Topic: Increasing our sensitivity to polarization changes

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If this message looks daunting or proves to be when you dig in, just skip to the "Bottom line?" block near the end. BUT PLEASE READ THAT MUCH.

Hi All:

While reading Blair's dissertation a month ago, I realized that we have been handling the polarization change (vs. time, data set, etc.) measurements in a "less than optimal" manner. Blair's code began it's life as an independent approach to P_{mu}xi. For that purpose, it was fine. But to study changes in P_{mu}, we would like something that measures such changes with the HIGHEST RELATIVE PRECISION. It does NOT need to have a trivial relation to one, or even a linear combination, of the Michel parameters.

-- What did Blair do?

He summed up the total number of events in the forward direction that fall within our standard fiducial. Call the yield F. He did the same in the backward direction. Call that B. Then he calculated (F-B)/(F+B).

-- What's wrong with that?

(a) Over a large part of our fiducial in the vicinity of x=0.5, the asymmetry is close to zero. These events add nothing to the signal. But they do contribute statistical noise, so they reduce the S:N ratio.

(b) In the region x<~0.4, the asymmetry is negative. These events REDUCE THE SIGNAL of interest, while also contributing statistical noise. They provide a double whammy to the S:N ratio.

(c) Regions of high sensitivity (p>50 MeV/c, |costh|>0.84) are excluded. These leave significant additional sensitivity in the bit bucket.

-- How can we help this? How much help will we get?

I wrote a simple Mathcad spreadsheet to calculate the sensitivity. The attachment Blair_asym_sens.pdf shows the results if you integrate over 20<p<50, 0.5<|costh|<0.84 -- close to the fiducial we have used to date. The predicted precision for 65M muon decays into 4pi (<~18M into our fiducial) is 1.1 parts in 10^3. This is very close to the sensitivity from actual fits that include a fixed decay time.

Obviously, (c) implies we should enlarge our fiducial. So I considered 20<p<51.5, 0.5<|costh|<0.94. These upper limits are realistic. Beyond 51.5 MeV/c, we will get too close to the endpoint calibration region. For costh, we might be able to get to 0.96 before the efficiency starts to drop off, but I chose to be "conservative". Over this expanded region, the sensitivity for the same 65M muon decays into 4pi is 7.7 parts in 10^4.

Similarly, (a) and (b) imply we should increase the lower momentum limit of the "polarization fiducial". Sure enough! It turns out that 40.5 MeV/c is "optimum" if we take pmax and the costh range as given. For 40.5<p<51.5, 0.5<|costh|<0.94, the sensitivity becomes 6.1 parts in 10^4.

This is NOT a small change. Shrinking an error bar to 55% of its former value with statistics would require taking 3.3 times as many events.

-- Can we do still better?

It seemed the answer to this question had to be yes. We have a lot of events with p<40.5 MeV/c where the asymmetry is still significant. We should be able to make use of them. The key is that we need to include them in a manner that reflects their sensitivity to polarization (or lack thereof). At this point, I started experimenting. My first try was to weight each event by its expected physics asymmetry. That helped. Then I tried higher powers. That looked like it might be even better. Eventually, I came up with a "generalized asymmetry" G_n, as follows:

(a) For each (x,costh) bin containing N_i counts, define A_i = Asym(x)*costh, where Asym(x) is the Born term analyzing power.

(b) G_n = Sum_i (A_i |A_i|^n N_i) / Sum_i (|A_i| |A_i|^n N_i)

If you find this hard to read, look at the Mathcad integrals in the attached .pdf file. That file also includes the integrals to compute sigma_{G_n}.

Note that G_{-1} = (F-B)/(F+B) if xmin >= 0.5, and G_{-1} = (B-F)/(B+F) if xmax <= 0.5. Meanwhile, my "first try", weighting each event by its expected physics asymmetry, is just G_0.

-- What does this give us?

For G_0, there is still an "optimum" lower limit. It's at 30~31 MeV/c, and yields a sensitivity of 5.4 parts in 10^4. This is a further 13% improvement in precision, again without taking any additional data.

For G_1, it looks like you can add more events without ever hurting yourself. But you win very little below pmin=31 until you get so low that we can't reconstruct reliably. This is a nice cut-off; it will help avoid misidentified beam positrons. It yields a sensitivity of 5.3 parts in 10^4. The attachment Weighted_asym_sens.pdf shows the corresponding Mathcad spreadsheet. The G_1 sensitivity is on page 2.

-- Bottom line?

(a) We have a new class of relative polarization measurement algorithms at our disposal. G_0 and G_1 are nearly equivalent. So is G_{0.5}. (And G_2 is only ~4% worse than G_1.)

Each of these algorithms reduces the relative statistical precision on a measure proportional to muon polarization by at least a factor of 2, compared to the procedure we've used in the past. By applying one of these algorithms to the data we are taking now, we will make every event 4 times as powerful. We've been expecting/hoping for a 3 sigma polarization change for {nominal vs. B2+6G} and a 6 sigma polarization change for TEC in {high P vs. low P}. These differences will now be 6 and 12 sigma, respectively. That will permit much stronger GEANT validations (or smaller deviations) to be obtained.

(b) Finally, there is an ancillary -- but not unimportant -- additional advantage. Now that Blair's black box has been opened, it might be possible for the determined sleuth to work backwards from the final P_{mu}xi value, through the various corrections, to the measured front-back asymmetries. This would reduce the degree of blindness in future analyses. By adopting a new relative polarization measurement technique, we will blind ourselves once again to the proportionality constant -- which in any case, will now involve a complex dependence on xi, delta, and rho.

Down the road, we can even change the choice of n with each future black box, thereby assuring blindness for each analysis. Therefore, I propose that we implement n as a parameter in the code, rather than just hard coding the n=0 algorithm (e.g., the simplest and "cleanest" version).

Carl

p.s. For implementation purposes, to calculate G_n each "bin" can be a single event. This will permit the necessary sums to be computed on a running basis during tree summing. Alternatively, each "bin" can be of finite size, with the calculations performed on histogram entries after tree summing. My guess is that the event-by-event implementation within tree summing will probably be more convenient, especially for computing the time dependence.

Blair_asym_sens.pdf
15.89 Kb

Weighted_asym_sens.pdf
18.88 Kb