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Extreme Light Infrastructure - Nuclear Physics *(ELI-NP) – Phase I*
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A Phenomenological Model of Radiation Reaction at ELI-NP

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Abstract

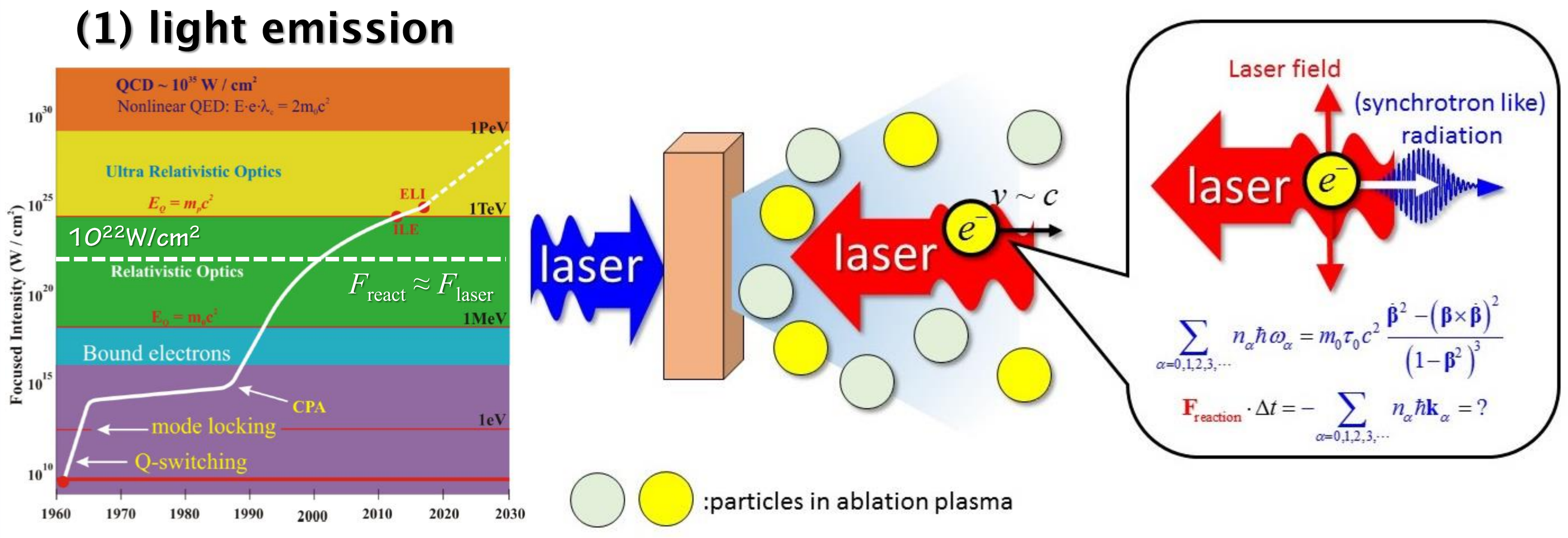
Due to the developments of high-power lasers, experiments with these may bring new information on fundamental questions in physics. ELI-NP also aims to push forward science by using high-intense light. Concerning the effects of strong light, we are interested in the light-electron interactions in the framework of QED. Generally speaking, the process of "radiation reaction" should govern the dynamics of an electron. Our group has developed this with QED modified radiation method by considering the variable charge and the mass of an electron in external high-fields. These charge and mass are given by certain Lorentz invariant functions. After the derivation of the new equation of a radiating electron's motion, we introduced the QED cross-section including the high-intense field correction for these functions as the fact by observations. If we choose the Sokolov's radiation spectrum, this model agrees well with the results by his model.

ELI-NP Working Group RA5-TDR: Combined Laser Gamma Experiments at ELI-NP
Editors: *K. Homma (conveners), O. Tesileanu (liaisons),* ***K. Seto,***
Y. Arai, S. Aogaki, B. Boisdeffre, L. D'Alessi, I. Dancus, D. Filipescu, M. Hashida, T. Hasebe, A. Ilderton, Y. Iwashita, M Kando, J. Koga, K. Matsuura, T. Moritaka, K. Nakajima, Y. Nakamiya, C. Petcu, S. Sakabe, M. Tataru, H. Utsunomiya

Radiation Reaction and ELI-NP

Radiation reaction – The problem of

(1) light emission



(2) an electron model

Theory of an Electron: Investigation of An Electron's Coupling in Strong Fields
- In 1905-1906: nonrelativistic-classical electron model by Lorentz and Abraham
- In 1928: Dirac equation in Quantum dynamics
- In 1938: relativistic-classical electron model by Dirac (LAD equation)
- 2014 ~ : Coupling correction (K. Seto, *et al.*, PTEP 2014,2015 + arXiv:2015)

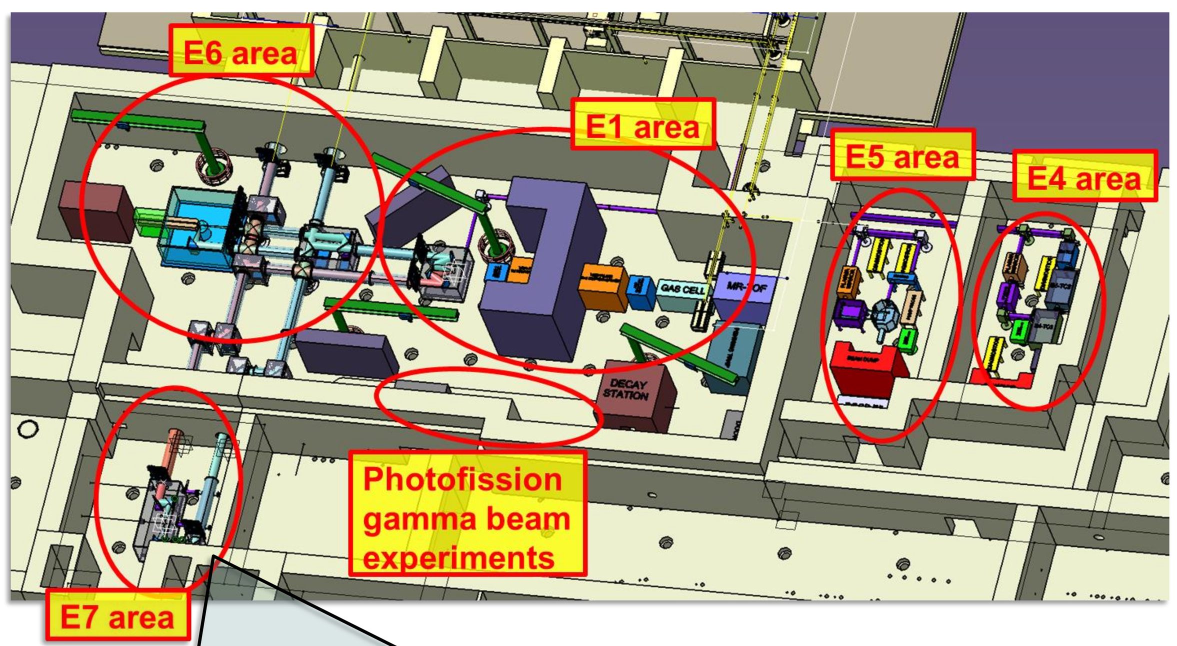
$$dm\frac{dw^\mu}{d\tau} = -d\mathfrak{E}^{\mu\nu\alpha\beta}\mathfrak{F}_{\alpha\beta}w_\nu$$

Charge/Mass ratio…
- Intensity dependence
- Anisotropy by Quantum vacuum

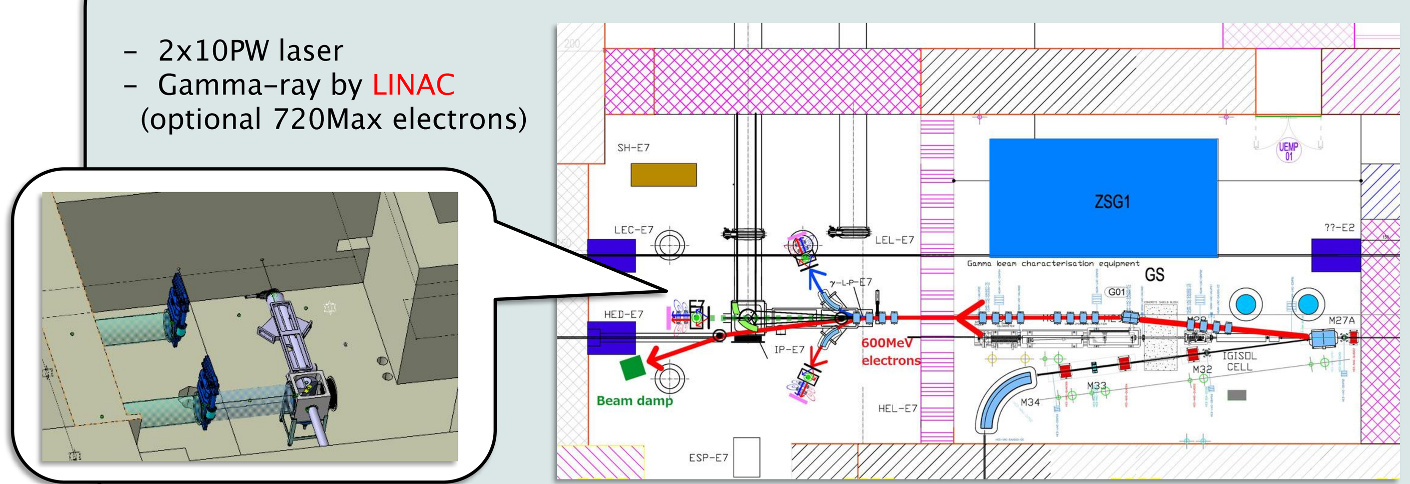
= field propagator correction

$$\left.\frac{e}{m_0}\right|_{\rm Fletcher\text{-}Millikan} \mapsto \left.\frac{d\mathfrak{E}^{\mu\nu\alpha\beta}}{dm}\right|_{\rm in\ High\text{-}fields}$$

ELI-NP Facility: High Power Laser Interaction Areas



E7 hall for Laser Gamma Experiments (RA5-TDR)
- 2x10PW laser
- Gamma-ray by LINAC (optional 720Max electrons)

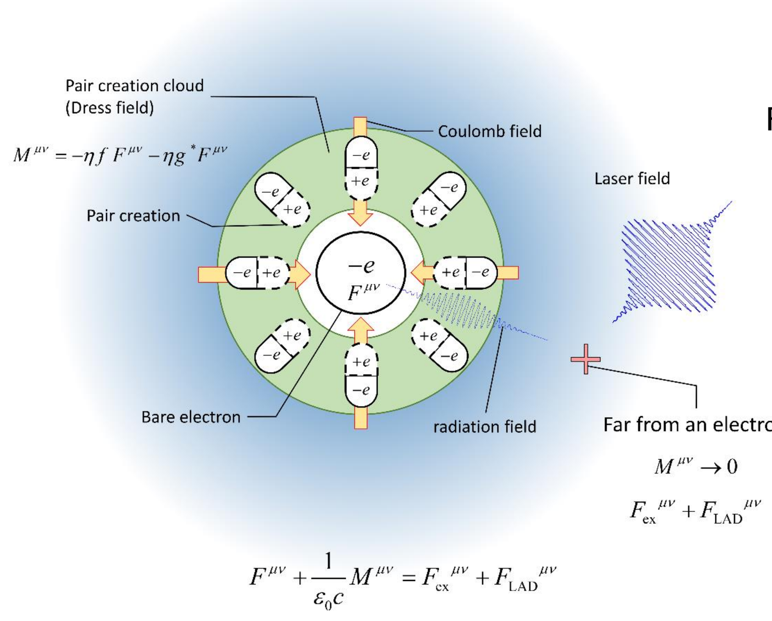


Theoretical Research for Radiation Reaction

1) Correction of Field Propagation: Modification by QED Vacuum

Seto, PTEP 2014, 2015

Question
Does Dirac's homogenous field $\mathfrak{F} = F_{ex} + F_{LAD} \in \mathbb{V}_M{}^4 \otimes \mathbb{V}_M{}^4$ act on an electron directly?
If NOT, Which Field should act on an electron?



Observable field
Filter field by QED vacuum

$$F^{\mu\nu} + \frac{1}{\varepsilon_0 c}M^{\mu\nu} = \mathfrak{F}^{\mu\nu}$$
$$(\mathbf{E},\mathbf{B}) + (\mathbf{P},\mathbf{M}) = (\mathbf{D},\mathbf{H})$$
$$m_0\frac{d(\gamma\mathbf{v})}{dt} = -e\mathbf{E} - e\mathbf{v}\times\mathbf{B} = -eF^{\mu\nu}w_\nu$$

Field acting on an electron — **Obserbable field** — **Dress field by QED vacuum**

$$F^{\mu\nu} + \frac{1}{\varepsilon_0 c}M^{\mu\nu} = \mathfrak{F}^{\mu\nu}, \quad (\mathbf{E},\mathbf{B}) + (\mathbf{P},\mathbf{M}) = (\mathbf{D},\mathbf{H})$$

Algebraic procedure

$$F^{\mu\nu} = \mathfrak{K}^{\mu\nu\alpha\beta}\mathfrak{F}_{\alpha\beta}$$
$$\mathfrak{K}^{\mu\nu\alpha\beta} = \frac{g^{\mu\alpha}g^{\nu\beta} + \frac{1}{2!}\varepsilon^{\mu\nu\alpha\beta}\times\frac{7}{4}\eta\langle\mathfrak{F}\,|\,{}^*\mathfrak{F}\rangle}{1-\eta\langle\mathfrak{F}\,|\,\mathfrak{F}\rangle}$$

Substituting them into $m_0\frac{dw}{d\tau} = -eF^{\mu\nu}w_\nu$

Equation of an electron's motion (**Seto I**: Seto, PTEP 2015)

$$m_0\frac{dw}{d\tau} = -e\mathfrak{K}^{\mu\nu\alpha\beta}\mathfrak{F}_{\alpha\beta}w_\nu$$

Field undressing filter: $\mathfrak{K}^{\mu\nu\alpha\beta}$
Observable field at outside of an electron: $\mathfrak{F}_{\alpha\beta}$

2) QED Radiation Correction: Modification of Radiation Spectrum

Seto, arXiv 2015, submitted to PTEP

We may not know how the coupling are running in high-field.

$$e_{\rm High\text{-}Intense} = e\times\Xi(\tau)$$
$$m_{\rm High\text{-}Intense} = m_0\times\Theta(\tau)$$

Maxwell equation:
$$\partial_\mu F^{\mu\nu} = \mu_0\left[-ec\int_{-\infty}^{\infty}d\tau'\,\Xi(\tau)w^\nu(\tau')\delta^4(x'-x(\tau'))\right]$$

Homogenous solution (Modified LAD field):
$$F_{\rm Mod\text{-}LAD}\big|_{x=x(\tau)} = -\frac{m_0\tau_0}{ec^2}\left[\frac{d^2(\Xi w)}{d\tau^2}\otimes w - w\otimes\frac{d^2(\Xi w)}{d\tau^2}\right]$$
$$= \Xi\times F_{\rm LAD}\big|_{x=x(\tau)} - \frac{2m_0\tau_0}{ec^2}\frac{d\Xi}{d\tau}\left(\frac{dw}{d\tau}\otimes w - w\otimes\frac{dw}{d\tau}\right)$$
$$\in \mathbb{V}_M{}^4\otimes\mathbb{V}_M{}^4$$

Observable field (including modified radiation)
$$\mathfrak{F}_{\rm hom} = F_{ex} + F_{\rm Mod\text{-}LAD}$$

$$\mathfrak{F} + \frac{1}{\varepsilon_0 c}M = \mathfrak{F}_{\rm hom}, \quad (\mathbf{E},\mathbf{B}) + (\mathbf{P},\mathbf{M}) = (\mathbf{D},\mathbf{H})$$

Polarization by QED vacuum (for the stability of motion)

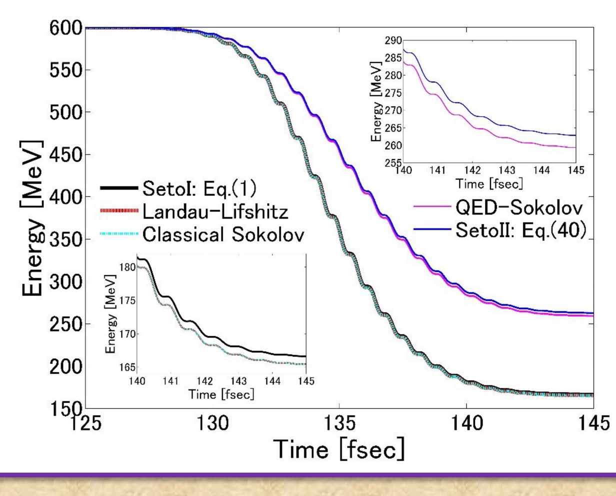
$$\mathfrak{F}^{\mu\nu} = \frac{(1-\eta f_0)\times g^{\mu\alpha}g^{\nu\beta} + \eta g_0\times\frac{1}{2!}\varepsilon^{\mu\nu\alpha\beta}}{(1-\eta f_0)^2 + (\eta g_0)^2}(\mathfrak{F}_{\rm hom})_{\alpha\beta}$$

$$m_0\Theta(\tau)\frac{dw^\mu}{d\tau} = -e\Xi(\tau)\mathfrak{F}^{\mu\nu}w_\nu$$
($m_0\Theta(\tau) = m_{\rm High\text{-}Intense}$, $e\Xi(\tau) = e_{\rm High\text{-}Intense}$)

Equation of an electron's motion (**Seto II**: Seto, arXiv 2015)

$$dm(x)\frac{dw^\mu}{d\tau} = -d\mathfrak{E}^{\mu\nu}{}_{\alpha\beta}(x)\mathfrak{F}_{\rm hom}{}^{\alpha\beta}w_\nu$$

Measure of mass: $dm(x)$
Measure of running charge (coupling): $d\mathfrak{E}^{\mu\nu}{}_{\alpha\beta}(x)$
"Observable field" at outside of an electron: $\mathfrak{F}_{\rm hom}{}^{\alpha\beta}$



Calcuration results in the case with

$$\Theta(\tau) = \Xi(\tau) = q(\chi) = \frac{9\sqrt{3}}{8\pi}\int_0^{\chi^{-1}}dr\,r\left[\int_{r_\chi}^{\infty}dr'K_{5/3}(r') + \chi^2 r r_\chi K_{2/3}(r_\chi)\right]$$

- Stabilization of LAD equation
- QED correction of radiation spectrum
  - Agree well with the QED Sokolov model
- Anisotropic e/m ratio (Radon-Nikodym derivative):

$$\frac{d\mathfrak{E}^{\mu\nu\alpha\beta}}{dm} = \frac{e\times\Xi}{m_0\times\Theta}\frac{(1-\eta f_0)g^{\mu\alpha}g^{\nu\beta} + \eta g_0\times\frac{1}{2!}\varepsilon^{\mu\nu\alpha\beta}}{(1-\eta f_0)^2 + (\eta g_0)^2}$$