Report of the

Wire-Based Beam-Beam Compensation Review

October 6, 2003

John Marriner, Chair, FNAL
Helen Edwards, FNAL
David Finley, FNAL
Jean-Pierre Koutchouk, CERN
Dan Wolff, FNAL
Frank Zimmermann, CERN

Comments

The committee was impressed with the work done in the last few months in preparation for this review. A substantial effort has been made in modeling the effects of fields generated by wires and calculating their effects on the beam. A number of characteristics of the beam have been calculated, but a particularly tantalizing result was the significant increase in the calculated dynamic aperture of a single antiproton bunch..

The work to date has been of an exploratory nature in a scenario of single wires placed at technically feasible machine positions. A detailed project with a clear strategy for the correction scheme, its operation and performance evaluation is not yet reached.

Recommendations

1. We recommend that wire based beam-beam compensation *not* be included as a formal Run II Upgrade task at this time.
    a. The goals and tasks of an R&D program can not be defined with enough precision to include them in a formal project structure
    b. It appears premature to begin work on any hardware (including an experimental version) until it is possible to state the experimental goals clearly.
2. We recommend further conceptual work on wire-based beam-beam compensation.
    a. We urge the Run II project management to encourage effort, monitor progress, and to set goals for the conceptual design study despite our recommendation that these efforts should remain off-project for now.
    b. An R&D task for wire-based beam-beam compensation should be added at a later time to the Run II upgrades if there appears to be a reasonable prospect for success with a plan of well-defined scope that can be carried out with the available resources.

c. Regardless of the outcome of the study of wire based beam-beam compensation, it seems likely that the study of this critical issue is useful for the insight that is likely to be developed.

3. We recommend that future conceptual work address be focused on the following issues:
    a. Specify the important Tevatron performance issues that could be addressed with non-linear magnetic fields such as those produced by wires.
    b. Consider the long-range beam-beam fields and the wire fields in a systematic fashion and show or suggest what the compensation is supposed to do at a fundamental level.
    c. Consider the conceptual design of possible hardware and examine basic feasibility.
    d. Consider the simplest proof-of-principle experiment that could realistically be performed in the 2004 to 2005 time scale.

    The above recommendation is rather vague, so we have tried to illustrate what we mean in a more detailed presentation below.
4. We recommend working in collaboration with CERN (possibly under the auspices of LARP) to take full advantage of both the theoretical and experimental work that they are doing and expect to do in the future. In particular, the CERN experiments seem to provide a good opportunity to obtain a benchmark for the calculational tools that are being developed.

Responses to Questions in the Charge

Is wire compensation of beam-beam effects potentially useful for increasing the luminosity?

For head-on collisions, the potential is huge, but the subject has a long history without much success. For long-range collisions, the field is rather new. The potential for increasing the peak luminosity seems moderate at the present performance level and could as well be promising for improving the lifetimeand backgrounds. Application to the Tevatron is challenging because of the helically separated orbits. A clearer understanding of the physics issues must be developed before an implementation can be contemplated.

How should the wire compensation complement the compensation with the Tevatron Electron Lens (TEL)?

As currently envisioned the TEL can provide bunch-by-bunch compensation for the linear part of the head-on beam-beam tune shift (although the beam can be shaped to provide some compensation for the non-linear part as well). The wire-based compensation is most effective for long-range interactions, and it provides the same field to all bunches. As such, the two techniques are properly considered to be complementary.

Are the right strategies being used for compensation?

In the sense that it is appropriate to pursue both the TEL and wire-based computation schemes, the answer is yes. However, we believe that the current approach suffers from too much reliance on numerical minimization, a process which may be difficult to understand and tune without some basic underlying understanding based on simple analytic considerations or qualitative arguments.

Is the engineering scope of the project well understood?

No, but we judge it likely that any design will probably be within the grasp of standard technology.

Should we proceed with an R&D project to build the system?

No, the concept and project goals need to be defined before an R&D project would make sense. We encourage further conceptual work at the theoretical level. We note that the situation could change dramatically in a few months at which point an experimental R&D program could be a crucial next step.

Suggestions for future work.

It is universally agreed that the application of wire-based beam-beam compensation to the Tevatron is complicated when compared to the LHC, where it *appears*, at least, to be relatively straight-forward. Given the high complexity, we suggest that it is important to try to develop a clear set of goals and simple models to explain how the system is supposed to work. The following is a list of suggestions we offer to guide future work. Our intent is to offer friendly advice (that should be critically evaluated) rather than to insist that we have really thought all this through carefully.

- We believe that a fundamental analysis of the beam-beam force that is being compensated should be provided. A baseline for comparison is the ideal (but unachievable) case where the long-range beam-beam collision is locally compensated by a wire of exactly the correct placement and current.
- A next step might be a study of the lumping requirements: what is the performance degradation when lumping the 72 correctors into a practical number of devices and wires placed at optimal positions? What is the further degradation when the positions are constrained? At this point ask whether multiple wires in a single device may be replaced by fewer plates of a larger cross-section which could be cooled by conduction. What is the additional loss in performance when the variation of the long-range force between different bunches is taken into account?
- A good starting point might be to adjust the strengths of the wires so that the long-range beam-beam tune shift and spread are cancelled on average.
- Another issue would be the strengths of resonances. Since the compensation is non-local, it is likely (inevitable?) that some resonance strengths would be increased. Certainly, one would like to evaluate (and

possibly) minimize the effect for resonances near the working point. We guess that resonances of order into the teens and twenties are probably important in store mode.
- The two above-mentioned steps would allow the evaluation of the results of numerical minimization strategies

- It is important to have a clear definition of the problem one is trying to solve. It seems that the wire-based scheme should be most effective in canceling long-range beam-beam interactions so one should try to make improvements in a situation where that effect is expected to dominate.
- One such effect is during the loading of the antiprotons. The effect is now noticeable, but became tolerable after tuning for a couple of years. The situation presumably deteriorates if we are ambitious enough to imagine increasing the proton bunch intensity by a significant amount. Could we compensate the increased long-range beam-beam force?
- Store mode is another possibility for a detailed investigation. Although the long-range beam-beam effect is not clearly dominant in this case, it may play a role and any relief from the problems of beam loss, beam lifetime, and emittance growth would be most welcome. In particular, one goal might be to increase the antiproton bunch intensity (six-fold, for example) without increasing the proton losses.
- Perhaps it would be useful to focus efforts of compensation of particular crossings that have large or dominant effects (perhaps those around the IR's are more serious).
- We do not believe that manipulating orbit separation with the non-linear fields produced by the wires is likely to be a useful technique. If non-linear fields were useful for this purpose (and we have our doubts), the existing superconducting octupoles would probably be better suited.
- Finally, we would point out that non-linear fields add non-linearly and that care should be exercised in attributing a phenomena to head-on beam-beam effects or long-range effects or non-linearities in the lattice. In reality, it may require a combination of forces to provoke undesirable beam behaviors and correcting the long-range part of the beam-beam force might result in some pleasant surprises.

- Machine performance can be characterized in many ways and it is useful to consider the problem from several points of view. However, we would recommend that studies focus on improving the dynamic aperture. We believe that the dynamic aperture is an important quantity and is related to other quantities of interest, such as beam loss. Of course, it will be necessary to simulate all the bunches in both beams while making realistic variations in the input parameters.

- Try to develop a simple model of how the compensation should work. If the compensation works as the result of a sophisticated minimization procedure in the computer model, one needs to understand how a similar

tuning process can be accomplished on the actual machine given a limited amount of time for tuning.

- Once the conceptual design principles have been established it will be time to bring in more people with practical experience to help reduce the concept to a practical system.

Management & Strategy Issues

We believe that people now working on wire-based beam compensation should be encouraged to bring this work to a practical conclusion in a time consistent with the RunII schedule by establishing some future goals and encouraging presentation of the results in a public forum or review.

We believe that the concept is of sufficient general interest to the physics of colliding beam accelerators that it should be pursued even if it does not seem to meet the Run II schedule.

The Tevatron Department role in the R&D phase should increase significantly if the further study indicates promise for the Tevatron.

Appendix

Wire-based Beam-Beam Compensation Review

Committee Report

Meeting: Monday, October 6, 2003, 8:30 - 16:00 hrs
8:15 - 11:30 The West Wing (WH10NW); 13:30 - 16:00 One East (WH1E)
(8:15 - 8:30 Committee Executive Session
8:30 - 11:30 Presentations
13:30 - 14:30 Q&A; Discussions (contd.)
14:30 - 15:30 Committee Executive Session
15:30 - 16:00 Closeout)
Note: Video-conferencing with CERN (morning session)

Goal:

Review the potential benefits of wire-based beam-beam compensation, assess status of studies and make decision on initiating R&D, with the expectation that the R&D would be further reviewed before a decision on a production system is made.
WBS 1.3.4.3.2.3 Scope review: Decision to proceed with wire station prototyping, based on modeling of beam-beam compensation

Review Committee Membership:

John Marriner (Chair)

Jean-Pierre Koutchouk (CERN)

Frank Zimmermann (CERN, by video)

Helen Edwards

David Finley

Dan Wolff

Charge:

Address the potential benefits of a wire-based system for active beam-beam compensation in the Tevatron and assess its role in the context of the Tevatron Electron Lens. Review status and adequacy of the studies carried out so far.

Provide guidance on the following specific issues:

- Is wire compensation of beam-beam effects potentially useful for increasing the luminosity?
- How should the wire compensation complement the compensation with the Tevatron Electron Lens (TEL)?
- Are the right strategies being used for compensation?
- Is the engineering scope of the project well understood?
- Should we proceed with an R&D project to build the system?

The committee should provide a preliminary assessment at the closeout meeting.

A final written report should be produced within a week of the review.

Agenda

Introduction and Charge - P. Bhat (5 min.)

Overview of beam-beam phenomena in the Tevatron - V. Shiltsev (30 min.)

Overview of wire compensation - T. Sen (30 min.)

Wire compensation studies - B. Erdelyi (45 min.)

Engineering aspects of a wire compensator - J. Kerby (15 min.)

Wire compensation experiments at CERN - J.P. Koutchouk (30 min.)

Documents:

http://www-bdnew.fnal.gov/run2upgrade/reviews/Tev_wire_BBC/

Project Personnel:

T. Sen (Project Manager)
B. Erdelyi (Studies)
J. Kerby (Engineering)

Contact: Pushpa Bhat
