Tampere University

Oseir

# Cold Spray Process Quality Assurance by Online Spray Monitoring

TSCF

Thermal Spray Center Finland

CSAT 2019

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# Oseir Ltd.

- Founded 1999
- Spin-off from TUT
  - Thermal spray diagnostic system dev project
  - Joint effort of Optics and Mat. Science laboratories
- Product lines
  - SprayWatch thermal spray sensors
  - HiWatch cold spray sensors
  - Other applications: PIV, pulp&paper, pharma, AM processes

# SprayWatch line

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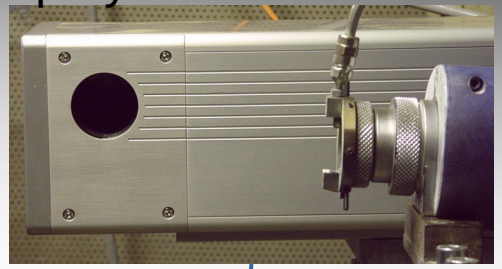
SprayWatch



2000

SprayWatch 2i


2002

SprayWatch 3i


2004

SprayWatch G


2012

SprayWatch 4S


2014

SprayWatch 2S


2015

# HiWatch line

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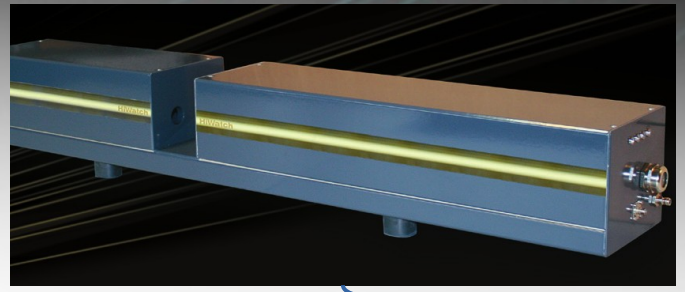
HW Compact



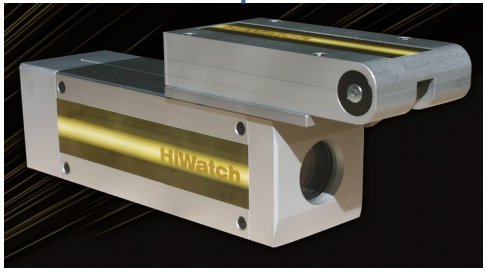
HW

HiWatch HR



HiWatch CS2


2002 2005 2011 2015 2017 2018 2019




HiWatch CS


ShotWatch


HiWatch HR2

# Online monitoring for cold spray QA

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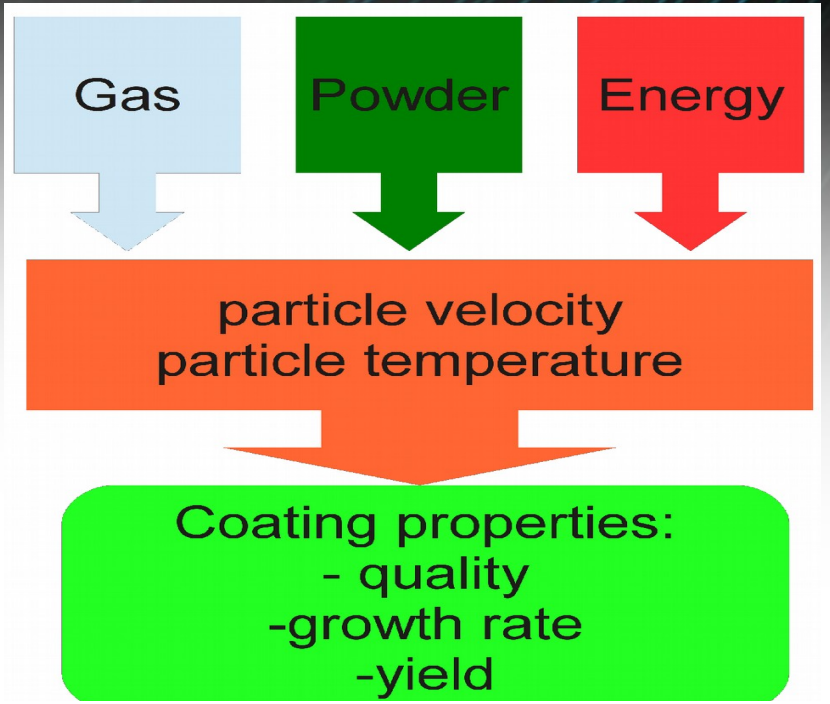
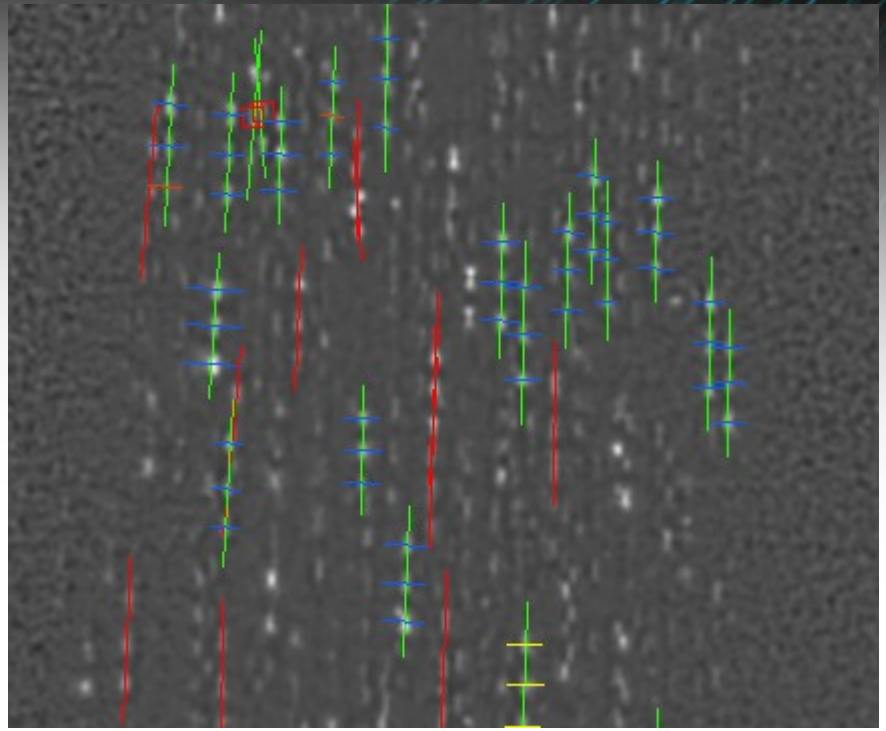
- Extreme conditions
  - High temperature
  - Fast velocity
  - Strong gradients
- Complex idnteractions
  - Models: 1D, Real world: 3D
- Restricted control
  - Mutually dependent parameters
- Repeatability
- Equipment condition
- Feedstock properties

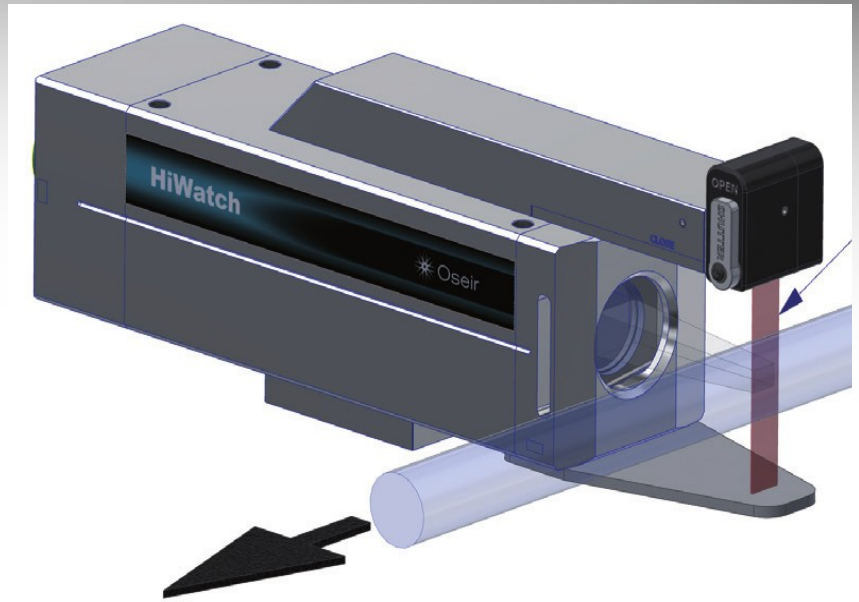


# Measurement basics

- Laser illuminated particle imaging
  - PTV, multi-streak detection
  - Sheet or backlight illumination
- Deliverables
  - Particle position
  - Particle velocity
  - Particle size

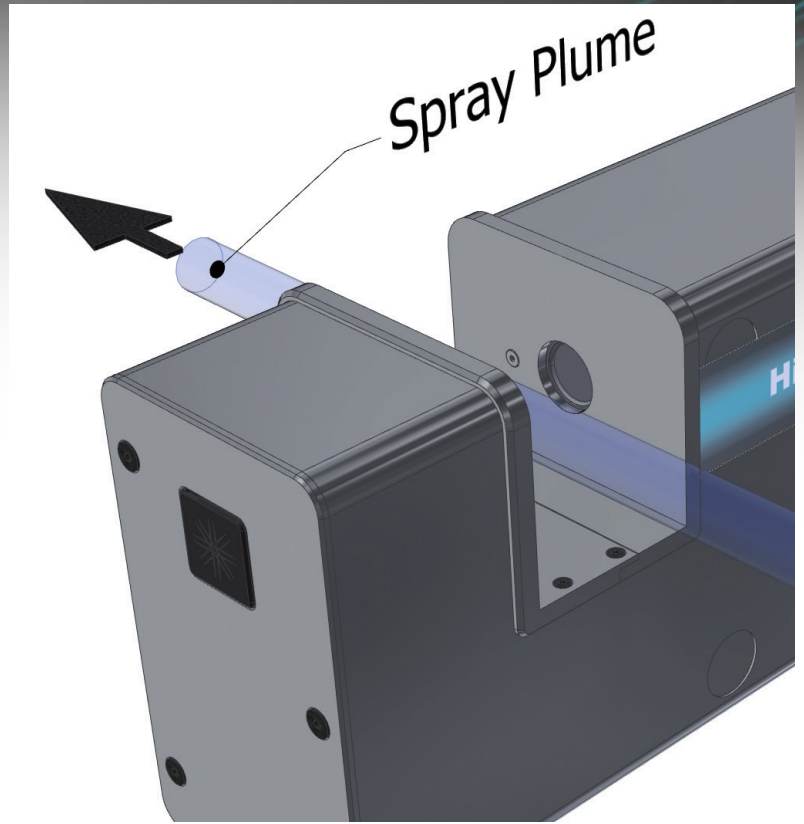


# HW CS2: sheet measurement




- Simple and lightweight
- Particles detected by scattering
- Results:
  - velocity
  - position
  - size estimate
- Measurement area 8x5mm$^2$
- 2MP, 50fps (GigE)

# HW HR2: backlight measurement




- Particles detected by light extinction (shadow imaging)
- Results:
  - velocity
  - position
  - diameter
- Measurement area 8x5mm$^2$
- 12MP, 15fps (USB3.1)

# 3-pulse illumintion: Sheet vs back

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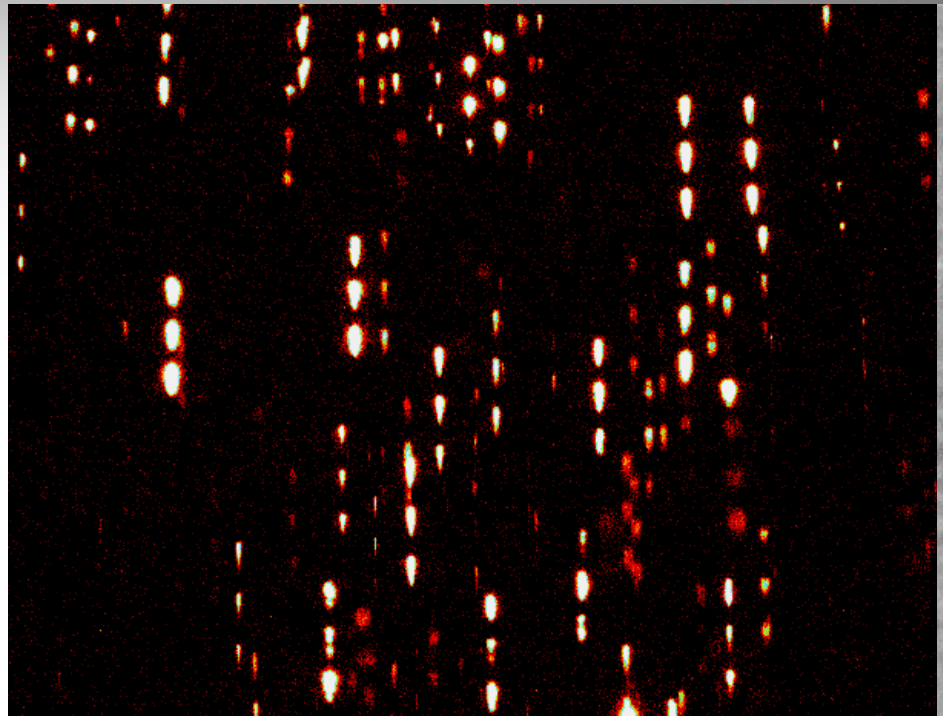
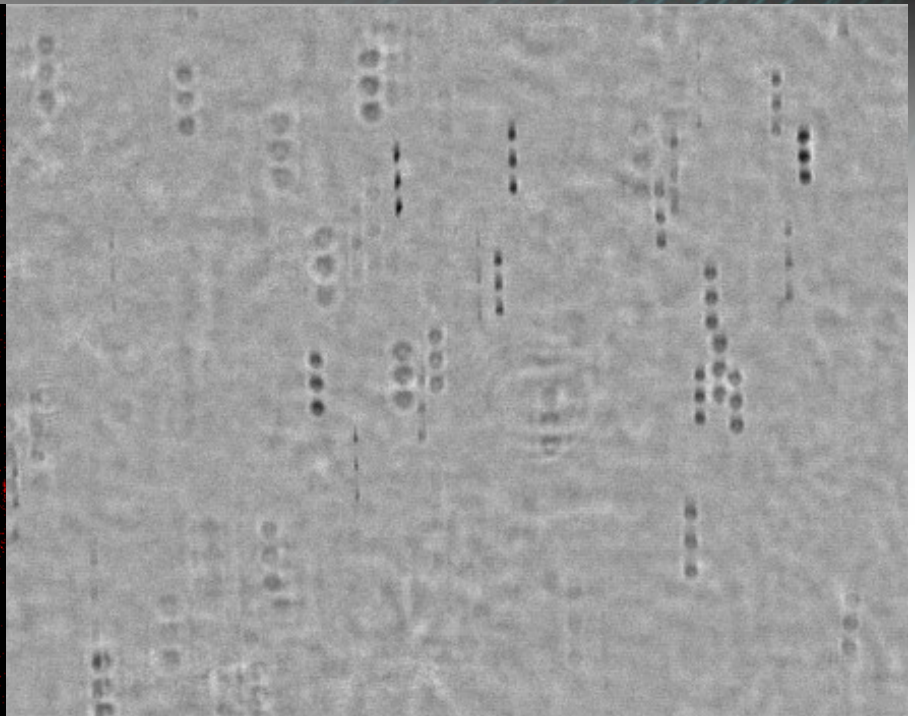
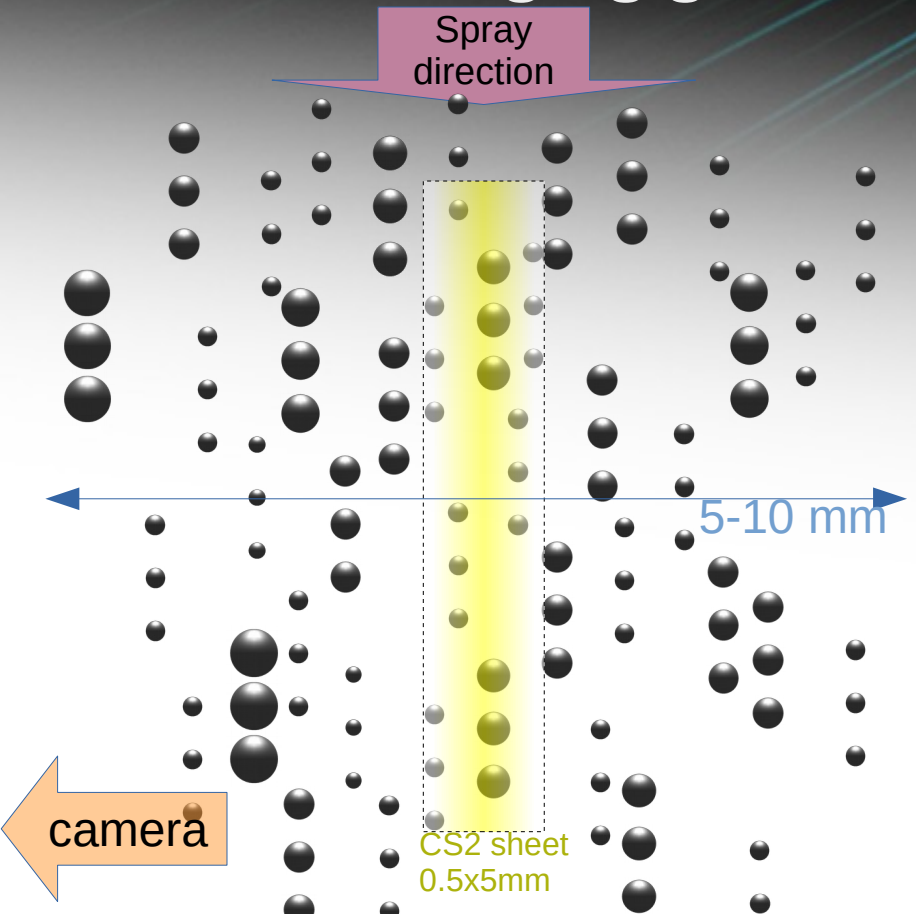




# Particle imaging geometry




- Sheet imaging
  - Only narrow cross section of spray covered
  - Precise alignment of spray nozzle with imaging plane needed
  - Stable mounting, fixed measurement position
  - Spray position may not be consistent with nozzle axis
- Uncertainty in fixed position measurement

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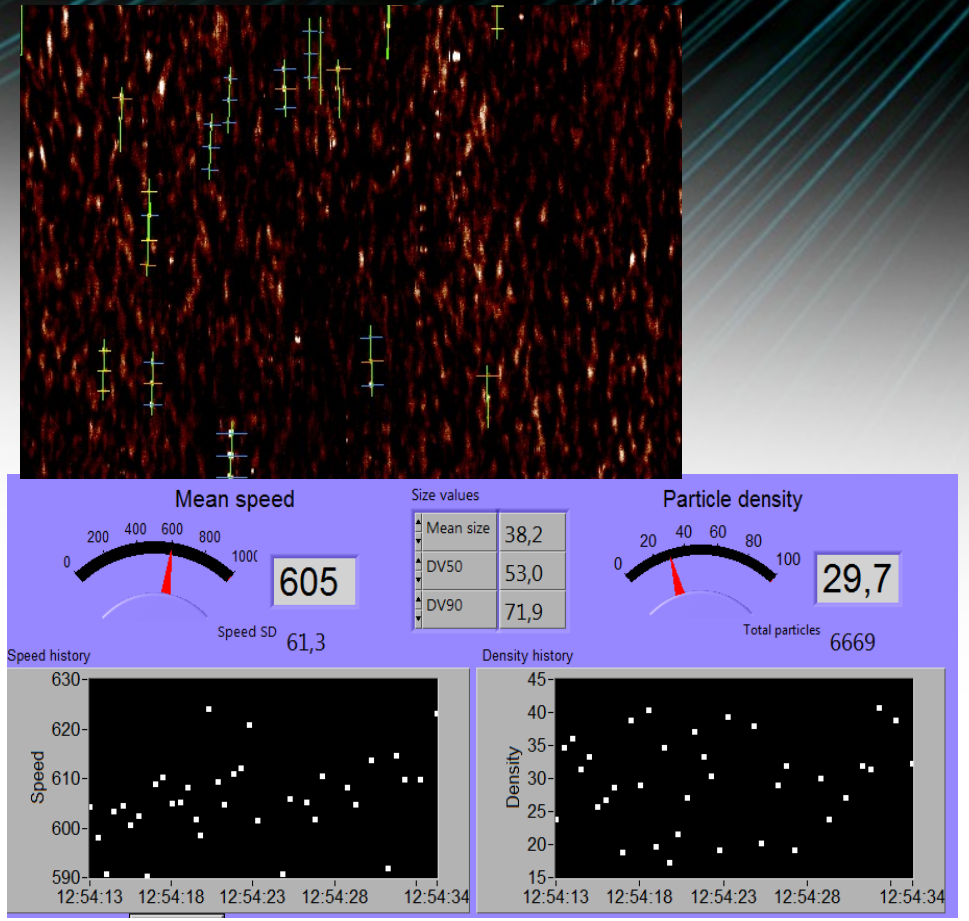
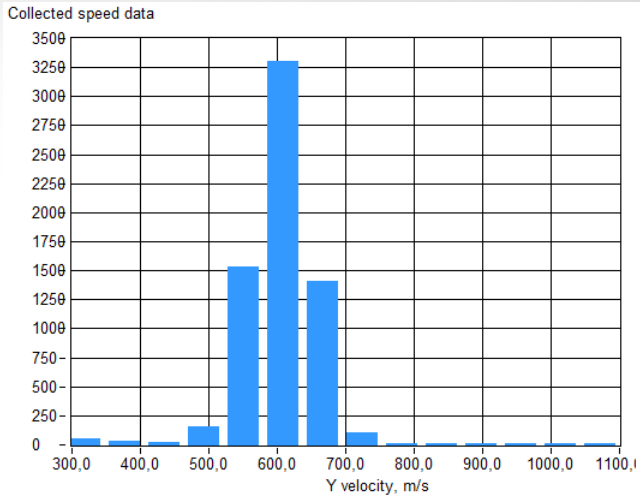
# Analysis software

- Automatic image processing
  - No need for raw image storage
  - Builds particle data collection
  - Mean values
  - Distributions
  - Crossplots
  - History graphs
- HTML report production
  - CSV tables for individual particle data

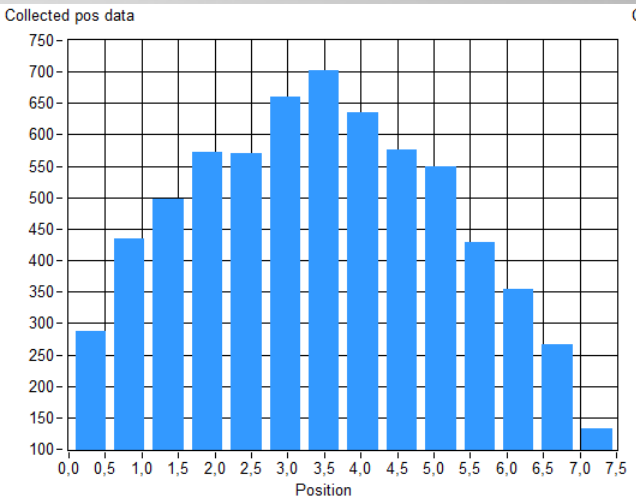


# Data gallery: distributions

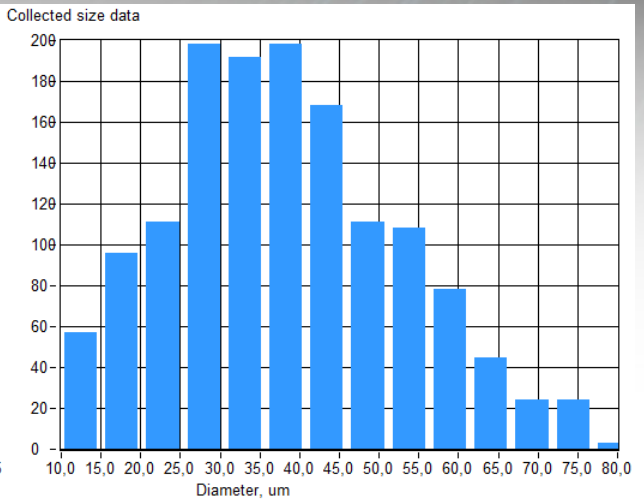
velocity




position

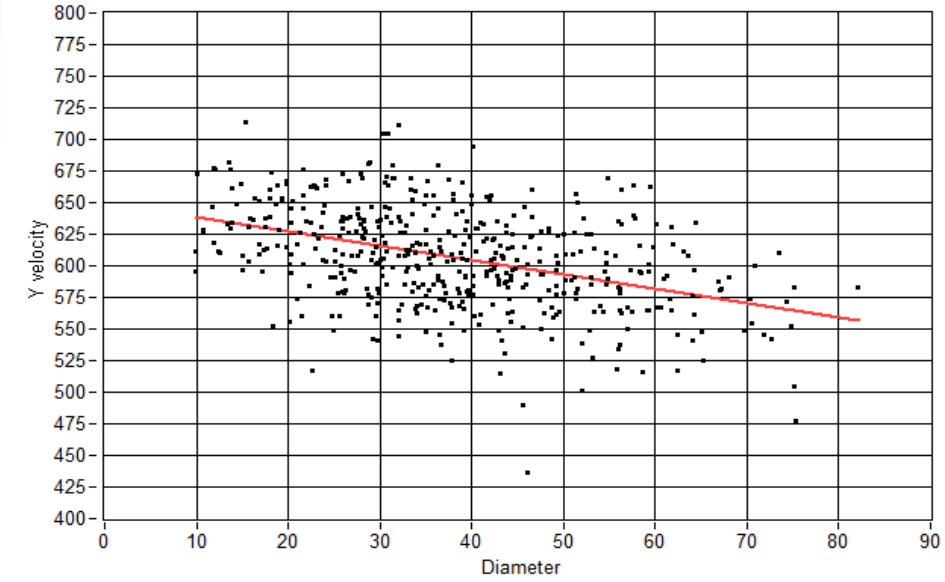



diameter

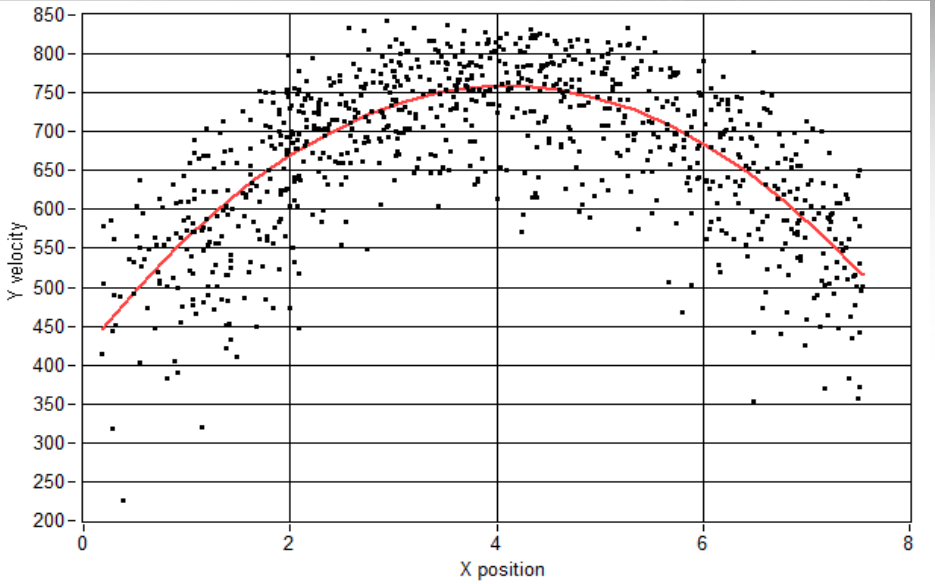


# Data gallery: crossplots with fit models

Diameter vs speed
Linear fitline

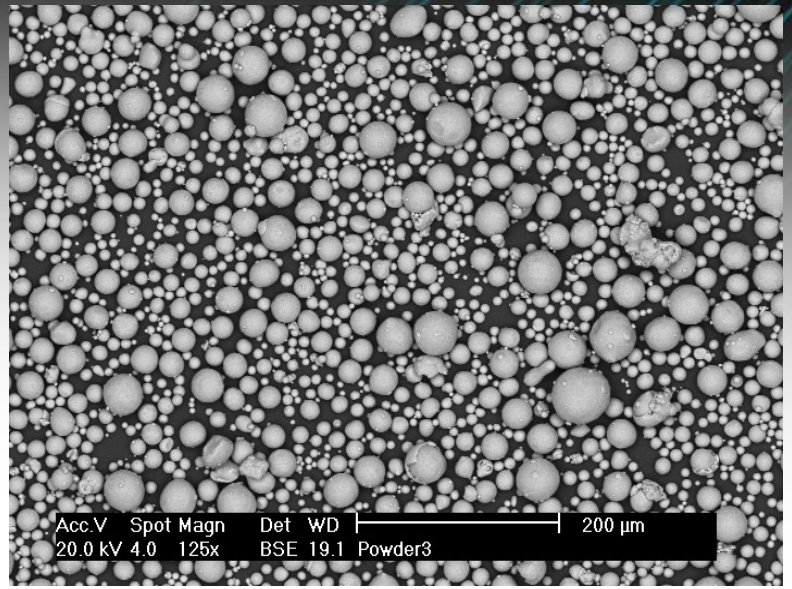



Lateral position vs speed
Quadratic fitline



# Case 1. Powder QA

- Powder shelf life not specified
- Properties may change during extended storage
- Powder QA required




Al 6061: nominal diameter 10-40 µm

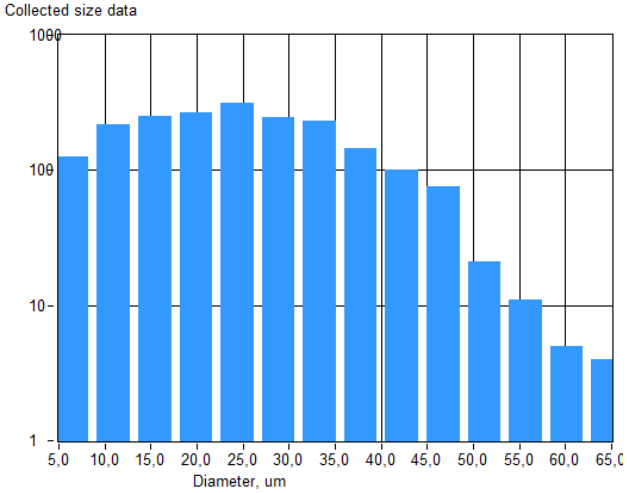
# Case 1. Powder QA

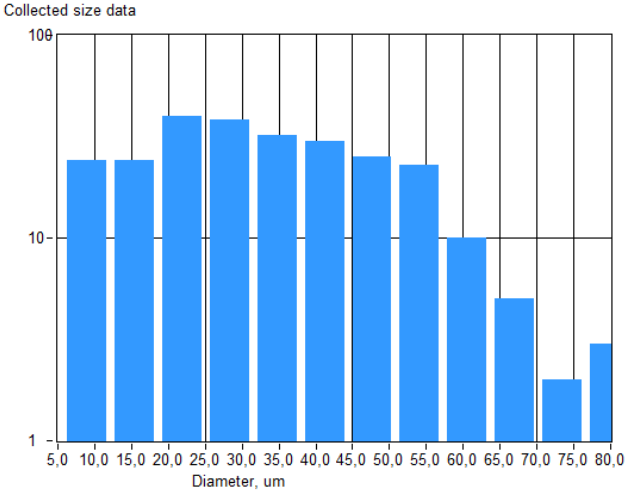
HR2 sizing of the same powder lot

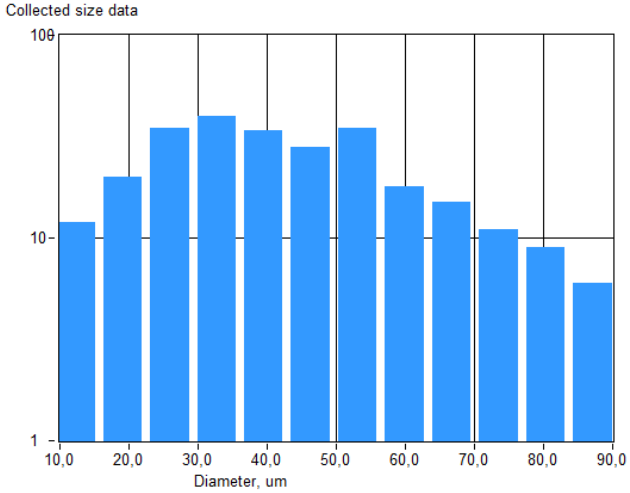
Feb 2019:
D50 25 µm
Mean velocity: 665 m/s
Plume density: 69

Mar 2019:
D50 33 µm
Mean velocity: 617 m/s
Plume density: 29

Jun 2019:
D50 64 µm
Mean velocity: 605 m/s
Plume density: 27

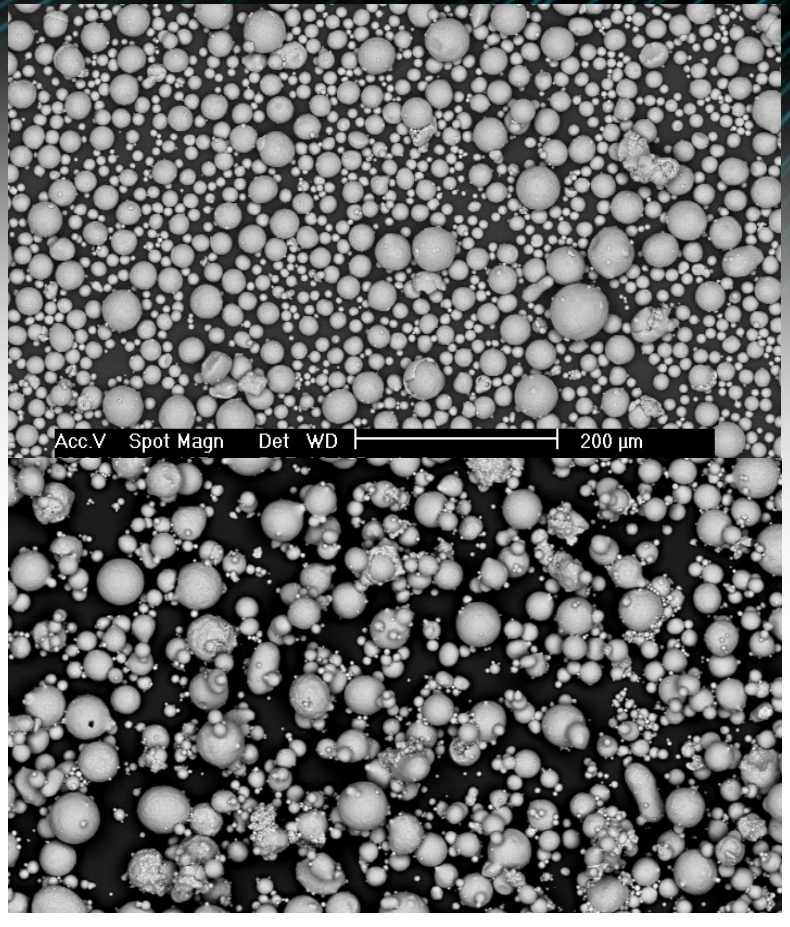


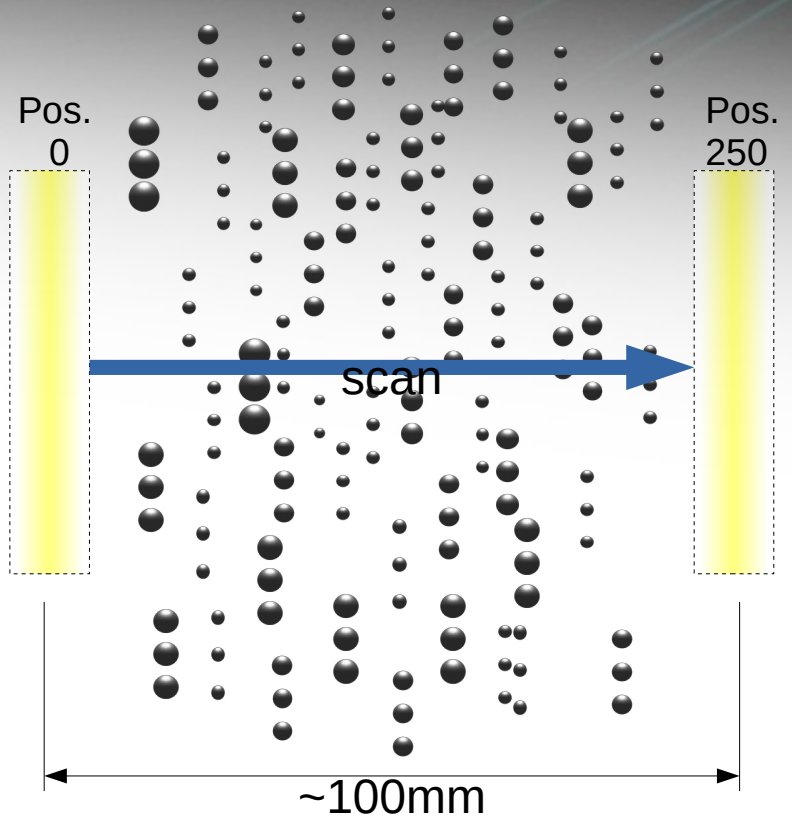



# Case 1. Powder QA

- Comparing SEM images of powders
  - agglomerates present after long storage
  - HR2 data suggests rapid change during one month
  - Coating yield 70% lower in latest deposition tests
- Periodic powder testing needed during long storage

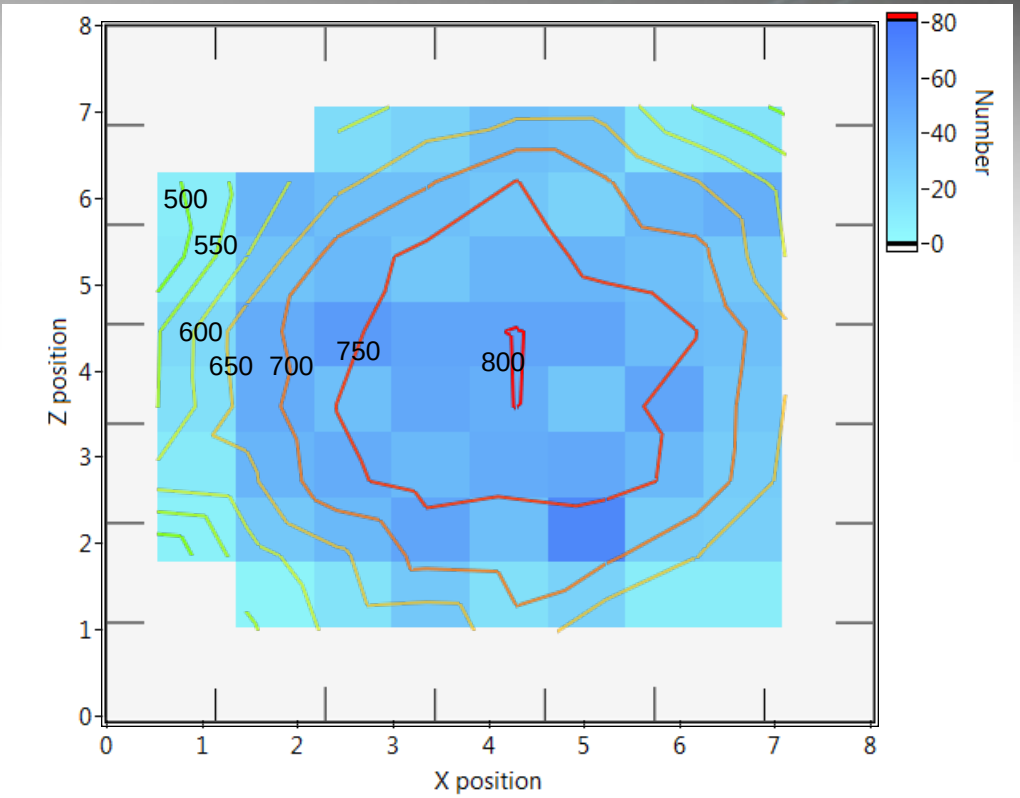


# Scanning plume mapping



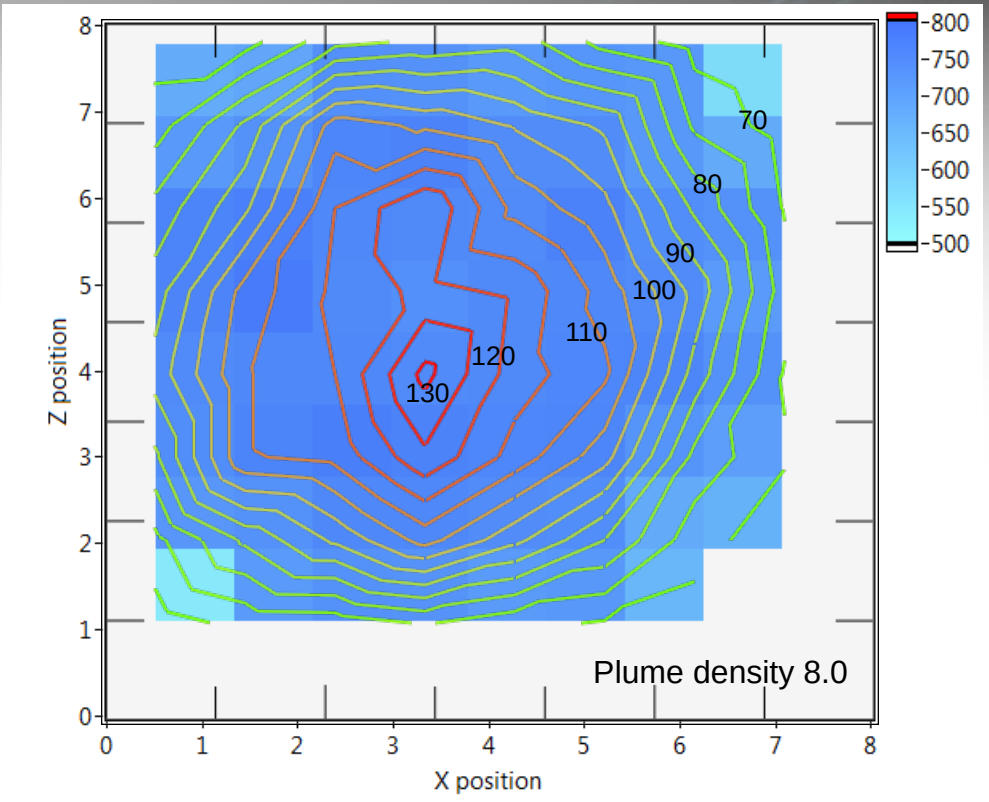

- Sheet translation with triggered burst imaging
  - Sheet traverses the spray plume during image capture
  - Typical sequence (CS2 system):
    - 1 mm/s scan speed
    - HW CS2: 250 captures
    - Depth resolution: 0.02 mm
  - Capture time: ~10s
  - Analysis time: ~15s (CS2) / 1 min (HR2)
- 2D map of particle properties
  - Position uncertainty eliminated

# Scan results: 8x8 mm$^2$
# Al 6061, 35bar, 400C, top speed 800



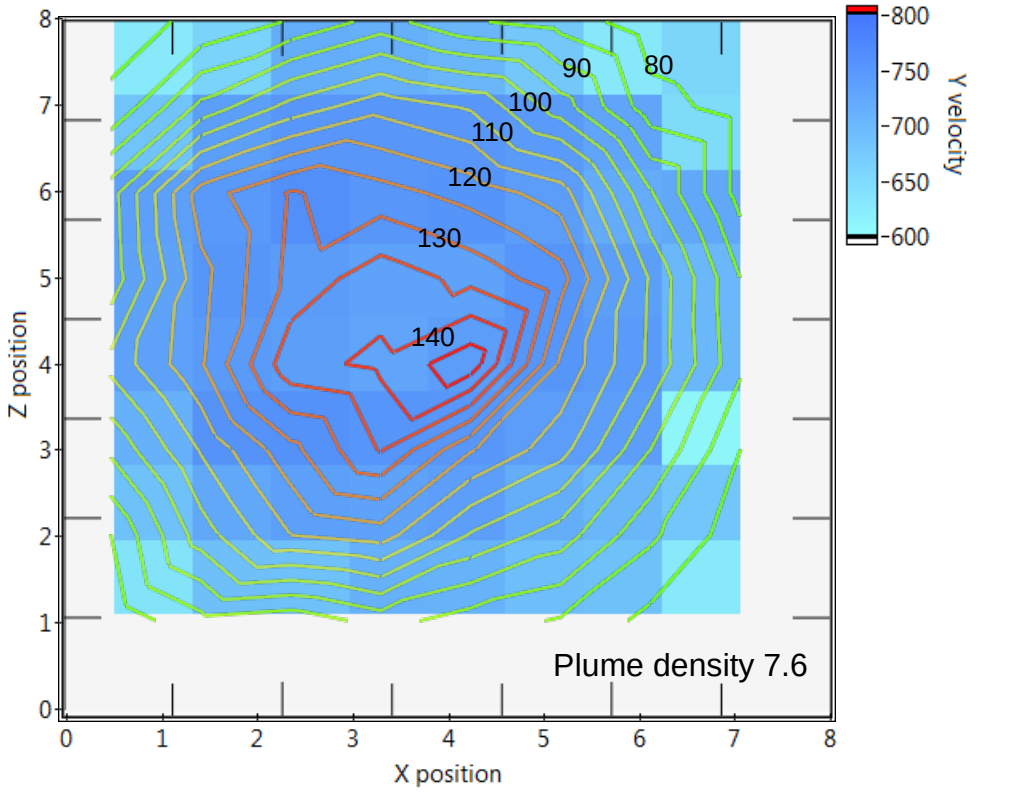

- 2D map:
  - Contour lines: Y velocity
  - Colormap: particle density
- 550 images
- 1900 particles
- CS2 scan time 11 s

# Case 2: Parametric variation



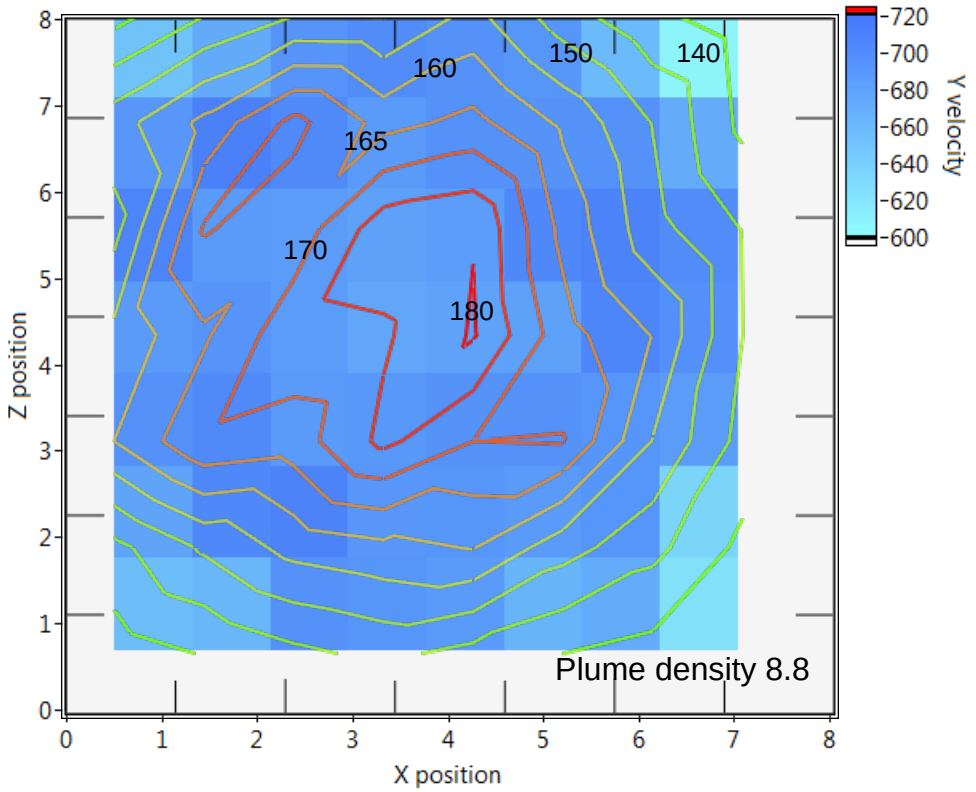

- Ti Powder
  - Diameter -45µm
  - 65bar
  - 1000C
- 2D map:
  - Contour lines: particle density
  - Colormap: Y velocity

# Case 2: Parametric variation




- Pressure at 55 bar
  - Narrower high velocity zone
  - Velocity drops at center axis

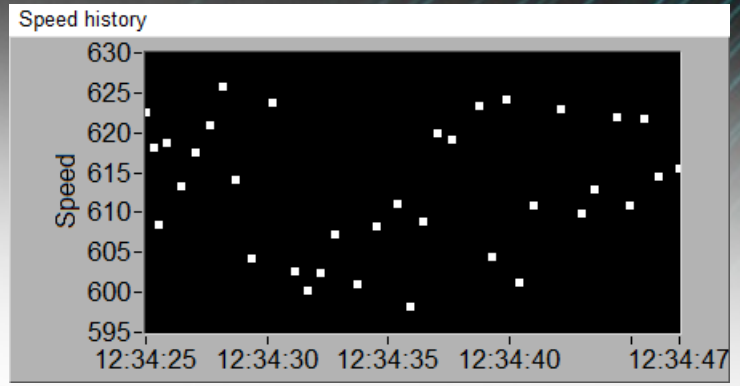
# Case 2: Parametric variation

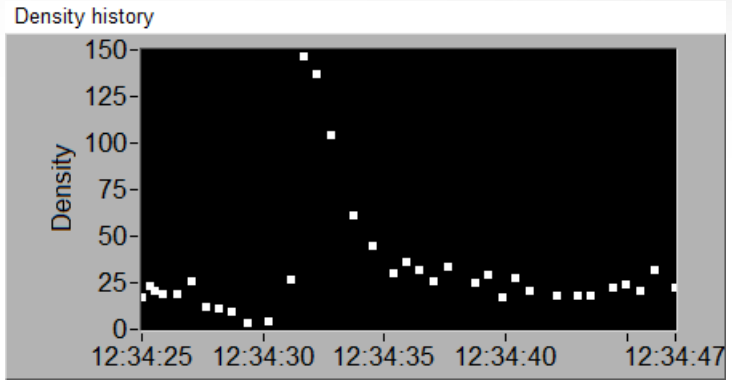



- System restarted, p=70bar
  - Highest pressure
  - Particle density higher
    - No change in feed settings
  - Velocity field annular
    - Low velocity values compared to lower pressure
- Unexpected result
  - Feed rate higher after restart?

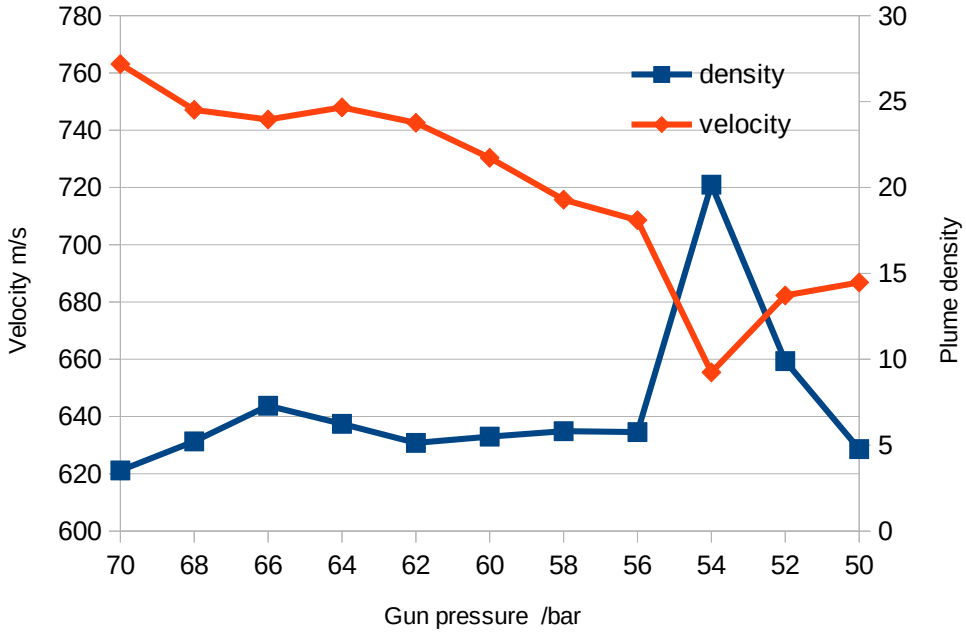
# Case 3: Time-resolved monitoring

- Ti -45µm, 70bar, 1000C
- Stationary free run
- Time resolved velocity and plume density
  - Unexpected burst: >6x density peak
  - Duration < 5s
  - Velocity almost constant



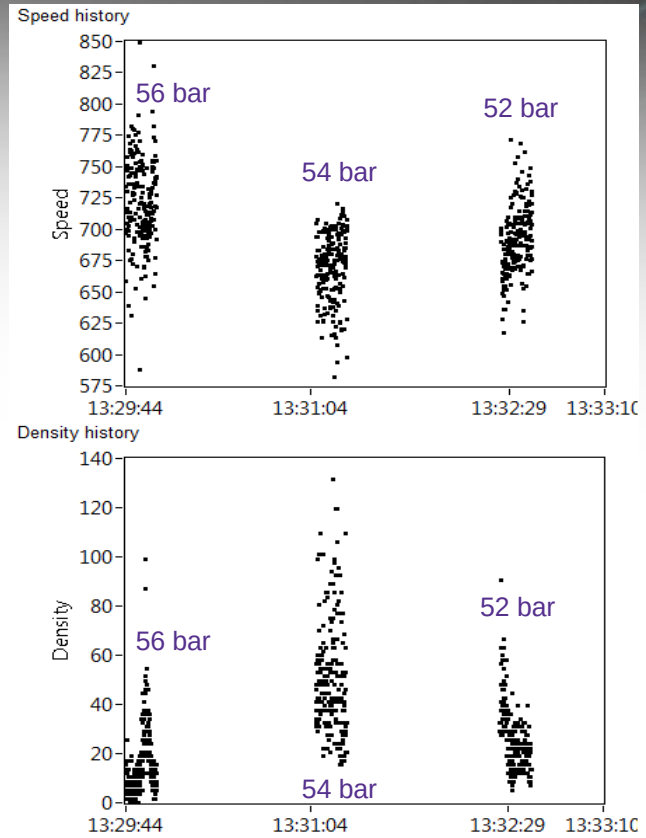



# Case 3: Time-resolved monitoring




- SS 316, industrial setting
- Series of tests
  - Gradually lowering pressure
  - Spontaneous 4x increase of feed at 54 bar
  - Smaller deviation at 52 bar
  - Velocity dropped up to 50 m/s from expected value

# Case 3: Time-resolved monitoring




- Time history of pressure drop test
  - Density anomaly is consistent during 54 bar setting
  - Returns to normal during 52 bar test
- Feed issue

# Sensors for QA in cold spray

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1. Set-up verification at test point
   - After system set-up changes / powder refill
   - Values within expected limits: Go/NoGo test
   - Sizing measurement: verify powder properties

# Sensors for QA in cold spray

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2. Periodic verification at test point
   - Every start-up, shutdown
   - At given intervals
   - Allows parameter adjustment for reaching operation setpoint

# Sensors for QA in cold spray

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## 3. Simple closed-loop at test point

- At test point, perform automatic parameter adjustment
- Generate trendlines and limits: predict failure point
- Tradeoff: test frequency vs. efficiency

# Sensors for QA in cold spray

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4. Continuous monitoring / closed-loop
   - Fixed measurement at spraying point
   - CS has slow adjustment response
     - interrupt operation to make corrections
   - Only method to avoid issues from intermittent deviations from setpoint
   - Current implementation: low pressure spray in production line
     - Limited to small diameter substrates

# Sensors for QA in cold spray

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## Future development:

- Mounting sensor to spray gun
  - Heavy system integration
  - Special optics needed to avoid interference with coating operation
- Yield prediction
  - Measured velocity/density/size maps
  - Combination with sticking models
  - Estimates of growth rate/DE/porosity

# Thank you!



HiWatch Oseir

Dr. H. Koivuluoto acknowledges The Scientific Advisory Board For Defence (MATINE), Ministry of Defence for the funding of the cold spray research.