# Beam Measurements
# @
# PHIN Photo-Injector

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(on behalf of the PHIN team)

CLIC Meeting 2009/Injectors Working Group - WG2

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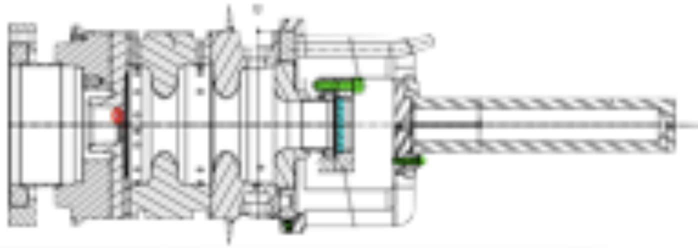
https://twiki.cern.ch/twiki//bin/view/CLIC/Photo-Injectors

- PHIN Beamline
  - RF Gun, laser and beam diagnostics
- Measurements
  - **Beam characterization measurements**
    - * **Beam Size, Emittance, Energy, Energy Spread, Charge**
  - Stability (ongoing PHIN run)
    - * Along the pulse train (1.2 micro s)
    - * RF
    - * Laser
- Simulations on performance optimization (in work)
- Conclusion and Outlook

## RF Photo Gun

A semiconductor, cesium telluride, cathode was introduced on one end of a 3 GHz RF gun with 2+1/2 cells in order to extract the electrons.

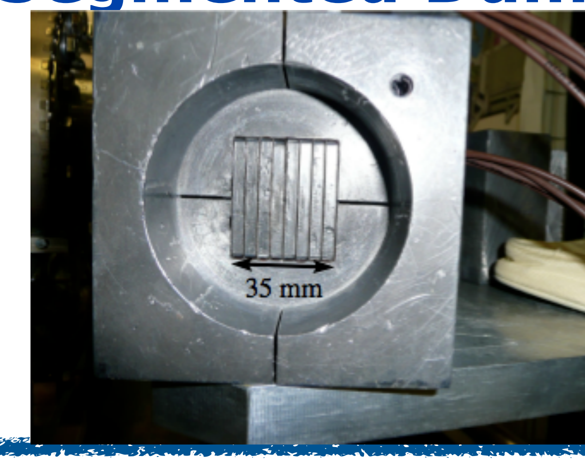


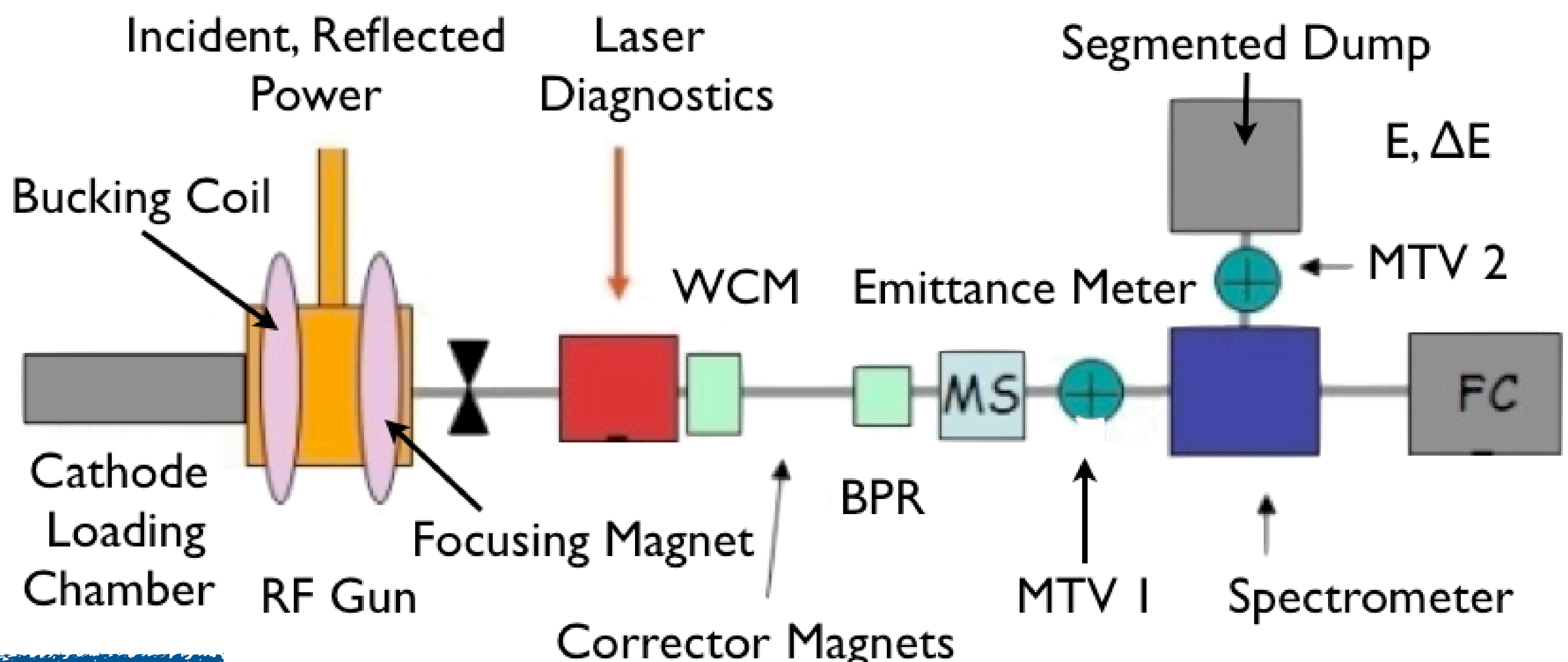
**M. Petrarca's Talk**

## LASER

A Nd:YFL oscillator produces the laser pulses at a repetition rate of 1.5 GHz with an average power of ~300mW. The oscillator has the fundamental wavelength of λ ~1047 nm and a pulse width of τ ~8 ps.

## Segmented Dump




## Measurement Section

- WCM, BPR
- Multi-slit
- Screens (aluminum, alumina)
- Intensified CCD camera
- FC
- Spectrometer **+ Seg. Dump**

Emittance Measurement

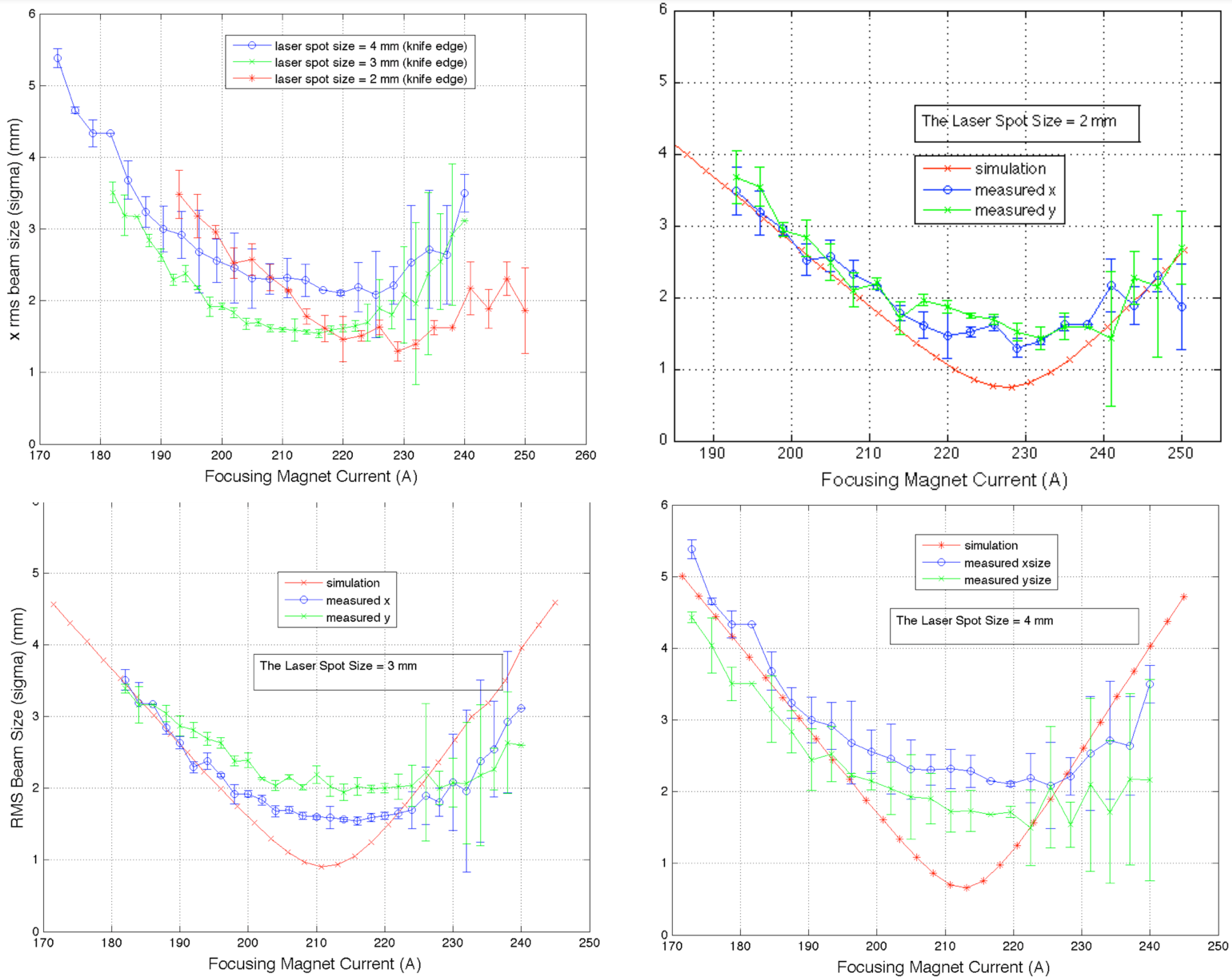
New! (Installed in 2009 1st run)

New! (Installed in 2009 1st run)

☑ **aluminum, silicon or ceramic screen**

☑ **time resolved measurements**

- A round laser beam spot has been provided for the measurements.
- Beam size scans have been also performed with respect to different laser spot sizes of **2, 3, and 4 mm** **at 5.5, 5.2 and 5.7 MeV**, respectively.
- Beam size scales with the laser spot as **1.3, 1.6, 2.1 mm**, respectively.



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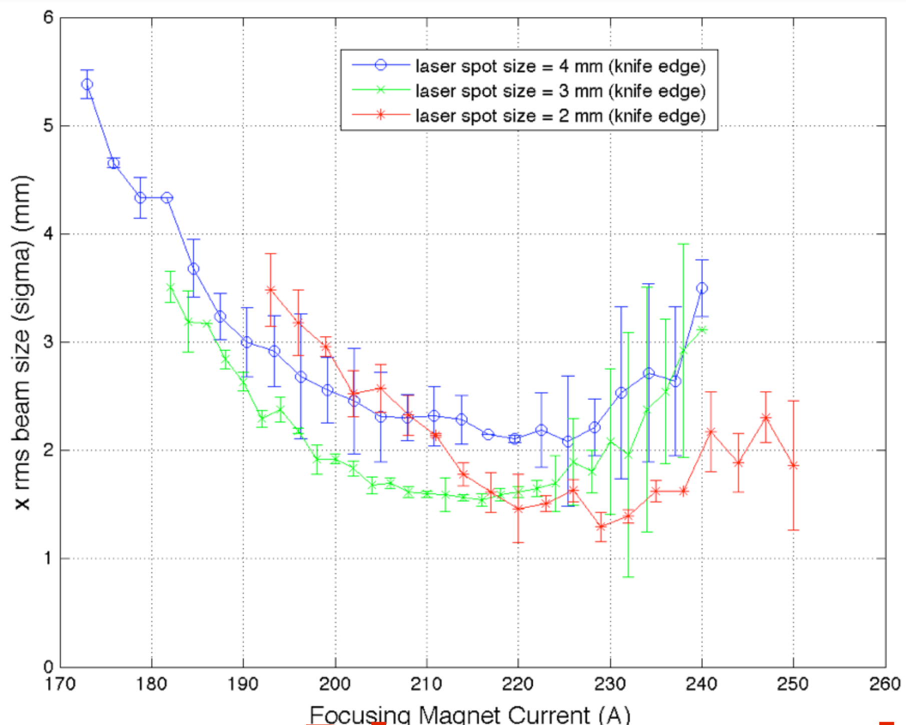
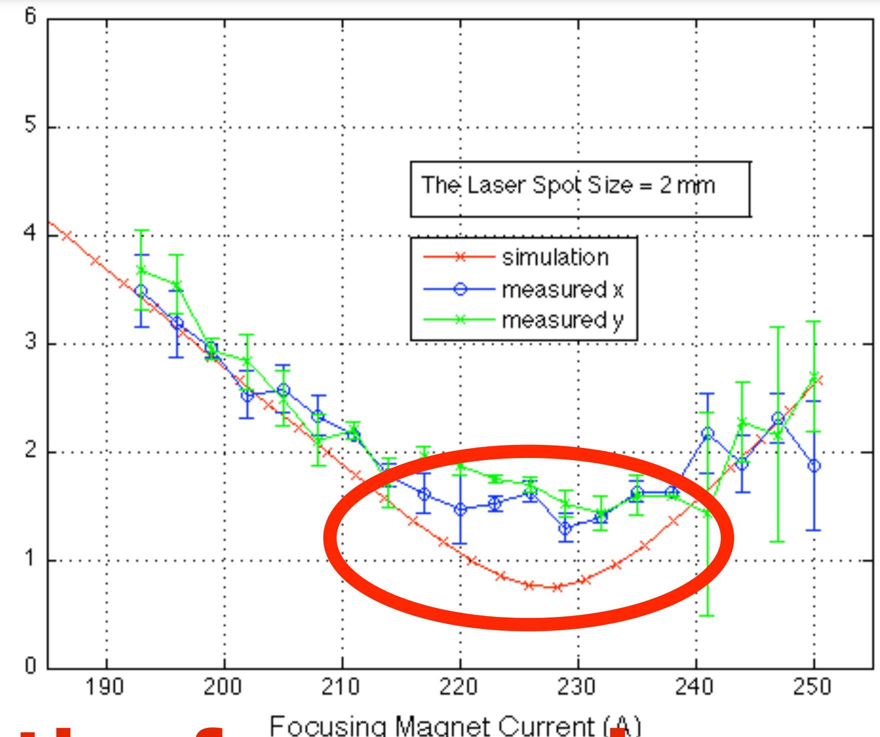
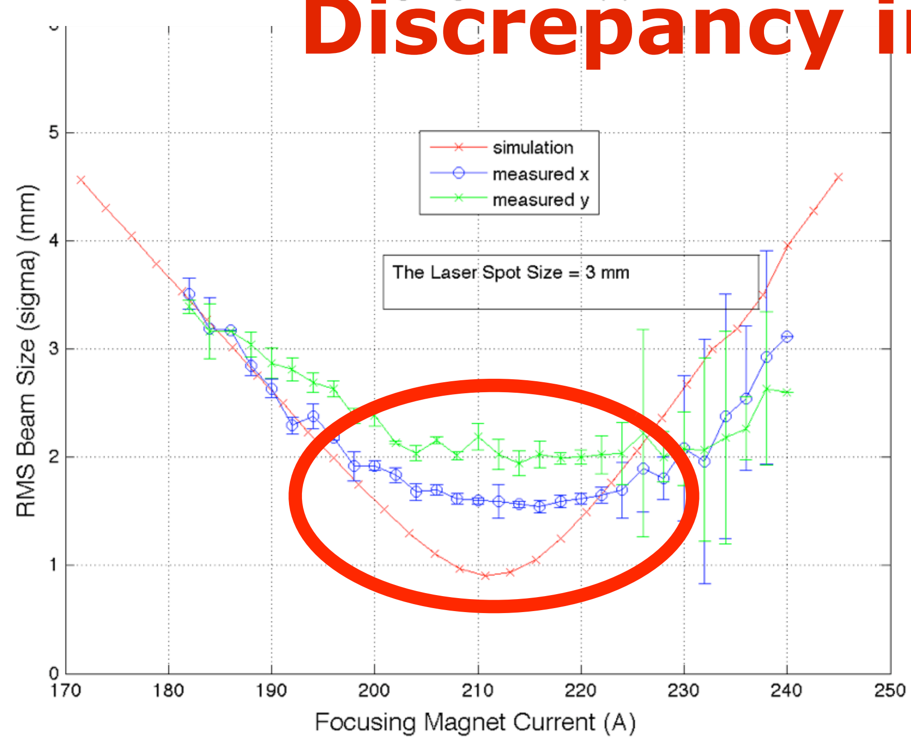
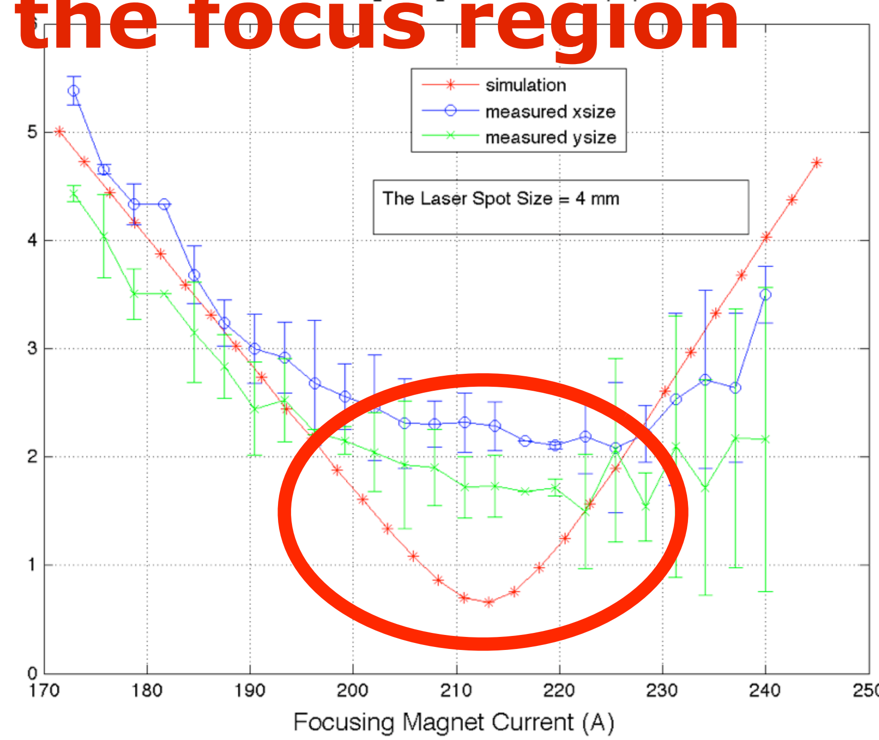


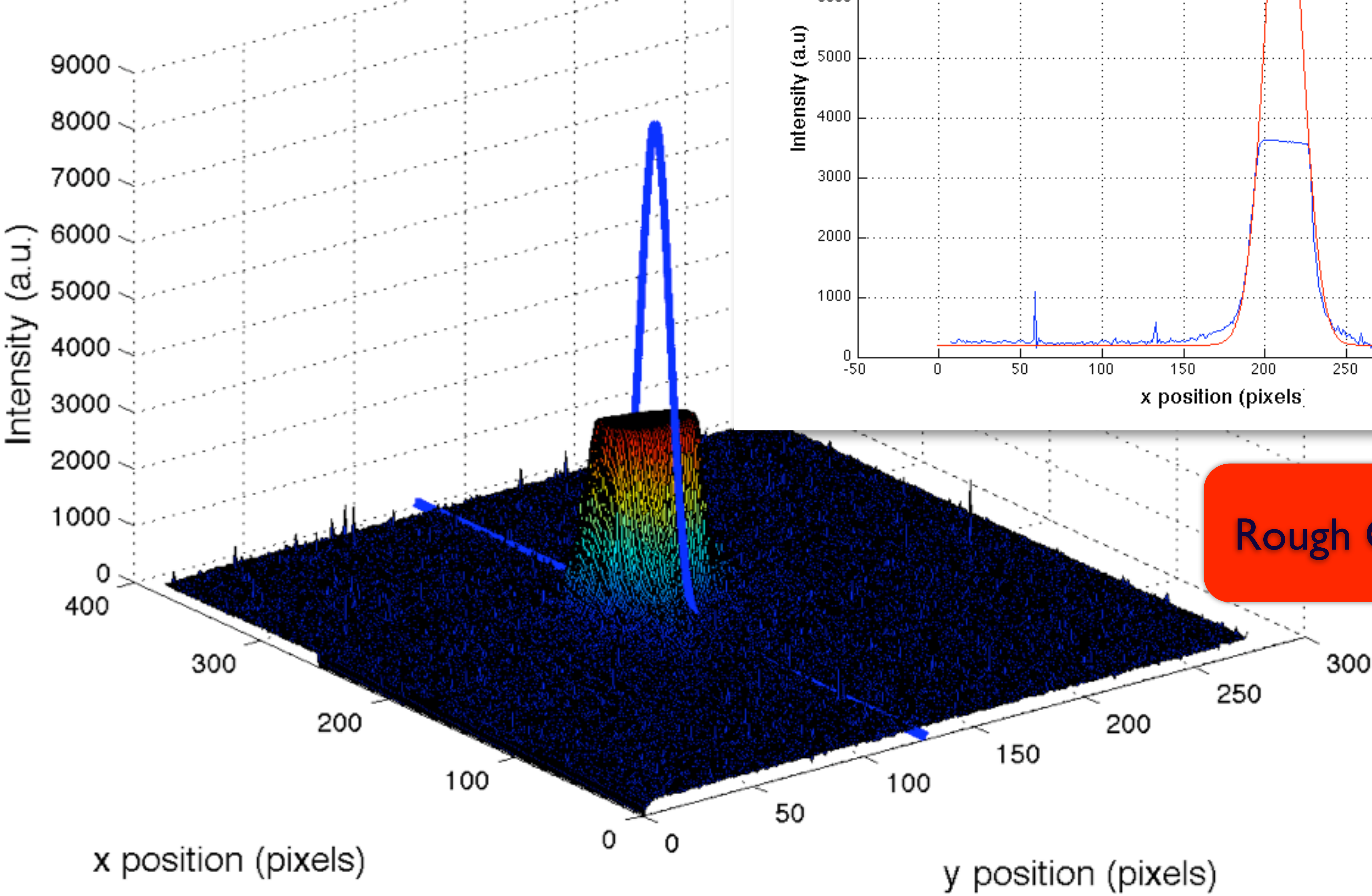



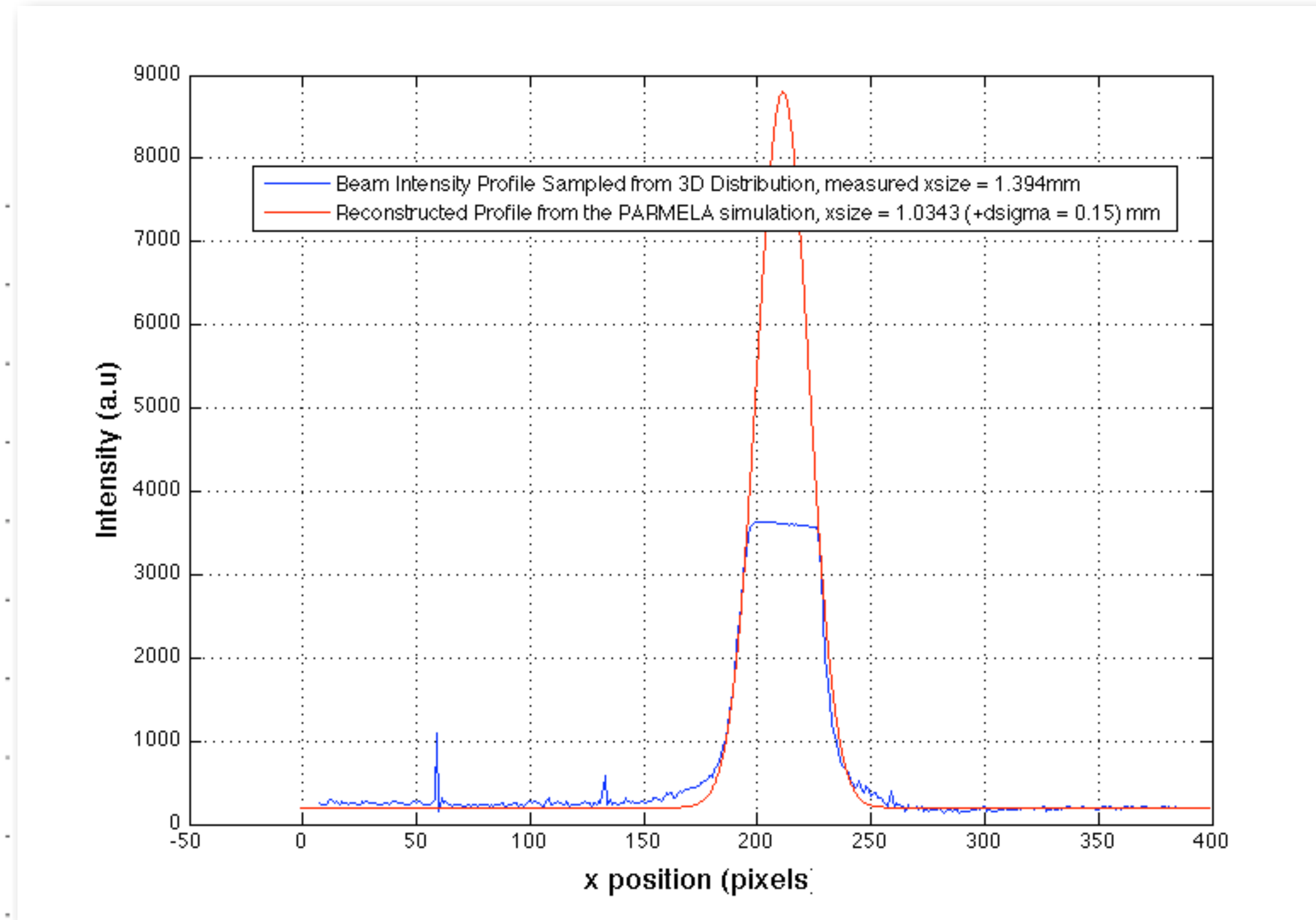

**Discrepancy in the focus region**



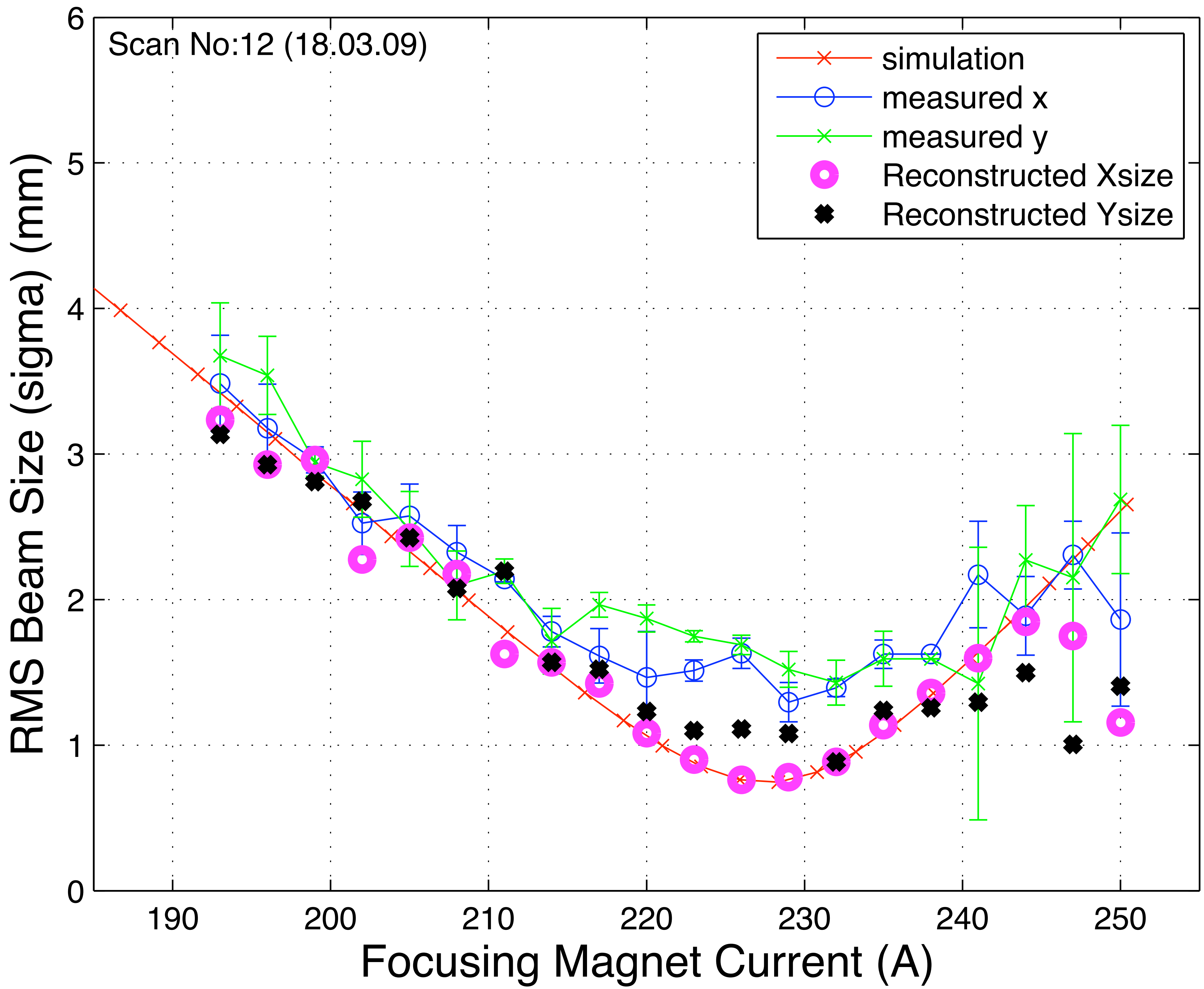



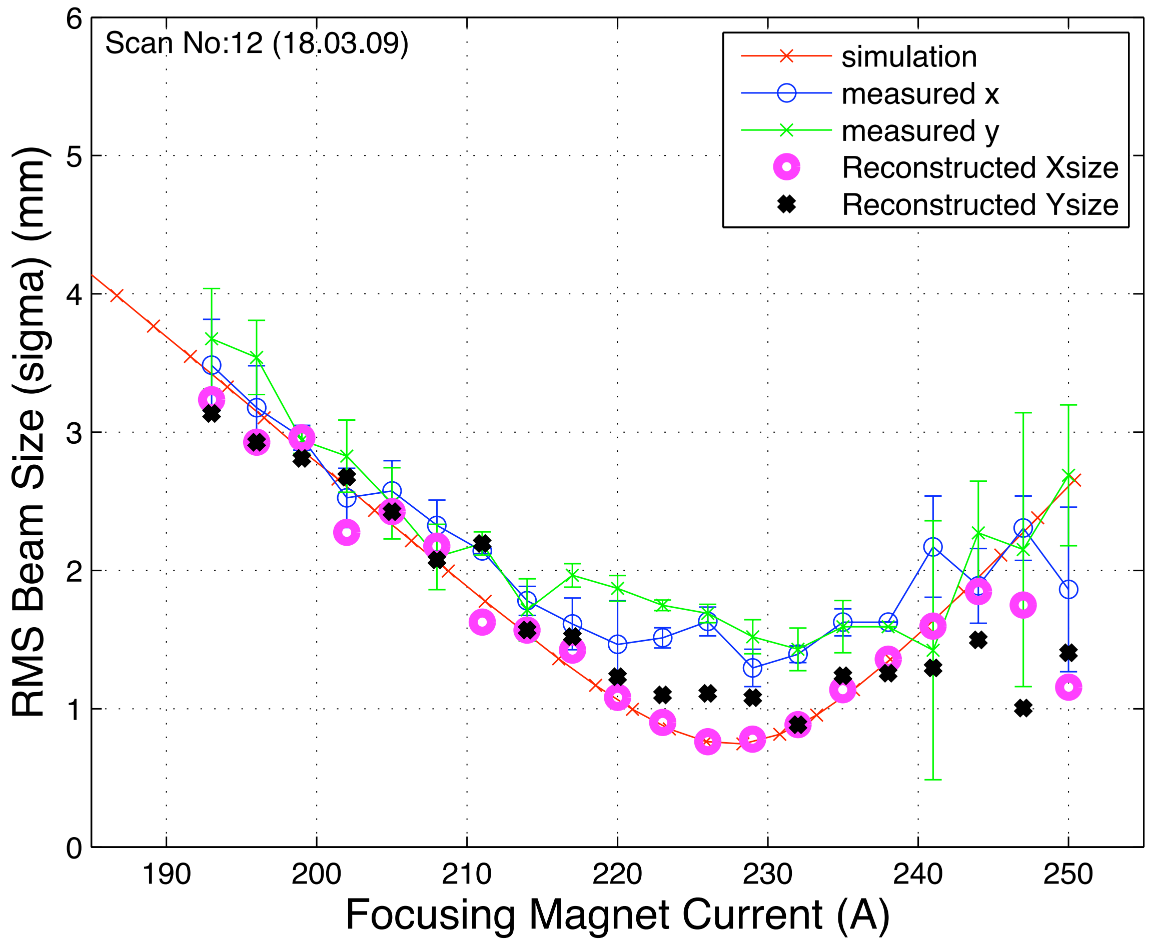
Reconstruction of the beam size measurement affected by CCD saturation.




Rough Optimization


Scan No:12 (18.03.09)
simulation
measured x
measured y
Reconstructed Xsize
Reconstructed Ysize
RMS Beam Size (sigma) (mm)
Focusing Magnet Current (A)
0
1
2
3
4
5
6
190
200
210
220
230
240
250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RMS Beam Size (sigma) (mm)
Focusing Magnet Current (A)
0
1
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190
200
210
220
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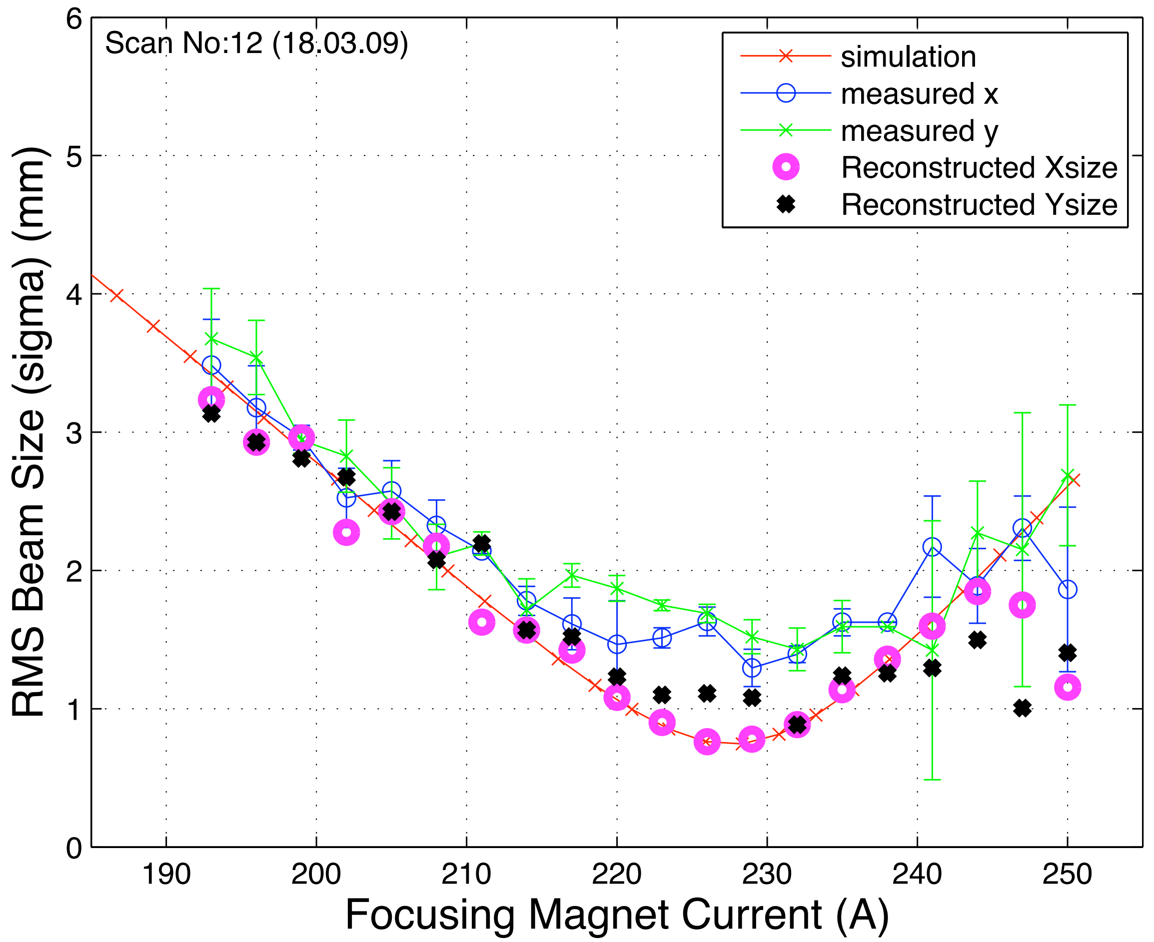
250

OUTs:

- CCD saturation
- Reflection from the screen edge

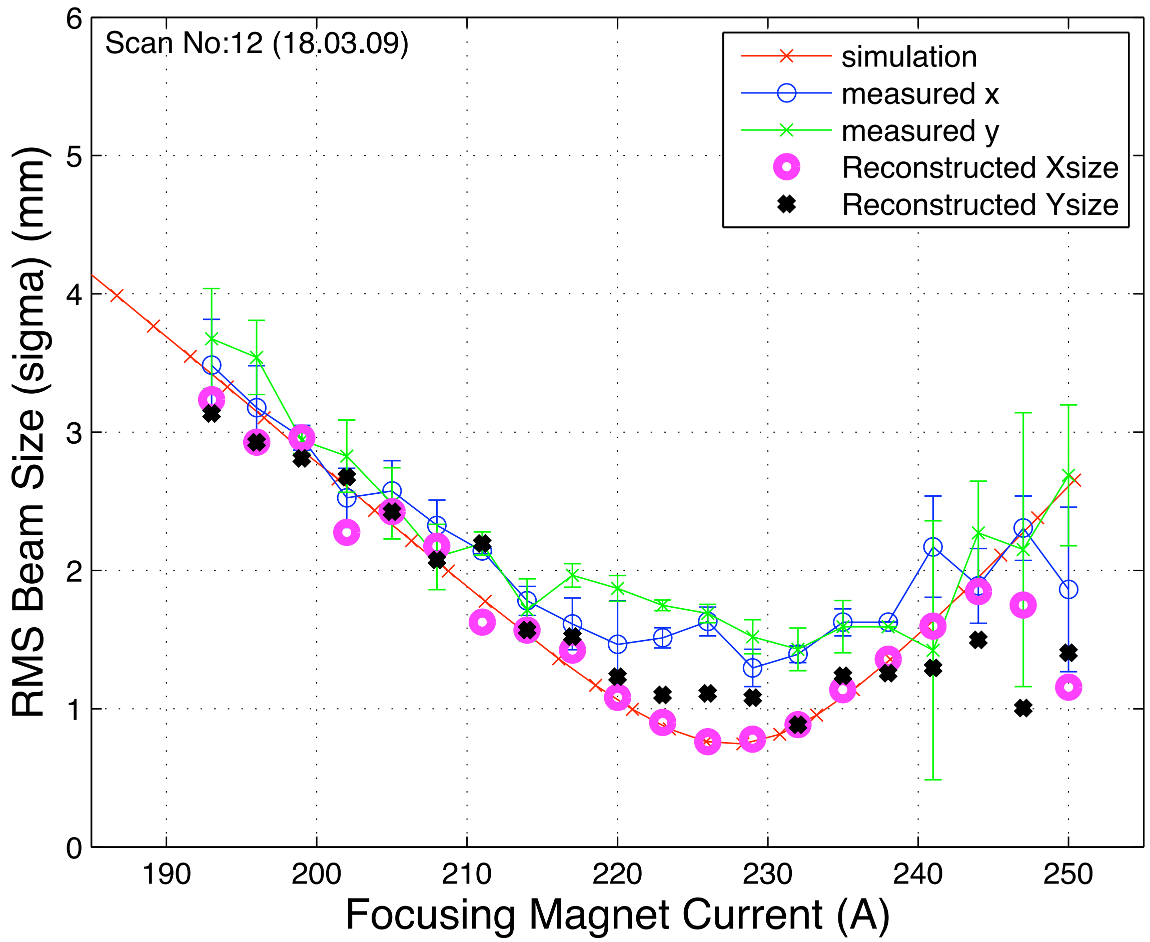


OUTs:

- CCD saturation
- Reflection from the screen edge

INs:

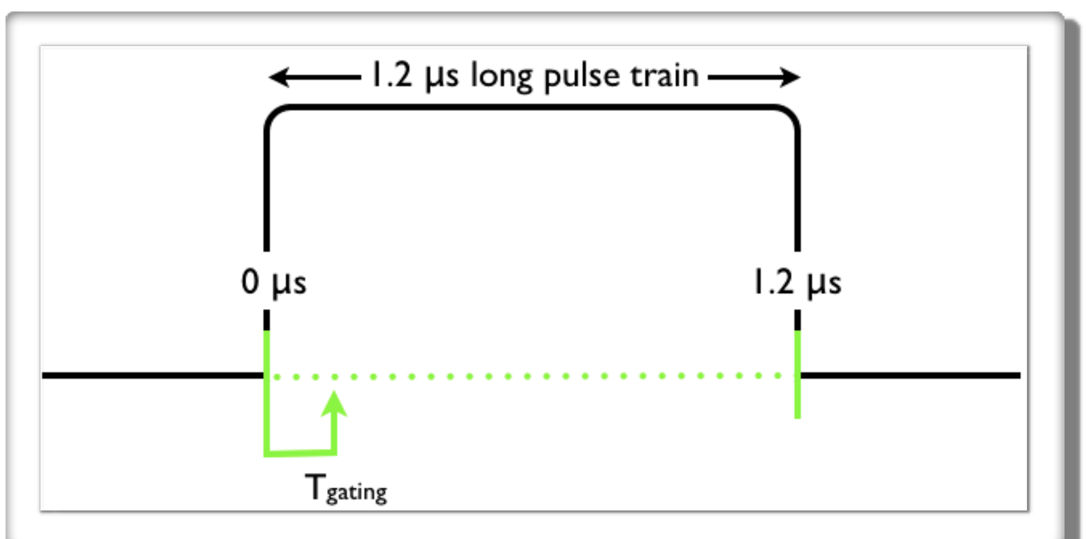
- Reconstructed scan agrees with simulation
- Reduce camera gain against saturation
- Black screen frame ready for next run to prevent the reflections

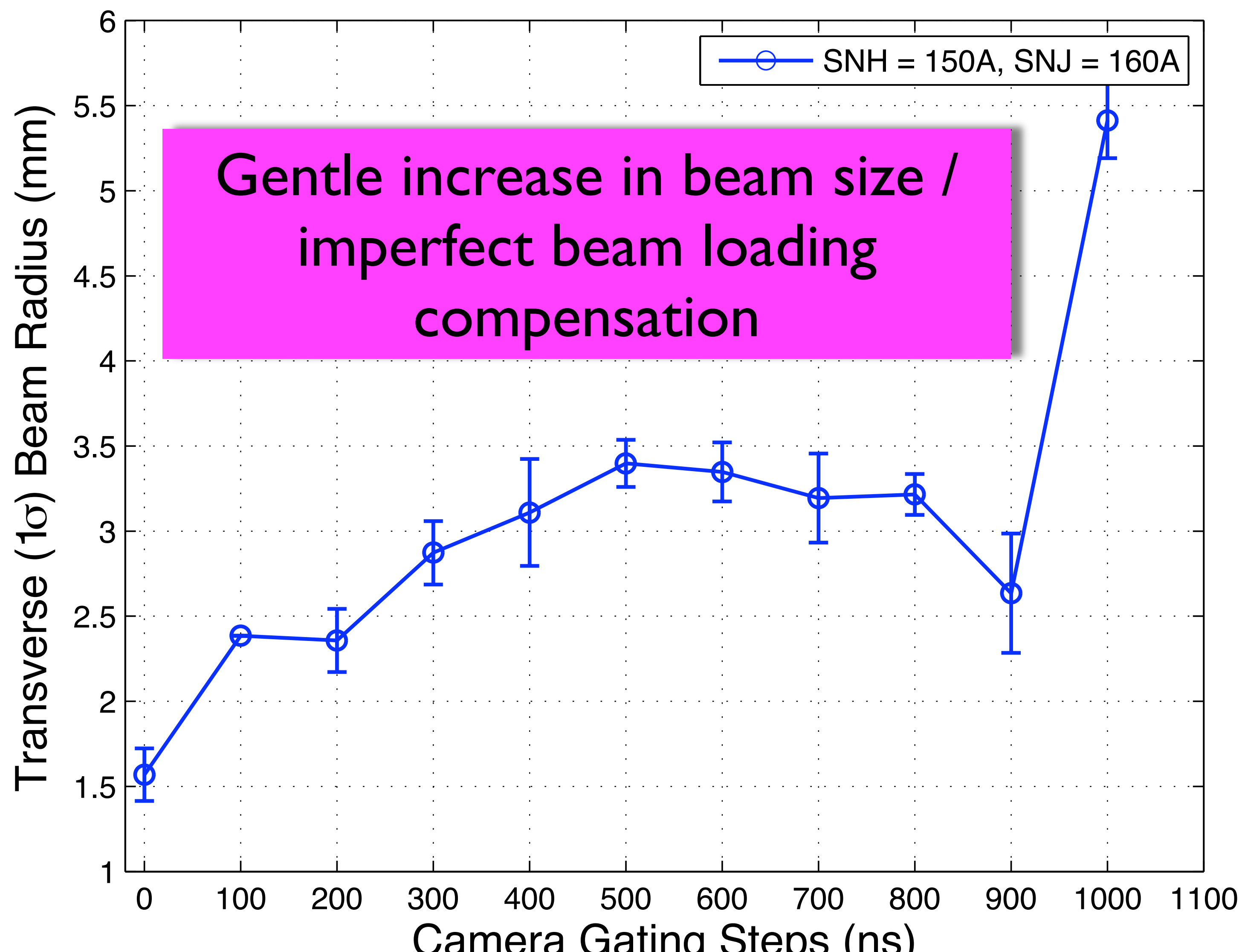


tested in the previous run

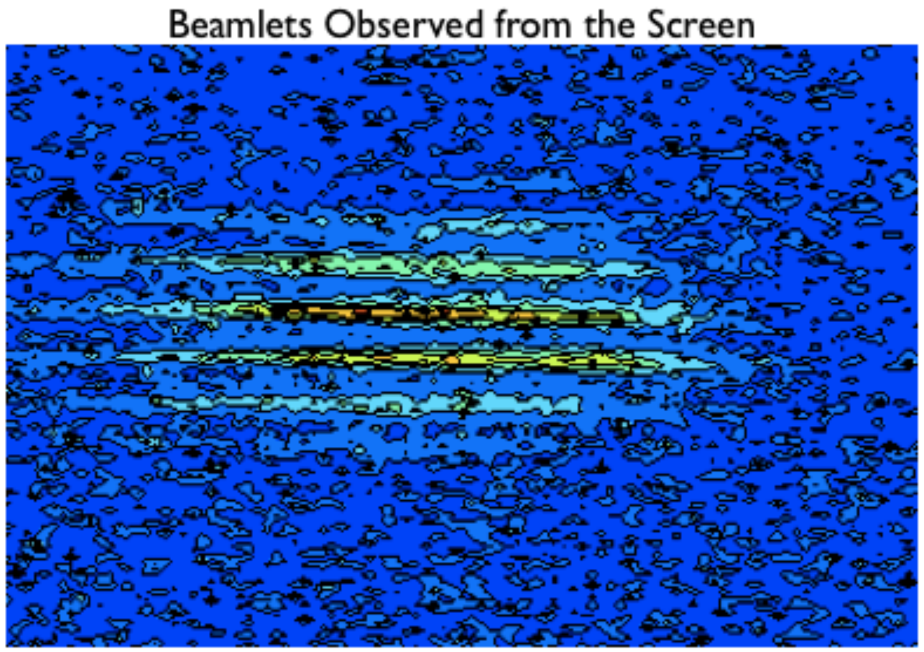
## Measurements along the pulse train with Gated Camera

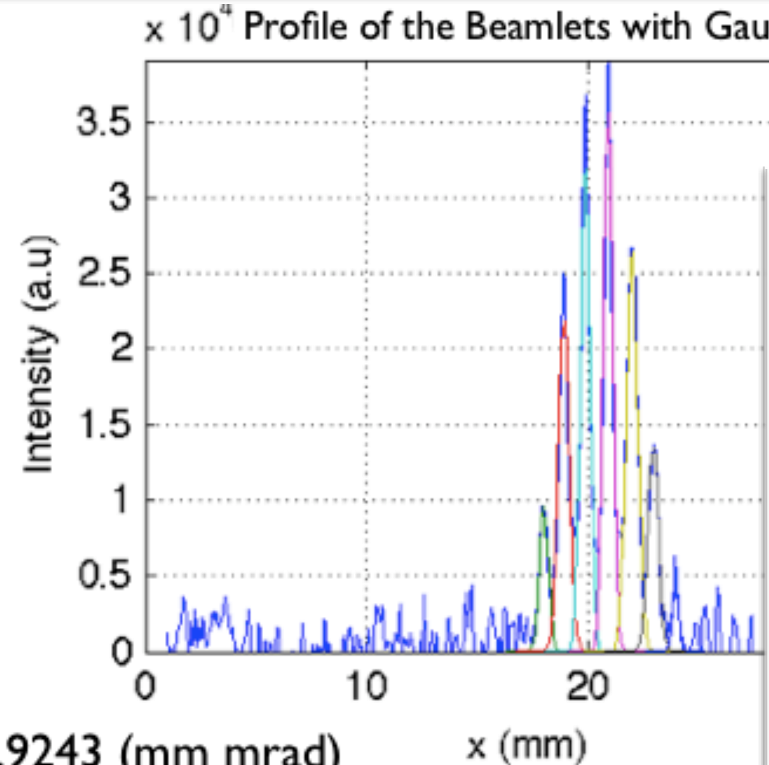
- The beam size has been also measured as a function of time along the train by using a gated camera.
- **More measurements along the pulse train in the current run**



Multi-Slit Method (back-up slides 1-3)



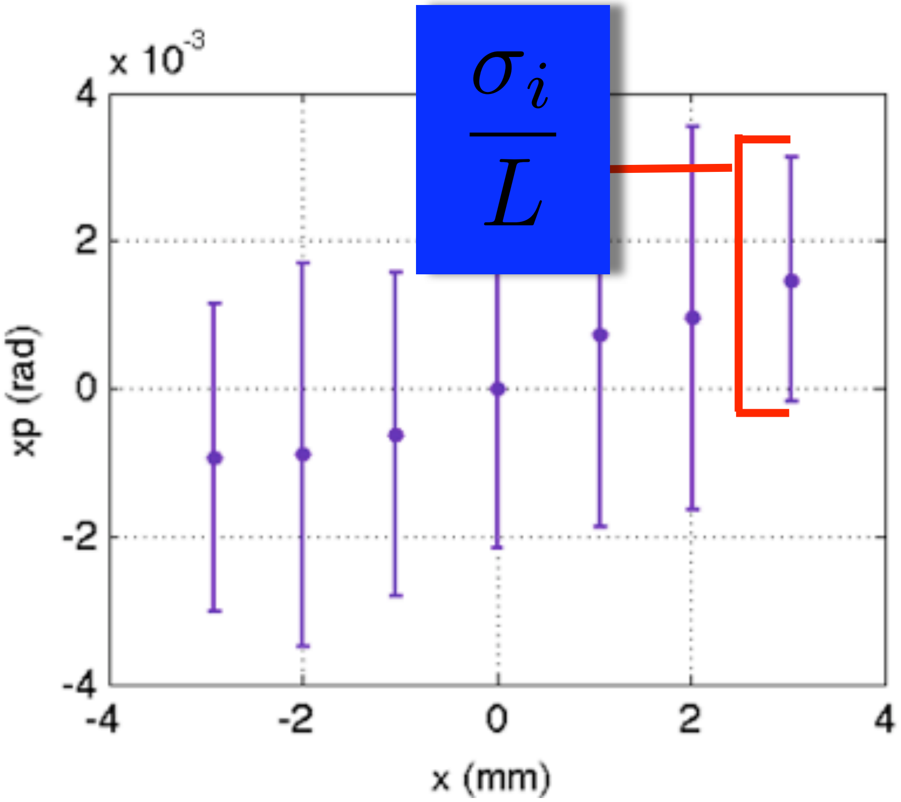




No contribution expected from the unstopped electrons by the slit-mask

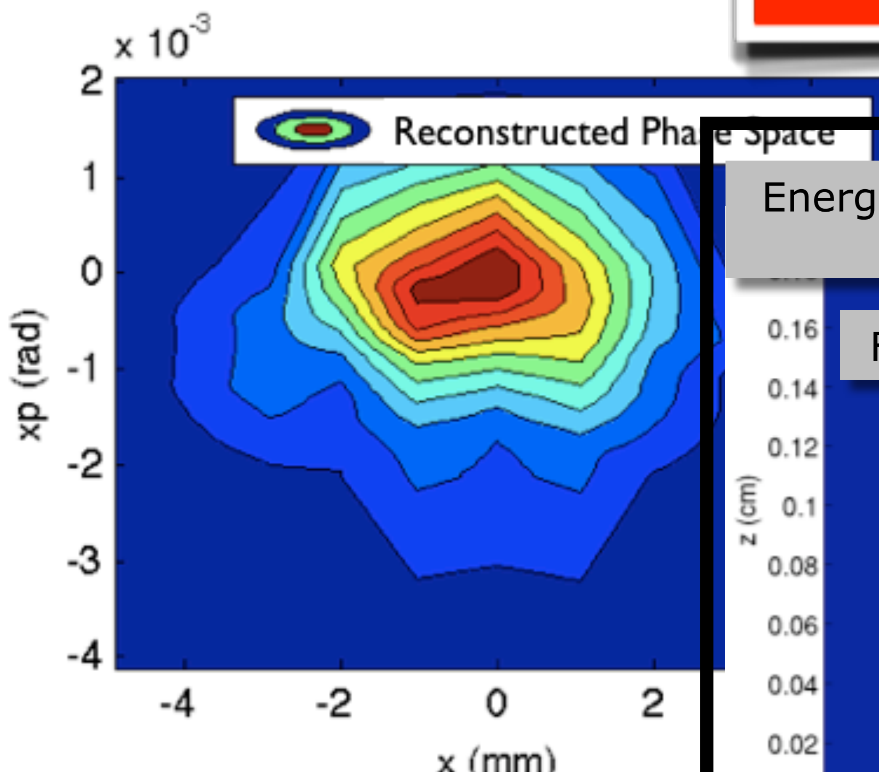
**Difficulties:**

- **Background**
- Determination of beamlets
- Effect from position&intensity fluctuations

The Transverse Normalized RMS Emittance = 7.9243 (mm mrad)

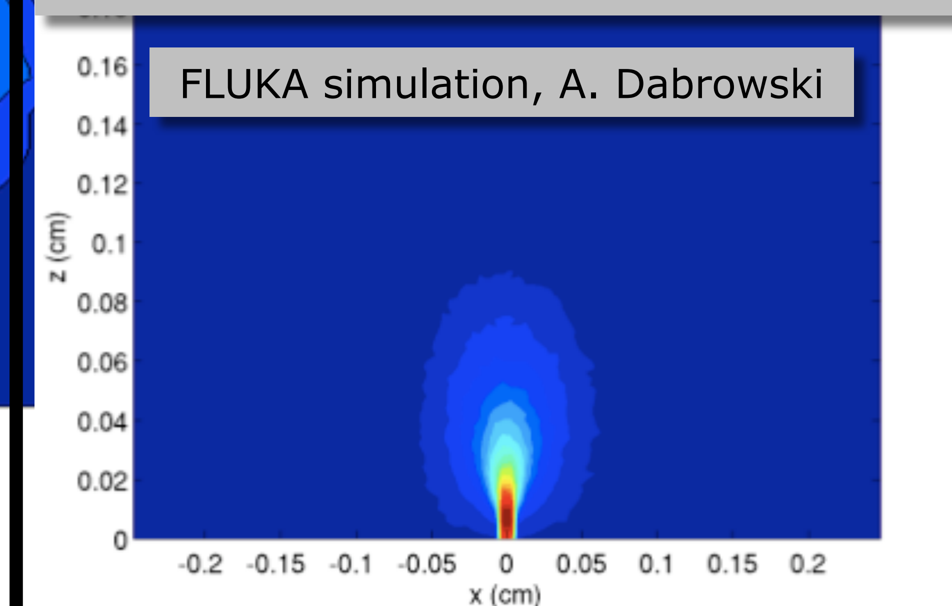



$$\frac{\sigma_i}{L}$$




Energy Deposition on 2 mm Tungsten Slab for 5.5 MeV e⁻ Beam

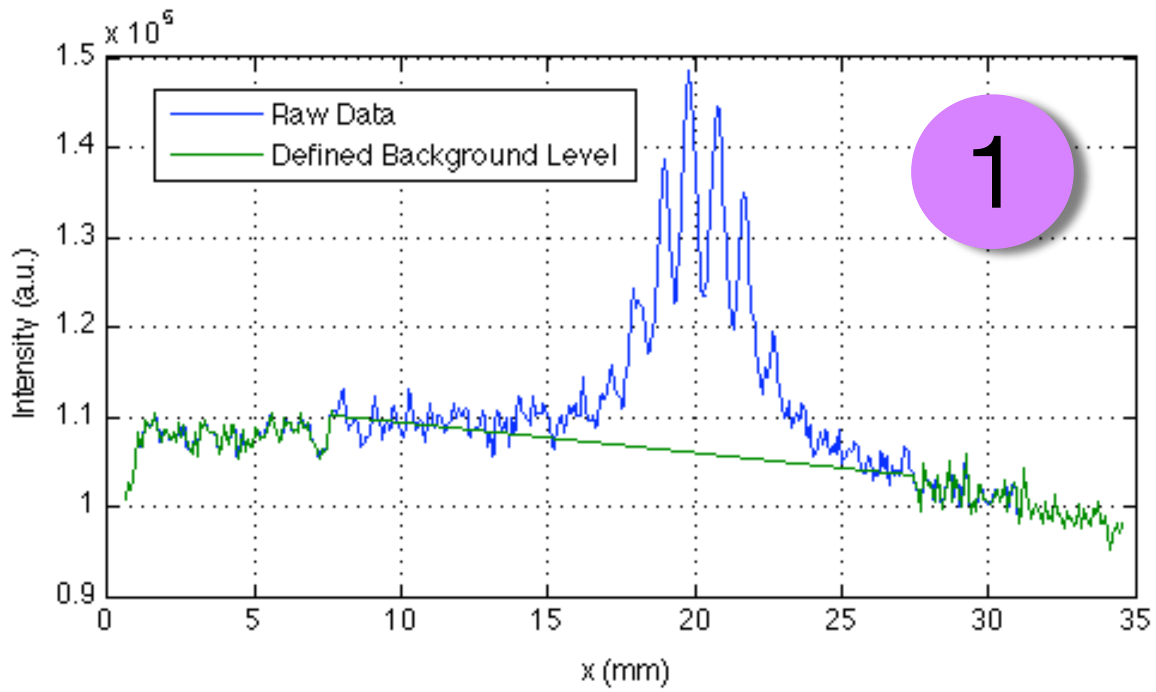
FLUKA simulation, A. Dabrowski

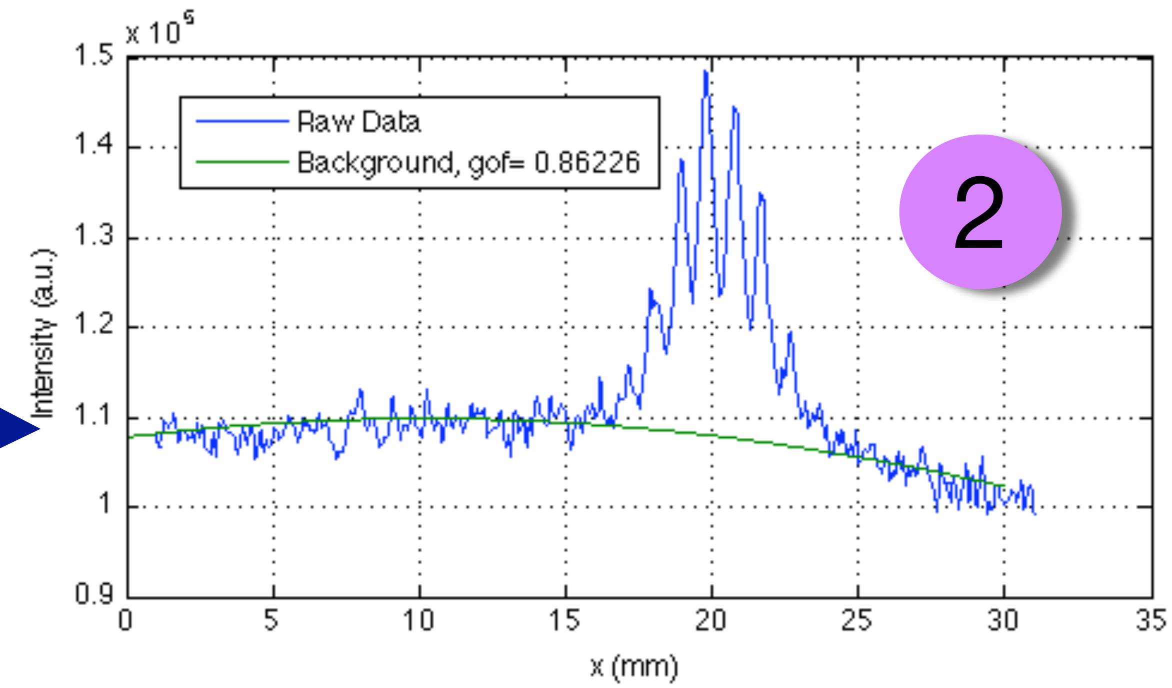


details --> back-up slide 8

Laser Spot = 3 mm
Energy =5.2 MeV
Charge/Bunch = 1.28 nC

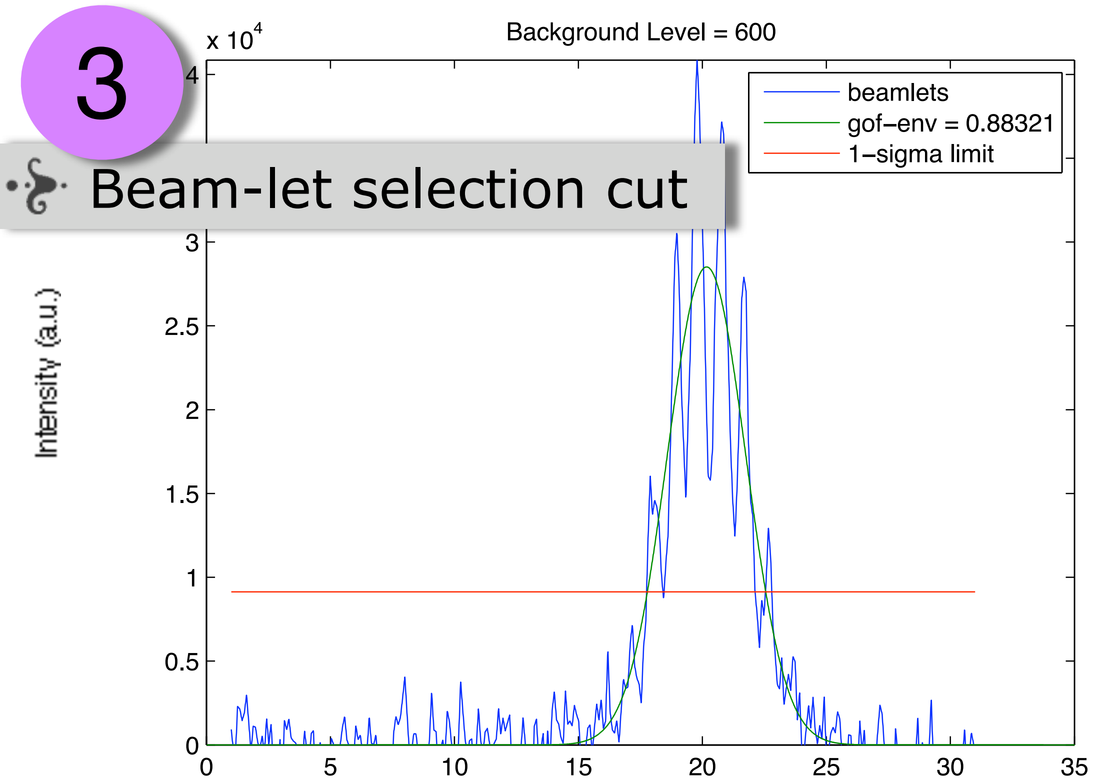
Determination of the optimum background model



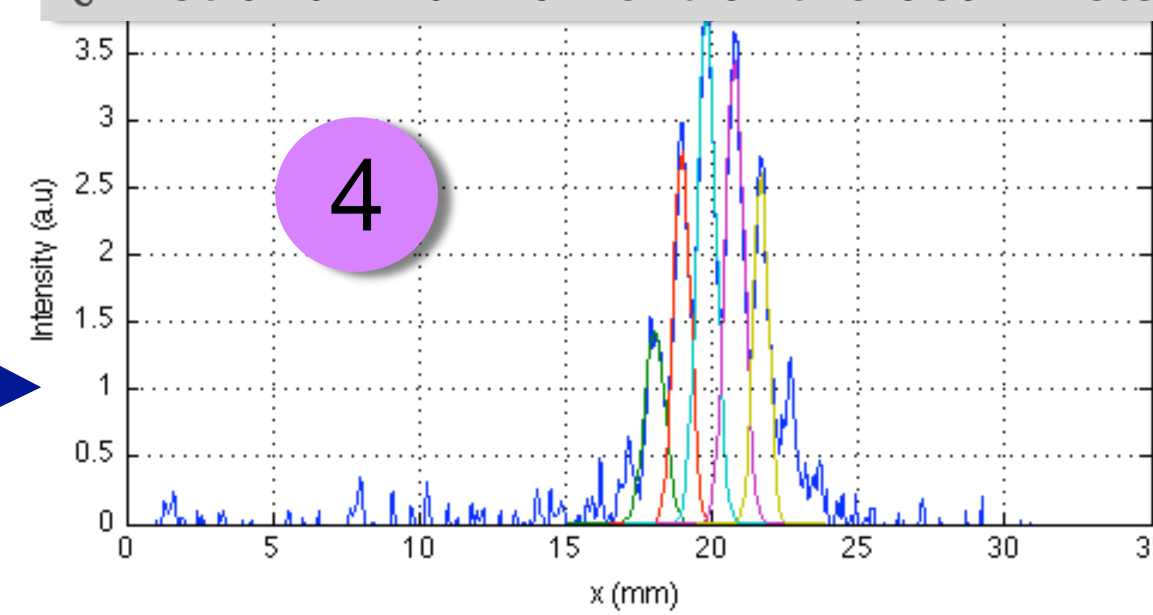




b)

Beam-let selection cut




1st and 2nd moment of the beam-lets



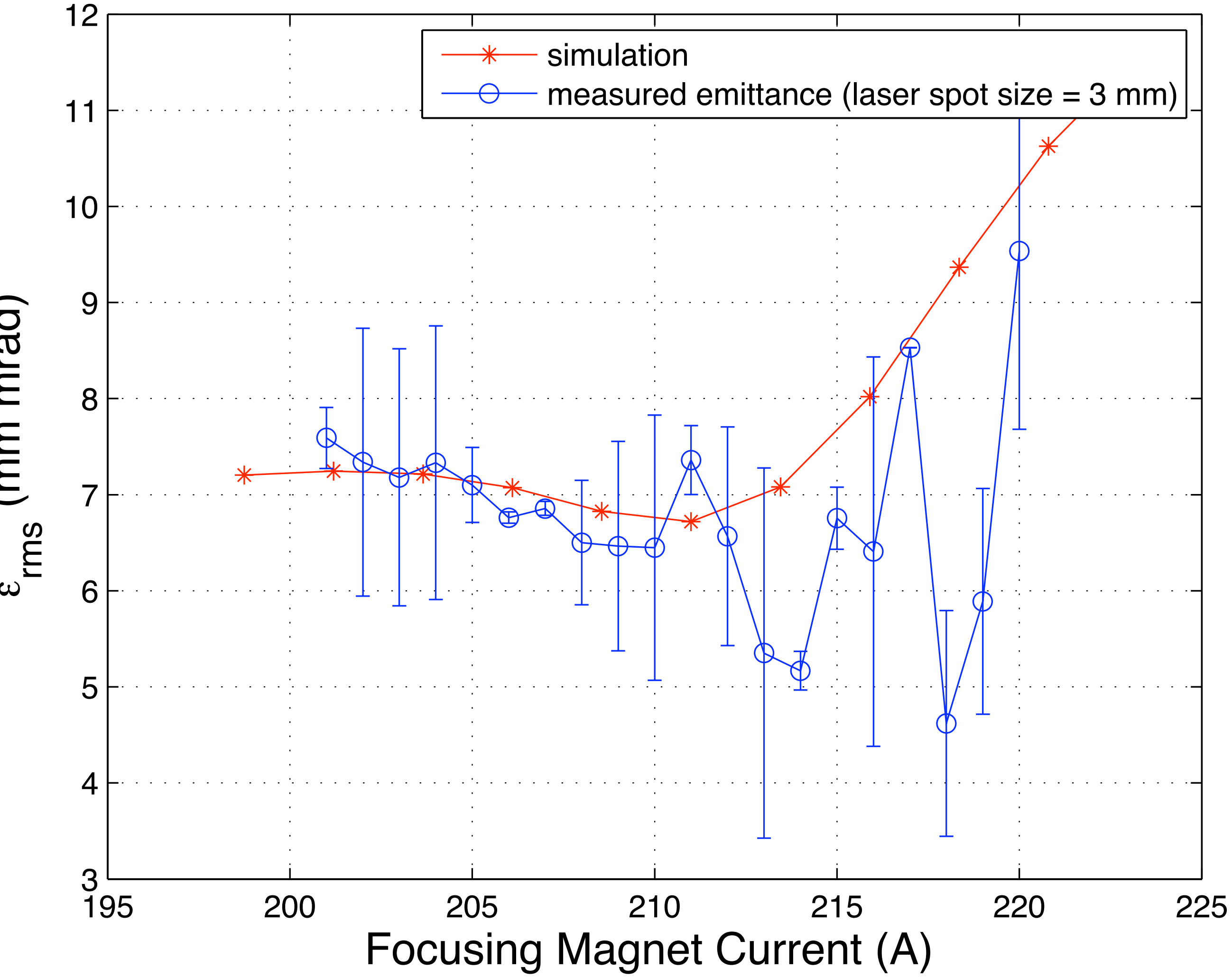

d)

Emittance has been also measured for different laser spots of 2, 3, 4 mm.

**Emittance Scan No:05 (17.03.09)**

**Electron Beam**
Energy: 5.2 MeV
Charge: 1.28 nC

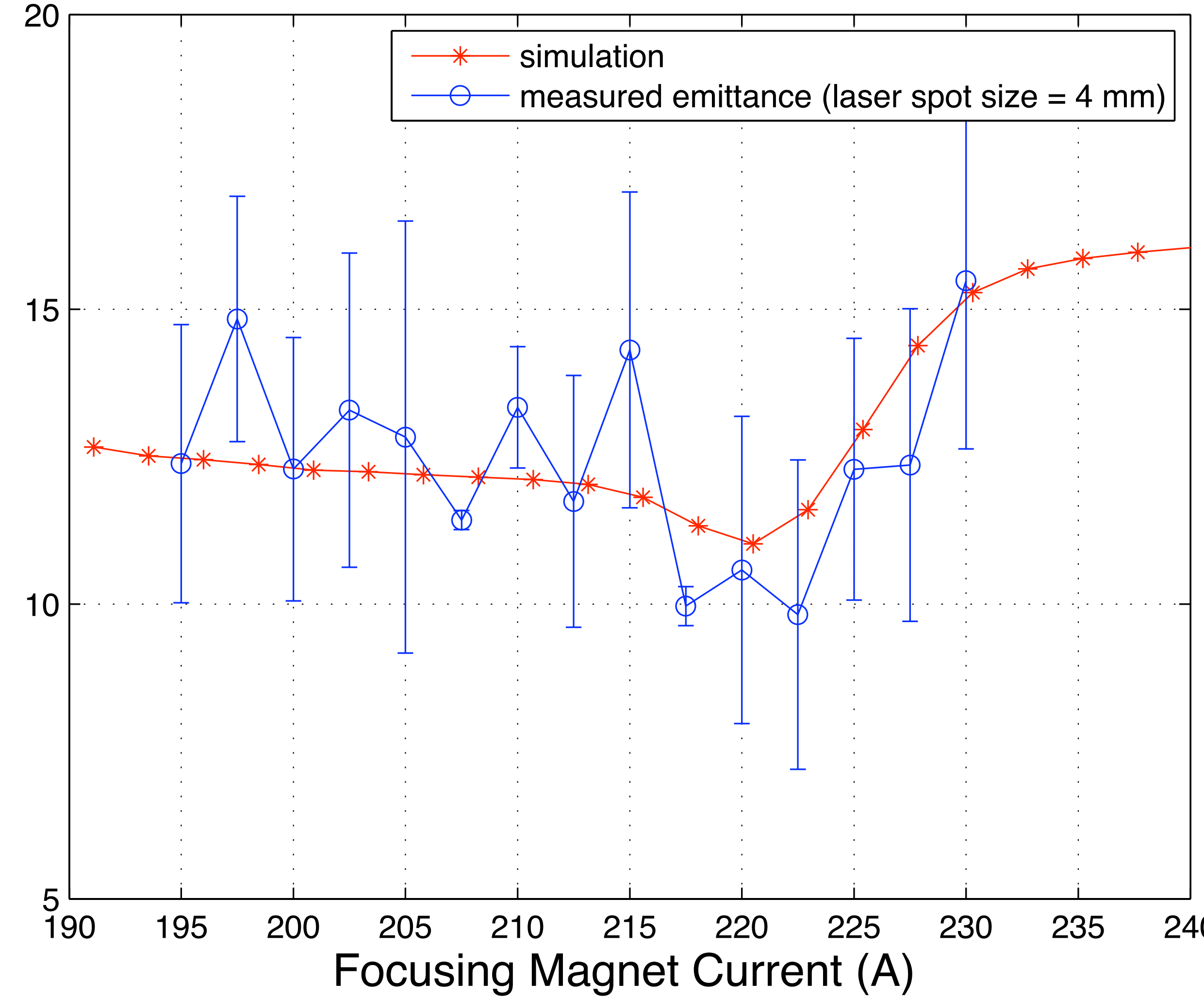
**Laser Beam**
Pulse Length: 200 ns
Energy: 80 µJ (per pulse)
Spot Size: 3 mm (knife edge (85%)




**Emittance Scan No:04 (17.03.09)**

**Electron Beam**
Energy: 5.512 MeV
Charge: 1.28 nC

**Laser Beam**
Pulse Length: 200 ns
Energy: 80 µJ (per pulse)
Spot Size: 4 mm (knife edge (85%)




Transverse emittance scales with the laser spot size as expected from the PARMELA simulations. Values are ~6, 7 and 12 mm mrad for 2, 3 and 4 mm laser spots, at the energies of 5.7, 5.2 and 5.5 MeV, respectively.

| | Value |
|---|---|
| Emittance (mm mrad) | 8.2444 |
| Slit Width (mm) | 0.1 |
| Mask-Screen Distance (mm) | 230 |
| Intensity Fluctuations (%) | 5 |
| $\Delta\varepsilon$ (mm mrad) | 1.1346 |
| $\Delta\varepsilon$ (%) | 13.7622 |

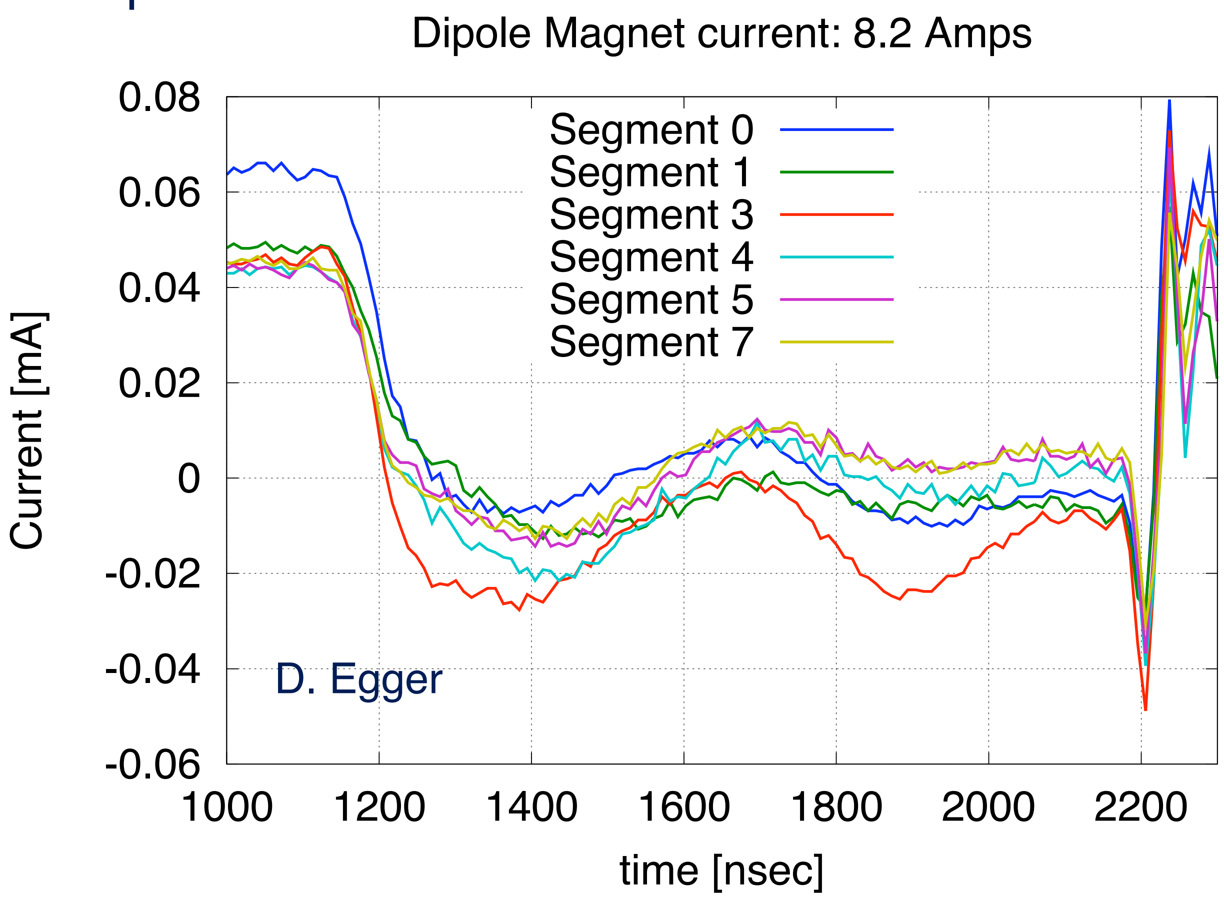
**Possible Systematic Error Sources:**

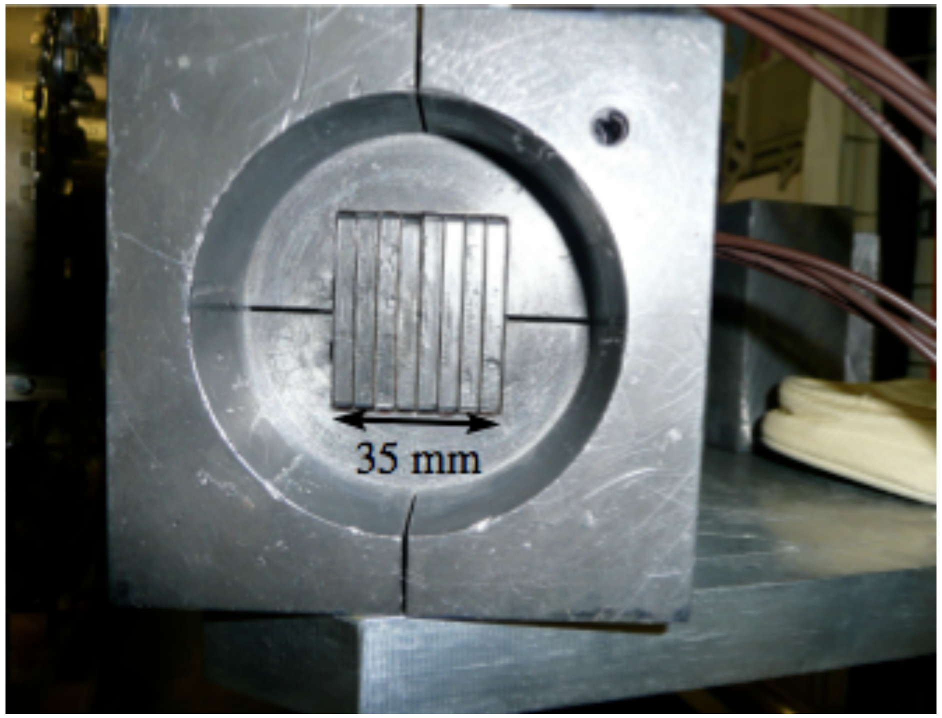
- Width of slits
- SlitMask-Screen distance
- Shot to shot intensity fluctuations

Details are in the back-up slide 4,5

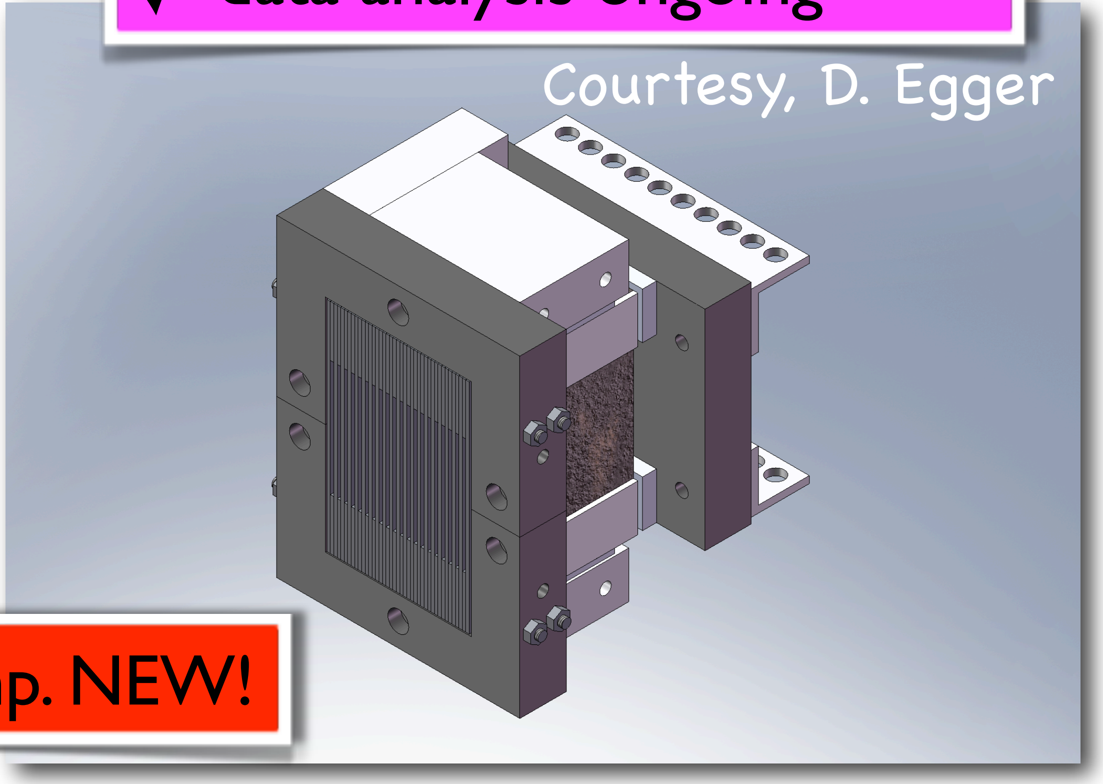
## Spectrometer

Time resolved energy of the beam was measured by using a segmented dump. Regarding the time resolved aspect of the measurement, the goal was to measure the time variation of the energy along the pulse train.



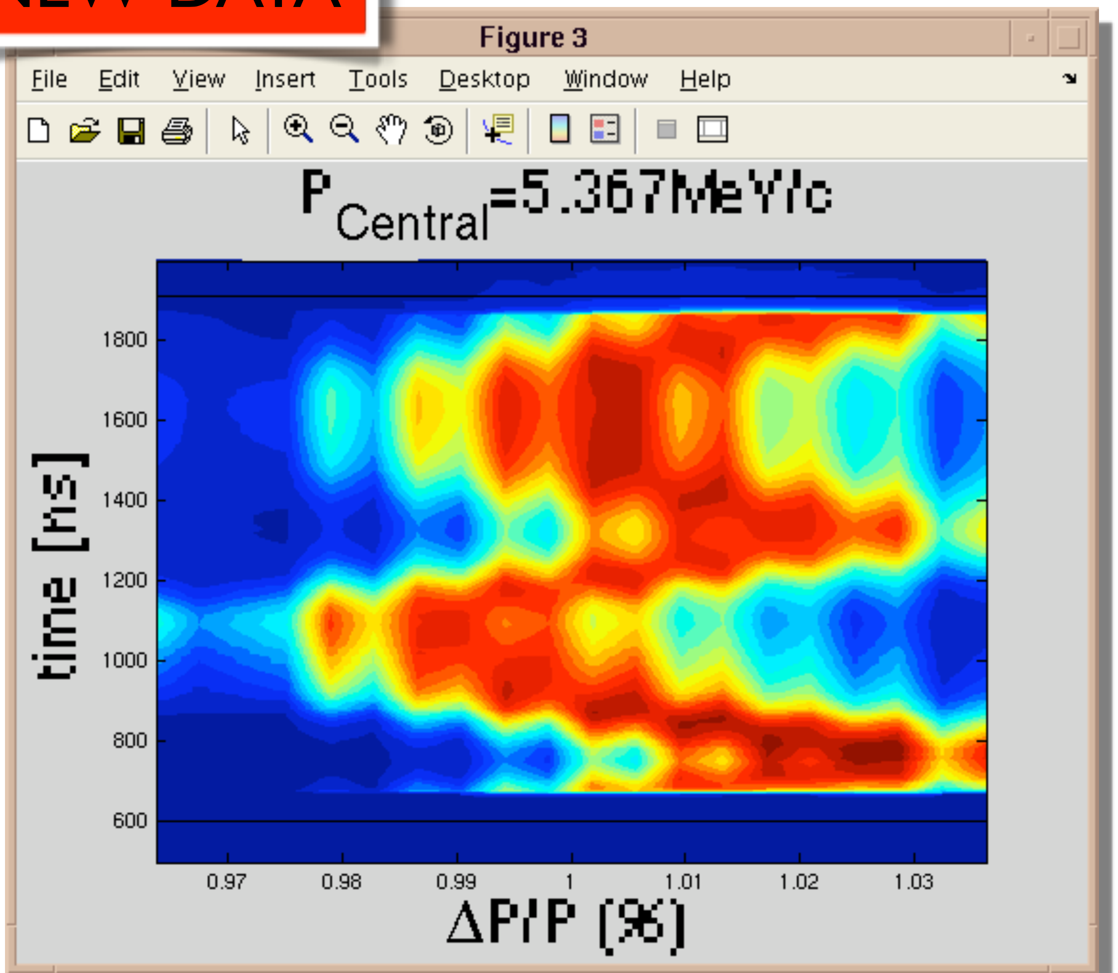

✓ tested in the current run
✓ data analysis ongoing

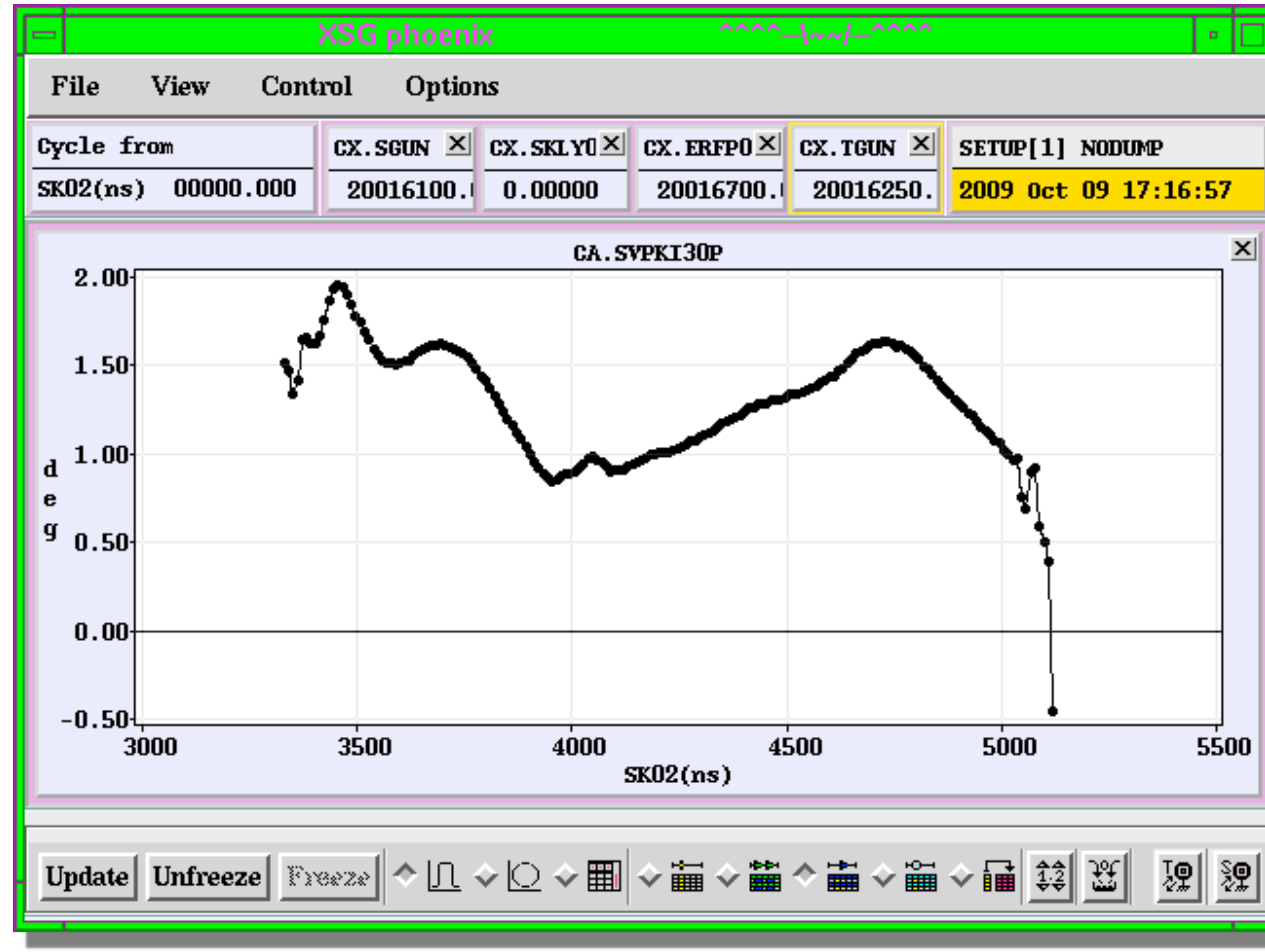



The measurement shows that the energy along the train is stable confirming the stability of the RF system.

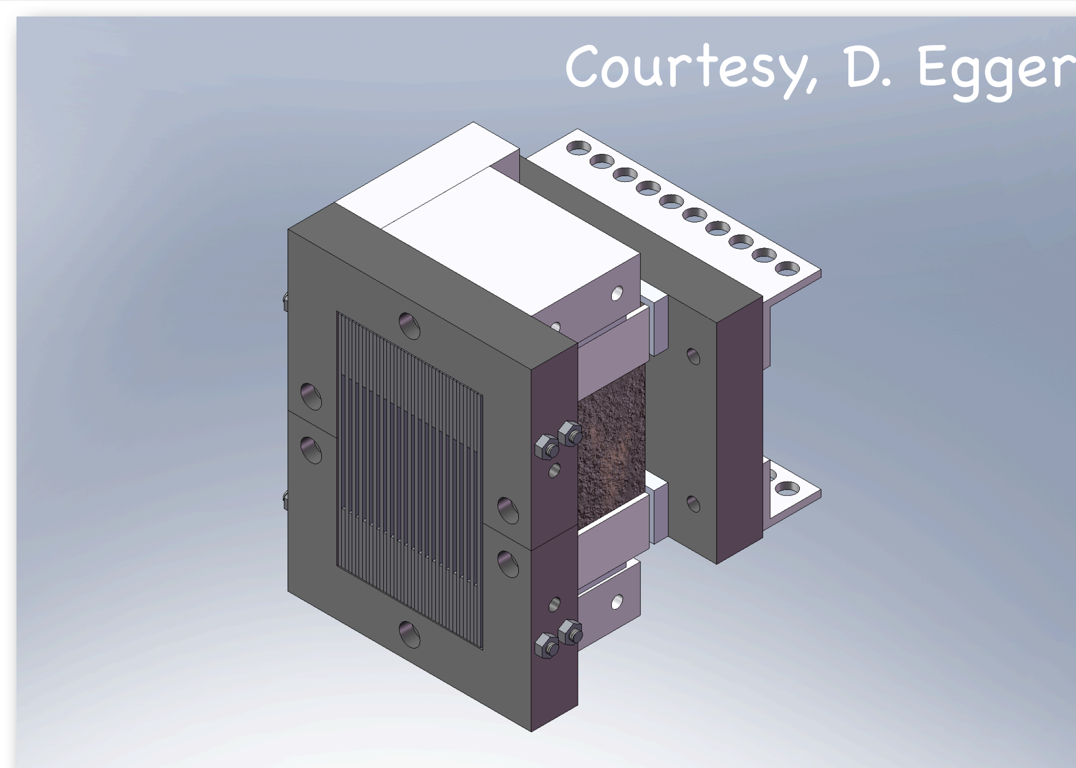
20 Channel Segmented Dump. NEW!

NEW DATA



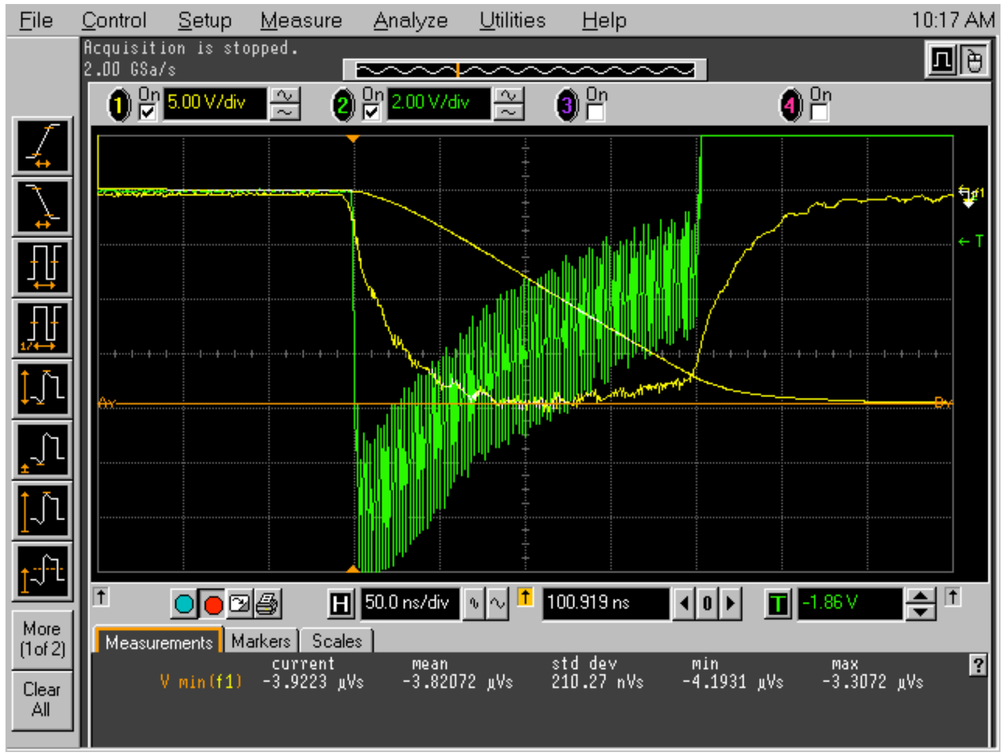



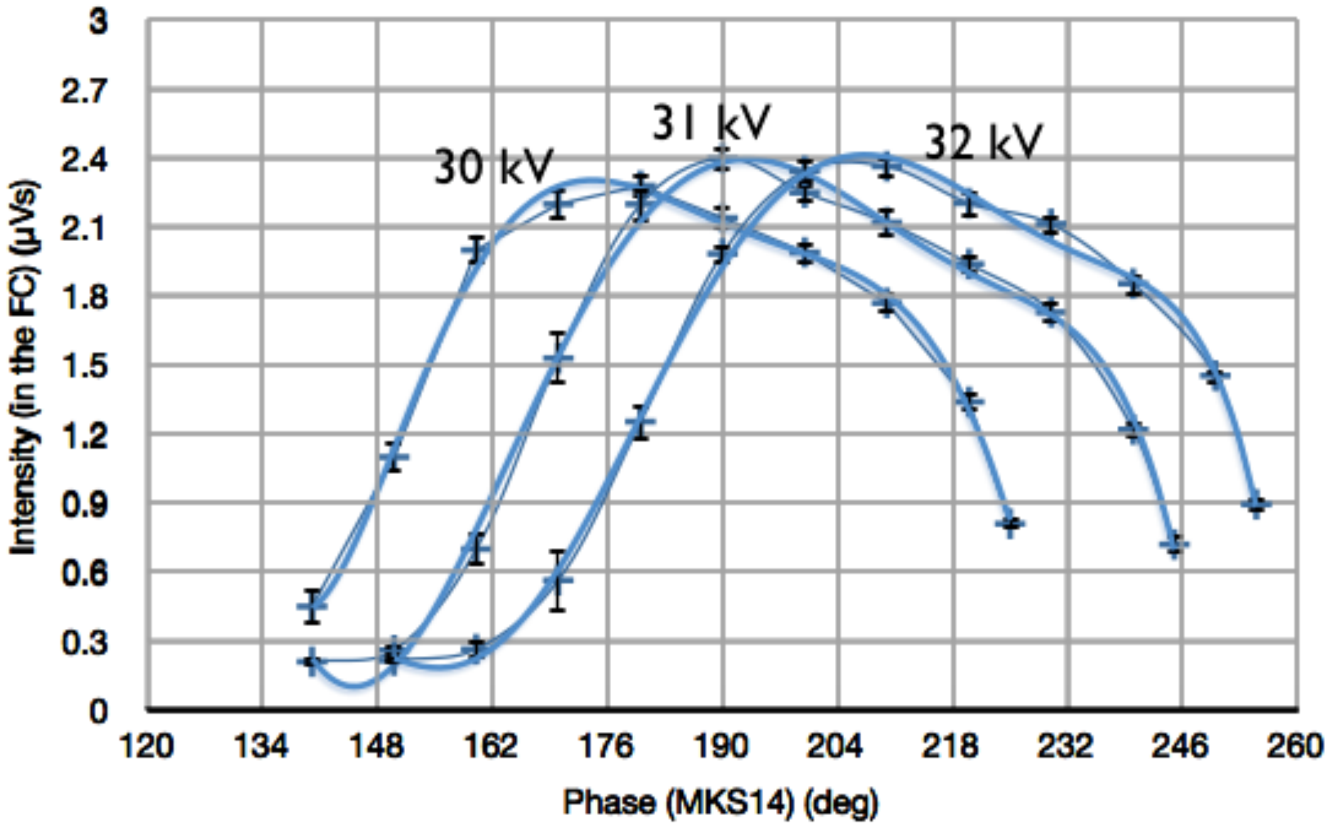

- ☑ time resolved measurements with new 20 channel segmented dump.
- ☑ Data is fresh!
- ☑ Analysis ongoing!
- ☑ the correlation with the RF stability is being investigated.




Work Daniel Egger (EPFL)

# Charge Measurement





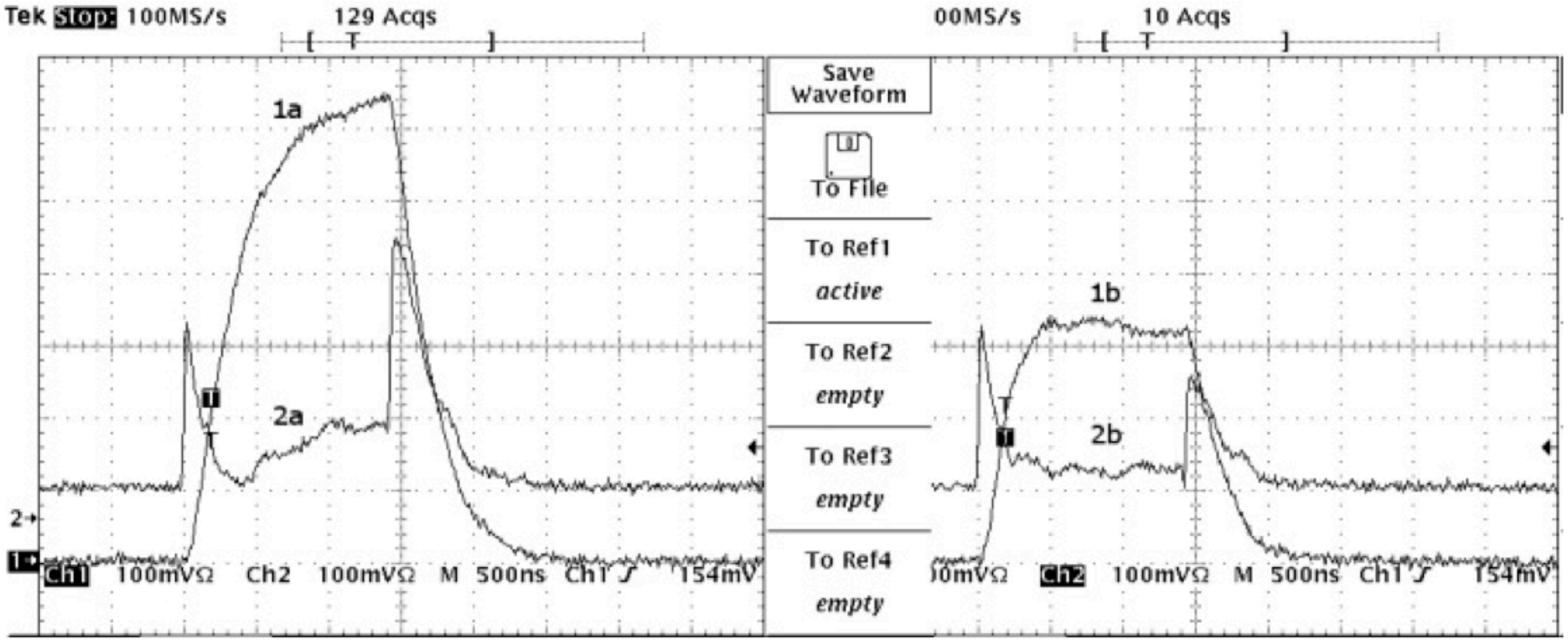

Charge has been measured by using the Faraday cup during the run. The beam consisted of 300 bunches with a charge of 1.28 nC for the measurements with the laser spot sizes of 3 and 4 mm. The measurements, at 2 mm laser spot size have also been done with a charge of 1.09 nC per bunch. **The highest achievable charge was 2.53 nC per bunch.**

**Design specification: 2.33 nC**

**stability issues/current run**

# Beam Loading Compensation

The beam loading compensation is studied and optimized for PHIN photo-injector by adjusting the timing of the beam versus the RF pulse. **In the presence of the beam a flat top RF pulse has been obtained resulting a mono-energetic beam.**

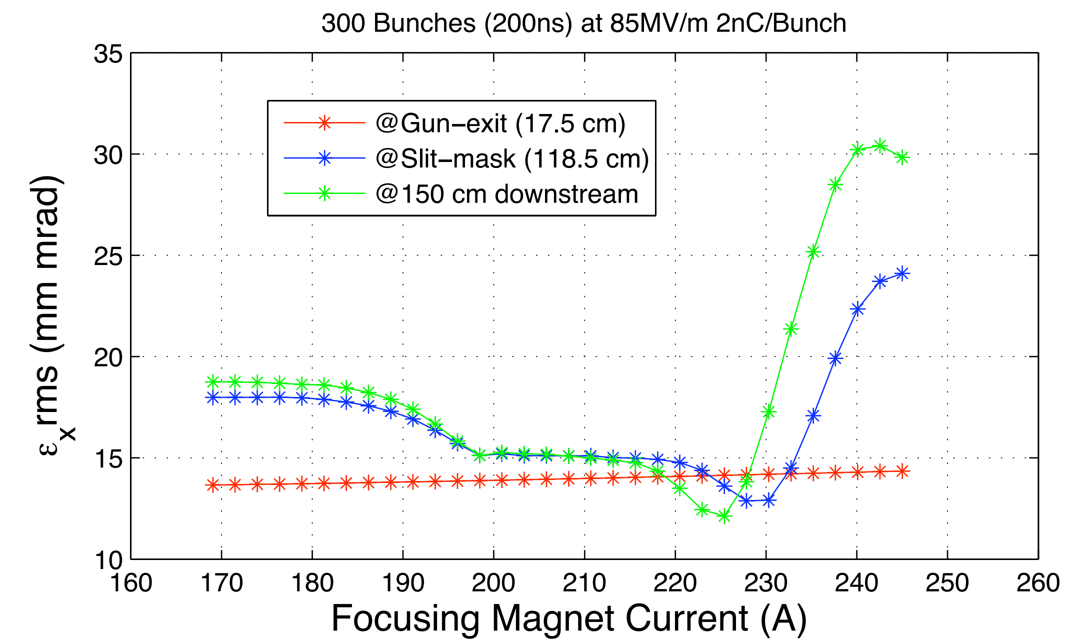


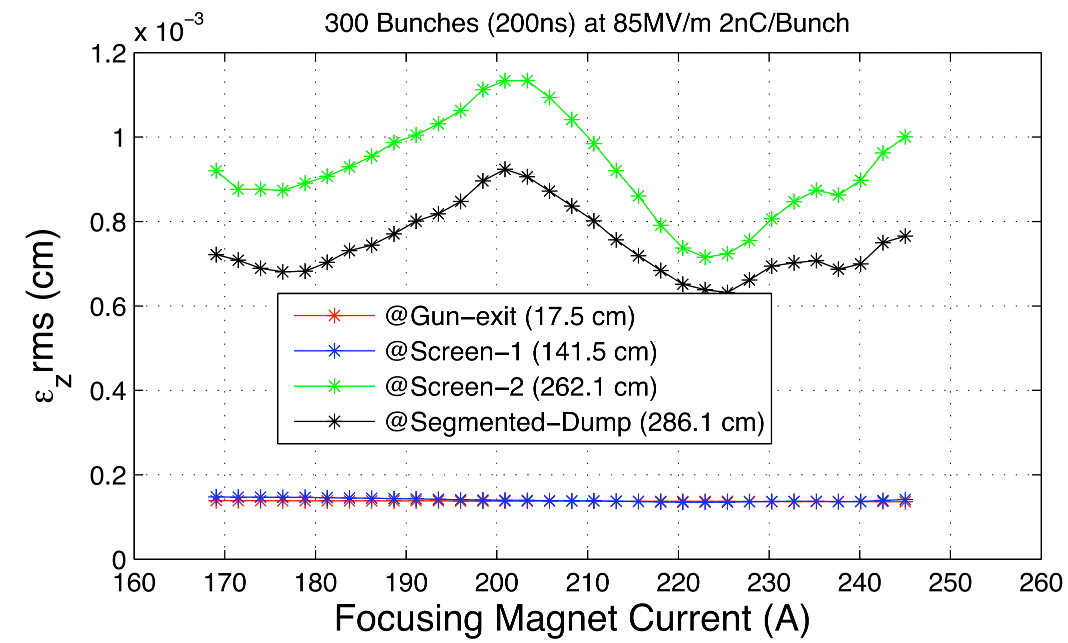

Left: RF power in the gun (1a) and reflected power (2a) when no beam is present. Right: RF power in the gun (1b) and reflected power (2b) when the beam is present.

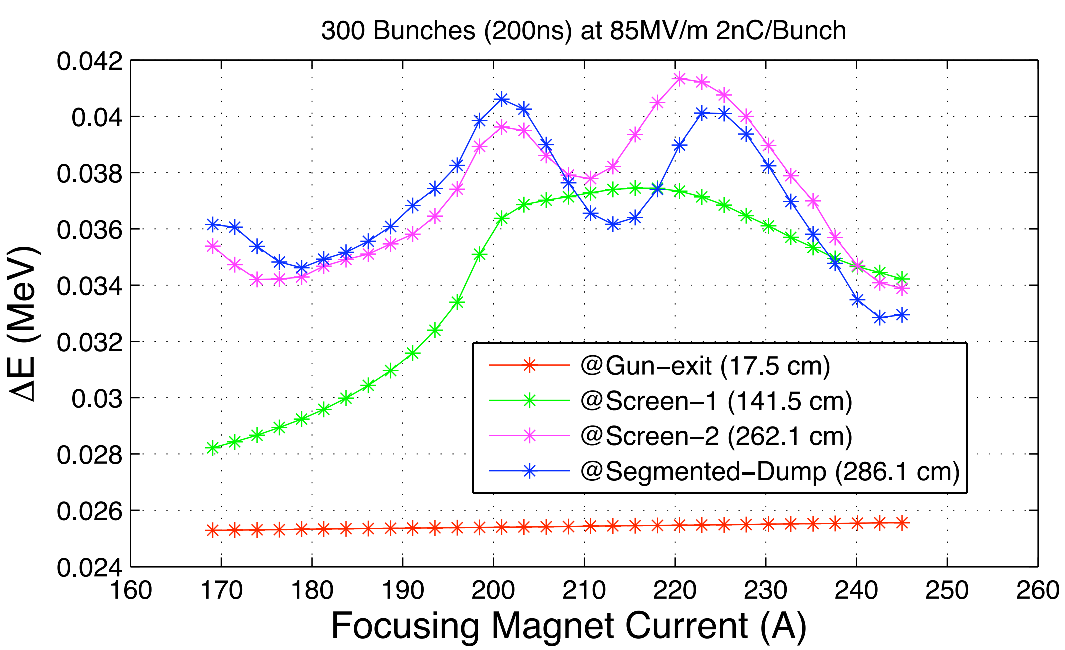
The effects of the beam on the cavity fields in the accelerating mode are referred as the *beam loading*. When the beam induced field in the accelerating mode becomes comparable to the field induced by the external generator, the net phase and amplitude will be satisfactory for beam acceleration only if a means of compensation for the effect of the beam is provided.
'RF Linear Accelerators, T. P. Wangler, Wiley'

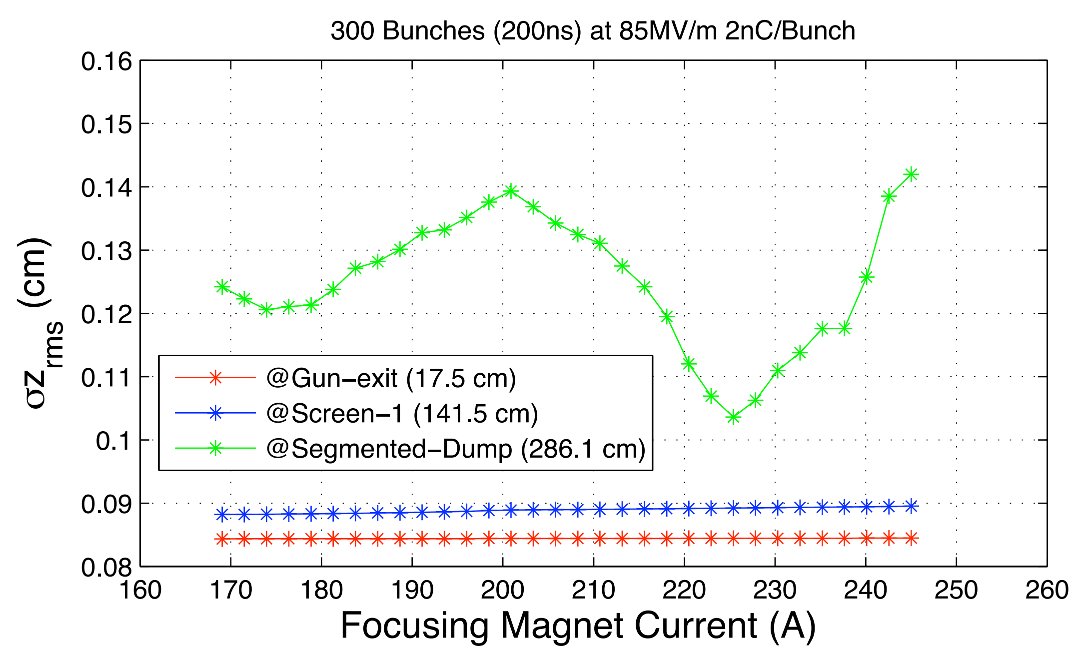
# Simulations:

- Operations settings for low energy spread and emittance have been determined, in a range of energy and charge values.
- Stability provided by current specifications / jitters --> phase, gradient, charge, laser parameters are being studies.




**Example Simulation for 2.5nC at 5.5MeV**

**Currently,**

- Expected behavior agreeing with simulations
- Improved emittance measurement -> Intensified CC camera + Aluminum (sensitivity < alumina)
- Aware of instrumentation limitations and calibrations (CCD sat. , laser alignment, reflections, beam load. comp.)

**Installations before the current 2009 run:**

- Black screen holder for emittance-meter
- Aluminum screen for spectrometer
- 2nd intensified CCD for spectline
- Emittance meter window(darkened by radiation exposure)
- **20 Channel New segmented dump**

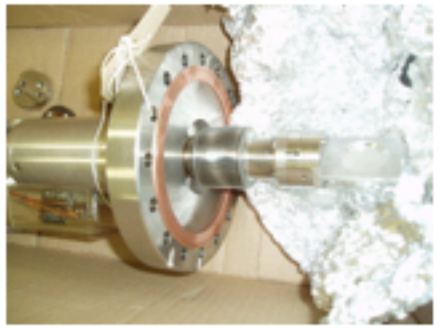
**Measurements:**

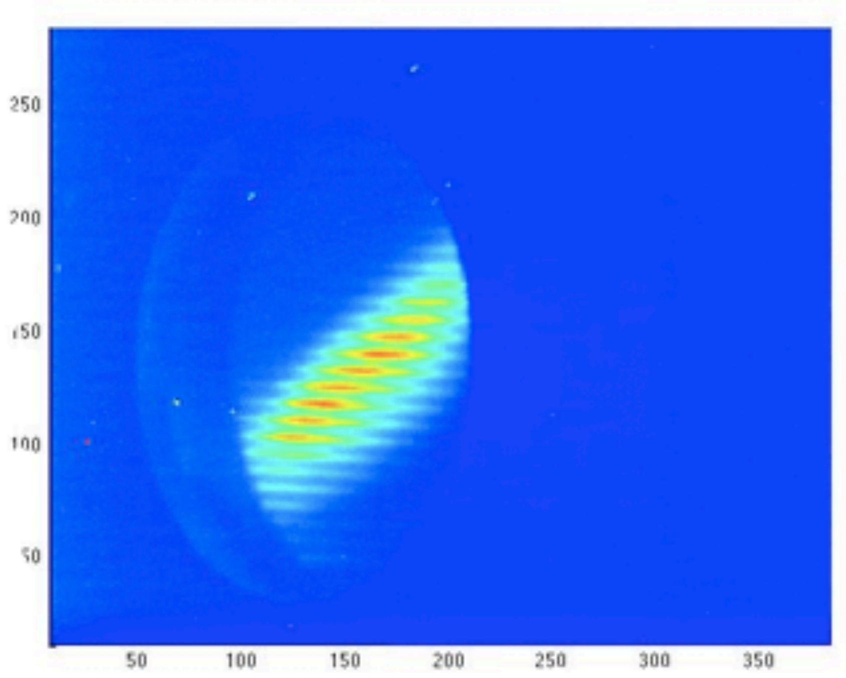
- Beam size, emittance
- **Stability along the pulse train (1.2μs train)**
- **Triggered Camera on laser table / shot to shot stability measurements of laser/ correlation with beam measurements**

**Thanks For Your Attention...**

# Emittance Measurement with Multi-Slit Method

- ☑ Slice up the beam into ‘beamlets’.
- ☑ Let the beamlets drift.
- ☑ Observe the momentum distribution with an OTR screen.
- ☑ Reconstruct the phase space out of these info.




for details of the method

- S.G. Anderson et al., Phys. Rev. Vol 5, 014201 (2002)
- Min Zhang, Fermilab-TM-1988

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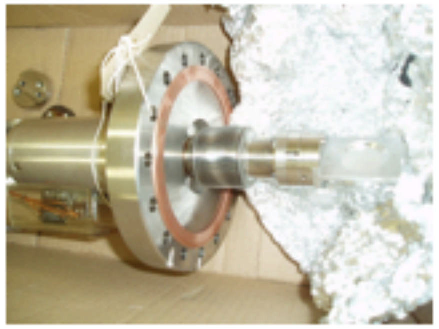
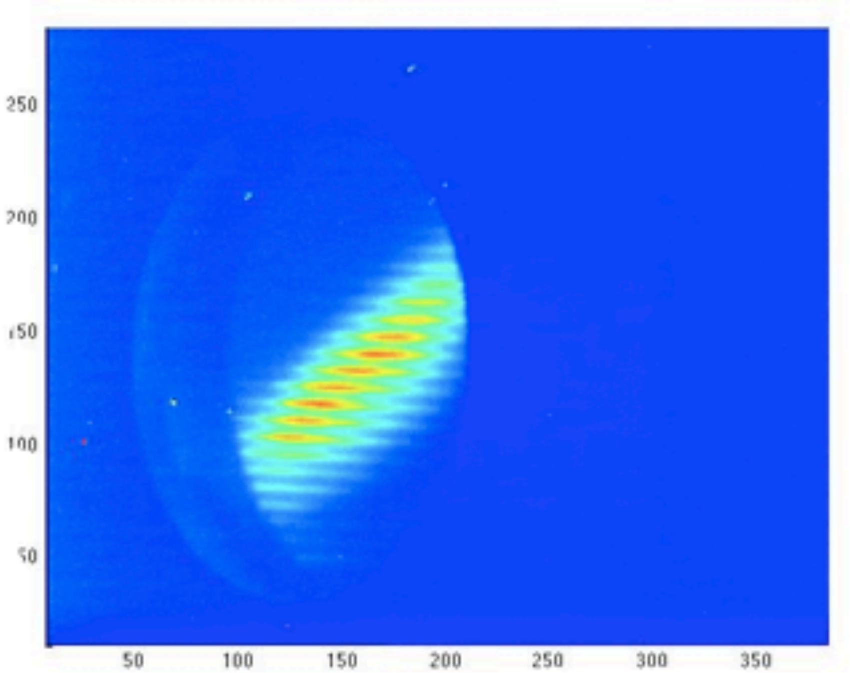
**25 slits with the width of 100 microns.**

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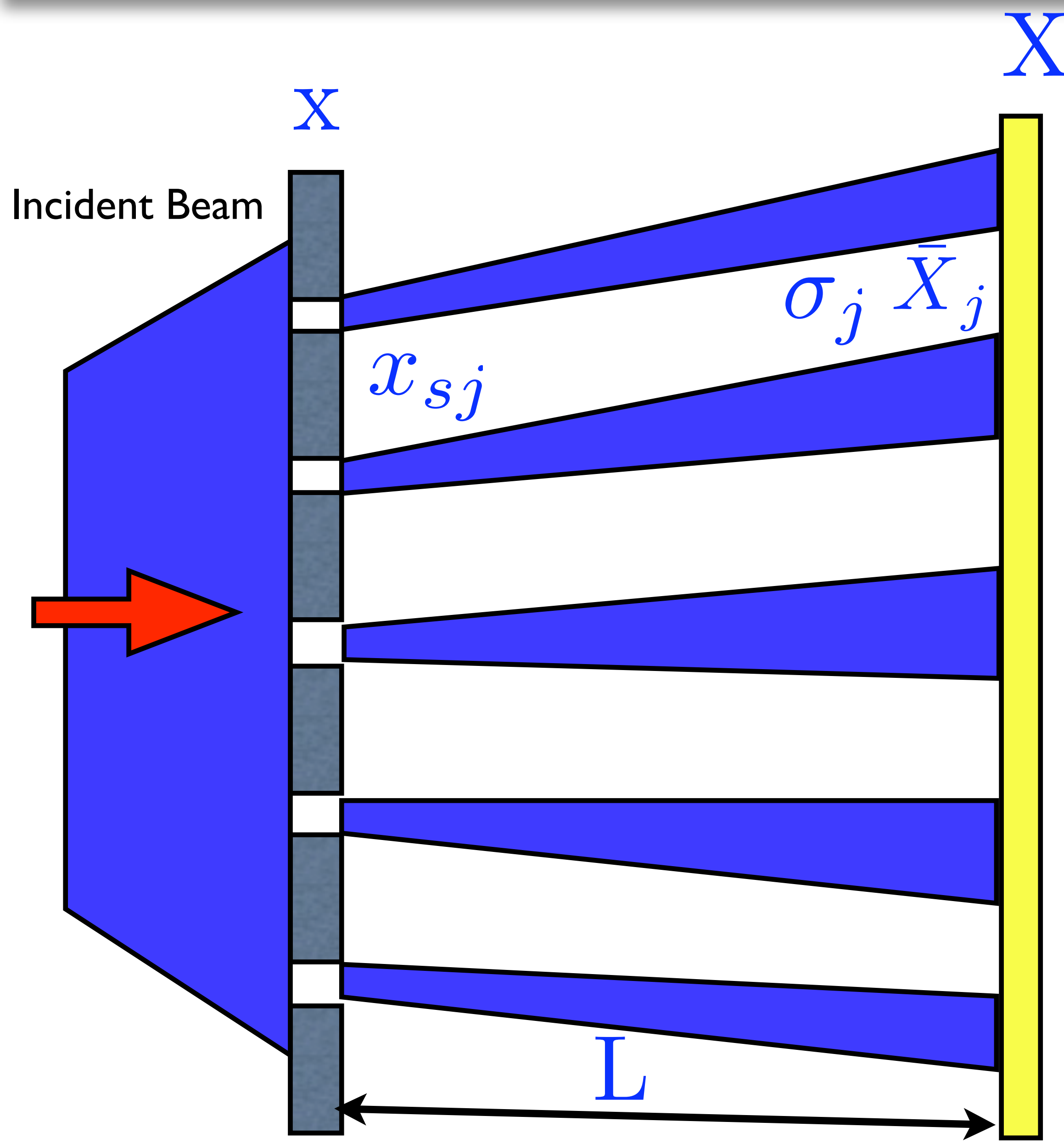
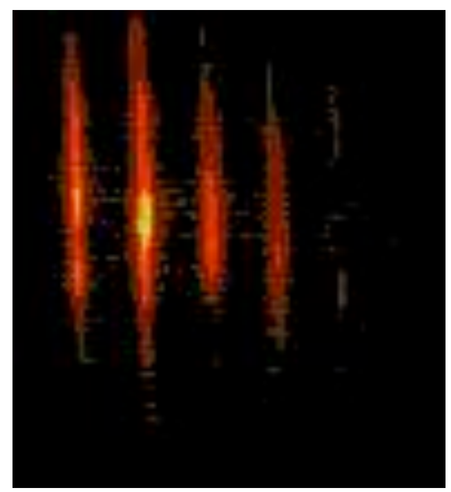
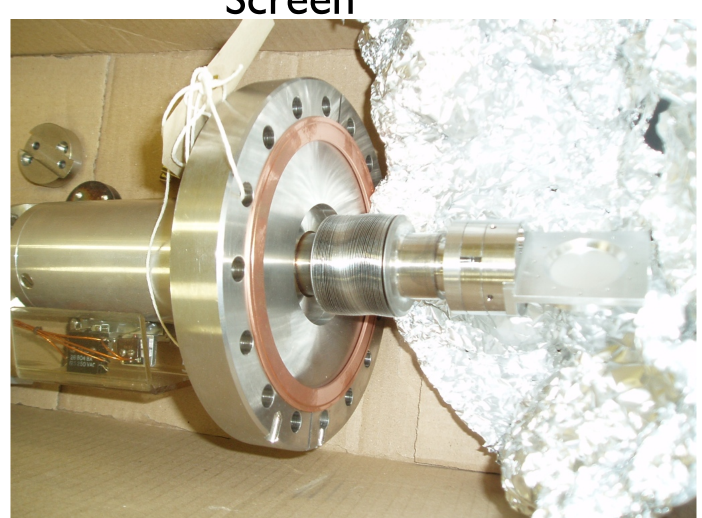



$$x'_i = \frac{X_i - x_i}{L}$$



Pepperpot / Slits

Screen



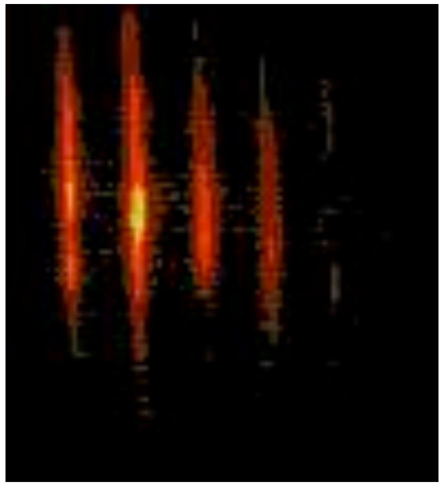
**Slits Parameters :**

- $x_{sj}$ jth slits' position
- $p$ total number of slits

**Screen Parameters:**

- $\bar{X}_j$ mean position of the spots
- $\sigma_j$ rms size of spots
- $\bar{x}$ mean position of all beamlets
- $\bar{x}'_j$ mean divergence of jth beamlet
- $\sigma_{x'_j}$ rms divergence of jth beamlet
- $\bar{x}'$ mean divergence of all beamlets

$$\epsilon_x \equiv \sqrt{< x^2 >< x'^2 > - < xx' >^2}$$



In terms of the parameters related with the image on the screen:

$$\epsilon_x^2 \approx \frac{1}{N^2}\{[\sum_{j=1}^{p} n_j(x_{sj} - \bar{x})^2][\sum_{j=1}^{p}[n_j\sigma_{x'_j}^2 + n_j(\bar{x}'_j - \bar{x}')^2]] - [\sum_{j=1}^{p} n_j x_{sj}\bar{x}'_j - N\bar{x}\bar{x}']^2\}$$

mean position of all beamlets

$$< x >= \frac{1}{N}\sum_{j=1}^{p} n_j x_{sj}$$

mean divergence of all beamlets

$$\bar{x}' = \frac{1}{N}\sum_{j=1}^{p} n_j \bar{x}'_j$$

rms divergence of the jth beamlet

from the measurement

$$\sigma_{x'_j} = \frac{\sigma_j}{L}$$

mean divergence of the jth beamlet

$$\bar{x}'_j = \frac{\bar{X}_j - x_{sj}}{L}$$

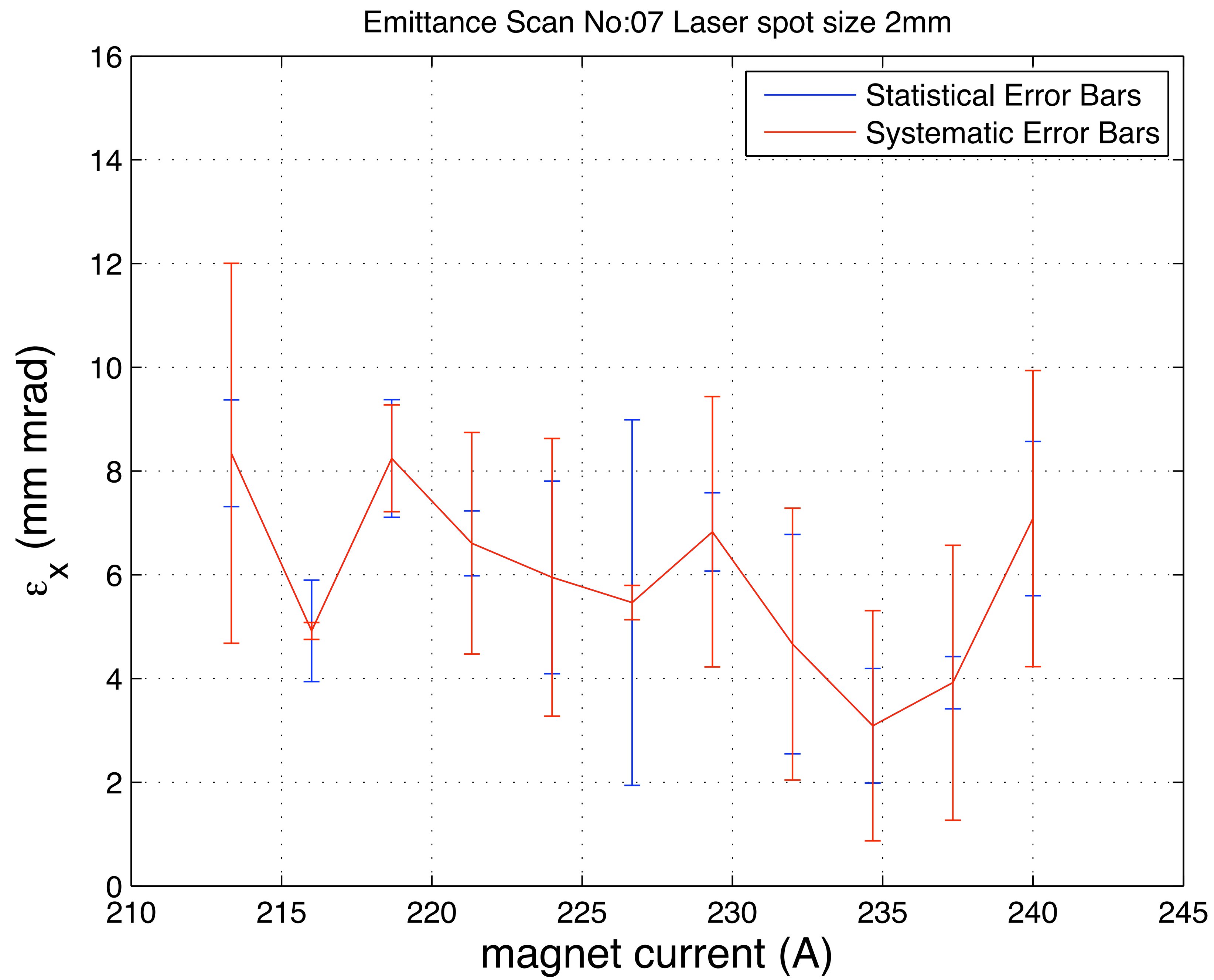
## The systematic error calculation

Data Acquisition and Error Analysis for Pepperpot Emittance Measurements
DIPAC09, S. Jolly, Imperial Collage, London

http://dipac09.web.psi.ch/ppp/papers/weoa03.pdf

| | FETS | | HITRAP | |
|---|---|---|---|---|
| | Value | $\sigma$ (%) | Value | $\sigma$ (%) |
| Beam radius (mm) | 45 | – | 17 | – |
| $\varepsilon_x$ ($\pi$ mm mrad) | 0.61 | – | 0.24 | – |
| Hole spacing (mm) | 3 | 1.8 | 1.6 | 2.2 |
| Angle res. (mrad) | 6.5 | 1.6 | 0.3 | 0.2 |
| Beam noise (%) | 10 | 1.3 | 10 | 0.3 |
| Noise floor (%) | 2 | $\sim 0$ | 10 | 1.2 |
| $\sigma_\varepsilon$ ($\pi$ mm mrad) | 0.029 | 4.8 | 0.010 | 3.9 |

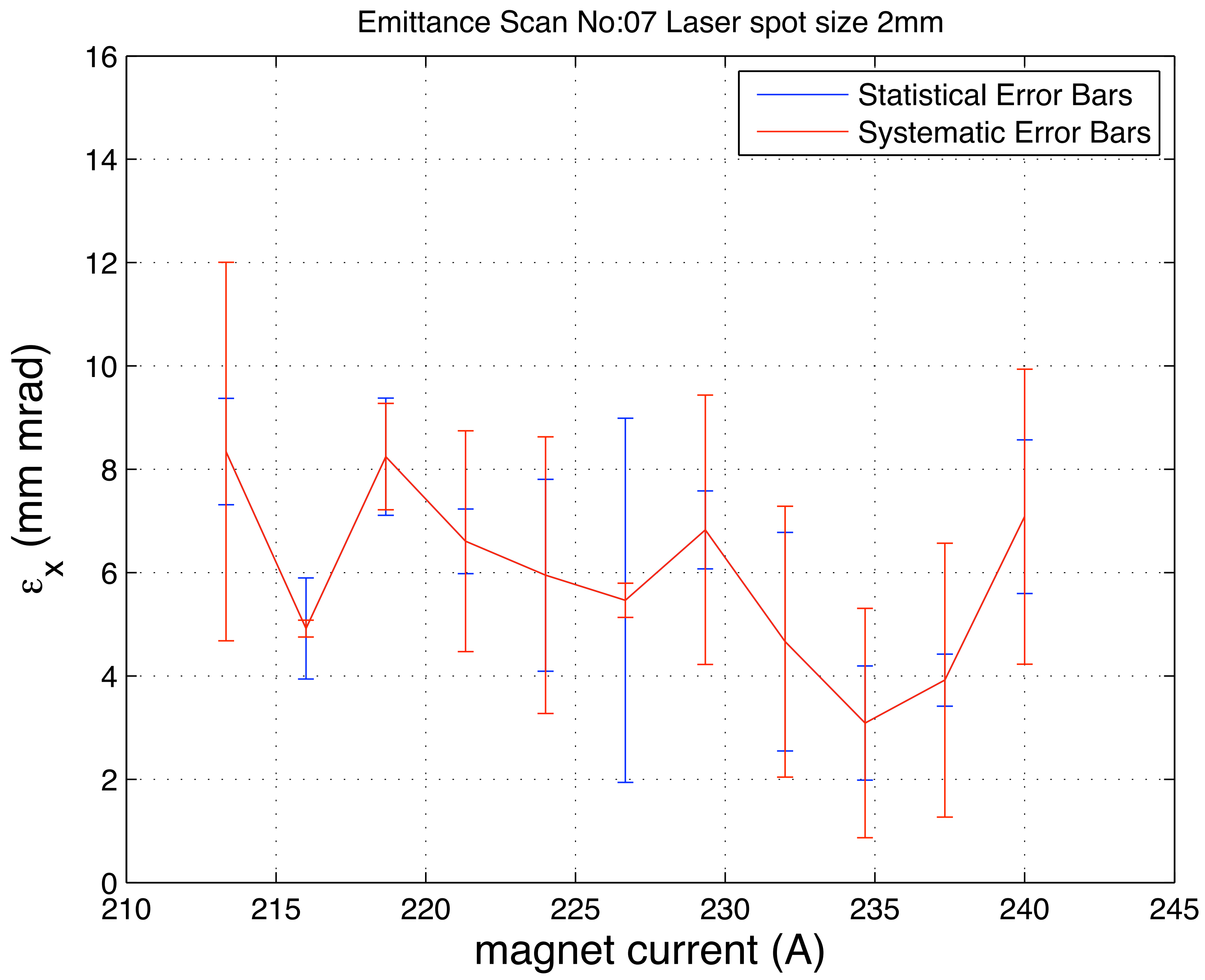
$$\sigma_\varepsilon^2 = \frac{\left(\sum_{i=1}^N \rho_i^2 x_i^2 \sigma_{x_i}^2 + \frac{x_i^4 \sigma_{\rho_i}^2}{4}\right)\left(\sum_{j=1}^N \rho_j x_j'^2\right)^2}{\varepsilon^2 \left(\sum_{k=1}^N \rho_k\right)^4}$$
$$+ \frac{\left(\sum_{i=1}^N \rho_i^2 x_i'^2 \sigma_{x_i'}^2 + \frac{x_i'^4 \sigma_{\rho_i}^2}{4}\right)\left(\sum_{j=1}^N \rho_j x_j^2\right)^2}{\varepsilon^2 \left(\sum_{k=1}^N \rho_k\right)^4} +$$
$$\frac{\left(\sum_{i=1}^N x_i^2 x_i'^2 \sigma_{\rho_i}^2 + \rho_i^2 x_i'^2 \sigma_{x_i}^2 + \rho_i^2 x_i^2 \sigma_{x_i'}^2\right)\left(\sum_{j=1}^N \rho_j x_j x_j'\right)^2}{\varepsilon^2 \left(\sum_{k=1}^N \rho_k\right)^4}$$
$$- \frac{2\left(\sum_{i=1}^N \rho_i^2 x_i^4 x_i'^4 \sigma_{\rho_i}^2 + \rho_i^4 x_i^2 x_i'^4 \sigma_{x_i}^2 + \rho_i^4 x_i^4 x_i'^2 \sigma_{x_i'}^2\right)}{\varepsilon^2 \left(\sum_{k=1}^N \rho_k\right)^4}$$
$$+ \frac{\varepsilon^2 \left(\sum_{i=1}^N \sigma_{\rho_i}^2\right)}{\left(\sum_{k=1}^N \rho_k\right)^2}$$



Emittance Scan No:07 Laser spot size 2mm
Statistical Error Bars
Systematic Error Bars
16
14
12
10
8
6
4
2
0
$\varepsilon_x$ (mm mrad)
210
215
220
225
230
235
240
245
magnet current (A)

**Possible Systematic Error Sources:**

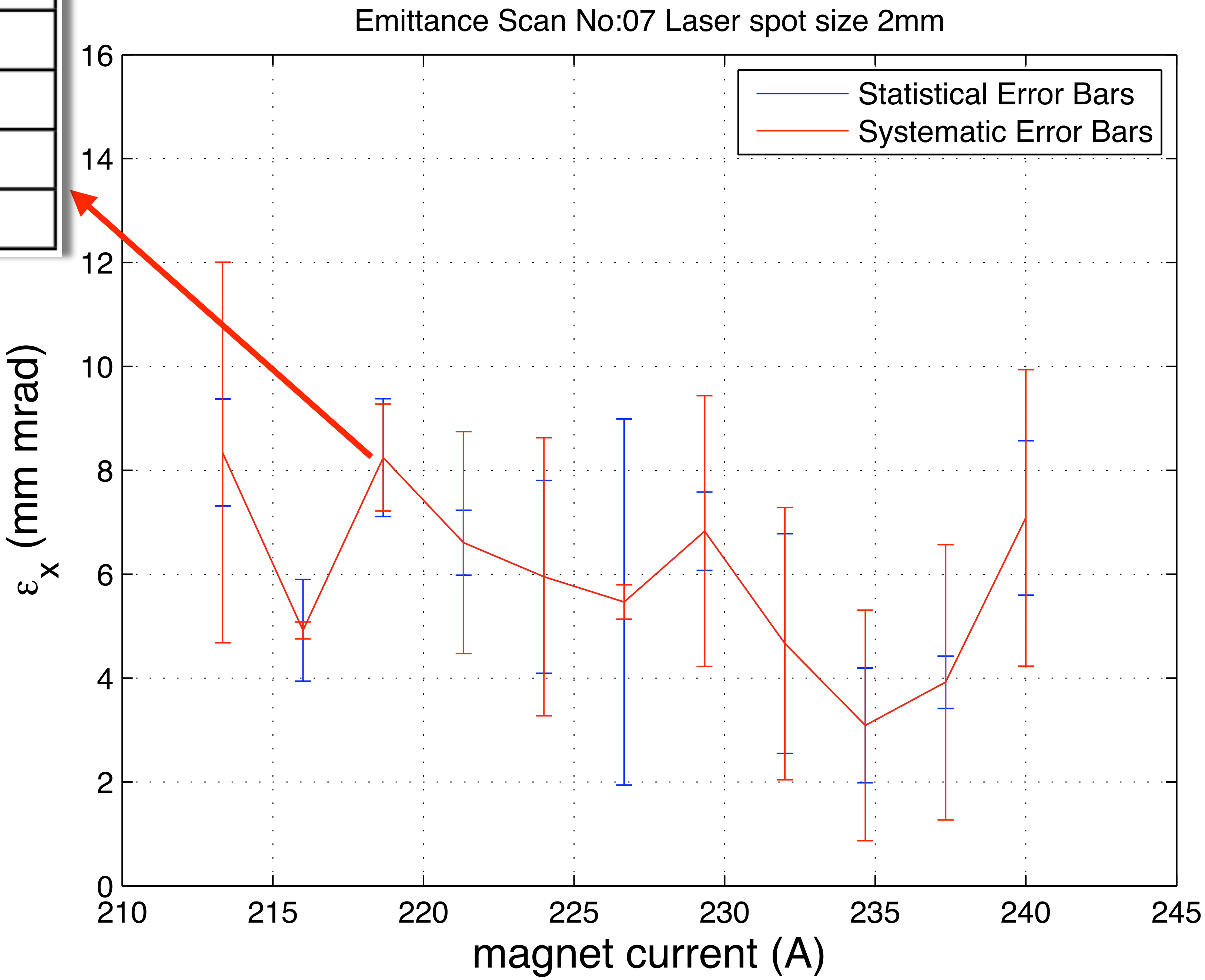
- Width of slits
- SlitMask-Screen distance
- Shot to shot intensity fluctuations



| | Value |
|---|---|
| Emittance (mm mrad) | 8.2444 |
| Slit Width (mm) | 0.1 |
| Mask-Screen Distance (mm) | 230 |
| Intensity Fluctuations (%) | 5 |
| σε (mm mrad) | 1.1346 |
| σε(%) | 13.7622 |

**Possible Systematic Error Sources:**

- Width of slits
- SlitMask-Screen distance
- Shot to shot intensity fluctuations



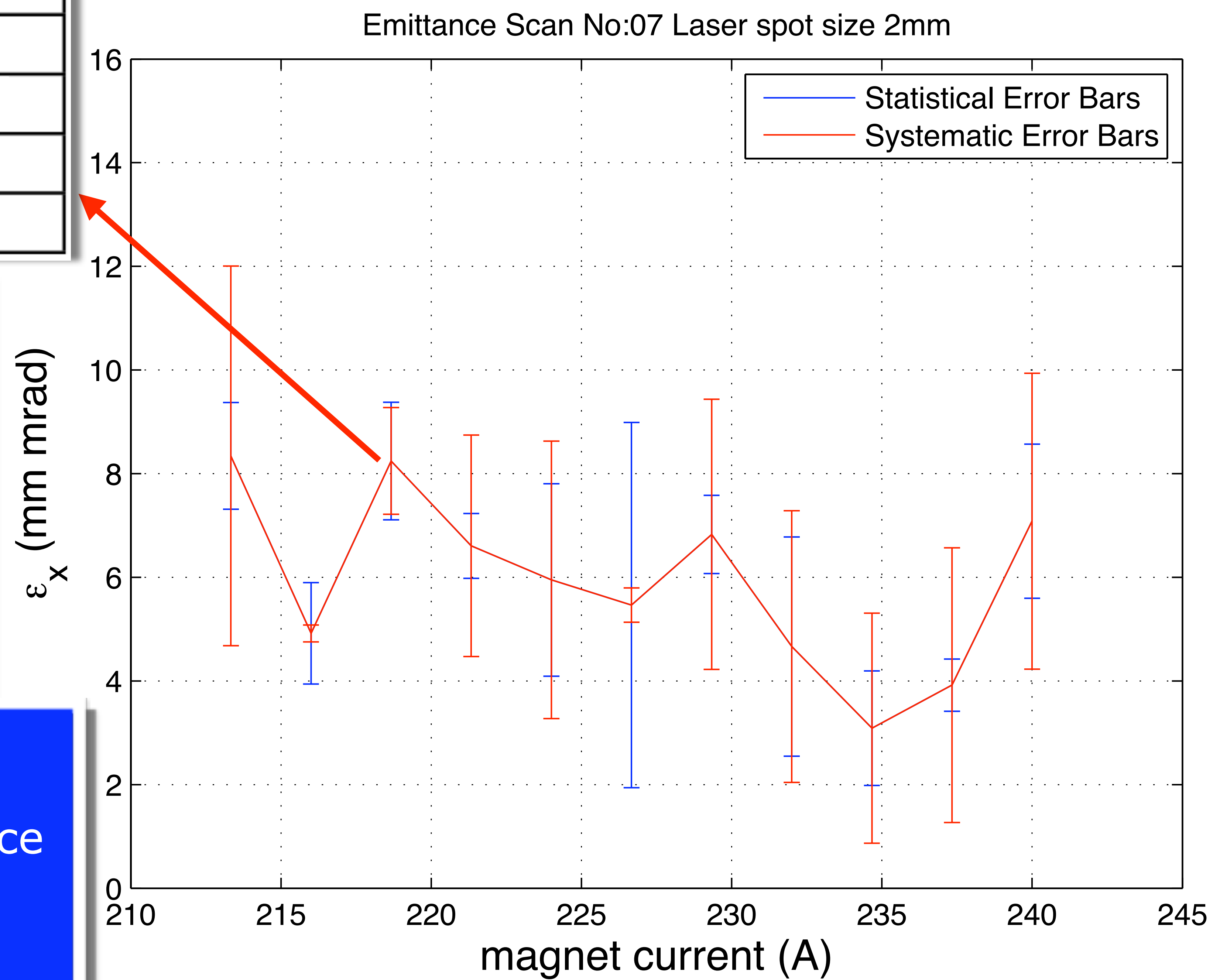
| | Value |
|---|---|
| Emittance (mm mrad) | 8.2444 |
| Slit Width (mm) | 0.1 |
| Mask-Screen Distance (mm) | 230 |
| Intensity Fluctuations (%) | 5 |
| σε (mm mrad) | 1.1346 |
| σε(%) | 13.7622 |

**Possible Systematic Error Sources:**

- Width of slits
- SlitMask-Screen distance
- Shot to shot intensity fluctuations

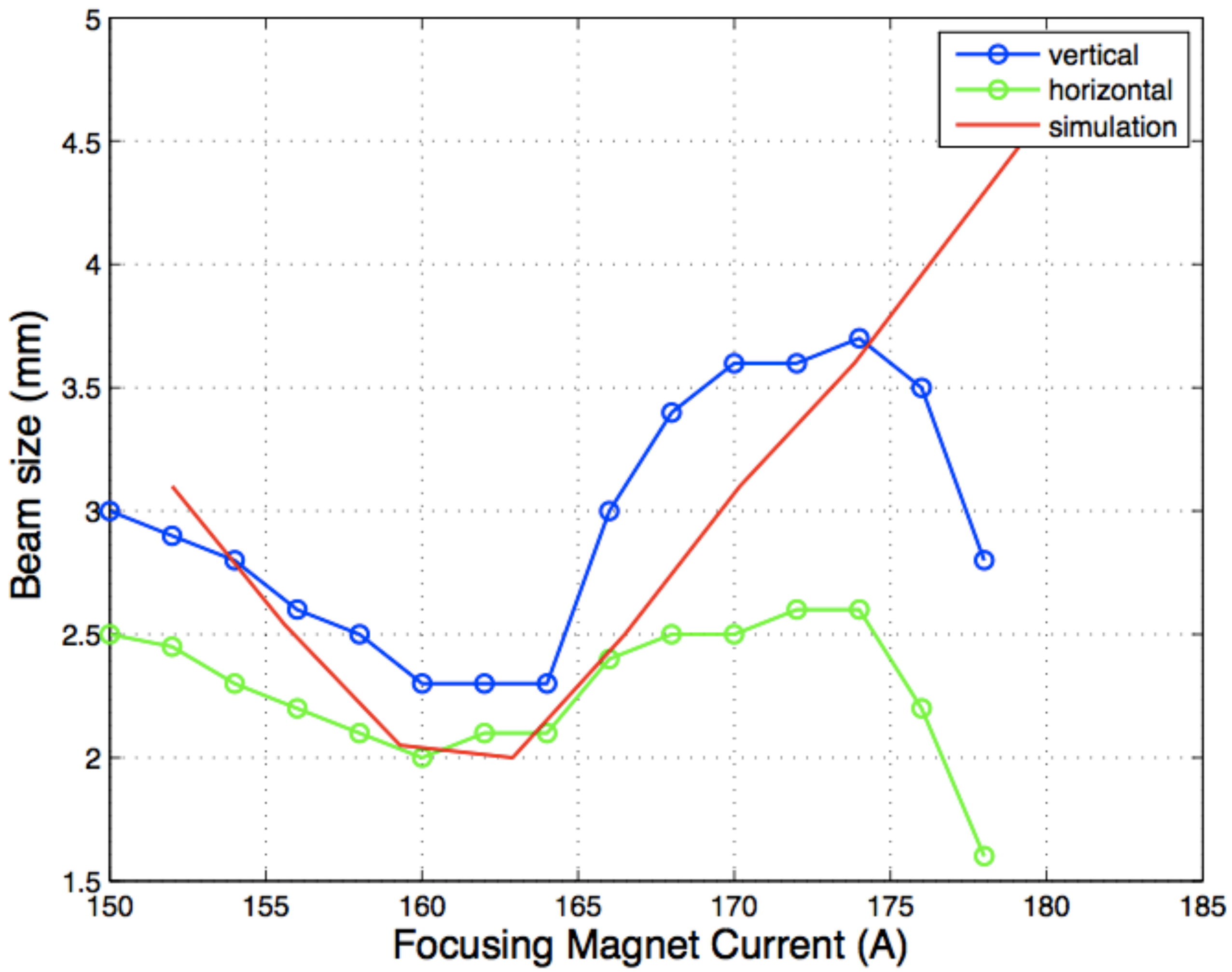
**Additionally,**

- Contribution to emittance from outer beam-lets
- %36 at 231.33 A (focusing magnet current)
- %10 at 240 A



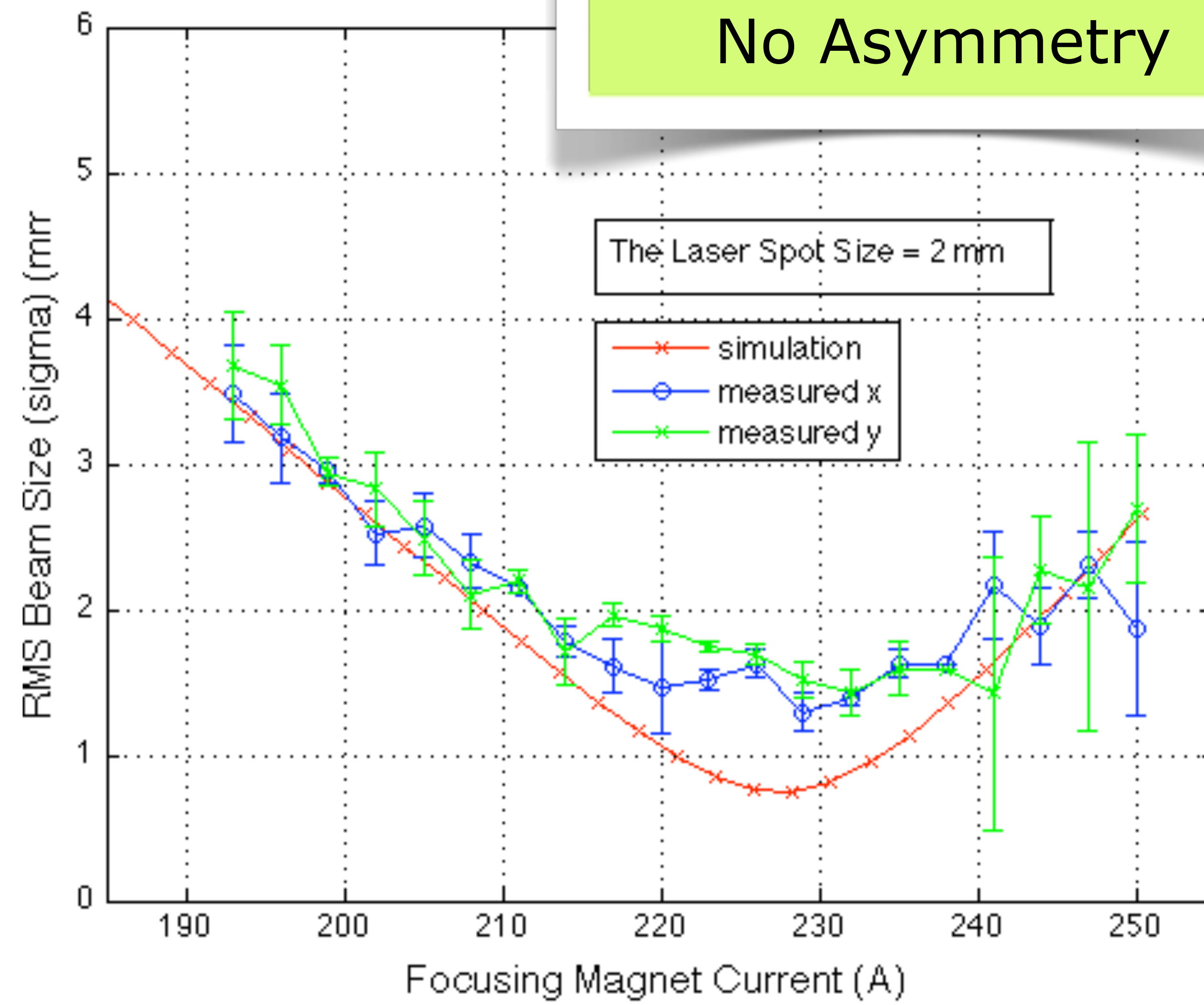
## Asymmetry between vertical and horizontal beam size.

Nov. 2008



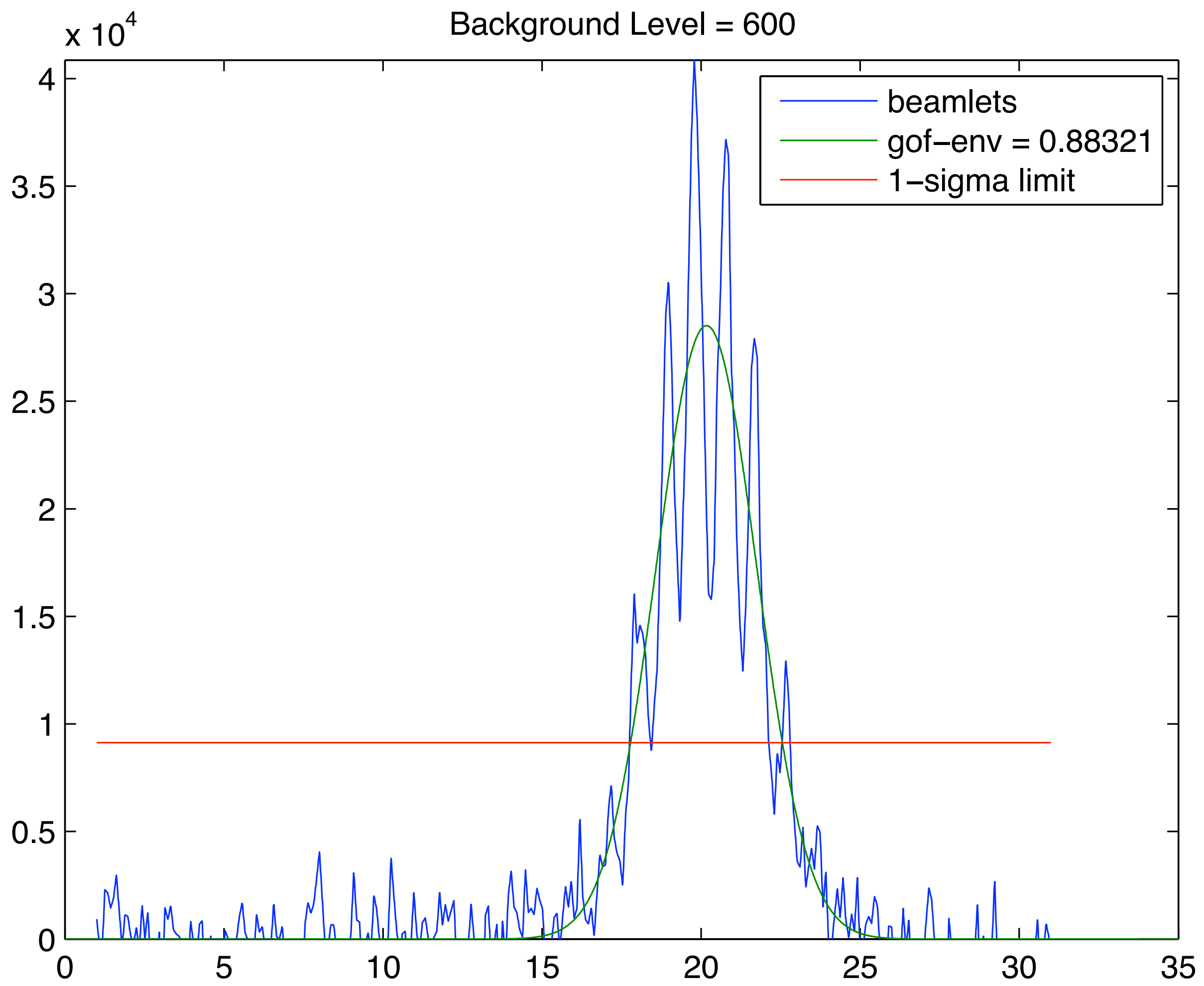

Mar. 2009

No Asymmetry

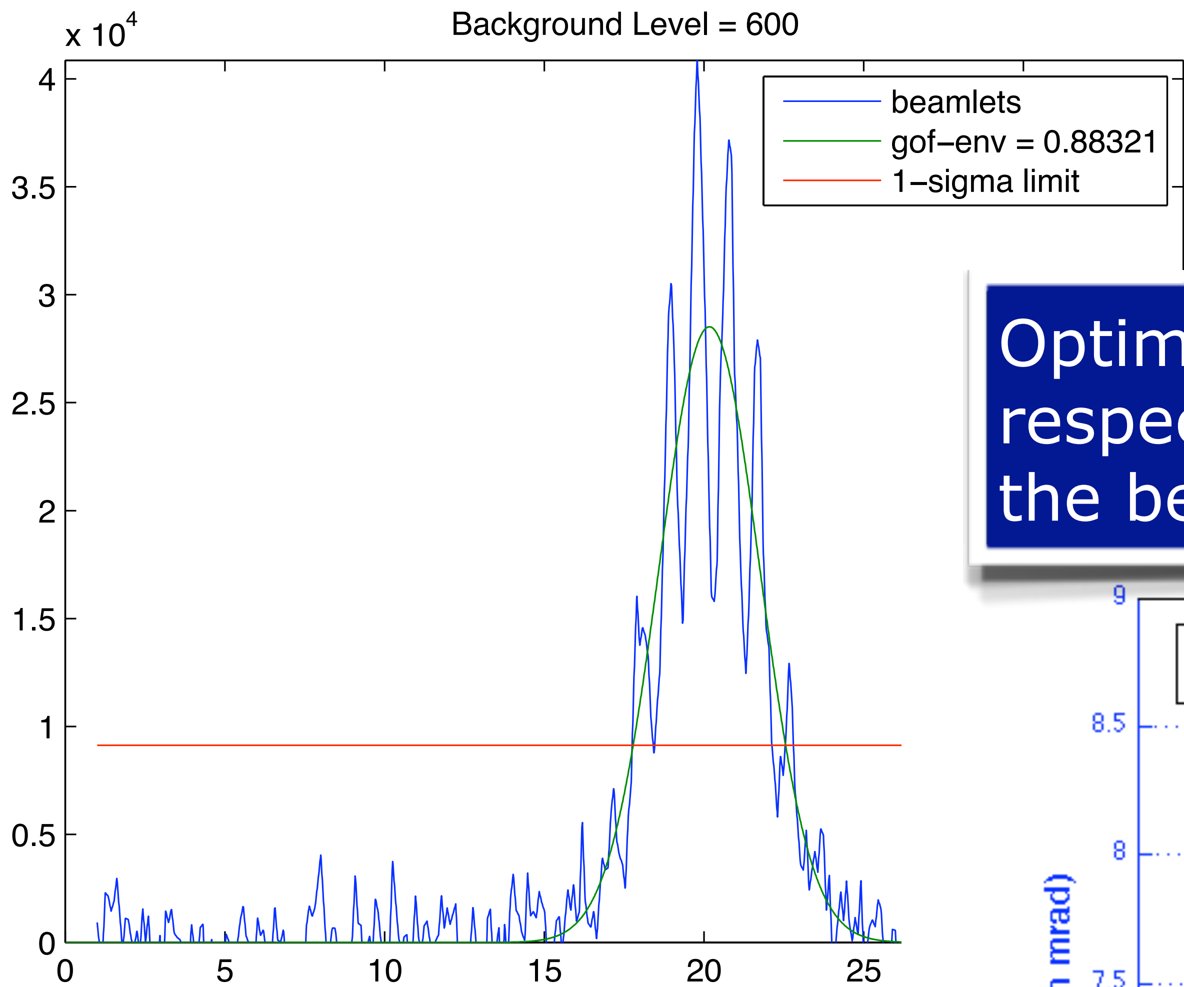



Investigations on the **laser alignment and positioning on the cathode**, and the background field by the magnetic components in the set-up have been considered as possible sources for the asymmetry. During 2009 run for the vertical and the horizontal beam sizes the asymmetry in the beam envelope was no longer present after the correction of the **laser alignment inside the gun**.

One can assume that the curve covering all beam-lets is Gaussian:

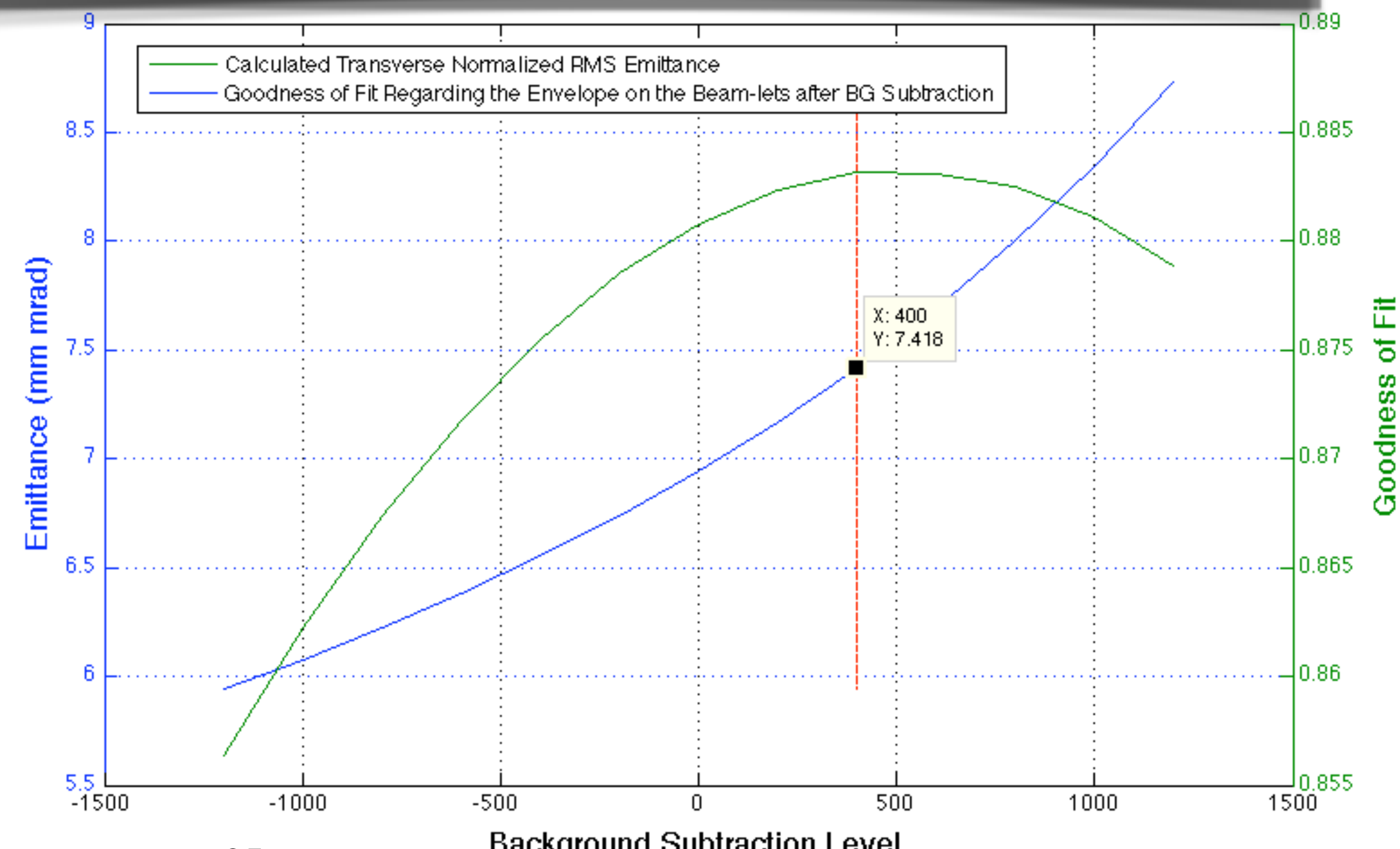


One can assume that the curve covering all beam-lets is Gaussian:

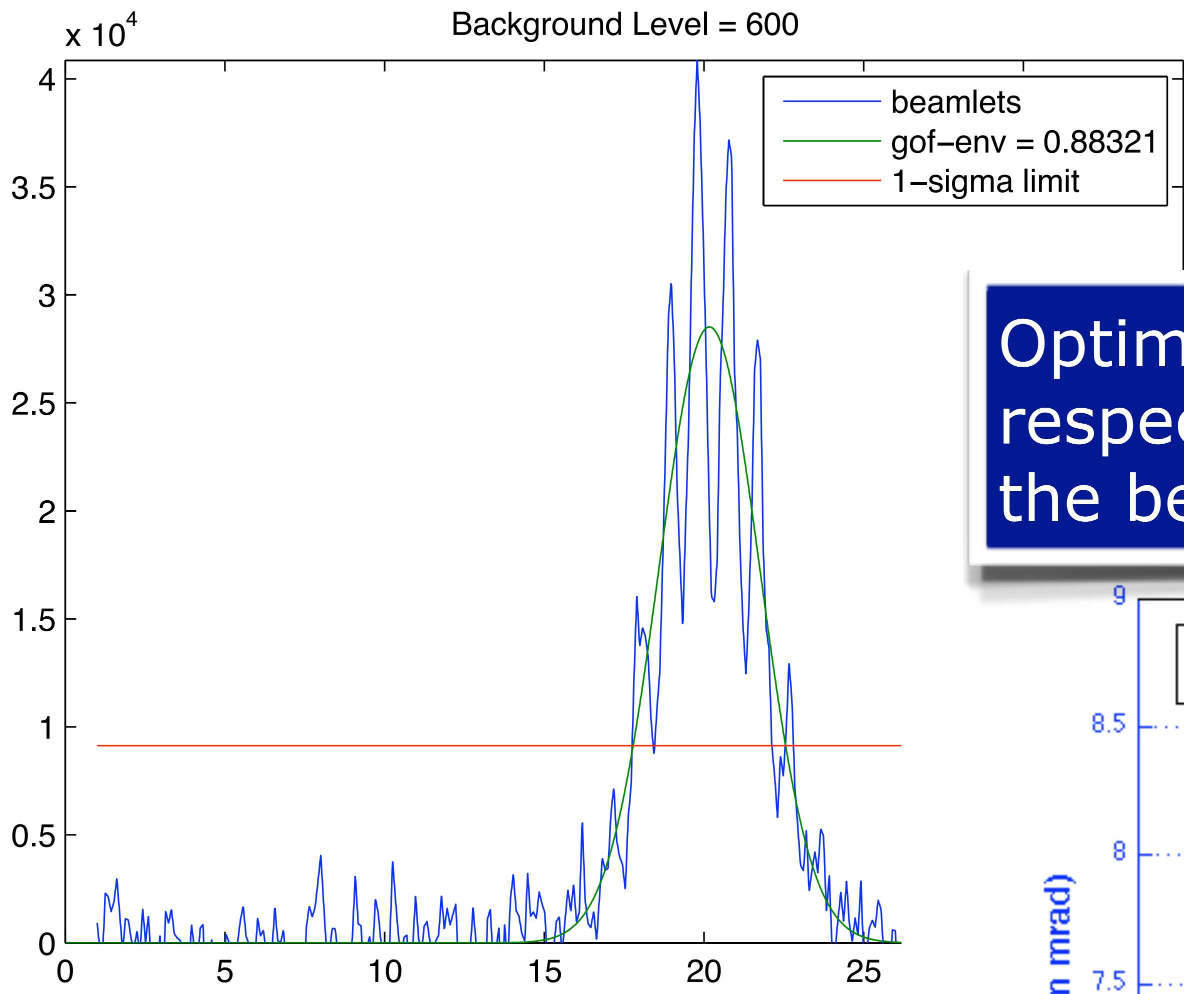



Background level (BG): Max. value for Gaussian background curve.

Optimum BG level can be determined with respect to the fit quality of the curve covering the beam-lets after the BG subtraction.

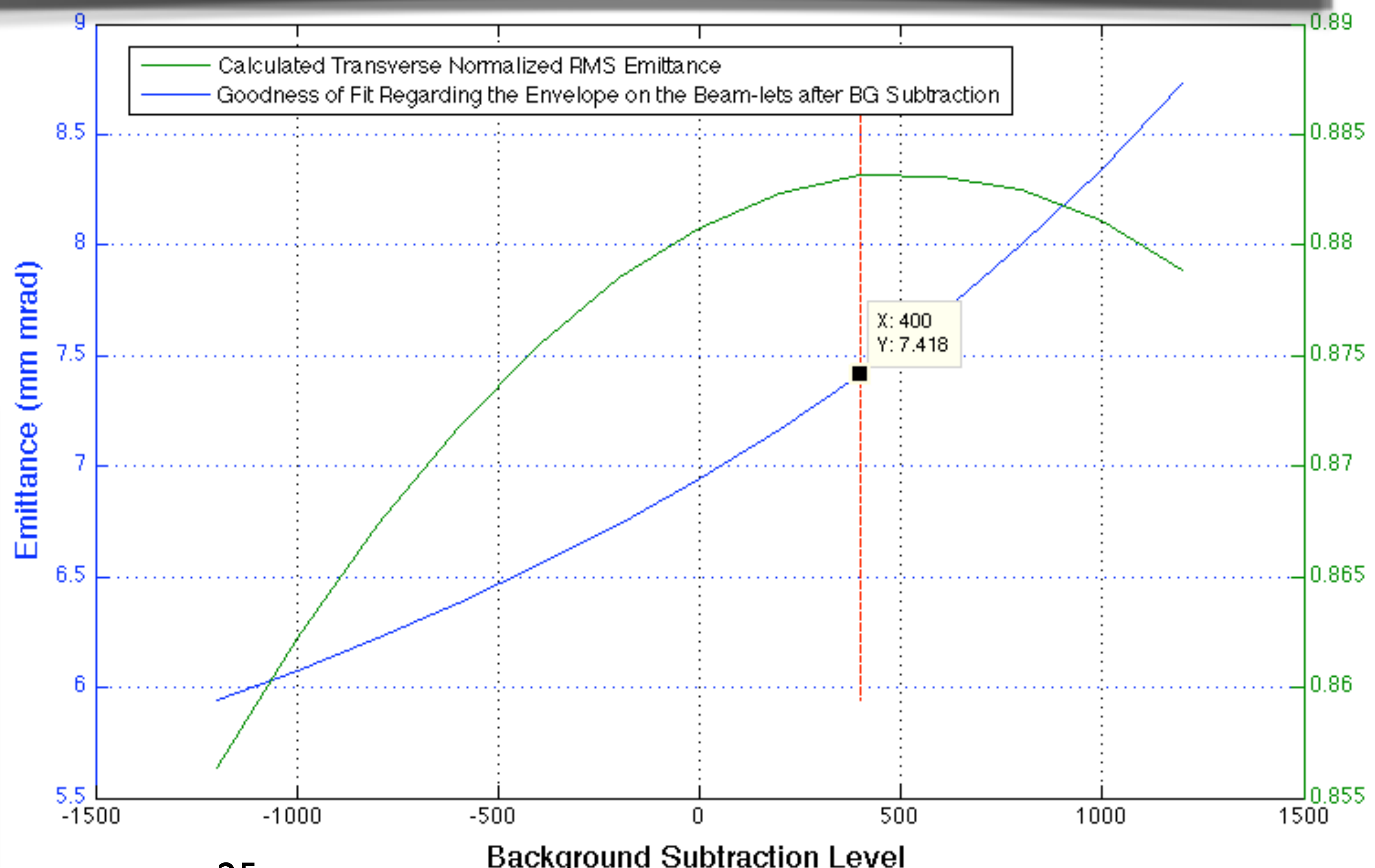


One can assume that the curve covering all beam-lets is Gaussian:




Background level (BG): Max. value for Gaussian background curve.

Optimum BG level can be determined with respect to the fit quality of the curve covering the beam-lets after the BG subtraction.




The optimum value of the emittance is chosen as the 7.418 mm mrad for this example. This value was obtained by applying the particular BG level giving the highest quality of fit.