SLAC-TN-10-081
LCLS-TN-05-16

LCLS Injector Straight Ahead Spectrometer•

C.Limborg-Deprey
Stanford Linear Accelerator Center
8th June 2005

Summary
The spectrometer design was modified to allow the measurement of uncorrelated energy spread for the nominal lattice. One bunch from every 120 each second would be sent to the straight ahead spectrometer while the transverse cavity is on. The implementation of this "stealing mode" will not be available for the LCLS commissioning and the early stage of operation. However, the spectrometer was redesigned to retain that option. The energy feedback relies independently on the beam position of the beam in the dispersive section of dogleg 1 (DL1).

The main modification of the spectrometer design is the Pole face rotation of 7.5 degrees on both entrance and exit faces. The location and range of operation of the 3 quadrupoles remains unchanged relative to those of the earlier design.

I- Geometry and Dimensions

Optimization of optical function

MAD was used to optimize the straight-ahead-spectrometer parameters, because the space charge effects are nearly negligible.
In the dispersive region, the rms beam size is the quadratic sum of the emittance term and the dispersive term, as shown in equation (1)

$$\sigma_x = \sqrt{\beta\varepsilon + D^2\sigma_\delta^2} \quad (1)$$

where

- β is the betatron function
- ε the beam emittance
- D the dispersion function
- σ_δ the rms of the relative energy spread (uncorrelated)

To achieve a good resolution of the uncorrelated energy spread σ_δ, the emittance term, $\beta\varepsilon$, needs to be smaller than the dispersive term. For our nominal 1nC tuning, at 135 MeV, the emittance ε is expected to be 1mm-mrad. To resolve a σ_δ = 3keV, this condition is then

$$\frac{\beta}{D^2} < 0.135 \quad (2)$$

• "Work supported in part by the DOE Contract DE-AC02-76SF00515.
This work was performed in support of the LCLS project at SLAC

The betatron and dispersion functions along the beamline (starting from the transverse deflecting cavity and down to the end of the straight-ahead spectrometer branch) are represented in figure 1. At the spectrometer screen, OTRS1, the dispersion function value of ~1m and the horizontal betatron function value of ~0.1m, meet the requirement of equation (2).

Spectrometer Characteristics

The dipole length was slightly readjusted from our initial design [Revision0]. The length is now of 0.50 m. A pole face rotation at the entrance and exit of 7.5 degrees has been introduced. Dimensions are given in table 1

Length	Angle θ	Pole Face*	Dist. to screen
0.5 m	35°	7.5 °	2.3 m

Table 1- Straight Ahead Spectrometer parameters
*Pole Face rotation of both poles

The visualization screen, 0TRS1, is located at 90 cm from the exit of QS03.

	QS01	QS02	QS03
Nominal K	6.71	-4.8	5.11

Table 2- Nominal Quadrupole gradient K, for the nominal tuning, K = $\frac{1}{B\rho}\frac{\partial B}{\partial x}$

The nominal K values are given in m-2.
They correspond to an effective length of 10.8cm (X-gamma type quadrupole).

Center	OTR2	Bend entrance	QS01	QS02	QS03	OTRS1
z from end TCAV1	2.88	7.374	8.236	8.744	9.252	10.206

Table 3- Location of straight-ahead spectrometer beamline components referenced to the exit of the transverse deflecting cavity z = 0

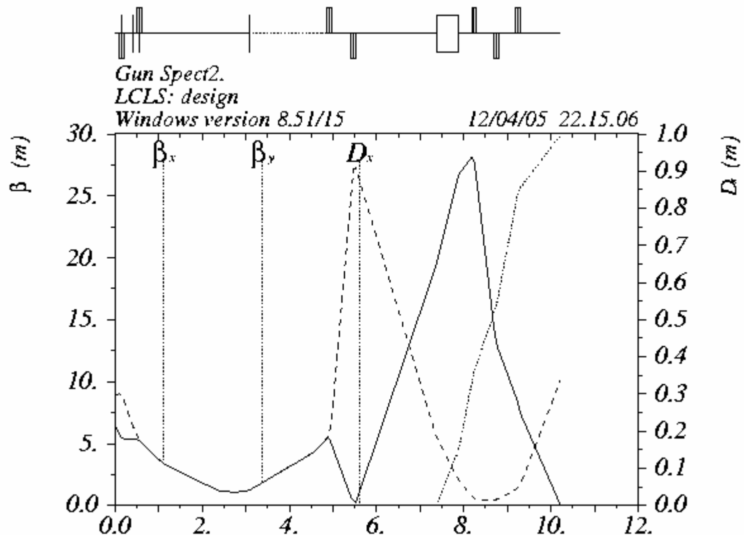

Figure (1)- Optical functions (betatron and dispersion) from TCAV1 to OTRS1 calculated with MAD

II- Sensitivity

In table 4, we report on the sensitivity of betatron function, dispersion function and beam size as a function of small deviation of the quadrupole strength about the nominal value. The definitions of rms quantities used in the table below are

$\sigma_x = \mathrm{sqrt}(\beta_x\ \varepsilon)$

$D\sigma_\delta$ = D. 3keV/135MeV

$\sigma_y = \mathrm{sqrt}(\beta_y\ \varepsilon)$

Using ε = 1mm.mrad /270 for an energy of 135MeV

	β_x	β_y	D	σ_x	$D\sigma_\delta$	σ_y
nominal	0.1100	10.0370	0.9950	20.2	22.1	192.8
+5% QS01	0.2050	10.2430	1.0180	27.6	22.6	194.7
-5% QS01	0.2330	9.8380	0.9730	29.4	21.6	190.9
+5% QS02	0.1260	10.1580	0.9790	21.6	21.7	194.0
-5% QS02	0.1200	9.9180	1.0120	21.1	22.5	191.7
-5% QS03	0.1150	9.8400	1.0170	20.6	22.6	190.9
+5% QS03	0.1150	10.2370	0.9740	20.6	21.6	194.7

Table 4- Variation of betatron function, dispersion function and of the rms contribution to beam size from the emittance and dispersion terms due to small deviations in quadrupole settings; an rms energy spread of 3keV is assumed for the dispersive term

Table 4 shows that the sensitivity is more critical for QS01 than for QS02 and QS03.

The resolution on the energy spread would be reduced by a factor of four if the emittance were as large as 2 mm-mrad. The increase of energy spread to 40keV rms when the laser heater is switched on would nevertheless be easily resolved.
For the 0.2 nC tuning the emittance could be as small as 0.5 mm-mrad. The energy spread resolution would be improved by a factor of 4, to a value below the keV level.

NB : files in C:\parmela\lcls\commissioning\spectrometer_end4\mad

III- PARMELA simulations

PARMELA simulations were run for the nominal 1nC case. They demonstrate that a direct measurement of the longitudinal phase space at the end of the injector beamline will be available when the beam is vertically deflected at TCAV1 transvserse deflecting cavity.
Using a cavity voltage of 0.8 MV/m, one estimates that the kick along the 3mm (10ps) electron beam will be of +/- 0.5 mrad, by applying formula (2) of [1]. This provides a vertical beam size at the screen of 12 mm. This could be reduced if the intensity was found to be too low.
The uncorrelated energy spread is artificially increased from 3 keV to 50 keV. The laser heater will increase the rms uncorrelated energy spread from 3keV to 40 keV [2,3].
The slice energy spread can be extracted following two methods:

1) extracting a vertical slice from the XY image
2) use of the horizontal projection of the entire distribution

The first method can be accurate only if the local betatron functions are known accurately.

These simulations show that we should be able to resolve energy to levels better than 10keV with either method. The increase of uncorrelated energy spread from 3keV to 40keV produced by the laser heater will be easily measured at this station. By controlling the increase of uncorrelated energy spread, we hope to detain a good calibration of this instrument.

This direct longitudinal phase space measurement will be compared with measurements performed using tomographic techniques.

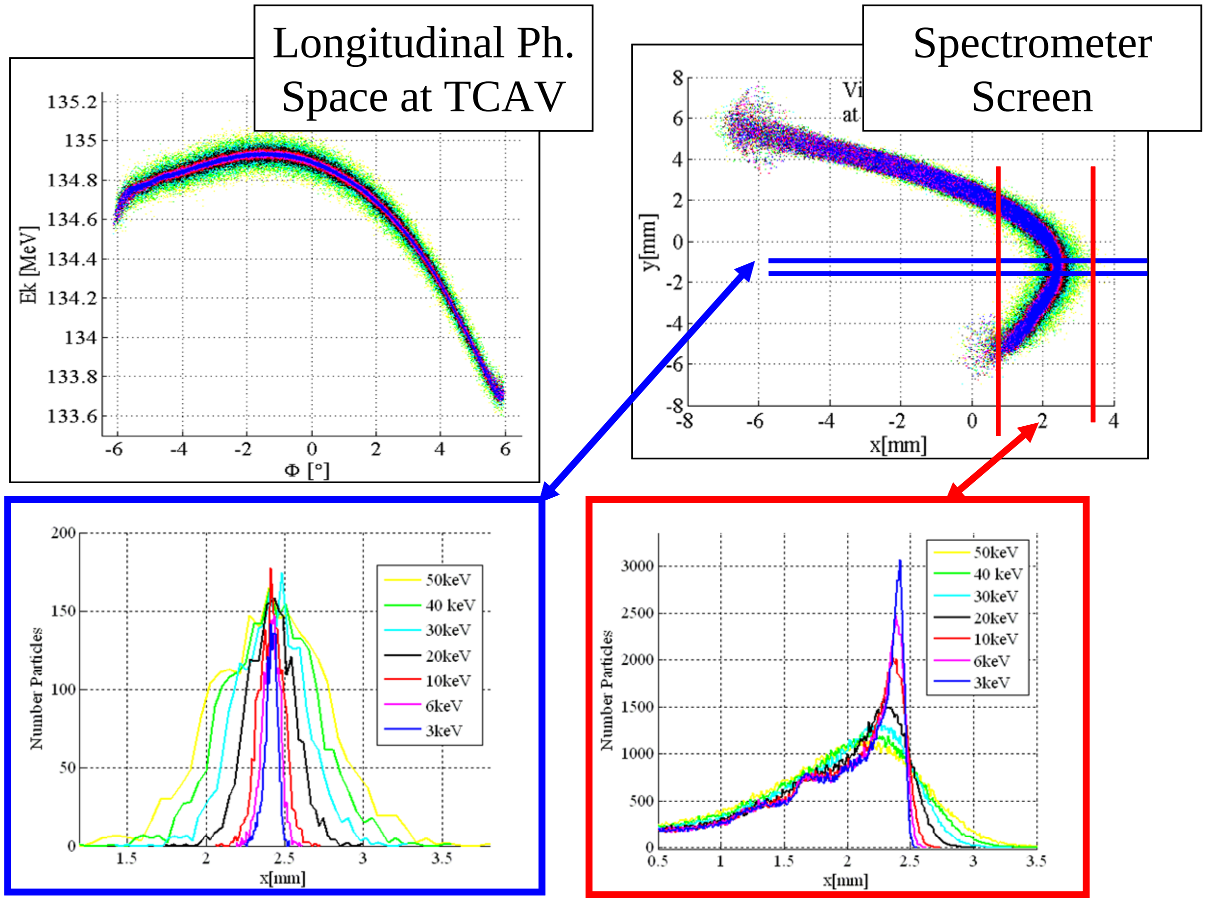

Figure 1 – for nominal beam conditions in the transverse plane but with the uncorrelated rms energy spread increases from 3 to 50 keV - (a) Longitudinal Phase Space at the transverse cavity location –(b) XY image at spectrometer screen- (c) Evolution of vertical slice –(d) Evolution of horizontal slice

References

[1] R.Akre et al. "A Transverse RF Deflecting Structure for bunch length and phase space Diagnostics", PAC01, Chicago
[2] P.Emma "Laser Heater Physics" LCLS-ESD 1.2-121, May 2004
[3] Z.Huang et al. "Suppression of Microbunching Instability in the Linac Coherent Light Source" ,SLAC-PUB -10334