# The characterization measurements of yttrium photocathode performed at the Cavity Test Facility at Elettra

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*On behalf of SPARC_LAB collaboration*

European Workshop on Photocathodes for Particle Accelerator Applications 2019, 11-13.09.2019, PSI, Villigen

# Outline

- Motivation
- Yttrium thin film and XRD pattern
- Cavity Test facility layout
- Experimental set up
- Quantum Efficiency measurements
- Total beam emittance measurements
- Conclusions

# Motivation

- High brightness (high current, low emittance) electron beam production by photoinjector is required by several applications in the accelerator physics field, e.g., Free Electron Laser (FEL) radiation sources and Plasma Wake Field Acceleration (PWFA) experiments.

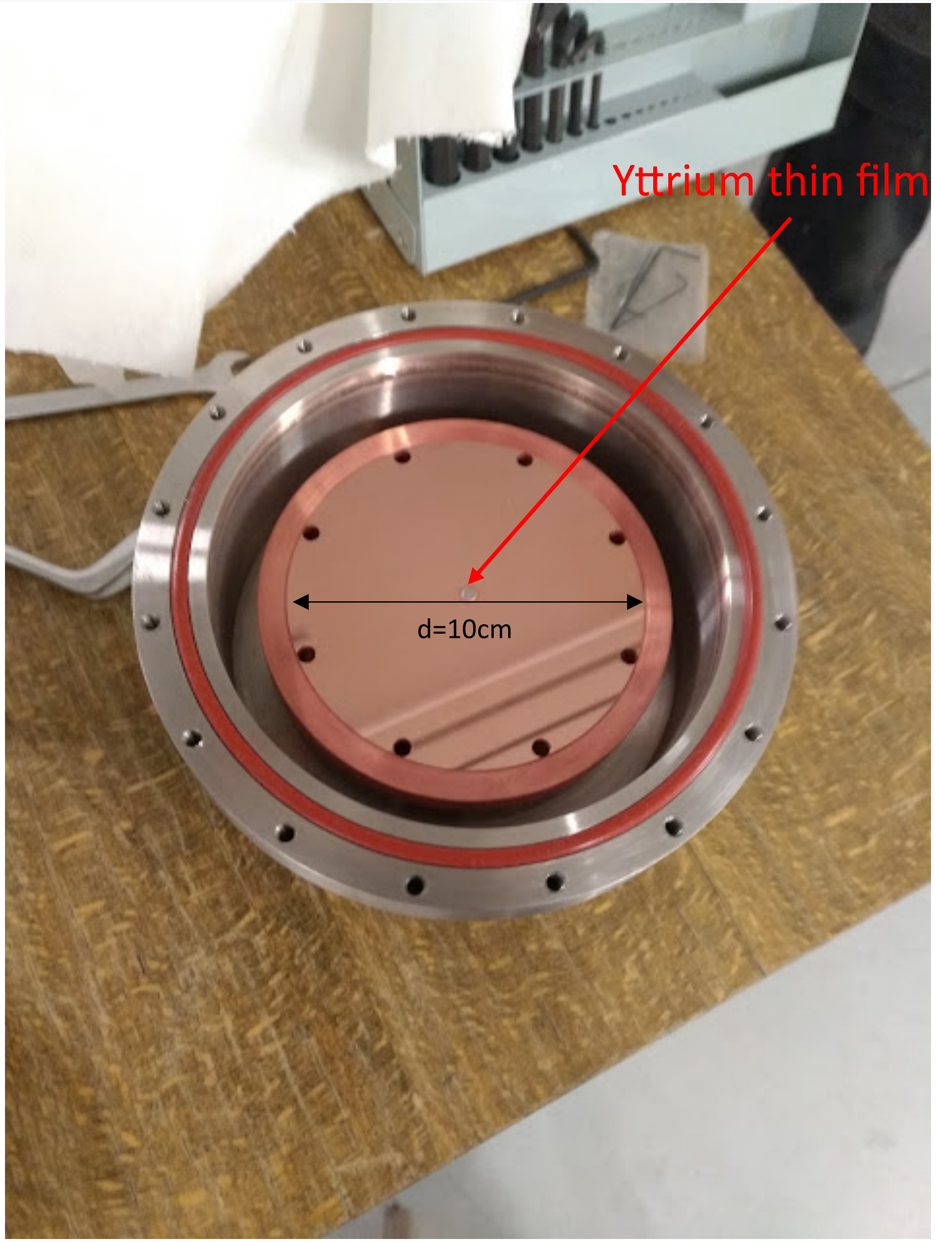
- A R&D activity on photocathodes is under development at the SPARC_LAB test facility at LNF in collaboration with the Cavity Test Facility at the Elettra–Sincrotrone Trieste in order to fully know and characterize each stage of the photocathodes “life” and to improve their performance.

# Yttrium thin film on Cu photocathode

- ✓ A yttrium (Y) thin film (1.2 μm thickness and d = 3 mm diameter) was grown by pulsed laser deposition (PLD) on a copper (Cu) polycrystalline photo-cathode(1) . The deposition has been done in the centre of the flange.

- ✓ PLD of yttrium on copper guarantees a highly adherent film with high quality (2).

- ✓ Yttrium is a transition metal that has a work function of $\varphi_{work} \sim 3$ eV ($\varphi^{Cu}_{work} \sim 4.6$ eV).

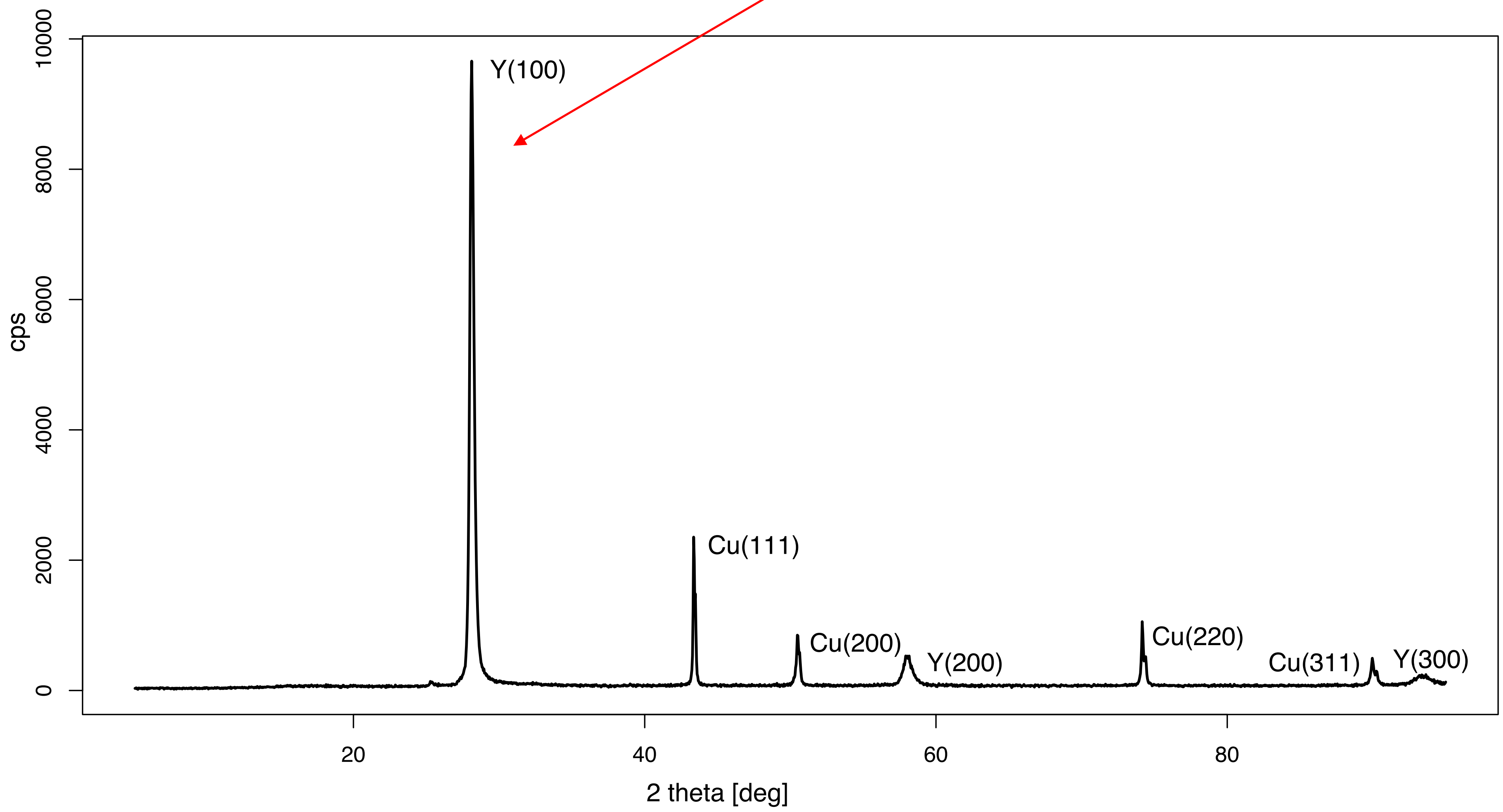



(1) A. Lorusso, M. Anni, A. Caricato, F. Gontad, A. Perulli, A. Taurino, A. Perrone, E. Chiadroni, Deposition of y thin films by nanosecond uv pulsed laser ablation for photocathode application, Thin Solid Films 603 (2016) 441–445.

(2) A. Lorusso, M. Trovò, A. Demidovich, P. Cinquegrana, F. Gontad, E. Broitman, E. Chiadroni, A. Perrone, Pulsed laser deposition of yttrium photocathode suitable for use in radio-frequency guns, Applied Physics A 123 (12) (2017) 779.

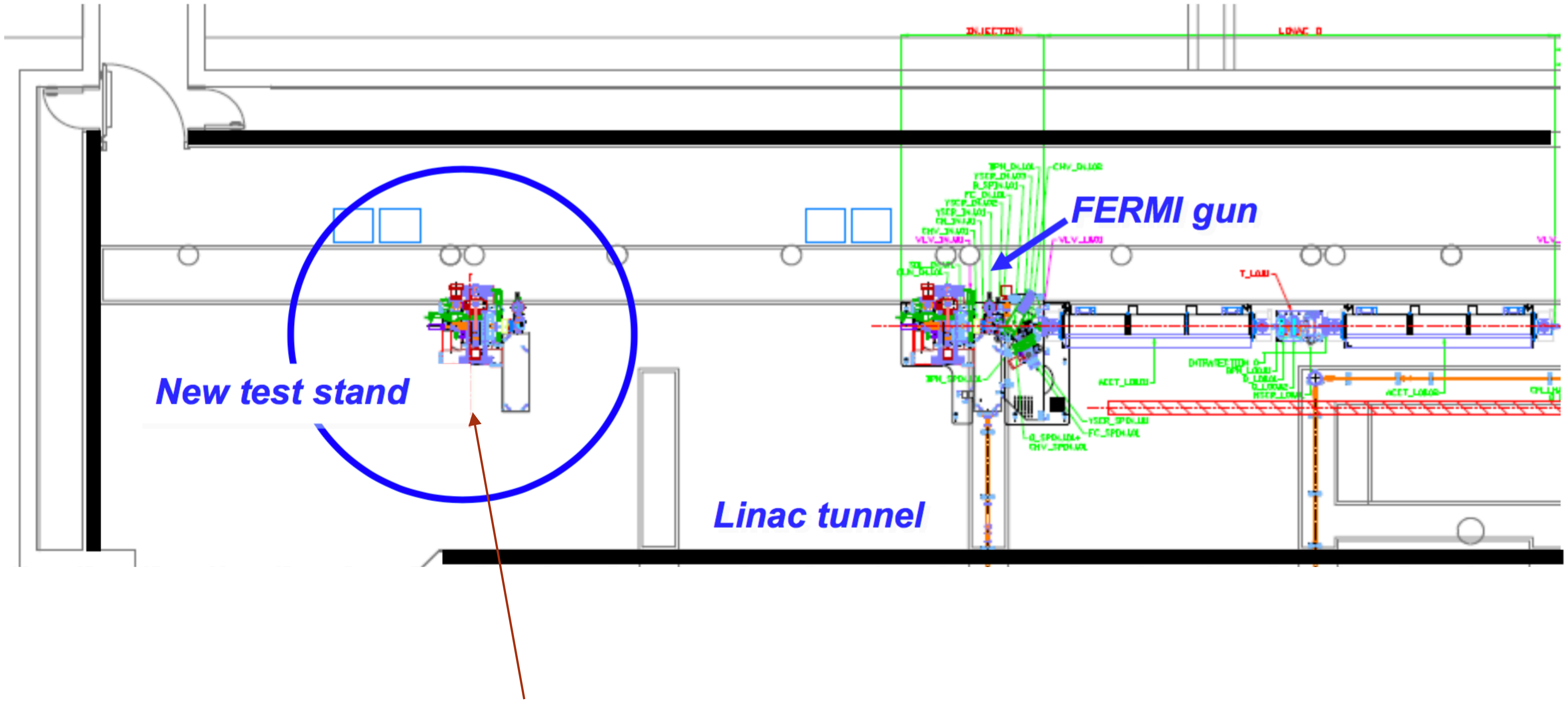
# XRD analysis

The XRD pattern shows the structure of the Y film with a preferred orientation along the (100) plane at 28.22°




*Courtesy of* S. Dabagov and *D. Hampai*
RXR facility of the *Laboratori Nazionali di Frascati*

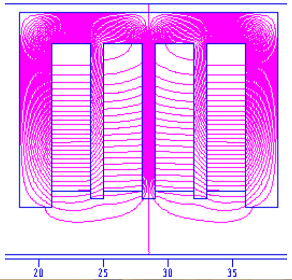
# Cavity Test Facility



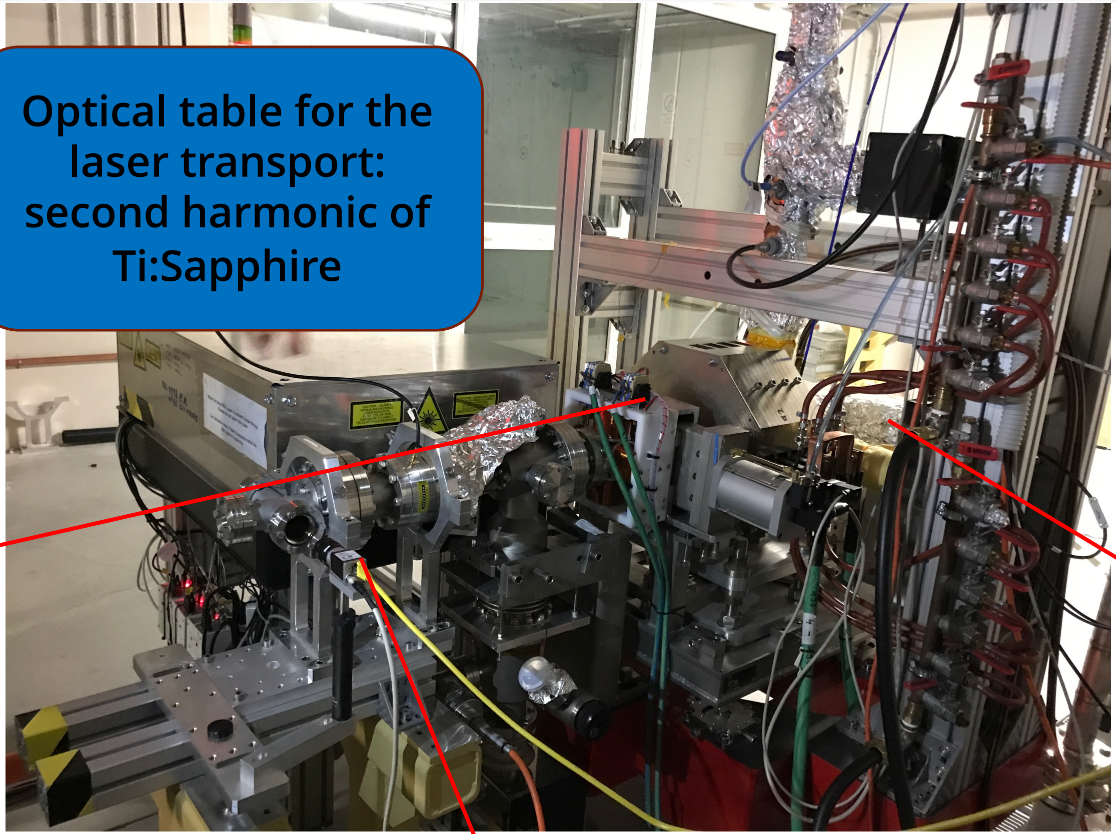

Layout of FERMI linac tunnel. The CTF has been installed in a free space behind the FERMI photoinjector.

# Experimental set up

Beam rotation ~ 0°



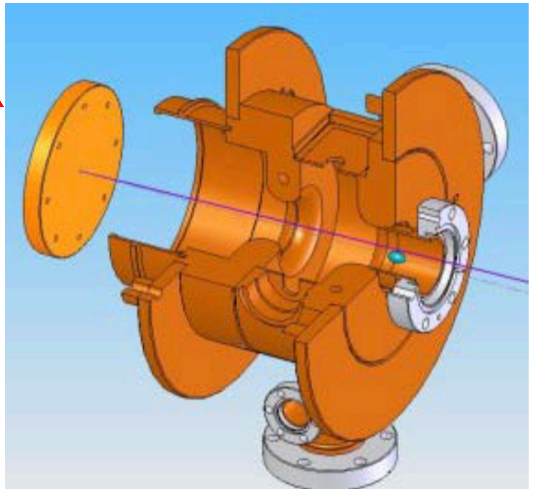

Gun cavity and solenoid



Optical table for the laser transport: second harmonic of Ti:Sapphire

BCM and YAG screen

1.6 cell
Gun 1 cavity
(by UCLA)



The continuous line is the laser trajectory.

# Theoretical Quantum Efficiency

$$QE(\omega) \approx \frac{1-R(\omega)}{1+\frac{\lambda_{ph}}{\lambda_{e-e}}} \frac{(\hbar\omega - \phi_{eff})^2}{8\phi_{eff}(E_F + \phi_{eff})}$$

Yttrium theoretical value of QE:

$QE_{theor}$= 1.43E-5 ($\lambda_{laser}$= 392nm, $E_{RF}$=95MV/m )

Cu theoretical value of QE:

$QE_{theor}$= 5.75E-5 ($\lambda_{laser}$= 266nm, $E_{RF}$=95MV/m)

| | k | R | $E_F$(eV) | $\Phi_{work}$(eV) | $\lambda_{ph}$ (Å) | $\lambda_{e-e}$ (Å) |
|---|---|---|---|---|---|---|
| Y (λ= 400 nm) (1) | 2.1 | 0.5 | 6.3 | 3.1 | 147 | 10 |
| Cu (λ= 262 nm)(2) | 1.7 | 0.4 | 7.0 | 4.7 | 120 | 22 |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# Yttrium Quantum Efficiency estimation

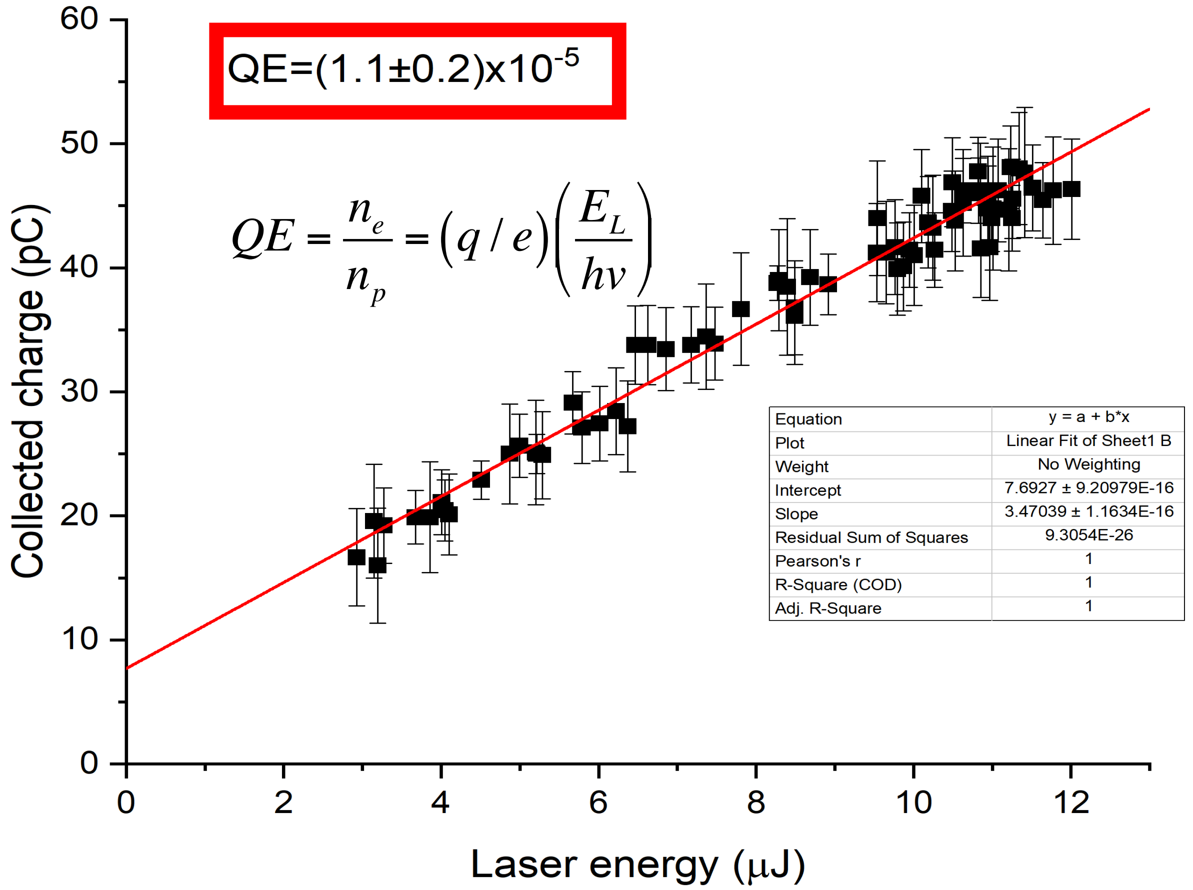
*Parameters*:

- $E_{RF}$ = 95.3MV/m
- Working RF phase=30°
- Laser pulse length=1ps - FWHM (Gaussian profile)
- Laser spot size, $\sigma_x \simeq$ 130 μm, $\sigma_y \simeq$ 160 μm (Gaussian profile)
- E= 4.15MeV - Electron beam energy
- $\lambda_{laser}$= 392nm (3.16eV)
- $\varphi_{work}$ = 3.1 eV
- Dark current ≃ 7.7 pC

Yttrium theoretical value of QE:

$QE_{theor}$= 1.43E-5 ($\lambda_{laser}$= 392nm )

*Y quantum efficiency experimental value*




$$QE = \frac{n_e}{n_p} = (q/e)\left(\frac{E_L}{h\nu}\right)$$

| | |
|---|---|
| Equation | y = a + b*x |
| Plot | Linear Fit of Sheet1 B |
| Weight | No Weighting |
| Intercept | 7.6927 ± 9.20979E-16 |
| Slope | 3.47039 ± 1.1634E-16 |
| Residual Sum of Squares | 9.3054E-26 |
| Pearson's r | 1 |
| R-Square (COD) | 1 |
| Adj. R-Square | 1 |

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# Intrinsic emittance theoretical value

*Parameters*:
- $E_{RF}$ = 95.3MV/m
- Working RF phase=30°
- Laser pulse length=1ps - FWHM (Gaussian profile)
- Laser spot size, $\sigma_x \simeq$ 130 µm, $\sigma_y \simeq$ 160 µm (Gaussian profile)
- E= 4.15MeV - Electron beam energy
- $\lambda_{laser}$= 392nm (3.16eV)
- $\varphi_{work}$ = 3.1 eV

**Theoretical intrinsic emittance:**

$$\varepsilon_{\text{int}} = \sigma_x \sigma_p = \sigma_x \sqrt{\frac{\hbar\omega - \phi_{eff}}{3mc^2}}$$

**where**

$$\phi_{eff} = \phi_w - \phi_{Schottky} = \phi_w - \alpha\sqrt{\beta E_{RF}} = \phi_w - e\sqrt{\frac{e}{4\pi\varepsilon_0}(\beta E_{RF})}$$

✓ **Theoretical value of Yttrium intrinsic emittance:**
**$\varepsilon_{intr,n}$= 0.46µm/mm ($\lambda_{laser}$= 392nm )**

In the same conditions for the Cu photocathode:

✓ **theoretical value of Cu intrinsic emittance:**
**$\varepsilon_{intr,n}$= 0.56µm/mm** ($\lambda_{laser}$= 266nm )

# Emittance measurements: method

***Solenoid Scan Technique:***

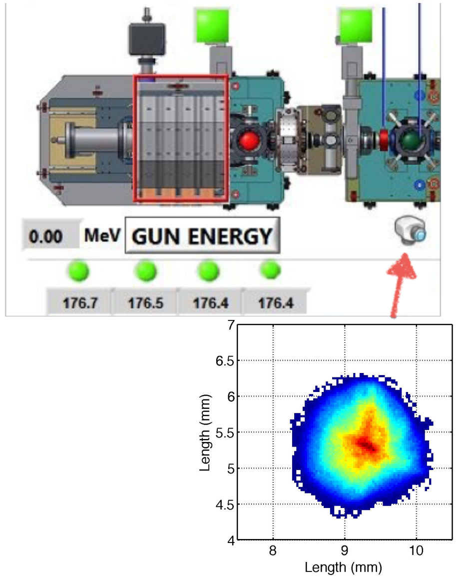
1. Measurements of beam size squared on YAG Screen for different solenoid fields are given by:

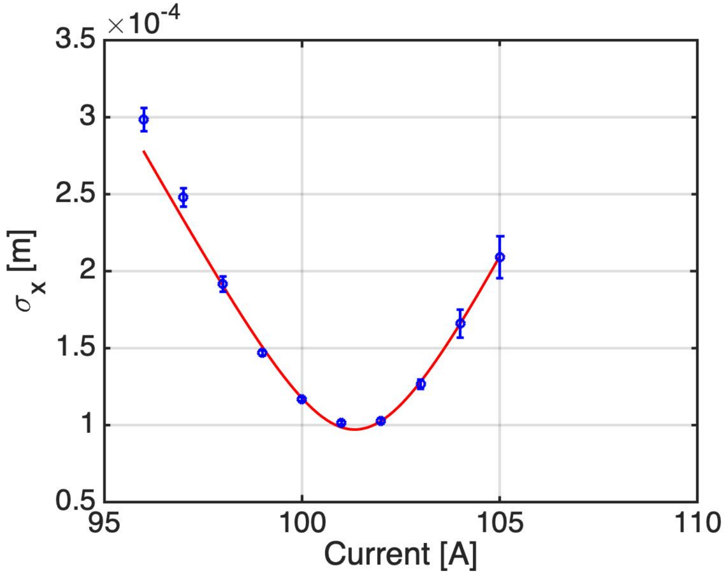
$$\langle x_i \rangle^2 = R_{11}^{(i)^2} \langle x_0^2 \rangle + 2R_{11}^{(i)} R_{12}^{(i)} \langle x_0 x_0' \rangle + R_{12}^{(i)^2} \langle x_0'^2 \rangle$$

   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:

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

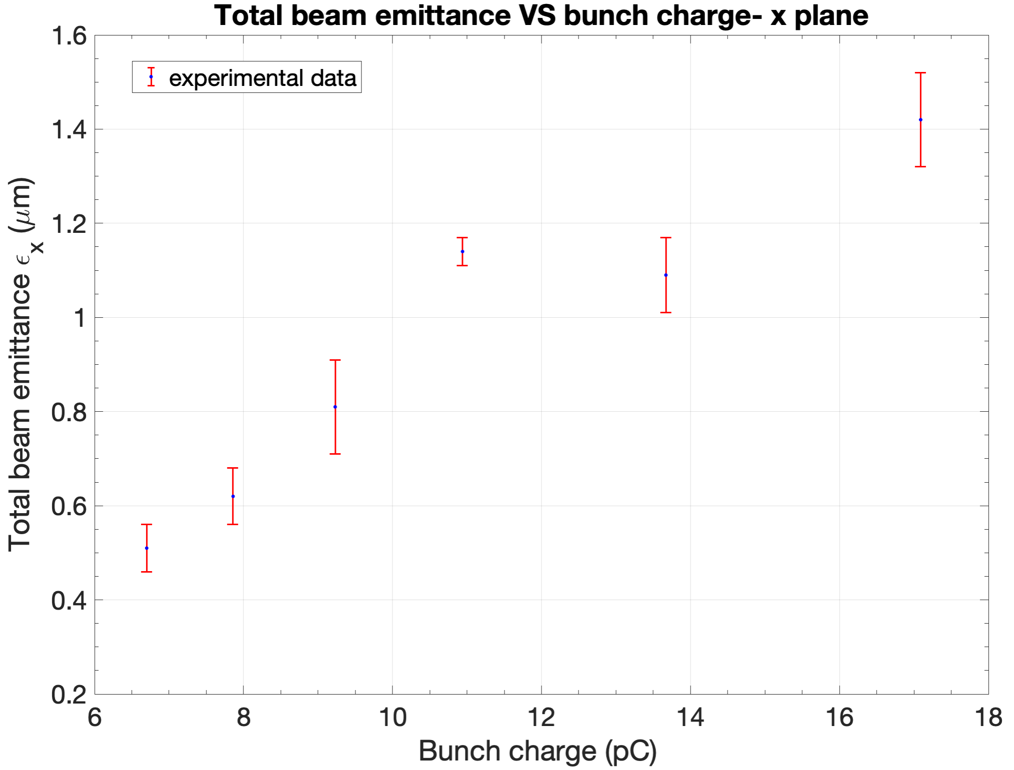


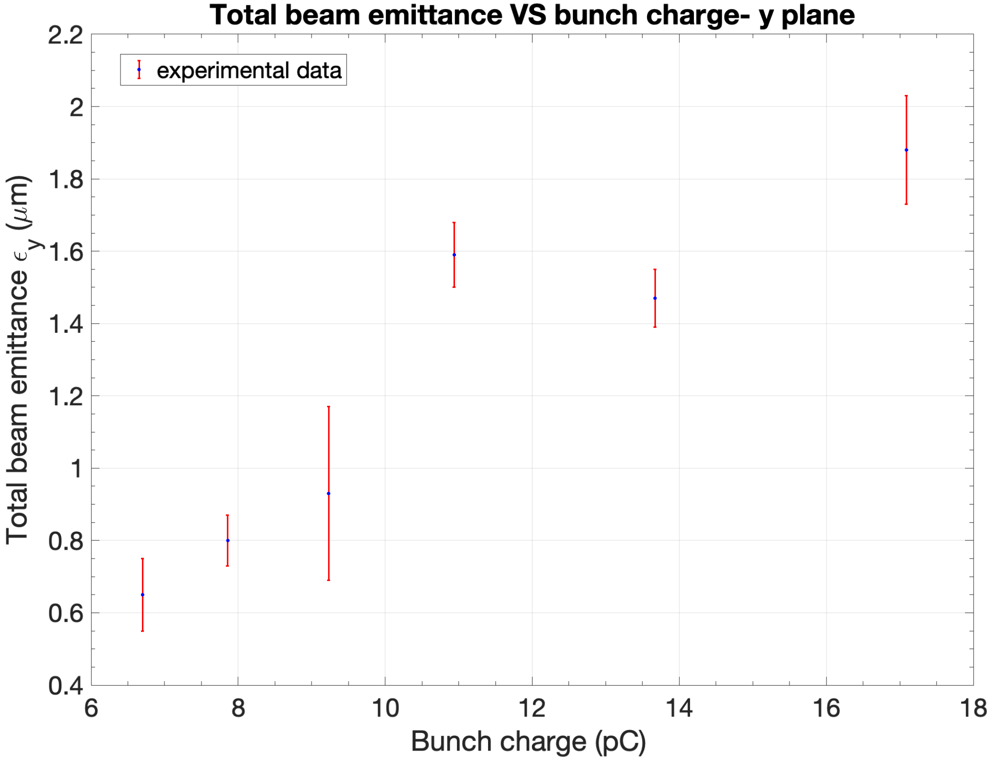



# Beam emittance versus bunch charge

*Parameters*:

- $E_{RF}$ = 95.3MV/m
- Working RF phase=30°
- Laser pulse length=1ps - FWHM (Gaussian profile)
- Laser spot size, $\sigma_x \simeq 130\ \mu m$, $\sigma_y \simeq 160\ \mu m$ (Gaussian profile)
- E= 4.15MeV - Electron beam energy
- $\lambda_{laser}$= 392nm (3.16eV)
- $\varphi_{work}$ = 3.1 eV



# Conclusions

- A new kind of metallic photocathode, Y-film ($\varphi_{work}$ = 3.1 eV) on Cu photocathode, has been tested using the second harmonic of Ti:Sa laser ($\lambda_{laser}$= 392nm )

- The experimental Quantum Efficiency value is in agreement with the theoretical value

- The total beam emittance has been measured in order to extrapolate the intrinsic emittance value

- Future work: intrinsic emittance computation and HomDyn / GPT simulations for the theoretical comparison

# Thanks to

- ✧E. Chiadroni, M. Ferrario, R. Pompili (INFN-LNF)
- ✧ A. Lorusso (Università del Salento, Dipartimento di Matematica e Fisica “E. De Giorgi”, INFN-Sezione di Lecce)
- ✧ P. Cinquegrana , M. Danailov, A. Demidovich, M. Trovò (Elettra Sincrotrone- Trieste)
- ✧ D. Garzella (CEA/IRAMIS/LIDyL)

# Finally it's over

**Thank you for your attention**