LA-UR- 11-03559

Approved for public release; distribution is unlimited.

Title: The PHELIX Pulsed Power Project: Bringing Portable Magnetic Drive to World Class Radiography

Author(s):
C. L. Rousculp
W. A. Reass
D. M. Oro
P. J. Turchi
B. J. Hollander
J. R. Griego
R. E. Reinovsky

Intended for: 18th IEEE Pulsed Power Conference
Chicago, IL, USA
19-23 June 2011

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

The PHELIX Pulsed Power Project: Bringing Portable Magnetic Drive to World Class Radiography

C. L. Rousculp, W. A. Reass, D. M. Oro, P. J. Turchi, B. J. Hollander, J. R. Griego, R. E. Reinovsky

IEEE PPC 2011, Chicago, IL

22 June 2011

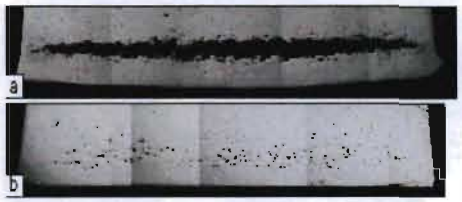
Abstract

The PHELIX pulsed power project will introduce magnetically driven hydrodynamics experiments to the Los Alamos National Laboratory's proton radiography facility (pRad). The Precision High Energy-density Liner Implosion eXperiment (PHELIX) has been commissioned at Los Alamos. A small footprint capacitor bank consisting of four parallel connected single-stage marx units (~500 kJ) is cable coupled to a toroidal, current step-up transformer to deliver multi-Mega-Ampere, ~10 μs current pulses to cm size cylindrical loads. In a sequence of tests the performance of each component (capacitor bank and transformer) was evaluated and compared to a circuit model. The transformer coupling was observed to be k ~ 0.93. The tests culminated in a liner implosion experiment in which an ~3 cm radius, 0.8 mm thick, ~3 cm tall aluminum liner was accelerated to a velocity of ~ 1 km/s. The suite of machine diagnostics included linear Rogowski coils and Faraday rotation for current measurements. The experimental diagnostics include B-dot probes, multi-channel photon Doppler velocimetry (PDV), and single-frame, flash X-radiography to evaluate the performance of the high precision liner implosion. Currently, work is focused on integrating PHELIX into normal operations with the 800 MeV proton radiography facility. There, high-resolution, high-frame-rate imaging of hydrodynamic experiments will be possible.

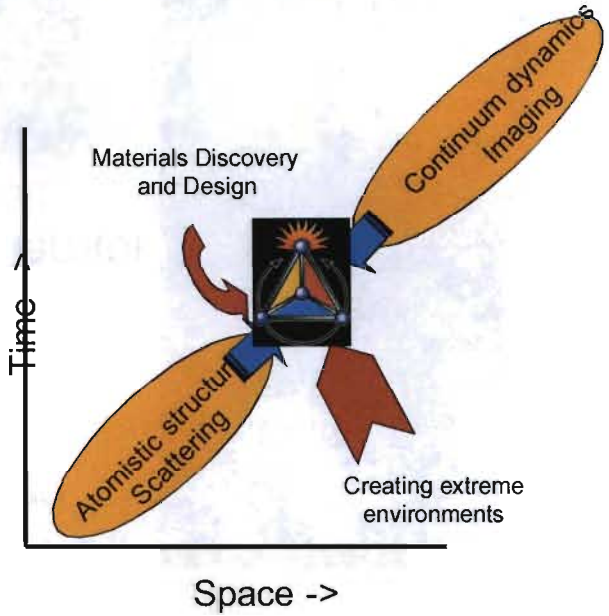
Strategic View: MaRIE (Matter and Radiation In Extremes) is LANL's, Next-Generation, Conceptual Signature Facility

- **Dynamic Materials Science**
  - Materials are a core LANL capability
  - Damage/Spall, EOS, Strength

Spall Characterization



- **Bridge the "Micron Gap"**
  - Crossover from continuum to atomic scale models
  - Interface between scattering & imaging
  - The domain of defect consequences and microstructure interactions that drive materials strength, damage evolution, etc.
  - Represents an experimental and theoretical frontier



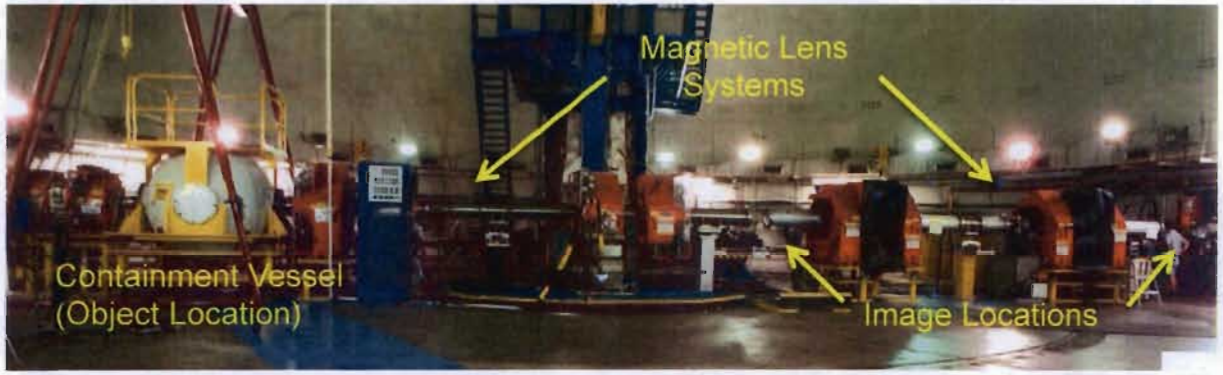
Transition from Observation and Validation to Prediction and Control

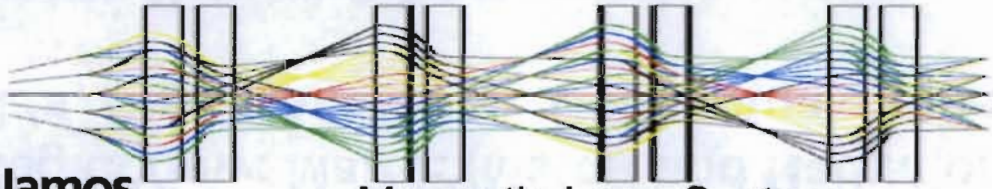
LANL Proton Radiography

- **800 MeV proton beam from LANSCE used as a probe in flash radiography**
- **> 300 dynamic experiments in 13 yrs**
- **6 month run cycle each year**

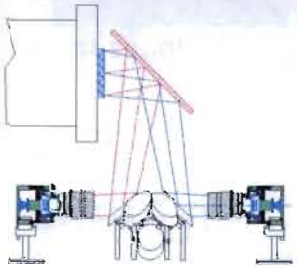
Area-C pRad

LANSCE Accelerator





Magnetic Lens System



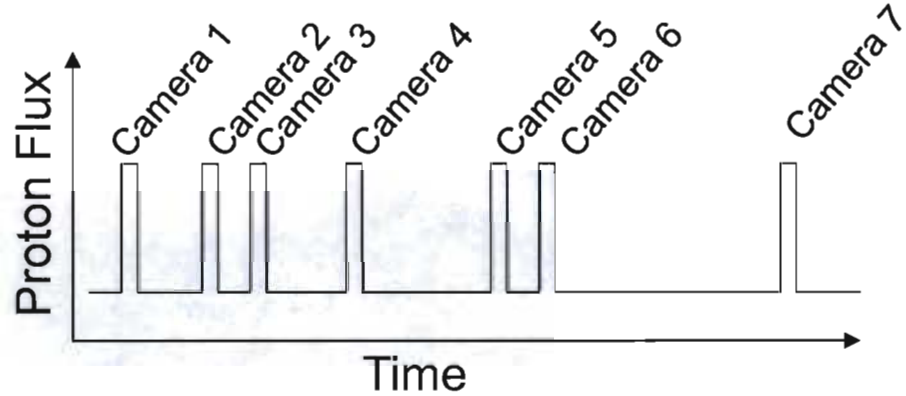
Imaging System

LANL Proton Radiography Provides High-Resolution, High-frame Rate Diagnostic

- **Proton Transmission a Function Areal Density, T(x)**
  - MCS
  - Nuclear Removal

$$T(x) = e^{-\frac{x}{\lambda_c}}\left(1 - e^{-\frac{\alpha}{x}}\right)$$

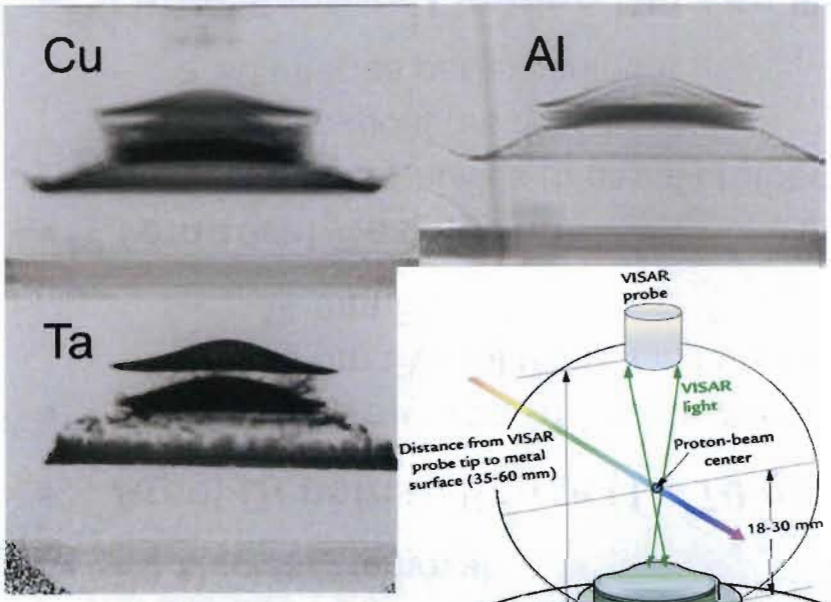
- **Areal Densities Range (1 – 70 g/cm^2 in iron)**
- **Spatial Resolution of 3x Magnifier**
  - 65 μm FWHM Gaussian Line blur
  - 44 mm FOV
- **Temporal Resolution**
  - Gated micro pulses (5 ns) of protons
  - 100 ns exposures typical
  - > 30 images per experiment

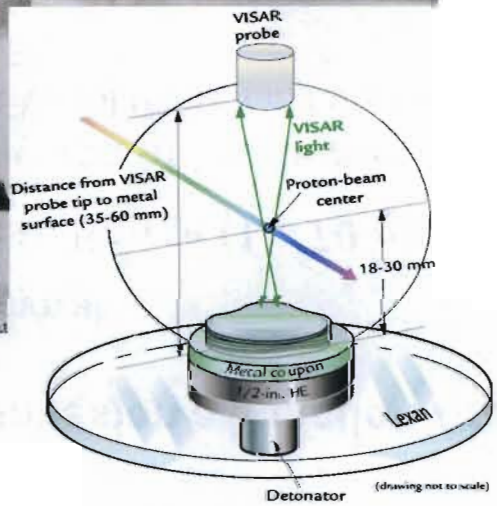


- **Other Factors Limiting Density Reconstruction**
  - Detector Blur
  - Chromatic Aberration
  - Limbing

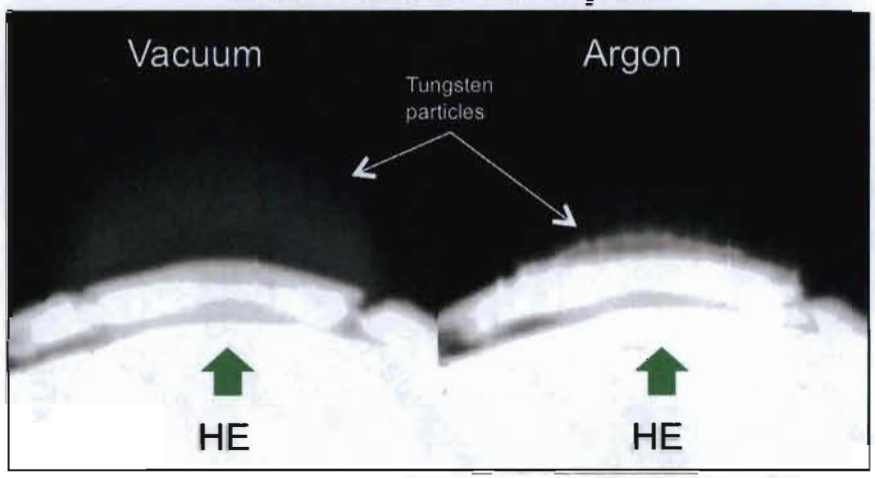
Proton Radiography has been used Extensively to Study High Explosive Driven Materials Science Experiments

Comparison of Spall

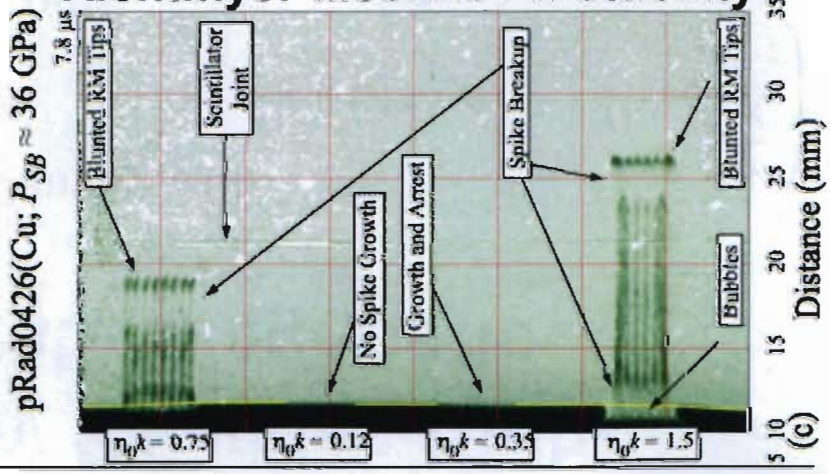




Particulate Transport



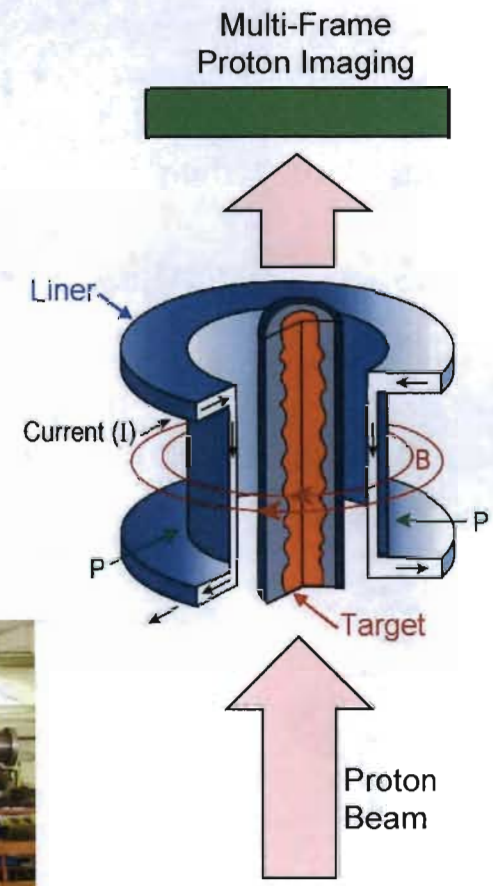
Richtmyer-Meshkov Instability



λ = 550 um

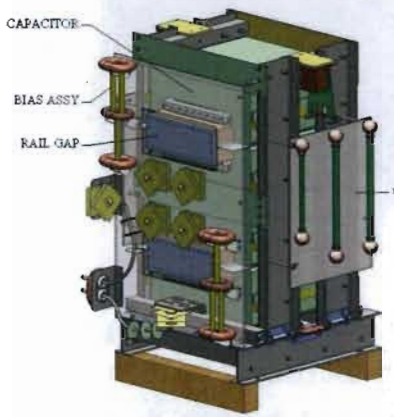
PHELIX Provides Proof of Principle for Imploding Liner Techniques Using Proton Radiography as Axial Diagnostic

- **Magnetic Drive Features**
  - Dial-able and Reproducible
  - Fundamentally cylindrical (converging geometry)
  - Liner implosion experiments have high azimuthal precision (< 50 micron / 1 cm)
- **Better diagnostic (pRad) resolution permits smaller drivers and lower energies.**
  - pRad offers possibility of resolving 70 micron features on cm-scale implosions with multi-frame imaging
  - Lower energies implies cheaper source and less collateral damage
  - Cheaper source implies higher data rate - 5-10 shots / year maps a 2-D parameter space in 1-2 years



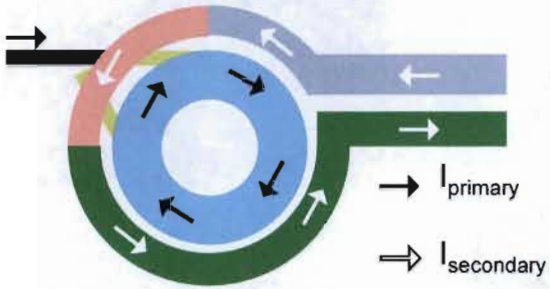
PHELIX = Precision High Energy-density Liner Implosion Experiments

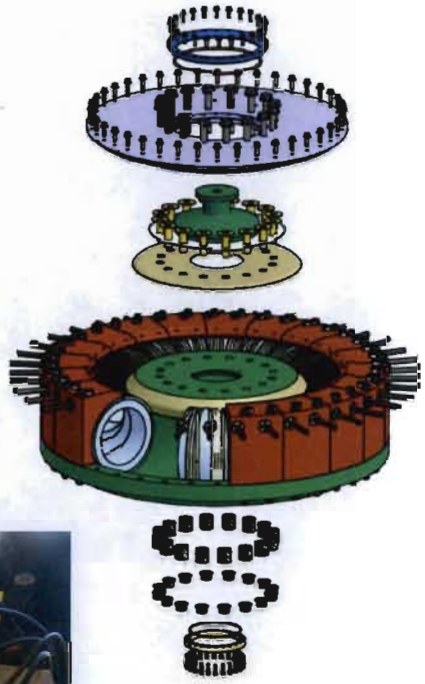
Toroidal, Current-Multiplying Transformer Efficiently Couples Marx Modules to Load



Two Air-Insulated
120 kV
Marx Modules (500 kJ)

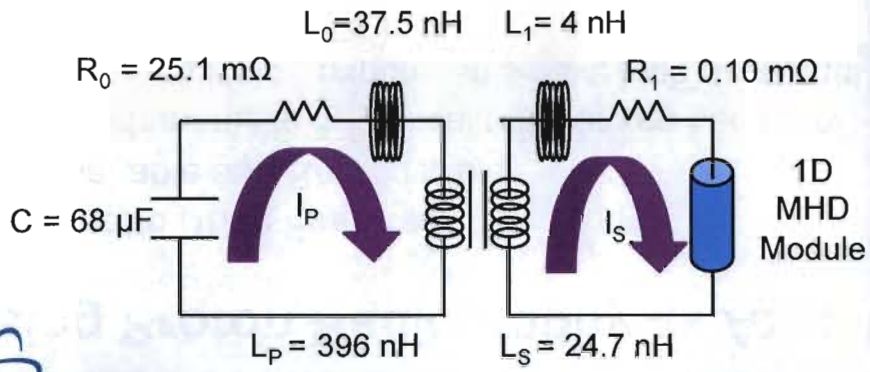
Transformer Cross Section





Toroidal Air-Core Transformer
40 Cables (4:1 Winding)
k = 0.93

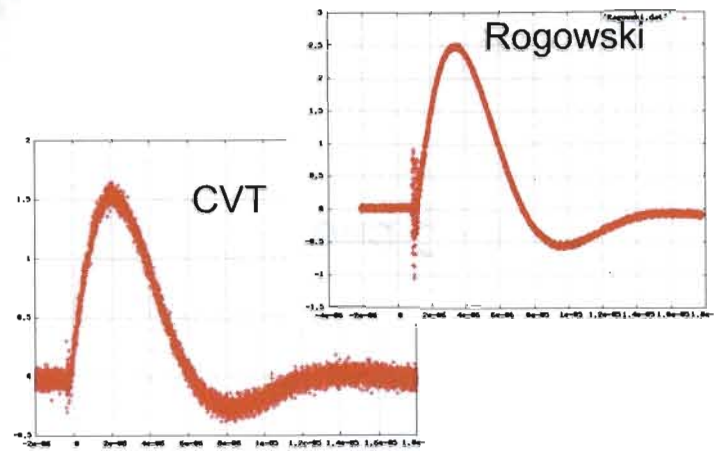
Circuit Model



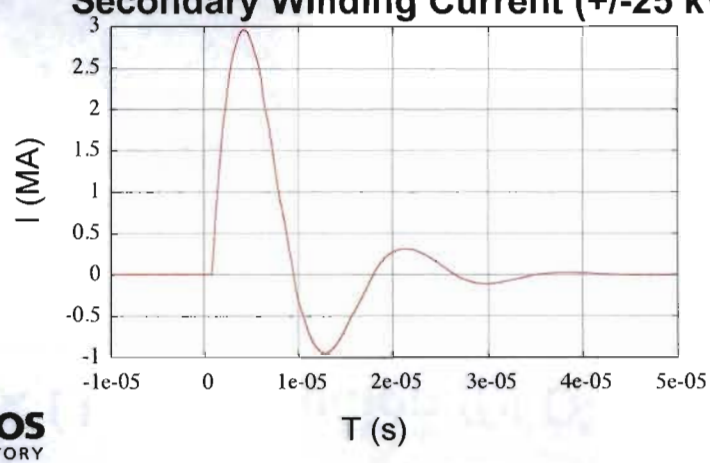
R_{major} ~ 33 cm
R_{minor} ~ 10 cm

PHELIX Prototype has been Successfully Tested

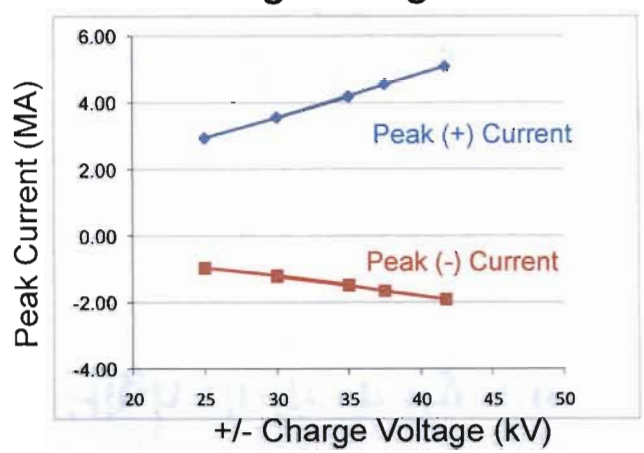
- **Cable Short Test**
  - Marx Modules Alone
  - 1 m Cables Current Viewing Transformers
  - Linear Rogowski Coils
- **Transformer Static Load Test**
  - Marx Modules Connected to Transformer
  - 16 Brass washers at Post Holes
  - Faraday Rotation Measures Secondary Winding Current



Secondary Winding Current (+/-25 kV)



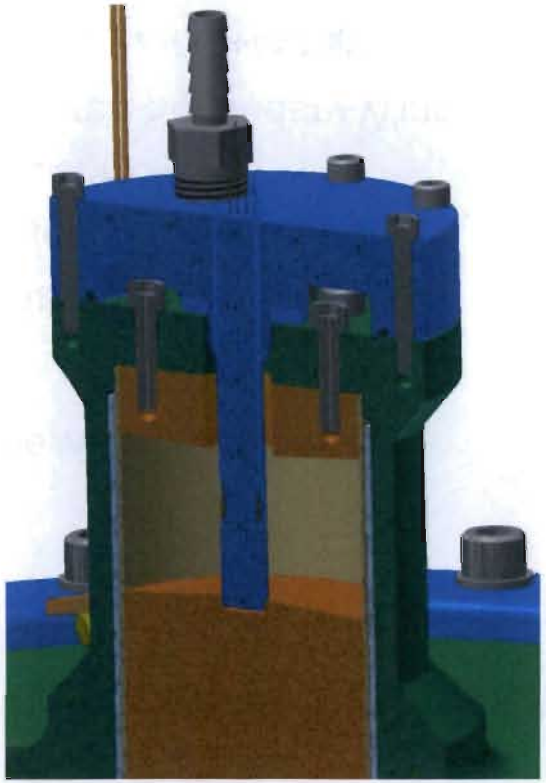
Charge Voltage Scan



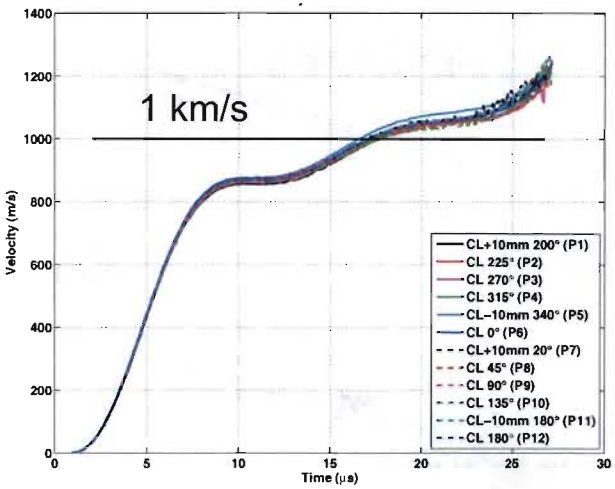
PHELIX Liner Implosion (PLD-1) Showed High Uniformity and Symmetry

Single Frame Flash X-Radiography

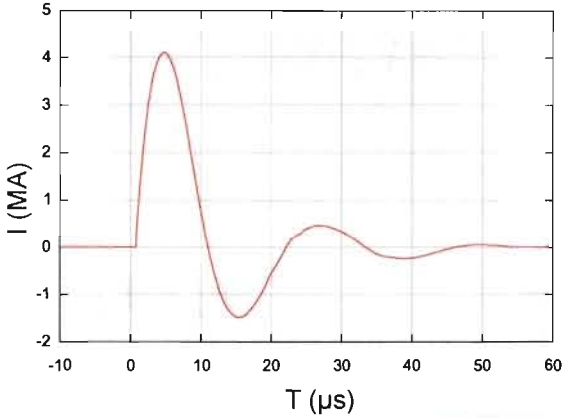
PLD-1 Load



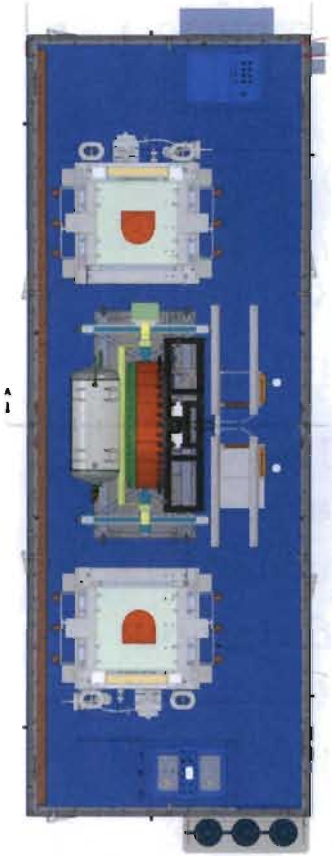
12 Channel PDV



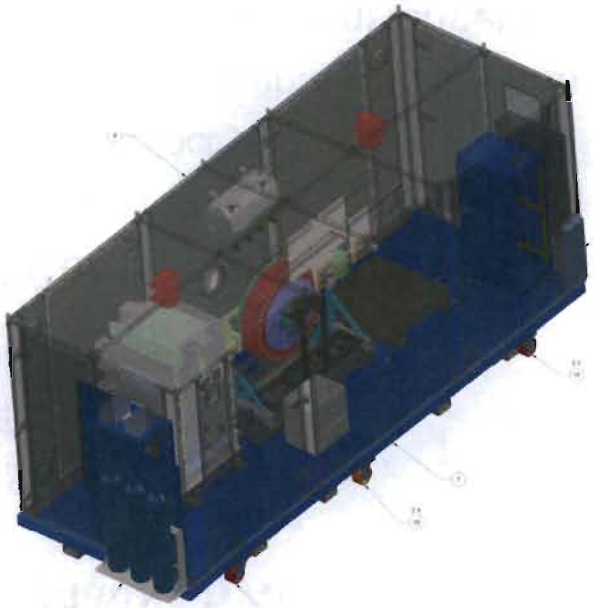
Load Current

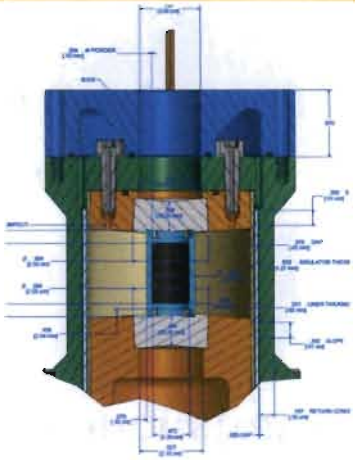


Portable PHELIX is Under Construction and will be Ready for Use in 2012



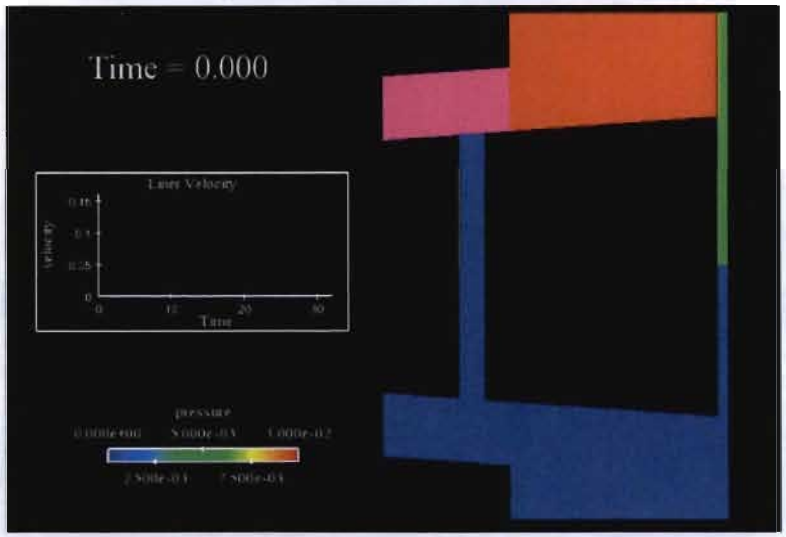
EMI Shielded Portable PHELIX





Liner/Target Load

2D Lagrangian Calculations



National Security Technologies LLC
Vision · Service · Partnership

Los Alamos NATIONAL LABORATORY EST. 1943

Conclusions

- **The LANL proton radiography facility utilizes an 800 MeV beam to diagnose dynamic hydrodynamics and material science experiments including**
  - Material Spall
  - Particle Transport
  - Shock Driven Instabilities
- **The PHELIX pulsed-power driver has been demonstrated**
  - > 4 MA load current
  - > 1 km/s liner velocity
  - Small footprint compatible with the pRad facility
  - First of its kind, toroidal transformer technology with k > 0.9
- **Portable PHELIX is under construction and will be ready for use in 2012**