Muon ID Vertical Review Committee Report

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1 Overview

The Muon ID Vertical Review was held on May 22, 2000 at Fermilab. The committee heard 14 talks on a variety of topics. The group taking responsibility in this area is actually the result of the merging of the Muon ID group (Dave Hedin and Daria Zieminska, co-leaders) and the Muon Algorithms group (Pushpa Bhat and Christophe Royon, co-leaders). The leaders have assembled a large team to tackle the job. An impressive amount of work has been done to date, generally touching upon all the relevant tasks.

2 General Comments and Recommendations

Specific comments and recommendations will be given with each topic below. The following are comments and recommendations that address the issues the committee felt were most pressing.

- An impressive list of names of members of the group was shown. There are 20 physicists working in the group with an additional three ex-members who are presumably still active at some level. However, it was not stated how many FTEs are involved. Many of those listed have responsibilities in other areas of the DØ upgrade. Although the group itself was looking for additional manpower in only a few instances, the committee felt the effort as a whole was short of manpower.
- There needs to be a closer connection between the work of the group and the needs of the muon detector group. The Algorithms/ID group should prioritize its work to facilitate the detector commissioning, particularly in the areas of calibration, monitoring, and triggering.
- Realistic detector response needs to be in the simulation to ensure the algorithms under development are robust under "real world" conditions. More coordination with those working on dØg* is needed.
- Very little was presented concerning the forward muon system. There needs to be more involvement with and from the FAMUS effort.
- A long list of calibration and monitoring jobs was included in the documentation but no presentation was made in this important area. Progress in this area has been lagging and it has a negative impact on current and future muon system commissioning. More manpower and priority should be given to this task as soon as possible.

- The L2 muon trigger is clearly short of manpower. As a result, only one algorithm has been partially implemented. The efficiency, background rejection and timing are unknown. The recent addition of the Munich group to L2 muon is a good step but progress needs to be monitored.

- Trigger timing is a concern. For the only trigger where measurements exist, Level 1, the timing is known to be tight. For Levels 2 and 3, the timing is unknown and therefore the amount of work to stay under budget is an open question.

- There is no schedule for the readiness of the L3 muon trigger. Implementation in the actual L3 hardware should be tried as soon as possible.

- There was very little written documentation available to the committee. Copies of slides from talks and links to the actual code do not constitute documentation.

- The integration of the muon offline reconstruction with global tracking (trf++) needs manpower for a timely completion.

- Monte Carlo studies of baseline physics signals has begun and looks promising. However, no quality variables or other muon ID criteria were presented or seem to exist. Cuts designed to provide efficient and clean identification of muons, isolated as well as non-isolated, must be developed.

- The overall efficiency and rejection of muon ID from L1 through offline has not been evaluated.

3 Detector and Triggers

3.1 Calibration

A long list of calibration and monitoring jobs was included in the documentation but no presentation was made in this important area. Progress in this area has been lagging and it has a negative impact on current and future muon system commissioning. More manpower and priority should be given to this task as soon as possible.

Other outstanding issues include the following

- Integration of the alignment and calibration data with the offline reconstruction.

- Specification of what information should go into the hardware database and the procedure for doing it. This task is hampered by DØ not making a choice of database.

- Measurement of time versus distance function for WAMUS with the nominal Run II gas and then propagation into the offline code.

3.2 Level 1 Trigger

The L1 muon trigger can form triggers using a combination of CFT, muon scintillator, and muon wire information. Studies of efficiencies, background rejections, and rates have been performed in UPG_GEANT and, more recently, using dØg*. The hardware is very flexible in defining trigger terms but the number that are available in a given run is limited. The rate for a loose single muon trigger is about 1 kHz and within budget.

Comments and recommendations

- With Freedy Nang's departure, the simulation effort is under-manned. Effort is underway to hire a replacement. If open postdoc positions at Arizona and Boston are filled, it is felt that the overall level of manpower for L1 muon will be adequate.
- A detailed study of L1 muon trigger timing was done. The indication is that the L1 muon trigger is ready within the specified budget but the timing is tight with only about 100ns to spare. Although based primarily on actual measurements, there is always some uncertainty is such an estimate and efforts should be made to ensure the L1 trigger arrives within the allowed time.
- An action item brought to the committee's attention was to determine whether or not the sign of low p_T muons is necessary at L1. The result has non-trivial implications for the trigger terms L1 muon forms.

3.3 Level 2 Trigger

The purpose of the L2 muon trigger is twofold: (1) reduce the L1 rate by a factor of 3–10 and (2) produce seeds for data unpacking at L3.

For the first L2 function, rejecting background, a list of algorithms was presented, each with the potential for some rejection. Background rejection is enhanced over L1 in two ways: better stand-alone muon ID in the L2 preprocessor and relation of muon candidate to other objects in L2 global.

Muon ID algorithm work has been slowed considerably due to lack of manpower in the L2 muon trigger project. To date, only the central A-layer track-stub-finding algorithm has been completed. It is difficult to assess the efficacy of the algorithm because L2 muon is not yet in the trigger simulator. Since L2 uses the same information as L1, albeit with higher granularity and precision, it is not obvious how large the L2 rejection will be or how the rejection improves/degrades with the number of interactions per crossing.

Limited timing studies were performed. The DSP algorithm that finds track stubs in the central A-layer appears to run comfortably under the 25μs budget. However, a concern is that the overall timing for the L2 muon trigger is currently unknown.

Concerning the second L2 function, finding seeds for L3, the lack of timing studies for L2 and L3 make it difficult to comment. Is there enough time for this function in L2? Is there enough time at L3 so that L2 seed finding is unnecessary? There is no way to tell from the studies done to date.

Preliminary documentation for the L2 trigger exists but is not complete.

Comments and recommendations

- Progress is clearly manpower limited. The addition of the Munich group and a Columbia student to the project will help.
- No work was presented on L2 for FAMUS. The Munich group will take this responsibility here but more involvement with the FAMUS detector group is important.
- The total L2 muon trigger timing needs to be evaluated soon.
- Incorporation of L2 muon into the trigger simulator is imperative for understanding the performance of the algorithms. Rates, efficiencies, and rejections should be calculated and optimized.

4 Algorithms for Offline/Level 3

4.1 General Comments

The addition contributions of the French and Dutch groups to the muon software has been and will continue to be vitally important. The new young people invigorate the rest of the group. Dave Hedin, through his experience and leadership, makes an important contribution in setting the priorities.

In almost every case, documentation at sub-task level points to either non-existent links, to class diagrams, or obtuse clips of source code. Nothing seems to point to something as description much less to demonstrations of effectiveness. The talks presented at the vertical review were well not organized.

4.2 Hits and Segments

4.2.1 Unpacking

There is no error handling.

4.2.2 Basis for MC Simulation

The MC basis for hits seems to be “particle impinges on cell volume” coupled with “cell is 100% efficient”. This seems naive. The electric field isn’t uniform in the corners making the effective cell volume oval-shaped. In Run I the oval was cut off towards the sides of the cells because of a time-gate, making the cell efficiency approximately 85%. While we don’t believe we will face that effect in Run II, we haven’t proved that we won’t. Something more sophisticated could be done such as requiring charged particles travel a larger minimum distance in the cell. The delta-time response has smaller uncertainty for hits at the far-end of the PDT than for hits at the near-end. Near-end hits have a signal which propagated the short distance to the amp-disc and a signal which had to propagate up to twice the wire length. The latter signal is smaller and slewed compared to the near end signal. Herman Haggerty has made measurements of the delta-time uncertainty vs. delta- time that could be put into the MC simulation. There is apparently no uncertainty in the MC reported drift-time. The diffusion limit is something like 500 μm for the Run II gas. There was no presentation of the WAMUS pad pulse height simulation. Similar comments applied to the MDT and scintillation counter hits are relevant. It is a good idea to make the MC raw data format the same as raw data format, however, data formats were not discussed.

4.2.3 WAMUS Use of Pads and Wires

The WAMUS segment algorithm produces a mini-track from the hits in the detector planes. It starts by identifying two planes with hits and then finds all hits appropriately close to a road through the those two hits. A segment is selected having the most hits and lowest χ^2. Used hits are marked and the segment-finder repeats. The algorithm is appropriate provided two hits are present. However, the PDTs have gaps between them that range between 2 and 6 inches wide. The cells are offset - one layer sticks out on one side and the other two cells on the other side (but by different amounts). Consequently a fair number of muons pass through only one cell in a layer. The tracking algorithm does not use these hits and wastes information otherwise available in the data. No attempt has yet been made to use the pad information. The pad hits comprise the PDTs 90° stereo information. The resolution for pads in Run I was about 5 cm provided that the correct solution was found for the wavelength, which repeats every $\sim$60 cm. In Run II, the pads are completely instrumented only in the A-layer (as a cost savings measure). A few cells in each B and C-layer FEBs are instrumented to monitor the gain. Looking at some documentation (4/00) on Mike Fortner's web page, it appears the class PDTHit doesn't contain the pad information. It should be priority to change that since algorithm writers will immediately become bogged-down in the low-level code when developing tracking algorithms that use the pad information. There are a couple reasons why the pad resolution, which is in the ϕ-direction, can be better in Run II. First, the pad electronics are improved. In Run I a bug that caused frequent re-firing of the pad integrators, resulting in an unacceptable rate of ADC overflows. The Run II design fixes this problem. The second reason is that local segment-finding provides a natural platform for finding the pad solution, especially since it is available only in the A-layer. Third, the A-ϕ counters, which are smaller than the pad wavelength, provide relatively unambiguous edges along the pad direction and could contribute in determining the correct pad solution. Finally, the speakers showed plots of the positions of segments showing a few hits where there were no detectors and a few holes where there were, clearly something to correct.

4.2.4 MDT Hits

There was little discussion of MDT hits. It may be the case that there was no one familiar with the MDTs in particular at the review.

4.2.5 Scintillation Counter Hits

Documentation seems to be non-existent. It should be a simple exercise for single PMT counters. However, some counters have two PMTs. How are these handled?

4.3 Muon Tracks

4.3.1 Track Fitting

There are two track-fitting algorithms. The first is described as a "combinatorial algorithm". In short, pairs of A and BC segments are matched at their intersection in the toroid assuming a uniform magnetic field. The second is described as a "fit algorithm" whereby a pair of segments is fit into a track via track propagation into the non-uniform field, taking into account multiple scattering and energy loss in the toroid, etc. The former is used in Level 3. Is the latter for use out-of-level 3, i.e. offline?

4.3.2 Combinatorial Algorithm

We presume the "combinatorial algorithm" is the faster of the two, but in fact, nothing was said in the whole software review about the speed of any algorithm, even though we queried. Weaknesses of this algorithm is that it has ¿14% inefficiency for CF muons because it requires A-Layer segments and there isn't any A-layer under the calorimeter. It wasn't clear if the information that muons originate from the luminous region was used in the fit. That tracks that cross octants aren't found, except where PDTs cross octants, is bound to hamper the efficiency for low-p_T muons. Some muons of the boundaries of CF and EF will hit PDTs and MDTs. Mixed-detector tracks (known as "mixed orientation" tracks in Run I) are not found; that must also have a negative effect on the efficiency as well as resolution. Because there is no such thing as a one-hit segment (see above), the tracking must suffer some additional inefficiency. There was no presentation of a χ^2 variable or a list of track features (such as the Run I IFW2 in MUOT) or momentum resolution achieved.

4.3.3 Fit Algorithm

The "fit algorithm" is fancier. It seems to have the assumption that tracks have A-layer and BC layer segments and therefore suffers the same efficiency penalty as the combinatorial algorithm. It does not seem to use the constraint that a muon from the collision comes from the direction of the collisions. It does handle tracks formed from hits in adjacent octants. Same comment as above on mixed-detector tracks. Same comment on one-hit segments. Same comment on track features variables, though possibly the treatment of scattering, magnet, and uncertainties will allow easier formation of a χ^2. Strangely, this algorithm uses MINUIT to perform the actual parameter fit. This is very undesirable from the overhead and timing points of view as well as unnecessary for this application. We advise a simpler fitting routine, written in c++, be implemented.

4.3.4 Comments

On the whole, it is more important to have one package that finds and tracks ALL of the muons than it is to have two that don't, especially where the two have such similar assumptions for the starting point of pattern recognition. The group seems bogged-down in tracking with the PDT/MDT information only. No tracks are found with the A-, B-, and C-Layer scintillators. It is unclear if scintillator information is used in pattern recognition and/or tracking. Perhaps every PDT/MDT segment and every in-time scintillation counter hit should be considered part of a muon track (even if just one layer).

4.4 Level 3 Tracking

At this stage we expected to see Muon ID and Tracking running in some L3 simulation framework including configuration files, preliminary definitions of "Golden" and "Tarnished" muons, muon selection parameters such as Number of muons, CFT track confirmation, CFT track p_T threshold, Musys p_T track threshold, $|\eta|$, Charge sign (could require opposite sign for 2 or more), Cal Conf, etc. The group said it wasn't their responsibility to provide such a tool, just to provide hits and segments. We believe this is shortsighted. The muon ID/Algorithms group clearly should be the ones finding muon tracks and defining good quality muons at L3. The L3 people should immediately move to setup the MUON Tool.

Great effort seems to have been dedicated to setting up the L3 muon tracking so that it didn't operate except where seeded by L2. The motivation was speed. Yet nobody could provide any information about the speed of the routines. If L3 is fast enough one might not be motivated to drastically curtail L3 but to track everywhere in the muon system. If unpacking the data is so slow that it hurts the physics capability, using a "smart" unpacker may be a way to save time. One example would be to divide the detector into L3 tracking units based on an $|\eta|$ filter parameter (that wasn't considered). If the L3 trigger isn't going to accept muons past $|\eta|$ of, say, 1.0 or 1.6, then don't track out there.

4.5 trf++

Some of the fundamental routines that trf++ requires for operating in the muon system don't yet exist. Daria said physicist manpower doesn't exist at this time to finish trf++ interface and we agree with her assessment. A Run II version of MTC is a likely muon algorithm implemented through trf++. It should be pursued with high-priority.

5 Vertical Performance

During Run I, a successful muon identification depended strongly on using components of the detector in addition to the muon PDTs. In fact, the Z dimuon trigger was the best source of cosmic rays we had for a while. Although the conditions for cosmic ray and fake hits background are expected to be different in Run II, the offline muon identification would certainly benefit from additional information provided by the calorimeter and the scintillators. The current offline muon identification seems to be reduced to matching track segments found from PDT hits and the central tracker. At this point, the errors provided with the track segments are not used in any way to evaluate the goodness of the fit. This is certainly an acceptable first step, but most likely completely inadequate to reconstruct prompt muons in the real Run II environment. The group needs to focus on defining quality control quantities. They could initially be based on muon only variables (χ^2 cuts on the track, number of hits on track, closeness to the vertex, etc.). It should soon evolve to take into account information from other subdetectors. In particular, the calorimeter information and the precise timing information provided by the scintillator counters have proven to be extremely effective in discriminating prompt muons from cosmic and combinatoric background during Run I. Additional variables, most likely combining calorimeter and central tracking information, should be identified to define isolated muons and muons in jets. Another area of concern is the lack of systematic studies. The evolution of quality control variables for muon events overlaid with different number of minimum bias events is the first systematic study that should be done.

6 Follow-up

While much work has been done, there is clearly much to do. Given the large number of open questions, a follow-up review at the end of summer seems prudent.