Latest News on Cooling the SSD

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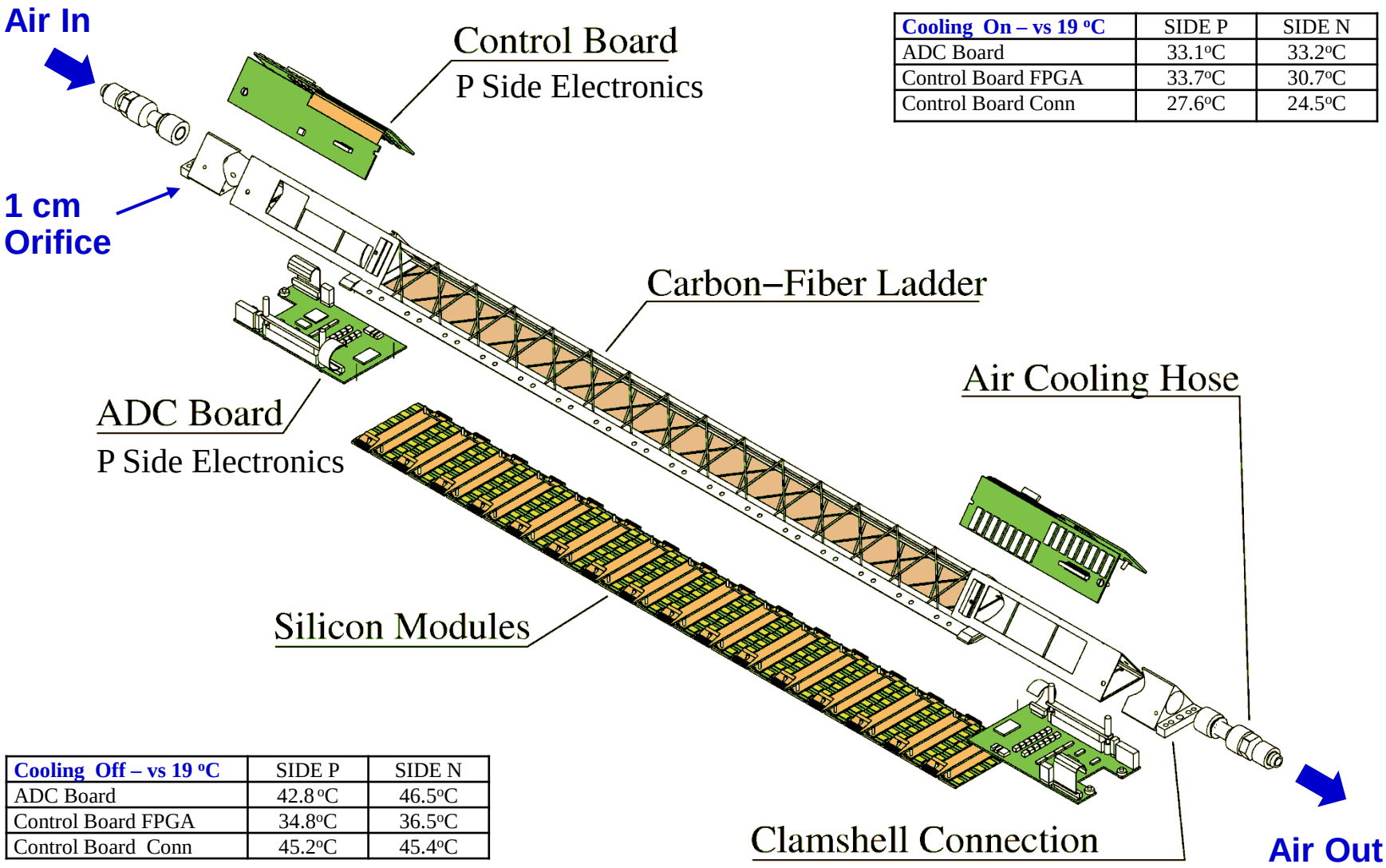
The SSD is air cooled – (tables show 2002 test results)

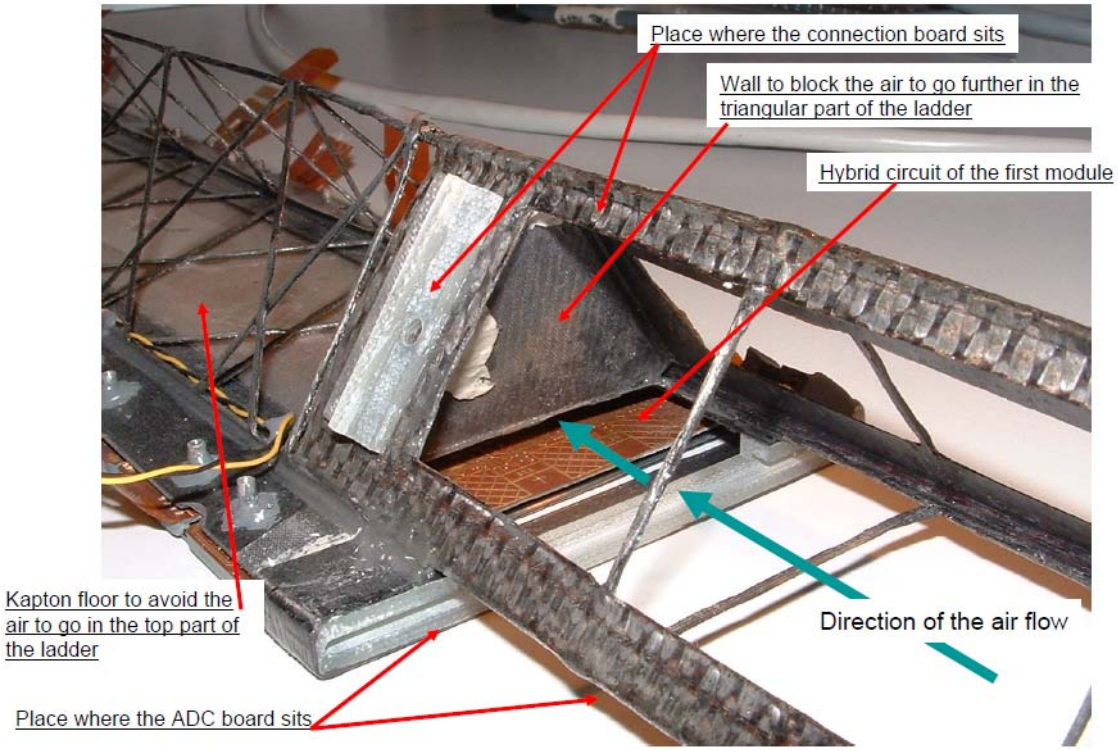


Cooling On – vs 19 °C	SIDE P	SIDE N
ADC Board	33.1°C	33.2°C
Control Board FPGA	33.7°C	30.7°C
Control Board Conn	27.6°C	24.5°C

Cooling Off – vs 19 °C	SIDE P	SIDE N
ADC Board	42.8 °C	46.5°C
Control Board FPGA	34.8°C	36.5°C
Control Board Conn	45.2°C	45.4°C

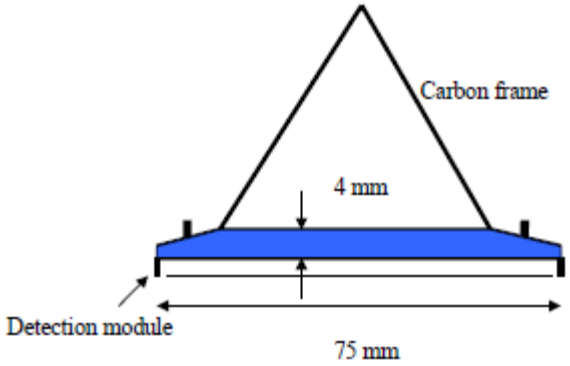
The performance of the old electronics was excellent when the cooling system was in perfect condition.

Air Path in an SSD Ladder



- **Air enters the ladder board region through an ~ 1 cm orifice**
- **The entire ladder is wrapped in mylar to trap the air flow inside the triangular structure of the ladder**
- **The air flow is blocked by a 'wall' to force the air over the Si detectors**

- **Air at the midline of the detector travels through a tunnel, 75 mm x 4 mm (or ~ 3 cm^2)**
- **Length of this air tunnel is ~ 68 cm (not including ladder board sections on ends)**
- **An air flow of 1 liter/sec through the tunnel corresponds to an air speed of 3.3 m/sec**



Heat Load – old electronics on ladder #0

FEE POWER	Number of elements	Predicted Power	**Measured Power**
Alice 128	12 per Module	44 mW	
Costar	2 per Module	44 mW	
Detection Module	16 per 1adder	616 mW	
TOTAL FEE		**9.8 W**	**10 W**

Electronics Boards	Number of elements	Predicted Power	**Measured Power**
ADC Board	2 per Ladder	1.0 W per card	
C2D2 Board	2 per Ladder	2.0 W per card	
Total Electronic Boards/Ladder		**6 W**	**6 W**

http://www.star.bnl.gov/public/ssd/STAR_technique/ssd_cooling_system_doc_2.pdf

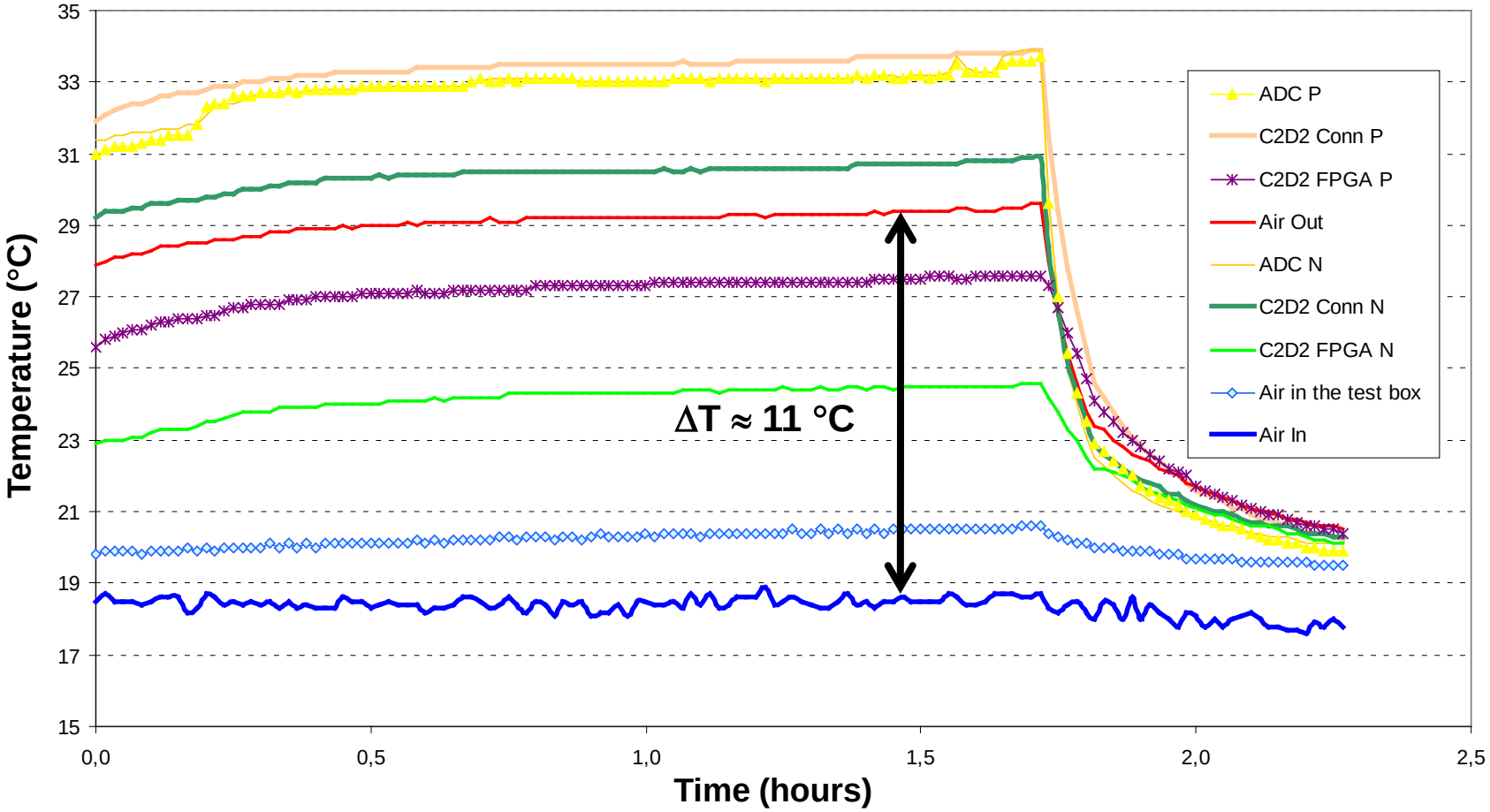
Total Consumption: 16 Watts per Ladder

Expectations based on design of old electronics

- 16 W per ladder, with 20 ladders (and 4 RDO boxes)
- Cross sectional area of each ladder (near Si wafers) is ~ 20 cm^2
- Thus a flow rate of 1 liter / sec requires an air speed of 0.5 m/sec near the ladder boards, and 3.3 m/sec over the Si detectors
- 16 Joules into 1 liter of air suggests a ΔT of ~ 13 degrees °K
  - Heat capacity of lab air is 0.0012 J / cm^3 / °K

1 liter/sec of air was extensively tested on the bench, and was shown to work, without vibration or other difficulties

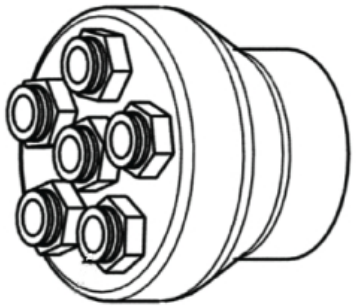
Performance of Cooling System on Ladder #0

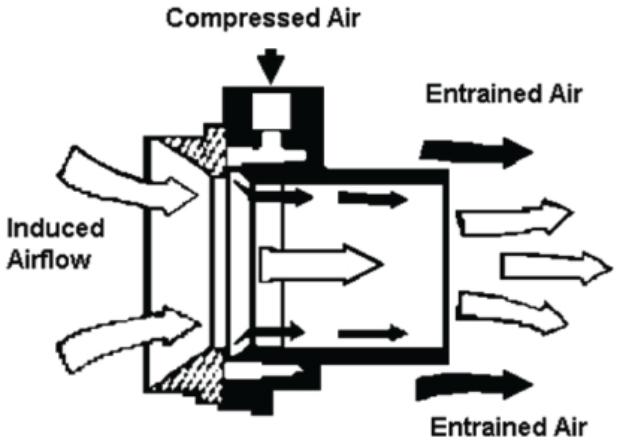


Measurements confirm that the majority of heat from the ladder is transferred to the cooling air stream. The system is efficient.

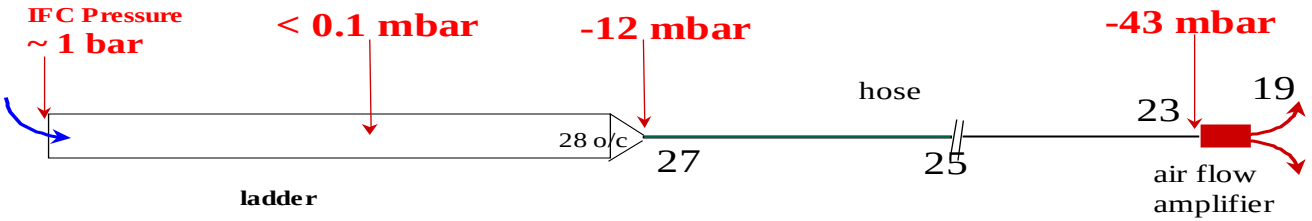
The Previous Solution – a Vortec Transvector

The previous solution was compact, convenient and clever



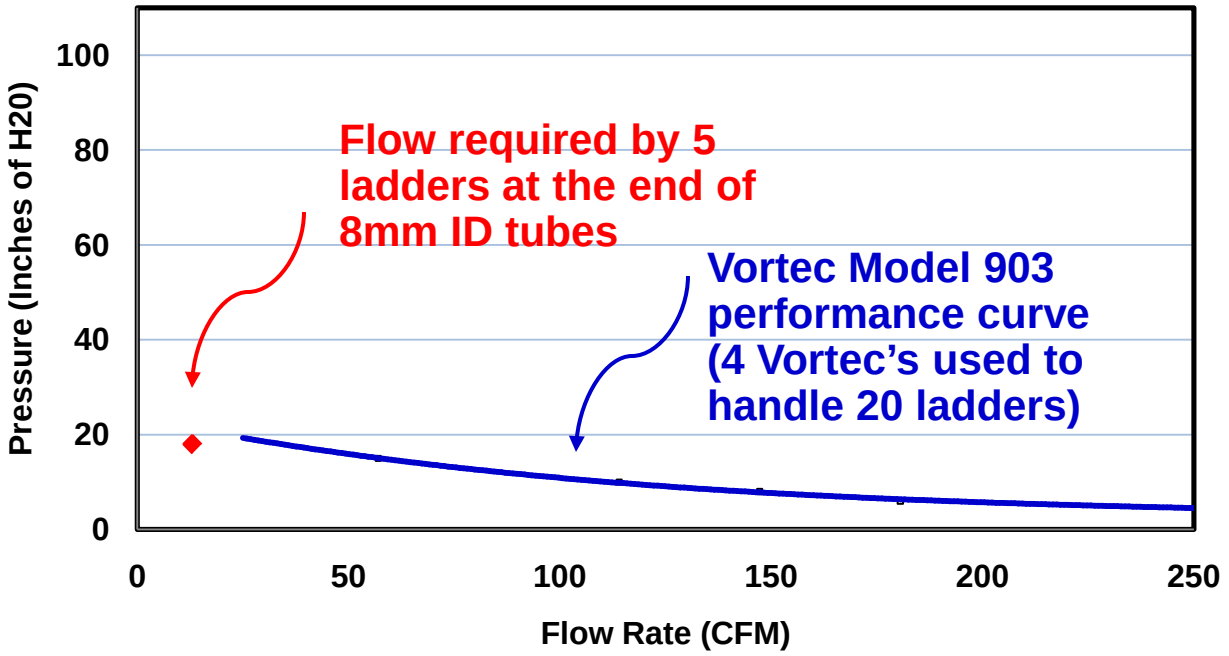


The left panel (above) shows the vacuum distribution manifold that transfers air from the small diameter tubes to the Transvector. The right panel shows the Transvector airflow amplifier and its principles of operation.



It worked. The Transvector drew air over the ladder by starting with air from the IFC (~1 bar). The system had a measured pressure drop of -12 mbar at the far end of the ladder and -43 mbar after 4.5 m of 8 mm (ID) plastic hose.

Vacuum Curve for the Vortec System



- **The operating point for the SSD is shown in red**
  - **Red diamond is for one Transvector = (5 ladders + 1 RDO)**
  - **The Transvector Vortec air flow amplifier is perfectly matched to the SSD operating conditions**
- **However, the curve is very flat and so there is not really any excess capacity in case of a kinked hose and no ability to increase the airflow if we continue to use 8 mm (ID) tubes.**

New Electronics – New Expectations

FEE POWER	Number of elements	Predicted Power	**Measured Power**
Detection Module w/ parallel readout	16 per 1adder	720 mW per module	
TOTAL FEE		**11.5 W**	

New Electronics Boards	Number of elements	Predicted Power	**Measured Power**
Ladder Boards	2 per Ladder	6.7 W per card	
Total Electronic Boards/Ladder		**13.4 W**	

Total Consumption: 25 Watts per Ladder
24 watts typical / 26 watts max

- **25 Joules into 1 liter of air suggests a ΔT of ~ 21 degrees °K at the old flow rate of 1 liter/sec** **(ambient air is 24° so total is 45°, which is in the danger zone).**
  - **Heat capacity of lab air is 0.0012 J / cm^3 / °K**
- **So to achieve the same ΔT as before, we need 1.6 liters/second of air flow with a velocity of 0.8 m/sec near the ladder boards and 5.4 m/sec over the Si detectors**

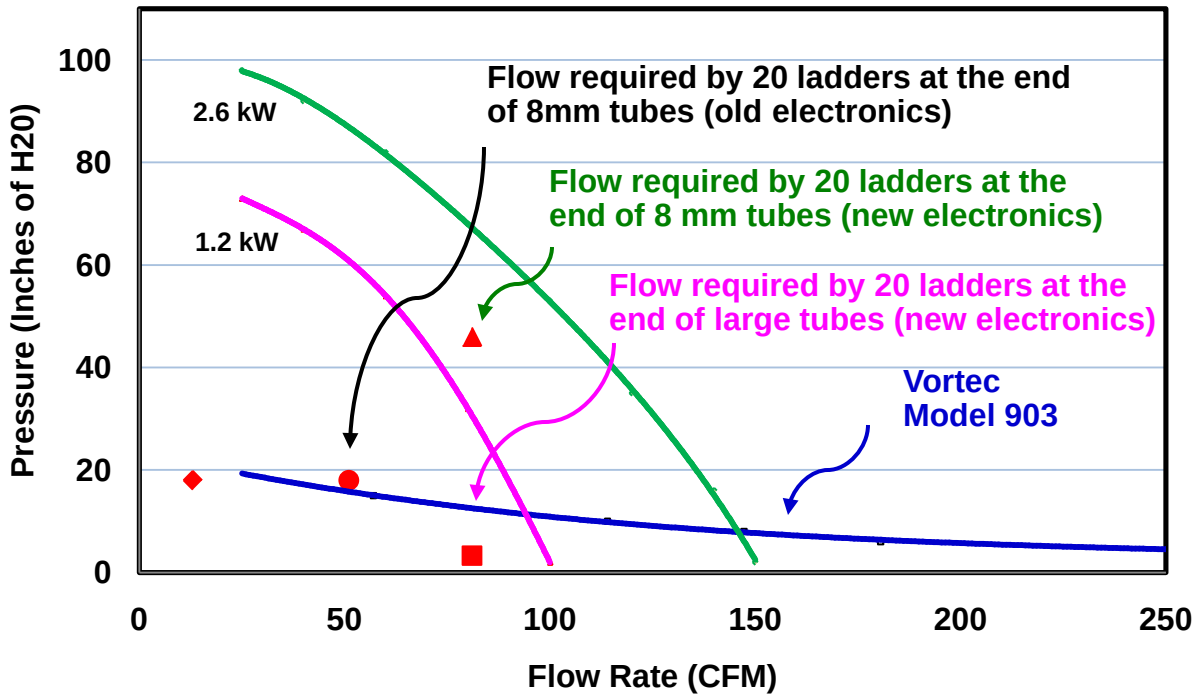
We need more air; but we must be careful that the ladders and/or mylar do not vibrate due to the increased flow rate

More Air

- **The wood products industry needs high volume vacuum sources to clear wood chips from around saws and lathes.**
- **Thus, there is a commercial line of vacuum sources that provide vacuum with more flow and pressure than we need.**
- **These vacuum sources can be purchased, off the shelf, and are designed for continuous operation. They run on 3 phase 240 VAC.**

http://www.dustcollectorsource.com/

Dust Collector Vacuum Sources



'Large tubes' means 4 long tubes with 2.5 cm (ID) each, then distributed locally to 20 ladders without additional pressure drop

- A wide variety of options are available. Shown above are the vacuum curves for a 1.2 kW and a 2.6 kW system from a company in Southern California. Cost is about $4K for the smaller system.
- Note that the 1.2 kW cooling solution will not work on the new electronics if we continue to use the 8 mm (ID) tubes

The airflow can be increased ~2x by using a bigger pump and larger tubes

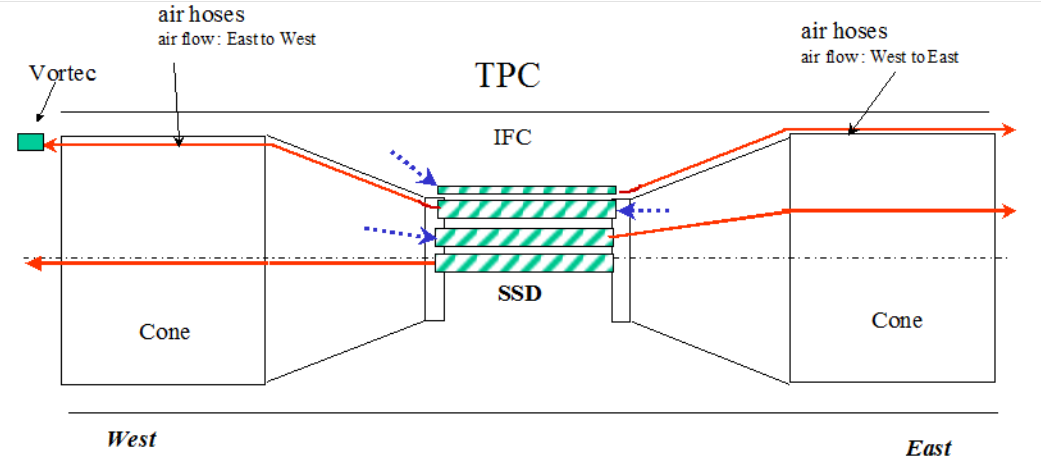
Losses are a function of distance and diameter

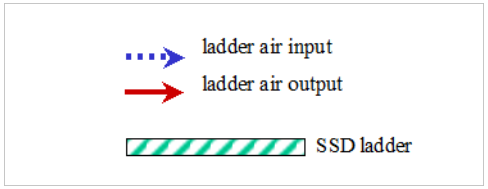
- The vacuum source will be mounted on the North Platform
  - Dirty power available here
- We will need approximately 30 meters (100 feet) of tubing to run between the source and the manifold on the face of the TPC.
  - Using the old manifold is reasonable and desirable
- The vacuum source is manufactured with 2 inch input ports
  - The pressure lost in a perfectly smooth 2 inch tube that is 100 feet long is approximately 4 inches of water.

    http://www.gates.com/industrial/pressure/airFlow.cfm
  - However, the pressure lost in a 3 inch tube is only 0.5 inches of H_2O
    - A caveat on running a long plastic tube: it is a good idea to provide a conductor inside the tube to dissipate static charge
- The pressure lost in an 8 mm (ID) tube that is 4.5 m (15 foot) long is 17 inches of water (43 mbar)
  - In good agreement with measurements
  - Note that 1 cm (ID) tubes loose 13 mbar … very sensitive to ID
  - We are still limited by the 1 cm orifice on the ladders but we can tolerate this (and other small diameter hardware) by keeping the overall length of these sections very short.

Bigger is better. We should use large tubes to conduct the vacuum.

Various options to increase cooling for the SSD





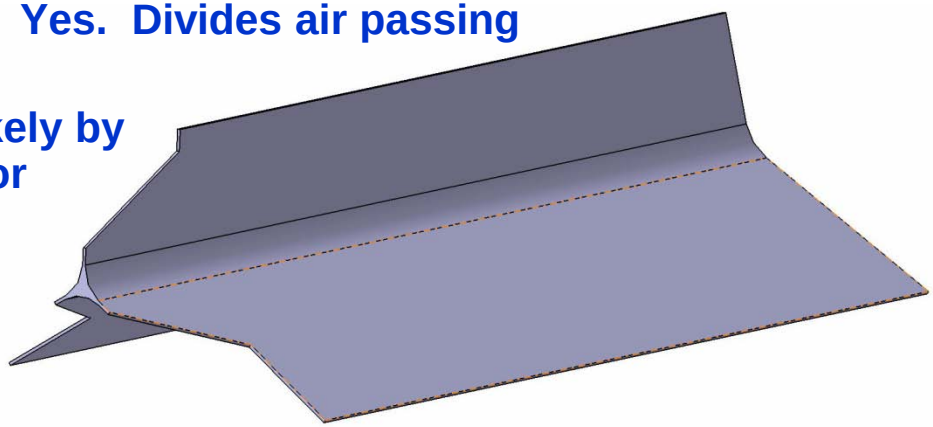
- **Eliminate the 8mm tubes**
  - **Use larger diameter tubes, this will increase the air flow over ladders … even with the old system it would have helped**
  - **4 x 3 cm is much better than 20 x 8 mm**

- **Decrease heat generated by the ladder boards**
  - **Air that passes over the ladder boards also passes over the Si detectors**
  - **Consider reducing voltage on regulators to decrease heat generated**
  - **Put regulators on outside of board so heat goes elsewhere (not into cooling air that passes over the Si)?**

More options

- **Build 2 (or more) air paths inside the ladder. One to go over the Si detectors and one to go through the upper area of the ladder triangle in order to pass the ladder board air.**
  - **This would need an air guide to force cool air over the Si detectors and hot air through a hole in the wall that separates the sections.**
  - **This idea has the undesirable and risky feature that it requires modifying the ladders.**
  - **Also, not guaranteed to work. Overall, it would be difficult to control the air flow over the Si detectors. It would depend, in part, on how well the mylar is wrapped around each ladder to prevent leaks.**

- **What is status of the existing carbon fiber 'cross'**
  - **Are these already installed? Yes. Divides air passing close to the ladder boards.**
  - **How do they work? Most likely by providing laminar flow and/or increasing the air velocity near the boards**



Recommendations

- **Use a more powerful vacuum source**
  - **This implies higher flow velocities inside the ladders.**
- **Use larger diameters pipes and tubes**
  - **1.25 inch (OD) plastic tube from TPC endcap to SSD (up to 15 ft)**
    - **Minimum of 4 required, but 10 would allow easy distribution at the SSD**
    - **4 x 1.25" hoses or 10 x 1.00" are OK but 20 x 0.75" is not good (0.5" ID).**
  - **1 cm (ID) tube from ladder to ladder on SSD (< 4 inches per ladder)**
  - **3 inch diameter plastic pipe from the vacuum source to the TPC endcap (up to 100 ft in length)**
- **Reduce heat output from the ladder boards by changing to low power components on the boards, if possible.**
  - **Reduce heat going into the air stream over the Si detectors by putting ladder board components on the outside of the boards?**
- **Add a 2nd air path - undesirable but possible:**
  - **Add a second air path through the upper part of the ladder to pass air from the 'far' ladder boards so that air does not pass over the Si detectors.**
  - **This would require cutting a hole in the wall that separates the ends of the ladders from the mid-section. Also not completely clear it would work.**
    - **I believe this is too risky to be done on an assembled ladder.**

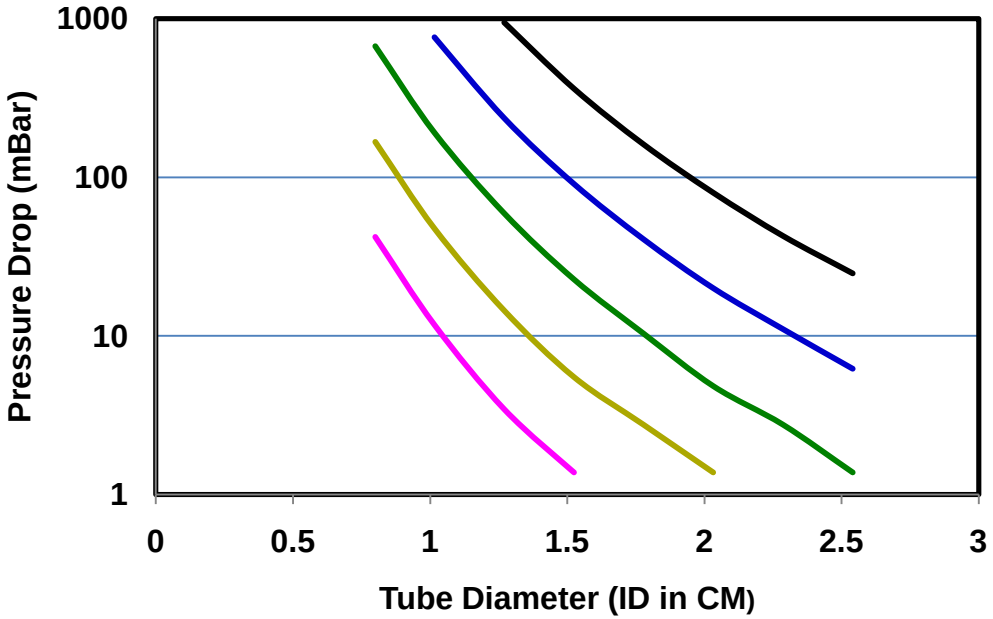
Summary

- **Satisfactory cooling can be achieved by using a vacuum source to pull air from the IFC across the ladders of the SSD**
  - **Extensive measurements show that it works when everything is working perfectly**
- **In order to achieve excess capacity to compensate for non-ideal conditions, we should go to a new source of vacuum**
  - **230 V / 3 Phase Siemens turbine. The motors are brushless and rated for continuous operation, 25 year lifetime, 65 dBA.**

- **We should use larger diameter hoses at each stage of the design**
  - **Internal hoses should be made stiff so they won't kink**
- **Consider redesigning the ladder boards to decrease the amount of generated heat**

Conversion units and scaling rules

- 1 inch of water = 2.49 mbar
- 1 psi = 68.9 mbar
- 1 CFM = 0.47 liters / second



Pressure Drop as a function of diameter for constant flow rates of 1, 2, 4, 8 and 16 liters / second through a 4.5 meter long tube. Pressure drop is logarithmic vs radius, linear vs length and approximately quadratic vs flow rate.

http://www.gates.com/industrial/pressure/airFlow.cfm

To Do

- **Make list of recommendations for final design**
  - Make a list of various pipe size combinations depending on how many allowed to run from TPC end cap to SSD. List the options.
    - Assume 2 liters / second through each ladder, try for pressure drop of no more than 12 mBar in the ladder, 12 mBar in pipe from SSD to TPC end cap, and then 12 mBar from TPC endcap to vacuum source.
    - 10 pipes is easy to distribute to SSD ladders with one T and two elbows, but fewer pipes would mean fewer penetrations through the cones.
  - Need calibrated air leak with an air filter on it. This is just a carefully managed hole in the pipe near the vacuum source with a circular canister type air filter. Decreases flow to ladders and as a consequence it decreases the pressure drop on the ladders.
    - Monitor flow and pressure near the vacuum source. Pressure increase is the only way we will know if ladders have kinked off or air filter is plugged up. This measurement needs to be done upstream of air leak, but perhaps downstream too just for reference. Need to find high quality instrumentation for these diagnostics.
  - Can we measure flow, or pressure drop, on each ladder?
  - Design how to distribute air near SSD ladders. Tricky and needs to be large diameter parts.
  - What happens if some of the hoses are kinked? Do we collapse the other ladders? How do we prevent this from happening?
    - Mylar will probably rip before other damage happens. Can we use this idea to create a safety release mechanism for each ladder? (tear away hole, inverse of a pressure release valve) Can we limit the flow with smaller diameter tubes over the long haul?