The crab-crossing angle and the beam dump at the photon collider

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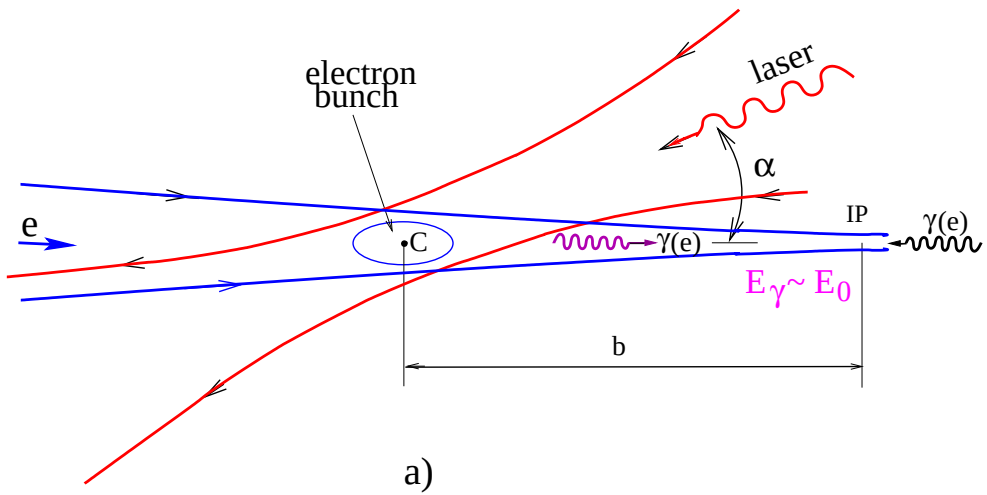
Special requirements for photon colliders:

- for removal of the disrupted beams the crossing angle at one of the interaction regions should be about 25-30 mrad (the exact number depends on the final quad design);

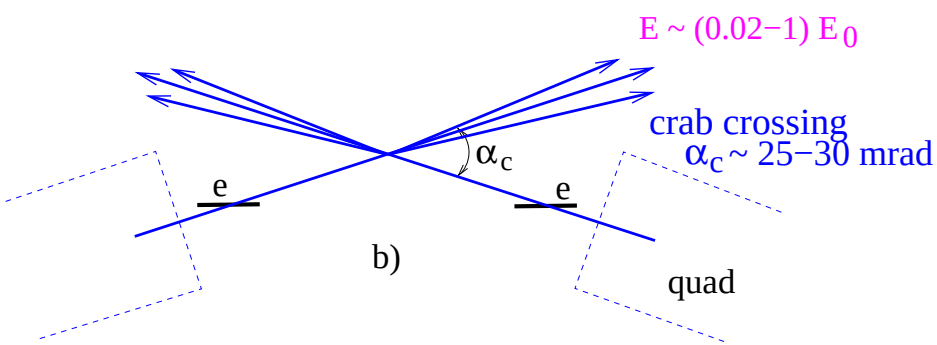
- the beam dump should withstand absorption of the narrow photon beams and which follow a straight line from the interaction point (deflection is not possible); used electron beams have a wide energy spread and large disruption angles.

- some others

The crossing angle



a)



b)

After the collision the beams have a large energy spread: $E \sim (0.02 - 1)E_0$ and disruption angles $\theta_d \sim 10$ mrad (the background from particles with $\theta > 10$ mrad is less than from unavoidable backgrounds).

The removal of disrupted beams need large crab-crossing angle:

$\alpha_c \sim R_{quad}/L^* + \theta_d$

$\sim 6/400 + 0.01 = 25$ mrad.

(For e^+e^- $\alpha_c = 20$ mrad is one of possible options.)

Large crossing angles lead to the increase of σ_y due to synchrotron radiation of electrons in the solenoid. After emission of the photon(s) the electron comes to the IP with some vertical deflection. This effect leads to the decrease of the luminosity. A simple theory gives $\sigma_{y,SR} \propto (L_s B_s \alpha_b)^{5/2}$.

There are statements that 20 mrad is OK, 25 mrad is too much for e^+e^-. In order to avoid further hot discussions we need quantitative comparisons.

The number of emitted photons per electron is about one ($N_\gamma \propto L_s B_s \alpha_b$), therefore the distribution on Δy is not Gaussian, also the fields in the detectors are rather complicated (the fringe field gives also a comparable contribution), therefore a detailed simulation is desirable.

The simulation was done using PHOCOL code (Telnov,1994), which simulated beam collisions at the LC in all modes. It was used for simulation of photon colliders for NLC ZDR, TESLA CDR, TESLA TDR.

The considered effect was account in the following way: using the map of the magnetic field in the detector we simulate separately SR and calculate the deviation of the electron from the case when there is no SR. This deviation is added to the Gaussian position of the electron at $z = 0$. Then all particles are shifted according to there coordinates and angles at $z = 0$ to there starting positions at $z > 5\sigma_z$ (or CP-IP distance at the photon collider) and the simulation with account of all collision effects starts.

In the given simulation (e^+e^- at $2E = 1$ TeV) only attraction between particles was switched on, other processes are not essential.

SiD ($B_{max} = 5$ T)

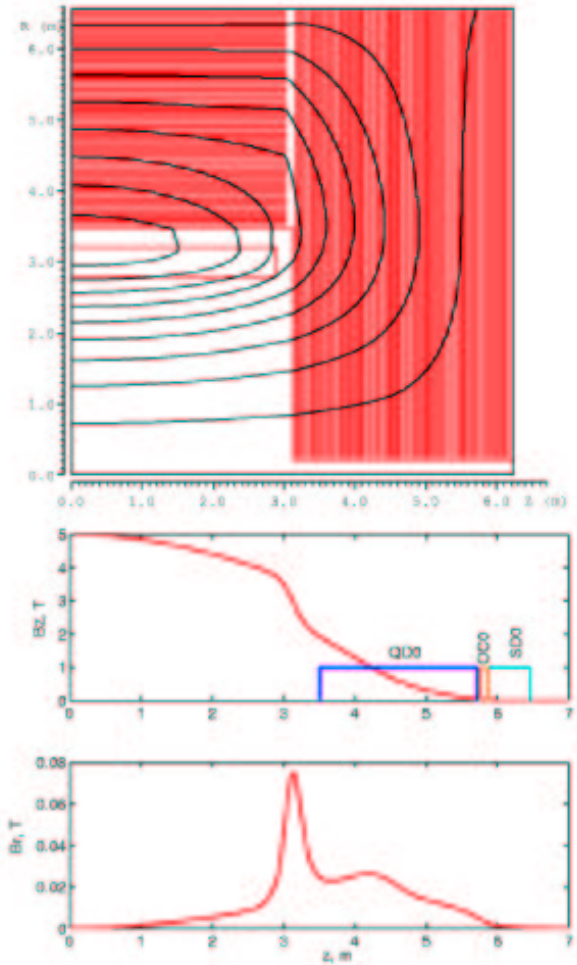


FIG. 3: The model of the Silicon Detector (SiD) with field lines calculated by ANSYS (top plot). Longitudinal and radial fields on the ideal beam trajectory with half crossing angle $\theta_c = 10$ mrad (bottom plots). Locations of the Final Doublet elements are also shown. IP is at $z = 0$ m.

LD ($B_{max} = 3$ T)

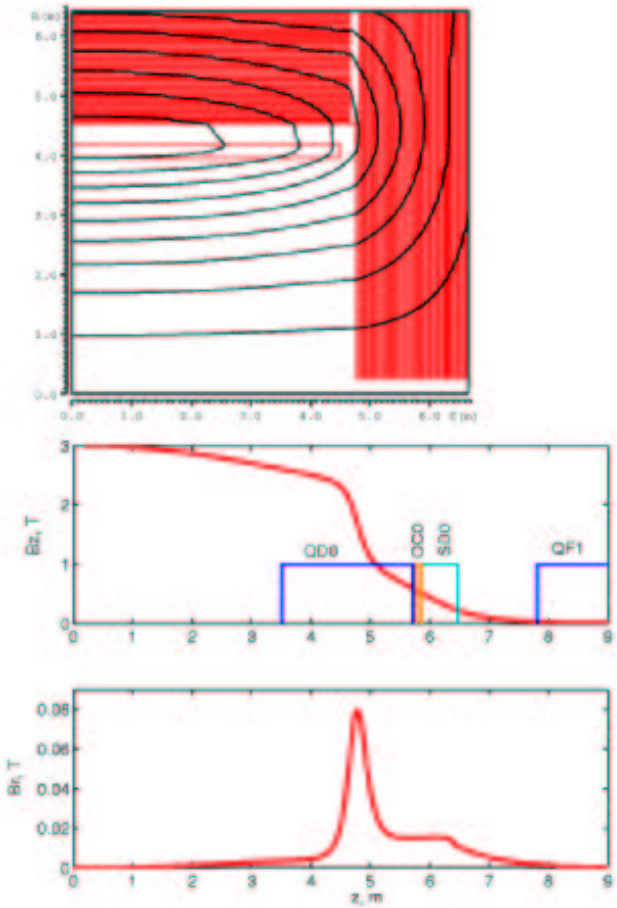


FIG. 4: The model of the Large Detector (LD) with field lines calculated by ANSYS (top plot). Longitudinal and radial fields on the ideal beam trajectory with half crossing angle $\theta_c = 10$ mrad (bottom plots). Locations of the Final Doublet elements are also shown. IP is at $z = 0$ m.

(from LCC-0142, Y.Nosochkov, A.Seryi)

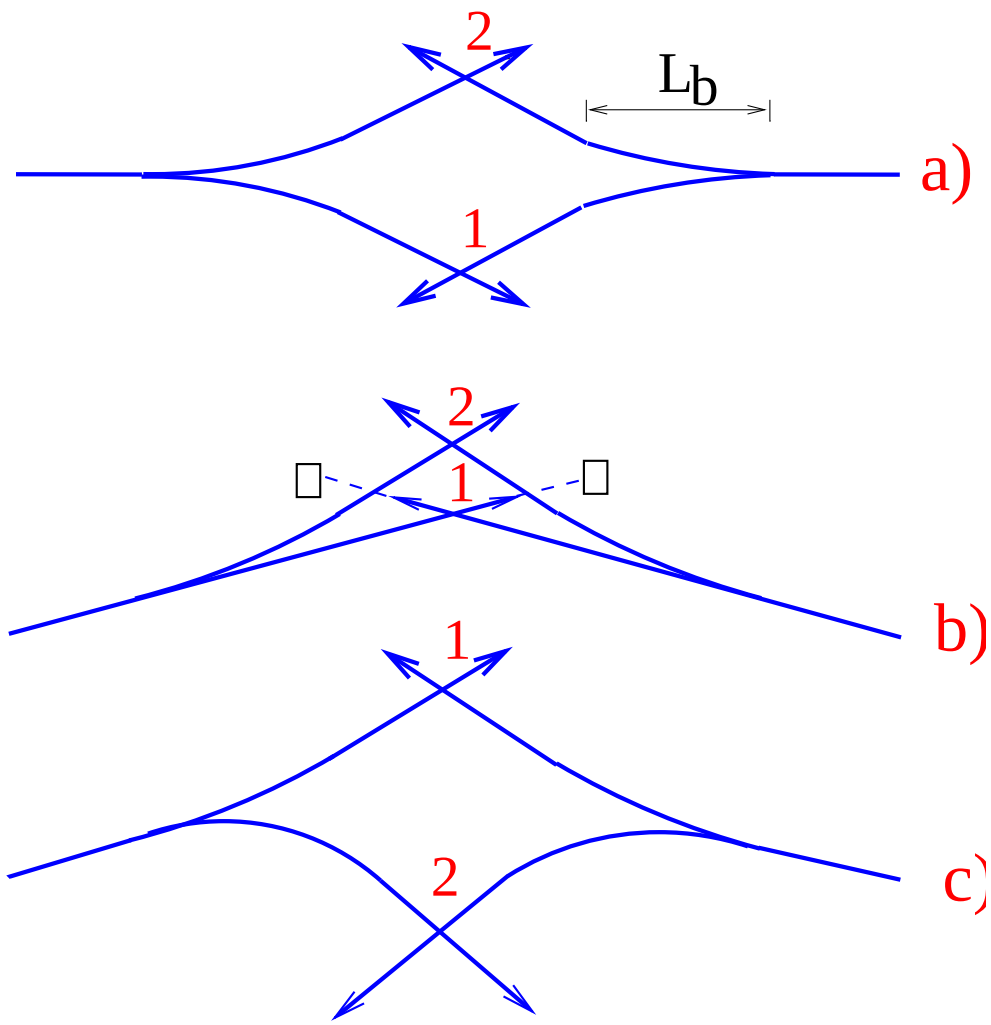
Parameters of beams are taken from U.S. Linear Collider Technology Option Study:
$2E_0 = 1$ TeV, $N = 2\times10^{10}$, $\sigma_z = 0.3$ mm, ϵ_{nx}=9.6×10^{-6} m, ϵ_{ny}=0.04×10^{-6} m, $\beta_x = 24.4$ mm, $\beta_y = 0.4$ mm, $\sigma_x = 490$ nm, $\sigma_y = 4$ nm.

$$L(\alpha_c)/L(0)$$

α_c(mrad)	0	20	25	30	35	40
LD	1	0.985	0.972	0.952	0.904	0.877
SiD	1	0.993	0.99	0.972	0.925	0.89

The are two other detectors under consideration: LD(TESLA-like) with $B \sim 4$ T and "Huge" detector with B=2.5–3 T. For all detectors the product $B_s \times L$ differ less than by factor of 1.2. The result strongly depends on details of the field. Accurate considerations are required, optimization of the detector field may be useful for reduction of the SR effect.
Resume: $\alpha_c = 25$ mrad seems OK.

The angle between tonnels, bending angle



The crab-crossing angle for e^+e^- (IP1) is about $\alpha_{c,1}$ = 0-20 mrad, smaller than for $\gamma\gamma$ (IP2) which is $\alpha_{c,2} \sim$ 25 mrad.

Scheme a), the angle between tonnels $\alpha_t = 0$, the simplest configuration. The only problem: for maximum beam energies the bending length L_b required for a small beam emittance dilution may be too long.

Scheme b) bending angles are minimum, but the disrupted beams from IP1 cross the beamlines of the IP2.

Scheme c) there is no problem with the beam dump. It is optimum for both IP in the case when bending angles for IP1 and IP2 are equal (smallest L_b),i.e.the angle between tonnels $\alpha_t = (\alpha_{c,1} - \alpha_{c,2})/2$. If the corresponding L_b is too large, then only one IP is optimized for achiving maximum beam energies.

Increase of the horizontal beam emittance due to SR in the big bend

$$\Delta\epsilon_{nx} \propto \frac{E^6 \alpha_b^5}{L_b^4}.$$

Taking the coefficient from the NLC ZDR one gets

$$\Delta\epsilon_{nx} = 1.8 \times 10^{-10} \left(\frac{2E_0}{\text{TeV}}\right)^6 \left(\frac{\text{km}}{L_b}\right)^4 \left(\frac{\alpha_b}{10\,\text{mrad}}\right)^5 \text{ m}$$

For $\epsilon_{nx} = 2 \times 10^{-6}$ m, $\alpha_b = 10$ mrad,
$\Delta\epsilon_{nx}/\epsilon_{nx} = 0.05$ at

$2E_0$ TeV	1	2	3	5
L_b km	0.2	0.57	1.04	2.25

The choice of the scheme depends on the assumed maximum energy of the collider in this tonnel. The total cost of the collider will be somewhat cheaper when only one IP reaches the maximum energy (without the luminosity degradation), the scheme c) with $\alpha_t \sim \alpha_{c,1}$.

From user's point of view, both IP should have similar energy reach. In the latter case, and $\alpha_{c,1} = 20$ mrad and $\alpha_{c,2} = 25$ mrad the optimum angle between tonnels in the scheme c) $\alpha_t = (25 - 20)/2 = 2.5$ mrad (not too much gain compared with zero angle).

Problems of a beam dump at the ILC

Parameters of beams:

Energy of electrons: (0.02–1)E_0; energy of photons (0-1)E_0.

Power: $\sim$ 10 MW, 50 % electrons, 50 % photons.

Beam diameter at the distance 100 m without beam collisions: $\sigma_x \sim 2-5$ mm, $\sigma_y \sim 1$ mm, determined by the electron beam emittancies.

Beam diameter at the distance 100 m with beam collisions(at $E_0 = 100$ GeV): $\sigma_x \sim \sigma_y \sim 35$ cm for 90%, and about 50 cm for 99%. Sizes are determined by repulsion of disrupted electron beams.

Problems

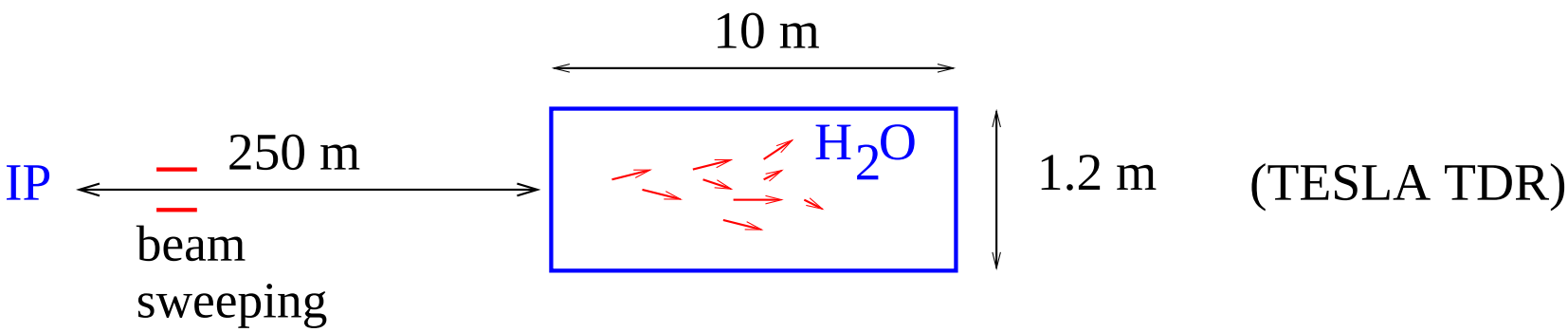
- The transverse size of the electron beam without disruption at the beam dump is very small, it can cause local overheating. Same problem for e^+e^- mode.

- The transverse size of the photon beam (photons after the Compton scattering) is very small, it can cause local overheating.

- Exit aperture for the disrupted beams at photon collider is large, backward neutrons from the beam dump can damage the vertex detector.

- Radiation problems, Tritium, etc, are very important, similar to e^+e^-.

Existing approach



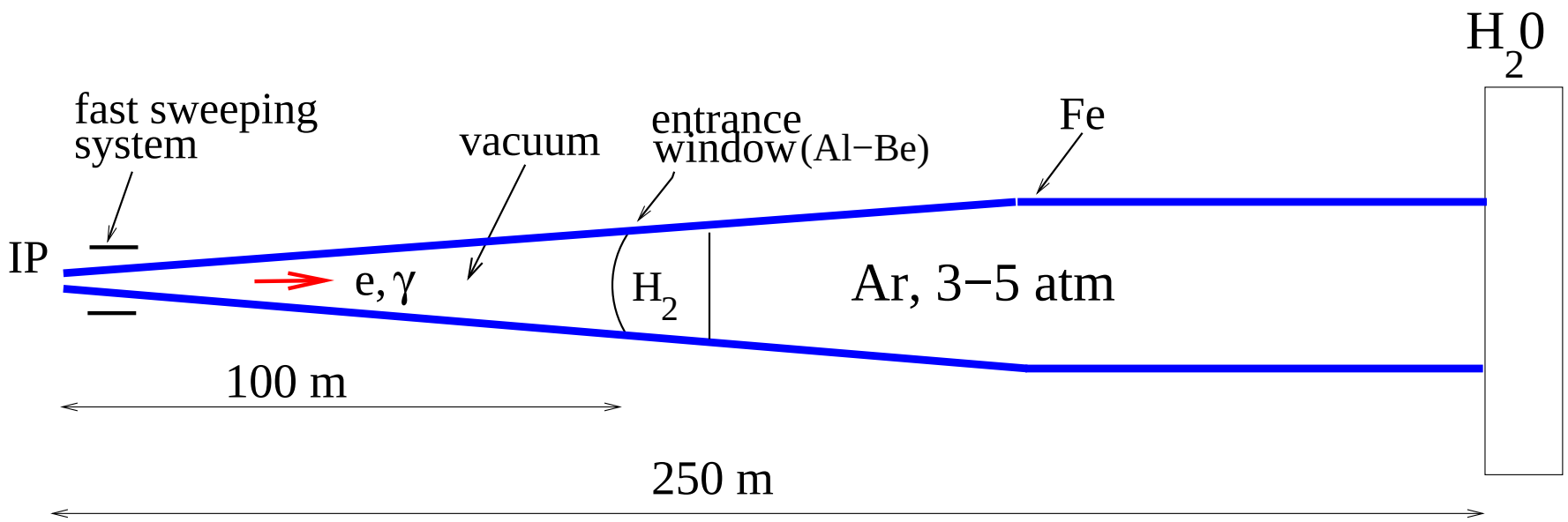
In this scheme the problem of boiling water after hitting of the electron bunch train to the dump is solved by sweeping the beam during the bunch train by the deflector. The heat is removed from the beam dump by flowing of water in the transverse direction.

Problems:

a): can not dump the narrow photon beam; in order to avoid boiling of the watter the r.m.s. beam size should be larger than 1.5–2 cm. For the photon beam $\sigma_x \times \sigma_y \sim 0.7 \times 0.2$ cm^2.

b) a neutron flux is larger than desired.

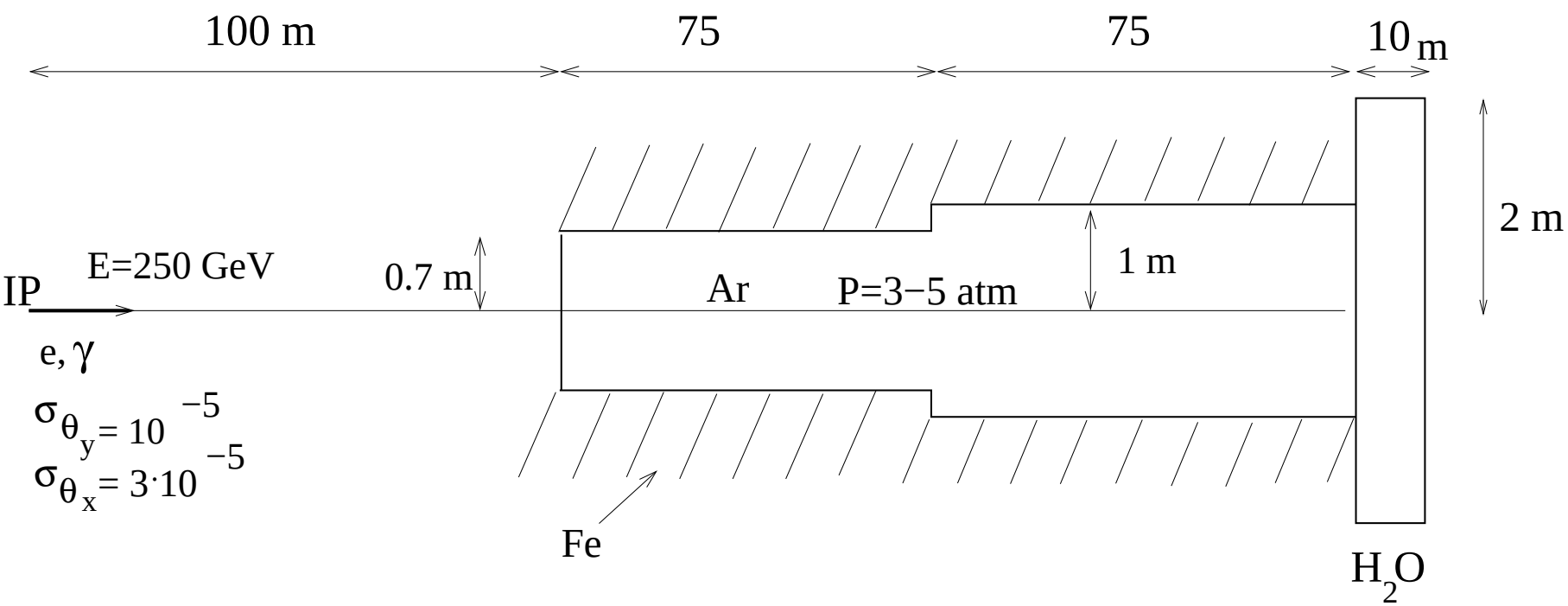
The beam dump for the ILC



The deflecting magnets rotate the electron beam (R=0.5-1 cm at 100 m from the IP) in order to reduce local temperature at the entrance window. The energy deposition by photons in the entrance window is small.

A gas volume (Ar at P=3-5 atm) of 4-5 X_0 rad. length thickness serves for conversion of photons and broadening of the shower before the water dump.

The scheme used in the simulation



Simulation results

Maximum local ΔT in the water dump after passage of the train from 250 GeV photons is 75, 50, 25° at 3, 4, 5 atm Ar, respectively and by a factor of 2 lower from electrons.

Maximum local ΔT at the exit Be-Ar (may be other material) window is small, $\sim 10°$.

The maximum ΔT at the entrance Be-Al window is about 40° for $\sigma_{\theta_x} = 3 \times 10^{-5}, \sigma_{\theta_y} = 10^{-5}$ and R=0.5 cm (sweeping radius). For the removal of the heat the thermal conductivity is sufficient (gas cooling can be added if necessary).

Note, the problem of the stress in solid materials in cold-LC beam dump is not important because the train duration is much longer than the decay time of local stress ($r/v_{sound} \sim 1$ μs). It is more serious for warm-LC with short train.

Neutron background at the IP

For 10^5 incident 250 GeV electrons and $P_{Ar} = 4$ atm there are 6 neutrons at the IP plain $z = 0$ with the radial coordinates $r = 1.5$, 2.5, 4.5, 14.5, 18.5 21.5 m. Due to the collimation by the Fe tube we do not expect the uniform density, the density per cm^2 should be larger near the axis. Assuming the uniform density for three neutrons closest to the axis we find the flux $5 \cdot 10^{-11}$ n/cm^2 per incident electron or about $1.5 \cdot 10^{11}$ n/cm^2 for 10^7 sec run time.

For comparison just the water dump at the distance 100 m gives 3×10^{11} n/cm^2 for the same time (quite similar).

It is remarkable that after the replacement of the first 20 m of Ar by H_2 at the same pressure there is only one neutron at $r = 1.5$ m for $8 \cdot 10^5$ incident electrons. With account of collimation by the tube it means the decrease of the neutron flux at least by a factor of ten!

Conclusions

- The luminosity decrease at the crab-crossing angle 25 mrad is small enough, should be checked for other considered detectors.

- The beam dump for the photon collider is not easy, there is possible approach, detailed study is needed.