Construction Project for the ATLAS Experiment

A Proposal to the National Science Foundation

The University of Michigan

1 Introduction

We request funds from the National Science Foundation to support the precision muon chamber construction and chamber electronics development project for the the ATLAS (**A** **T**oroidal **L**HC **A**pparatu**S**) experiment [1] at the University of Michigan in 2002.

The LHC (Large Hadron Collider), now under construction at CERN, will collide protons at a center-of-mass energy of 14 TeV with a beam crossing rate of 40 MHz and resulting luminosities of $\geq 10^{34} cm^{-2} s^{-1}$. This unique facility will enable physicists from all over the world to explore new frontiers of particle physics. The collider is scheduled to start operation in 2006 and run for at least a decade. It is designed to provide sufficient energy and event rate to probe deeply into the multi-TeV mass region and address some of the most interesting fundamental and unanswered questions in particle physics.

The ATLAS detector, 44 meters long, 22 meters high, and consisting of three major detector components (the inner detector, the calorimeter and the muon spectrometer), is one of the largest and most elaborate particle experiments ever designed. A world-wide collaborative construction of this experiment is underway to exploit the full physics discovery potential offered by the LHC.

The University of Michigan ATLAS Group, composed of 6 faculty (H. Neal, J. Chapman, M. Campbell, G. Tarle, R. Thun and B. Zhou), 5 research scientists (E. Diehl, S. Goldfarb, D. Levin, S. McKee and Z. Zhao), 3 mechanical technicians (J. Reece, H. Schick, C. Weaverdyck), and 2 electronics engineers (P. Binchi, and T. Dai), has taken major responsibilities in the construction of the ATLAS experiment. Our construction tasks include building 80 of the largest precision muon chambers for the ATLAS Endcap Muon system, and developing the muon detector front-end electronics.

In the last three years, remarkable progress has been achieved by the Michigan ATLAS group in our construction project. We have established a large precision muon detector production site and have constructed nearly half of the required 80 muon chambers. We have also successfully produced 10,000 electronics readout channels for ATLAS muon chamber testing, and designed an essential component for the precision chamber readout – the CSM (Chamber Service Module).

For the next year, our tasks are extremely challenging. We must construct 24 of the larger muon chambers and perform intensive system tests. We must finish the design and test work for producing final chamber readout electronics–CSM. In addition, we have assumed a major role in the endcap chamber test activities using the H8 test beam facility at CERN. A MoU of 2002 [2] for the project has been signed between the University of Michigan and the US ATLAS Project Office. Our ATLAS project funding request to the NSF is part of the agreement described in the 2002 MoU.

2 Precision Muon Chamber Construction

US ATLAS has established three MDT chamber production sites: BMC (Boston Muon Consortium), the Univ. of Michigan and the Univ. of Washington to build inner and middle rings of the ATLAS endcap muon precision chambers (total 240 chambers). The Michigan group is to construct the 80 largest precision MDT chambers (in five types: EMS4, EMS5, EML3, EML4, and EML5) consisting of 31,000 pressurized drift tubes (in 40 different length ranged from 3m to 6m) for the ATLAS Endcap muon system. The wire position accuracies are 10 μm for a tube, and 20 μm for a chamber. The different types of chambers require complex tooling and significant time is spent on the change-over and re-survey of tooling for each type of chamber.

During the past three years, we renovated the physics department high bay area for chamber construction and designed and built large, sophisticated facilities to assemble and test the precision tubes and chambers. After intensive R&D activities and assembly tooling construction, we successfully produced our first full-sized prototype chamber (Module 0) in June 2000 and achieved 16 μm (rms) wire position accuracy. We started chamber mass production in Oct. 2000, and rapidly ramped up to full speed. As of March 2002, we have completed nearly half of the Michigan production: 15,000 tubes and 38 chambers. The chambers produced comprise all 16 of the EMS5 type, 16 of EMS4, and 6 of EML3. Figure 1 shows the Michigan tube and chamber production rates since production onset. As the chart shows, production rates have stabilized at 200-250 tubes per week and 3 chambers per month.

In addition to meeting our production rate goals we have been able to maintain very high quality standards. MDT tubes and chambers must pass a number of stringent quality tests. Our overall tube failure rate is below 2%. During chamber gluing, multiple redundant mechanical and optical measurements are made to ensure mechanical precision. The ultimate test for chambers is the 3D x-ray tomography measurement done at CERN. Michigan has had 3 chamber measured in the the x-ray tomography, our module 0, a production EMS5 chamber, and an EMS4 chamber. All easily met the requirement of wire positions accurate to 25 μm (RMS).

It should be noted that as time goes on, tube and chamber production becomes more involved and complicated. Each new chamber type is larger than the last, and so logistics of tube and chamber handling become more difficult. For example, for EMS4 and EMS5 chambers, all tube lengths could be carried in our building elevator. For EML3 chambers, a quarter of the tubes are too large for the elevator and must be carried by hand up and down stairs between our labs; for EML5 chambers, our final chamber, all tubes will have to be hand carried, a considerably more tedious task. In addition, as time progresses, more parts become available, and more of the complete chambers are finished at Michigan. For example, at the start of EMS4 production, gas system components became available, and so we began installing and leak certifying gas systems on chambers as we built them[1]. At the start of EML3

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[1] EMS5 chambers were shipped to CERN with no gas systems. However, we have now pre-assembled the

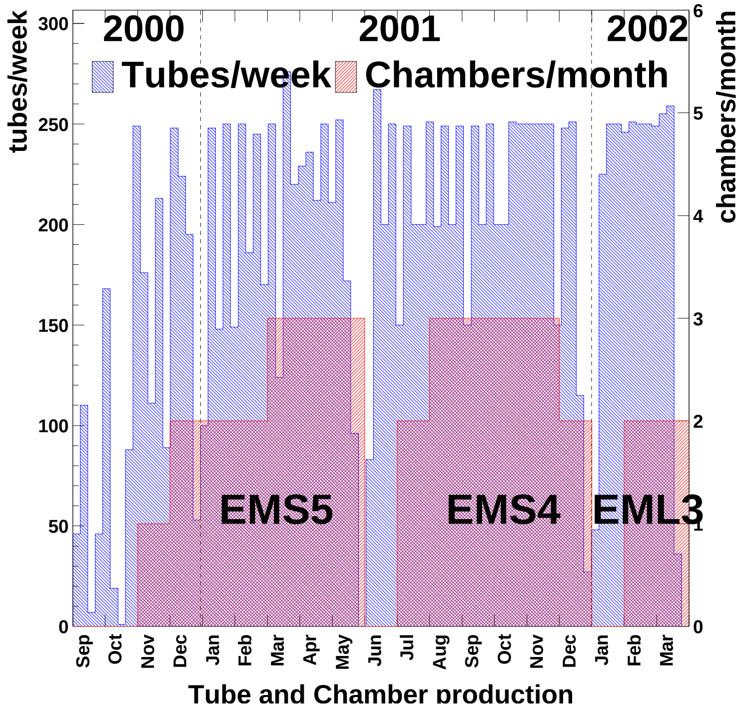

Figure 1: Tube and chamber production rates. Production was slower at first as we debugged our system. Production stopped in June, 2001 to change tooling from the EMS5 to EMS4 chamber type, and in January 2002 to change over from EMS4 to EML3.

production, temperature sensors, and survey platforms have become available, and we are now mounting these on production chambers. We have been able to add extra building steps into our production process and yet maintain our production rate of 8 working days per chamber through a combination of increased efficiency and increased labor. Table 1 shows the key milestones for the next year precision chamber production task at the University of Michigan.

Based on the mass production experience of the past years, Michigan is confident that we can complete our tasks in a timely and cost efficient manner while maintaining high quality standards.

3 Muon Chamber Front-end Electronics

Michigan's electronics role in the MDT detector development is the design and production of the Chamber Service Module, the CSM. This unit is a high speed multiplexer for concentration of the time measurements from multiple ASD/TDC cards into a single fiber for transmission to the Readout Drivers. In addition this fanin role, the unit provides for clock distribution to the

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required gas bars and will install these on EMS5 chambers at CERN in summer 2002

WBS	**Key Milestones**	Baseline Date
1.5.7	MDT Chamber production	
1.5.7.8	Michigan Chamber Production	
1.5.7.8.1	EMS5 Chamber service installation at CERN	9/1/02
1.5.7.8.2	Complete EMS4 series	1/30/02
1.5.7.8.3	Complete EML3 series	8/31/02
1.5.7.8.4	Start EML4 series	9/30/02

Table 1: Michigan 2002 Chamber fabrication milestones.

ASD/TDC cards and also provides for the capture of all environmental data on the voltages and temperatures of the ASD/TDC cards. The introduction of the CSM into the MDT clocking and readout guarantees that the specifications can be met while avoiding potentially serious problems. These problems suggest unacceptable risk for the design. The addition of the CSM provides for:

- Removal of the VME based data multiplexers from within the collision hall where there are problems of radiation exposure, heat elimination, fan operation in a magnetic field, and debugging of complex device within an area that is inaccessible by personnel during collider operation.
- The elimination of 40MHz clock signals distributed in 7 chamber groups over 15,000 copper pairs of 15m. With the on-chamber CSM the clocking over copper cables is shielded by individual chamber grounds and typically 1-2m in length. Grounding and shielding is particularly important given that the ASD thresholds for the MDT are required to be at the 20fc level. The 15,000 copper pairs will be replaced by 1200 optical fibers from the central LHC trigger, timing, and control system.
- Compression the 40MHz clocked data output from individual ASD/TDC cards into a single optical fiber eliminating the distribution of this data over 15,000 copper pairs of 15m length. As with the trigger, timing, and control clocking to the chamber, the data collection merges at the CSM.
- And additional benefit of the CSM design is its attachment to the detector control system, DCS, which provides for all environmental monitoring for the MDT. This system provides for temperature, magnetic field, voltage, and alignment monitoring. It is to be located adjacent to the CSM and accepts voltage and temperature monitoring data from the ASD/TDC cards. The clustering of all data from the ASD/TDC cards at the CSM localizes the monitoring data.

There are two challenges in the implementation of the on-chamber fanin-fanout. One is its parts density given the constraints of small space available. For the smallest chambers the length and width of the CSM are limited to 140mm x 80mm. This implies a very dense unit that accepts 760 lines from the ASD/TDC cards and DCS system. Two Optical fibers, one input

WBS	**Key Milestones**	Baseline Date
1.5.9	Front-end Electronics	
1.5.9.4	CSM-1 Prototype	August 2002

Table 2: CSM 2002 development milestones.

timing and one output data connect the unit to the external electronics in the underground hall. This requires the technology of a notebook computer. The second challenge is design for low cost fabrication. With attention to this process, it appears that CSM units can be manufactured in 1000 unit quantities for significantly under $1000 each. Design manpower is not a small fraction of the cost even at the 1000 unit quantity. Some of these costs can be recovered in a simplification of the readout driver, ROD, following the CSM in the data flow, most cannot.

The CSM schedule is shown in the overall ATLAS muon plan and can be summarized in the Table 2. The prototype CSM, called a CSM-0, is operational and in the field. It is based on a 6U VME card and contains the components of the CSM and the ROD but without the rate capability of the optical fiber elements. This unit was designed for cosmic ray testing of chambers and mates with the prototype ASD/TDC cards. These units have been used at various locations including the CERN test beam and will continue to be used for at least another year. The CSM-1 prototype is the first miniaturized multiplexer that outputs to a high speed fiber.

4 Budget Description

The total request from the NSF for 2002 ATLAS Project support at the University of Michigan is $487,300. The amount of $387,300 will be used for the MDT chamber production, and $100,000 will be used for the electronics development and testing.

Personnel

The proposed compensation is consistent with that paid to other personnel engaged in similar work both within and outside the University of Michigan.

The budget requests total 60 month technicians (5 junior technicians) salary support in 2002 to construct the MDT chambers. The tasks include the precision tube assembly and test, and the large chamber assembly and test at the Michigan Production site.

Fringe Benefits

Benefits are charged at the rate of 28% of professional salaries, effective June 29, 1995, in accordance with the university's rate agreement with the Department of Health and Human Services. This rate was used to estimate fringe benefits costs for the entire project period.

Fabrication Materials

We are requesting funds to support the cost for the construction tasks including raw materials purchase, the chamber crating and shipment, and the parts machining using the Michigan shop. The budget is based on the past years experience.

Total Indirect Costs

The University of Michigan's predetermined indirect cost rate for off-campus research is 26% of MTDC. The off-campus rate is based on a preponderance of integrated major ATLAS research effort over the next 15 years at CERN, Geneva.

For a summary of the requested funds, please see the NSF budget sheet (FORM 1030).

References

[1] ATLAS Technical Proposal for a General Purpose pp Experiment at the Large Hadron Collider at CERN, CERN/LHCC/94-43 (Dec. 1994); The ATLAS Collaboration.

[2] U.S. ATLAS MOU NO. 32/02, "Amendment to Memorandum of Understanding between University of Michigan and the U.S. ATLAS Project Office for Fiscal Year FY 2002".