Emittance Measurements with Multi-slit Method at A0 Photo Injector

Beam: 1nC- 4 nC Beam, Solenoid Current: 200-270 Amp

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Emittance

Emittance is a measure of Transverse and longitudinal temperature of a beam. Is defined as the hypervolume occupied by all beam particles in 6-dimensional phase space (x,px,y,py,z,pz). This phase-space is equivalent to $(\underbrace{x,x',y,y'}_{\text{Transverse Phase Space}},\Delta E,t)$

Longitudinal Phase Space

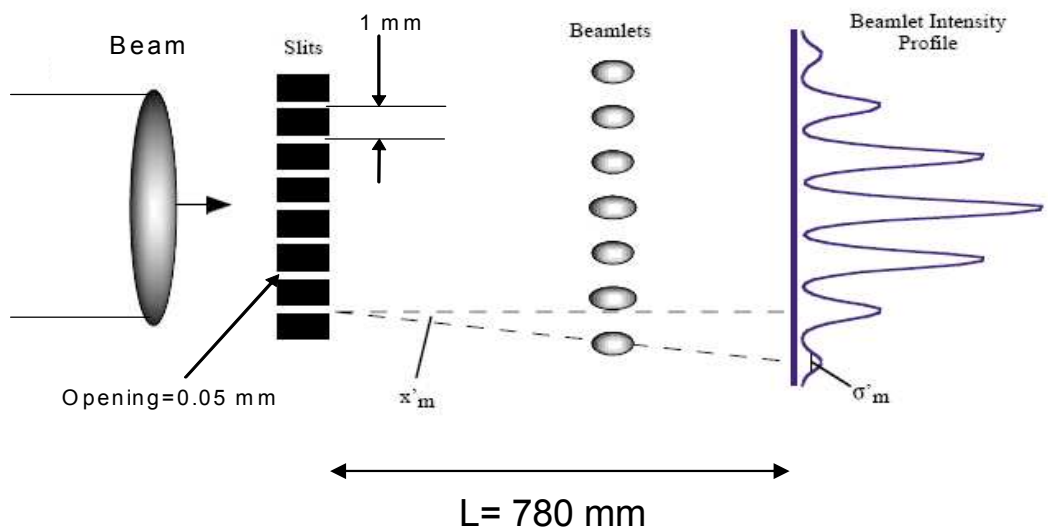
Conceptually, emittance is measure of degree of how beam particle are parallel to one another during their propagation

Measurement of Transverse Emittance with Multi-slit Method

Refs:

C. Lejeune and J. Aubert, Adv. Electron.Electron Phys., Suppl. 13A, 159 (1980)

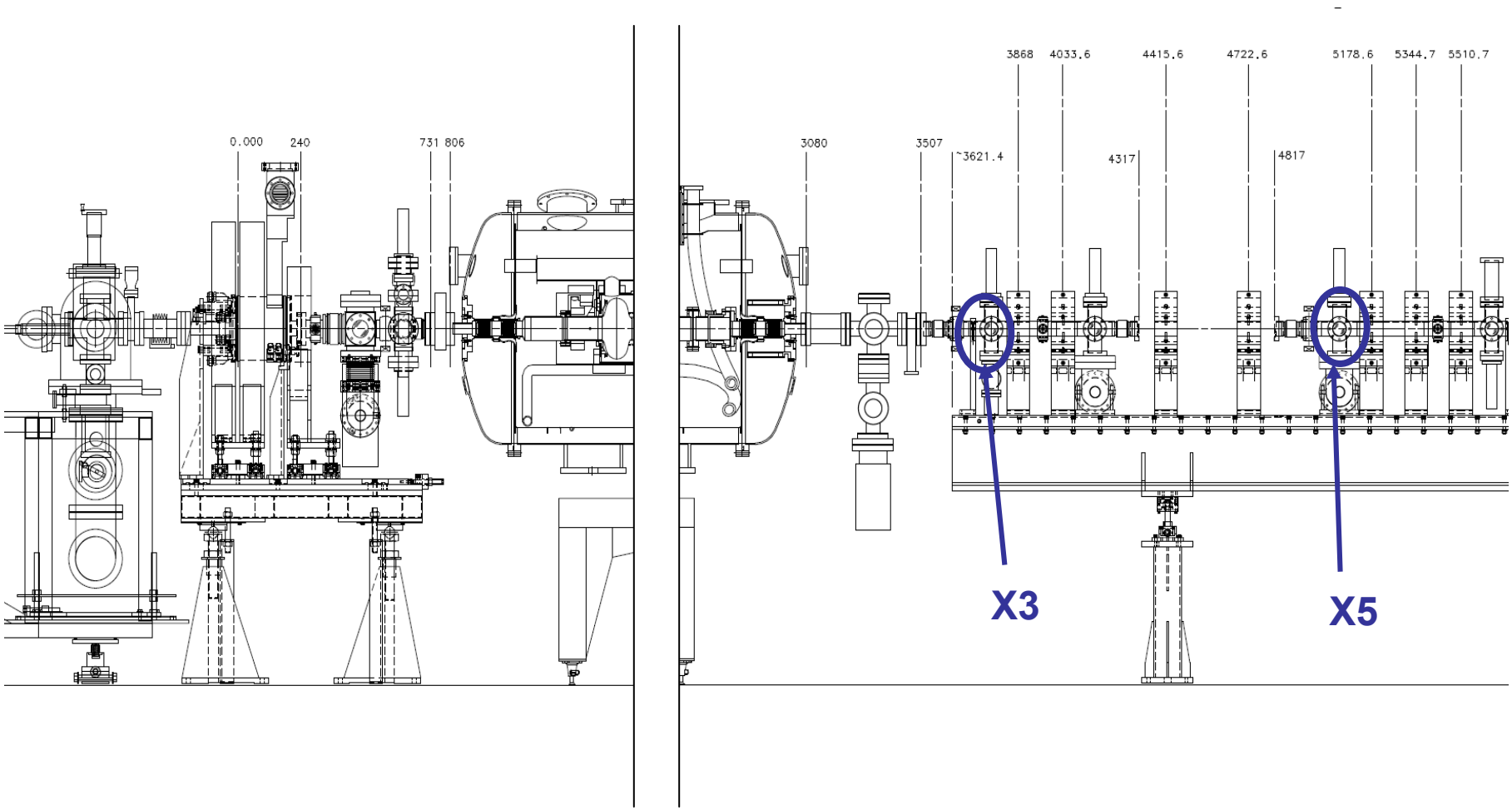
Anderson et al, PRST, Accel. and Beams Vol. 5, 014201(2002)



RMS emittance is given by

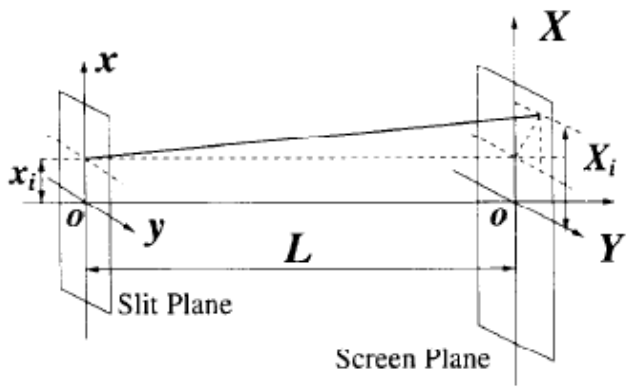
$$\varepsilon_x \equiv \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

Transverse Beam Emittance at A0 Photo-Injector



Emittance Formula

(Ref: M. Zhang, Fermilab-TM-1988)



$$\epsilon_x^2 = \langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2$$

$$\approx \frac{1}{N^2} \left\{ \left[\sum_{j=1}^{p} n_j (x_{sj} - \bar{x})^2 \right] \left[\sum_{j=1}^{p} [n_j \sigma_{x'_j}{}^2 + n_j (\bar{x'_j} - \bar{x'})^2] \right] - \left[\sum_{j=1}^{p} n_j x_{sj} \bar{x'_j} - N \bar{x} \bar{x'} \right]^2 \right\}$$

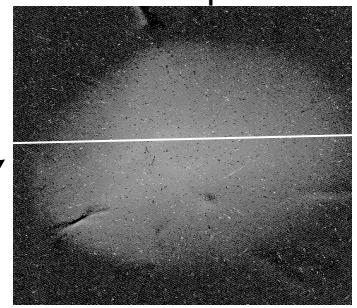
- x_{sj} – j-th slit's position;
- p – total number of slits;
- n_j – number of particles passing through j-th slit
- $\bar{x}$ – mean position of all beamlets (Eq. (5));
- $\bar{x'_j}$ – mean divergence of j-th beamlet (Eq. (10));
- $\bar{x'}$ – mean divergence of all beamlets (Eq. (11));
- $\sigma_{x'_j}$ – rms divergence of j-th beamlet (Eq. (21)).

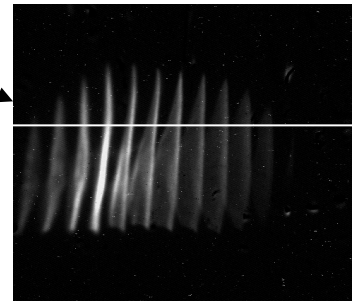
Here we have assumed that the beamlet distributions are symmetric about their centroids

EXCEL Spread Sheet

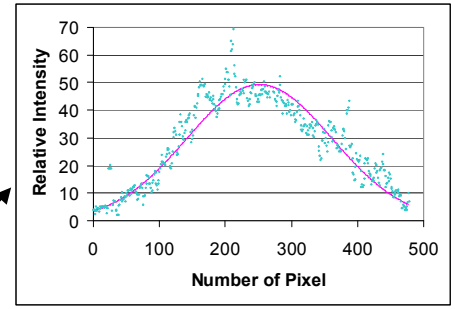
- Raw data
  - X3 beam profile
  - X5 Screen data
- Optimize for the fit
- Get Numbers

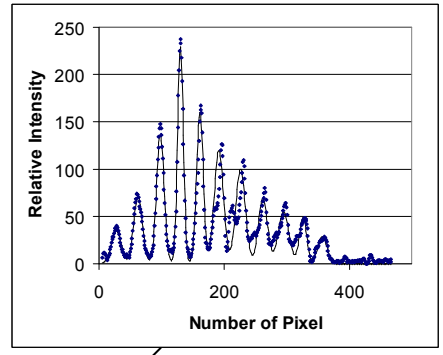
Horizontal profile





Input to EXCEL



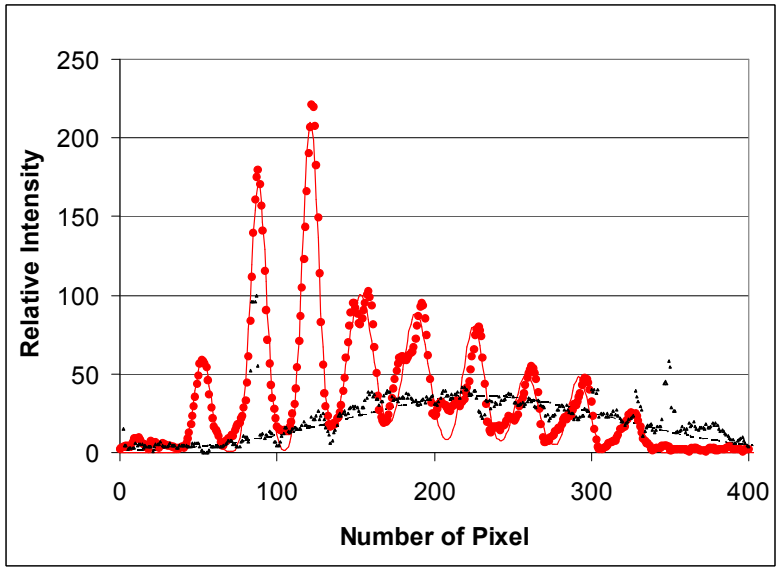


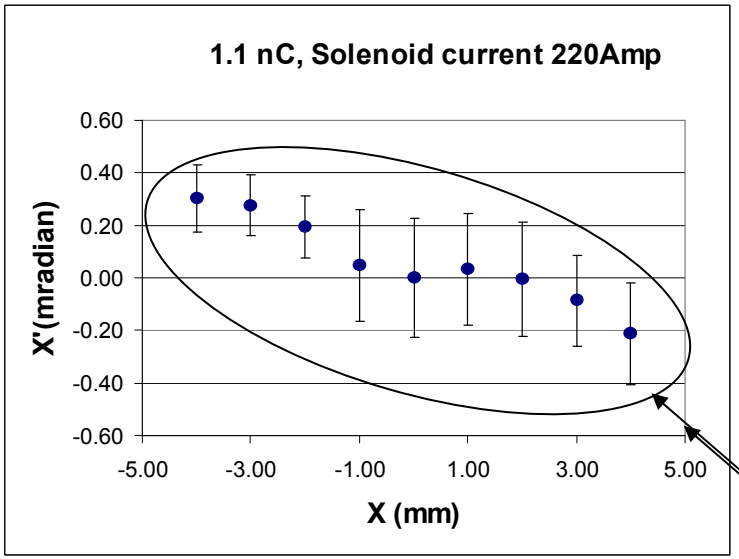
Parameter	1st Guess	Fit parameters		
i1	49	49.3	sigma=	3.07 mm
c1	250	251.5	RMSW=	2.50 mm
w1/2	120	128.9		

FWHM

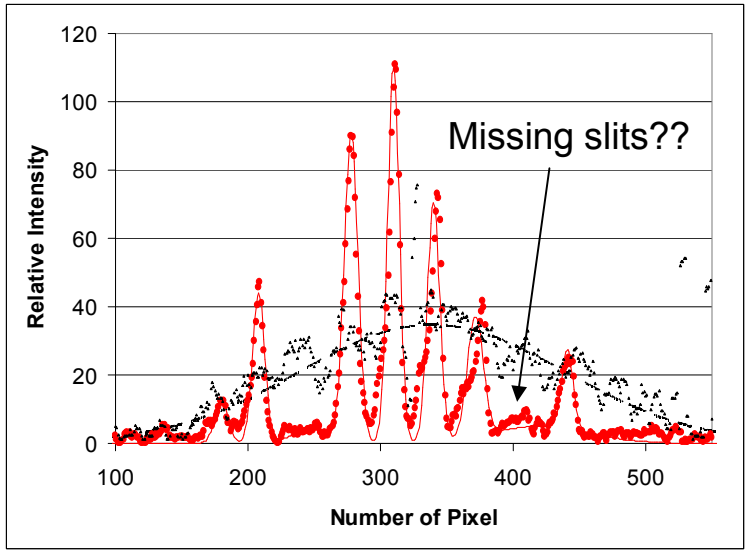
Peak	Area	Center	Width	Height	sigma (pix)	sigma mm
1	674.7	27.5	9.0	35.0	7.7	0.2
2	1227.7	62.4	8.1	70.8	6.9	0.2
3	2063.8	98.1	7.1	136.6	6.0	0.2
4	2665.8	130.3	5.4	230.0	4.6	0.1
5	2145.1	161.3	6.3	160.0	5.3	0.1
6	2204.2	191.6	8.6	120.0	7.3	0.2
7	1916.7	226.3	9.0	100.0	7.6	0.2
8	1241.4	262.0	8.4	69.0	7.2	0.2
9	1171.3	295.1	10.0	55.0	8.5	0.2
10	707.6	326.2	6.8	48.8	5.8	0.2
11	519.3	357.3	8.6	28.5	7.3	0.2

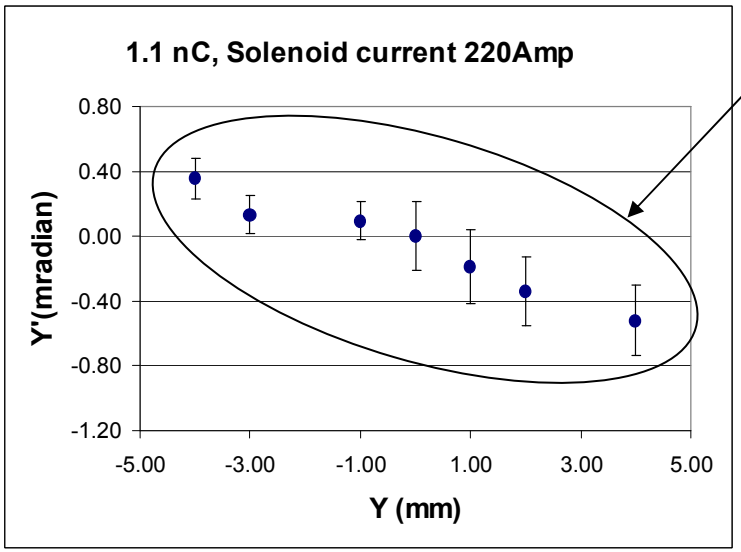
1nC Data Analysis





The phase-space ellipse should look like





1 nC data analysis

Energy of electrons =	15.000	MeV
beta*gamma=	29.412	

X3_cal(X)= 27.85 micro-m/pix

X3_cal(Y)= 28 micro-m/pix

Analysis Results Without Correlations

X3_X_1.1nC_20b

Current, A	Sigma, pix	Sigma, mm	RMSW, pix	RMSW, mm
220	94.94	2.64	108.51	3.02
	108.78	3.03	107.88	3.00
	88.36	2.46	104.85	2.92
Mean	97.36	2.71	107.08	2.98
std	10.42	0.29	1.96	0.05

X3_Y_1.1nC_20b

Current, A	Sigma, pix	Sigma, mm	RMSW, pix	RMSW, mm
220	83.77	2.35	87.81	2.46
	78.52	2.20	77.45	2.17
	70.30	1.97	75.42	2.11
Mean	77.53	2.17	80.23	2.25
std	6.79	0.19	6.64	0.19

X5_cal(X)= 27.85 micro-m/pix

X5_X_1.1nC_20b

Current, A	Sigma, µm	(Sigma-50) µm	error (µm)	
220	147.58	97.58	20.84	
	150.36	100.36	21.44	
	151.58	101.58	33.89	
Mean	149.84	99.84		
std		14.98		

X5_cal(Y)= 28 micro-m/pix

X5_Y_1.1nC_20b

Current, A	Sigma, µm	(Sigma-50) µm	error (µm)	
220	198.80	148.80	38.57	
	181.82	131.82	35.47	
	184.05	134.05	35.95	
Mean	188.22	138.22		
std		21.19		

V-Emittances without correlations

Current, Amp	Emix_V	error	EmitVN	error
	mm-mr	mm-mr	mm-mr	mm-mr
220	0.35	0.06	10.2	1.9

H Emittance without correlations

	Emit_H	error	EmitHN	error
	mm-mr	mm-mr	mm-mr	mm-mr
220	0.38	0.07	11.3	2.0

V-Emittances with correlations

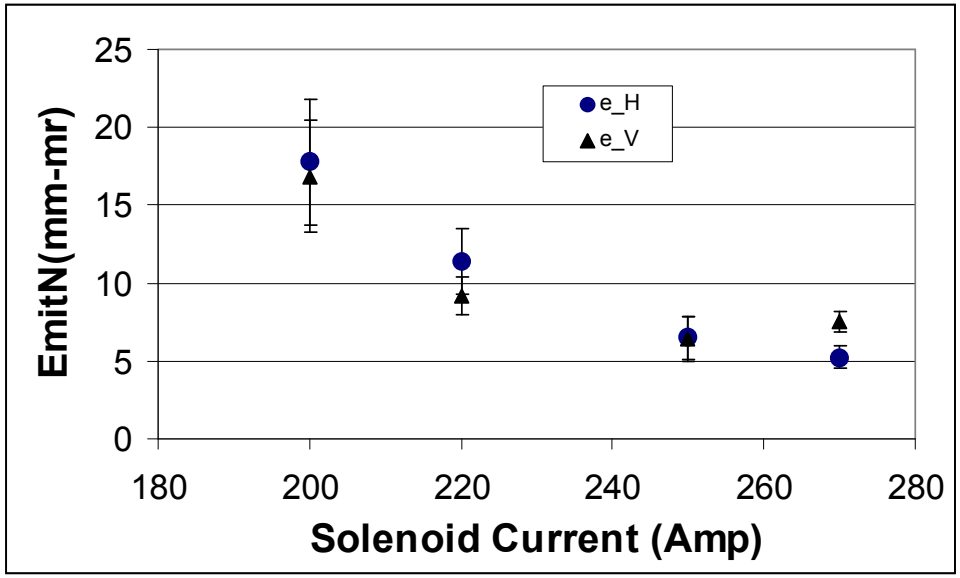
Current, Amp	Emix_V	error	EmitVN	error
	mm-mr	mm-mr	mm-mr	mm-mr
220	0.22	??	6.5	??

H Emittance with correlations

	Emit_H	error	EmitHN	error
	mm-mr	mm-mr	mm-mr	mm-mr
220	0.39	??	11.5	??

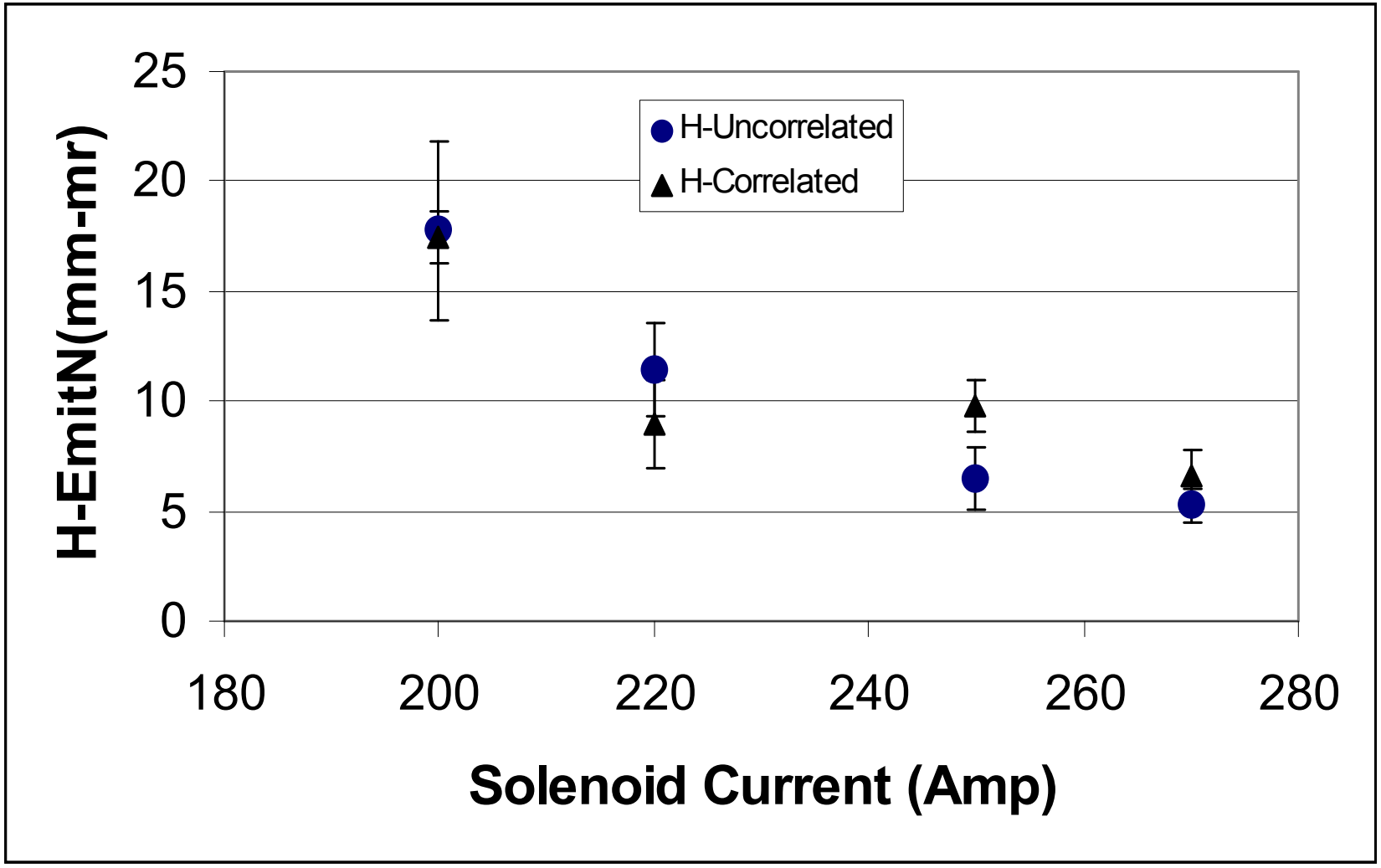
2.1 nC Data Analysis

V-Emittances without correlations					H-Emittance without correlations				
Current, Amp	Emix_V	error	EmitVN		Current, Amp	Emix_H	error	EmitHN	
	mm-mr	mm-mr	mm-mr	mm-mr		mm-mr	mm-mr	mm-mr	mm-mr
200	0.57	0.12	16.8	3.6	200	0.60	0.14	17.8	4.1
220	0.31	0.04	9.2	1.2	220	0.39	0.07	11.4	2.1
250	0.22	0.05	6.4	1.4	250	0.22	0.05	6.5	1.4
270	0.26	0.02	7.5	0.7	270	0.18	0.03	5.2	0.7



2.1 nC Data Analysis

With and without Correlation

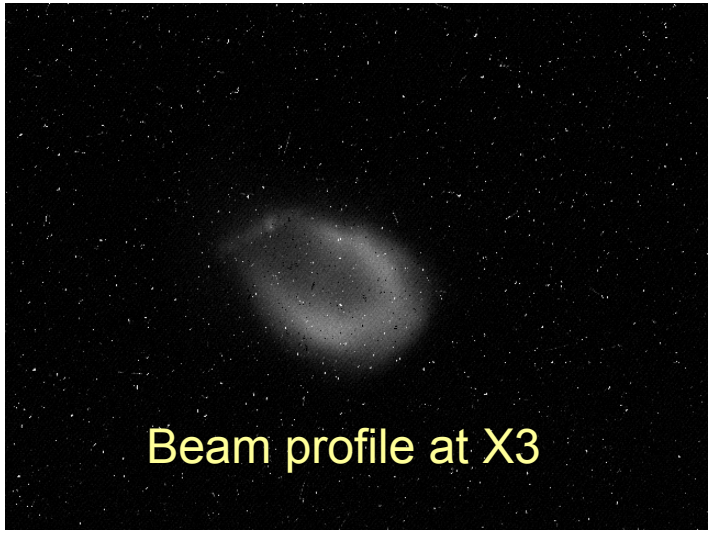


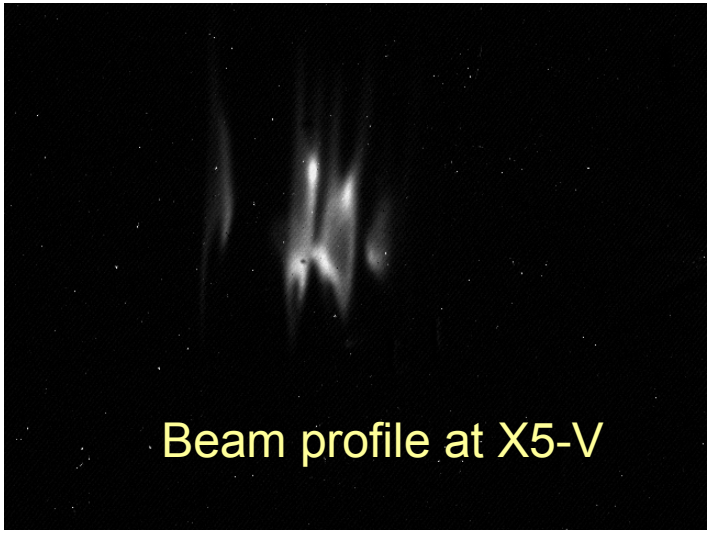
4 nC data Analysis

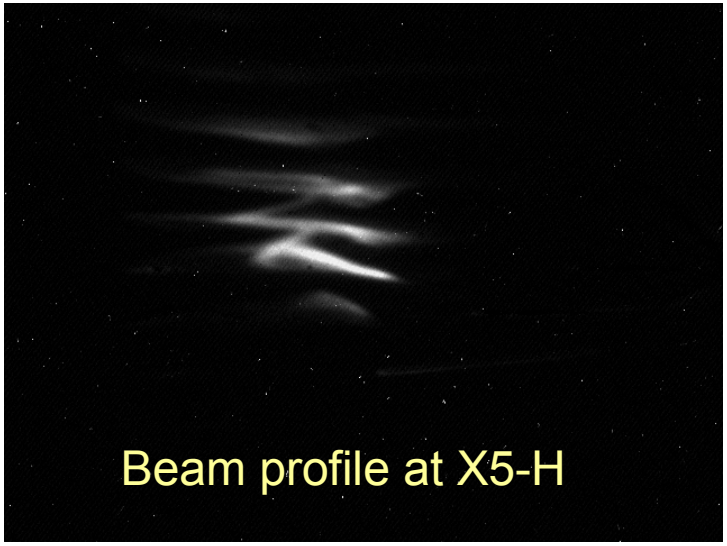
Analysis based on clean region of the beam profile

V-Emittances without correlations					H Emittance without correlations				
Current, Amp	Emix_V	error	EmitVN			Emit_H	error	EmitHN	
	mm-mr	mm-mr	mm-mr	mm-mr		mm-mr	mm-mr	mm-mr	mm-mr
200									
220									
250	0.22	0.04	6.5	1.2		0.22	0.05	6.5	1.6
270	0.34	0.02	10.1	0.6		0.24	0.04	6.9	1.0

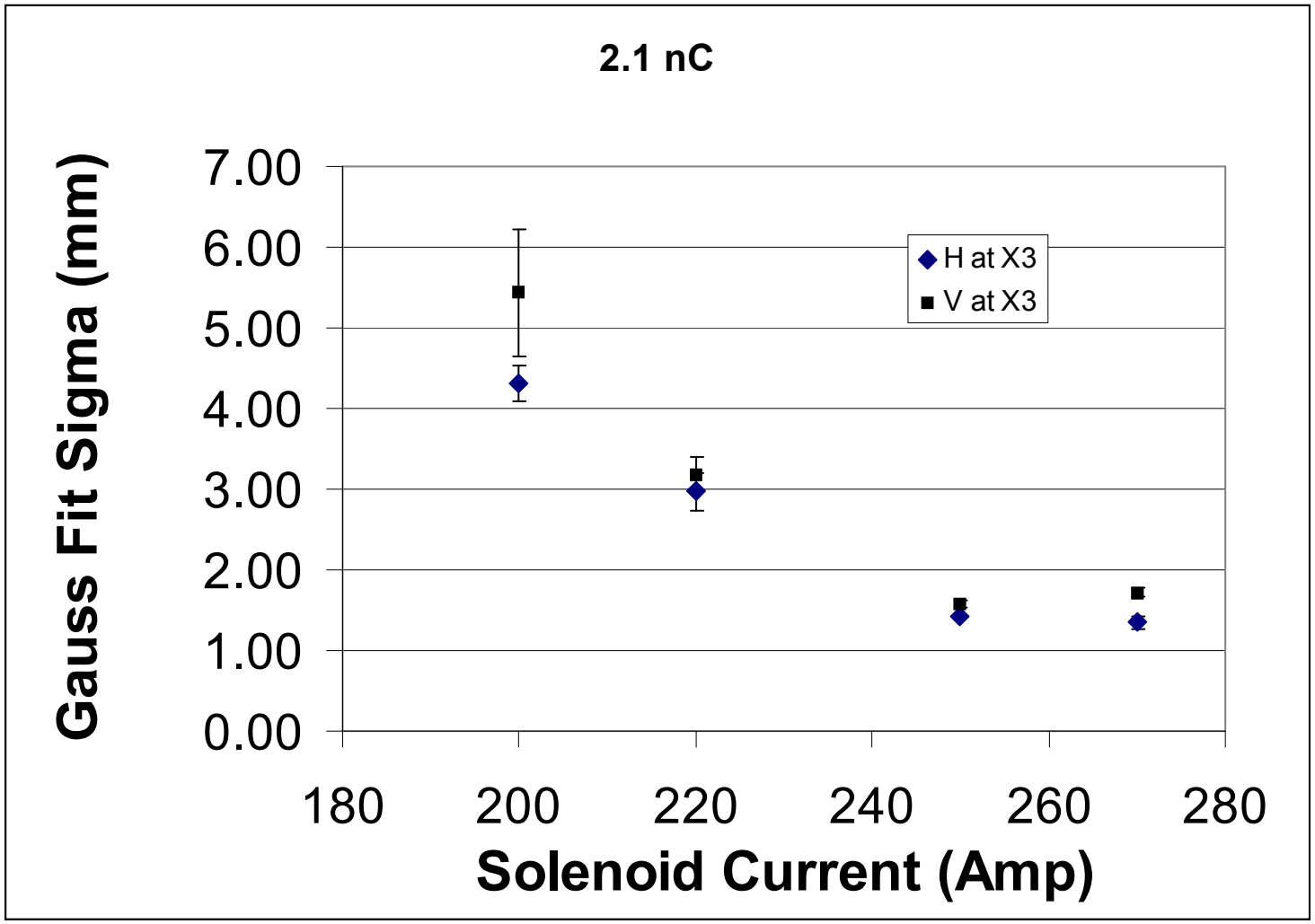
Issues: 4 nC beam with solenoid current = 270 Amp







Beam Size at X3



Summary and Conclusions

- Recently we have taken Mult-slit data for electron emittance measurements at 15 MeV at A0 Photo Injector. The data have been taken at beam intensities 1.1nC, 2.1 nC and 4 nC with solenoid current from 200, 220, 250 and 270 Amp
- We have carried out preliminary data analysis and extracted beam emittances
  - EXCEL spread sheet based analysis (by Chandra Bhat)
  - ORIGIN based analysis (Grigory Kazakevich)
- An EXCEL spread sheet program is written to analyze the data based on refs:
  - PRST, Accel. and Beams Vol. 5, 014201(2002) and
  - Fermilab-TM-1988

- The beam at all the intensities mentioned above are space-charge dominated. Measured transverse emittances for
  - 1nC data are reasonable
  - Analysis results for for 2.1nC and 4 nC data are biased. Mult-slit data analysis need improvements. This work is in progress.