Introduction to bunch length measurements using the PITZ TDS

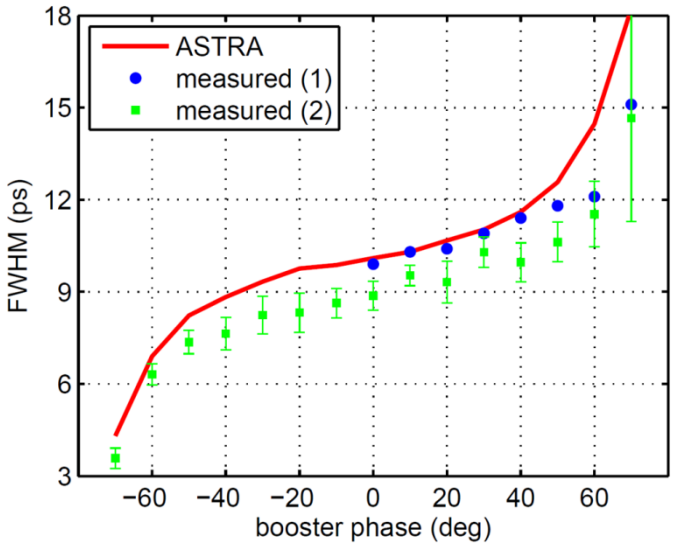
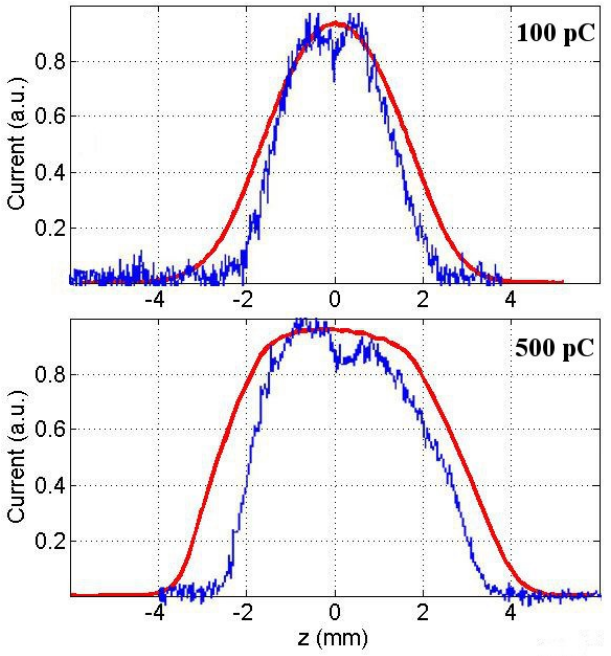
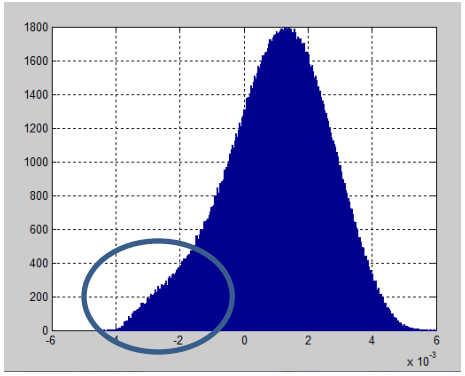
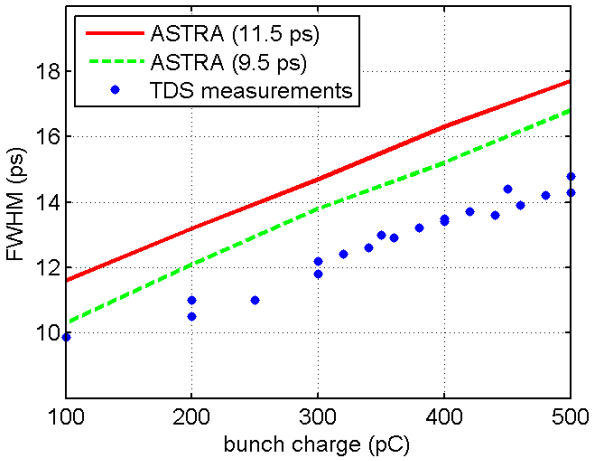


Fig. 6: FWHM bunch lengths versus booster phase for a bunch charge of 100 pC, measured with the TDS and simulated (red line) using the measured transverse laser profile from the first data set (blue dots) as input.



Core + halo simulation for higher charges:
FWHM not representative due to „shoulder“ not seen in experiment





TDS tool news (many thanks also to Bolko Beutner!)

- A noise-cut function automatically creates a mask of interest around the beam, cuts everything else and subtracts the average noise level from the image (more later).
  - But first, background images are taken (once for focused beam and once for streaked beam) and subtracted.
  - A manual ROI should still be used to pre-filter edge flickering.

- TDS_main window should currently be used ONLY to start the „calibration“ window and should be minimized afterwards.
- All images of the calibration curve are saved (.mat) and used for statistics of the actual bunch length.
- Bunch lengths are calculated as „real“ FWHM of vertical profiles for each image, then averaged.
- Both slopes of the TDS RF are scanned, results are then quadratically averaged and the focused beam size is quadratically subtracted (see next slide).

Bunch lengths of tilted beams

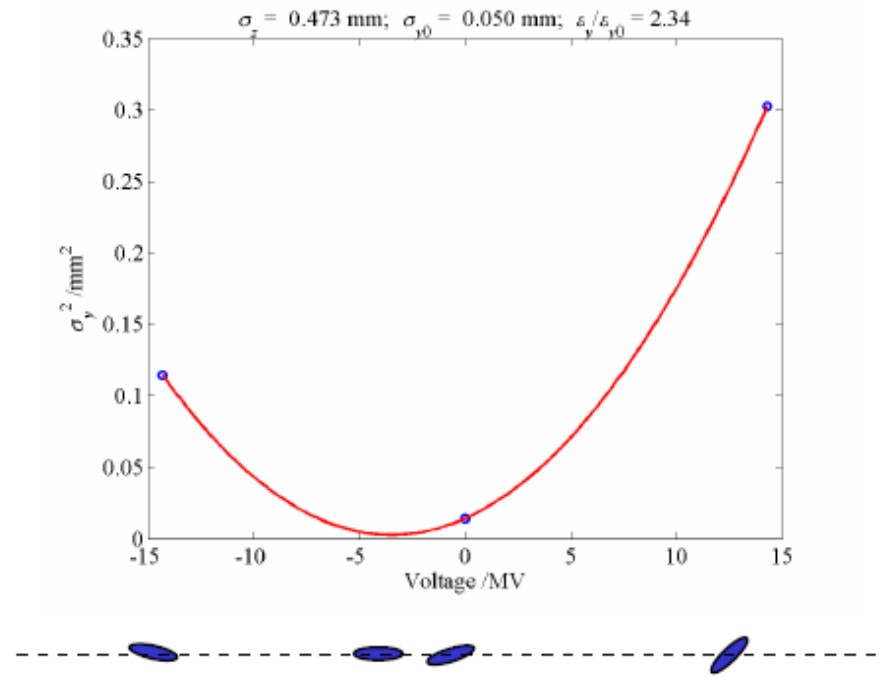
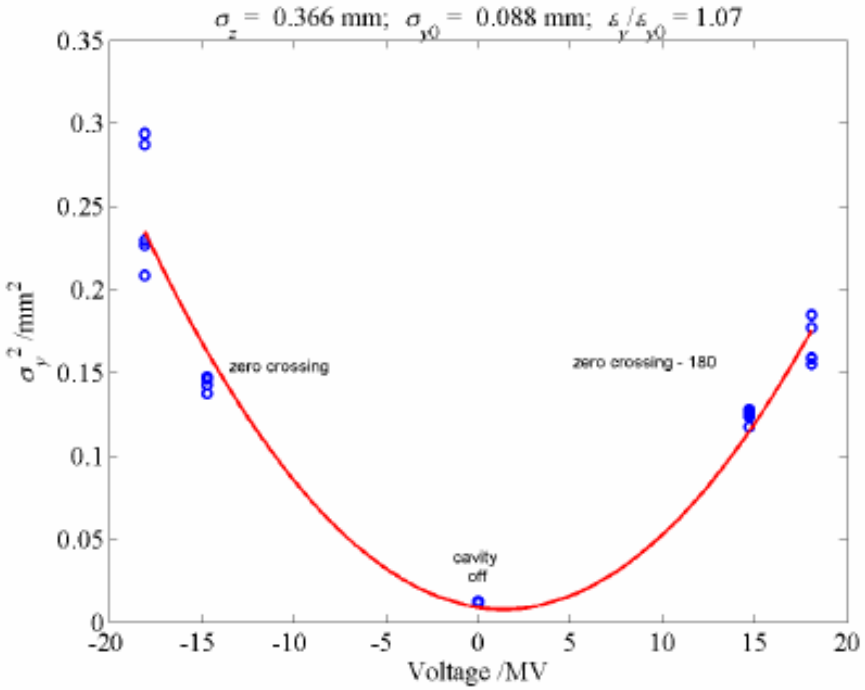
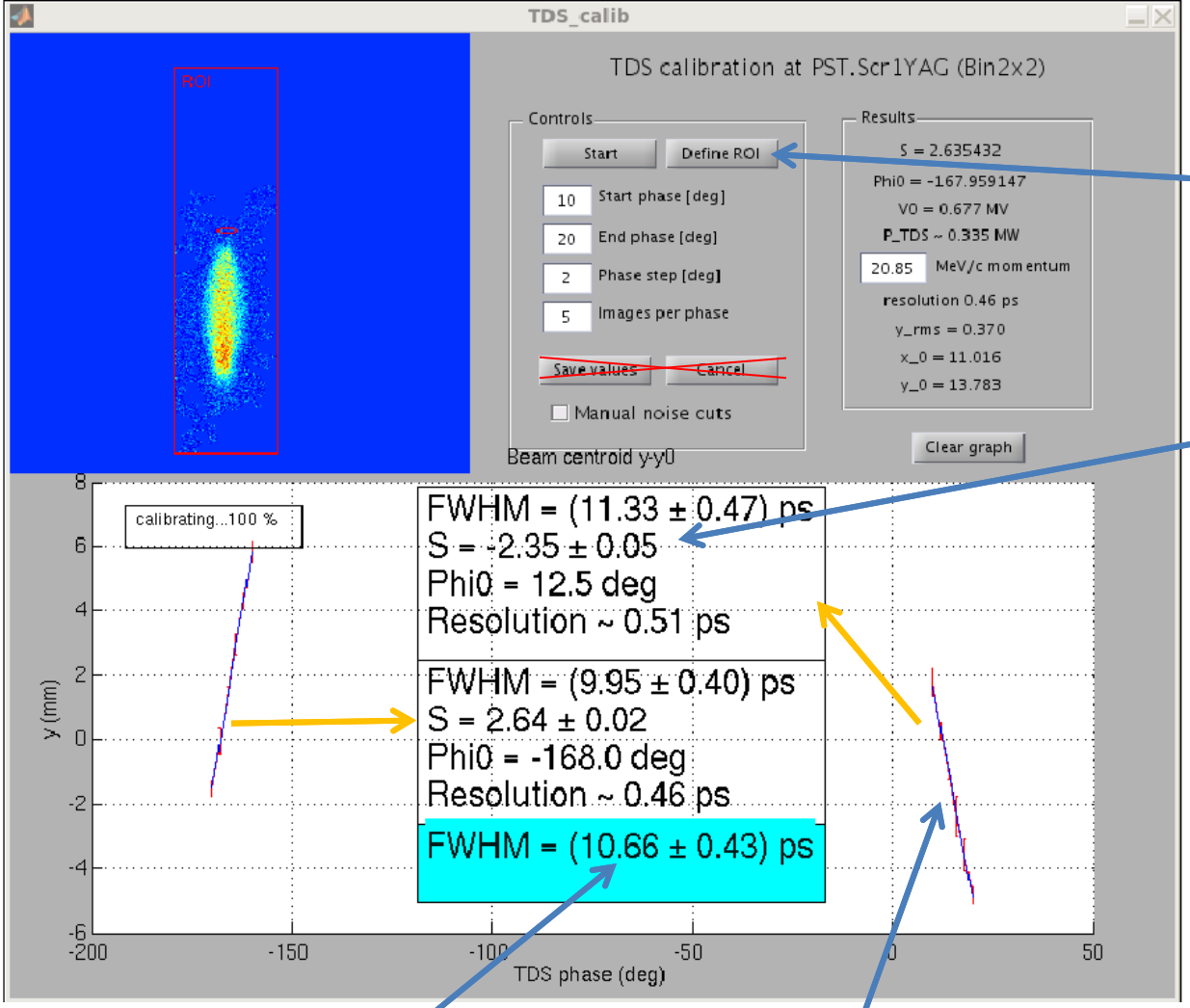


Figure 5: An asymmetric beam size scan with RF voltage indicates an incoming transverse-longitudinal correlation in the bunch, shown in the lower illustration, which is cancelled by the cavity at $V\left(\sigma_{y\min}^2\right)$.



SLAC-PUB-9241
May 2002 (EPAC 02)
R. Akre, L. Bentson, P. Emma, P. Krejcik

- Turns out that quadratic fit is the same than quadratically averaging the two zero-crossings and quadratically subtracting the focused beam size!

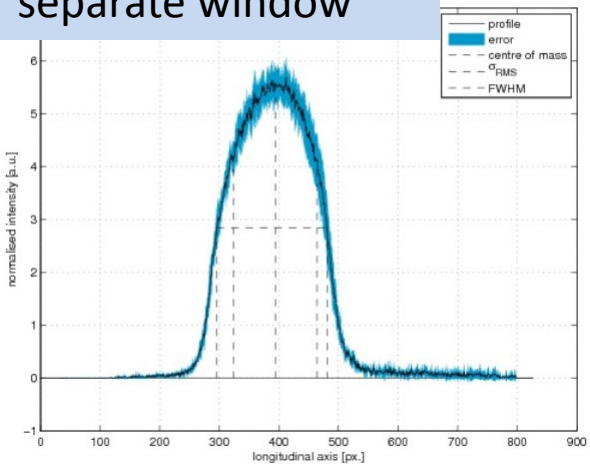


Draw ROI before measurement to mask the bright screen edges

Errors should be <5%.

Also, the two „S“ and „Phi0“ should not differ too much

Temporal profiles in separate window



Combined FWHM (parabola fit)

Phase scan with linear regression (180 deg away from other scan)

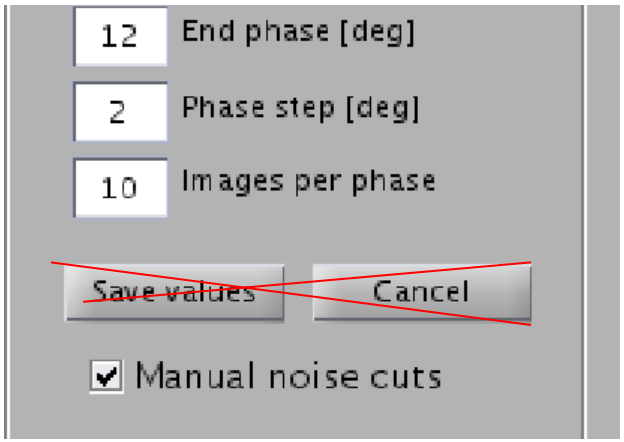
Basic functionality of noisecut.m (Bolko Beutner)

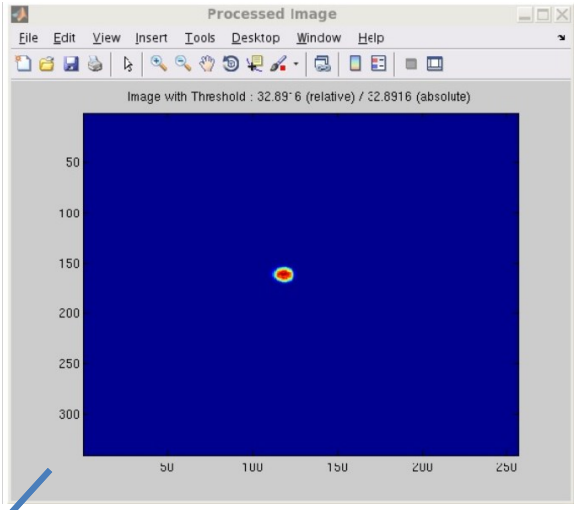
- Goal: create a mask of interest around the beam, cuts everything else and subtracts the average noise level from the image.

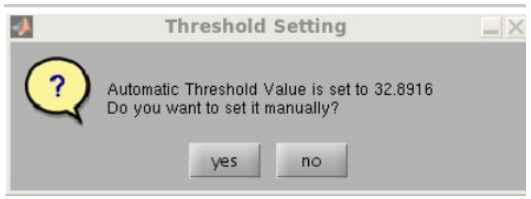
1. Smooth image with Gaussian filter.
2. Find the actual beam profile, fit it with a 2D-Gaussian (robust).
3. Define a threshold pixel intensity (manually or automatically).
4. Every pixel below threshold is „masked“, i.e. discarded.
5. From the remaining image, subtract the average noise level (averaged before masking).

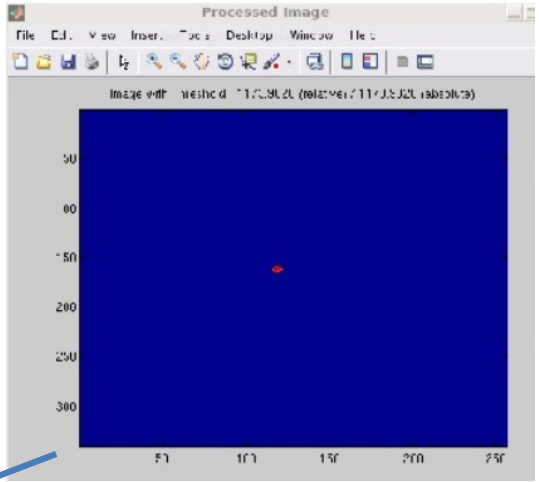
- Step 1&2 only work reliably for a certain range of spot sizes
- The automatic version (noisecut2.m) uses a lot of other magic (A.I.)
- The noise threshold should be selected so that cutting LESS will hardly affect the result (e.g. rms spot size), but cutting MORE will strongly reduce it (see next slide)…

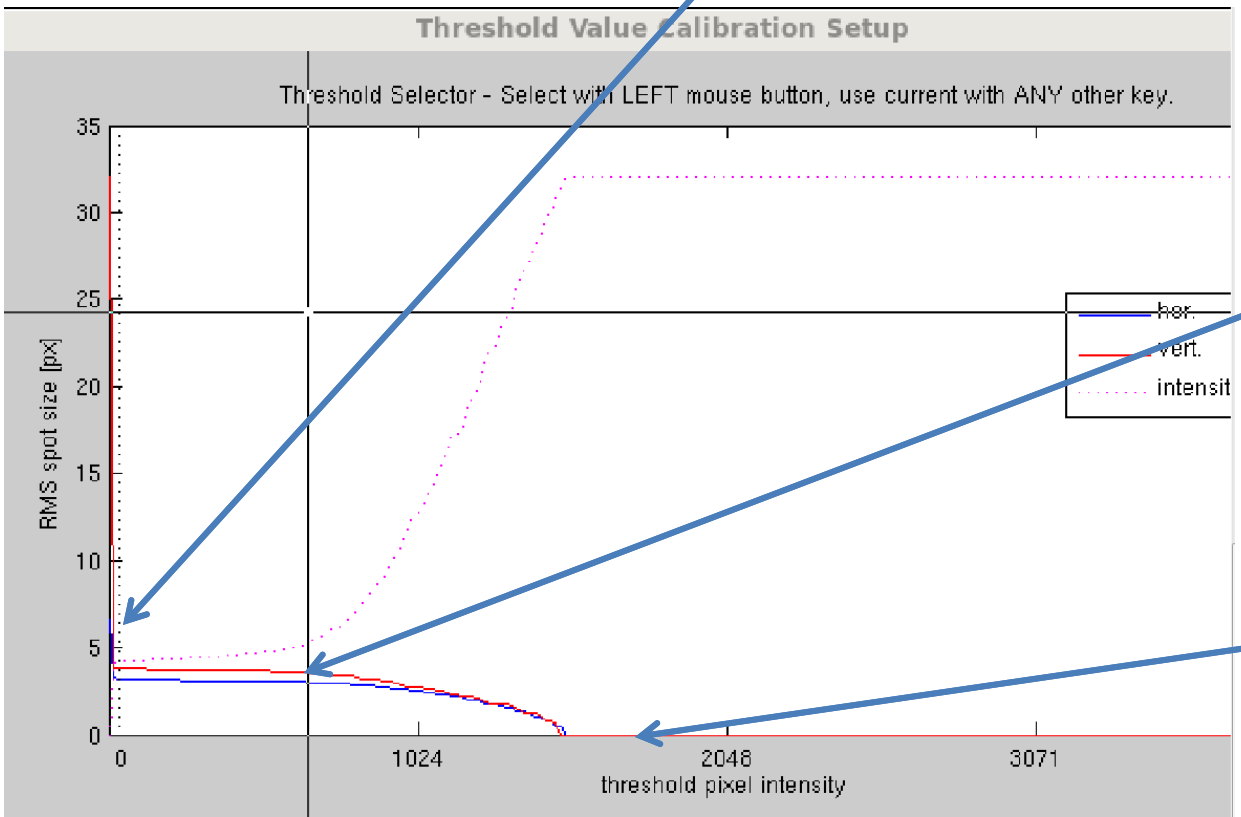
Manually adjusting the noise cut threshold („experts only“)

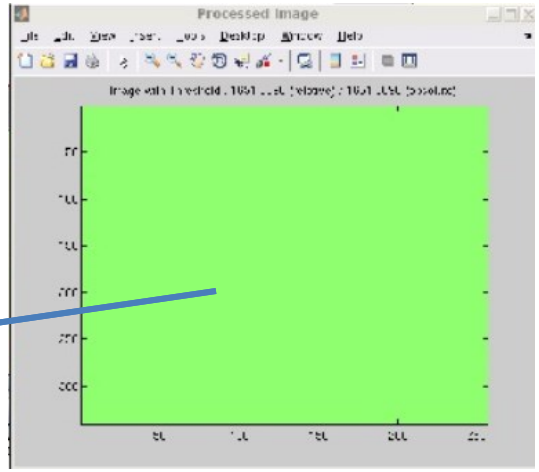








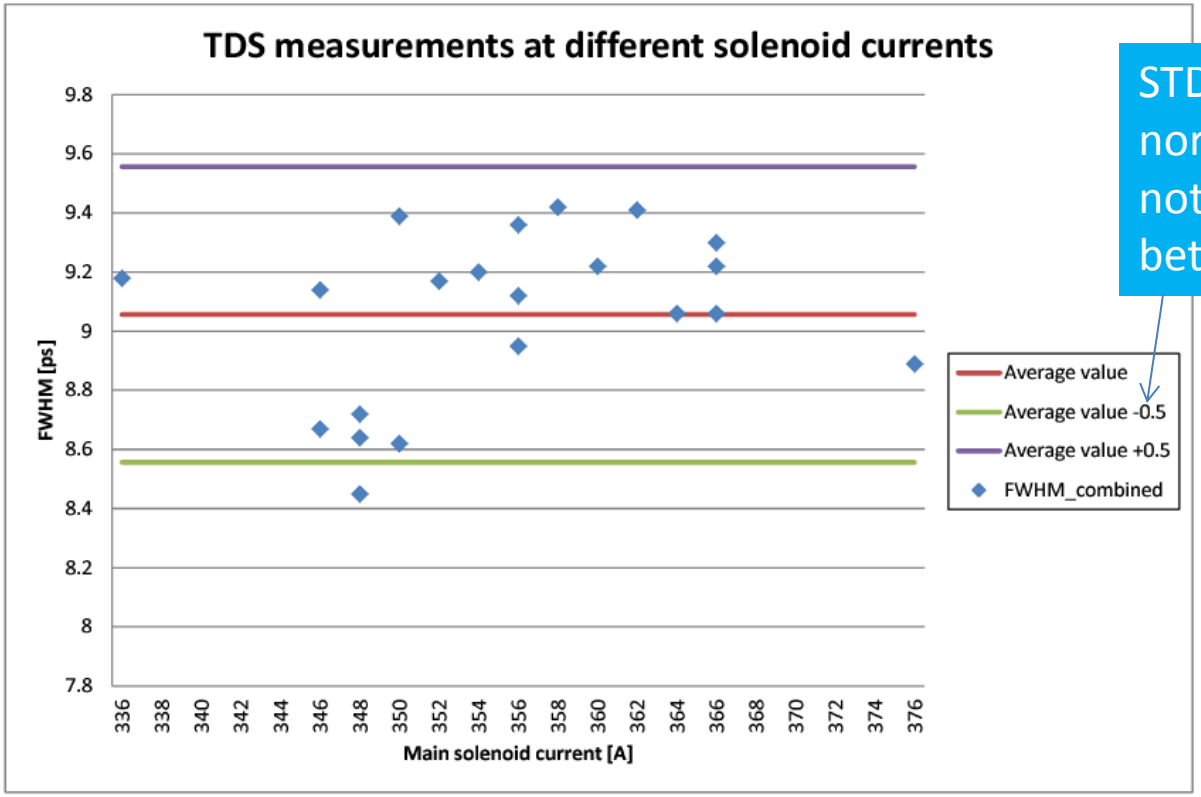




TDS quick manual

- Set TDS power to less than 75 dBm klystron reflection.
- Adjust non-streaked beam on PST.Scr1: focus with Q9/Q10 to some 3-10 pixel diameter of green and red color without BG in VideoClient.
- In matlab, run /doocs/measure/scripts/SVN/matlabscripts/TDS/TDS_main.
- Enter framegrabber number when asked.
- Press „calibrate“ button, then minimize the main window.
- In the TDS_calib window, press „Define ROI“, then drag the ROI to mask edges.
- Enter proper phase range (e.g. range of 8°, step size 2°, 10 img/phase).
- Adjust TDS timing so that the beam is streaked.
- Press „Start“ button.
- When asked, adjust beam intensity. This is the most important task in order to obtain reliable measurements. Luckily (compared to EMSY measurements), we have also the beam focus in both axes (Q9 and Q10) as free parameters.
    - Rule of thumb: „some“ images should be without white pixels.
    - On bottom there will be more white pixels. Don‘t use too large range.
- After the scan, the cyan text field shows the main result (FWHM +- STD).
- It is recommended to press clear graph before next scan (ignore all other buttons).
- In case of large errors (4% is normal, both for linearity S and for FWHM), try again with different beam intensity.
- In case of NaNs or matlab errors or green images, first close the TDS_calib window and then try again with different beam intensity…
- If everything fails, try manual noise cut thresholds.

Bunch length vs. solenoid current (100 pC)



STD of 0.5 ps is normal and does not get better with better statistics!

- At least for 100 pC, a broad range of solenoid currents does NOT affect the measured bunch length. (strange exception: 348 A, although still inside error bars)
- That means, we can do e.g. phase scans without worrying/optimizing solenoids
- Same is true for focusing with Q9/Q10, which should be used for optimizing intensity on the screen
- Discrepancies seen before could be tracked down to wrong noise cuts (or even camera losses) due to low intensity (compare EMSY beamlets and correction factor!)

Some tips…

- **Good intensity is crucial for TDS measurements. It should be adjusted as diligently as for emittance measurements.**
  - **play with camera gain**
  - **use 1 or 2 laser pulses**
  - **use PST.Scr1 (Bin 4x4) or 2x2 or 1x1 binning**
  - **use either camera lens**
- **However, too small spot sizes (~<5 pixel) in either direction can yield matlab errors or systematic errors (e.g. overestimation due to image smoothing).**
- - we do NOT need to know the beam momentum for bunch length measurements!
  - (but we do for slice emittance measurements)
- - between gun phase MMMG -15 and +15, TDS zero crossing changes by ~10 deg => booster phase adjustment is probably NOT necessary, because no significant bunch length changes are expected with booster MMMG phase +-10 deg * 1.3GHz/3GHz.
- - TDS phase range of 8 or 10 deg with step size of 2 is fine.
- - Q9 current approx. between 4A and 5A, Q10 current between -4A and -5A.
- - main solenoid can stay at 356A (although it doesn't seem to matter much).