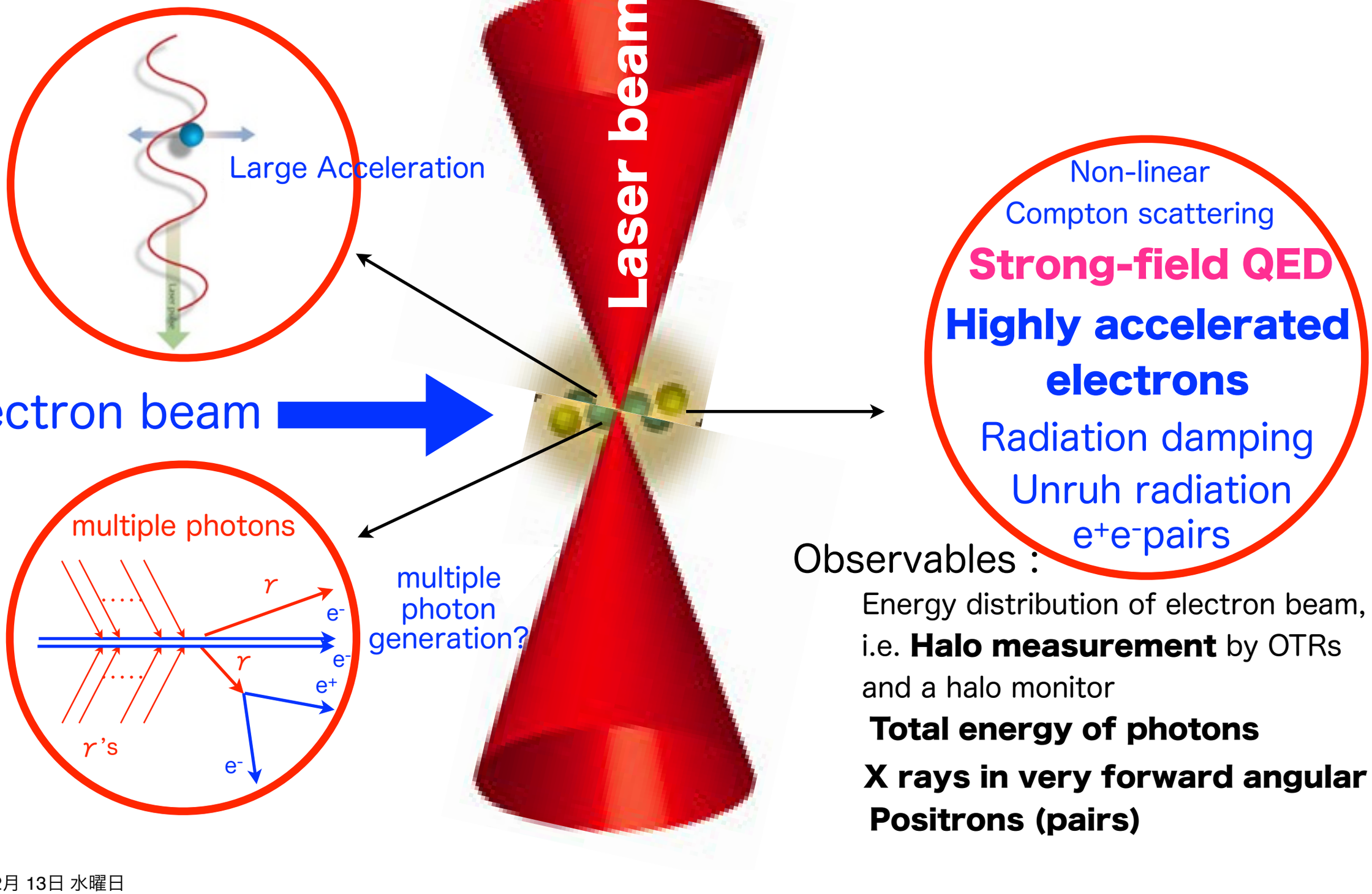
Experimental Study on Strong-Field QED

by collisions between electron beam and high intensity laser

QED is the most precise theory tested in the perturbation regime but very few in the Strong field; GRB, magnetar, Lepton epoch in the Universe.



Observables :

Energy distribution of electron beam,
i.e. **Halo measurement** by OTRs
and a halo monitor

Total energy of photons

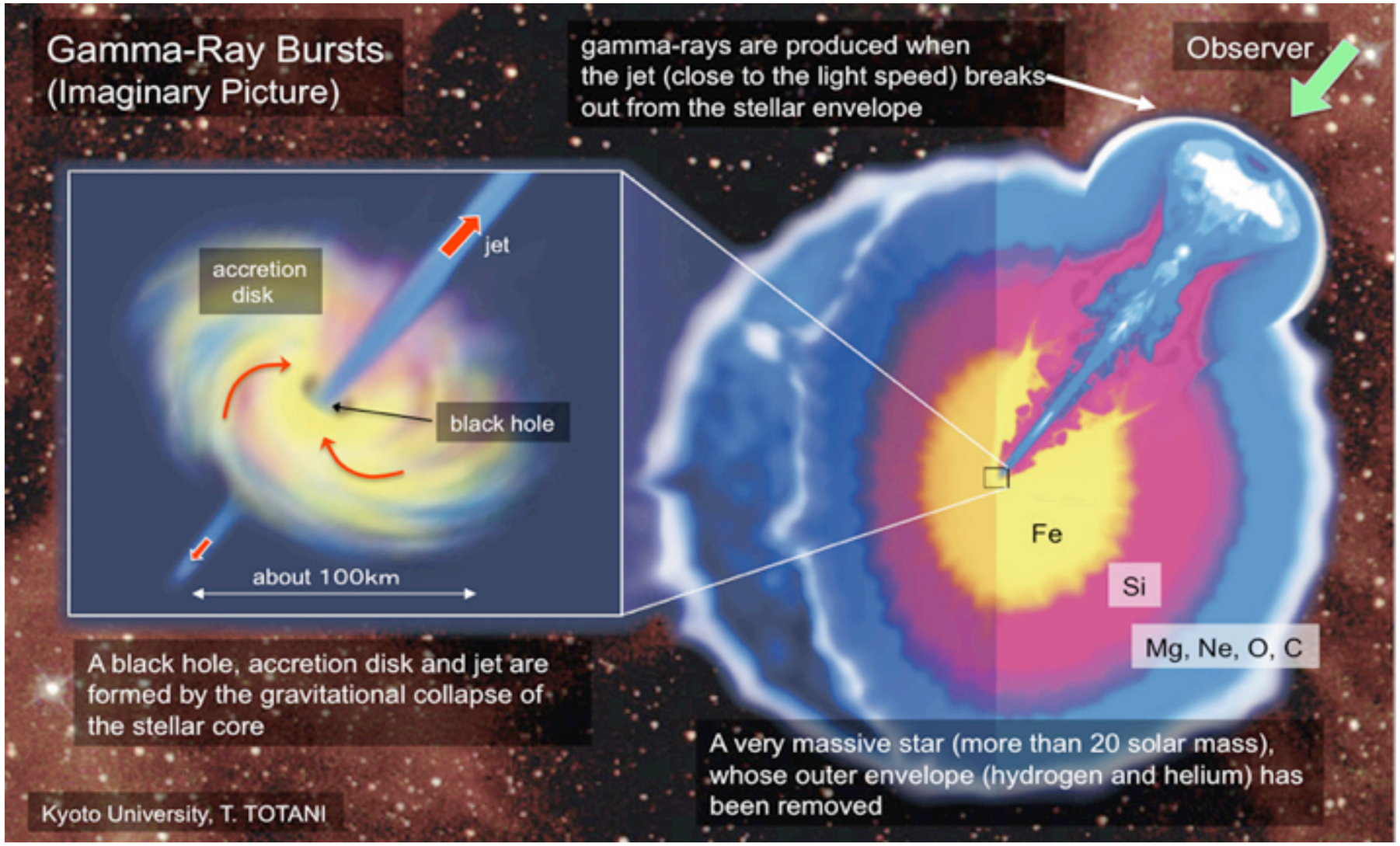
X rays in very forward angular region

Positrons (pairs)

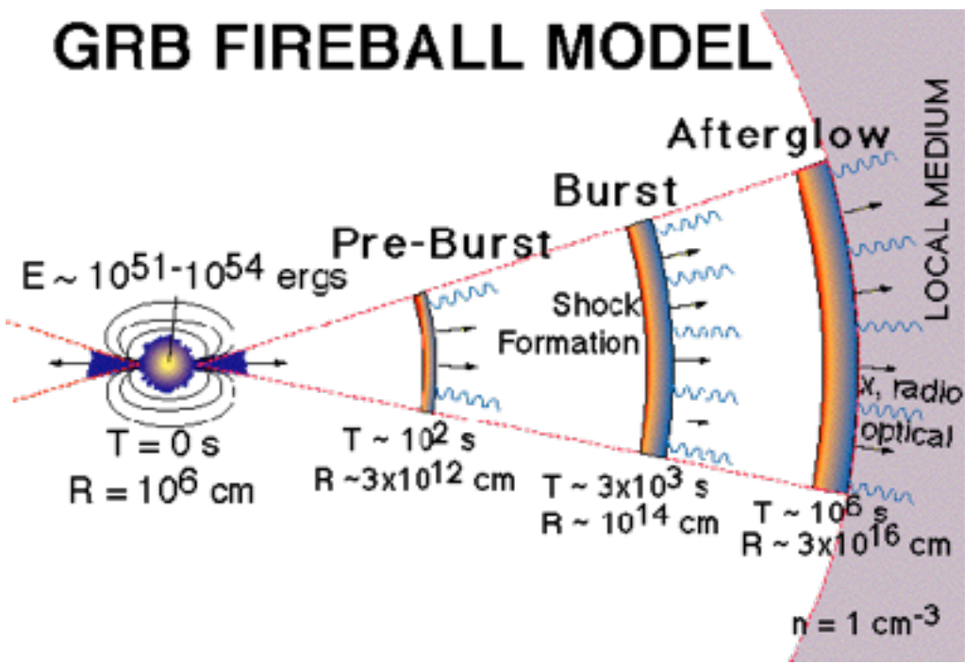
GRB

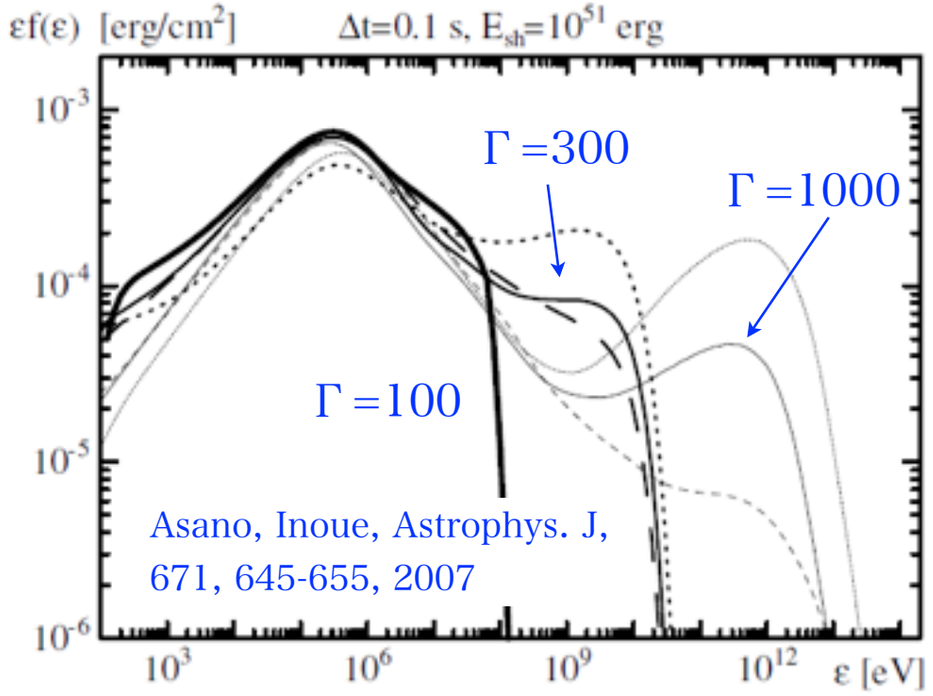
probe for physics in the early universe

or the most distant universe (~1 billion years)



Gamma ray generation by Self-Synchrotron Compton (SSC)





ATF2 : 1.3 GeV Electron Beam

In–vacuum 300TW
laser pulse compressor

Final Focus System

β mat-ching

Diagnostic

Reconfiguration of extraction line
for reduction of dispersion

57000

41179.42

IP:focal point σ_y=37nm, σ_x=2.8μm

Cooling Facilities
for Damping Ring

EXIT

Proposed 300TW
Laser facility
(~ 7 x 10 m)

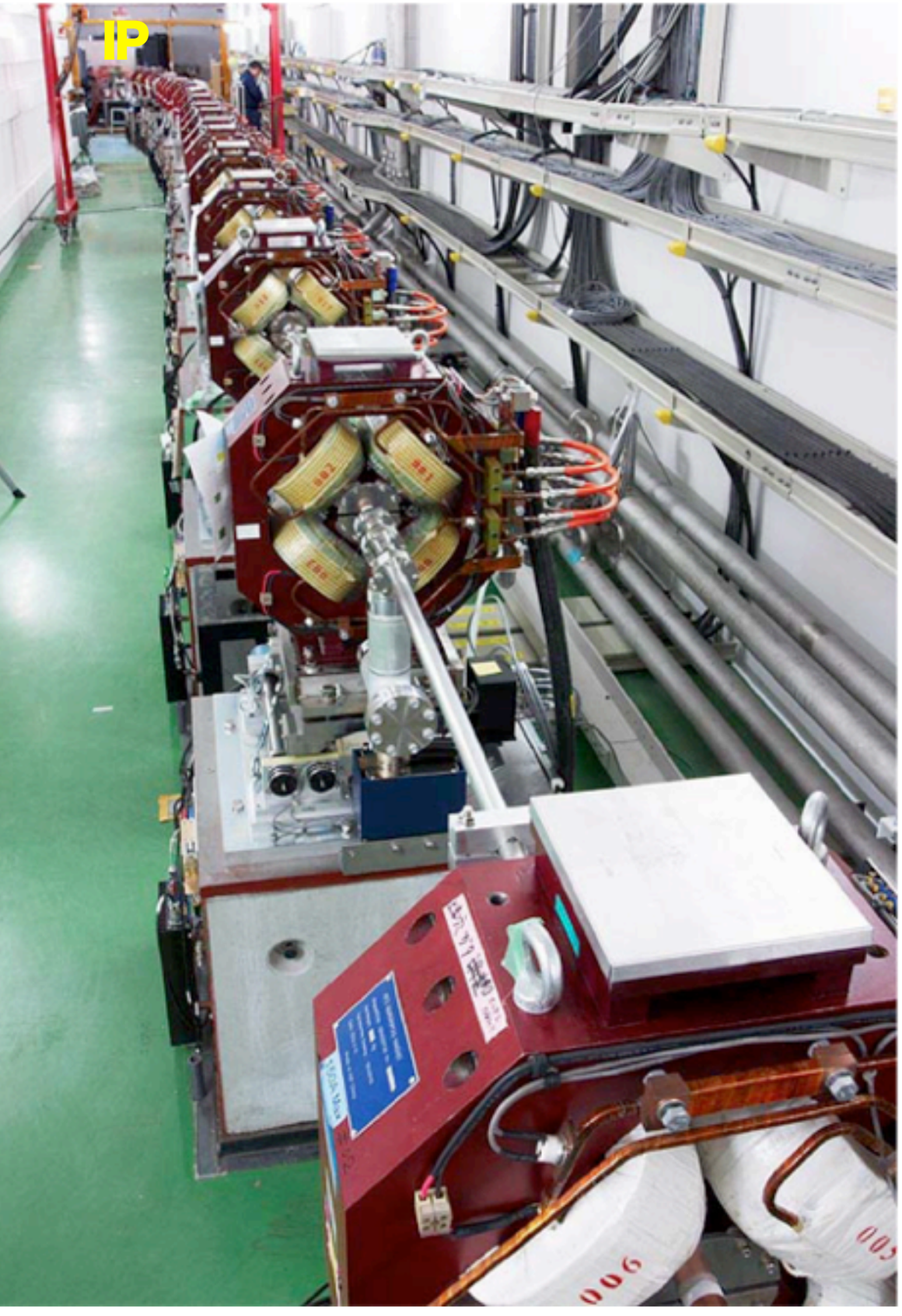
Present
0.45TW
Laser facility

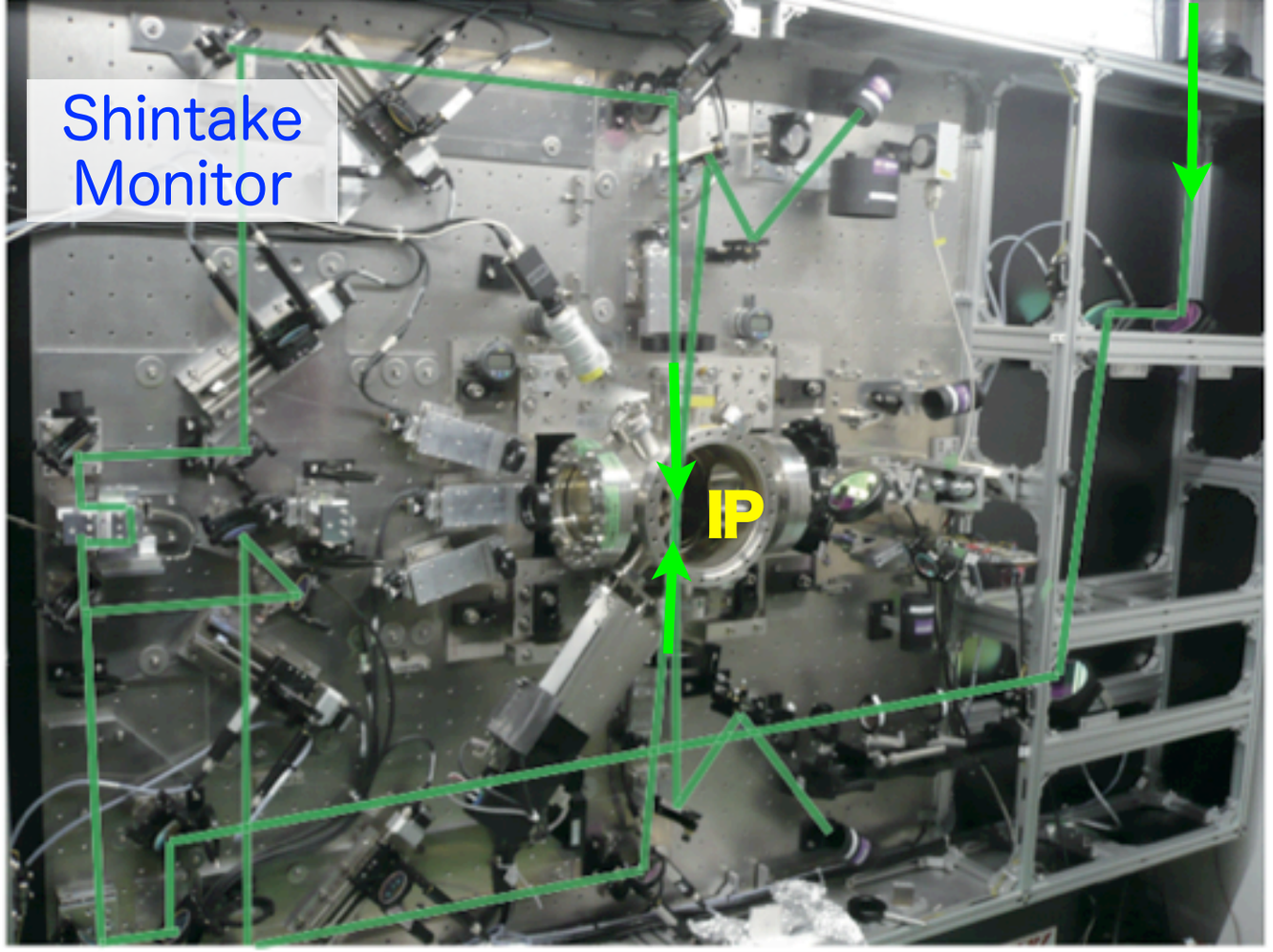
ATF - DR

Injection LINAC (S-band, 1.3GeV)

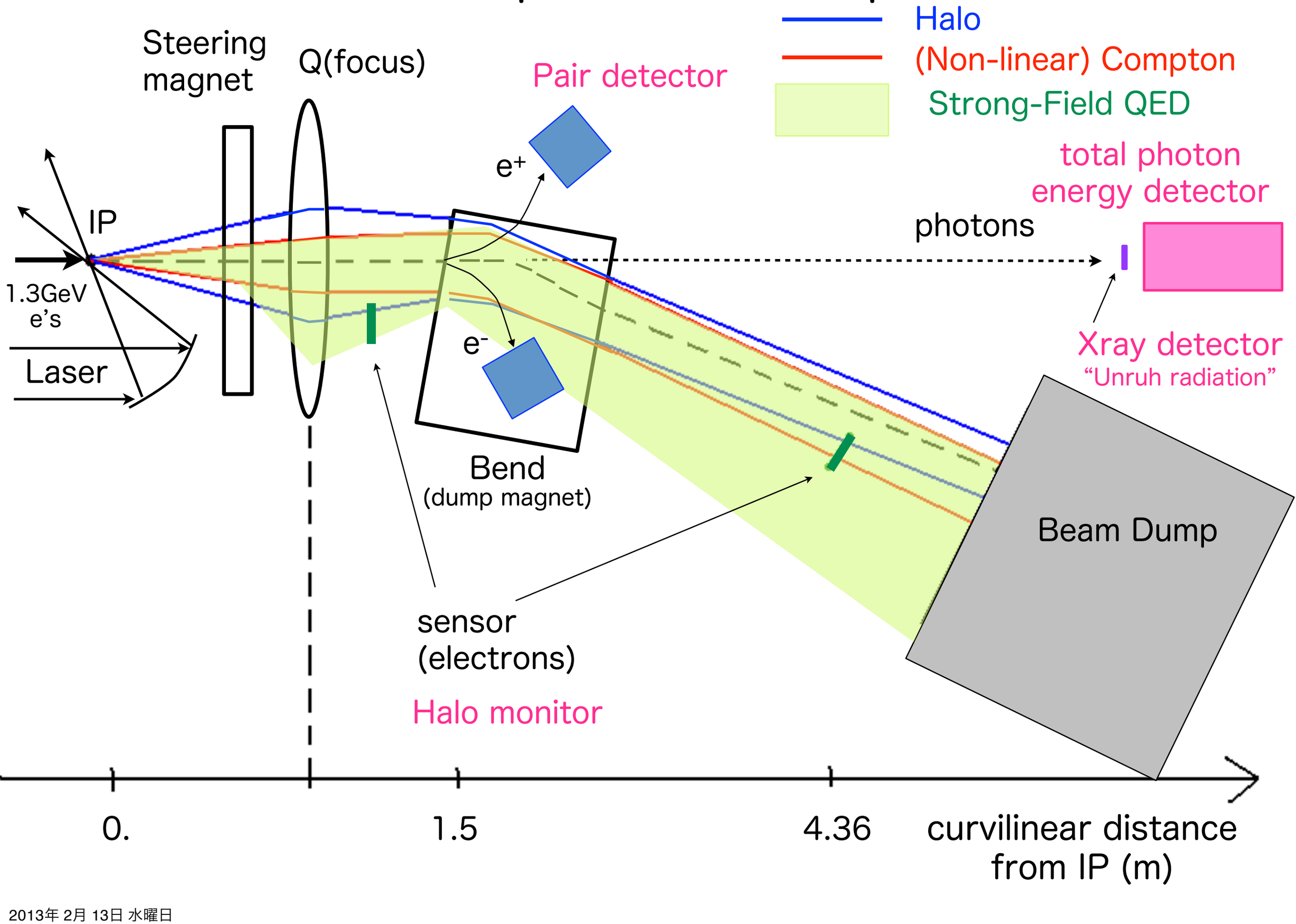
- Vacuum Laser transport line

ATF2 Beam Line



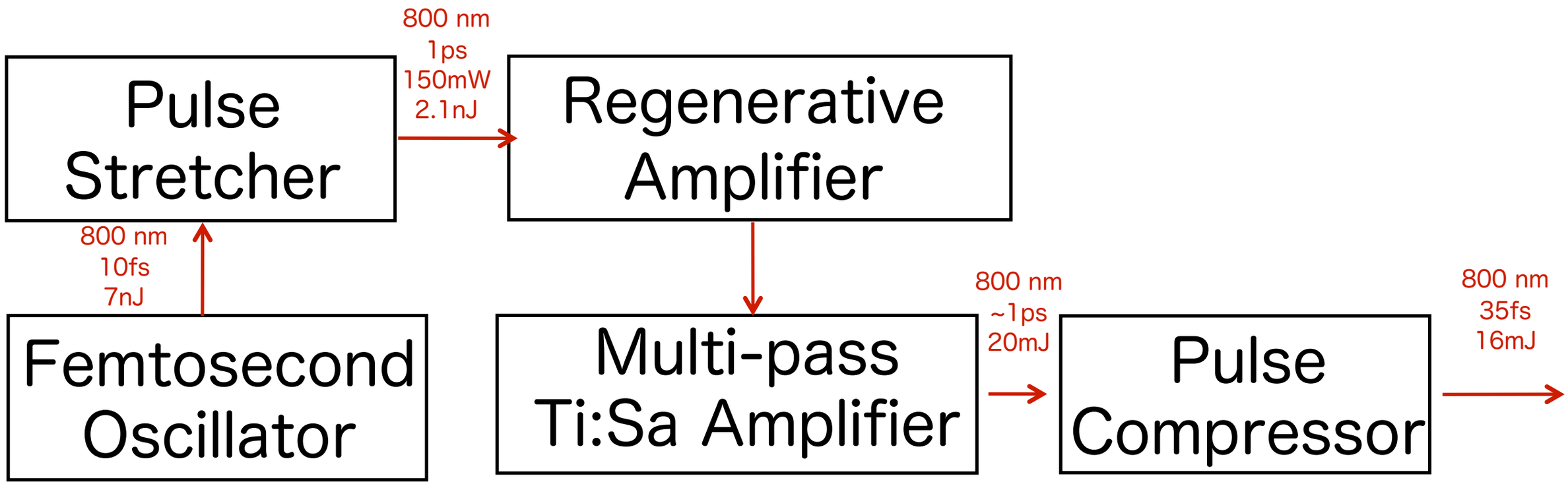


Experimental Setup



1. Present laser systems

(1) Titanium-Sapphire Laser :0.45TW, 800nm, 16mJ/pulse, 35fs, 10Hz



(2) LW system : 1.3GW, 532nm, 0.4J/pulse, 0.3ns, 10Hz

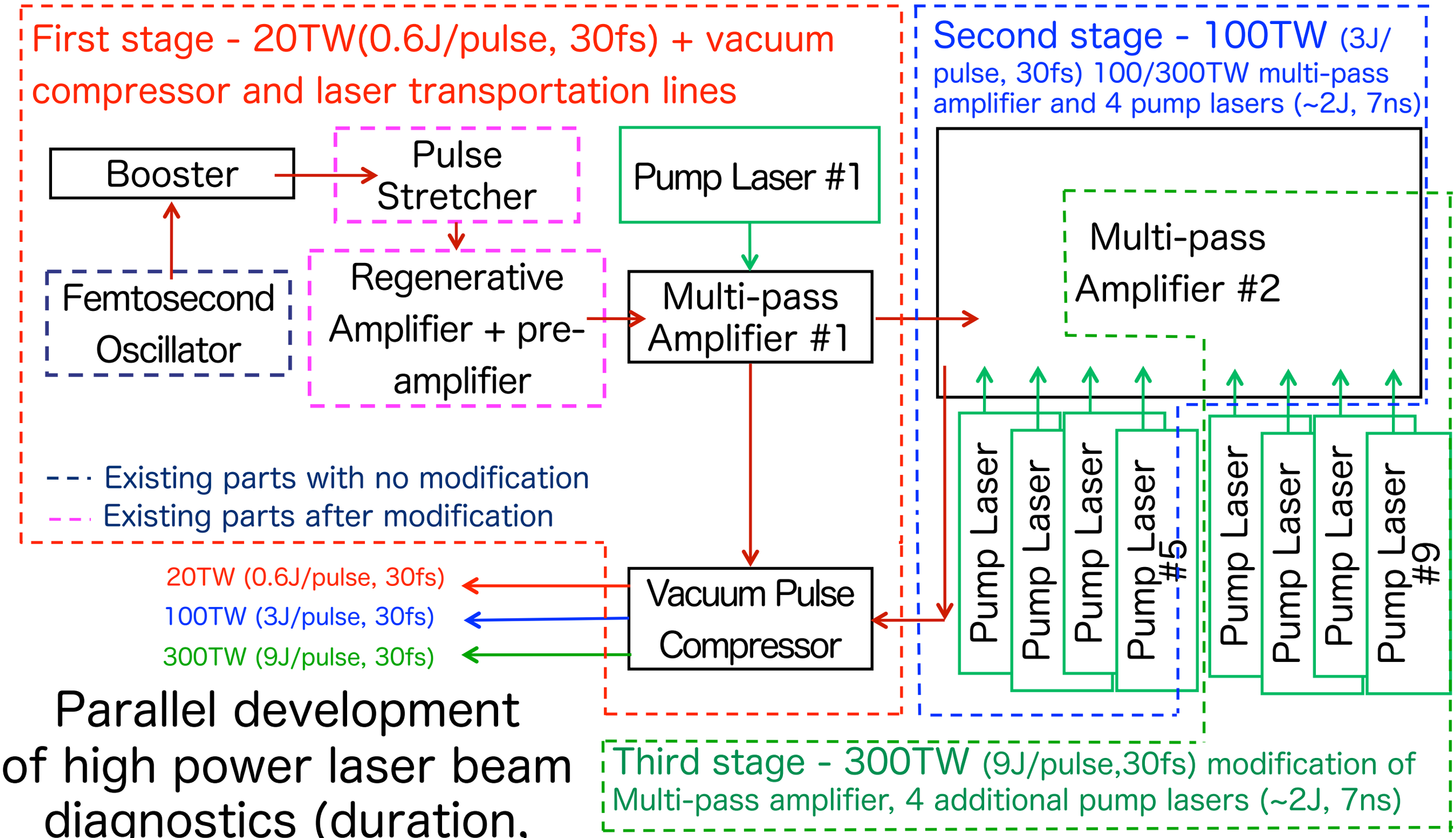
Appropriate size hut.

1.5 x 6.0 m Optical table with supporting system

Nd:VAN seed laser, Nd:YAG RGA, Nd:YAG flash lamp Amplifier

(3) Shintake monitor : 0.19GW, 532nm, 1.5J/pulse, 8ns, 10Hz

2. Upgrade plan to 300TW laser system



Parallel development of high power laser beam diagnostics (duration, position, profile)

3. Upgrade plan to larger a_0

Base plan : 800nm, $\sigma_{r,laser}$=3um (f#=6) and 30fs : a_0=2.9/6.4/11@20/100/300TW

(1) 300TW, a_0=67 with $\sigma_{r,laser}$=0.5um

A strong focus system (f#=2) will be developed;

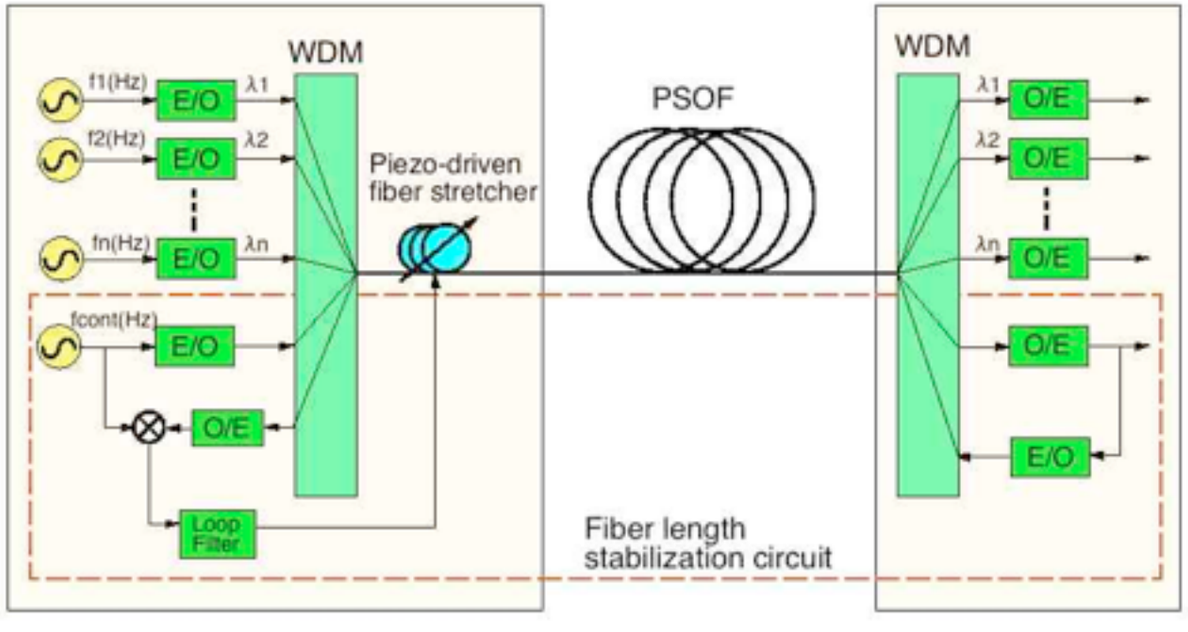
with a final lens of larger diameter for smaller f

(2) 300TW, a_0=100 with $\sigma_{r,laser}$=0.5um

More compression to 15fs with the strong focus system

4. Collisions with a femtosecond laser

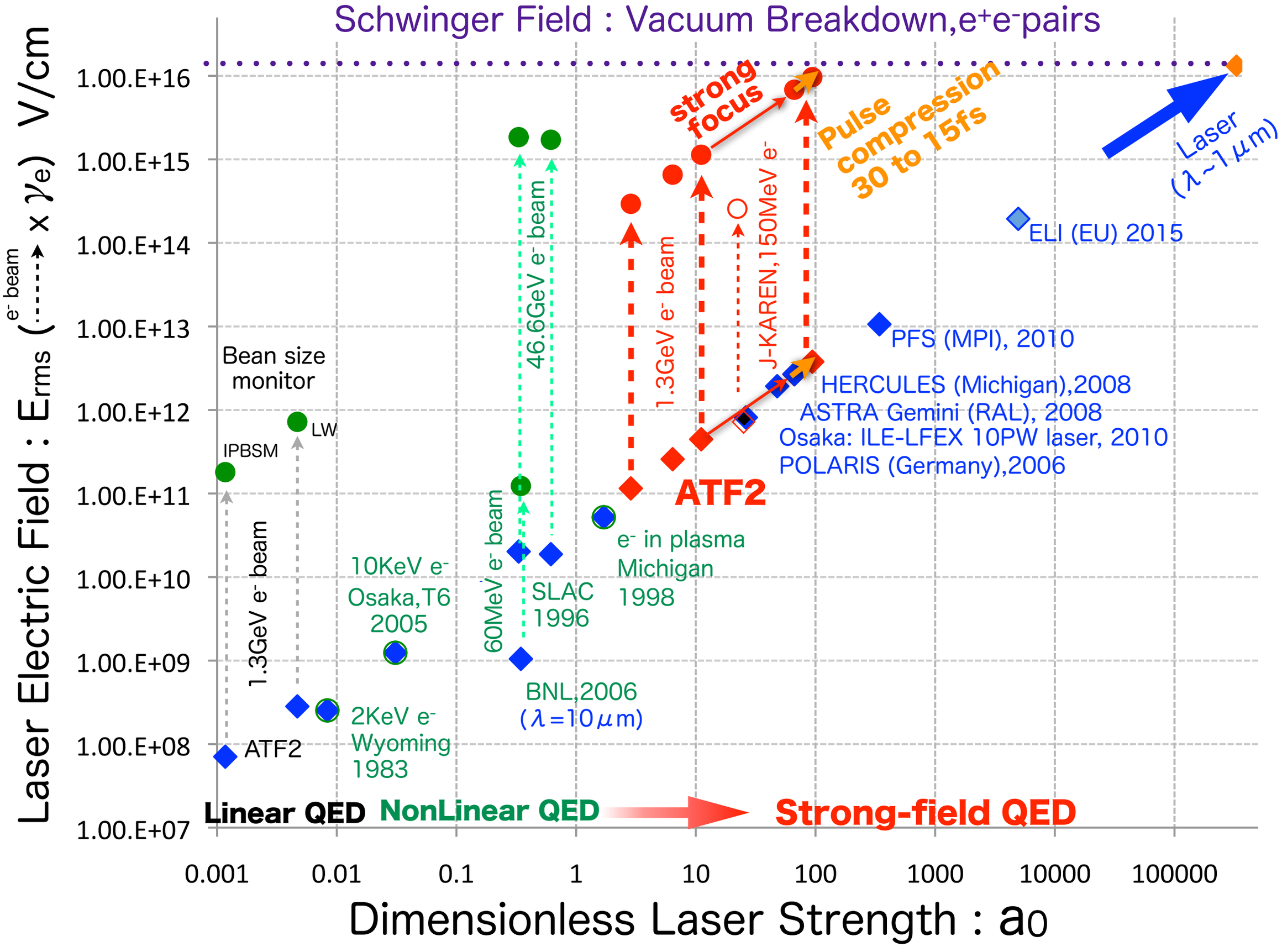
A timing distribution system with femtosecond stability has recently been developed at KEK.
Present stability is 40(160) fs at 2.856(1.3)GHz. Stabilization of 10fs will be developed.



Timing distribution system with femtosecond stability at KEK :

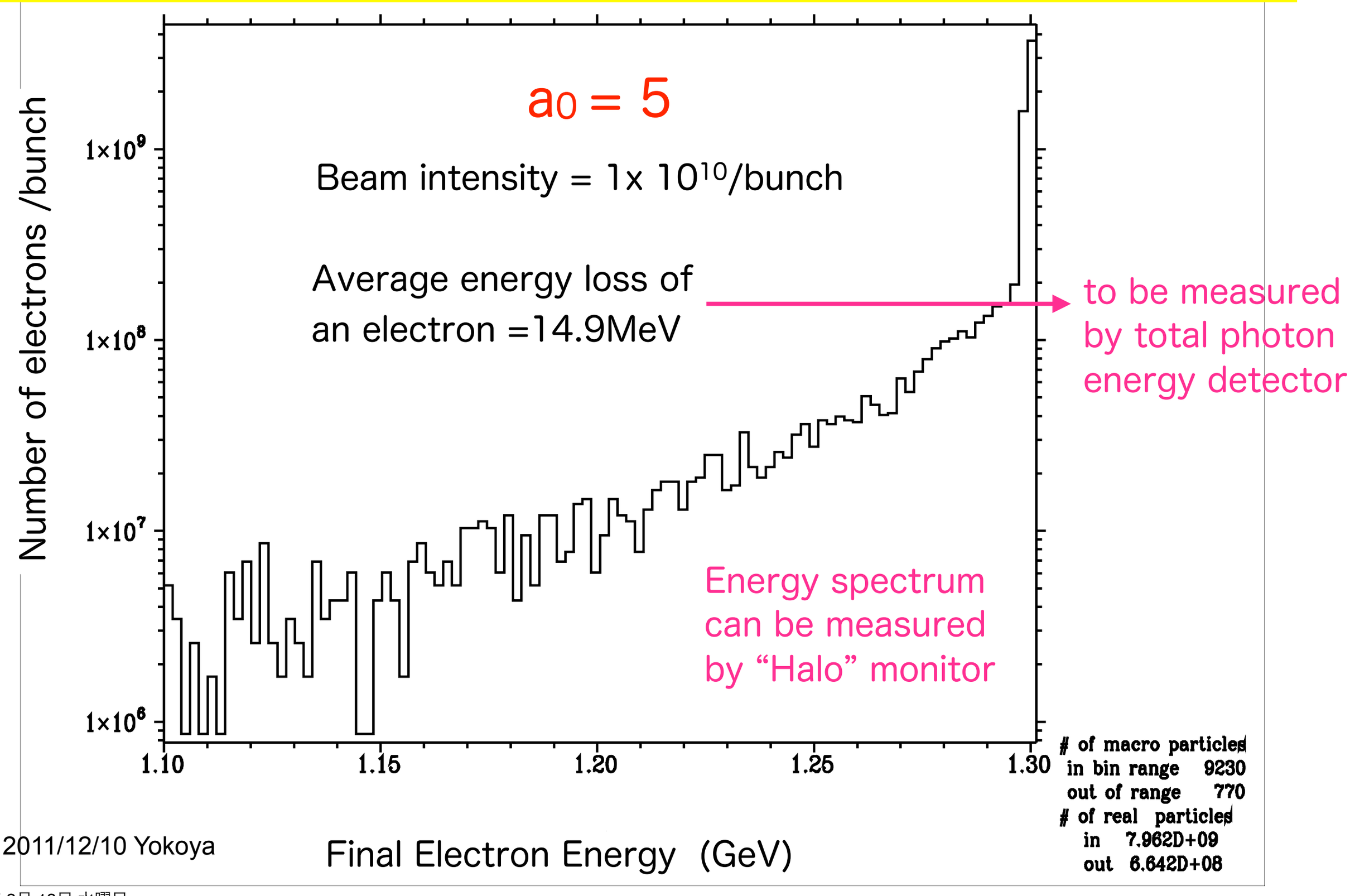
Overall Layout of the distribution system. E/O:electrical/optical converter, O/E:optical/electrical converter, WDM: wavelength division multiplexing, PSOF: phase stabilized optical fiber, T. Naito et al., MOPC146, proceedings of IPAC2012.

Our proposal and high intensity lasers in the world



Perturbative QED experiment

Non-linear Compton scattering (head-on); simulation by CAIN



“Strong-Field” QED experiment (1)

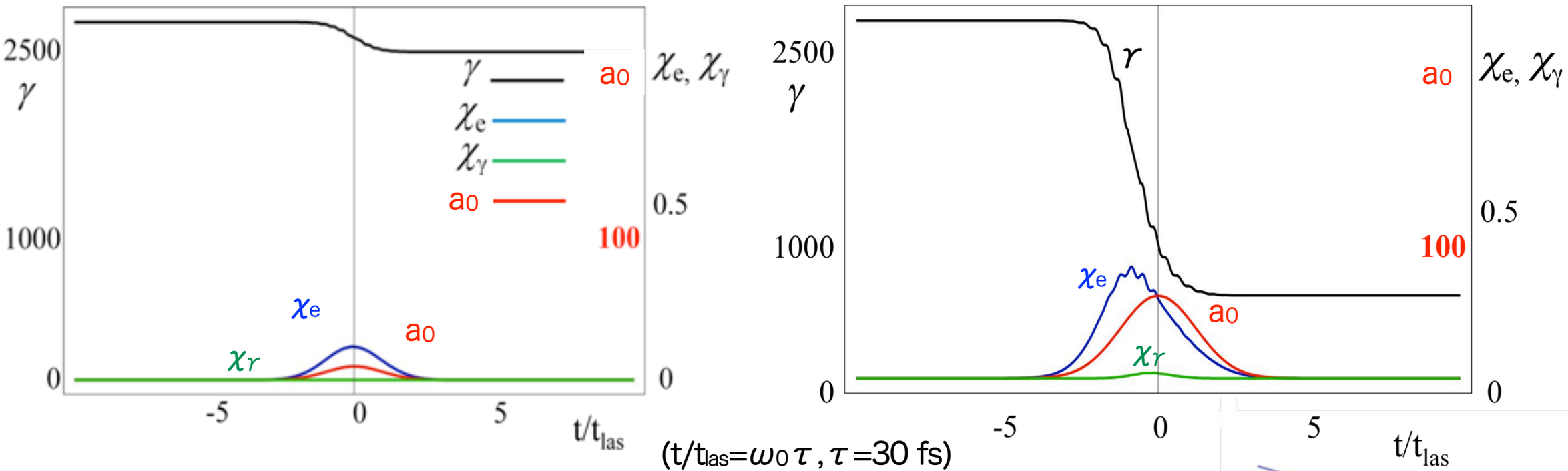
Head-on collision with the high intensity laser

An electron will loose its energy by radiating many photons. $N_\gamma \approx \frac{3\pi}{4}\alpha a_0$

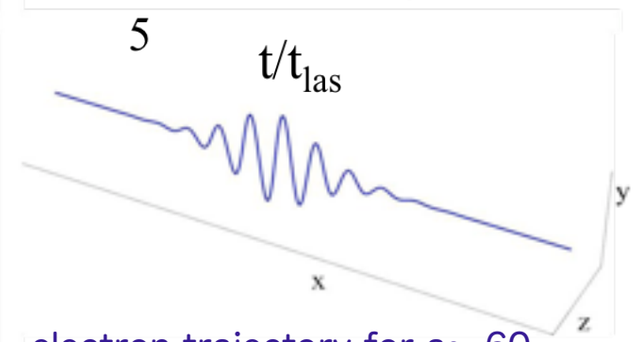
This interaction is called as “Radiation Damping”. $\hbar\omega_m \approx 1.2 a_0 \gamma_0^2 \hbar\omega_0$

a 1.3GeV electron $\xrightarrow{a_0 = 10}$ 1.2GeV

a 1.3GeV electron $\xrightarrow{a_0 = 60}$ 0.325GeV



(t/t_las=$\omega_0 \tau$, τ =30 fs)



electron trajectory for a_0=60

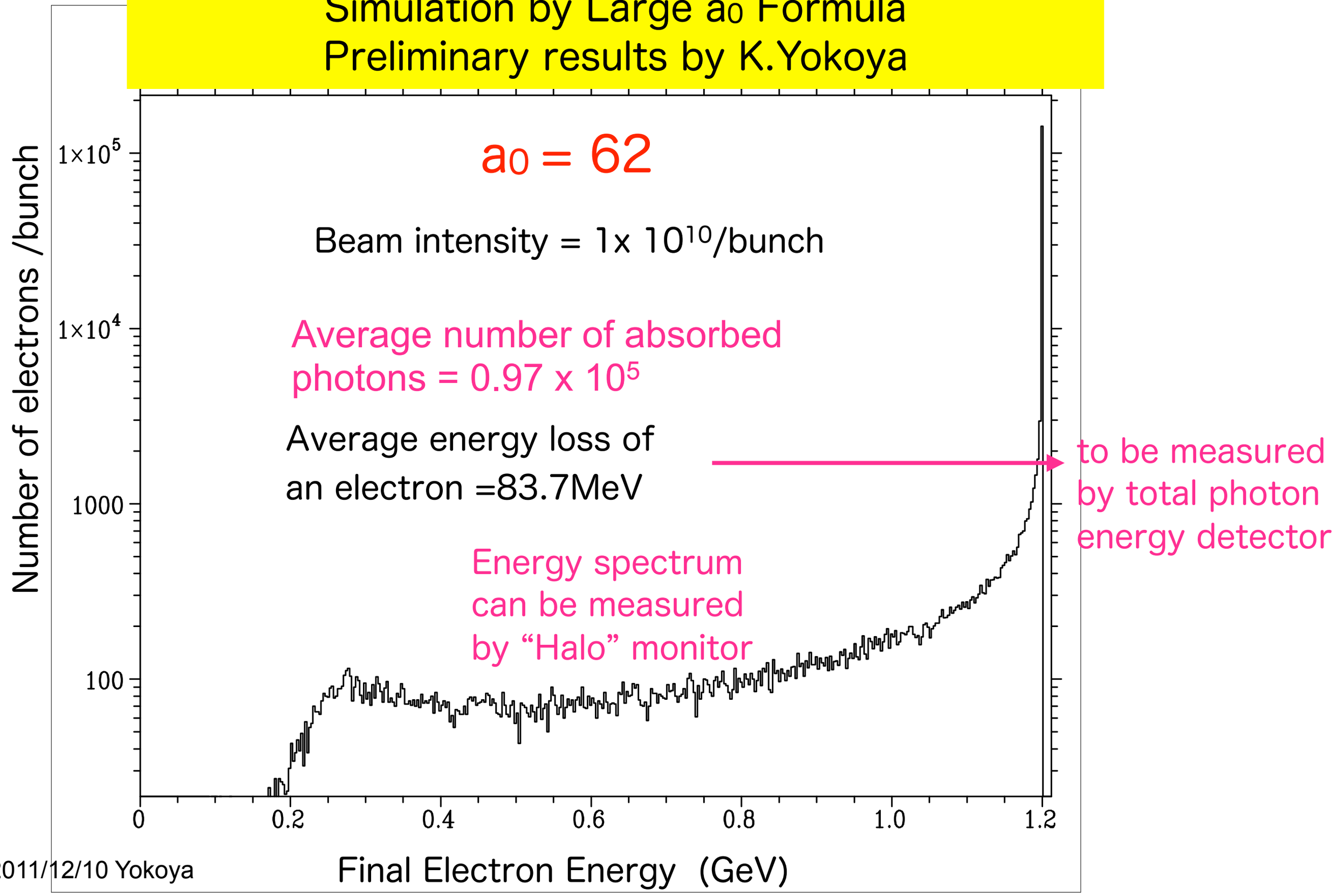
Time dependence of the electron and photon parameters for a 1.3 GeV electron beam interacting with a 30 fs laser pulse (a_0=9.9 in left and a_0=60 in right): the electron energy γ (black); χ_e (blue); laser intensity a_0 (red), χ_γ (green).

$\chi_e = 2\gamma a_0 / a_{QED}$, $\chi_\gamma = 2\omega_\gamma{}^{max}/m_e \cdot a_0 / a_{QED}$, $a_{QED} = m_e c^2 / \hbar\omega_0$

Ref : ON THE DESIGN OF EXPERIMENTS FOR THE STUDY OF EXTREME FIELD LIMITS IN THE INTERACTION OF LASER WITH ULTRA RELATIVISTIC ELECTRON BEAM, S.V.Bulanov et al., NIM A660 (2011) 31-42

“Strong-Field” QED experiment (2)

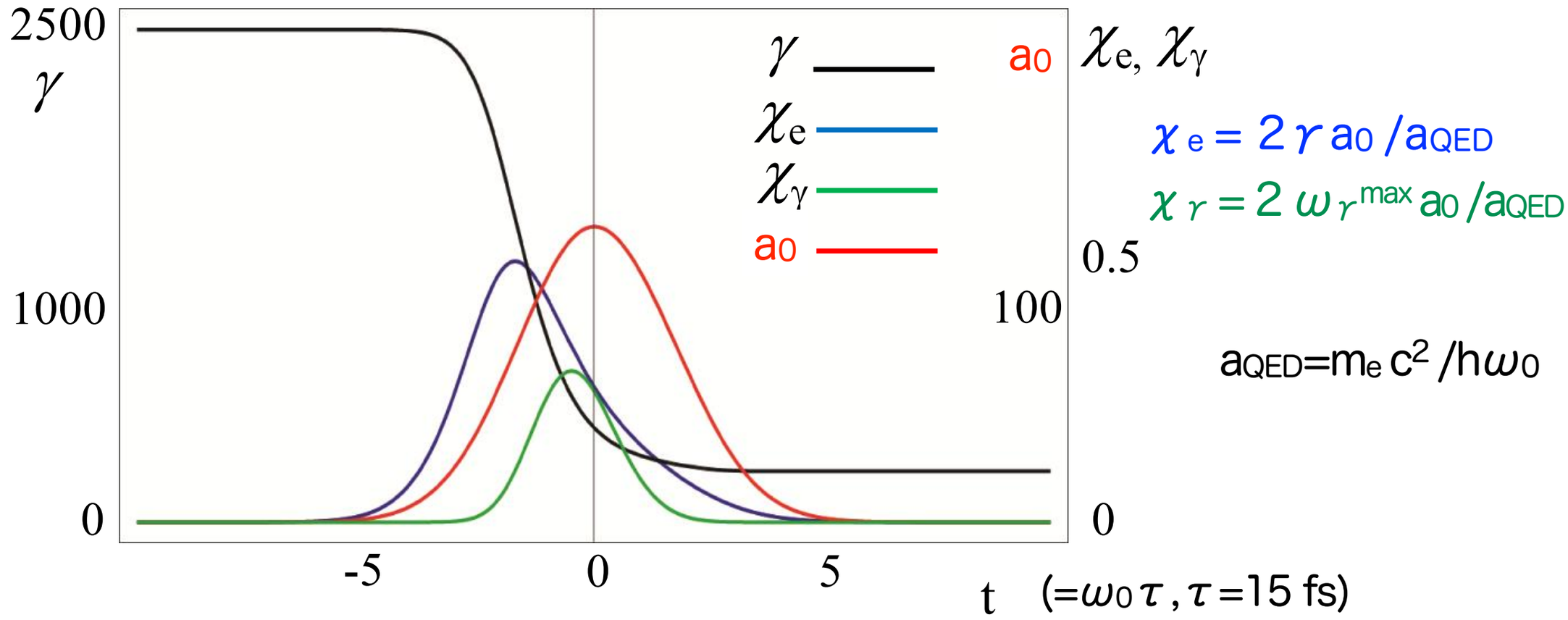
Simulation by Large a_0 Formula
Preliminary results by K.Yokoya



“Strong-Field” QED experiment (3)

$a_0 = 100$

a 1.25GeV electron ⟶ 0.25GeV



$\chi_e = 2\gamma a_0 / a_{QED}$

$\chi_\gamma = 2\omega_\gamma^{max} a_0 / a_{QED}$

$a_{QED} = m_e c^2 / \hbar\omega_0$

Figure 5. Time dependence of the electron and photon parameters for a 1.25 GeV electron beam interacting with a 15 fs PW laser pulse ($a_0 = 100$): the electron energy - black; parameter χ_e - blue; laser pulse profile – red, parameter χ_γ - green. $\chi_\gamma = 2\gamma_0 a_0 \hbar\omega_0 / m_e c^2$

Note : e^+e^- pairs will be created for χ_γ =0.3 in collisions between a 1.25GeV electron and laser with a_0=100.
i.e. we would probe physics in the Schwinger field.

Ref : ON THE DESIGN OF EXPERIMENTS FOR THE STUDY OF EXTREME FIELD LIMITS IN THE INTERACTION OF LASER WITH ULTRA RELATIVISTIC ELECTRON BEAM, S.V.Bulanov et al., NIM A660 (2011) 31-42

Hawking Radiation in Black Hole

(1) Photon production

in vacuum near the horizon

(2) The energy spectrum

in the Planck distribution

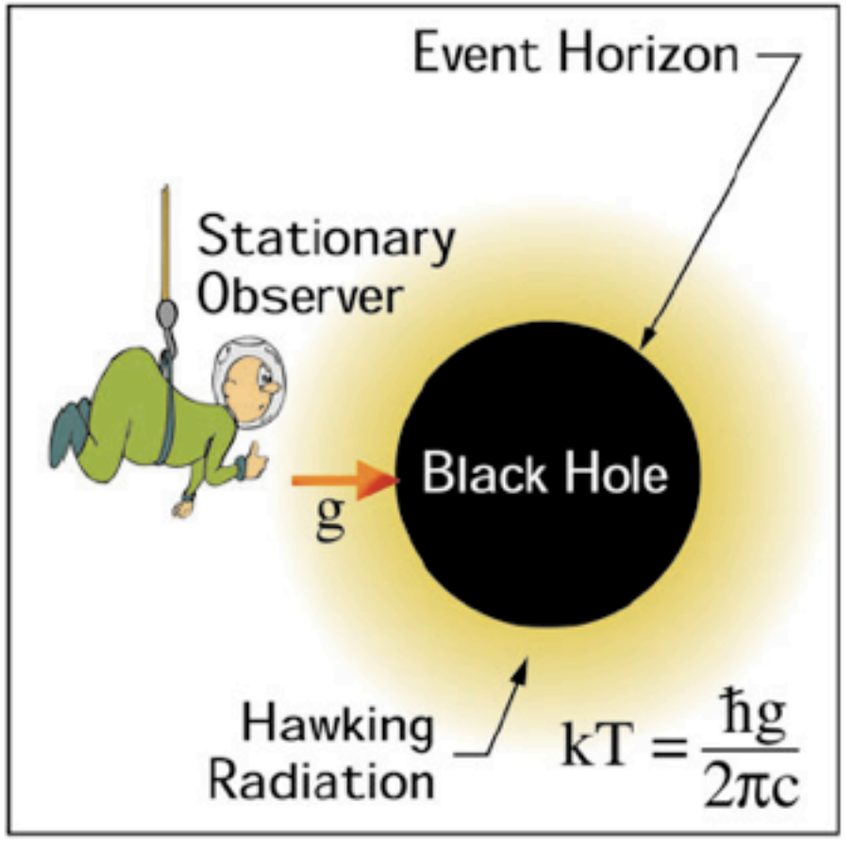
"Vacuum polarization near Event Horizon"
, but Thermal radiation

The same phenomenon would be realized in an accelerated system by Principle of Equivalence between gravitational and inertial forces .

Unruh Radiation in Acceleration

expect the interaction of electrons in ultra-intense fields,

i.e. electron beams and the lasers



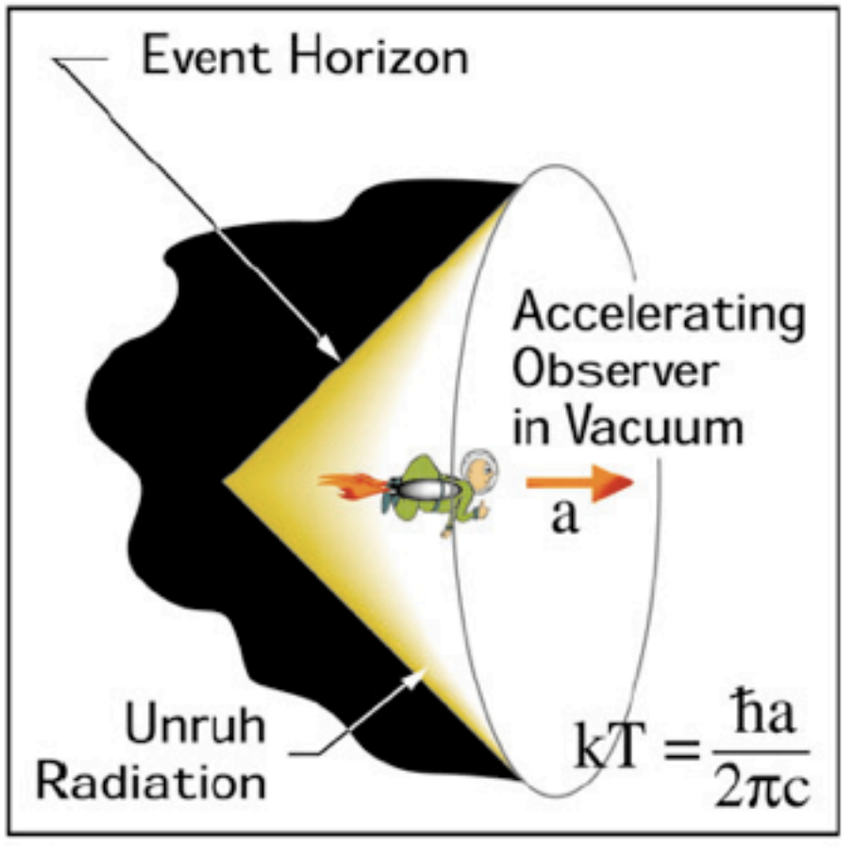
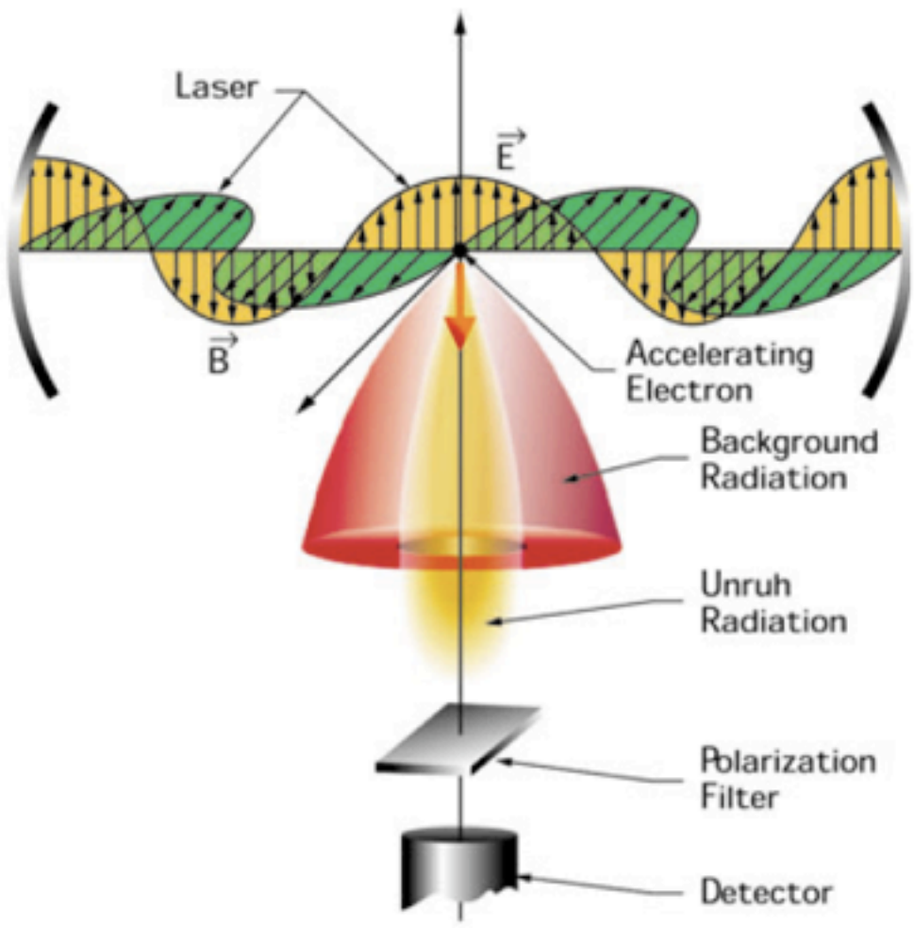


Fig. 11: Analogy between Hawking and Unruh effects.
Pisin Chen, AAPPS Bulletin February 2003

Experimental test of Unruh radiation

These have been many debates on reality of the radiation.



Schematic Diagram for Detecting Unruh Radiation

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

Nanometer electron beam at ATF2

1.3GeV energy

37nm vertical beam size at IP

in 90° collision with the intense Laser

interference as Shintake monitor

λ = 800nm

a_0=66, 300TW laser, σ=0.5um

intensity =1.9 x 10^{22}W/cm^2

Unruh radiation ∝ a_0^3

Acceleration ($a=a_0\omega c$)=4.7x10^{25}m/s^2

Temperature($\mathrm{kT} = \hbar a/2\pi c$) = 16eV

X rays in the blind spot expected !

Do electrons have enough time to be accelerated close to the event horizon?

Is full thermalization needed for Unruh radiation ?

Summary

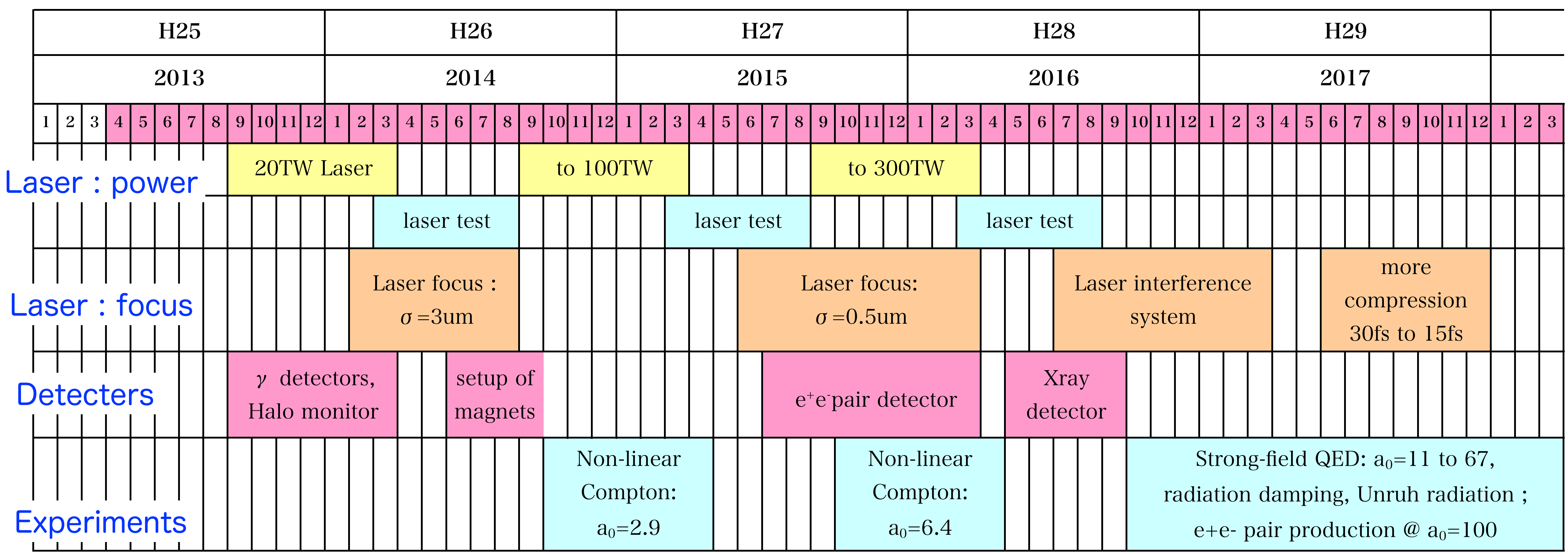
1. Test of Strong-Field QED can be executed with;

   Non-linear Compton scattering

   Radiation damping

   Schwinger field is closely approached with the a_0=100 laser.

2. Unruh radiation will be tested.

   So, we could probe physics at the event horizon.

3. Schedule