Pixel Detector Vacuum System Description
Feb. 27, 2003 (revised Sept. 19, 2003)

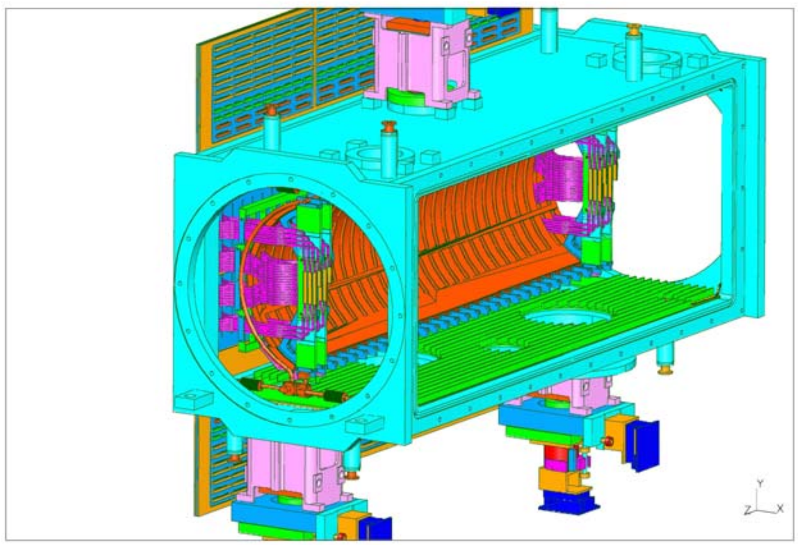
Introduction

The pixel detector operates in a vacuum chamber connected directly to the Tevatron vacuum system. This arrangement has required a number of design solutions, which the pixel group has been developing over the past two years. First, the out-gassing rate of the pixel components have been measured and a pumping scheme for achieving the required pressure has been developed and tested. Second, a multi-layer printed circuit board design has been developed and tested as the feed-through for thousands of electrical signals. Finally, a cooling system has been designed that has no direct cooling fluid-to-Tevatron vacuum joints.

This report presents a summary of the Pixel Vacuum System design and development work for approval by the Beams Division. An approval would indicate that these are acceptable design concepts and a Pixel Detector with these design elements could be connected to the Tevatron after the designs are fully developed and demonstrated.

General Description

The BTeV silicon pixel detector contains 30 planar stations of multi-chip modules that reside inside the vacuum of the Tevatron close to the beam. The detector sits within a 1.5 Tesla analysis magnet. The silicon detector contains ~1700 electrical cables and generates a heat load of ~ 3 kW. The pixels are as close as 6 mm from the beam during operation and are retracted to a distance of 20 mm from the nominal beam axis during beam injection. Components in the central portion of the detector are chosen to minimize mass in the active region. The primary pumping for the pixel system is provided by large LN_2 cooled panels. Additional pumping is provided for non-condensable gases. The signal cables connect to a large multi-layer printed circuit board, which provides the vacuum feed-through of the signals outside of the vacuum vessel. The feed-through boards mount to the sides of the vacuum vessel. The pixel stations are cooled by LN_2 supplied in 4 parallel stainless steel cooling tube loops. The stations are thermally connected to the cooling tubes with high thermal conductivity graphite. All cooling line joints are isolated from the Tevatron vacuum.



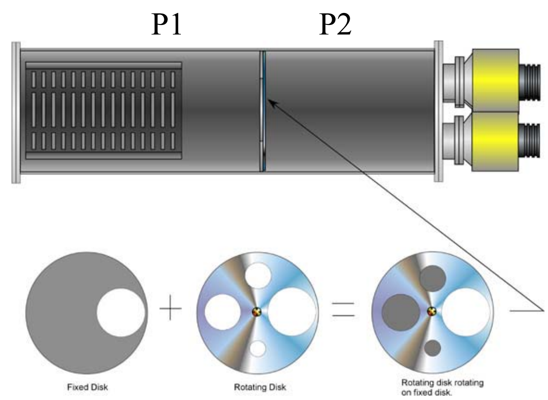
Pumping Design and Development

A complete separation from the Tevatron vacuum was considered in the early stages of the vacuum system design. Due to the limitation on material, any separating barrier would need to be very lightweight, such as .150 mm thick aluminum foil. Such a foil would need to be evacuated on both sides to maintain its shape. Besides being difficult to make leak-tight, any such foil would be vulnerable to damage from any vacuum upsets that generated a differential pressure across the foil. The fundamental problem with this solution however, was that the gap between the two foils presents a gas conduction limitation that reduces the effective pumping speed in the particle beam region to a very low level. This low pumping speed combined with the inability to perform an in-situ bake-out leads to a pressure that is much higher than acceptable.

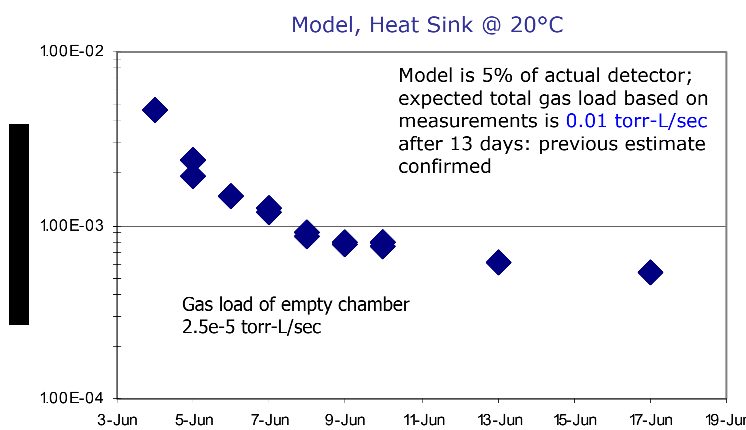
The solution developed to solve this problem was to place the pixel detectors directly in the Tevatron vacuum and provide enormous pumping with LN_2 cooled panels located in the pixel vacuum vessel. The panels provide a pumping speed greater than 100,000 L/s for water, which is the main gas component. Additional pumping for other gases would be provided by other means. The concept was tested with an assembly, which contained 5% of the material that would be used in the final detector.

In the final design, wires or strips will run through the detector to carry the beam image current and shield the detector from the RF effects of the beam. This feature is described in a separate document.

The test setup is shown below. The setup involved a split chamber with a variable conductance aperture and three turbo-pumps with a combined speed of 1300L/s for N_2. The chamber was instrumented with ion gages, thermocouples and an RGA. The setup was calibrated with a controlled leak.



The device under test consisted of a carbon fiber support structure (⅓ final length), 6 pixel half-station assemblies with cables (1/10 final quantity) and one LN_2 cooled panel (¼ final size). The pixel stations were assembled with the materials and techniques typical for silicon detectors. The out-gassing rates of the empty chamber and pixel assembly were measured at various temperatures and pressures. The graph to the right shows the gas load over two weeks. When cooled to the nominal pixel detector operating temperature of -10° C, the gas load was reduced by a factor of 2. The components of the gas were also measured and water was the largest component by a factor of 100.



Next the cryo-panel was cooled with LN_2 and the pressure was measured with the pixel detector at 20° C and -10° C. The pressure was also measured for various orifice settings, which control the additional pumping. The results are summarized in the following table.

Model Temp	Heat Sink Temp	Orifice setting	P1 (torr)	P2 (torr)	Q (torr-L/sec)	RGA H2O reading	RGA N2 reading
20ºC	20ºC	Large	3.40E-07	3.40E-07	5.20E-04	**4.80E-08**	5.00E-10
		2”	2.08E-06	3.36E-07		**3.20E-07**	2.90E-09
-10ºC	-10ºC	Large	1.70E-07	1.60E-07	2.60E-04	3.50E-08	
		2”	1.10E-06	1.60E-07		1.80E-07	
20ºC	-160ºC	Large	1.26E-08	1.86E-08			
		2”	2.07E-08	1.63E-08		1.00E-09	
-10ºC	-160ºC	Large	1.04E-08	1.08E-08		**7.20E-10**	1.00E-10
		2”	1.62E-08	7.40E-09		**7.90E-10**	5.30E-10
		Blank	1.20E-07	5.90E-09		**9.70E-10**	1.00E-08
		Large	9.20E-09	8.70E-09			

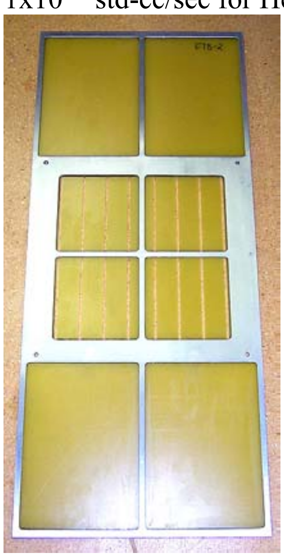
The following are the highlights from this phase of the testing. The cryo-panel pumping speed for water was determined to be ~ 19,000 L/s. The partial pressure of water was reduced by more than a factor of 50 due to a combination of cryo-pumping and lower out-gassing. An operating pressure lower than 1×10^{-8} Torr was achieved.

The conclusion from this testing is that an operating pressure < 1×10^{-7} Torr can conservatively be achieved for the full size pixel detector.

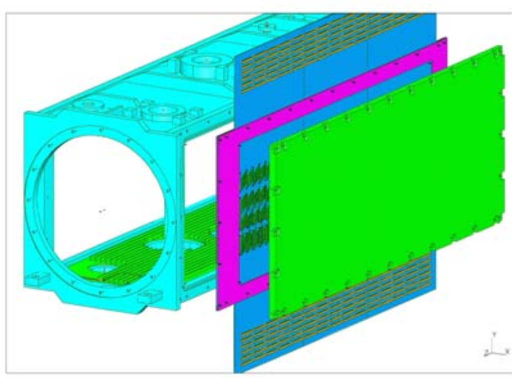
Additional development work still remains to optimize the performance of the pixel vacuum system. This includes: optimizing the cryo-panel geometry, verifying the long term pumping speed of the LN_2 panel, configuring additional pumping for N_2 and other gases not condensable on the LN_2 panel.

Feed-through Board Testing

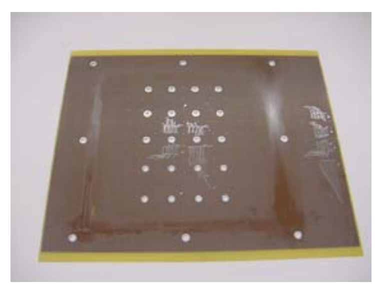
The silicon detector contains ~1700 electrical cables which carry the power and data for the pixel stations. An assembly of 6 multi-layer printed circuit boards is used to feed thousands of lines through the vacuum vessel. A 1/3 length prototype of the assembly has been built and tested to be leak tight at 1×10^{-10} std-cc/sec for He.



1/3 Length board assembly



The circuit board assembly is sandwiched between the vacuum vessel and a cover flange. O-ring seals are made to aluminum frames on both faces of the circuit board assembly. Multi-layer circuit boards and circuit board assemblies have been successfully leak checked.

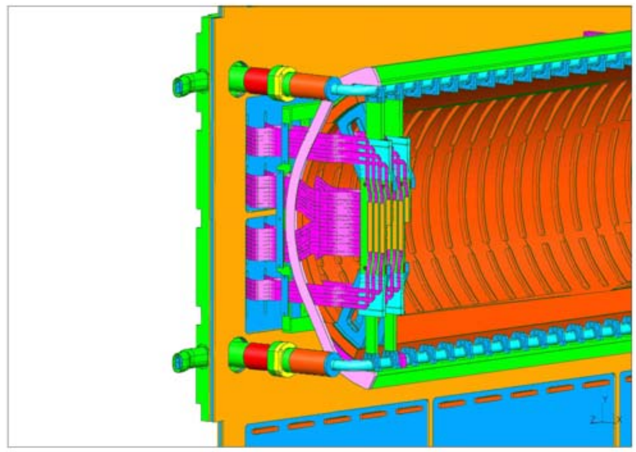


Multi-layer printed circuit board

Cooling Connections

Each of the 30 pixel stations generates 100 W of power in the sensors and readout electronics. To minimize the long term effects of radiation damage, the sensors will be cooled to -10° C. The sensors are located in the active region of the detector where mass must be kept to a minimum. To provide leak free operation in vacuum, the cooling connections must be very reliable or avoided completely

To satisfy these requirements a design has been developed to provide cooling by LN_2 supplied in 4 parallel stainless steel tube loops. Heat is transferred to the cooling tubes with thermal conduction connections from the pixel stations. The large temperature gradient between the silicon sensors and the cooling tubes allows minimum material to be used in the thermal conduction connection. The material for this connection is high thermal conductivity graphite.



The LN_2 flow requirements can be met with ½ inch diameter tubing. The operating pressure will be 45 psig, which implies an LN_2 boiling temperature of -185° C. The exit quality (mass of vapor/total mass) will be 0.4 and the total flow for all 4 loops will be 200 L/h.

Temperature balancing and control will be accomplished with resistive heaters mounted to the pixel stations.

The LN_2 insulation vacuum will terminate inside the pixel detector thus isolating any LN_2 connections from the Tevatron vacuum.

Pressure in Beam Pipe Sections

The pressure in the beam pipe section that runs between the pixel detector and the low beta quad on the detector side of the C0 hall should be similar to the pressure of the CDF or D0 beam pipes. The pressure in the beam pipe section on the side of the C0 hall opposite the detector should be better than the CDF or D0 beam pipes since it should be possible to add pumps at an intermediate location along this section.

References

More detailed information can be found in the following reference documents.

BTeV-doc-2005 Cyrogenic Pumping System for the BTeV Pixel Detector

BTeV-doc-318 Analysis of the BTeV Vertex Detector Vacuum System

BTeV-doc-812 Outgassing Rate of 5% Model of the Pixel Detector

BTeV-doc-1097 BTeV Silicon Detector Integration Issues