# On Soot Reduction by Post Injection Under Dilute Low Temperature Diesel Combustion

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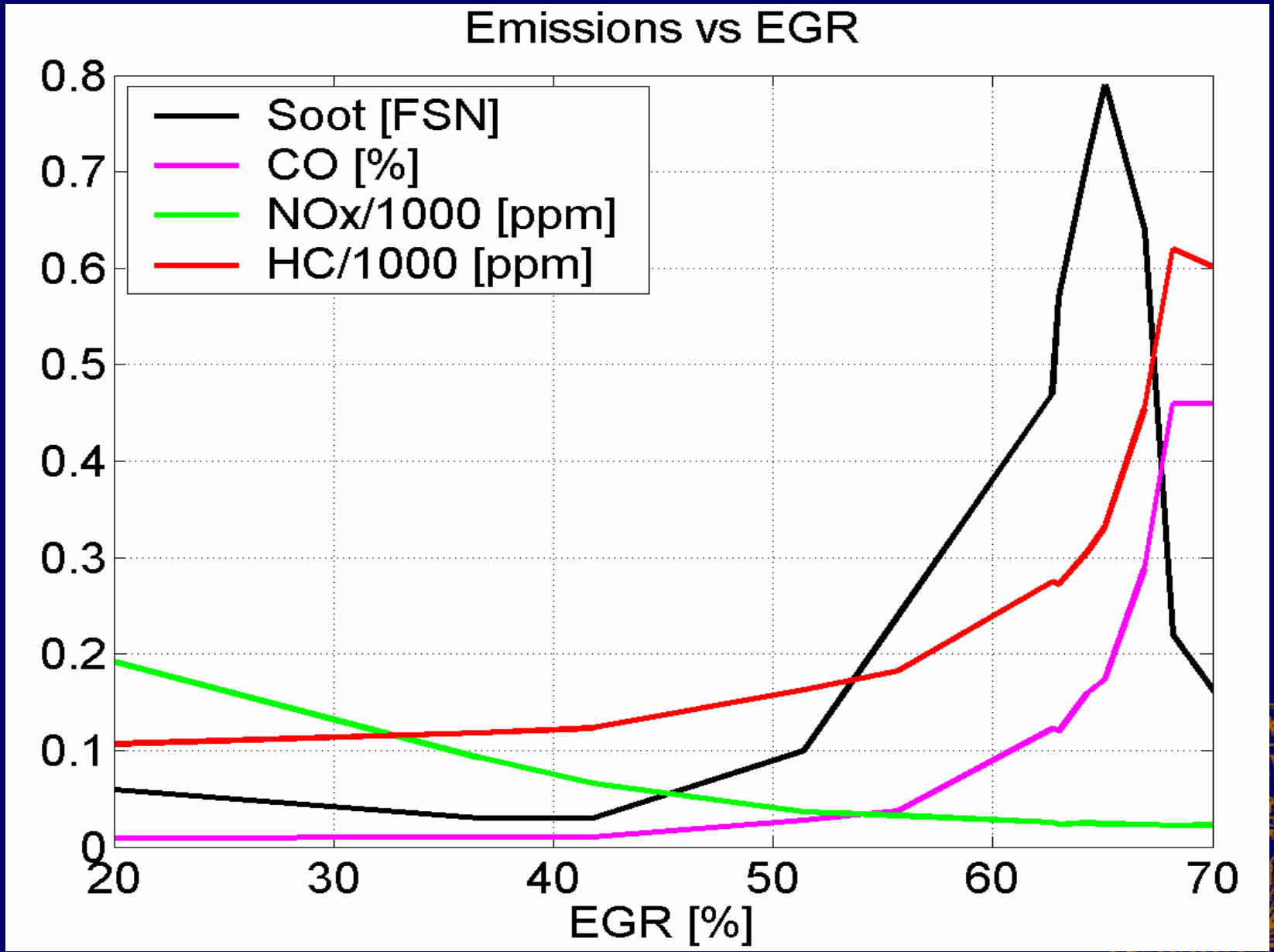
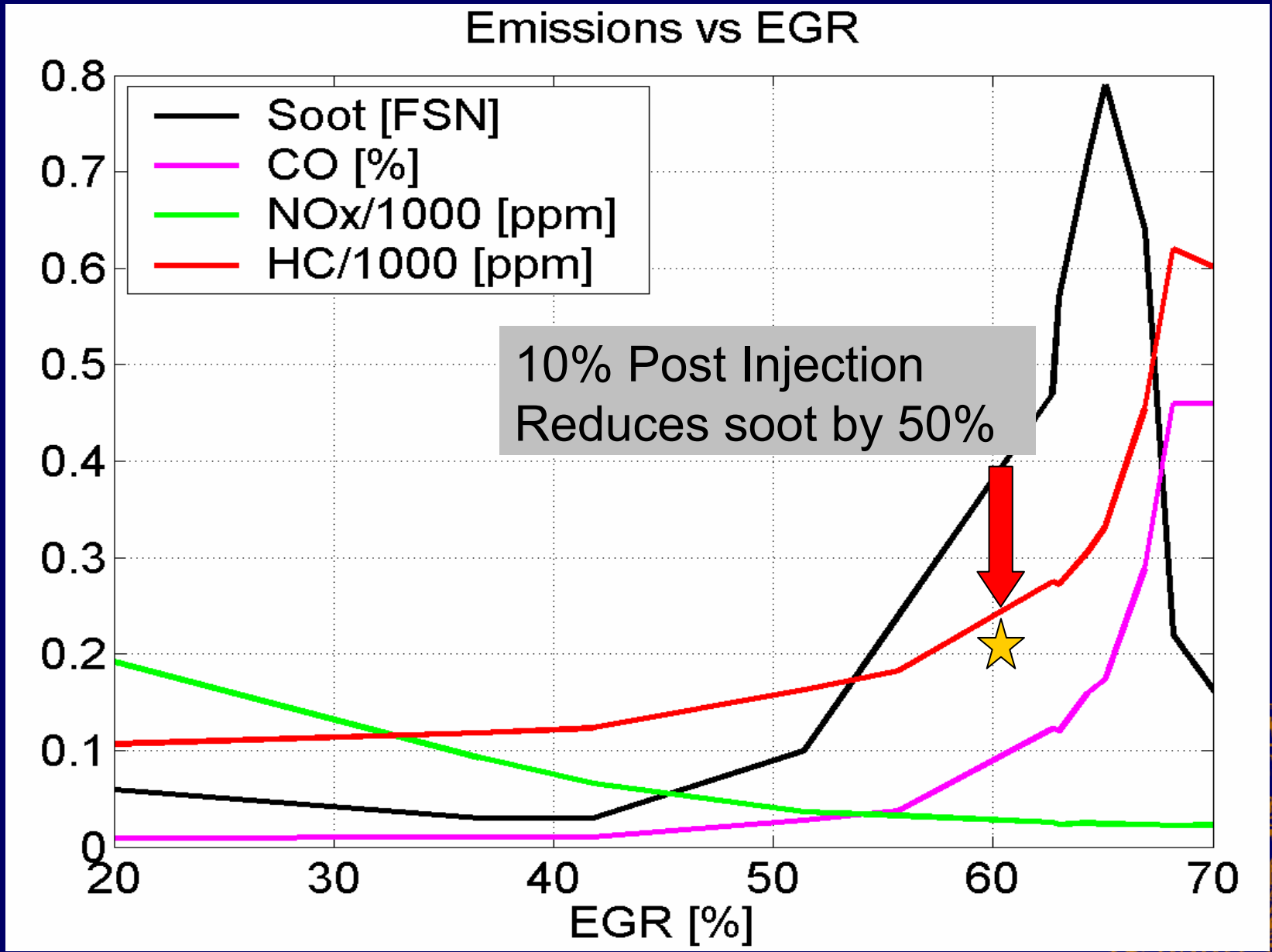
# Background


Emissions vs EGR
Soot [FSN]
CO [%]
NOx/1000 [ppm]
HC/1000 [ppm]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
30
40
50
60
70
EGR [%]

# OBSERVATION – Post injection



# Hypothesis

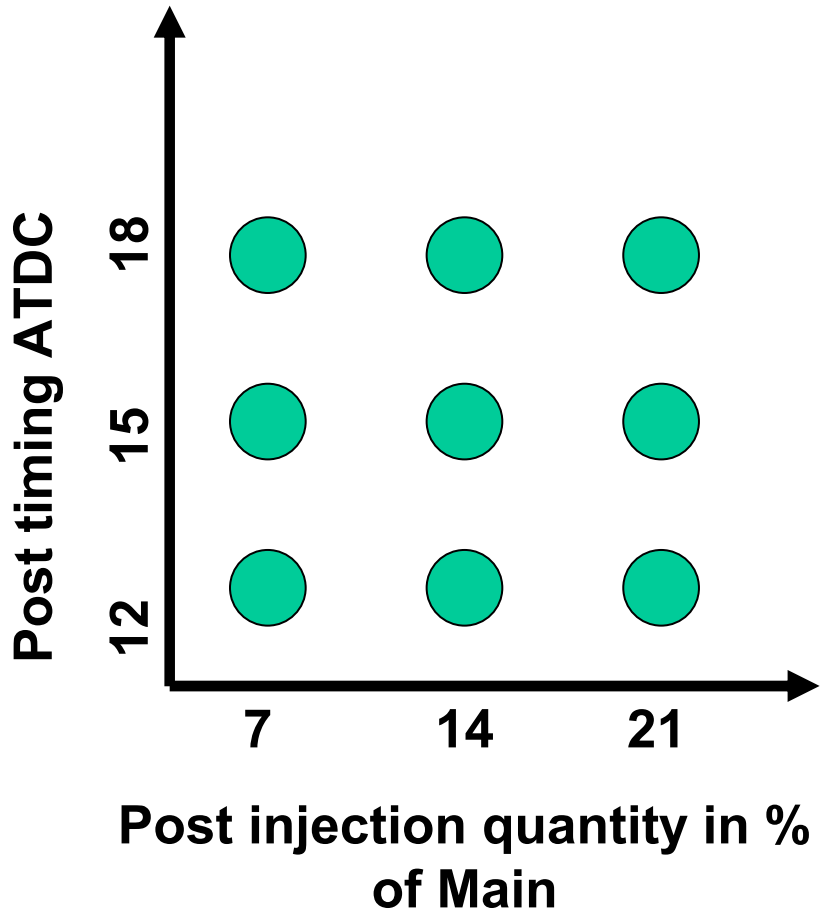
- The reduction of soot is due to
  - enhanced late cycle mixing
  - increased late cycle temperature

# Questions

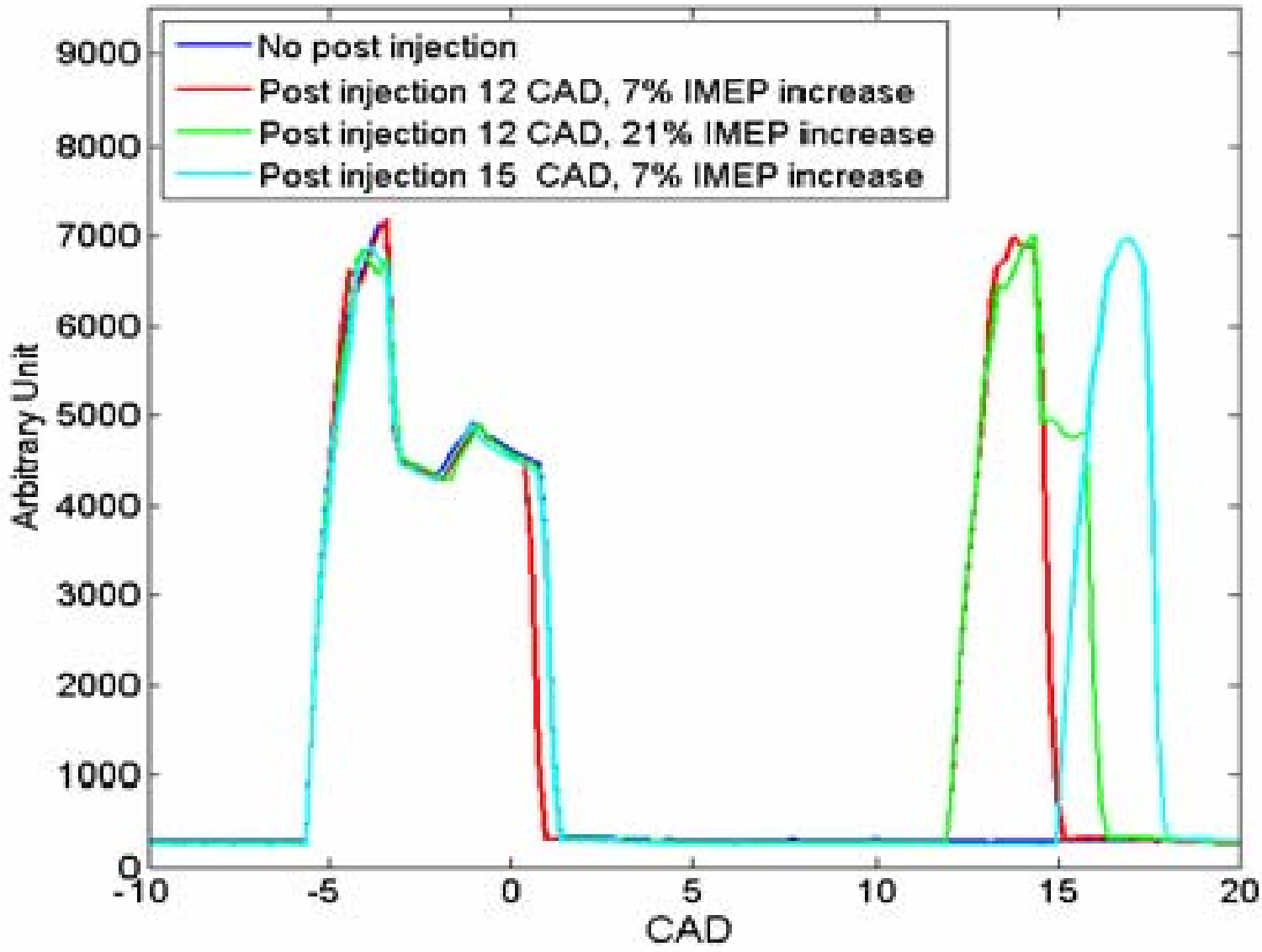
- Which mechanism is dominant?
- What is important to consider when optimizing?

# Operating points & test matrix

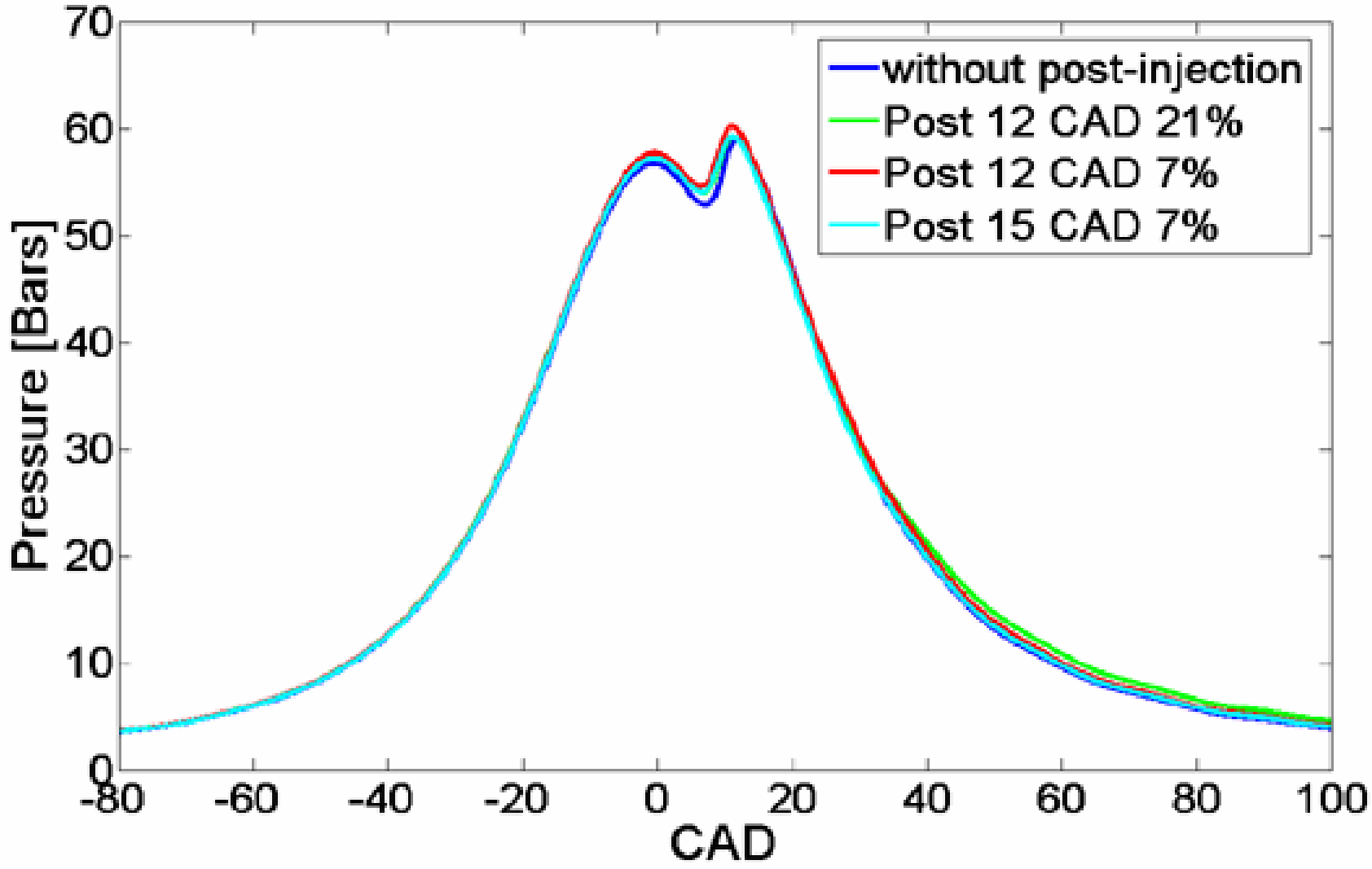
- Main injection 5,8 CAD BTDC
- Lambda: ~ 1,6 – 1,7
- EGR : 62%
- IMEP 4 bar (without post injection)
- Total load increase



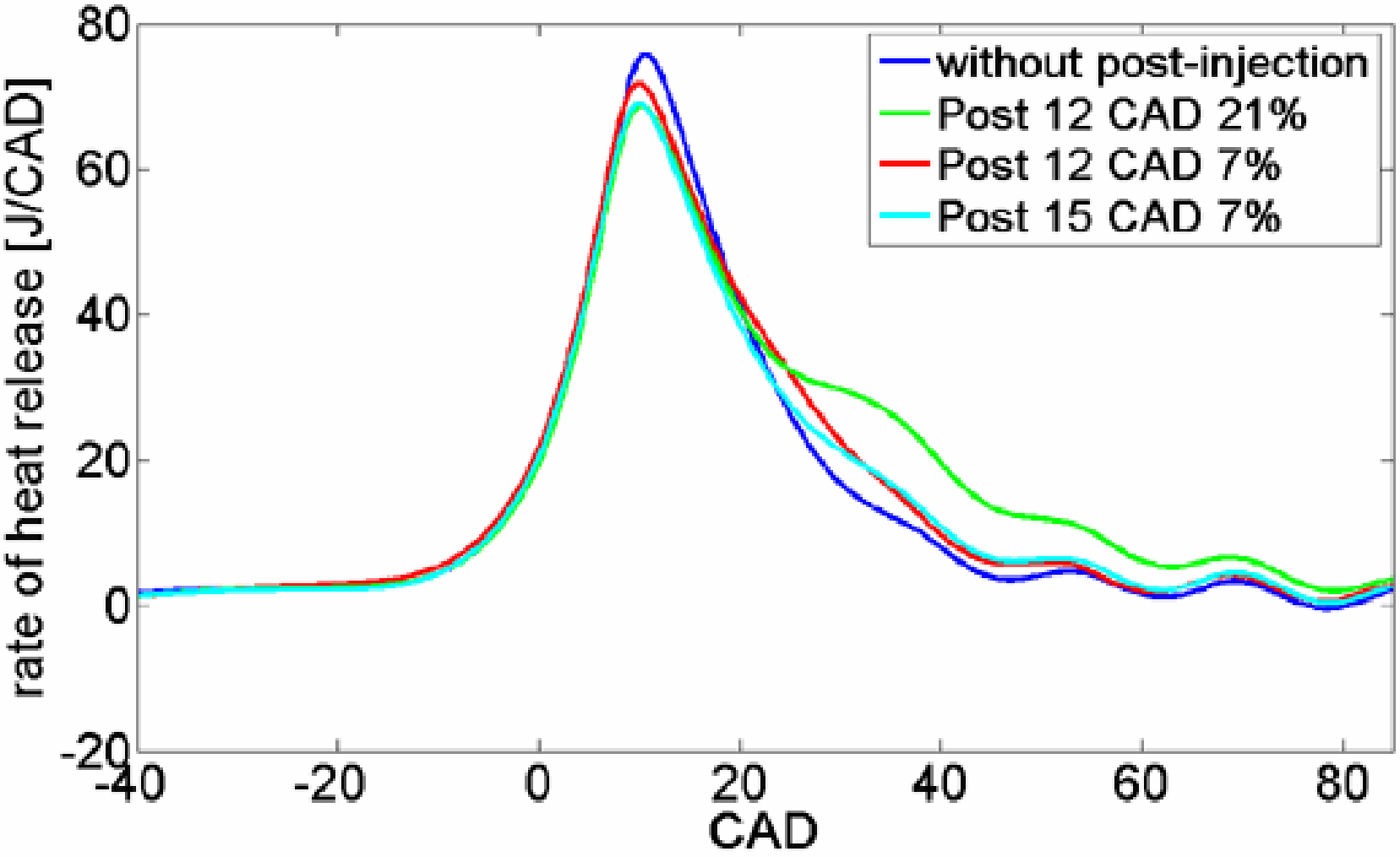
# Injection events



# Cylinder pressure

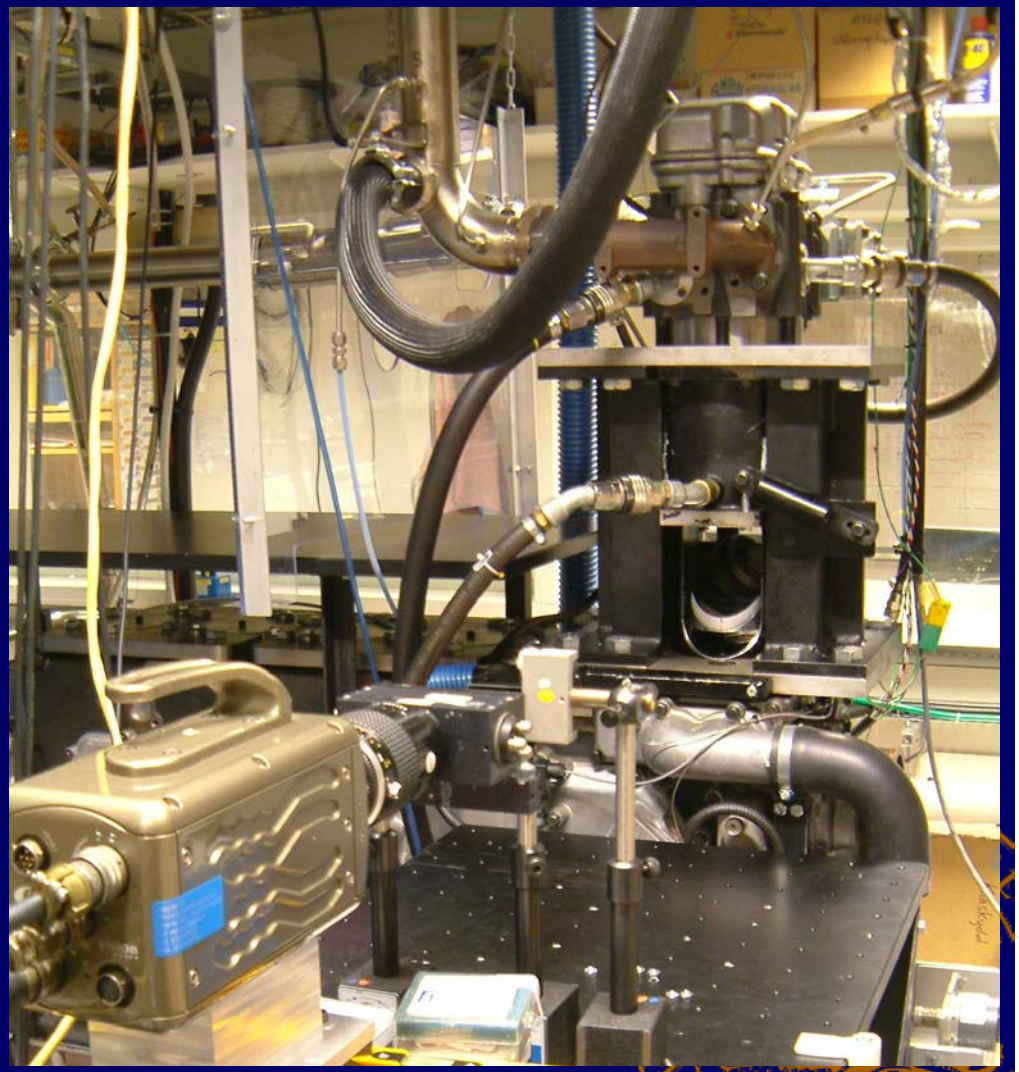


# Combustion characteristics



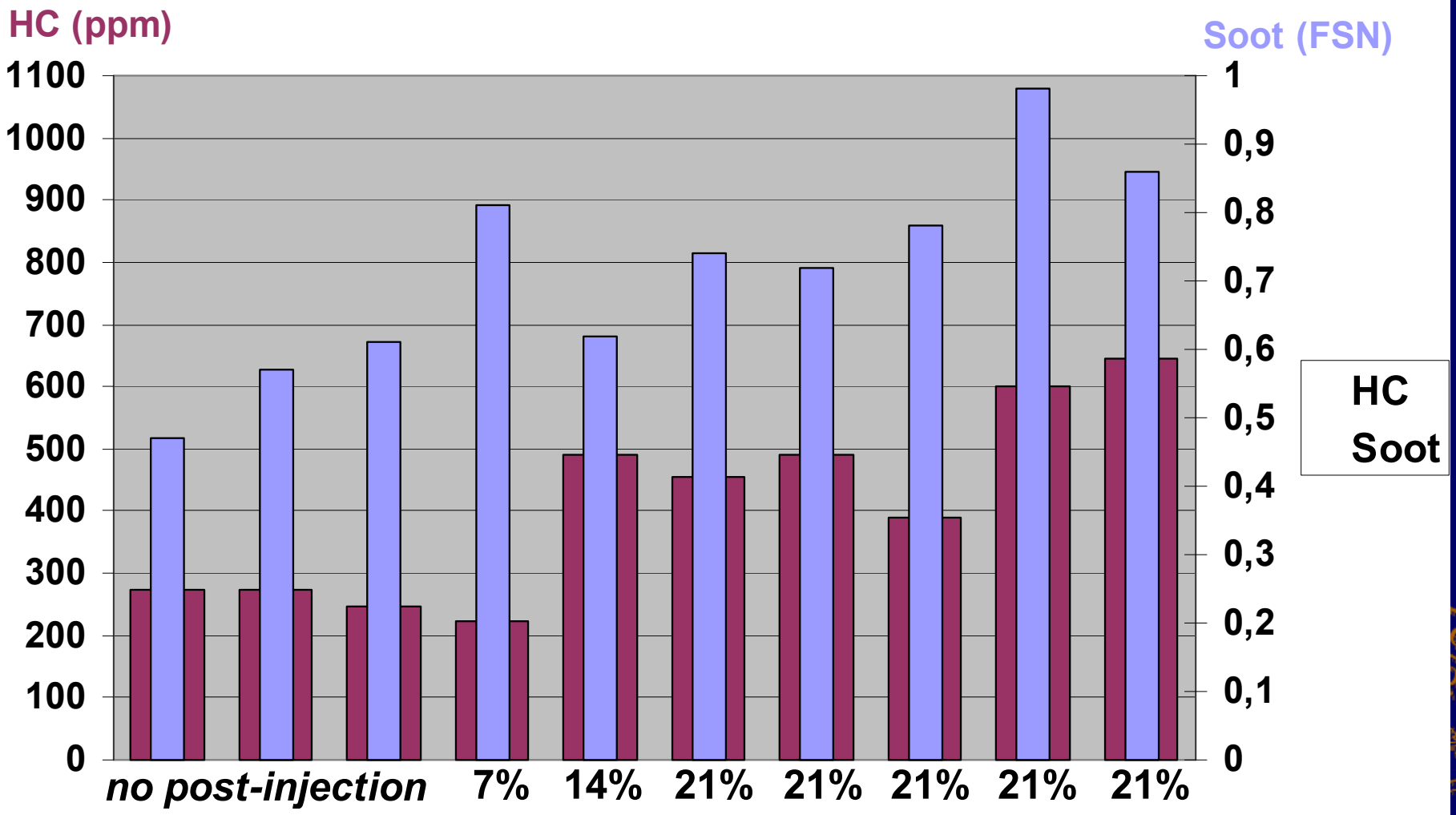
# Scania engine modified for optical access

- Bore x Stroke : 127x154 mm
- Displacement: 2 l/cyl.
- Compression ratio 15.5:1.
- Inj. 8 x 0.18 mm x 150 deg.
- Common rail inj. system
- Injection pressure: 750 bars



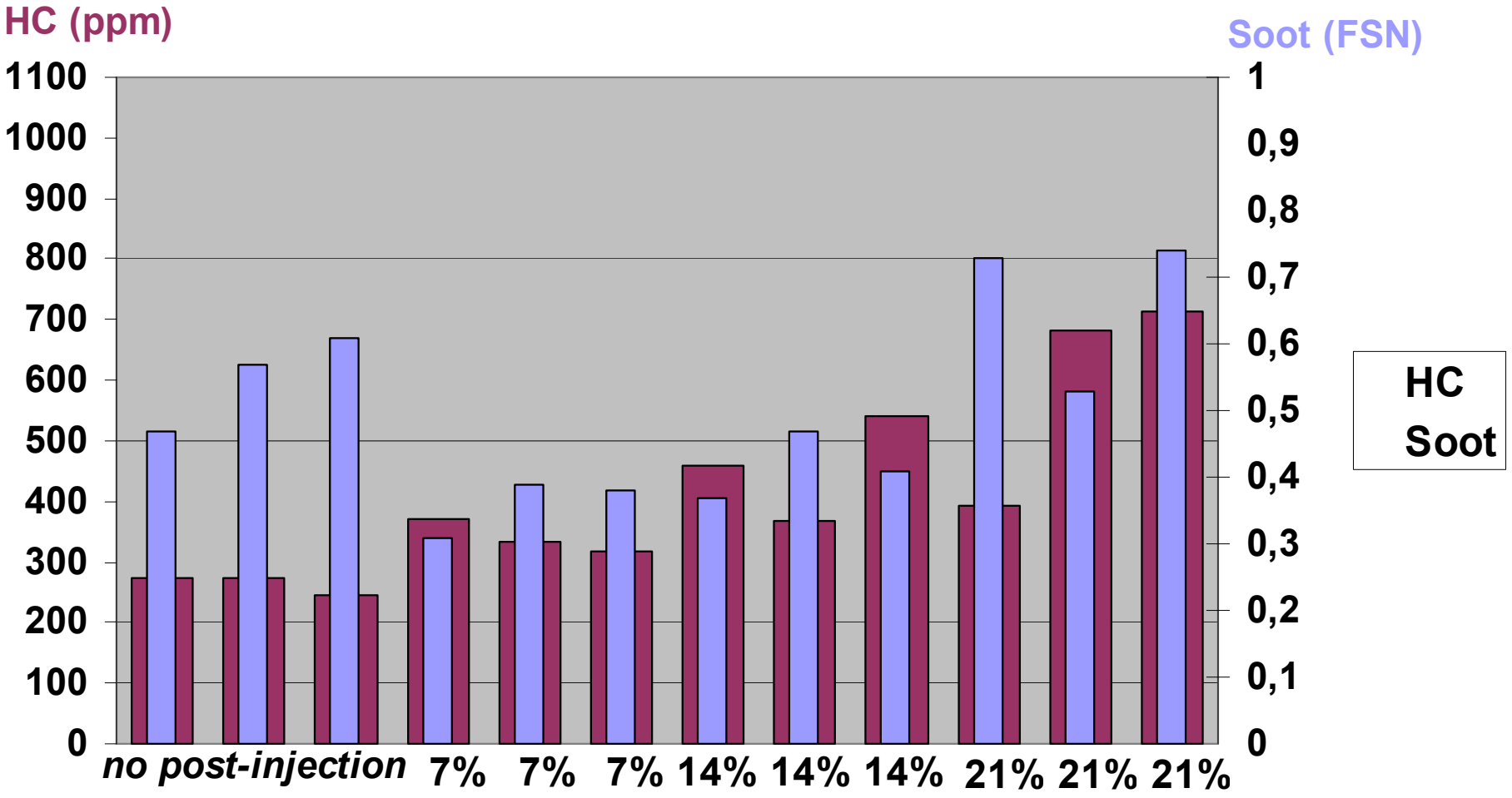
# Emission characteristics

***Post-injection timing : 12 CAD ATDC***



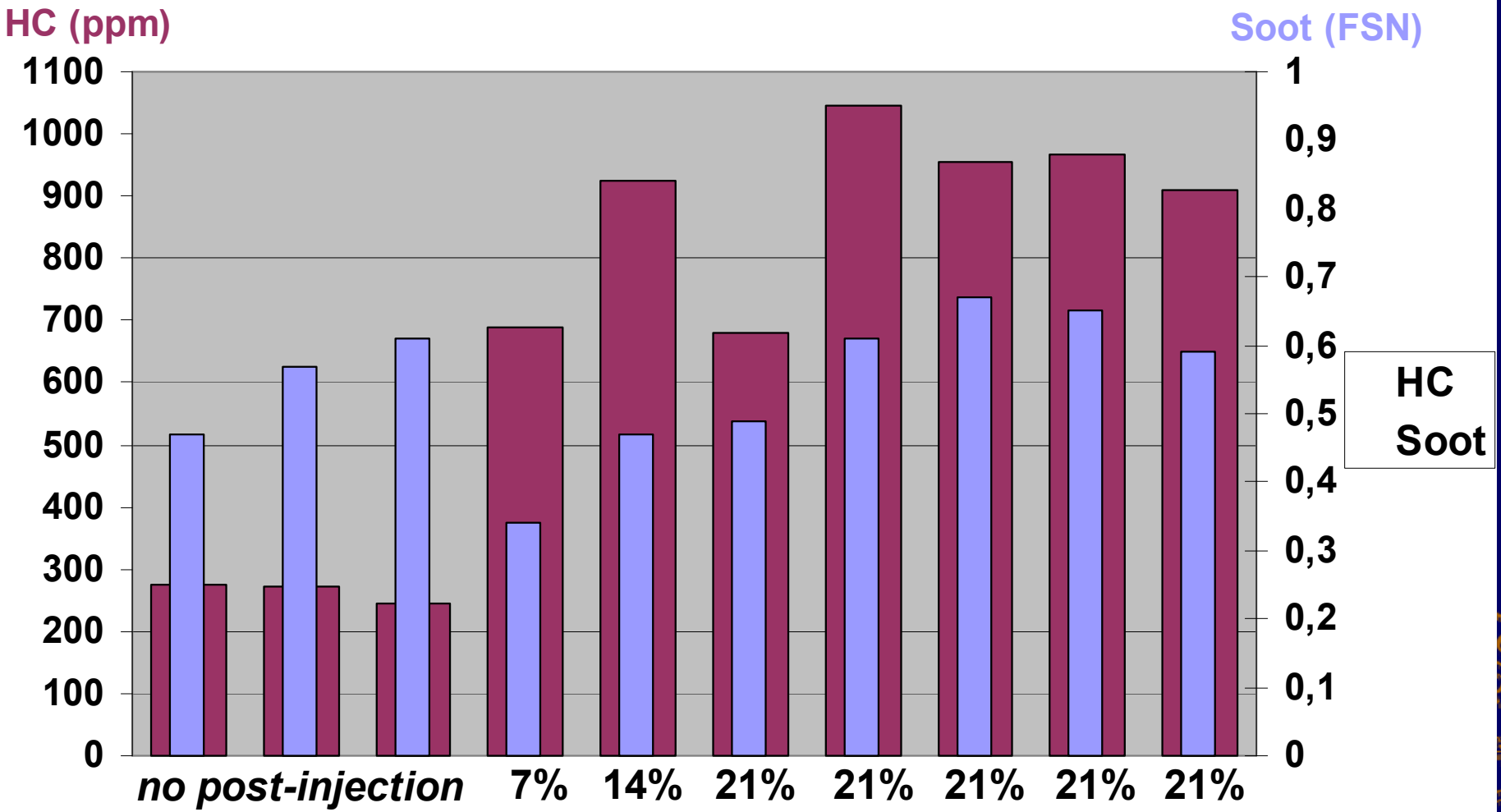
# Emission characteristics

***Post-injection timing : 15 CAD ATDC***

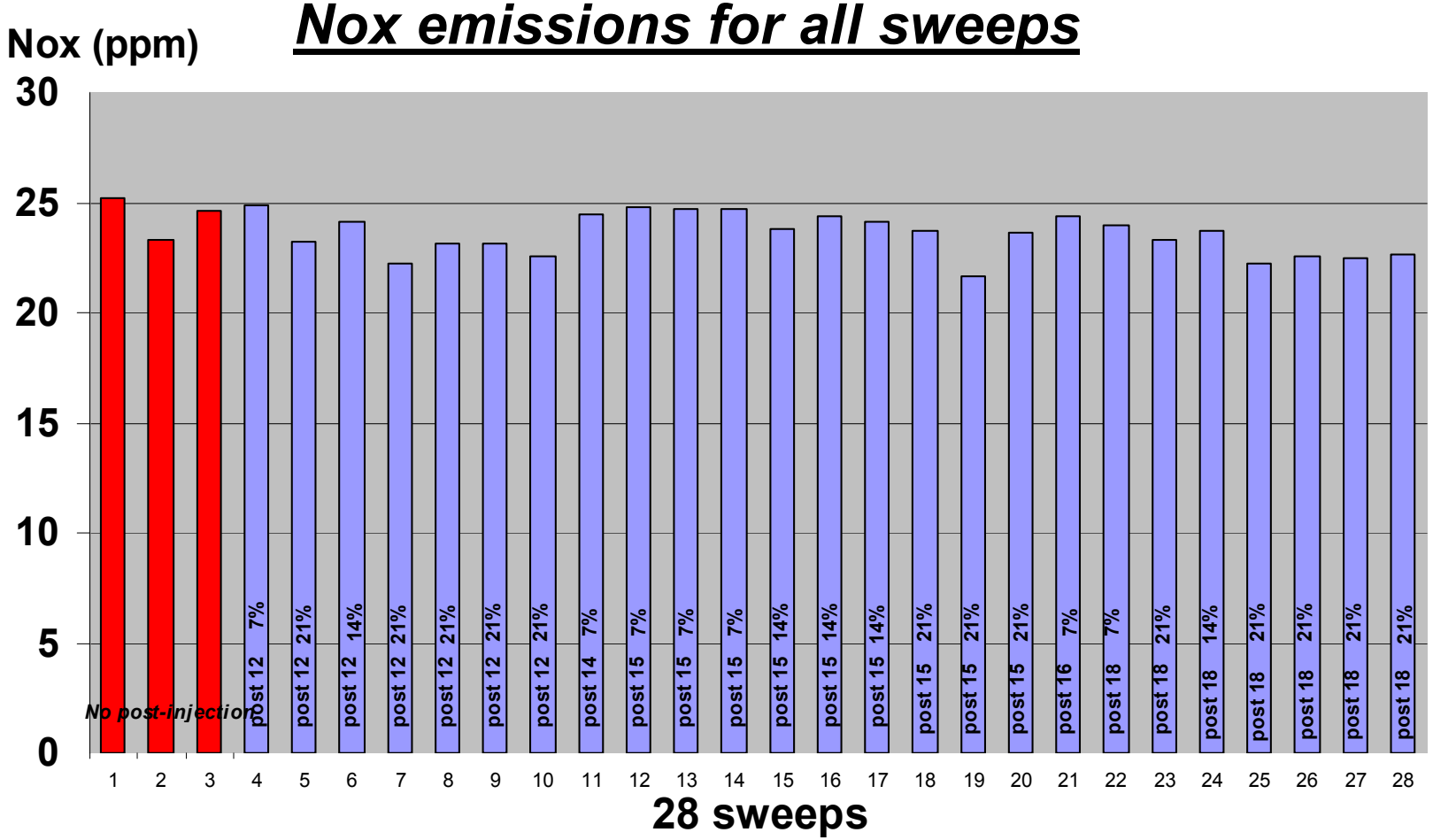


# Emission characteristics

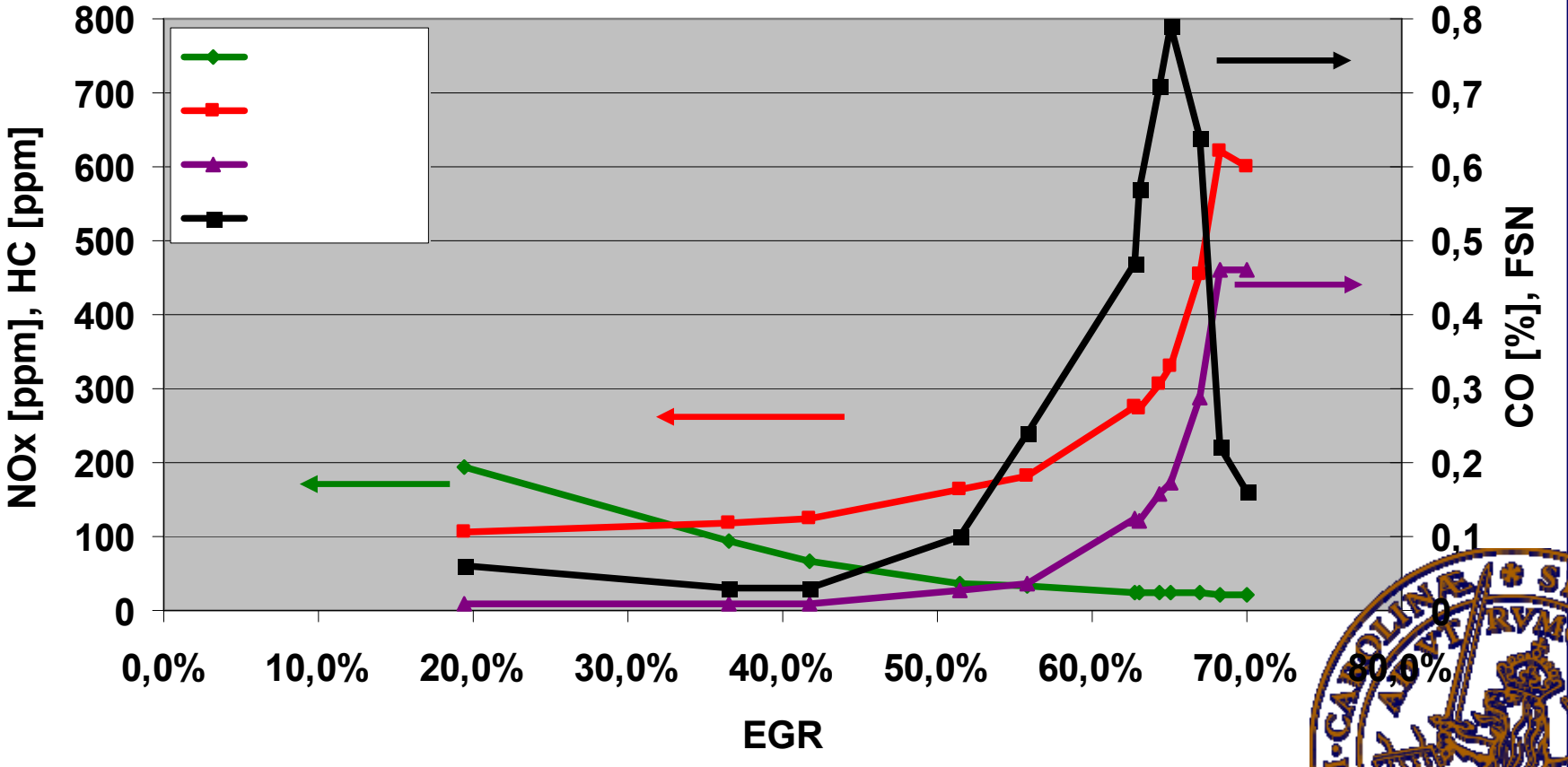
***Post-injection timing : 18 CAD ATDC***

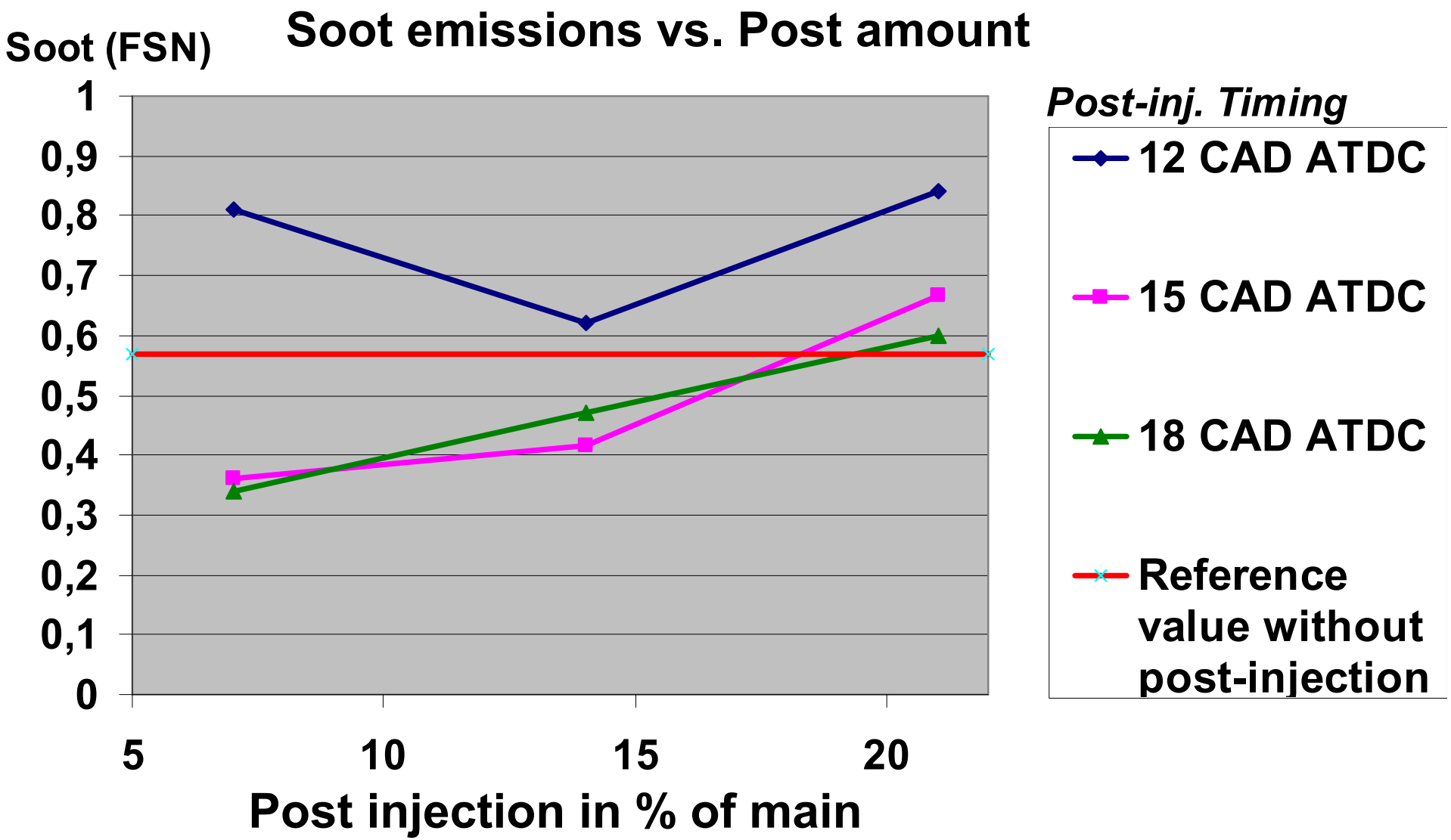


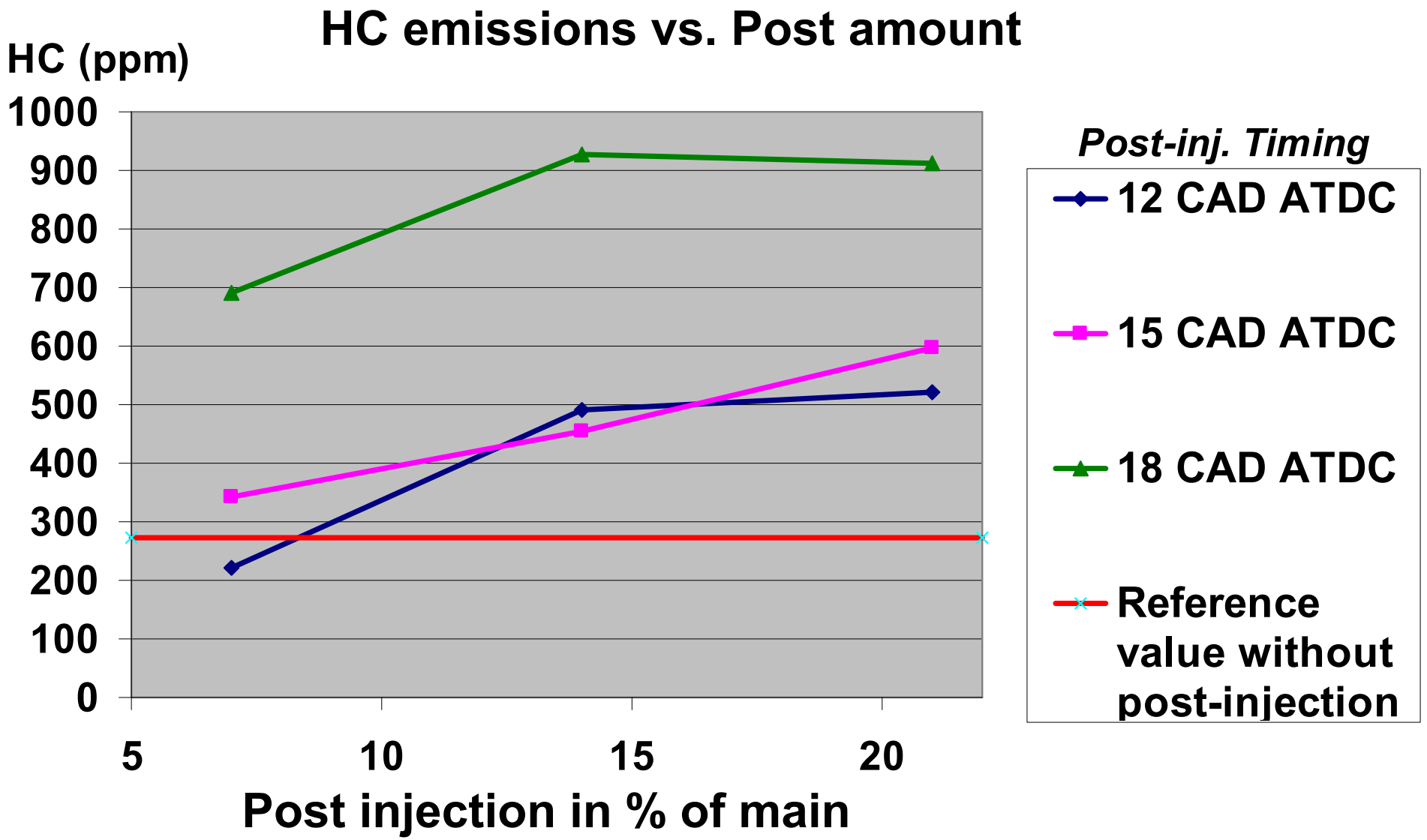
# Emission characteristics



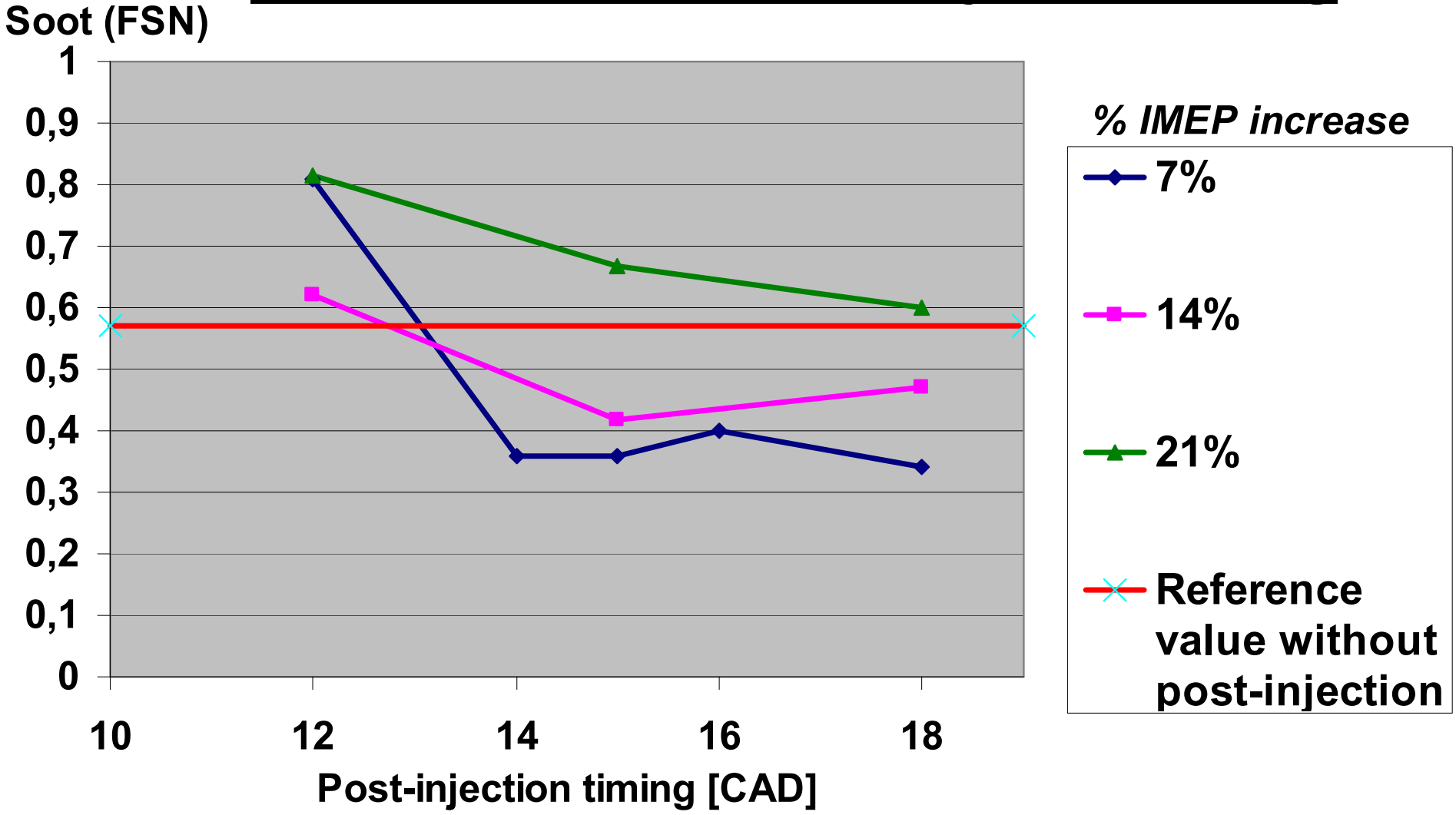
# Emissions vs. EGR ratio



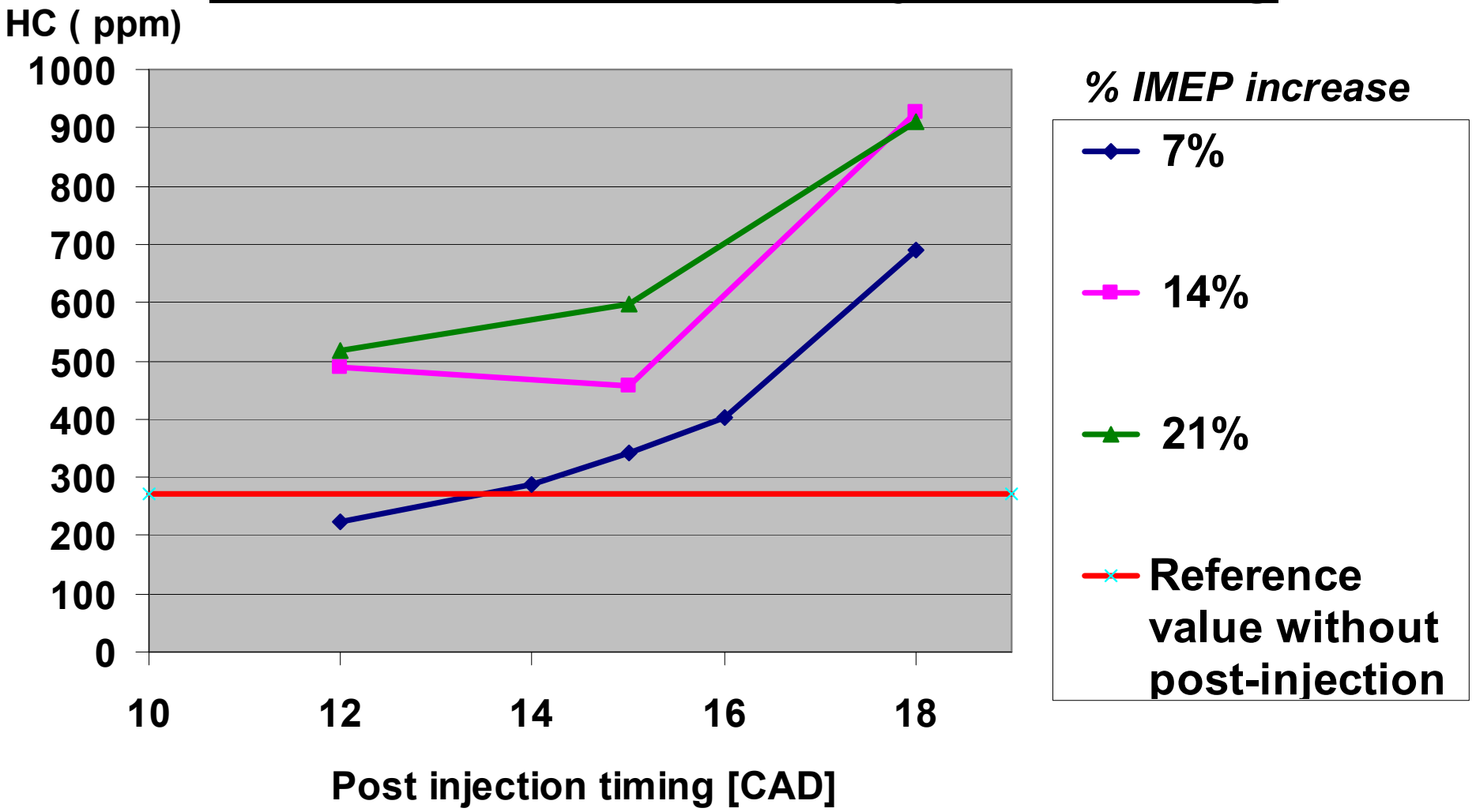

Soot emissions vs. Post amount
Soot (FSN)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
5
10
15
20
Post injection in % of main
Post-inj. Timing
12 CAD ATDC
15 CAD ATDC
18 CAD ATDC
Reference value without post-injection


HC emissions vs. Post amount
HC (ppm)
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
Post injection in % of main
Post-inj. Timing
12 CAD ATDC
15 CAD ATDC
18 CAD ATDC
Reference value without post-injection

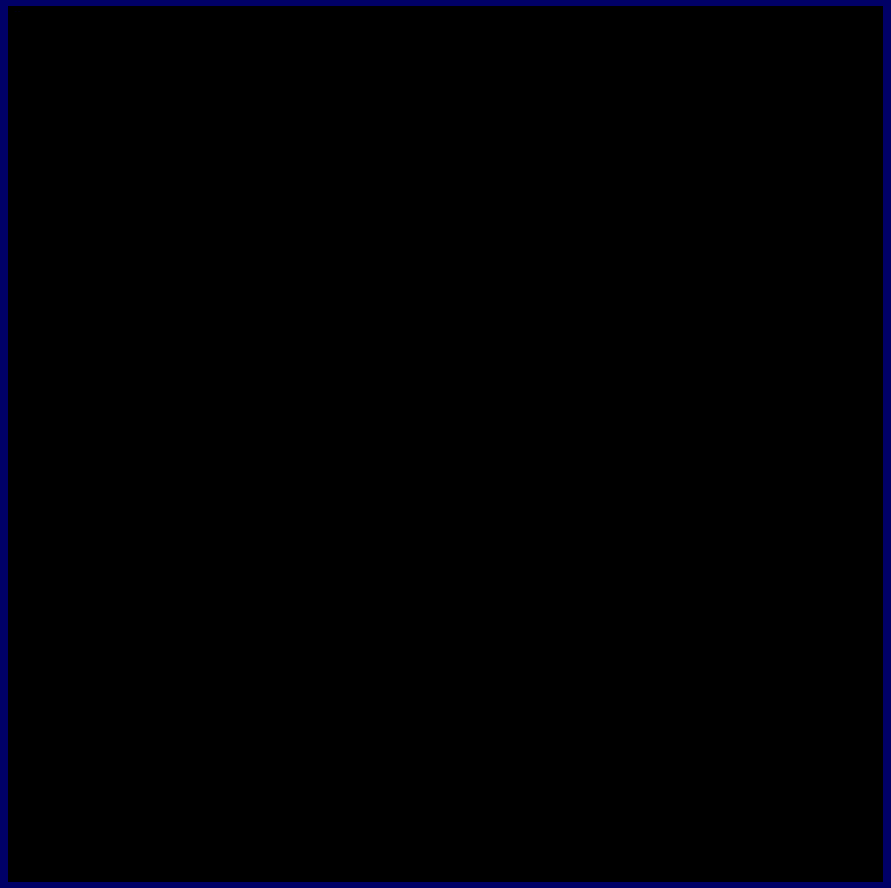
# Soot emissions vs. Post-injection timing



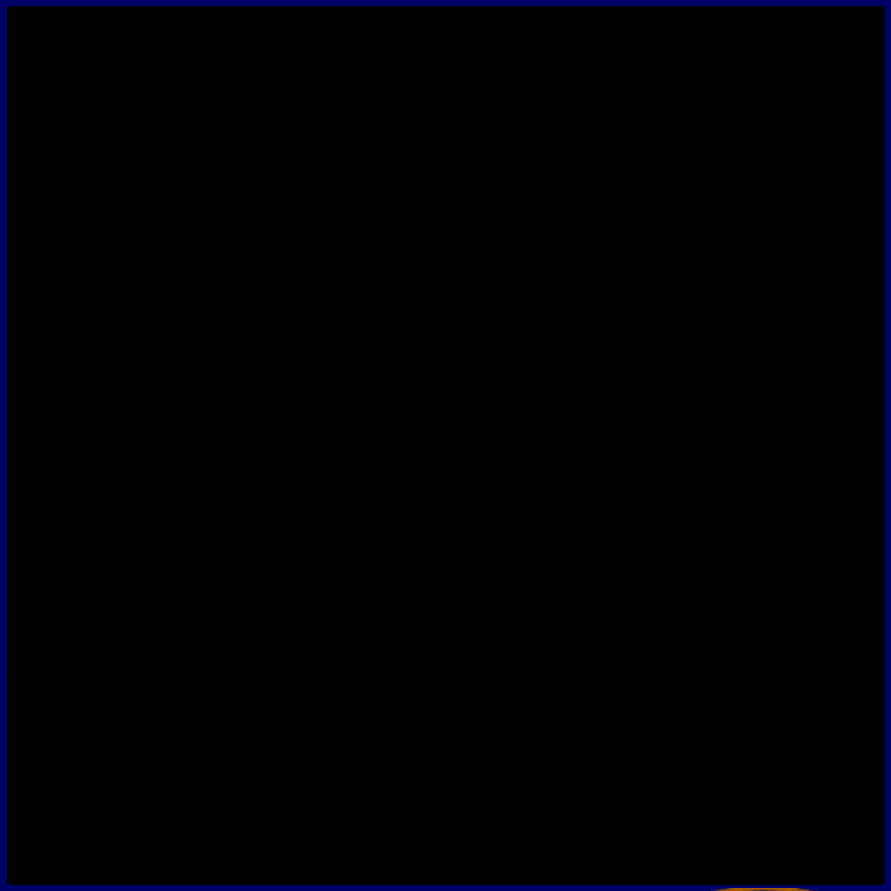
# HC emissions vs. Post-injection timing



# Combustion process visualization



**Without post injection**



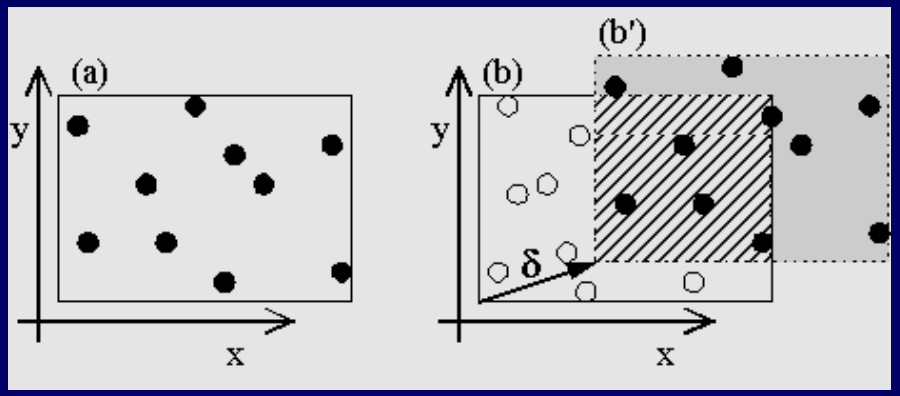
**Post 12 CAD 21%**

*All videos start at CAD +10 and stop at +50*

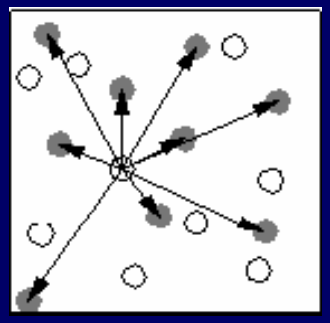
# Analysis of transport velocity of radiating soot

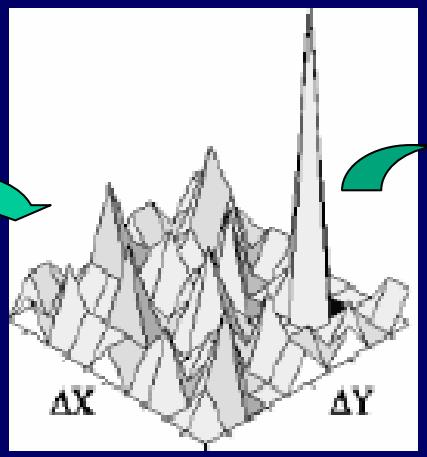
## PIV principle:

**The velocity vectors are derived from sub-sections of the target area ( called interrogation windows) of the flow by comparing the position of particles (contrasts) in 2 successive images.**




$$\vec{v} = \frac{\Delta \vec{x}}{\Delta t}$$



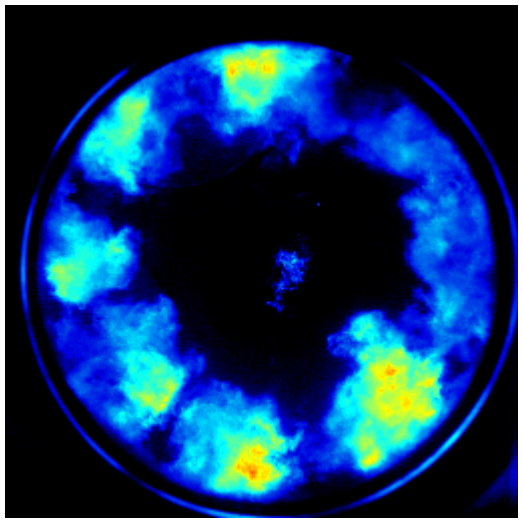


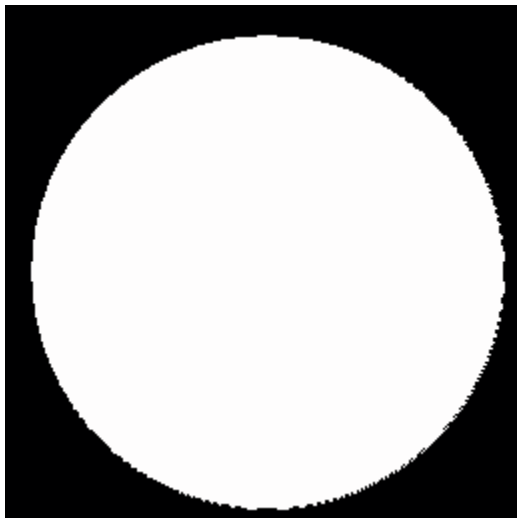

$\overline{v(t)}$

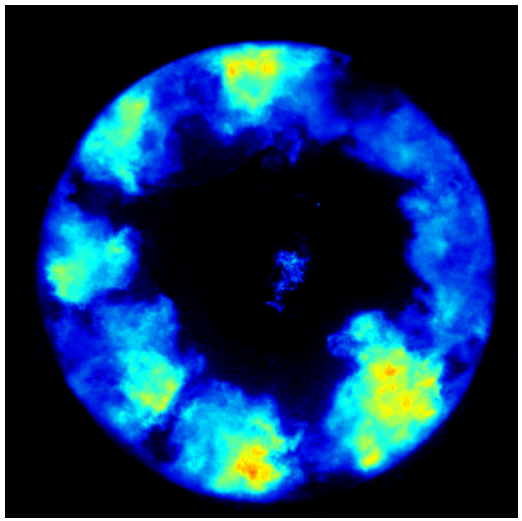
# PIV parameters

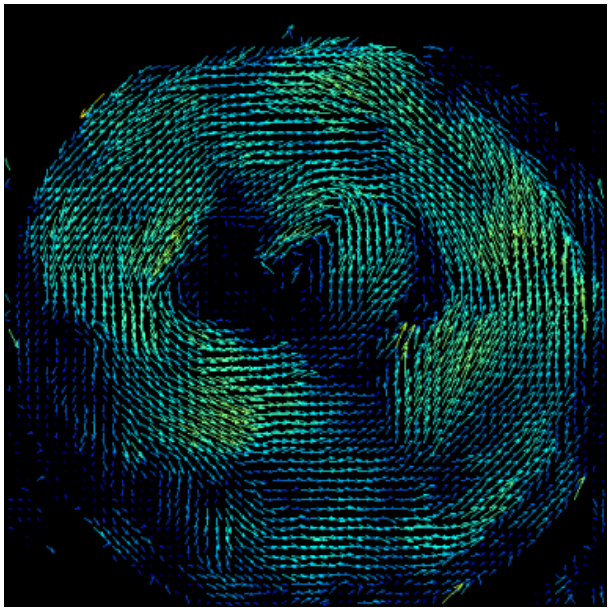
- PIV from 512x512 Tiff images extracted from .cin files recorded by the High Speed Camera. 139microsecond between 2 images gives 1 image/CAD at 1200rpm.
- Sequential cross-correlation (0-1, 1-2, 2-3…) using normalized correlation function
- Multi pass with decreasingly window sizes 32x32 and 16x16 pixels
- 50% overlapping
- -> final grid spacing of 8 pixels
- Use of a mask
- No post processing (spatial averaging of 9 pixels used for single point velocity analysis)

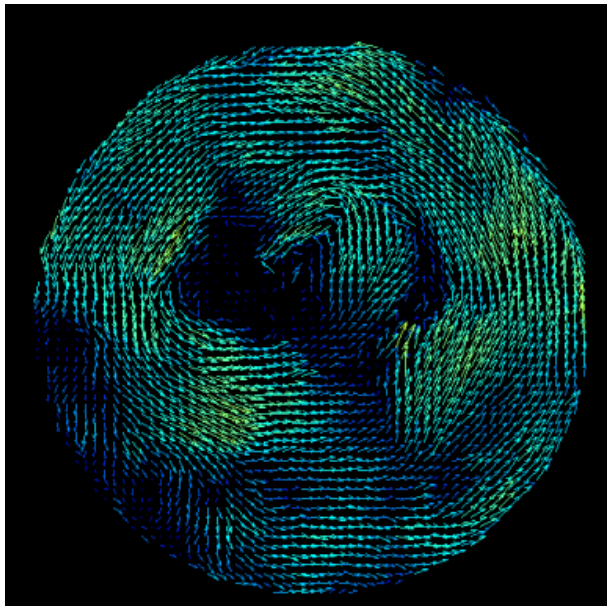
## Applying a mask:



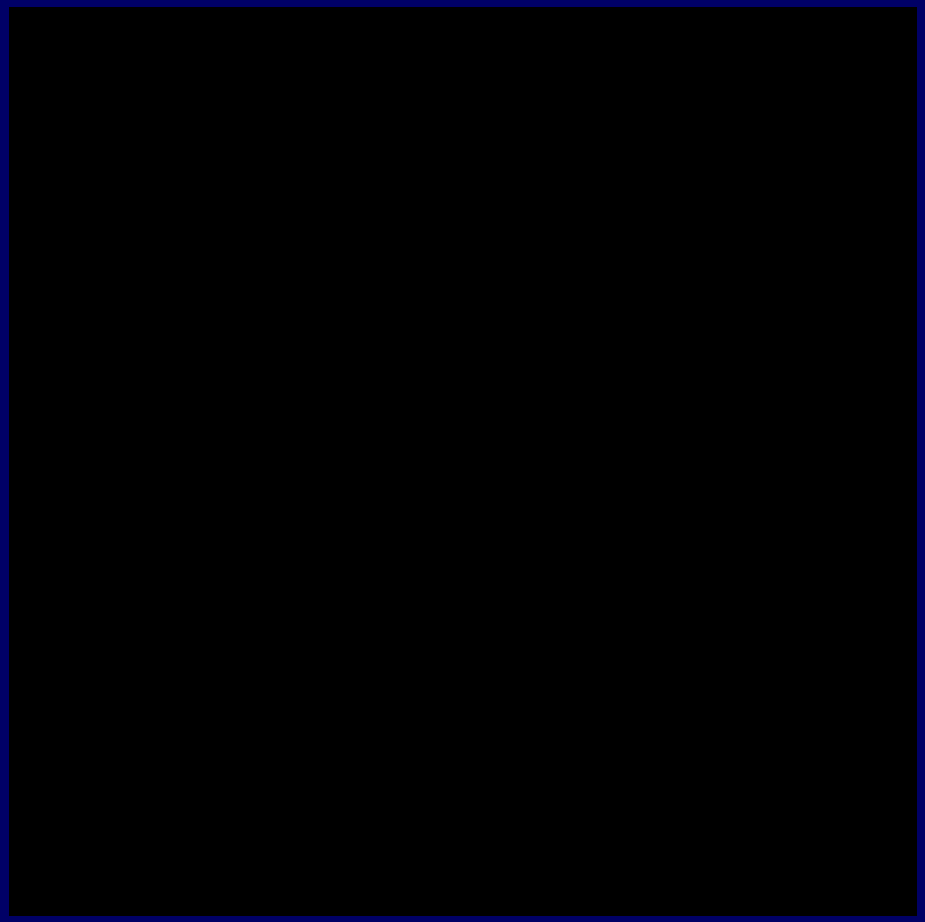




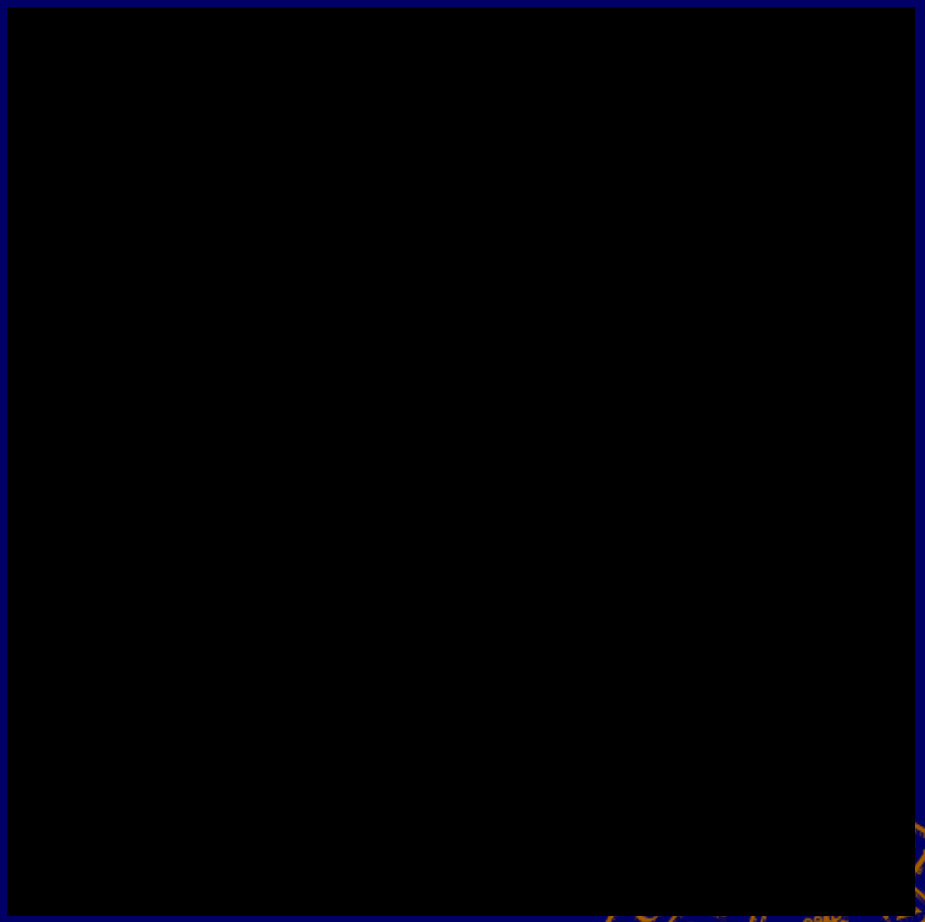




# Resulting velocity fields

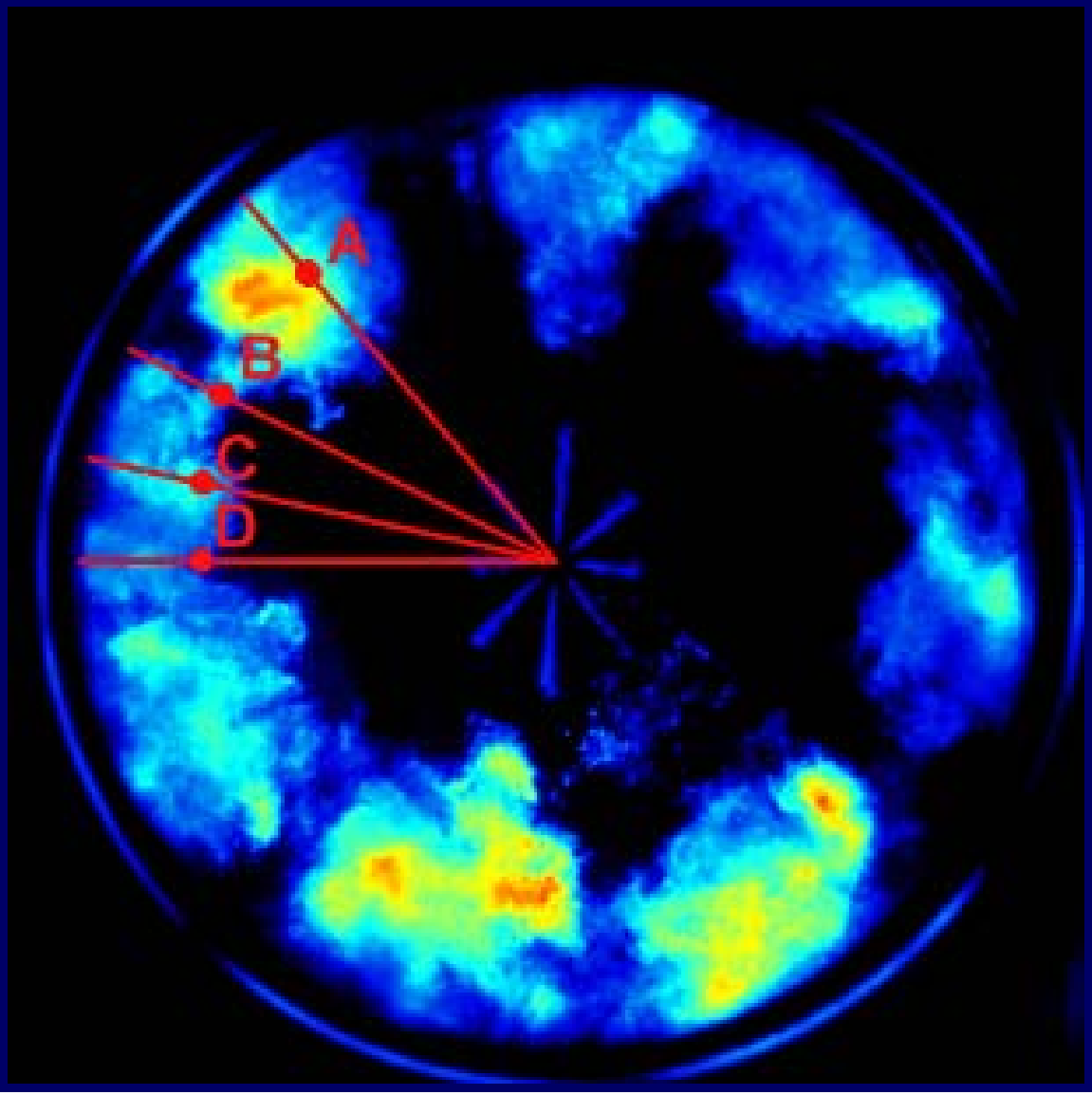


Single cycle

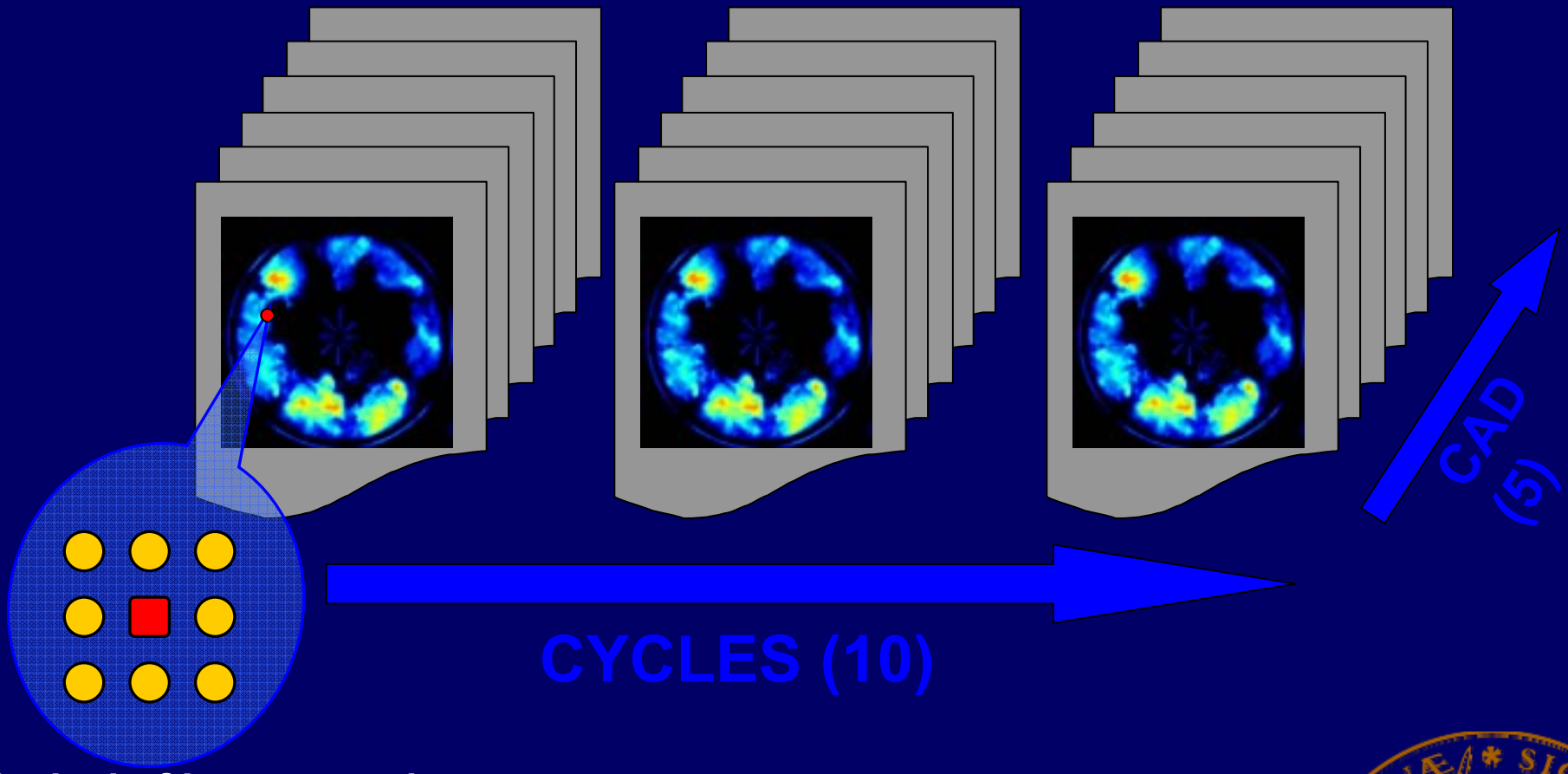


Average of 10 cycles

# Analyzed Points

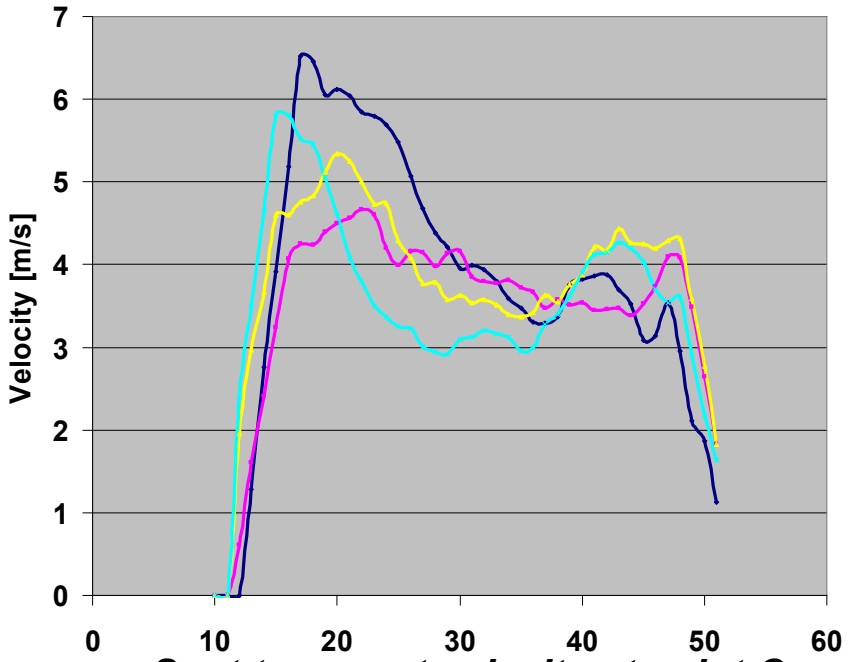


# Averaging in space, time & over cycles

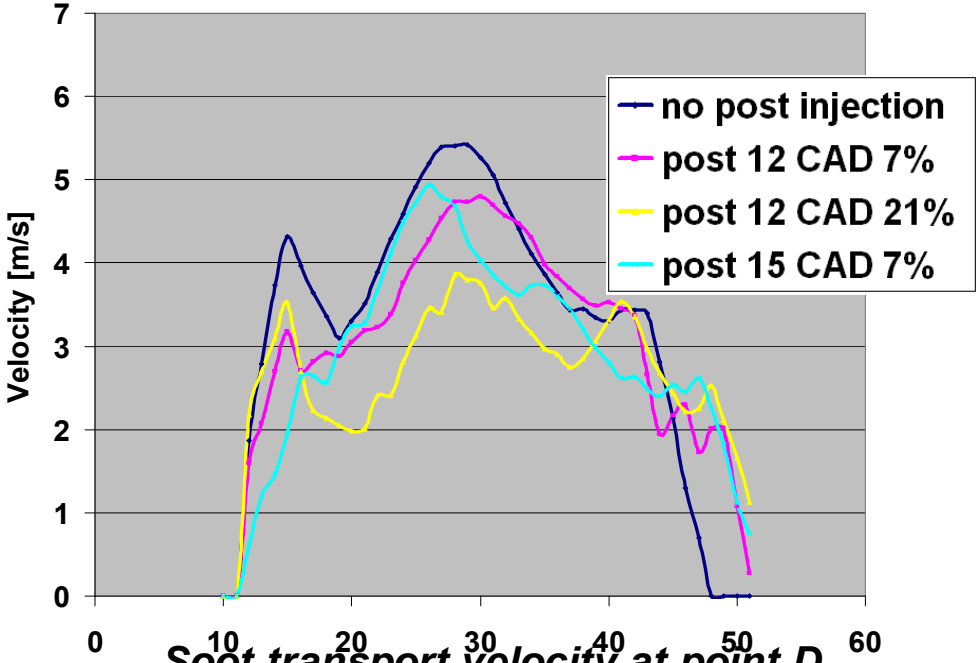



A pixel of interest and
its 8 closest neighbours

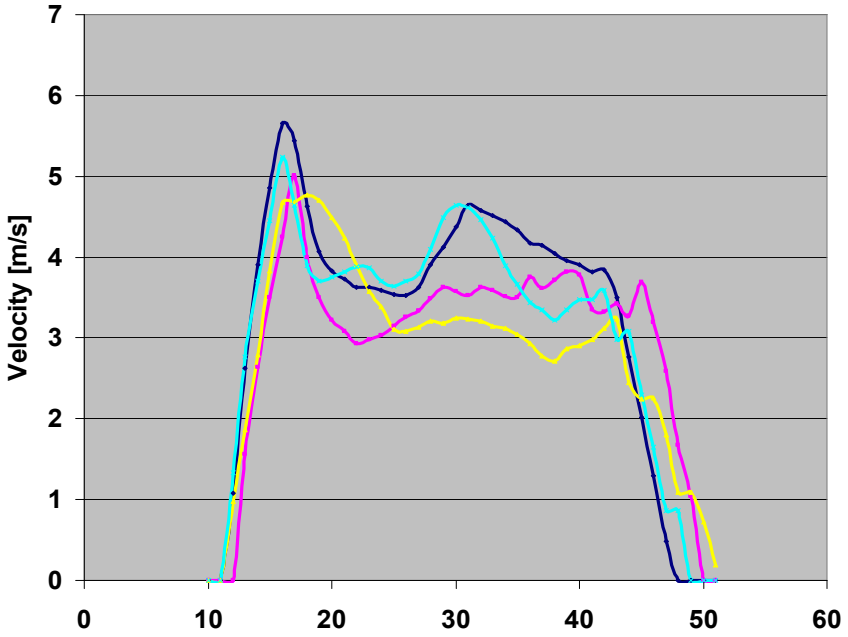
## Soot transport velocity at point A



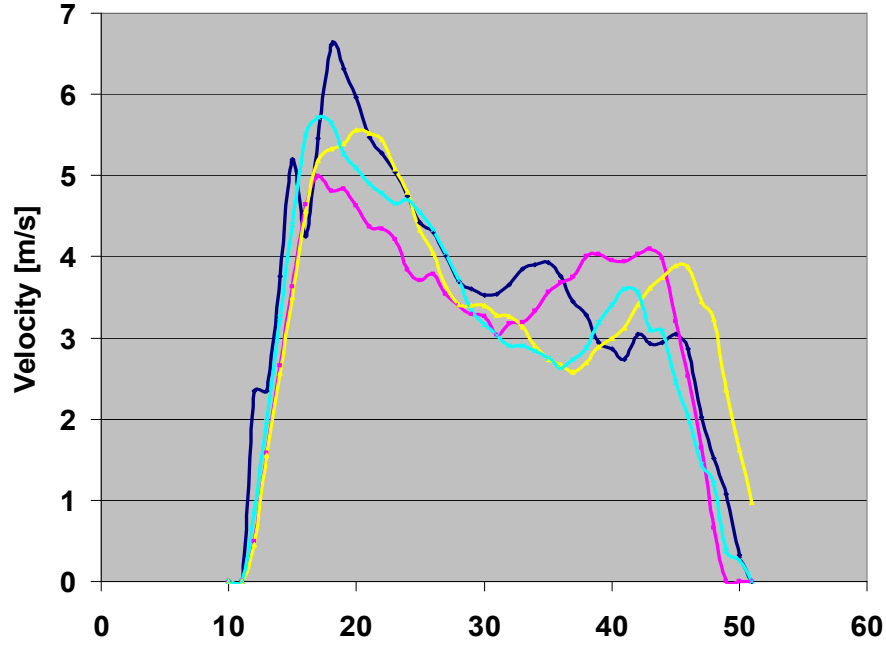

## Soot transport velocity at point B



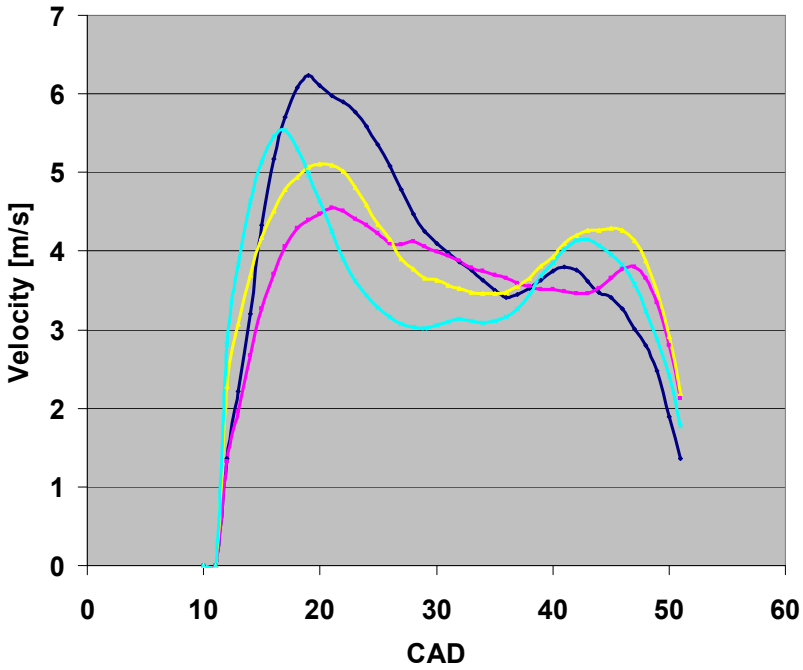

## Soot transport velocity at point C



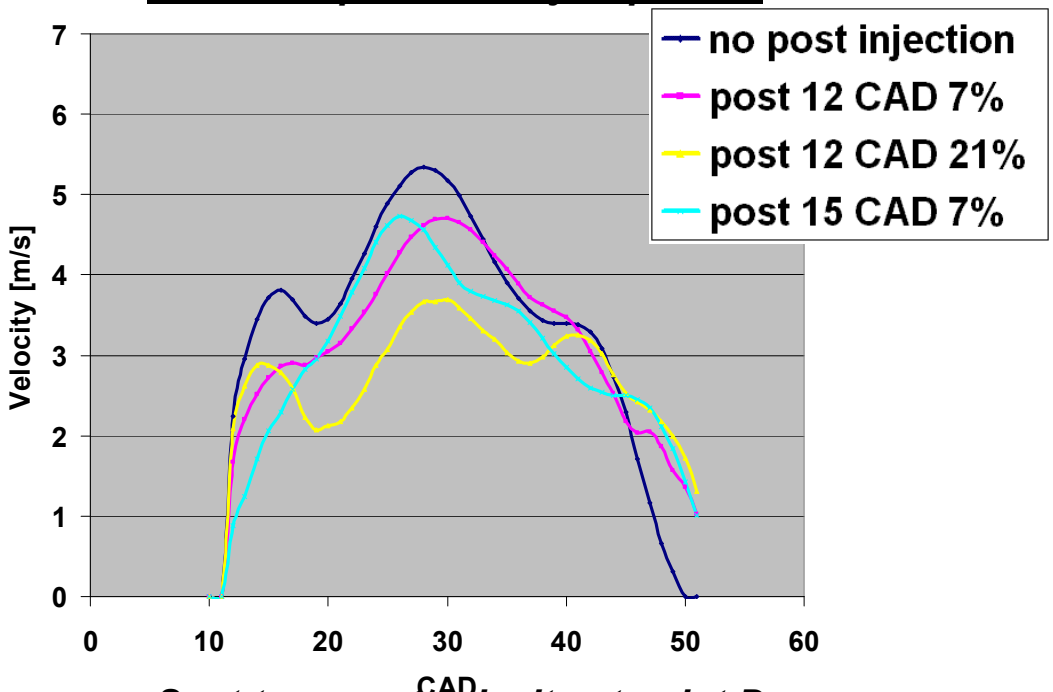

## Soot transport velocity at point D



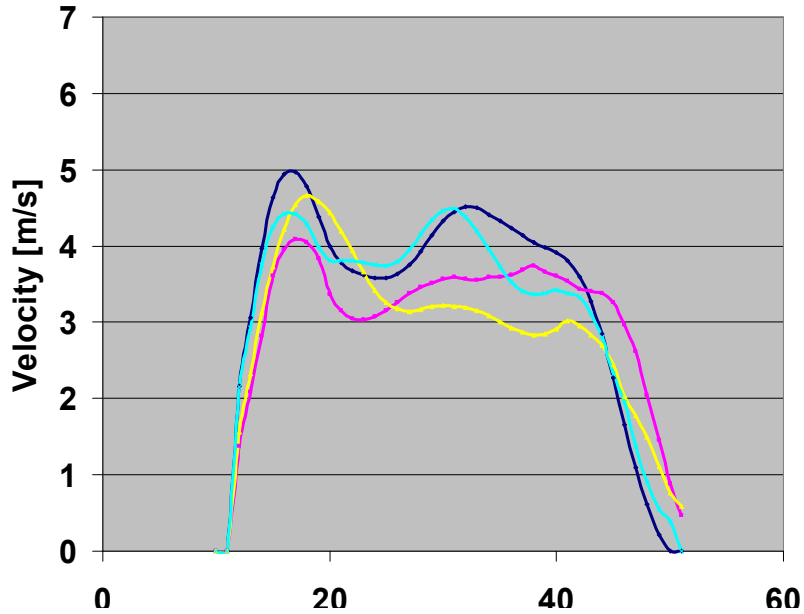
## Soot transport velocity at point A



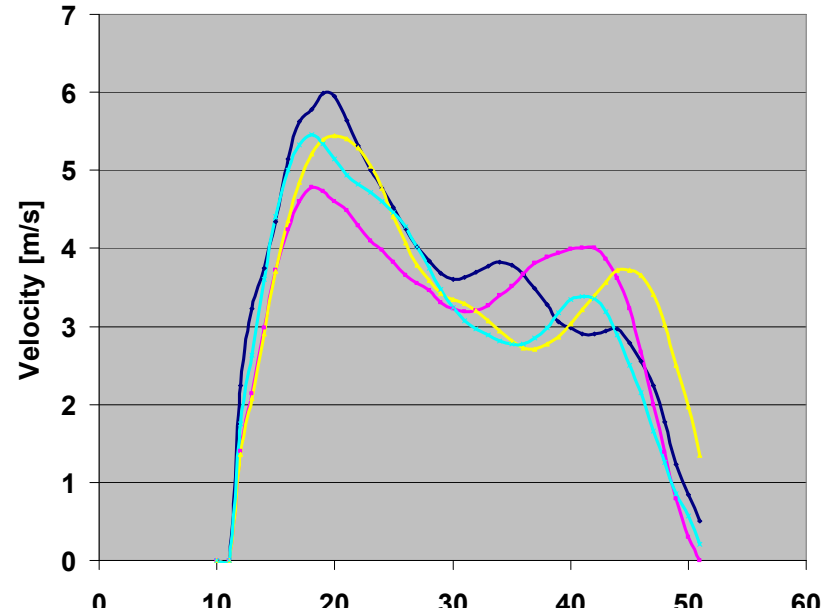

## Soot transport velocity at point B



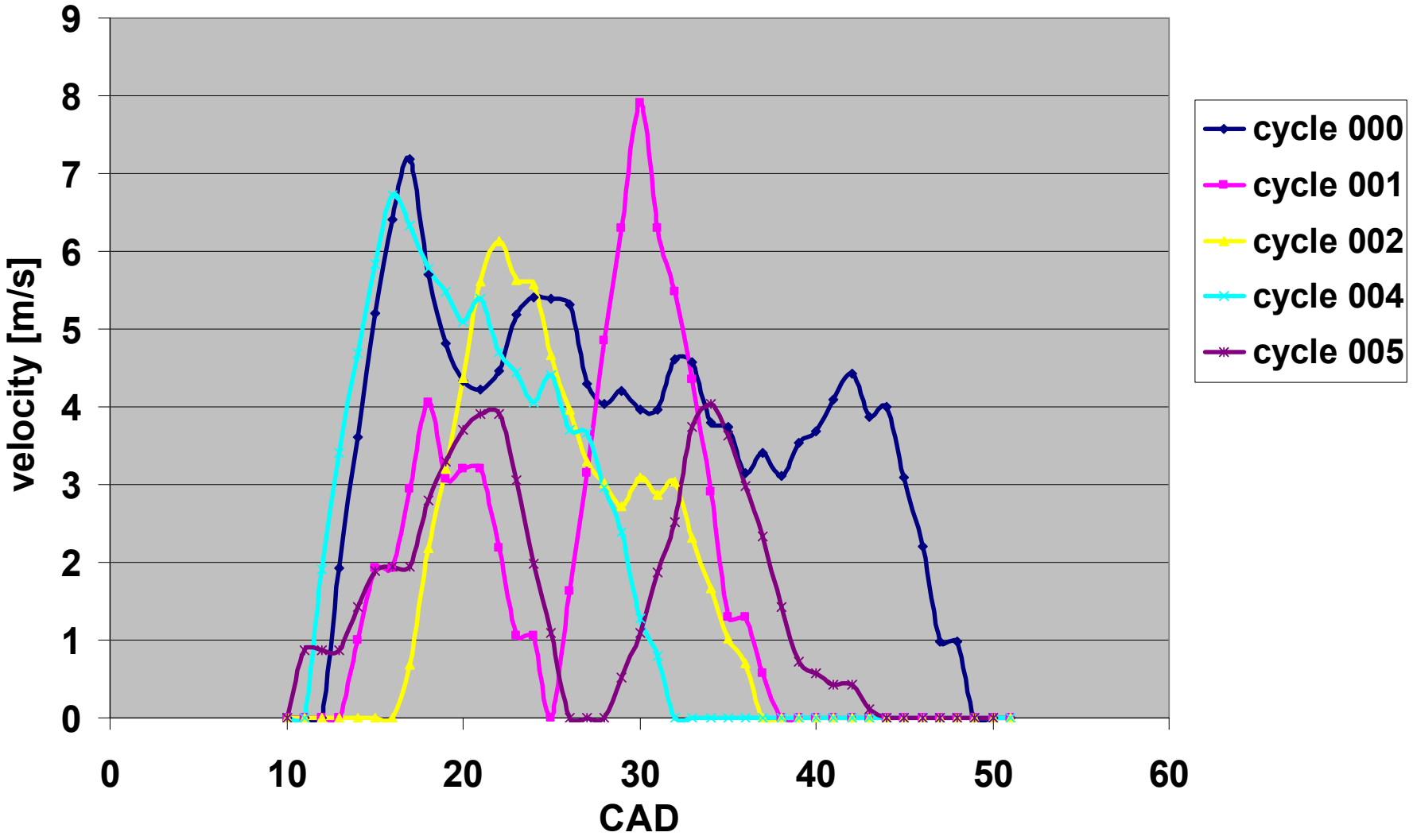

## Soot transport velocity at point C



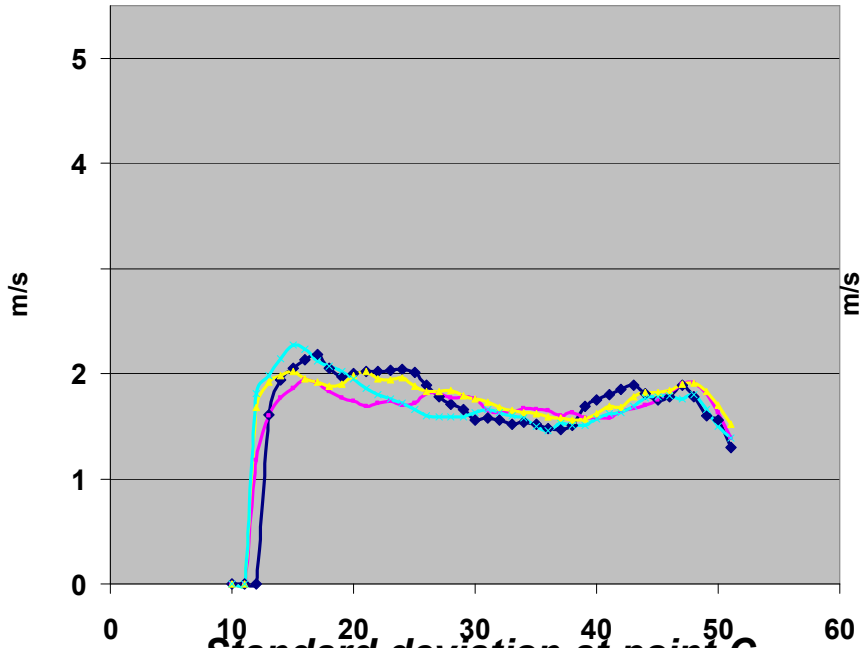

## Soot transport velocity at point D



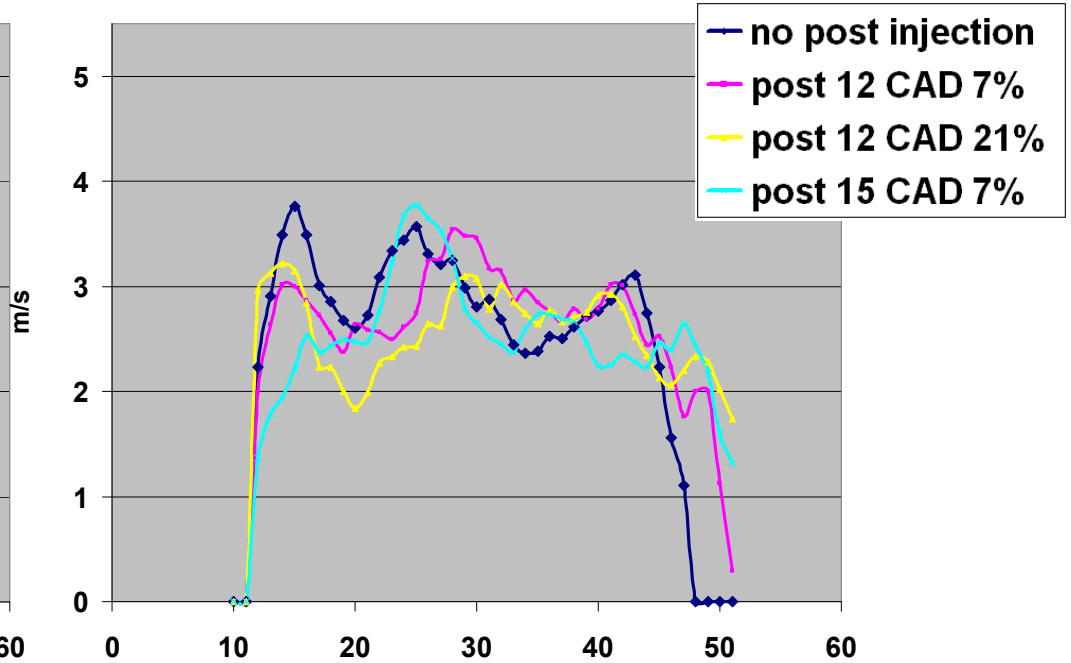
## Cycle to cycle variation for the soot transport velocity at point C without post injection



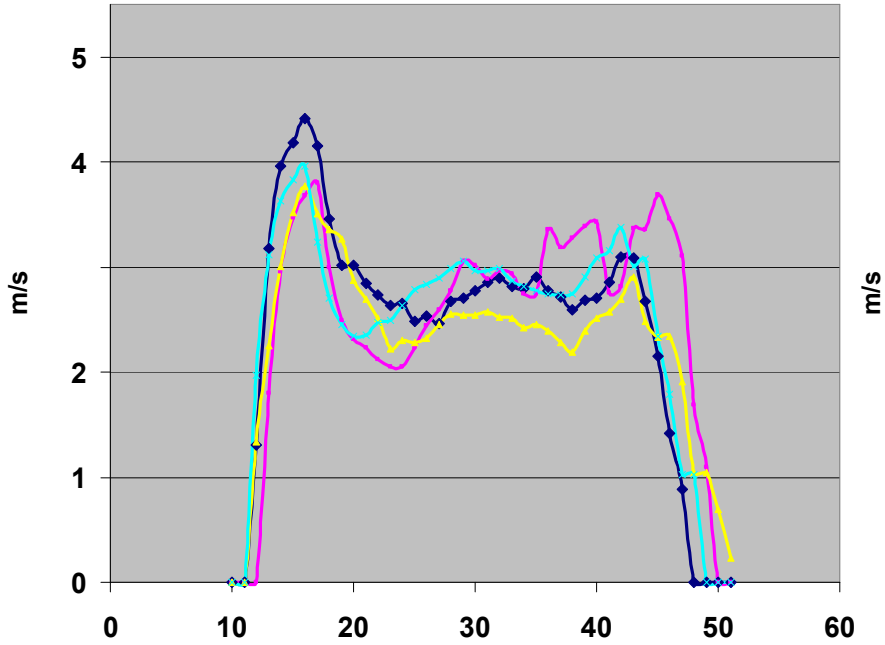
## Standard deviation at point A



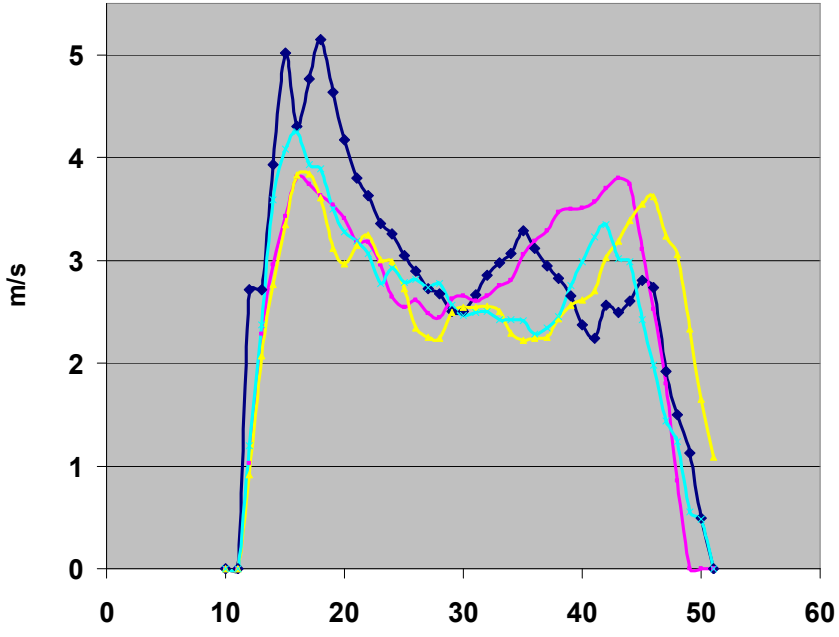

## Standard deviation at point B



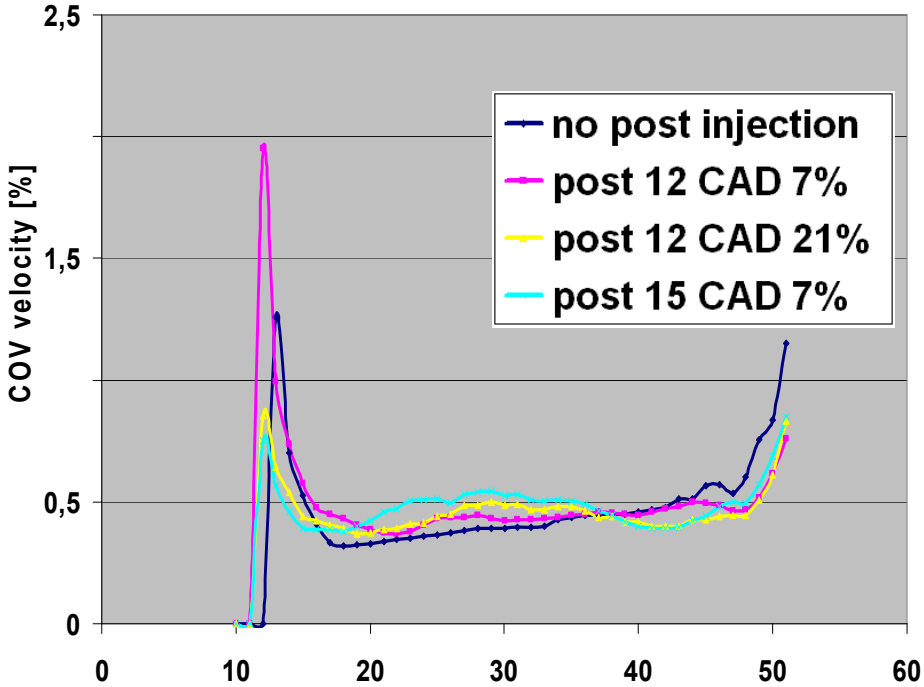

## Standard deviation at point C



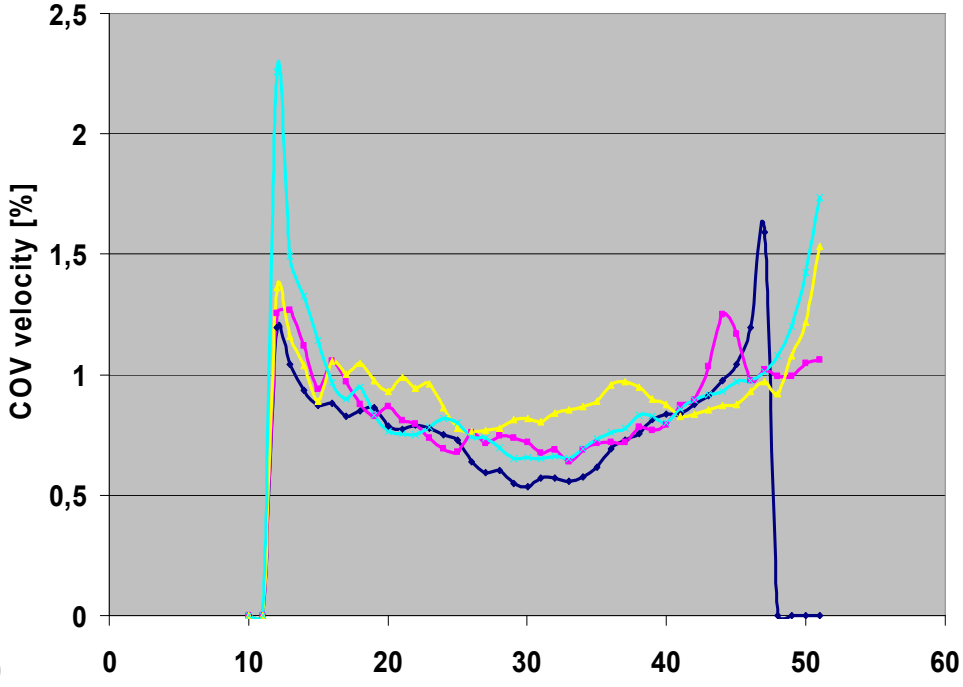

## Standard deviation at point D



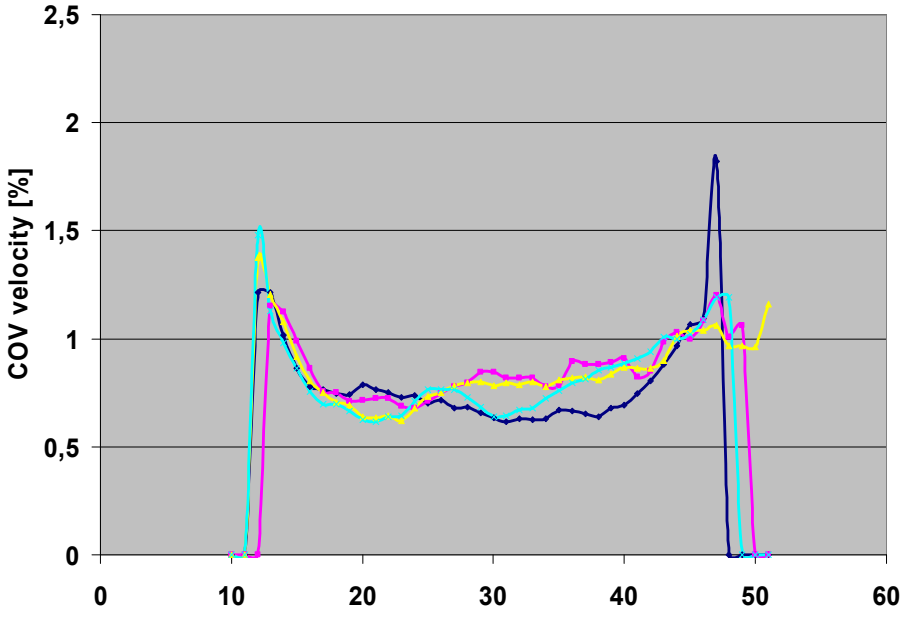
## Coefficient of variation at point A



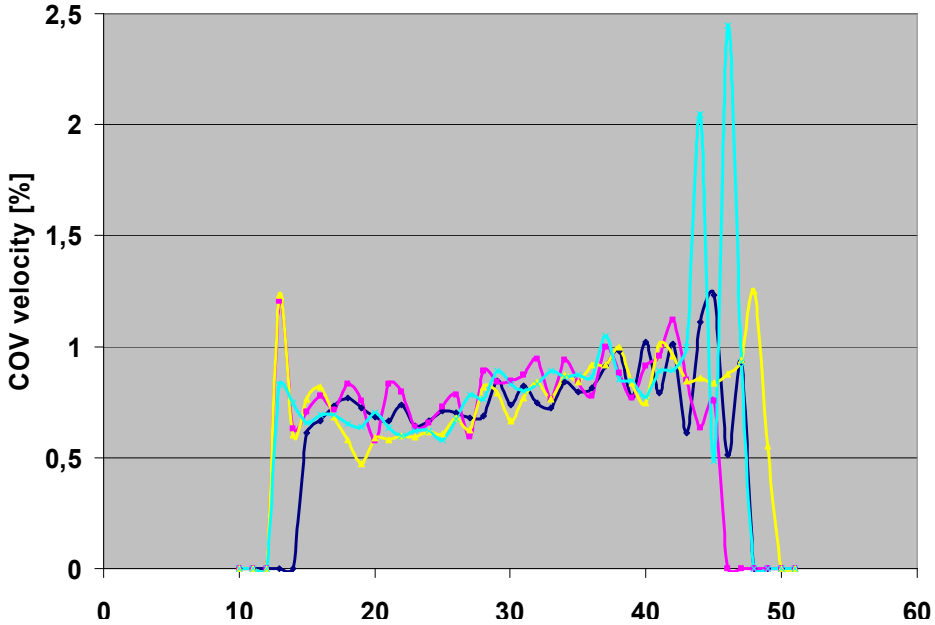

## Coefficient of variation at point B




## Coefficient of variation at point C




## Coefficient of variation at point D



# Summary & Conclusions

- Roughly a 50% reduction of soot obtained by using a post injection of 7% of the main
- There is an optimum timing and quantity of the post injection event.
- Too EARLY post injection gives higher soot
- Too LATE post injection gives higher UHC & CO
- Particle image velocimetry (PIV) analysis gave velocity fields representing the radiating soot movement

# Summary & Conclusions

- Space, time & cycle averaging produced estimates of velocities and mixing (COV)
- Very large cycle-to-cycle variations were found
- No significant influence of the post injection could be found in the velocity data
- Proper PIV or LDV needs to be performed
- Enhanced late cycle mixing seems to be the key.

# Acknowledgements


- Clement Chartier, grad. student
- Swedish Energy Agency (STEM)
- Sandia National Laboratories