Nano(n)-machining, surface analysis and characterization measurements of a copper photocathode at SPARC_LAB

Jessica Scifo
On behalf of SPARC_LAB collaboration

Outline

- Motivation
- Machining and results before and after machining
- Fourier transform of AFM images and surface roughness induced emittance
- Total beam emittance measurements
- Preliminary study of Yttrium photocathodes
- Conclusions

Motivation

- High brightness (high current, low emittance) electron beam production by photoinjector at SPARC_LAB

- A R&D activity on photocathodes is under development at the SPARC_LAB test facility in order to fully know and characterize each stage of the photocathode "life"

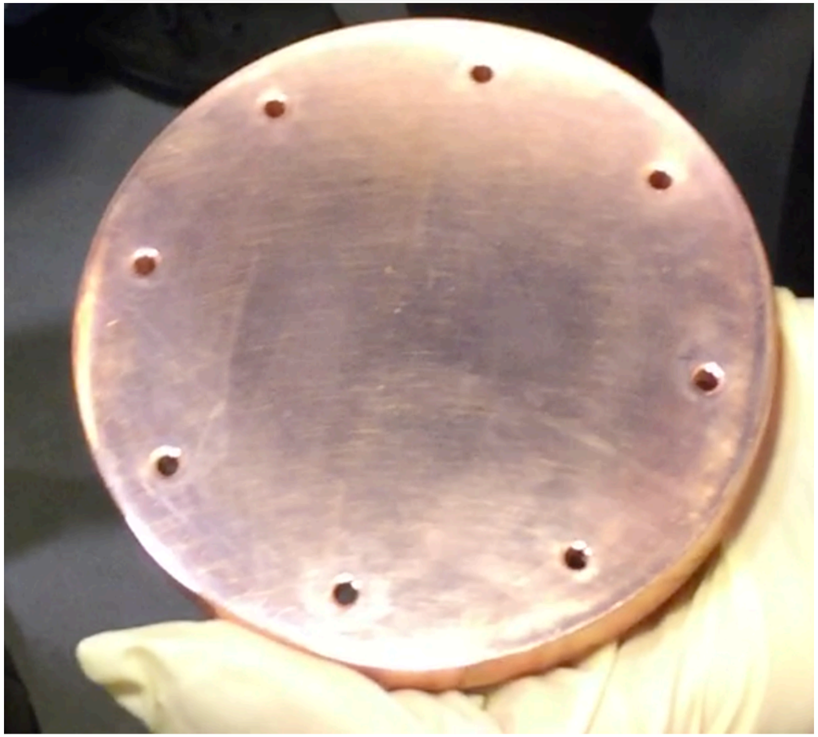
- The n-machining is used to reduce roughness, that is one of contributions to the total beam emittance, and avoid surface contamination caused by other procedures, for example the polishing with diamond paste or the machining with oil

The Machining

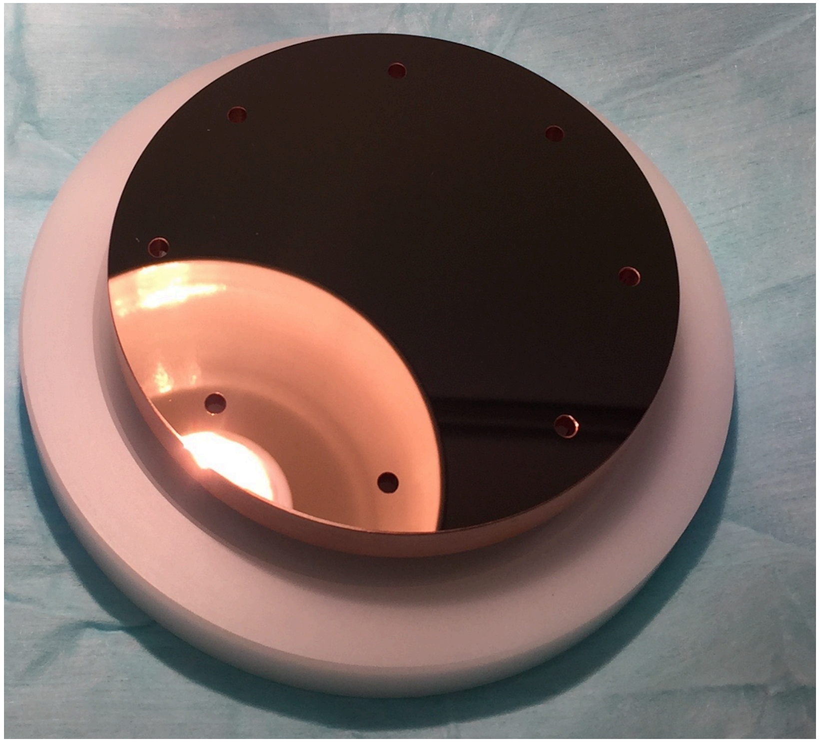
- The photocathode surface has been machined by means of diamond milling and blown with nitrogen. The machining has been done without the use of any oil or cooling fluid (dry machining).

BEFORE MACHINING

Our cathode time life was about 6 years

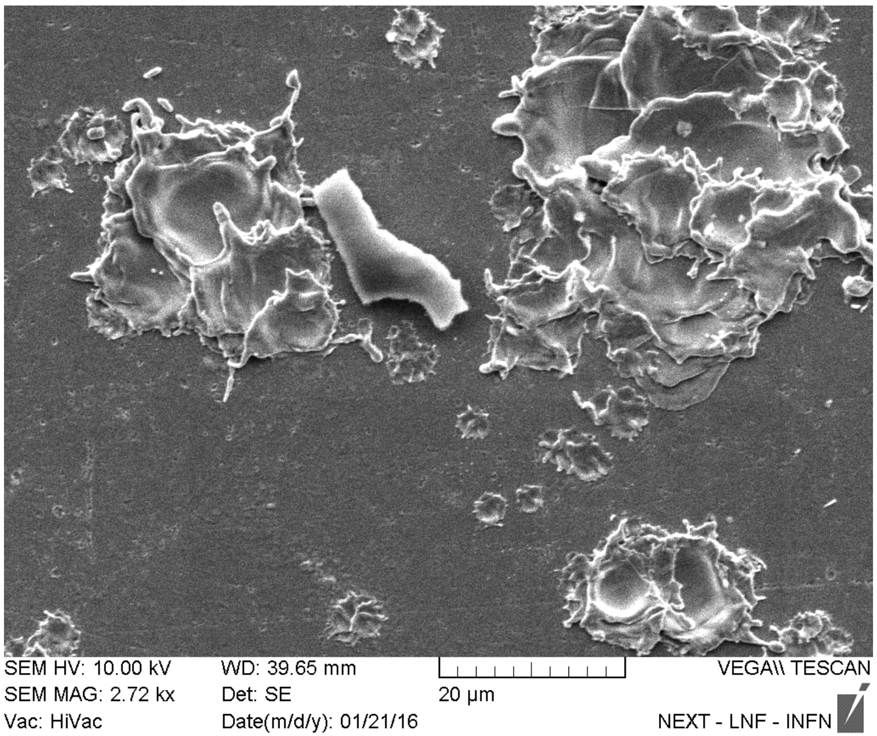


AFTER MACHINING

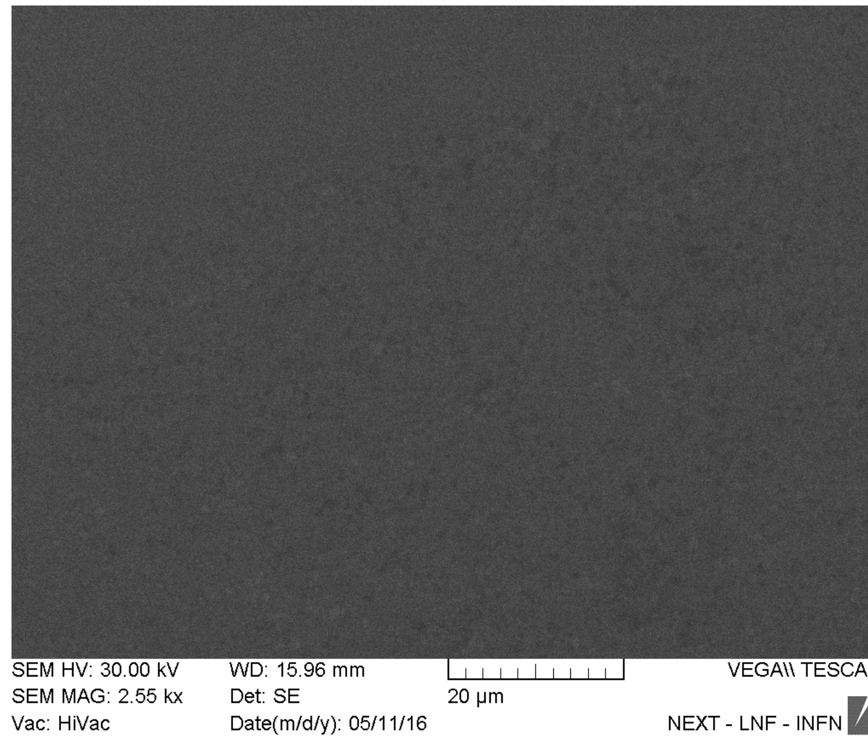


The Machining

BEFORE MACHINING

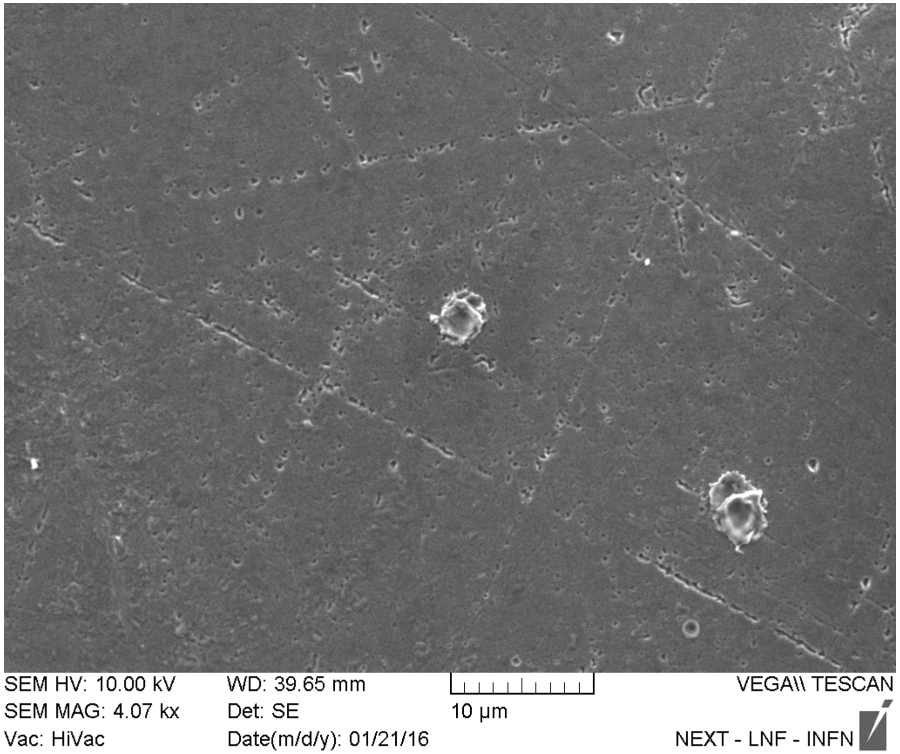


AFTER MACHINING

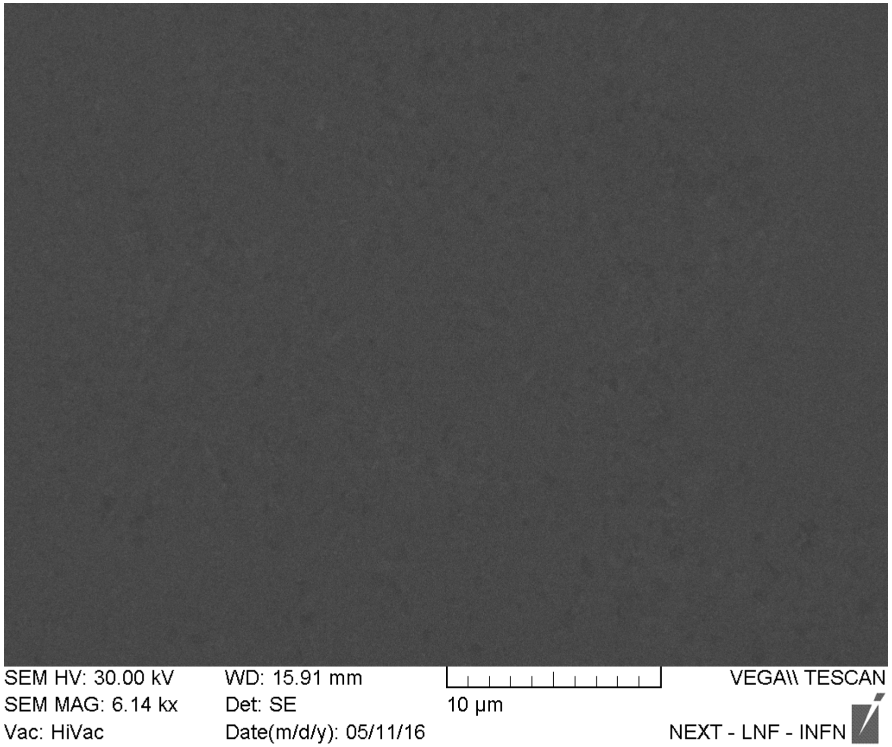


The Machining

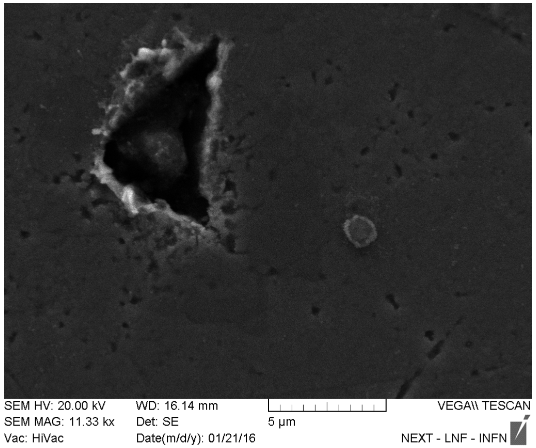
BEFORE MACHINING

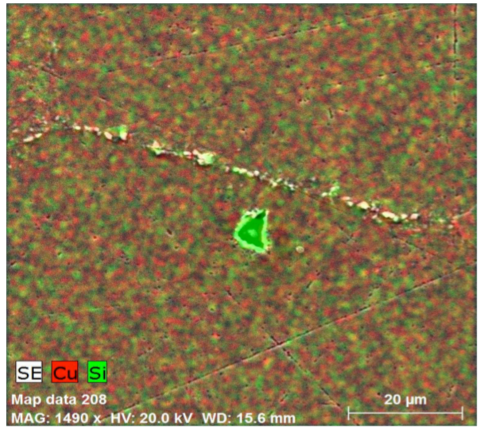


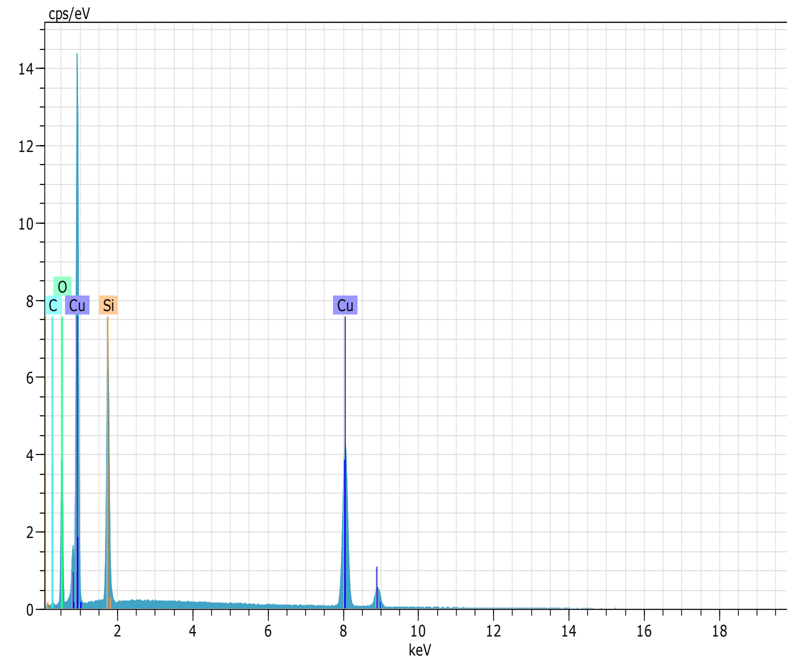
AFTER MACHINING



Chemical composition before machining



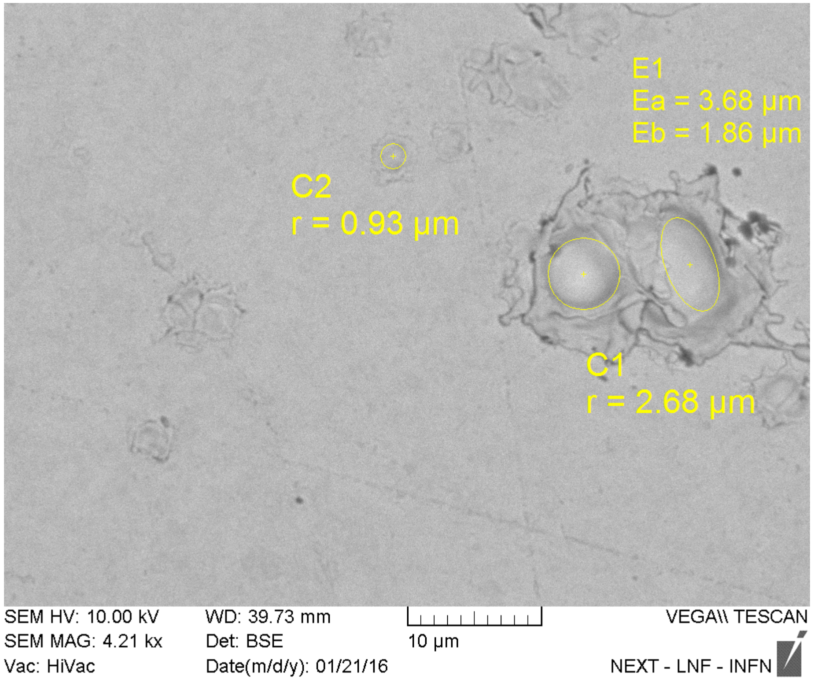


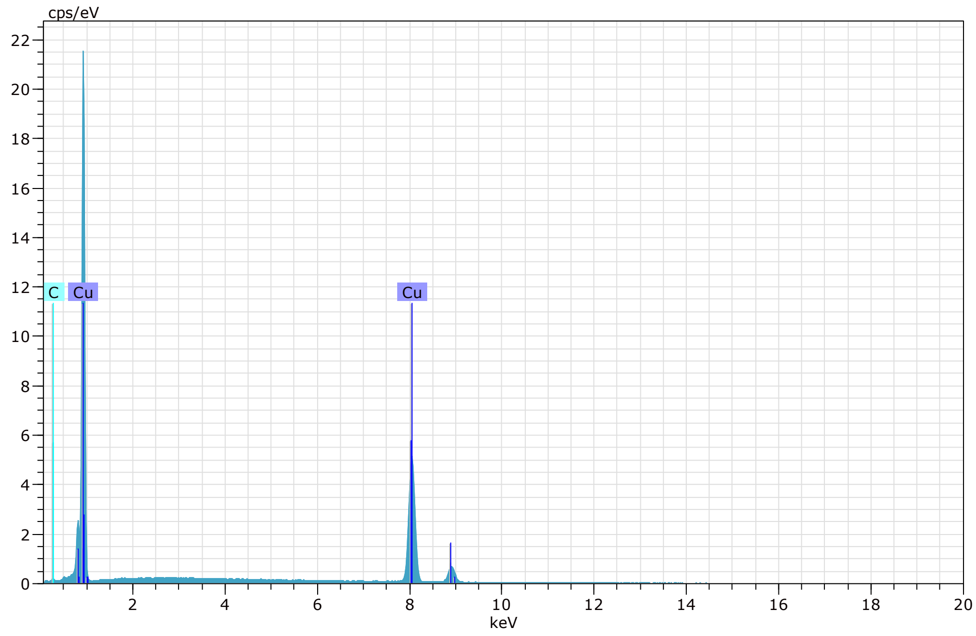


Spectrum: Acquisition 862 - particella.spx

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]	K fact.	Z corr.	A corr.	F corr.
Cu	29	K-series	62.20	63.79	34.62	1.72	0.548	1.114	1.000	1.044
O	8	K-series	17.08	17.51	37.76	2.31	0.377	0.464	1.000	1.000
Si	14	K-series	15.46	15.86	19.47	0.69	0.131	1.203	1.000	1.004
C	6	K-series	2.77	2.84	8.15	0.76	0.077	0.369	1.000	1.000
		Total:	97.51	100.00	100.00					

Chemical composition before machining

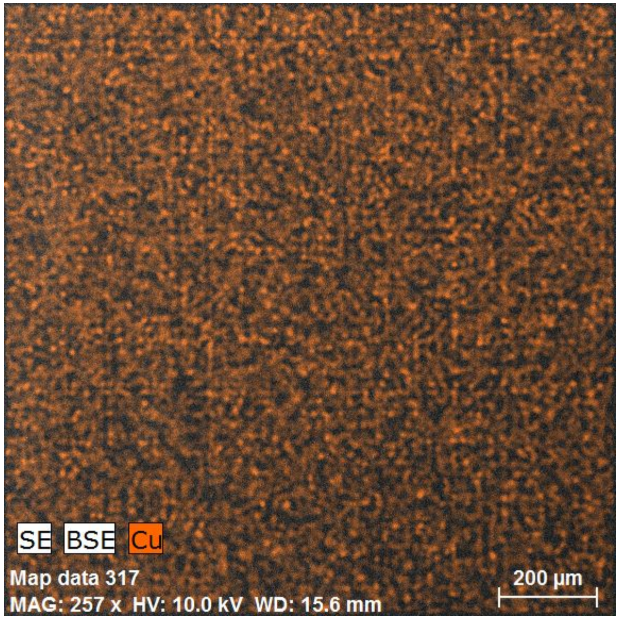


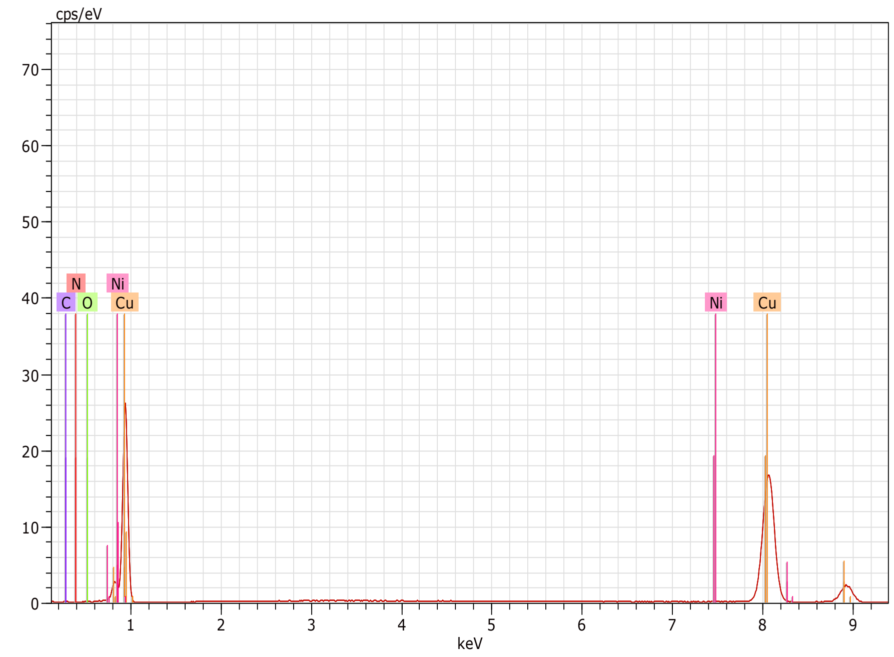


Spectrum: Acquisition 861-Generale.spx

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]	K fact.	Z corr.	A corr.	F corr.
Cu	29	K-series	88.20	96.47	83.80	2.42	0.862	1.078	1.000	1.039
C	6	K-series	3.22	3.53	16.20	0.86	0.091	0.387	1.000	1.000
		Total:	91.43	100.00	100.00					

Chemical composition after machining



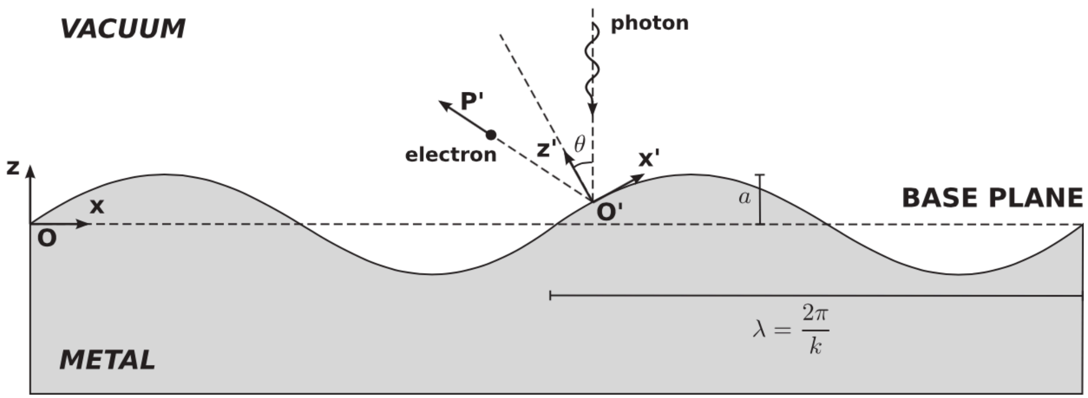


Spectrum: Acquisition 877

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
Cu	29	L-series	289089	98.81	98.81	95.69	10.64
C	6	K-series	1280	0.47	0.47	2.39	0.12
Ni	28	L-series	1453	0.34	0.34	0.35	0.09
O	8	K-series	1150	0.22	0.22	0.86	0.07
N	7	K-series	466	0.16	0.16	0.71	0.07
			Total:	100.00	100.00	100.00	

Surface roughness induced emittance

- Surface roughness on cathode introduces a transverse electric field that increases the transverse momentum, causing emittance growth.

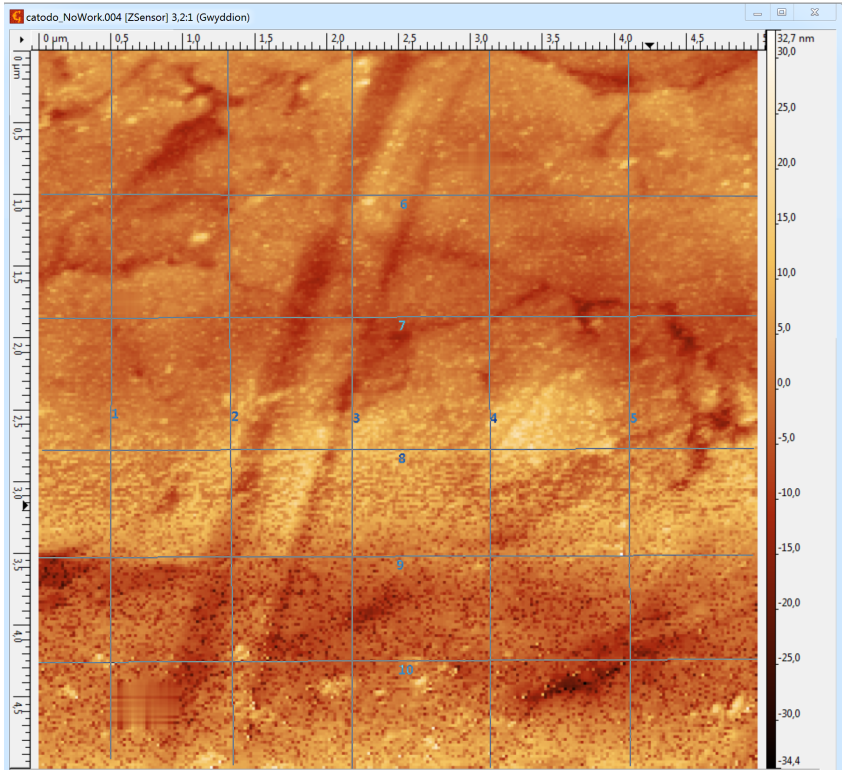


- $z = a \cos((2\pi/\lambda)x)$, surface morphology function
- **a**, amplitude of the uneven surface
- **λ**, period of fluctuation

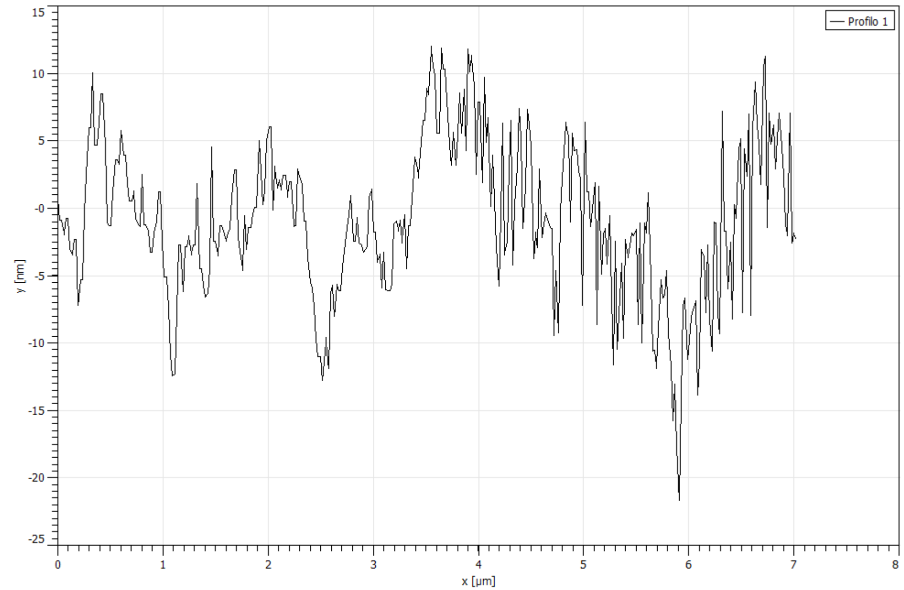
$$\varepsilon_{ns} = \sigma_x \sqrt{\frac{e\pi^2 a^2 E_{rf} \sin\vartheta_{rf}}{2m_0 c^2 \lambda}}$$

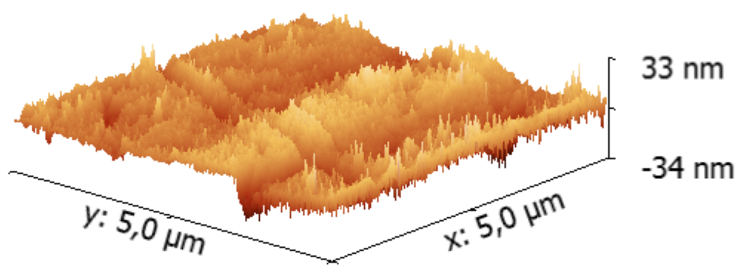
Z. Zhang and C. Tang, *Analytical study on emittance growth caused by roughness of a metallic photocathode*, PRST-AB 18, 053401 (2015)
D. Xiang et al., *First principle measurements of thermal emittance for copper and magnesium*, Proc. of PAC07, Albuquerque, New Mexico, USA

AFM analysis before n-machining



Profile of images





Statistical parameters:

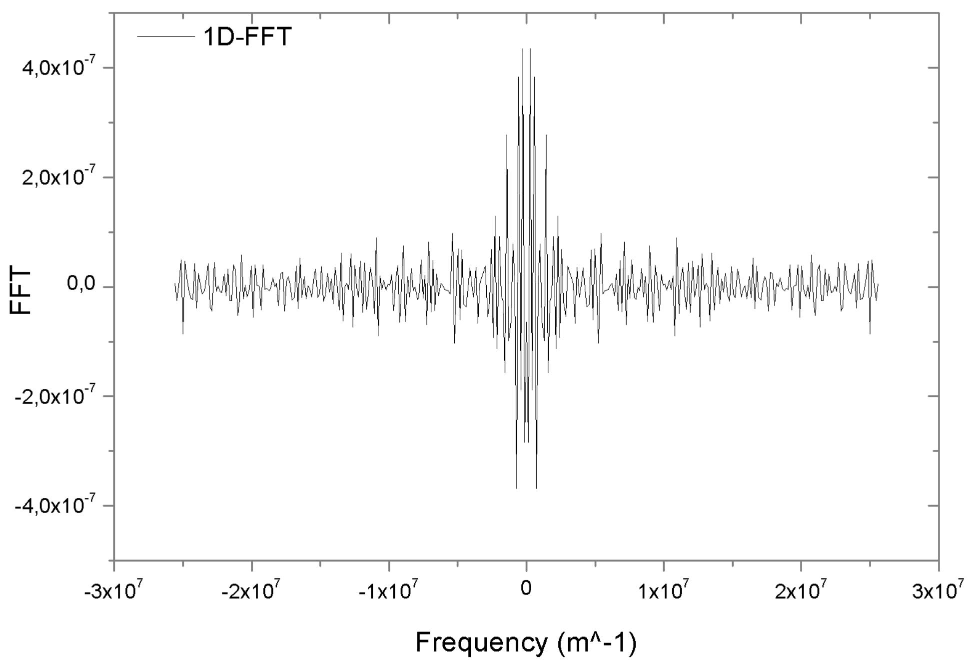
Min_value:	-34,4 nm
Max_value:	32,6 nm
Ra (Sa):	4,3 nm
Rms (Sq):	5,7 nm

J. Scifo

Fourier transform of AFM image

$$Re\{F[l]\} = \frac{1}{N}\sum_{n=0}^{N-1} Re\{f[n]\}\cos 2\pi \frac{n}{N} l$$

1D-DFT

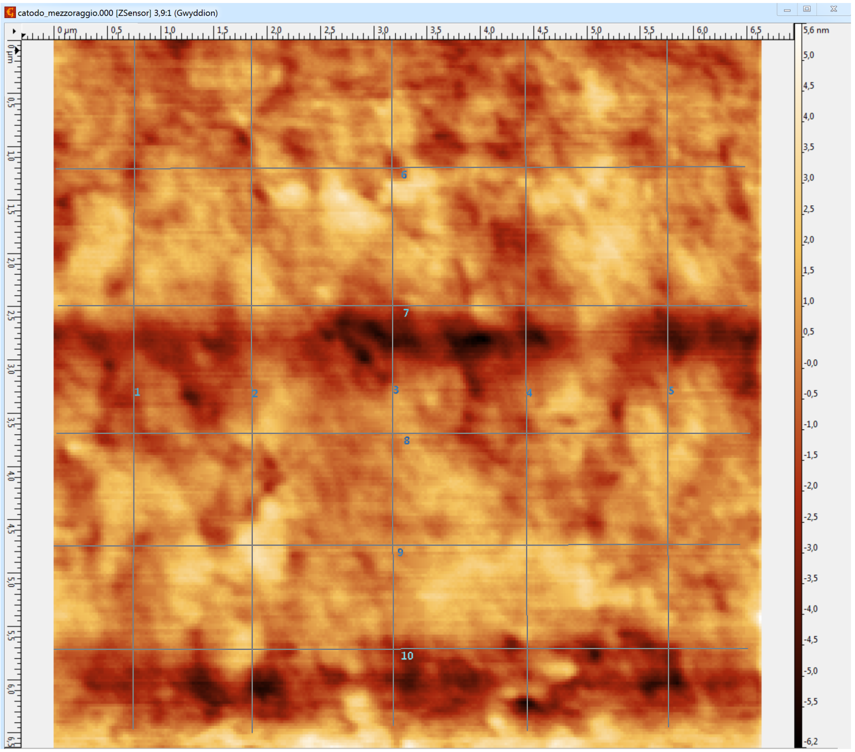


$$a_n = \mathrm{Re}\{f[n]\}$$

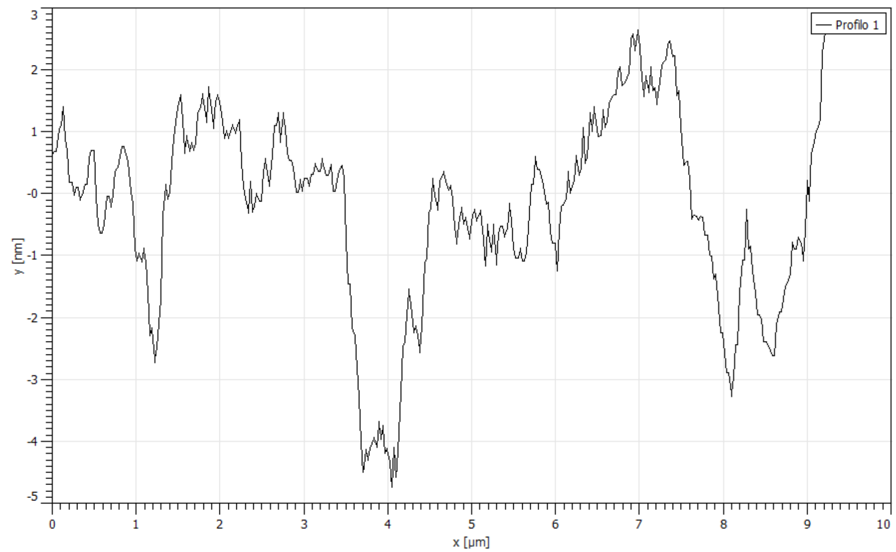
$$\lambda_n = \frac{L_{cathode}}{n}$$

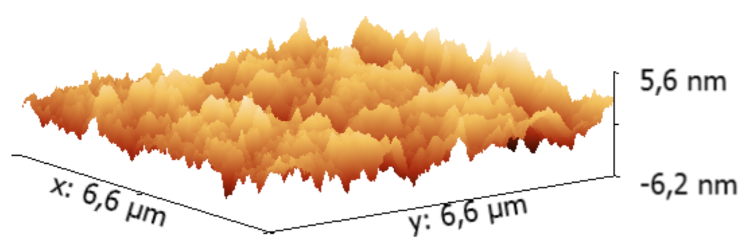
$$\sum_{n=0}^{N-1} \frac{a_n^2}{\lambda_n} = 3.13e-11m$$

AFM analysis after n-machining



Profile of images





Statistical parameters:

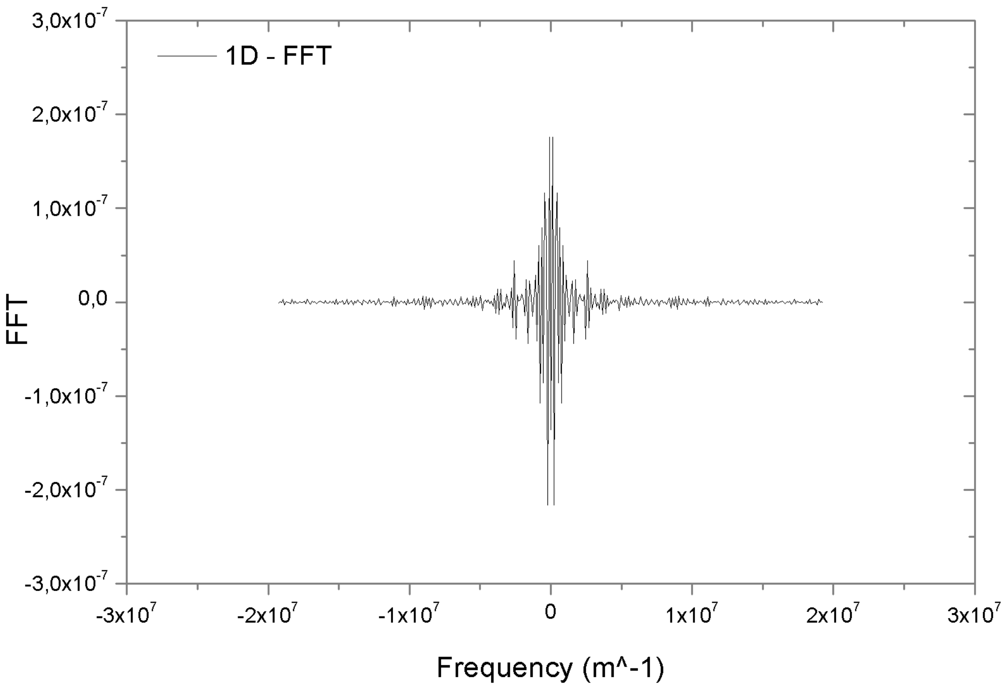
Min_value:	-6,16 nm
Max_value:	5,60 nm
Ra (Sa):	1,18 nm
Rms (Sq):	1,501nm

J. Scifo

Fourier transform of AFM image

$$Re\{F[l]\} = \frac{1}{N}\sum_{n=0}^{N-1} Re\{f[n]\}\cos 2\pi \frac{n}{N} l$$

1D-DFT



$$a_n = \mathrm{Re}\{f[n]\}$$

$$\lambda_n = \frac{L_{cathode}}{n}$$

$$\sum_{n=0}^{N-1} \frac{a_n^2}{\lambda_n} = 4e-13m$$

Surface roughness induced emittance and Fourier transform of AFM image

$$\epsilon_{total}^2 = \sum_{n=0}^{N-1} \epsilon^2(a_n, k_n) = \sigma_x{}^2 \frac{\pi^2 e E_{rf} \sin\theta_{rf}}{2mc^2} \sum_{n=0}^{N-1} \frac{a_n{}^2}{\lambda_n}$$

$$E_{rf} = 97 MV/m$$

$$\vartheta_{rf} = 30^\circ$$

$$\sigma_x = 0.3mm$$

Before n-machining

$$\sum_{n=0}^{N-1} \frac{a_n^2}{\lambda_n} = 3.13e-11m$$

$$\sqrt{\varepsilon_{total}^2} = 0.04\,\mu m$$

After n-machining

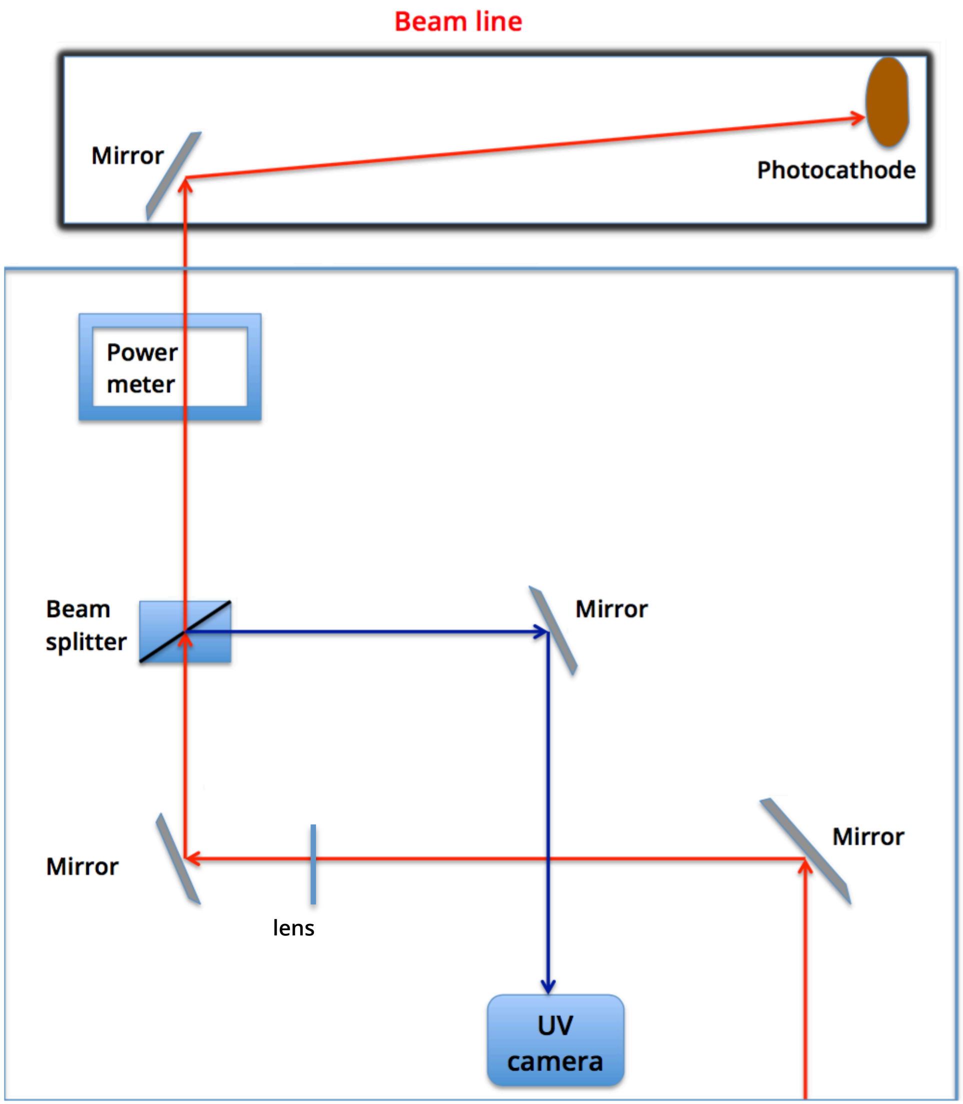
$$\sum_{n=0}^{N-1} \frac{a_n^2}{\lambda_n} = 4e-13m$$

$$\sqrt{\varepsilon_{total}^2} = 0.004\,\mu m$$

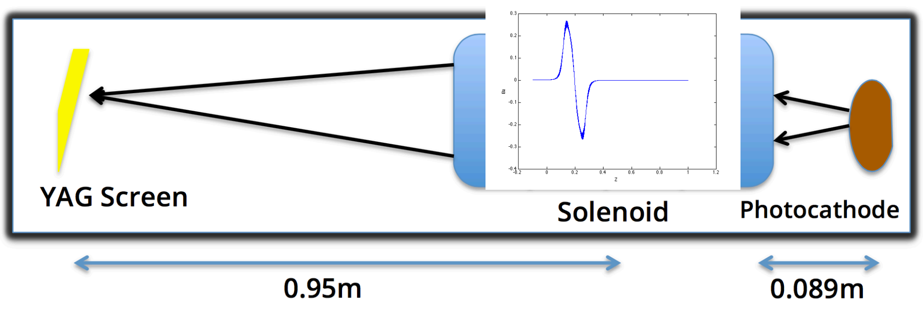
Private communication with David H. Dowell

Emittance measurements: experimental set up

- Photocathode laser



- Beam line



<u>**Solenoid is in not-rotating configuration, that is no x/y coupling**</u>

Emittance measurements: measurements method

Solenoid Scan Technique:

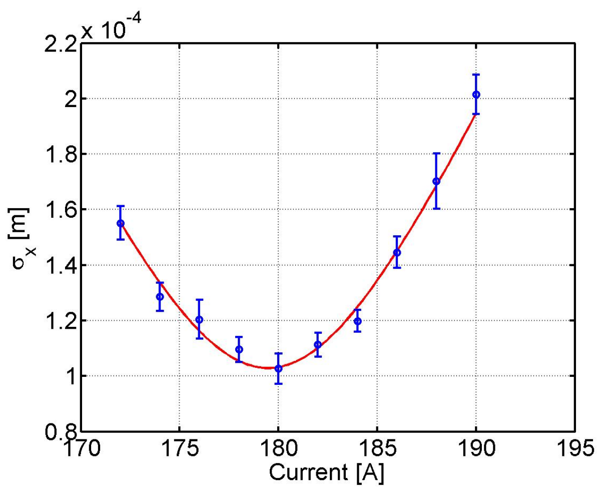
1. Measure of beam size squared on YAG Screen for different solenoid field is given by:

$$\langle x_i \rangle^2 = R_{11}^{(i)^2} \langle x_0^2 \rangle + 2R_{11}^{(i)} R_{12}^{(i)} \langle x_0 x_0^{'} \rangle + R_{12}^{(i)^2} \langle x_0^{'2} \rangle$$

Where the coefficients R_{11} and R_{12} are the elements of beam line transfer matrix.

2. Total normalized emittance has been computed at the entrance of gun solenoid:

$$\varepsilon_{nx,rms} = \gamma\beta\sqrt{\langle x_0{}^2 \rangle \langle x_0{}^{'2} \rangle - \langle x_0 x_0^{'} \rangle^2}$$



At the entrance of gun solenoid:

$$\varepsilon_{nx} = 0.16 \pm 0.01 mmmrad$$

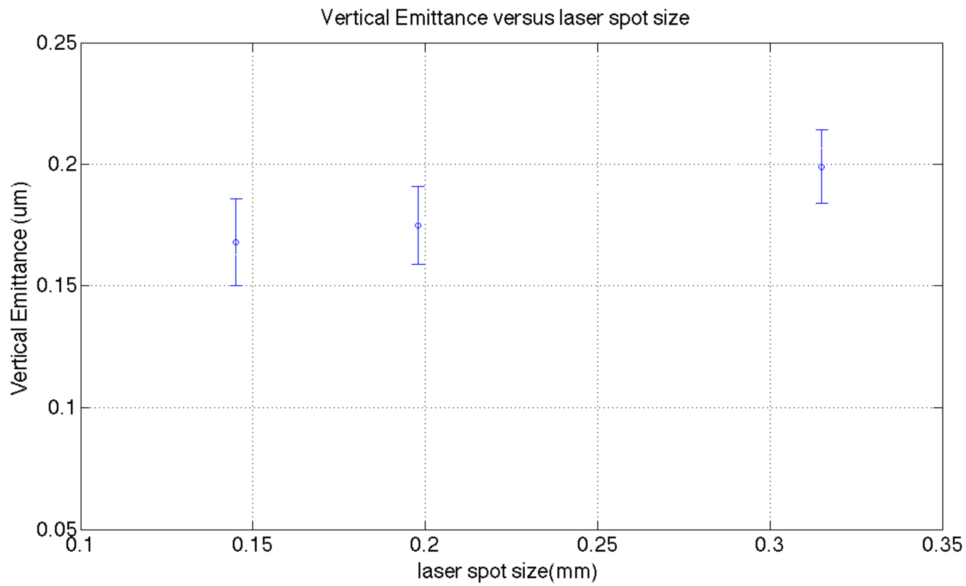
$$\beta x\_in = 0.38 \pm 0.04 m$$

$$\alpha x\_in = -6.8 \pm 0.8$$

Scaling of emittance with spot size of laser

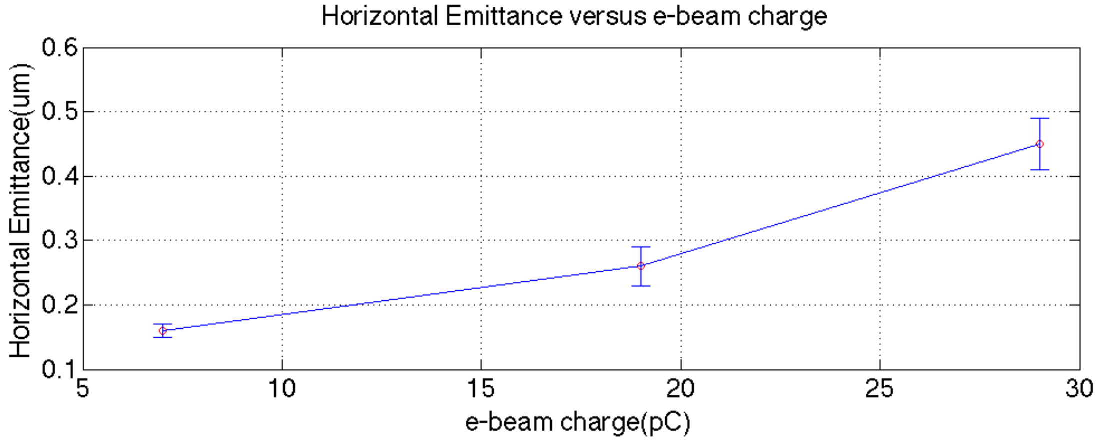
***Parameters*:**

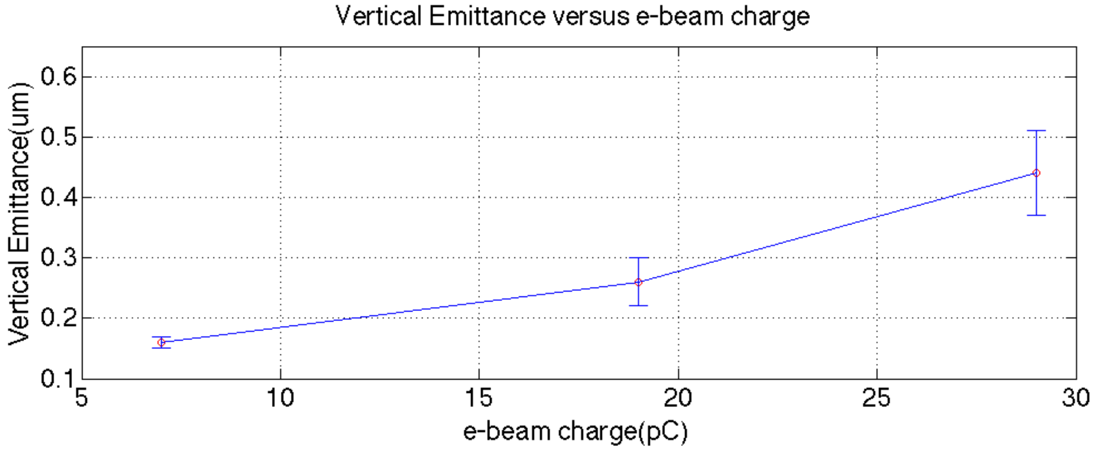
- Epeak= 84MV/m
- Working RF phase=30°
- Laser pulse length=5ps - FWHM (Gaussian profile)
- E= 4.01±0.05MeV - Energy at the gun exit
- Bunch charge≅ 6pC



Scaling of emittance with e- beam charge

***Parameters*:**
- Epeak= 97MV/m
- Working RF phase=30°
- Laser pulse length =5ps - FWHM (Gaussian profile)
- E= 4.53±0.05MeV - Energy at the gun exit
- $\sigma_{x,yrms}$ (Laser spot)≅0.3mm (Flat top profile)



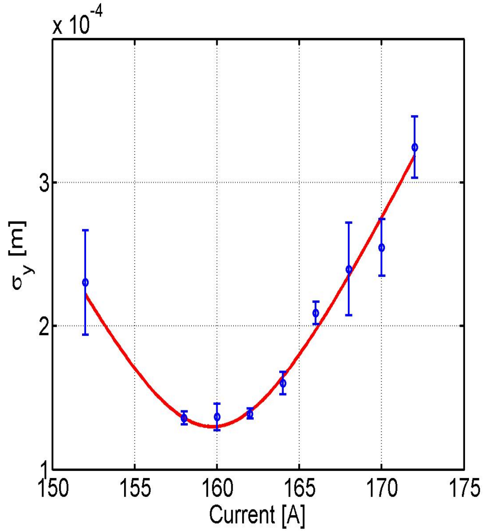


Emittance measurements before n-machining

Before n-machining

Parameters:

- Epeak= 84MV/m
- Working RF phase=30°
- Laser pulse length=5ps - FWHM (Gaussian profile)
- E= 4.01±0.05MeV - Energy at the gun exit
- Bunch charge≅ 6pC



At the entrance of gun solenoid:

$$\varepsilon_{nx} = 0.28 \pm 0.04 mmmrad$$

$$\beta x\_in = 0.42 \pm 0.06 m$$

$$\alpha x\_in = -7.33 \pm 0.13$$

Emittance measurements before and after n-machining

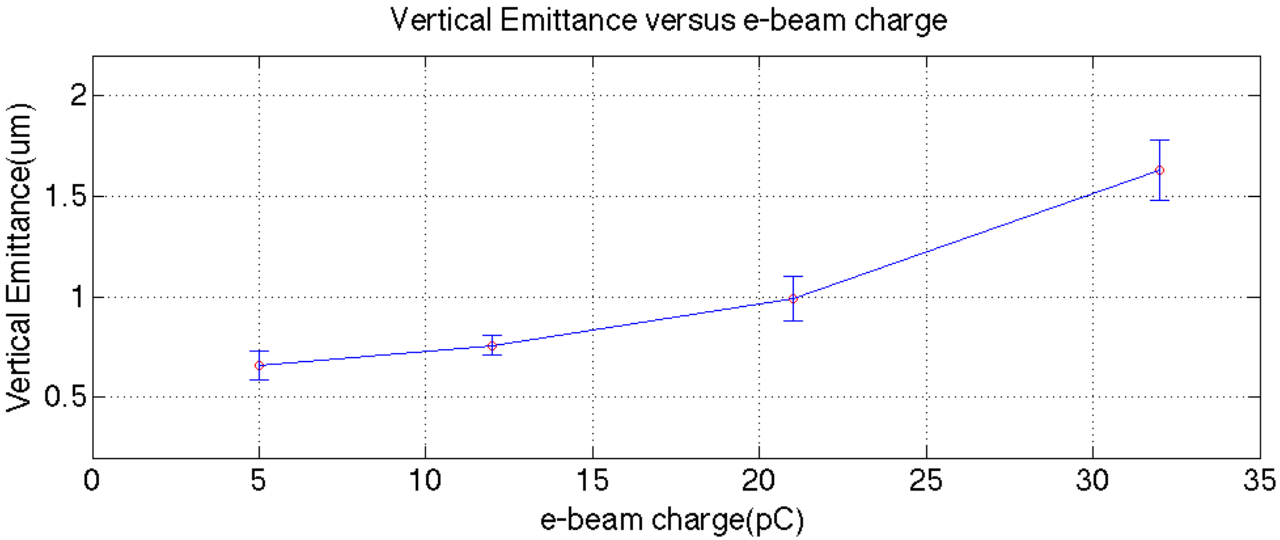
Parameters:
- Epeak= 84MV/m
- Working RF phase=30°
- Laser pulse length =5ps - FWHM (Gaussian profile)
- Bunch charge≅ 6pC

	Before n-machining		***After n-machining***	
E_acc (MV/m)	**ε_x(mmmrad)**	**ε_y(mmmrad)**	**ε_x(mmmrad)**	**ε_y(mmmrad)**
84	0.24±0.04	0.28±0.04	0.105±0.012	0.114±0.010

Yttrium preliminary results: total beam emittance measurements

***Parameters*:**

- Epeak= 110MV/m
- Working RF phase=30°
- Laser pulse length =5.3ps - FWHM (Gaussian profile)
- E= 4.66MeV - Energy at the gun exit
- $\sigma_{x,yrms}$ (Laser spot)≅0.11mm (Gaussianprofile)



Conclusions

- For our applications the dry machining is a good procedure because we don't have residual of diamond paste or oil

- We obtain an excellent roughness (≤ 2nm) typical of monocrystalline copper cathode

- With the n-machining we improved of a factor 2 the total beam emittance

- Future work: intrinsic emittance computation for Copper and Yttrium photocathodes, HomDyn / GPT simulations for the theoretical comparison and QE measurements

Thanks to

- D. Alesini, M.P. Anania, M. Bellaveglia, S. Bellucci, A. Biagioni, F. Bisesto, F. Cardelli, E. Chiadroni, G. Costa, D. Di Giovenale, G. Di Pirro, R. Di Raddo, A. Giribono, M. Ferrario, F. Micciulla, R. Pompili, L. Piersanti, V. Shpakov, A. Stella, F. Villa (INFN-LNF)

- **A. Cianchi** (INFN-Roma To Vergata and Università di Roma "Tor Vergata")

- Andrea Mostacci, **Daniele Passeri** (SBAI- Università di Roma "La Sapienza")

- **A. Lorusso** (Università del Salento, Dipartimento di Matematica e Fisica "E. De Giorgi", INFN-Sezione di Lecce)

- Mauro Trovò (Elettra - Sincrotrone Trieste SCpA)

Finally it's over

Thank you for your attention