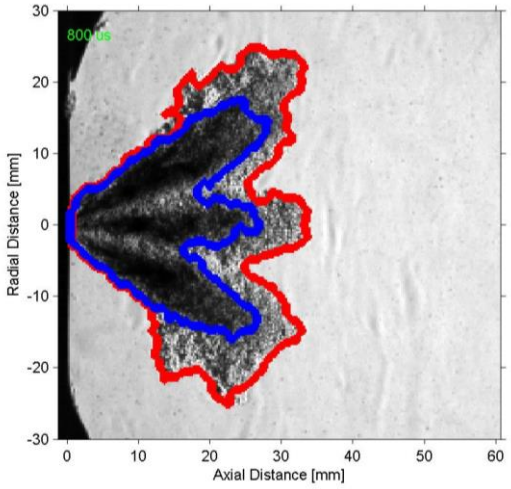
Gasoline Spray (Spray G)
ECN5 Workshop

Spray G Organizers:
Scott Parrish (GM)
Lyle Pickett (Sandia)



Spray G – ECN5 Program

8:30	Introduction - **Scott Parrish (GM)**
	Topic 8 – Spray G Nozzle Geometry and Internal Nozzle Flow
	Organizer: Chris Powell (Argonne)
8:40	Nozzle geometry and near-nozzle experiments - **Katie Matusik (Argonne)**
9:20	Internal and near-nozzle flow modeling - **David Schmidt (Umass-Amherst)**
10:00	**Break**
	Topic 9 – Evaporative Spray G
	Organizer: Daniel Vaquerizo (CMT)
10:30	Liquid and vapor visualization experiments and modeling - **Daniel Vaquerizo (CMT)**
11:00	Liquid and vapor velocity experiments - **Panos Sphicas (Imperial College)**
11:15	Lagrangian modeling of Spray G - **Lyle Pickett (Sandia)**
12:00	**Lunch**
	Future Directions
	Organizer: Scott Parrish (GM)
13:00	Spray G at flashing conditions – **Josh Lacey (Melbourne)**
13:20	Multiple-injection conditions – **Scott Parrish (GM)**
13:40	Engine experiments - **Scott Parrish (GM)**

Spray G - Injector Specification

- Considerations for injector specification
  - Hopefully the output of the group will be transferable and relevant to *future advanced* engine implementations
  - It is important to keep in mind the spray requirements of advanced applications such as stratified spray-guided, HCCI and boosted dilute systems
  - The interaction between adjacent spray plumes is of great importance to both current production and advanced gasoline applications
  - Spray plume interaction is influenced by a number of things including:
    - spray pattern
    - L/D ratio
    - hole manufacturing method
    - proximity of the holes on the nozzle
  - Successful mixture preparation relies on a proper combination of all these parameters

Spray G - Injector

Parameter	
• Number of holes	8
• Spray shape	circular
• Spray angle	80°
• Bend angle	0 °
• L/D ratio	1.4
• Hole shape	straight
• Manufacturing	EDM
• Flow rate	15 cc/s @ 10 MPa

Spray G – Operation Conditions

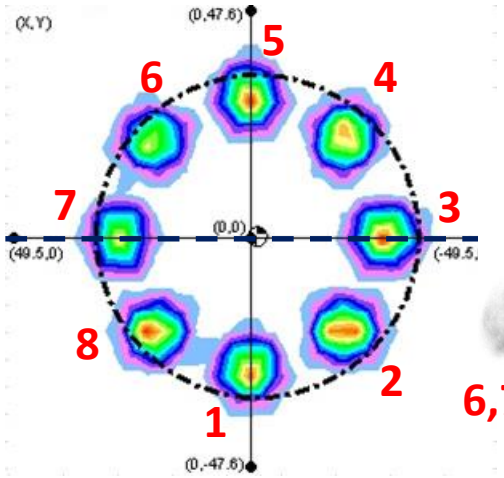
- Considerations for choosing operating conditions
  - Operating conditions of gasoline engines vary widely
  - Most all current production engines operate with early injection where sprays can be subjected to low pressures resulting in flash boiling
  - Most advanced engine concepts rely on late injection where sprays are subjected to elevated ambient pressures and temperatures

Spray G – Operating Conditions

Parameter	Spray G (ECN2)	Spray G2 (ECN3)	Spray G3 (ECN3)
• Fuel	Iso-octane	Iso-octane	Iso-octane
• Fuel pressure	20 Mpa	20 Mpa	20 MPa
• Fuel temperature	90° C	90° C	90° C
• Injector temperature	90° C	90° C	90° C
• Ambient temperature	300 C	60 C	60 C
• Ambient density	3.5 kg/m^3	0.5 kg/m^3	1.12 kg/m^3
• Ambient Pressure	6 Bar (N_2)	0.5 Bar (N_2)	1 Bar (N_2)
• Injected quantity	10 mg	10 mg	10 mg
• Number of injections	1	1	1

Spray G - Injector Orientations

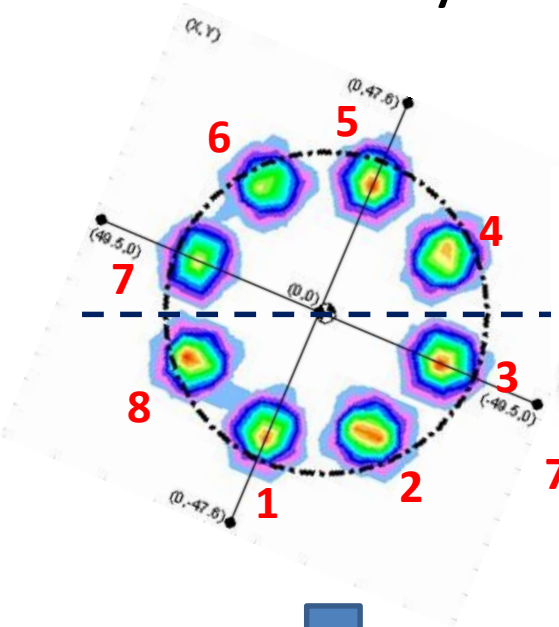
Primary



6,7,8 1,5 2,3,4

Camera

Secondary



7,8 1,6 2,5 3,4

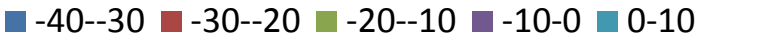
Camera

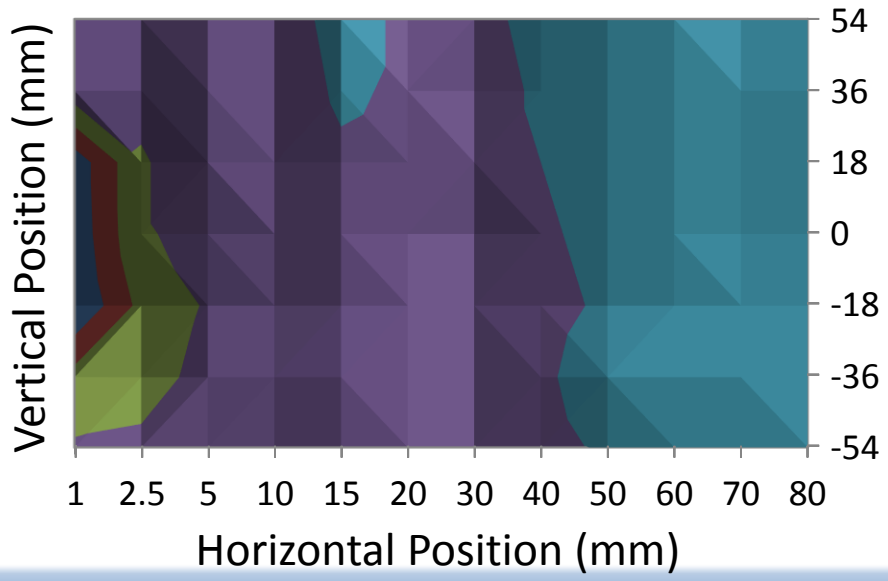
Spray G – Boundary Condition Verification

Spray G – Boundary Condition Verification

Vertical Plane

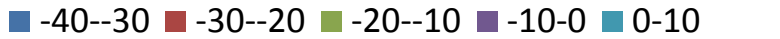
	1	2.5	5	10	15	20	30	40	50	60	70	80
54	-2	-5	-1	-3	2	-1	-2	2	5	6	4	4
36	-4	-7	-2	-4	1	-1	-3	1	4	5	4	4
18	-36	-11	-4	-5	-1	-2	-3	0	3	4	3	3
0	-37	-11	-7	-6	-2	-3	-5	-1	2	3	2	2
-18	-40	-17	-9	-7	-3	-3	-5	-2	1	2	2	2
-36	-16	-14	-7	-5	-2	-3	-5	-1	3	3	3	2
-54	-9	-8	-7	-6	-3	-3	-5	-2	1	2	2	2

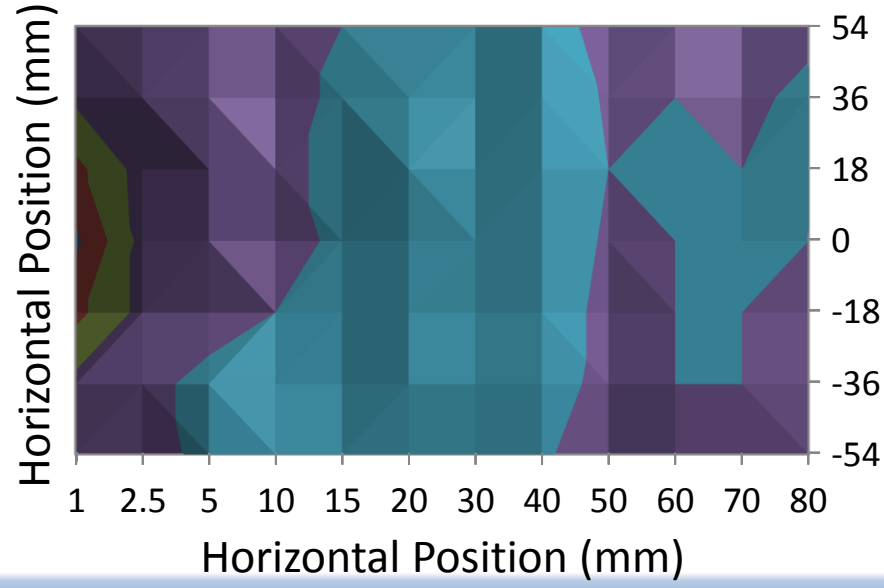




Horizontal Plane

	1	2.5	5	10	15	20	30	40	50	60	70	80
54	-8	-3	0	-2	0	1	2	5	-4	-2	-3	-1
36	-8	-2	0	-2	1	3	3	6	-1	0	-1	1
18	-23	-6	-1	-1	1	5	4	6	0	0	0	1
0	-32	-7	-2	-2	1	4	4	5	-1	0	0	0
-18	-23	-7	-3	0	1	4	3	4	-2	0	0	-1
-36	-7	-2	2	1	1	4	3	3	-2	0	0	-1
-54	-6	-3	2	2	2	2	1	1	-4	-2	-2	-2





Spray G – Program (A look back at ECN3)

13:00 Introduction

Experimental Activities

13:15 3.1 Injector geometry assessment
- **Yongjin Jung* (KAIST), Peter Hutchins (Infineum/ESRF)**

13:20 3.2 Rate-of-injection
- **Raúl Payri* (CMT), Scott Parrish (GM),**

13:30 3.3 Spray Visualization (liquid/vapor penetration & angle)
- **Julien Manin* (SNL), Gilles Bruneaux (IFPEN), Scott Parrish (GM), Luigi Allocca (IM), Josh Lacey (Melbourne)**

14:00 3.4 Drop size measurement (Phase Doppler Interferometry)
- **Scott Parrish* (GM)**

Modeling Activities

14:15 3.5 Internal flow modeling using ideal geometry
- **Ron Grover* (GM)**

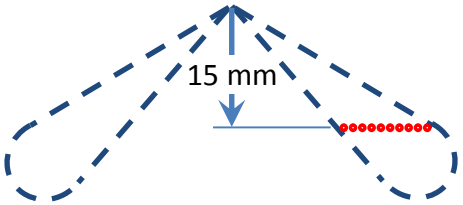
14:30 3.6 Spray modeling
- **Noah Van Dam* (UW), Lucchini (Politecnico di Milano), Som (ANL)**

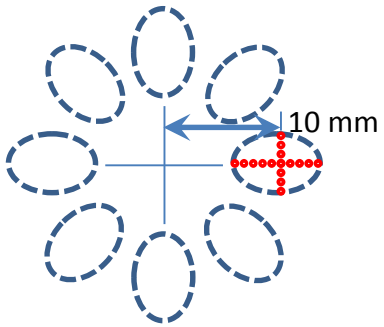
15:00 Discussion Period

15:30 Break

***Discussion Leader**

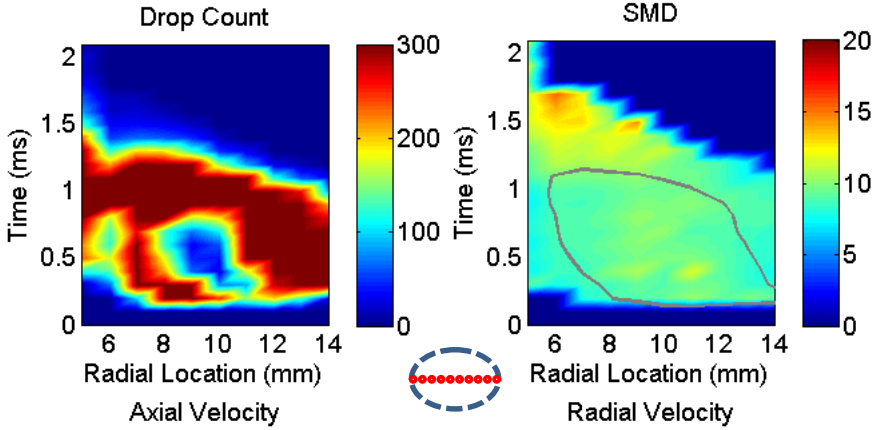
Spray G – Drop Sizing (ECN3)



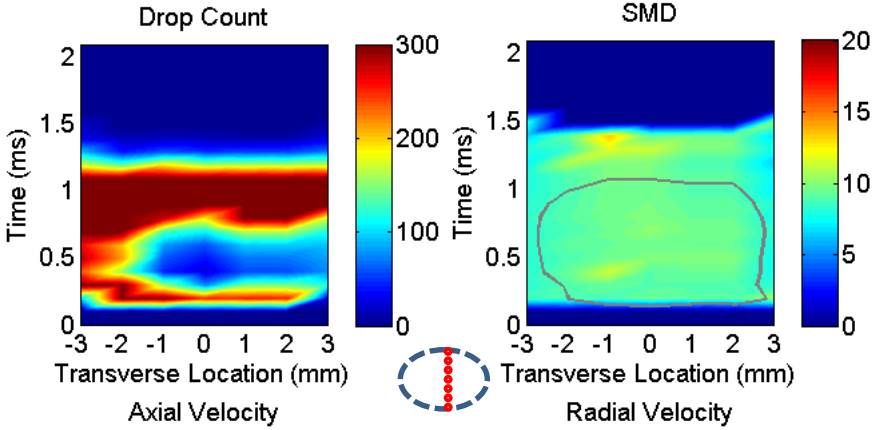


GM

Radial Scan



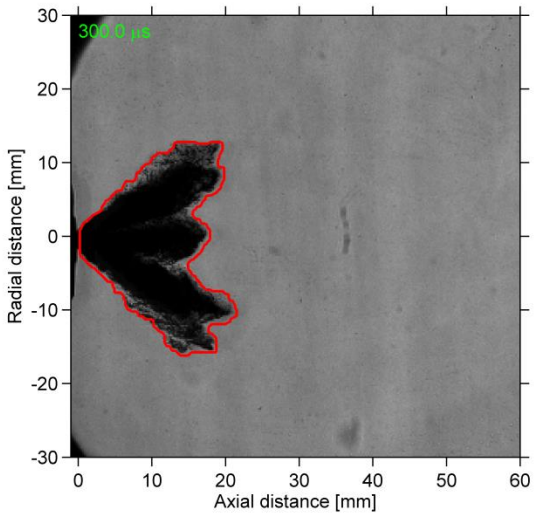
Transverse Scan

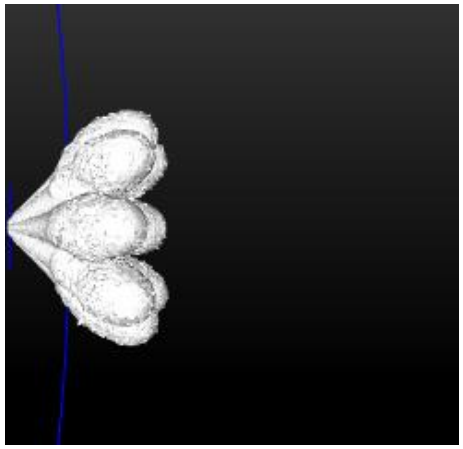


Spray G – Spray Modeling (ECN3)

0.3 ms ASOI

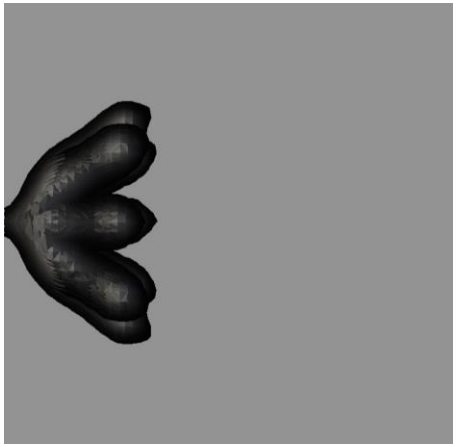
Experiment

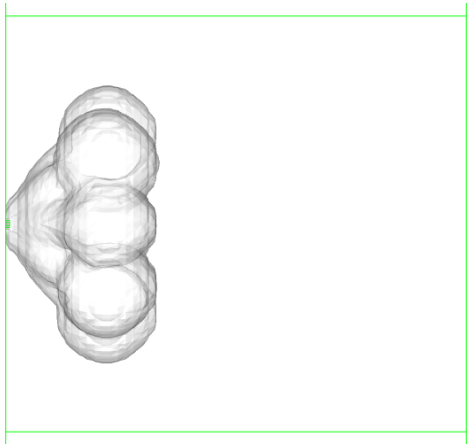




ANL

PoliMi





UW

Spray G – Program (A look back at ECN4)

9:30 Introduction

Topic 8 – Spray G Nozzle Geometry and Internal Nozzle Flow

Organizer: Chris Powell (Argonne)

9:40 Nozzle Geometry and Near-Nozzle Experiments
- **Daniel Duke (Argonne)**

10:20 Internal and Near-Nozzle Flow Modeling
- **Ron Grover (GM)**

11:00 Break

Topic 9 – Evaporative Spray G

Organizer: Daniel Vaquerizo (CMT)

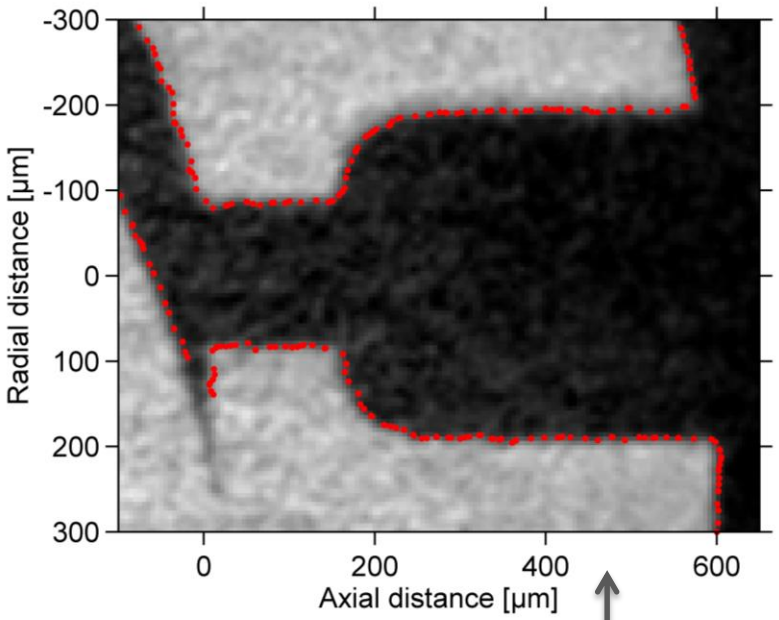
11:30 Macroscopic Spray Visualization and Modeling
- **Josh Lacey (Melbourne)**

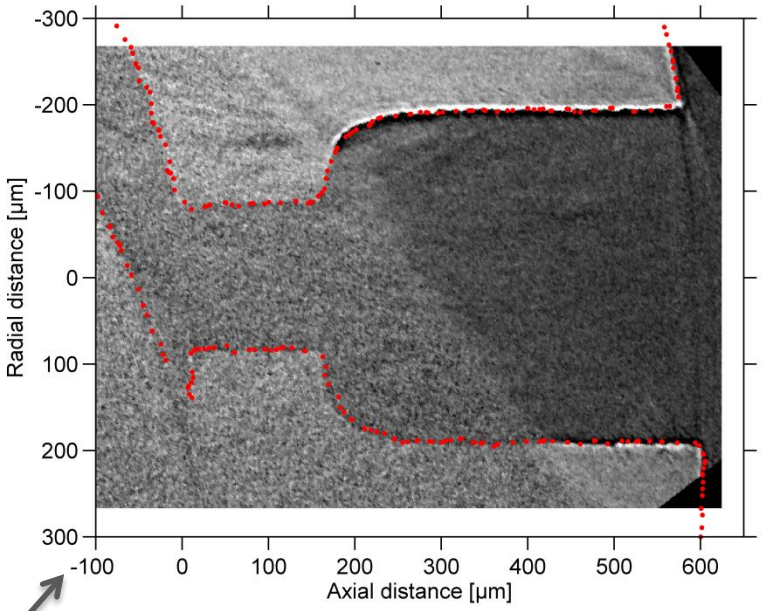
12:10 Spray Mixing Experiments and Modeling
- **Lama Itani (IFPEN) & Lyle Pickett (Sandia)**

12:50 Discussion Period

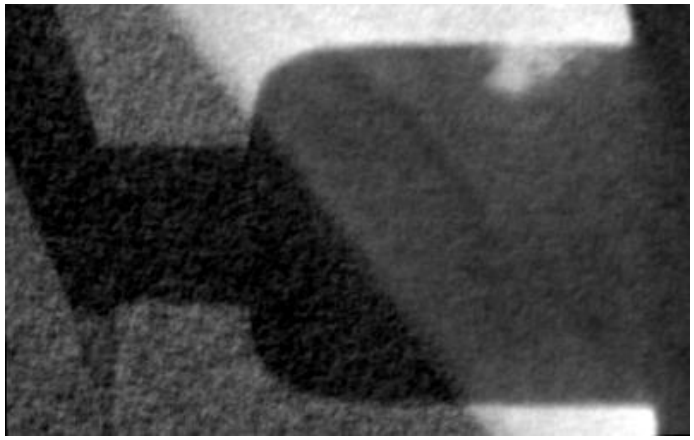
13:00 Lunch

Spray G – X-Ray Tomography (ECN4)





- Northstar tomography (5.07 micron)
  - Low resolution
- ESRF tomography (1.325 micron)
  - Poor SNR, big dataset
- ANL tomography (1.845 micron)
  - *Open source reconstruction code*
  - Less resolution, better SNR
  - Currently too large to isosurface



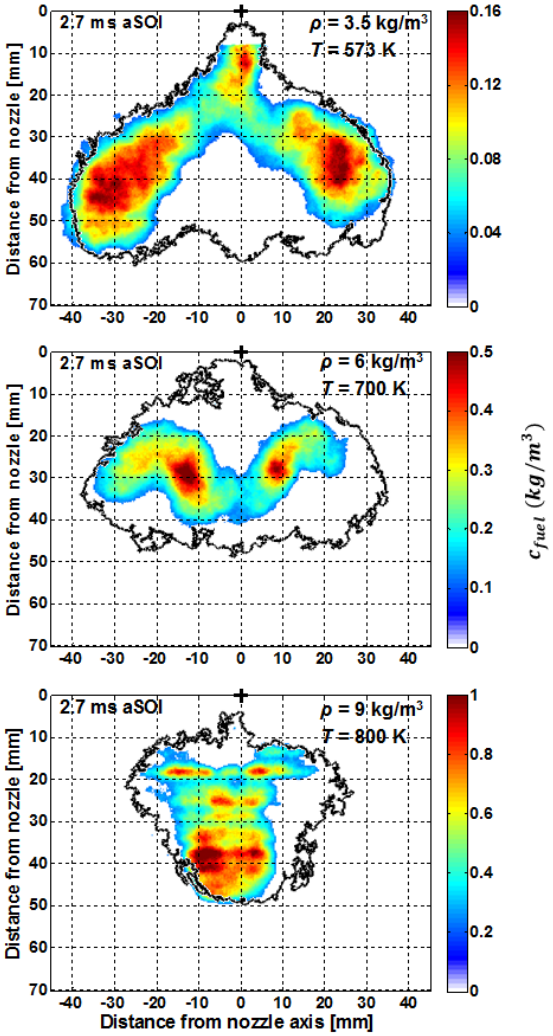
Spray G – Fuel Concentration PLIF (ECN4)

IFPEN

Spray G

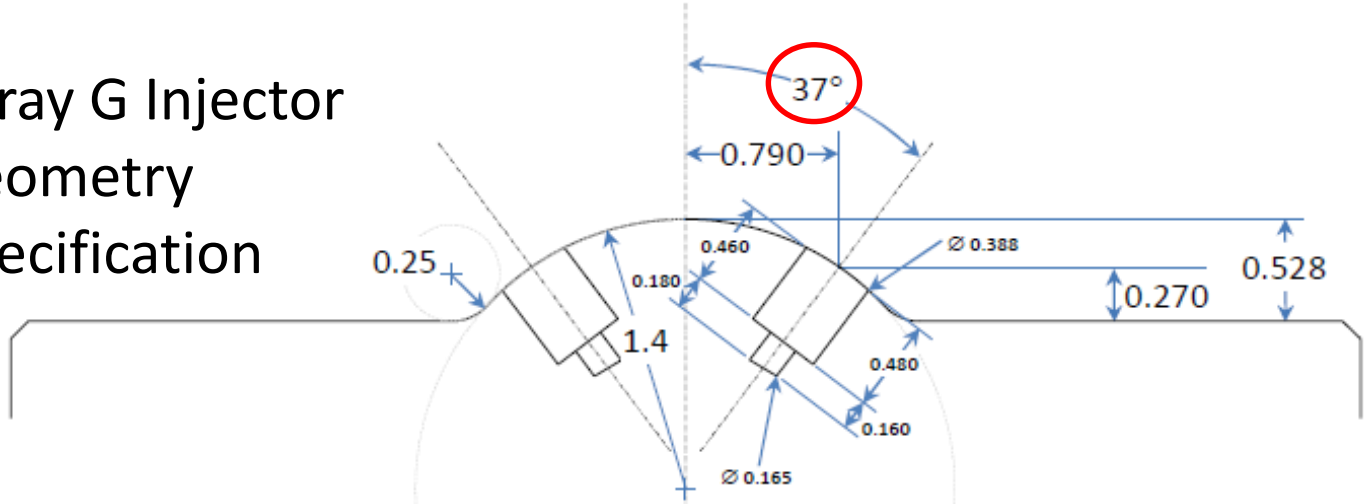
ρ = 6 kg/m³
T = 700 K

ρ = 9 kg/m³
T = 800 K



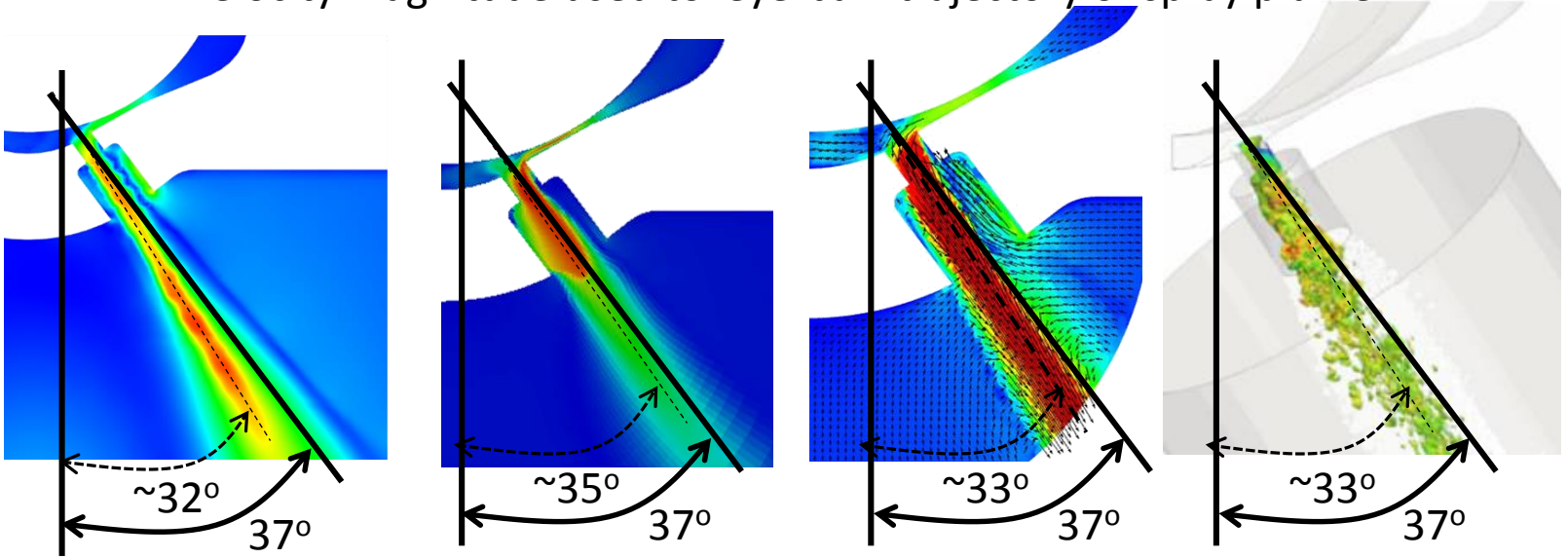
Spray G – Plume Trajectory (ECN4)

Spray G Injector Geometry Specification



ANL | **PoliMi** | **UMass/GM** | **DELPHI**

Velocity magnitude used to 'eye-ball' trajectory of spray plume



Spray G – ECN5 Program

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	Topic 8 – Spray G Nozzle Geometry and Internal Nozzle Flow
	Organizer: Chris Powell (Argonne)
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11:15	Lagrangian modeling of Spray G - **Lyle Pickett (Sandia)**
12:00	**Lunch**
	Future Directions
	Organizer: Scott Parrish (GM)
13:00	Spray G at flashing conditions – **Josh Lacey (Melbourne)**
13:20	Multiple-injection conditions – **Scott Parrish (GM)**
13:40	Engine experiments - **Scott Parrish (GM)**

Backup Slides

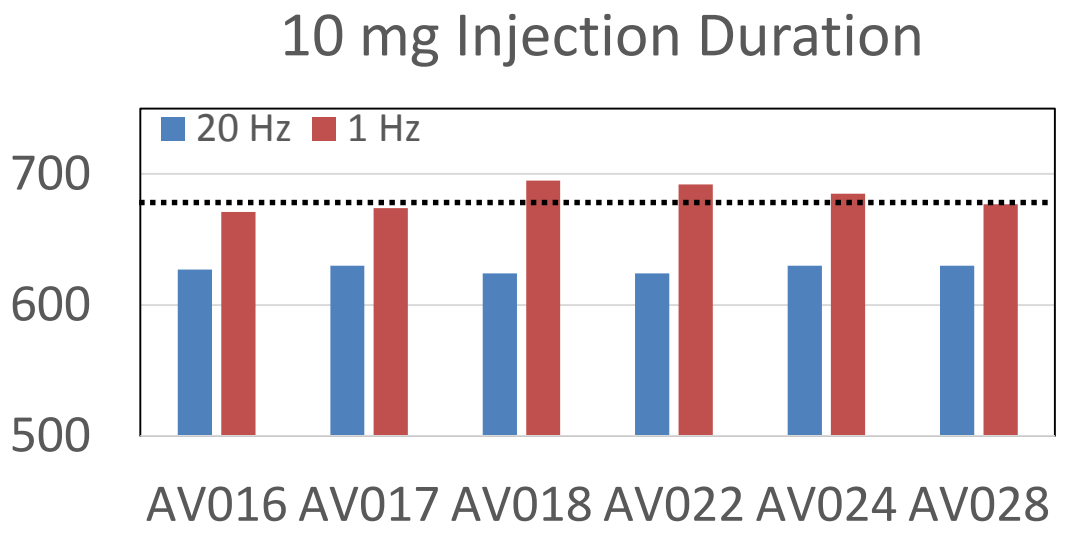
Spray G – Preliminary Data (Delphi)

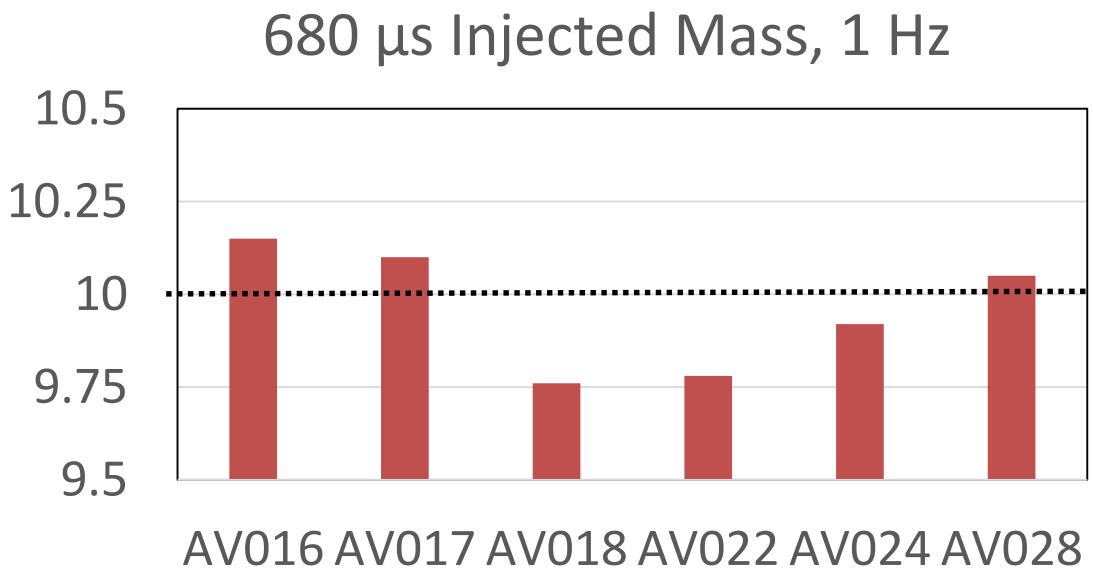
Thanks to Delphi! Dan Varble, Lee Markle

- "Burn In" (20 million cycles)
- Leak rate
- Spray patternation (high resolution mechanical)
- Spray imaging (spray angle, penetration)
- Drop sizing (laser diffraction)
- High-speed near tip imaging (end of injection quality)
- Flow curves (5,10,15,20 Mpa)
- Maximum opening pressure

Note: Preliminary spray data from Delphi was acquired according to the SAE J2715 standard NOT at Spray G conditions

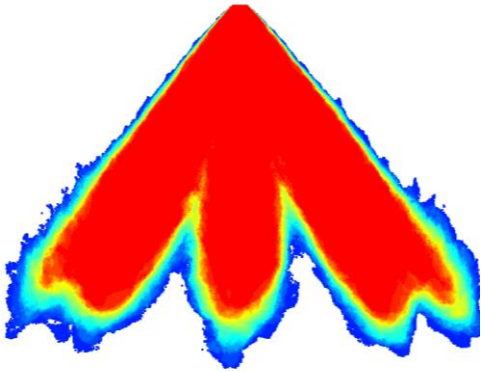
Spray G - Average Flow (GM)



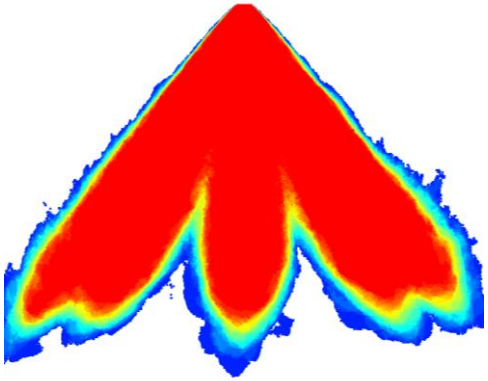


Spray G - Spray Imaging (Delphi)

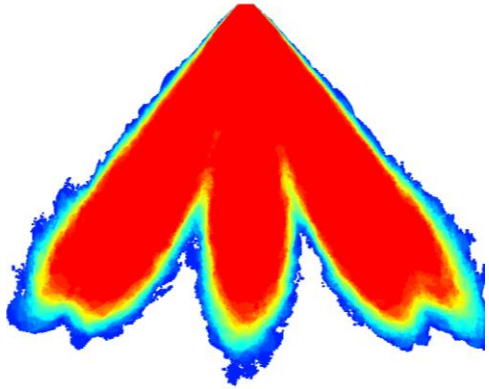
Injector 16



Injector 17



Injector 18



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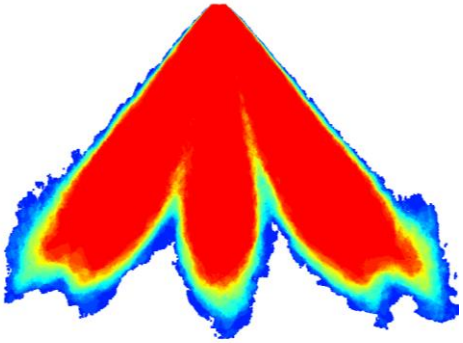

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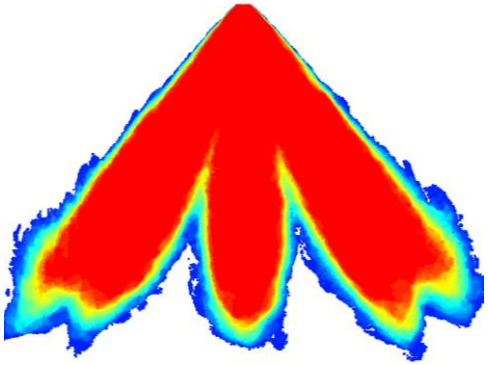

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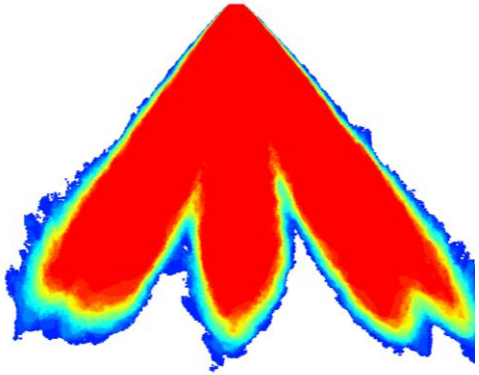
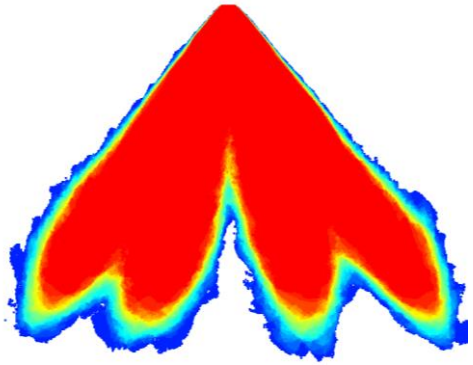


Spray G - Spray Imaging (Delphi)

Injector 16



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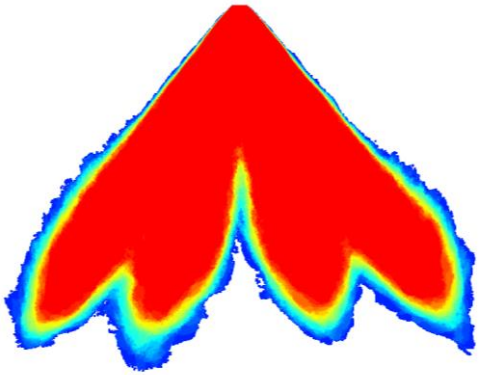

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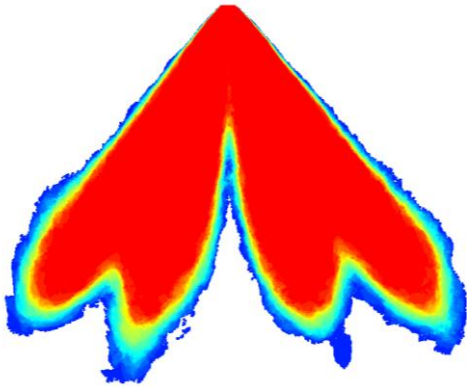

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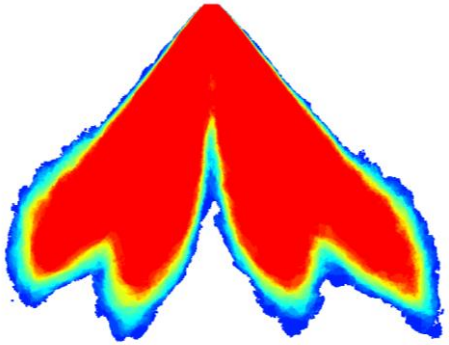

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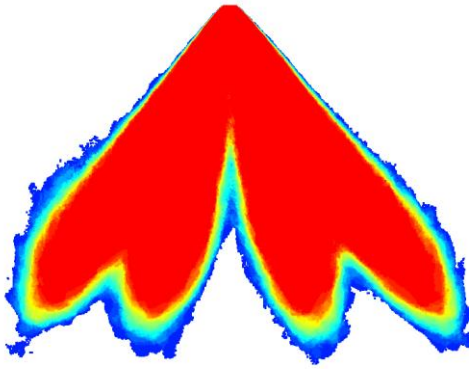

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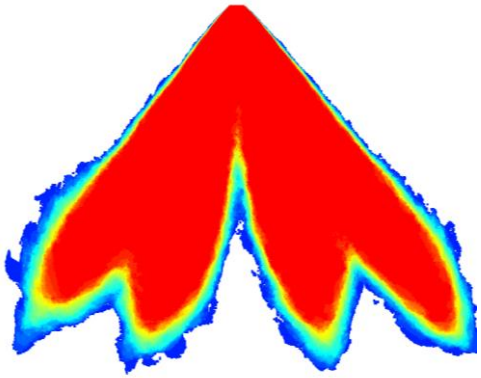
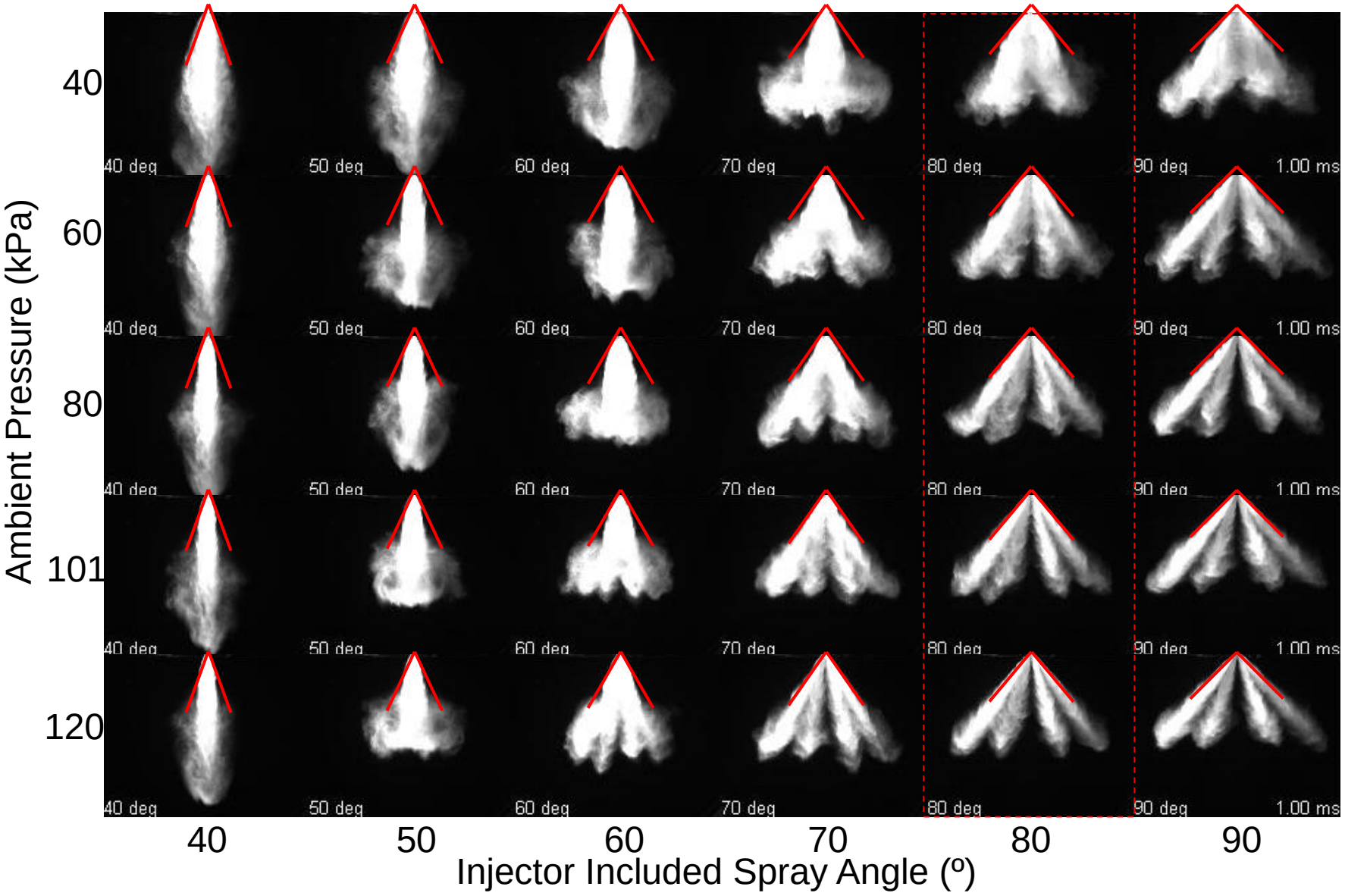
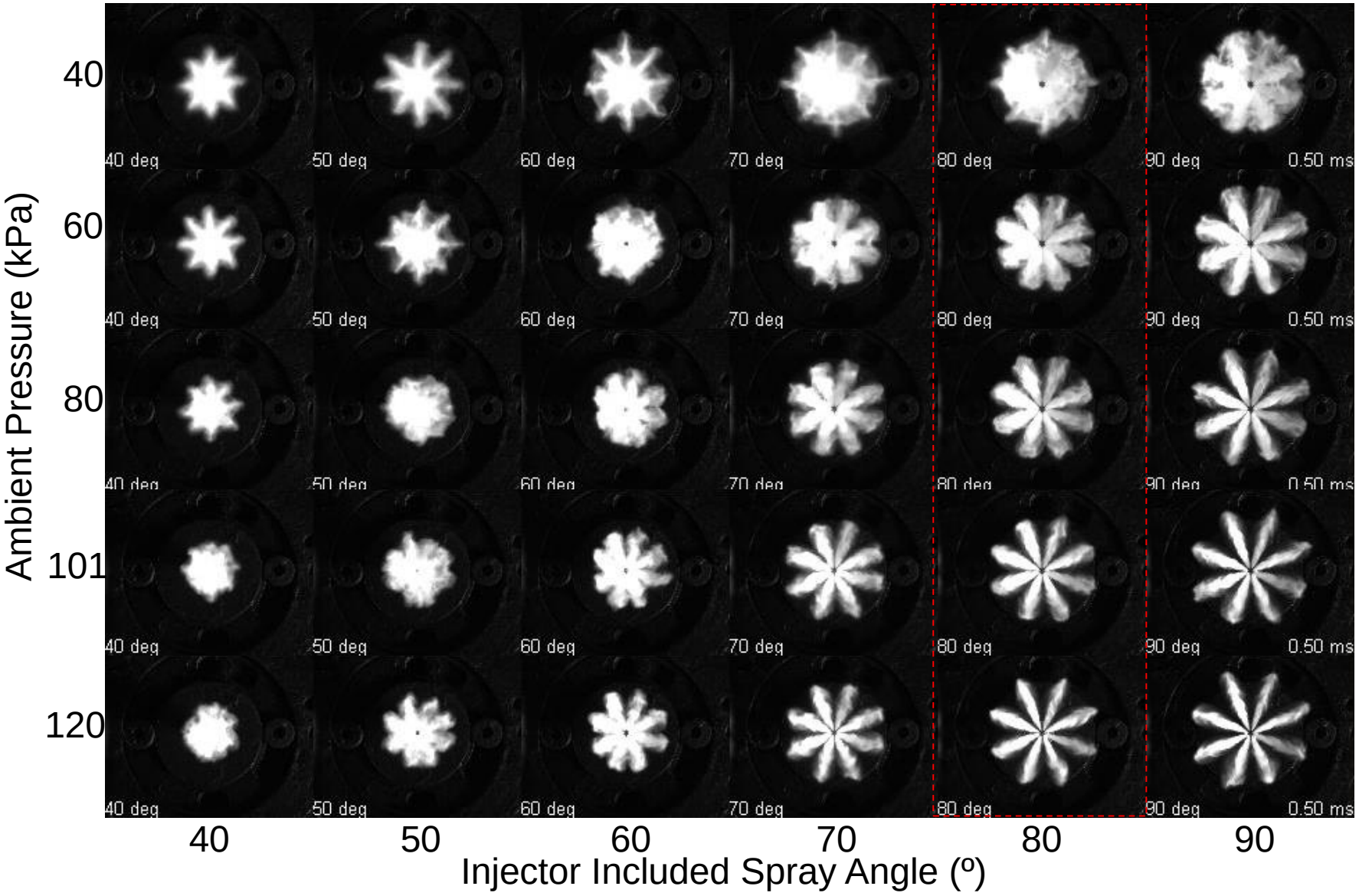


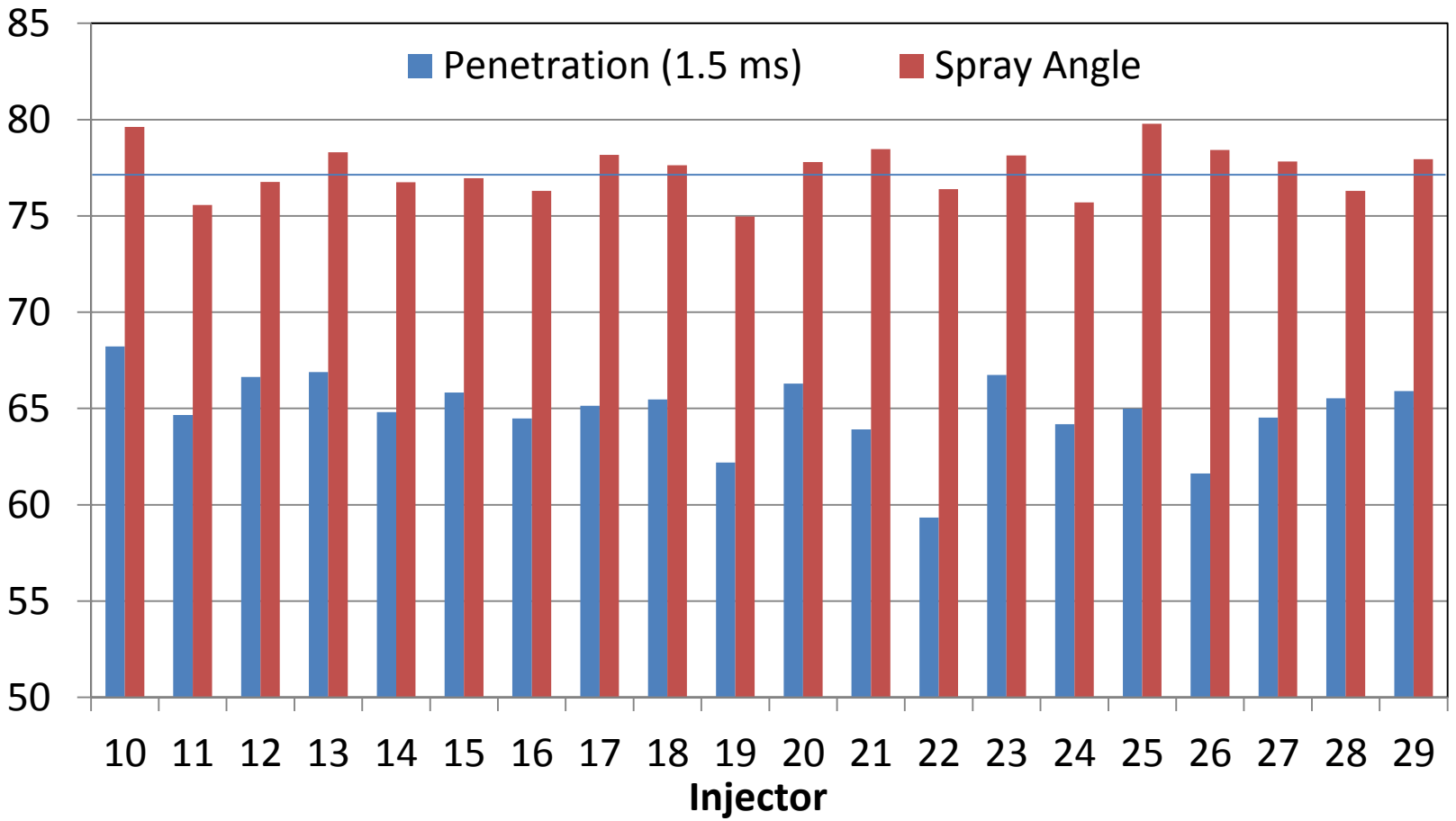
Spray G - Flash Boiling Conditions



Spray G - Flash Boiling Conditions

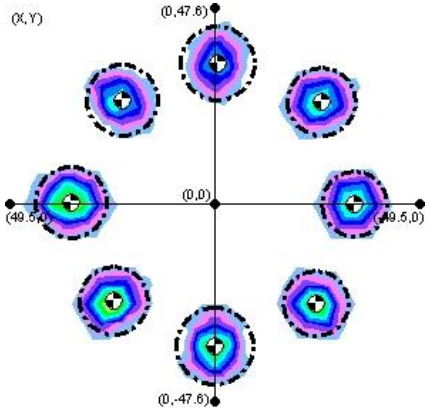


Spray G - Axial Penetration, Spray Angle (Delphi)

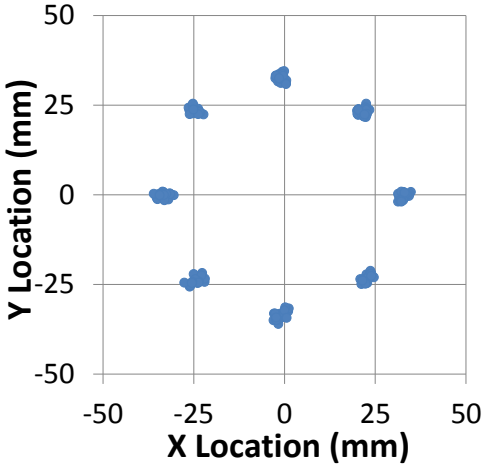


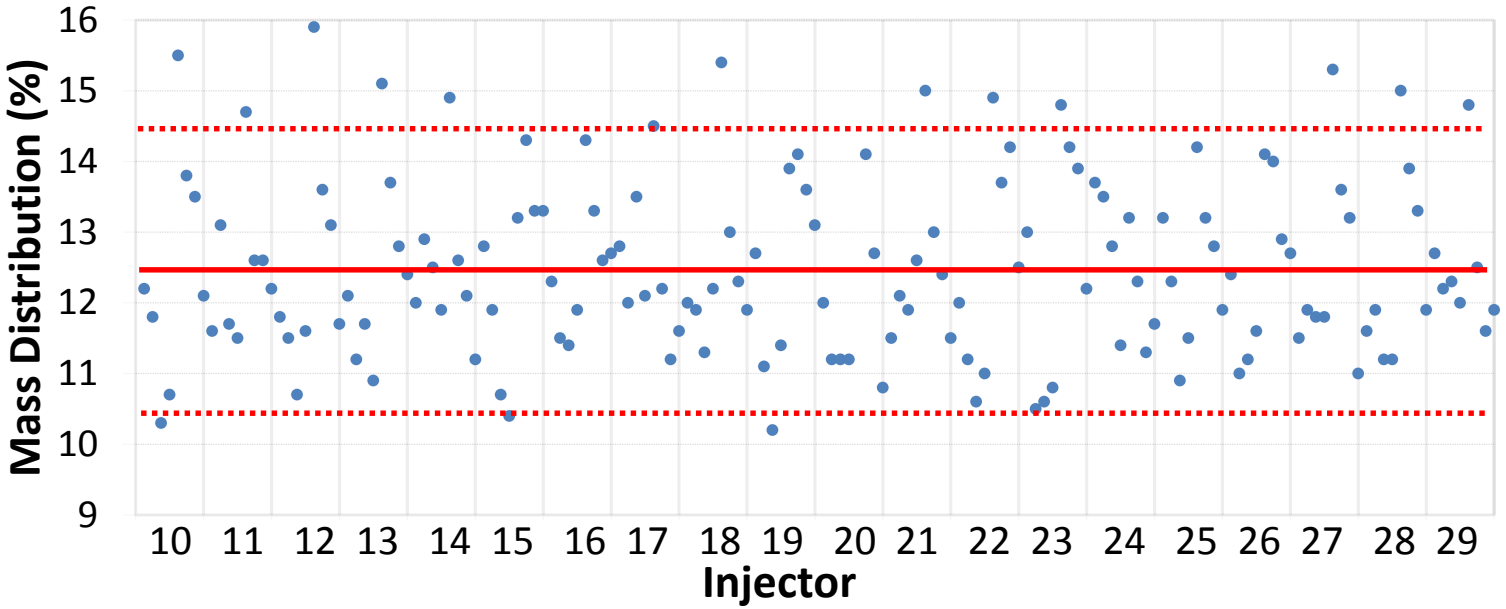
Spray G – Mechanical Patternation (Delphi)

Patternation Example



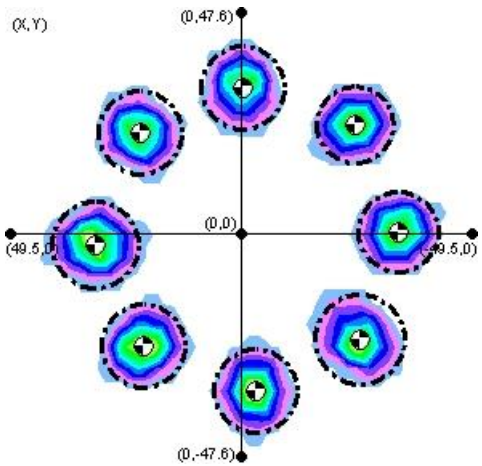
Plume Centroid Locations





Spray G - Mechanical Patternation (Delphi)

Injector 16



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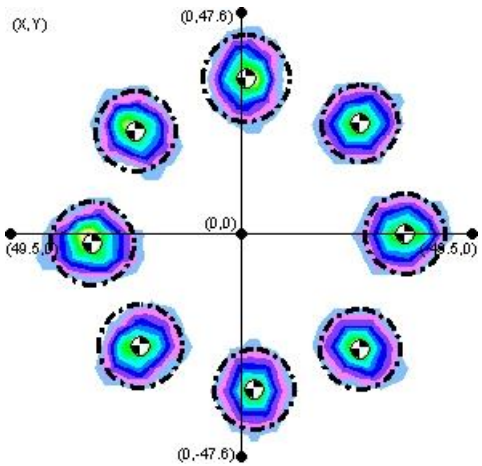

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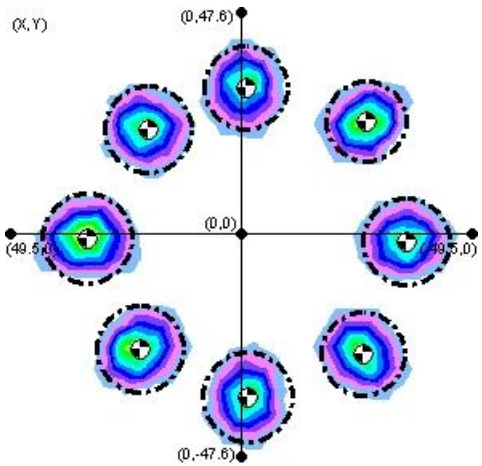
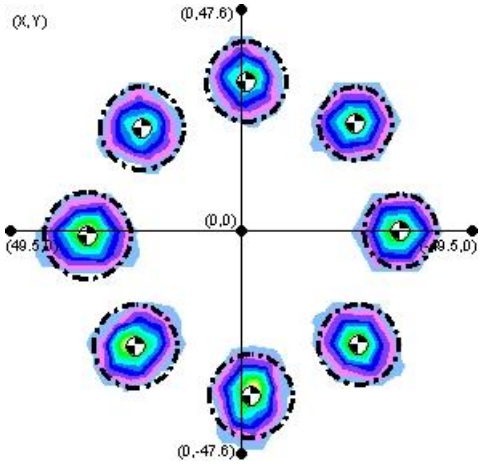


Injector 22



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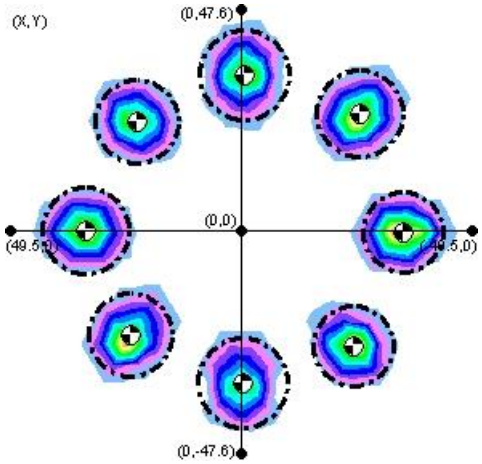

Injector 28