The BTeV Detector Technical Design Report

March 2004

Spokespersons
J. Butler
Fermilab, PO Box 500, Batavia, IL 60510, USA
S. Stone
Syracuse University, 201 Physics Bldg., Syracuse, NY 13244-1130, USA

G.Y. Drobychev, A.S. Lobko, A.R. Lopatik and R.F. Zouevsky
Belarussian State University, National Science and Education Center, 240040, Minsk
P. Yager
University of California at Davis, Exp. High Energy Group, One Shields Ave., Davis CA 95616-8677 USA
J. Cumalat, P. Rankin and K. Stenson
University of Colorado, High Energy Physics, Campus Box 390, Boulder, CO 80309, USA
J. A. Appel, E. Barsotti, C. N. Brown, J. Butler, H. Cheung, D. Christian,
S. Cihangir, M. Fischler, I. Gaines, P. Garbincius, L. Garren, E. E. Gottschalk,
A. Hahn, G. Jackson, P. Kasper, P. H. Kasper, R. Kutschke, S. W. Kwan, P. Lebrun,
P. McBride, J. Slaughter, M. Votava, M. Wang, and J. Yarba
Fermilab, PO Box 500, Batavia, IL 60510, USA
P. Avery
University of Florida, Gainesville, FL 32611, USA
A. Daniel, K. Lau, M. Ispiryan, B.W. Mayes, V. Rodriguez, and S. Subramania, and G. Xu
University of Houston, Houston, TX 77204-5506, USA
R.A. Burnstein, D.M. Kaplan, L.M. Lederman, H.A. Rubin, and C. White
Illinois Institute of Technology, Chicago, IL 60616, USA
M. Haney, D. Kim, M. Selen, V. Simaitis, and J. Wiss
University of Illinois at Urbana-Champaign, High Energy Physics, 441 Loomis Lab. of Physics, 1110 W. Green St., Urbana, IL 61801-3080, USA
M. Bertani, L. Benussi, S. Bianco, M.A. Caponero, F. Fabbri, A. Felli, M. Giardoni,
A. LaMonaca, E. Pace, M. Pallotta and A. Paolozzi
INFN - Laboratori Nazionali di Frascati, CP 13, via E. Fermi 40, 1-00044, Frascati, Roma, Italy
G. Alimonti, M. Citterio, M. Dinardo, L. Edera, S. Erba, D. Lunesu, S. Magni, D. Menasce,
L. Moroni, D. Pedrini, S. Sala and L. Uplegger
INFN and University of Milano, Italy

G. Boca, G. Cossali, G. Liguori, F. Manfredi, M. Manghisoni, M. Marengo, L. Ratti,
V. Re, M. Santini, V. Speviali, P. Torre, and G. Traversi
INFN - Pavia, Dipartimento di Fisica Nucleare e Teorica, Universita' di Pavia,
Sez. di Pavia, Italy
A. A. Derevschikov, Y. M. Goncharenko, V. Yu. Khodyrev, V. Kravtsov, A. P. Meschanin,
V. Mochalov, D. Morozov, L. V. Nogach, P. Semenov, K. E. Shestermanov, L. F. Soloviev,
A. Uzunian and A. N. Vasiliev
Institute of High Energy Physics (IHEP), Protvino, Moscow Region, Russia
P. Ratcliffe and M. Rovere
University of Insubria in Como
C. Newsom and R. Braunger
The University of Iowa, Department of Physics & Astronomy,
Iowa City, IA 52242-1479
J. Hietala, Y. Kubota, B. Lang, R. Poling, and A. Smith
University of Minnesota, High Energy Physics, Tate Laboratory of Physics,
116 Church St. S.E., Minneapolis, MN 55455, USA
T. Y. Chen, D. Gao, S. Du, Ming Qi, B.P. Zhang, Z. Xi Zhang, and J.W. Zhao
Nanjing University, Dept. of Physics, Nanjing 210008, China
V. Papavassiliou
New Mexico State University
J. Rosen
Northwestern University, Dept. of Physics, Evanston, IL 60208
K. Honscheid, and H. Kagan
Ohio State University, HEP Group, Dept. of Experimental or Theoretical Physics,
Smith Lab, 174 W. 18th Ave., Columbus, OH 43210, USA
W. Selove
University of Pennsylvania, Philadelphia, PA 19104, USA
A. Lopez, H. Mendez, J. E. Ramirez, and W. Xiong
University of Puerto Rico, Mayaguez, Puerto Rico
G. Datao, L. Hao, Ge Jin, T. Yang and X.Q. Yu
University of Science and Technology of China, Department of Modern Physics,
Joint Institute for High Energy Physics, Hefei, Anhui 230027, China
C.F. Feng, Yu Fu, Mao He, J.Y. Li, L. Xue, N. Zhang, and X. Y. Zhang
Shandong University, High Energy Physics Group; Jinan, Shandong 250100, China
T. Coan and M. Hosack
Southern Methodist University, Dallas, TX 75275, USA
M. Artuso, S. Blusk, J. Butt., C. Boulahouache, O. Dorjkhaidav, J. Haynes,
N. Menaa, R. Mountain, H. Muramatsu R. Nandakumar, L. Redjimi, R. Sia, T. Skwarnicki
S. Stone, J. C. Wang, and K. Zhang
Syracuse University, 201 Physics Bldg., Syracuse, NY 13244-1130, USA
T. Handler and R. Mitchell
University of Tennessee, Knoxville, TN 37996-1200, USA

W. Johns, P. Sheldon, E. Vaandering, and M. Webster
Vanderbilt University, Department of Physics and Astronomy,
Nashville, TN 37235, USA
M. Arenton, S. Conetti, B. Cox, and A. Ledovskoy, H. Powell, M. Ronquest,
D. Smith, B. Stephens and Z. Zhe
University of Virginia, High Energy Physics Group, Charlottesville, VA 22901, USA
G. Bonvicini, D. Cinabro, and A. Schreiner
Wayne State University, Department of Physics and Astronomy,
666 W. Hancock, Detroit, MI 48202, USA
M. Sheaff
University of Wisconsin, Phenomenology Inst., Dept. of Physics,
1150 University Ave., Madison, WI 53706, USA
S. Menary
York University, Dept. of Physics
4700 Keele St., Toronto, ON M3J 1P3, Canada

Contents

I Physics drivers for the BTeV technical design

1 Detector Requirements based on Physics Drivers **1-1**
- 1.1 Requirements Based on the Physics of B Production at $\sqrt{s}$ of 2 TeV 1-1
  - 1.1.1 The $b\overline{b}$ Production Cross-Section 1-2
  - 1.1.2 Characteristics of Hadronic b Production 1-3
- 1.2 Requirements Based on the Characteristics of B Decay Modes 1-6
- 1.3 Requirements Due to Characteristics of the Tevatron and the C0 Interaction Region 1-7
- 1.4 Quantitative High Level Requirements 1-8
- 1.5 Summary 1-10

II General description of the BTeV detector

2 Description **2-1**

III Detector Components

3 Magnets, Toroids, and Beam Pipes **3-1**
- 3.1 Overview 3-1
- 3.2 Requirements 3-5
  - 3.2.1 Requirements on the Vertex Magnet 3-5
  - 3.2.2 Requirements on the Toroid 3-6
  - 3.2.3 Beampipe Requirements 3-6
  - 3.2.4 Fault Tolerance 3-7
  - 3.2.5 Installation and Surveying 3-7
  - 3.2.6 Control and Monitoring 3-8
  - 3.2.7 Electrical Requirements 3-8
  - 3.2.8 ES&H Requirements 3-8
  - 3.2.9 Dependencies with Respect to Other Detectors 3-9
- 3.3 Technical Description and Design of the Magnets, Toroids, and Beampipes . 3-9
  - 3.3.1 Vertex Magnet 3-9

3.3.2 Muon Toroids . . . 3-20
3.3.3 Beampipes . . . 3-31
3.4 Power Supply Summary . . . 3-33
3.5 Integration and Testing Plan . . . 3-34
3.5.1 Vertex Magnet tests and integration into the BTeV spectrometer . . . 3-35
3.5.2 Toroid tests and Integration into the BTeV spectrometer . . . 3-36
3.5.3 Tests and Integration of the beampipe sections into the BTeV spectrometer . . . 3-39
3.6 Completed and Planned R&D . . . 3-40
3.6.1 Vertex Magnet . . . 3-40
3.6.2 Muon Toroids . . . 3-40
3.6.3 Beampipes . . . 3-40
3.7 Vertical Trajectory of Beams in C0 . . . 3-41

4 The Pixel Vertex Detector 4-1
4.1 Introduction . . . 4-1
4.2 Requirements . . . 4-1
4.2.1 Resolution . . . 4-2
4.2.2 Efficiency . . . 4-2
4.2.3 Radiation Tolerance . . . 4-3
4.3 Overview . . . 4-3
4.4 Summary of completed R&D . . . 4-5
4.4.1 Introduction . . . 4-5
4.4.2 Sensor Development . . . 4-6
4.4.3 Pixel readout chip . . . 4-14
4.4.4 Bump bonding development . . . 4-21
4.4.5 Multichip Module . . . 4-24
4.4.6 RF shielding issues . . . 4-29
4.4.7 Mechanical support, cooling and vacuum system . . . 4-30
4.5 Technical Description . . . 4-46
4.5.1 Pixel Detector Specifications . . . 4-46
4.5.2 Front-end chip . . . 4-46
4.5.3 Sensor . . . 4-49
4.5.4 Bump Bonding . . . 4-51
4.5.5 Modules . . . 4-51
4.5.6 Readout and control . . . 4-53
4.5.7 Mechanical Support . . . 4-54
4.5.8 Vacuum vessel . . . 4-61
4.5.9 Cooling . . . 4-62
4.5.10 Vacuum system . . . 4-64
4.5.11 Feed-through board . . . 4-70
4.5.12 Actuators . . . 4-70

4.5.13 RF shielding . . . 4-73
4.5.14 Power distribution . . . 4-73
4.5.15 Control and Monitoring . . . 4-73
4.6 Remaining R&D . . . 4-74
4.7 Production - QA and Testing . . . 4-76
4.7.1 Overview . . . 4-76
4.7.2 Sensor Tests . . . 4-78
4.7.3 Pixel Readout chips . . . 4-79
4.7.4 Bump Bonding . . . 4-79
4.7.5 HDI and interconnect flex cable . . . 4-80
4.7.6 Data Combiner Board . . . 4-80
4.7.7 Substrate . . . 4-80
4.7.8 Substrate support structure . . . 4-80
4.7.9 Feed-through board . . . 4-81
4.7.10 Database . . . 4-81
4.8 Performance . . . 4-82
4.8.1 Spatial Resolution . . . 4-82
4.8.2 Pattern Recognition Capability . . . 4-83
4.8.3 Radiation Hardness . . . 4-83
4.8.4 Material Thickness . . . 4-84
4.8.5 Readout Speed . . . 4-86
4.8.6 Physics Capability . . . 4-86
4.9 Cost, schedule and Risk analysis . . . 4-86
4.9.1 Cost . . . 4-86
4.9.2 Schedule . . . 4-87
4.9.3 Production Risk Analysis . . . 4-87
4.9.4 Operation Risk Analysis . . . 4-90

5 Charged Particle Identification System 5-1
5.1 Introduction . . . 5-1
5.2 Requirements . . . 5-2
5.2.1 Physics Requirements . . . 5-2
5.2.2 Radiation hardness . . . 5-3
5.2.3 Geometrical Requirements . . . 5-3
5.2.4 Mirror Requirements . . . 5-3
5.2.5 Electronics Requirements . . . 5-4
5.2.6 Readout Requirements . . . 5-5
5.2.7 Electrical and magnetic interference . . . 5-5
5.2.8 Mechanical Properties of the front end hybrids . . . 5-6
5.2.9 Cooling System . . . 5-6
5.2.10 Gas and Liquid Systems . . . 5-6
5.2.11 Power Supplies . . . 5-7

5.2.12 Monitoring . . . 5-7
5.2.13 Electrical Requirements . . . 5-8
5.2.14 Electronics Protection . . . 5-8
5.2.15 Functional Requirements . . . 5-8
5.2.16 Requirements on Rest of BTeV . . . 5-8
5.3 System Overview . . . 5-9
5.4 Technical Description . . . 5-9
5.4.1 Selection of RICH Radiators . . . 5-9
5.4.2 Liquid Radiator . . . 5-14
5.4.3 Gas Radiator . . . 5-16
5.4.4 Mirrors . . . 5-17
5.4.5 Photodetector Planes and Tank Structure . . . 5-19
5.4.6 Photodetectors for the C_4F_8O radiator . . . 5-22
5.4.7 Photodetectors for the C_5F_{12} Liquid Radiator . . . 5-30
5.4.8 Power Supplies . . . 5-32
5.4.9 Monitoring . . . 5-33
5.5 Completed R & D . . . 5-34
5.5.1 Development of MAPMT System for the Gas Radiator . . . 5-34
5.5.2 Development of HPD System for the Gas Radiator . . . 5-38
5.5.3 Mirrors . . . 5-43
5.5.4 Liquid Radiator . . . 5-50
5.5.5 Radiation Damage Studies . . . 5-55
5.6 Planned R&D . . . 5-56
5.6.1 Beam Test of Photodetection Systems . . . 5-56
5.6.2 Beam Test of the Liquid Radiator . . . 5-57
5.6.3 R&D on Mirrors . . . 5-57
5.6.4 Mirror And MAPMT Plane Alignment . . . 5-61
5.7 Production Quality Assurance and Testing . . . 5-65
5.7.1 Photon Detectors for Gas System . . . 5-66
5.7.2 Single Anode PMTs . . . 5-69
5.7.3 Readout Electronics . . . 5-69
5.7.4 Mirror Tile testing . . . 5-70
5.7.5 Liquid and Gas Radiators . . . 5-71
5.7.6 Testing of High and Low Voltage Power Supplies . . . 5-71
5.7.7 High and Low Voltage Cables . . . 5-73
5.7.8 MAPMT and PMT Electronics Cooling Cooling System . . . 5-73
5.8 Expected Performance of the RICH . . . 5-73
5.8.1 Detector Simulations . . . 5-74
5.8.2 Signal Simulations . . . 5-87
5.9 Cost, Schedule and Risk Analysis . . . 5-94
5.9.1 RICH Risk Analysis and Management . . . 5-94
5.10 Participants and Group Organization . . . 5-95

5.10.1 Level 2 Project Management 5-95
5.10.2 Participants 5-95

6 Electromagnetic Calorimeter 6-1
6.1 General Overview 6-1
6.2 Basic Requirements 6-3
6.3 Lead Tungstate Crystals 6-3
6.3.1 Test Bench Measurements 6-7
6.3.2 IHEP Test Beam Facility 6-9
6.3.3 Resolutions 6-11
6.3.4 Electromagnetic shower transverse profile 6-15
6.3.5 Light response non-uniformity 6-17
6.3.6 Radiation Hardness 6-22
6.3.7 Crystal Specification 6-33
6.4 Photodetectors and Read-out Electronics 6-34
6.4.1 Photomultipliers 6-34
6.4.2 PMT gain variations and monitoring 6-36
6.4.3 High Voltage Distribution System 6-38
6.4.4 Front-End Electronics 6-38
6.5 Calibration and Light Monitoring System 6-41
6.5.1 Energy Calibration using Electrons 6-42
6.5.2 Light Pulser System 6-45
6.5.3 Light Monitoring System for BTeV Calorimeter 6-53
6.6 Mechanical Structure 6-58
6.6.1 Cooling and Humidity Control System 6-60
6.7 Detector Assembly, Installation and Integration 6-62
6.7.1 Testing Prior to Moving to C0 6-62
6.7.2 Transportation of Elements to C0 6-63
6.8 Detector Performance 6-63
6.8.1 ECAL Simulation 6-63
6.8.2 Photon and π^0's Reconstruction Procedure 6-64
6.8.3 Physics Simulation 6-66
6.9 Future R & D Studies Plan 6-72
6.9.1 Testbeam Study at Protvino and Fermilab 6-73
6.9.2 Crystal Quality Assurance Study 6-73
6.9.3 Crystal Calibration 6-76
6.10 Schedule and Costs 6-77
6.10.1 Planning 6-77
6.10.2 Costs 6-77
6.11 Organization 6-77
6.11.1 Participating institutes 6-77
6.11.2 Responsibilities 6-78

7 Muon Detector **7-1**
7.1 Introduction . . . 7-1
7.2 Muon System Overview . . . 7-1
7.2.1 General design considerations . . . 7-1
7.2.2 Baseline muon system . . . 7-2
7.3 Requirements for the BTeV Muon System . . . 7-4
7.3.1 Physics requirements . . . 7-5
7.3.2 Toroid requirements . . . 7-5
7.3.3 Proportional tube performance requirements . . . 7-5
7.3.4 Detector installation and support requirements . . . 7-6
7.3.5 Geometry requirements . . . 7-6
7.3.6 Correction dipole requirements . . . 7-6
7.3.7 Control and monitoring . . . 7-7
7.3.8 Software requirements . . . 7-7
7.3.9 ES&H requirements . . . 7-8
7.3.10 Electrical requirements . . . 7-8
7.3.11 Front-end electronics requirements . . . 7-8
7.3.12 Internal Interlocks . . . 7-9
7.4 Technical Description . . . 7-9
7.4.1 Muon detectors . . . 7-10
7.4.2 Front-end electronics . . . 7-11
7.4.3 Mounting, support, and infrastructure . . . 7-12
7.5 Design trade-offs . . . 7-16
7.5.1 Magnetized vs. non-magnetized toroids . . . 7-16
7.6 Past Research and Development Work . . . 7-19
7.6.1 Summer 1999 beam test . . . 7-19
7.6.2 Plank design/construction . . . 7-19
7.6.3 Plank and gas tests . . . 7-21
7.6.4 Construction database . . . 7-23
7.6.5 Wire tension measurement . . . 7-23
7.6.6 Detector construction and support . . . 7-24
7.6.7 Front-end electronics . . . 7-25
7.7 Planned Research and Development Work . . . 7-27
7.7.1 MTEST beam test . . . 7-27
7.7.2 High dose test . . . 7-28
7.7.3 Prototype electronics and plank interface . . . 7-29
7.7.4 Mechanical refinements and tests . . . 7-30
7.7.5 Octant test stand . . . 7-32
7.7.6 Plank construction jig . . . 7-32
7.7.7 Prototype gas system . . . 7-33
7.7.8 C0 background studies . . . 7-33
7.7.9 Simulation and reconstruction work . . . 7-33

7.8 Production Plan . . . 7-34
7.8.1 Construction overview . . . 7-34
7.8.2 Plank fabrication . . . 7-37
7.8.3 Fabrication of manifolds, support ribs, and Delrin inserts . . . 7-38
7.8.4 Electronics QAP . . . 7-41
7.8.5 Octant assembly and QAP . . . 7-41
7.9 Installation, Integration and Testing Plans (at C0) . . . 7-42
7.9.1 Transportation of muon detector octants to C0 . . . 7-42
7.9.2 Installation of muon system elements at C0 . . . 7-42
7.9.3 Testing of muon system elements at C0 . . . 7-46
7.10 Performance . . . 7-47
7.10.1 Occupancies . . . 7-47
7.10.2 Dimuon trigger . . . 7-48
7.11 Test Results . . . 7-49

8 Forward Straw Detector 8-1
8.1 Introduction . . . 8-1
8.2 Requirements . . . 8-1
8.3 Baseline Design . . . 8-2
8.4 Detector Components . . . 8-2
8.4.1 Module Description . . . 8-2
8.4.2 Module Components . . . 8-5
8.4.3 Half-view frame description . . . 8-8
8.4.4 Half-view frame components . . . 8-9
8.4.5 Special Module for Forward Silicon support . . . 8-16
8.4.6 Station 7 . . . 8-16
8.4.7 Beam-Line Supports . . . 8-18
8.4.8 Material Budget . . . 8-20
8.5 Calibration, Monitoring and Control Systems . . . 8-21
8.5.1 Straw Gas System . . . 8-21
8.5.2 Water Cooling System . . . 8-23
8.5.3 Environmental Control and Monitoring . . . 8-24
8.6 Performance . . . 8-24
8.6.1 Resolution . . . 8-24
8.6.2 Occupancy and Tracking efficiency . . . 8-24
8.7 Front-End Electronics . . . 8-28
8.7.1 Introduction . . . 8-28
8.7.2 Anode Pinning Plate (APP) . . . 8-28
8.7.3 High Voltage Network Card (HVNC) . . . 8-29
8.7.4 High Voltage/Low Voltage Bus (HVLVB) . . . 8-30
8.7.5 Preamplifier/Discriminator Card (PDC) . . . 8-30
8.7.6 Time to Digital Converter Card (TDCC) . . . 8-31

8.7.7 TDC ASIC . . . 8-32
8.7.8 I/O Interface . . . 8-33
8.7.9 Data Combiner Board (DCB) - Straw Daughter Card . . . 8-41
8.7.10 Straw High Voltage System . . . 8-42
8.7.11 Straw Low Voltage System . . . 8-42
8.8 Installation, Integration and Testing Plans . . . 8-43
8.8.1 Summary of Testing Prior to Moving to C0 . . . 8-43
8.8.2 Transportation of Straw Detector Equipment to C0 . . . 8-43
8.8.3 Installation of Straw Detector at C0 . . . 8-43
8.8.4 Testing at C0 . . . 8-45
8.9 R&D , Open Design Issues . . . 8-45
8.9.1 Prototype Detector . . . 8-45
8.9.2 Straw Material . . . 8-46
8.9.3 Gas Studies . . . 8-47
8.9.4 Aging studies . . . 8-58
8.9.5 Capillary Fusing . . . 8-62
8.9.6 Magnetic Field Effects . . . 8-67
8.10 Production, Production Testing, and Quality Assurance Plan . . . 8-70
8.10.1 Straw Preparation Site . . . 8-70
8.10.2 Anode Preparation Site . . . 8-70
8.10.3 Module Assembly Sites, including MOX-Silicon Support . . . 8-70
8.10.4 Half-View Assembly Sites . . . 8-71
8.10.5 Electronics Sites . . . 8-71
8.10.6 Survey Site . . . 8-72
8.10.7 Gas and Environmental Monitoring Site . . . 8-72
8.10.8 Other Systems . . . 8-73
8.10.9 Various tooling and fixtures . . . 8-73
8.10.10 Test Beam Studies . . . 8-73

9 Forward Silicon Tracker 9-1
9.1 Introduction . . . 9-1
9.2 Forward Silicon Tracker general requirements . . . 9-2
9.2.1 Resolution and mass . . . 9-3
9.2.2 Readout . . . 9-3
9.2.3 Radiation hardness . . . 9-4
9.2.4 Dimensions . . . 9-4
9.2.5 Electrical & Magnetic Interference . . . 9-5
9.3 Sensors . . . 9-5
9.4 Electronic Readout . . . 9-8
9.4.1 Readout chip . . . 9-8
9.5 Hybrids and Flex cables . . . 9-14
9.6 Mechanical support and cooling system . . . 9-15

9.6.1 Requirements . . . 9-15
9.6.2 Implementation . . . 9-19
9.6.3 Fiber grating positioning monitor . . . 9-22
9.6.4 Cooling system . . . 9-24
9.7 R & D . . . 9-26
9.7.1 Sensors characterization and irradiation tests . . . 9-26
9.8 DAQ system for tests and production . . . 9-32
9.8.1 Introduction . . . 9-32
9.8.2 Description . . . 9-33
9.9 Silicon Strip Detector Production Plan . . . 9-37
9.9.1 Introduction . . . 9-37
9.9.2 Logical Organization of the Production . . . 9-37
9.9.3 Half-Plane Production . . . 9-37
9.9.4 External Support Mechanics . . . 9-40
9.9.5 Cooling System . . . 9-41
9.9.6 External Cables . . . 9-41
9.9.7 Low & High Voltage Power Supplies . . . 9-41
9.9.8 Junction Cards . . . 9-41
9.9.9 Data Combiner Boards . . . 9-42
9.10 Installation, Integration and Testing Plans (at C0) for the micro-strip Forward Tracker . . . 9-42
9.10.1 Introduction . . . 9-42
9.10.2 Summary of Testing Prior to Moving to C0 . . . 9-42
9.10.3 Transportation of Level 2 Subproject Elements to C0 . . . 9-43
9.10.4 Installation of Level 2 Subproject Elements at C0 . . . 9-43
9.10.5 Testing at C0 . . . 9-44

10 Front End Electronics 10-1
10.1 Introduction . . . 10-1
10.2 Pixel Detector . . . 10-2
10.2.1 Overview . . . 10-2
10.2.2 Component Quantities and Locations . . . 10-3
10.2.3 Data Structure . . . 10-3
10.2.4 Occupancy and Data Rate Estimate . . . 10-4
10.2.5 Initialization, Control, and Monitoring . . . 10-5
10.3 RICH Detector . . . 10-5
10.3.1 Overview . . . 10-5
10.3.2 Component Quantities . . . 10-6
10.3.3 Data structure . . . 10-7
10.3.4 Occupancy and Data Rate Studies . . . 10-8
10.3.5 Initialization, Control and Monitoring . . . 10-9
10.4 Electromagnetic Calorimeter . . . 10-9

10.4.1 Overview . . . 10-9
10.4.2 Component Quantities and Locations . . . 10-10
10.4.3 Data Structure . . . 10-10
10.4.4 Occupancy and Data Rate Estimate . . . 10-12
10.4.5 Initialization, Control, and Monitoring . . . 10-12
10.5 Muon Detector . . . 10-12
10.5.1 Overview . . . 10-12
10.5.2 Component Quantities and Locations . . . 10-13
10.5.3 Data Structure . . . 10-14
10.5.4 Occupancy and Data Rate Estimate . . . 10-14
10.5.5 Installation, Control and Monitoring . . . 10-15
10.6 Forward Straw Detector . . . 10-16
10.6.1 Overview . . . 10-16
10.6.2 Component Quantities and Locations . . . 10-16
10.6.3 Data Structure . . . 10-16
10.6.4 Occupancy and Data Rate Estimate . . . 10-17
10.6.5 Initialization, Control, and Monitoring . . . 10-18
10.7 Forward Silicon Detector . . . 10-19
10.7.1 Overview . . . 10-19
10.7.2 Component Quantities and Locations . . . 10-19
10.7.3 Data Structure . . . 10-19
10.7.4 Occupancy and Data Rate Estimate . . . 10-20
10.7.5 Initialization, Control, and Monitoring . . . 10-21
10.8 Data Rate Summary . . . 10-21

IV Data Acquisition, Monitoring and Control, and Trigger Electronics

11 The BTeV Trigger 11-1
11.1 Introduction . . . 11-1
11.2 Overview . . . 11-1
11.3 Requirements . . . 11-5
11.3.1 Rate Requirements . . . 11-5
11.3.2 Algorithm Requirements . . . 11-6
11.3.3 Output Data Rate Requirements . . . 11-6
11.3.4 Rejection and Efficiency Requirements . . . 11-6
11.3.5 Global Level 1 Requirements . . . 11-8
11.3.6 Livetime and Uptime Requirements . . . 11-9
11.3.7 Excess Capacity and Scalability Requirements . . . 11-10
11.3.8 Flexibility Requirements . . . 11-10
11.3.9 Fault Tolerance and Security Requirements . . . 11-10

11.3.10 Detector Performance Envelope . . . 11-11
11.3.11 Supervision and Monitoring Requirements . . . 11-11
11.3.12 Support for Commissioning and Debugging . . . 11-12
11.3.13 Electrical Requirements . . . 11-12
11.3.14 Software Requirements . . . 11-12
11.3.15 Safety Requirements . . . 11-13
11.4 Technical Description and Implementation . . . 11-13
11.4.1 Overview . . . 11-13
11.4.2 L1 Pixel Trigger . . . 11-16
11.4.3 L1 Muon Trigger . . . 11-20
11.4.4 Global Level 1 Trigger . . . 11-26
11.4.5 L2/3 Trigger . . . 11-27
11.5 L1 Pixel Trigger Hardware and Simulations . . . 11-27
11.5.1 Data Flow Analysis . . . 11-27
11.5.2 Pixel Preprocessor . . . 11-31
11.5.3 Segment Finder Hardware . . . 11-32
11.5.4 Level 1 Track and Vertex Farm Switch . . . 11-37
11.5.5 L1 Pixel Trigger Algorithm Timing Studies . . . 11-39
11.5.6 L1 Hardware Hash Sorter . . . 11-43
11.5.7 FPGA Segment Matcher . . . 11-47
11.5.8 Pre-prototype L1 Track and Vertex Hardware . . . 11-49
11.5.9 L1 Performance . . . 11-58
11.5.10 L1 Muon Trigger Hardware and Simulations . . . 11-65
11.5.11 GL1 Trigger . . . 11-72
11.6 L2/3 Hardware, Software and Simulations . . . 11-74
11.6.1 L2/3 Hardware . . . 11-74
11.6.2 L2/3 Software . . . 11-84
11.6.3 Risk Mitigation for L3 Processing Speed and Event Size Reduction . 11-92
11.7 Trigger Supervision and Monitoring . . . 11-96
11.7.1 Overview . . . 11-96
11.7.2 Architecture . . . 11-99
11.7.3 TSM Software . . . 11-101
11.8 RTES . . . 11-104
11.8.1 Overview . . . 11-104
11.8.2 RTES Deliverables . . . 11-105
11.8.3 R&D Activities . . . 11-108
11.9 Production Plan . . . 11-113
11.9.1 L1 Pixel Trigger . . . 11-113
11.9.2 L1 Muon Trigger . . . 11-116
11.9.3 Global Level 1 Trigger . . . 11-117
11.9.4 L2/3 Hardware . . . 11-118
11.9.5 L2/3 Software . . . 11-119

12 Event readout and control electronics software 12-1
12.1 Introduction . . . 12-1
12.2 Readout and Controls System Requirements . . . 12-1
12.2.1 Rate Requirements . . . 12-2
12.2.2 Excess Capacity and Scalability . . . 12-2
12.2.3 Readout Electronics . . . 12-2
12.2.4 Highway Switch and Event Building . . . 12-3
12.2.5 Timing and Control . . . 12-4
12.2.6 Firmware . . . 12-4
12.2.7 Test and Maintainability . . . 12-4
12.2.8 Readout, Control and Monitor Software . . . 12-5
12.2.9 Run Management . . . 12-5
12.2.10 Partitioning . . . 12-5
12.2.11 Trigger and Detector Managers . . . 12-6
12.2.12 Data Storage . . . 12-6
12.2.13 Slow Controls . . . 12-7
12.2.14 Control and Data Network . . . 12-7
12.2.15 Control Room . . . 12-7
12.2.16 Databases . . . 12-7
12.2.17 Test Stands . . . 12-7
12.2.18 Safety and Security . . . 12-8
12.3 System Overview and Requirements . . . 12-8
12.4 Technical Description . . . 12-11
12.4.1 Timing and Control . . . 12-12
12.4.2 Front-End Interface and Data Combiner . . . 12-15
12.4.3 Data Combiner . . . 12-16
12.4.4 Optical Links . . . 12-17
12.4.5 L1 Buffers . . . 12-18
12.4.6 Network . . . 12-20
12.4.7 Event Identification, Event Building and Event Distribution . . . 12-22
12.4.8 Data Logging . . . 12-24
12.4.9 Common Electronics Features . . . 12-24
12.4.10 Software Infrastructure . . . 12-24
12.4.11 Readout Software . . . 12-25
12.4.12 Detector Support . . . 12-26
12.4.13 Detector Control System (DCS) . . . 12-27
12.4.14 Databases . . . 12-28
12.4.15 Test Stand and Test Beam Support . . . 12-30
12.4.16 Integration Test Facility . . . 12-30
12.4.17 Infrastructure: The BTeV Counting and Control Rooms . . . 12-30
12.5 R&D . . . 12-32
12.5.1 Architecture . . . 12-32

12.5.2 Front-end . . . 12-33
12.5.3 Serial Links . . . 12-35
12.5.4 Built-in Test . . . 12-35
12.5.5 Embedded Processing . . . 12-36
12.5.6 Network . . . 12-36
12.5.7 Readout Software . . . 12-37
12.6 Production, Testing and Integration . . . 12-37
12.6.1 Read-Out Electronics . . . 12-37
12.6.2 Data Acquisition Software . . . 12-39
12.6.3 Detector Control System . . . 12-39
12.6.4 Databases . . . 12-40
12.6.5 Control and Data Networks . . . 12-40
12.6.6 Infrastructure and Integration . . . 12-40
12.7 Performance . . . 12-40
12.8 Cost, Schedule, and Risk Analysis . . . 12-40
12.9 Organization . . . 12-40

V Integration, Installation, and Commissioning

13 Integration, Installation, and Commissioning 13-1
13.1 Introduction . . . 13-1
13.1.1 Interface to WBS 2.0 and WBS 3.0 . . . 13-2
13.1.2 Interfaces to Detector subprojects . . . 13-4
13.2 Requirements . . . 13-5
13.2.1 Installation Requirements . . . 13-5
13.2.2 Integration requirements . . . 13-6
13.2.3 Commissioning Requirements . . . 13-7
13.3 Infrastructure . . . 13-8
13.3.1 Physical Infrastructure . . . 13-8
13.3.2 Electrical and Electronics Infrastructure . . . 13-14
13.3.3 BTeV Detector Grounding Scheme . . . 13-18
13.4 Common Installation Activities . . . 13-22
13.4.1 Overview of BTeV Relay Racks . . . 13-22
13.4.2 Counting Room Racks . . . 13-24
13.4.3 Collision Hall Racks and Access Platforms . . . 13-24
13.4.4 Cables . . . 13-25
13.4.5 Slow Controls and Monitoring . . . 13-27
13.4.6 Gas and Coolant Distribution Systems . . . 13-29
13.4.7 Survey and Alignment . . . 13-30
13.5 Installation Sequence . . . 13-33
13.5.1 Installation Overview . . . 13-33

13.5.2 Detailed Installation Sequence 13-34
13.6 Detector Installation Details 13-41
13.6.1 Magnets and Beam Pipes 13-41
13.6.2 Pixel Detector 13-43
13.6.3 RICH 13-46
13.6.4 Electromagnetic Calorimeter 13-49
13.6.5 Muon Chambers 13-50
13.6.6 Straw Tracker 13-52
13.6.7 Silicon Strip Tracker 13-55
13.6.8 Trigger 13-56
13.6.9 DAQ 13-58

VI Equipment Safety and Protection

14 Equipment **14-1**

VII Project Management

15 Project Management **15-1**
15.1 The BTeV Management Task 15-1
15.2 BTeV Project Office and Overall Project Management 15-2
15.2.1 Composition and Mission of the Project Office 15-3
15.2.2 Functions of the Project Management Office 15-4
15.2.3 Key Roles in BTeV Project Management/Project Office 15-6
15.2.4 BTeV Technical Board 15-9
15.3 BTeV Detector Work Breakdown Structure 15-10
15.4 BTeV Management Procedures 15-12
15.4.1 Internal Reviews 15-12
15.4.2 BTeV External Review of Project Management 15-13
15.4.3 External Agency or Fermilab Reviews 15-14
15.4.4 Reporting 15-14
15.4.5 Assignment of Responsibility for Work 15-14

Appendices

A Effects on BTeV Sensitivities of Different Tevatron Bunch Spacings **A-1**
A.1 Introduction A-1
A.2 Effects on the Trigger A-3
A.2.1 The Detached Vertex Trigger A-3
A.2.2 The di-Muon Trigger A-4
A.3 Effects on the Charged Particle Tracking A-6

A.4 Effects on the Particle Identification by the Ring Imaging Cherenkov Counter (RICH) A-9
A.4.1 The Gas Radiator System A-9
A.4.2 The liquid radiator system A-13
A.5 Effects on the Reconstruction of π^o's and η's by the Electromagnetic Calorimeter A-14
A.5.1 Effects on $B \rightarrow \rho^+\pi^-$ due to changes in π^o's A-14
A.5.2 Effects on $B_s \rightarrow J/\psi\eta$ due to changes in η's A-15

Part I

Physics drivers for the BTeV technical design