ELECTRON BEAM ABSOLUTE ENERGY MEASUREMENT REALIZATION POSSIBILITY BY RESONANT ABSORPTION METHOD

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In this report presented an electron beam absolute energy measurement method with accuracy of <10^{-4}. An approved spectroscopic method as differential absorption (DIA) method is used to measure the electron energy in the magnetic field. The analysis of the needed experimental conditions, as well as the state of the art equipment and materials, shows the reliability of this method.

As known the energy of the electron beam in a magnetic field has a discrete spectrum that allows the laser photons to be absorbed. The DIA method is based on the resonance absorption (RA) of laser radiation by electrons. The laser beam, with a wavelength coinciding with the absorption line of electrons after interaction records by registration system. The laser beam intensity decreases at the amount absorbed by electrons. The absorbed amount depends on RA conditions as the magnetic field induction B and the laser beam wavelength λ.

To exclude the radiation decrease by other reasons, another laser radiation not coinciding with the RA conditions emits along the same trace and detected by the same registration system. The comparison of these two signals allows defining the signal change, related only to the RA. To exclude the influence of the laser output power instabilities, both signals had to be previously normalized to the laser output beam intensity.

Tuning B or λ can be found the maximum electron beam absorption conditions.

THEORETICAL BACKGROUND

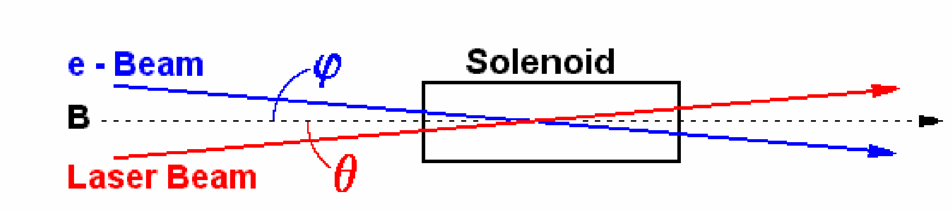
The measurement of the both parameters, that are the magnetic field induction B **and laser beam frequency** ω_L**, with accuracy of the order of** $<10^{-4}$ **will allow defining the electron beam absolute energy** $\mathcal{E}_o$ **with the same order [2].**

$$\Delta\mathcal{E} / \mathcal{E} = \pm \Delta B / B \pm \Delta\omega_L / \omega_L \qquad \textbf{(1)}$$

As shown in [1] electron energy can be defined from:

$$\mathcal{E} = mc^2 \frac{\Omega \pm \cos\varphi\cos\theta\sqrt{\Omega^2 - 1 + (\cos\varphi\cos\theta)^2}}{1 - (\cos\varphi\cos\theta)^2} \qquad \textbf{(2)}$$

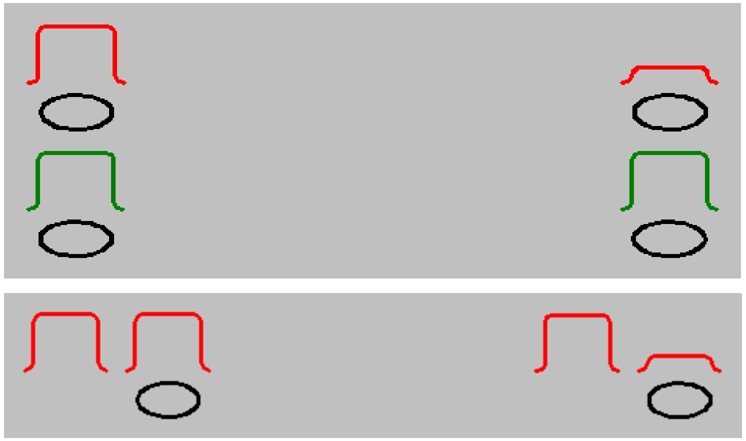
Where Ω = eB / mcω_L**.**



For small angles [2] of electron (φ) **and laser** (θ) **beams with magnetic field axes, electron beam absolute energy measurement with accuracy of** $<10^{-4}$ **defines as [2]:**

$$\mathcal{E} = \frac{mc^2 \hbar}{4\mu_B} \frac{\omega_L}{B} \qquad \textbf{(3)}$$

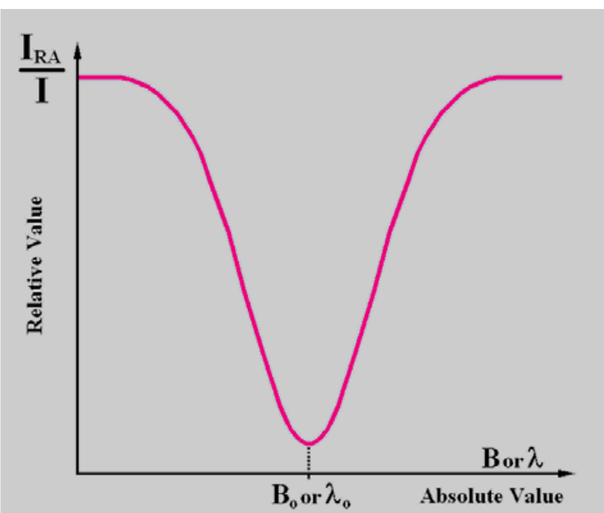
THE DIFFERENTIAL ABSORPTION METHOD



Three versions of the differential RA method.

1. **Shifting the magnetic field** B **with simultaneously soft tuning of the laser wavelength** λ.
2. **Shifting the laser wavelength** λ **with simultaneously soft tuning of magnetic field** B.
3. **Timing the laser pulse on/off coincidence with electron bunches with simultaneously soft tuning of the magnetic field** B **or the laser wavelength** λ **as well as they both.**

All the three versions can be used for bunched electron beam absolute energy measurement. For the third version, the laser pulse repetition rate had to be twice more than the repetition rate of the electron bunch/train. For continues (unbunched) electron beams the third version is not useable.



For collinear beams coinciding with the magnetic field axes electron beam absolute energy defines from:

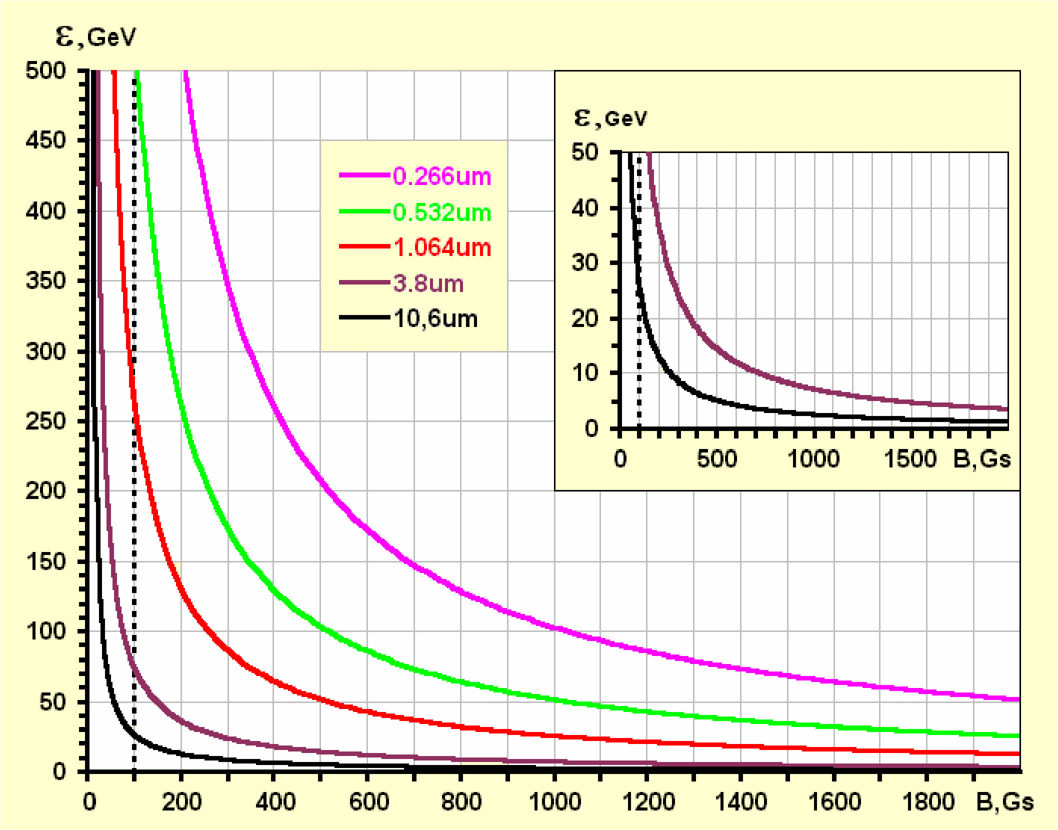
$$\varepsilon_o = \frac{mc^2 \hbar}{4\mu_B} \frac{\omega o}{Bo} \qquad (4)$$

Soft tuning of the magnetic field B **for fixed laser beam wavelength** λ **(or vice versa) threw resonance, measures the ratio of the laser beam intensities in and out of the resonance conditions, that is pulse-to-pulse shifting of the** B, λ **or the time. The measured curve minimum will correspond to the RA conditions that are** B_o **and** λ_o **values.**

THE CHOICE OF THE SOLENOID PARAMETERS AND THE LASER WAVELENGTH

To reach the absorption of photons by electrons a magnetic field is needed to induce corresponding electron energetic levels. The levels of electron energies dictate the solenoid magnetic field induction B **value. The solenoid had to be designed taking into account the following main factors:**

- **The RA method realization with the help of state of the art lasers (0.266μm < λ < 10.6 μm).**
- **The possibility of scanning and measurement of B with accuracy of** $\Delta B/B < 10^{-4}$.
- **Feasible dimensions including the length (~1m) and enough space inside for electron and laser beams interaction.**



The figure shows that more energies must be measured the shorter laser wavelengths λ are needed to satisfy the condition $\Delta B / B < 10^{-4}$.

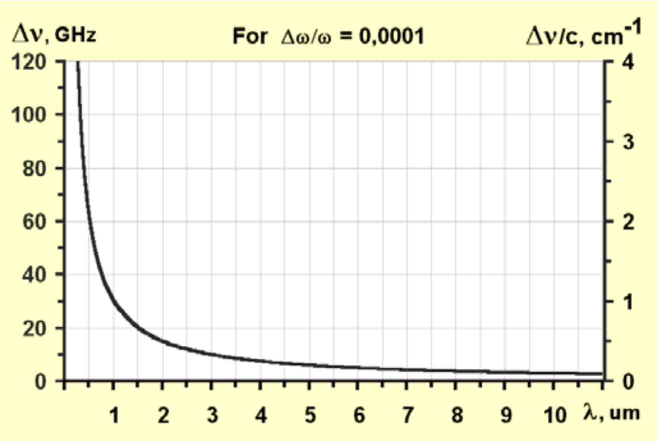
Taking into account the difficulties of changing and controlling $\Delta B / B$ **with accuracy of** $<10^{-4}$ **for levels of** B **< 100Gs the choice of the** B **will come out from the application of the state of the art lasers, as well as from the range of the electron energy ε measurement reliable with the help of the same solenoid and laser.**

THE LASER RADIATION LINEWIDTH AND PULSE DURATION

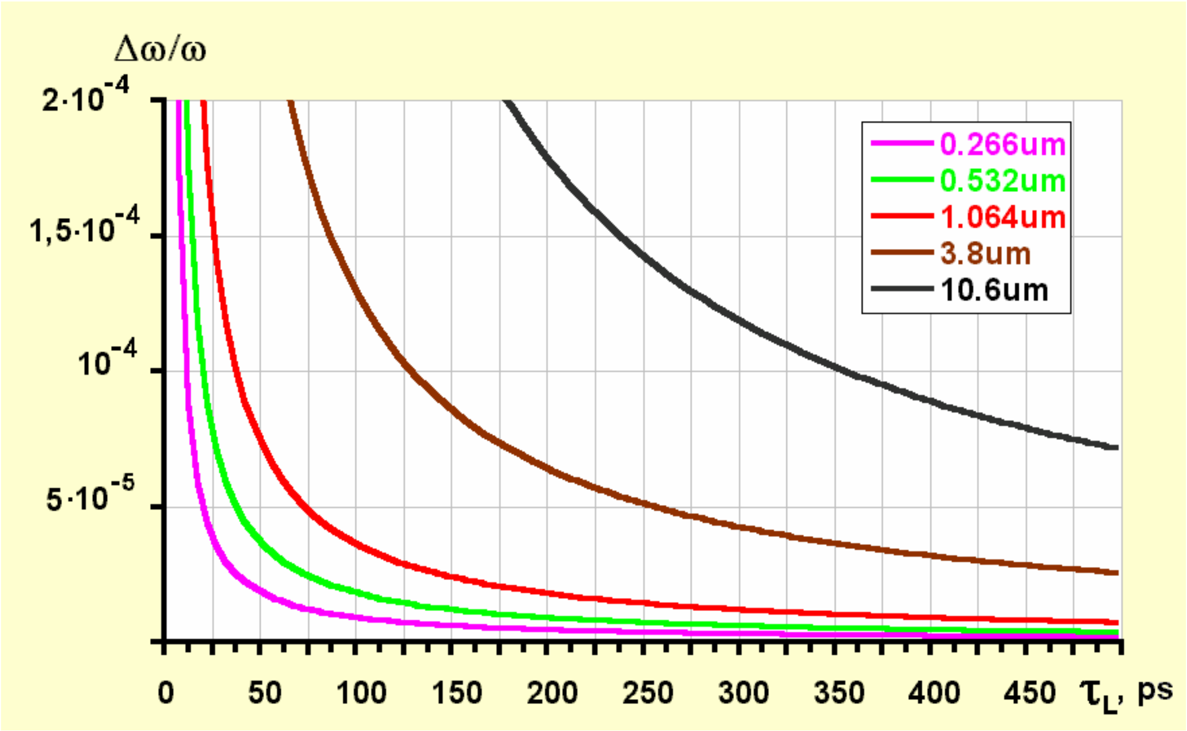
The condition $\Delta\omega/\omega < 10^{-4}$ limits the laser radiation linewidth and pulse duration.

The limitations of the laser radiation linewidth and pulse duration depends on the laser beam wavelength. This fact, hand in hand with the magnetic field B, will dictate the choice of the laser wavelength.

The limitation of the laser pulse duration will have an influence on the laser pulse and electron bunch temporal overlap.

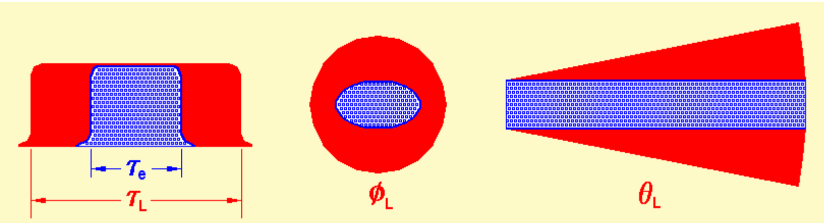


The curve is the top limit of the laser beam line width.



The lines are the bottom limits of the laser pulse duration.

THE LASER OUTPUT PULSE ENERGY



The definition of the laser output minimum pulse energy will come out from the amount of photons that can be absorbed by electrons and energy loses in the setup components as well as from the temporal, spatial and angular overlaps of the laser and electron beams.

ELECTRON BEAM	
Electron Energy, GeV	250
Repetition rate, Hz	5
Beam pulse length, μs	950
No. bunches per pulse	2820
Bunch spacing, ns (MHz)	337 (2.97)
Charge per bunch	$2x10^{10}$
Beam size, μm	10
Bunch length, psec	1
Beam Divergence, rad	$5x10^{-6}$

LASER BEAM	$YAG:Nd^{3+}$	SHG
Wavelength, um	1,064	0.532
Repetition rate, Hz	10	10
Energy per pulse, J	$2.2x10^{-3}$	$4.4x10^{-3}$
Beam diameter, mm	1.3	1.3
Pulse duration, psec	35	35
Beam divergence, rad	10^{-3}	10^{-3}
$\Delta\omega/\omega$	10^{-4}	$0,5x10^{-4}$
$\Delta\nu/c$, cm^{-1} ($\Delta\nu$, GHz)	O,94 (28.2)	1,88 (56,4)
Pulse power, W	$63x10^{6}$	$126x10^{6}$

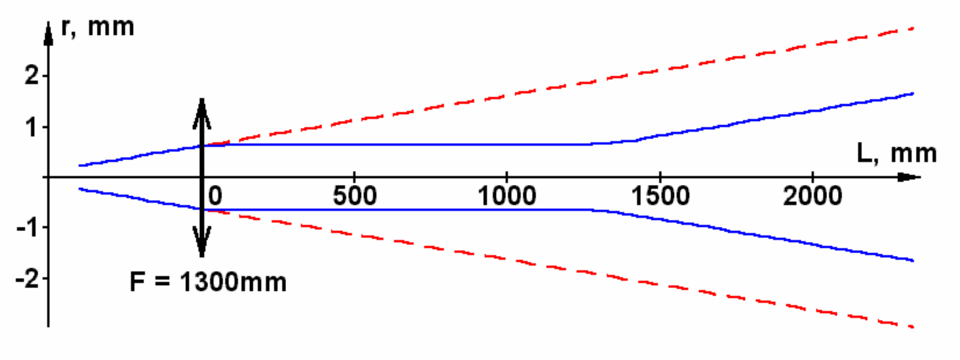
Estimations for
one electron bunch
absolute energy measurement.

Beams overlaps factor	$35x130^{2}$	
Pulse intensity, W/cm^2	$4.7x10^{9}$	$9.5x10^{9}$
Energy to be Absorbed by bunch, J	$3.73x10^{-9}$	$7.47x10^{-9}$
Focal length, m	1.3	1.3
Magnetic field induction, Gs	100	200
Pulse power RA reduction, W	$3.73x10^{3}$	$7.47x10^{3}$

THE SIGNAL TO NOISE RATIO

How to overcome the fact, that the theory of this method based on beams with interaction angles smaller than real laser diffraction limited beam divergences???

The answer is: Collimate the laser beam for the length of the interaction zone!!!



This principle gives a chance to neglect the angular overlap of the electron and the laser beams.

This principle is used for needed laser output energy estimations.

The example estimation shows that the time and space overlaps force to use ~ $6x10^5$ times more laser pulse energy than needed for absorption by electrons. In any case, the calculated laser parameters are among state of the art ones.

The unusable part of energy as a noise had to be filtered on its way to photo detector.

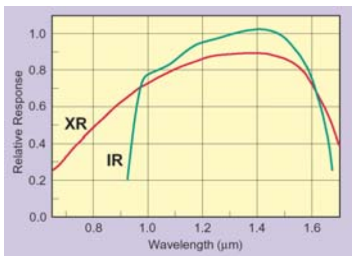
Concerning the Gaussian distribution of the laser beam, for measurements will be used the narrow region ($1/130^2$) of its peak.

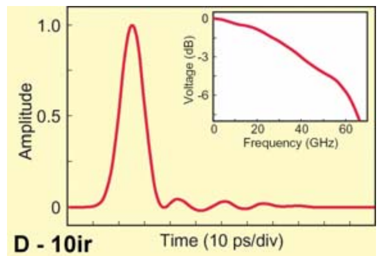
Taking into account that a negligible part of the laser pulse energy used for one electron bunch energy measurement, the laser pulse can be returned to the interaction region several times to measure the energies of the other electron bunches.

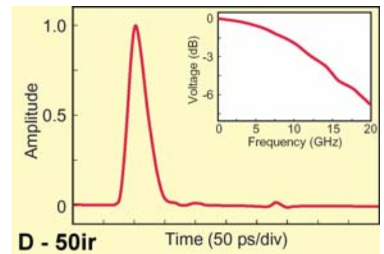
The sensitivity of this method can be increased by using laser intracavity RA schemes.

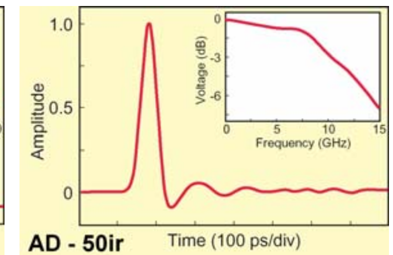
PHOTO DETECTORS

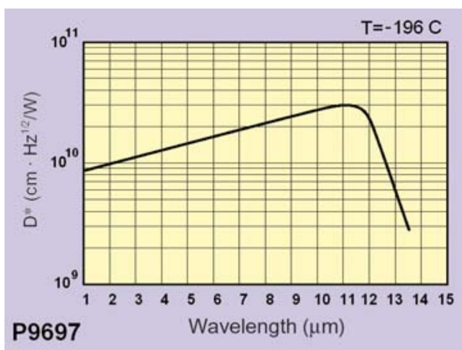
	Newport InGaAs				Hamamatsu MCT (HgCdTe)		
Model	D-10ir	D- 50ir	AD- 50ir	AD- 50	P7752-10	P9697- 01	P9697- 02
Spectral Response, um	0.95 – 1.65	0.95 – 1.65	0.95 – 1.65	0.4 – 1.7	6.5 – 13.5	6.5 – 13.5	6.5 – 13.5
Impulse Response, ps	10	50	50	50	---	---	---
Rise Time, s	10×10^{-12}	45×10^{-12}	45×10^{-12}	---	10^{-6}	0.15×10^{-6}	0.2×10^{-6}
Frequency Response (- 3dB), GHz	40	10	10	10	0.14×10^{-3}	---	---
Responsivity, A/W	0.3	0.9	---	---	---	3	3
Conversion Gain (50Ω), V/W	15	45	425	100	2×10^{6}	---	---
Dark Current (25°C), A	20×10^{-9}	20×10^{-9}	---	---	---	---	---
NEP, $W/Hz^{1/2}$	60×10^{-12}	20×10^{-12}	25×10^{-12}	150×10^{-12}	3×10^{-12}	1.5×10^{-12}	3×10^{-12}
Input Diameter, mm	0.05	0,05	0,05	0.05	1	0.5	1
Output Impedance, Ω	---	---	50	50	50	500	200







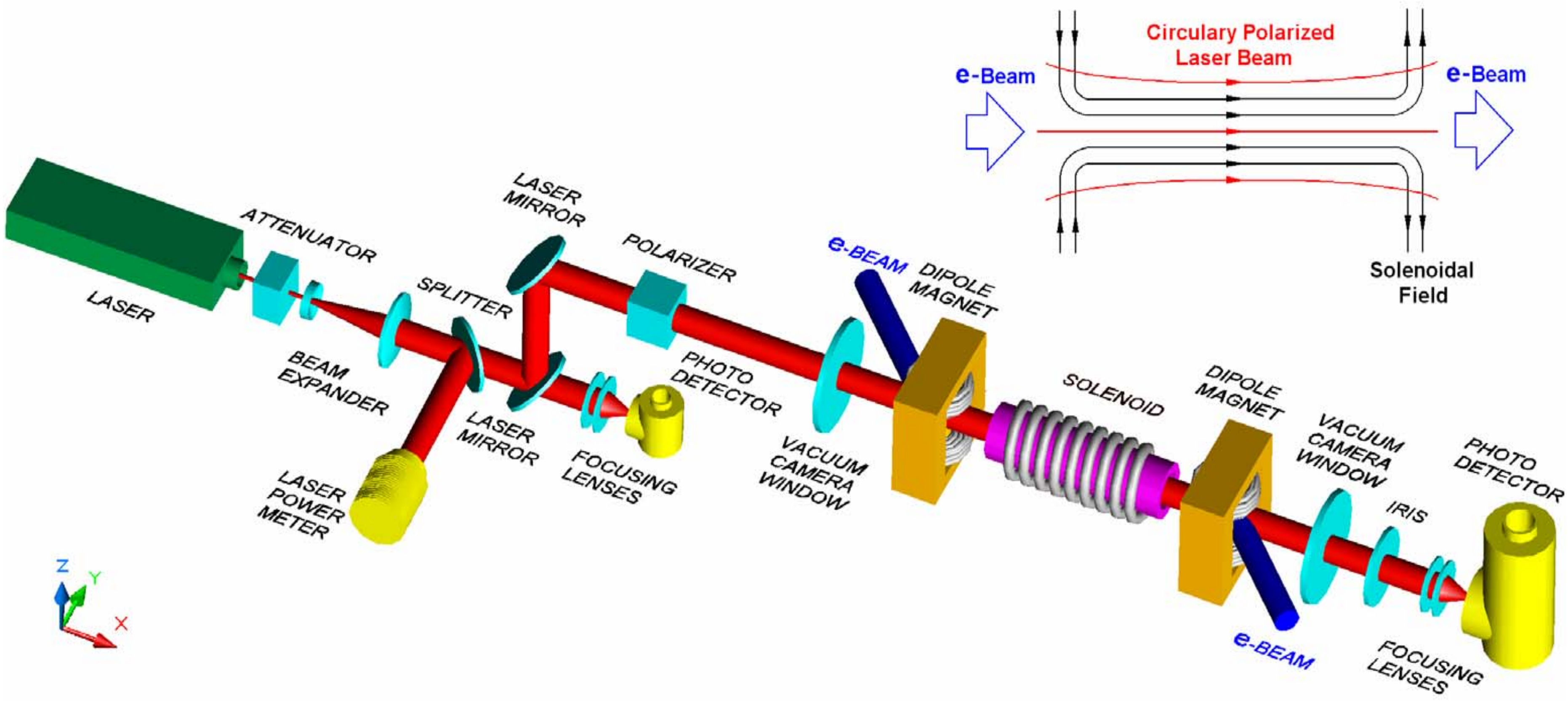




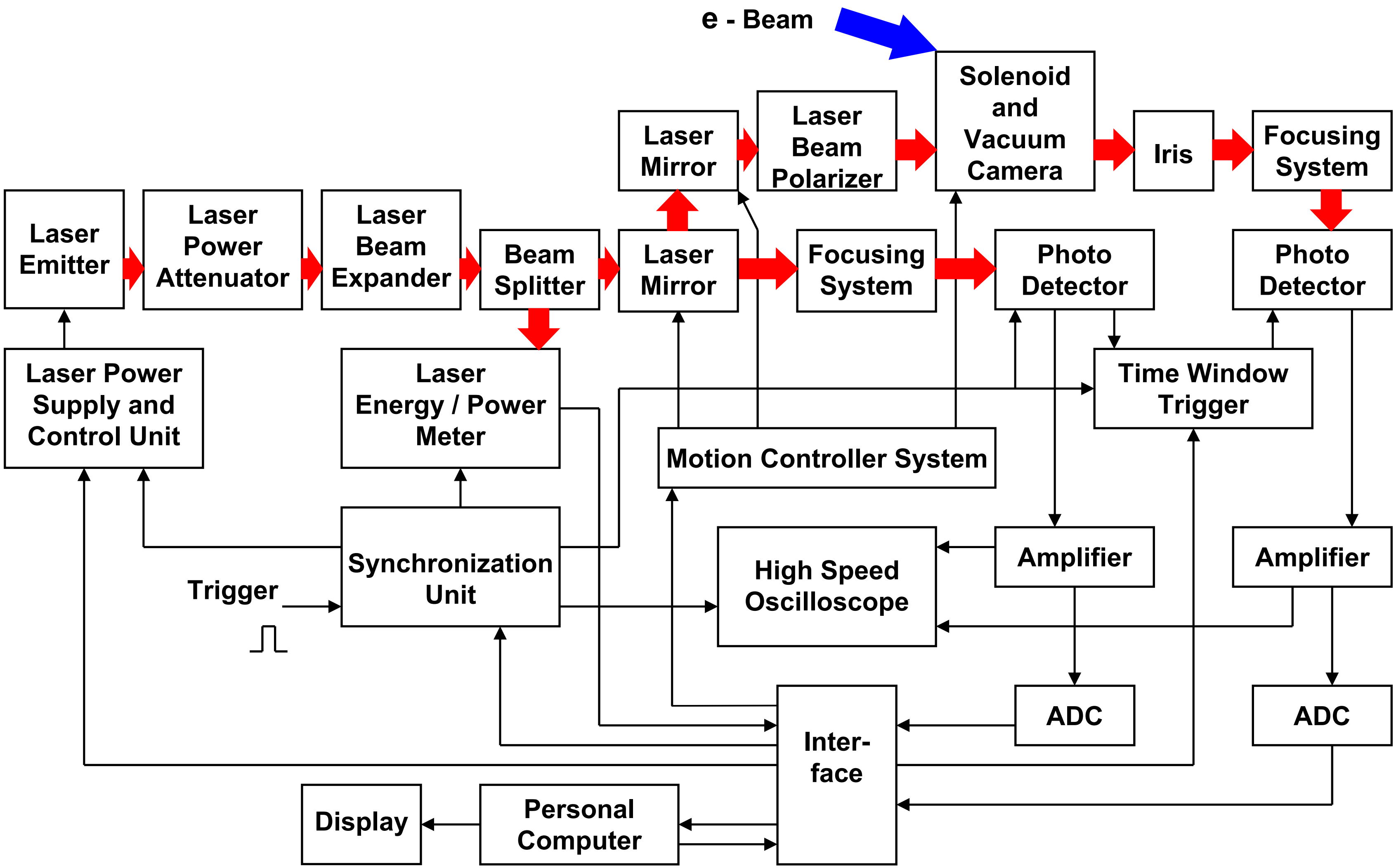
The photo detector specifications as the spectral and impulse response will have an additional investment into the needed laser energy.

The noise related to the laser and electron beams temporal overlap could be filtered by triggering (time window) of the photo detector.

OPTICAL SETUP FOR ELECTRON BEAM ABSOLUTE ENERGY MEASUREMENT BY RESONANSE ABSORPTION METHOD



OPTICAL SETUP AND REGISTRATION SYSTEM BLOCK DIAGRAM



SUMMARY

1. **Proposed three versions of the experimental realization of RA method for the electron beam absolute energy measurement with accuracy of $<10^{-4}$.**
2. **Is shown the reliability of the electron beam absolute energy measurement by RA method by means of the state of the art equipment.**
3. **Considered and indicated the all main equipment parameters needed for elaboration and showed their definition ways.**

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