Advanced Photon Source

Flat Beam Generation

Kwang-Je Kim
Argonne National Laboratory
and
The University of Chicago

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Workshop on Nanometre-Size Colliding Beams
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Flat Beam Generation

Beam adapter:

Ya. Derbenev, A. Burov, S. Nagaitsev

Theory; Burov, Nagaitsev & Derbenev

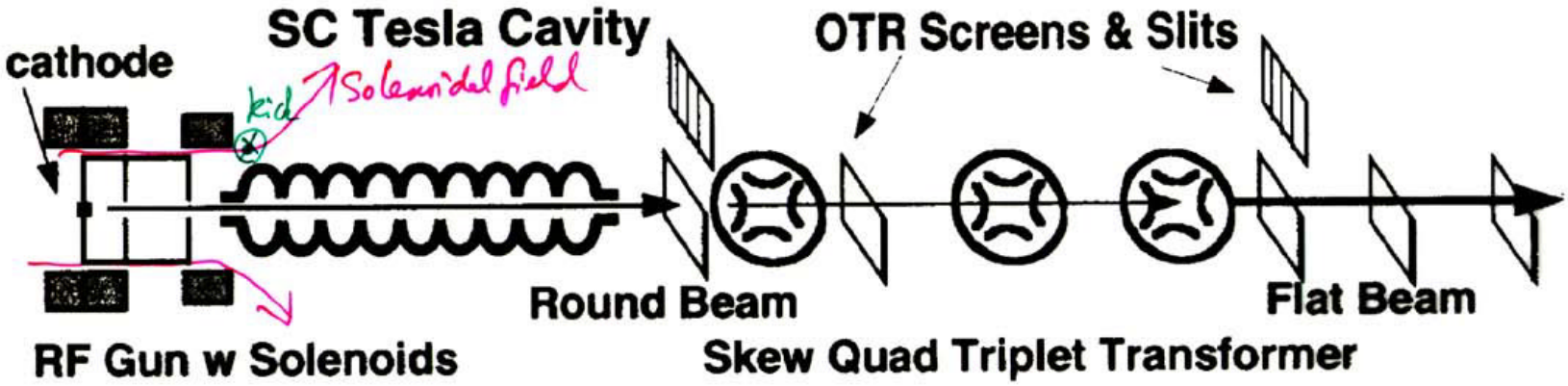
Application to flat beam:

R. Brinkmann, Ya. Derbenev, and K. Floetmann

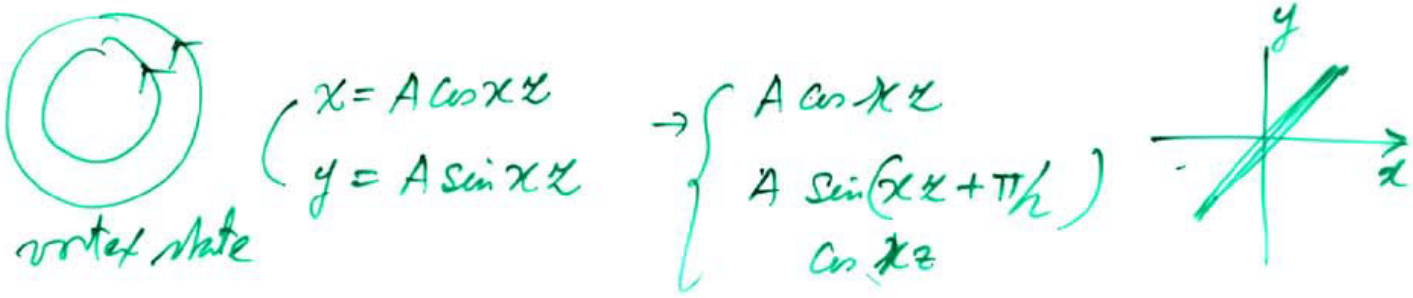
Experiment:

FNPL at Fermilab

D. Edwards, H. Edwards, et al.



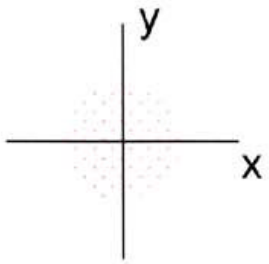
Schematic rendition of the layout at Fermilab for flat beam experiment.



Phase Space Coordinates

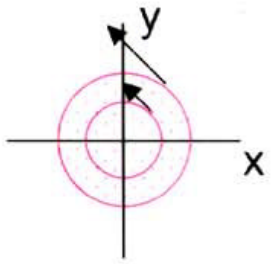
I. After cathode

$X_I = (x, x', y, y')$



II. After solenoid (short)

$X_{II} = (x, x' \pm \kappa y, y, y' - \kappa x'), \kappa = \left(\frac{eB}{2P_s} \right)$



($\frac{1}{2}$ of Larmor frequency)

III. After quadrupole channel

$$X_{III} = R^{-1}\begin{bmatrix} M, & 0 \\ 0 & FM \end{bmatrix} R \cdot X_{II}$$

$$R = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix}, M = \begin{bmatrix} \cos\mu, & \beta\sin\mu \\ -(\sin\mu)/\beta, & \cos\mu \end{bmatrix}, F = \begin{bmatrix} 0, & \beta \\ -\frac{1}{\beta}, & 0 \end{bmatrix}$$

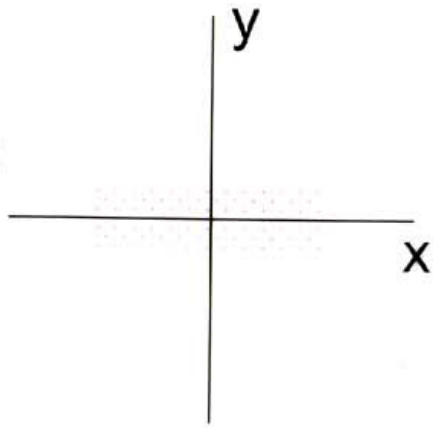
Skew

final transport

$+(\pi/2)$

Choose β (match)

$$X_{IV} = \begin{pmatrix} 2bx + 2ay + \beta(ax' - by') \\ -\frac{2a}{\beta}x + \frac{2b}{\beta}y + bx' + ay' \\ -\beta(bx' - ay') \\ ax' + by' \end{pmatrix} \quad \text{for} \quad \beta = \kappa^{-1}$$



→ 0 for $x' = y' = 0$

$$a = \frac{1}{2}(\cos\mu + \sin\mu),\ b = \frac{1}{2}(\cos\mu - \sin\mu)$$

Flat beam for $x' = y' = 0$!

Beam Moment Matrix

$$\Sigma = \left\langle XX^{T} \right\rangle = \begin{pmatrix} \langle x^2 \rangle, \langle xx' \rangle, \langle xy \rangle \langle xy' \rangle \\ \langle x'x \rangle, \langle x'^2 \rangle, \langle x'y \rangle, \langle x'y' \rangle \\ \langle yx \rangle, \langle yx' \rangle, \langle y^2 \rangle, \langle yy' \rangle \\ \langle y'x \rangle, \langle y'x' \rangle, \langle y'y \rangle, \langle y'^2 \rangle \end{pmatrix}$$

$$\Sigma_{\mathrm{I}} = \begin{pmatrix} \sigma^2 & 0 & 0 & 0 \\ 0 & \sigma'^2 & 0 & 0 \\ 0 & 0 & \sigma^2 & 0 \\ 0 & 0 & 0 & \sigma'^2 \end{pmatrix} \text{(round beam, no correlation)}$$

$$\mathrm{Det}\left(\Sigma_{\mathrm{I}}\right) = (\sigma\sigma')^2$$

$$\Sigma_{II}=\begin{pmatrix} \sigma^2 & 0 & 0 & -\kappa\sigma^2 \\ 0 & \sigma'^2+\kappa^2\sigma^2 & \kappa\sigma^2 & 0 \\ 0 & \kappa\sigma^2 & \sigma^2 & 0 \\ -\kappa\sigma^2 & 0 & 0 & \sigma'^2+\kappa^2\sigma^2 \end{pmatrix}$$

$$\text{Det}\ (\Sigma_{II}) = (\sigma\sigma')^2$$

if x-x' only

$$\epsilon_x \approx \sigma\sqrt{\sigma'^2+x^2\sigma^2}$$

(Thus is not really emittance)

Choosing $\beta = x^{-1}$

$$\Sigma_{III} = \begin{bmatrix} \varepsilon_x \mathbf{T} & \varepsilon_{xy} \mathbf{S} \\ \varepsilon_{xy} \mathbf{S} & \varepsilon_y \mathbf{T} \end{bmatrix}$$

$$\varepsilon_x = \frac{2\sigma^2}{\beta} + \frac{\beta \sigma'^2}{2}, \varepsilon_y = \frac{\beta}{2}\sigma'^2, \quad \mathbf{T} = \begin{bmatrix} \beta, & 0 \\ 0, & 1/\beta \end{bmatrix}, \quad \varepsilon_{xy} = \frac{\beta \sigma'^2}{2}$$

$$\mathbf{S} = \begin{bmatrix} -\beta \cos\mu, & \sin 2\mu \\ \sin 2\mu, & \dfrac{\cos\mu}{\beta} \end{bmatrix}$$

Det **S** = -1

$$\text{Det } \Sigma_{III} = \varepsilon_x \varepsilon_y - (\varepsilon_{xy})^2 = (\sigma \cdot \sigma')^2$$

Choose $1 - x^2\beta^2 = \dfrac{\beta^2\sigma'^2}{\sigma^2}$

$$\Sigma = \frac{1}{2}\begin{bmatrix} \beta\varepsilon_x & 0 & 0 & 0 \\ 0 & \varepsilon_x/\beta & 0 & 0 \\ 0 & 0 & \beta\varepsilon_y & 0 \\ 0 & 0 & 0 & \varepsilon_y/\beta \end{bmatrix}$$

!!

$$\varepsilon_x = \frac{1}{2}\left[\frac{(1+x\beta)^2}{\beta}\sigma^2 + \beta\sigma'^2\right]$$

$$\varepsilon_y = \frac{1}{2}\left[\frac{(1-x\beta)^2}{\beta}\sigma^2 + \beta\sigma'^2\right]$$

$$\varepsilon_x\varepsilon_y = (\sigma\sigma')^2$$

also $$\frac{\varepsilon_x}{\varepsilon_y} = \frac{(1+\beta x)^2\sigma^2 + \beta^2\sigma'^2}{(1-\beta x)^2\sigma^2 + \beta^2\sigma'^2}$$

Choose $r = \left(\dfrac{\beta\sigma'}{\sigma}\right)^2 \ll 1$

flat beam ratio (BDF)

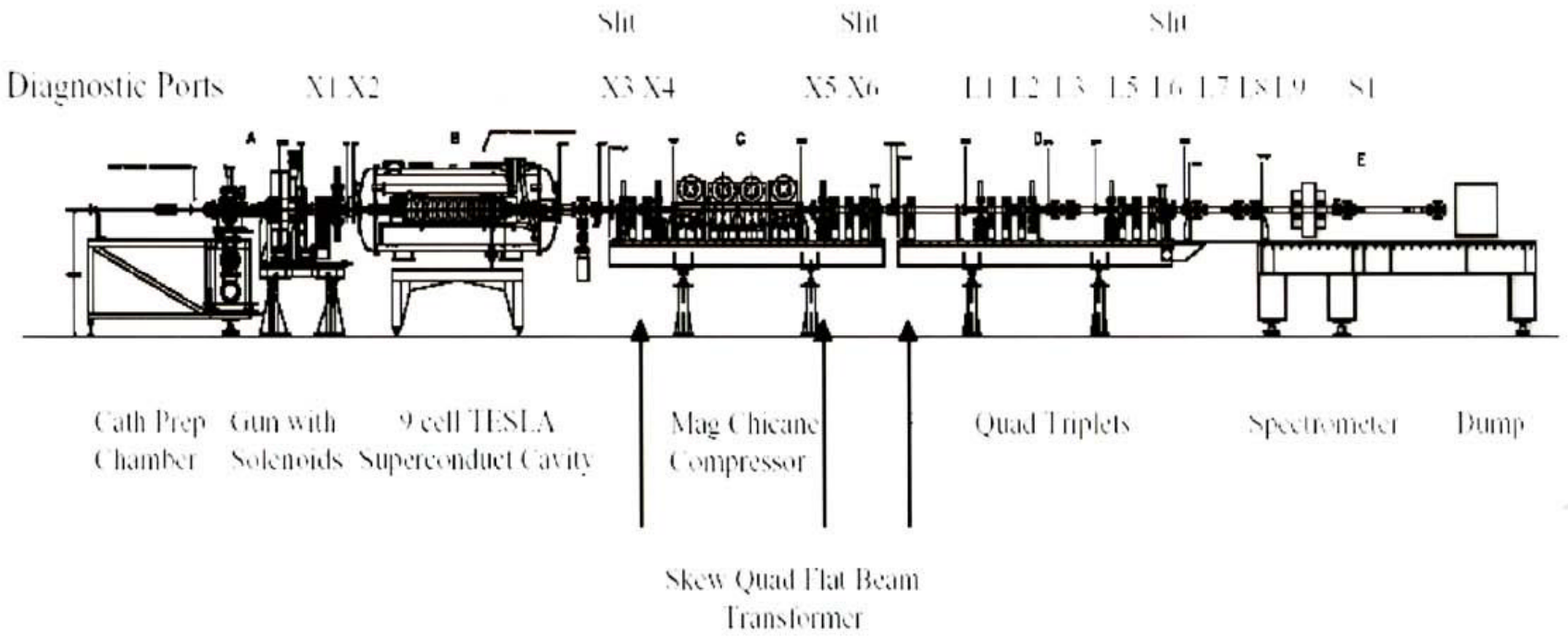
$$\varepsilon_x/\varepsilon_y \Rightarrow 4x^2\sigma^2/\sigma'^2$$

	TESLA	NLC	CLIC
Q (nC)	3	1.6	0.6
ε_x (mm-mrad)	12	4.5	0.68
ε_y	0.03	0.1	0.02
$\sqrt{\varepsilon_x \varepsilon_y}$	0.6	0.7	0.12

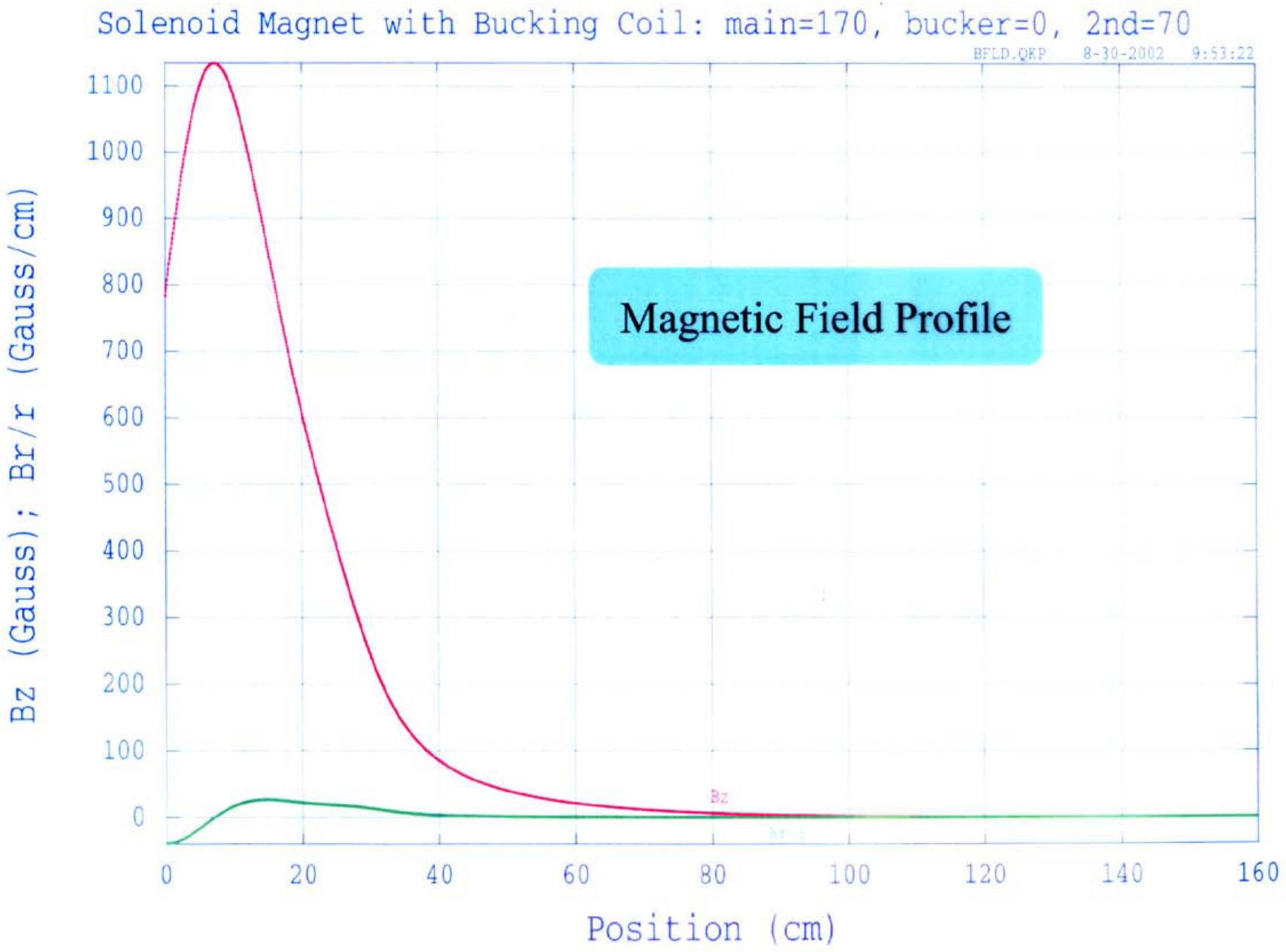
Current state of art

$\sqrt{\varepsilon_x \varepsilon_y} \sim$ 1 mm-mrad @ $Q \approx 1$ nC.

FermiLab/NICADD PhotoInjector



Layout taken from PAC01 paper of D. Edwards etc.


Solenoid Magnet with Bucking Coil: main=170, bucker=0, 2nd=70
BFLD.QKP 8-30-2002 9:53:22
Magnetic Field Profile
Bz (Gauss); Br/r (Gauss/cm)
1100
1000
900
800
700
600
500
400
300
200
100
0
Bz
0
20
40
60
80
100
120
140
160
Position (cm)

Cathode and beam prior to the skew-quad channel

Virtual Cathode (VC)

X3

X4 slit image

X5 slit image

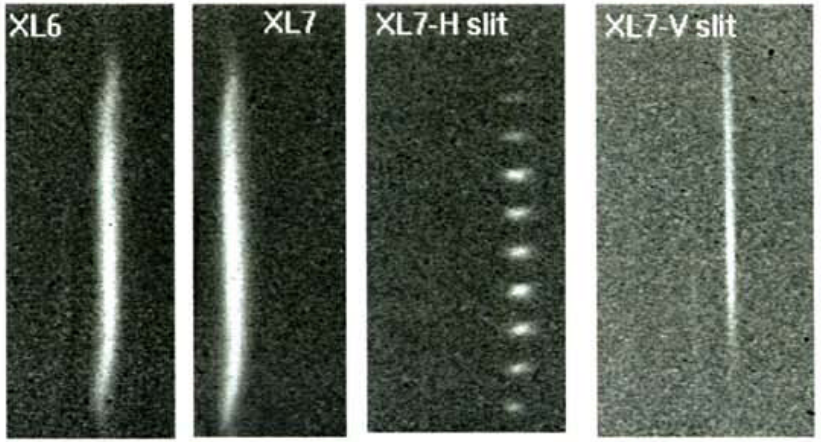
XS4

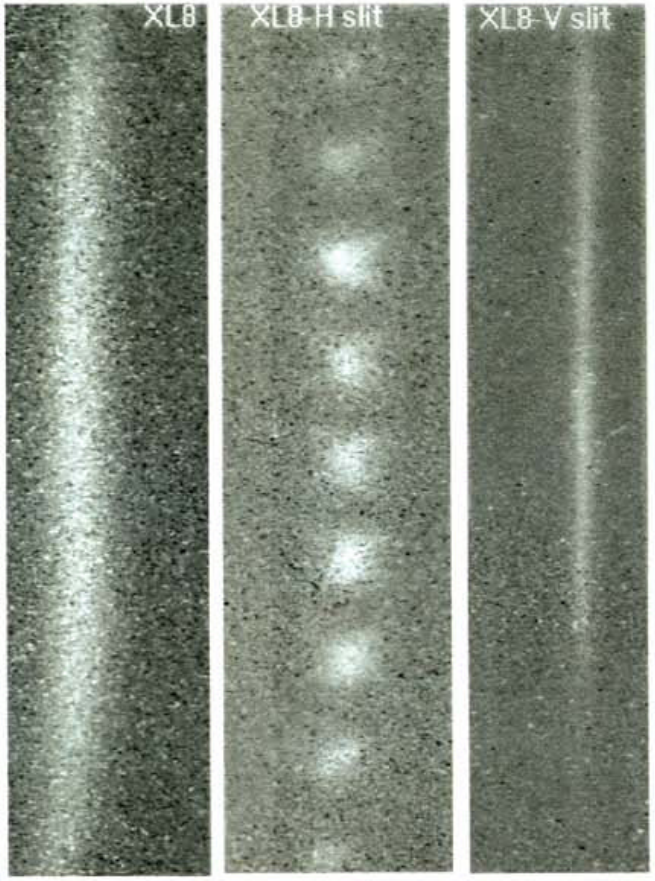
RMS VC	RMS beam size at X3	Normalized Emittance
0.73mm	1.66mm	6.44 mm mrad

VC is an image of the laser spot on the cathode.

Beam energy at the exit of the 1.6 RF gun is about 4 MeV. After the 9-cell SC cavity, beam energy is about 16 MeV. Notice that X3 is after the 9-cell SC cavity.

Flat electron beam profile at 9.6m from the cathode (XL6) and horizontal and vertical beamlets used for emittance measurements downstream at XL7 and XL8. The transverse emittance ratio is about 41 in the example shown here.





$$\frac{\varepsilon_n^y}{\varepsilon_n^x} = \frac{38.85 \ \ mm \ \ mrad}{0.95 \ \ mm \ \ mrad} = 41$$