Electromagnetic Processes at High-Energies with “Half-Bare” Particles

N.F.Shul’ga

Akhiezer Institute for Theoretical Physics of NSC KIPT, Kharkov, Ukraine

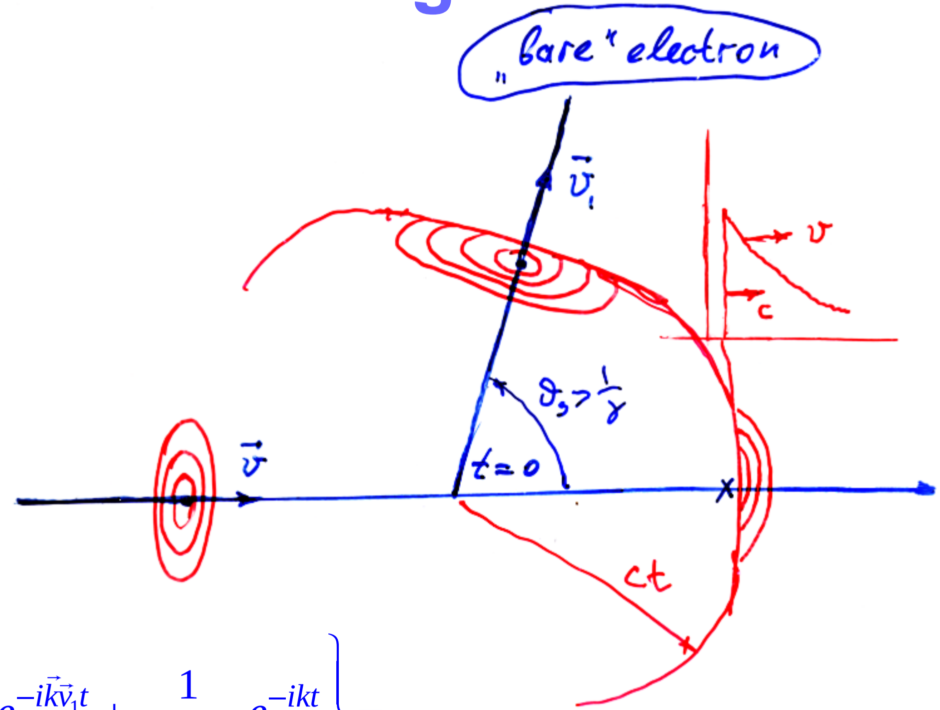
e-mail: shulga@kipt.kharkov.ua

Capri, Italy 2014.

CONTEXT

- “Half-bare” electron
- TSF-effect
- Radiation on two plates
- CB in ultra thin crystal
- CB at beam-beam collision
- Transition radiation
- Ionization energy losses
- Another processes

Evolution of electromagnetic field at electron's scattering



$$\left(\Delta-\frac{\partial^2}{\partial t^2}\right)\varphi=4\pi e\delta\left(\vec{r}-\vec{r}\left(t\right)\right)$$

$$\varphi_v\left(\vec{r},t\right)=\frac{e}{\sqrt{\left(z-vt\right)^2+\rho/\gamma^2}},\qquad t<0$$

$$\varphi_{ret}\left(\vec{r},t\right)\Big|_{t>0}=\frac{e}{2\pi^2}\mathrm{Re}\int\frac{d^3k}{k}e^{i\vec{k}\vec{r}}\left\{\frac{1-e^{-i\left(k-\vec{k}\vec{v}_1\right)t}}{\omega-\vec{k}\vec{v}}e^{-i\vec{k}\vec{v}_1 t}+\frac{1}{k-\vec{k}\vec{v}}e^{-ikt}\right\}=$$

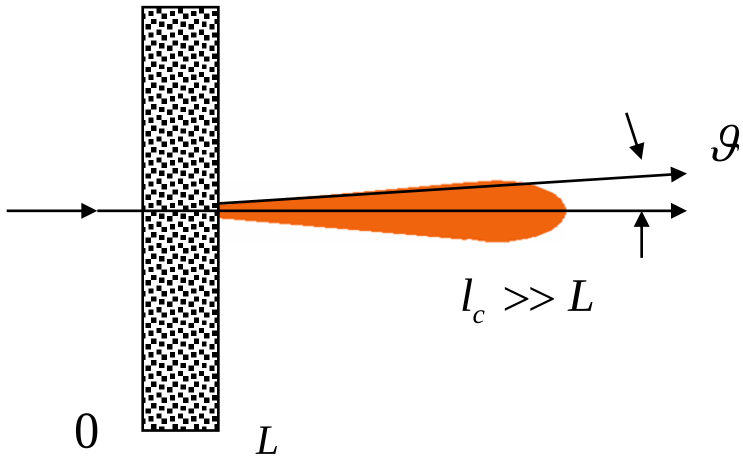
$$=\Theta\left(t-r\right)\varphi_{v_1}\left(\vec{r},t\right)+\Theta\left(r-t\right)\varphi_v\left(\vec{r},t\right)$$

$\Delta t \sim \left(k-kv_1\right)^{-1}\approx 2\gamma^2/v=l_c$ For $\varepsilon=50MeV,\quad \lambda=1cm,\quad l_c=200\ m$

E.Feinberg JETP 50(1966)202, A. Akhiezer, N.Shul'ga, S.Fomin Sov.Phys.Usp. 30(1987)197
Phys.Lett.A 114(1986)148

Radiation in thin target (TSF-effect)

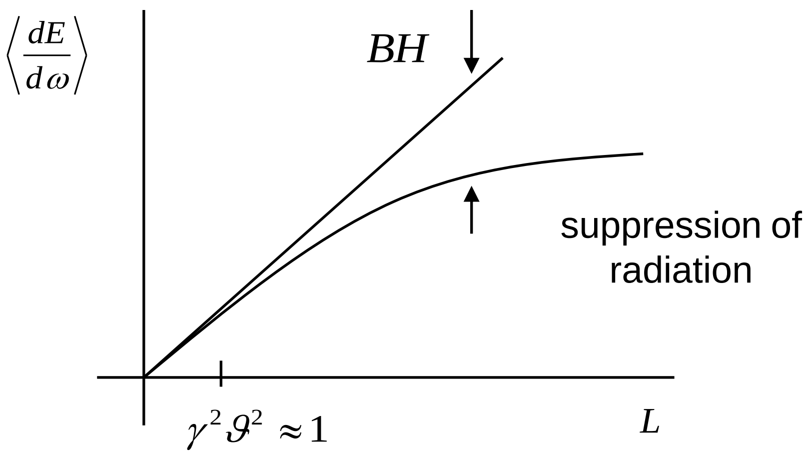
F. **T**ernovskii, JETF 1960, N. **S**hul'ga, S. **F**omin JETP Lett. 1978, 1996



$$l_c = \frac{2\gamma^2}{\omega} \gg L$$

$$\left\langle \frac{dE}{d\omega} \right\rangle = \frac{2e^2}{\pi} \left\langle \left[\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}} \ln\left(\xi + \sqrt{\xi^2+1}\right) - 1 \right] \right\rangle \approx$$

$$\approx \frac{2e^2}{3\pi} \begin{cases} \gamma^2 \overline{\vartheta^2} \\ 3\ln \gamma^2 \overline{\vartheta^2} \end{cases} \approx \begin{cases} E'_{BH} \\ < E'_{BH} \end{cases}$$



$$\xi = \frac{\gamma\vartheta}{2}$$

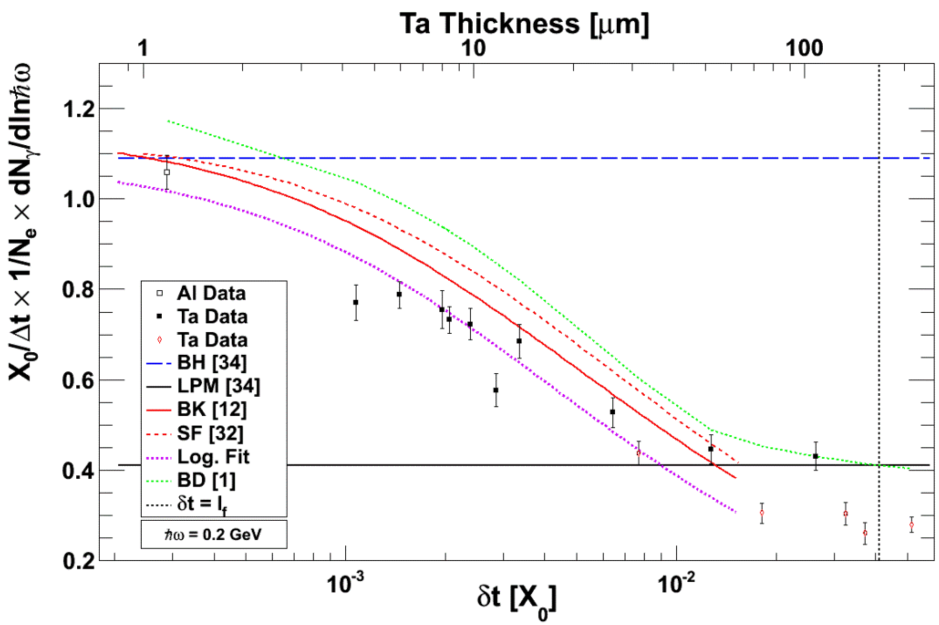
Suppression of radiation by relativistic electrons in a thin layer of matter (TSF effect)

Predicted at KIPT - <u>1978</u> - ***N.F.Shul'ga, S.P.Fomin,*** *JETP Letters,* ***27****(1978)126.*

Confirmed at CERN - <u>2009</u> - ***H.D.Thomsen et al.,*** *Physics Letters B* ***672*** *(2009) 323.*

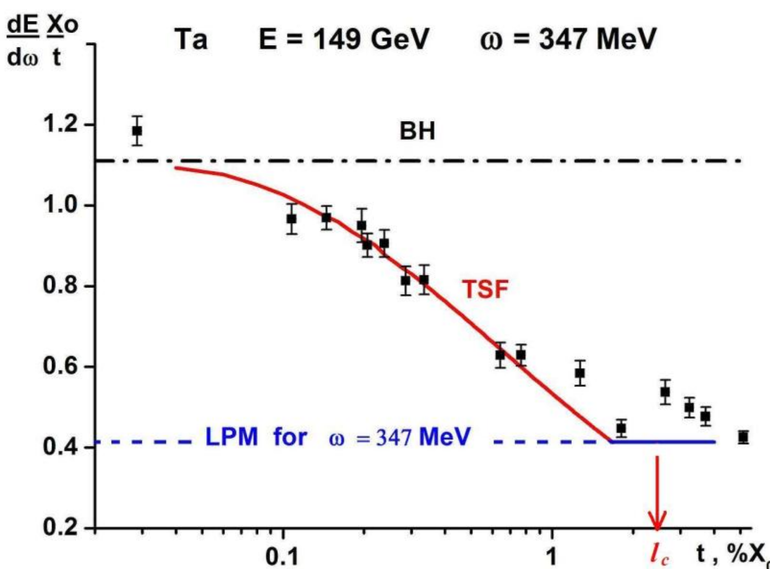
H.D.Thomsen et al., *Physical Review D* ***81*** *(2010) 052003.*

CERN NA63 SPS ***E = 149 GeV***



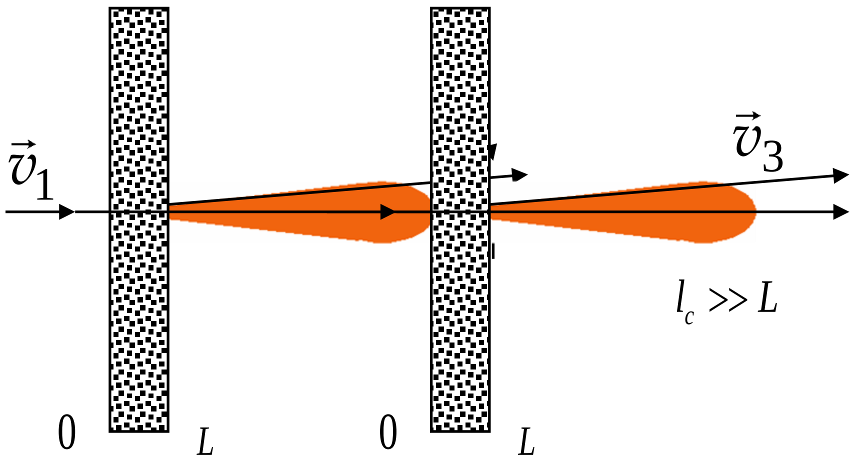
A.S.Fomin, S.P.Fomin, N.F.Shul'ga

Nuovo Cimento (2011)



U. Uggerhøj : … we have seen the half - bare electron !

Radiation on two plates



$$\langle \exp(...) \rangle = \exp\langle ... \rangle$$

qualitative theory

R. Blankenbecler

Phys. Rev. D55 (1997) 2441

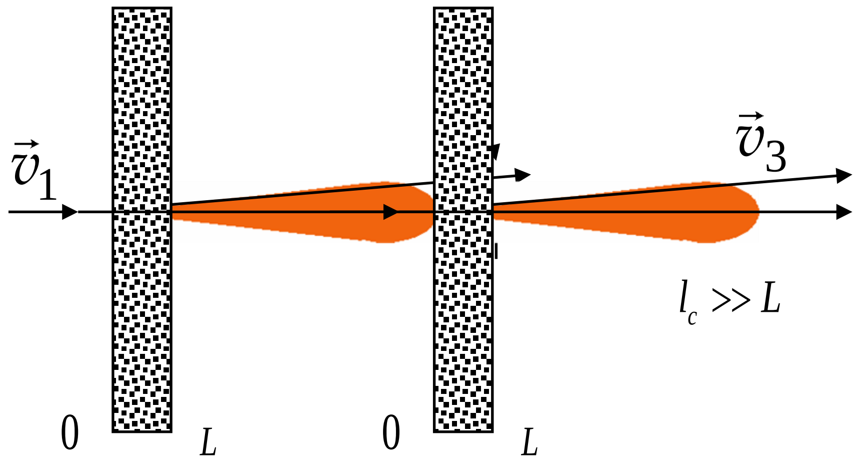
V.Baier, V.Katkov

Phys. Rev. D60 (1999) 071802

$$l_c = \frac{2\gamma^2 / \omega}{1+\gamma^2 \langle \vartheta_s^2 \rangle} \qquad ?$$

Radiation on two plates

N. Bondarenco, N. Shul'ga arxiv: 1406.7269v.1 27.07.2014: Phys. Rev. D 2014



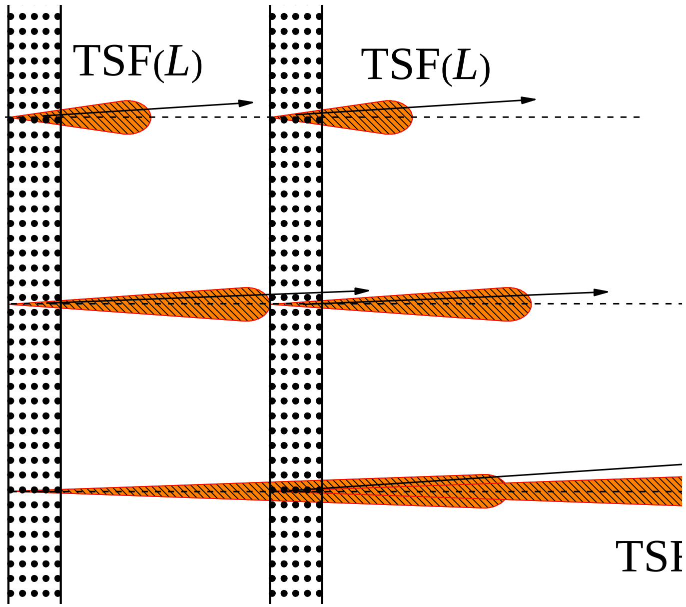
$$\frac{dE}{d\omega do} = \frac{e^2}{4\pi^2}\left|\int dt\, e^{i\omega(t-\vec{n}\vec{r}(t))}\frac{d}{dt}\frac{\vec{v}(t)}{1-\vec{n}\vec{r}(t)}\right|^2$$

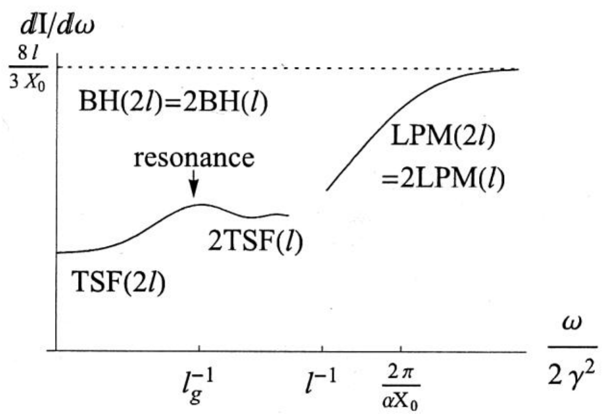
$$\left\langle\frac{dE}{d\omega}\right\rangle = \frac{e^2}{4\pi^2}\left\langle\int do\left|\vec{n}\times\vec{J}_{21}+\vec{n}\times\vec{J}_{32}\cdot e^{i\psi}\right|^2\right\rangle$$

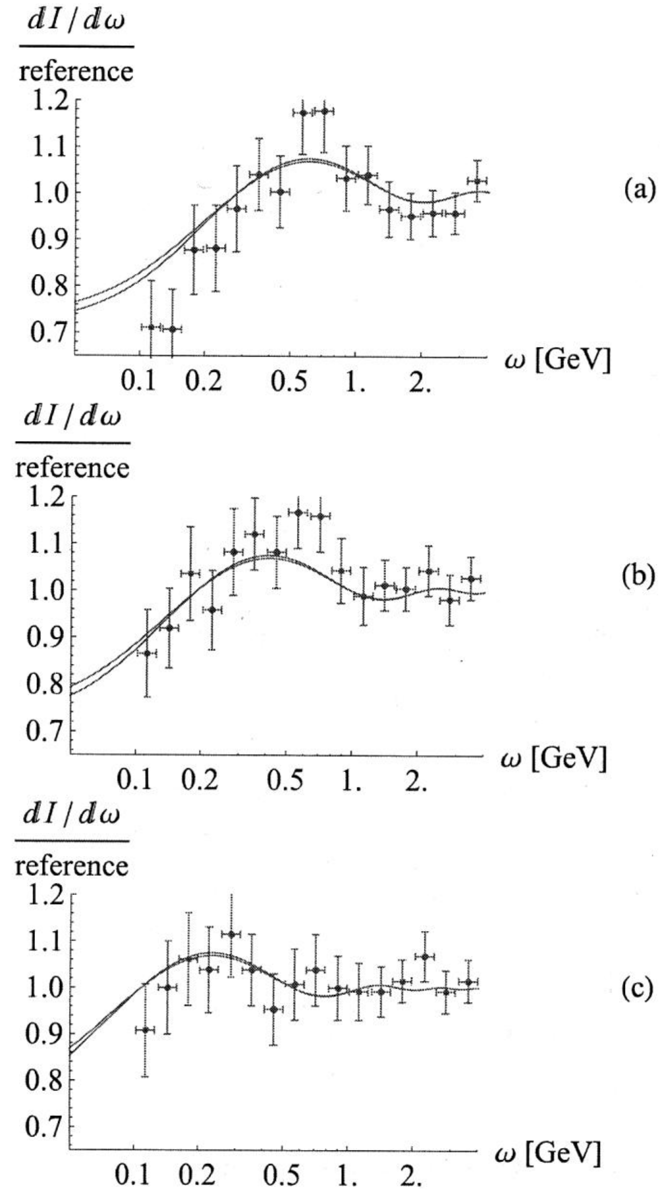
$$\vec{J}_{21} = \frac{\vec{v}_1}{1-\vec{n}\vec{v}_1} - \frac{\vec{v}_2}{1-\vec{n}\vec{v}_2}$$

$$\psi = \omega(t_2 - t_1)(1-\vec{n}\vec{v}_2)$$

Radiation on two plates

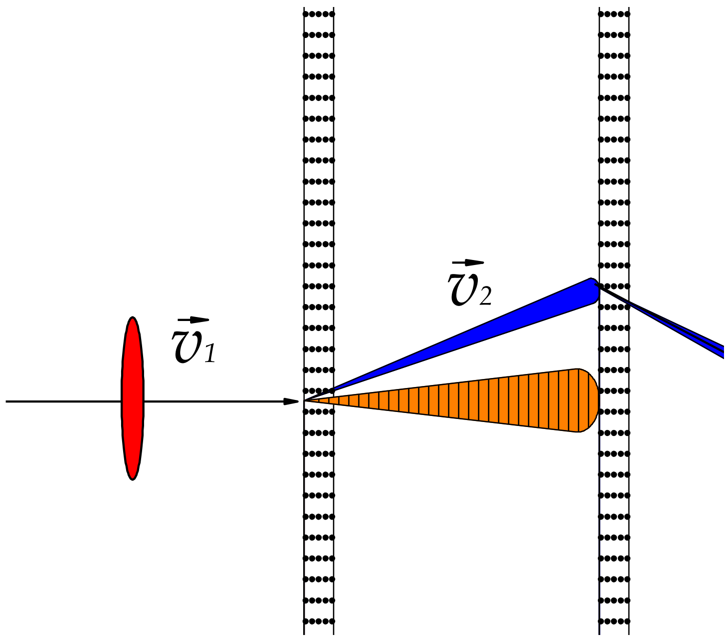


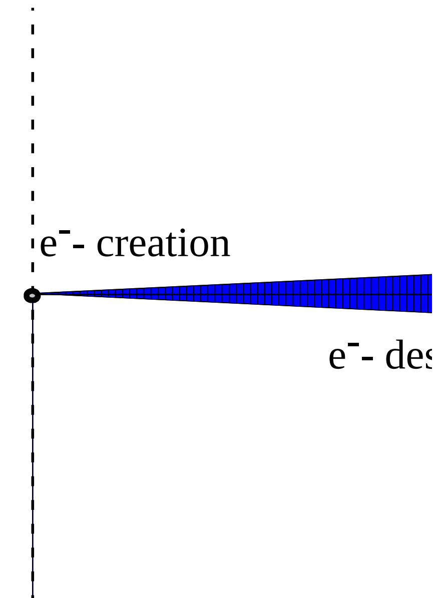




N. Bondarenco, N. Shul'ga. Channeling-2014 (poster)

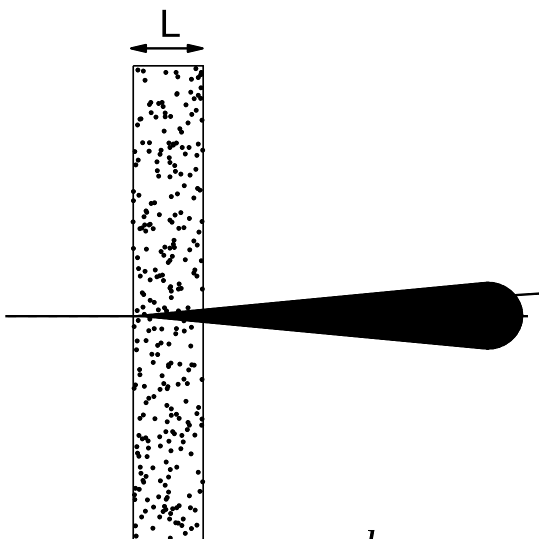
Radiation on two plates (qualitative picture)

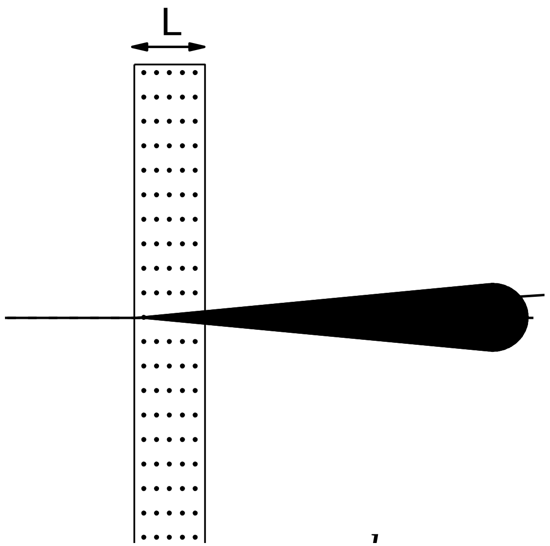




"half-bare electron"

Coherent Radiation in ultrathin crystal

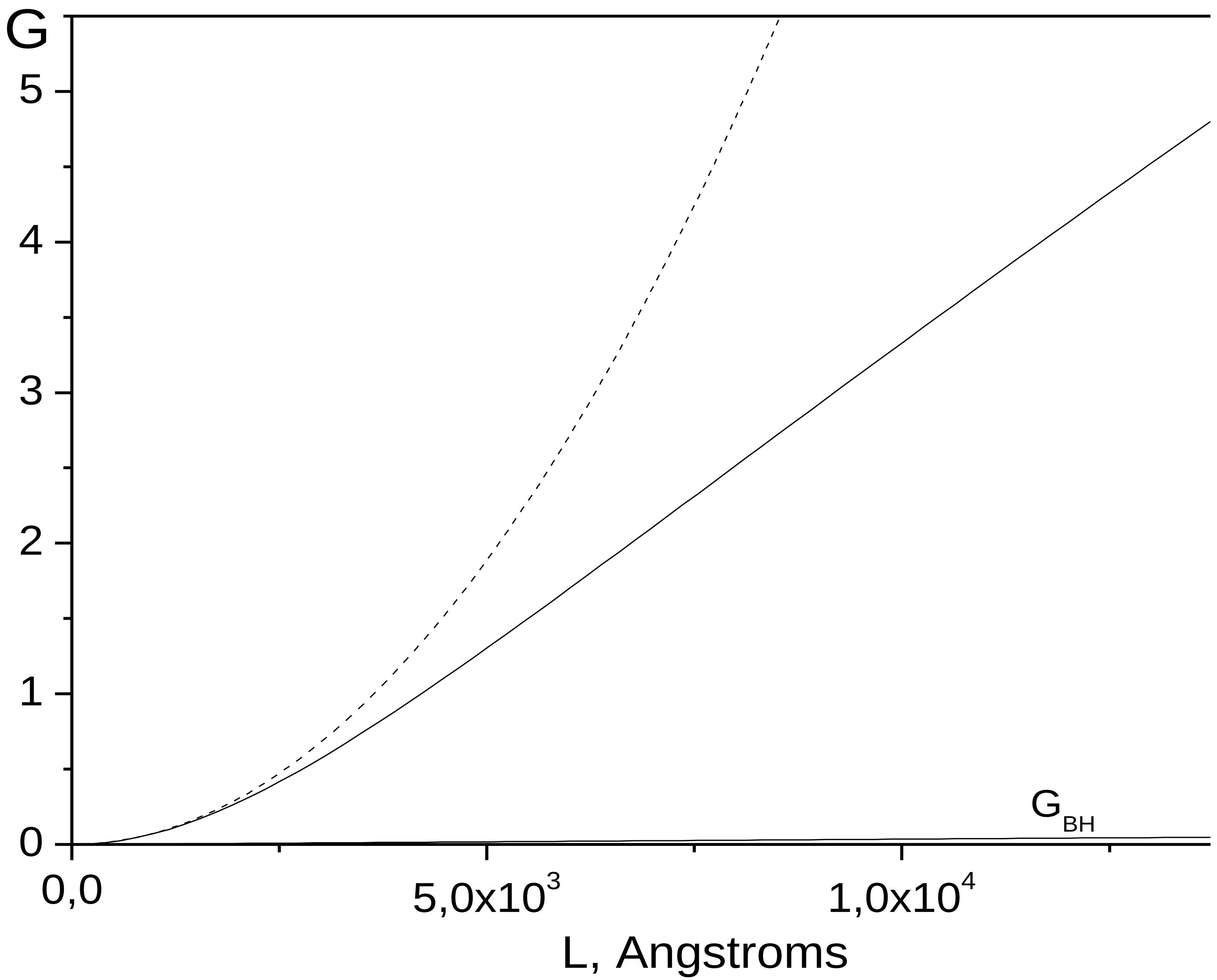




N.Shul’ga, S.Shul’ga, Phys. Lett. A378 (2014) 3074
(Report on Channeling-2014)

CB and suppression of CB in ultrathin crystal

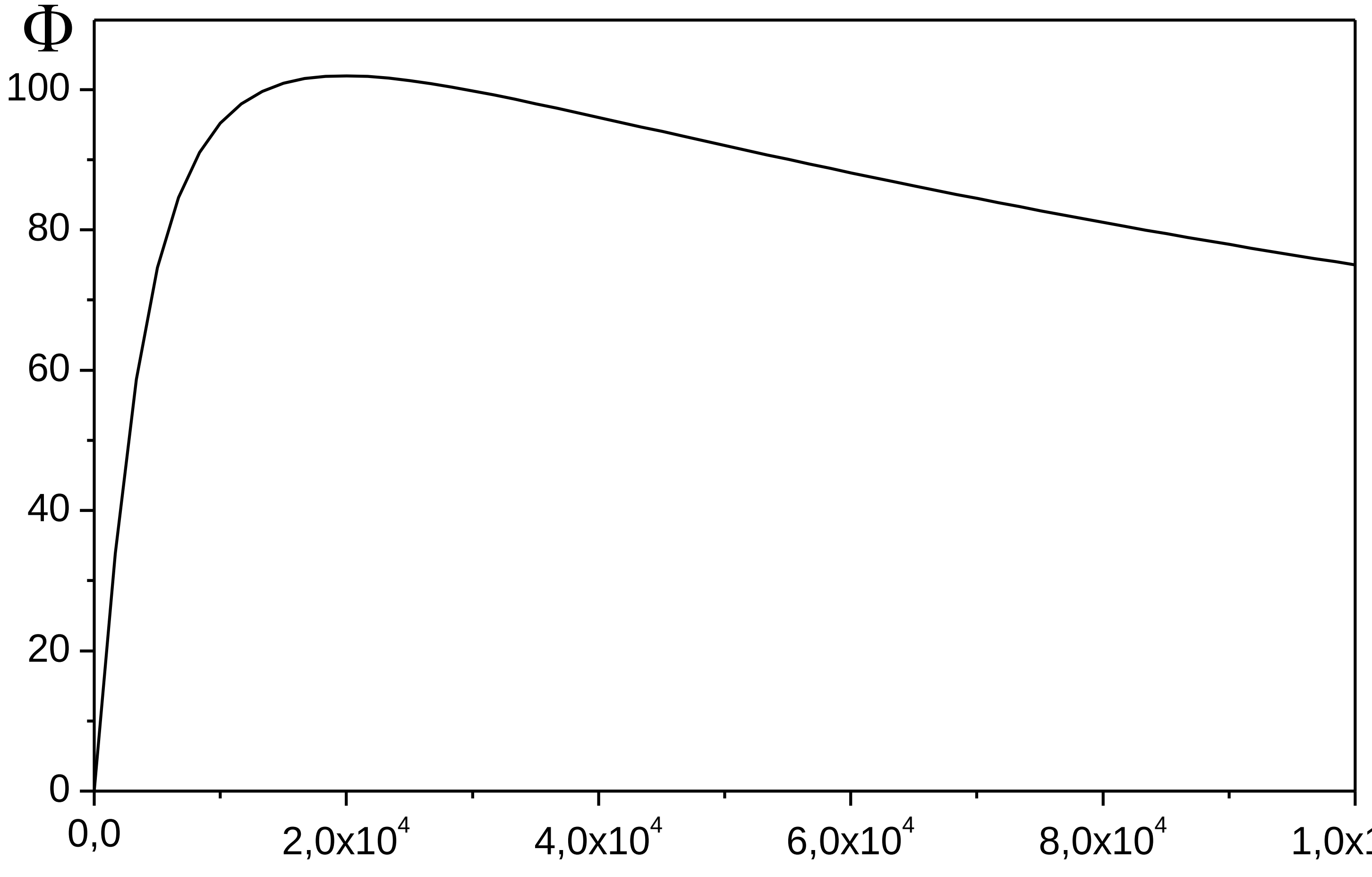
$$G = \frac{1}{A}\frac{d\sigma_c}{d\omega}$$



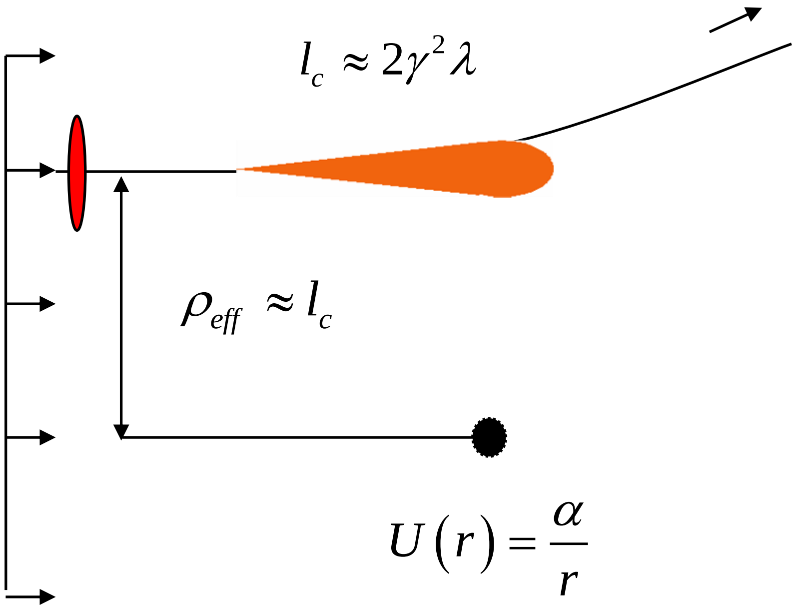
CB and suppression of CB in ultrathin crystal

N.Shul'ga, S.Shul'ga, Phys. Lett. A378 (2014) 3074

$$\Phi = \frac{d\sigma_c / d\omega}{d\sigma_{BH} / d\omega}$$

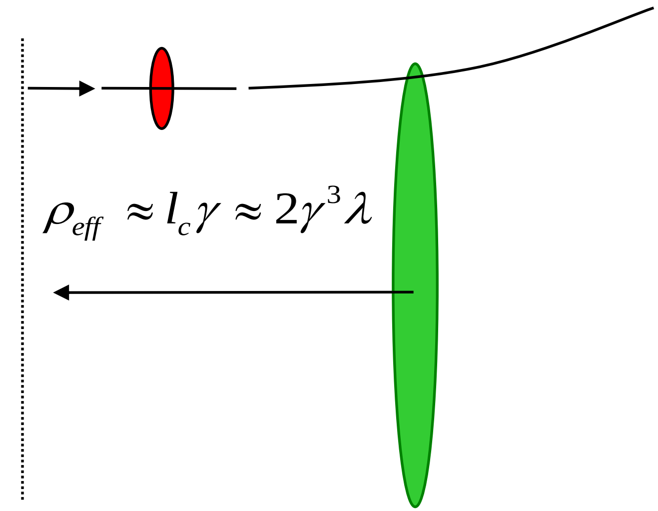


Radiation in Coulomb field of relativistic particle



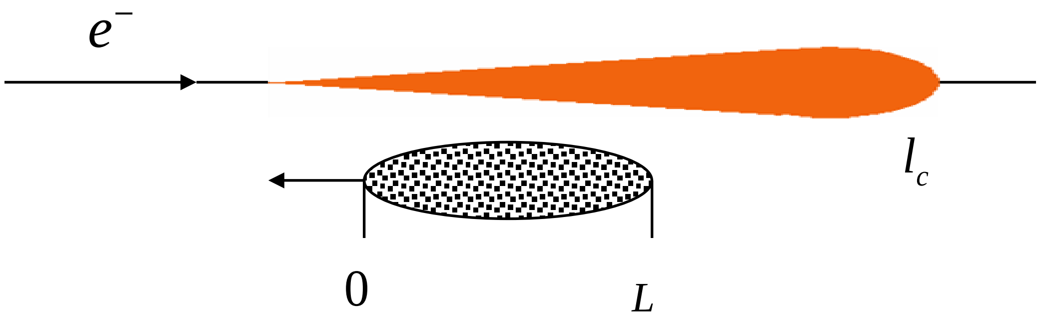
$$U(r) = \frac{\alpha}{r}$$

!!!

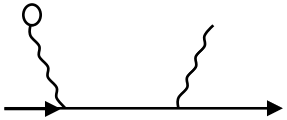


$$U(r) = \frac{\alpha}{\sqrt{(z + vt)^2 + \rho^2 / \gamma^2}}$$

Coherent radiation at electron-beam collision



$$\frac{dE_B}{d\omega} \approx N_B^2$$

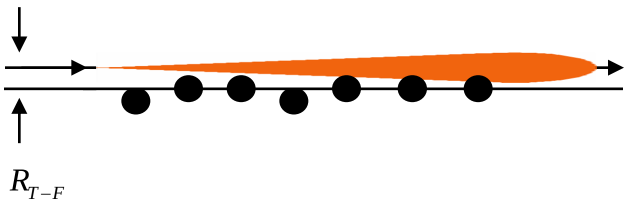


I. Ginzburg, G. Kotkin, S. Polityko, V. Serbo
Phys. Lett. B286 (1992) 395
Phys. Rev. E51 (1995) 2493

$$\frac{N_B e^2}{\hbar c} << 1$$

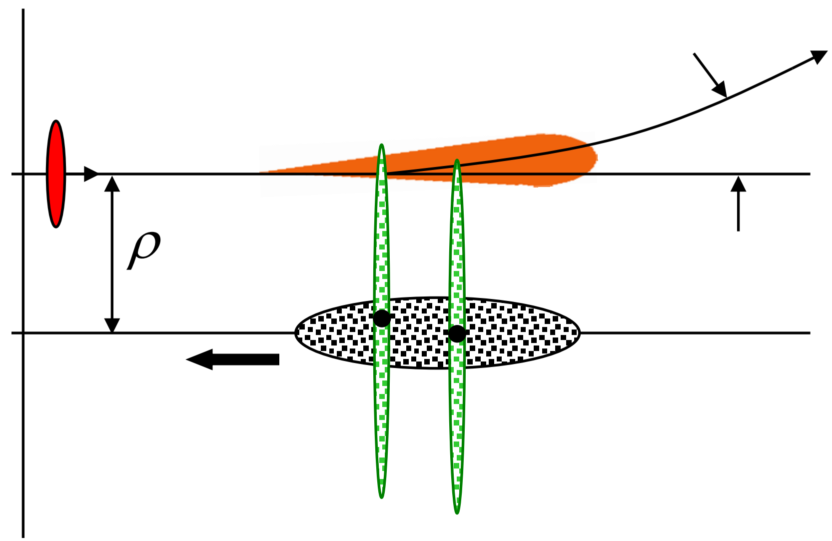
Coherent radiation in crystal and at electron collision with a short bunch

crystal atomic string



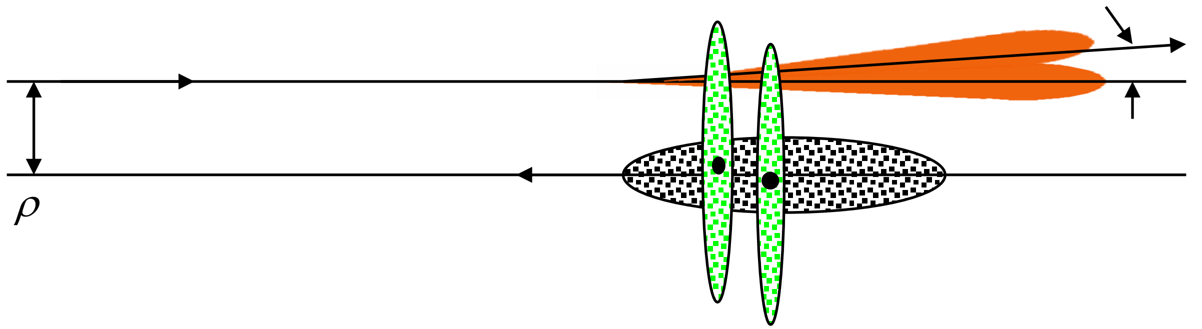
bunch

$$\vartheta_N = \frac{2Ne^2}{\varepsilon\rho}$$



N. Shul'ga, D. Tyutyunnik, JEPT Lett. 78(2003)700., Proc. of SPIE, v. 5974(2005)60.

Suppression of coherent radiation (analog of LPM-effect)



$$\vartheta_N = \frac{2Ne^2}{\varepsilon\rho}$$

$$\frac{dE_N}{d\omega} = \frac{2e^2}{\pi}\left[\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}}\ln\left(\xi+\sqrt{\xi^2+1}\right)-1\right], \qquad \xi = \frac{\gamma\vartheta_N}{2}$$

$$\frac{dE_N}{d\omega} \approx \begin{cases} N^2\dfrac{e^6}{m^2\rho^2} & \gamma\vartheta_N \ll 1 \\ 4e^2\ln\left(\dfrac{Ne^2}{m\rho}\right) & \gamma\vartheta_N \gg 1 \end{cases}$$

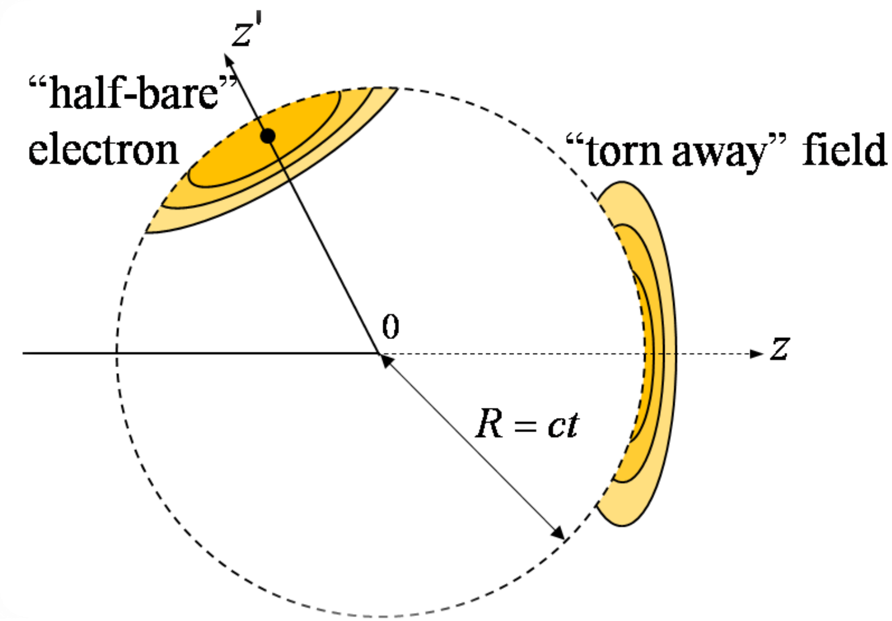
ε=5 Gev, L=0.1 cm, ρ=0.01 cm, N=10^{10}, $\omega_c = 4\gamma^2/L \approx 50kev,$ $\gamma\vartheta_N \approx 1$

N. Shul'ga, D. Tyutyunnik. JETP Lett. 78 (2003) 700.
NiM B227 (2005) 152

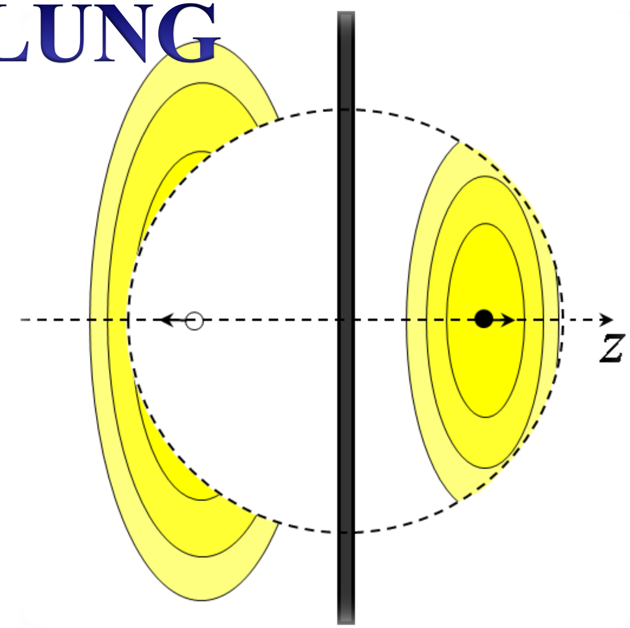
Transition radiation by "half-bare" electron

THE ANALOGY IN

AHLUNG



Bremsstrahlung



Transition radiation

The total field for $t > 0$ **:**

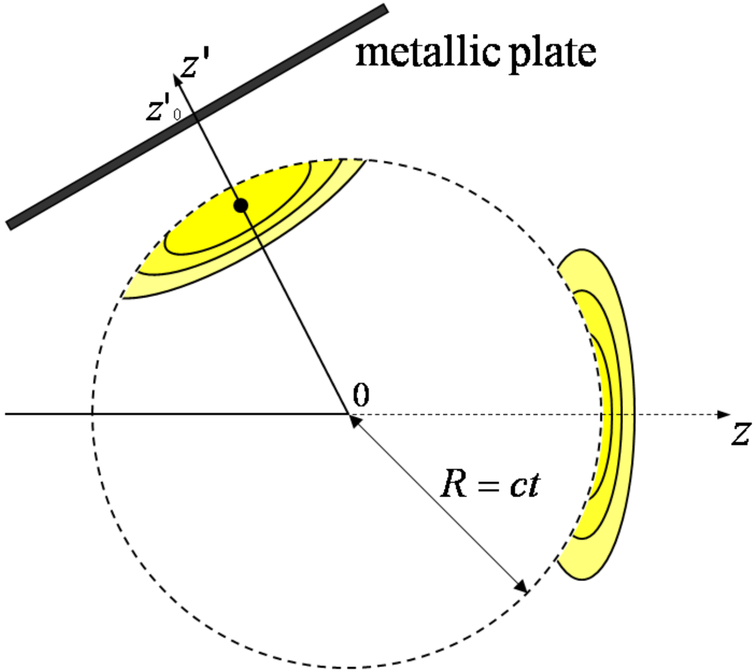
$$\varphi(\vec{r},t) = \theta(r-t)\varphi_{\vec{v}}(\vec{r},t) \; + \; \theta(t-r)\varphi_{\vec{v}\,'}(\vec{r},t)$$

A. Akhiezer, N. Shul’ga *High Energy Electrodynamics in Matter*, 1996

N. Shul’ga, V. Syshchenko, S. Shul’ga // Phys. Lett. A, 2009

TRANSITION RADIATION BY ELECTRON WITH NONEQUILIBRIUM FIELD

N.Shul'ga, S. Trofymenko, V. Syshchenko JETP Lett., 93 (2011) 1



Transition radiation by "torn away" field :

$$\frac{d\mathcal{E}}{d\omega do} = \frac{e^2}{\pi^2} \frac{\vartheta^2}{\left(\gamma^{-2} + \vartheta^2\right)^2}$$

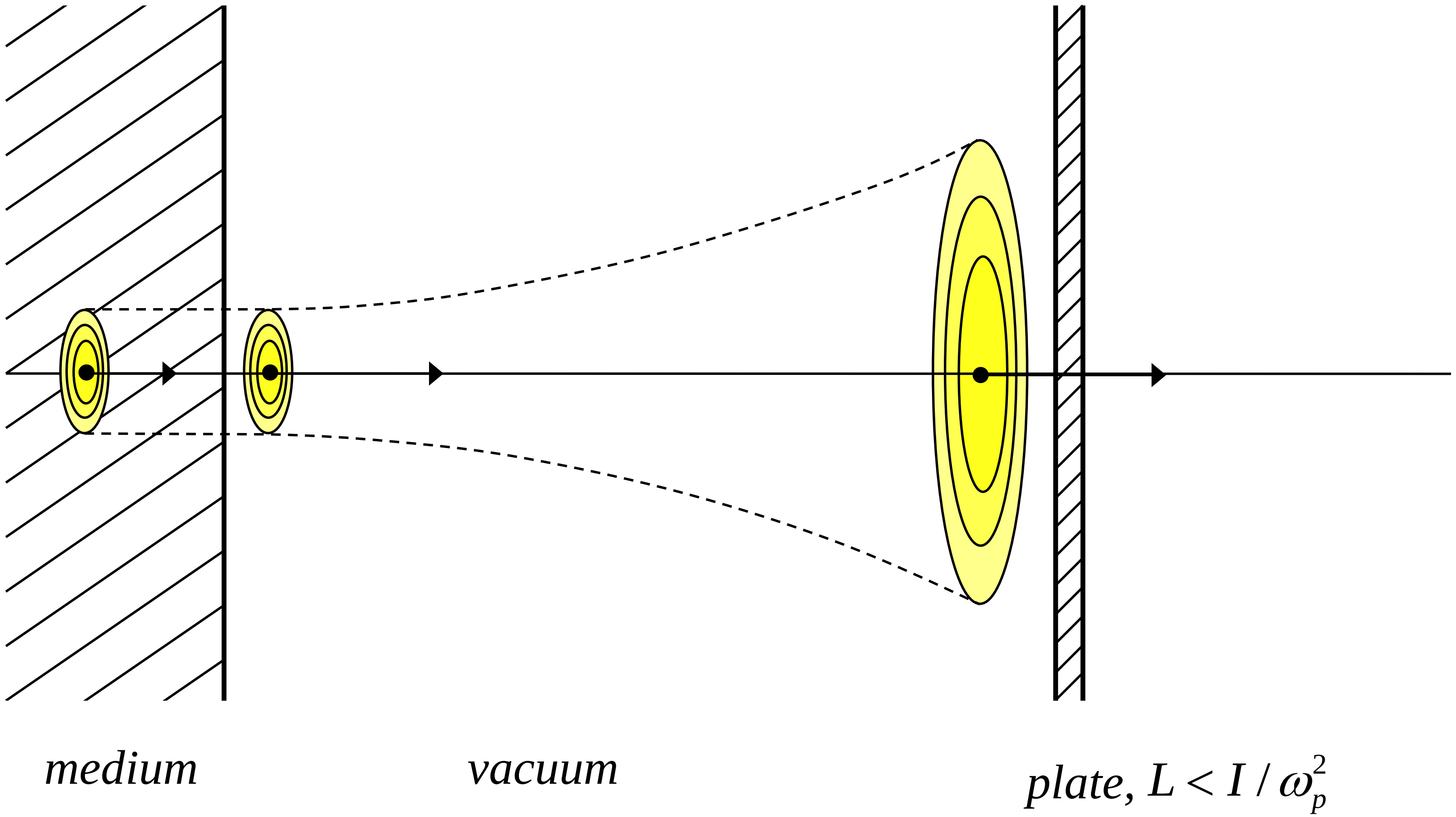
does not depend on z_0

Transition radiation in wave zone by electron with nonequilibrium field :

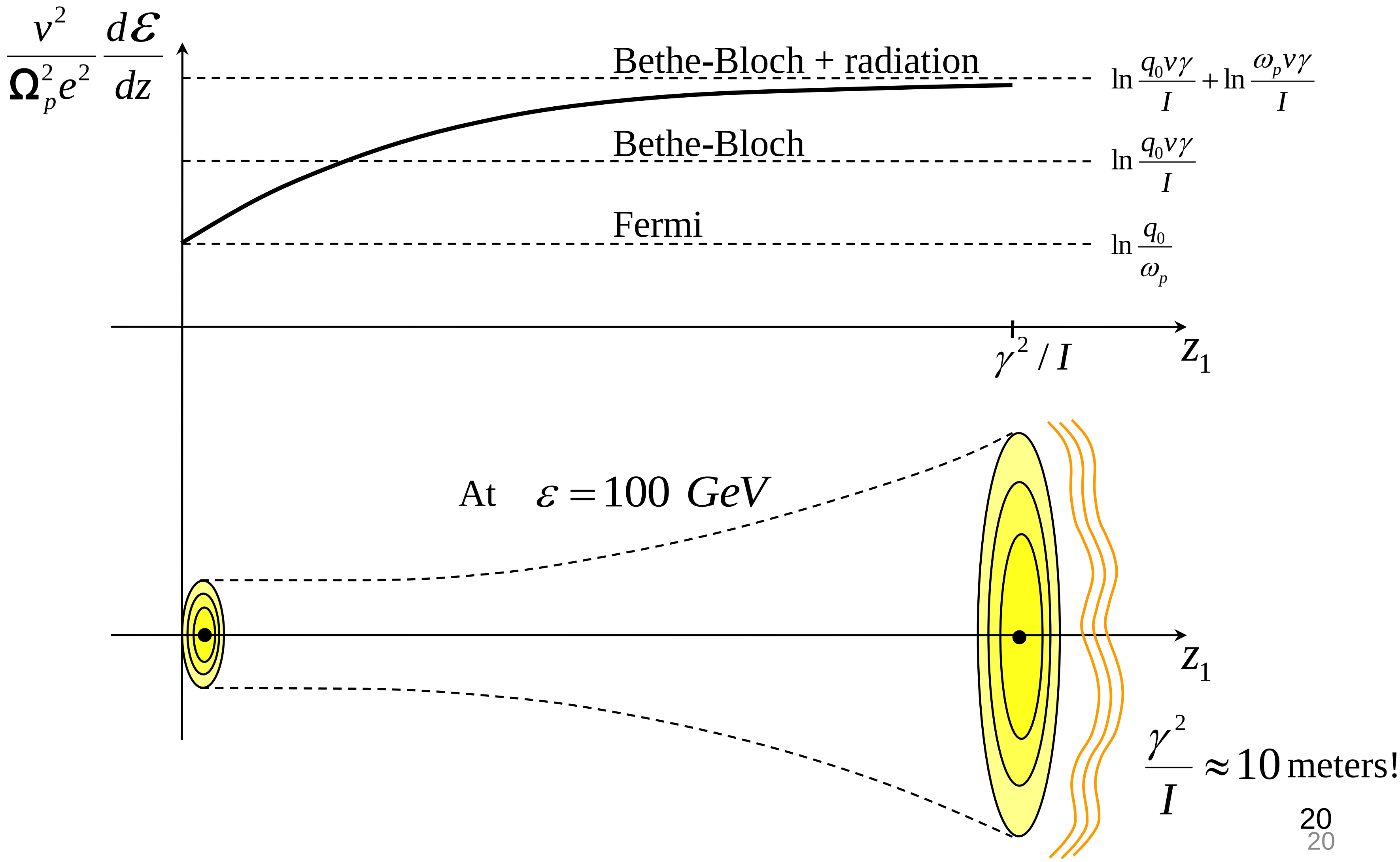
$$\frac{d\mathcal{E}}{d\omega\, do} = \frac{e^2}{\pi^2} \frac{\vartheta^2}{\left(\vartheta^2 + \gamma^{-2}\right)^2} 2\left\{1 - \cos\left[\frac{\omega\, z'_0}{2}\left(\gamma^{-2} + \vartheta^2\right)\right]\right\}$$

IONIZATION ENERGY LOSSES BY HALF-BARE ELECTRON

N. Shul'ga, S. Trofymenko, Phys. Lett. A, 2012



IONIZATION ENERGY LOSSES BY HALF-BARE ELECTRON (from Fermi to Bethe-Bloch formula)

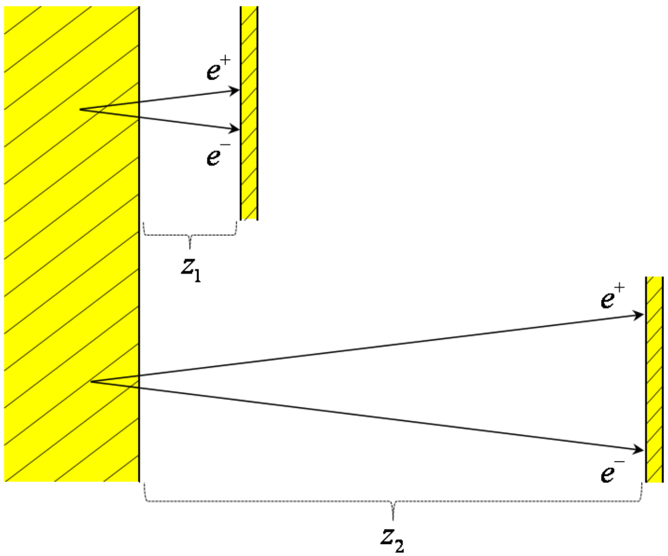


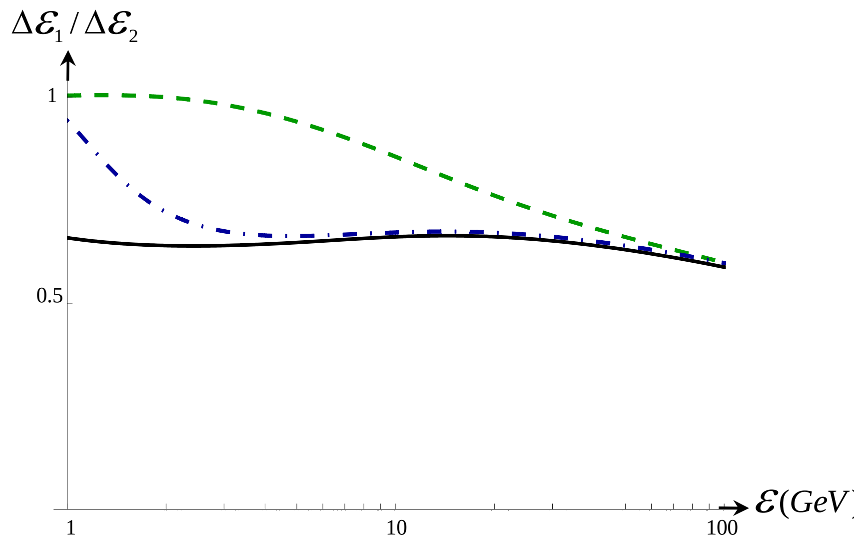
20

Ionization energy losses of e^+e^- pair

under conditions of CERN experiment (Phys.Rev.Lett., 2008)

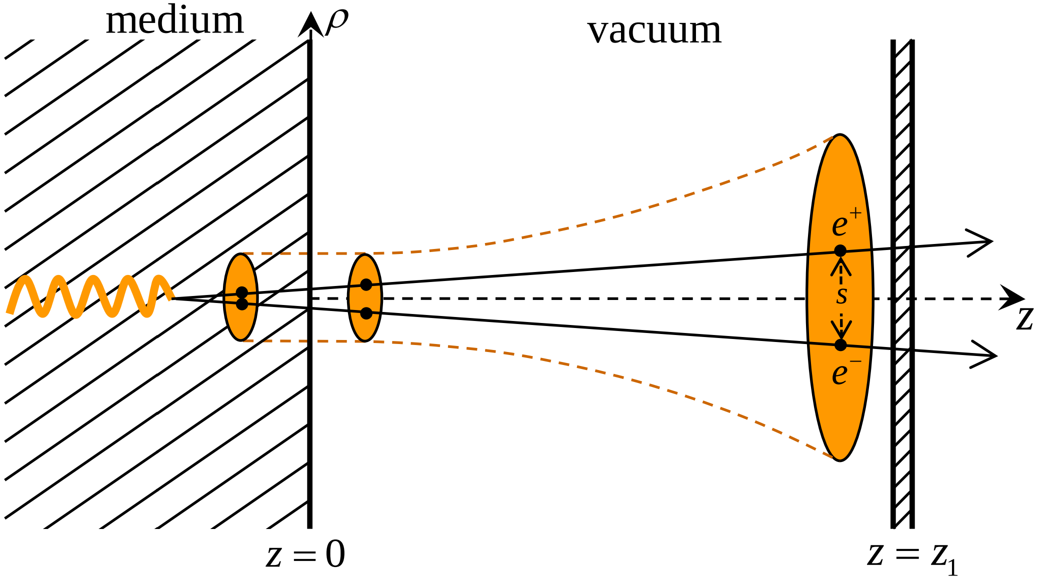
Proposal for CERN (N. Shul'ga, S. Trofymenko, Phys.Lett. 2013)

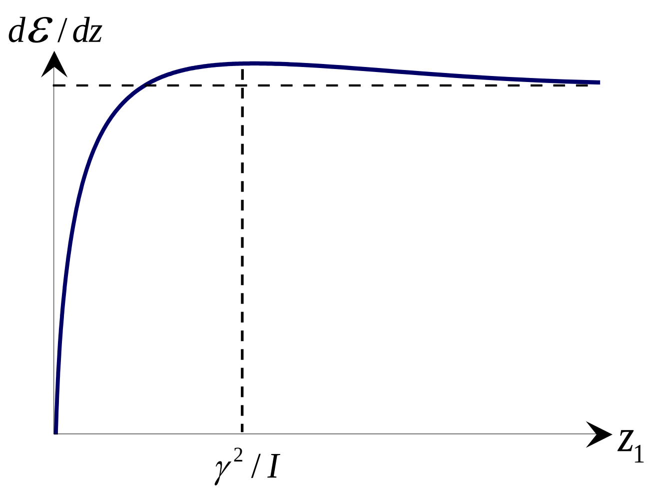


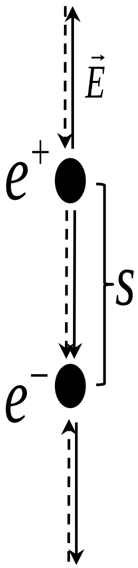


Anti-Chudakov effect

Proposal for CERN and DESY (N. Shul'ga, S. Trofymenko, Phys.Lett. 2013)







CONCLUSIONS

- Evolution in space and time
- High energy wave packets
- Suppression of pair production ("half-bare" photons)
- Ionization energy losses of e^+e^--pair (S. Trofymenko et al. Report on Channeling 2014)
- Anti-Chudakov effect
- Transition radiation experiments (G. Naumenko et al.)
- Measurement of electron field at large (~ 1 meter) orthogonal distances (A. Calcaterra et al. Frascati, arXiv 2012)
- Processes with high energy particles (quark-gluon plasma, …)