SUMMARY OF WORKING GROUP 4: SR AND SHIELDING

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Abstract

In this paper a summary of the work done in Working Group 4, Synchrotron Radiation and Shielding, is presented. A short description of the topics discussed and future issues to be addressed in this field by high energy circular colliders designers is given.

TALKS PRESENTED

The talks presented in WG4 two sessions and summarized in this paper are the following:

1. Monte Carlo Simulations of Synchrotron Radiation for CEPC Vacuum System, by Z. Ma (IHEP);
2. Vacuum System requirements for a HF e+e- Accelerator, by R. Kersevan (CERN);
3. Synchrotron Radiation Effects in the HF Injector, by Y. Papaphilippou (CERN)
4. Electronics shielding in the tunnel, by L. Esposito (CERN);
5. Infrared Synchrotron Methods and Systems for Monitoring and Controlling Particle Beam in Real Time, by M. Maltseva (TENZOR);
6. Lost Particles in the IR and Beam Induced Backgrounds in a Higgs Factory, by M. Boscolo (INFN);
7. Synchrotron Radiation Absorption and Vacuum Issues in the IR, by J. Seeman (SLAC).

VACUUM AND SR

Talks 1 and 2 addressed the impact of the SR on the design of the vacuum system.

CEPC

Radiation protection topics addressed were:

- synchrotron radiation shielding;
- thickness of the main tunnel;
- shielding for straight tunnel, beam dump, collimate station, injection section, maze, duct, shielding doors, RF station, etc…;
- induced radioactivity analysis: cooling water, ventilation air, accelerator component, local shielding concrete, ground water, environmental samples, etc…;
- personal safety interlock system;
- radiation dose monitoring system.

Since there are different radiation thresholds for different operational zones, like inner and outer tunnel, all areas should be clearly defined after the functional structures are determined.

A Monte Carlo simulation of the Synchrotron Radiation (SR) in the CEPC beam pipe has started. A model of the beam pipe similar to the LEP design was assumed for the first calculations (see Figure 1) with two material options: a few millimeters of Al covered by 3 or 8mm of Pb or only a few millimeters of Cu.

A comparison between LEP2 and CEPC SR parameters is shown in Table 1.

Table 1: SR Parameters for CEPC and LEP2

Parameter	CEPC	LEP2
Beam Energy (GeV)	120.	100.
Beam current (mA)	16.6	5.5
Bending radius (m)	6094.	3104.
Power/unit length (W/m)	1305	805
Critical energy (keV)	629.	709.
Bending angle (mrad)	3.17	6.4
Solid angle (μrad)	4.3	5.1

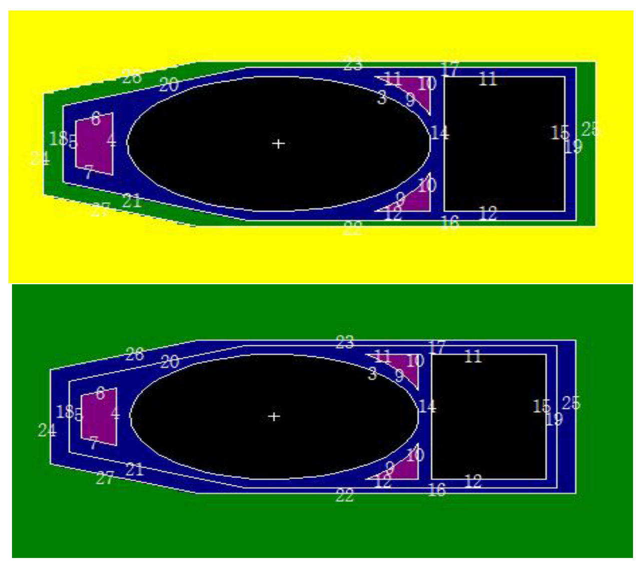

Figure 1: Cross section of the simulated beam pipe, Al&Pb (upper), Cu (lower).

The dose rate in the tunnel for CEPC is mainly dominated by synchrotron radiation. Copper seems to be a good material for beam pipe from the point of radiation protection, but manufacture/price and other points of view

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have to be taken into account before making the final choice.

Detailed simulations have still to be done for reliability verification, actual structure, thermal analysis, etc.

FCC

The requirements on the FCC vacuum systems were presented, such as:

- Beam Physics →Beam-gas lifetime specification
- Lattice →Gap (dipoles) or ID (quads/sextupoles) → cross-section of chambers → specific conductance → Effective pumping speed
- Lattice → Chamber vs. chamber-antechamber analysis
- Distributed vs. discrete SR absorbers
- Distributed vs. discrete pumping
- Outgassing: thermal and SR-induced
- Materials: Al, Cu, SS
- Heat dissipation (SR, Compton-scattered)

To start, for half FCC FODO cell distributed SR fan as a function of localized absorbers were computed (Ray-tracing with SYNRAD+). Photon fan profiles were converted into outgassing profiles via η(mol/ph) and a pressure profile calculation via 3D Monte Carlo code (Molflow+) was performed (see Figure 2).

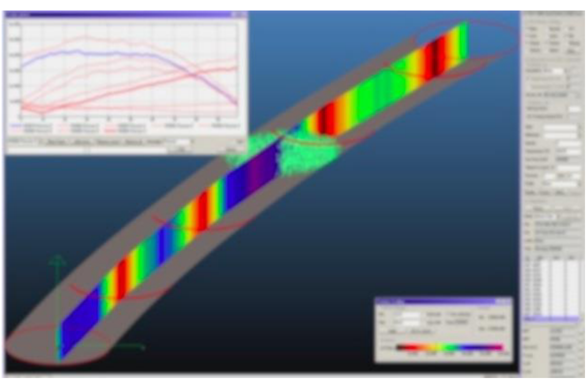

Figure 2: Example of Pressure profile calculation via 3D Monte Carlo code (Molflow+) for an FCCee half-FODO cell.

Some conclusions were presented.

1. Any design of a Higgs Factory with beam energies in the 45~175 GeV range inevitably makes a powerful source of SR.
2. A comprehensive ray-tracing analysis of SR fans is mandatory. Especially for delicate areas, such as IR, SRF, wigglers.
3. A careful choice of vacuum chamber material is needed.
4. The vacuum system geometry and pumping system must be carefully analysed and designed.
5. A special care has to be taken for any cross-sectional changes (tapers), and devices (BPMs, stripline kickers, RF cavities, gate-valves, etc…): proper shielding from SR and cooling for HOMs.
6. The operation of LEP and B-factories, and the design of low-emittance light sources can help a lot in the design of a HF's vacuum system.
7. The chamber vs. chamber/antechamber solutions must be carefully evaluated.
8. The distributed vs. discrete pumping solutions must be carefully evaluated.
9. Low-SEY coatings for e-cloud in the e^+ beam chamber are needed.
10. In-situ bake-out is recommended.

HF INJECTION SYSTEM

A first look at the injector complex and SR losses for FCCee was given in Talk 3. A booster ring of the same size as the collider, hosted in the same tunnel, is needed to provide top-up injection at full energy in the ring/rings. Booster characteristics:

- same size of the RF system, with lower power (~MW),
- top-up frequency of ~0.1 Hz,
- injection energy ~20 GeV,
- long chicanes to bypass the experimental detectors.

A sketch of the injector complex for electron and positrons at 20 GeV is shown in Figure 3.

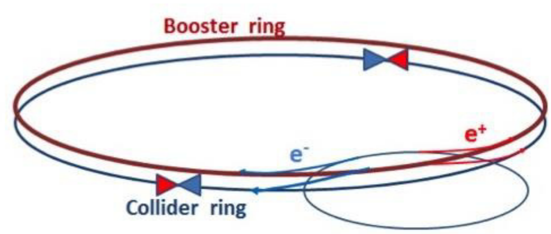

Figure 3: Sketch of the HF injector complex.

Target injector parameters for a Higgs factory, compared to LEP2, are listed in Table 2.

The SR power in the booster ring is much lower than in the collider, but the critical energy is similar: absorbers and shielding are also needed. The vacuum chamber design may become complex: needs for anti-chambers, coatings for SEY reduction and pumping, eddy currents. The pre-injector requirements are similar to a typical electron Linac, but the positron production system needs a careful design for the required yield and associated power deposition (damage) and shielding from radiation.

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Table 2: Injector Parameters for HF Compared to LEP2

Parameter	Z	W	H	tt	LEP2
E (GeV)	45.5	80	120	175	104
I (mA)	1442	151	30	7	1
N. bunches	16700	4490	1360	98	4
Bunch population (10^{11})	1.8	0.7	0.46	1.4	4.2
Lifetime (sec)	298	73	29	21	434
Time between injections (sec)	361.	88.	35	25	263
Injected top-up bunch population (10^{11})	601.2	62.9	12.5	2.7	0.34
Required particle flux for top-up (10^{11}p/sec)	2.1	0.89	0.44	0.13	0.001
Required particle flux for full filling (10^{11}p/sec)	31.3	3.3	0.7	0.1	0.02
Booster injector ramp rate (GeV/sec)	5.2	12.2	20.4	31.6	17.1

TUNNEL SHIELDING

The need for shielding of the detector and accelerator electronics hosted in the tunnel was addressed in Talk 4.

As an example, in the CNGS 2007 run single event upsets in ventilation electronics caused ventilation control failure and interruption of communication (see Figure 4).

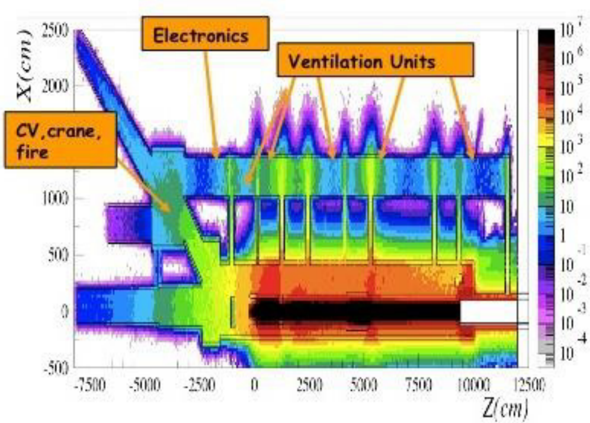

Figure 4: Example of ventilation control failure in CNGS 2007 run due to nuclear cascade.

Profiting of the LHC experience, a project called R2E was setup at CERN to estimate the radiation environment and sources, the effects of radiation on the electronics and the radiation levels for FCCee.

For LHC the sources of radiation are of a different kind:

- direct losses, such as collimators and collimator-like objects, injection, extraction and dump. Their levels scale with the beam intensity;
- collisions losses near the experiments, scale with the luminosity;
- beam-residual gas scattering losses, all around the ring. They scale with both intensity and residual gas density.

For a lepton collider losses are mainly due to the dipole emitted synchrotron radiation, which scales with both intensity and energy.

The total ionizing dose to the electronics has both stochastic (immediate effects such as rupture, bit flip…) and cumulative effects (integration over time, critical for injection lines), which start with performances worsening to finish with electronics and material damage.

The R2E project activities are:

- radiation monitoring,
- calculations,
- test facilities,
- developments,
- radiation tests,
- production and implementation.

As an example, for the LHC selected energy deposition studies were performed, and the agreement between the high energy hadrons flux simulation and the measured one was within 30%. The radiation field in the FCCee tunnel has been computed, including neutrons from photonuclear interactions, see Figure 5.

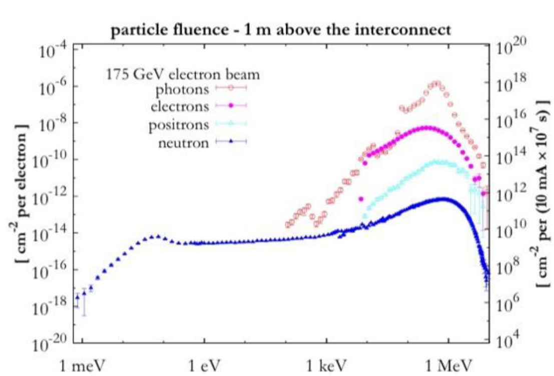

Figure 5: Radiation field in the FCC tunnel.

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Figure 6 shows the total radiation levels in FCCee compared to those of LHC.

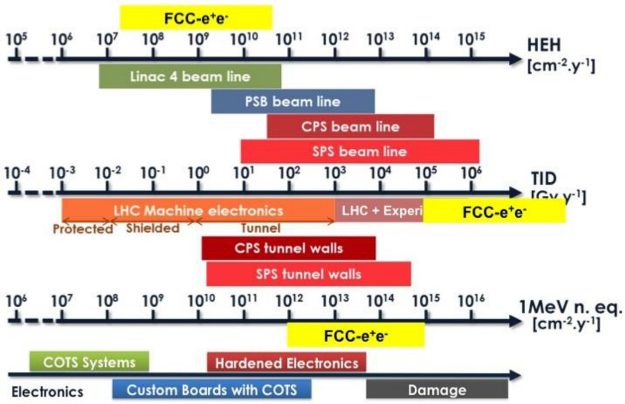

Figure 6: Radiation levels in FCCee compared to LHC.

The radiation to the electronics represents a crucial issue to be taken into account when designing any high energy and intensity machine. The Total Integrated Dose effect has to be mitigated through a carefully shielding design. The R2E project at CERN allowed creating a diffuse knowledge and expertise covering all the aspects of radiation hardening.

DIAGNOSTICS

Talk 5 dealt with the synchrotron radiation diagnostics. It is very important to have:

- non-destructive monitors,
- high resolution IR optical devices,
- wide spectral range,
- distributions of SR power can be calculated,
- use modern devices for IR and ultraviolet,
- computerized opto-electronics (>100 µsec),
- spectrometric detection systems (0.4–40 µm),
- non-cryogenics systems.

Figure 7 shows a typical synchrotron radiation diagnostics device.

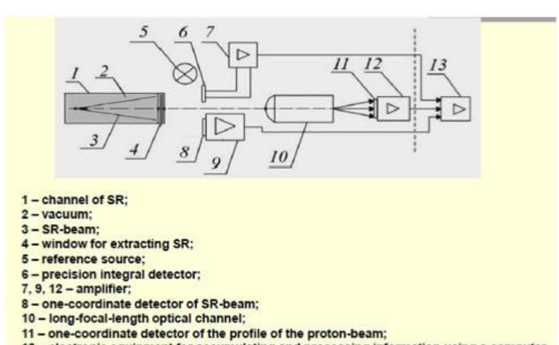

Figure 7: A typical synchrotron radiation diagnostics device.

IR PARTICLE LOSSES AND BACKGROUNDS

The topics of main background sources, such as SR and beam particles effects (beam-beam, Touschek, beam-gas, etc…), were addressed in Talk 6. The design of the Interaction Region (IR) is a critical issue for the achievement of goal performances. This includes a trade-off of the machine and detector constraints, such as physical acceptance, smallest possible beam pipe radius, detector solenoid design with realistic field shaping and compensation, distance of the first quadrupole from the Interaction Point (IP). In this framework, a realistic simulation of all the effects inducing beam backgrounds is essential.

A Monte Carlo simulation tool, already tested at different colliders, is in place to estimate backgrounds from all these different sources, to compute the total beam lifetime and to find the appropriate masks and collimators location, with realistic IR physical aperture. For all estimations the ring energy acceptance is a very important parameter and should be included in lifetime calculations. A preliminary study of Touschek scattering simulation in CEPC IR was done, however the evolution of the IR design needs more iterations. Also radiative Bhabha trajectories in CEPC IR (old version) were computed, as shown in Figure 8. A constant 3cm aperture was assumed everywhere; losses are of course concentrated at high β_x locations.

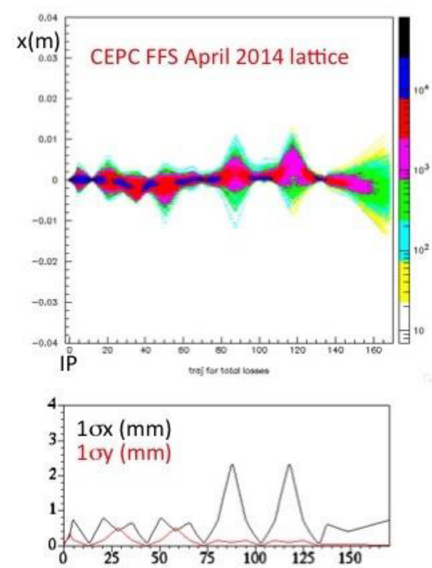

Figure 8: First estimate of CEPC radiative Bhabha trajectories (top) and beam size envelopes (bottom).

For the estimation of the SR in the IR care must be taken in evaluating: the compatibility of the stay clear apertures with an effective masking of the incoming SR, the edge scattering from the upstream SR masks, the backscattering from downstream aperture limitations.

SR ABSORPTION AND VACUUM ISSUES IN THE IR

A discussion of how the SR photons absorption was done in the PEP-II IR vacuum chamber, with the deposited power taken away and the emitted gasses pumped away not to cause beam-gas backgrounds, together with implications for a Higgs Factory, were presented in Talk 7.

The PEP-II IR design was particularly complicated due to the head-on collision of two beams, of very different energies, coming from two rings vertically separated. A permanent magnet (B1) very close to the IP was used to provide early separation of the two beams, but was also producing unwanted SR in the IP region. The design of the beam pipe masking for power absorption, backgrounds and High Order Modes required special care. PEP-II masks are shown in Figure 9.

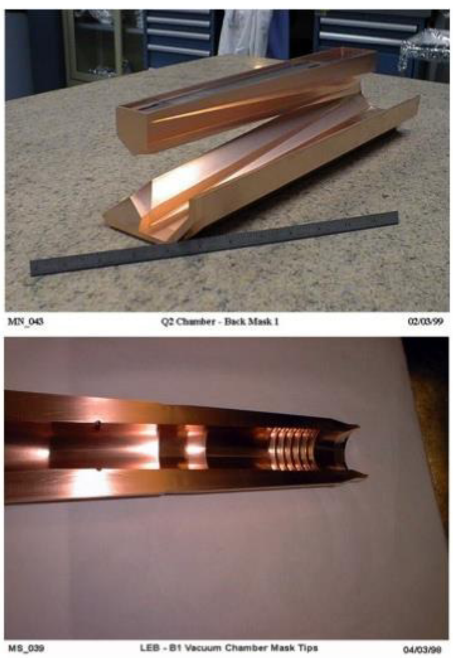

Figure 9: PEP-II IR masks near the Babar detector.

An example of the SR fans in the PEP-II IR of the High Energy Ring (HER) is shown in Figure 10.

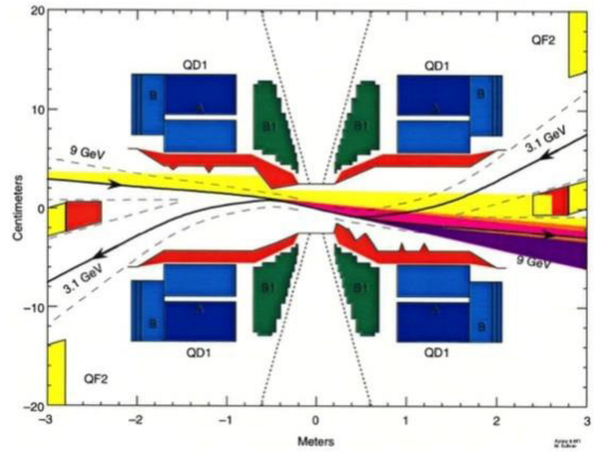

Figure 10: PEP-II IR HER X-rays fans.

CONCLUSIONS

The key future topics for what concerns the SR and shielding in a Higgs Factory were identified:

A. Stabilize the storage ring parameters so that the injector parameters and power losses will stabilize.
B. Carryout the next layer of design of the injector chain.
C. Develop a tunnel design with shafts/cranes/CV etc, to study surrounding radiation effects and electronics shielding.
D. Design a vacuum system for the hard areas: SCRF, injection, IR, wigglers.
E. Need a next layer (realistic) of IR design.
F. Study in detail the SR power lost in the Interaction Region.
G. Develop a vacuum-pumping scheme for the IR.
H. Develop a masking scheme for the detector from x-rays and lost particles.
I. Develop non-destructive diagnostics with wide spectral range and high sensitivity.

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