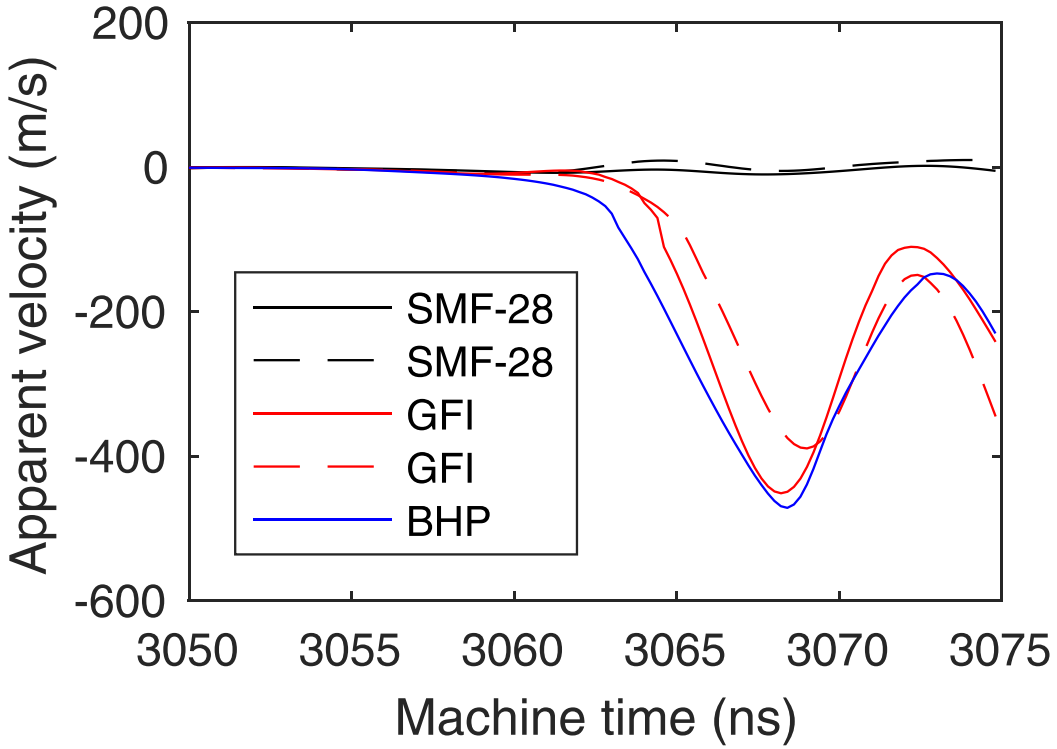


Possible explanations

- Irradiated silica collapses to higher density
  - Index goes up, apparent velocity < 0
- Radiation creates color centers
  - Visible absorption accompanied by infrared index changes (Kramers Kronig relations)
  - More likely for Ge-doped silica than pure material

Testing the role of Ge doping

- Photo-sensitive fiber
  - 30-40% more Ge than SMF-28
  - Different doping profiles
- Z ride along test
  - 2-3 ns pulse
  - 57 kJ
  - 5-16 keV
  - 830 mm distance



Summary

- PDV can detect anything the modifies refractive index
  - Apparent direction is the inverse of the dn/dt
- Plasma detection is easy
  - Density calculation relies on several assumptions
- Radiation sensing needs to be calibrated
  - Type/energy discrimination
  - Material sensitivity (Ge concentration, …)
- Potentially fast response (< 1 ns)

Dolan et al., J. Appl. Phys **123**, 034502 (2018).

Acknowledgements

- Sheri Payne and Darrell Ramsey (MSTS)

- Tom Avila, Ed Scoglietti, and Gary Chantler