Lecture 12: Architecture of An Injector for 4^{th} Generation Light Sources

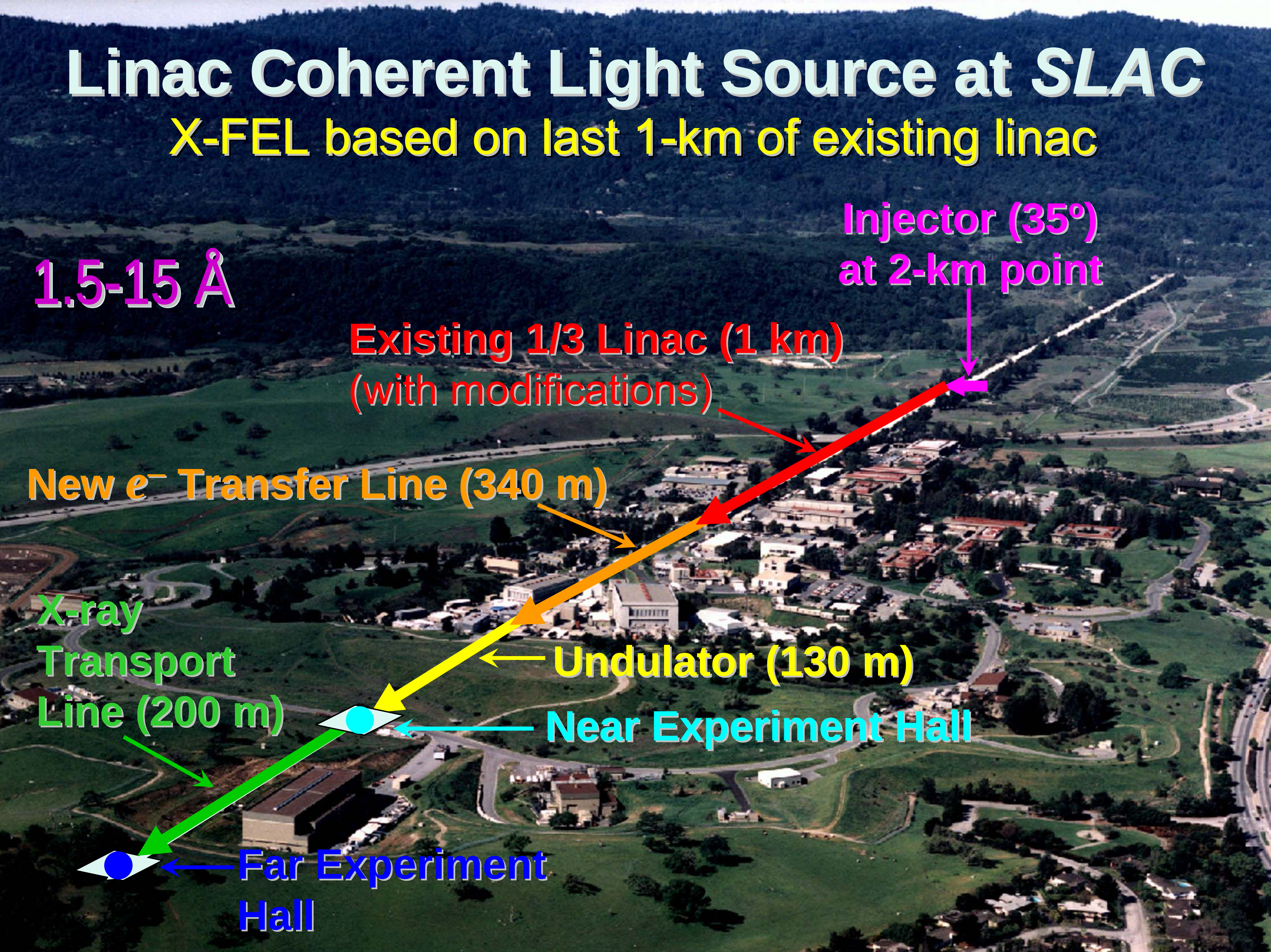
D. H. Dowell, SLAC

- *The objective of this lecture is to describe the components and their functions of a high-brightness injector for SASE light source.*
- *The student will learn what is required to meet the stringent beam requirements for 4^{th} generation light sources operating in the x-ray region. The LCLS facility is used as the archetypal light source.*

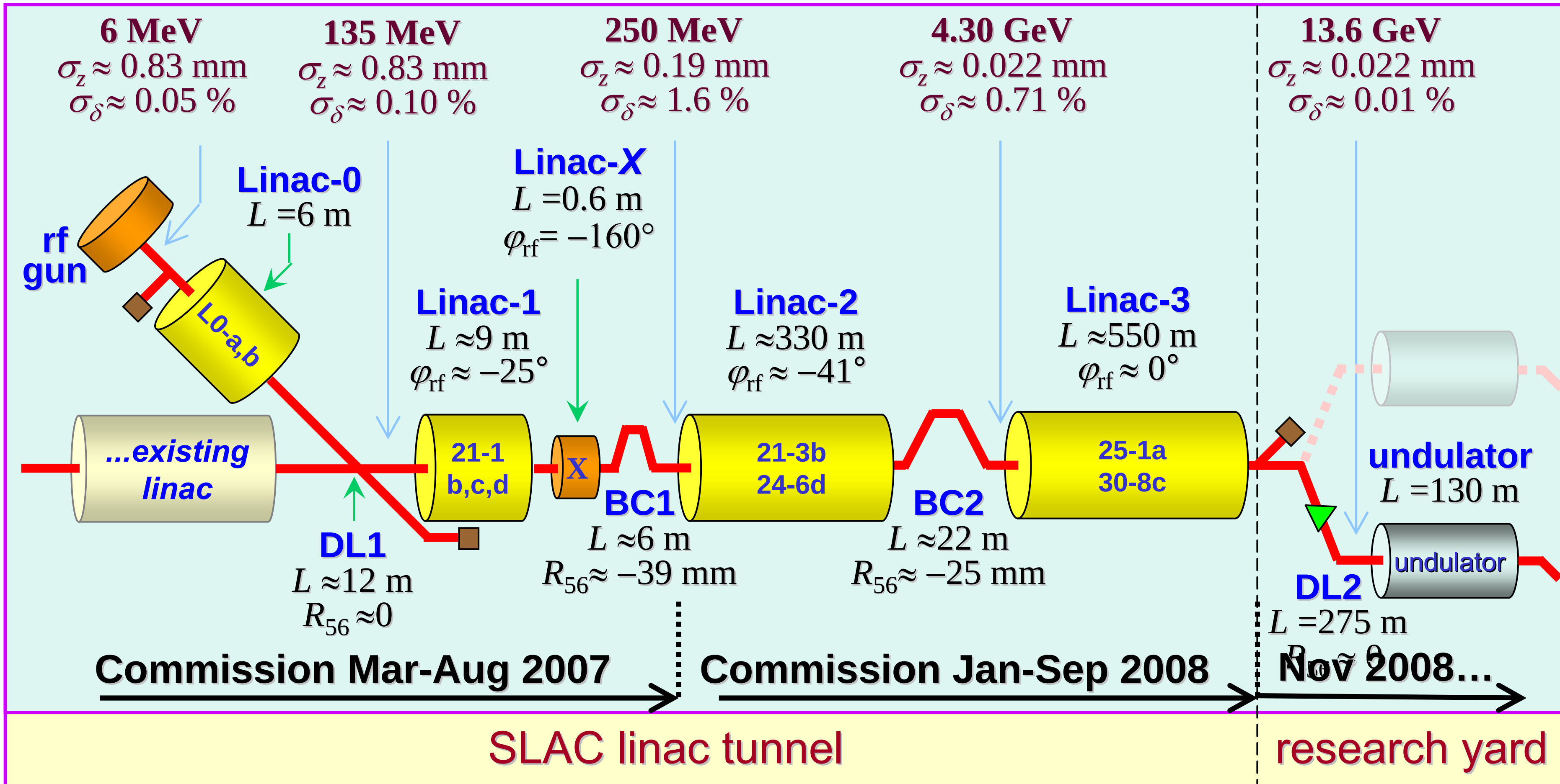
LCLS Design Parameters

Fundamental FEL Wavelength	*1.5*	*15*	*Å*
Electron Beam Energy	*13.6*	*4.3*	*GeV*
Normalized Slice Emittance (rms)	*1.2*	*1.2*	*mm-mrad*
Peak Current	*3.4*	*3.4*	*kA*
Energy Spread (slice rms)	*0.01*	*0.03*	*%*
Bunch/Pulse Length (FWHM)	*≤ 200*	*≤ 200*	*fs*
Saturation Length	*87*	*25*	*m*
FEL Fundamental Power @ Saturation	*8*	*17*	*GW*
FEL Photons per Pulse	*1*	*29*	10^{12}
Peak Brightness @ Undulator Exit	*0.8*	*0.06*	10^{33} *

** photons/sec/mm²/mrad²/ 0.1%-BW*

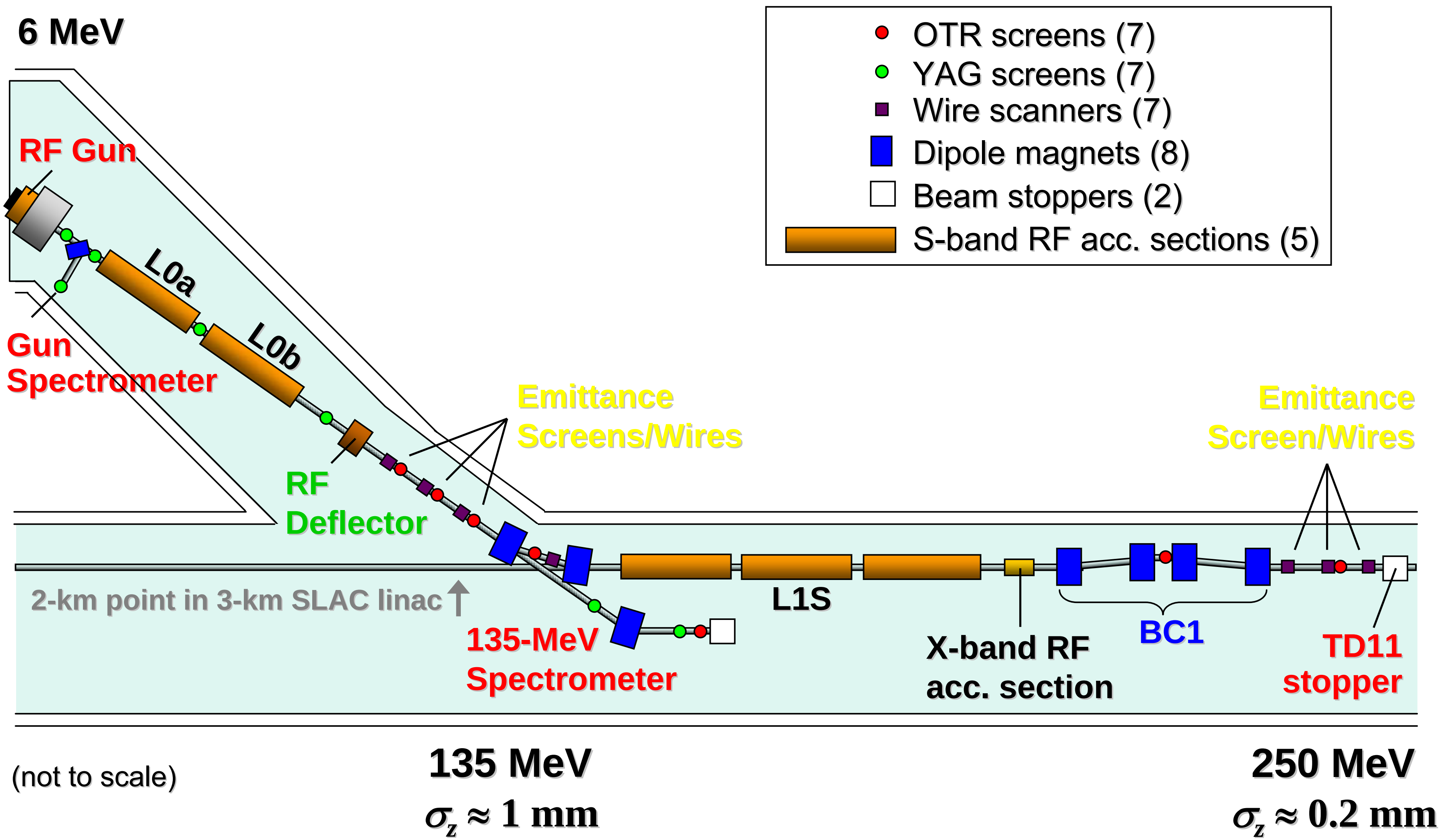

Linac Coherent Light Source at *SLAC*
X-FEL based on last 1-km of existing linac
1.5-15 Å
Injector (35º) at 2-km point
Existing 1/3 Linac (1 km)
(with modifications)
New e^- Transfer Line (340 m)
X-ray Transport Line (200 m)
Undulator (130 m)
Near Experiment Hall
Far Experiment Hall

LCLS Accelerator Schematic

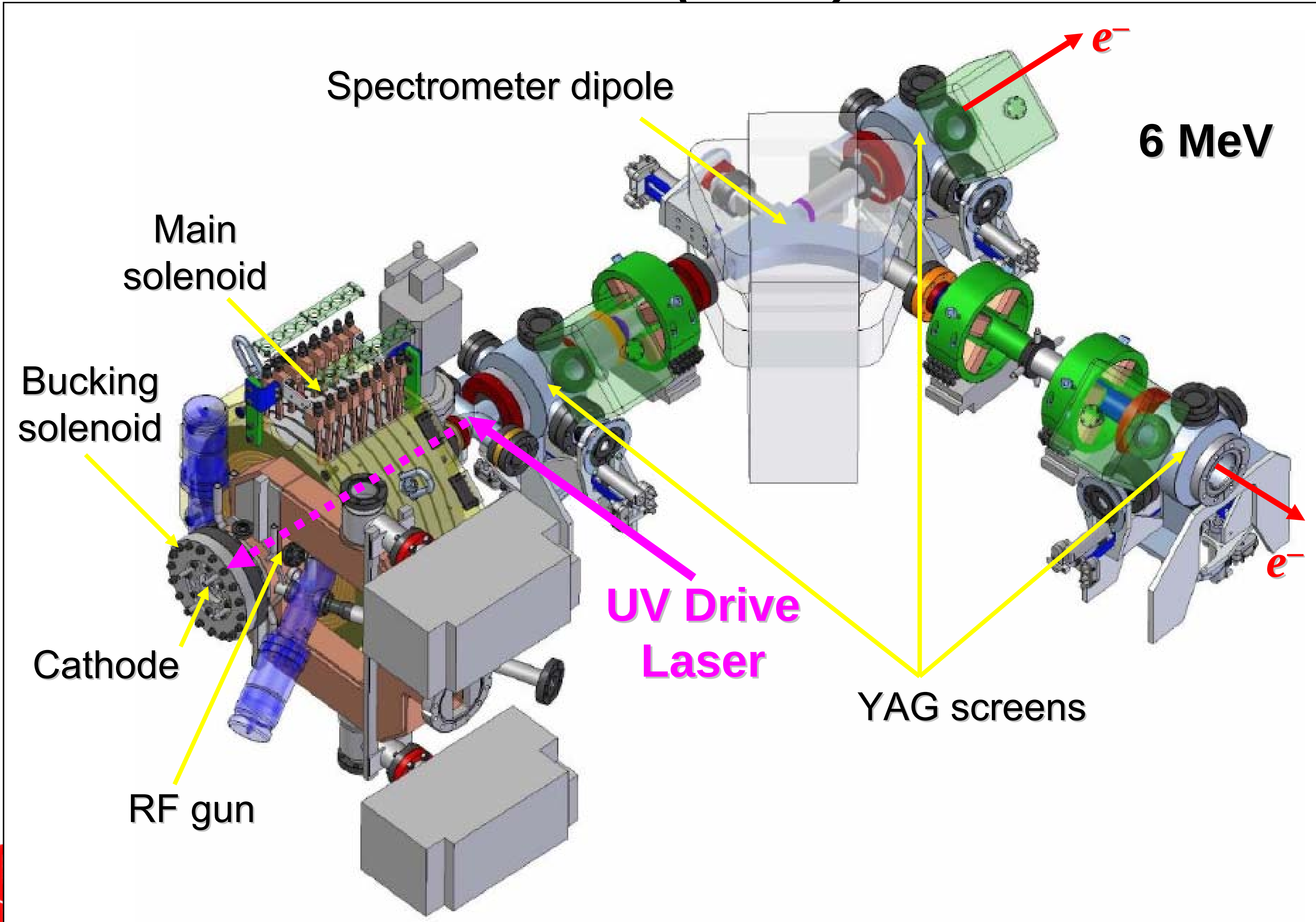


X-rays in spring 2009

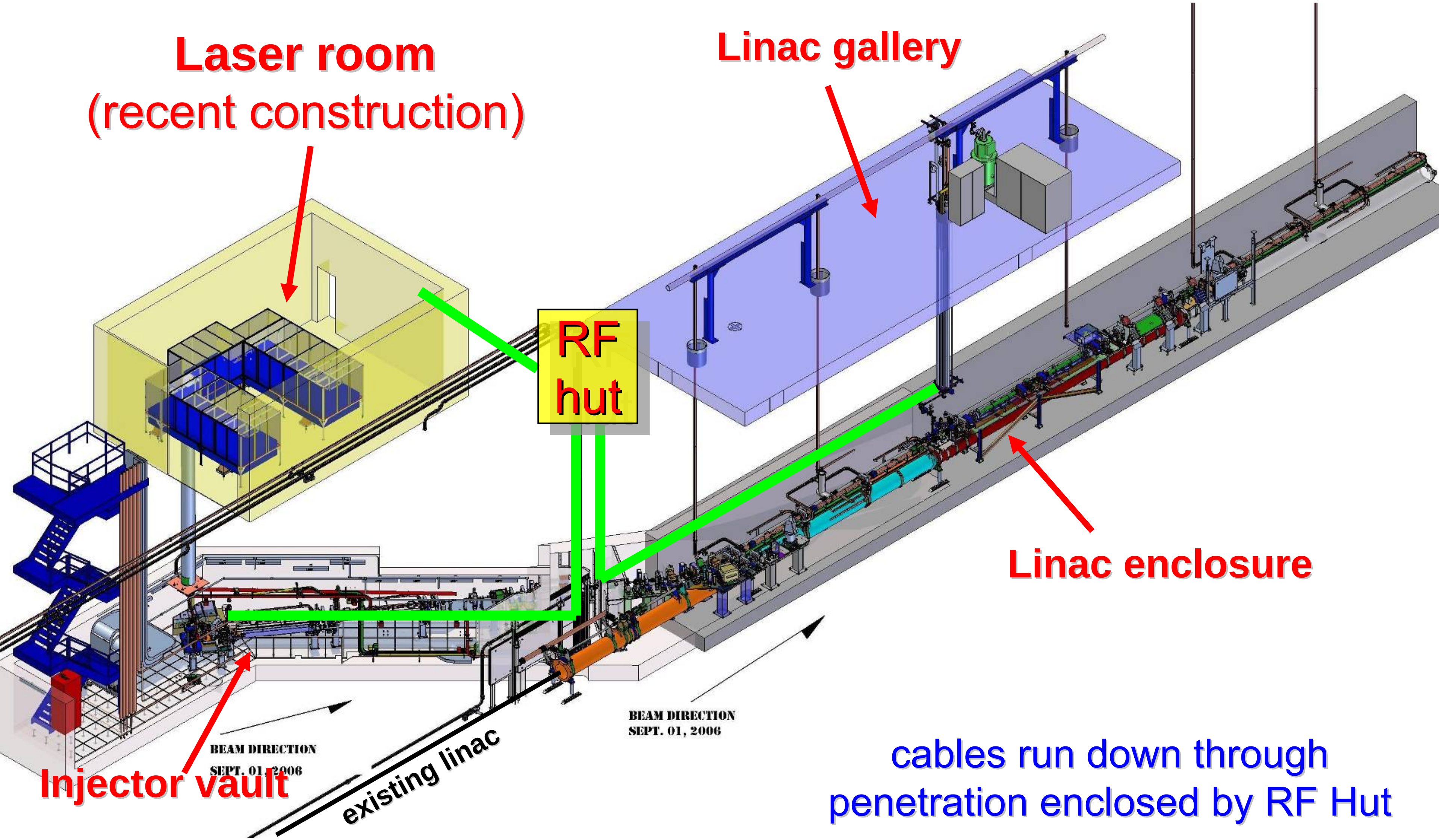
LCLS Injector Layout



Gun-To-Linac (GTL) Section

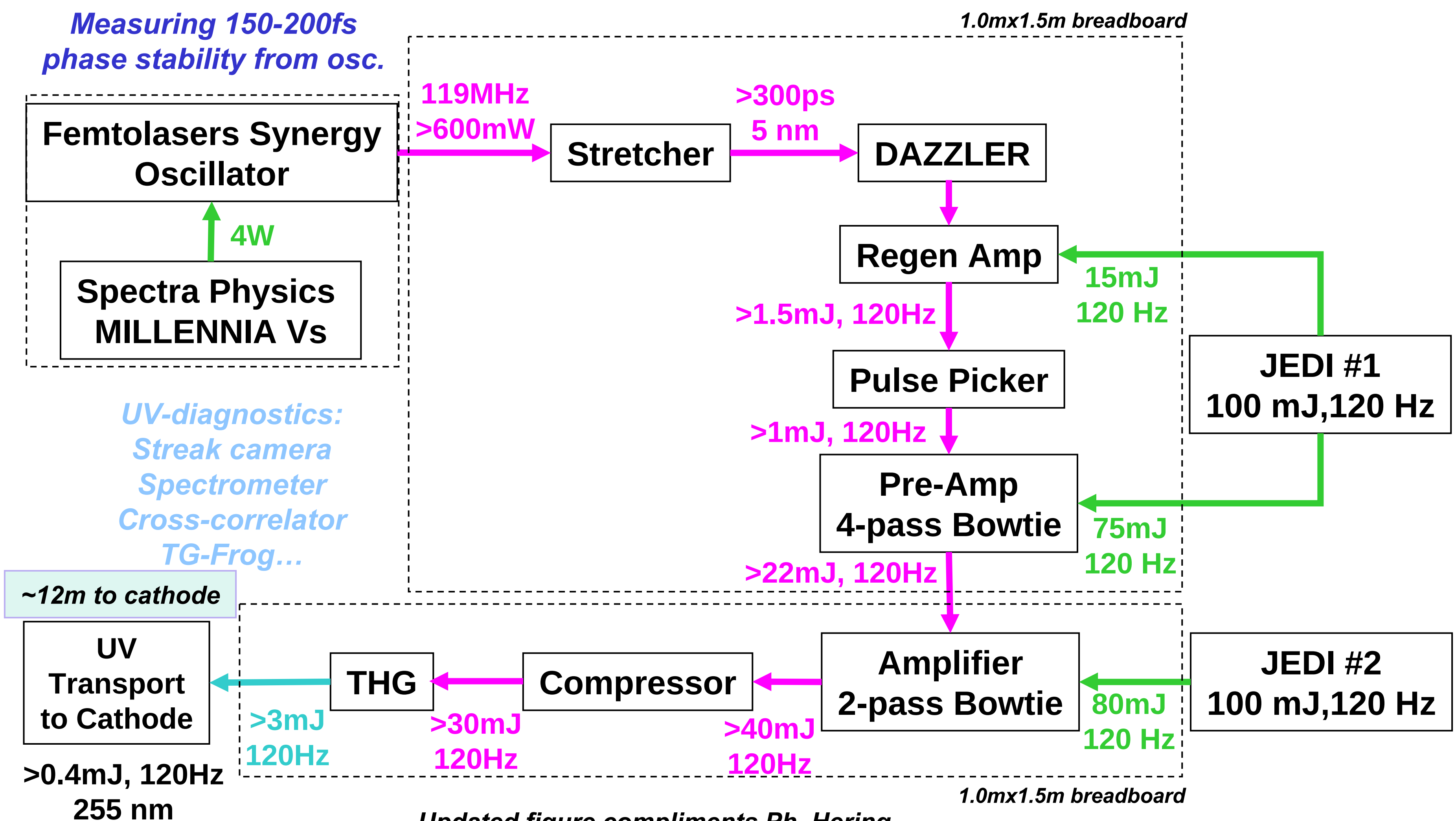


Laser Room and Injector Vault



cables run down through penetration enclosed by RF Hut

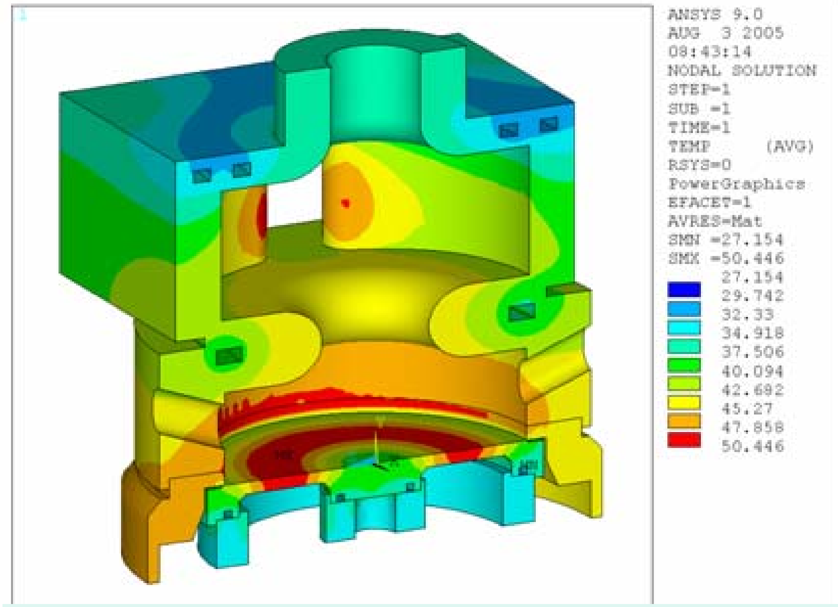
Thales Drive Laser System



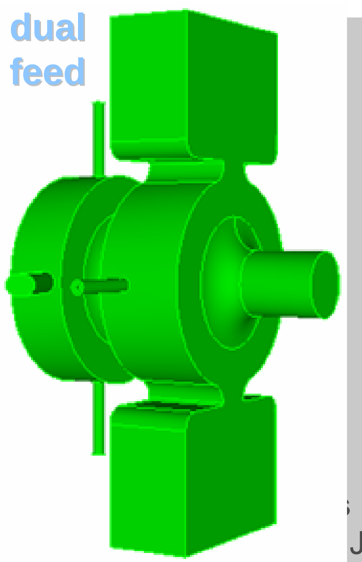
Updated figure compliments Ph. Hering

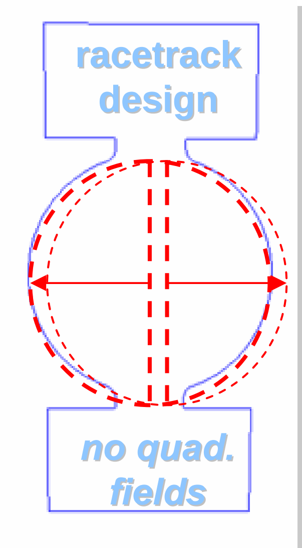
RF Photo-Cathode Gun

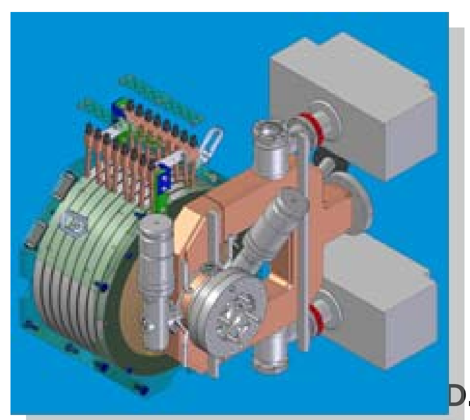
- ***1.6-cell S-band (2856 MHz - BNL/SLAC/UCLA)***
- ***Copper cathode***
- ***120-Hz repetition rate***
- ***140-MV/m cathode field (max)***
- ***Axially symmetric RF fields***
- ***Dual RF-feed***



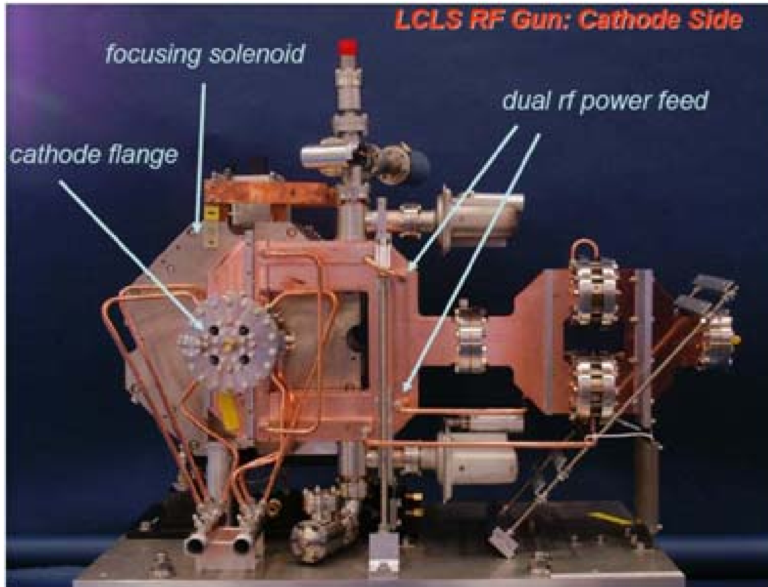
ANSIS model of thermal profile

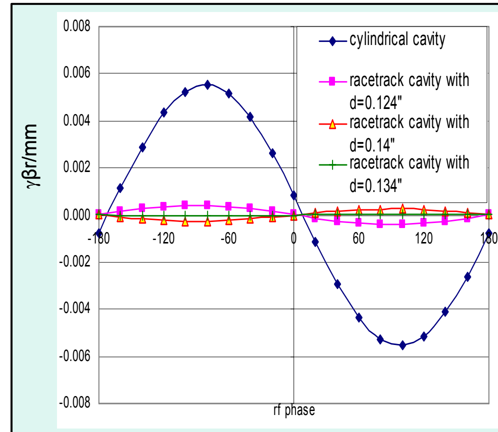


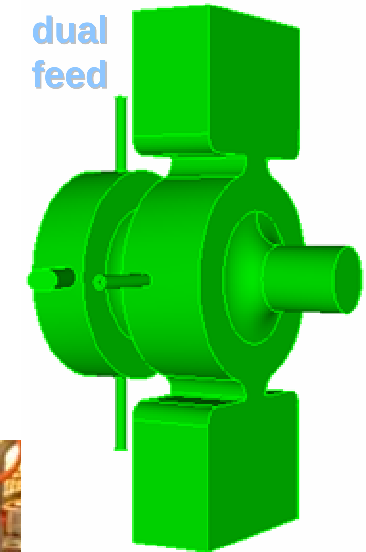


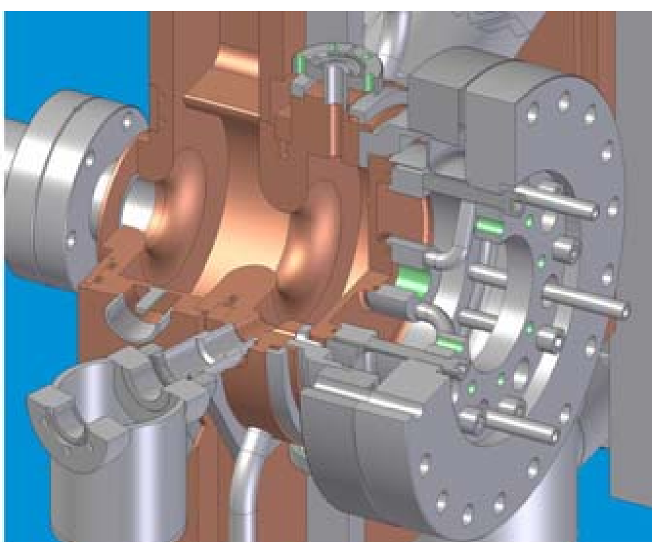


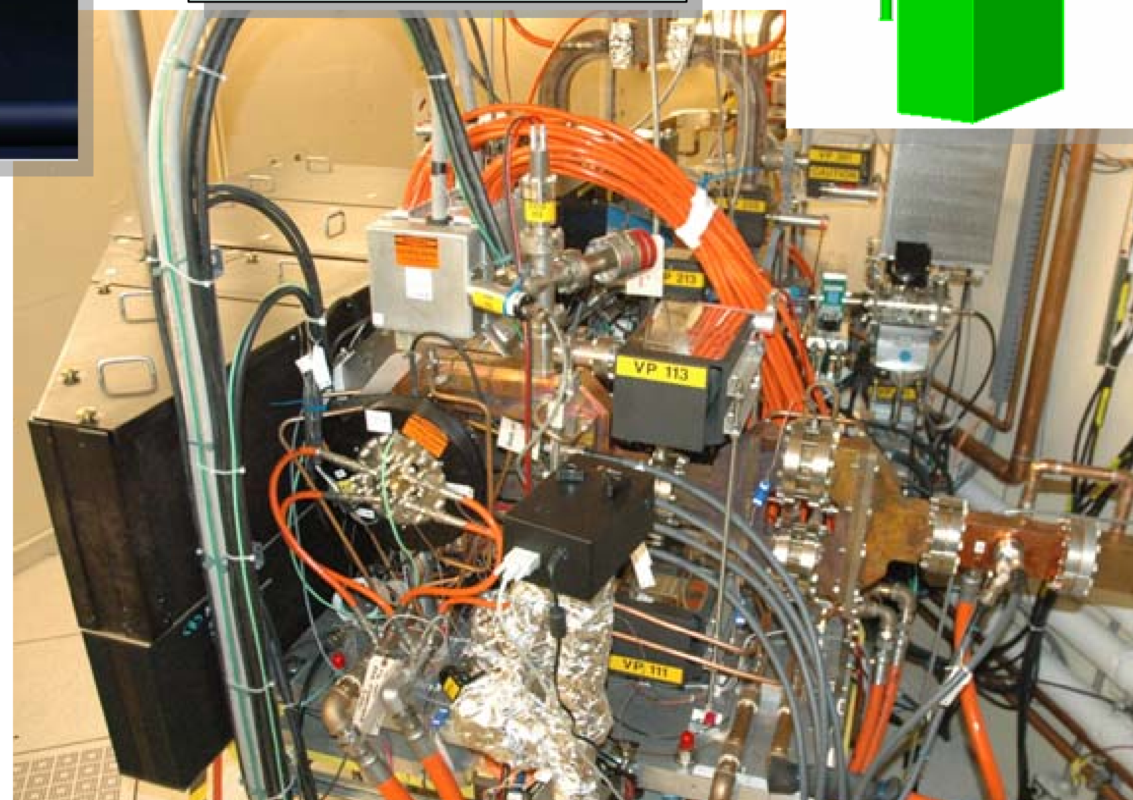
Details of the RF Gun and GTL









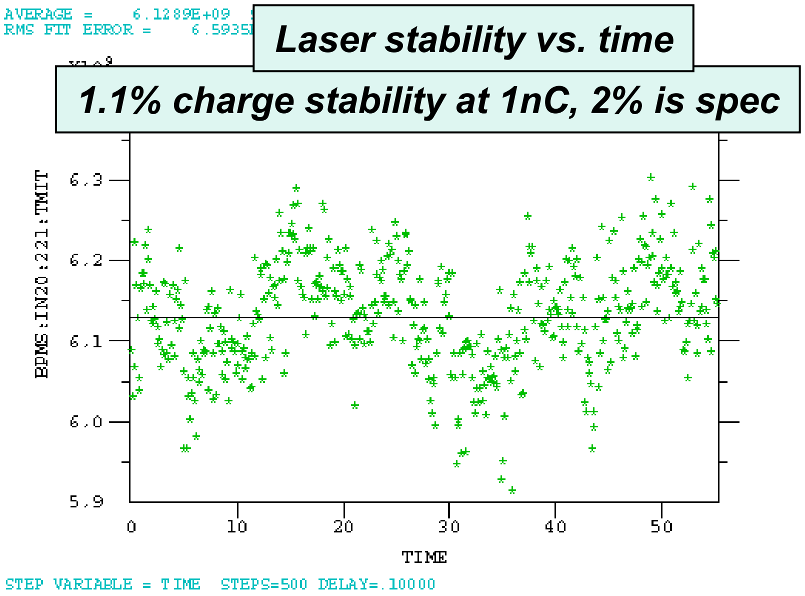


Drive Laser Performance

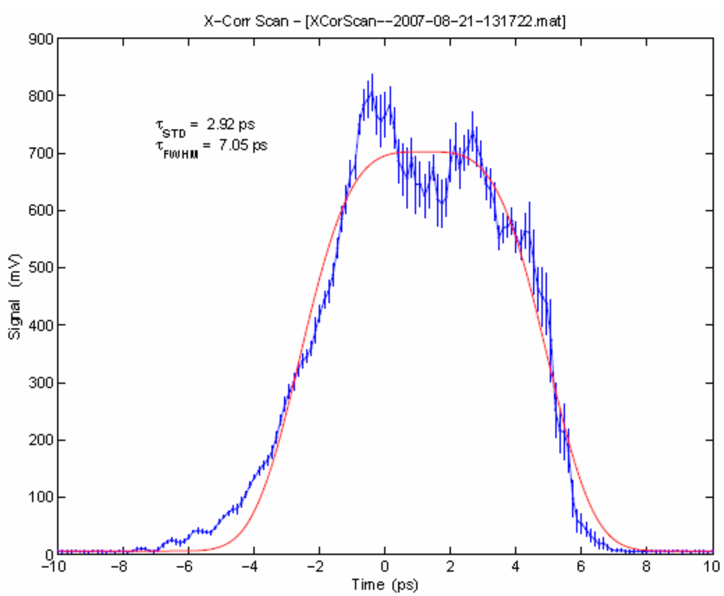
- *Laser reliability is very good: Up-time > 90%*
  - *Excellent support from Thales & Femtolasers*
- *Delivering > 400 microJoules to cathode (250 is spec)*
- *Shaping needs work, but still producing good emittances*
- *Excellent energy stability (1.1%)*
- *Position stability on cathode, ~10-20 microns.*

Laser stability vs. time

1.1% charge stability at 1nC, 2% is spec



X-Correlator Measurement of Laser Pulse



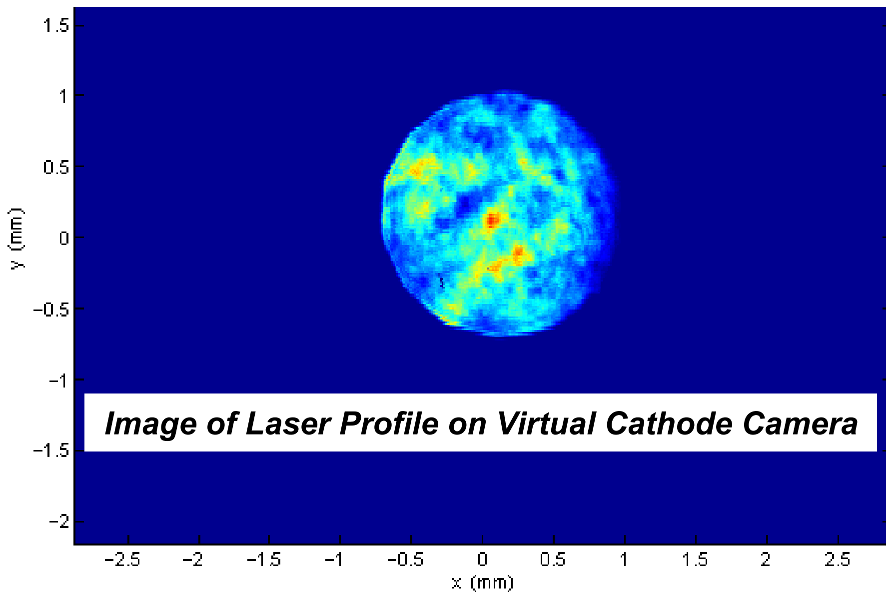
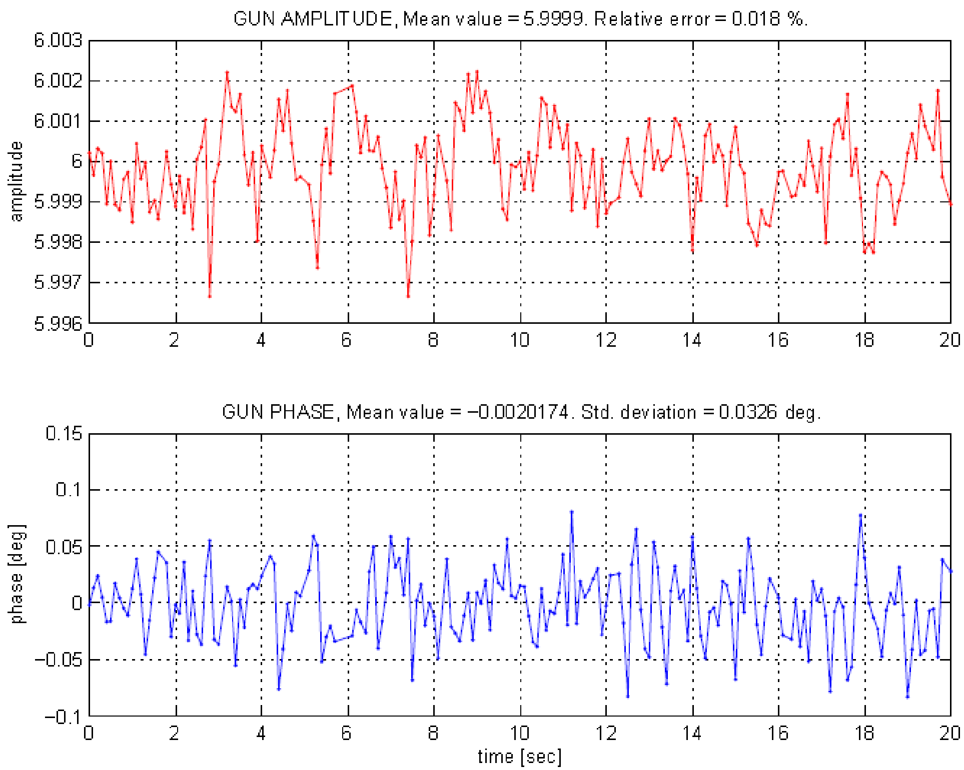


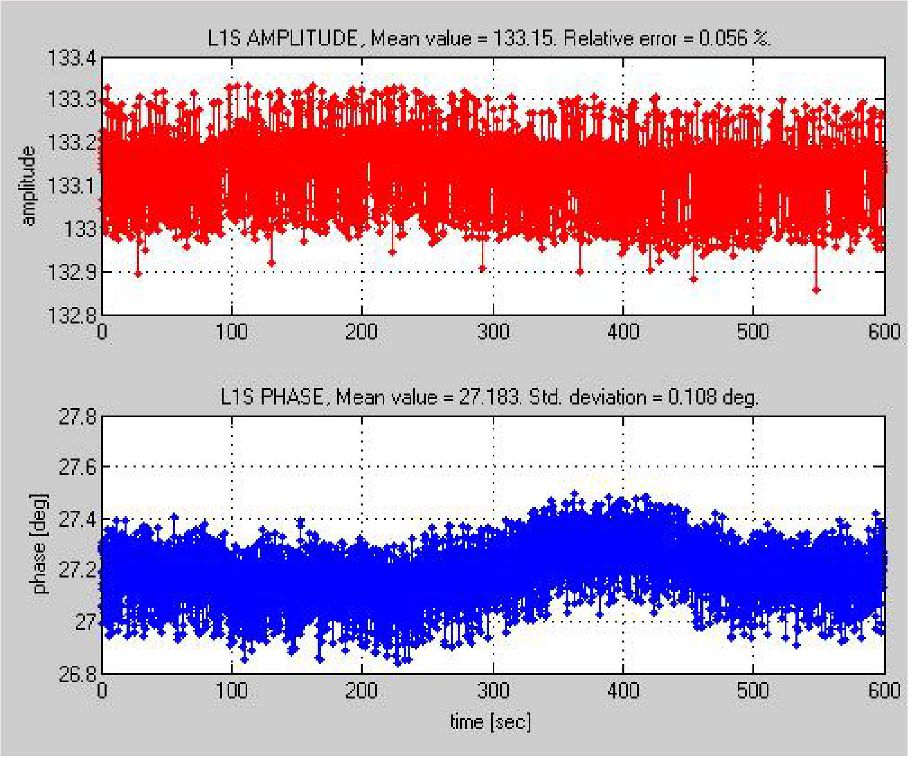
Image of Laser Profile on Virtual Cathode Camera

RF Phase & Amplitude Stability

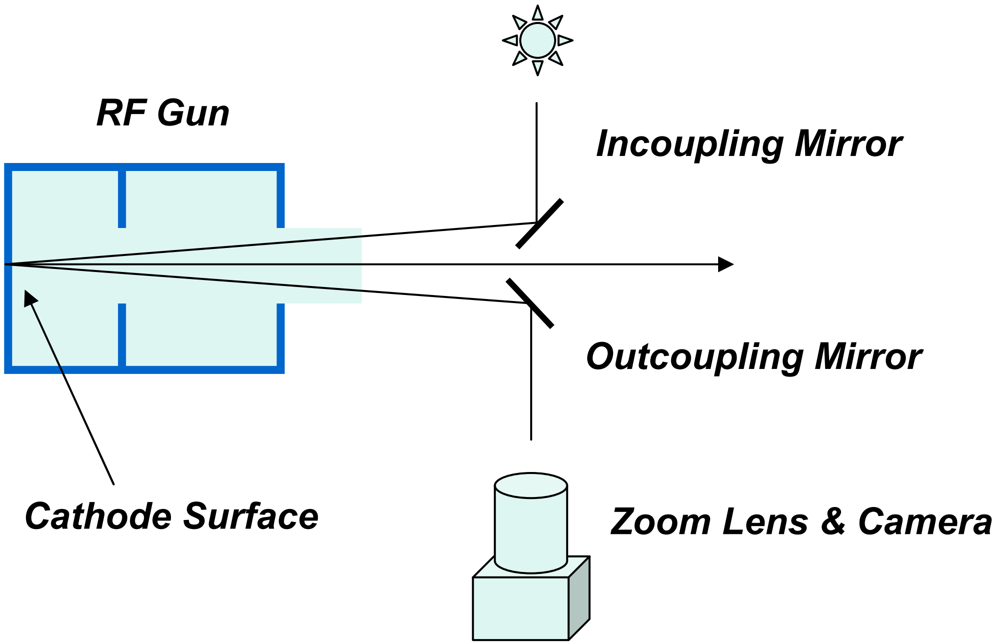
Gun:
rms amplitude error = 0.018%
rms phase error = 0.032 degS



Linac:
rms amplitude error = 0.056%
rms phase error = 0.108 degS

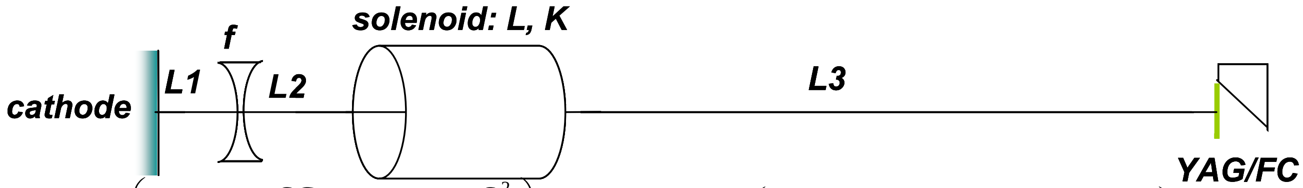


Viewing the Cathode and Laser Mirror Surfaces



- ***Changing the zoom allows imaging of the mirrors and cathode surfaces***

Imaging Cathode Emission on YAG at 5-10 pC

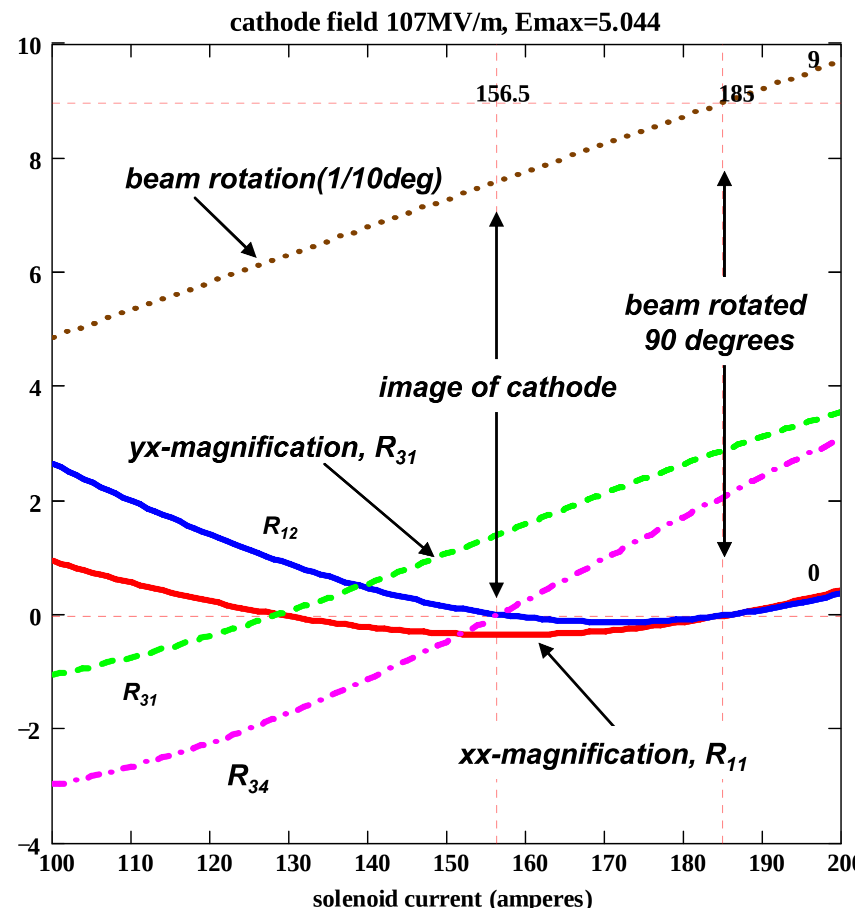


$$R_{YAG} = \begin{pmatrix} 1 & L_3 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} C^2 & \frac{SC}{K} & SC & \frac{S^2}{K} \\ -KSC & C^2 & -KS^2 & SC \\ -SC & \frac{-S^2}{K} & C^2 & \frac{SC}{K} \\ KS^2 & -SC & -KSC & C^2 \end{pmatrix} \begin{pmatrix} 1 & L_2 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_2 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ \frac{E_0 \sin\phi_{exit}}{mc^2} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{E_0 \sin\phi_{exit}}{mc^2} & 1 \end{pmatrix} \begin{pmatrix} 1 & L_1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$K(B_{solenoid}, p_{beam}) = \frac{B_{solenoid}(kG)}{2 \cdot 0.033356\ p_{beam}(MeV/c)} (m^{-1})$$

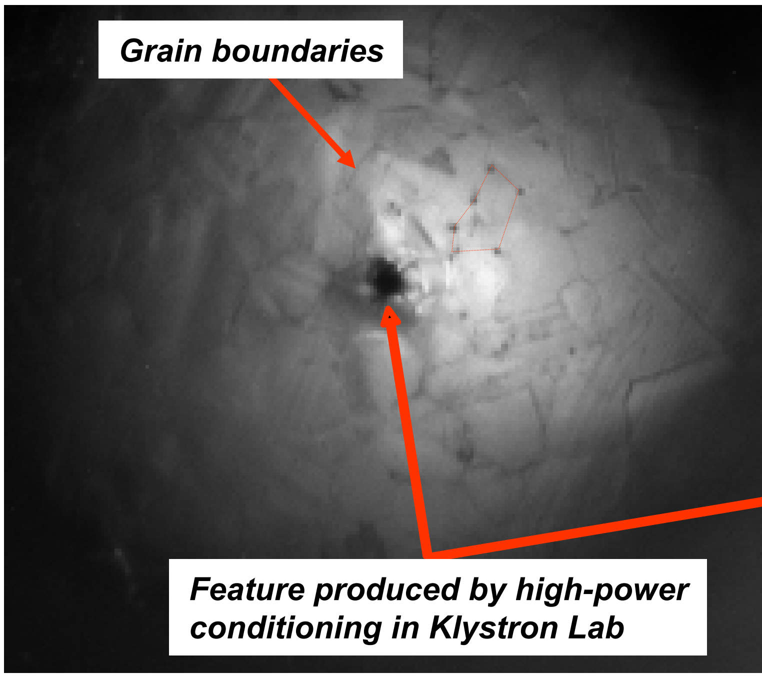
$$S = \sin(KL_{solenoid}) \qquad C = \cos(KL_{solenoid})$$

See: D. H. Dowell, E. Jongewaard, C. Limborg-Deprey, J. Schmerge and A. Vlieks, "Measurement and Analysis of Field Emission Electrons in the LCLS Gun," Proceedings of PAC2007.

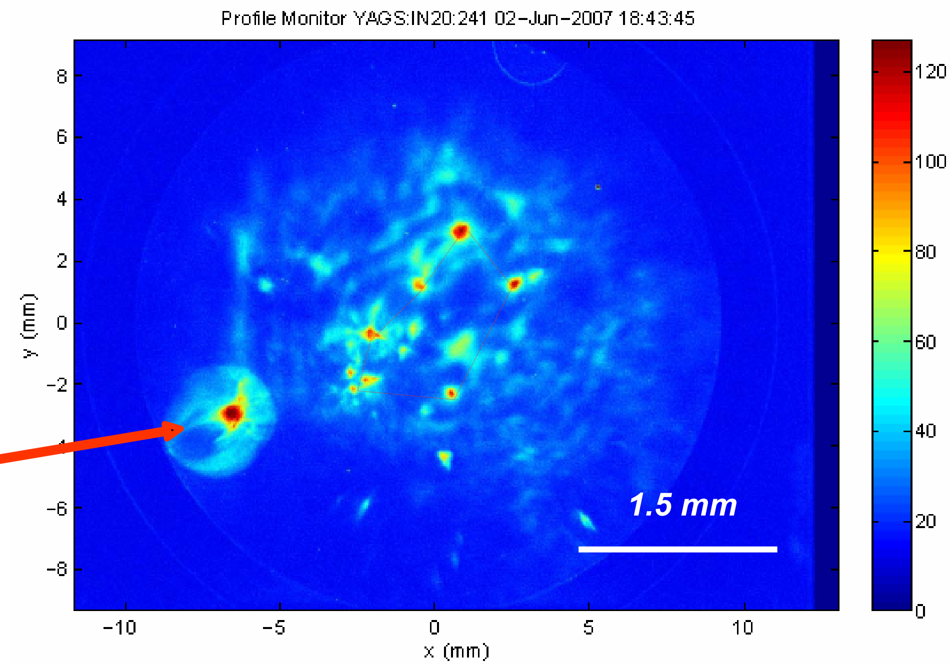


Cathode Uniformity: Comparison of White Light & Electron Emission Images

June 6, 2007
White light cathode image



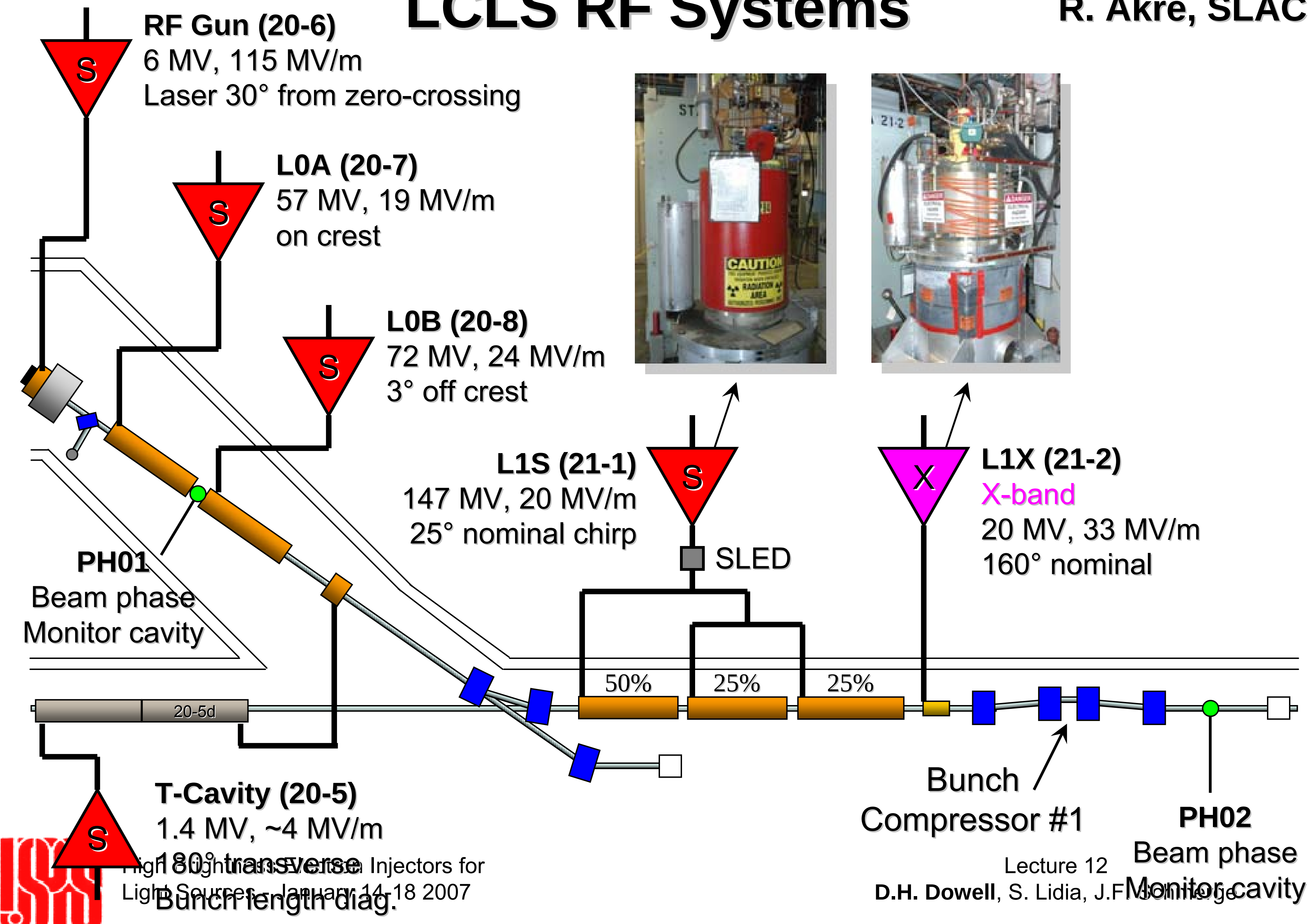
June 2, 2007
Electron beam image of cathode @ ~9pC



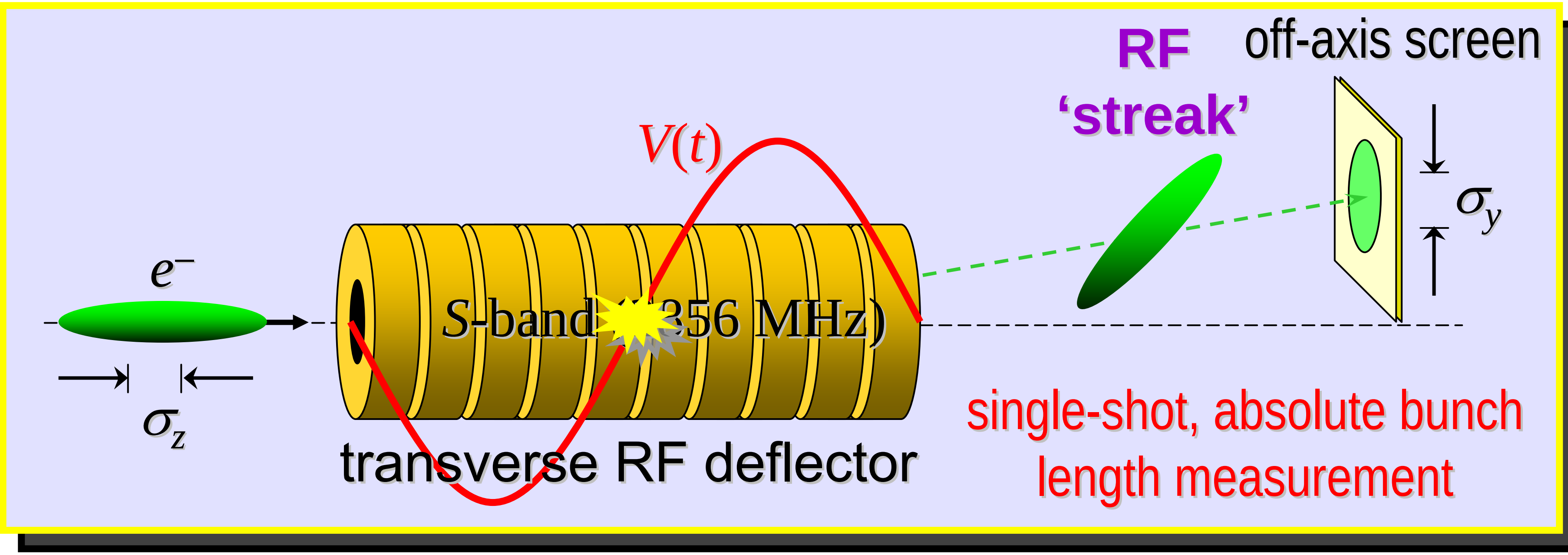
- ***Emission is very non-uniform on the 10-micron scale***
- ***Perform ~weekly inspection of the cathode surface***

LCLS RF Systems

R. Akre, SLAC



Bunch Length Measured
with Transverse RF Deflectors:
One at 135 MeV & Another at 14 GeV

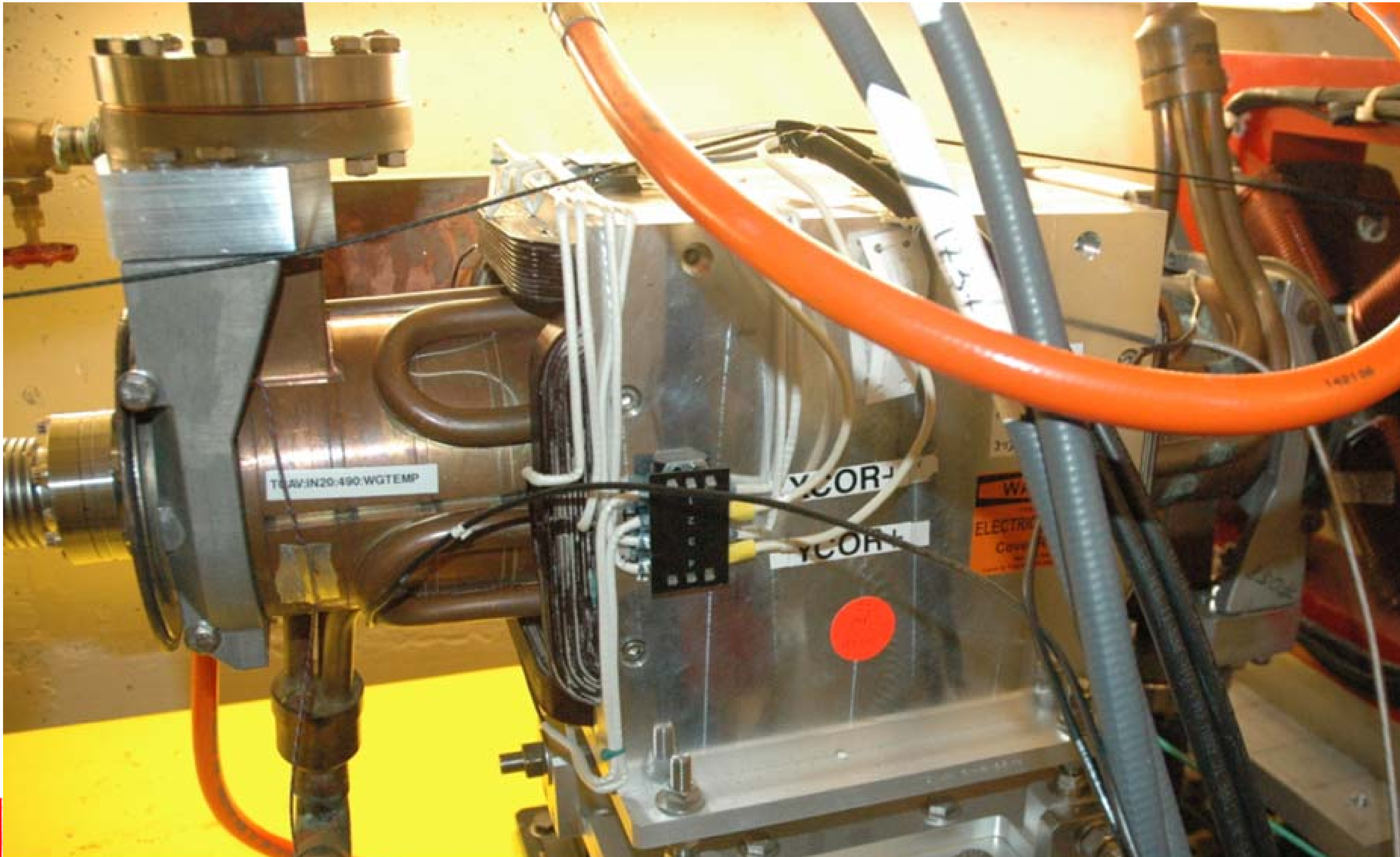


Deflector used to measure:

1. *absolute bunch length,*
2. *time-sliced x-emittance, and*
3. *time-sliced energy spread*

Transverse RF Deflector in Injector (135 MeV)

(55 cm long, ~1 MV)

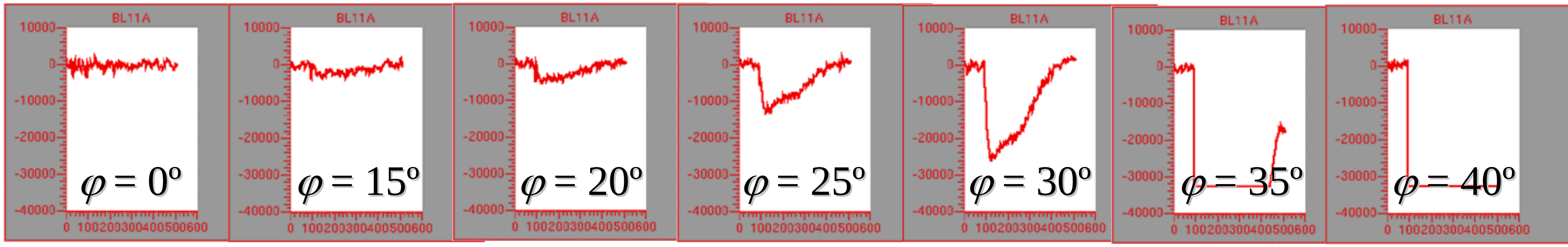


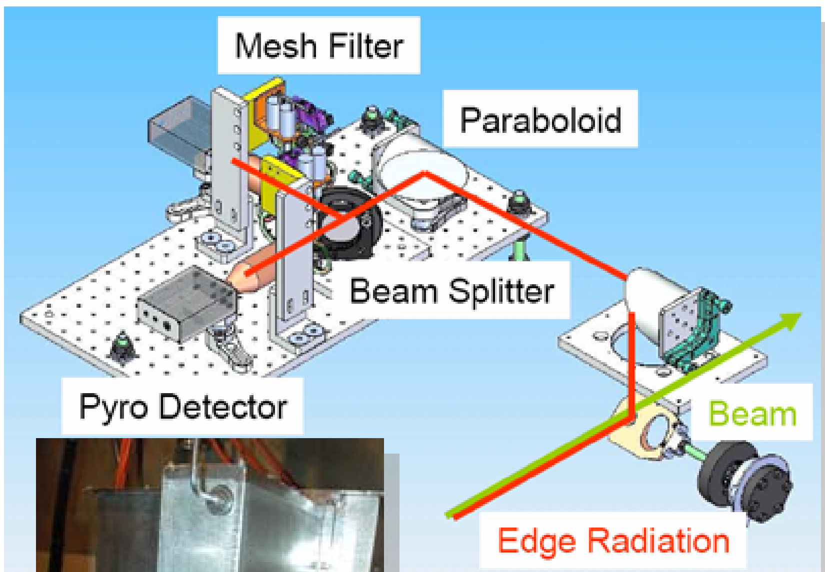
BC1 Chicane in Linac Enclosure

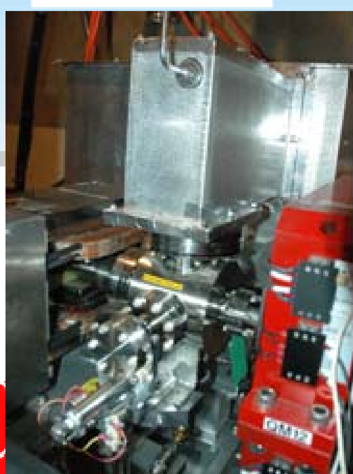
Chicane length 6.3 m, 250 MeV, 5º bends

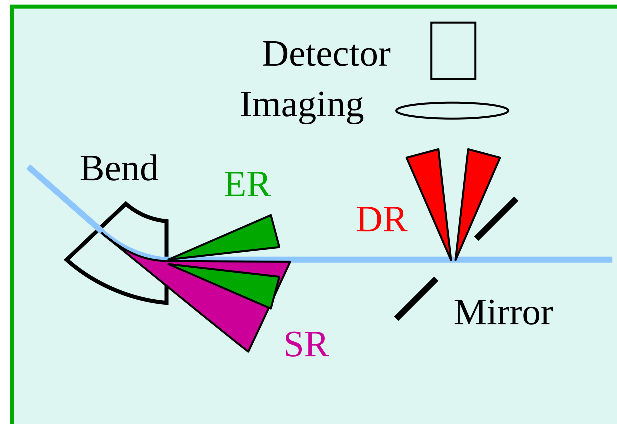
Coherent Edge Radiation used for Compressor Diagnostics

L1S-linac RF phase:

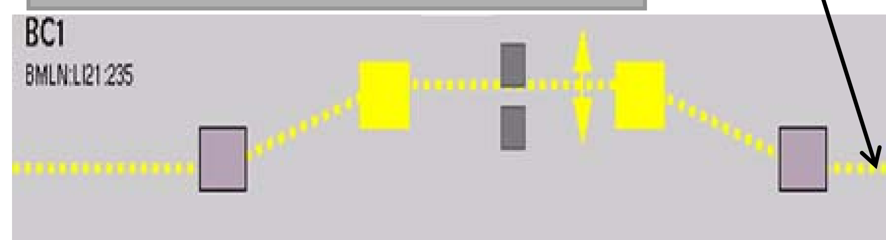








Coherent edge radiation (CER) detector after BC1

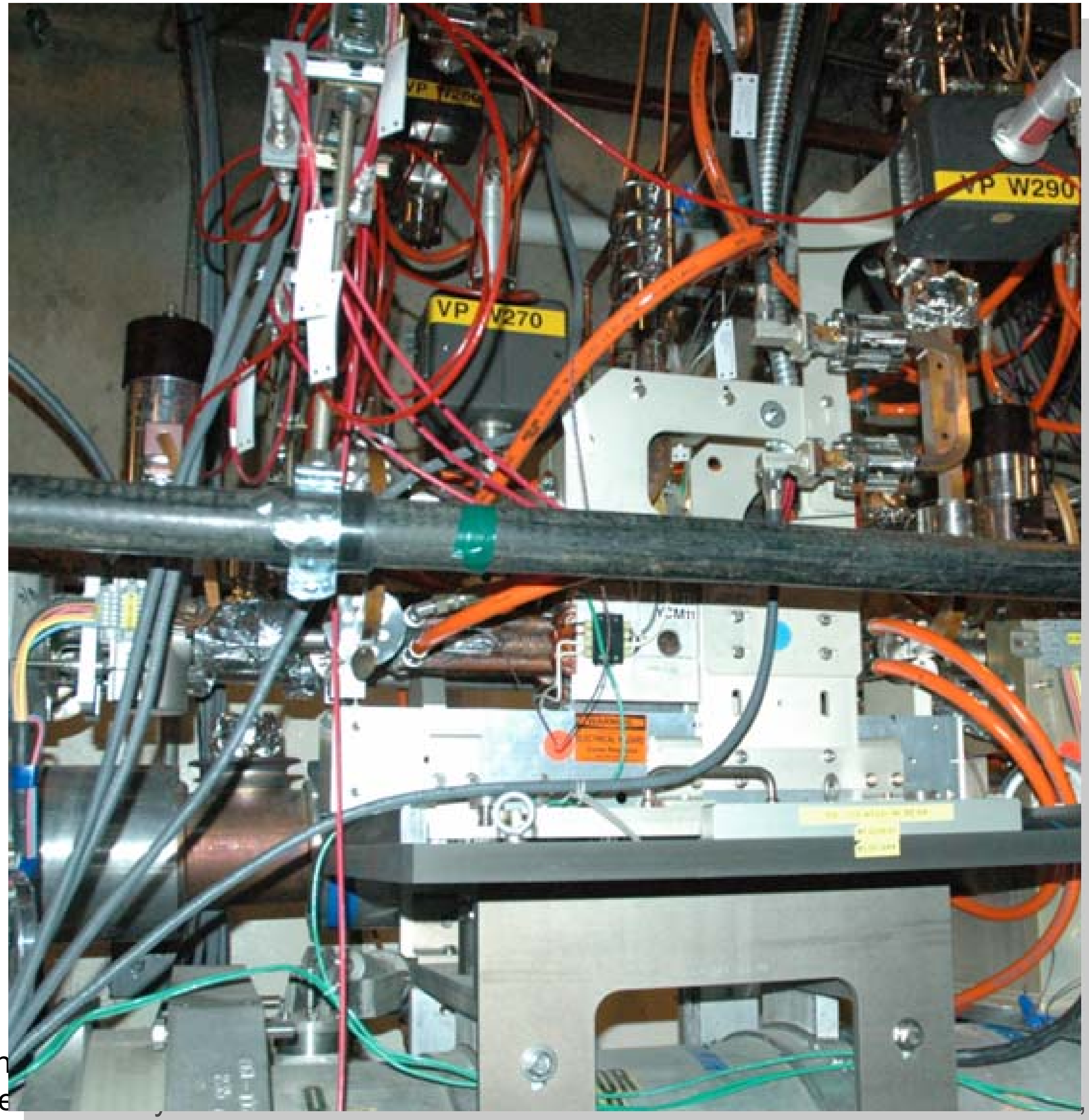


used to drive bunch length feedback

(J. Wu, D. Fairley)

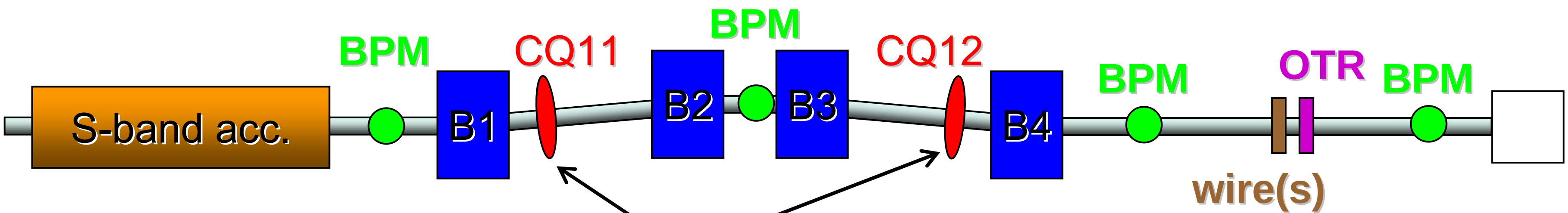
Find the X-band RF Structure in the Linac

Length 60 cm, 20 MV, –160º



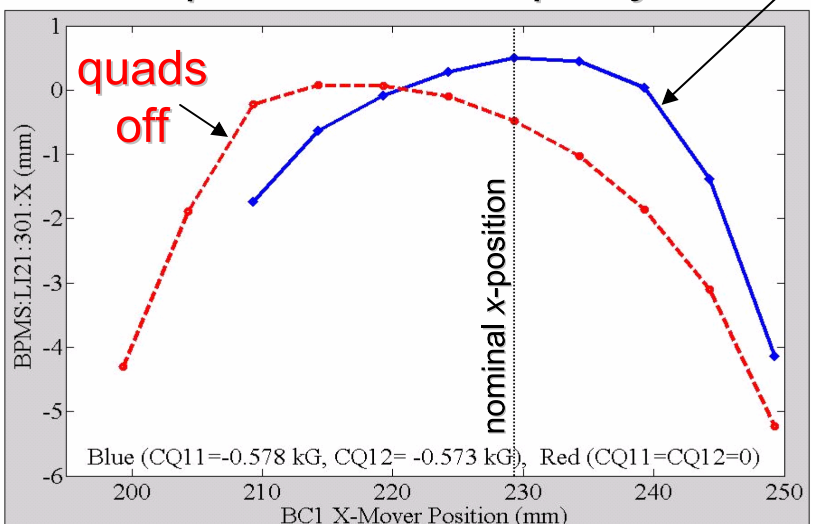
Compliments P. Emma

BC1 Chicane Emittance Growth



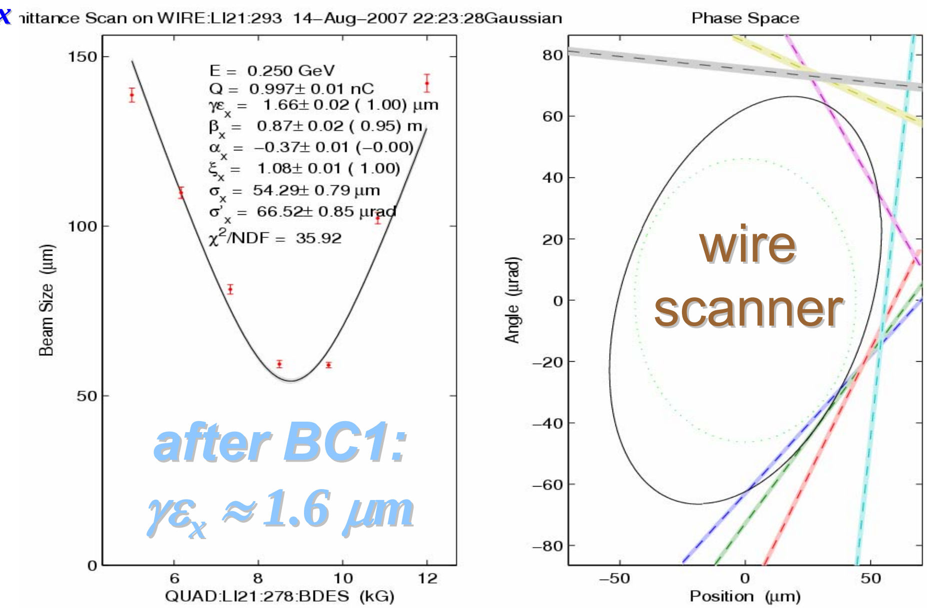
quads correct η_x

poor bend field quality



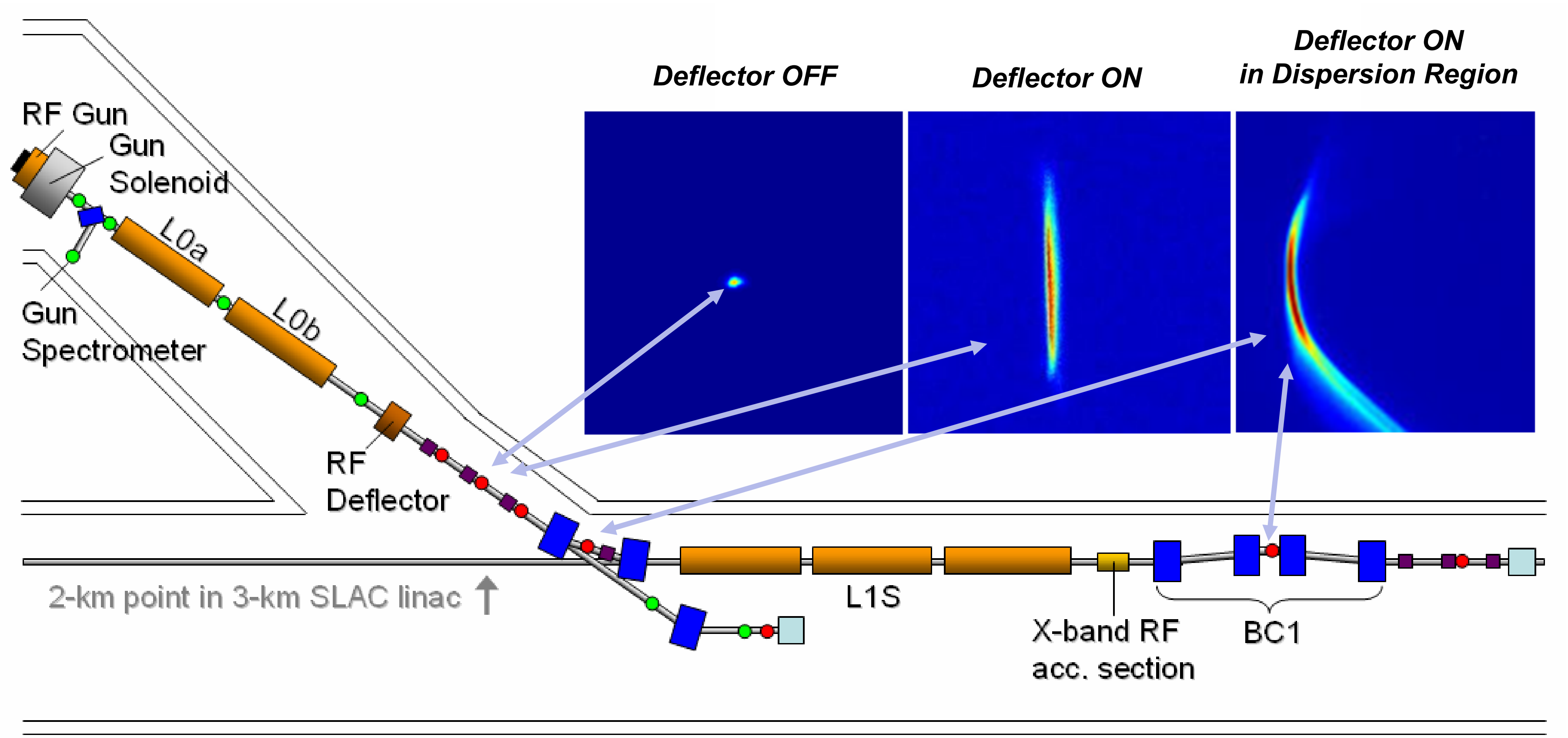
read BPMs while scanning BC1 mover

best emittance transfer

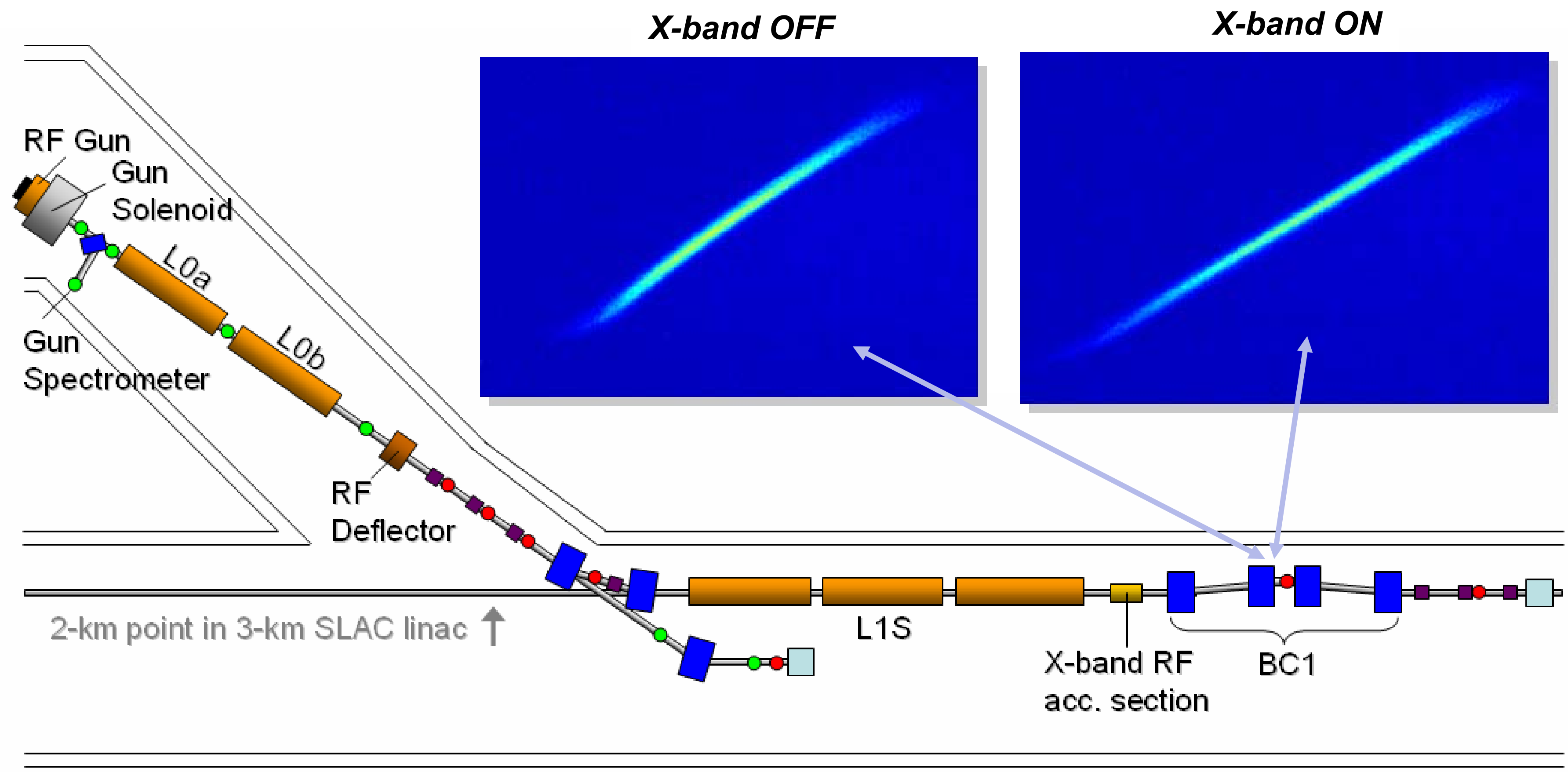


- ***Best $\gamma\varepsilon_x$ after BC1 with nom. (& more) compression is 1.6 μm (& larger)***
- ***Poor bend field quality (grad. + sext.) – $\Delta E/E$ scan shows 1st & 2nd-order η***
- ***Screen image biased by COTR – wires vibrate – variable results (& in y)***
- ***Bends will be upgraded in fall '07 + proper chirp set (now >2% → 1.6%)***

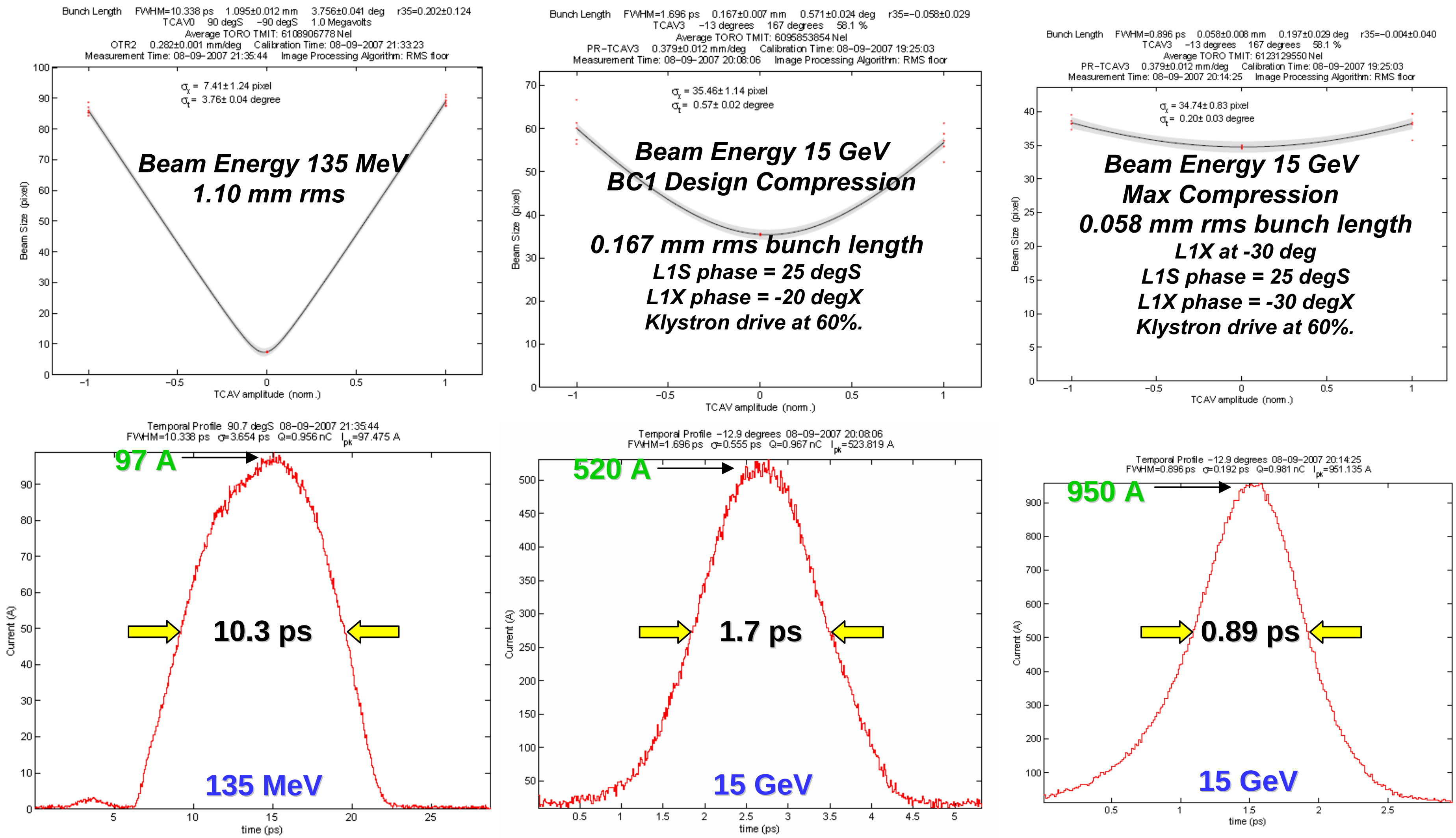
Transverse Cavity (RF-Deflector) Measurements of Bunch Length



Linearization of Longitudinal Phase Space Measured Using the RF Deflector & OTR Screen in Center of BC1



Bunch Length Measurements at 135 MeV & 15 GeV



Design and Demonstrated Parameters

Parameter	**sym**	**dsgn**	**meas.**	**unit**
Final injector e^{-} energy	γmc^2	14	16	GeV
Bunch charge	Q	1	1	nC
Init. bunch length (fwhm)	Δt_0	9	11	ps
Fin. bunch length (fwhm)	Δt_f	2.3	0.4-10	ps
Initial peak current	I_{pk0}	100	100	A
Projected norm emittance	$\gamma\varepsilon_{x,y}$	1.2	1.2	μm
Slice norm. emittance	$\gamma\varepsilon^s{}_{x,y}$	1.0	0.9	μm
Slice energy spread (rms)	$\gamma\varepsilon^s{}_{x,y}$	<5	<6	keV
Single bunch rep. rate	f	120	10-30	Hz
RF gun field at cathode	E_g	120	110	MV/m
Laser energy on cathode	u_l	250	300	μJ
Laser wavelength	λ_l	255	255	nm
Laser diameter on cath.	$2R$	1.5	1.7	mm
Cathode material	-	Cu	Cu	
Cathode quantum eff.	QE	6	2	10^{-5}
Commissioning duration	-	8	5	mo