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COMBUSTION RESEARCH FACILITY

Progress Towards In-Cylinder PIV Measurements throughout the Full Intake and Compression Strokes

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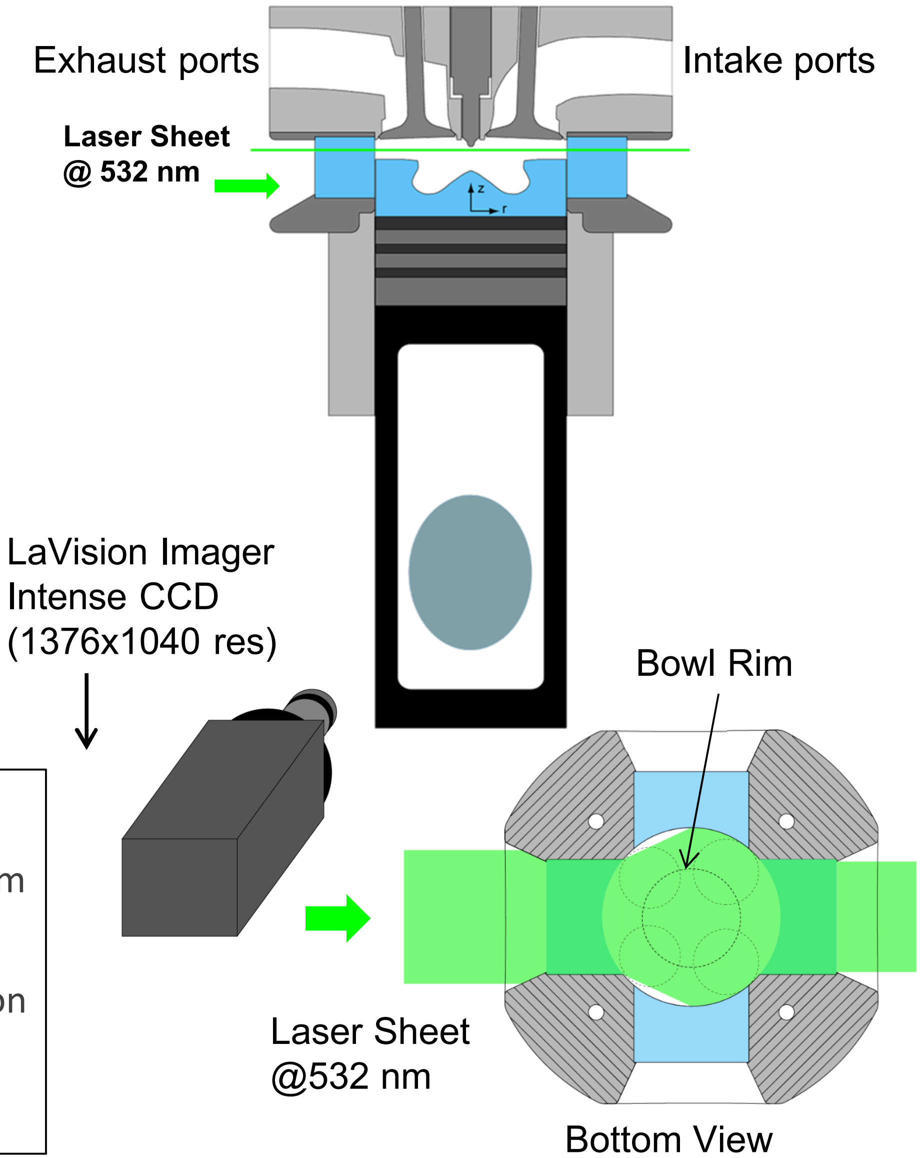
Swirl-Plane PIV Measurement Test Cases

GM 1.9 L Diesel Engine	
Bore	82 mm
Stroke	90.4 mm
Displacement Volume	0.477 L
Geometries CR	16.7
Squish Height	0.78 mm
Intake / Exhaust Valves	2 / 2
Swirl Ratio	1.5, 2.2, 3.5
Engine Speed	1500 rpm
Intake Pressure	1.5 bar
Intake Temperature	99 degC
Coolant Temperature	~89 degC
O2 Mole Fraction	10%

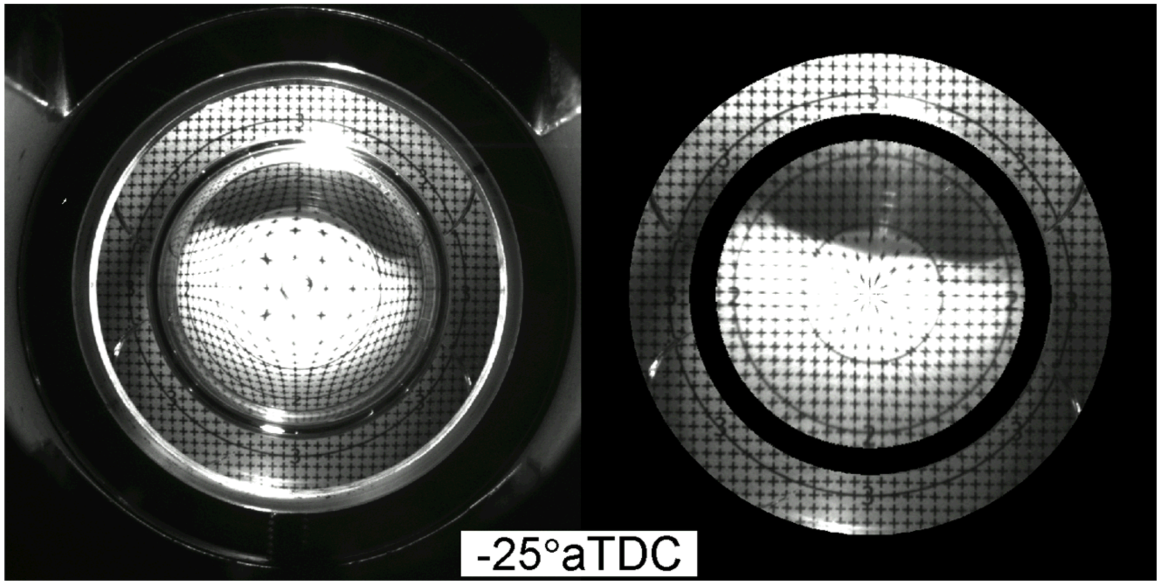
Improvement

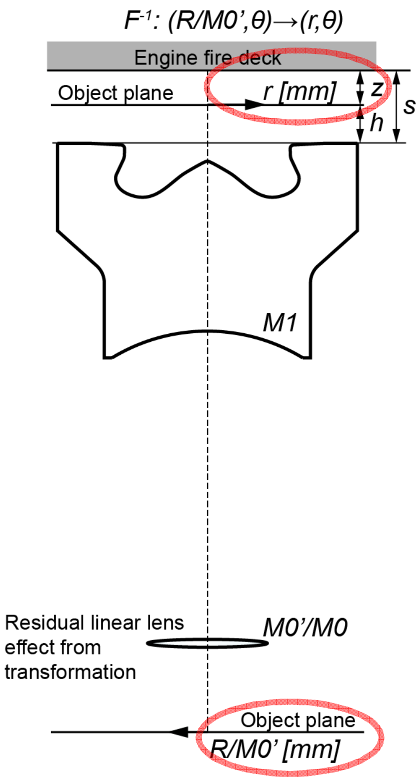
- Less perspective error (thinner laser sheet, minimum waist thickness ≈500 μm).
- Less background interference (black-painted piston and chamber).
- Optimized camera aperture opening ($f^{\#} = 11$).



Radial Mapping Function

Raw Target Image Dewarped Target Image



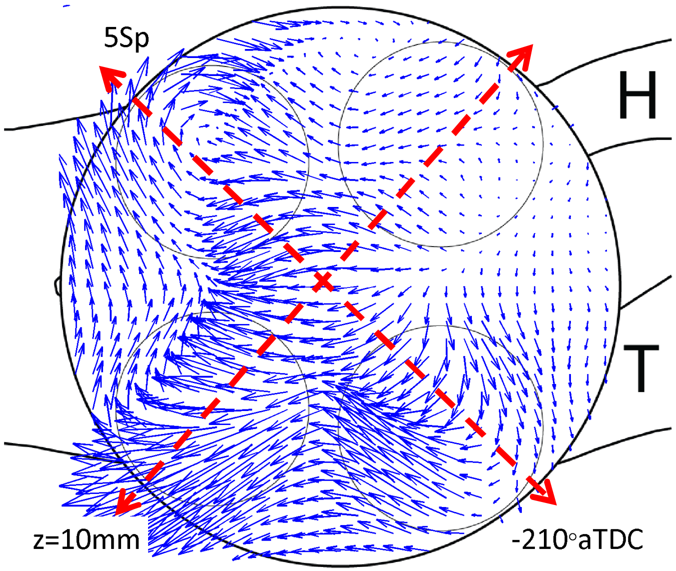


- Optical distortion induced by this piston geometry is spatially and temporally dependent.
- The transformation pattern is different in the bowl, injector exit, squish zone and valve cut-out region.

Data Processing Method Comparison

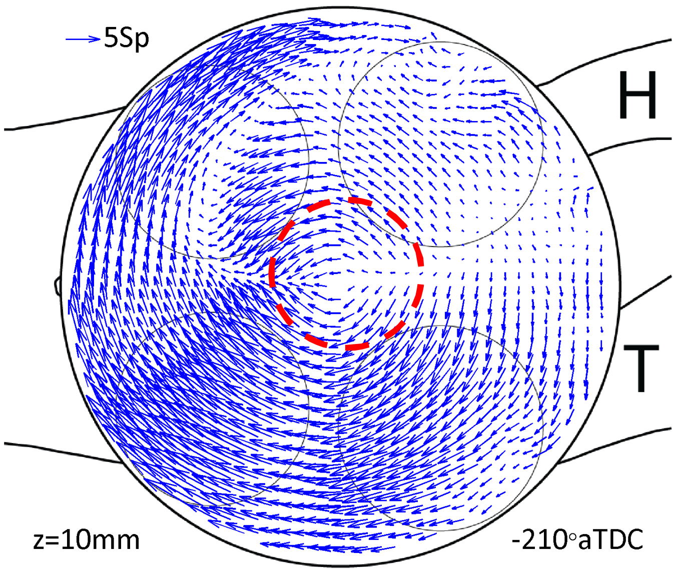
Method A

- Step1: Dewarp the image
- Step2: Perform the cross-correlation

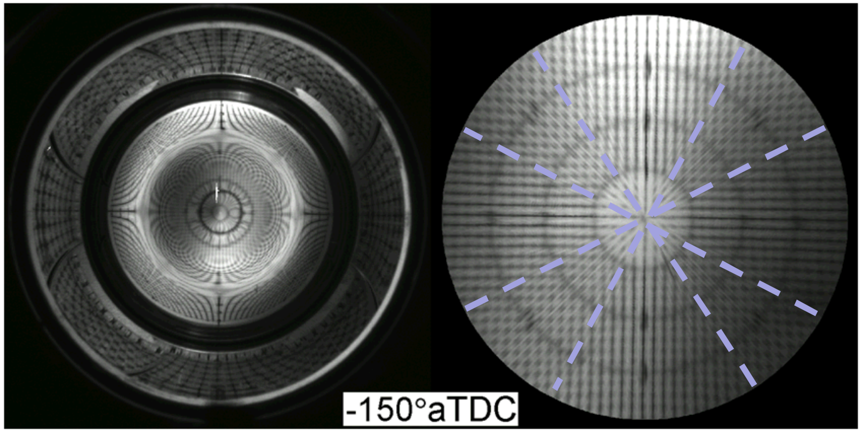


Method B

- Step1: Perform the cross-correlation
- Step2: Dewarp the velocity vectors



Raw Target Image | Dewarped Target Image

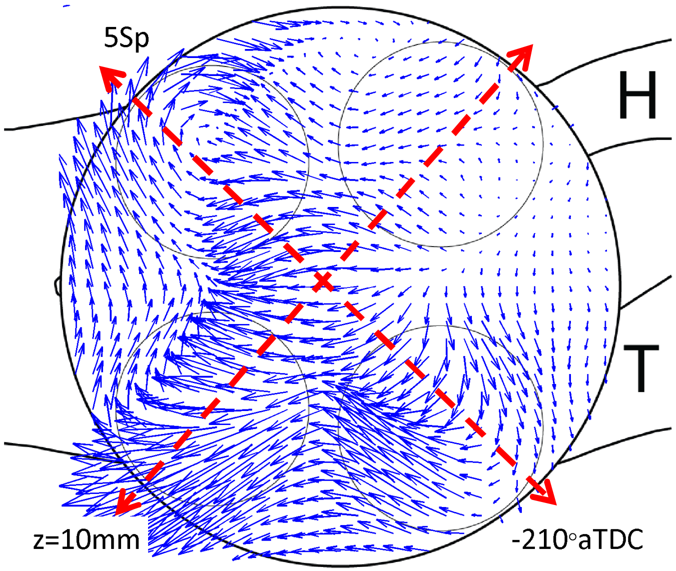


- Advantage: avoid radial velocity error near BDC.
- Disadvantage: vectors near center is less reliable.

Data Processing Method Comparison

Method A

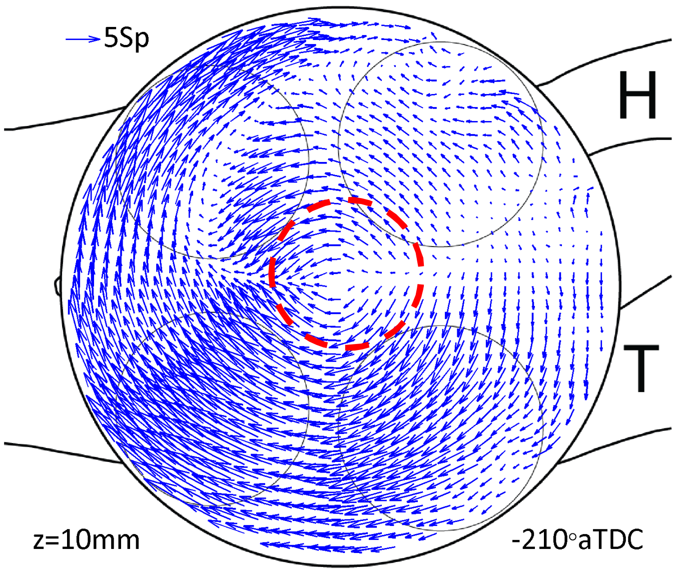
- Step1: Dewarp the image
- Step2: Perform the cross-correlation



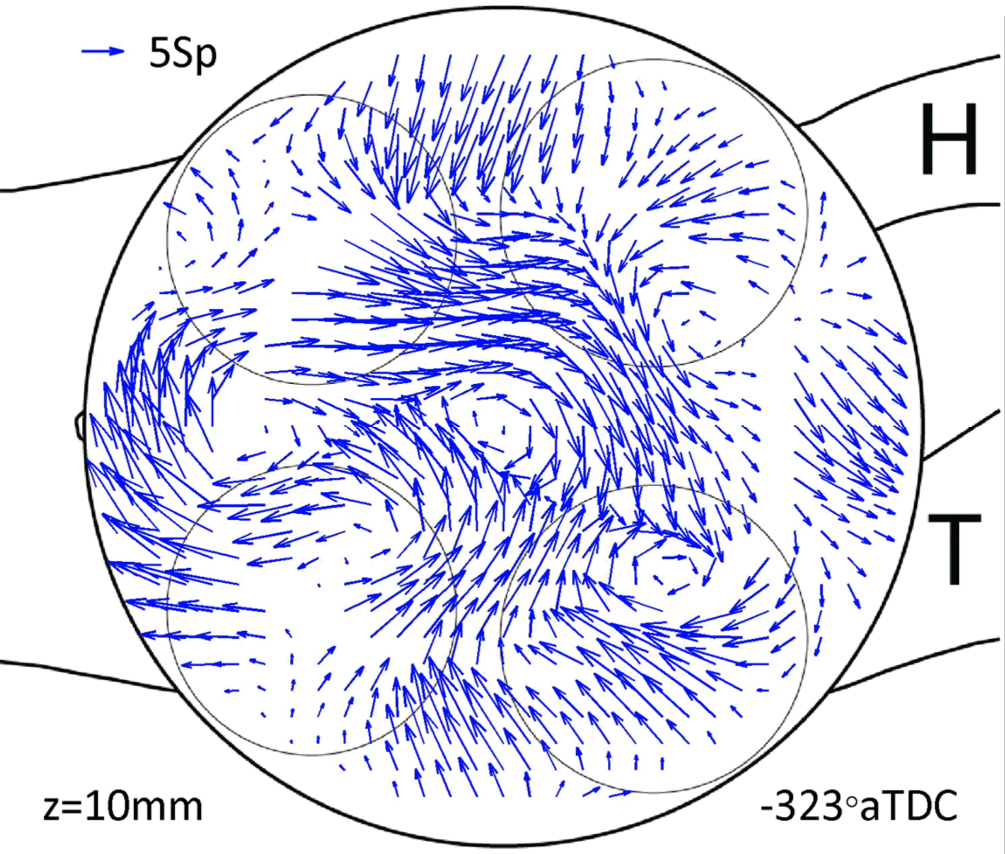
- Disadvantage: create large radial velocity error near BDC.
- Advantage: velocity near center is more reliable.

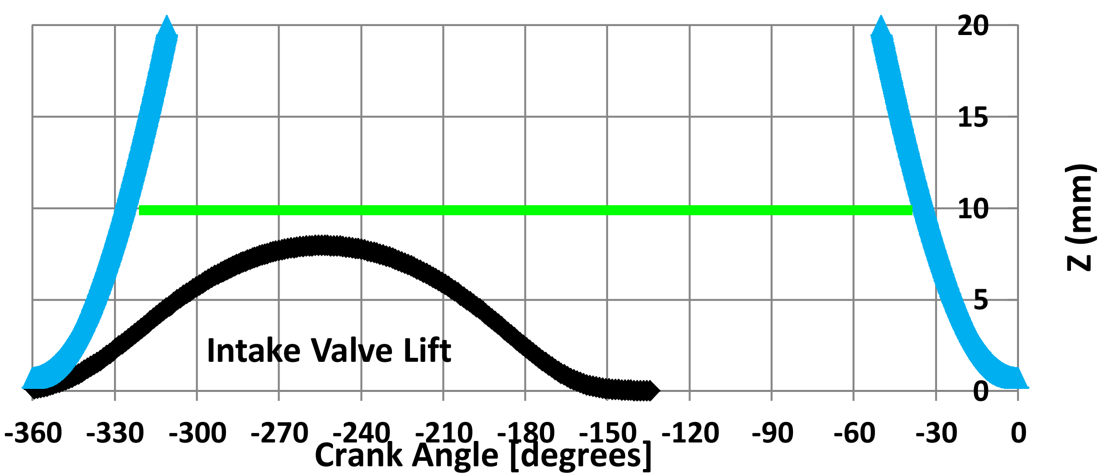
Method B

- Step1: Perform the cross-correlation
- Step2: Dewarp the velocity vectors



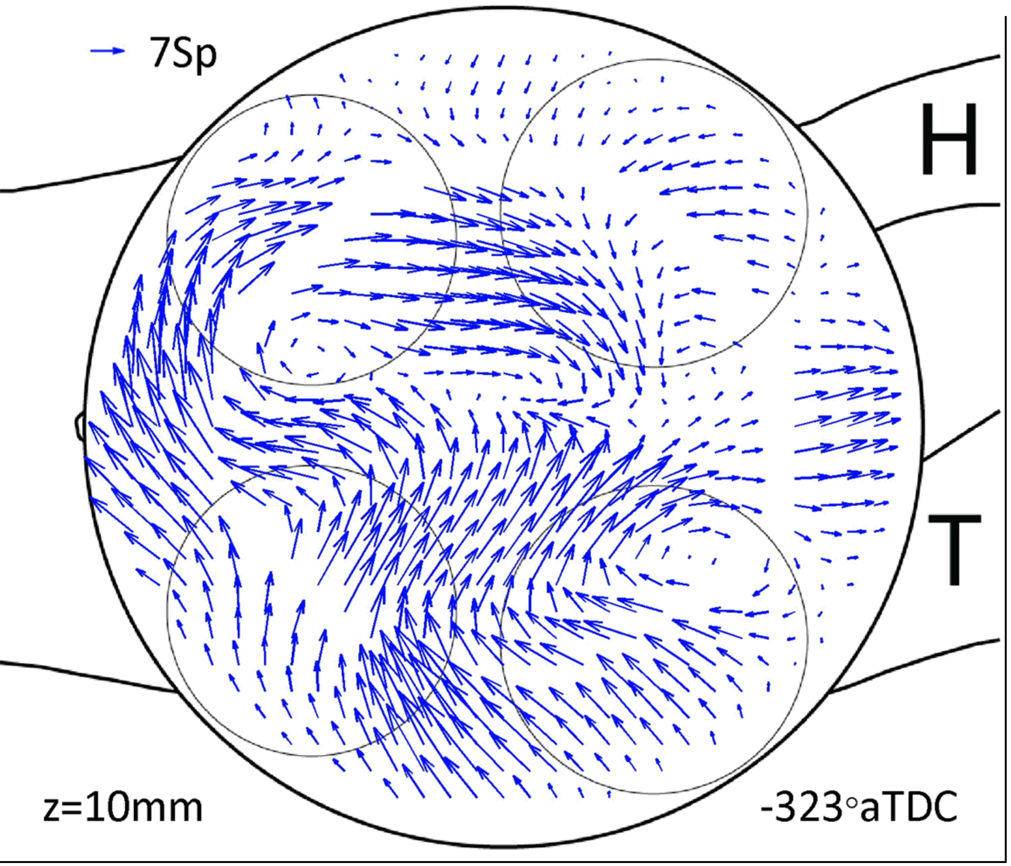
- Advantage: avoid radial velocity error near BDC.
- Disadvantage: velocity near center is unreliable, will induce error in swirl center detection.

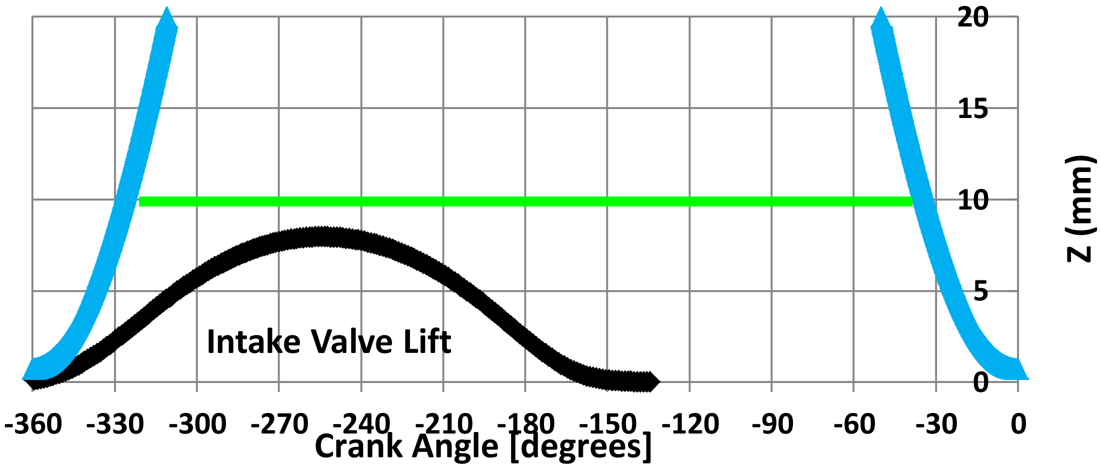




- Method A is used for PIV in the early intake stroke and late compression stroke.
- Method B is used for PIV in the late intake stroke and early compression stroke.
- Near maximum valve lift, the counter-clockwise flow from helical port behave as a “momentum wall” and a recirculation zone is observed facing the clockwise tangential flow.
- As intake valve is closing, both clockwise and counter-clockwise flow velocity is getting smaller.
- Large scale swirl feature is observed in z=10mm plane at BDC.

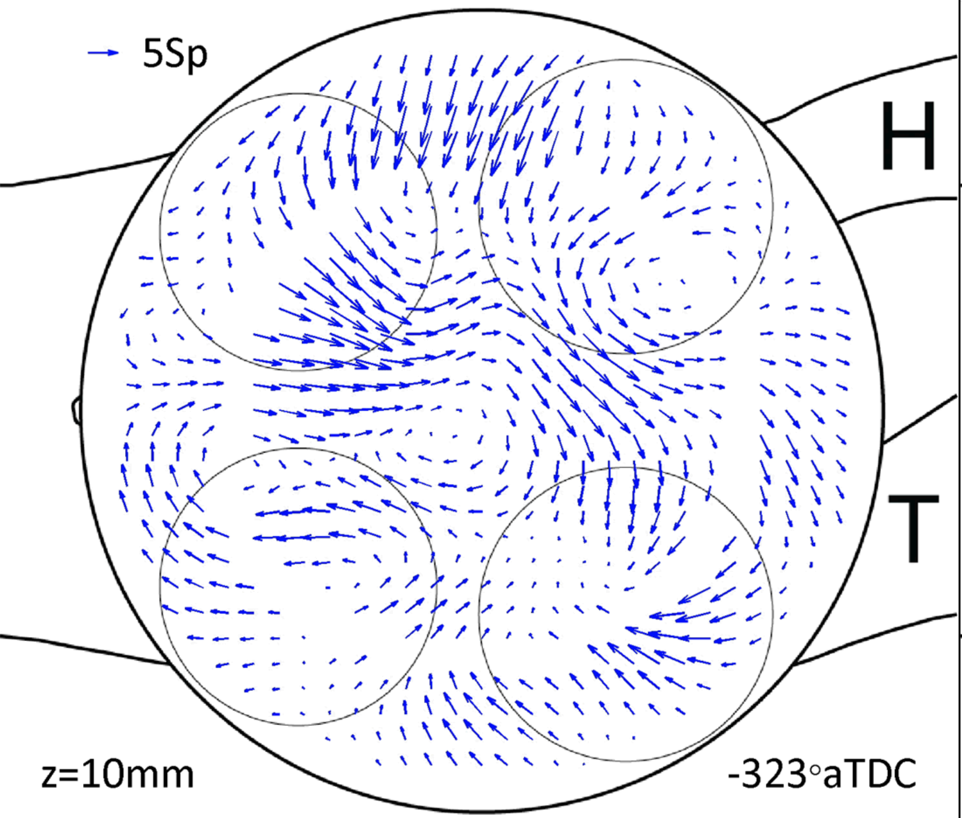
Rs=3.5

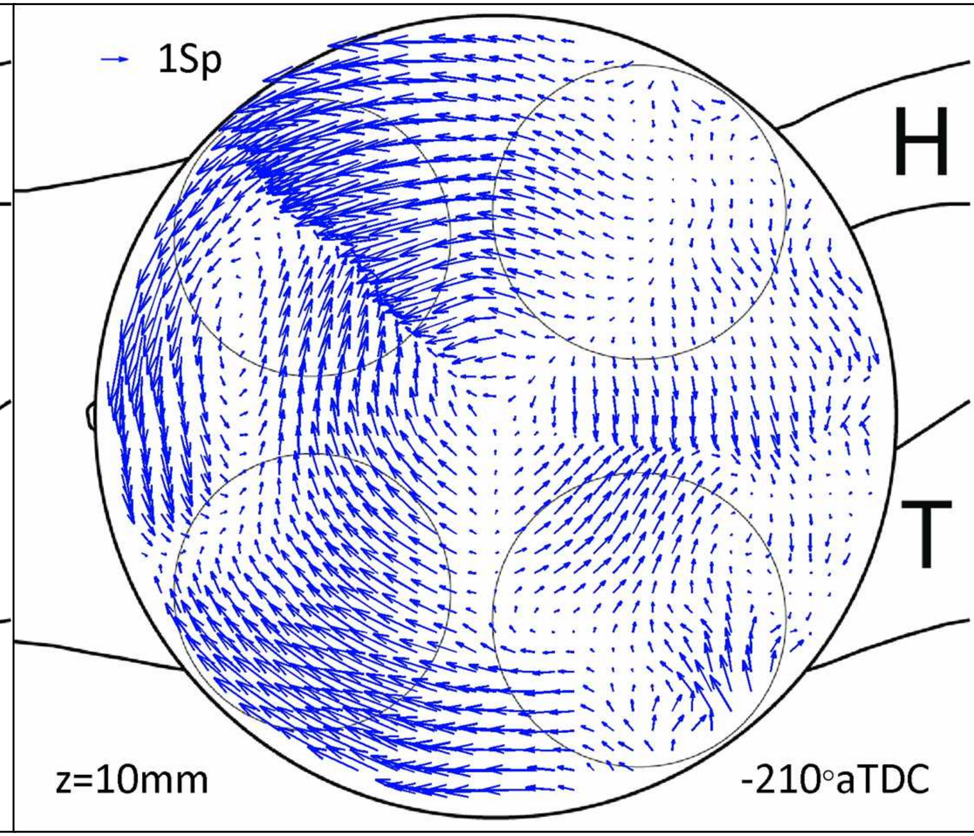


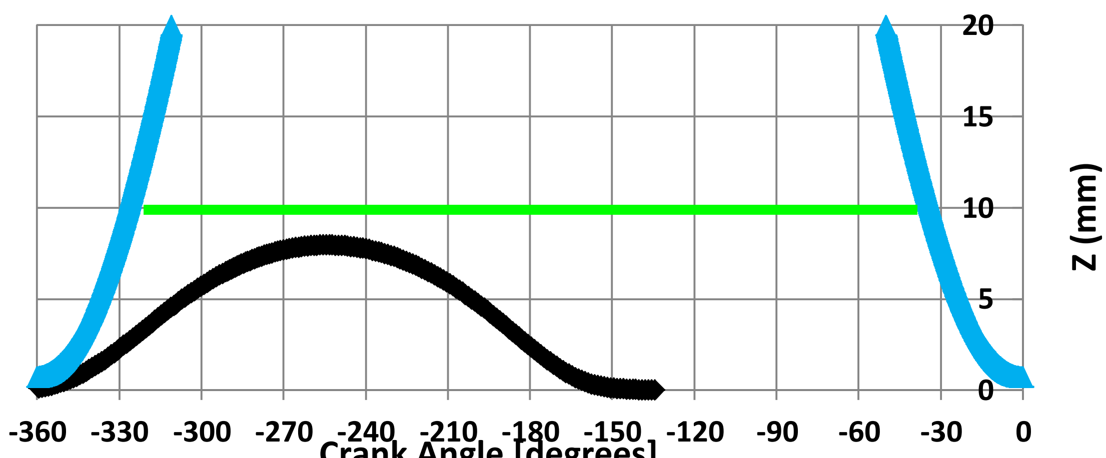


- Since the helical port is throttled, the wide open tangential port generates strong clockwise angular momentum which leads to larger swirl ratio.
- As intake valve is closing, both clockwise and counter-clockwise flow velocity is getting smaller.
- Large scale swirl feature is observed in z=10mm plane at BDC.

Rs=1.5

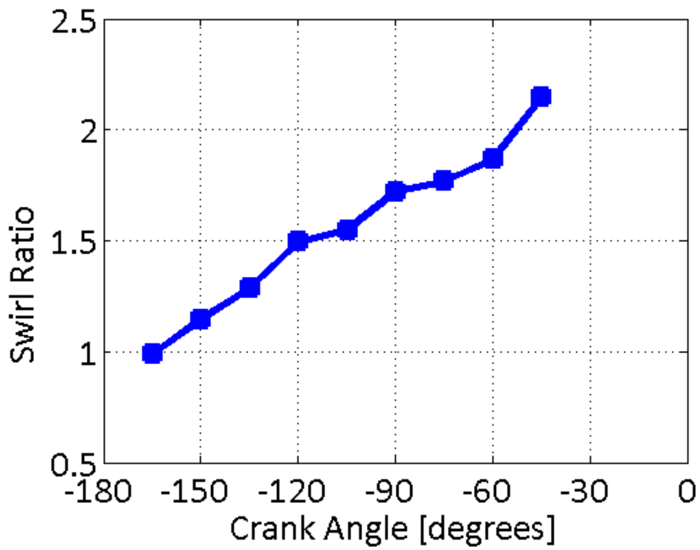




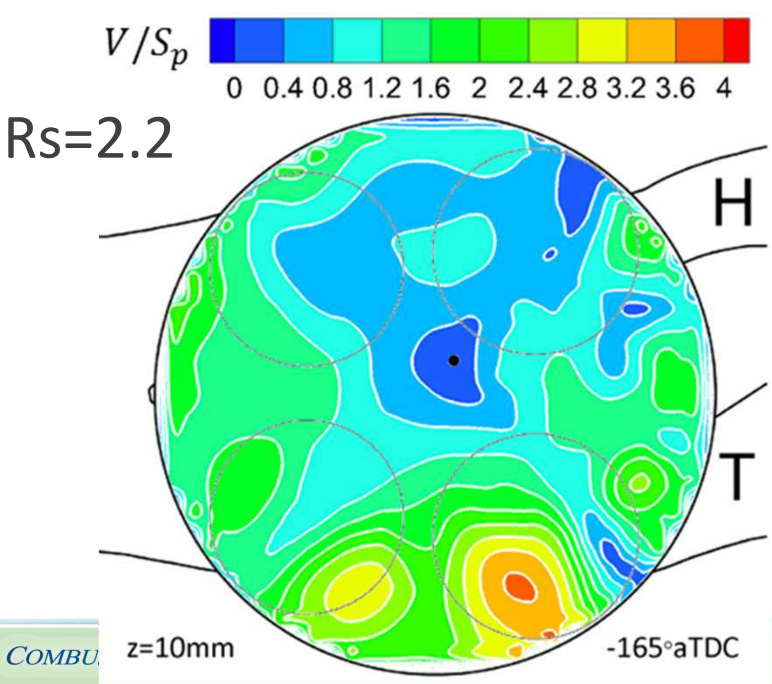


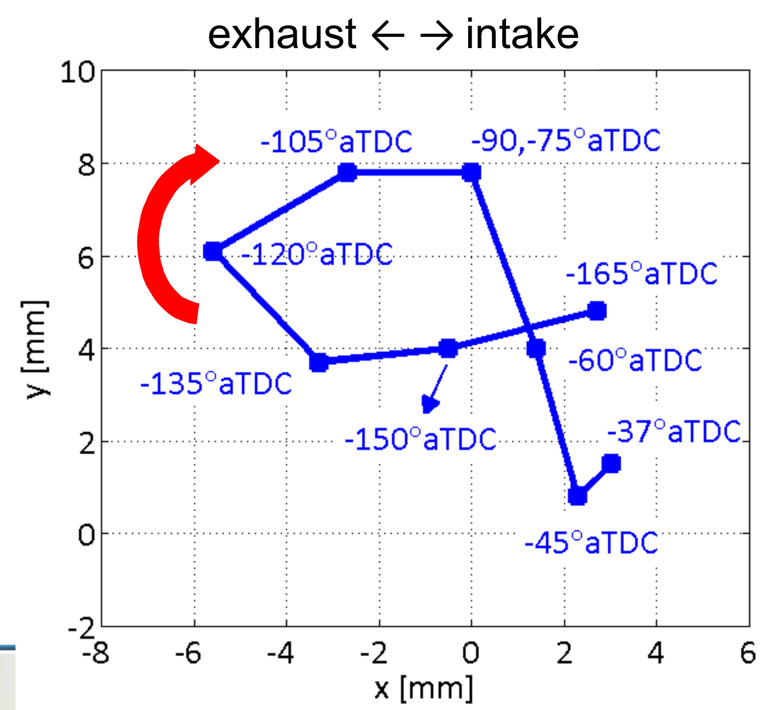
- Clockwise and counter-clockwise flow are both present at intake valve close (around -150^{o}aTDC).
- Until the end of compression stroke at -45^{o}aTDC, clockwise flow is observed in z=10mm plane.

Swirl Ratio Evolution and Swirl Center Location

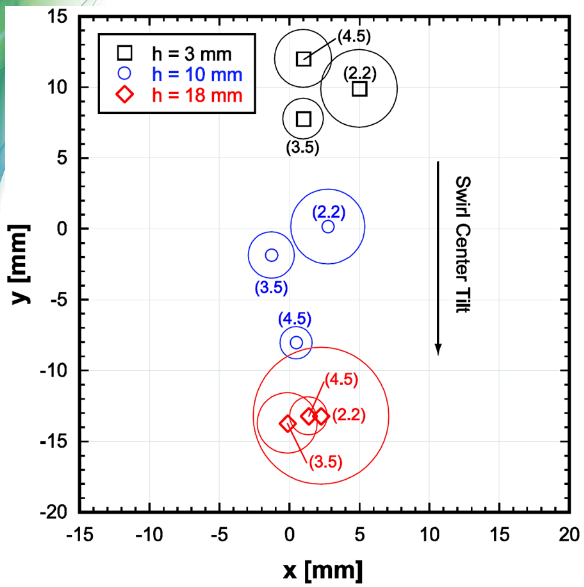


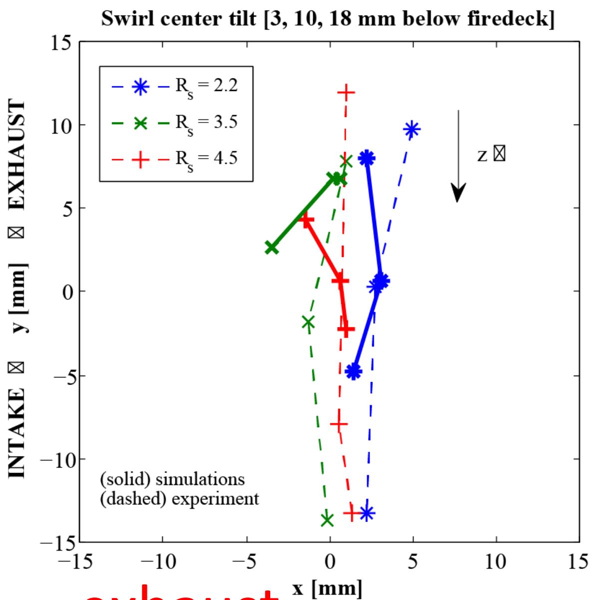
- The swirl ratio measured within each plane increases as the piston approaches the firing TDC.
- In the z=10mm plane, the swirl center precession exhibits clockwise motion in general.

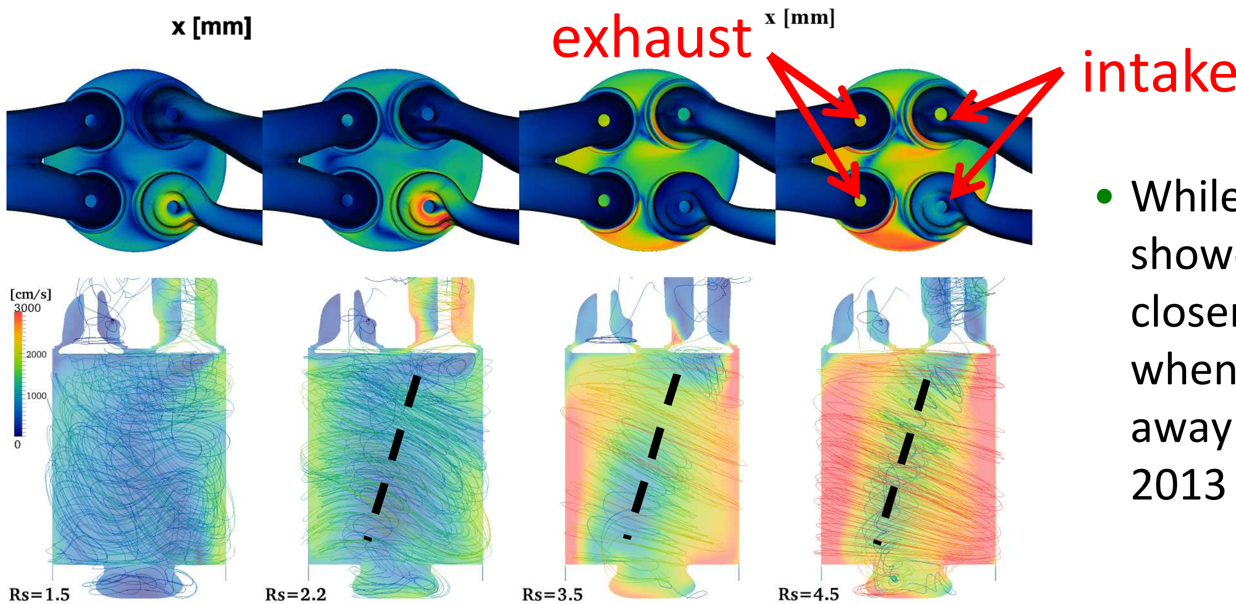




Swirl Center Location in Different Planes



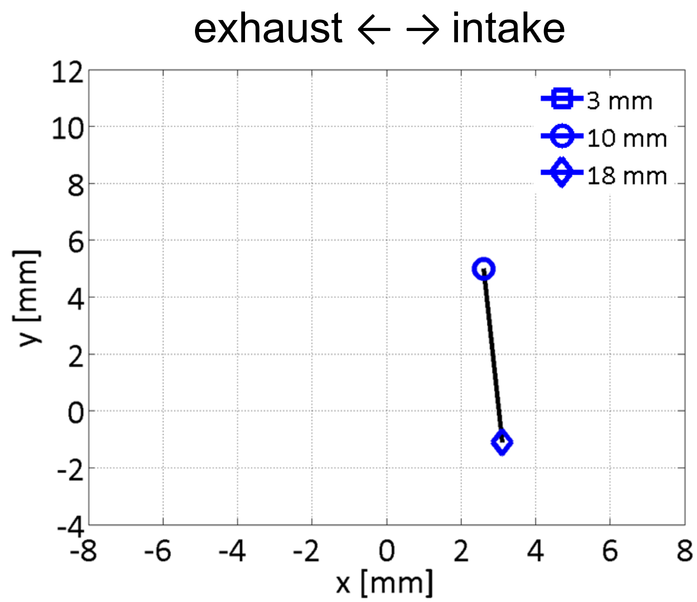


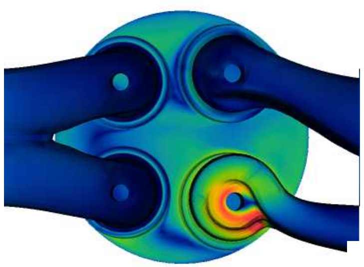


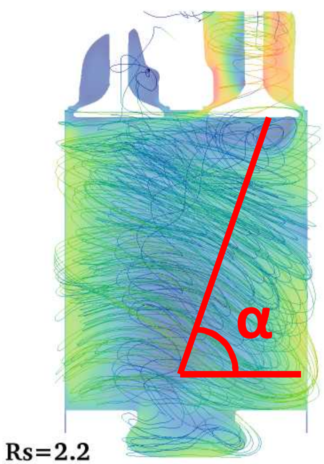
- Both experiment and simulation showed that the swirl center is closer to the intake ports when the swirl plane is farther away from the fire deck, at 50bTDC. (Petersen, SAE2011-01-1285 and Perini 2013 Computers & Fluids)

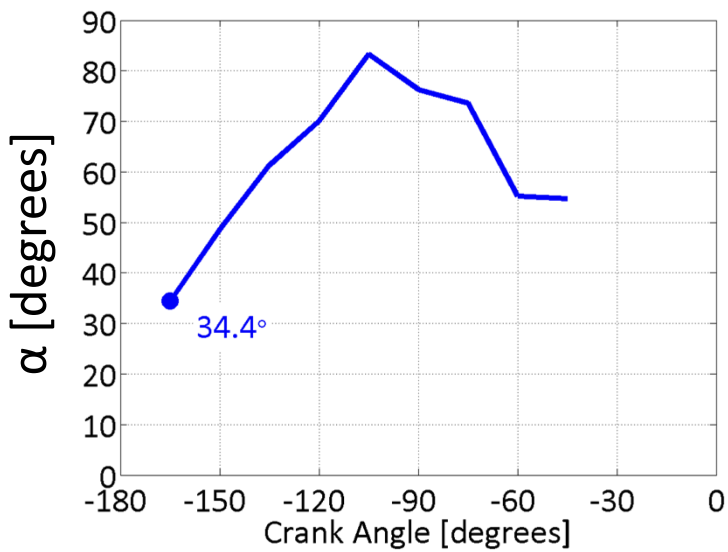
- While at BDC, simulation showed that swirl center is closer to the exhaust ports when the swirl plane is farther away from the fire deck. (Perini 2013 Computers & Fluids)

Vertical Tilting of Swirl Center Axis

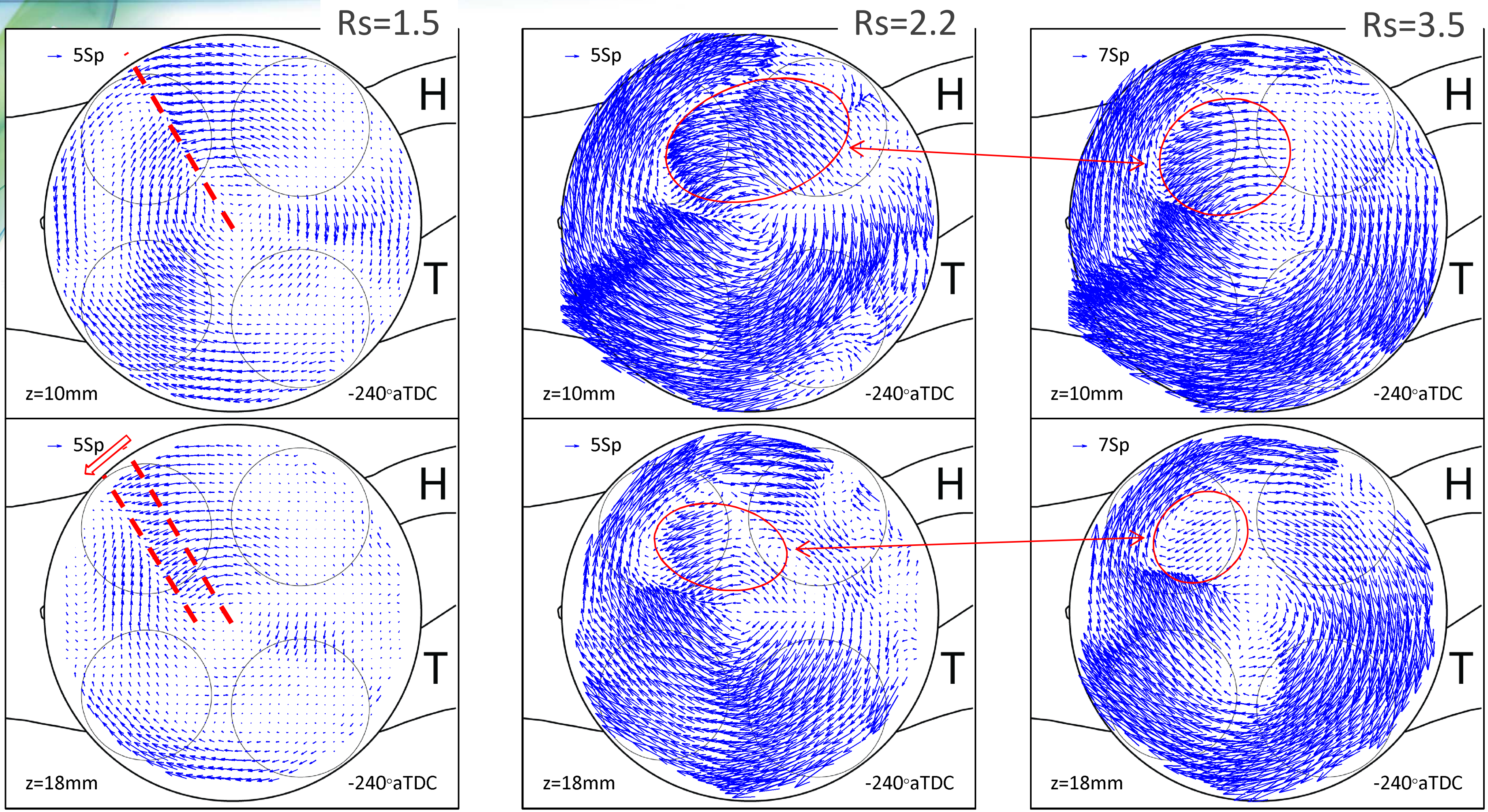




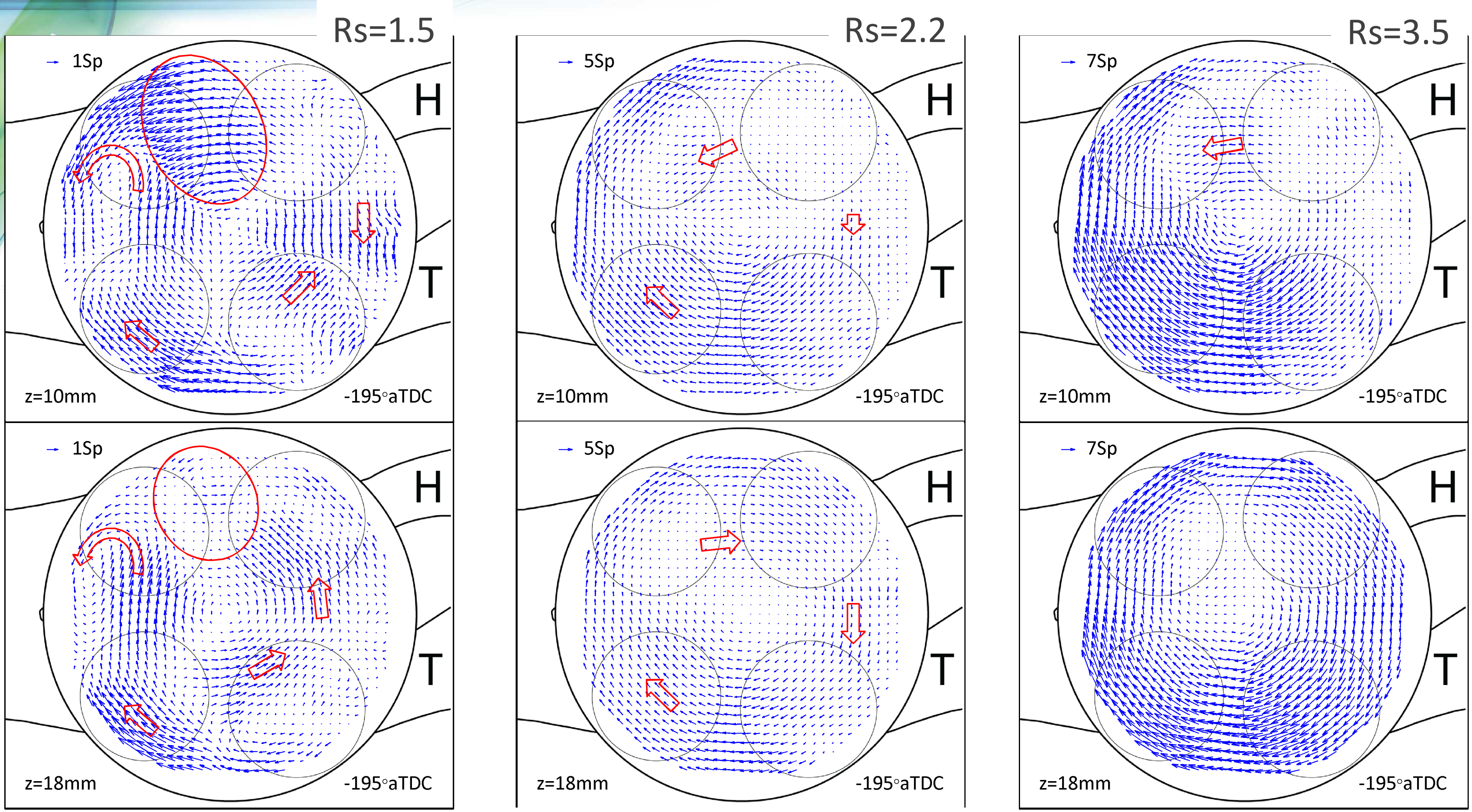




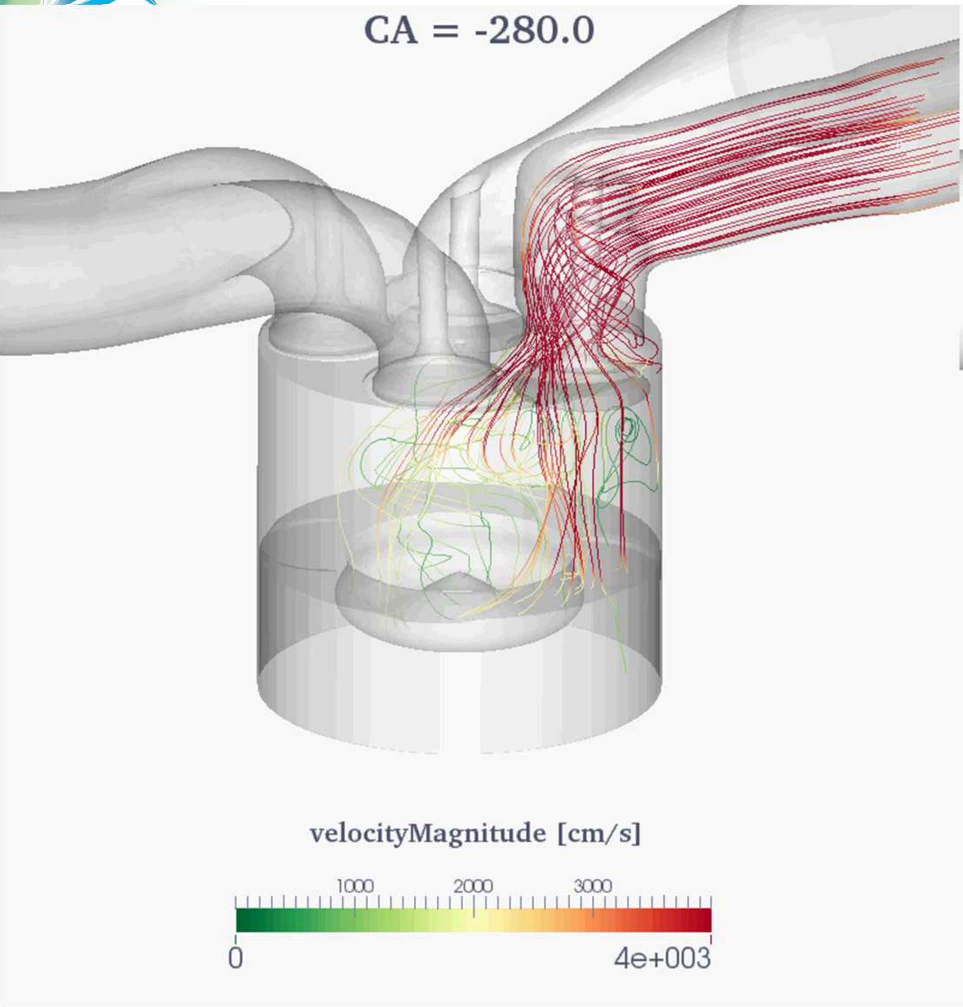
- Our current swirl-plane PIV results with Rs=2.2 confirm the previous findings (Petersen, SAE2011-01-1285 and Perini 2013 Computers & Fluids).
- With swirl center location calculated at three different plane, vertical tilting of swirl center axis is quantified.
- After IVC (-150°aTDC), tilting towards exhaust ports becomes less as piston proceeds to -105°aTDC.
- As the compression continues, the tilting switches to intake ports, and is getting worse until the TDC is approaching.

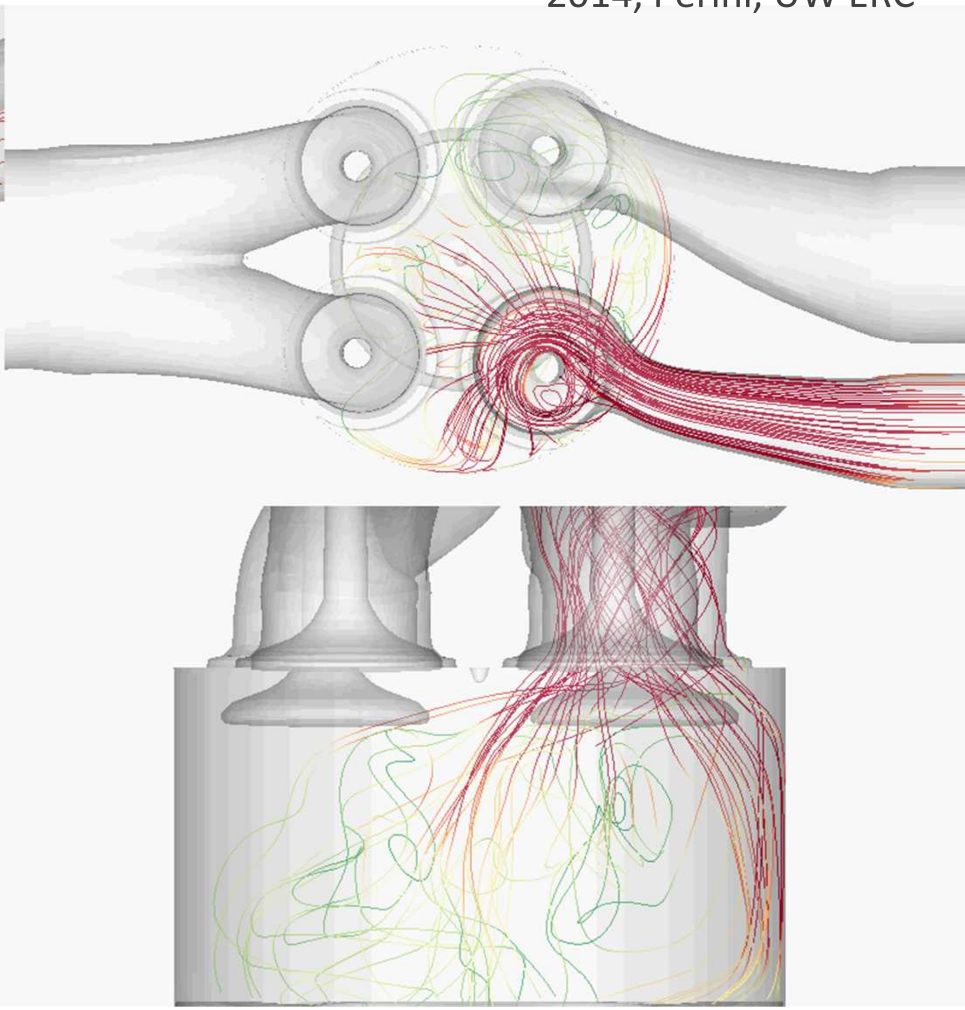


- Counter-clockwise flow is weaker for Rs=3.5 because helical port is throttled, with a constant intake mass flow rate, flow becomes stronger from tangential port.
- For Rs=1.5, helical flow is relatively stronger than tangential flow. The "momentum wall" boundary extended farther away from helical port at lower plane.

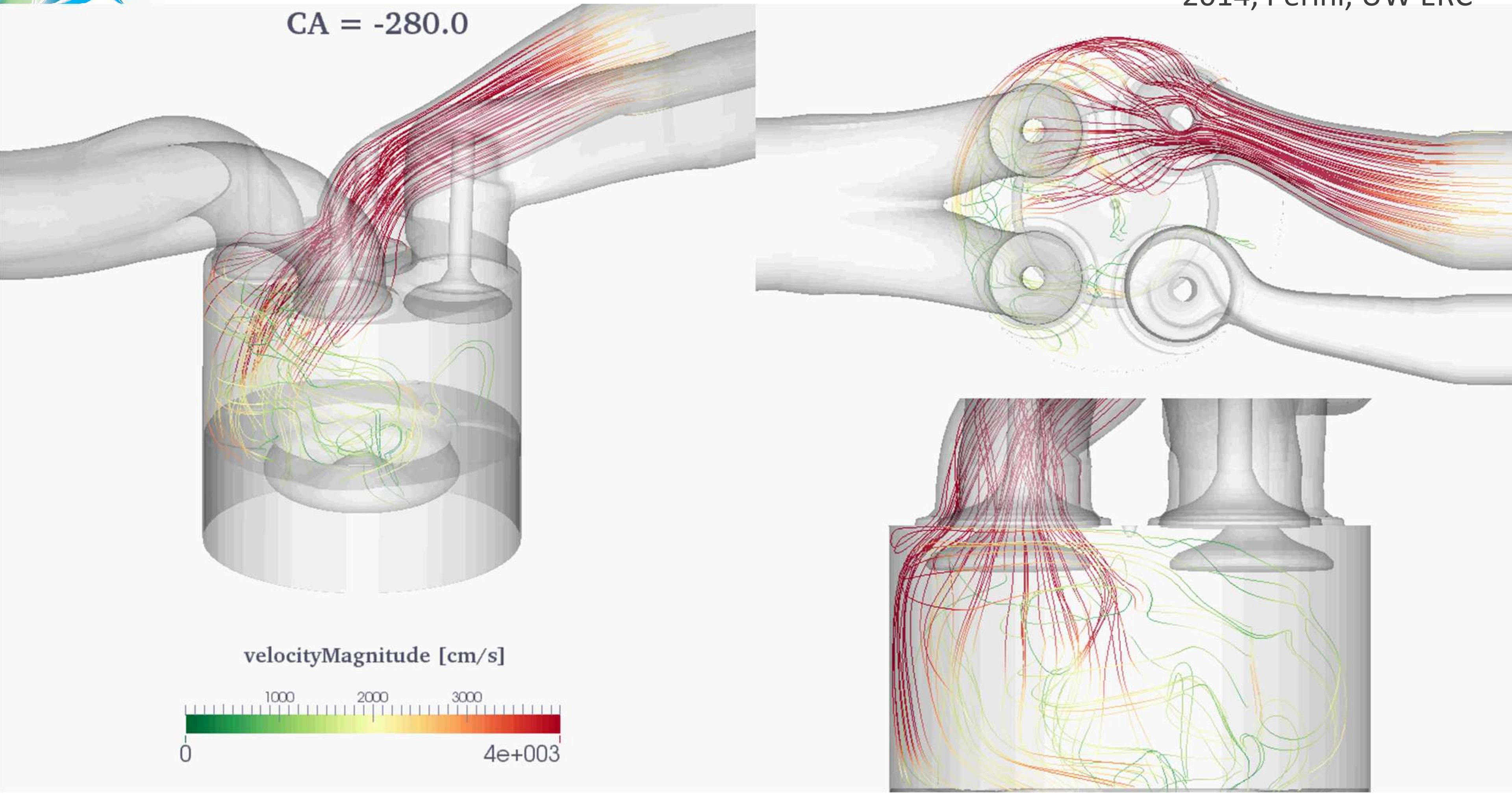


- The farther down from the fire deck, the weaker helical flow.
- The farther down from the fire deck, the earlier swirl formed.
- For Rs=1.5, flow topology is more complex.



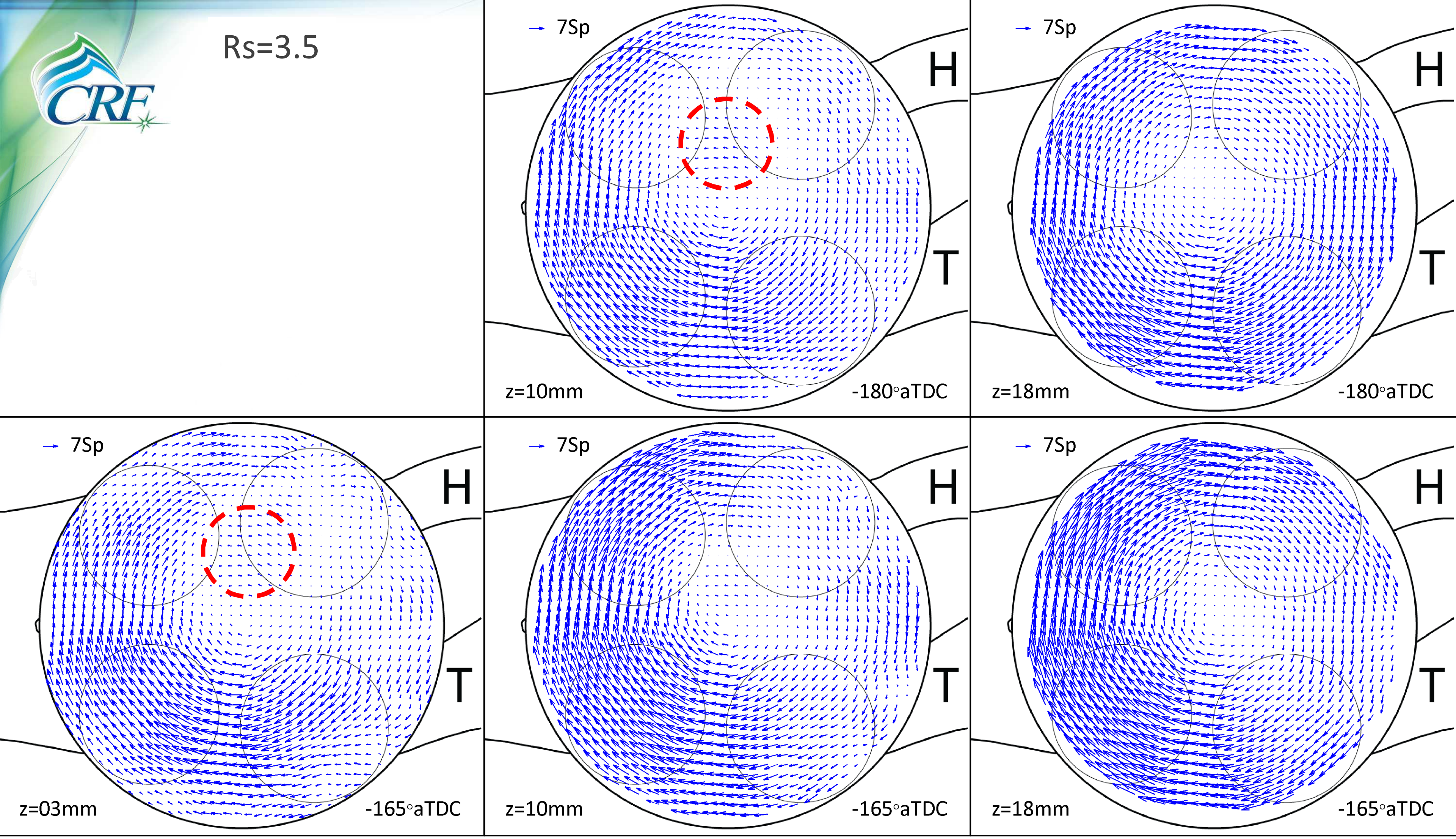


- The farther down from the fire deck, the weaker helical flow (consistent with PIV).
- Flow from helical port has significant vertical velocity component.



- Swirl is initially formed near the bowl.

Rs=3.5



- When intake valves are closing to small valve lift, the residual counter-clockwise flow from the helical port is likely to dominate the initial swirl center location.

Summary

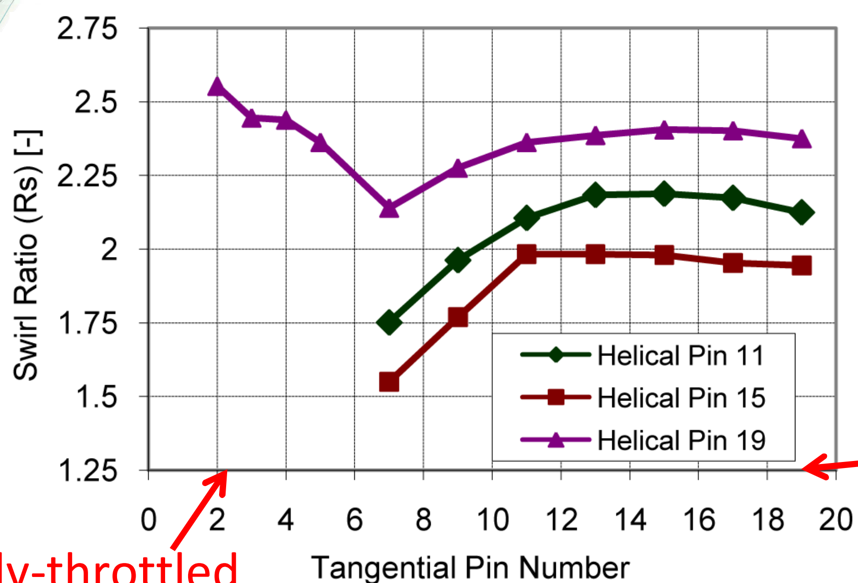
- A new method is developed to avoid the artificial radial velocity brought by dewarping low resolution frame near BDC.
- Swirl-plane PIV results are available through full intake and compression stroke for Rs=1.5, 2.2 and 3.5.
- Both PIV and simulation confirm that the farther down from the fire deck, the earlier swirl formed.
- The residual counter-clockwise flow from the helical port is likely to be responsible for the initial swirl center location.
- At the z=10mm plane, with Rs=2.2, the swirl center location exhibits clockwise behavior in the compression stroke.
- After IVC (-150^{o}aTDC), swirl center vertical tilting towards exhaust ports becomes less as piston proceeds to -105^{o}aTDC. As the compression continues, the tilting switches to intake ports, and is getting worse until the TDC is approaching.

Future Work

- Combine method A and method B for minimum velocity error.
- Investigate two different bowl geometries to study the impact of bowl geometry on the flow structure.
- Compare with CFD simulation results.

Thanks for Your Attention!

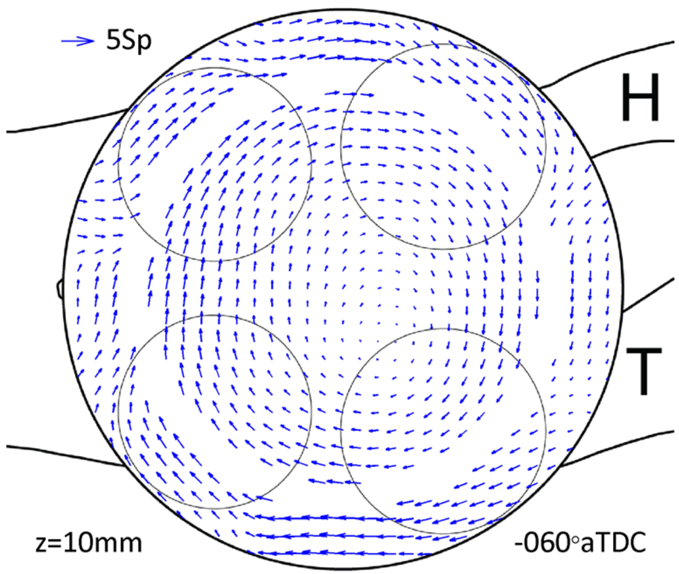
Swirl Ratio Behavior with Various Intake Port Throttling

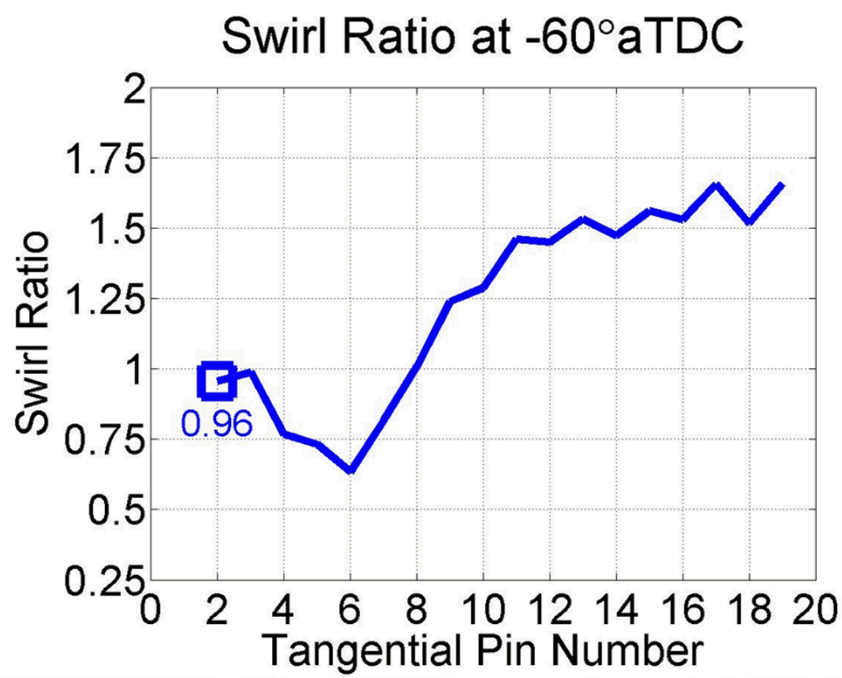


- A non-monotonic behavior of the swirl ratio (flow bench) with various tangential port throttling, helical port un-throttled Pin19 (SAE2009-01-1124).
- A similar trend is observed with the swirl-plane PIV measurements at -60^{o}aTDC.

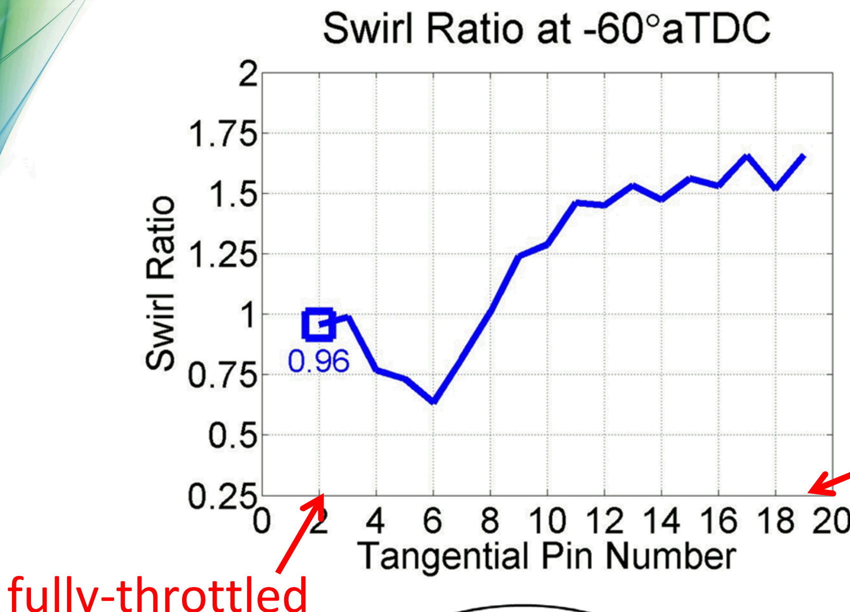
un-throttled

fully-throttled

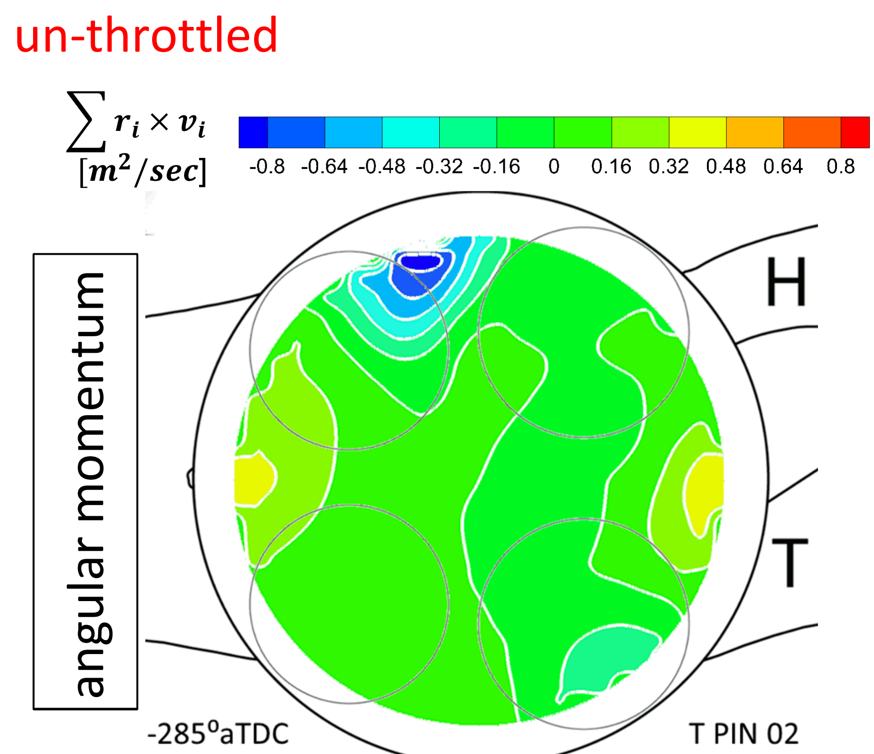


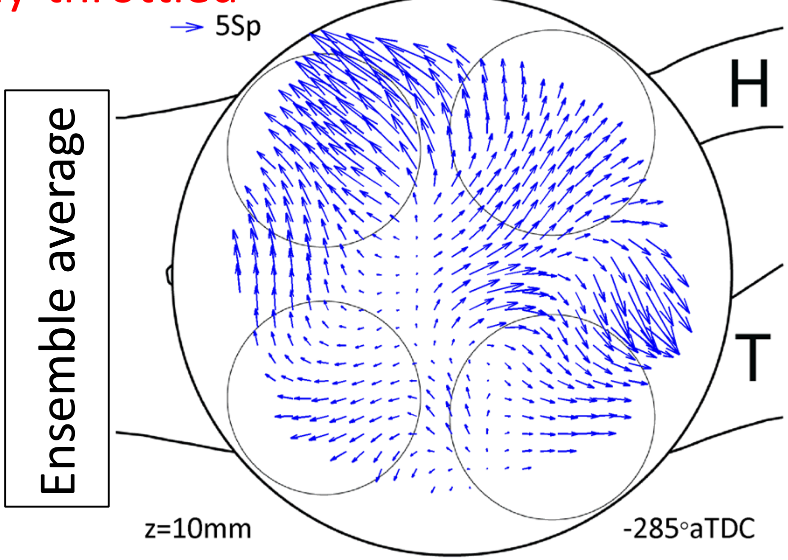


Swirl Ratio Behavior with Various Intake Port Throttling

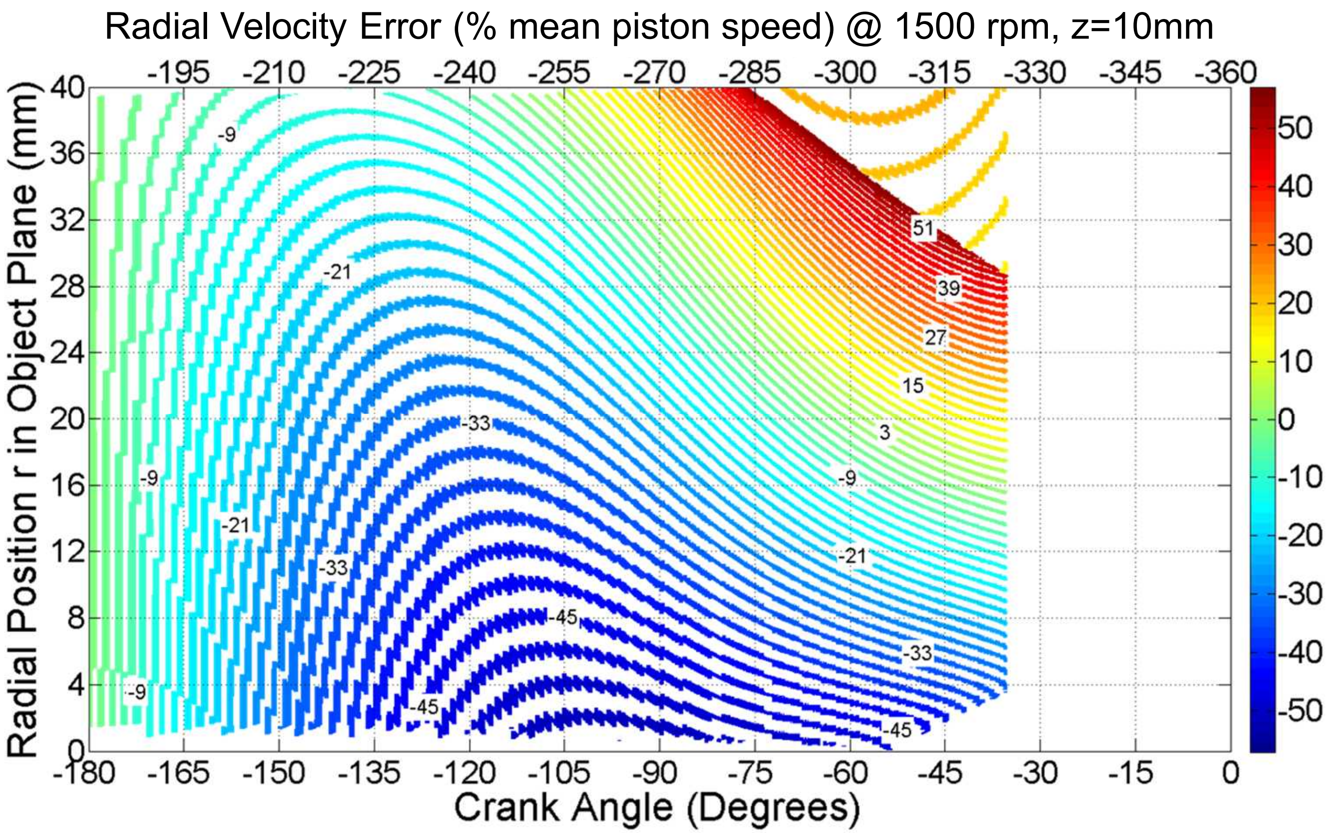


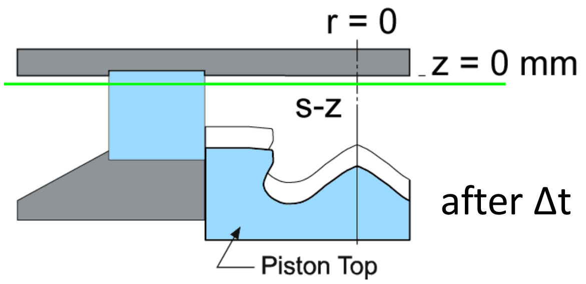
- Angular momentum from tangential port is linearly correlated with the increase of swirl ratios.
- The reason why the swirl ratio increases with further tangential port throttling remains unclear.





Radial Mapping Function





- Neglecting the transformation change during the laser pulse interval Δt can result in large error (±50%) in the radial velocity measured.