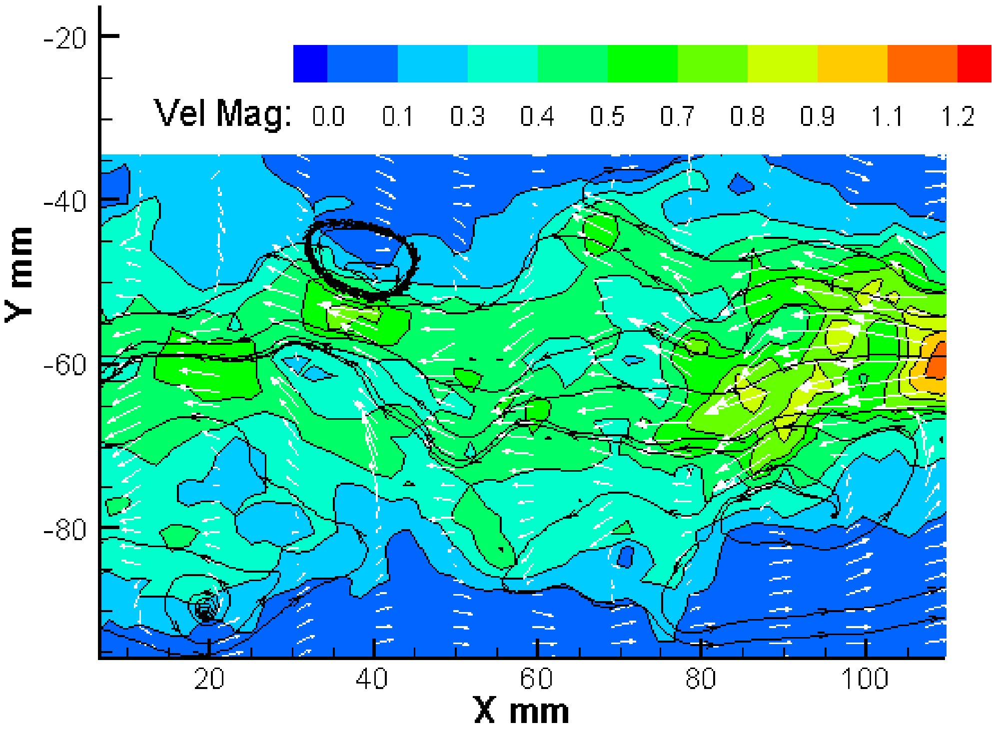
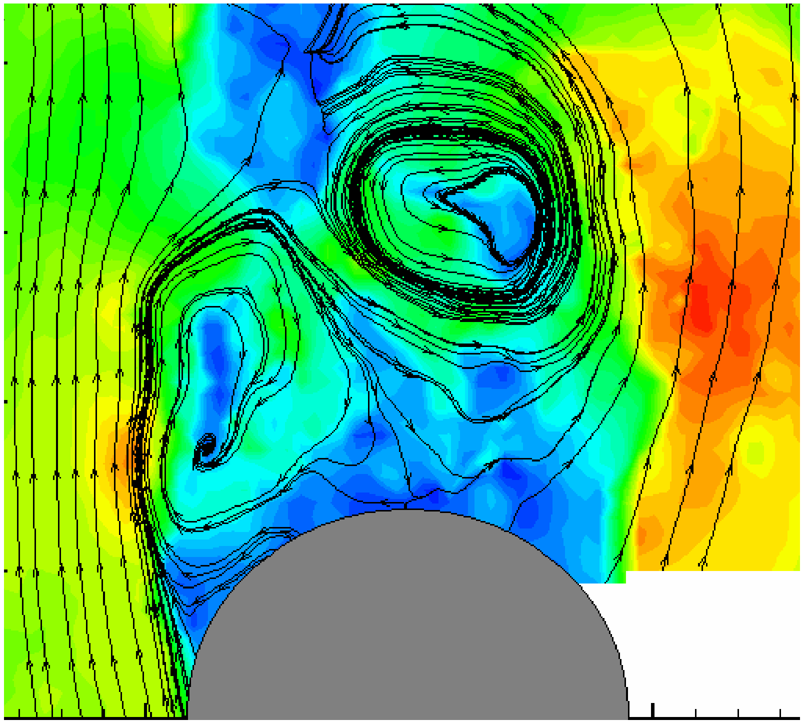
Tutorial for Processing PIV Images





TSI Incorporated

Introduction

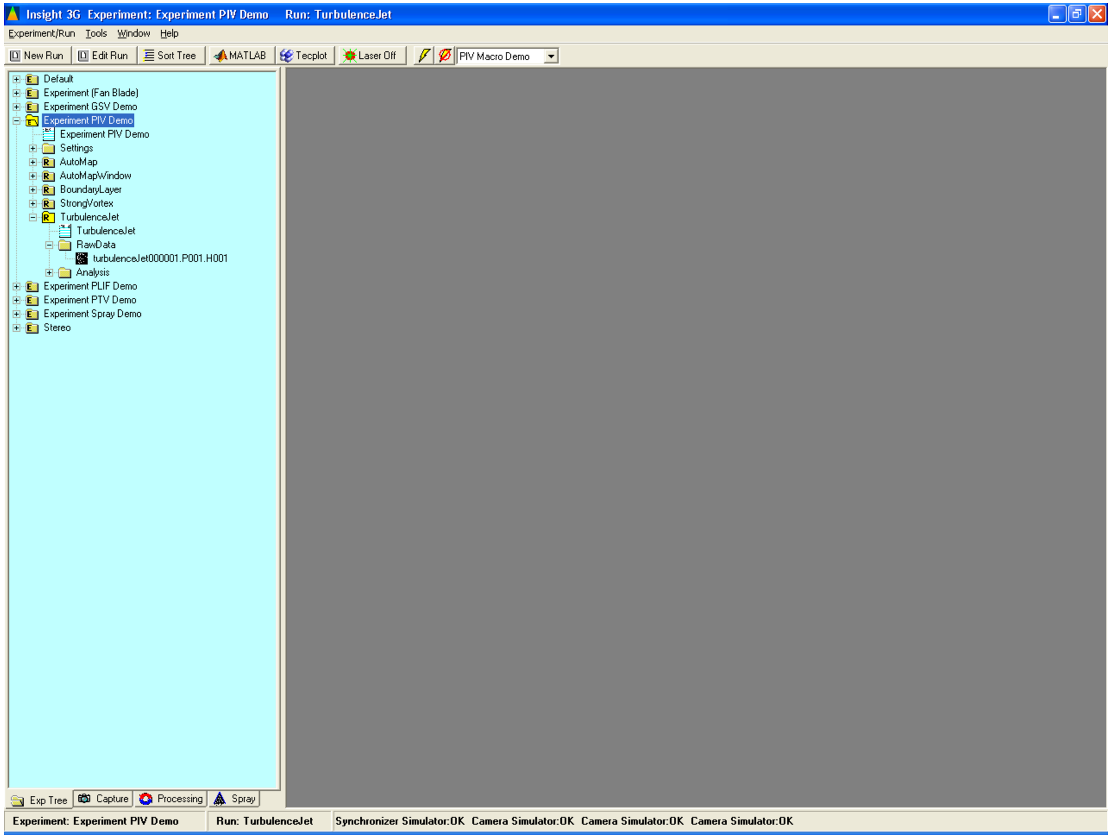
•***Interpreting PIV data can be a daunting task***, given the number of processing algorithms available. Even within one commercial software package such as TSI's INSIGHT3G, there are over 100 possible combinations of the Grid Engine, Spot Mask Engine, Correlation Engine, and Peak Engine, not to mention the choice of interrogation window spot size, and the maximum displacement.

•This tutorial is by no means meant to cover every possible combination. Only experience, extensive study of the papers and literature, and "getting your hands dirty" will give you the knowledge to know which algorithms work best under which circumstances.

•That being said, this tutorial *is* meant to give the PIV user a tool to begin to understand a couple of the most commonly used algorithms for processing PIV data, and an understanding of how they are different, and when it is most beneficial to use them. Keep in mind that the explanations presented here are based on the research and studies found in published works, and therefore, please refer to the references section at the end of the tutorial for more details on the ideas presented herein.

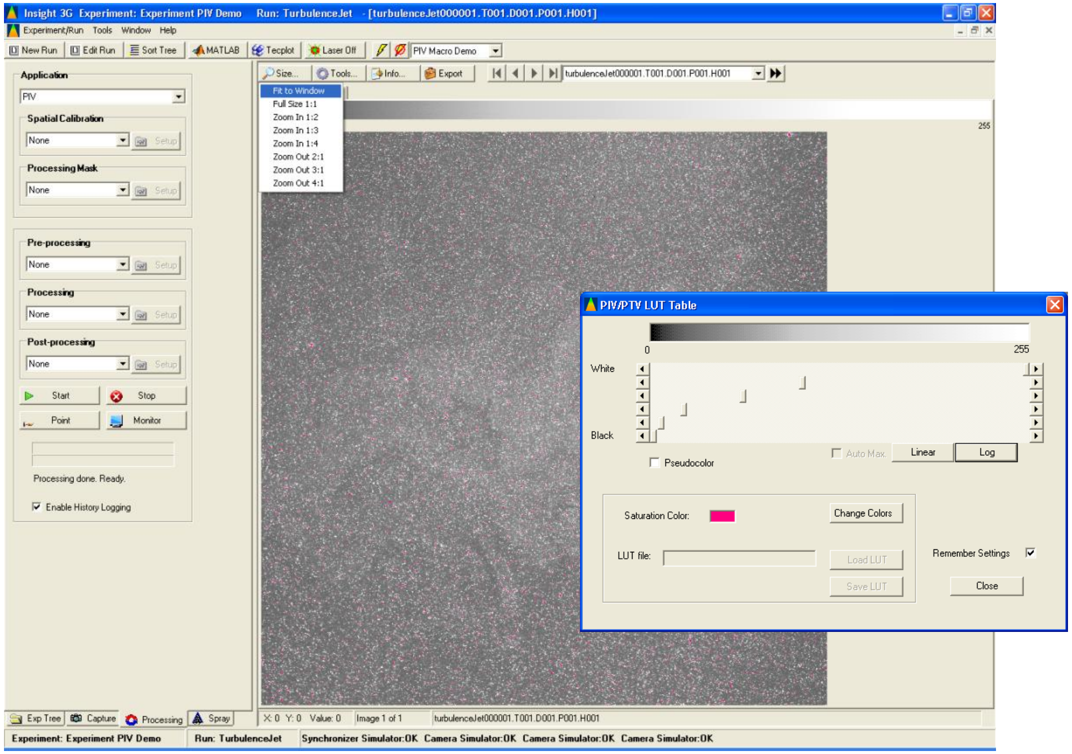
Starting Out

- When you first open INSIGHT3G, you'll see the experiment tree. This is where all of the images and vector fields are organized.
- To analyze an image, select it from the RawData folder within a Run folder, and drag and drop it into the active area (gray region).
- Click on the "Processing" tab in the lower left corner to begin processing.



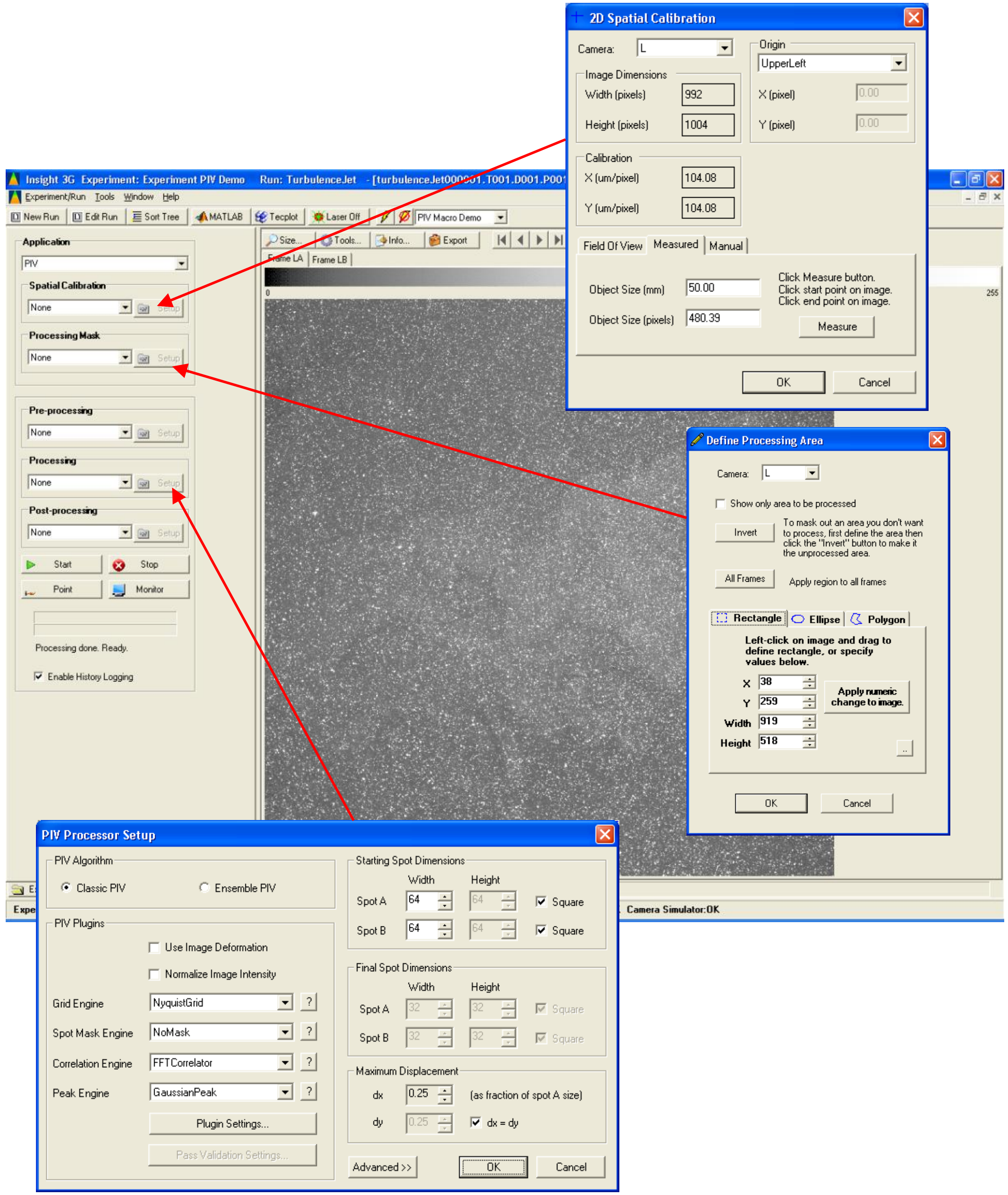
Looking at an Image

- We'll first look at a couple of different ways you can look at the image.
- Right click anywhere on the image and draw a rectangle to zoom in on that region. To go back to full size, click on the "Size…" button and select "Fit to Window"
- Click on the "Tools" button and select "LUT Table." Here you can move the slider bars around and select "Linear" or "Log" to change the way the image appears on the screen. Note: this does not change the raw data, only the way it appears on the screen. This is useful for accentuating dim particles.
- Click on Pseudocolor, then "Change Colors" to change the colorbar, or the saturation color. The default saturation color is Pink, so that it is alarming and warns the user that the image is saturated, but it can be changed to other colors as well. Here, we'll change it to white.



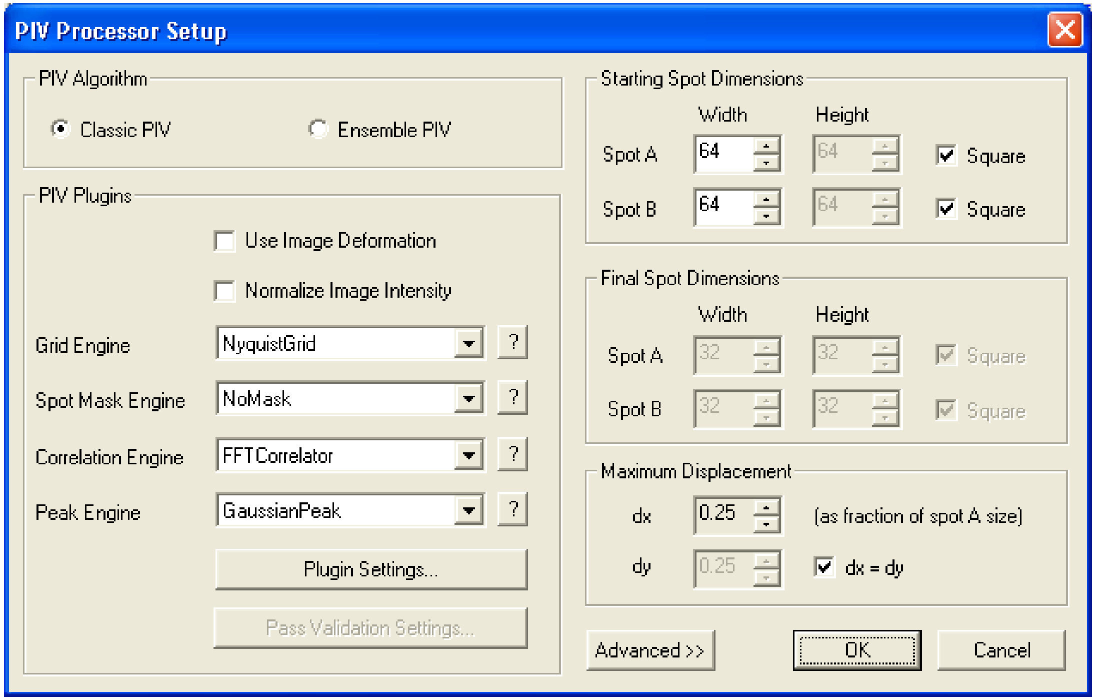
"Default" PIV Processor

- Application:
  - PIV
- Spatial Calibration:
  - Create New…
  - Name it.
  - Click the Measured tab, and enter the size of an object in the flow, then click Measure and click on 2 points on the image corresponding to the size of the object.
  - Click OK.
  - If you do not use a spatial calibration, displacement magnitudes are calculated in pixels.
- Processing Mask
  - Create New…
  - Name it.
  - Draw a rectangle on the image, this is where you will end up getting vectors.
  - OK.
  - If you do not use a processing mask, the entire image is processed.
- Processing
  - Create New…
  - Name it.
  - Use all the defaults
  - OK.
- Click "Start"



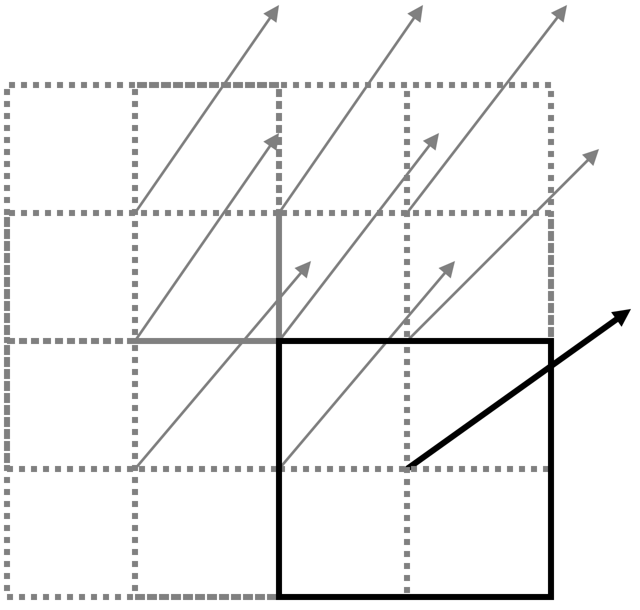
“Default” PIV Processor

- The default PIV processor in INSIGHT3G uses the settings seen to the right.
- This processor is useful for getting a general idea of what is happening in your flow.
- The next several slides describe what each setting does.



“Default” PIV Processor

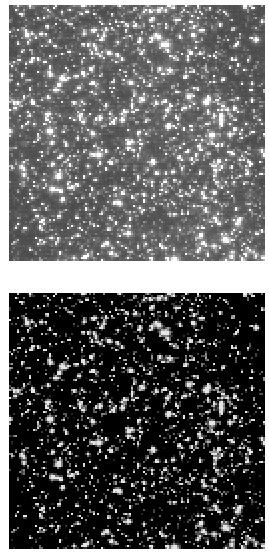
- Nyquist Grid
  - Defines the spots to be processed. Spot offsets are defined in the grid engine.
  - Much like CFD data, the area of interest must first be divided up into a grid, of course, PIV data is always arranged in a rectangular grid.
  - The Nyquist Grid plugin is used for the fastest results; it is the classic PIV grid. It sets vectors with the x-spacing equal to half Spot A width and the y-spacing equal to half Spot A height. No spot offsets are used and the processing uses only a single pass.
  - This gives a vector grid with 50% spot overlap fitting the Nyquist sampling criteria.



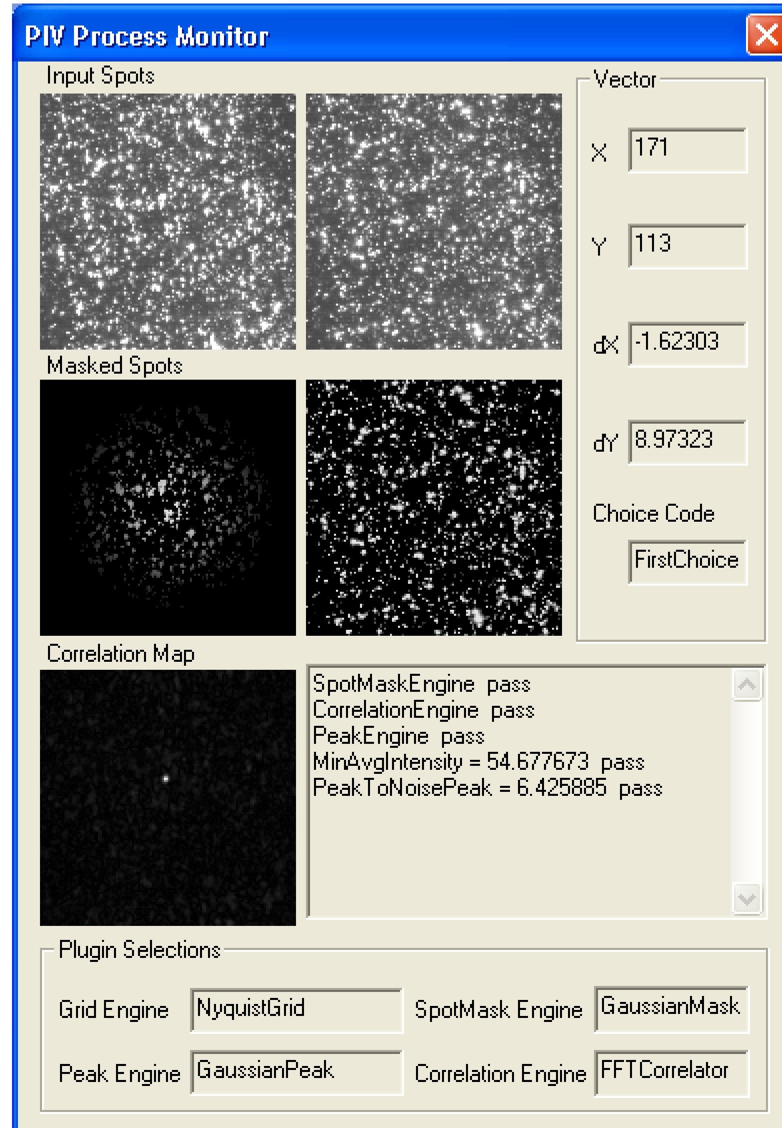
“Default” PIV Processor

- No Mask
  - This setting means that you will not be using a mask.
  - The spot mask is for modifying the image spots before correlation.
  - An example of a mask is the “Gaussian Mask,” which multiplies each pixel value in spot A by a Gaussian weighing function so that the spot is bright in the center and dark around the edges. This weighting gives more value to the center pixels and less to the edge pixels (This is useful since the particles near the edge have a higher probability of “leaving” the interrogation region, and thus we would like to give them less importance in determining the correlation (particle displacement)).

Toggling Between Frame A and Frame B

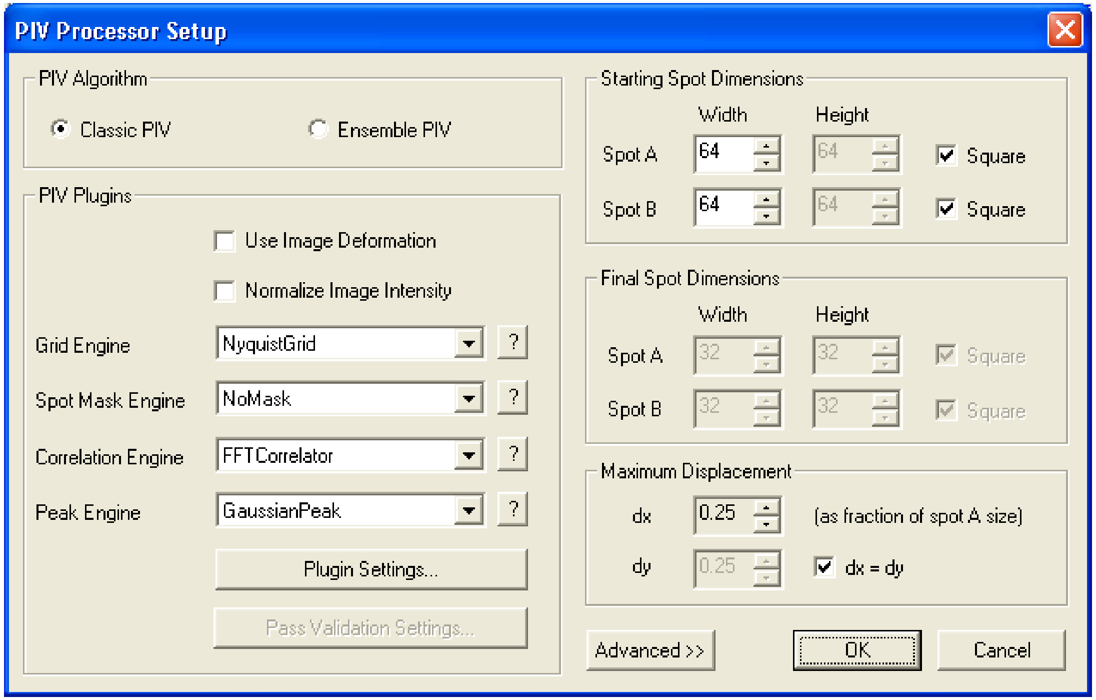


Example of Gaussian Mask:



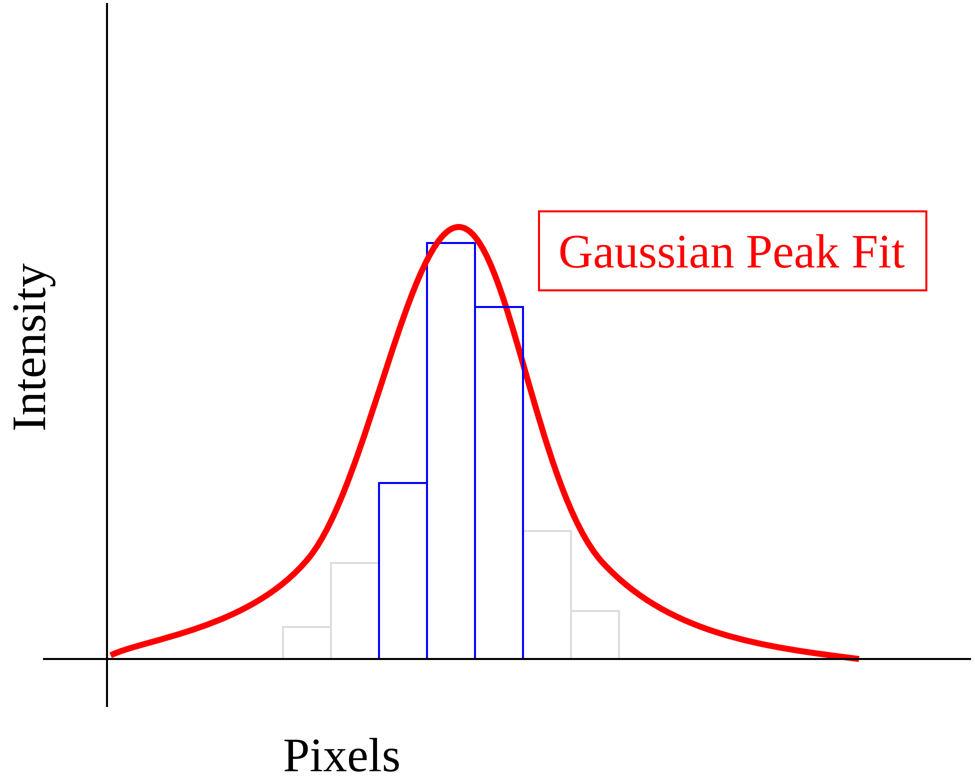
“Default” PIV Processor

- FFT Correlator
  - Computes the correlation using Fast Fourier Transform (FFT). The spots must be square powers of two and Spot A must be the same size as Spot B.
  - If the spot size is not square, the Zero Pad Mask is automatically used to pad the non-square part of the window for FFT correlation.



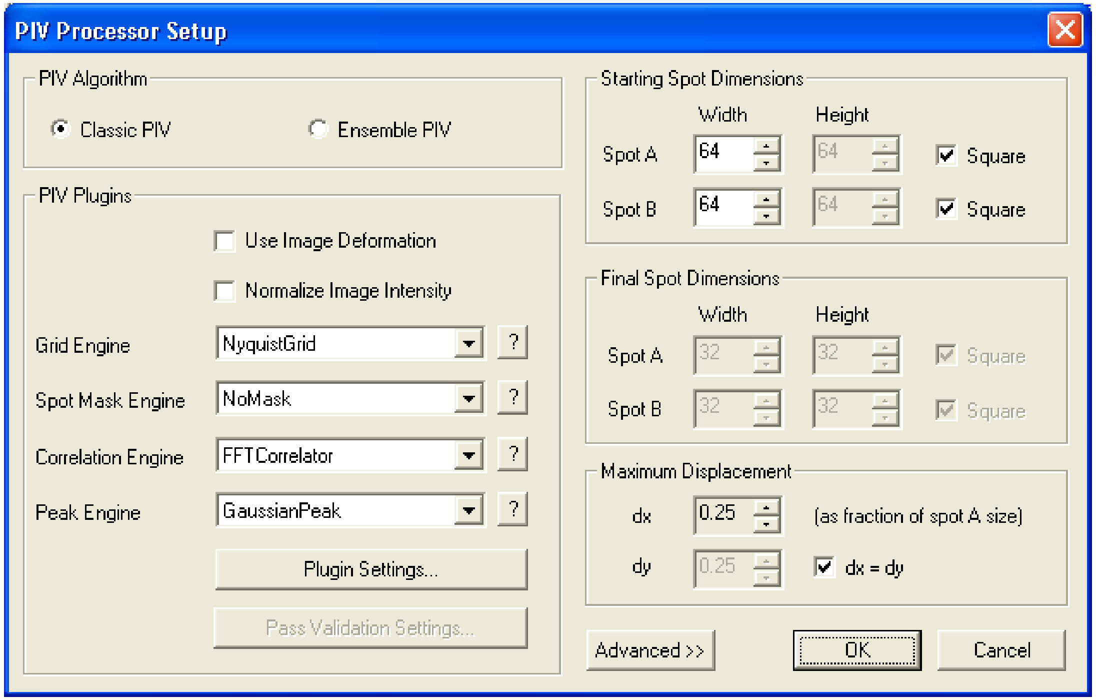
“Default” PIV Processor

- Gaussian Peak
  - Locates the correlation map peak with sub-pixel accuracy by fitting a 3-Point Gaussian in X and 3-Point Gaussian in Y with the peak pixel used in both.



“Default” PIV Processor

- Notice that the Starting Spot Dimensions are 64 x 64 for Spot A, and 64 x 64 for Spot B. The correlation spots in A and B do not necessarily have to be the same size. Sometimes Spot B is chosen to be larger so that it is more likely to match particles that have “left” the Spot A interrogation region.
- 64 x 64 or 32 x 32 pixels is probably the most common interrogation region window size. Of course this value should be chosen so that there are at least *9-10 particles in the interrogation region.* If you find that there are fewer than 9 particles, you may need to increase the interrogation window size. (eg 128 x 128 pixels).
- The “Maximum Displacement” refers to the maximum particle image displacement, in pixels, that will be looked for in processing. The Peak Engines use this value to limit the correlation map search area to ±max displacement pixels from the zero pixel. Some Correlation Engines, such as Hart, use this value to limit the size of the correlation map to increase processing speed and decrease memory usage.

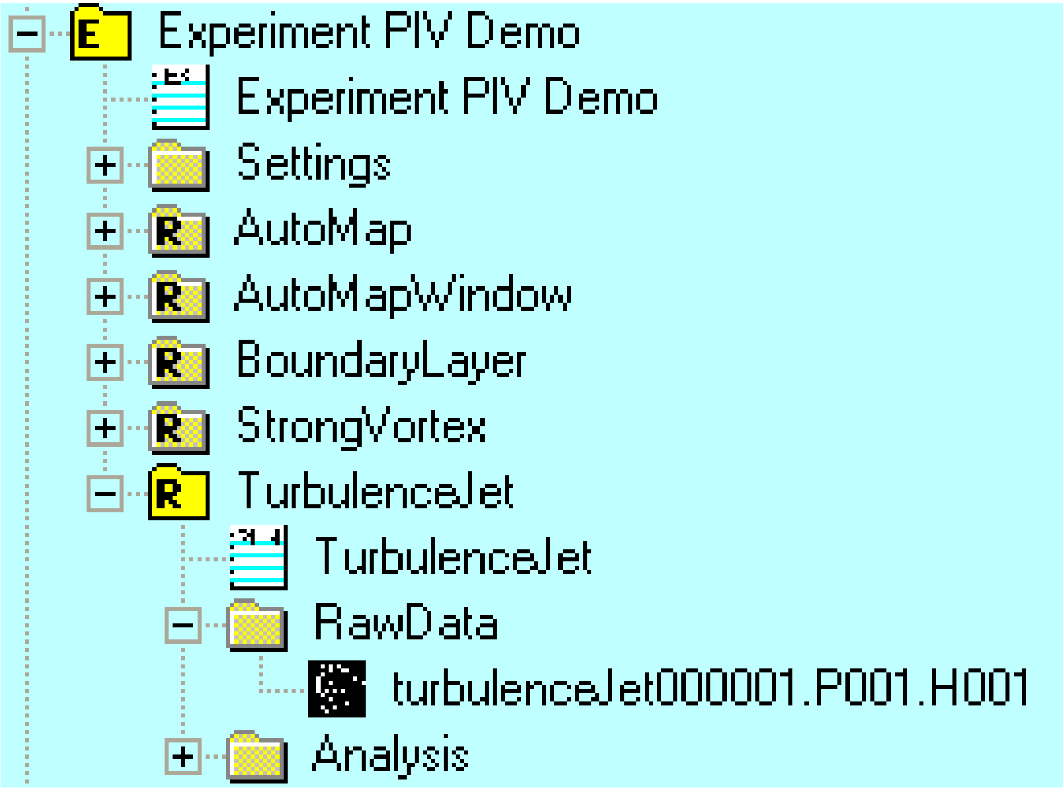


Example

- Now we'll look at an example. We will use the default PIV processor to get an idea of the flow field, and then optimize the settings for the fewest number of spurious vectors.

INSIGHT3G Demo Data

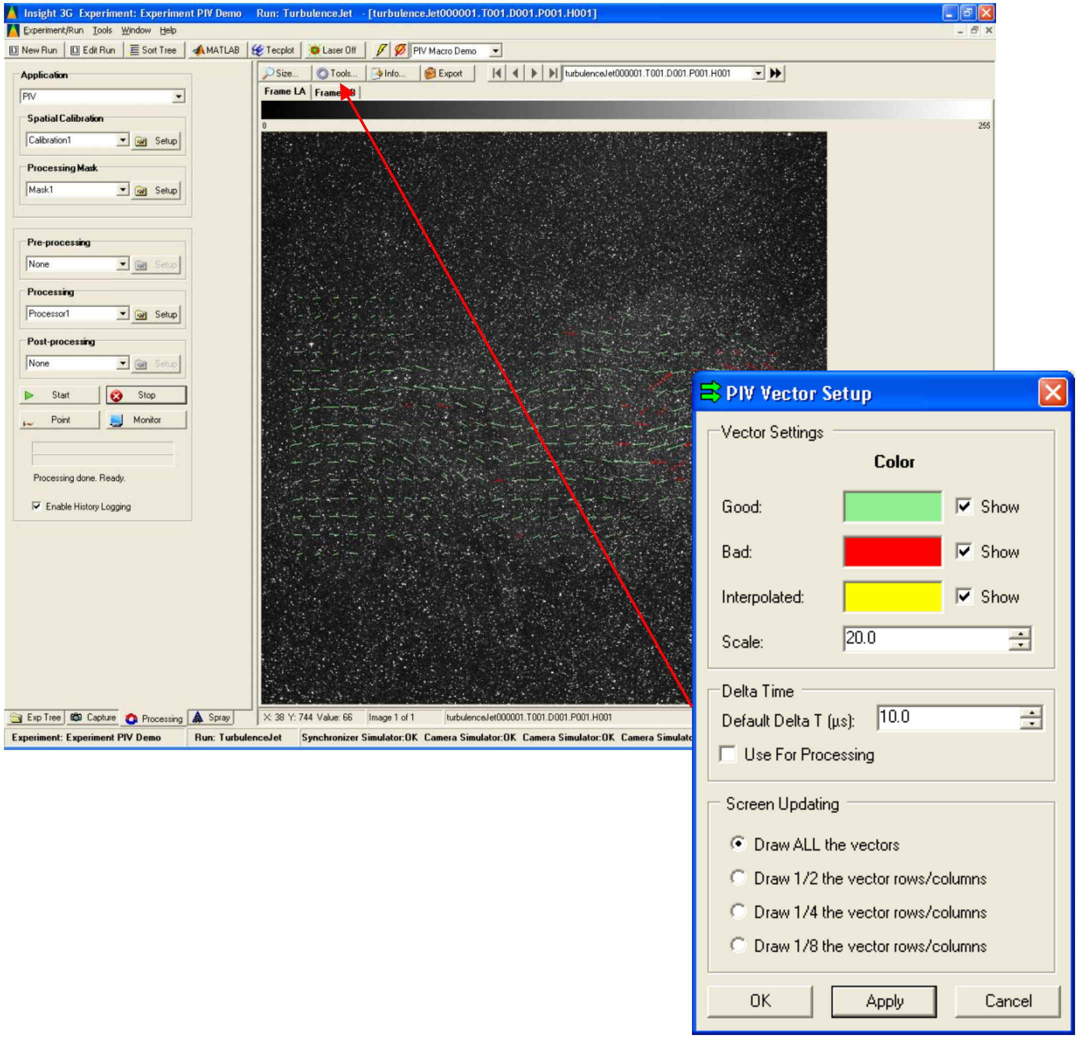
- We’ll use the demo image pair called turbulenceJet000001 included with INSIGHT3G under:



C:\Experiments7\Experiment PIV Demo\TurbulenceJet\RawData

Default Processor with 64 x 64 pixel Interrogation Window Size and 16 pixel Maximum Displacement (0.25 of 64)

- This is the result of processing "turbulenceJet000001" with the Default PIV processor.
- Green Vectors are "good data" that have passed the signal to noise ratio tests in the processor.
- Red Vectors are "bad" vectors. They did not pass the SNR or Minimum Avg Intensity tests.
- Go to "Tools…" Button and click on Vectors >> Setup… Here you can choose whether or not to show the "Bad" vectors. You can also change the vector scaling and color.
- If you had imported your image from a non-TSI camera, you could set the ΔT value on this screen. (For TSI cameras, ΔT is saved in the *.tif header, and the value on this screen is ignored)



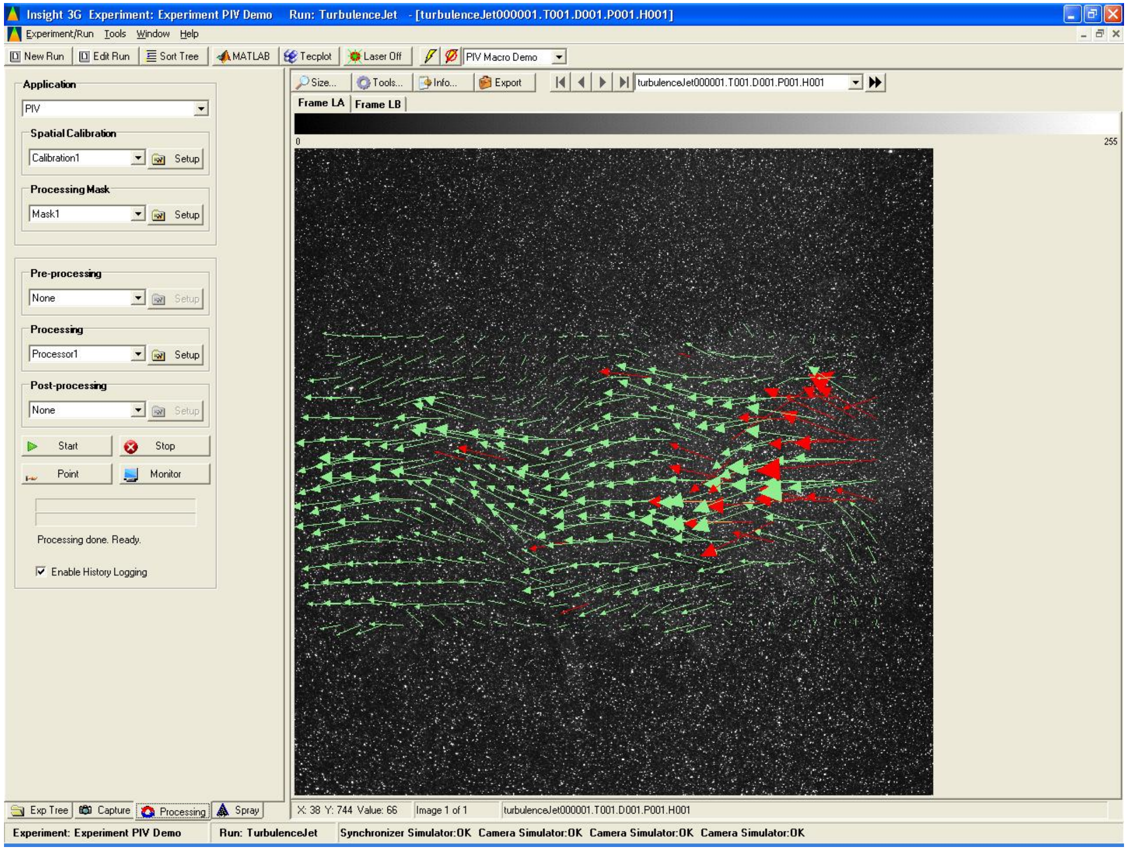
Default Processor

A few things to notice:

- First of all, the dominant flow direction is from right to left.
- The places where we are "missing" the most vectors, seems to be along the right side, where the velocity would be at a maximum. This tells us that perhaps
  - ΔT was too large,
  - spot size is too small, or
  - maximum displacement is too small.
- Since we cannot go back and re-capture the images with a different ΔT value, let's do the best we can.
- In practice, often times 'perfect' PIV images are just not possible. If they were easy, someone else would have already made the measurements!
- Let's try to figure out what the particle displacement is along the edges, using "Point Process."

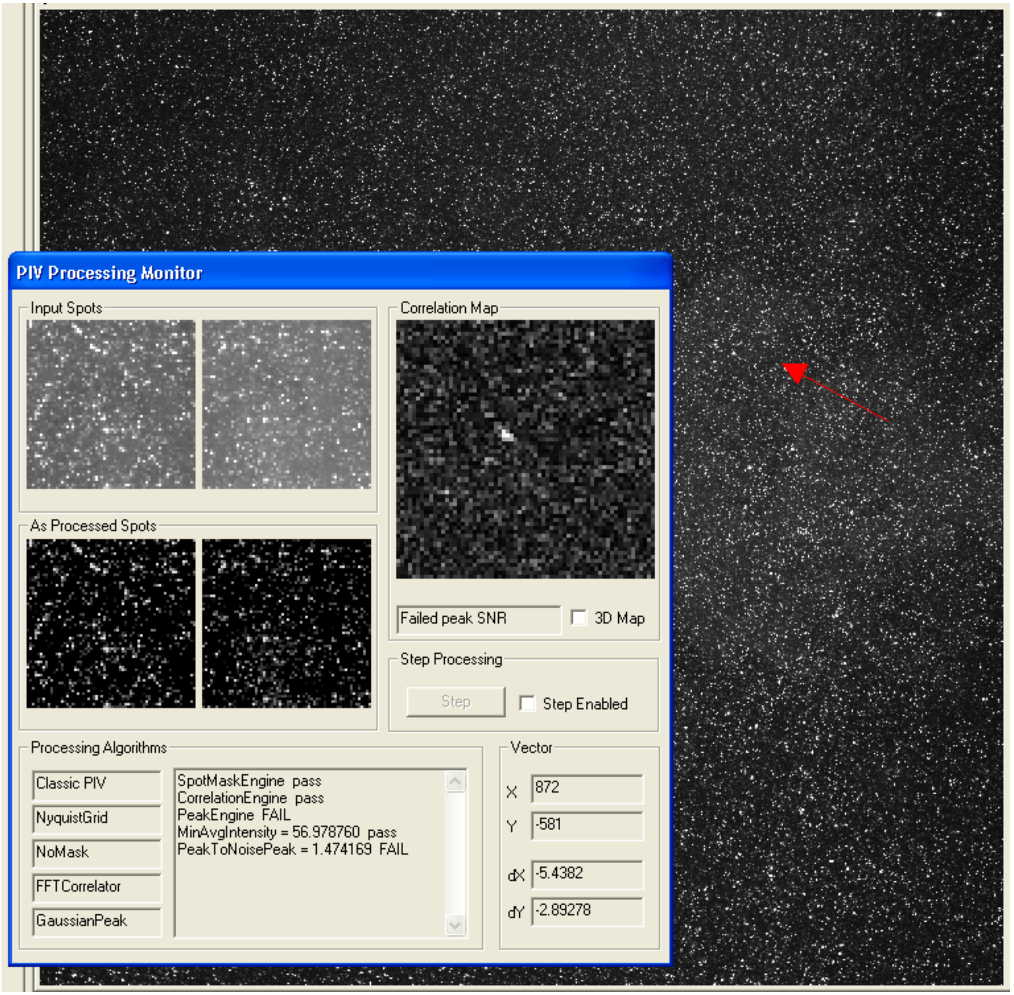
Default Processor

- Here we have increased the vector scale from 5 to 20.
- The data doesn't look too bad, but we are losing some good vectors on the far right (red vectors that appear to be following the flow, not random).
- Let's check if these are good vectors.
- Click on the "Point" button. We are going to have the software analyze one interrogation spot at a time, to get an idea of why the red vectors are failing.
- Click anywhere on the image, for this case, we will click on the right, where we are getting failing vectors.



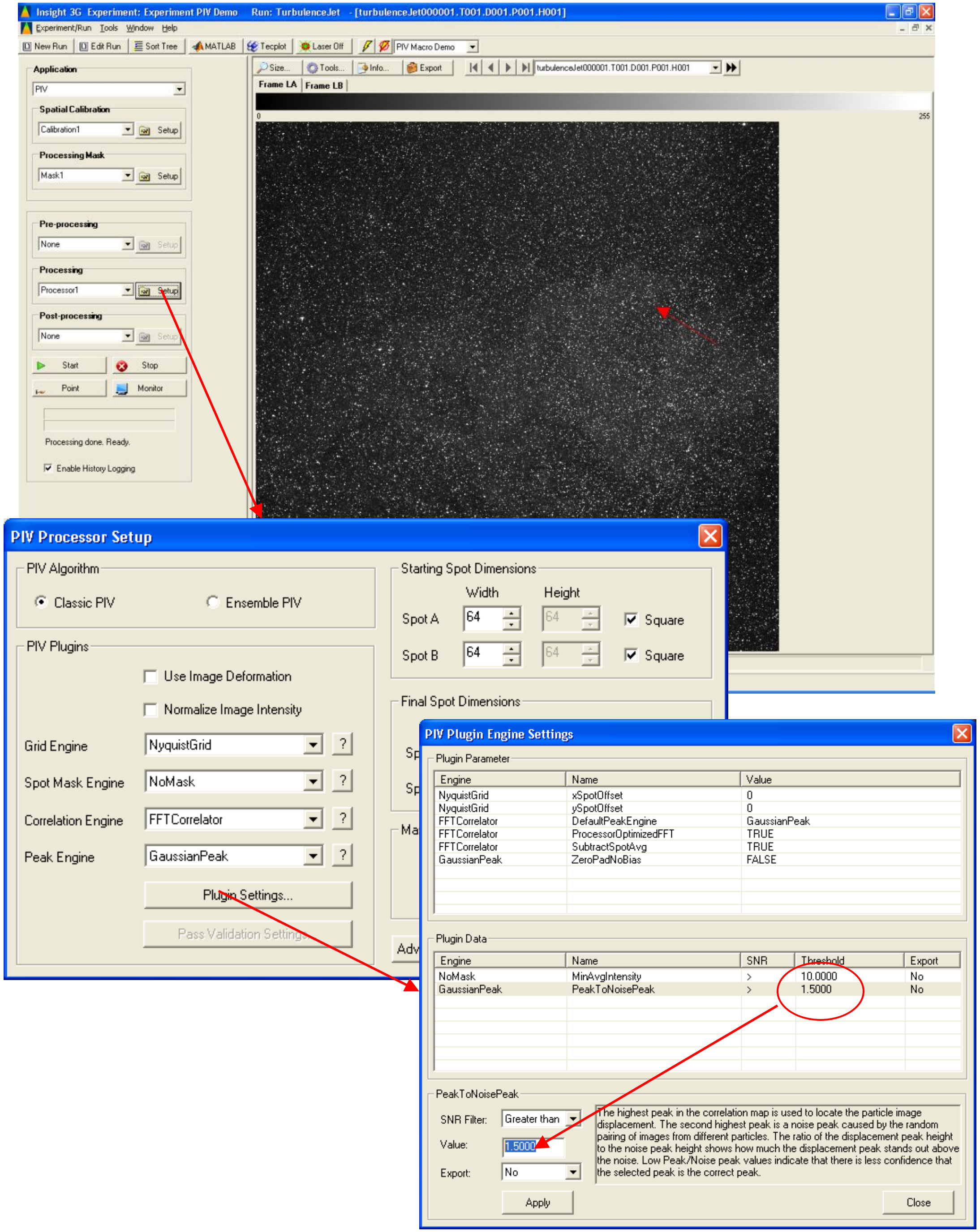
Point Processing

- The Processing Monitor tells us that this particular interrogation spot failed due to the PeakToNoisePeak, which was only 1.47, this must be at least 1.5 (the default value).
- We can try lowering the SNR threshold, to see if the data gets better.
- Also notice, that for this vector, the pixel displacement dX was -5.4 and dY was -2.89 (Y is inverted)
- Click “Point” again to make the Processing Monitor close.



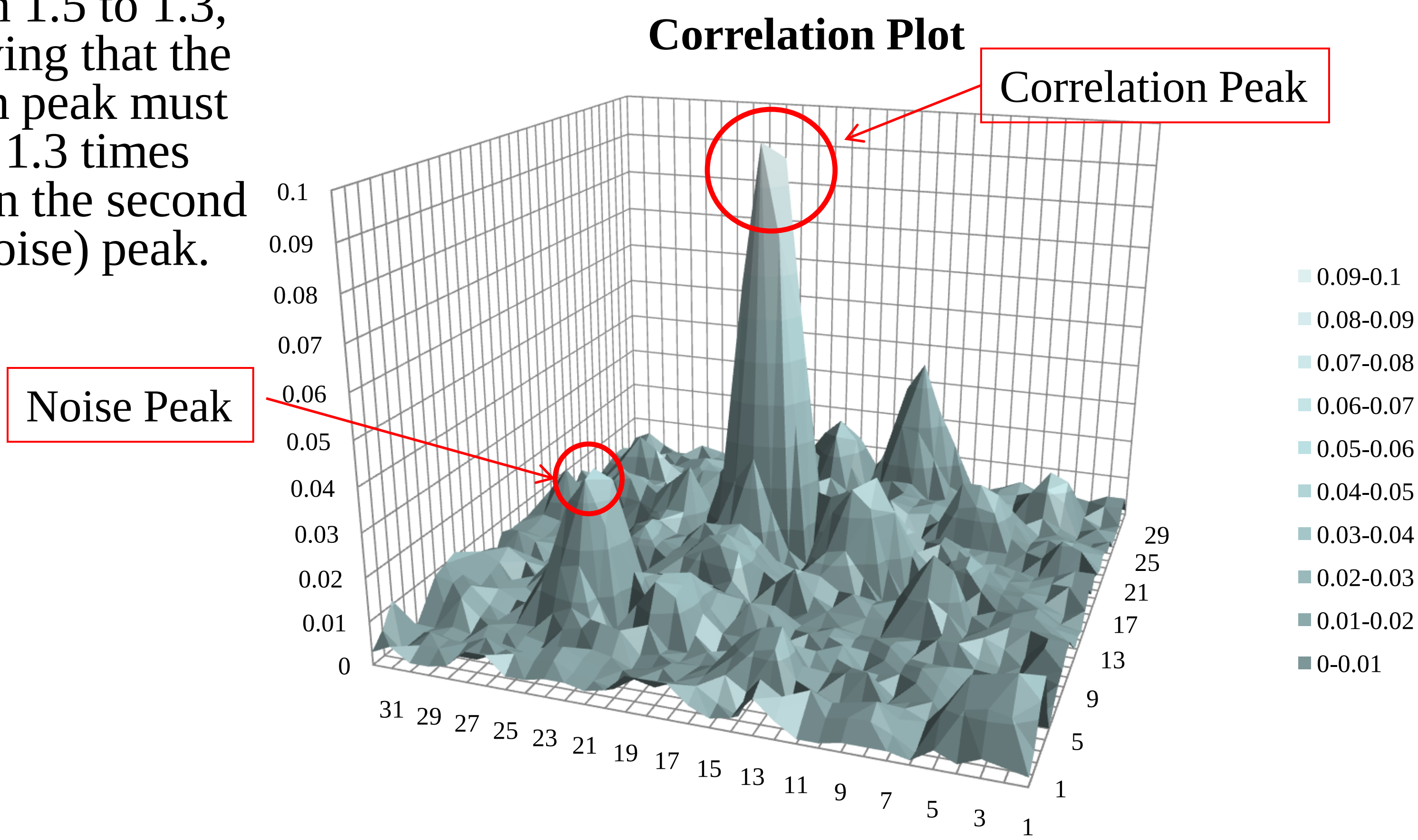
Change SNR Value

- Click on “Setup” next to the processor.
- Click on Plugin Settings…
- Here are the default settings of the processor. You can change these values by clicking on a line, and then changing the value in the lower left corner. Be sure to press “Apply” after making each change.
- Here, we will lower the SNR filter value to 1.30



Change SNR Value

- By changing the SNR value from 1.5 to 1.3, we are saying that the correlation peak must be at least 1.3 times higher than the second highest (noise) peak.



Default Processor with Spot Offset

- This helped slightly, but we still have some bad vectors.
- Another way to recover vectors is to introduce a spot offset. Since we know that the dominant displacement is to the left, we can offset the Spot B to the left. As we recall from a previous slide, the offset was approximately -5 in the X direction. Let’s go back to the process setup, Plugin Settings, and put in an offset of -4 for xSpotOffset.
- When we process, the vector fields gets slightly better, but not too much.
- Let’s now try an image pre-processor…

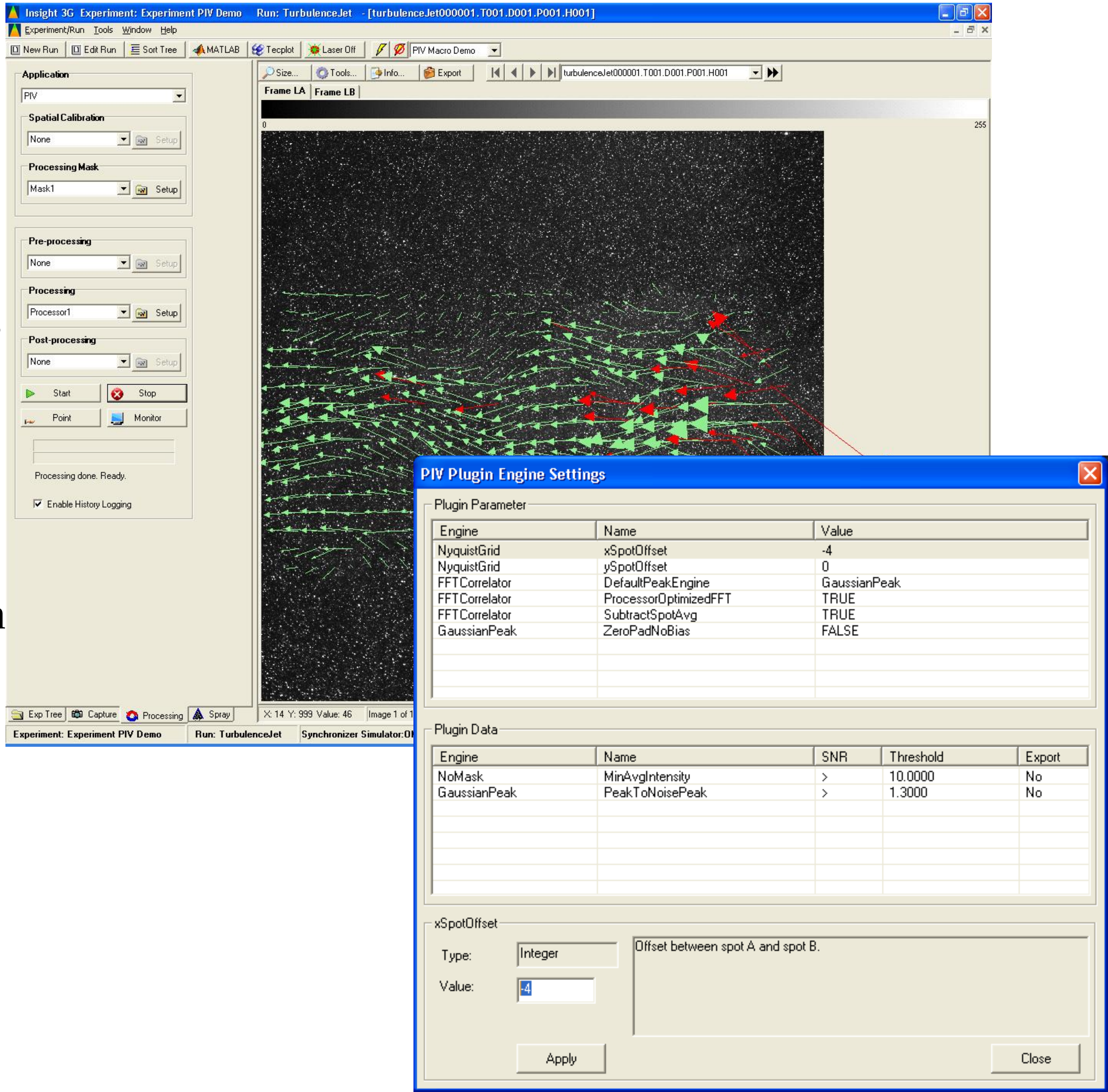
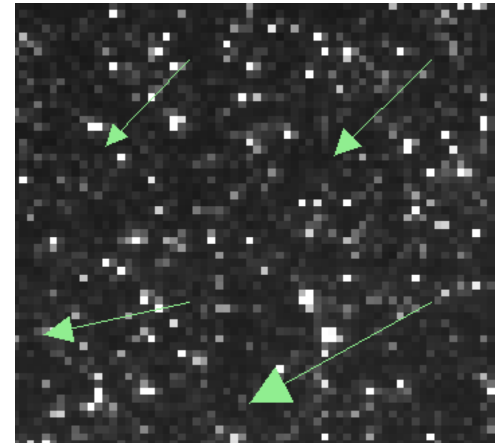


Image Pre-Processor



- If we zoom-in on the image, each particle seems to occupy only 1-2 pixels.
- Ideally we want 2.5 pixels or more.
- The best way to do this is to re-capture the images, with a different magnification, or different seeding particles. Since we already have the image, let's work with it from here.
- Let's add an image pre-processor that will blur the particles so that they encompass a larger area. This also has the effect of boosting the brighter particles, and diminishing the dimmer particles.
- Under "Pre-processing", select Create New. Name this one "Blur"
- Select "Image Filter," then double-click it to enter Gaussian, 5, and 0.6.

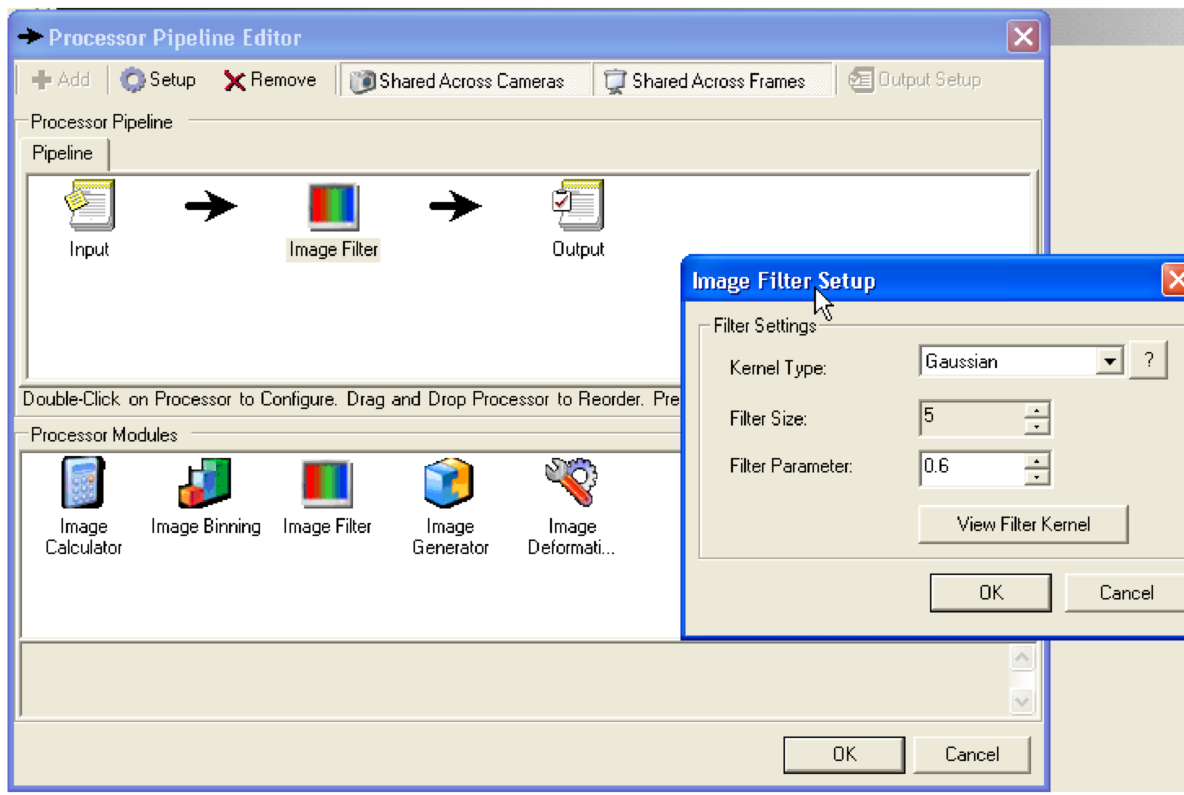
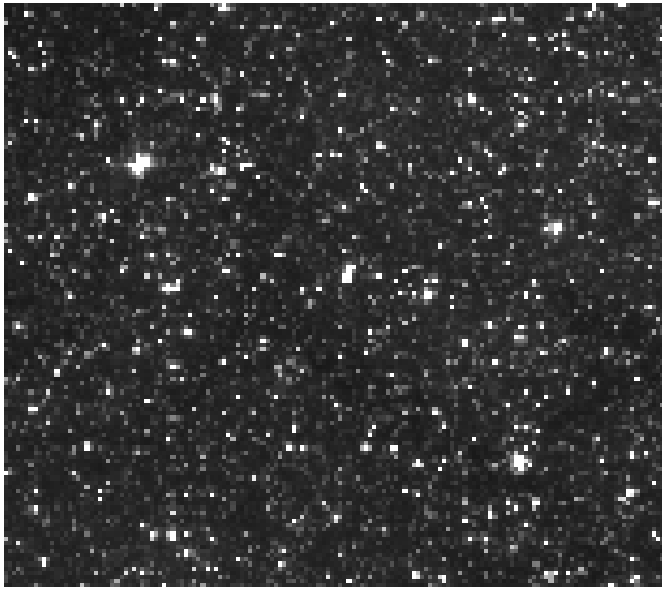
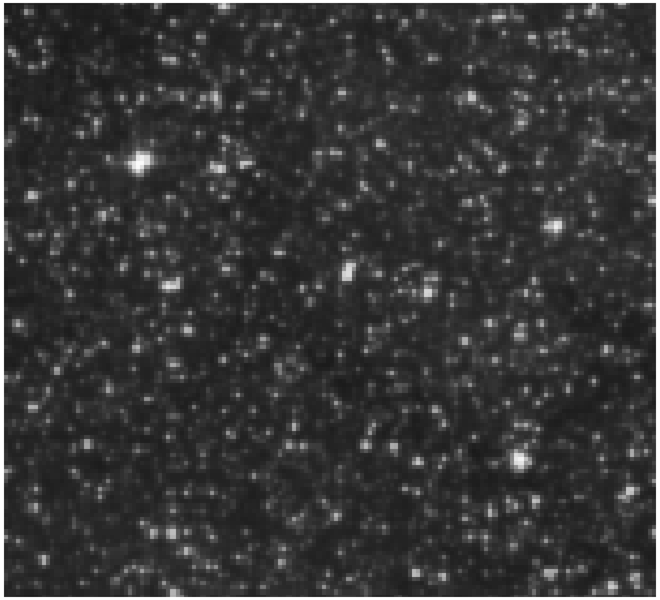


Image Pre-Processor

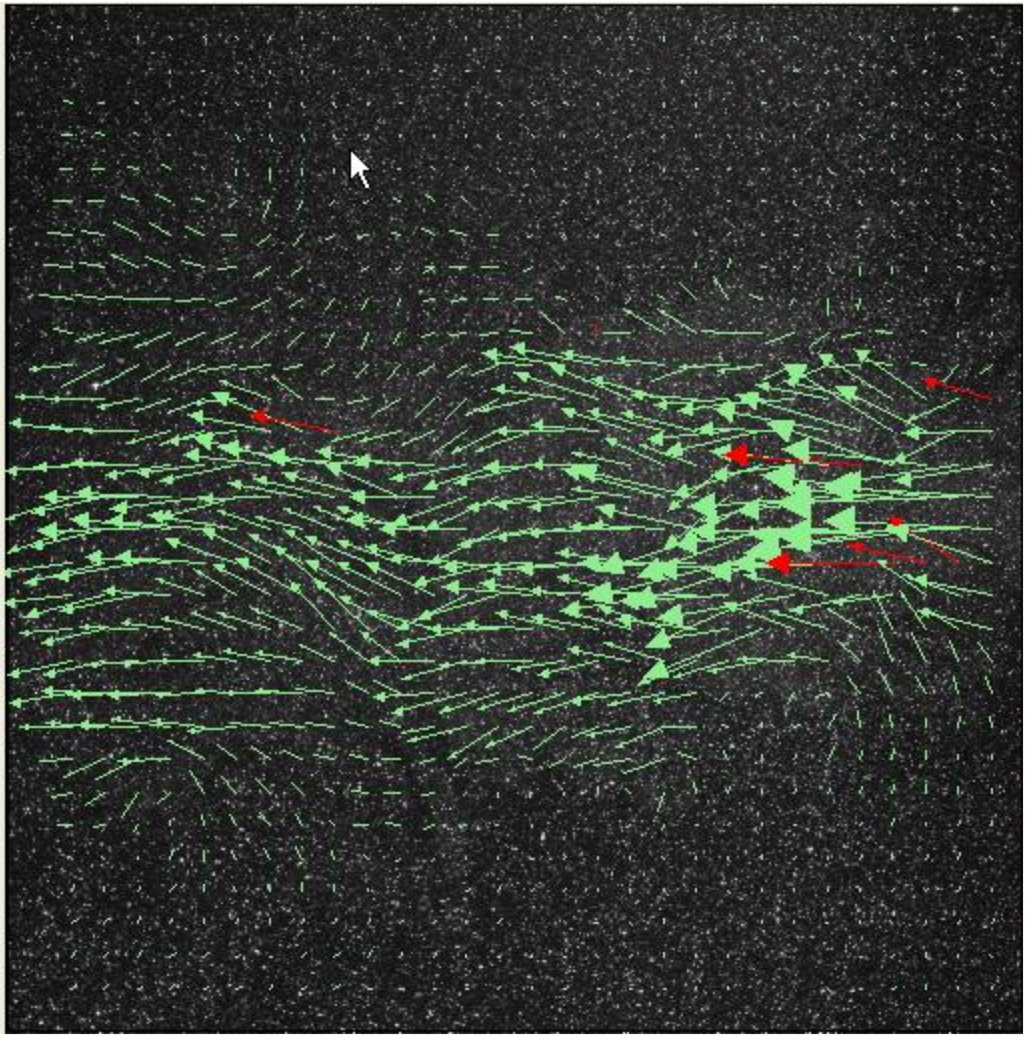
- Here are the before and after snapshots.
- Notice how the final image has particles which encompass more than 1-2 pixels.





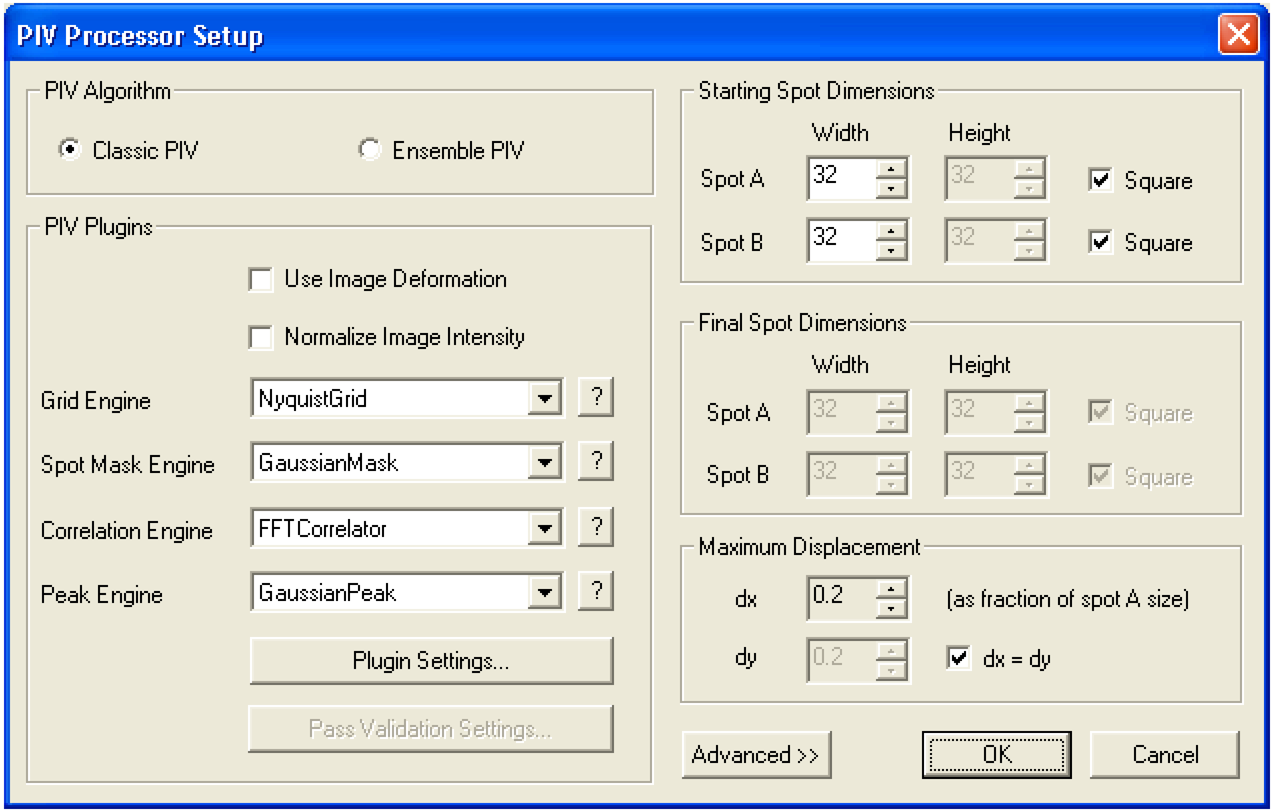
Processed Image

- The vector field looks much better.
- Let's see if we can go to higher spatial resolution…



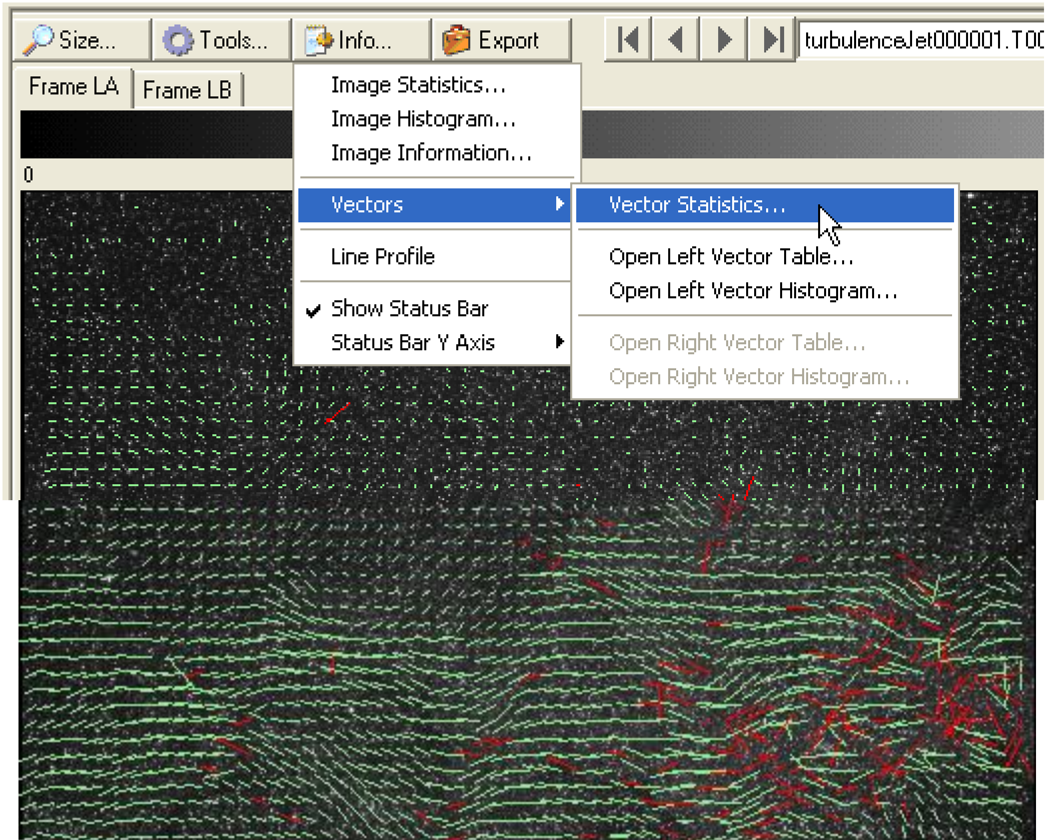
Increase Spatial Resolution

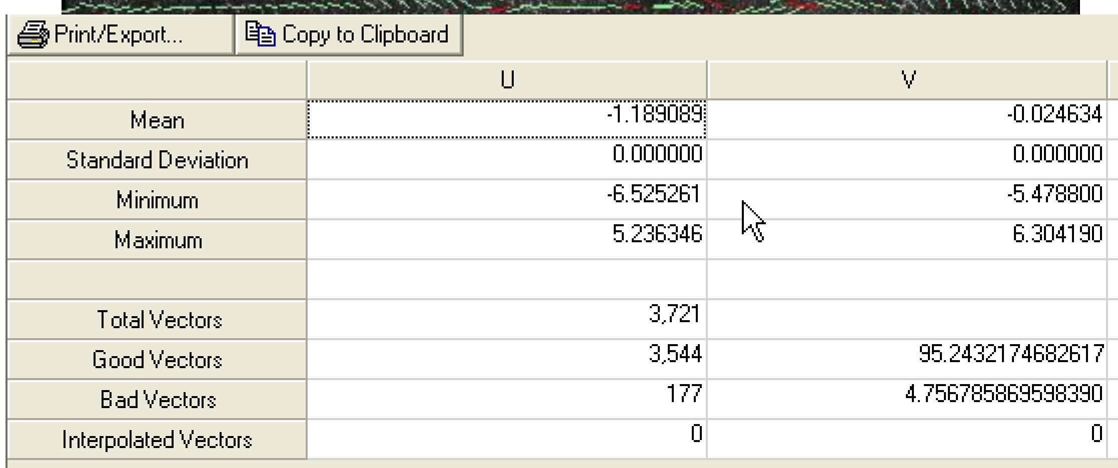
- Instead of 64 x 64 pixels, let's try 32 x 32 pixels.



32 x 32 Pixels

- Here we find that we have more vectors total, but also more bad vectors. To determine the number of bad vectors, we can go to the Info… >> Vectors >> Vector Statistics…, to find the Total Vectors (3,544) vs. Bad Vectors (177) or,
- 95.2% good, and 4.76% bad.

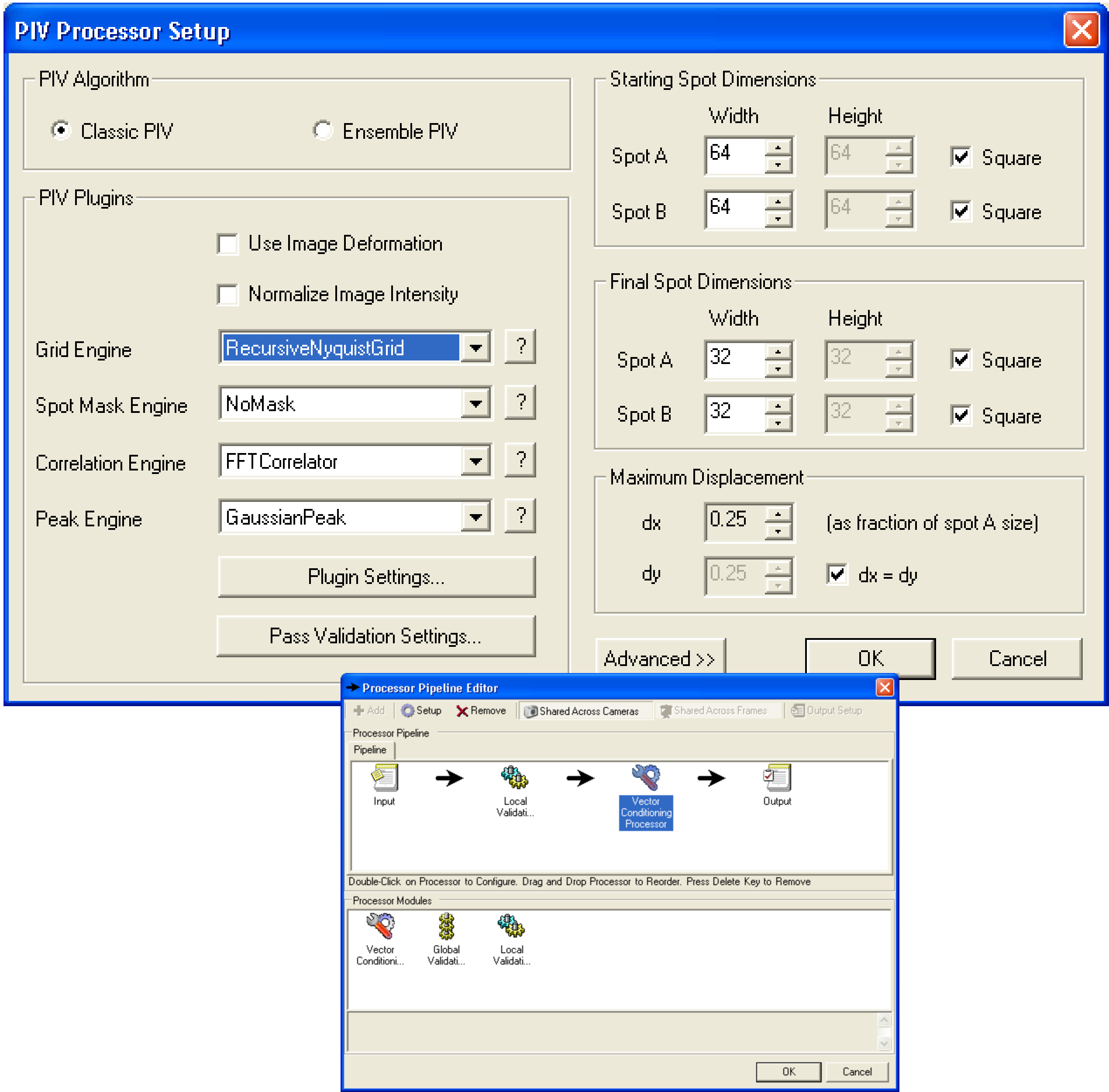




	U	V
Mean	-1.189089	-0.024634
Standard Deviation	0.000000	0.000000
Minimum	-6.525261	-5.478800
Maximum	5.236346	6.304190
Total Vectors	3,721	
Good Vectors	3,544	95.2432174682617
Bad Vectors	177	4.756785869598390
Interpolated Vectors	0	0

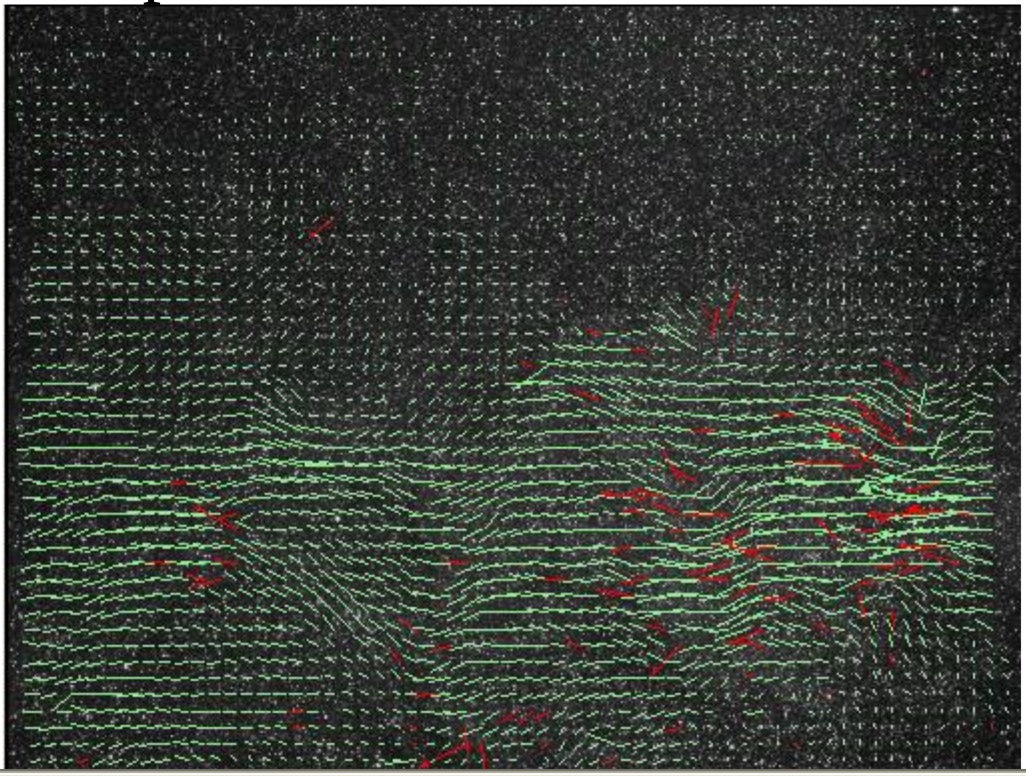
Recursive Nyquist Processing

- Recursive Processing is a multi-pass method, in which the first pass is used as an estimate for the spot offset in the second passes.
- Go to the Processor "Setup"
- For "Grid Engine," select "RecursiveNyquistGrid"
- Change the starting spot size to 64 x 64 and the final spot size to 32 x 32 pixels
- Click "Pass Validation Settings" to filter bad vectors after the 1st pass.
- Double-click "Local Validation" and "Vector Conditioning"
- (Double click the icon once it is in the Pipeline, to change the default parameters)
- Click OK.
- Go back to the "Plugin Settings…" and change the xSpotOffset to -4 and verify that the SNR filter is still set to 1.3
- Click OK.



Recursive Nyquist with 64 pixel starting spot and 32 pixel final spot

- The vector field looks much better.
- We now have 96.7% good vectors.
- In general, we want to have at least 95-97% or more good vectors before we run the Post Processing (vector validation) step.

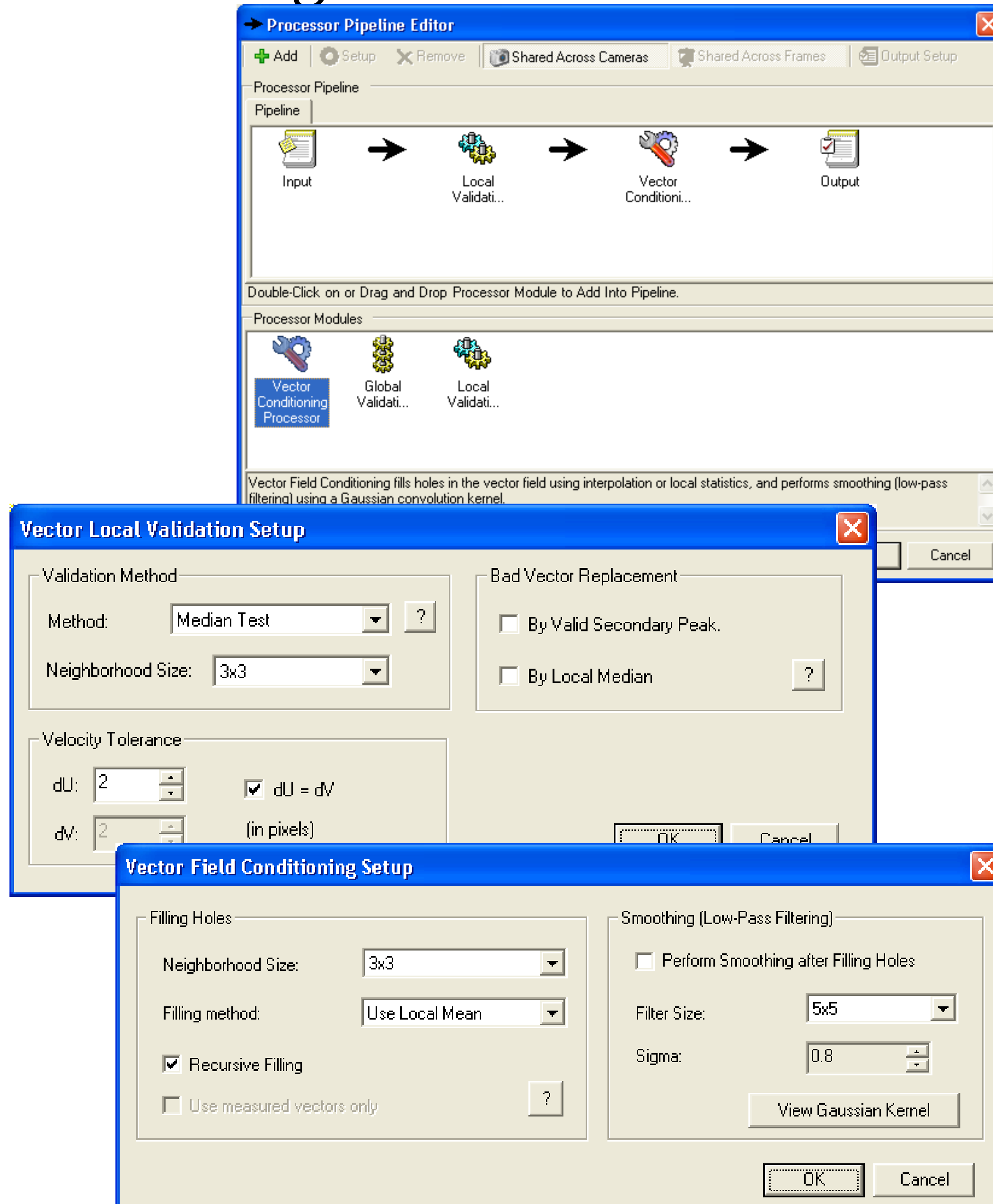


Print/Export... Copy to Clipboard

	U	V
Mean	-1.312760	-0.016887
Standard Deviation	0.000000	0.000000
Minimum	-13.175680	-4.237676
Maximum	1.842940	6.307543
Total Vectors	3,416	
Good Vectors	3,304	96.7213134765625
Bad Vectors	112	3.27868843078613
Interpolated Vectors	0	0

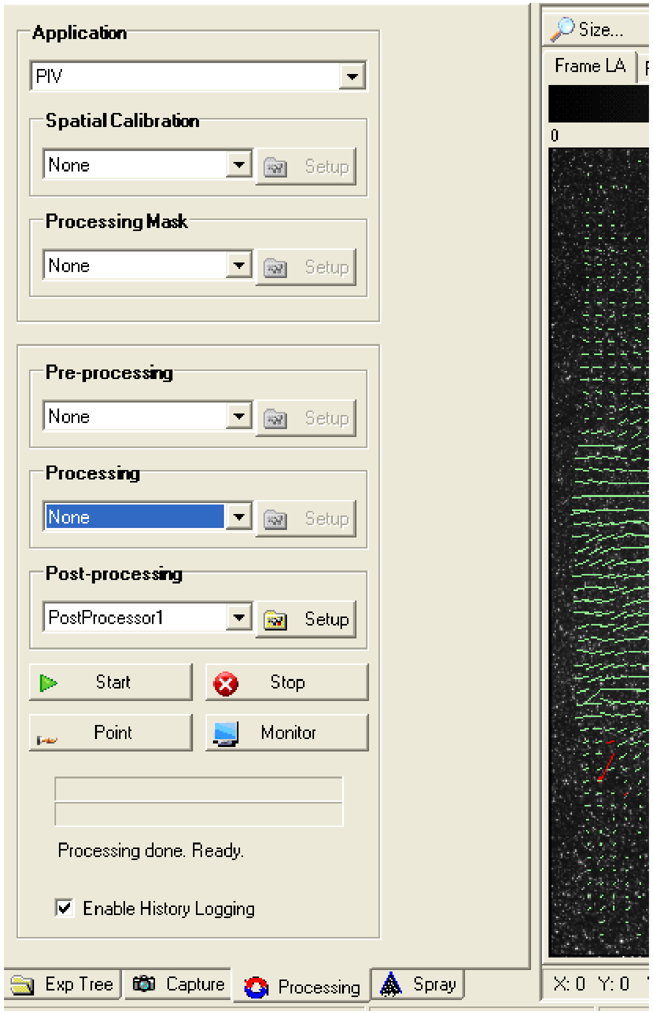
Post-Processing

- Under "Post –processing," click "Create New…" and give it a name.
- Double click the "Local Validation" and the "Vector Conditioning" icons to add them to the pipeline.
- Double-click the "Local Validation" icon.
- Here you have the option to change the validation method. Click OK
- Double-click the Vector Conditioning icon.
- Here you have the option to change the "Hole Filling" method, or have the option of "Smoothing" (Low-pass filtering) the data.
- Let's leave the default values.
- Click OK
- Click OK



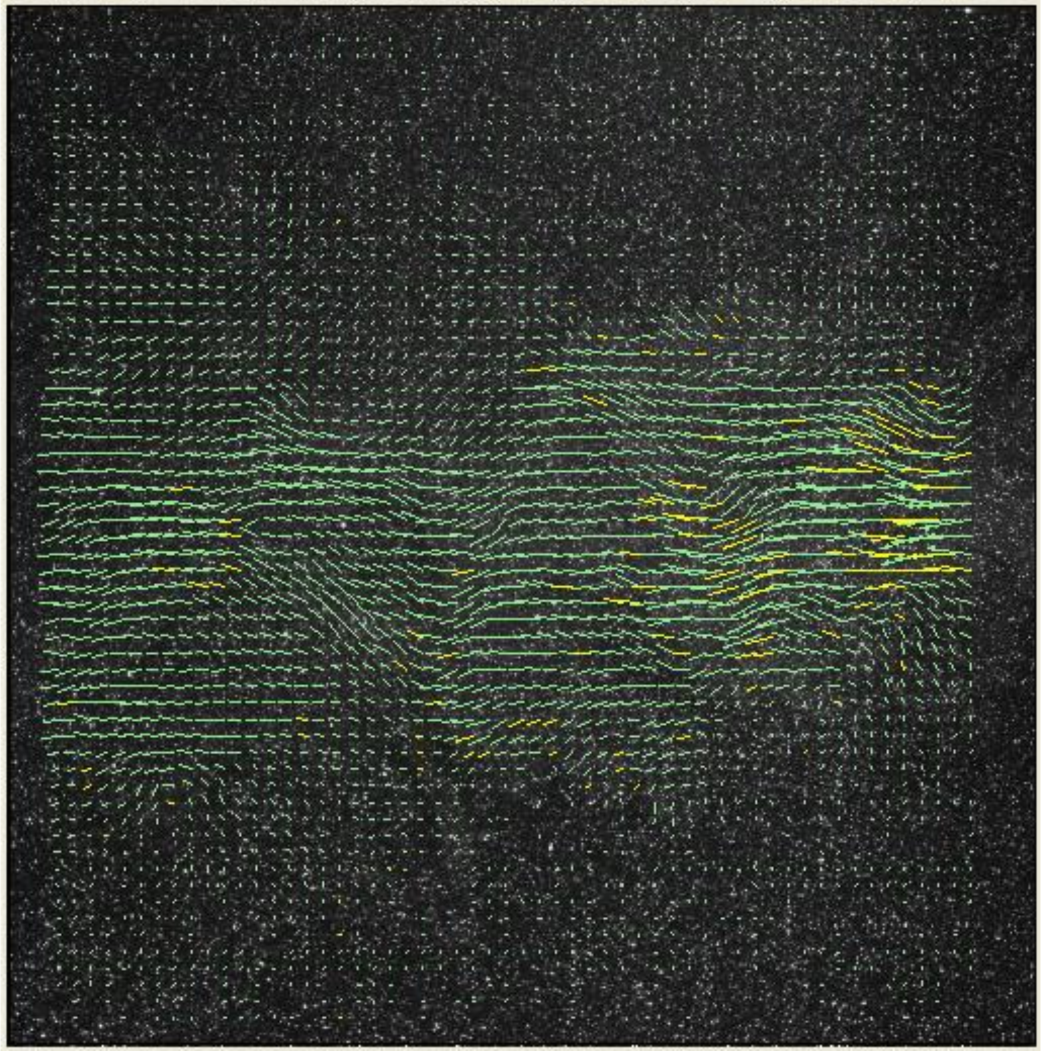
Post-Processing

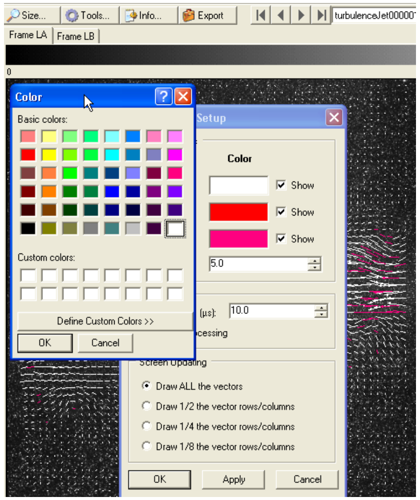
- Back on the Processing Tab, you can select "None" for Processor, and Select only a Post-Processor (since we already have the vector field, we do not need to repeat this step, we only need to do the post-processing step)
- Click "Start"



Vector Field

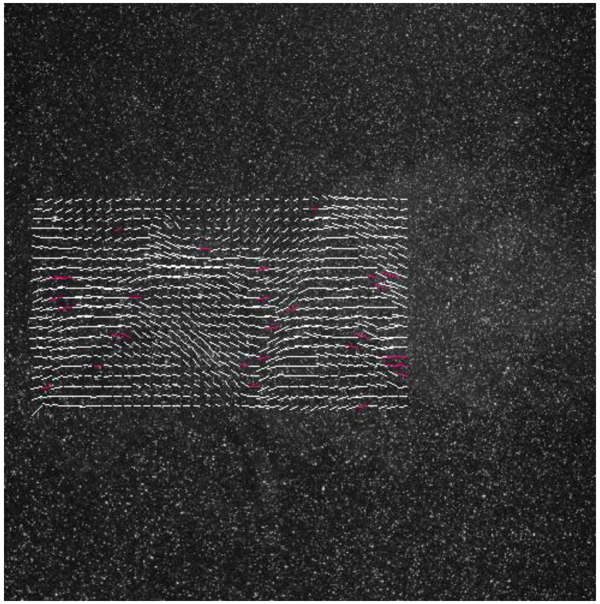
- Vectors that have been interpolated are shown in Yellow, original vectors are shown in Green.
- Lets change the vector colors.
- Go to Tools >> Vectors >> Setup, and change the vector colors to White and Pink, double-click the color to change it.

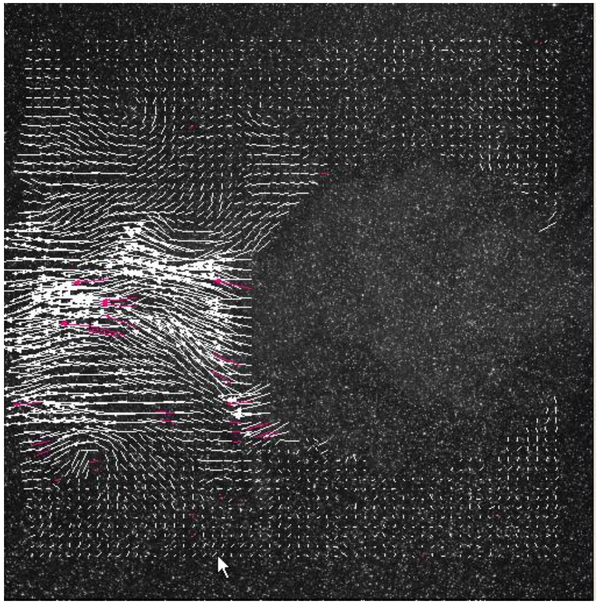




Mask

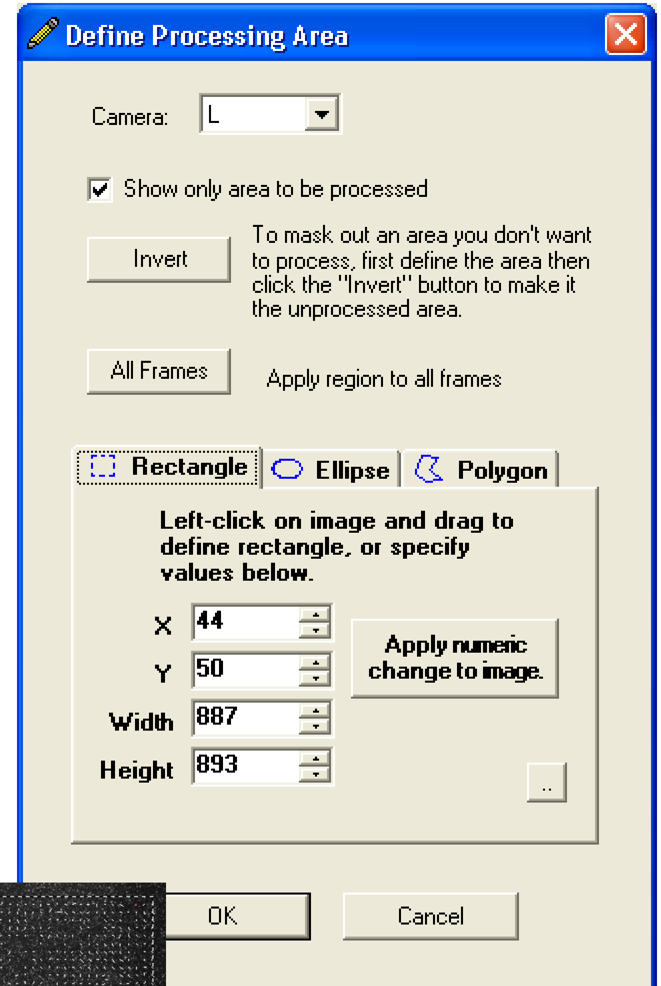
- Perhaps you do not want vectors covering the entire PIV image. There are several options for processing only part of the image.
- Region of Interest Processing – This is done by using the left mouse button to drag a region on the image. When you start processing (with a processor and a post-processor), you will end up with vectors only in this region.
- Mask – This option allows you to mask in (and mask out) regions of the image that you want to process.

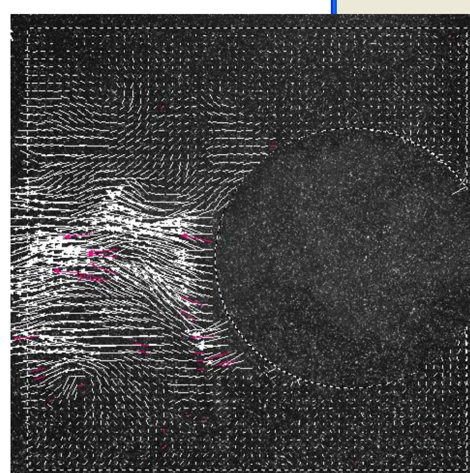




Mask

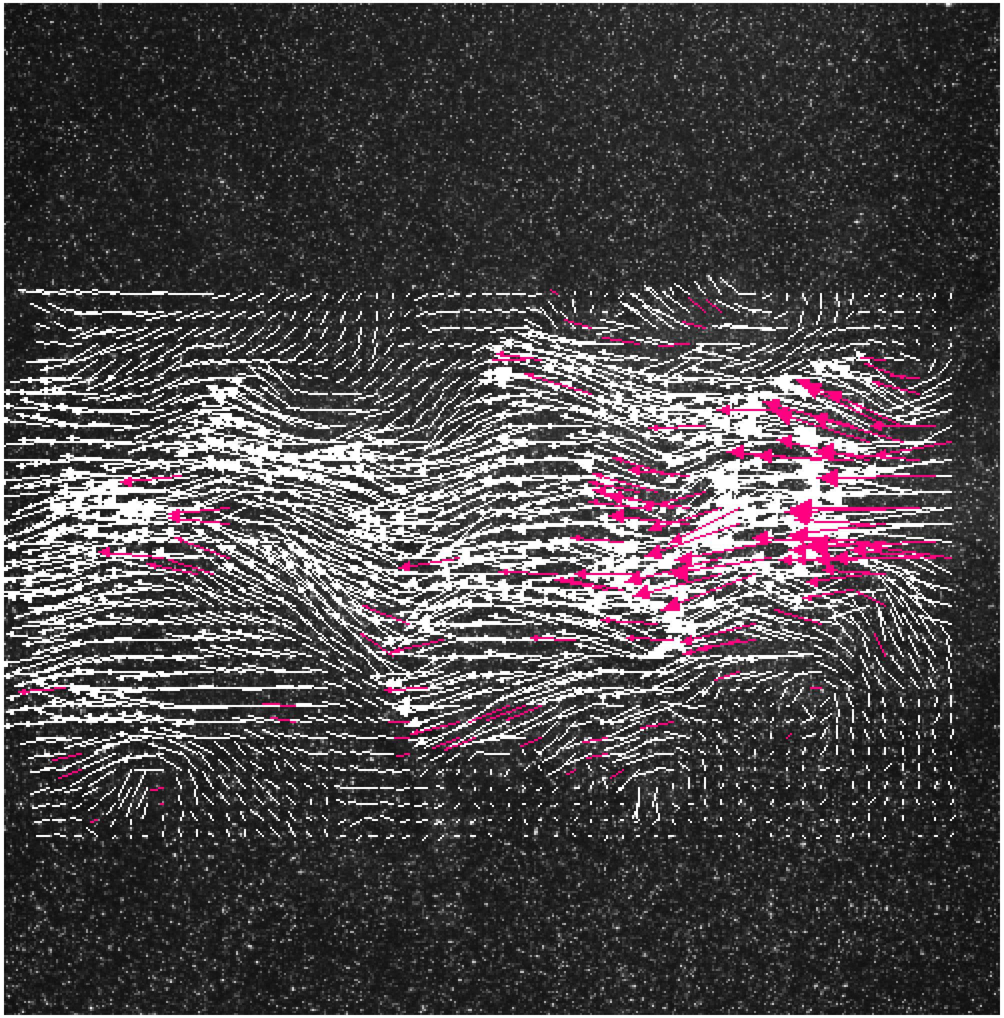
- In the “Processing Mask” box, select “Create New…” Name it.
- Here you can create a mask that is a Rectangle, an Ellipse, a Polygon, or any combination.
- To have a Rectangle and an Ellipse simultaneously, draw the Rectangle First, click on the “ellipse” tab, then hold the control button, and draw the ellipse.
- Create a Mask of the center part of the jet, then click OK.





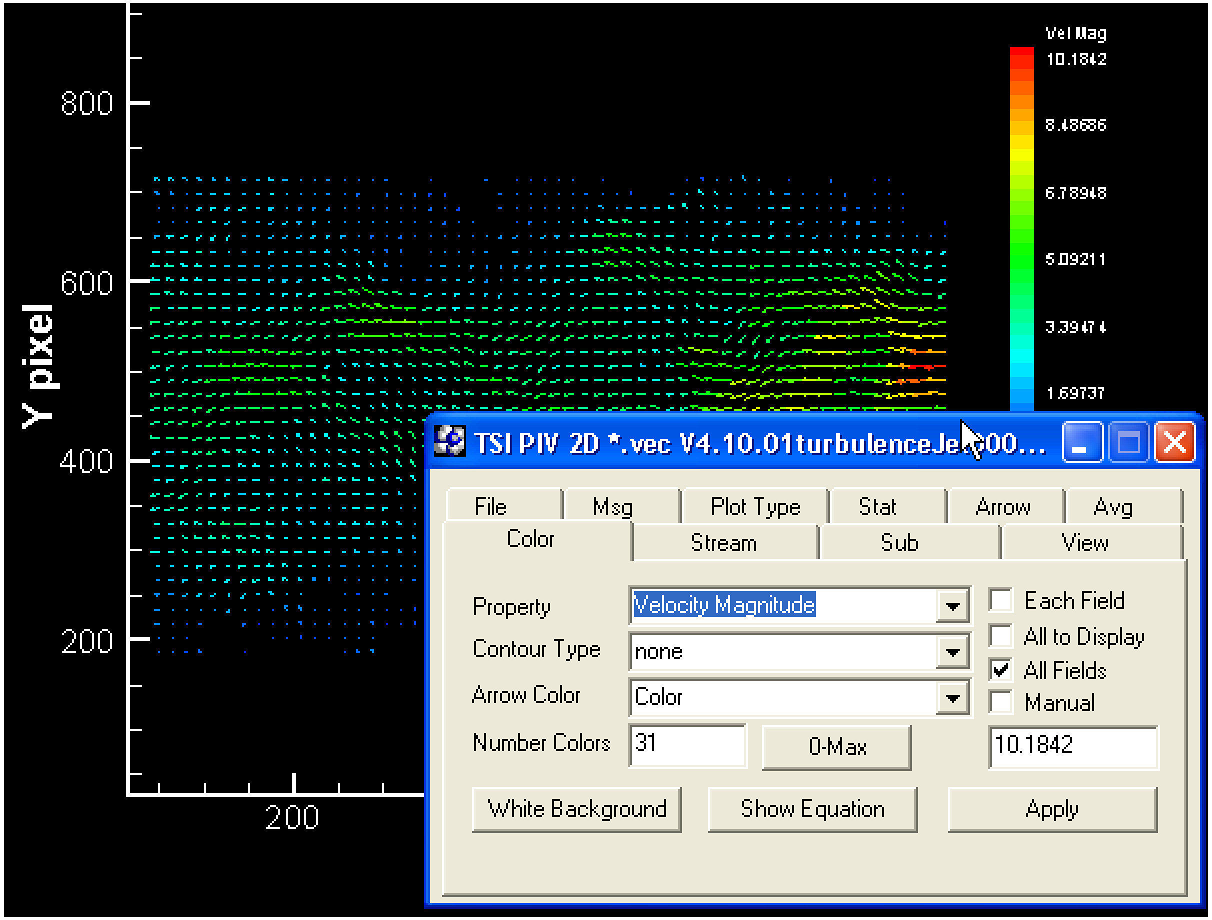
Processed Image

- Re-process the image, with the Mask Selected, the Processor selected, and the Post-Processor Selected.



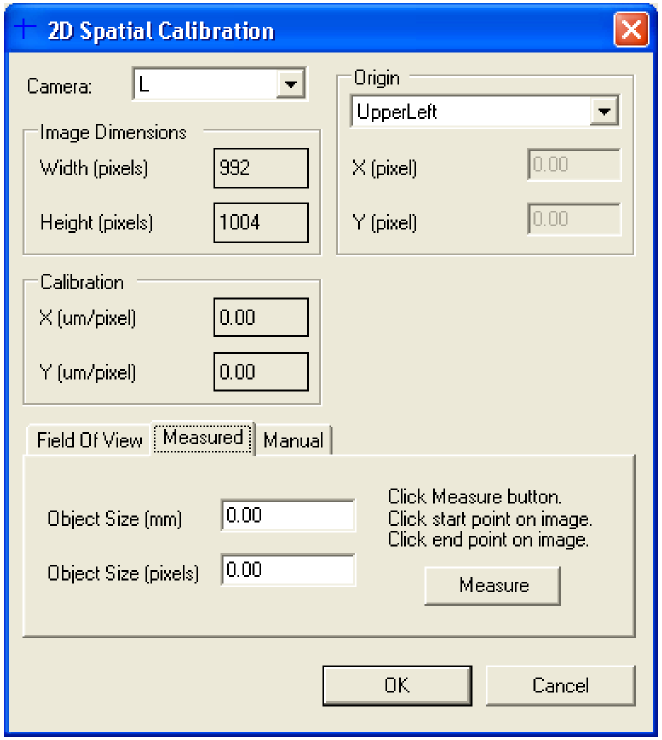
Viewing Vector Field in TecPlot

- Click on the “TecPlot” icon button. The last vector field that was processed, is automatically loaded into the TSI-TecPlot Macro, and displayed on the screen.
- Change the “Contour Type” to “Flood”, and the “Arrow Color” to “Black”.
- Click on the “Arrow” tab and make the vectors longer by clicking on the “Longer” button.
- Note that the units are in Pixels and Pixels/Second. This is because we have not yet calibrated the PIV image. It gives us an idea of the pixel displacement, but typically physical units are more useful. Let’s calibrate.



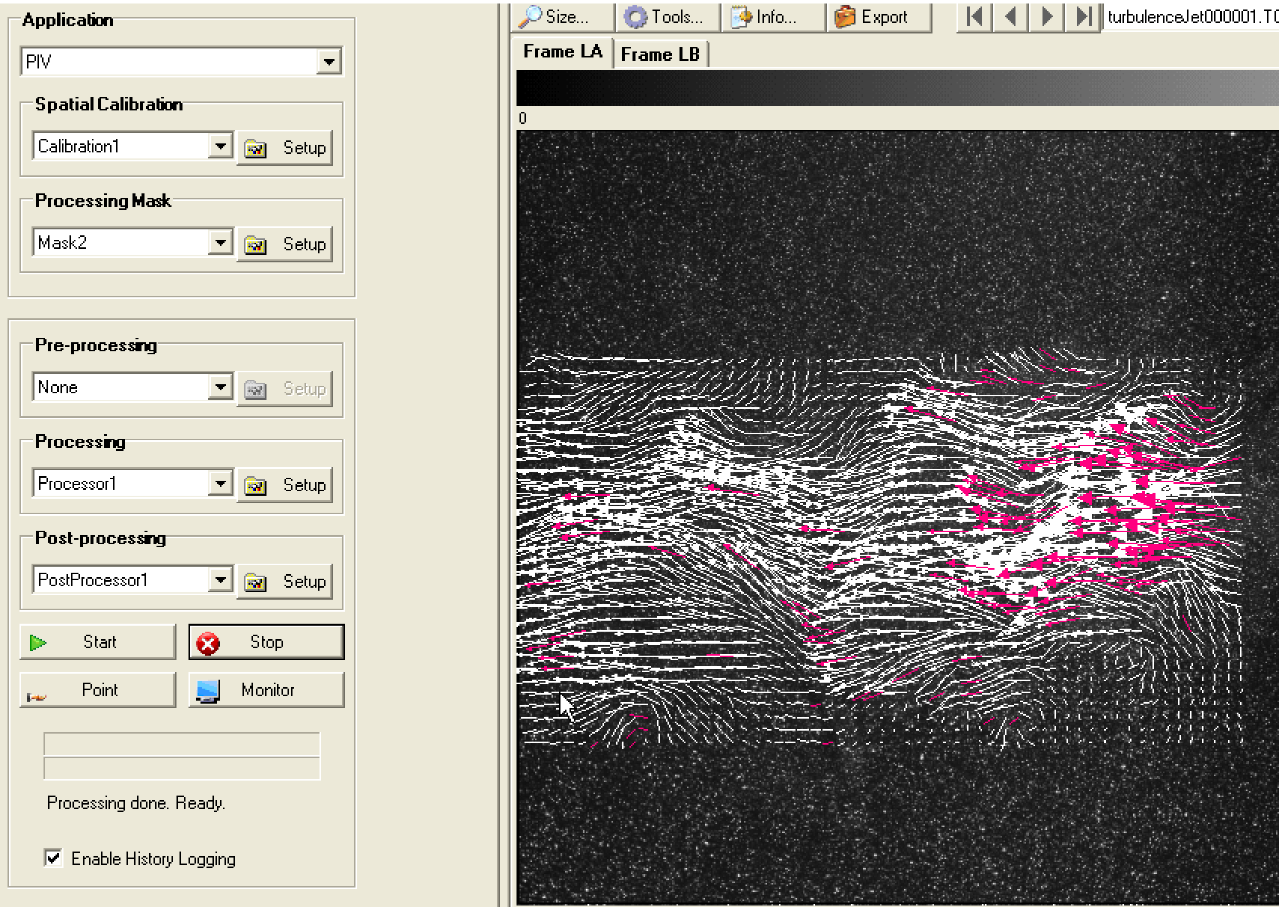
Calibration

- Back in INSIGHT3G, clear the vectors by clicking the Tools Button >> Vectors >> Clear.
- Click “create new” under the Spatial Calibration box, and give the calibration a name.
- The box at the right appears.
- To calibrate the image, we need to associate the pixel size (after magnification through the camera lens) with a physical size (typically in microns).
- (Note: we cannot just enter the actual size of the pixels here, unless the magnification is exactly 1:1)
- The most common way to calibrate the image is to measure something in the field of view, for example a ruler that has been placed in the plane of the light sheet. Since we do not have an image of a ruler for this example, let’s assume that the distance from the top of the image to the bottom of the image is 120 mm.
- Type 120 in the “Object Size (mm)” field.
- Click the “Measure” button.
- Click on the top of the image, then click on the bottom of the image. The distance between these 2 points in pixels will appear in the “Object Size (pixels)” field, and the um/pixels calibration factor will appear above.
- Note: It is often useful to “Zoom-in” on the image while clicking on the 2 points. This can be done by clicking the “Size” button and selecting a magnified field of view. Additionally, to ensure a straight line, it is often useful to draw the line near the edge of the image, using the edge as a reference.
- Click OK.



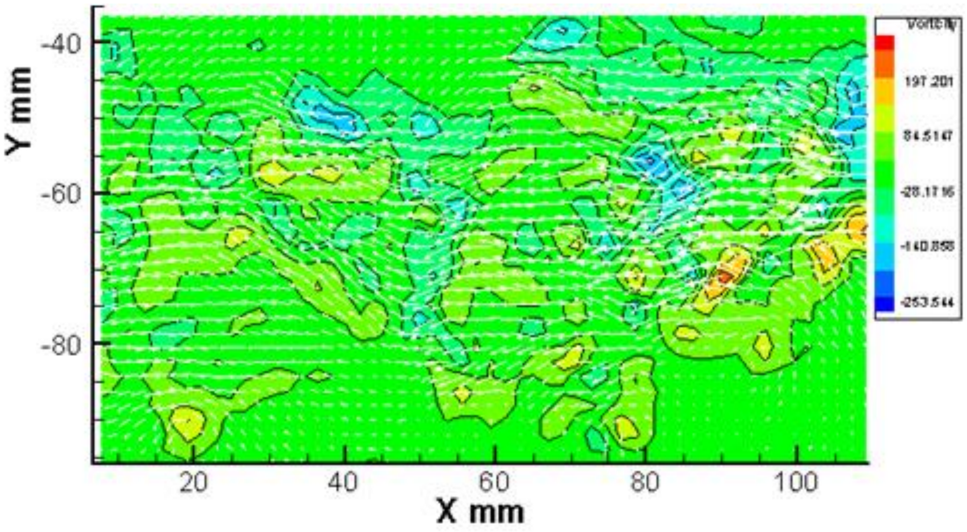
Final Process

- We can now process the image with the calibration, mask, processor, and post-processor selected.
- Click “Start”



Final Plot

- Click the TecPlot button (or if TecPlot is already running, the plot will automatically load).
- Play with the settings to plot a flood of Vorticity.
- The version of TecPlot that comes with INSIGHT3G is a full version, so manipulations of the data outside of the macro are okay.



Conclusion

- Congratulations! You have processed a PIV image pair. Of course there is a lot more to PIV data processing than was shown here, but hopefully this has given you an idea of what steps should be followed, and what is possible with PIV software.