xBSM bunchby-bunch measurements in EC conditions at CesrTA

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+ the xBSM group

ECloud10
2010.10.10

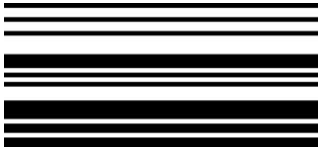
xBSM @ CesrTA

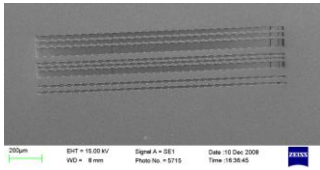
- Group: Dan Peterson, Jim Alexander, Walter Hopkins, Nic Eggert, Ben Kreis, Mike Cunningham… and many others.
- X-ray optics available:
  - Coded Aperture (CA)
  - Fresnel Zone Plate (FZP)
  - Hevimet slit ("Pinhole")
- Detector: InGaAs array on 50 um pitch.
- Bunch-by-bunch, turn-by-turn readout electronics

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 and flux-limiting monochromator not needed.

We need such a wide aperture, wide spectrum technique for shot-by-shot (single bunch, single turn) measurements.





Uniformly Redundant Array (URA) for x-ray imaging being used at CesrTA. Pseudo-random pattern gives relatively flat spatial frequency response.

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

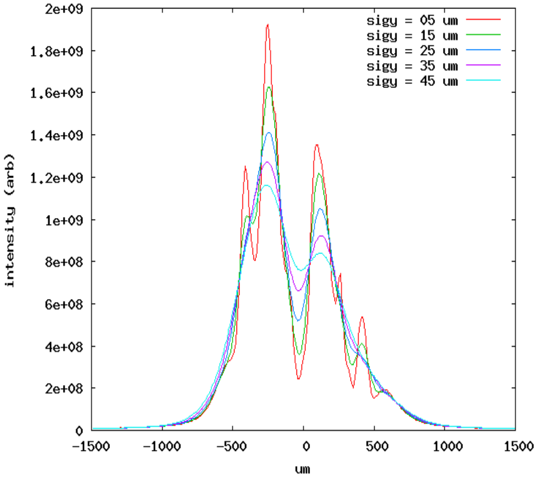
$$X = \gamma\psi,$$

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

+

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

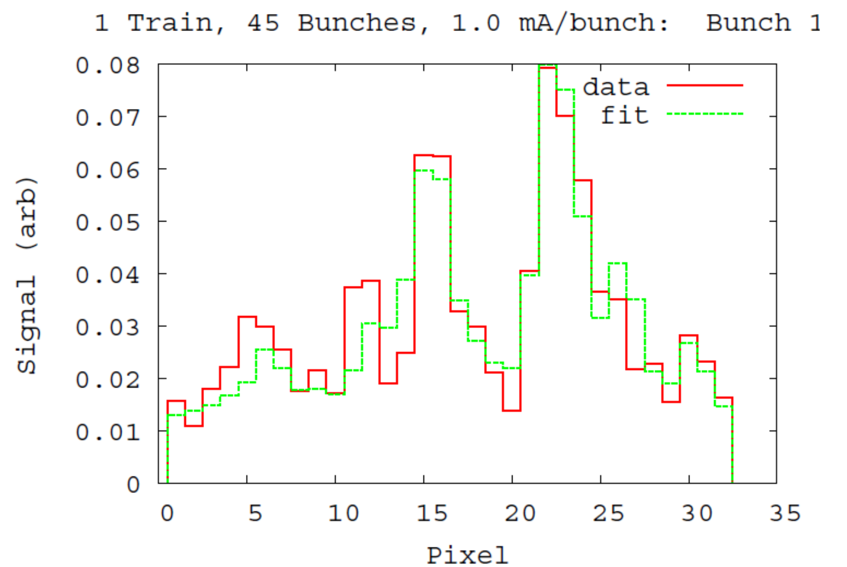
$$A_{\sigma,\pi}(y_d) = \frac{iA_{\sigma,\pi}(\text{source})}{\lambda}\int_{\text{mask}}\frac{t(y_m)}{r_1 r_2}e^{i\frac{2\pi}{\lambda}(r_1+r_2)} \times \left(\frac{\cos\theta_1+\cos\theta_2}{2}\right)\mathrm{d}y_m,$$



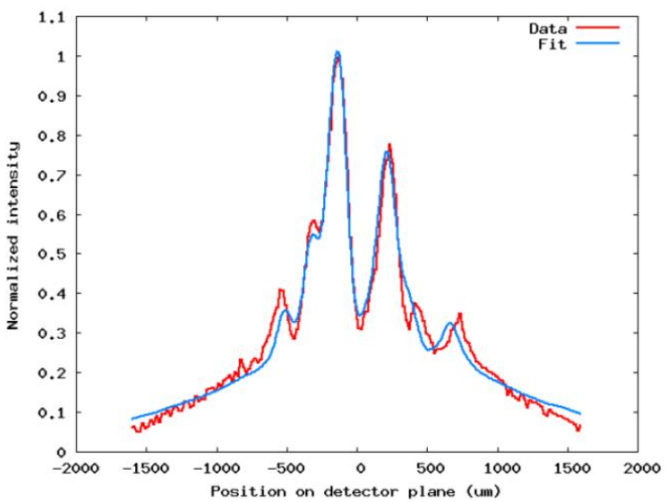
Simulated detector response for various beam sizes at CesrTA

Data Analysis

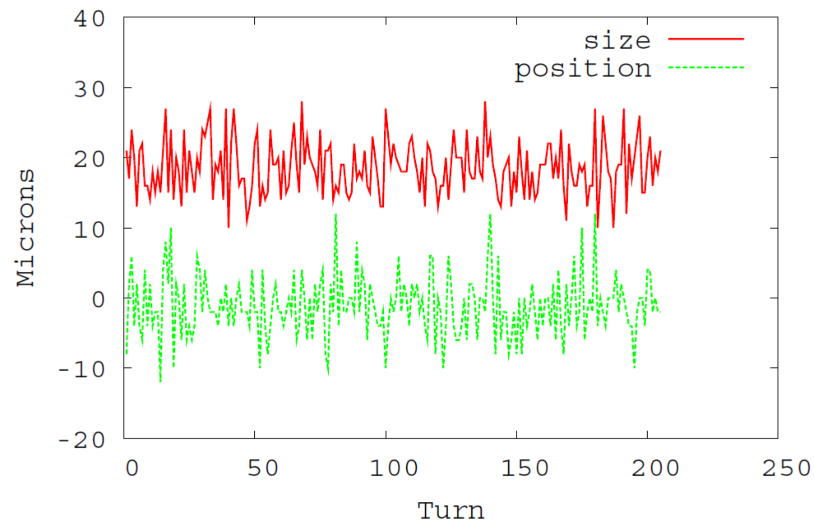
- 1) Simulate point response functions (PRFs) from various source positions to detector, taking into account beam spectrum, attenuations and phase shifts of mask and beamline materials, and detector response.
- 2) Add PRFs, weighted to possible proposed beam distributions.
- 3) Find best fit to detector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

What we expect to see

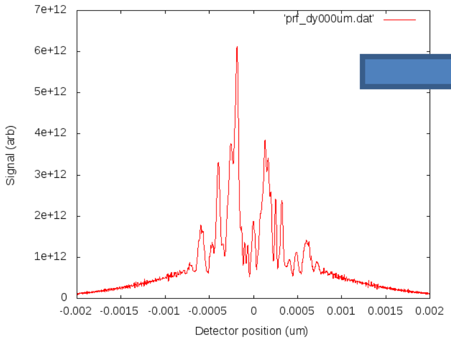
- From studies at KEKB LER:
  - Beam size should start to blow up at a certain point along the bunch train, where electron cloud density goes over the threshold for fast head-tail instability.
  - This should be accompanied by the appearance of synchro-betatron sidebands.

E-Cloud study data w/Feedback on

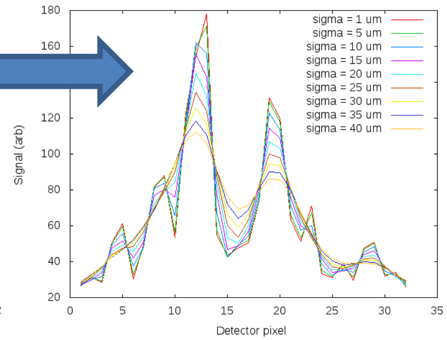
- Data taken night of 10/11 May at D Line (e+)
- Fill pattern: 45 bunches, 14 ns spacing
- FEEDBACK ON (horizontal, vertical, longitudinal)
- Bunch currents: 0.5, 1.0, 1.15, 1.3 mA
- Using 3C-4 detector
  - 2 sick channels (low gain)
- X-ray optics: CA and FZP
  - FZP data analyzed same way as CA data
    - Fit data to templates generated by sets of point response functions, which are weighted over the assumed source distribution. 3-D grid of templates in y, σ_y and normalization used.
  - FZP is treated as being *one-dimensional*. (Cylindrical lens.)
  - FZP is being used *without monochromator.*

CA

Point Response Function

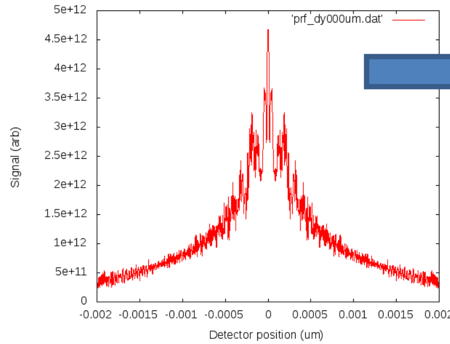


Smeared and binned templates

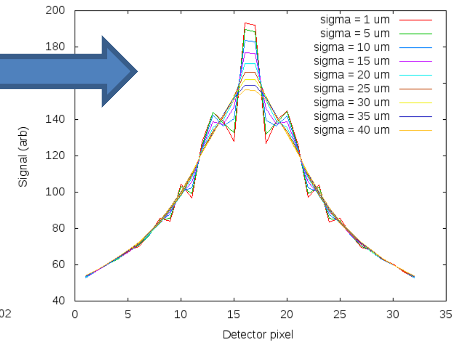


FZP

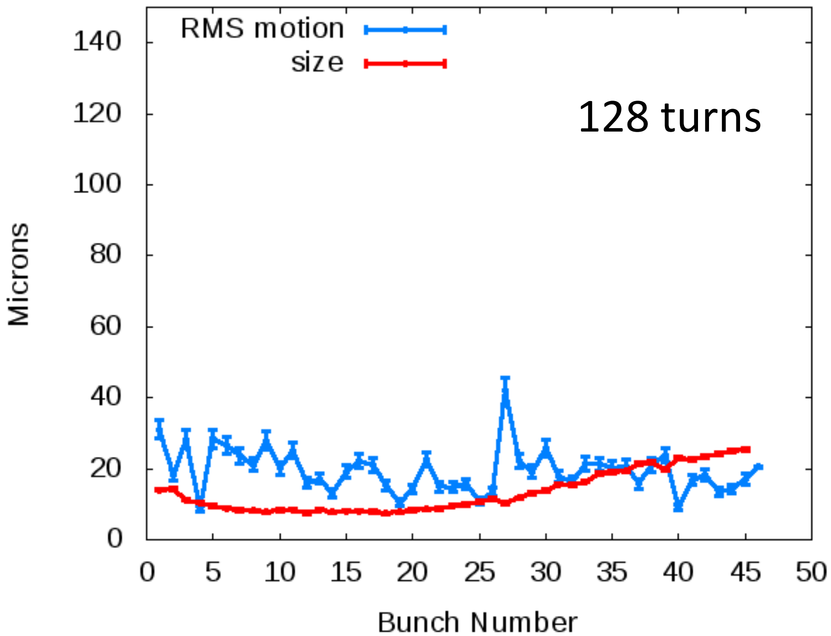
Point Response Function



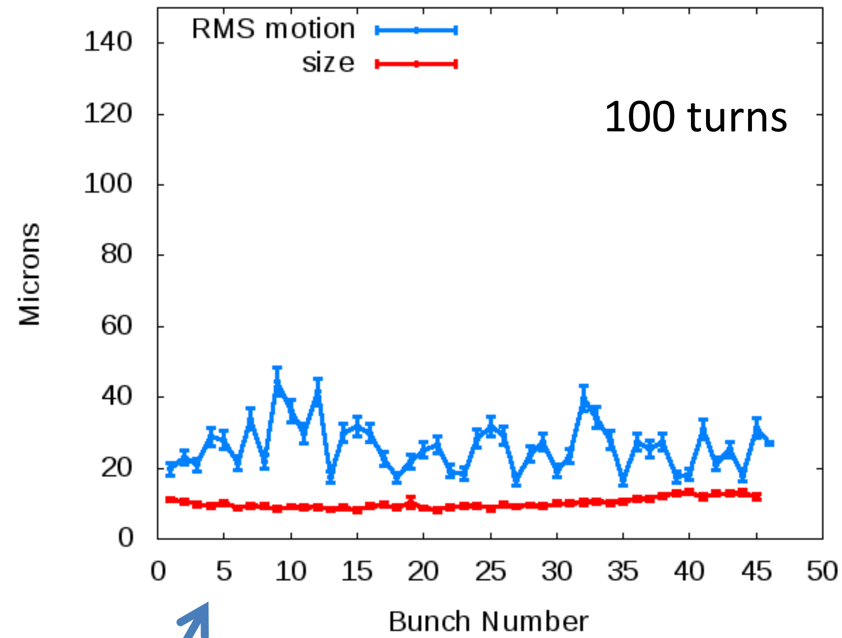
Smeared and binned templates

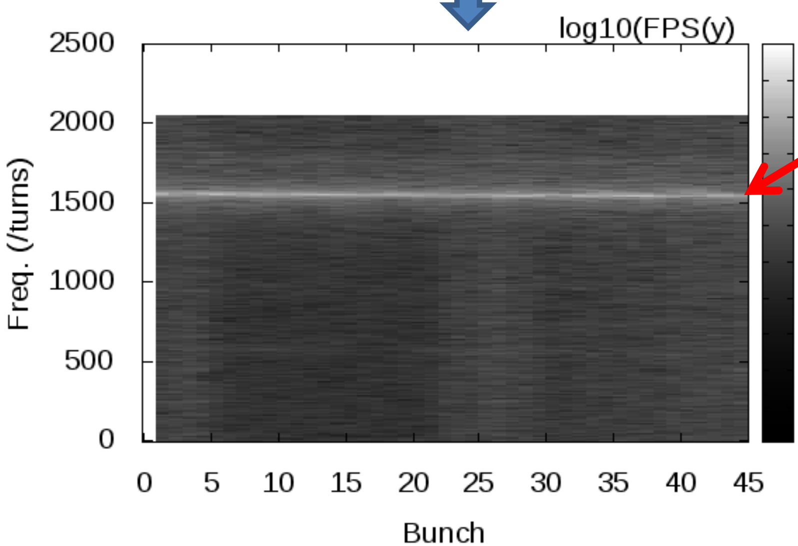


CA



FZP





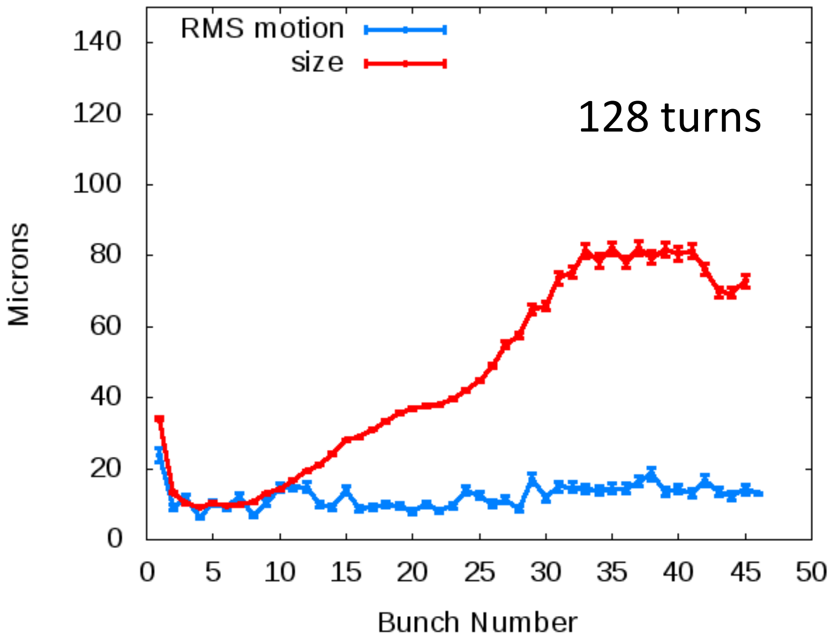
V. tune

Single-bunch, single-turn fits averaged over turns

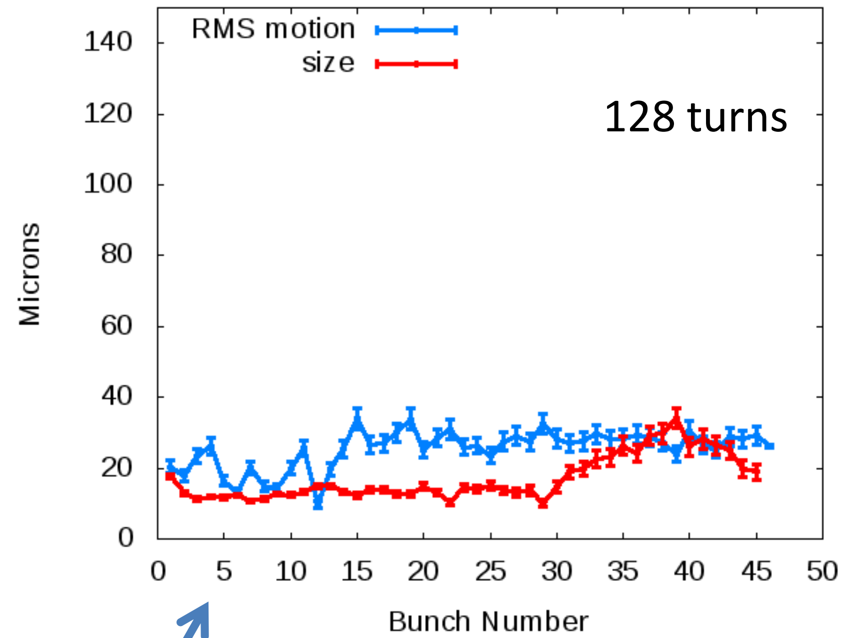
Bunch-by-bunch position spectra

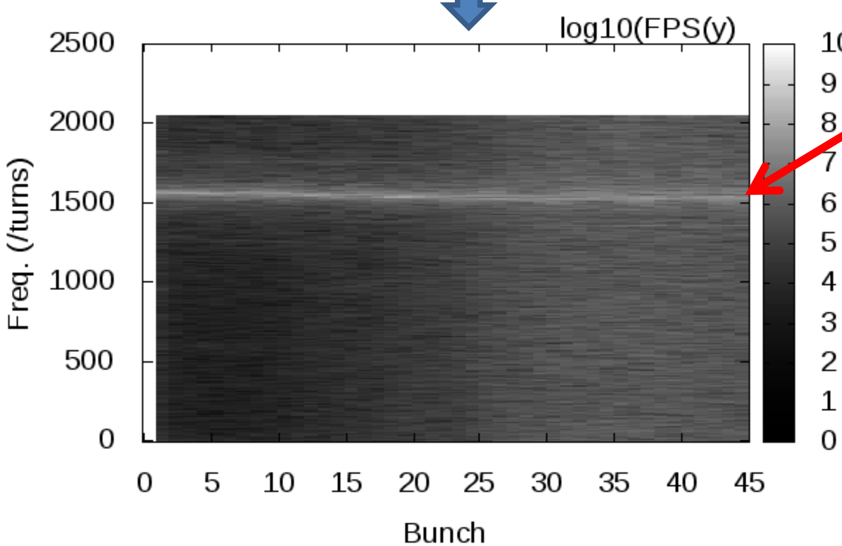
0.5 mA /bunch

CA



FZP





V. tune

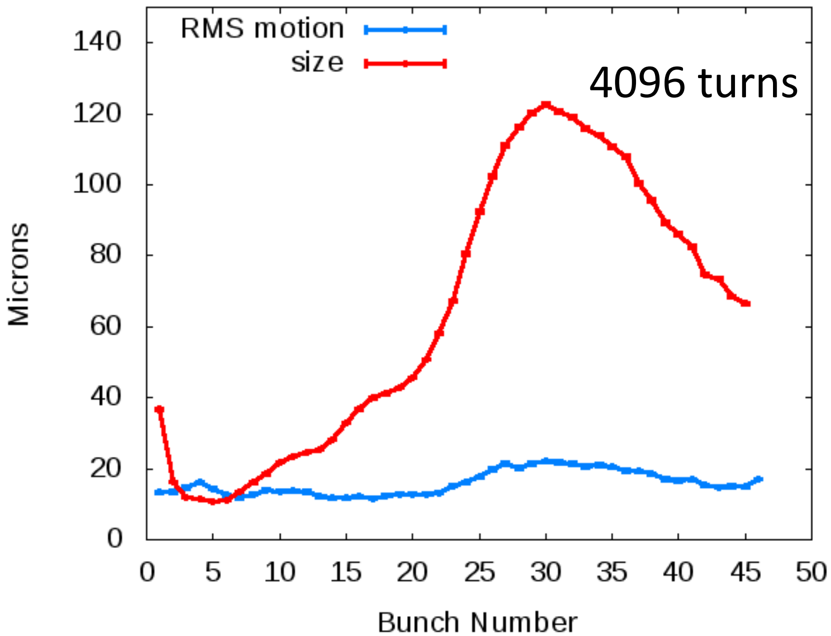
Single-bunch, single-turn fits averaged over turns

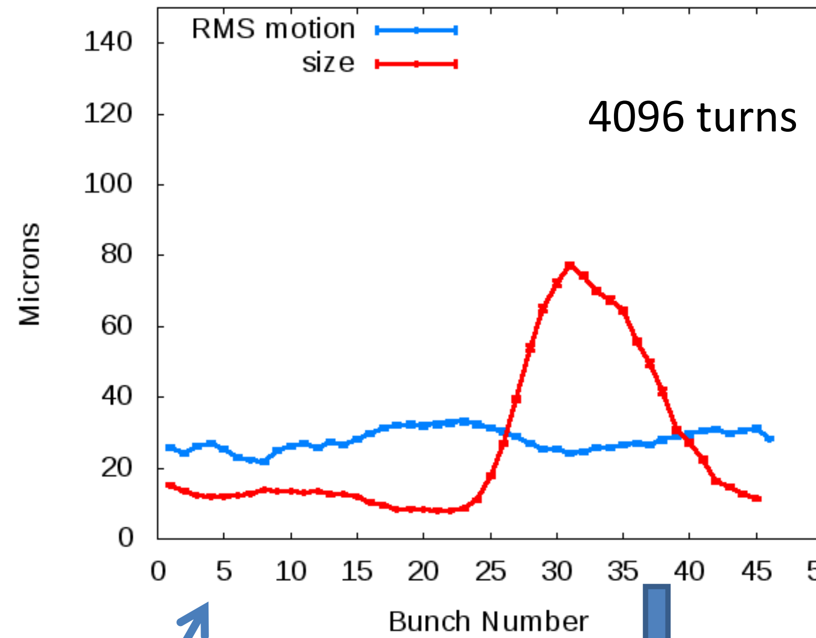
Bunch-by-bunch position spectra

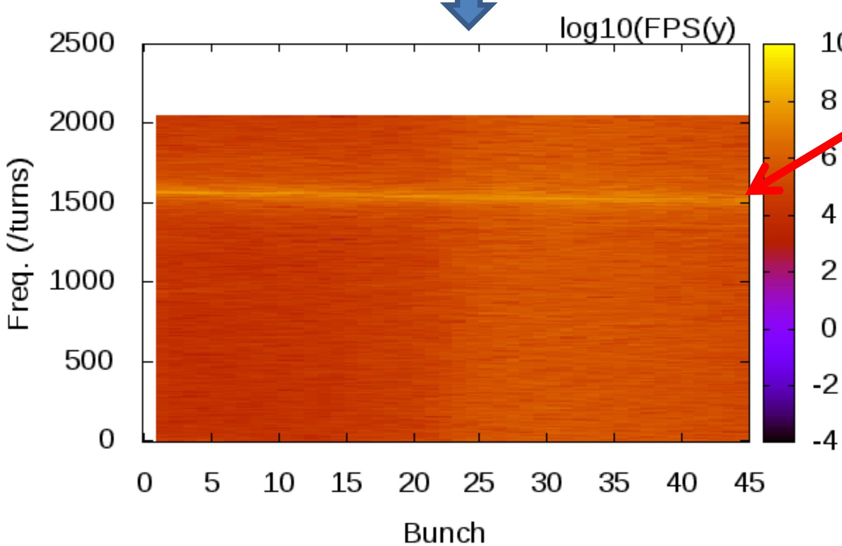
1.0 mA /bunch

CA

FZP



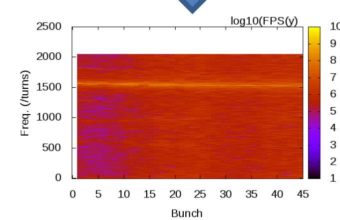




V. tune

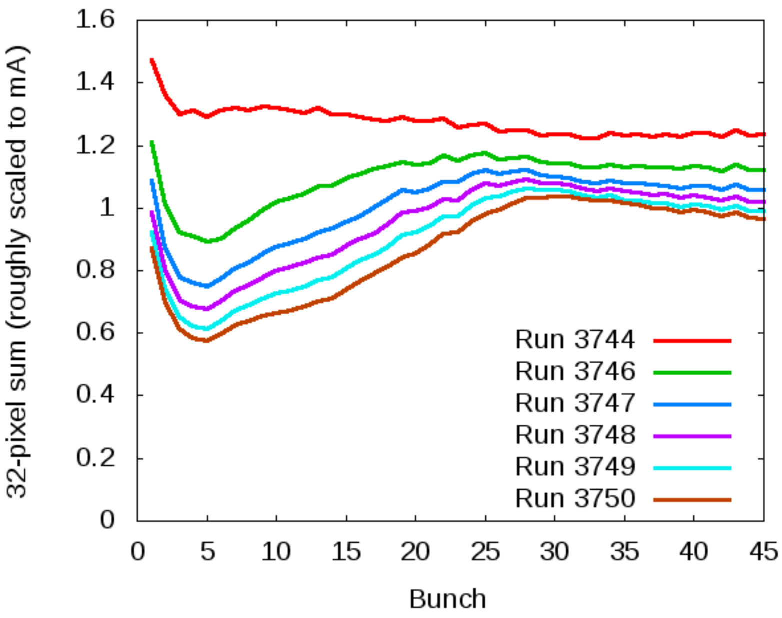
Single-bunch, single-turn fits averaged over turns

Bunch-by-bunch position spectra



1.3 mA /bunch

X-ray signal heights (“X-ray Bunch Current Monitor”)



- Bunch currents along train for successive runs (~5 minutes apart)
- Initially 1.3 mA/bunch
- Lifetime pattern resembles measures sizes.
  - Minimum at ~ bunch 4
  - Maximum at ~bunch 30
- First bunch appears to be really blown up.
  - Residual cloud?
    - Dugan/Billing experiment with precursor bunch suggests so.

Individual bunch-by-bunch sizes @ 1.3 mA

CA:

Size pattern at head of train agrees with lifetime.

Gradual ramp seen up to ~bunch 23

Scatter of fitted sizes larger after threshold

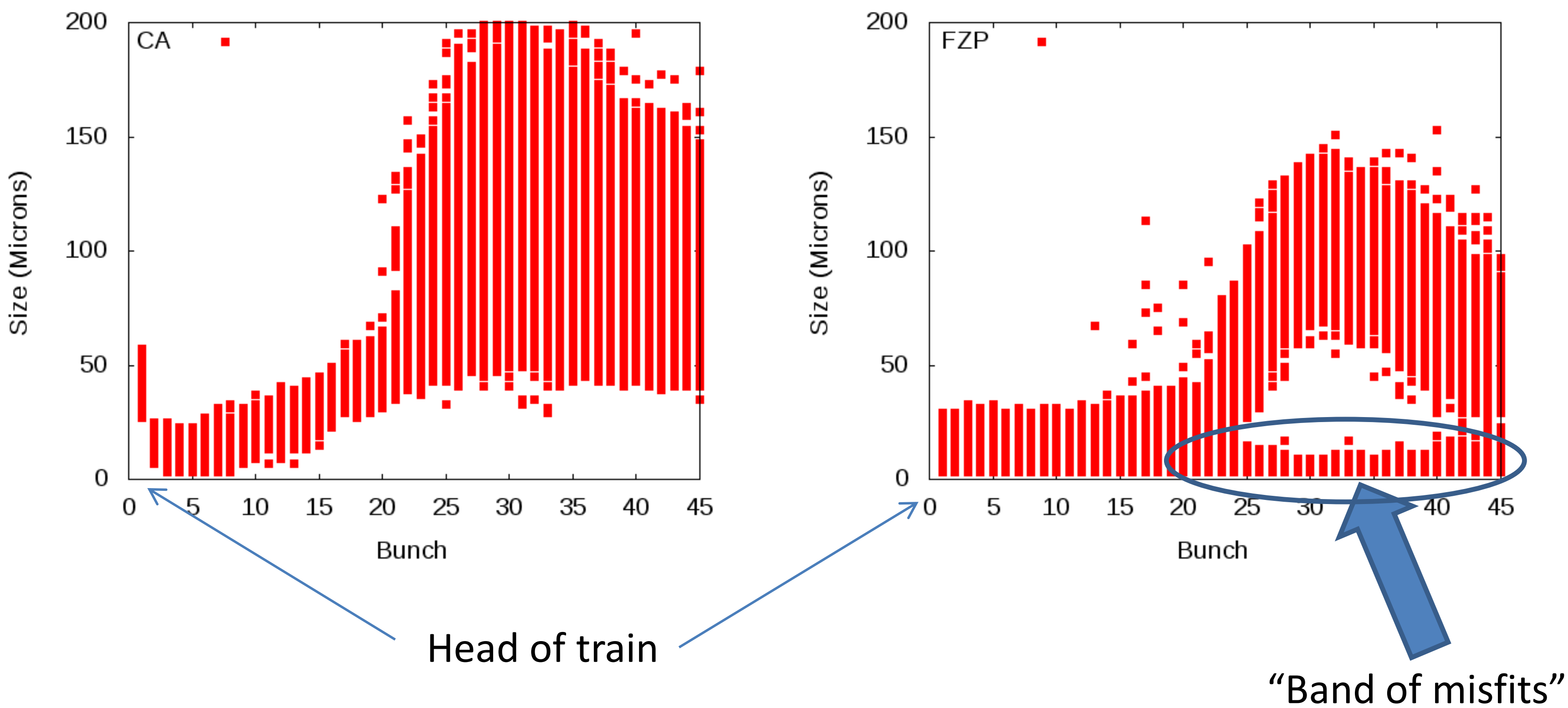
FZP:

Size pattern at head of train does not agree with lifetime

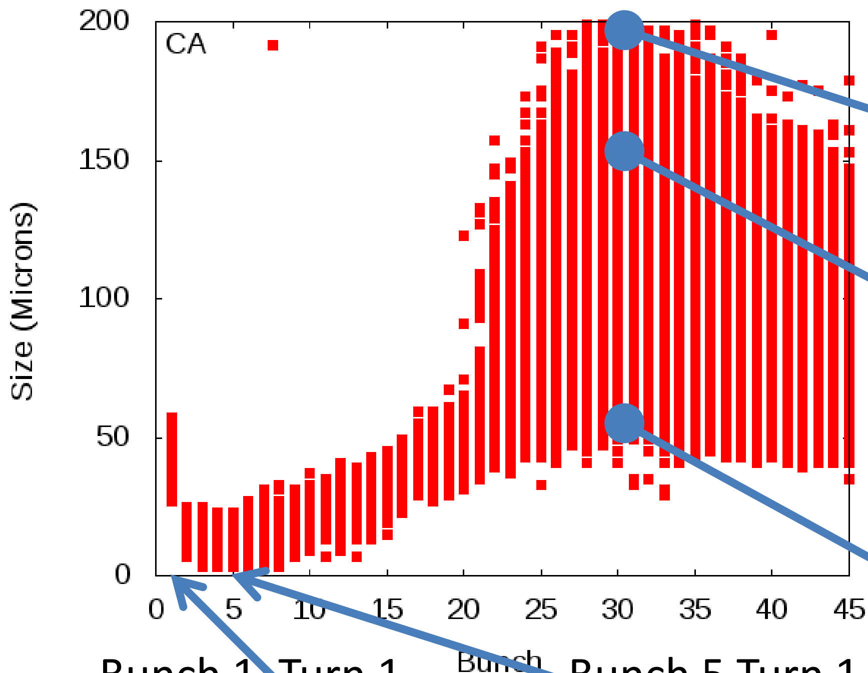
Little evidence of ramp seen below bunch 23

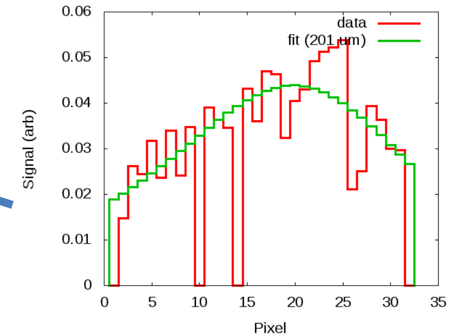
Scatter increases after that, but to lesser extent than CA

Band of misfits (?) to low beam sizes seen across train, which pulls down average of blown-up bunches.

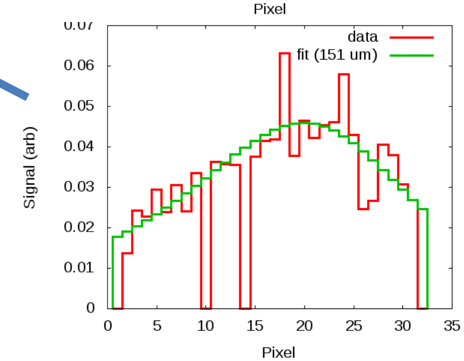


CA individual fits @ 1.3 mA

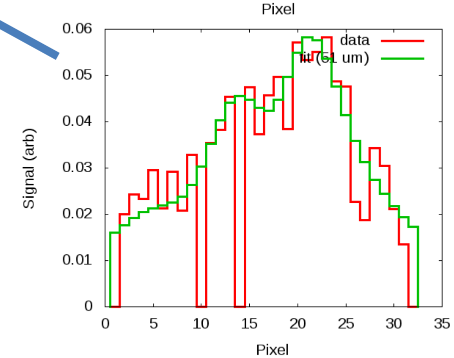




Bunch 30
Fit = 201 um

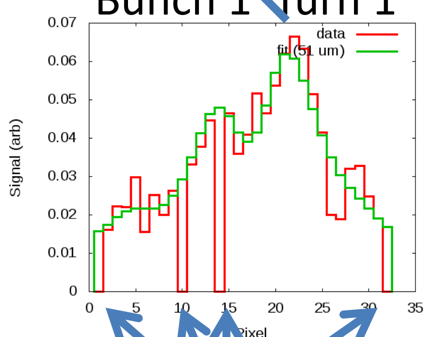


Bunch 30
Fit = 151 um

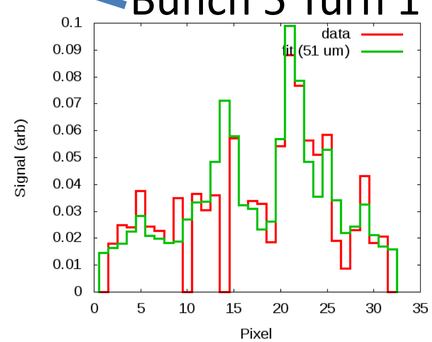


Bunch 30
Fit = 51 um

Bunch 1 Turn 1



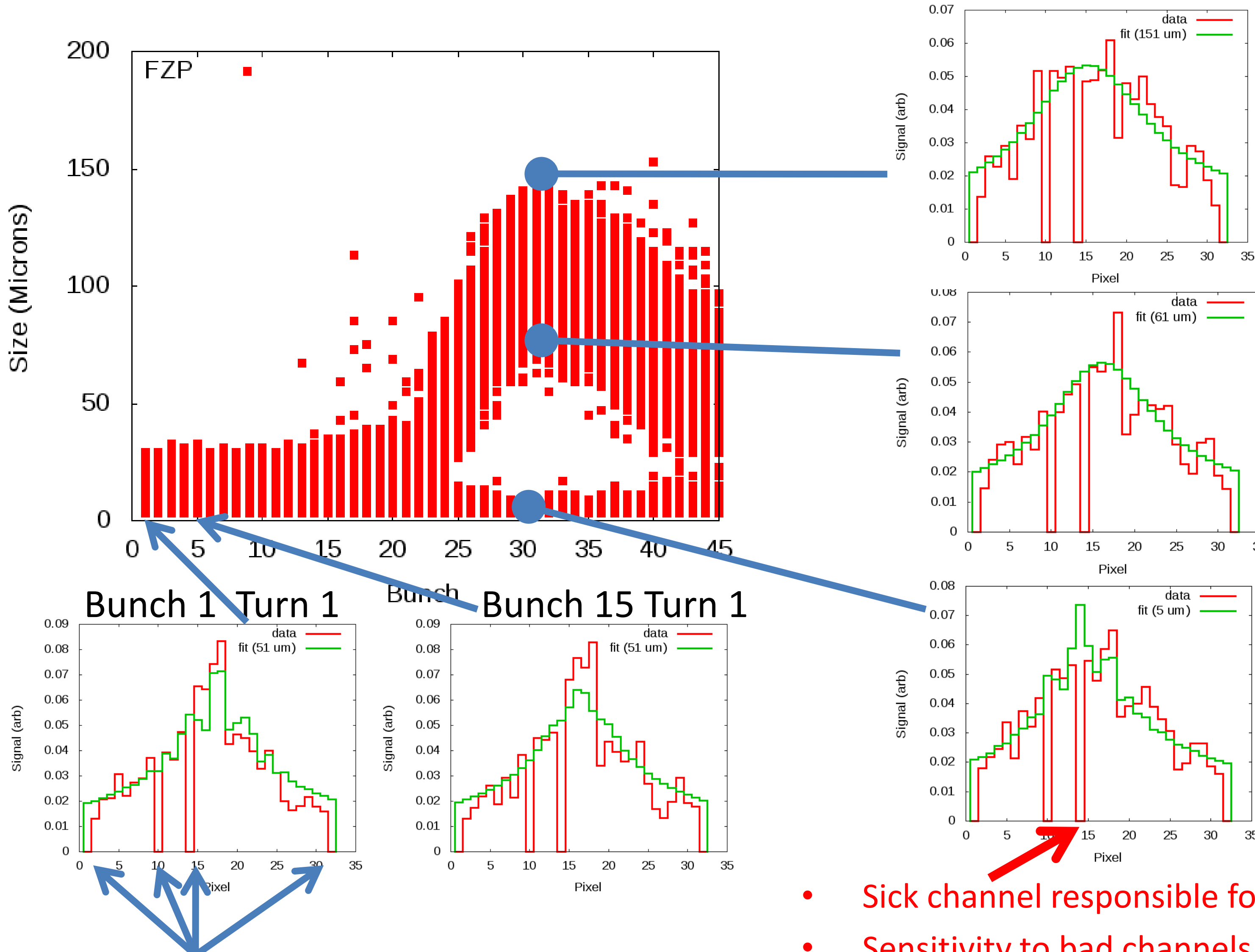
Bunch 5 Turn 1



Note: edge and sick channels removed from fit.

- No clear evidence of terrible fits.
- Resolution at larger beam sizes needs further study.

FZP individual fits @ 1.3 mA



Bunch 30
Fit = 151 um

Bunch 30
Fit = 61 um

Bunch 30
Fit = 5 um

Note: edge and sick channels removed from fit.

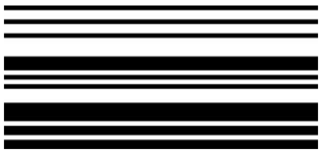
- Sick channel responsible for band of misfits?
- Sensitivity to bad channels needs further study.

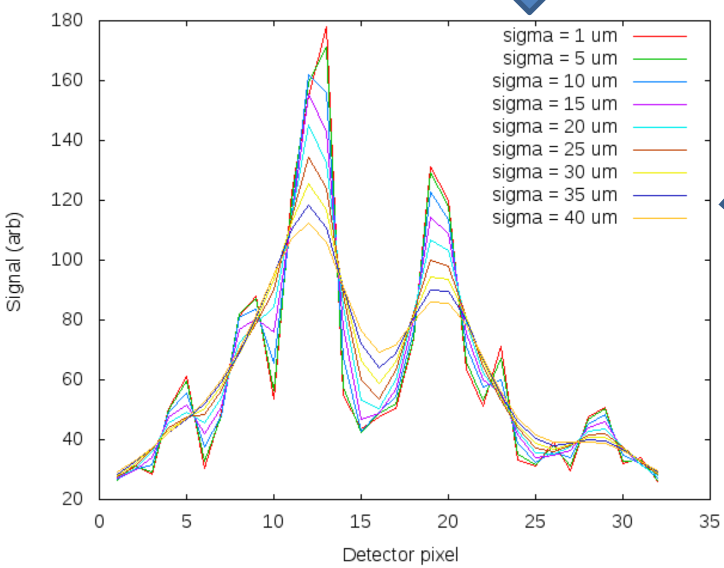
Resolution Estimates

- **Procedure:**
  - Simulate detector images for beams of σ_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.**

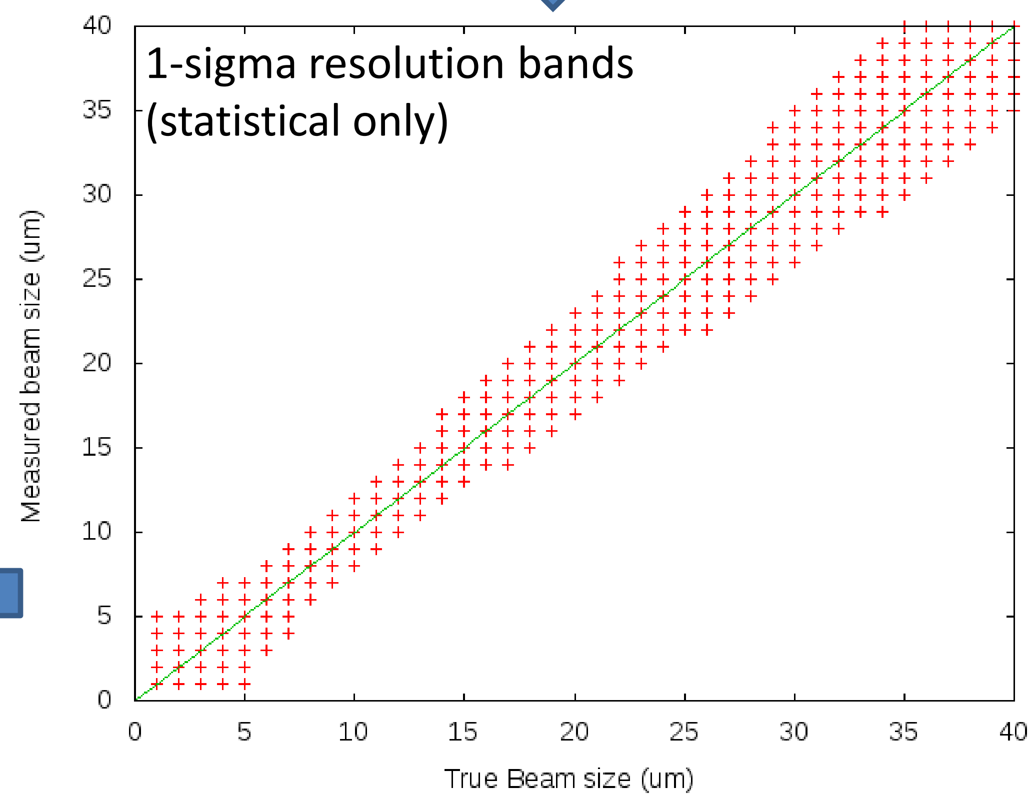
10 μm, 31-element CA mask @ D Line 2 GeV

Generate detector images for various beam sizes:





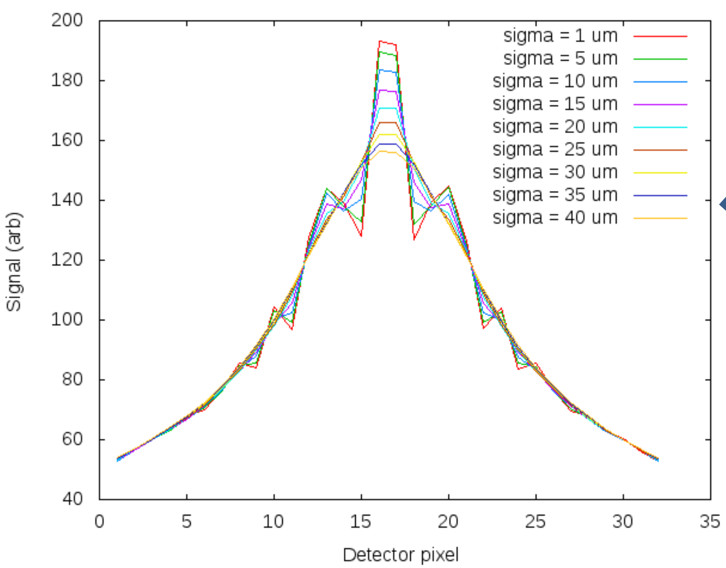
Cross-fit between beam sizes.
Plot 1-sigma statistical confidence regions,
Assuming 200 photons/pixel average
(=> 0.56 mA at 2 GeV):



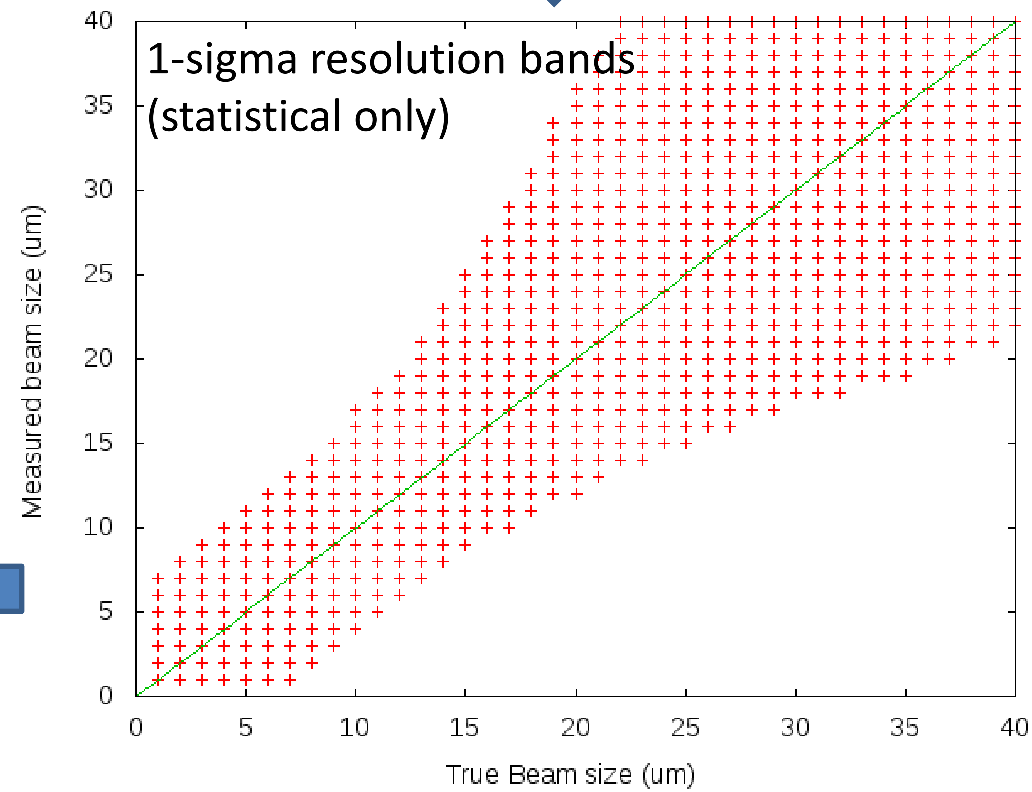
Statistical single-shot resolution at 10 μm beam size = +/- ~2 μm
(Assuming ideal detector.)

FZP@ D Line 2 GeV

Generate detector images for various beam sizes:



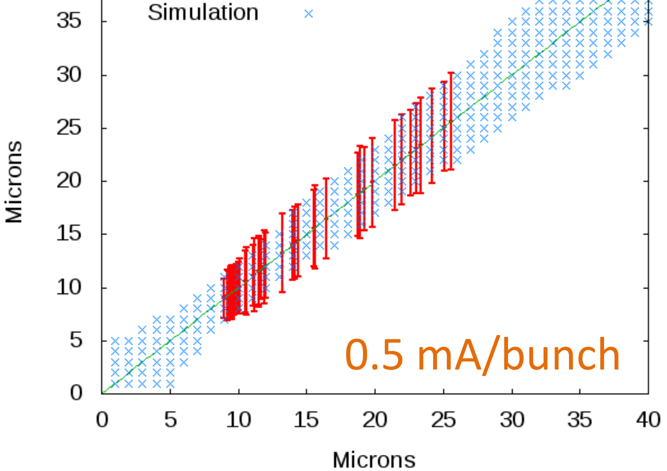
Cross-fit between beam sizes.
Plot 1-sigma statistical confidence regions,
Assuming 200 photons/pixel average
(=> 0.56 mA at 2 GeV):

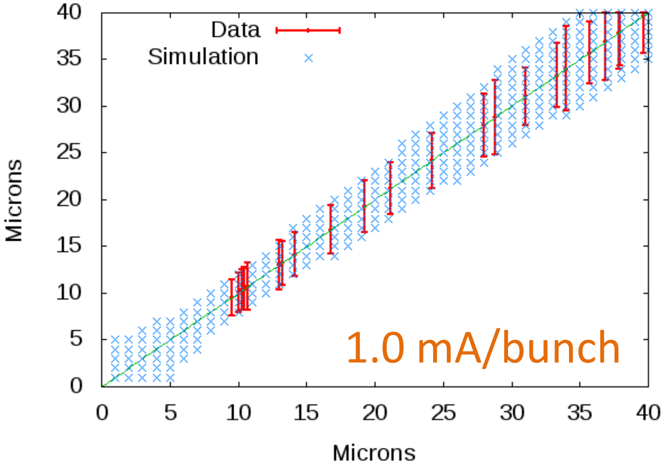


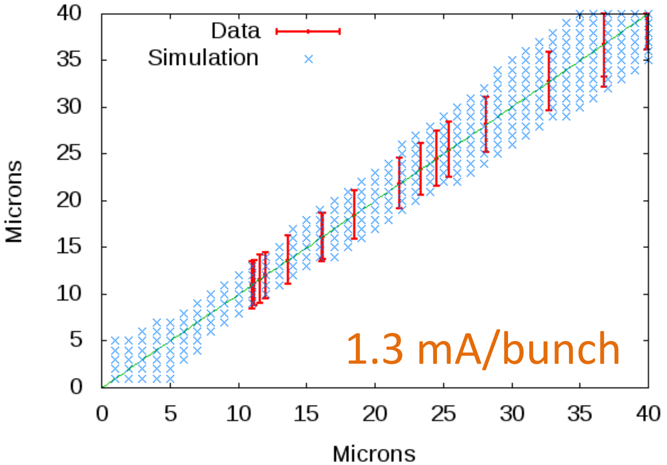
Statistical single-shot resolution at 10 µm beam size = +/- ~6.5 µm
(Assuming ideal detector.)

Resolution data vs simulation: CA

- Using May 10 2010 E-Cloud study data as data source.
- Simulation statistical confidence bands assume
  - Perfect, noiseless detector
  - 200 photons/pixel/shot on average
    - =>0.56 mA/bunch
    - Higher bunch currents should have smaller spreads than simulation due toimproved photon statistics.
- Shot-by-shot spread in data is closest to simulation at nearer to 1 mA.
  - Not using a perfect, noiseless detector.
- Seems reasonable agreement

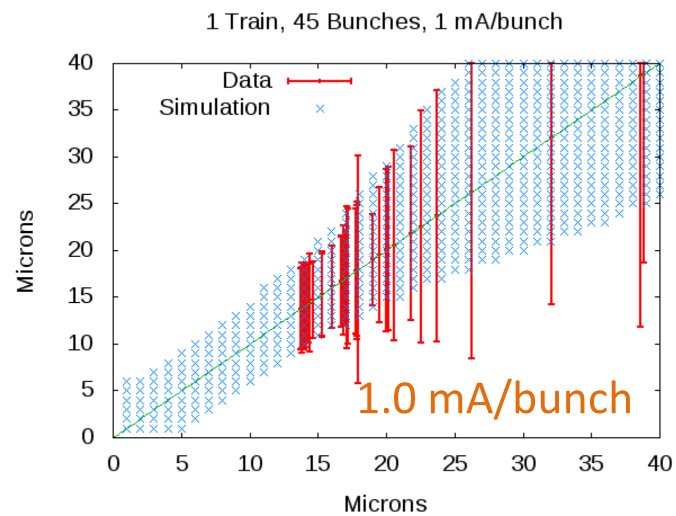


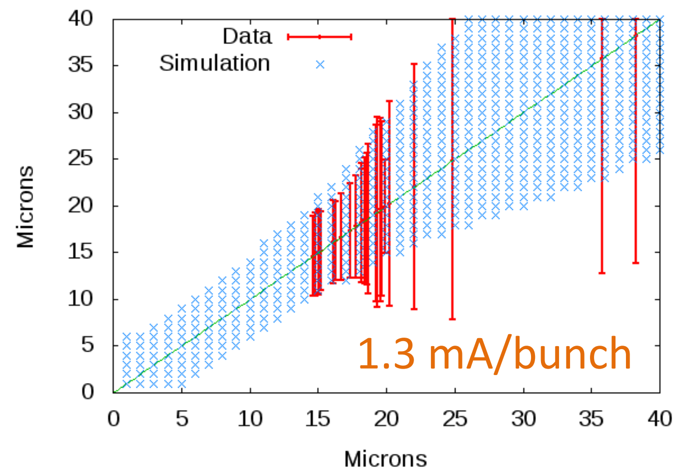




Resolution data vs simulation: FZP

- Using May 10 2010 E-Cloud study data as data source.
- Simulation statistical confidence bands assume
  - Perfect, noiseless detector
  - 200 photons/pixel/shot on average
    - =>0.56 mA/bunch
    - Higher bunch currents should have smaller spreads than simulation due toimproved photon statistics.
- Not so good agreement above ~18 um:
  - Actual spread larger than simulation.
  - Due to band of low misfits?





FEEDBACK ON data summary

- Instrumentation:
  - Expected resolution and measured size-dependent measurement spread agree, except for FZP above ~18 um.
    - Band of misfits?
  - Resolution sensitivity to bad channels needs further study.
    - Causes FZP to fit erroneously small sometimes?
    - Causes CA to fit erroneously large sometimes?
- Beam dynamics:
  - Bunch sizes blow-up threshold seen at ~bunch 30 at 1.0 mA/bunch, ~bunch 25 at 1.3 mA/bunch.
    - Mike Billing has observed synchrobetatron sidebands due to electron clouds appearing at those same threshold bunches.
      - If true, this behavior would agree with similar measurements made at KEK.
  - Evidence of slow emittance growth below that threshold.
  - Bunch-by-bunch lifetime pattern supports measured beam size pattern.
  - Head bunch is also somewhat blown up
    - Precursor bunch studies by Gerald Dugan and Mike Billing suggest this is due to long-lasting electron clouds.
  - No large dipole motion observed, though vertical tune can be seen in the bunch position spectra.
    - No sidebands seen in x-ray data.

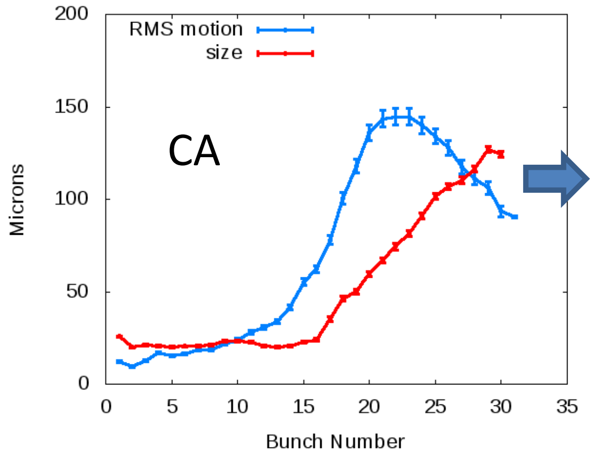
E-Cloud study data w/Feedback (mostly) off

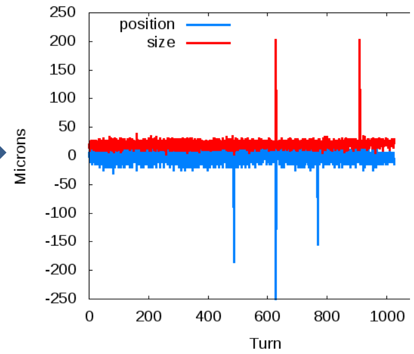
- Data taken night of 28/29 September at D Line (e+)
- Using 3C-5 detector
  - 3 sick channels
- Fill pattern: 30-45 bunches, 14 ns spacing
- FEEDBACK MOSTLY OFF
  - Longitudinal, vertical feedbackOFF.
  - Horizontal at 20%.
    - This is the recent “standard” set, for better observation of sidebands.
- Parameters changed:
  - Bunch currents
  - Vertical chromaticity
  - Vertical emittance
    - Coupling bump through wigglers

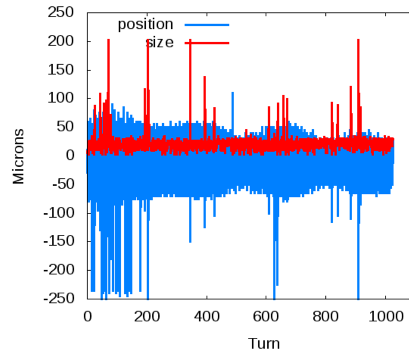
HOWEVER

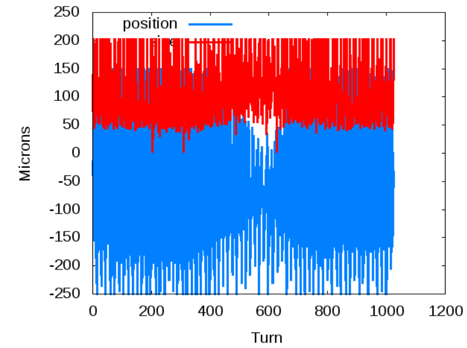
- With feedbacks off, severe dipole motion sets in mid-train.
- Beam with large dipole motion shows a much higher proportion of misfits, rendering the data taken problematic.
- An example:

1 mA/bunch, FB OFF/Low





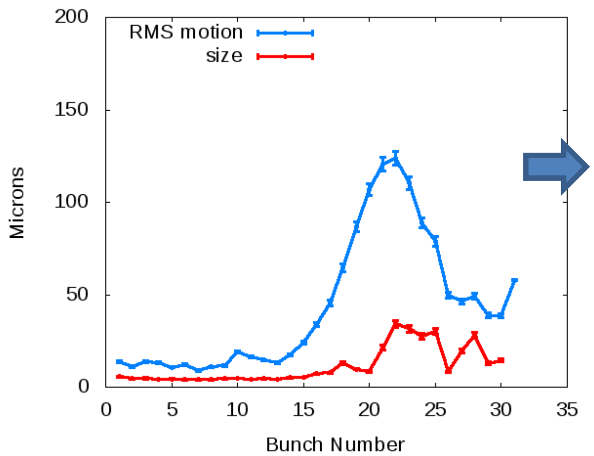


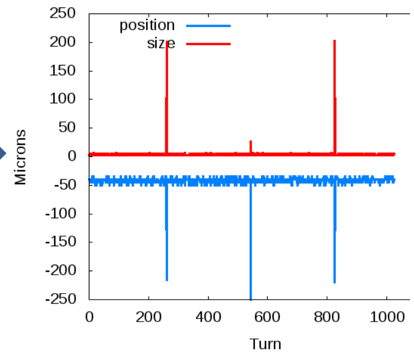


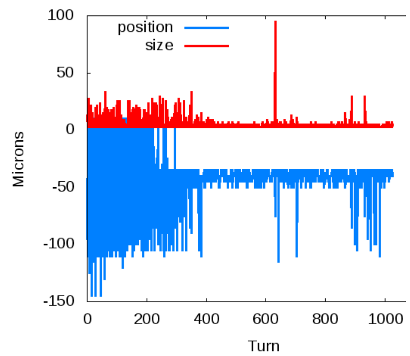
Bunch 5
Time series

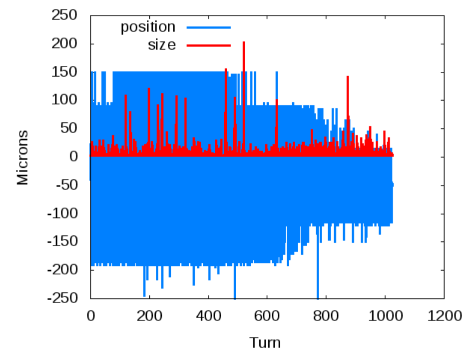
Bunch 15
Time series

Bunch 25
Time series



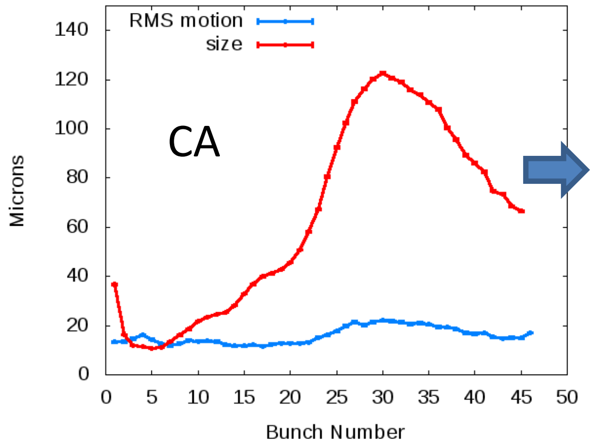


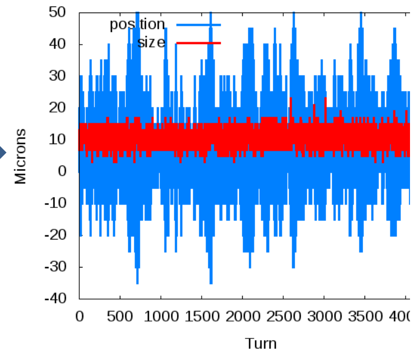


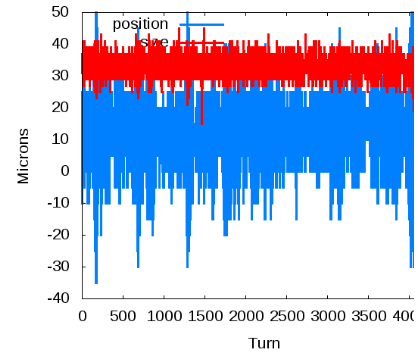


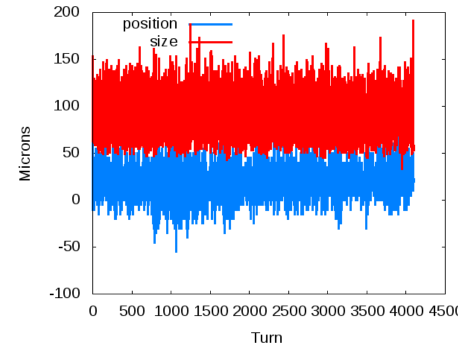
Both CA and FZP show frequent size spikes, often accompanying position spikes. Frequency of such misfits increases as beam size increases. FZP additionally shows tendency to hug bottom of fitting range.

As opposed to: FB ON (1.3 mA/bunch)





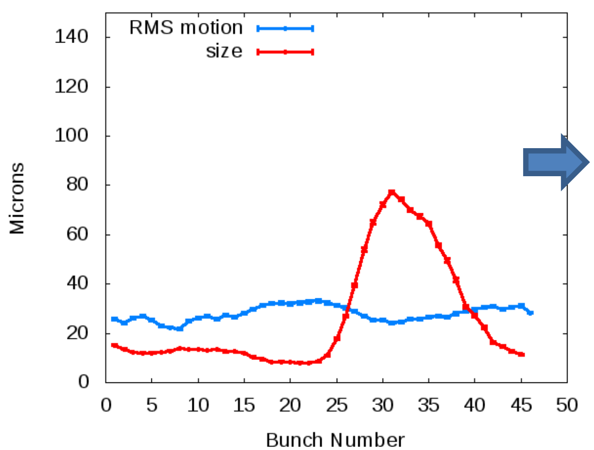


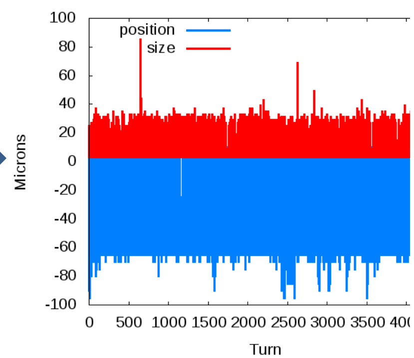


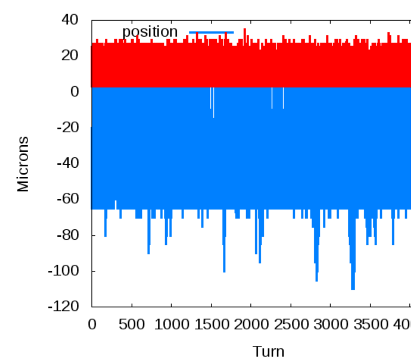
Bunch 5
Time series

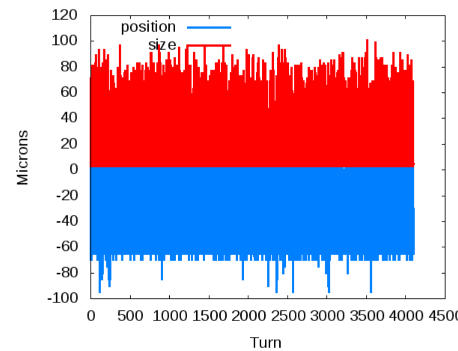
Bunch 15
Time series

Bunch 25
Time series









No obvious pathologies seen in CA data
No spikes seen in FZP data, but tendency to misfit to bottom of size range seen.

FEEDBACK OFF data summary

- Dipole motion is severe with feedback off.
- This dipole motion increases vastly the chance of misfits for some reason.
  - Not nearly as big a problem in the May data with FB on.
  - More crossing of sick channel regions?
  - More sick regions?
- FZP seems more susceptible to fitting to zero due to greater dependence on just a small part of the image for resolution. CA is somewhat more robust (gets information from more pixels), but is perhaps more likely to make overly large fits.
- Until this is resolved (New detector? Improved analysis algorithm?), we should avoid making e-cloud blow-up measurements with the (at least transverse) feedbacks off.
  - Make measurements with FB ON (xBSM) and OFF (BPM).
  - Or at least keep transverse FB on all the time?

Overall Summary

- Beam:
  - Beam blow-up appears to occur at about the same location as sidebands appear when FB on.
    - Should also check with sideband measurements to see if exact threshold location is the same, and moves the same.
    - Attempt to do so in September was marred by excessive dipole motion of beam, and detector sensitivity to same.
    - Need parallel set of measurements with FB ON/OFF for xBSM and BPM data, with otherwise same (varying) parameters.
- Hardware:
  - Coded aperture optics seem to be working more or less as expected.
  - Large dipole motion seems to generate misfits.
    - Resolution dependence on bad channels needs more study.
    - Or have no bad channels…