Magnetomechanical Compression of a Solid Lithium Liner for Magnetized Target Fusion

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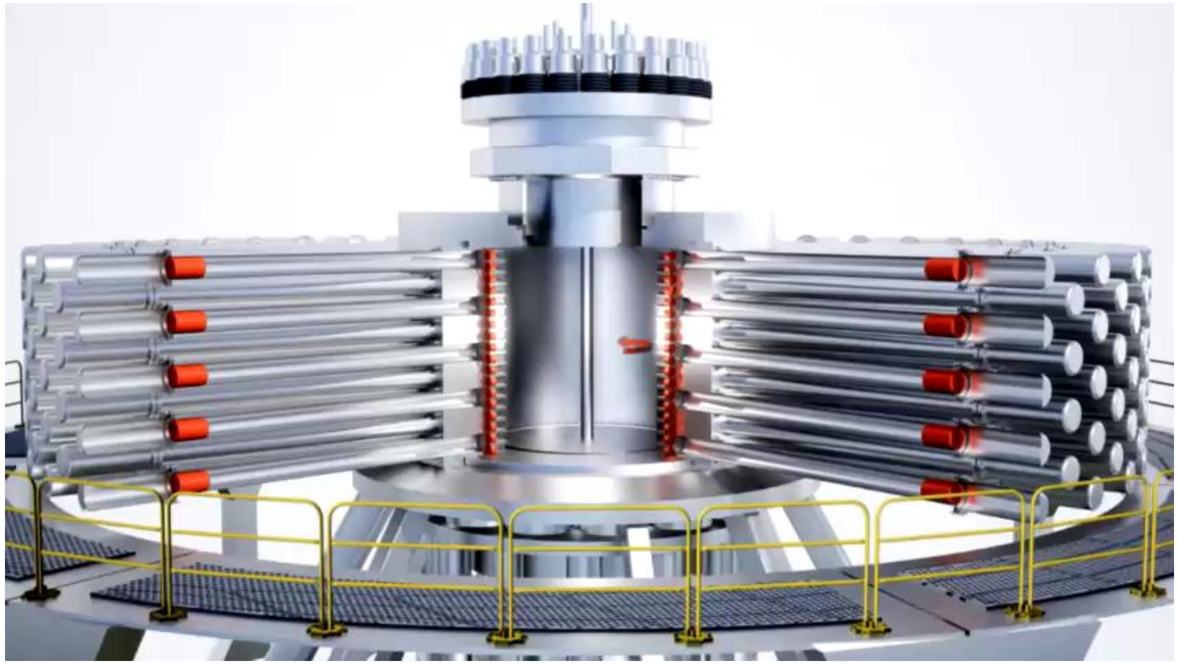


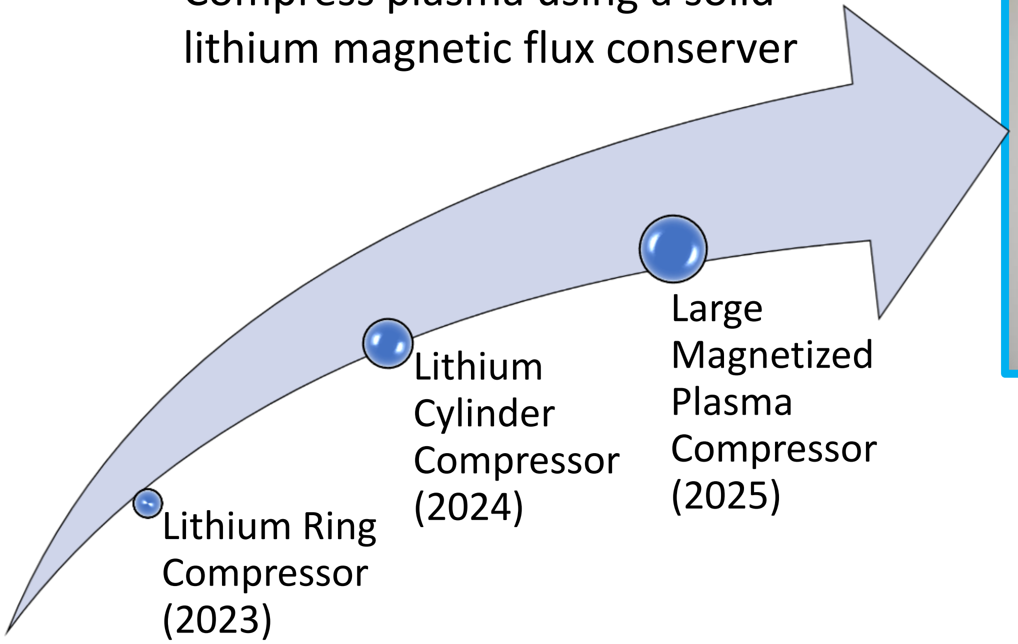
Magnetized Target Fusion (MTF) powerplant concept

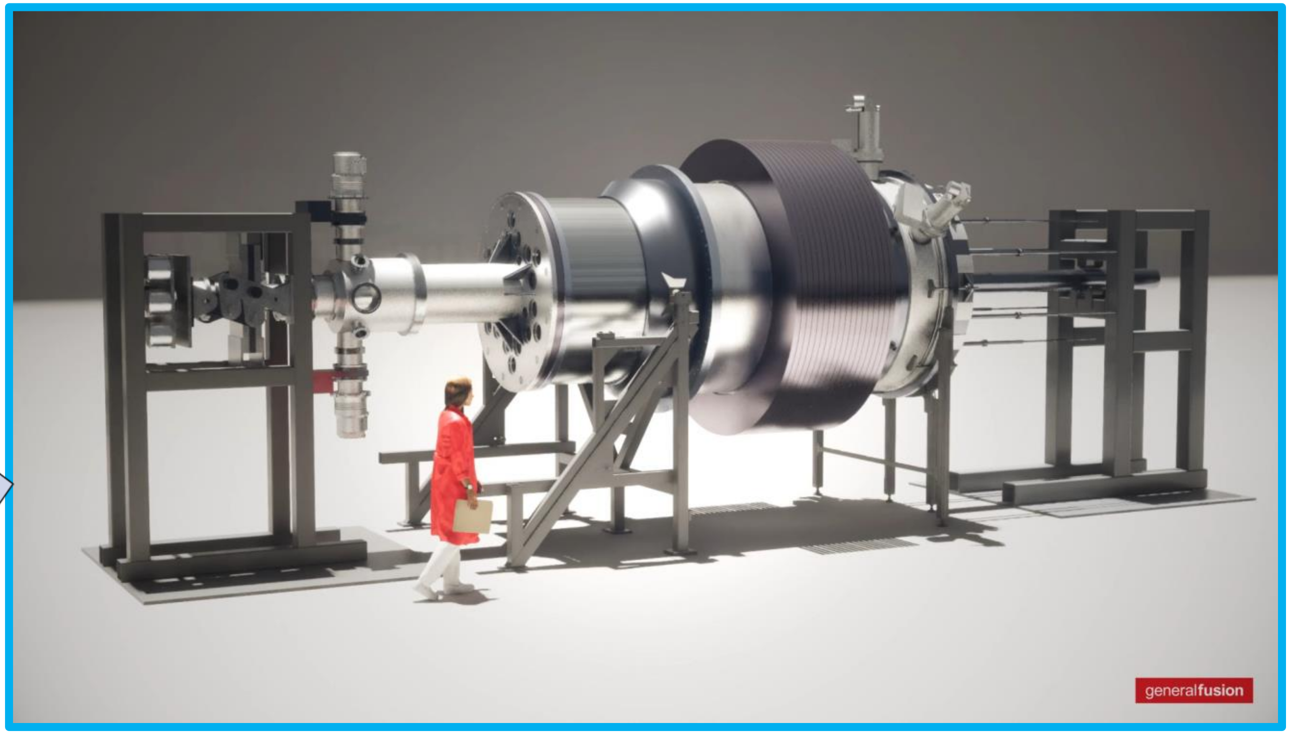
generalfusion

Veryst Engineering

Plasma Compression Science for MTF

- Objective:
  - Reach fusion conditions in LM26 machine
- How:
  - Form a plasma using plasma injector
  - Compress plasma using a solid lithium magnetic flux conserver





LM26 Machine → Lawson criterion, scientific equivalent breakeven

Simulation Challenges

COMSOL

- 3 electromagnetic compressors to build in 2 years
  - Quick iterations (simplification to 2D-axi) ☑
  - Flexible data extraction for post-processing ☑
- Multiphysics
  - Non-linear plastic hardening material (lithium) ☑
    - Large deformation
  - Low-Frequency Electromagnetics ☑
    - Ohmic heating
    - Lorentz Force ☑
  - Fully Coupled Solver

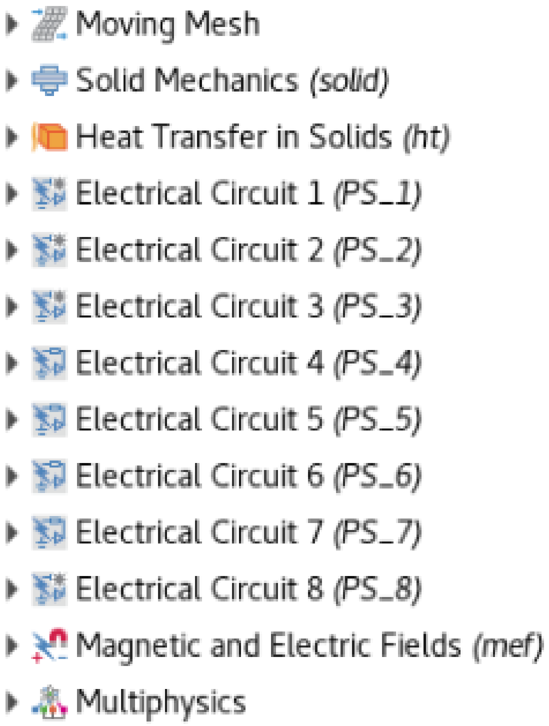
Modeling Methodology Highlights

Physics:

- Moving Mesh
- Solid Mechanics *(linear)*
  - Plasticity (JC)
  - Contact Mechanics (Penalty)
- Magnetic & Electric Field (*quadratic*)
  - Lorentz Force
- Coil excitation from electrical circuits
- Heat Transfer (*quadratic*)
  - Ohmic heating

Solver:

- Time dependent
  - BDF 2nd order scheme
- Fully Coupled
- Automatic Remeshing



COMSOL Modeling Tree

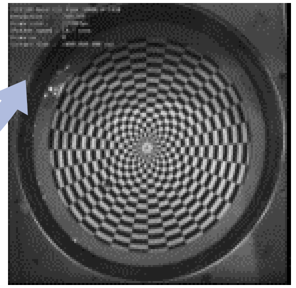
Modeling Validation Strategy

Material Characterization

- Tension/Compression
- Temperature range (20– 120°C)
- Strain & strain-rate hardening

Lithium Ring Compressor

- Azimuthal symmetry
- Ring trajectory validation with COMSOL



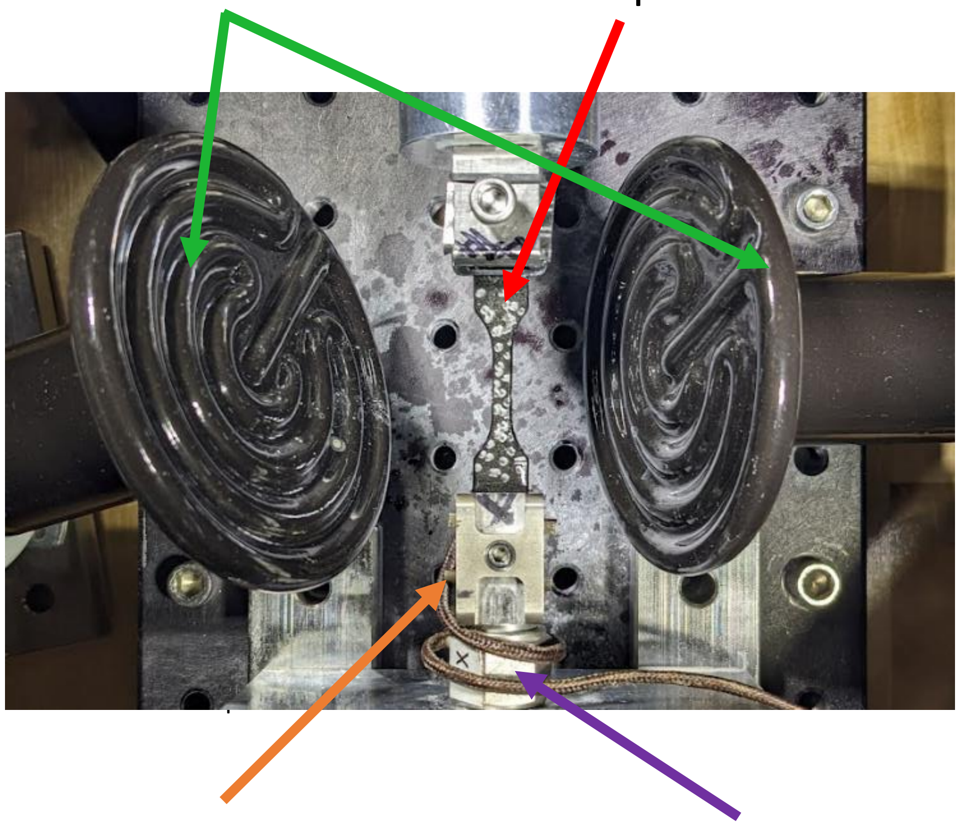
Lithium Cylinder Compressor

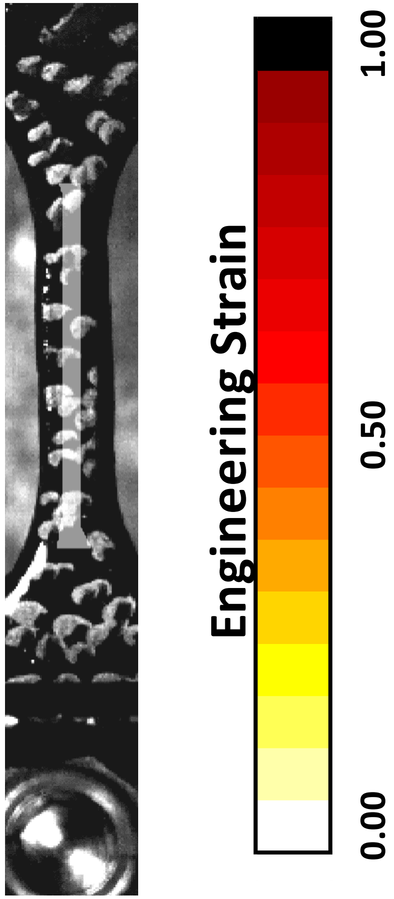
- Lithium / cone high speed impact
- Cylinder shape validation with COMSOL

Material Characterization

Experimental Setup

- Lithium Melting Temperature: 181°C
- Tensile Test
  - ASTM D638 Type V dogbones, oiled
  - Digital Image Correlation with speckle pattern applied with paint
  - 23 to 120 °C
  - ϵ_p up to 0.9
  - $\dot{\epsilon}_p$ Up to 100 (1/s)
- Compressive Test
  - Platen motion with fiducial markers to measure strain
  - 23 to 90 °C
  - ϵ_p up to 0.9
  - $\dot{\epsilon}_p$ Up to -300 (1/s)





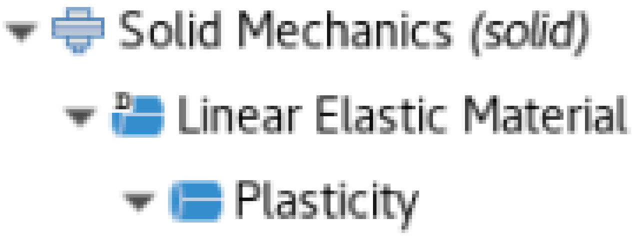
Test Video

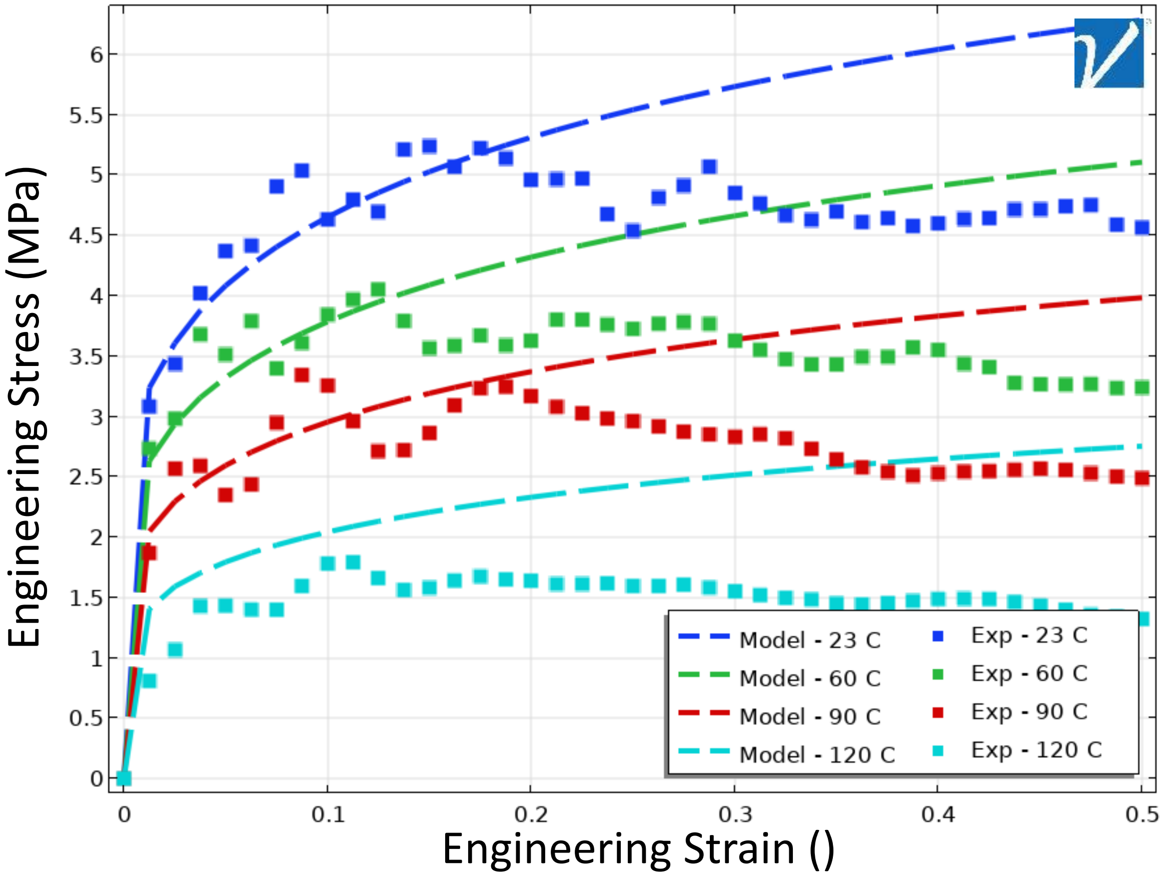
50 ms

Material Characterization

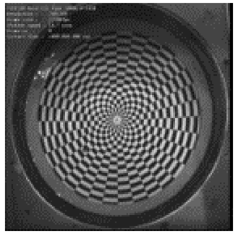
Numerical Setup

- Johnson-Cook Model, calibrated with COMSOL and MCalibration
  - $\sigma = \left(\sigma_y + B\varepsilon_p^n\right)\left(1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{ref}}\right)\left(1 - T^{*m}\right)$
  - σ_y : Yield stress of the material under reference conditions, 0.76 [MPa]
  - B : Strain hardening constant, 2.96 [MPa]
  - n : Strain hardening coefficient, 0.31
  - C : Strengthening coefficient of strain rate, 0.12
  - m : Thermal softening coefficient, 1.27





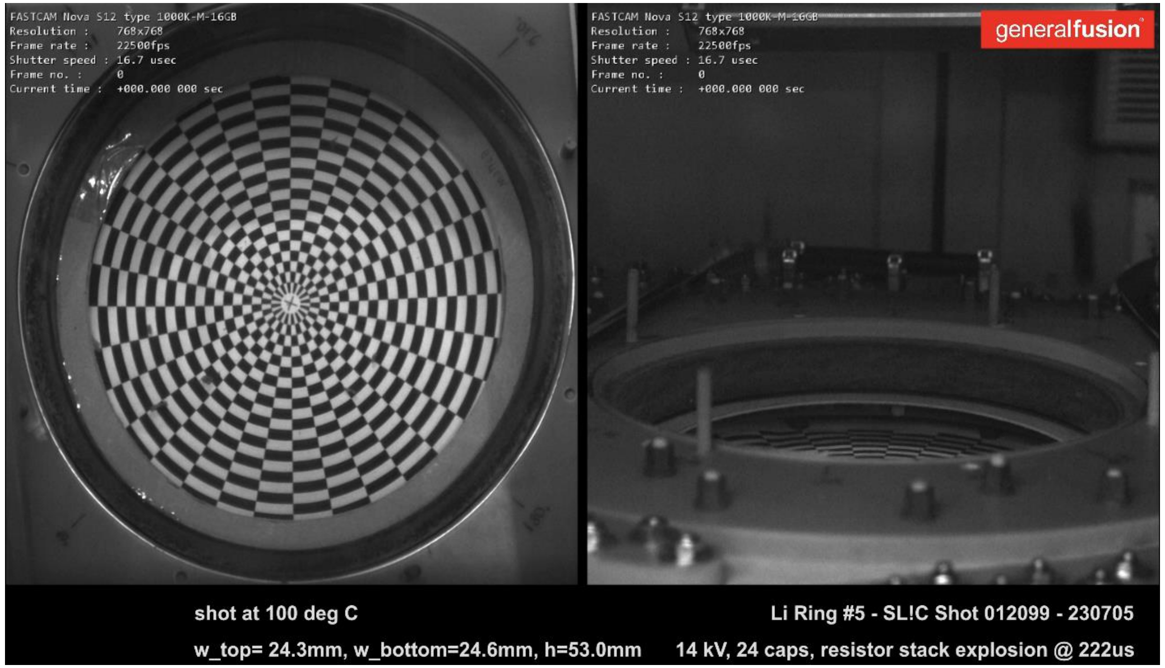
Comparison of Material Model and Experimental Tensile Measurements for at 100 [1/s]



Lithium Ring Compressor

Experimental Setup

Electromagnetic Ring Compression Video



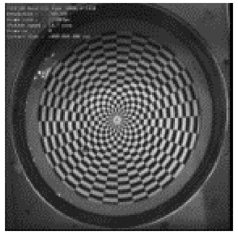
Spin cast lithium ring

Electromagnetic Compressor Test Section

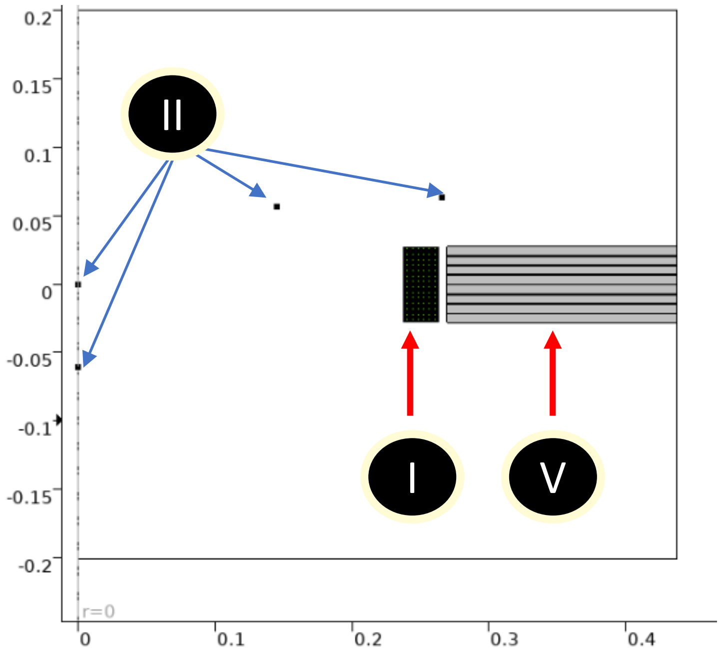
- Coils:
  - 2 x 4 turns
  - ID: 539 mm
  - Total Height: 56.2 mm
- Operated in dry air
- Power Supply:
  - 16 kV
  - 24 x 104 μF
- Spin cast Lithium rings:
  - OD: 527mm
  - Thickness: 20-25mm
  - Temperature up to 120C

Lithium Ring Compressor

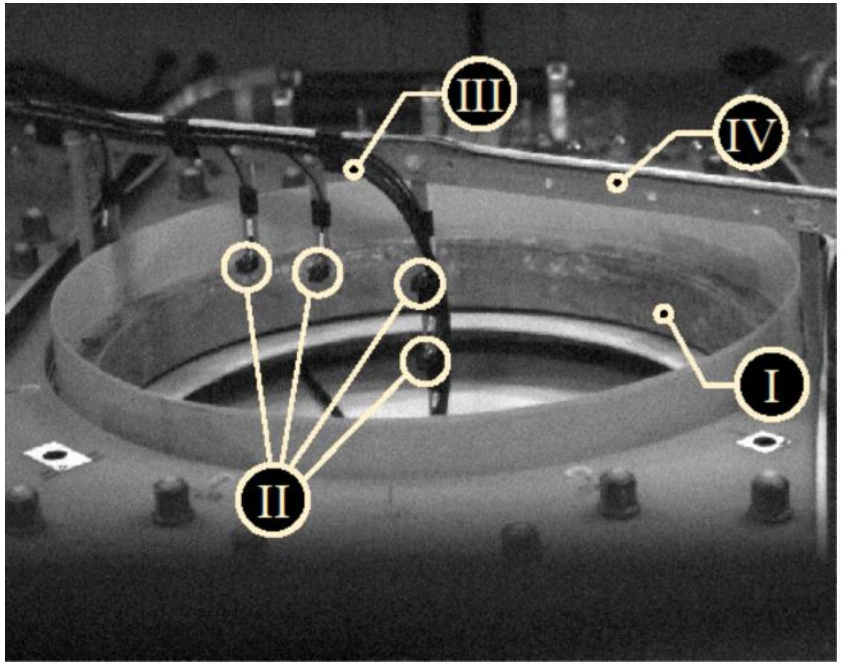
Numerical Setup



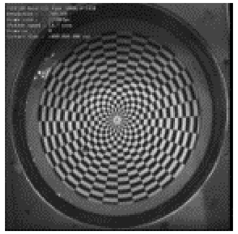
I. Lithium Ring
II. Magnetic Field Probes (B-probes)
III. Rogowski loop(current measurement)
IV. Support structure
V. Coils



COMSOL 2D-axisymmetric Model with location of B-probes

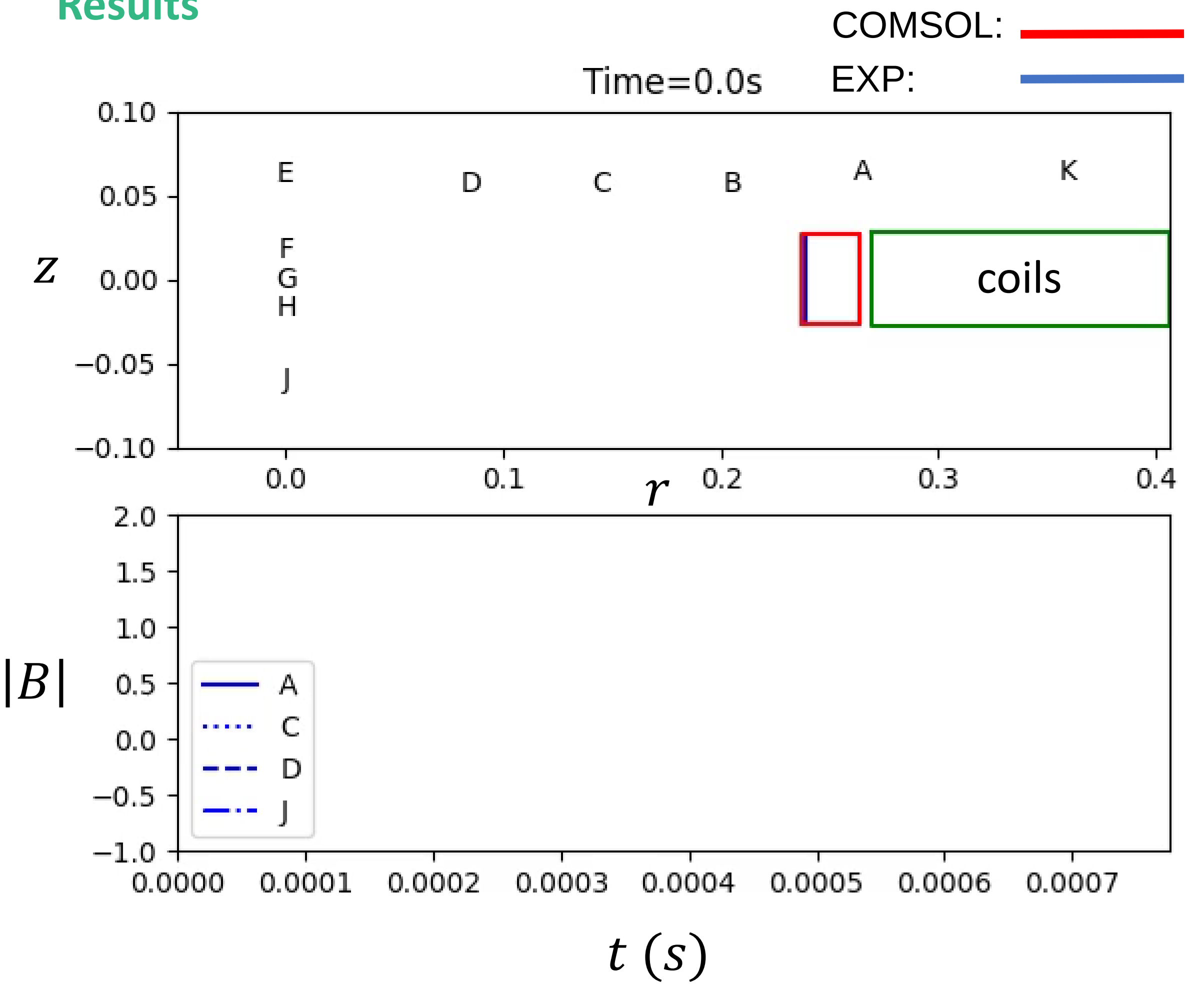


Ring compressor with location of B-probes

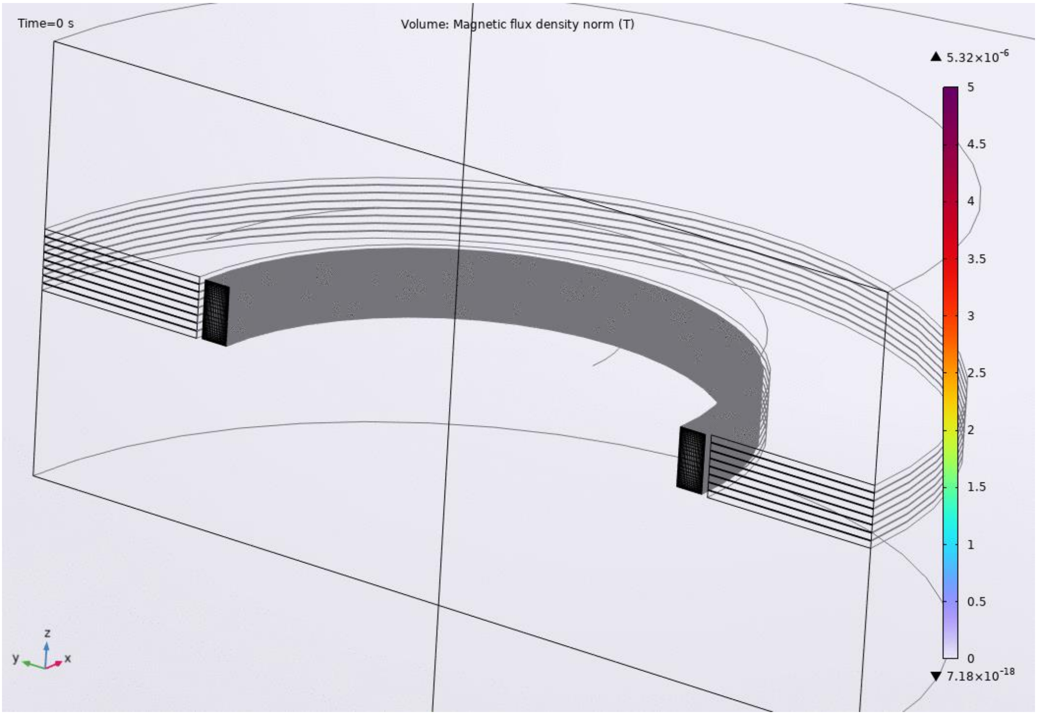


Lithium Ring Compressor

Results



Animation comparing experimental trajectory and b-probe measurements with numerical simulation

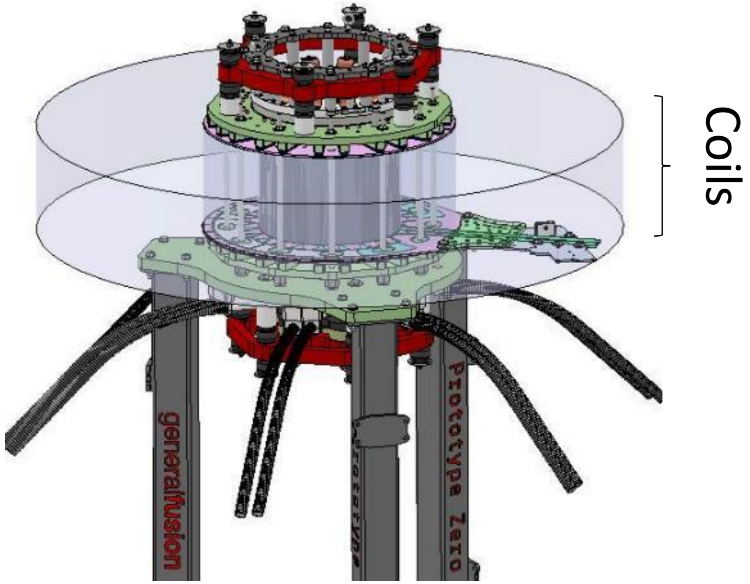


Norm of the magnetic flux density
2D rotated dataset

Lithium Cylinder Compressor

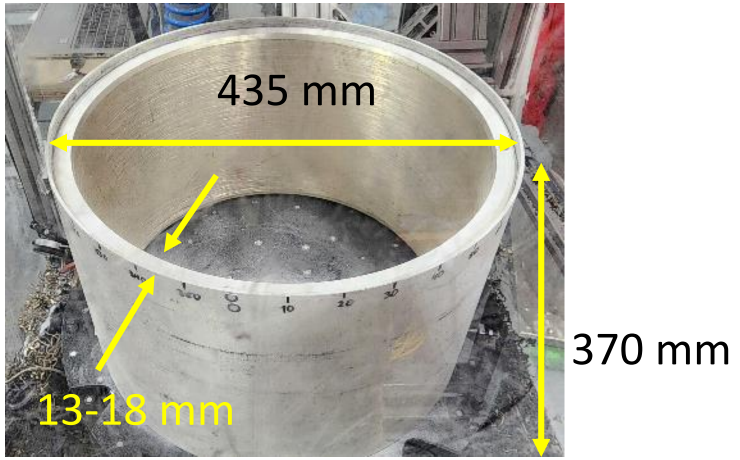
Experimental Setup

CAD Model of the Cylindrical Compressor

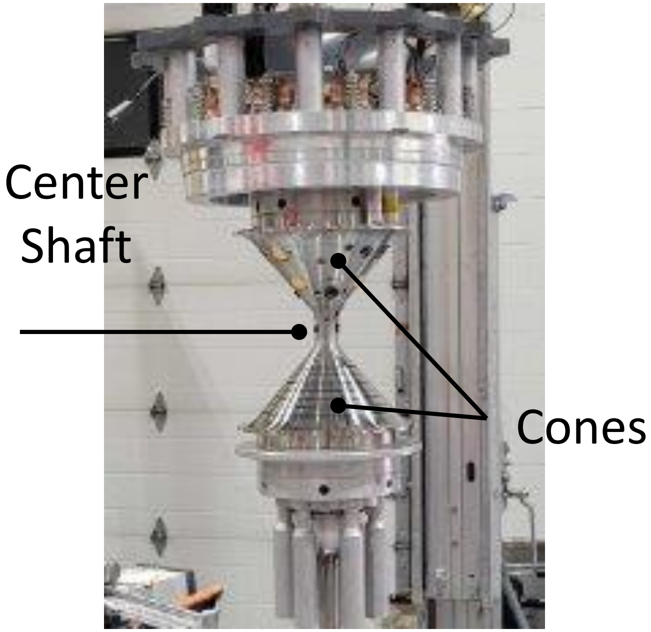


- Operated in vacuum
- Coils:
  - 16 x 3 turns
  - ID: 468 mm
  - Total Height: 370 mm

Lithium cylinder machined in argon vessel



- Power Supply:
  - 16 kV
  - 96 x 104 μF

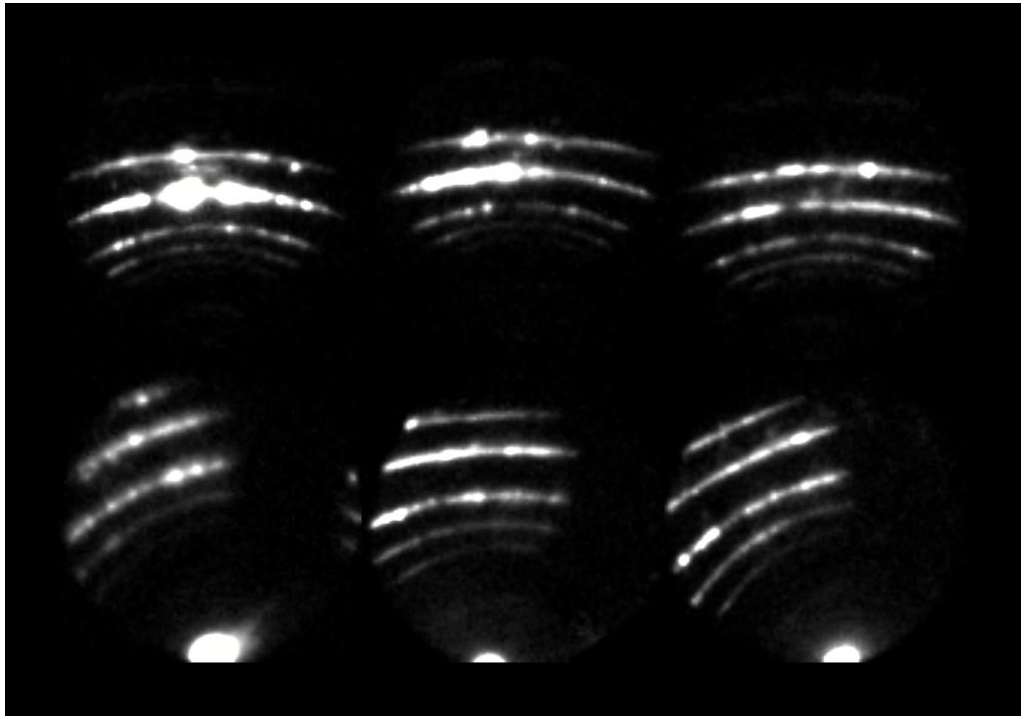


Center shaft and cones prior to installation in the compressor

Lithium Cylinder Compressor

Experimental Setup

- Structured Light Reconstruction (SLR)
  - Technique developed at General Fusion to measure deformation of liners
  - Pattern reconstruction of the reflections from laser sheets
- Photo Doppler velocimetry (PDV)
  - Located in the shaft
  - Extract velocity of the liner at a point near equator



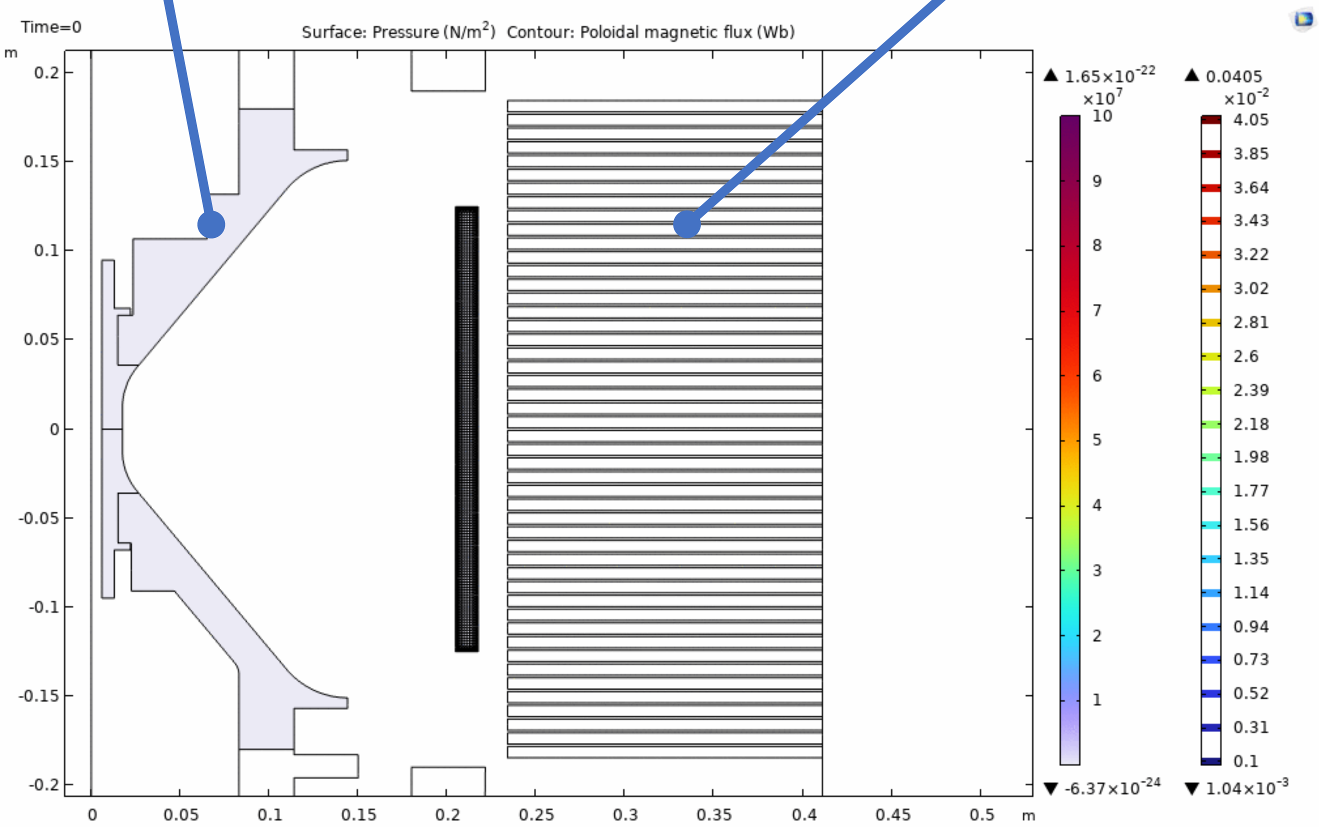
Laser light reflected by liner during compression as seen by fisheye lenses

Lithium Cylinder Compressor

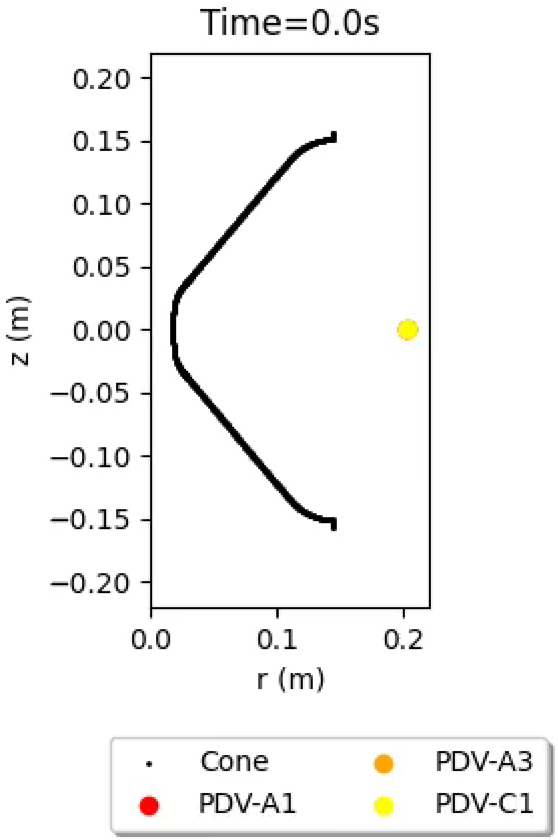
Numerical Setup and Results

Conical Structure

Coils connected to power supply



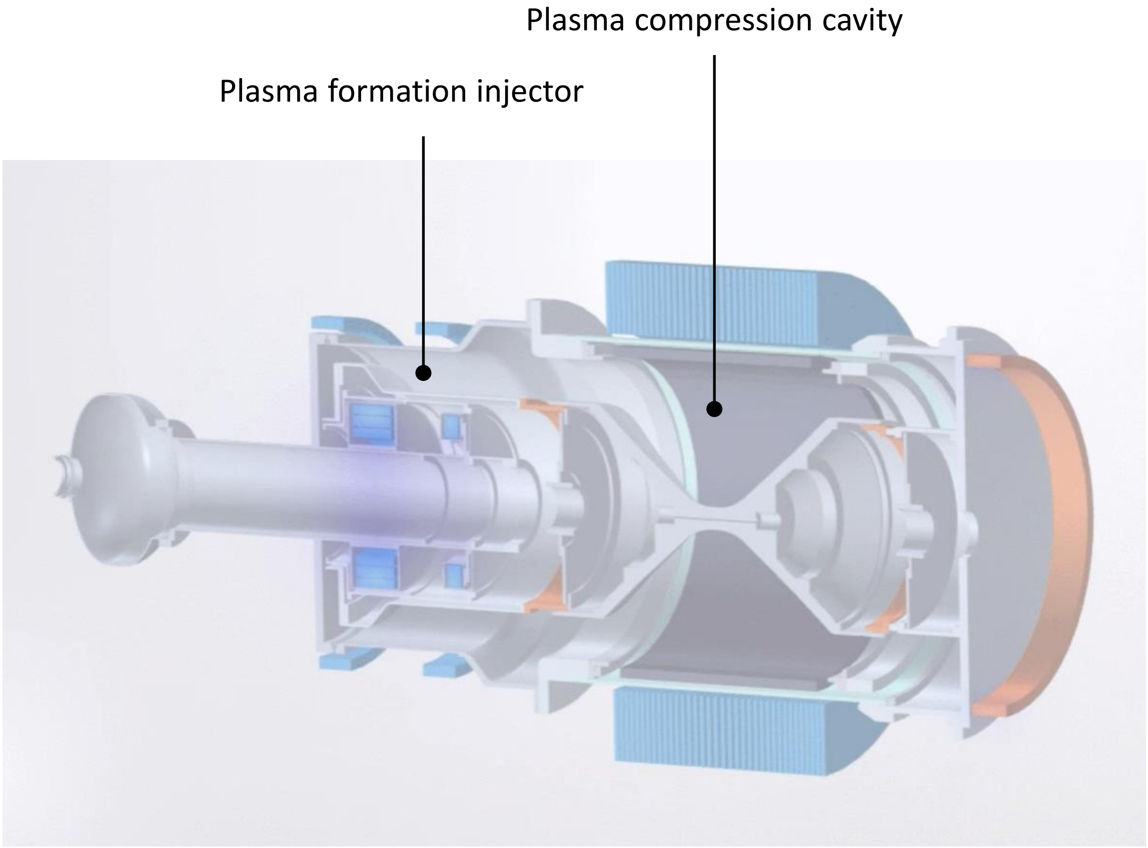
Hydrostatic pressure and poloidal magnetic flux contour



Comparison sample between COMSOL, SLR and PDV channels

Conclusion

- Summary:
  - We use COMSOL Multiphysics to rapidly iterate electromagnetic compressor designs
  - A rate-dependent Johnson-Cook Material model of lithium was calibrated using high-strain rate data
  - Simulation models aligned closely with measured trajectories and magnetic probe data
- Outcomes:
  - The design and operating conditions of the LM26 plasma compressor were driven by COMSOL Multiphysics simulations
  - Fusion conditions should be achieved on schedule in 2025



LM26 Plasma compressor COMSOL Multiphysics model, colored by norm of magnetic flux density