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Spin Requirements for STAR Scalers

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1 Introduction

Our working assumption here is that the spin program poses the greatest challenges to the scaler requirements. In the spin program, unlike all other operational conditions of STAR, different kinds of beams (polarization states) are run simultaneously in the same ring. It is probable that these requirements will drive the STAR scaler requirements.

1.1 Asymmetries and Measured Quantities

To illustrate some of the issues, we describe a simple thought experiment. Consider an experiment with one beam polarized, and some physics process whose rate depends on the beam polarization state. Define the asymmetry A as:

$$A \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

and the cross section for unpolarized beam[1] as:

$$\sigma \equiv \frac{\sigma_+ + \sigma_-}{2}$$

From these definitions, we can express the cross sections for 100% polarized beams in terms of the spin-averaged cross section and the asymmetry:

[1]This is assuming the beam is composed of spin-1/2 particles. The possibility of polarized nuclei complicates this.

$$\sigma_+ = \sigma(1 + A)$$
$$\sigma_- = \sigma(1 - A)$$

Measuring σ and A is therefore sufficient to completely specify the cross-sections for different polarization states. To measure these quantities, we need to know the integrated luminosity of the beam with each of the two polarization states $\mathcal{L}_+$ and $\mathcal{L}_-$. We can define the beam polarization P,

$$P \equiv \frac{\mathcal{L}_+ - \mathcal{L}_-}{\mathcal{L}_+ + \mathcal{L}_-}$$

and the total luminosity $\mathcal{L}$

$$\mathcal{L} \equiv \mathcal{L}_+ + \mathcal{L}_-$$

From this, we can calculate the number of events N in our sample:

$$N = \frac{1}{2}\mathcal{L}\left[(1 + P)\sigma_+ + (1 - P)\sigma_-\right]$$

by noting

$$\mathcal{L}_\pm = \frac{\mathcal{L}}{2}(1 \pm P).$$

Next, by substituting the definition of A in, we can express this as

$$N = \mathcal{L}\sigma(1 + PA).$$

Clearly, to measure A, one needs to measure N_1 and N_2 at two different polarizations P_1 and P_2. These polarizations do not have to be equal and opposite (or even to have different sign), although the larger the difference in polarizations, the larger the measured asymmetry and the easier it is to measure the physics asymmetry A. As a practical matter, $P_1 = -P_2$, since you want a large polarization (make P_1 as large as possible) and a large difference (make $|P_2|$ as large as possible, with the opposite sign of P_1.)

With some algebra, one can write down the expression for A:

$$A = \frac{(\frac{N_1 \mathcal{L}_2}{N_2 \mathcal{L}_1}) - 1}{P_1 - (\frac{N_1 \mathcal{L}_2}{N_2 \mathcal{L}_1}) P_2}$$

This then allows us to determine the sensitivity of our measurement of A to various other measured quantities, recalling

$$\Delta A = \frac{\partial A}{\partial X} \Delta X.$$

The sensitivity of A to $\mathcal{L}_2/\mathcal{L}_1$ is clearly something which will drive the scaler requirements.

$$\frac{\partial A}{\partial \mathcal{L}_2/\mathcal{L}_1} = \left(\frac{N_1}{N_2}\right)(P_1 - P_2)\frac{A^2}{(\frac{N_1 \mathcal{L}_2}{N_2 \mathcal{L}_1} - 1)^2}$$

$$= \left(\frac{N_1}{N_2}\right)(P_1 - P_2)\frac{A^2(1 + P_2)^2}{A^2(P_1 - P_2)^2}$$

$$= \left(\frac{N_1}{N_2}\right)\frac{(1 + P_2)^2}{(P_1 - P_2)}$$

For typical RHIC conditions ($P_1 = -P_2 = 0.7$), this expression tells us that we need to be twice as accurate on the measurement of the relative luminosities than our desired accuracy on A. For 50% polarization instead of 70% polarization, this factor of 2 becomes 2.25.

Therefore, whatever process that we choose to monitor the luminosity with must have the following two characteristics:

- It must have a rate at least 4-5 times larger than whatever we want to measure the asymmetry of.

- It's own asymmetry must be known to no worse than half the asymmetry we are trying to measure.

Beam Condition	Bit Pattern Set
Positive Polarization (+)	11
Negative Polarization (-)	10
Empty Bucket (0)	00

Table 1: Scalers set based on one beam's polarization state

Beam Condition	Bit Pattern Set	Hexadecimal Representation
+ +	1111	F
+ 0	1100	C
+ -	1110	E
0 +	0011	3
0 0	0000	0
0 -	0010	2
- +	1011	B
- 0	1000	8
- -	1010	A

Table 2: Scalers set based on the polarization state of both beams

The highest rate process that we intend to study would probably be 10 GeV jets. (Prescaled) At $\sqrt{s} = 500$ GeV, this makes up about 1% of the total inelastic cross-section. Therefore, the absolute minimum event rate for the normalizing process must be 5% of the inelastic cross section.

Note that we are more interested in double-spin asymmetries, but the point of this derivation is still valid: we need to be able to measure the luminosity with high accuracy from a largely unbiased sample.

2 RHIC Polarization

In the scaler board design, each scaler is assigned a bit-mapped address, and each crossing, a bit-mapped pattern is sent to the scaler unit, a patten which encodes which scalers are to be incremented. The nine polarization states can be coded into 4 bits, no fewer. The most natural way of doing this is to assign 2 bits to each beam: one for beam on-beam off, and one for polarization positive and the other for polarization negative. The following tables show how this would work for various beam conditions.

There are seven unused combinations (1,4,5,6,7,9,D) here - corresponding to the 16 available states less the nine allowed beam states. A clever physicist might be able to pack more information into these unused combinations. Of particular use would be redundant combinations: if A and B are mutually exclusive (such as beam polarized up and beam polarized down), scaling A, B and (A OR B) will provide a check on the operation of the scalers. Because scalers play a critical role in extracting these small asymmetries, having redundant counters allows STAR to identify failures, and terminate the run while these failures are corrected.

Ideally, we would want a bunch-by-bunch scaling. The reason is that a double-spin asymmetry is proportional to ΣP^2, but measuring a single beam polarization gives us only $(\Sigma P)^2$. The error induced is therefore related to the difference in beam polarization bunch by bunch. Measuring P for each bunch crossing (as a function of time) would be ideal, but the proposed polarimetry is not capable of doing this. We expect to be able to measure the polarization averaged over bunches at two times: the beginning of a store and at the end of intentionally terminated stores. There is no point in scaling quantities that cannot be provided by the polarimeter, so we do not make any provision for bunch-by-bunch scaling.

3 Normalizing Processes

Some physics process has to be chosen to measure the luminosity. As described above, this has to have two properties: high rate, and a known asymmetry (preferably zero). Unfortunately, since nobody has seen a 200 GeV or 500 GeV polarized pp collision, we don't know the asymmetries for any processes. Our only alternative is to scale several types of events and hope that we find one that is spin symmetric. This is not as hard as it sounds: we expect high rate, low p_T processes to be close to spin symmetric. However, expectations are not the same as measurements.

How many separate measurements do we need? Well, clearly one is too few. We won't know if it is right or wrong. Two is too few. If the measurements disagree, which one is right? [2] Three is the absolute minimum, but can fail if there are two methods that show non-zero but different asymmetries. Only with four or more luminosity measurements can one be reasonably confident of the result.

Worse, there is no completely unbiased way to select events. (Hence the description "minimum bias" rather than "zero bias" for these events.) If we decide there is a collision based on CTB information, for example, we need to place some threshold on the signal so that we do not misidentify electronic noise and dark current as real events. Doing this, we blind ourselves to events with relatively few central tracks, which biases our sample somewhat.

[2] A man with one watch always knows what time it is. A man with two watches never knows.

This bias may select events that have a production rate dependent on polarization. If this is the case, it will cause our luminosity measurement to be polarization-dependent, which will induce a systematic error on all measured asymmetries. The obvious fix for this is to take data that is less biased, but equally obviously the selection for minimum bias events will be as unbiased as practical. Therefore, the way we understand the bias induced is to select events that are *more* biased. If the minimum bias sample selects events that have some ADC above 100 counts, we should scale events that have this same ADC above 200 counts. If this sample shows no asymmetry, we can be reasonably confident that the less biased sample shows no asymmetry either. If this sample shows an asymmetry, it allows us to correct for this bias, provided that it is linear. A third sample at a still higher threshold would allow us to correct for a quadratic bias, or to place uncertainties on a linear correction.

Several possibilities present themselves for detectors used to identify minimum bias:

- The VPD, requiring an East-West Coincidence between one or more scintillator telescopes.

- The CTB, requiring more than a certain number of charged particles in the central region.

- The barrel EMC, requiring ΣE_T above some threshold in the central region.

- The MWC, providing the CTB functionality in the $1 \leq \eta \leq 2$ region.

- The endcap EMC, requiring ΣE_T above some threshold in the $1 \leq \eta \leq 2$ region.

Providing three thresholds for all of these gives us fifteen different luminosity measurements that need to be scaled. This is probably excessive. A more reasonable proposal would be to pick one quantity as the primary luminosity measurement, and scale it over three thresholds. Have the other four scaled with only two thresholds. That gives us eleven quantities to be scaled, which is more tractable.

Our preference for the primary luminosity measurement would be based on the VPD. The spin program at STAR is designed around high p_T processes, so the most independent measurement is of the high rate, low p_T forward processes.

It is probably possible to get away with scaling fewer than 11 quantities. It is unlikely that there will be much difference between the central and endcap regions, so after a small amount of data taking to verify this, it should be possible to return two high threshold bits back to the pool. So, initially, we need 11 bits, but for steady-state running, 9 is the minimum.

Should it turn out that these quantities do posses polarization dependences, they

Bit Pattern Set	Fast Detectors	Slow Detectors
11	Ready	Ready
01	Ready	Not Ready
10	Not Ready	Ready (should never occur)
00	Not Ready	Not Ready

Table 3: Scaler bits set based on the STAR deadtime condition.

still need to be scaled: to be used as polarimeters.

4 Live Time

Since there are periods of time where STAR is "dead", that is, not in a ready condition for the next trigger, we need to scale both the true beam luminosity and the live beam luminosity. It's not sufficient to multiply the true beam luminosity (separated by polarization states) by a constant live time fraction, because the live time fraction is something that (like the polarization) varies from bunch to bunch.

We could set a scaler bit signifying the readiness condition for every slow detector in STAR. However, it is unlikely that we would be interested in events where (e.g.) the FTPC and SVT is live but the main TPC is dead. Life is much simpler if we consider an event with any slow detector dead as one that has all the slow detectors dead, or (equivalently), all the slow detectors have to be live for any slow detector to be treated as live. This way, we have exactly four states, described by two bits:

Note that in this proposal we do not scale "total beam", that is, beam independent of whether STAR is able to record it. However, we can recover this quantity in two ways: we can add the scaled quantities for "fast detectors live" and "fast detectors dead", or we can add the scaled quantities for "slow detectors live" and "slow detectors dead". These quantities should agree. In fact, there should be a monitor process running in the control room that compares these quantities as the run progresses. Should these quantities ever differ by a significant amount, this monitor should announce a scaler failure and terminate the run, so that no data with dubious luminosity will be collected. The shift crew can then go about solving the problem.

5 Scaler Proposal

It appears that a single 16-bit scaler board will suffice, although two such boards would provide extra security in the case where spin asymmetries are seen in all the "minimum bias" samples. The allocation of bits would be as follows:

- Four bits for the beam polarization states
- Two bits for the STAR live-time status
- 9-11 bits for the luminosity monitoring

That gives us 15-17 bits. Initially, we can use only one live-time bit to establish that the luminosity monitors are insensitive to the polarization, fitting this into a single 16 bit board. After this has been established, we can stop scaling one luminosity quantity at high threshold and return the bit for use in monitoring live time. Having two scaler boards would allow us to do this without swapping bits.

For AA running, we might be interested in having more conditions describing live time: for example, each slow detector having its own bit defining whether it is live. However, we do not need to have nearly as accurate a handle on luminosity, so we can probably reduce the number of luminosity bits from 11 to 2 or 3. The total should easily fit in 16 bits.