Tevatron End-of-Run Beam Experiments

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Contributors

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Introduction

- Over the course of the Tevatron Collider Run II, the accelerator program has seen a remarkable success. Many novel accelerator physics ideas were studied and applied at the collider as well as at other machines of the complex.

- During the last two years, the machine was operating in a stable configuration.
  - This gave the possibility to plan and carry out beam physics experiments for the benefit of future machines.
  - There was strong interest from CERN, BNL, LBNL to study a number of topics at Tevatron before it is switched off forever.

- This talk presents the highlights of the last year experiments, including
  - Collimation with bent crystals (T980)
  - Collimation with hollow electron beam lens (HEBC)
  - Beam-beam effects
Approach to Planning

- Many of the studies were performed parasitically during HEP operation or made use of 1-2 hour periods at the end of collider stores, thus minimizing impact on the integrated luminosity.

- The parasitic approach is best: experiments can be done as convenient, with plenty of time for set-up and analysis.
  - HEP experiments require stable beam conditions and were reluctant to allow in-store configuration changes. However, it was established that certain actions are safe.
  - A comprehensive set of tests was performed to establish the experimental procedure and demonstrate the experiment’s safety and ‘transparency’ for HEP operation.
  - Experiments with Tevatron Electron Lenses are a good example: an estimated 40 hours of tests with e- beam were done in 2009-10 with collider not in HEP mode.
Approach to Planning

- Studies that either required special beam conditions or were deemed unsafe for concurrent HEP, would be carried out in dedicated periods. In 2011, two two-week periods were allotted to:
  - Collimation with bent crystals and hollow electron beam. May 15 to May 27. Used 34 hours for T980 and 7 hours for HEBC.
  - Beam-beam studies. Aug. 15 to Aug. 29. Used 43 hours.

- During the two-week periods, special studies would interleave with collider stores.
  - Lumping studies in a compact period makes it convenient for planning, especially when experts from other laboratories are involved.
  - Interleaving with collider stores allows for data analysis and/or modifications to the experimental set-up in between the studies. This also makes it possible to schedule experiments at convenient time.
Collimation with Bent Crystal

Amorphous target $\theta = 17 \, \mu\text{rad}$ (rms)

Crystal deflection $\theta = 50\text{--}200 \, \mu\text{rad}$

Layout of Tevatron Experiment
D. Still

Ray Fliller- Halo 03

Pin diode Detector (LE0PIN)
Scintillator (T:CCLTOT)
Scintillator Detectors (T:E1LTOT)

D49 tungsten target
Vertical Goniometer
Horizontal Goniometer
2 Plane Pixel Detector
Secondary Collimator E03
BLM (LE033)
Synergy with detector R&D – used CMS pixel detector.
Crystal Collimation Results

- Observed channeling of circulating Tevatron beam halo.
- Characterized a number of crystals.
- Demonstrated that Pixel Detector is a good tool for evaluation of crystals as collimation targets.
- Attempted two-plane collimation
- Experiments will continue at LHC

T980 Results
D. Still et al. MOPPD082

Movie courtesy D. Mirarchi (CERN)
Collimation with Hollow e⁻ Beams

- Compared to the conventional collimators, HEBC offers some advantages
  - Can be much closer to the main beam (no material damage, low impedance)
  - Tunable strength (‘soft’ collimator, $\theta=0.2\mu$rad), no mechanical moving parts

V. Shiltsev, Proc. 3rd CARE-HHH-APD Workshop (LHC- LUMI-06)
Antiproton collimators:

Primary (F49)

Secondary (F48)

Secondary (D17)

Tevatron electron lens


A. Valishev, Tevatron Beam Physics
Collimation with Hollow $e^-$ Beams

- Demonstrated that HEBC does not affect the circulating beam core
- Observed suppression of loss spikes due to low frequency beam jitter and hard collimator movement
- Measured diffusion coefficient vs. amplitude with and without HEBC
- Test at the LHC is under consideration

G. Stancari et al., IPAC11

A. Valishev, Tevatron Beam Physics
List of topics

- **AC dipole with colliding beams**
  - AC dipole is a device that adiabatically excites transverse oscillations of the beam. Turn-by-turn detection of these oscillations allows to restore the beam optics. It is the method currently in use at the LHC.

- **Effect of Beam-Beam interaction on coherent stability**
  - Colliding beams represent a system of coupled oscillators with their eigen-frequencies determined by beam and machine properties. Also, coherent instabilities driven by machine impedance are affected by the nonlinearity of beam-beam interaction.

- **Beam-Beam resonances vs. transverse separation**

- **Effect of bunch length to beta-function ratio (betatron phase averaging)**
AC Dipole with Beam-Beam

- The goal was to excite the “weak” beam through the strong beam using the AC-dipole
- We had to reverse the weak-strong set-up since the BPM system operates in a turn-by-turn mode for protons only - use lowest possible proton intensity against nominal low emittance pbars
- Record the turn-by-turn BPM data around the ring
- Changes to the linear lattice function due to BB can be derived from a reference measurement with protons only

- Successfully demonstrated the technique with colliding beams (3x3 bunches in collision configuration)! No instability or emittance growth after multiple excitations.

- Difficulties
  - “Strong” antiproton beam is also excited.
  - Coupling was strong.
  - Weak proton beam => BPM noise worse than usual.
Beta-Beating with Beam-Beam

- Expected
- $1\sigma$ Kick
- $2\sigma$ Kick

Relative difference between $1\sigma$ and $2\sigma$ kick
The threshold betatron tune chromaticity was studied as a function of beam-beam interaction.

Nominally Tevatron operated at $C=+14$ without collisions and +5 at collisions.

It was observed that for the nominal bunch intensity the instability is very fast slightly above $C=0$, causing a quench.

During the studies it was verified that whenever beam-beam interaction is present, any chromaticity value can be dialed in without causing the head-tail instability.

The effect was independent of the tune working point.

**Difficulties**

- Studies of the effect of beam brightness were not performed due to unavailable bright antiprotons.
- Instrumentation did not acquire quantitative data on the instability increment.
Effect of Transverse Separation

- Transverse separation scans were performed both in the horizontal and vertical plane.
- Emittance growth was not observed during the scans.
- Losses peak at the transverse separation of 1 to 1.5$\sigma$, consistent with simulations.
- The effect is working point-dependent
Effect of $\beta^*/\sigma_z$

- The goal was to collide bunches at different bunch length/beta* ratios
- This was achieved by cogging (moving antiproton bunches longitudinally wrt protons, thus colliding off beta minimum)
- Produced excellent data, in qualitative agreement with expectations! Good for benchmarking simulations.
The Tevatron collider accelerator physics program culminated with several dedicated experiments on topics of interest for the future machines.

The studies were successful in many aspects, in particular they:

- Made maximum use of parasitic mode, simultaneous with the luminosity production, or utilized end-of-store periods with low luminosity.
- Provided foundation for collaboration between experts from many laboratories worldwide, and produced data for quality scientific publications and theses.
- Established viability of novel accelerator physics concepts, such as the bent crystal and hollow electron beam collimators, with potential application at the LHC

Carefully planned beam physics experiments give highly valuable return for the relatively small investment in the accelerator time.