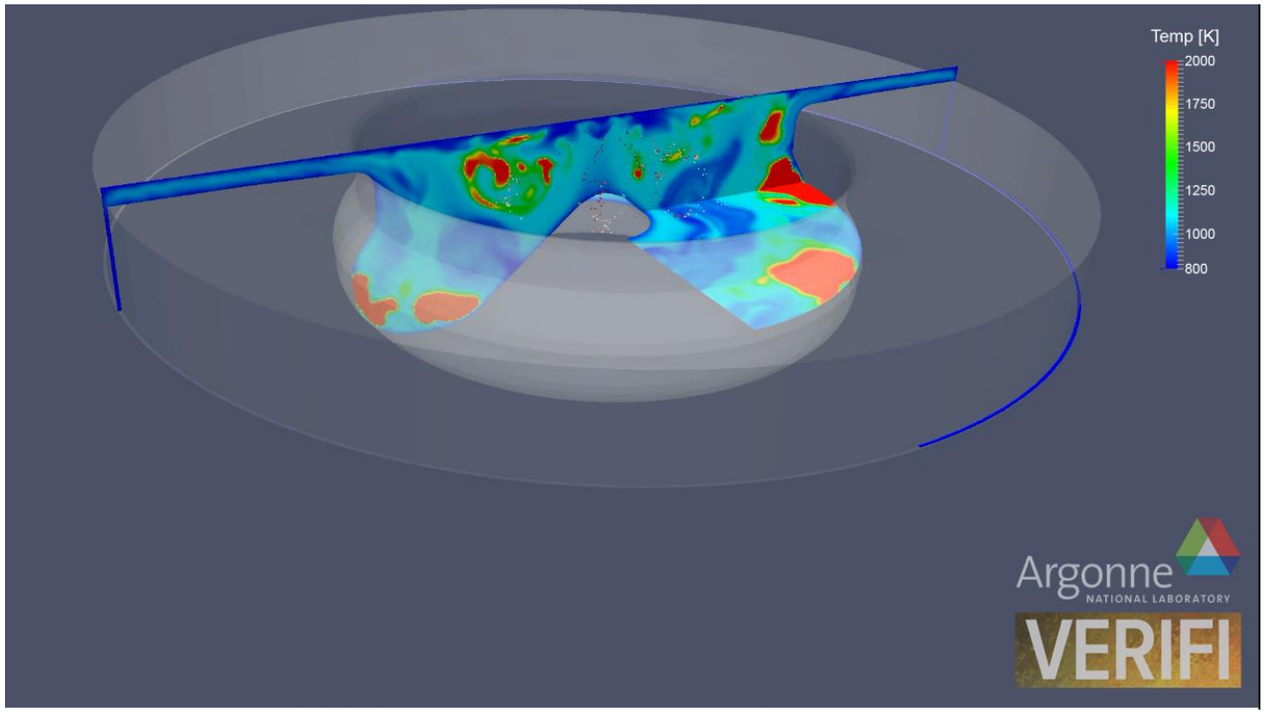
Overview of Gasoline Compression Ignition

and

Background for VERIFI Hands-On simulations



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VERIFI Workshop Hands-on Session (11/13/2014)

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- ALCF : Marta Garcia, Kevin Harms, Joe Insley
- ES : Chris Kolodziej, Steve Ciatti, Sibendu Som, Yuanjiang Pei
- CSI : Priyesh Srivastava, Shaoping Quan, Keith Richards

Gasoline Compression Ignition (GCI) at Argonne*

87 octane gasoline
(no ethanol)

1.9 L Euro IV production 4-cylinder GM diesel engine

- Early direct injection of gasoline - sequential autoignition
- Run engine on 87 octane gasoline over entire speed/load range
- **CFD** - optimize control knobs for stable combustion

*experiments by Kolodziej et al. SAE 2014-01-1302

Engine Specifications

Cylinders	4
Geometric CR	17.8
Effective CR (CFD)	17.5
Bore (mm)	82
Stroke (mm)	90.4
Connecting Rod Length (mm)	145.4
IVC/EVO(˚ aTDC)	-132 / 116
Number of injector nozzle holes	7
Nozzle hole diameter (µm)	141
Nozzle inclusion angle (deg.)	148
Injection pressure (bar)	250

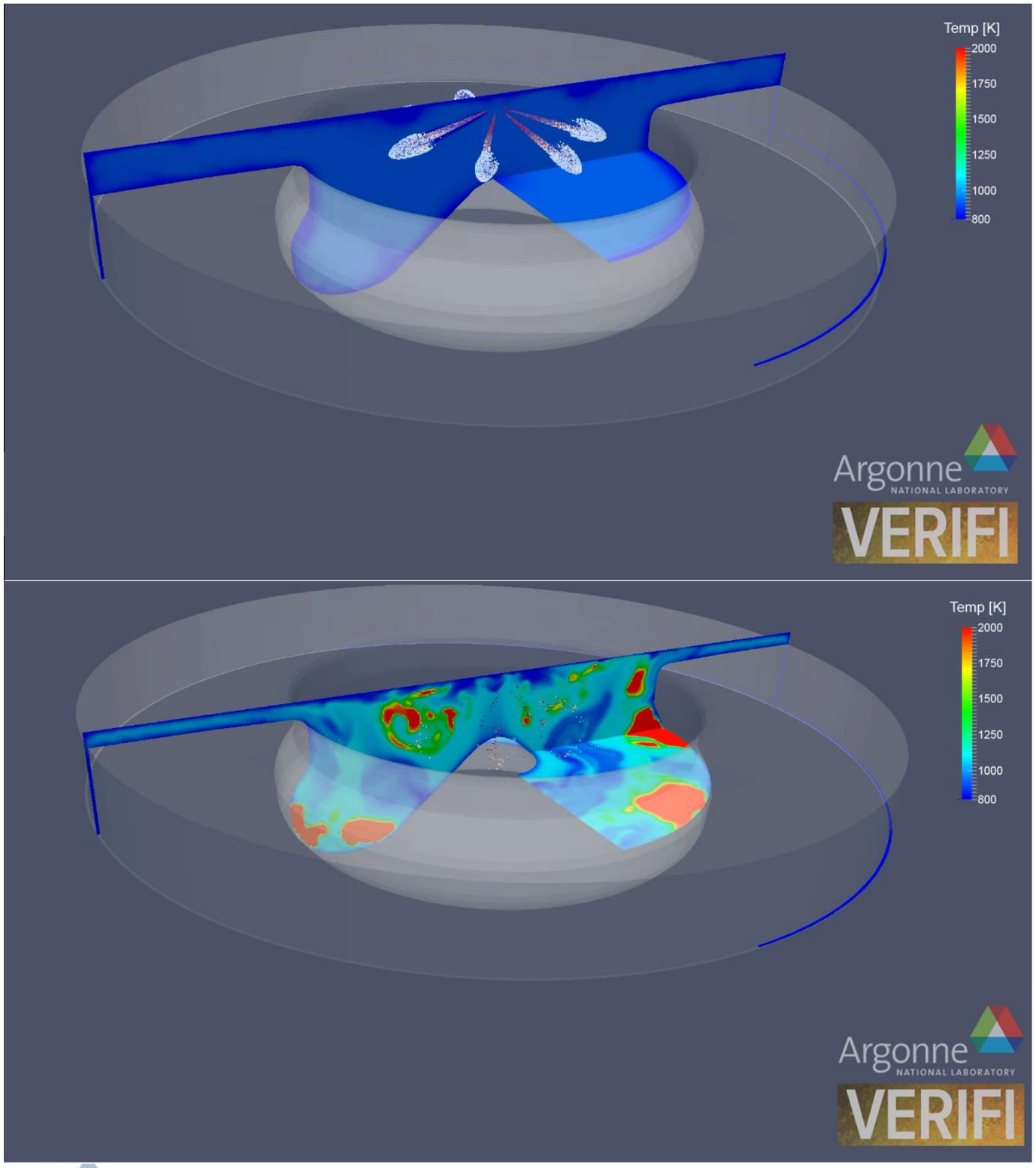
Traditional Diesel Combustion

Low ignition delay

Non-premixed

High Soot and NOx

Gasoline Compression Ignition



Early injection

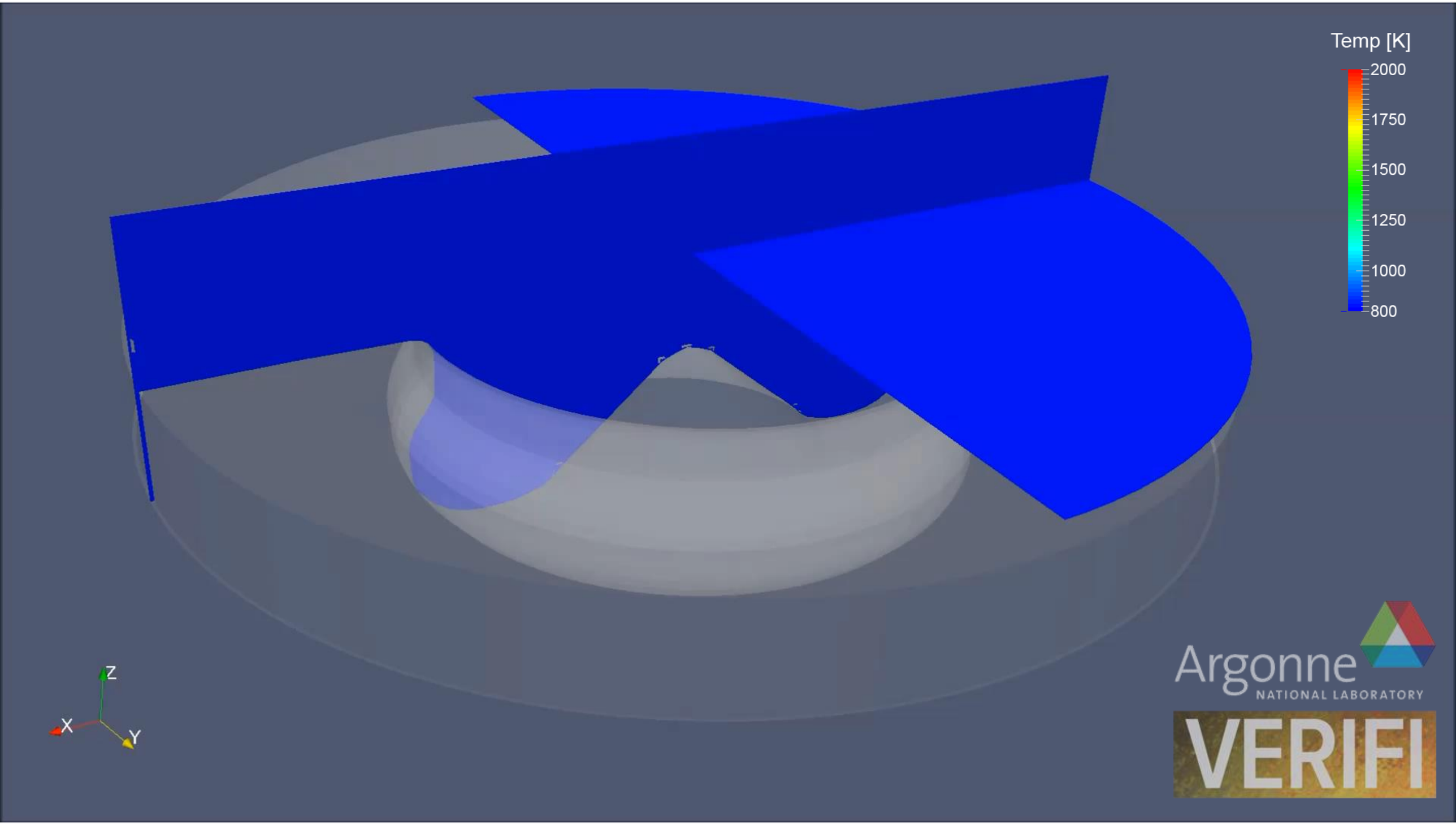
SOI at -15 to -40˚aTDC

Long ignition delay

Partially premixed

Distributed ignition

Gasoline Compression Ignition



*All visualization done by Joe Insley using ParaView

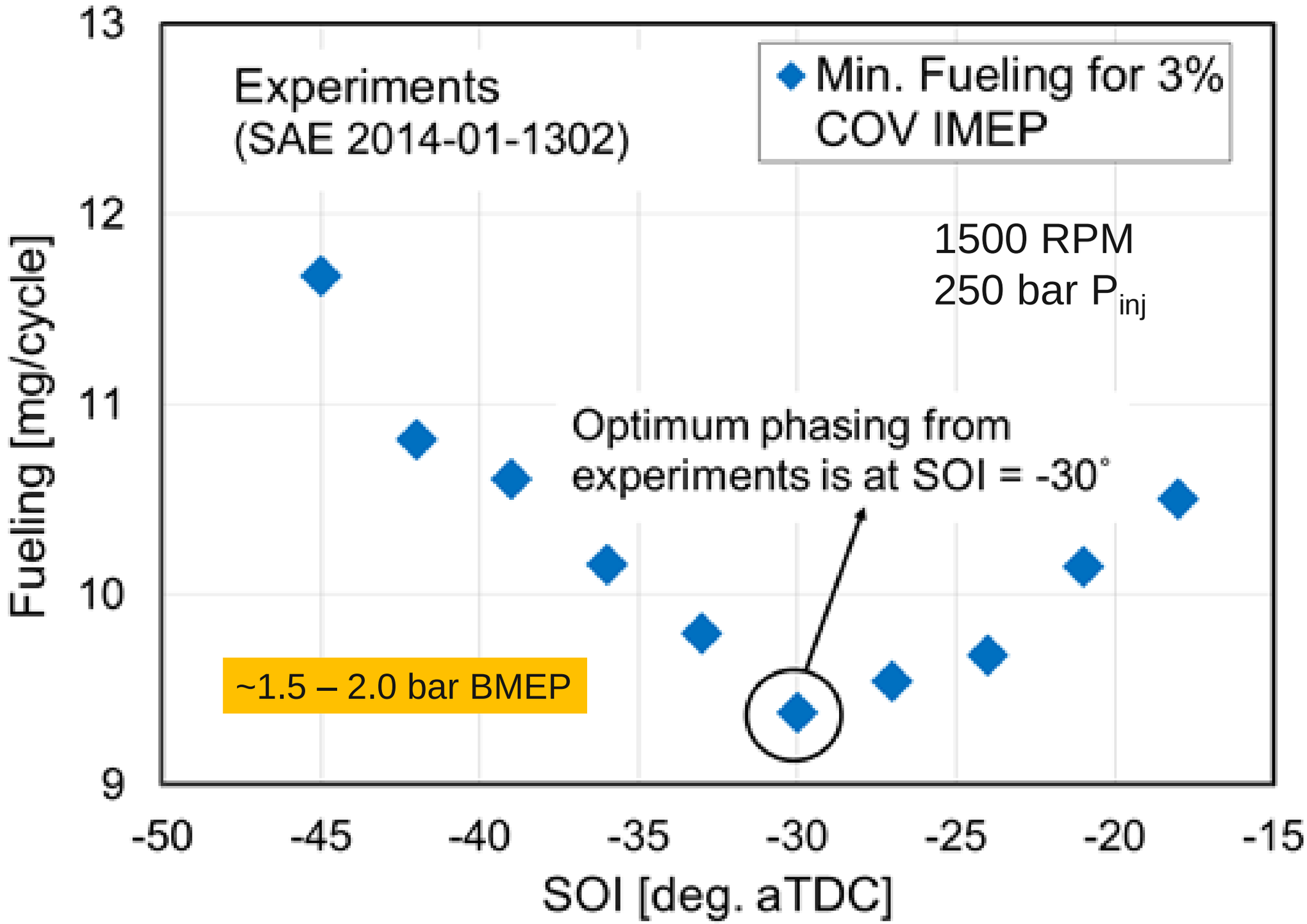
Challenges

Low load operation a challenge!

Hard to ignite gasoline at low loads/fueling

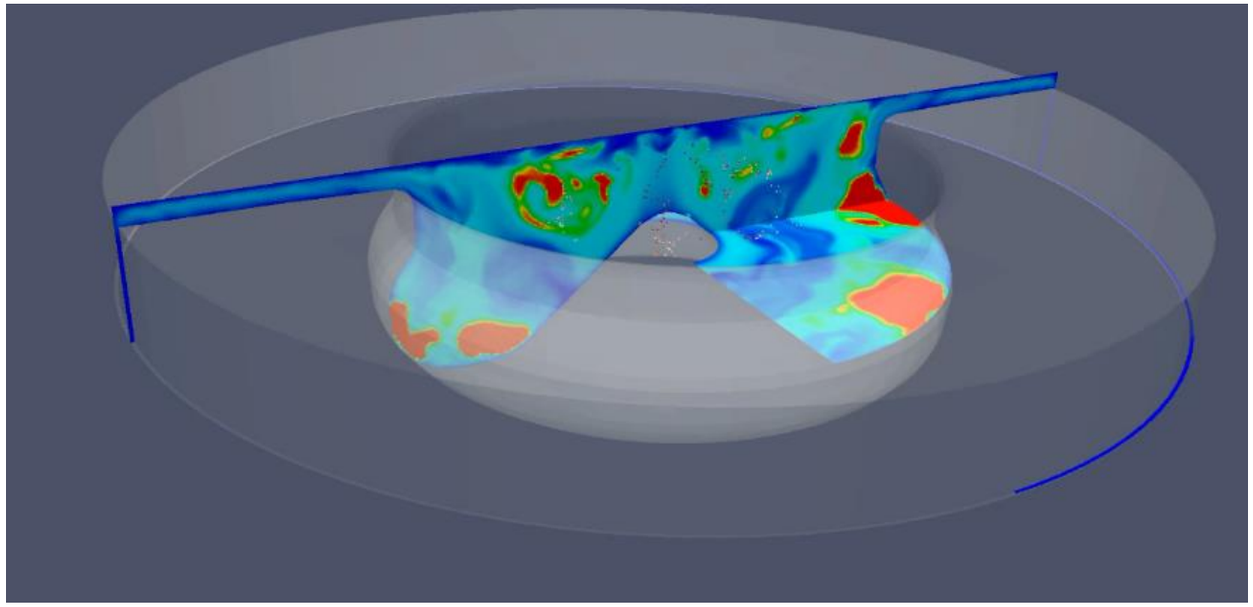
Can injection be used to control/enhance reactivity?

Injection timing versus minimum fueling possible



*Experiments : Kolodziej et al, SAE 2014-01-1302

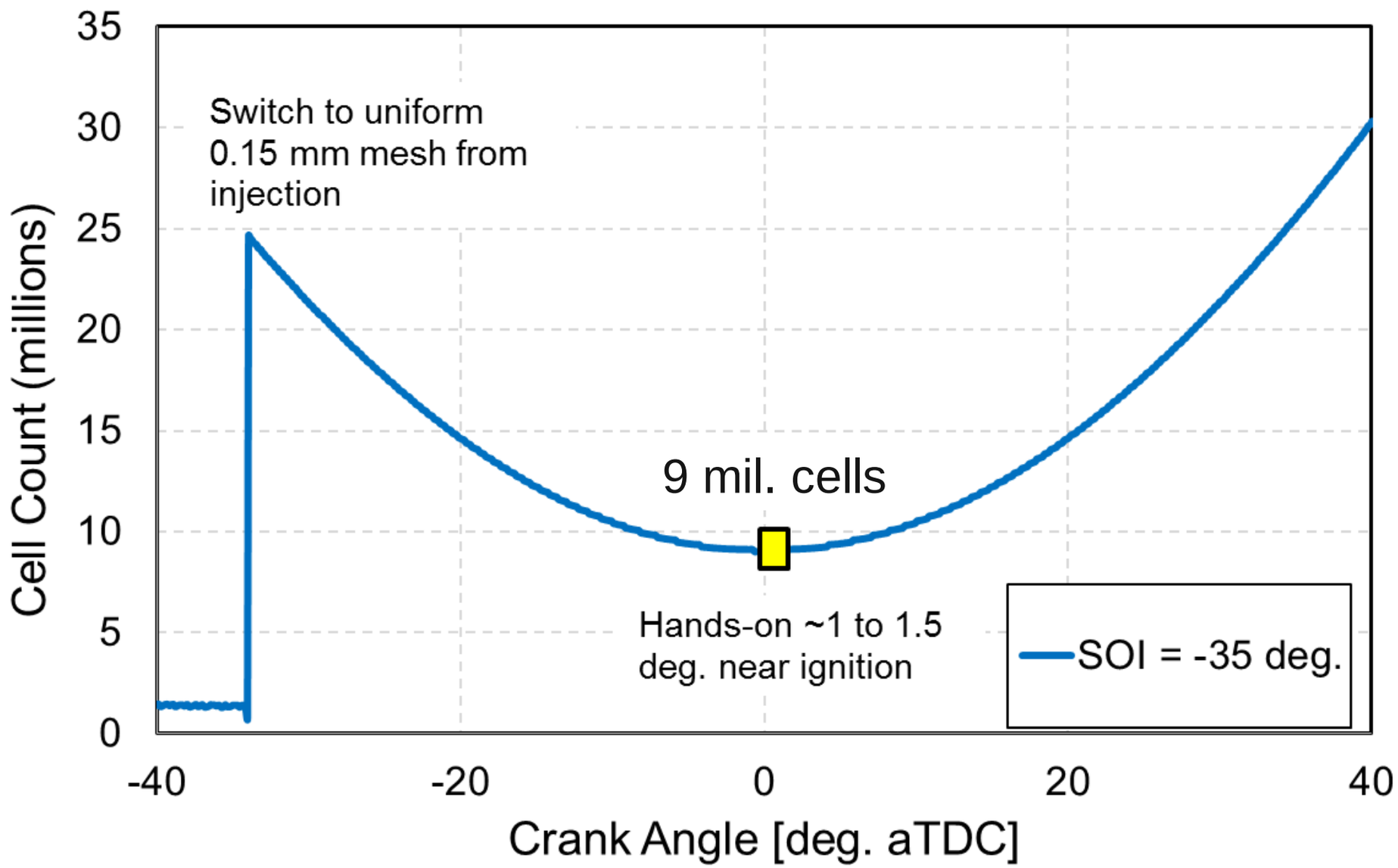
CFD Simulation setup



Largest LTC simulation to our knowledge with peak cell count of 30 million cells

Base mesh (up to SOI)	0.60 mm
Embedding/AMR (up to SOI)	2 levels on vel. and temp.
Minimum cell size (up to SOI)	0.15 mm
Fixed mesh from SOI (using gridscale)	0.15 mm
Cells (TDC)	9 million
Peak cell count	30 million
Combustion model	SAGE in every cell
Turbulence Model	LES (Dynamic Structure)

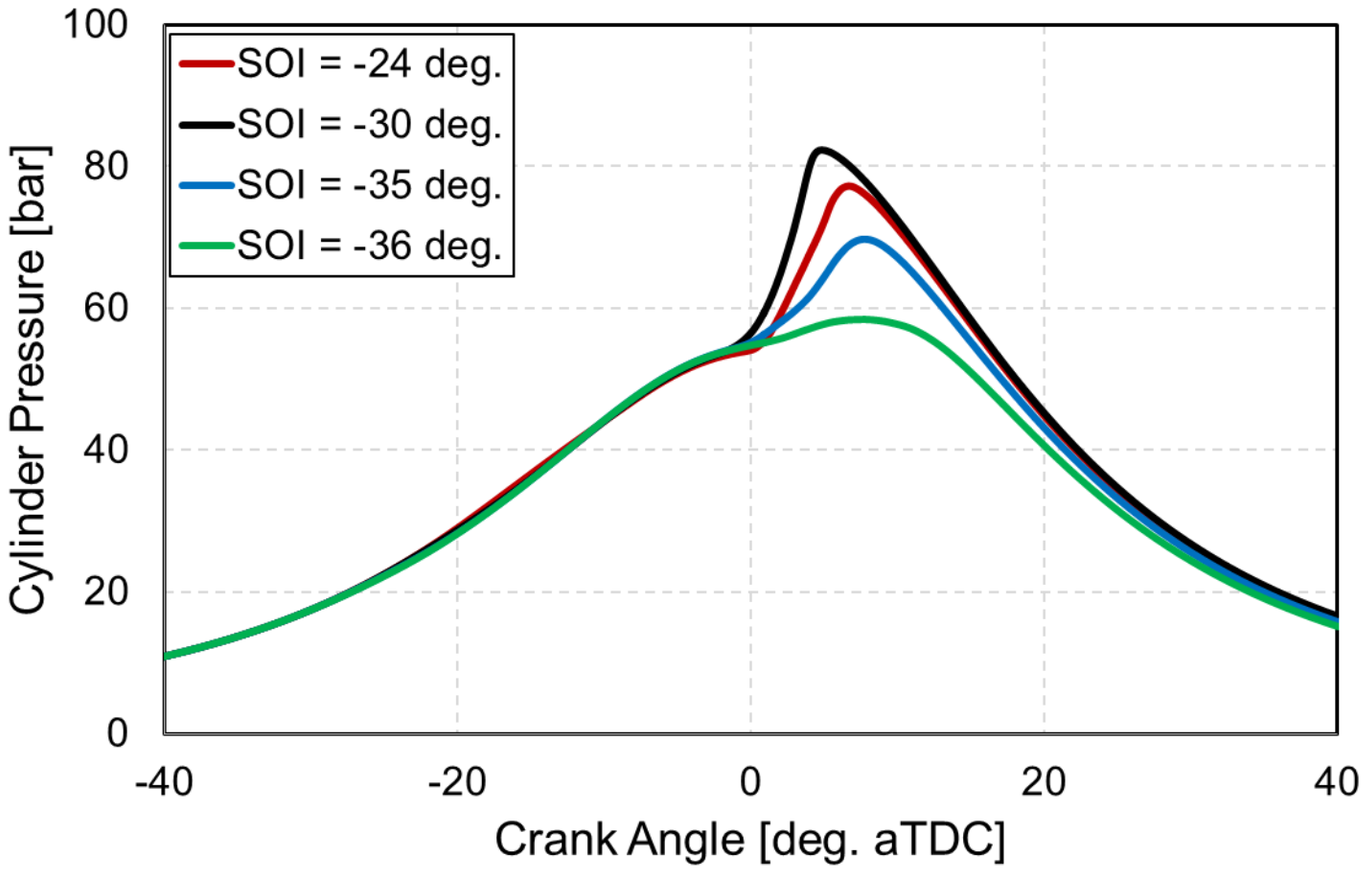
Cell count as a function of crank angle



CFD Simulation setup

RPM	1500
T_{liner} (K)	380
T_{head} (K)	400
T_{piston} (K)	400
Simulation start (˚aTDC)	-132
Simulation end (˚aTDC)	45
Kinetic Mechanism (PRF)	Liu et al. (48 sp. 152 rxn.)
Fuel Surrogate composition for simulations	
Isooctane (% by mass)	87
n-heptane (% by mass)	13

Numerical SOI sweep – Effect of injection timing

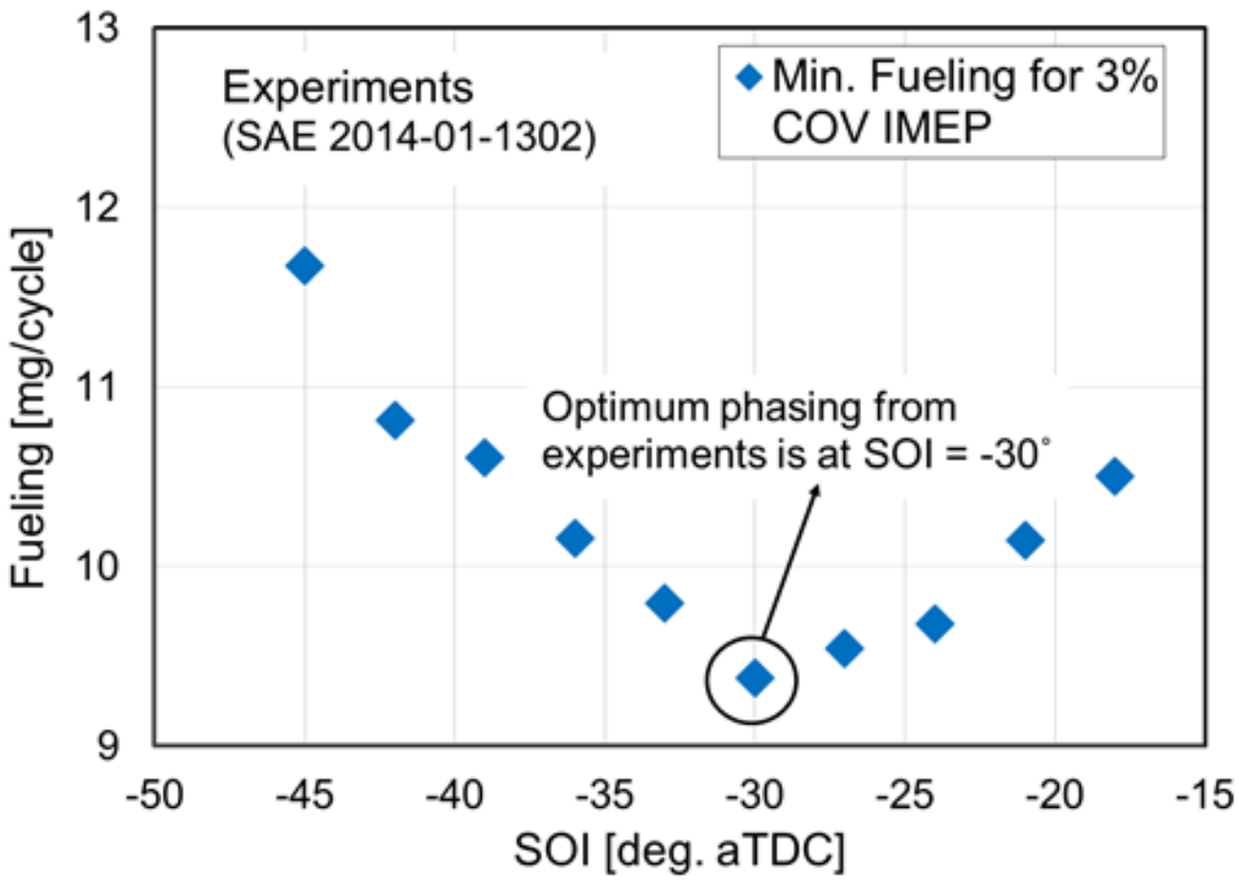


Parameter	Value
Fuel mass (mg)	9.68
Inj. Dur. (deg.)	10.08
T_{IVC} (K)	397
P_{IVC} (bar)	1.41
Φ	0.24
Overall EGR	10%

- Keep fueling constant as well as injection duration
- Constant IVC conditions and boundary conditions
- Only vary SOI timing
- Ignition timing used as metric for low-load reactivity

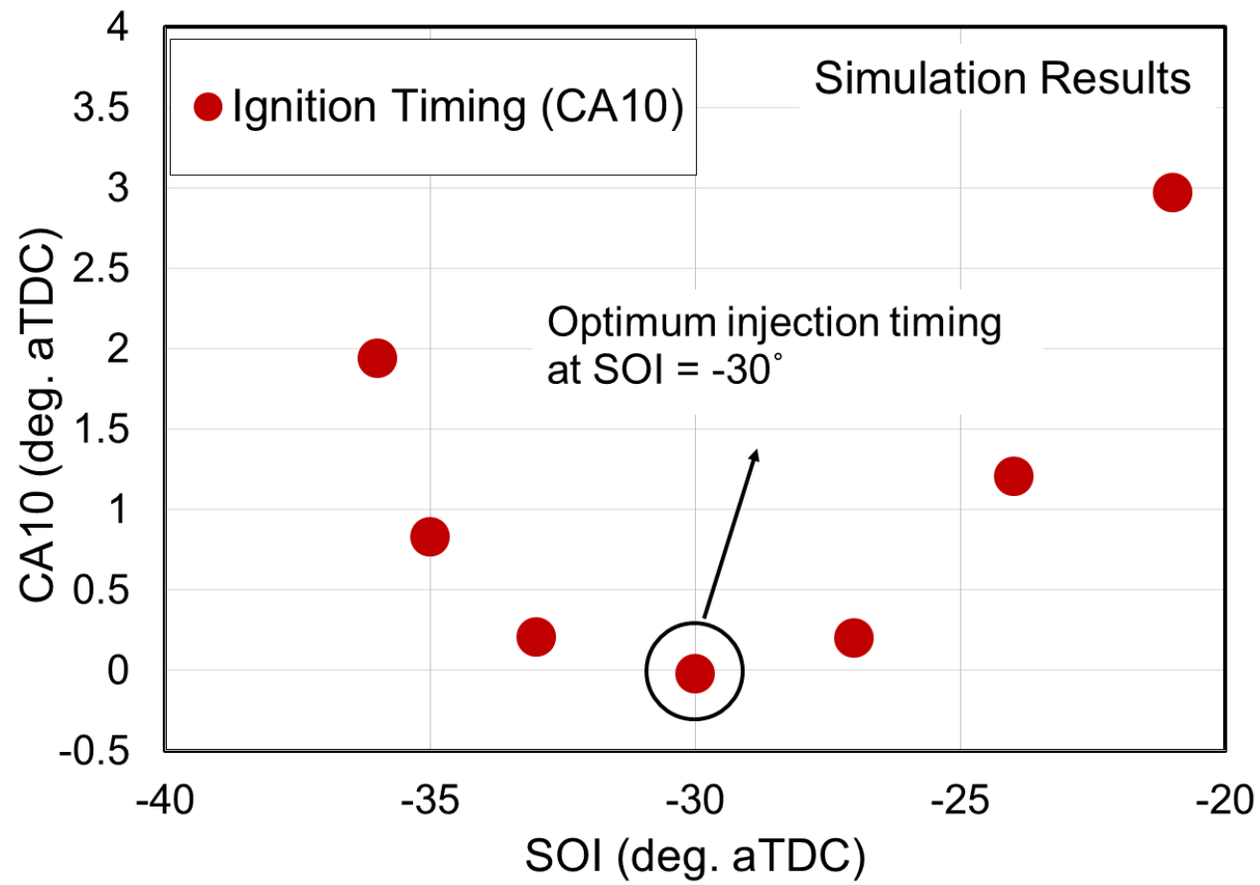
CFD captures experimental trend

EXPERIMENTS*



Variable Fueling: 9.4 – 11.7mg /cycle

CFD SIMULATION

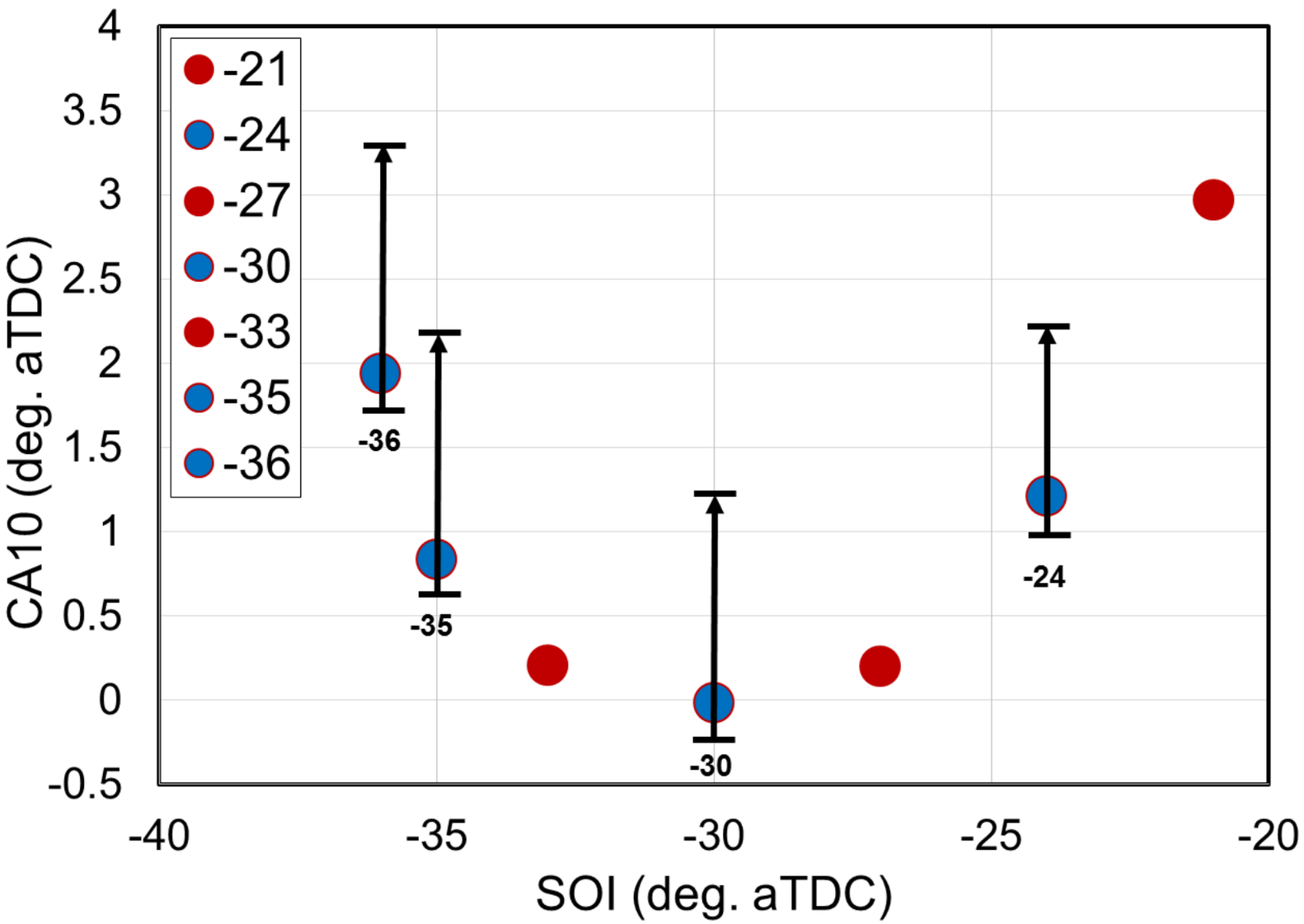


Fixed Fueling: 9.68 mg /cycle

*Experiments : Kolodziej et al, SAE 2014-01-1302

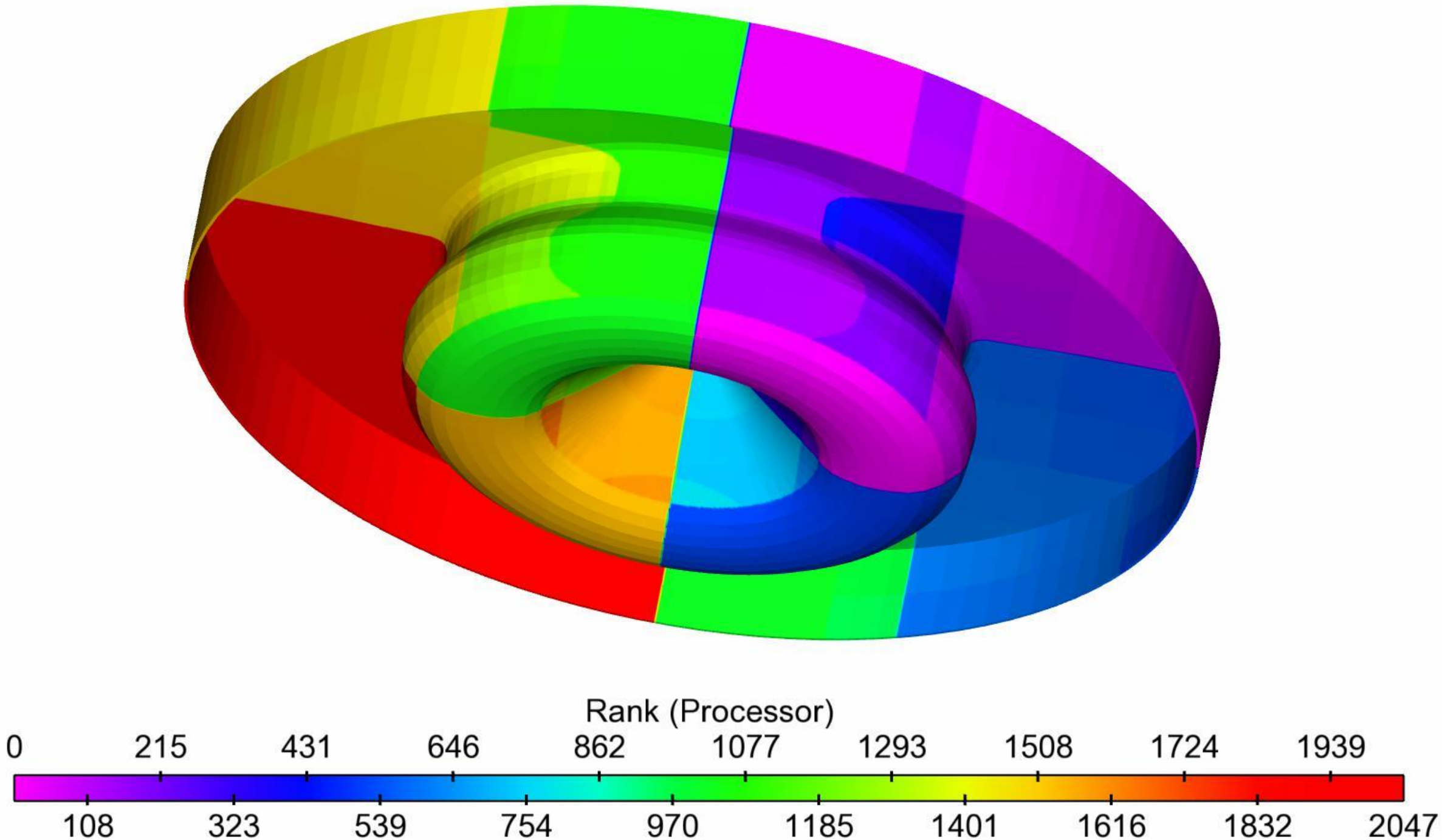
1500 RPM, 250 bar P_{inj}

CFD Simulation for hands-on

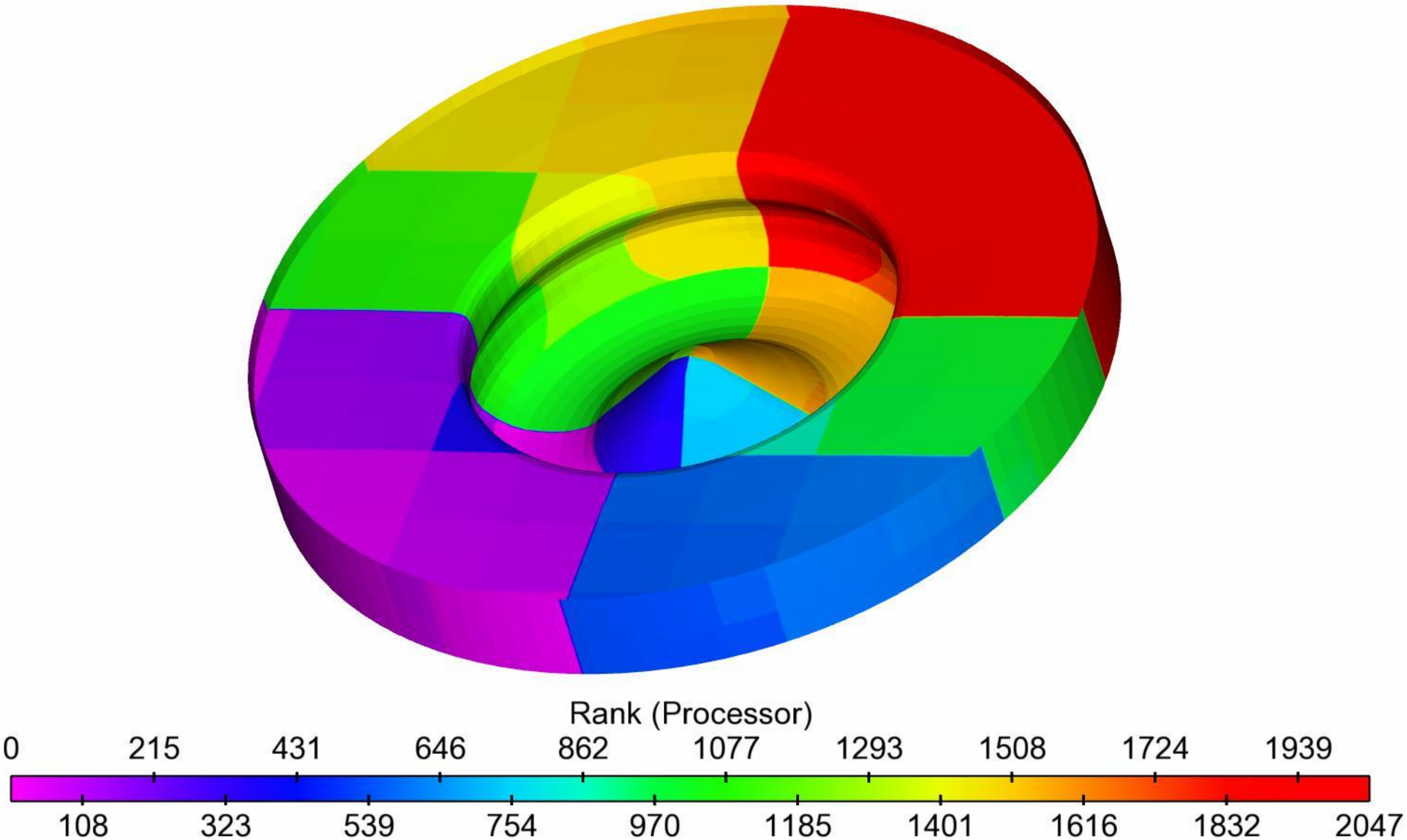


- Start from restarts ~ CA10
- Run 1 to 1.5˚ in 3 hours
- 2048 processors/case
- 4 cases
- Total: **8192 procs**
- 1 mid-plane of MIRA
- 26 participants
- 13 racks on MIRA

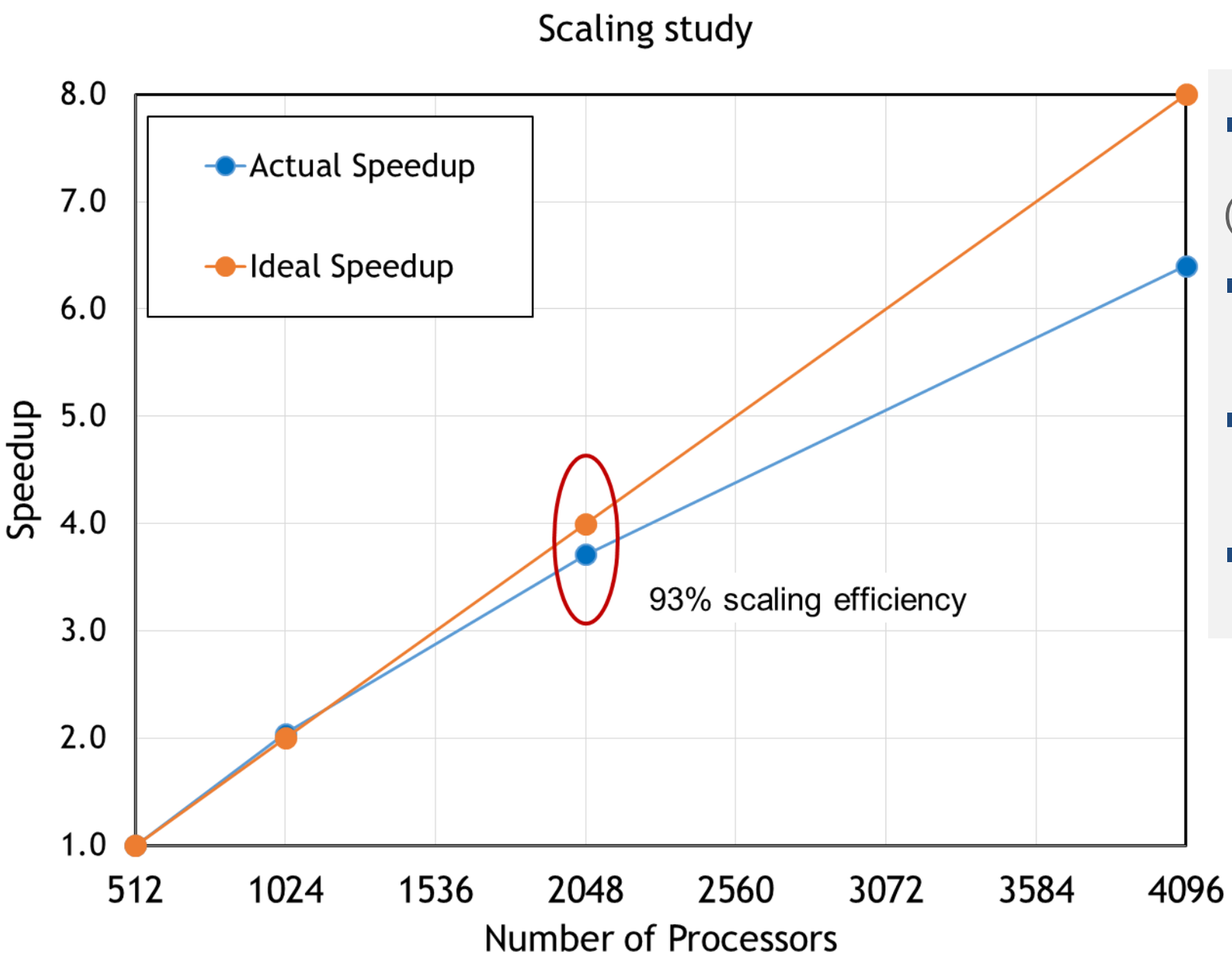
Domain partitioning – fluid mechanics



Domain partitioning – fluid mechanics



Running on 2048 processors – do we scale well?



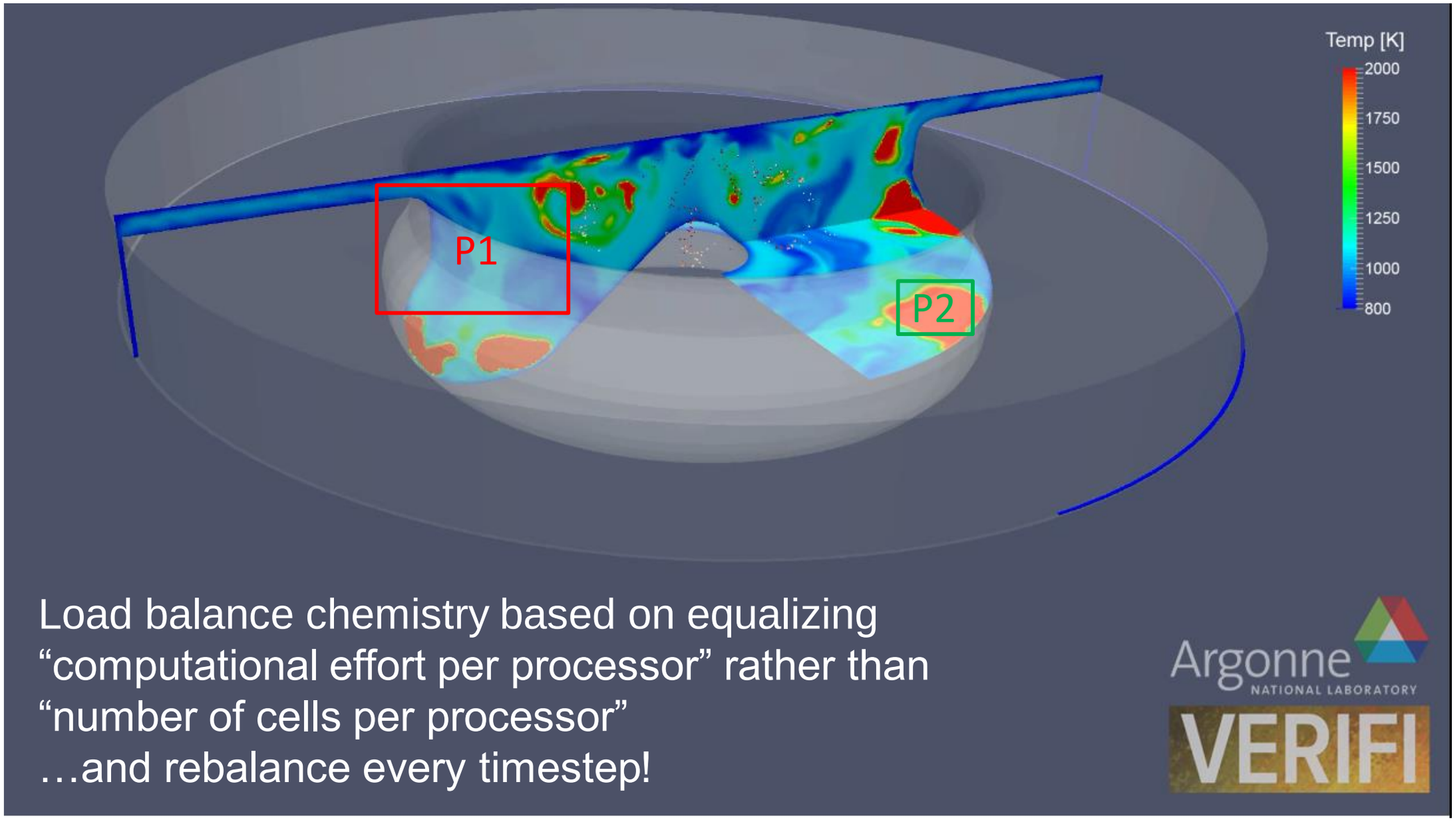
- Actual Speedup = 3.7 X

$(\text{Solution Time})_{512} / (\text{Solution Time})_{2048}$

- Ideal speedup
  - 2048/512 = 4 X
- Scaling eff.
  - Actual / Ideal *100= 93%
- Example of “strong scaling”

We are at 93% scaling efficiency on 2048 processors (cores) – pretty good…

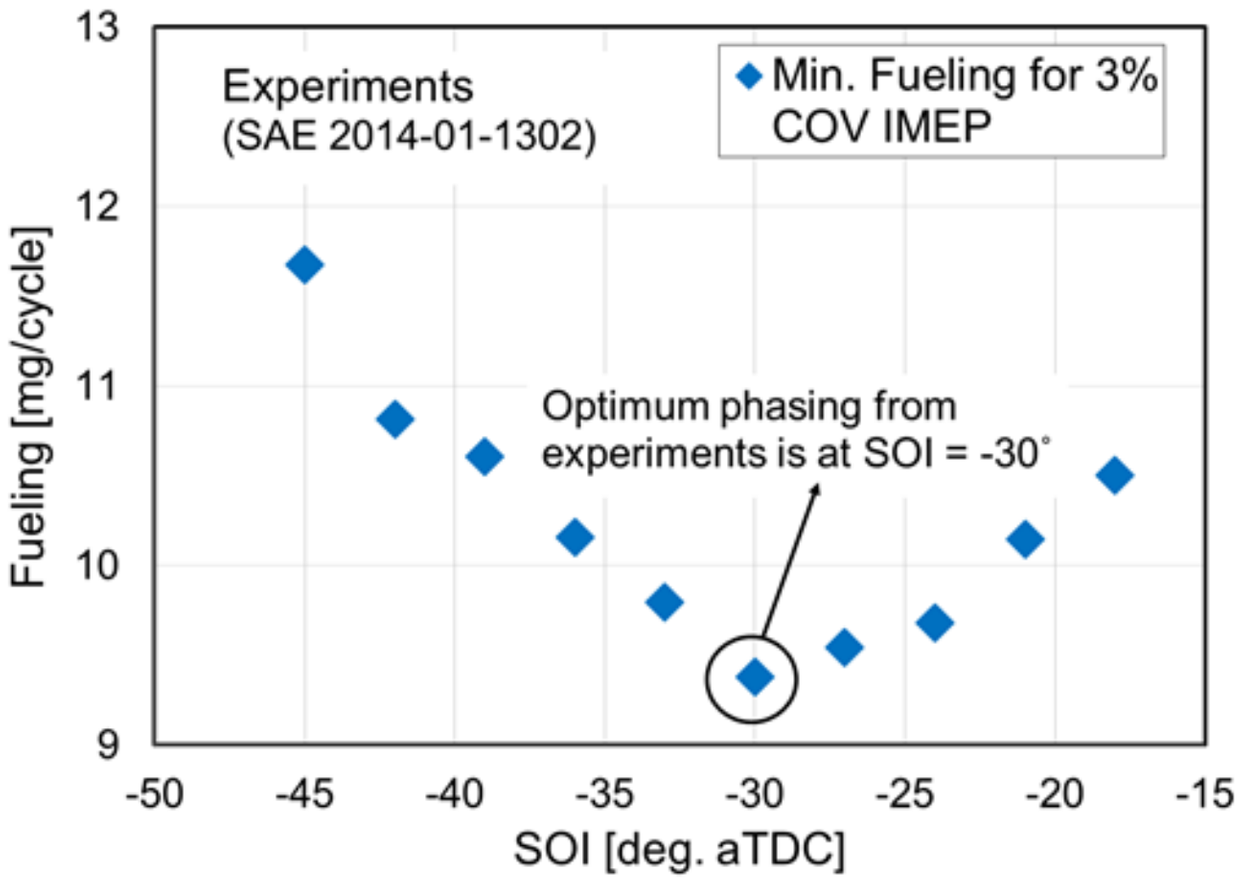
Role of chemistry load balancing in scaling



Better chemistry load balancing by Argonne/CSI was key
More details in Kevin’s presentation…

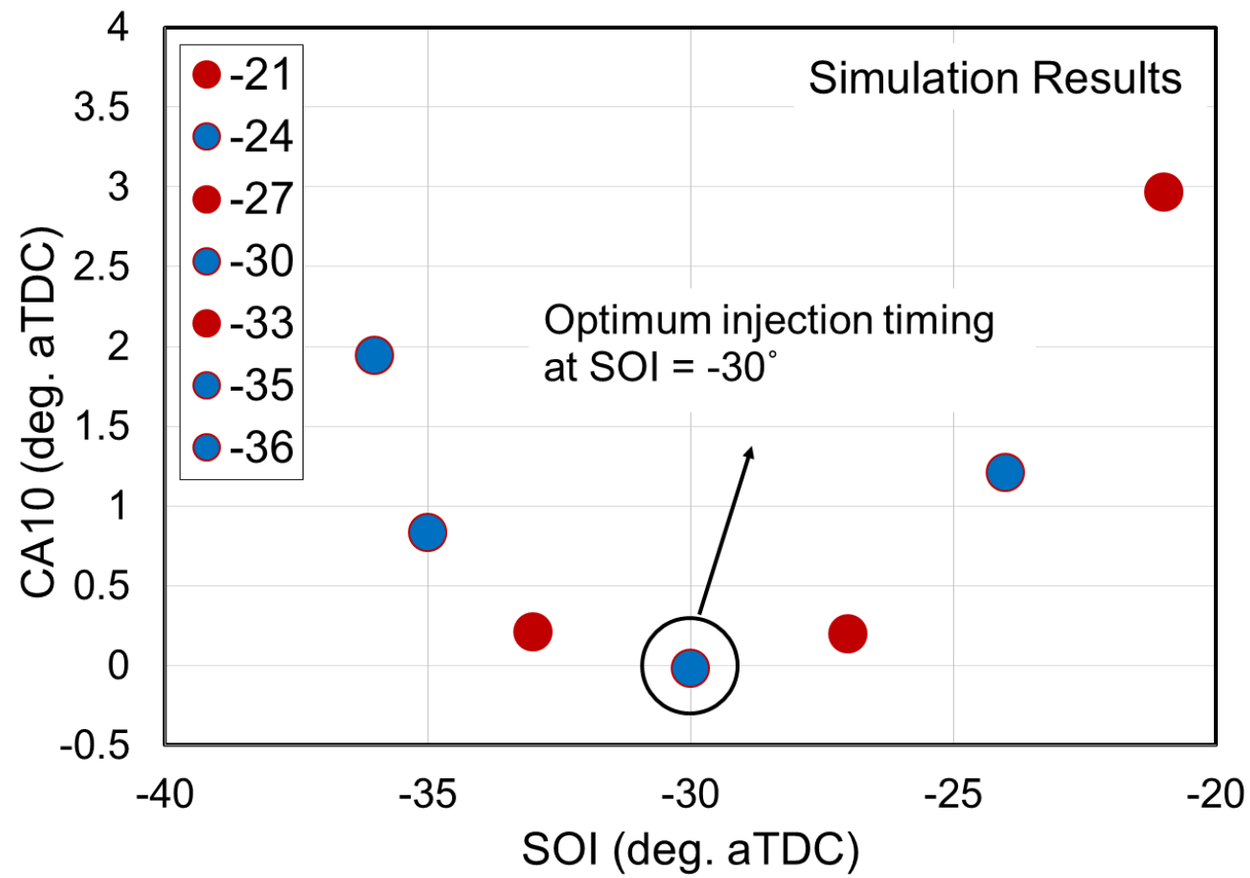
CFD captures experimental trend

EXPERIMENTS*



Variable Fueling: 9.4 – 11.7mg /cycle

CFD SIMULATION

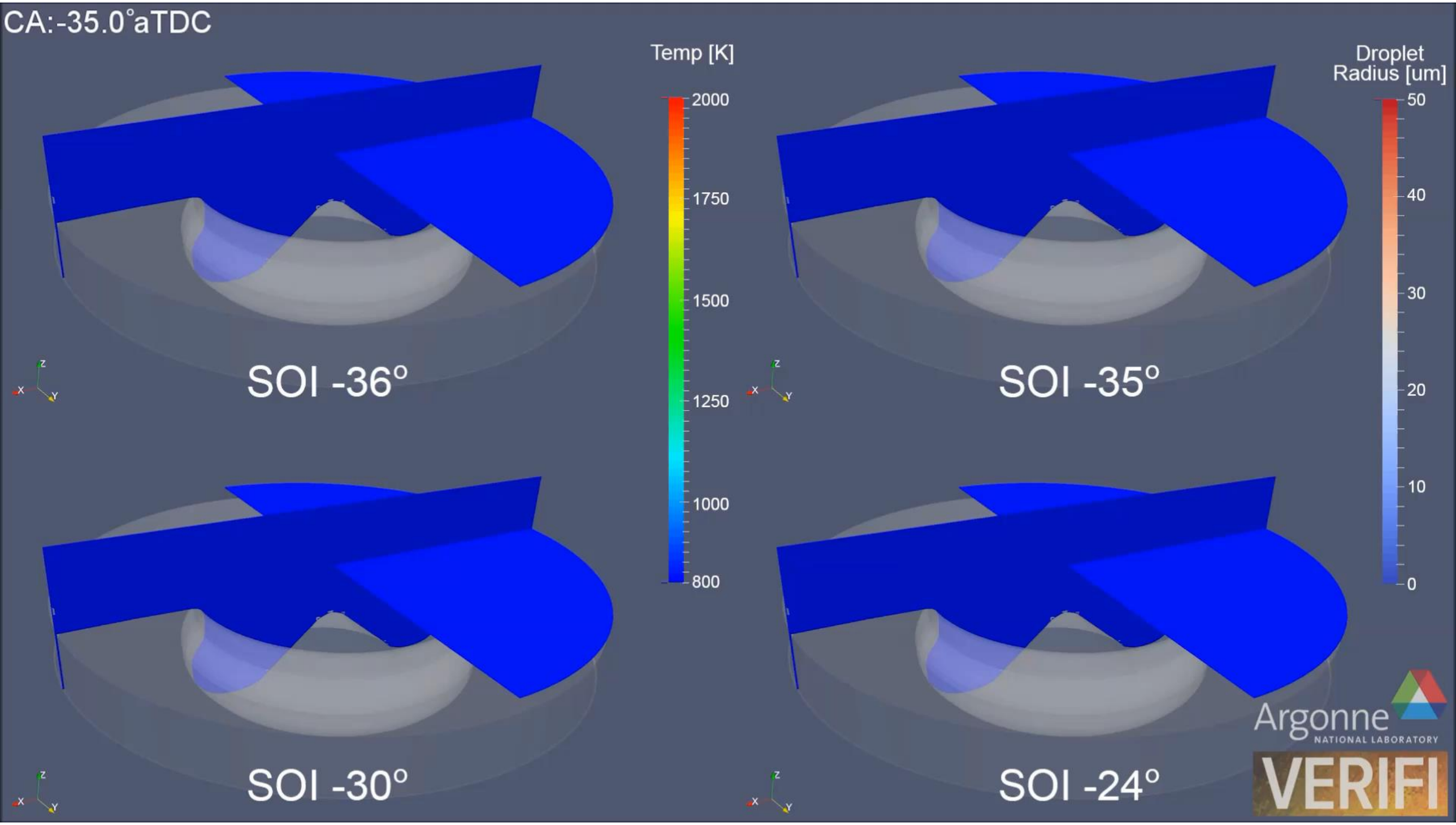


Fixed Fueling: 9.68 mg /cycle

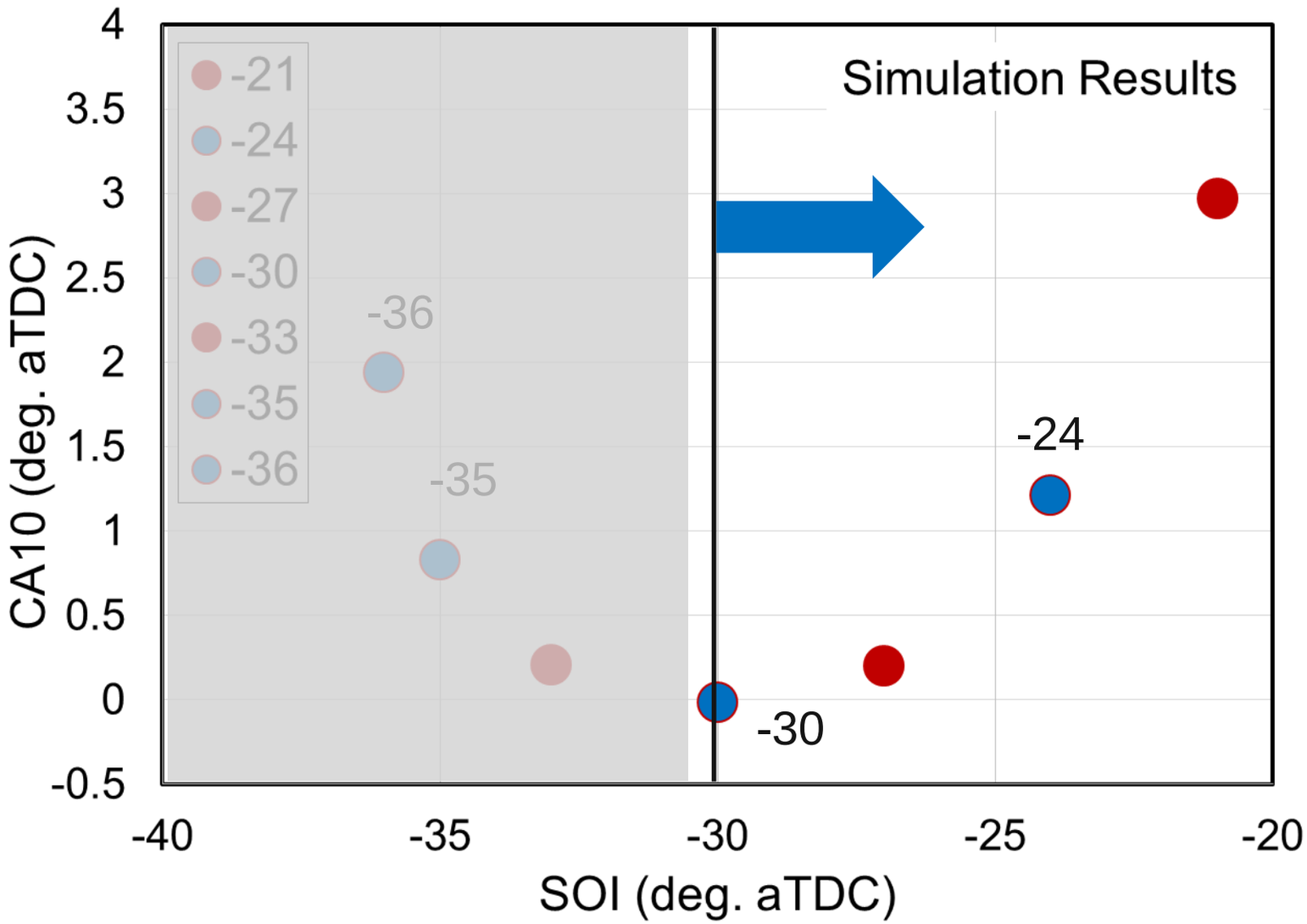
*Experiments : Kolodziej et al, SAE 2014-01-1302

1500 RPM, 250 bar P_{inj}

Effect of injection timing

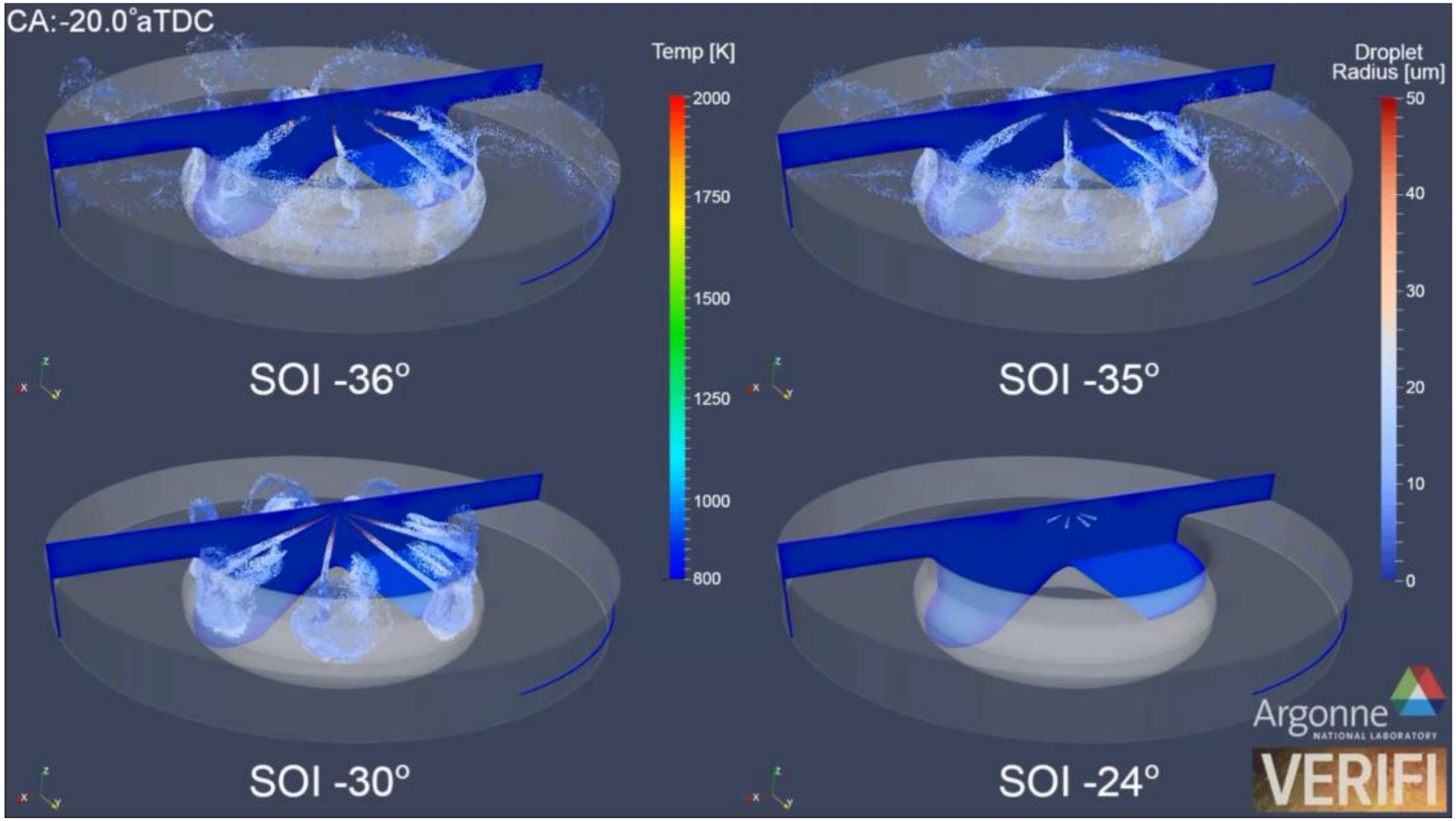


Effect of late injection



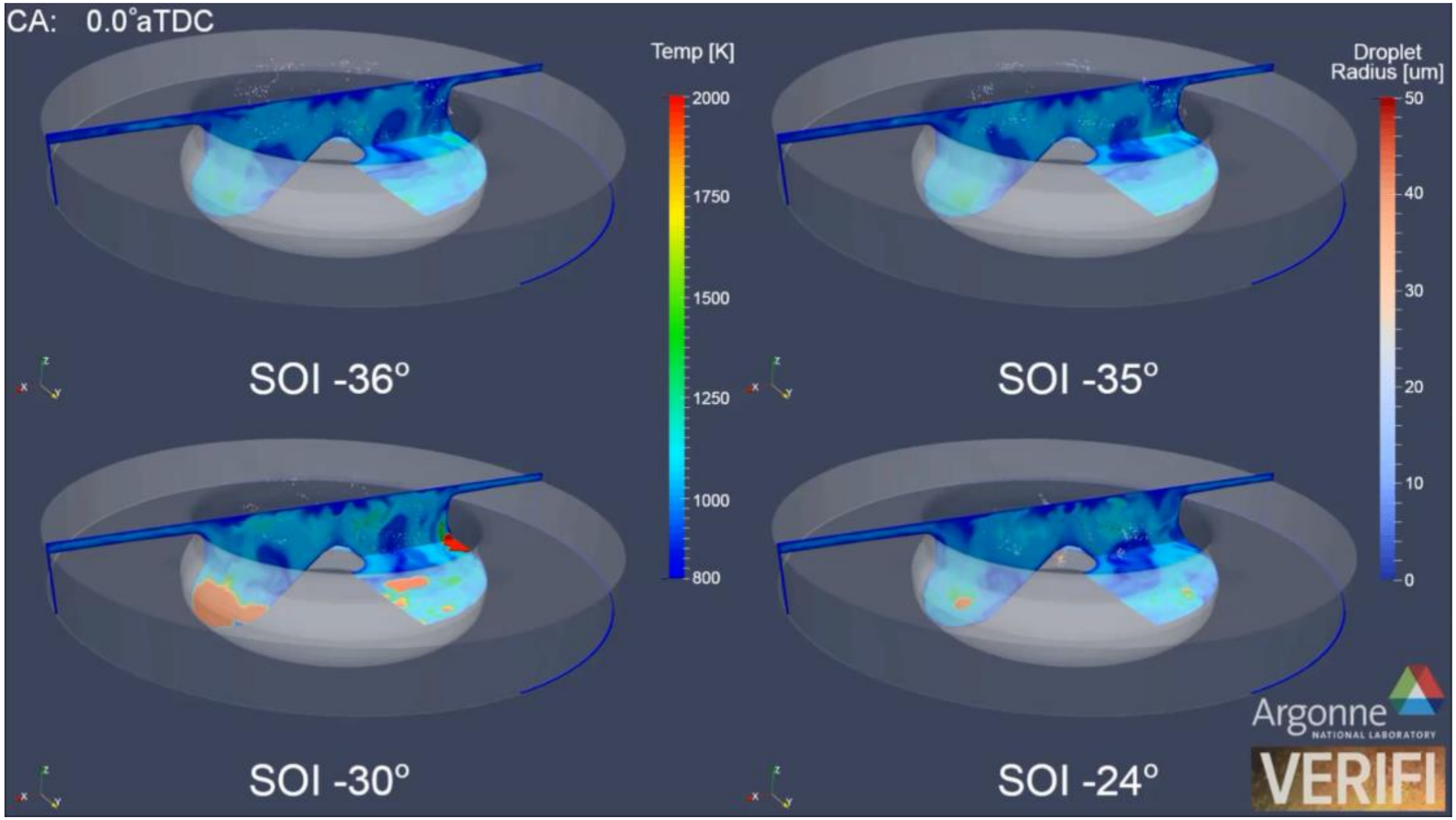
- Let's compare -30˚ with the later injection timing of -24˚

Effect of later injection – Reduced residence time



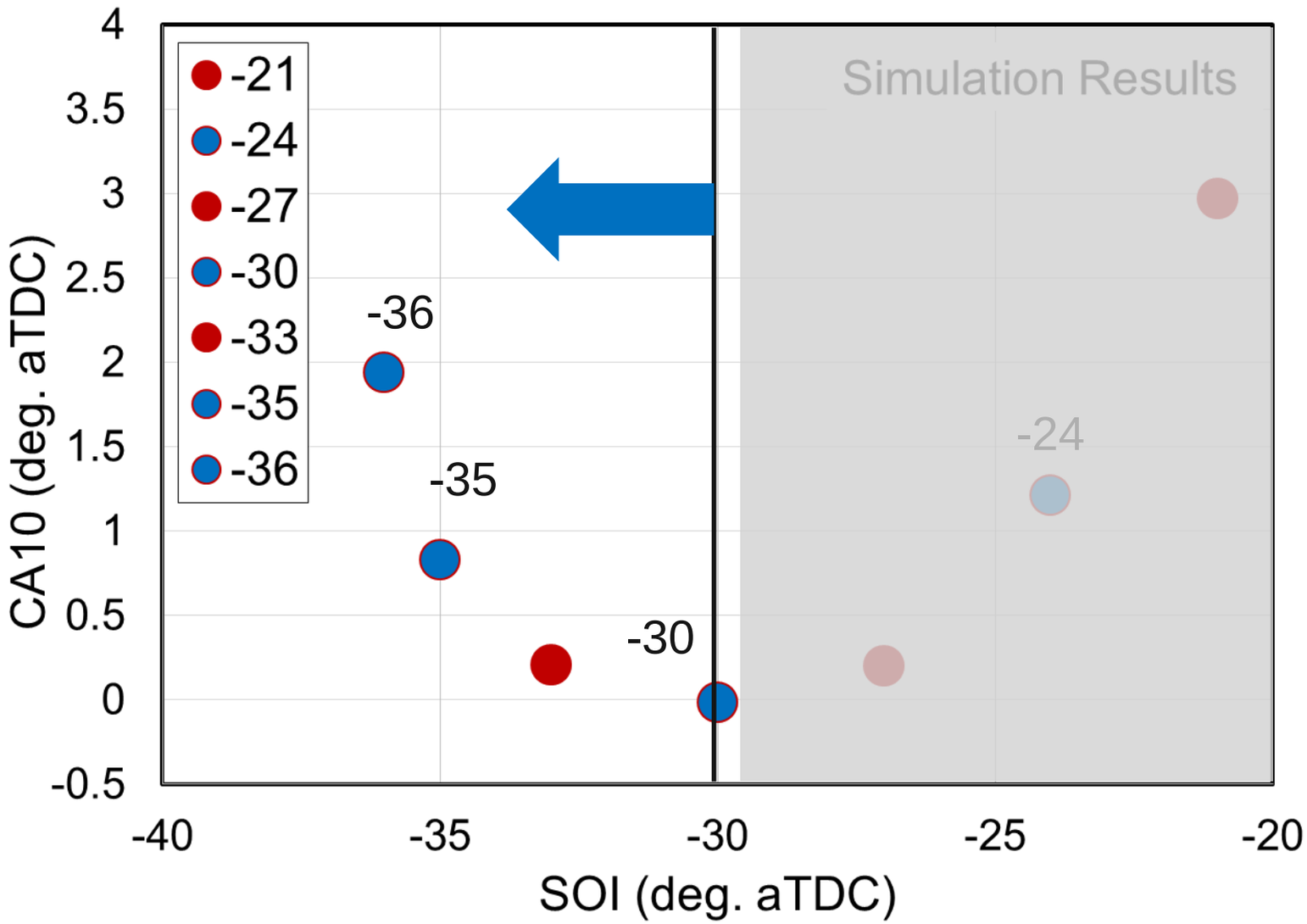
- Less time for fuel to breakdown, and react by TDC

Effect of later injection – Later ignition



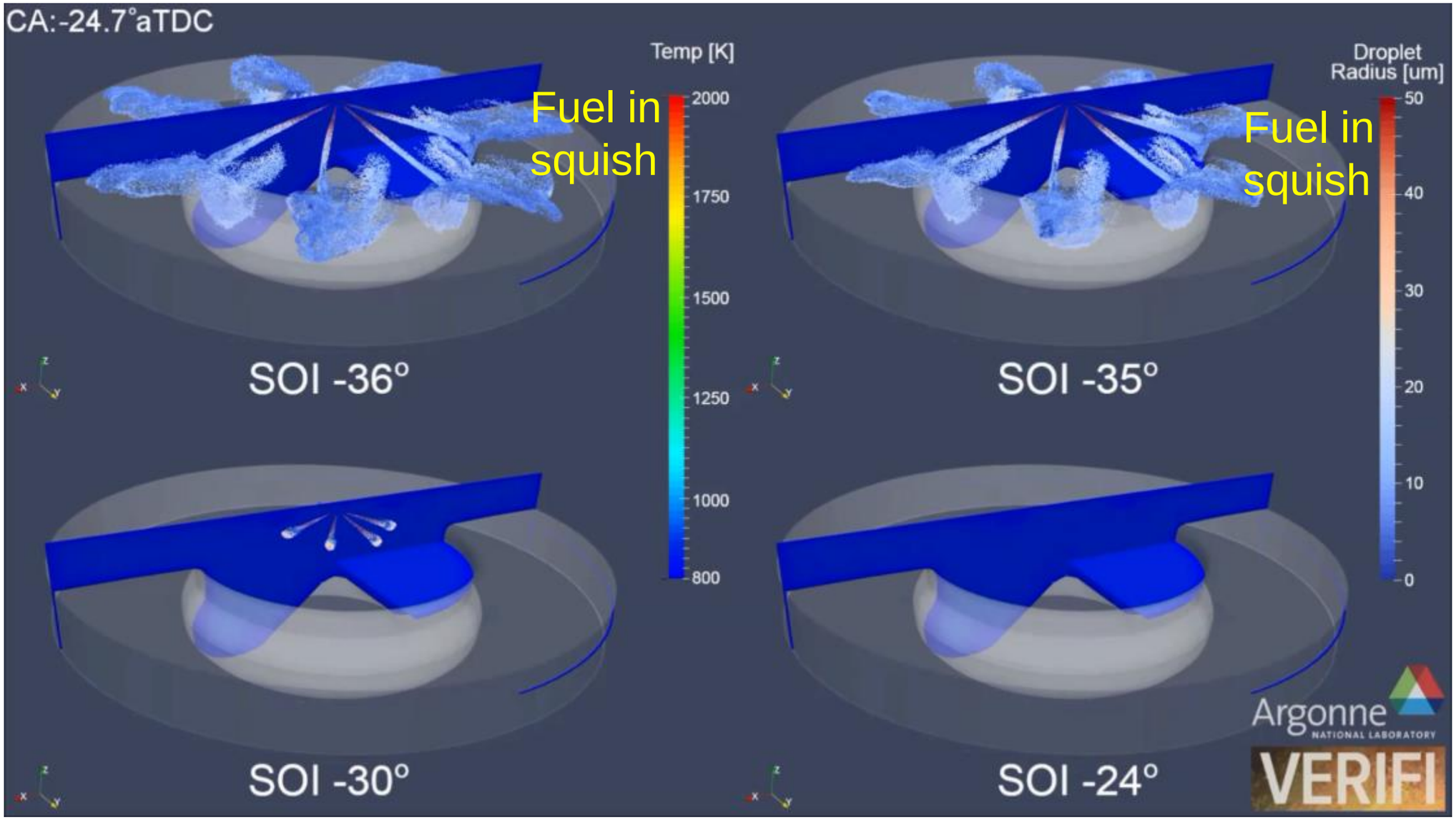
- Later CA10 timing is related to delay in SOI

Effect of early injection



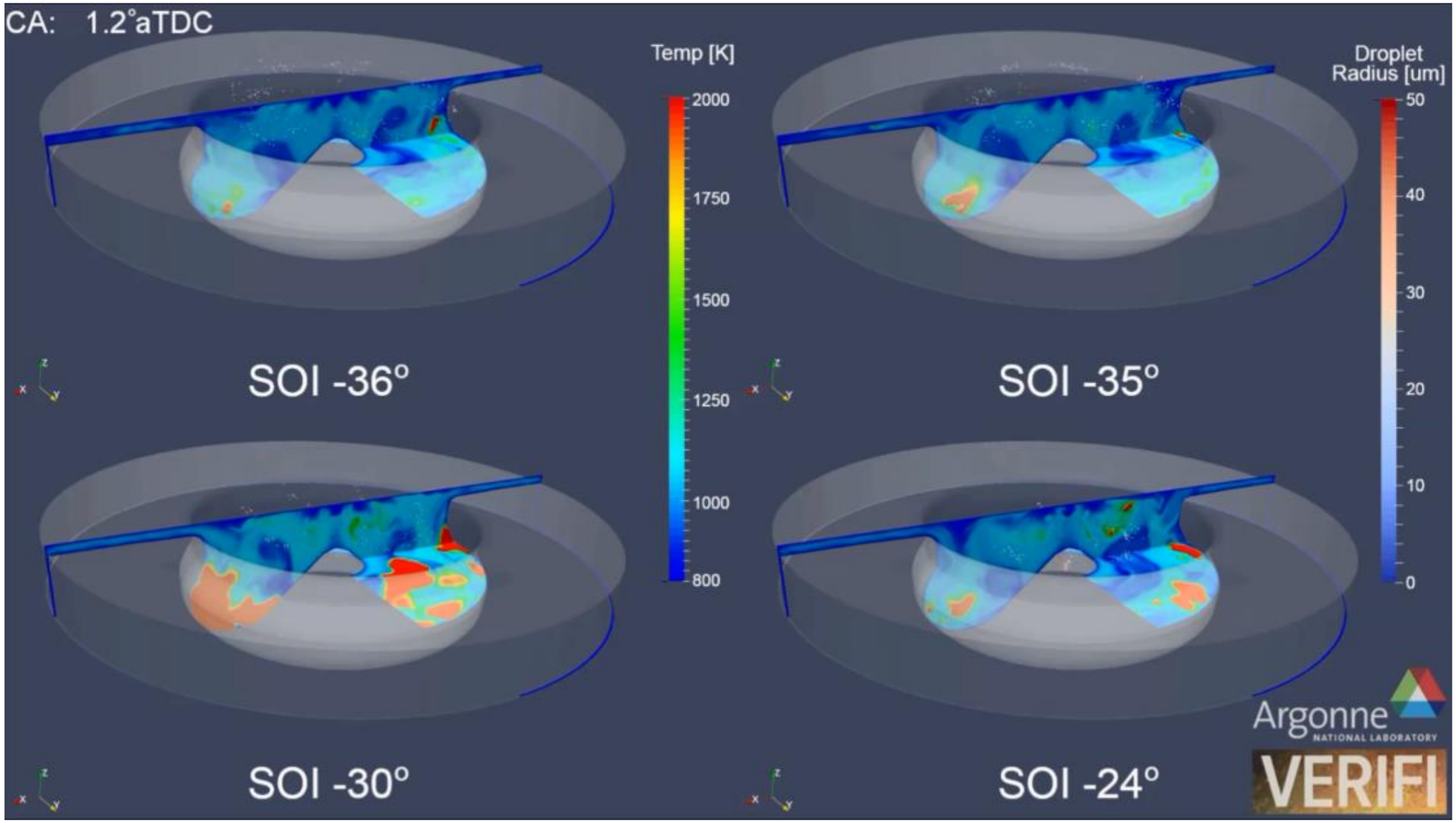
- Let's compare -30˚ with the earlier injection timings of -35˚ and -36˚

Effect of early injection – Fuel in squish



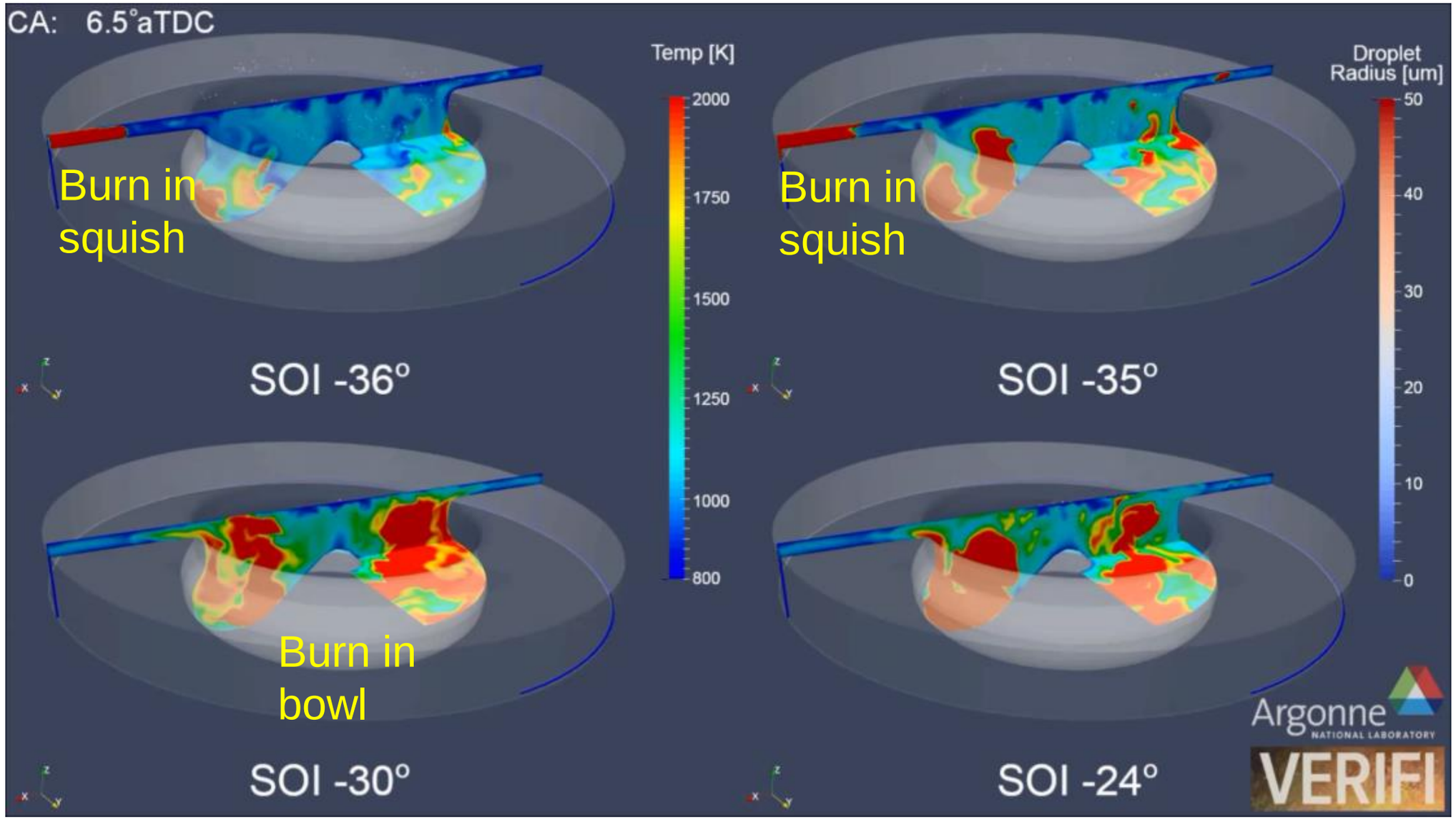
- Fuel in squish is less reactive – higher rate of heat loss
- Overall reactivity of mixture is reduced – ignite later

Effect of early injection – Later ignition



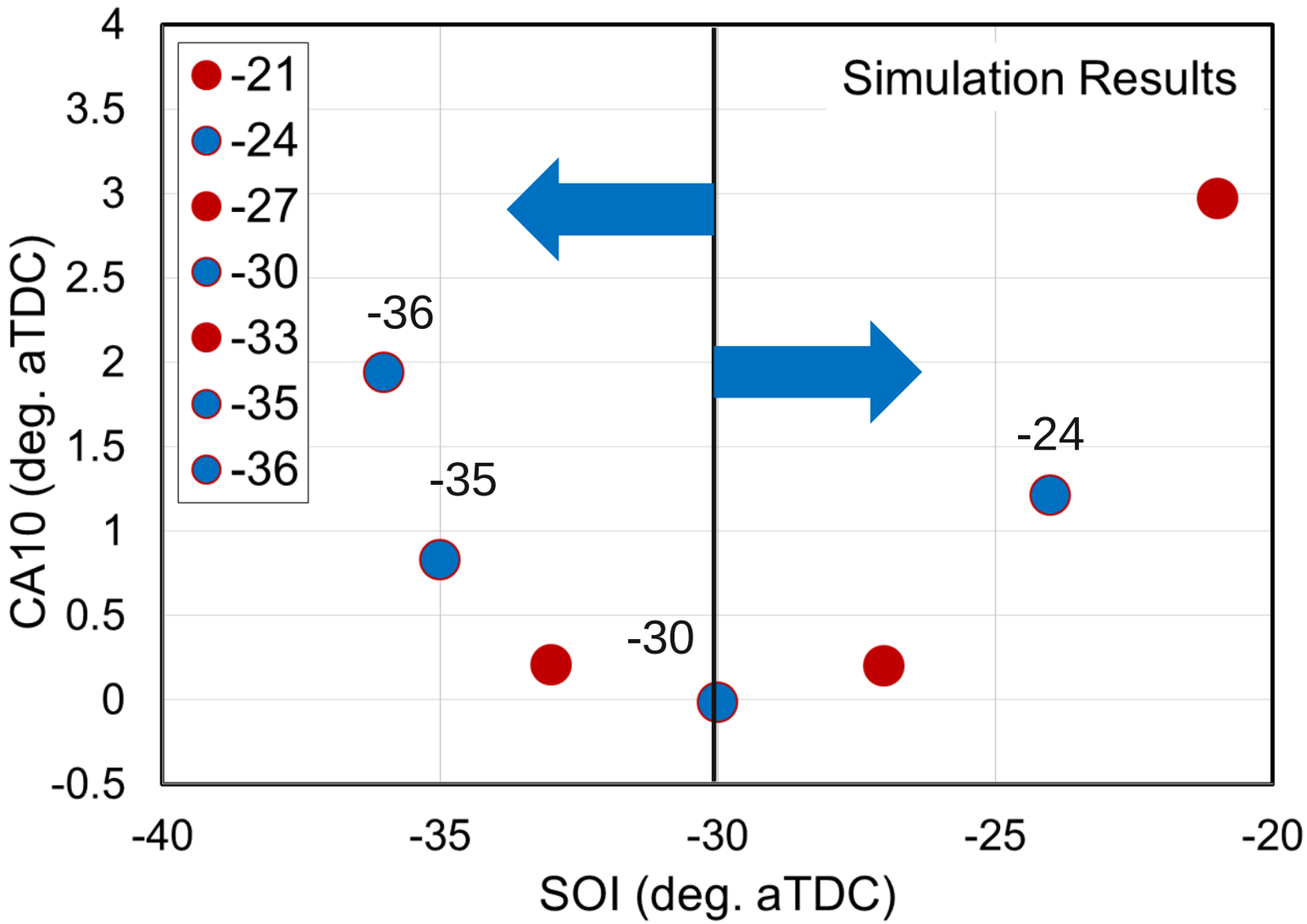
- Ignite later for the early injection cases (SOI = -36˚ and -35˚)

Effect of early injection – Burn slower



- Fuel in squish burns slower lowering the overall rate of heat release
- Further reduces combustion stability

Explanation for CA10 vs. SOI trend

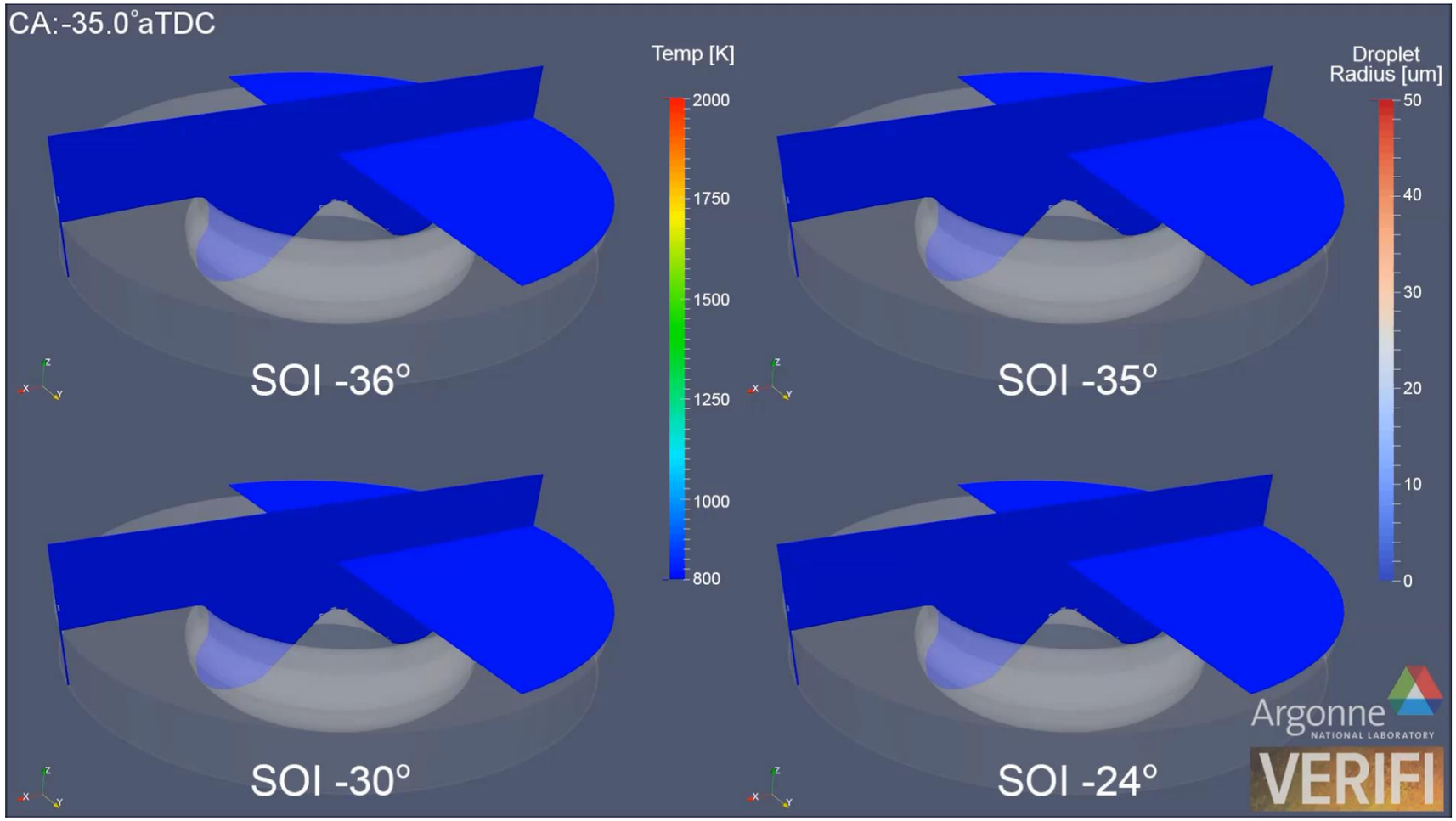


- Inject late – less time for fuel to breakdown and autoignite
- Inject early – fuel in squish, less reactive, ignites later, burns slower

Summary of Insights and Future Work

- CFD captures experimental trend in combustion stability vs. SOI
- Optimum SOI timing identified from simulations
  - Injecting earlier than optimum – fuel in squish
  - Injecting later than optimum – reduction in residence time
- Insights
  - Use smaller nozzle angle, say 120˚
  - Study effect of injection pressure and swirl
- Future work:
  - Optimization of injection pressure, inclusion angle, swirl using CFD
  - Open-cycle, multi-cylinder, multi-cycle simulations
  - HPC Front: ~ 100 million to 1 billion cells, 1 rack of Mira (16K processors)

Thank you



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