Three-Dimensional Simulation of Gas Conductance Measurement Experiments on Alcator C-Mod and NSTX

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Note: This poster is available on the Web at:
`http://w3.pppl.gov/degas2/`

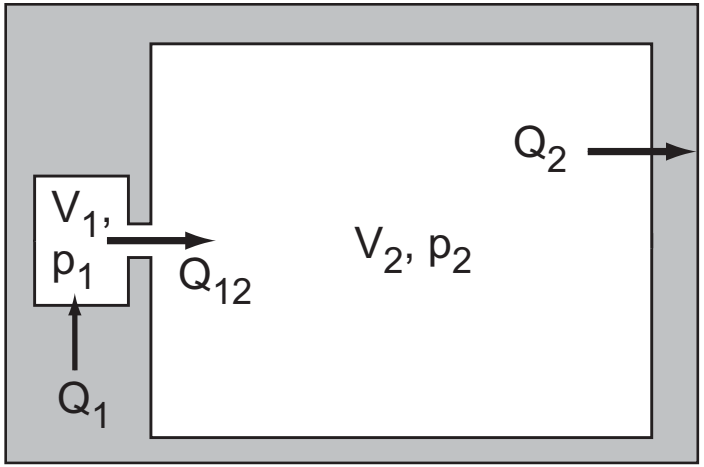
Introduction

- Previous simulations of C-Mod divertor bypass experiments yielded too little neutral pressure,
- Lisgo reduced discrepancy to factor of 2 by examining variety of assumptions,
  - Found axisymmetric treatment of subdivertor gas flows inadequate.
- LaBombard did experiments on C-Mod to quantify these gas flows.
- Here: benchmark DEGAS 2 Monte Carlo neutral transport code against them,
  - Compare 3-D results with axisymetric values.
- 3-D capability also useful in studying NSTX gas flows.

Summary

1. 3-D simulations of neutral gas transport possible,
   - In some case, practical with massively parallel computers.
2. Effective conductance of earlier axisymmetric geometry significantly exceed actual values,
   - Confirms Lisgo's finding that 3-D treatment is needed.
3. 3-D DEGAS 2 simulated conductances roughly agree with measured values,
   - Remaining differences may be due to details not simulated,
   - And / or inadequate spatial resolution.

Two Chamber Model Aids Interpretation of Results



$$U_{12} \equiv Q_{12}/(p_1 - p_2).$$

- Solve equations with constant U_{12}, initial p_1, p_2, and $Q_2 = 0$,
  - For $t \gg V_1 V_2 / U_{12}(V_1 + V_2)$, $p_1 - p_2 = \frac{1}{U_{12}} \frac{V_2 Q_1}{V_1 + V_2}$.
- If Q_2 due to pump of speed S, $Q_2 = S p_2$, have steady state solution

$$p_1 = Q_1 \left(\frac{1}{S} + \frac{1}{U_{12}} \right); p_2 = \frac{Q_1}{S}.$$

D_2 - D_2 Collisions Only - No Plasma

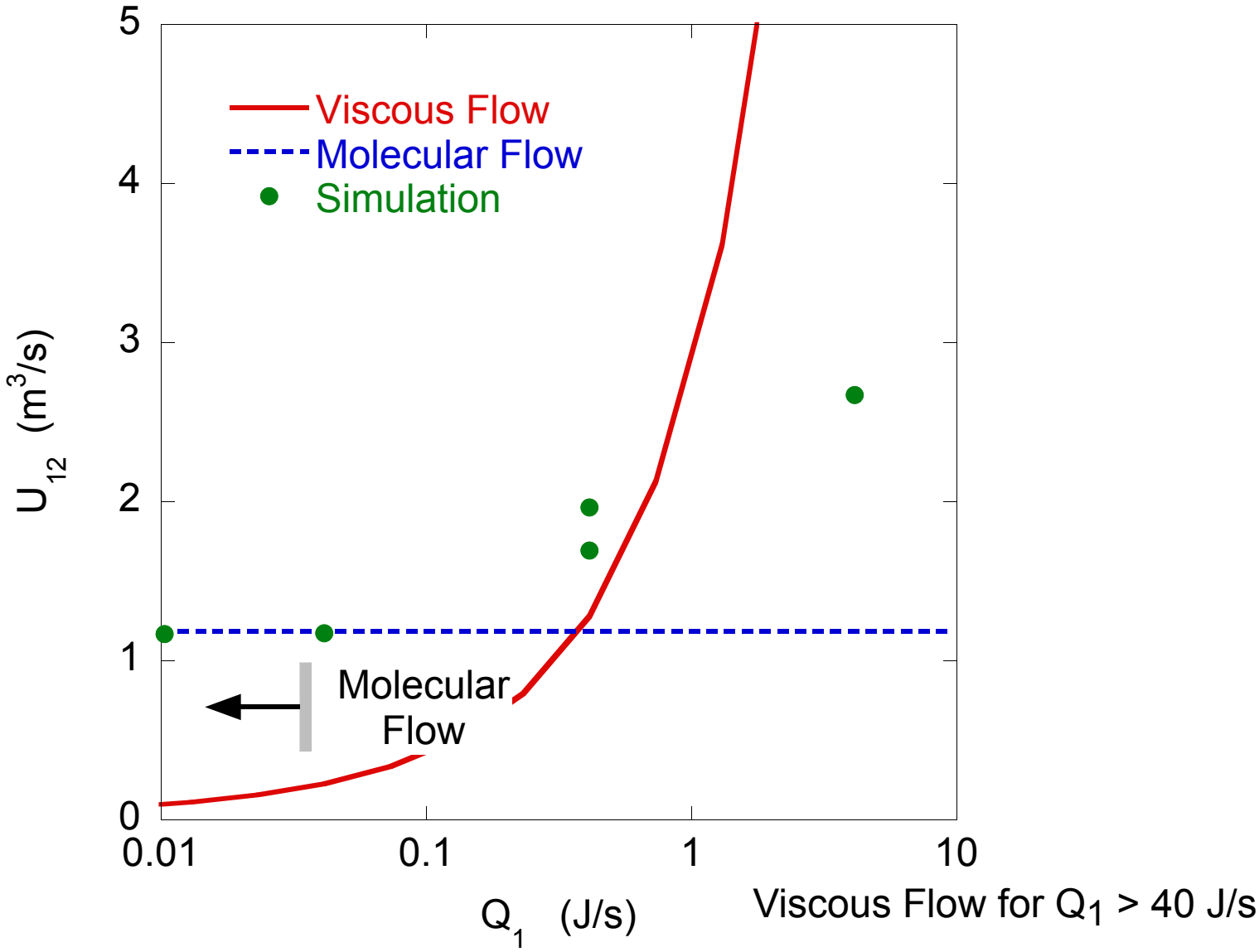
- Only treating D_2 - D_2 elastic scattering,
  - Iterative, BGK treatment with $\vec{v}$-independent $\langle \sigma v \rangle$,
  - Set $\langle \sigma v \rangle = kT/\eta$ using measured viscosities η.
- Molecules striking walls absorbed / desorbed with 100% recycling,
- Sample desorbed molecules with 300 K Maxwell flux distribution.
- Gas source also 300 K, Gaussian in energy, cosine in angle.

Use Simple Pipe Flow Case to Validate DEGAS 2 Physics & Illustrate Conductance Changes with Flow Regime

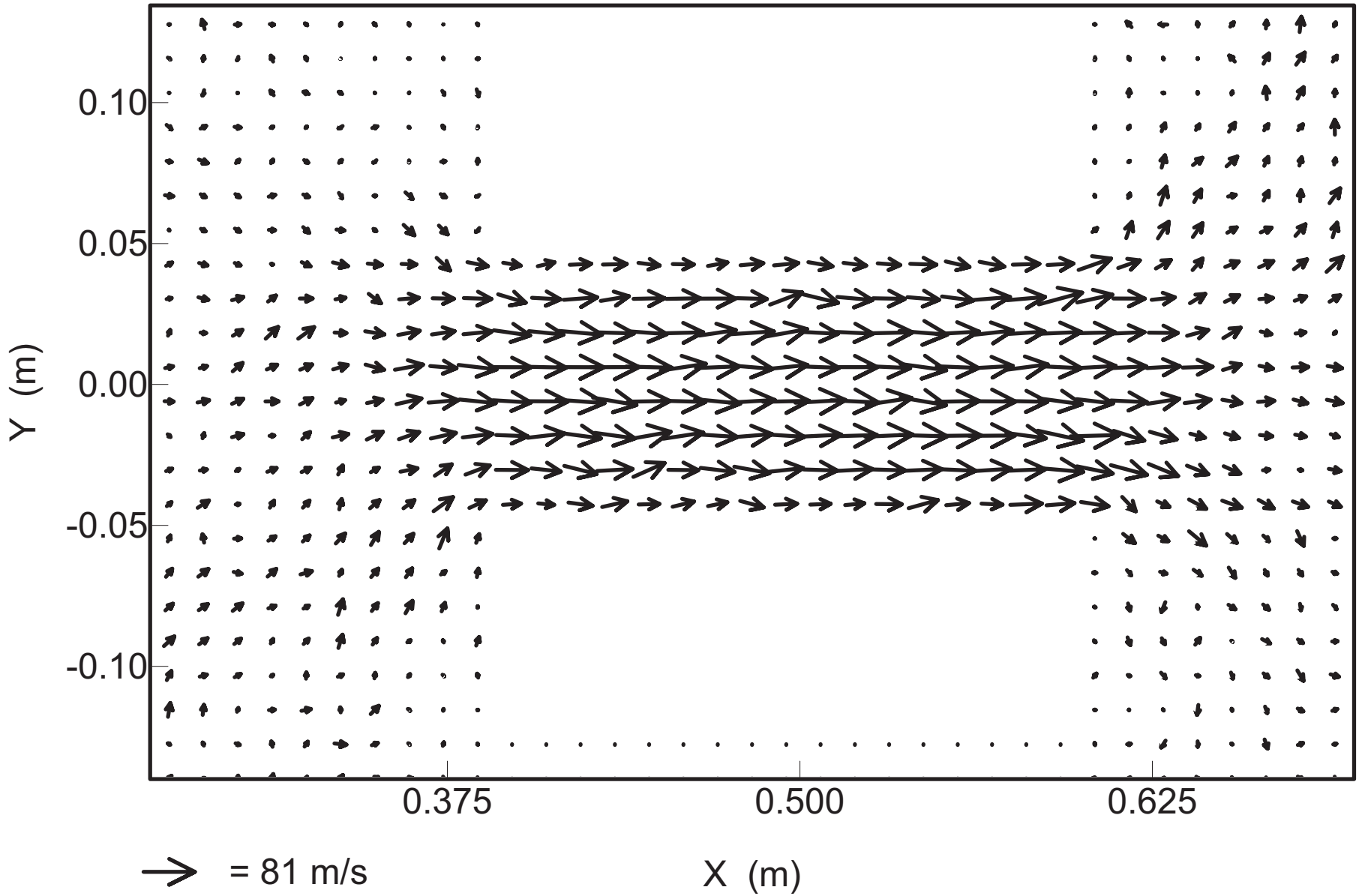
- Flow regime characterized by $K = \lambda/d$,
  - $K > 3 \Rightarrow$ "molecular flow" regime, $U_{12} \propto p^0$,
  - $K < 0.01 \Rightarrow$ "viscous flow" regime, $U_{12} \propto p^1$,
  - In between: "transition" regime.

- Consider flow through 0.205 m long, 0.1 m square pipe,
  - Molecular flow: $U_{mf} = A\frac{\bar{v}}{4}W$,
  - Viscous flow: $U_{vf} = \frac{1}{12\eta}\frac{a^2b^2}{L}\bar{p}Y$.
    - Use U definition and $p_2 = Q_1/S$ to get $U_{vf}(Q_1)$.

Comparison of Simulated & Predicted Pipe Conductances



Velocity Shear Across Pipe Center in Q_1 = 0.4 Simulation



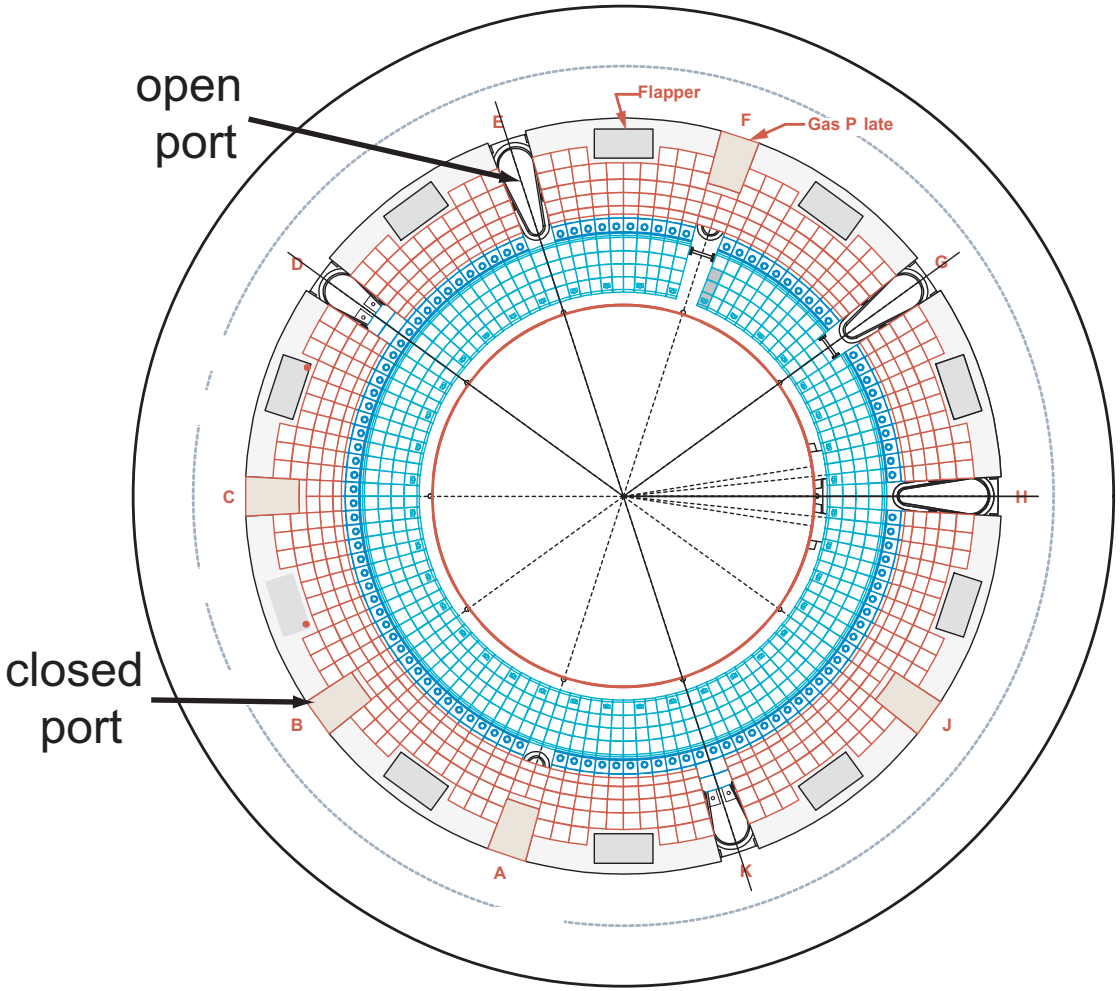
Code Works Well for Molecular Flow / into Transition Regime; Denser Flows More Difficult

- Low Q_1 results agree with U_{mf} to within 2%.
- Have viscous flow for $Q_1 > 40$ J/s.
- Two points at $Q_1 = 0.4$ have different spatial resolution in pipe,
  - Impacts U because need to resolve flow shear across pipe cross section,
- Appears to affect $Q_1 = 4.$ case even more strongly.

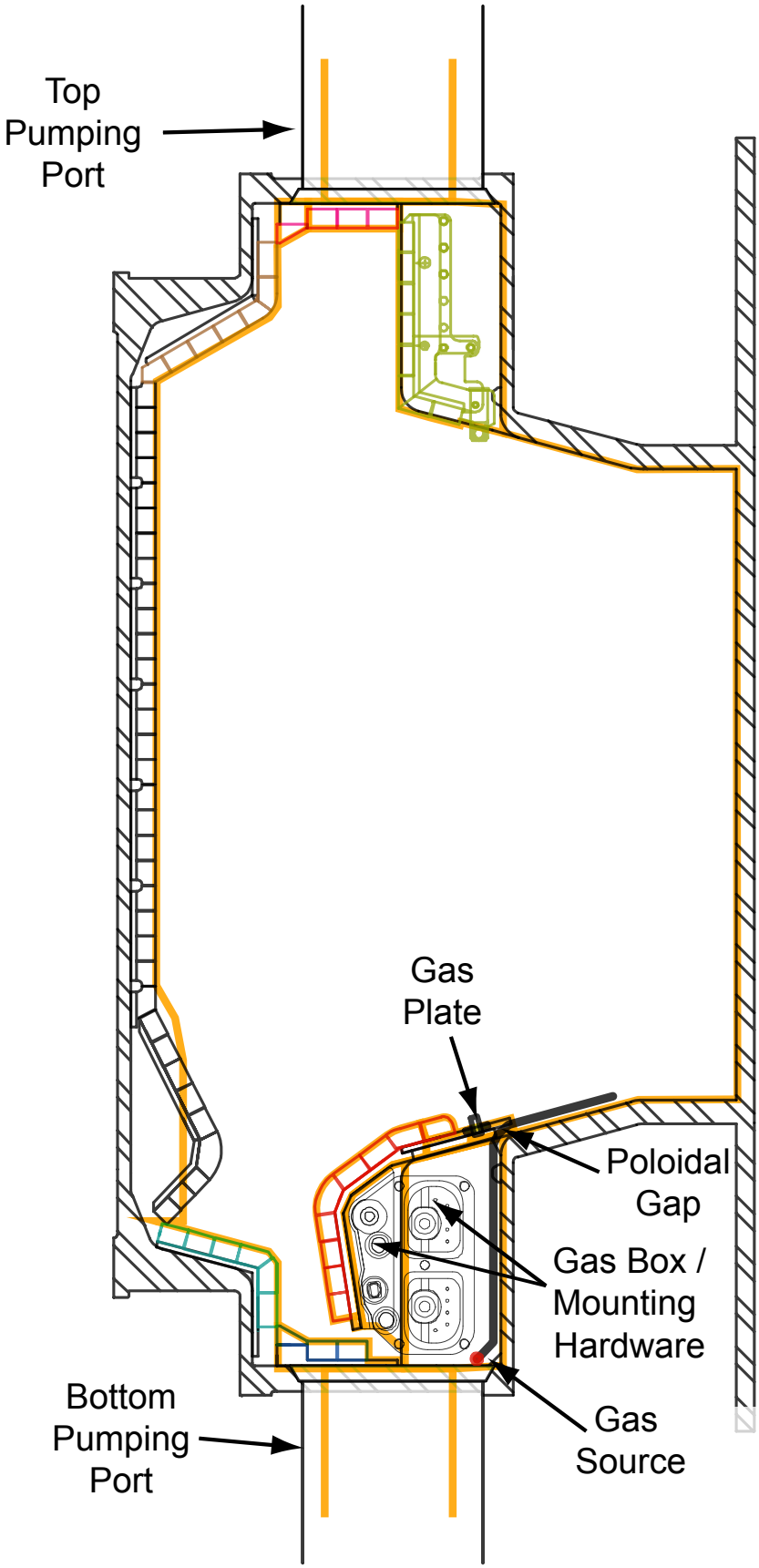
Measure Conductances Through C-Mod Divertor

- Install gas capillaries & pressure gauges to measure flow out of “open” and “closed” divertor ports,
  - “Closed”: main flow through slot under outer divertor,
  - “Open”: divertor plate / tiles removed for diagnostic access.
- Puff gas into gas box,
  - Calibrate Q_1 from dp_2/dt in main chamber & known torus volume,
  - Measure p_1 at bottom of pumping port,
  - Take p_2 in main chamber,
  - $\Rightarrow$ compute U_{12}.
- Note that conductances hold steady as pressures rise.

Plan View of C-Mod Lower Divertor

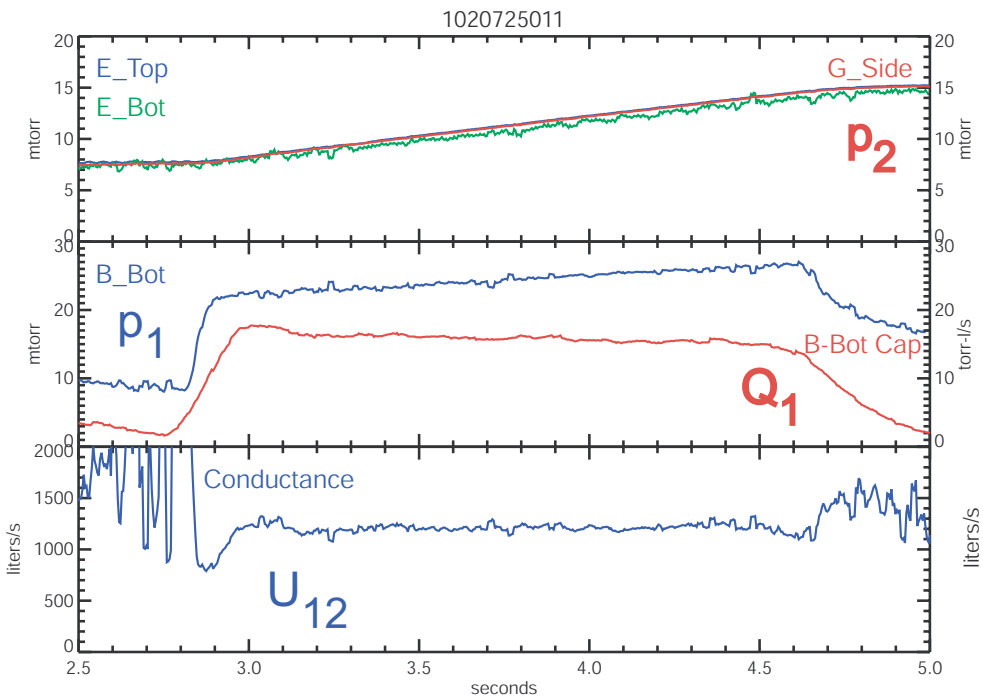


DEGAS 2 Polygons Overlaid on C-Mod Closed Port Cross Section

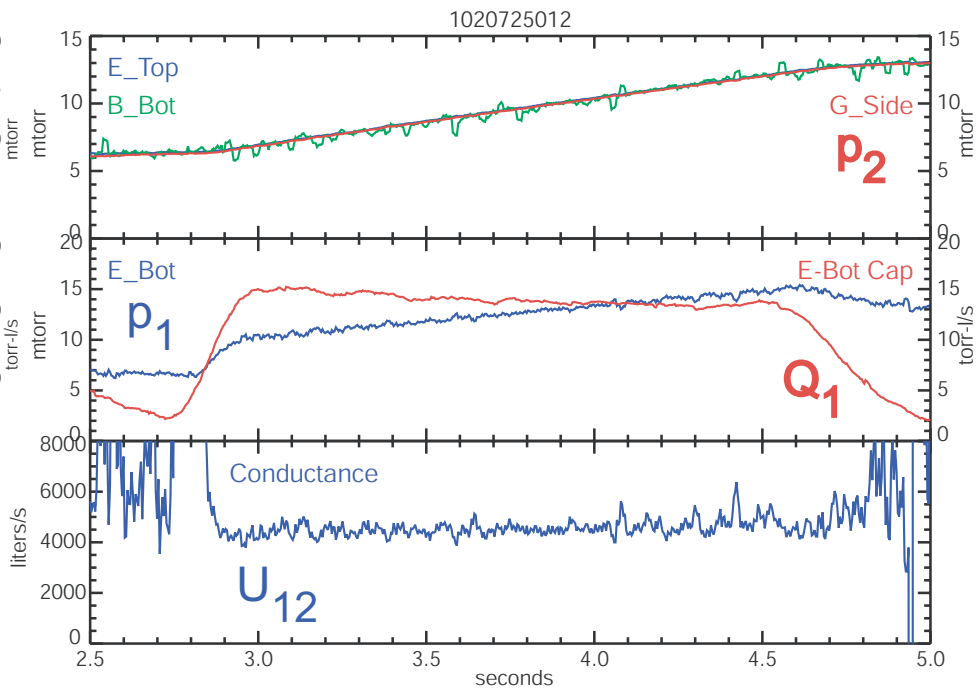


Experimentally Pressures Rise Linearly Conductances Hold Steady

Closed



Open



Use Pie Slice Model to Describe Toroidal Variation of C-Mod Hardware

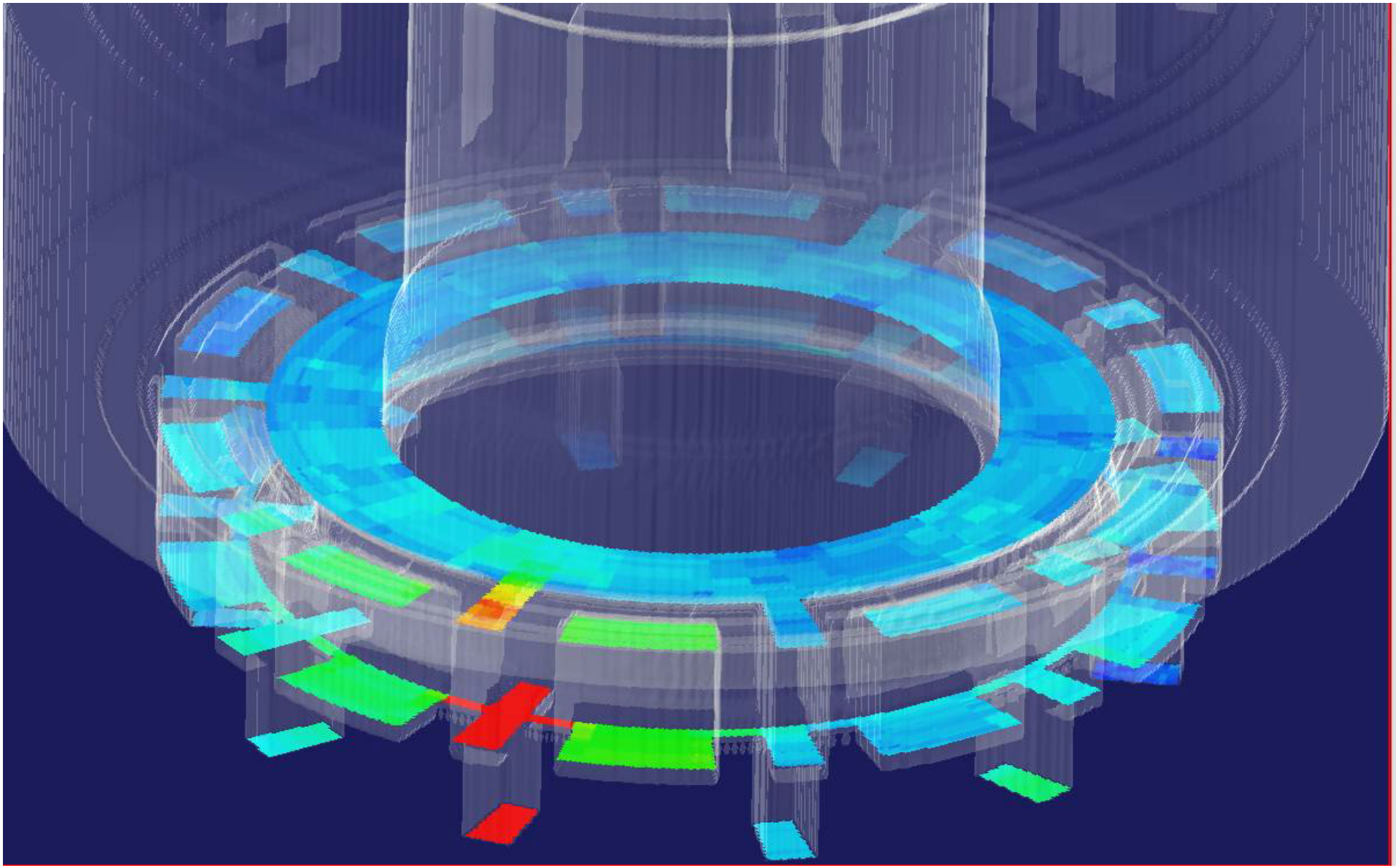
- Represents modest extension of existing 2-D geometry setup tools.

- Principal toroidal variation:
  - Vertical pumping ports: 6° wide, to $Z = \pm 1.9$ m,
  - Divertor mounting hardware: 6° wide solid on either side of ports,
  - Vacuum elsewhere: gas box.
  - Outer divetor plate / tiles: solid except 6° gaps at "open" ports & 3 mm gaps at "closed" ports.

- Also have 0, 2, or 4 mm gap at top of gas box.

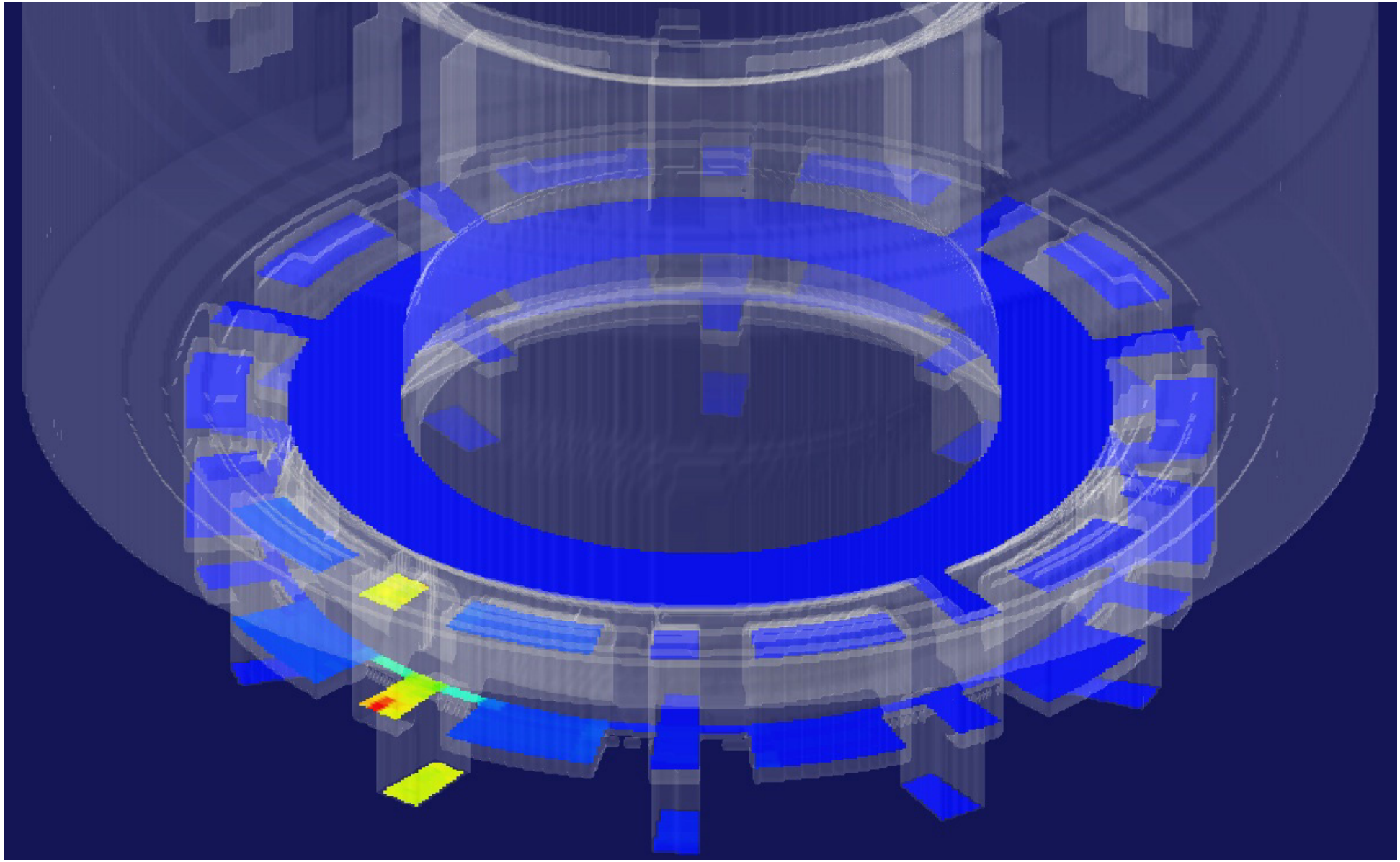
- 10% sink at top of upper ports $\Rightarrow$ steady state simulations.

Visualization of Open Port Simulated Neutral Pressure



Visualization by S. A. Klasky

Visualization of Closed Port Simulated Neutral Pressure



Visualization by S. A. Klasky

Compare Simulated & Measured Pressures & Conductances

Run	p_1 (Pa)	p_2 (Pa)	Q_1 (J/s)	U_{12} (m^3/s)
Axisymmetric	0.21	0.16	1.99	40.
Open	1.46	1.22	1.86	7.8
Open - expt.	1.46	1.05	1.86	4.5
Closed (base)	3.7	1.29	1.99	0.83
Closed - expt.	3.7	2.04	1.99	1.2
2 mm pol. gap	3.9	1.30	1.99	0.76
Reduce source	0.26	0.085	0.124	0.71
Increase source	16.5	5.0	8.0	0.69

("Experimental" p_2 values computed from measured U_{12}, Q_1, and simulation p_1.)

Discussion

- Detailed 3-D simulations of gas transport possible,

- Compare axisymmetric & 3-D cases:
  - Imagine spreading 3-D source amongst 10 C-Mod bays,
  - Compute $U_{eff} = Q_1/(\overline{p_1} - p_2)$,
  - With $\overline{p_1} = 0.1 \sum_{i=1}^{10} p_{1,i}$, & $p_{1,i} = p_2 + (0.1 Q_1)/U_{12,i}$,
  - $\Rightarrow U_{eff} = 20/(U_c^{-1} + U_o^{-1}) = 15$ sim. (19 expt.) m^3/s.
  - $\Rightarrow$ axisymmetric conductance too high,
  - At least partly explains too-low pressures seen previously.

- Simulated “open” & “closed” conductances in comparatively better agreement with measurements.

- Consider remaining differences,

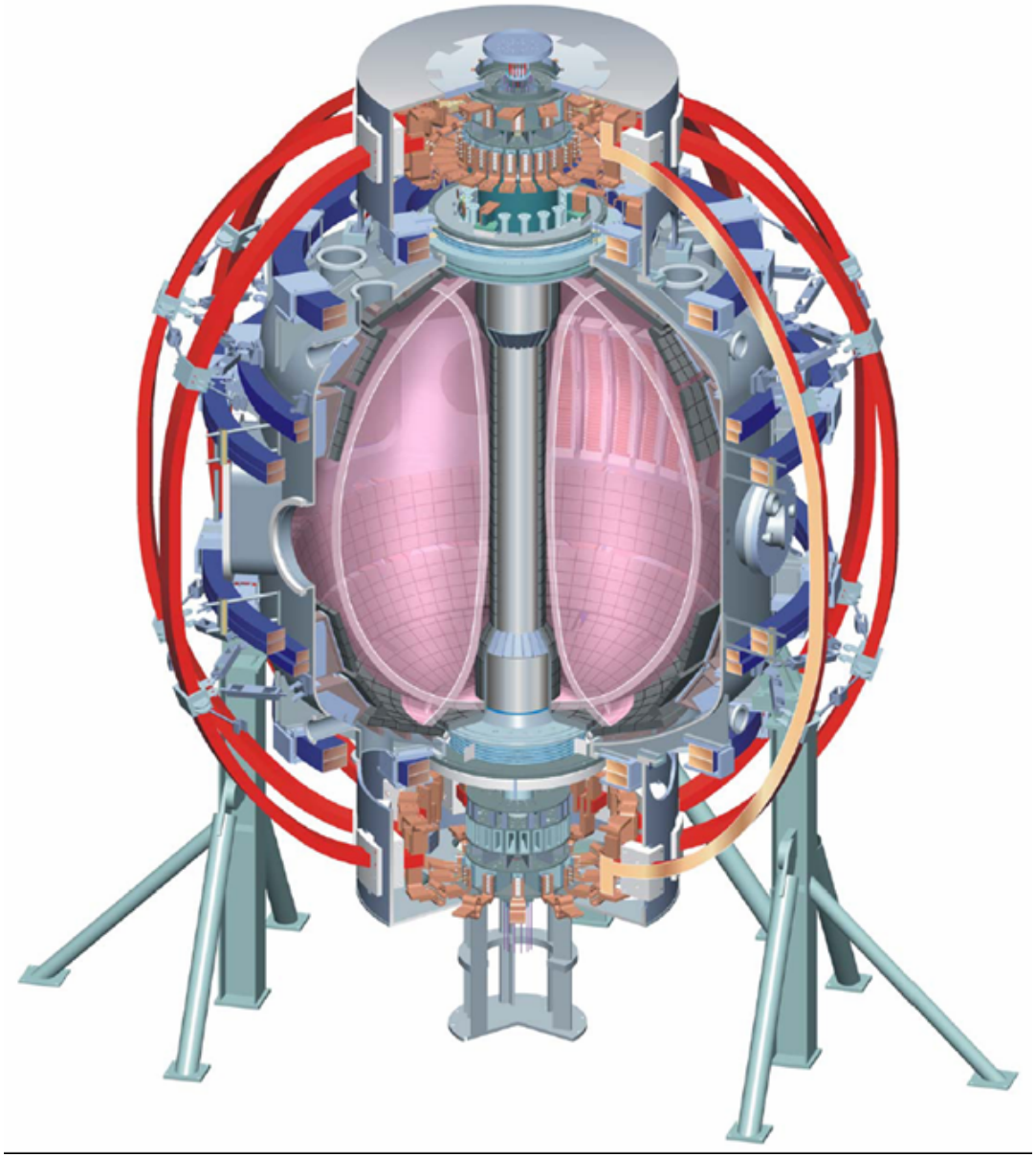
  - One too high, one too low $\Rightarrow$ still missing important details in geometry & experimental arrangement?

  - Pipe flow results suggest examining spatial resolution in gaps.

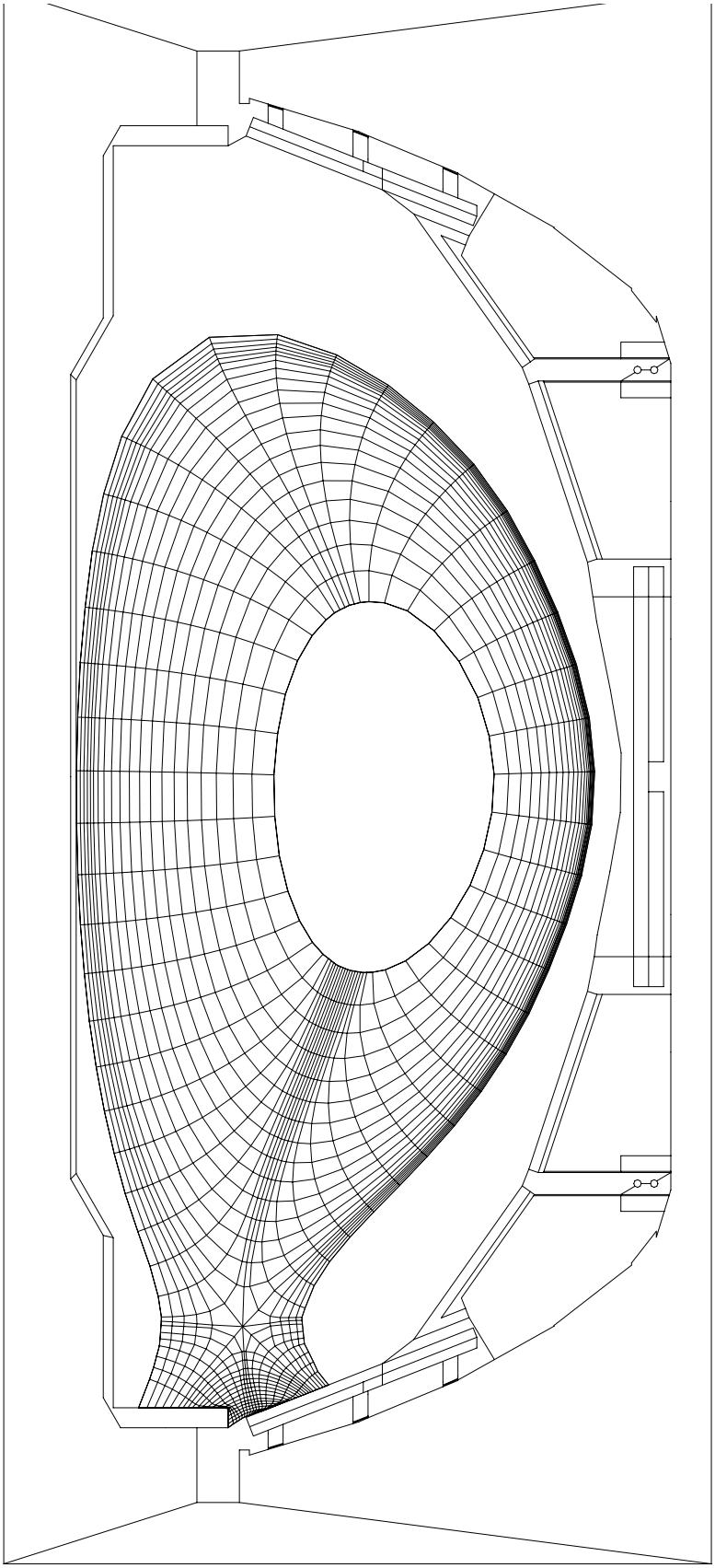
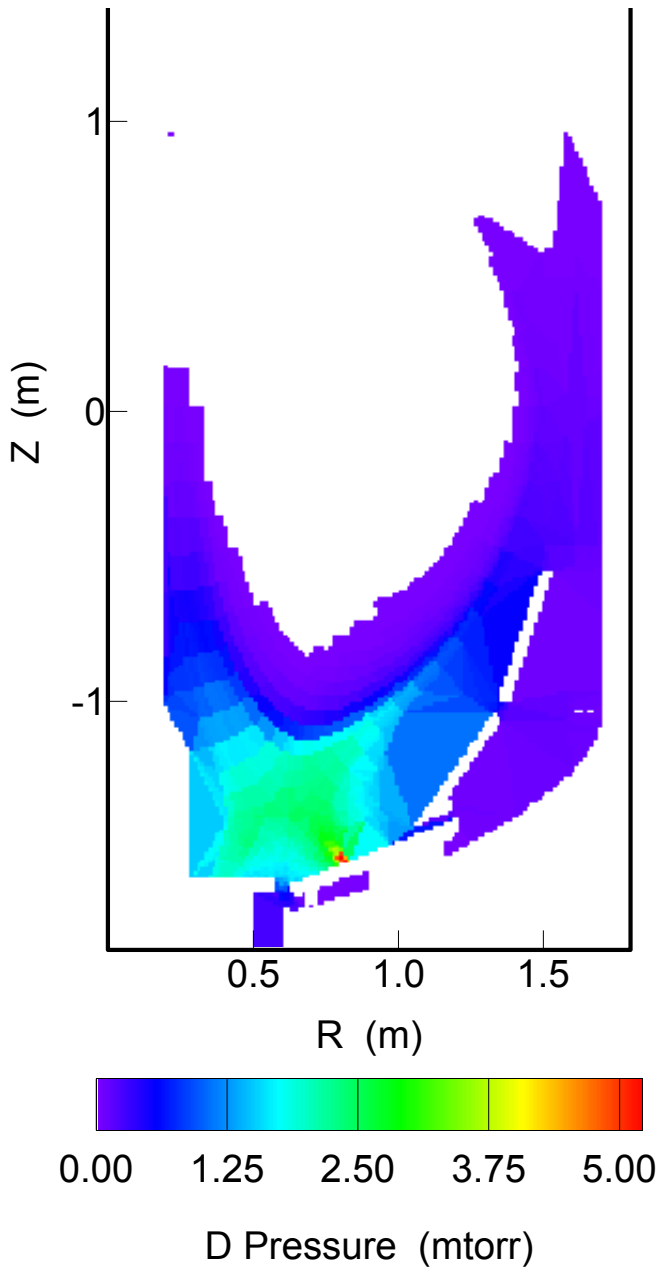
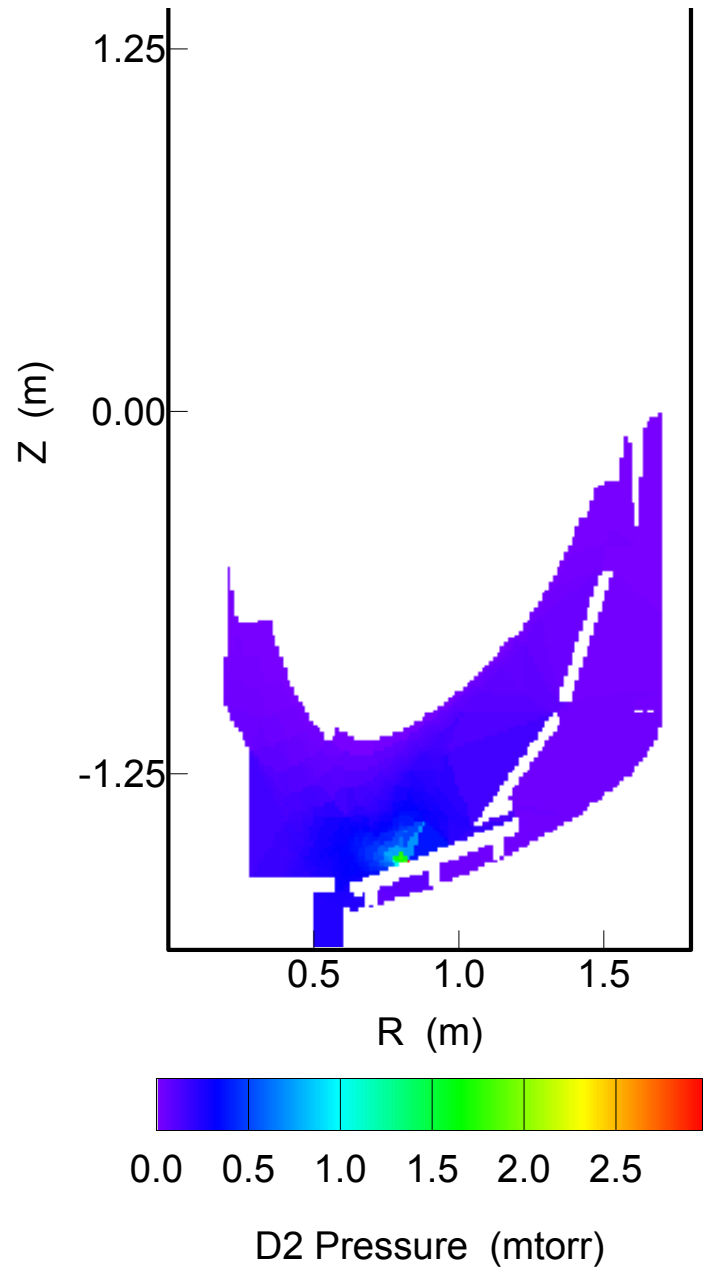
NSTX Simulations

- Neutral pressures surprisingly insensitive to plasma density,
- Begin examining 3-D gas conductance pathways in search of explanations.
- This work will feed into cryopump design effort.
- Have laid out on paper approximate 3-D component configuration,
  - Need more suitable engineering drawings!
- Have done initial axisymmetric simulation,
- Currently building 3-D DEGAS 2 geometry.

NSTX Vacuum Vessel
Full of 3-D Gas Pathways



DG File for DEGAS 2 Simulation of NSTX



Neutral Pressures in Axisymmetric NSTX Simulation