"Microscale effects in gas flows through perforated plates"

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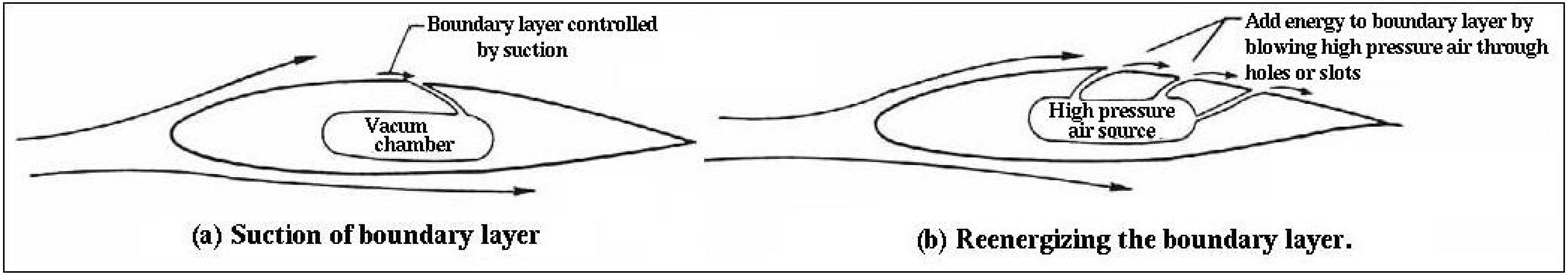
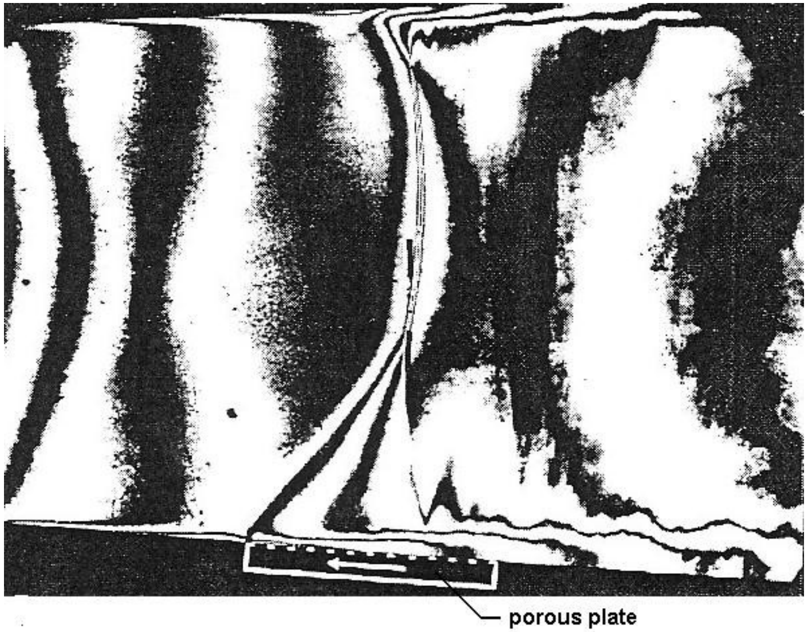
Motivation

- Boundary layer control





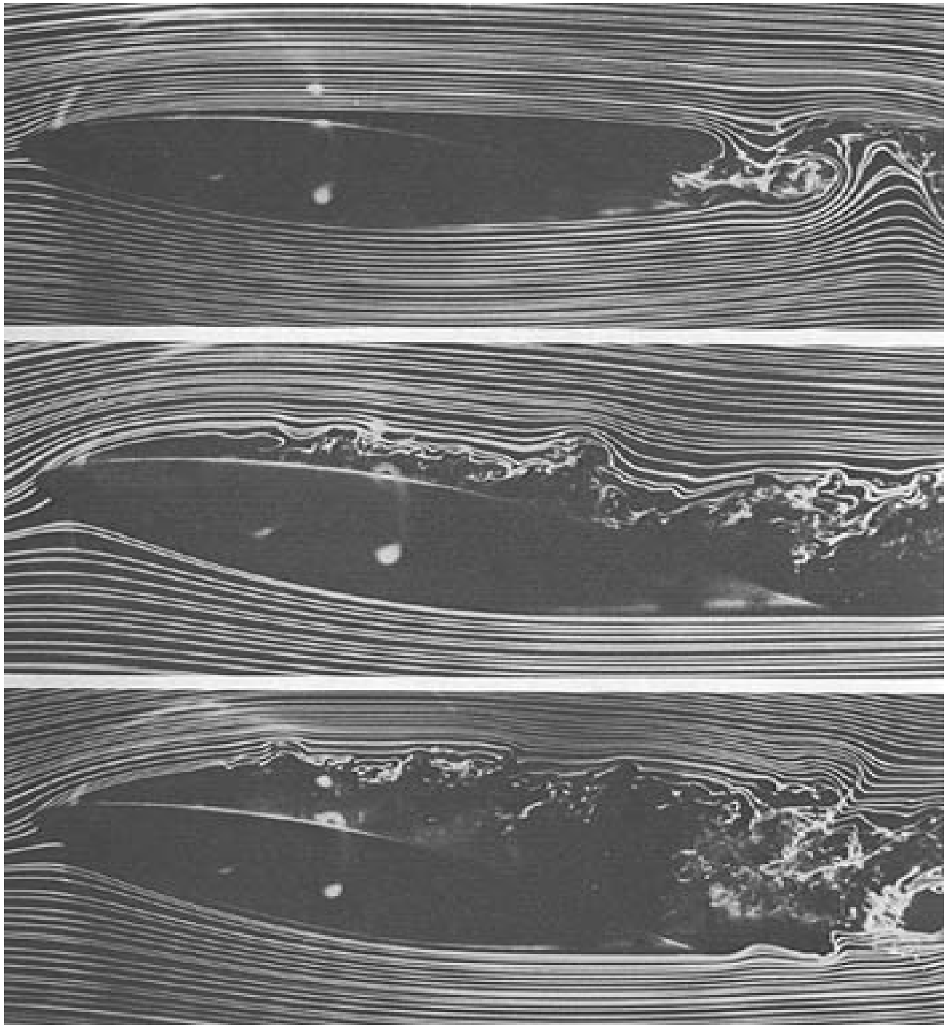
Is it better to control the flow by bigger or smaller holes ?

Agenda

- Boundary layer definition
- Experimental methods of boundary layer examination
- Flow in microchannel
- Boundary layer examination in microflows
- Conclusions

Boundary layer definition

The layer of fluid where the velocity is changing from zero to a constant value, shear stresses are significant and the inviscid-flow assumption may not be used.



Prandtl equations for boundary layer:

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} + V_y \frac{\partial V_x}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu \frac{\partial^2 V_x}{\partial y^2}$$

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = 0$$

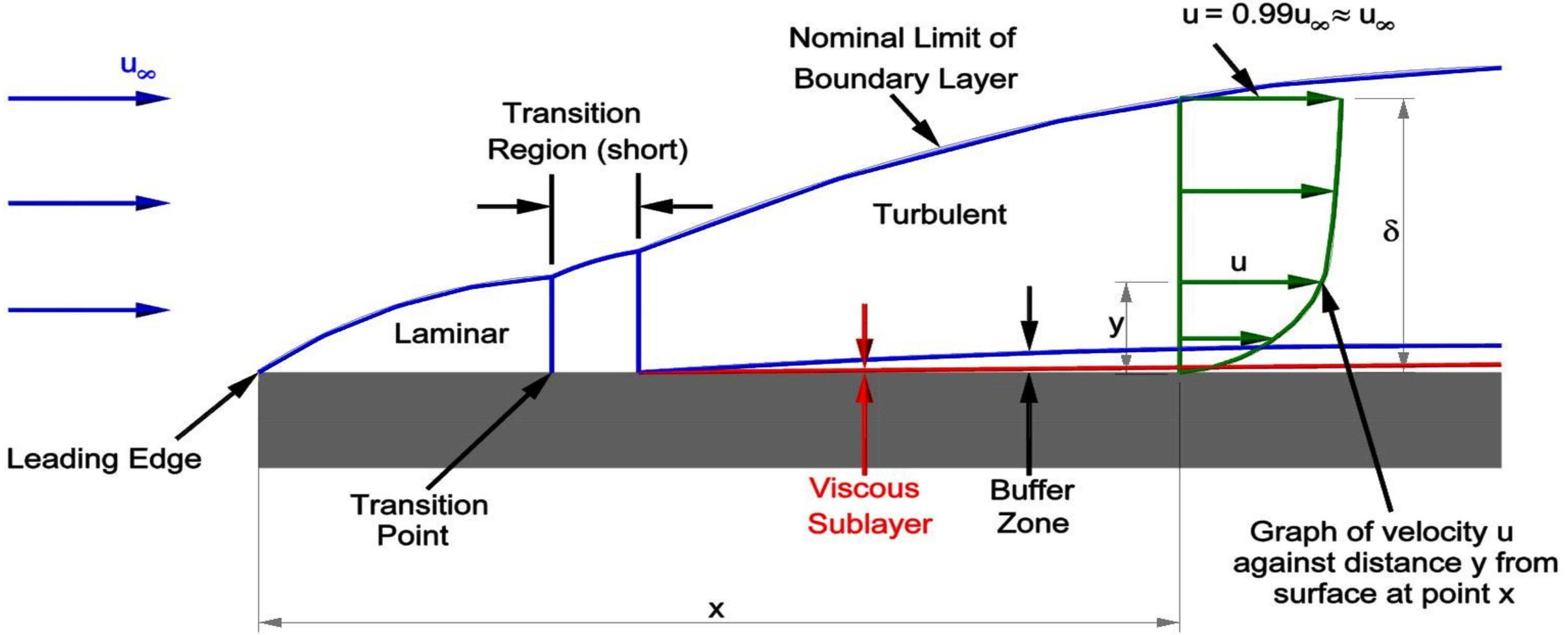
Boundary layer definition

Laminar boundary layer

$$\delta(x) = 5 \cdot \sqrt{\frac{\nu \cdot x}{u_\infty}}$$

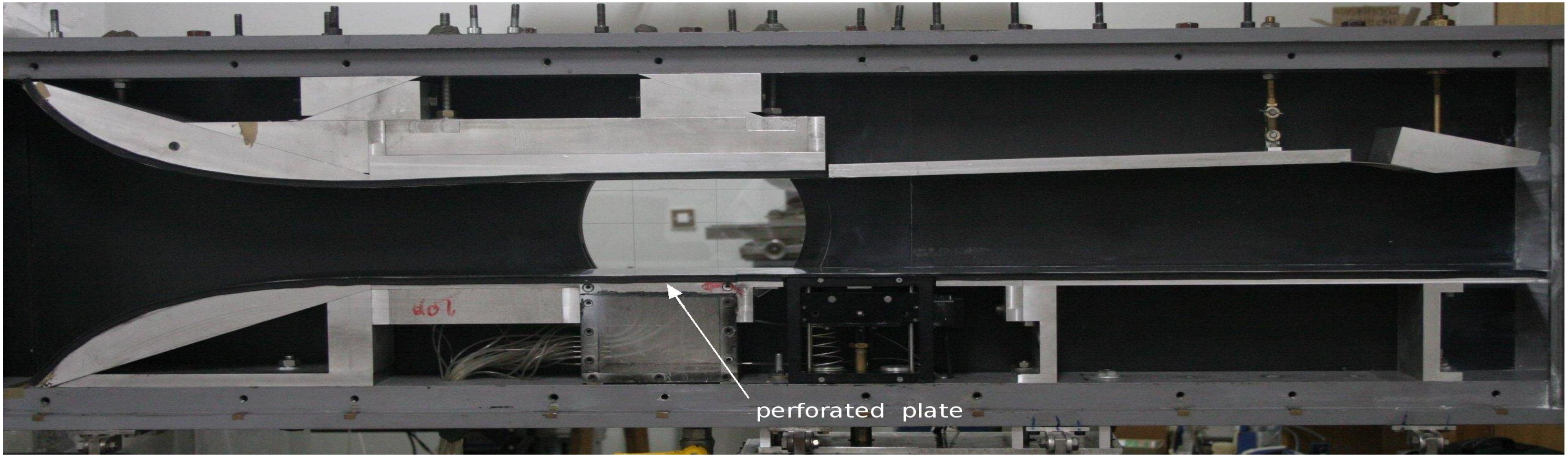
Turbulent boundary layer

$$\delta(x) = 0{,}37\, x \cdot \left(\frac{u_\infty \cdot x}{\nu}\right)^{-1/5}$$

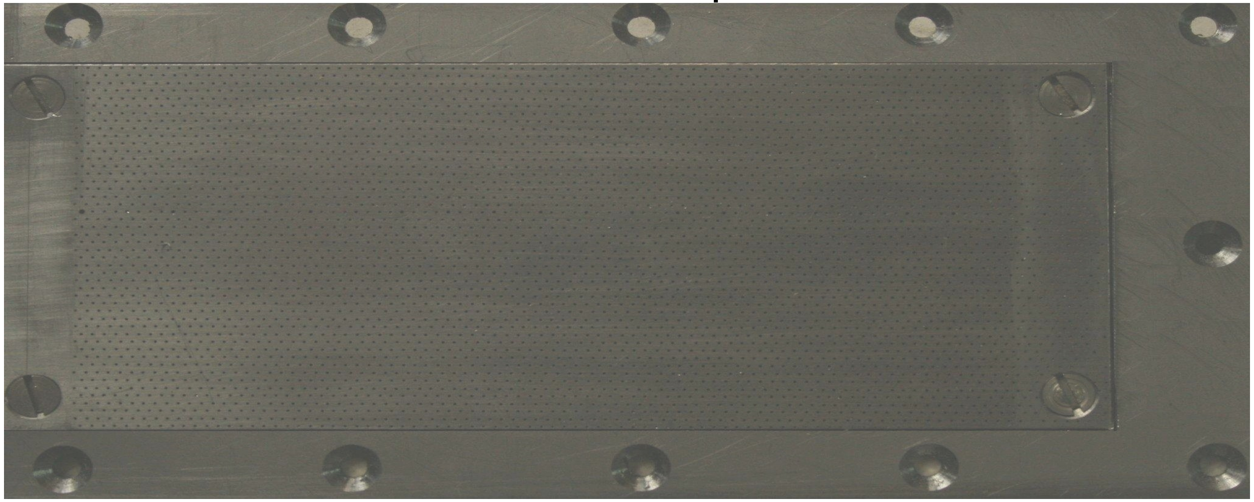


Experimental methods

Transonic wind tunnel



Perforated plate



Flow in microchannel

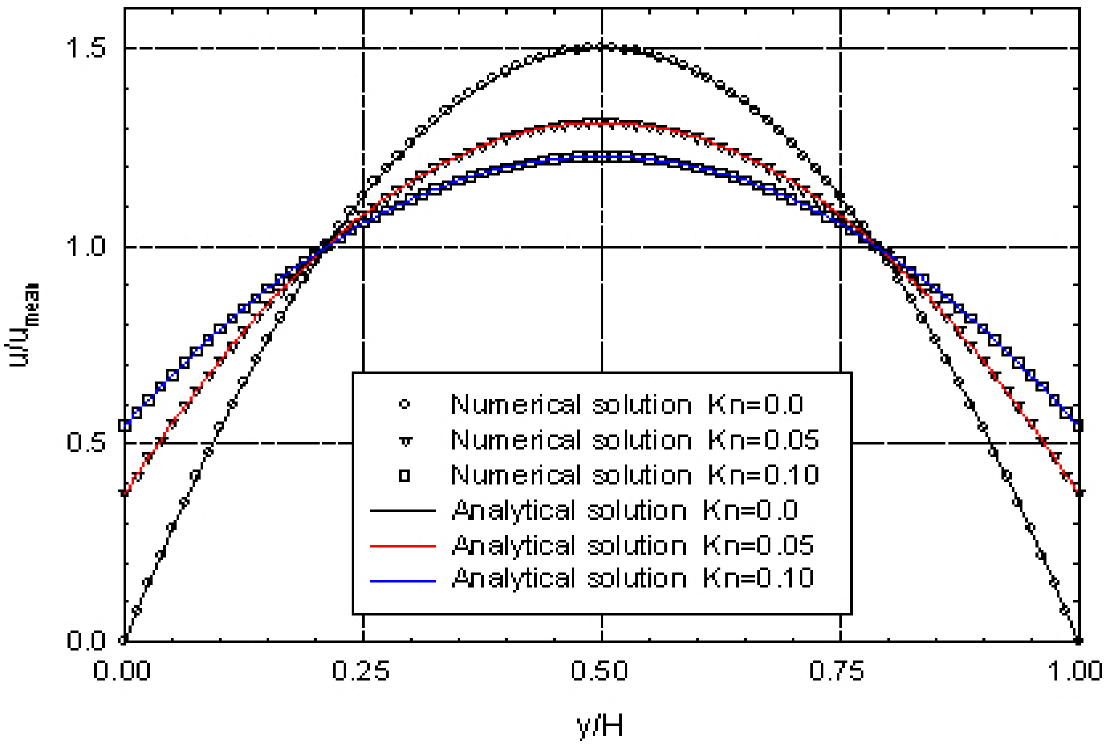
- Change of boundary condition on the wall – slip condition

Maxwell velocity-slip boundary condition

$$u_{fluid} - u_{wall} = \frac{2-\sigma_v}{\sigma_v} \lambda \frac{\partial u}{\partial y} + \frac{3}{4} \frac{\mu}{\rho T} \frac{\partial T}{\partial x}$$

Smoluchowski temperature jump condition

$$T_{fluid} - T_{wall} = \frac{2-\sigma_T}{\sigma_T} \frac{2\gamma}{\gamma+1} \frac{\lambda}{Pr} \frac{\partial T}{\partial y}$$



Microchannel flow research - numerical simulation

Setup description

Software: **Fluent 6.3.26**

Two types entrance:

- straight inlet
- cone inlet

Grid: structural with 27k cells

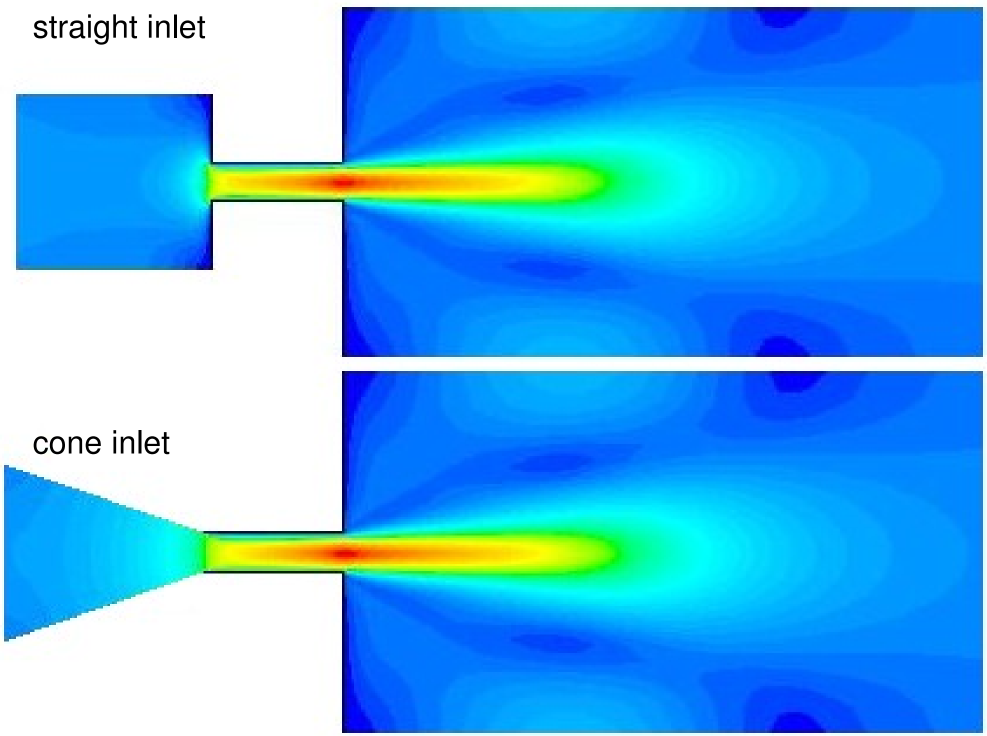
Boundary conditions:

- inlet-pressure boundary condition
- outlet-pressure boundary condition

Perforation: 5%

Dimensions of the channel:

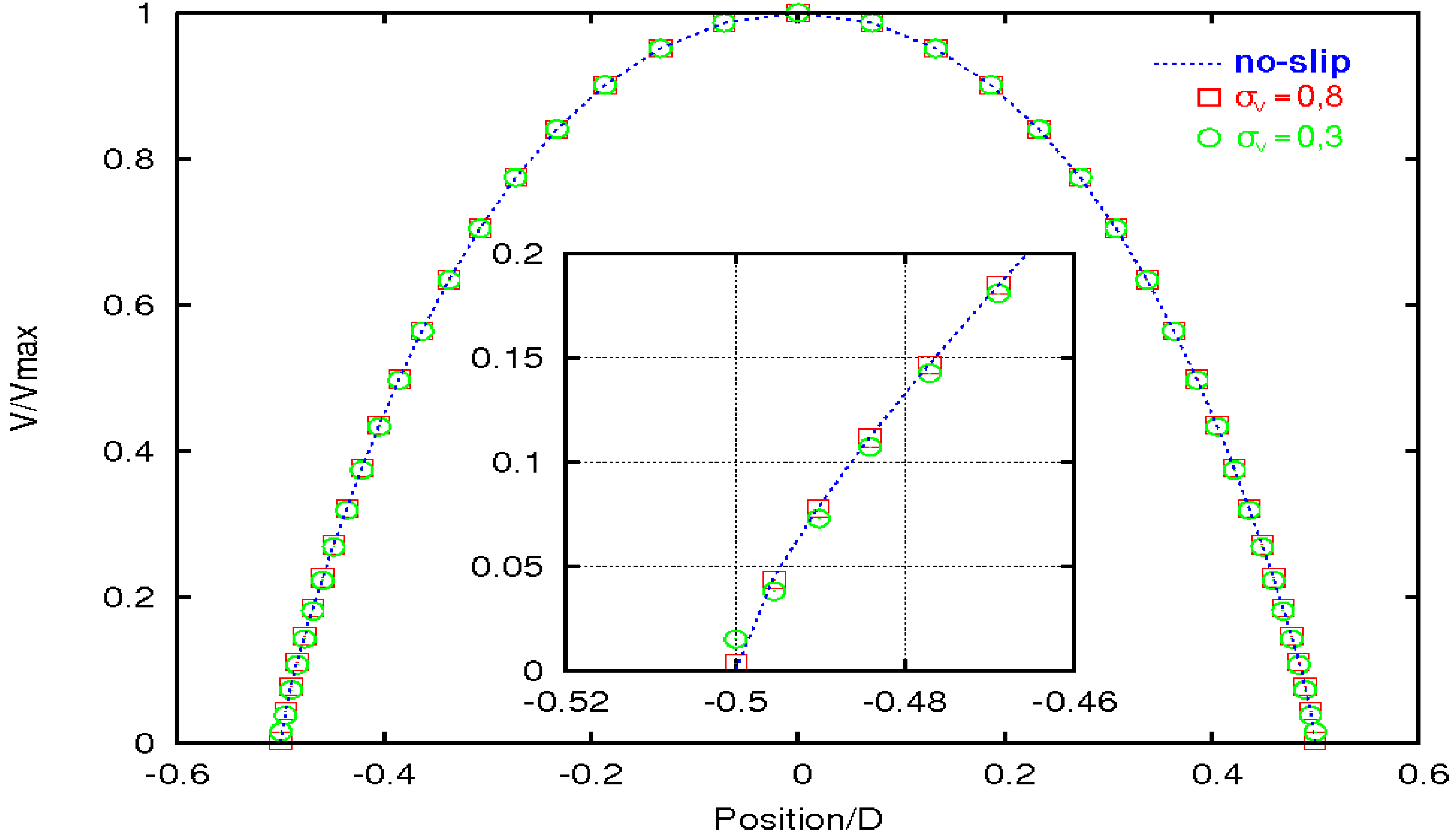
- diameter: 300µm
- channel length: 1000µm



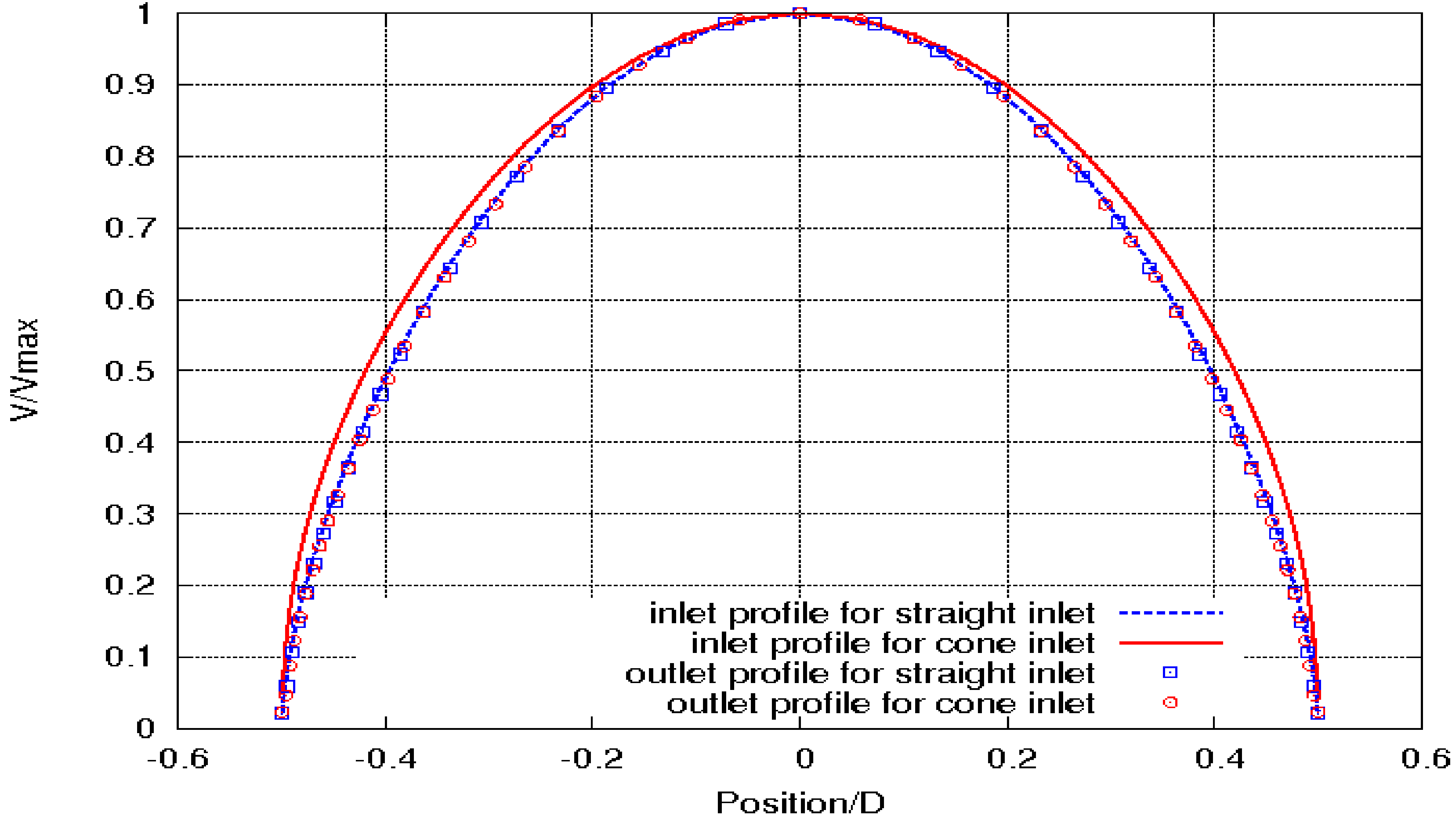
Cases

Kn	Laminar slow Re < 1	Laminar fast Re >10	Turbulent Re > 100
0,0002	-	-	+
0,004	+	+	+
0,008	+	+	+
0,011	+	+	-

Difference between flows with and without slip

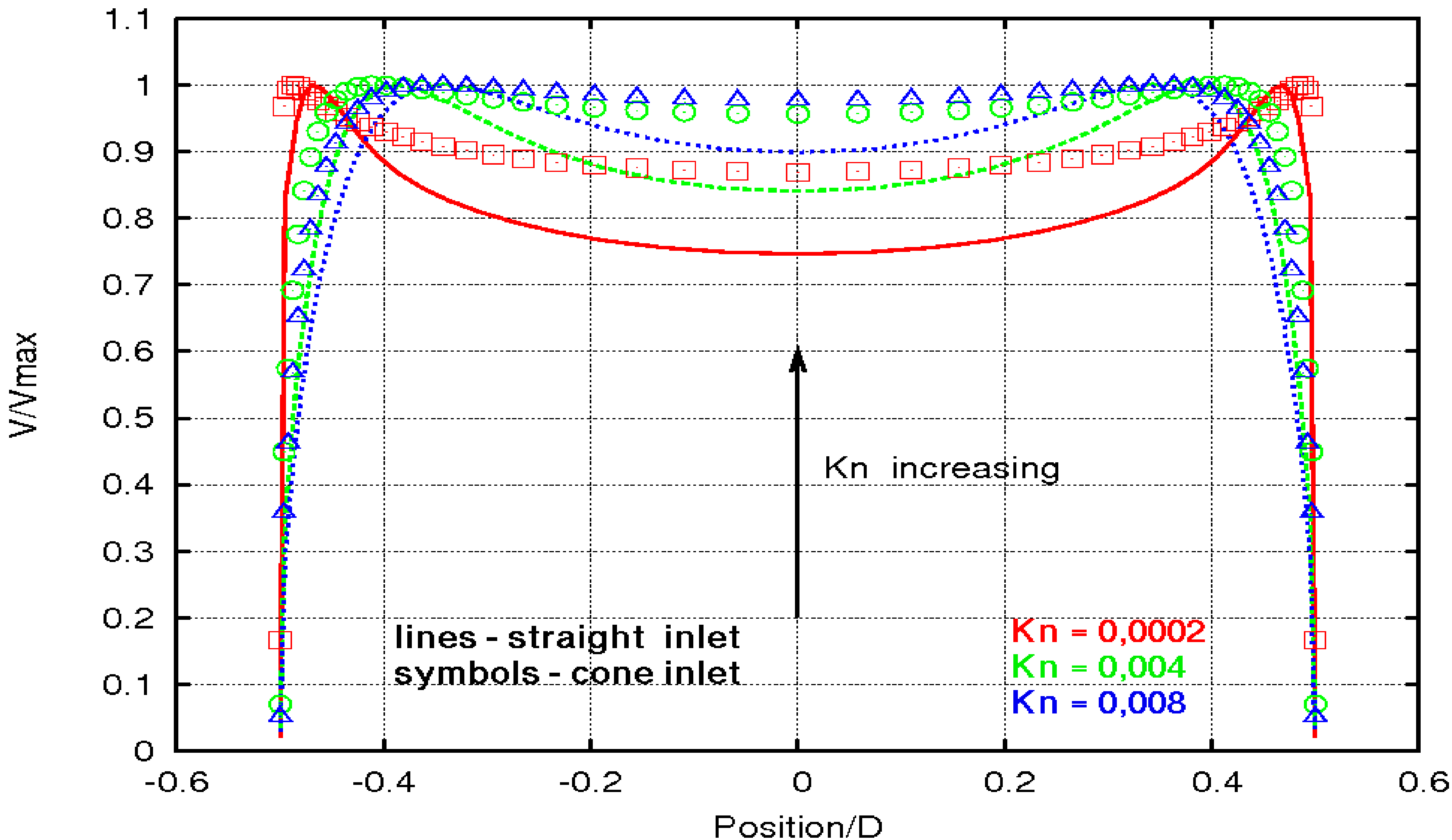


The influence of inlet on velocity profiles characteristic – **lam Re < 1**

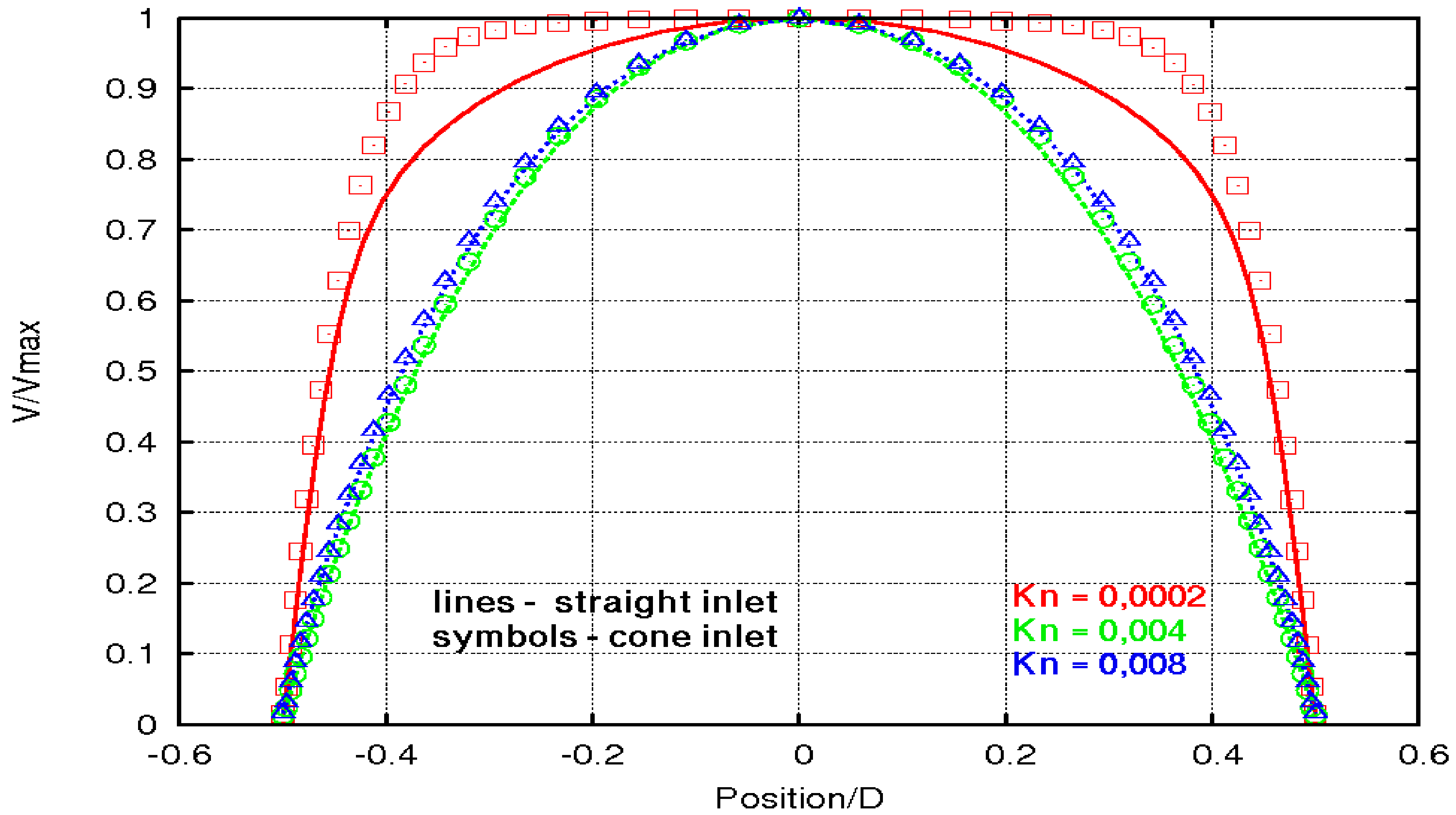


Velocity profiles for inlet and outlet for two geometries, Kn 0,004 - 0,011

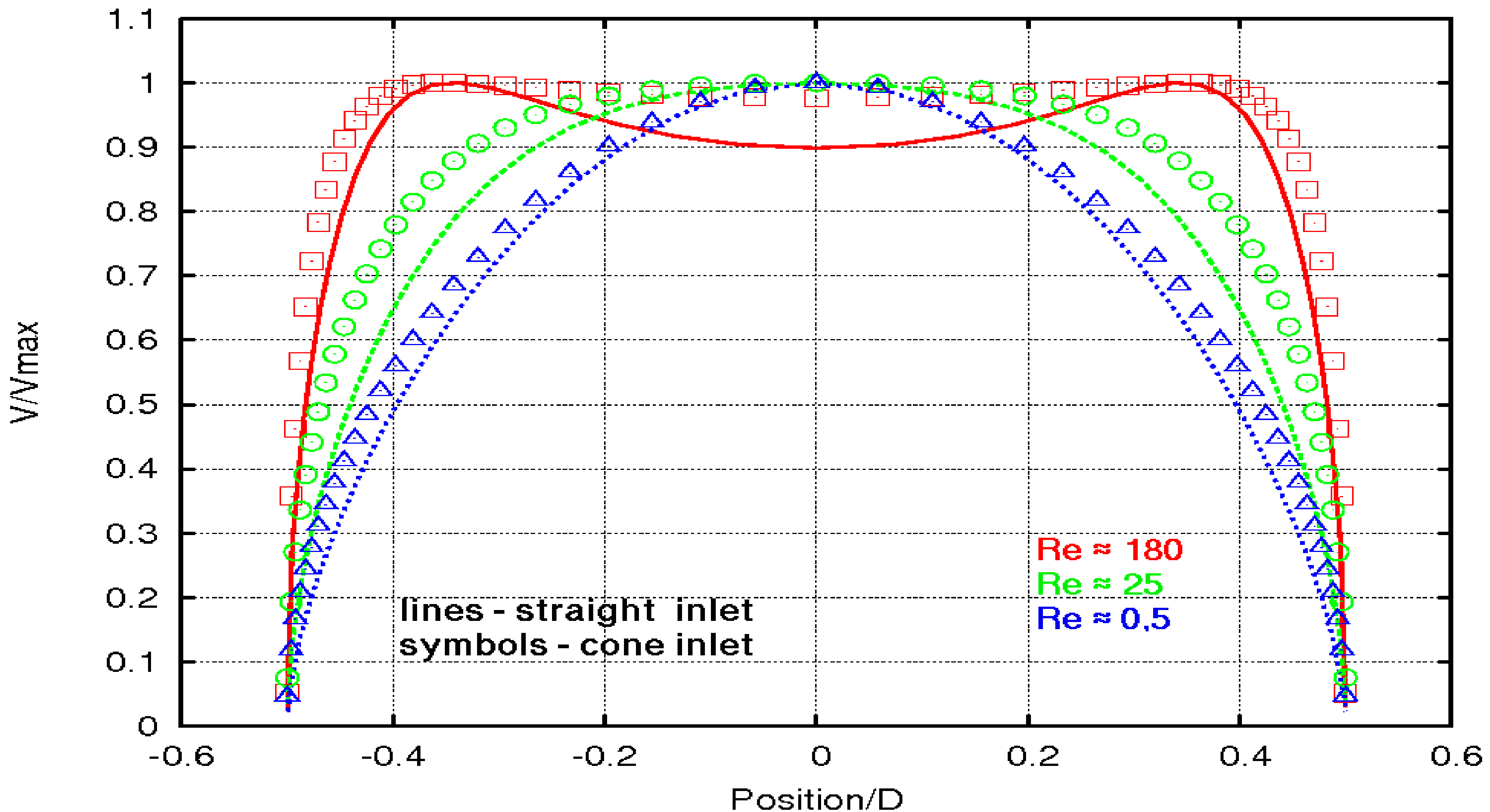
The influence of inlet on inlet velocity profiles characteristic – **turb Re > 100**



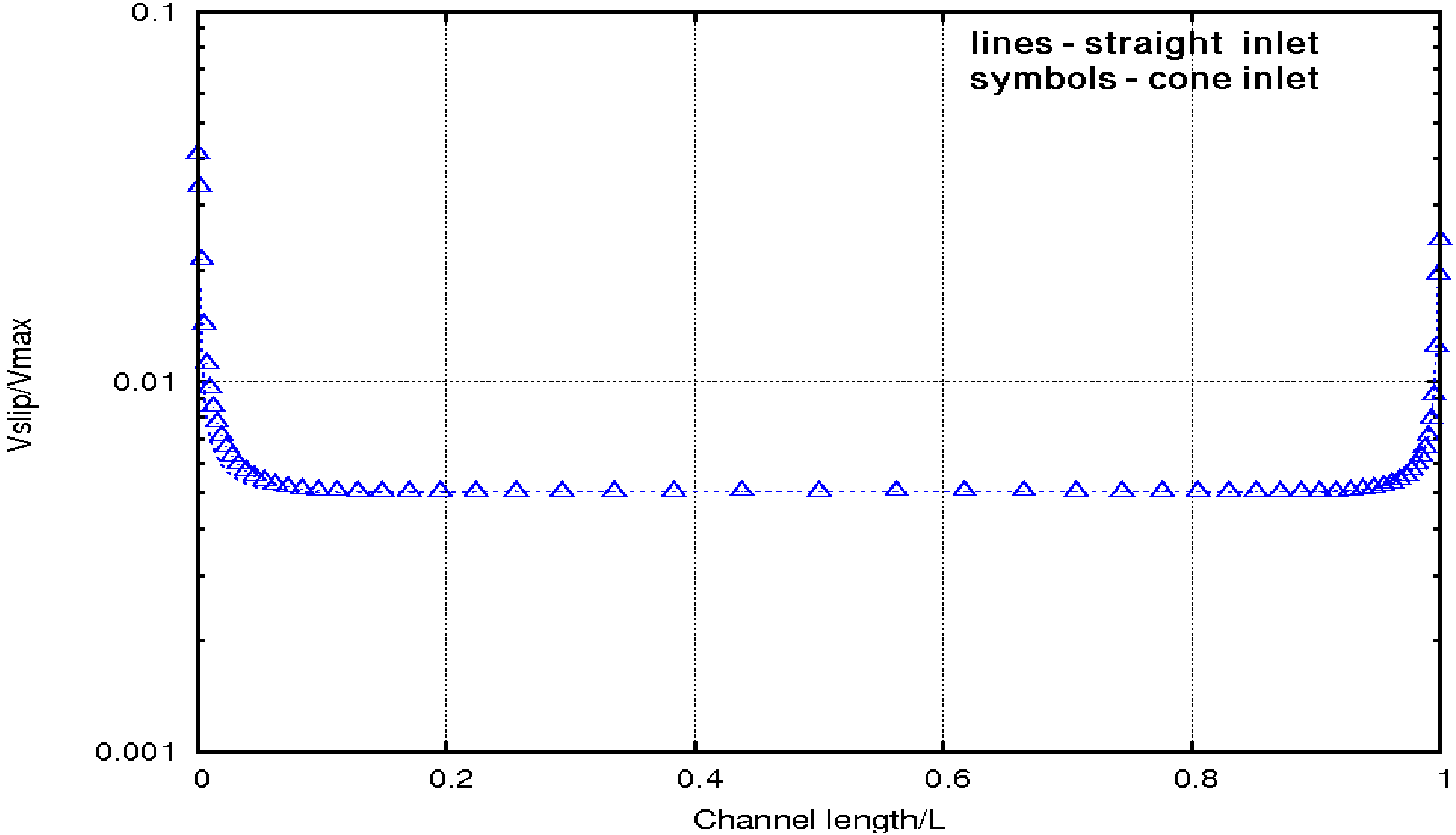
The influence of inlet on outlet velocity profiles characteristic – **turb Re > 100**



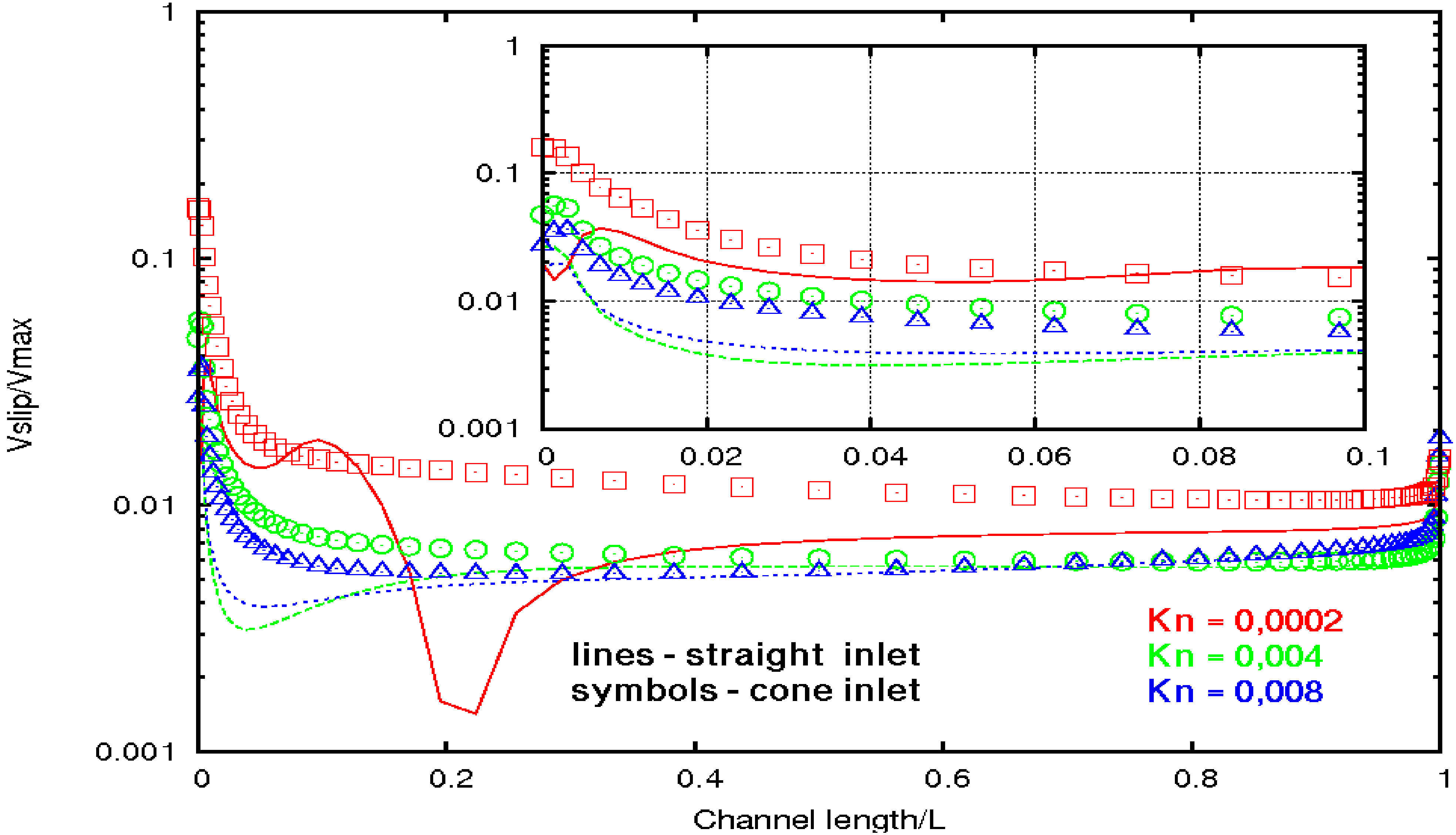
The influence of Re on inlet velocity profiles characteristic – **Kn = 0,008**



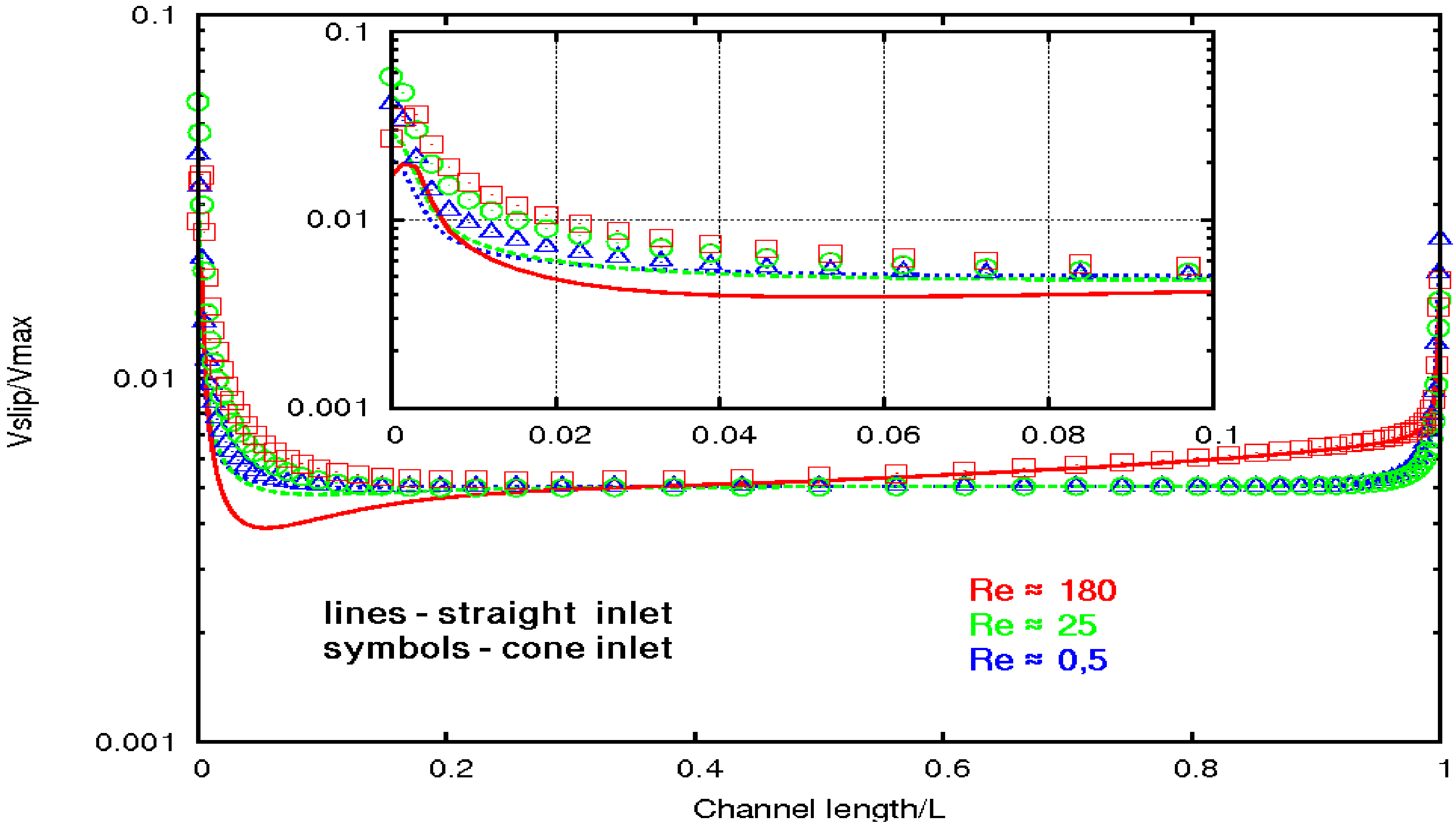
The characteristic of flow along the microchannel – **laminar Re < 1**



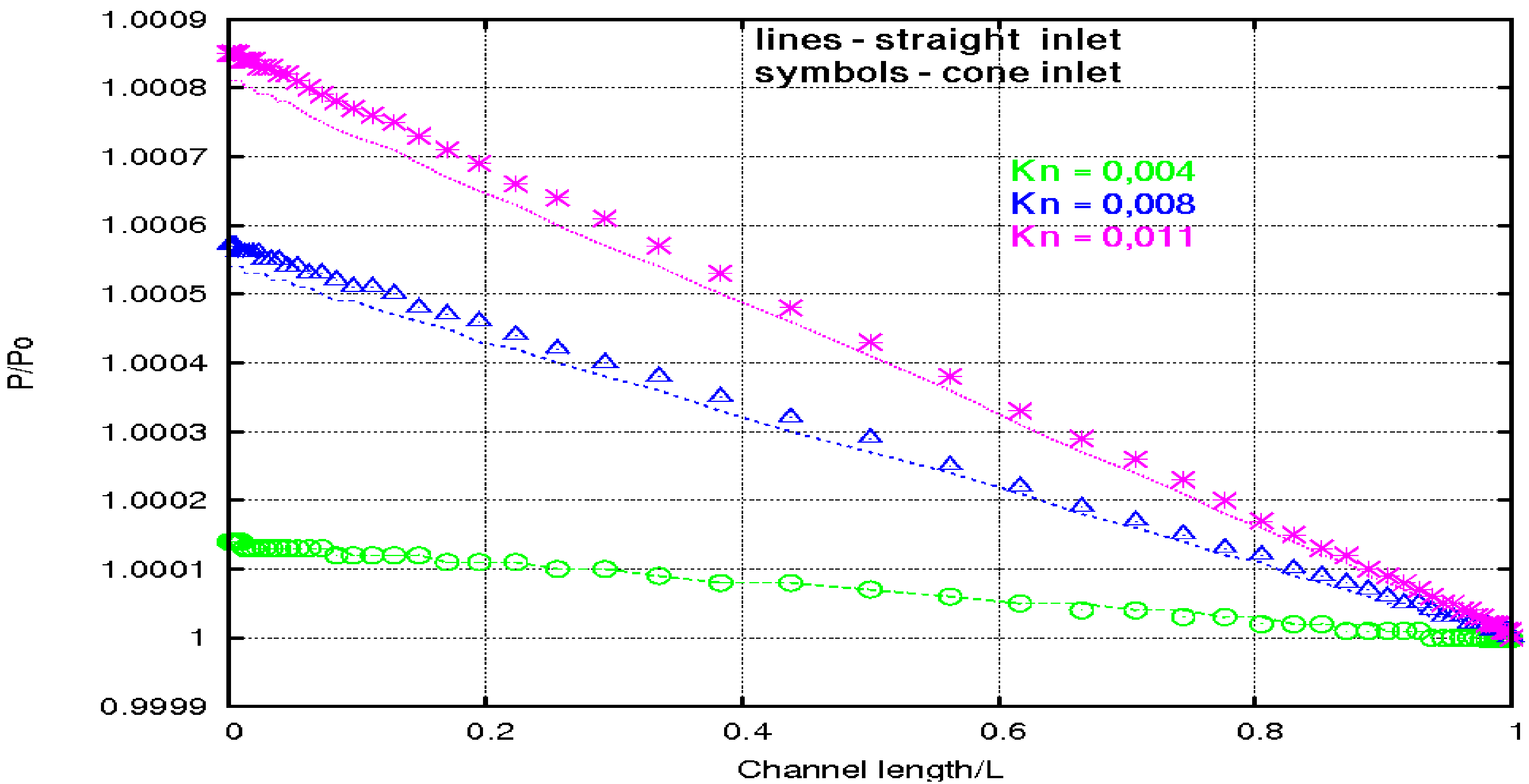
The characteristic of flow along the microchannel – **turbulent Re > 100**



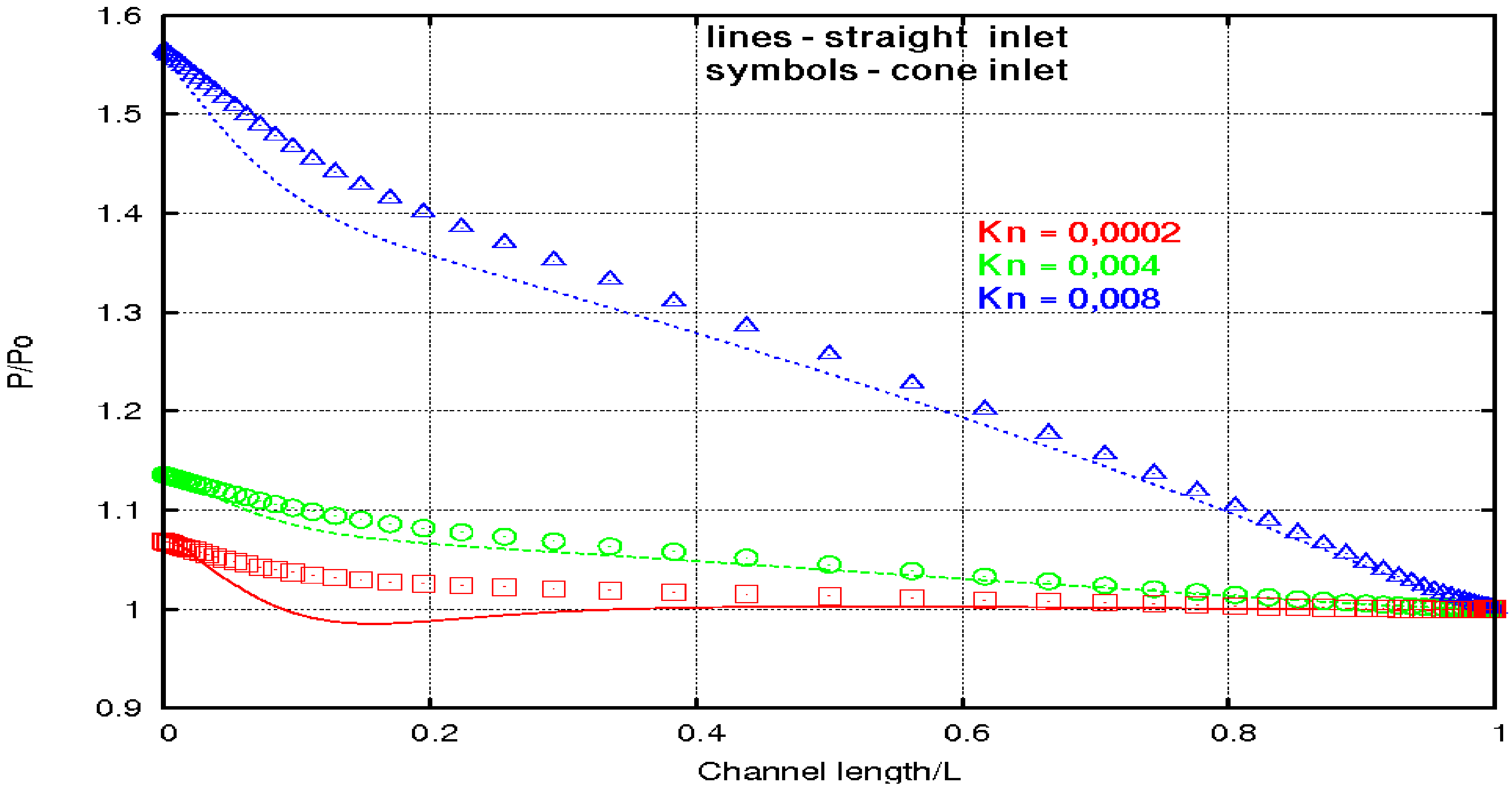
The characteristic of flow along the microchannel – **Kn = 0,008**



The influence of inlet on the characteristic of the flow along microchannel – **laminar Re < 1**



The influence of inlet on the characteristic of the flow along microchannel – **turbulent Re > 100**

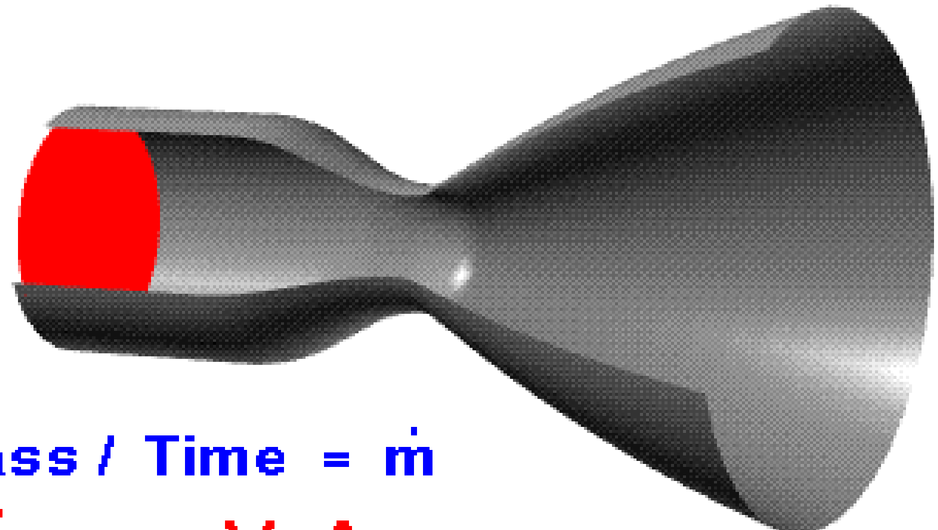


Mass flow rate

r = Density

V = Velocity

A = Area



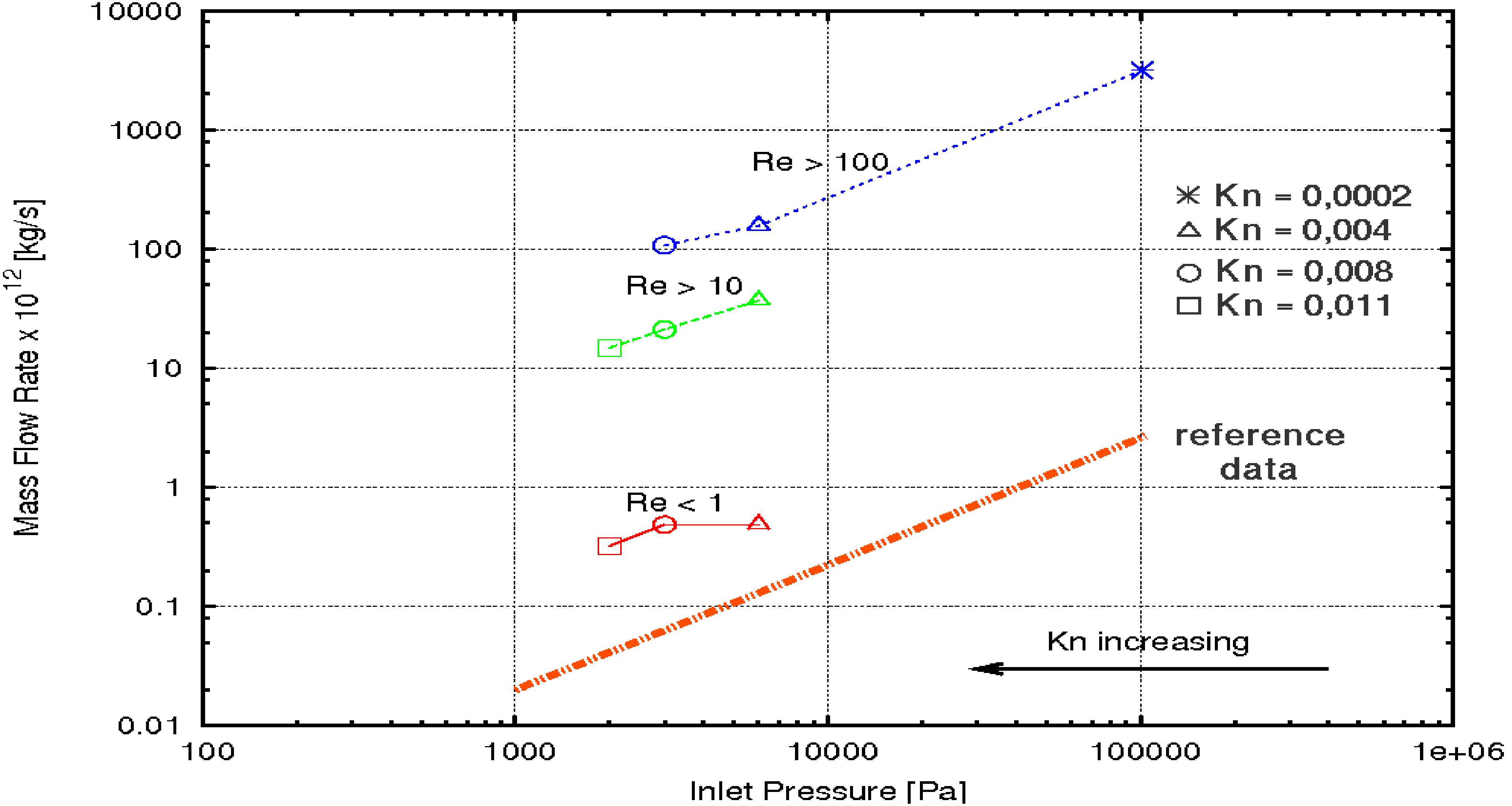
Mass Flow Rate = Mass / Time = $\dot{m}$

$$\dot{m} = r\ V\ A$$

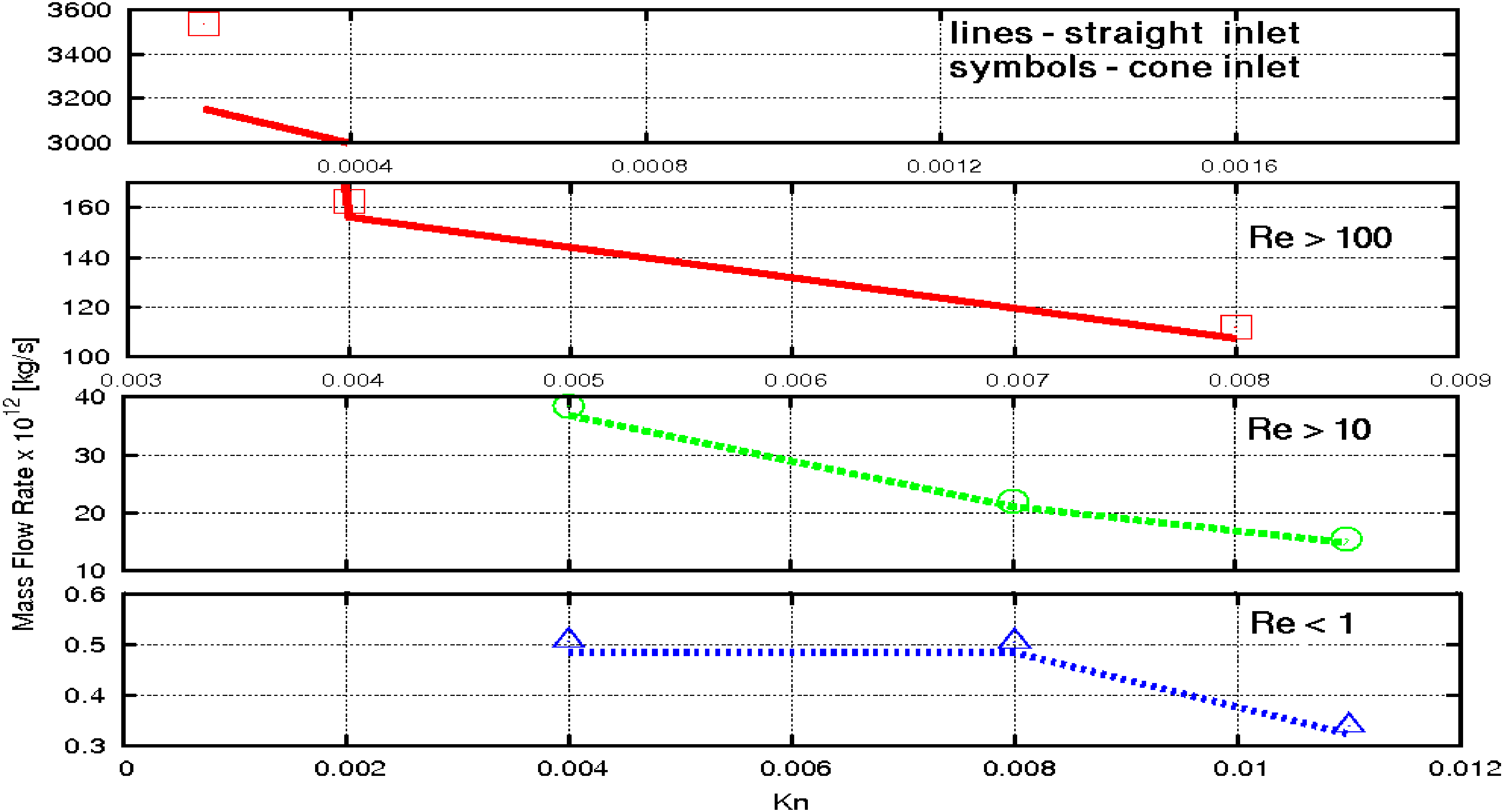
Units Check: $\dfrac{\text{mass}}{\text{length}^3}\ \dfrac{\text{length}}{\text{time}}\ \text{length}^2 = \dfrac{\text{mass}}{\text{time}}$

Continuity : $r\ V\ A = \text{Constant}$

The influence of Re and Kn on mass flow rate



The influence of inlet geometry on mass flow rate.



Conclusions

- Mass flow rate is strongly dependent on Re and Kn numbers $\dot{M}\uparrow \mathrm{Re}\uparrow \mathrm{Kn}\downarrow \mathrm{D}\uparrow$
- Mass flow rate depends on inlet geometry very weakly
- $\dot{M}_{cone\ \ inlet} > \dot{M}_{straight\ \ inlet}$
- Mass flow rate depends on the length of **microchannel penetration**

Mass flow rate depends not only on diameter but also on the ratio of diameter and microchannel length

Conclusion

Flow control depends on flow parameters (Re); holes magnitude; perforation and plate thickness.

Acknowledgements

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