*BTeV Detector Systems*
*Preliminary High Voltage Requirements*

**BTeV Document (number to be assigned)**

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# 1 Introduction

This document describes the high-level requirements for BTeV's six front-end detector high-voltage systems. Most of the high-voltage systems are likely to require a very large number of individually controllable voltages. In order to simplify the operation of BTeV, all of the BTeV high voltage systems must be controllable through a single control interface. It is highly desirable that all BTeV high voltage systems be of a single type, differing only in which plug-in modules are used. The requirements of the various BTeV detector subsystems as they are currently understood are summarized in Table 1.

| Detector Subsystem | Polarity | ~ Max. Channels (without spares) | Voltage Range | Current Range | Readback Precision |
|---|---|---|---|---|---|
| Pixels | Negative | 1426 | 0-1000 | 10 nA – 10 mA | 0.1% of F.S. V<br>0.1% of I range |
| Strips | Positive | 870 | 0-1000 | 10 nA – 10 mA | 0.1% of F.S. V<br>0.02% of I range |
| Straws | Positive | 3700 | ~ 0-2200 | 0-10 μA | 0.5% of F.S. V<br>1% of I |
| RICH | Negative<br>Negative<br>Positive | 286<br>143<br>143 | 15 kV-22 kV<br>10 kV-17 kV<br>0-100 | 0-100 nA<br>0-100 nA<br>0-10 μA | 0.1% of F.S. V, 1% of I<br>0.1% of F.S. V, 1% of I<br>0.1% of F.S. V, 10% of I |
| EM Cal. | Negative<br>Negative<br>Negative<br>Negative | 230<br>230<br>230<br>690 | 0-400<br>0-600<br>0-800<br>0-1000 | 0-10 mA<br>0-2 mA<br>0-0.5 mA<br>0-0.1 mA | 0.02% of F.S. V, 0.1% of I<br>0.02% of F.S. V, 0.1% of I<br>0.01% of F.S. V, 0.1% of I<br>0.01% of F.S. V, 0.1% of I |
| Muon Chambers | Positive | 2496 | ~ 0-2000 | 0-12 μA | 1% of F.S. V<br>1% of I |

**Table 1: Summary of BTeV High Voltage Requirements.**

# 2 Requirements Common to all Detector Subsystems

## *2.1 Setting and read back*

All BTeV high voltages must be controllable by setting the voltage of an individual channel or group of channels. The detector system grounds must be defined locally at the detectors that are being powered. This implies that the high-voltage power supplies must 'float' with respect to their local ground. The current must be limited to a maximum value, settable for an individual channel or a group of channels within a module. Both voltage applied and current drawn must be monitored for every channel.

- **Requirement 2.1-1:** Each high voltage channel must have computer control of the following. Having 'computer control' means being controlled and monitored using a standard protocol and physical layer (*e.g.,* Ethernet, CAN):
  - Output voltage settable to 0.1% of the maximum rated voltage.
  - The output voltage value must be computer readable (See next to last bullet for set value readback requirements).
  - Output current limit settable to 5% of the maximum rated current for the operating range.
  - The output current value must be computer readable.
  - The recovery from overcurrent must be manually re-settable by either a local panel control button or remotely by a computer command.

    Note: Automatic recovery when the fault is removed may also be required. Vendor should indicate additional estimated costs, if any, if this feature is provided.
  - Output voltage over-limit and under-limit thresholds must be settable to 5% of the set point voltage.
  - The recovery from overvoltage must be manually re-settable by either a local panel control button or remotely by a computer command.

    Note: Automatic recovery when the fault is removed may also be required. Vendor should indicate additional estimated costs, if any, if this feature is provided.
  - Output must have on/off control and must be computer-controllable and monitored. There must be local on/off control (see Section 2.9).
  - Any set point fault must send an "alarm" message to the control computer. A visual and/or audio alarm is also desirable.
  - All computer settable controls (registers) must be computer readable.
  - An computer-readable identification method for all different types of plug in units and any calibration constants is required.
- **Requirement 2.1-2:** Each high-voltage power supply output must be able to have its current limit trip point remotely settable and monitored (computer-controlled). A manual test of this limit is also allowed in addition to the computer test.

  Note: This requirement might be eliminated if cost estimates to implement are too high.
- **Requirement 2.1-3:** Each high-voltage power supply output must be able to have its overvoltage and undervoltage limit trip points remotely settable and monitored (computer-controlled). A local and manual test of these limits is also allowed in addition to the computer tests.
- **Requirement 2.1-4:** The absolute accuracy of the computer-controlled settings for output high voltages may be only 1% (or better). The system must be able to be externally and remotely calibrated to the accuracies required in this document and be stable within the required tolerances for a minimum of eight hours over the specified operating range.

## 2.2 Input and Environment

- **Requirement 2.2-1:** The supplies must meet all specifications stated over an ambient operating temperature range of 10 ºC to 40 ºC.
- **Observation 2.2-1:** It is preferred that the supplies must operate with a nominal 120 VAC, single phase, 60 Hz input. The supplies must meet the specifications stated over an input voltage range of 105 VAC to 135 VAC, and a frequency variation of 55 Hz to 65 Hz. 208 VAC operation may be acceptable if 120 VAC operation is not normally available with the vendor's products.
- **Requirement 2.2-2:** The supplies must comply with MIL-STD-461B (similar to CE03 specification) for conducted and radiated emissions.
- **Requirement 2.2-3:** The modules must comply with the ESD requirements IEC 60297-5-103 (IEEE 1101.10) and EN 61000-4-2.

## 2.3 Output Characteristics & Connectors

The details of the output voltage and currents ranges are given for each subsystem in Section 3. Only the general features are called out in this section.

- **Requirement 2.3-1:** The output voltages must "float" so that ground is defined at the load. This requirement has safety issues associated with it that are discussed in Section 2.8.

  Note: The term "float" implies high-impedance to ground relative to frequencies from DC to low multiples of 60Hz. It is desirable that the manufacture provide appropriate testing data if available.

- **Requirement 2.3-2:** The output connectors shall meet safety code as described in FNAL Occupational Health and Safety Document, Chapter 5045: *High Voltage Coaxial Connectors,* Rev. 1/99. This document is available at: http://www-esh.fnal.gov/FESHM/5000/5045.html.
- **Requirement 2.3-3:** All output connectors of lower-voltage supplies must be identical and type-keyed as to their output voltage if possible. All output connectors of higher-voltage supplies must also be identical and type-keyed as to their output voltage if possible.

  Note: An SHV connector may be chosen for all lower-voltage supplies. These are BNC-sized connectors and may prohibit denser packaging of supplies. Another reliable and safe connector may be chosen for lower-voltage supplies if this is the case. Type-keyed connectors, if available, are preferred.

- **Requirement 2.3-4:** On turn-on and turn-off, the ramp rate of each output voltage from off to full on and on to full off, respectively, must be limited to several hundreds of milliseconds minimum.

  Note: This requirement might be eliminated if cost estimates to implement are too high.

- **Requirement 2.3.5:** The peak-to-peak ripple of all outputs must be such that no measurable noise is introduced for the systems described in Section 3.

  Note: Fermilab will test prototype high-voltage power supply modules provided by the vendor to assure that this requirement is met.

- **Requirement 2.3-6:** The long-term (eight hours minimum) stability must be such that intervention is not required to maintain preset voltage and current levels.
- **Requirement 2.3-7:** The impedance of each high-voltage output shall be such that when deactivated, the output capacitors see sufficient impedance in which to discharge such that significant current spikes are eliminated.

## 2.4 Cable Lengths & Remote Sense

The high-voltage power supplies will most probably be located in an area outside the collision hall and consequently not in a radiation environment. There is a possibility they will be located in the BTeV collision hall. If so, it is understood that high-voltage components tend to fail in high neutron environments. Section 2.5 gives expected radiation levels in the collision hall where the power supplies would be located if in the collision hall. If the power supplies are located in the collision hall, the cables that distribute voltage to the detectors will be relatively short (15 meters or less). If the power supplies are located in the counting room, the cables that distribute voltages to the detector will be relatively long (80 meters). At least one of the following two requirements must be satisfied:

- **Requirement 2.4-1a:** If the power supplies are located out of the collision hall, they must operate with output cables up to 80 meters in length.
- **Requirement 2.4-1b:** If the power supplies are located in the collision hall they must operate with output cables up to 15 meters in length. If this condition exists, then Section 2.5 requirements must be met.
- **Observation 2.4-1:** If necessary, the high voltage system may operate with remote sense cables. Some issues with safety may need to be addressed (see Section 2.8).

## 2.5 Radiation Tolerance

Supplies that operate in the collision hall must be sufficiently radiation tolerant so that their performance will not be significantly degraded after ten years of running at the highest anticipated luminosity. It may be possible to relax the radiation tolerance requirement by approximately a factor of ten by judicious placement of the supplies and/or the use of shielding.

- **Requirement 2.5-1:** The high voltage system operating properties must not be degraded by the exposure (over 10 years) to 10 kRad of ionizing particles and a total fluence of $2 \times 10^{12}/cm^2$ of low energy (< 14 MeV) neutrons. Degradation is defined here as something that no longer lets the system meet all the specification contained in this document.

## 2.6 Packaging

The system must mount in standard racks to that they can share rack space with other electronics.

- **Requirement 2.6-1:** The unit must be packaged in a subrack base unit that mounts in standard 19 inch EIA racks.
- **Observation 2.6.1:** The base subrack may contain the AC power input, computer monitor interface, and general system safety components. Plug-in units for these functions may also be used. Mean-Time-To-Repair (MTTR) might be reduced if plug-in units are used.
- **Requirement 2.6-2:** The system must be a modular design with the high-voltage plug-in units into the base subrack. The number of channels must be maximized on the subrack level. A desirable minimum number of outputs per subrack is 128. In the case of 10 kV and higher units, this number may be less because of high-voltage distance clearance issues.

A desirable feature of the system would be to have different output voltage modules plug into a common base subrack. This could make a more efficient use of rack space and reduce the number of spare subracks that are required.

## 2.7 Maintainability

During data taking, maintenance downtime must be minimized.

- **Requirement 2.7-1:** The system must be designed so that the MTBF (Mean Time Between Failures) of a module is 50,000 hours.

- **Requirement 2.7-2:** The system must be designed so that the MTTR (Mean Time To Repair) is less than five minutes after the technician is at the location of the defective unit.
- **Requirement 2.7-3:** If the fault is in a defective module (not the main subrack) the replacement must be accomplished without removing power from the entire subrack.

## *2.8 Personnel Safety*

Since the supply outputs will be referenced at the loads, it is necessary that the system limit the extent that the output may float with respect to local ground at the power supply. All "normal" personnel safety standards must also be respected. Many of these safety issues are discussed in Fermilab's ES&H Manual (FESHM; see 'Safety Manuals' at URL: http://www.fnal.gov/faw/fermilab_at_work.html).

- **Requirement 2.8-1:** The output ground potential must not exceed 50 V when disconnected from the load ground.
- **Requirement 2.8-2:** Since the output ground is floating, the output must protect personnel with a ground fault interrupt circuit.

  Note: The vendor should be prepared to describe his/her company's implemented method to assure personnel safety.

- **Requirement 2.8-3:** The power supply, subrack and modules, must follow the guidelines described in Fermilab's ES&H Manual, Chapter 5046 (FESHM5046) and the rules given in Chapter's 4 and 9 of the DOE Handbook of Electrical Safety.

  Note: The DOE Handbook of Electrical Safety can be accessed at URL: http://www-d0.fnal.gov/~hance/doe_esh.pdf

- **Requirement 2.8-4:** The modules must comply with the safety ground specifications in IEC 60950 (1991-10) and IEC 61140 (1997-11).

## *2.9 On/Off Control, Fault Monitoring & Safety Interlock Provisions*

High-voltage power supplies connected, for example, to a single detector plane are turned off in a potential or actual emergency situation both quickly and at the same time. The high-voltage power supply module must provide external safety interlocking of the high-voltage power supplies.

- **Requirement 2.9-1:** Each module must provide external isolated input(s) to be used as an interlock to unconditionally prevent high-voltage outputs from being turned on, either manually or by computer control. This interlock must be fail safe (*e.g.* interlock cable break is a fault). The design of the interlock may impact hot swap and the vendor should discuss this possible conflict.
- **Requirement 2.9-2:** Each module must provide one front-panel LED that indicates an internal or external fault condition initiated a disabling of one of its high-voltage outputs (*e.g.,* load overvoltage or overcurrent). The LED must be illuminated only when this disabling condition exists. Any safety interlock to this module must not illuminate the LED.
- **Requirement 2.9-3:** Each type of failure mode must be able to be monitored by computer control. This includes information if the interlock caused the module's outputs to be disabled (see Requirement 2.9-1).
- **Requirement 2.9-4:** Each module must provide an external isolated output that can be daisy-chained and that indicates an internal or external fault condition (*e.g.,* overcurrent, over temperature, *etc.*). This output must be able to be used directly as an input to disable the high-voltage outputs of the module or other modules.

# Requirements Unique to Each Subsystem

This section gives a brief description of each detector subsystem, and lists requirements that are not common to all subsystems.

## *2.10 Pixel Detector*

The silicon pixel vertex detector is located in a vacuum vessel mounted inside the BTeV dipole spectrometer magnet. The pixel sensors are arranged in planes roughly perpendicular to the path of the proton and antiproton beams. Each plane is made up of a number of modules rather like a tile roof is constructed using shingles. The pixel sensor modules are reverse biased silicon high voltage diodes. Before exposure to radiation, the diode leakage current, which is supplied by the high voltage supply, is very low. For sensor modules very close to the circulating beams, exposure to ionizing particles will significantly change the sensor properties during the life of the detector. As the sensors become radiation damaged, it will be necessary to increase the applied high voltage, and the leakage current will increase by many orders of magnitude. While it is unclear how many modules may be biased with a single high voltage channel, the modules closest to the beam certainly will not share with any others.

- **Requirement 3.1-1:** The supply must produce a negative voltage that is adjustable over the range of 0 V to 1000 V. The computer monitor must be accurate to 0.1% of full scale.
- **Requirement 3.1-2:** Ripple and noise must be less than 0.1%, peak to peak, of the output over a frequency range of 20 Hz to 20 MHz.
- **Requirement 3.1-3:** Stability of the output voltage (after 30 minute warm up) over an eight-hour period of less than 0.1% from 0 to 40º C.
- **Observation 3.1-1:** The current may be adjusted in three ranges: 10 nA to 1 µA, 400 nA to 100 µA, and 40 µA to 10 mA.
- **Requirement 3.1-4:** The current monitor resolution must be 0.1% of the range setting.

It is not yet determined what, if any, electromagnetic shield will be located between the pixel sensors and the circulating beams. If there is not sufficient shielding, the circulating beams will induce currents in the metal traces or wires carrying high voltage and ground to the sensors. The particle beams are not DC, but bunched, with bunch length of ~ 75 cm. The induced currents will represent a common mode noise source that will have very high frequency components.

- **Requirement 3.1-5:** The manufacturer must provide an alternate quotation for high voltage units listed above that have a peak-to-peak common mode voltage of less than 10 V and a frequency spectrum of ~0 to 100 MHz between the unit output and the load.

## *2.11 Silicon Strip Detector*

Silicon strip detectors (SSD's) will be employed as part of the forward tracking system. These detectors are reverse biased high voltage diodes similar to the pixel vertex detector sensors. From the point of view of the high voltage system, the biggest difference between the pixel system and the SSD system is that the SSD's will use positive high voltage and the pixel system will use negative high voltage. Like the pixel system, each SSD "station" will be composed of a number of separate modules. Once again, modules closer to the beam will radiation damage faster than modules further away from the beam. Consequently, while it may be possible for a number of modules to be biased by a single high-voltage channel, it will be necessary to have more than one high voltage per station.

- **Requirement 3.2-1:** The supply must produce a positive voltage that is adjustable over the range of 0 V to 1000 V. The computer monitor must be accurate to 0.1% of full scale.
- **Requirement 3.2-2:** Ripple {unknown at this time}

- **Requirement 3.2-3:** Stability {unknown at this time}
- **Observation 3.2-1:** The current may be adjusted in three ranges: 40 nA to 4 µA, 2 µA to 200 µA, and 100 µA to 10 mA.
- **Requirement 3.2-4:** The current monitor resolution must be 0.1% of the range setting.

## *2.12 Straw Detector*

Straw tube drift chambers will be employed as part of the forward tracking system. These are segmented multiwire proportional chambers. Each straw tube contains a small diameter sense wire, which is held in the center of the tube. The straw is metalized and will be connected to a "ground" voltage that will be defined by the straw tube analog front-end electronics. The sense wire will be connected to positive high voltage. A blocking capacitor will allow the front-end electronics to operate at low voltage with respect to local ground. High voltage will be distributed to the sense wires by the same printed circuit board that holds the front-end electronics. Each printed circuit board is expected to service 32 straws. The baseline BTeV design calls for the use of only one straw tube diameter, but it is possible that this design will be changed, and two or three different diameter straw tubes will be employed. In principal, all straw tubes channels with the same diameter straws will be able to operate at a single high voltage. In practice, it is likely that it will be desirable to bias straws very close to the beam using a separate high voltage channel. The maximum number of high voltage channels quoted here and in Table 1 corresponds to biasing each group of 32 straw tube channels with a separate high voltage channel.

- **Requirement 3.3-1:** The supply must produce a positive voltage that is adjustable over the range of ~ 0 V (supply may be a hundred volts or so from zero) to 2200 V. The computer monitor must be accurate to 0.5% of full scale.
- **Requirement 3.3-2:** Ripple {unknown at this time}
- **Requirement 3.3-3:** Stability {unknown at this time}
- **Requirement 3.3-4:** The current must be adjusted to 1% in the range of 0 to 10 µA.
- **Requirement 3.3-5:** The current monitor resolution must be 1% of full scale.

## *2.13 RICH Detector*

There will be two Ring Imaging Čerenkov Counters, one in each arm of the BTeV spectrometer. High-energy charged particles emit light in the Čerenkov radiator materials at an angle with respect to the particle flight direction that is determined by the particle velocity. The Čerenkov angle can be measured for each particle by focusing the light onto an image plane where the photons fall on a ring image, the radius of which is a simple function of the Čerenkov angle, and thus the particle velocity. The measurement of the particle velocity, coupled with the momentum measurement provided by the forward tracking system, allows charged particles to be identified by type (mass). The BTeV baseline design calls for the Čerenkov photons to be detected using "Hybrid Photon Detectors" (HPDs). These are vacuum tubes in which photoelectrons produced by interactions of incident photons in a photocathode on the inside face of a clear vacuum window are accelerated through a 20,000 V potential and detected by a silicon pad detector, which is also located inside the vacuum tube. The baseline design calls for 2080 HPDs, multiplexed in groups of 15. Each HPD requires three negative high voltages (two for focusing electrodes): 20,000 V, 19890 V, and 15830 V. In addition, the silicon pad detector located in each HPD requires a positive bias voltage of 60 V.

- **Requirement 3.4-1a:** The Type A supply must produce a negative voltage that is adjustable over the range of 15,000 V to 22,000 V. The computer monitor must be accurate to 0.1% of full scale.
- **Requirement 3.4-1b:** The Type B supply must produce a negative voltage that is adjustable over the range of 10,000 V to 17000 V. The computer monitor must be accurate to 0.1% of full scale.

- **Requirement 3.4-1c:** The type C supply must produce a positive voltage that is adjustable over the range of 0 V to 100 V. The computer monitor must be accurate to 0.1% of full scale.
- **Requirement 3.4-2:** Ripple {unknown at this time}
- **Requirement 3.4-3:** Stability {unknown at this time}
- **Requirement 3.4-4:** The module must have a Reynolds Industries P/N167-3517 or equivalent connector for the output high voltage for 17 kV or higher. Any safe connector may be used for the 100V unit.
- **Requirement 3.4-5:** The current must be adjusted to 5% in the range of 0 to 100 nA for the 17 KV or higher units. The 100 V units must have a current range of 0 to 10 µA.
- **Requirement 3.4-6:** The current monitor resolution must be 1% of the range setting for the high voltage units and 10% for the 100 V units.

## *2.14 EM Calorimeter Detector*

There will be two electromagnetic calorimeters, one in each arm of the BTeV spectrometer. The active elements of the calorimeters will be light producing lead tungstate ($PbWO_4$) crystals. For incident electrons or photons, the amount of light produced is directly proportional to the photon or electron energy. Each crystal will be instrumented with a photomultiplier tube. Since the light output of $PbWO_4$ is a strong function of temperature, the photomultiplier tubes will not be biased using conventional bases, which use standing current in a chain of resistors to generate different voltages for the dynode stages of the tubes. Rather, each tube will be directly provided 4 - 6 different high voltages. Six voltages will be required if each dynode stage is biased separately. It may be desirable to bias the first few (low current, high voltage) stages using a conventional resistor chain, in which case only four voltages will be required. Each calorimeter will contain 11,500 crystals and 11,500 photomultiplier tubes. Groups of 100 tubes will be biased by a single group of high voltage channels.

Most of the BTeV detector elements are rather insensitive to the exact value of the applied high voltage. The EM Calorimeter photomultiplier tubes however, are very sensitive to the high voltage. The magnitude of the photomultiplier signal is proportional to the amount of light produced in the crystal, but depends exponentially on the applied high voltage. In order to monitor sources of gain drift, it is important to monitor the applied high voltage values with good precision.

- **Requirement 3.5-1a:** The Type A supply must produce a negative voltage that is adjustable over the range of 0 V to 400 V. The computer monitor must be accurate to 0.02% of full scale.
- **Requirement 3.5-1b:** The Type B supply must produce a negative voltage that is adjustable over the range of ~0 V to 600 V. The computer monitor must be accurate to 0.02% of full scale.
- **Requirement 3.5-1c:** The type C supply must produce a positive voltage that is adjustable over the range of 0 V to 800 V. The computer monitor must be accurate to 0.01% of full scale.
- **Requirement 3.5-1d:** The type D supply must produce a positive voltage that is adjustable over the range of 0 V to 1000 V. The computer monitor must be accurate to 0.01% of full scale.
- **Requirement 3.5-2:** The peak-to-peak ripple must be less than 100 mV.
- **Requirement 3.5-3:** The output must be stable to 0.2 V over a 24-hour period.
- **Requirement 3.5-4:** The current must be adjusted to 0.1% in the range. The following maximum currents are required: 10 mA for the 400 V units, 2 mA for the 600 V units, 0.5 mA for the 800 V units, and 0.1 mA for the 1000 V units.
- **Requirement 3.5-5:** The current monitor resolution must be 0.1% of the range for all units.
- **Requirement 3.5-5:** The current monitor resolution must be 0.1% of the range for all units.

## 2.15 *Muon Chambers Detector*

Muon identification will be provided in the BTeV spectrometer by two systems of proportional wire chambers and solid iron torroid magnets. The chambers will be electrically similar to the straw tube chambers, but instead of lightweight straws, the tubes will be 3/8 inch diameter stainless steel. The system will contain 2304, 32-channel "planks," each serviced by a 32-channel front-end electronics card, which will also distribute high voltage. Since all of the muon tubes will be the same size, it may be possible to bias a large number of planks with a single high voltage channel.

- **Requirement 3.6-1:** The supply must produce a positive voltage that is adjustable over the range of ~0 V (supply may be a hundred volts or so from zero) to 2000 V. The computer monitor must be accurate to 0.1% of full scale.
- **Requirement 3.6-2:** Ripple {unknown at this time}
- **Requirement 3.6-3:** Stability {unknown at this time}
- **Requirement 3.6-4:** The current must be adjusted to 1% in the range of 0 to 12 μA.
- **Requirement 3.6-5:** The current monitor resolution must be 1% of the range setting.