Summary of the SPL workshop presentation on cryogenics and cryo-modules

U.Wagner, V.Parma

<u>Heat loads and required cryogenic capacities at 2 K</u>

Heat Loads. Recalling the values reported in the "Yellow Book" SPL (3.5 GeV, cryo duty cycle 6%), the 2K heat loads module are presented for the following scenarios at 704 MHz:

1. LP-SPL (4 GeV); cryo duty cycle = 0.4%; nominal
2. LP-SPL (4 GeV); cryo duty cycle = 0.4%; ultimate
3. HP-SPL (5 GeV); cryo duty cycle = 4%; nominal
4. HP-SPL (5 GeV); cryo duty cycle = 4%; ultimate
5. HP-SPL (5 GeV); cryo duty cycle = 8%; nominal
6. HP-SPL (5 GeV); cryo duty cycle = 8%; ultimate

The values of these scenarios were rescaling of the values of the "Yellow Book" based on the new base-line layouts:

- LP-SPL: 160 cavities at β=1, and 42 cavities at β=0.65
- HP-SPL: 200 cavities at β=1, and 42 cavities at β=0.65

and assuming that (though not explicitly mentioned in the talk):

a. $\beta=1 \rightarrow R/Q=570\ \Omega$; $\beta=0.65 \rightarrow R/Q=290\ \Omega$
b. Nominal: $\beta=1 \rightarrow E_{acc}=25$ MV/m; $\beta=0.65 \rightarrow E_{acc}=19$ MV/m; Qo=1·10^10
c. Ultimate: $\beta=1 \rightarrow E_{acc}=27.5$ MV/m; $\beta=0.65 \rightarrow E_{acc}=20.9$ MV/m ; Qo=0.5·10^10
d. Active cavity length of 1.064 m
e. proportional dependence with cryo duty factor

Focusing on the scenario giving the highest loads (HP-SPL β=1 modules at 8% duty cycle and in ultimate operation), the total heat load per cavity at 2 K is 37 W (or 19.5 W/m on cryomodule length), therefore about 30% higher than the "Yellow Book" figures (28 W/cavity, or 2.15 W/m on cryomodule length).
Just for comparison with the values of ILC, reported in the 2007 ILC *Reference Design Report* , the highest heat loads of the HP-SPL cavities are about 20 times those of the ILC cavities. It should be underlined that the ILC report does not mention an ultimate operation scenario and that this scenario more than doubles the cavity heat loads in SPL.

Converting total heat loads into installed cryogenic capacity by using the formula:

$$Q_{installed} = \max\{1.5\cdot(1.5\cdot Q_{st}+Q_{dyn.nom.});\ 1\cdot(1.5\cdot Q_{st}+Q_{dyn.ult})\}$$

applied for each temperature level, the resulting 4.5K equivalent installed capacity for the HP-SPL is 27.8 kW, which is 76% higher than the "Yellow Book", but still remains in the range of existing state-of-the-art cryogenic plants. However, the meaningfulness of an ultimate mode, which more than doubles the heat loads, should be discussed.

Heat loads and required cryogenic capacities at 4.5 K

Making the assumption (based from values in literature, for example Sang-ho Kim & I.Campisi, papers on SNS) that moving to 4.5K increases heat loads by a factor of 10, and calculating the required heat capacities for the scenarios listed above, yields the following values for LP and HP SPL (and compared to 2K values):

	T operation	Equiv. capacity at 4.5 K	El. power	Refrigerator cost
	[K]	[kW]	[MW]	[MCHF]
LP SPL	2.0	4.8	1.3	7.5
LP SPL	4.5	9.1	2.5	9.5

	T operation	Equiv. capacity at 4.5 K	El. power	Refrigerator cost
	[K]	[kW]	[MW]	[MCHF]
Yellow Book	2.0	15.8	4.0	15.0
HP SPL 4% duty	2.0	15.8	4.0	15.0
HP SPL 4% duty	4.5	47.2	10.3	24.2
HP SPL 8% duty	2.0	27.8	6.5	21.2
HP SPL 8% duty	4.5	88.0	18.6	35.2

The required installed capacities for LP SPL remain within reasonable values (9 kW) but HP SPL 4.5K scenarios, even when running at 4% duct cycle, are extremely high (47 kW and above) requiring multiple large cryo plants (2x25 kW and above) probably unfeasible in terms of space and utilities demand (electricity, cooling water…).

Cryogenic schemes and hardware implications

The general cryogenic layout of the Yellow Book (3 cryo string, 1 for low beta and 2 for high beta) still remains a viable option. The same cryogenic scheme adopted for ILC may be used though the implications of the slope in terms of helium flow in the bi-phase need to be studied, but not more than this needs to be investigated for a laser-straight ILC.

Since SPL is a much shorter machine as compared to ILC/XFEL, other schemes requiring more control equipment (helium filling and level control on each module for example) could be considered.
Operating at 4.5 K in saturated pool boiling would offer the advantage of being at a higher pressure than atmospheric (1.3 bars), thus limiting helium contamination due to air leaks. But operating in boiling regime requires venting of helium vapor bubbles from the uppermost point of all closed envelopes. This would require a specific design of helium vessels, considerably different from ILC/XFEL designs.
Preliminary sizing of the gas return pipe indicates that for all scenarios of the HP SPL, in order to pump the large mass flows of vapors with a limited pressure difference along the entire length of the machine (~500m), an inner diameter of 250 mm or more is needed.
The experience of ILC and XFEL in the design of modules and cryogenics is certainly to be exploited, but the possible reuse of hardware from XFEL is limited to the vacuum vessel. At this stage of the SPL study, however, it is recommended not to restrict the design to the design constraints of XFEL equipment.

<u>Conclusions</u>

- Under the assumption of the heat load extrapolation at 4.5K, due to the large cryogenic capacity requirements, operating at lower temperature (around 2K ?) seems the only viable option;
- HP SPL at 2K at 4% is consistent, in terms of cryogenics, with the study of the Yellow Book; operating at 8% requires further investigation;
- LP SPL at 4.5 K could also be pursued, but is it an interesting option?
- Module design experience from XFEL/ILC should be exploited, but it is felt that at this stage of the study, adopting existing hardware designs is premature for SPL.