Chapter 2

Baseline Detector

2.1 Introduction

The PHENIX detector configuration is essentially unchanged from that presented in the Conceptual Design Report (CDR). The solid angle coverage of the inner detectors, the central arms and the forward muon arm is the same, except for slight modifications that were required as the subsystem designs became more realistic. Channel counts remained nearly unchanged as the designs for the detector subsystems matured.

In the CDR a "Baseline" version of the detector was defined. In the baseline version, certain subsystem components were deferred for budgetary reasons. These included the muon arm instrumentation, the inner coils of the central magnet, and high level triggers for the data acquisition system. Other subystem components were regarded as future upgrades. These included the transition radiation detection (TRD) capability of the time expansion chamber (TEC), the high resolution scintillating crystals (HRX) in the electromagnetic calorimeter (EMCal), and the inner hadron-blind detector (HBD). The present version of the detector retains the same menu of deferrals and upgrades.

At the time the CDR was written, a number of technology choices remained to be decided. These included the layout of the multiplicity/vertex detector (MVD), the cathode geometry of the pad chambers (PC) and the focal plane detector of the ring imaging cherenkov counter (RICH). These choices have now all been made.

Chapters 4 through 12 present the details of design changes and technology choices that have been made during the 10 months since the CDR was submitted. Chapter 12, which describes the offline computing effort, is new. The rest of this chapter is devoted to a brief summary of these updates to the baseline detector. Table 2.1 is a basic parameter list for the baseline detctor.

2.2 Coverage and Geometry

As indicated above, the basic layout and coverage of the three spectrometer arms and the inner detectors remains unchanged. Small adjustments have been made in the course of

Table 2.1: Parameter List for the Baseline PHENIX Detector

Detector	Solid Angle		Radial Allocation	Spatial resolution	2 Particle Resolution	Timing Resolution	Number of Channels	Preamp Gain	Shaping TC	Storage Type	ADC Word	Digital Conversion
	$\Delta\eta$	$\Delta\phi$	(mm)	(mm)	(mm)			(mv/fc)	(ns)		Width*	
BB	±(3.1- 4.0)	360°	-	25	-	70 ps	132	(pmt)	(pmt)	DMU	10/10	Flash ADC
MVD	±2.7	360°	50-200	0.2 (z)	-	-	34816	40	60	AMU	8/8	ADC
DC	±0.35	90°+90°	2050-2450	0.15 (r-ϕ)	1.5	-	10240	15	10	DMU	9/16	pTDC
PC1	±0.35	90°+90°	2475-2525	2 (r-ϕ) 2 (z)	8 (r-ϕ) 8 (z)	-	15616	3	400	AMU	11/11	ADC
RICH	±0.35	90°+90°	2575-4100	1° (θ) 1° (ϕ)	2° (θ) 2° (ϕ)	-	6400	(pmt)	(pmt)	DMU	8/8 8/8	TAC/ Flash ADC
PC2	±0.35	90°+90°	4150-4210	3 (r-ϕ) 3 (z)	12 (r-ϕ) 12 (z)	-	15232	2	400	AMU	11/11	ADC
TEC	±0.35	90°+90°	4217-4910	0.25 (r-ϕ)	4 (r-ϕ) 5 (z)	14 ns	28032	20	70	DMU	5/9	Flash ADC
PC3	±0.35	90°+90°	4910-4980	4 (r-ϕ) 4 (z)	16 (r-ϕ) 16 (z)	-	15552	2	400	AMU	11/11	ADC
ToF	±0.35	30°	5030-5180	15 (r-ϕ) 15 (z)	15 (z)	80 ps	2048	(pmt)	(pmt)	AMU	10/10 12/12	TAC/ADC
EMCal - PbSc	±0.35	90°+45°	5030-5930	8 @ 1 GeV	70	180 ps @ 0.5 GeV	15552	(pmt)	(pmt)	AMU	11/15	TAC/ADC
EMCal - PbGl	±0.35	45°	5230-6130	6 @ 1 GeV	50	310 ps @ 0.5 GeV	9984	(pmt)	(pmt)	AMU	11/15	TAC/ADC
Muon Tracking	1.15-2.35	360°	-	0.2	1.5	-	19680	15	30	DMU	7/16	pTDC
Muon ID	1.15-2.35	360°	-	1° (ϕ) 5.6° (θ)	2° (ϕ) 11.2° (θ)	<100 ns	18360	1	70	AMU	8/8	ADC

* For the ADC word width the first value is the number of ADC bits and the second is the effective resolution with ranging.

integrating the mechanical design. Table 2.1 summarizes the coverage (θ and ϕ) of the detectors in the central and forward arms, and the inner detectors subsystem.

2.3 Magnets

Numerous refinements in the magnet system have been made in the course of finalizing the design. However, the basic specifications of both magnets are unchanged since the CDR was submitted. The final design is reviewed in Chapter 4; salient changes are listed here.

1. The shape of the CM polefaces has been slightly modified to reduce the fringe field in the region of the RICH focal plane, and to make it possible to move the frames of DC and PC1 further from the active area of the central arms. This was found to be important in reducing the photon-conversion background in the RICH.

2. The bore in the MM piston was increased from 12 to 22 cm diameter. This allows sufficient clearance for the beams in asymmetric (p + A and A + p) running conditions, with less than a 1% reduction in the field strength of the MM.

3. The five upper "lampshade" plates of the MM flux return have been segmented, and the ends of these lampshade plates nearest CM form a fixed arch. See Chapter 4 for figures and details. This change has several technical virtues, the main ones being that (a) the downstream, removable parts of the lampshade are now all independently removable, and (b) the upstream and downstream edges of the fixed arch provide simple, stable mounting surfaces for μT stations #1 and #2.

4. Following discussions with potential fabricators, the CM steel has been segmented differently than in the CDR version. The result is that all parts are now small enough to be cast or forged by all fabricators.

5. A rail system for the CM and the central carriages has been designed so that it will be relatively easy and quick to move CM 1.5-m upstream of the collision point, allowing access to the BB array near MM and to the μT station #1. The rail system, which is described in detail in Chapter 13, also allows motion of CM and the central carriages in and out of the collision hall, although this is not designed to be a quick operation.

2.4 Central Arms

The central arms are composed of detector elements that perform the functions of charged particle tracking and momentum measurement, electron and photon energy measurement, and particle identification. Although the arrangement and function of the central arm components is unchanged, there have been slight adjustments in the radial boundaries between detectors. These are summarized in Table 2.1. In addition, the subsystems outside the RICH (i.e., PC2, TEC, PC3, TOF, and EMCal) have now been subdivided into four sectors per arm instead of two. This is a better approximation to a cylindrical design and improves the performance by limiting the range of incident angles of charged particles on these detectors. Figure 2.1 is a cross-section of the PHENIX detector thats shows the central arm detector layout at the nominal collision point in the major facility hall, along with the radial dimensions of the detectors. An isometric view of the PHENIX detector is shown in Fig. 2.2.

2.4.1 Charged Particle Tracking and Momentum Measurement

The magnetic field and tracking chamber arrangement is the same as that in the CDR. The implementation of the TEC has been changed to reflect further study of its eventual upgrade to a TRD tracker. In the present design, all six layers of the TEC chamber will be built and installed in the baseline detector, whereas only four of six were previously planned. However, in the baseline, only four of the six layers will be instrumented with electronics. The radiator packs, the xenon recirculating system, and the additional electronics will be built and installed in the upgrade.

2.4.2 Electron and Photon Energy Measurements

A minor change in the dimensions of PbSc calorimeter modules and supermodules has been made in light of the resegmentation of the EMCal walls. The final dimensions of individual elements of the PbSc are 5.5×5.5 cm^2. This has reduced the channel count, as reflected in Table 2.1.

2.4.3 Particle Identification

The philosophy of particle ID for electrons and hadrons in the central arms is unchanged from the CDR. The current status of particle ID components is listed below:

1. **Time-of-Flight:** A compact design of the precision TOF elements, with the PMTs folded back along the scintillator slats using 180° light guides, has been shown to work well. Beam tests give $\sigma_t \approx 88$ ps. The mechanical design of the precision TOF wall has been finalized, using this type of element.

2. **Cherenkov Counter:** At the time the CDR was written the focal plane detector technology for the RICH had not been chosen. The choices were an array of PMTs, and a readout based on a parallel-plate avalanche counter with cathode pads and a solid CsI photocathode. In spite of very encouraging test results with the CsI-based technology, a decision was taken to use the PMT version in the Baseline. Although the CsI system might eventually be less expensive than a PMT-based readout, it was determined that it is now too early in its development to base such a large-scale detector upon it. An essentially similar readout technology is still being studied for a hadron-blind detector (HBD) that might serve as an inner tracker for Dalitz rejection. The HBD is a possible upgrade for PHENIX and is presented in Chapter 16.

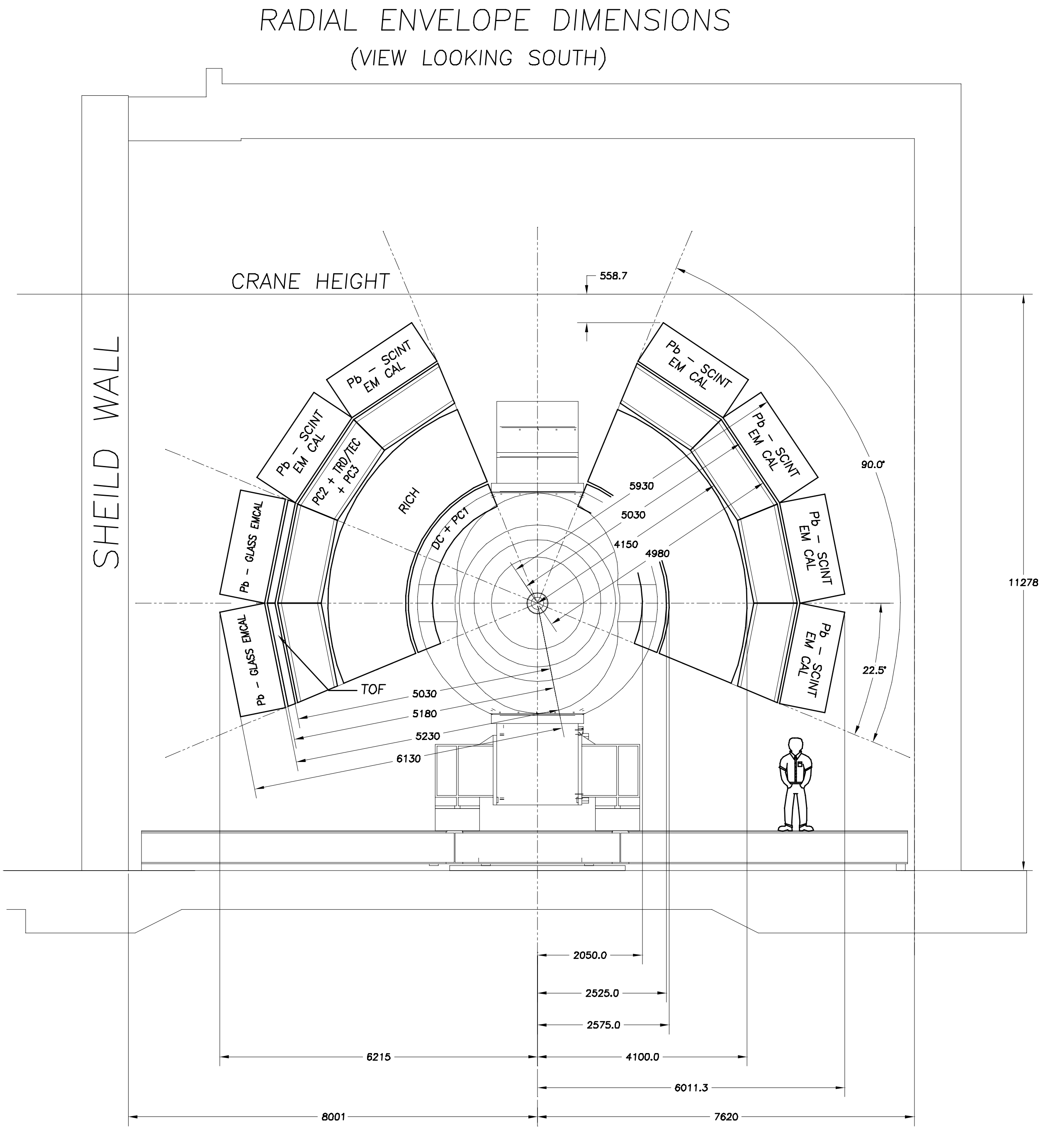

Figure 2.1: Cross-section of the detector through the nominal collision point, showing the layout of detector subsystems in the central arms and the radial boundaries between subsystems.

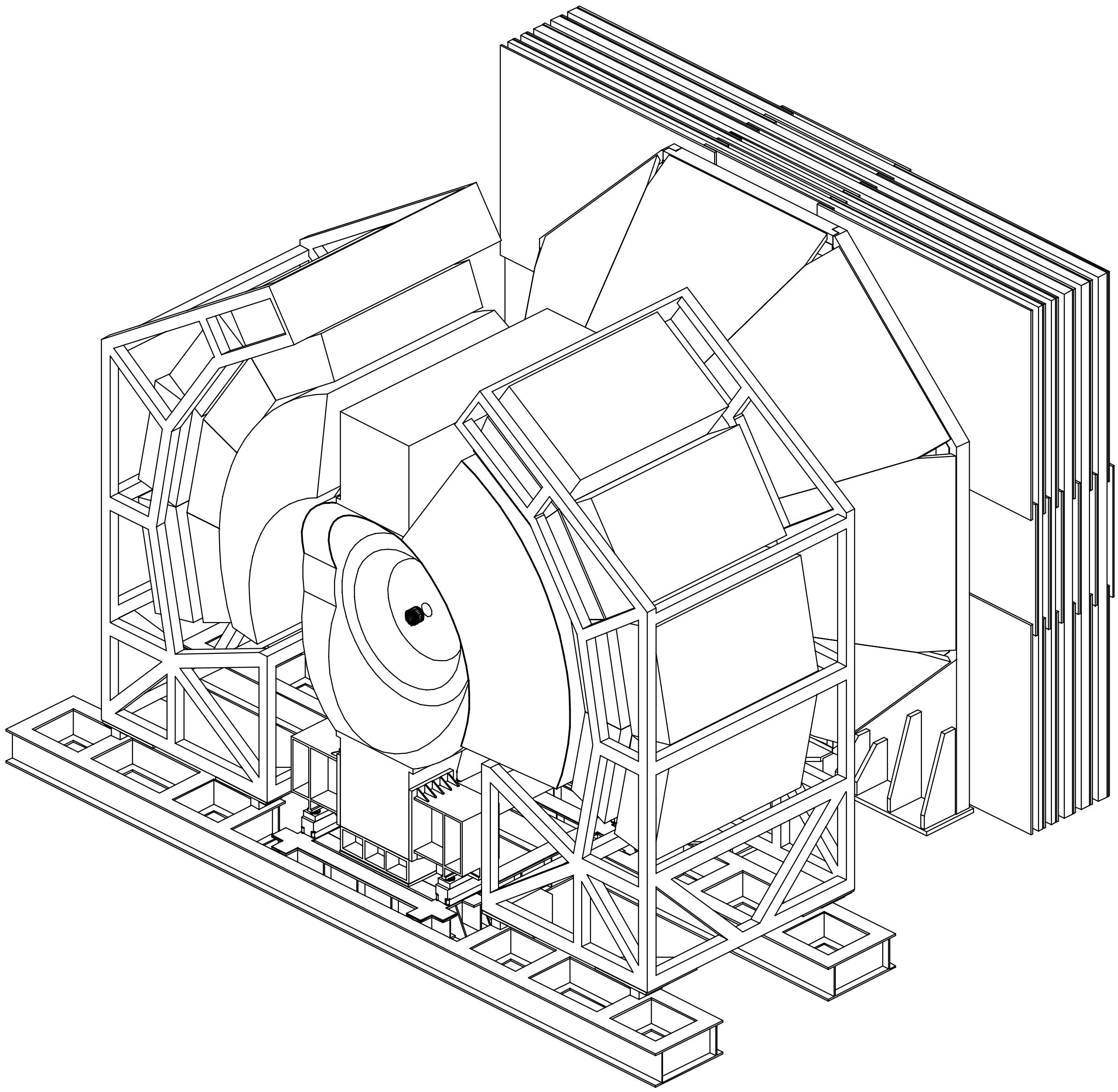

Figure 2.2: Isometric view of the PHENIX detector.

3. **Time Expansion Chamber:** As mentioned above, the current plan calls for construction of all six layers of the TEC in the Baseline, as compared to four in the CDR version. This plan simplifies the conversion of the TEC to a TRD tracker later on.

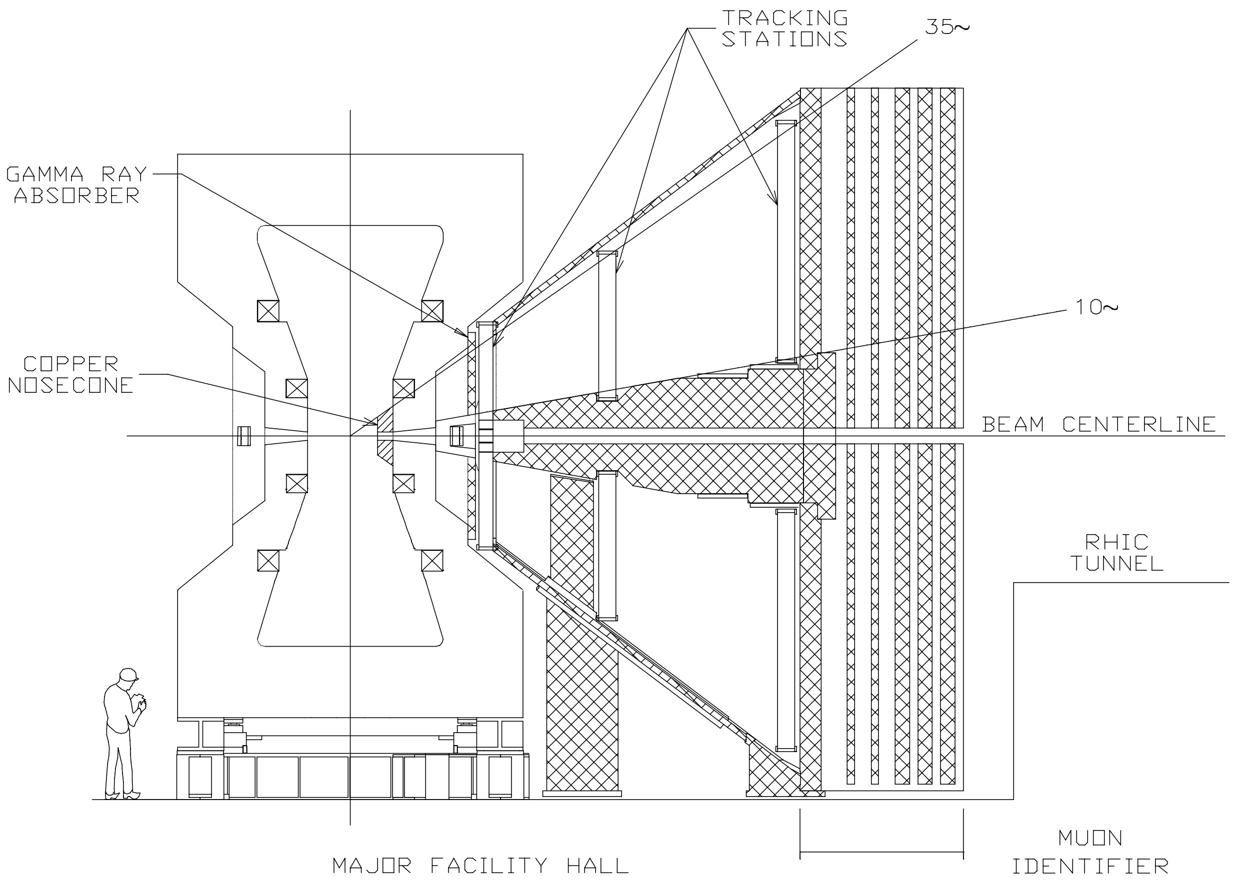

Figure 2.3: Cross-section showing the layout of detectors in the muon arm, and its longitudinal (z) location in relation to the position of the central magnet.

2.5 Muon Arm

Since the submission of the CDR, there has been considerable refinement of the design concepts for the muon arm instrumentation. Table 2.1 summarizes the operating parameters and coverage of the detector elements in this subsystem. Figure 2.3 shows in cross-section the detector layout in the muon arm.

Progress has been made in the design of the muon arm since the submission of the CDR in the following areas:

1. The muon arm implementation plan, involving early fabrication of the MM and deferral of the μT and μID instrumentation, was reviewed by a special committee covenened in June 1993. The physics goals of the muon arm, the present design of the instrumentation, and the schedule impact of various installation scenarios were all reviewed. In brief, the committee had positive findings in all these areas. As a result, design work on the MM (and the μID absorber) has continued, and is now essentially finished, on the basis of an early, fixed installation.

2. The μID absorber, which was shown as two layers of concrete in the CDR, has reverted to an earlier design of five layers of steel. This was shown at the June muon arm review to be much superior in performance, although more costly. The present design consists using five layers behind the MM backplate, allowing for a total of six active μID detector layers. The details of the design, including simulations of trigger performance and hadron rejection, are given in Chapter 10.

3. Optimization of the design of the μT instrumentation led to the relocation of station #2 inside MM, moving it "upstream" by about 0.5 m. This improved the resolution slightly and reduced the size of the station #2 chambers.

4. Although the present design of the muon arm instrumentation (multiplane drift chambers in μT and limited streamer tubes in μID) was found to be adequate at the June review, R&D work is in progress on other detector technologies that could improve performance. Cathode strip chambers are under consideration for muon tracking. These are in an advanced state of development for the GEM detector at SSC and could provide more robust chambers with less dead area and better spatial resolution. Resistive plate counters are under study as an alternate to the limited streamer tubes. Development of this technology was also supported by GEM R&D. These could provide a muon trigger within the required 112 ns; limited streamer tubes of smaller than standard size would be required to meet this requirement. Because the muon instrumentation is presently deferred, it is felt that there is some time available to evaluate potentially better technologies. Decisions will be made on both during FY 1994.

2.6 Inner Detectors

The functions and the coverage of the inner detectors, listed in Table 2.1, remain as they were in the CDR. An issue of the photon conversion background produced by the MVD has been resolved. The result is a single configuration that retains full azimuthal coverage for multipliticity measurements, provides adequate vertex reconstruction efficiency for all RHIC running conditions, and does not dominate other sources of background electrons. Compared to the CDR version, the present configuration also has somewhat reduced silicon area and channel count. Chapter 5 gives a full account of the new baseline configuration and simulation results.

The beam-beam (BB) counter design and function has remained essentially unchanged, although subsequent R&D has led to an improved design of the quartz radiators and a final specification for the PMT. Since the submission of the CDR, the location of the BB arrays has undergone reevaluation. The issue is access to the array on the same side as the muon arm. As described above, the current design of the rail system on which the CM and carriages sit allows relatively easy access to the BB array.

2.7 Trigger and Data Acquisition

The electronics for PHENIX deals with signals coming from a variety of different detectors, applies selective level-1 (LVL-1), level-2 (LVL-2) and level-2.5 (LVL-2.5) triggers to the data stream, and, because of the large event size and high luminosity, has to acquire data and build events at a very high rate. The front-end electronics is described in the chapters dealing with the individual subsystems. The design philosophy of the Baseline electronics is basically the same as in the CDR, although much progress has been made in the detailed implementation of this philosophy. The hardware and software for triggering, data acquisition and on-line computing and archiving are described in detail in Chapter 11. The Baseline configuration is described briefly below.

2.7.1 Front-end Electronics

Although PHENIX contains a number of different detector technologies, a strong effort has been made in the design of the front-end electronics (FEE) to minimize the number of different types of electronics chains. Reasonable success was achieved in this effort. However, it is not possible, for reasons of cost and power consumption, to digitize everything in real time directly on the detectors for all subsystems. The PHENIX detector will digitize in real time for all signals from the BB, RICH, DC, TEC, and μT, but not for the MVD (power/heat) or for the PC, TOF, EMCal, and μID (cost). Consequently, digitized output is stored in digital memory units (DMU) for the first group and in one of at most three types of switched-capacitor analog memory units (AMU) for the second group. Digitization of the data in the AMU will be done following an “accept” from the LVL-1 trigger in a local ADC servicing a channel or group of channels. The AMU/DMU pipelines are made 64 cells deep in order to accomodate LVL-1 time latency and the buffering of up to seven events pending digitization following a LVL-1 “accept.”

Another design goal for the FEE is to include the capability of calibrating every channel, under program control. This feature is included explicitly in the cost estimate.

The readout electronics must perform zero-suppression at the earliest possible stage in order to shrink the data volume and to reduce the computing power needed to do subtractions and corrections to the data. This is done immediately after digitization and the initial ordering and labelling of the data for readout. Zero-suppression reduces the data volume by nearly a factor of 20 for central Au + Au events and nearly a factor of 1000 for p + p events. Gain corrections and calibrations are applied to the remaining valid data after this step. Both zero-suppression and the correction/calibration step are performed in data collection modules (DCM) sitting in Futurebus+ crates located near the detector or on the support carriage. Data from the DCMs are made available to the Level-2 trigger, to the event builder, and to the monitoring ports. The DCMs contain reprogrammable elements so that raw data may be transmitted and the parameters for the zero-suppression and calibration algorithms may be adjusted.

2.7.2 Level-1 Trigger

The LVL-1 trigger will be deadtimeless to enable PHENIX to examine all bunch-crossings at the highest available luminosities for physics events. It is synchronized with the machine bunch-crossing clock and must be "pipelined" in order to be deadtimeless. The LVL-1 delivers a trigger decision each beam crossing for a beam crossing occuring a fixed time earlier. The "local" LVL-1 algorithms deliver detector information to the global level-1 (GL1) trigger within 32 crossings after the event. The GL1 trigger examines information from the entire detector and makes the initial "accept" or "reject" decision for the event in another 10 crossings. This is accomplished by means of routing layers (cascaded parallel lookup tables and scaledown units), all of which are programmable. As described in Chapter 11, the design for LVL-1 uses input from BB, MVD, TOF, RICH, EMCal and μID.

The LVL-1 trigger also provides several thousand pointers to detector elements satisfying certain conditions. These are passed on as data to the DCMs and the LVL-2 trigger in order to steer computational loops at that trigger level.

2.7.3 Level-2 and Level-2.5 Triggers

The LVL-2 and LVL-2.5 triggers are also pipelined processes. They are event-driven, unlike LVL-1 which is clock-driven. The distinction between levels 2 and 2.5 is that LVL-2 operates on partial (local LVL-2) or full (global LVL-2) trigger data but only local digitized detector data, whereas LVL-2.5 operates upon the full digitized data set from the detector, as constructed by the event builder. The LVL-2 trigger is event pipelined and the LVL-2.5 trigger is event-parallel because completion of the LVL-2 and LVL-2.5 algorithms will take longer than the mean time (selected as 40 μs) between events accepted by LVL-1. Typical processing by LVL-2 includes the following steps:

1. Additional computation in the DCMs and following processors at the subsystem level (e.g., application of corrections to get better primitives for time of flight, calorimeter energy clusters, track segment direction cosines, or vertex location).

2. A number of algorithms, running simultaneously on parallel processors, to generate higher level primitives (e.g., identification of $e^{\pm}$, $\mu^{\pm}$, $K^{\pm}$, and γ).

3. A global LVL-2 merger of the relevant primitives to produce event signatures (e.g., "e^+e^- pair" or "high p_T photon" or "hadron pair with $\Delta Q < 10$MeV/c").

The LVL-2.5 processors operate on fully assembled events and can apply mass versus p_T cuts, refine tracking fits and tag rare events, such as those containing J/ψ or η mesons. Events accepted by LVL-2.5 are recorded on archival storage and sent to the on-line computing system (ONCS) for on-line monitoring, display and analysis. For the Baseline configuration described here, the LVL-2 trigger is deferred in the same way as the inner CM coils and instrumentation for the muon arm. We believe that deferral of this second level of trigger selectivity is consistent with the expected demands on the data acquisition system during early operations at RHIC. The overall trigger and data acquisition architecture is designed to accomodate the LVL-2 trigger and increased bandwidth at all levels, as required by the design luminosity and future enhancements of luminosity. Implementation of the LVL-2 trigger is expected as soon as funding permits. This is motivated by the need to gain experience with the LVL-2 hardware and algorithms well before allowing them direct the event selection in PHENIX.

2.7.4 Event Builder, Data Archiving and On-Line Computing System

By the parallel nature of processing in the trigger, accepted events must be assembled from subevents in an "Event Builder". The event builder must be able to assemble the correct subevents in a robust and reliable fashion. It must accomodate expansion on both the input and output sides to cope with higher event and data rates. The design thus employs parallelism on the trigger side and a large number of output streams on the data logging side. The design is able to build events at data rates in excess of 1 GB/s. Initial operation of PHENIX at RHIC design luminosities only requires operation at rates up to 50 MB/s, but planned RHIC luminosity upgrades and the goal of PHENIX to measure infrequent events require ability to increase the bandwidth by at least an order of magnitude.

The on-line computing system is responsible for archiving data, monitoring and controlling the data flow through the system, downloading the more than 2000 embedded processors in the data acquisition system, configuring the entire on-line system, handling calibrating and monitoring tasks, providing needed databases, presenting a uniform interface to users wishing to operate the system or analyse results, providing needed software tools and code management facilities to enable software development, and monitoring and controlling all "slow" aspects of PHENIX such as high voltage systems, gas systems, AC and DC power systems, and temperature monitors. An approach based on a standardized realtime workstation and a distributed database and monitoring processors is being developed. This system will enable users to access all parts of PHENIX susceptible to computer monitoring and control via a common set of protocols.

The baseline data acquisition system will be able to archive data at 20 MB/s. At RHIC design luminosities this can keep up with the 2% most central Au + Au collisions and with p + p collisions, although not with p + A and some lighter A + A minimum-bias collisions. Thus in early running, or until RHIC reaches the design luminosities, the data acquisition system will be able to collect data with this taping capability and without the LVL-2 trigger. The bandwidth of the entire system, including the implementation of the LVL-2 trigger, will increase to keep up with expected increases in rates.

2.7.5 Off-line Computing

The high data archival rate of 20 MB/s results in very large requirements for data storage and cpu power. A combined total of 0.3–0.5 PB of raw, reconstructed and simulated data will have to be stored each year. The main storage medium is likely to be 19-mm video tapes recording at 16 MB/s and each storing 100 GB. A selected sample of events will be stored in 10–20 TB storage robots. The event reconstruction and simulation will require 50–100 GFlops of continuous CPU power, if all events are fully reconstructed. The current "straw-man" model for RHIC computing assumes that the main CPU servers used for PHENIX event reconstruction and data analysis, as well as data recording and storage facilities, will be provided by the RHIC computing facility.

An important task for the off-line system will be to organize the large amount of very varied data within the collaboration. This will be accomplished through a set of databases tailored to the different types of data, but with a common user interface. The reconstruction and data analysis codes will be highly modular and be designed with special emphasis on utilizing the parallel architecture of computer farms or massive parallel processors.

2.8 Facility Engineering and Detector Integration

This item, which deals with detector infrastructure, has been expanded to include all integration and installation efforts, as well as structures and facilities. Significant progress, described in Chapter 13, has been made in this area, which benefited from an increase in the amount of available engineering resources at BNL devoted to this effort. Among the important areas of progress are:

1. As mentioned above, a system of permanent and temporary rails for the major facility hall (MFH) has been designed, allowing several kinds of detector motion for installation, servicing, and major upgrading.

2. Additional space near the MFH for run control and on-line computing has been specified and discussions are underway with Plant Engineering on the detailed design. The space requirements have been derived from an understanding of where various online functions will be located.

3. An installation plan has been worked out consistent with the overall RHIC schedule constraints and with the detector construction timelines. Resources for all of the installation effort have been integrated within this area of the PHENIX work break down structure (WBS) to make possible a reliable estimate of the total.

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