A Tevatron Based Program at Fermilab

Names

Abstract: This document describes the physics potential of a Fixed Target program based on a 1 TeV proton source. Two sources may be: the existing Tevatron at Fermilab and a posssible upgrade to the SPS at CERN, called SPS+. The possible Fixed Target beams which can be provided are described. The goals and tentative layout of some experiments which could run in such a program are considered. The physics which is highlighted are examples which are either unique to the program, or difficult to accomplish at other venues. From this one can see that these experiments represent opportunities complementary to the ongoing program

1 Introduction

This describes the motivation – why do we need such a program? How does it complement the existing program? How does it compete? There is a good chance this will not run until 2015, so we need to address that the physics will be relevant then.

2 Accelerators which can Provide TeV Beams

The Tevatron is an existence proof. Building a program off of it is the least expensive and fastest way to move forward. Timescale for installing fixed target extrction is approximately 2012.

The SPS+, which upgrades the SPS to 1 TeV, is an interesting alternative option. However, if motivation for upgrades is provided by LHC first results, then this is likely to move forward. The timescale for decision is 2012.

2.1 Running Fixed Target from the Tevatron

Previous 800 GeV fixed target operation of the Tevatron ran with a maximum throughput of roughly 25-28 $\times 10^{12}$ protons (25-28 Tp) per pulse every 60 sec with a duty cycle of roughly 33-40%. The beam was shared, over a 20-23 sec flat-top period, between slow spill experiments and neutrino experiments which required fast extracted beams. To meet the demands of NuSOnG, the facility needs to be able to deliver approximately 2×10^{20} protons on target over five years of running at 66% overall operation efficiency per year. This translates to an average particle delivery rate during running of about 1.8 Tp/sec. Assuming that only a 40 second ramp will be required for NuSOnG, then each ramping of the Tevatron would need to deliver about 75 Tp, more than 2.5 times the previous record intensity. The subsections below address some of the major issues regarding re-institution of a Tevatron fixed target program, and issues associated with meeting the above intensity demand.

2.1.1 Magnet Ramping

The original Tevatron fixed target program ran at 800 GeV, and stress and strain on the superconducting magnets was a major issue early in the program. Issues with lead restraints within the cryostat were eventually identified and all dipole magnets were repaired in the tunnel in the late 1980's. Since that time, the Tevatron has been able to average over 250,000 cycles between failures of dipole magnets [**?**]. This "rate" includes failures of Collider-specific magnets, such as low-beta quadrupoles. Note that a neutrino program which demands 2×10^{20} POT, using a synchrotron that delivers 75 Tp every cycle, requires about 2.7 million cycles – thus, on the order of 10 failures could be expected during the course of the experiment.

Once the fixed target operation was halted, and only Collider operation was foreseen, the capability to repair and rebuild Tevatron magnets was greatly reduced at the laboratory. However, assuming no need for building new magnets from scratch, capabilities still exist to perform repairs and, along with the given inventory of spare Tevatron magnets and corrector packages, a multi-year fixed target operation consistent with the above is sustainable from this aspect [**?**].

Ramp rate studies of Tevatron dipole magnets have been performed, and rates of 200-300 A/sec can be maintained at 4.6° K without quenching [**?**]. The current power supply system can still perform at this level. To increase reliability, however, some PS system components may need to be upgraded. Additionally, the Tevatron RF system is still capable of running in the fixed target state, though beam loading effects and appropriate compensation will need to be investigated for the anticipated higher intensity operation. Two Main Injector pulses would be used to fill the Tevatron. At 3 sec per 150 GeV MI cycle, this constitutes a 15% impact on other MI demands.

2.1.2 Comments on High intensity

The record intensity extracted from the Tevatron in a cycle at 800 GeV was almost 30 Tp, in 1997, though 20-25 Tp was far more typical. At that time, the bunch length during acceleration would shrink to the point where a longitudinal instability at higher energies ($\sim$600 GeV), resulting in aborts and sometimes quenches. This was compensated as well as possible with "bunch spreading" techniques (blowing up the emittance via RF noise sources). Today, the Main Injector is capable of providing greater than 40 Tp per pulse, which could, in principle, fill the Tevatron to 80 Tp. Many improvements to the Tevatron beam impedance have been made during Run II, including, for example, reduction of the Lambertson magnet transverse impedances which were identified as major sources. Additionally, advances in RF techniques/technology and damper systems, *etc.*, may allow, with enough studies and money, much better compensation of these effects, if required. This is a primary R&D point, if intensities near 75 Tp are to be realized in the Tevatron.

2.1.3 Re-commissioning of Extraction System

Returning the Tevatron to fixed target operation would require the re-installation of the extraction channel in the A0 straight section from which beam would be transported to the existing Switchyard area and on to the experimental target station. The electrostatic septa were located at the D0 straight section and could straightforwardly be reinstalled in the original configuration. All of this equipment is currently in storage and available for use. The B0 straight section, currently housing the CDF detector, would either be de-tuned, or perhaps replaced with standard long straight section optical components.

The other piece of hardware required is the slow-spill feedback system, referred to as "QXR" which employs fast air-core quadrupoles installed at warm straight sections in the Tevatron for fast feedback tune adjustment during the resonant extraction process. Again, this equipment mostly still exists, though it may be desirable to perform a low-cost upgrade to some electronic components.

The neutrino experiment being discussed has requested "pinged" beam, short bursts of particles brought about by the QXR system. NuSOnG will likely require tens of *pings* per cycle, during an assumed 1 sec flat-top. Resonant extraction is an inherently lossy process, on the scale of 1-2%, determined by the particle step size across the thin electrostatic septum wires. Historically, loss rates were tolerable with between 20-30 Tp extracted over 20 seconds. Extracting 2.5 times this amount in 1/20-*th* the amount of time without quenching the Tevatron will need further study, thought should be feasible. Alternative methods for fast extraction could be contemplated, though perhaps at a price. For instance, if an appropriate RF bunching scheme (using a 2.5 MHz RF system, for example) can be employed to prepare bunches spaced by 400 ns, then a fast kicker magnet system might be able to extract 50 such bunches one-by-one to the switchyard, a much cleaner extraction process. Spreading the beam across fewer, longer bunches may also help to mitigate coherent instability issues. This opens up another possible R&D point to pursue. To set the scale, the highest intensity extracted in a single pulse (*i.e.*, not during a slow spill) without quenching the Tevatron was about 10 Tp[**?**]. (Also, this was a test, not a normal operational procedure.)

The exact method used for 800 GeV operation would be a point closely negotiated between the laboratory and the experiment(s) using the beam. Both resonant extraction and kicker methods should be feasible within reasonable constraints.

2.1.4 Tevatron abort system

The abort system used during high intensity fixed target operation was located at C0 and was capable of delivering 1 TeV proton beams at 30 Tp, repeatedly every "several" seconds, to the abort dump. While not used in Collider operation, this beam dump and beam delivery equipment near the C0 straight section is still available and still accessible, and requires re-installation of extraction devices and their power supplies. The ultimate parameters of the neutrino experiment being discussed pushes the beam stored energy from about 3.5 MJ (27 Tp at 800 GeV) toward 10 MJ. The design limits of this system would need to be re-examined, and the implications and environmental impact of re-establishing this area as the primary abort must be looked at carefully.

2.2 The SPS+ Option

3 Extracted Beams

3.1 Slow-spill Beams

3.2 Neutrino Beams

A 1 TeV machine can create a unique ultra-high-energy neutrino facility. The facility would impinge protons on a target and a dump. This produces two beams which can run simultaneously. A very pure sign-selected ("SSQT") high energy ν_μ beam can be created. At the Tevatron a beam with 20 times the intensity of the previous NuTeV experiment can be produced. At SPS+ the rate will be **xxx** times the rate supplied to NuTeV. At the same time, using the beam dump, a flux enriched in ν_τs which are above charged current (CC) threshold can be produced. This is the only practical source of ν_τs above threshold, since long-baseline experiments, which produce ν_τs through oscillations, must run at low energies. We will assume that the relative ν_μ to ν_τ rate will be the same as was achieved by DONuT. The flux in one year of running will be greater than 150 times that of the previous DONuT Experiment, depending on the source. The flux distributions of DONuT and NuTeV are shown in Fig. 1, illustrating the unique energy and flavor distributions. The intensity goals, which are challenging, were developed in consultation with the Tevatron Department. Two public documents on this facility are available:
http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2222;
http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2849.
We estimate that the beams can be available by 2015.

The neutrino experiments will require a calibration beam for the detectors. This necessarily requires slow-spill on a regular basis and so the neutrino and slow-spill program would need to be run simultaneously.

Figure 1: Energy weighted fluxes for NuTeV (left) and DONuT (right)

4 Physics of a Slow-Spill Experimental Program

4.1 A Charm Mixing Experiment

4.2 A study of the HyperCP Anomaly'

5 Physics of a Neutrino Experimental Program

As a way to emphasize the discovery potential and the uniqueness of this program, note that the combination of experiments discussed below offers orders of magnitude more data across all neutrino species:

Neutrino Species	Reconstructed CC interactions	Tevatron Program Expectation	Tevatron Experiment
ν_e	$\sim$ 500k events [?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?]	$>$ 6M events	NuSOnG
ν_μ	$<$ 20M events [?, ?, ?, ?, ?, ?, ?, ?, ?]	$>$ 600M events	NuSOnG
ν_τ	10 events [?]	1000 to 1M events	see ν_τ expts. below

Table 1: In combination, the Tevatron Neutrino Program offer orders of magnitude more events than all existing experiments for all neutrino species.

With such large data samples, experiments can explore for processes which are within the Standard Model, but rare, or Beyond the Standard Model which have not been studied before.

5.1 NuSOnG

5.2 ν_τ Experiments

5.3 Searches for Exotic Neutrinos'

5.4 A Low Mass Detector for charm and oscillation studies

6 Tests of General Relativity in a TeV Circulating Beam

7 Conclusions

References