Science & Technology Facilities Council
ASTeC

Lee Jones

Accelerator Physics Group

Accelerator Science and Technology Centre

STFC Daresbury Laboratory

ERL'15

The Cockcroft Institute of Accelerator Science and Technology

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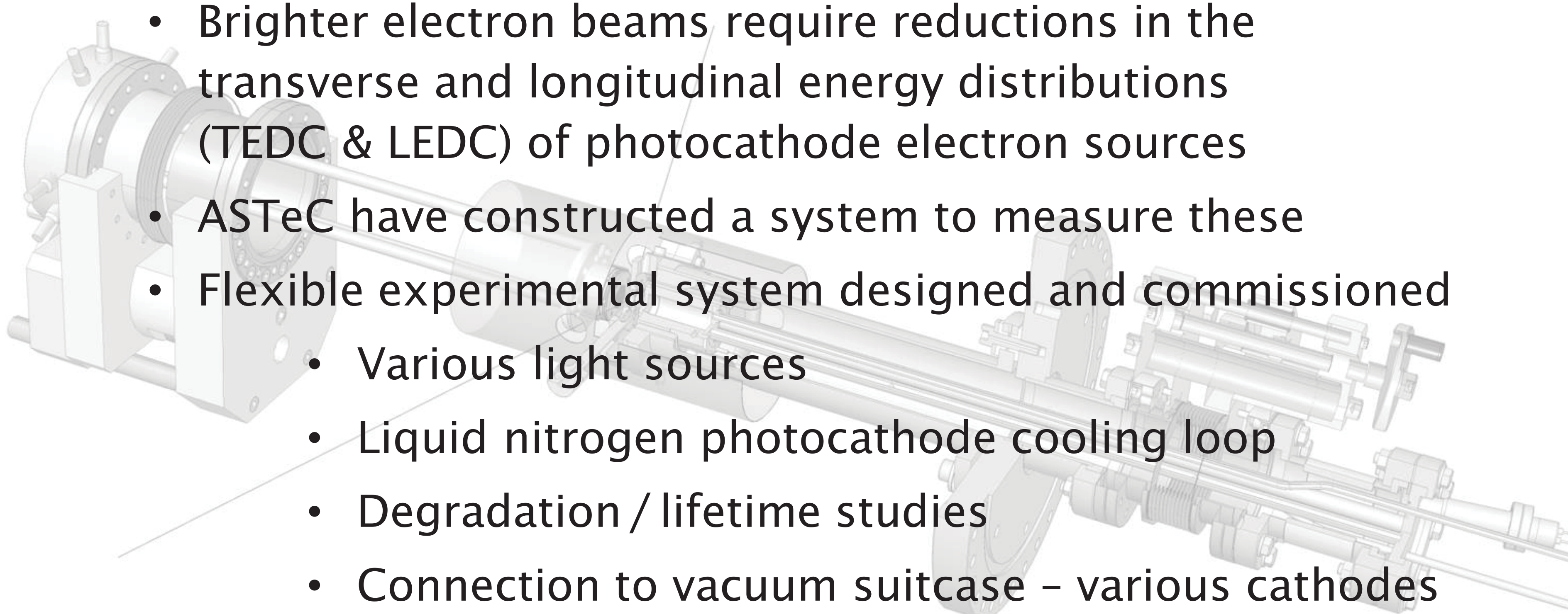
Accelerator Physics Group

GaAs Photocathode R&D: Energy spread measurements and the nature of the activated p-GaAs(Cs,O) activation layer

- Overview of the TESS experimental system
- The nature of the p-GaAs(Cs,O) activation layer

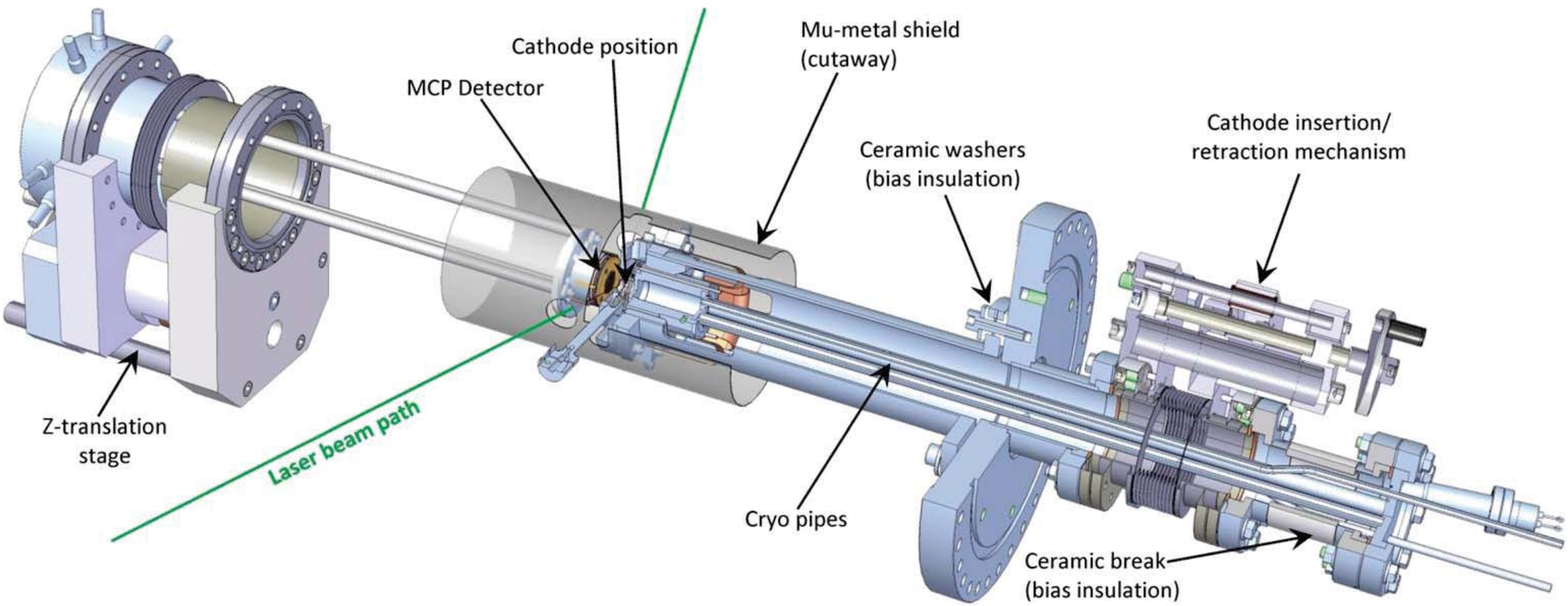
Characterising photocathode sources: *Transverse & Longitudinal Energy Distribution*



- Brighter electron beams require reductions in the transverse and longitudinal energy distributions (TEDC & LEDC) of photocathode electron sources
- ASTeC have constructed a system to measure these
- Flexible experimental system designed and commissioned
  - 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

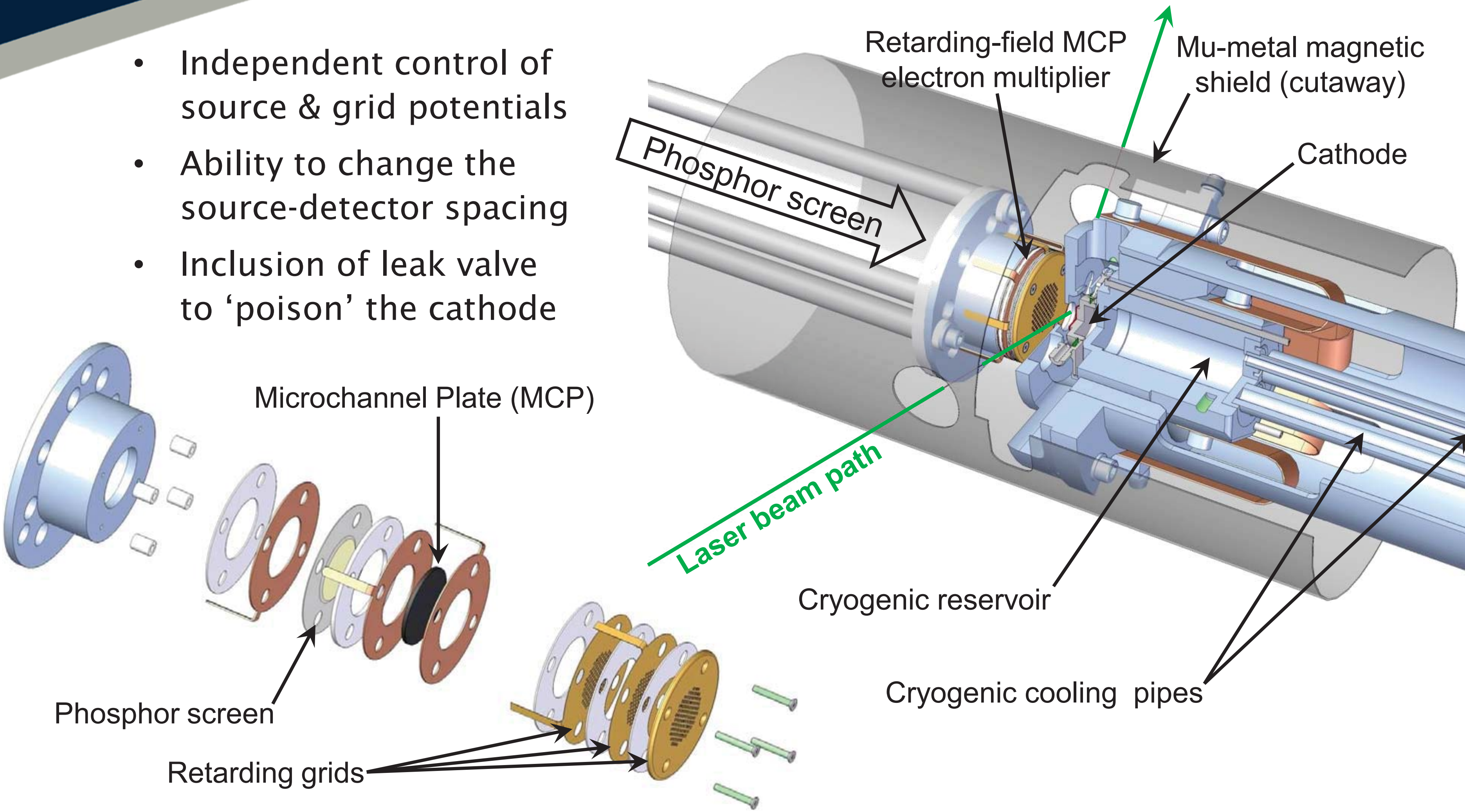
Increasing beam brightness:
The intrinsic energy of NEA GaAs photocathodes



TESS – The Transverse Energy Spread Spectrometer

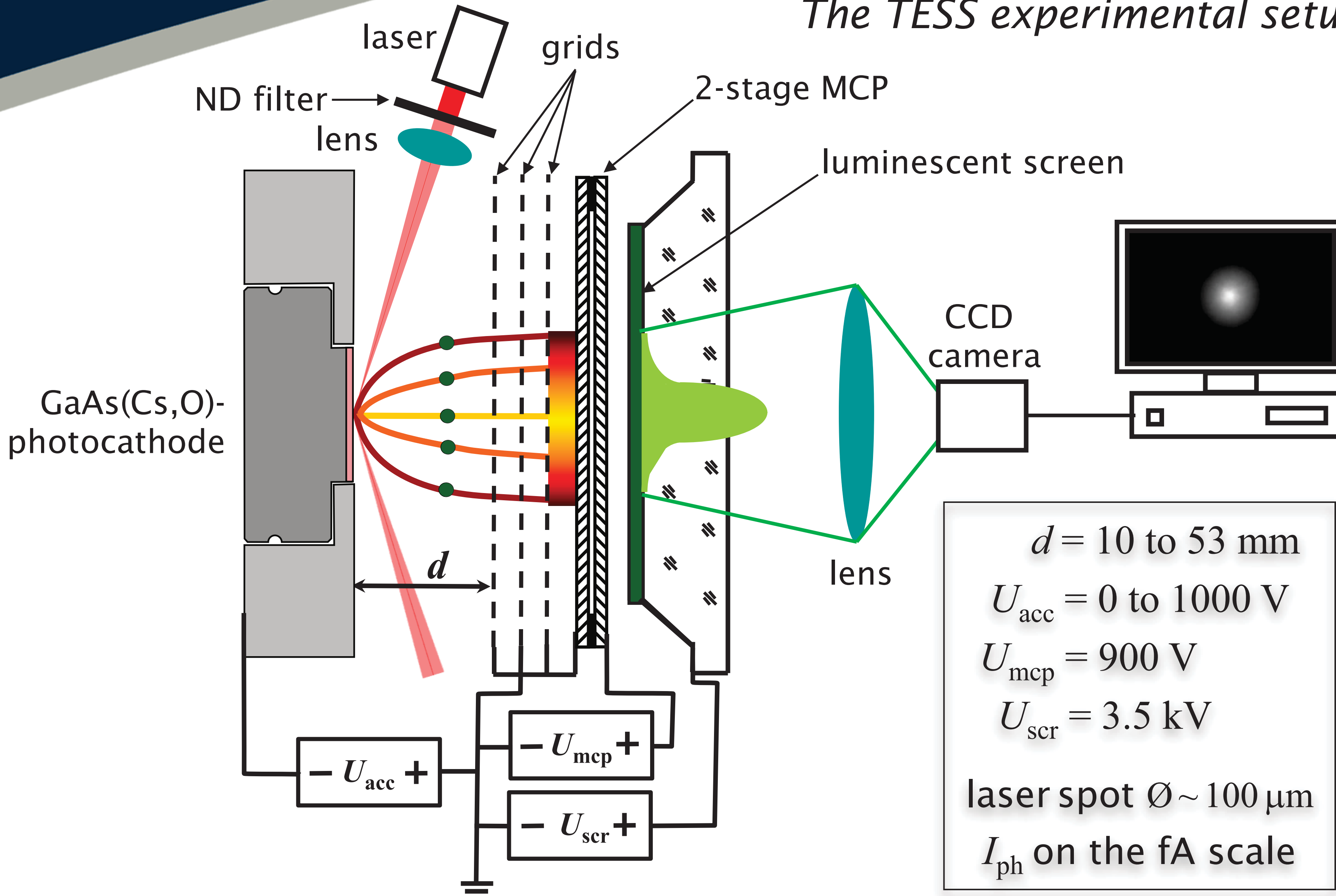
Increasing beam brightness:
The intrinsic energy of NEA GaAs photocathodes

- 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

Increasing beam brightness:
The TESS experimental setup



$d = 10$ to 53 mm

$U_{acc} = 0$ to 1000 V

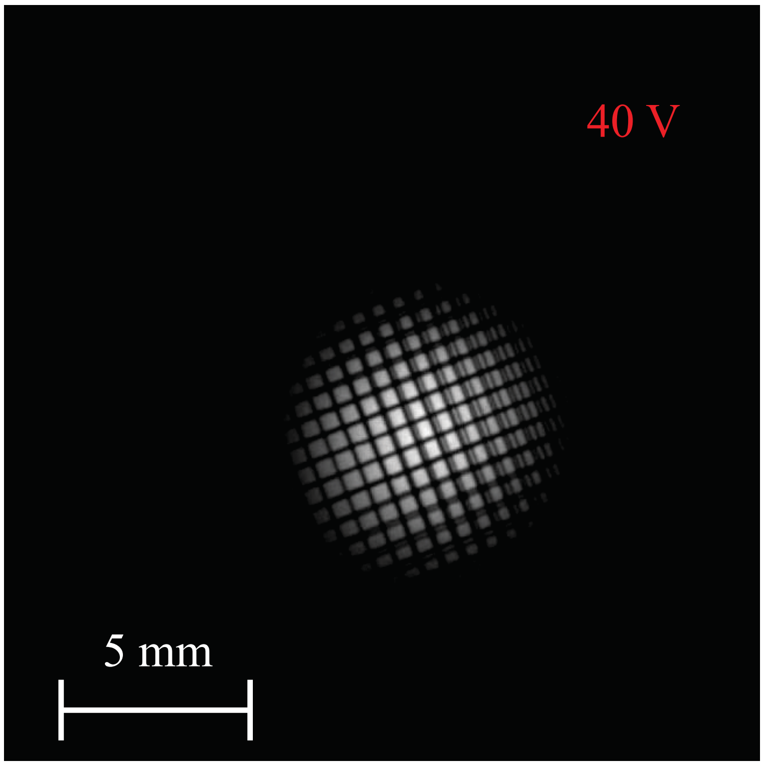
$U_{mcp} = 900$ V

$U_{scr} = 3.5$ kV

laser spot Ø ~ 100 μm

I_{ph} on the fA scale

TESS Commissioning:
TEDC measurements at
different accelerating voltages



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

$T = 300$ K

17.06.2013 p-GaAs(Cs,O) photocathode

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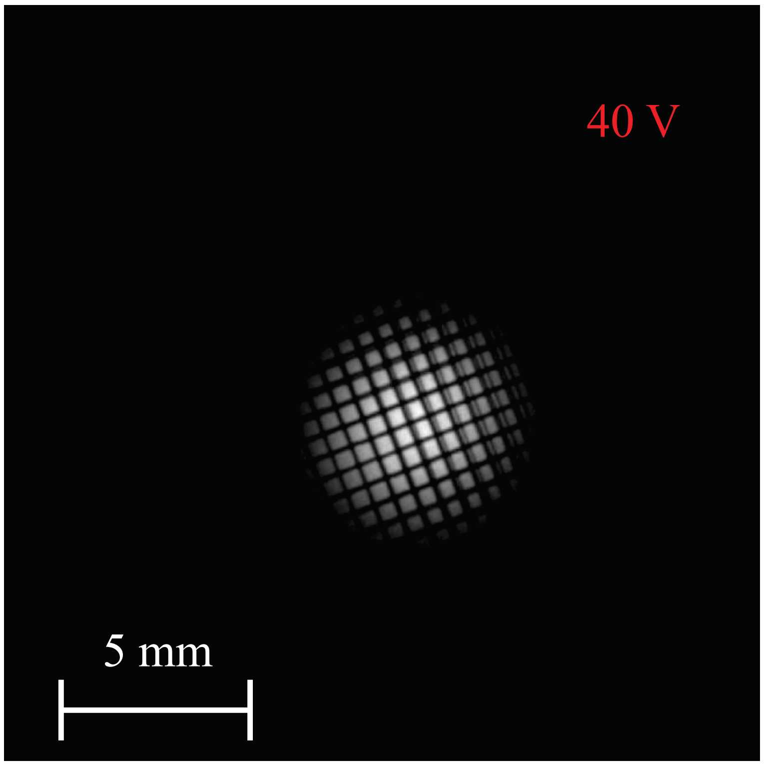
TESS Commissioning:
TEDC measurements at different accelerating voltages



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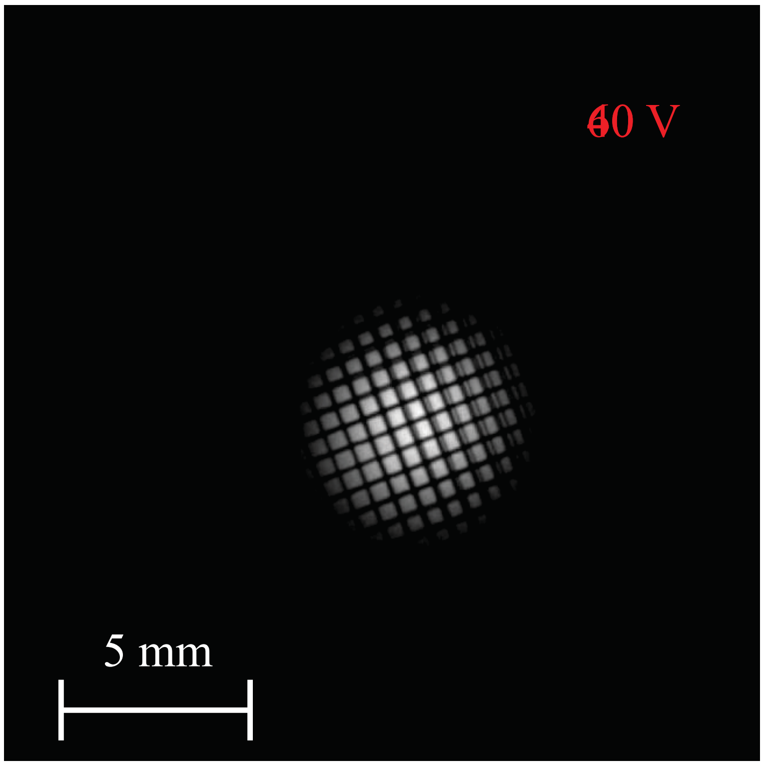

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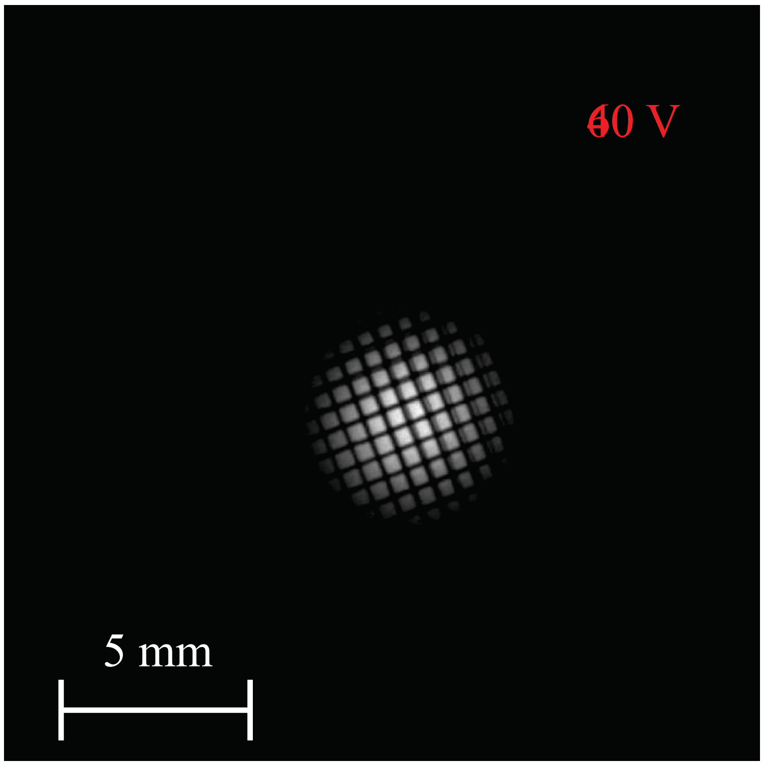

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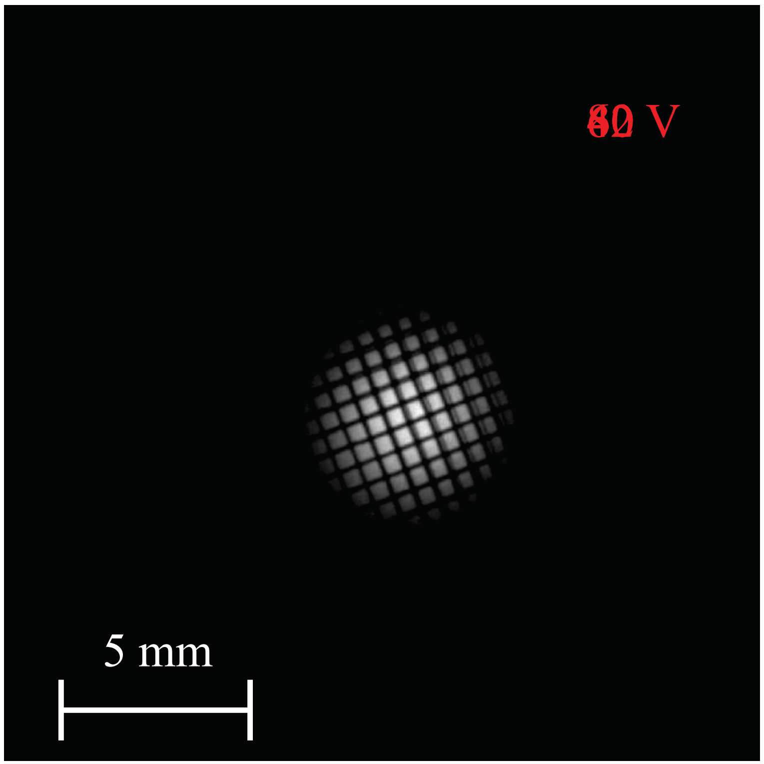

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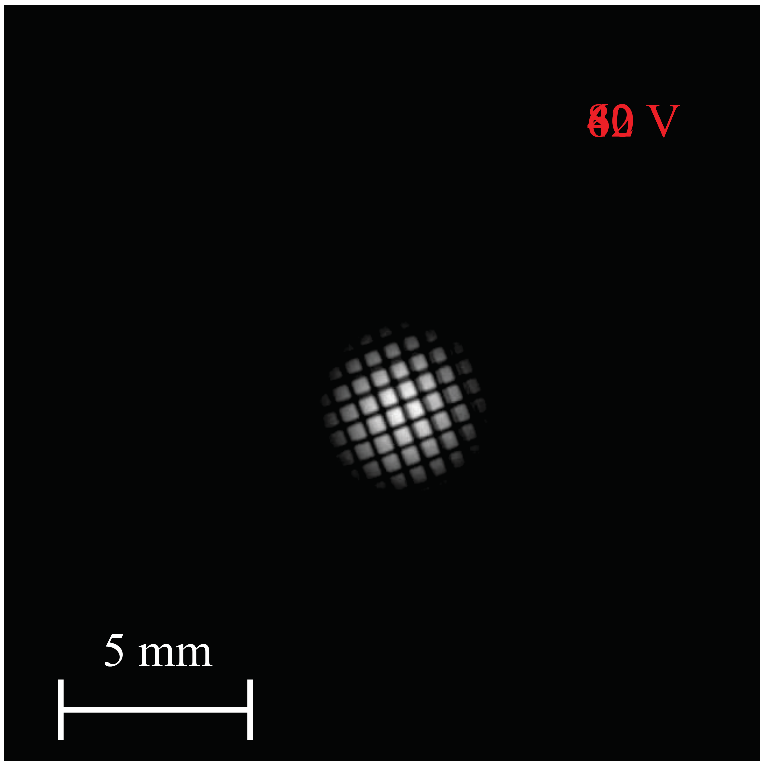

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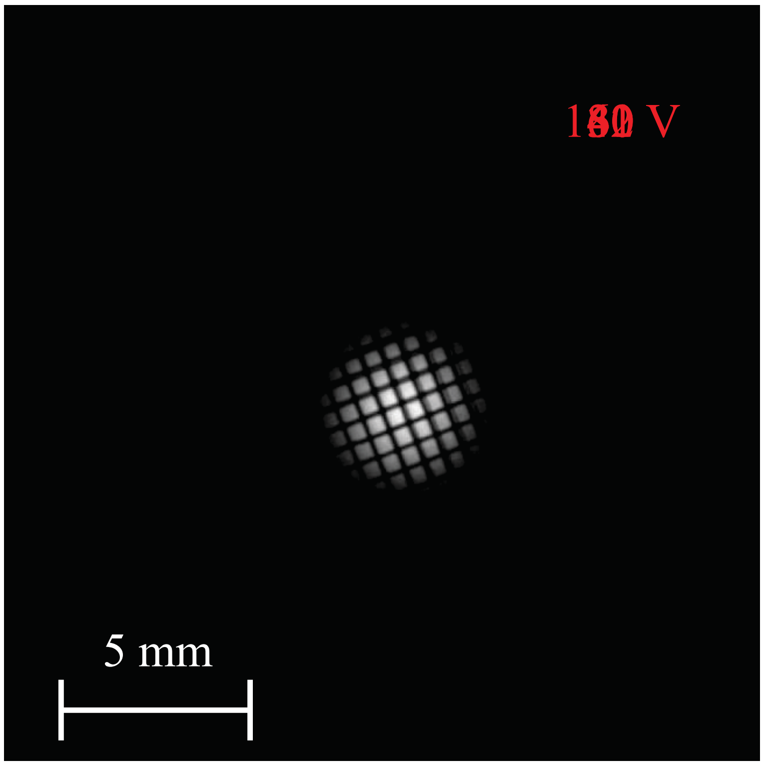

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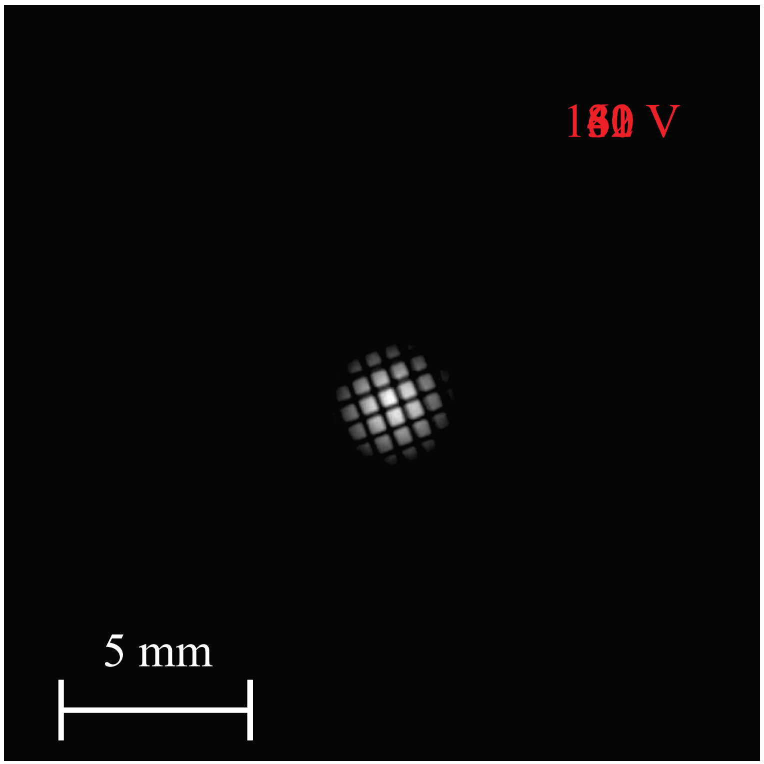

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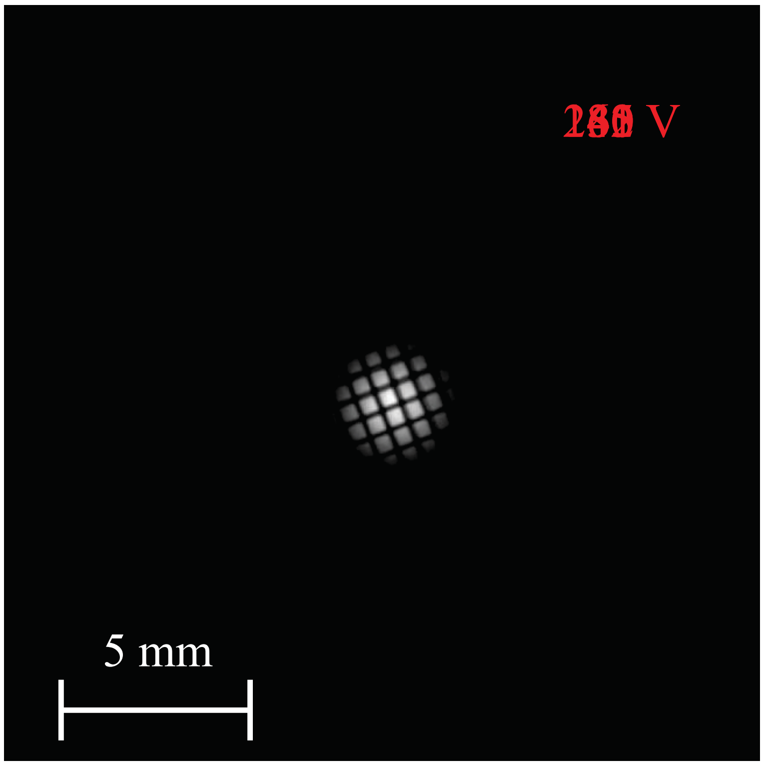

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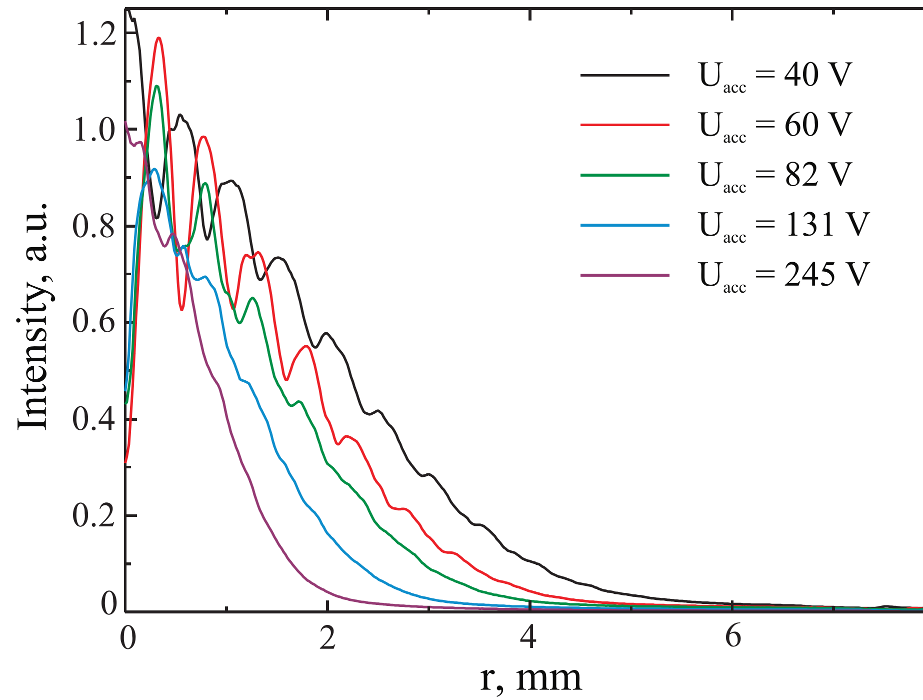
Screen luminescence profiles



$$\tau = d \times \sqrt{\frac{2\, m_e}{e\, U_{acc}}} \Rightarrow r_2 = r \times (U_{acc}/40)^{1/2}$$

17.06.2013 p-GaAs(Cs,O) photocathode

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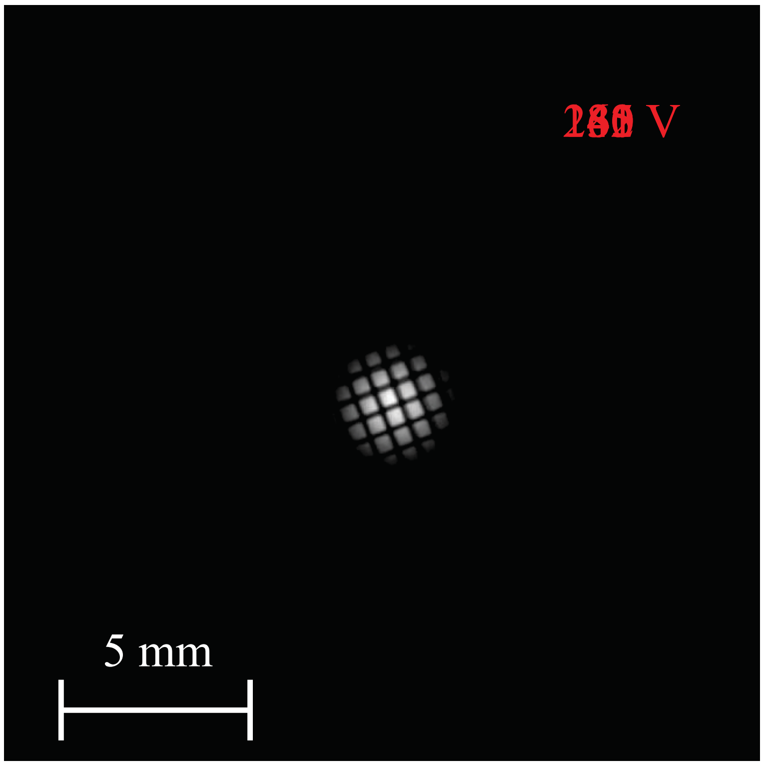
TEDC measurements at different accelerating voltages



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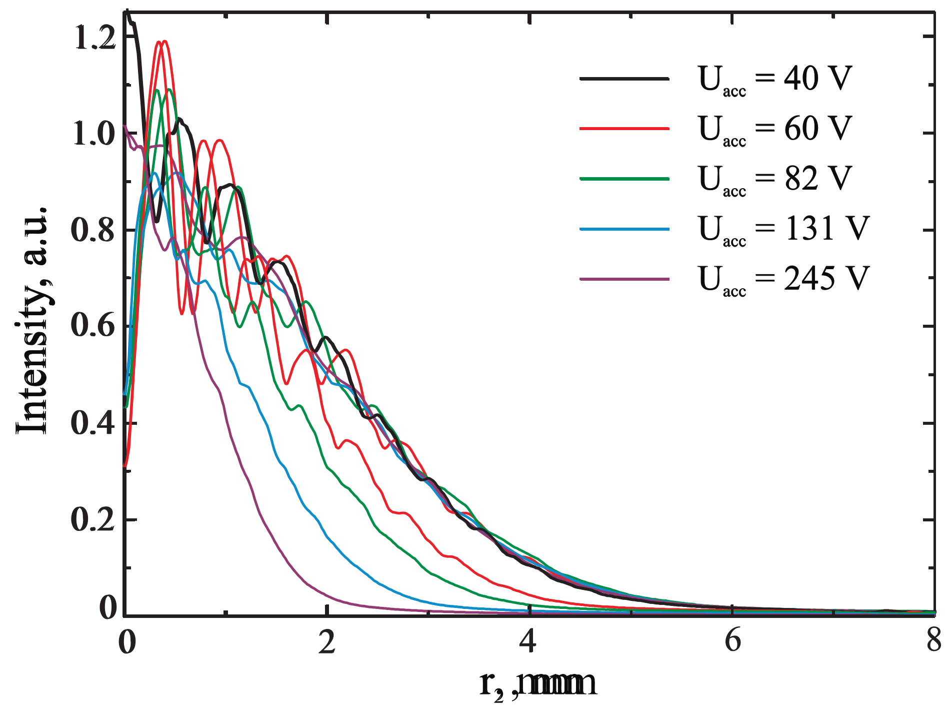

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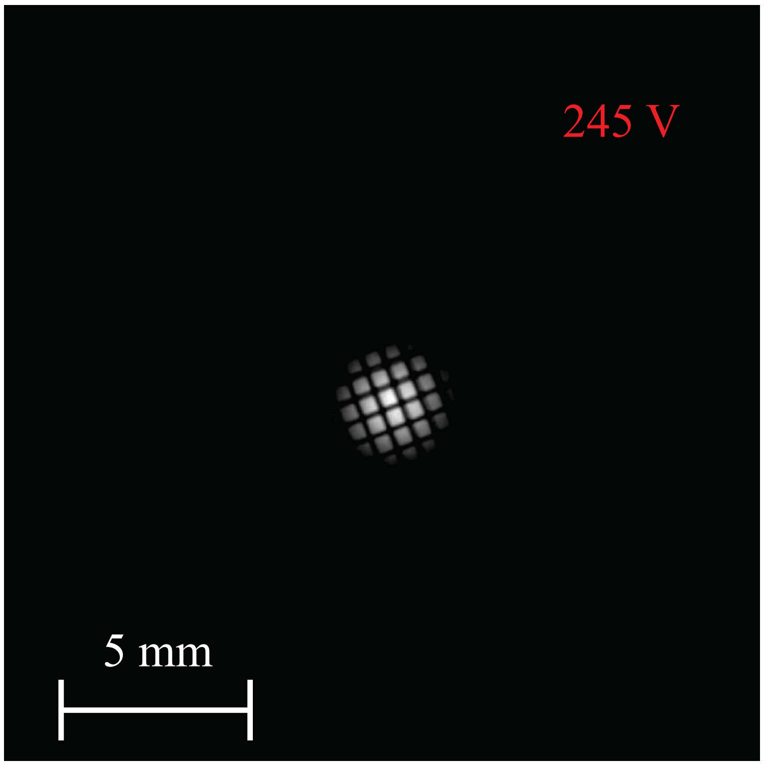

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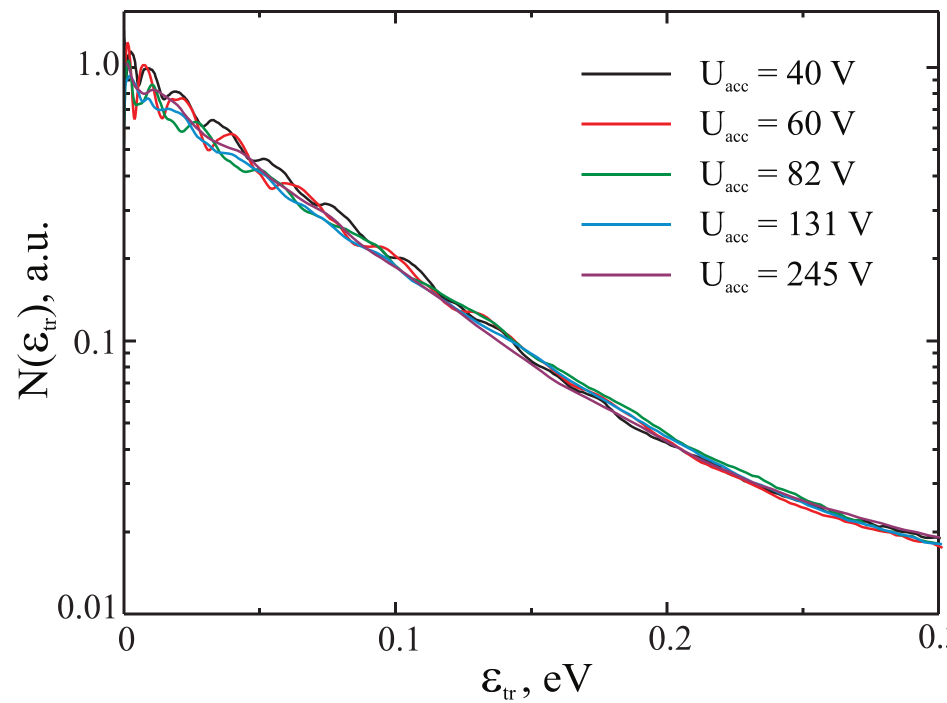
Transverse energy distribution profiles



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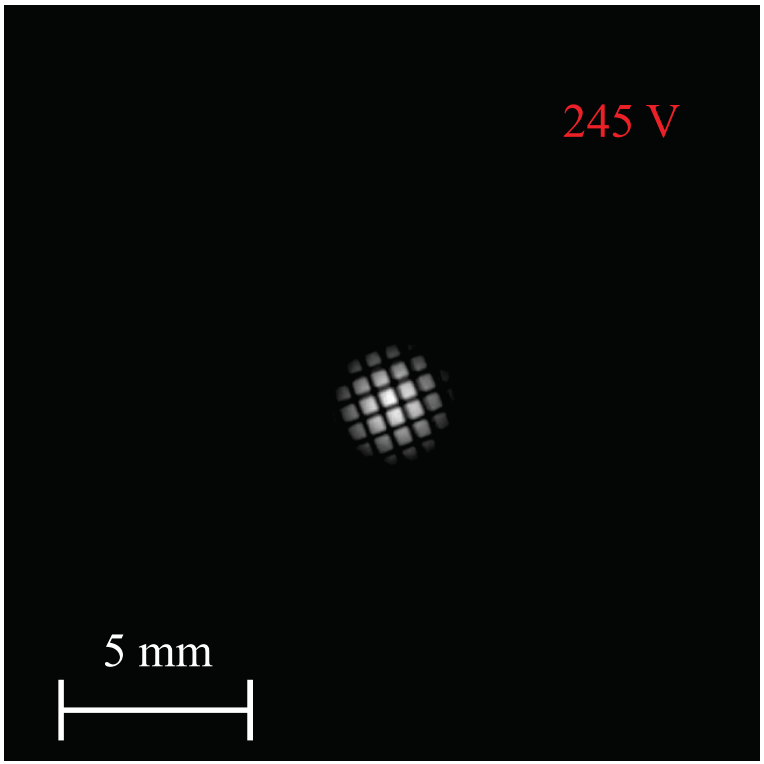

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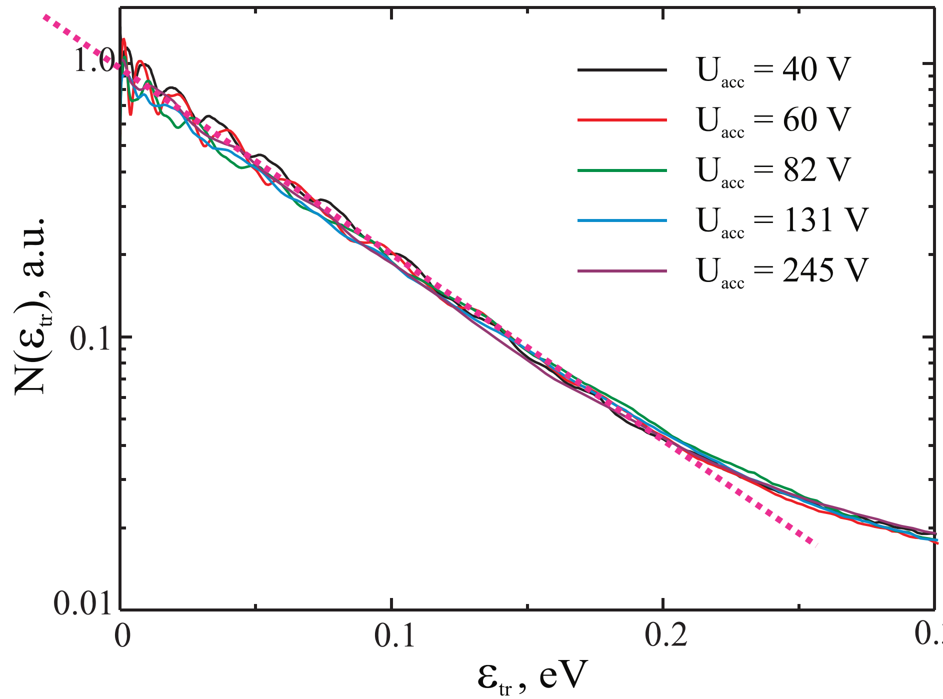

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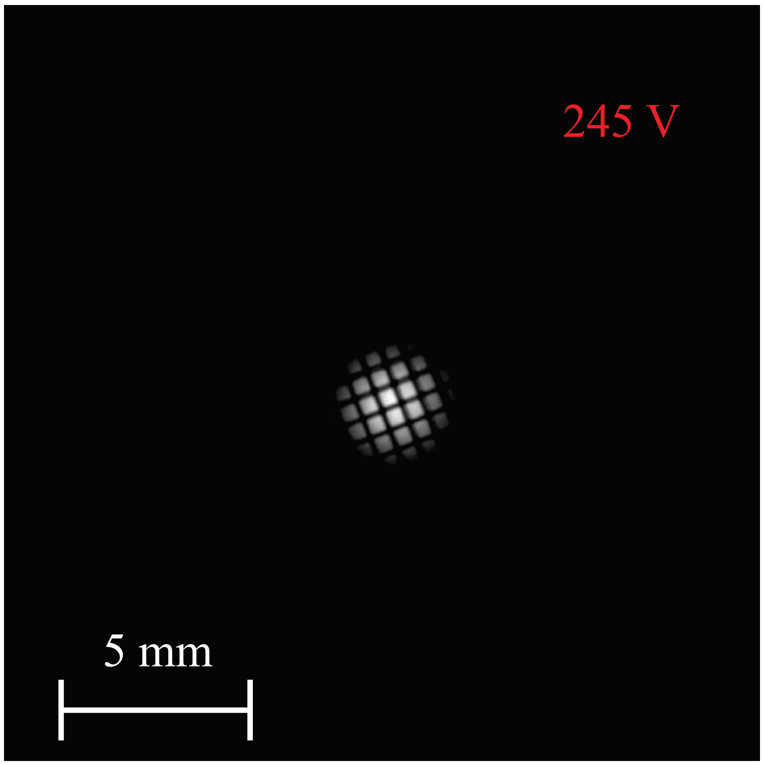

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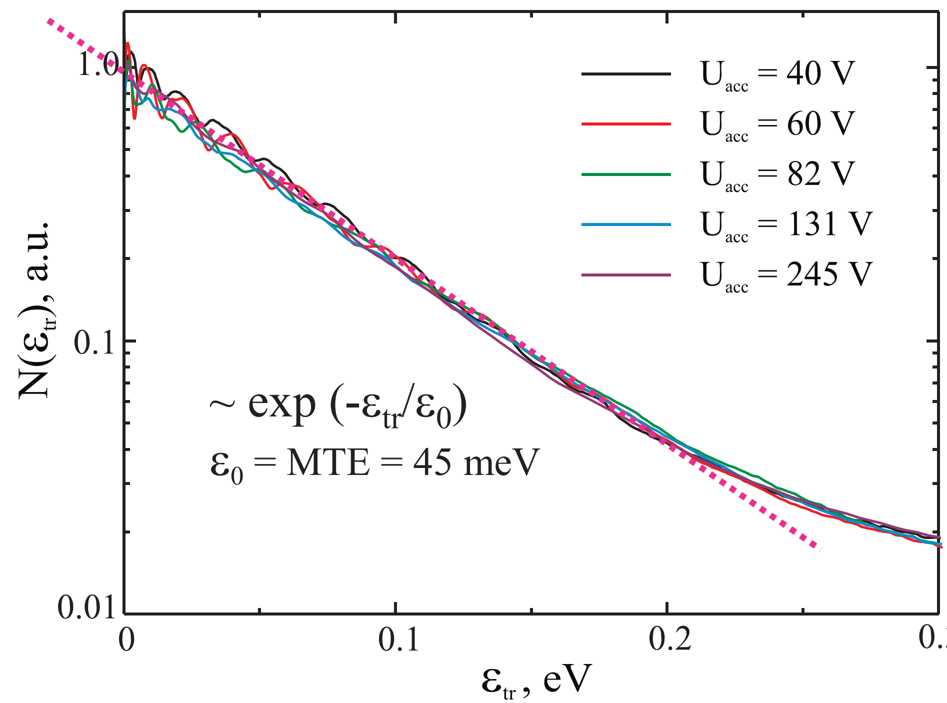

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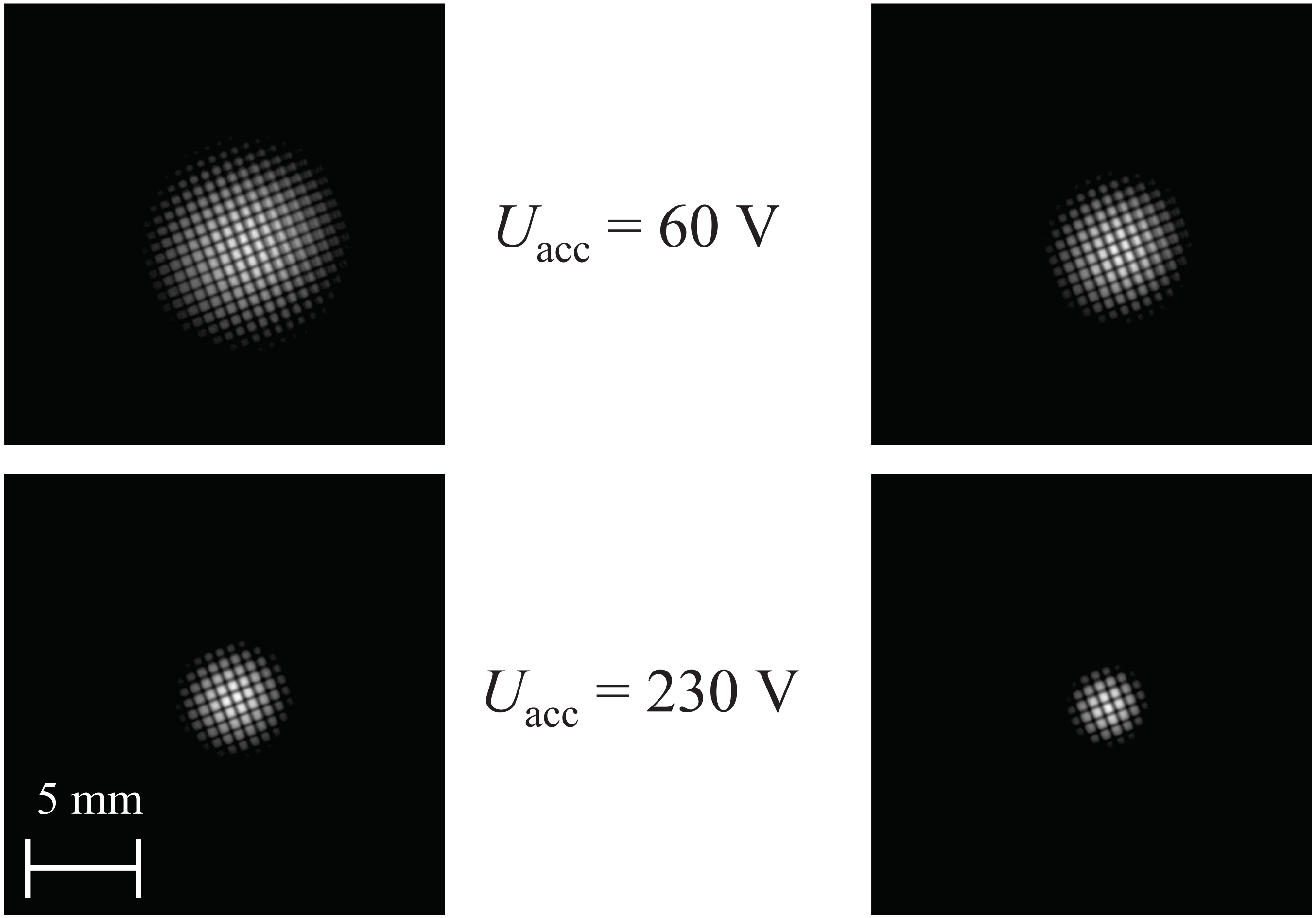
TESS Commissioning:
TEDC measurements with different wavelengths of light

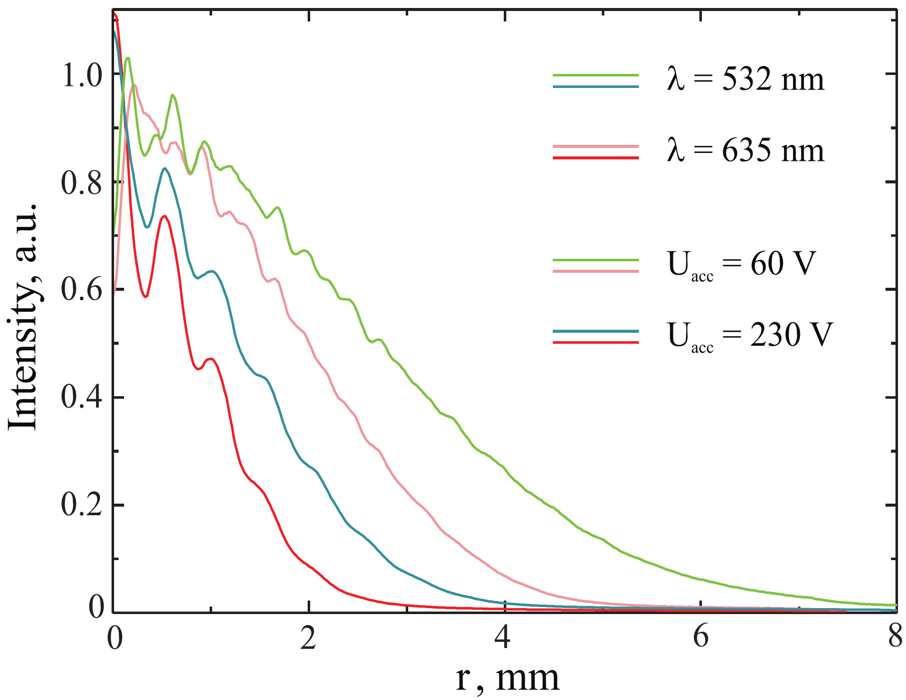
$\lambda = 532$ nm $\qquad\qquad$ $\lambda = 635$ nm



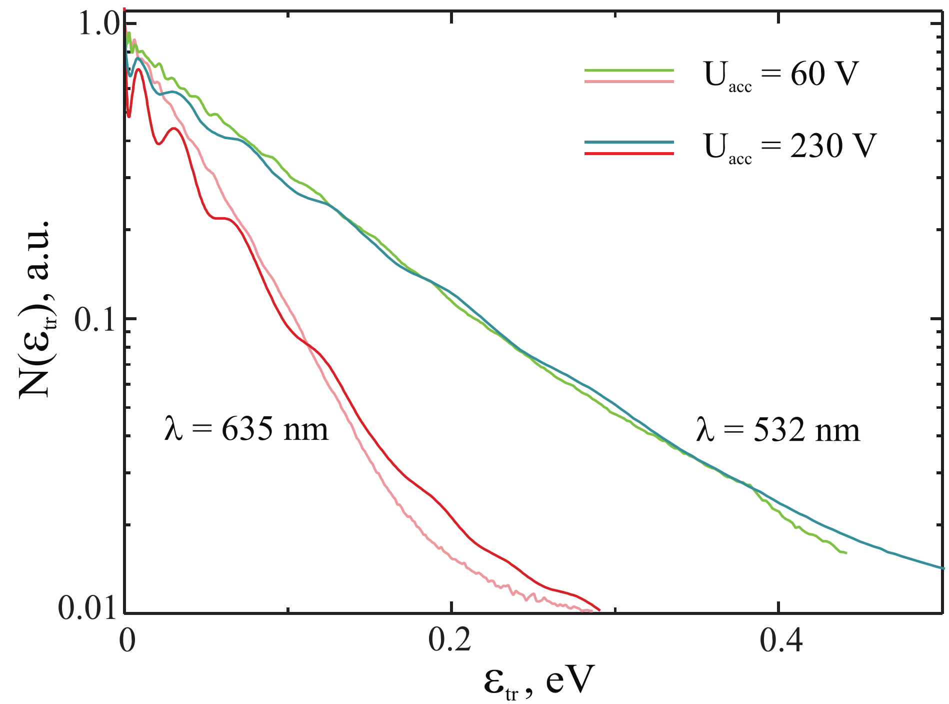
21.06.2013 p-GaAs(Cs,O) photocathode $d \approx 43$ mm $T = 300$ K

TESS Commissioning:
Summary of TEDC results

Screen luminescence profiles



Transverse energy distribution profiles



21.06.2013 p-GaAs(Cs,O) photocathode *d* ≈ 43 mm *T* = 300 K

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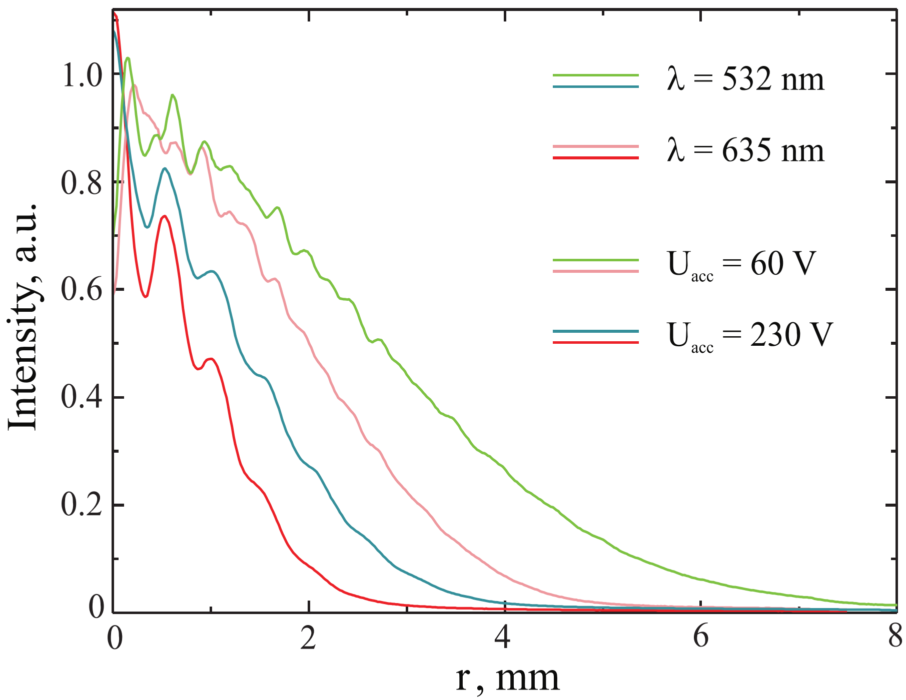

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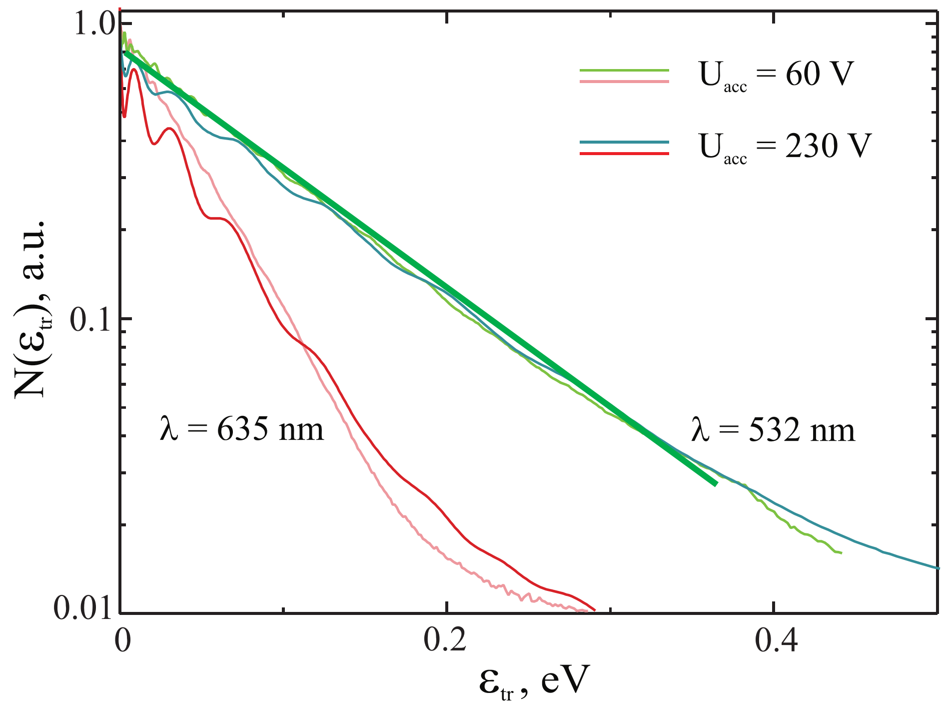

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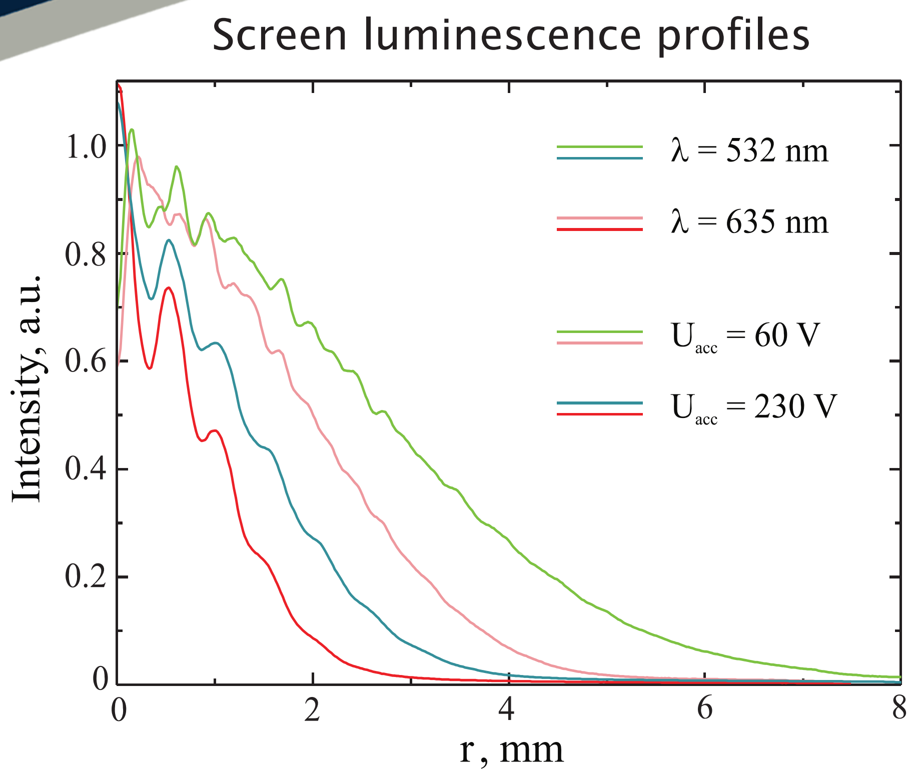

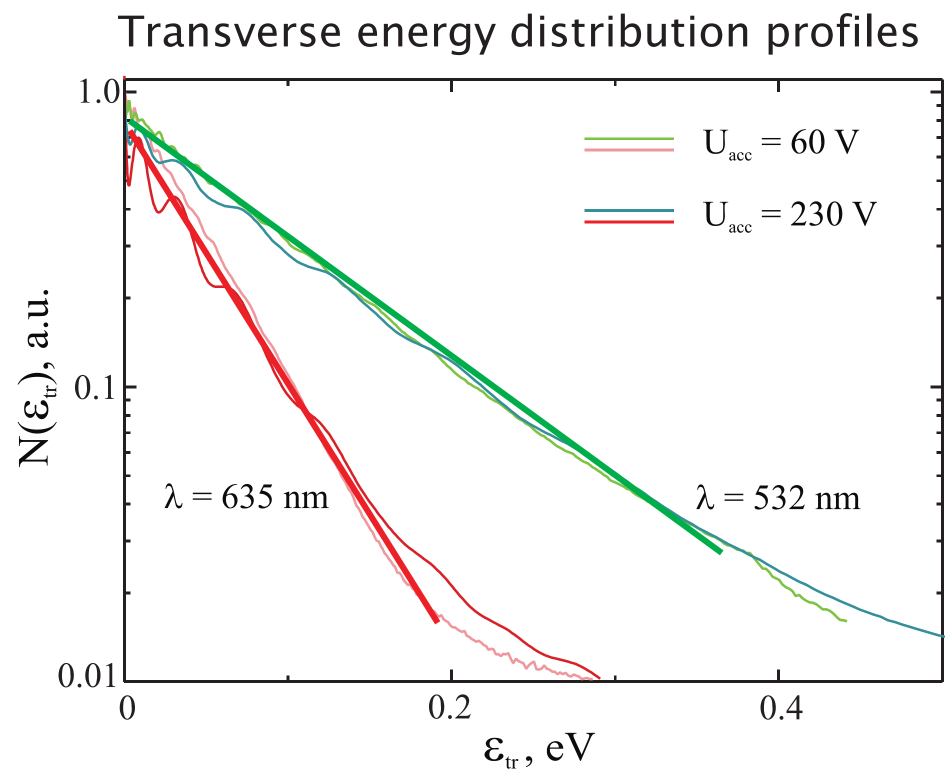

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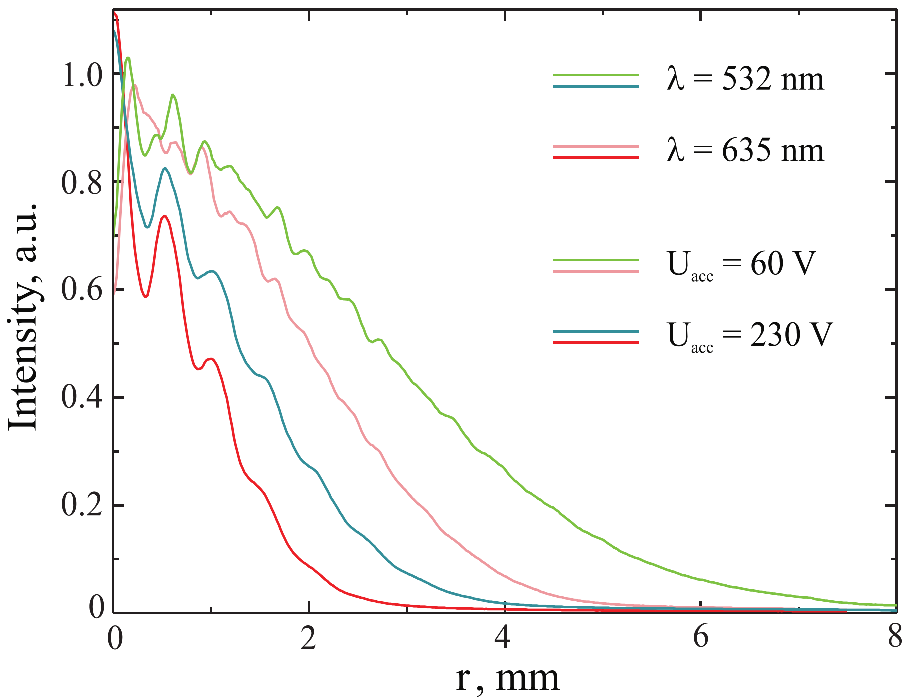

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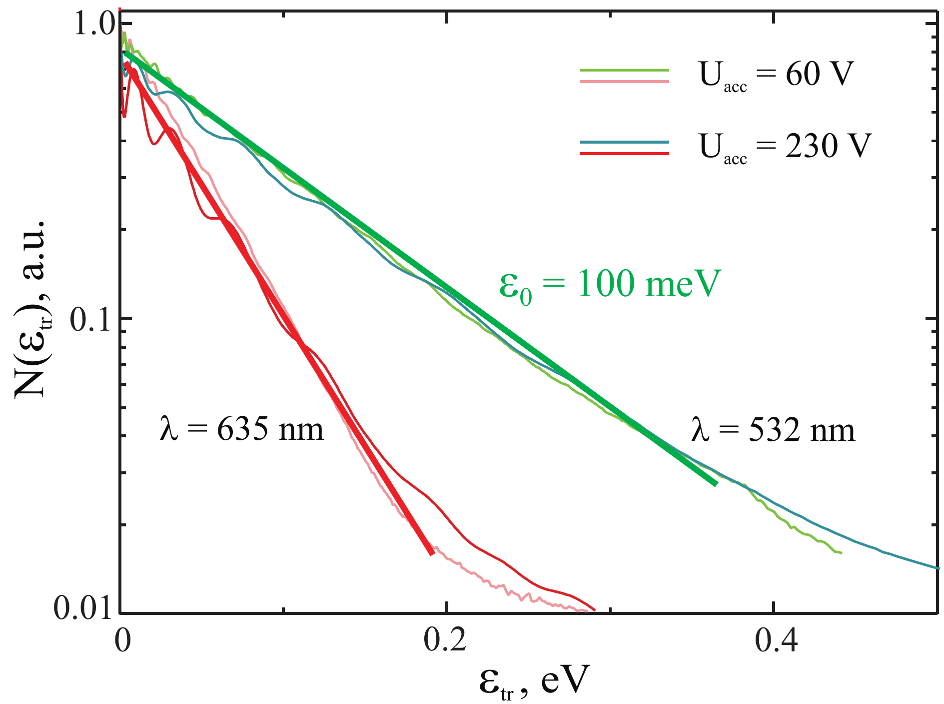

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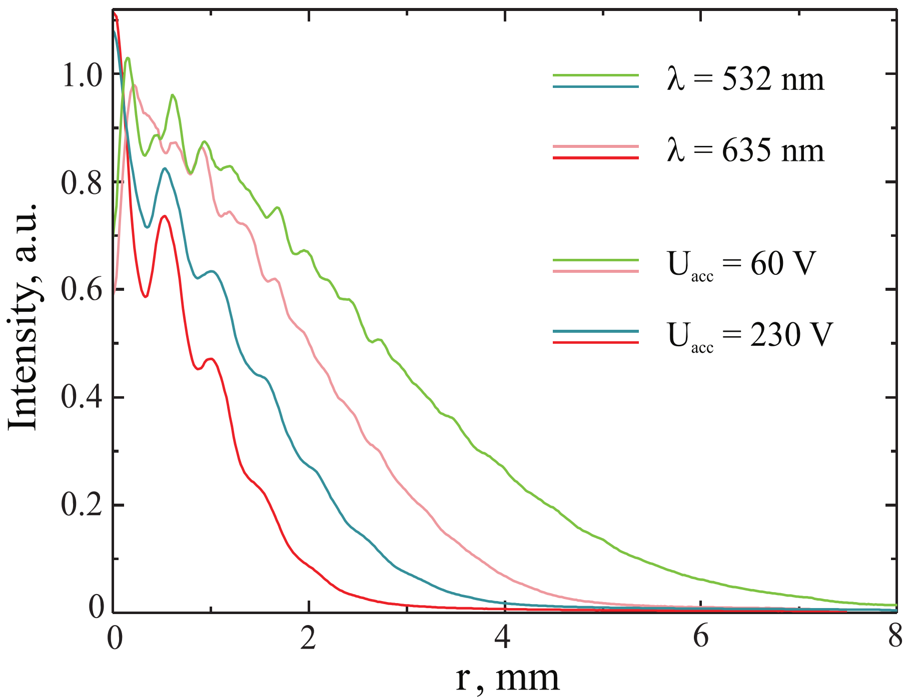

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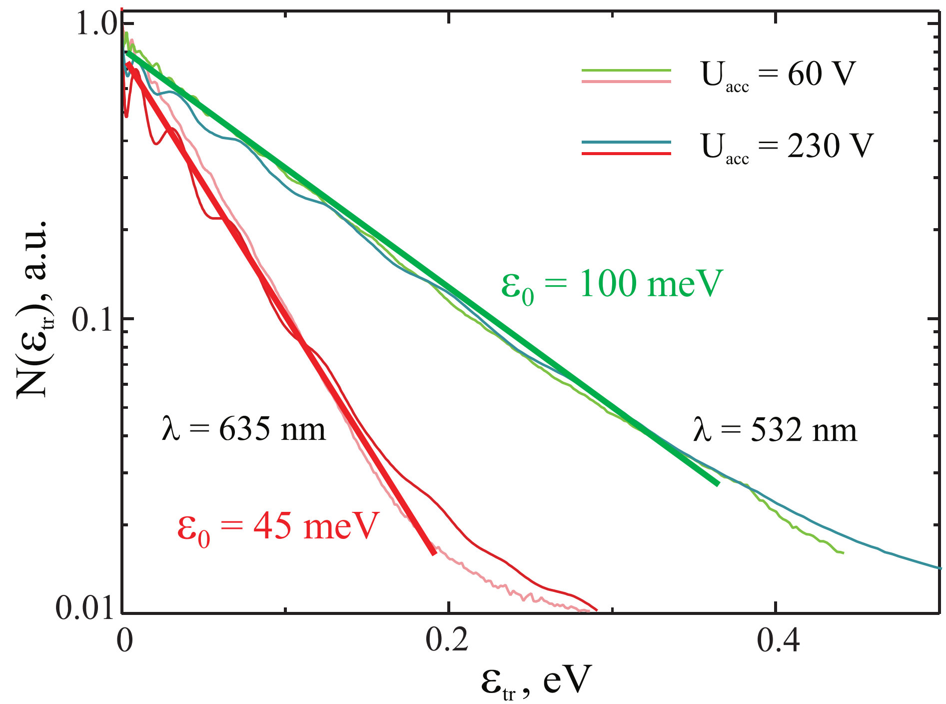

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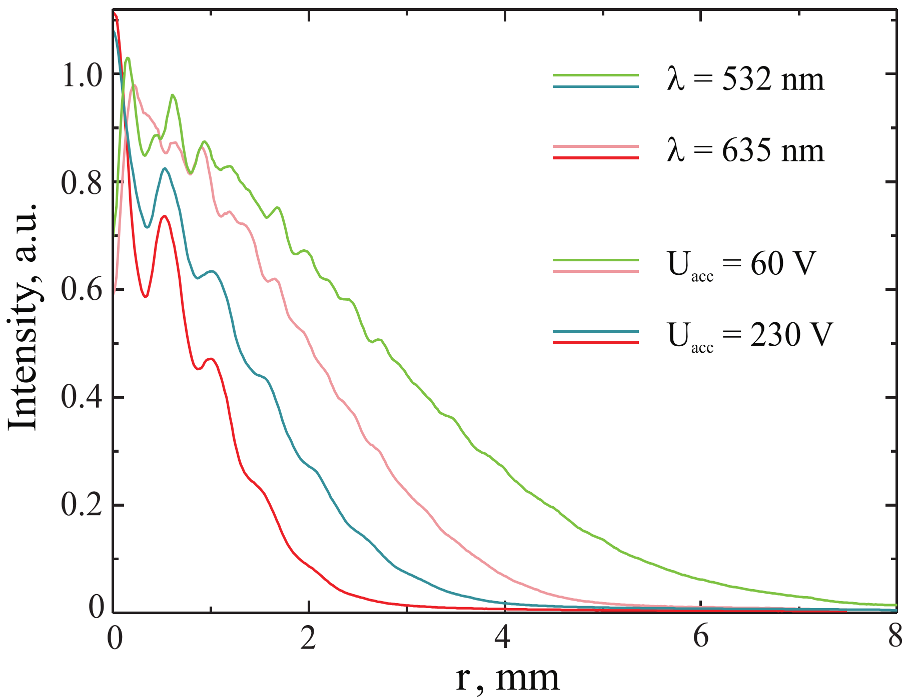

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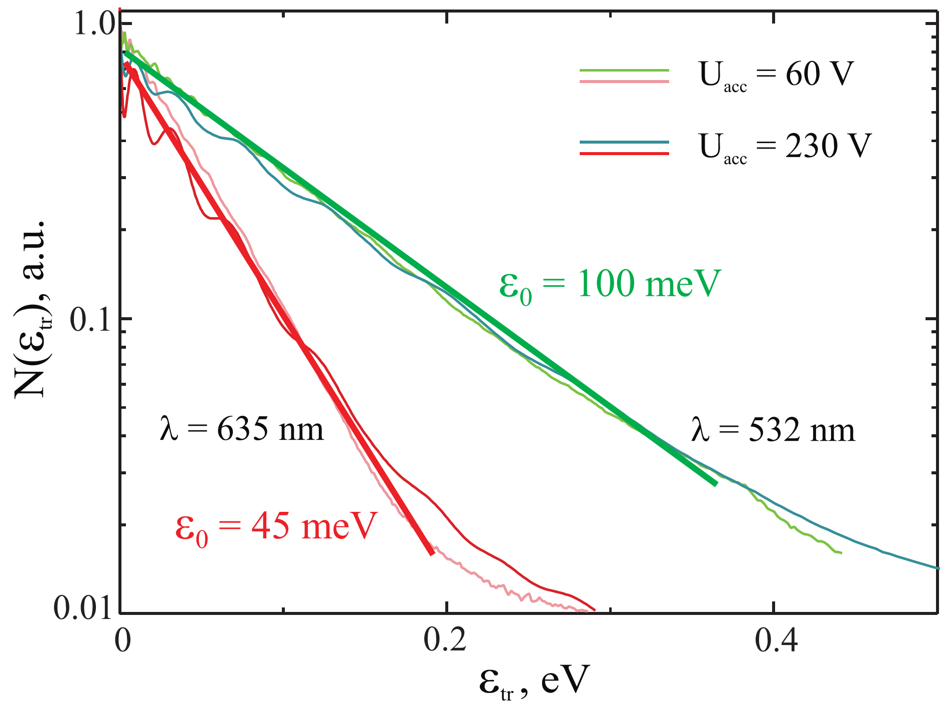

$MTE_{635} = 45 \pm 7$ meV

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

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

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Part 2:

GaAs Photocathode R&D: Energy spread measurements and the nature of the activated p-GaAs(Cs,O) activation layer

- Overview of the TESS experimental system
- The nature of the p-GaAs(Cs,O) activation layer

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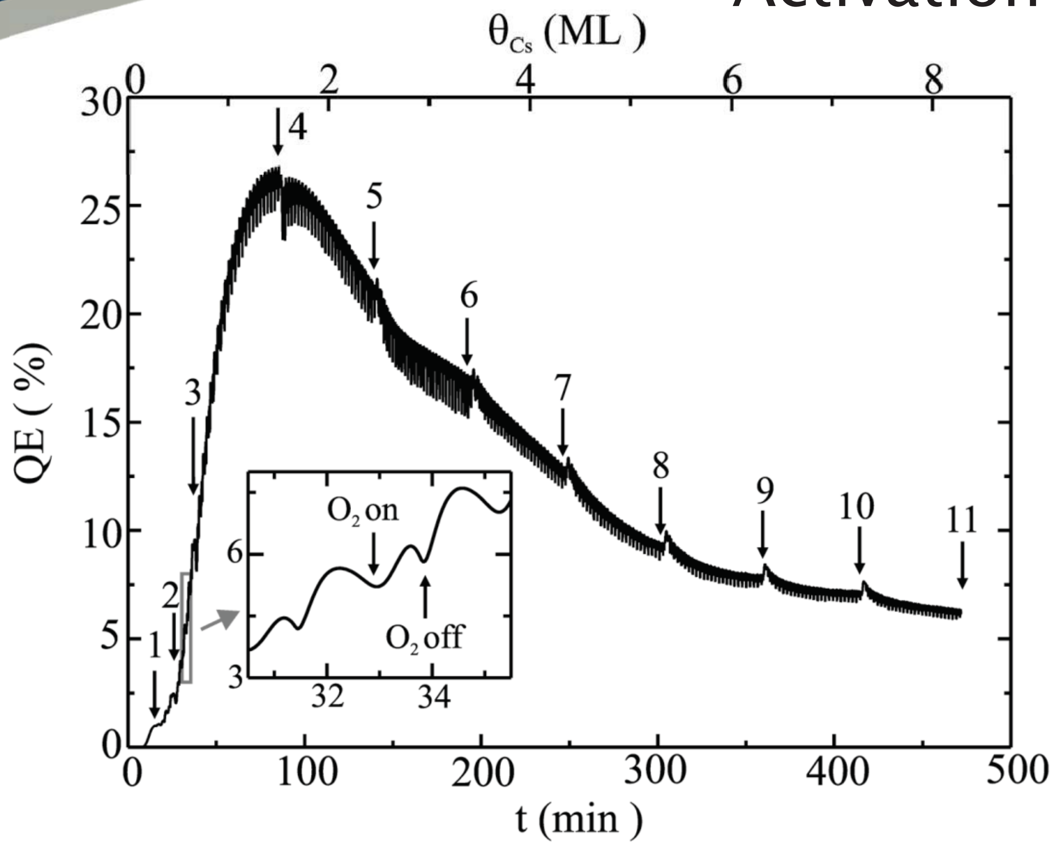
p-GaAs (Cs,O):
Activation Layer Model

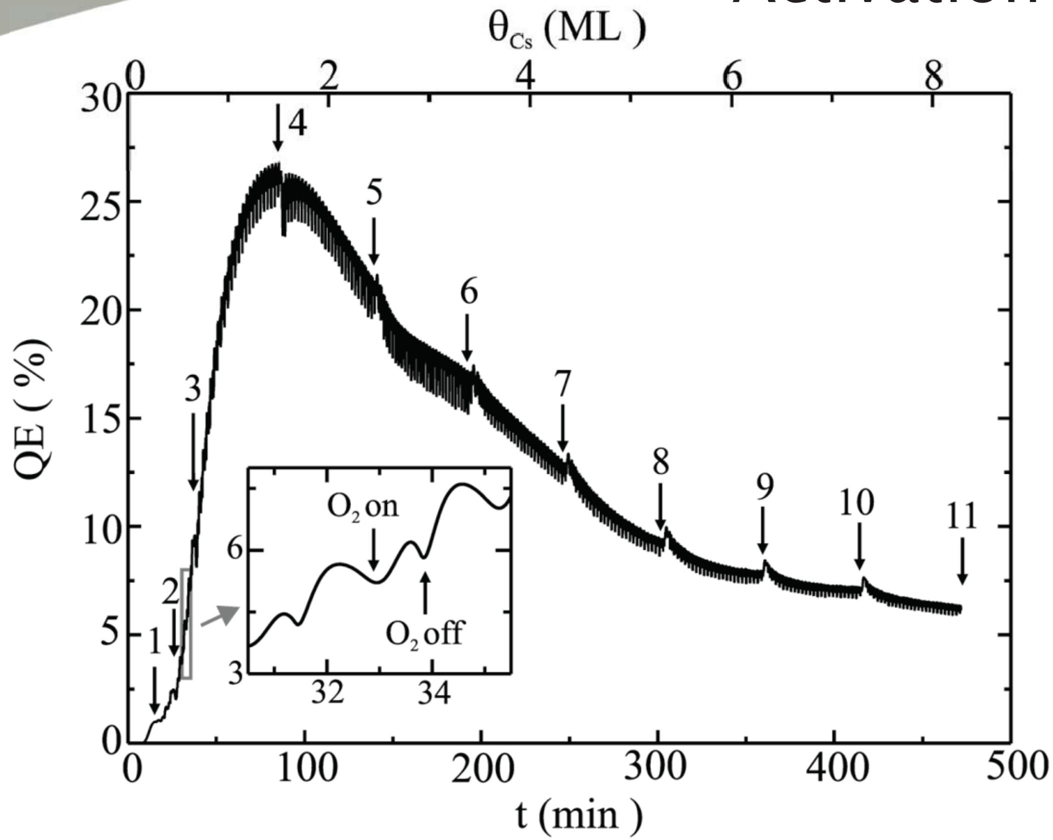
- The growth of GaAs photocathodes and photoelectron scattering phenomena in this material are well-understood
- The atomic and electronic properties of the p-GaAs(Cs,O)-vacuum interface layer remain the focus of much research
- Several layer models proposed, with two likely candidates:
  - The ***Dipole Layer*** (DL) model, applicable to '*thin*' layers
  - The ***Hetero Junction*** (HJ) model, applicable to '*thick*' layers
- p-GaAs (Cs,O)-photocathodes with reasonably high *Q.E.* can be created with (Cs,O)-layers conforming to both models
- The domains of validity for these models have not been defined
- This has hindered our understanding of the interrelations between the *intrinsic characteristic parameters* of the (Cs,O)-layers and the *performance characteristics* of p-GaAs(Cs,O)-photocathodes

p-GaAs (Cs,O):
Activation Layer Model



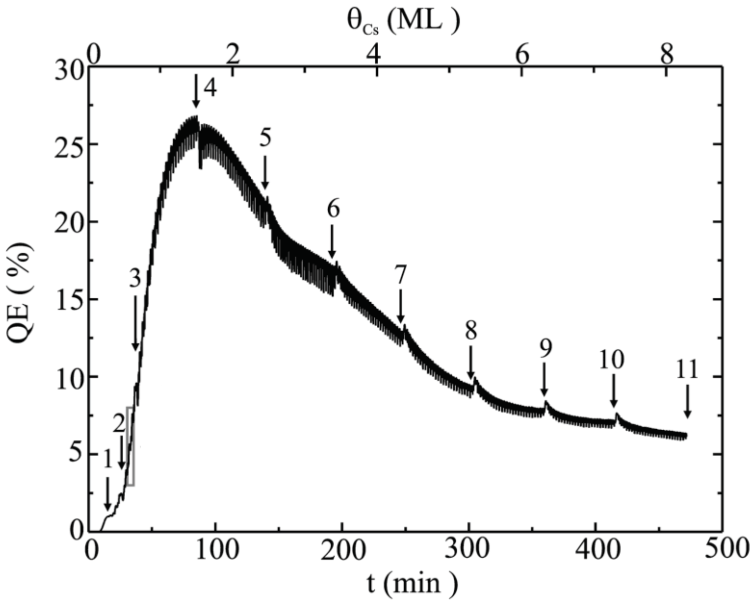
- Photocathode grown by MOCVD on a (001) GaAs substrate
- Activation under *near-equilibrium* conditions with illumination at 635 nm
- First Cs peak reached in 25 minutes. Deposition rate is 0.02 ML/min
- O_2 applied when photocurrent (J_{ph}) fallen to 98% of maximum value

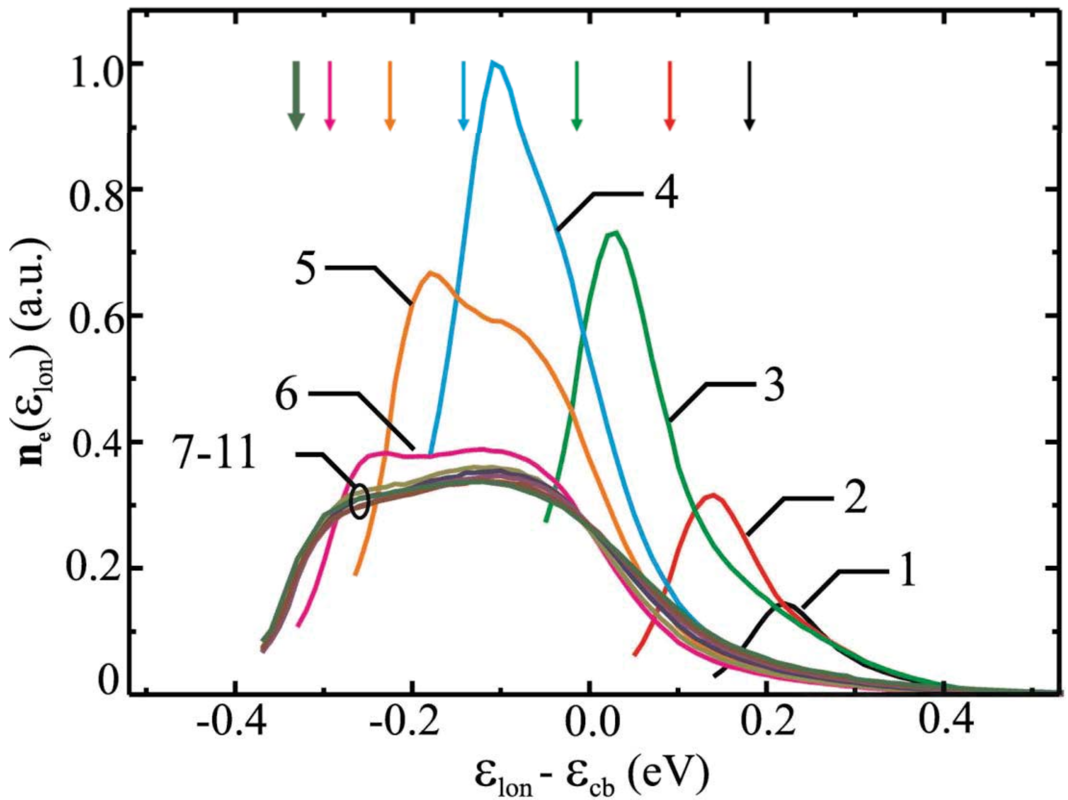
p-GaAs (Cs,O): Activation Layer Model



- Activation interrupted periodically to measure the longitudinal energy spread (LEDC), $n_e^i(\varepsilon_{lon})$ at positions i = 1 to 11 using a parallel plate analyser to record photocurrent (J_{ph}) as a function of retarding voltage (U_{ret})

p-GaAs (Cs,O):
Activation Layer Model

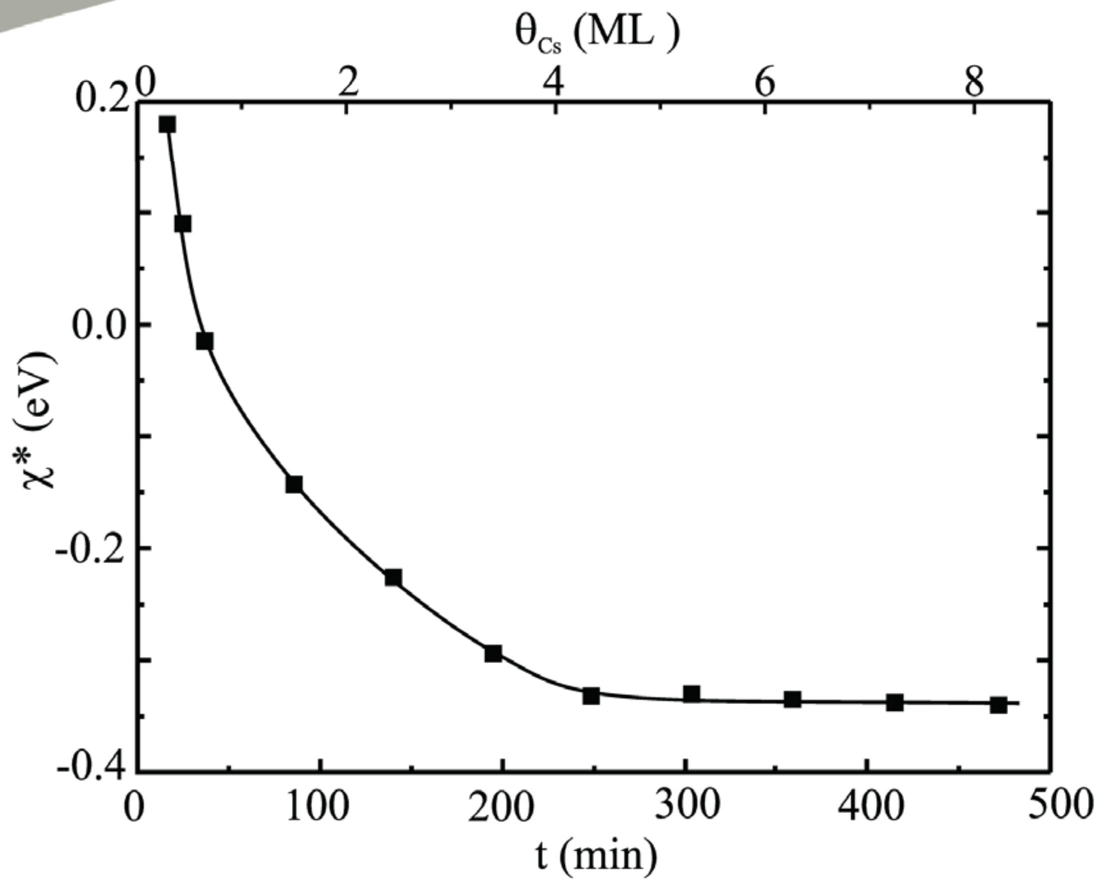




- Activation interrupted periodically to measure the longitudinal energy spread (LEDC), $n_e^i(\varepsilon_{lon})$ at positions $i = 1$ to 11 using a parallel plate analyser to record photocurrent (J_{ph}) as a function of U_{ret}
- ε_{lon} varies according to $Q.E.(t)$, but is constant after measurement #7

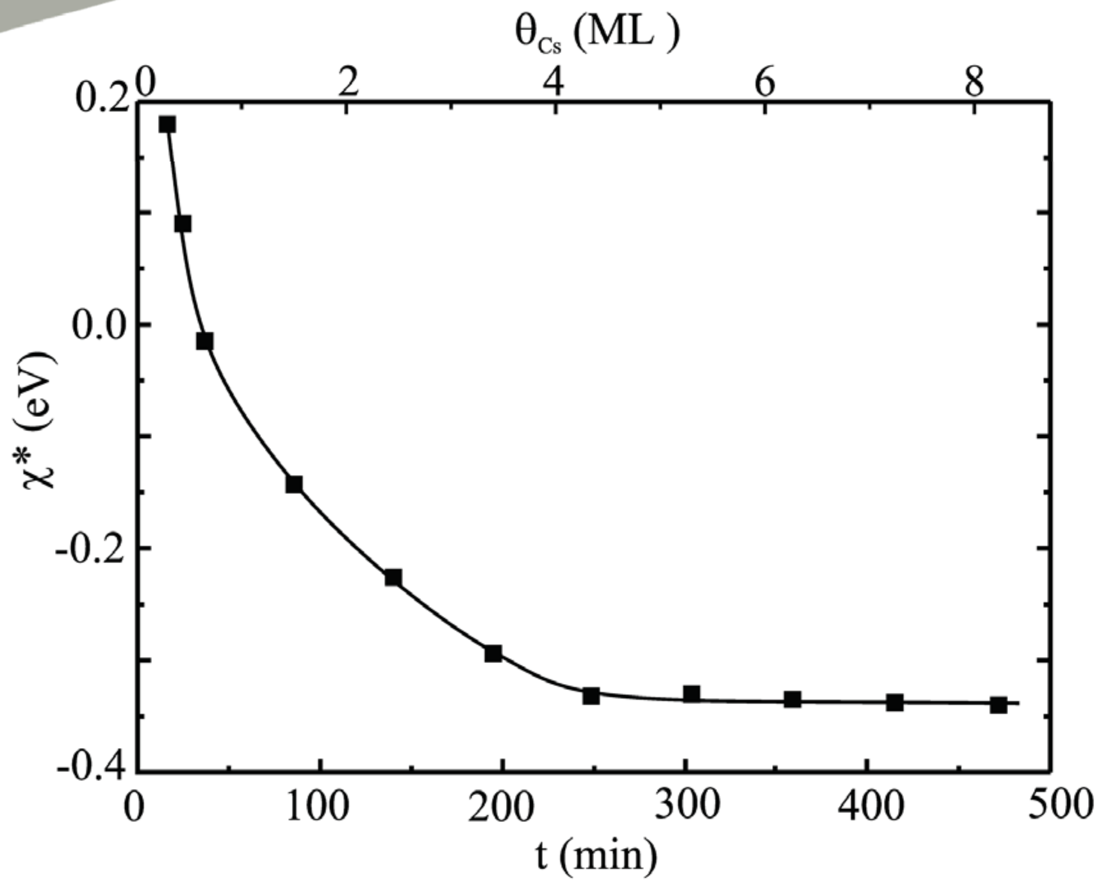
p-GaAs (Cs,O):

Activation Layer Model



- Effective electron affinity, $\chi^* = \varepsilon_{vac} - \varepsilon_{cb}$, calculated for points 1 to 11
  - ε_{vac} coincides with the electron energy where $\delta n_e(\varepsilon_{lon})/\delta\varepsilon_{lon}$ is maximum
  - $\varepsilon_{cb} = e \cdot U_{ret}$ where $\delta^2 J_{ph}(U_{ret})/\delta U_{ret}^2$ has its minimum value

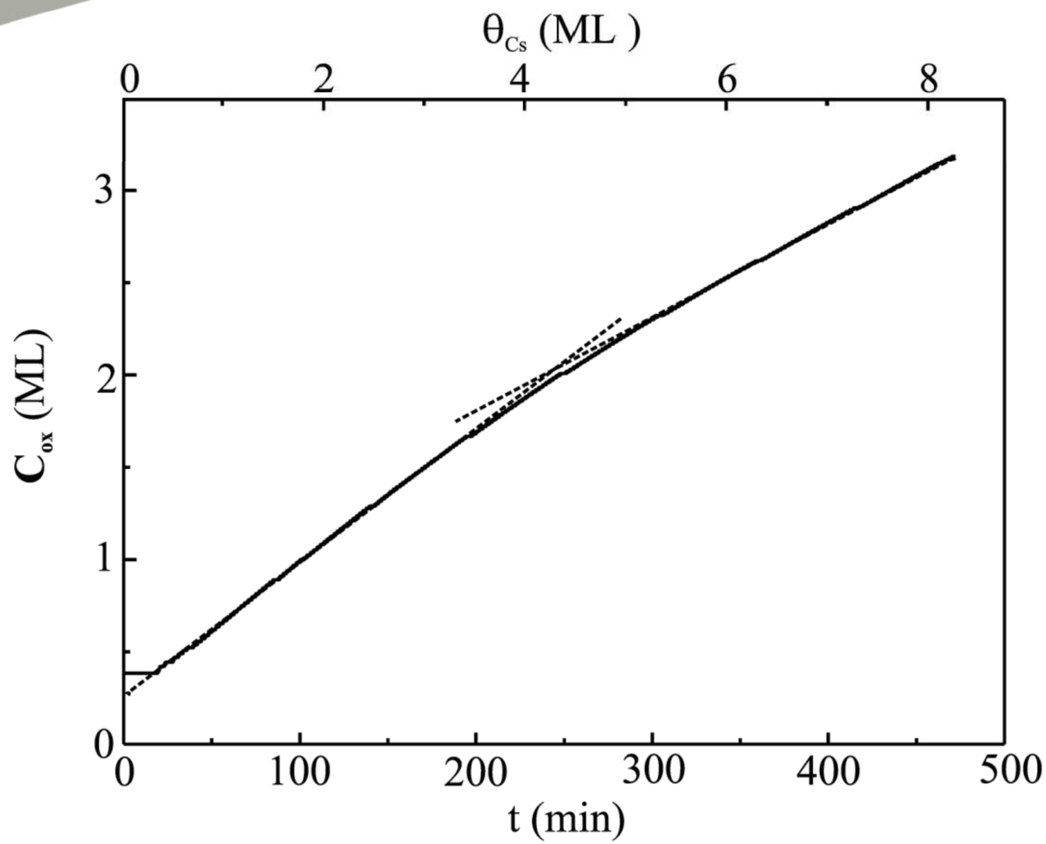
p-GaAs (Cs,O):
Activation Layer Model



Electron affinity reaches its minimum value after 250 minutes.

The data show that the energy diagram for the p-GaAs(Cs,O)-surface remains un-changed for $t > 250$ min, ***as predicted by the HJ model***.

p-GaAs (Cs,O):
Activation Layer Model



Evolution of the oxygen content (C_{ox}) within the (Cs,O)-layer during activation.
The dotted lines are linear extrapolations of the measured (solid) curves.

The data show that the energy diagram for the p-GaAs(Cs,O)-surface remains un-changed for $t > 250$ min, ***as predicted by the HJ model***.

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p-GaAs (Cs,O):
Activation Layer Model

APPLIED PHYSICS LETTERS **106**, 183501 (2015)

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p-GaAs(Cs,O)-photocathodes: Demarcation of domains of validity for practical models of the activation layer

V. V. Bakin,[1] K. V. Toropetsky,[1] H. E. Scheibler,[1] A. S. Terekhov,[1,a)] L. B. Jones,[2] B. L. Militsyn,[2] and T. C. Q. Noakes[2]
[1]*Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue, Novosibirsk 630090, Russia*
[2]*STFC Daresbury Laboratory, ASTeC and the Cockcroft Institute, Warrington WA4 4AD, United Kingdom*

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The (Cs,O)-activation procedure for p-GaAs(Cs,O)-photocathodes was studied with the aim of demarcating the domains of validity for the two practical models of the (Cs,O)-activation layer: The dipole layer (DL) model and the heterojunction (HJ) model. To do this, the photocathode was activated far beyond the normal maximum of quantum efficiency, and several photocathode parameters were measured periodically during this process. In doing so, the data obtained enabled us to determine the domains of validity for the DL- and HJ-models, to define more precisely the characteristic parameters of the photocathode within both of these domains and thus to reveal the peculiarities of the influence of the (Cs,O)-layer on the photoelectron escape probability. [http://dx.doi.org/10.1063/1.4919447]

……… for the full story, download the open access paper.

TESS :
Planned future work

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TESS :
Planned future work

- Continue to work with the Institute of Semiconductor Physics
  - Repeat the activation layer experiment at Daresbury measuring the ***transverse energy spread*** with the TESS
- Construction of a vacuum suitcase (nearly complete)
- Building a collaboration with the source group at CERN
- Studies of the energy spread from NEA GaAs photocathodes subjected to programmed degradation
- Energy spread measurements from cooled GaAs photocathodes
- Integration of a broadband light source with the TESS system
- Studies of energy spread from metal photocathodes

TESS :
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Thank you!

The ASTeC photocathode team:

Dr. Boris Militsyn
Dr. Tim Noakes
Dr. Lee Jones
Dr. Keith Middleman
Dr. Reza Valizadeh
Dr. Mark Surman
Prof. Elaine Seddon (consultant)

Sonal Mistry (Ph.D. student)
Paolo Pizzol (Ph.D. student)
Stuart Wilde (Ph.D. student)
Bruno Camino (Ph.D. student)

Ryan Cash (engineering)
Barry Fell (engineering)

The ISP photocathode team:

Prof. Alexander Terekhov
Dr. Heinrich Scheibler

Dr. Konstantin Toropetsky
Dr. Vasiliy Bakin

lee.jones@stfc.ac.uk