Knowing the Fire Sprinkler Spray

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The Science of Suppression
FireSEAT
Edinburgh, Scotland UK

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Sponsors: FM Global, NSF

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Overview

- Introduction
  - How do we quantify sprinkler sprays?
- Objective
  - Evaluate discharge characteristics through measurements
- Measurements and Results
  - **Stream** Formation
  - **Stream** Breakup
  - Initial **Spray**
  - Dispersed **Spray**
- Summary

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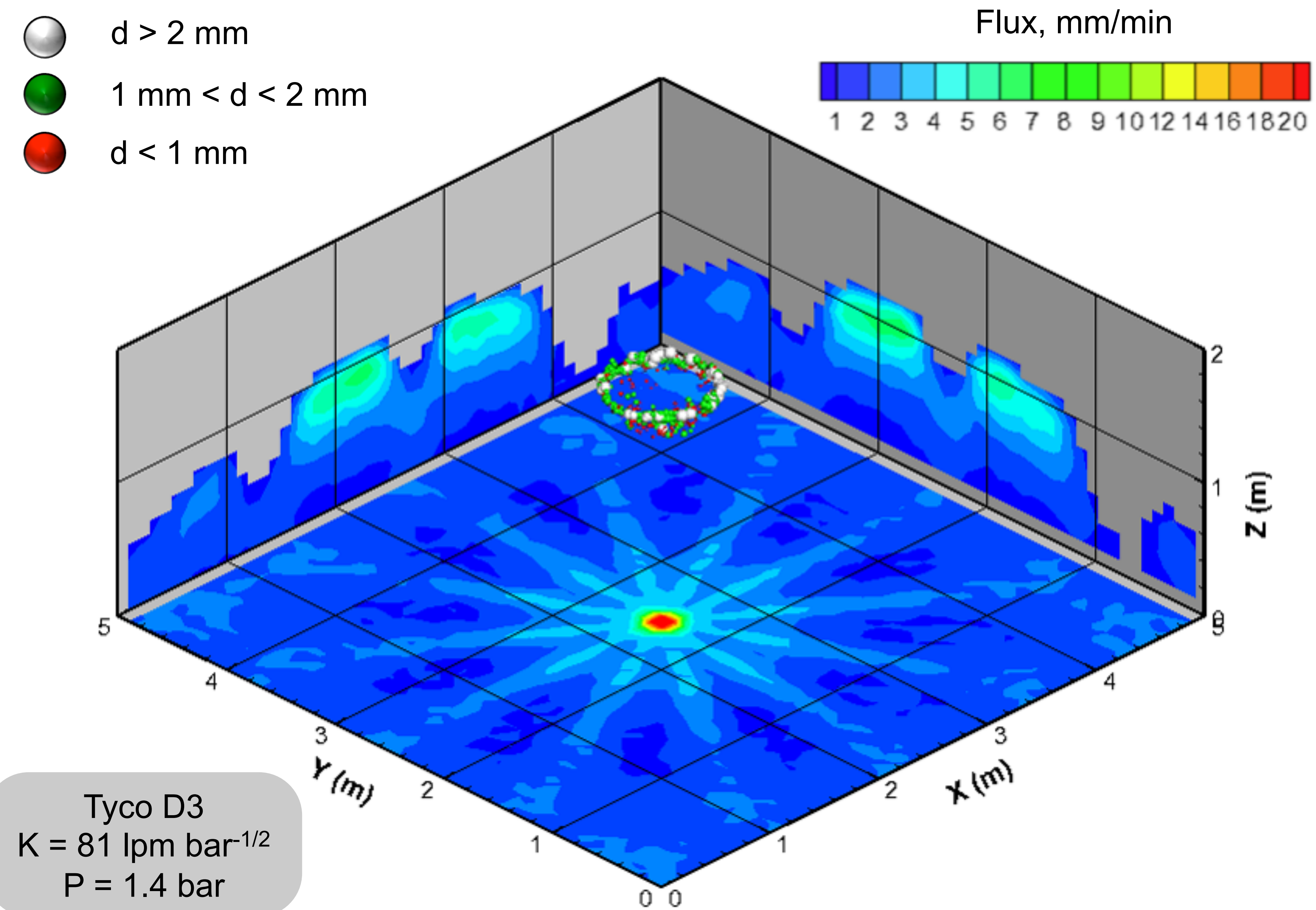
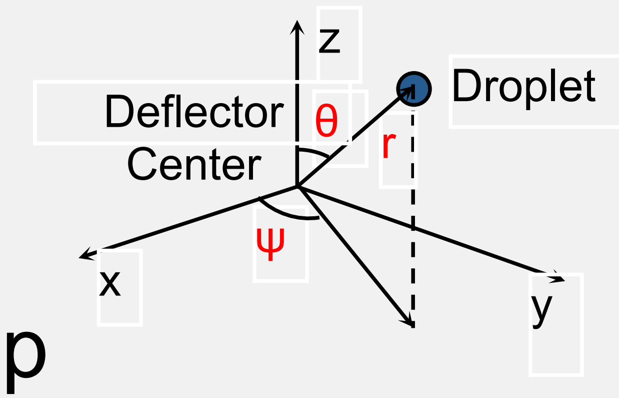
Introduction – Sprinkler Spray Example



Tyco D3
K = 81 lpm bar$^{-1/2}$
P = 1.4 bar

Introduction – Sprinkler Spray Characteristics

- How do we quantify sprinkler sprays?



Spray Discharge

	Discharge Properties
d_{v50} (mm)	2.1
u_{inj} (m/s)	10.5
θ_{inj} (deg)	95
q'' (mm/min)	1.5
r_{cov} (m)	4

Drop by Drop

	r (m)	*θ* (deg)	*ψ* (deg)	*d* (mm)	*u* (m/s)
1	0.35	95	100	2.3	10.2
2	0.35	99	92	0.5	9.8
3	0.35	92	275	3.1	8.9
4	0.35	90	117	1.2	11.1
. . . . .	. . . .	. . . .	. . . .	. . . .	. . . .
1,000,000	0.35	97	342	0.3	10.7

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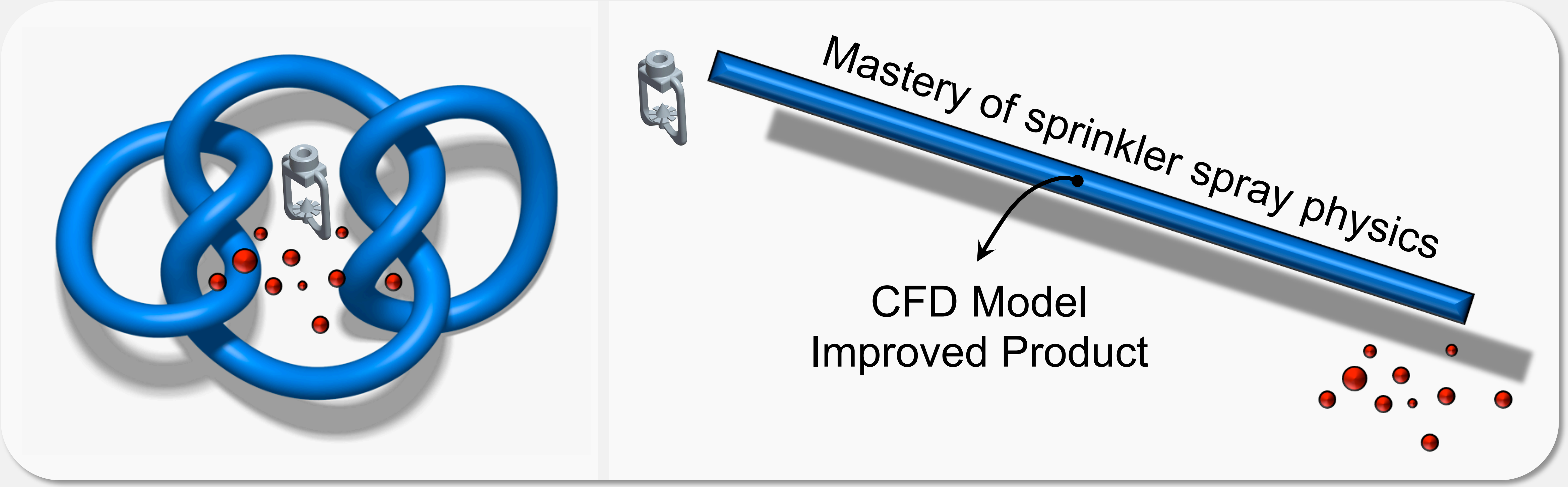
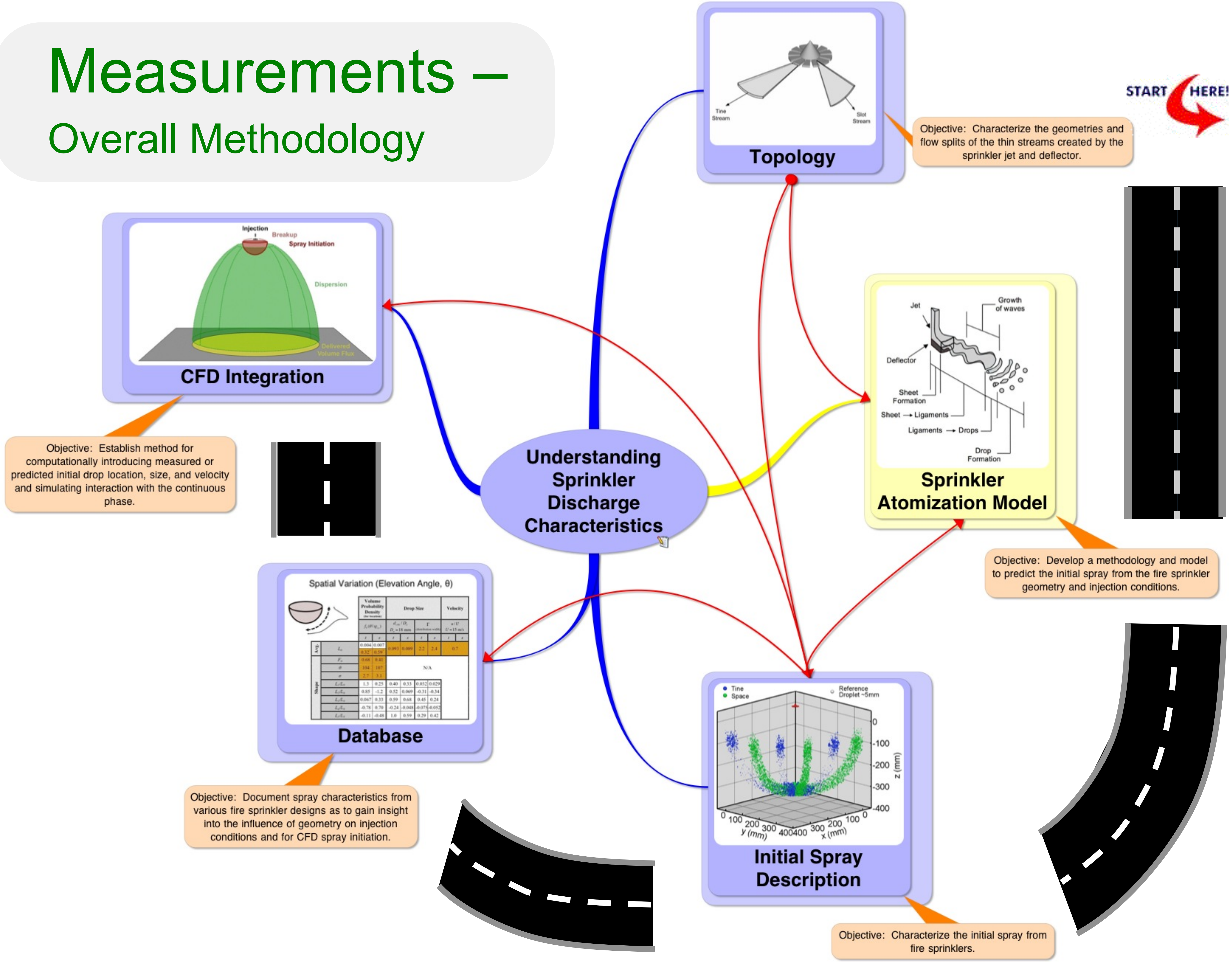
Objective

- **Evaluate discharge characteristics** from fire suppression devices from **measurements** to support CFD model and fire suppression product development (nozzle and system)



Measurements –
Overall Methodology



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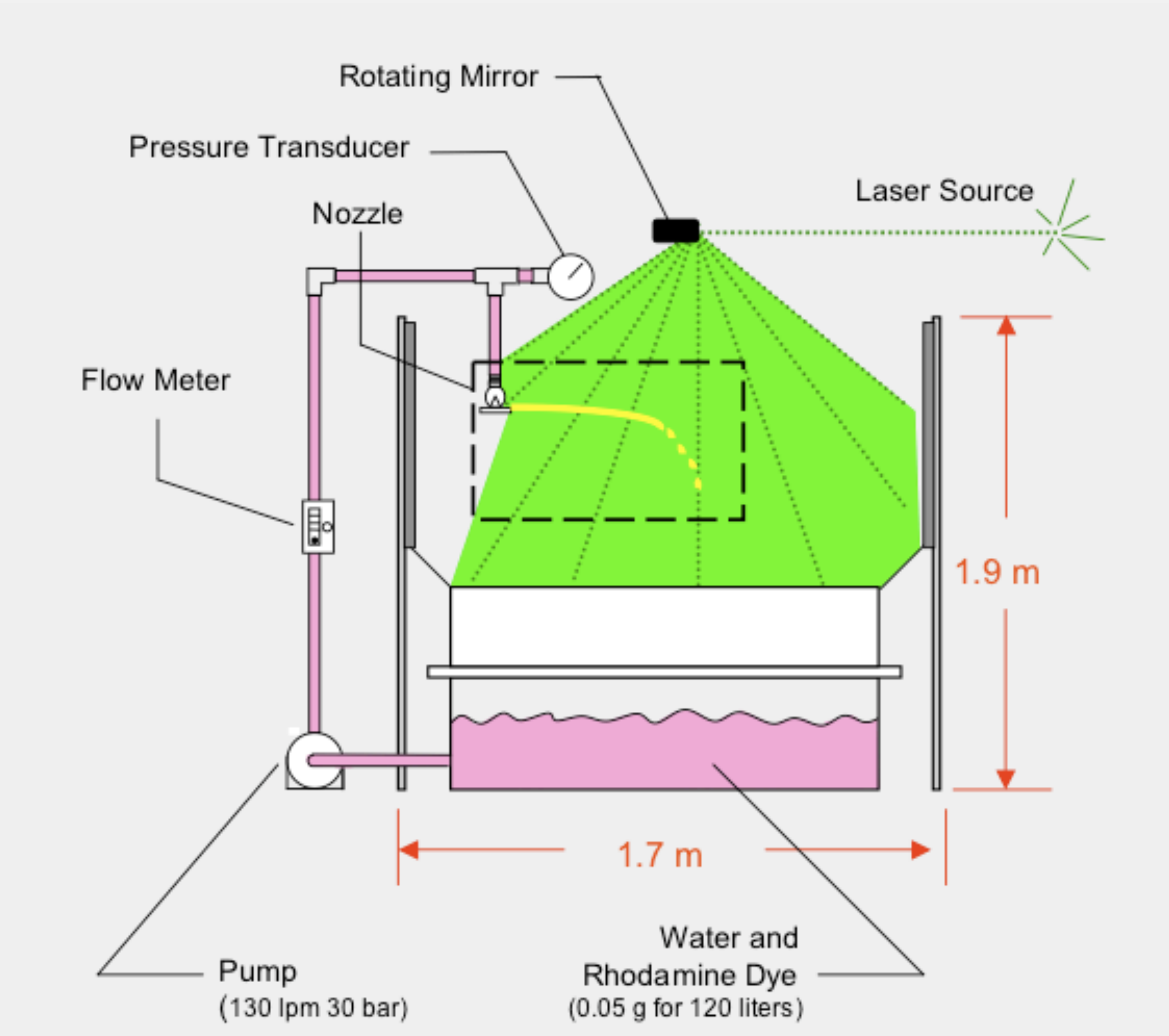
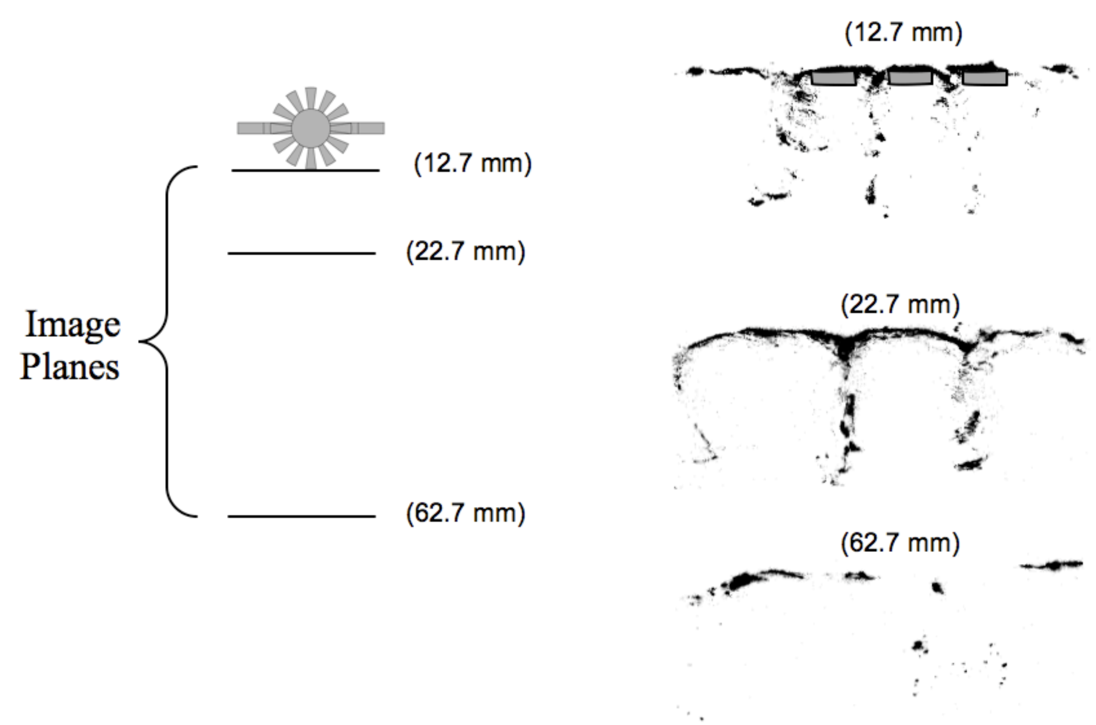
Approach – Stream Formation

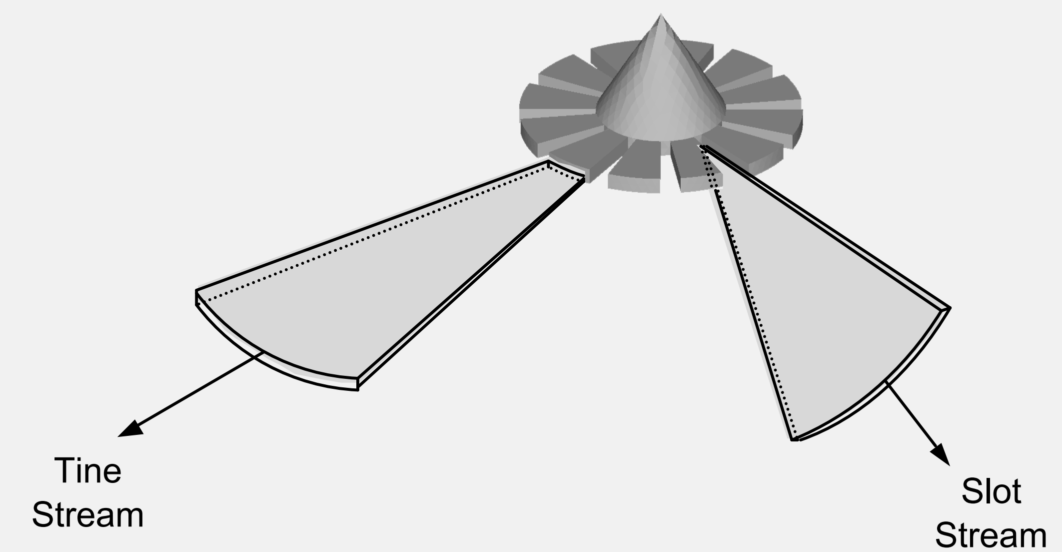
Planar Laser Induced Fluorescence (PLIF)



- Qualitative view of sheet topology.
- Difficulty measuring exact sheet thickness due to deflector surface reflections.
- High speed camera would provide breakup visualization.

Results – Stream Formation

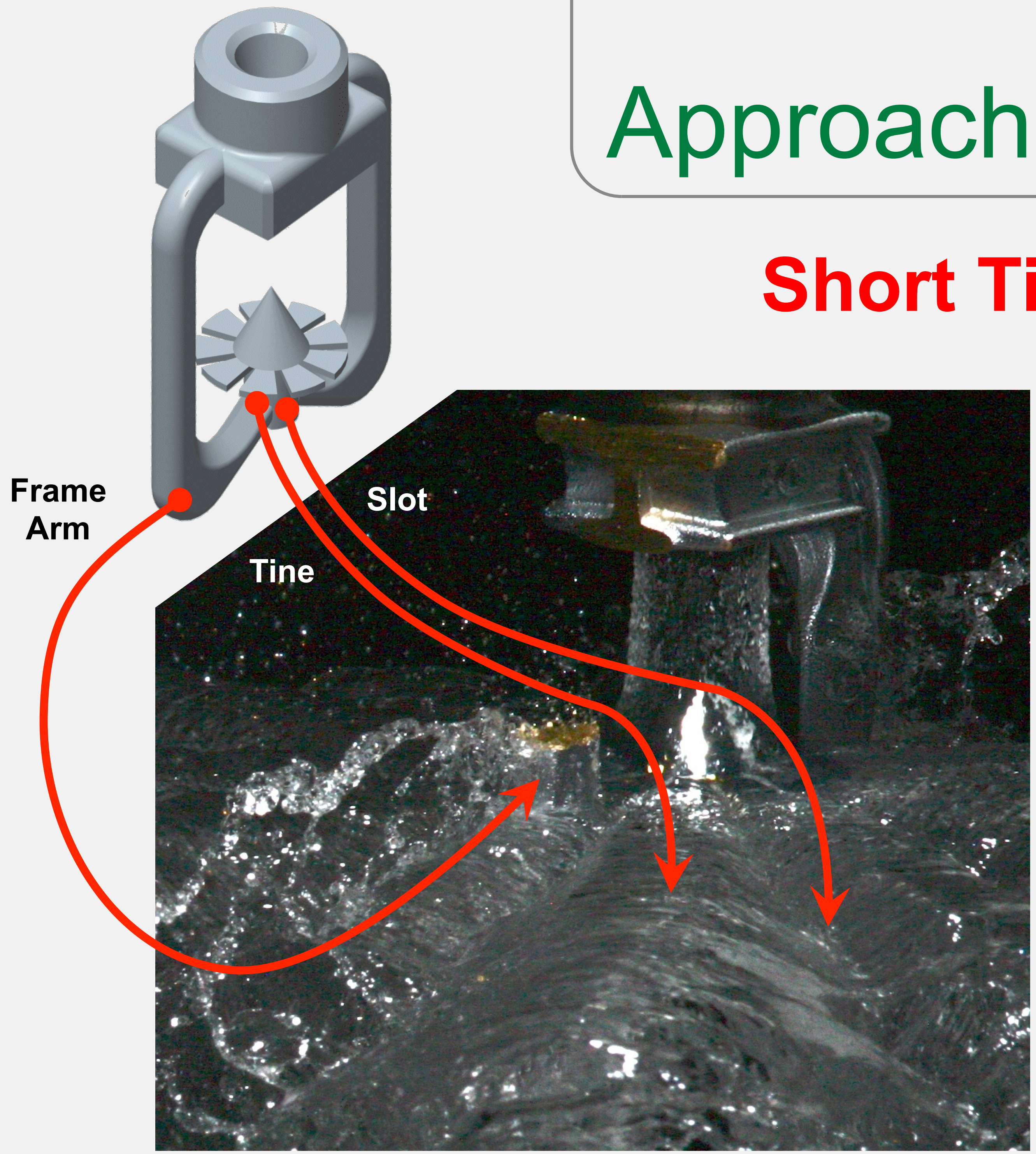


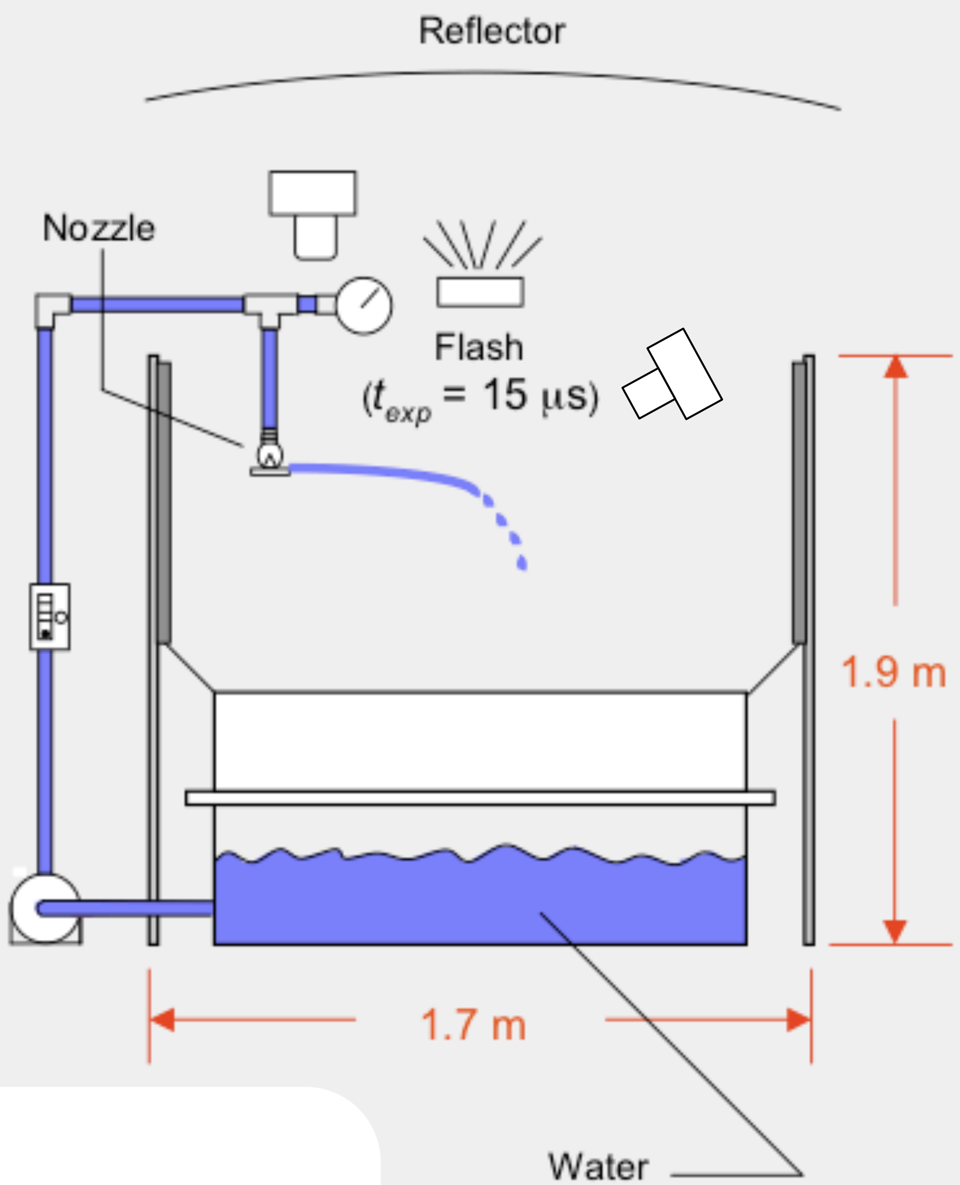


- Two distinct streams are formed.
- Flow split between these streams governs the sheet thickness and the resulting drop size

Approach / Results – Stream Formation

Short Time Exposure Photography

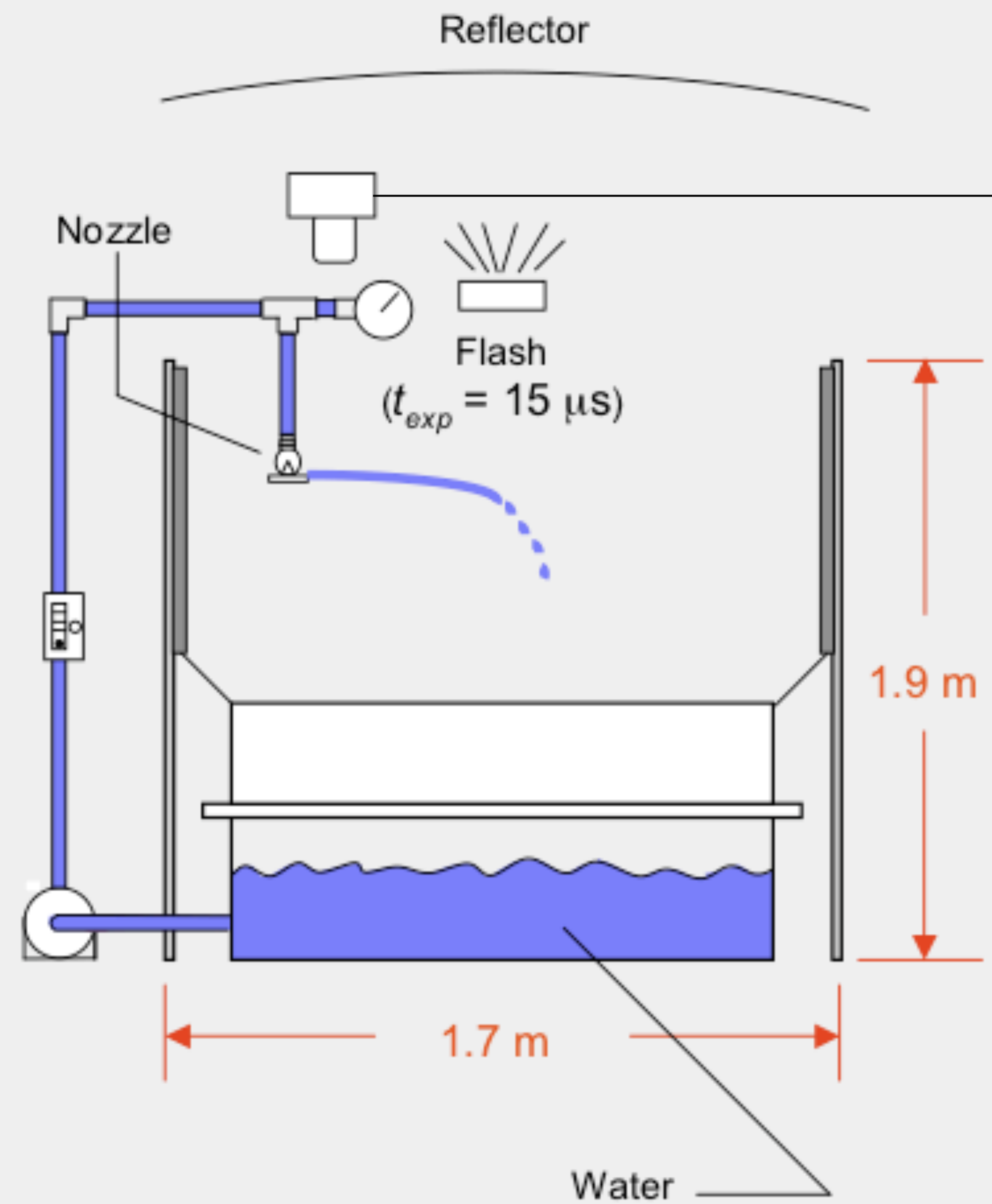


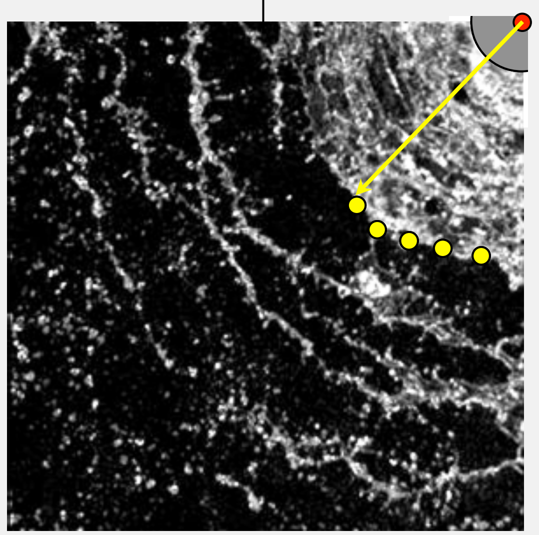


- Qualitative view of sheet topology

Approach – Stream Breakup

Short Time Exposure Photography





Canon 12-bit 3.4 Mpixel Digital SLR Camera

Results – Stream Breakup

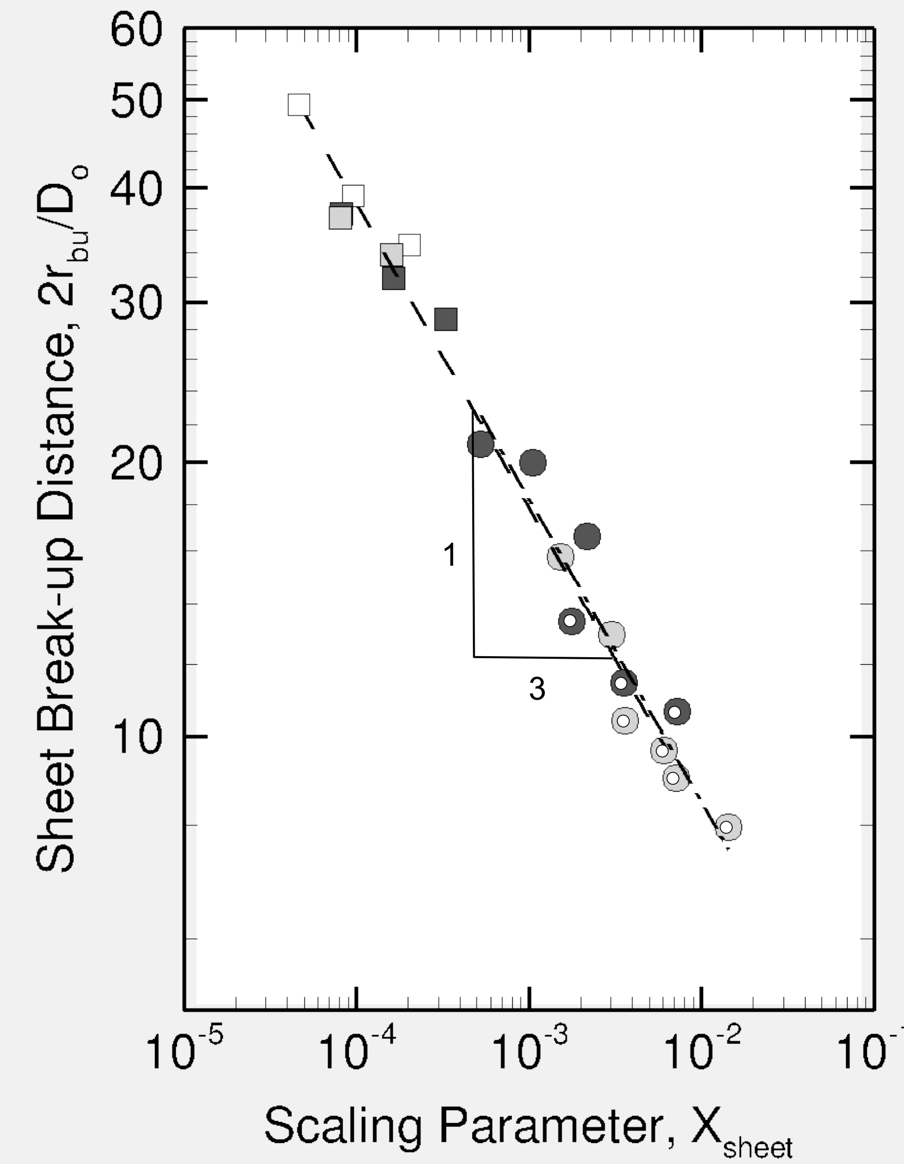
Ambient Condition

$$X_{sheet} = \frac{(\rho_a/\rho_l)^2}{f_o^{\,2}}(We/\beta^3\gamma)$$

Injector Disturbances

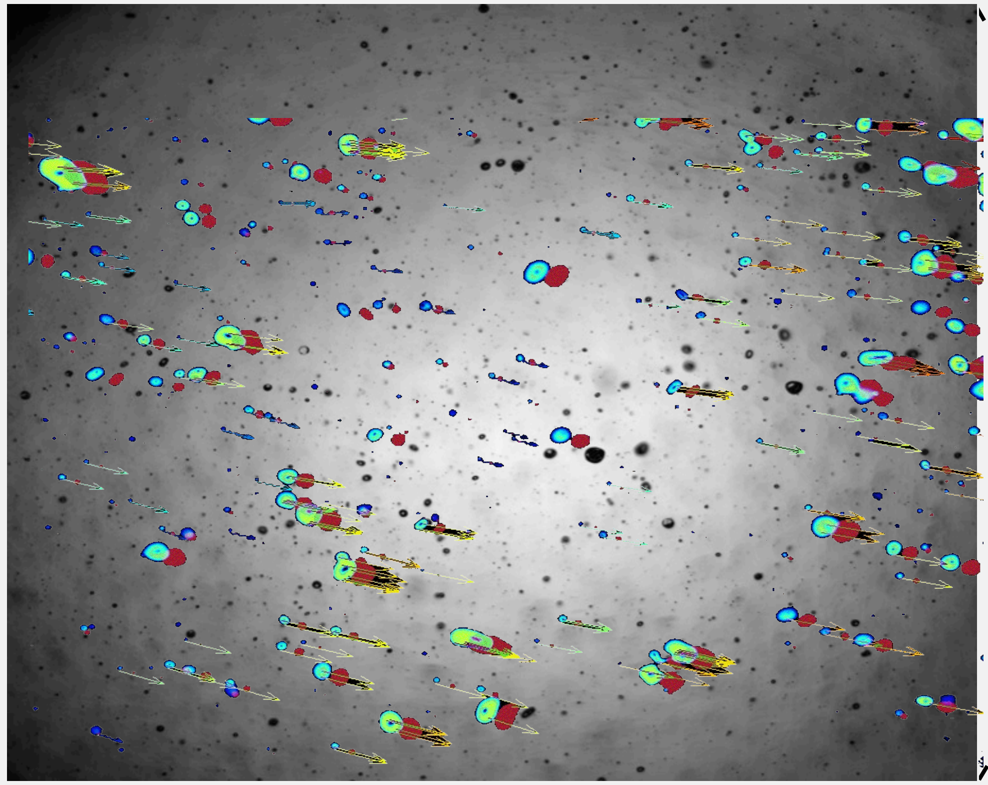
Modified Weber Number

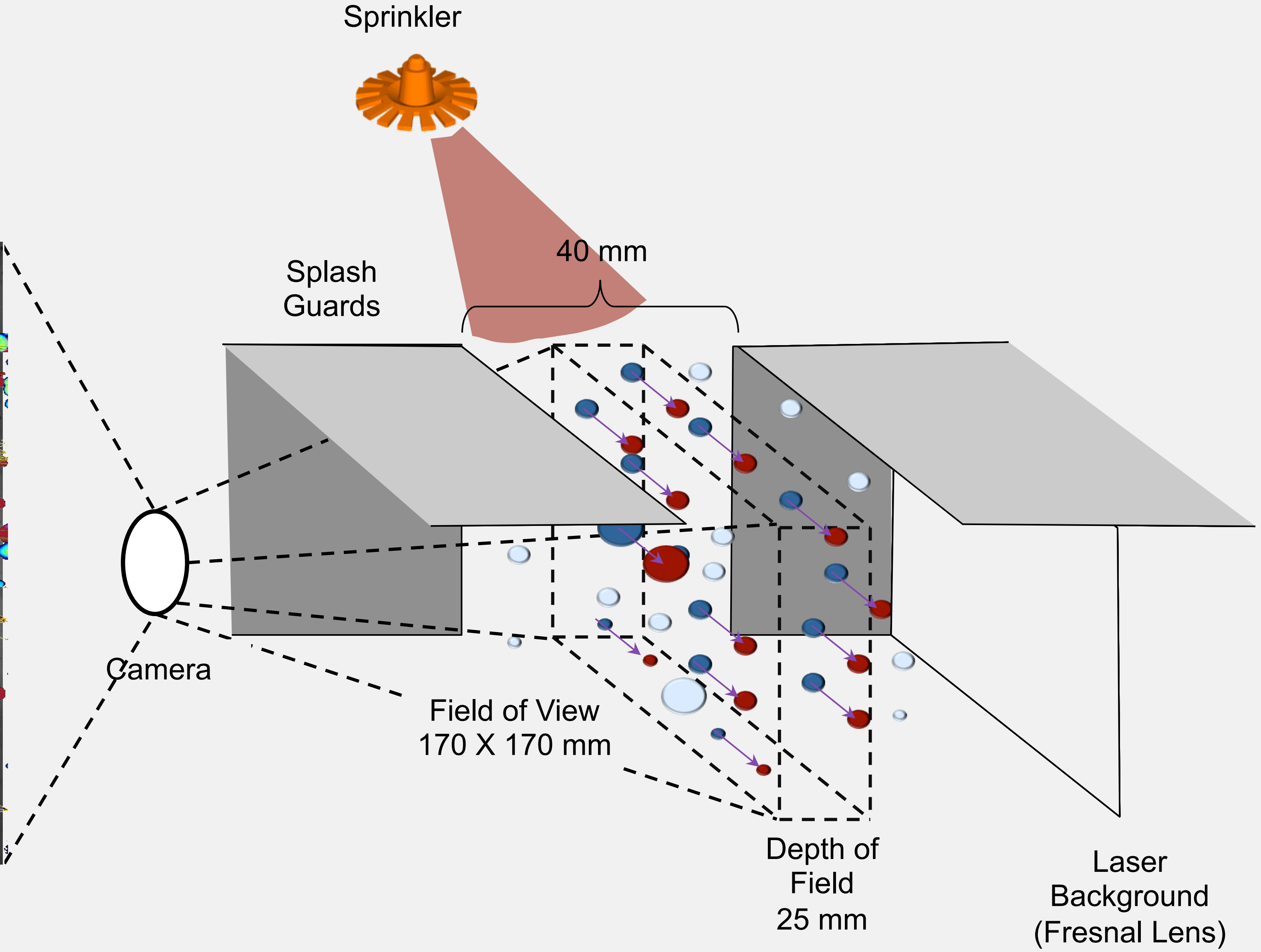
□	D_o=3.5mm	Basis Nozzles
■ (light grey)	D_o=6.7mm	
■ (dark grey)	D_o=9.7mm	
● (light grey)	D_o=6.35mm	Standard Nozzles (Tine)
● (black)	D_o=12.7mm	
◎ (light grey)	D_o=6.35mm	Standard Nozzles (Slot)
◎ (black)	D_o=12.7mm	



Approach – Initial Spray

Shadowgraph/PTV (Drop Size/Velocity) Measurements





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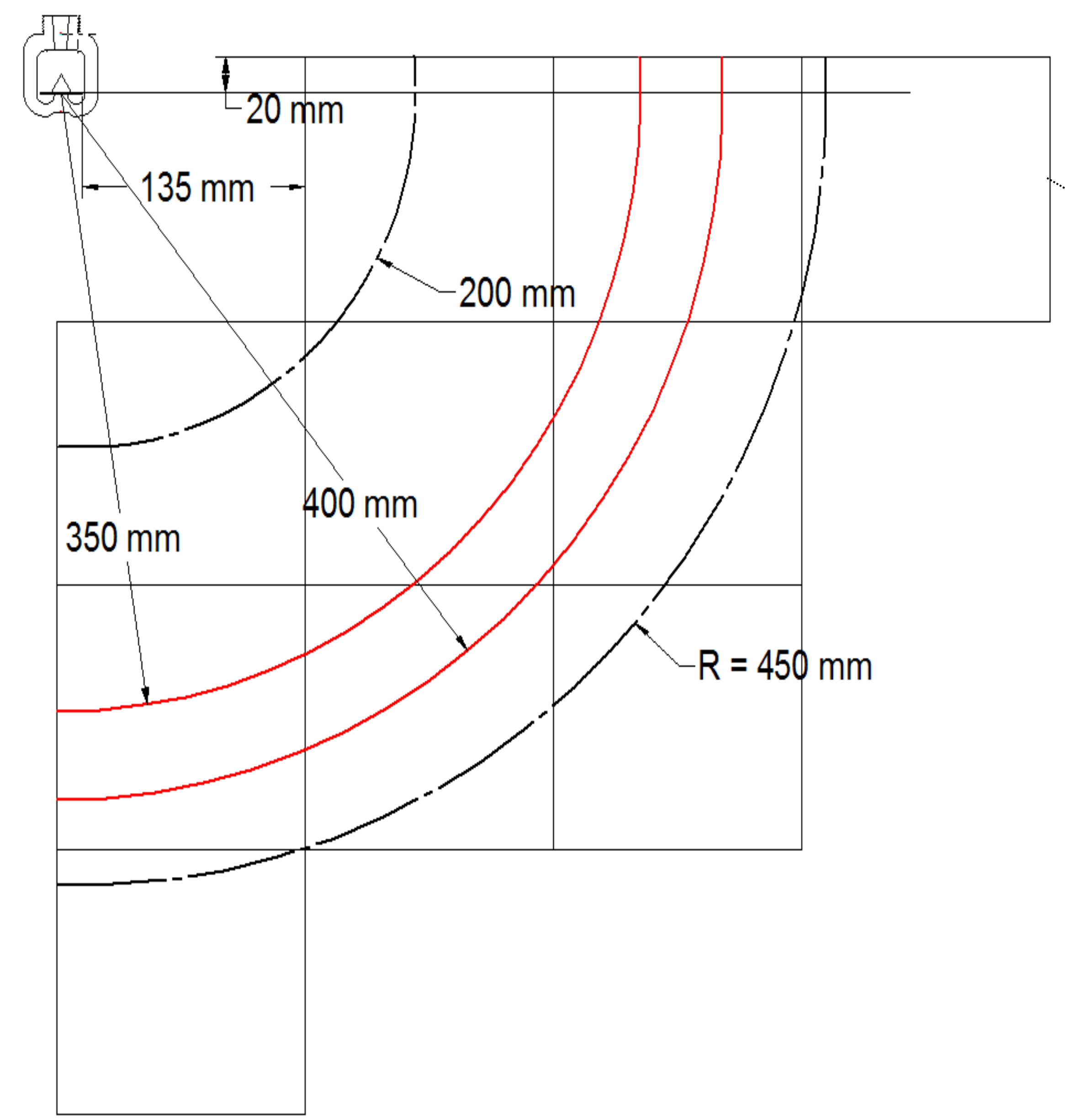
Approach – Initial Spray



Area used: 150X150 mm

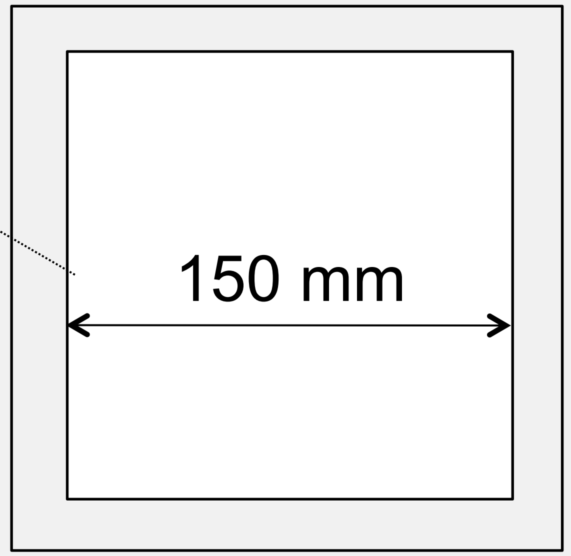


Image size: 170X170 mm

Minimum drop resolved: ~0.2mm

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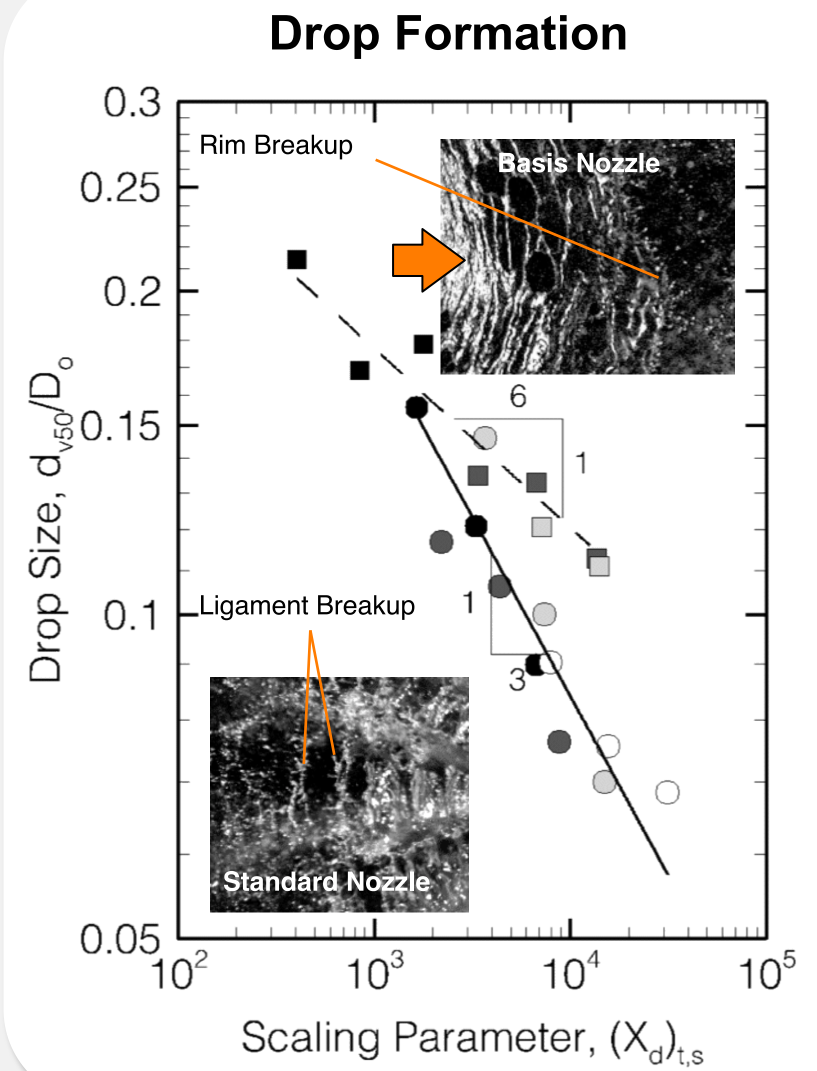
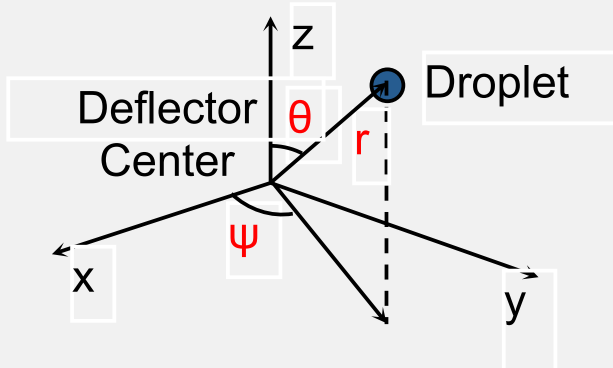
Std Nozzles (D3): ● D_o = 6.2 mm - tine, ● D_o = 11.0 mm – tine, ○ D_o = 6.2 mm - slot, ○ D_o = 11.0 mm - slot; Basis Nozzles: ■ D_o = 3.2 mm, ■ D_o = 6.2 mm, □ D_o = 9.5 mm

Results – Initial Spray

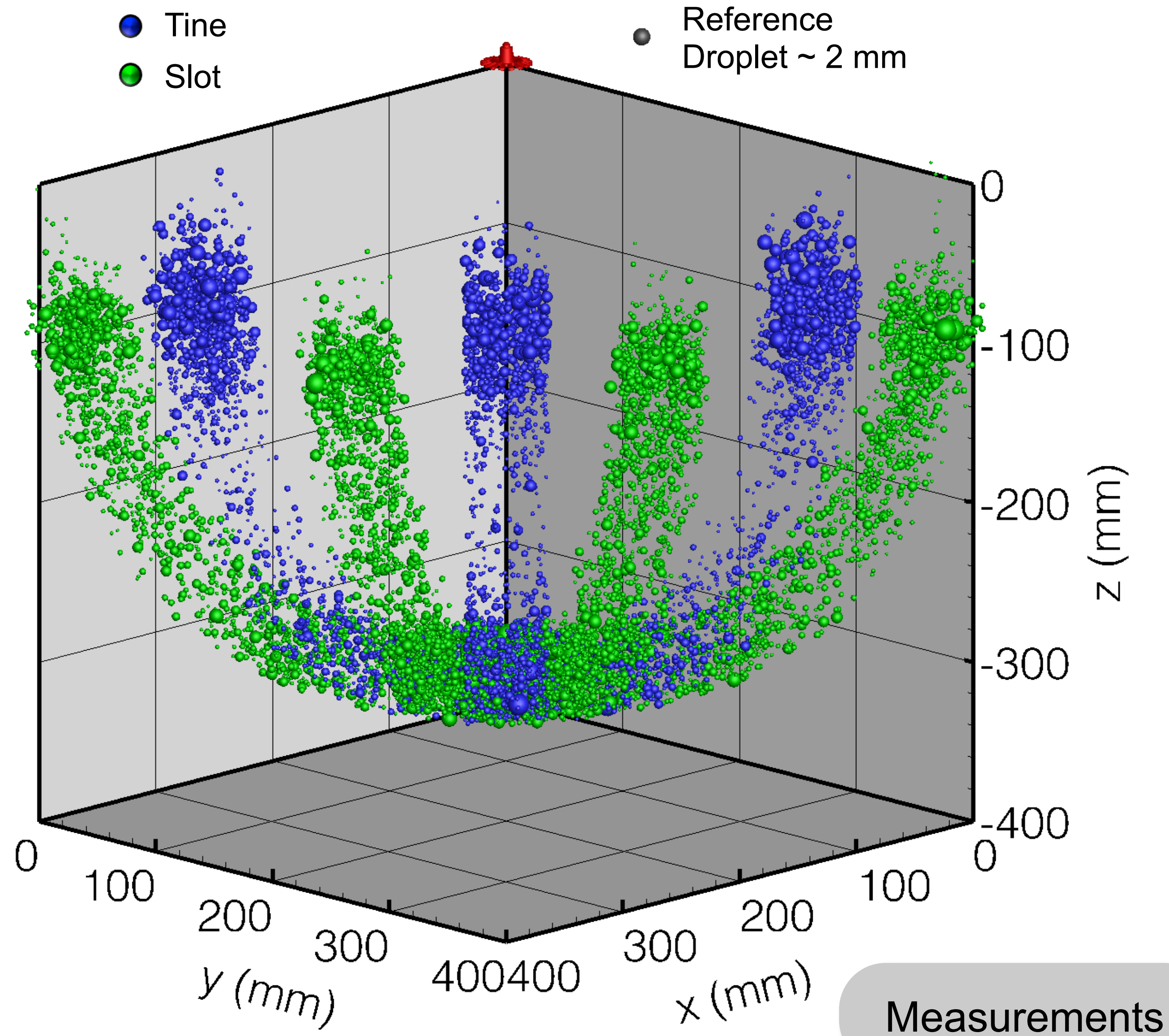


$$X_{drop} = (\rho_a/\rho_l)^{1/2} f_o(We/\beta^3\gamma)$$

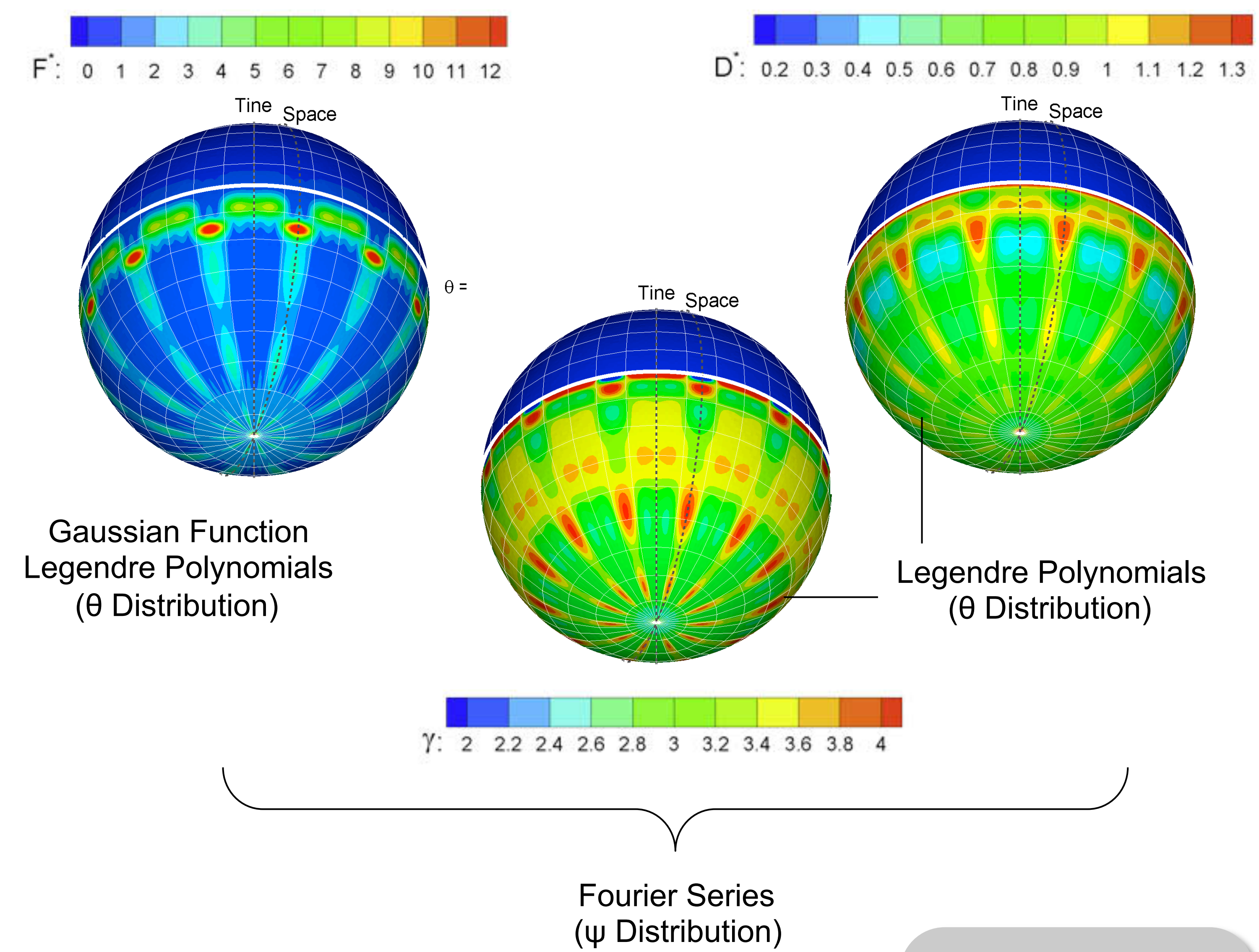


Results – Initial Spray Description

Tyco D3
K = 81 lpm bar$^{-1/2}$
P = 1.4 bar



Measurements



Basis Functions

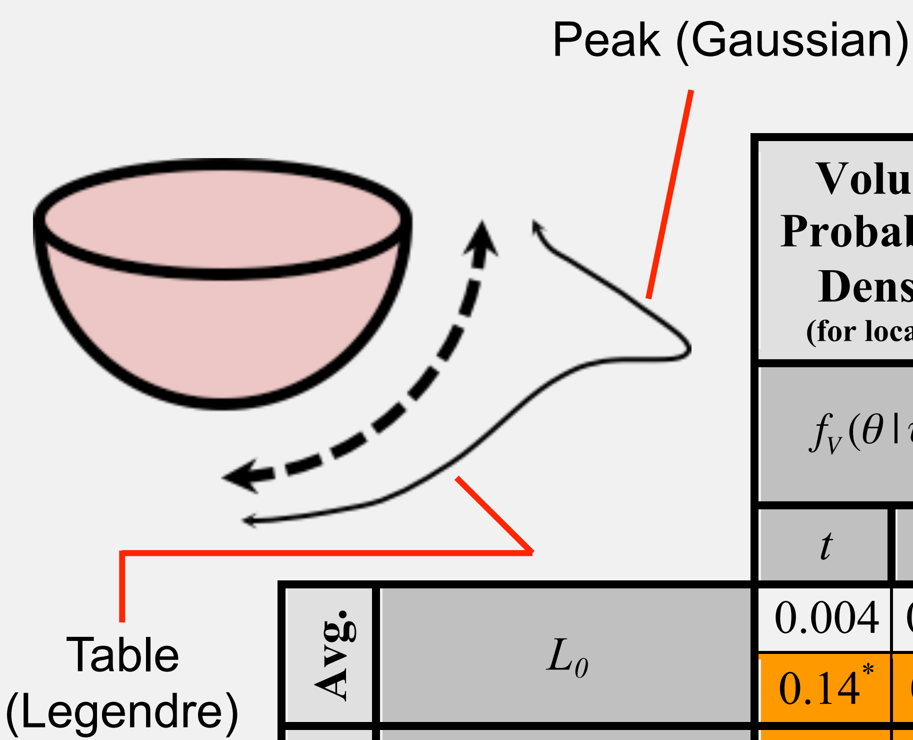
Ren, N., Baum, H., & Marshall, A., “A comprehensive methodology for characterizing sprinkler sprays,” *Proceedings of the Combustion Institute* , 2010, pp. 2547–2554

Results – Initial Spray

Tyco D3
K = 81 lpm bar$^{-1/2}$
P = 1.4 bar

Sprinkler Discharge

- Physically rational compact description of spray.
- Provides a framework for spray evaluation and insight.
- **48** coefficients describe (and can generate) the 3D stochastic spray.
- **15** first order coefficients describe primary spray characteristics.



		Volume Probability Density (for location)		Drop Size				Velocity	
		$f_V(\theta \mid \psi_{t,s})$		d_{v50}/D_o, $D_o = 11$ mm		Γ (distribution width)		u/U, $U = 15$ m/s	
		t	s	t	s	t	s	t	s
Avg.	L_0	0.004 / 0.14*	0.007 / 0.46*	0.11	0.10	2.9	2.8	0.62	
Shape	F_0	0.86	0.54	N/A					
	θ (°)	102	107						
	σ (°)	3.4	2.6						
	L_1/L_0	0.59	0.69	-0.012	0.33	-0.085	0.016		
	L_2/L_0	-0.95	-1.1	0.48	0.052	0.053	-0.36		
	L_3/L_0	0.46	-0.027	0.067	0.60	0.016	0.40		
	L_4/L_0	-0.31	0.80	0.097	-0.17	0.063	0.046		
	L_5/L_0	0.26	-0.63	0.43	0.56	0.037	0.46		

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Results – Initial Spray

Tyco D3
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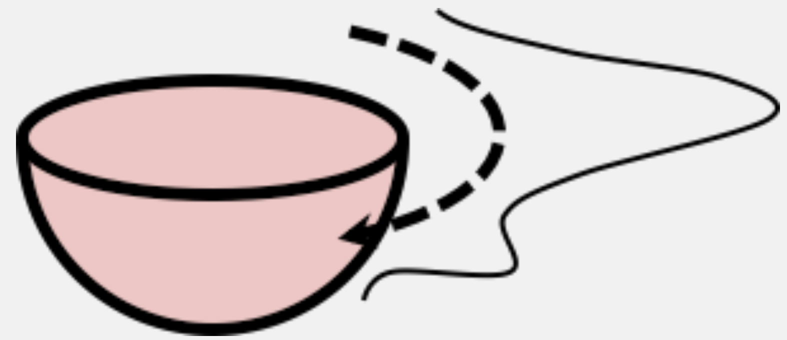
P = 1.4 bar



		Fourier Coefficients
Shape	a_0	1.333
	a_1	0.551
	a_2	-0.276

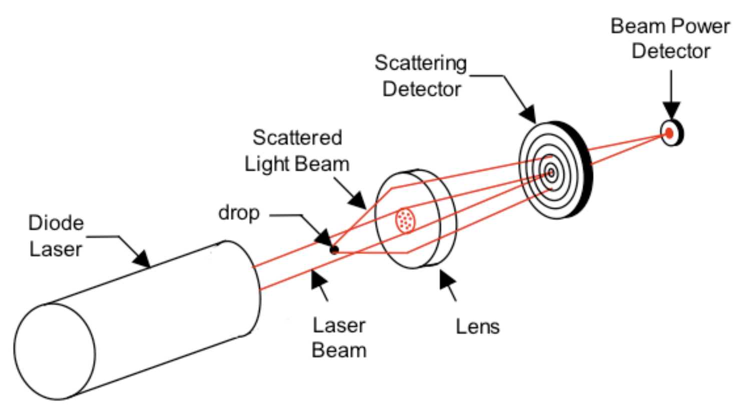
	Volume Probability Density (for location) $f_V(\psi_{t,s})$	
	t	s
Shape	0.0029	0.0025

$$f_v(\psi_s)/f_v(\psi_t) = 0.86$$

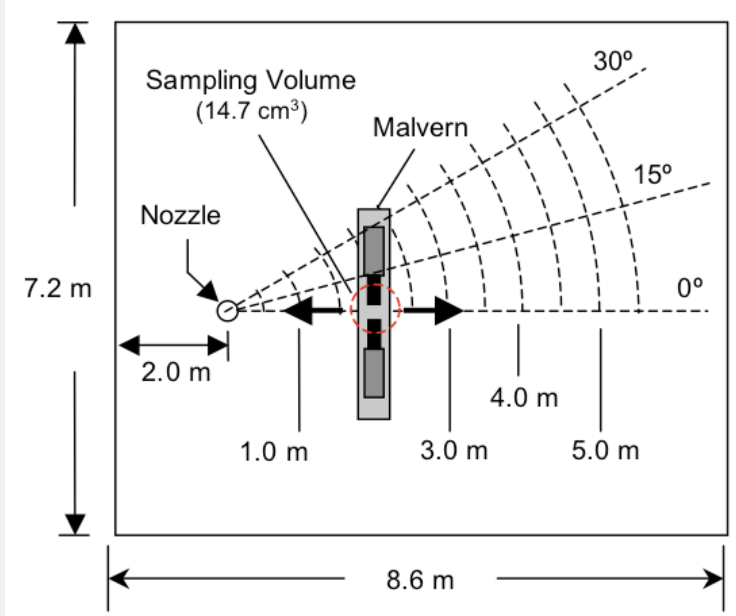
Approach – Dispersed Spray

Malvern Drop Size Measurements

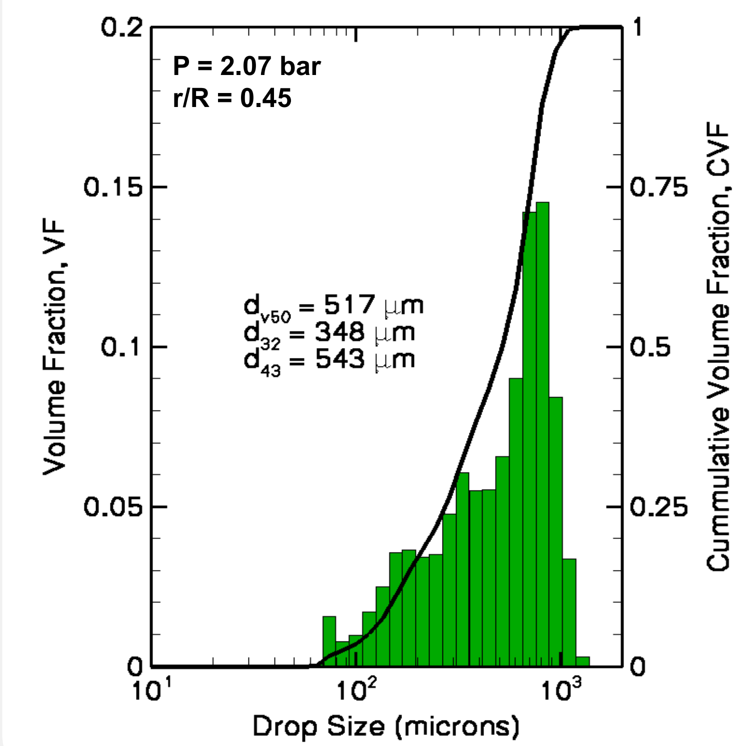
Malvern Spraytec Analyzer (Light Diffraction Technique)



Local Measurements



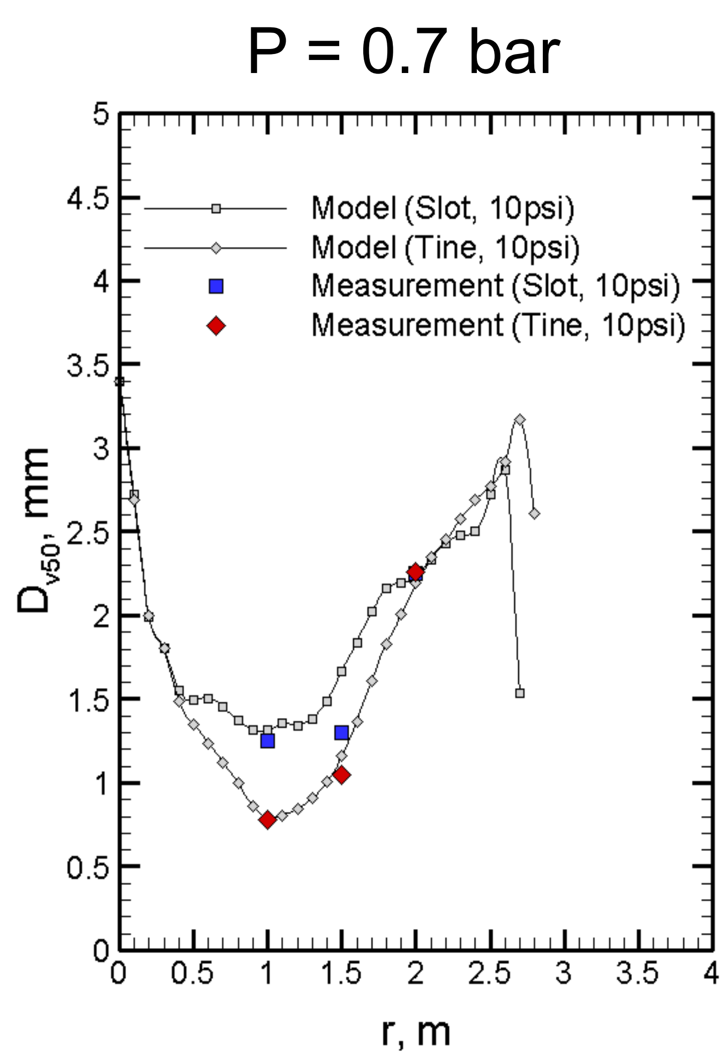
Local Drop Size Distribution

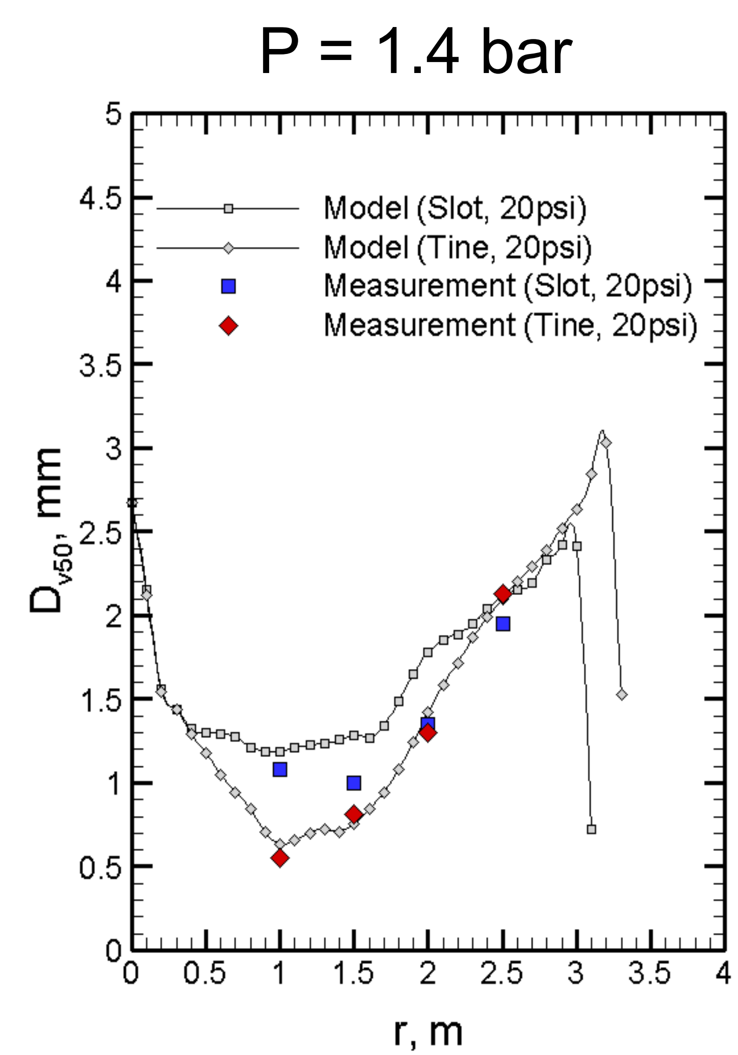


- Drop size limit (~ 0.8 mm)

Results – Drop Size Comparison

Tyco D3
K = 81 lpm bar$^{-1/2}$





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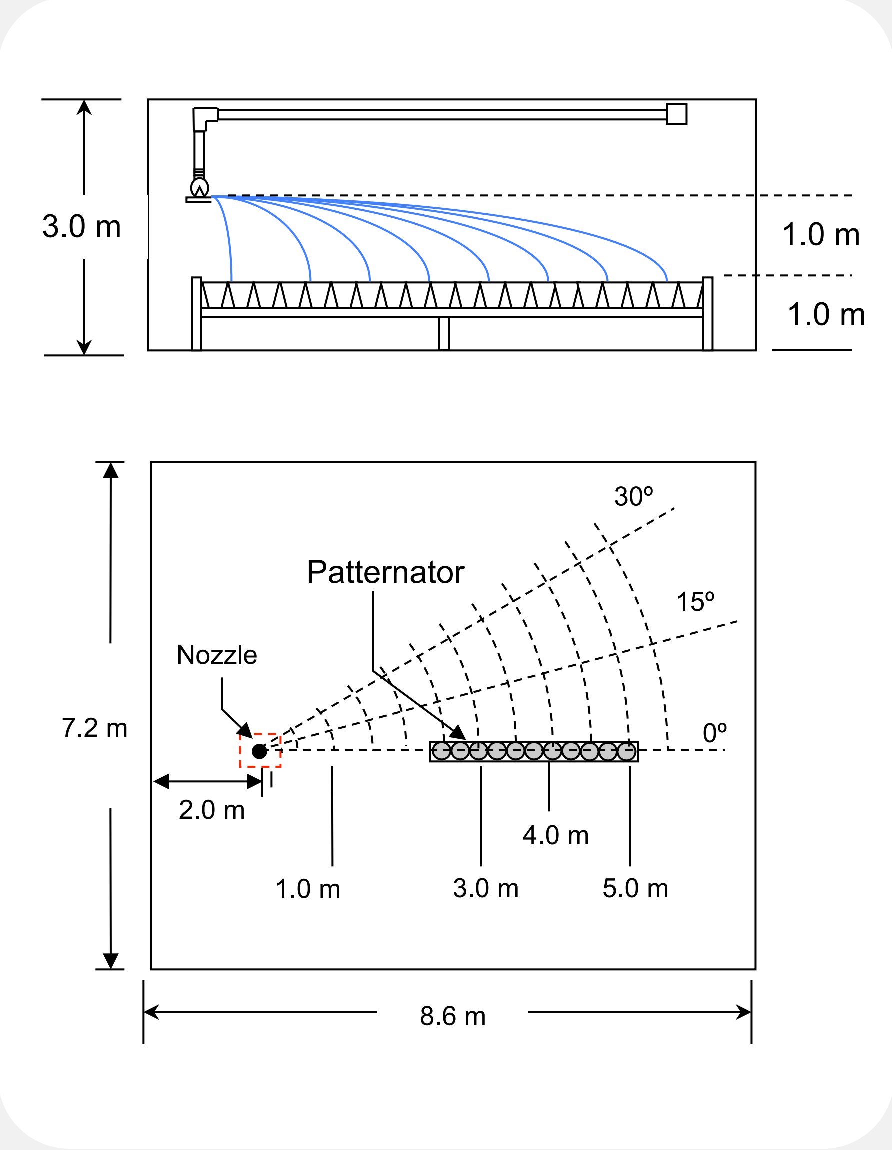
Approach – Dispersed Spray

Volume Flux Measurements



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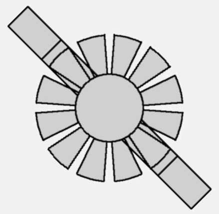
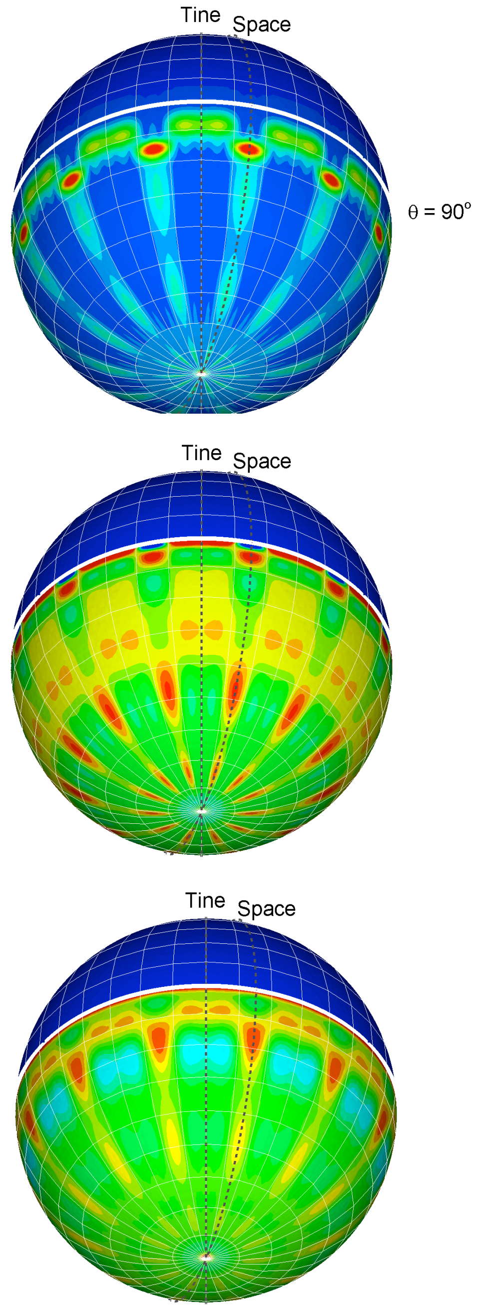


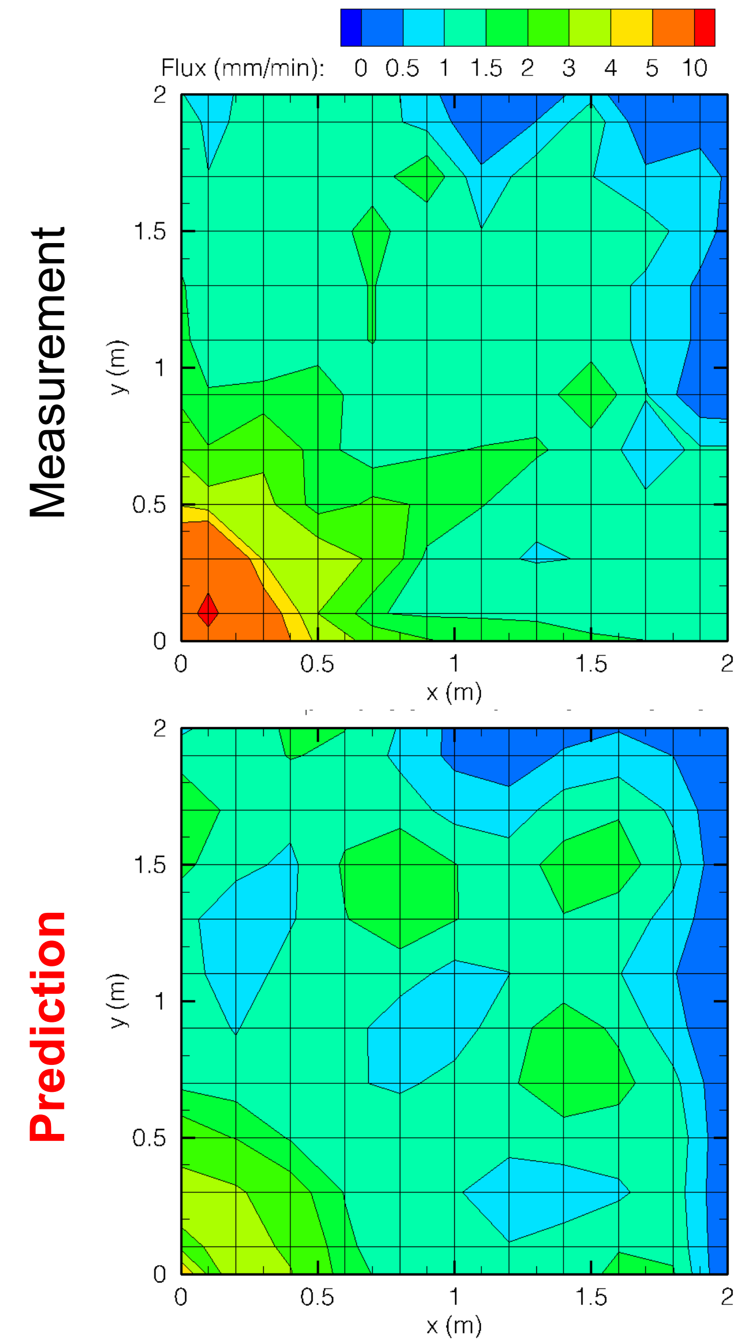
Tyco D3
K = 81 lpm bar$^{-1/2}$
P = 1.4 bar
2.9 mm/min

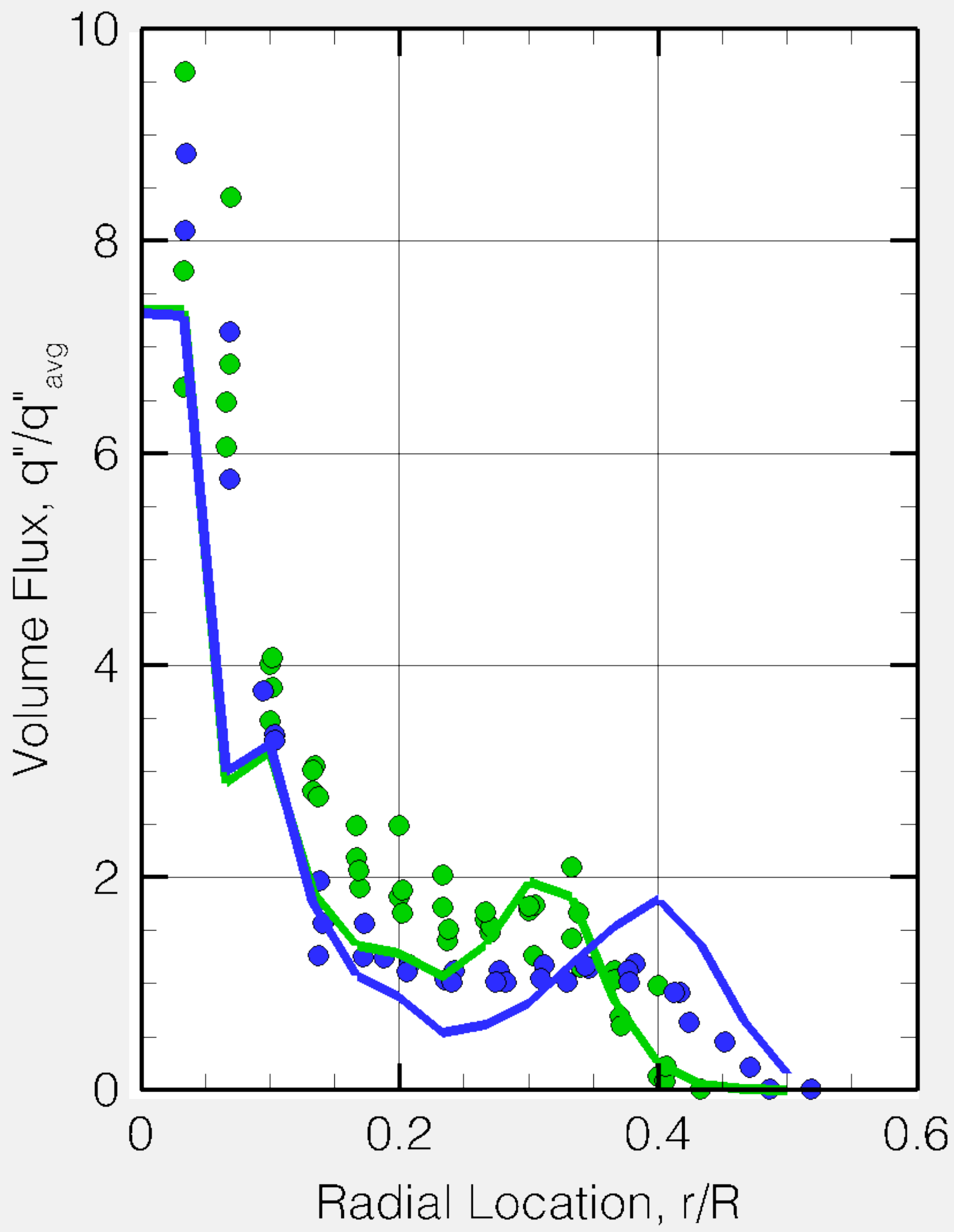
Results – Dispersed Spray

Initiation Sphere



Patternation (z= -1 m)





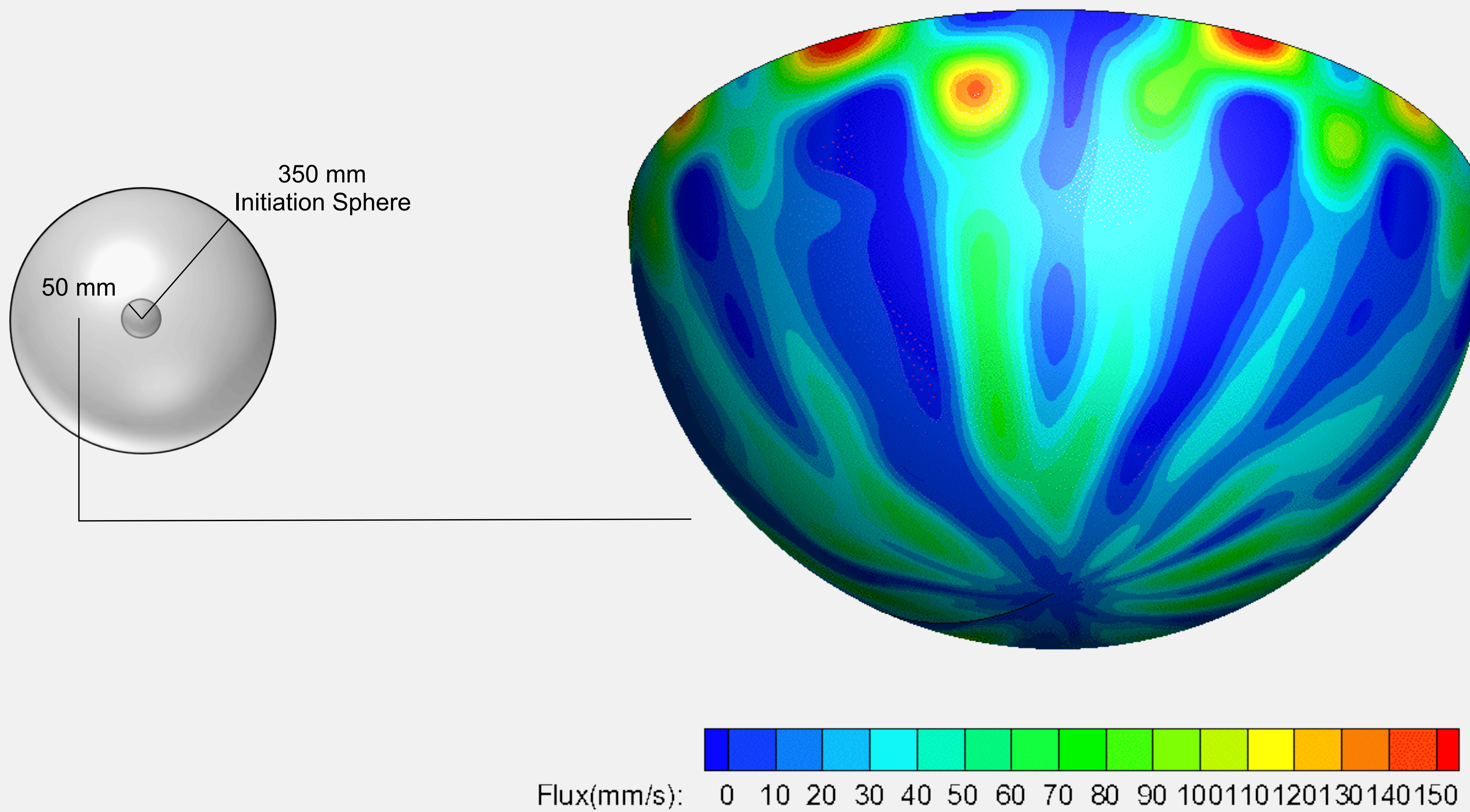
Summary

- Focused measurements provide insight into the discharge characteristics of sprinkler sprays.
- Qualitative and quantitative measurement methods are available to explore sprinkler spray behavior from stream formation to the dispersed spray.
- These measurements provide insight into basic features of the spray (images/ comprehensive framework), relationship with nozzle geometry (scaling laws), CFD modeling input (detailed measurements), and suppression performance (volume flux measurements).

Future Work - Measurements

Tyco D3
K = 81 lpm bar$^{-1/2}$
P = 0.7 bar

Near Field Patternation Measurements



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UM Fire Suppression Spray Group

Current	Graduates
Dr. Howard Baum	Mr. Ning Ren
Dr. Ning Ren	Mr. Paolo Santangelo
Dr. Paolo Santangelo	Mr. Chi Do
Ms. Yinghui Zheng	Mr. Andrew Blum
Mr. Giovonni Bendetto	Ms. Di Wu
	Ms. Delphine Guillemin