Simulation of X-Ray photo-electron detection by MCP

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GodParents Review

Emissive material: WO3

- Photon energy: 1 – 10 keV
- Thickness: 100-250 nm
- Density: 6.4 g/cc (Jeff Elam's experiment)
- Ionization energy: 506.3 eV (calculated)
- Calculated photon absorption ranges: 3.9e-5 cm (1 keV), 1.87e-3 cm (10 keV).
- Electron absorption energy: under investigation
- Photon absorption energy: under investigation
- QE is calculated as the number of PE leaving the surface of the material per photon: $\gamma = 10^{-4} – 10^{-3}$
- QE of glass

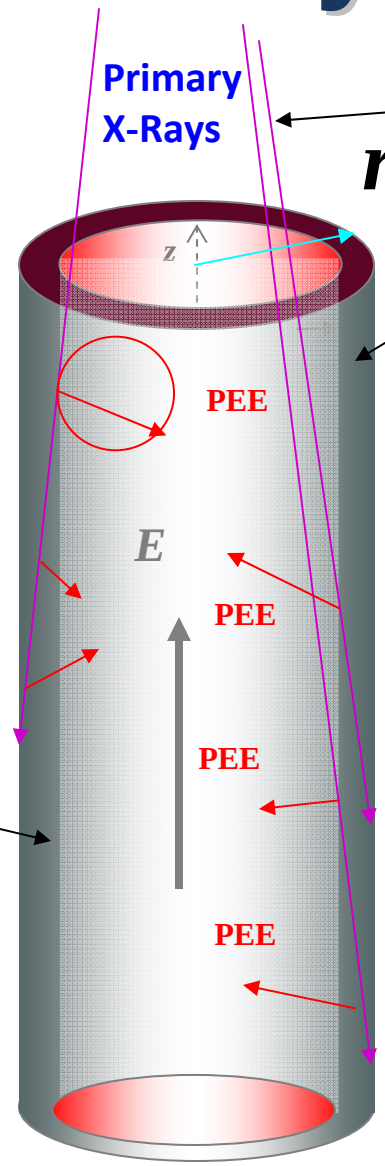
MCP for X-Ray detection

Cylindrical symmetry

r = 20 mm
Δr = 10-100 nm
Aspect ratio 60

Coating materials

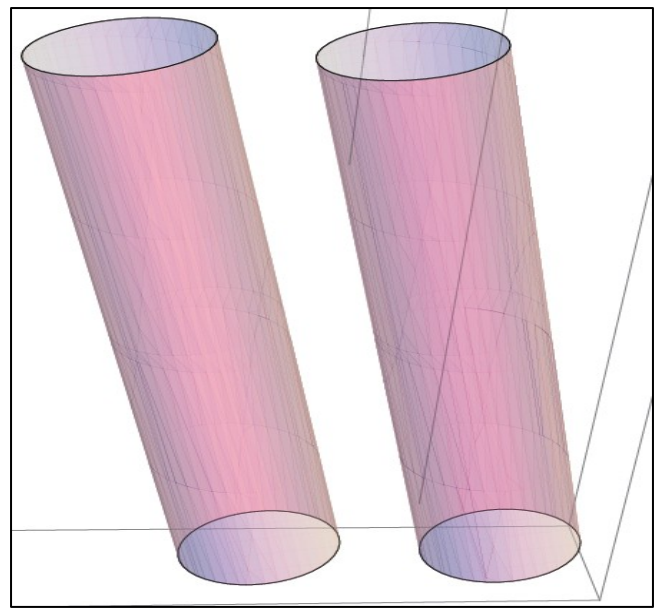
Al_2O_3+ZnO
WO_3+ZnO
WO_2+ZnO



X-Ray divergence is < 0.1 mrad (we can assume that they are parallel to the pore walls)

Δr = 10-100 nm

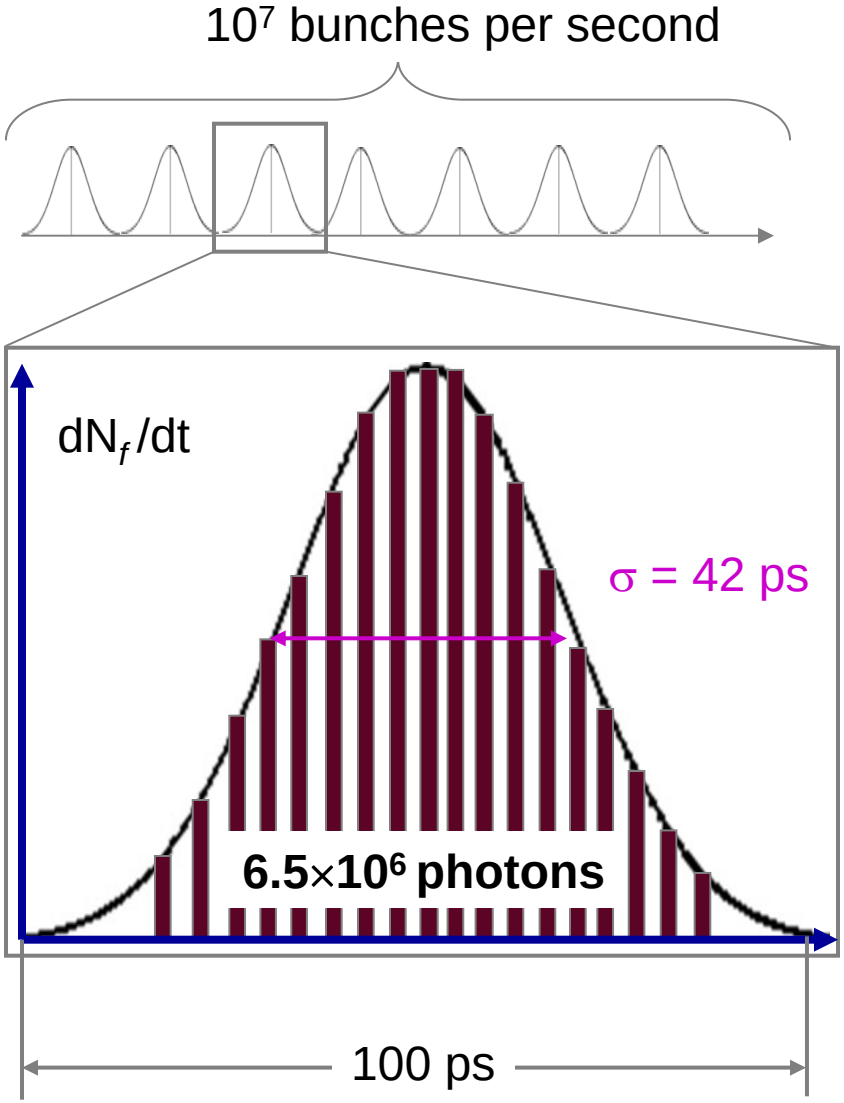
Biased pores



Photon flux

Photons are coming from synchrotron as bunches with the following flux:

- **6.5×10^{6} photons per bunch (f=6.5MHz)**
- **1×10^{7} bunches per second**
- **1×10^{13} photons per second**



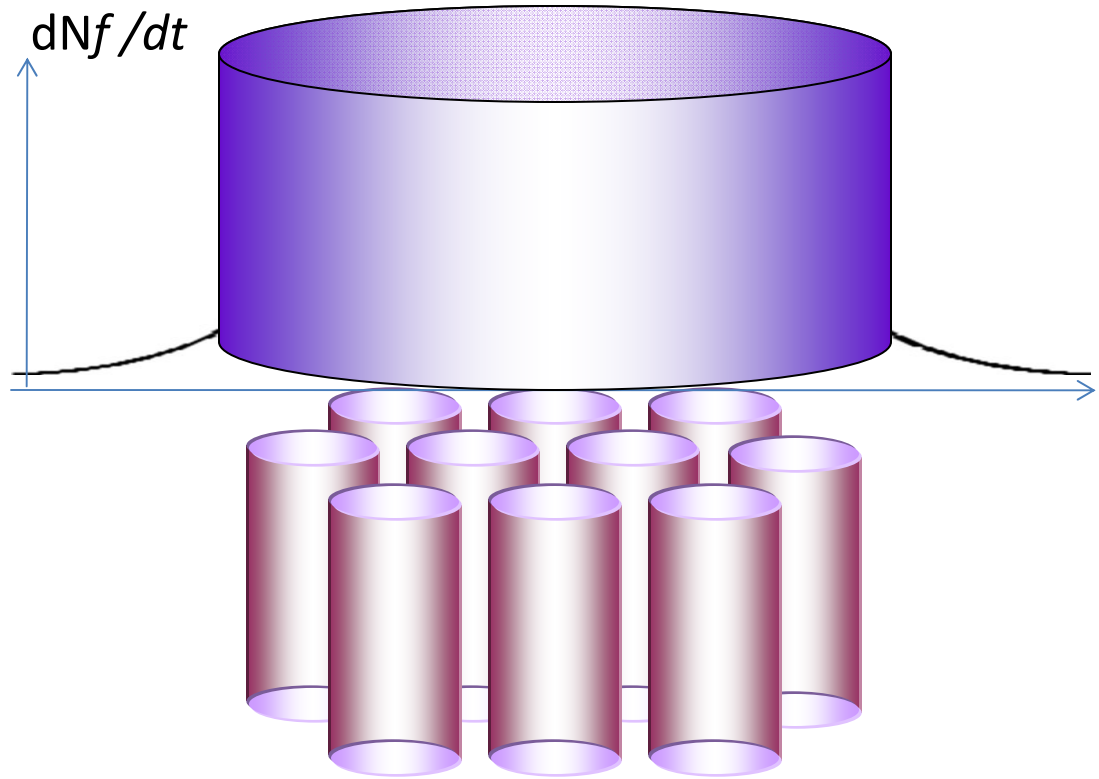
Parameters of photon bunch

Photon flux

τ =100 ps, σ = 42 ps

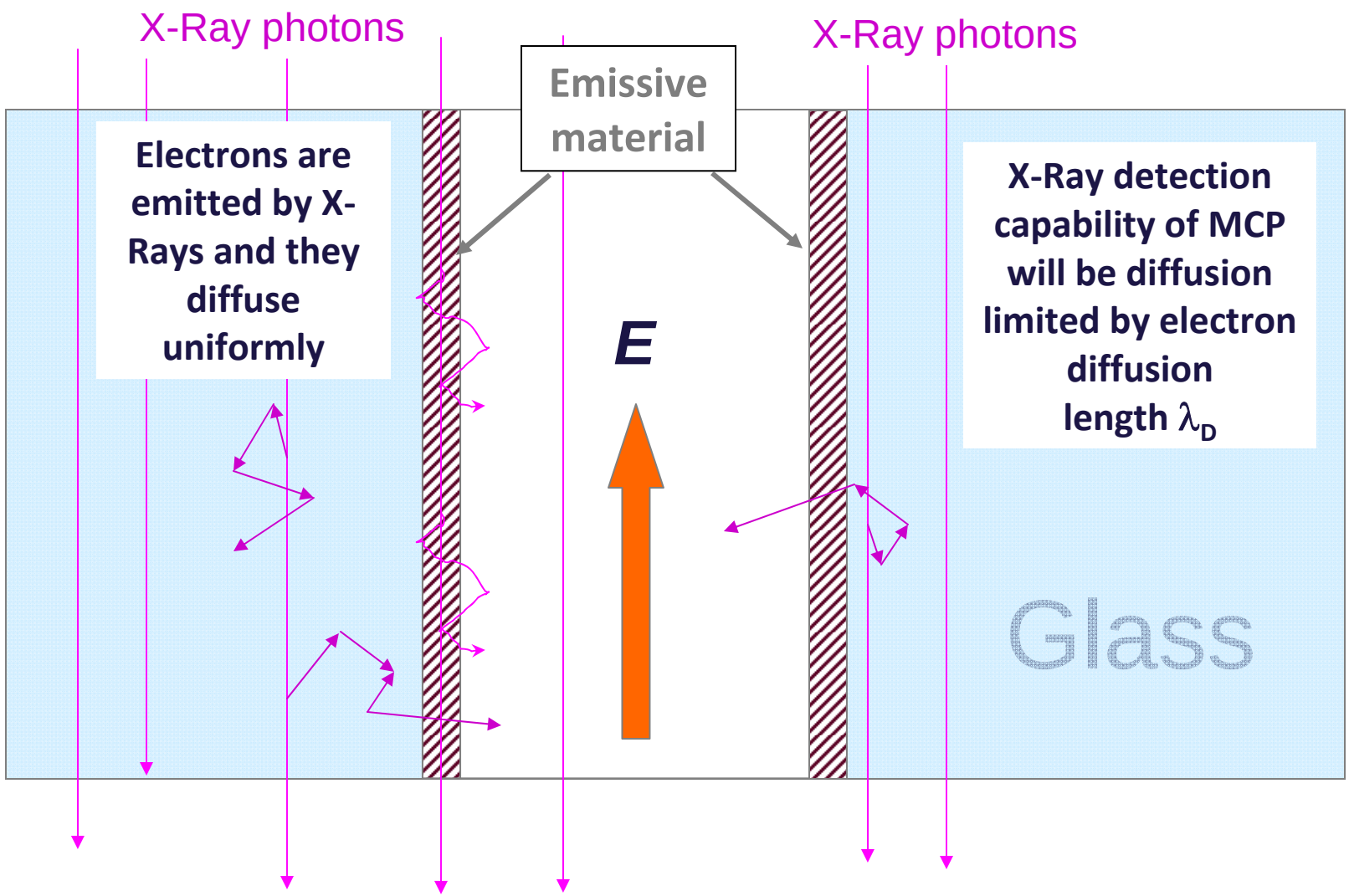
Photons are coming from synchrotron as bunches with the following flux:

- **6.5×10^{6} photons per bunch (f=6.5MHz)**
- **1×10^{7} bunches per second**
- **1×10^{13} photons per second**
  6.5×10^{6} per pore surface

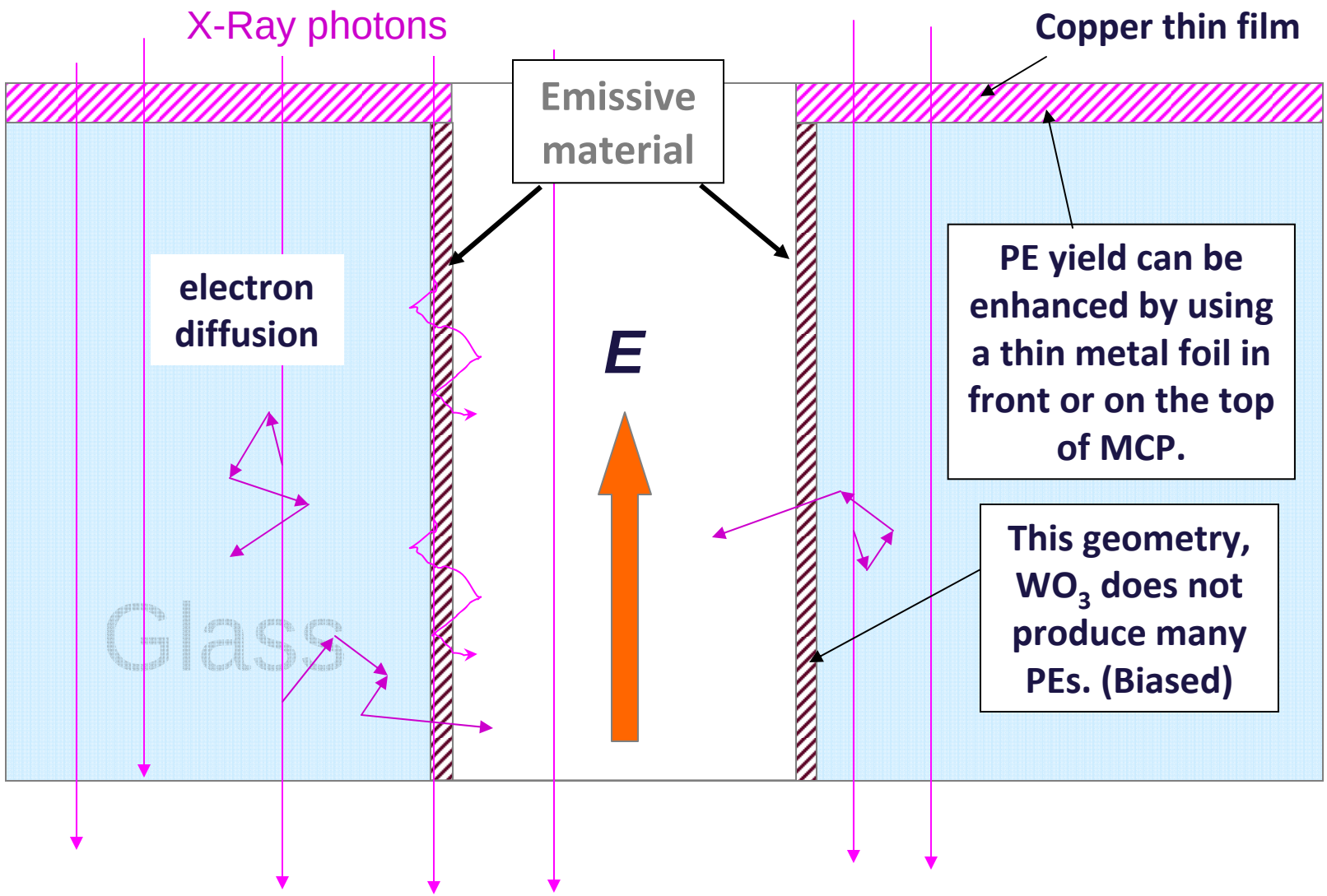


The photon bunch spot covers about 10 pores, which means that 6.5×10^{5} photons cover the pore surface.

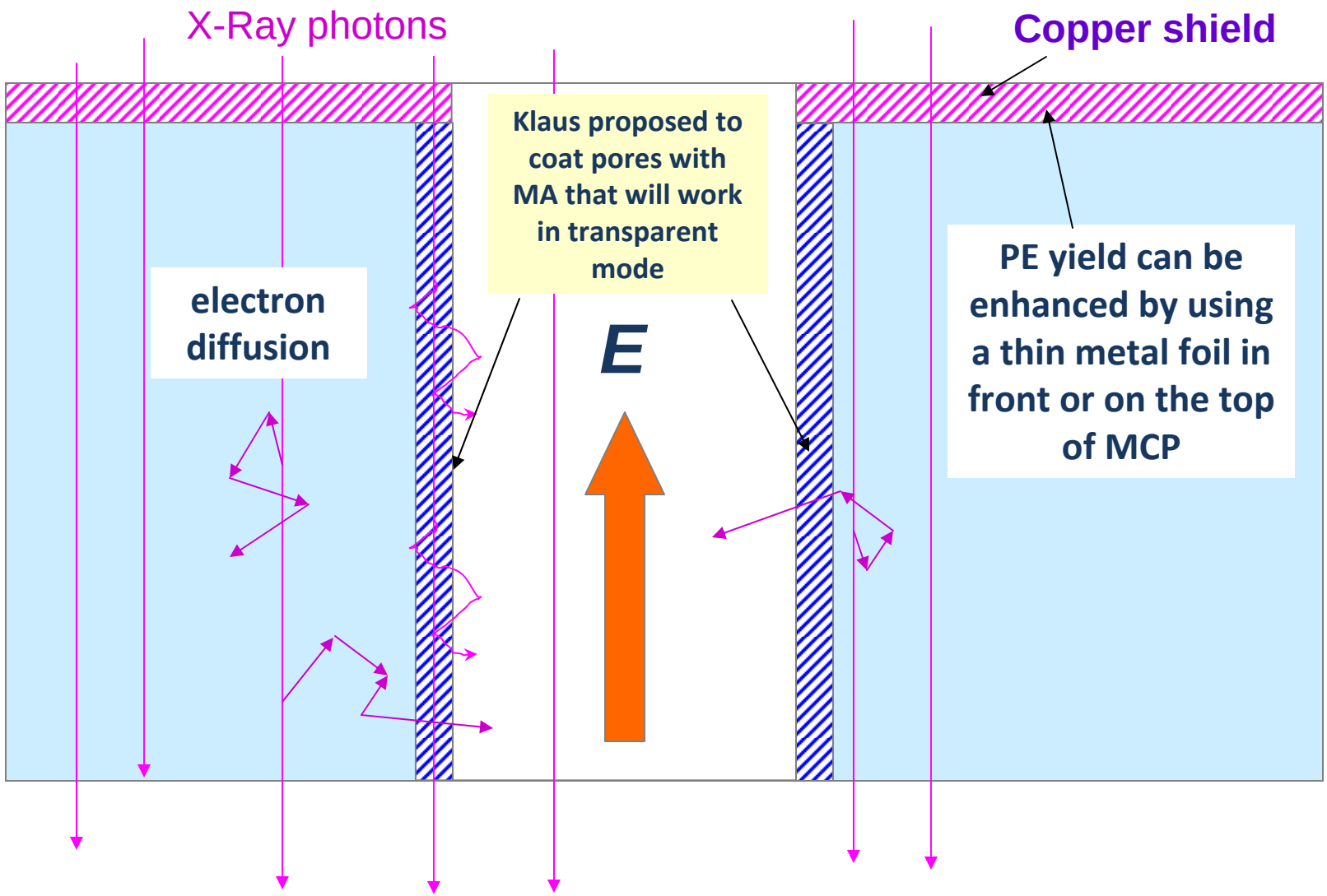
X-Ray Photo-Detector processes



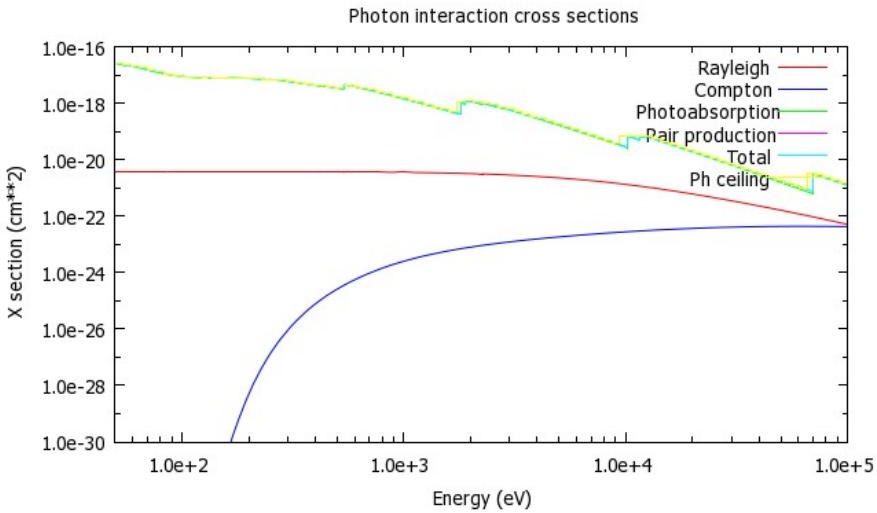
X-Ray yield enhancement

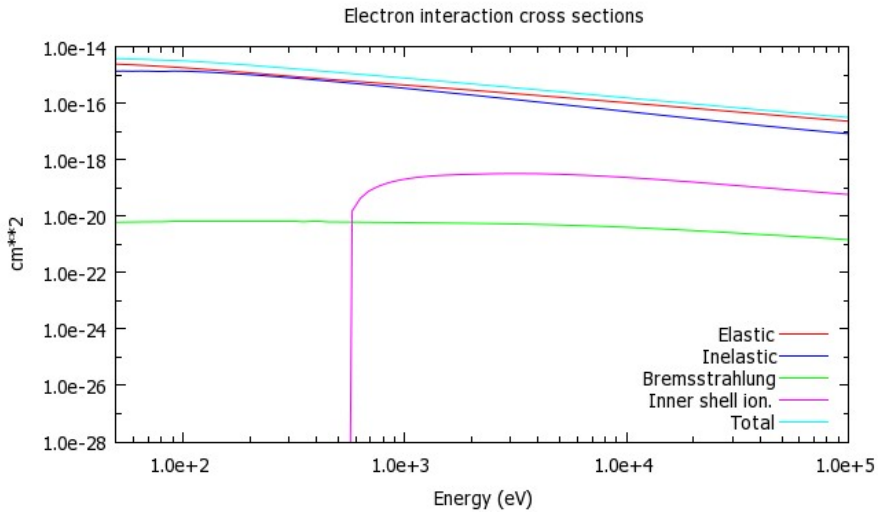


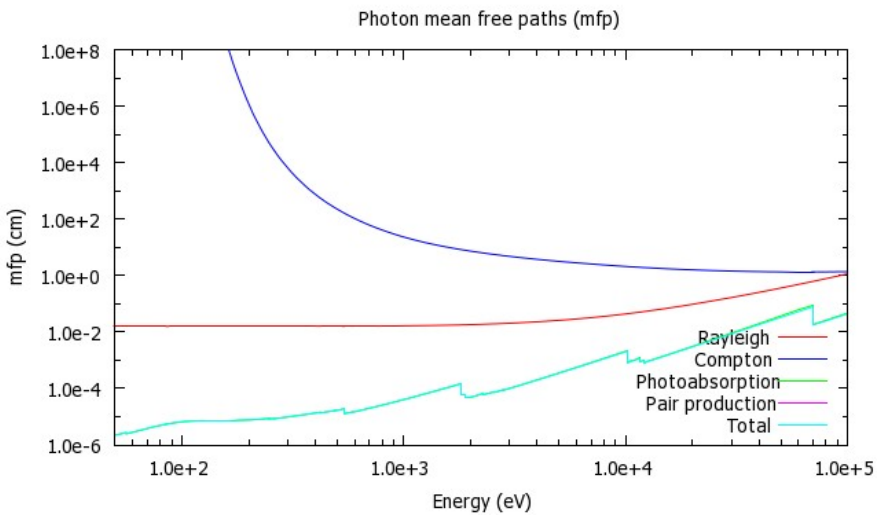
Multi-Alkaly pore coating

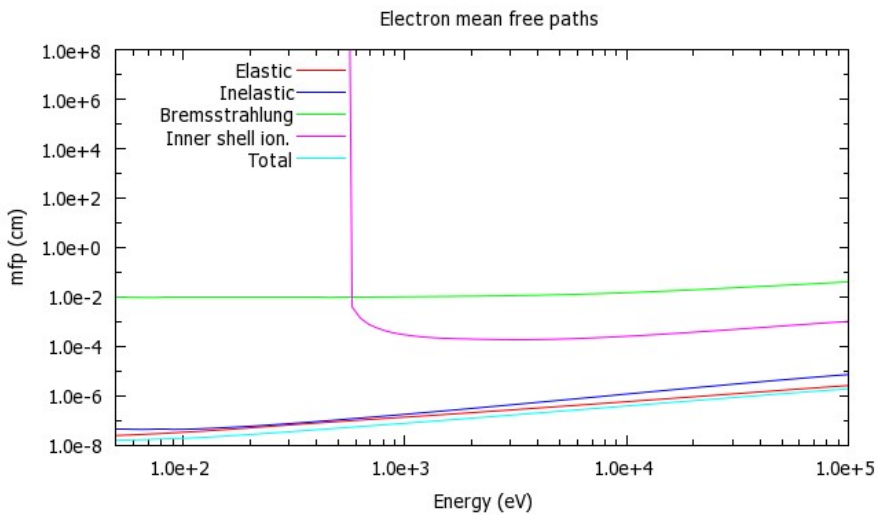


Calculated material features

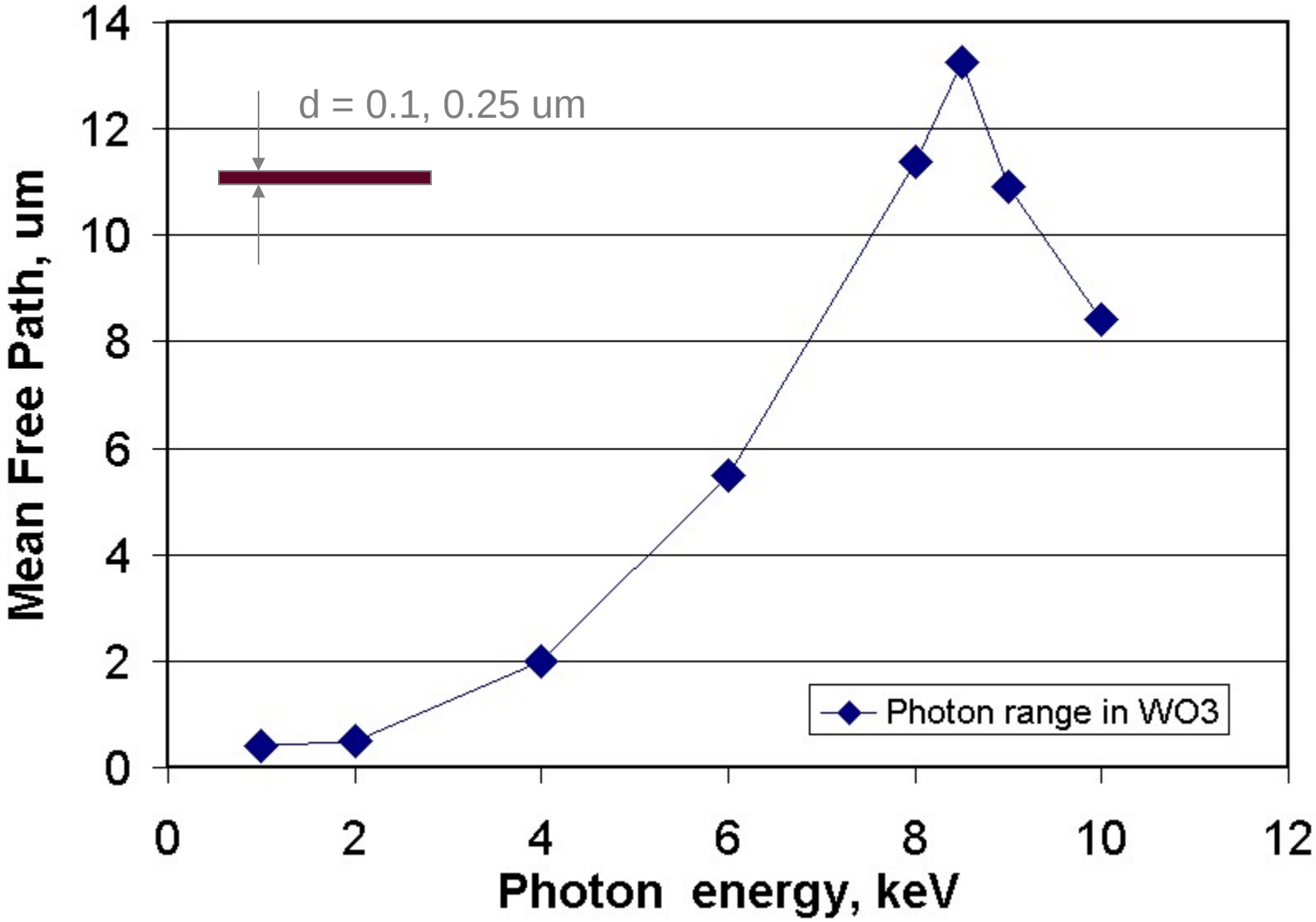








Photon ranges



Quantum efficiency of WO3

- **QE can be estimated via the Spicer's three-step model [1]**

$$Y_i(h\nu) = \frac{\alpha_{PE}(h\nu)/\alpha(h\nu)}{1+\frac{1}{L\alpha(h\nu)}} R(h\nu)B(h\nu),$$

α_{PE} the abs. coeff. for exc. above the vacuum level,

L is a characteristic escape length,

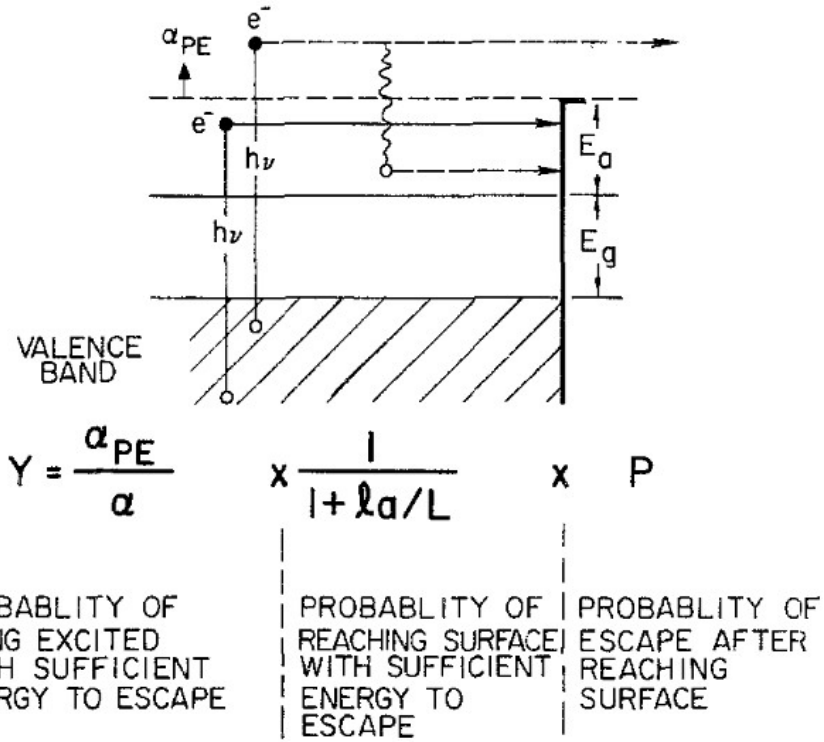
$B(h\nu) = A(h\nu)P_s(h\nu)$

$A(h\nu)$ is between 1 and 1/2,

$P_s(h\nu)$ probability of escape at the surface.

$L = \sqrt{D\tau} = \sqrt{\mu\tau(kT/e)}$ the e - diffusion length

$Y = Y_{MC} \cdot P_s, P_s \sim 1$ for NEA



$QE_{WO3} = 10^{-4} - 10^{-3}$ @ $h\nu$ = 1-10 keV

[1] W. Spicer, Appl. Phys. 12, 115--130 (1977)
[2] James, Moll, and Spicer, Phys. Rev. (1967)

Diffusion of PEs in the MCP

- An MCP based X-Ray photo-detector will collect the photo-electrons (PEs) generated both in glass and in the thin WO3 layer.
- This is opposite to a conventional SEY MCP detector where the SE are emitted from the coated layers.
- PEs from Glass drift/diffuse to the nearest open pore and form a cascade.
- The material should protect neighboring pores from collecting PEs from remote locations.
- This can easily be done by:
  - Controlling the diffusion lengths of PEs
  - Engineering Electric fields

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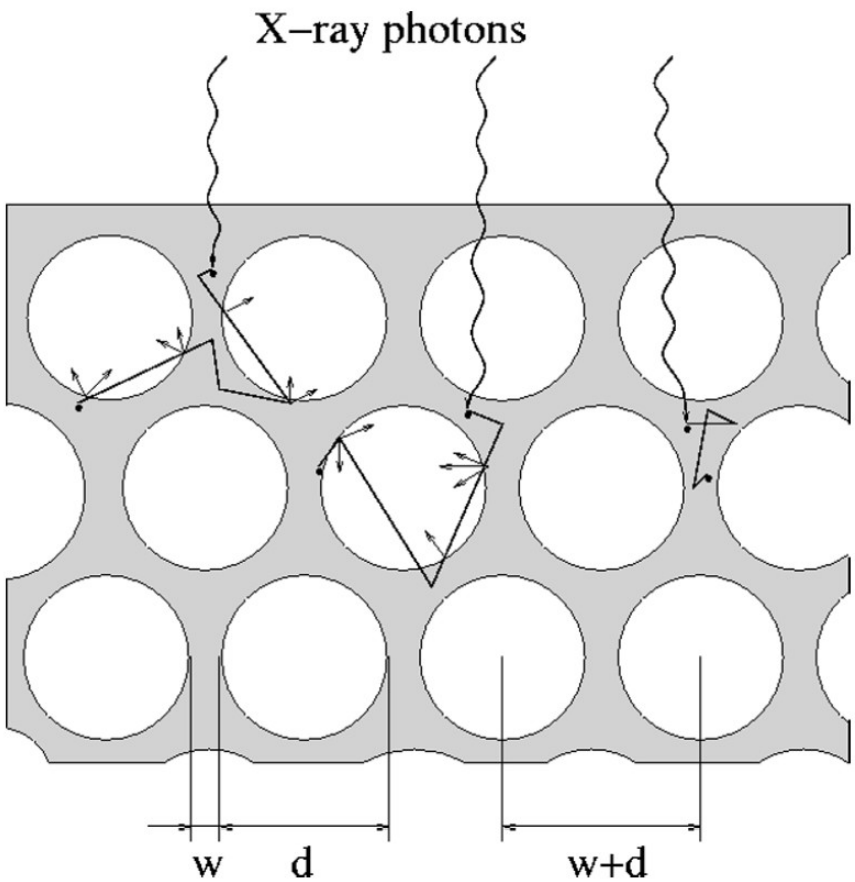
Collection of PE emitted by glass

- PEs emitted in glass diffuse to pores



Shikhaliev, NIMB (1996)

Glass QE

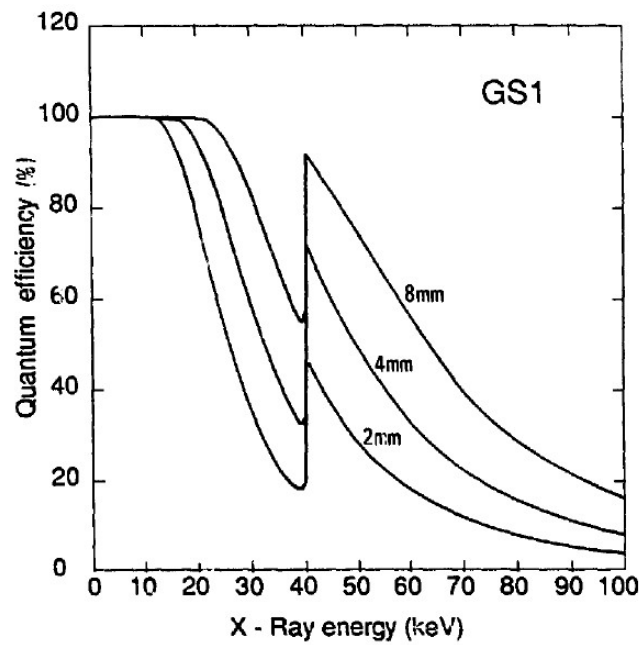


Fig. 1. X-ray quantum efficiency of the GS1 glass for three different glass thicknesses.

G. Zanella, R Zannoni, NIMB (1990)

Diffusion-drift kinetics of PEs

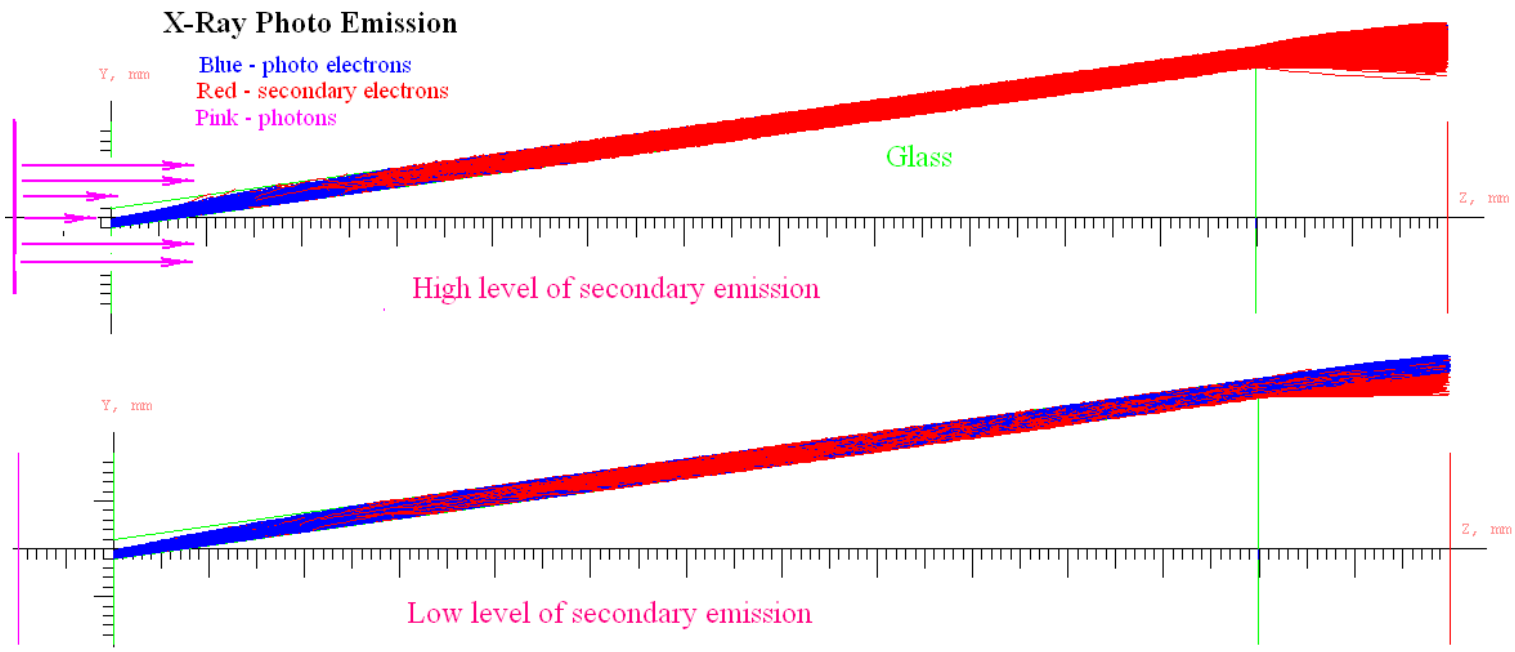
- End-to-end Device simulation is needed to mitigate the time-delay of PEs in a diffusion limited process.
- Charging effect is significant – SBIR is possible.
- This can be done by adding a thin high-Z metal foil on the top of MCP
  - Use as a mask to increase pore response?
- Interactive set of diffusion/drift equations for the electrons in glass/pore should be solved to define the quantum efficiency and the best choice of the MCP materials.

First simulation of X-Ray photoelectron detection by MCP

The code status

- The current version of the MCS-code can simulate both:
  - i) the photo-emission from PC,
  - ii) SEY from the pore surface.
- Some improvements in the code were done to include the model of X-ray emission excited by the photons come directly to the pore surface.
- We should work on more generous model to study the interaction X-ray/bulk material in order to evaluate the quantum yield more accurately.
- The current PE and SEY model lacks the charging effect that will be the subject of our future SBIR to DOE.

Simulation results-1

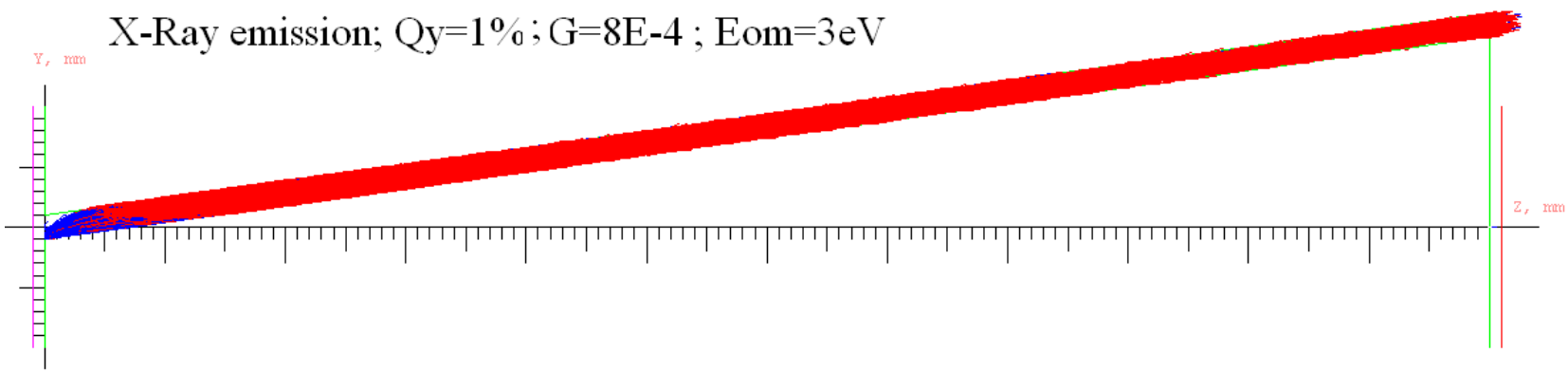


- **The total efficiency Q = QE×G, where**
  - **Qy – quantum yield for photo emission; G – gain.**
  - **$G = Q_{se}/Q_{ph}$ – gain;**
  - **Q_{se} – total number of secondaries at the exit of the pore;**
  - **Qph = QE × Q_0 – total number of photo electrons; Q_0 – total number of photons per bunch.**

Simulation results-2

The following parameters were used: Q_0=6.5×10^5 photons; QE = 0.1;
Secondary emission properties are characterized by the material constants:
σ_m – the SEY maximum, and ε_m – the energy of strike corresponding to the σm;
The constants for WO3 are shown in the table below:

σ_m	ε_m, eV	G
1.7	300	0.1066
1.0	300	0.0409



Summary

- The PE are emitted by Glass/WO3, the concept should be modified compared to the conventional MCP detection.
- The following important effects should be mitigated:
  - i) diffusion-limited kinetics of PEs in bulk glass
  - ii) charging effect should be significantly suppressed
  - iii) surface roughness inside the pore
- The MCS code was developed that takes into account both X-ray PEs and SEY that can calculate large variations of the physical parameters and is capable to engineer the device.
- We should increase our efforts to improve the physical model of X-Ray interaction with the emissive materials, to better understand the phenomena which are not well studied.

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