Thermal-Hydraulic Studies in Support of the ARIES-CS Divertor Design

S. I. Abdel-Khalik, L. Crosatti, D. L. Sadowski,
J. B. Weathers, M. Yoda, and the ARIES Team

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Georgia Institute of Technology
The George W. Woodruff School of Mechanical Engineering
Atlanta, GA 30332–0405 USA

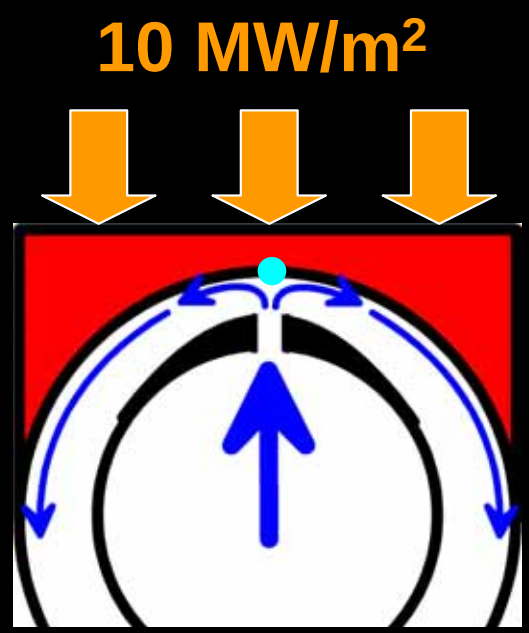
OUTLINE

- Introduction/Overview
  - The ARIES T-Tube Divertor Design
- Numerical Study
- Experimental Apparatus & Procedures
- Results
  - Comparison Between Experimental Data and Numerical Results
- Summary/Conclusions

Introduction/Overview

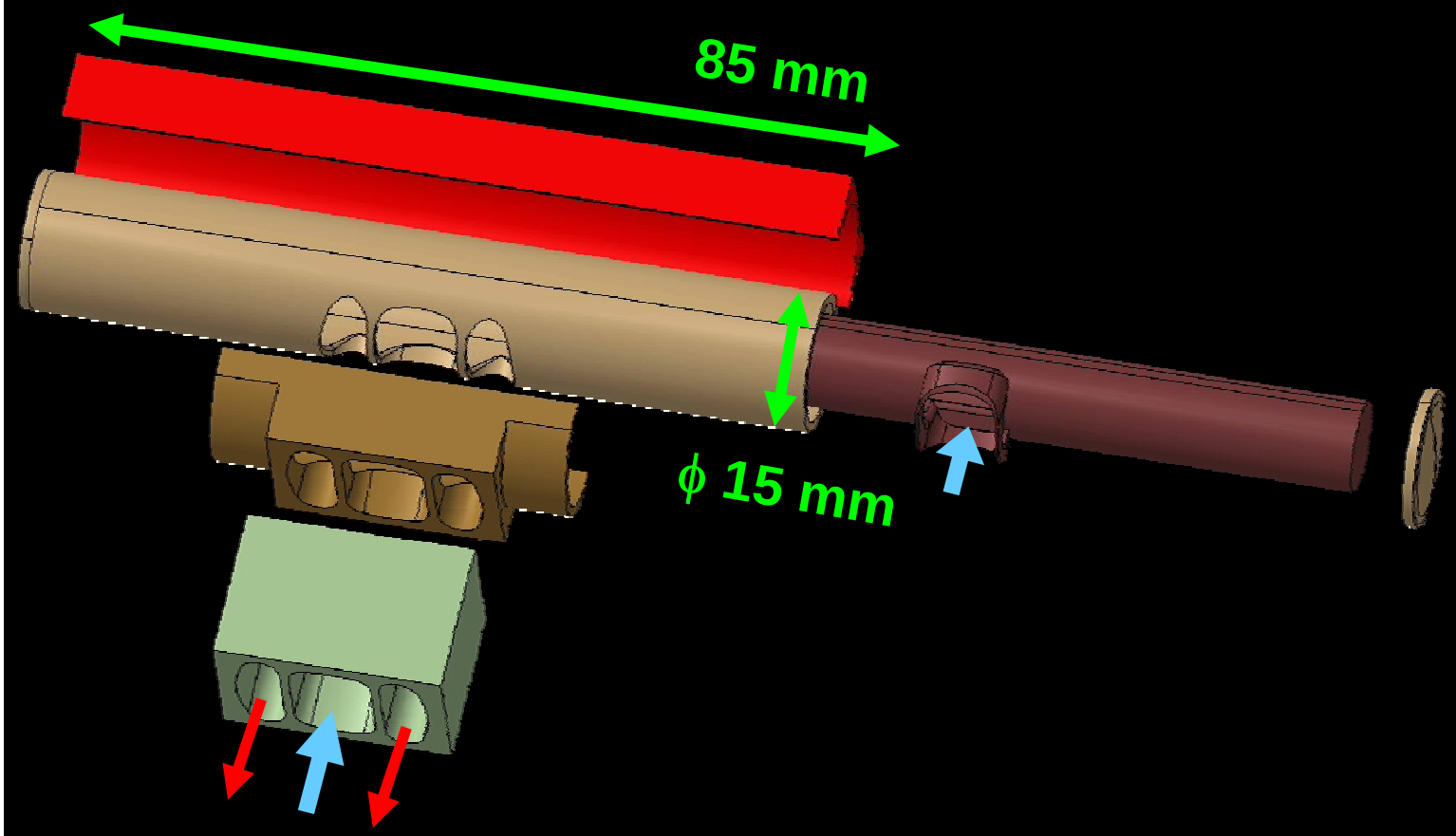
As part of ARIES-CS, 2D and 3D analyses were performed to assess the thermal performance of He-cooled T-tube divertors

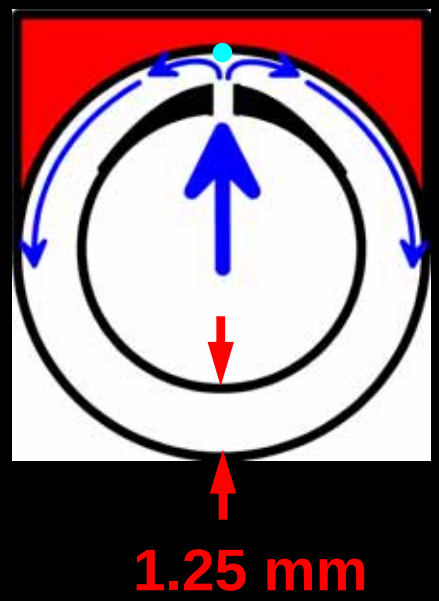
- **Heat fluxes up to 10 MW/m^2**
- **Design 'robust' with respect to manufacturing tolerances, variations in flow distribution**
- **Heat transfer coefficients above 40 kW/(m^2·K) predicted near *stagnation point***



It was deemed necessary to experimentally validate the numerical results especially these extremely high heat transfer coefficients

ARIES T-Tube Divertor





- Helium Pressure = 10 MPa
- Inlet Temperature = 600 ° C
- Exit Temperature = 680 ° C
- Flow Rate/Length = 0.4 kg/(s-m)

- $>10^4$ modules total

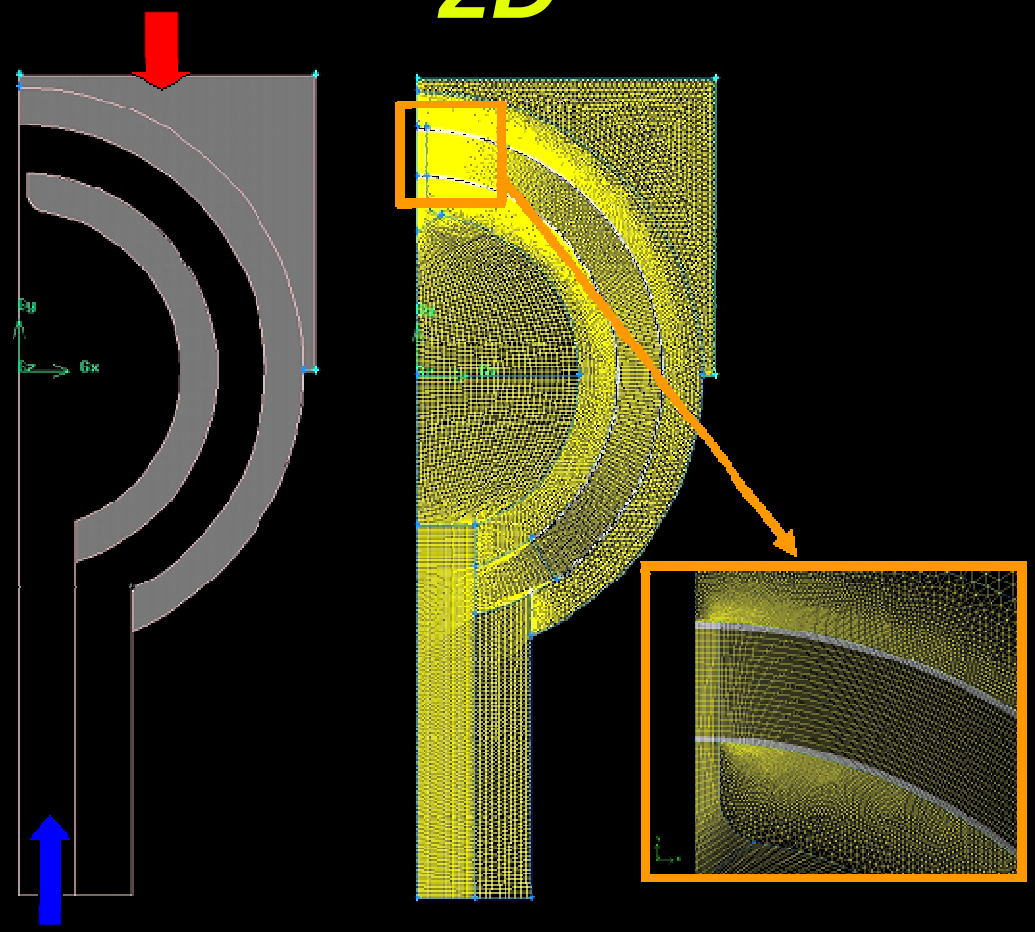
Courtesy T. Ihli and R. Raffray

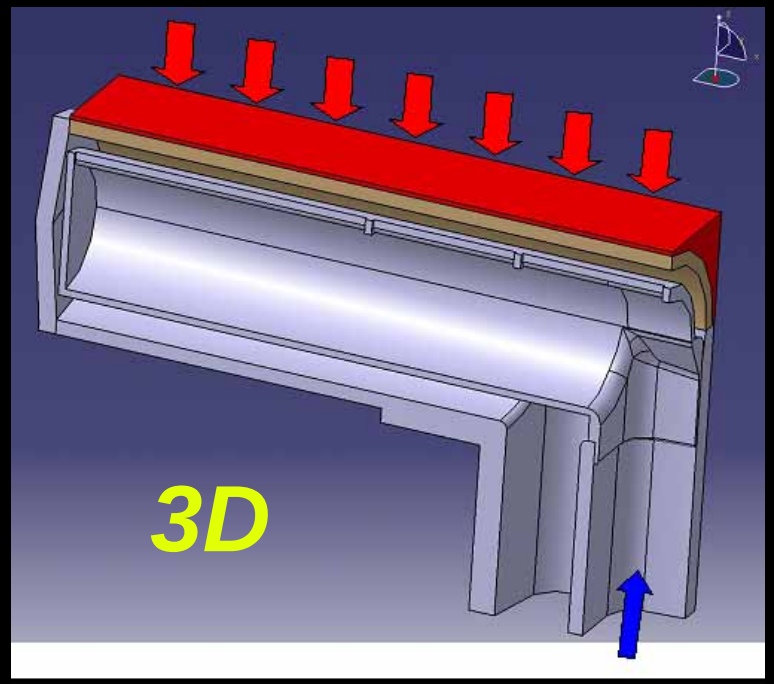
Numerical Study: Objectives

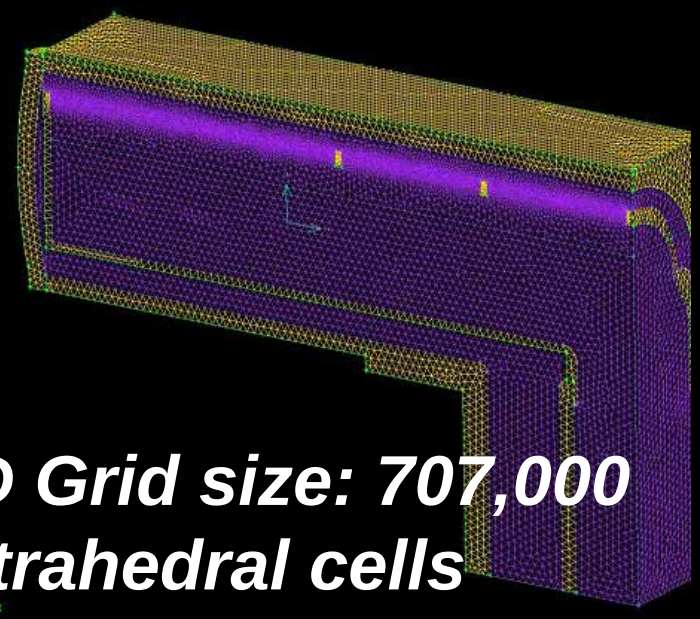
- **Evaluate the thermal performance of the T-Tube, helium-cooled, divertor design at the nominal design and operating conditions**
- **Conduct parametric studies to assess the sensitivity of thermal performance to changes in geometry and operating conditions (due to manufacturing tolerances and/or flow mal-distribution between modules)**

T-Tube CFD Models

2D







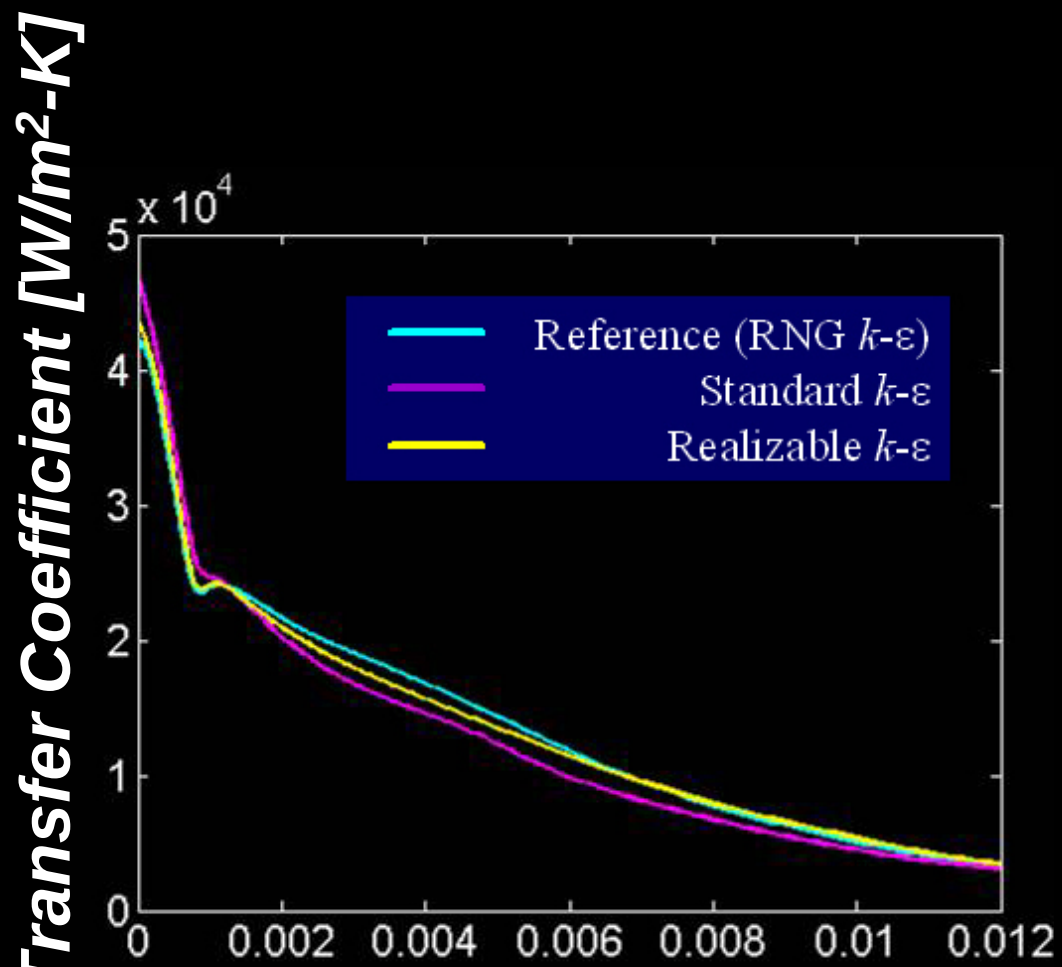
2D Grid size: 35,600 cell elements

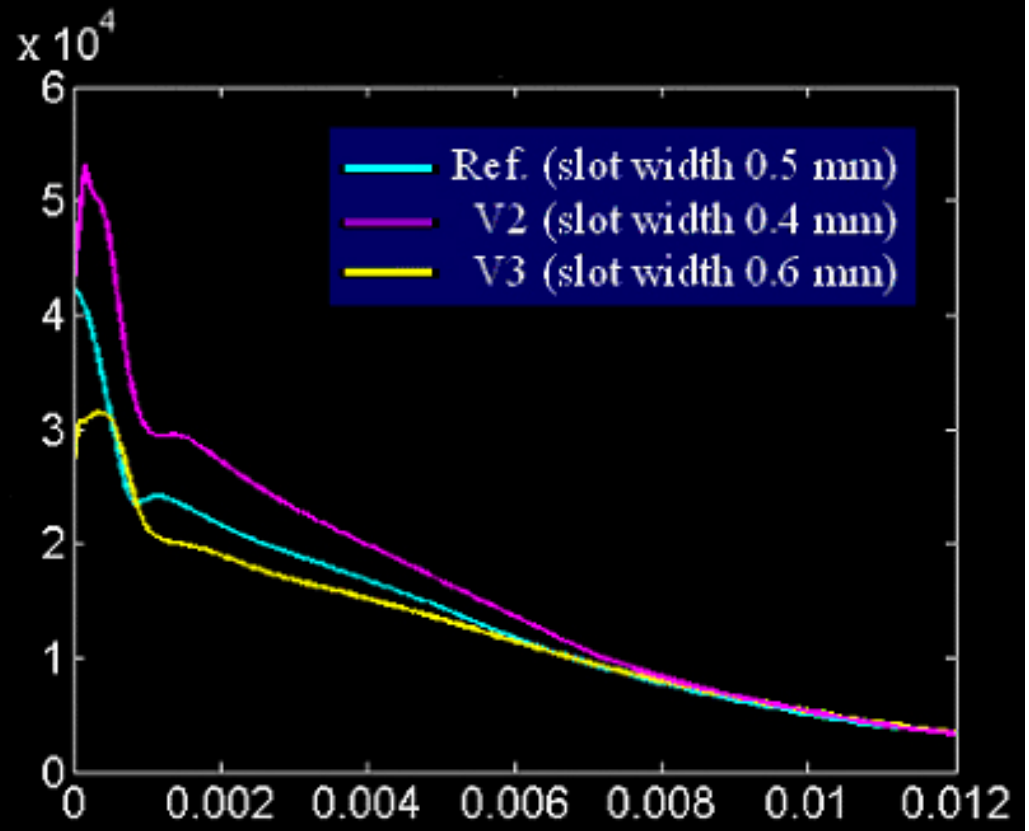
3D Grid size: 707,000 tetrahedral cells

3D Studies – Effect of Parameters

PARAMETER	Max Tile T [K]	Max T [K] Tube/Tile Interface	ΔP [Pa]
3D Ref. (m = 0.4 kg/(s·m); P_{out} = 10 MPa; slot width = 0.5mm; annular gap = 1.25mm)	1699	1523	1.06×10^5
Mass flow rate = 3.3/4.7 kg/(s·m)	1782/1646	1607/1466	$0.76/1.55\times10^5$
P_{out} = 9/11 MPa	1701/1719	1523/1543	$1.07/1.07\times10^5$
Slot width = 0.4/0.6 mm	1621/1720	1452/1545	$1.67/0.86\times10^5$
Annular Gap Thickness = 1.0/1.5 mm	1728/1716	1557/1545	$0.89/0.90\times10^5$

Heat Transfer Coefficient (2D)





Heat Transfer Coefficient [W/m²-K]

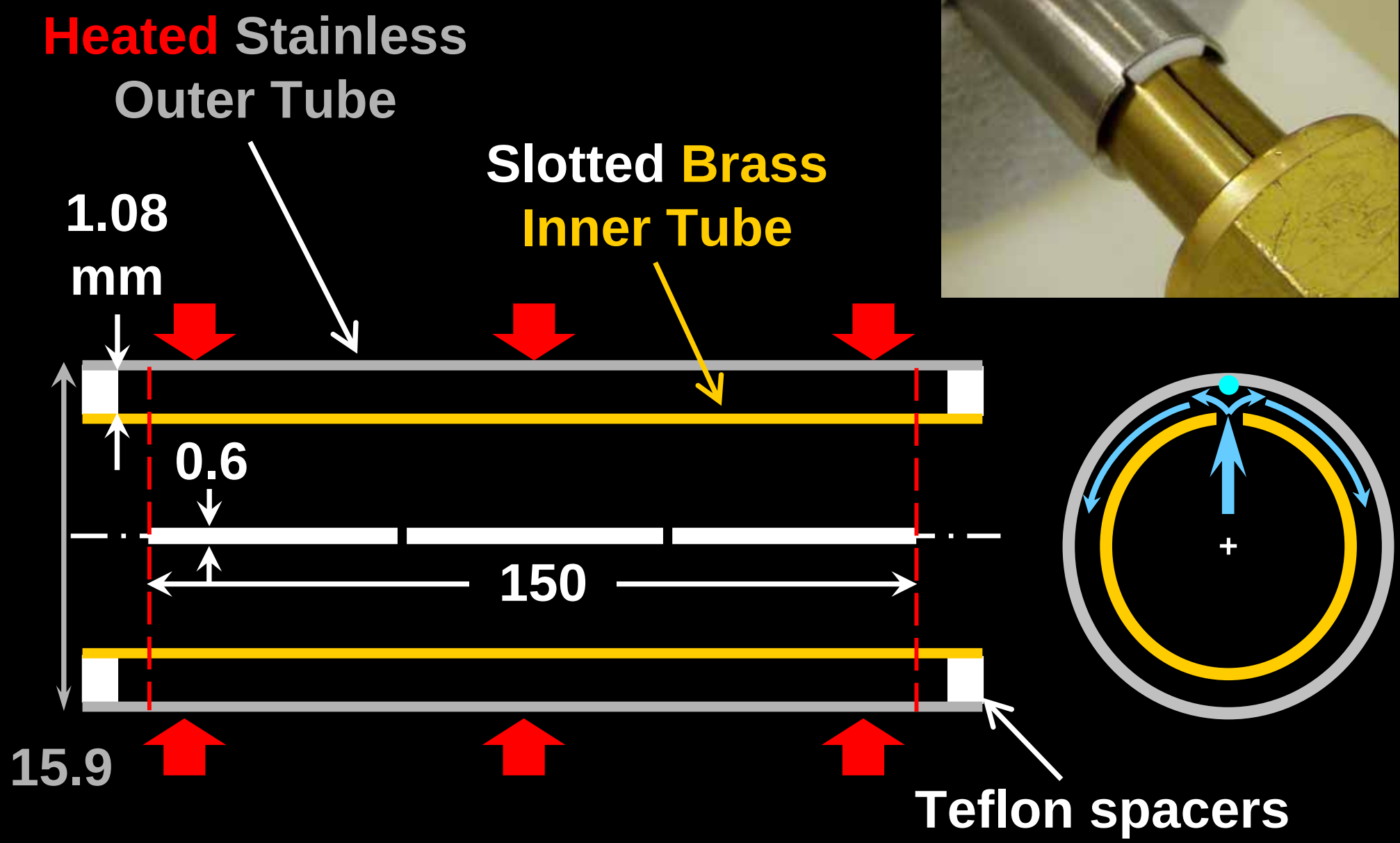
Curved length [m]

Experimental Study: Objectives

Experimentally validate numerical (FLUENT) models and use such models to evaluate/design high heat flux plasma-facing components in MFE applications

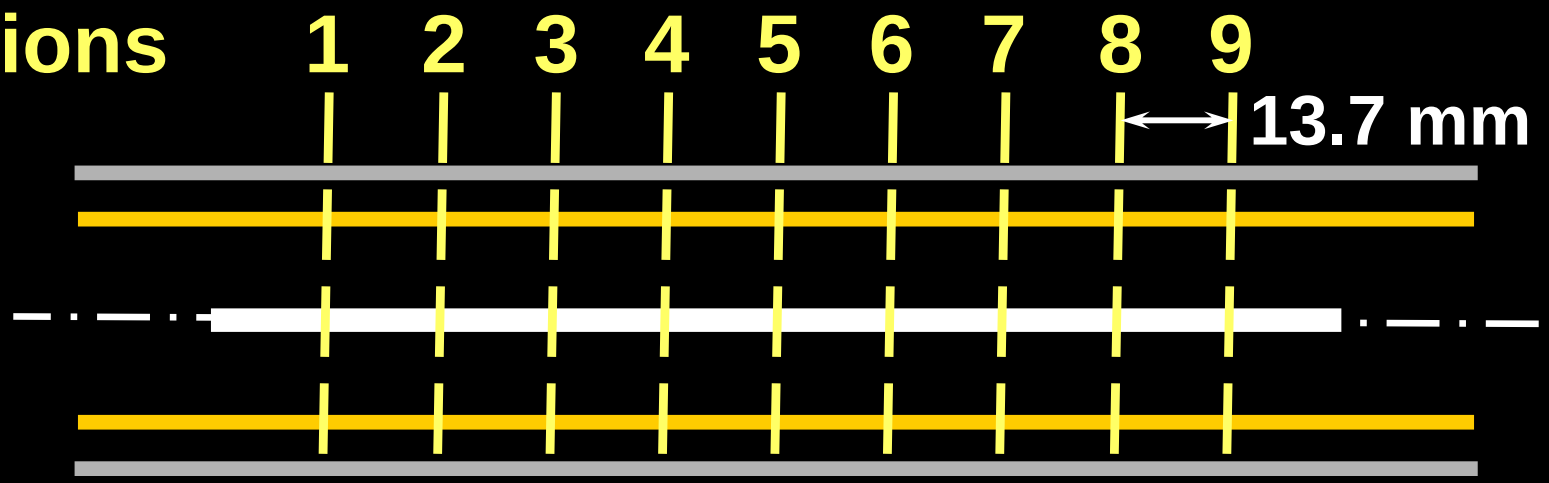
- Experimentally measure axial and azimuthal temperature profiles in a test module modeling the helium-cooled T-Tube divertor under typical operating conditions
- Use FLUENT to compute wall temperature profiles and heat transfer coefficients for this test module
- Compare experimentally- and numerically-based heat transfer coefficients

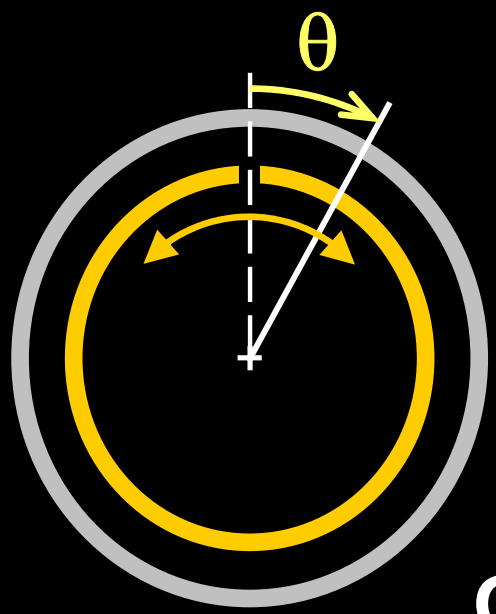
Test Section

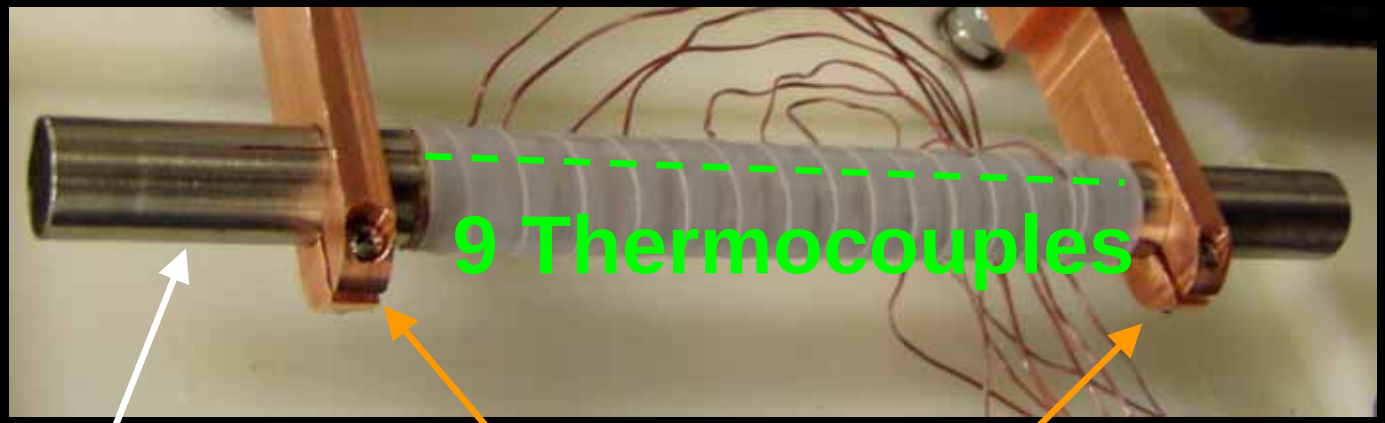


Temperature Measurements

TC Locations







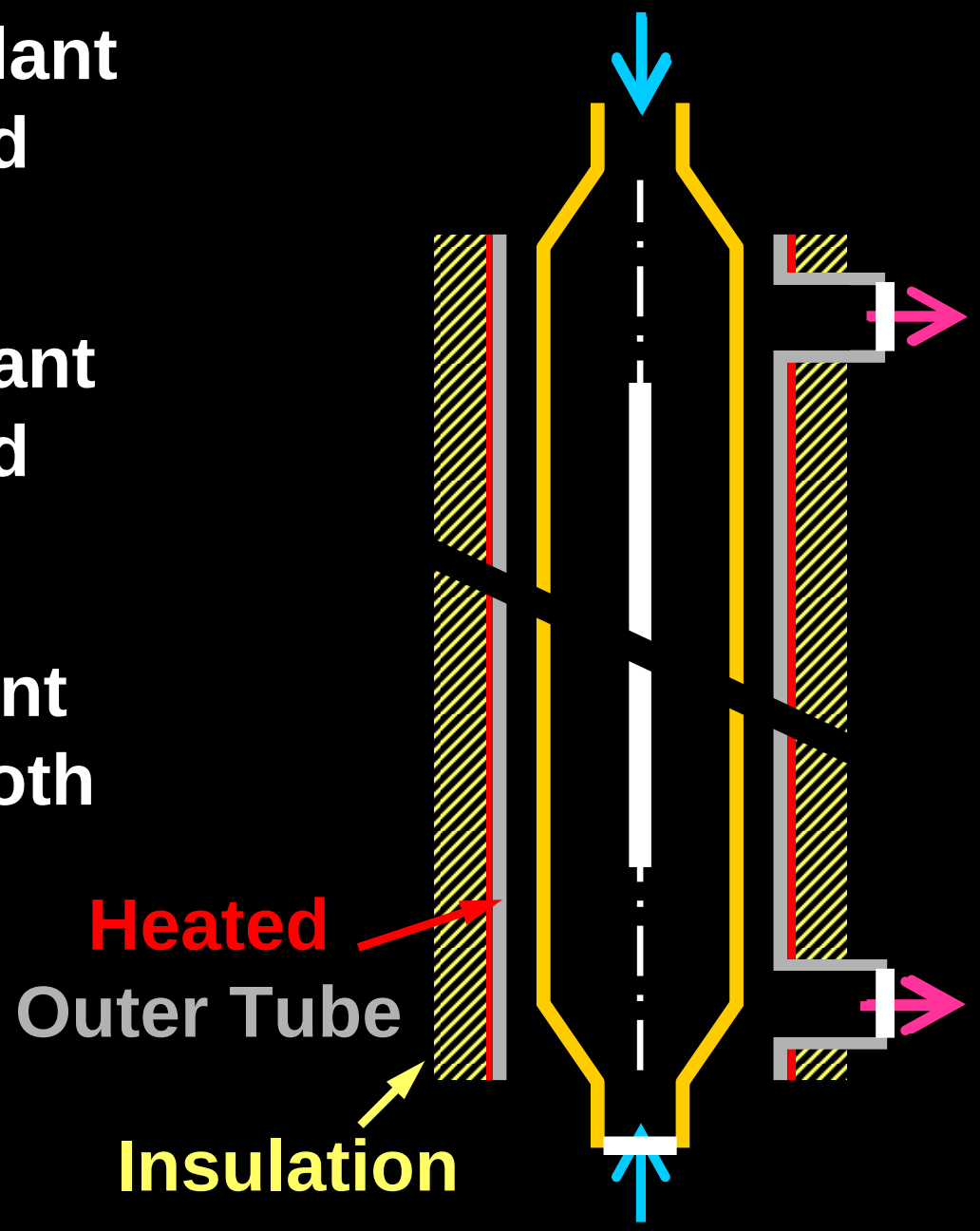
Thermal-Hydraulic Parameters

- Experimental non-dimensional parameters match those for He-cooled T-Tube divertor (double inlet)

Parameter	Air (low flow)	Air (med. flow)	Air (high flow)	Helium
Operating Pressure	100	300	600	10^4 kPa
Pressure Drop	3.7	30	200	100 kPa
Mass Flow Rate	27	100	180	400 g/(s·m)
Inlet Temp.	20	20	20	600 ° C
Re	2900	11000	20000	19000
Pr	0.71	0.71	0.71	0.66

Flow Loop

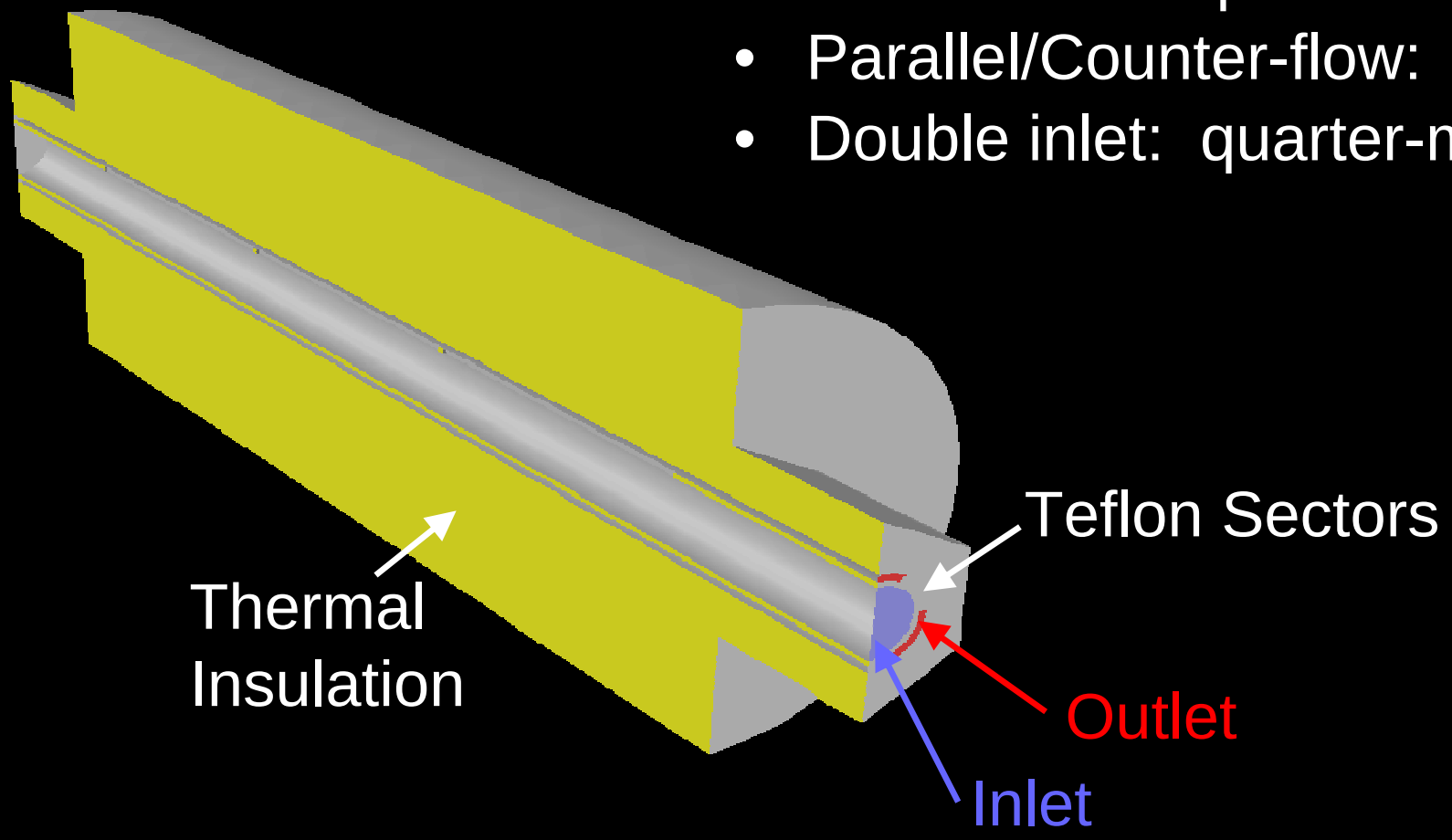
- ***Counter Flow*:** **Coolant enters at one end and exits at same end**
- ***Parallel Flow*:** **Coolant enters at one end and exits at opposite end**
- ***Double Inlet*:** **Coolant enters and exits at both ends**



CFD Model

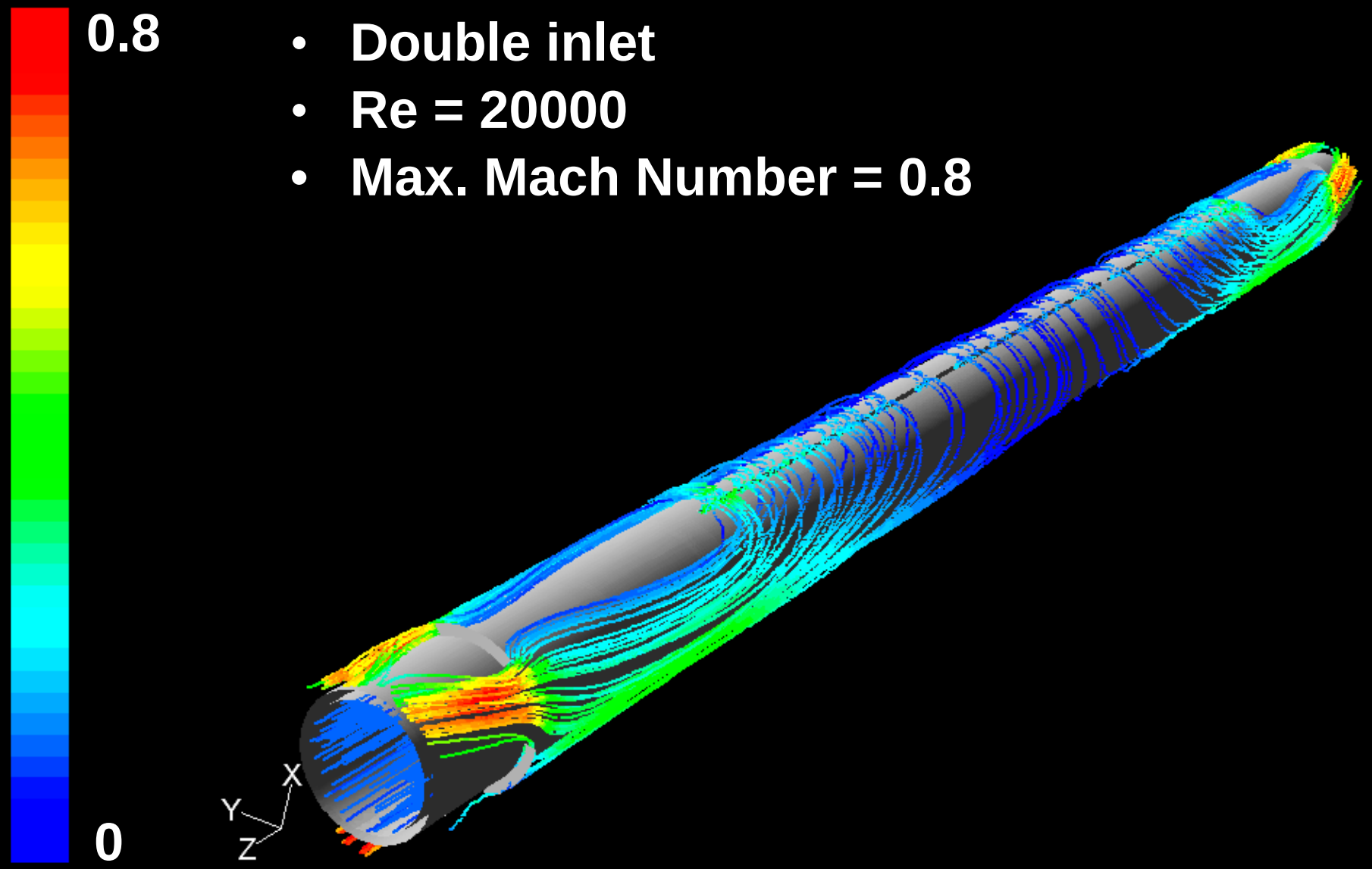
- *FLUENT*®, steady-state, two-point closure turbulence model (Standard or RNG k-ε)
  - Grid size: up to 10^6 cells
- Parallel/Counter-flow: half-model
- Double inlet: quarter-model

Half-model for counter-flow case



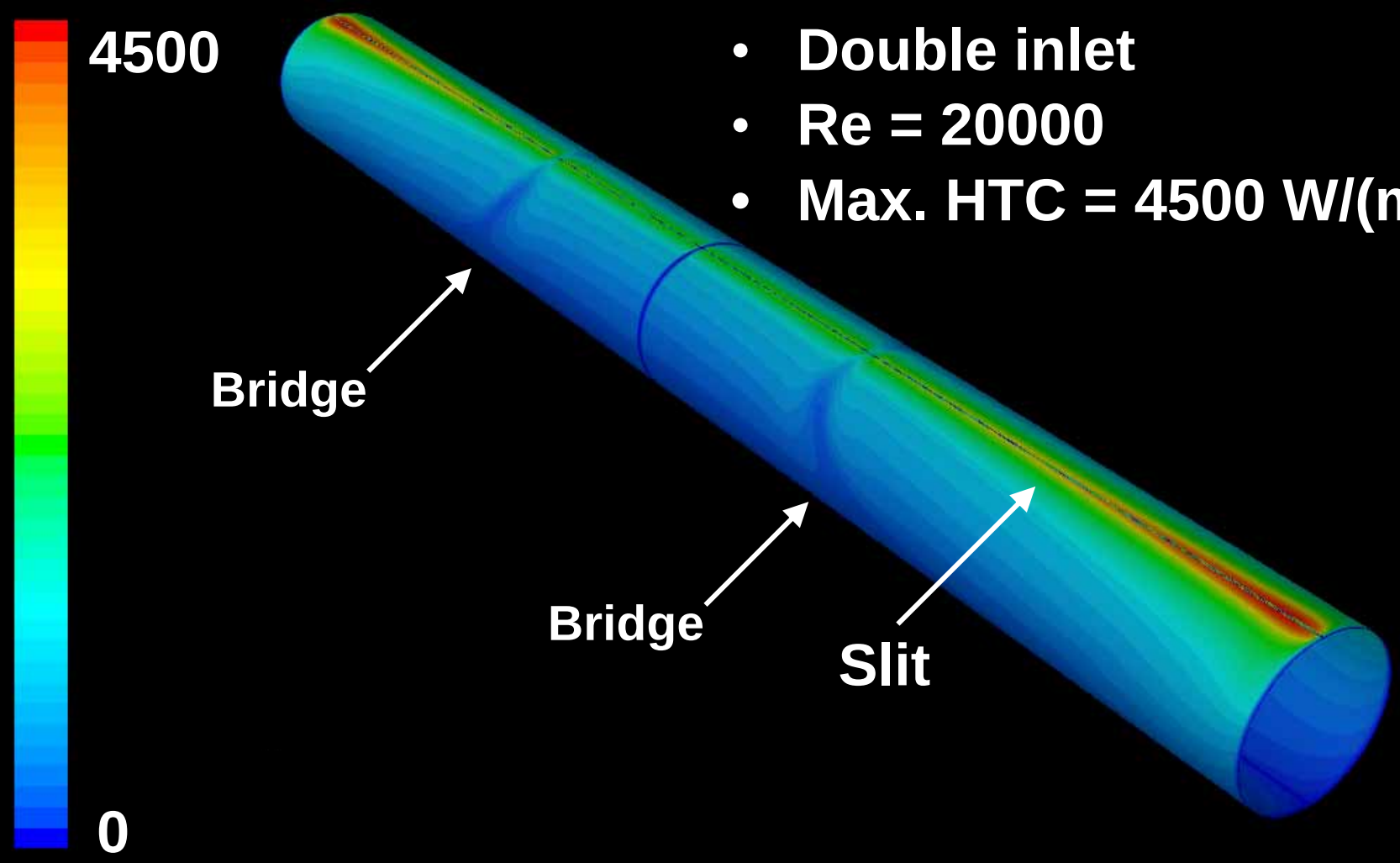
CFD Path Lines Results

- Double inlet
- Re = 20000
- Max. Mach Number = 0.8



Path Lines colored by Mach Number [-]

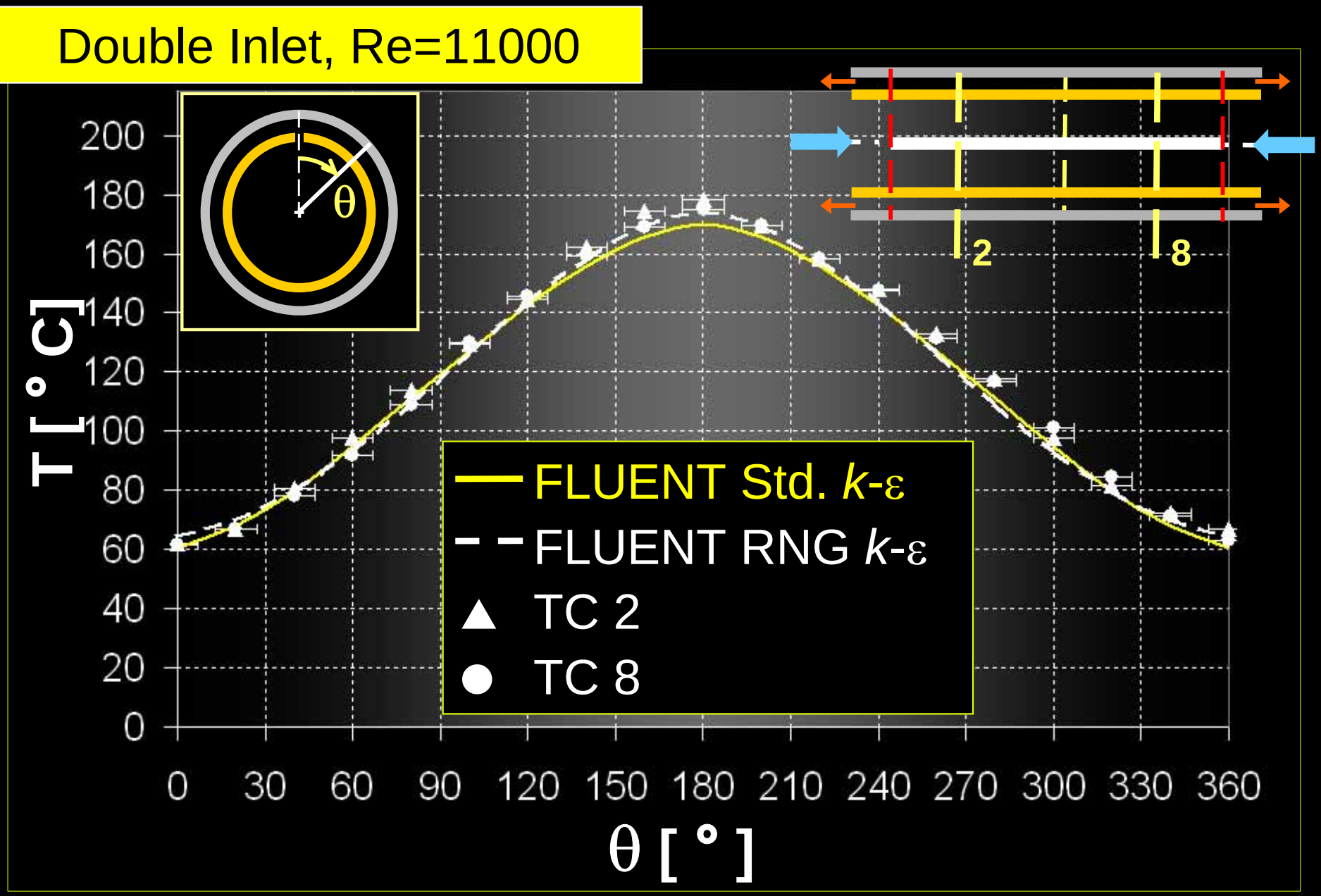
CFD HTC Results



- Double inlet
- Re = 20000
- Max. HTC = 4500 W/(m^2·K)

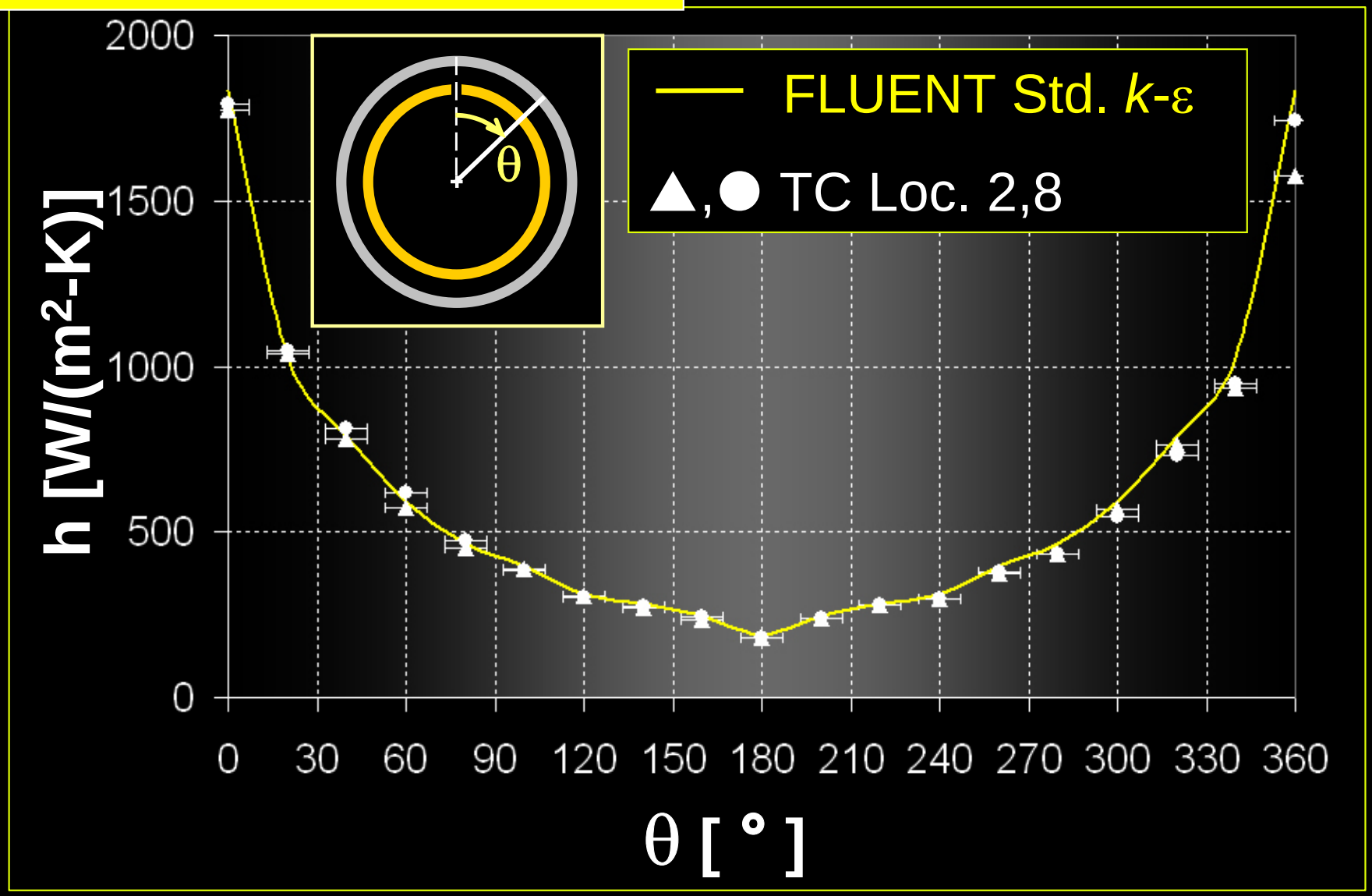
Surface Heat Transfer Coefficient [W/(m^2·K)]

Azimuthal Temperature



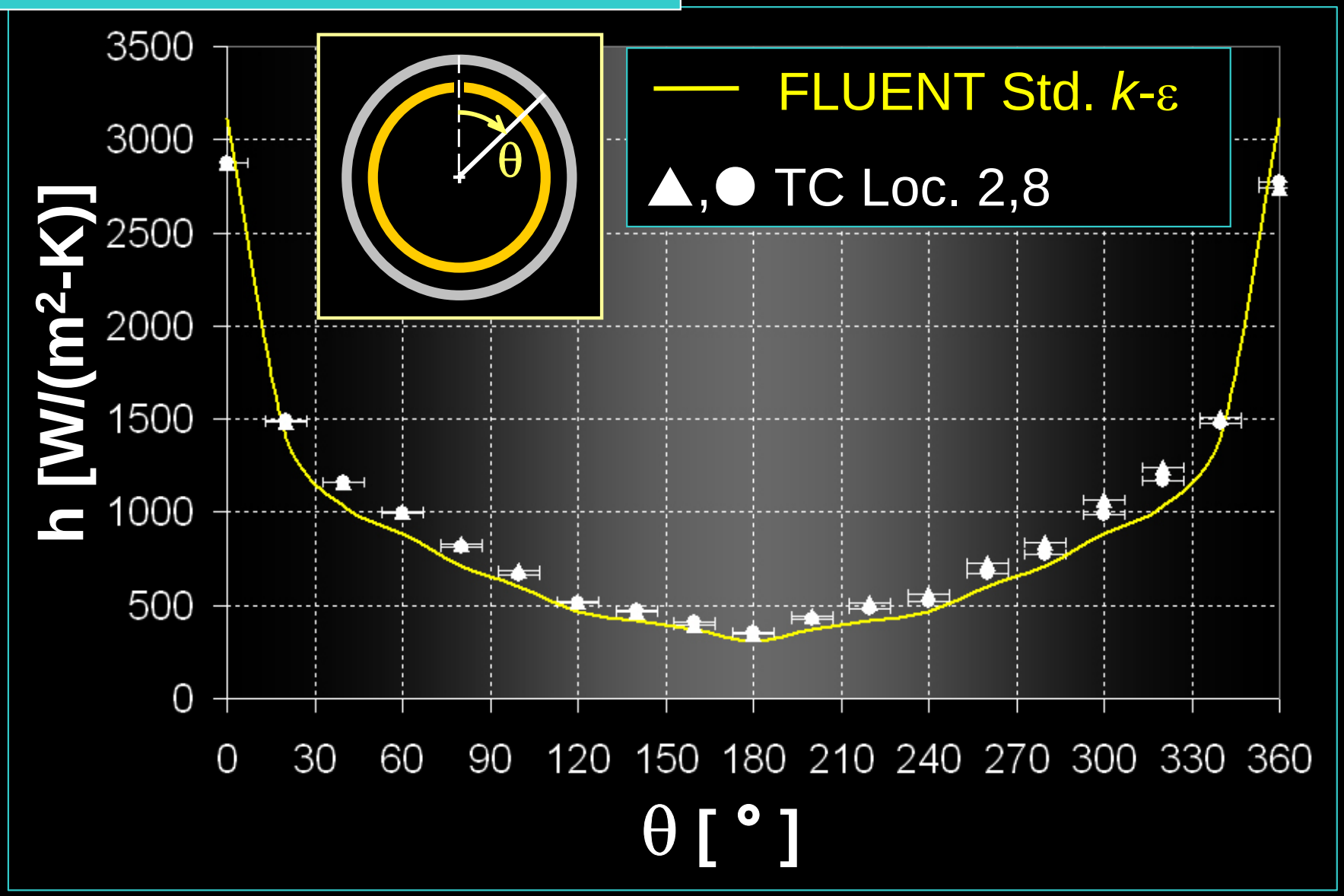
Azimuthal HTC

Double Inlet, Re=11000



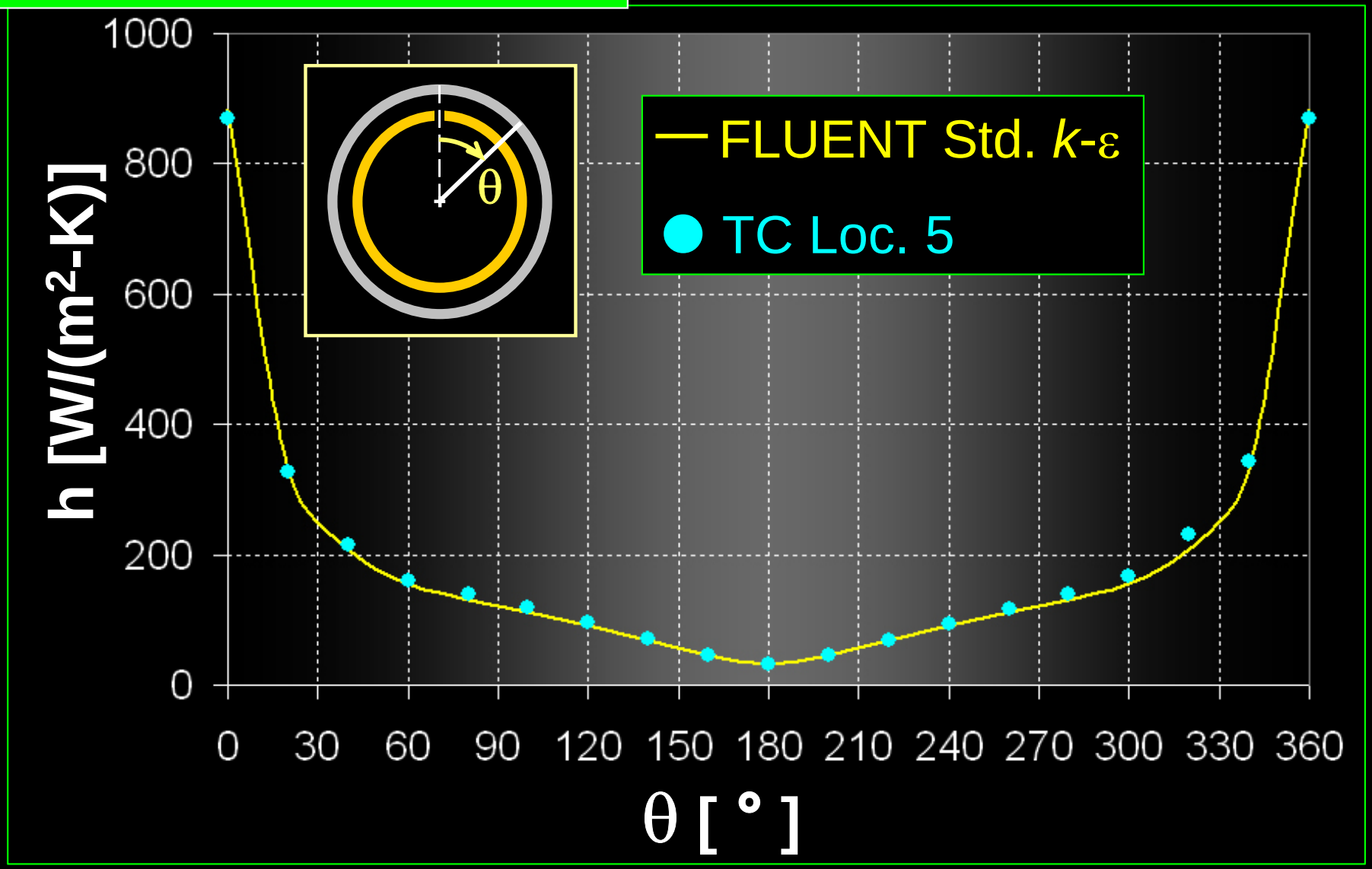
Azimuthal HTC

Double Inlet, Re=20000

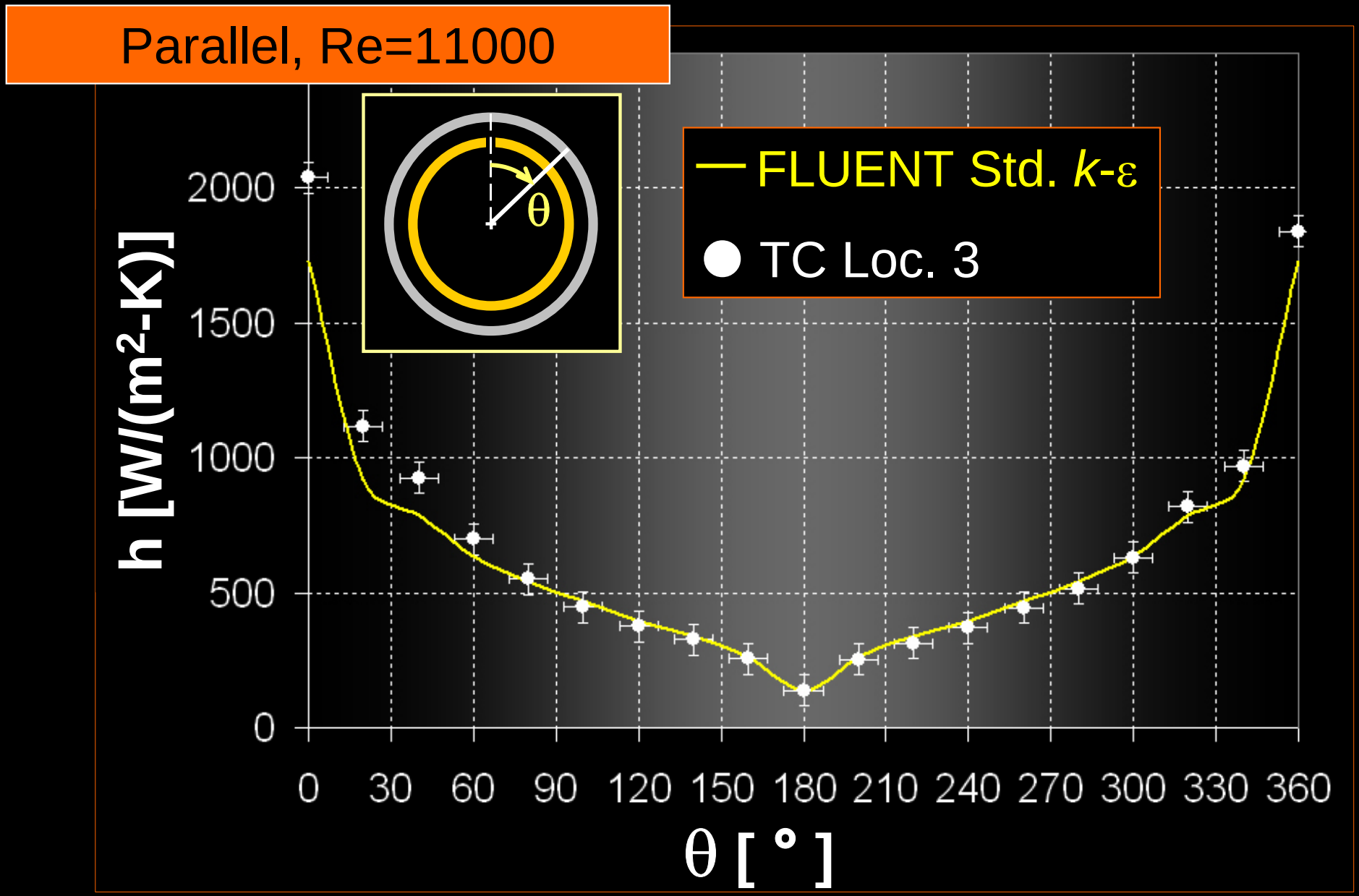


Azimuthal HTC

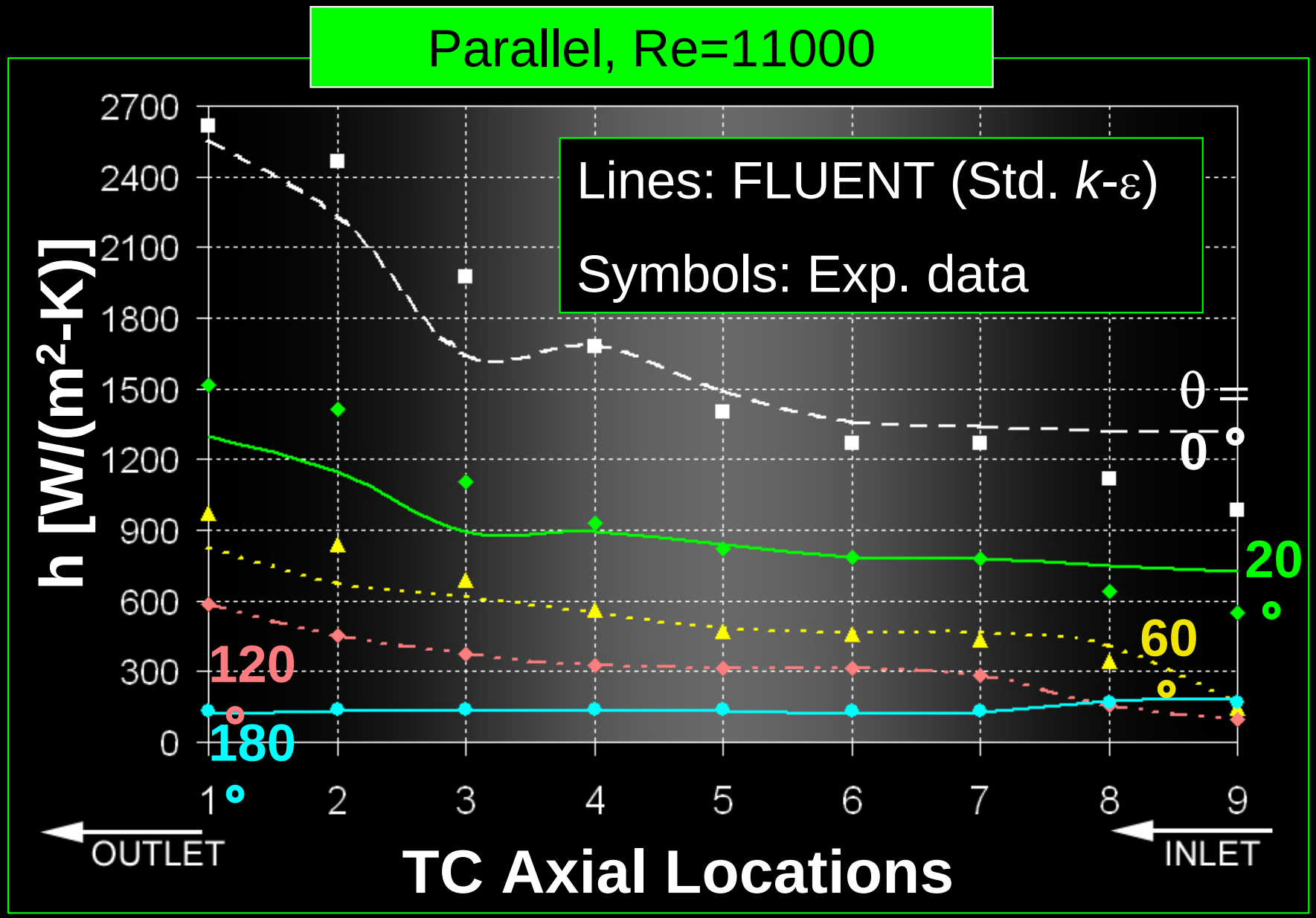
Counter, Re=2900



Azimuthal HTC



Axial HTC


Parallel, Re=11000
Lines: FLUENT (Std. k-ε)
Symbols: Exp. data
h [W/(m²-K)]
2700
2400
2100
1800
1500
1200
900
600
300
0
θ = 0°
20°
60°
120°
180°
1
2
3
4
5
6
7
8
9
OUTLET
INLET
TC Axial Locations

Summary

- Axial and azimuthal temperature profiles measured in an experimental model of the T-tube divertor proposed for ARIES-CS over a wide range of operating conditions
- CFD used to predict surface temperature profiles and local heat transfer coefficients
- Experimental data and CFD predictions in good agreement for all flow configurations and operating conditions

→Validated *FLUENT*® models can be confidently used to guide design of T-tube and similar gas-cooled high heat flux components