

Trajectory and Optics Control of the Electron Beam for VISA

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April 30, 2001

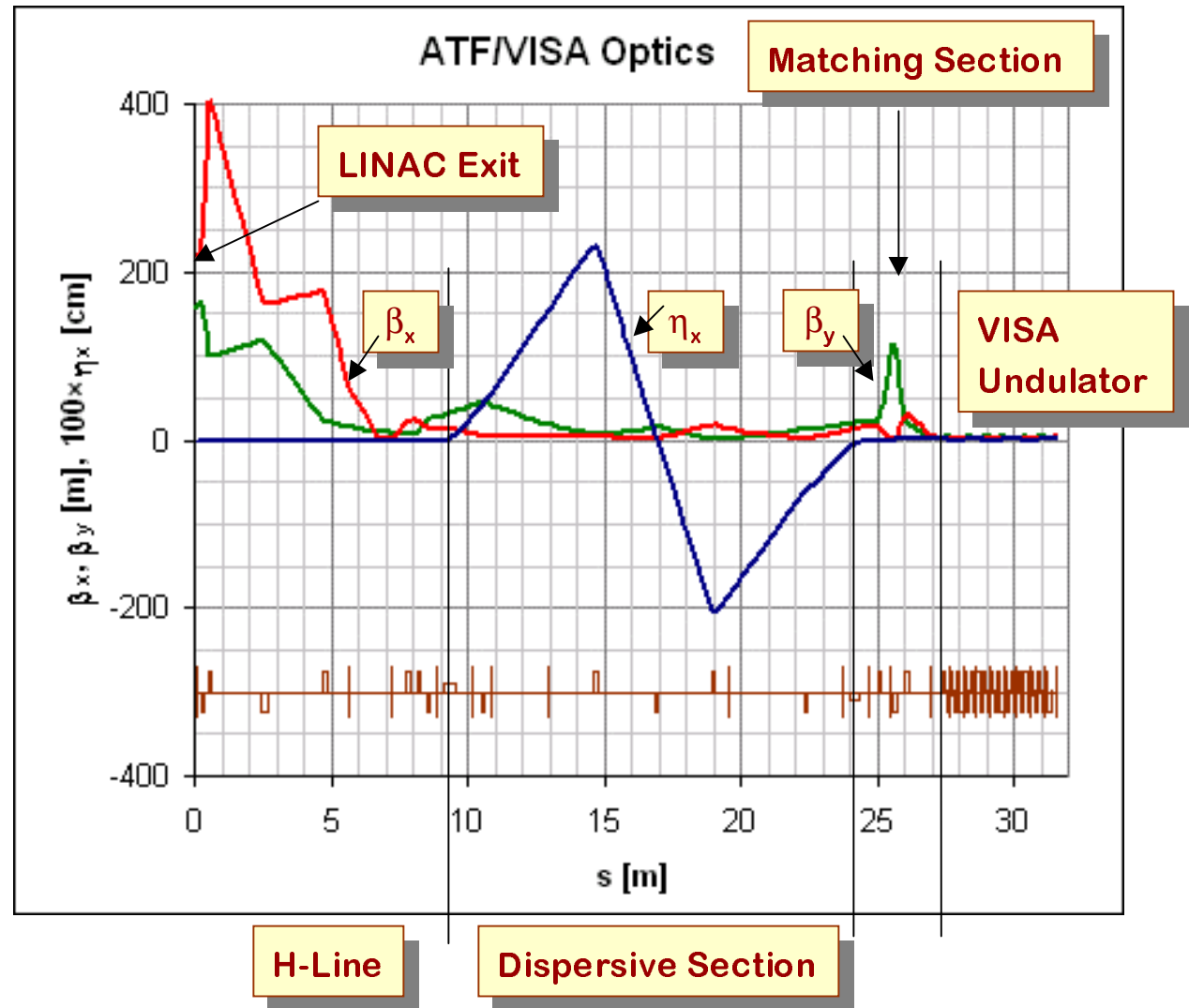
- Baseline Parameters
- Optics Matching
- Trajectory Control
- Beam Size Measurement

Basic FEL Parameters

		Design	Exp.	
Wavelength	λ_r	8000	8300	nm
Electron Energy	E	70.8	71	MeV
	γ	139.5	139.9	
Uncorrelated Energy Spread	$\Delta\gamma/\gamma$	0.18	0.16	%
Bunch Charge	q	1000	170	pC
Peak Current	I_{pk}	200	75	A
Normalized Emittance	ϵ_n	2	0.7	mm mrad
FWHM Bunch Length	L_B	1500	680	μm
1D FEL Parameter	ρ	85	80	10^{-4}
3D Power Gain Length	L_G	0.180	0.185	m
3D Saturation Length	L_{sat}	3.5	~3.6	m
3D Peak Saturation Power	P_{sat}	59	7	MW

Fitted ATF / VISA Optics

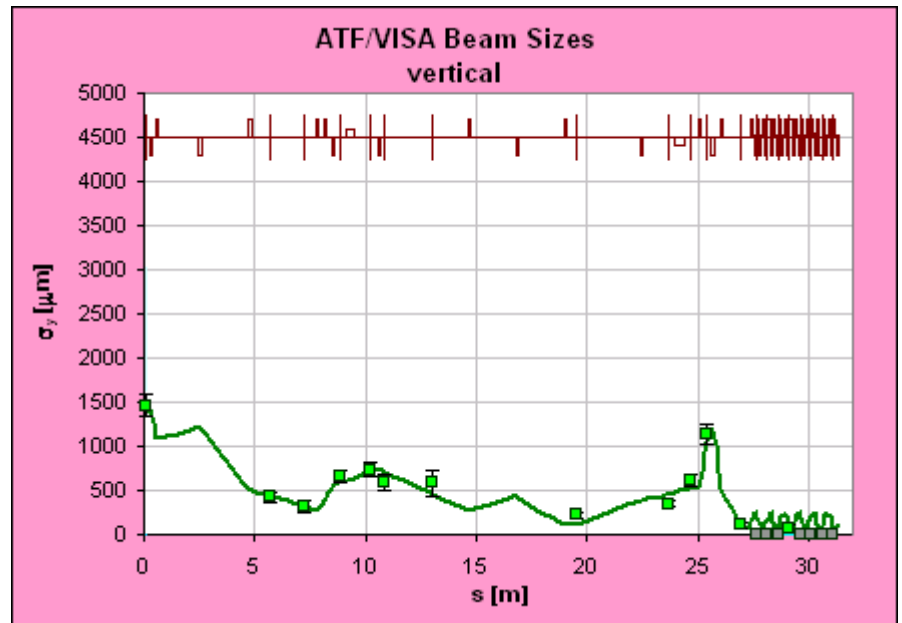
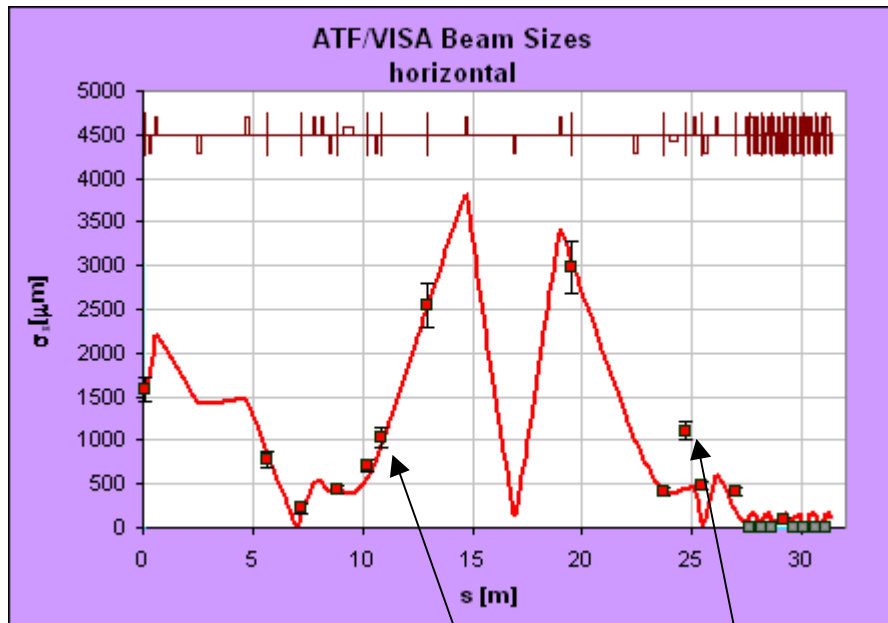
Beam Parameters		
Energy:	71	MeV
σ_y (ini):	0.23	
$\Delta\gamma/\gamma$:	0.16	%
$\epsilon_{n,x}$:	1.7	mm-mrad
$\epsilon_{n,y}$:	1.7	mm-mrad
β_x (ini):	214	m
α_x (ini):	-28.7	
β_y (ini):	152	m
α_y (ini):	-25.5	



ATF / VISA Beam Envelope Measurement

Solenoid	109.65 A
Laser	6.6 μm
ϕ (Gun)	23 deg
Q (Beam)	0.240 nC

ATF / VISA optics from magnet currents and dimensions.
Initial optics functions fitted; Emittance measured separately.



Profile Monitor Readings

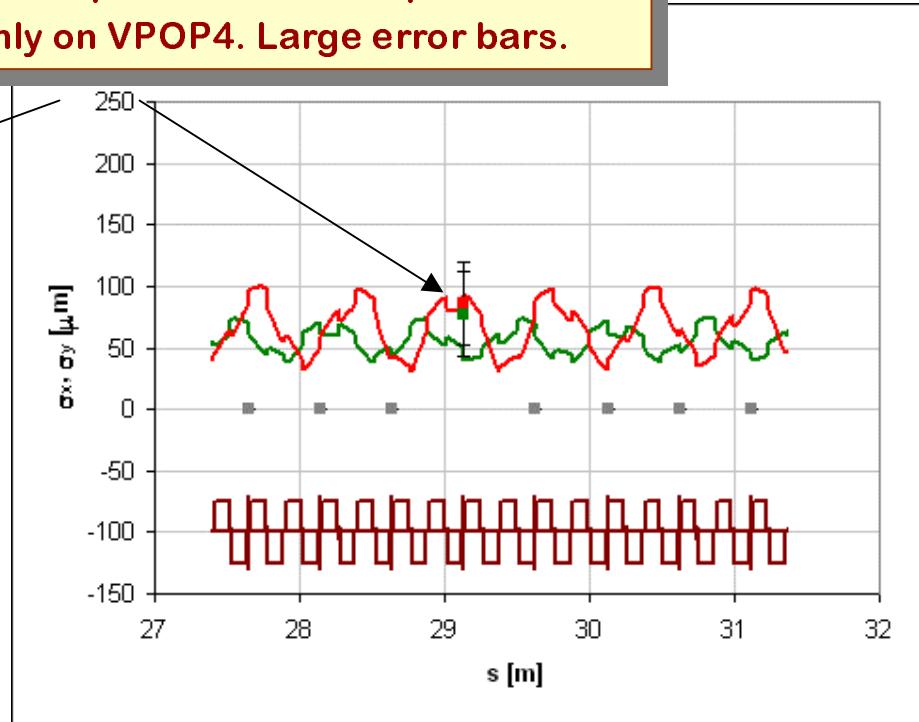
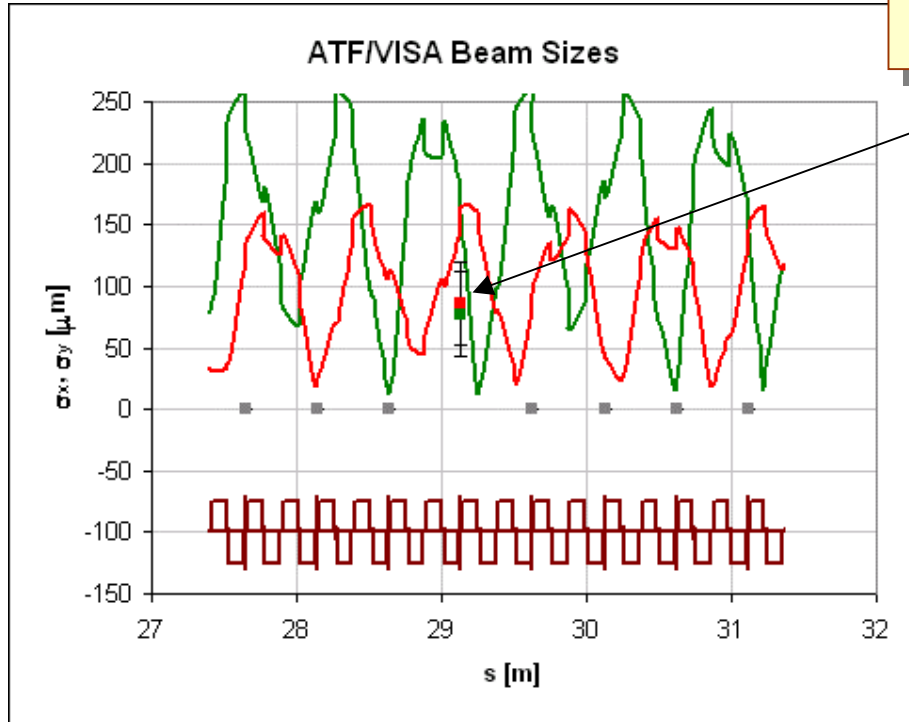
One reading does not fit optics.

April 17, 2001

In general, good agreement with model.

VISA Envelopes

Envelope measurement possible only on VPOP4. Large error bars.

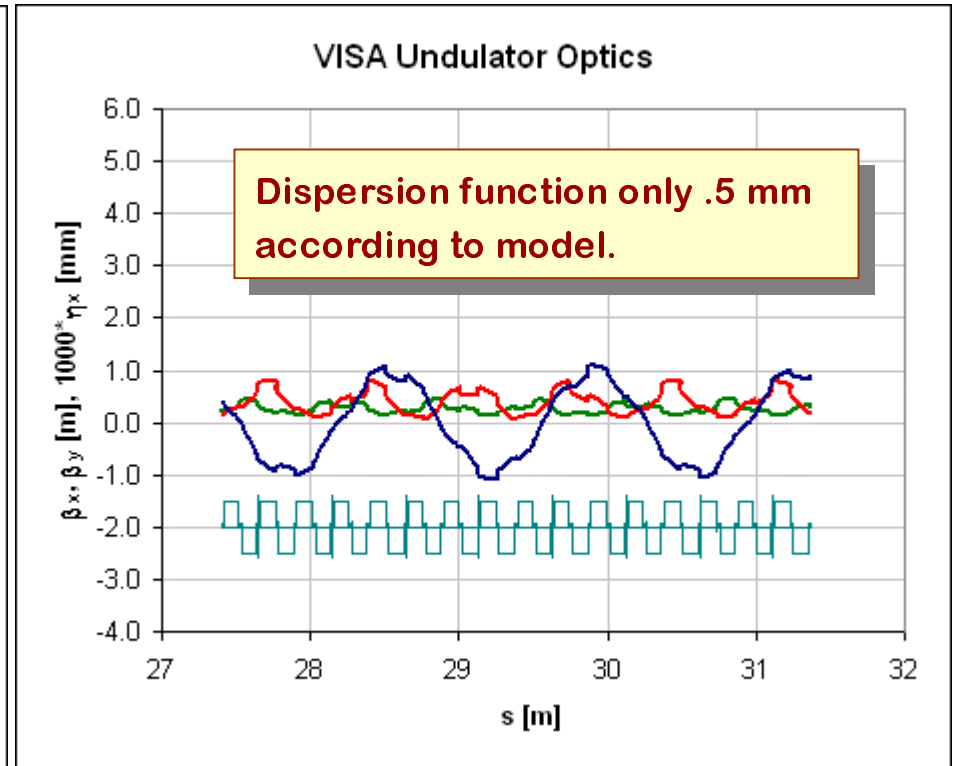
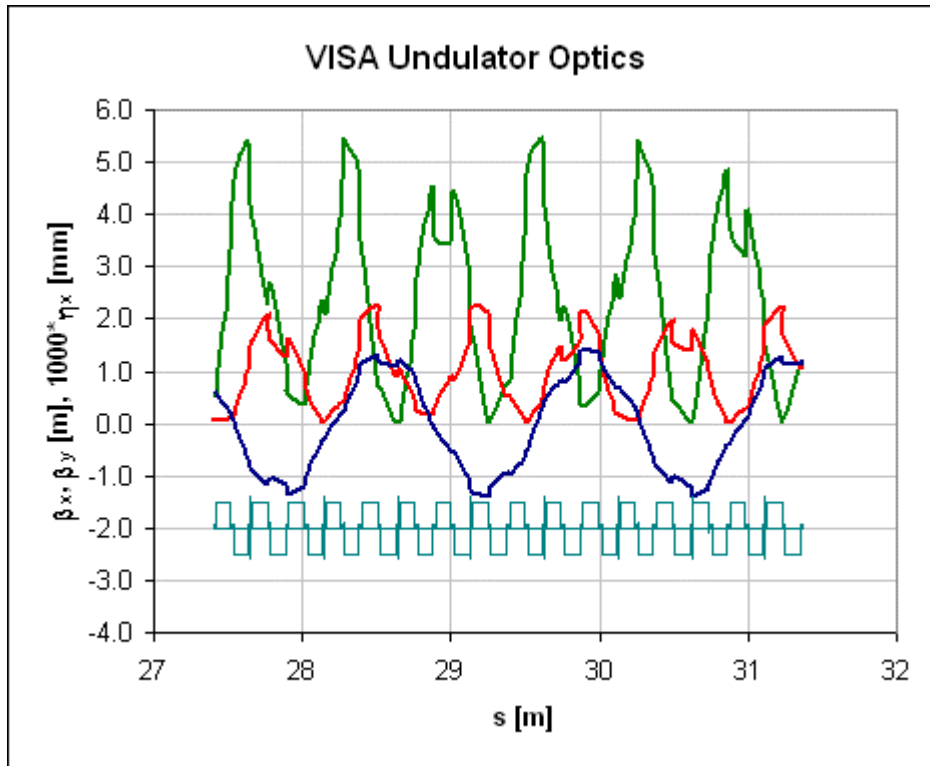


Magnet currents as used.
Values optimized by gain tweaking.

Quadrupole FQ10 changed by 1.5 A.

Actual optics matching might be acceptable.

VISA Undulator Optics

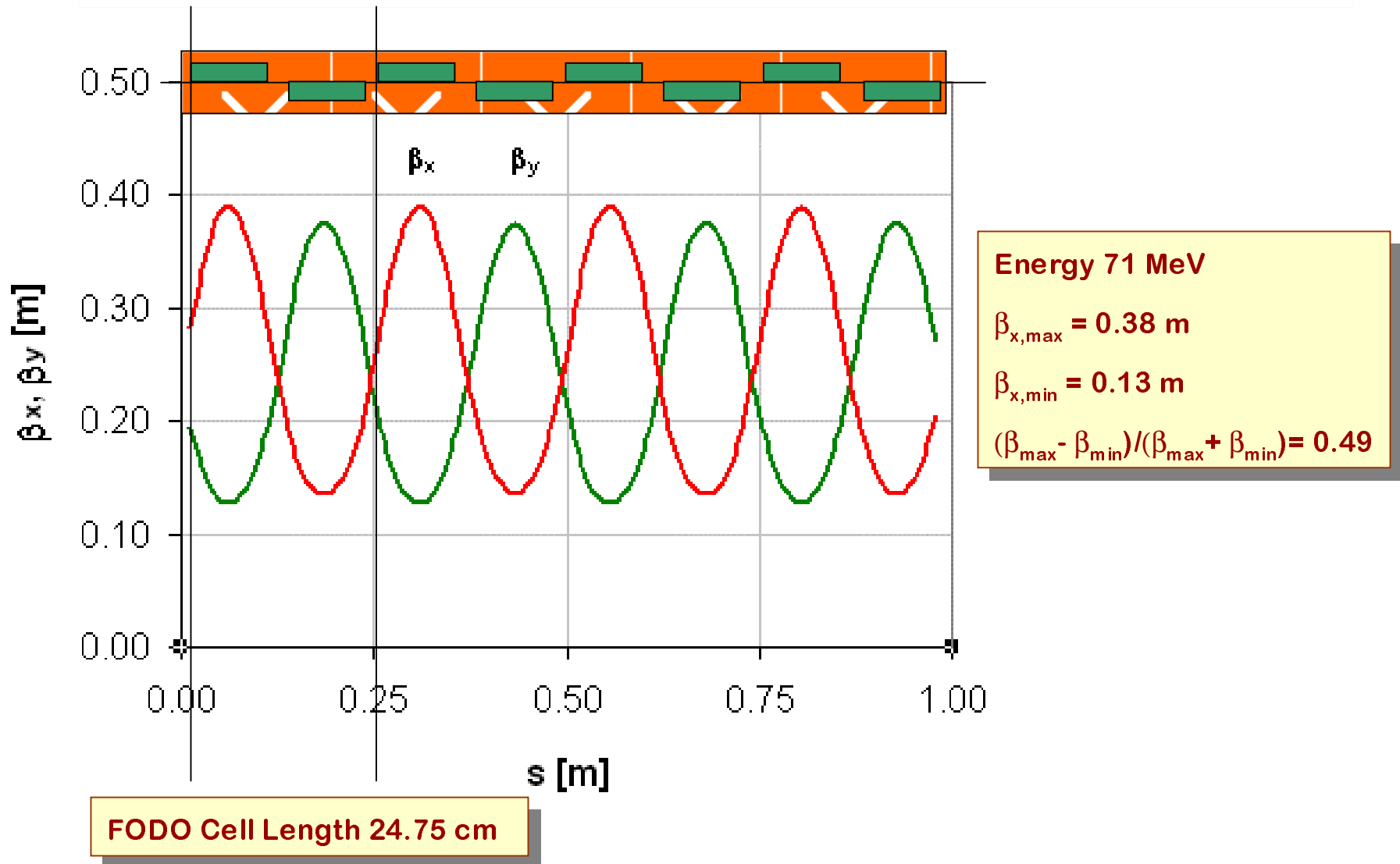


Magnet currents as used.
Values optimized by gain tweaking.

Quadrupole FQ10 changed by 1.5 A.

OTR signal too weak for confirming measurement.

VISA Matched FODO Optics

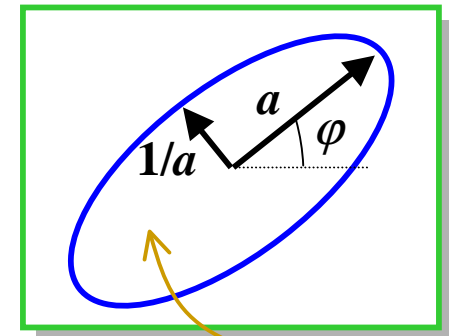


VISA Undulator Optics Matching

$$B_{mag} = \frac{1}{2} \left(a^2 + 1/a^2 \right)$$

$$B_{mag} \equiv \frac{1}{2} (\beta\gamma_0 - 2\alpha\alpha_0 + \gamma\beta_0) \geq 1$$

$\beta_0, \alpha_0, \gamma_0$: Matched Twiss parameters
 β, α, γ : Beam's Twiss parameters



Area = 1

Undulator Entrance	x	y
β_0 [m]	0.2410	0.2310
α_0	-1.7150	1.6630

Undulator Entrance	x	y
β_1 [m]	0.0905	0.5083
α_1	0.7387	-2.5657



$B_{mag,x}$: 4.07
 $B_{mag,y}$: 10.3

Small Gain.

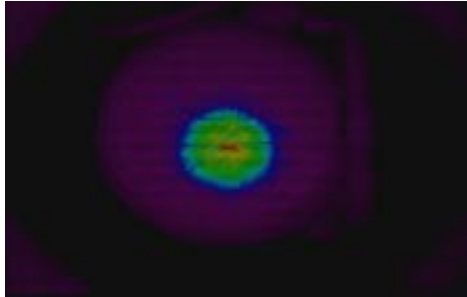
Undulator Entrance	x	y
β_2 [m]	0.1318	0.2520
α_2	-1.6052	1.3069



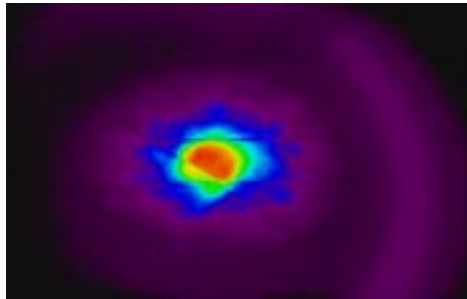
$B_{mag,x}$: 1.60
 $B_{mag,y}$: 1.12

L_G 10 % smaller.

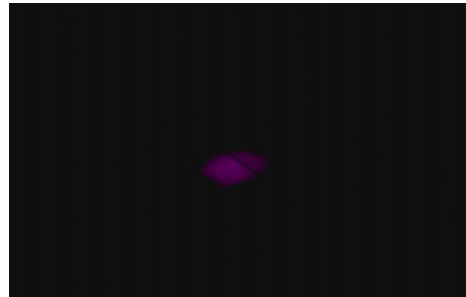
ATF L/H-Line Profile Monitor Images



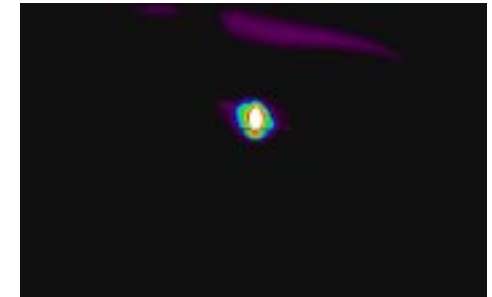
LPOP-1



HPOP-1



HPOP-1.5



HPOP-2



BPM-5

ATF F-Line Profile Monitor Images



FPOP-1



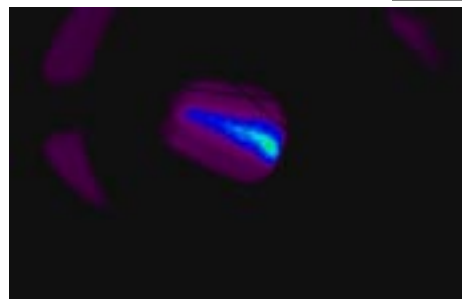
FHES



FPOP-2



FPOP-3



FPOP-4



FPOP-5



FPOP-6



FPOP-9

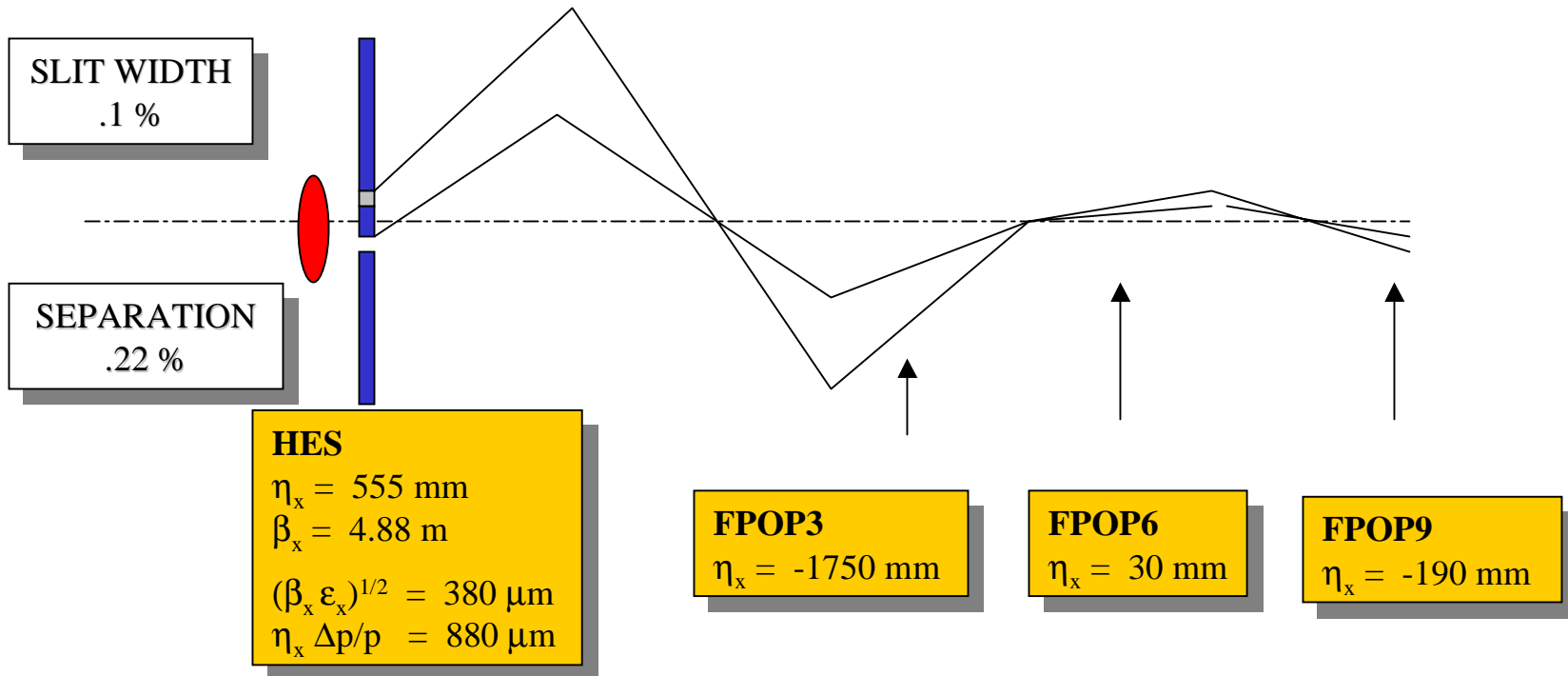
Beam Envelope Measurements

- Beam Envelope Measurements worked very well for the ATF beamline.
- No Beam Envelope Measurements obtained at the operational parameters because of low charge.
- Measurements at high charges will result in larger envelopes due to space charge related emittance increase.
- Solutions:
 - Increase of system sensitivity for low charges
 - Measurement of envelopes for entire beamline at large charge to allow measurement of beam matching into undulator.

Trajectory Control

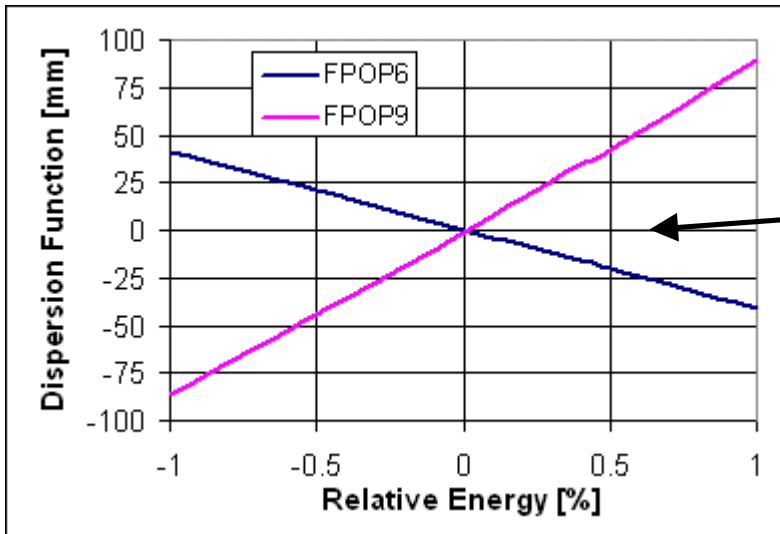
- Beam steering through the center of the ATF linac and the ATF H-Line and F-Line quadrupoles essential for system performance and has been achieved.
- Beam straightness tolerance in the undulator of $50 \mu\text{m}$ RMS has not yet been verified.
- Main problem is the observed shot-to-shot beam motion at amplitudes of more than $100 \mu\text{m}$, dependent on monitor.
- It is presently understood that the source of the motion is found in the system dispersion.

Dispersion Measurement



Dispersion at FPOP6 and FPOP9 larger than predicted by model

Second Order Dispersion



Dispersion function at beam monitors located before the undulator depends strongly on energy.

$$x = \eta_1 \frac{dp}{p} + \eta_2 \left(\frac{dp}{p} \right)^2$$

FPOP6:

$$\eta_1 = 1 \text{ mm}$$

$$\eta_2 = 88 \text{ mm}$$

FPOP9:

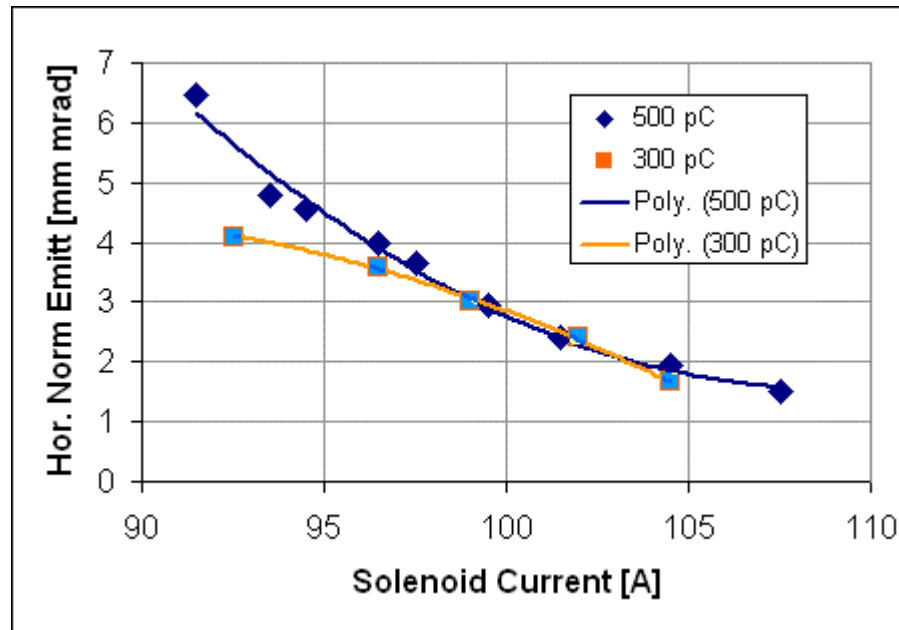
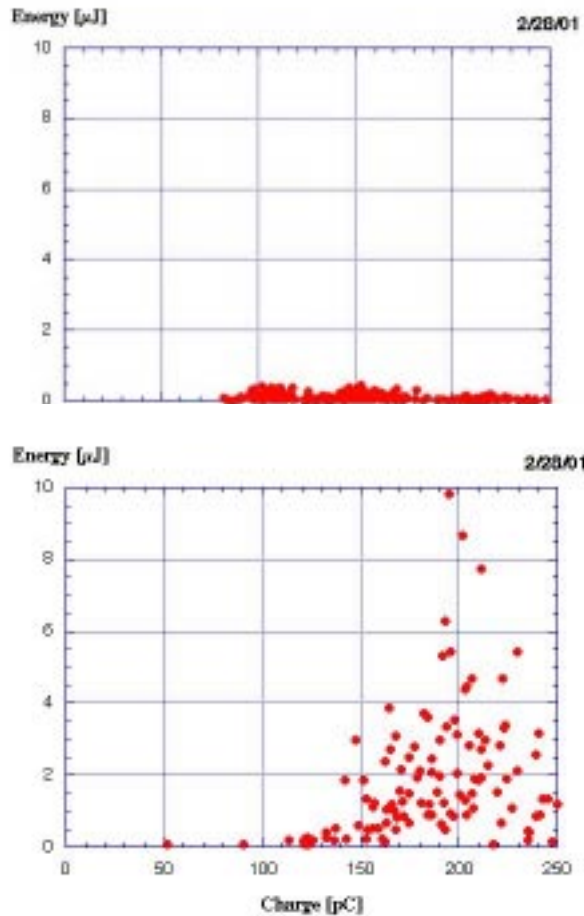
$$\eta_1 = 0.3 \text{ mm}$$

$$\eta_2 = -41 \text{ mm}$$

Second order dispersion can be corrected with sextupoles.

Gun Emittance Working Point

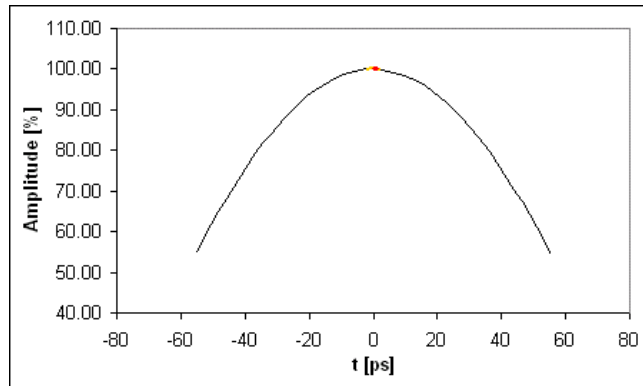
Quadrupole Scans: HQ5
Beam Sizes from BPM5



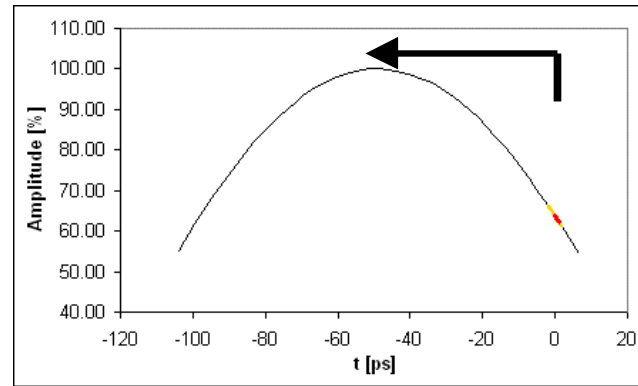
NEW SOLENOID
WORKING POINT

ATF Bunch Length Measurement

Linac Section I
36 MeV pk



Linac Section II
36 MeV pk



~45 degrees phase shift
(varied)

Magnetic Beamline
Components, Scaled
with Reduced Energy

$\Delta p/p = 1.7\% \text{ RMS}$
 $\beta_x = 4.88 \text{ m}$
 $\eta_x = 0.54 \text{ m}$

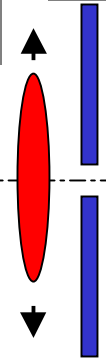
SLIT

FARADAY CUP

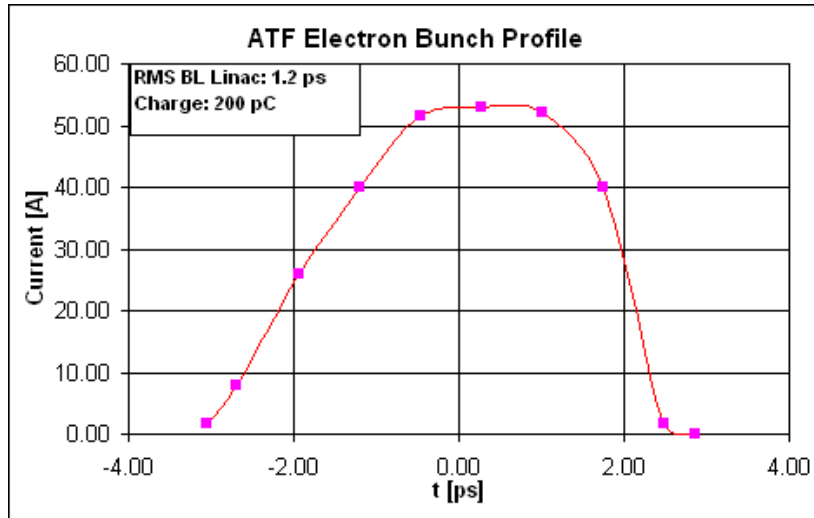
On Crest Acc: $\sigma_r = 460 \mu\text{m}$
Off Crest Acc: $\sigma_r = 9300 \mu\text{m}$



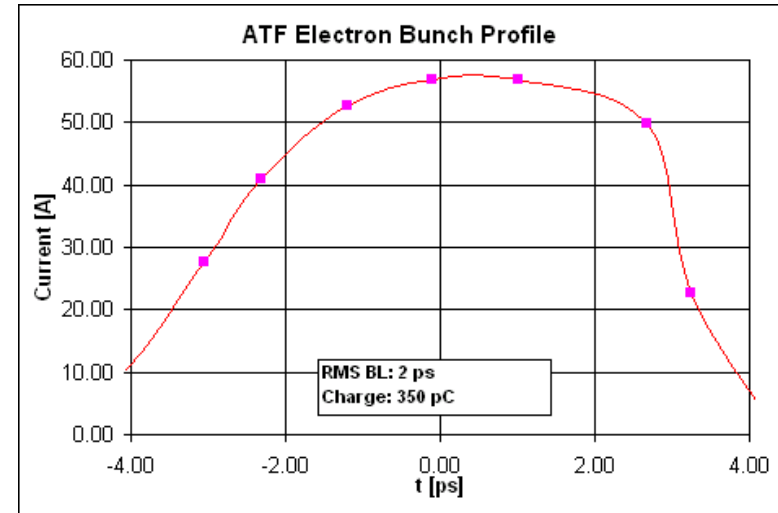
KNOB: SEC II PHASE



ATF Bunch Length Measurement Results

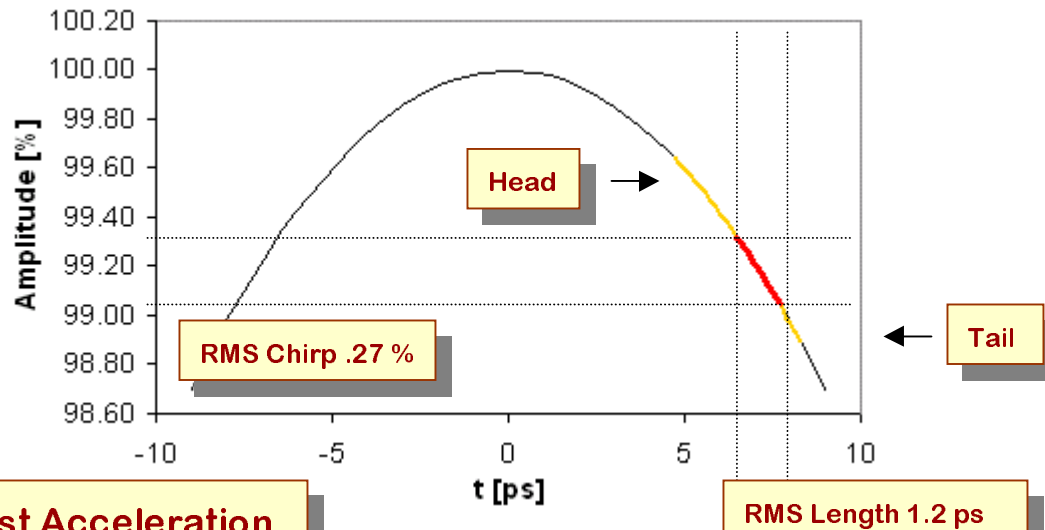


Total Charge 200 pC



Total Charge 350 pC

Bunch Compression



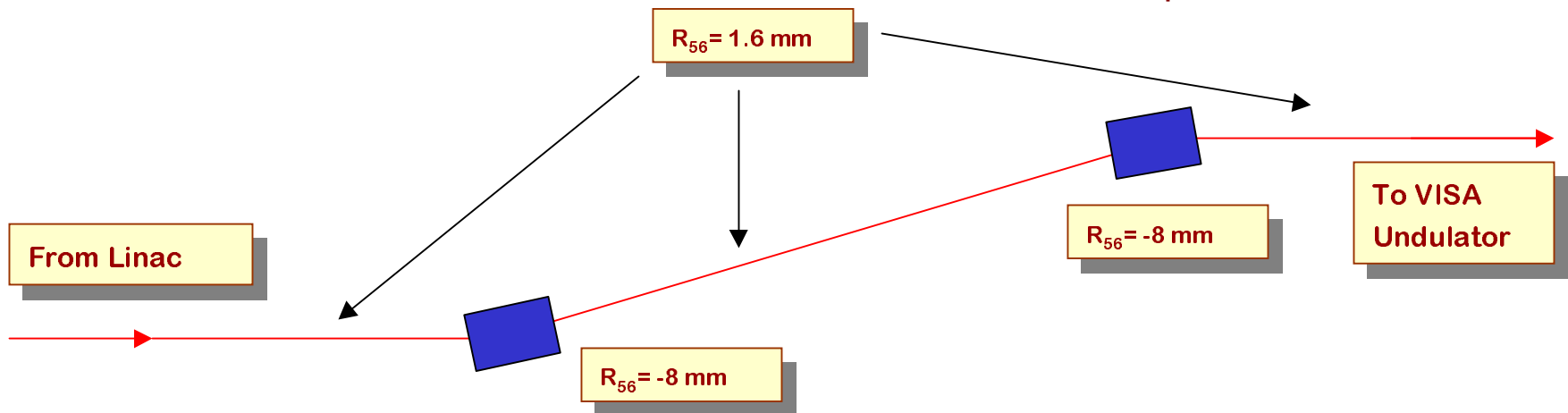
$$\sigma_t^c = \sigma_t + R_{56} * \Delta p/p$$

$$\sigma_t^c - \sigma_t = 0.13 \text{ ps}$$

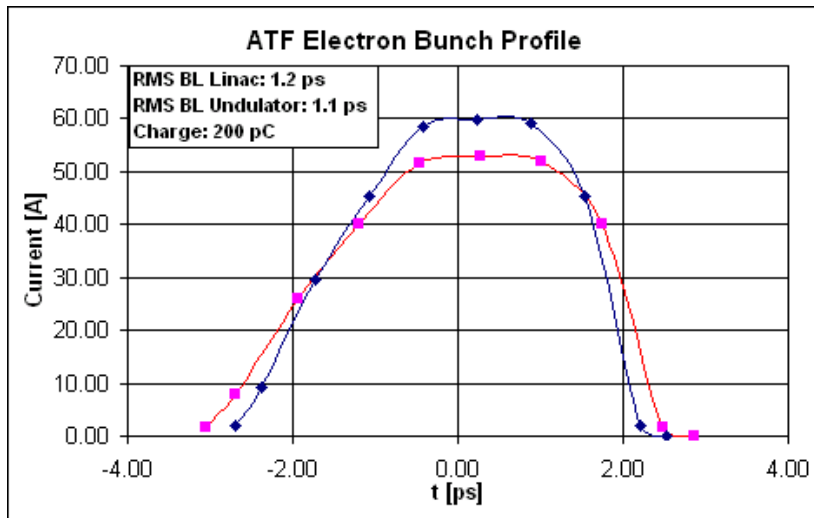
$$R_{56} = 14.4 \text{ mm}$$

$$\Delta p/p = 0.28 \% \text{ RMS}$$

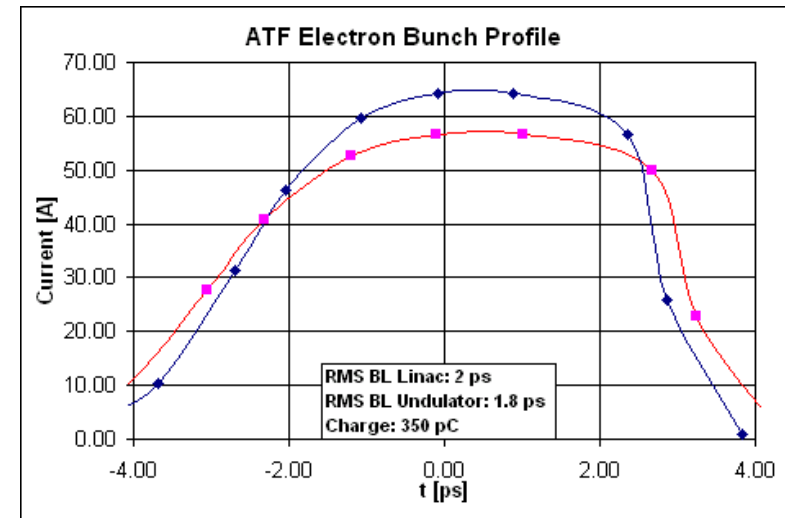
Off-Crest Acceleration



ATF Bunch Length and Bunch Compression



Total Charge 200 pC



Total Charge 350 pC

Effect of wakefields are not included.

Summary

- VISA was successful in achieving large gain and showing evidence of saturation.
- The results are important for the LCLS.
- The real benefit for the LCLS comes from a precise analysis of the source properties and the comparison with FEL theory.
- Important Electron Beam Parameters could not yet be sufficiently verified.
 - Peak Current at the Undulator Entrance
 - Electron Trajectory in the Undulator
 - Optics Matching