Capsule areal density asymmetries and time evolution inferred from 14.7-MeV protons in OMEGA implosions

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Charged-particle spectra are used to study capsule areal density $(\rho R)$ asymmetry and time evolution

- Charged-particle spectra are measured simultaneously from different directions during individual OMEGA implosions.
- Experiments demonstrate the presence of low $\ell$-mode $\rho R$ asymmetry in direct-drive capsule implosions.
- No single source of low $\ell$-mode has been identified to dominate measurements of $\rho R$ asymmetry.
- Data indicate time evolution of $\rho R$ and $\rho R$ asymmetry between shock coalescence and compression burn.
- The first proton core imaging provide burn profiles at the times of shock coalescence and compression burn.
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- F. J. Marshall et al., GO2.007
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- T. C. Sangster et al., RI1.006
- B. Schwartz et al., KP1.147
- F. H. Seguin, et al., GO2.013
- V. A. Smalyuk et al., QI1.005
- J. M. Soures et al., GO2.005
Outline

• Charged-particle spectroscopy on OMEGA
• Measurements of $\rho R$ asymmetry
• Possible sources of $\rho R$ asymmetry
• Evolution of $\rho R$ and $\rho R$ asymmetry
To study $\rho R$ asymmetry, we measure energy loss of 14.7-MeV $D^3He$ protons

$D + \ ^3He \rightarrow \alpha + p$ (14.7 MeV)
Two kinds of charged-particle spectrometers are used to study $\rho R$ asymmetry and time evolution.

**“Wedge-Range-Filter” spectrometer (WRF)**

- Incident protons
- Al "wedge" filter
- CR-39

Particle energies identified from local thickness $t$ and diameter of etched proton tracks in CR-39.

**Magnet-based spectrometers (CPS)**

- 7.6 kG MAGNET
- 50 keV
- 200 keV
- 600 keV
- 1.0 MeV
- 3.0 MeV
- 10 MeV
- 30 MeV

Particle energies identified from trajectories.
Up to eleven ports can be used for charged-particle spectrometry on the OMEGA target chamber.

- **Yellow** = WRF spectrometers
- **Blue** = Magnet-based CPS’s
Charged-particle spectra are measured simultaneously from different directions during an individual OMEGA implosion.

Shot 21240

Experiments demonstrate low $\ell$- mode $\rho R$ asymmetry
2D DRACO simulation indicates the low \( \ell \)-mode \( \rho R \) asymmetry at the time near peak burn.

Shot 25697
1-ns square, 23 kJ
beam imbalance \(~6\%\) rms
Measured $\rho R$ asymmetry is correlated with beam energy imbalance when it is $\sim 25\%$ rms ($\sigma_{\text{rms}} \sim 9\%$ after beam overlap)
ρR asymmetry is correlated with energy imbalance when this imbalance is ~25% rms.
Under current OMEGA experimental conditions, possible sources of low-mode number $\rho R$ asymmetry include:

- Irradiation non-uniformity *
  - Beam energy/power imbalance $\leq 5\%$ rms ($\sigma_{\text{rms}} = 1-2\%$ after beam overlap)
  - Capsule offset from TCC $\leq 5\,\mu m$ ($\sigma_{\text{rms}} \leq 1\%$)
  - Beam mispointing $\leq 20\,\mu m$ ($\sigma_{\text{rms}} \sim 1.9\%$)
  - Beam mistiming $\leq 10\,\text{ps}$ ($\sigma_{\text{rms}} \sim 1\%$)
  - Beam shape ($\sigma_{\text{rms}} \sim 1.1\%$)

- Capsule imperfections

* F. J. Marshall et al., GO2.007 in this conference
When beam energy imbalance is \( \sim 5\% \text{ rms} \) \( (\sigma_{\text{rms}} \sim 1-2\% ) \), \( \rho R \) asymmetry is uncorrelated with this imbalance.
Measured $\rho R$ asymmetry is uncorrelated with offset of the capsule from the target chamber center (TCC) when this offset is $\leq 80 \, \mu m$.

*J. M. Soures et al., GO2.005 in this conference*
For contiguous shots, similarities in asymmetries suggest that \( \rho R \) asymmetry is uncorrelated with capsule imperfections.
During a two-week interval, $\rho R$ asymmetries are randomly distributed over space and time.

$D^3$He(18)CH[20]
23 kJ, 1-ns square

![Graphs showing data distribution](image)

(a) $\Delta \langle E_p \rangle$ (MeV)
(b) $\rho R_{total}$ (mg/cm²)

Port Location

- Each port averaged over 18 shots
- Each shot averaged over 7 ports
No single source of low-order $\ell$ modes has been identified to dominate the measured $\rho R$ asymmetry

Next questions

- How do $\rho R$ and $\rho R$ asymmetries evolve with time?
- How much are these asymmetries amplified over time?
Evolution of $\rho R$ has been studied at the time of shock-coalescence and ~400 ps later, at the time of compression burn.

- $t \approx 2.1$ ns
  Compression burn
  ("bang time")

- $t \approx 1.7$ ns
  Shock coalescence

$\rho R$ grows from 13 to 70 mg/cm$^2$ during the ~400ps from shock coalescence to bang time.

Are there any correlations in $\rho R$ asymmetry between shock-coalescence time and compression burn time?

Shot 24811
1 ns square, 23kJ

Energy (MeV)
Does the asymmetry seen at compression burn amplify from the time of shock coalescence?

F. H. Seguin, et al., GO2.013 in this conference
Charged-particle spectroscopy could be used to study high \( \ell \)-mode \( \rho R \) modulations at the time of shock coalescence.

Width of shock yield (D\(^3\)He proton) \( \rightarrow T_i \)

Ratio of DDp yield to D\(^3\)Hep yield \( \rightarrow T_i \)
Proton-core-image-spectroscopy (PCIS) potentially provides a method for studying $\rho R$ evolution.
Measured proton core images at the time of shock coalescence and \(~400\) ps later, at compression burn.

\[
\begin{align*}
D + ^3\text{He} & \Rightarrow p (14.7 \text{ MeV}) + \alpha (3.6 \text{ MeV}) \\
D + D & \Rightarrow p (3.0 \text{ MeV}) + t (1.0 \text{ MeV})
\end{align*}
\]

Measured fusion burn profiles for Shot 27806.
Summary/Conclusions

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