CFD Modeling of Pleated Filter Elements with the Experimental Validation using PIV

Seungkoo Kang, David Y. H. Pui, and Jacob Swanson
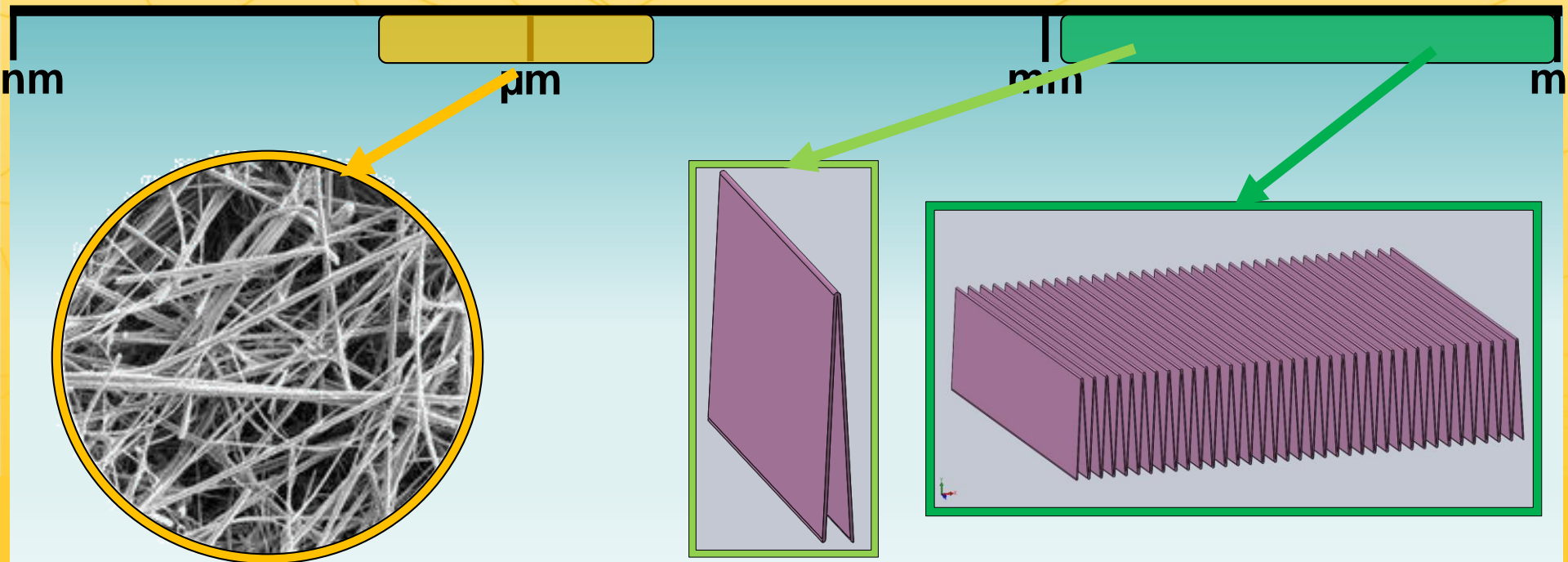
Particle Technology Laboratory
University of Minnesota

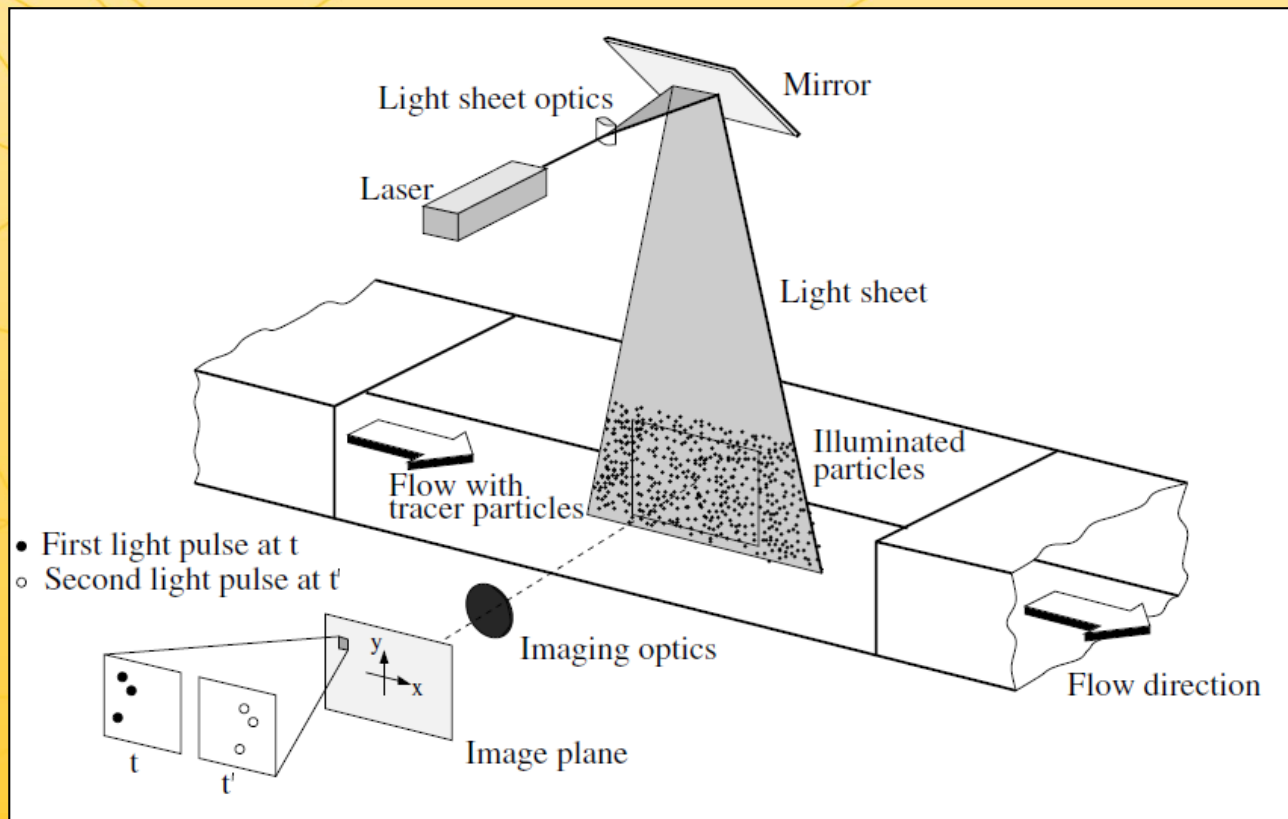Center for Filtration Research

UNIVERSITY OF MINNESOTA

Accurately modeling filtration performance requires resolving microstructures of pleated filters

➡️ **tremendous computational resources and time**
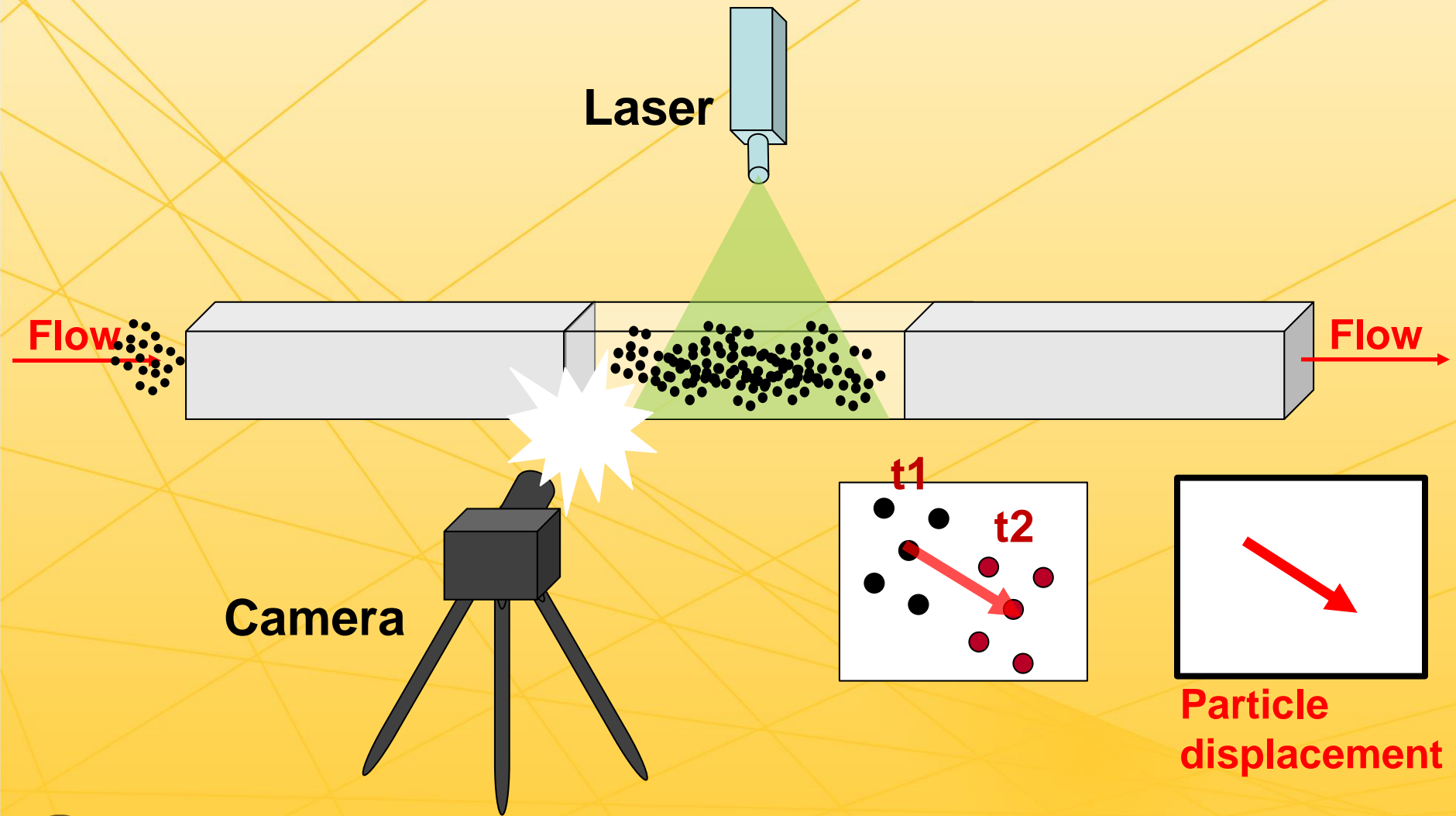
PIV Particle image velocimetry

- Measure **fluid** velocity vectors at many points in a flow field simultaneously
- From <u>mm/s</u> to <u>supersonic</u> velocity

Raffel et al. Particle Image Velocimetry (2007)

PIV Particle image velocimetry

Laser
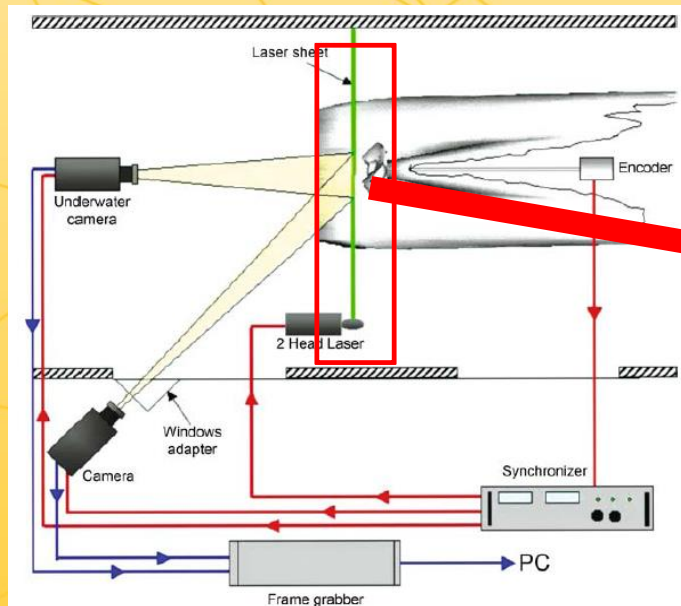
Flow

Flow

Camera

t1

t2

Particle displacement

an optical imaging technique to measure fluid or particle velocity vectors at many points in a flow field simultaneously
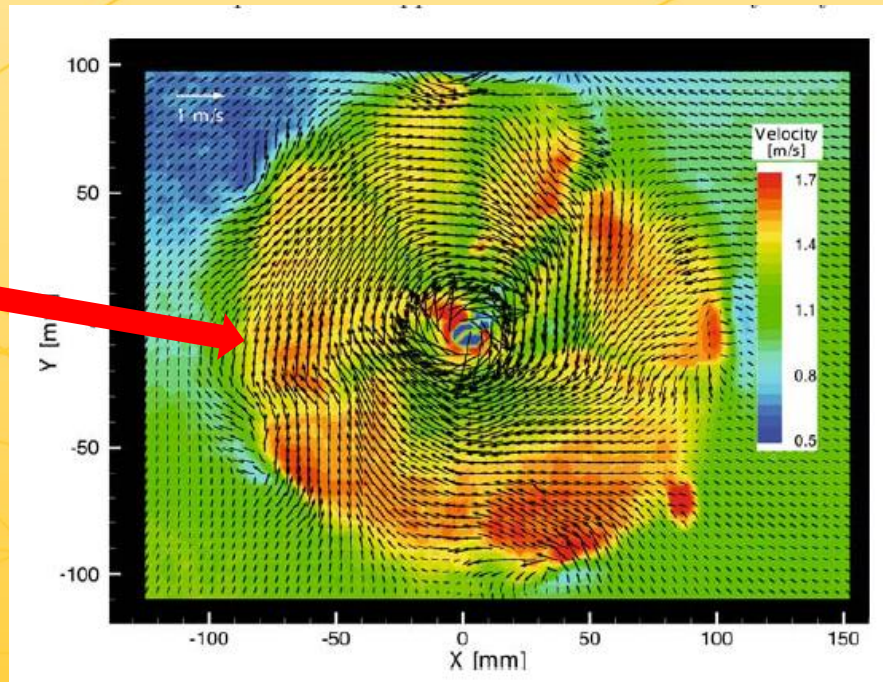
Application example of PIV measurement

PIV technique is applied to a wide range of possible applications:

Gas turbine combustor, Automotive, Aerospace, Propulsor hydrodynamics, Biomedical devices, Electronics, Airplanes, Helicopters, …
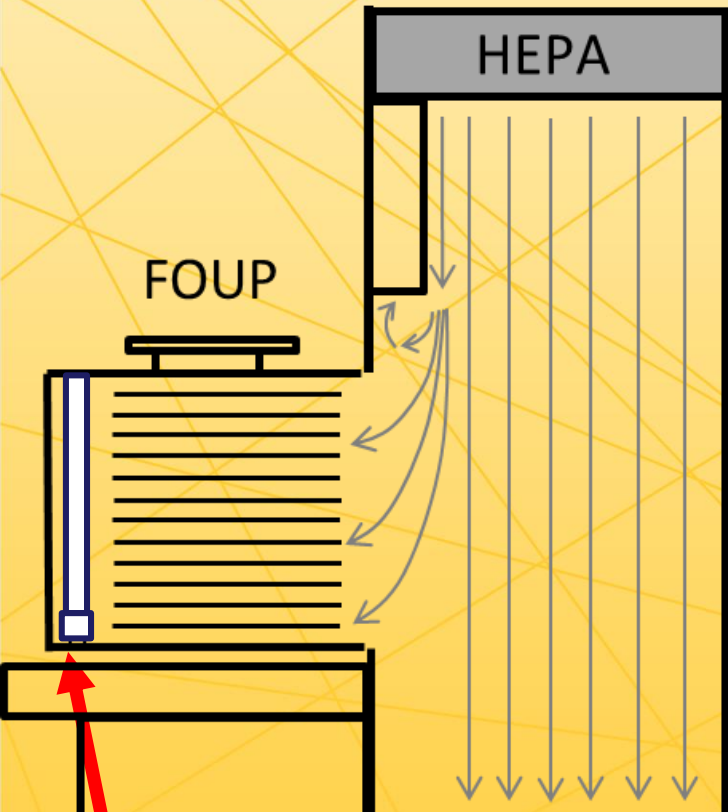
Experimental setup of the **propelled ship model**

Velocity map of near-propeller wake

Schröder et al. Particle Image Velocimetry (2008)
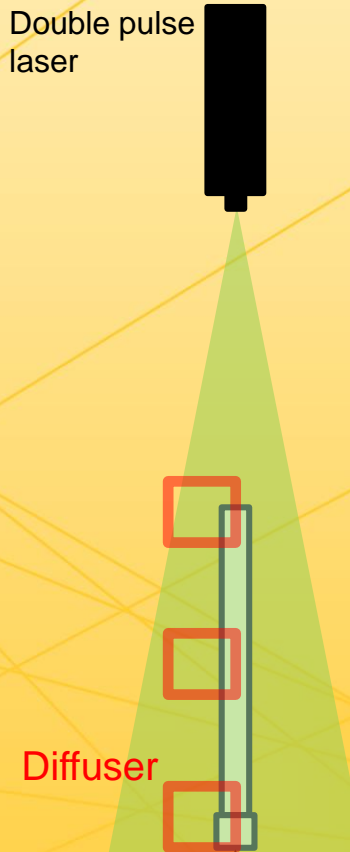
Application example of PIV measurement

Diffuser purging concept

HEPA

FOUP

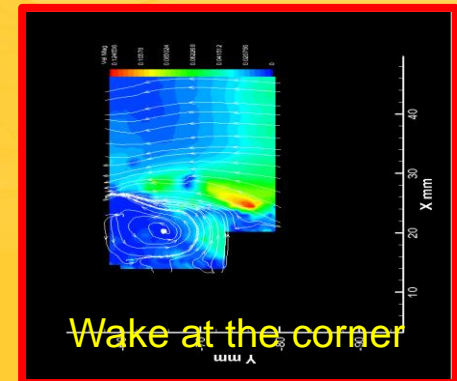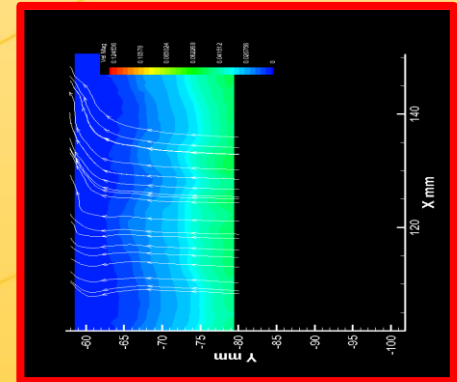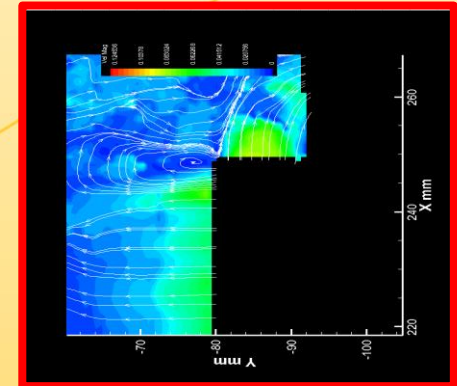**Diffuser** to purge out humid air using laminar flow.
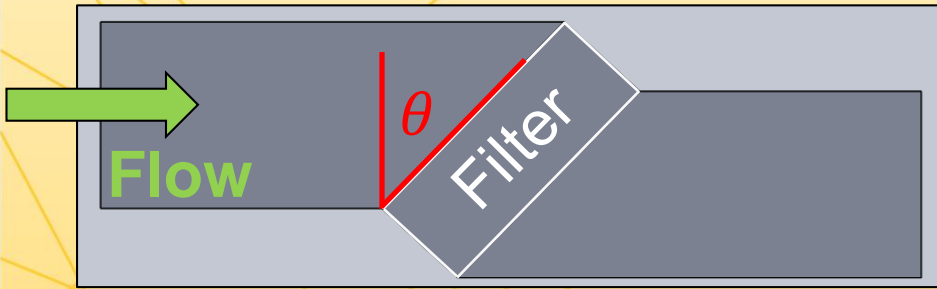
Diffuser flow measurement using PIV

Double pulse laser

Diffuser

Mass flowmeter

CDA

Atomizer

Wake at the corner

Objectives

Flow apparatus

Vertical orientation

Horizontal orientation

- **Measure flow profiles up/downstream: PIV system**
- **To conduct a CFD simulation**

  Find a proper model for the effective CFD modeling of pleated filter

- **To compare pressure drop and velocity profiles between the experiment and simulation**

Last CFR meeting

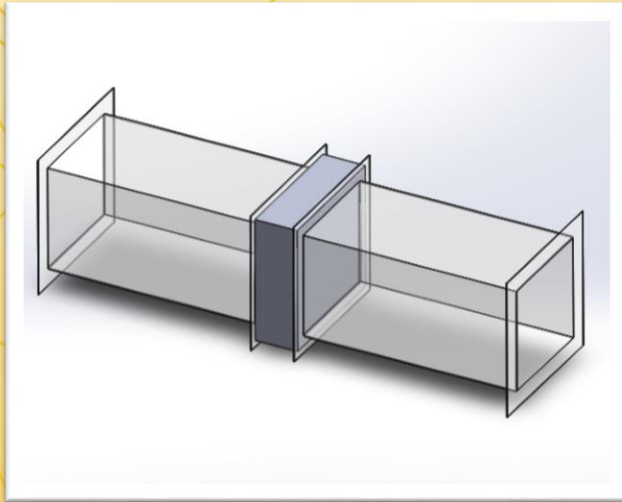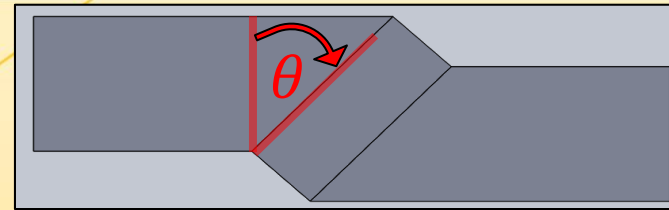- Preliminary data collection
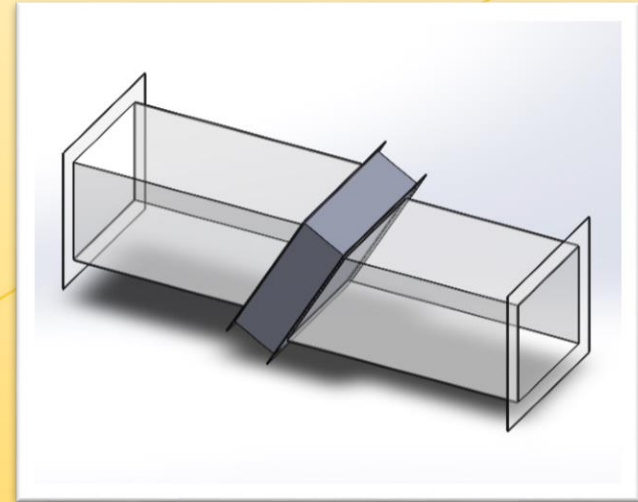- CFD mesh independence study

This presentation

- Velocity distribution comparison
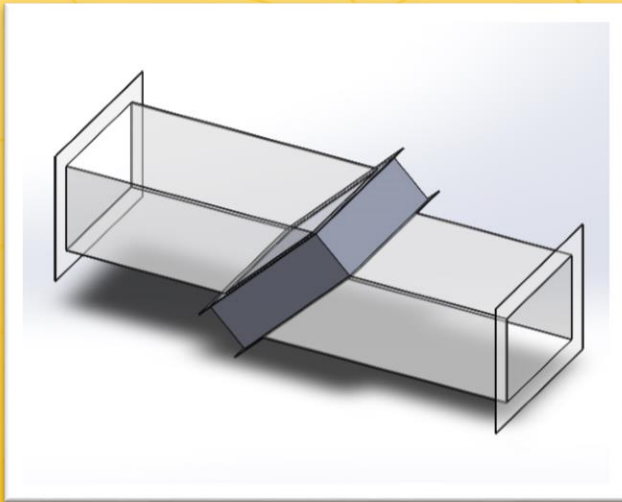- Pressure drop comparison

Filter orientation

0 Degree

30 Degree

45 Degree
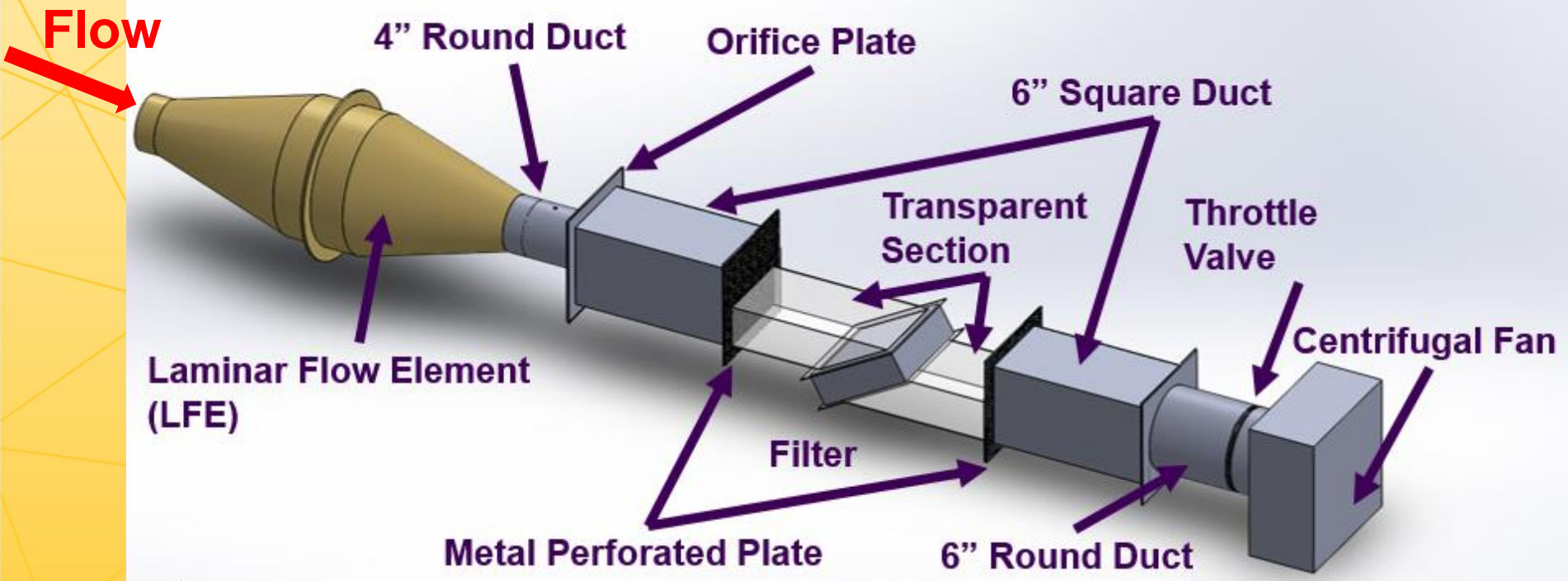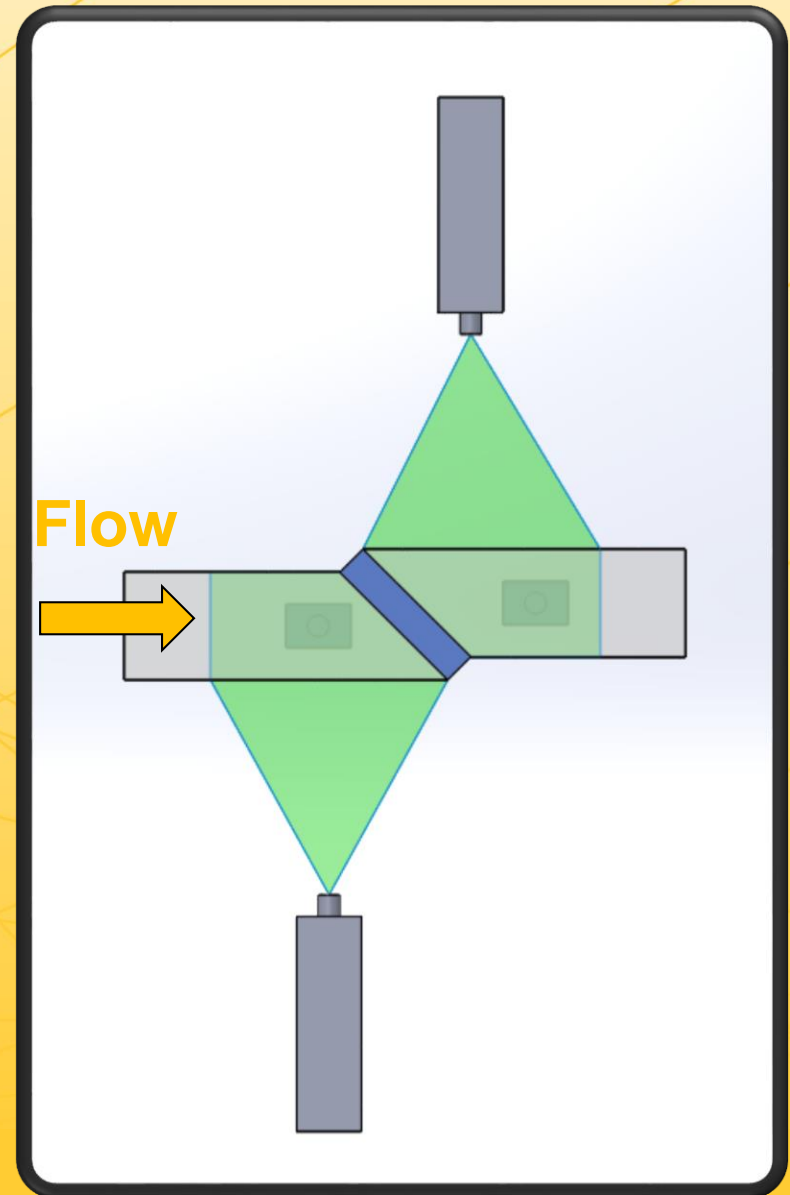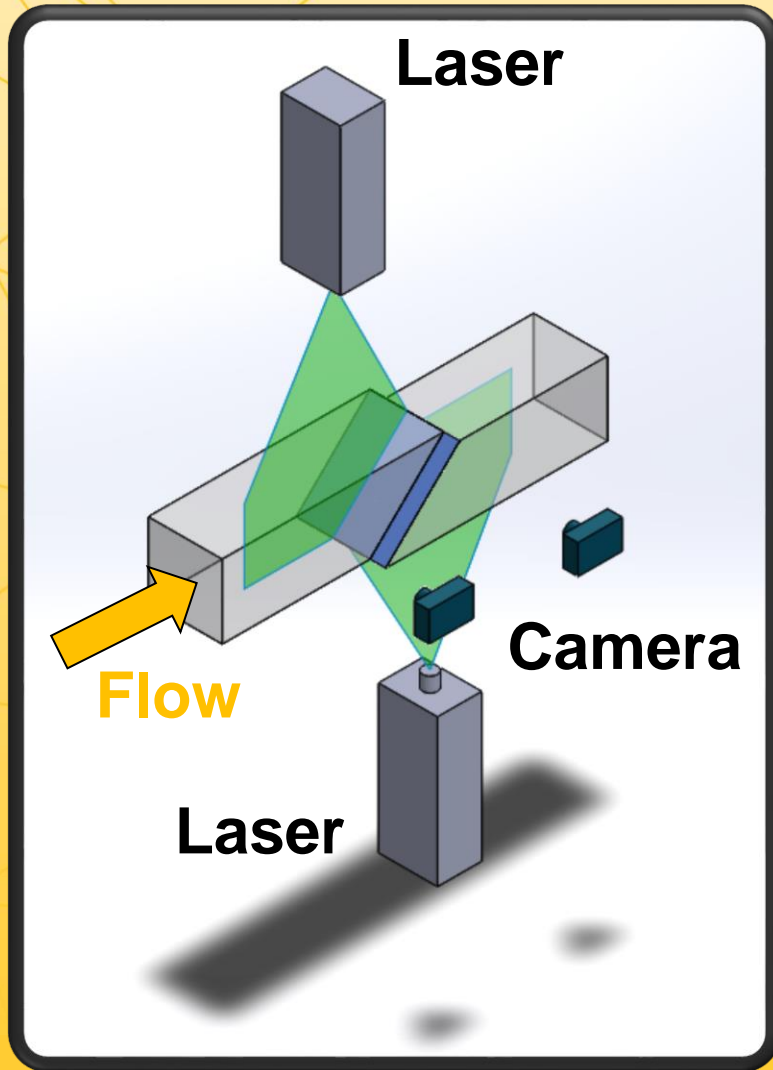
Experimental setup

Flow

4" Round Duct

Orifice Plate

6" Square Duct

Transparent Section

Throttle Valve

Centrifugal Fan

Laminar Flow Element (LFE)

Filter

Metal Perforated Plate

6" Round Duct

PIV setup

Experimental condition

Inclined angles	0				30				45			
Filter orientation	Horizontal		Vertical		Horizontal		Vertical		Horizontal		Vertical	
Flow rates	21	43	80	107	21	43	80	107	21	43	80	107
Measured plane	Plane1		Plane2		Plane1		Plane2		Plane1		Plane2	

0 degree

30 degree

45 degree

Vertical

Horizontal

Flow
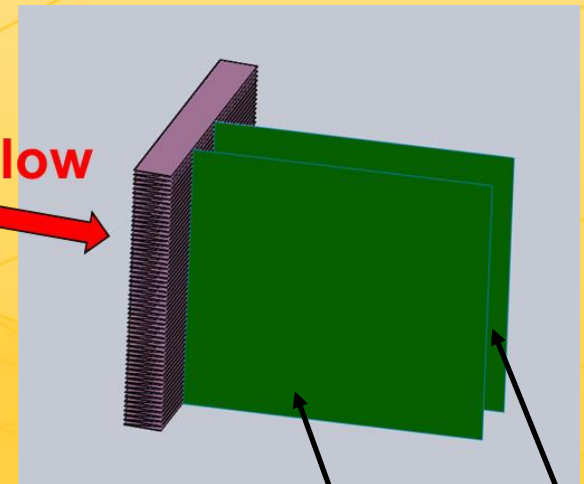
plane1

plane2

CFD modeling of pleated filter

Flow

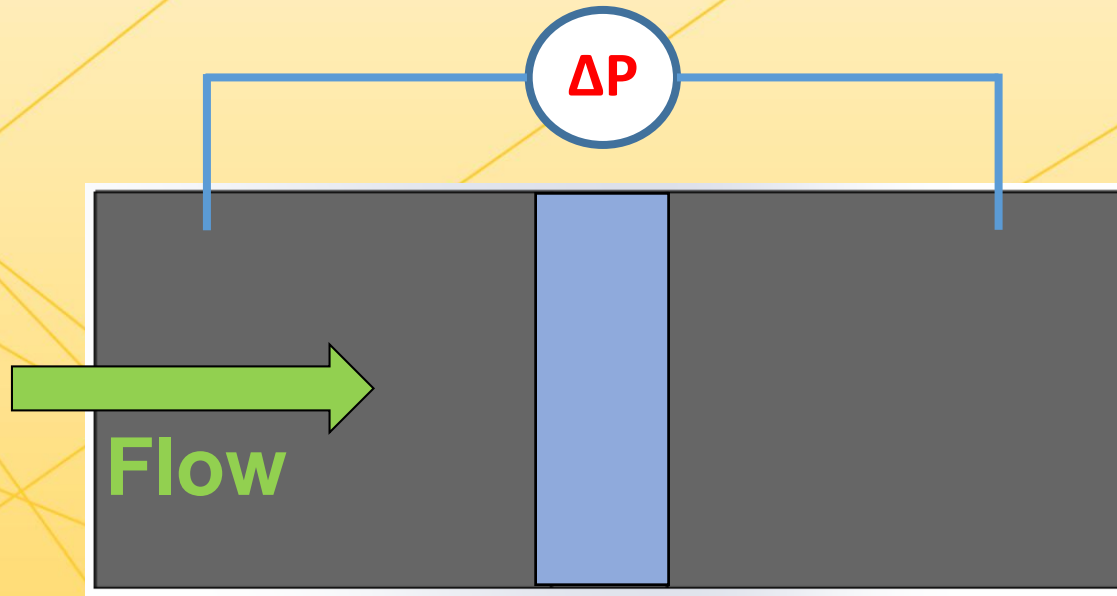**Flow**
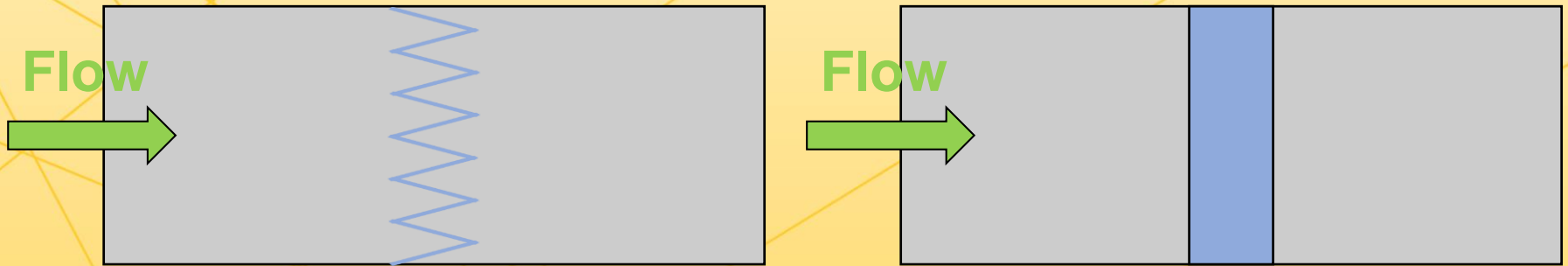
- **For computational fluid dynamics (CFD) modeling, Pleated filter media ➡ Porous domain**

- **Experimental pressure and velocity data ➡ porous coefficients**
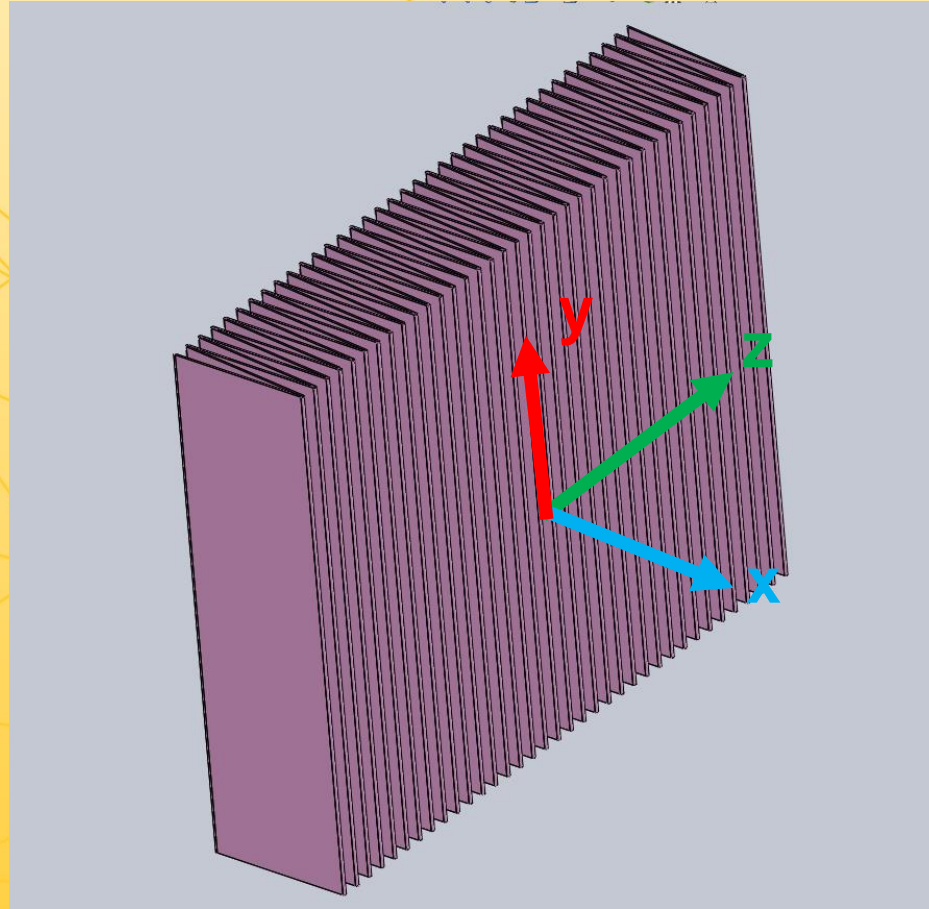
Porous coefficient derivation

Porous coefficients (α, C_2) can be obtained experimentally

$$\Delta P = \frac{C_2 \rho \Delta n}{2} v^2 + \frac{\mu}{\alpha} \Delta n \, v,$$

$C_2 = Inertial\ resistance\ factor, \qquad \frac{1}{\alpha} = viscous\ resistance\ factor$
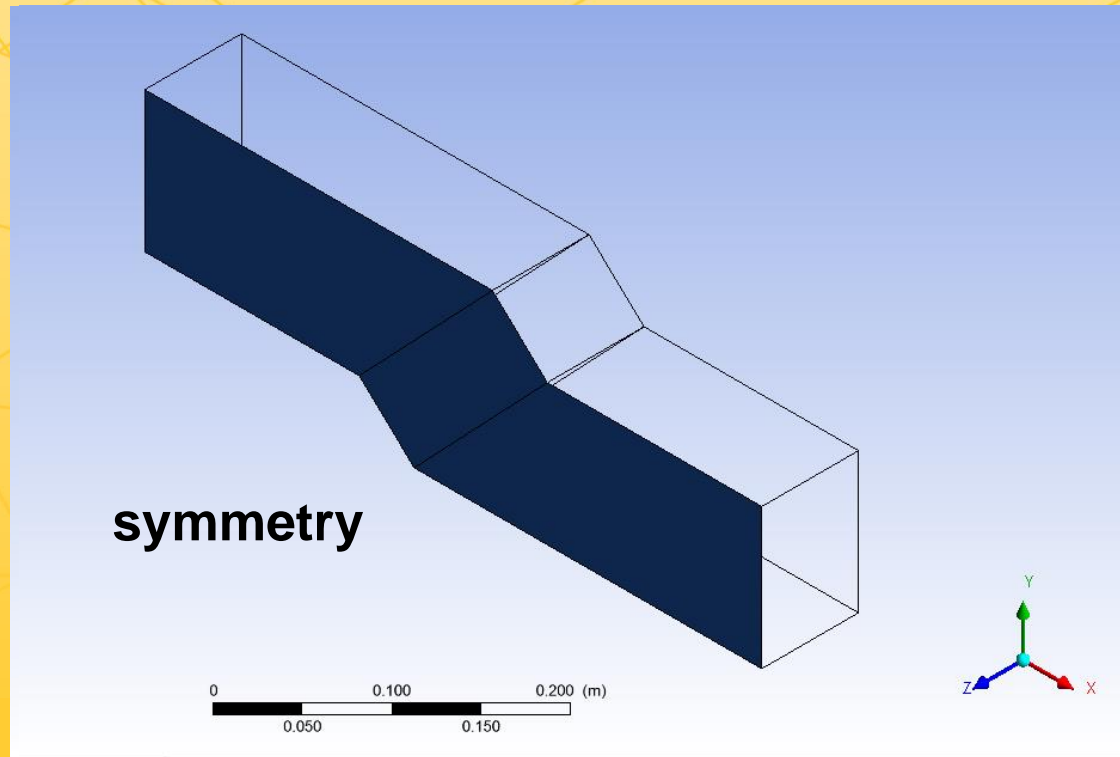
$\alpha = permeability, \quad \Delta n = filter\ thickness$

Porous coefficient determination

Applying proper x, y, z tensor values is important for modeling pleated filter media

CFD simulation

- **Fluent version: 16**
- **Physics model: k-ω SST**
- **Boundary conditions**
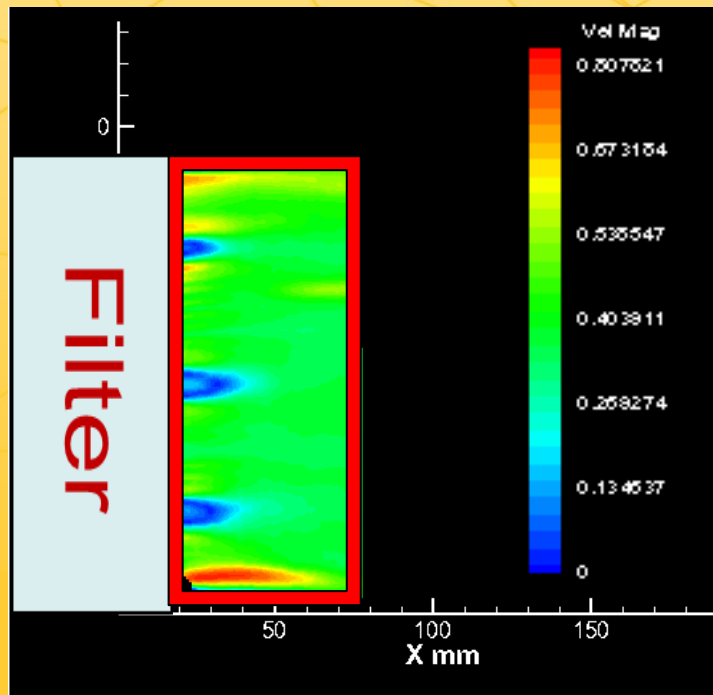

symmetry

Pressure drop

Inclined angle (degree)	Volumetric flow rate (CFM)	Δp		Error
		Experiment (Pa)	CFD (Pa)	%
0	21	26	25	3%
	43	55	53	3%
	80	109	108	1%
	107	154	152	2%
30	21	25	25	0%
	43	53.5	52	2%
	80	107	107	0%
	107	150	149	0%
45	21	25	26	2%
	43	55	54	2%
	80	108	110	2%
	107	154	156	1%

CFD data is in good agreement with experimental data

0 degree contour plot (21CFM)

Flow

Filter

Vertical arrangement

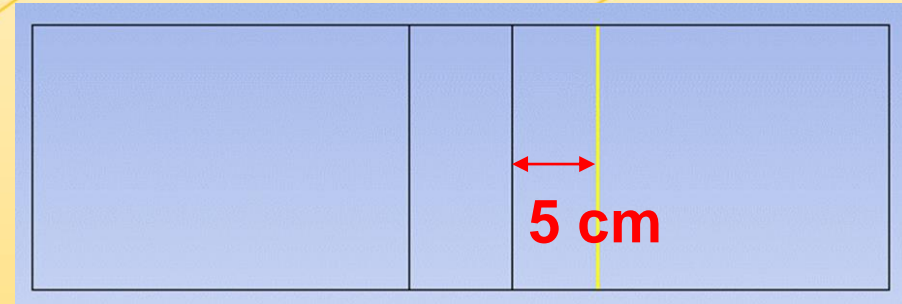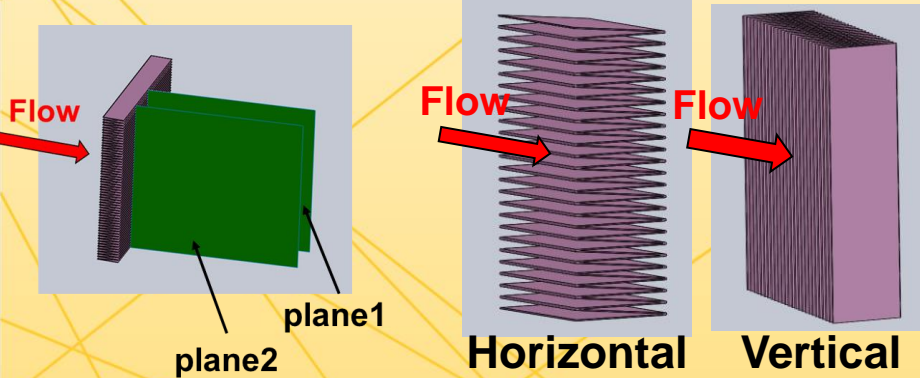## Horizontal arrangement
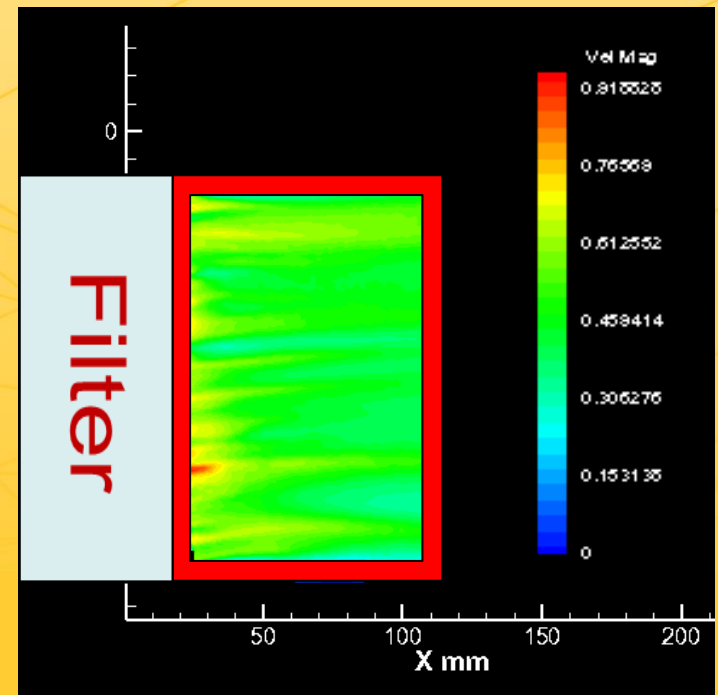
Velocity distribution comparison
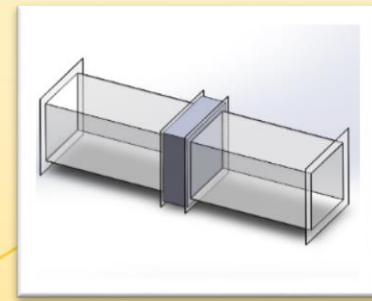
Velocity u (m/s) vs Y (mm)

Filter

0 cm

22 cm
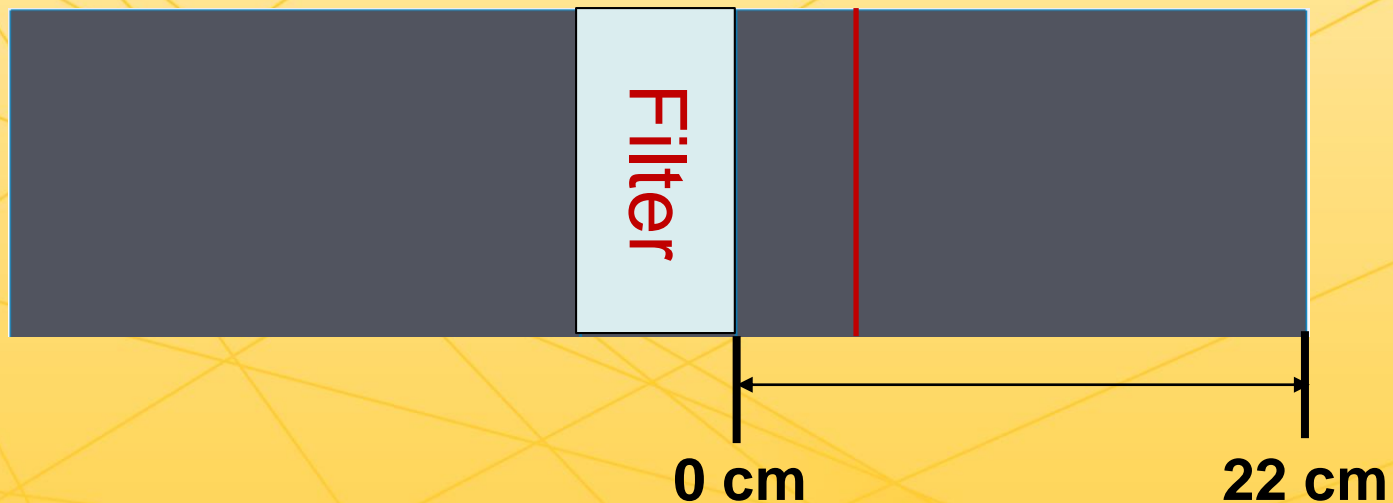
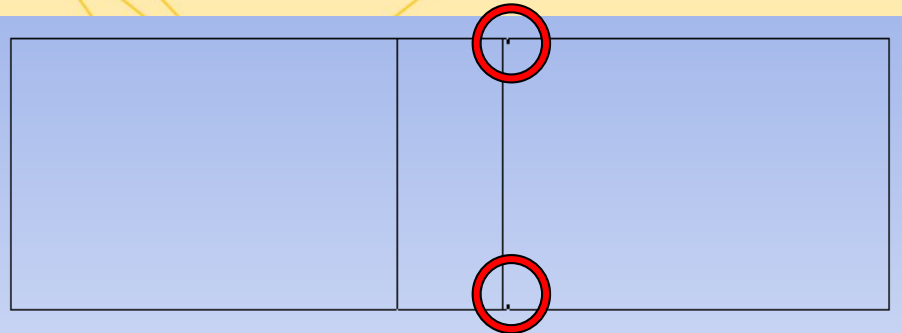**Velocity will be compared between CFD and PIV data after filter**

Velocity distribution comparison (5cm)

Flow

plane1
plane2

Flow   Flow

Horizontal   **Vertical**

5 cm

21CFM_Plane1

— Fluent
● PIV_Horizontal
● PIV_Vertical

y (mm)

velocity u (m/s)

21CFM_Plane2

— Fluent
● PIV_Horizontal
● PIV_Vertical

y (mm)
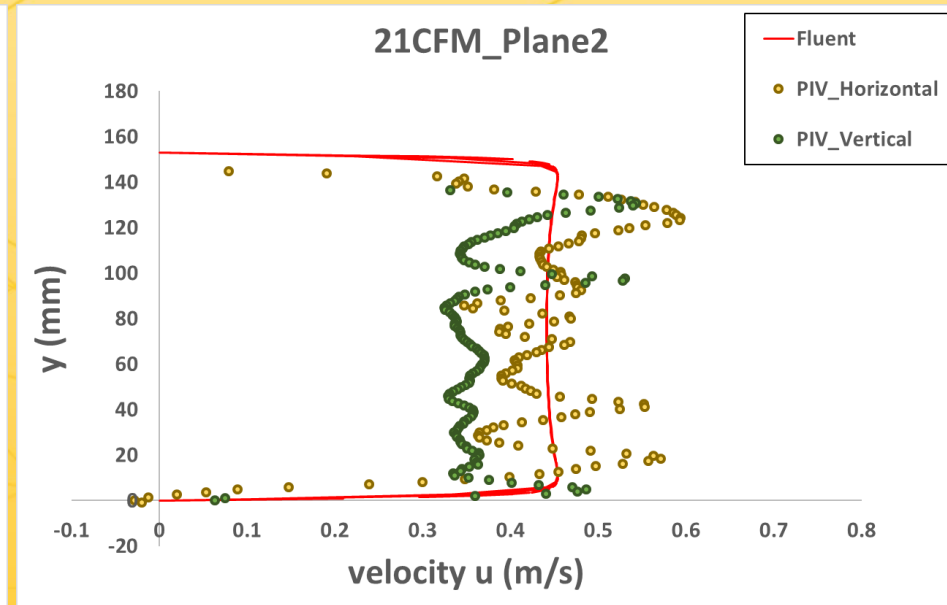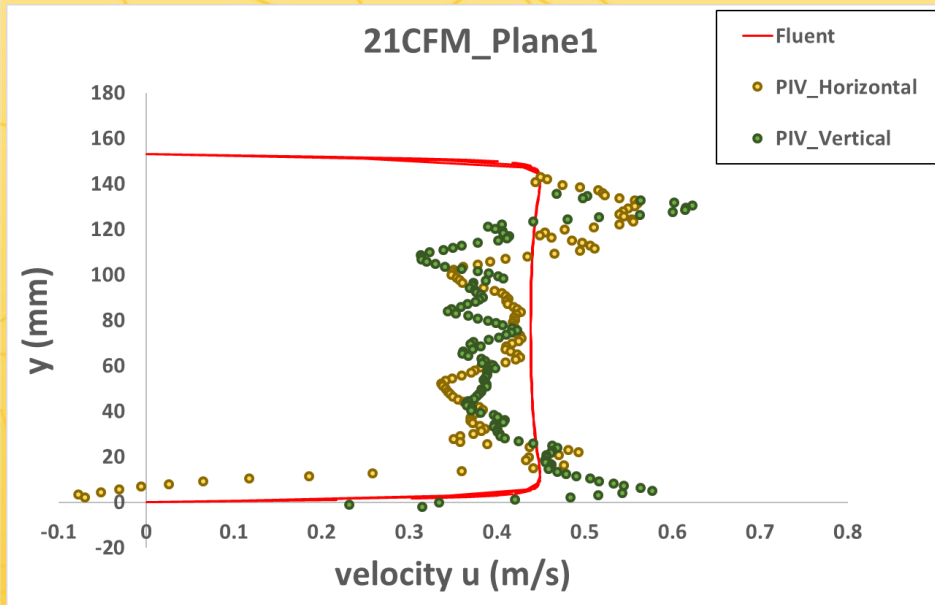
velocity u (m/s)

Experimental data is averaged over 100 flow profiles

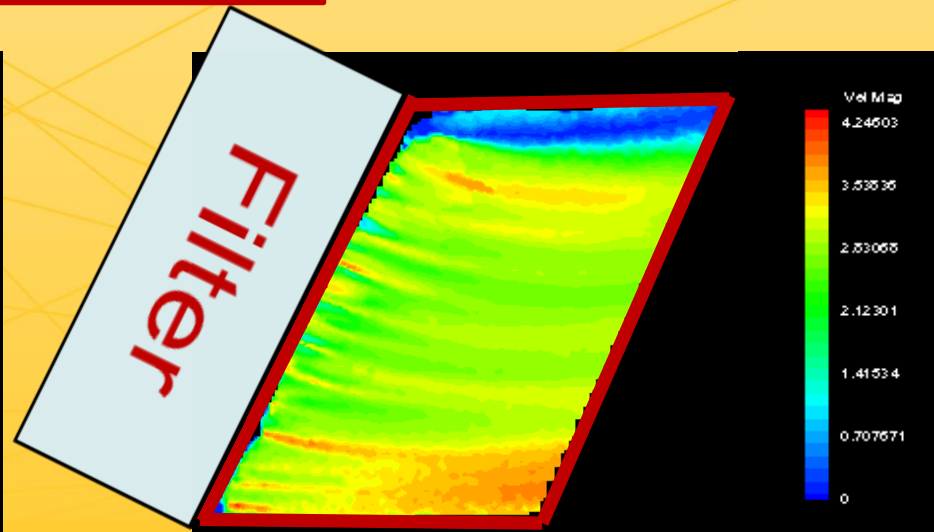# Velocity distribution comparison (15cm)

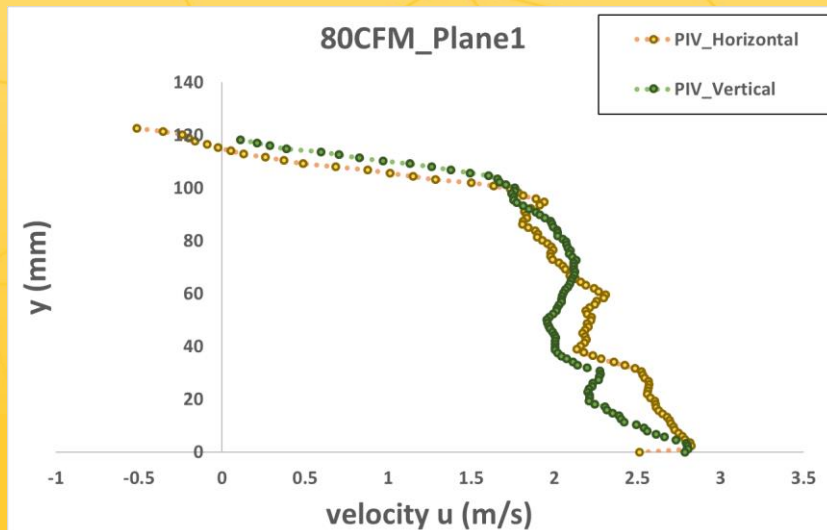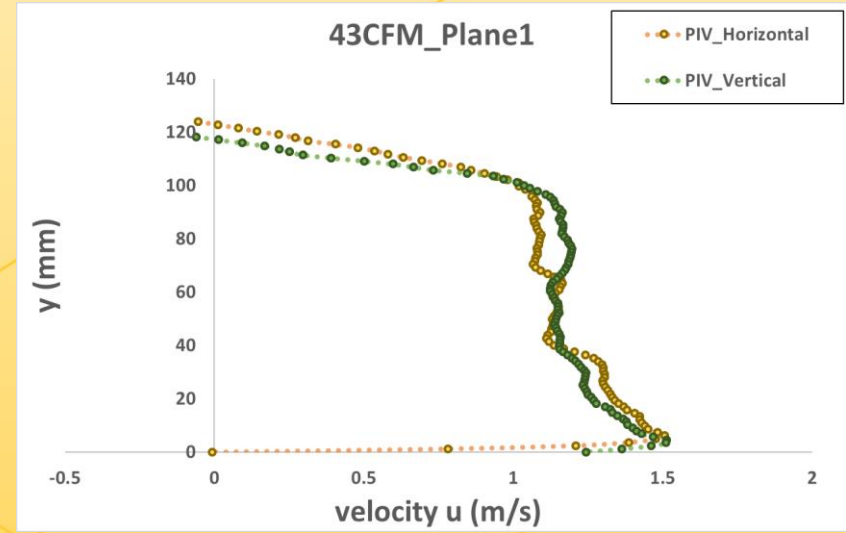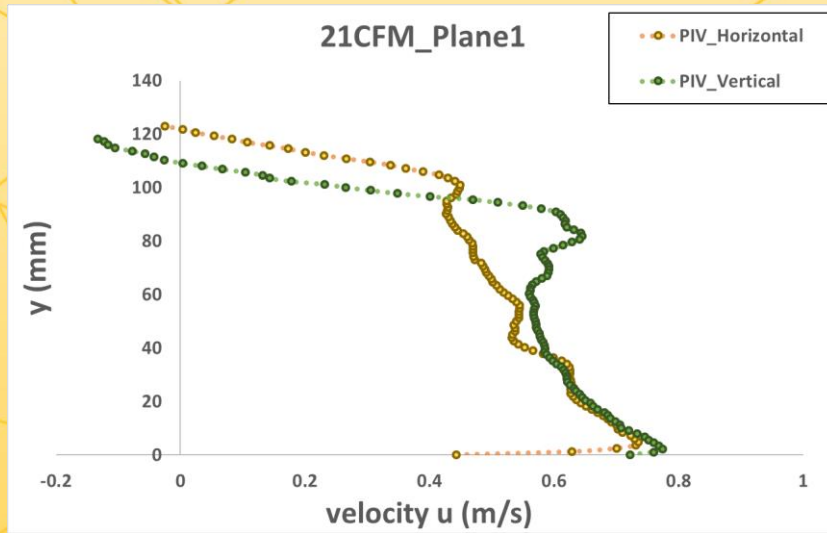# 30 degree_107CFM_plane2

CFD simulation

PIV experiment

Vel Mag
4.45045
3.71707
2.97366
2.23024
1.45653
0.743414
0

Vertical arrangement

Vel Mag
4.24503
3.53636
2.83066
2.12301
1.41534
0.707671
0
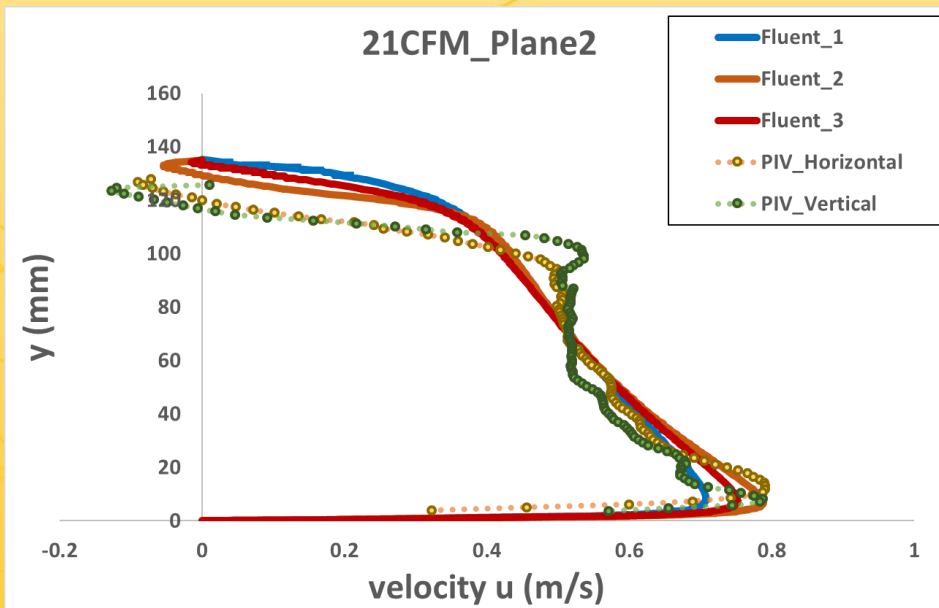
Horizontal arrangement

Filter
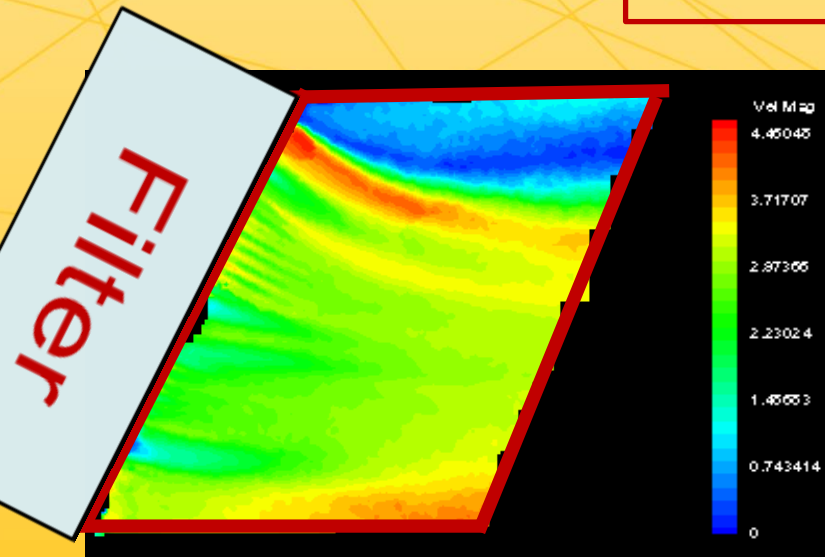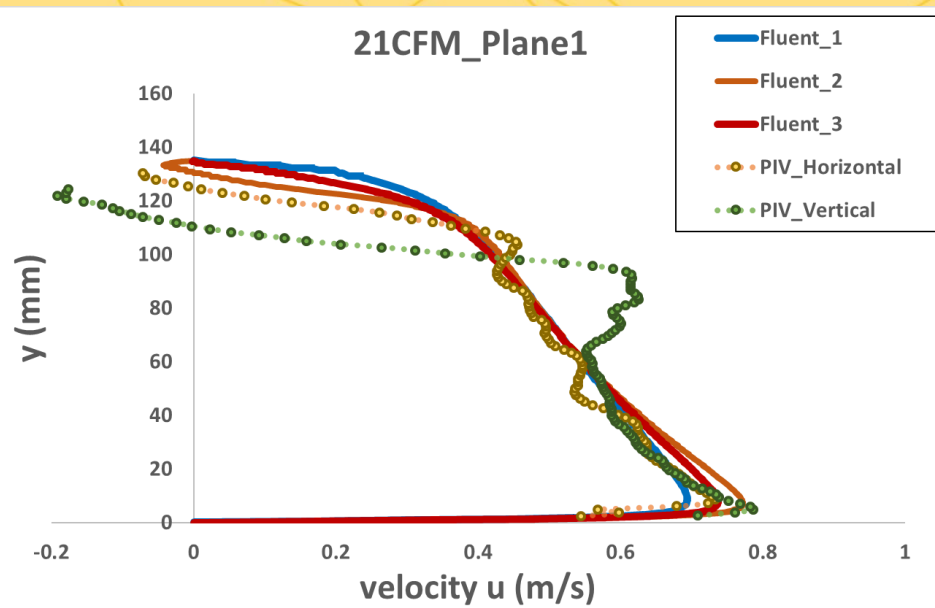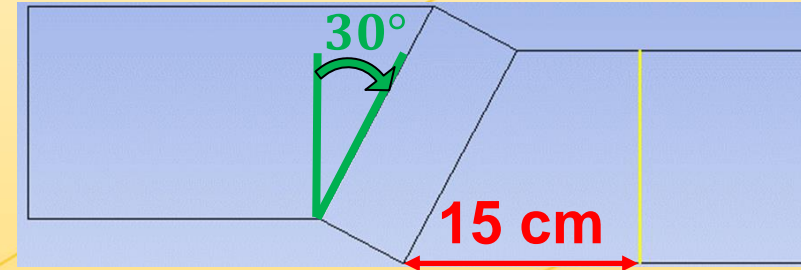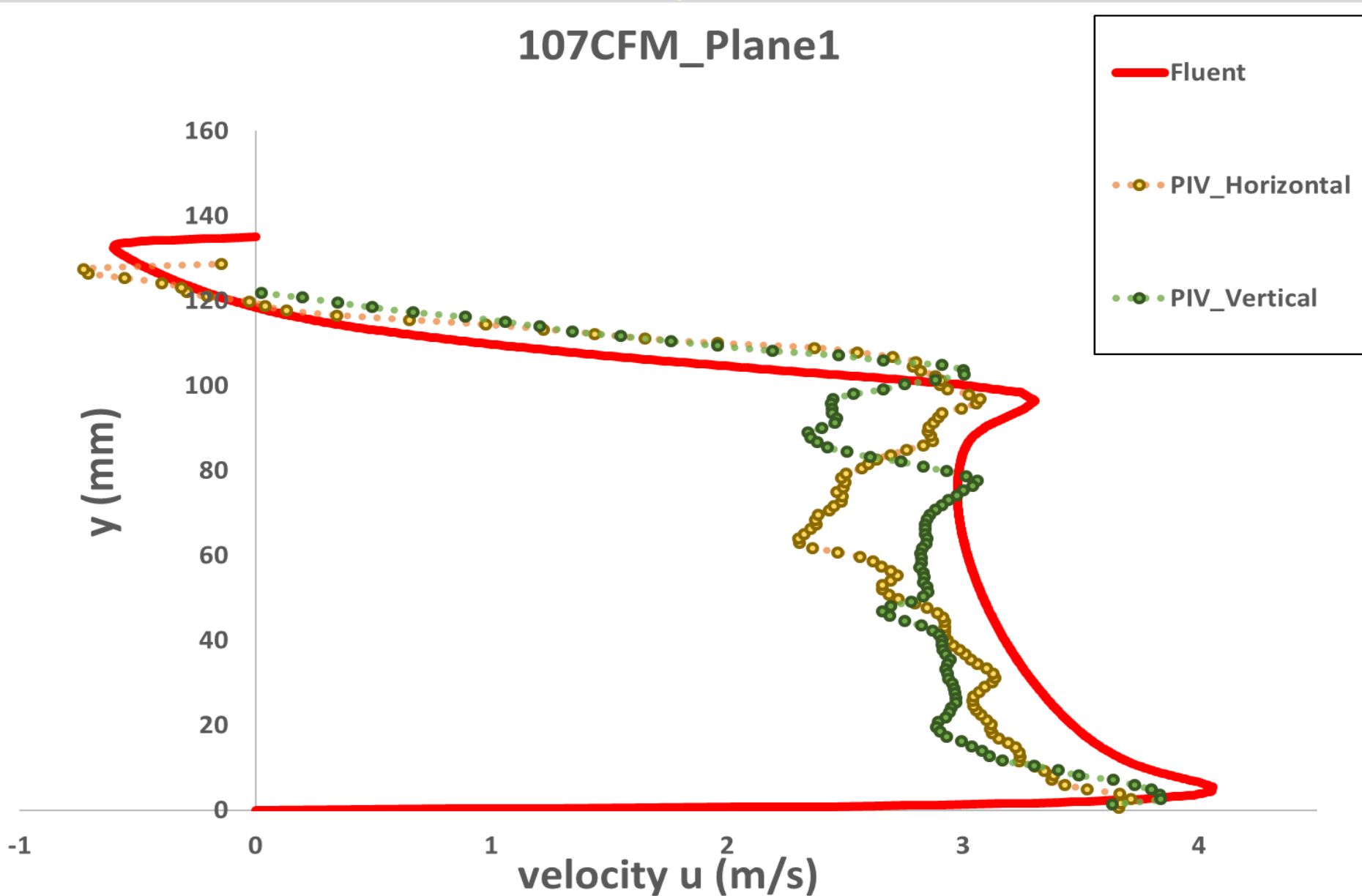
30degree

Horizontal vs Vertical arrangement

Velocity distribution comparison (15cm)

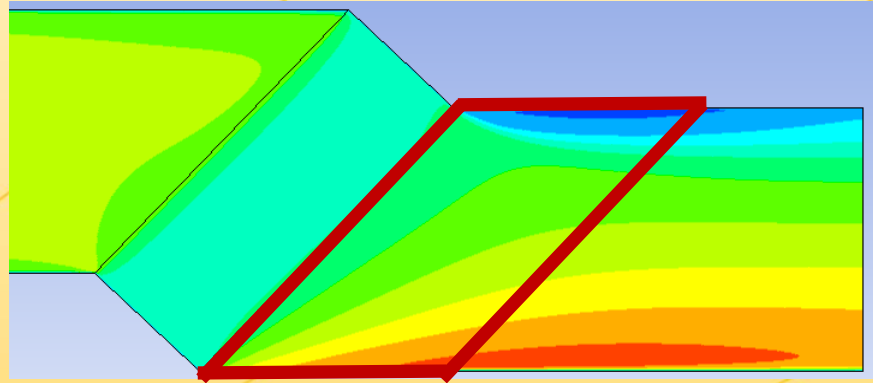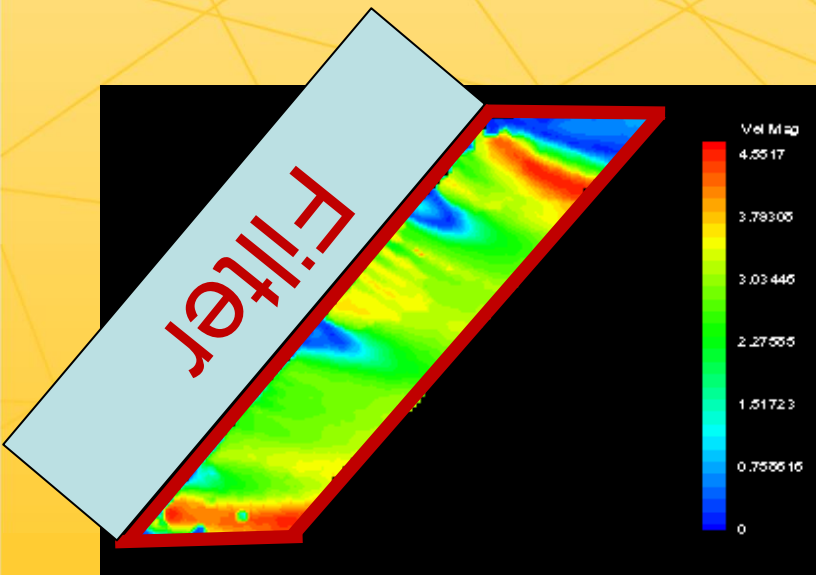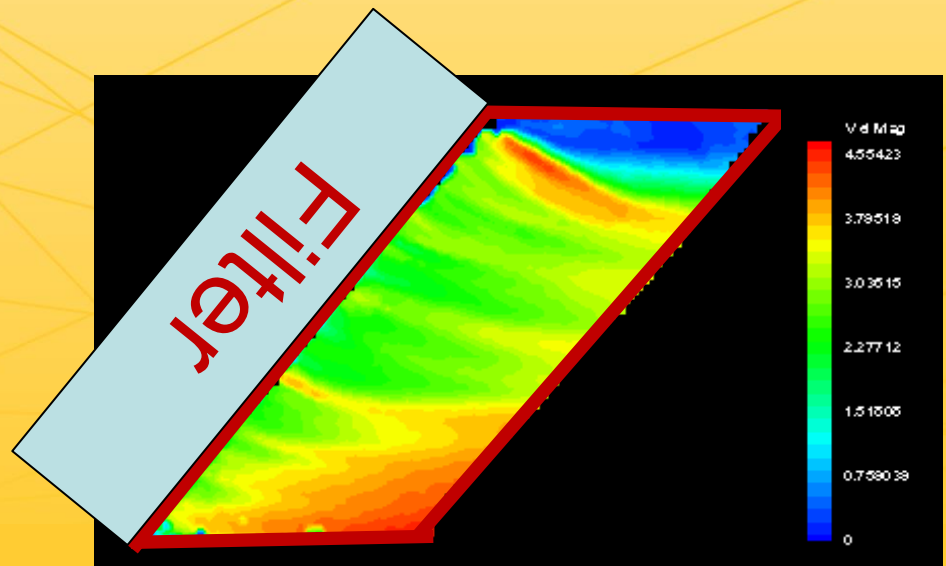|	Fluent_1	Fluent_2	Fluent_3
Coeff. in x	α_x, $C_{2,x}$	α_x, $C_{2,x}$	α_x, $C_{2,x}$
Coeff. in y	0	$0.5*\alpha_x$, $0.5 C_{2,x}$	$100*\alpha_x$, $100*C_{2,x}$
Coeff. in z	0	$100*\alpha_x$, $100*C_{2,x}$	$0.5*\alpha_x$, $0.5*C_{2,x}$

Velocity distribution comparison (15cm)

45 degree_107CFM_plane2

CFD simulation

PIV experiment

Vertical arrangement

Horizontal arrangement
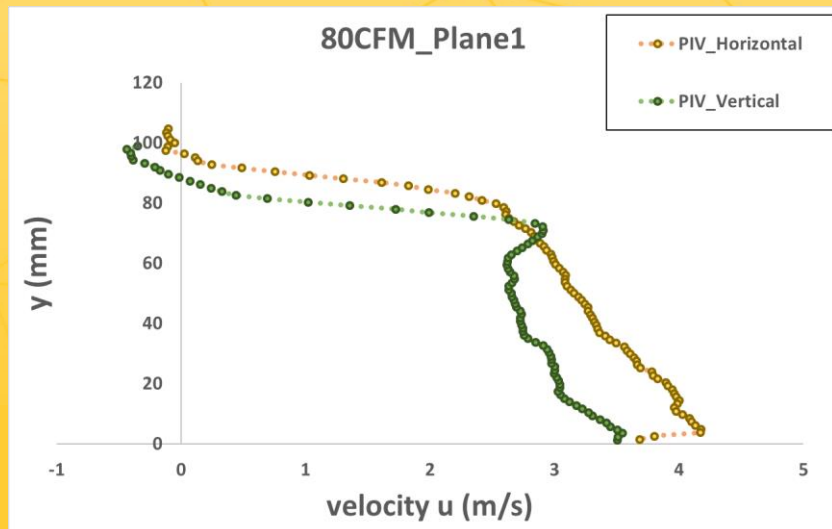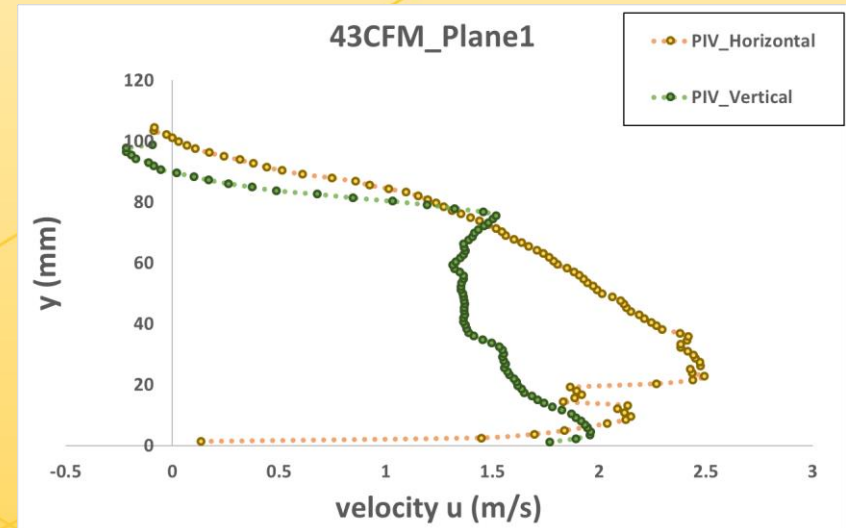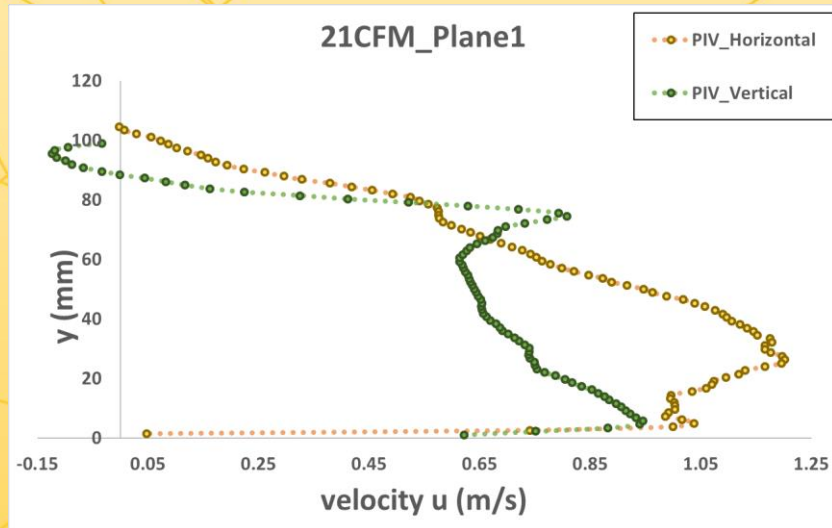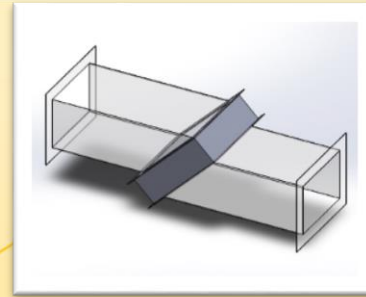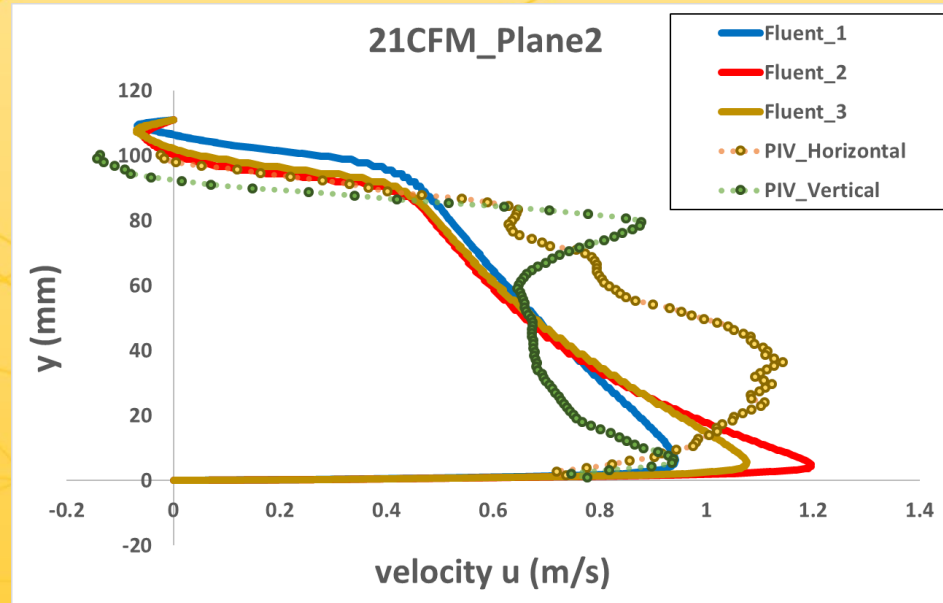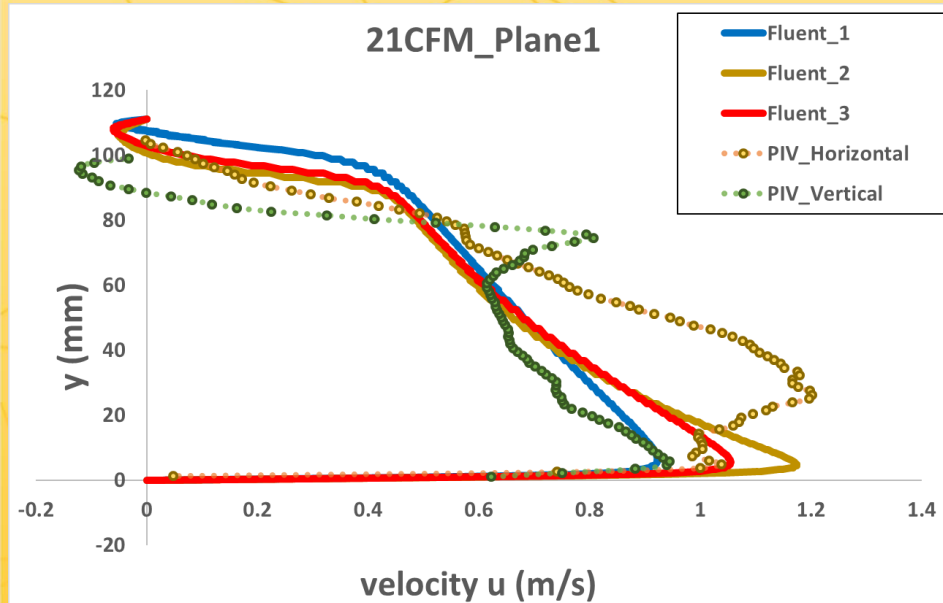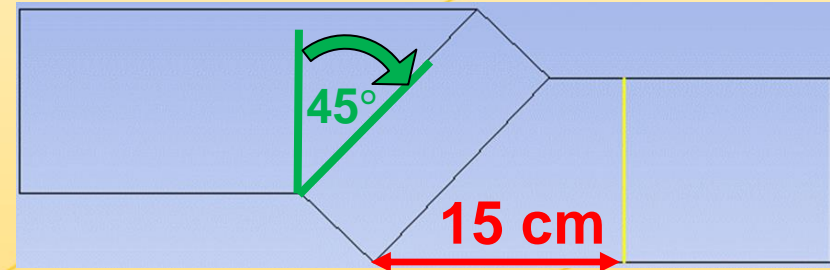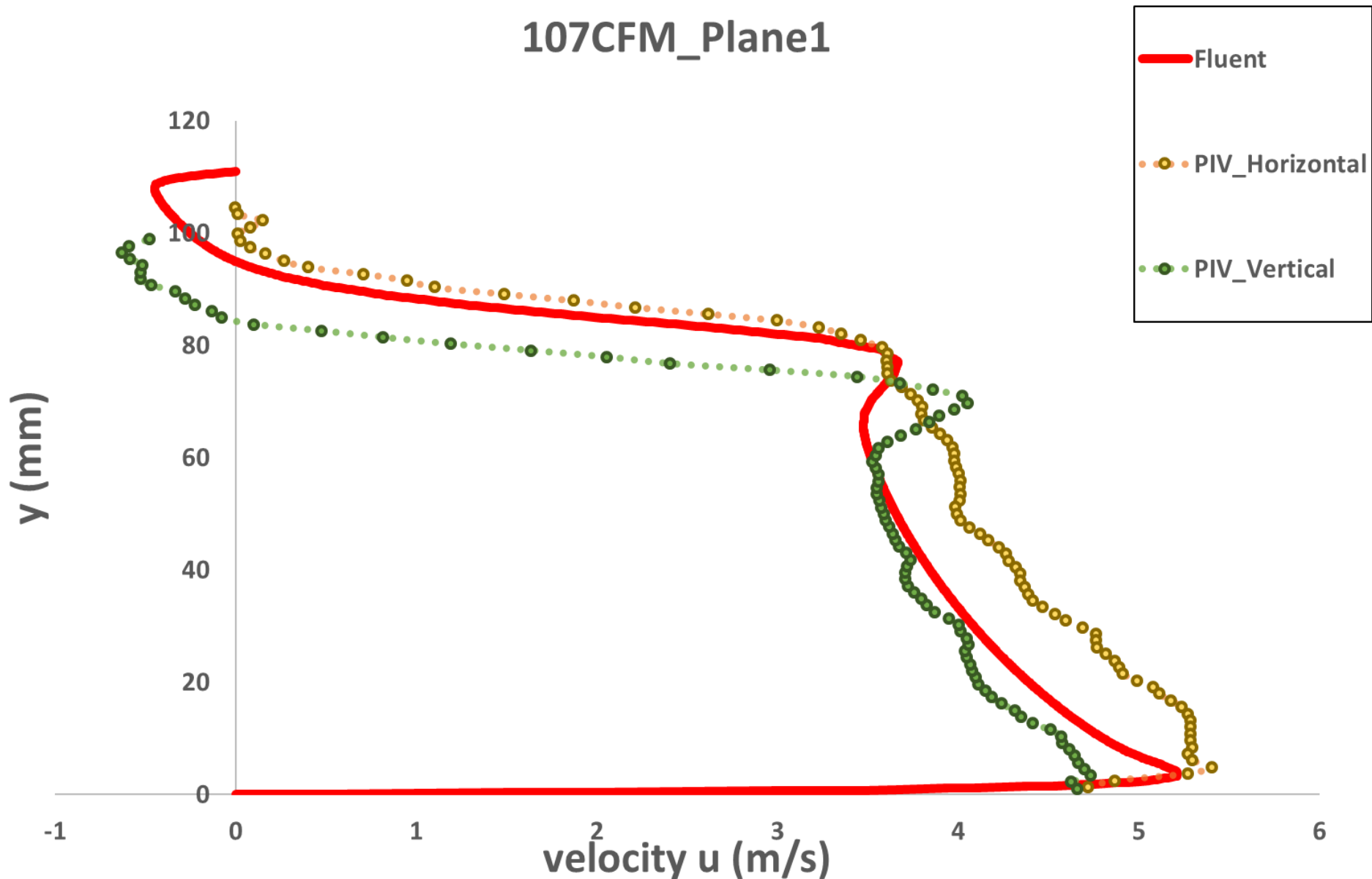
45degree
Horizontal vs Vertical arrangement
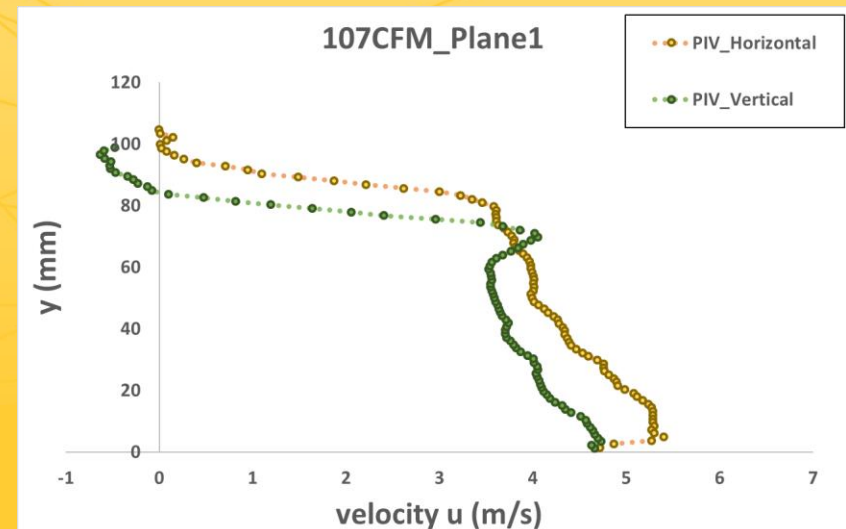
Velocity distribution comparison (15cm)

	Fluent_1	Fluent_2	Fluent_3
Coeff. in x	α_x, $C_{2,x}$	α_x, $C_{2,x}$	α_x, $C_{2,x}$
Coeff. in y	0	$0.5*\alpha_x$, $0.5*C_{2,x}$	$100*\alpha_x$, $100*C_{2,x}$
Coeff. in z	0	$100*\alpha_x$, $100*C_{2,x}$	$0.5*\alpha_x$, $0.5*C_{2,x}$

Velocity distribution comparison (15cm)

107CFM_Plane1

Summary

- **CFD and PIV experimental results were compared**
- **0 and 30 degree CFD models agree well with PIV experimental data**

Future works

- **Verify the behavior of the flow with different pleated filter media**

Thank you

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