CLIC Vertex Detector Mechanics

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Design Motivations

- Goal: Identify heavy-flavour quark states and tau-leptons with high efficiency
- To do that: Measure impact parameter point and the charge of tracks originating from the secondary vertex.
- Simulations show that can be accomplished with a single-point resolution ~3 μm and a material budget of $X/X0 < 0.2\%$ for the beam pipe and for each of the detector layers.
- $X/X0 = 0.2\%$ corresponds to equivalent silicon and beryllium thicknesses of 187 μm and 706 μm, respectively.
- A single-point resolution of ~3 μm can be achieved with 20 μm x 20 μm pixels using an analogue signal readout.
- The goal of the mechanical design is to provide a structure which ensures that sensor positions are known with a precision small in comparison with 3 μm, and for which material contributions from readout, cabling, signal communications, and cooling are acceptable.
- Ultimately, physics performance is determined by geometry, the point resolution of sensors, and the amount of material.

Considerations

- At least twelve factors should be considered in the vertex detector mechanical design:
    - Vertex detector geometry
    - Integration with the beam pipe
    - Integration with the tracker and other sub-detectors
    - Ease of fabrication and assembly
    - Sensor tiling
    - Precision of assembly
    - Stability of support
    - Heat removal
    - Material contributions
    - Power delivery
    - Cabling
    - Servicing
- Only a few of these considerations will be discussed in this talk.
- However, linkages exist among many of them and should not be forgotten or neglected.

Vertex Detector CDR Parameters

- CDR parameters are summarized below.

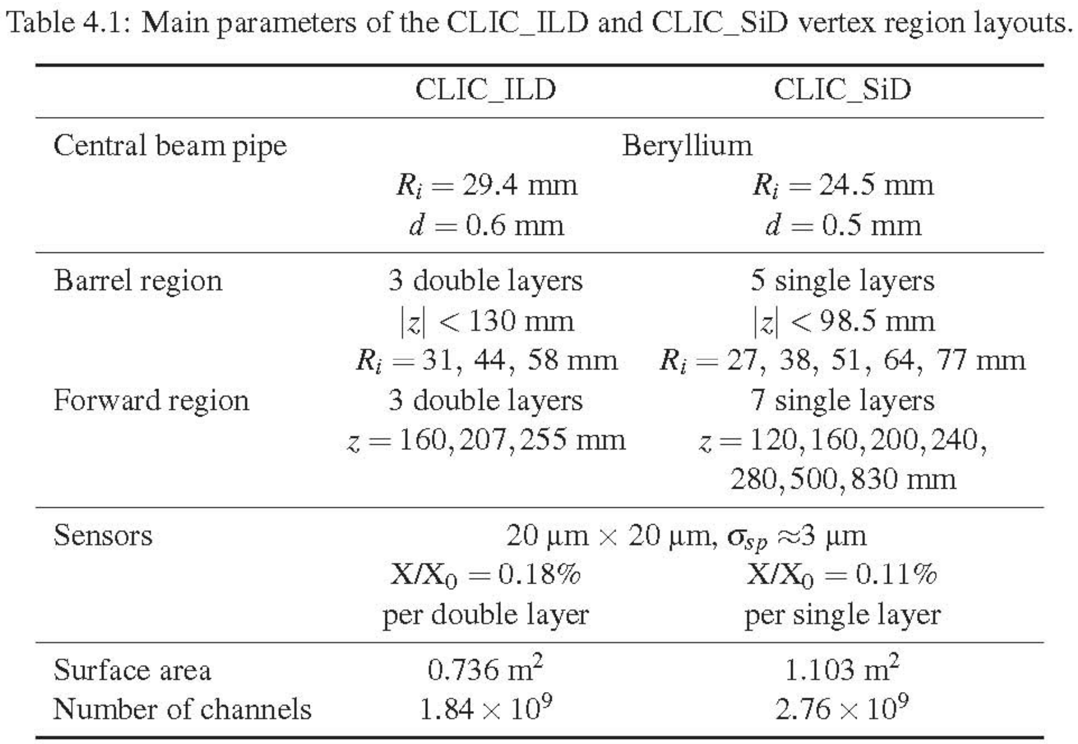


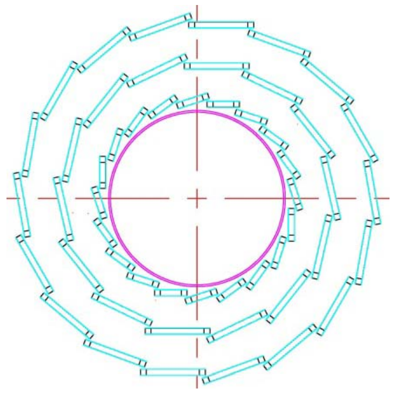
Table 4.1: Main parameters of the CLIC_ILD and CLIC_SiD vertex region layouts.

	CLIC_ILD	CLIC_SiD
Central beam pipe	Beryllium	
	$R_i = 29.4$ mm	$R_i = 24.5$ mm
	$d = 0.6$ mm	$d = 0.5$ mm
Barrel region	3 double layers	5 single layers
	$\lvert z\rvert < 130$ mm	$\lvert z\rvert < 98.5$ mm
	$R_i = 31,\ 44,\ 58$ mm	$R_i = 27,\ 38,\ 51,\ 64,\ 77$ mm
Forward region	3 double layers	7 single layers
	$z = 160, 207, 255$ mm	$z = 120, 160, 200, 240,$ $280, 500, 830$ mm
Sensors	20 µm × 20 µm, $\sigma_{sp} \approx 3$ µm	
	$X/X_0 = 0.18\%$ per double layer	$X/X_0 = 0.11\%$ per single layer
Surface area	0.736 m^2	1.103 m^2
Number of channels	1.84×10^9	2.76×10^9

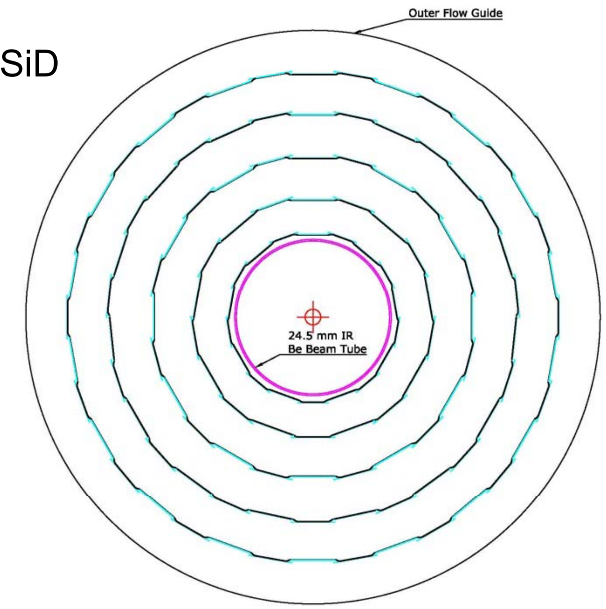
Geometry

- End views of layouts under consideration for CLIC_ILD and CLIC_SiD are shown below. Naturally, features found to work well in one concept could be adopted for the other.
  - CLIC_ILD assumes a “spiral” geometry. Sensors are supported by a foam (SiC) core. Depending on location, ladders may have sensors on both core surfaces or on only one surface.
  - CLIC_SiD assumes an A- and B-layer geometry. Sensors may be supported from carbon fiber half-cylinders or glued together to form half-cylinders.
  - In both cases, end rings assist in maintaining out-of-round stiffness.

CLIC_ILD

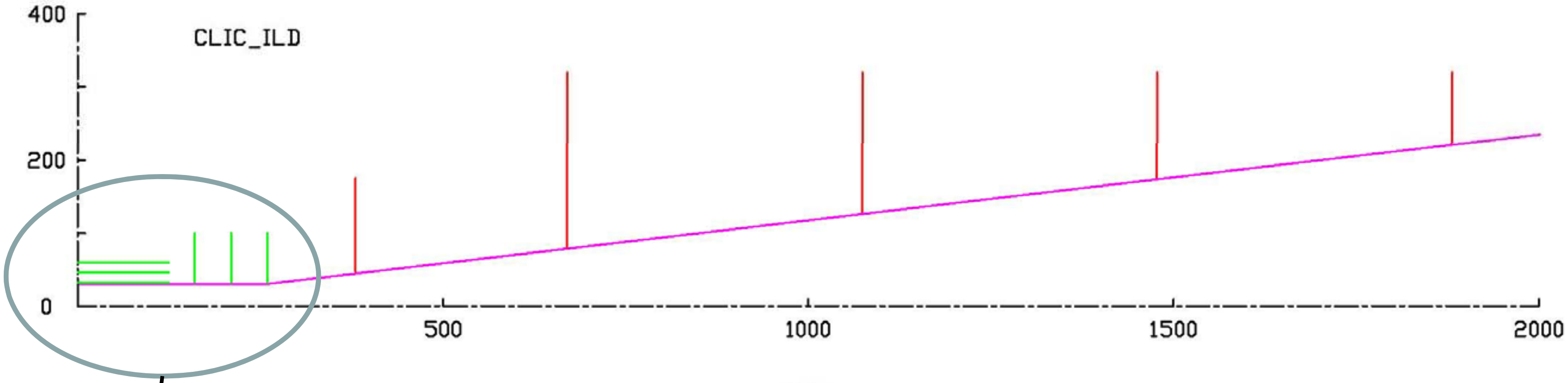


CLIC_SiD

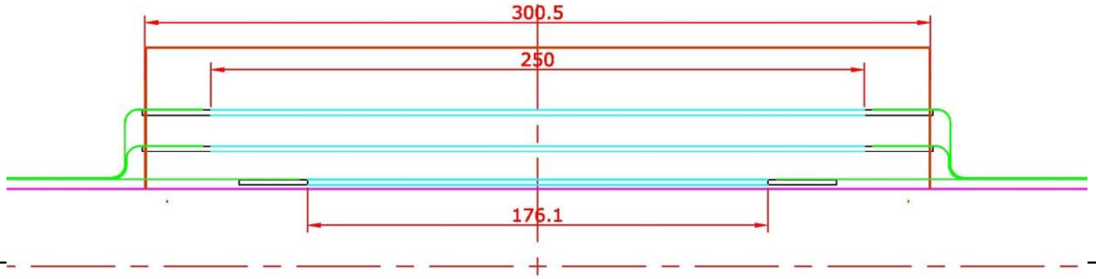


Side Elevations

- The CLIC_ILD vertex detector assumes a central barrel supplemented by forward / backward disks.
- A side elevation and a snapshot of an evolving approach for the ILD barrel from the PLUME collaboration are shown.
  - The innermost layer is mounted on the beam pipe.
  - The outer two layers are supported from beryllium end disks which are tied to one another by a beryllium outer cylinder.
  - Cabling is gathered on the beam pipe.

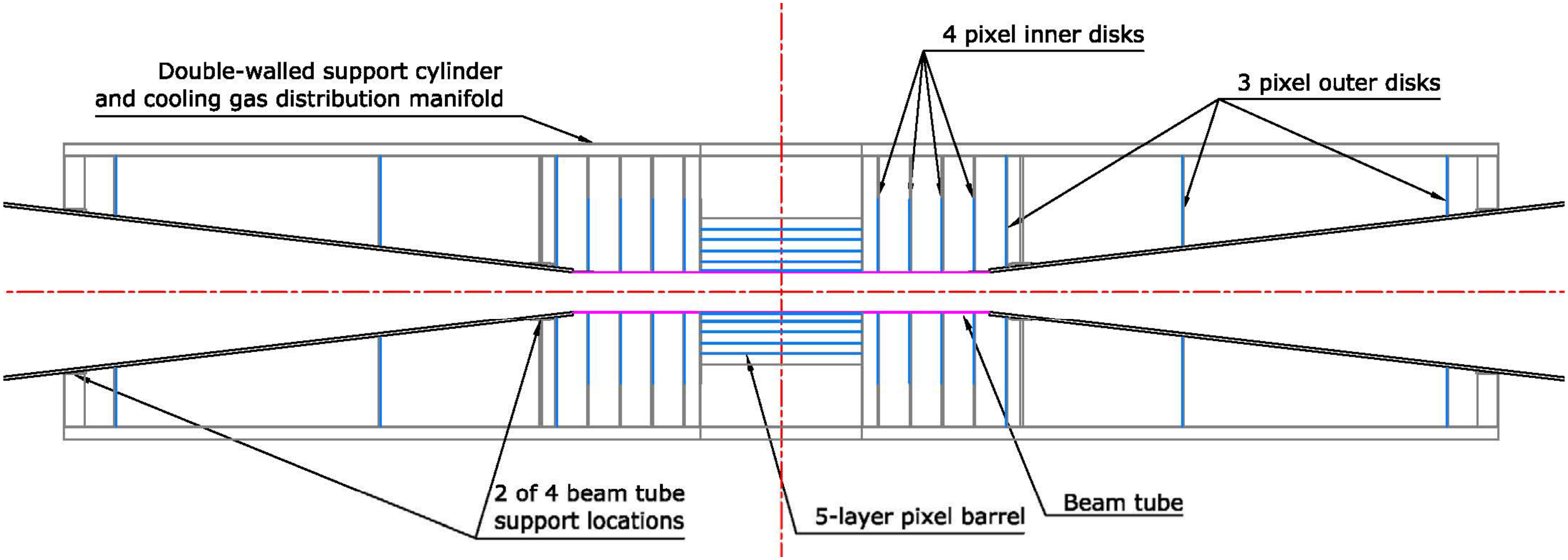


Vertex detector



Side Elevations

- A side elevation of CLIC_SiD is shown below.
- The length of the central barrel is 197 mm, shorter than CLIC_ILD.
- The beam pipe supports the vertex detector outer support cylinder.
- The support cylinder holds the central portion of the beam pipe straight.
- Maximum deflection of the structure / beam pipe was 75 µm for SiD.
  - The deflection needs to be checked for CLIC_SiD.

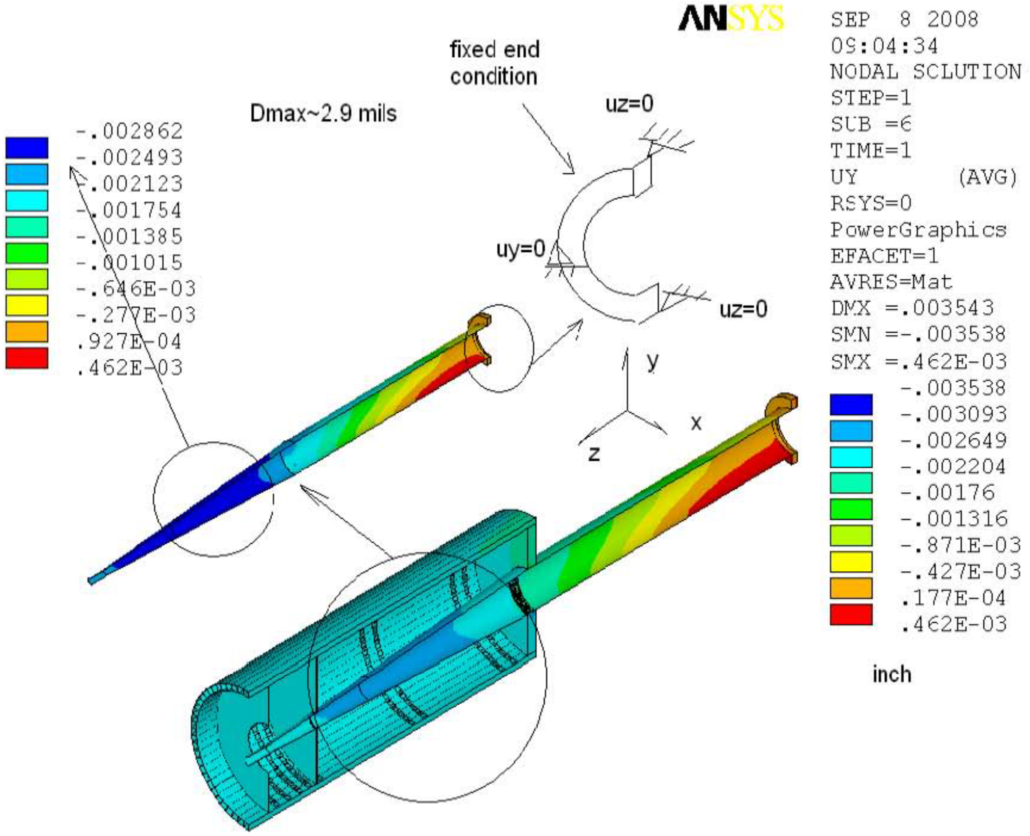


SiD FEA

Beam Pipe + Exoskelton

(Deflection due the vacuum load+gravity for a fixed support)

- "Fixed supported (uy=0 at 0/180 degree and uz=90/-90 degree)
- 0/45/45/90/90/45/-45/0 for outer/inner/silicon disk
- 0/90/90/0 for the front/back /rib

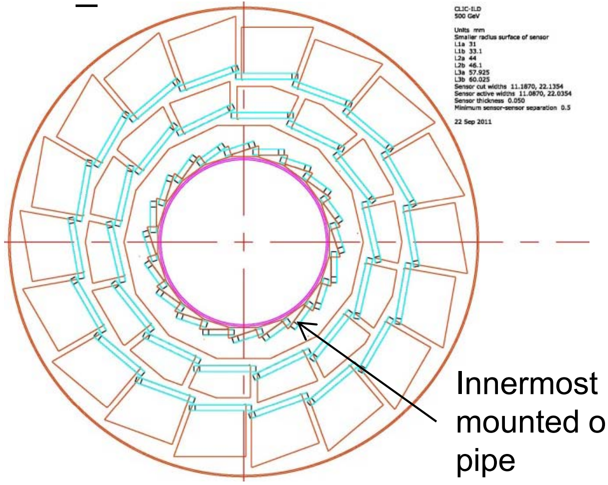


9/11/2008 A. Lee

Barrel end views

- In CLIC_SiD, VTX structures are built as top and bottom halves.
  - End support disks join layers to form a half-barrel.
  - Allows installation around the beam pipe and removal for servicing
- In CLIC_ILD, ladders are inserted as units through end support disks.

CLIC_ILD



CLIC-ILD
500 GeV

Units mm
Smaller radius surface of sensor
L1a 31
L1b 33.1
L2a 44
L2b 46.1
L3a 57.925
L3b 60.025
Sensor cut widths 11.1870, 22.1354
Sensor active widths 11.0870, 22.0354
Sensor thickness 0.050
Minimum sensor-sensor separation 0.5

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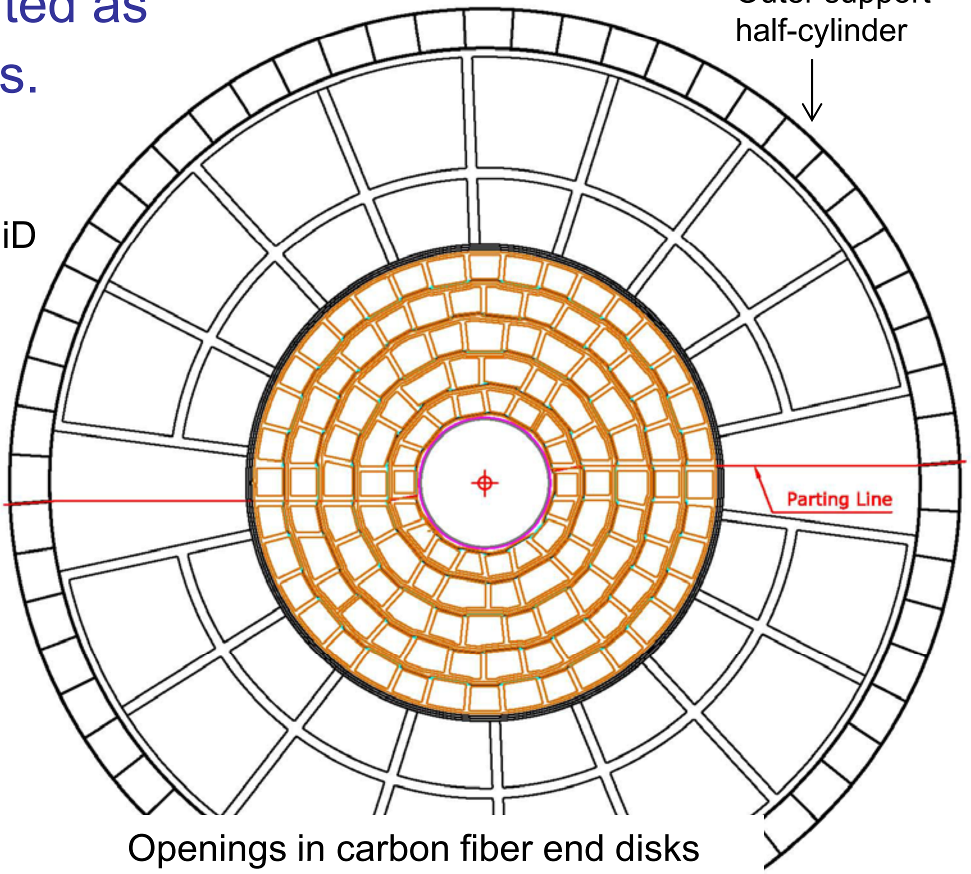
Innermost layer mounted on beam pipe

Openings in beryllium end disks need to be large enough to allow ladders to be inserted and cables and gas to pass.

CLIC_SiD



Outer support half-cylinder

Openings in carbon fiber end disks need to be large enough to allow cables and gas to pass.

Cooling

- To satisfy radiation length requirements, gas cooling is assumed wherever practical.

CLIC_ILD, 0.05 W/cm^2
$A_{sensors}$ = 0.736 m^2
$P_{sensors}$ = 368 W
Flow for 3^{o}C $\Delta T_{air} \approx$ 0.10 m^3/s

CLIC_SiD , 0.05 W/cm^2
$A_{sensors}$ = 1.103 m^2
$P_{sensors}$ = 552 W
Flow for 3^{o}C $\Delta T_{air} \approx$ 0.15 m^3/s

- Cooling for the disks needs attention.
  - Supplemental cooling may be needed if sensor power dissipations are too large.
- End-to-end gas flow is assumed for the central barrel and has been evaluated for power dissipations ranging from 0.013 to 0.13 W/cm^2.
  - Calculated results with a power dissipation of 0.05 W/cm^2 will be shown.
  - These calculated results will need to be confirmed by measurements.
  - Please see the talk that follows.
- Heat can be removed from both surfaces of a barrel module provided module structures have sufficient thermal conductance.
  - For the same power dissipation per sensor, the heat to be removed via a given gas flow path is effectively doubled if both module surfaces are populated with sensors.

Barrel Cooling with Gas

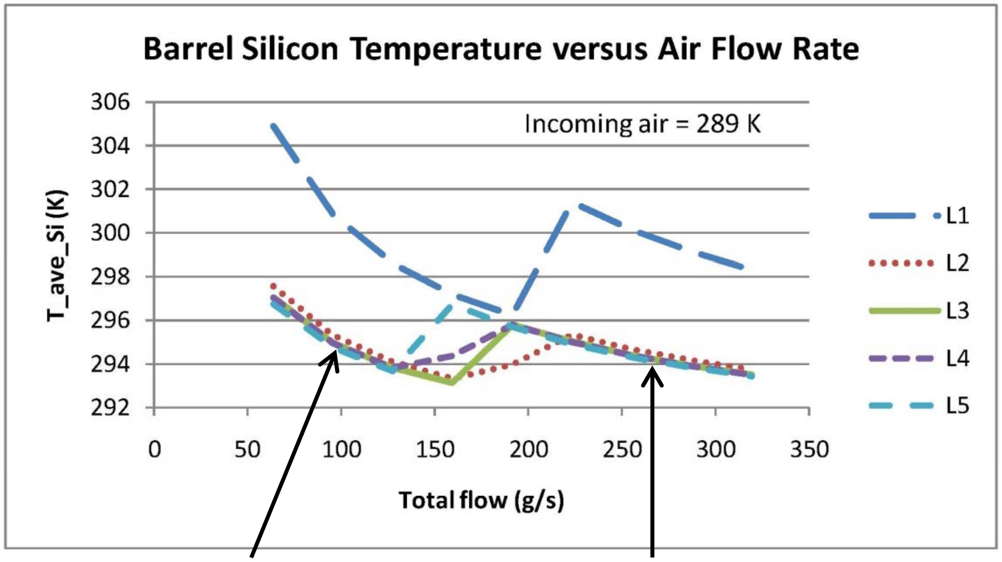
- The end-to-end pressure difference and the rate of heat removal from a surface depend on whether gas flow is laminar or turbulent.
- For laminar flow through a round tube, flow is azimuthally symmetric and follows a parabolic profile with the highest flow velocity at the tube center.
  - The standard assumption is that flow velocity at the tube wall is 0.
  - At other radial locations, the flow velocity depends on gas viscosity and the associated friction.
- This picture breaks down at higher Reynold's numbers, for which flow becomes turbulent.
- The bulk velocity (the average velocity) is normally used to characterize the flow rate in either flow regime.
- Many of us are familiar with calculations of pressure drop and other fluid flow parameters.
- For that, the laminar to turbulent transition is normally assumed to occur between a Reynold's number of 2300 and a Reynold's number of 3000.
- For heat flow, the effects of the transition occur at higher Reynold's numbers.

Barrel Cooling with Gas

- To estimate what can be expected, a flow rate through one possible flow passage was chosen.
- Then flow rates through other passages were adjusted to obtain the same end-to-end pressure difference.
  - This assumption is reasonable, but isn't quite correct, since some pressure difference occurs from one barrel layer to the next.
- Once flow rates through the various possible passages were determined, heat transfer coefficients from each surface to air were calculated.
- Temperature rise of the gas was obtained assuming constant heat input per unit surface area and the calculated heat transfer coefficients.
- Contributions from heat conduction along the length of sensors were assumed to be negligible.

Barrel Cooling with Gas

- Calculated results for the CLIC_SiD geometry are shown below.
- The effects of transitions from the laminar to the turbulent heat transfer regime can be clearly seen.

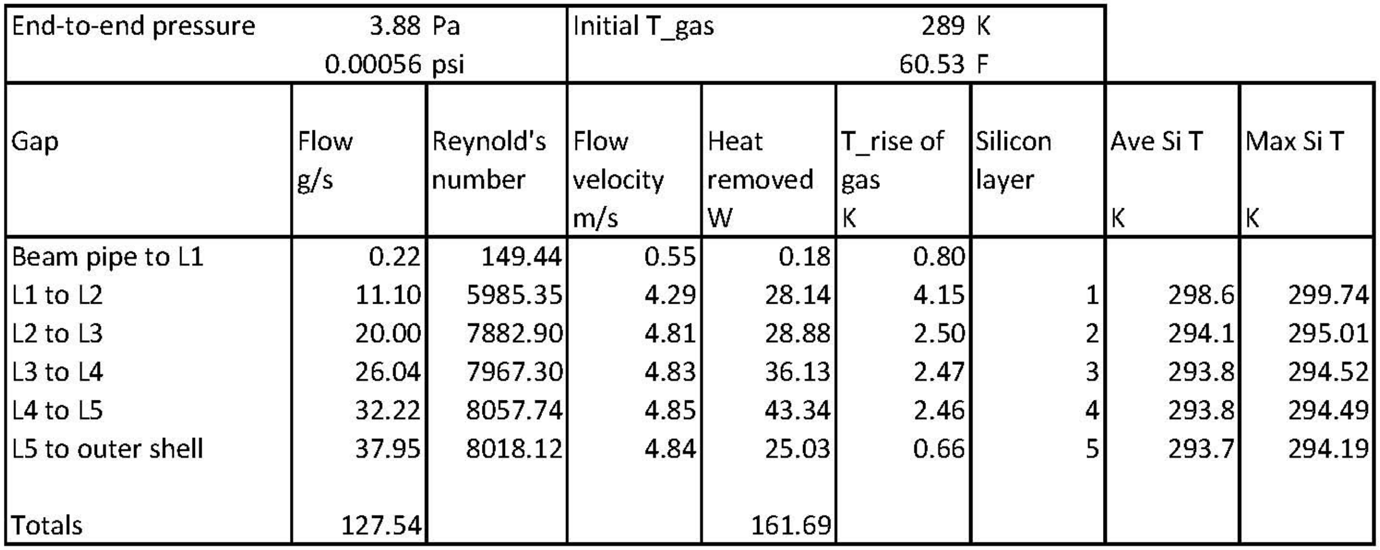


Laminar-like heat removal Turbulent-like heat removal

- The laminar to turbulent transition is normally avoided.
- Because the flow area is so small, little flow occurs between the inner surface of L1 and the beam pipe.
  - Almost all the L1 heat is removed from its outer surface, which leads to higher temperatures.
- We may wish to provide a lower incoming gas temperature.

Barrel Cooling with Gas

- Representative results for the CLIC_SiD geometry are shown.
- Reminder: for these Reynold’s numbers, fluid flow would be characterized as turbulent for all but the region between L1 and the beam pipe.
  - Heat conduction is still laminar-like.
- Flow velocities are moderately high to limit the differences between sensor temperatures and air temperature.
  - This appears to be a necessary consequence of allowing so large a power dissipation per unit area.



End-to-end pressure	3.88	Pa	Initial T_gas	289	K
	0.00056	psi		60.53	F

Gap	Flow g/s	Reynold's number	Flow velocity m/s	Heat removed W	T_rise of gas K	Silicon layer	Ave Si T K	Max Si T K
Beam pipe to L1	0.22	149.44	0.55	0.18	0.80			
L1 to L2	11.10	5985.35	4.29	28.14	4.15	1	298.6	299.74
L2 to L3	20.00	7882.90	4.81	28.88	2.50	2	294.1	295.01
L3 to L4	26.04	7967.30	4.83	36.13	2.47	3	293.8	294.52
L4 to L5	32.22	8057.74	4.85	43.34	2.46	4	293.8	294.49
L5 to outer shell	37.95	8018.12	4.84	25.03	0.66	5	293.7	294.19
Totals	127.54			161.69				

Power delivery

- Pulsed power is assumed to reduce average power consumption to a level compatible with air cooling.
- Beam structures of both CLIC and ILC are consistent with a power reduction factor of 100.
  - Some of the time that would be available goes towards ramp up/down.
  - The rep rate of 50 Hz for CLIC versus 5 Hz for ILC requires that ramp up occur more quickly.
- In the ideal world, power pulsing would occur at the sensor.
  - Then filter capacitors near the sensor could remain charged throughout the power cycle and ramp-up time could be short.
  - This would place additional circuitry on or near the sensors, where material is the greatest issue.
  - An arrangement for serially powering sensors may be possible but would also require additional elements to control the bypass of current.
- DC-DC conversion allows material contributions of upstream cable conductors and total power dissipation to be reduced.
  - The goals are a DC-DC conversion efficiency of 80% and a voltage reduction factor of ~8 to 10.
  - Compromises will be needed between the material of converters, the material of cables, and total power to be removed.

Vibrations

- Vibrations from pulsed power in a magnetic field are a concern.
  - Testing is planned of both DC-DC conversion and pulsed power in a magnetic field (Yale University and collaborators).
- Vibrations may also occur from cooling air flow, either directly or via motions of cabling.
  - Those will need to be checked.
  - We also need to verify that cabling and support infrastructure don’t impede cooling gas flow too much.

Beryllium beam pipe

- The central portion of beam pipe is intended to be made of beryllium.
- The required wall thickness is set by beryllium porosity, vacuum collapse, and fabrication techniques.

CLIC_ILD
IR = 29.4 mm
Wall thickness = 0.6 mm

CLIC_SiD
IR = 24.5 mm
Wall thickness = 0.5 mm

- Porosity can become an issue for a wall thickness ≤ 0.5 mm.
- Vacuum collapse depends on the roundness of the pipe, the extent to which its ends are held round, and moments and forces exerted on its ends.
  - For pipes made by boring billet, roundness can be controlled very well.
  - That technique has been demonstrated in beryllium pipes up to 0.75 m in length with an IR = 14.7 mm and wall thickness of 0.51 mm (CDF and D0 Run IIb). Wall thickness was driven by porosity.
  - A “rolled” beryllium pipe of IR = 18.5 mm and wall thickness 0.51 mm was used in D0 Run IIa.
  - The larger radii needed for CLIC are expected to primarily affect cost.
- Moments applied to the beryllium pipe must be limited.

Issues affecting vertex mechanics

- Sensor development, tiling, and heat removal remain major issues.
  - Many groups are working to on sensors which can meet heat removal and material budgets.
- The PLUME group has continued work that was begun by LCFI and Japanese groups on ladder concepts, materials, stability with temperature change, fabrication methods, and measurement of heat removal. Progress has been very good.
- Overall support structures are understood in principle, but test structures should be built.
- Power delivery has been receiving reasonable attention: that needs to continue.
- Many aspects of the disks need attention - from mechanical support to sensor tiling to heat removal.
- Cabling and cooling gas delivery systems should not be forgotten.
- In summary, the CLIC CDR provides a good description of what is needed and indicates the details that will need attention.

- Thank you!