Thermal Analysis of the Beryllium Beampipe at Interaction Point 6 of the Electron Ion Collider

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This note presents the results of the computational fluid dynamics thermal analysis of the beryllium beampipe at Interaction Point 6 (IP6) of the Electron Ion Collider, performed using Ansys Fluid Flow Fluent software. The analysis determines for the first silicon layer's (L1's) temperature function $L1_T(\Delta r, T_a, v)$, the values of the radial separation between L1 and the beampipe (annulus) Δr, the ambient air temperature T_a, and the ambient air flow rate in the annulus v, for which $L1_T(\Delta r, T_a, v)$ is less than 50°C, when the beampipe is at 100°C.

The beryllium beampipe at IP6 will be heated to 100°C to remove contaminants. L1, which surrounds the beampipe, is to be located as close as possible to the beampipe to achieve the required vertex resolution [1]. Because of L1's proximity to the beampipe, L1's temperature $L1_T$ will increase, which if above ~50°C, could damage L1. Figure 1 shows the layout of the silicon detector around the beampipe.

The Ansys simulation model [2] comprises the beryllium beampipe, L1, and an enclosure, Fig. 2 and Table I. The enclosure volume was created as a fluid domain to control the ambient air temperature surrounding the model. Table II shows the material and thermal properties of the components of the model. Materials, domains (fluid or solid) for components, and boundary conditions for analysis were set up with Ansys Fluid Flow Fluent software.

For the simulations, the beampipe's inner face was set at 100°C. The viscous, k-omega, shear stress transport equation option was used. The input and output airflow directions in the annulus and the enclosure for heat transfer by forced convection is shown in Fig. 3.

Since $L1_T$ is a function of $(\Delta r, T_a, v)$, simulations were performed for combinations of $\Delta r \in$ [1.24, 2, 3, 4, and 5 mm], $T_a \in$ [14, 16, 18, and 20°C], and $v \in$ [0, 1, 5, 8, 10 and 20 m/s].

Figure 4 shows $L1_T$ vs. v for the model with $\Delta r = 5$ mm. As v increases, $L1_T$ decreases; for $v > 4$ m/s, $L1_T < 50$°C for all ambient temperatures considered.

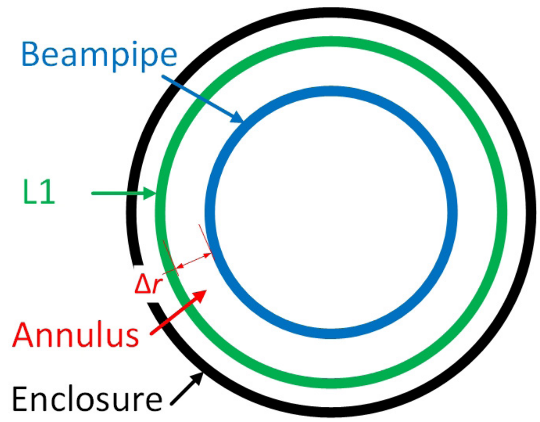

FIG. 2. Locations of beryllium beampipe, L1, annulus, and enclosure.

Part name	ID [mm]	OD [mm]	Thickness [mm]	Length [mm]
Beryllium beampipe	62	63.52	0.76	1470.0
L1	66	66.08	0.04	320.5
Enclosure	200			320.5

TABLE I. Model dimensions.

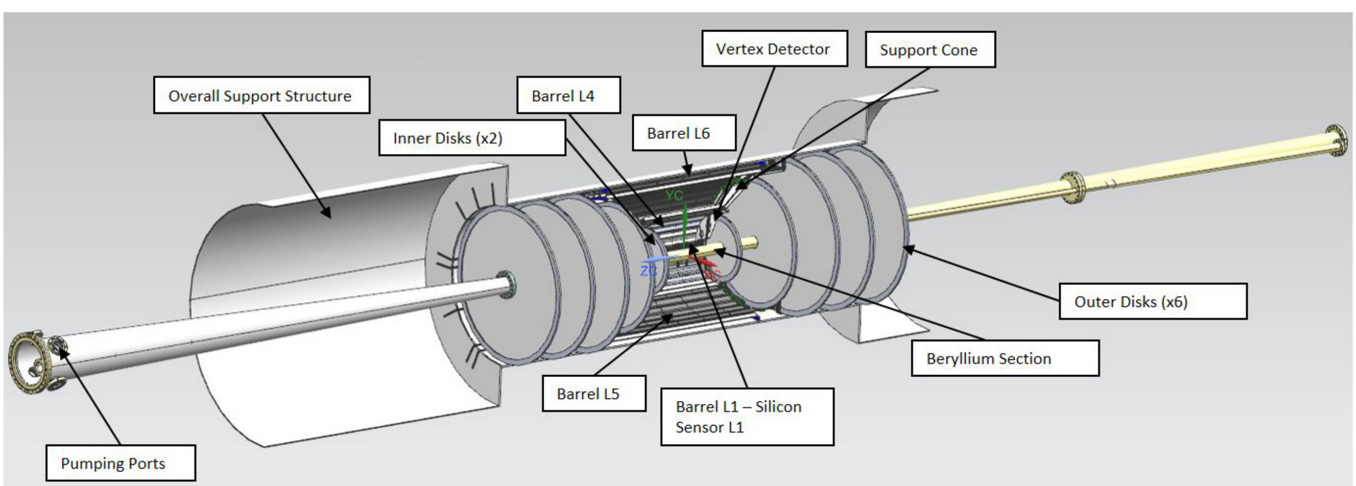

FIG. 1. Conceptual design of the detectors at IP6.

Component	Material	Density [Kg/m3]	Specific heat [J/KgK]	Thermal conductivity [W/mK]
Beryllium pipe	beryllium	1850	1825	190
L1	silicon	2330	700	148
Annulus and enclosure	air	1.225	1006.43	0.0242

TABLE II. Model material properties.

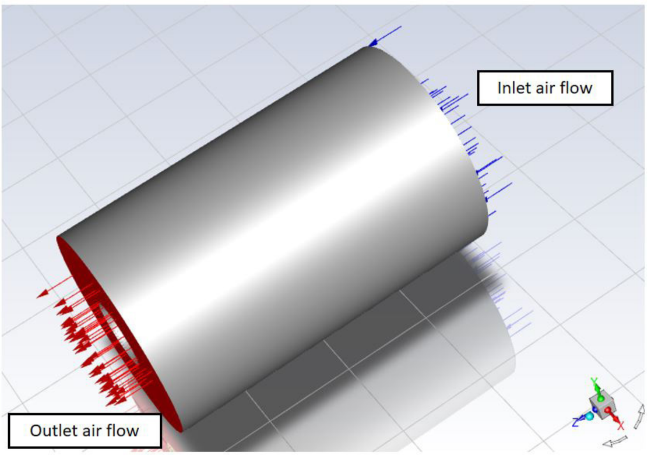

FIG. 3. Red arrows represent output air flow, blue arrows input air flow.

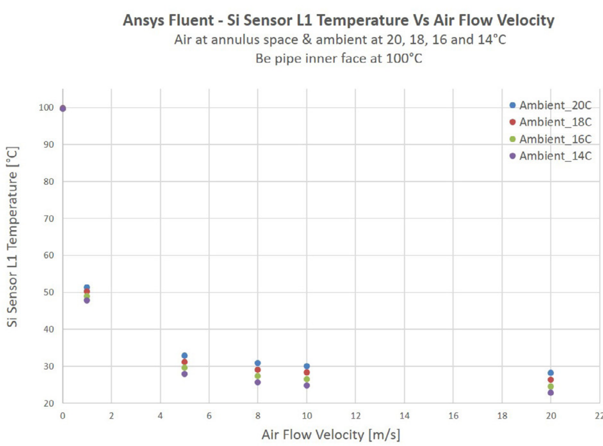

FIG. 4. $L1_T$ vs. v; Δr = 5 mm.

Figures 5, 6, and 7 are plots of $L1_T(\Delta r, T_a, v)$, in which one variable is constant and the other two are varied.

To conclude, analysis indicates that there are several 3-tuple combinations of $(\Delta r, T_a, v)$ that satisfy $L1_T(\Delta r, T_a, v) < 50$°C. However, when the assembly of L1, the ambient air temperature, and a low flow velocity is taken into consideration, the appropriate values for $(\Delta r, T_a, v)$ seem to be (5 mm, 20°C, 5 m/s); with these values, $L1_T$(5 mm, 20°C, 5 m/s) is ~30°C.

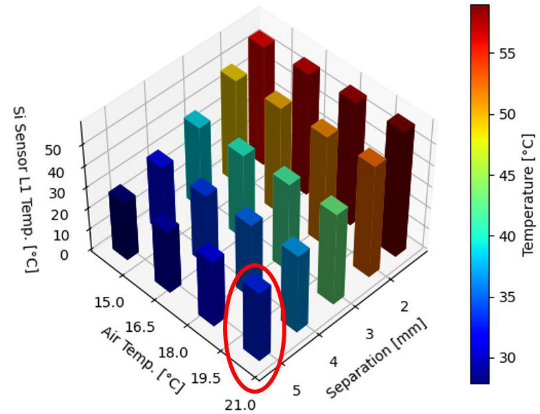

FIG. 5. 3D bar plot of $L1_T(\Delta r, T_a \mid v = 5$ m/s). Red loop indicates $L1_T$(5 mm, 20°C |v =5 m/s) ≈30°C.

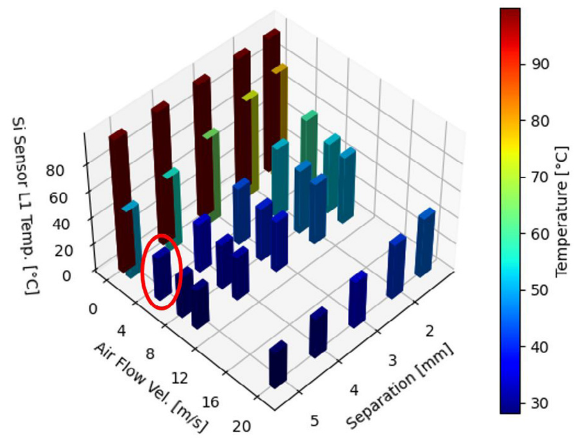

FIG. 6. 3D bar plot of $L1_T(\Delta r, v \mid T_a = 20$°C). Red loop indicates $L1_T$(5 mm, 5 m/s $|T_a$ = 20°C) ≈30°C.

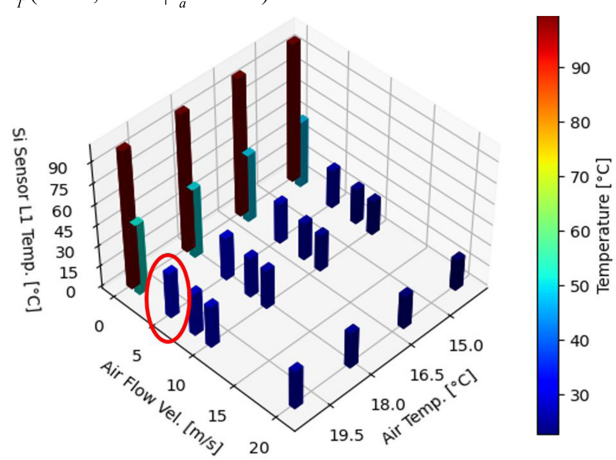

FIG. 7. 3D bar plot of $L1_T(T_a, v \mid \Delta r = 5$ mm). Red loop indicates $L1_T$(20°C, 5 m/s | Δr = 5 mm) ≈30°C.

[1] W. Akers, et al., *Electron Ion Collider Conceptual Design Report Experimental Equipment*, November 2020.
[2] P. Campero, et al. *EIC –Thermal Analysis of Beryllium Section of Beampipe*, DSG Talk 2022-13, June 2022.