Surface analysis and n-machining of the copper photocathode at SPARC_LAB

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On behalf of SPARC_LAB collaboration

PhD ACTIVITY REPORT

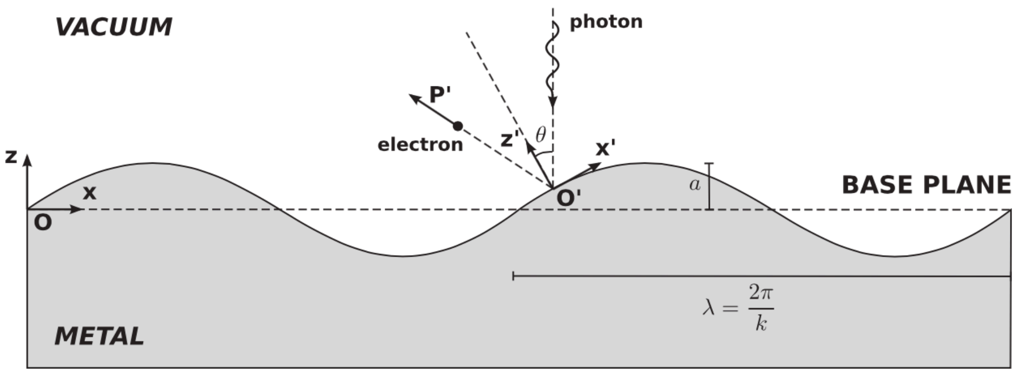
Outline

- Motivation
- Background
- Surface Analysis Techiques
  - Scanning Electron Microscopy with Energy Dispersive Spectroscopy
  - Atomic Force Microscopy
- Machining and Results
- Conclusions

Motivation

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

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



a, amplitude of the uneven surface
λ, period of fluctuation

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

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

Motivation

- 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 useful to reduce roughness and to avoid surface contamination caused by other procedures, for example the polishing with diamond paste or the machining with oil

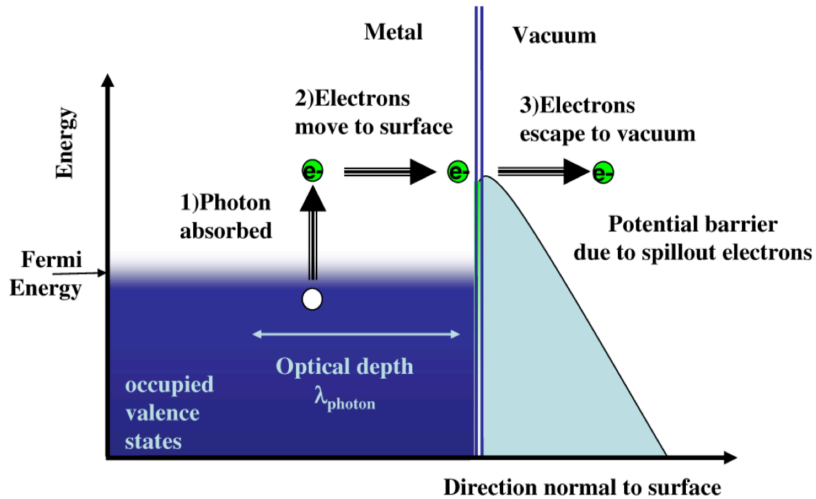
Background

➤ **ELECTRON EMISSION PROCESS OF METALLIC PHOTOCATHODES AND THE 3-STEP MODEL**

Photoelectric emission from a metal given by Spicer's 3-step model:

1. Photon absorption by the electron
2. Electron transport to the surface
3. Escape through the barrier

QE and emittance depend upon electronic structure of the cathode



D. H. Dowell, K.K. King, R.E Kirby and J.F. Schmerge, PRST-AB 9, 063502 (2006)

The ***Quantum Efficiency (QE)*** is:

$$QE = \frac{n_e}{n_p} = \frac{h\upsilon[eV]}{E_{laser}[J]} q[C]$$

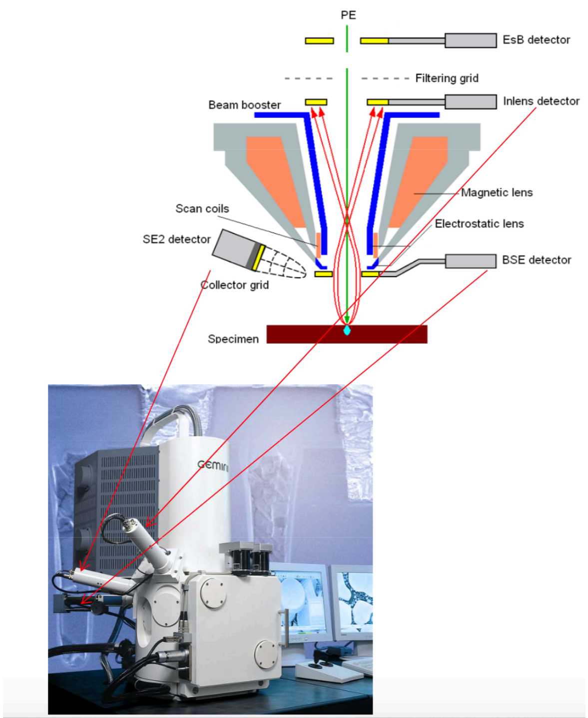
The ***thermal emittance (ε_{th})*** is:

$$\varepsilon_{th} = \sigma_x \sigma_{p_x} = \sigma_x \sqrt{\frac{\hbar\omega - \phi_{eff}}{3mc^2}}$$

The electric potential energy is:

$$e\phi_{eff} = e\phi_{work} - \frac{e^2}{16\pi\varepsilon_0 x} - eE_0 x$$

SEM (Scanning Electron Microscope) – EDS (Energy Dispersive Spectroscopy)



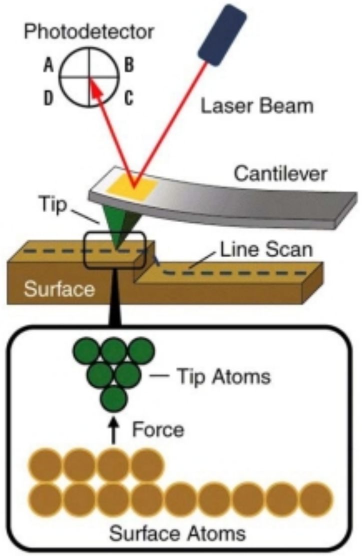
The types of signals produced by a SEM include:

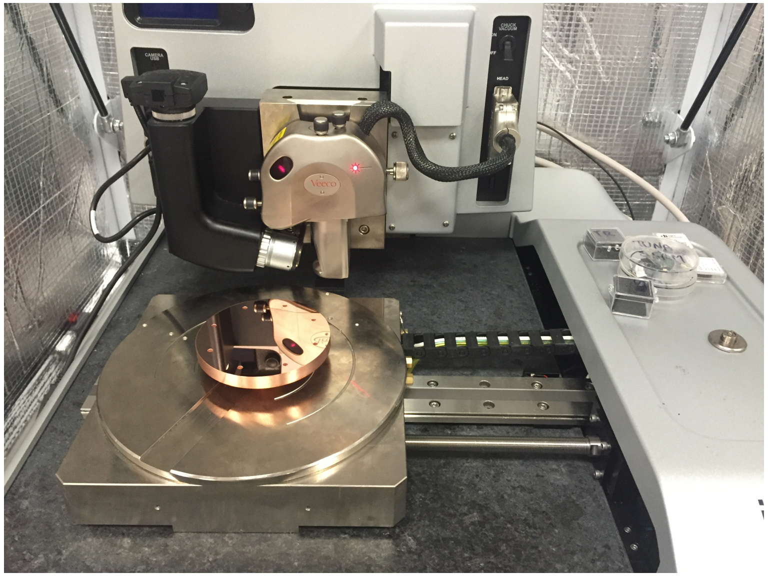
- secondary electrons (***SE***), emitted from very close to the sample surface (***morphology***);
- back scattered electrons (***BSE***): electrons beam that are reflected from the sample by elastic scattering (**atomic number, *Z***).

Technical features	
Emitter	Tungsten filament
High vacuum resolution (SE)	3.0 nm at 30 kV
Low, medium vacuum resolution (BSE)	3.5 nm at 30 kV
Magnification	Continuous from 4x to 10^6x
Acceleration voltage	200 V to 30 kV
Beam current	1 pA to 2 μA

➢ **We are able to determine the chemical composition of the test sample with the Energy Dispersive Spectroscopy (EDS).**

AFM (Atomic Force Microscopy)





The surface roughness is represented by two different values :

$$\begin{cases} R_a = (1/L)\int_0^L |Z(x)|dx \\ RMS(R_q) = \left[(1/L)\int_0^L Z(x)^2\,dx\right]^{1/2} \end{cases}$$

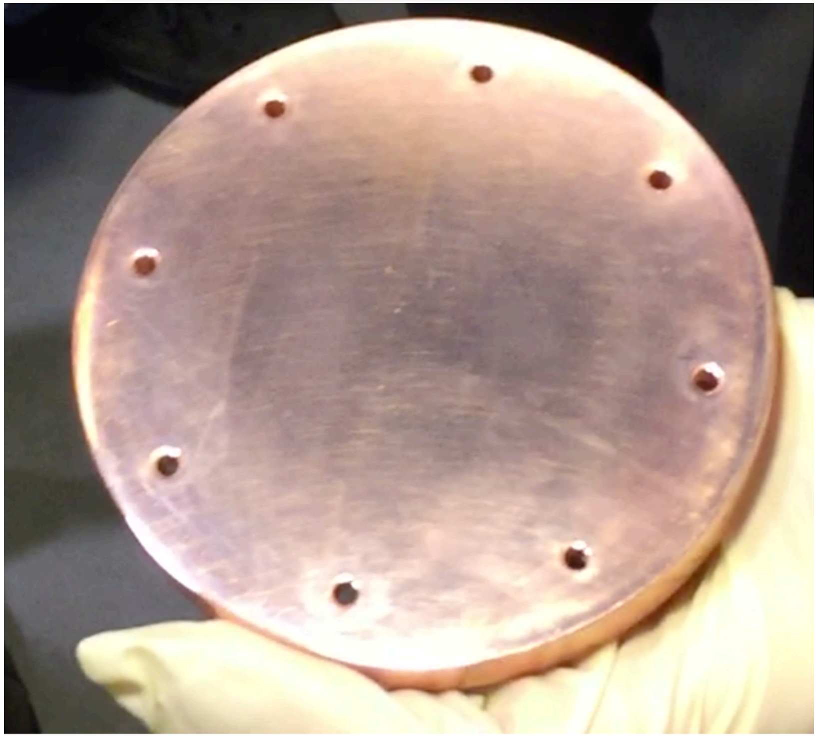
Where: L= evaluation length;
Z(x) = the profile height function.

The Machining

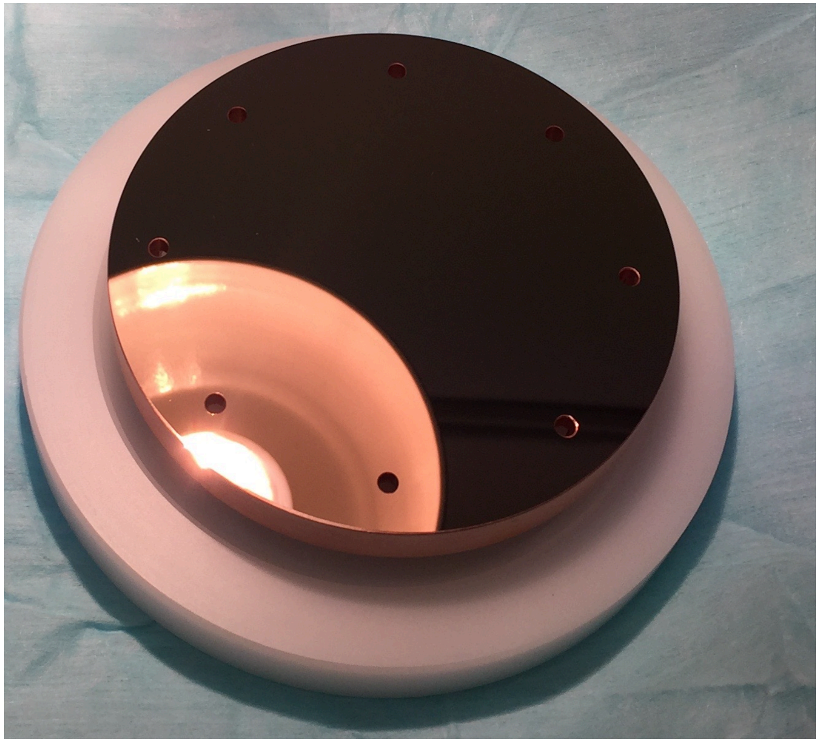
➢ The cathode surface has been machined by means of diamond milling and blowed with nitrogen. The machining has been done without the use of any oil or cooling fluid (dry machining).

BEFORE MACHINING

Our cathode time life was about 6 years

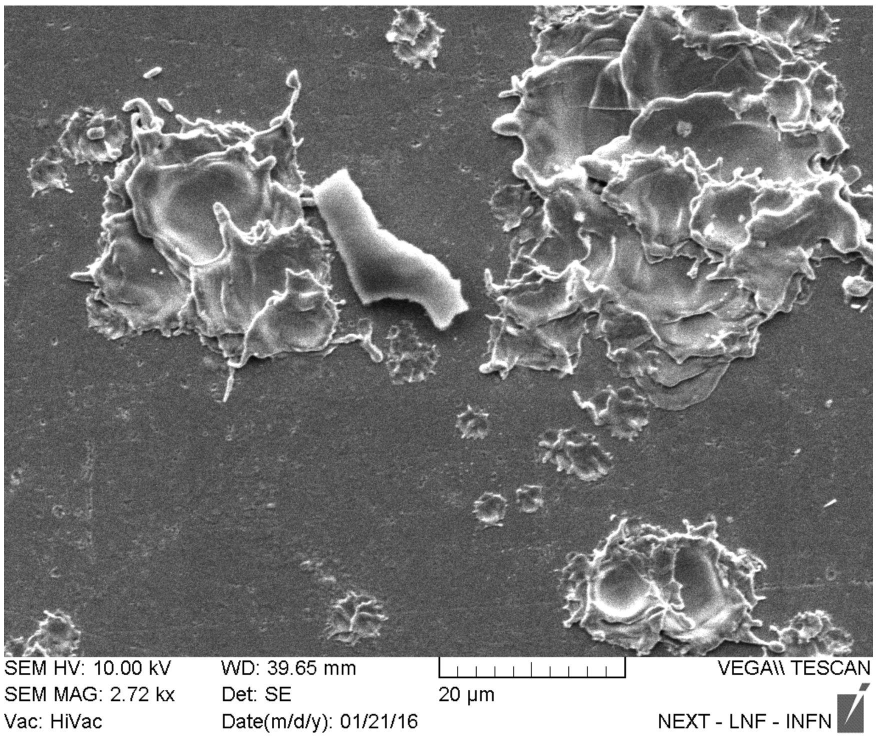


AFTER MACHINING

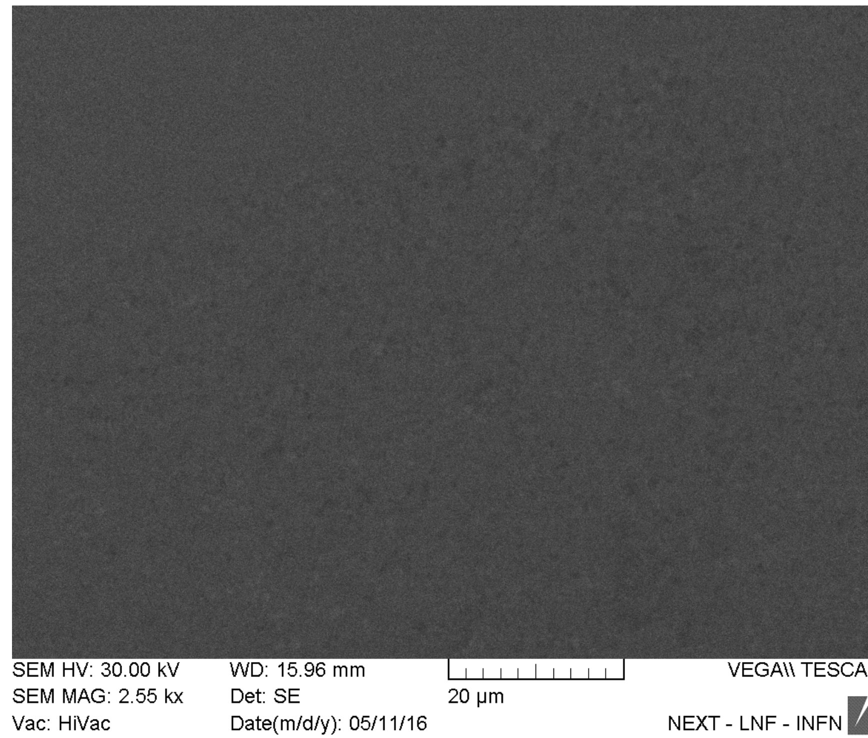


The Machining

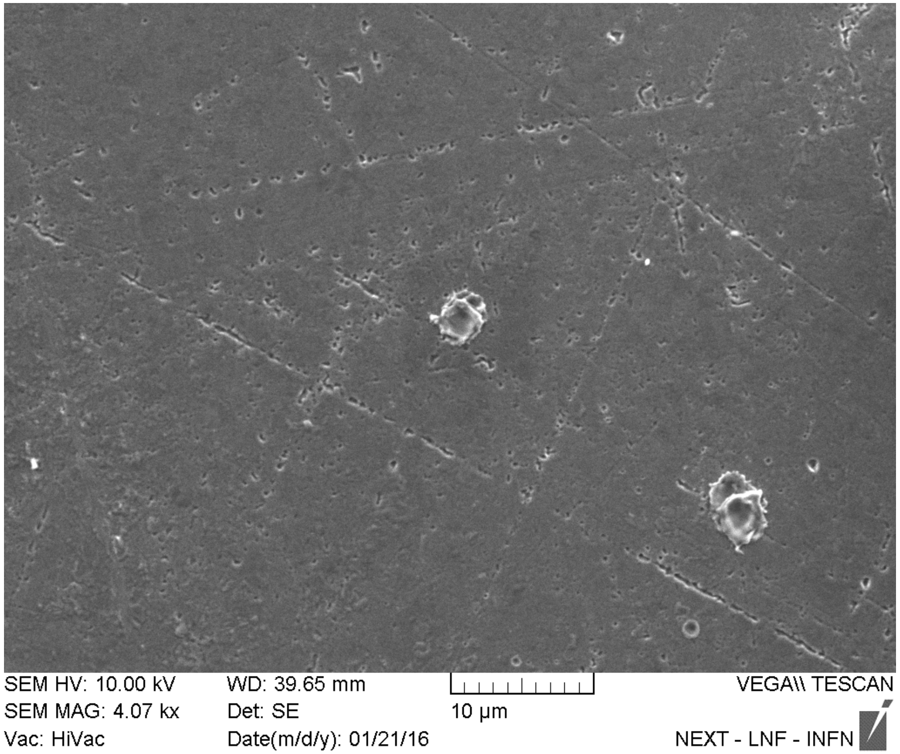
BEFORE MACHINING

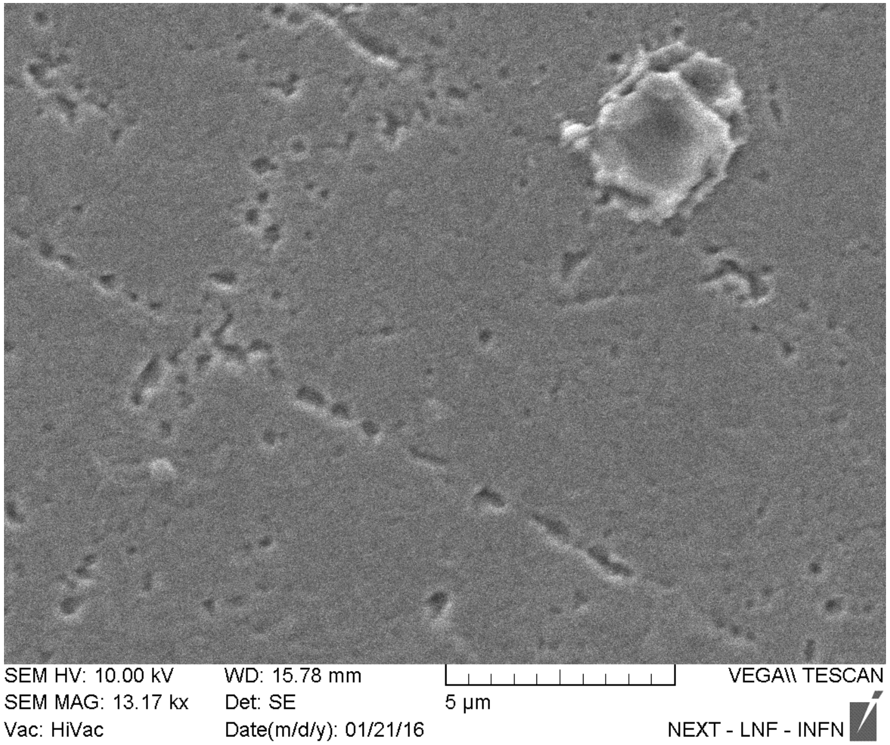


AFTER MACHINING

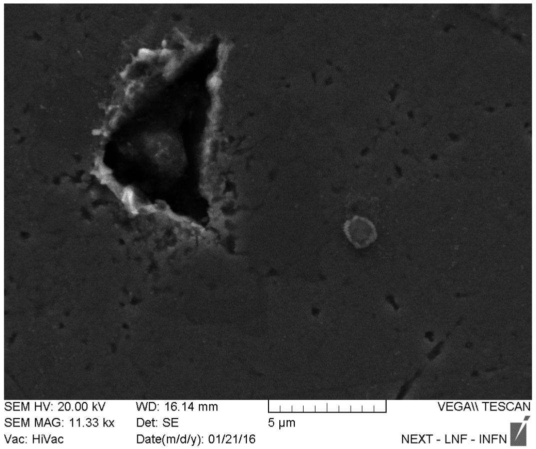


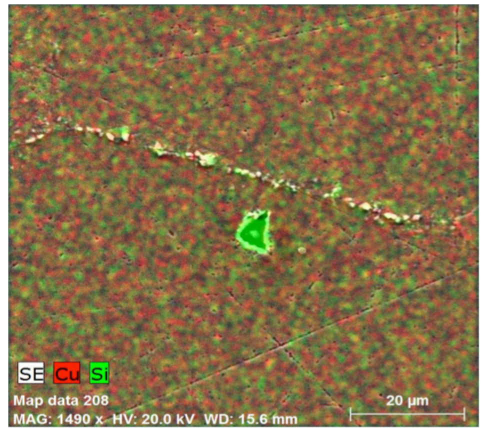
Measurements before machining

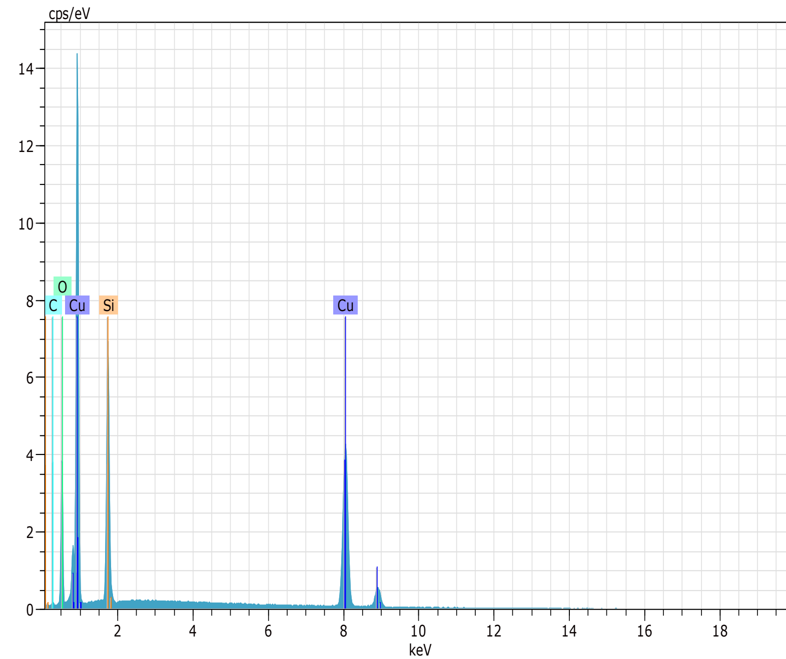




Chemical composition



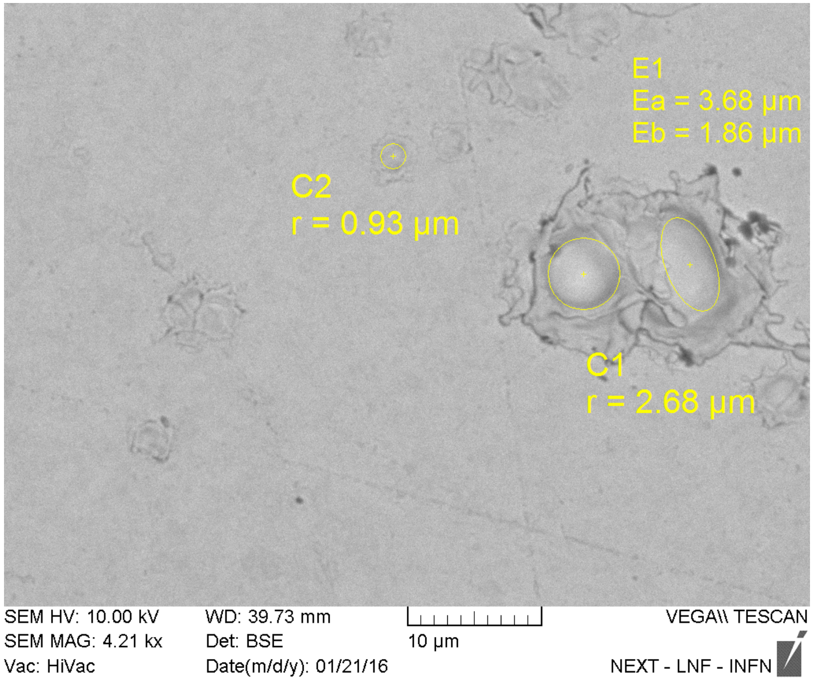


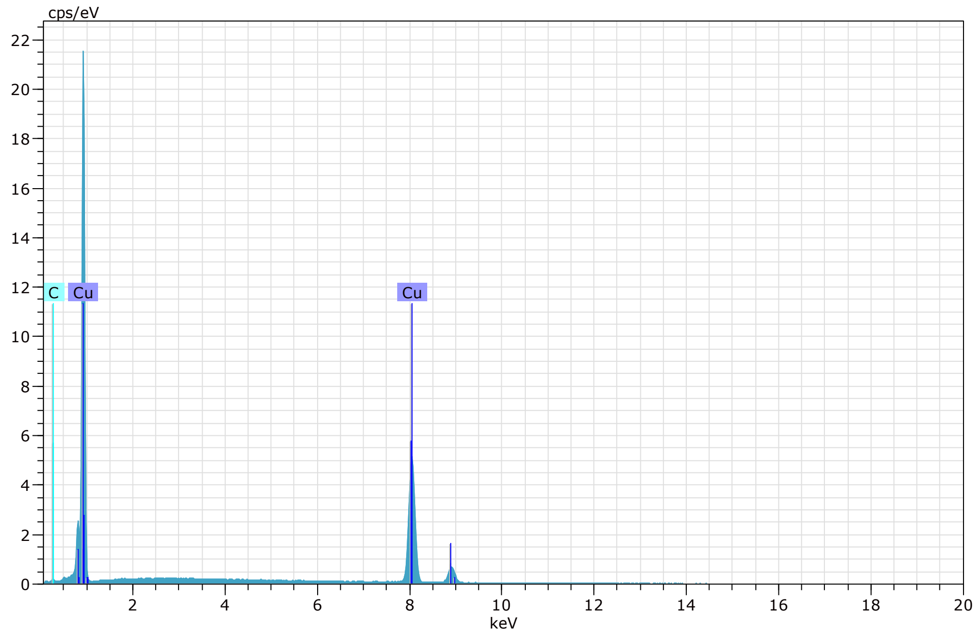


Spectrum: Acquisition 862 - particella.spx

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

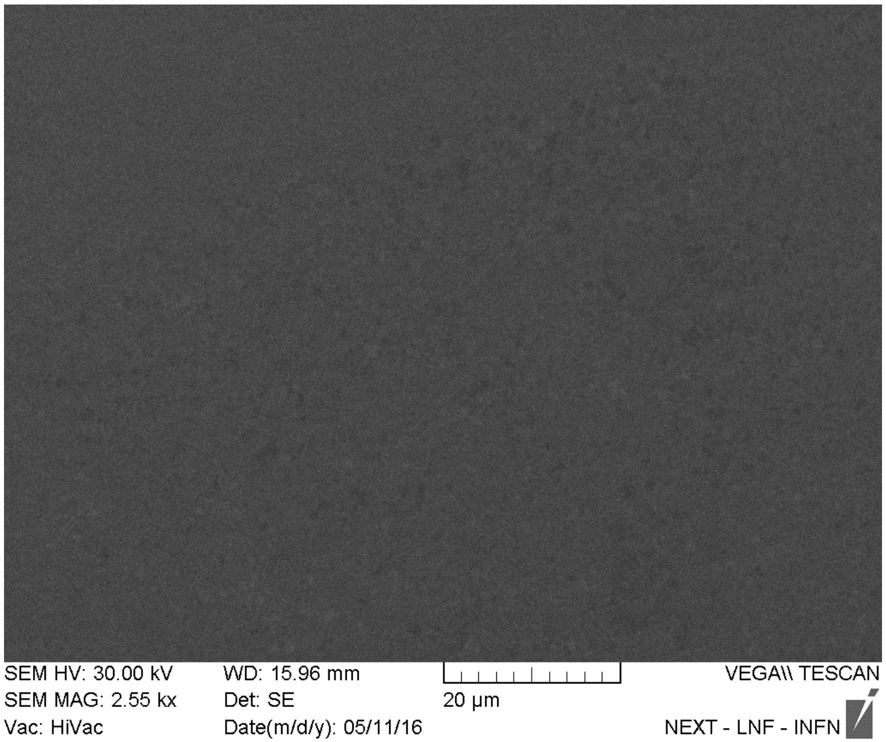


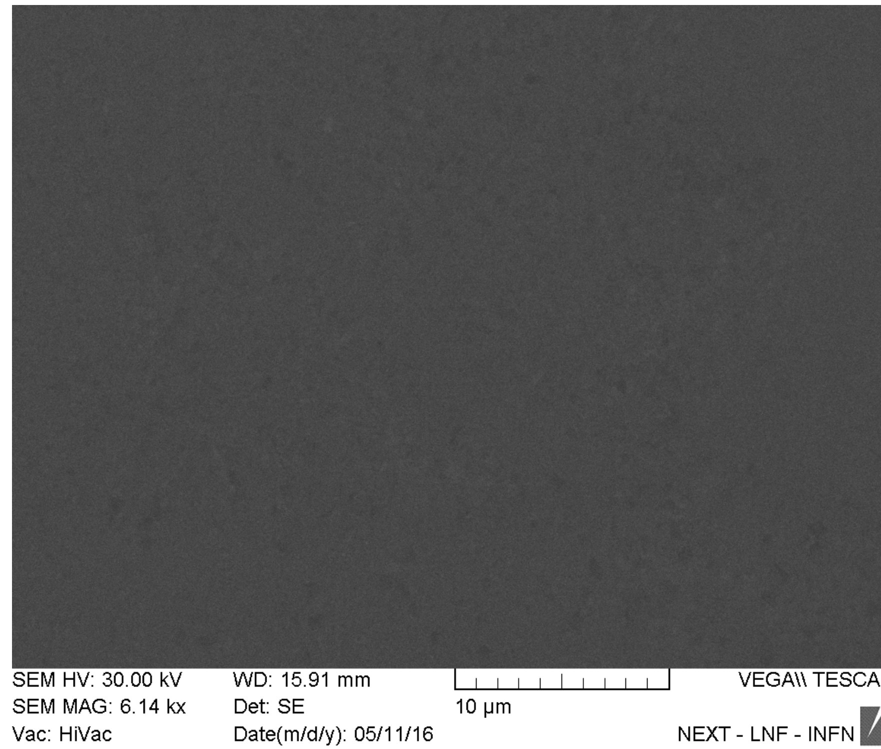


Spectrum: Acquisition 861-Generale.spx

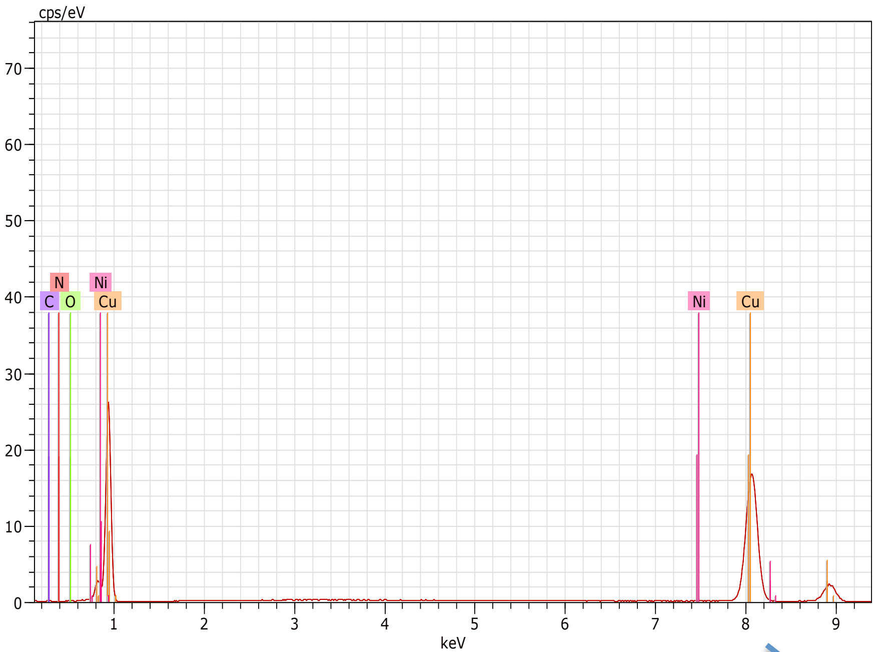
El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]	K fact.	Z corr.	A corr.	F corr.
Cu	29	K-series	88.20	96.47	83.80	2.42	0.862	1.078	1.000	1.039
C	6	K-series	3.22	3.53	16.20	0.86	0.091	0.387	1.000	1.000
		Total:	91.43	100.00	100.00					

Measurements after machining



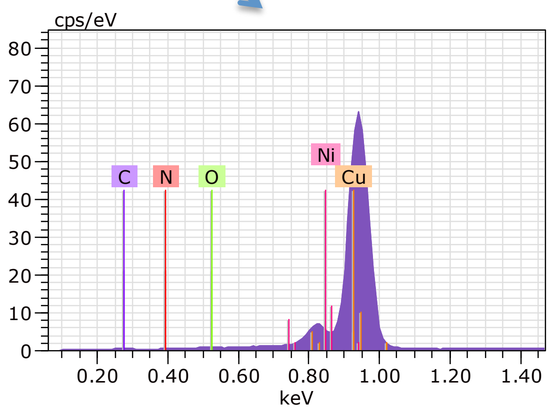


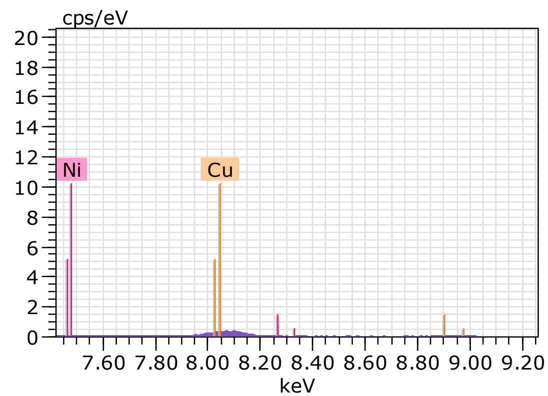
Chemical composition



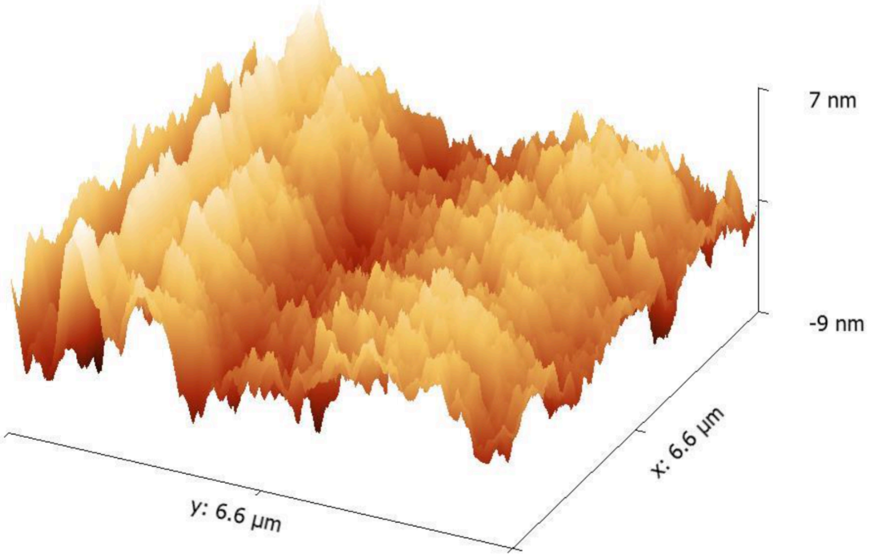
Spectrum: Acquisition 877

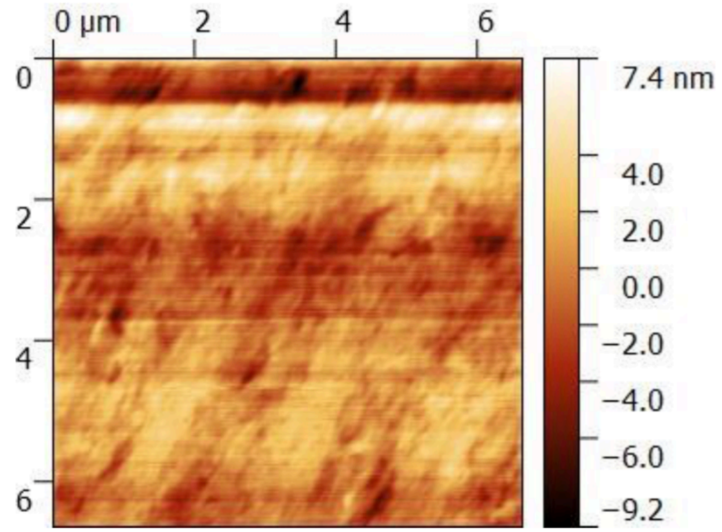
El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
Cu	29	L-series	289089	98.81	98.81	95.69	10.64
C	6	K-series	1280	0.47	0.47	2.39	0.12
Ni	28	L-series	1453	0.34	0.34	0.35	0.09
O	8	K-series	1150	0.22	0.22	0.86	0.07
N	7	K-series	466	0.16	0.16	0.71	0.07
			Total:	100.00	100.00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

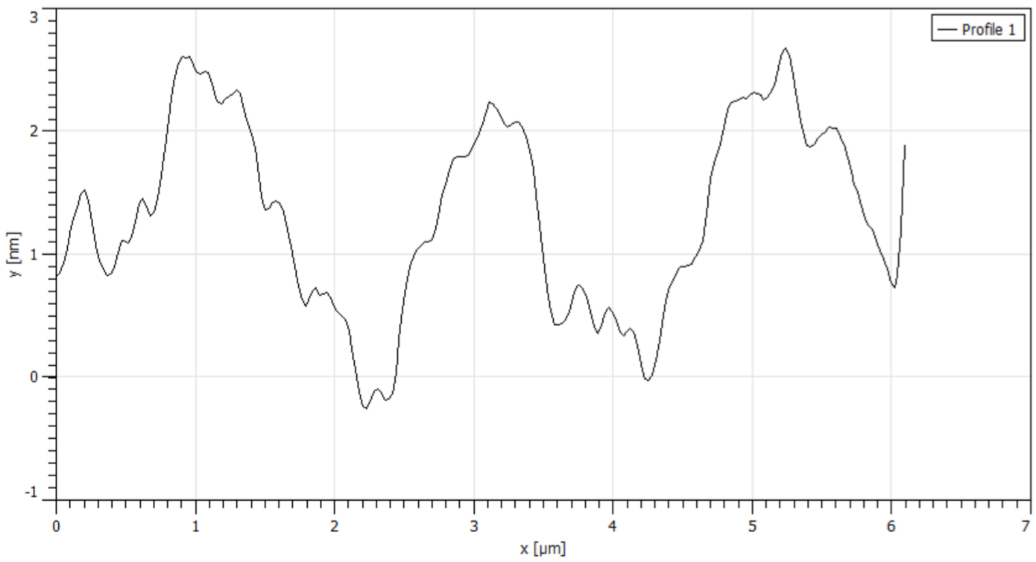




AFM analysis







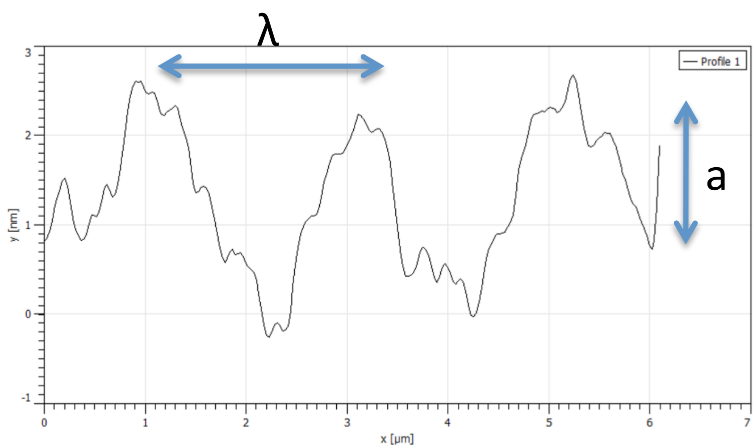
R_a = 1.1802 nm

Rms (R_q)=1.5041 nm

SURFACE ROUGHNESS INDUCED EMITTANCE

➢ After machining the expected emittance contribution due to surface roughness for the copper photocathode at ***SPARC_LAB*** is negligible

$$E_{rf} = 120 MV/m$$
$$\vartheta_{rf} = 30°$$
$$\sigma_x = 0.5mm$$
$$a = 1.3nm$$
$$\lambda = 2\mu m$$



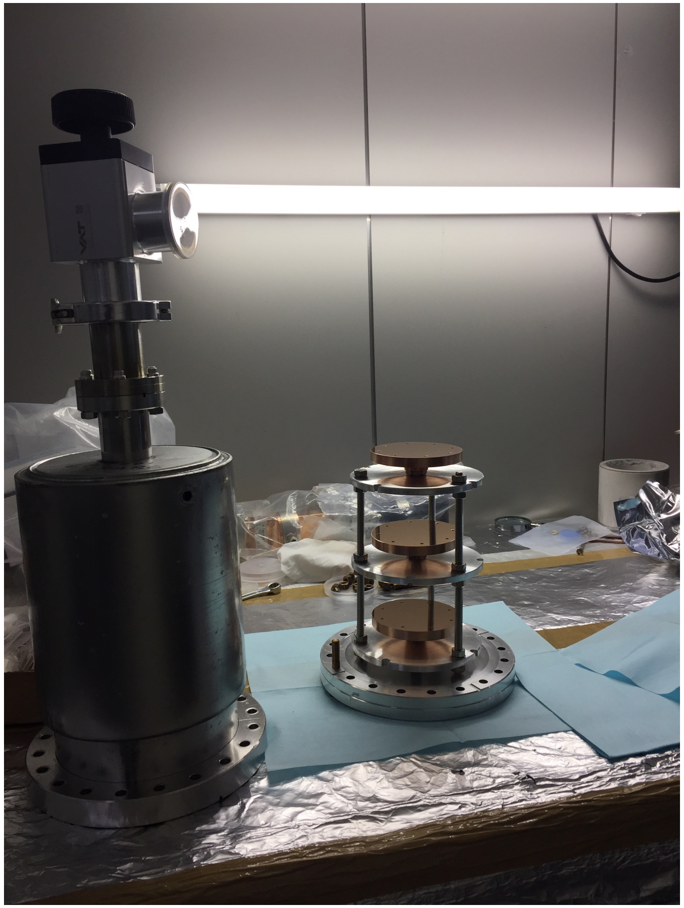
$$\varepsilon_{ns} = \sigma_x \sqrt{\frac{e\pi^2 a_n{}^2 E_{rf} \sin\vartheta_{rf}}{2m_0c^2\lambda_n}} \approx 0.011\mu m$$

D. Xiang et al., *First principle measurements of thermal emittance for copper and magnesium*, Proc. of PAC07, Albuquerque, New Mexico, USA

Conclusions

- For our applications the dry machining is a good procedure because we don't have traces of diamond paste or oil
- We obtain an excellent roughness (≤ 2nm) typical of monocrystalline copper cathode
- Likely a surface roughness induced emittance will be negligible

Photocathodes chamber



It can hold three cathodes at a time.

It's a clean chamber with nitrogen over pression.

Conclusions

- For our applications the dry machining is a good procedure because we don't have traces of diamond paste or oil.
- We obtain an excellent roughness ($\leq$ 2nm) typical of monocrystalline copper cathode.
- Likely a surface roughness induced emittance will be negligible.

Thanks to

- **D. Alesini, S. Bellucci, A. Biagioni, E. Chiadroni, R. Di Raddo, M. Ferrario, F. Micciulla** (INFN-LNF)
- **A. Cianchi** (INFN-Roma Tor Vergata and Università di Roma "Tor Vergata")
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- **Daniele Passeri** (SBAI- Università di Roma "La Sapienza")

Publications

- Nuclear Instruments and Methods in Physical Research A**, The SPARC_LAB Thomson source,** C. Vaccarezza, D. Alesini, M.P. Anania, A. Bacci, A. Biagioni, F. Bisesto, M. Bellaveglia, P. Cardarelli, F. Cardelli, A. Cianchi, E. Chiadroni, M. Croia, A. Curcio, P. Delogue, D. Di Giovenale, G. Di Domenico, G. Di Pirra, I. Drebod, M. Ferrario, F. Filippi, A. Gallo, M. Galletti, M. Gambaccini, A. Giribono, B.Golosio, ,W.Li , A. Mostacci, P. Oliva, D. Palmer, V. Petrillo, M. Petrarca, S. Pioli, L. Piersanti, R. Pompili, S. Romeo, A.R. Rossi, J. Scifo, L. Serafini, G. Sulimani, F. Villa (Sept 2016)
- Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment, **Beam manipulation with Velocity Bunching for PWFA applications,** R. Pompili, M.P. Anania, , A. Biagioni, F. Bisesto, A. Cianchi, E. Chiadroni, M. Croia, A. Curcio, D. Di Giovenale, M. Ferrario, F. Filippi, A. Gallo, M. Galletti, A. Giribono, W.Li , A. Marocchino, A. Mostacci, M. Petrarca, V.Petrillo, S. Romeo, A.R. Rossi, J. Scifo, V.Shpakov, C. Vaccarezza F. Villa, J. Zhu (2016)
- New J. Phys. 18 (2016) 083033, **Femtosecond timing-jitter between photo-cathode laser and ultra-short electron bunches by means of hybrid compression,** R Pompili, M P Anania, M Bellaveglia, A Biagioni, G Castorina , E Chiadroni, A Cianchi, M Croia, D. Di Giovenale, M Ferrario, F Filippi, A Gallo, G Gatti, F Giorgianni, A Giribono, W Li, S Lupi, A Mostacci, M Petrarca, L Piersanti, G Di Pirro, S.Romeo, J Scifo, V Shpakov, C Vaccarezza and F Villa
- Phys. Rev. ST Accel. Beams **18**, 082804 , **Six-dimensional measurements of trains of high brightness electron bunches,** A. Cianchi, D. Alesini, M. P. Anania, A. Bacci, M. Bellaveglia, M. Castellano, E. Chiadroni, D. Di Giovenale, G. P. Di Pirro, M. Ferrario, A. Gallo, L. Innocenti, A. Mostacci, R. Pompili, A. R. Rossi, J. Scifo, V. Shpakov, C. Vaccarezza, and F. Villa (2015)

Publications

- SPIE 2015, Volume: Proc. SPIE 9512, Advances in X-ray Free-Electron Lasers Instrumentation III, 95121Q, **Operational experience on the generation and control of high brightness electron bunch trains at SPARC-LAB,** A. Mostacci, D. Alesini, M. P. Anania, A. Bacci, M. Bellaveglia, A. Biagioni, F. Cardelli, M. Castellano, E. Chiadroni, , A. Cianchi, M. Croia, D. Di Giovenale, G. P. Di Pirro, M. Ferrario, F. Filippi, A. Gallo, G. Gatti, A. Giribono, L. Innocenti, A. Marocchino, M. Petrarca, L. Piersanti, S. Pioli, R. Pompili, S. Romeo, A. R. Rossi, J. Scifo, V. Shpakov, C. Vaccarezza, F. Villa, L. Weiwei

Finally it's over

Thank you for your attention