Submitted 3-Dec-06

Chairman's Report

AMS Review
25-Sept-06

This is a summary report of the AMS review made by the chair, Barry Barish. I try in this letter to capture what I believe were the main points that came out during the review, both in the presentations and discussions with the AMS collaboration, in the executive session that followed and in the conclusions expressed by individual reviewers. Finally, I should comment that we delayed submitting our individual letters until we could individually do some follow-up work after the review on some issues that were raised during the review. I also include here some of the main points that were reported from those post-review inquiries.

The one day review took place in Washington DC, and the agenda and charge are attached. The reviewers were Barry Barish (chair), Elliott Bloom (Stanford Linear Accelerator Center), Jim Cronin (University of Chicago), Stephen Olsen (University of Hawaii), George Smoot (UC Berkeley), Paul Steinhardt (Princeton) and Trevor Weekes (Harvard-Smithsonian Center for Astrophysics).

Overall Conclusions

The AMS experiment is designed to perform precision measurements of unprecedented sensitivity of the primary cosmic ray spectrum using both particle identification and precision momentum measurement with a large aperture superconducting magnet. Such cosmic ray measurements will provide very important new information on cosmic rays astrophysics and on various high energy phenomena. Such measurements will lead to important new understanding of the nature of our galaxy. There is also the exciting possibility that AMS could make some fundamental new discoveries.

All committee members were extremely impressed by the powerful detector that has been developed for AMS and also by the considerable strength of the AMS international collaboration. The committee members found that there is a strong scientific case for deploying AMS, with the exception of one member, who had reservations both regarding the science and the approach of the collaboration.

The Science of AMS

1. Cosmic Ray Physics

The sensitivity of the instrument will be well beyond that of any previous instrument put in space to study high energy cosmic rays. Putting such a powerful new instrument in space gives strong justification on rather general grounds, because of what we can anticipate it will contribute to cosmic ray physics, due to its ability to make a whole variety of new quantitative measurements. It can be expected that such new data will have a large impact on the field.

AMS will make high statistics measurements of the momentum distribution of protons and heavier nuclei up to ~ 1000 GeV. On the low energy side, they have already observed effects of the geomagnetic cutoff in AMS-1 and now can extend this measurement to near the knee in the cosmic ray spectrum. They also could shed light on the secondary to primary flux, which is observed to be dropping with energy at low energy and they can extend this measurement to much higher energy. Detailed measurements of the isotopic composition are especially important in that they will give insight into the scales of propagation times of charged particles in the galaxy and, in turn, information on galactic magnetic fields. Finally, a more detailed knowledge of the properties of the primary comic ray flux is needed to model neutrino fluxes and such information can significantly reduce the uncertainty in the flux.

The particle separation in AMS will also enable them to do measurements of positrons up to about 100 GeV, well beyond that available from balloon experiments. We know how cosmic-ray positrons are produced, which is mostly through p-p interactions in interstellar space. The goal of these measurements will be to compare the intensity and spectrum measured in AMS with the expected production rate. This comparison can help us understand how the energy spectrum is deformed by diffusion or radiative energy losses in the galaxy.

The physics questions for antiprotons are quite complementary. They are also produced mostly in p-p collisions, but in this case the only significant loss mechanism is diffusion. The astrophysics of positron and antiproton observations is quite significant, and may well be the most important contribution of AMS to cosmic rays physics, independent of the possible discovery potential in these measurements.

2. Prospects for Discovery Physics

The original motivation for AMS was to search for antimatter in the Universe. One of the major goals remains to set an improved experimental constraint on antimatter. The idea is that the baryon asymmetry in the early universe caused non uniformities, where there are regions of the universe dominated by matter and others dominated by antimatter. This appears unlikely, as both theory and experiment (e.g. WMAP) have constrained these possibilities and now it seems difficult to make a consistent picture where matter and antimatter have stayed unmixed in separate regions. Although the probability of discovery of antimatter appears unlikely, improved experimental limits are of value themselves.

A second and more promising discovery goal that was presented to us was the searches for dark matter. The signature being sought are excesses in the antiparticle (positrons, antiprotons, etc) spectra resulting from dark matter particle annihilations. Hints of excesses that have been reported and AMS will provide much more precise data. Even with much better data, the interpretation will be challenging due to uncertainties in the production models from normal processes. It is worth noting, however, that AMS will provide comprehensive cosmic ray data that will help better constrain these models.

Lastly, we were presented with the prospects for detecting strangelets, a new form of strange quark matter conjectured by Ed Witten in 1984. The existence of hadronic states with more than three quarks is allowed in QCD and ultra-dense matter, like that found in neutron stars, might form such matter. Although limits have been set on strangelets from accelerators, strangelets with $A>8$ cannot be made by coalescence at accelerators the question of the existence of strange quark matter require a different approach like using astrophysics searches. The idea is that there will be a substantial flux of strangelets in the cosmic radiation due to binary collisions of strange stars.

AMS will measure charge, mass, and momentum and can search for strange quark matter by looking for anomalously low mass/charge or A/Z. This search was already tried in AMS-01 and two possible candidate events were found, but the limited statistics and resolution did not rule out that they were background events, so this result was not published. AMS-02 will provide a much more sensitive search.

The strangelet search appears to be the most promising discovery channel that has been conjectured from known physics. Of course, discoveries of unanticipated phenomena remain an important possibility, resulting from putting a new very sensitive instrument with such powerful capability into space.

3. PAMELA Mission

The committee noted and several committee members expressed concern that some of the "cream would be skimmed off the top" of AMS-02 by the PAMELA mission, which was launched in July 2006. We could not fully analyze the capabilities of PAMELA, but it is a significant step beyond AMS-01. However, it has no where near the promised sensitivity of AMS-02, which has about 200 times greater sensitivity and has other important capabilities (e.g. transition radiation detectors) not employed on PAMELA as launched. Nevertheless, some initial discovery potential lies with PAMELA, even though it can be argued that AMS-02 will be even more justified if PAMELA demonstrates early some of the rich science that will be seen by AMS-02.

Progress on Fabrication of the Detector

AMS is designed to be a powerful new instrument in space. It is based on a large aperture superconducting magnet instrumented to be a precision experiment with very good background rejection. The goals are to separate anti-helium from helium to 1 part in 10^{10}, to separate positrons from protons to 1 part in 10^6 and to measure spectra to 1%

accuracy. To accomplish these goals, AMS has large bending power of $BL^2 = 8000\ Gm^2$ using the first superconducting magnet designed to be put in space, has minimal material in the particle paths and makes repetitive measurements of momentum and velocity. This combination makes a powerful instrument with time resolution of $\Delta t = 100$ ps, spatial resolution of $\Delta x = 10\ \mu m$, and measurements of velocity with accuracy of $\Delta v/v = 0.001$

Progress in building and assembling AMS-02 has been excellent. We heard reports on all the subsystems:

The superconducting magnet has been the responsibility of Switzerland. It has been especially engineered for space with a new type of superconducting cable that eliminates quenches, and numerous other innovations to prepare the first superconducting magnet for space. It recently passed a system review performed by the DoE (July 2006) and chaired by Bruce Strauss. It appears on track for a final readiness review before launch.

The Transition Radiation Detector (TRD) is designed to give a p/e+ rejection of greater than 10^2 up to 250 GeV. That goal appears well in hand as demonstrated in a beam test at CERN yielding a rejection of better than 10^2 over the entire range, and in fact a rejection of about 10^3 below 150 GeV. The time-of-flight system measures the time of relativistic particles to ~ 100 picoseconds. An elaborate veto system with improved electronics and light collection system over AMS-01 has measured inefficiency for minimum ionizing particles of better than 10^{-4}. Production is complete on the large silicon tracker -- 8 planes, 6.6 m^2. The ring imaging Cerenkov counter has almost 11K channels and we were shown impressive performance tests from a test beam of E=158 GeV/n. The electromagnetic calorimeter makes 3 dimensional, 16 X_0 measurements of the direction & energy of gamma rays and electrons and again we were shown measurements reaching the resolution goals in energy and angle. Finally, the electronics, developed in Taiwan, also appears to be well advanced. It is based on accelerator detector technologies and is ~ 10 times faster than commercial space electronics.

Overall, the committee members were uniformly impressed with the ambitious technical design and the actual realization of the detector. This impressive detector has been carefully developed with special care to achieve the technical goals. It is within a few months of being ready to begin the final integration phase.

Readiness for Deployment

AMS-01 was a very important and successful demonstration mission. It successfully used much of the AMS-02 technologies in space and successfully exploited the considerable cosmic ray science.

The AMS-02 detector subsystems are now almost completed and the next big step will be the integration phase preparing for launch.

Integration of the detector subsystems has been proceeding at CERN and the next big step will be the full integration. CERN and ESA have been providing AMS with strong logistic support during the period 2006-2008 to assemble the detector, to calibrate the detector in a test beam and to ensure the temperature of the detector is controlled to 1°C. We were told that ESA will provide a 45 day Thermal-Vacuum test at Noordwijk

Serious integration of the full instrument system is scheduled to begin soon - early 2007 - with the goal of shipping a flight ready payload to Kennedy Space Port in late 2008. Pending completion of integration, test, and calibrations leading to a strong Flight Readiness Review result, the Agencies (NASA with DOE concurrence) should plan in 2008 to manifest AMS for a Shuttle flight to deployment on ISS.

The results presented for the subsystems (most of them) indicated reasonable expectation for meeting the science and launch requirements. Integration is still a key episode in that it is only then that full compatibility, performance, and schedule can be confidently predicted. In space based experiments, it is not uncommon to discover problems late in environmental testing, or to find that important components have fatal problems in the space environment from vendors and/or other missions. However, as the AMS collaboration controls the instrument readiness aspects of the mission (vs. NASA control of safety), they may be somewhat mitigated compared to other recent missions. The costs of this final integration step were also a concern to some committee members. It is certainly not small and it is not clear at this time how much resources will be required and how they will be paid.

AMS Role in International Collaboration on Major Scientific Projects.

The role of AMS in the area of international collaboration on major scientific projects is truly outstanding. When the AMS-02 detector is integrated, it will bring together the efforts of many nations and groups across the globe. In fact, this experiment has crystallized its collaboration around the international contributions to the space station itself. There have been very large contributions to AMS coming from Italy, China, France, Taiwan, and the US, with significant contributions by five other countries, and some contribution from six others. The committee particularly noted the uniqueness of having Taiwan and the PRC together on AMS. It was emphasized by Professor Shih-Chang Lee in his presentation that they agree on the importance of having AMS-02 on the ISS.

The national governments of the participants, through their ministries of science, have regularly reviewed and expressed enthusiasm for the project. The Review Committee heard representative scientists from nearly all of the participating nations. One had to be impressed by how each group is making an important contribution to the whole and how the disparate groups have been coordinated to work together smoothly and efficiently with one another. Indicative of the cooperation was the fact that a single presenter described to the Review Committee As one reviewer commented, "In addition to what it accomplishes scientifically, the AMS project is sure to be viewed as a model for international collaboration in science."

The total project is clearly well managed by Professor Ting. In general, the committee had only praise and some wonder of this effort. One committee member however, felt that the structure of the overall project management, beyond the leadership of S. Ting has not been made clear.

FINAL REMARKS

AMS-02 is poised to soon begin its final integration phase. The very strong AMS collaboration has carried out a very successful demonstration mission, AMS-01, and has done a magnificent job of designing and building a state of the art device for deployment on the space station. The science potential of AMS-02 is very broad, including a wide variety of measurements fundamental to understanding high energy cosmic rays and their origins. In addition, such a sensitive detector may well make some fundamental discoveries. The collaboration is exceptionally strong and is made from an international team with cohesion and outstanding technical skills. The leadership and management of AMS is effective and dedicated. In the opinion of this review committee, the AMS mission is ready for the next step and plans should be made to place it onto the space station, in order for it to carry out its promising science.

AMS REVIEW CHARGE

September 25, 2006

The panel is asked to review the AMS experiment; a U.S. led international collaboration under the direction of Professor S. Ting of MIT. The AMS experiment is aimed at **precision measurements of** cosmic rays in low earth orbit with a sensitive magnetic spectrometer. This experiment is designed to be placed in the U.S. National Laboratory on the International Space Station.

The Department of Energy is the sponsor for the experiment. The detector fabrication is near completion. The Department desires your evaluation of the scientific value and worthiness of the **AMS scientific program**, the progress to date on fabrication of the detector **and** readiness for deployment, **and the role of AMS in the area of international collaboration on major scientific projects**.

We would appreciate receiving a letter report from each panel member by October 1, 2006 **and a summary report from the Chairman by October 15, 2006. The summary report should summarize the views expressed in the individual reports**. Please send your reports by email attachment to Robin Staffin, with copies to Aesook Byon-Wagner, P.K. Williams and Saul Gonzalez.

Review of the AMS Experiment

by the U.S. Department of Energy
Review Panel

25 September 2006

Agenda

08:00-08:30	Executive Session	*Robin Staffin*
08:30-09:30	Introduction	*Samuel C.C. Ting, U.S.*
09:30-09:45	Physics of AMS: Strange Quark Matter Search	*Jack Sandweiss, U.S.*
09:45-10:30	AMS Superconducting Magnet	*Stephen Harrison, U.K.*
10:30-11:00	TRD	*Stefan Schael, Germany*
11:00-11:30	Tracker	*Roberto Battiston, Italy*
11:30-11:45	Time of Flight	*Andrea Contin, Italy*
11:45-12:00	Veto Counters	*Wolfgang Wallraff*
12:00-13:00	Lunch	
13:00-13:30	RICH	*Javier Berdugo, Spain*
13:30-14:00	ECAL	*Franco Cervelli, Italy*
14:00-14:30	Electronics	*Mike Capell, Jinchi Hao*
14:30-14:45	Integration of AMS into NASA System	*Stephen Porter, NASA JSC*
14:45-15:30	Report on International Commitments	
	from Italy	*Roberto Battiston*
	from Switzerland	*Maurice Bourquin*
	from Germany	*Klaus Lübelsmeyer*
	from China & Taiwan	*Shih-Chang Lee*
	from Spain	*Manuel Aguilar*
	from France	*Jean-Pierre Vialle*
	from Russia	*Yuri Galaktionov*
	from the United States	*Susan Marks Ting*
	Conclusion Remarks	*Jack Sandweiss*
15:30-17:00	DOE Executive Session	*Robin Staffin*