Report from “Characterization of High Brightness Beams” Workshop in Zeuthen

Bolko Beutner, DESY

Beam Dynamics Meeting 9.6.2008

Introduction

- Workshop on "Characterization of High Brightness Beams" from 26.- to 30. May 2008
- Goals:
  - get a common basis on data taking and data analysis and be able to produce comparable results allowing transmission of results of one facility to the others
  - review experimental results and get some light into the theory, including beam dynamics near to the cathode (what is believed to be true and what is in the simulations) and the definition of the quantity thermal emittance.
  - for comparisons of measurements with corresponding simulations find out what are the most critical parameters in the different simulation codes for tuning them to the measurements, report the state of the art of slice emittance diagnostics
  - describe COTR in detail and try to find theoretical explanation

Monday

- Goal was the comparison of emittance measurement methods and the definition of common methods
- Description of data taking and analysis techniques of different labs
- Emittance calculations with data from one lab and the methods of another

Draft agenda for **Monday (May 26th, 2008):**

8.30 – 9.00 Welcome, Organizational, and Introduction to DESY, Zeuthen site
9.00 – 10.10 SLAC talks on data taking and data analysis:
a1) Henrik Loos: "Emittance measurement and analysis tools for LCLS" → 35+10 minutes
a2) Henrik Loos: "Analysis of FLASH emittance measurement data with SLAC tools" → 15+10 minutes

10.10 – 10.40 Break

10.40 – 12.10 SPARC talks on data taking and data analysis:
a1) Andrea Mostacci, "Movable emittance-meter data analysis methodology and emittance computation from measured phase space analysis" → 35+10 minutes
a2) Enrica Chiadroni, "Application of SPARC data analysis tool to benchmark data" → 15+10 minutes
a3) Valeria Fusco, "Spatial autocorrelation as a transverse beam quality factor" → 15+5 minutes

12.10 – 12.35 Additional contributions
- Thorsten Kamps: "Beam Diagnostics for the SRF photo injector" → 15+10 minutes

12.35 – 14.00 Lunch break

14.00 – 15.45 PITZ talks on data taking and data analysis:
a1) Lazar Staykov: "Data taking, data analysis and results of emittance measurements at PITZ" → 35+10 minutes
a2) Sakhorn Rimjaem: "Analyzing SPARC data with PITZ analysis tools" → 8+5 minutes
Roman Spesyvtsev: "Analyzing SLAC data with PITZ analysis tools" → 8+5 minutes
Galina Asova: "Analyzing FLASH data with PITZ analysis tools" → 8+5 minutes
a3) Mikhail Krasilnikov: "Principal limitations and systematic deviations regarding the slit measurement method" → 15+5 minutes

15.45 – 16.15 Break

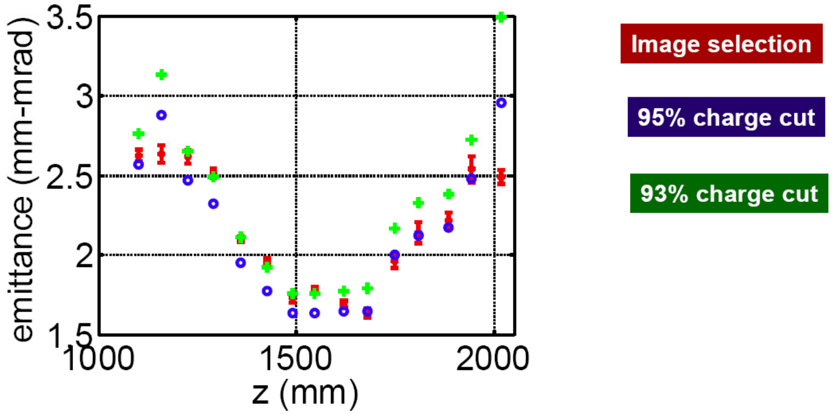
16.15 – 17.50 FLASH talks on data taking and data analysis:
a1) Christofer Gerth: "Emittance measurement and analysis tools for FLASH" → 35+10 minutes
a2) Christofer Gerth: "Analysis of LCLS emittance measurement data with FLASH tools" → 15+10 minutes
a3) Yauhen Kot: "Optics solutions for the XFEL injector diagnostics" → 15+10 minutes

HELMHOLTZ GEMEINSCHAFT

Mo

Emittance from trace space: results

SPARC data ->



M.Krasilnikov on
Principal limitations and systematic deviations of the the slit measurement method

Conclusions

- Factors affecting slit scan measurements:

Factor	Effect on measured emittance	Solution/remark
Phase space nonlinearity	-10..-30%	correction term experimentally ~-2..-3%
Scan step dx	~1% if dx<200um	dx~100um
Beam position jitter	+5% @ 50 um rms jitter	• improve stability • ?measurement with synchronized BPM?

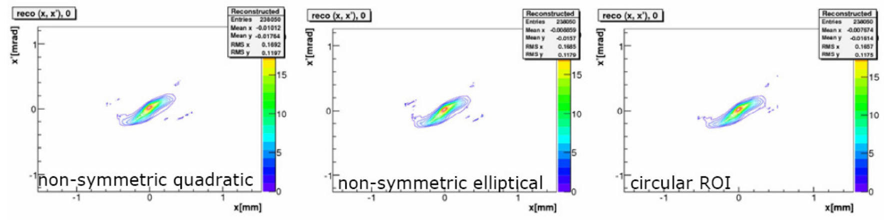
- Combined factors (dx=100um X 50um position jitter) resulted in 0…+4% measured emittance overestimation
- There is an influence of the intensity (charge) cut (not discussed here) resulting in the emittance underestimation (i,e. -5..-30% for 5% charge cut)

SPARC

Andrea.Mostacci@uniroma1.it

Reconstruction result

- MENT algorithm used over each set, 20 iterations
- Mean value and standard uncertainty calculated



	non-symmetric quadratic	non-symmetric elliptical	circular ROI
$\epsilon_{x,N}$ =	3.51±0.17 mm mrad	3.33±0.16 mm mrad	2.61±0.05 mm mrad
$\epsilon_{y,N}$ =	3.48±0.24 mm mrad	3.37±0.23 mm mrad	2.67±0.09 mm mrad

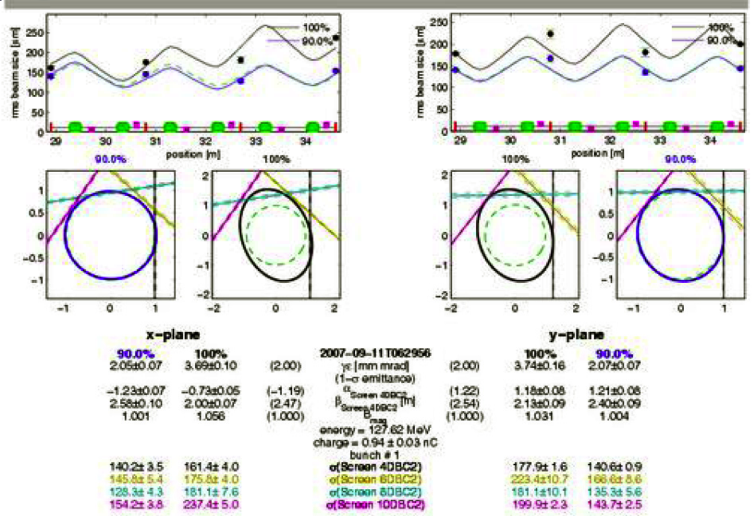
Basic phase space shape is very similar, peculiarities differ.
The effects of the ROI should be studied.

PITZ phase space tomography (G. Asova)

Monday II

FLASH emittance data analysed with FLASH and LCLS methods

Logbook entry 2007-09-11 6:34h



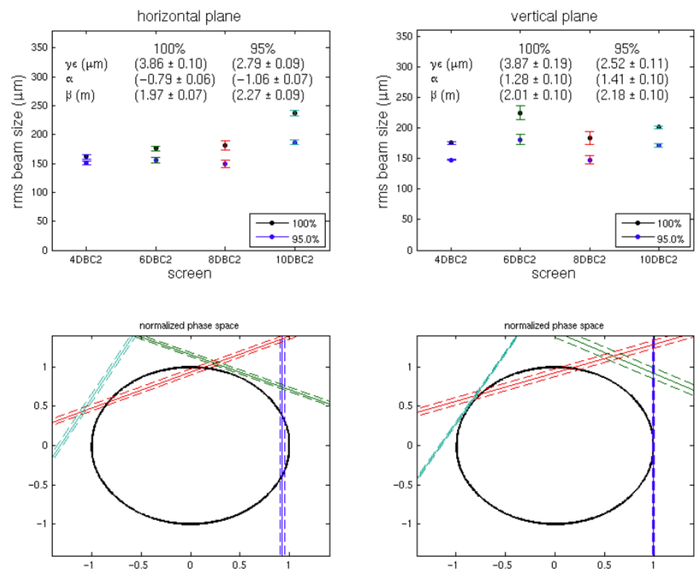
	100%		100%
Result WS:	3.86	γε [mm mrad]	3.87

Transfer matrices calculated for different energy: 120MeV instead of 127MeV (-5%)

31

C.Gerth

Final Results (step 5)



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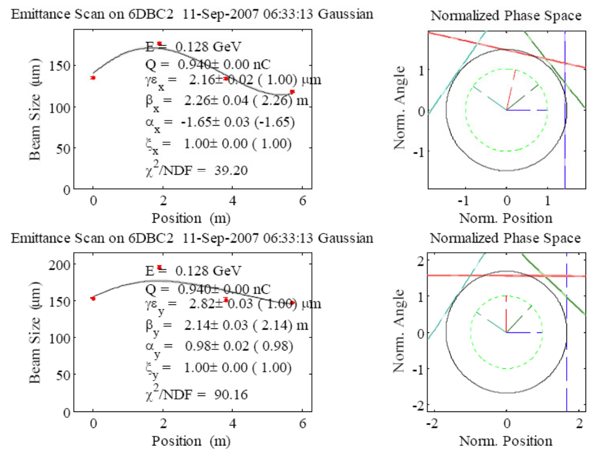
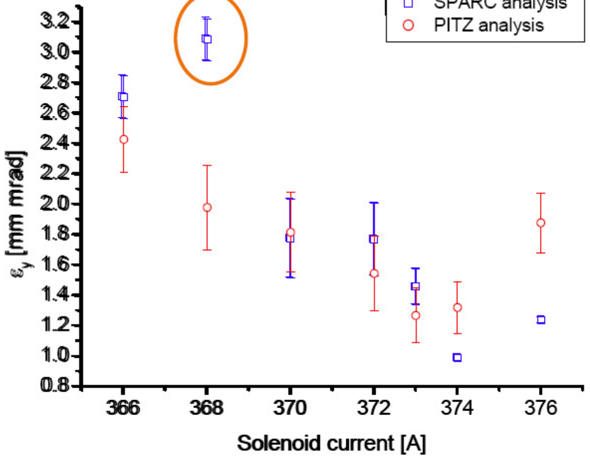


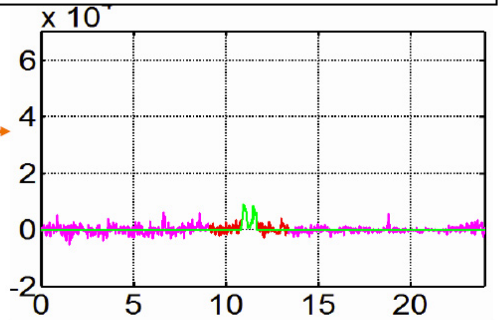
Henrik Loos
loos@slac.stanford.edu

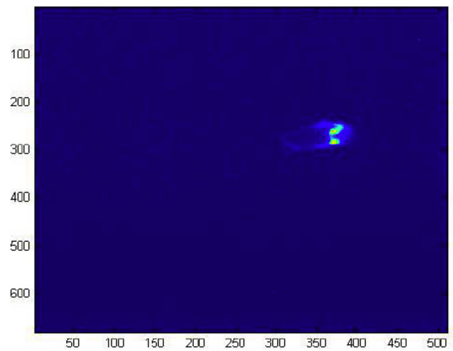
Monday III

SPARC Data Analysis of PITZ Data

Analysis Results







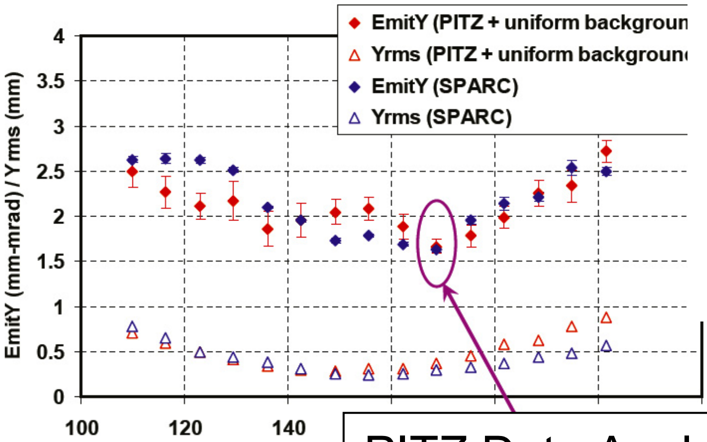
"Characterization of High Brightness Beams"
DESY-Zeuthen, May 26-30, 2008

enrica.chiadroni@lnf.infn.it 14

$$\pm_y = E_y\sqrt{\left(\frac{\pm_{beam\,size}}{Y_{rms}}\right) + \left(\frac{\pm_{divergence}}{Y'_{rms}}\right)}$$

uniform background from part of

- Minimum vertical emittance at z=1687 mm
- Emittance uncertainty: use beam size uncertainty value fr divergence uncertainty from 15 beamlet images



PITZ Data Analysis of SPARC Data

of the beam at this position and the chosen area for background image is really outside the beam.

S. Rimjaem Analyzing SPARC data with PITZ analysis tools 8

Monday/Tuesday

- Discussion on emittance measurements to define common standards on:
  - Beam size measurement (camera system)
  - Beam size analysis (image analysis)
  - How to cut charge profiles?
  - Comparison of ROI procedures
  - What kind of data should be stored?
  - Background subtraction
  - Simulations
  - Systematic uncertainties

Wednesday

- Experimental results on beam dynamics near the cathode
  - Thermal emittance
  - QE
  - Schottky effect
- Discussion on:
  - high QE against small thermal emittance
  - other cathode types

Wednesday, May 28th, 2008

Subjects: QE and thermal emittance

Goal: review experimental results and get some light into the theory, including beam dynamics near to the cathode (what is believed to be true and what is in the simulations) and the definition of the quantity thermal emittance.

Possible realization: people from different groups report about experimental results, someone will report what is done in the different simulation codes, there are new developments ongoing at SLAC for a better understanding of the thermal emittance which probably can be reported.

Draft agenda for **Wednesday (May 28th, 2008):**

8.30 – 10.30
Luca Cultrera, "Characterization of SPARC photo injector cathode" → 20+10 minutes
Giancarlo Gatti, "Thermal emittance measurement for Cu photo-cathode at SPARC" → 20+10 minutes
Sven Lederer: "QE at PITZ and FLASH" → 20+10 minutes
Sven Lederer: "Thermal emittance studies at PITZ" → 20+10 minutes

10.30 – 11.00 Break

11.00 – 12.30
Cecile Limborg-Deprey: "QE and Thermal Emittance Measurements for the LCLS Injector" → 40+20 minutes
Weishi Wan: "The Photocathode R&D Program at LBNL" → 20+10 minutes

12.30 – 14.00 Lunch break and taking a photograph of the workshop participants

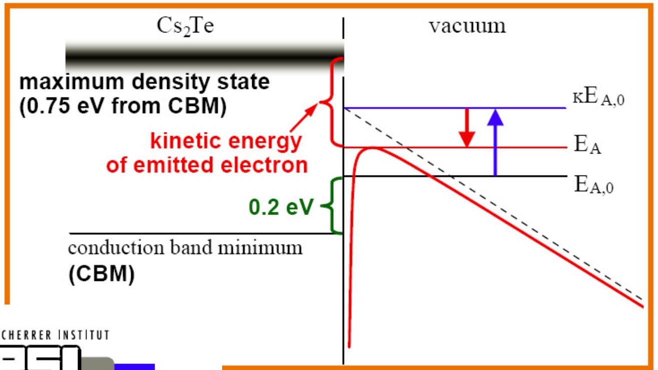
14.00 – 16.30
Xijie Wang: "Magnesium Cathode QE Characterization and Thermal Emittance minimization With Oblique Incident Optics at the NSLS SDL" → 20+10 minutes
Romain Ganter: QE measurements from metallic cathodes in Pulsed Diode Gun configuration → 20+10 minutes
Yujong Kim: Realistic Thermal Emittance Measurements at the Low Emittance Gun (LEG) Test Facility for PSI XFEL Project → 20+10 minutes
Jang-Hui Han: "Electron emission features in simulation codes" → 20+10 minutes
Ivan Bazarov: "Thermal emittance and response time from negative electron affinity photo cathodes" → 20+10 minutes

16.30 – 17.20 working break and general discussion:
- high QE against small thermal emittance
- other cathode types

17.20 – 18.00
Hiromitsu Tomizawa on
a) fiber bundle laser shaping with backward illumination
b) electron emission using z-polarized laser and photo voltage effect
→ 30+10 minutes

Wednesday II

Photoemission – QE and Energy



electron affinity increase due to surface contamination

$$E_A = \kappa E_{A,0} - \sqrt{\frac{e^3}{4\pi\varepsilon_0}\beta_{ph} E_{emit}}$$

electron affinity decrease due to the Schottky effect

Potential barrier decrease by the electric field

/ variation results in
change
y change of emitted electrons
ttance)

κ : surface contamination factor
β_{ph}: field enhancement factor
E_{emit}: electric field at emission

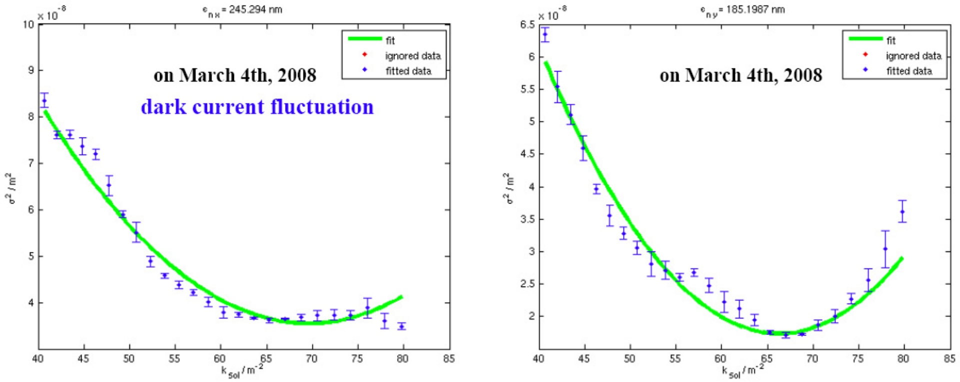
diamond

Excellent Thermal Emittance ~ 0.2 µm range

PAUL SCHERRER INSTITUT PSI

Measured emittance on February 27th. 2008
normalized horizontal emittance ~ 0.29 ± 0.014 µm
normalized vertical emittance ~ 0.26 ± 0.013 µm

When we scanned MSL40 several times with the same (or similar) machine conditions, measured emittances were reproduced three times on February 27th, one time on February 28th, and one time on March 4th.
Their range was about 0.18 ± 0.011 µm ~ 0.29 ± 0.014 µm.

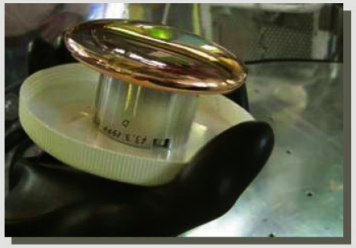


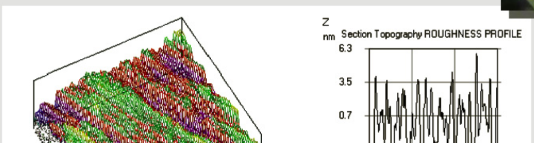
FEL G — Low Emittance Gun based PSI XFEL Project - Yujong Kim of Swiss Light Source, Switzerland

Wednesday III

Diamond Turned Copper (OFHC)

PAUL SCHERRER INSTITUT PSI — FEL G

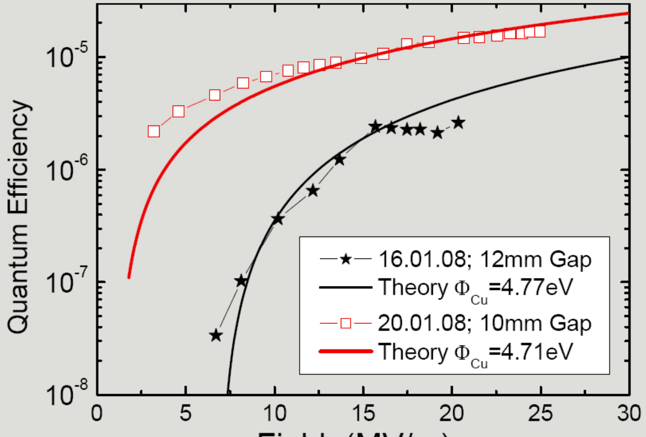




Roughness: Ra ~ 2 nm
Peak to Valley: 20 nm

Comparison with Theory

PAUL SCHERRER INSTITUT PSI — FEL G



266 nm, 6 μJ, 10 Hz

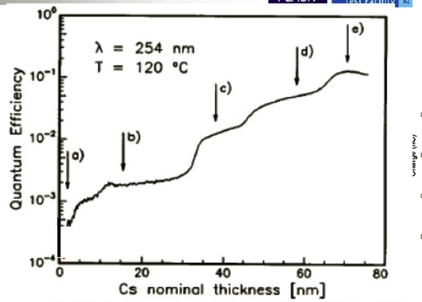
Measured Reflection:
R_{Cu}(266 nm) ~ 25 %

R. Ganter

Cs_2Te photocathodes

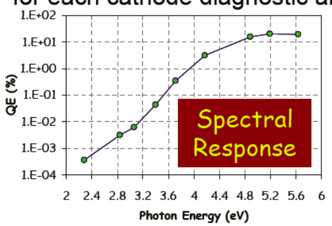
Preparation of the Cs2Te film

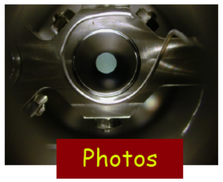
- substrate: polished Mo-plug
- during preparation plug stays at 120 deg C
- deposition of 10 nm Te
- starting Cs evaporation
- during Cs deposition monitoring of QE
- max. QE → Cs evaporation stopped

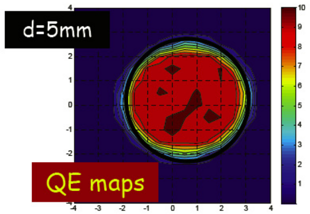


P. Michelato et al., NIM A ***393*** *(1997), 464*

for each cathode diagnostic after deposition:

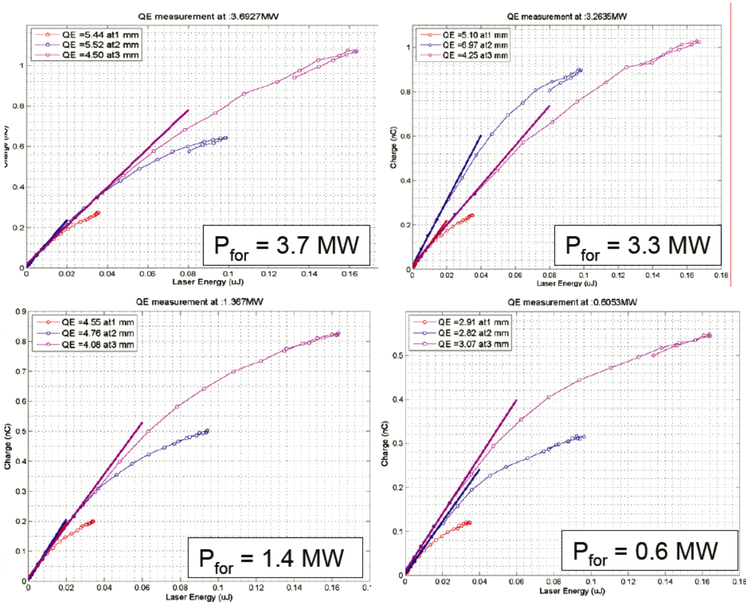






L. Monaco FLASH seminar, April, 2008

Analysis at FLASH and PITZ
2. pulsed QE measurements



Cathode #123.1

For each graph P_{for} was fixed and the iris varied

Thursday

- comparisons of measurements with corresponding simulations
- Definition of critical parameters in the different simulation codes for tuning them to the measurements
- report the state of the art of slice emittance diagnostics

Thursday, May 29th, 2008

Subjects: simulations and slice emittance diagnostics

Goals: for comparisons of measurements with corresponding simulations find out what are the most critical parameters in the different simulation codes for tuning them to the measurements, report the state of the art of slice emittance diagnostics

Possible realization: the different groups report about their experience in comparing measurements with simulations and their slice emittance measurement tools

Draft agenda for Thursday (May 29th, 2008):

8.30 – 10.30
- Mikhail Krasilnikov: "Comparisons of measurements and simulations for bunch charge vs. phase, transverse beam size vs. solenoid current, and emittance as a function of various machine parameters (solenoid current, gun phase, cathode laser transverse size) at PITZ" → 20+10 minutes
- Juliane Rönsch: "Comparisons of measurements and simulations for bunch temporal profiles, beam longitudinal momentum profiles and longitudinal phase space at PITZ" → 20+10 minutes
- Concetta Ronsivalle, "Transverse beam dynamics simulations vs. measurements in the SPARC emittance meter" → 20+10 minutes
- Daniele Filippetto, "Longitudinal beam dynamics simulations vs. measurements in the SPARC emittance meter" → 20+10 minutes

10.30 – 10.50 Break

10.50 – 12.50
- Henrik. Loos or Cecile Limborg-Deprey about comparison of transverse phase space in simulations and measurements at LCLS → 20+10 minutes
- Zhirong Huang: "Measurements of CSR and its Impact on the LCLS Electron Beam" → 20+10 minutes
- Eduard Prat about comparison of transverse phase space in simulations and measurements at FLASH → 20+10 minutes
- Bolko Beutner about comparison of longitudinal phase space in simulations and measurements at FLASH → 20+10 minutes

12.50 – 14.00 Lunch break

14.00 – 15.25
- Ivan Bazarov: "Space charge codes benchmarking using a DC gun" → 15+10 minutes
- Henrik Loos on the LCLS slice emittance measurement method → 10+10 minutes
- Michael Röhrs on the slice emittance measurement method and results at FLASH → 20+20 minutes

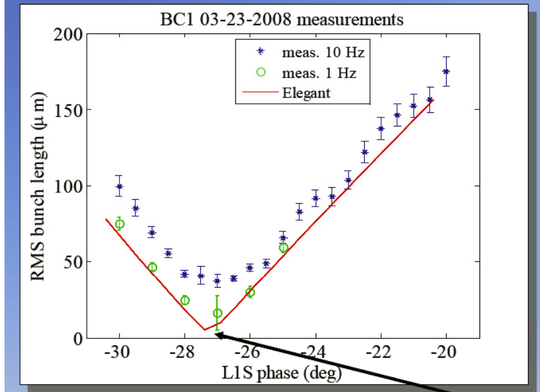
15.25 – 15.50 Break

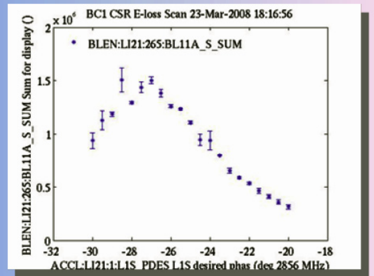
15.50 – 18.00
Yevgeniy Ivanisenko: "Slice emittance measurements at PITZ using energy chirp in booster" → 10+5 minutes
Roman Specyvtsev: "Slice emittance measurements at PITZ using quad scan with streak readout" → 10+5 minutes
- Barbara Marchetti, "Slice emittance measurements at SPARC" → 20+20 minutes

Thursday II

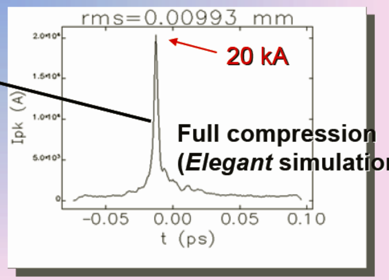
- CSR Studies at LCLS

Bunch compression measurements





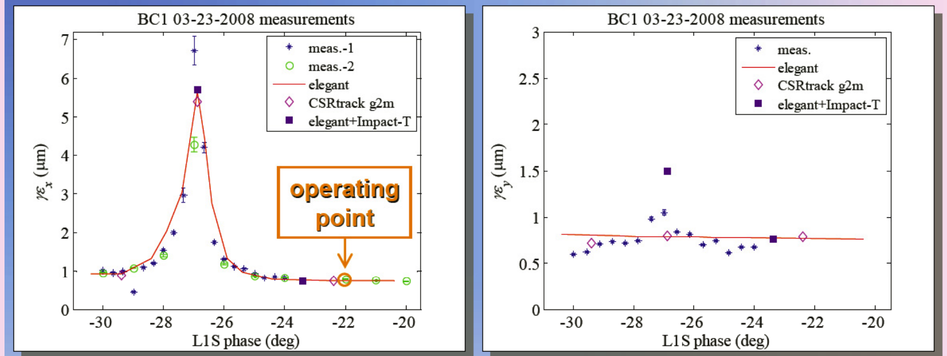
bunch length monitor (BL11A) signal



Full compression (*Elegant* simulation)

- Absolute bunch length measured by downstream deflecting cavity
- A Phase shift of -0.4 deg is added to the ***Elegant*** simulations

CSR Emittance growth after BC1 (250pC)



- ***Elegant*** (1D CSR with transient) shows good agreement with data
- ***CSRtrack*** (2D self-field) uses 100k particles, g2m, reads ***Elegant*** output at BC1 entrance, tracks BC1 up to WS12; agrees with ***Elegant***
- ***Impact-T*** (3D space charge, no CSR) reads ***Elegant*** output at BC1 exit, compute to WS12 (3.3 m downstream) ➔ suggests that small vertical emittance growth due to space charge at full compression (need to rule out instrumental effects)

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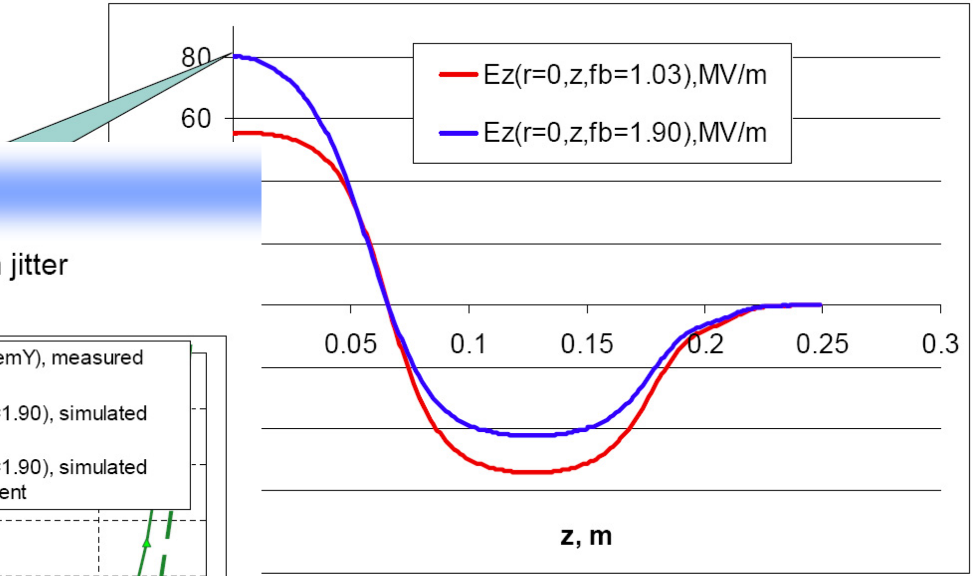
Measurements of CSR and its impact on the LCLS beam
Z. Huang

Thursday III

PITZ-1.6: Simulations vs. measurements

M.Krasilnikov

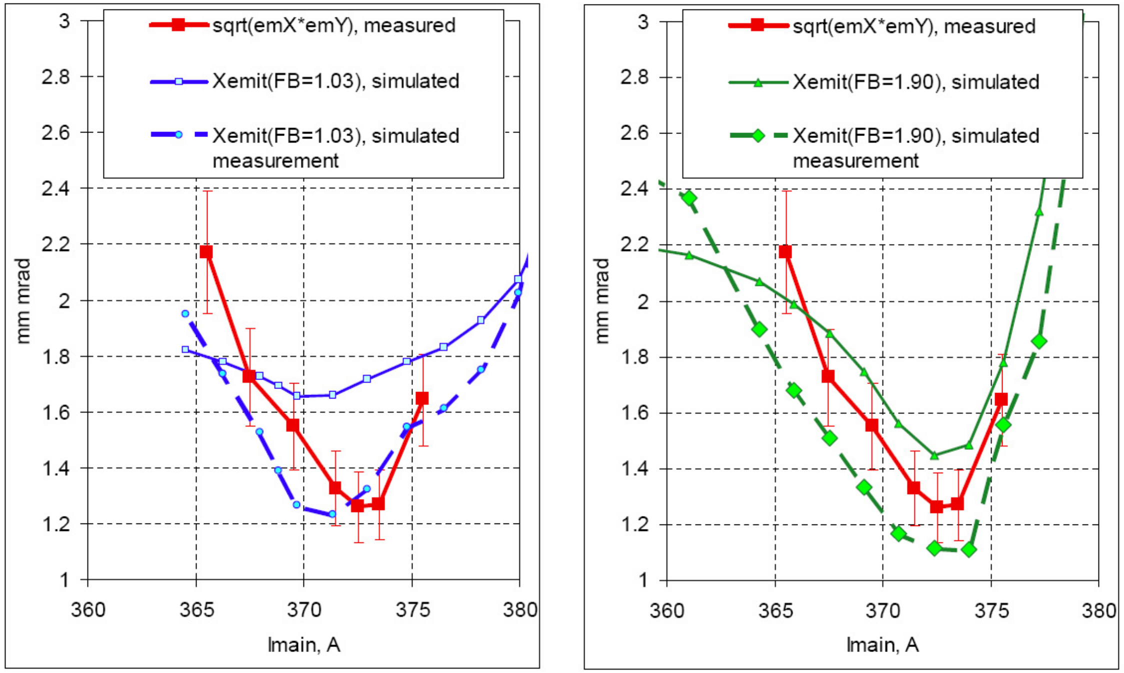
Gun Phase scans simulations for F=1.90. Gun field



Krasilnikov, CHBB-2008 15

Beam emittance simulations

Slit scan: 100um step, 5% charge cut, 50um position jitter
(*preliminary*)

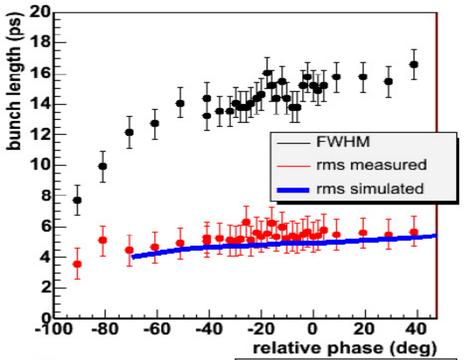


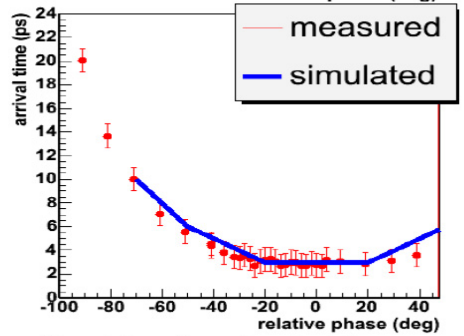
M.Krasilnikov, CHBB-2008 20

Thursday IV

studies at PITZ (J. Roensch) =>

Longitudinal phase space at PITZ

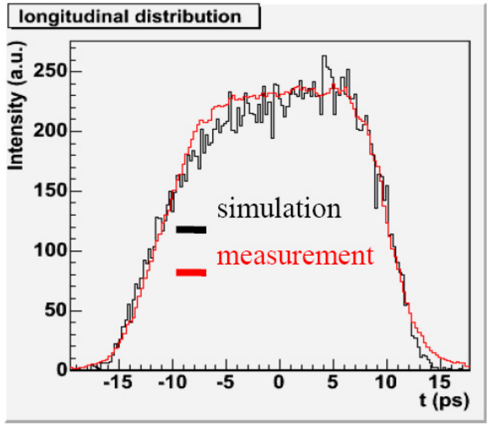




Bunch length and arrival time as a function of `the booster phase

- 1 nC
- transv. laser diameter = 1.5mm
- Flat-top laser
- opt. gun phase

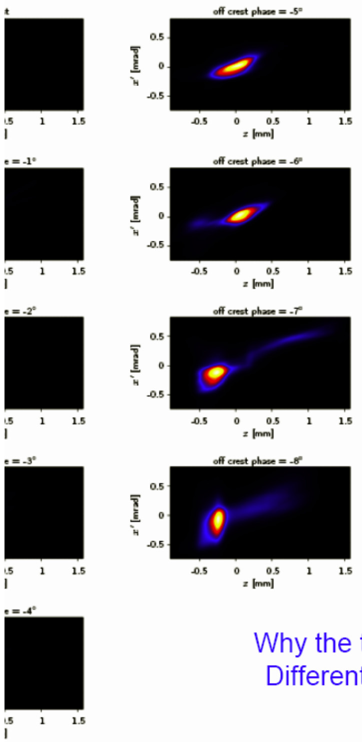
•Beam density distribution for: opt. booster phase



Juliane Rönsch (Hamburg University), May 29th, 2008 11

ACC1 phase scan
Horizontal phase space

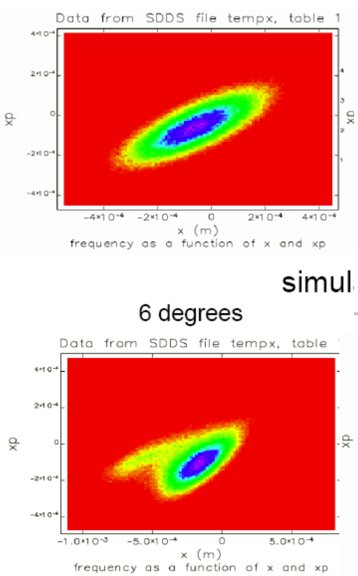
measurements

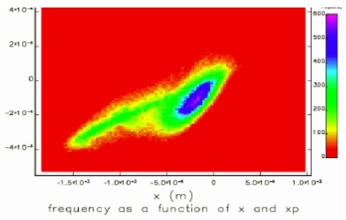


0 degrees

simul

6 degrees





<= studies at FLASH (E. Prat)

Why the the substructure is *mirrored* from 7 deg.?
Different matching (done with 90% of the beam)

eduard.prat@desy.de

Bolko Beutner, DESY

Thursday V

HELMHOLTZ GEMEINSCHAFT

SPARC

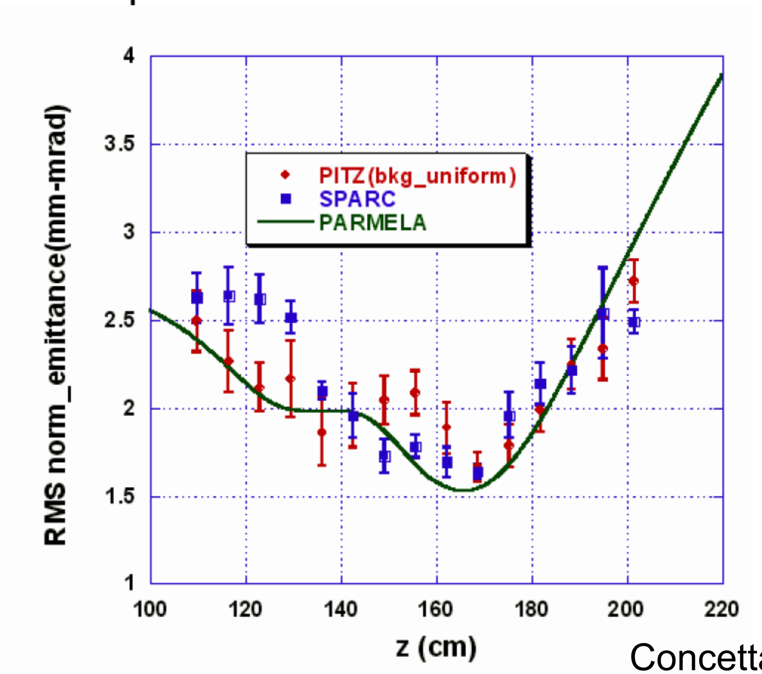
Slit energy measurements Vs sims

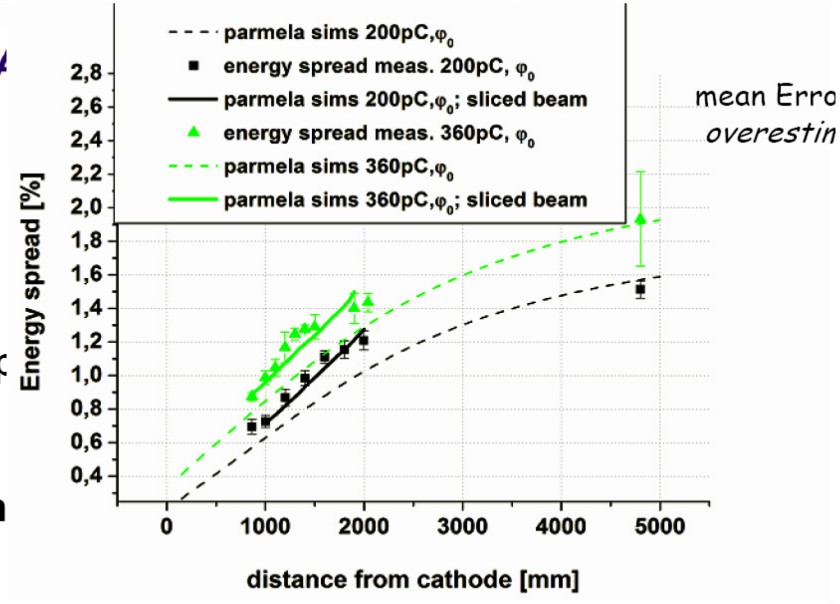
Verify the feasibility of the experiment and make a first test.
Central slit selected (maximum energy spread)
Two different phases and two different beam charges used.

SP

mean Erro
overestin

LONGITUDINAL EFFECTS: pulse shape comparison





Mini Workshop – CHHB08

Benchmark on SPARC data

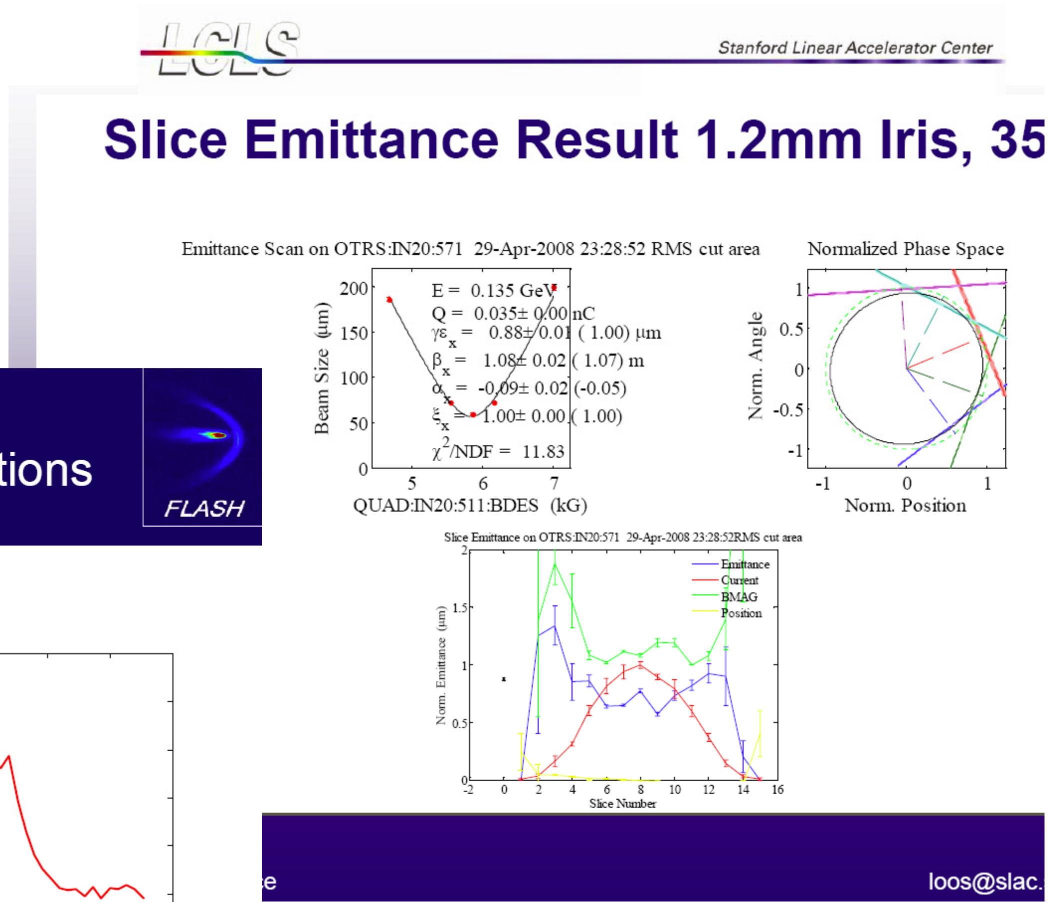
CHBB, 2008, DESY zeuthen

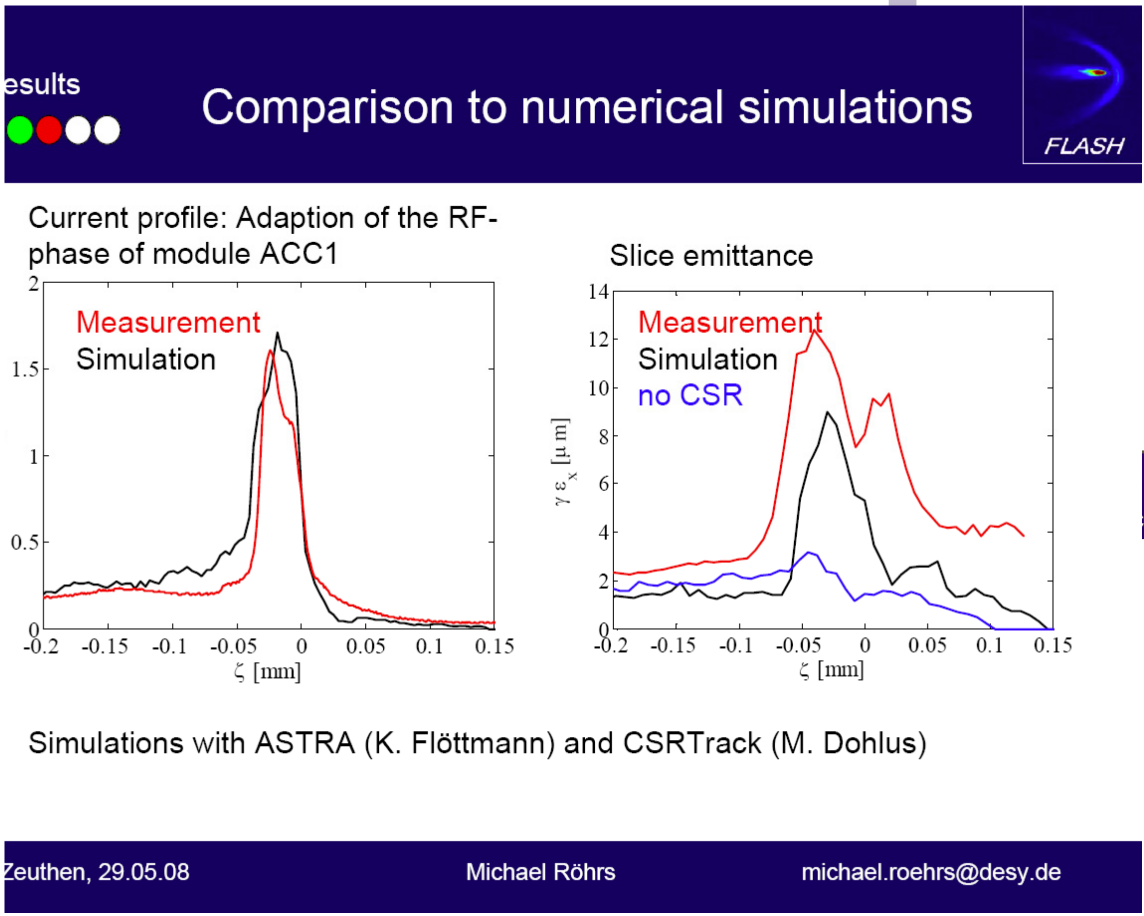
Daniele.Filippetto

Concetta Ronsivalle, ENEA Frascati

Thursday V

Slice emittance measurements at LCLS => H. Loos





<= M. Roehrs

Measurements at FLASH

Bolko Beutner, DESY

Friday

- Description of COTR effects in different labs
- Theoretical understanding
- Effects on beam diagnostics
  - Emittance measurements
  - Matching
  - …
- Discussion on mitigation of such effects

Friday, May 30th, 2008

Subjects: **1) COTR** (coherent light at visible wavelength from view screens)
2) to be defined

Goal: describe COTR in detail and try to find theoretical explanation.

possible realization: SLAC will report about their findings in detail, in the meantime also experiments at FLASH will be performed to look for the effect and the results will be reported, some theoretical work on this effect is ongoing at SLAC and can be reported, SPARC and PITZ will probably not have possibility to study this effect

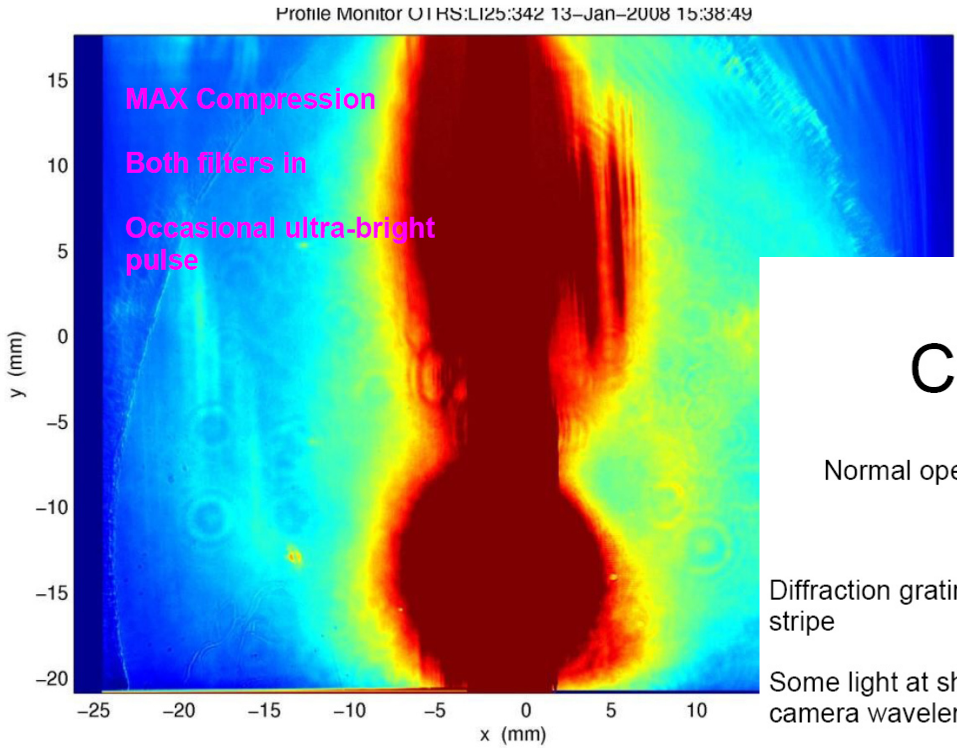
Draft agenda for **Friday (May 30th, 2008):**

8.30 – 10.00
Josef Frisch: "SLAC observations of COTR" → 20+10 minutes
Zhirong. Huang: "COTR from longitudinal space charge microbunching instability" → 20+10 minutes
Henrik Loos: "Imaging of micro bunched electron beams with COTR" → 20+10 minutes

10.00 – 10.30 Break

10.30 – 12.30
Bolko Beutner on findings on this topic at FLASH → 20+10 minutes
Discussion:
- Impact of COTR on beam diagnostics for high brightness electron beam facilities
- Mitigation of COTR effects in OTR based beam diagnostics
- Alternative diagnostic methods for optically bunched beams

COTR at LCLS I



COTR Spectrum after BC2

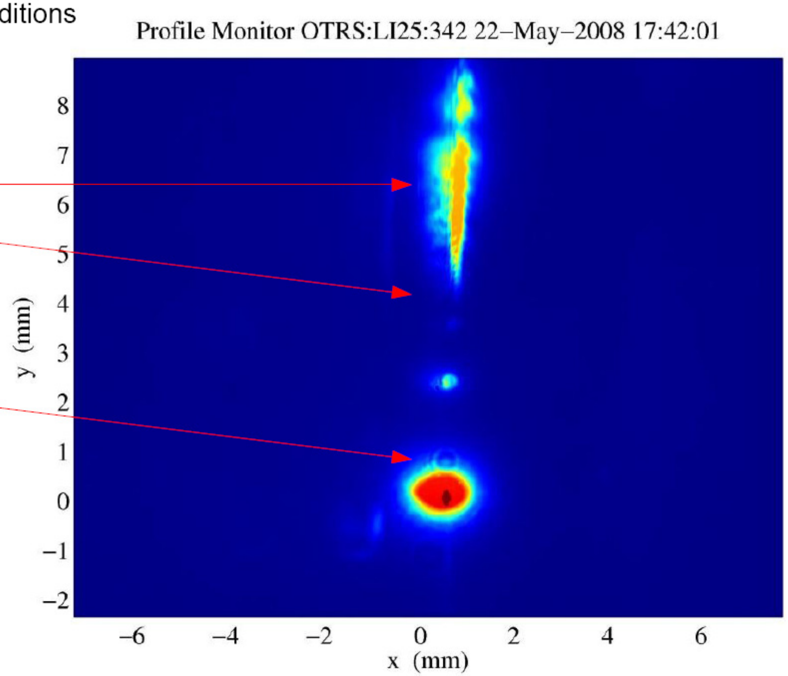
Normal operating conditions

Diffraction grating spectral stripe

Some light at shortest camera wavelengths

Note diffraction rings suggesting coherence

Plan to measure power at 200nm



COTR at LCLS II

SLAC Observations of COTR
J. Frisch

COTR in dispersed region of BC2

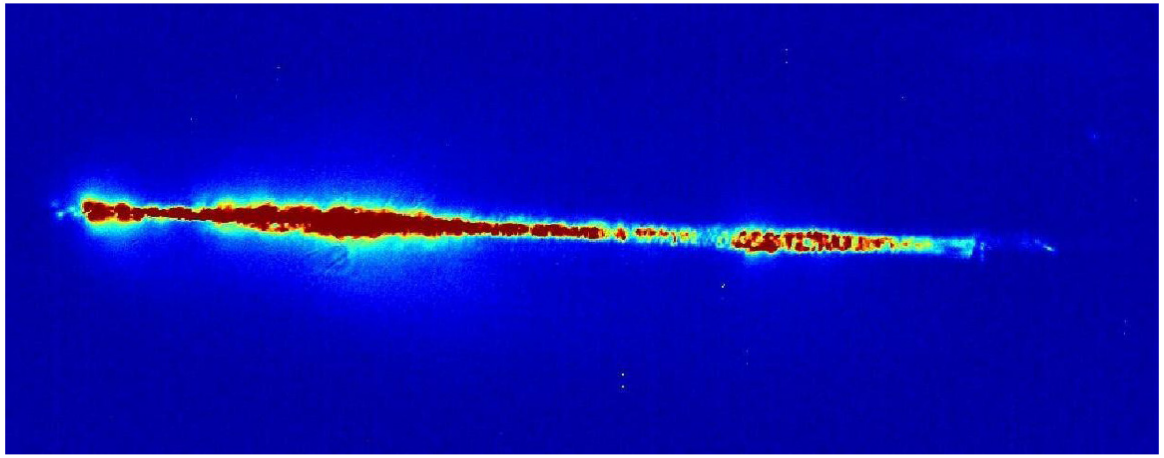
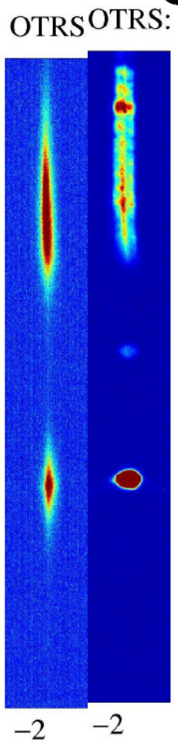


Image taken with both filters inserted (X30), at normal compression, energy is horizontal in this image. The strong COTR even the the dispersed region makes it impossible to make quantitative spectral measurements.

COTR Spectrum



Spectral Stripe from diffraction grating

Comparison
OTR light aft
stronger at lo

Main Spot

OTR12, with OTR 11 inserted (incoherent), or removed (coherent)

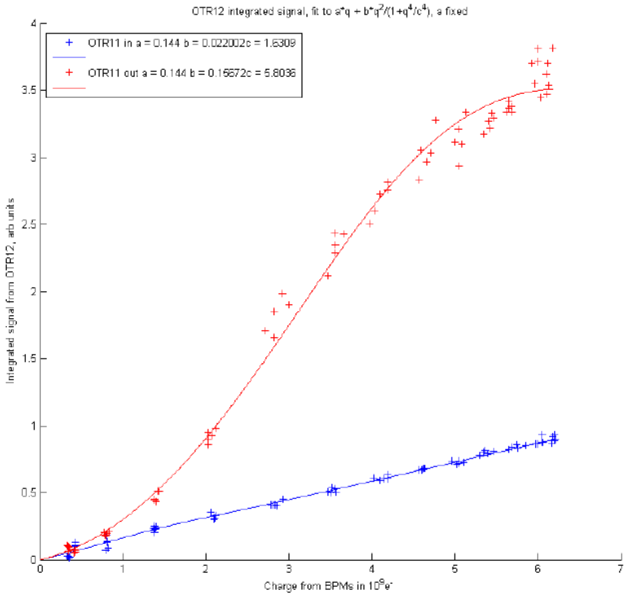
Note, signal on right is saturated, and has bit depth reduce from 12 to 6 (x64 change in intensity)

COTR at LCLS III

- LCLS

am foil (OTR11) reduces
nlinearity on OTR12

urve



Integrated optical signal vs. Charge

Measured at OTR12 (after 1st bunch compressor). With compressor OFF (straight), L1S, L1X on crest.

Fit to $I = a*q + b*q^2(1+q^4/c^4)$

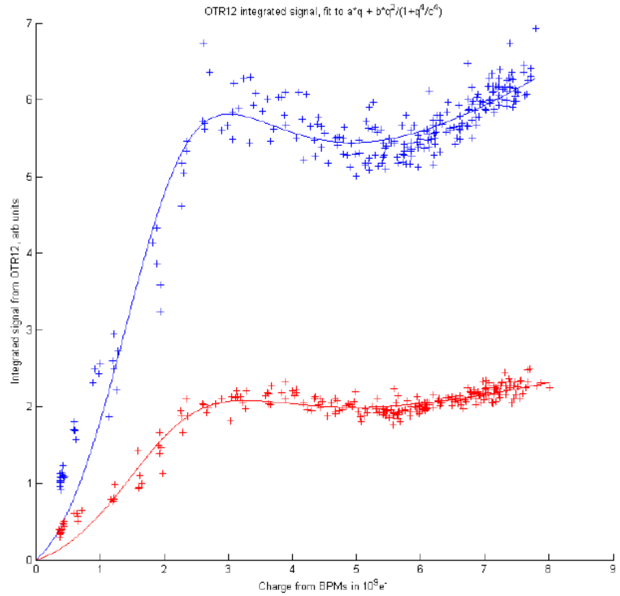
a is liner term $0.69/10^9$.

b is coherent term

c is damping of coherence at high charge (energy spread?), emperical.

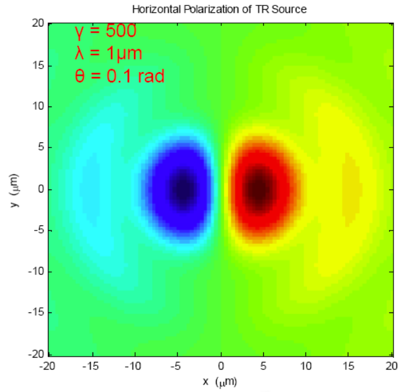
Nonlinear response to charge shown with, and without X3 filter.

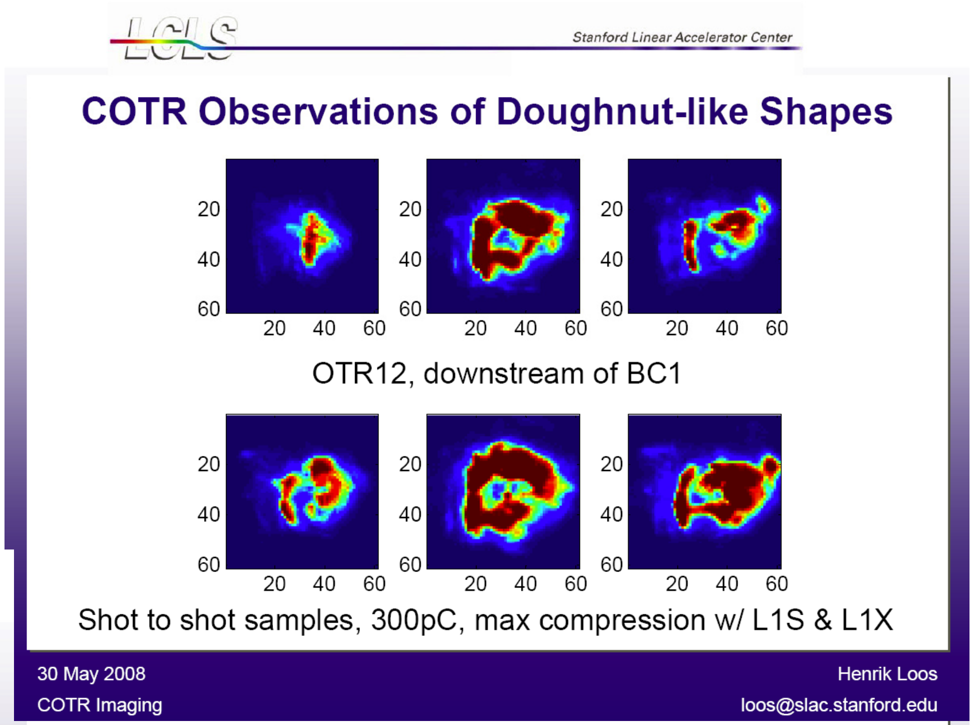
a,b,c scale as expected, no evidence that camera is non-linear

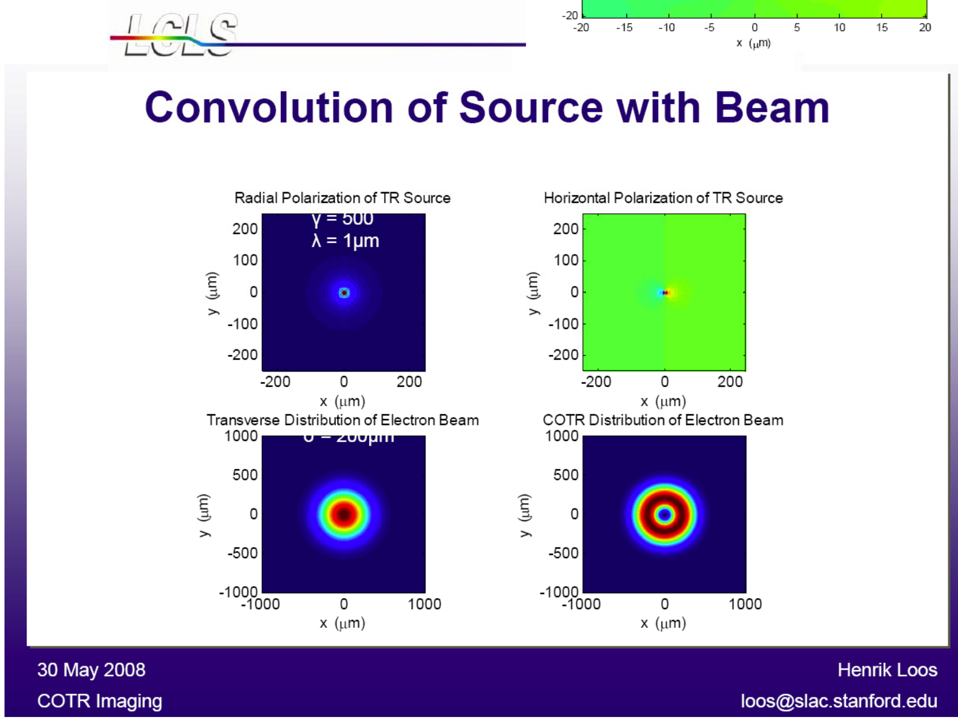


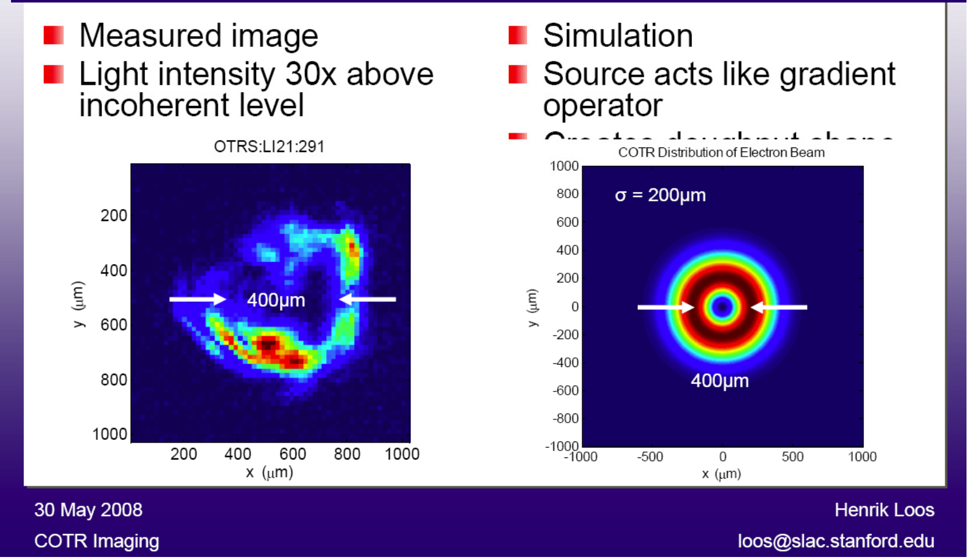
OTR Theory

H. Loos on “Doughnut” structures and theoretical explanation from OTR theory









Microbunching/COTR I

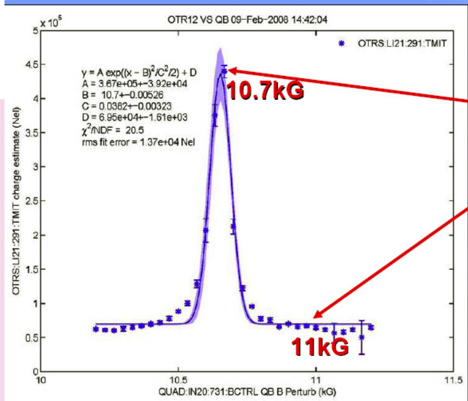
Z. Huang on
microbunch instabilities

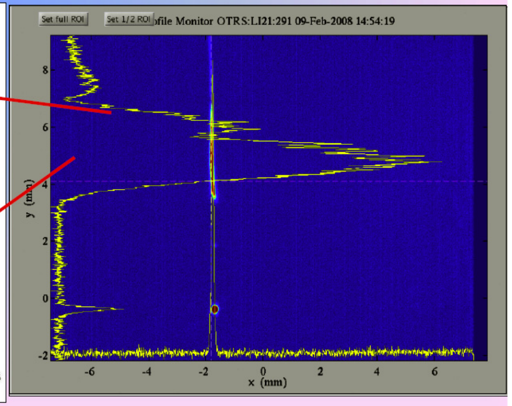
OTR12 Spectral Analysis I

- Analyzed diffraction grating spectral data on OTR12
- 2 images with BC1 off, 250pC (D. Dowell)

No COTR (QB = 11 kG, nonzero R51&R52 after DL1 suppress μ-bunching)

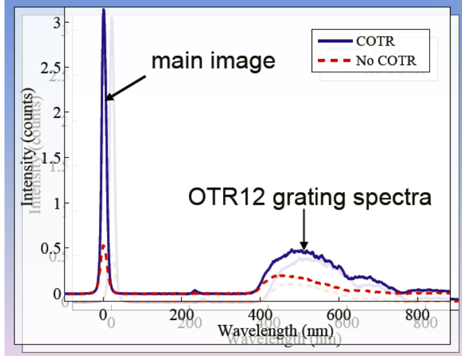
COTR (QB = 10.7 kG, DL1 is linear achromat and enhances μ-bunching)

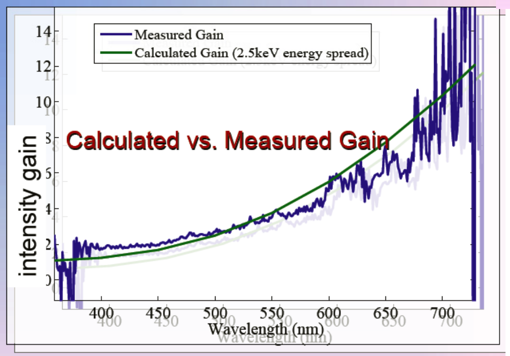




OTR12 Spectral Analysis II

- Measured intensity gain by ratio of COTR to No COTR spectra
- Calculated intensity gain with 40 A peak current (BC1 off), 1 μm norm. emittance and fit to 2.5keV slice rms energy spread)



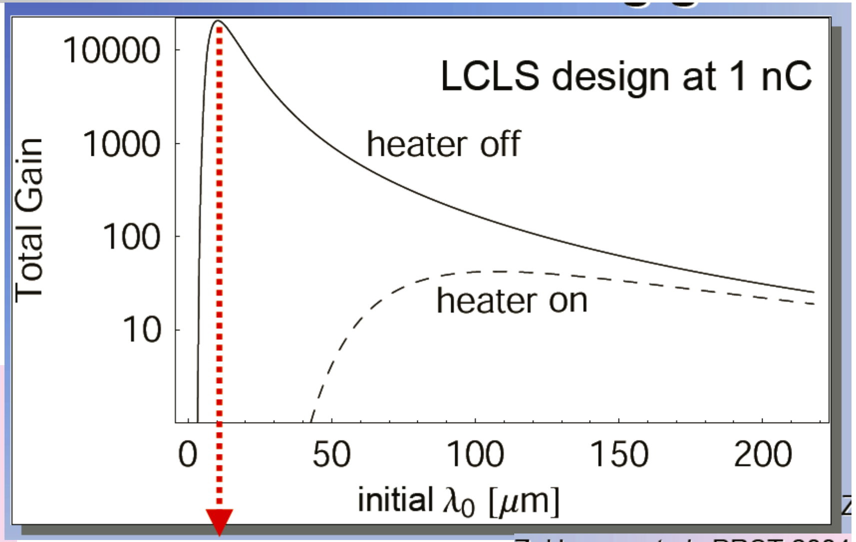


D. Ratner

Measurements on micobunch gain curve with a diffraction grating spectrometer

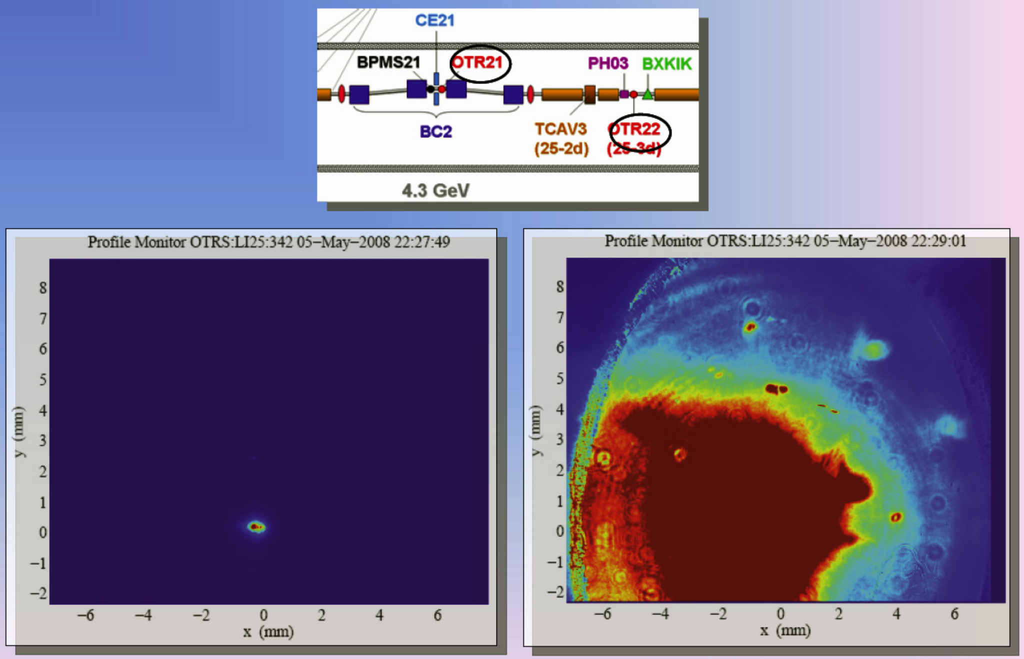
Microbunching/COTR II

Reduction of microbunching by a laser heater in simulations



Z. Huang, *et al.*, PRST 2004

OTR22 after BC2



with OTR21 screen inserted (smoothes μ-bunching)

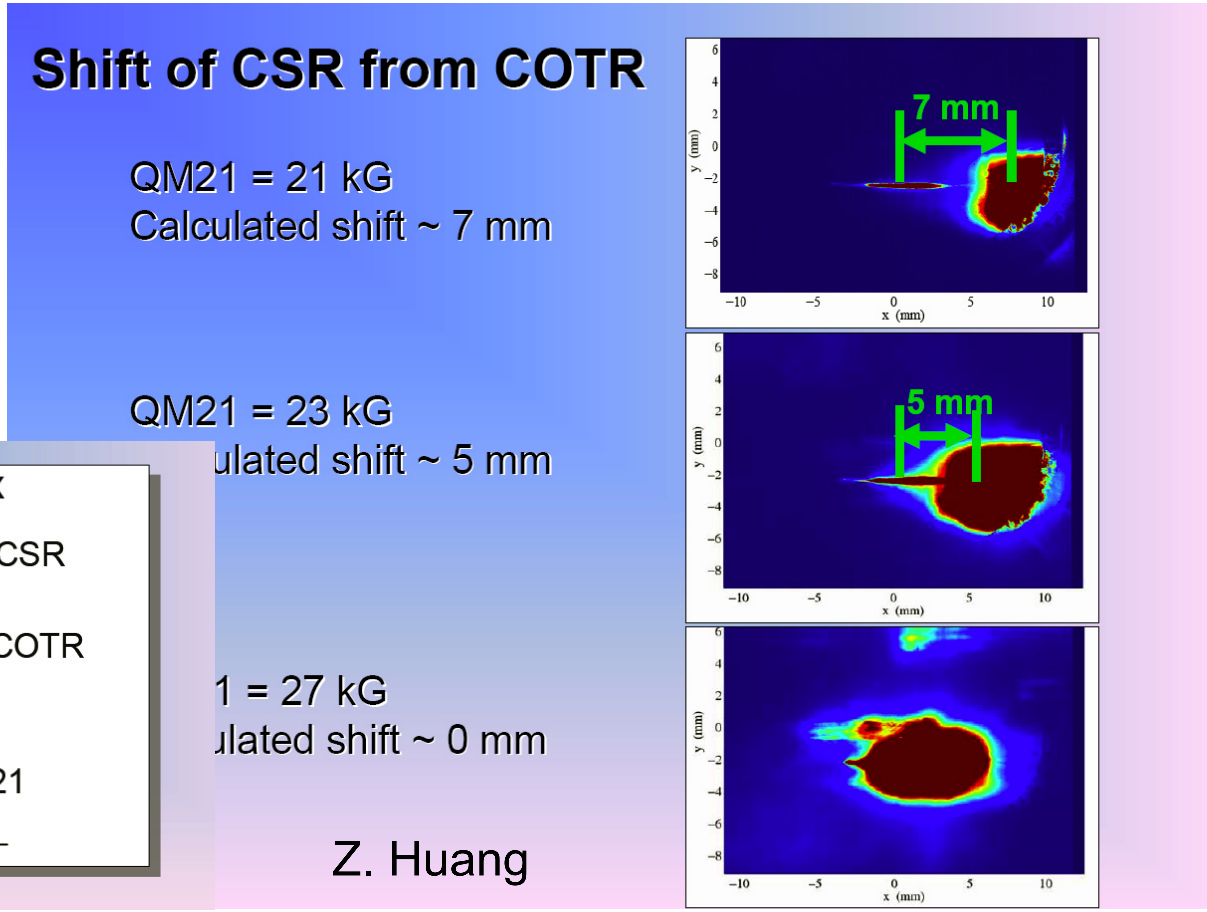
with OTR21 screen OUT (μ-bunching present – COTR!)

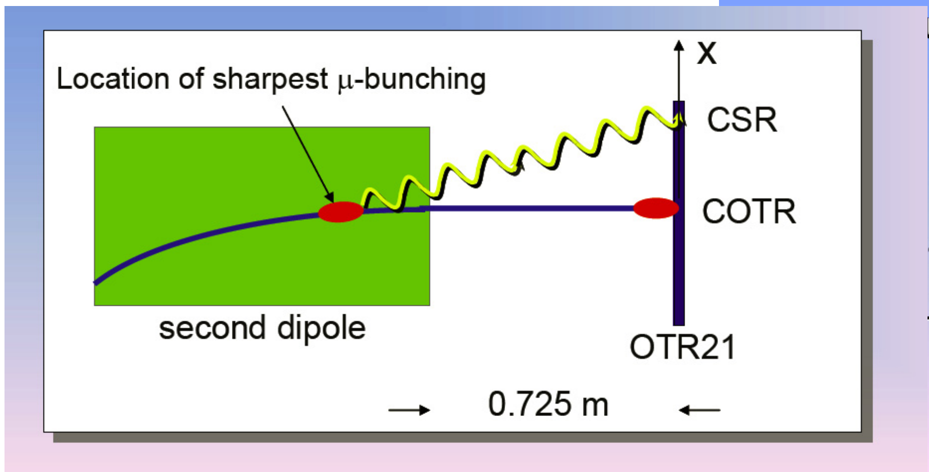
"simulation" of laser Heater in measurements by an OTR screen upstream

=> Expected reduction of COTR effects with the upcoming laser heater

COTR/CSR

- CSR is visible on the screen inside the chicane
- CSR can be separated from beam spot with the dipole setting



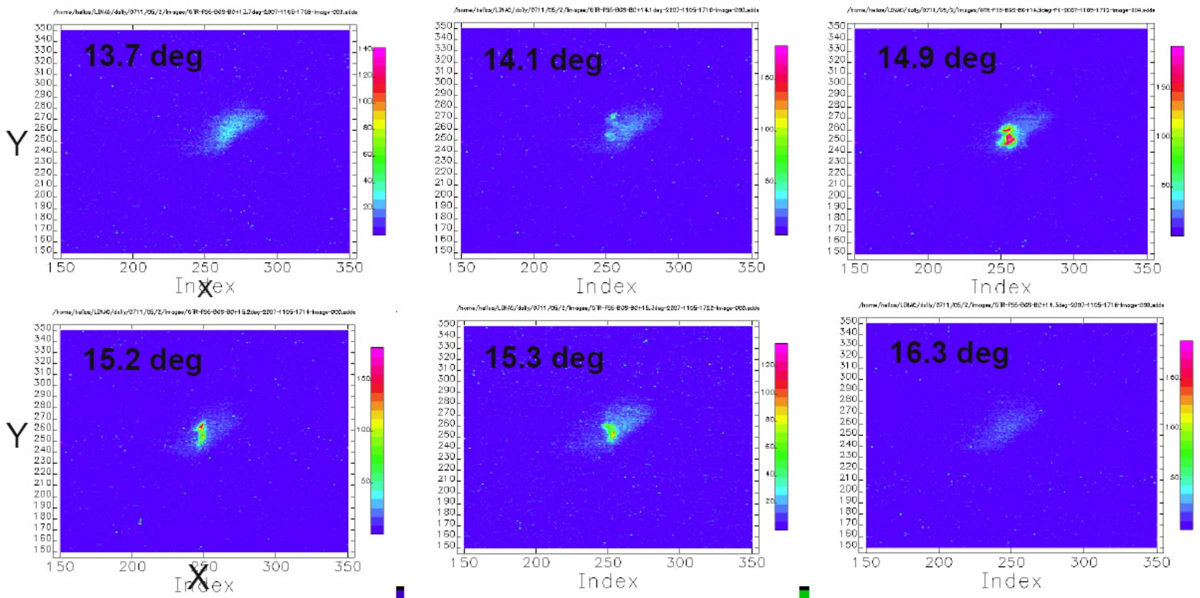


COTR at APS

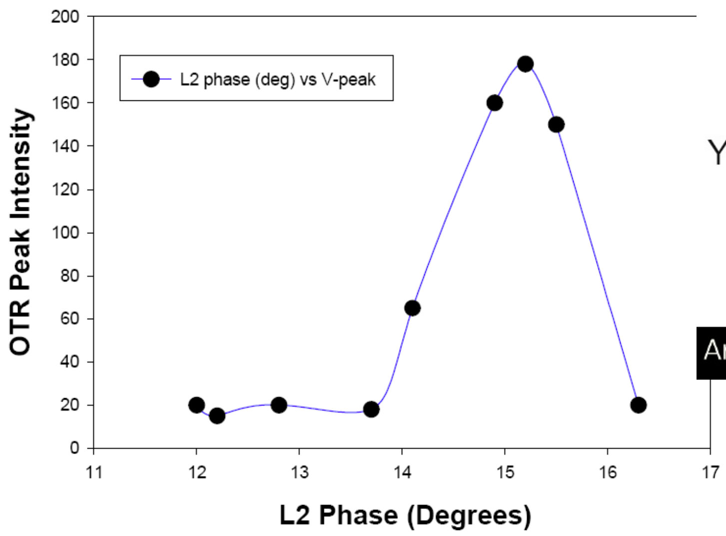
K. Harkay (Argonne)

OTR Beam Image Structures Vary with L2 Phase

- Images develop enhanced peaks in x-y space with compression. Footprint is similar to 11-05-07 data (~45 µm/pixel).



e Analysis on OTR Peak Intensity Con Effect (11-05-07 Data)

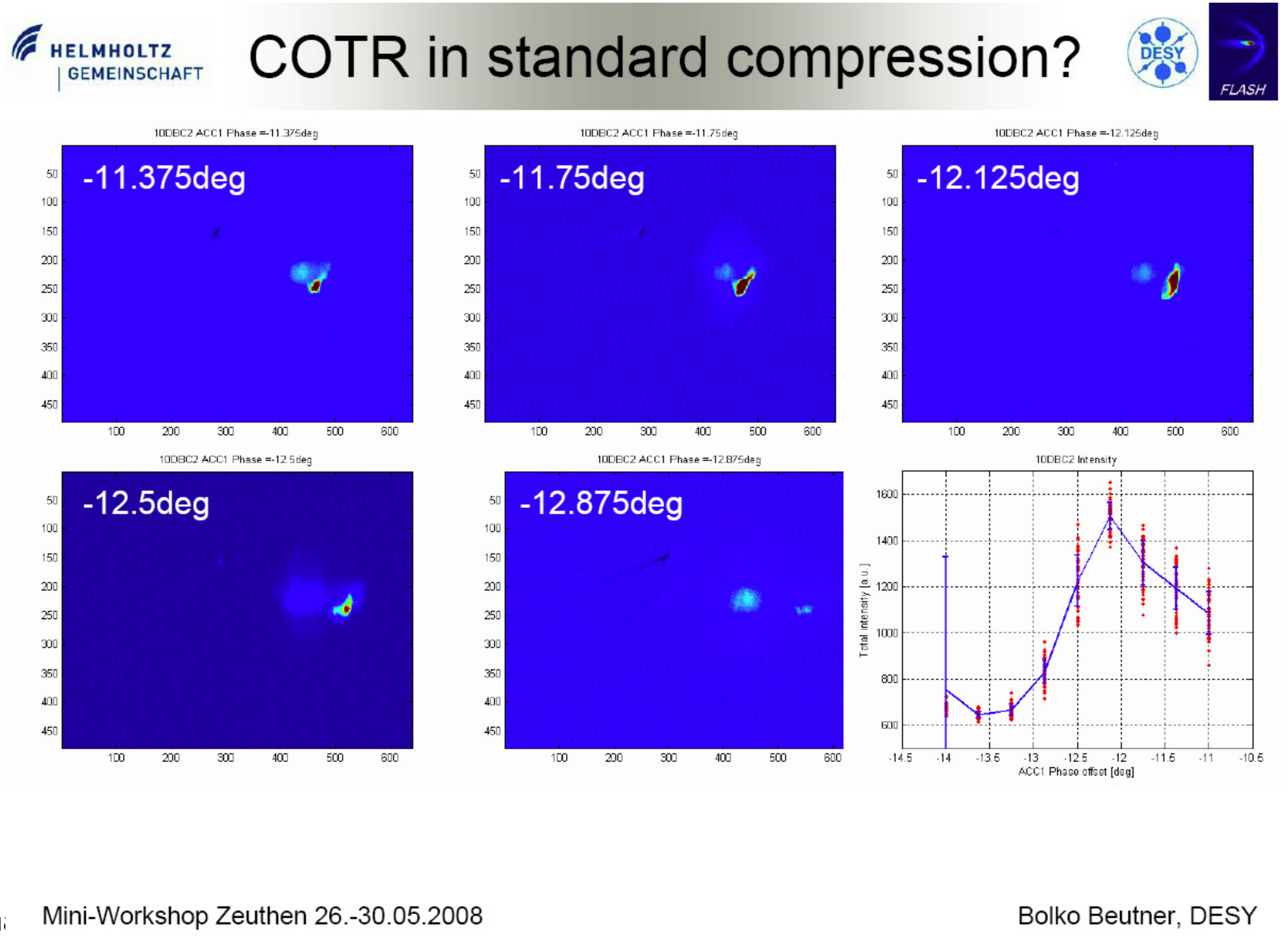


Localized peak intensity from single-column samples (10 images at each phase point).

Lumpkin et al., BIW08

COTR at FLASH

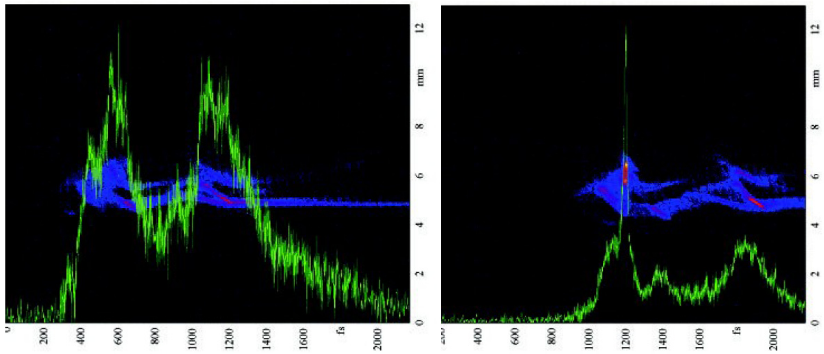
Observations at FLASH are similar to the Argonne results



COTR Summary

- Reports and discussions on microbunching instabilities
  - Beam dynamics / emittance growth
  - Laser heater
- Effects of COTR on diagnostics
  - OTR screens
  - Emittance measurements
  - Wire scanners
  - Laser heater
  - Why a problem at LCLS and not at FLASH or APS?
  - XFEL diagnostic layout

Pictures From DESY LOLA (2005)



Comparison of 2 beam pulses taken under the same conditions at TTF on the OTR screen after the LOLA deflection cavity

Summary

- Total of 44 contributions
  - 9 from FLASH
  - 12 from PITZ
  - 8 from LCLS
  - 8 from SPARC
  - 7 from other labs like BESSY, APS, BNL, PSI, …

- Comparable emittance measurement results from different labs
- Discussions to define common procedures for emittance measurements
- In general a good agreement between simulations and measurements
- COTR is an issue for beam diagnostic of high brilliance beams