# *Bridging the Gap between Fundamental Physics and Chemistry and Applied Models for HCCI Engines*

W.E. Lay Automotive Laboratory

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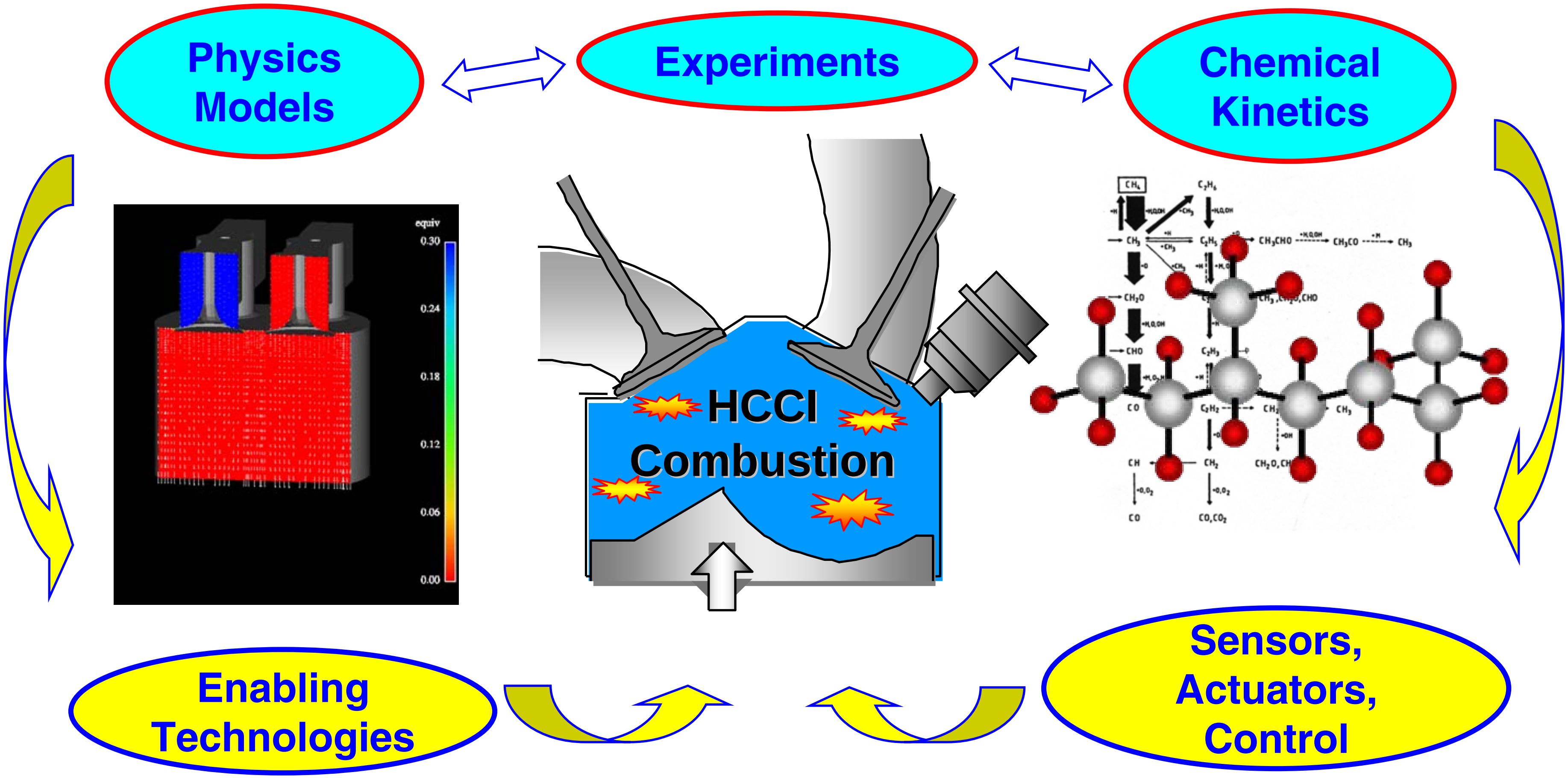
DEER Conference
August 20-25, 2005
Chicago, IL

# HCCI Engine Grand Challenges



# A University Consortium on Homogeneous Charge Compression Ignition Engine Research - Gasoline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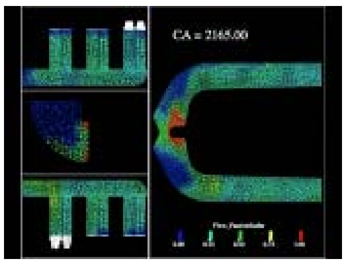
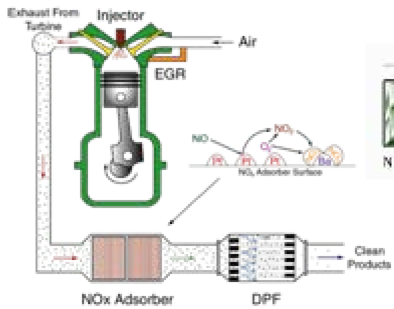
# Acknowledgements

GM Collaborative Research Laboratories Engine Systems Research

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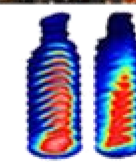
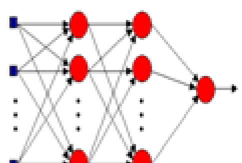


Research Ford Motor Company

Sandia



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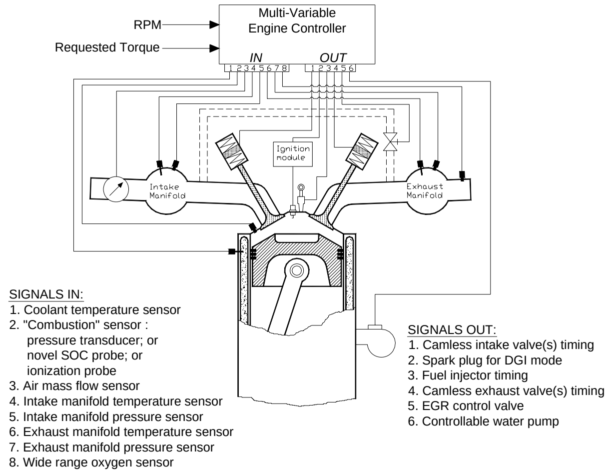
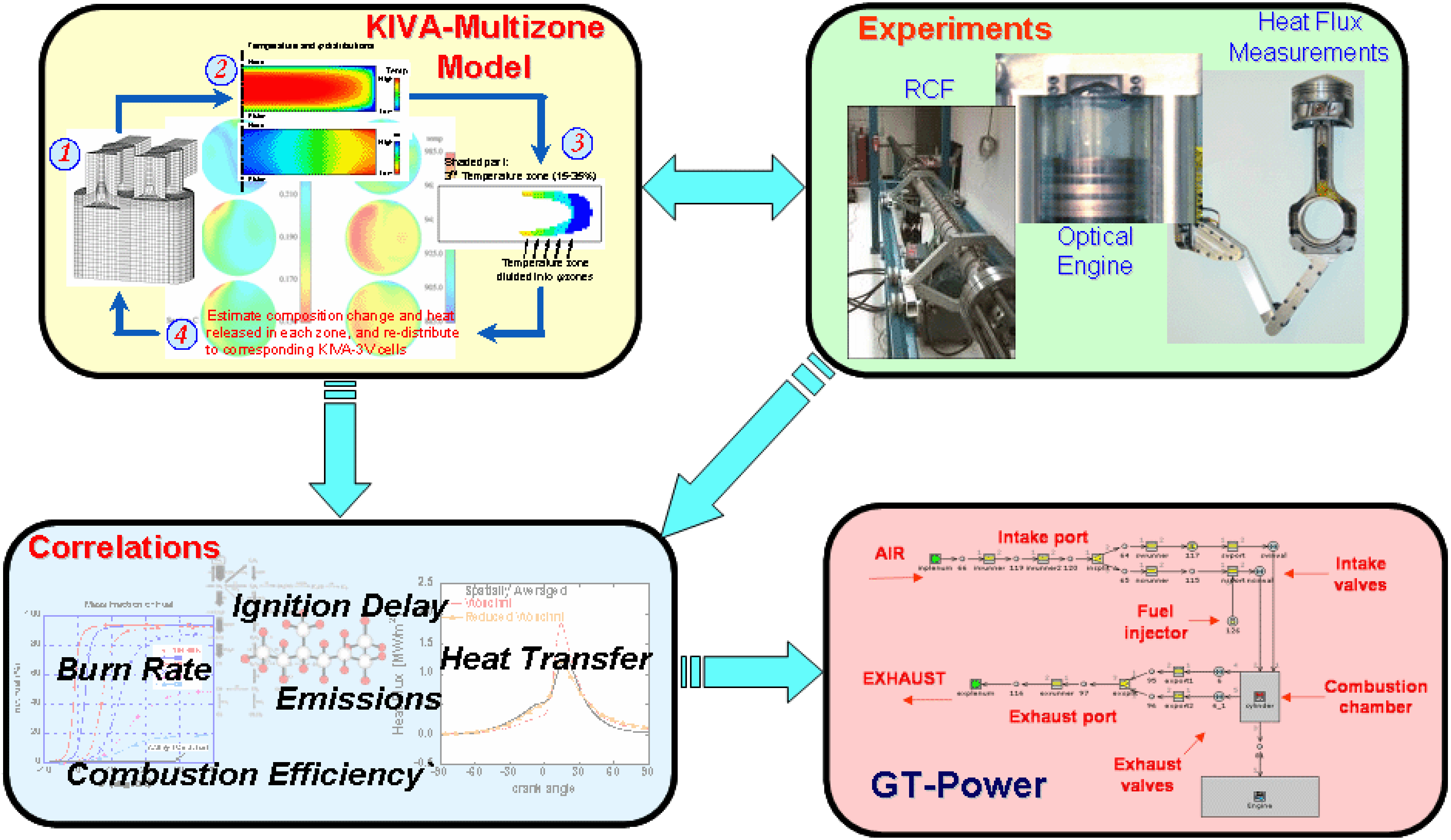
# Objectives

- Bridge the gap between fundamental HCCI physics and chemistry considerations and applied models
  - Balance model fidelity with computational expediency and ultimate goal in mind
- Demonstrate a cascade sequence where high fidelity models and experiments feed phenomenogical models appropriate for systems analysis
- Apply system models to assess candidate control schemes



# Approach



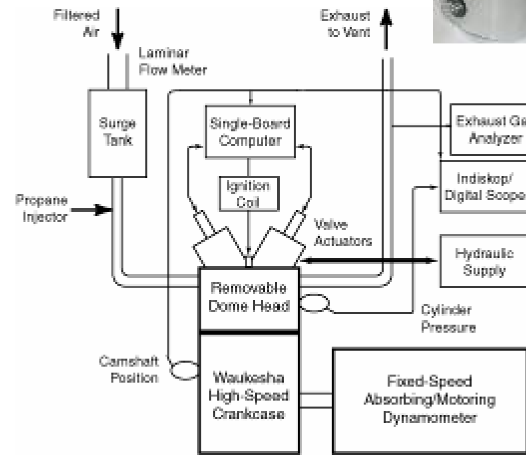

Bridging the Gap Between HCCI Fundamentals and Applied Models

# Engine University Consortium Set-Ups

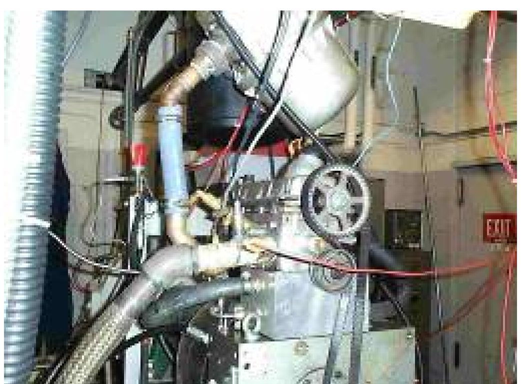
UM Optical Engines

UM Heat Transfer Engine

Stanford Camless




MIT VW Engine with VVT

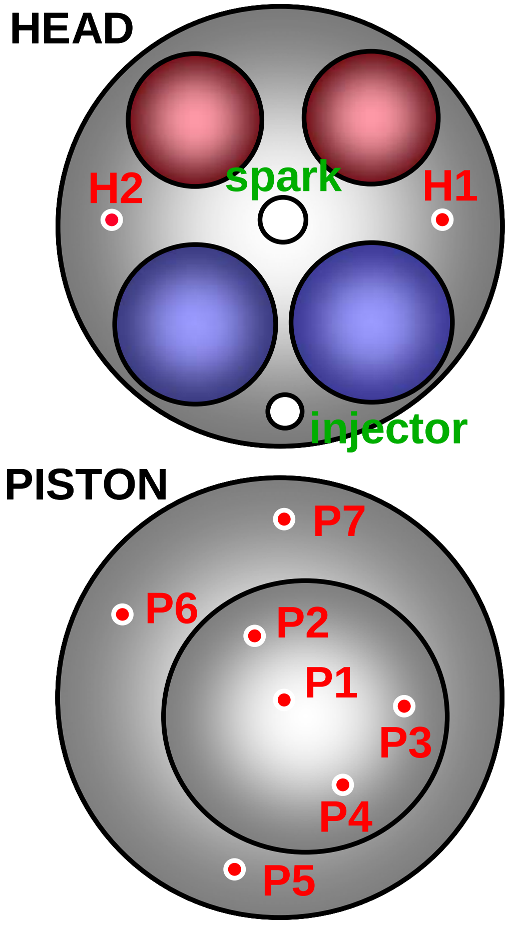



UCB VW TDI engine

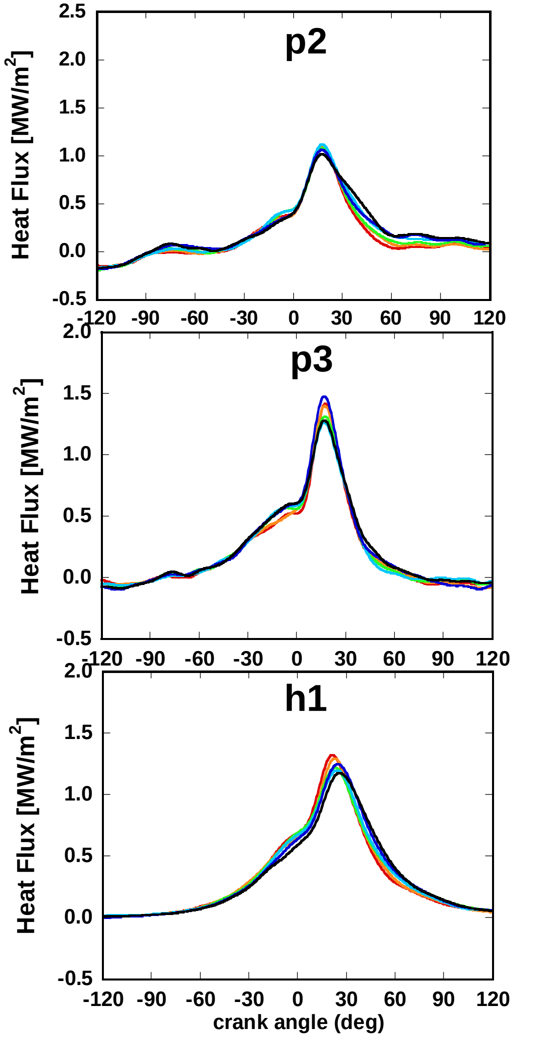
UCB CAT Single Cylinder

# Local Heat Fluxes



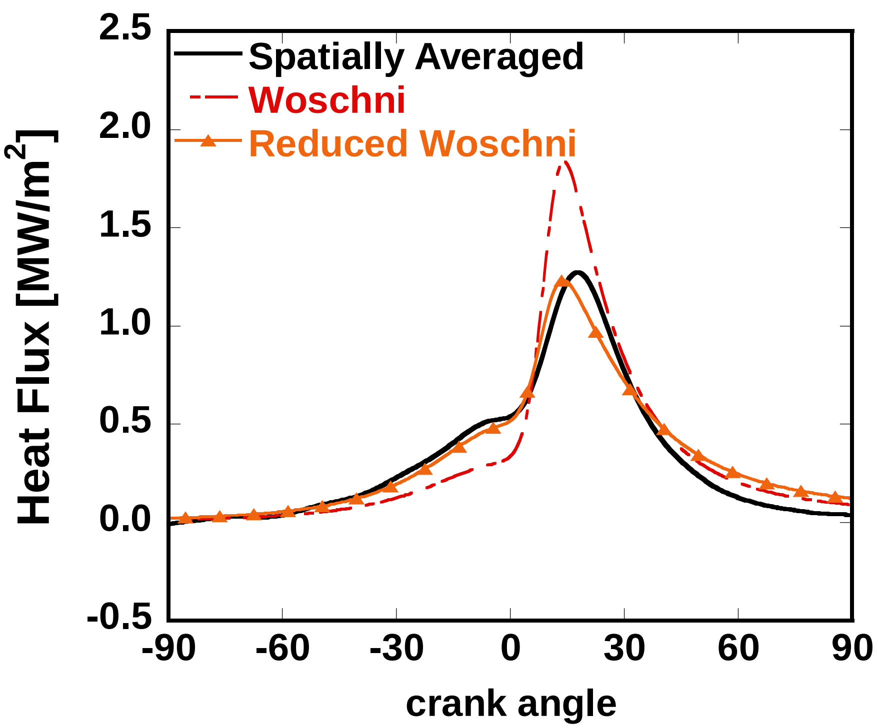






# Concept of Modified Woschni Correlation

Models need to be calibrated to provide accurate total heat loss




- Classic Woschni underpredicts heat transfer during compression and leads to unrealistic ignition predictions
- Modified Woschni heat transfer model:
  - Original: $A_2 = 1$
  - Modified: $A_2 = 1/6$

$$h = \chi_{\text{Woschni}} \; 3.26 \cdot B^{-0.2} \cdot p^{0.8} \cdot T^{-0.53} \cdot w^{0.8}$$

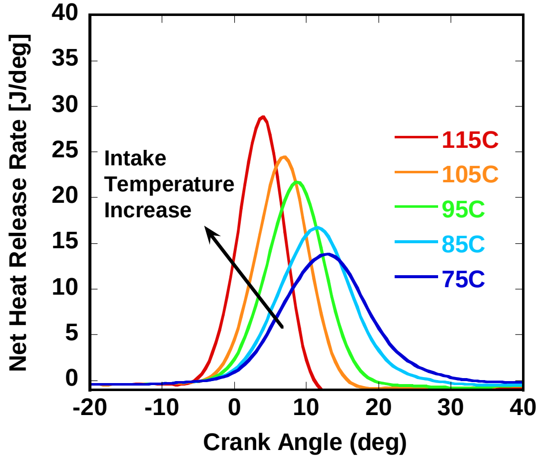
$$w = A_1 C_1 \bar{S}_p + A_2 C_2 \frac{V_d T_r}{p_r V_r} (P - P_m)$$

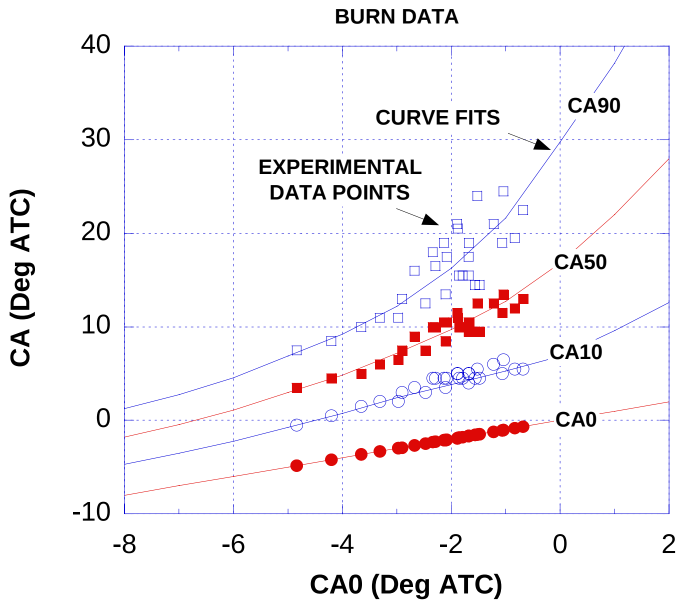
$$C_1 = 2.28 + 0.308 \frac{\pi \; B \; w_p}{\bar{S}_p}, \quad C_2 = 0.00324$$

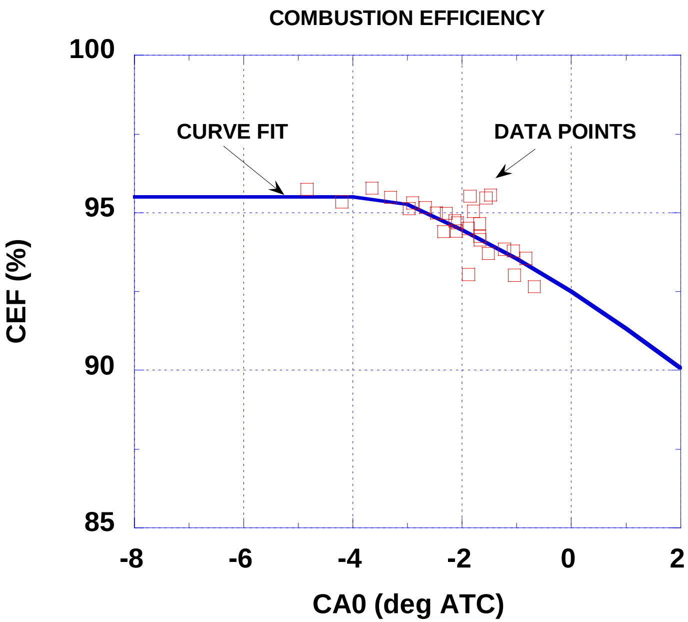
# Experimental Burn Rate Data

- Varying RPM, load, $T_{cool}$, $T_{inlet}$, A/F ratio
- Generate correlations as function of ignition timing (one variable)

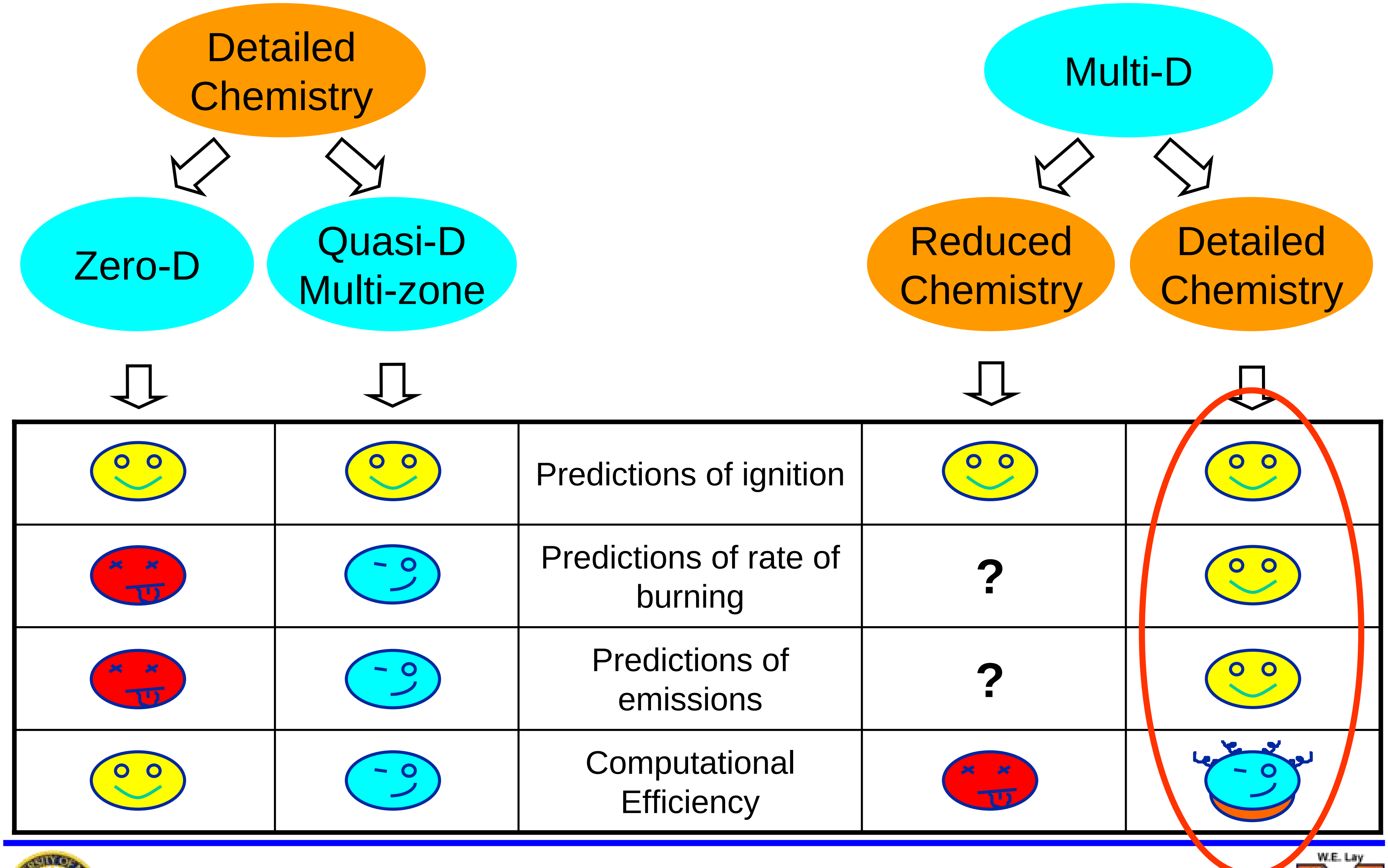
$$x_{NORM} = 1 - \exp[-((\theta - \theta_0)/\Delta\theta)^{w+1}]$$



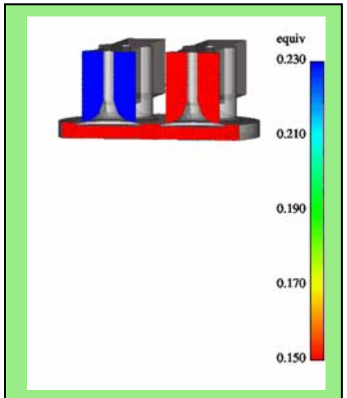



# Modeling Approaches for HCCI Engines



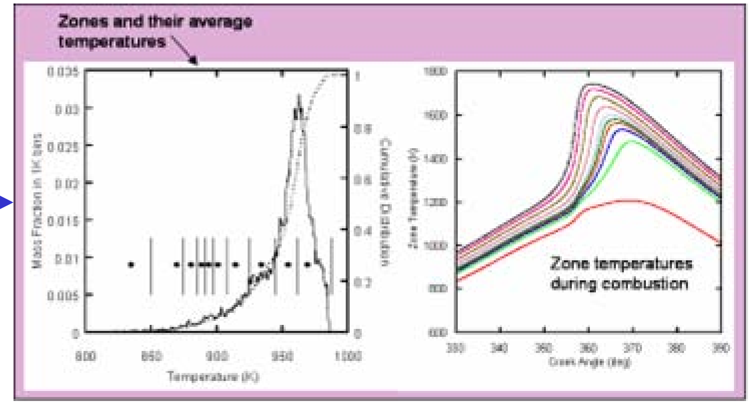
# Initial Modeling Approach: Sequential CFD + Multi-zone Model

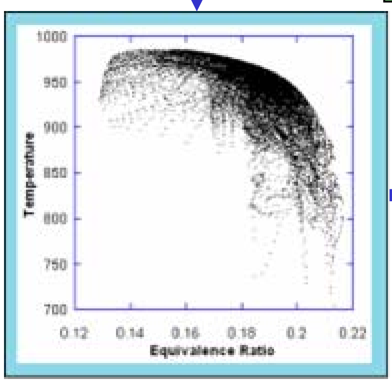
1 Open-cycle calculation using Kiva-3V



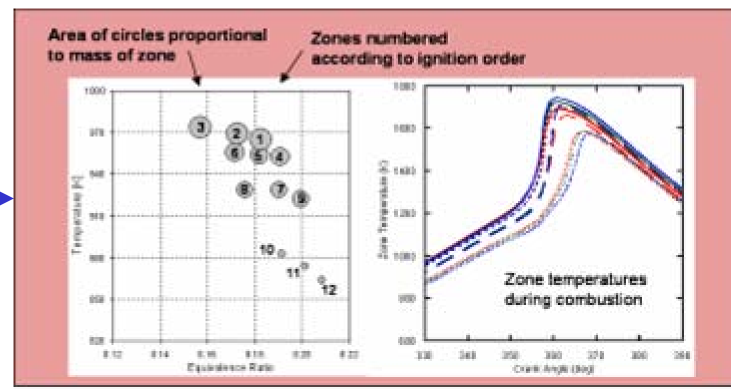

**TRANSITION POINT**

3a Calculation of combustion event using Multi-zone model with Temperature Zones only




2 Temperature / Equivalence Ratio distribution obtained before TDC

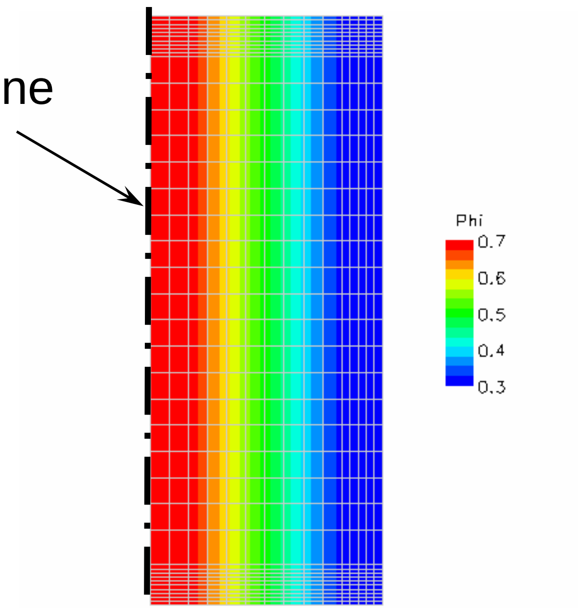


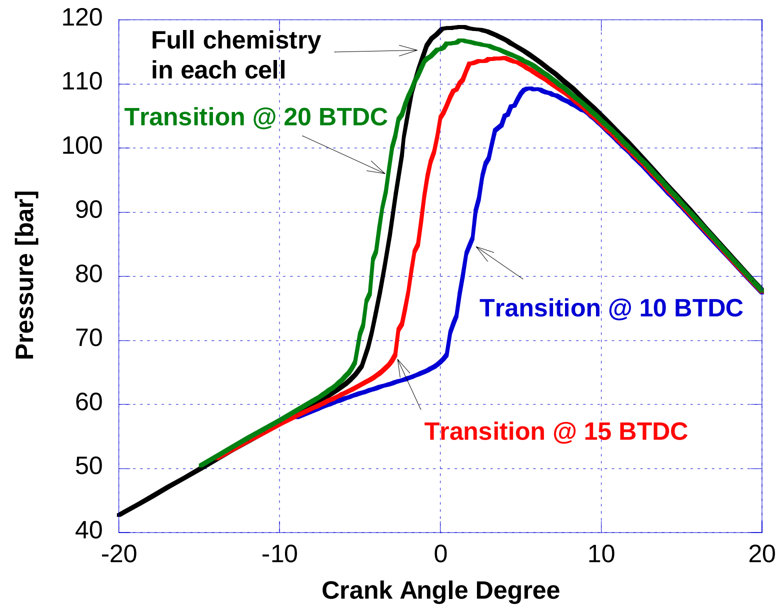

3b Calculation of combustion event using Multi-zone model with *T/Φ* Zones

# Sensitivity to Transition Timing

- Calculations at LLNL showed that the point of transition from KIVA to the multi-zone code can affect the results (SAE 2005-01-0115)
  - Imposed $\Phi$ distribution on a 2D coarse grid (Fuel $CH_4$)
  - Solution obtained using sequential multi-zone approach compared against detailed solution (KIVA-3V linked with Chemkin)
  - Implication: Temperature and composition stratification is important

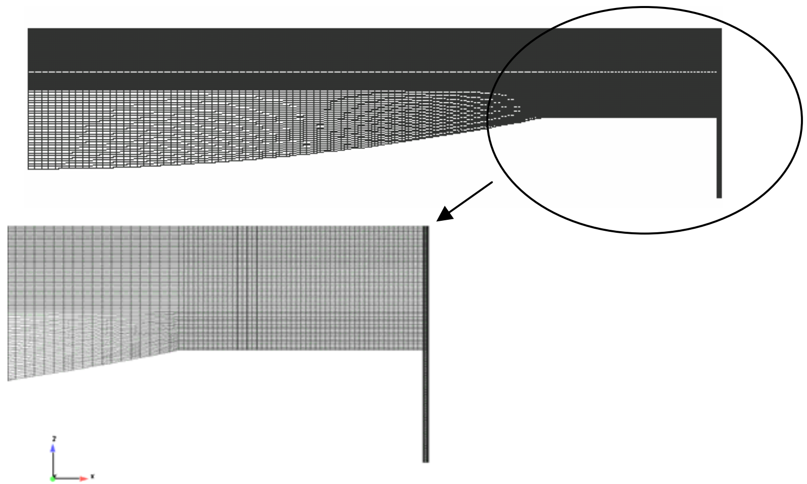
Centerline

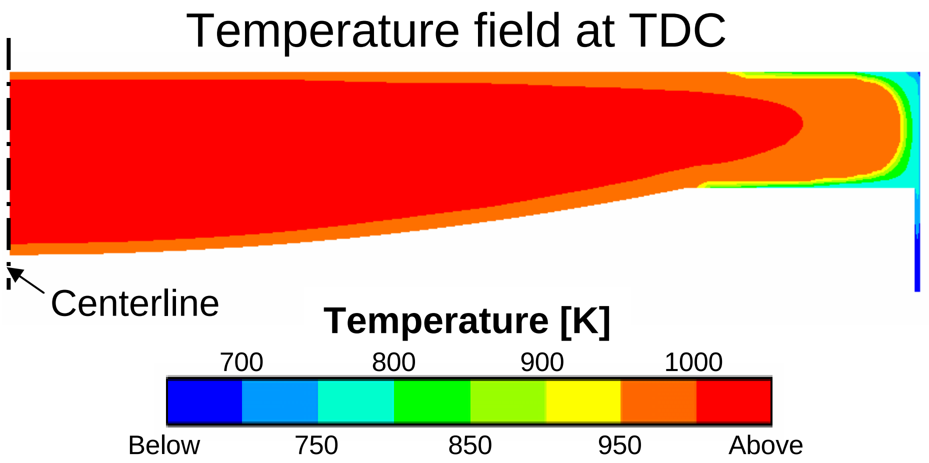


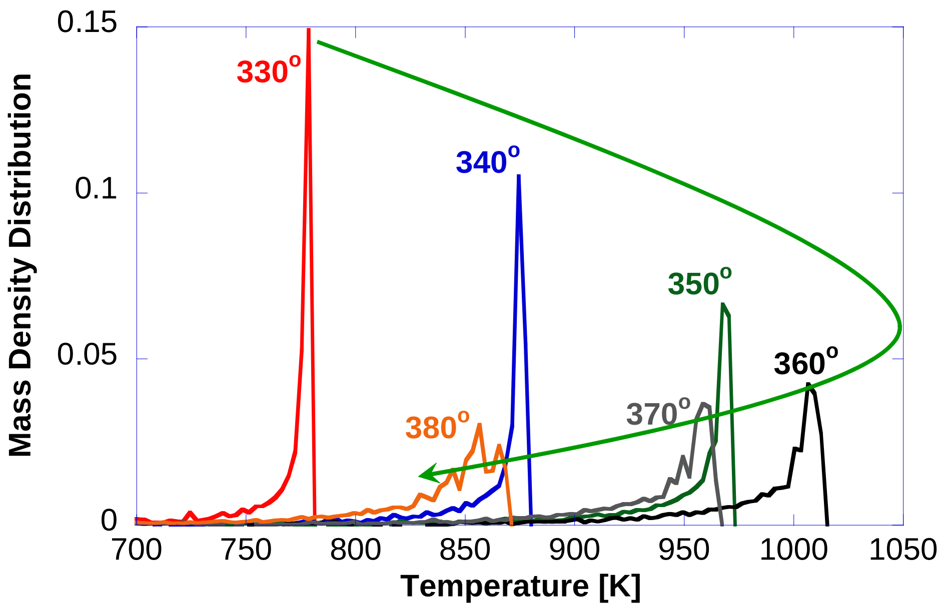
# Naturally Occurring Thermal Stratification

*Collaboration with Sjöberg and Dec (Sandia) - SAE 2004-01-2994*

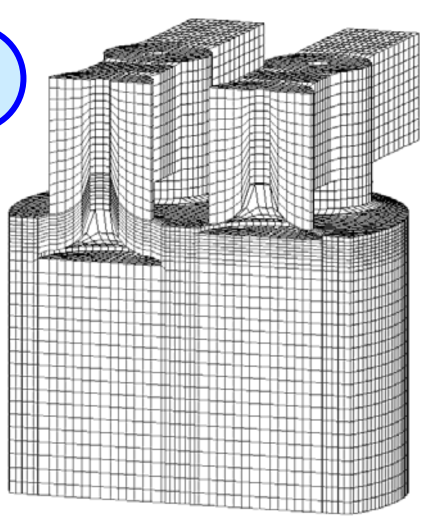




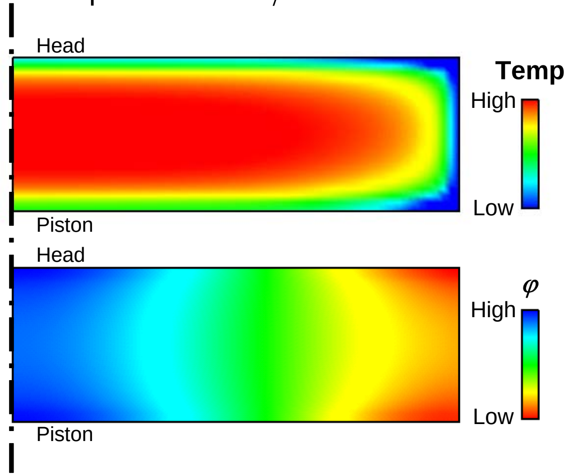

Temperature and composition distributions continue to evolve until late in the compression stroke. Decoupling of flow and chemistry is problematic.



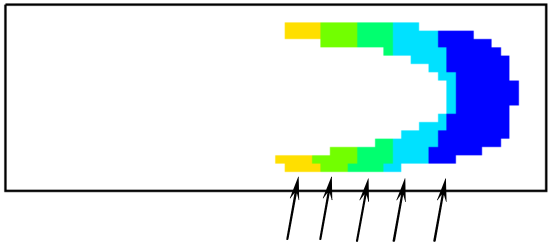
# Coupling of KIVA-3V with Multi-Zone Model (KMZ)



Temperature and $\varphi$ distributions




Shaded part:
3rd Temperature zone (15-35%)

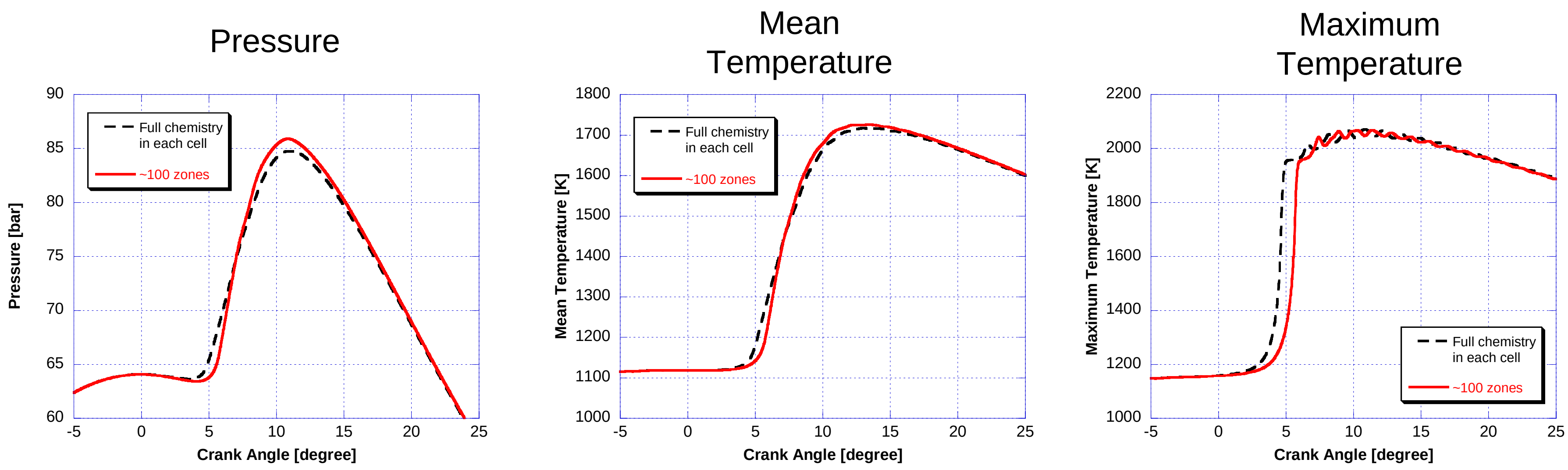


Temperature zone divided into $\varphi$ zones

Instead of solving for detailed chemistry in each cell, at each timestep divide into zones of cells with similar properties (i.e. $T$ and $\varphi$), and assume they behave in a similar manner

Estimate composition change and heat released in each zone, and re-distribute to corresponding KIVA-3V cells

# Validation of Fully Coupled Kiva-3V with Multi-Zone Model



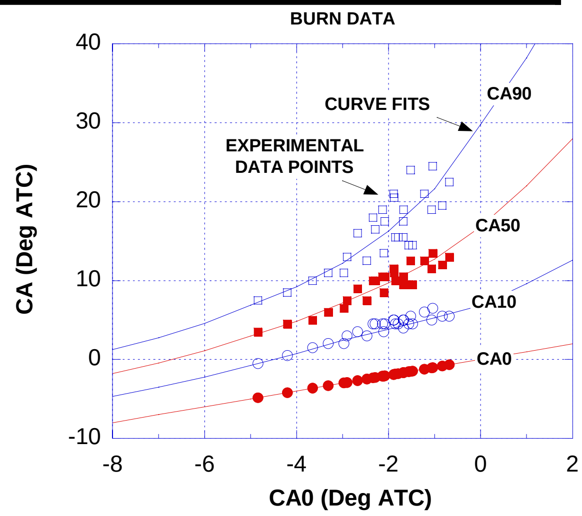

- The new model gives results that match very well the "exact" solution obtained by solving for detailed chemistry in every cell
- Computational time is reduced significantly (~90% for 10,000 cells)

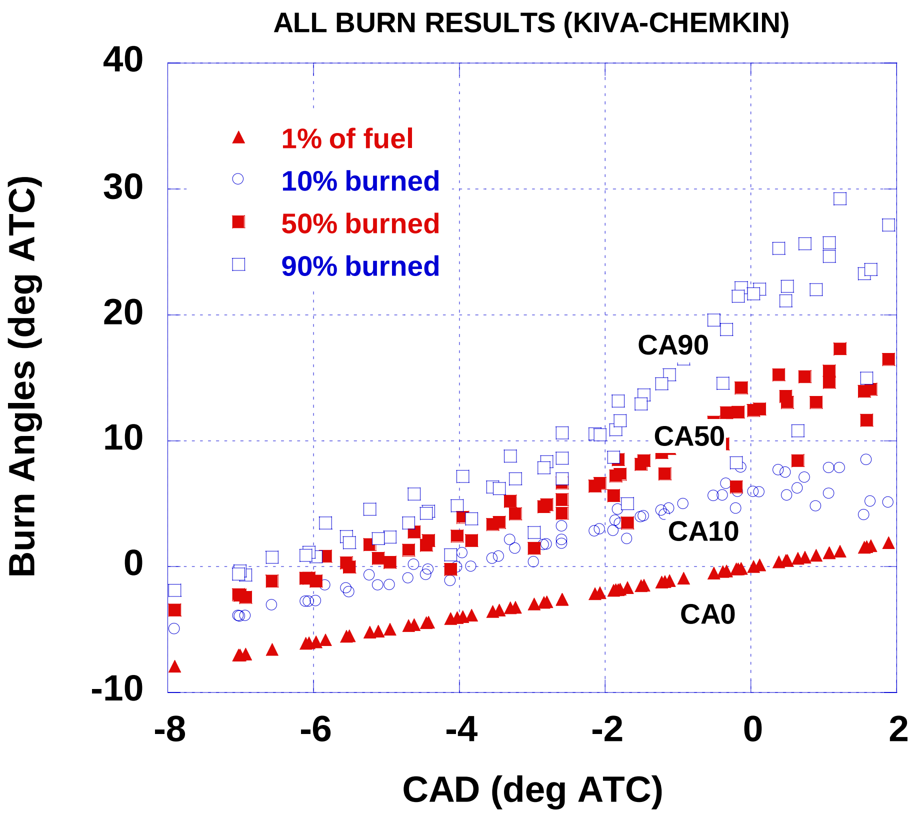
# Numerical Experiments: KMZ generated "data"

- Run T sweeps of KMZ model for various operating parameters
- Generate burn angles as function of ignition timing, as well as other variables

| Variable | Sweeps |
|---|---|
| CR | 16, 9 |
| RPM | 2000, 1200 |
| Load (fuel) | 9, 13 mg |

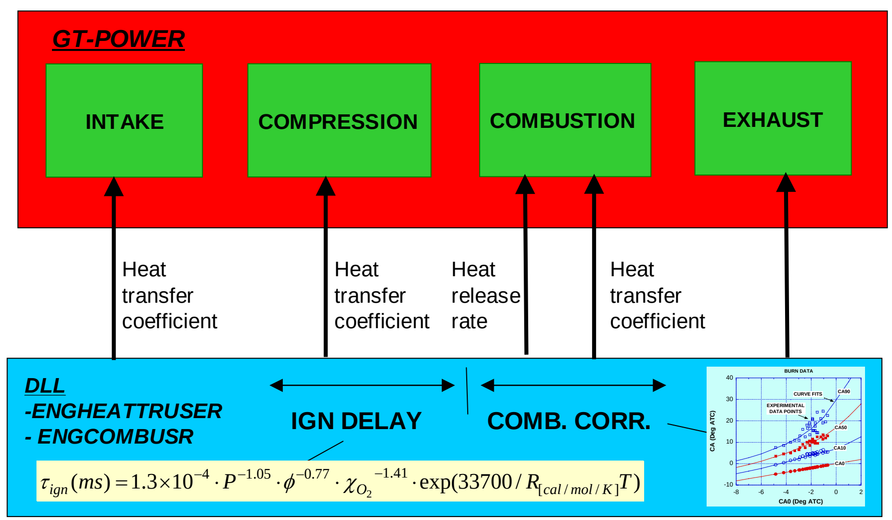
Experimental Data



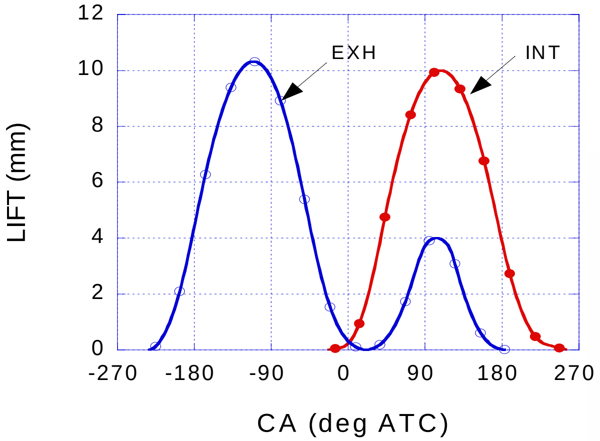



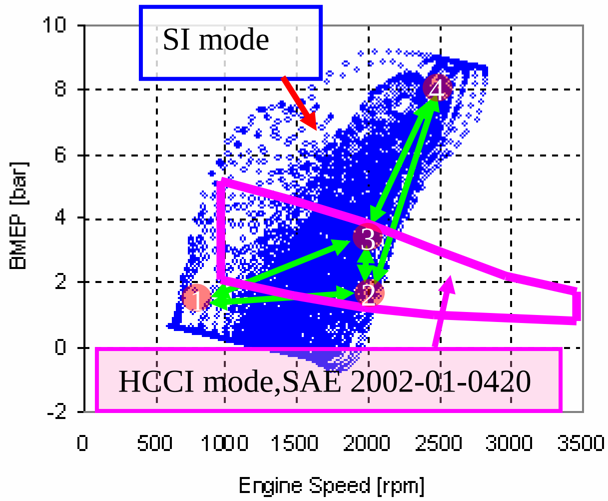
# System Studies Approach

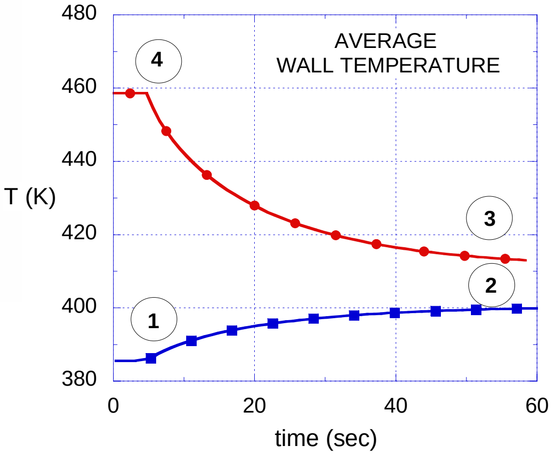
- Use GT-Power as platform for system modeling
- Use experiments and CFD models to provide simplified combustion models with correct trends for ignition, burn rates and combustion efficiency
- Develop single-cylinder engine model with manifolds including thermal system submodel
- Explore implementation issues at multi-cylinder and vehicle level, especially related to thermal transients



# Thermal Transients – Simulating the UM Engine

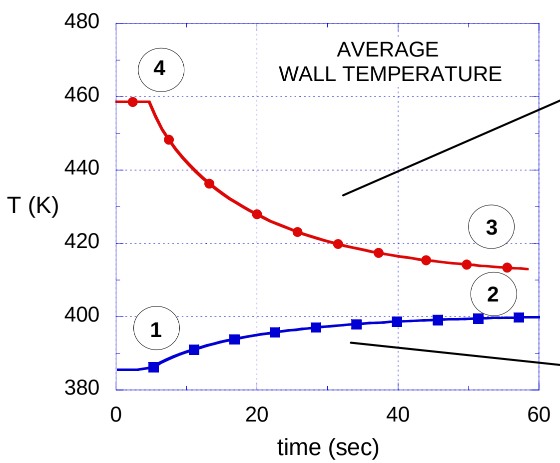


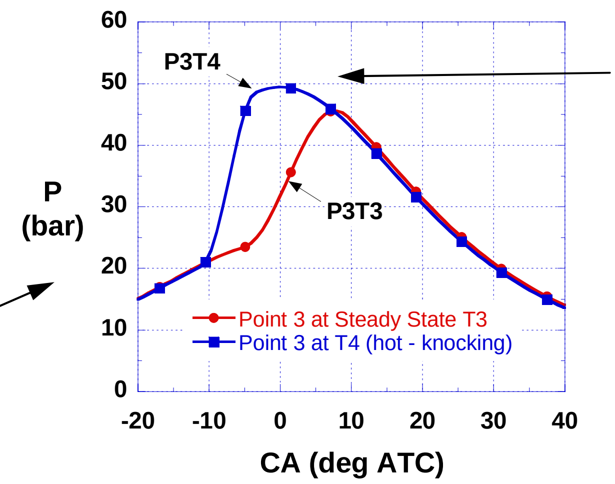



# Thermal Transients – Challenges

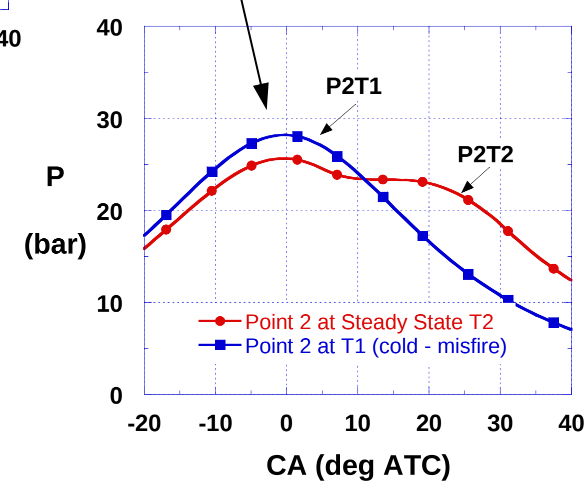
- Stable operation possible at steady state thermal points




Advanced / knocking

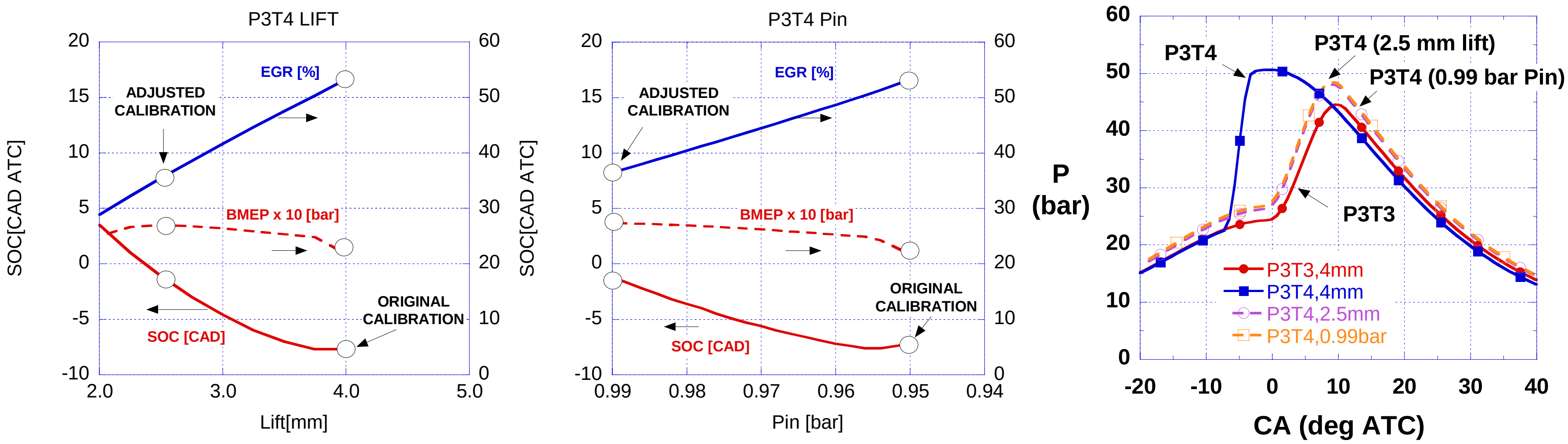
Retarded / misfire




- Transient operation unsatisfactory

# Transient Compensation

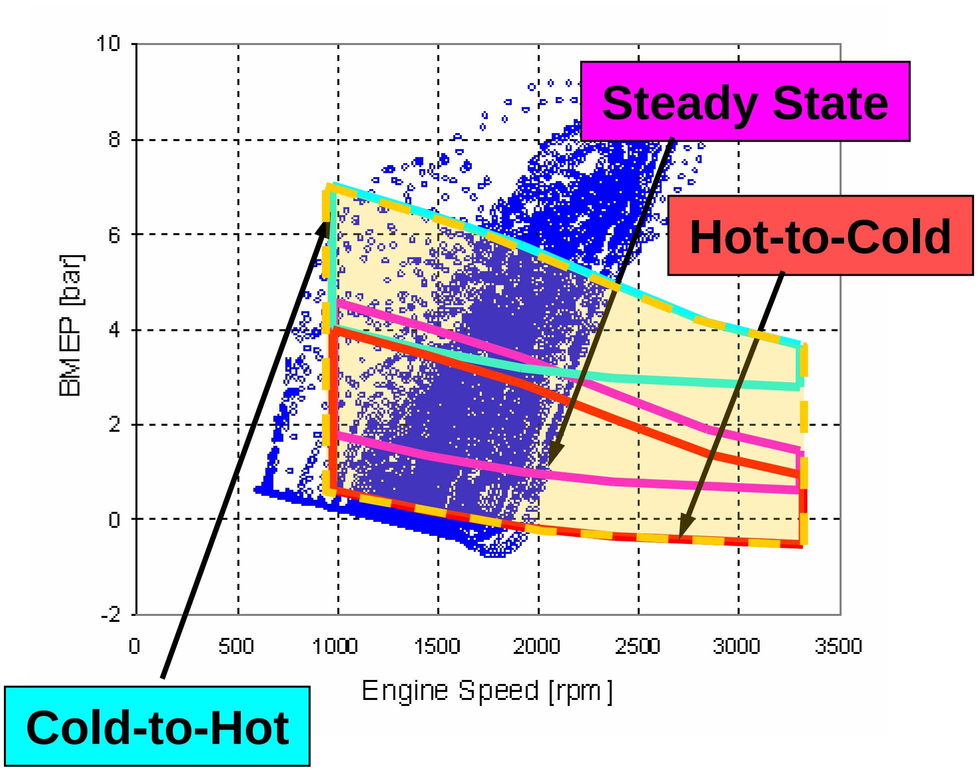
- Hot-to-cold compensation possible by reducing rebreathing lift or increasing $P_{inlet}$ (both decrease EGR)




- Cold-to-hot compensation not achievable (not enough EGR heat is available)

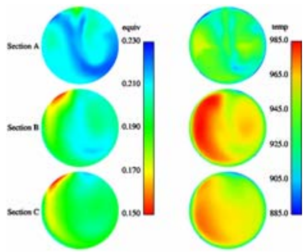
# Thermal Transients - Implications

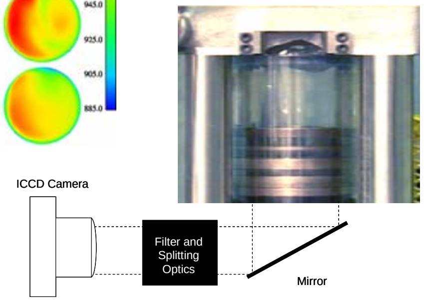
- HCCI regime is shifted depending on direction of transient
- Hot-to-cold will extend the low load HCCI region
- Cold-to-hot will require SI operation until walls warm up
- Challenge is to maximize HCCI operating regime

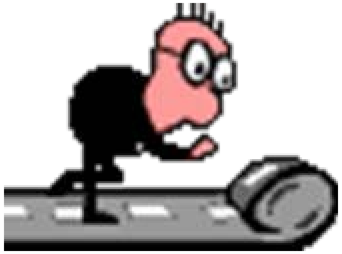


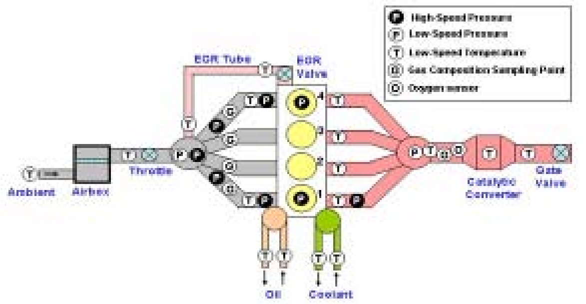
# Future Work

- Refine modeling approaches and validate them against optical and metal engine measurements – emphasize DI, stratified operation
- Extract knowledge developed from detailed CFD + comprehensive chemistry models and capture it into practical correlations compatible with “smart” phenomenological single-zone models
- Provide a single-cylinder module to multi-cylinder system level, controls-oriented simulations
- Use models to develop strategies for HCCI engine in-vehicle operation with alternative fuels







# Acknowledgements


- **University of Michigan**

  Dr. Aris Babajimopoulos, Dr. George Lavoie, Dr. Zoran Filipi, Dr. Junseok Chang, Dr. Kukwon Cho, Orgun Guralp, Mark Hoffman, Yanbin Mo, Kyoung Joon Chang

- **General Motors Research Laboratories**

  Rod Rask, Paul Najt, Tang Wei Kuo, Jim Eng

- **Lawrence Livermore National Laboratories**

  Salvador Aceves, Dan Flowers

- **Sandia National Laboratories**

  John Dec, Magnus Sjoberg