Fermilab

Closeout Presentation

Director's Independent Conceptual Design Review of the Muon g-2 Project

June 5-7, 2013

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Table of Contents

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Executive Summary

The g-2 experiment at Fermilab proposes to measure the anomalous magnetic moment of the muon to an unprecedented level of precision, improving on past measurements at BNL E821 by a factor of four or more. The experiment is currently under development through support by the Department of Energy, and received Critical Decision 0 (CD-0) approval in September 2012. This Independent Conceptual Design Review is being conducted as part of the requirements for CD-1, which is currently scheduled for late summer 2013.

The g-2 Project consists of well-defined project elements broken into five WBS Level 2 systems. The Project Office personnel and Level 2 and Level 3 managers are in place and highly engaged. The lines of authority within the Project are clearly delineated, and well understood by all of the principals. The Project structure well supports an efficiently managed engineering and design effort. There is active and close collaboration between the Project and the Collaboration, which has introduced the added benefit of enabling the effective integration of students and post-docs into the design and simulation effort.

The Project Team is strong, dedicated and enthusiastic, and is highly capable of delivering suitably optimized preliminary and final designs. The Team consists of both former (E821) g-2 experimenters and new collaborators. The former E821 experimenters are very well integrated into the experiment and design process. Lessons learned from E821 have been successfully transferred, and risks have been identified and mitigation processes have been developed. The Committee found the proposed design for the storage ring to be technically feasible and cost effective, with well-defined risks; the technical designs of the various accelerator-related components to be sound and achievable; and the detector designs to be highly advanced and greatly improved relative to E821, being properly informed by past detector experience and technology advances.

The Project Team is to be applauded for the level of attention they have paid to value engineering. No effort has been spared in trying to use pre-existing accelerator and experiment components as various designs and technology choices have been considered. Final design choices that have been made are soundly based on considerations of cost, risk, experience with the technology within the Project, and impact to the physics. This approach has been fully integrated into the Project's engineering, design and development process.

The Project's integration of past experience on g-2, coupled with its considerable efforts related to design improvements and optimization, have resulted in a design that is well beyond the conceptual stage. The Committee finds the maturity of a number of elements of the CDR to be consistent with that expected at the Preliminary Design stage. The CDR is comprehensive, detailed and complete, and contains a full description of the underlying physics and its justification. Design alternatives that well address the targeted physics have been developed. Adequate backup material is provided in the CDR, which included risk assessments and mitigation, quality assurance, ES&H, and value engineering considerations.

The success of the Project and its design are predicated on highly collaborative efforts between g-2 and various Laboratory Divisions, and the integration of seven AIP and GPP projects for the shared Muon Campus infrastructure. Strong coupling between the accelerator and the experiment is particularly important for realizing the g-2 goals, including a successful final design. The AIP/GPP projects are also managed for the Laboratory by the g-2 WBS Level 2 manager for the accelerator systems, which has provided an invaluable interface between these projects and g-2. This arrangement also provides an important line management interface to the Laboratory Directorate. Owing in large part to the dedication of the principals, including the engagement of a strong collaboration, the development of the design has evolved with efficiency and coherence. The Project does not yet have a Configuration Management Plan in place, but plans for doing so were presented and discussed. The Project is aware of its importance to the success of the g-2 engineering and design effort, and appears to be well poised to develop such a plan by CD-1.

The Committee compliments the Laboratory and the DOE for their support of g-2 in the midst of a very difficult funding climate. The Project is at a relatively advanced design stage, and is ready to begin moving through the approval process. We encourage the Laboratory and funding agency to find a means to proceed expeditiously with this world-class, and cost-effective, next-generation experiment.

1.0 Introduction

A Director's Conceptual Design Review of the Muon g-2 Project was held on June 5-7, 2013 at the Fermi National Accelerator Laboratory. The object of this review was to assess the status and adequacy of the overall CMS Detector Upgrade conceptual design effort to meet the requirements for a DOE Critical Decision 1 (CD-1) "Approve Alternative Selection & Cost Range". The charge included a list of topics and specific questions to be addressed as part of the review. The assessment of the Review Committee is documented in the body of this closeout presentation.

Each section in this closeout presentation is generally organized by Findings, Comments and Recommendations. Findings are statements of fact that summarize noteworthy information presented during the review. The Comments are judgment statements about the facts presented during the review and are based on reviewers' experience and expertise. The comments are to be evaluated by the project team and actions taken as deemed appropriate. Recommendations are statements of actions that should be addressed by the project team. The remainder of this presentation has the answers to the review charge questions.

The Muon g-2 Project is to develop a response to the review recommendations and present it to the Laboratory Management and regularly report on the progress during the Project's Project Management Group Meetings (PMGs) and at the Performance Oversight Group (POG). The recommendations will be tracked in the iTrack system where progress to closure will be tracked.

2.0 Accelerator

Primary Writer: Mike Syphers

Contributors: Bob Webber

We recognize and commend the great efforts applied and impressive progress achieved leading to efficient and effective conceptual accelerator and beam line designs that will support both g-2 and Mu2e programs. The added complexity of meeting the demands of both experiments has been handled with great care and foresight, utilizing the existing infrastructure from the Tevatron program as much as possible.

The g-2 team has done an admirable job analyzing the antiproton production target station for its potential use in the preparation of a pion beam for g-2, with a very favorable outcome resulting in significant cost and risk savings. This involved much simulation and experimental effort over the past 2-3 years and clearly demonstrates the level of expertise amongst the collaboration and the laboratory.

Throughout the presentations, many other value-engineering efforts were described and have resulted in cost and risk benefits to the project. Many aspects of the g-2 project are advanced well beyond a conceptual design stage. The technical designs of the accelerator-related components for g-2 and associated projects are sound and achievable. A talented, dedicated, and enthusiastic team of scientists and engineers are actively planning and pursuing the designs required for the project to be successful.

The Accelerator Subcommittee heard talks on the target station, beam line design and optics, beam instrumentation, reconfiguration of the injection/extraction straight section of the Delivery Ring including kicker requirements, and accelerator controls and safety system considerations including radiation safety. Also included were an overview talk on the updated process for preparing bunched beam in the Recycler ring for g-2, and an update on the expected muon rates through the system and into the storage ring. All talks were well prepared and substantive.

2.1 Target Station

Findings

- A new bunch formation scheme in the Recycler has been formulated using two Booster cycles; the bunching scheme has been successfully demonstrated in Main Injector.

- Particles of momentum 3.1 GeV/c were successfully produced at the existing target station and transported through the present beam line system to the entrance of the future Delivery Ring; measured beam intensities are consistent with estimates from simulation.

- The Lithium Lens and pulsed magnet system used for antiproton production has been demonstrated to be adequate for use for pion production at 3.1 GeV/c for delivery to g-2.

- The beam dump downstream of the target, which has a water leak, is to be replaced as part of the project.

- A new focusing scheme has been designed to reduce beam spot size on the target and increase secondary yield.

- Value engineering has been done to assess the benefits of a new/modified target design; the result is a decision to move forward using the existing system. Value engineering has also determined that using the existing lithium lens system (and upgrading the power supply for increased pulse rates) is preferable to a focusing system using DC quadrupoles. A cost/benefit analysis has found that replacing the existing primary beam absorber, which has a cooling water leak, with a copy of the same design is preferable to either attempting repair of the leak or designing a new smaller absorber design better matched to the g-2 beam power requirement.

Comments

- The ability to reuse the AP0 target system and infrastructure is a very positive outcome for the experiment, an outcome that was in question a few years ago. The project is to be commended on its pursuit in understanding this system and to verify its applicability.

- The AP0 beam dump replacement constitutes a risk, as this has never been replaced, but this risk has been recognized by the project.

Recommendations

None.

2.2 Beam Lines, Optics, and Instrumentation

Findings

- Many alternatives have been explored. Combinations of existing magnetic elements and various schemes for matching and transport have been investigated. Further investigations, especially in the M2/M3 crossover region, are foreseen which may bring about further savings and optimization.

- A revised optics in front of the target hall provides a smaller, better-optimized beam spot on target.

- The beam lines from target to the delivery ring have been designed with a 40 pi-mm-mr transverse acceptance with > +/- 2% dp/p, largely reusing existing magnets and many other repurposed components.

- Most magnets used in the design are reused from antiproton operation. The magnets that remain to be constructed are duplicates or easily extended designs of existing magnets.

- Mismatches in optics, especially in dispersion, between the beam delivery system and the muon storage ring still exist – as they did in E821 – but to a lesser degree, and further reduction schemes continue to be explored.

- The strong interplay between meeting the needs of both g-2 and Mu2e is well incorporated into the design of the beam lines.

- The M4/M5 transfer line system design, complicated by the necessity to partially serve Mu2e as well as g-2, has been part of the optimization of the final footprint for the Muon Campus, including the determination of the rotational orientation of the g-2 ring within the MC-1 building.

- A generic suite of beam instrumentation to measure beam intensity, position, losses, and parasitically transverse profiles for the primary proton and secondary beam lines was described with conceptual designs and alternatives for each.

- The low-intensity secondary beam presents beam instrumentation challenges.

Comments

- Careful analysis and utilization of accelerator shutdowns need to be implemented to keep tasks on schedule. Changes in shutdown schedules and priorities can have profound effects on the schedule of g-2.

- Analyses of the spin dynamics of the polarized muon beam were not presented.

- It is not clear if various alternatives to the beam line configurations have been well documented.

- A larger number of focusing elements are employed in the new M2/M3 transport line design, however the number of steering correction elements is only about half that number. The steering system needs further optimization and implications of fewer steering elements need to be further quantified.

- Correction elements for the M4/M5 beam line design were not indicated in the presentation.

- Requirements for primary proton beam, mixed secondary beam, and muon beam instrumentation are generally well understood, as are the characteristics of the beams to be measured.

- Instrumentation concepts are at an appropriate stage for moving to CD-1 and beginning preliminary design.

- Instrumentation of the primary proton beam is straightforward and expected to be accomplished with existing (or copies of existing) systems.

- Alternative solutions for instrumenting the secondary beams are currently under consideration and evaluation. Beam tests planned for this summer will inform decisions among the alternatives. There is considerable existing hardware (from FNAL and BNL) that is available for re-use.

- Instrumentation costs (especially manpower costs) will depend heavily on the ultimate technical solution and will be difficult to estimate accurately until the solution decisions are determined.

- Specialized manpower will be required to produce the necessary instrumentation on schedule.

Recommendations

1. Results of particle spin tracking from target to storage ring, including effects of kicker pulse shape, should be compiled and presented at future reviews.

2. An analysis of steering errors and optimization of correction magnets in the M4/M5 beam lines needs to be performed and documented.

3. Beam tests planned for this summer to gain improved understanding of secondary production rates and performance of possible secondary beam instrumentation devices should be given sufficiently high priority by the Laboratory to ensure that they actually happen; this was identified as the last opportunity for these beam tests.

4. Determine and document whether any specific beam parameter measurements (e.g. bunch shape) are required from the g-2 experimental perspective in the beam lines upstream of the storage ring.

2.3 D30 Reconfiguration and Kickers

Findings

- The D30 straight section of the Delivery Ring is to be configured to serve injection of 3.1 GeV/c pion/muon beams from the target for g-2 as well as to extract the muon beam toward the storage ring after an appropriate number of revolutions about the Delivery Ring.

- Many components removed from the present Accumulator and Accumulator-to-Debuncher beam lines will be re-used for the new M2-M5 beam lines.

- Much of the g-2-related work will involve relocation of cables and utilities in this region of the existing tunnel.

- Muon g-2 will require injection/extraction kickers in the D30 straight section, will utilize an abort kicker for Mu2e for extinguishing protons, and will rely upon new kickers in the Recycler being built under an AIP.

- All kicker requirements have been identified and early modeling of the systems has been performed. The kickers reuse as much existing hardware as possible, though mostly will require new components.

- A first draft of an installation schedule has been generated.

- The Project recognizes cost and schedule risks due to uncertainties and unknowns in the D30 work, including interfaces between g-2 and the various other Muon Campus projects.

Comments

- The effort for this package is straightforward but requires much planning; good first steps have been taken and efforts/issues have been identified. It was not clear which portions of the task were being handled specifically under the g-2 project.

- Clear coordination between g-2 and the other Muon Campus projects – Mu2e, AIPs and GPPs – is obviously required for the D30 reconfiguration. Considerable AIP/GPP and g-2 work is required in areas un-accessible during normal Fermilab beam operations, so careful planning for and coordination with operational shutdown schedules will be necessary.

- A 'decision schedule' for design issues in each of the Muon Campus AIP/GPP/g-2/Mu2e projects that can have impact on designs of any of the others might be useful to prevent surprises or re-design work. An example of such a design issue is the design of Mu2e-required, in-tunnel shielding at D30.

Recommendations

5. For future reviews, clarify which portions of the D30 straight section work is on-project and which portions are not.

2.4 Controls and Safety

Findings

- The new accelerator components will be controlled through the standard Fermilab Accelerator controls system and controls devices. During the construction of the Muon Campus communication signals from the accelerator complex will be disconnected to the entire area and reconfigured. Only the portion of the work involving MC-1 is charged under the g-2 project.

- Personnel and equipment safety will be handled through the existing safety systems for the accelerator complex.

- The radiological environment for g-2 throughout the complex will be at or well below the historical levels of this area. The beam power on target will be 20% of the power on target for antiproton production. The beam power in the tunnels and in the Delivery Ring will be 1% of that under previous running conditions.

- The shielding design for M4 and M5 enclosures and shielding upgrades to the Delivery Ring straight sections are driven by Mu2e, not g-2, considerations. The enclosures are not part of the g-2 project.

- All radiation safety parameters for the g-2 muon experiment are well within acceptable limits.

Comments

- Appropriate consideration is being given to the delivery of control signals and communications to the Muon Campus, in particular re-routing of signals to the Delivery Ring and its service buildings and to MC-1.

- Radiation and personnel safety issues have been appropriately addressed.

Recommendations

None.

3.0 Ring

Primary Writer: Matthias Perdekamp

Contributors: Mike Tartaglia

3.1 Storage Ring

Findings

- The Muon g-2 experiment will re-use the BNL E821 storage ring magnet, which has been disassembled and whose parts are being shipped to Fermilab.

- Improvements to the magnet thermal insulation and design of MC-1 experimental hall characteristics (temperature control and floor stability) are expected to allow improved performance to achieve the E989 goal of decreased errors on the ω_P measurement.

- A conceptual plan for reassembling and commissioning the ring exists and is fairly advanced. The Ring team has the calculational tools and expertise for shimming the ring to the desired field uniformity and the plan for shimming is quite advanced well beyond the conceptual stage.

- Transportation of the superconducting rings from BNL to FNAL has begun, and the rings will arrive at Fermilab in late July, well in advance of the MC-1 building occupancy in ~January 2014. Some basic checks of instrumentation and coil status can be made at that time to compare with baseline measurements made at BNL, but cold commissioning will not occur until ~mid CY14 after installation of the entire ring and cryogenic infrastructure.

- Obtaining beneficial occupancy to the MC-1 experiment hall is on the critical path to reassembly, commissioning, and shimming the ring. The project has allocated considerable time in their schedule to accomplish these complex activities.

Comments

- A "near miss" incident occurred during the 1996 E821 shimming effort at BNL, in which a pole piece plug was magnetically ejected from a bolt hole. This should be reviewed and added to the list of ES&H considerations.

- Because of vertical forces between coil and yoke, it is important that the outer coil vertical position is less than 1 mm above the mid-plane when cold and powered. Plans for commissioning should include making observations of coil positions (at azimuthally spaced cryostat windows) during the cool down and powering in stages.

Recommendations

None.

3.2 Controls & Instrumentation

Findings

- Controls and Instrumentation include cryogenic vacuum and vacuum pumps, coils, cryogenics, power supplies, and quench protection systems for the Storage Ring and Inflector magnets.

- As with the magnet storage ring, the design and much equipment from E821 will be re-utilized; plans exist to test, evaluate and refurbish components, or to acquire new replacements where it is necessary or makes sense to do so.

- An interface with the AD cryogenics department is established and plans for a helium refrigeration system have been made.

- The Ring team is interested in early testing of the Inflector, to determine early if identified risks need to be addressed. However, plans for a test stand were not presented.

Comments

- There is a potential risk that a known small helium-to-vacuum leak (which was manageable with added pumping in E821) may become worse as a result of stresses to the coils during transport. The worst case scenario (cold-leak only, inadequate insulating vacuum) would require some disassembly of the ring, and cutting into the cryostat to make repairs. This risk should be identified in the risk registry.

- Thresholds for Inflector quench detection were high due to noise issues on voltage signals. These are suspected to be due to the power supply; if so, a new low noise supply would be a good investment.

- A modern system to capture coil voltage histories would be a valuable addition to the quench protection system.

Recommendations

6. Develop plans for a superconducting inflector test stand in the g-2 hall.

3.3 Beam Vacuum Chambers

Findings

- The vacuum chambers from E821 will be re-utilized, and modified to improve performance of other systems that operate within them.

- Modifications are considered for in-vacuum straw detectors, outer surface grooves for additional NMR probes, new in-vacuum mid-plane NMR probes, reduction of eddy currents induced by the kicker, and plunge-probe motion enhancement.

- Risks are considered to be low.

Comments

None.

Recommendations

None.

3.4 Superconducting Inflector

Findings

- The baseline E989 plan is to re-use the E821 Inflector magnet.
- There is no spare Inflector magnet. A second inflector was originally used in E821, but repairs following a problem during operation compromised the passive superconducting shield, which caused ring field quality distortions far outside tolerable limits.
- The E821 Inflector should work, but there is some risk of problems from aging or transportation, so early testing is desired.
- Material used in the E821 Inflector passive superconducting shield is no longer available.
- Many ideas for improved Inflector features have been considered to improve the quality and intensity of the stored muon beam.

Comments

- Advances in superconductors and magnet technology could be applied to the design of an improved Inflector.
- Magnet experts at RAL and BNL have been consulted on possibilities to develop a new alternative Inflector design.
- To mitigate risk, the project should develop specifications and interfaces for a new Inflector as quickly as possible, and actively engage potential collaborators on the possibilities for them to deliver a new Inflector.

Recommendations

None.

3.5 Quadrupoles and Collimators

Findings

- The electrostatic quadrupoles of the E821 experiment and the collimators will be refurbished and reused in E989. The scientific goals of the experiment require a reduction of the systematic uncertainties from coherent betatron oscillations (CBO) from 0.07ppm to 0.03ppm and muon losses during storage from 0.09ppm to 0.02ppm. The first outer quadrupole plates downstream of the inflector exit window will be moved to larger radius to avoid multiple scattering of the injected muons, this will increase the number of stored muons by a factor 1.6 as required to reach the statistics goals for the measurement.

- An increase of the quadrupole HV from 25kV to 32kV will increase the CBO frequency and make it possible to separate CBO harmonics from the g-2 frequency. The replacement of the half aperture collimators for E821 with elliptical full aperture collimators will reduce the muon losses to the required level and the proposed relocation of the first outer quadrupole plate will increase the number of stored muons as specified.

- The design is based on the existing design for E821 that has been constructed, installed and operated successfully. All design changes are incremental and well within the performance boundaries for the systems established in E821. Most changes address lessons learned from E821.

Comments

- All E989 design updates concerning the quadrupoles, collimators and trolley rail systems will be feasible during construction, installation, operation and maintenance.

- An early test of the increased high voltage for the electric quadrupoles would allow to pursue alternative solutions for the reduction of the CBO systematics should the test be unsuccessful.

Recommendations

7. Developing the E989 design from existing E821 hardware greatly benefits from the expertise in the BNL group. It should be evaluated if the BNL group has the staff needed to fully contribute its knowledge in different areas through active contributions in the simulation and R&D efforts.

3.6 Kicker

Findings

- The E989 kicker design is based on a Blumelein pulse forming network. Compared to the E821 kicker the new design aims to limit the kick to the first revolution of the injected bunch. The shape of the kicker plates has been modified to increase the magnetic field in the beam region. In combination these measures will increase the number of muons stored by a factor 1.4.

- The increased kick of 14 mrad makes it possible to change the half beam collimators in E821 to full beam collimators in E989 as needed for better control of systematic uncertainties from beam losses.

- A kicker test stand has been prepared at Cornell University and first pulse shapes have been measured. The rise time observed is determined by the time constant of the thyratrons used.

Comments

- In E821 the trolley rails were integrated with the kicker plates. After trolley runs kicker high voltage instabilities were observed. In the E989 design the trolley rails are separate from the kicker plates and are at ground potential. It seems possible that in this new configuration high voltage instabilities (caused through small particles left behind from wear on the trolley wheels) might not settle as quickly.

- The use of faster thyratrons could provide a “flat-top” kicker field for the duration of a 120ns long bunch and eliminate systematic effects related to differences in the kick along the bunch. A kicker current with fast rise and fall time also would provide the option to eliminate the non-gaussian tails in the bunch structure by limiting the kick to the central gaussian.

Recommendations

None.

3.7 Precision Field

Findings

- The precision field measurement system will be upgraded from the unique system developed by Heidelberg and Yale for E821. The collaboration has outlined a clear path for improving and augmenting the E821 precision field measurement system so that the total systematic uncertainty for magnetic field measurements will be reduced to 0.07ppm in E989 from 0.17ppm in E821.

- A strong field measurement team has been formed including collaborators from UMass, University of Washington, FNAL and Argonne. The level 3 manager for the field measurement was a leader of the E821 field team. All available documentation and microprocessor codes from Heidelberg have been collected.

- A survey of the E821 field measurement hardware is underway and a detailed plan to either repair or to replace faulty components has been developed. Notable efforts to replace components include certain passive and active shims, fixed NMR probes and parts of the electronics needed for the NMR system. Where possible, old custom electronics is replaced with commercially available electronics. For custom electronics that cannot be replaced it is planned to acquire spare components.

- Critical boundary conditions for the improved field precision in E989 include the greatly improved temperature stability of the experimental hall, the better thermal insulation of the magnet and the stability of the floor that supports the magnet.

- The different sources of systematic uncertainties have been analyzed and for each source concrete steps to reduce the uncertainties to the error budget of E989 have been identified. Improvements include the quality of the trolley rails, the accuracy in the measurement of the trolley position, more frequent and more exact probe cross-calibrations, the use of modern field simulation techniques in support of the shimming operation and possibly the development of a second probe for absolute calibration.

Comments

- It appears prudent to make the funds available immediately that are necessary to acquire potentially obsolete components that are only available through aftermarket vendors.

- New trolley wheels of a suitable material might help to avoid the HV instabilities in the kicker observed in E821 after trolley runs.

- The cost to replace not only faulty but all fixed NMR probes appears to be small compared to the advantages that will result from using probes that have been produced and selected according to uniform production steps and acceptance QA.

- The field team mentioned using a large bore uniform field (MRI) superconducting solenoid for making systematic NMR probe and trolley studies. A magnet exists and would be a valuable test facility, if costs allow.

Recommendations

8. The field team considers developing a second, new absolute calibration probe. The absolute calibration aims at a precision of 0.035ppm. A second independent calibration probe will help to establish the calibration at the high level of precision. In the development process the group would gain detailed insight in all aspects of the absolute calibration. The committee recommends going forward with the development of a second calibration probe.

4.0 Detectors

Primary Writer: Alan Hahn

Contributors: Harry Cheung

4.1 Tracker

Findings

- The primary motivation for tracking is to measure and monitor the muon beam profile in multiple locations in the ring. This is needed to reduce systematics in the g-2 measurement due to beam dynamics. Minimal multiple scattering is important to extrapolate the track back the muon decay vertex.

- The tracking is also used for a secondary calibration of calorimeter through measuring the positron momentum, and provides a cross calibration of the pileup subtraction. In addition, the tracking is needed for the muon EDM measurement.

- A straw tracker was selected to minimize the positron multiple scattering due to material. They are also located in the vacuum chamber for the same reason. A silicon-based tracking detector was considered but rejected as it did not meet the multiple scattering requirements.

- ASDQ chips from CDF, which can be obtained at no cost, will be used to instrument the FE of the straw detector.

- A TDC will be developed from a FPGA and located adjacent to the ASDQ within a tightly constrained container within the vacuum.

- A straw detector design is being developed to allow construction to be done reliably by university undergraduate students.

Comments

- Being in the vacuum the straw detector has some tight constraints, e.g. space constraints for the straw electronics. A realistic engineering mockup of the designed components would be useful to check that constraints are satisfied.

- A multi-channel straw prototype detector located in vacuum is planned to be run in a test beam in January 2014 at Fermilab, this will be important to demonstrate the expected resolution and performance in vacuum can be achieved. We encourage the proponents to use parts with as many of the reference design features as possible.

Recommendations

None.

4.2 Calorimeter, FE and WFD, Laser calibration, Bias control

Findings

- The calorimeter is the central component of the detector system needed to measure g-2. Building on the past experience of E821 a decision was made to design a segmented calorimeter to minimize pileup effects. PbF2 crystals were chosen for their fast signals (also a pileup consideration), compact size and short radiation length. Each of the 24 calorimeter stations consists of 54 (9x6) crystals.

- The goal of 0.14 ppm uncertainty on the g-2 measurement is achieved with goals of 0.10 ppm for each of the statistical and systematic uncertainties. The systematic uncertainty goal is equally split between uncertainties in the B-field measurement (ω_p) and the spin precession measurement (ω_a). The 0.07 ppm systematic uncertainty in ω_a was projected assuming only the T analysis method is used (based on counting decays with positrons above threshold).

- The Cherenkov light from the PbF2 crystals is being read out using SiPMs. The design is being optimized to minimize the effects of temperature and bias changes on the gain.

- SiPM pulses will be continuously digitized by a 500 MS/s ADC. This sampling rate is well matched to the calorimeter signals for pileup separation, and a "0" threshold can be used which enables a separate analysis (Q) method based on looking at the total integrated charge. The WFD are supported in a uTCA technology developed by the CMS experiment.

Comments

- SiPMs are known to be very sensitive to temperature changes and bias voltage. A vigorous R&D effort is being performed to minimize the temperature changes at the SiPM location and to control the SiPM bias to a 1 mV level. In addition the effort to investigate new SiPMs that are being designed which could have lower sensitivity to temperature and bias changes is important and should be continued.

- The E821 total systematic uncertainty includes a sizeable ~0.10 ppm data-driven systematic. It is difficult to project the size of a corresponding uncertainty for E989, however it should be significantly reduced due to increased statistics. The upgraded detector components will provide many addition handles to understand residual systematic effects. One important addition is the Q analysis method with quite different systematics from the T method.

- The largest source of ω_a systematics in E821 was from gain changes. The goal for this systematic is to reduce this by a factor of 6. It would help to separate out this improvement into a factor that depends on the detector (i.e. because of a segmented design to lower rates, by keeping the temperature and bias more stable, and to a better laser calibration) and a factor due to the absence of hadronic flash in E989.

- A laser calibration system is needed to achieve a gain stability of 0.1%, which is important to achieve the gain-related 0.02 ppm systematic goal. It is important to try to demonstrate as early as possible that this is achievable in a laser system with the full light distribution chain. Funding from INFN to support this would be an important step towards this.

- A planned test beam run at SLAC in summer 2014 with a 25 channel prototype calorimeter will provide an opportunity to demonstrate the design performance of the calorimeter. Since the calorimeter is the central detector component to achieving the physics goals of the g-2 measurement, this would be an important step towards finalizing the baseline design. Receiving approval from NSF for this crucial component of the detector would keep ensuring the excellent progress.

Recommendations

None.

4.3 DAQ

Findings

- The DAQ is based on commodity hardware (microprocessors, GPU’s) running a MIDAS Data Acquisition Framework.

- MIDAS has tools that also support slow controls and a database.

Comments

- The building of the data-streams occurs in the DAQ. The raw data from the WFD is not saved except on occasions it is streamed directly onto disk for systematic checks. This implies that the software that is making the data-streams needs to be available and checked out prior to the start of mainstream running.

- The choice of MIDAS as a framework was based on the E989 familiarity with the system from previous experiments and its extensive library of available tools. This allows the project to leverage manpower.

Recommendations

None.