Physics with High Intense lasers at ATF2

T.Takahashi
Hiroshima Univ.

June 10 2009
ATF2 meeting

Background

Once ATF2 has accomplished its primary goal

- ATF2 provides highest quality GeV electron beam
- Techniques experiences of laser technologies with electron beam
  - **optical cavity, alignment, etc.**

→ new possibility

- In previous ATF/ATF2 meeting
  - **$\gamma\gamma$ collider test beds (Gronberg, T.T)**
  - **physics with high intense laser field (Tajima, T.T)**

→ up date of laser physics

Brief History

- JFY 2008
  - Budget proposal to JSPS but not successful
- December 2008
  - started discussion to organize new working group
    - making attractive scenario(solid +exotic)
    - making reliable project plan
- March 2009
  - Visited UK to discuss possible plan
- JFY 2009
  - first local meeting at KEK April 22
  - Second meeting May 27
  - third one will be in July

from meeting on Apr 22

Status of Intense laser technology

高強度レーザー技術の状況

近藤公伯　K.Kondo　JAEA

(独)日本原子力研究開発機構
関西光科学研究所
量子ビーム応用研究部門
次世代レーザー開発研究グループ

平成21年4月22日(水)

Status of High power lasers

In Japan

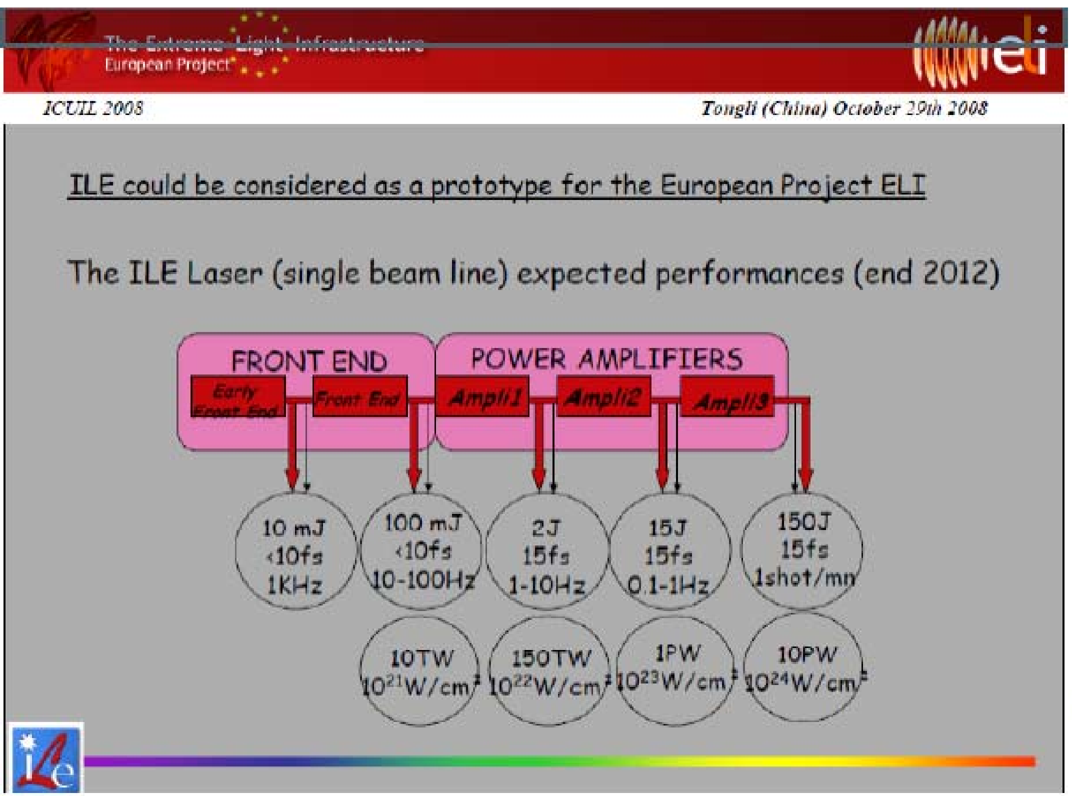
- 100TW, 10Hzチタンサファイアレーザー

K. Yamakawa, et al., Opt. Lett. (1998)

- シングルショット1PW、20fsチタンサファイアレーザー

M. Aoyama, et al., Opt. Lett. (2003)

ミシガン大　HERCULES レーザー
300TW /0.1Hz
～10^{22}W/cm^{2}の集光強度

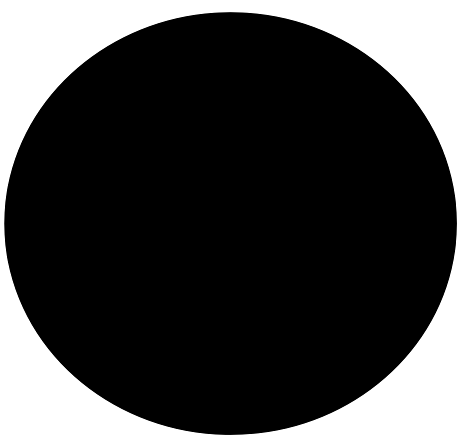


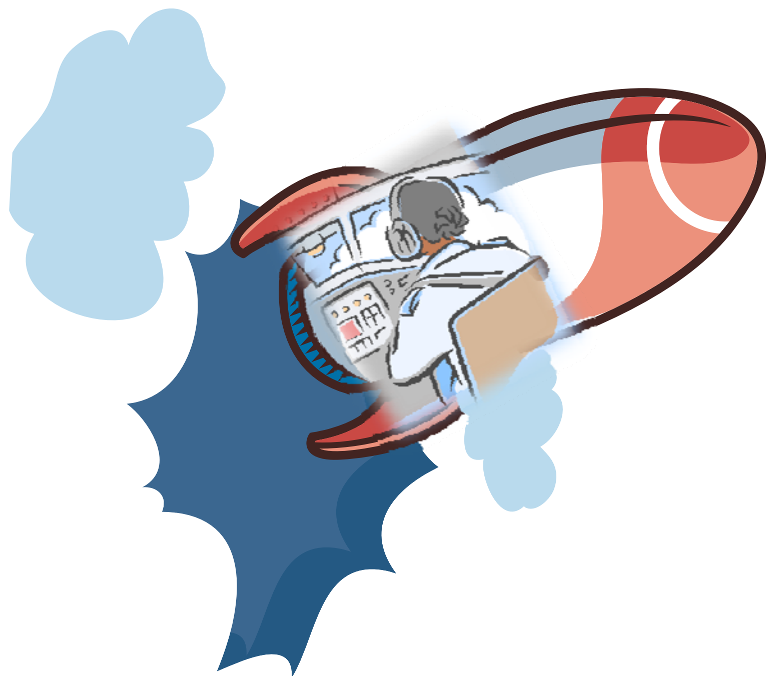
>10^{22}W/cm can be an assumption for study

Hawking /Unruh Radiation

Hawking radiation

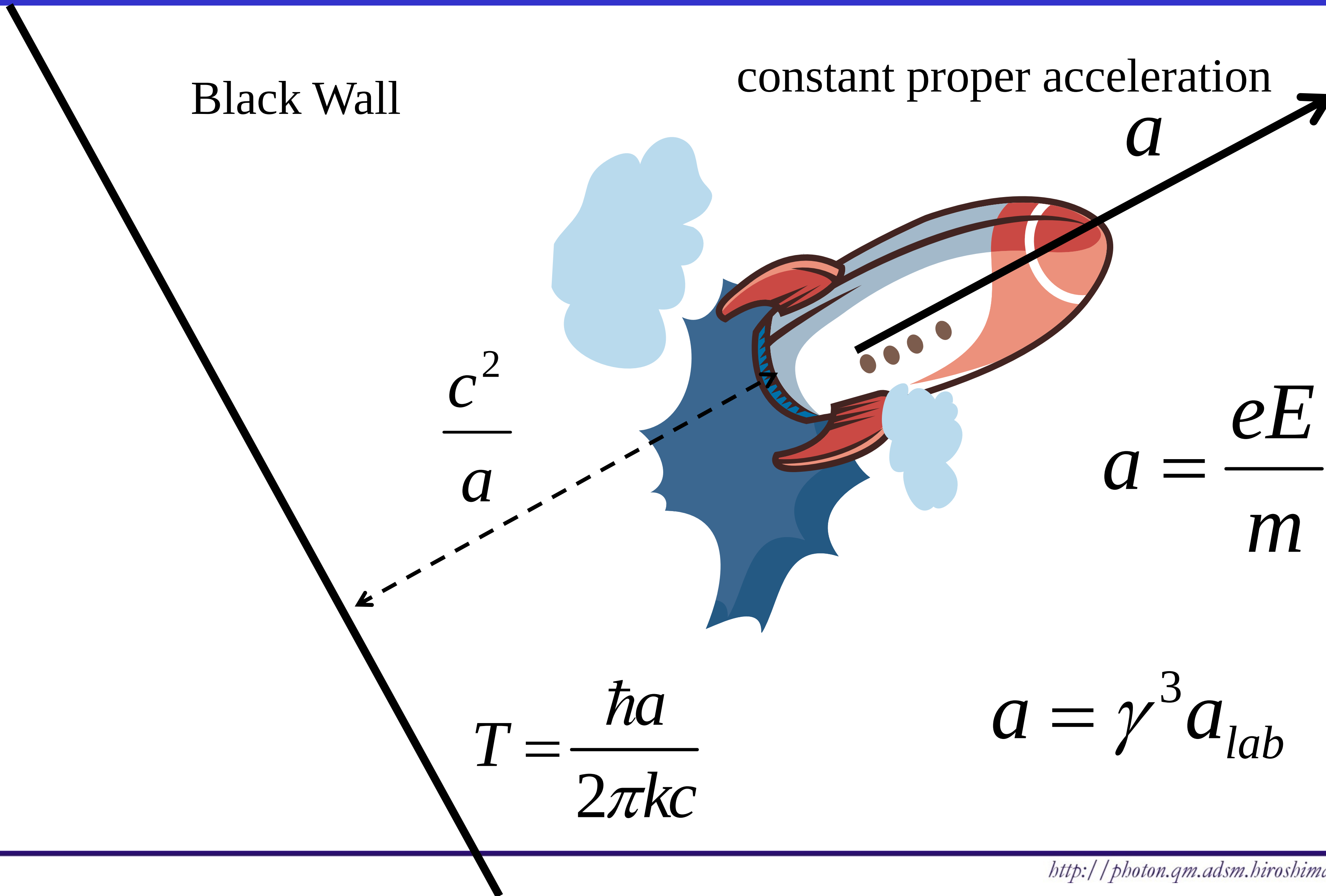
Black Hole





$$T = \frac{\hbar c^3}{8\pi k G M}$$

Hawking Radiation for accelerated observer



$$a = \frac{eE}{m}$$

$$T = \frac{\hbar a}{2\pi kc}$$

$$a = \gamma^3 a_{lab}$$

Discussion is sill on going

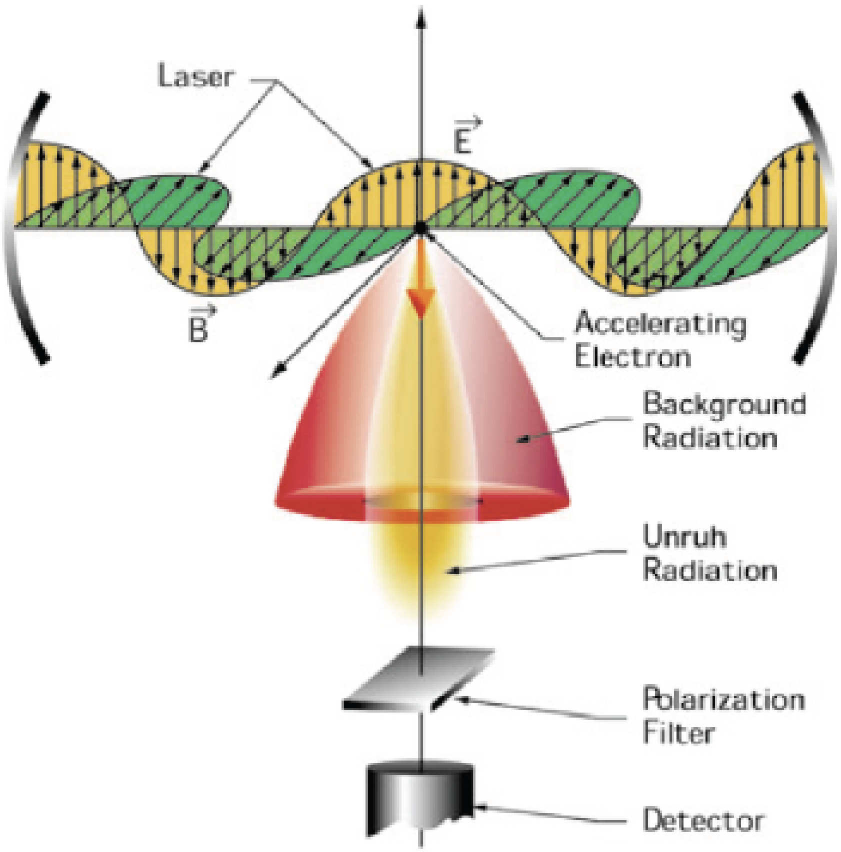
- Unruh effect is
  - **nothing more than QED if calculated in inertial frame**
  - **new phenomena as the event horizon play crucial role**

⇨ both view is correct,,,,,,, not just a QED phenomena
important test of fundamental physics,
physics in acc. system
lab. test of Hawking effect

- toward the experiment
  - **need calculation of realistic condition**
    - previous calculation used some unclear assumption
    - not 3-dim calculation
    - acceleration in the laser is not constant or infinite time

Experiment for Unruh radiation

T.Tauchi



Schematic Diagram for Detecting Unruh Radiation

. 12: *A conceptual design of an experiment for detecting the Unruh effect.*

Facilities at KEK

Nanometer electron beam at ATF2

1.3GeV energy

37nm vertical beam size at IP

Ultra-intense Laser beam in future

λ = 1um

intensity >10^{22}W/cm^2

Parameters of Unruh radiation with Backgrounds

Formulas by P.Chen and T.Tajima

P. Chen and T. Tajima, Phys. Rev. Lett. 83, 256 (1999)

Unruh radiation only at ATF2

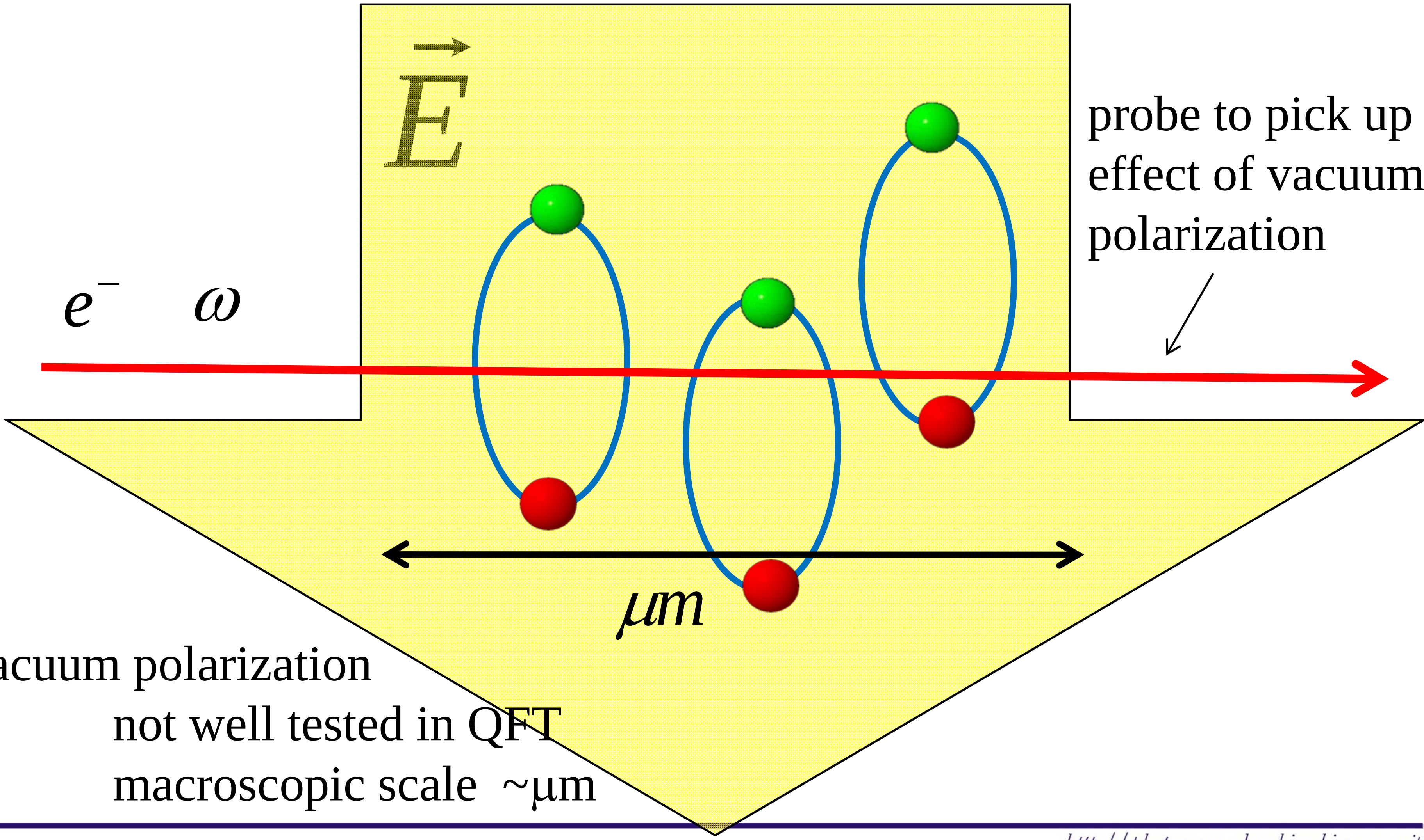
	critical proper time	Larmor radiation	Unruh radiation	Unruh / Larmor	electron beam					
	$\tau_c=2\pi c/A$ $=2\pi/a_0\omega_0$ $(\gamma=a_0)$	$(4\pi/3)$ $r_e mc^2 a_0^2\omega_0/c$	$(12/\pi)\, r_e hc a_0^3$ $\omega_0^2\log(a_0/\pi)/c^2$		E_e	γ_e	$KT\gamma_e$	Larmor radiation	Unruh radiation	Unruh rad/$KT\gamma_e$
	s	eV	eV		GeV		eV	eV	eV	n_γ/e
New ATF2	5.51E-17	1.39E+02	5.48E-02	3.95E-04	1.3	2544	3.03.E+04	3.52E+05	1.39E+02	4.59E-03
4MeV	5.51E-17	4.30E-05	-6.91E-08	-1.61E-03	1.3	2544	3.03.E+04	1.09E-01	-1.76E-04	-5.79E-09
FFTB@SLAC	4.84E-15	9.49E-03	-3.12E-08	-3.29E-06	46.6	9.1.E+04	1.24.E+04	8.65E+02	-2.85E-03	-2.30E-07
$a_0=1$	1.74E-15	7.30E-02	-3.51E-07	-4.81E-06	46.6	9.1.E+04	3.44.E+04	6.66E+03	-3.20E-02	-9.31E-07

Quantum effect

Compton scattering

	vacuum pol. $\Upsilon=2\gamma E/E_{crit}$	vacuum pol. $\kappa=(2E_\gamma^{max}/mc^2)(E/E_{crit})$ $=2h\omega/mc^2)(\lambda_c/\lambda)a_0$	90° collision $x=4E_e h\omega$ $\cos^2 45°/(mc^2)^2$ $=2\gamma^2 h\omega$	90° collision $E_\gamma^{max}=$ $E_e{}^*x/(x+1)$	vacuum pol. κ $=(2E_\gamma^{max}/mc^2)(E/E_{crit})$ $=2h\omega/mc^2)(\lambda_c/\lambda)a_0$	Headon $x=4E_e h\omega$ $\cos^2 0°/(mc^2)^2$	Headon $E_\gamma^{max}=$ $E_e{}^*x/(x+1)$ $=4\gamma^2 h\omega$	Synchrotron γ : $\omega_c=2/3\cdot\gamma^3 c/R$ R=3.887m
		for Comp. γ	for Comp. γ	MeV	for Comp. γ	for Comp. γ	MeV	eV
New ATF2	0.746	0.01	1.24E-02	1.59E+01	0.02	2.47E-02	3.13E+01	5.58E+02
4MeV	0.746	0.75	3.98E+04	1.30E+03	0.75	7.97E+04	1.30E+03	5.58E+02
FFTB@SLAC	0.305	0.14	8.40E-01	2.13E+04	0.19	1.68E+00	2.92E+04	2.57E+07
$a_0=1$	0.846	0.39	8.40E-01	2.13E+04	0.53	1.68E+00	2.92E+04	2.57E+07

another aspect of intense field



vacuum polarization

not well tested in QFT

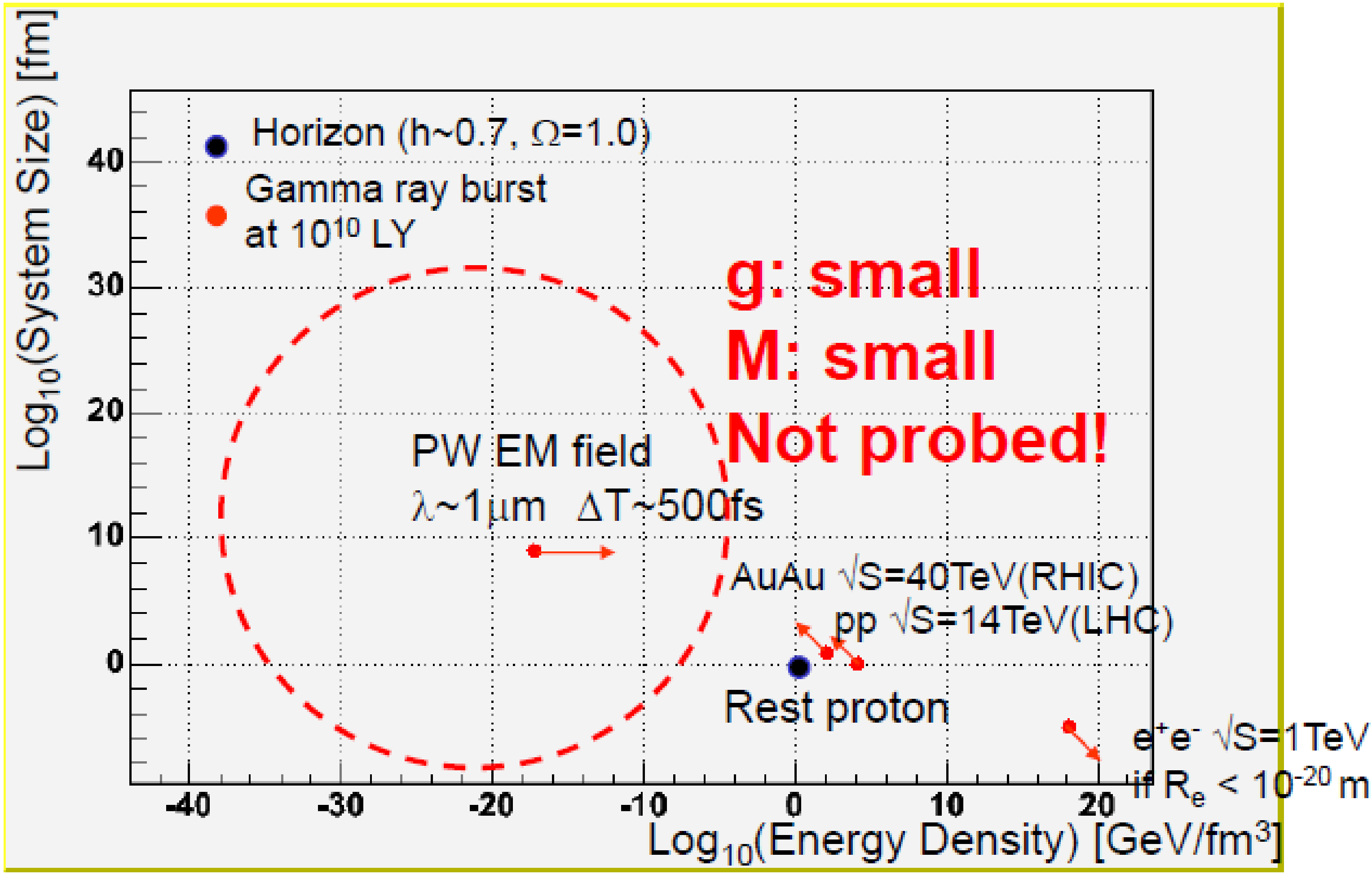
macroscopic scale ~µm

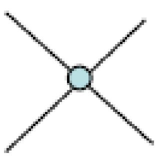
Vacuum we have probed so far

Cosmological observation

g: Small
M: 0

1/g





$(g/M)^2$

g: large
M: large

High energy collider

Birefringence by QED and others

Euler-Heisenberug effective one loop action

$$\frac{1}{360}\frac{\alpha^2}{m^4}[4(F_{\mu\nu}F^{\mu\nu})^2+7(F_{\mu\nu}\widetilde{F}^{\mu\nu})^2]=\frac{2}{45}\frac{\alpha^2}{m^4}[(\vec{E}^2-\vec{B}^2)^2+7(\vec{E}\cdot\vec{B})^2]$$

Refractive index depends on polarization relation

hort distance

$O(10^{-42}$b)

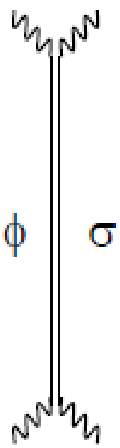
$$n_{\parallel}=1+\frac{16}{45}\frac{\alpha^2 U}{U_e},\quad n_{\perp}=1+\frac{28}{45}\frac{\alpha^2 U}{U_e}$$

$$U_e=m_e^4c^5/\hbar^3\approx 1.42\times10^6\ \mathrm{J}/\mu\mathrm{m}^3$$

E. B. Aleksandrov, A. A. Ansel'm, and A. N. Moskalev, Sov. Phys. JETP **62**, 680 (1985).

$\Delta n_{QED}\sim\alpha^2/m^4\ \varepsilon$ $\varepsilon\sim1[\mathrm{J}/\mu\mathrm{m}^3]\rightarrow\Delta n\sim10^{-11}$

.ong distance

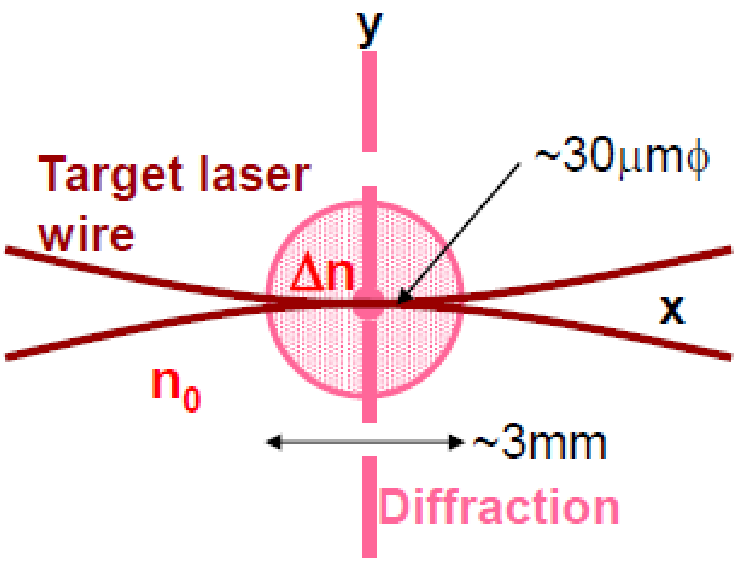


If light scalar φ and/or pseudo scalar σ are hidden in vacuum, it may couple to photons

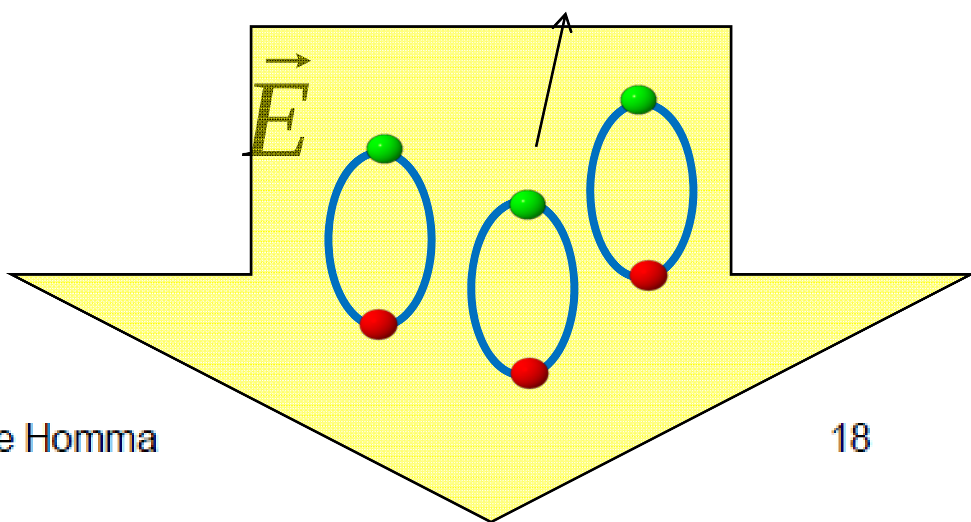
$$\phi(F_{\mu\nu}F^{\mu\nu})^2\quad\sigma(F_{\mu\nu}\widetilde{F}^{\mu\nu})^2$$

It would change the balance between 1st and 2nd term, that is, the polarization dependence deviates from QED.

If we could manage to realize wire shape in vacuum

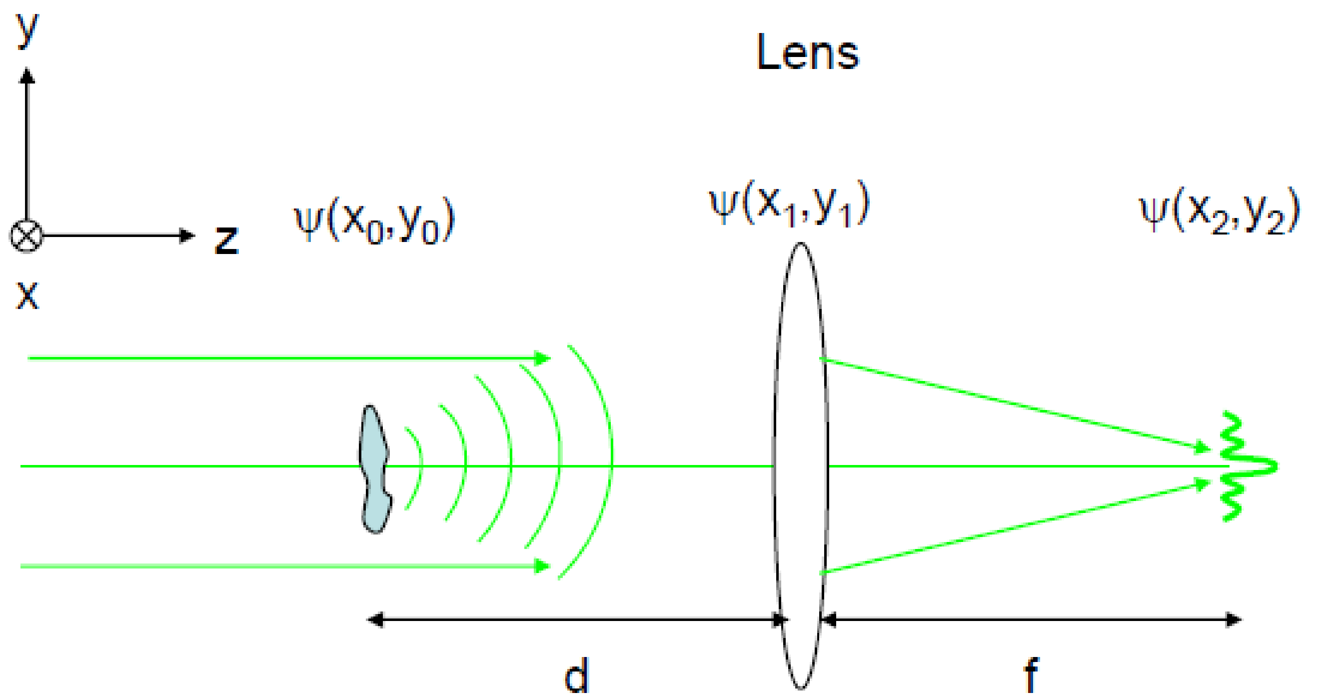


$\Delta n_{QED} \sim \alpha^2/m^4 \, \varepsilon$ $\quad \varepsilon \sim 1[J / \mu m^3] \rightarrow \Delta n \sim 10^{-11}$



How to extract small phase retardation ?

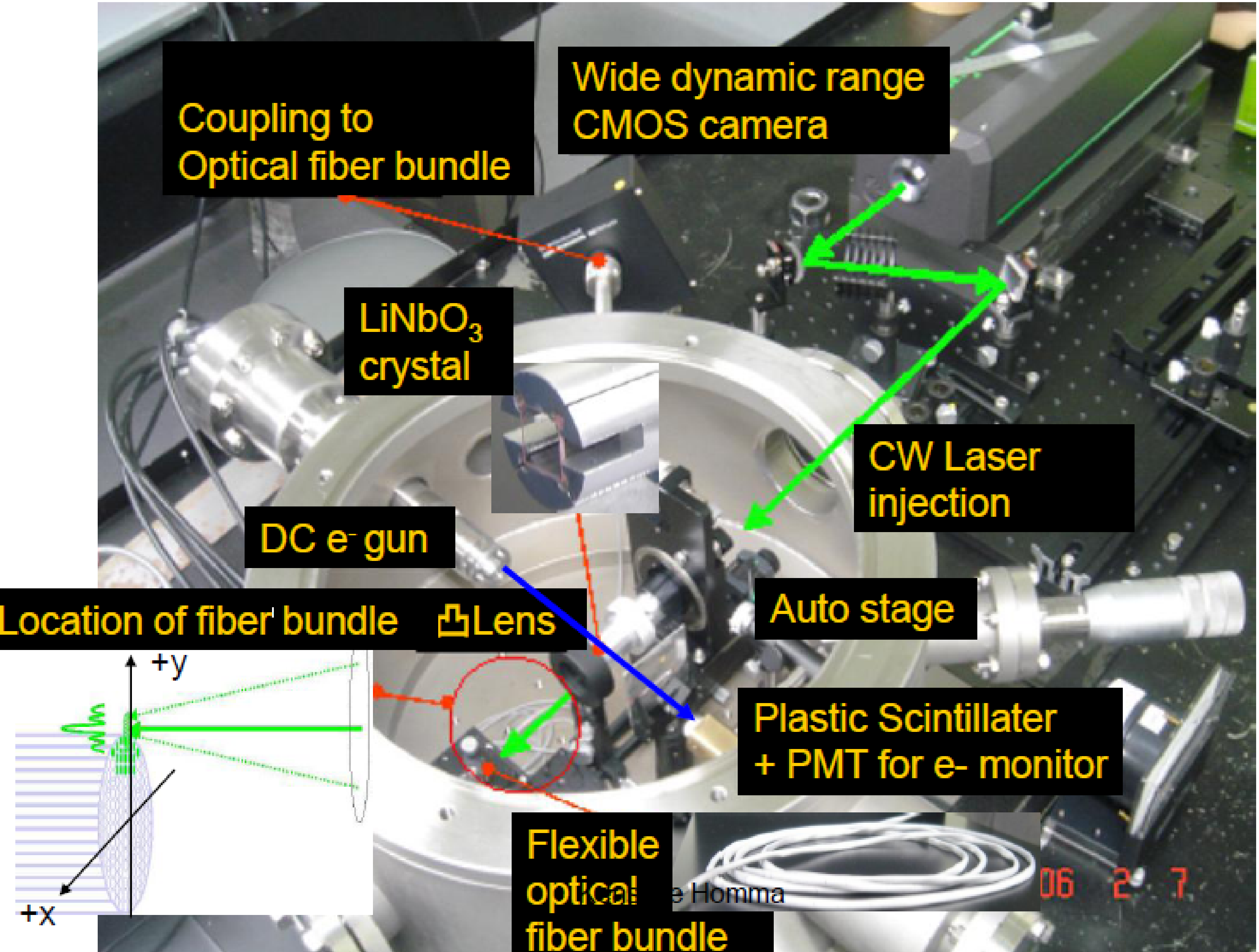
Fraunhoffer diffraction at an infinite distance can be obtained by lens at a short distance.



$$|\psi(\omega_{x2},\omega_{y2})|^2 = (\lambda f)^{-2} F^2\{\psi(x_0,y_0)\}$$

The diffraction pattern **at the focal plane** corresponds to Fourier transformation of input shape of a refractive medium.

Experimental setup

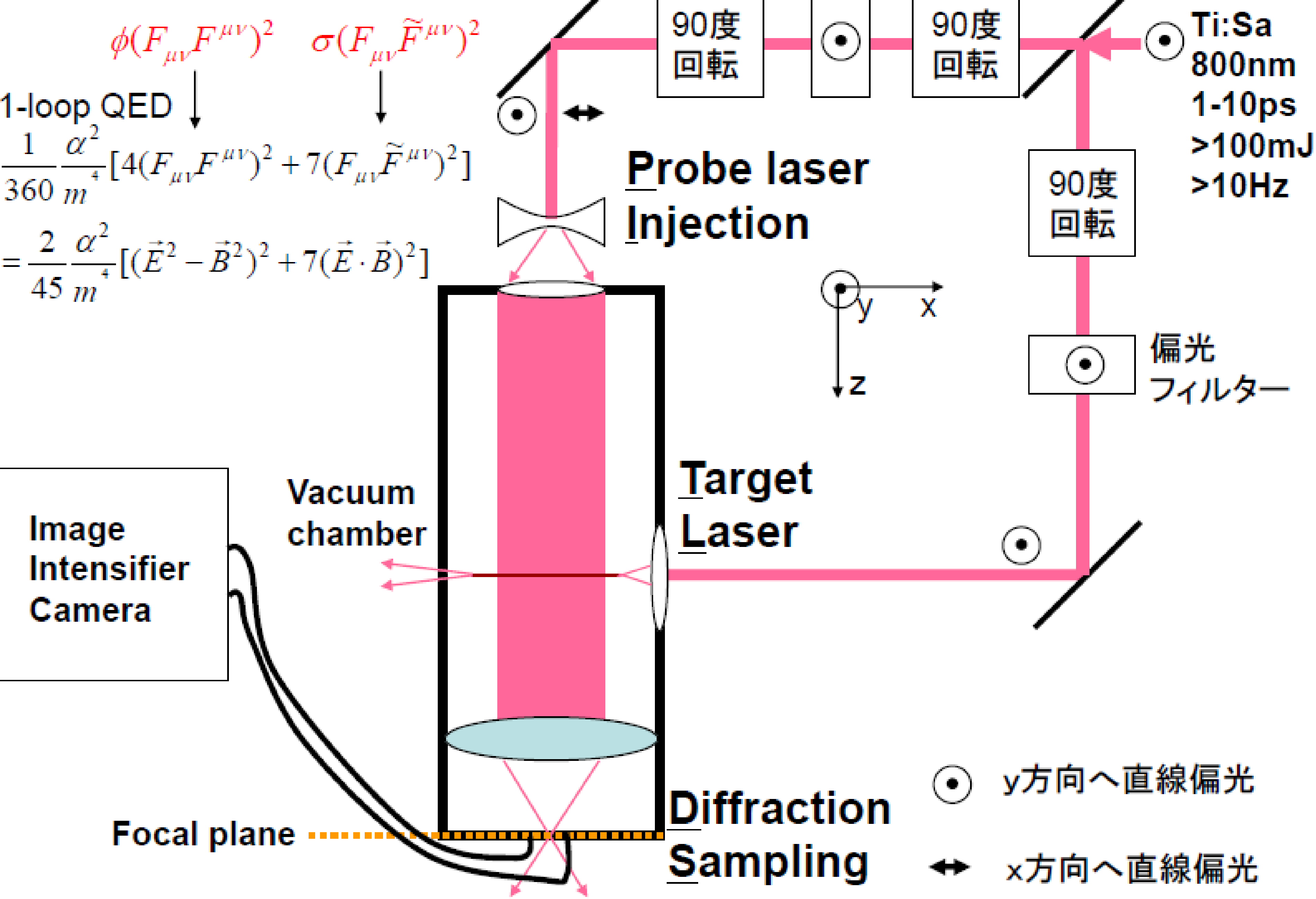


$\phi(F_{\mu\nu}F^{\mu\nu})^2$ $\sigma(F_{\mu\nu}\tilde{F}^{\mu\nu})^2$

1-loop QED

$$\frac{1}{360}\frac{\alpha^2}{m^4}[4(F_{\mu\nu}F^{\mu\nu})^2 + 7(F_{\mu\nu}\tilde{F}^{\mu\nu})^2]$$

$$= \frac{2}{45}\frac{\alpha^2}{m^4}[(\vec{E}^2 - \vec{B}^2)^2 + 7(\vec{E}\cdot\vec{B})^2]$$



Summary

- ATF2 beam + intense field
  - **a unique place for intense field physics with**
    - high quality GeV electron beam
    - laser technology
      - optical cavity with electron beam
- needs
  - **making attractive and reliable physics scenario**
  - **experimental plan**
- next meeting July (probably July 14)
    - electron interaction in intense field Bulanov JAEA
    - Status of theoretical calculation for Unruh effect
    - status and prospect for experiment
- test experiment TW laser + 40MeV e-
  - **AIST**

What can we discuss from macroscopic vacuum under a strong electromagnetic field?

K,Homma

Birefringence via γ–γ scattering with photon probes:

- Higher order QED and possibly QCD

- ***Effect of hidden scalar field (Extra dimensional effect etc.)***

- ***Effect of hidden pseudo scalar field (Axion type particles)***

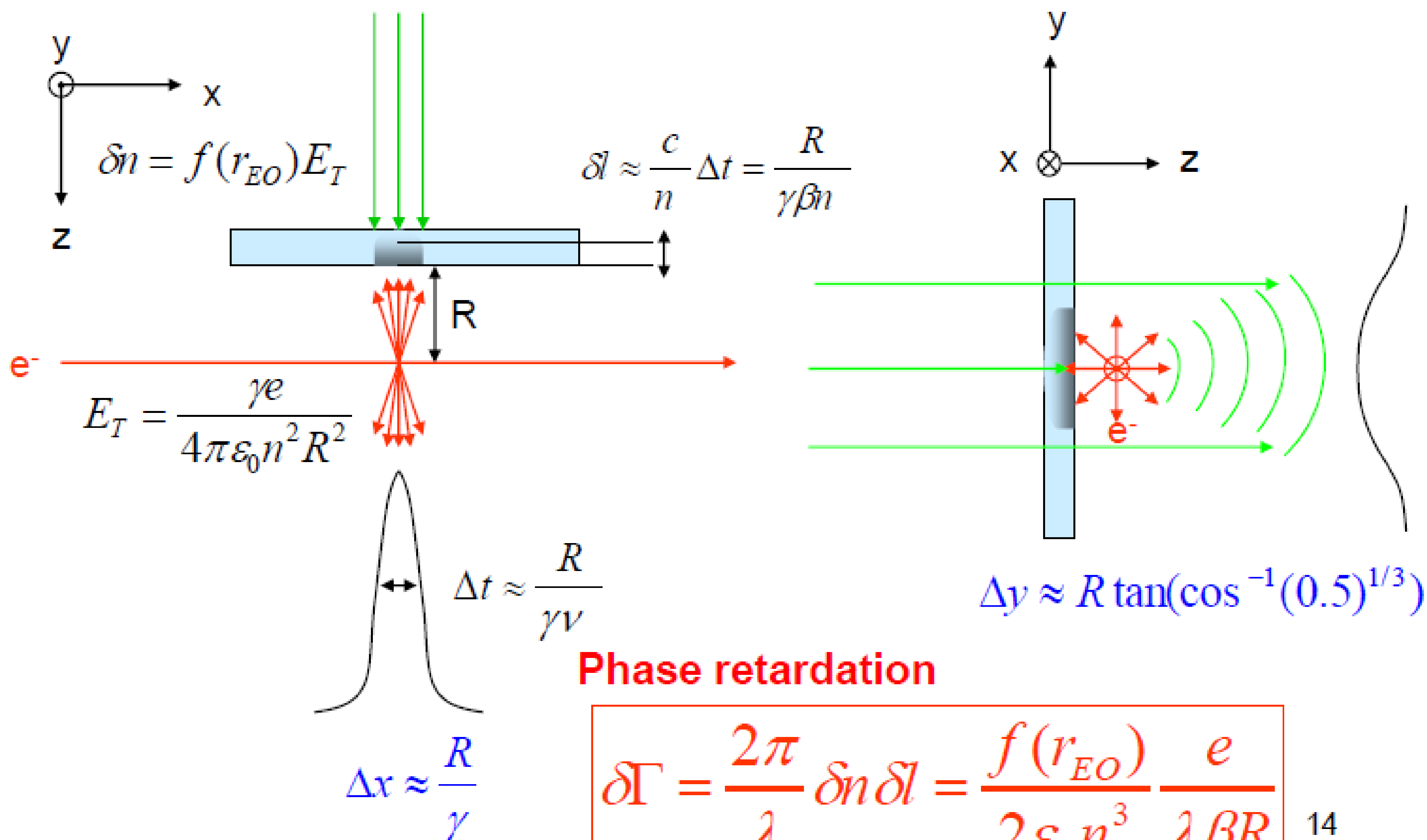
Physics of accelerating field with electron probes:

- Classical scattering such as Larmor scattering

- ***Unruh radiation (analogy to radiations from a black hole horizon)***

Experimental test

Measure instantaneous variation of refractive index in Electro-Optical crystal by external electric fields.



Phase retardation

$$\delta\Gamma = \frac{2\pi}{\lambda}\delta n\,\delta l = \frac{f(r_{EO})}{2\varepsilon_0 n^3}\frac{e}{\lambda\beta R}$$

Requirement to Laser

Intensity > 10^{22} W/cm^2

Wave length > 1μm

Standing wave with linear polarization at IP

for larger a^o, Unruh radiation $\propto (a^o)^3$

Lamor radiation $\propto (a^o)^2$

Note : beam size at ATF2-IP, σ_x=2.8μm, σ_y=37nm