Fermilab

PPD Project Review of the COUPP 4 kg Detector

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1. Charge to the COUPP 4kg Review

The COUPP 4kg bubble chamber completed a successful run in the MINOS underground area in the fall of 2009. The experiment achieved significantly lower internal background rates relative to prior runs through the use of a synthetic silica vessel and improved fluid handling. In addition, they successfully deployed a system of acoustic sensors for α discrimination. The result of this run has been world's best limits in spin dependent WIMP searches. The run ended in December with a controls/DAQ problem that resulted in damage to the bellows.

The COUPP collaboration proposes to repair the 4kg chamber and deploy it at SNOLAB by summer 2010. The goals of operation at this deep underground site include determining the rejection power of the acoustic sensors and a new physics run. While estimated resource requirements for this effort are modest, the available labor resources are very limited and there are currently no DOE funds available for this activity. The COUPP collaboration is also busy deploying the 60kg chamber at MINOS and plans to deploy the 60kg chamber at SNOLAB within the next year.

The purpose of this review is to evaluate the technical and scientific merits of operating the 4kg chamber at a deep underground site and the feasibility of the proposed deployment plan. This plan should be evaluated within the context of the overall COUPP experimental program.

Scientific and Technical Merit:

1. Will operation at a deep underground site significantly advance the state of the art of bubble chambers for DM searches?
2. Are the proposed science goals significant enough to warrant operation of the 4 kg chamber in a deep site, in light of the expected deployment of the 60kg chamber within the next year?
3. What are the conflicts or synergies between operation of the 4kg and 60kg devices?

Technical preparedness:

1. Have the controls and DAQ problems encountered in December 2009 been satisfactorily resolved?
2. Is the system robust enough for extended operation in a remote location?

Resource requirements:

1. Does the proposed plan cover all of the steps likely to be required for this deployment?
2. What labor (scientific, engineering and technician) and M&S resources will be needed?
3. Are the estimates reasonable and well justified?
4. Are the resource estimates consistent with past experience with the 4kg chamber?
5. Are there areas that are likely to require contingency beyond the estimates?
6. What is the plan for operating the 4kg chamber at SNOLAB, in light of the need to simultaneously operate the 60 kg chamber in the NUMI tunnel? Evaluate the manpower and travel required to accomplish this.
7. Will work on the 4kg deployment by technicians, engineers or scientists incur any significant delays in commissioning the 60kg chamber in the MINOS underground area?
8. How does COUPP propose to fund this effort?

2. The Committee

Kurt Biery
Fritz DeJongh
Debbie Harris
Kurt Krempetz
Ron Ray

3. Agenda

8:30-8:45 Executive Session
8:45-9:15 Tour of 4kg chamber in Lab F
9:15-11:20 Presentations:
  1) Overview of the COUPP program: 4-kg, 60-kg, and 500-kg Chambers
  2) Deep Site Goals for the 4-kg chamber.
  3) 4-kg Chamber Technical Overview
  4) 4-kg Chamber Operations and Experience
  5) (Re-)Deployment Plan
  6) Resources Required (including simultaneous needs for COUPP 60kg)
11:20-11:40 Discussion
11:40-12:00 Executive Session

4. Scientific and Technical Merit

Findings

- The COUPP-4 data at NUMI has demonstrated that the acoustic signal can be used to reject alpha decays at the 80% level or better. The data suggests that the remaining background is from neutrons and the rejection is actually much better.

- A 3-month run at SNOLAB would enable a measurement of alpha rejection at the 99% level. If the run were background-free, spin-independent limits competitive with CDMS and XENON would be achieved.

- Passive shielding will be used to stop ambient neutrons.

- A following run, with alpha decays injected into the liquid, would explore alpha rejection at the 10^{-4} level. This would enable high-statistics background studies while COUPP-60 is preparing for a low-background run.

- The COUPP strategy includes having one detector operating, another detector under construction, planning for a chamber after that, as well as acoustic test stands to understand the fundamentals of acoustic detection.

Comments

- There's a risk that injecting alpha decays will contaminate the chamber with long-lived isotopes. Demonstration of a technique that avoids this would be of great benefit for future bubble chambers.

- An alpha rejection of 10^{-4} combined with state of the art radio-purity would motivate consideration of multi-ton bubble-chamber experiments.

- The proposed measurement of alpha rejection would apply specifically to the COUPP-4 chamber. On one hand, other chambers would not necessarily do as well; on the other hand, any observed limitations in alpha rejection are not necessarily a fundamental limitation in the technique. Analysis of these results along with data from an acoustic test stand would help develop a predictive capability.

- Scientific effort in the COUPP collaboration continues to increase. New postdocs are coming on board at both Fermilab and Chicago.

Recommendations

- Given the low cost and the possibility of achieving a zero-event background level, we find that the goals of the proposed 3-month science run warrant operation of COUPP-4 at SNOLAB.
- We find that the low-background run as well as a following run with injected alpha decays will significantly advance the state of the art of bubble chambers.
- The collaboration should present a detailed plan for alpha injection, with an analysis of the risks of long-lived contamination.
- The collaboration should present a plan for operating acoustic test stands.

5. Technical Preparedness

Findings

- The 4kg chamber has operating procedures and an Engineering Note for the vessel. Also an Engineering Note for the pump cart exists.
- The documentation required to operate in SNOLAB was not clearly presented and appears to be somewhat unknown at this time.
- Electrical documentation was not presented and needs to be completed.
- The 4 kg chamber, the data acquisition system and trigger ran reliably from August 2009 through December 2009 while the chamber was deployed in the MINOS near detector hall. However, a data acquisition failure on December 18, 2009 resulted in the experiment running without a functioning trigger overnight and caused a hyperextension of the chamber's pressure balancing bellows. The source of the failure was a hang in the video driver that caused stale images to be returned from the cameras and the image acquisition time to drop from 10 msec to 2 msec. This disabled the video trigger (which compares subsequent images looking for the formation of bubbles). It also desensitized the pressure trigger when the time between pressure readings also dropped from 10 msec to 2 msec, but the time interval was assumed to be a constant 10 msec.
- The lack of integrated pressure, volume, and temperature monitoring in the controls system contributed to the hyperextension of the bellows when the DAQ failure occurred.
- To avoid a repeat of the December failure, the following steps are planned:
    - Add error checking in the DAQ to detect a failure in the video driver

- Add cross-checking of the time interval when calculating pressure changes over time
- Move the temperature monitoring from the DAQ into the controls system
- Perform a formal failure mode analysis of the DAQ and controls systems; remedy any failure modes that do not result in the system moving to the safe mode after a failure

- There is the possibility of an upgrade to the DAQ system Linux host and instrument I/O cards.

Comments

- The presenters spent a lot of time and effort to support the physics case for the 4 kg chamber, and it was impressive. However, that same effort did not appear in demonstrating the completeness of the documentation.

- The planned improvements to the DAQ and controls software will prevent a reoccurrence of the failure that happened in December. A formal failure mode analysis of the DAQ and controls systems should identify any additional potential failure modes.

Recommendations

- A serious effort should be mounted to collect the existing mechanical documentation and complete the electrical documentation.

- The documentation required to operate at SNOLAB needs to be further investigated and understood.

- Since it appears that we are going to be working at SNOLAB for some time into the future, Fermilab Management should initiate contact with SNOLAB management to develop a set of procedures that streamlines the process of sending equipment from one place to the other. Such an agreement exists with Soudan and it has made working there much easier.

6. Resource Requirements

Findings

- Detailed M&S estimates and some labor estimates were presented.

- Specific contingency estimates were not given for each task or job.

- The labor resource requirements were estimated at the following:

- 2-3 weeks of Mark Rushman's time,
- 1-2 days of an Engineer's time,
- a few days of effort of Sten Hansen
- a few days of an Electronics Assembly Technician.

- In addition, there were 3 physicists listed, but it wasn't stated if those physicists would need to work 100% on these tasks, 50%, or 200%. Also, "a few days of effort" was required of two people "et al", from IUSB.
- It was stated by the Collaboration that there is no interference between the COUPP-4 and COUPP-60 efforts.
- The physicist effort on the overall COUPP program has doubled in the last year and the Collaboration believes that they have enough scientific manpower to cover both the 4 kg and 60 kg efforts.
- A list of possible funding sources for this work was presented along with the statement that COUPP did not intend to resolve the issue at the present time.

Comments

- The M&S estimates appeared well thought out and understood.
- The labor estimates seemed to have some problems. The scientific and Design/Drafting labor estimates were not given. The engineering and technician estimates appeared to be low by at least a factor of 2.
- Most tasks are fairly well understood and only a small contingency is needed, ~10%.
- The required documentation needed to operate at SNOLAB was not well known so a large amount of contingency is needed and is probably beyond what is being planned for.
- The proposed plan as outlined by Mike Crisler paints a general picture of what is required for deployment, but there seem to be a few steps that were not listed in the talk, although they were mentioned in the presentation. Some of these steps are as follows:
    - Purchase of the acoustic sensors: these are not yet procured because the thought was that they are constantly improving them, so the later the sensors are purchased, the higher quality they will be.
    - Make a complete inventory of what piping components have to be replaced because of the tighter plumbing requirements in Canada, and procure those new

parts.

  - Decide what components will be cleaned to be suitable for use in a class 2000 clean room, and what components will be purchased new, and then either clean or procure those new components.

- Customs issues at the border were not discussed.

- It would be helpful to attach a time estimate and a personnel estimate to each of the steps that were listed on slides 3 through 15 of Mike Crisler's talk *Deployment Plan and Resources Required*. Similarly, it would be interesting to see how long each of those steps took to accomplish the first time around, and what increases in speed one might assume based on having that prior experience.

- There were also steps described on slides 17 and 19 of Mike's talk that had to do with the DAQ and the slow controls systems, and there was no time estimate given there either. Are the 3 physicists listed the same one who will do this work, or are there others (who are mostly involved with the 60kg device) who will also be needed here?

- The people responsible for implementing the improvements to the DAQ and controls software are also responsible for significant other work that is needed to prepare for a deployment at SNOLAB.

- The planned improvements to the DAQ system appear on the task list, but the failure mode analysis does not.

- An upgrade of the DAQ system hardware would provide a number of advantages, but any software or communications changes that would be needed would require additional development and testing time.

- A plan for handling the replacement of failed DAQ system components with spare equipment while deployed at SNOLAB was not discussed.

- At first glance it appears that the technician and engineering resources are under-estimated, and a more detailed accounting would be helpful to demonstrate the accuracy of the estimates. The physicist resources are appear to be under-estimated as well.

- It was not clear if the resource estimates were consistent with past experience with the 4kg chamber. It is possible that the resource estimates for the actual assembly work involved are consistent, but there were no resource estimates for replacement or procurement work, and no accounting for any other "end effects".

- It was stated that different people were doing the work on the 4 kg and 60 kg devices and that there was no interference between the two. It was less clear if this would remain true

if problems or delays were encountered with one of the devices. If this were to happen, it was not clear to the Committee, or possibly even the Collaboration, which device would take priority.

Recommendations

- Some additional work is required to better understand the labor needed to install the 4 kg chamber at SNOLAB.
- Continue communications with SNOLAB and start as early as possible the approval process to run the detector at SNOLAB.
- The amount of time needed for the planned improvements to the DAQ and controls systems, the failure mode analysis, and the work needed to upgrade the DAQ hardware should be estimated and included in the planned schedule of work. Contingency should be added to the schedule to allow for fixing any issues that are identified in the failure mode analysis. As much as possible, known failure modes should be tested by artificially creating the failure conditions.
- COUPP should become familiar with the customs procedures that are required for getting a device of this sort into Canada for an extended period of time.

7. Charge Questions

Scientific and Technical Merit:

1. *Will operation at a deep underground site significantly advance the state of the art of bubble chambers for DM searches?*

   Yes. What COUPP has been able to achieve thus far is quite impressive and we expect that trend to continue.

2. *Are the proposed science goals significant enough to warrant operation of the 4kg chamber in a deep site, in light of the expected deployment of the 60kg chamber within the next year?*

   It could be argued that any science result from COUPP-4 will eventually be eclipsed by COUPP-60. However, in a field that is very competitive and moving very quickly, COUPP-4 advances the ball down the field more quickly and we would all prefer to be in the position of making a discovery rather than confirming one made by others. In addition, the planned alpha rejection studies with COUPP-4 have the potential to make COUPP-60 a better detector.

3. *What are the conflicts or synergies between operation of the 4 kg and 60 kg devices?*

   The Synergies include the alpha rejection studies and the exercise of getting a detector

operating at SNOLAB, both of which offer potential benefits to all future bubble chamber activities. If problems develop with either the 4 kg or 60 kg device there is the potential for resource conflicts as the people required to make one device work may be the same people required or available to fix the other device.

Technical preparedness

1. *Is the 4kg chamber sufficiently well documented to be reviewable with respect to electrical and mechanical engineering and ES&H?*

   Operating procedures for the 4 kg chamber exist as well as an engineering note for the vessel. There is some electrical documentation that remains to be completed. The documentation required to operate in SNOLAB did not appear to be well know at the time of the review.

2. *Have the controls and DAQ problems encountered in December 2009 been satisfactorily resolved?*

   Yes, once the planned improvements are implemented.

3. *Is the system robust enough for extended operation in a remote location?*

   Likely yes, but an analysis of DAQ and controls failure modes should be done, and any modes that are identified, but not already handled by the system, should be addressed.

Resource requirements

1. *Does the proposed plan cover all of the steps likely to be required for this deployment?*

   The DAQ and controls failure mode analysis needs to be added to the plan. The work needed to perform the DAQ hardware upgrade and any associated software changes should also be included. And, it would be advantageous to schedule dedicated testing time.

2. *What labor (scientific, engineering and technician) and M&S resources will be needed? Are the estimates reasonable and well justified?*

   The M&S estimates appear to be well understood. The Committee generally feels that the labor estimates are too low. The Engineering and technician estimates are thought to be low by at least a factor of two. The scientific resource needs also appear to be low.

3. *Are the resource estimates consistent with past experience with the 4kg chamber?*

   Based on what was presented it was not clear if the resource estimates were consistent with past experience with the 4 kg chamber.

4. *Are there areas that are likely to require contingency beyond the estimates?*

Any changes that are identified by the DAQ and controls failure mode analysis and the documentation required to operate at SNOLAB.

5. *What is the plan for operating the 4 kg chamber at SNOLAB, in light of the need to simultaneously operate the 60 kg chamber in the NUMI tunnel? Evaluate the manpower and travel required to accomplish this.*

   Once the 4 kg chamber is operating, there is no plan for a continuous presence at SNOLAB. This assumes problem-free running. This places a small burden on SNOLAB to take responsibility for the device in the event of a problem. The details of this relationship remain to be worked out. It was a good sign that SNOLAB representatives were willing to come to Fermilab for discussions.

6. *Will work on the 4kg deployment by technicians, engineers or scientists incur any significant delays in commissioning the 60kg chamber in the MINOS underground area?*

   It was stated that different people were doing the work on the 4 kg and 60 kg devices and that there was no interference between the two. It was less clear if this would remain true if problems or delays were encountered with one of the devices. If this were to happen, it was not clear to the Committee, or possibly even the Collaboration, which device would take priority.

7. *How does COUPP propose to fund this effort?*

   A list of possible funding sources was presented along with the statement that COUPP was not prepared to resolve the issue at this time.