Channeling 2008, Erice, 26 oct. – 1 nov.

"Shadowing" of the electromagnetic field of a relativistic electron

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[3] *Tomsk Polytechnic University, Russia.*

About the shadow effect

E L Feĭnberg, *SOV PHYS USPEKHI*, 1979, **22** (6)

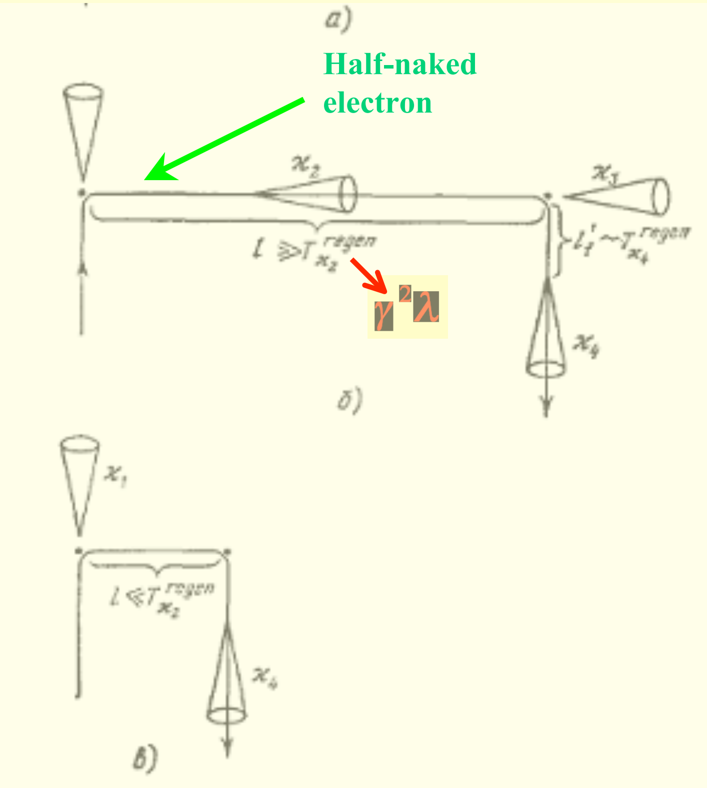


Fig. 2. Bremsstrahlung at a single and double scattering.

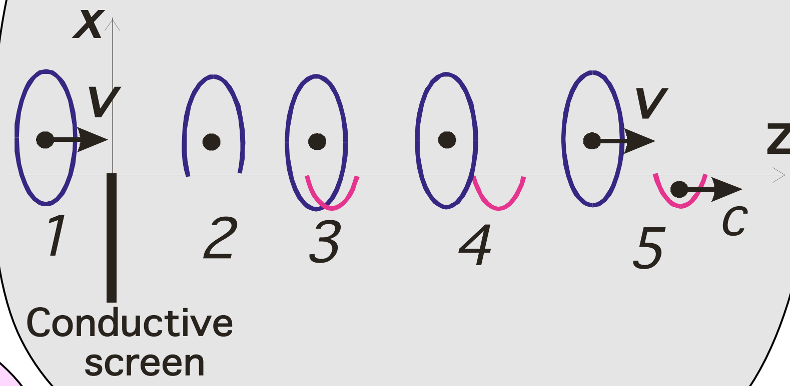
N.F. Shul'ga and V.V. Syshchenko. Journal Physics of Atomic Nuclei, 63, 11, (2000), 2018

V.V. Syshchenko, N.F. Shul'ga
syshch@bsu.edu.ru (in Russian)

… half-naked electron …

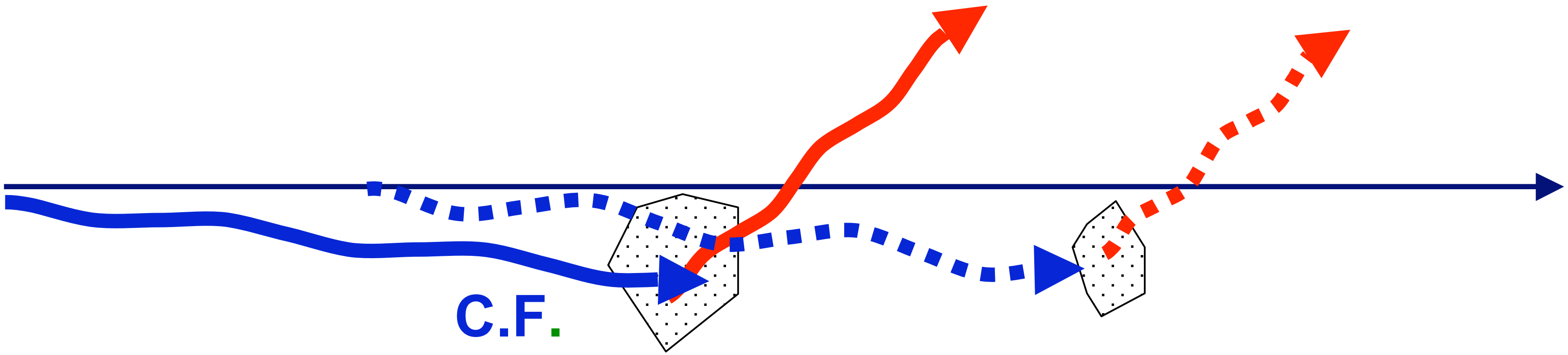
… in ionization loses ….

B. M. Bolotovskil
Preprints of Lebedev Institute of Physics, Russian Academy of Sciences,Vol 140 p. 95



X. ARTRU. Interference and shadow effects in the production of light by charged particles in optical fibers. RREPS-07, NIM B 266 (2008) 3725.

Shadowing



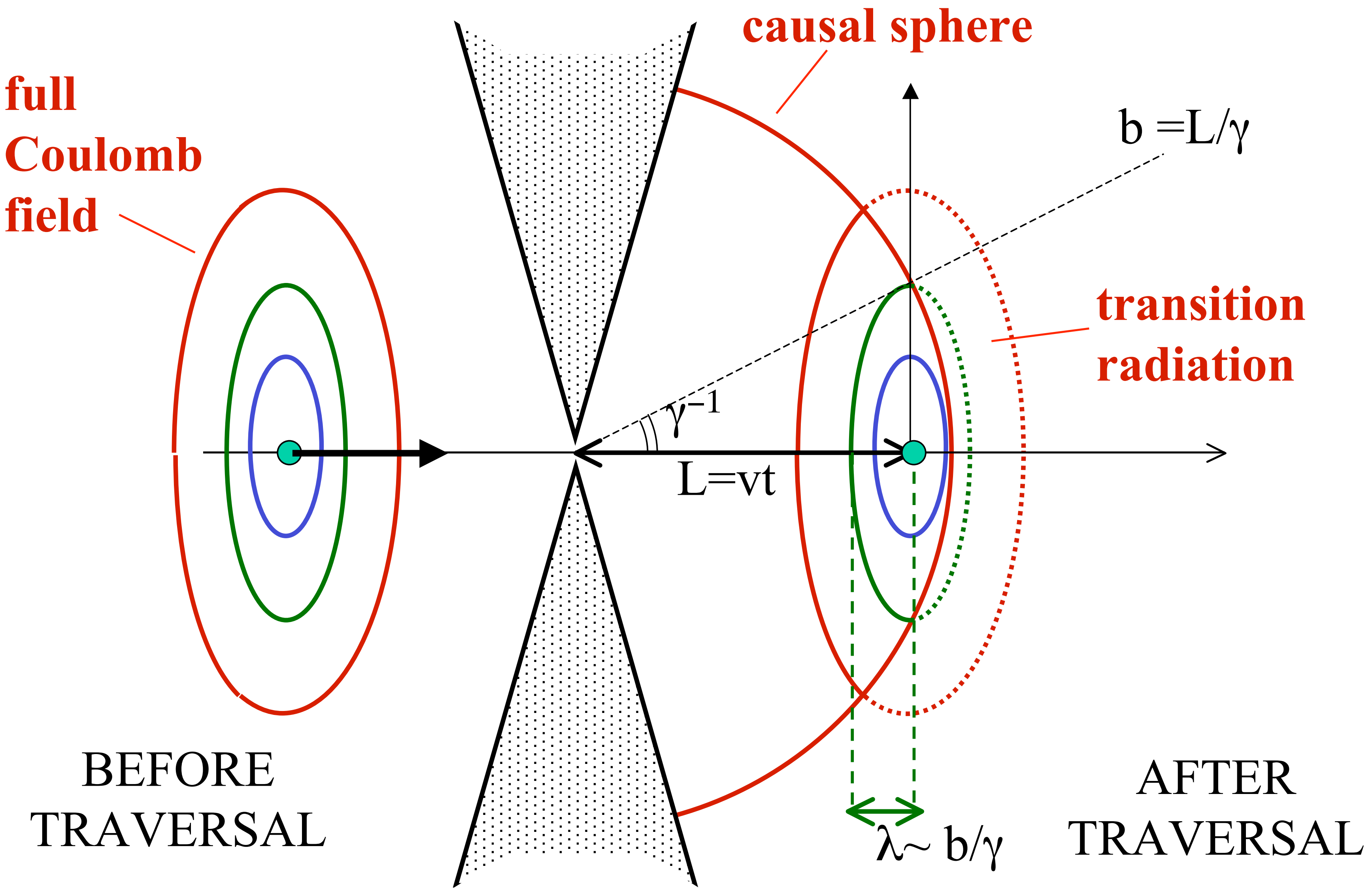
The Coulomb field (C.F.) is considered as beam of quasi-real photons.

The second target is in the **shadow** of the first one.

The Coulomb field is « repaired » after a distance

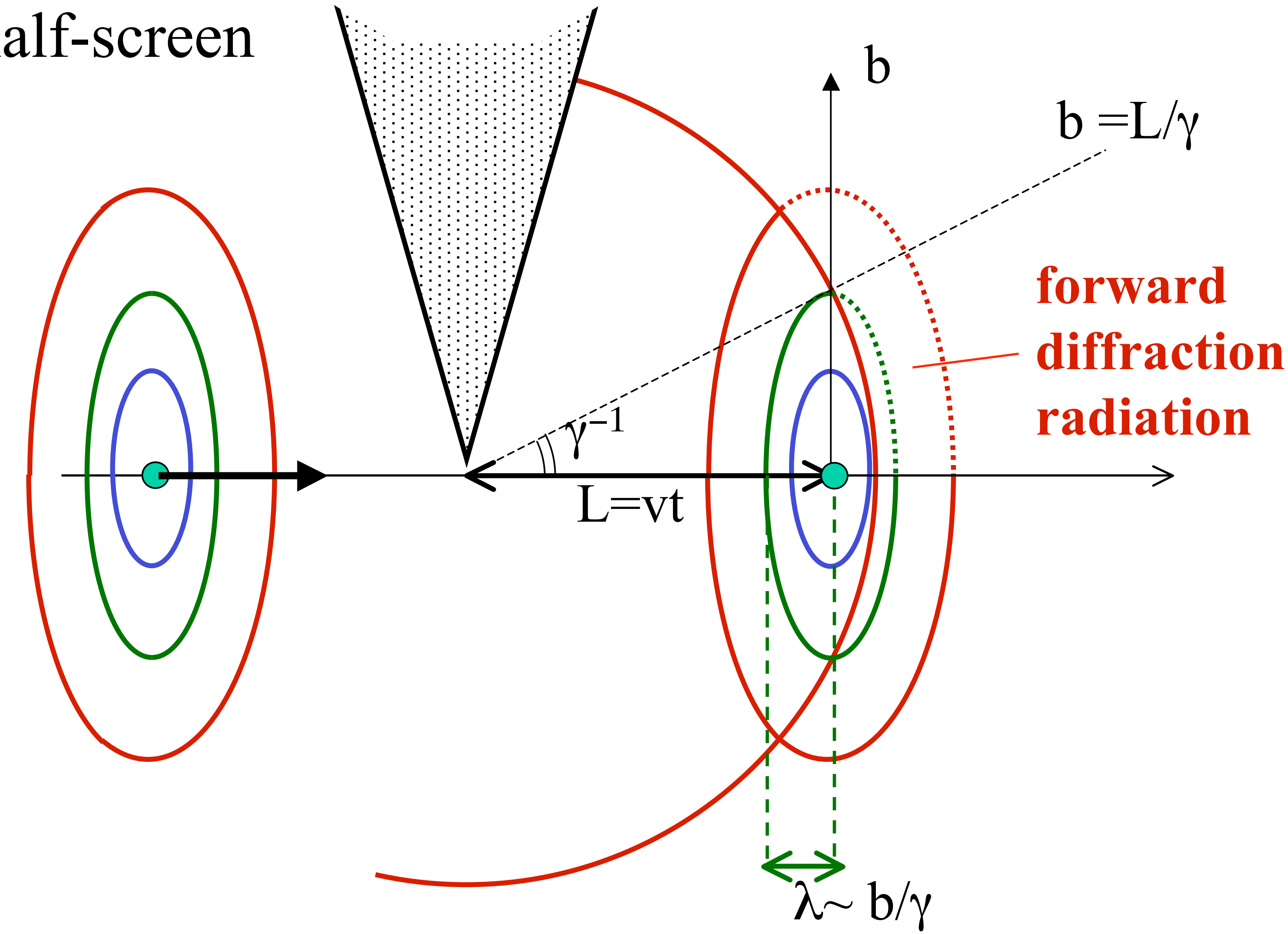
$$L \sim \gamma\, b \sim \gamma^2 \lambda \qquad (\lambda \sim b/\gamma)$$

Particle passing through a narrow hole



~ Figs.1.1,2.4 of *High Energy Electrodynamics in Matter,* by Akhiezer and Shul'ga

Particle passing near a half-screen

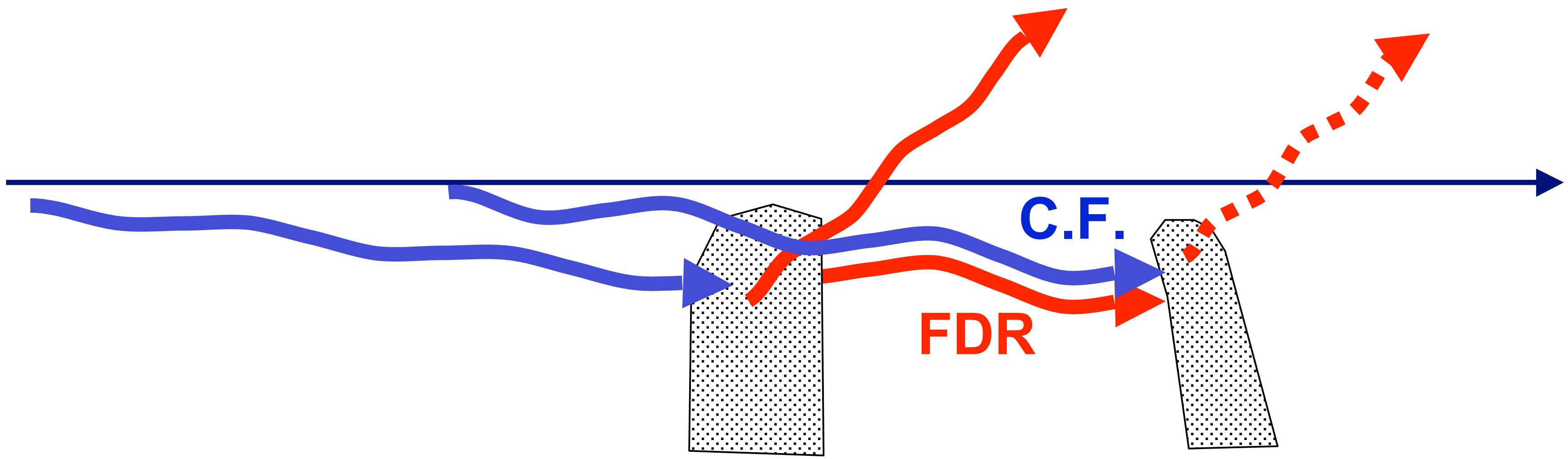


Difference with the last figure:

only **one side** of the Coulomb field was removed.

THIS NEED TO BE TESTED EXPERIMENTALLY !

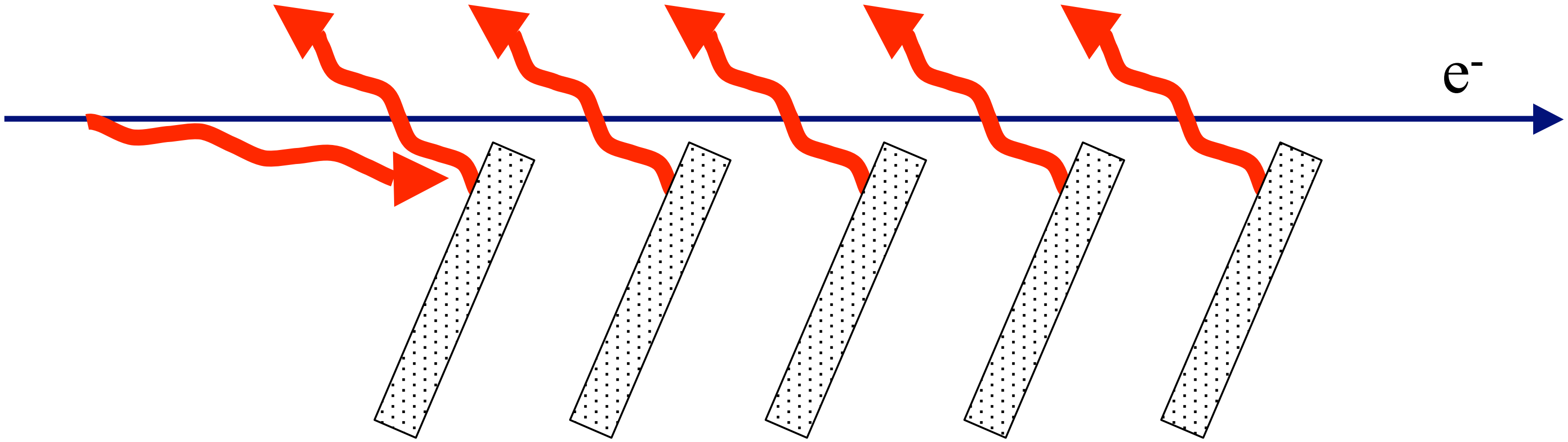
Another point of view of shadowing



The Coulomb field (**C.F.**) of the particle and the Forward diffracted radiation (**FDR**) interfere ***destructively.***

→ Shadow effect is a *rescattering* effect (like the *dynamical effect* in PXR)

Shadow effect in Smith-Purcell radiation

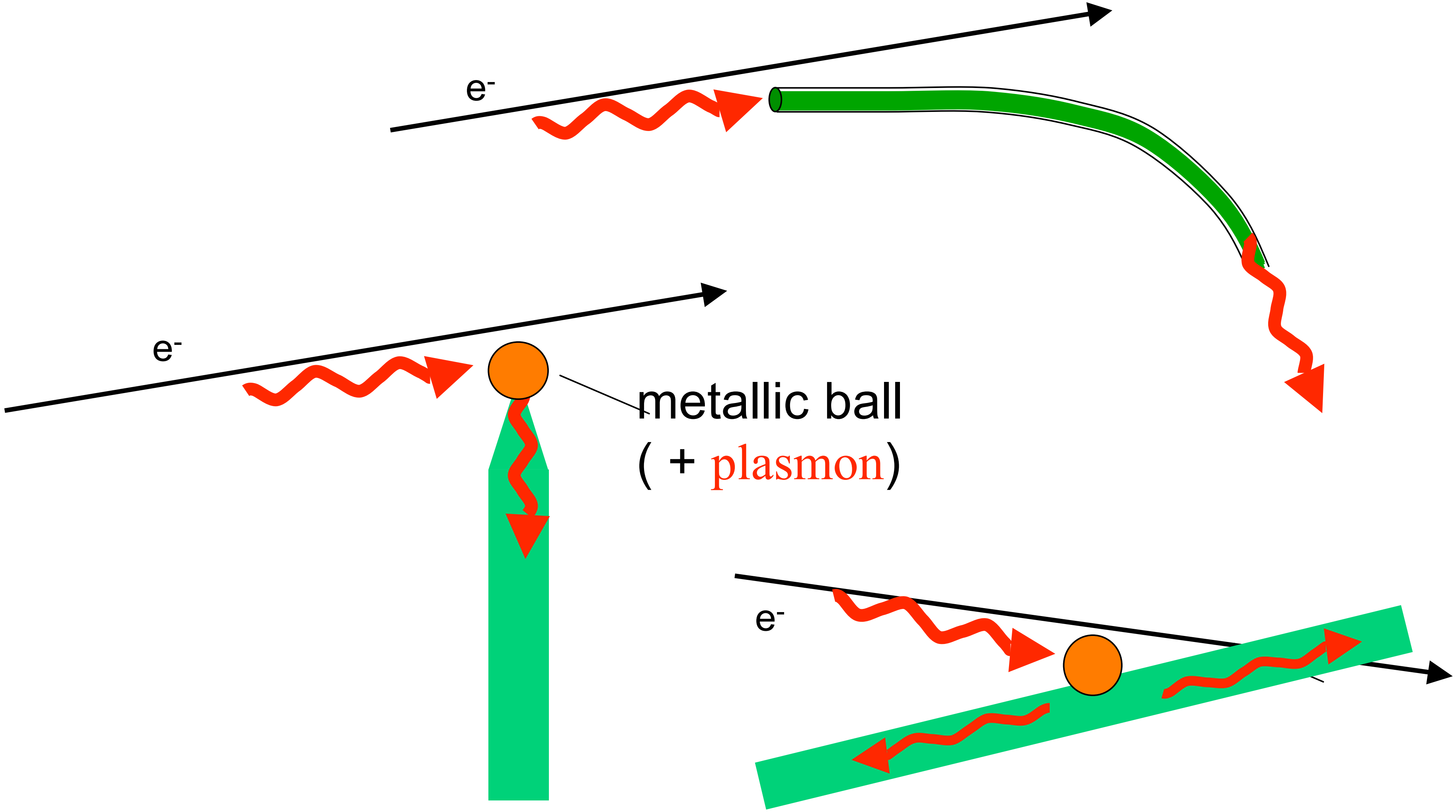


Example: periodic set of foils.

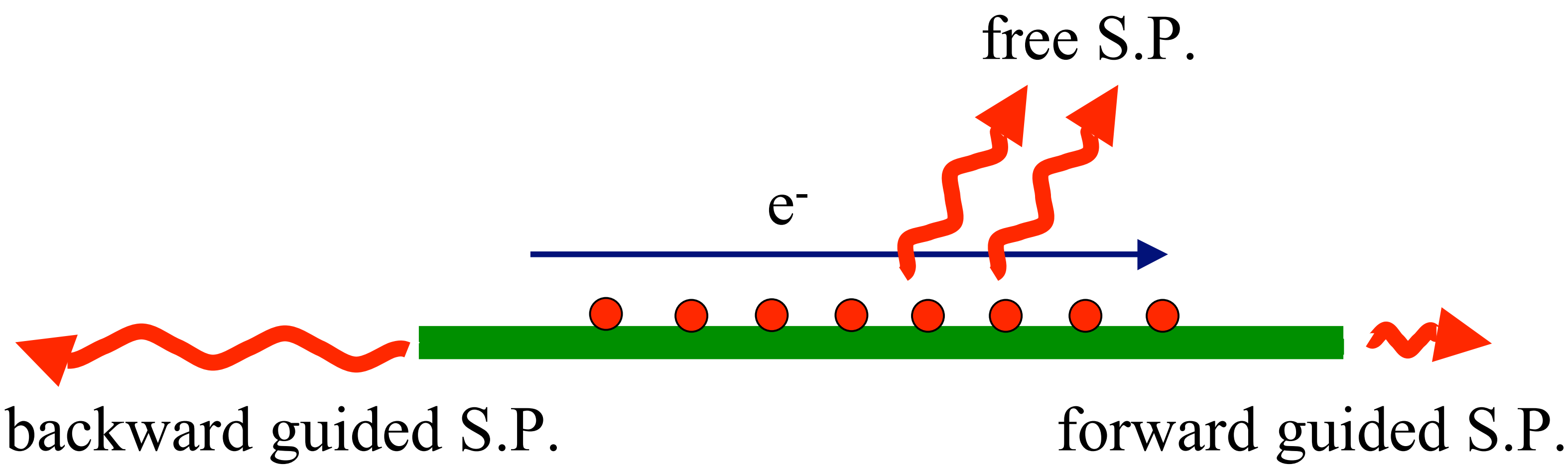
Adding the single-foil Diffraction Radiation amplitudes amplitudes (i.e., neglecting the shadow effect) leads to **over-estimate** the radiated energy.

Another example of light production:
Capture of virtual photons in an optical fiber

(X. A., C. Ray, RREPS'O7)



Regularly spaced balls:
→ *free* and *guided* Smith-Purcell radiations



Due to shadowing, the free and guided wave amplitudes are less than the *coherent addition* of single-ball amplitudes

Possible « universal » bound for Smith-Purcell Radiation

Can one increase the *total linear power* dW/dz of a S.P. radiator ?

- decrease the groove spacing ?
- increase the groove depth ?

In both cases shadowing will take place !
This suggests an universal upper bound for dW/dz:

$$dW/dz < C\, Z^2 \alpha / b^2 \qquad (\text{for } \gamma >> 1),$$

where b is the impact parameter and C a numerical constant, independent from the radiator material.

- this bound is independent on γ.
- it applies to the *total* energy loss:

W = **radiated** energy + **absorbed** energy.

Rough derivation of the bound

- Total energy in *Diffraction Radiation* from a single foil:

$$W = 3/8\ \gamma\ Z^2\alpha/b \qquad (\ h/2\pi = c = 1\ ;\ \alpha=1/137\ )$$

- Necessary length to « repair » the Coulomb field:

$$L_{min} \sim \gamma\ b$$

The maximum energy is obtained when the foils are spaced by L_{min} ,

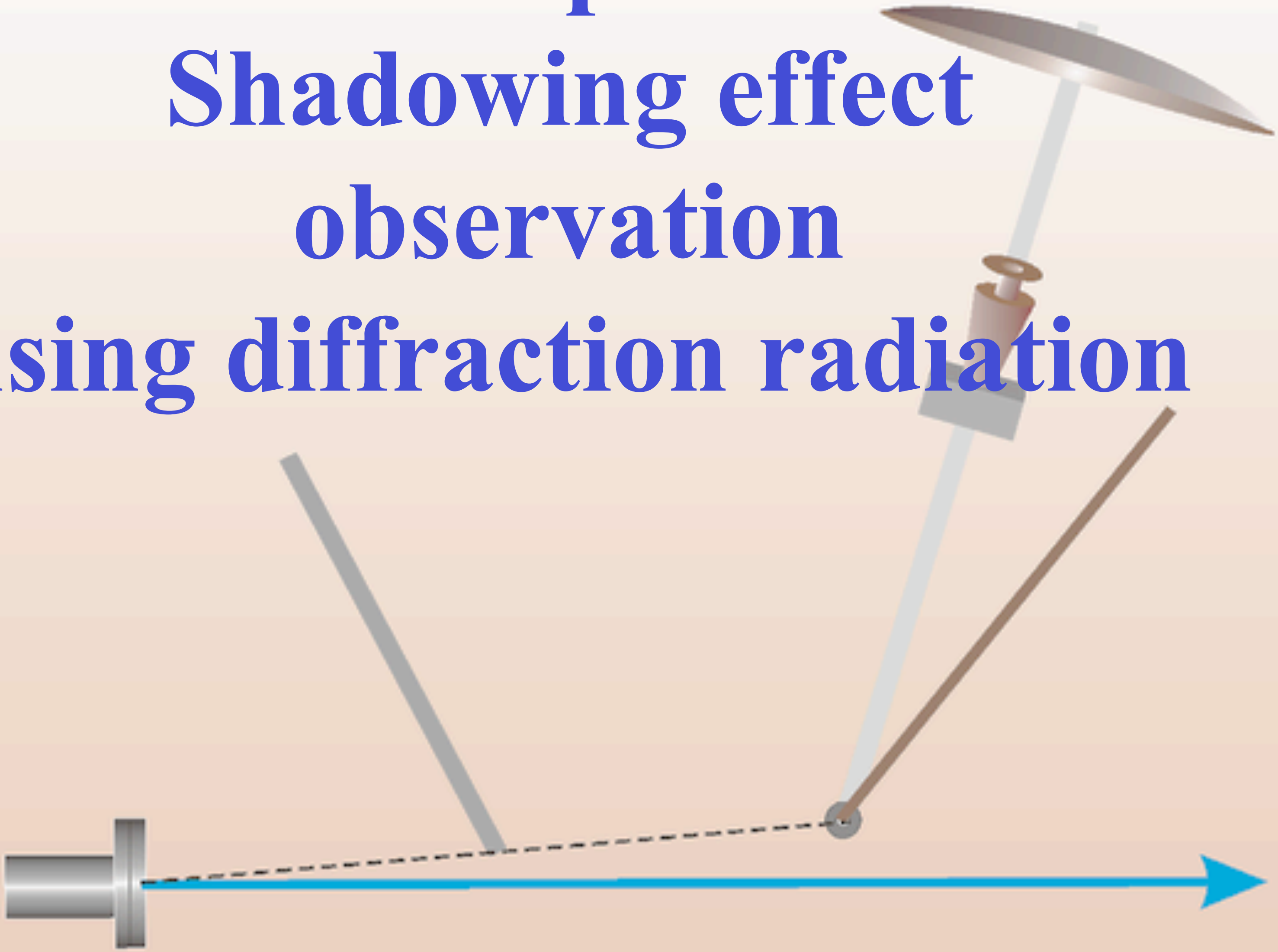
$$(dW/dz)_{max} = W / L_{min} \sim 3/8\ Z^2\alpha\ /b^2,$$

this gives C ~3/8

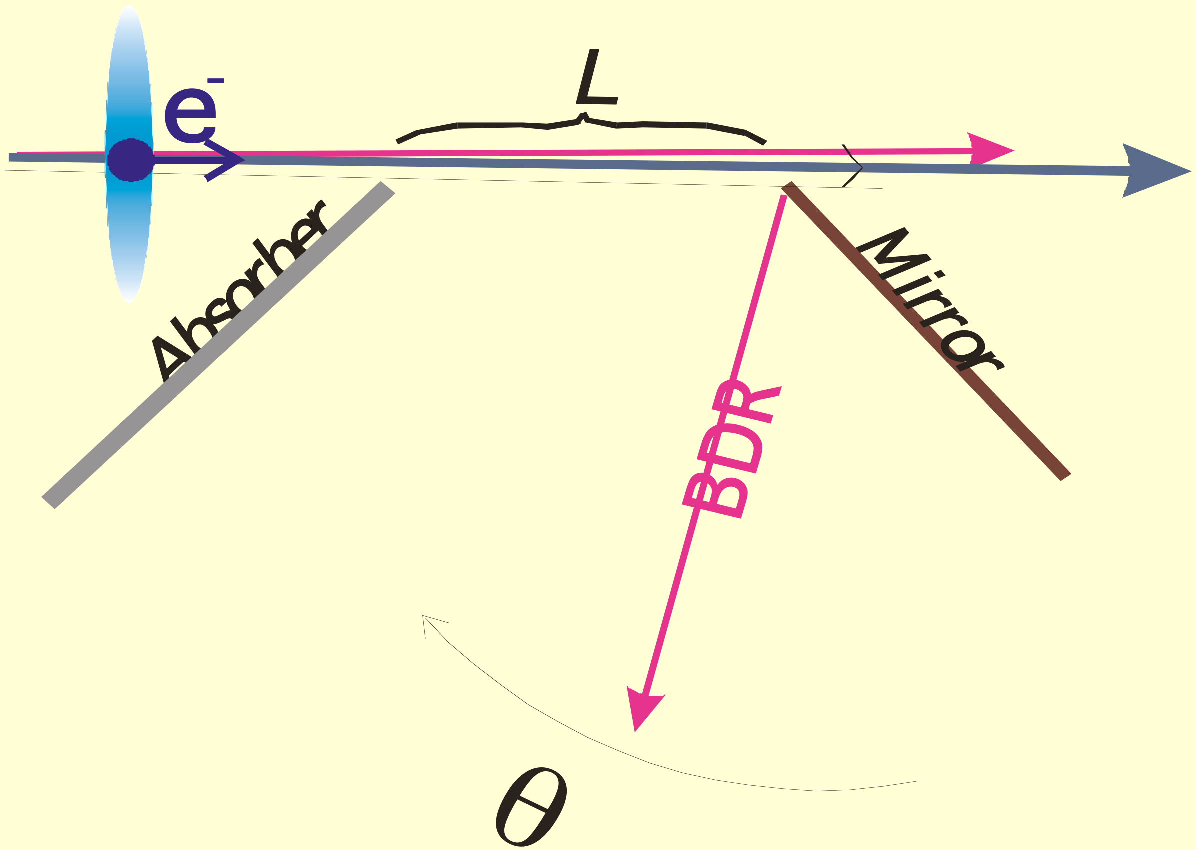
Theoretical question:

- Can this bound be proven rigorously, and eventually improved ?

Tomsk experiment: Shadowing effect observation using diffraction radiation



Scheme of the experiment



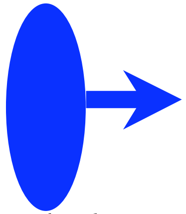
Use **bunch-coherent** radiation:

- to increases the signal by several (~8) orders of magnitude
- to make the incoherent backgrounds unimportant

Tomsk microtron electron beam

Beam parameters

bunch



$N \approx 10^8$

$\sigma_l \approx 1.6\ mm$

$\lambda > 9mm$

Coherent radiation

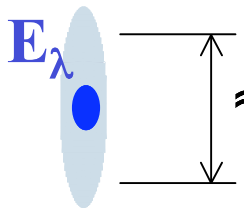
$$\left|\vec{E}\right|^2 = N^2 \left| f\left(\frac{\lambda}{\sigma}\right)\right|^2 \cdot \left|\vec{E}_e\right|^2$$

J. Nodvick, … // Phys.Rev. 96 - 1 (1954) P. 180.

Formation length

$$\frac{\gamma^2\lambda}{4} \approx \frac{12^2 \cdot 11\ mm}{4} = 0.4\ m$$

Electron field size



$\approx 2\gamma\lambda$

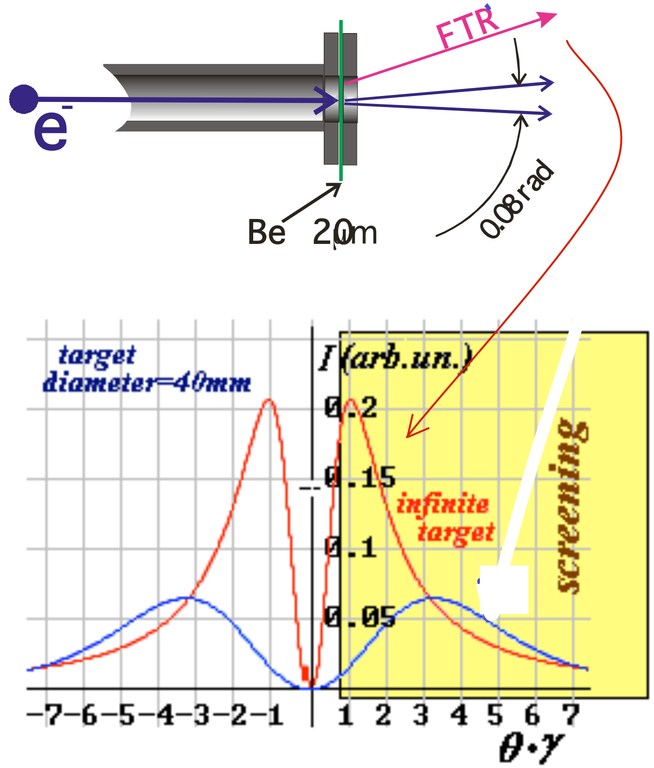
$$\gamma\lambda \approx 12 \cdot 11\ mm = 130\ mm$$

Experimental equipment and technique

Beam parameters

Electron energy	6.1 MeV
Macro-pulse duration	2~6 ms
Pulse repetition rate	1~8 Hz
Micro-pulse length	≈ 6 mm
Electrons number per micro-pulse	$\approx 10^8$
Micro-pulses number per macro-pulse	$\approx 10^4$
Beam size at the output	4×2 mm^2
Emittance: horizontal	$3\cdot10^{-2}$ mm ×rad
vertical	$1.5\cdot10^{-2}$ mm ×rad

Beam extraction



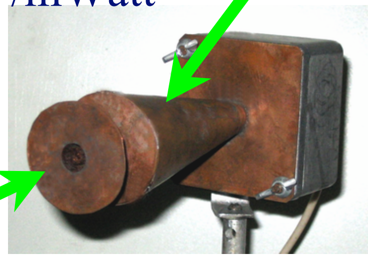
Detector

The detector efficiency is declared by the manufacturer in the wavelength region λ=3 ~16 mm as a constant with accuracy ± 15%

Detector parameters :

wavelength range: = 3 ~ 16 mm, ***Horn***

sensitivity = 0.3 V/mWatt



λ_{cut}**=17 mm**

Beyond cutoff waveguide

Broad bend detector

γ=12; λ=9~17 mm

Coherency

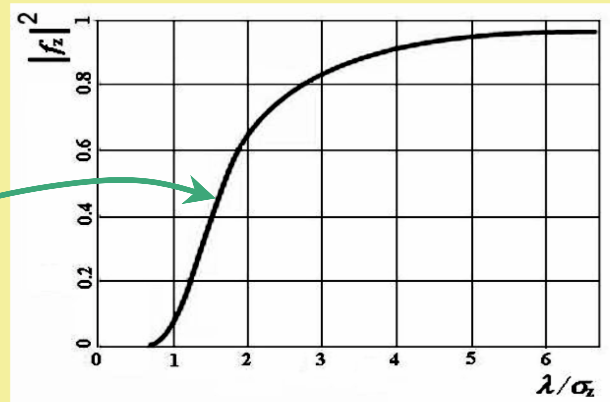
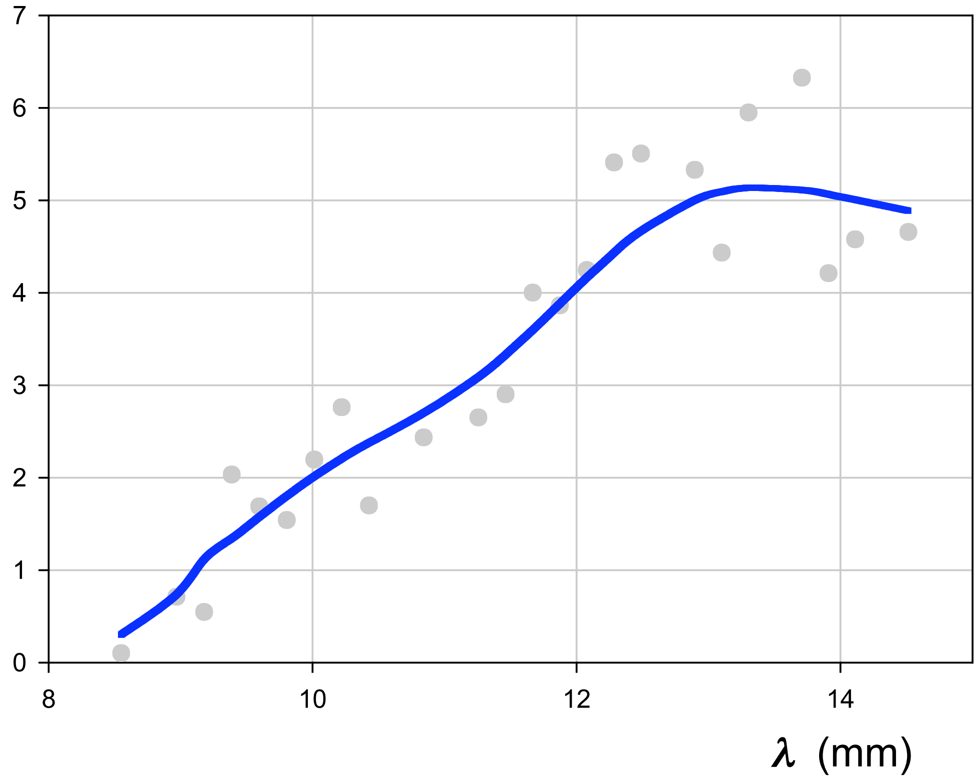


Fig.4 Dependence of the squared form-factor module on the radiation wavelength for the gaussian longitudinal distribution of electrons in a bunch.

Coherent radiation spectrum

BTR spectrum in wavelength region λ=8~15 mm, using the spectrometer of the grating type



Test of BTR, using the discrete wave filters, type of K.Hanke (CLIC note 298, 19. 04.1996) shows also, that the radiation is absent for λ<9mm

So $\lambda > 9$ mm

$\gamma = 12$

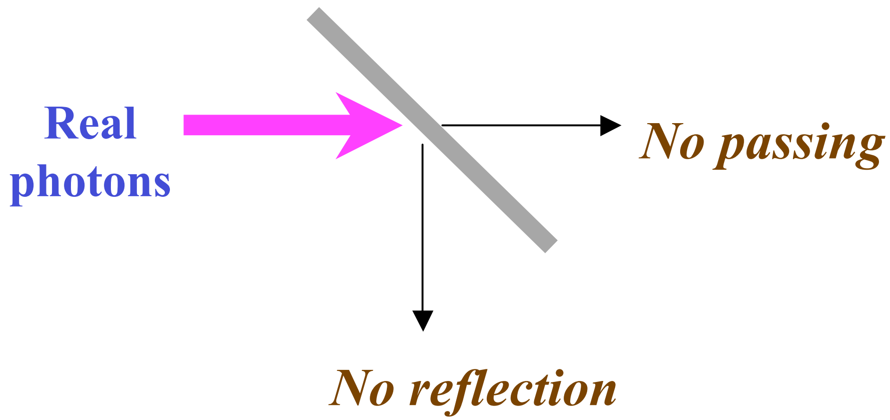
$\gamma\lambda > 110$ mm

$\gamma^2\lambda/4 > 300$ mm

Tests of absorber

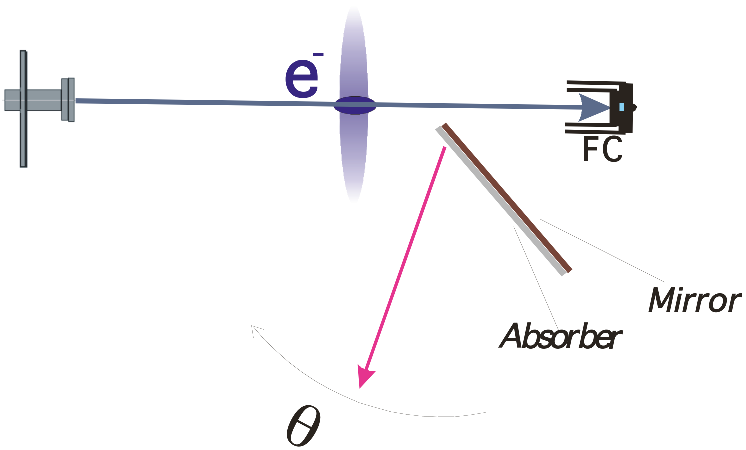
- ***Test on real photons***

  Test was performed using the 6 mm wavelength radiator



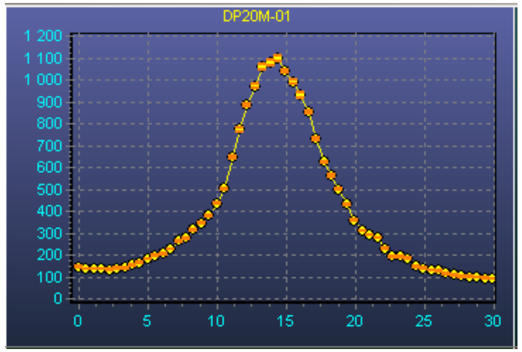
- ***Test on pseudo-photons***

Backward DR angular distribution

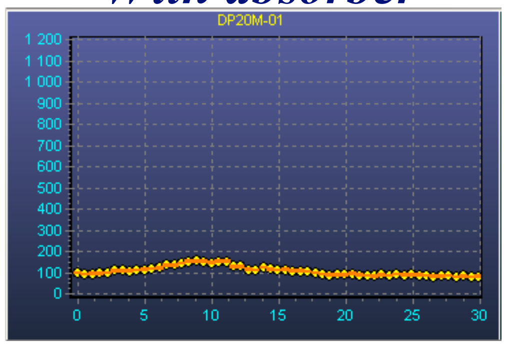


No reflection registered

Without absorber



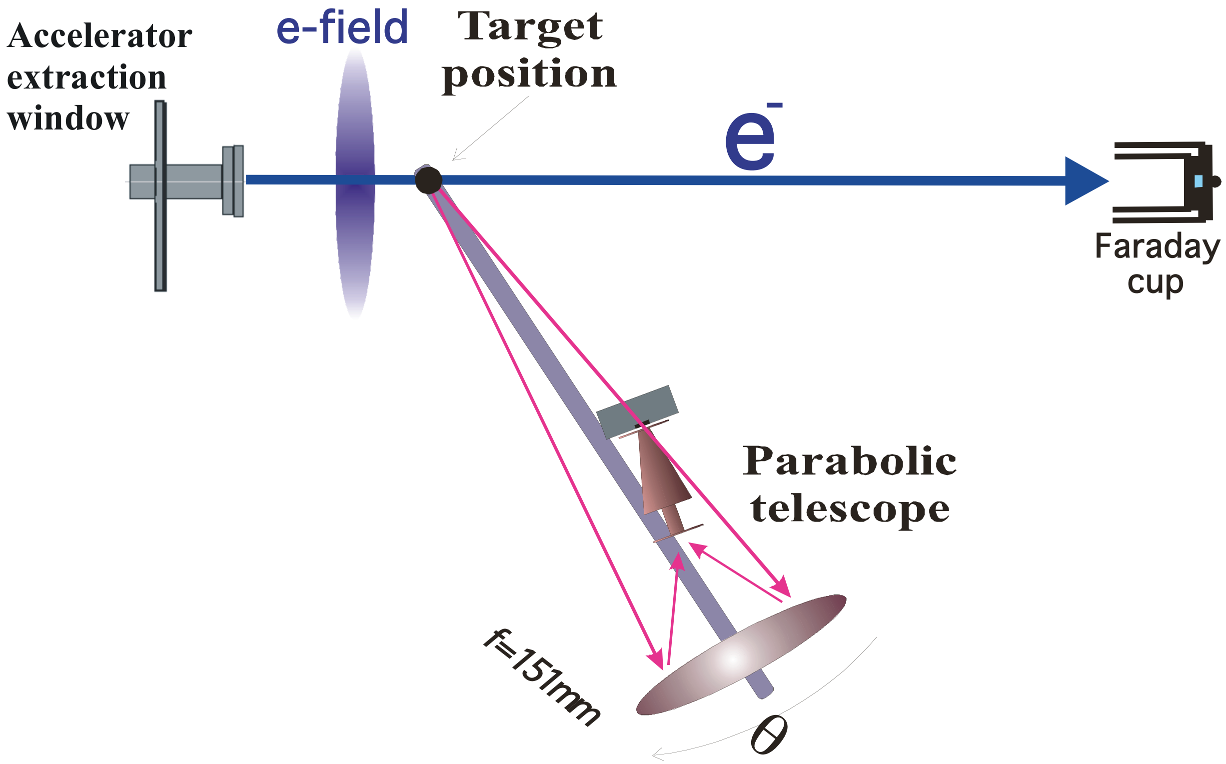
With absorber



Method of angular distribution measurements

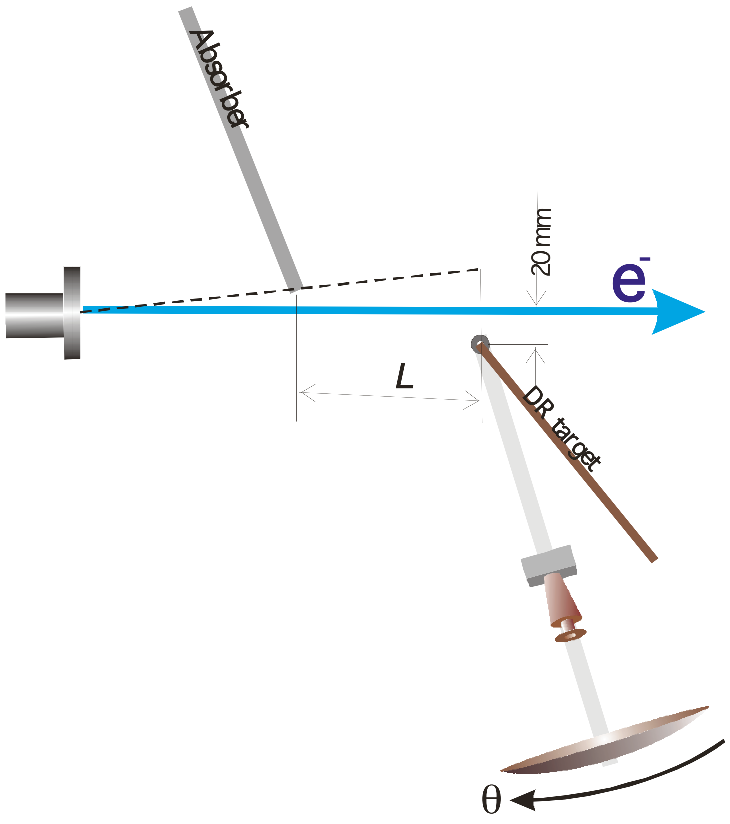
Parabolic telescope was used for angular distribution measurement to exclude the "pre-wave" zone effect contribution.

B.N. Kalinin, G.A. Naumenko, A.P. Potylitsyn et al, JETP Letters, 84, 3, (2006), p. 110.

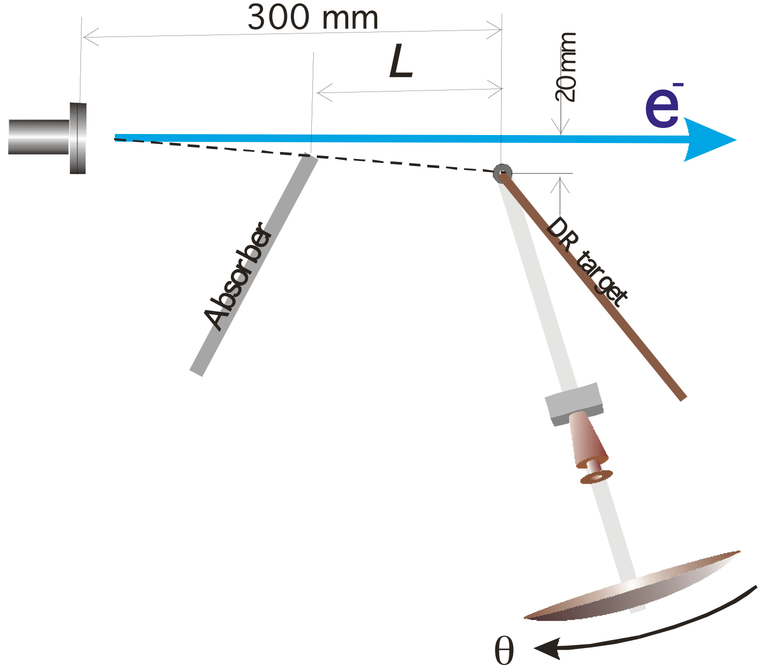


Experimental results

a) opposite sides



b) same side

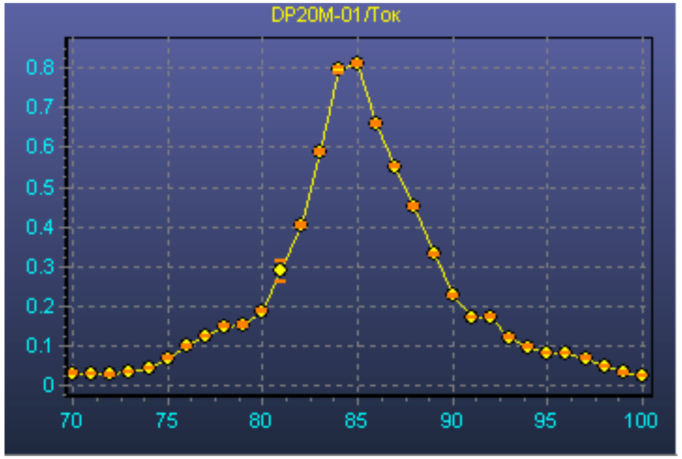


BDR angular distribution

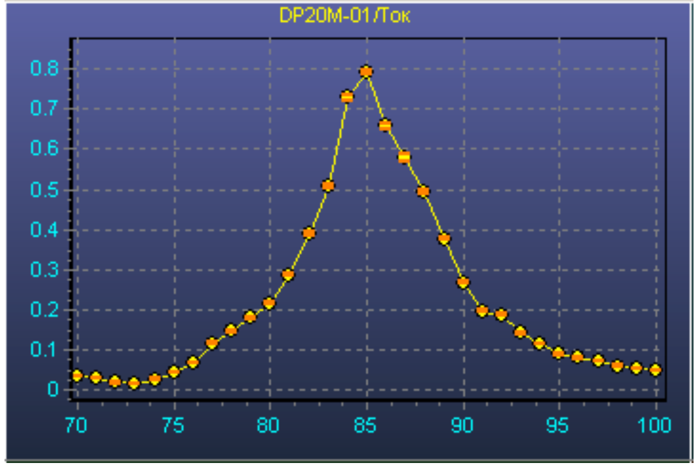
Scans on *L* with step=20 mm (**samples,** with the same scale)

a) opposite sides

L=20 mm

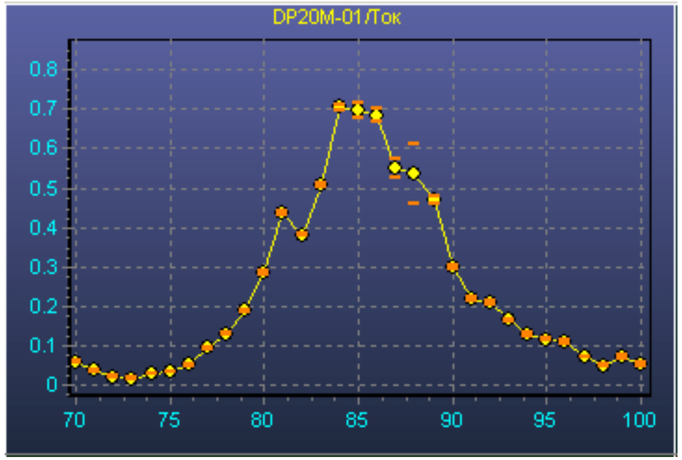


L=80 mm

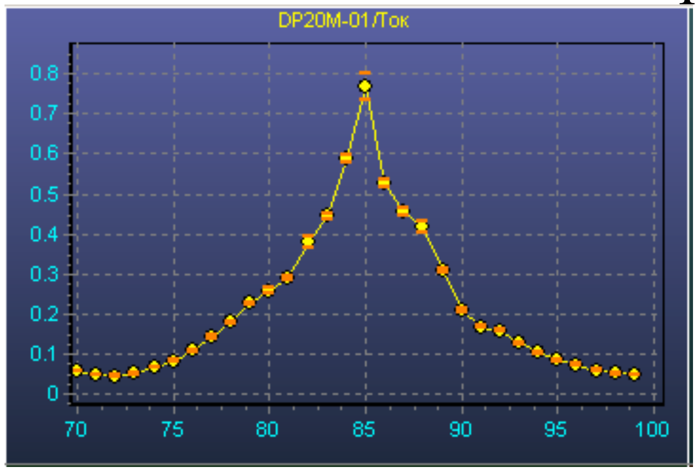


~ No L dependance!

L=160 mm



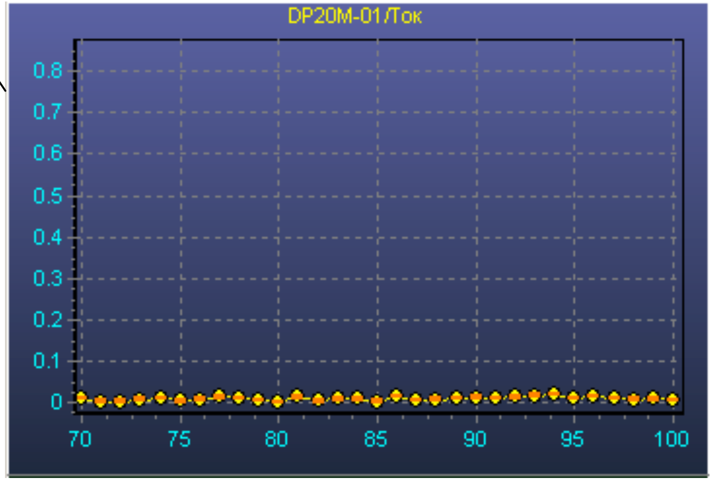
L=220 mm



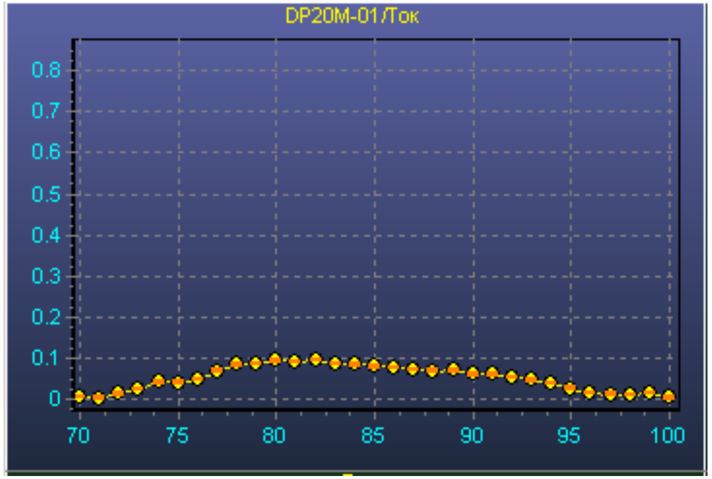
b) Same side

complete shadowing

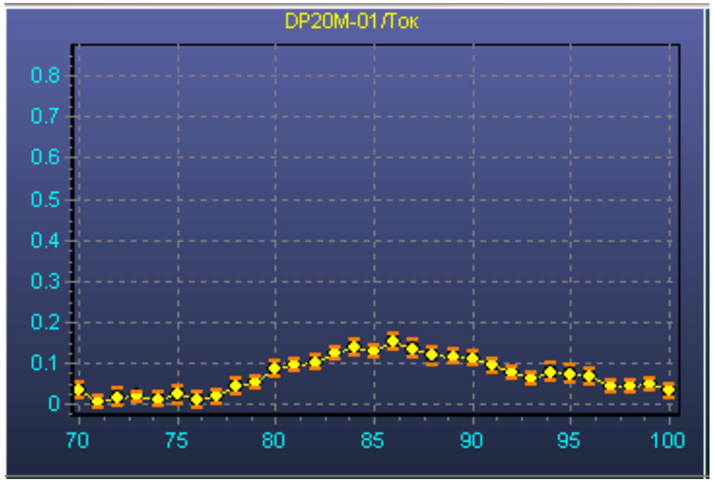
L=20 mm



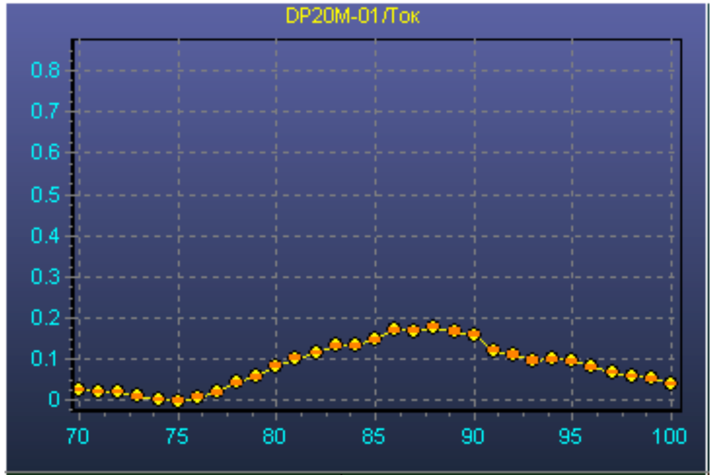
L=80 mm



L=160 mm



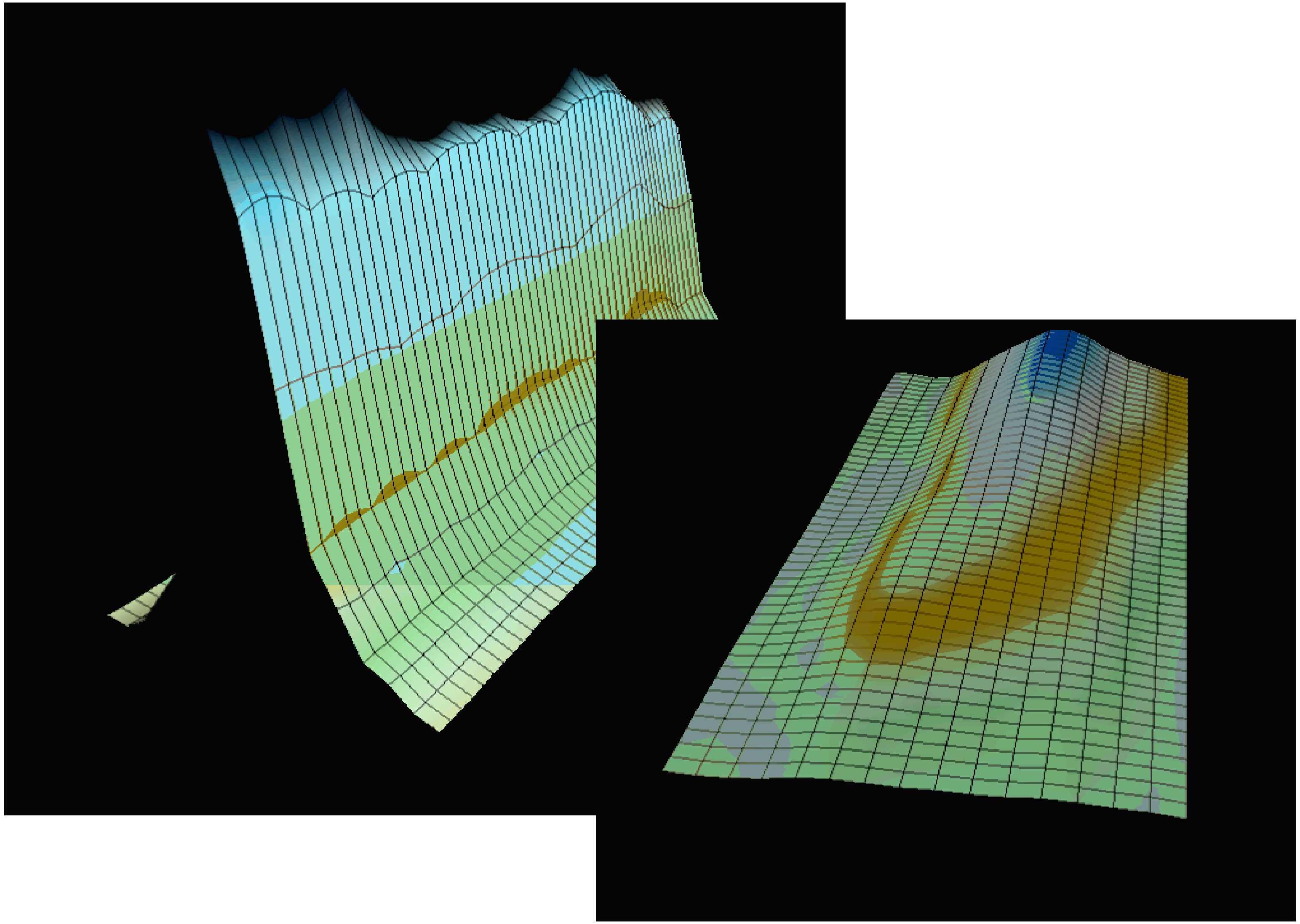
L=220 mm



partial shadowing

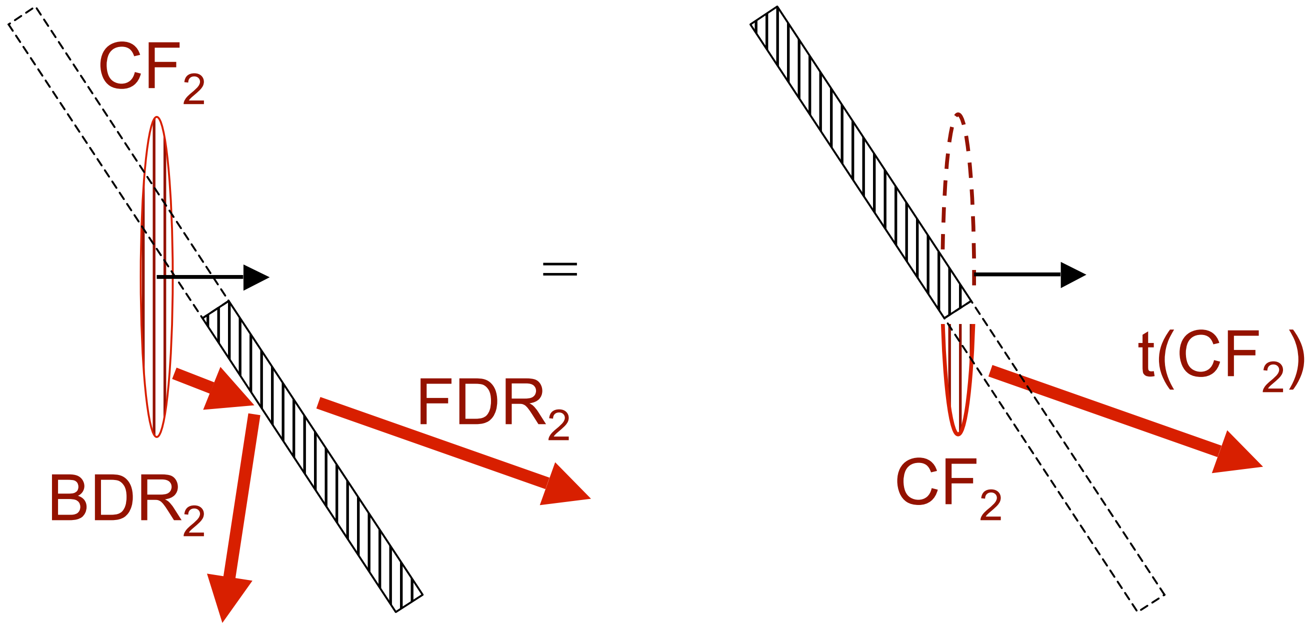
Total dependencies

***a*) *b*)**

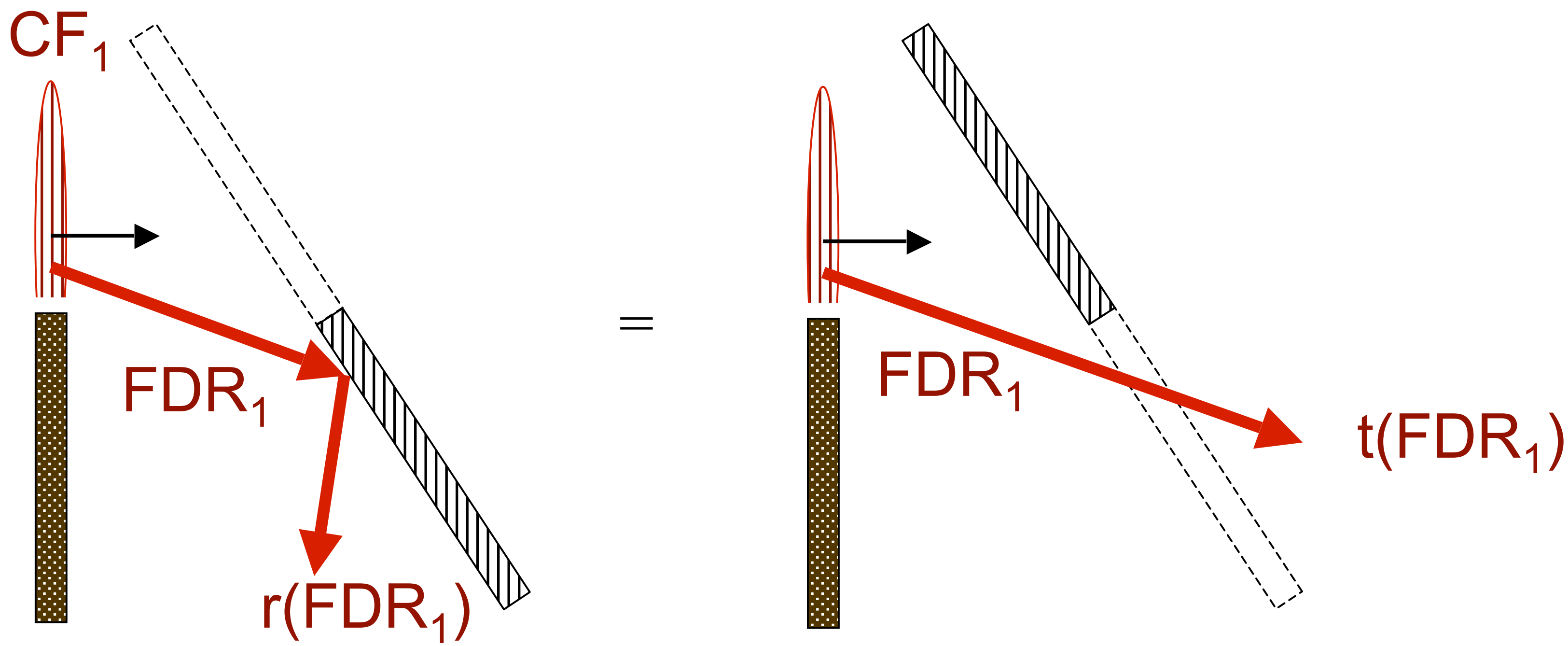


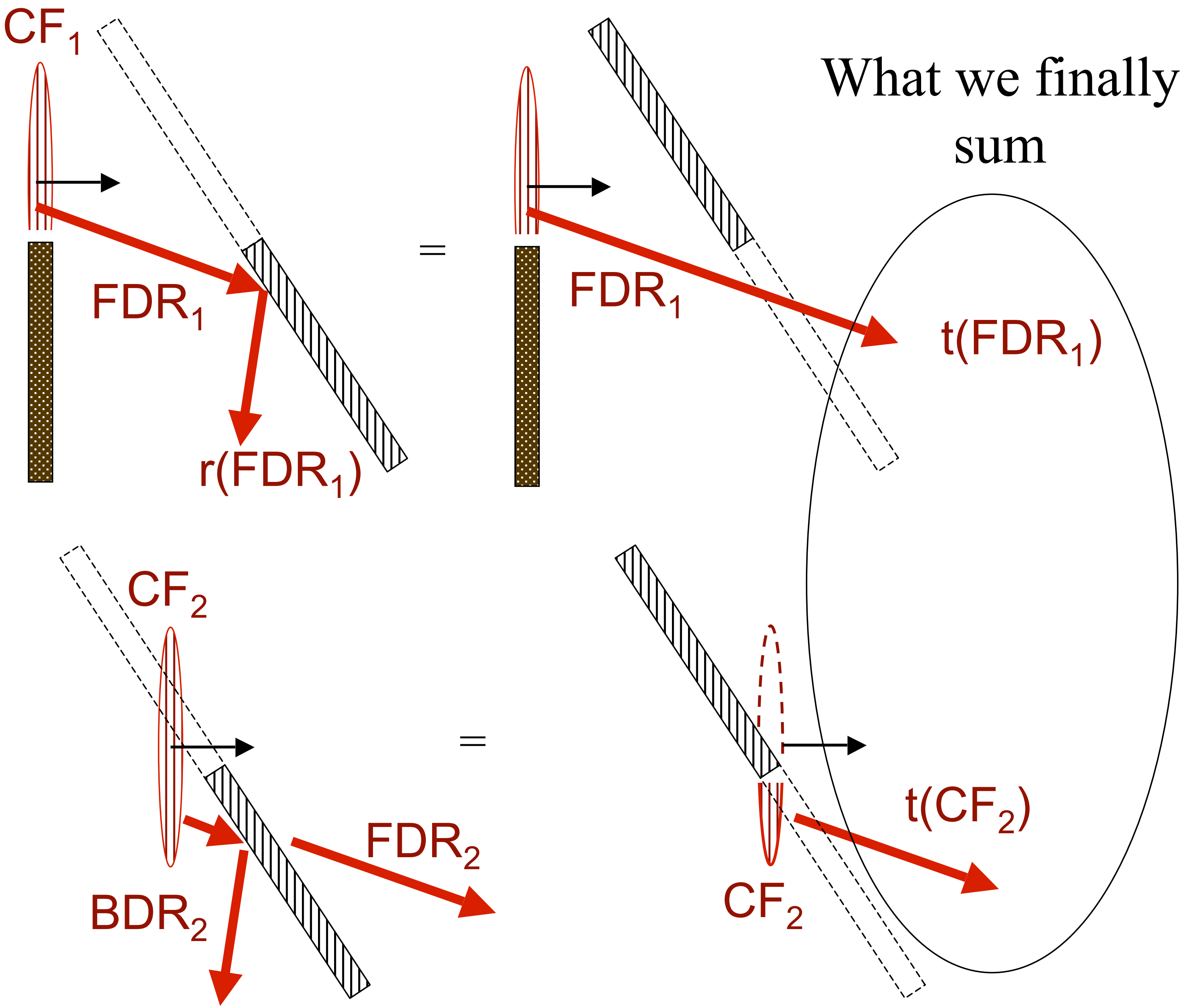
Theoretical treatment or FDR and BDR

(2 = the mirror)



Theoretical treatment.
FDR from absorber





CF1
FDR1
r(FDR1)
=
FDR1
What we finally sum
t(FDR1)
CF2
BDR2
FDR2
=
t(CF2)
CF2

Résumé

1. **The shadowing of an electron electromagnetic field in macroscopic mode was observed; the asymmetry of the shadow was checked.**
2. **Theoretical calculations of BDR from shadowed electron field have been undertaken** (considering the interference of FDR from absorber with BDR from conductive target)
3. **Wanted: a rigorous proof (or disprove) of an upper bound of the form $dW/dz < C\, Z^2\alpha/b^2$ for the Smith-Purcell power.**

Thanks to the organizing committee
and to you for attention