EXPERIMENTAL GOALS AND METHOD

- **Goal:** Determine experimentally the influence of cross-section shape on energy transport in L mode and H mode

- **Method:** While changing the elongation, hold fixed:
  - Toroidal field at geometric center
  - Minor radius
  - Density profiles in normalized radius
  - Temperature profiles in normalized radius
  - Toroidal rotation profile in normalized radius
  
  and to compare with theory
  - \( q \) profile in normalized radius

  or to compare with global scalings
  - Plasma current

- **Note:** Since densities are large and no uncertainty analysis has been performed, only one-fluid power balance results are shown
FLUX-AVERAGED EQUATIONS GIVE SIMPLE FORMULAS FOR THE EFFECT OF CROSS SECTION CHANGES

- By definition:

\[ q_H = -n\bar{\chi} \frac{\partial T}{\partial \rho_b} \frac{1}{\rho_b} \]

\[ P = \frac{\partial V}{\partial \rho} \frac{\partial}{\partial p} q_H. \]

(\( \rho_b^2 \) is the boundary value of the normalized toroidal flux). The change in diffusivity when the cross section is varied with \( n(\hat{\rho}), T(\hat{\rho}) \) constant:

\[ \frac{\bar{\chi}_2}{\bar{\chi}_1} = \frac{q_{H2}}{q_{H1}} \frac{\rho_{b2}}{\rho_{b1}} = \frac{(P_2/H_2)}{(P_1/H_1)} \]

where \( H = \frac{\partial V}{\partial \rho} (4\pi^2 R_o \hat{\rho} \rho_b) \).

- The change in global confinement can be estimated by

\[ \tau = \rho_b^2 / \bar{\chi}. \]

Then

\[ \frac{\tau_2}{\tau_1} = \left( \frac{\rho_{b2}}{\rho_{b1}} \right)^2 \frac{\bar{\chi}_1}{\bar{\chi}_2}. \]

If the diffusivity is independent of cross-section shape, then \( \tau \propto \rho_b^2 \sim \kappa \).
Shape variation for H–mode elongation scans

$\kappa = 2$
$\kappa = 1.7$

Shape variation for L–mode elongation scans

$\kappa = 1.8$
$\kappa = 1.2$
CONCLUSIONS

- Characterizing the cross-section shape effects using $\kappa$, and the effect on diffusivity as a power law $\chi \propto \kappa^a$, there is a strong influence of shape on transport: $\alpha = -(1.5–2.0)$

- Changes in cross-section shape at fixed current will be strongly affected by the change in $q$. It is necessary to maintain fixed $q$ to isolate the effects of cross-section shape on energy transport.

- The constant current scans can be qualitatively reconciled with the constant $q$ scans using $\chi \propto q^2$ as measured in DIII–D H–modes.

- No theoretical understanding of such a strong dependence on cross-section shape is available at this time.
Transport is reduced with increasing elongation

\[ \chi \propto \kappa^\alpha \]

\( \chi \) ratio
\( \kappa \) ratio
PROFILE MATCH FOR CONSTANT I H–MODE SCAN

\[ \kappa = 1.70 \]

\[ \kappa = 2.02 \]
Transport increases with increasing elongation

\[ \chi \propto \kappa^\alpha \]
## H MODE GLOBAL CONFINEMENT RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Constant q Scan</th>
<th>Constant I Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{th}$ (ms)</td>
<td>190/135</td>
<td>137/128</td>
</tr>
<tr>
<td></td>
<td>2.0/1.71</td>
<td>2.02/1.70</td>
</tr>
<tr>
<td>$\rho_b^2$ (m$^2$)</td>
<td>0.63/0.517</td>
<td>0.604/0.513</td>
</tr>
<tr>
<td>$H_{98Y2}$</td>
<td>0.99/1.20</td>
<td>1.15/1.20</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>2.19</td>
<td>0.41</td>
</tr>
</tbody>
</table>

$H_{98Y2}$ is the ratio of $\tau_{th}$ to the H–mode confinement scaling in the ITER Physics Basis

$(\tau_{th} \propto \kappa^\alpha)$

<table>
<thead>
<tr>
<th></th>
<th>Constant q Scan</th>
<th>Constant I Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I$ (MA)</td>
<td>1.08/0.84</td>
<td>0.84/0.84</td>
</tr>
<tr>
<td>$B$ (T)</td>
<td>1.93/1.93</td>
<td>1.93/1.93</td>
</tr>
<tr>
<td>$\bar{n}$ ($10^{19}$ m$^{-3}$)</td>
<td>5.2/5.1</td>
<td>4.7/4.6</td>
</tr>
<tr>
<td>$P$ (MW)</td>
<td>2.69/3.37</td>
<td>3.60/3.37</td>
</tr>
</tbody>
</table>
PROFILE MATCH FOR CONSTANT $q$ L-MODE SCAN

\[ \kappa = 1.17 \]

\[ \kappa = 1.77 \]
Transport is reduced with increasing elongation.

\[ \chi \propto \kappa^\alpha \]

\[ \chi \text{ ratio} \quad \kappa \text{ ratio} \]

\[ \hat{\rho} \]

\[ \hat{\rho} \]
PROFILE MATCH FOR CONSTANT I L–MODE SCAN

\[ \kappa = 1.17 \]

\[ \kappa = 1.79 \]

\[ n_e \left(10^{19} \text{ m}^{-3}\right) \]

\[ T_e \text{ (keV)} \]

\[ T_i \text{ (keV)} \]

\[ \omega_T \text{ (rad/s)} \]

\[ Z_{\text{eff}} \]

\[ q \]

\[ \hat{\rho} \]
Transport increases at higher elongation

\[ \chi \propto \kappa^\alpha \]

- $\chi$ ratio
- $\kappa$ ratio
## L MODE GLOBAL CONFINEMENT RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Constant q Scan</th>
<th>Constant I Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{th}$ (ms)</td>
<td>90.0/46.2</td>
<td>56.6/348.7</td>
</tr>
<tr>
<td></td>
<td>1.77/1.17</td>
<td>1.79/1.17</td>
</tr>
<tr>
<td>$\rho_b^2$ (m²)</td>
<td>0.73/0.46</td>
<td>0.684/0.462</td>
</tr>
<tr>
<td>$L_{IPB}$</td>
<td>0.69/1.12</td>
<td>1.23/1.18</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1.61</td>
<td>0.35</td>
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</tbody>
</table>

$L_{IPB}$ is the ratio of $\tau_{th}$ to the L–mode thermal confinement scaling in the ITER Physics Basis.

$L_{IPB}$ is the ratio of $\tau_{th}$ to the L–mode thermal confinement scaling in the ITER Physics Basis.

$\tau_{th} \propto \kappa^{\alpha}$
DISCUSSION

- The discrepancy in the constant $q$ and constant $I$ scans is expected in H mode on the basis of the $q$ scaling measurements on DIII–D ($\chi \propto q^2$) [1]. Such strong and opposing dependences will require a careful error assessment to yield an accurate estimate for the true scaling with shape.

- Preliminary analysis gives a power law dependence of $\alpha \simeq -(1-4)$ for all cases assuming $\chi \propto q^2$ (see figure at right).

- Such a strong dependence on shape was not anticipated by theoretical calculations (for example [2]). However, physics-based models derived for circular geometry [3] have included strong shaping effects ($\chi \propto \kappa^4$).

Main conclusion is that a reasonable q dependence ($\chi \propto q^2$) is in the correct direction and has sufficient magnitude to reconcile the constant q and constant I scans.

Measurement uncertainties may not allow a quantitative correction.