Proposal for

Investigations on the

# LHC Long-Range Beam-Beam Effect

with an application to a

# Wire Compensation

and an

# Early Beam Separation Scheme

at RHIC

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# 1 Motivation and Goals

The nominal LHC IR layout with a crossing angle of 300 $\mu$rad was chosen as a result of long-range beam-beam (LRBB) investigations. Simulation studies and a series of wire excitation experiments in the SPS indicate that an average beam-beam separation of $9.5\sigma$ is sufficient. All on-going IR related upgrade studies have to prove and are judged by their performance with respect to the LRBB. Currently there are two alternative LRBB-upgrade proposals being studied: The wire compensation and the early separation scheme. In order to validate the various proposed upgrade paths, it is necessary to experimentally verify their simulated effectiveness and identify/quantify their weaknesses. This will help to the decide for one or the need for a combination of both.

Thus more studies in the SPS are planned, but they will not be able to clear several major issues. For example studies including the interplay of a head on collision and LRBB (mimiced by a wire) are not possible at all. Therefore it had already been proposed and agreed in the US-LARP program to perform LRBB related studies at RHIC profiting from the significantly higher potential in accuracy provided by the long RHIC beam lifetime and the performance of a collider instrumentation. In order to allow a focusing of the upgrade studies on realistic schemes it is necessary to carry out this experimental work with a larger range of parameters.

Upgrade studies for both - the wire compensation and an early separation scheme will profit from a better understanding of the LRBB effect, from a confirmation of the expected energy scaling and a benchmarking of simulation codes. Furthermore RHIC provides a unique chance of studying the interplay of Head-on and LRBB.

## 1.1 Wire compensation

The idea of a wire compensation is fairly simple: One attempts to cancel the perturbations due to LRBB by the field of a current carrying wire locally. The strength of this scheme lies in its simplicity and rather small effort. Still, in order to be able to rely on it for an upgrade path experimental proofs are needed. It may be necessary to install the device even before the official upgrade after a few years of LHC operation. The main issues are: How precise must the wire be positioned? This question can easily be answered by a beam-wire scan in RHIC. How precise must the current match the beam conditions? Can one find a trade off between nominal and Pacman bunches? This will be answered by a current scan at RHIC. How does the wire perform alone and in combination with a Head on collision? While in normal accelerator operation one can not separate them, RHIC would offer the possibility to study these effects separately and one could for once clearly identify the different contributions. Other questions like "Is the phase advance between the LRBB and the wire crucial" or "Can one wire compensate several LRBB collisions at different beam-beam separations" will unfortunately not be addressed right away but will be better answered by benchmarked simulation codes.

## 1.2 Early separation scheme

In case of a drastically reduced $\beta^*$, an upgrade requires a larger physical crossing angle to keep the beam separation at $9.5\sigma$ or higher in case of a beam current increase. The loss of luminosity due to the geometrical loss factor becomes then rapidly overwhelming. A solution to this problem is an early separation scheme. In practice however, an ideal scheme is not possible and a few long-range encounters must occur at a reduced normalized separation. It is essential for this scheme to investigate what is the number of encounters that can be tolerated at a reduced beam separation. For that purpose, it is sufficient to extend the agreed experiment with measurements for a reduced wire current simulating 2, 4, 6 long-range encounters at a separation that is reduced in steps from $9.5\sigma$ to a minimum (3 to $5\sigma$). It does not seem possible at this time to study experimentally the effect of simultaneously occurring LRBB collisions at different normalized beam-beam separations (e.g. $5\sigma$ to $9.5\sigma$) at RHIC.

# 2 Experimental requirements

In the experiments the new RHIC wire compensator(125 Am maximum) will be used to excite or compensate perturbations in the gold (weak) beam. The emittance of the weak gold ion beam may be adjusted to fulfill the scaling laws. Indeed 317Am would be necessary to simulate the LHC with the LHC beam emittance (2 IP's and nominal beam current). For the experiments without head on collision only one ring is necessary.

The most important observable is the one that is used to identify a beam-beam limit, i.e. the beam lifetime. To improve reliability, other observables should be recorded: beam losses close to the wire, transverse beam profile, tune footprints, beam transfer functions. Ideally, a measurement of the diffusion for sufficiently large amplitudes carries a lot of information: This could be done by blowing up the weak beam, scraping at a certain amplitude, retracting the scraper and observing the time constant of the scraper losses with a BLM. A tune comparable to the LHC tune would be an asset if feasible. In any case, a tune scan is necessary to avoid observations that would be too specific for a given tune.

# 3 Off-line preparation

1. The wire in blue ring is at position 3792m (=41.5m upstream of IP6). The Twiss parameter at this position are $\beta_x = 1199.59$, $\beta_y = 388.67$, $\alpha_x = -30.01$ $\alpha_y = -15.26$ (compared to $\beta_x = 21.3$, $\beta_y = 21.2$ a tthe shifted LRBB interaction point at 10m). According to MADX there is a bpm at 3796.95m and one at 3767.2m. Their functionality should be checked.

2. Prepare a horizontal orbit bump to move the beam horizontally at the position of the wire. (This is necessary to align the beam into the plane of the wire).

3. Prepare compensation strategies for the tune and orbit distortions for different wire current and positions. The aim of the simulation is to have the strength of the two orbit correctors as a function of the wire's position and current. The same exercise should be done for the tune shift and its correctors

4. Scaling of beam distance unit ($\sigma$) and wire current to reproduce the LHC situation: assuming an additive effect of the two high luminosity insertions (worst case) with 15 long-range encounters on each side of each IP, the wire integrated current must be 324 Am for an invariant emittance of $3.75E - 6\mu rad$

| variable | RHIC (AU) | LHC |
|---|---|---|
| $\epsilon_n$ (rms) | 1.5E-6 | 3.75E-6 |
| $\gamma$ | 108.4 | 7461 |

Table 1: Comparisson of RHIC and LHC beam parameter

$$I_w = 324 \frac{\epsilon_{n,RHIC}}{\epsilon_{n,LHC}} Am \tag{1}$$

5. The distance between the beam and wire center should equivalent to 9.5 $\sigma_{LHC}$ in order to reproduce the LHC case. Therefore the separation should be chosen to be 9.5 $\sigma_{RHIC}$ in the vertical plane at the RHIC wire location is:

$$1\sigma = \sqrt{389 \cdot 1.3837638376383763837638376383764e-8} \approx 2.32mm \tag{2}$$

For comparison: the wire has 3.5 mm radius

The basic setup should be tested at the end of a preceding physics runs.

# 4 Experimental Preparations

The measurements require some common routines, which are described here:

## 4.1 Preparing the machine

1. Verify that the beam lifetime is large enough: a few percent loss per hour?
2. Record observables: Q, Q', orbits, I, lifetime, footprint, transverse beam profile, BLM signals.

## 4.2 Powering and moving of the wire - tune and orbit correction

This procedure will need to be followed every time the wire is moved or differently powered.

1. Adjust tunes and chromaticities to what is known appropriate for a long lifetime in RHIC: Q'=2?, wire OFF Correct the orbit with wire OFF to maximize aperture all around the machine. Constrain the horizontal orbit to vanish at the wire position.
2. Move the wire to the wanted beam-wire position and switch it on stepwise: For each step:
   - Calculate the expected tune shift both planes: The linear tune shift due to the wire is given by:

     $$\Delta Q = \frac{K\beta_x}{4\pi}\frac{1}{d^2} \tag{3}$$

   - Calculate the nescessary corrector strengths
   - The dipolar contribution due to the wire is:

     $$\Delta y' = \frac{K}{d} \tag{4}$$

     where $K = -sign(q)\frac{\mu_0 l I}{2\pi B_d \rho}$
   - Calculate the nescessary corrector strengths
   - apply wire current change
   - apply the orbit correction
   - apply the tune correction
   - measure if the correction worked, if it did not correct

### 4.3 Wire position and current calibration

As the effective length of the wire (design: 2.5m) is not determined exactly, it is also necessary to calibrate the current.

1. Prepare the machine (see refsec:Preparethemachine).
2. Adjust beam wire (OFF) distance to $9.5\sigma_{lhc}$
3. For $I_w = 5$ to 125, steps: 20,do:
   - measure tune and orbits
   - compute tune shift and orbit distortion
   - compare with MAD

The closed orbit and tune shifts should be enough to detect a beam position offset

### 4.4 Measurement of the diffusion rate

**Scraper** : If a vertical scraper is available, investigate whether this measurement can be done and whether the displacement of the scraper is fast enough to allow an observation of the increase of losses. Investigate by how much the scraper has to be displaced (0.5 to 1 sigma?)

**Fast bump** : If a fast bumping method toward an aperture restriction would be available, one could bump the beam rather than move a scraper

## 5 Measurements at the end of physics runs

Checking the basic setup and do some “parasetic” experiments at the end of physics runs would be very interesting. This would allow to get the equipment set up for the dedicated days, allow to make experiments including HO collisions and one would profit from a well set up beam. In addition loosing the beam is no problem, as its getting dumped anyway.

## 6 Measurements

The following parameters can be changed:

**Wire current** I - to simulate a different number of long range interactions or different beam currents

**Beam-wire distance d** - to simulate the effect of different crossing angles or separation schemes

**Tune Q** - to find the optimal or bad one

**Other nonlinearities** - to see how the different perturbations interact

- Long range beam beam. - To try compensation
- Head on at other IP's. The combination causes a folding of the tune footprint and drives beam blow up at low amplitudes

The following sequence is proposed.

## 6.1 Dedicated MDs

At dedicated MD times we propose the following sequence of measurements

- Distance scan at 125 Am
- Distance scan at 125 Am at one other tune
- Compensation of 1 LR encounter
- Current scan at less separation
- Distance scan at 10 Am (corresponding to 1 long range encounter in LHC
- Current scan at $9.5\sigma$
- Current scan at $9.5\sigma$ at one other tune
- Distance scan at 125 Am at several other tunes
- If possible make Head-on collision at one Ip, Lr at the shifted IP6 and compensate by the wire

## 6.2 At the end of physics

- Distance scan at 125 Am with a HO
- Currentscan at $9.5\sigma$

### 6.3 Details on some measurements

#### 6.3.1 Distance scan

1. prepare the machine (see: 4.1
2. Switch ON wire at 125 Am
3. For a wire-beam separation $d_W = 12\sigma_{LHC}$ down to $3\sigma_{LHC}$ , step $1\sigma_{LHC}$ , do:
   - correct distortions (see: 4.2)
   - Record observables
4. When a marked degradation of the lifetime is observed, explore the vicinity of the transition with half steps. The separation at the transition is called $d_{Wt}$

#### 6.3.2 Compensation of 1 LR encounter

1. measure the uncompensated LRBB effect for different beam-beam separations
   - Move the strong beam to a given beam-beam separation
   - Correct orbit and tune
   - Measure observables
2. redo the same with the optimal wire compensation current

# 7 Open issues and questions

- Are the cases at the end of a physics run possible? Can the RHIC experiments live with the possibly occurring background spikes, so that one can even do some things overlapping? This would allow to get the equipment set up for the dedicated days, allow to make experiments including HO collisions and one would profit from a well set up beam.
- What orbit correctors are available? Which ones are close by? If possible some that are for both beams separately
- Is it possible to have 1 Lr at the shifted position and a head on at another IP?

- Are the BPM positions correct?
- Scraper - Is scraping and blowing up possible, Fast bump possible?
- Is it possible to do the experiments at the LHC tune? This would be optimal but as far as we know this is not the case. Then one will perform the experiments at the nominal ion tunes.
- Beam energy: injection is always easier but the very different behavior found at RHIC between injection and collision would favor selecting collision energy. Do we start with injection energy to debug all procedures and make a first measurement?
- List of operational equipment: Is there: Beam Transfer function, Schottky, ac dipole..?
- Is is possible to make the $\beta$-functions at the shifted LR-IP elliptic (same ration like at the wire location)
- Is it possible to change the $\sigma$ (e.g by scraping/blow up) in a clean way?

# 8 my issues

- J.P: "RHIC seems to use the tunes mirror-symmetric versus 0.5. What are the possible issues?" I don't know how to handle this point.
- Wolfram:"There is a feedback, but it is possibly excites the beam." Is it possible to turn it on just for the very short moment of the movement, gaining that we do not move around in the tune diagram, and one the movement is done, we turn it off again to see the lifetime only due to wire perturbations