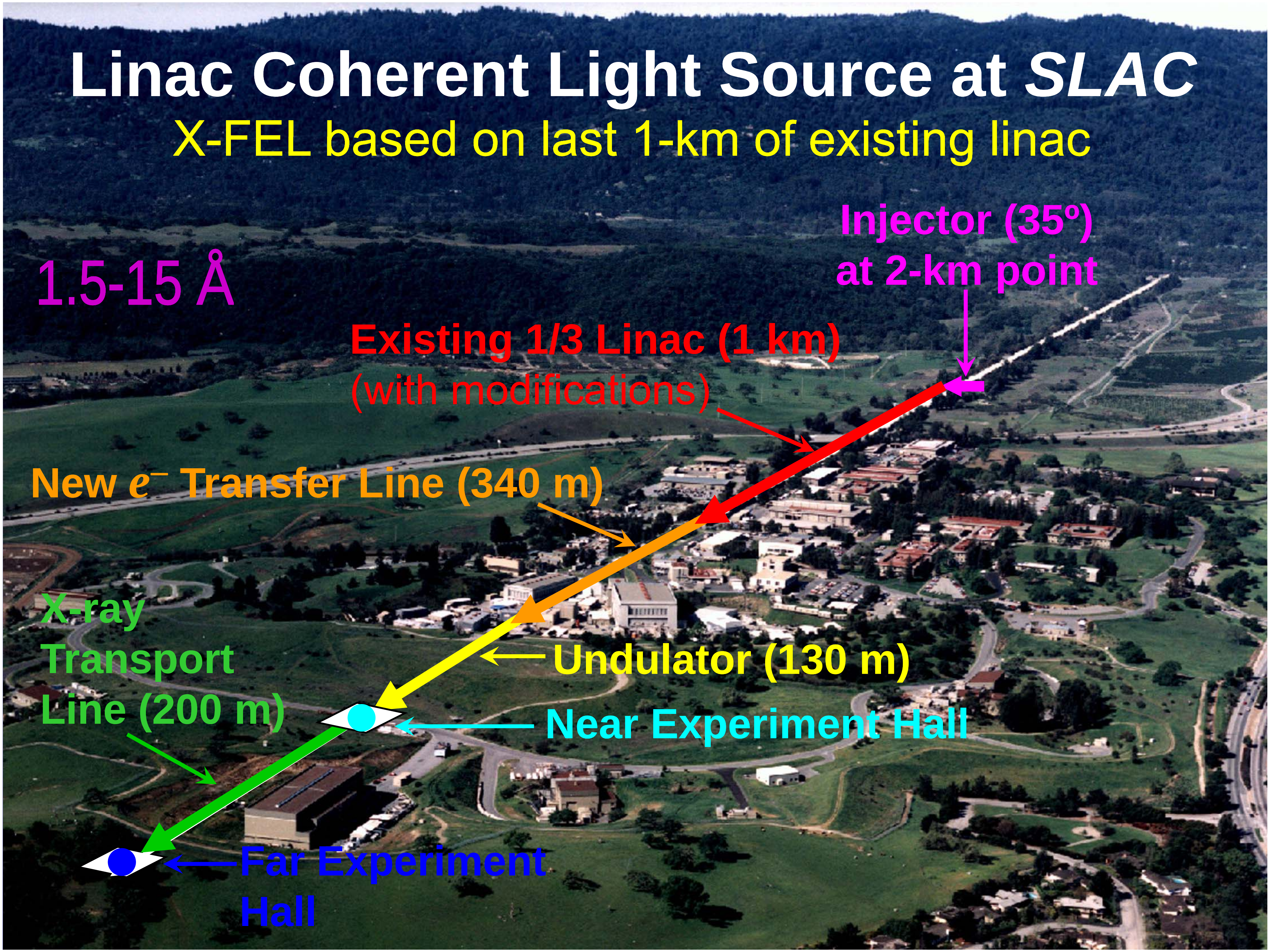
Commissioning of the LCLS Linac

Henrik Loos for the LCLS
Commissioning Team

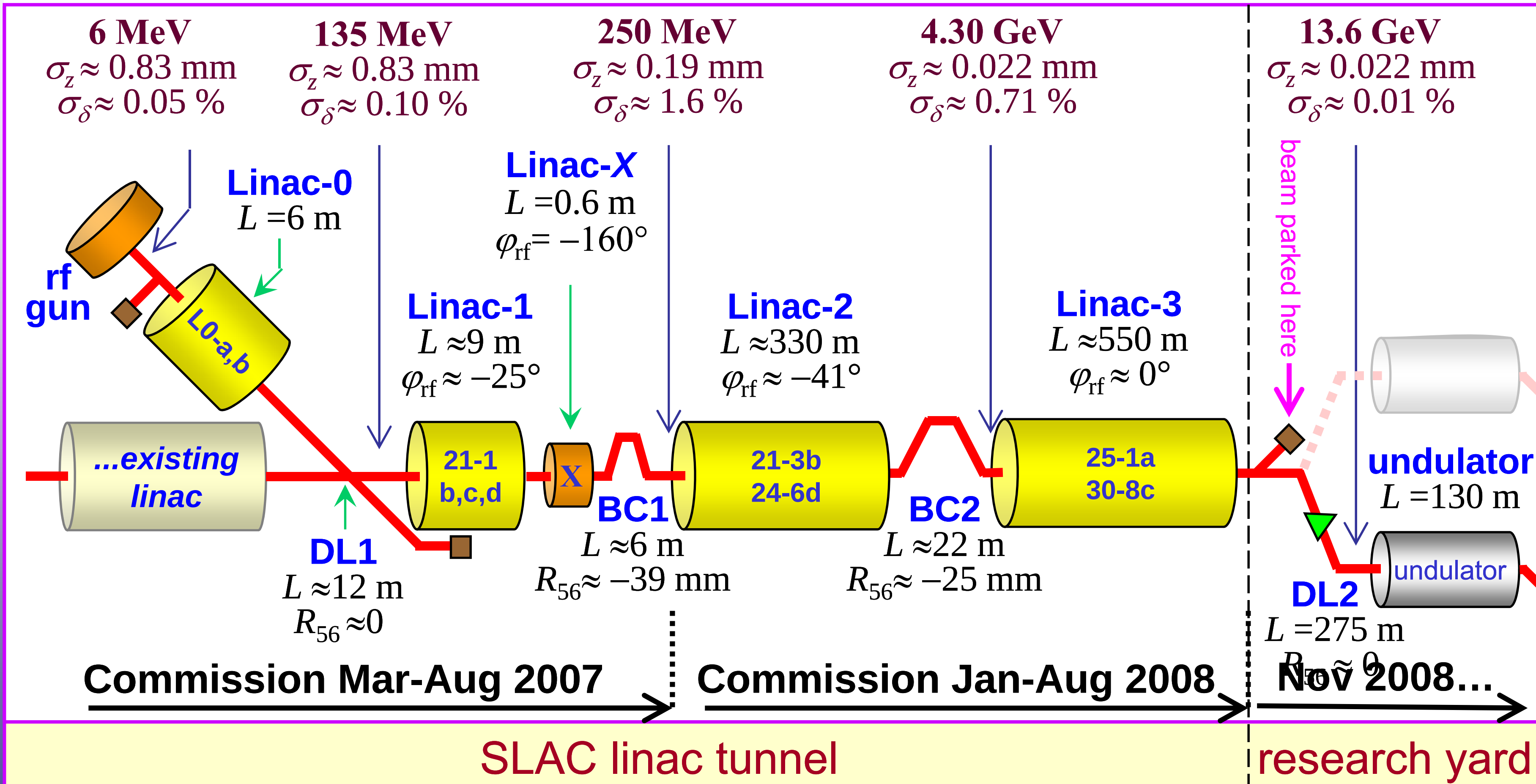
Henrik Loos
loos@slac.stanford.edu

Linac Coherent Light Source at *SLAC*

X-FEL based on last 1-km of existing linac

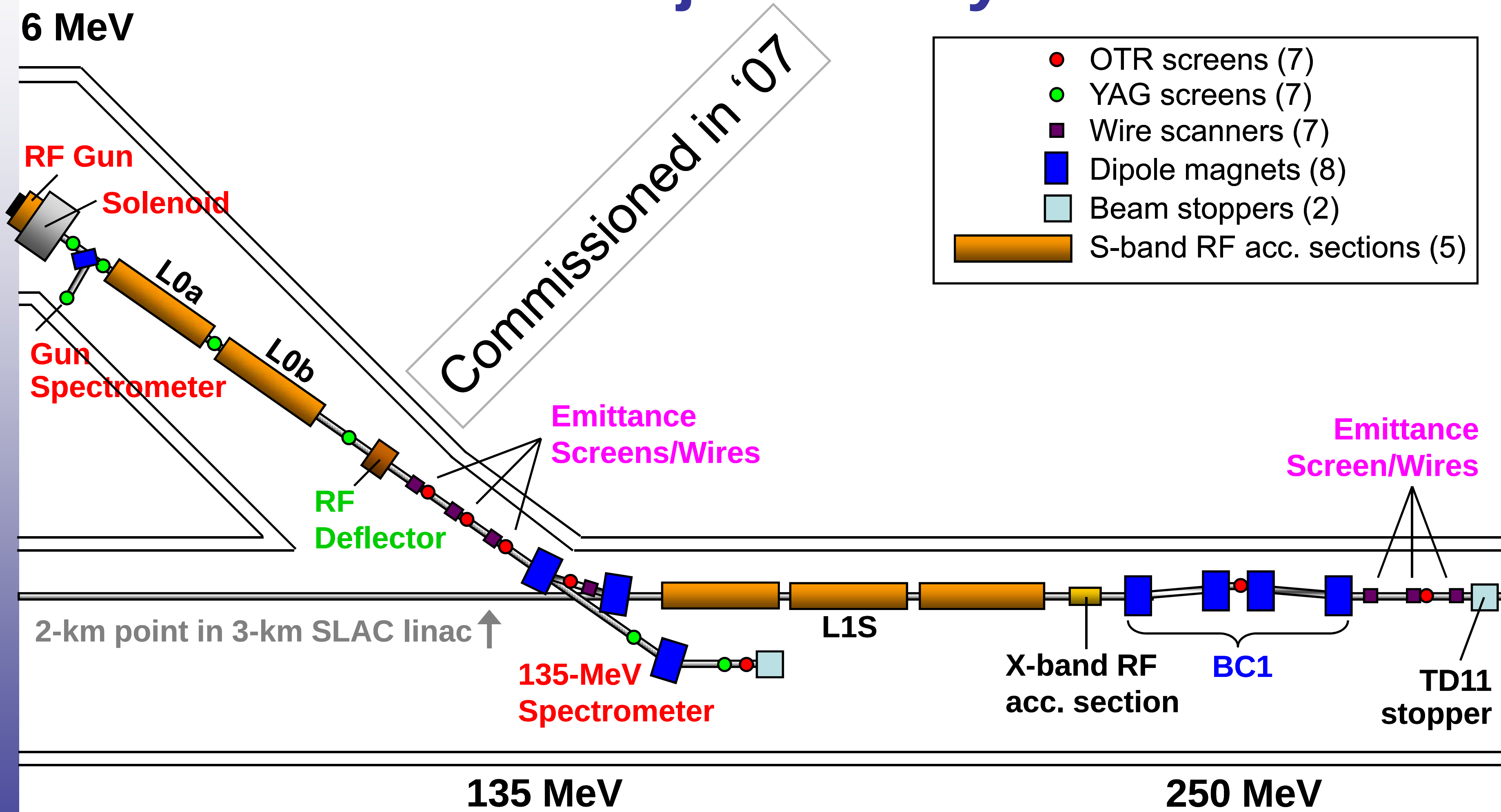


LCLS Accelerator Layout



X-rays in spring 2009

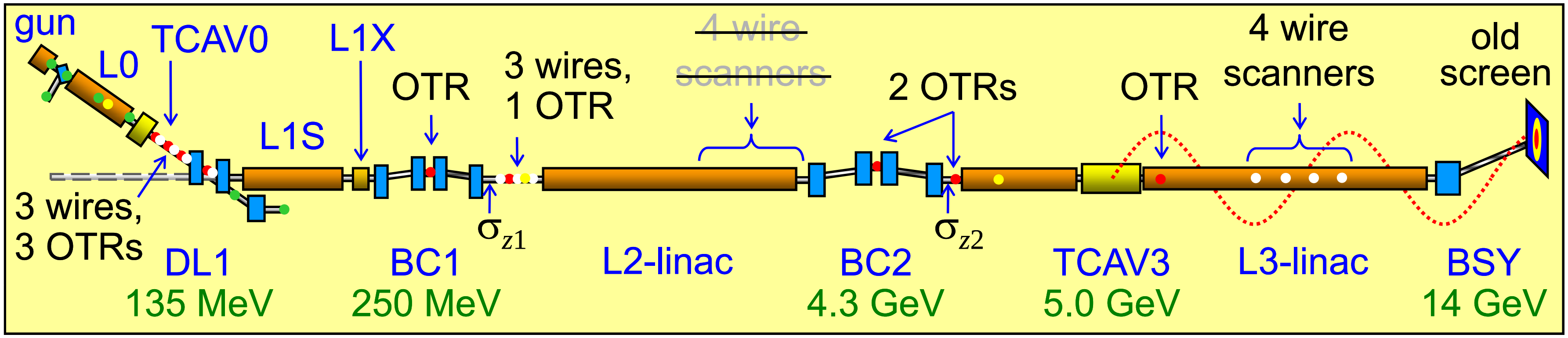
LCLS Injector Layout



Commissioning Highlights

- Done: Injector commissioning & Phase II commissioning
- Great drive-laser uptime (**99%**) and performance
- Projected emittances **0.7-1.6 μm** near linac end
- Routine 30-Hz e^- to 14 GeV (~24/7 with ~90% up-time)
- BC1 dipoles & chicane motion fixed!
- BC2 compression fully demonstrated
- CSR effects measured and agree with codes
- Cathode replaced and design QE achieved
- Many beam & RF feedback systems running well
- Coherent OTR compromises most screens
- Electron beam bright enough for **1.5-Å** FEL

LCLS Beam Diagnostics (no Undulator)

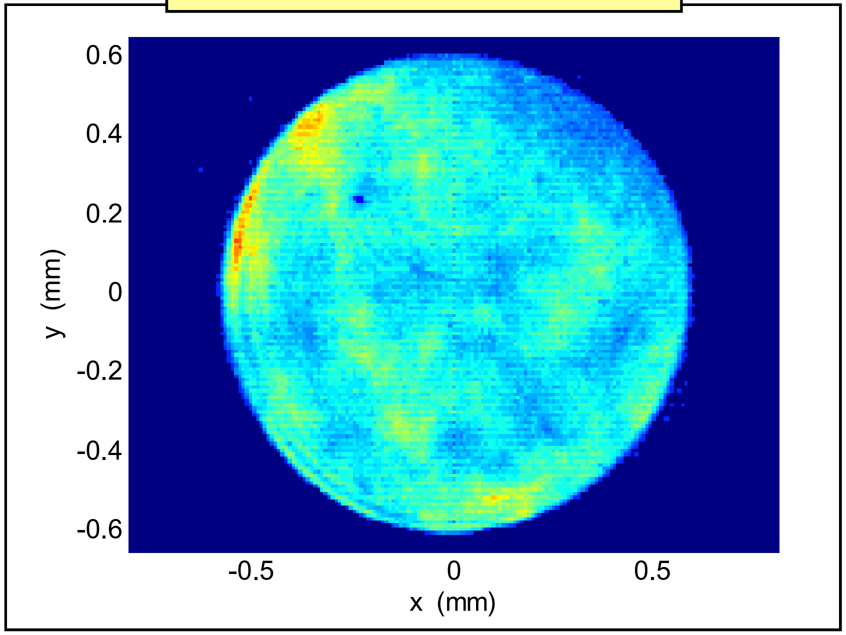


- 2 Transverse RF cavities (135 MeV & 5 GeV)
- ~120 BPMs and toroids (75 more coming)
- 7 YAG screens (at $E \leq$135 MeV)
- 9 OTR screens at $E \geq$ 135 MeV (3 more coming at 14 GeV)
- 11 wire scanners (each with x & y wires, with 4 more coming)
- CSR/CER pyroelectric bunch length monitors at BC1 & BC2
- 3 beam phase monitors (2856 – 51 MHz, 1 more coming)
- Gun spectrometer line + injector spectrometer line

• YAG screens
• OTR screens
• Wire scanners
• Phase monitors

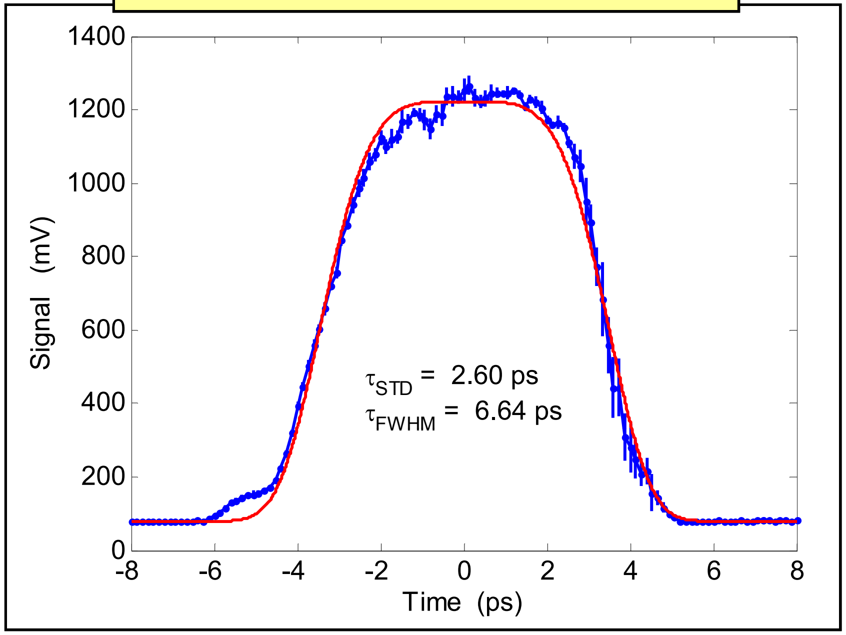
Injector Drive Laser

Cathode Laser Spot



Shaping with iris Ø1.2 mm

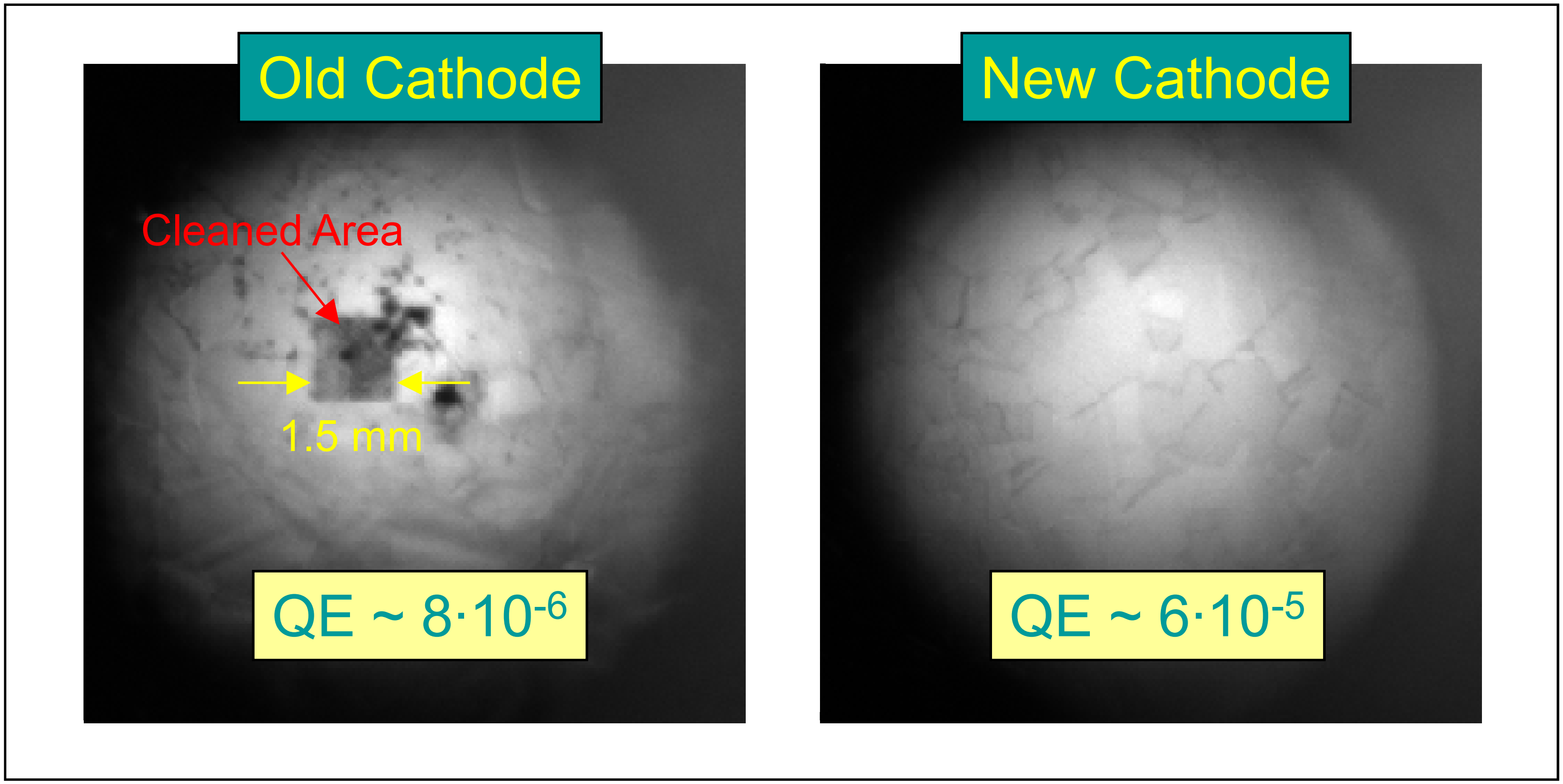
Temporal Pulse Shaping



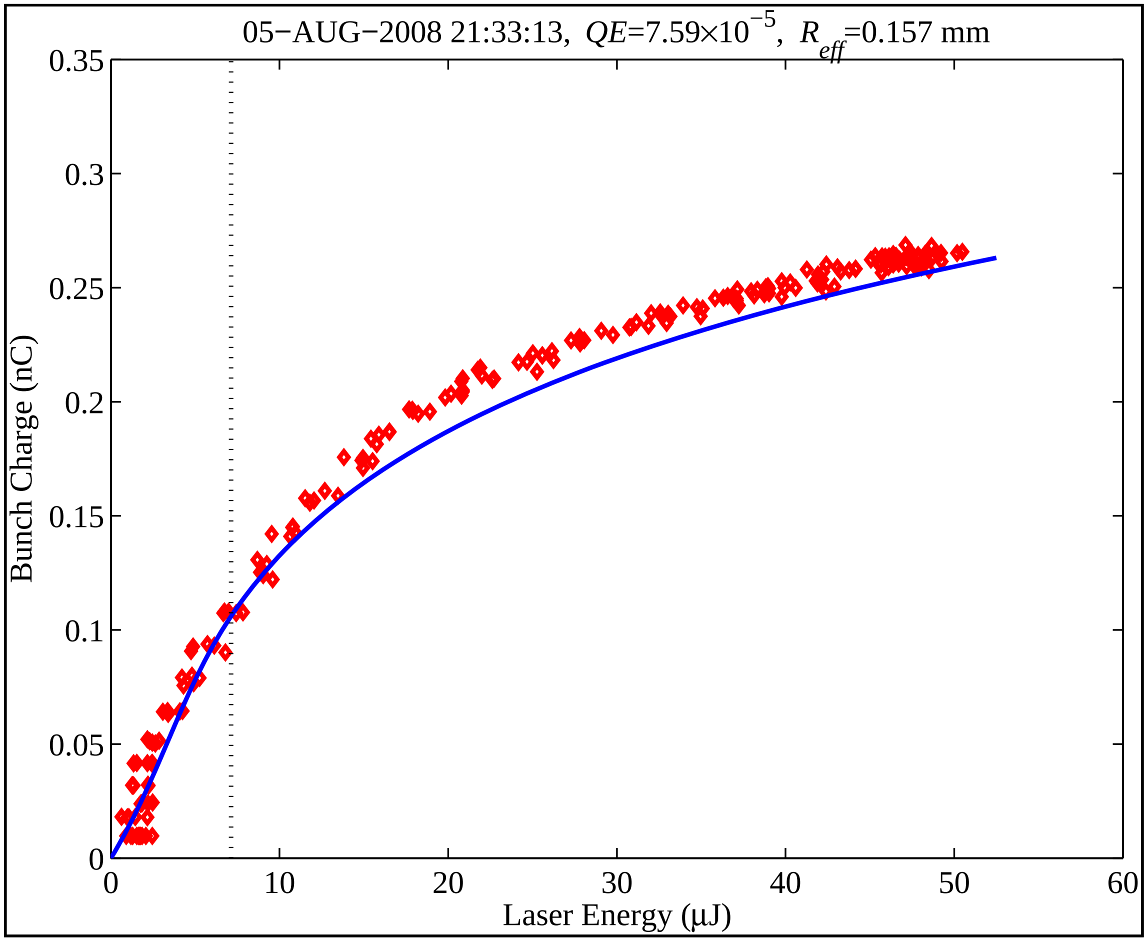
Shaping with DAZZLER

S. Gilevich, G. Hays, P. Hering, A. Miahnahri, W. White

Laser Cleaning and New Cathode



Cathode Quantum Efficiency



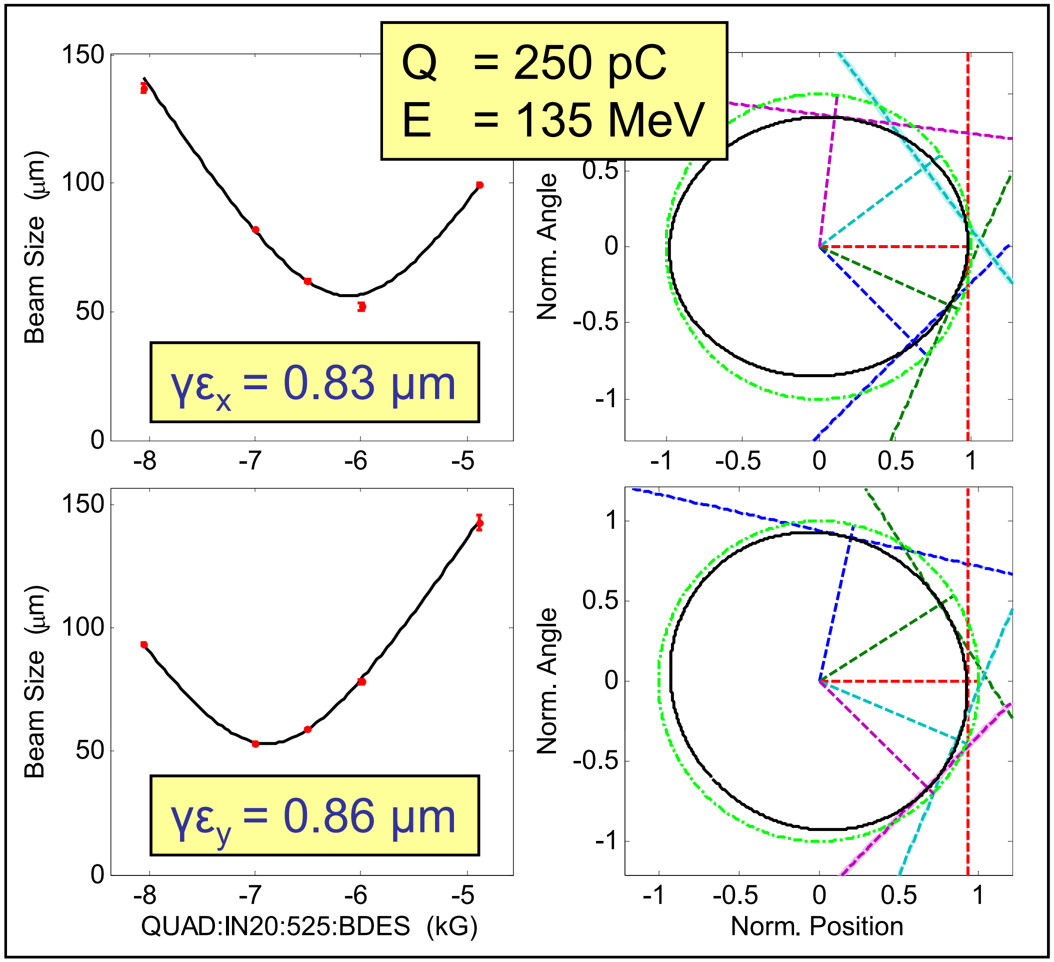
Henrik Loos
loos@slac.stanford.edu

Design and Achieved Parameters

	Design	Typical measured	Unit
Repetition Rate	120	30	Hz
Energy	13.6	13.6	GeV
Charge	1	0.25	nC
Bunch length	20	8-10	µm
Peak Current	3	3	kA
Projected emittance (injector)	1.2	0.7-1	µm
Slice emittance (injector)	1	0.6	µm
Projected emittance (linac end)	1.5	0.7-1.6	µm
Laser energy	250	20-150	µJ
Gun field at cathode	120	115	MV/m
Cathode quantum efficiency	6	0.7-7	10^{-5}

Henrik Loos
loos@slac.stanford.edu

Injector Emittance Commissioning

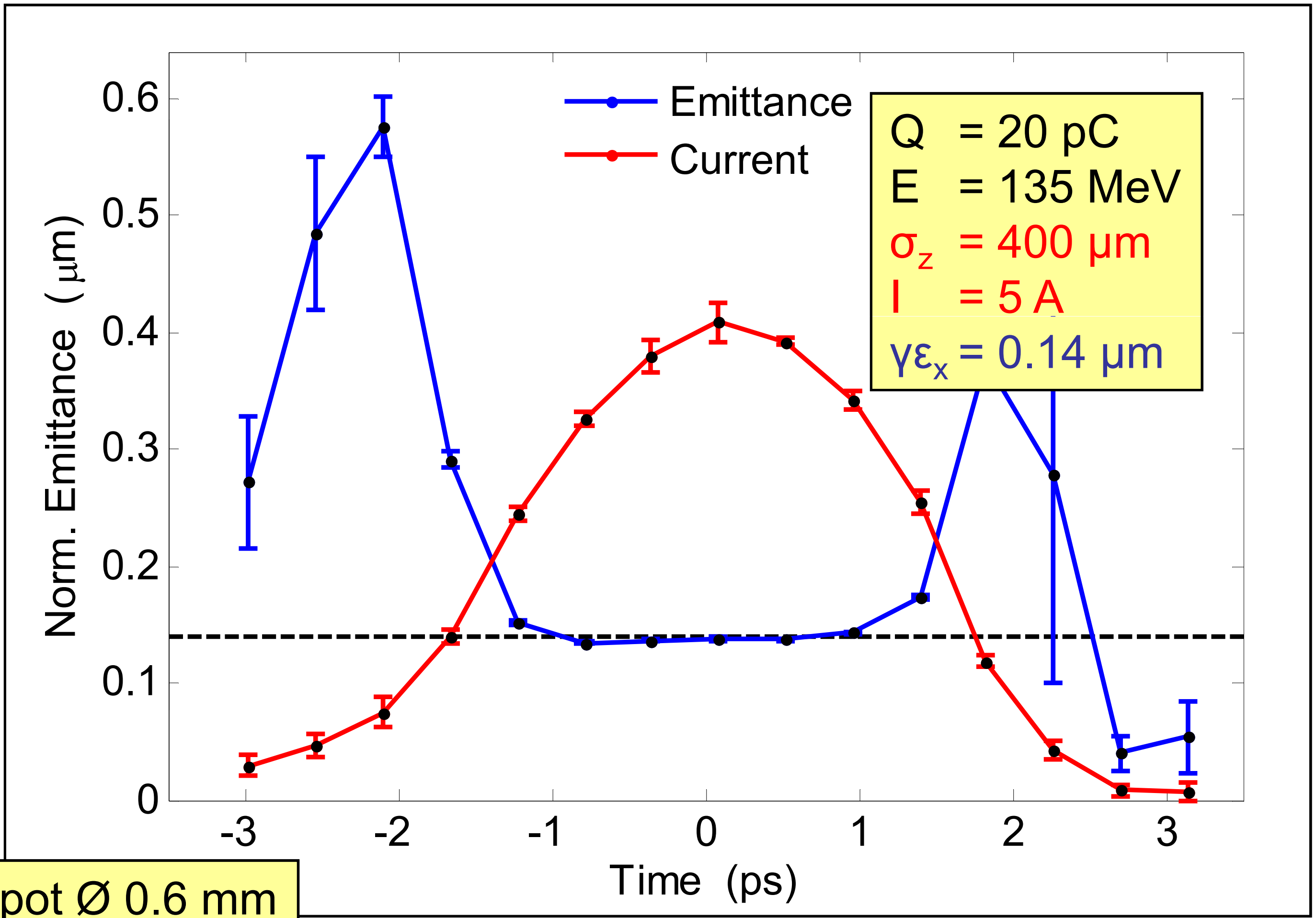


Emittance measured at OTR screen with upstream quad scan for 95% charge

Iterative Optimization with gun solenoid & quads, steering correctors, and matching to design Twiss

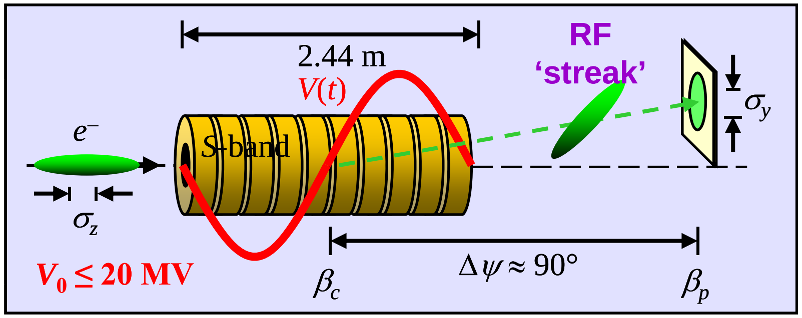
For 1 nC
$\gamma\varepsilon_x = 1.07\ \mu m$
$\gamma\varepsilon_y = 1.11\ \mu m$

Low Charge Time Slice Emittance

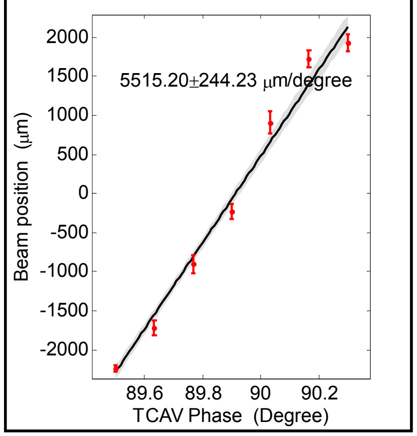


Laser Spot Ø 0.6 mm

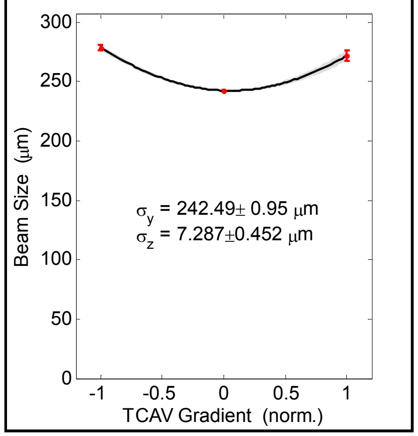
Bunch Compression in BC2



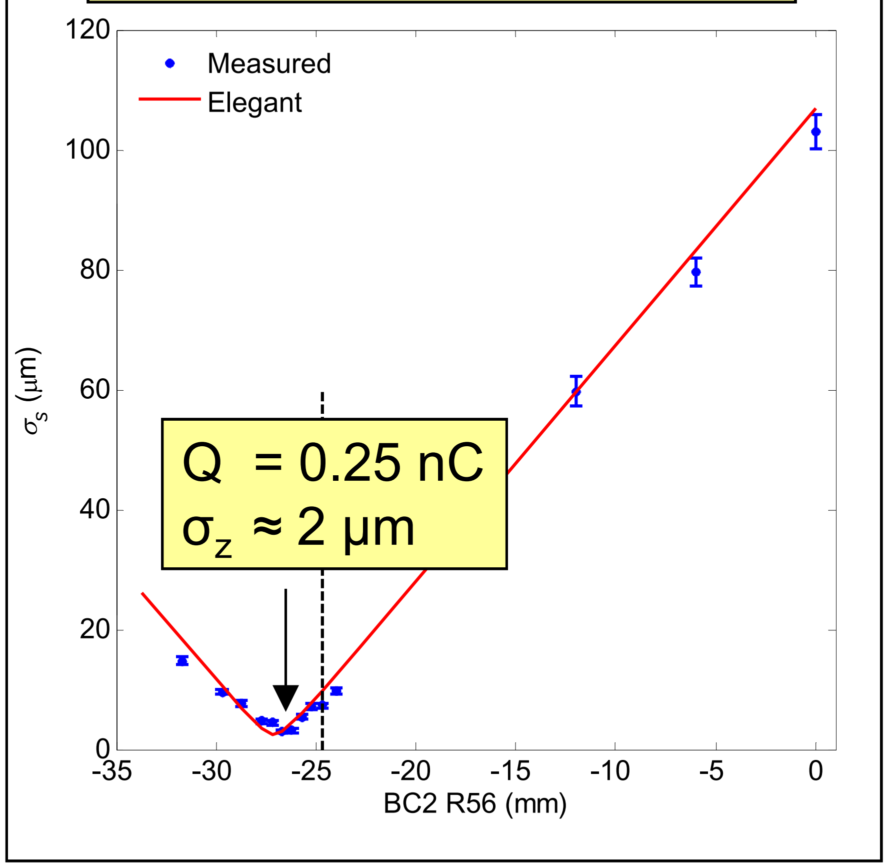
Calibration



Measurement



Bunch Length vs. Compression



$Q = 0.25$ nC
$\sigma_z \approx 2$ μm

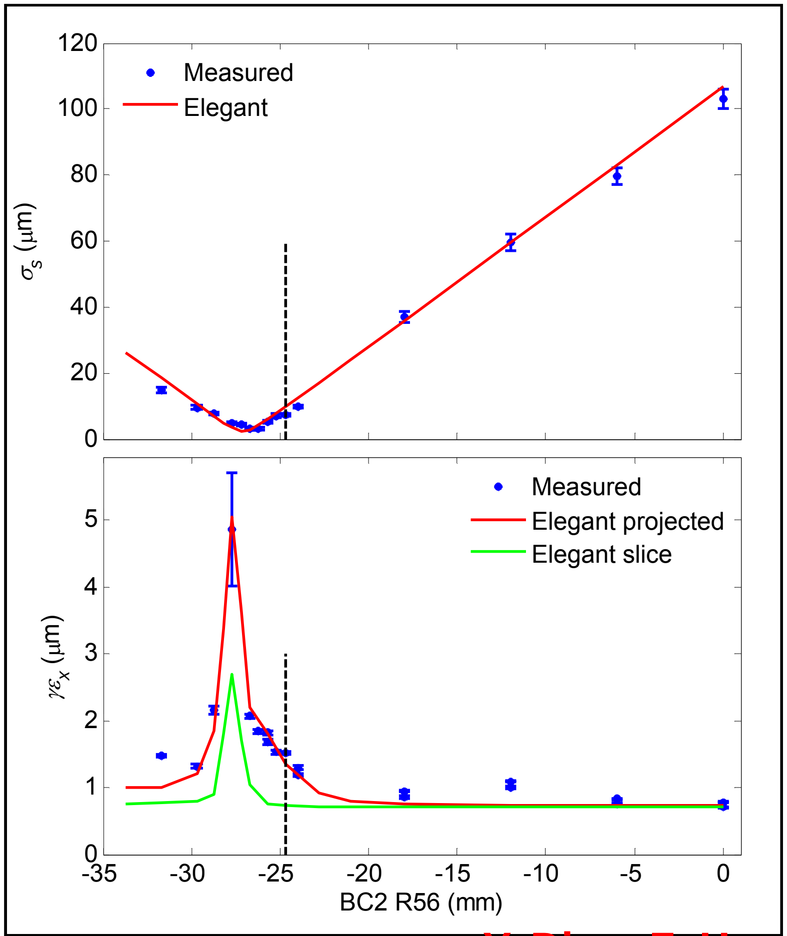
CSR Emittance Growth in BC2

Good agreement with Elegant simulation

Confirms 100% projected emittance growth at operating point -24.7 mm R_{56}

Slice emittance not effected at operating point

Also measured CSR energy loss and emittance growth after BC1

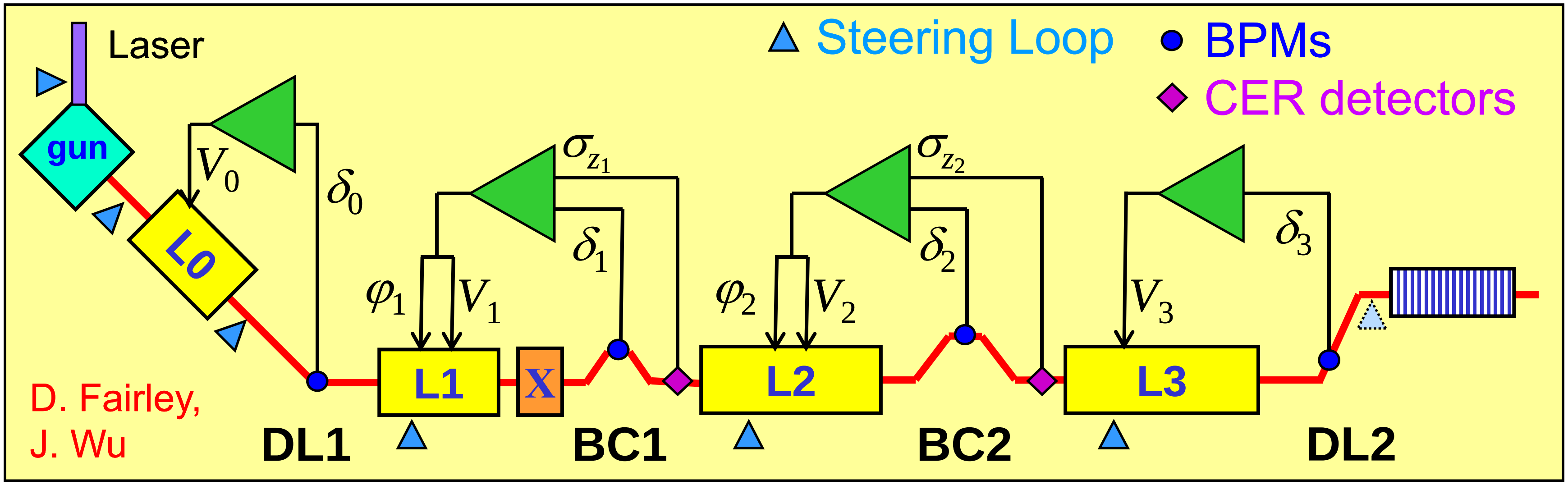


Y. Ding, Z. Huang

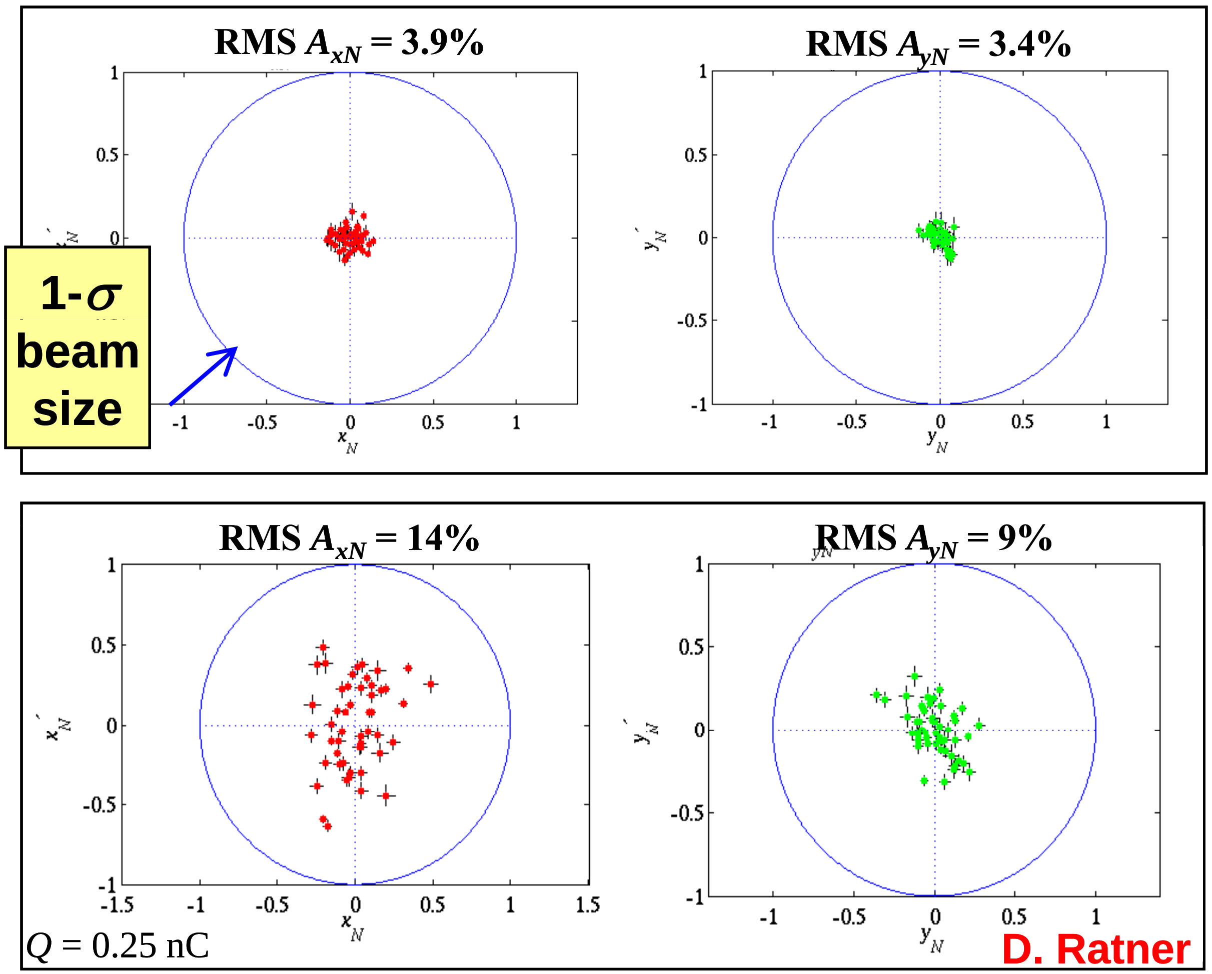
Laser & Electron-Based Feedback Systems

Transverse Loops Stabilize:
- Laser spot on cathode
- Gun launch angle
- Injector trajectory
- X-band cavity position
- Linac trajectory (2)
- Undulator traj. (future)

Longitudinal Loops Stabilize:
- DL1 energy
- BC1 energy
- BC1 bunch length
- BC2 energy
- BC2 bunch length
- Final energy



Normalized Phase Space Centroid Jitter



After BC1
~ 4% of rms beam size

Near end of linac
10-15% of rms beam size
Stability is not so far from the goal (~10%)

ΔE/E jitter ≈ 0.03%
ΔQ/Q jitter ≈ 1.5%

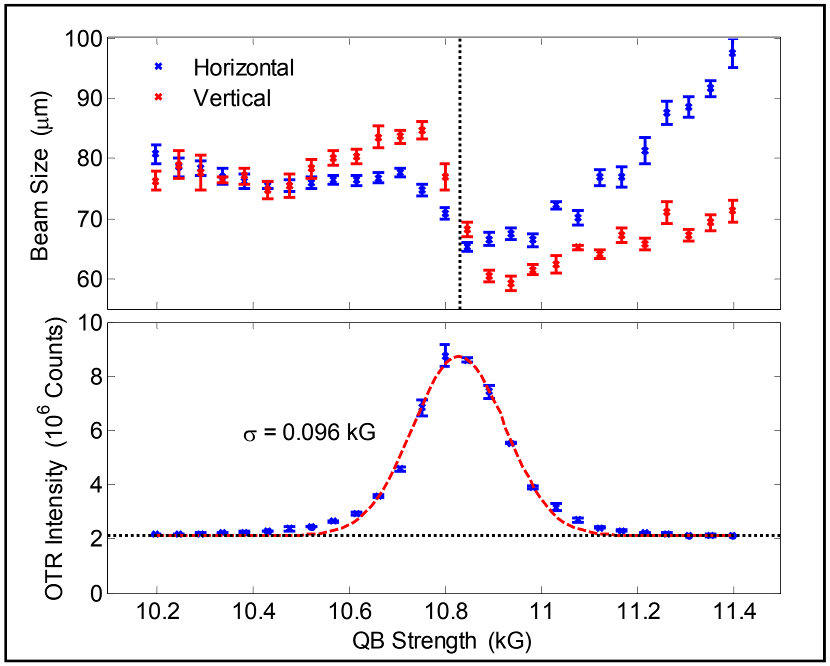
Henrik Loos
loos@slac.stanford.edu

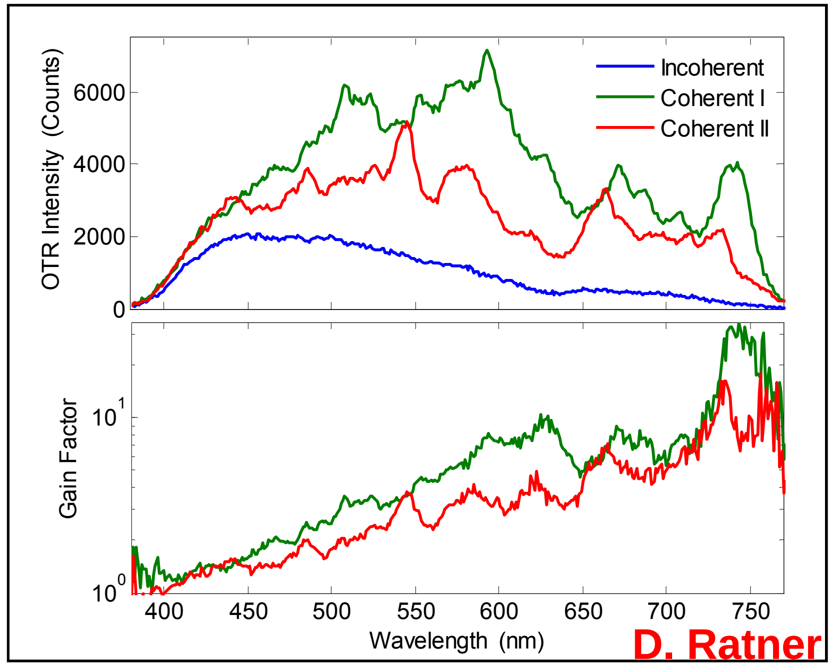
Coherent Radiation Observations

OTR of uncompressed beam DS of DL1

Scan dispersive quad → change $R_{51} \neq 0$
Washout of micro-bunching time structure

Spectrum of OTR & COTR
Gain factor for longitudinal space charge instability agrees with theory assuming 3 keV energy spread





D. Ratner

COTR Transverse Distribution

Observations for highly compressed beams after BC1 & BC2

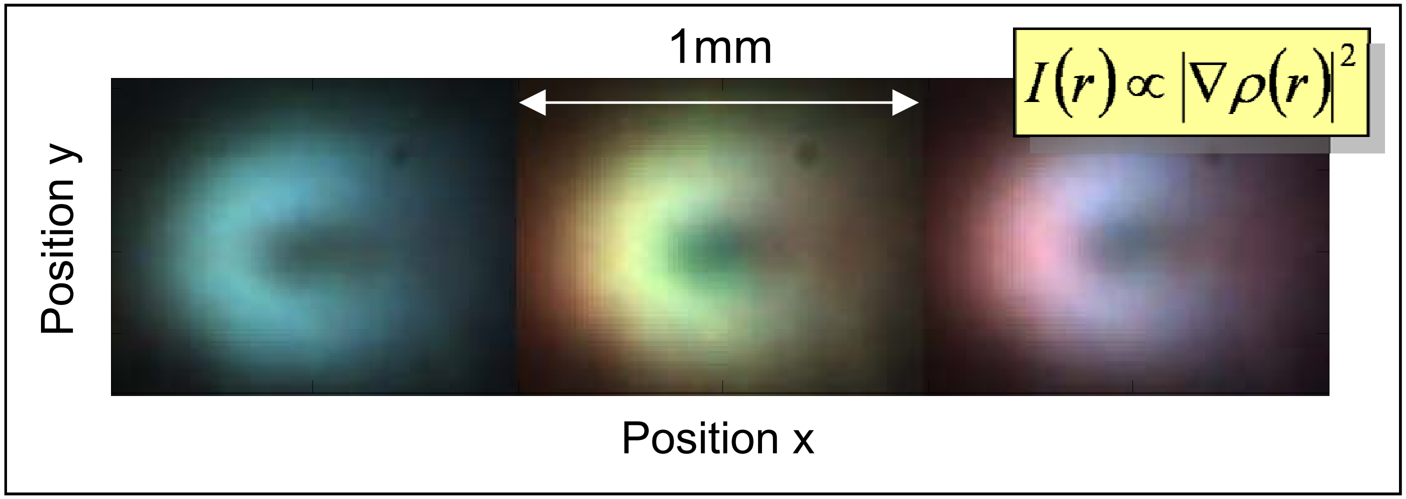
Little resemblance of transverse distribution of COTR to electron beam

Light intensity increases up to 10^5

Fully transverse coherent micro-structure explains doughnut shape

Light intensity increases up to 10^5

Destructive interference creates hole in beam center

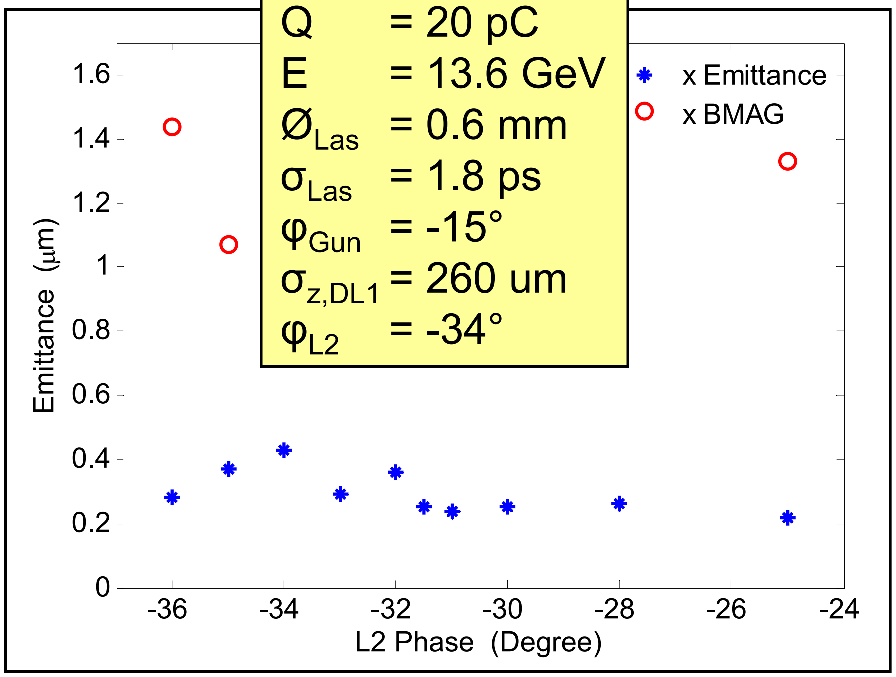


$$I(r) \propto \left|\nabla \rho(r)\right|^2$$

Henrik Loos
loos@slac.stanford.edu

Ultra Short Low Charge Bunch Mode

Utilize high brightness injector beam at 20 pC for ultra short electron and x-ray beam



Q	= 20 pC
E	= 13.6 GeV
$\varnothing_{Las}$	= 0.6 mm
σ_{Las}	= 1.8 ps
φ_{Gun}	= -15°
$\sigma_{z,DL1}$	= 260 um
φ_{L2}	= -34°

Y. Ding, Z. Huang

Initial experiment

Small CSR increase to from 0.2 µm to 0.4 µm at max compression

1 µm bunch length supported by COTR enhancement of 10^4 at max compression

Elegant Simulations

Bunch length 0.8 µm (max compr.) – 1.4 µm (over compr.)

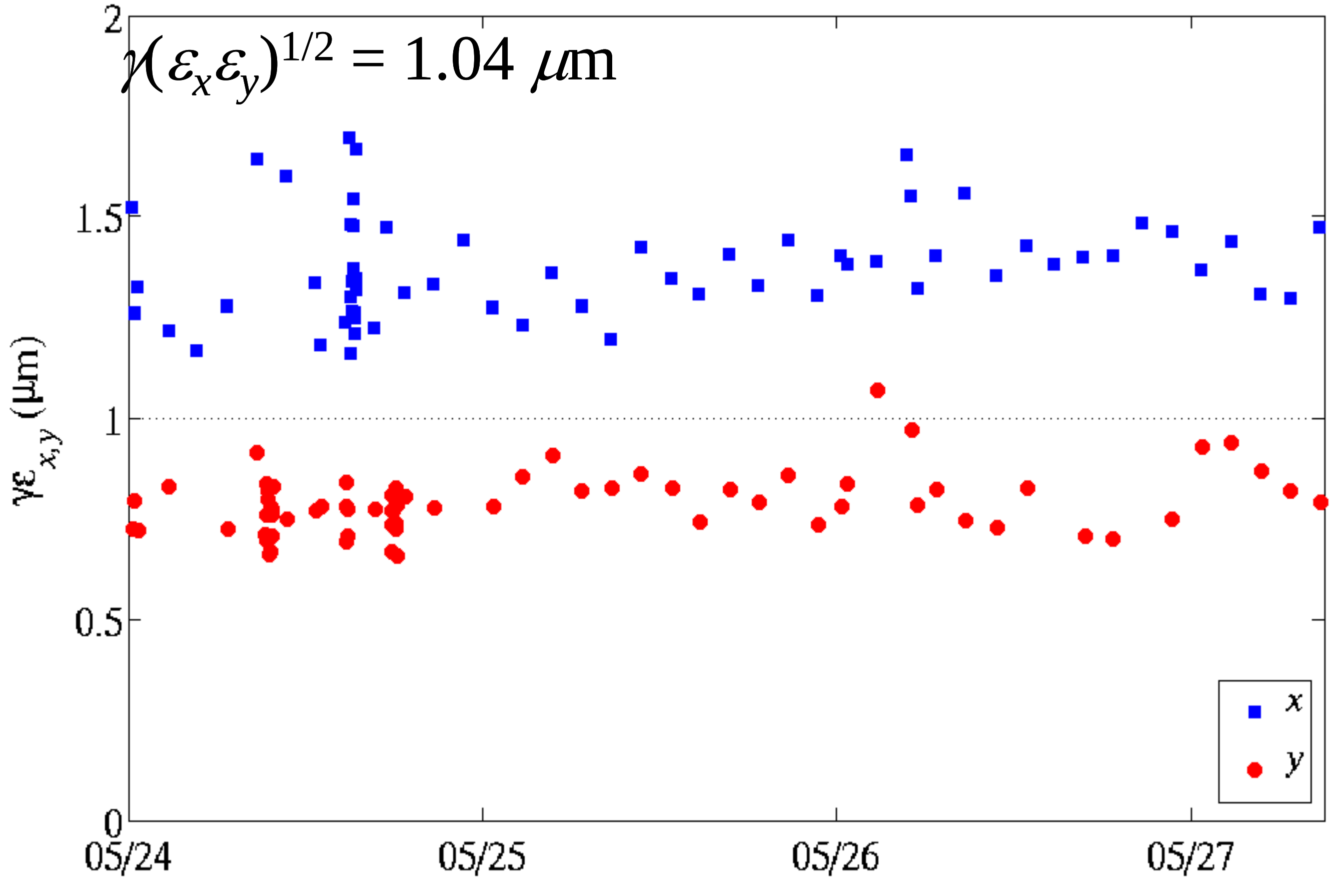
Up to 4 kA peak current

FEL Simulations at 1.5 Å

$3.6 \cdot 10^{11}$ photons

300 GW power during 2 fs x-ray pulse

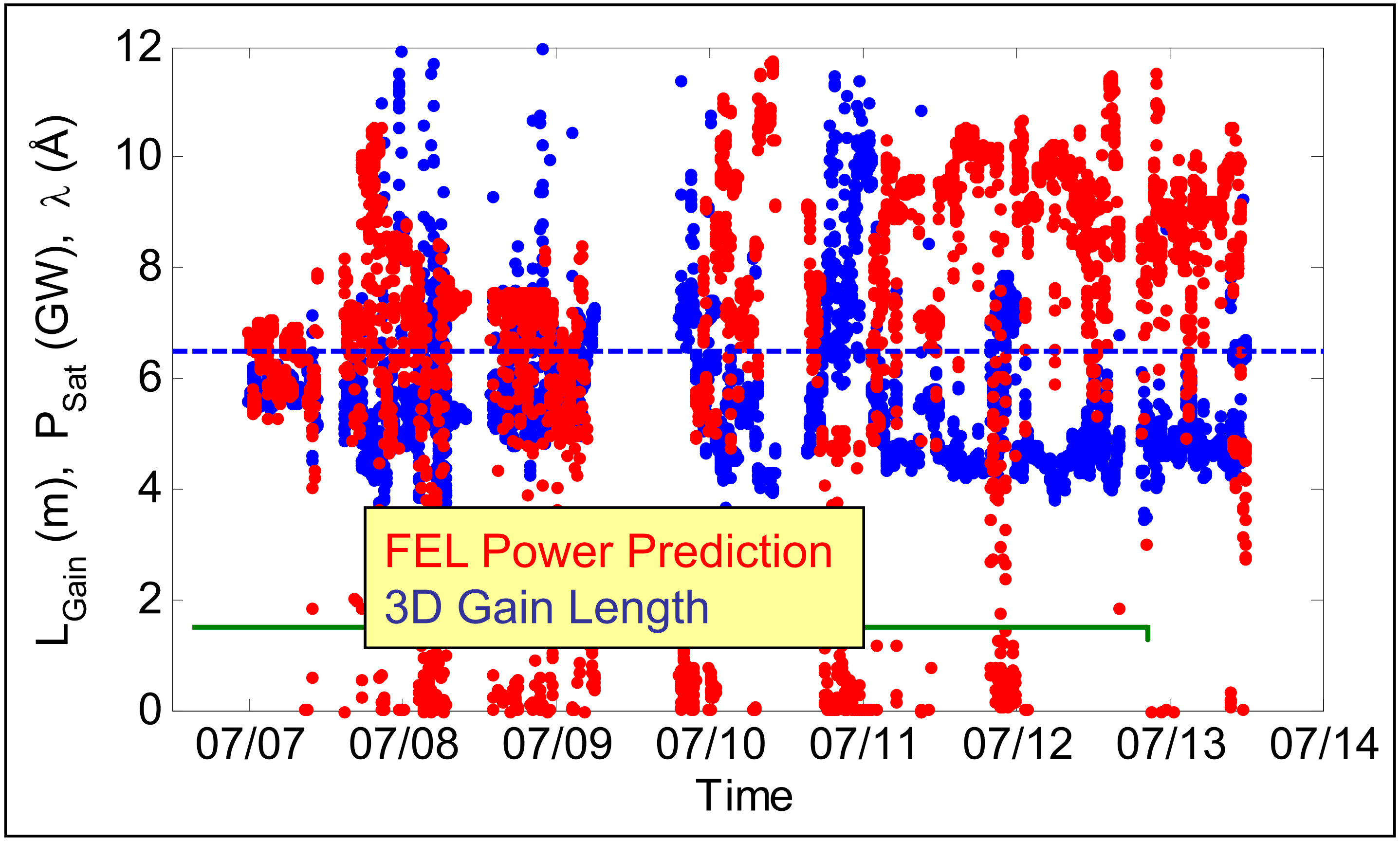
Emittance Near End of Linac Over Weekend



(3.3 days) May 24, 2008 00:01 to May 27 09:00

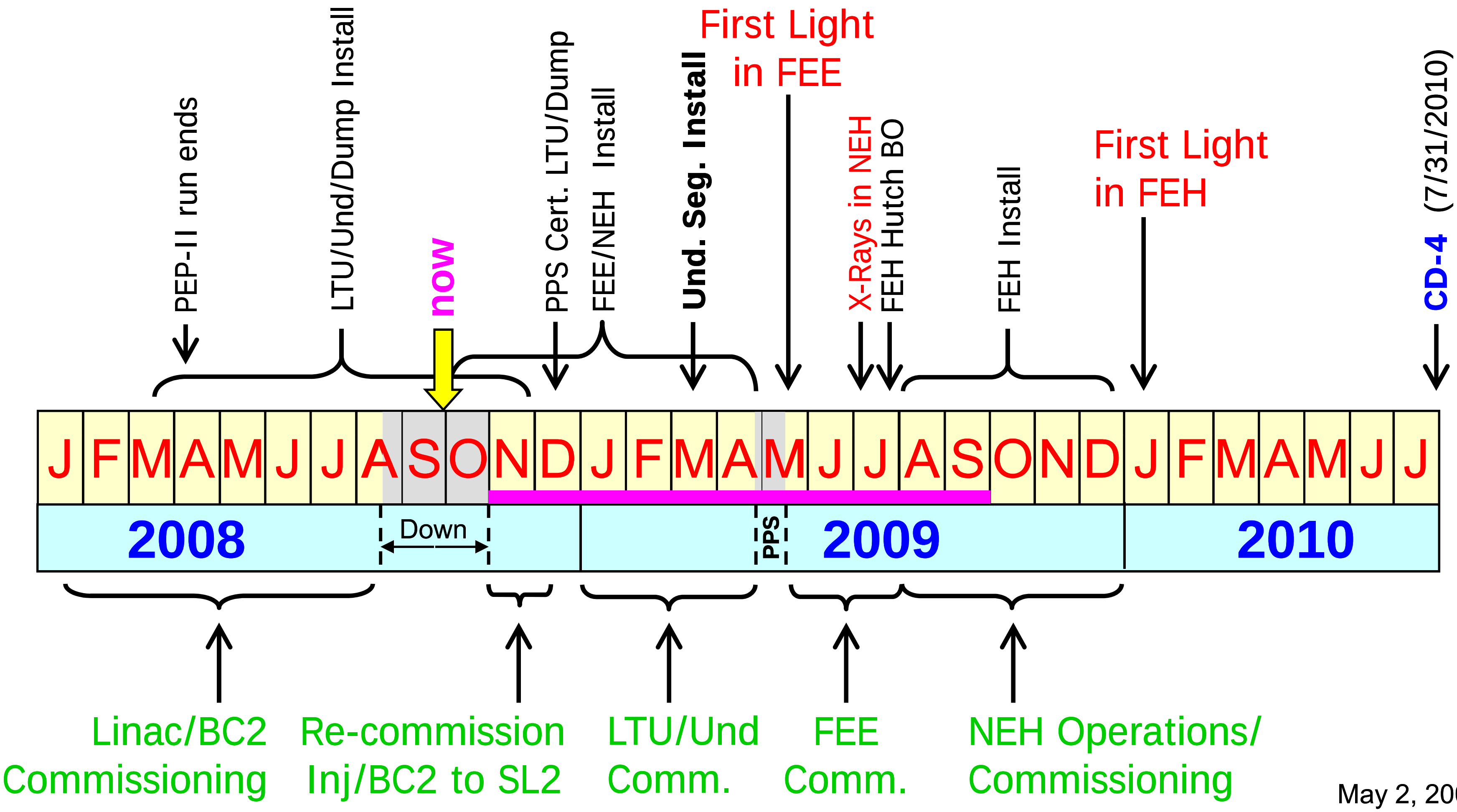
long weekend run at 0.25 nC with no tuning

Electron Beam Reaches Brightness for 1.5 Å



Gain length and saturation power calculated from measured electron beam parameters

LCLS Installation and Commissioning Time-Line



May 2, 2008

LCLS Commissioning Team

R. Akre
A. Brachmann
F.J. Decker
Y. Ding
D. Dowell
P. Emma
J. Frisch
S. Gilevich
G.R. Hays
Ph. Hering
Z. Huang
R. Iverson
C. Limborg-Deprey
H. Loos
A. Miahnahri
S. Molloy
H.-D. Nuhn
D. Ratner
J. Turner
J. Welch
W. White
J. Wu

Henrik Loos
loos@slac.stanford.edu