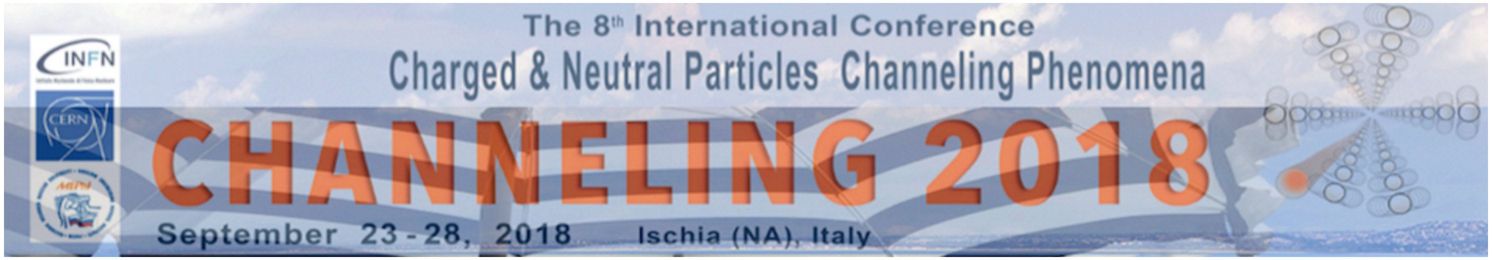

Observation of the X-ray Cherenkov Effect Near 100 eV Photons Energy

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INTRODUCTION

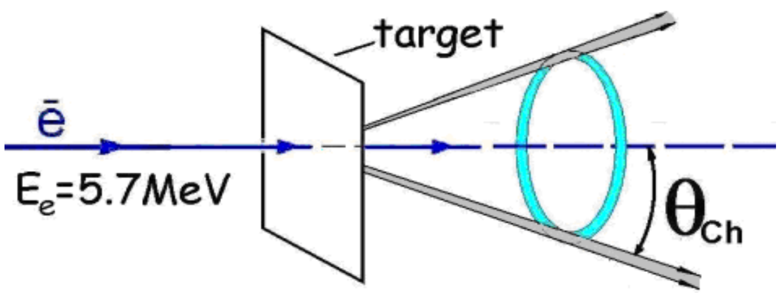
As is well known, the Cherenkov radiation is generated by a charged particle in a medium having a refractive index n > 1 for the wavelength of observed emission, provided that the speed of the particle b> 1 / n. In addition to the optical wavelength range, the condition n > 1 holds for certain substances in narrow ranges of the spectra of vacuum ultraviolet and soft X-rays near the absorption edges.

For the optical frequency the Cherenkov radiation (VCR) has been well studied both experimentally and theoretically. There are a number of instruments and devices that use this phenomenon. At the same time, in soft X-ray and VUV ranges, VCR mechanism was experimentally investigated a little. We know only a few studies [1-3], in which the effect of VCR was studied experimentally. Previously VCR effect was observed for the C (carbon), Si, V and Ti targets in a narrow spectral band with the width of a few eV near K and L absorption edges of the said elements.

1. Bazylev V. A., Glebov V. I., Denisov E. I., Zhevago N. K., Khlebnikov A. S., Tsinoev V. G., Chertov Yu. P., Shramenko B. I. // JETP Letters, 1981, Vol. 34, No.3, pp.97–101.
2. Moran M.J., Chang B., Schneider M.B.,.Maruyama X.K//Nucl.Inst. Meth. B48,1990,pp.287-290.
3. Knults W., Luiten O.J. and van der Wiel M.J., Verhoeven J. //Appl. Phys. Lett. V79,N18,2001,pp. 2999-3001.

INTRODUCTION

Recently [1] we have reported about the observation of the Cherenkov effect on the L-edge of the absorption of the aluminium. This report presents new results are provided in experimental study of the X-ray Cherenkov effect with Al, Be and Si. Here, we are study of the angular density of ultra-soft X-ray radiation (USXR) generated by 5.7 MeV electrons from a thin foil in forward direction at normal incidence of electron beam on the surface of target.



$$\cos(?_{Ch}) = (?n(?))^{-1},$$

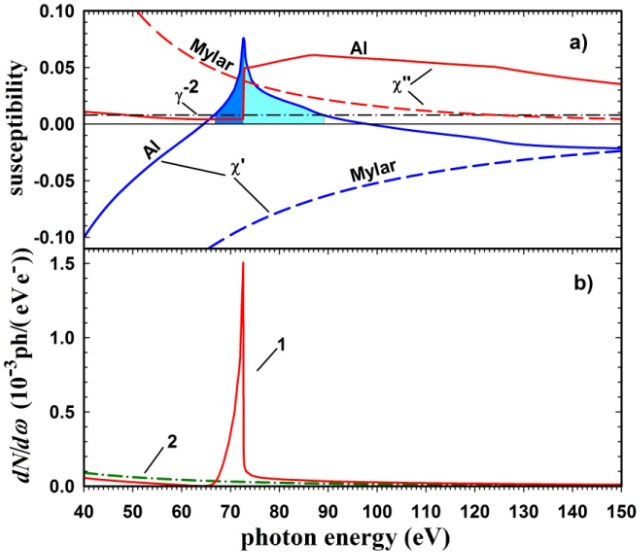
$$n^2(?)=?(?),$$
$$?(?)=1+?'(?)+i?''(?),$$

$$?_{Ch} = (?'(?) - ?^{-2})^{1/2}$$

1. Uglov S., Vukolov A., Kaplin V., Sukhikh L. and Karataev P., *EPL*, 118 (2017) 34002

INTRODUCTION

Some basic properties of the spectrum of Cherenkov radiation can be obtained from the analysis of data on the dielectric susceptibility ?' and ?".



a)The solid and dashed lines show the complex susceptibility around the L absorption edges for Al and Mylar, respectively, the dash-dotted line indicates the Cherenkov threshold for 5.7MeV electrons. Fields marked with a color fill correspond to the range of photon energy when for electrons with an energy of 5.7 MeV, the Cherenkov effect in Al is possible
b) The spectra of Cherenkov and transition radiations calculated with Pafomov's theory for Al (1) and Mylar (2).

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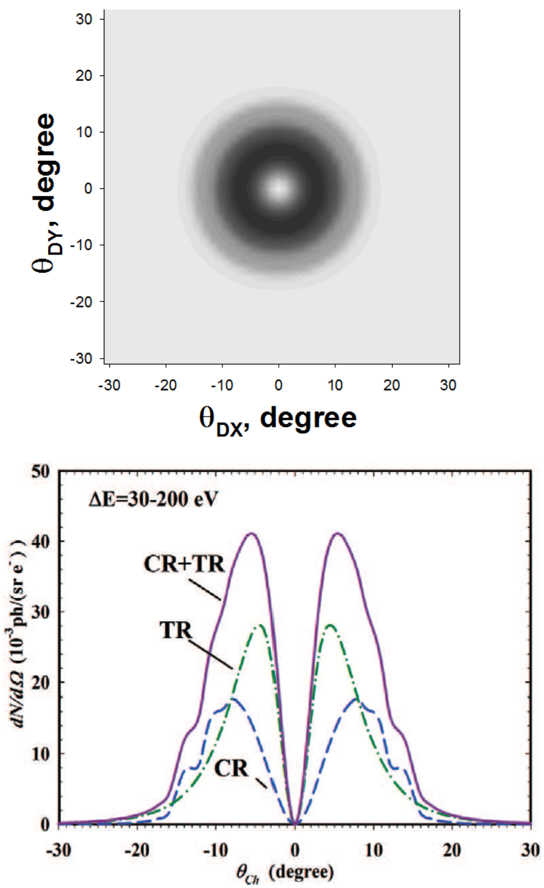
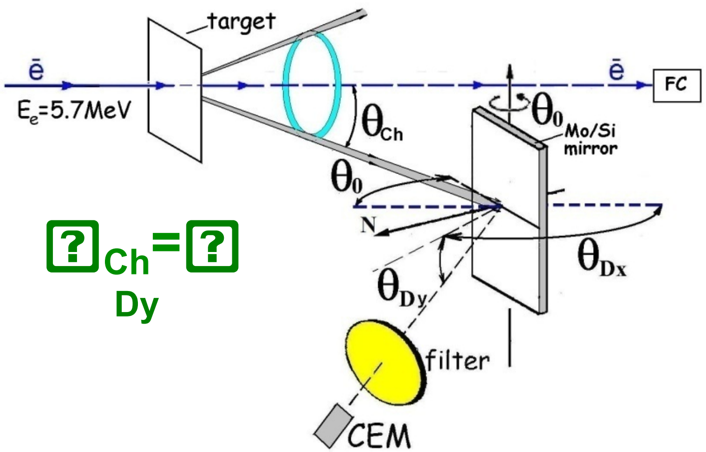
Angular distributions



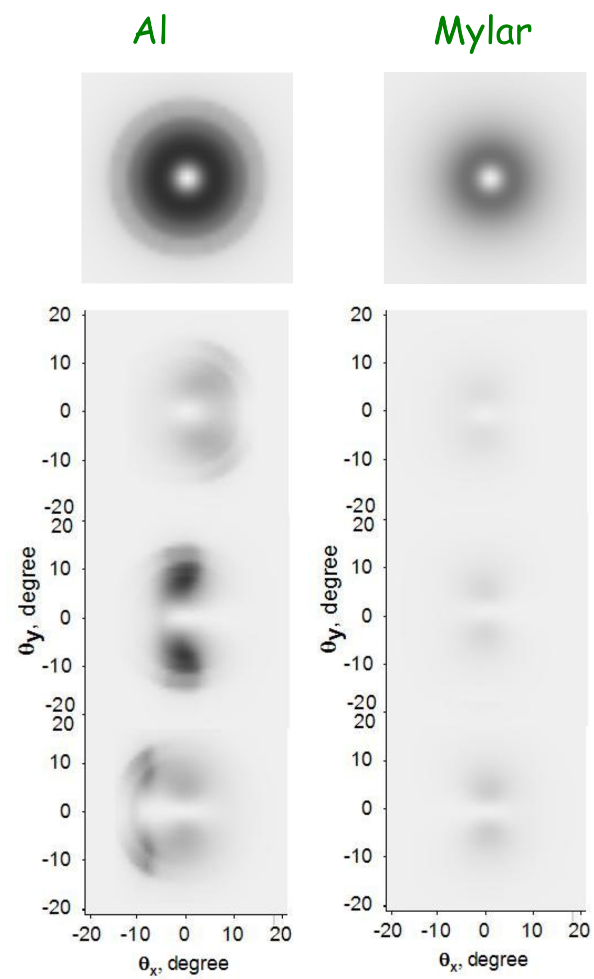
V.E. Pafomov. Proceedings P.N. Lebedev Physics Institute, Consultants Bureau, New York, 1971.
Henke-www.esrf.fr/computing/expg/subgroups/theory/DABAX/dabax.html.

The method of observation

Layout of interaction



?$_{Ch}$=?$_{Dy}$



?$_0$=66^0

?$_0$=56^0

?$_0$=46^0

Targets:

Al-with t=9 ?m
Si- with t=4 ?m
Be-with t=26 ?m
Mylar with t=20 ?m

Multilayer mirrors:

1) 50 pairs of Mo/Si layers
   d= 11.32 nm d_{Mo}=3.4 nm,d_{Si}=7.92 nm
2) 100 pairs of Mo/B_4C layers
   d= 7,56 nm, $d_{Mo}=d_{B4C}$

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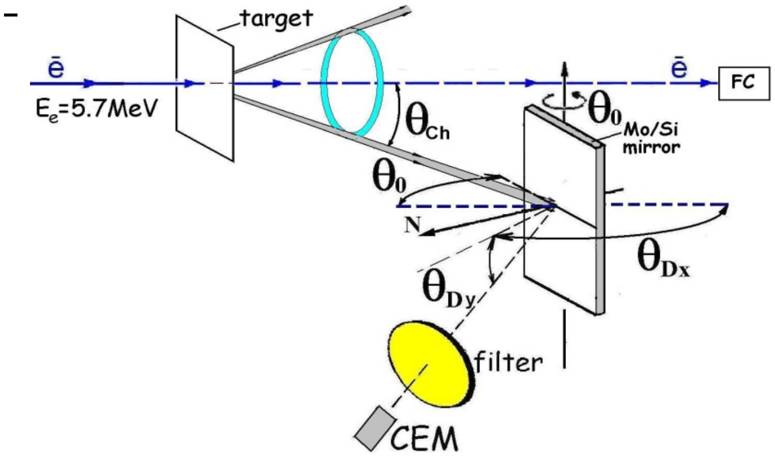
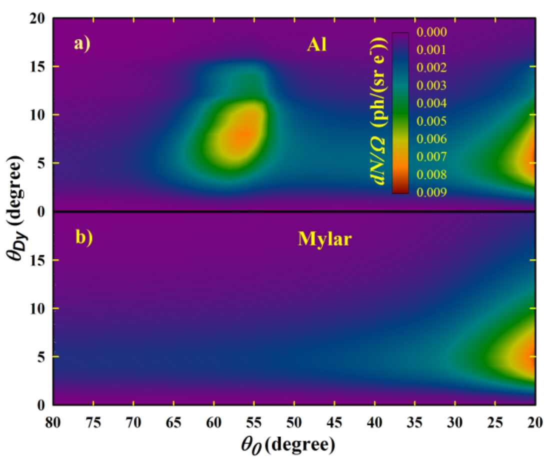
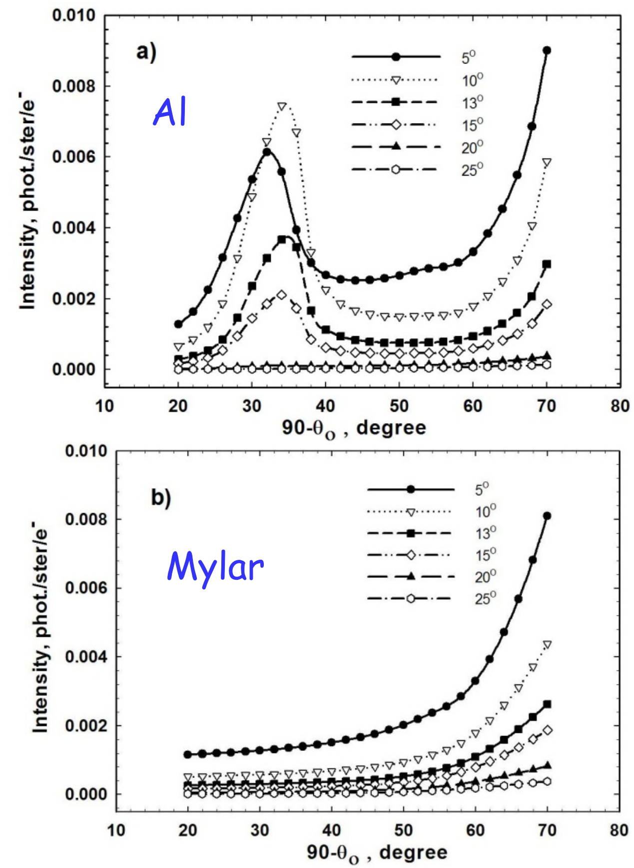
L. G. Parratt and C. F. Hempstead Phys. Rev. 94, 1593 (1954)

The method of observation





Intensity of USXR reflected by the multilayer [Mo/Si]50 mirror vs. angle ?$_0$ at an angle ?$_{Dy}$: (a) Al, (b) Mylar.



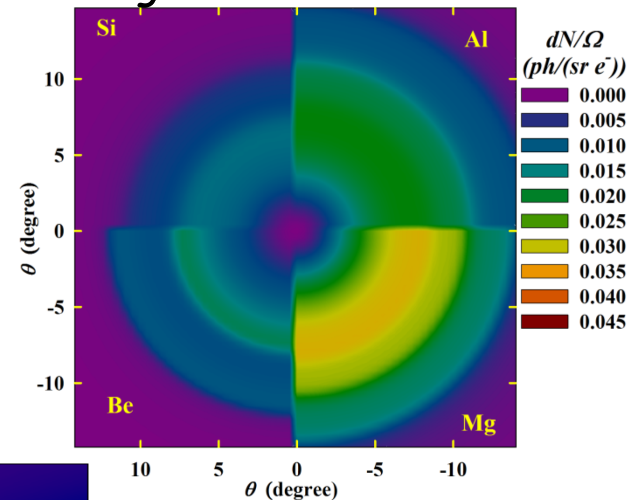
Intensity of USXR reflected by the multilayer [Mo/Si]50 mirror vs. angle ?$_0$ at an angles ?$_{Ch}$= ?$_{DY}$ (5°, 10°, 13°, 15°, 20°, 25°); a) Al, b) Mylar.

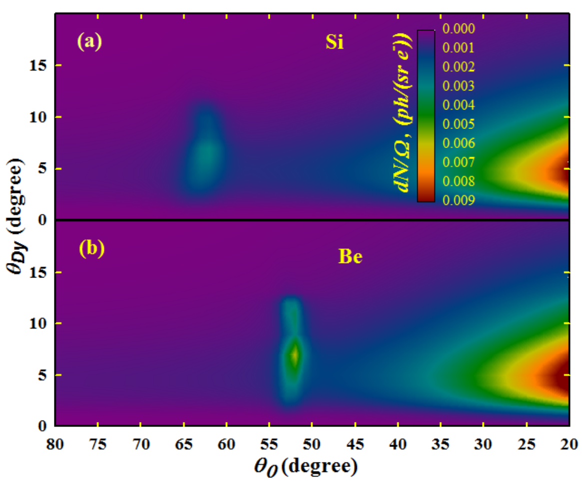
The method of observation

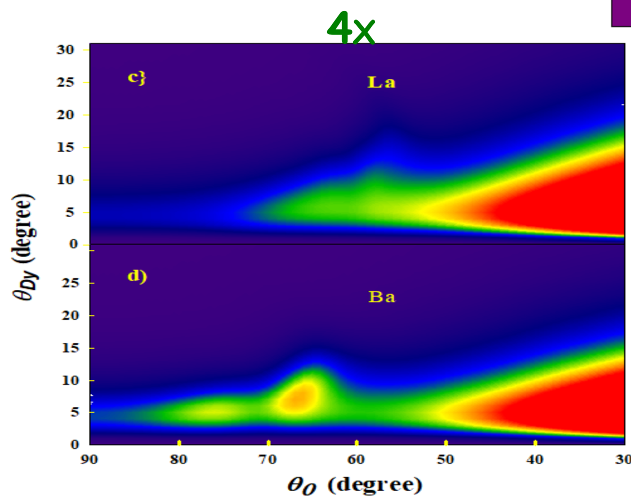
Table Specific yields of Cherenkov emitters

	Mg	Al	Si	Be
E, eV	49.5	72.6	99.8	111.5
dE, eV	1.1	1.3	1.0	0.3
$dN/d\Omega_{max}$, ph/(e^-sr) 10^{-2}	3.1	2.03	1.14	1.66
Yield, ph/e^- 10^{-3}	4.64	3.24	1.04	1.528

Angular distributions

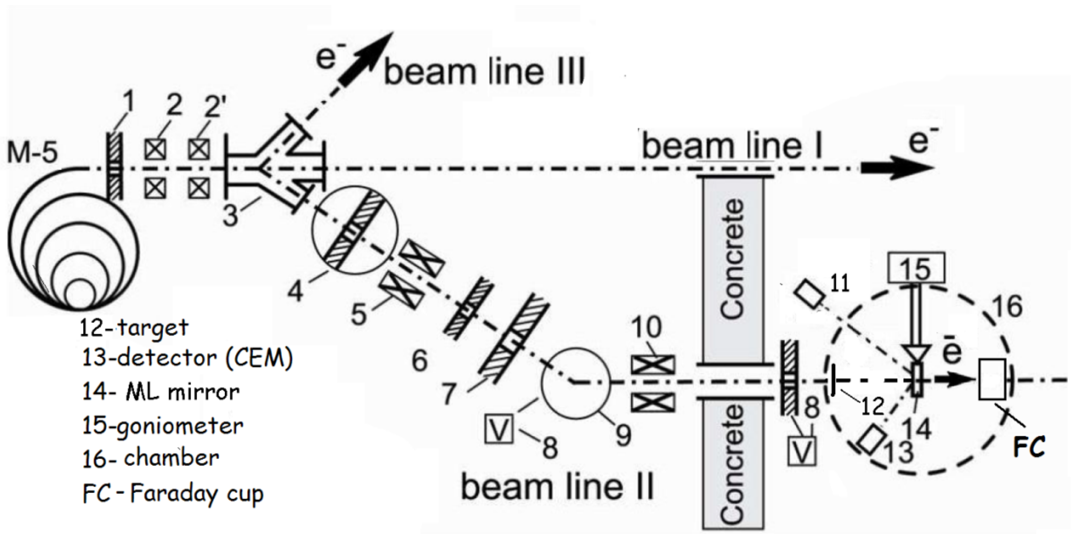


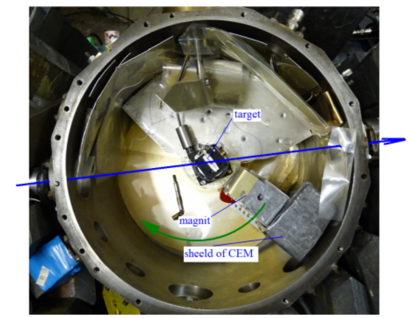




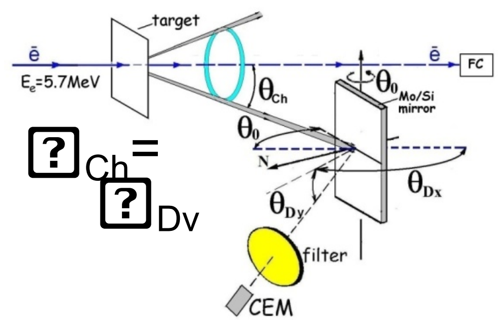
Intensity of USXR reflected by the multilayer [Mo/B4C]$_{100}$ mirror with period d=7.56 nm vs. angle ?$_0$ at an angle ?$_{Dy}$:
a) - Si, E_L = 99.8 eV
b) - Be, E_K = 111.5 eV
c) - La, E_N ~ 110 eV
d) - Ba, E_N ~ 97 eV

Experimental setup based on microtron M-5



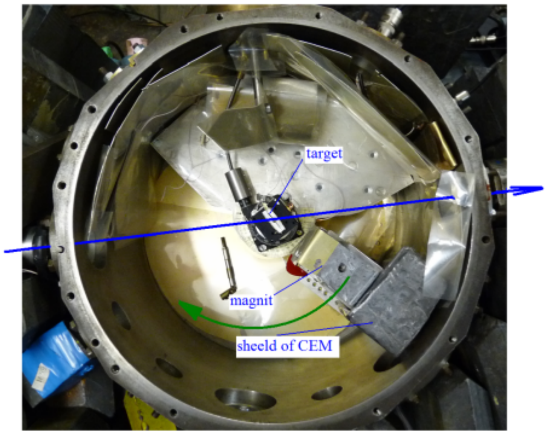


Electron energy -5.7 MeV
Repetition – 25/50 Hz,
Pulse duration – 0.4 μs
Size of beam – 2 mm
Current on target – 4pC per pulse

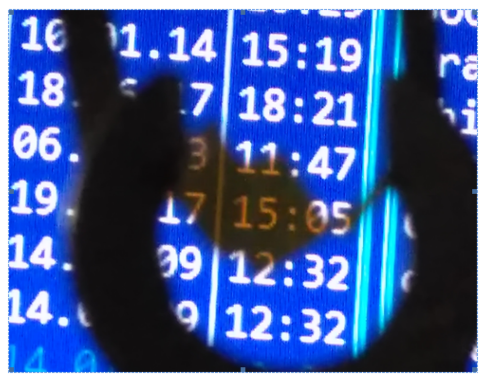


The properties of some equipment

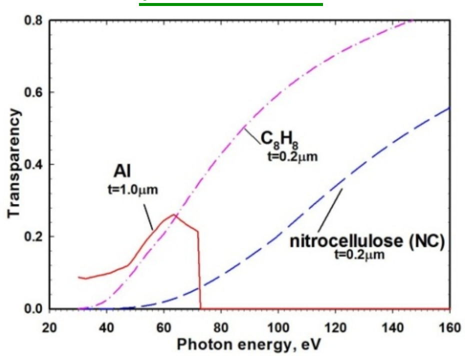
Vacuum chamber



Thin Si ($t=4$ μm) in the target holder



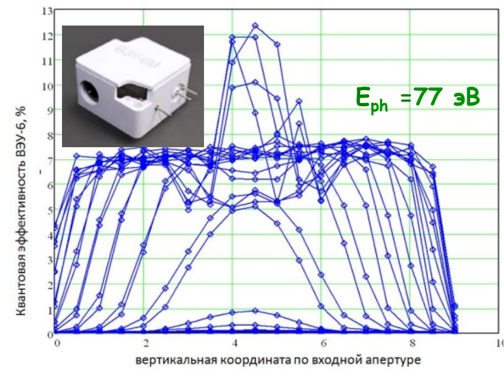
Filters:

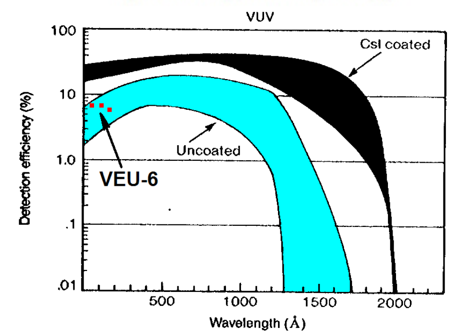


Nitrocellulose $t=200$ nm,
Al $t=1.$?m, C_8H_8 $t=200$ nm

Detector

Channeling electron multiplier (CEM)
Model – "ВЭУ-6"

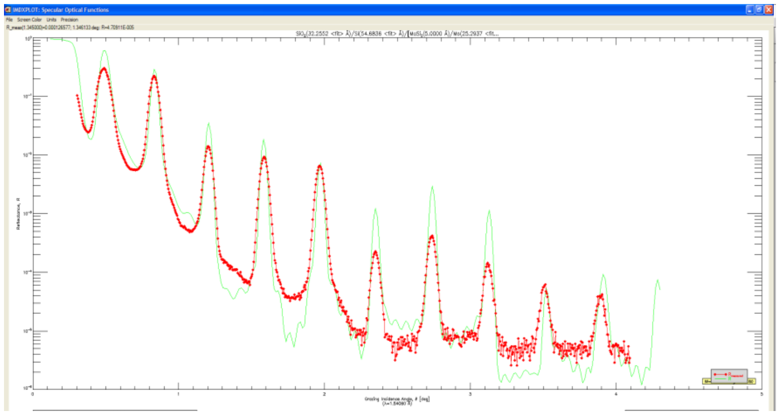


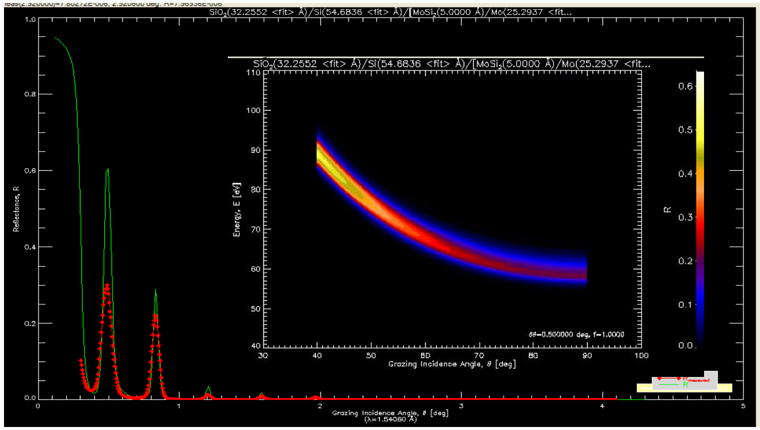


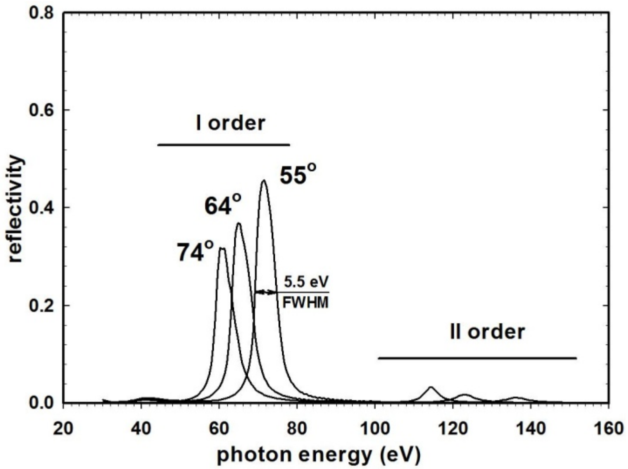
Typical efficiency of registration of the soft X-ray by CEM.
Red points are correspond to model ВЭУ-6.

Multilayer mirrors [Mo/Si]$_{50}$

Testing of a multilayer mirror by Cu-Ka X-ray beam

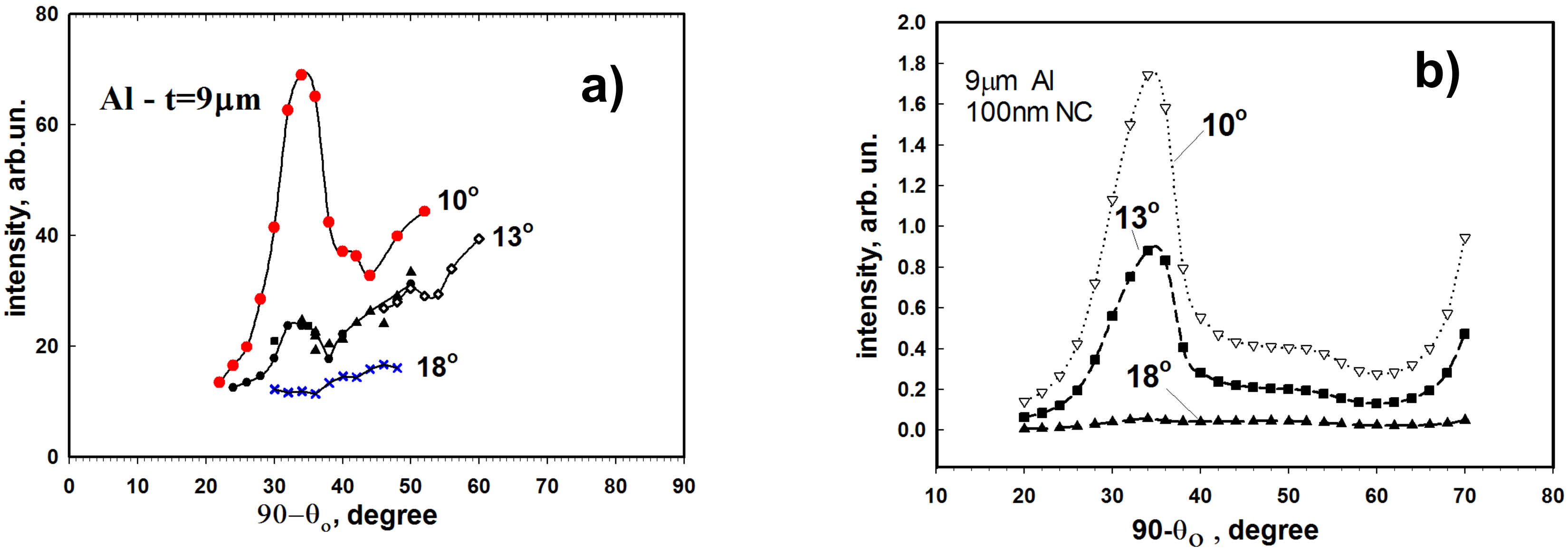






L. G. Parratt and C. F. Hempstead Phys. Rev. **94**, 1593 (1954)

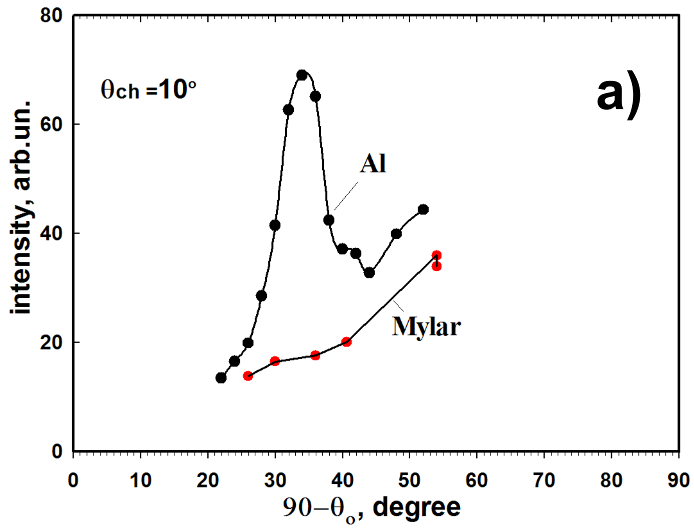
Result for Al target

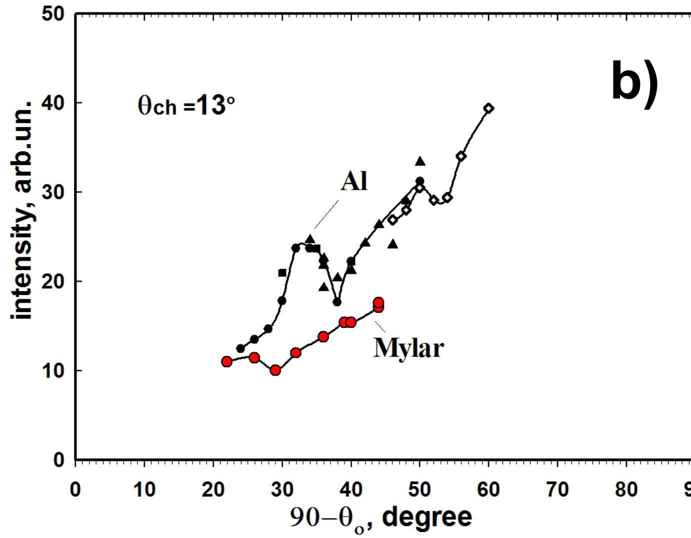


Measured (a) and calculated (b) detected yields as a functions of angle electron incidence (90°-?$_o$) on the plane of the multilayer mirror at a series detector angle ?$_{Ch}$ = ?$_{DY}$ (10°, 13°, 18°) for Al.

The figures give for comparison the measured data for a Al target for several angles ?$_{DY}$ within the radiation cone. The curves for 10 and 13 degrees comprise maxima near angle 90^0-?o = 34° which correspond to the contribution of the Cherenkov with photon energy of 72.6 eV. For ?$_{Ch}$ = 18 degrees the measured emission spectrum is uniform. The behavior of the experimental curves are generally in good agreement with calculations that confirms the observation the X-ray Cherenkov radiation for Al in this experiment.

Result for Al and Mylar

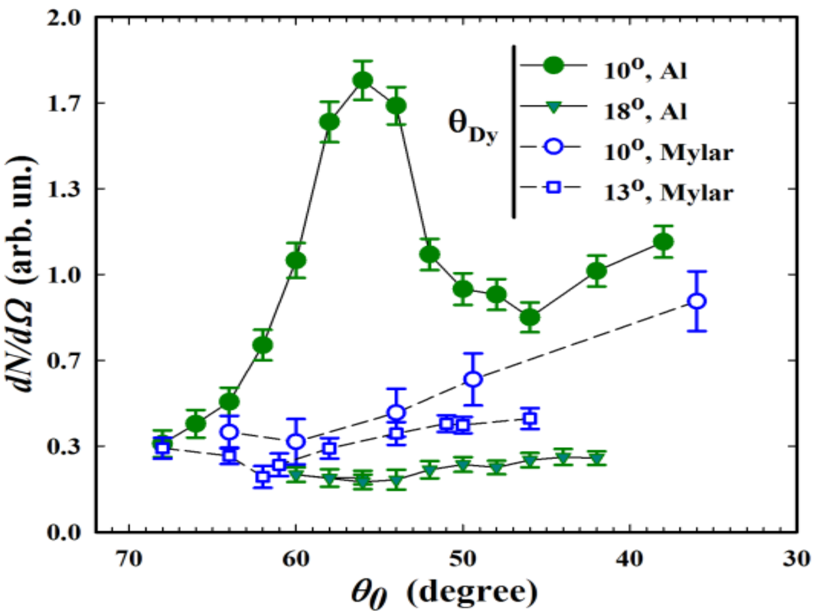


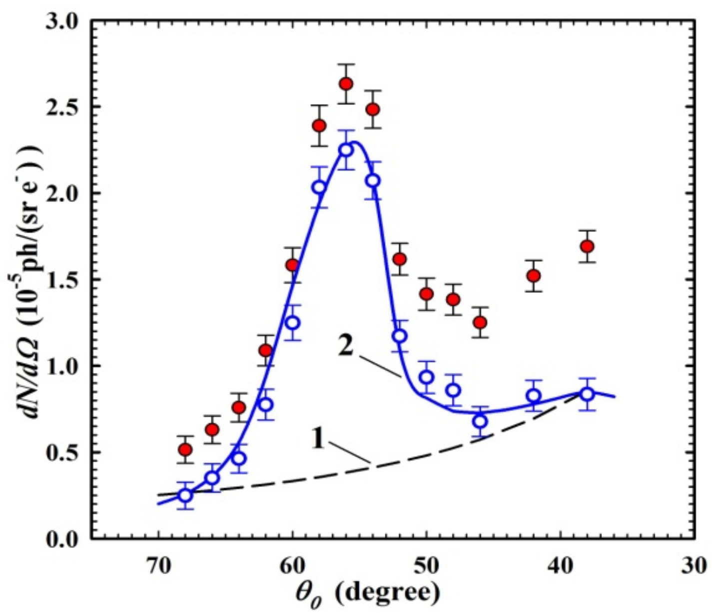


Measured detected yield as a function of angle of incidence (90°-?$_o$) on the multilayer mirror at a detector angle ?$_{ch}$ = 10° (a) and ?$_{ch}$ = 13° **(b)** for Al and Mylar.

The figures given for comparison measurement data for the aluminum and Mylar targets. The curves shown in the figures confirm that the emission spectra of Aluminum and Mylar targets measured under the same conditions are different. The case of Mylar target has no singularities in the radiation spectrum as expected.

The measurement results





Comparison for Al and Mylar

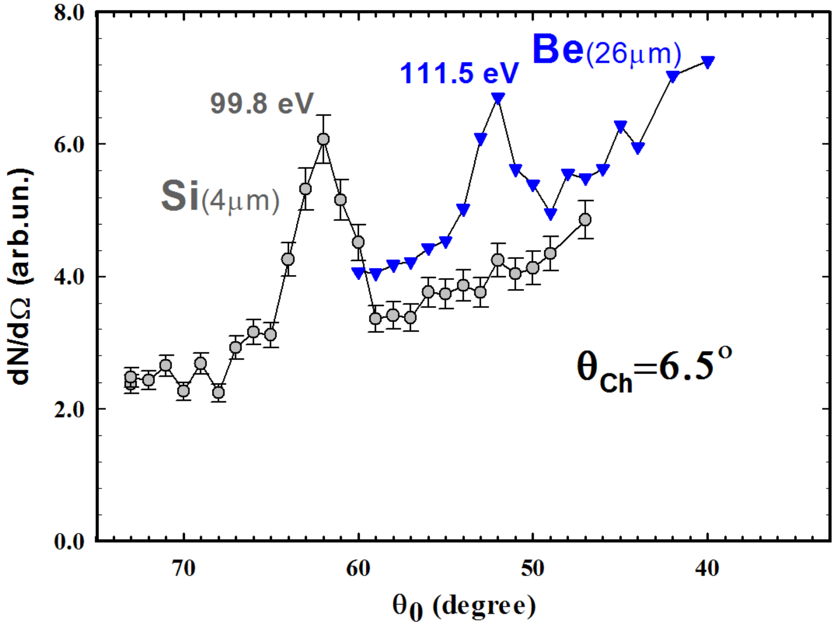
Intensity of the reflected radiation as a function of angle ?$_0$ of the $[Mo/Si]_{50}$ mirror for Al (dark circles and triangles) and Mylar (open circles and squares) targets; circles, squares and triangles are for ?$_{Dy}$ = 10◦, 13◦ and 18◦,

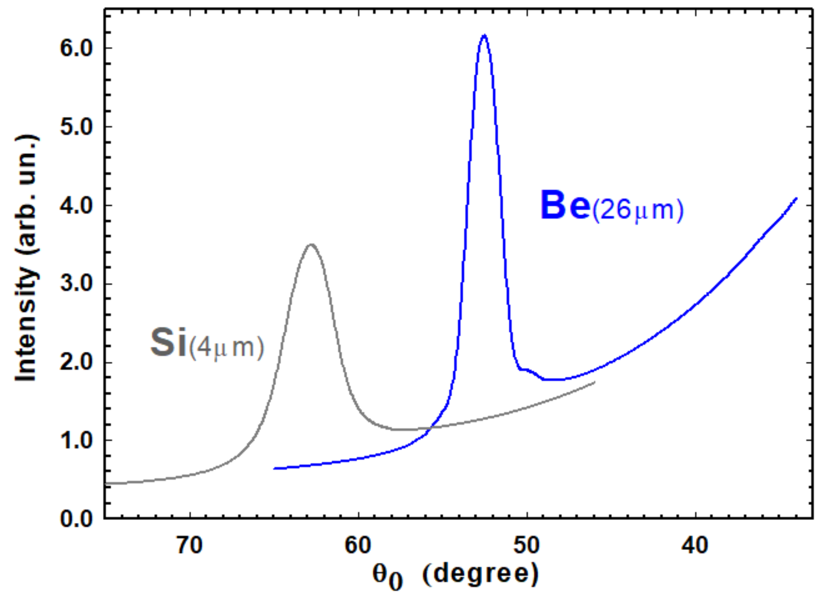
Comparison with calculation

Dark and open circles: measurements of radiation without and with subtraction of background, respectively;

curve 1: evaluated background; curve 2: calculation accounting for the detector efficiency = 0.063 and the filter thickness of 0.21 μm.

The measurement results for Silicon and Beryllium

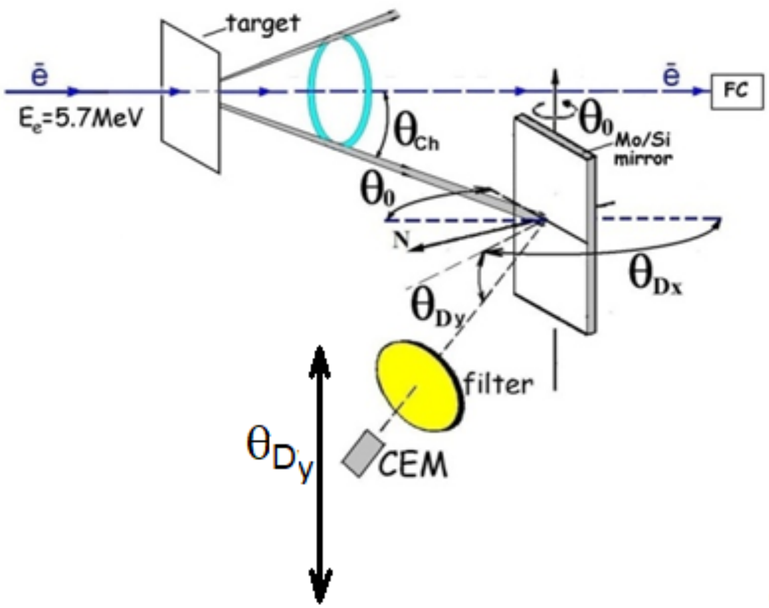


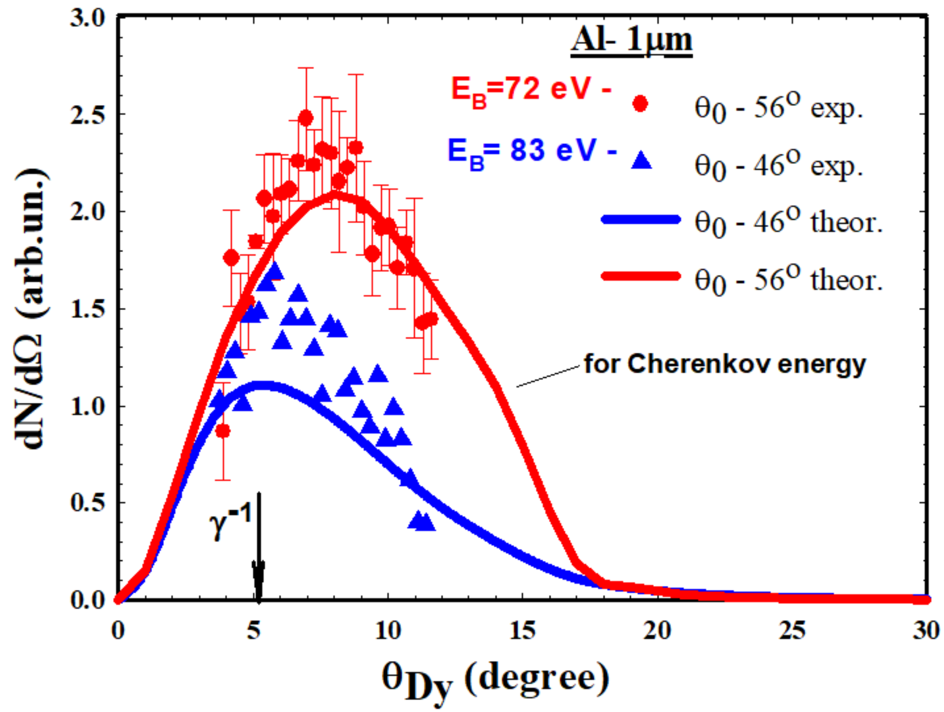


Measurements
Intensity of the reflected radiation as a function of angle ?$_0$ of the $[Mo/B_4C]_{100}$ mirror for Si (grey circles) and Be (blue triangles) targets; ?$_{Dy}$ = 6.5^0

Calculation
Intensity of the reflected radiation as a function of angle ?$_0$ of the $[Mo/B_4C]_{100}$ mirror for Si (grey circles) and Be (blue triangles) targets; ?$_{Dy}$ = 6.5^0

The measurement of the angular distribution





Conclusion

1. The Cherenkov effect for the soft X-ray region has been observed for Si, Al and for the first time for Be.

2. The values of the Cherenkov radiation energy measured for Al, Si, and Be agree well with the calculations.

3. The maximum angular density of radiation measured for beryllium, about 2 times less than expected from calculations.

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