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Lee Jones

Accelerator Physics Group

Accelerator Science and Technology Centre
STFC Daresbury Laboratory

EWPAA 2017

European Workshop on Photocathodes for Particle Accelerator Applications
20-22 September 2017

HZB Helmholtz Zentrum Berlin

The Cockcroft Institute of Accelerator Science and Technology

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The TESS Facility: Photocathode energy spread measurements and the effects of surface roughness on photocathode performance.

- Overview of the TESS experimental system
- Energy spread & work function of rough cathodes
- New detector & laser-driven plasma light source
- Future work

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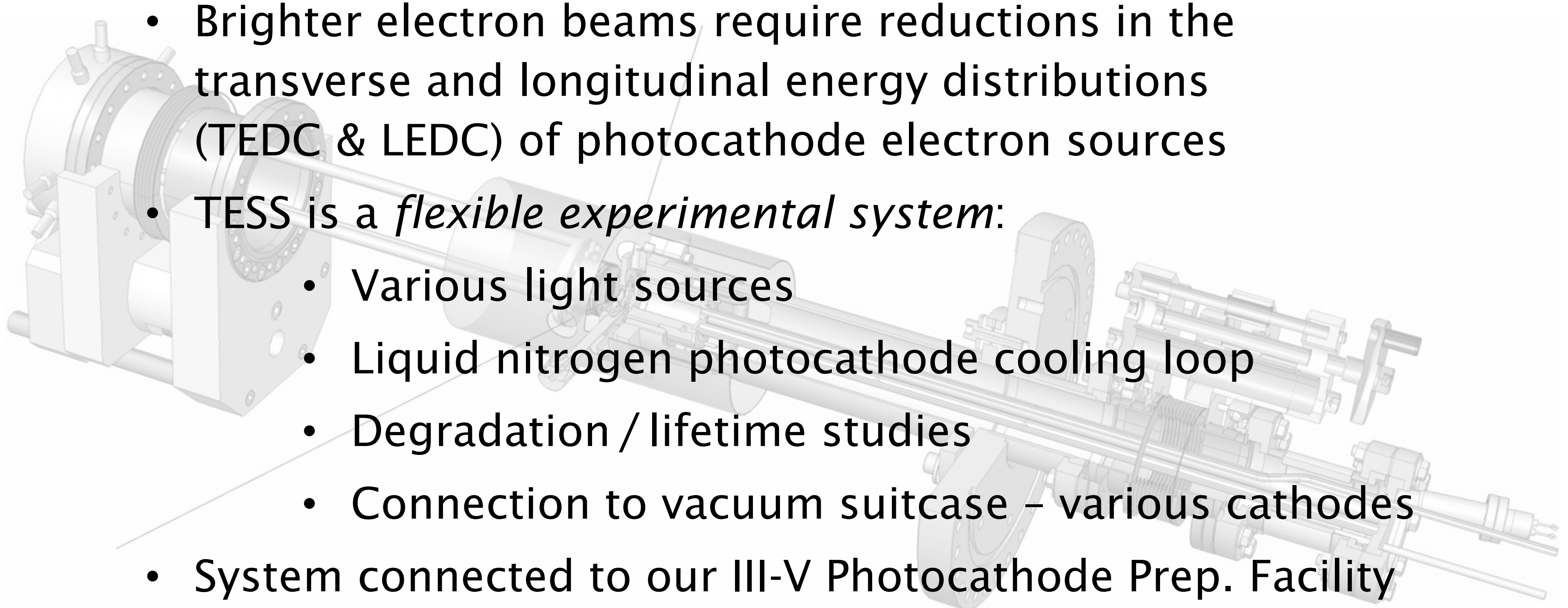
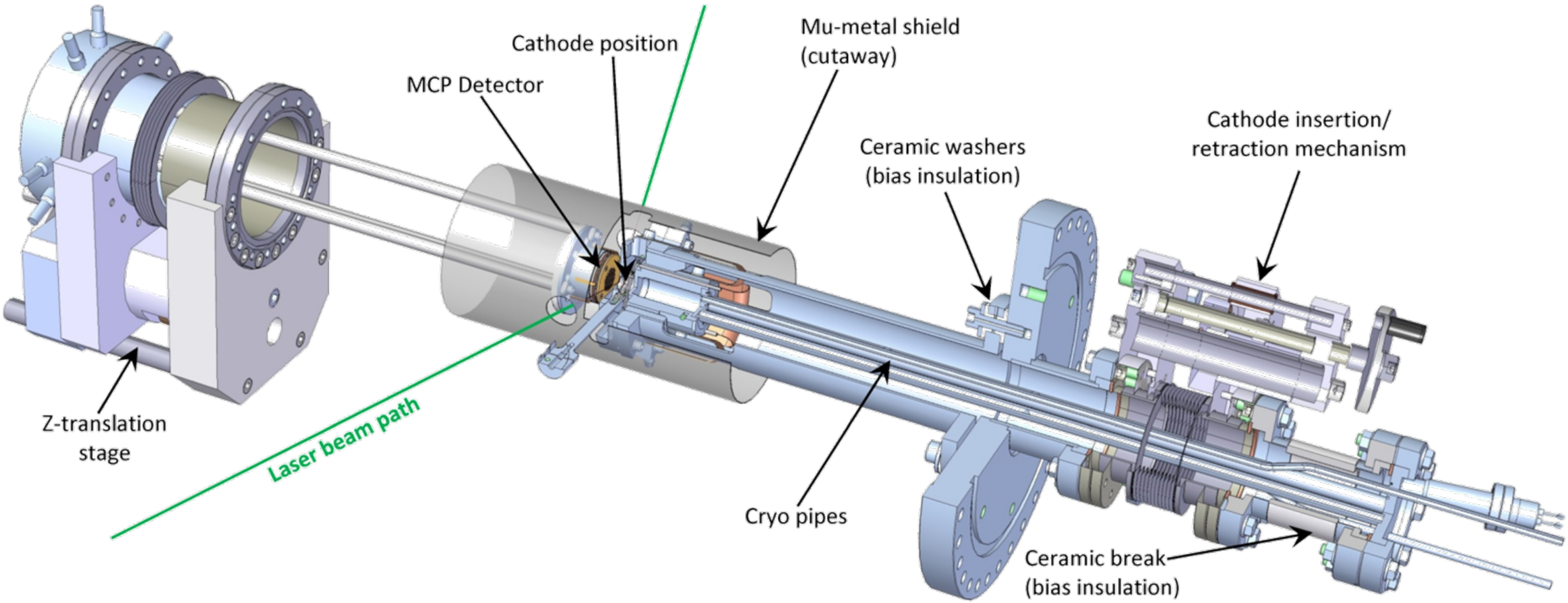
Increasing beam brightness:
Transverse and longitudinal energy distribution



- Brighter electron beams require reductions in the transverse and longitudinal energy distributions (TEDC & LEDC) of photocathode electron sources
- TESS is a *flexible experimental system*:
    - Various light sources
    - Liquid nitrogen photocathode cooling loop
    - Degradation / lifetime studies
    - Connection to vacuum suitcase – various cathodes
- System connected to our III-V Photocathode Prep. Facility

TESS – The Transverse Energy Spread Spectrometer

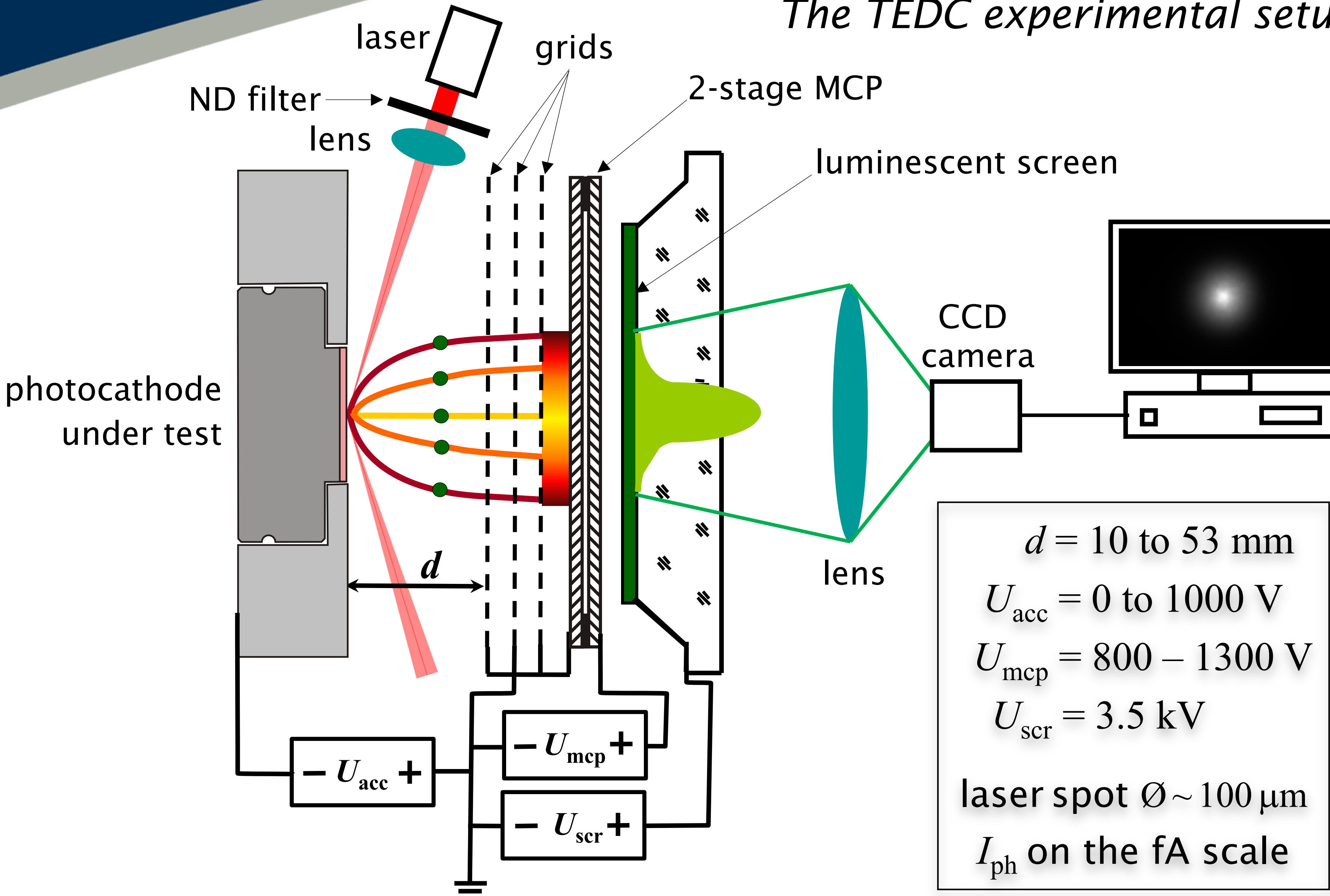
Increasing beam brightness:
Transverse and longitudinal energy distribution



TESS – The Transverse Energy Spread Spectrometer

Increasing beam brightness:

The TEDC experimental setup



$d = 10$ to 53 mm

$U_{acc} = 0$ to 1000 V

$U_{mcp} = 800 - 1300$ V

$U_{scr} = 3.5$ kV

laser spot $\varnothing \sim 100\ \mu m$

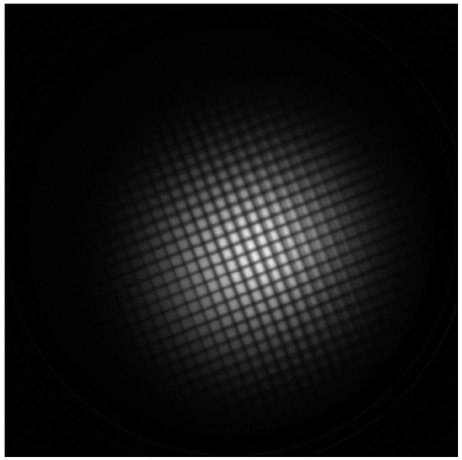
I_{ph} on the fA scale

TESS Commissioning:

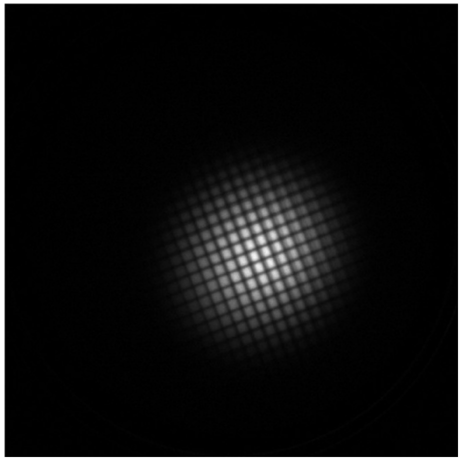
TEDC measurements with different wavelengths of light

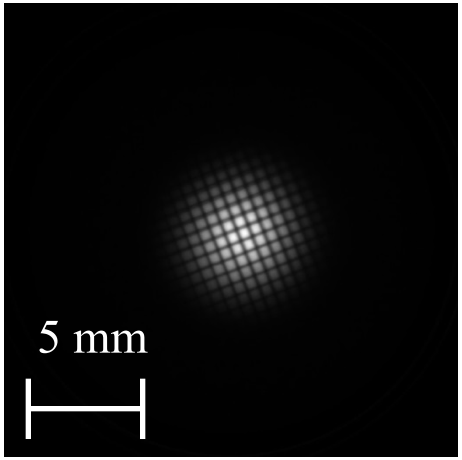
$\lambda = 532$ nm

$\lambda = 635$ nm

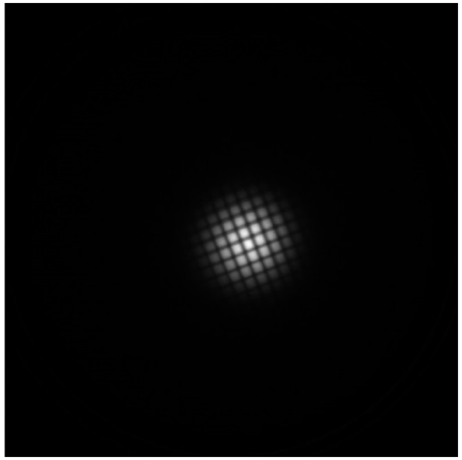


$U_{\mathrm{acc}} = 60$ V





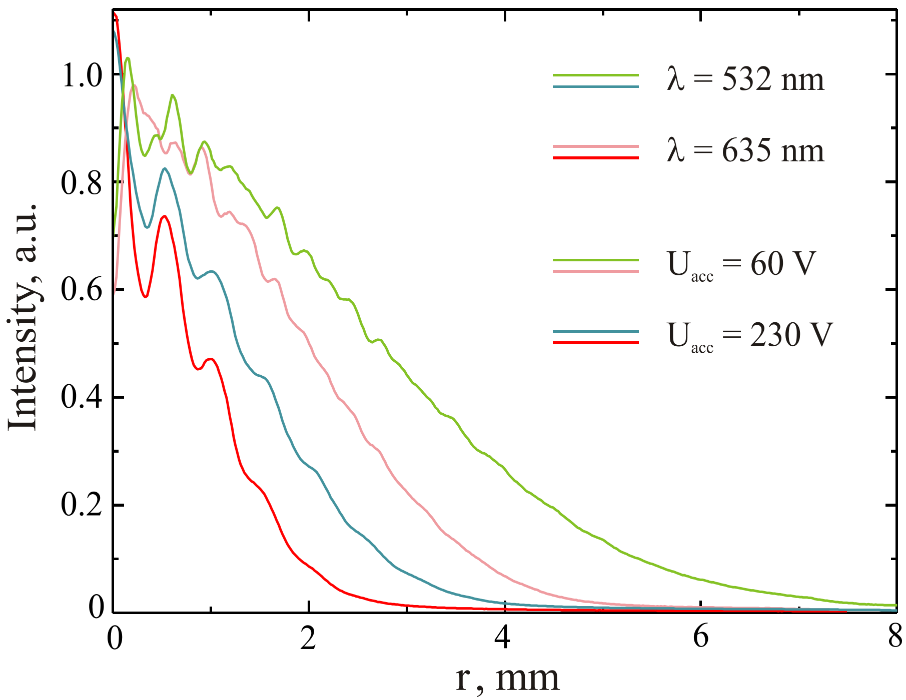
$U_{\mathrm{acc}} = 230$ V



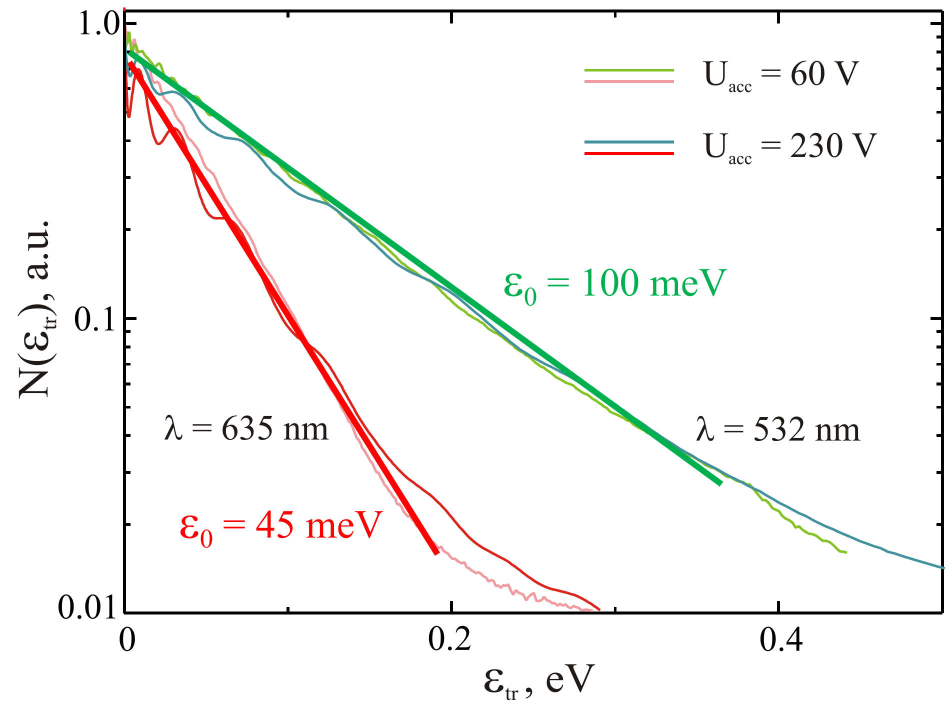
21.06.2013 p-GaAs(Cs,O) photocathode $d \approx 43$ mm $T = 300$ K

TESS Commissioning:
Summary of TEDC results

Screen luminescence profiles



Transverse energy distribution profiles



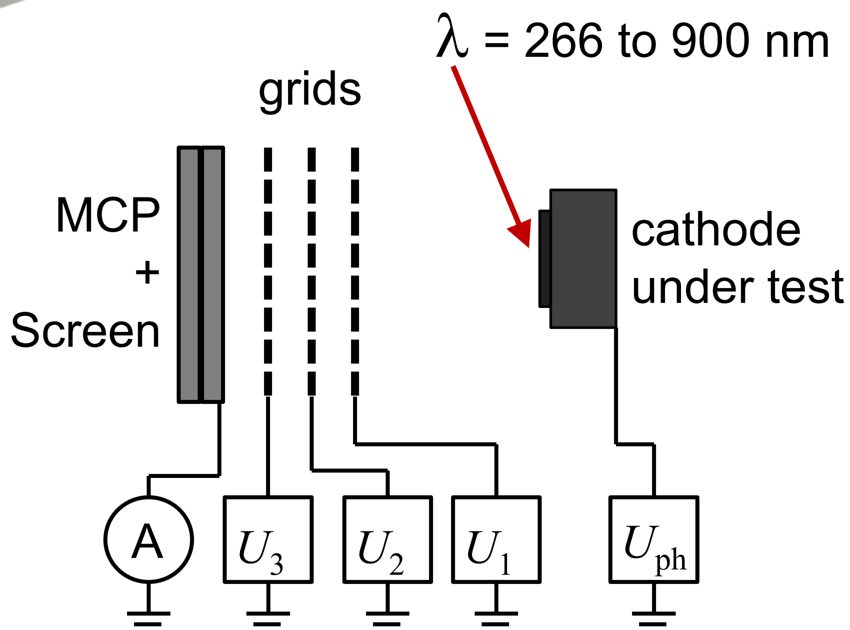
Proc. FEL '13, TUPS033, 290 - 292

$MTE_{635} = 45 \pm 7$ meV

$MTE_{532} = 100 \pm 15$ meV

21.06.2013 p-GaAs(Cs,O) photocathode $d \approx 43$ mm $T = 300$ K

Increasing beam brightness:
The LEDC experimental setup



$U_1 = 60$ V

$U_2 = 2/3 \times 60 = 40$ V

$U_3 = 1/3 \times 60 = 20$ V

$U_{ph} = $ -10 V to +10 V

- Non-imaging technique - Uses the MCP front plate as a charge collector
- Cathode bias (U_{ph})swept in small steps
- Photocurrent measured from $\text{MCP}_{\text{front}}$ using phase-sensitive detection
- Variant of the '*parallel plate*' setup installed at the ISP

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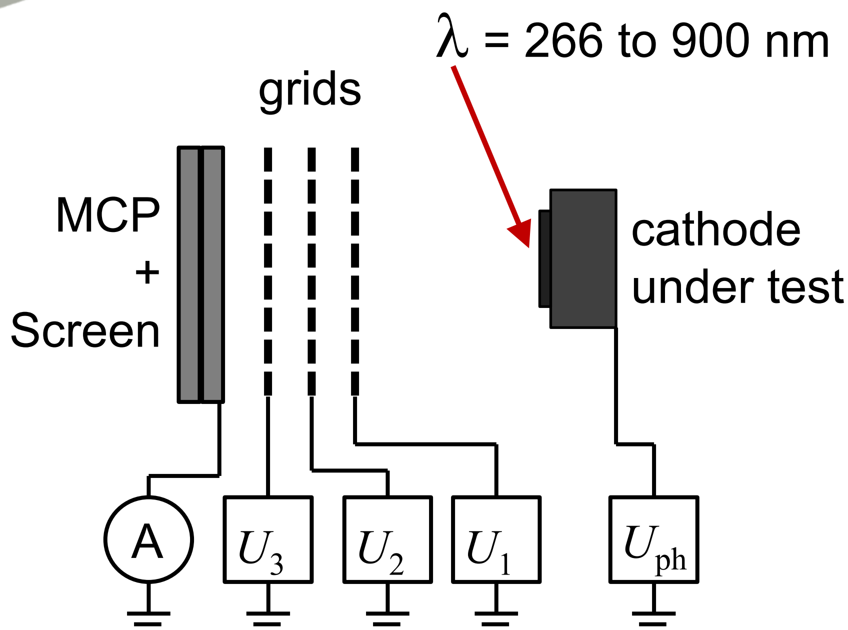
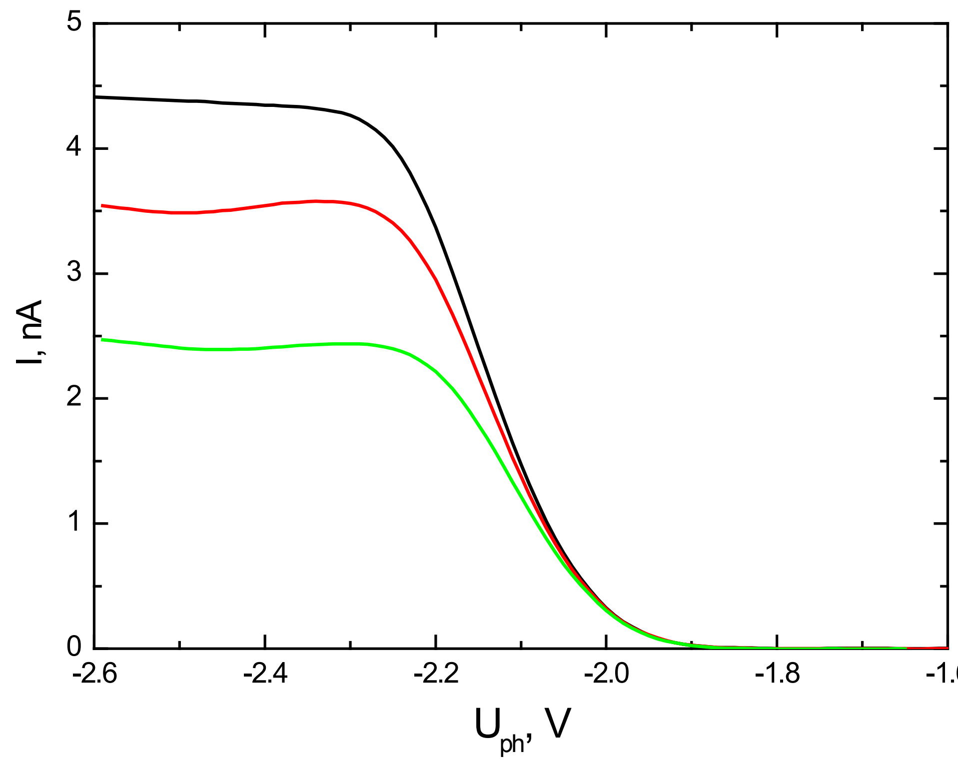
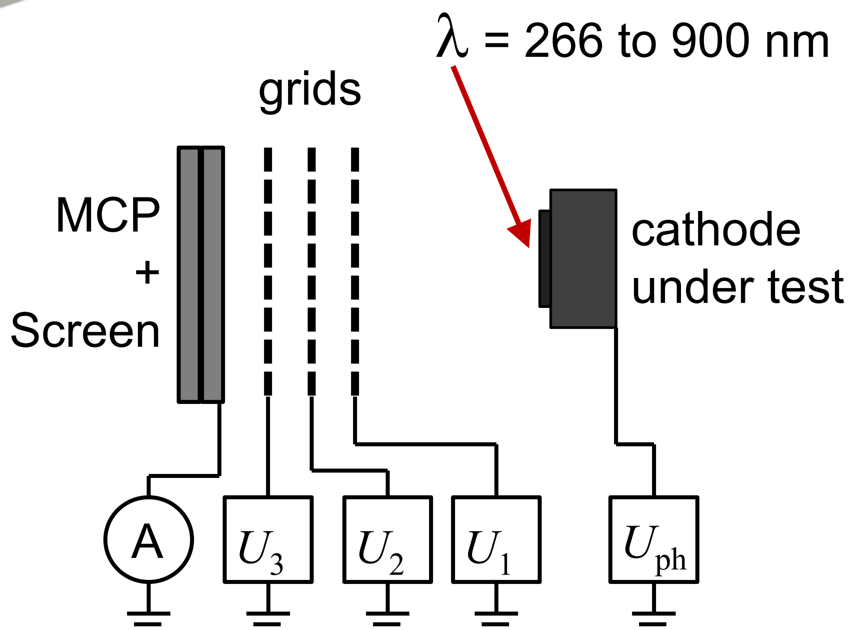
Increasing beam brightness:
The LEDC experimental setup

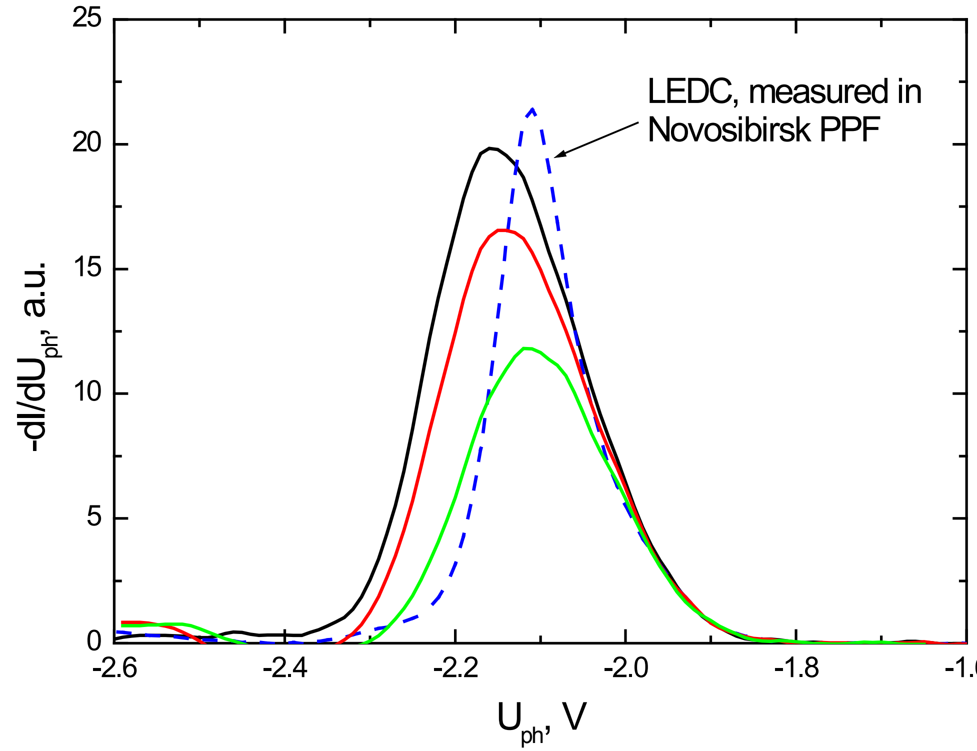




The current measured through MCP_{front} contains information on the longitudinal energy content of the photo-emitted electrons

Increasing beam brightness:
The LEDC experimental setup





Differentiating the photocurrent reveals the longitudinal energy spread, and allows us to extract the LEDC for the photo-emitted electrons

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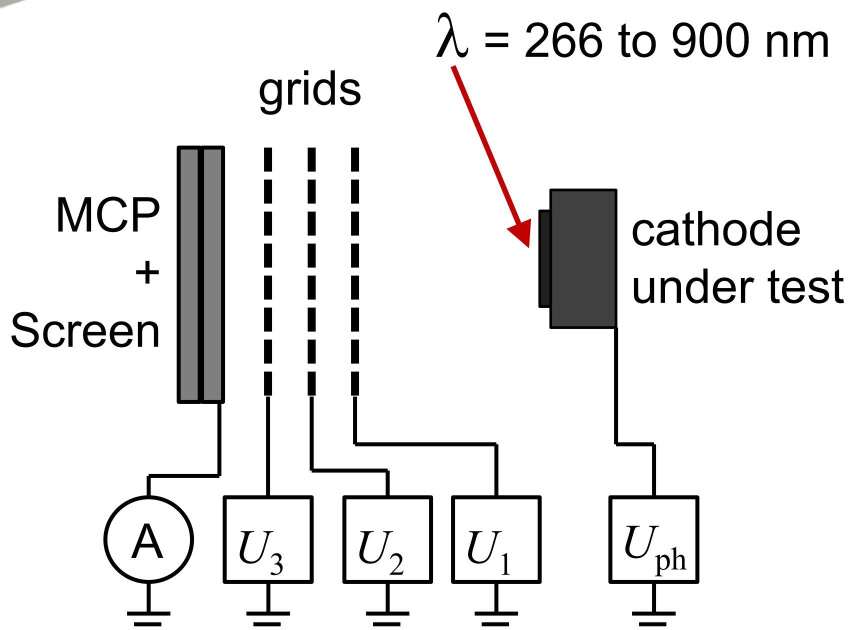
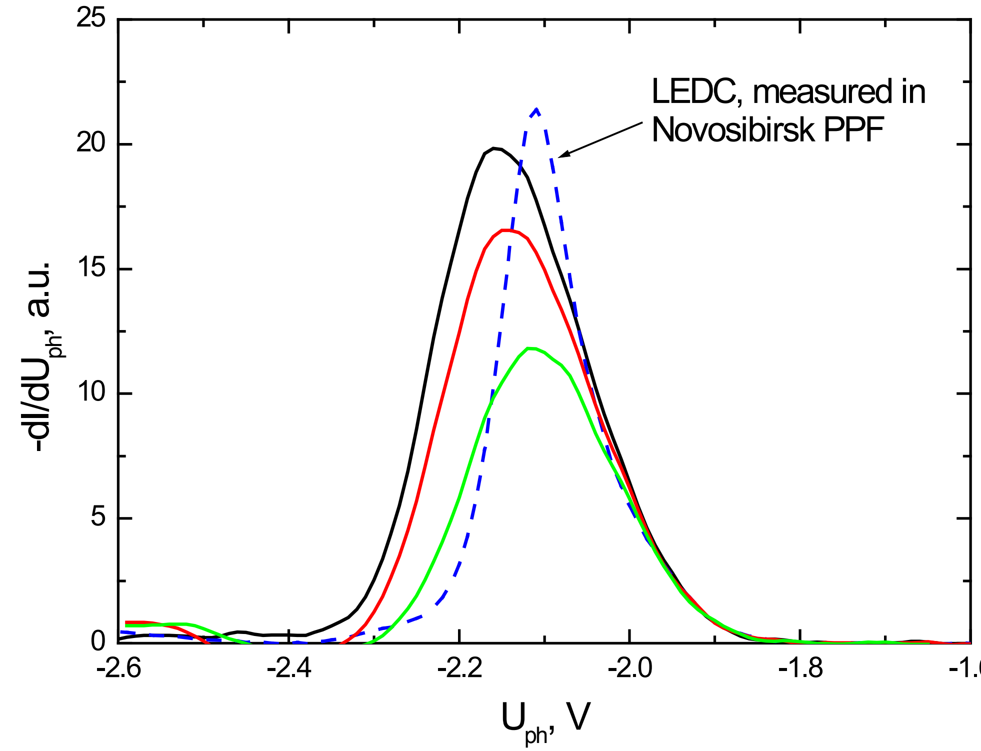
Increasing beam brightness:
The LEDC experimental setup





Poster: ***Measurement of the Longitudinal Energy Distribution of Electrons in Low Energy Beams using Electrostatic Elements***

D.P. Juarez-Lopez, L.B. Jones, T.C.Q. Noakes, C.P. Welsch, L. Devlin, O. Karamyshev, B.L. Militsyn

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Increasing beam brightness:
The MTE of electrons from rough photocathodes

- Three metal photocathode samples tested: 2 × Cu and 1 × Mo
- Surface roughness measured using 2 techniques:
  - DME HS100M AFM with a DS 95-50 scanner (50 × 50 μm^2)
  - ADE PhaseShift MicroXAM (173 × 131 μm^2)

Sample	AFM [nm]		μXAM [nm]	
	TPH (S_z)	RMS (S_q)	TPH (S_z)	RMS (S_q)
Cu.DT	728.6	83.4	919.7	81.9
Cu.EF	1083.2	143.9	1080.0	147.2
Mo			1691.6	241.4

Where $S_q = \sqrt{\frac{1}{MN}\sum_{J=l}^{N}\sum_{i=l}^{M}\eta^2\left(x_i, y_j\right)}$ and $S_z = \frac{1}{5}\left[\sum_{i=l}^{5}|\eta_{pi}| + \sum_{i=l}^{5}|\eta_{vi}|\right]$

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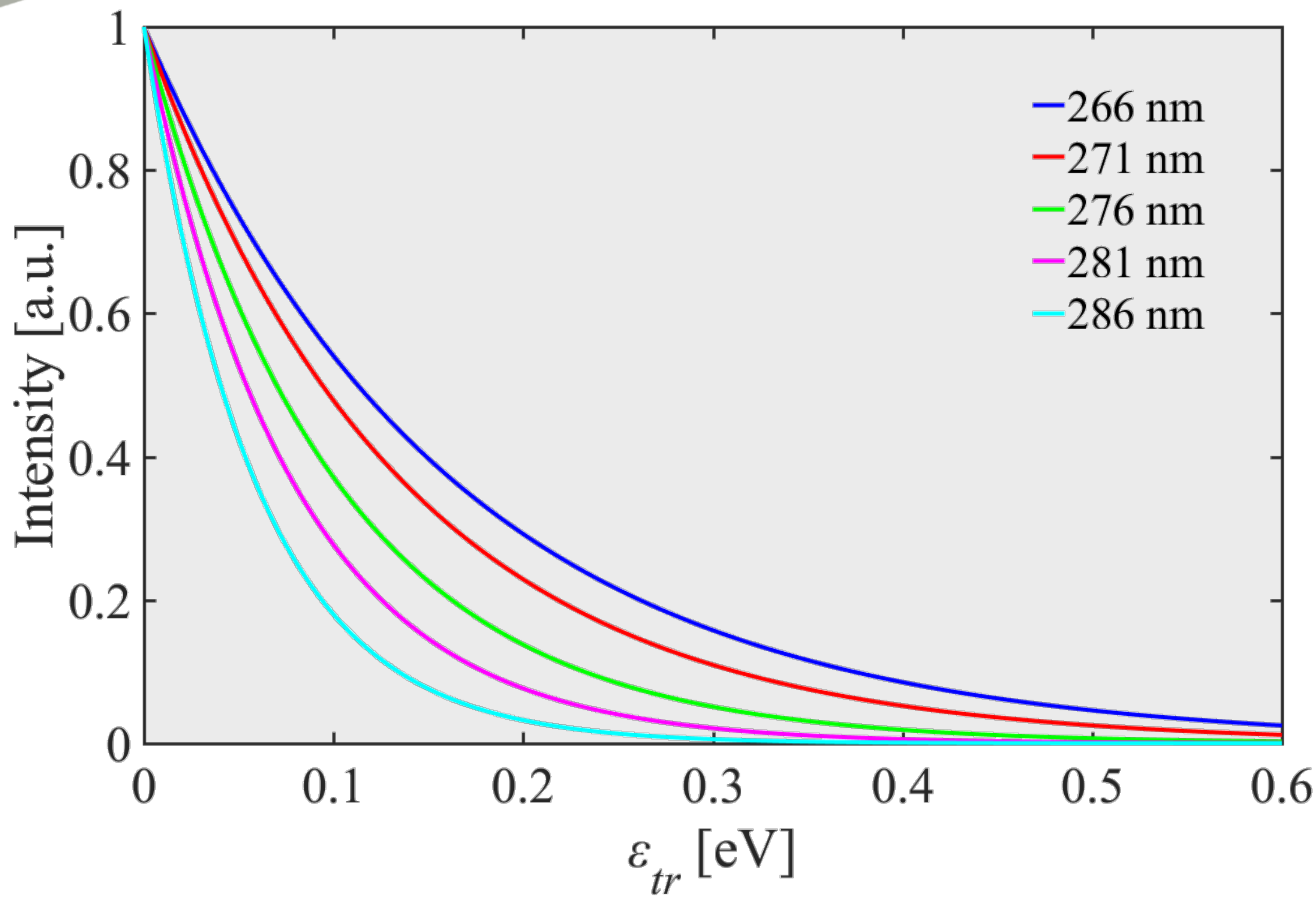
Increasing beam brightness:
The MTE of electrons from rough photocathodes

- Samples were de-greased in acetone, then argon plasma-cleaned
  - Henniker Plasma HPT-200, 20 minutes @ 200 W
- Samples loaded into the PPF and heat-cleaned in-situ
  - 450 °C for 1 hour (base pressure typically $5E^{-10}$ mbar)
- Samples then transferred into the TESS (typically $4E^{-11}$ mbar)
- TEDC measured at various illumination wavelengths

Increasing beam brightness:
The MTE of electrons from rough photocathodes



Graph showing fitted curves to data taken for the Cu.DT sample

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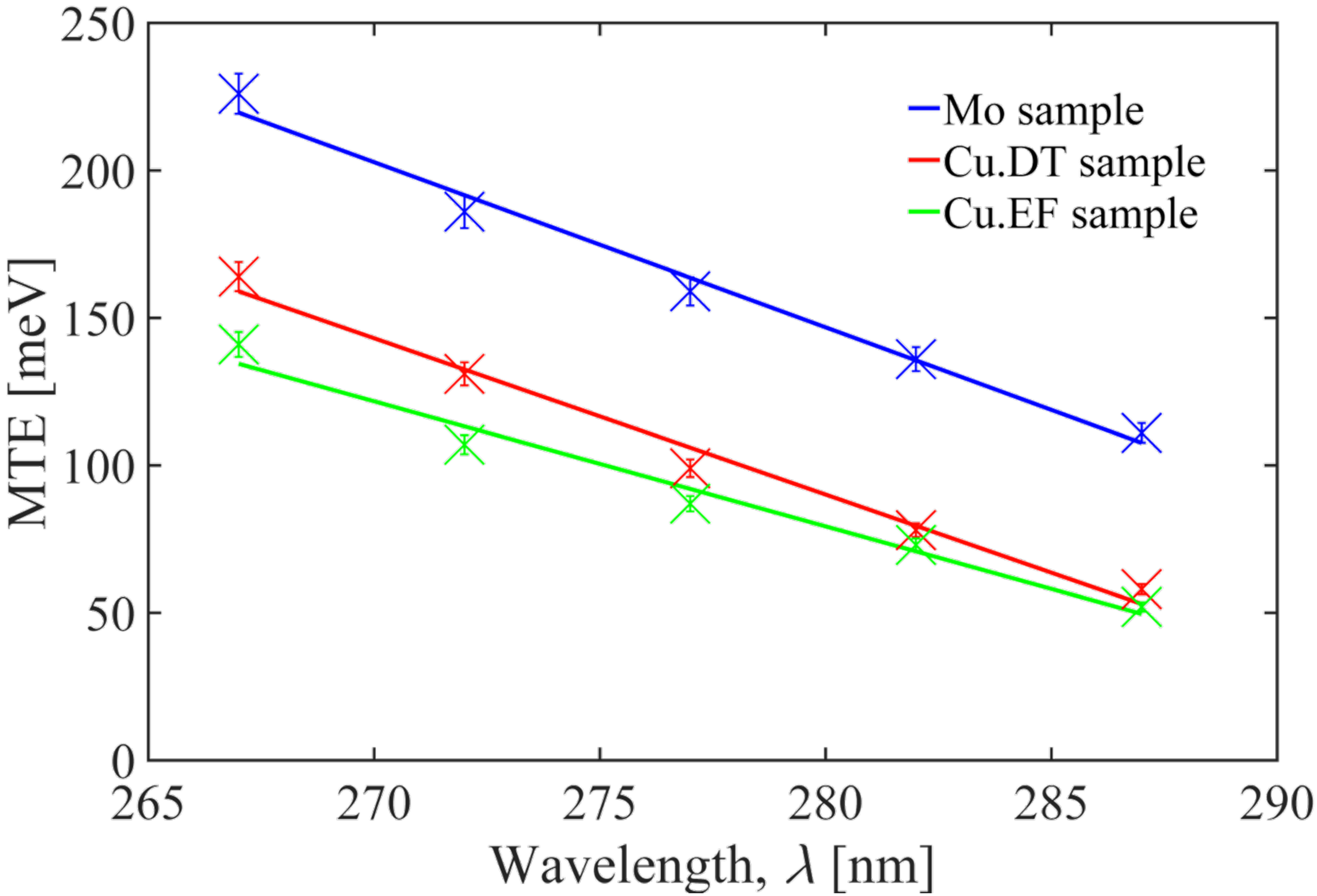
Increasing beam brightness:
The MTE of electrons from rough photocathodes

Wavelength, λ [nm]	Sample, MTE [meV]		
	Cu.EF	**Cu.DT**	**Mo**
266	137.2	162.6	225.9
271	105.7	135.7	186.4
276	87.1	100.9	158.5
281	73.8	77.9	136.4
286	53.0	59.4	111.7

Table summarising the MTEs for all of the photocathode samples

Increasing beam brightness:
The MTE of electrons from rough photocathodes



Graph showing the trend in the MTE for all photocathode samples

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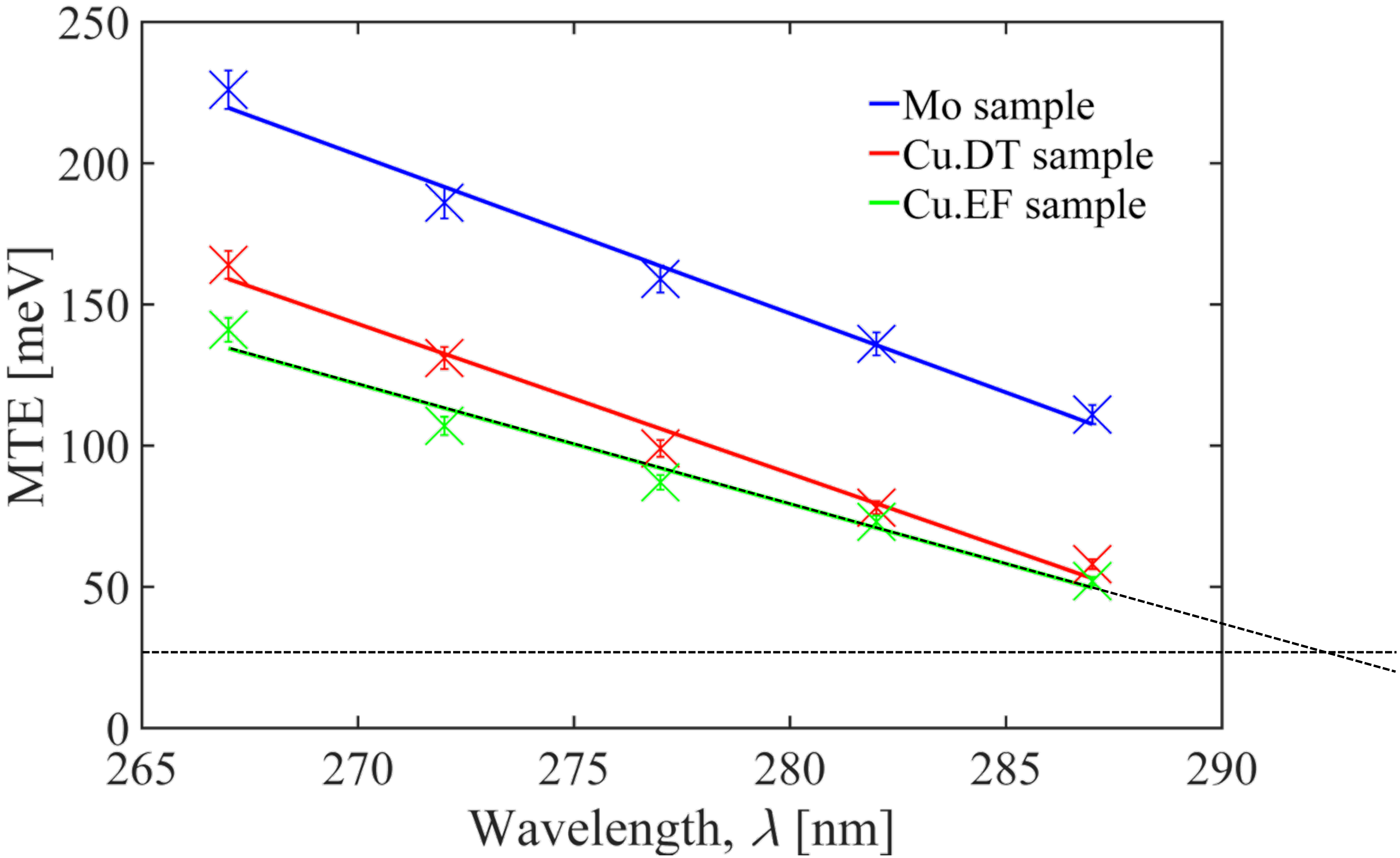
Increasing beam brightness:
The MTE of electrons from rough photocathodes



Threshold of photoemission: $\mathrm{MTE} = kT$ ➔ Can extract λ and hence ϕ_0

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Increasing beam brightness:
The MTE of electrons from rough photocathodes

Sample	Workfunction, ϕ_0 [eV]	
	Published	**Measured**
Cu.DT	4.65 *	4.26
Cu.EF		4.24
Mo	4.0 – 4.3 **	4.11

* O. Renault, R. Brochier *et al.*; Surf. Int. Anal. 38, 375 (2006)

** R.G. Wilson; J. Appl. Phys. 37 (8), 3170 (1966)

Table summarising the workfunctions for all of the photocathode samples

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Conclusions from this work:

- Surface roughness and workfunction affect the MTE of a photocathode
  - Results not as expected
- Extrapolation of the MTE at different illumination wavelengths to the kT threshold provides a useful measure of the photocathode workfunction
- Insufficient data to extract meaningful conclusions

- Laboratory relocation dictated that work be suspended
- Further work planned using a wide range of photocathode samples

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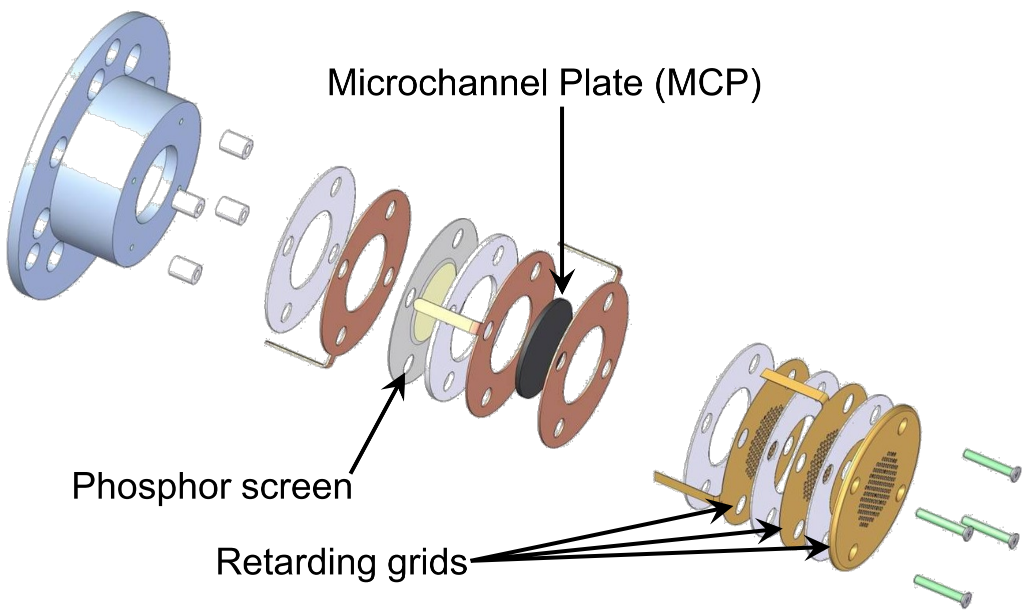
- Relocation of the Cockcroft Institute has forced a suspension in work due to laboratory relocation
    - An opportunity !
- New (larger) VISTA laboratory space created:

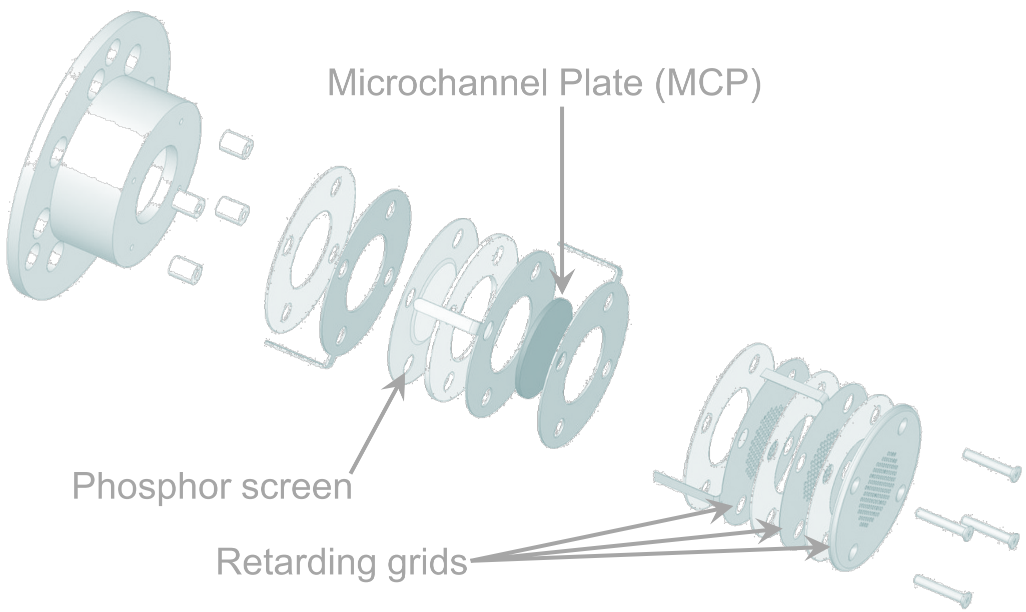
  Vacuum Interface and Surface Technologies for Accelerators
- Currently re-populating new laboratory with experimental systems, and re-commissioning/upgrading systems

TESS Detector upgrade:
No grids and increased screen intensity



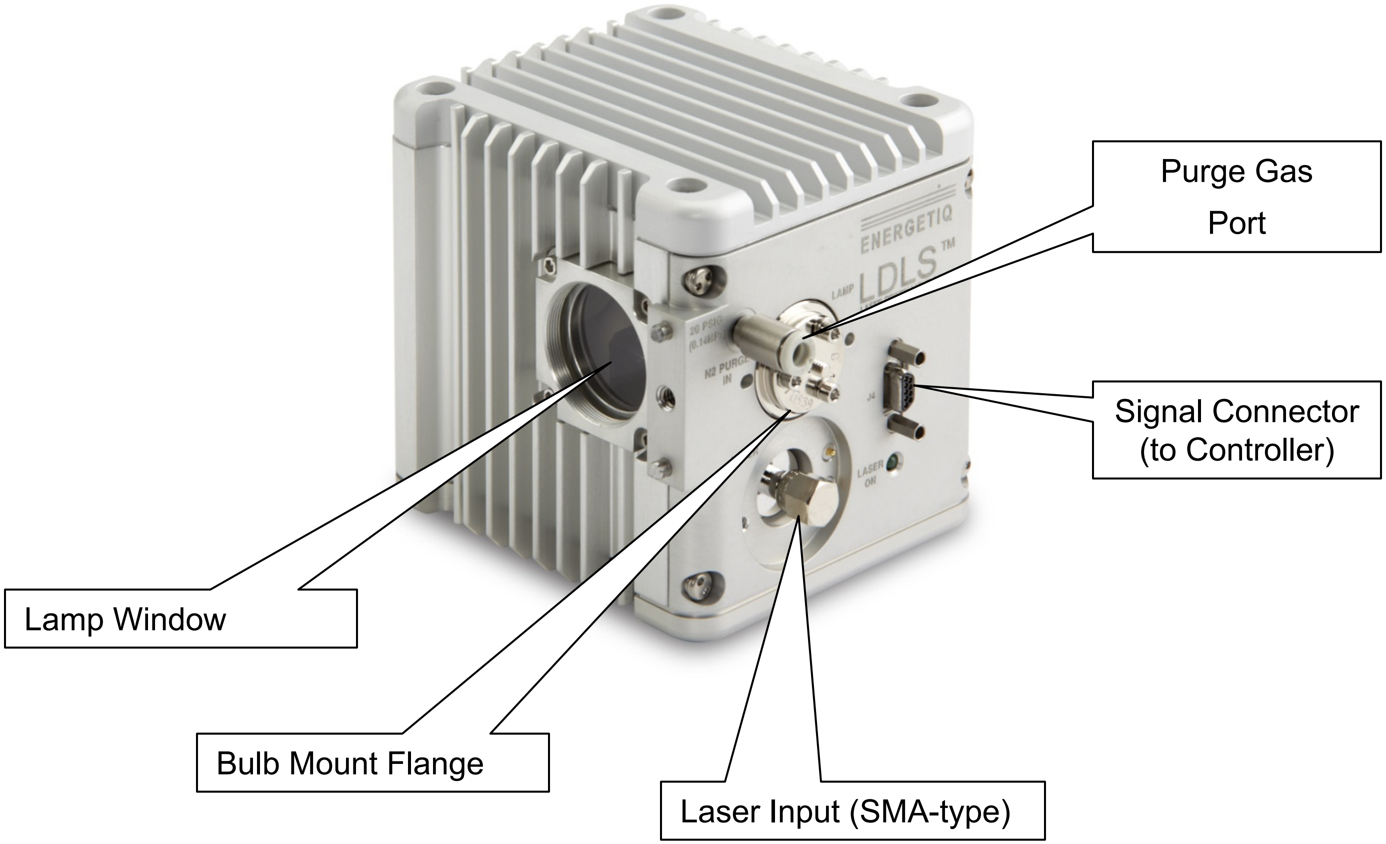
Original 3-grid electron multiplier and imaging detector

TESS Detector upgrade:
No grids and increased screen intensity



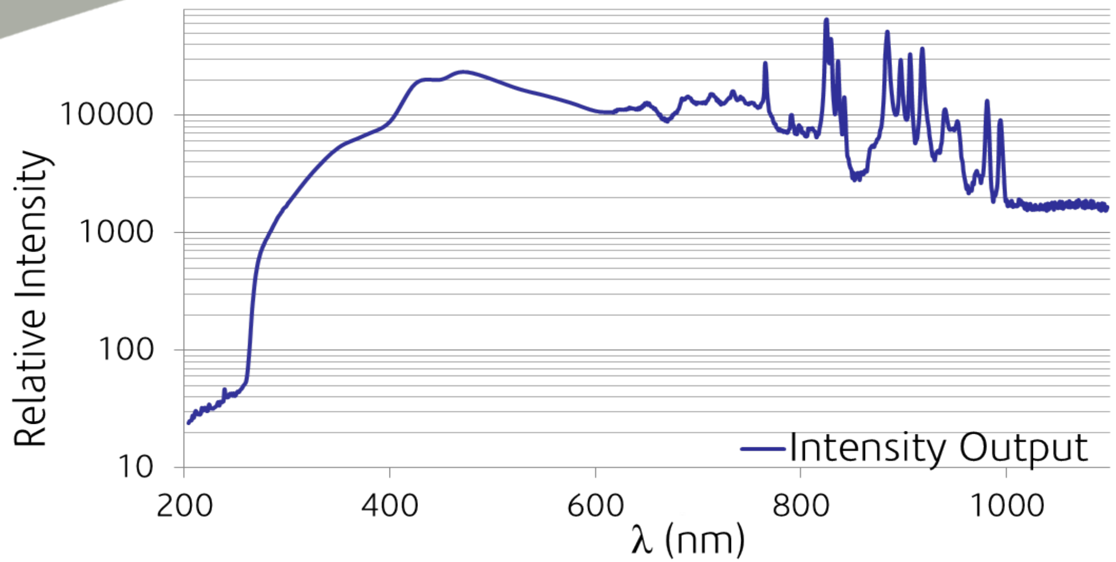
New electron multiplier and imaging detector with single demountable grid

TESS Light source upgrade:
New broadband light source

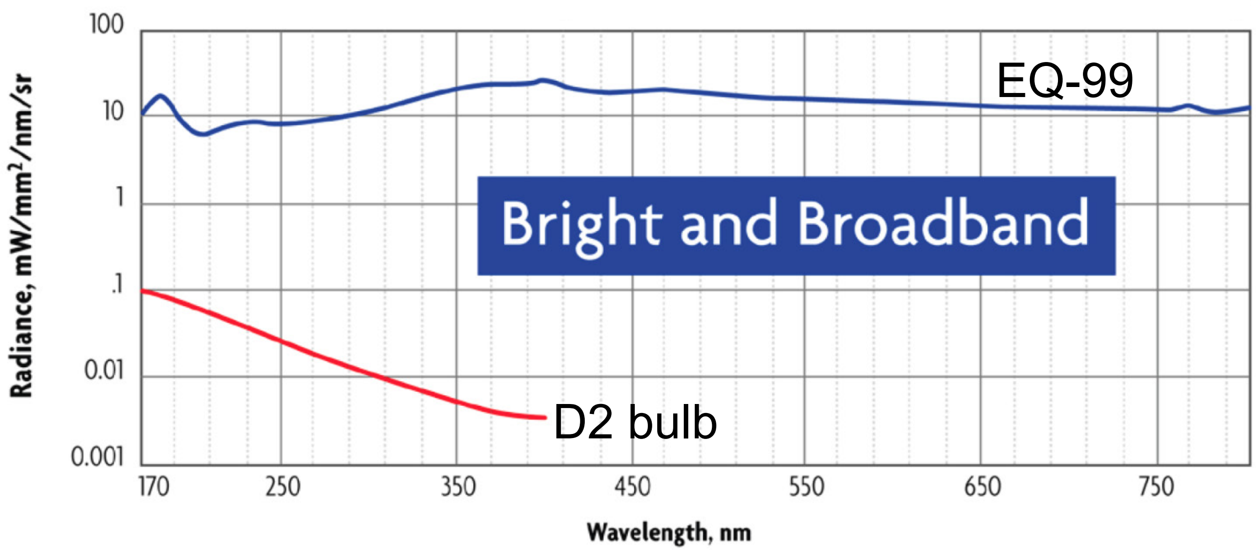


Energetiq EQ-99X laser-driven plasma broadband light source

TESS Light source upgrade:
New broadband light source



AST-XE-175EX
200 W xenon
bulb source



EQ-99
laser-driven
plasma light
source

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Future work:

Coming weeks:

- Configure LDPLS light source and install on the TESS
- obtain first electron emission footprint from the new TESS detector (re-commissioning)

Coming months:

- Experiments on different metallic samples
  - Cu, Mo, Nb, Ag, Mg, Pb, Y (and some oxides ?)
  - Mixture of single-crystal and polycrystalline samples
  - Measured levels of surface roughness

Longer term:

- Experiment to map surface QE of soft copper (W. Wuensch)
- MTE measurements of CsTe photocathodes from CERN

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Thank you!

The ASTeC photocathode team:

Dr. Tim Noakes	Sonal Mistry	(Ph.D. student)
Dr. Boris Militsyn	Pavel Juarez	(Ph.D. student)
Dr. Lee Jones	Victor Chang	(Ph.D. student)
Dr. Keith Middleman	Bruno Camino	(now Post Doc.)
Dr. Reza Valizadeh	Tom Beaver	(UG student)
Dr. Mark Surman	Ryan Cash	(engineering)
Prof. Elaine Seddon (consultant)	Barry Fell	(engineering)

The ISP photocathode team:

Prof. Alexander Terekhov	Vasiliy Bakin
Dr. Heinrich Scheibler	Dmitry Gorshkov
Dr. Sergei Kosolobov	Stanislav Rozkov

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EXTRA SLIDES

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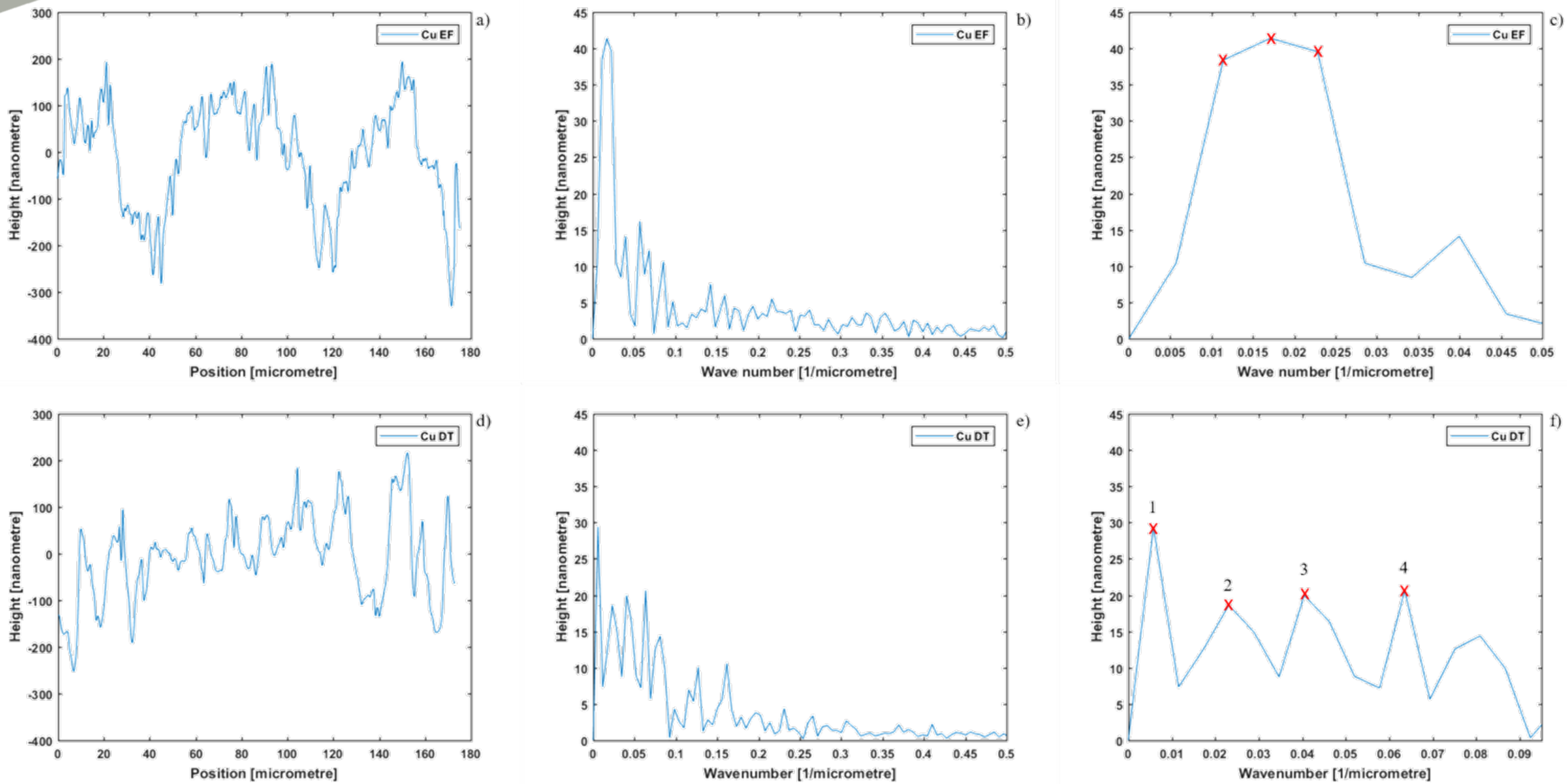
Increasing beam brightness:
The MTE of electrons from rough photocathodes

(Courtesy: S. Mistry)



Roughness measurements using MicroXAM for Cu.DT and Cu.EF samples

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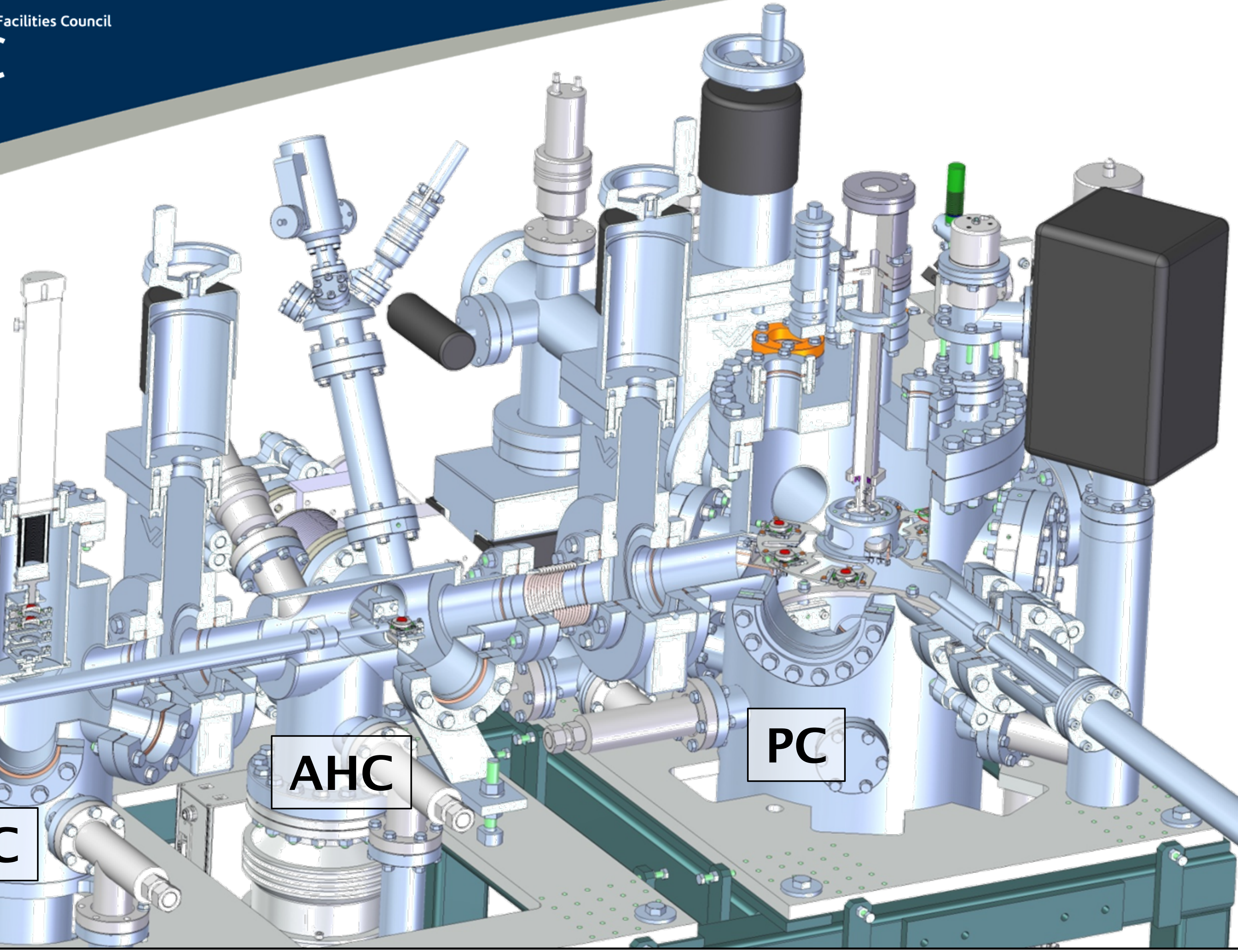
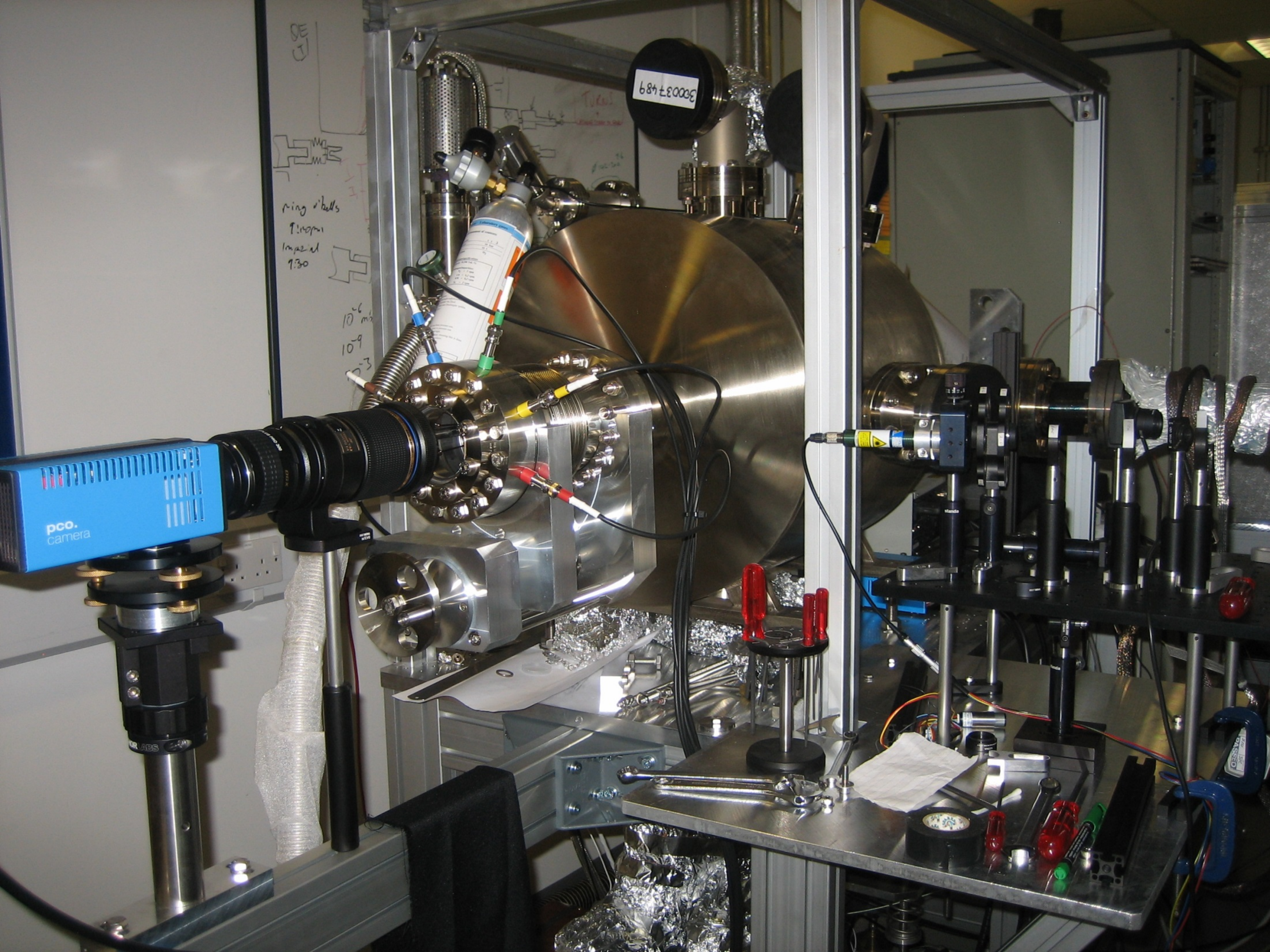
Photocathode
Puck

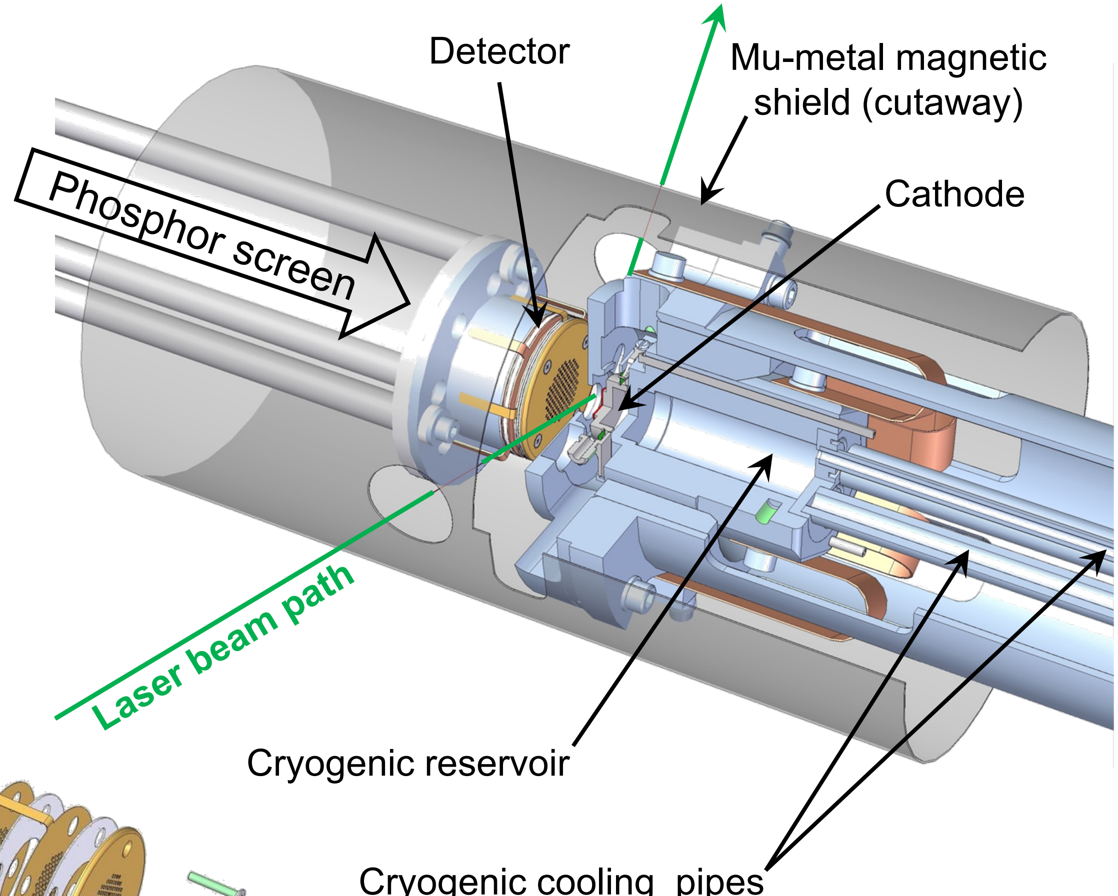


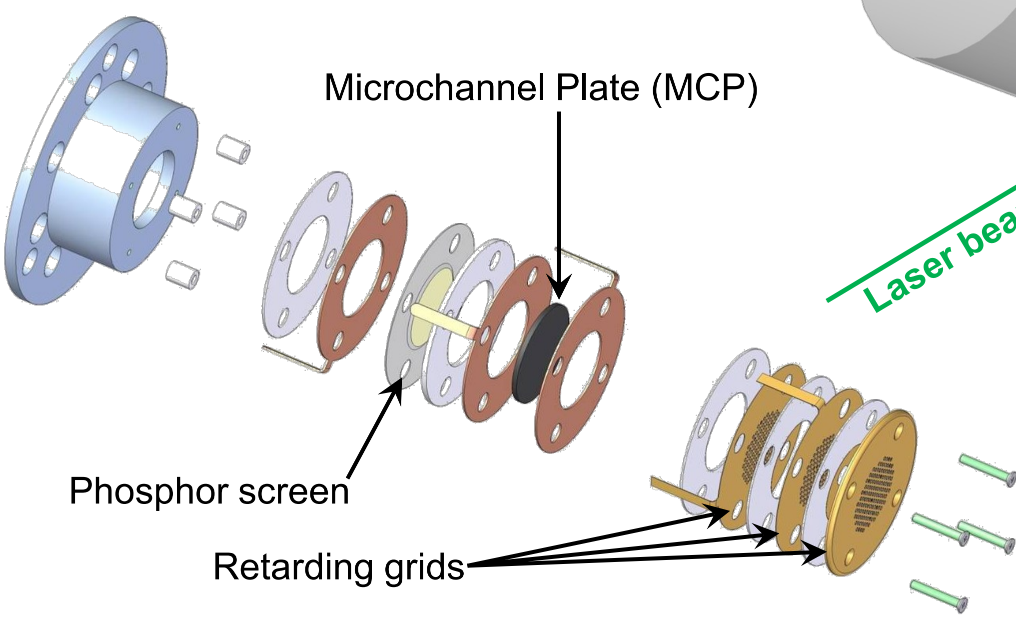
The PPF comprises a loading chamber (LC), atomic hydrogen cleaning chamber (AHC), and a photocathode preparation chamber (PC)


pco.
camera
30003 7489

Increasing beam brightness:
The intrinsic energy of NEA GaAs photocathodes

- Independent control of source & grid potentials
- Ability to change the source-detector spacing
- Inclusion of leak valve to ‘poison’ the cathode

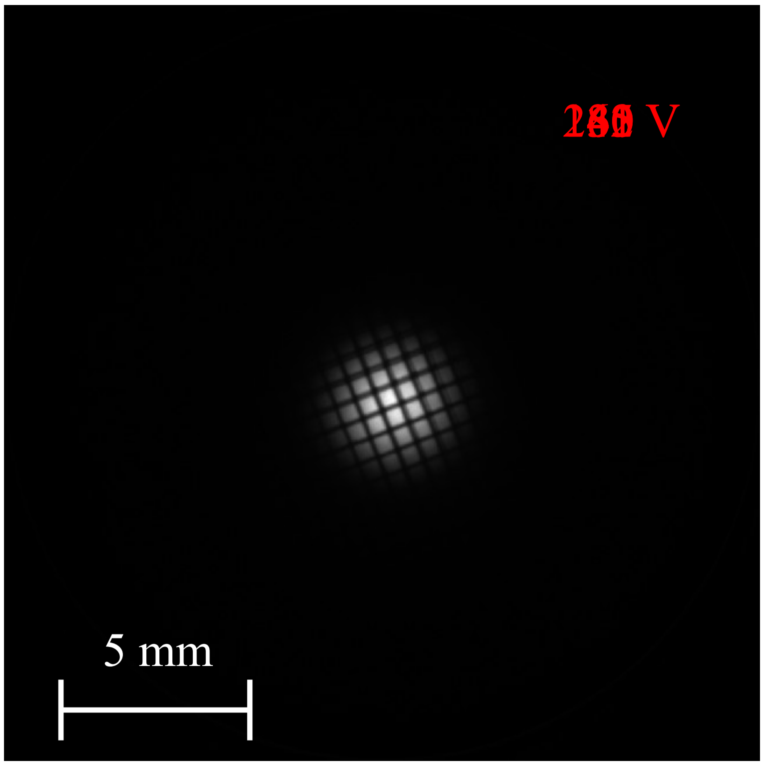




TESS – The Transverse Energy Spread Spectrometer

TESS Commissioning:

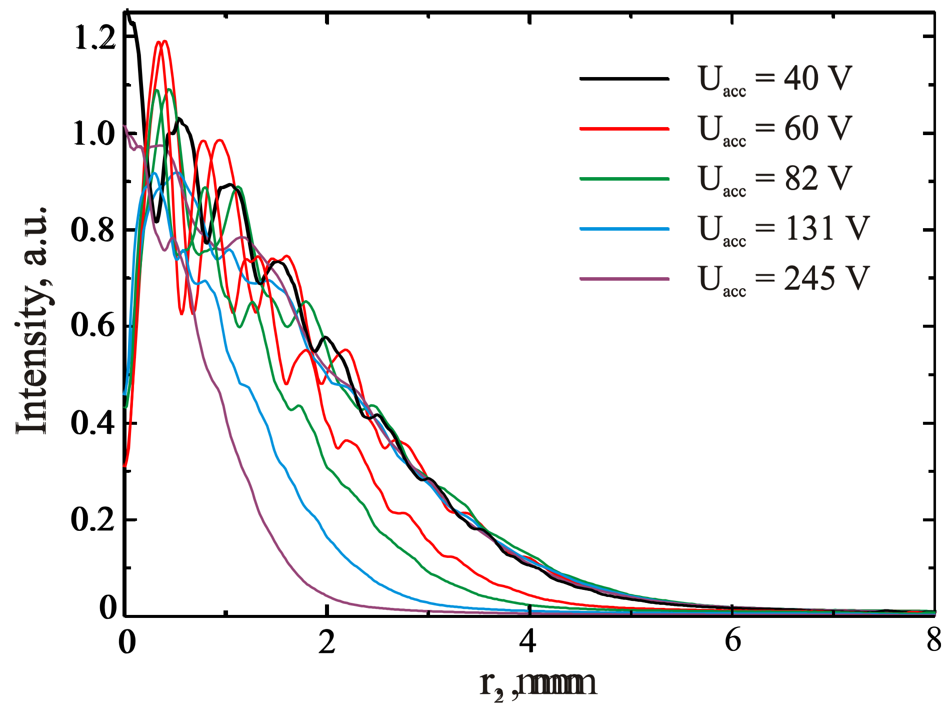
TEDC measurements at different accelerating voltages



$$d = 33\ \text{mm} \quad \lambda = 635\ \text{nm}$$

$$T = 300\ \text{K}$$

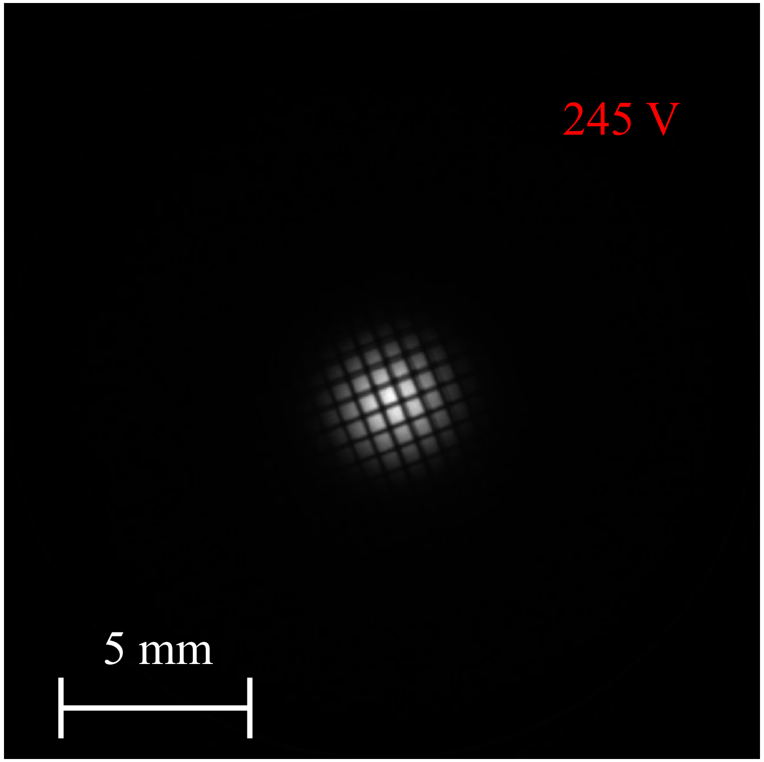
Screen luminescence profiles



$$\tau = d \times \sqrt{\frac{2\, m_e}{e\, U_{acc}}} \quad \Rightarrow \quad r_2 = r \times \sqrt{\frac{U_{acc}}{40}}$$

17.06.2013 p-GaAs(Cs,O) photocathode

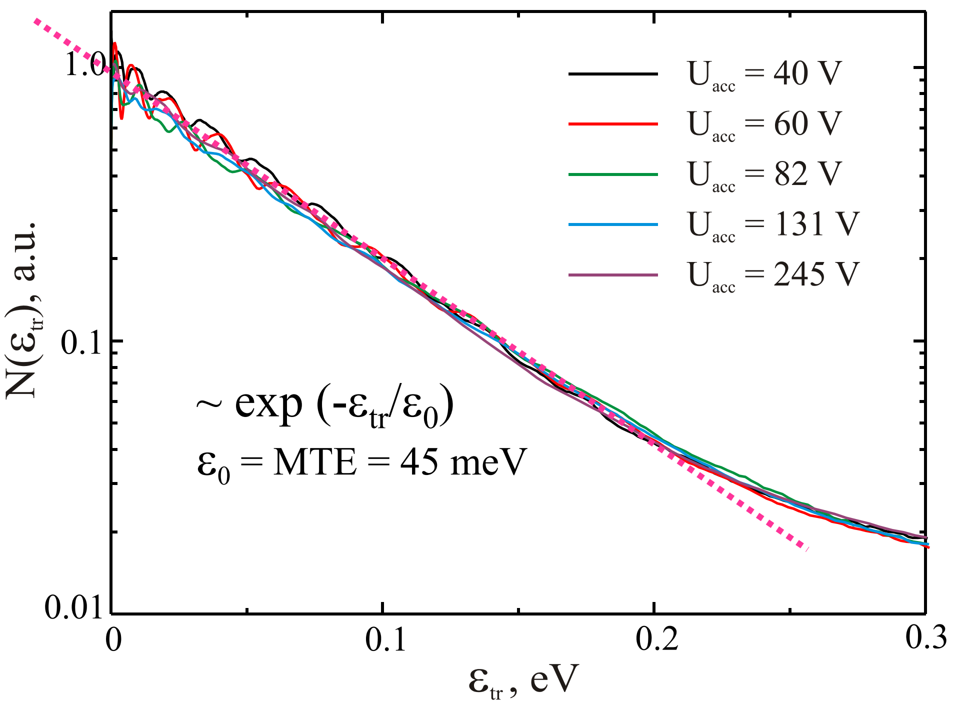
TESS Commissioning:
TEDC measurements at different accelerating voltages



$d = 33$ mm $\lambda = 635$ nm

$T = 300$ K

Transverse energy distribution profiles



17.06.2013 p-GaAs(Cs,O) photocathode