# xBSM data from May 2010 run

J.W. Flanagan

CesrTA WebEx

2010.7.13

# Contents

- E-cloud study data (CA, FZP)
- Resolution estimates and comparison with e- data at D Line 2 GeV
- Resolution estimates for other lines and energies (C and D, 2 and 4 GeV)

- Not: Calibration not yet done, so all data shown are with uncalibrated interpixel gains.

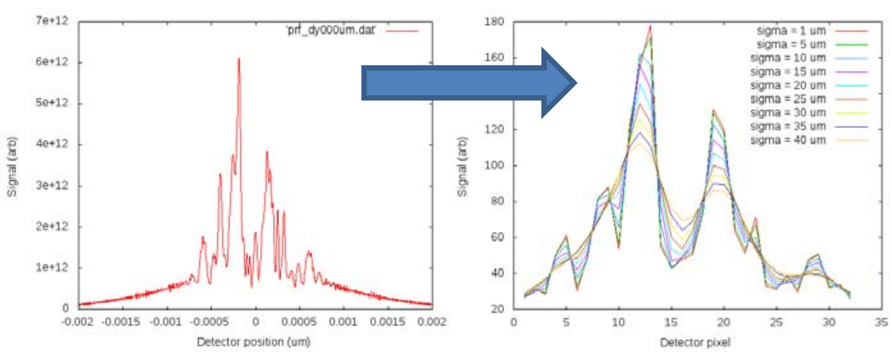
# E-Cloud study data

- Data taken night of 10/11 May at D Line (e+)
- Fill pattern: 45 bunches, 14 ns spacing
- Bunch currents: 0.5, 1.0, 1.15, 1.3 mA
- X-ray optics: CA and FZP
  - FZP data analyzed same way as CA data
    - Fit data to templates generated by sets of point response functions, which are weighted over the assumed source distribution. Grid of templates in y and $\sigma_y$ used.
  - FZP is treated as being *one-dimensional*. (Cylindrical lens.)

## CA

Point Response Function

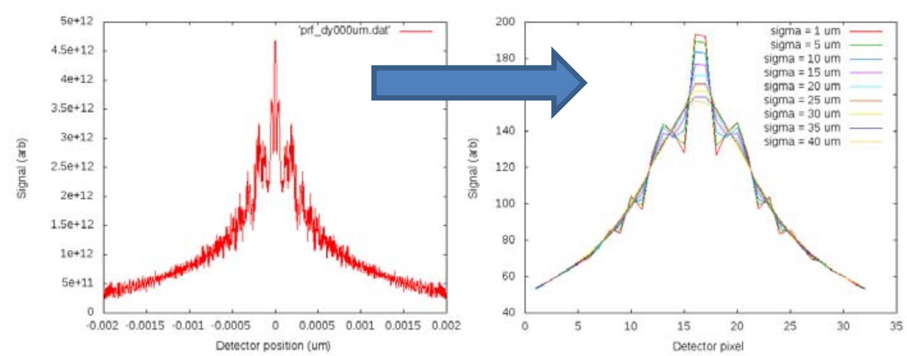
Smeared and binned templates



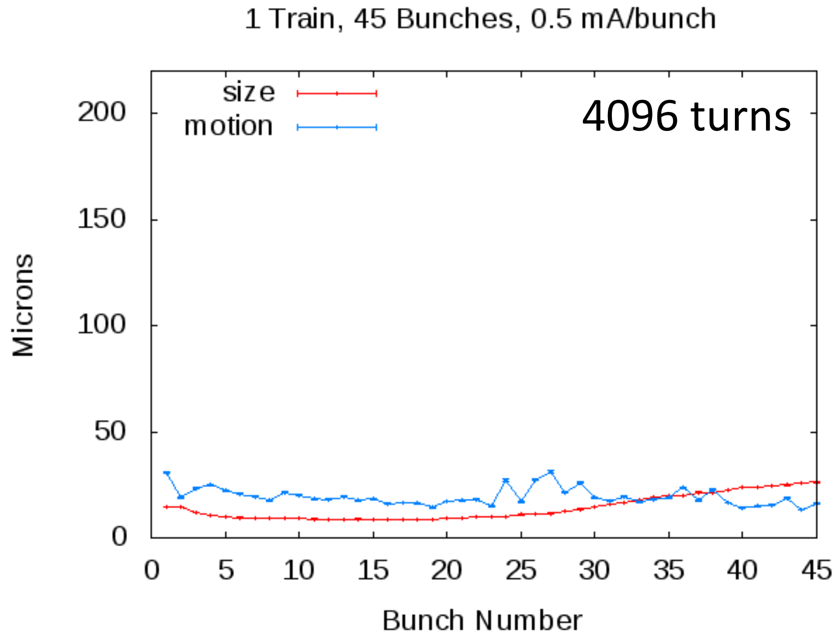

## FZP

Point Response Function

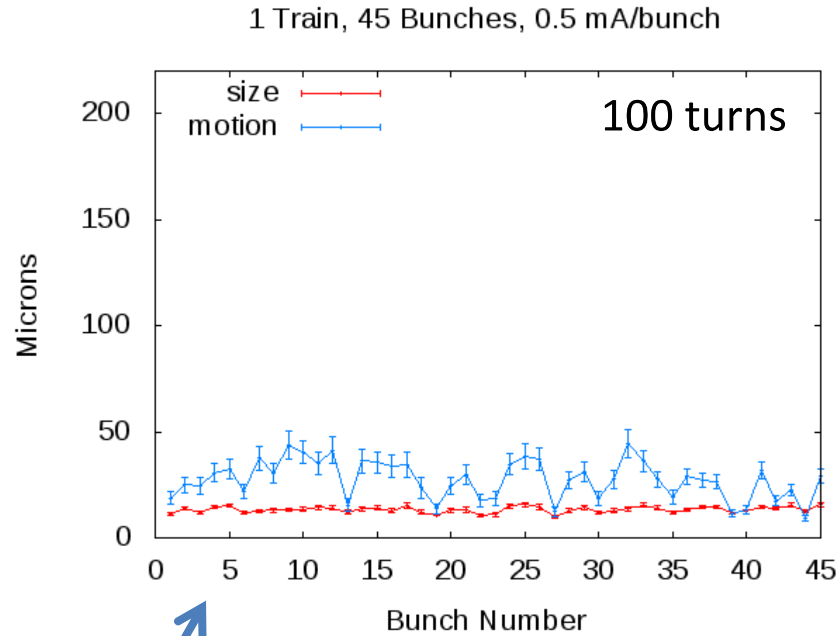
Smeared and binned templates

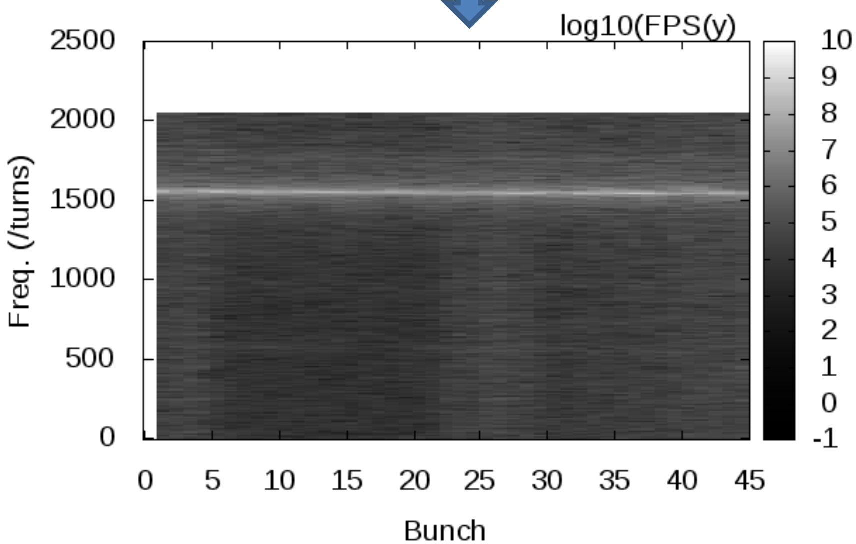


# CA




# FZP



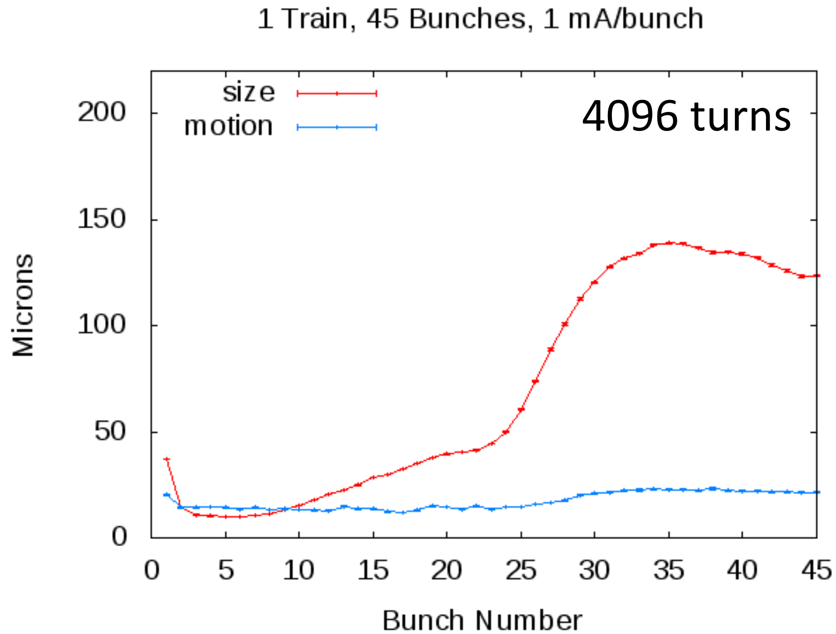




Single-bunch, single-turn fits averaged over turns

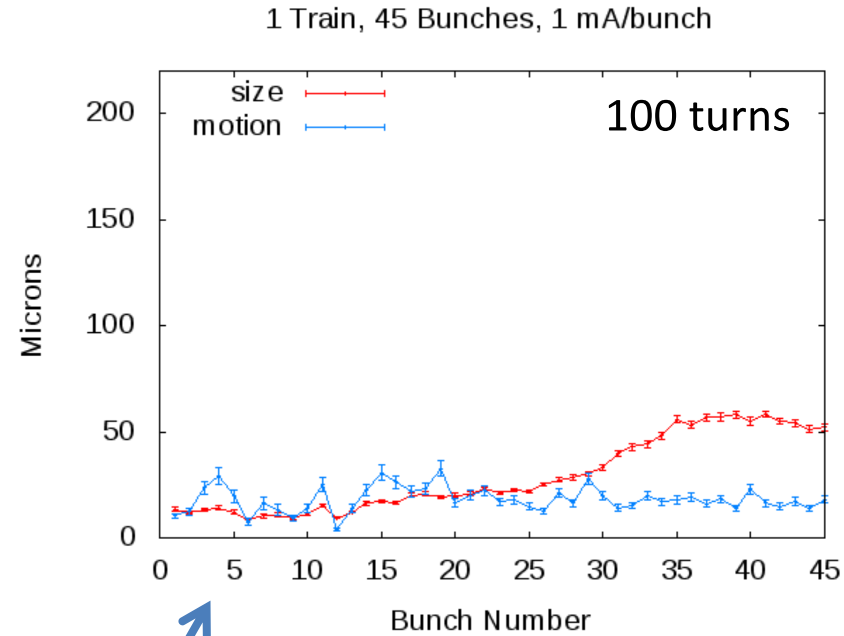
Bunch-by-bunch position spectra

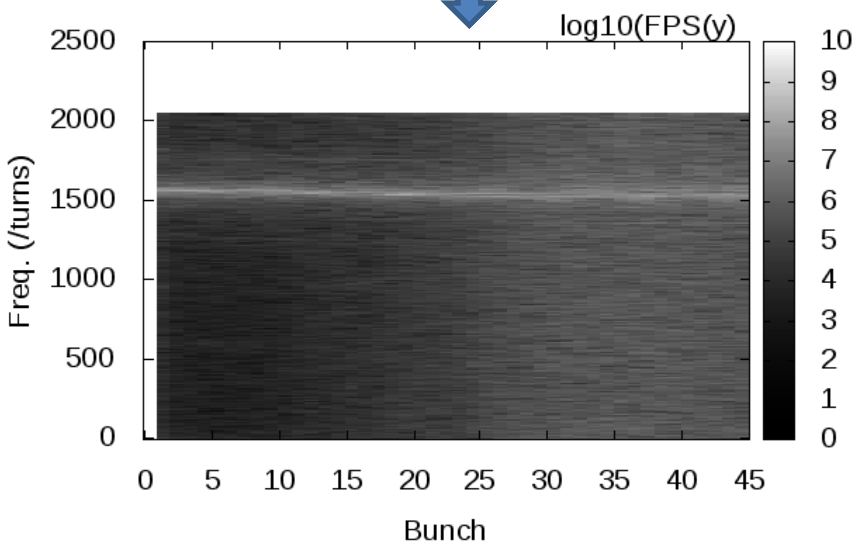
**0.5 mA /bunch**

# CA




# FZP



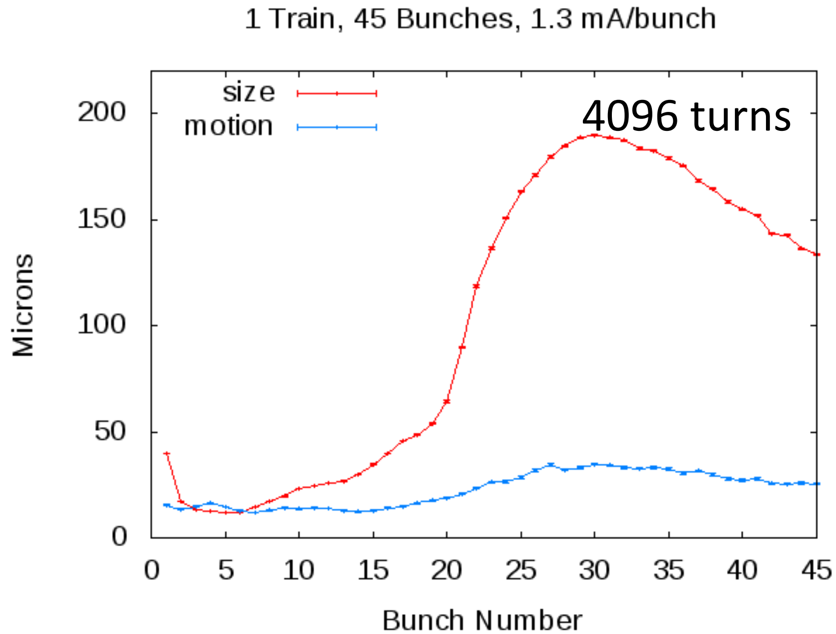




Single-bunch, single-turn fits averaged over turns

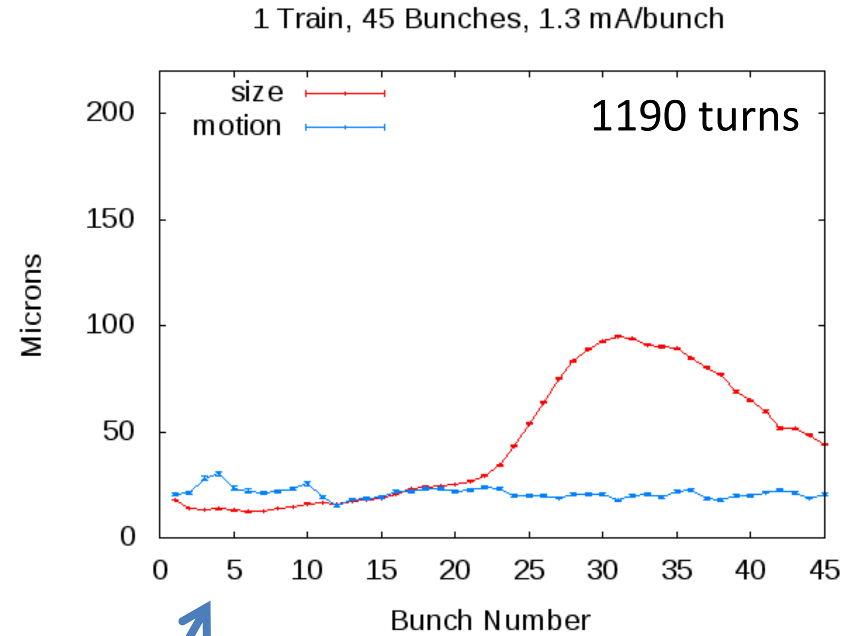
Bunch-by-bunch position spectra

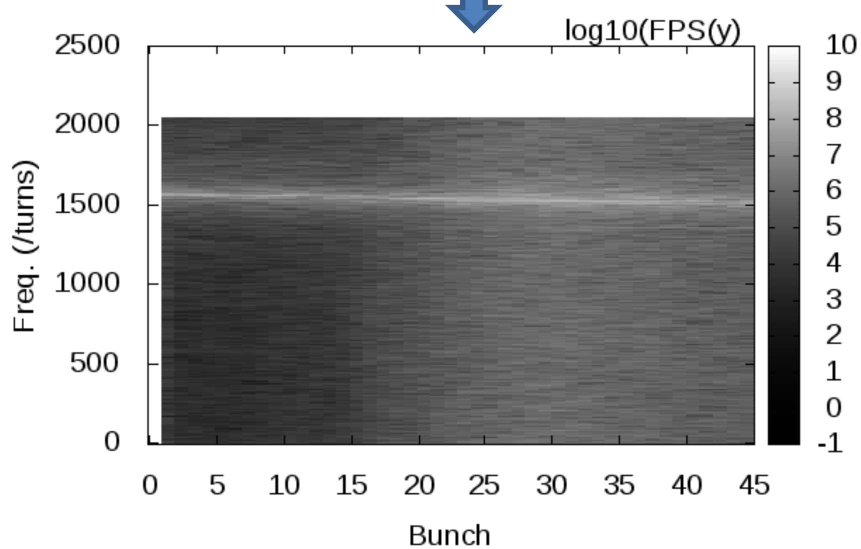
1.0 mA /bunch

# CA




# FZP




Single-bunch, single-turn fits averaged over turns

Bunch-by-bunch position spectra

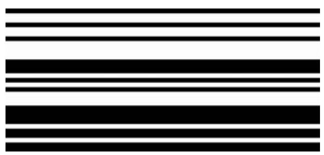
**1.3 mA /bunch**

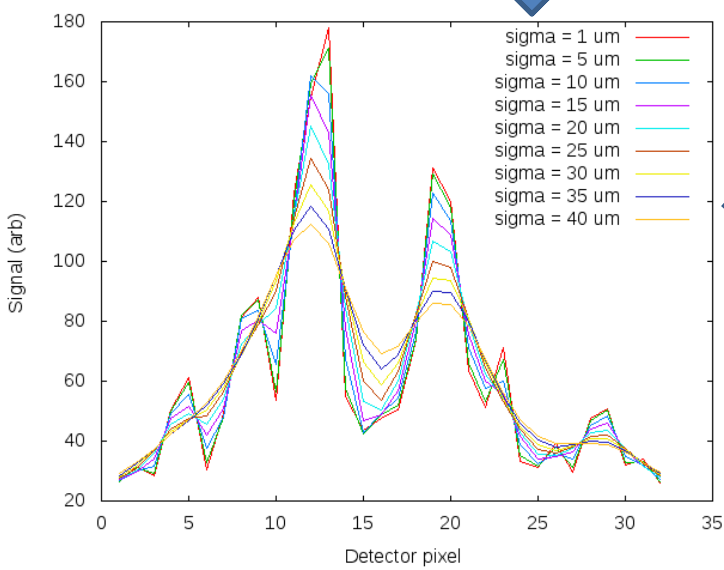
# Resolution Estimates

- **Procedure:**
  - Simulate detector images for beams of $\sigma_y$=1-40 μm.
  - Fit images against each other. Chi-squared is calculated for cross-fits:
    - Chisq/nu = (1/(N-n-1))*SUM[(y_i-y(x_i))^2 / sigma_i2^]
    - E.g., 5-μm pattern is checked for fit against 1-, 2-, 3-, … μm patterns.
    - Bin (pixel) weights are assumed to be statistical (sigma_i = sqrt(y(x_i))), assuming average bin height represents 200 photons.
      - Expect ~360 photons/pixel/turn/mA/bunch at 2 GeV with low-energy chip
      - Expect ~240 photons/pixel/turn/mA/bunch at 4 GeV with high-energy chip
  - Chi-sq 70% exclusion values are taken to represent the resolution contours.
    - Should approximate something like 1-sigma contours.
- **Note that these are *single-shot* resolutions.**
    - **Detector noise is not included, only photon statistics**

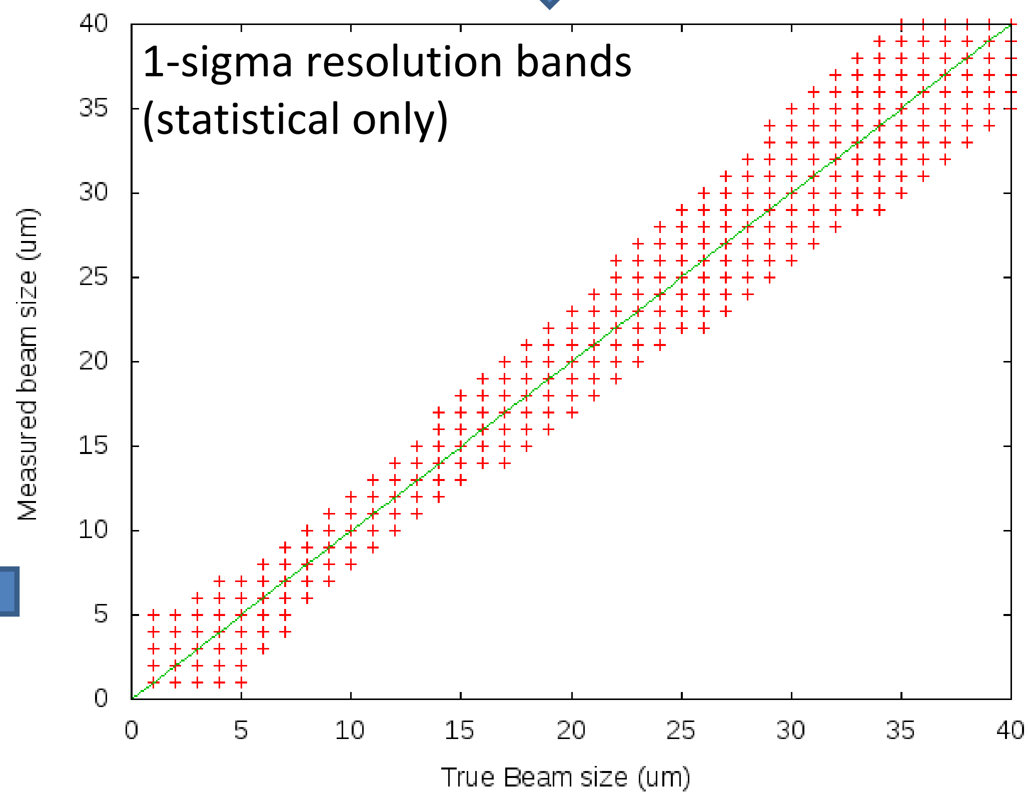
# 10 μm, 31-element CA mask @ D Line 2 GeV

Generate detector images for various beam sizes:





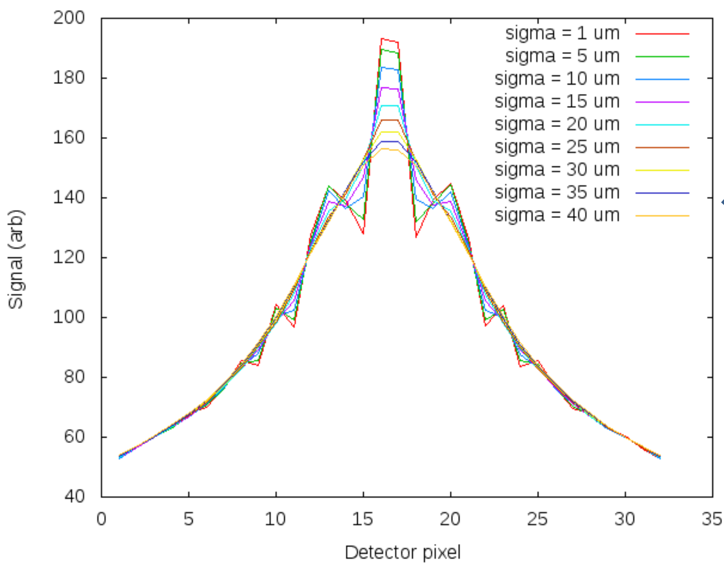

Cross-fit between beam sizes.
Plot 1-sigma statistical confidence regions,
Assuming 200 photons/pixel average
(=> 0.56 mA at 2 GeV):



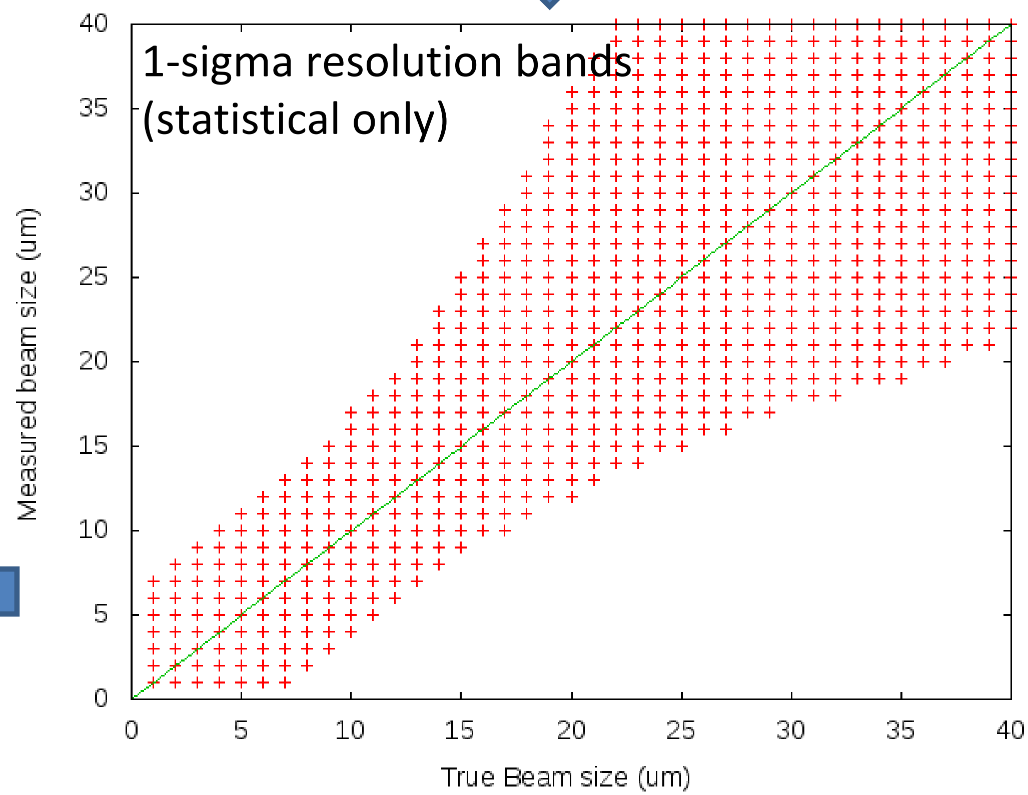

Statistical single-shot resolution at 10 μm beam size = +/- ~2 μm
(Assuming ideal detector.)

# FZP@ D Line 2 GeV

Generate detector images for various beam sizes:




Cross-fit between beam sizes.
Plot 1-sigma statistical confidence regions,
Assuming 200 photons/pixel average
(=> 0.56 mA at 2 GeV):

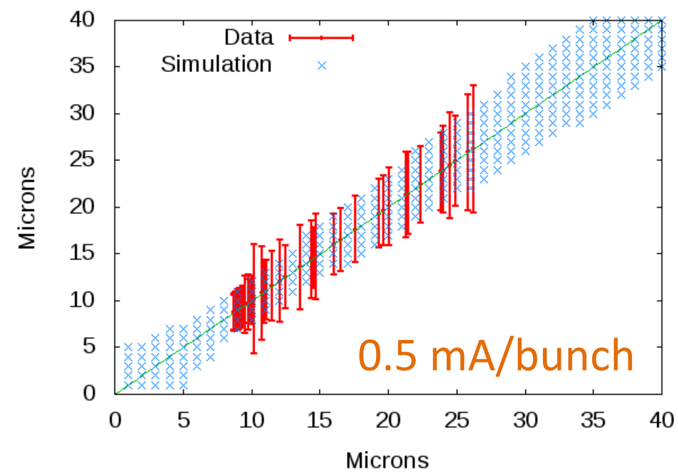


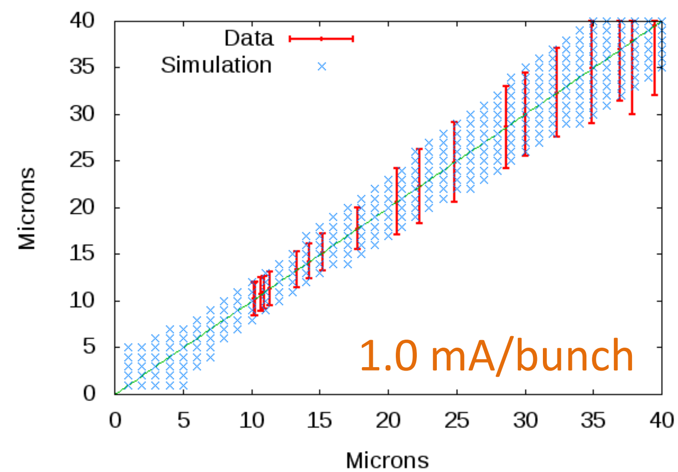

Statistical single-shot resolution at 10 μm beam size = +/- ~6.5 μm
(Assuming ideal detector.)

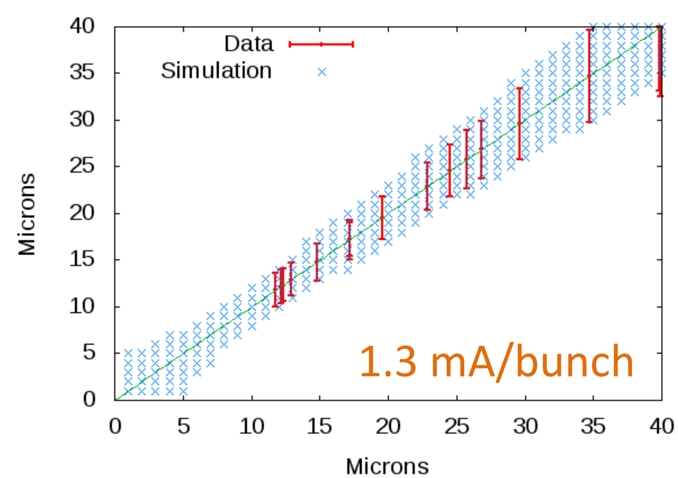
# Resolution data vs simulation: CA

- Simulation statistical confidence bands assume
  - Perfect, noiseless detector
  - 200 photons/pixel/shot on average
    - =>0.56 mA/bunch
- Shot-by-shot spread in data is closest to simulation at nearer to 1 mA.
  - Not using a perfect, noiseless detector.

- Seems reasonable agreement

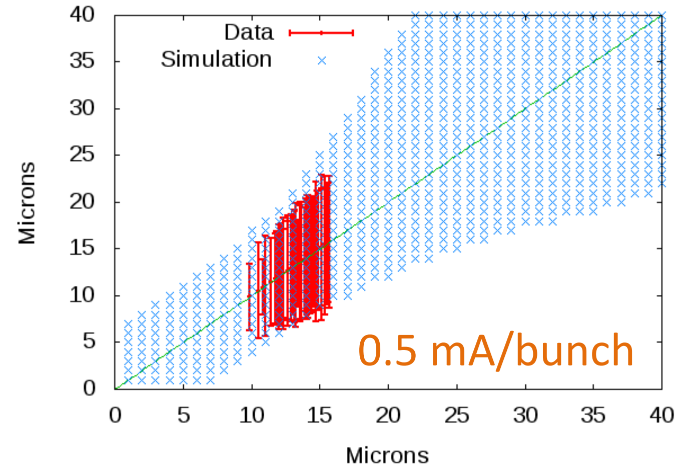


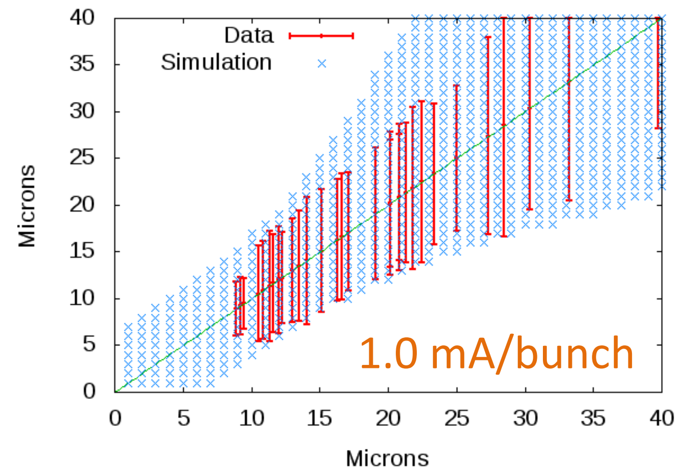



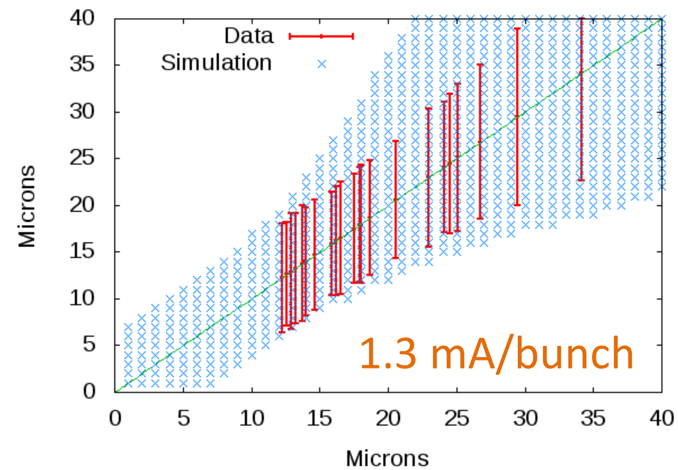



# Resolution data vs simulation: FZP

- Simulation statistical confidence bands assume
  - Perfect, noiseless detector
  - 200 photons/pixel/shot on average
    - =>0.56 mA/bunch
- Not so good agreement at ends:
  - >= ~18 um:  Actual spread smaller than simulation. (?)
  - < ~10 um:  Smaller spread due to cutoff in fits?
    - Fits at edge of grid (5 um) are thrown away, and FZP has a lot of “underflow fits” at small beam sizes.

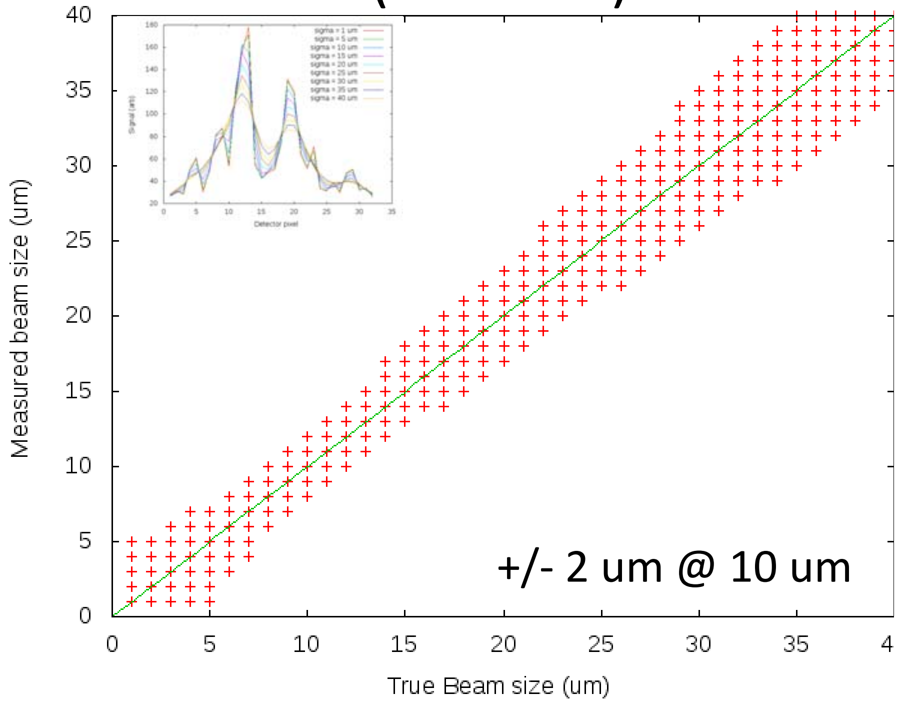


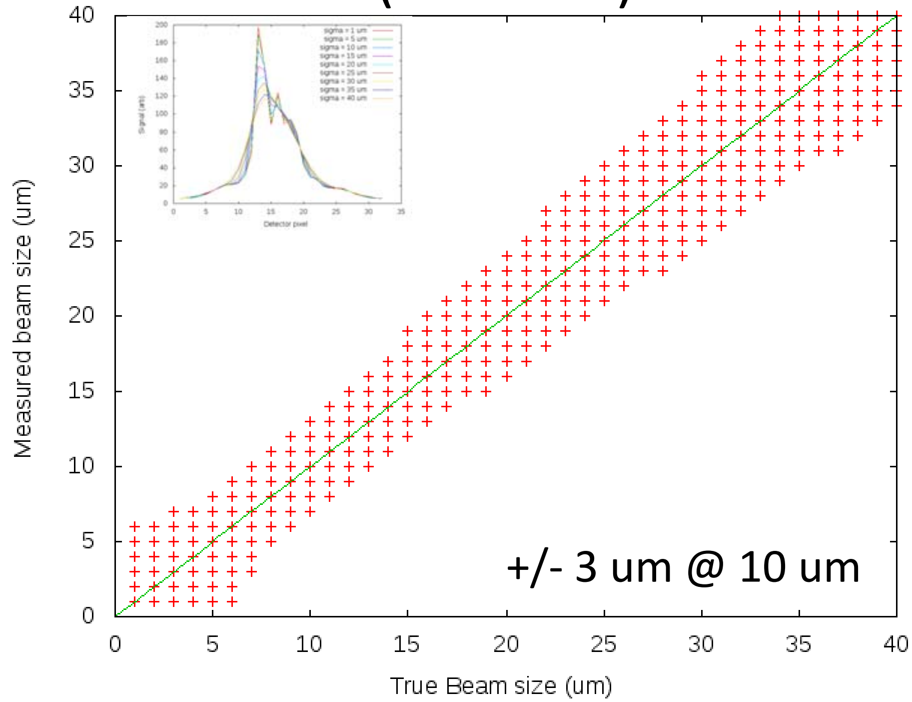



# 2 GeV CA Resolutions

## D Line, 10 um 31-pixel CA (Installed)



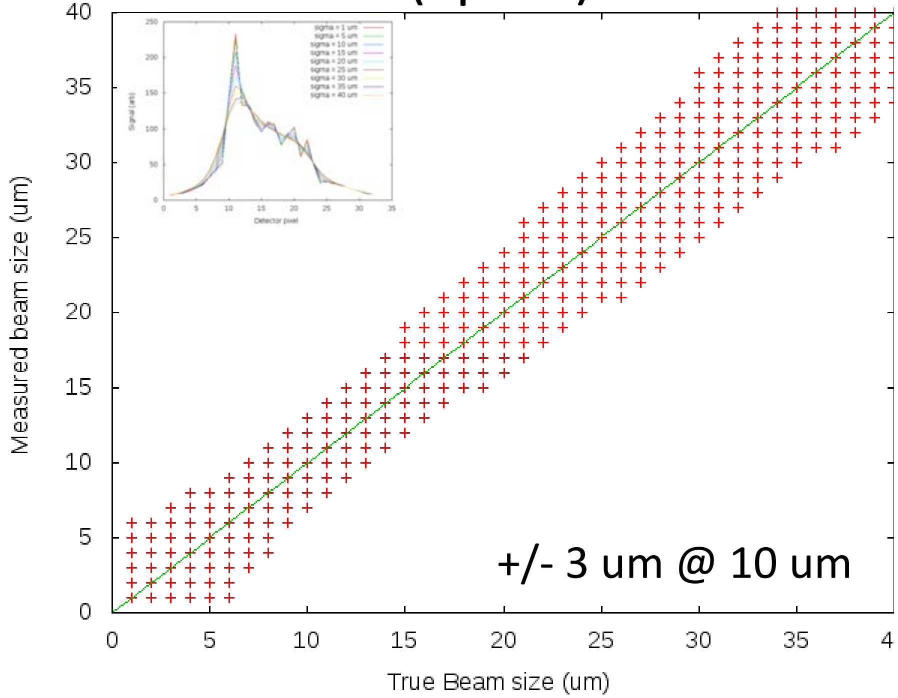

## C Line, 5 um 31-pixel CA (Installed)



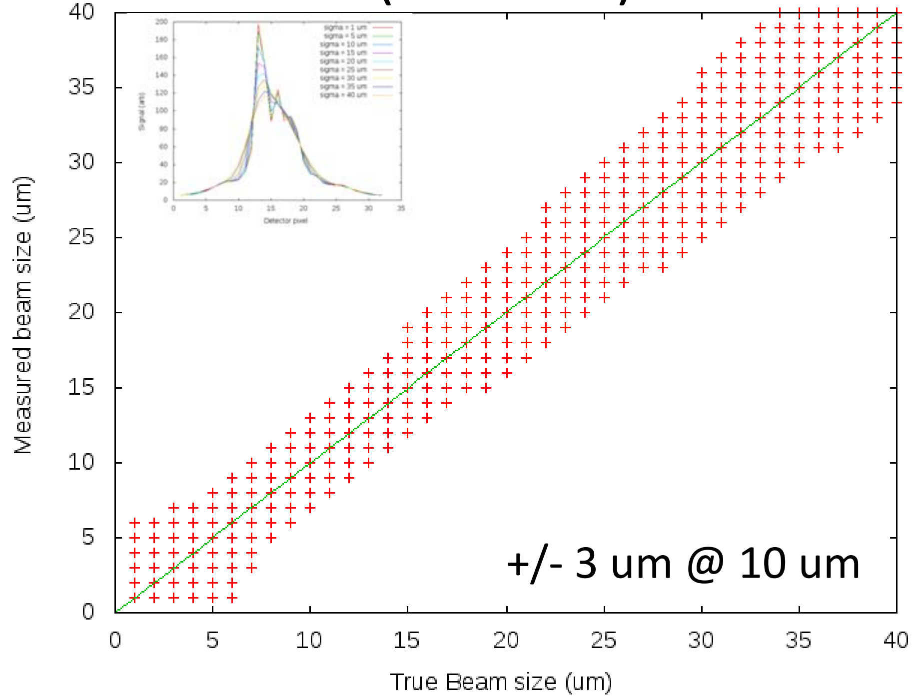

10 um mask is better…

# 2 GeV CA Resolutions

## C Line, 5 um 47-pixel CA (Spare)



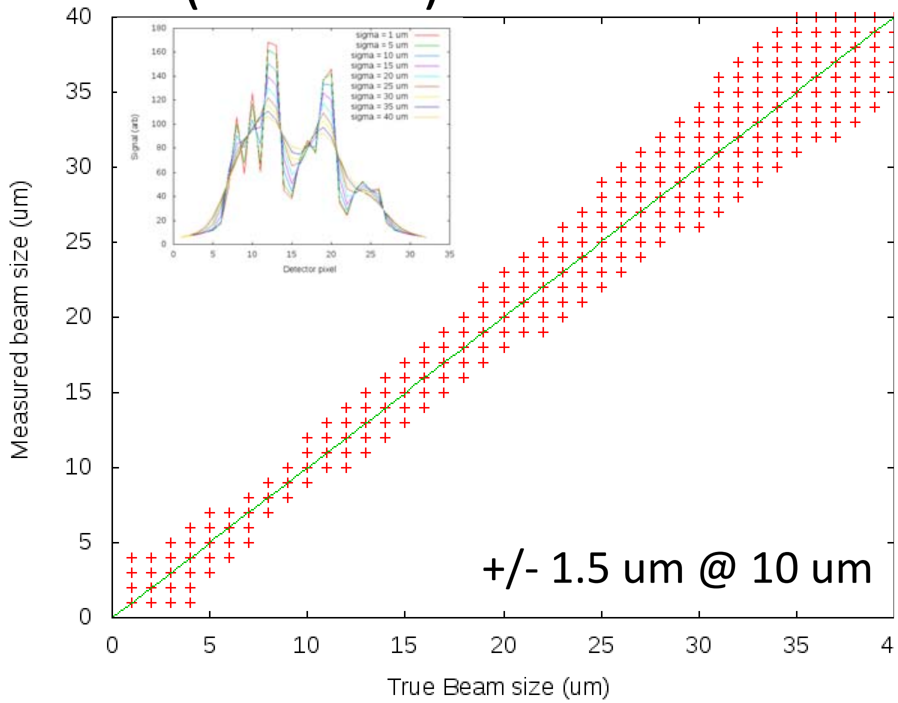

## C Line, 5 um 31-pixel CA (Installed)



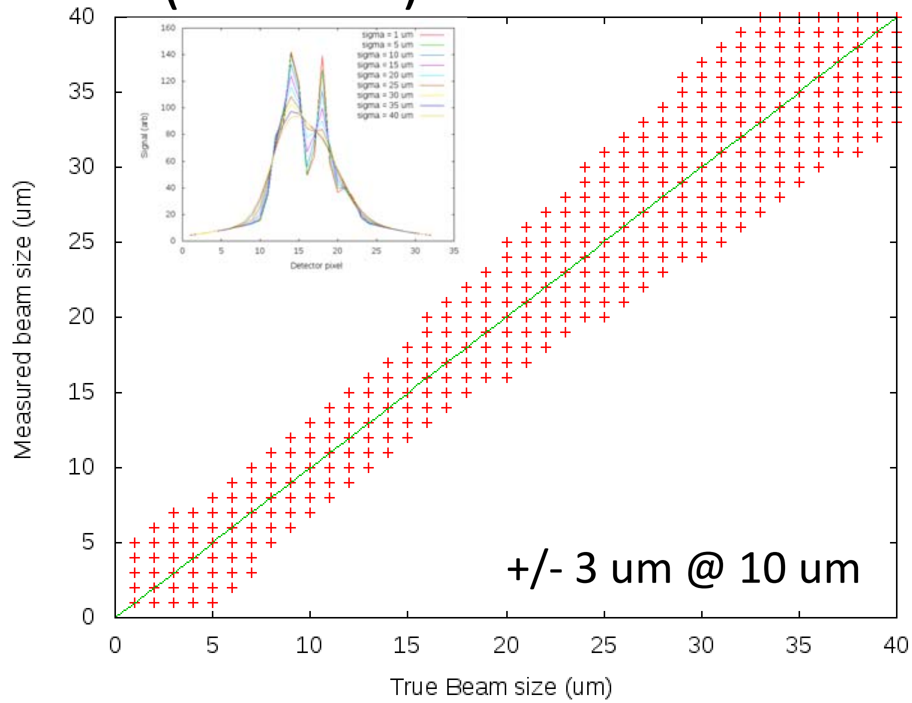

47-pixel mask is no improvement over 31.

# 4 GeV CA Resolutions

D Line, 10 um 31-pixel CA (Installed)



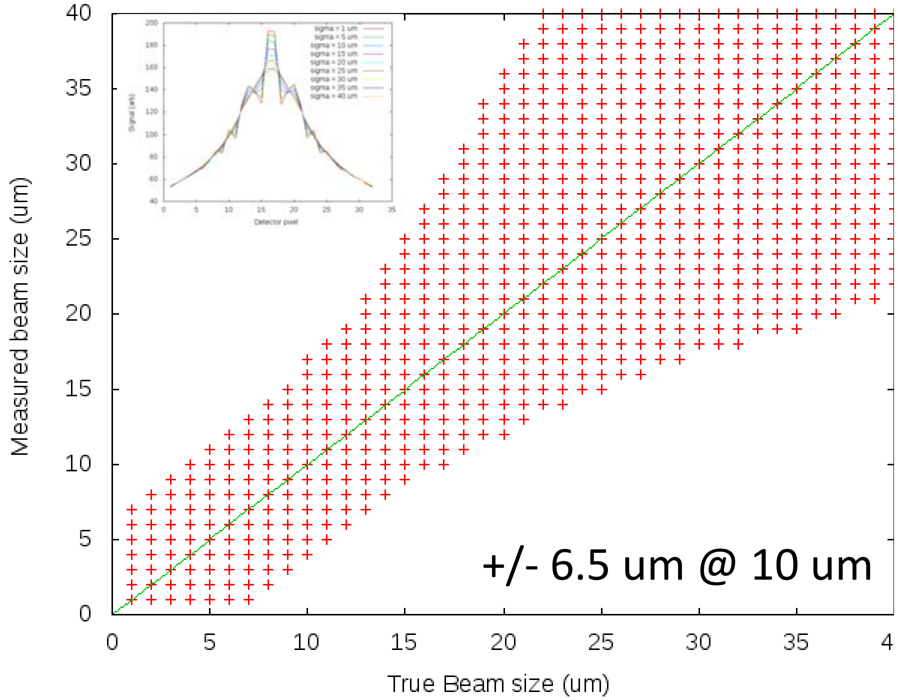

C Line, 5 um 31-pixel CA (Installed)



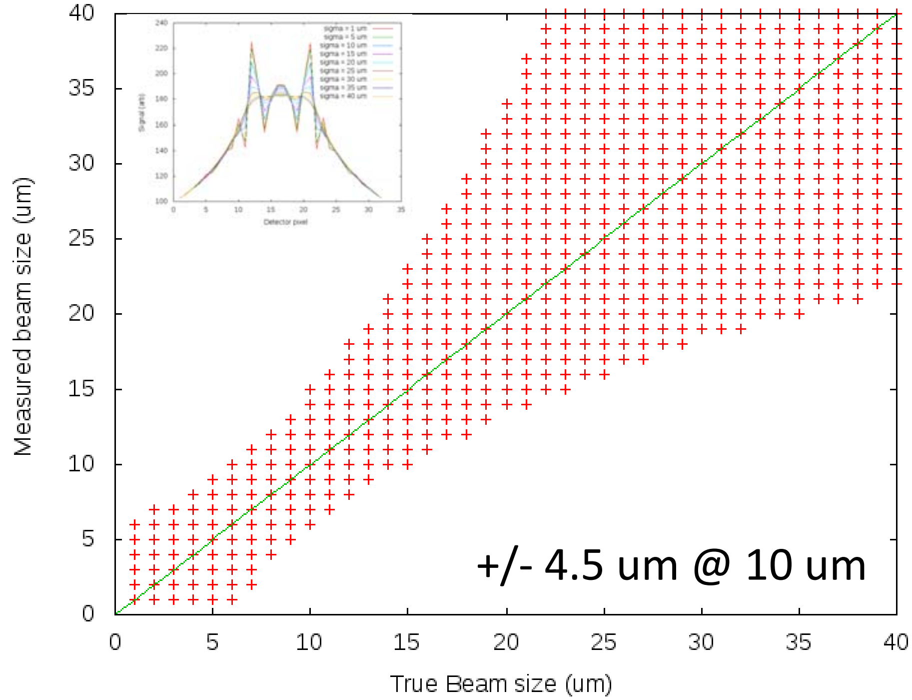

10 um mask is better.

# 2 GeV FZP Resolutions

D Line, Applied Nanotools
(0.55 um Au)



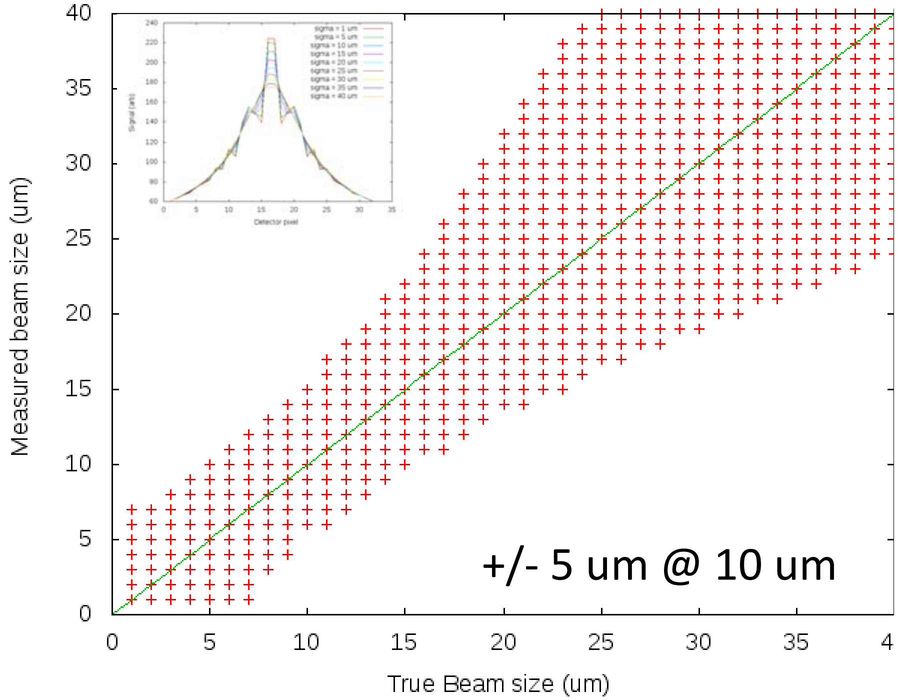

C Line, NTT-AT
(4 um Ta)



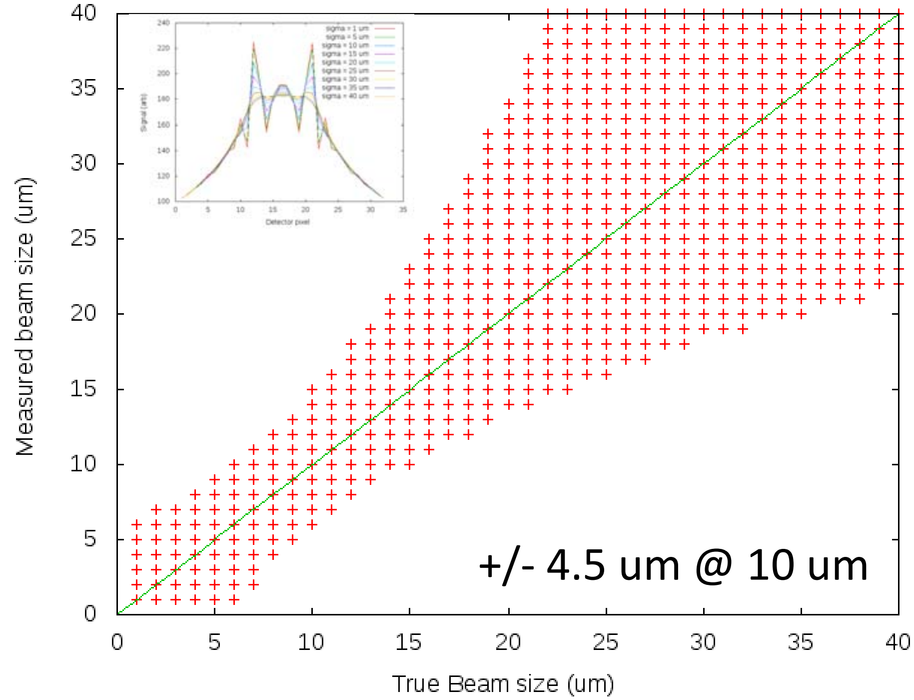

C Line slightly "better" due to mask material?
→Better if template fitting, due to horns.
→Worse if using FWHM.

# 2 GeV FZP Resolutions

C Line, Applied Nanotools (0.55 um Au)




C Line, NTT-AT FZP (installed) (4 um Ta)




Mask material does makes a difference in detector image, though not so much in resolution achieved (if template fitting.)

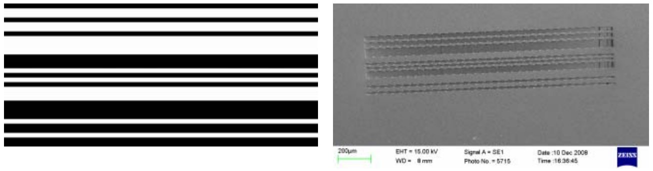
# Summary

- E-cloud data demonstrate ability to measure bunch-by-bunch, turn-by-turn size (down to ~10 um) and position data.
  - At larger beam sizes (>~ 50 um), CA seems more prone to misfits than FZP.
- Method of estimating resolution seems to agree with CA data pretty well
  - Uncertainties in detector noise and inter-pixel calibration.
  - CA resolution: +/- ~2 um at 10 um.
  - FZP resolution: +/- ~6 um at 10 um.
- Resolutions estimated for all installed optical elements.
  - CA 10 um somewhat better than 5 um at both 2 GeV and 4 GeV.
  - Either CA better than FZP.
  - Applied Nanotools and NTT-AT FZPs show some feature differences due to mask material thickness. Which is better depends on what fitting method is used (template fitting or FWHM measurement.)
- We have elements installed now that can measure beam sizes to <~ 10 um.
  - Can we go lower?
- We also have procedure that seems to work for evaluating designs in order to optimize resolution.

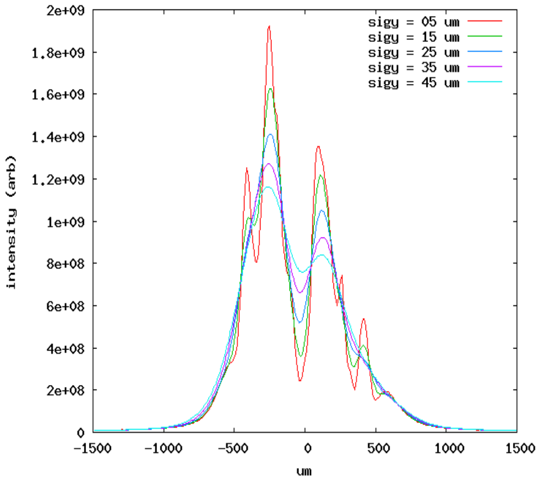
# Spares

# Xray Beam Size Monitors

- Coded Aperture Imaging:
  - Technique developed by x-ray astronomers using a mask to modulate incoming light. Resulting image must be deconvolved through mask response (including diffraction and spectral width) to reconstruct object. Open aperture of 50% gives high flux throughput for bunch-by-bunch measurements. Heat-sensitive monochromator not needed.



Uniformly Redundant Array (URA) for x-ray imaging being tested at CesrTA




Simulated detector response for various beam sizes at CesrTA

Source distribution:

$$\begin{bmatrix} A_\sigma \\ A_\pi \end{bmatrix} = \frac{\sqrt{3}}{2\pi}\gamma\frac{\omega}{\omega_c}\left(1+X^2\right)(-i)\begin{bmatrix} K_{2/3}(\eta) \\ \frac{iX}{\sqrt{1+X^2}}K_{1/3}(\eta) \end{bmatrix},$$

where

$$X = \gamma\psi,$$

$$\eta = \frac{1}{2}\frac{\omega}{\omega_c}\left(1+X^2\right)^{3/2},$$

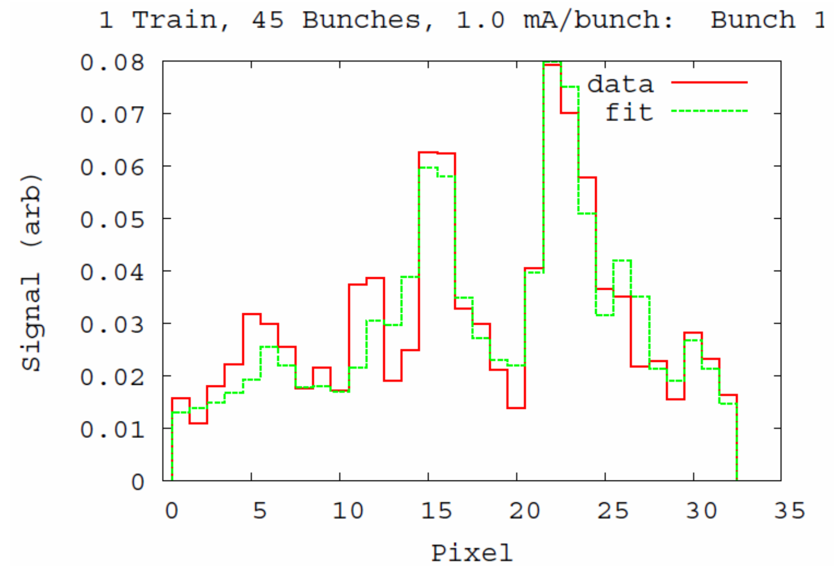
+

Kirchhoff integral over mask (+ detector response)
→ Detected pattern:

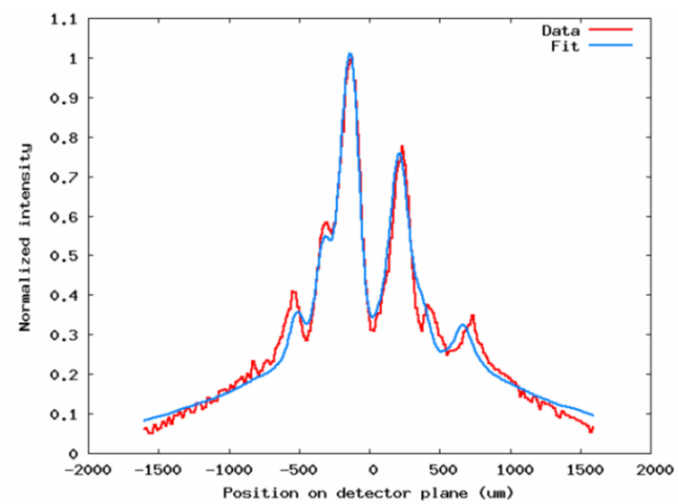
$$A_{\sigma,\pi}(y_d) = \frac{iA_{\sigma,\pi}(\text{source})}{\lambda}\int_{\text{mask}}\frac{t(y_m)}{r_1 r_2}e^{i\frac{2\pi}{\lambda}(r_1+r_2)} \times \left(\frac{\cos\theta_1+\cos\theta_2}{2}\right)\mathrm{d}y_m,$$

# Data Analysis

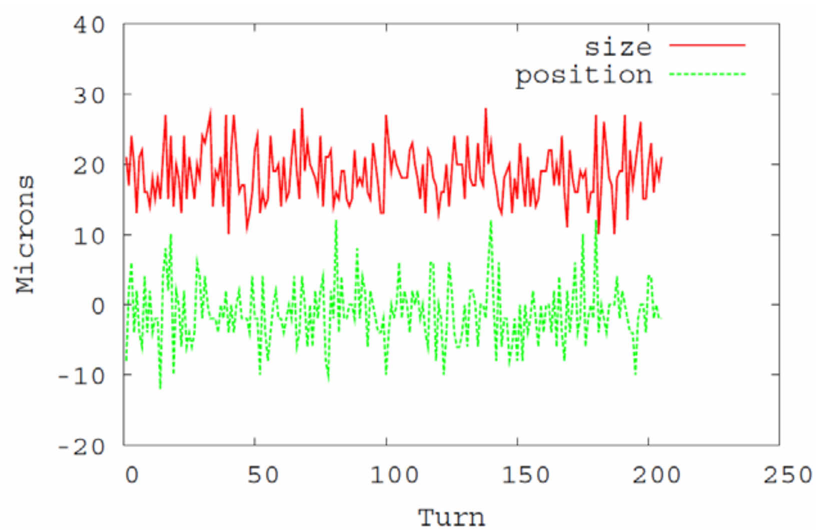
- 1) Simulate point response functions (PRFs) from various source positions to detector, taking into account beam spectrum, attenuations and phase shifts of mask and beamline materials, and detector response.
- 2) Add PRFs, weighted to possible proposed beam distributions.
- 3) Find best fit to detector data.




Example of single-shot data (single-bunch, single-turn)

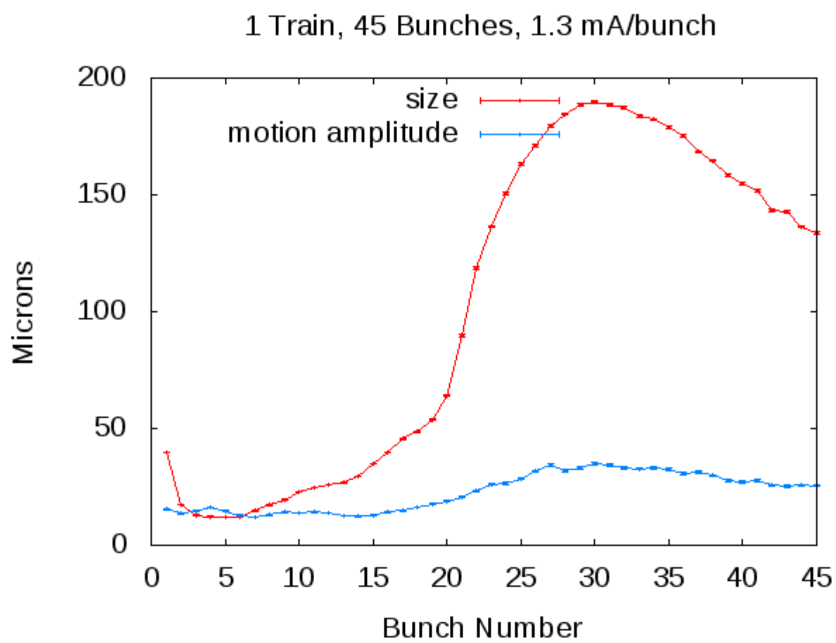



Measured slow-scan detector image (red) at CesrTA, used to validate simulation (blue)




Example of turn-by-turn data (one bunch out of train)

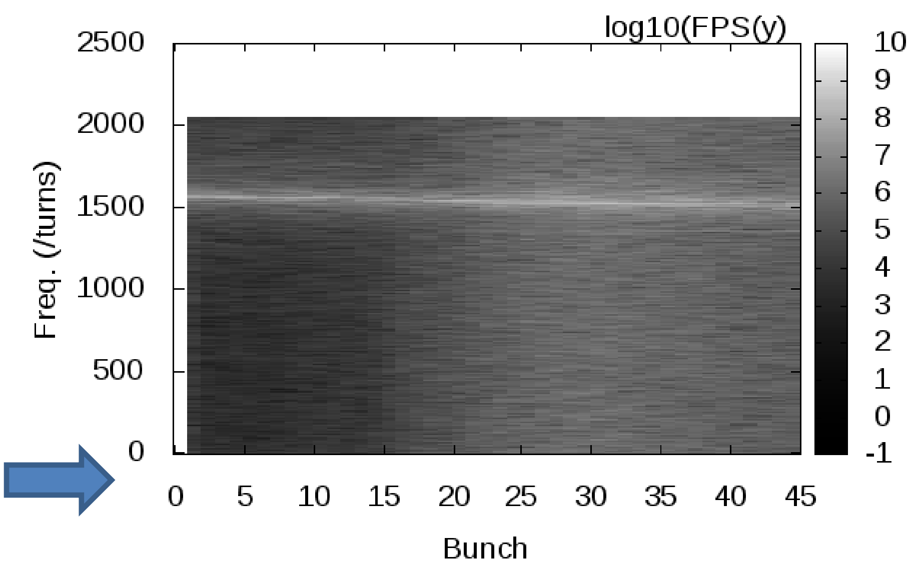
# Example of electron-cloud study data taken at CesrTA




Progress so far at CesrTA:

- Validated simulation code with real beam.
- Demonstrated measurement of beam sizes down to ~10 μm (preliminary) .
- Demonstrated bunch-by-bunch, turn-by-turn size measurements.

Bunch-by-bunch size and centroid RMS motion.
4096 turns, fitted separately then averaged for each bunch.
(Error bars statistical.)




Fourier power spectrum of fitted beam position