IX International Symposium «RREPS-11»
Radiation from Relativistic Electrons in Periodic Structures
September 12-16, 2011

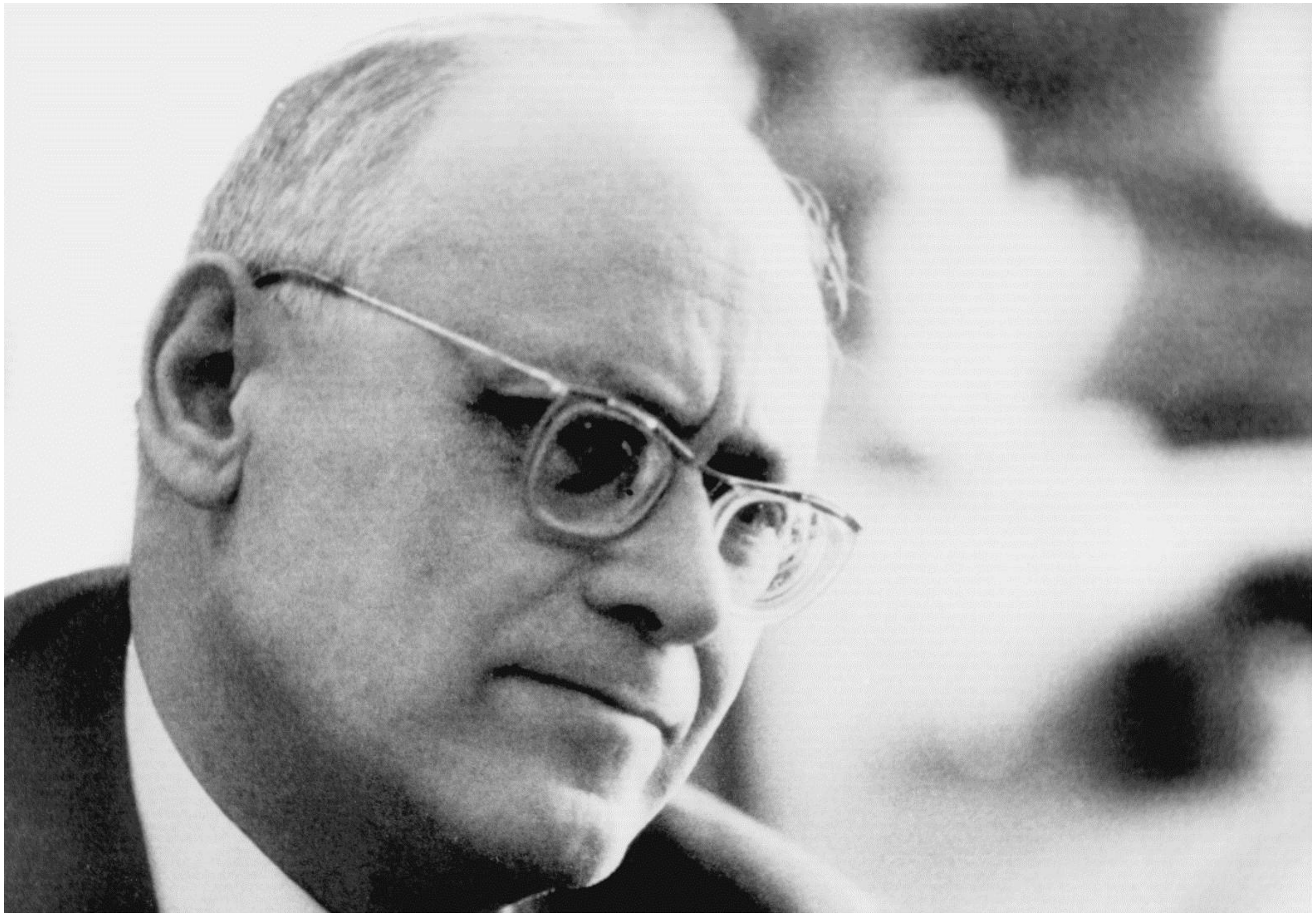
Radiation by relativistic electrons at ultra large formation lengths of radiation process
(to the 100-th anniversary from the birth of A.I. Akhiezer)

N. F. Shul’ga

Akhiezer Institute for Theoretical Physics of NSC KIPT

Kharkov, Ukraine

e-mail: shulga@kipt.kharkov.ua



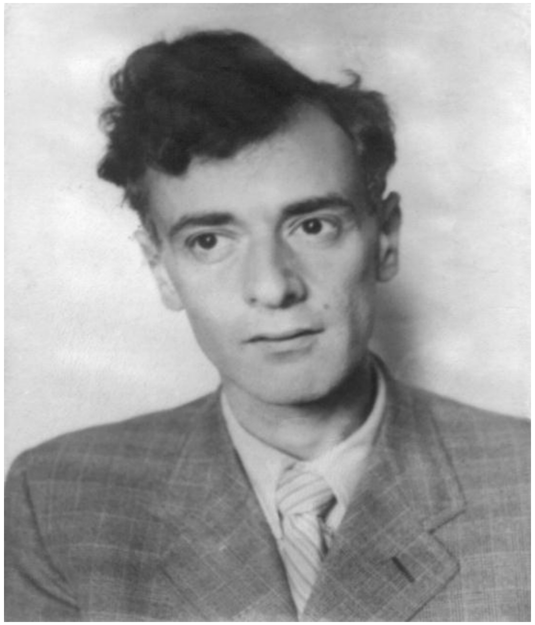
Alexander Ilyich Akhiezer
1911-2000

Alexander Akhiezer

- 31.X.1911 — born in Cherikov (Belarus')
- 1929-1934 — Kiev Polytechnic Institute
- 1934 - 2000 — worked in Kharkov in UPhTI
- 1938-1988 — head of the theoretical department of UPhTI

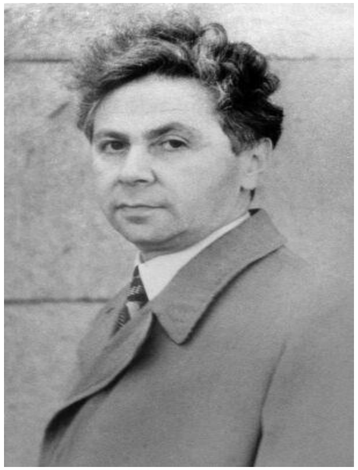
Lev Landau

The head of the theoretical department of UPhTI from 1932 to 1937.



- Creation of the school for theoretical physics
- Creation of the course of theoretical physics since 1935
- Mechanics (with L.Pyatigorskii)
- Statistical physics (with E.Lifshitz)
- Electrodynamics (started with L.Pyatigorskii)
- Revision of the system of teaching the course of physics

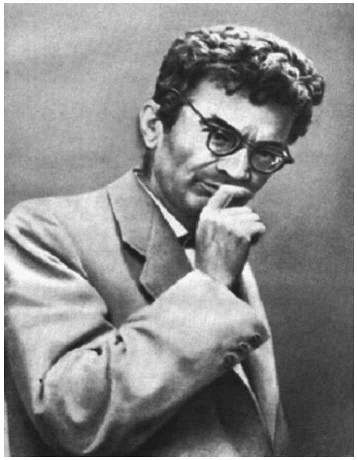
School of Landau (UPhTI -1934)



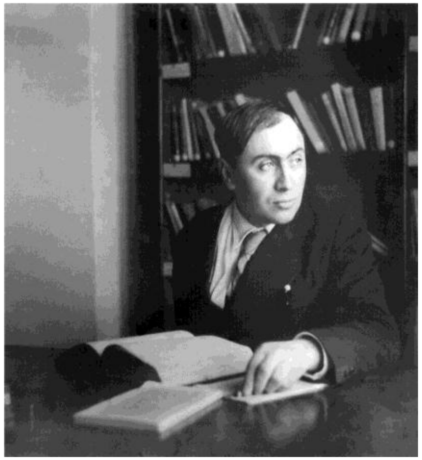
A.Kompaneetz

E.Lifshitz

A.Akhiezer



I.Pomeranchuk



L.Pyatigorsky

L.Tisza

E.Teller recommended him to work in Kharkov

UPhTI (1930-s)

P.Dirac –member of the Council of UPhTI
P.Kapitza, G.Gamow, P.Ehrenfest – scientific consultants of UPhTI
L.Shubnikov – research worker at UPhTI (1930-s)
F.Hautermans – research worker at UPhTI (1930-s)
V.Weisskopf – research worker at UPhTI (1933-1934)

«I could not get a job in England, neither in France. In 1933 I went ... to Kharkov where it was possible to get a job which provided with means of subsistence.»

Вот были же времена, сейчас бы так…

Those persons came and worked for a long time in UPhTI:

N.Bohr, P.Dirac, P.Ehrenfest, P.Kapitza, G.Gamow, R.Peierls, V.Fock, B.Podolsky, Yu.Rumer, L.Gurevich…

Alexander Akhiezer

The head of the theoretical department of UPhTI-KIPT from 1938 to 1988.

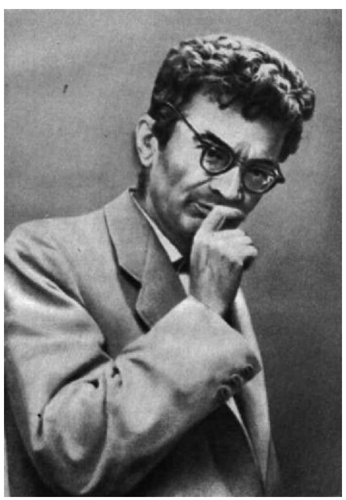
- School of theoretical physics (Ya.Fainberg, V.Bar’yakhtar, S.Peletminsky, D.Volkov, A.Sitenko, P.Fomin, V.Aleksin, K.Stepanov, M.Rekalo, Yu.Berezhnoj, G.Lyubarsky, E.Kuraev, R.Polovin, Ya.Shifrin, N.Shul’ga et al.)

- Monographs (50)

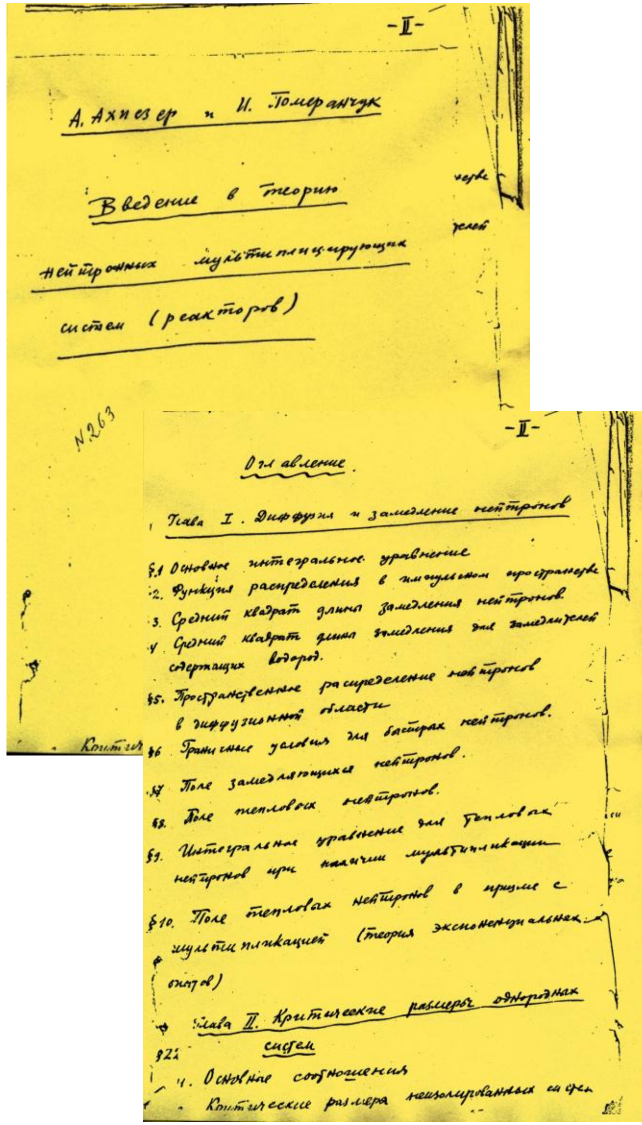
- Creation of physico-technical faculty of Kharkov State University and the chair of theoretical nuclear physics of Kharkov State University.

1946, Kharkov – UPhTI Laboratory #1 of Atomic Project of the USSR)

A.I. Akhiezer



I.Ya. Pomeranchuk



-II-

А. Ахиезер и И. Померанчук

Введение в теорию нейтронных мультиплицирующих систем (реакторов)

N263

-II-

Оглавление

Глава I. Диффузия и замедление нейтронов

§1 Основное интегральное уравнение

2. Функция распределения в импульсном пространстве

3. Средний квадрат длины замедления нейтронов

4. Средний квадрат длины замедления для замедлителей содержащих водород.

§5. Пространственное распределение нейтронов в диффузионной области

§6 Граничные условия для быстрых нейтронов.

§7 Поле замедляющихся нейтронов.

§8. Поле тепловых нейтронов.

§9. Интегральное уравнение для тепловых нейтронов при наличии мультипликации

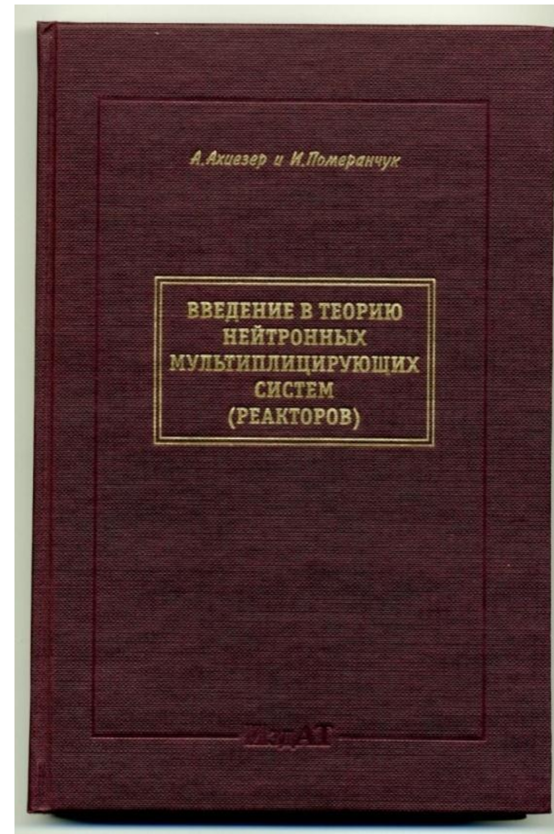
§10. Поле тепловых нейтронов в призме с мультипликацией (теория экспоненциальных опытов)

Глава II. Критические размеры однородных систем

1. Основные соотношения

Критические размеры неизолированных систем

For some reasons, this book was classified "Top secret"



2001

A. I. AKHIEZER
V. B. BERESTETSKII
QUANTUM ELECTRODYNAMICS
Authorized English Edition Revised and Enlarged by the Authors
G. M. Volkoff
INTERSCIENCE PUBLISHERS
JOHN WILEY & SONS
ACHIESER-BERESTEZKI
Quanten-Elektrodynamik
TRADUIT DU RUSSE
PHYSIQUE
Électromagnétisme et ondes électromagnétiques
A. AKHIEZER
I. AKHIEZER
А.И. АХИЕЗЕР, В.Б. БЕРЕСТЕЦКИЙ
Квантовая электродинамика
А. Ахиезер и И. Померанчук
ВВЕДЕНИЕ В ТЕОРИЮ НЕЙТРОННЫХ МУЛЬТИПЛИЦИРУЮЩИХ СИСТЕМ (РЕАКТОРОВ)
ランダウ, アヒエゼール, リフシッツ
物理学
—力学から物性論まで—
小野周
豊田博慈 訳
岩波書店
ЭЛЕКТРОДИНАМИК
АДРОНОВ
FIELDS AND FUNDAMENTAL INTERACTIONS
A. I. AKHIEZER AND S. V. PELETMINSKY
A. I. AKHIEZER
V. B. BERESTETSKII
ELEMENTS OF QUANTUM ELECTRODYNAMICS
TRANSLATED FROM RUSSIAN
OLDBOURNE PRESS, LONDON
FIZYKA OGÓLNA
Mechanika i fizyka cząsteczkowa
L. D. Landau
A. I. Achijezer
E. M. Lifszyc
International Series in Natural Philosophy
Methods of Statistical Physics
A I Akhiezer
S V Peletminskii
Pergamon Press
ЭЛЕКТРОДИНАМИКА ПЛАЗМЫ
А. И. Ахиезер
С. В. Пелетми
ТЕОРИЯ
ФУНДАМЕНТАЛЬН
ВЗАИМО
ДЕЙСТ
HIGH-ENERG
ELECTRODYNAMIC
IN MATTER
A. I. Akhiezer
N.F. Shul'ga
GORDON AND BREACH PUBLISHERS
L. Landau
A. Ajiezer
E. Lifshitz
CURSO DE FISICA GENERAL
Mecánica y Física molecular
Editorial
International Series of Monographs in Natural Philosophy, Volume 7
Pergamon Press
Collective Oscillations in a Plasma
A. I. Akhiezer, I. A. Akhiezer, R. V. Polovin, A. G. Sitenko and K. N. Stepanov
Mechan
und
Molekula
physik
L. D. LANDAU
A. I. ACHIESER
E. M. LIFSCHITZ
А.И. АХИЕЗЕР
Развивающаяся физическая картина мира
А. И. АХИЕЗ
В. Г. БАРЬЯХТА
С. В. ПЕЛЕТМИНСКИ
СПИНОВЫЕ ВОЛНЫ
А. И. АХИЕЗЕР
Н. Ф. ШУЛЬГА
ЭЛЕКТРОДИНАМ
ВЫСОКИХ
ЭНЕРГИЙ
В ВЕЩЕСТ
Springer Series in Nuclear and Particle Physics
A. I. Akhiezer
A. G. Sitenko
V. K. Tartakovskii
Nuclear Electrodynamics

“If you really want to achieve something you should, at least a little, go against the stream”

«Если ты хочешь действительно достичь чего-нибудь, придется хотя бы немного, но пойти против течения»

“Where is a deception? – If there is no deception then it is not theoretical physics, it is mathematics”

«А где обман? – Если нет обмана, то это уже не теорфизика, а математика»

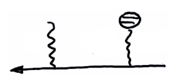
“In science everything is simple, until you begin to solve concrete problems”

«В науке все просто, пока не начинаешь решать конкретные задачи»

A. Akhiezer

The main Akhiezer's idea (1969)

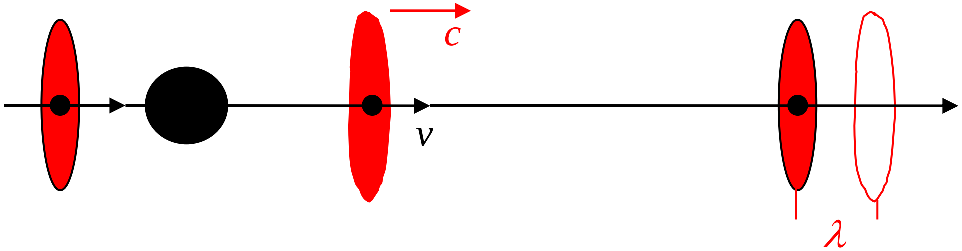
- For coherent bremsstrahlung



$$d\sigma_{coh} >> d\sigma_{BH}$$

- The idea: relative contribution of higher Born approximation can also be large!!!

ULTRATRAHIGH FORMATION (COHERENT) LENGTHS



$$v_{rel} = c - v$$

$$\lambda = (c-v)\Delta t_c \to \Delta t_c \approx 2\gamma^2\lambda$$

$$\boxed{l_{coh} = 2\gamma^2\lambda >> \lambda}$$

$E \sim 100\,GeV$ $\quad \omega \sim 500\,MeV$ $\quad l_c \sim 10^{-3}\,cm$

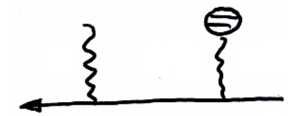
$E \sim 50\,MeV$ $\quad \lambda \sim 0.1cm$ $\quad l_c \sim 20\,m$

$$\alpha_{coh} = N_{coh}\frac{Ze^2}{\hbar c}, \qquad N_{coh} = \frac{l_{coh}}{a}$$

Problems

- **Methods of description of radiation (Born, eikonal, semiclassical approximations, operator semiclassical, classical electrodynamics, …)**
- **S-matrix and boundary conditions**
- **Evolution in space and time**
- **Medium influence on radiation**
- **Essentially new effect in radiation at channeling**

Radiation in Born approximation:



$$l_c = 2\varepsilon\varepsilon' / m^2\omega$$

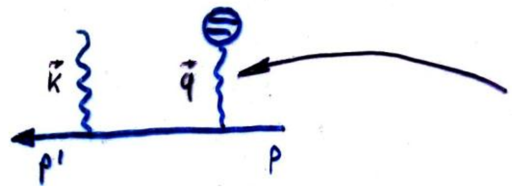
$$d\sigma \approx \int d^2 q_\perp \int_{q_{\min}}^{\infty} dq_\parallel \frac{q_\perp^2}{q_\parallel^2} \left|U_q\right|^2 \qquad \varepsilon = \varepsilon' + \omega, \qquad \mathbf{p} = \mathbf{p}' + \mathbf{k} + \mathbf{q}$$

$$q_{\parallel eff} = q_{\parallel \min} = \omega m^2 / 2\varepsilon\varepsilon'$$

$$r_{\parallel eff} \approx q_{\parallel eff}^{-1} \approx l_c = 2\varepsilon\varepsilon' / m^2\omega \qquad r_{\perp eff} \approx 1 / q_{\perp eff} \approx R$$

Coherent Bremsstrahlung in Born Approximation

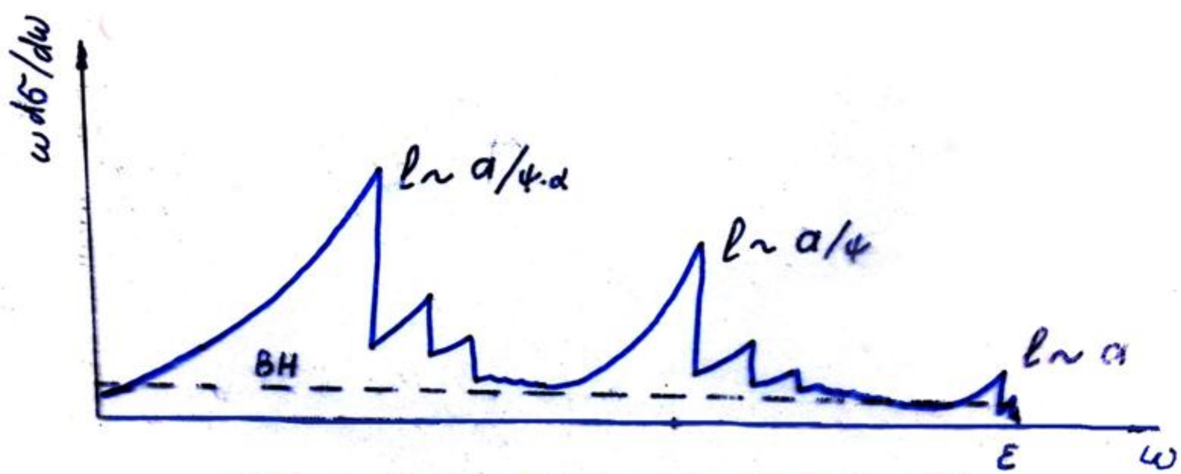
Ferretti 1950, Ter-Mikaelian 1952, Überall 1956

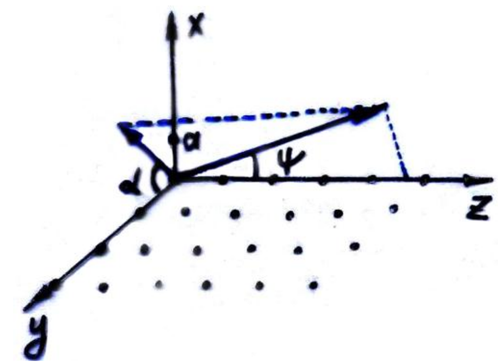


$U(\vec{r}) = \sum_n u(\vec{r}-\vec{r}_n)$

$$\omega \frac{d\sigma}{d\omega} = \frac{2e^2\delta}{m^2\Delta}\frac{\varepsilon'}{\varepsilon}\sum_{\vec{g}}\frac{g_\perp^2}{g_\parallel^2}\left[1+\frac{\omega^2}{2\varepsilon\varepsilon'}-2\frac{\delta}{g_\parallel}\left(1-\frac{\delta}{g_\parallel}\right)\right]\left|U_g\right|^2 e^{-g^2\overline{u^2}}$$

$$q_\parallel \geq \delta = \omega m^2/2\varepsilon\varepsilon', \qquad g_\parallel = g_z + \psi\left(g_y\cos\alpha + g_y\sin\alpha\right) \geq \delta$$

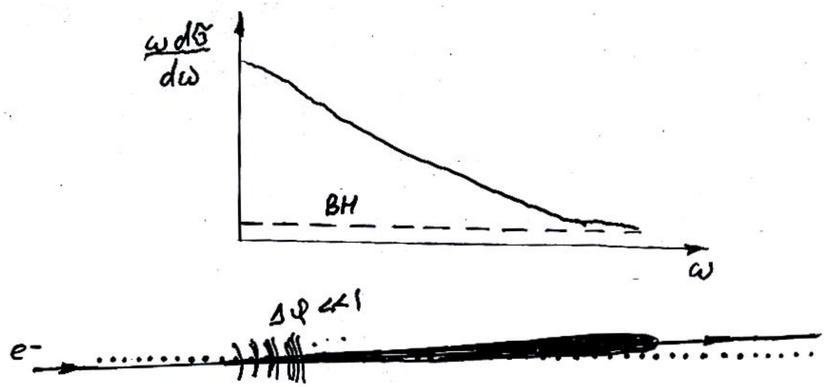


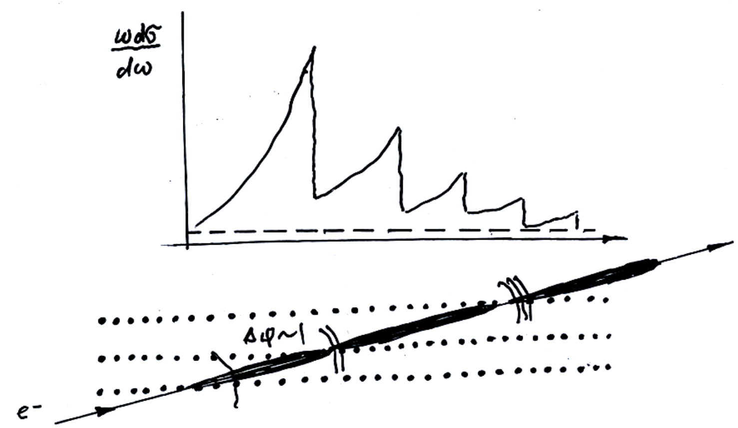


Akhiezer, Shul'ga Sov.Phys.Usp. 1982 v.25 p.54

COHERENT RADIATION IN CRYSTAL

Ter-Mikaelian 1953





Coherent effect

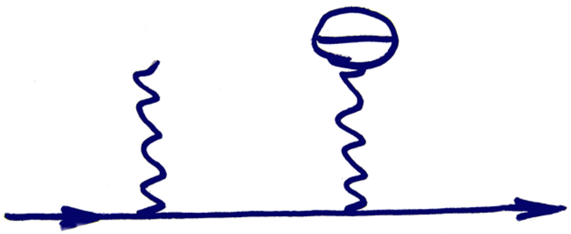
Coherence + Interference

$$\theta_c^2 << \theta^2$$

$$N_c Z e^2 / \hbar c < 1, \quad \text{where } N_c = \frac{l_c}{a}$$

The main idea:

-For



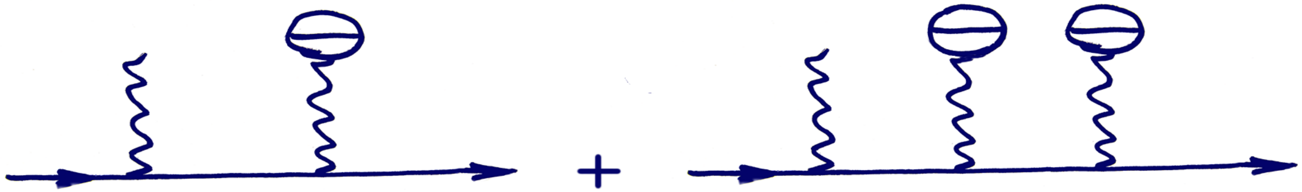
$$d\sigma_{coh} >> d\sigma_{atom}$$

-The relative contribution of higher Born approximation can be also increased (A.Akhiezer, P.Fomin, N.Shul'ga 1971)

Contribution of the second Born approximation

ħω<<ε (A.Akhiezer, P.Fomin, N.Shul'ga, 1971)

ħω ~ ε (N.Shul'ga, V.Syshchenko, 2002)



$$\omega\frac{d\sigma}{d\omega}=\frac{e^2}{2\pi}\frac{\varepsilon'}{\varepsilon}\frac{\delta}{m^2}\int d^3q\frac{q_\perp^2}{q_\parallel^2}\left\{F\left|U_q\right|^2+\frac{1}{\varepsilon}\left[F+\frac{\omega}{\varepsilon'}\left(1-4\frac{\delta}{q_\parallel}\left(1-\frac{\delta}{q_\parallel}\right)\right)+\frac{\omega^2}{2\varepsilon\varepsilon'}\left(1-\frac{\delta}{q_\parallel}\right)\right]\times\right.$$

$$\left.\times U_q\,\mathrm{Re}\int\frac{d^3q'}{(2\pi)^3}\frac{(\vec q-\vec q')_\perp\vec q'_\perp}{(\vec q-\vec q')_\parallel\vec q'_\parallel}U_{\vec q-\vec q'}U_{q'}\right\}$$

$$q_\parallel\geq\delta \qquad\qquad F=1+\frac{\omega^2}{2\varepsilon\varepsilon'}-2\frac{\delta}{q_\parallel}\left(1-\frac{\delta}{q_\parallel}\right)$$

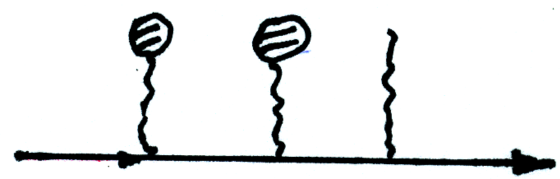
For Coulomb field

$$\omega\frac{d\sigma}{d\omega}\sim\left\{1-\frac{e}{|e|}\frac{\varepsilon+\varepsilon'}{2\varepsilon\varepsilon'}\frac{\pi Ze^2}{2}q_\perp\right\}$$

Symmetrical for $\varepsilon\leftrightarrow\varepsilon'$

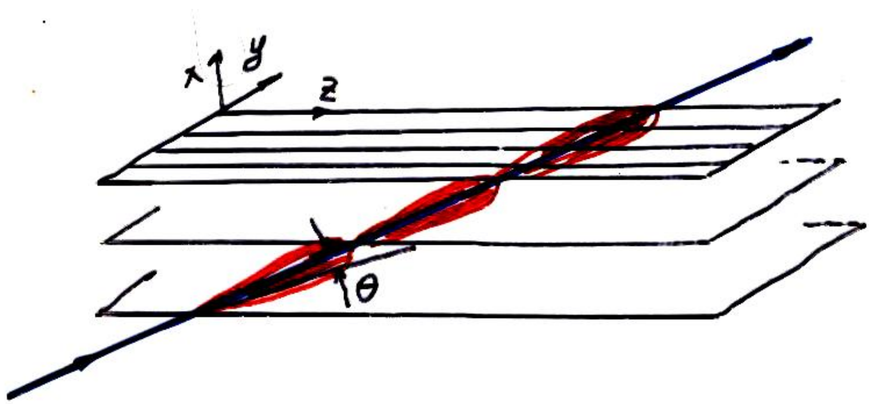
Second Born approximation in CB theory

A.Akhiezer, P.Fomin, N.Shul'ga (1970)



$$d\sigma_c = d\sigma_{coh}^{Born} \cdot \left(1 \pm \eta \frac{\theta_c^{\,2}}{\theta^2}\right), \qquad \hbar\omega \ll \varepsilon$$

$\eta \ll 1$ $\qquad\qquad$ θ_c – crytical channelling angle



$$l_{coh} = 2\gamma^2/\omega \approx a/\theta$$

Higher Born approximation in the CB theory

A.Akhiezer, N.Shul'ga (1975)

$$N_{coh} \sim \min\left(\frac{l_{coh}}{a}, \quad \frac{R}{\psi_a}\right), \qquad l_{coh} = 2\gamma^2/\omega >> a$$

$$\frac{Ze^2}{\hbar c} \ll 1 \quad \rightarrow \quad N_{coh}\frac{Ze^2}{\hbar c} \sim \frac{R}{\psi a}\frac{Ze^2}{\hbar c} \ll 1$$

Quickly destroys for $\psi \rightarrow 0$

New directions of investigations:

The interaction of high-energy particles with matter in conditions of effectively strong interaction of the particle with atoms of media (eikonal, semiclassical, classical approximations)

$$N_c \frac{Ze^2}{\hbar c} >> 1$$

Operator semiclassical method

(V. Baier, V. Katkov, 1973)

$$\omega \frac{d\sigma}{d\omega} = \frac{e^2}{4\pi^2} \int d^3\rho \int d^2\theta \ \frac{\varepsilon^2 + \varepsilon'^2}{2\varepsilon'^2} \left\{ \left|\vec{n} \times \vec{I}\right|^2 + \frac{\omega^2 m^2}{\omega^2 \left(\varepsilon^2 + \varepsilon'^2\right)} \left|I\right|^2 \right\}$$

$$\left(\vec{I}, I\right) = \int_{-\infty}^{\infty} dt \left(\vec{\upsilon}(t), 1\right) \exp\left[i \frac{\varepsilon}{\varepsilon'} \omega \left(1 - \vec{n}\vec{r}(t)\right) \right]$$

$\vec{r}(t)$ – for initial particle

$$\boxed{\frac{e\hbar\left|\nabla U\right|}{\varepsilon^2} << 1}$$

Operator semiclassical method + expansion on potential

(V. Boyko, N. Shul'ga, 2008)

$$\hbar\omega \sim \varepsilon\,, \qquad \frac{e\hbar\left|\nabla U\right|}{\varepsilon^2} << 1$$

$$\omega\frac{d\sigma}{d\omega} = \frac{e^2}{2\pi}\frac{\varepsilon'}{\varepsilon}\frac{\delta}{m^2}\int d^3q\,\frac{q_\perp^2}{q_\parallel^2}F\left\{\left|U_q\right|^2 - \frac{1}{\varepsilon}U_q\,\mathrm{Re}\int\frac{d^3q'}{(2\pi)^3}\frac{\left(\vec{q}-\vec{q}'\right)_\perp\vec{q}'_\perp}{\left(\vec{q}-\vec{q}'\right)_\parallel\vec{q}'_\parallel}U_{\vec{q}-\vec{q}'}U_{q'}\right\}$$

For Coulomb potential

$$\omega\frac{d\sigma}{d\omega} \sim \ldots\left\{1 - \frac{e}{|e|}\frac{1}{\varepsilon}\frac{\pi Ze^2}{2}q_\perp\right\}$$

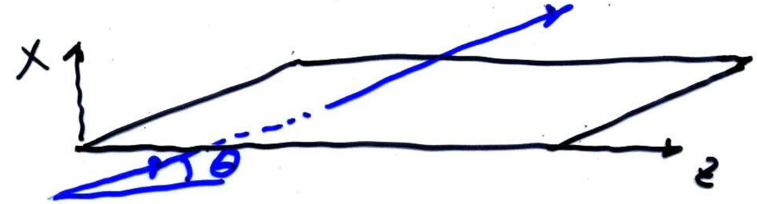
Not symmetrical for $\varepsilon \leftrightarrow \varepsilon'$

Second Born approximation

$$\omega\frac{d\sigma}{d\omega} \sim \left\{1 - \frac{e}{|e|}\frac{\varepsilon+\varepsilon'}{2\varepsilon\varepsilon'}\frac{\pi Ze^2}{2}q_\perp\right\}$$

Symmetrical for $\varepsilon \leftrightarrow \varepsilon'$

Radiation in the field of continuous potential of crystalline plane



Feinman Diagram Technique

$$d\sigma = N\frac{16\pi Z^2 e^6}{a_y a_z \theta^2}\frac{\varepsilon'}{\varepsilon}\frac{\delta}{m^2}\frac{d\omega}{\omega}\int_{\delta/\theta}^{\infty} dg_x \frac{1}{\left(g_x^2+R^{-2}\right)^2}\left\{F(g_x)+\frac{e}{|e|}\frac{4\pi Z e^2 R}{\varepsilon a_y a_z \theta^2}\left[F(g_x)+\right.\right.$$

$$\left.\left.\frac{\omega}{\varepsilon'}\left(1-4\frac{\delta}{\theta g_x}\left(1-\frac{\delta}{\theta g_x}\right)+\frac{\omega^2}{2\varepsilon\varepsilon'}\left(1-\frac{\delta}{\theta g_x}\right)\right)\right]\frac{g_x^2+R^{-2}}{g_x^2+4R^{-2}}\right\},$$

$$F(g_x)=1+\frac{\omega^2}{2\varepsilon\varepsilon'}-\frac{2\delta}{\theta g_x}\left(1-\frac{\delta}{\theta g_x}\right).$$

Operator Semiclassical Method

$$d\sigma = N\frac{16\pi Z^2 e^6}{a_y a_z \theta^2}\frac{\varepsilon'}{\varepsilon}\frac{\delta}{m^2}\frac{d\omega}{\omega}\int_{\delta/\theta}^{\infty} dg_x \frac{F(g_x)}{\left(g_x^2+R^{-2}\right)^2}\left\{1+\frac{e}{|e|}\frac{4\pi Z e^2 R}{\varepsilon a_y a_z \theta^2}\frac{g_x^2+R^{-2}}{g_x^2+4R^{-2}}\right\}.$$

$\delta^{-1} \sim 2R/\theta.$

$\alpha_p \sim \dfrac{4\pi Z e^2 R}{\varepsilon a_y a_z \theta^2}. \ll 1$

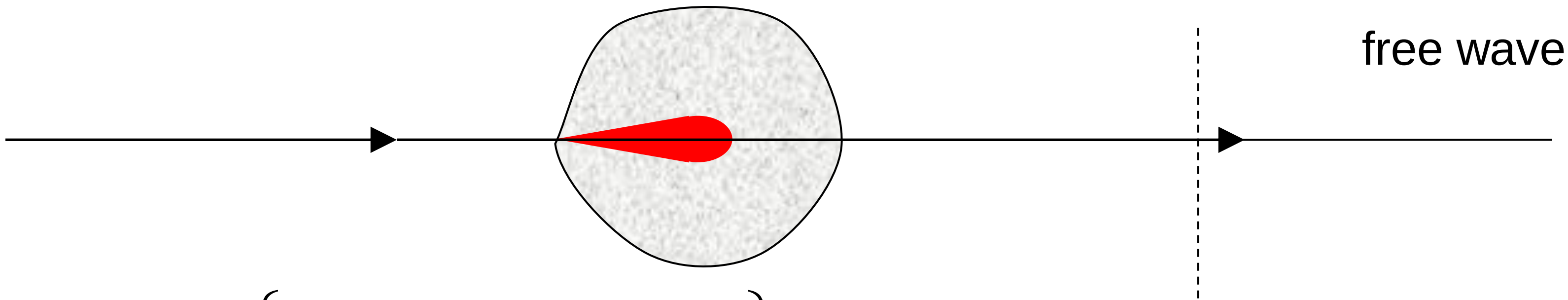
Conclusions #1

- Feynman diagram technique and operator semiclassical method produce different results in second approximation on potential for $\hbar\omega \sim \varepsilon$

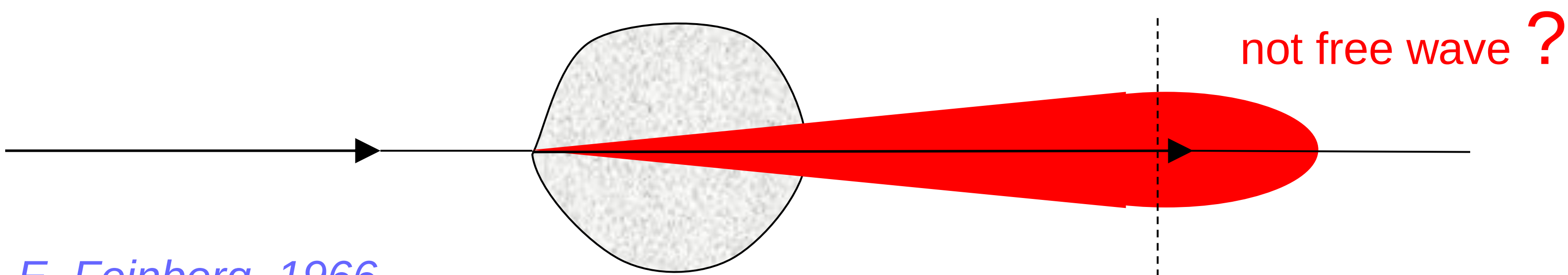
- It is needed an analysis of validity conditions of operator semiclassical method for description of radiation process in the region $\hbar\omega \sim \varepsilon$ and revision of results obtained on the basis of this method

- This is very important for crystal

S-matrix and Boundary Conditions for Ultra-High Coherent Lengths



$$S = T\exp\left\{ ie^2 \int_{-\infty}^{\infty} dt \int d^3r\, J_\mu A_\mu \right\}$$

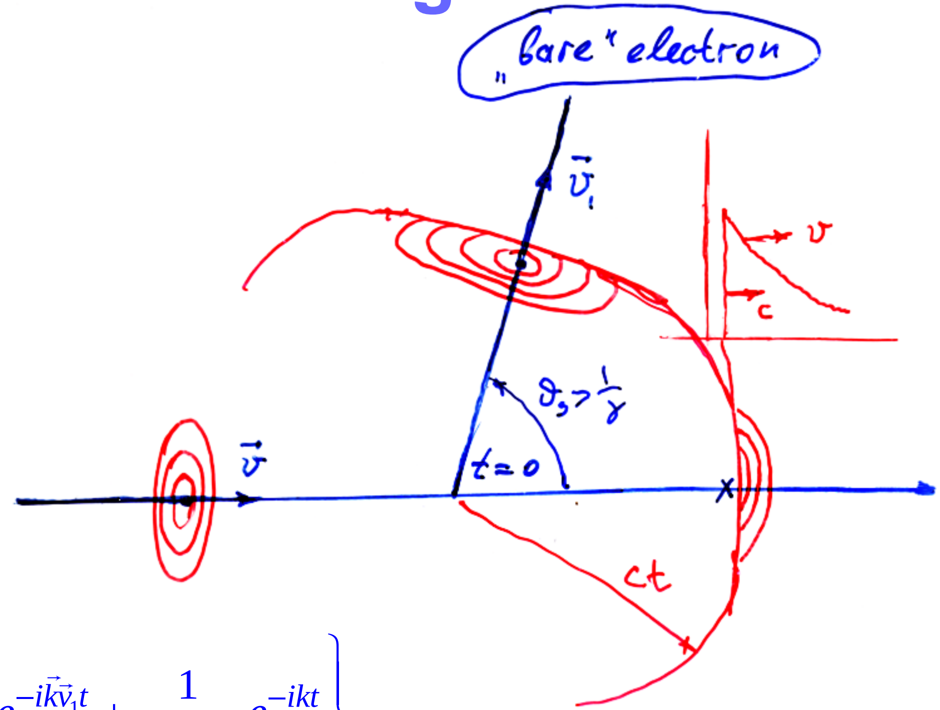


E. Feinberg, 1966

$$S = T\exp\left\{ ie^2 \int_{-\infty}^{T} dt \int d^3r\, J_\mu A_\mu \right\}$$

???

Evolution of electromagnetic field at electron's scattering



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

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

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

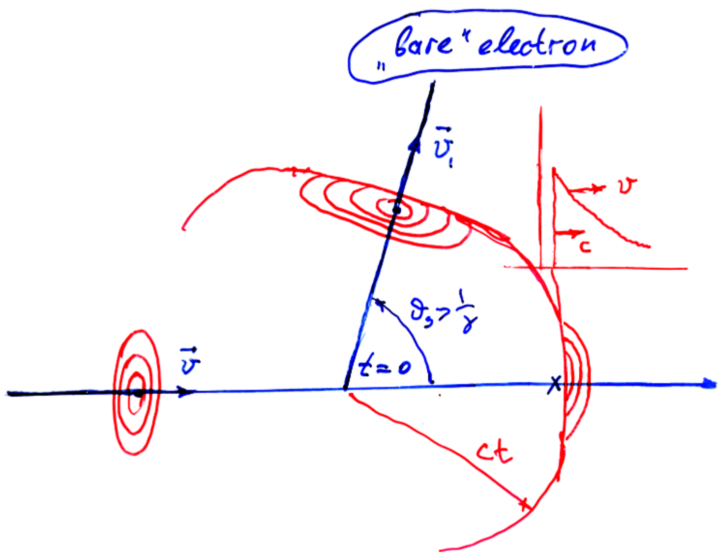
$$= \Theta(t-r)\varphi_{v_1}(\vec{r},t) + \Theta(r-t)\varphi_v(\vec{r},t)$$

$$\Delta t \sim (k - kv_1)^{-1} \approx 2\gamma^2/v = l_c$$

For $\varepsilon = 50 MeV$, $\lambda = 1 cm$, $l_c = 200\ m$

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

FOURIER TRANSFORMATION OF ELECTRON'S FIELD
COHERENT LENGTH, WAVE ZONE



$$\varphi(\vec{r},t) = \frac{e}{2\pi^2} \mathrm{Re} \int \frac{d^3k}{k} e^{i\vec{k}\vec{r}} \left\{ \frac{1 - e^{-i\left(k - \vec{k}\vec{v}_1\right)t}}{\omega - \vec{k}\vec{v}_1} e^{-ikv_1t} + \frac{1}{k - \vec{k}\vec{v}} e^{-ikt} \right\}$$

$$l_c = 2\gamma^2 / \omega$$

APPROXIMATION OF THE COULOMB FIELD BY THE PACKET OF PLANE WAVES

$$\varphi_{free}(\vec{r},t) = \mathrm{Re}\int \frac{d^3k}{(2\pi)^3} e^{i(\vec{k}\vec{r}-kt)} C_k$$

$$C_k = \frac{8\pi e\,\Theta(k_z)}{k_\perp^2 + k_z^2/\gamma^2}$$

$$\varphi_{free}(\vec{r},t) = \mathrm{Re}\int dk\varphi_k(\vec{r},t)$$

$$\varphi_k(\vec{r},t) = \frac{2}{\pi} e^{ik(z-t)} \int_0^\infty \frac{\theta d\theta}{\theta^2 + \gamma^{-2}} J_0(k\rho\theta) e^{-ikz\theta^2/2}$$

WAVE AND PRE-WAVE ZONES

$$\varphi_k(\vec{r},t) = \frac{2}{\pi} e^{ik(z-t)} \int_0^{\infty} \frac{\theta\, d\theta}{\theta^2 + \gamma^{-2}} J_0(k\rho\theta) e^{-ikz\theta^2/2}$$

pre-wave zone

$$\varphi_k(\vec{r},t) \approx \frac{2}{\pi} K_0(k\rho/\gamma) e^{-ik(z-t)} \qquad kz\vartheta^2/2 << 1$$

$$\varphi(\vec{r},t) = \frac{e}{\sqrt{(z-t)^2 + \rho^2/\gamma^2}} \qquad z << l_c$$

wave zone

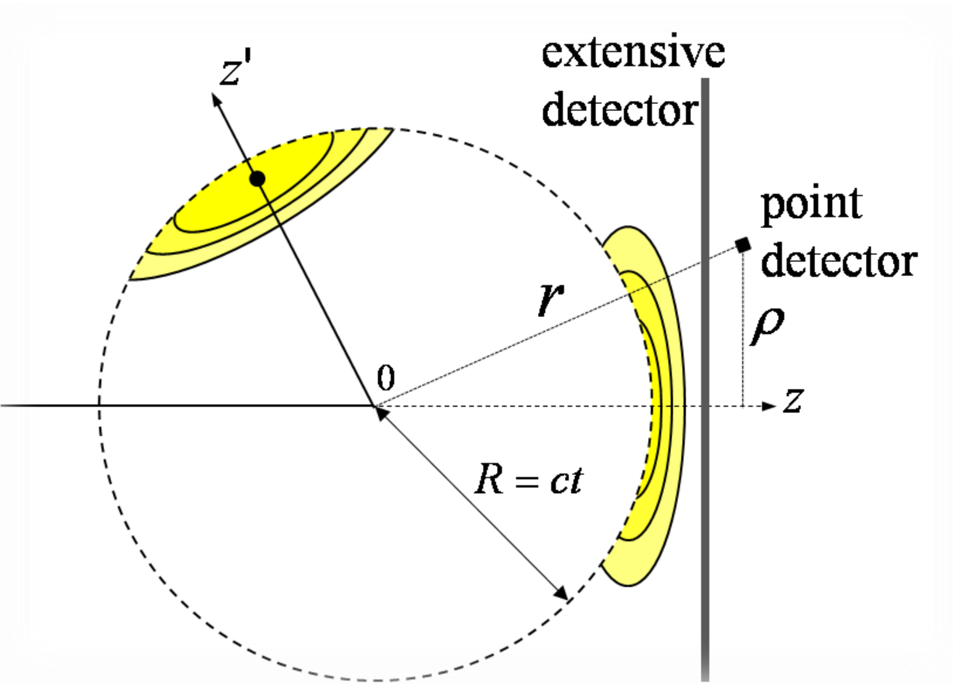
$$\varphi_k(\vec{r},t) = -\frac{2i}{\pi} \frac{1}{\vartheta_0^2 + \gamma^{-2}} \frac{1}{kr} e^{ik(r-t)} \qquad kz\vartheta^2/2 >> 1$$

$$\vartheta_0 = \rho/z \qquad z >> l_c$$

N.Shul'ga, V. Syshchenko, S. Shul'ga. Phys. Lett. A 374 (2009) 331

The Problem of Bremsstrahlung Radiation Measurement

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



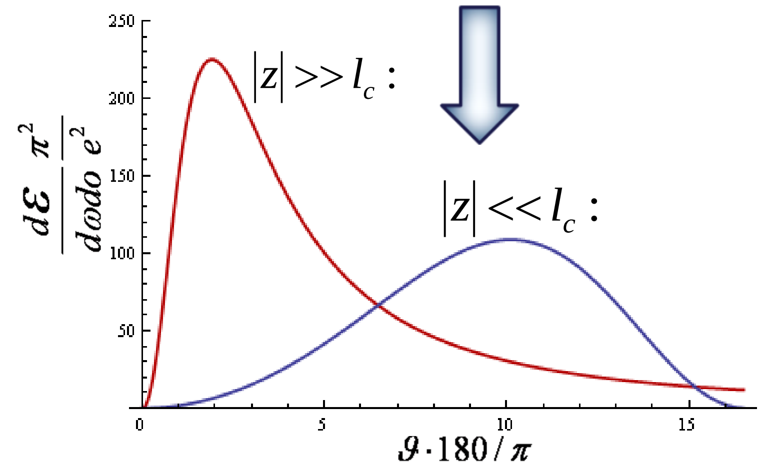
Point detector: $\Delta\rho << \gamma/\omega$

$|z| >> l_c$:

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

$|z| << l_c$:

$$\frac{d\mathcal{E}}{d\omega do} = \frac{4e^2}{\pi^2}\frac{1}{\vartheta^2}\sin^2\left(\frac{\omega\,|z|\vartheta^2}{4}\right)$$



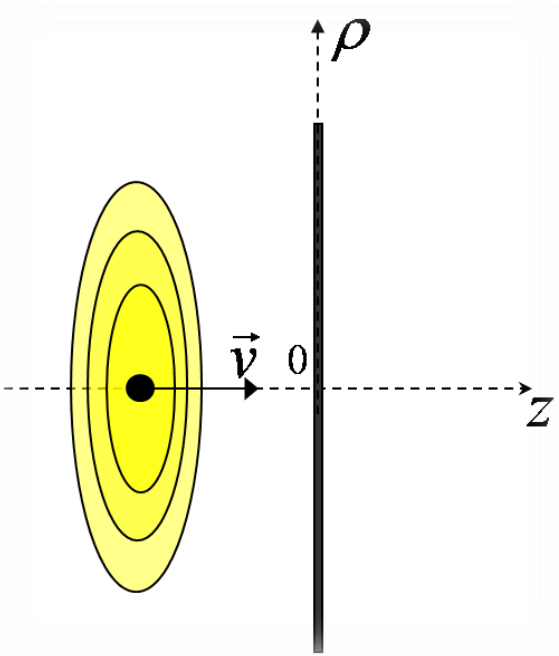
Extensive detector: $\Delta\rho >> \gamma/\omega$

any Z:

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

TRANSITION RADIATION BY ELECTRON WITH NONEQUILIBRIUM FIELD

S. Trofymenko et al (oral report RREPS-11)



Total field:

$$\varphi = \varphi^{C} + \varphi^{f}$$

Boundary condition:

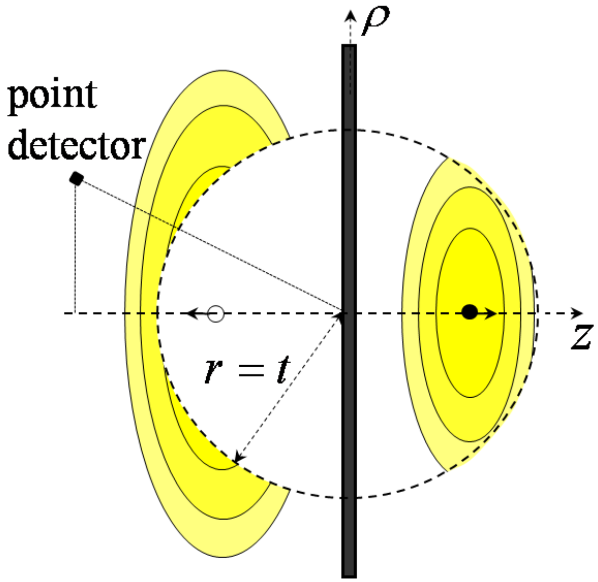
$$\vec{E}_{\perp}^{C}(\vec{\rho}, z=0, t) + \vec{E}_{\perp}^{f}(\vec{\rho}, z=0, t) = 0$$

Fourier integral for radiation field:

$$\varphi^{f}(\vec{r},t) = -\frac{e}{2\pi^{2}v}\int d^{2}k_{\perp}\int_{-\infty}^{\infty} d\omega \frac{1}{k_{\perp}^{2} + \omega^{2}/p^{2}} e^{i\left(z\omega\sqrt{1-k_{\perp}^{2}/\omega^{2}} - \omega\ t + \vec{k}_{\perp}\vec{\rho}\right)}$$

STRUCTURE OF TR ELECTROMAGNETIC FIELD

N.Shul'ga, S. Trofymenko, V. Syshchenko, Nuovo Cimento (2011)



$$E = 50Mev \qquad \lambda \approx 0.1cm$$

$$l_C \approx 2\gamma^2\lambda \approx 20m \qquad l_T \approx \gamma\lambda \approx 10cm$$

For $t > 0$ **:**

$$\mathbf{z>0:}\quad \varphi(\vec{r},t) = \left[\frac{e}{\sqrt{\rho^2\gamma^{-2}+(z-vt)^2}} - \frac{e}{\sqrt{\rho^2\gamma^{-2}+(z+vt)^2}}\right]\theta(t-r)$$

$$\mathbf{z<0:}\quad \varphi(\vec{r},t) = \left[-\frac{e}{\sqrt{\rho^2\gamma^{-2}+(|z|-vt)^2}} + \frac{e}{\sqrt{\rho^2\gamma^{-2}+(z-vt)^2}}\right]\theta(r-t)$$

It is not the same as in *B. Bolotovsky, A. Serov // Phys. Usp., 2009*

Conclusions #2

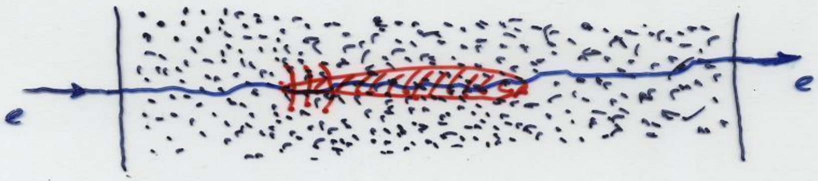
- Quantum description of electromagnetic processes at ultrahigh formation lengths

- Boundary conditions problem

- Wave and pre-wave zones in transition radiation and bremsstrahlung

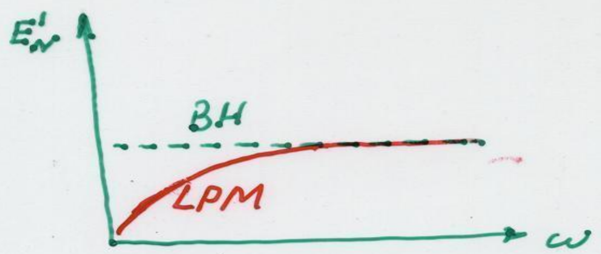
- Evolution of radiation processes in space and time

LPM – effect (1953)



$$\frac{dE_{BH}^{(N)}}{d\omega} = N\,\frac{dE^{(1)}}{d\omega}$$

Landau – Pomeranchuk 1953



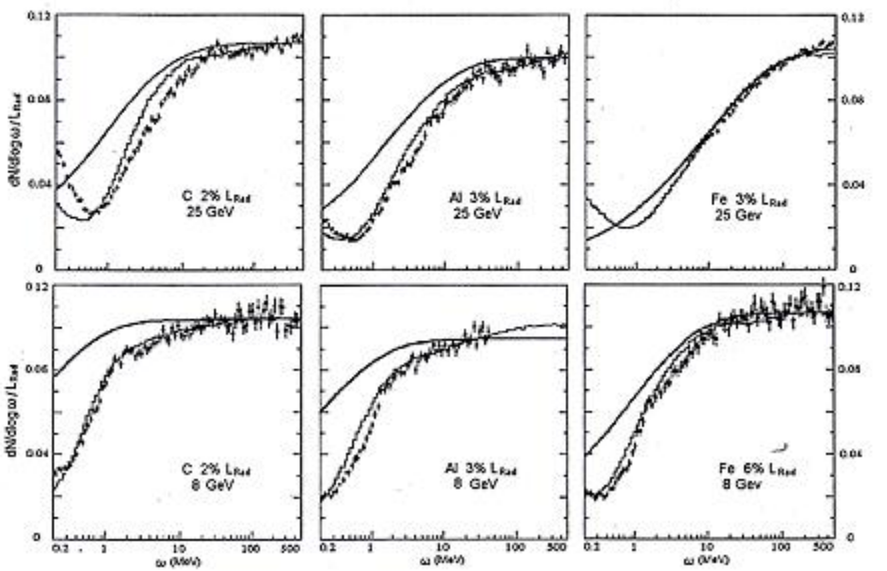
$$\frac{dE_{BH}}{d\omega} = \frac{4}{3}\frac{L}{X_0}\frac{E'}{E}\left(1 + \frac{\omega^2}{EE'}\right)$$

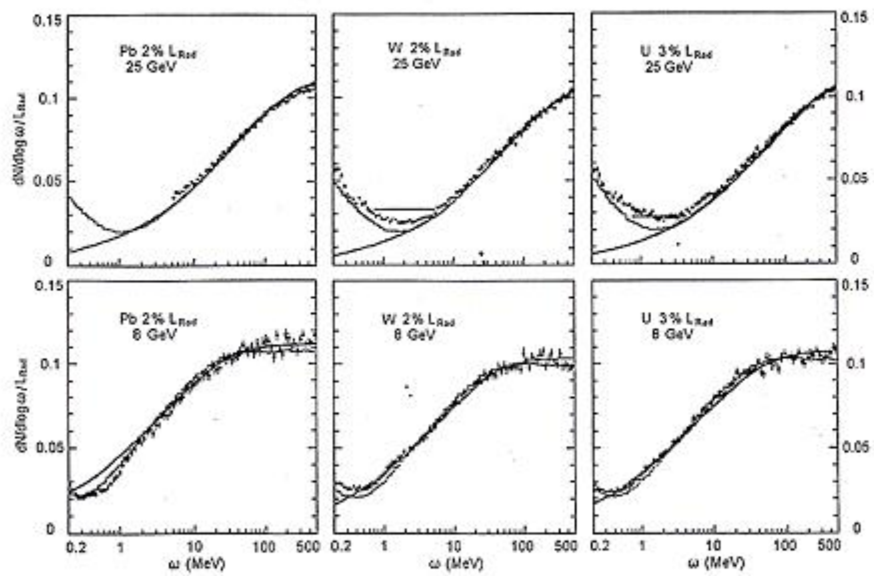
$$X_0^{-1} = \frac{4Z^2 e^6 n}{m^2}\ln\left(mR\right)$$

$$\frac{dE_{LP}}{d\omega} \approx \frac{L}{X_0}\sqrt{\frac{2\pi}{3}\frac{\omega E_0}{E}}$$

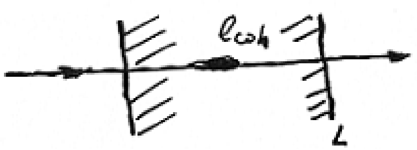
An effect confirmed after 40 years!

(SLAC – experiment Phys.Let. (1995); Rev.Mod.Phys. (1999)





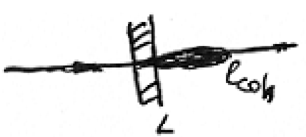
LPM



CERN Courier 1994

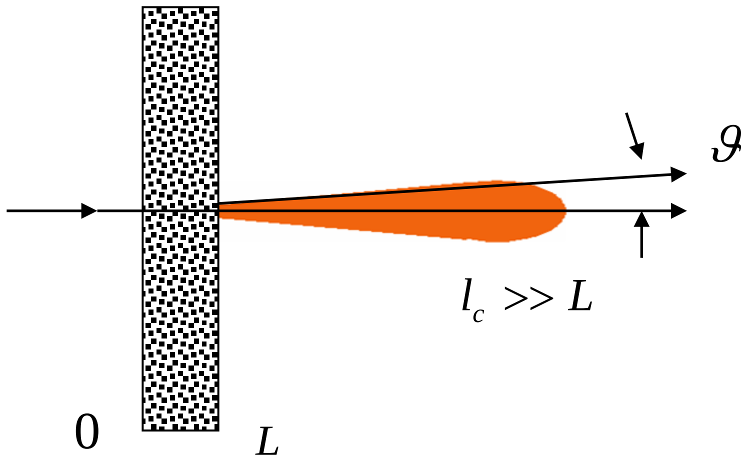
E. Feinberg Природа 1994

TSF

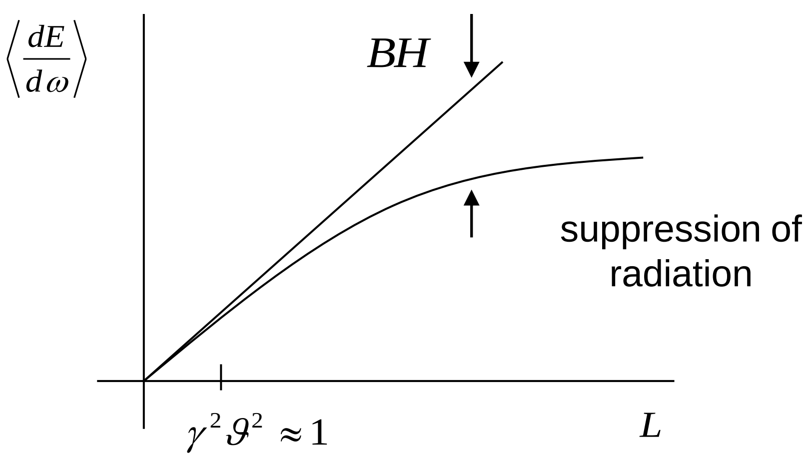


Radiation in thin target (TSF-effect)

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



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

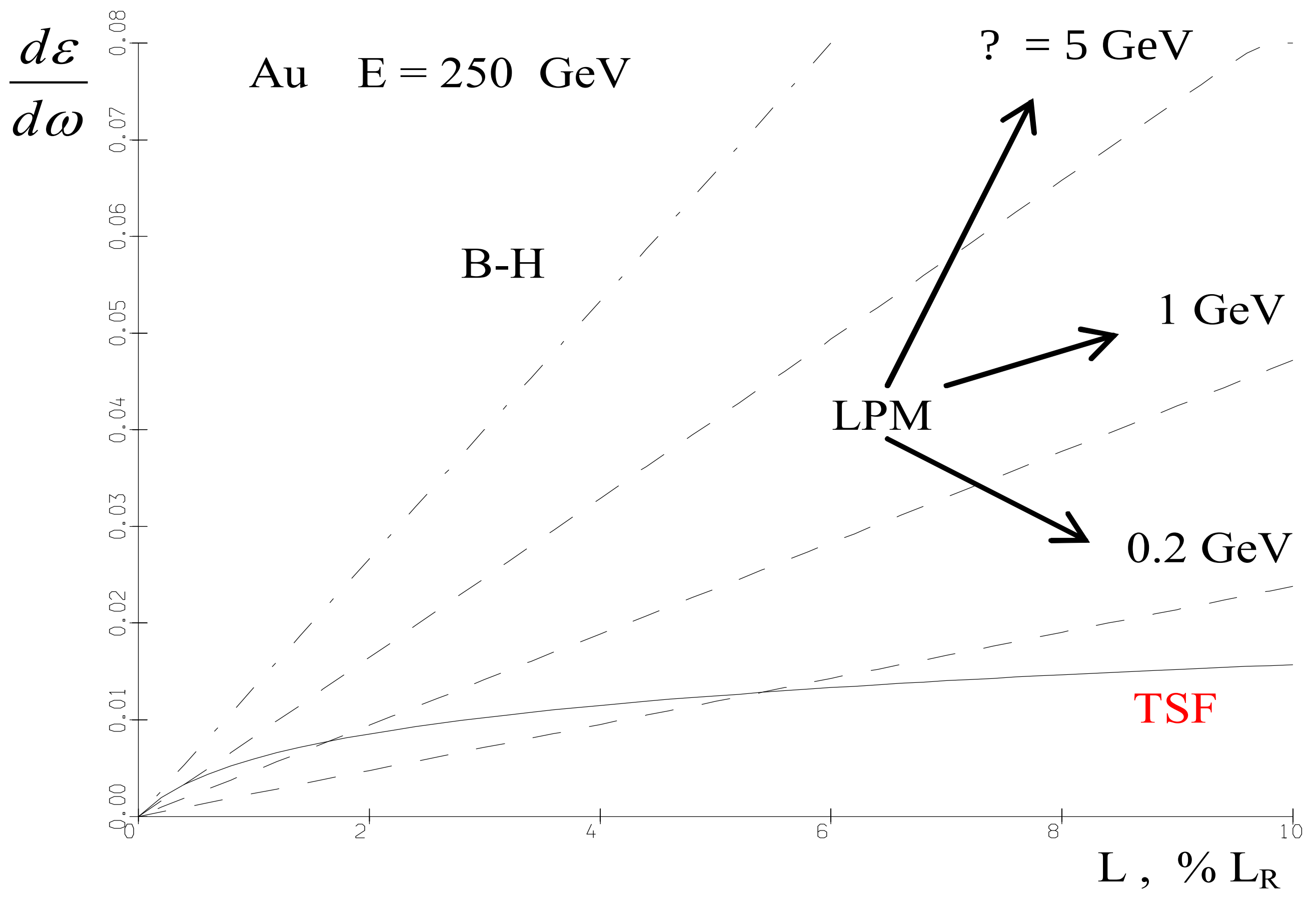


$$\left\langle \frac{dE}{d\omega} \right\rangle = \frac{2e^2}{\pi} \left\langle \left[\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}} \ln\left(\xi + \sqrt{\xi^2+1}\right) - 1 \right] \right\rangle \approx$$

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

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

Dependence on thickness



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.*

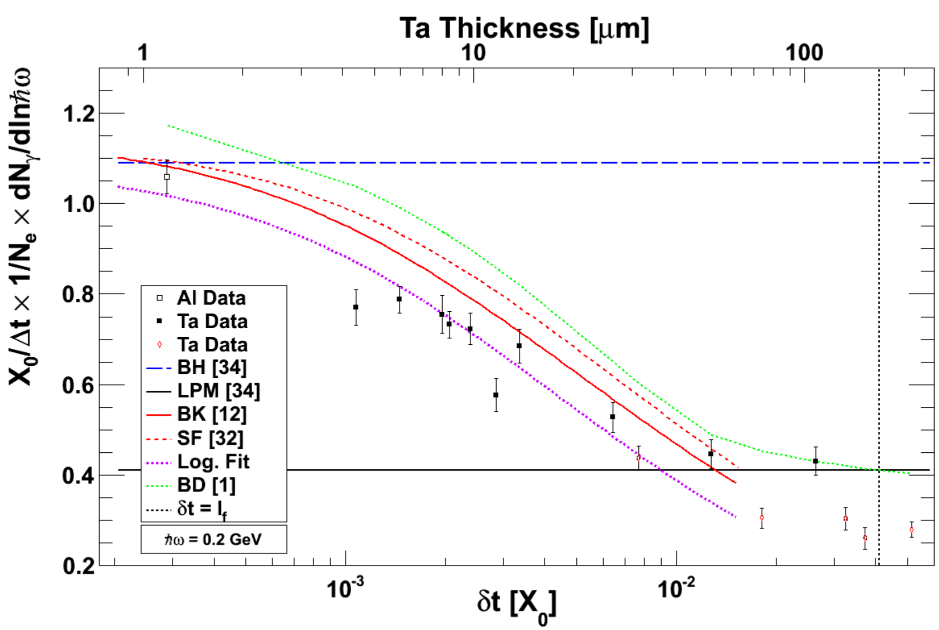
H.D.Thomsen et al., Physical Review D 81 (2010) 052003.

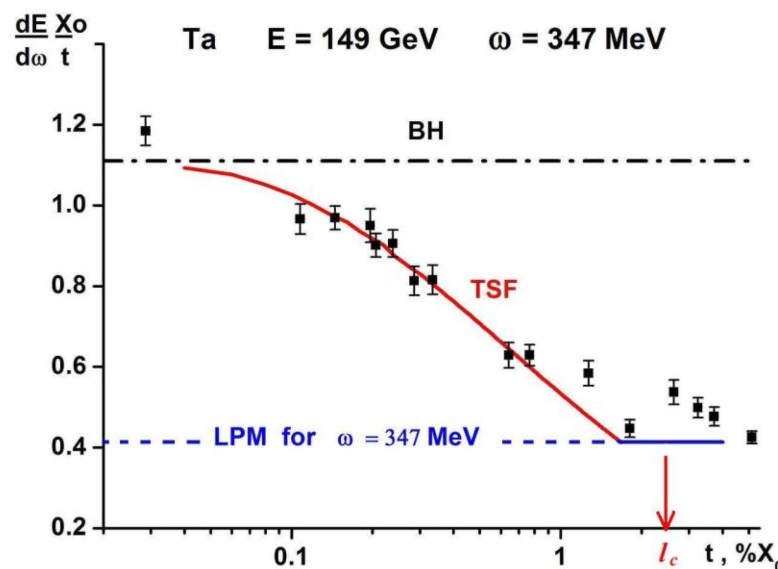
CERN NA63 SPS E = 149 GeV

"Channeling 2010", Ferrara, Italia

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

Nuovo Cimento (2011), in press

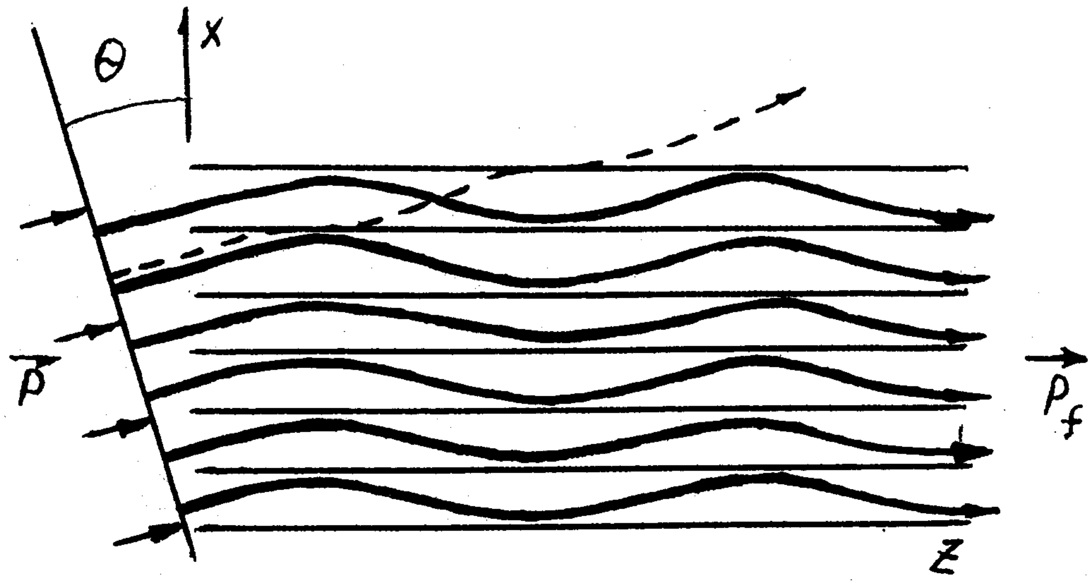




U. Uggerhoj : … we have seen the half - bare electron !

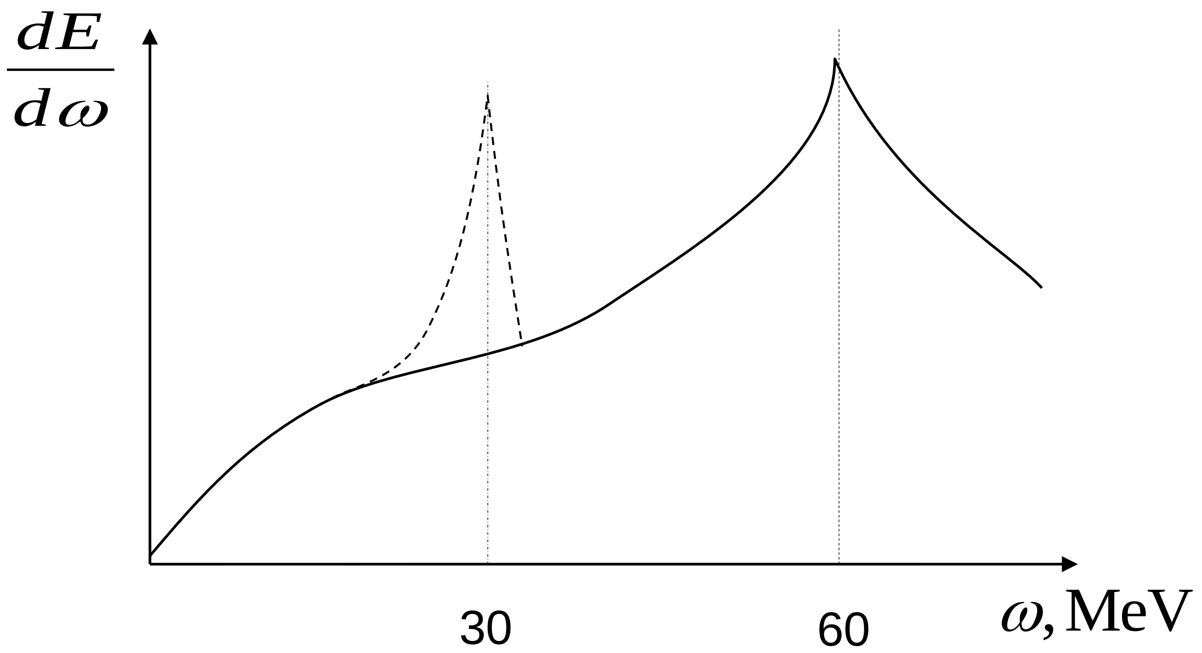
New Interference Effect in Radiation at Channeling

N. Shul'ga. Dokl. Acad. Nauk of USSR v.310 (1990) 348



A. Akhiezer, N. Shul'ga. Physics Reports v.234 (1993) 297

New Interference Effect in Radiation at Channeling



e^+

$\varepsilon = 1GeV$

$Si, (110)$

$$\omega_{new} = \frac{\omega_d}{1+\frac{3}{2}\alpha^2} \qquad \omega_{chan.} = \frac{\omega_d}{1+\frac{1}{2}\alpha^2}$$

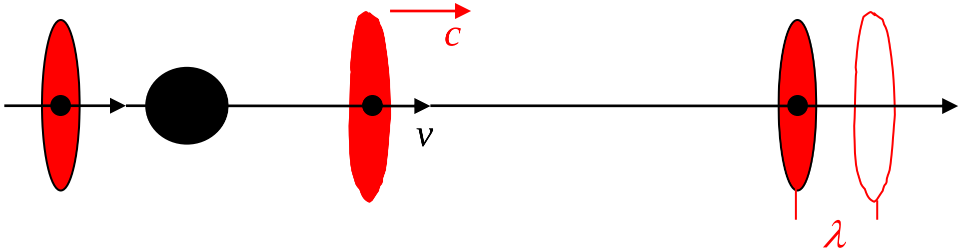
$$\omega_d = 2\gamma^2\theta_c / a, \quad \alpha = \gamma\theta_c$$

THANK YOU FOR ATTENTION!

HOW DOES ELECTRON RADIATE?

The excitation is small

$\gamma\theta_{scat} << 1$

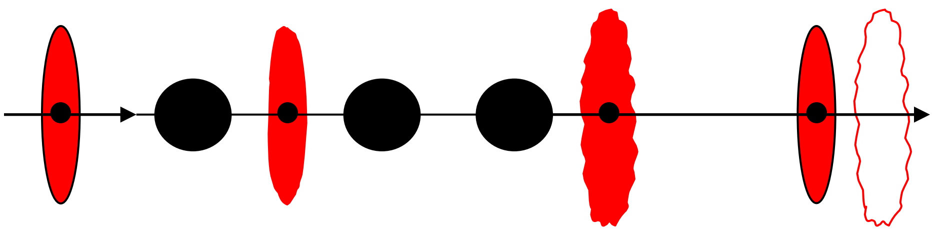


$$v_{rel} = c - v$$

$$\lambda = (c - v)\Delta t_c \rightarrow \Delta t_c \approx 2\gamma^2 \lambda$$

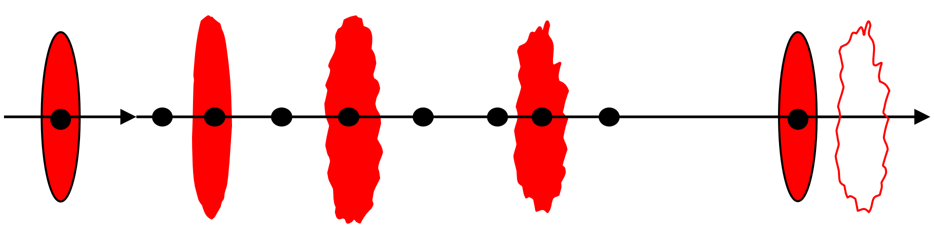
The excitation is increased

$\gamma\theta_{scat} \approx 1$

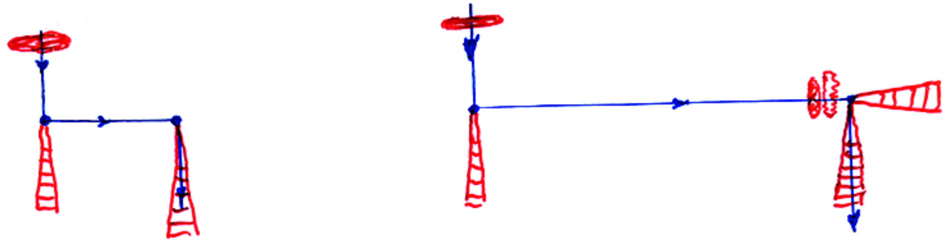


The excitation is strong

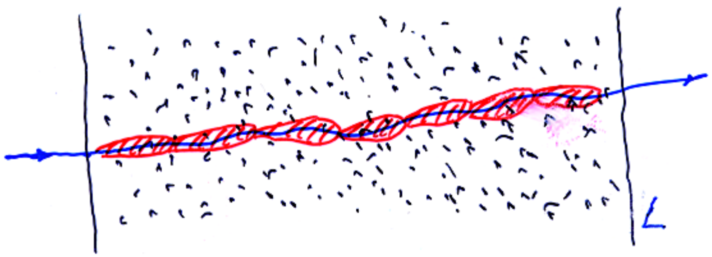
$\gamma\theta_{scat} >> 1$



E. Feinberg (JETP, 1966, v. 50, 202)



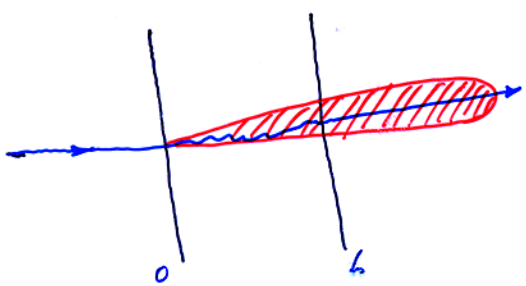
LPM case



$l_c \ll L$

balance = e^- is undressed + e^- is dressed

N. Shul'ga, S. Fomin (1978)



$l_c \gg L$

Electron is "bare" for all collisions !!!