Report of the Visiting Committee on ATLAS

Meeting Held in Jerusalem November 16-17, 2006

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Executive Summary

On November 16-17, 2006, under the auspices of the Israel Academy of Sciences and Humanities, a committee comprising Jonathan Dorfan (Stanford Linear Accelerator Center; Committee Chair), David Hitlin (Caltech), Peter Jenni (CERN), Yossi Nir (Weizmann Institute of Science), Morris Pripstein (Lawrence Berkeley National Laboratory; on assignment at US National Science Foundation) and Eliezer Rabinovici (Hebrew University, ex officio) met in Jerusalem to assess and review Israel's scientific contribution and involvement in the ATLAS Project at CERN. The Committee report will form the basis of subsequent actions to be taken by the Israel Science Foundation (ISF) and the Israel Committee on High Energy Physics.

Attachment 1 is the agenda for the meeting. Attending the dinner on Thursday evening were: the Committee; the President of the Israel Academy, Menahem Yaari; the Director of ISF, Joseph Klafter; the Chairman of Council for Higher Education, Shlomo Grossman; and the Director General of Council for Higher Education, Steven Stav. The Committee reviewed background material provided prior to the meeting including: 1995 Review Committee Recommendations regarding Israel's participation in ATLAS, the 1999 Progress Report of the Israel ATLAS Project, the 2001 Report of the Israel ATLAS Project Review, a proposal for Computing for ATLAS in Israel and a cost estimate for the proposed ATLAS Israel Tier 2 Computing Facility. Following the proponent's presentations and the Committee deliberations, a closeout summarizing the Committee's assessment and recommendations was held with Prof. Yaari. This report covers the Committee's assessment and recommendations, the highlights of which were shared with Prof. Yaari.

Since joining the ATLAS Collaboration in 1995, the Israeli group, comprising members of the high energy physics (HEP) groups at the Technion, Tel Aviv University and Weizmann Institute of Science, have performed outstandingly well in a highly competitive environment made up of many of the best HEP groups internationally. Under the excellent leadership of Prof. Giora Mikenberg of Weizmann, the group undertook an ambitious set of tasks, mainly concerning the muon particle tracking and identification system. This large undertaking has involved the design, engineering, fabrication, testing and installation of a very large number of highly sophisticated "thin gap" muon tracking chambers (TGCs), their readout electronics and software, their calibration hardware and software and muon detection software. This task has been undertaken in collaboration with groups from Japan and China, adding additional challenges to the leadership role played by the Israeli groups.

The Committee was highly impressed by the work accomplished by the Israeli groups: their performance has been outstanding. The chambers have all been fabricated and tested, on time and within budget. Installation of the full system is nearing completion. Final testing of the full chamber system at CERN has been accomplished using the production readout and data acquisition systems. This includes the detection and successful reconstruction of cosmic-ray muons. The quality of the chambers is uniformly excellent and all detector performance specifications have been met.

The sharing of a common ATLAS focus has engendered an effective and coherent working relationship between the three Israeli groups, which positions Israel significantly more strongly now to make relevant and highly visible contributions to ATLAS and beyond. The synergy and cohesion of the three groups was more evident at this review than in any of the previous ATLAS Israel reviews. The level of participation and the effectiveness of the Tel Aviv and the Technion groups has increased significantly.

As mentioned above, the Israeli groups have provided excellent leadership in all phases of the TGC construction. In addition, several individuals, most notably but not exclusively Prof. Giora Mikenberg, have been highly visible and very effective in the larger decision-making structures of ATLAS.

It should also be noted with satisfaction that Israeli industries, through the competitive tendering process, have been involved in some key areas of the LHC machine, fabricating highly specialized hardware, as well as developing expert software components.

With regard to future involvement, Israel must assert its strong ongoing commitment to the ATLAS program and to the current roles and responsibilities of the Technion, Tel Aviv and Weizmann groups. It is crucial that Israel continue the current level of base funding, represented to the Committee as $400K per annum, for the support of the scientific manpower and infrastructure for the three groups. This support, and that of the Tier-2 budget discussed below, should not come at the expense of the other Israeli HEP experimental programs, albeit that they are much smaller in scale.

Even though the detector construction is well advanced, it has to be realized that major hardware activities still remain before the construction phase can be declared complete. Adequate resources must be planned for the support of: a) system experts and technical manpower in residence at CERN; b) near-term commissioning and c) long-term maintenance and operation of the TGC system. Further, the successful hardware construction effort must be well documented, thereby providing a well-defined closing milestone for an impressive achievement by the Israeli HEP community.

The Israeli group has the potential to make a strong impact in the physics analysis at ATLAS. Yet, the preparations for physics analysis by the various Israeli groups are presently at a rather exploratory stage. To realize the potential to its full extent, there is a need for a coherent, cohesive and focused Israeli effort. The analysis goal should be to create an interesting 'niche' that will be internationally identified with the Israeli group. If many small-scale projects on diverse topics are pursued, it is likely that the depth and impact of this effort will be small. The Israeli group would be better served were they to be selective. It should collectively identify a small number of topics with good theoretical motivation and preferably with relation to the specific detector expertise of the Israeli group. The Israeli HEP phenomenologists should take part in some, if not all, the meetings to discuss physics analyses. A dialogue with the Israeli phenomenologists might be helpful towards a better grasp of the significance (or lack of it) of various possible projects and is likely to generate new ideas.

The establishment of a distributed Tier-2 center with resources at all three institutions requires a great degree of coordination for successful operation and professional expertise at each institution. A single, clearly designated leader must be elected and given the attendant authority to be in charge of the Tier-2 center and must be recognized as such within ATLAS Israel and by the international ATLAS collaboration. This designation needs to be done very soon. The availability soon of 2-3 FTE computing professionals, distributed across the three institutions, is essential for the required support of the center operations. Such highly qualified personnel are necessary from the outset and since they are in great demand elsewhere, an aggressive recruiting effort should be mounted now.

A *distributed* Tier-2 center model empowers the three institutions and will create the synergism to enhance the combined effectiveness of the participating scientists. To make this model work, all three institutions must provide the vital physical infrastructure needed for success, such as space, power and cooling. Upon further study, it may turn out that inter-university network connectivity may also be needed, which likewise should be provided by the institutions. If these infrastructure contributions cannot be realized, then the distributed model may need to be abandoned in favor of a Tier-2 center at one of the three institutions: it is hoped that this would not be necessary.

Because first beams at the LHC are not far away, it is also imperative that the uncertainties regarding network connectivity bandwidth internationally and within Israel be resolved quickly, with the "Quality of Service" (QOS) solution as a leading possibility.

The Tier 2 budget and its annual profile, must be fully supported at the requested level, namely a total of $2317K ($3471K), spread over the next four (six) fiscal years as follows: $362K in 2007, $743K in 2008, $548K in 2009, $663K in 2010, $555k in 2011 and $600K in 2012. After a careful scrutiny of the proposal, and with comparisons to similar efforts elsewhere, the Committee concluded that the requested budget is appropriate and that the funding profile is crucial to realize the important opportunity for ATLAS Israel, which would otherwise evaporate while the rest of ATLAS moves into physics-analysis high gear.

Scientific Motivation and Relevance

"Particle physics is the unbelievable in pursuit of the unimaginable. To pinpoint the smallest fragments of the universe you have to build the biggest machine in the world. To recreate the first millionths of a second of creation you have to focus energy on an awesome scale." **The Guardian.**

The recent discovery of the dominant presence of Dark Energy and Dark Matter, have reshaped the leading questions about the birth and evolution of our Universe. Consequently, the so-called Standard Model, the theory we use to describe the interactions of elementary, sub-atomic, particles and the forces that they feel, whose emergence must be an integral part of this early cosmology, now leaves yet more unresolved questions. These questions must be answered by a new era of discovery in particle physics, and the Large Hadron Collider (LHC) at CERN, Geneva, scheduled to start operating in 2007, may indeed herald this new era. (See for instance http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/). With a much higher luminosity and capable of producing collision energies that exceed by a factor of 7 what is achieved today at Fermilab, the LHC will probe physics at distances much shorter than ever achieved before. In particular, LHC experiments will explore the dynamics of sub-atomic particles at the currently inaccessible energy scale associated with electroweak-symmetry breaking (EWSB), while at the same time giving access to the physical particles which might well be the source of dark matter.

Electroweak symmetry breaking is responsible for many of the unique features of the weak force, such as its short range and the way that it shapes particle decays. EWSB is also thought to be the source of all elementary particle masses – in the absence of EWSB all particles would be massless. The LHC is expected to reveal the particles and interactions associated with this symmetry breaking.

Within the Standard Model, which encodes our present understanding of the fundamental particles and their interactions, EWSB is driven by a scalar field, the Higgs field, with a simple potential that exhibits spontaneous symmetry breaking. Associated with this field is a spin-zero, neutral particle called the Higgs particle. The LHC is expected to discover this particle, measure its mass and probe some of its couplings to matter-particles and to force-carriers. The Higgs particle is the only missing piece of the Standard Model.

The Higgs mechanism that is incorporated in the Standard Model to explain electroweak symmetry breaking may very well be just an effective low-energy description of some more fundamental physics. Indeed, since the Higgs particle is a scalar, its mass parameter, which determines the scale of EWSB, is unstable against quantum corrections, so it seems very likely that some new physics, beyond the Standard Model, is associated with EWSB. Candidate EWSB theories abound, and include, among others,

- supersymmetry, in which quadratic corrections to the Higgs mass are protected by a new fermion-boson symmetry;
- models involving flat extra-dimensions, in which corrections to the Higgs mass are cut-off by the true Planck scale, which is close to the EWSB scale;
- models involving warped extra dimensions, in which corrections to the Higgs mass are suppressed due to the geometry of five-dimensional space-time;
- Technicolor theories, in which the Higgs is a composite of new strong interactions.

The LHC will test whether any of these theories in realized in Nature. Evidence for any of these theories, will lead to a revolution in our understanding of Nature.

The LHC is also likely to shed light on one of the most intriguing puzzles in particle cosmology, and that is the puzzle of the dark matter. We now have ample evidence that about twenty two percent of the energy density of the Universe comes from massive particles that have no electric charge (and hence are "dark"). Within the Standard Model there are no particles with the requisite properties. If the dark matter particles have been in thermal equilibrium in the early Universe, then their present energy density is related to the typical scale of their interactions. That scale turns out to be close to the scale of EWSB. It is thus quite possible that the proton-proton collisions of the LHC will be energetic enough to produce the mysterious dark matter particles and frequently enough that we can actually measure various properties of these particles. Thus, the LHC may well discover the dark matter particles.

LHC and ATLAS Detector/Collaboration

The LHC accelerates two beams of counter-rotating protons, contained in a 27 Km evacuated, circular accelerator housing, to provide head-on proton-proton collisions at an unprecedentedly high energy (14 TeV) and intensity (luminosity of 10^{34} $cm^{-2}s^{-1}$). At four points, the so-called interaction regions, the protons are magnetically steered into collision. Each interaction region contains a large experiment – ALICE, ATLAS, CMS, and LHCb – which detects the particles that emerge from the energetic proton-proton collisions. Two of these, ATLAS and CMS, explore the physics issues described above, that is physics at the electroweak symmetry breaking scale. A group of experimental high-energy physicists from the Technion, Tel Aviv University and the Weizmann Institute, collaborate on the ATLAS ("A large Toroidal LHC ApparatuS) experiment, which is one of the largest collaborative efforts ever attempted in the physical sciences.

The installation of the LHC is nearing completion in the circular, underground tunnel which housed previously the electron-positron collider LEP (at which the OPAL detector, with strong Israeli participation, took data from 1989-2000). The LHC is a very complex project at the forefront of superconducting accelerator technology. It involves many innovative developments, spanning a diverse a set of challenges ranging from high-field dipole magnets to sophisticated control systems.

It should be noted with satisfaction that Israeli industries, through the competitive tendering process, have been involved in some key areas of the LHC machine, fabricating highly specialized hardware, as well as developing expert software components.

The ATLAS detector is an ambitious and sophisticated general purpose instrument to fully exploit the physics discovery potential of the LHC. The construction of the detector, as well as the preparations for its operation, data handling and physics analysis are shared by a world-wide collaboration comprising almost 2000 scientists from more than 165 universities and laboratories in 35 countries. The three Israeli groups have been charter members of the ATLAS Collaboration and thanks to their coherent effort, they have been able to make a major impact on the project, contributing intellectually to the conception and design of the detector, as well as to building a large, novel detection system optimized for the detection of muons. Muons are extremely valuable, as they are markers for identifying weak and supersymmetric particle decays, which, as emphasized in the introduction, are two of the key topics that the LHC will confront.

Figure 1 shows a picture of the ATLAS detector, overall 25 m in diameter and 46 m long, which uses a superconducting magnet system with a central solenoid around the inner tracking detector and large air-core toroid magnets for the muon spectrometer. Between the two are the Liquid Argon (LAr) and tile calorimeters. A hierarchical trigger and data acquisition system collects the data for the collaboration-wide computing and physics analysis activities.

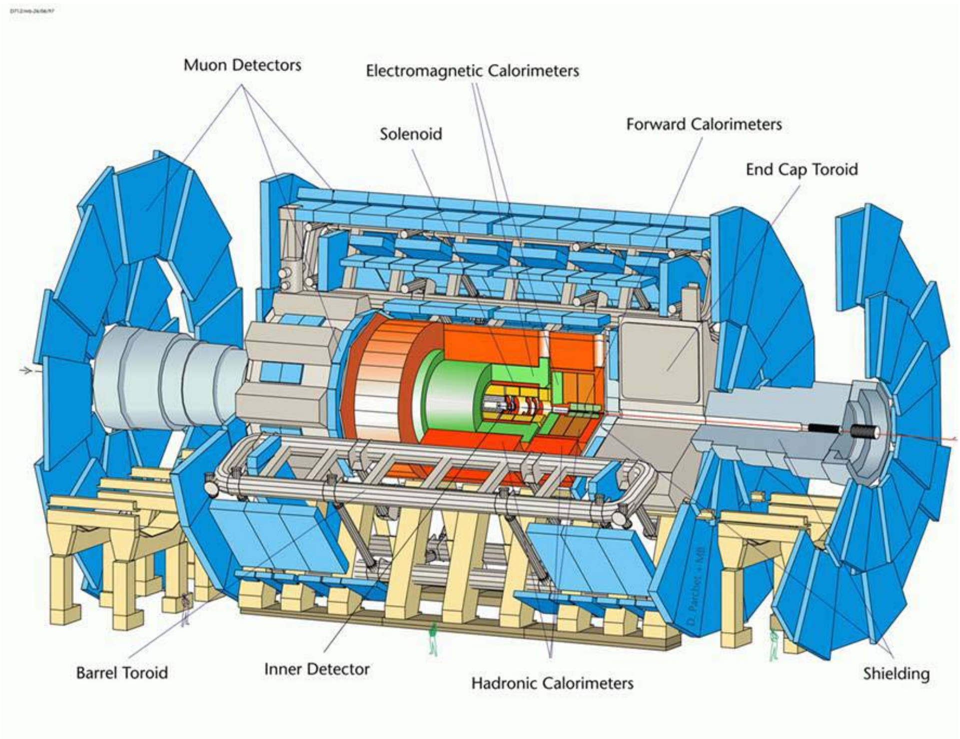

Figure 1. Schematic of the ATLAS detector

The ATLAS detector is now in its final phase of installation in the underground cavern at Interaction Point-1 of the LHC. The schedule foresees readiness of the detector for the first colliding beams expected in November 2007. In the meantime the commissioning of the detector components, as they are installed and cabled up, has started. Figure 2 is a snap-shot from the installation of the central part of the ATLAS detector. Figure 3 shows the first completed 'Big Wheel' of end-cap muon trigger chambers (Thin Gap Chambers, TGCs), built by the Israeli groups and their collaborators in Japan and China, mounted in the ATLAS cavern.

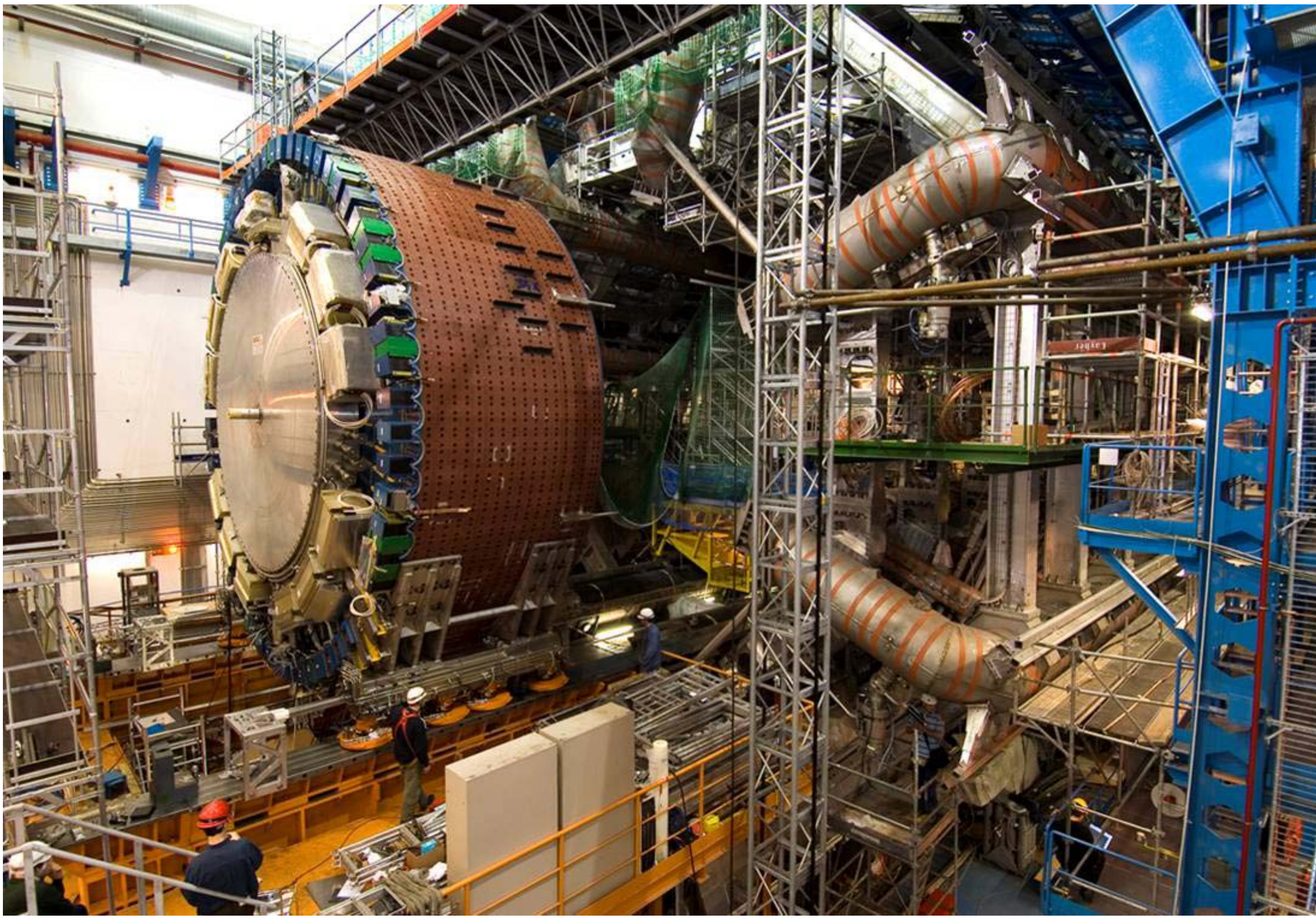

Figure 2. ATLAS under construction

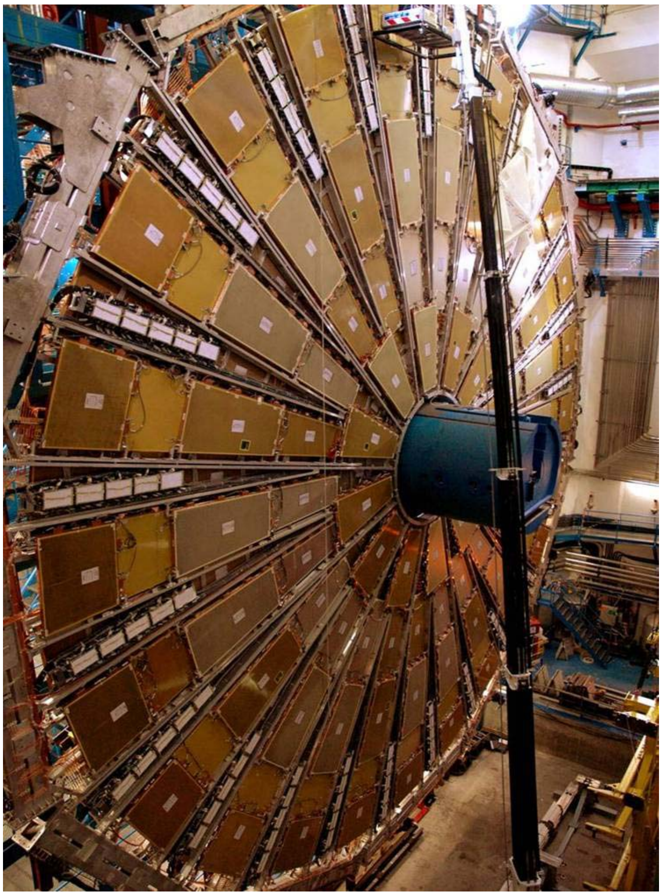
Figure 3. The first Big Wheel installed into ATLAS

The first LHC collisions will be at the injection energy of 450 GeV per beam and will allow the ATLAS Collaboration to commission both the detector hardware and the full chain of data handling, based on the world-wide computing grid structure. After a three-month shutdown of the LHC early in 2008, the first major physics run with collisions at 14 TeV will start in Summer 2008 and last for the rest of the calendar year.

ATLAS Israel

The construction and utilization of the ATLAS detectorat the LHC is the central activity in Experimental HEP in Israel. Following the strategy for Israel's previous involvement in a major CERN experiment, namely on OPAL at the LEP facility and following an external review, it was decided that the three major HEP Experimental Groups (Technion, Tel Aviv University and Weizmann) should join forces to work in a single LHC experiment and futher collaborate on a single detector sub-system. The original proposal had 29 co-authors, including graduate students. The chosen experiment was ATLAS and the sub-detector system the End-Cap Muon Trigger System, based on the TGC Technology, previously developed for OPAL. The ATLAS end-cap Muon Trigger system is a collaboration between Israel, Japan and China. Through the efforts of the chair of the ICHEP (D. Horn/E. Rabinovici) and the chair of the ISF (the late P. Singer), a construction budget of 5.8M$ over 8 years was made available. This, combined with an ISF Center of Excellence, contribution from various Institutions (1.5M$) and various Bi-National Contributions, allowed for the 10M$ needed for the construction project, to be spent over 9 years. That commitment now comes to an end and this Committee has been convened to review the follow-on funding request.

Although CERN has played an important role as a meeting place and in particular it was the place where Scientific Relations between Germany and Israel started, the first official agreement between the Government of Israel and CERN occurred in 1990. A Protocol to the Agreement, signed in August 1991, has since been renewed several times. The next renewal is expected to take place at the end of 2006. The agreement is financed by the Ministries of Science and Technology (15%) and of Industry and Trade (85%). The overall contribution corresponds to 20% of what would be the total contribution of Israel if it were a CERN Member State. The framework of this agreement provides 30% in cash and 70% in-kind, the latter by Israeli firms participating in CERN tenders. In October 2004 an additional Protocol to the Agreement was signed, by which Israel increases its contribution by 50% for a period of 2 years. The additional contribution is intended to help the LHC experiments and the GRID project, by covering 50% of the cost of products purchased in Israeli Industry. The new agreement, to be signed in two weeks, increases the total Israeli contribution to 25% of full membership. Part of the Israeli in-kind contribution has been applied to the experiments broadly, to ATLAS specifically and also to the LHC itself.

The remainder of the report concerns itself with the Israeli contributions to the construction of ATLAS and makes recommendations on the scope and cost of the future of the Israel ATLAS contributions.

Hardware Contributions

Thin gap chamber construction

The Muon Endcap Trigger System, the main Israeli construction responsibility in ATLAS, is built around the thin gap chambers (TCG's) originally developed in Israel for the OPAL experiment at LEP. The TGC's meet the ATLAS experiment's stringent requirements for a system that has high-rate capability and fast time resolution in the endcap region down to a rapidity of 2.7. The system provides two independent triggering systems at low and high rapidity.

The chambers are fabricated in wedge-shaped segments, the size largely dictated by the available size of material for the chamber walls. The system is subdivided into different types according to the rapidity region covered and detailed function. The endcap muon trigger system consists of 3,968 individual chambers, with a total of 6,200 m^2 of active area. The chambers have a 2.8 mm gap, a wire pitch of 1.80 mm and a maximum wire length of 1.7 m. They are mounted on large circular frames ("Big Wheels" and "Small Wheels"), the largest containing 24 azimuthal and 5 radial segments, which overlap to provide full geometric efficiency. To the greatest practical extent, every sector is fully independent, with its own trigger and readout logic

The use of graphite cathodes in the TGC's allows for flexible readout geometry and robust operational characteristics. The optimization of cathode resistivity, to balance robust operation versus maximum total rate capability, was done for the anticipated LHC conditions. The inner chambers will have to be replaced with a different technology in the event of a significant LHC luminosity upgrade.

The group is to be commended for the strong leadership effort that delivered a high-quality detector system, built in three countries, in a timely way. There are 44 different types of detectors, with associated tooling. To ensure uniformity of approach, all technical drawings were done by Weizmann engineers. The construction of the TGC's was divided between Israel (2500), Japan (1050) and China (500), following the Israeli lead. Care was taken to make the three assembly sites similar to one another and to ensure that there was a single supplier of the various parts for each assembly site. These parts were made in Israel and distributed to the three sites. Quality assurance and quality control were taken seriously, which was crucial in an endeavor of this magnitude. The development of a detailed production manual and a comprehensive production database were vital to the success of the project, as was comprehensive training of the construction crew.

A detailed and comprehensive set of tests was important to ensure the quality of the finished chambers. These included cosmic ray scans and in many cases, exposure in a high radiation facility. After carefully transporting the chambers to CERN, every detector, integrated with its electronics, was then "burned in" for three weeks before mounting. These tests include irradiation with a strong radioactive source (producing a rate of 300 Hz/cm^2 to 1 KHz/cm^2, for ½ hr), coupled with a requirement that chamber dark current should return to within 1 μa of its original value after irradiation, and that the differential rate increase should not be larger than 0.1 Hz/cm^2. The failure rate during cosmic and radiation tests was 2.7%, much of which was easily recovered in post testing. A map of measured chamber efficiency is then made a part of the system's database. This careful procedure will certainly substantially reduce the rate of "infant mortality" in the assembled system.

The pre-assembly of the sectors is being done by a combination of Israeli, Japanese, Chinese and Pakistani personnel, with tooling from Pakistan. Sectors for three of the six TGC ("Big") wheels are nearly complete; one wheel has been installed with all services except power supplies (see figure 3). All mechanical parts of the first wheel fit well. Services have been installed and certified, except for the optimization of the gas flow. The alignment system, crucial to the realization of the specified system resolution, appears to work well. The final certification and installation of the rest of the system will continue through the Spring of 2007.

All of the EIL4 "Small Wheel" stations have been completed as individual sectors and nine have been installed. Small Wheel assembly will begin in December.

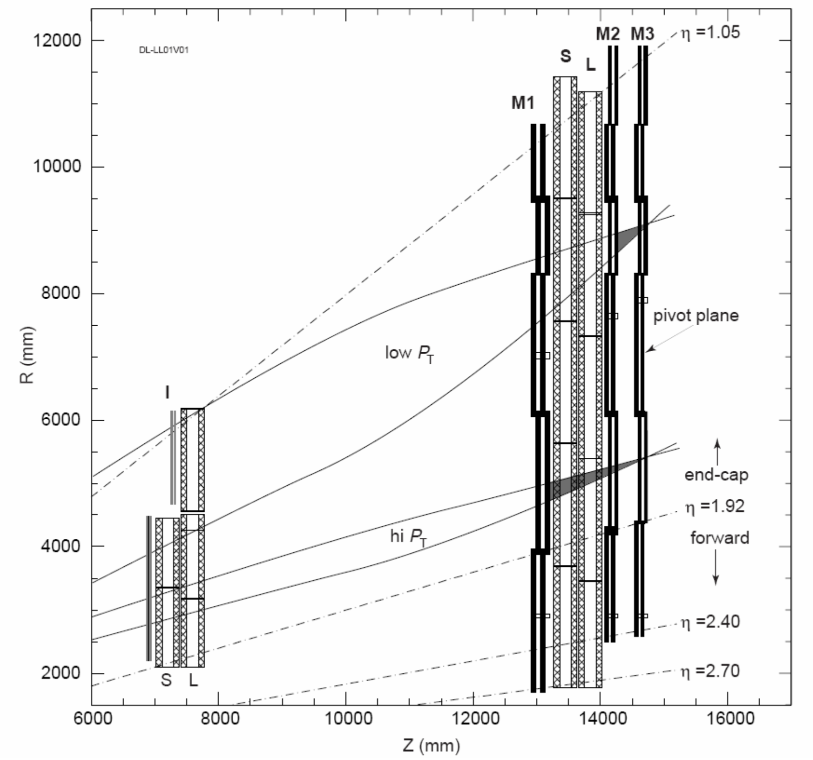

Figure 4. Elevation view of the endcap muon system chambers.

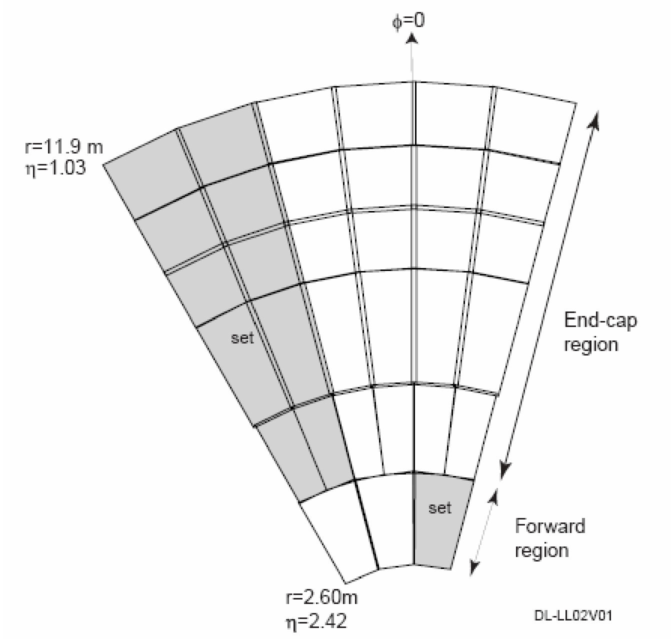

Figure 5. View of a sector of a Big Wheel

Data Control System, Alignment, Tracking

A noteworthy feature of the construction activity is the effective distribution and coordination of responsibilities among the three institutions: with the Weizmann group spearheading the construction, the Data Acquisition System (DAQ) and the monitoring; Tel Aviv, the QA/QC and data base development mentioned above; and the Technion, the Detector Control System (DCS) and alignment and tracking development effort. While these indicate primary responsibilities, the effort is often pursued at several institutions, such as in the cosmic ray and radiation testing.

An important component of the TGC system performance is the DCS, whose goal is to monitor and control as automatically as possible the operation of the system, consisting of almost 49,000 readout channels of 8 different types. The DCS will provide information to the operators when automatic corrective action fails, as in the case of hardware malfunctions. In addition, the DCS is to be used to monitor the assembly, integration and commissioning stages to pinpoint assembly and cabling errors. The development of the DCS involves hardware deliverables, including four different types of electronic boards and considerable custom software innovations. This is a sophisticated system and has evolved very well, with most of the components now in place. It is already being used extensively, even if not fully complete, in TGC integration and commissioning. The plans for the completion of the full system are well thought out and should be readily available in a timely fashion. The group has also developed the software for both the chamber alignment system, which is necessary to achieve the required muon tracking resolution, the muon identification and trigger software which have become part of the ATLAS standard software package. The quality of the work in all these areas has been very high and should allow the muon system to achieve its design performance goals.

DAQ and Monitoring

The data acquisition and the control and monitoring systems for the endcap muon detectors are also an Israeli ATLAS responsibility. The data acquisition and trigger system begins with front-end electronics mounted on the detector, which is organized on a per sector basis and transmitted off the detector using fiber optics to a Readout Driver (ROD). Initial coincidence logic is achieved for detectors within a layer to reduce the bandwidth impact of uncorrelated background hits, as well as to enforce 3-out-of-4 coincidences that mitigate the effects of any chamber inefficiencies. On a per sector basis, η and ϕ coincidences are made, the p_T threshold is applied and the highest p_T candidates are found. These are sorted into p_T bins and further processed to provide trigger candidates with single beam-crossing time resolution.

Configuration and control functions, compliant with ATLAS Run Control standards, are provided in the Rod Crate Processor (RCP), along with monitoring of a sample of unbiased events. The complexity of the DAQ system requires an elaborate software and database management system with a readily accessible interface. Both the hardware and software systems have been very successfully employed in initial testing and in the commissioning of the first Big Wheel in the experimental cavern using cosmic rays. It was possible to test 9 ½ sectors of the wheel in two weeks. The existence of a well-understood and functioning system was crucial. It was possible to find cabling errors, unlatched connectors and faulty cables and backplanes, as well as faulty on-detector electronics boards during the checkout. It would not have been possible to do this without a well-designed and fully functioning DAQ and monitoring system.

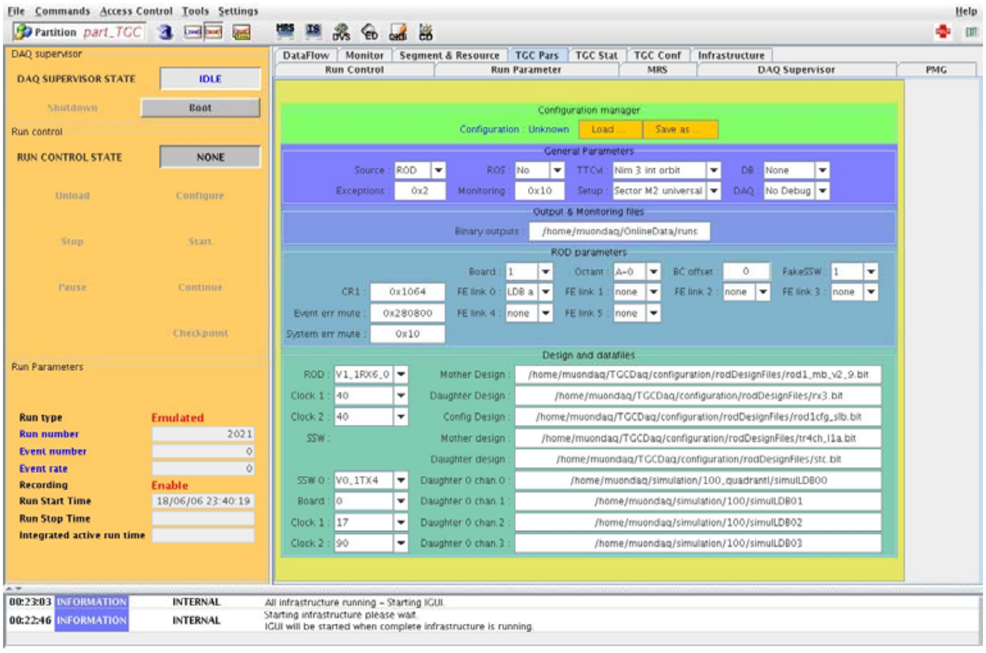

Figure 6. Screen shot of the TGC Configuration Manager

Physics Preparation

Overview

The expected high-class performance and the exciting physics potential of the ATLAS detector have been documented early on in the project and culminated in the two volumes of the Detector and Physics Performance Technical Design Report to the LHC Experiments Committee (CERN/LHCC/99-14 and 15) in May 1999, with significant input from the Israeli groups. Since then, the ATLAS Collaboration has gradually built up a structure and organization to cover all aspects required for extracting high-quality physics results from the data, in an efficient way. The physics preparation is done within the framework of a collaboration-wide approved Operation Model and naturally the highly appreciated Israeli efforts are to be seen as part of this overall coherent plan. Major activities for the physics preparation include optimization of the trigger performance, data quality monitoring, offline alignment of the detector elements and particle track reconstructions. The Israeli groups are leading these activities in the domains where the TGC are involved, namely the muon trigger in the large end-cap regions. For example, more than half of the expected Higgs discovery signal involving muons will directly depend on the performance of the TGCs and the quality of this data.

The physics analyses are organized in ATLAS in several Physics Working Groups (WGs). Physicists from the Israeli groups have been strongly visible and inventive members in several of them, notably in the Higgs WG, the SUSY WG, and the *B* physics WG. In part, they have benefited from their experience of searches in the OPAL LEP experiment, but they have also developed new methods, which are promising for discoveries in the challenging environment of a hadron collider.

Focus of the Israeli effort

The various Israeli groups have started their preparations for the physics analysis. Some of the projects involved are based on a long tradition of expertise in the corresponding areas of research, most noticeably the analysis of Higgs physics by the Weizmann group and B physics by the Technion group. Much of the analysis is at exploratory stages. It has helped the various groups to gain experience in using and improving the available tools and it has allowed them to get acquainted with new theoretical topics. We here describe the various research projects that have been carried out in preparation for the physics analysis.

1. Higgs Physics

One of the ways to observe the Higgs particle is through its decays to a pair of tau-leptons, $H \rightarrow \tau^+ \tau^-$. The work was performed in the framework of ATLAS fast simulation. The Weizmann group has introduced a novel method for tau lepton identification. This is an algorithm-based method that can be used as an alternative to the parameterization-based method and has some advantages. The method has been applied to a suggestion to measure the Yukawa coupling of the top quark, via the process *t anti-t H* → *t anti-t* $\tau^+ \tau^-$.

More recently, the group has shifted its focus of Higgs searches from the framework of the Standard Model to that of the minimal supersymmetric Standard Model (MSSM). Within the MSSM, if tan β is large, it may be possible to find the Higgs particle when it is produced by bottom quark Yukawa interactions and decays into muons or tau-leptons. The group has begun a study of these processes. Is has also started a study of the charged Higgs boson search via its decay to tau lepton.

Work related to Higgs physics has been published in
E. Gross, G. Martinea, G. Mikenberg, L. Zivkovic, ATL-PHYS-2003-001;
E. Gross, L. Zivkovic, ATL-PHYS-INT-2005-003.

2. B Physics

While there has naturally been much emphasis on high p_T physics, LHC also has substantial capabilities at lower p_T processes, such as those in *b* quark decays. Muons produced in such decays provide a trigger, with a trigger threshold $p_T > 6$ GeV/*c*. The three Israeli ATLAS groups have begun to explore the potential of such LHC *b* physics. The Committee heard a presentation on three preliminary studies:

The first explores measurement of the Λ_b polarization via $\Lambda_b \rightarrow \Lambda(p\pi)\ J/\psi(\mu^+\ \mu^-)$. This will constitute the first measurement of the Λ_b polarization and asymmetry using this decay channel.

The second project is a study of the measurement of B_s oscillations, using the decay channels $B_s \rightarrow D_s\ \pi\ (a_1)$, $D_s \rightarrow \varphi\ \pi$. The original motivation for this study was based on the fact that ATLAS has sensitivity to mass difference between the neutral B_s mesons that is much higher than present experiments. This motivation is, however, lost by now, given that the CDF at Fermilab experiment has recently measured $\Delta m(B_s)$.

A third project aims to measure the CP violating angle γ of the unitarity triangle using $B \rightarrow DK$ decay modes.

The Technion group is also developing new analysis tools and, in particular, an analysis framework that uses object-oriented coding methods.

The capabilities of the currently-operating *BABAR* and Belle detectors, samples that will likely total 2 ab^{-1} by 2010, together with those of the specialized detector LHC*b*, are such that the major contributions of the high p_T LHC detectors, ATLAS and CMS, to *B* physics, are likely to be in the area of very rare decays, such as $B_s \rightarrow \mu^+\mu^-$, that could provide evidence for, or strong constraints on, physics beyond the Standard Model in the flavor sector. Thus, the subjects of the three presentations, viewed as learning exercises, are quite useful, but it would perhaps be wise to focus the Israeli *B* physics effort more directly on those areas, such as rare decays, in which there is likely to be substantial physics impact.

3. Supersymmetry

In a particularly interesting analysis, the Technion and Weizmann groups have studied the effects of quasi-stable charged particles, in particular, the long lived supersymmetric scalar partner of the tau lepton, the *stau*. The stau might be produced with such a low momentum that it could reach the muon spectrometer only after 25 ns and will be erroneously assigned to the next bunch crossing. This analysis is well motivated by various scenarios of supersymmetry breaking. Furthermore, it has generic applications beyond the supersymmetric framework. The analysis makes good use of the measurements and triggering related to the parts in the detector built by the Israeli group.

Relevant publications are
S. Tarem, S. Bressler, E. Duchovni, L. Levinson, ATL-PHYS-PUB-2005-022;
S. Tarem, N. Panikashvili, ATL-SOFT-2004-003.

The Weizmann group has developed the LSL algorithm, whereby deviations from the Standard Model predictions are searched for in a rather generic way. The basic assumptions, inspired by generic properties of supersymmetric models, are that the relevant events involve large missing transverse energy and a large number of energetic jets.

E. Duchovni, E. Prosso, P. Renkel, Eur. Phys. J. C 40N5, 43 (2005);
SN-ATLAS-2004-043.

The Weizmann group has investigated various aspects of supersymmetry with *R*-parity violation and the discovery potential of ATLAS for this version of supersymmetry.
E. Duchovni, A. Melamed-Katz, ATL-PHYS-PUB-2005-025.

4. Other New Physics projects

The Tel Aviv group has studied processes of di-boson production as a way to measure trilinear gauge boson couplings ($WW\gamma$, $ZZ\gamma$, WWZ and ZZZ). Relevant problems in existing event generators were pointed out and treated. It was shown that ATLAS measurements will improve the accuracy in constraining deviations from the Standard Model.

The Weizmann group has studied topics related to extra dimensions. First, the distribution of di-lepton masses in the presence of Kaluza-Klein excitations of the photon and the Z^0-boson were studied. Second, black hole production and decay, particularly into *Z*-bosons and to dark matter particles, were studied.

GRID Computing Initiative

Context: GRID WORLD/ATLAS

The enormous data flux and the complexity of the event data coming from the LHC detectors, has called for a major development in the field of data handling and computing. For the past several years the HEP community has led the pioneering efforts to realize GRID computing ideas. GRID developments are being pursued in many fields beyond HEP, but it is fair to say that with the concrete necessity for managing the LHC data on the near horizon, much of the first large and broad-based user implementations are happening in the HEP environment and in particular for the LHC experiments. The GRID is the backbone of the ATLAS Computing Model.

The GRID computing for the LHC experiments is developed within the framework of a common CERN project called the World-wide LHC Computing GRID (WLCG), of which ATLAS is an active and important partner. The WLCG has set up a tier structure which will provide the computing framework for ATLAS. The data selected by the trigger and event filter system at the ATLAS detector at Point-1 will be transferred to the single Tier-0 site located at the CERN computer center. From there data will be distributed to 10 Tier-1 centers associated with ATLAS, roughly speaking, large regional centers. These, in turn, are connected to some 30-40 Tier-2 centers, typically serving a community of the size of the three Israeli groups. As with the constructions of the experiments, the framework of the WLCG is governed by Memoranda of Understanding with CERN and the funding partners.

Key Elements of the Israeli Proposal

A critical component to the success of the physics program of the Israel ATLAS group is to have the necessary computing and physics analysis tools to be competitive within the collaboration. This would also capitalize on the team's already significant contribution to the detector hardware. In the context of the GRID-based ATLAS Computing Model, the proposed Tier-2 computing facility seems to be an excellent choice to provide those needs. The proposal is well thought-out and its support request is reasonable by comparison to Tier-2 centers elsewhere for teams of this size -- perhaps even on the modest side, but sufficient to provide an effective, if lean, resource. Its success depends on a number of key elements -- organizational, hardware, infrastructure and support personnel -- most of which are addressed in the proposal. It would also put the ATLAS resource in the Israeli vanguard for using the GRID in scientific computing.

The Israeli team has opted for a distributed Tier-2 center embracing all three institutions (Weizmann, Tel Aviv, Technion). This model has also been chosen, and is being successfully developed, at several other regional centers in the LHC collaborations. With the appropriate coordination and infrastructure support, it can provide synergism to enhance the effectiveness of the scientists at the three institutions, so that the total impact could be greater than the sum of the individual institutional efforts.

Within the ATLAS computing model, the ATLAS-Israel Tier-2 center has the dual purpose of producing Monte-Carlo event simulations for the entire collaboration and providing access to data for end-user analysis. More specifically, it needs to provide facilities for: (1) its pro-rata share (1.3%) of the ATLAS simulation, (2) for most Israeli ATLAS physics analysis, dedicated simulations and specialized reconstructions in support of 21-24 Israeli-based physicists and (3) for performing some part of the TGC monitoring. The needed resources being requested consist of hardware (computing power [CPUs] and network storage), network connectivity (nationally and internationally) and manpower to manage these resources and the GRID middleware. Not included in the proposal is the necessary physical infrastructure (space, power, cooling, etc.), which is assumed to be supplied by the host institutions. While this could be a considerable cost to be leveraged by the host institutions, it is vital to the establishment of the distributed Tier-2 center.

The profile for the increase in CPUs is compatible with that of the ATLAS collaboration and is shown in the table below (reproduced from the cost estimate portion of the proposal, Table 2. The entire proposal is also included here as Appendix 1). These are standard, commodity, rack-mounted processors, with two-Intel or AMD dual-core processors per box and 1 gigabyte of memory per core. The cost estimates seem reasonable, including the traditional assumption that the cost of the processors drops by a factor of two every two years and that the hardware will be replaced every four years. This replacement scenario is conservative and is consistent with the approach in many centers in Europe, although the planning in U.S. centers is for replacement every three years.

In their planning for storage capacity, the group is anticipating an initial shortfall in the international network bandwidth available and will wisely attempt to compensate by having more storage space, based on experience elsewhere, such as with the large Phenix experiment at the RIHC facility at Brookhaven National Laboratory. This is a valid solution up to a point, but the issue of network connectivity will eventually have to be addressed. Because of cost considerations, the group is proposing a combination of a smaller subset of higher-performance, moderate-reliability disk storage (class "A" in the table) and a larger amount of lower-performance, lower-reliability storage (class "B" in the table). With the group's limited manpower, management of the disk space and its usage is a priority. Networked disks are required. Class A will be used for data actively analyzed locally on a day-to-day basis, while Class B is to be used for large data sets required less frequently and for data to be provided via the network to ATLAS. The proposed distribution of Class A & B resources and costs are shown in the table below and seem reasonable.

A major factor in the effectiveness of the Tier-2 center will be the network connectivity within Israel and internationally. At present there are a number of uncertainties regarding possible available bandwidth, which must be resolved in the near future. Firstly, in networking between Israeli ATLAS sites, many of the files stored in Israel will be used by all three institutions, making it essential that data at one site be directly accessible by another site. There is, as yet, no detailed model as to how the data would be shared and therefore it is not yet known whether the Machba network within Israel can support the traffic. Hopefully it can; but if not, then dedicated links may be required. In such an event, perhaps the cost could be borne by the host institutions, since it is intrinsic to the infrastructure needed for a distributed Tier-2 center. Secondly, with regard to the international network connectivity within the ATLAS model, most Tier-2 sites are assumed to be connected to their Tier-1 site by 1-2.5 Gb/sec links, usually via GEANT, the European academic and research network, to which the Israeli academic network is also connected. Israel ATLAS has properly dismissed the possibility of purchasing its own link to GEANT because of the large yearly support costs. Instead, it is exploring a much more affordable solution, based on the fact that most of its network traffic, though a large volume, consists of bulk file transfers which do not need high priority. Therefore, transferring these files via the Machba network only when the network is not otherwise busy, called "Quality of Service " (QOS) support, would probably be sufficient and avoid the need for an expensive, dedicated network connection. This is the case within the present bandwidth for Israeli academe and could remain so, depending on future Machba network sizing. This solution needs to be pursued aggressively. Because of the present uncertainties, the network cost estimates in the table represent contingency for the QOS support, but do not include cost estimates of a private dedicated network, either between the Israeli sites or internationally.

Finally, to make the Tier-2 center viable, it is essential to have the appropriate professional computing manpower available to address the myriad needs and responsibilities required of sophisticated operation. The requested number of people in the ATLAS computing proposal of 2-3 FTEs, shared across the three institutions, is reasonable and commensurate with staffing at other such centers, when extrapolated to the size of the Israel center. If the manpower falls below 2 FTE computing professionals, the effectiveness of the center would be noticeably affected. It will be a real challenge to find sufficiently well-qualified personnel to provide the appropriate support; such professionals must be able to perform at the cutting edge of GRID computing while faced with unprecedented data-flow and deadline pressures. The needed support to be provided includes: hardware and infrastructure support; system management, storage management and cyber security; Grid middleware installation, localization and operation; ATLAS software management and liaison with ATLAS software group; helping physicists and students run ATLAS software.

In summary, the Committee concluded that the size and time profile of the resources requesteded are required to be successful within the ATLAS computing model and need to be met if the Israel ATLAS group is to remain competitive.

Table 2: Spending profile for hardware, network and manpower

Q1:	2007	2008	2009	2010	2011	2012
Processing power						
% of previous year or, for 2007, % of 2008	13%	749%	154%	191%	134%	125%
increase of CPU (KSI2k)	61	395	247	641	459	459
total CPU power (KSI2k)	61	456	703	1344	1803	2261
cost of CPU ($/kSI2k)	$750	$532	$377	$268	$190	$135
replace old CPUs					k$12	k$53
spending for each year (k$)	k$46	k$210	k$93	k$171	k$99	k$115
"A" class storage						
% of previous year or, for 2007, % of 2008	33%	300%	167%	140%	114%	113%
increase in disk space (TB)	10	20	20	20	10	10
total disk space (TB)	10	30	50	70	80	90
cost of disk space k$/TB	k$5.0	k$4.0	k$3.2	k$2.6	k$2.0	k$1.6
replace old storage					k$20	k$33
spending for each year	k$50	k$80	k$64	k$51	k$41	k$49
"B" class storage						
% of previous year or, for 2007, % of 2008	13%	756%	170%	174%	144%	131%
increase in disk space (TB)	22	147	118	212	220	220
total disk space (TB)	22	169	287	499	719	940
cost of disk space k$/TB	k$2.0	k$1.5	k$1.1	k$0.8	k$0.6	k$0.5
replace old storage					k$14	k$70
spending for each year	k$45	k$220	k$133	k$179	k$154	k$174
total disk space (TB)	32	199	337	569	799	1030
Network switches	k$30	k$16	k$16	k$10	k$10	k$10
Israeli & Int'l network	*k$0*	*k$25*	*k$50*	*k$60*	*k$60*	*k$60*
Manpower	k$180	k$180	k$180	k$180	k$180	k$180
Travel	k$12	k$12	k$12	k$12	k$12	k$12
total yearly expenditure	**k$362**	**k$743**	**k$548**	**k$663**	**k$555**	**k$600**
4 year total				**k$2,317**		

Ongoing Budgetary support beyond the GRID request

The Committee asked for, and was given, a budgetary estimate for the support of the current scientific personnel – namely faculty, staff, postdocs and students -- and funds for their travel and other non-construction-funded efforts. That estimate is $550K per annum. $150K of this is provided outside of the ISF and is not of concern here; which leaves a need of $400K per annum. At present, $300K comes from the ISF Center of Excellency funding and is approved for two more years. An additional $50K is also provided by the ISF. With regard to ATLAS, these funds are critical to sustain the on-going vitality and smooth-functioning of the three Israeli groups. Hence, provision must be made for the $50K shortfall, and plans must be made to continue, three years from now, the $300K which is currently supported by the Center.

Assessment of Work to Date and Recommendations for Future Involvement

Appraisal of Work to Date:

The Committee was highly impressed by the work accomplished by the Israeli groups: their performance has been outstanding. The chambers have all been fabricated and tested, on time and within budget. Installation of the full system is nearing completion. Final testing of the full chamber system at CERN has been accomplished using the production readout and data acquisition systems. This includes the detection and successful reconstruction of cosmic-ray muons. The quality of the chambers is uniformly excellent and all detector performance specifications have been met.

By sharing a common focus within ATLAS, The Israeli groups have developed an effective and coherent working relationship, which positions Israel yet more strongly now to make relevant and highly visible contributions to ATLAS and beyond. The synergy and cohesion of the three groups was more evident at this review than in any of the previous ATLAS Israel reviews. The level of participation and the effectiveness of the Tel Aviv and the Technion groups has increased significantly.

It should be noted with satisfaction that Israeli industries, through the competitive tendering process, have been involved in some key areas of the LHC machine, fabricating highly specialized hardware as well as developing expert software components.

Recommendations:

1) Reaping the Scientific Rewards

Israel is a founding member of the ATLAS collaboration and has been an exceptional collaborating nation to date. It has delivered on all of its commitments and has, in addition, provided collaboration-wide leadership in many notable areas. The return on these investments will be participation in the scientific program that is soon to begin. The Committee recommends:

- That Israel assert its strong commitment to the ATLAS program and to the current roles and responsibilities of the Technion, Tel Aviv and Weizmann groups.

- That ISF (or alternate sources if needed) provide the necessary level of base funding, represented to the Committee as $400K per annum, for the support of the scientific manpower and infrastructure for the three groups. Details of what is needed in which fiscal year is covered in the sub-section "Ongoing Budgetary support beyond GRID request", Support beyond the base funding is covered below under item 4).

2) Hardware contributions

Even though the detector construction is well advanced, substantial additional effort will be required before the construction phase can be declared complete. The final assembly of the TGC sectors and their underground installation into the 'Big Wheels', highly constrained by the sequence of availability of other components outside the control of the Israeli groups is critical to the schedule of the entire ATLAS project. In parallel, much effort needs to be spent on commissioning the hardware and controls to ensure they are fully operational prior to the first LHC data-runs. These activities will be particularly intense during 2007 and 2008; only when this phase is complete can one expect to reach a stable 'Maintenance and Operation' (M&O) regime for the hardware and controls.

The Committee therefore recommends:

- In order to complete the assembly, installation and commissioning of the TGC system, adequate resources must be provided for the support of system experts and technical manpower in residence at CERN.
- A budget and structure for the long-term maintenance and operation of the TGC system must be established.
- Further, the committee considers it mandatory that the successful hardware construction effort be well-documented, thereby providing a well-defined closing milestone for an impressive achievement by the Israeli HEP community.

3) Physics Analysis

The Israeli group has the potential to make a strong impact in the physics analysis at ATLAS. This statement is based on the fact that this potential was realized in the Israeli involvement in the LEP experiment and on the fact that some of the first steps taken are promising. Yet, the preparations for physics analysis by the various Israeli groups are presently at a rather exploratory stage. To realize the potential to its full extent, the Committee recommends the following:

- To make an impact, there is a need for a coherent, cohesive, and focused Israeli effort. Each of the three groups is rather small, in terms of financial and, in particular, human resources. The number of faculty, post-docs and students is small compared to many other groups in ATLAS. All three groups need to work together. They should meet regularly, exchange ideas and collaborate on common analysis projects.

- Israeli HEP phenomenologists should take part in some, if not all, the meetings to discuss physics analyses. A dialogue with the Israeli phenomenologists might be helpful towards a better grasp of the significance (or lack of it) of various possible projects and is likely to generate new ideas. Drawing in the Israeli phenomenologists to the LHC effort will benefit not only the experimentalists but also the phenomenologists themselves. The meeting on November 12-16, 2006 at Weizmann, Physics at the LHC: Part I, is a very encouraging development in this regard.
- The analysis goal should be to create an interesting 'niche' that will be internationally identified with the Israeli group. If many small-scale projects on diverse topics are pursued, it is likely that the depth and impact of this effort will be small. The Israeli group would be better served were they to be selective. It should collectively identify a small number of topics with good theoretical motivation and preferably with relation to the specific detector expertise of the Israeli group.

4) GRID Computing

The choice of a distributed Tier-2 center with resources at all three institutions requires a great degree of coordination for successful operation as well as the development of professional expertise at each institution. Based on experience and observation elsewhere, the Committee recommends:

- That a single, clearly designated leader be elected and given the attendant authority to be in charge of the Tier-2 center and recognized as such within ATLAS Israel and by the international ATLAS collaboration. This designation needs to be done very soon.

- That the availability of 2-3 FTE computing professionals, distributed across the three institutions, be ensured soon, so as to provide the required support of the center operations. Such highly qualified personnel are necessary from the outset and, since they are in great demand elsewhere, an aggressive recruiting effort should be mounted now.

The Committee supports the *distributed* Tier-2 center model which empowers the three institutions and will create the synergism to enhance the combined effectiveness of the participating scientists. The Committee recommends that:

- All three institutions provide the vital physical infrastructure contributions needed for success, such as space, power and cooling. Upon further study, it may turn out that inter-university network connectivity may also be needed, which likewise should be provided by the institutions. If these infrastructure contributions cannot be realized, then the distributed model may need to be abandoned in favor of a Tier-2 center at one of the three institutions: it is hoped that this would not be necessary.

- Because first beams at the LHC are not far away, it is also imperative that the uncertainties regarding network connectivity bandwidth internationally and within Israel be resolved quickly, with the "Quality of Service" (QOS) solution discussed earlier as a leading possibility.

- The Tier 2 budget, and its annual profile, must be fully supported at the requested level, namely a total of $2317K ($3471K), spread over the next four (six) fiscal years as follows: $362K in 2007, $743K in 2008, $548K in 2009, $663K in 2010, $555k in 2011 and $600K in 2012. After a careful scrutiny of the proposal and comparison to similar efforts elsewhere, the Committee finds that the budget requested is appropriate and that the funding profile is crucial to realize the important opportunity for ATLAS Israel, which would otherwise evaporate while the rest of ATLAS moves on.