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Fixed Target Issues for the TEVATRON Upgrade*

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Abstract

The Tevatron Upgrade poses some interesting prospects for the Fixed-Target program if an option to extract the high energy proton beam is preserved. This paper presents a summary of the advantages of increased energy for fixed target experiments, and evaluates some of the more challenging technical issues. In particular, Bottom production, muon and neutrino interactions, and polarized $\bar{p}$ experiments would benefit substantially from a higher energy primary beam. The new Main Injector will also be important for fixed target experiments as a source for test beams and intense kaon and neutrino beams.

Introduction

In order to extend the physics reach of collider detectors at Fermilab, a machine upgrade will be required after 1993 [1] [2] [3]. The upgrade may take any one of several forms, including an increase in energy to about two TeV or a conversion to a p-p collider configuration. This article will concentrate on the issues that will pertain to a fixed target program if the accelerator upgrade includes the option of an increase in energy to two TeV. It should be noted first that the highest energy beam that could be extracted to the fixed target areas will be limited by length of straight sections available for extraction, maximum fields attainable in extraction magnets, and available Switchyard geometry, and is likely to be no more than 1.5 TeV [1]. To be conservative, in this article we will calculate yields for primary beam energies up to 1.4 TeV.

An energy upgrade for the fixed target areas must be based on new physics that would be achieved with higher energy. The last fixed target energy upgrade, Tevatron II, cost nearly $50 million and established four new major experimental halls. That upgrade also made 800 GeV primary beam available to all experiments in the fixed target areas. The physics results from Tevatron II are not yet complete, but already we have impressive inroads established in charm physics, the resolution of discrepancies in neutrino interactions, new measurements in sigma beta decay, new measurements in CP violation, and much more. What could we expect from an additional increase in primary energy?

The new physics that might be achieved in an energy upgrade would depend on the scope of the upgrade. We could imagine construction of new facilities and the upgrade of beam energy for existing experiments. However, the complexity of the present system of extracted beamlines does not easily permit the addition of new facilities except where they would replace an existing facility. The addition of new beamlines would merely reduce the operating efficiency of the program. In this regard a new energy upgrade in the fixed target program would differ markedly from Tevatron II, which included a distinct expansion of facilities.

Test Beams

We must also consider the likely future demand of the fixed target areas for test beams for collider detectors. This demand may increase in the 1990's until beam is available at the SSC site. These test beam facilities would be capable of delivering higher energy to the user if an energy upgrade were to take place, and might more nearly approximate the facilities planned for the SSC where energy of up to one TeV will be available for test beams. However, of greater importance for test beams would be to achieve reliable and stable operation of accelerator and beamlines. Also of greater significance is the need for test beams to be available throughout the calender year. Very often no test beam facilities are available anywhere when the Tevatron operates in a collider mode. For these purposes it would be a great benefit to the entire ex-

*Submitted to Snowmass 1988
[1] Communication from Sam Childress.

perimental community if primary beam of 100 GeV or more were available for test beams somewhere at Fermilab at all times. It would be of even greater benefit if such beams could be available to the existing fixed target areas at all times.

The fixed target program would use a low energy primary beam not only to provide test beams but to test and calibrate experiments in preparation for the start of a run. It is estimated that the availability of low energy beams before the start of a fixed target run could save two months of setup time for many experiments. Given the fact that fixed target experiments receive an average of six months of beam every two years, the increment in efficient use of running time would be very significant for the fixed target program.

Experiments

Aside from the role the fixed target program must play in providing test beams, an increase in primary energy implies an extension of physics for many of the experiments. A list of advantages of 1.4 TeV can be viewed as follows:

For beams that operate at x_F[2] greater than 0.6 we will be able to produce much more intense beams if higher energy primaries are available. For example, the NM muon beam flux could be increased by nearly an order of magnitude at 550 GeV if 1.4 TeV protons were available[3]. See Table 1 for comparable rates for experiments in the high energy pion beams.

The physics potential of experiments that look at Bottom production by machine energy protons will also be improved by an energy increase. The production of Bottom might increase by as much as a factor of 3.5 for E-771, because of the increase in production cross-section, and the "folding-forward" of the produced B's to better match the spectrometer acceptance [4]. Similar increase in rates would be achieved in E-690, P-789 and for the anticipated proton beam run for E-706/672. For comparison, the increase in Bottom production for these experiments in raising the primary beam energy from 800 to 900 GeV would be about 40%.

The increase in production of Bottom in photon beams may be even more dramatic, because the production cross-section rises very rapidly at current energies, and the photon flux is also a strong function of primary beam energy. E-687 should see an increase of factor of seven in Bottom production at 1400 GeV[5]. Similarly, Bottom production by pion beams, as might be carried out by E-706, would increase by a factor of 6.5 due to higher beam flux and increased production cross section. See Table 2.

For experiments that rely on the identification of jet structure in nucleon interactions, such as E-706 and E-683, the produced jets would be more energetic and therefore easier to identify. This qualitative feature could be important for experiments like E-706 and E-683.

A proposal for a Tagged Neutrino Facility is being evaluated for the fixed target program at the present time. This facility would replace the old neutrino beam, and would be built to study neutrino oscillations and to extend current measurements in neutrino interactions. The capability of this type of beam would benefit considerably from an energy upgrade: There would be twice as many neutrino interactions for each tagged kaon. (Although the tag might be more difficult because of the higher energies involved.) The conventional neutrino physics would also benefit because the neutrino interaction cross-section increases linearly with energy. It should be mentioned, however, that a certain class of neutrino interactions would benefit most from an intense neutrino source as might become available when the new Main Injector is built. For example, the search for neutrino oscillations in the mode $\nu_\tau \rightarrow \nu_\mu$ could be carried out at a new experimental area built to accept beam from the 100 GeV injector. The proposed extraction frequency of 0.5 Herz at $> 10^{13}$ protons per cycle for 150GeV[6] could supply beam for a powerful new neutrino facility.

The potential for physics of an intense kaon source is being evaluated for Fermilab. Neutral kaon beams do not benefit greatly from an increase in available primary energy. As can be seen from Table 1, one can anticipate a 70% increase in K^0 flux[7] at 1.4 TeV. Much more promising for a kaon factory would be a facility that could extract 100 GeV primary beam from a new Main Injector to a new targeting area. Such a facility could improve the potential statistics of experiments such as E-731 and E-773 by up to three orders of magnitude.

The effects of higher primary energy on hyperon experiments are complex and not always advantageous. For experiments dealing with polarized hyperons, the increased production at say 350 GeV by 1.4 TeV protons is greatly offset by the fact that hyperons are not polarized when produced at low x_F [8]. Furthermore,

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[2] x_F is used to indicate the ratio between secondary and primary energy.

[3] Estimate by Jorge Morfin.

[4] Estimate by Brad Cox.

[5] Estimate by Peter Garbincius

[6] Communication with Steve Holmes

[7] Estimate by G. Bock.

[8] Based on a discussion with G. Rameika.

Table 1: Particle Yields vs Primary Energy[10]

Exp. Number	Secondary Beam Energy GeV	Relative Particle Yields 900 vs 800 GeV	1400 vs 800 GeV
E-773	100 K^0	1.1	1.7
E-704	200 $\bar{p}\uparrow$	1.4	2.2
E-687	350 e^-	1.6	4.7
E-791	500 π^-	2.0	9
E-706	530 π^-	2.3	12
E-665	550 μ^+	1.6	8

pion backgrounds tend to be enhanced by high energy production. Polarized hyperon experiments would have to be carried out at higher x_F, or a secondary energy of 700 GeV or more. This would require a completely reconfigured apparatus, particle identification at higher energy, and higher spatial resolution to measure smaller decay angles. The availability of high energy protons may be important for Ω^- production in which the relative yield at 350 GeV might be a factor of four higher for 1.4 TeV production.

Related to hyperon production is the polarized proton experiment E-704. Proton polarization is determined by the decay asymmetry of the parent Λ^0, and as such is not dependant on the production mechanism of the parent beam. A polarized proton beam at 200 GeV could therefore be produced by 1.4 TeV primaries, but the gain in yield for this low energy beam would be on the order of 10% over production at 800 GeV. A much more crucial factor for the polarized proton experiments is the gain in $\bar{p}$ production which is predicted to be a factor of 2.2 increase over 800 GeV production[9].(See Table 1.)

This discussion of particle production and yield for the variety of experiments currently operating or planned for the fixed-target program does not consider the ability of the experiments to respond to the increase in flux. As an example, the estimate that the muon beam could yield a factor of eight increase in flux with 1.4 TeV on target, implies that the detector (E-665) will take data eight times faster to take advantage of this increase in flux. This implies that an upgrade in the detector and data acquisition system might be required to take full advantage of the energy upgrade for this experiment. Similarly, other detectors might require improvements to take advantage of the anticipated increase in data collection rates.

Table 2: Relative Bottom Production Rates

Exp. Number	Secondary Beam Energy[11]	Relative Rates 900 vs 800 GeV	1400 vs 800 GeV
E-706	530, 610, 925 π^-	1.6	6.5
E-687	225, 265, 395 γ	1.8	7

Technical Issues

So it is that one can see substantial benefits for many fixed target experiments in an energy upgrade. However, there are some technical issues that must be considered before an energy upgrade could be fully implemented. The problems associated with primary beam transport in the Switchyard have been evaluated by Childress[12]. Similar issues must also be addressed in the transport system from the Switchyard to the experimental area targets. Namely, all of the cryogenic bend strings would have to be replaced with the high field magnets, all of the conventional bends would have to be replaced with cryogenic magnets, and the targeting quads would require that additional magnets be added. This implies an increased reliance on cryogenic personnel to operate the beamlines. Furthermore, some civil construction would be needed to maintain the splitting stations in the NEast and PEast beams.

Aside from these issues of beam optics, the second technical issue would be the target piles. In the target piles the primary beam in separated from the secondary beam by passing through a string of bending magnets. The primary beam then enters a dump, while the secondary beam passes along side of the dump. Because this is a high radiation area, the bend magnets in the pile cannot be replaced by cryogenic magnets. To provide for a dumping scheme at energies above one TeV, the target piles would be lengthened. This involves civil construction, and modification of the primary and secondary beam optics. There are eight target piles in the fixed target

[9]Estimates made by Dave Carey

[10]Based on reference [4], and estimates by Bock, Garbincius and Rameika.

[11]Secondary beam energy for 800, 900, and 1400 GeV primary beam respectively.

[12]Presentation at Snowmass 1988.

areas, and they are MWest, MCenter, MP, NMuon, PWest, PCenter, PEast, and PB. Notable exceptions are those beams that transport machine energy protons directly to the experiment: Namely, MEast, NEast, PWest, and MWest when running in the primary beam mode.

The target pile problem may not be serious for most applications, because it is critical only for positive secondary beams that must target at zero degrees. Any secondary beam can operate as a negative beam with 1.4 TeV targeting and a positive beam can operate with targeting angles greater than one milliradian with no target pile modifications [13]. Roughly speaking, this implies that positive beams would be limited to operating at 50% of their peak intensity at 300 GeV, and 25% of peak intensity at 600 GeV. The NM muon beam, for example, would gain a factor of two in μ^+ yield at the experiment if the target pile were not modified, whereas operating at zero degrees, which would require a target pile modification, would increase the interaction rate by 8 at 550 GeV. (See Table 1.) The NM beam is an interesting example because the FODO channel could be easily modified to operate at 1.2 TeV. The increase in beam energy is important for muon experiments to measure structure functions at high q^2 and the wee x region. The inclination in the muon beam would therefore be toward a full scale energy upgrade with modifications to the target pile to permit zero degree targeting, if only to take advantage of the existing capability of the FODO channel.

A third technical issue that must be addressed concerns muon shielding[14] . To account for the increase in radiation due to muons created by dumping 1.4 TeV protons would require the addition of earth berms of about one kilometer in length or the addition of magnetic shielding. In the NM muon beam, for example, the intensity of the muon beam that reaches the site boundary is controlled by a vertical bend located at the downstream end of the Muon Lab. To accommodate the higher primary energy, this bend string would be doubled in length, a relatively minor modification. For beamlines that are located underground, such as those in the Proton Area, the increase muon energy should not a problem, since the muons will simply range out in the earth. However, care is required to locate depressions and valleys and to account for muons punching through due to the earth's curvature. The Neutrino beam already has a substantial berm that is adequate for personnel shielding, and as such the NWest beam that operates parasitically off the Neutrino primary beam could operate with no modifications. New neutrino experiments that might try to operate in the higher energy beam may well require modification to the berm, perhaps by adding steel shielding. The muon shielding problem is most serious in the NEast beam and in all of the Meson Area beams; That is, in beamlines that are located above ground and are thinly shielded. The modifications for these beams might require halo spoilers along the beam and vertical sweeping magnets at the end of the beamline. The design of adequate muon shielding for these beamlines could be a difficult and expensive problem.

A fourth technical issue involves the problem of upgrading secondary beam energy and will be limited by the fact that the target position and the experiment must remain fixed. These beam energies can be increased by the addition of magnets, and in some cases, with some civil construction. Schemes for energy upgrades already exist for PWest, PEast, and NEast. Secondary beam upgrades will be more difficult for those beams that require the construction of a new target pile.

[13] From a discussion with R. Tokarek. For example, in the MWest target pile we could target 1.2 TeV at zero degrees with no modifications. The installed magnet strength already has this capability.

[14] Based on a discussion with Don Cossairt.

Conclusion

Summing it all up, an energy upgrade in the fixed target areas could have substantial benefits for many experiments. Bottom physics, muon interactions, neutrino physics, and polarized $\overline{p}$ experiments could see substantial gains in physics opportunities. A great deal could also be achieved if the new Main Injector could provide protons of 100 GeV or so for test beams, to calibrate fixed target detectors, and for intense new kaon and neutrino beams. The cost of an upgrade could be substantial, especially if the scope includes raising primary and secondary beam energies for all existing facilities. In particular, the increased dependance on cryogenic magnets would require a substantial increase in support personnel to implement and maintain the beamlines.

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