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Note on Polarized RHIC Bunch Arrangement

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Spin Note

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Summary

We discuss what combinations of bunch polarization in the two RHIC rings are necessary to do the physics measurements at various interaction regions. We also consider the bunches for both the pion inclusive and p-p elastic polarization measurements.

Important factors to consider are the direction of the polarization with respect to the momentum in each bunch, the beam gas backgrounds, and the simulation of zero polarization in one beam by averaging + and - helicity, and luminosity monitoring for normalization. These considerations can be addressed by setting the relative number of each of the 9 combinations possible at each of the 6 interaction regions. The combinations are (+ empty -) yellow X (+ empty -) blue, where yelow and blue are the counter-rotating rings.

PHYSICS CONSIDERATIONS

There are several different kinds of physics asymmetries to be addressed. These are

1) Vertically polarized beam in one ring on unpolarized target.
   This is done separately for the pion polarimeter in each ring.
2) Vertically polarized in one ring interaction on vertically polarized in the other ring.
   This is done for the parity conserving structure function measurement of h11.
   This is also done for the Ann and An parameters in pp to pp for beam polarization measurements.
3) Longitudinally polarized beam in one ring interaction with longitudinally polarized beam in the other ring. Certain combinations are for the measurements of parity conserving quantities, and certain other combinations are for measurement of parity violating quantities.

In measuring a rate asymmetry involving longitudinally polarized beams, it shold be remembered that some of the interactions such as (V-A) involve the beam momentum direction as well as the spin direction in each beam, as well as the direction of the final state

particles. It is not sufficient only to tag the spin directions.

Furthermore, even though some symmetry is introduced by using p-p rather than pbar-p, neither STAR nor PHENIX detectors are symmetric with respect to beam direction and/or helicity.

We give some examples, first just looking at the physics with symmetric detectors, then with the complications in measurements with asymmetric detectors.

Notation:
AL PV blue is the longitudinal on longitudinal rate asymmetry for the parity violating combinations of helicities of the two beams, done with an average over helicity in the yellow beam.
We also have AL PV yellow, which is not equivalent with respect to a direction in the lab.
ALL PC is the parity conserving rate asymmetry spins aligned - spins anti-aligned.
There are several combinations of helicities which give this, and they would be identical in the absence
of asymmetries in the detectors or rings.
(++) is both beams having positive helicity, spin aligned with momentum,
(+-) is one beam positive helicity, other negative.
Helicity is (sigma dot p)/E.
cos(th-Wcm) is the direction of the electron or muon from W decay in the W cm frame with respect to, for example, the blue beam.

We start with a simple picture of a parity violating asymmetry and build up to the realistic case.
With one beam, blue, polarized and the other not, we could have a simple one spin asymmetry
AL = [(+0) - (-0)] / [(+0) + (-0)].
This is parity violating for any direction of the secondary particles.
The next step is to have the second, yellow, beam polarized also, but to average over it.
Including the physics of what is detected, this gives

AL PV blue = (1 + cos(th-Wcm)) [(++) + (+-) - (-+) - (--)] / sum
AL PV yellow = (1 - cos(th-Wcm)) [(++) - (+-) + (-+) - (--)] / sum

Note the sign difference with respect to the laboratory.

We can go a step further and re-express these in terms of rapiity and add the blue plus yellow to get ALL PV, as J. Soffer has done.

ALL PV #1 = f1(y) [(++) - (--)] / sum Sz =0
ALL PV #2 = f2(y) [(+-) - (-+)] / sum Sz =1
The first is parity violating just looking at the initial state.
The second requires that we look at some laboratory direction.
Note that Sz refers to the protons, while the constituents could have either helicity with respect to the proton.

With detector acceptance asymmetric in theta relative to the blue beam, acceptance has odd powers of cos(th). For example a dummy acceptance = cos(th-lab) gives us:

AL PV blue = cos(th-lab) (1+ cos(th-Wcm)) [(++) + (+-) - (-+) - (--)] / sum
AL PV yellow = cos(th-lab) (1- cos(th-Wcm)) [(++) - (+-) + (-+) - (--)] / sum

Note that at 90 degrees in the W frame, AL PV blue = AL PV yellow.
However, the W is formed from quarks in one proton and anti-quarks in the other, and on average has some momentum with respect to the PP cm and the beam crossing point. 90 degrees in the lab is not that frame for either blue or yellow.

For parity conserving interactions, the useful asymmetry is the difference between spins aligned ,Sz=1, and spins not aligned, Sz=0. This is what is used to study the polarized gluon distribution function.

ALL PC = [(+-) + (-+) - (++) - (--)] / sum
ALL PC = [(+-) - (++) + (-+) - (--)] / sum
This is like Sz=1 - Sz=0 in terms of the initial protons.
ALL PC could in principle be found from [(+-) - (++)] alone, etc but with bigger systematic errors.

The simplest situation is vertically polarized beam interacting on an unpolarized target in the beam polarimeters.
We then have An = (+0) - (-0) / sum

LUMINOSITY NORMALIZATION

As a further step toward reality, the physics asymmetries are actually cross sections measured with respect to Luminosity for the bunch combination. Since we are taking differences, we only need relative luminosities for each of the 9 combinations.

AL = angular factors [(++) /L++ + (+-) /L+- - (-+) /L-+ - (--) /L--] / sum

The luminosity monitoring will be done with lower Pt events than the physics, using processes that are believed to have zero or very small asymmetry. We use lower Pt processes in order to get adaquate rate and statistics. This luminosity monitoring must be done with the same interaction diamond with the same vertex cuts as the physics events. It will therefore be done by each experiment using the physics detector.

BEAM GAS:

The beam-gas background problem is different for the colliding beam experiments than it is for the polarimeters with fixed targets. In both cases, the secondaries from the interaction travel along roughly with the velocity of the bunch within which the interaction occured. In both cases, the beam gas interactions have a spin asymmetry. In colliding beams with longitudinal polarization, the parity conserving asymmetry from beam gas should be zero, while the parity violating asymmetry is probably quite small because the fixed-target center of mass energy is below the W mass. In colliding beams with transverse asymmetry, the left-right asymmetry can be large from Ann with the beams colliding, and from An from beam-gas.

To a good approximation, the colliding beam experiments are sensitive to beam-gas interactions occuring anywhere between the DX magnet and the interaction point. This is for each beam separately. The DX magnets should act as sweepers to reduce the beam-gas secondaries originating far away from the interaction regions. The true beam-beam interactions can be eliminated and the beam-gas background measured by eliminating the bunch in one beam and not the other. This should be done separately for both directions.

The Beam-Gas backgrounds will be different for the physics events of interest than for the relative Spin Luminosity measurements done in each experiment. The physics

Asymmetries can only be calculated with respect to the luminosity of each bunch combination. The luminosity monitoring will be done with lower Pt events than the physics, using processes that are believed to have zero or very small asymmetry. The luminosity monitor could be contaminated in rate by beam gas events close to the beam crossing, and in asymmetry by events where the spin is not longitudinal upstream of the DX magnets.

In the polarimeter, the only way to remove the real events in order to determine the background is to remove the target. The target may be 3 micron carbon fiber or an unpolarized hydrogen gas jet. A source of accidentals in the polarimeters is beam gas interactions either upstream or downstream of the target. The secondaries from these may get into the hodoscopes by paths that are blocked to secondaries from the target.

BUNCH PATTERNS:

We assume the following constraints in searching for an appropriate pattern of +,- and empty bunches. First, we assume 60 RF buckets around the ring, with at least 3 in a row empty to allow for the rise time of abort magnets, etc. We then want the interaction regions in use to get each of the 9 combinations. We want the non-empty combinations to occur in roughly equal numbers and more often than the empty combinations. The 9 combinations are (+,empty,-)blue X (+,empty,-)yellow.

We first considered a simple +-+-... alternating pattern in each beam. This does not give the right combinations an any interaction region. We then tried generating all the bucket fillings by means of random numbers. some solutions were found, but the relative numbers of combinations was not attractive for doing the experiments. We were thus led to consider

a hybrid of pre-determined pattern and random generation in order to find a solution.

We put start with a pattern of +-+-+- etc. in one ring and ++--++--++-- etc. in the other. We then randomly make some of the buckets empty, and check that the resulting combinations (clocked around the ring) satisfy the constraints. With less than 10 minutes of CPU time an a VAX Alpha, we found 4 solutions good at all 6 interaction regions, and many good at a few regions. The 4 solutions are shown here, although we have a factor of 10 more available .

Note that the relative location of the successive empty buckets may not have the relative position for aborts if there is some constraint relating the two beams. This will be studied in the future.

Solution 1:

EMPTY + good patterns >5 int regions A B

- + - + - + - + - + - E - + - + - + - + - + - + E + - E - +
- + - + - + E E - + - + - E - + E + - + - + - E E E E + - +

+ - - + + - - + + - - + + - - + + - - + + - - E E E - + + -
- + E - - + + - - + + E - + + - E + + - - + + - - + + - - +

Solution 2:

EMPTY + good patterns >5 int regions A B

- + - + - + - E E + - E E E - + - + - + - + - + - + - + - +
E + - + - + - + - + - + - + - + - + - + - + - + - + - E - +

E E E + + - E + + - - E + - - + + - - + + - E + + - - + + -
- + E - - + + - - + + E - + + - - + + - - E + - - + + - - +

Solution 3:

EMPTY + good patterns >5 int regions A B

- + - + E + - E - E - + - + - + - + - + - + - + E + - + - +
- + - + - + - + - + - + E + - + - + - + - + - + - E E E - +

+ - - + + - - + + - - + + - - + + - - + + - - + + - - E E E
- + E - - + + - E + + - - + + - - + + - - + E - - E + E - +

Solution 4:

EMPTY + good patterns >5 int regions A B

E + - + - + - + - + E + - E - + - + - + - + - + E + - + - +
E E E + - + - + - + - + - + - + - E - + - + - + - + - E - +

+ - - + + - - + + - - + E - - + + - - E + - - E + - - + + -
- + + - - + + - - E E E - + + - - + + E - + + - - + + - - +

TAGGING BUNCHES FOR EXPERIMENTS

In order to do spin physics at RHIC, we must keep track of the polarization directions of each bunch and keep track of which bunches are involved in each crossing. There are three possibilities for polarization, up, down and empty for each beam, making 9 combinations. It is conceivable that we might want to keep track of other information on each bunch but
this may be a red herring.

Here is a concept for a way to do this. This is only conceptual and probably not the real way to do it.

I assume 60 positions around the ring for bunches, 3 of which are empty, so there are 57 bunches and 60 positions.

We can have two rings of 60 registers, like long shift registers coupled back on themselves. The width of each can be 2 bits or more. Ring A gets clocked one way and ring B the other way. We put a 4 (or more) bit register between the rings at the position of STAR or PHENIX. .
For each event the data in the crossing register is the combination of the data from the appropriate bunch in each ring. In the case of STAR the crossing register would be used to gate open one of 9 groups of scalers in the level 0 trigger. Physics events and luminosity
events would go into the appropriate scalers within a group.

The data in the shift rings would be loaded at the fill time for the acclerator rings. When the RF adiabatic spin flipper was used on a RHIC ring, the data in the matching shift ring would be reversed, complemented or whatever.

One pitfall which I don't have info on yet is whether cogging in the beam storage setup in RHIC could move bunches far enough to collide different bunches than originally assumed. I assume this would be easy to handle electronically if necessary.

APPENDIX

numbers of each combination at each crossing

Solution #1

EMPTY + good patterns >5 int regions A B

- + - + - + - + - + - E - + - + - + - + - + - + E + - E - +
- + - + - + E E - + - + - E - + E + - + - + - E E E E + - +

+ - - + + - - + + - - + + - - + + - - + + - - E E E - + + -
- + E - - + + - - + + E - + + - E + + - - + + - - + + - - +

At 6 int. regions:

numb ++,--,+-,-+	10	11	12	12	
numb +e,-e,e+,e-,ee	2	2	5	4	2
numb ++,--,+-,-+	12	10	10	13	
numb +e,-e,e+,e-,ee	2	2	2	7	2
numb ++,--,+-,-+	10	12	12	12	
numb +e,-e,e+,e-,ee	2	1	5	3	3
numb ++,--,+-,-+	11	10	11	12	
numb +e,-e,e+,e-,ee	2	3	4	6	1
numb ++,--,+-,-+	9	11	13	11	
numb +e,-e,e+,e-,ee	2	3	7	3	1
numb ++,--,+-,-+	11	11	10	12	
numb +e,-e,e+,e-,ee	3	2	4	6	1

Solution #2

EMPTY + good patterns >5 int regions A B

- + - + - + - E E + - E E E - + - + - + - + - + - + - + - +
E + - + - + - + - + - + - + - + - + - + - + - + - + - E - +

E E E + + - E + + - - E + - - + + - - + + - E + + - - + + -
- + E - - + + - - + + E - + + - - + + - - E + - - + + - - +

At 6 int. regions:

numb ++,--,+-,-+	11	12	11	12	
numb +e,-e,e+,e-,ee	4	3	3	2	2
numb ++,--,+-,-+	11	12	11	12	
numb +e,-e,e+,e-,ee	4	3	3	2	2
numb ++,--,+-,-+	11	12	12	12	
numb +e,-e,e+,e-,ee	3	3	3	1	3
numb ++,--,+-,-+	12	11	11	12	
numb +e,-e,e+,e-,ee	3	4	2	3	2
numb ++,--,+-,-+	12	12	10	11	
numb +e,-e,e+,e-,ee	4	4	3	3	1
numb ++,--,+-,-+	11	12	10	12	
numb +e,-e,e+,e-,ee	5	3	3	3	1

Solution #3

EMPTY + good patterns >5 int regions A B

- + - + E + - E - E - + - + - + - + - + - + - + E + - + - +
- + - + - + - + - + - + E + - + - + - + - + - + - E E E - +

+ - - + + - - + + - - + + - - + + - - + + - - + + - - E E E
- + E - - + + - E + + - - + + - - + + - - + E - - E + E - +

At 6 int. regions:

numb ++,--,+-,-+	11	12	12	11	
numb +e,-e,e+,e-,ee	3	3	3	3	2
numb ++,--,+-,-+	10	10	12	13	
numb +e,-e,e+,e-,ee	4	3	2	5	1
numb ++,--,+-,-+	10	12	12	11	
numb +e,-e,e+,e-,ee	4	3	4	3	1
numb ++,--,+-,-+	11	10	12	12	
numb +e,-e,e+,e-,ee	3	4	2	5	1
numb ++,--,+-,-+	11	13	12	10	
numb +e,-e,e+,e-,ee	3	3	4	2	2
numb ++,--,+-,-+	11	10	12	12	
numb +e,-e,e+,e-,ee	3	4	2	5	1

Solution #4

EMPTY + good patterns >5 int regions A B

E + - + - + - + - + E + - E - + - + - + - + - + E + - + - +
E E E + - + - + - + - + - + - + - E - + - + - + - + - E - +

+ - - + + - - + + - - + E - - + + - - E + - - E + - - + + -
- + + - - + + - - E E E - + + - - + + E - + + - - + + - - +

At 6 int. regions:

numb ++,--,+-,-+	12	12	13	9	
numb +e,-e,e+,e-,ee	1	4	4	3	2
numb ++,--,+-,-+	12	10	13	11	
numb +e,-e,e+,e-,ee	1	4	2	5	2
numb ++,--,+-,-+	11	12	13	10	
numb +e,-e,e+,e-,ee	2	3	4	3	2
numb ++,--,+-,-+	11	10	13	11	
numb +e,-e,e+,e-,ee	2	4	3	5	1
numb ++,--,+-,-+	11	11	13	10	
numb +e,-e,e+,e-,ee	2	4	4	4	1
numb ++,--,+-,-+	11	11	13	12	
numb +e,-e,e+,e-,ee	2	2	2	4	3