Efim Centennial
Fradkin Conference
Lebedev Institute / September 2-6, 2024

Spin Radiation Effects in Quantum and Classical Electrodynamics

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Outline

I. λ and P in QED: characteristic features, interpretation

II. Technical details

III. Classical vs quantum asymptotic expressions for *Im(AEM)*

IV. Reflections apropos of the correspondence principle

V. Quadratic spin terms and semi classical spin

VI. Conceptual experimental scheme to observe some more of spin dependence of SR

Radiation rate and radiation power of SR in QED

$$\lambda^{QED} = \lambda_{orb}\left[1 - \frac{8\sqrt{3}}{15}\chi + \frac{7}{2}\chi^2 + \cdots + \frac{3}{5}\tilde{\gamma}\left(1 - 4\sqrt{3}\chi + \cdots\right)\right]$$

Ritus, 1969 - cross.f.
Baier et al, 1971
Tsai, Yildiz, 1973 } - mag.f.
LS, 2011 – el. f.

Rest-frame MM energy →

$$-\tilde{\gamma}m = -\frac{e}{2m}\zeta\mathbf{H}_{\mathbf{RF}}$$

$$P^{QED} = P_{orb}\left[1 - \frac{55\sqrt{3}}{16}\chi + 48\chi^2 + \cdots + 3\tilde{\gamma}\left(1 - \frac{35\sqrt{3}}{4}\chi + \cdots\right)\right]$$

Ternov, Bagrov Rzaev, 1964;
Tsai, Yildiz, 1973;
Bordovitsyn, Ternov, Bagrov, 1995 } – mag.f.

Usability condition for semi-classical analysis: $\chi \ll 1\,, \qquad \gamma \gg 1$

Schwinger (1949, 1954)
Sokolov, Klepikov, Ternov (1953)

Dynamic Invariants

$$\mathcal{F} = \frac{(eF_{\mu\nu})^2}{4m^4}, \qquad \mathcal{G} = \frac{e^2 F_{\mu\nu} F^*_{\mu\nu}}{4m^4}$$

$$\chi = \frac{1}{m^3}\sqrt{(eF_{\mu\nu}p_\nu)^2} \le \delta \equiv \frac{\hbar\omega_{ph}}{E} \sim 10^{-5} \div 10^{-4}$$

$$\tilde{\gamma} = \frac{ep_\mu F^*_{\mu\nu} S_\nu}{2m^3} \simeq \frac{\mu F}{m} \sim \chi \qquad \tilde{\gamma}_e = \frac{ep_\mu F_{\mu\nu} S_\nu}{2m^3}$$

$$E \sim 5\text{GeV}(\text{Novosibirsk}) \quad E \sim 30\ \text{GeV},\ \chi \sim 10^{-6} \div 10^{-5}\ (\text{HERA})$$

Crossed-Field Universality (Nikishov, Ritus 1964):

$$\mathcal{E} \ll \mathcal{E}_c,\ \mathcal{H} \ll \mathcal{H}_c \qquad (a)$$

$$\frac{\mathcal{E}}{\mathcal{E}_c} \ll \chi \qquad (b)$$

On this conditions the probabilities of different radiation processes in 1-particle sector of QED coincide

Characteristic features:

i) the recoil and MM effects are of the same order of magnitude wrt χ

ii) crossed-field universality $\Rightarrow$ coincidence of χ - dependences in zero-th order wrt γ^{-2}

iii) the puzzle associated with the sign of major spin terms

Considered options: $\mathcal{F} > 0\,, \quad \mathcal{F} = 0\,, \quad \mathcal{F} < 0\,, \quad \mathcal{G} = 0$

With linear (in χ) accuracy:

$$\lambda^{QED} = \lambda_{orb}\left[1 - \frac{8\sqrt{3}}{15}\chi + \cdots + \frac{3}{10}\,\mathrm{sign}\,(e)\zeta\chi\right], \qquad \to \lambda_s^{QED}$$

$$P^{QED} = P_{orb}\left[1 - \frac{55\sqrt{3}}{16}\chi + \cdots + \frac{3}{2}\,\mathrm{sign}\,(e)\zeta\chi\right], \qquad \to P_s^{QED}$$

$$\varsigma = \pm 1$$

$$\lambda_{so}^{CED} = -\frac{1}{5}\lambda_{orb}\,\mathrm{sign}\,(e)\zeta\chi\,,$$

LS, 2002

$$P_{so}^{CED} = -\frac{1}{2}P_{orb}\,\mathrm{sign}\,(e)\zeta\chi$$

Bordovitsyn, 2002

Spin light (Frenkel model)

$$\lambda_{orb} = \frac{5\alpha}{2\sqrt{3}}\gamma\frac{|eF|}{m}, \quad P_{orb} = \frac{2}{3}\alpha\left(\frac{e\hat{F}(p-eA)}{m^2}\right)^2$$

$$\mathcal{M} \to m + m_{Fr}, \quad m_{Fr} = -\mu\left(\dot{x}\cdot F^*\cdot S\right) = -\tilde{\gamma}m$$

$$\lambda_{orb}(\mathcal{M}) = \lambda_{orb}(m) + \left(\frac{\partial\lambda_{orb}}{\partial m}\right)_{x,v} m_{Fr},$$

$$P_{orb}(\mathcal{M}) = P_{orb}(m) + \left(\frac{\partial P_{orb}}{\partial m}\right)_{x,p} m_{Fr}.$$

The growth of magnetic energy increases the values of MM contributions and decreases inertial one. The latter effect prevails

Magnetic moment contributions

Inertial contributions

$$\lambda_s^{Fr} = \lambda_{so}^{CED} + \left(\frac{\partial\lambda_{orb}}{\partial m}\right)_{x,v} m_{Fr} = \lambda_s^{QED}$$

$$P_s^{Fr} = P_{so}^{CED} + \left(\frac{\partial P_{orb}}{\partial m}\right)_{x,p} m_{Fr} = P_s^{QED}$$

II. Technical details: λ^{CED} and P^{CED}

–Ritus (1981) LS (2005,2014)

$$\Delta W = \frac{1}{2}\int dx\, dx'\, J_\mu(x) D_{\mu\nu}(x,x') J_\nu(x')|_0^F$$

$$J_\mu(x) = j_\mu^{orb}(x) + j_\mu^{s}(x)$$

$$\Delta W = -\left(\Delta m_{or} + \Delta m_{so} + \Delta m_{ss}\right) T$$

$$\frac{1}{\hbar}\Im \Delta W = \int \frac{d\mathcal{E}_{\mathbf{k}}}{\hbar\omega}\ , d\mathcal{E}_{\mathbf{k}} = |J_\mu(\mathbf{k})|^2 \frac{d^3\mathbf{k}}{16\pi^3}$$

$$\Delta m_{or} \sim \chi\,, \quad \Delta m_{so} \sim \chi^2\,, \quad \Delta m_{ss} \sim \chi^3$$

$$|\exp(i\Delta W)|^2 = \exp(-2\Im \Delta W) < 1$$

$$\lambda_{so}^{CED} = -2\Im \Delta m_{so}$$

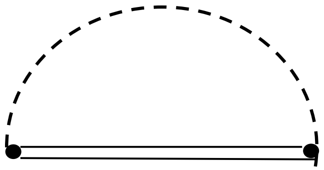
$$\begin{cases} \dot{S} = \kappa \widehat{F} S + \kappa \mathtt{Fr}\, \dot{x}(\dot{x}\widehat{F}S)\,, \\ \ddot{x} = \frac{e}{\mathcal{M}}\widehat{F}\dot{x}\,, \Rightarrow \dot{x}^2\,, S^2\,, \dot{x}S,\ \mathcal{M} = \text{const} \end{cases}$$

$$\mathtt{Fr} \equiv 1 - \frac{2}{g}\frac{m}{\mathcal{M}}$$

$$\Delta m_{so} = \frac{\mu e}{2\pi^2}\int d(\Delta\tau)\, \frac{(x'-x)\wedge \dot{x}'\wedge \dot{x}\wedge S}{((x-x')^2+i0)^2}\Bigg|_{\gamma\gg 1} = \frac{\mu e}{8\pi\sqrt{3}}\,\frac{\dot{x}\wedge\ddot{x}\wedge x^{(3)}\wedge S}{\sqrt{\ddot{x}^2}}$$

formation time: $\Delta\tau_f \cong \sqrt{12/\ddot{x}^2} \sim \frac{1}{\gamma\omega}, \quad \omega = |eF|/m$

III. Anomalous electric moment

$$\Delta m = ie^2 \langle p,\zeta|$$  $$|p,\zeta\rangle$$

$$\Delta m = \Delta m_0 + <AMM> \tilde{\gamma} + <AEM> \tilde{\gamma}_e \qquad \frac{<AEM>}{<AMM>} \sim \gamma^{-2}$$

$$\lambda^{QED} = -2\Im\Delta m \quad \xrightarrow[\chi \ll 1,\ \gamma \gg 1]{} \quad \lambda^{CED} = -2\Im\Delta m^{CED}$$

$$\Re\Delta m^{CED} = 0$$

$$\Re\Delta m_e = -\frac{10}{3\pi}\frac{\alpha e^3}{m^5}\beta(SF\dot{x})\left[\ln\left(\frac{\gamma_E\sqrt{3}}{\chi}\right) - \frac{9}{4}\right] \qquad \Im\Delta m_e = \frac{5}{8\sqrt{3}}\frac{\alpha e^3}{m^5}\frac{\beta(SF\dot{x})}{\chi}$$

(Ritus, 1978)

$$\Re\Delta m_{so}^{(e)} = 0 \qquad \Im\Delta m_{so}^{(e)} = -\frac{1}{2\sqrt{3}}\frac{\alpha e^3}{m^5}\frac{\beta(SF\dot{x})}{\chi}$$

$\beta = \boldsymbol{EH}$

IV. Correspondence principle

The possible reasons for discrepancy in Im(AEM)

1. Ritus' Δm is a mean value of mass operator (not the eigenvalue)
2. The major spin terms in the total QED Λ and P arise from non-flip components of the transition amplitude but the origin of terms in the γ^{-2}- order is still unknown
3. The presence of electric field could change the formation time value
4. Success at $\mathcal{G} = 0$

V. Quadratic spin terms and semi classical spin

$$\lambda^{QED} = \lambda^{(nf)} + \lambda^{(f)}, \quad \lambda^{(f)} = \gamma W_{\uparrow\downarrow}$$

J. Schwinger, W. Tsai (1974)

$$W_{\uparrow\downarrow} = \frac{1}{2T_{QED}} \left(\underbrace{1 + \zeta_3 \frac{8\sqrt{3}}{15}} - \frac{2}{9}\zeta_v^2 \right)$$

A. Sokolov,
I.Ternov (1963)

V. Baier,
V. Katkov,
V. Strakhovenko
(1970):

$$\vec{\zeta} = \langle \vec{\sigma}(t) \rangle$$

CED

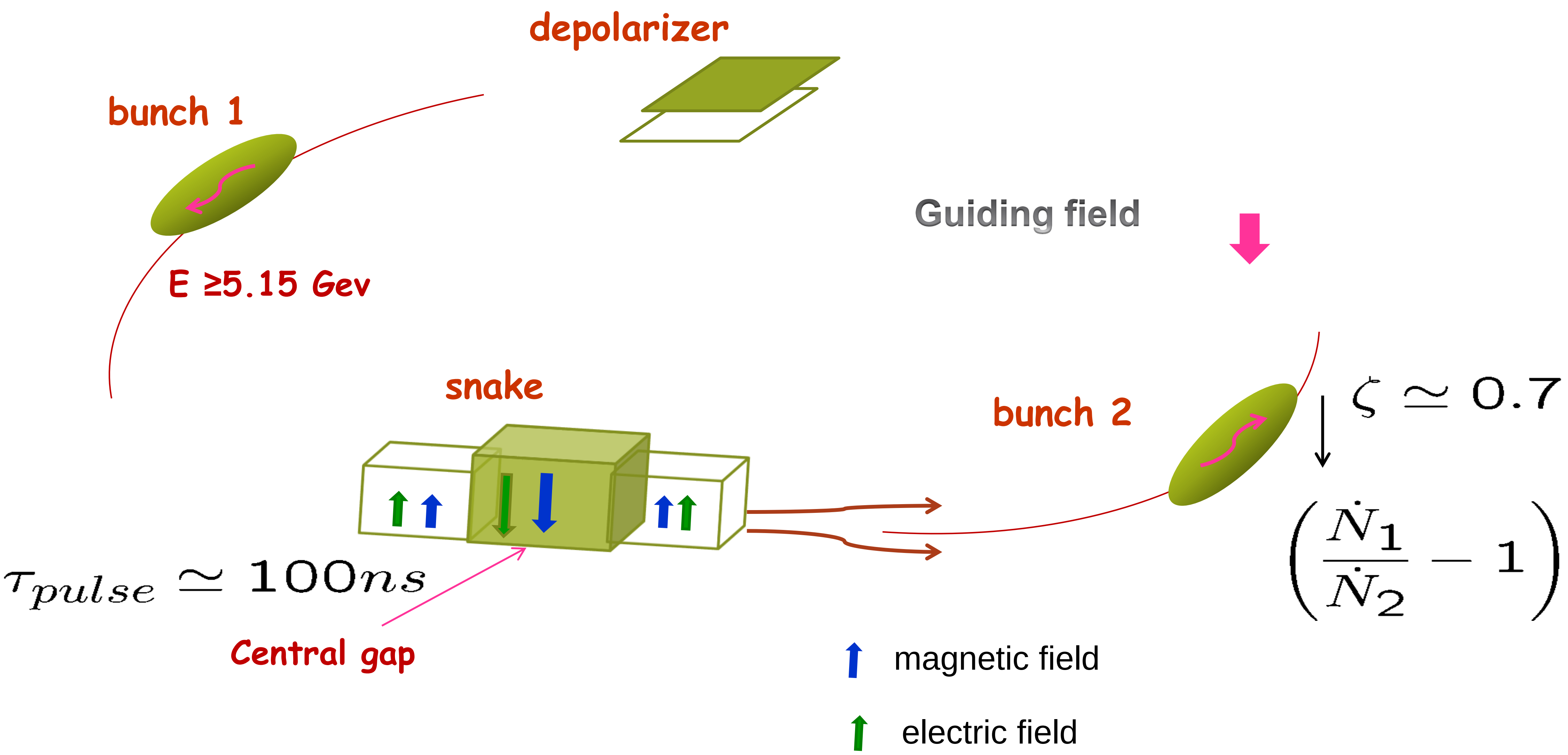
$$\lambda(\vec{\zeta}) = -2\Im \Delta m^{CED} = \lambda_{or} + \lambda_{so} + \lambda_{ss}$$

$$\sim \chi \qquad \sim \chi^2 \qquad \sim \chi^3$$

$$\lambda(\vec{\zeta}) = \lambda_{or} + a\zeta_3 + k\vec{\zeta}^2 - b\zeta_3^2 - c\zeta_v^2$$

$$b = \frac{1}{4}\frac{\gamma}{T_{QED}}, \quad c = \frac{1}{15}b$$

VI. Conceptual experimental scheme



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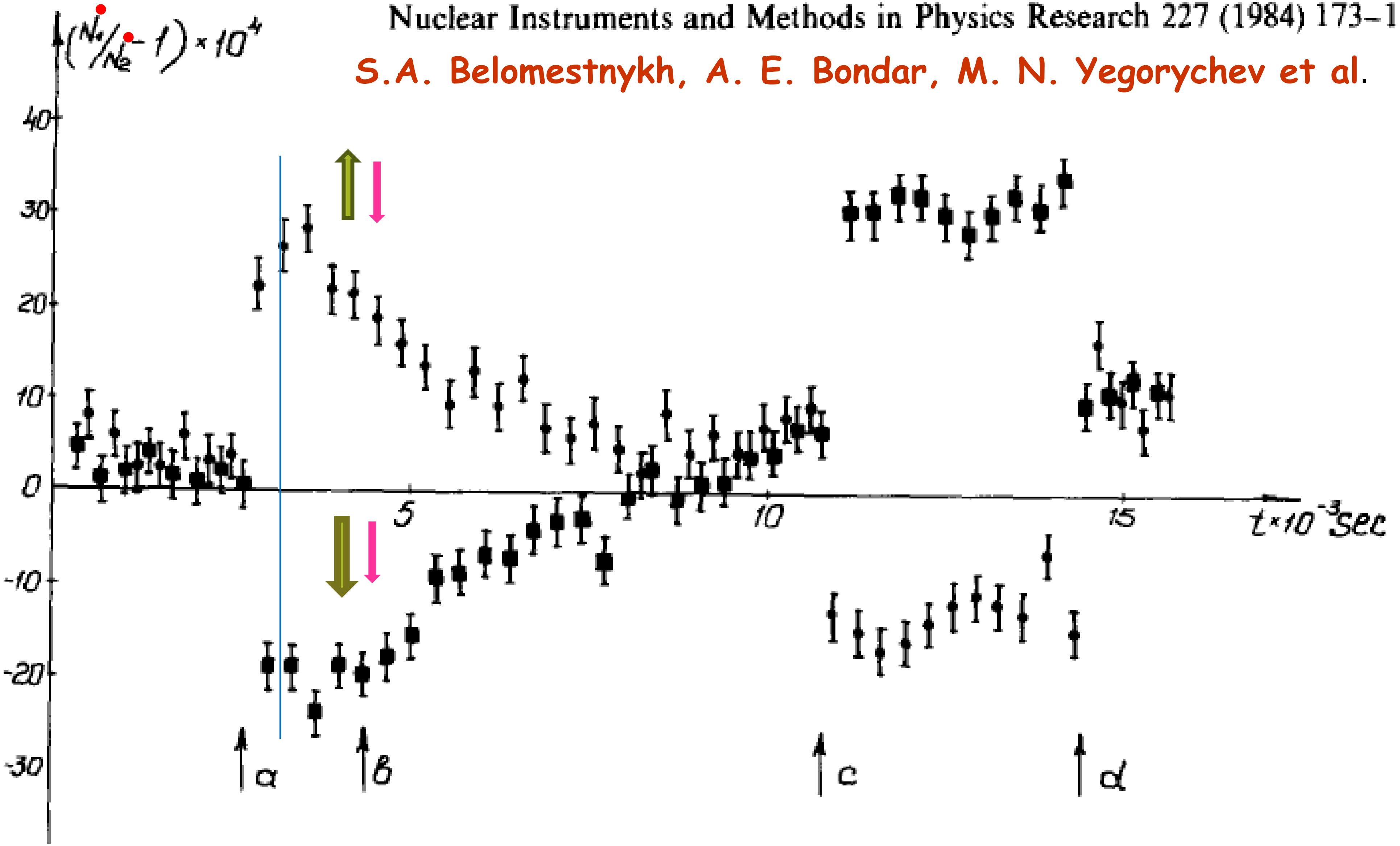

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