Response 2 to CPP-NPP ERR Questions.
May 24, 2021

A. What is the efficiency the physics requires (with an error bar)?

It's important to note that the MWPCs built for the CPP measurement are not used for triggering or tracking. Triggering is handled by the TOF counter, and tracking by the FDCs. The detection of true pion events (our signal) is unaffected by the MWPC efficiency since pions may be absorbed by the FCAL, and no hits are required in the MWPCs to tag them as pions. However, the MWPC efficiency will affect the measured number of pions through the mis-identification of muons. The measured efficiency will be used as input to the Bethe-Heitler simulation of $\mu^+\mu$ hits in the MWPC, with the simulated chamber hits being used to train the muon response of the π/μ neural-net. Actual $\pi^+\pi^-$ data taken during CPP running will be used to train the pion response of the π/μ neural-net. The pion response is self-calibrating and doesn't require a-priori knowledge of MWPC efficiency.

The MWPC efficiency ε enters the analysis in the classification of tracks as pions or muons. Up to a certain level, higher MWPC efficiency does give better π/μ PID. However "super-efficient" MWPCs, $\varepsilon > 0.999$, are not essential to the measurement because at that level we're limited by effects other than chamber inefficiency, such as multiple scattering in the iron, and E.M. backgrounds in the chambers. Based on our previous experience with wire chambers of this type operating in an environment such as the Hall D beam line, we believe that a chamber efficiency of 99% is reasonable and doable.

As part of the effort described in detail in the ERR response, we are currently updating the CPP simulation to include muon hits in FCAL, and pion and muon hits in the MWPCs. We plan to use simulated pion and muon hits in these detectors to design and train the π/μ neural-net, and then use the neural-net to make detailed studies of the sensitivity of PID to MWPC efficiency.

Simulation studies in progress will provide the definitive answer regarding sensitivity to MWPC efficiency. However, we'll consider a "back-of-the-envelope" estimate for what an efficiency of $\varepsilon = 0.99$ implies for PID in the absence of any complicating factors. Previous neural-net studies indicate the last two MWPCs are the most important of the six chambers for PID, and for this estimate we consider only the response of the last two chambers. For a chamber efficiency of $\varepsilon = 0.99$, the probability for the last two MWPCs to not fire on either of the μ^+ and μ^- tracks from a Bethe-Heitler $\mu^+\mu^-$ event is extremely rare, $(.01)^4 = 10^{-8}$. Assuming that the flux of pion tracks is filtered to zero at the last 2 chambers, and a ratio of $\mu^+\mu^-$ to $\pi^+\pi^-$ pairs in the threshold Primakoff region of 10:1, then the projected muon fraction in the $\pi^+\pi^-$ data sample is negligibly small, 10^{-7}. Of course, this numeric estimate isn't realistic because, (i) a small fraction of pions survive to the last pair of MWPCs and get tagged as muons, (ii) muons can multiple scatter out of sensitive areas of the MWPCs and get tagged as pions, (iii) and E.M. backgrounds in the chambers complicate PID, most likely causing pions to get tagged as muons (see our ERR response for a quantitative estimate of these rates). Our conclusion is that a chamber efficiency of 99% is not a limiting factor in π/μ PID, although we reiterate that simulation studies in progress will provide the definitive answer.

B. How does an efficiency uncertainty impact the final physics?

How the uncertainty in the MWPC efficiency impacts the extracted yield of $\pi^+\pi^-$ pairs is something we plan to study in detail using the simulation currently in progress. To get an approximate idea of the sensitivity, we go back to the simple argument presented in section A of this response, reducing the efficiency from 99% to 95%, and seeing how this changes the muon fraction in the $\pi^+\pi^-$ sample. With a chamber efficiency of 95% the muon fraction increases to about 10^{-4} assuming a μ/π ratio of 10:1, still negligibly small and certainly at a level where other complicating factors will dominate PID. We believe that reasonable uncertainties in the MWPC efficiency will not have a significant impact on the final physics result.

C. Please provide a quantitative argument that the goals outlined in [A, B] can be achieved by the efficiency measurements planned by the Collaboration.

As described in our ERR response, the plan is to make a "standard" chamber efficiency measurement throughout CPP data taking, using tracks that go through the last two MWPCs and a scintillator mounted behind the chambers. The wires for these chambers will be oriented vertical, as will the scintillator paddle. The scintillator will have PMTs on both ends, allowing for a coarse longitudinal position measurement. The scintillator paddle will be shorter than the 60" long wires in the MWPCs to ensure that a track hitting the scintillator should go through both MWPCs. The sketch below shows the basic idea of the measurement. These scintillators are available in Hall D.

Our experience has been that chamber efficiency measurements like this can be accurate to a few 0.1% level, provided the charged tracks actually go through all three detectors, and scintillator hits aren't room or beamline backgrounds. Backgrounds usually cause an under-estimation of the true chamber efficiency. It will also be possible to use the FDCs to identify tracks that originate from the target and are projected to hit the scintillator.

The described technique allows us to measure the in-situ efficiencies for MWPC #5 and #6, which are the most important chambers for PID. However, it doesn't directly measure the efficiencies of chambers #1, #2, #3, and #4. Note that all six chambers will be running with the same gas and at the same operating voltage. Previous studies at UMass have shown when running the same gas at the same HV, the eight MWPCs have identical gains as measured with a ^{55}Fe x-ray source. Our experience has been that if the chamber gains and electronics are identical, then the efficiencies are identical. During CPP running we'll be able to test this observation by comparing the measured efficiencies of chambers #5 and #6. Finally, the estimated E.M. backgrounds in the chambers are not identical, chamber # 1 receiving the highest rate and the other chambers much less. But the projected rates aren't at a level that we expect a significant change in chamber efficiency. Our conclusion is that it should be possible to obtain a useful measurement of MWPC efficiency at the level of a few 0.1%.