Some thoughts concerning the SR- Monitor at 24 m for the LUMI upgrade

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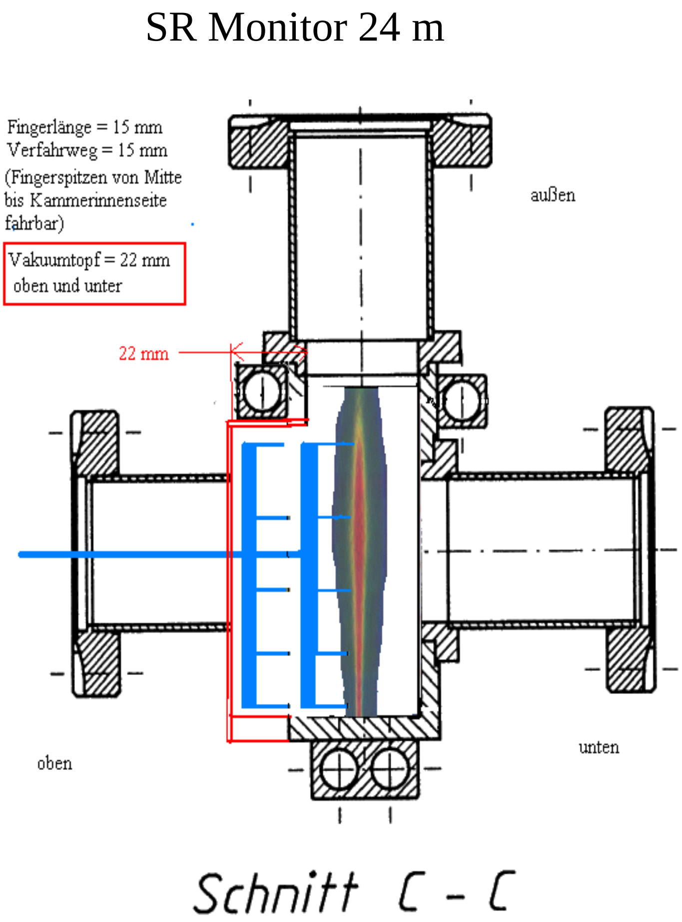

Fig. 1: Idea of the Monitor

All of the following calculations are done for a beam energy of 30 GeV and a current of 58 mA.

Problem 1: Heat load of the Fingers:

a: What is the energy-spectrum of the photons
b: How many photons will hit the finger
c: What is the energy deposition and the temperature increase
d: cooling by radiation and secondaries and heat transport

1a) What is the energy-spectrum of the photons

Fig. 2 a, b shows that the critical energy E_c is widely spread between 10 and 200 keV. E_c is define by: $E_c = \hbar\ 2/3\ \gamma 3\ c/R$, R = bending radius.

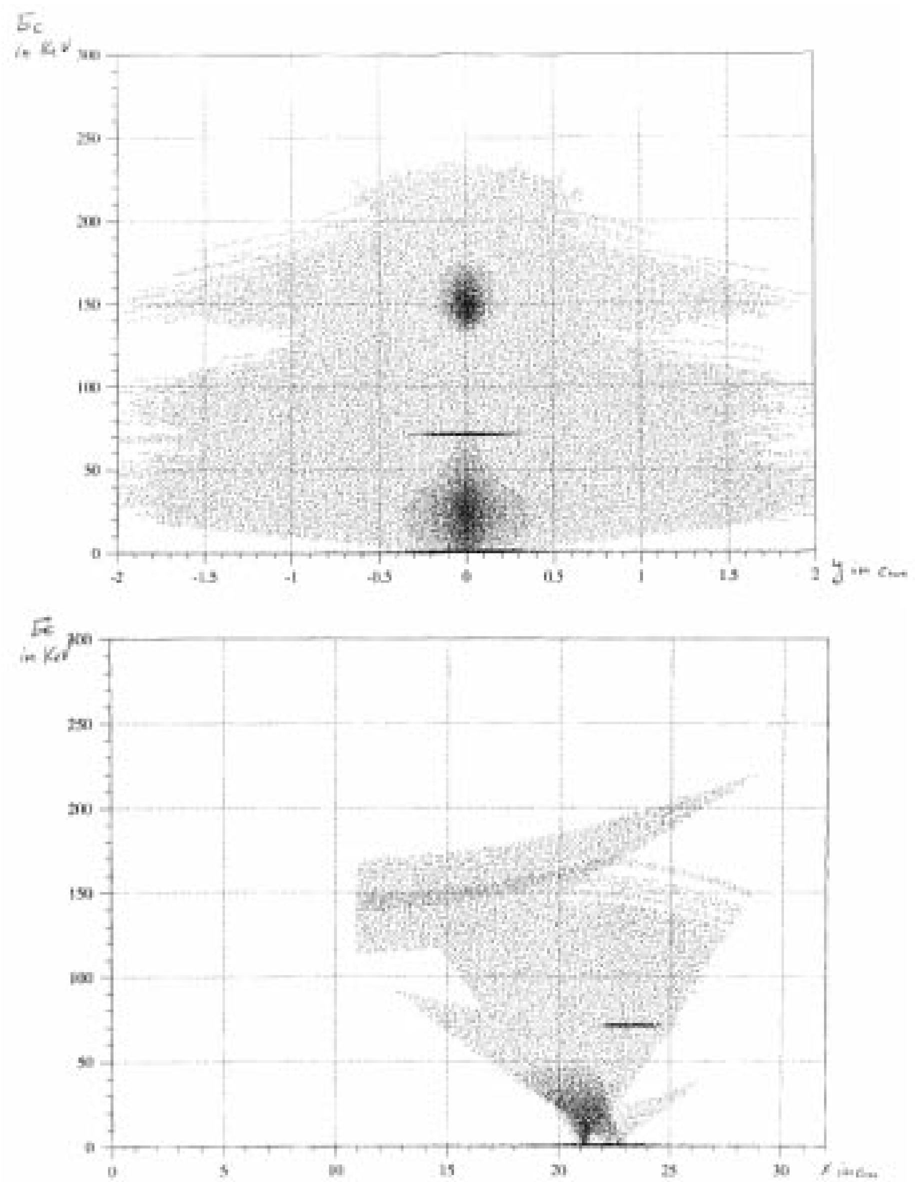

Fig. 2 a, b) Critical Energy E_c versus position at the SR-monitor (x = horizontal, y = vertical) by A. Mesek

The critical energy divides the power spectrum into two equal half's. Here the number of photons N is than derived from the total power by $N/s = P/ E_c$. Therefore for the heat load calculation one can use photons with $E_\gamma = 100$ keV

1b) How many photons will hit the finger

We simulate a finger of 1 cm width in the SR-beam at x = 19-20 cm and at y =-0.5 – 0.5 cm. The amount of photons/s hitting the finger when driving in was calculated. The finger starts at y = 2 cm and the other at x = 32 cm, respectively. The integral number of photons from this point to the end of the finger at x' (y') is displayed in Fig. 4.

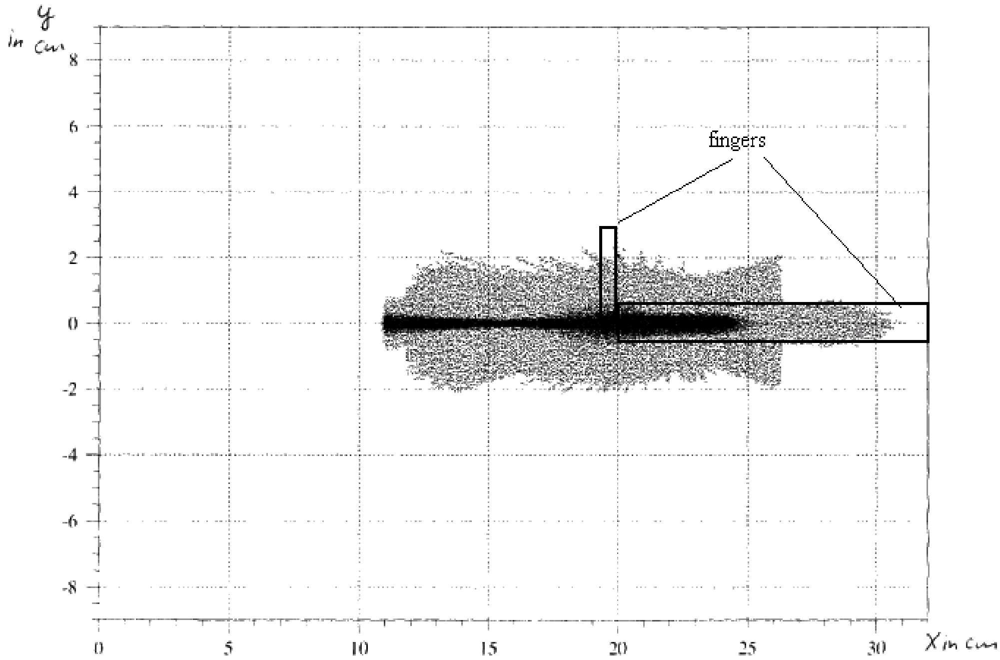

Fig 3: Photon distribution at the monitor with two fingers in measurement position; by A. Mesek

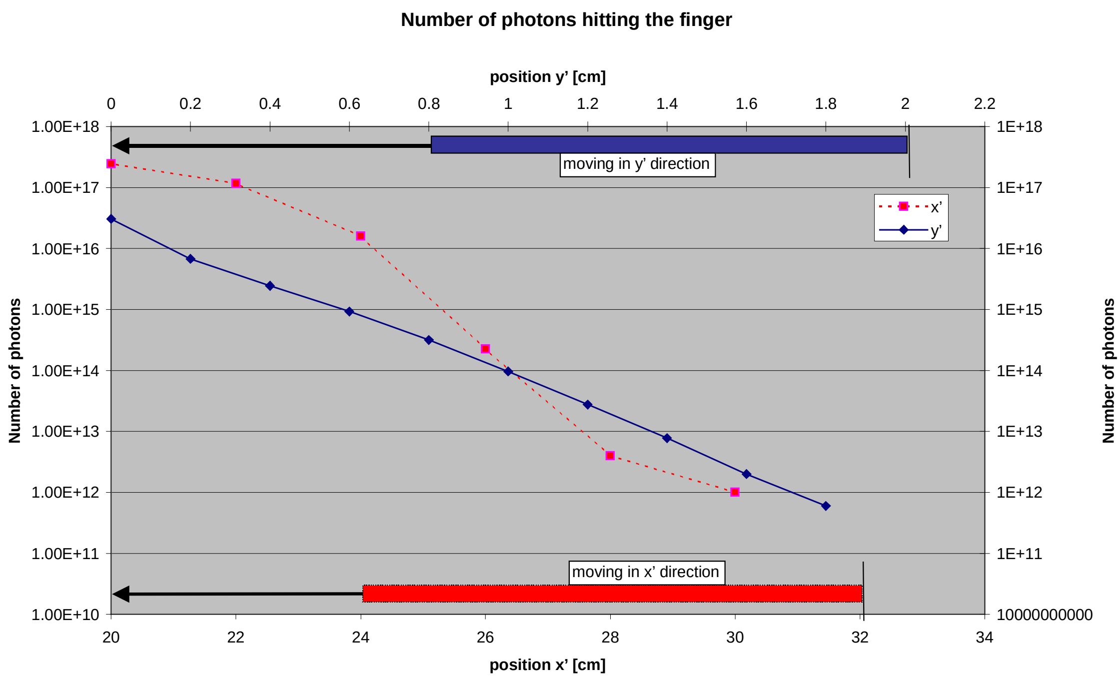

Fig. 4: Number of photons $N_{x', y'}$/s on the finger versus position of the finger

1c) What is the power deposition and the temperature increase

Let us assume a Tungsten finger with a length of 3 cm (vertical) and 14 cm (horizontal) with a width of 1.0 · 1.0 cm^2. A 100 keV Photon will be fully absorbed in 1 cm Tungsten. There is only a small amount <5% of backscattered photons. The deposed power can be calculated at any position of the finger by:

$P = 100 \cdot 1000eV \cdot N_{x', y'}/s \cdot K$ [W] with $K = 1.6\ 10^{-19}$ eV/J

If the finger reaches the middle of the SR one will have:

$P(y' = 0) = 480$ W, $P(x' = 20) = 3920$ W

The temperature increase ΔT can be calculated by:

$\Delta T = P/(c_p \cdot G)$ with G = weight [g] = V ρ, ρ = 19.39 g/cm^3 and c_p = spec. heat cap. = 0.134 J/(^{0}C g)

$\Delta T(y' = 0) = 46\ ^0C/s$; $\Delta T(x' = 20) = 107\ ^0C/s$ with $V_{y'} = 4\ cm^3$ and $V_{x'} = 14\ cm^3$

In any case, this cannot be cooled down and has to be avoided! Maybe one can think about of three orders of magnitude less, because there will be no efficient cooling mechanism! Therefore y' = 1cm and x' = 26 cm.

Other solutions:

- Water cooling of the fingers: no space
- Angle of 30^0 between SR and fingers: Factor 2 in length of finger gives factor 2 more material and therefore a reduction of factor 2 in temperature. Much smaller angles and therefore longer fingers do not fit into the monitor.
- Thinner fingers in SR direction: Reduction of $N = N_0 \cdot \exp(-d \cdot \rho / \lambda)$ with d = thickness and λ = photon attenuation length ≈ 0.5 g/cm^2 for 100 keV photons and W. Even with a 1mm thin tungsten finger (in SR direction) the absorption of the photons is still above 90 % (including backscattered photons). In this case the temperature is increased by the missing material by 1 order of magnitude. Much thinner fingers may help, but they do not have enough mechanical stability. And note also, that a huge number of photons with $E_\gamma << E_c$ and therefore with a much smaller absorption length will hit the finger.
- Other thin materials: Much lighter materials with a high melting point will help: Carbon (diamond) and Beryllium. For C: λ = 5 g/ cm^2, ρ = 2.2 g/cm^3 => only 5% absorption; but $(c_p \cdot G)_C/(c_p \cdot G)_W = 0.4$ => Factor 2.5 more ΔT. But expensive (diamond) and not easy to handle (Be). However, the cross section for the photo effect goes with Z^5, which is important for the signal yield (photocurrent).
- Thinner fingers transversal to SR direction: Assuming that (especially for the vertical finger) the distribution of the photons is homogeneous in the transversal plane, N is reduced by the width of the finger, but with the same amount the weight becomes reduced. Therefore no effect.
- Thin wires (Ref. 1) scanning the SR – beam: With this method, one will loose detailed information of the shape of the SR – beam. However, thin wires may be better cooled by radiation cooling and may be more rugged concerning the temperature issue.

1d: Cooling by radiation and secondaries and heat transport

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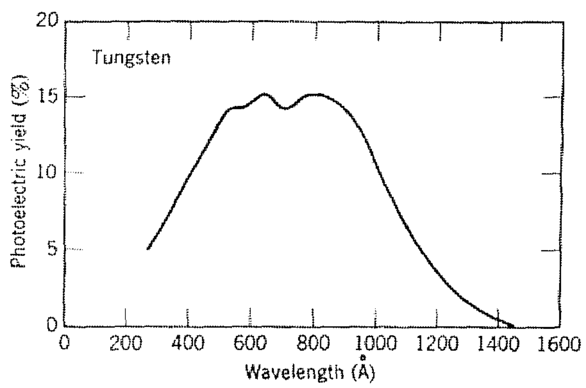
2) Signal

The signal comes from the emission of electrons due to the photoeffect. What is the efficiency of this process?
Some simplifications:
Let us assume that the radiation is a result of a simple bending magnet, so that
Ec = 100 keV. => $R = \hbar\, 2/3\, \gamma 3\, c/ E_c = 266$ m.
According to [A3] in the appendix the total power/s is:
$P_{tot} = \alpha \cdot W$
while α includes the geometry, the beam current and other approximations.
Setting: $P_{tot} = P(x' = 26\text{ cm}) \approx 4$ W than $\alpha = P(x' = 26) / W = 4\text{ W}/7.7 \cdot 10^{-6}\text{ W} = 5.2 \cdot 10^{5}$.
and for y: $P_{tot} = P(y' = 1\text{ cm}) \approx 0.4$ W than $\alpha = P(x' = 1) / W = 0.4\text{ W}/7.7 \cdot 10^{-6}\text{ W} = 5.2 \cdot 10^{4}$.
α is now the calibration constant which is true for power calculations within a certain photon energy ($\hbar\,\omega$) range, especially for $\omega << \omega_c$ which is the important range for calculating the photo current (see Fig. 5 and A2). Note that the opening angle Θ of the SR for all photon energies will be neglected here because of the high γ ($\Theta \sim 1/\gamma$). (is this also true for visible light?)

What is the interesting energy range for the photons producing photo current?
See Ref. 3! pages 224 – 244
For tungsten:



Photoelectric yields of W as a function of wavelength, normal incidence
Fig. 5, from Ref. 3

From Fig. 5: A Yield of approx. 10% / incident photon can be assumed over the wavelength between 200 to 1200 A (20 – 120 nm)
λ_1 =20 nm => $2\pi c/\lambda$ [1/s] = $\underline{9.4 \cdot 10^{16} = \omega_1}$
λ_2 =120 nm => $2\pi c/\lambda$ [1/s] = $\underline{1.57 \cdot 10^{16} = \omega_1}$

Using Formula A1:

$$W = \alpha \cdot 0.52 \cdot \frac{e^2}{4\,\pi\,\varepsilon_0\,R} \cdot \int_{\omega_1}^{\omega_2} \left(\frac{\omega\,R}{c}\right)^{1/3} d\omega \qquad = 6.5 \cdot 10^{-5}\text{ W for x' = 26 cm}$$

Assuming a mean wavelength of λ = 70 nm => One photon gives an Energy of $E_\gamma = \hbar\,\omega = 2.8 \cdot 10^{-17}$ J . To reach a Power of *W* one need $N = W/ E_\gamma = 2.3 \cdot 10^{12}$ Photons/s. With a photoelectric yield of 10% one will have $2.3 \cdot 10^{11}$ Photoelectrons/s or a photocurrent of $\underline{I_\gamma = 37\text{ nA}}$.

This value should scale linear with the heat load (neglecting opening angle of SR). It agrees with experience from DORIS where at a total heat load of 27 W a Signal of in the order of some μA can be measured (Ref. 4). To measure the SR distribution (horizontal), the dynamic range of the electronic readout should cover at least 4 decades (1 μA – 0.1 nA). However, more will be better, but it should be extended to smaller currents. In this case we do not have to move each finger separately, because of the dynamic range of the readout and therefore in position (more than 1 cm vertical and more than 6 cm horizontal).
Note that this result do not depend on the beam energy (as long as $\omega << \omega_c$) but it depends on the beam current linear. This has to be taken into account when designing the dynamic range (about a factor 10)

Other Problems:
1) There is measured a cross talk of some ‰ between the fingers in DORIS (Ref. 4). Bias and shielding has to be designed carefully.
2) How the Power on the Finger will dissipate? This is the question of the insulation heating.
3) At high temperatures of the finger one will have thermal electrons emitted.

More important notes:

From ref. 5 one can get some efficiency numbers for the x-ray photoeffect (at 9 keV). The efficiency is about 5%. that means, that there will be some big contributions to the calculated signal due to this effect. therefore the calculation gives more or less a lower limit!
Some Numbers: Let us assume a efficiency of 2% between 1 keV – 20 keV photon energy.
In this range one get $1 \cdot 10^{14}$ Photons/s (10keV) or 16 μA.
Maybe a filter which removes the Vacuum- ultraviolet may improve the monitor conditions because of reflections of low energy photons on the beam pipe walls?

AND: In case of this higher photon energy, one will have photoelectrons in the energy range of more than keV. Therefore a Bias of less than kV will not remove the cross talk between the fingers completely!!!!

Appendix: Some curves

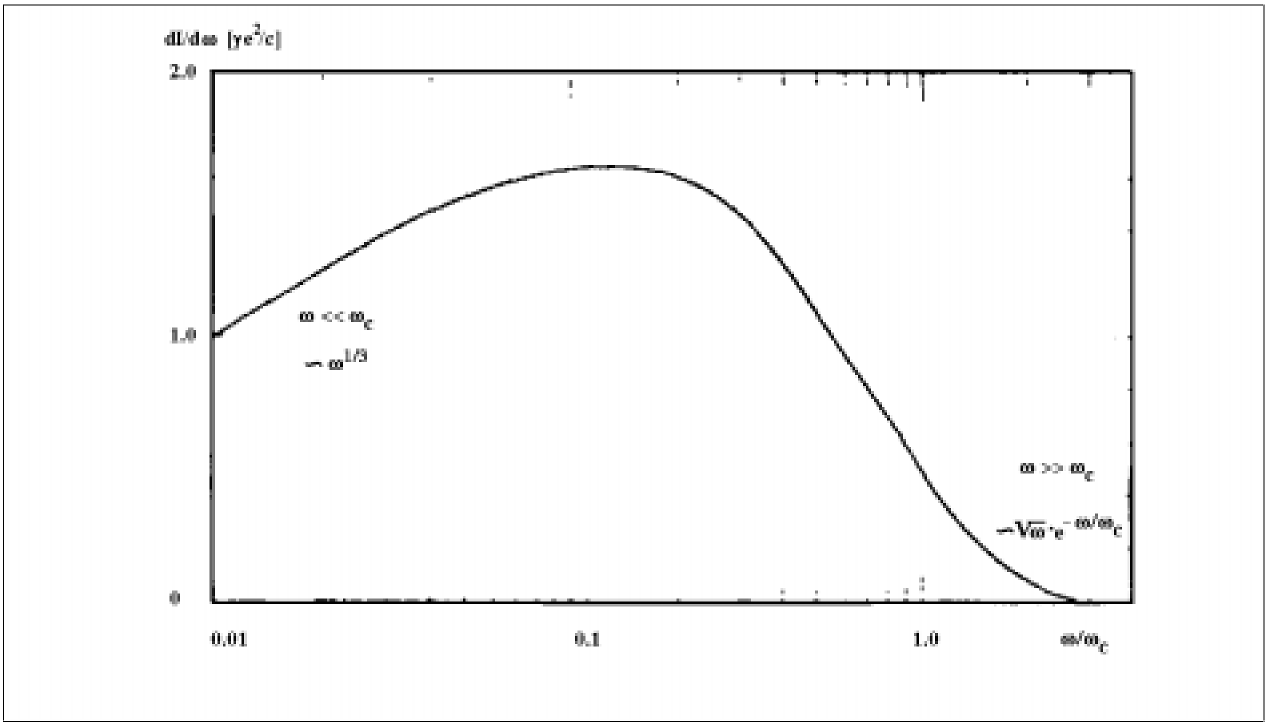


Fig. A1: Frequency - Spectrum of the Synchrotron Radiation.

Ref. 2 gives two approximations for the total radiated energy per turn electron and frequency interval dω of the photons (in MKSA units):
:
For $\omega << \omega_c$ with $\omega_c = E_c / \hbar$ (note that there is no dependence on the energy of the beam!):

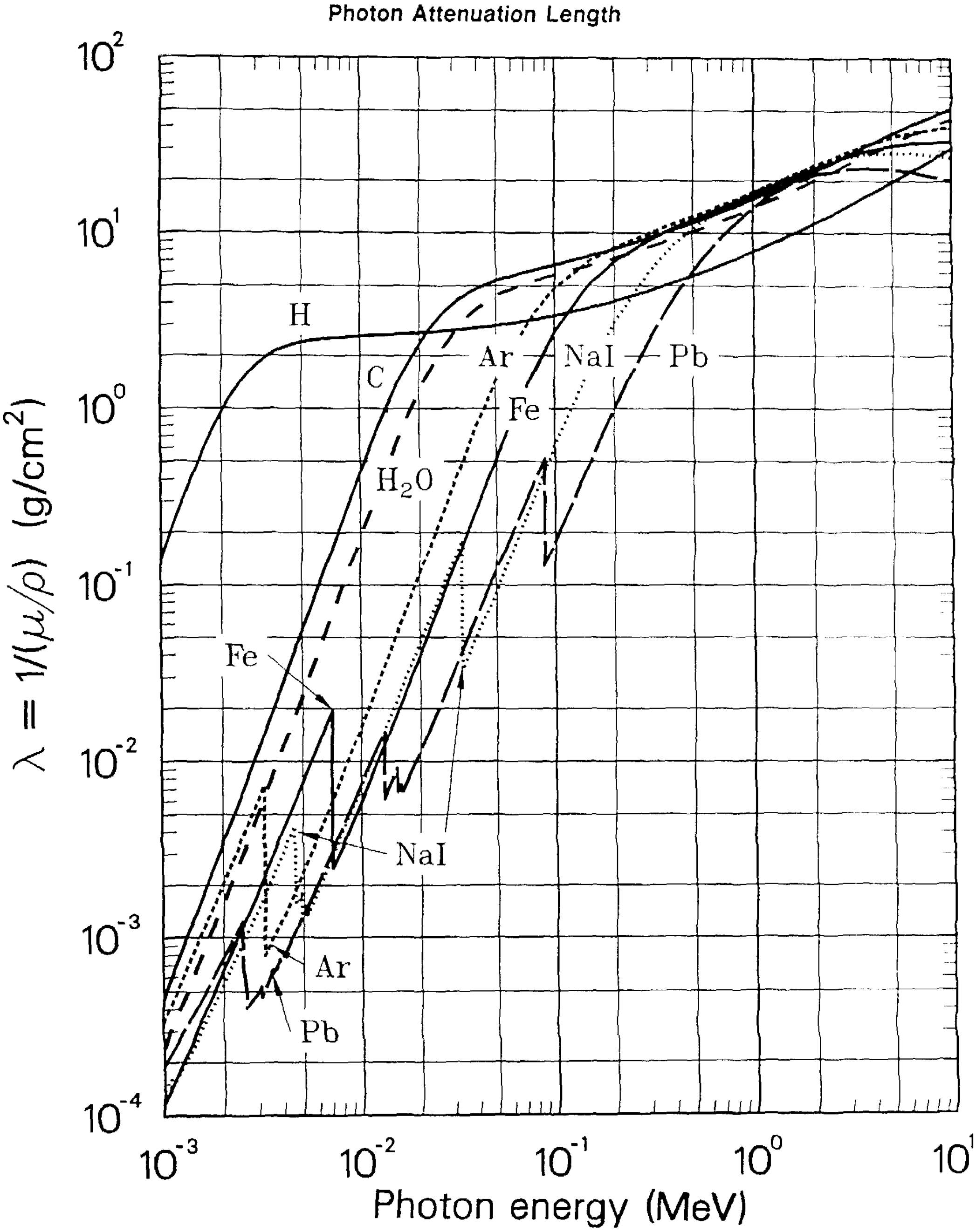
$$\frac{dW}{d\omega} = 0.52 \cdot \frac{e^2}{4\,\pi\,\varepsilon_0\,R} \cdot \left(\frac{\omega\,R}{c}\right)^{1/3} \text{ [Joule]} \qquad \text{[A1]}$$

and for $\omega >> \omega_c$:(note that there is no dependence on the energy of the beam!)

$$\frac{dW}{d\omega} = 2.17 \cdot \frac{e^2}{4\,\pi\,\varepsilon_0} \cdot \frac{\gamma}{c} \cdot \sqrt{\frac{\omega}{\omega_c}} \cdot e^{-\frac{\omega}{\omega_c}} \quad \text{[Joule]} \qquad \text{[A2]}$$

and for the total radiated Power:

$$W = \frac{1}{4\,\pi\,\varepsilon_0} \cdot \frac{2}{3} \cdot \frac{c\,e^2 \gamma^4}{R^2} \quad \text{[Watt]} \qquad \text{[A3]}$$



The photon mass attenuation length $\lambda = 1/(\mu/\rho)$ (also known as mfp, mean free path) for various absorbers as a function of photon energy, where μ is the mass attenuation coefficient. For a homogeneous medium of density ρ, the intensity I remaining after traversal of thickness t is given by the expression $I = I_0 \exp(-t\rho/\lambda)$. The accuracy is a few percent. *Interpolation to other Z should be done in the cross section* $\sigma = A/\lambda N_A$ cm^2/atom, where A is the atomic weight of the absorber material in grams and N_A is the Avogadro number. For a chemical compound or mixture, use $(1/\lambda)_{\mathrm{eff}} \cong \sum w_i (1/\lambda)_i$, accurate to a few percent, where w_i is the proportion by weight of the i^{th} constituent. See next page for high energy range. The processes responsible for attenuation are given in the bottom figures of the next page. Not all of these processes necessarily result in detectable attenuation. *For example, coherent* Rayleigh scattering off an atom may occur at such low momentum transfer that the change in energy and momentum of the photon may not be significant. From Hubbell, Gimm, and Øverbø, J. Phys. Chem. Ref. Data **9**, 1023 (1980). See also J.H. Hubbell, Int. J. of Applied Rad. and Isotopes **33**, 1269 (1982). Data courtesy J.H. Hubbell.

Fig. A2: Photon attenuation length for different materials, from Rev. Particle Properties, Phys. Letters B, Vol. 204, 1988

References

Ref. 1: **A WIRE SCANNING TYPE POSITION MONITOR FOR AN UNDULATOR RADIATION**. By X.W. Zhang, H. Sugiyama, M. Ando (KEK, Tsukuba), Shao-Jian Xia (Beijing, Inst. High Energy Phys.), H. Shiwaku (JAERI, Tokai). 1994. Published in Rev.Sci.Instrum.66:1990-1992,1995

Ref. 2: J.D. Jackson; **Klassische Elektrodynamik**
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Ref. 3: J.A.R. Samson; **Techniques of Vacuum-Ultraviolet Spectroscopy**, John Wiley &Sons, Inc. New York

Ref. 4: M. Seebach, M. Werner; DESY MKI, privat communication, and **Photon beam position monitors at DORIS**, DIPAC, Frascati

Ref. 5: M.A Rumsh and V.N.Shchemelev, **Role of secondary emission phenomena in the x-ray photoeffect in metallic cathodes**; Soviet Physics – Solid Stade, Vol. 5, No. 1 (1993, pp. 46-50

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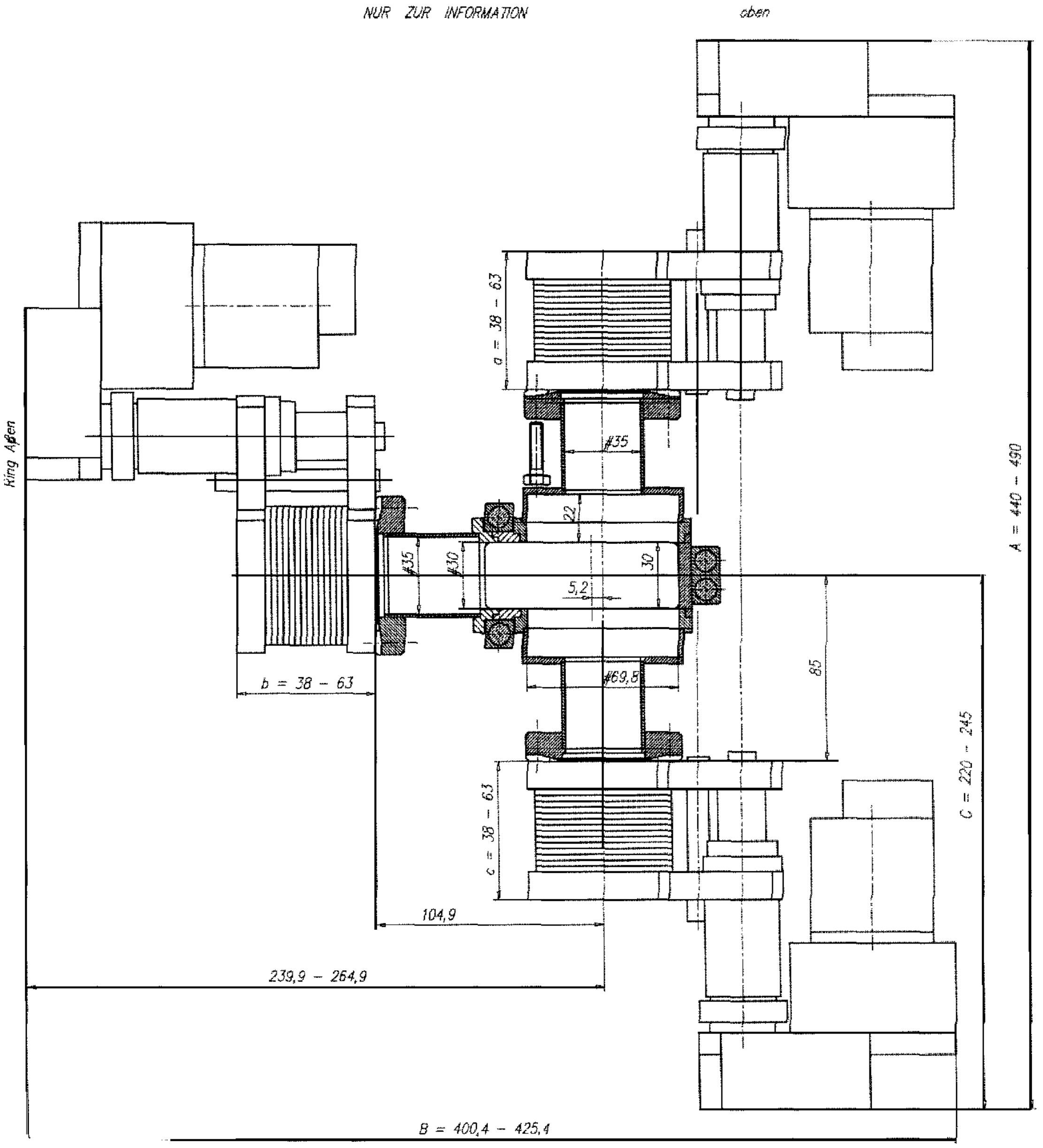

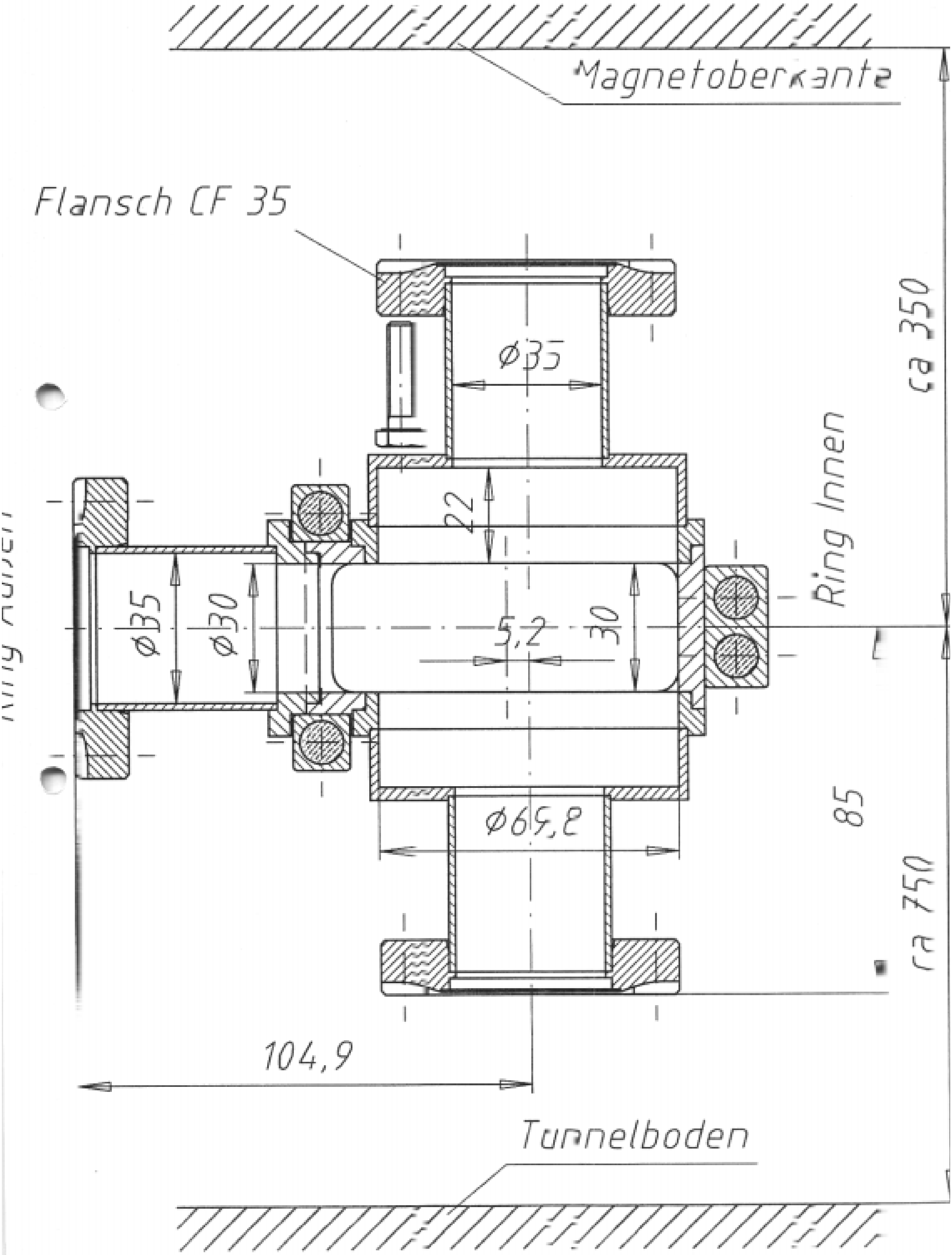

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