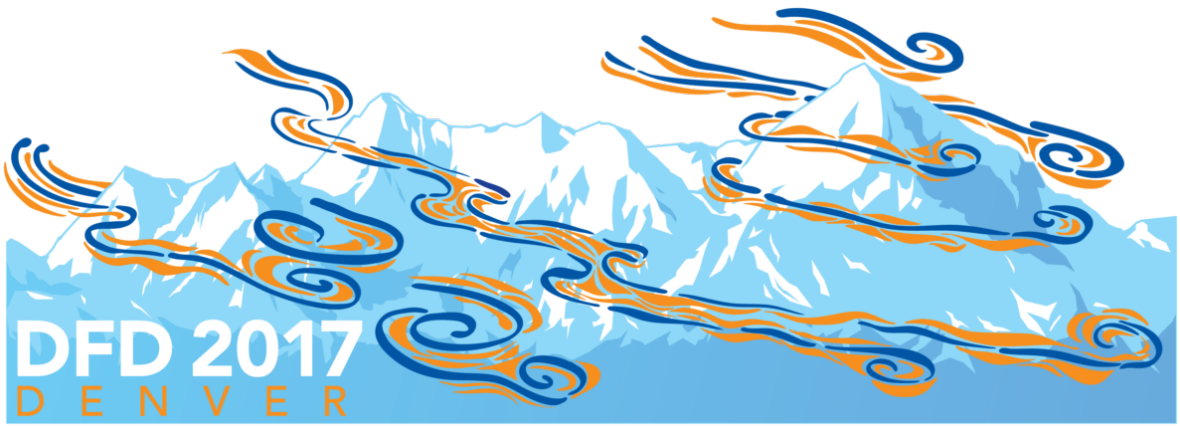
High-Fidelity PIV of a Naturally Grown High Reynolds Number Turbulent Boundary Layer

D. Biles, C. Klewicki, N. Marino, C. White, J. Klewicki, G. Chini
University of New Hampshire



20 November 2017

University of New Hampshire

Objectives / Motivation

- Develop high fidelity measurement system
- Examine high Reynolds number data for the existence of uniform momentum zones (UMZs) and vortical fissures (VF)
- Statically characterize the UMZ/VF observed from the flow to inform reduced order models

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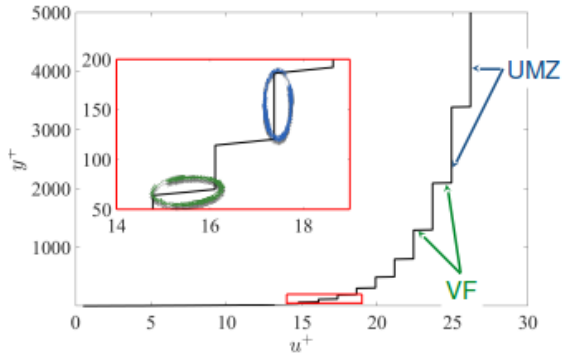

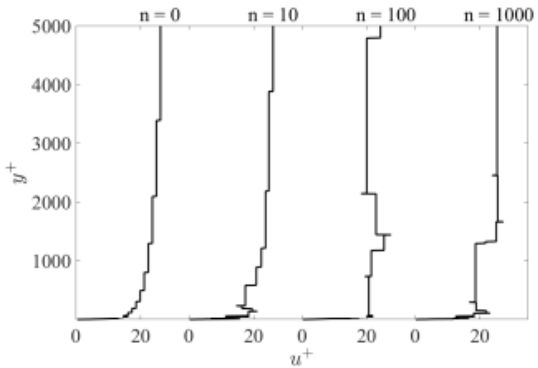

Q28.12, Tuesday 15:13 rm 207,
Vortical step mode of the turbulent boundary layer.
A. Ebadi, J. Cuevas Bautista,
C. White, G. Chini, J. Klewicki

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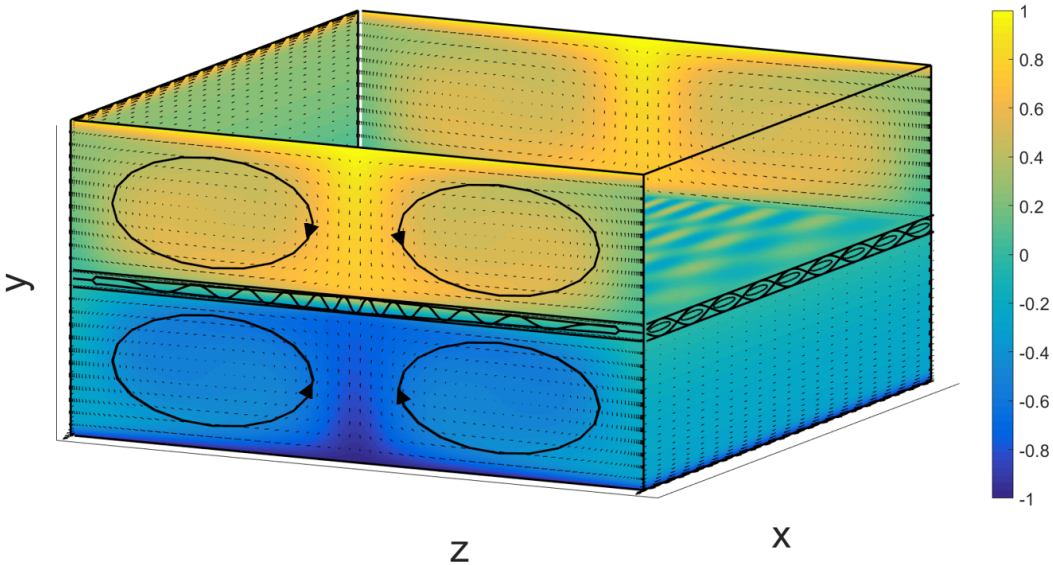
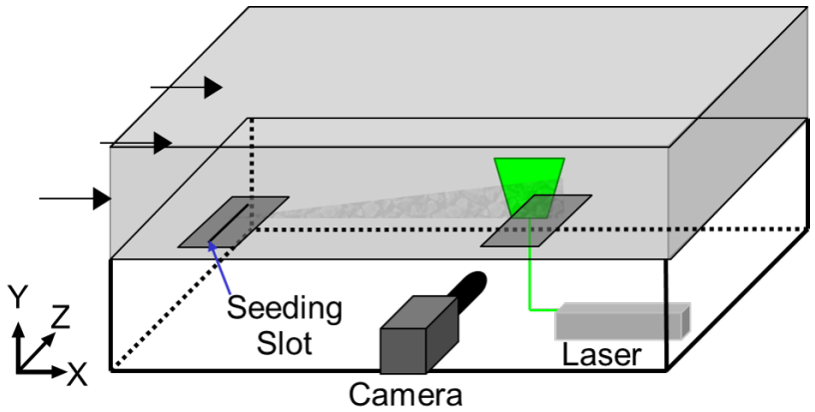


Q28.06, Tuesday 13:55 rm 207,
Viscous versus inviscid exact coherent states in high Reynolds number wall flows.
B. Montemuro, J. Klewicki,
C. White, G. Chini

PIV System: Overview



Seeding Mechanism

- $6mm$ slot width
- $1m$ slot length
- Slot angle 60^o
- Dispersive inlet manifold

High Speed Camera

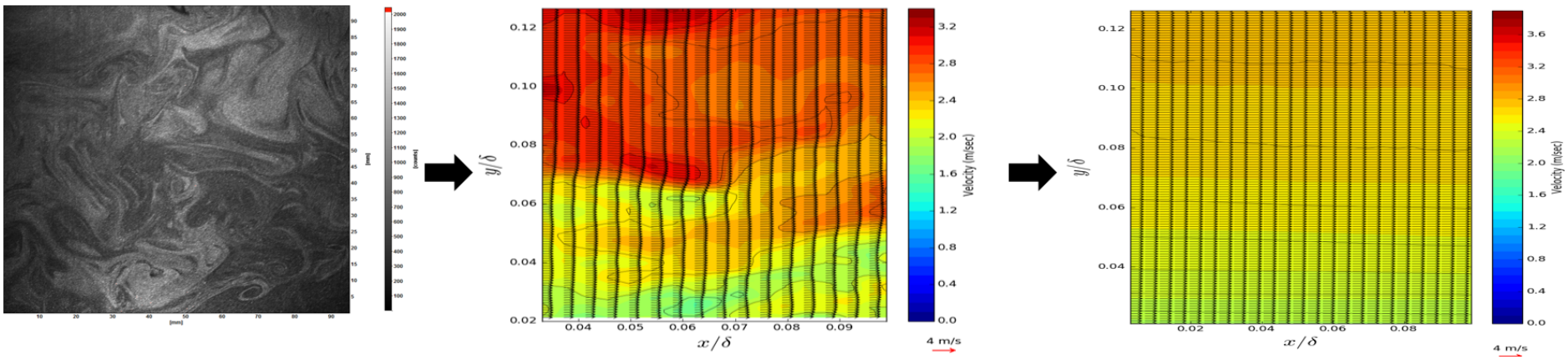
- Photron Fastcam SA4
- CMOS - 12bit
- FOV: $95mm$ x $95mm$
- Magnification: 4.6 : 1
- 1024 x 1024 pixels
- $3.6kHz$ at full FOV

High Speed Laser

- Photonics Nd:Ylf Laser
- $14m$ from injection slot to FOV

Flow Physics Facility

Experimental Overview



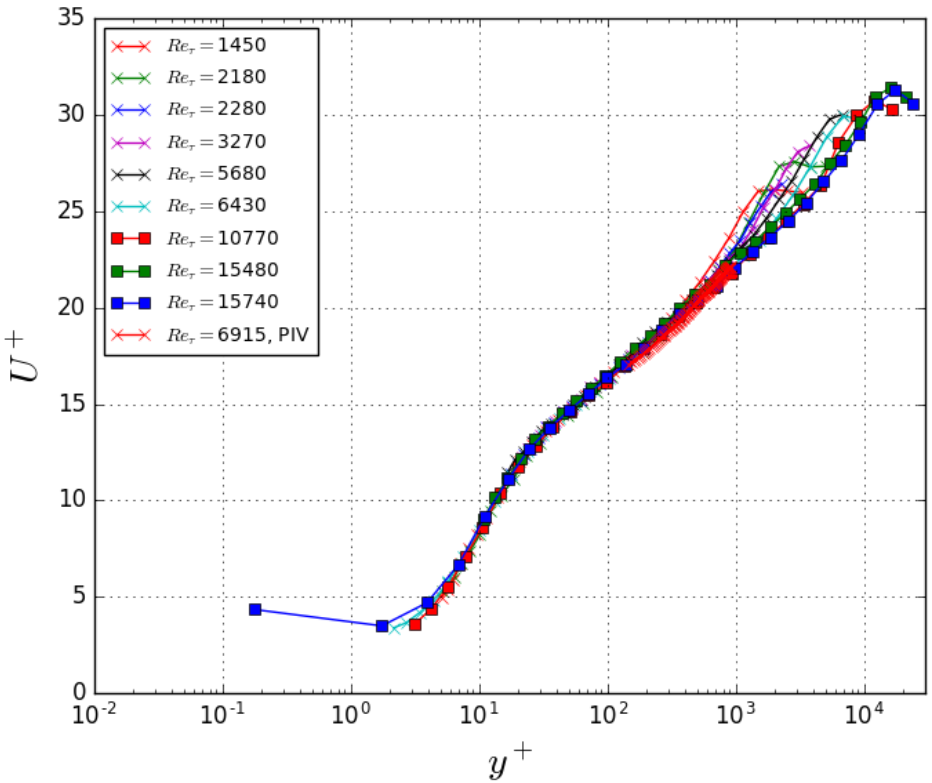
Experimental Parameters

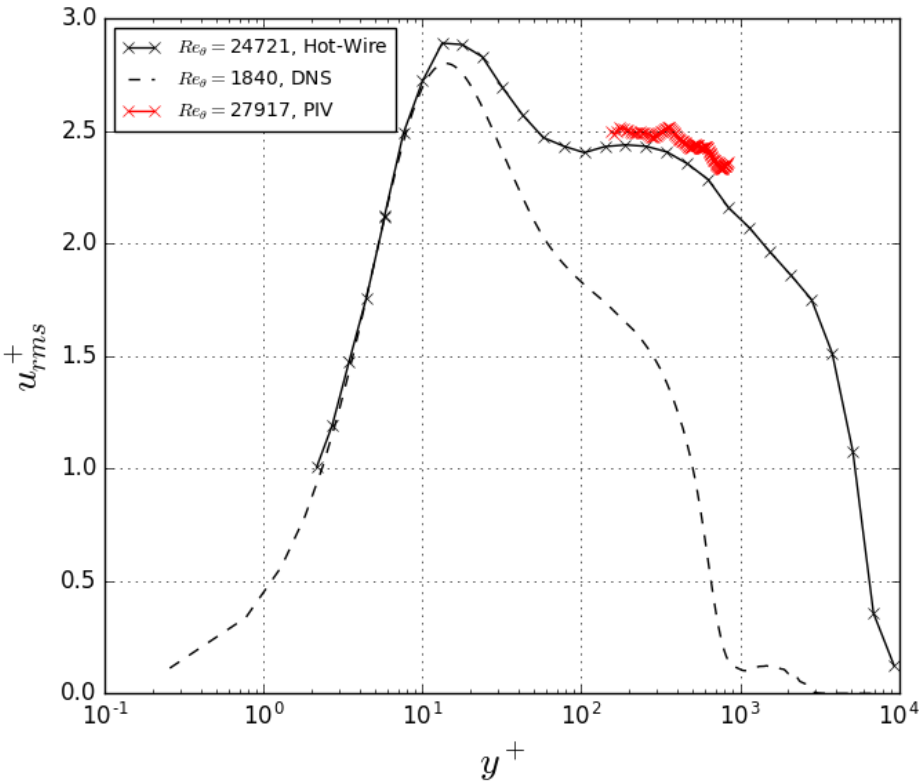
- $Re_{\delta^+} = 6900$
- $x = 59m$
- Frame rate $= 1kHz$
- FOV: 800 x 800 viscous units
- Resolution $= 8y^+$

Vector Calculation Parameters

- Pre-Processing: count normalization
- Processing: multi-pass decreasing int. area technique
- Post-Processing: STD filter for spurious images and vectors

Velocity Validation





$$y^+ = \frac{y u_\tau}{\nu},\ U^+ = U/u_\tau$$

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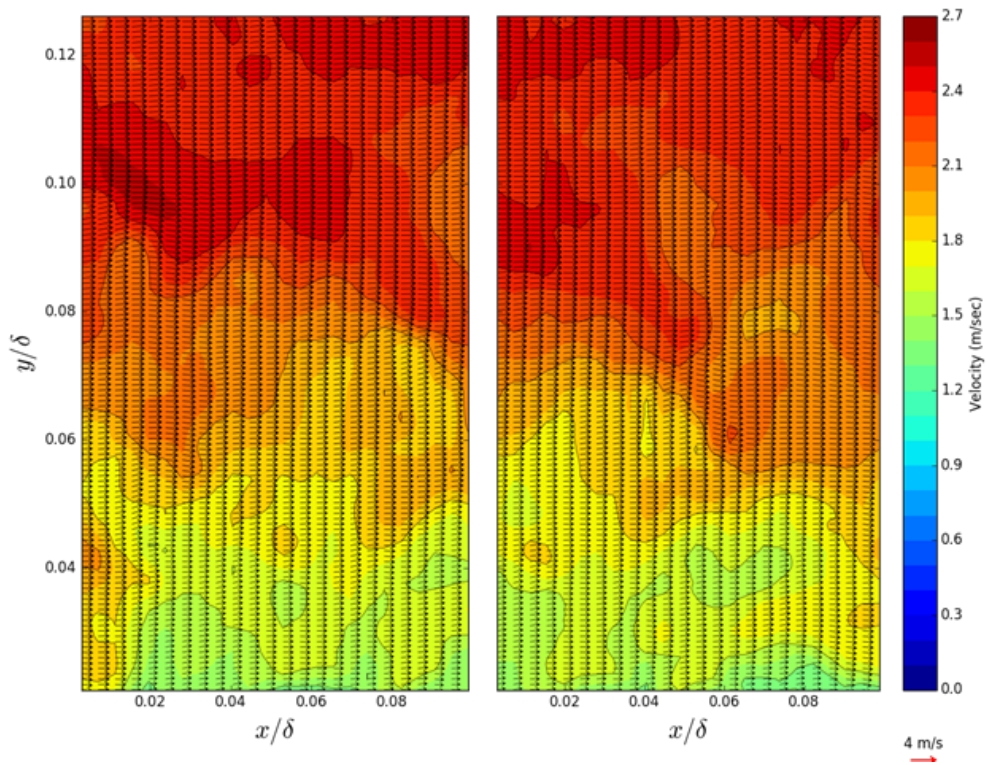
Temporal Stitching

- Utilize high temporal resolution to "stitch" vector fields in time following a Taylors frozen flow hypothesis.
- Following R. Mejia-Alvarez *et al.* (2014), mathing is performed by minimizing rms error between figures: $\epsilon_{rms}(t) = \sqrt{\frac{1}{NxM}\sum_{i=1}^{N}\sum_{j=1}^{M}(u_{ij}(t) - u_{ij}(t+\Delta t)^2}$



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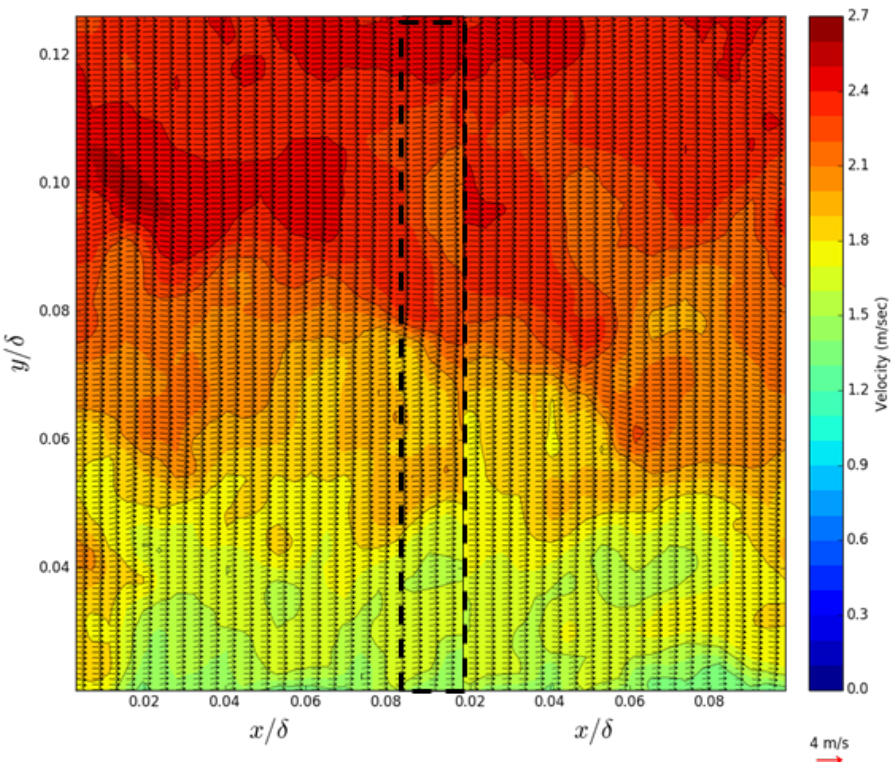

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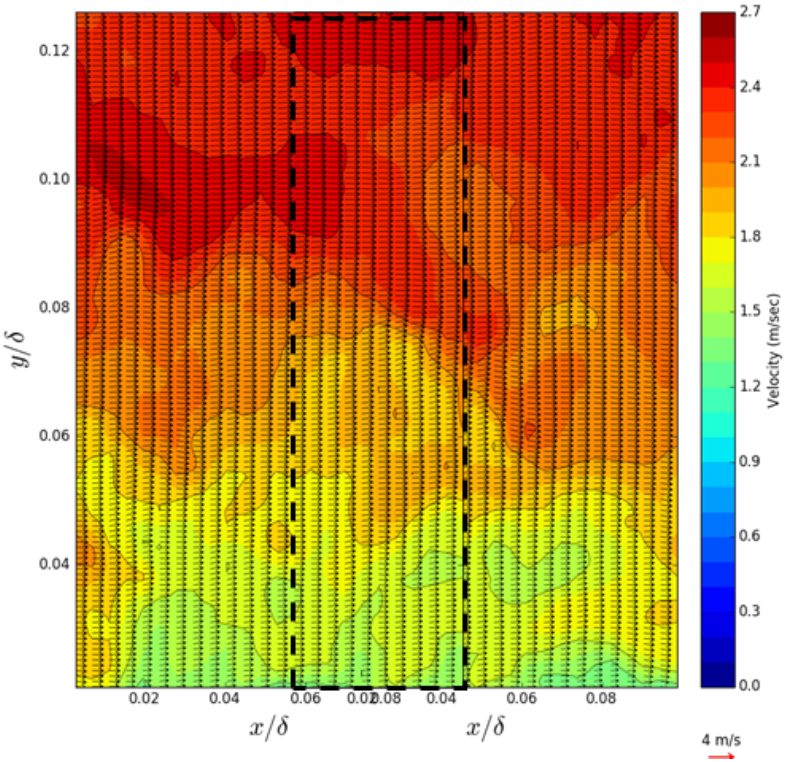

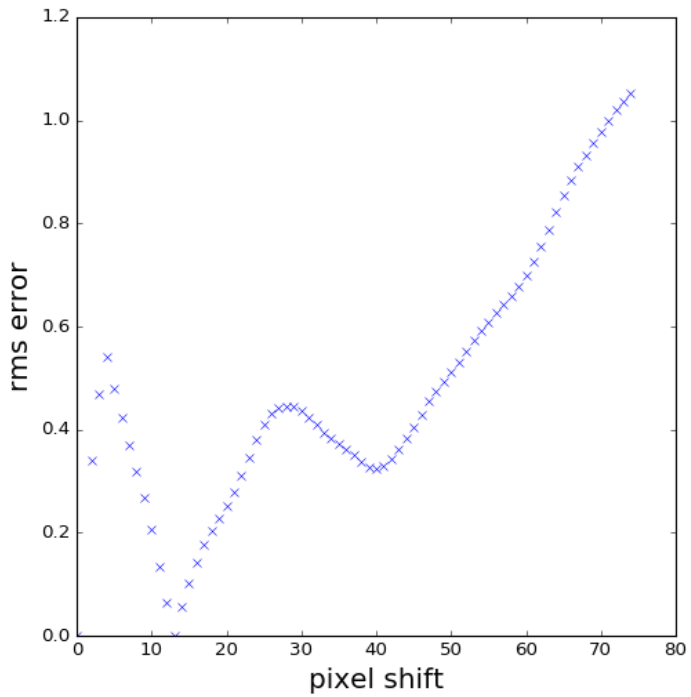

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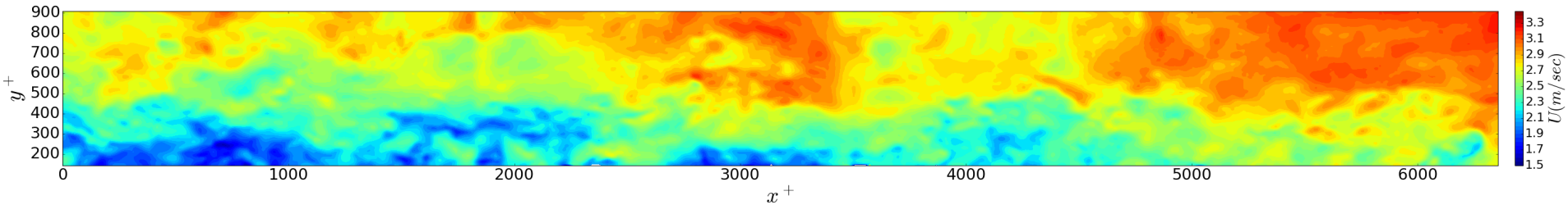
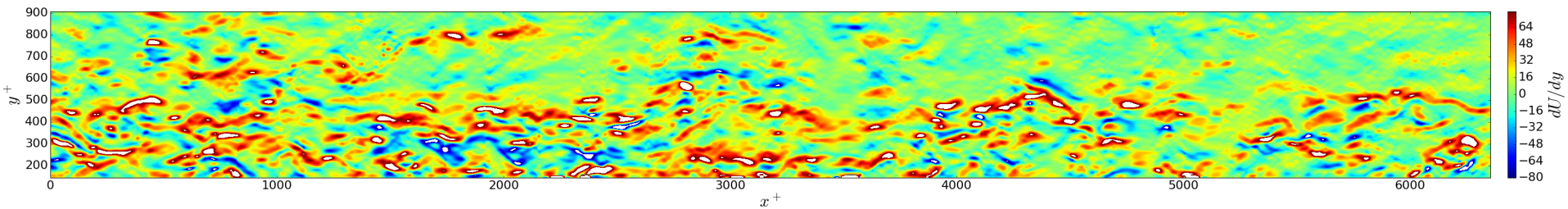
Large FOV Fields



- 10 HFR-PIV images are stitched together to create a streamwise FOV δ



- Computed dU/dy utilizing a Richardson non-unifrom method

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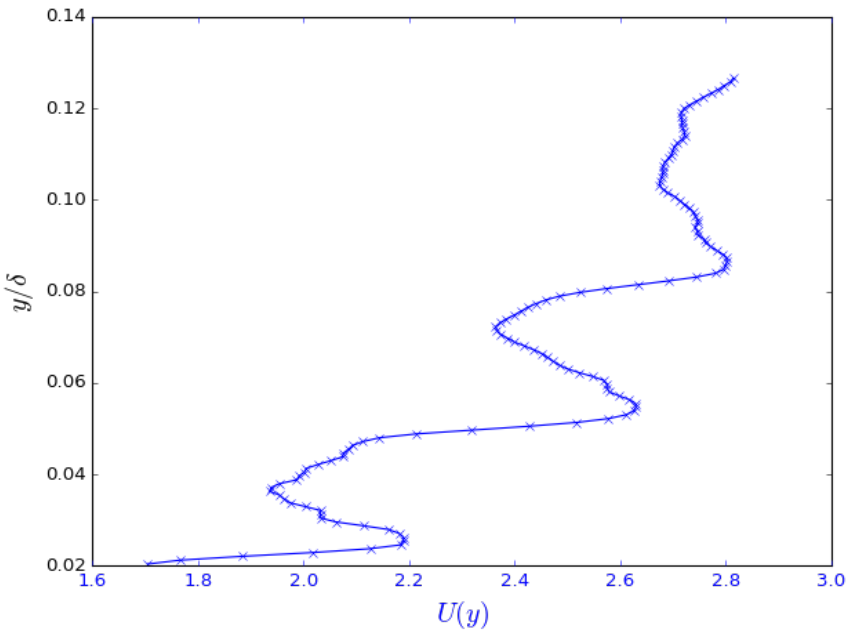
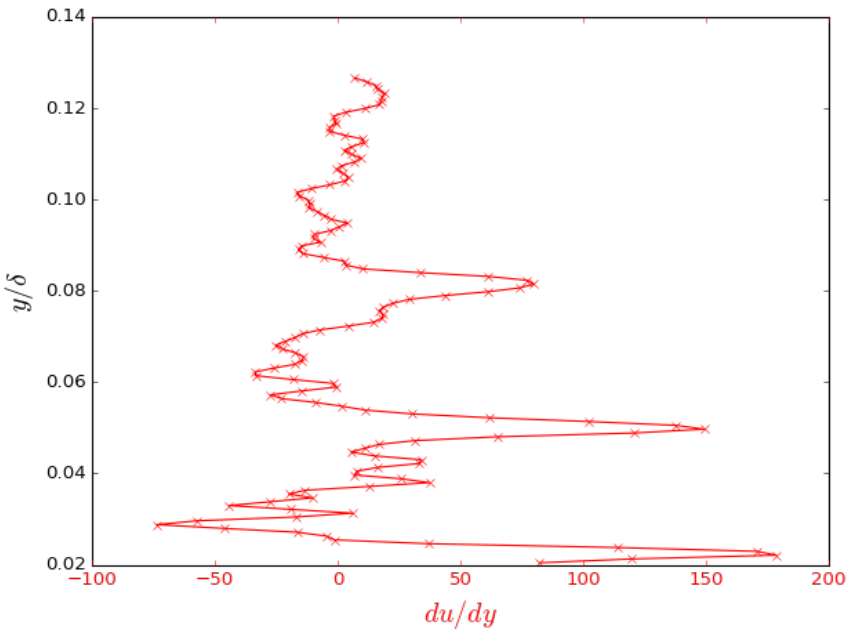
Uniform Momentum Zones(UMZ) and Vortical Fissure (VF) Detection





- Instantaneous profiles for $U(y)$ and dU/dy.

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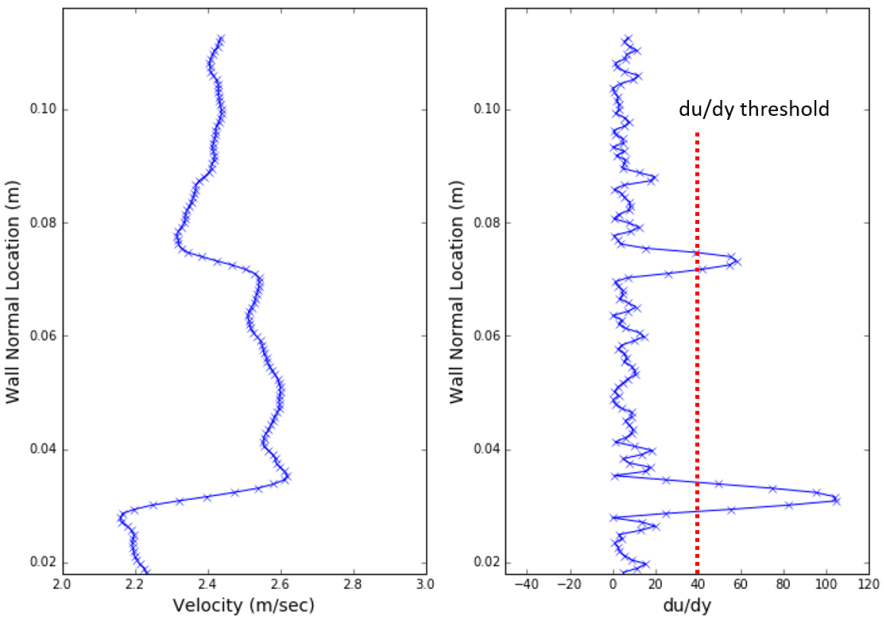
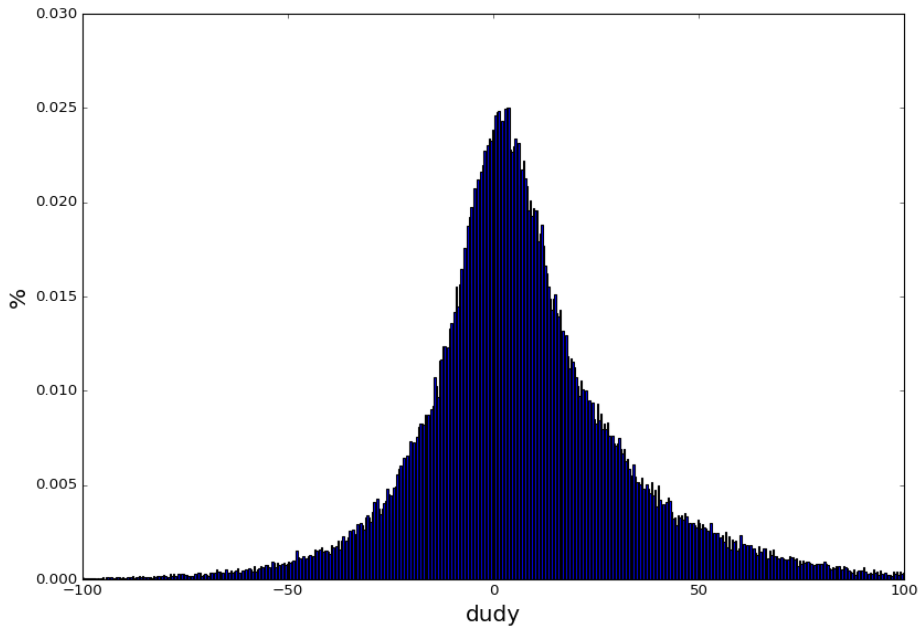
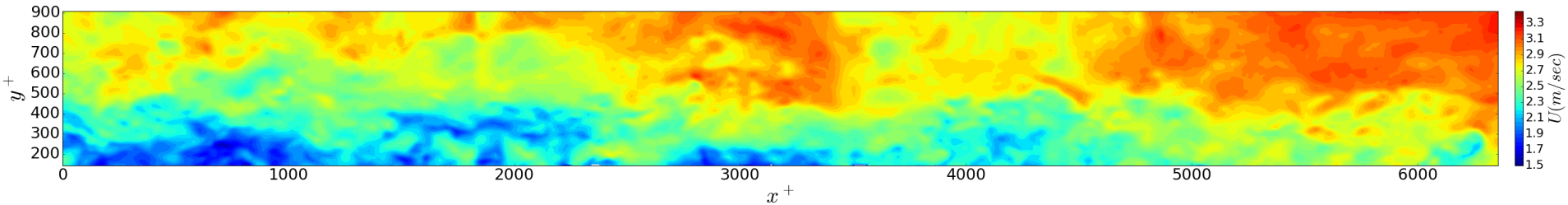




- By taking the value at σ, a threshold of $dU/dy = 40$ can be used to run a detection algorithm.

UMZ/VF Detection



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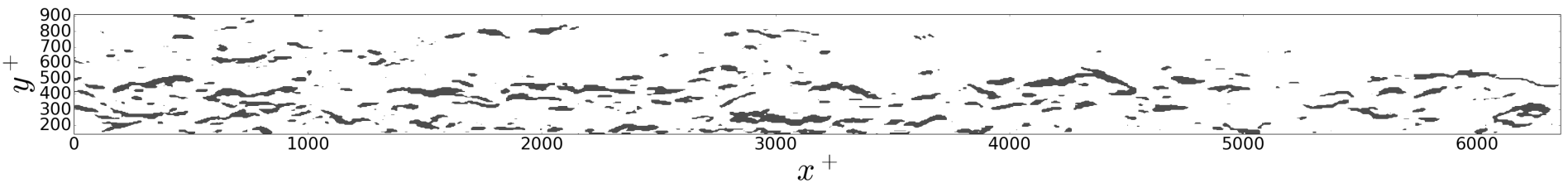

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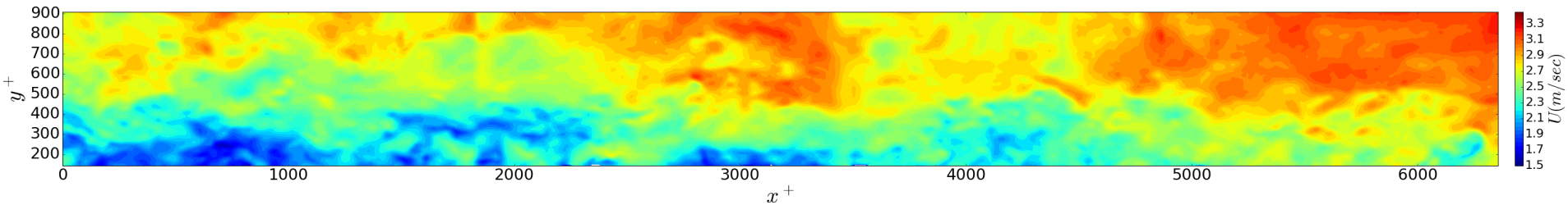
UMZ/VF Detection



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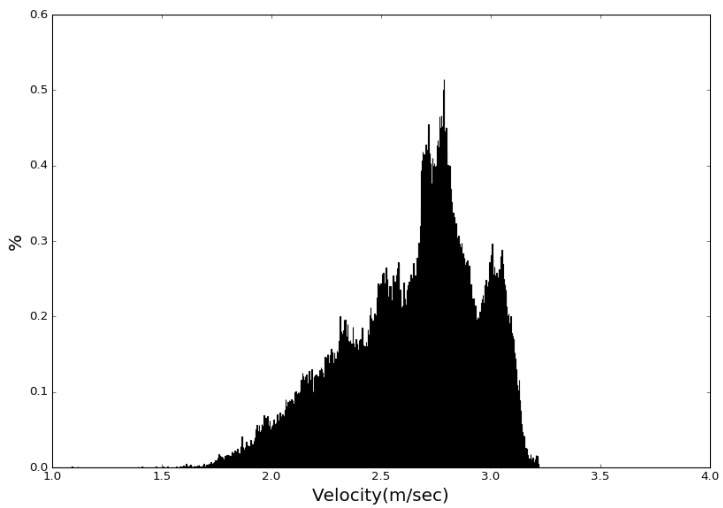

- Categorize velocity at current FOV to search for groupings of velocity.

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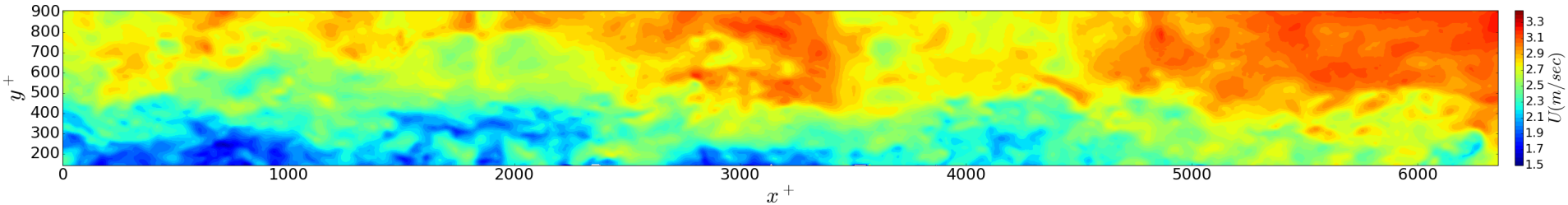
UMZ/VF Detection



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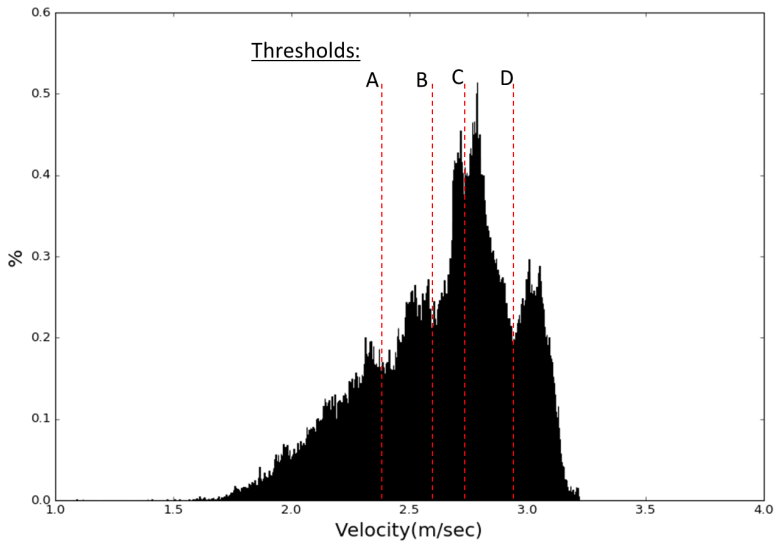

- Categorize velocity at current FOV to search for groupings of velocity, which has been utilized previously be de Silva *et. al(2017)*

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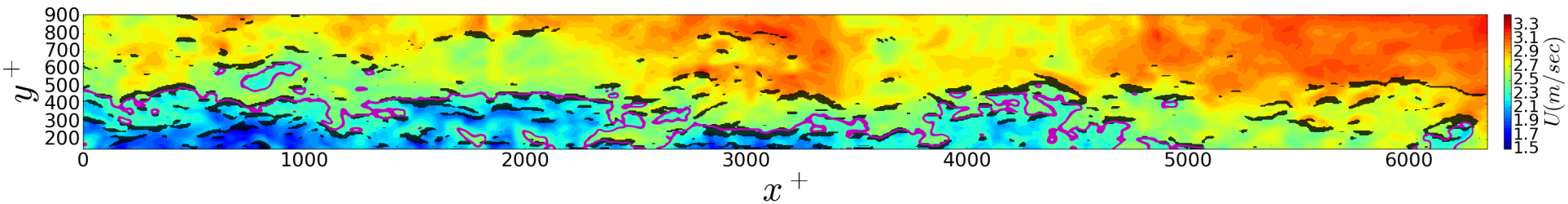
UMZ/Vortical Fissures Description

- Threshold A



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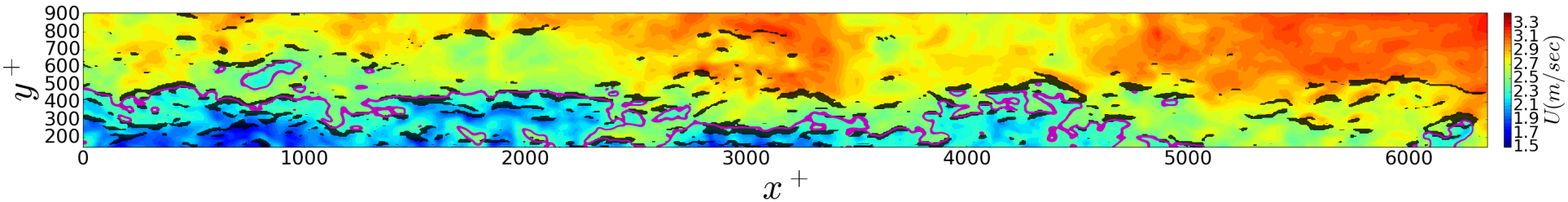
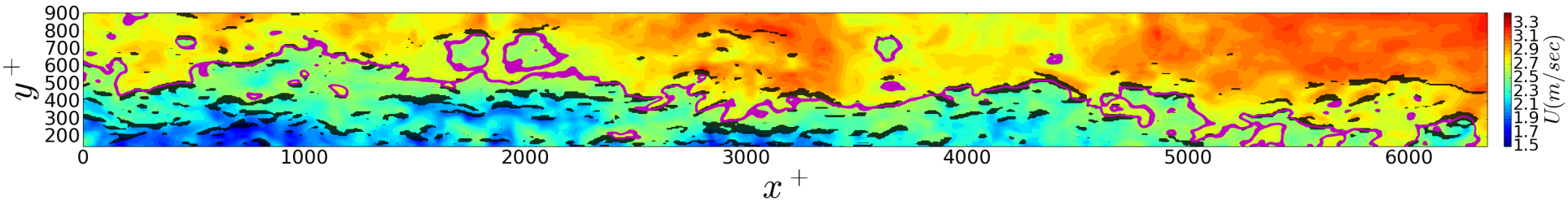


- Threshold B



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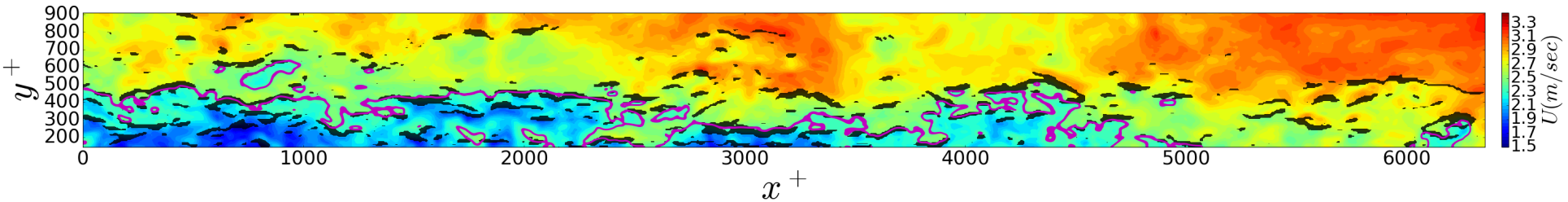
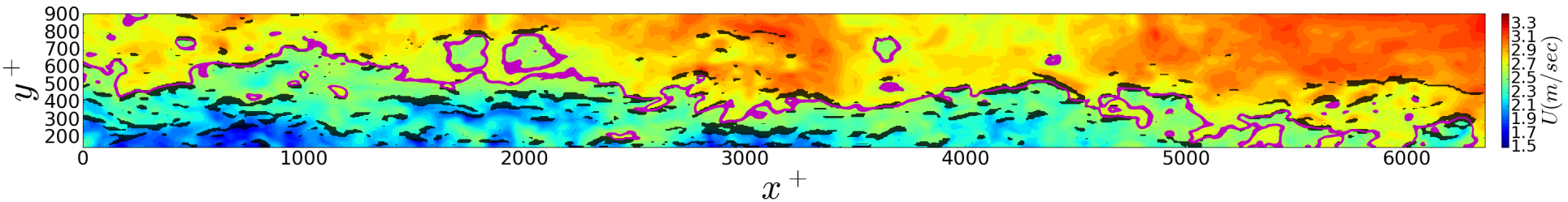
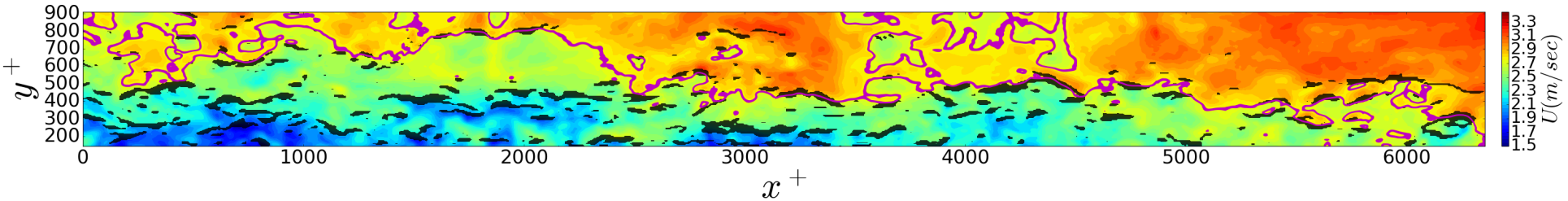


- Threshold B



- Threshold C



UMZ/Vortical Fissures Description

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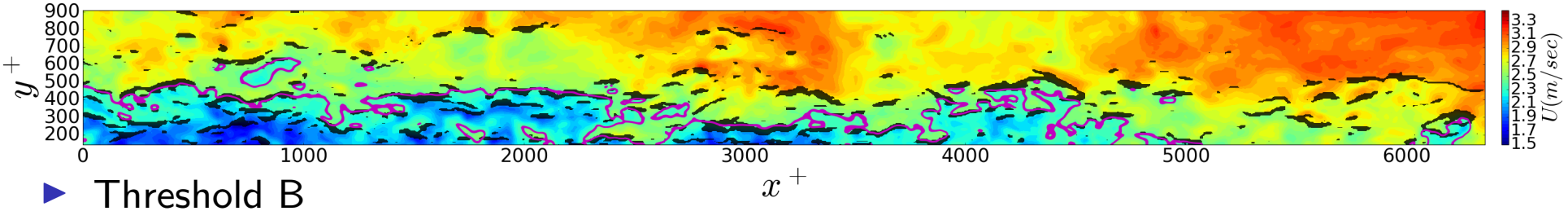
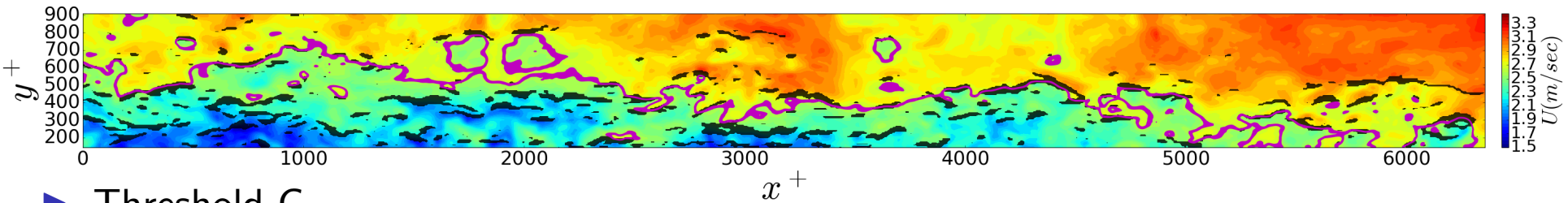
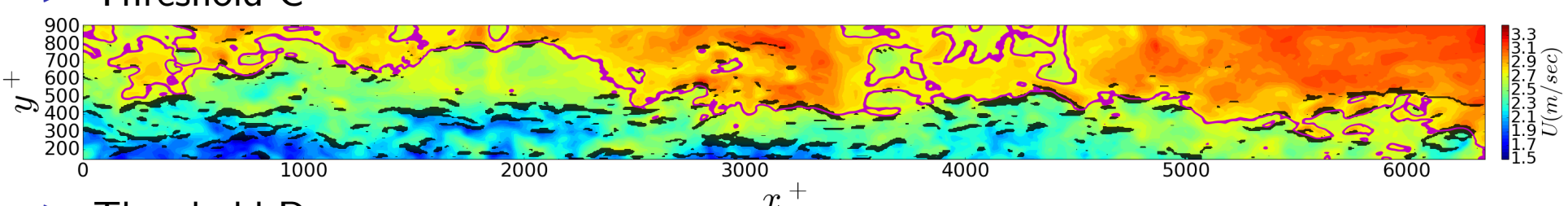


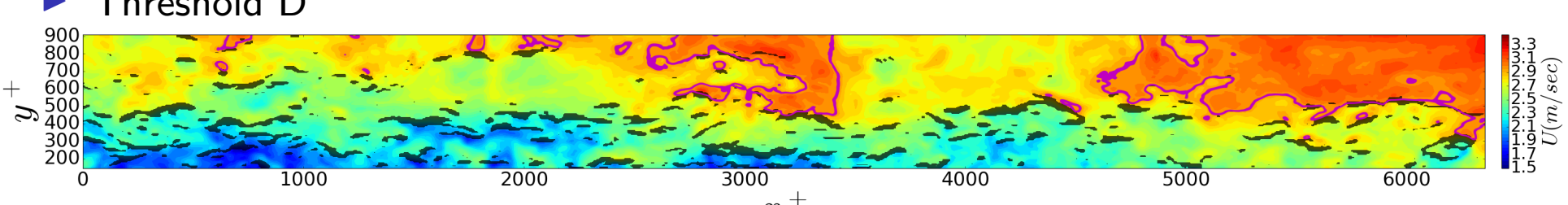
- Threshold B



- Threshold C



- Threshold D

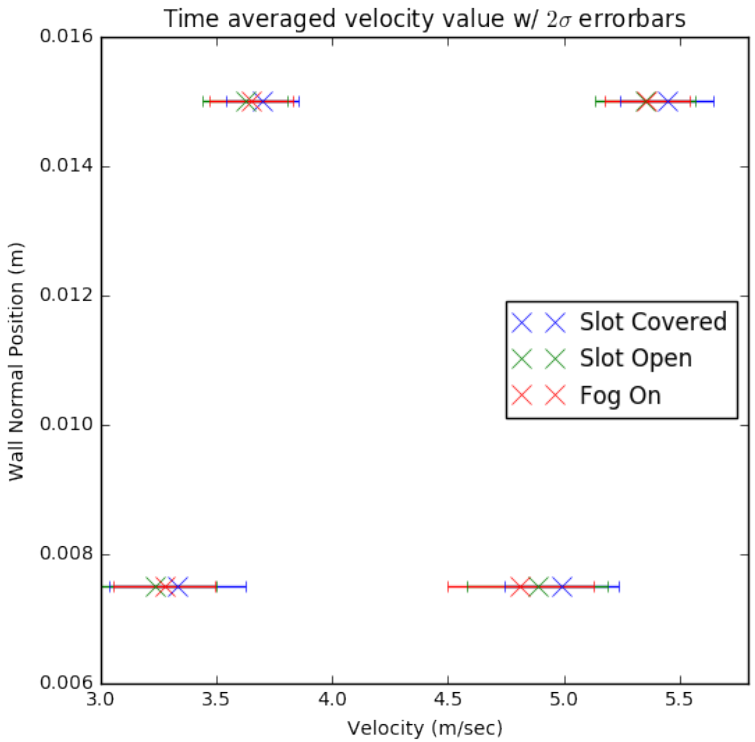


Summary and Conclusions

- HFR-PIV measurements of a turbulent boundary layer at high Reynolds number have been acquired in the FPF at UNH.
- Identified UMZ/VF behavior at high Reynolds number
- Vortical fissures have been detected and are distributed across the FOV examined with a slight bias towards lower wall normal locations.
- Uniform momentum zones (UMZ) were identified using the histogram method. The interface between adjacent UMZ correlate well with regions of large dU/dy.

Thanks for your attention!

Supporting Slides



- By taking multiple single point measurements at a range of flow speed it can be said that the effects induced by the slot do not significantly alter the momentum field at the measurement location.

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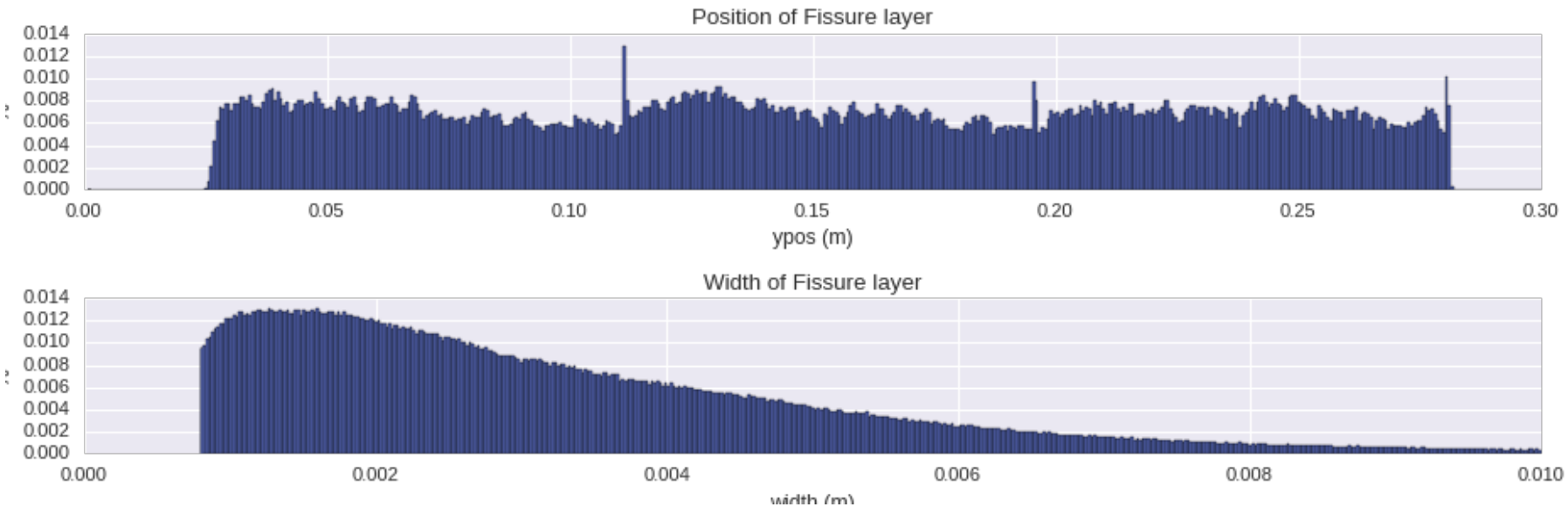
Supporting Slides



- Threshold value of 20 ($1/2\sigma$)

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