SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Minnesota DOT – RDM Experience

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Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Acknowledgements

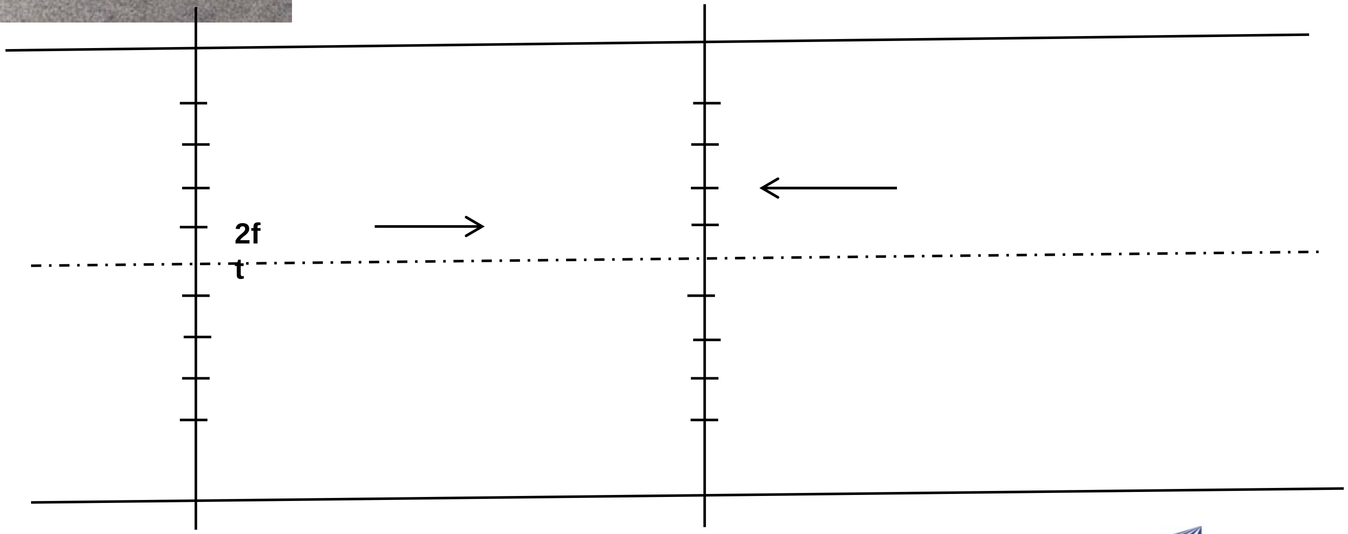
- FHWA/AASHTO for providing RDM
- MnDOT district materials and constructions
- UMN students

Why MnDOT is interested in?

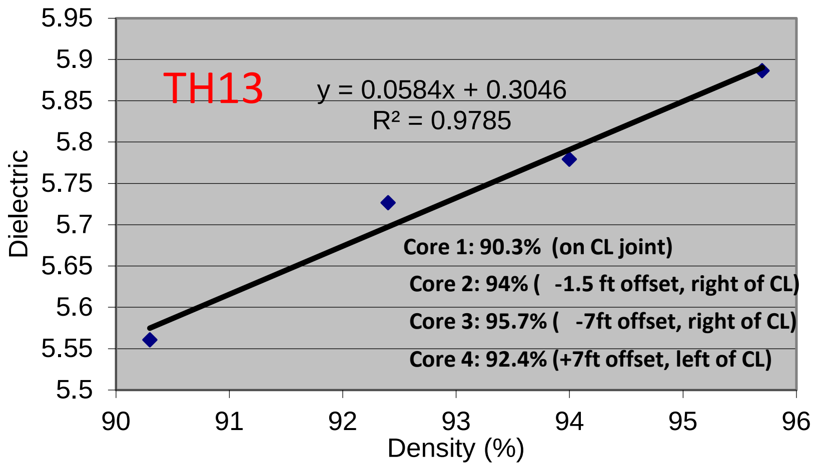
- Longitudinal Joint deterioration
- MnDOT Uses Cores Density for Acceptance
- IC and IR Implementation
  - MnDOT plans to fully implement IC&IR in 2018.
  - IC&IR are QC tools
  - RDM (GPR) can be a QA tool
- GSSI Horn Antenna System in 2013
- RDM in 2015

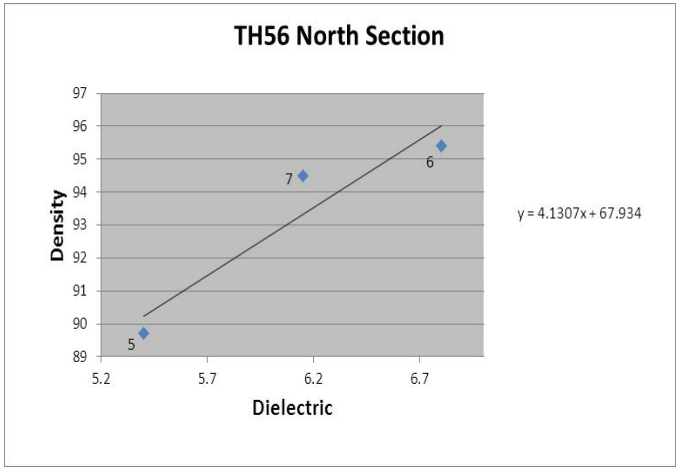
Photo 1

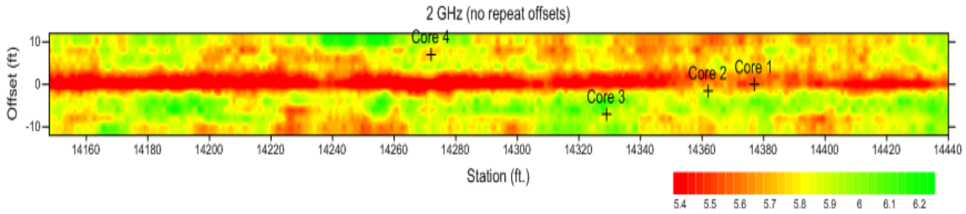
$$\varepsilon_{HMA} = \left(\frac{1 + \frac{A_0}{A_P}}{1 - \frac{A_0}{A_P}} \right)^2$$

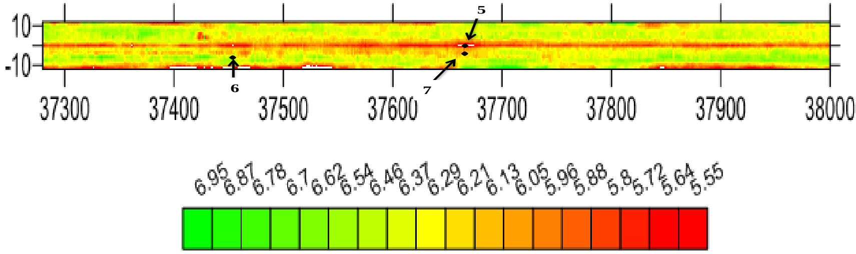


TH13 and TH52





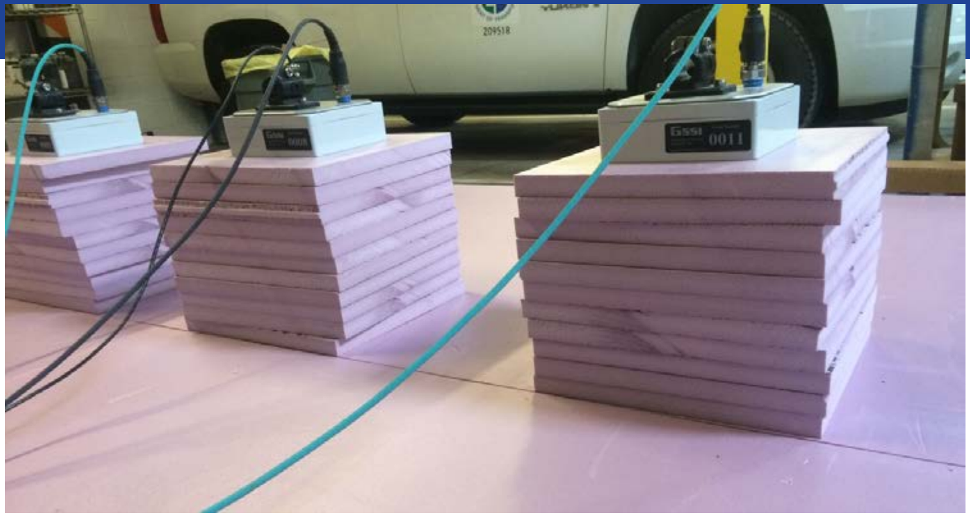




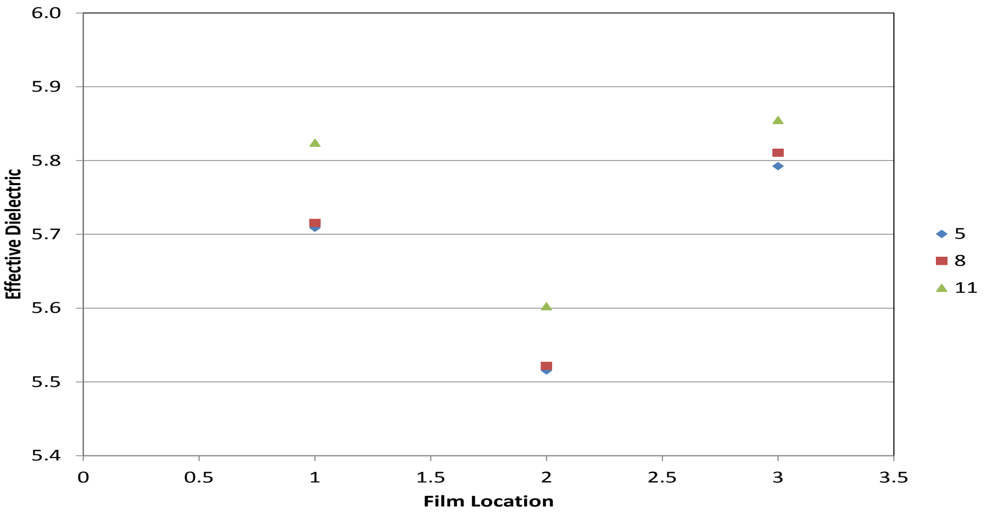
Equipment Calibration – RDM

- Obtained RDM in 2015
- Measurement difference among the antenna pairs?
  - Need Uniform Material for Calibration
  - Started with window film tint (GSSI): reflection coefficient "effective dielectric" is similar in magnitude to asphalt (5.5)



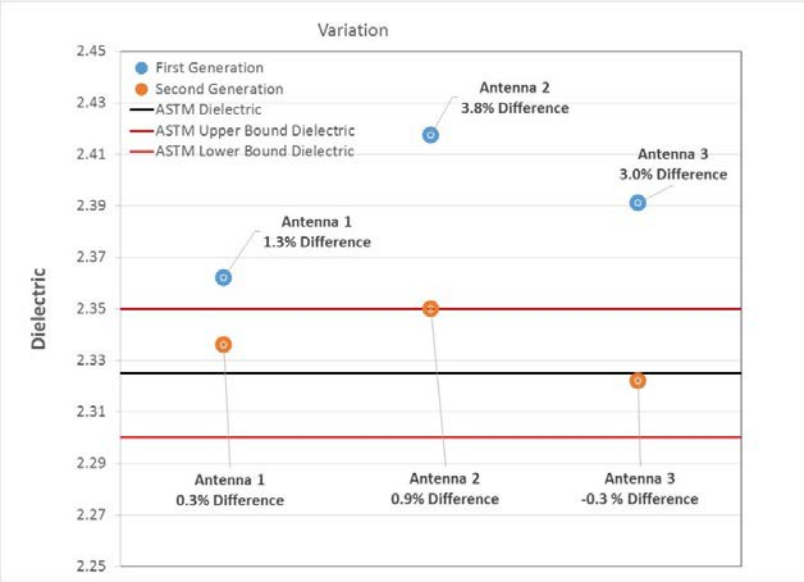
Trials	Left Sensor	Center Sensor	Right Sensor
1,2,3	5	8	11
4,5,6	11	5	8
7,8,9	8	11	5

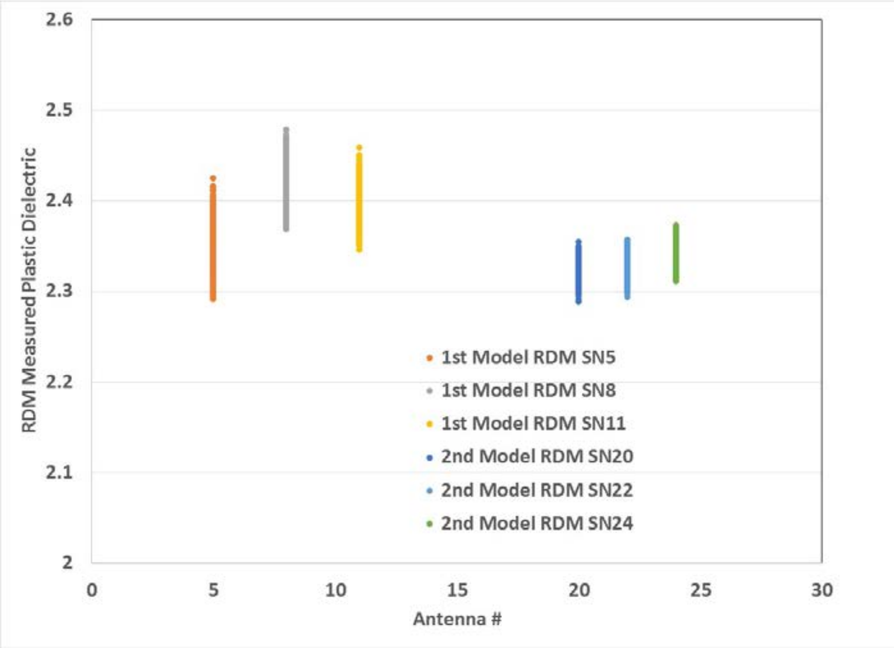


Equipment Calibration

- High Density Polyethylene (HDPE)
  - Reported dielectric: 2.3-2.35

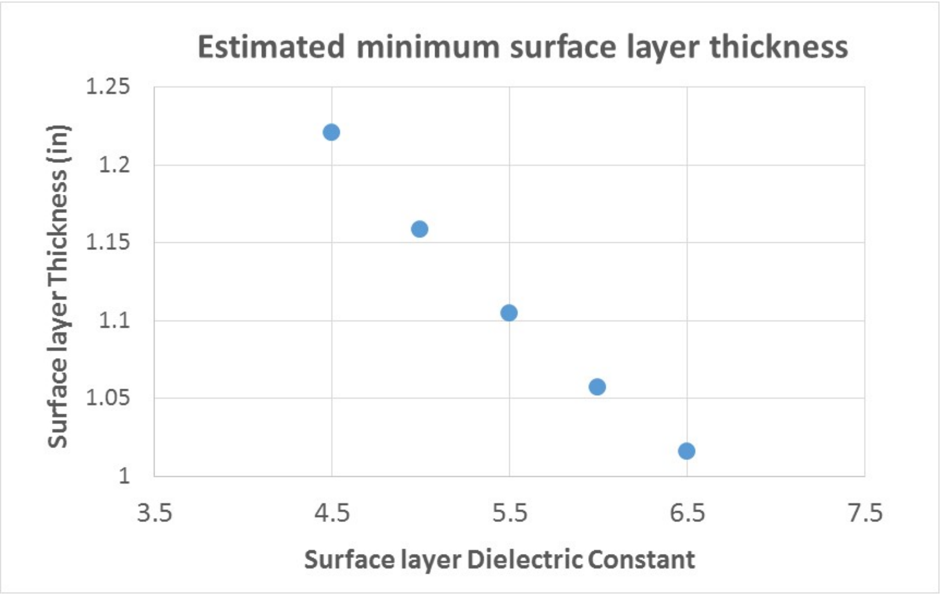
$$\varepsilon_{HMA} = \left(\frac{1 + \frac{A_0}{A_P}}{1 - \frac{A_0}{A_P}} \right)^2$$

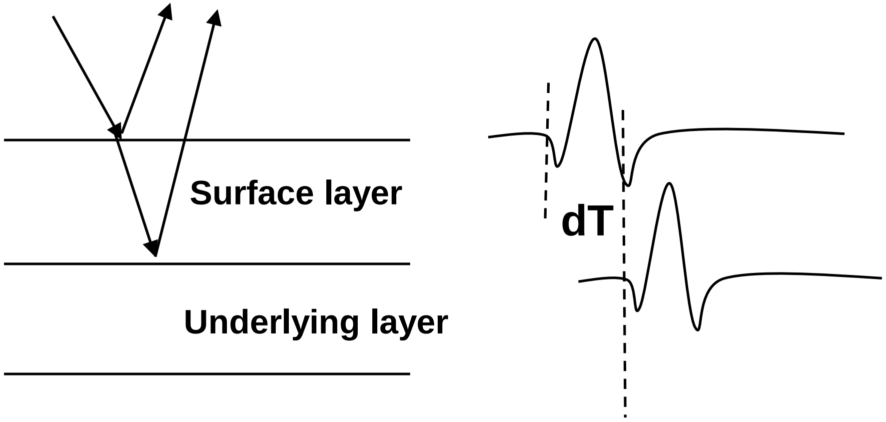




➢Underlying layer effect on surface measurement?

- ➢ How thick does the HMA layer need to be so that the underlying layer (agg. base) has no effects?





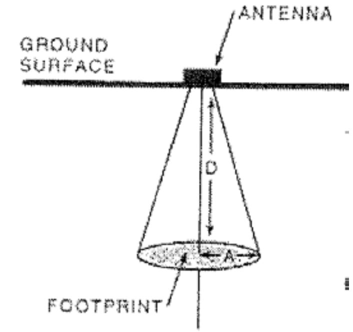
$$h_1 = v * \Delta t_1 / 2$$
$$v = c/\sqrt{\varepsilon_1}$$

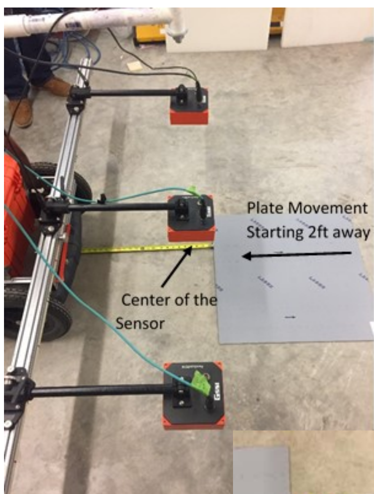
dT ~ 0.439us

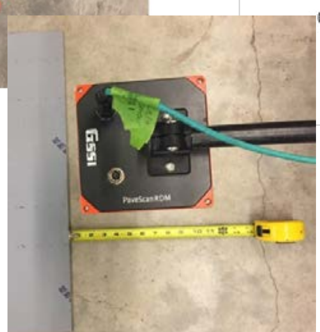
➢Footprint area of an antenna (Fresnel Zone)?

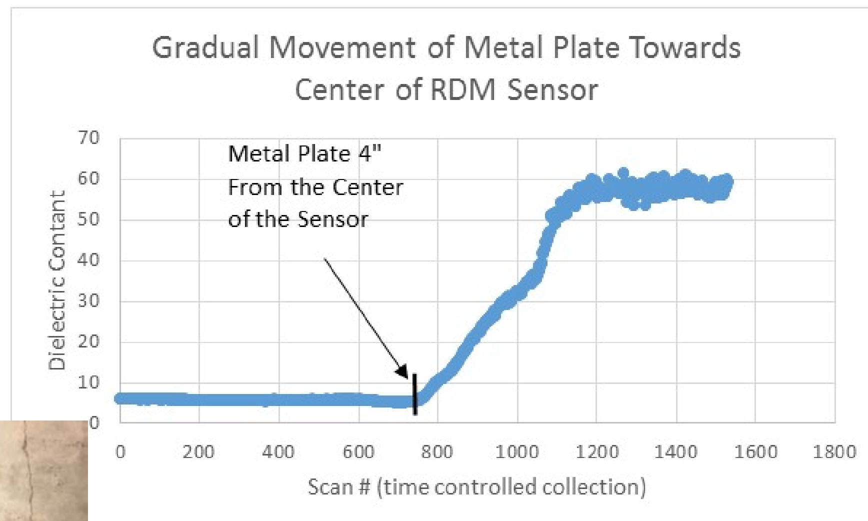
$$Fr \sim 0.5\ v\ (tr/fc)^{1/2}$$

D=12”, Fr (Radius) ~ 3.6” (for 2.7Ghz-RDM)



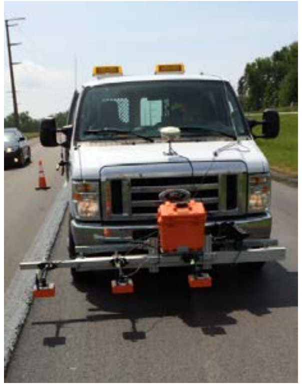






MnDOT's Plan

- 2016 Field Testing:
  - TH52 and TH14: Surveyed about 18miles.
- 2017 Field Testing
  - I35; Th52; Th22; Th60; CR86; Th110; CSAH13 and MnROAD
  - Hired American Engineering Testing (AET) to collect data
    - Educating consultant and contractors on this new technology
    - Testing application feasibility of vehicle mounted RDM system on construction projects.



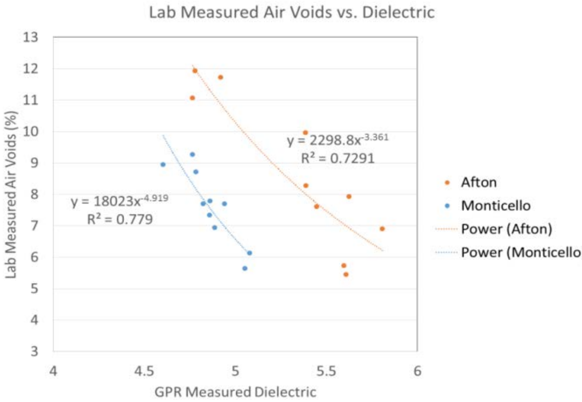
- 2018 Plan
  - IC, IR&RDM on CIR&FDR projects. A consultant will be hired for more data collection.
  - Further improve the system based on feedback.
  - Develop a pilot RDM specification.

Future Improvements for Implementation

- Sensitivity Study
  - How does each component in a mixture affect dielectric constant, such as aggregate type, gradation, binder type and content?

    Develop a guideline on when contractor should notify agency if there is mixture change during construction.

- Establish Calibration Curve in Lab
  - Potentially no field core needed
  - Currently use field cores for calibration
    - Location accuracy ?



- Use Gyratory Specimen?
  - Initial Experiment:

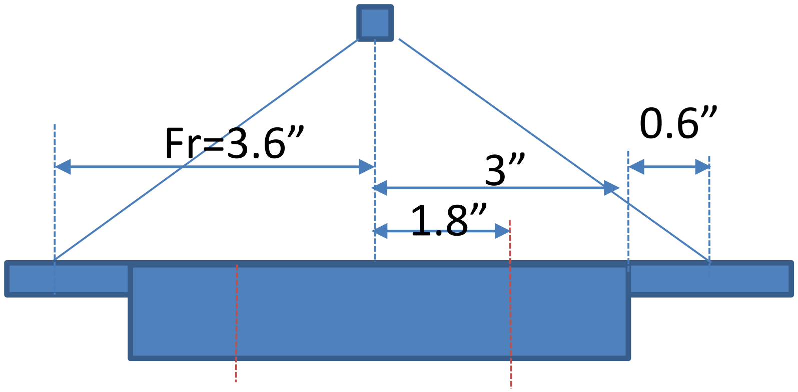
Garolite: Reported: 4.8 Or 5

Composite:

D=12”: S21=5.52

S22=5.7

S24=5.8



$$\varepsilon_{HMA} = \left(\frac{1 + \frac{A_0}{A_P}}{1 - \frac{A_0}{A_P}} \right)^2$$

Fr ~ 0.5 v (tr/fc)$^{1/2}$

D=12", Fr (Radius) ~ 3.6" (for 2.7Ghz-RDM)

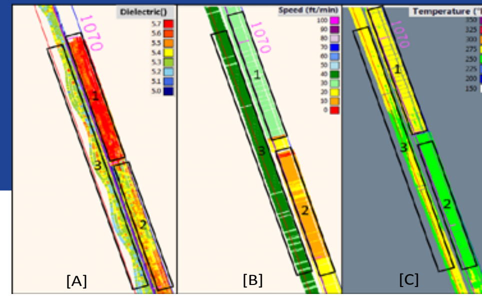
How to obtain dielectric constant of the core?

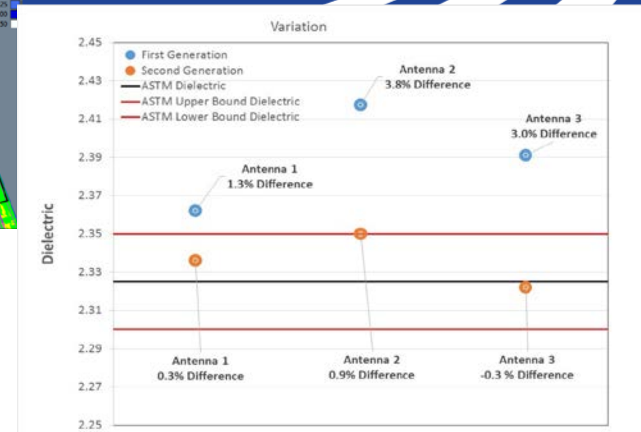
practice, the spatial resolution is substantially better. Sheriff [1985] discusses an effective Fresnel zone as equal to half the size of the first Fresnel zone. Therefore, it can be shown that when such a reflector occupies only 25 percent of the Fresnel zone, its reflected amplitude decreases only by 40 percent. This result emphasizes the fact that even

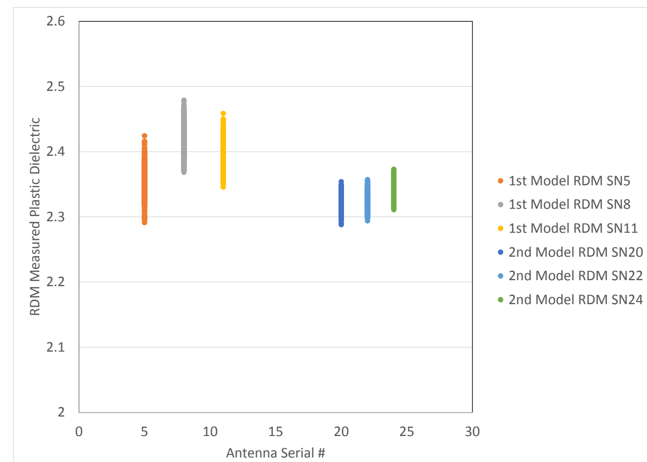
Means 60% of reflected peak value from center 25% of the zone.

* 25% of the zone: R=1.8"

* How the rest of 1.2"HMA and 0.6" Garolite contribute to A_o?







- Software Improvements
  - Distance from antenna to pavement surface (?)
  - Cloud to Send RDM data directly into VETA
  - GPS Accuracy
  - Etc.
- Equipment Precision and Accuracy
  - Method for check/verify precision
  - Current: HDPE and Garolite; other materials?
- Calibration Procedure
  - Current: High-density polyethylene (HDPE) and Garolite
  - Swerving on field: max difference of 0.08 ?

- AASHTO Protocol
  - Drafted AASHTO by Kyle
    - Survey Set Up
    - Survey Data Collection
    - System Performance Measures
  - Quality Assessment Criteria
    - Compaction Uniformity
    - Density: Mainline and Longitudinal Joint

Standard Practice for

Asphalt Surface Dielectric Profiling System using Ground Penetrating Radar

AASHTO Designation: XX ##-## (2017)
Release: Group #

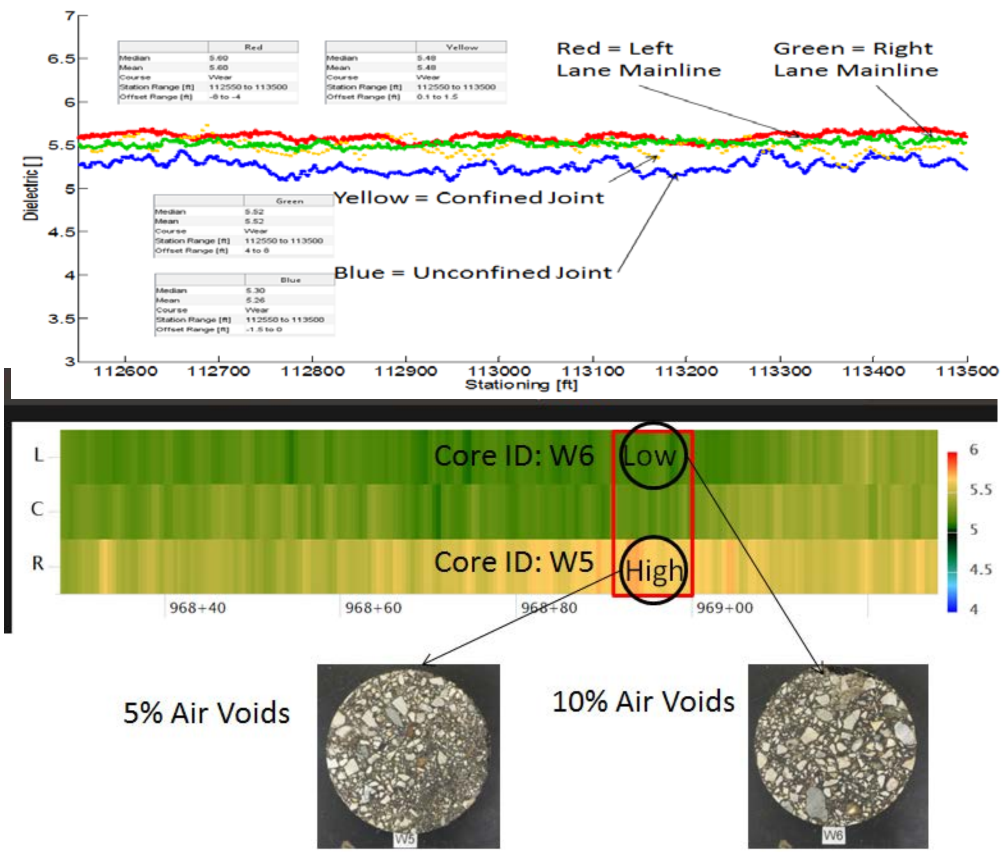
AASHTO
American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

- Local Support for RDM from GSSI in Future?
  - If fully implemented in construction projects

- Use of data in PM system for evaluating Long-term Performance?

Results

- On-Site Identification of high and low levels of compaction

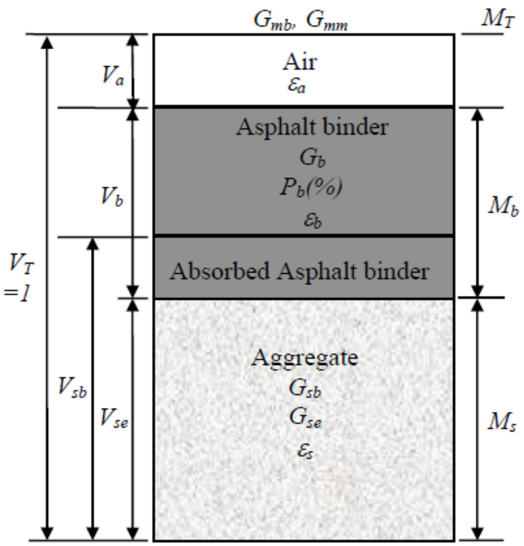


Mainline Survey: multiple passes

Joint Survey: one antenna close to joint

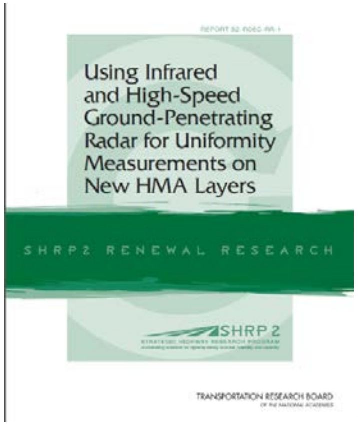
Mix Model

Al-Qadi, Leng, Lahouar, and Baek



G_{mb} = bulk specific gravity of HMA
G_{mm} = maximum specific gravity of HMA
V_T = total volume
V_a = volume of air
V_b = total volume of binder
V_{sb} = bulk volume of aggregate
V_{se} = effective volume of aggregate
M_T = total mass
M_b = total mass of binder
M_s = mass of aggregate
G_b = specific gravity of binder
G_{sb} = bulk specific gravity of aggregate
G_{se} = effective specific gravity of aggregate
ε_a = dielectric constant of air = 1.0
ε_b = dielectric constant of binder
ε_s = dielectric constant of aggregate
P_b = binder content

FIGURE 3 HMA volume and mass composition



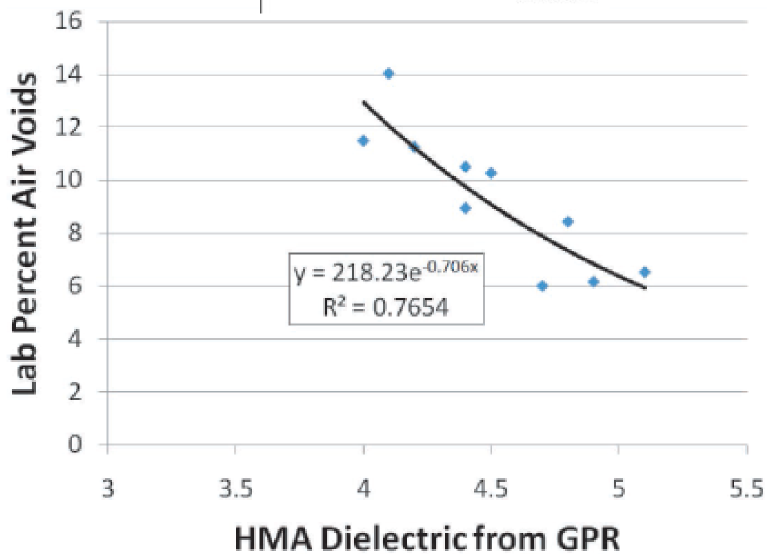
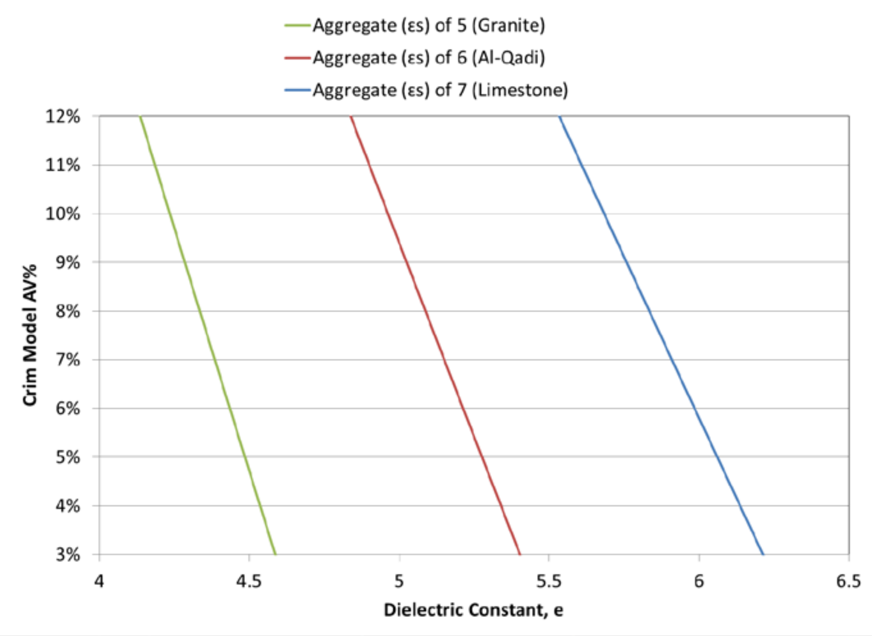
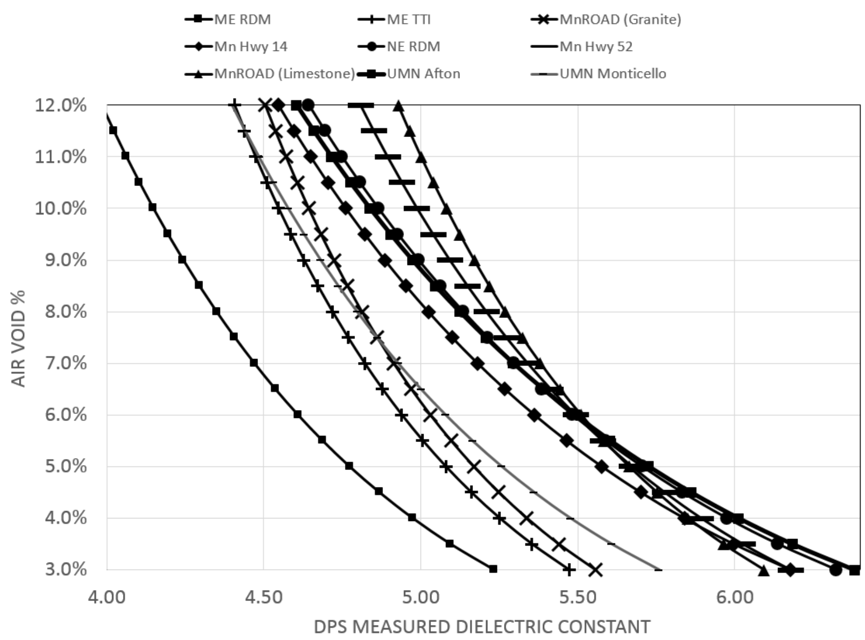


Figure 3.50. Calibrating GPR to predict in-place air voids from Region 2 data.

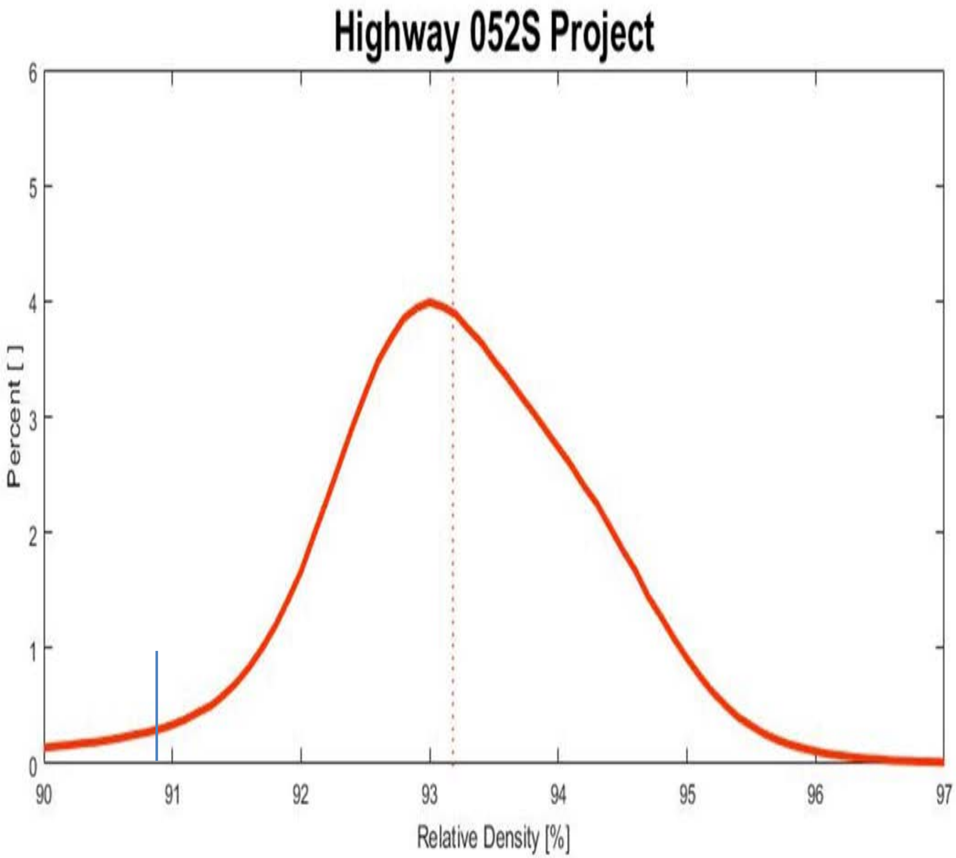
Mix Model Slope (AV%/e) ~ Double Field Observed





Analysis Approach: Histogram

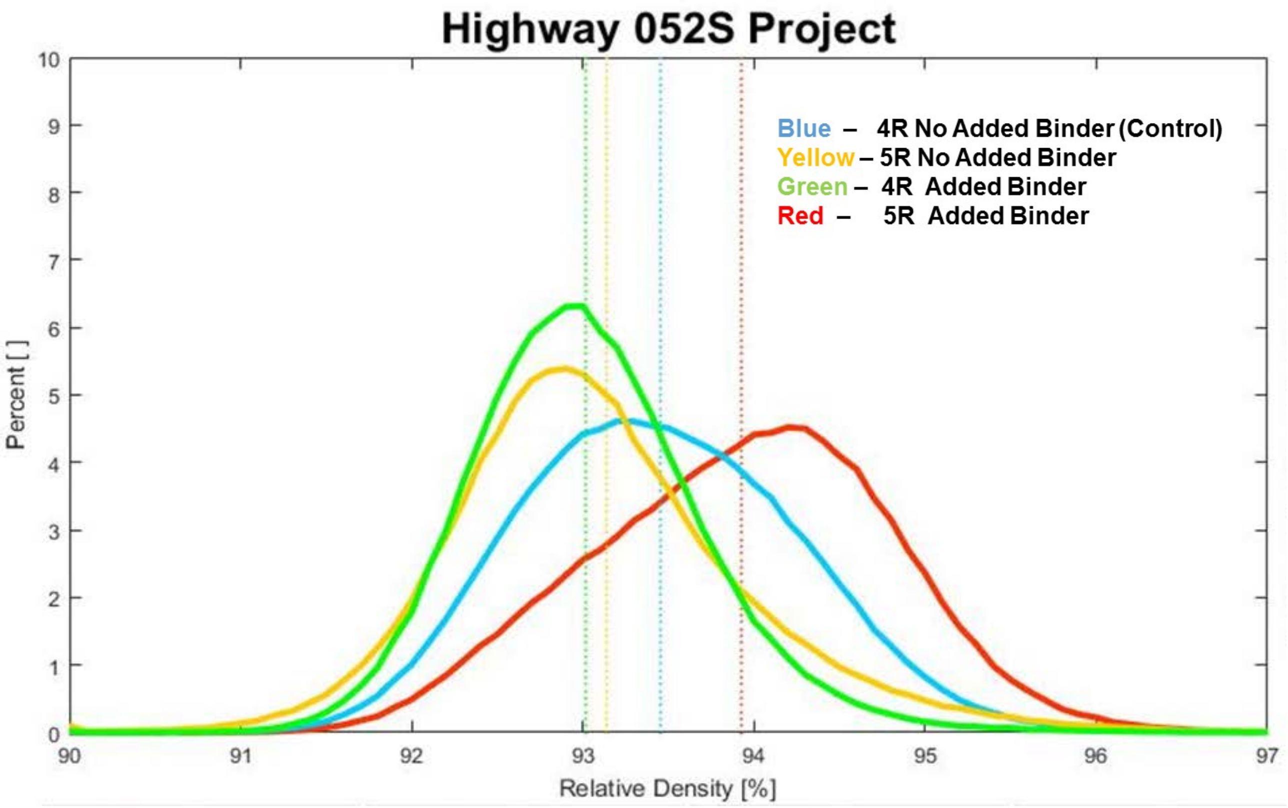
- **Use histogram to assess uniformity and quality.**



- All Data Collected
  - Sampling Rate = 0.4 in/scan.
  - > 26 million measurements
  - Analysis based on 4 in. moving average
  - Equivalent to >1 million cores
- Summary Stats
  - 93.2% median density
  - STD: 1.18
  - 97.5% locations density> 90.8%

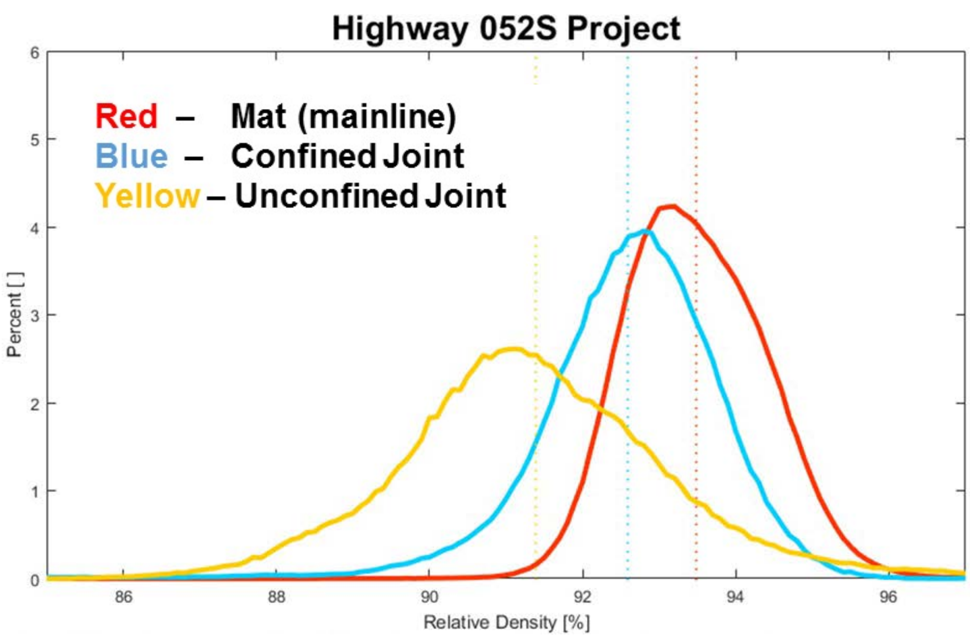
2016 Experiments: TH 52 – Mainline

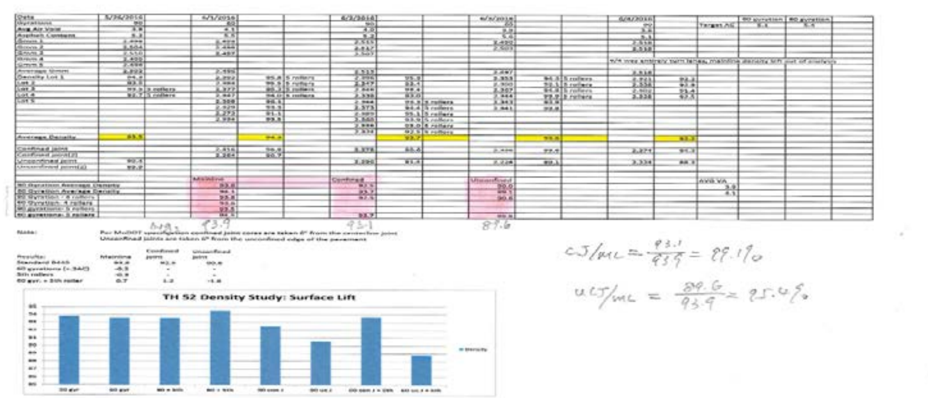
- Number of Roller Effects
- **Section with added binder+5 rollers has highest density**



- Median Density:
  - Blue: 93.4%
  - Yellow: 93.1%
  - Green: 93%
  - Red: 94%

2016 Experiments: TH 52 – Longitudinal Joint

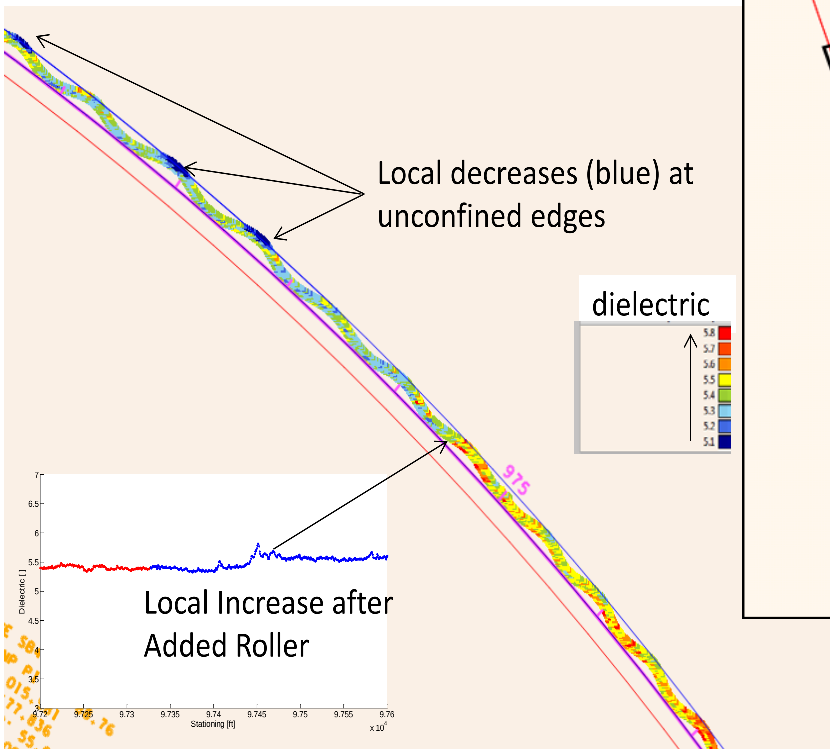


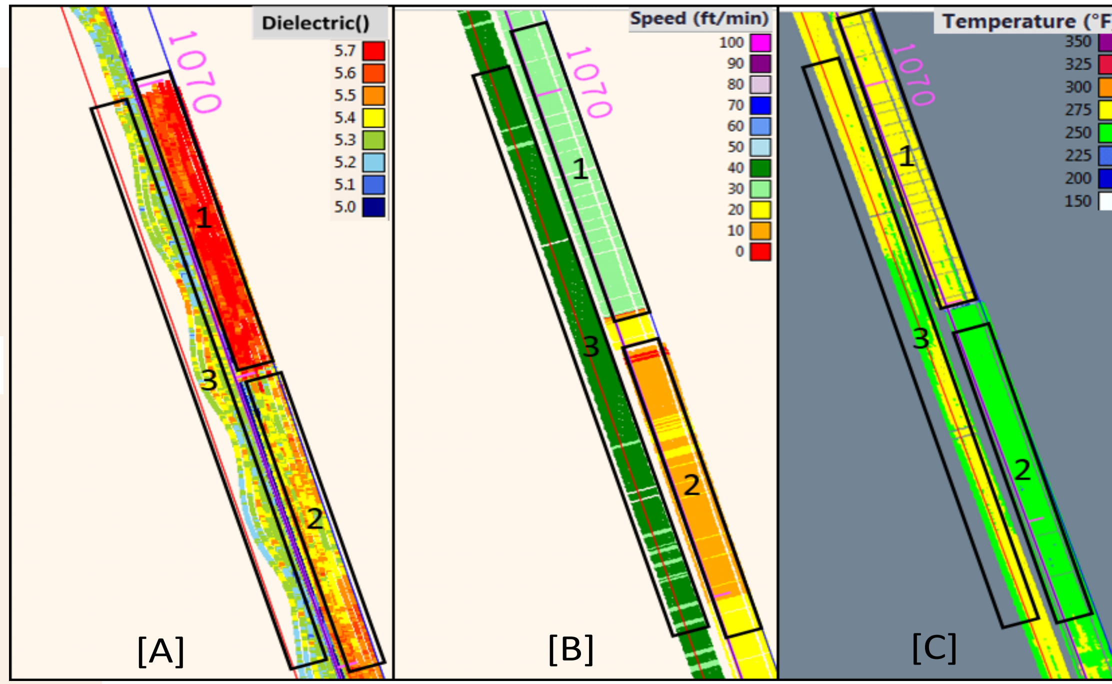


- Top lift Mainline vs Confined and Unconfined Joints Summary:
- **93.5% (ML), 92.6%(CJ) and 91.4%(UCJ)**
- **SD: 0.94(ML); 1.22(CJ); 1.8(UCJ)**
- **Density:**
  - UCJ/ML=97.7%; CJ/ML=99%
  - Core data: UCJ/ML=95.1%
    CJ/ML = 99.1%
- **97.5% locations:**
  - **> 91.6%(ML),**
  - **> 90.2% (CJ)**
  - **> 87.8% (UCJ)**

2016 Experiments: TH 52:Comparison with Construction Factors

Import RDM data into Veta for comparison with IR and other data



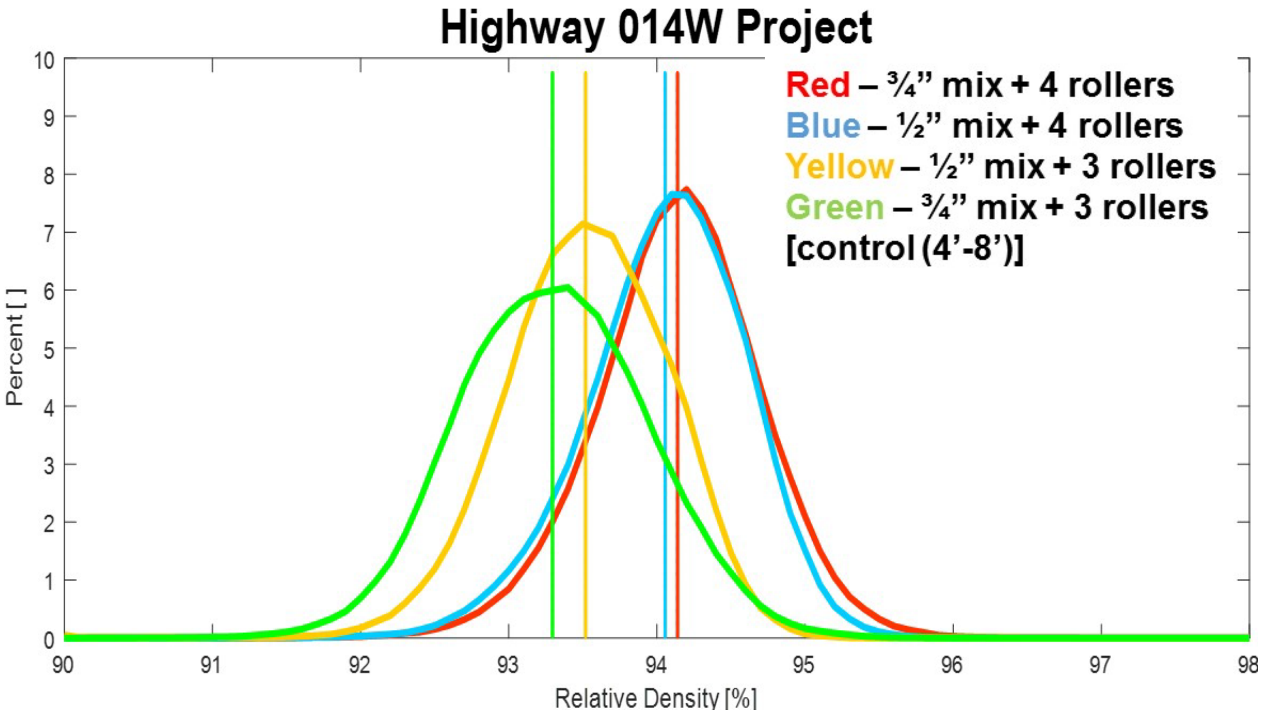


TH 14 – Mainline

- Comparison of Test Sections

- **Mix B (3/4-) to A(1/2-): not much difference on compaction.**

- **Adding a roller: density slightly increased on this project.**



- Median Density:

  Blue: 94.1%

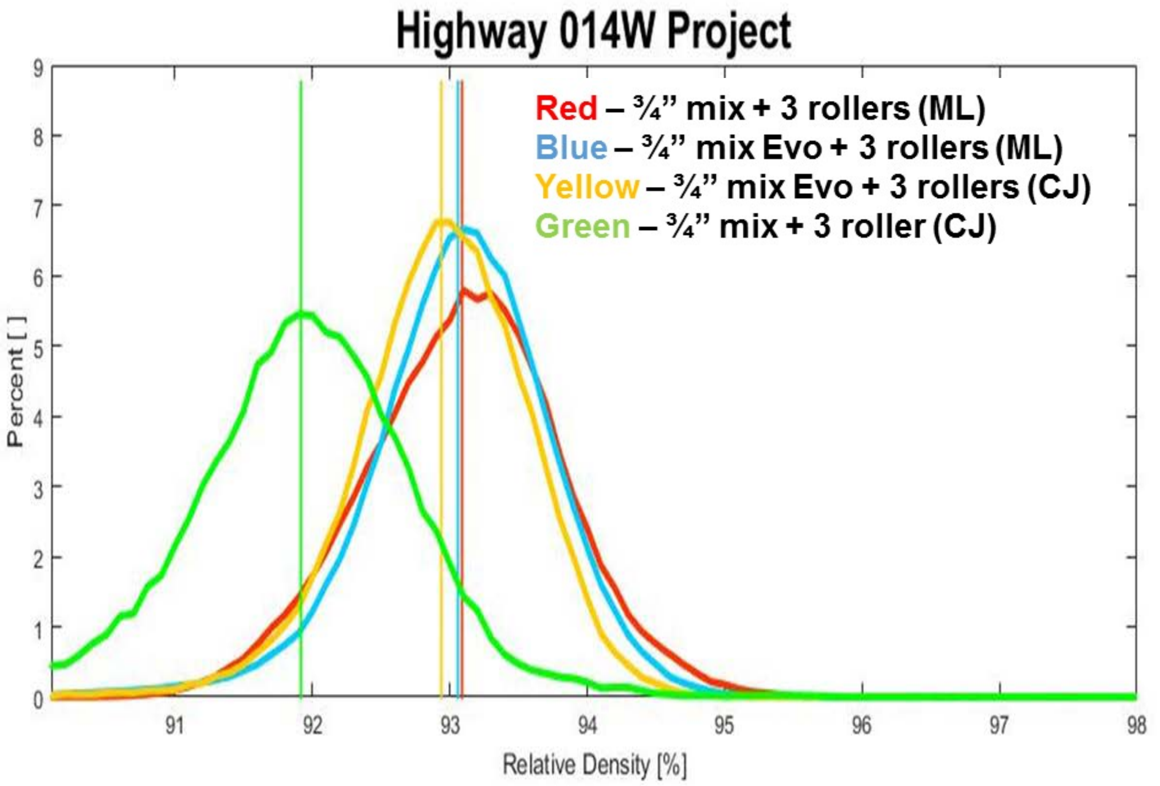
  Red: 94.2%

  Yellow: 93.5%

  Green: 93.3%

TH 14 – Longitudinal Joint

- **Evotherm helped on the joint compaction density**

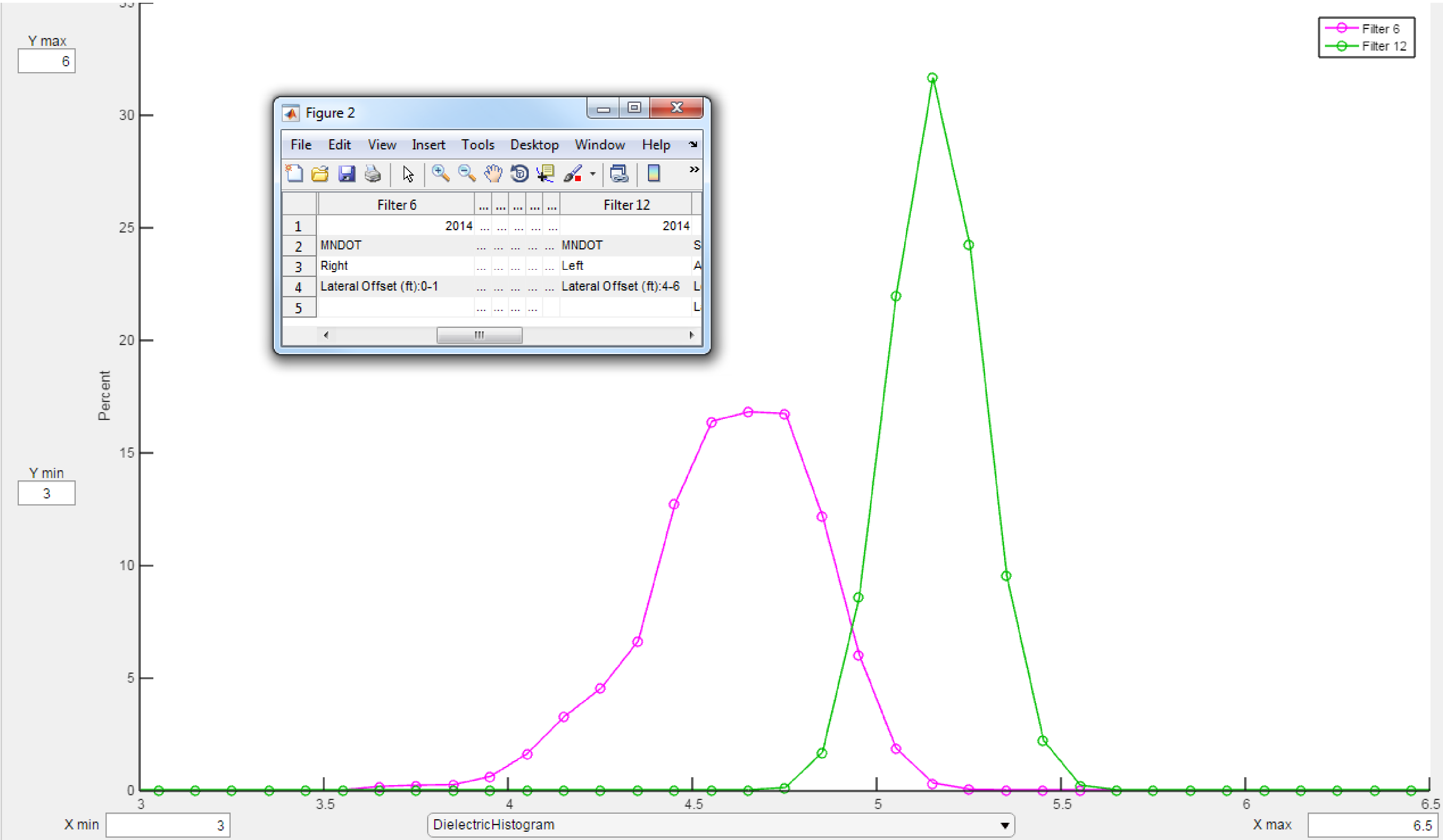


- Median Density:
  Red: 93.1% (ML)
  Blue: 93.1% (ML)
  Yellow: 92.9%(CJ+Ev)
  Green: 91.5% (CJ)
  (CJ+Ev)/ML=99.7%
- Core:
  93.8%(ML)
  93.5%(CJ+Ev)- only 2 cores
  CJ/ML= 99.6%

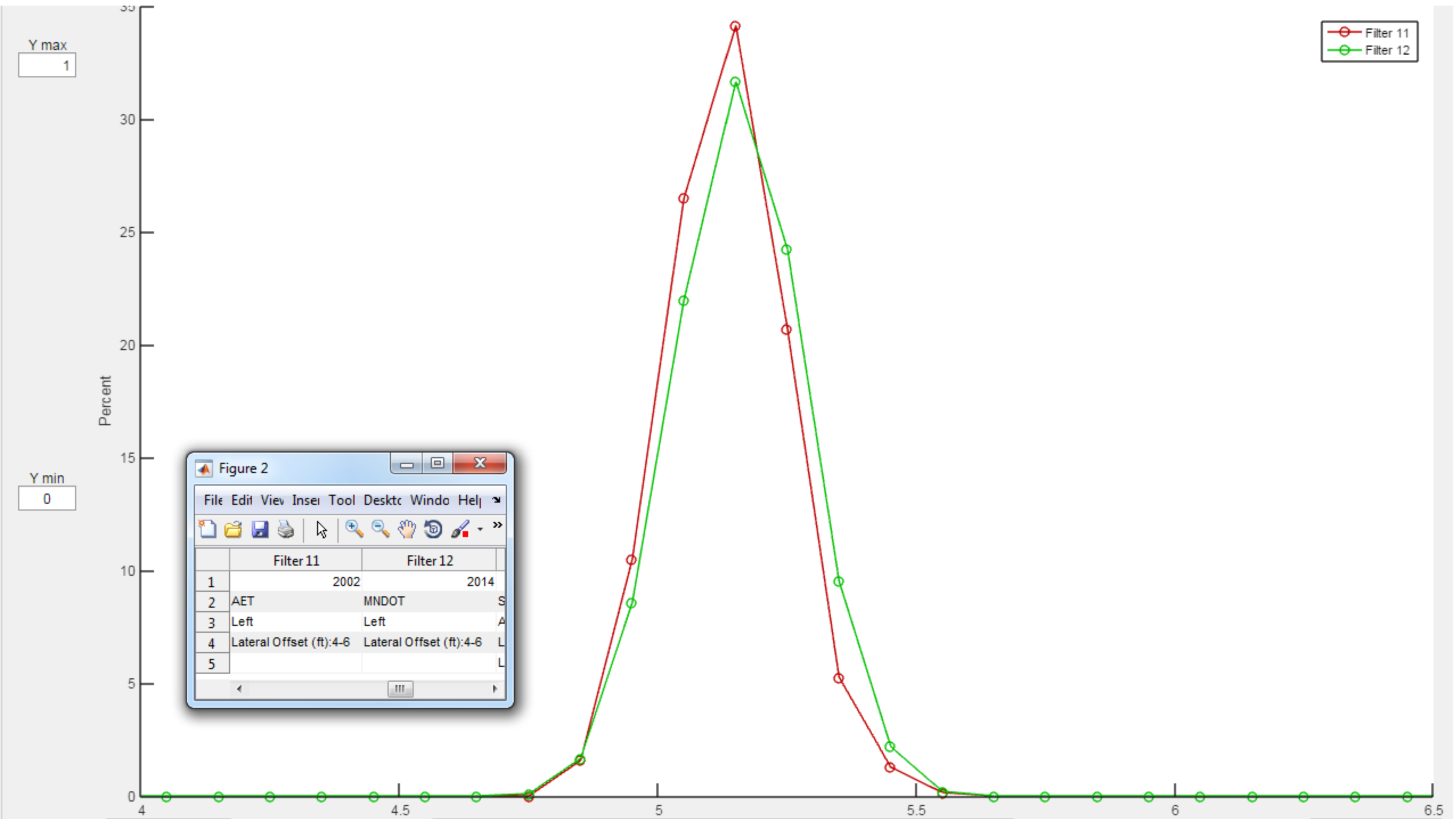
2017 Projects

1. CSAH 13 (AET Training+Comparison w/ MnDOT)
2. I35 (echelon paving)
3. TH 52
4. CSAH 86
5. Hwy 110
6. CSAH 22 (AET)
7. TH60 (AET + MnDOT)
8. MnROAD

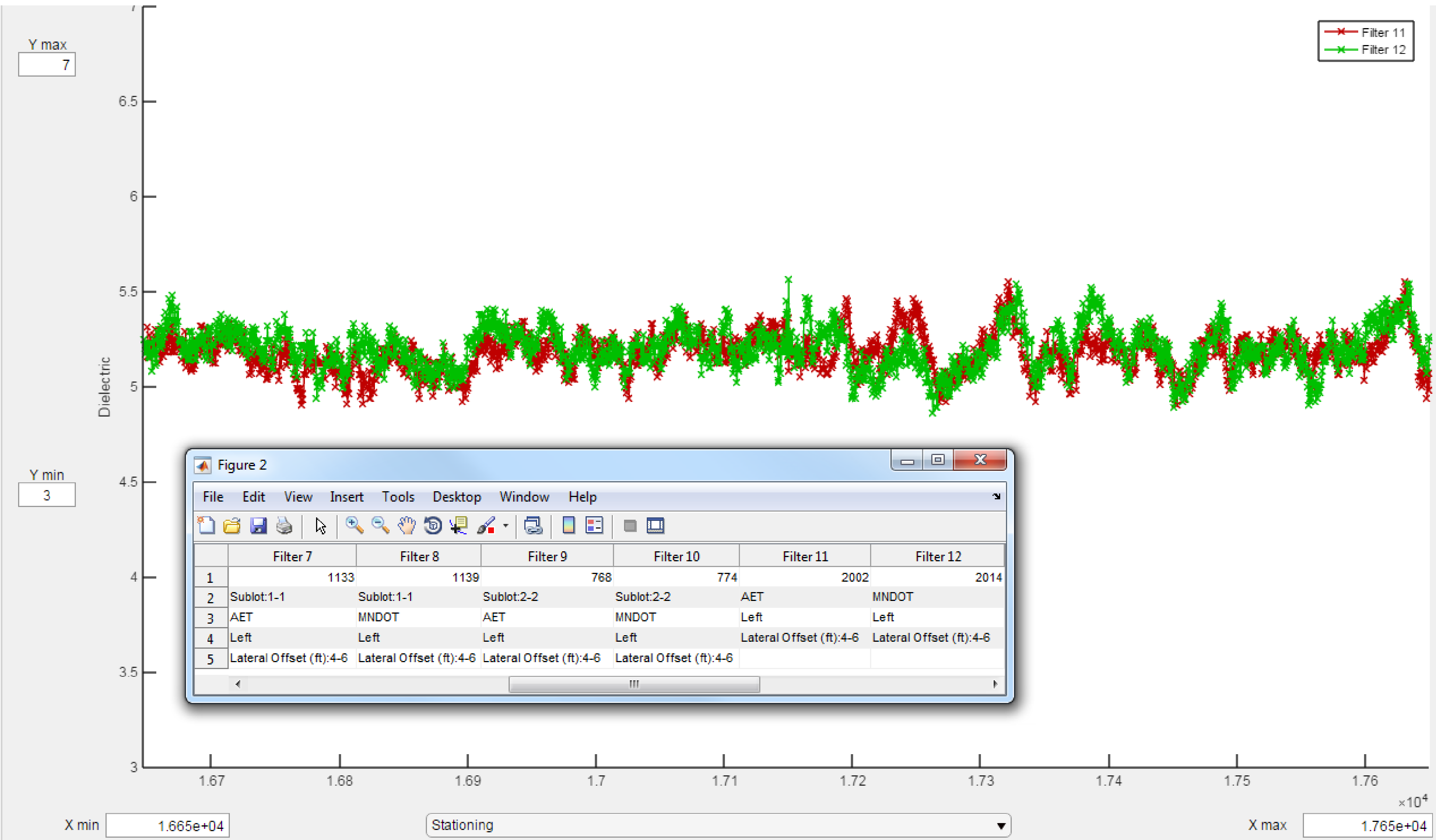
CSAH 13: Unconfined Joint Vs Mat



CSAH 13: Comparison with AET: Mat

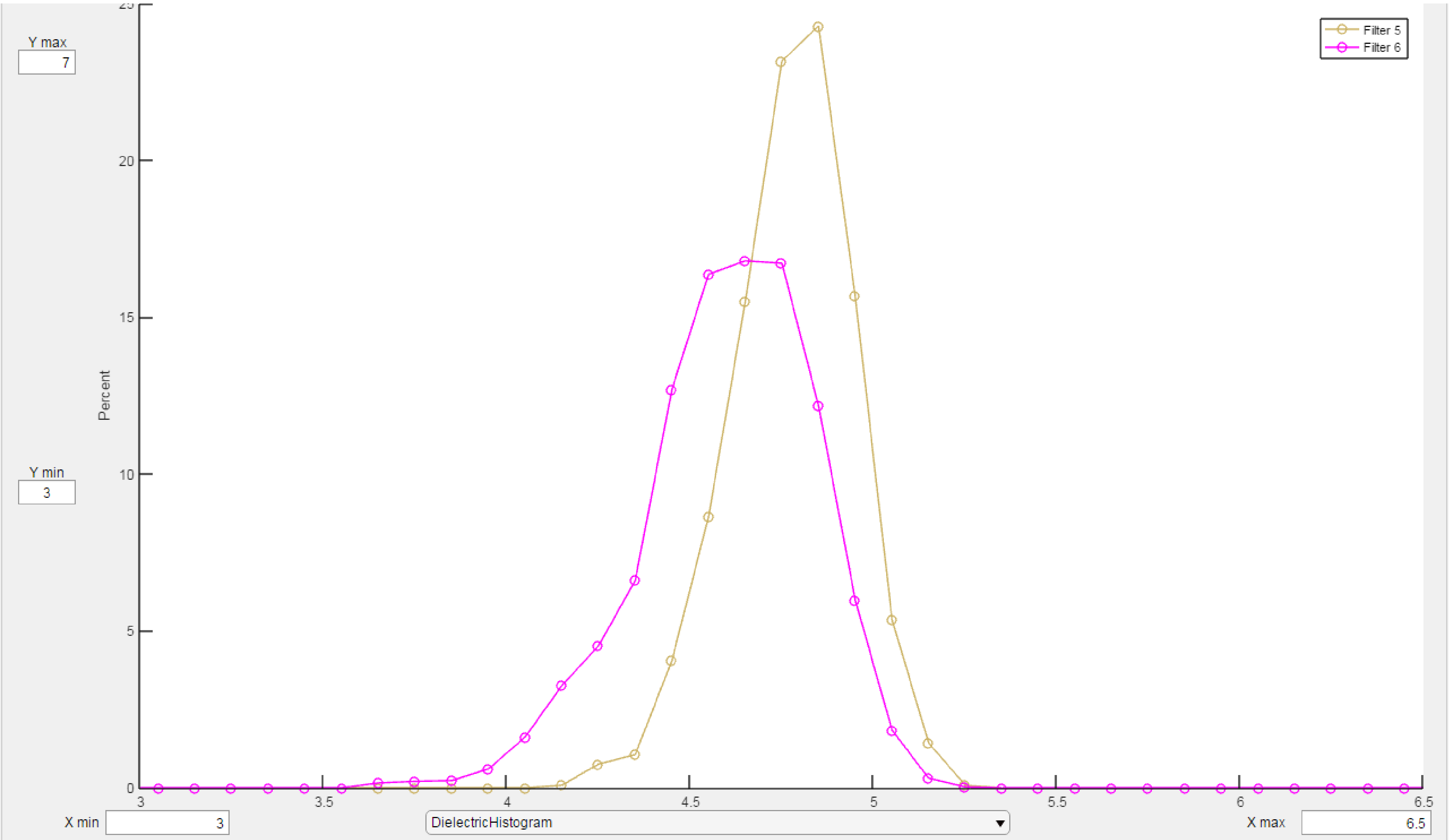


CSAH 13: Comparison with AET: Mat

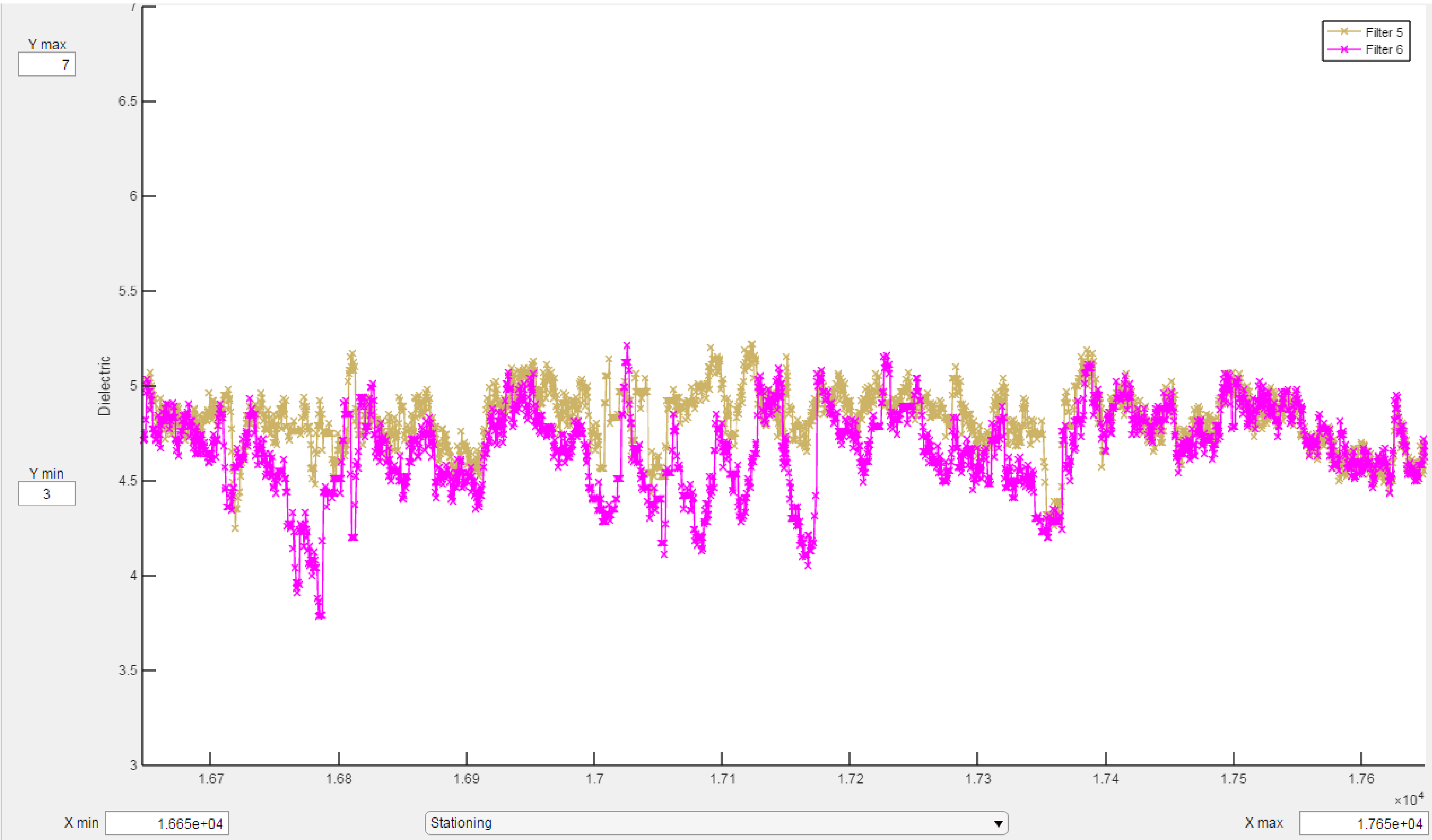


	Filter 7	Filter 8	Filter 9	Filter 10	Filter 11	Filter 12
1	1133	1139	768	774	2002	2014
2	Sublot:1-1	Sublot:1-1	Sublot:2-2	Sublot:2-2	AET	MNDOT
3	AET	MNDOT	AET	MNDOT	Left	Left
4	Left	Left	Left	Left	Lateral Offset (ft):4-6	Lateral Offset (ft):4-6
5	Lateral Offset (ft):4-6	Lateral Offset (ft):4-6	Lateral Offset (ft):4-6	Lateral Offset (ft):4-6		

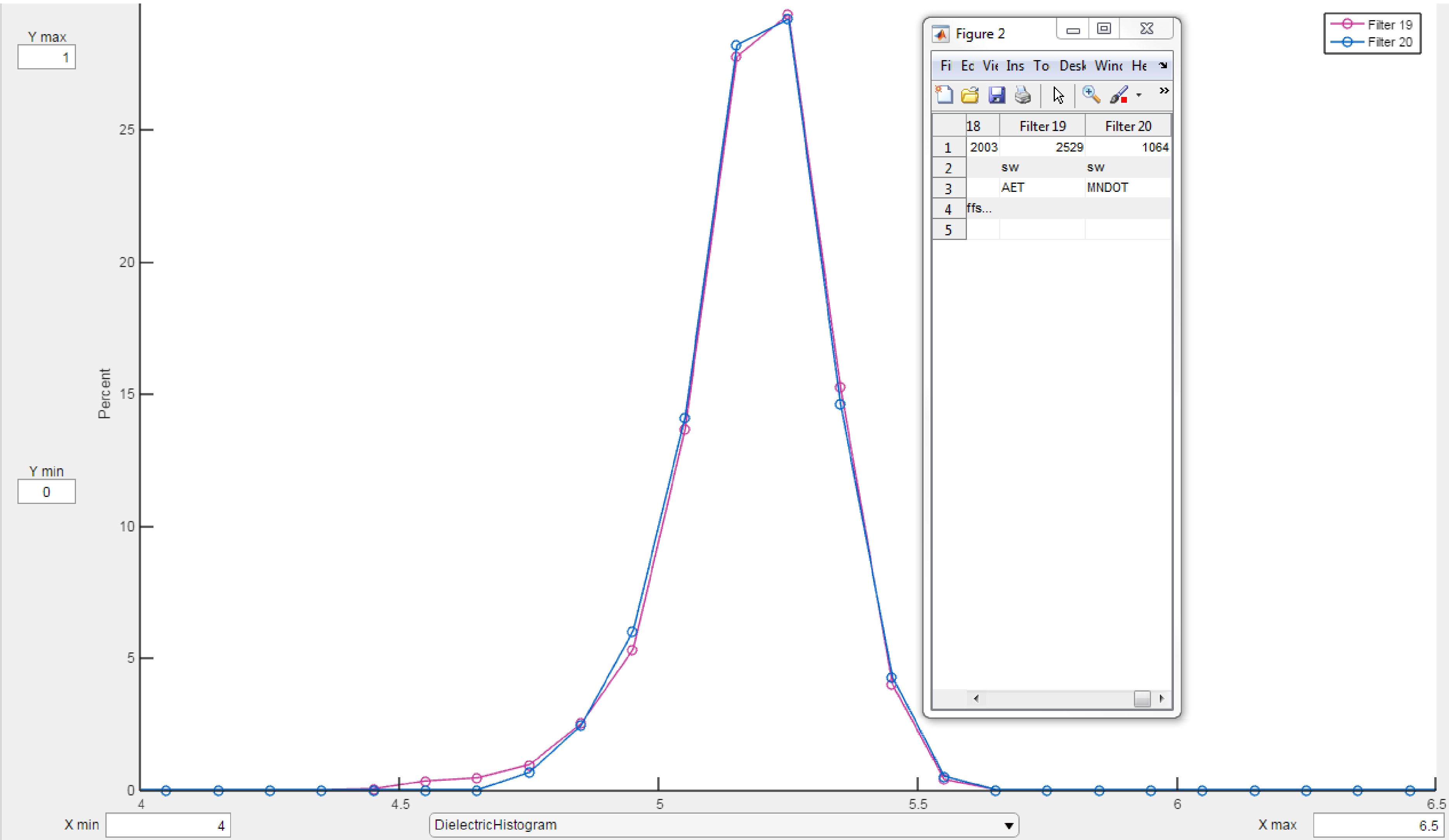
CSAH 13: Comparison with AET: Joint



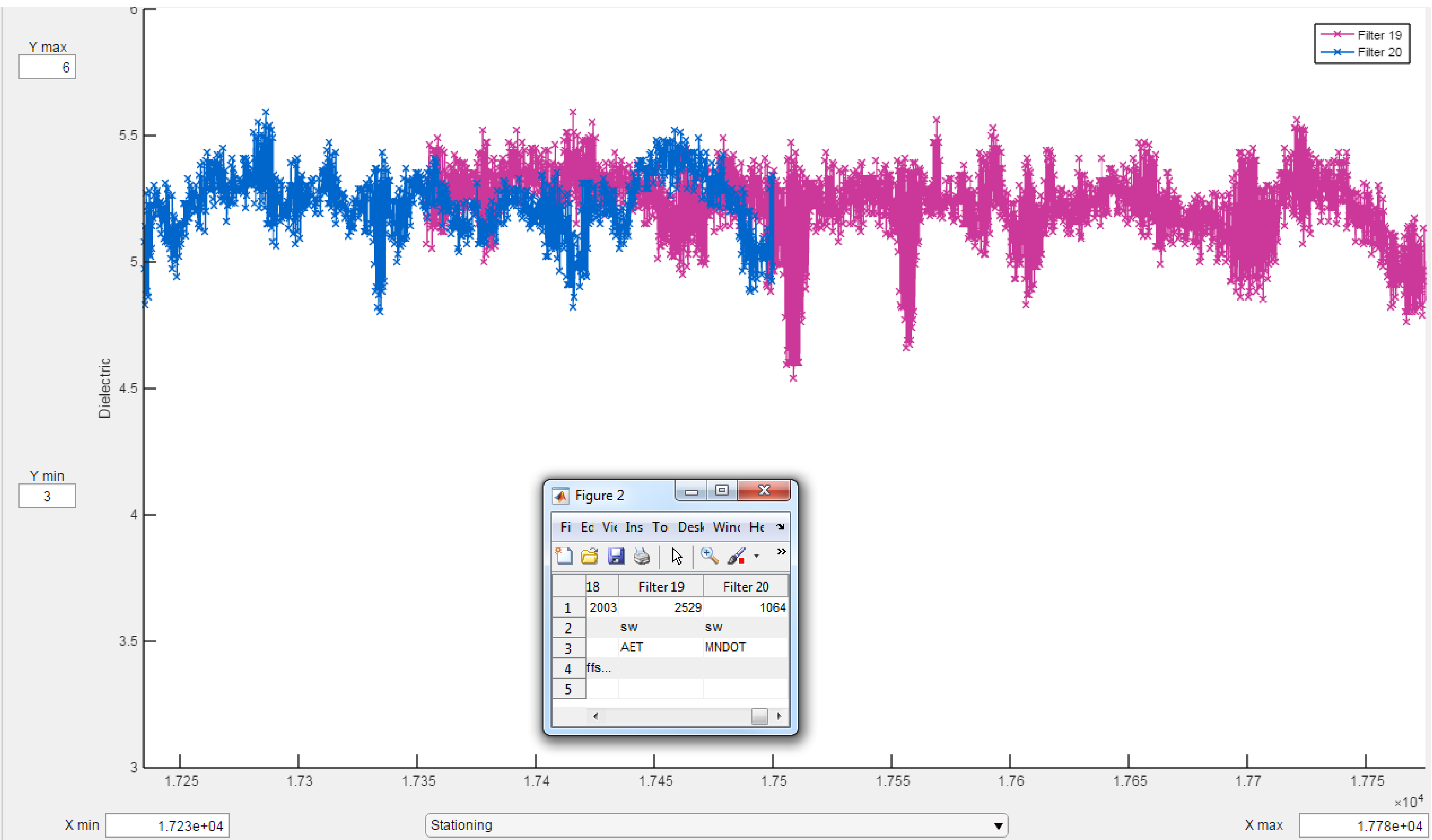
CSAH 13: Comparison with AET: Joint



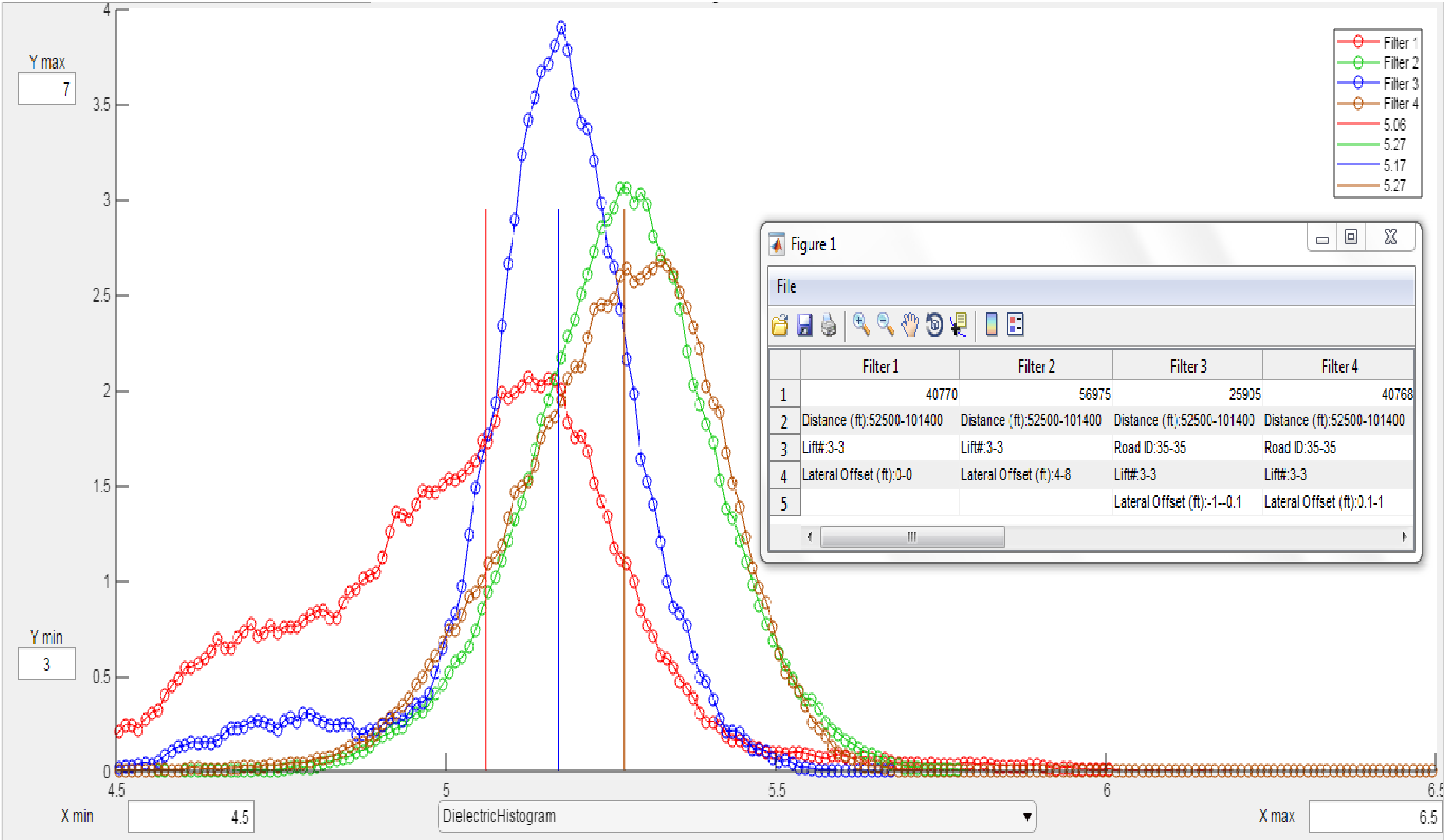
CSAH 13: Comparison with AET: Swerve



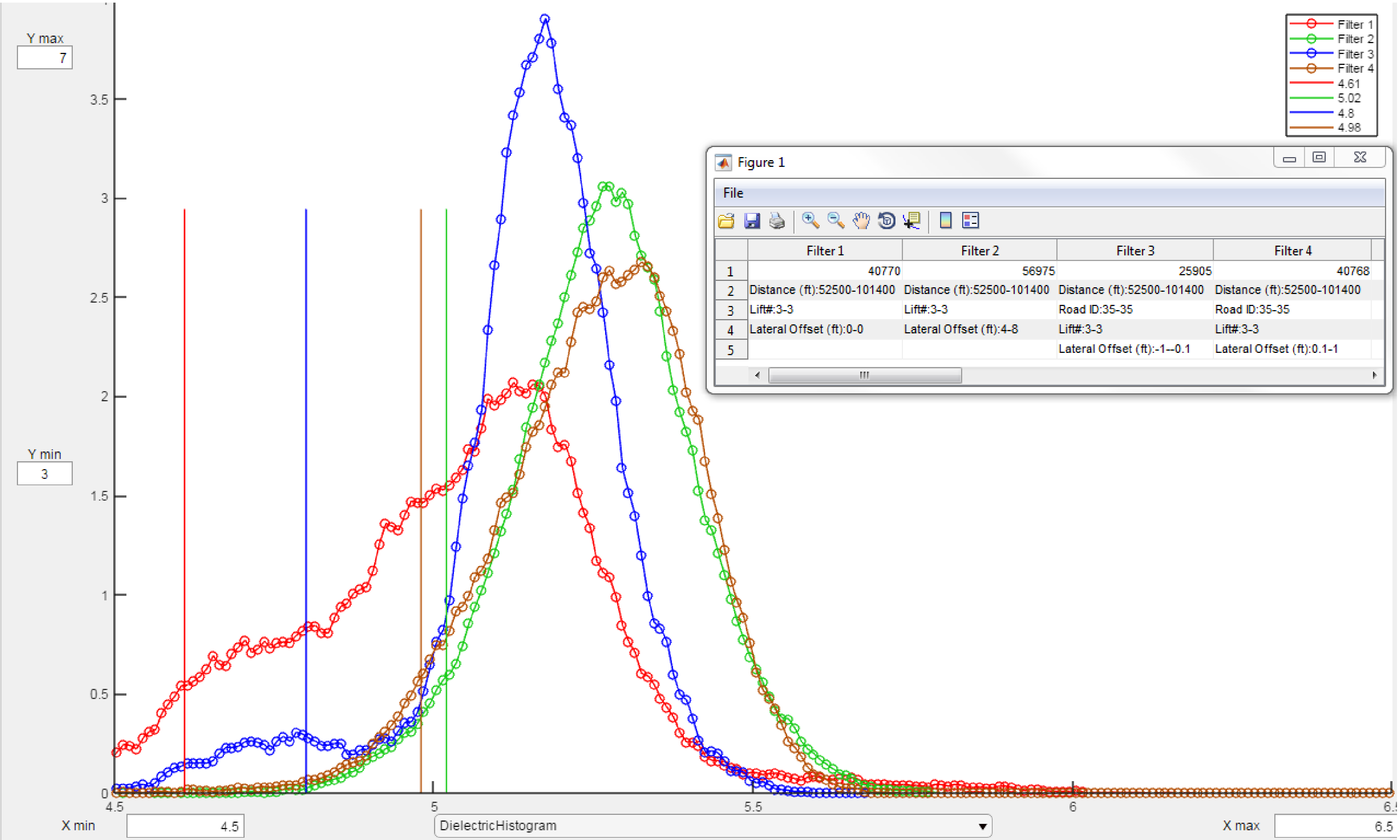
CSAH 13: Comparison with AET: Swerve



I35 (Echelon Paving): All Offset Categories

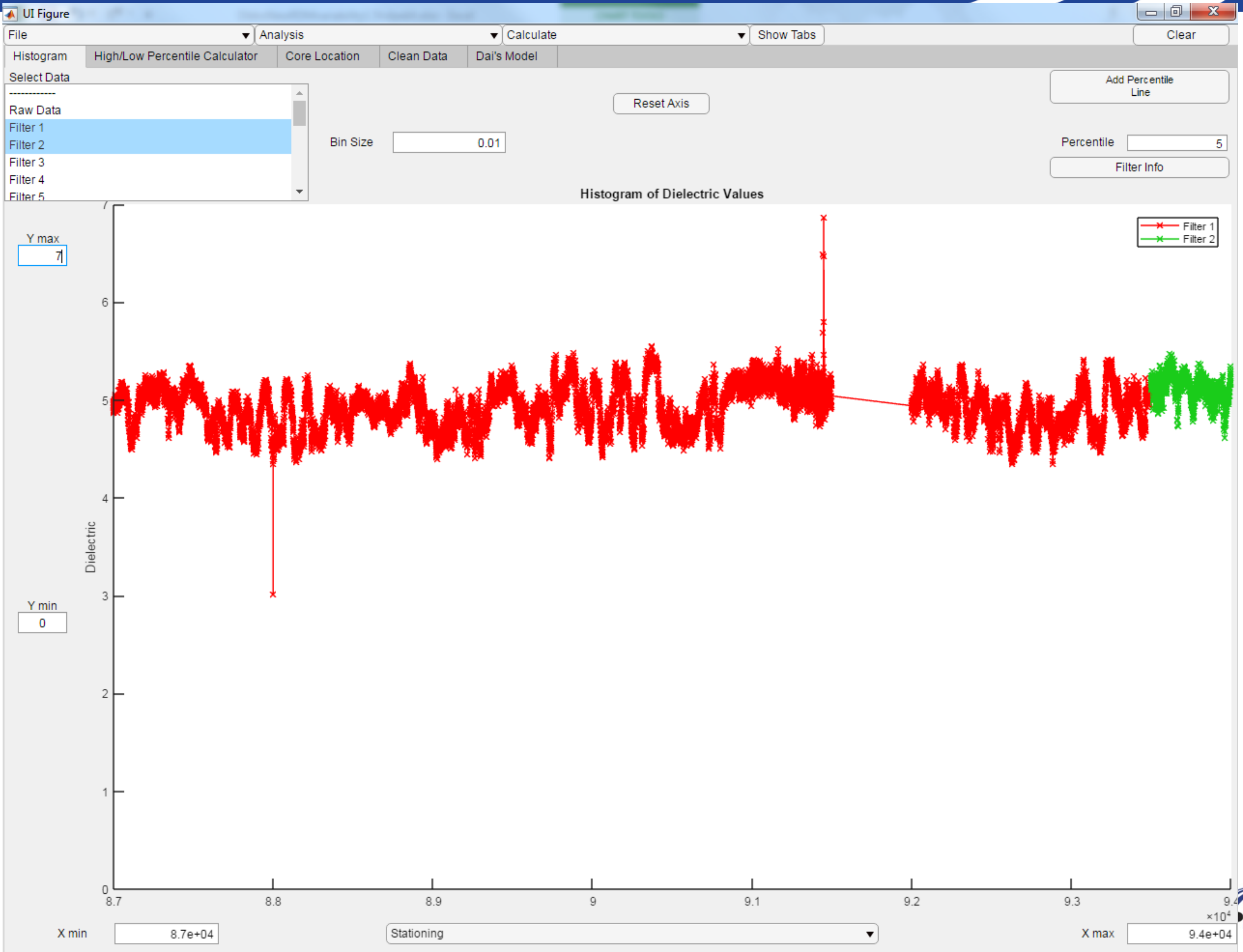


I35 (Echelon Paving): All Offset Categories

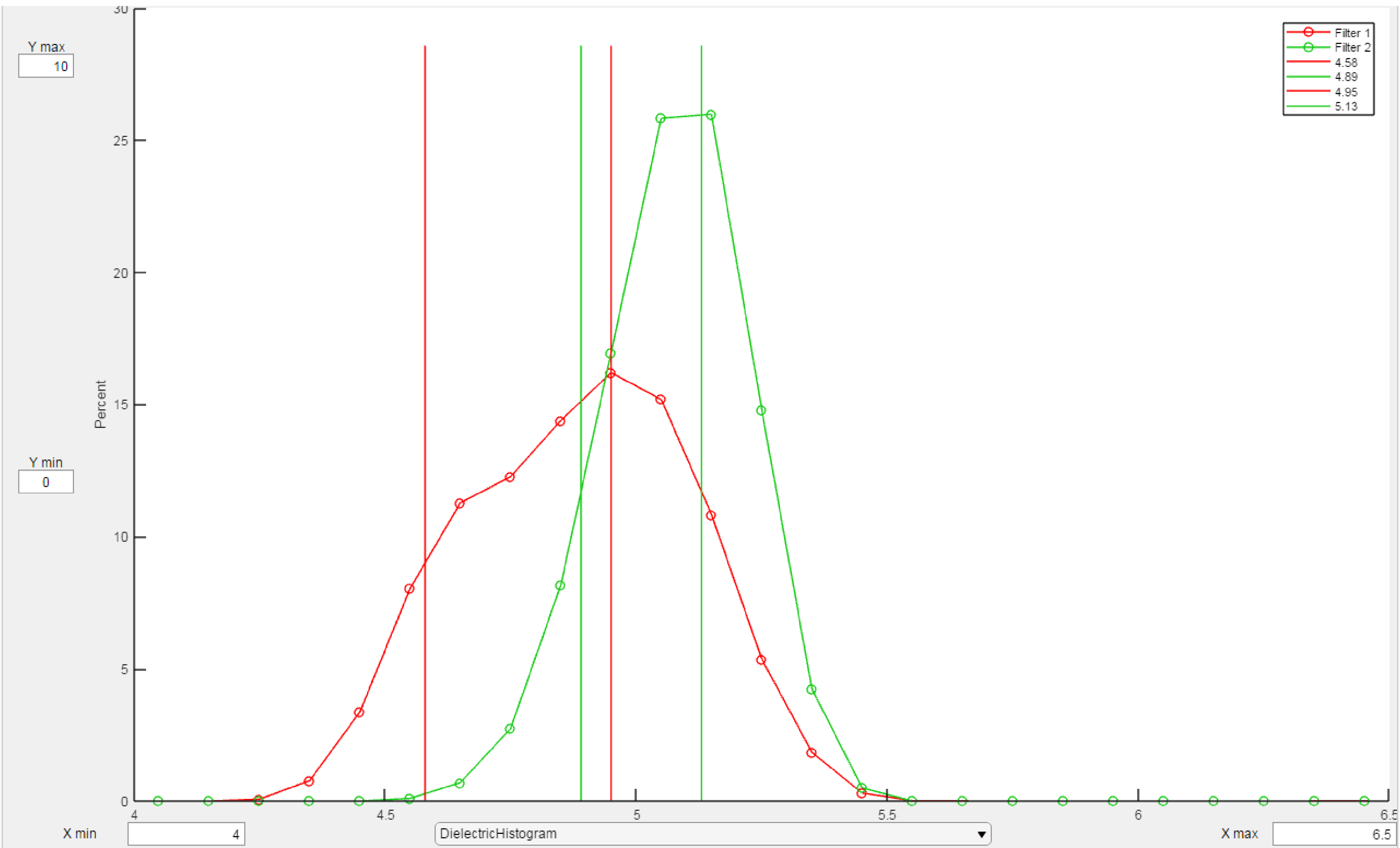


	Filter 1	Filter 2	Filter 3	Filter 4
1	40770	56975	25905	40768
2	Distance (ft):52500-101400	Distance (ft):52500-101400	Distance (ft):52500-101400	Distance (ft):52500-101400
3	Lift#:3-3	Lift#:3-3	Road ID:35-35	Road ID:35-35
4	Lateral Offset (ft):0-0	Lateral Offset (ft):4-8	Lift#:3-3	Lift#:3-3
5			Lateral Offset (ft):-1--0.1	Lateral Offset (ft):0.1-1

I35 Smush vs Overlap



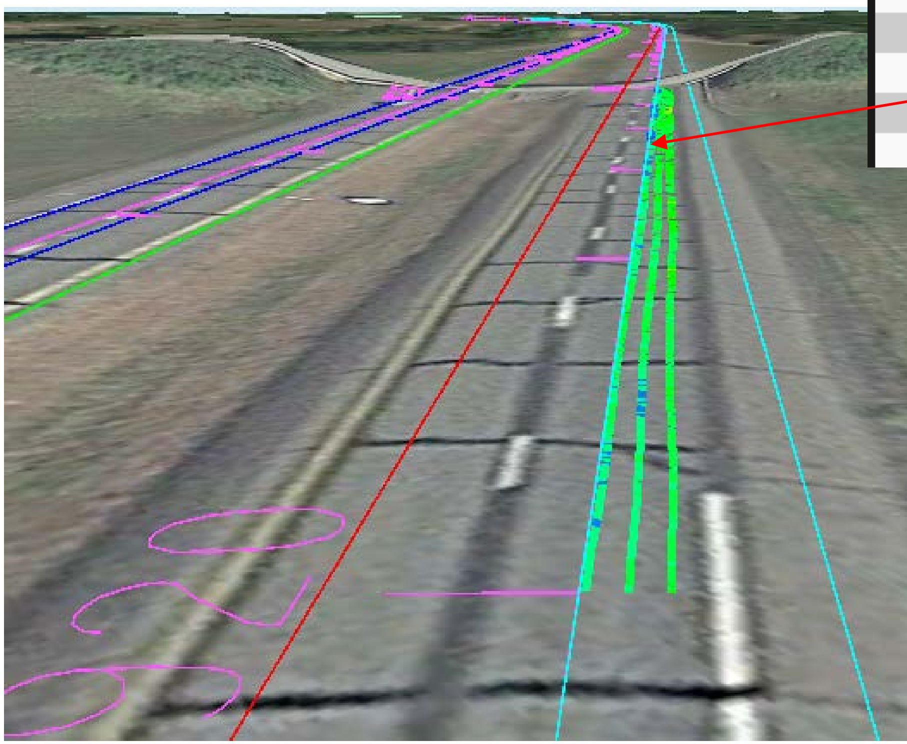
I35 Smush vs Overlap

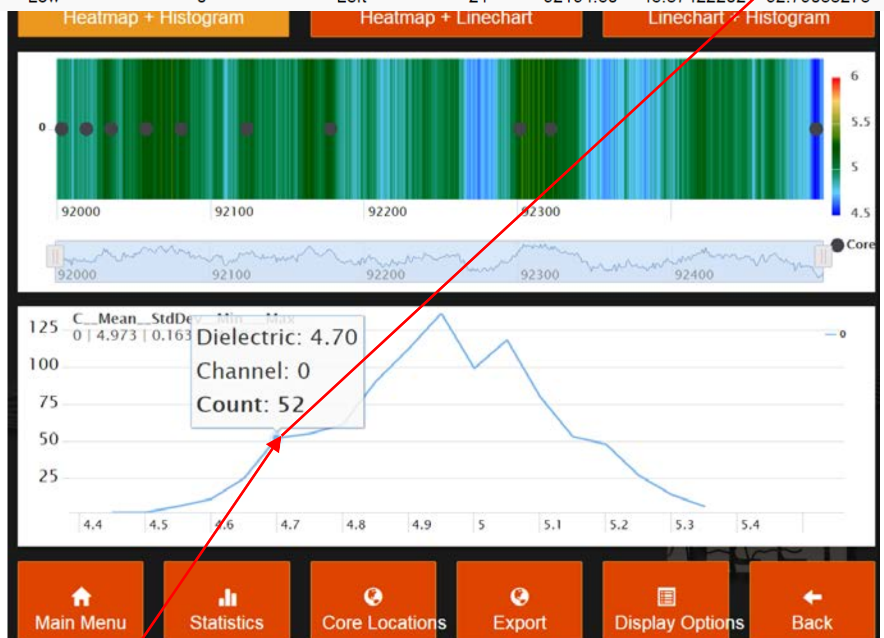


Example On-Site Analysis:
I35 Echelon Paving "Smush" Technique:

Relative Dielectric	Lateral Offset	Sensor Position	Serial #	Distance	Latitude	Longitude	Dielectric
Low	0	Left	21	92267.60	46.37439352	-92.79043042	4.63
Low	0	Left	21	92356.70	46.37460081	-92.79024525	4.64
Low	0	Left	21	92283.70	46.37443148	-92.79039668	4.67
Low	0	Left	21	92212.00	46.37426246	-92.79054654	4.70
Low	0	Left	21	92377.70	46.37465045	-92.79020131	4.70
Low	0	Left	21	92489.70	46.37491206	-92.78996672	4.73
Low	0	Left	21	92194.60	46.37422202	-92.79058275	4.80

Core Measured % Density: 89.6%

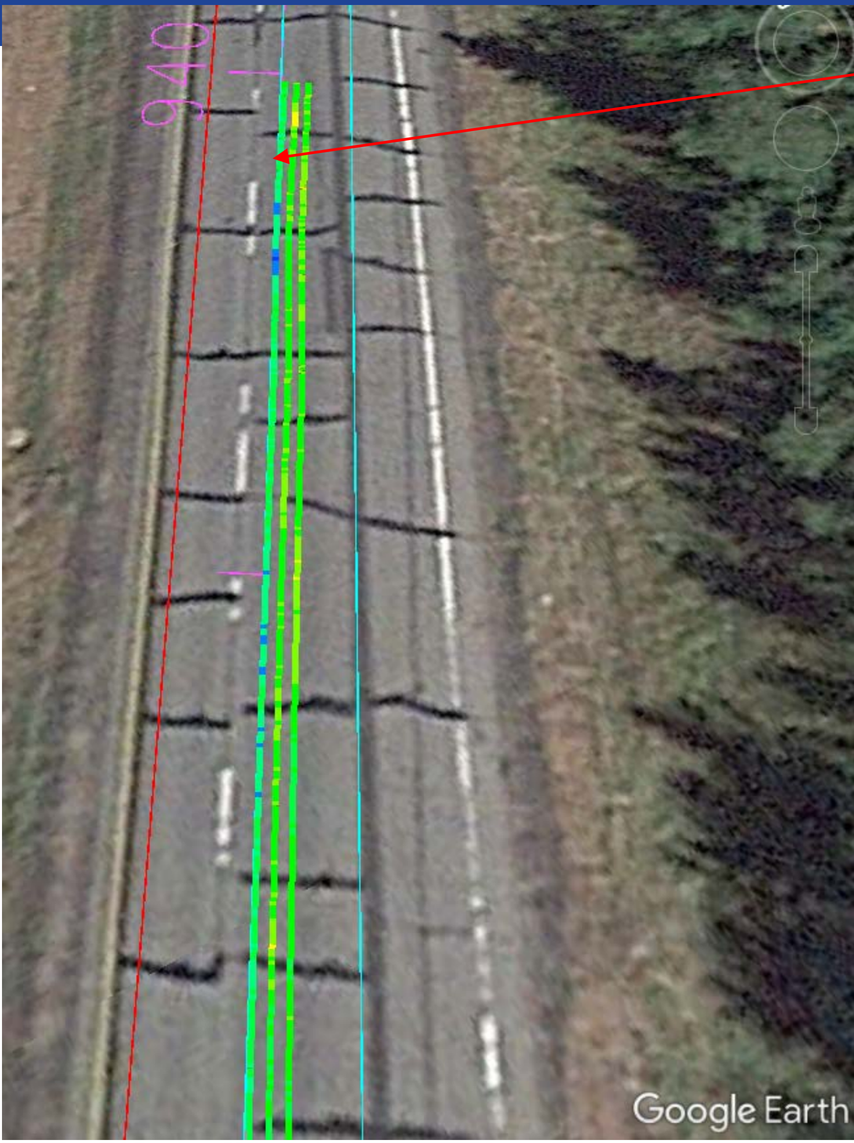




Lateral Offset	Sensor Position	Serial #	Start Dist	End Dist	Total Dist	Median	Average	Min	Max	Standard Dev	Histogram 5%
0	Left	21	92000	92498.2	498.1	4.97679	4.97369	4.41121	5.46776	0.170425	4.68724

Example On-Site Analysis:
I35 Echelon Paving Overlapping Technique:

93985	-92.78685725	46.37839142
93985.5	-92.7868562	46.37839252
93986	-92.78685519	46.37839362
93986.5	-92.78685413	46.37839478
93987	-92.78685306	46.37839592



Relative Dielectric	Lateral Offset	Sensor Position	Serial #	Distance	Latitude	Longitude	Dielectric
Low	0	Left	21	93959.00	0.00000000	0.00000000	4.62
Low	0	Left	21	93891.20	0.00000000	0.00000000	4.86
Low	0	Left	21	93565.80	0.00000000	0.00000000	4.88
Low	0	Left	21	93758.20	0.00000000	0.00000000	4.89
Low	0	Left	21	93872.30	0.00000000	0.00000000	4.89
Low	0	Left	21	93532.90	0.00000000	0.00000000	4.96
Low	0	Left	21	93986.00	0.00000000	0.00000000	4.96

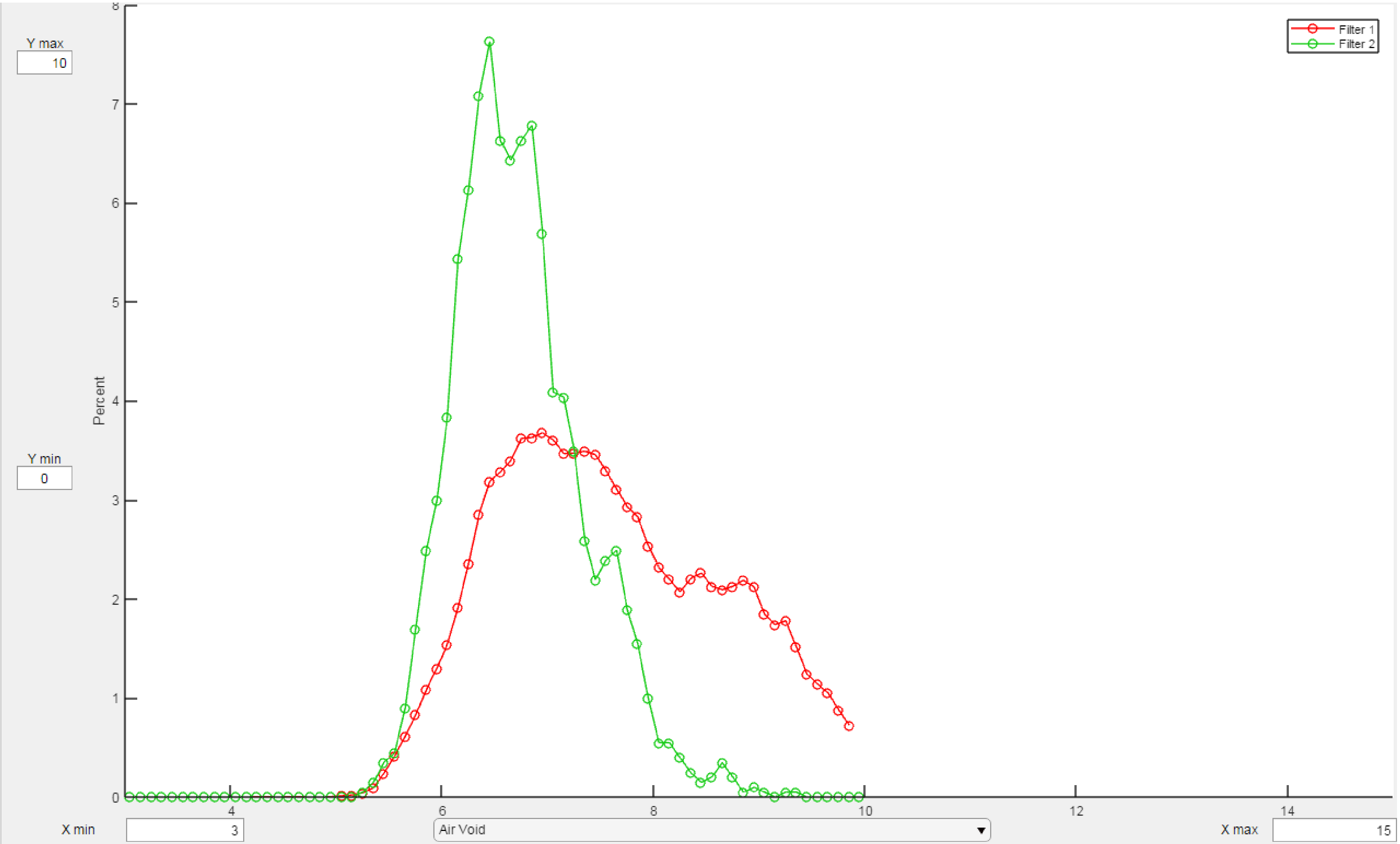
Median	Average	Min	Max	Standard Dev	Histogram 5%
5.12877	5.12103	4.31786	5.54892	0.142291	4.87549

Switch to Overlap improved density ~ by 3% air void content

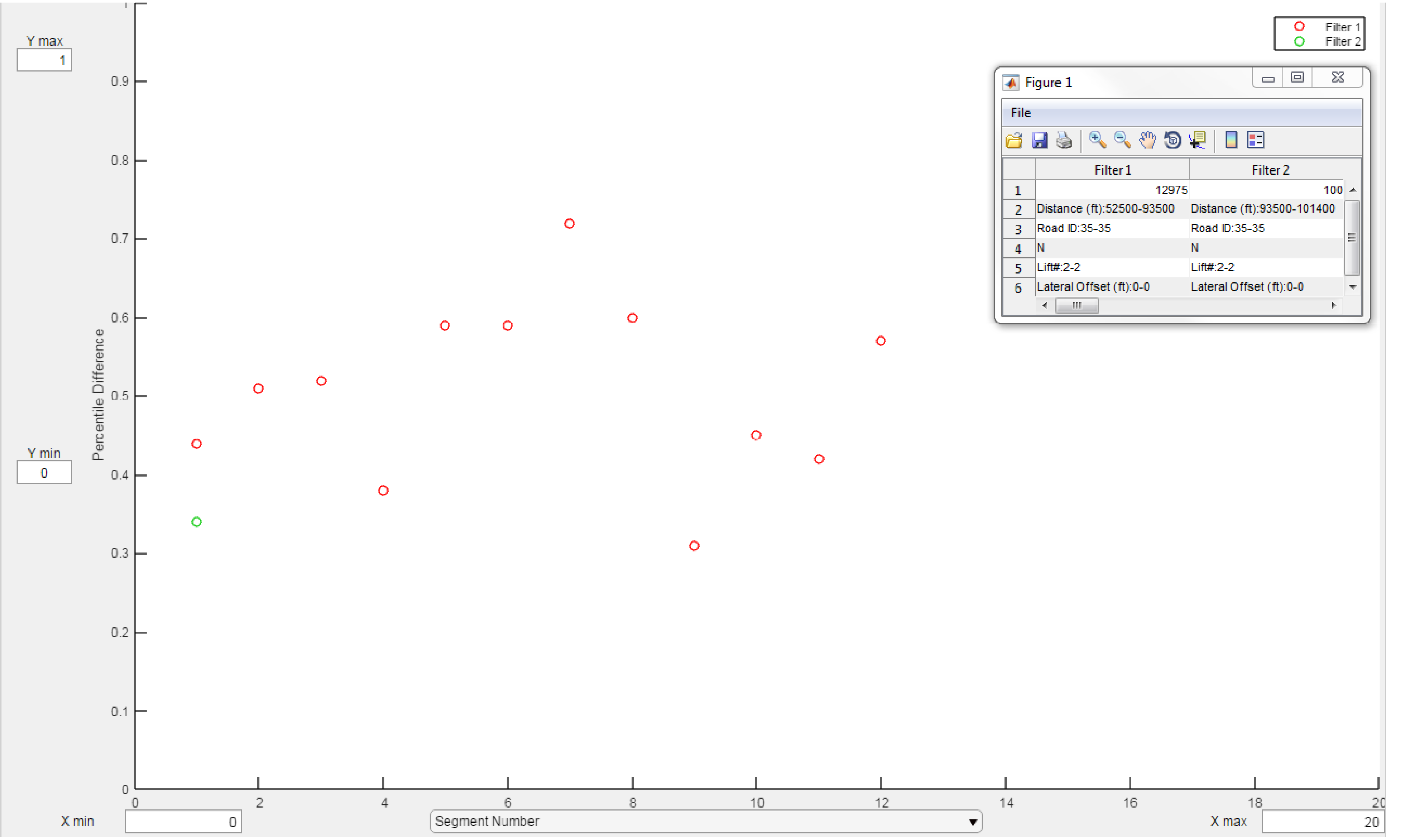
Median	Average	Min	Max	Standard Dev	Histogram 5%
4.97679	4.97369	4.41121	5.46776	0.170425	4.68724

Core Measured % Density: 93.0%

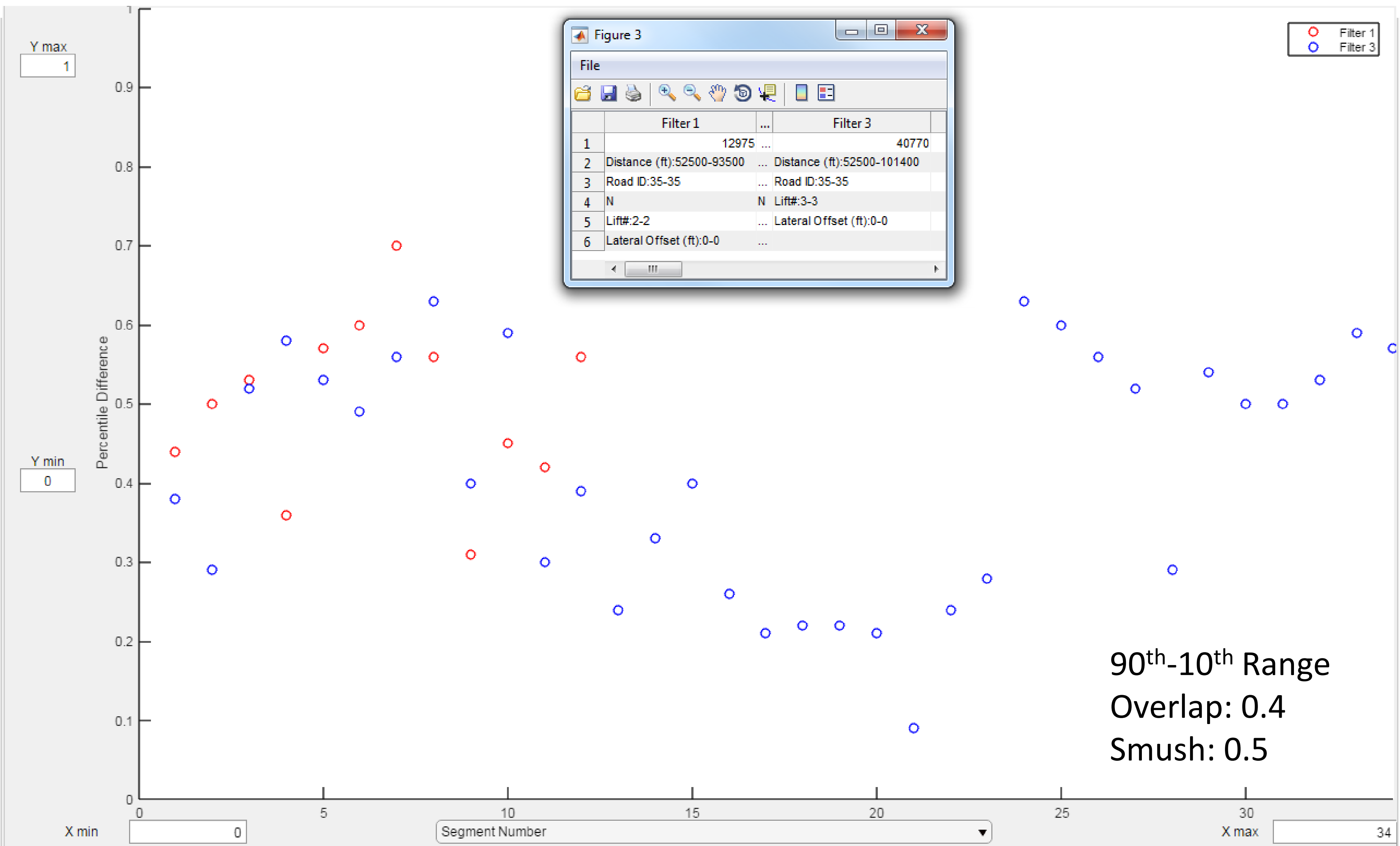
I35 Smush vs Overlap



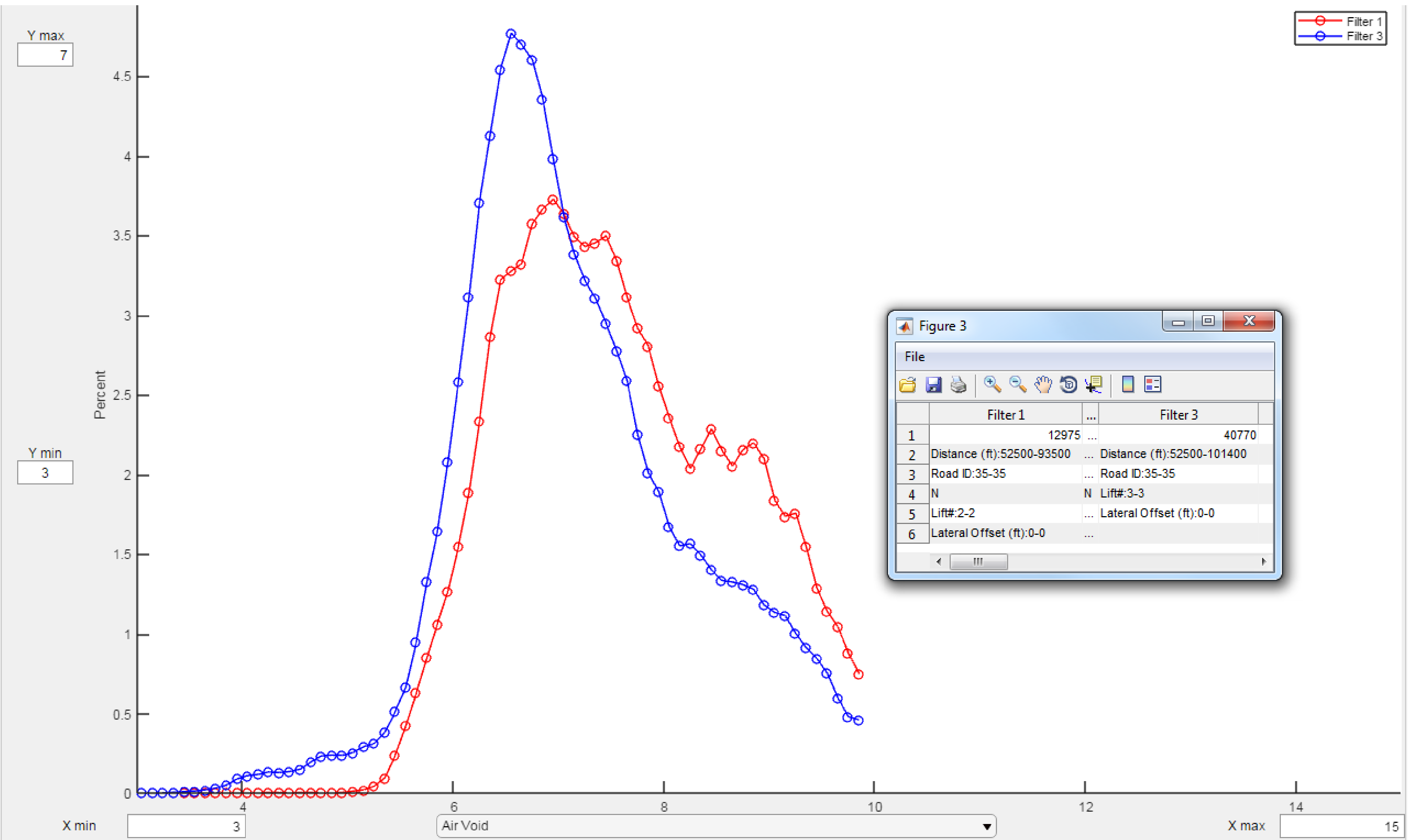
I35 Smush vs Overlap



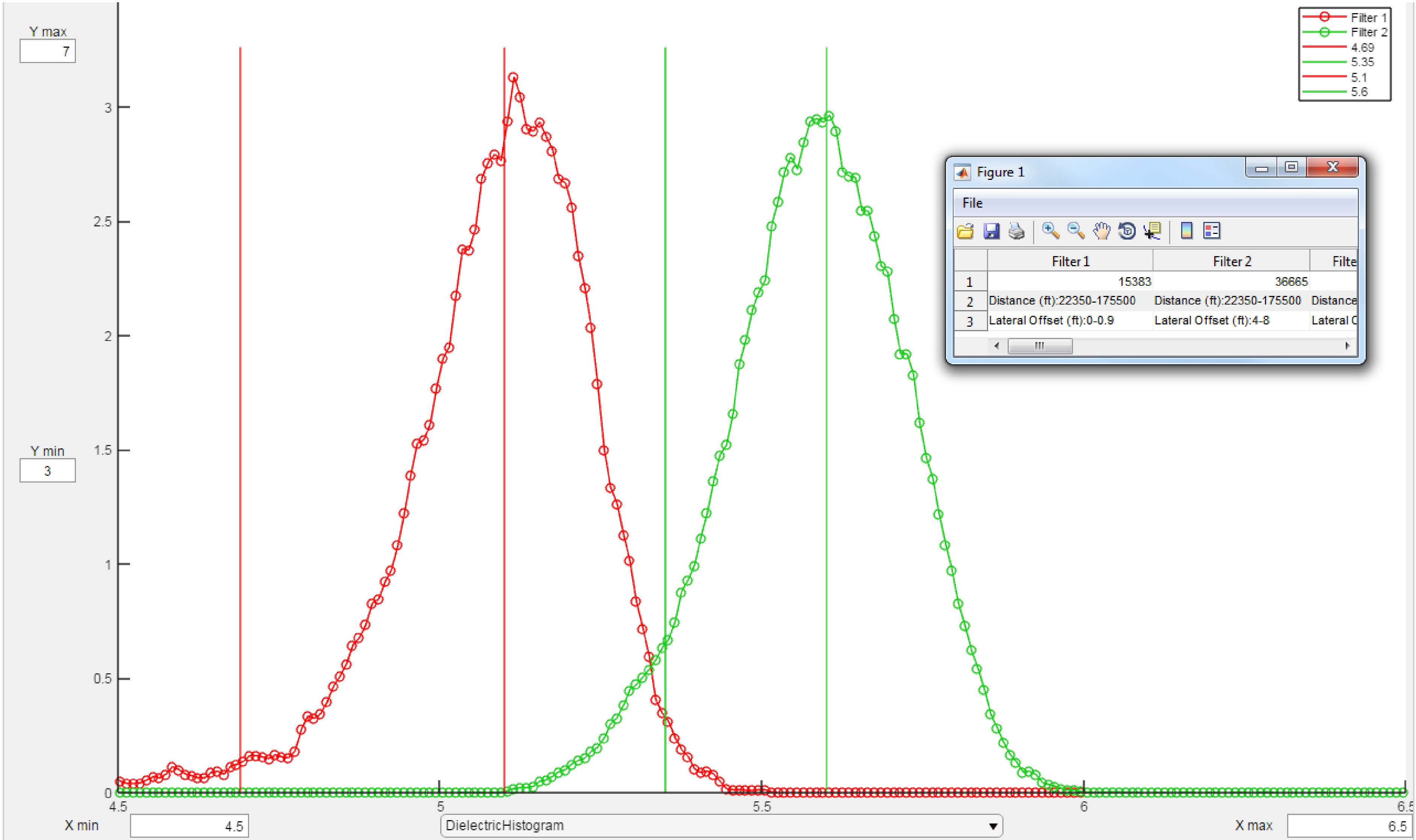
I35 Switch from “Smush” to Overlap



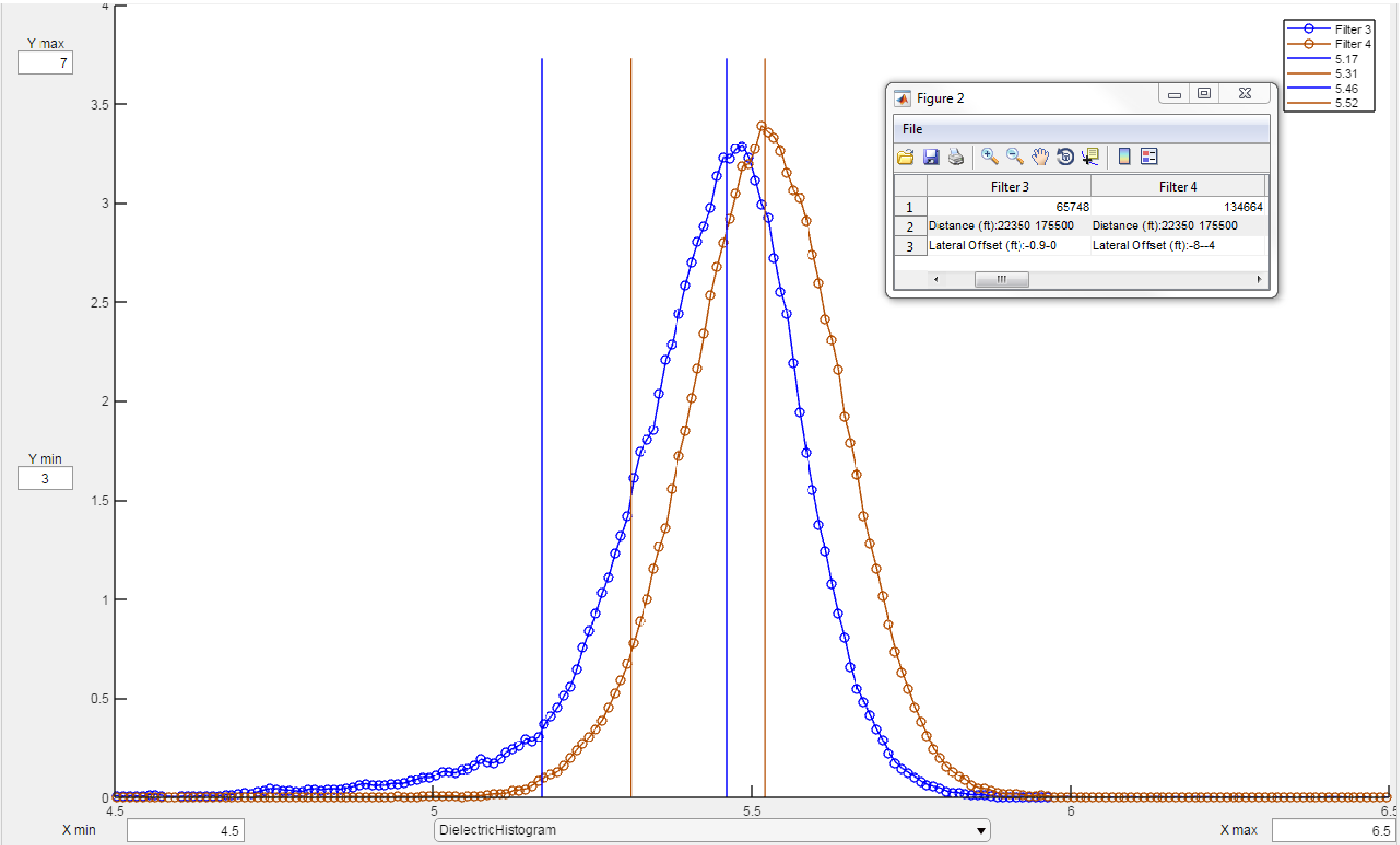
I35 Switch from “Smush” to Overlap



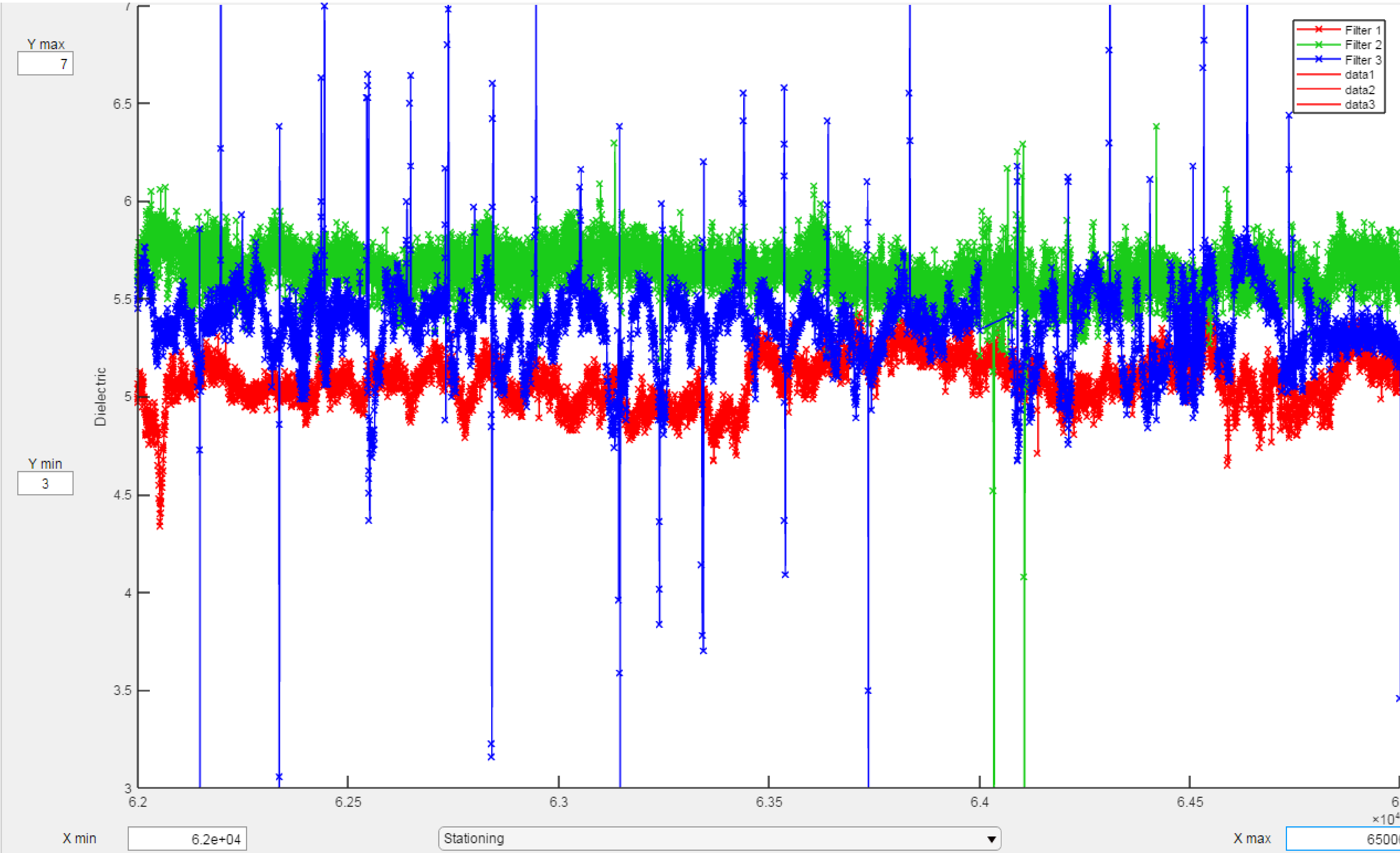
TH52N 2017: Unconfined Joint



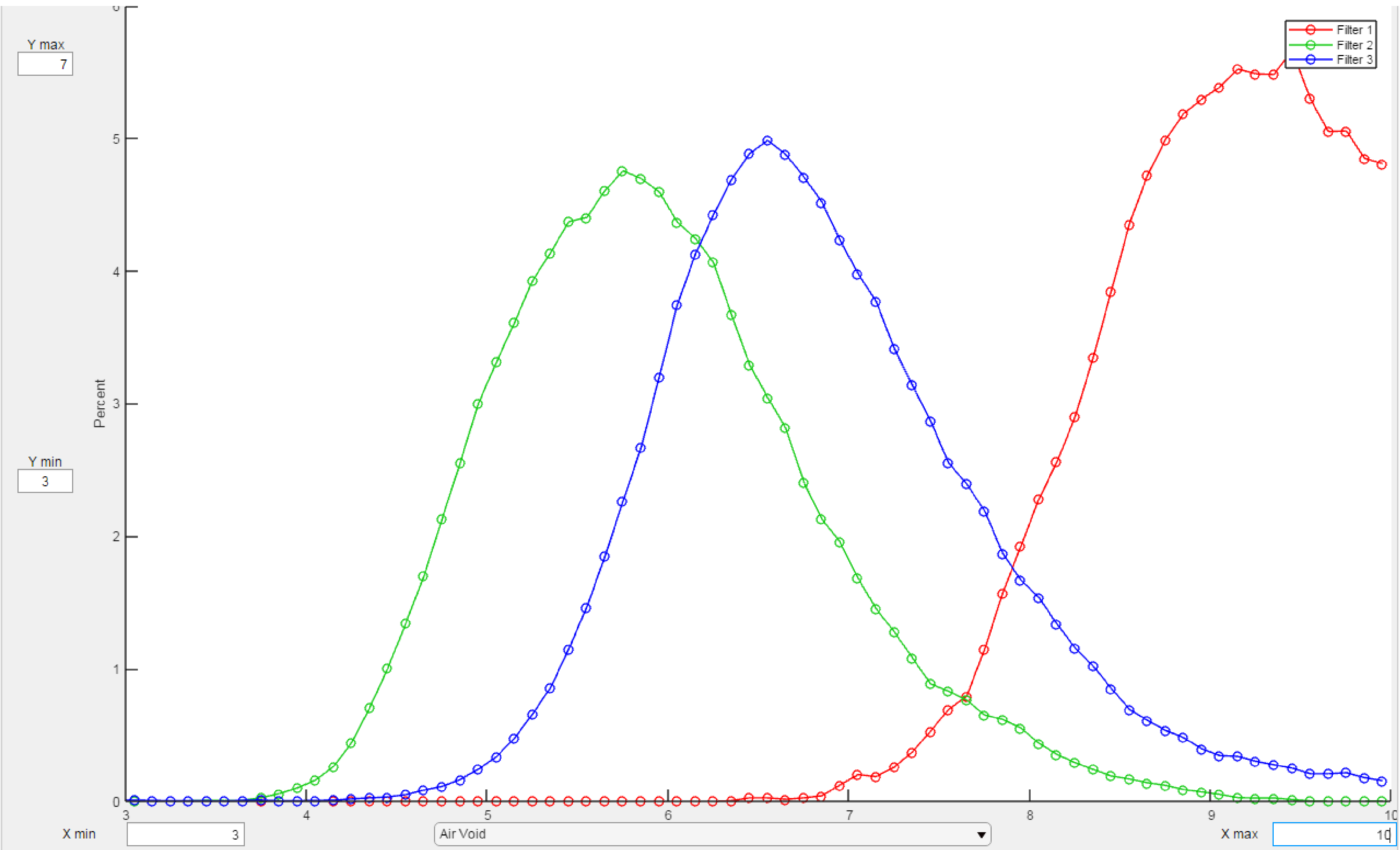
TH52N 2017: Confined Joint



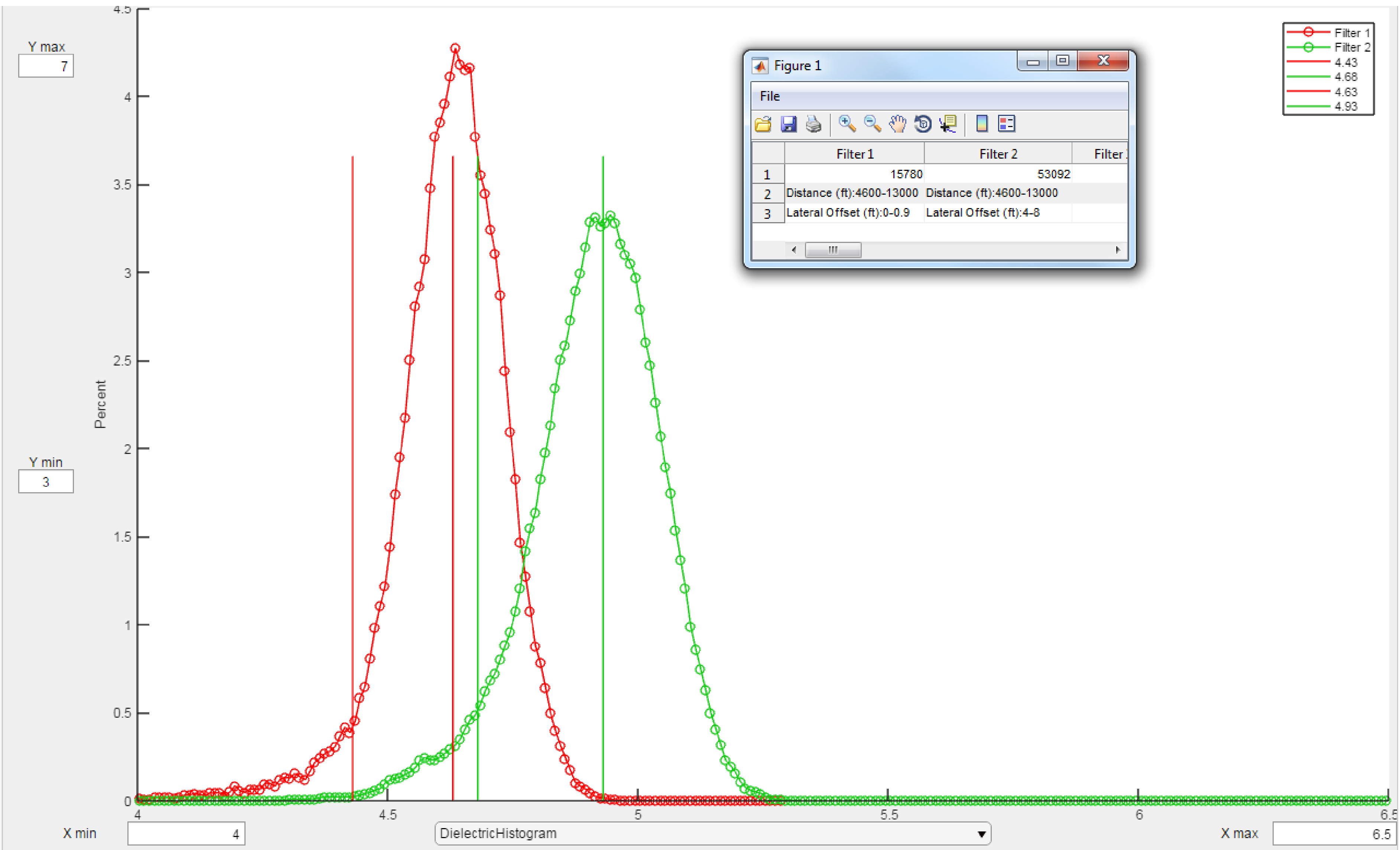
TH52N 2017: Example Scatter Plot



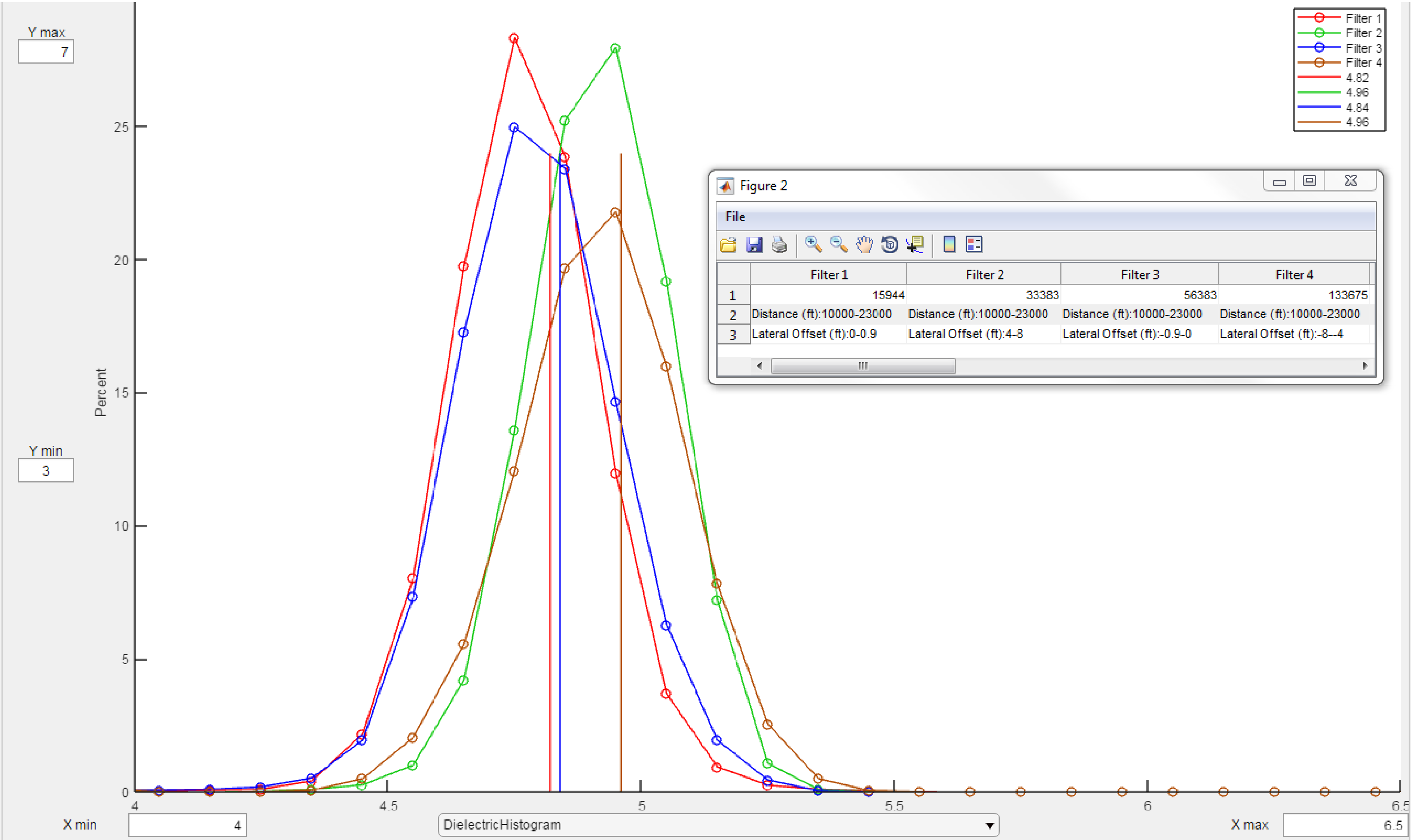
TH52N 2017: Converted to Air Voids



CSAH 86 2017: Joint vs Mainline

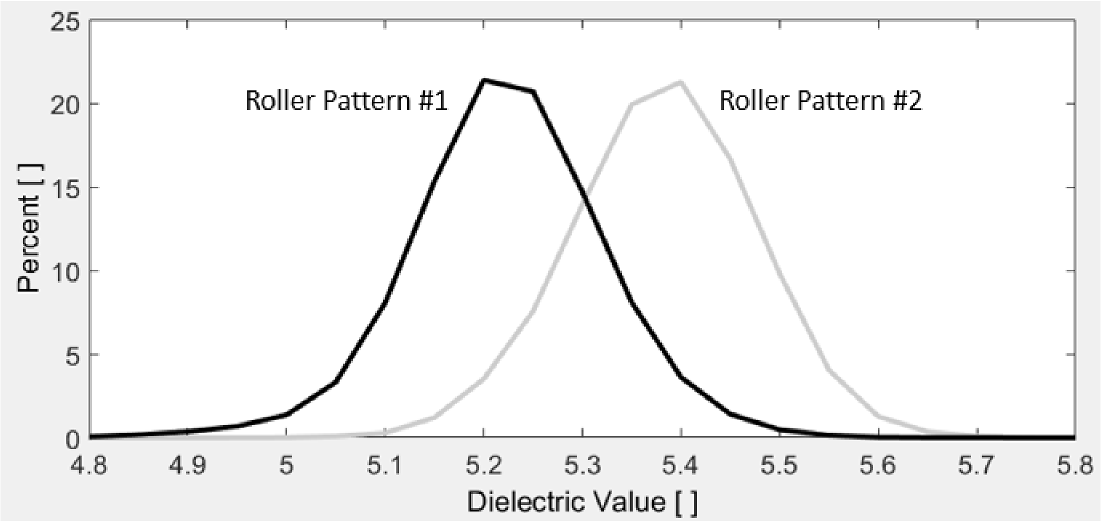


TH 110 2017: Joint vs Mainline

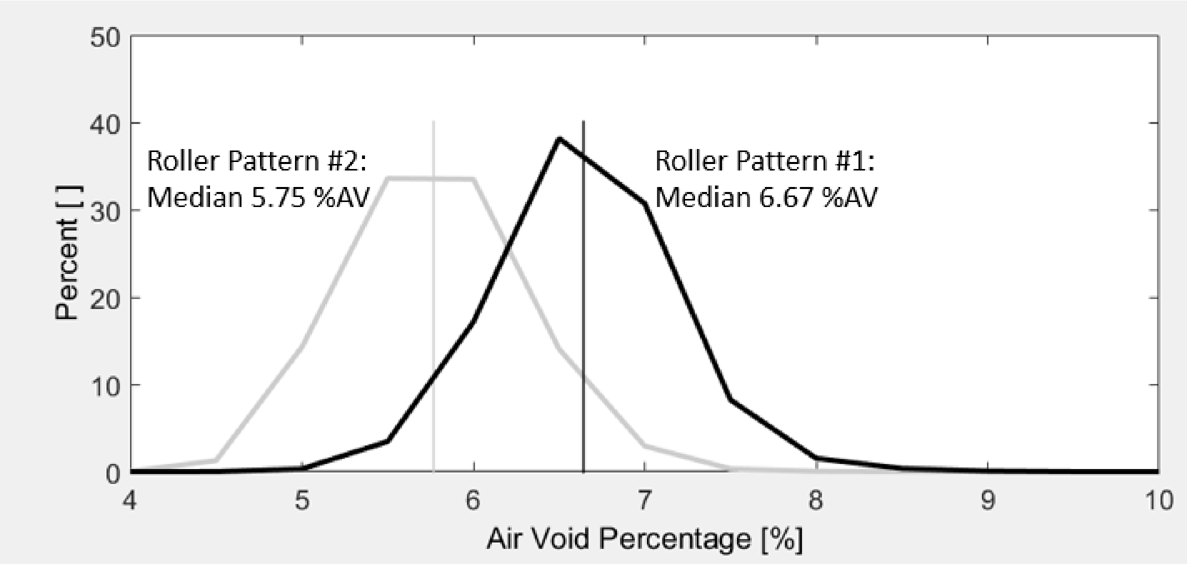


	Filter 1	Filter 2	Filter 3	Filter 4
1	15944	33383	56383	133675
2	Distance (ft):10000-23000	Distance (ft):10000-23000	Distance (ft):10000-23000	Distance (ft):10000-23000
3	Lateral Offset (ft):0-0.9	Lateral Offset (ft):4-8	Lateral Offset (ft):-0.9-0	Lateral Offset (ft):-8--4

Example Simple Use of Technology:
TH14 roller pattern #1 vs Roller Pattern #2

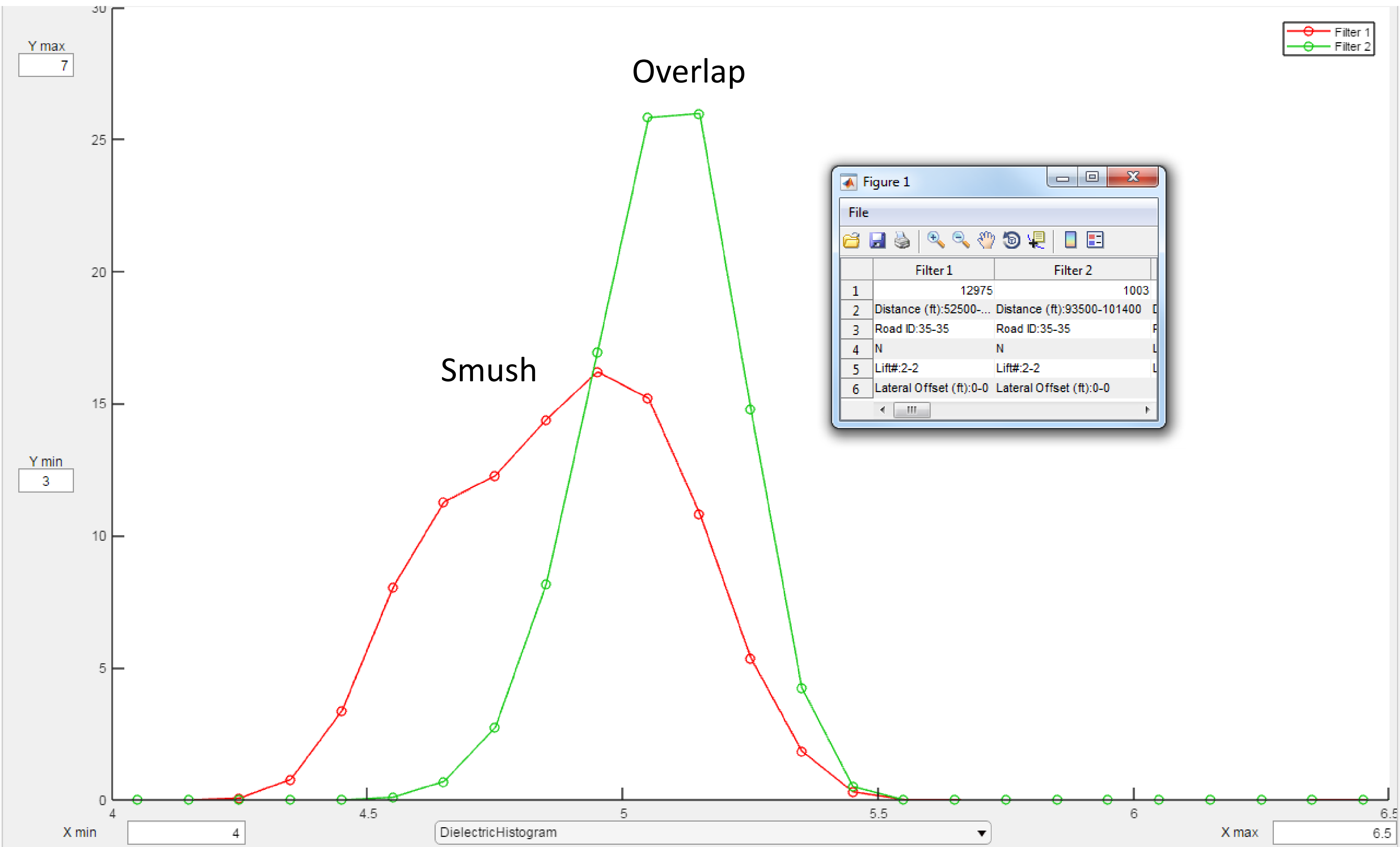


On-Site



After Core Calibration

Example Simple Use of Technology: I35 Echelon Roller Technique: Smush vs. Overlap



Summary

- RDM is a good tool for mapping a continuous coverage of the relative compaction levels (higher dielectric = higher compaction)
- Histograms and general statistics can be used to give a complete assessments of the in-place compaction
- Potential Improvements

- **Reduce need for field cores**
  - Calibrate based on plant mix material
  - Sensitivity study to determine mix changes/tolerance levels that trigger need for recalibration
  - Percentile/PWL type approach
- **Items previously listed for previously listed for discussion**