Tevatron End-of-Run Beam Experiments

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Contributors

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IPAC12, New Orleans LA

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

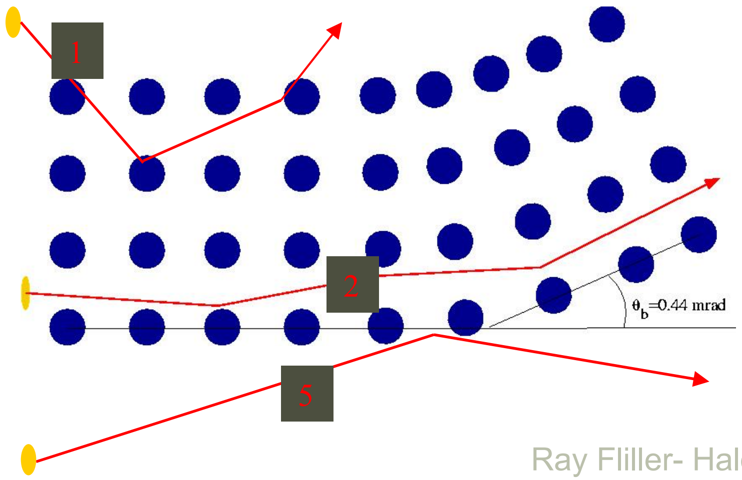
- Many of the studies were performed parasitically during HEP operation or made use of 1-2 hour periods at the end of collider stores, thus minimizing impact on the integrated luminosity.

- 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. May15 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.

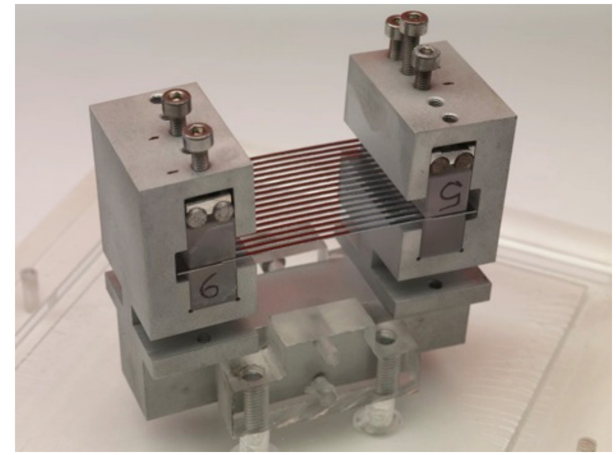
Collimation with Bent Crystal



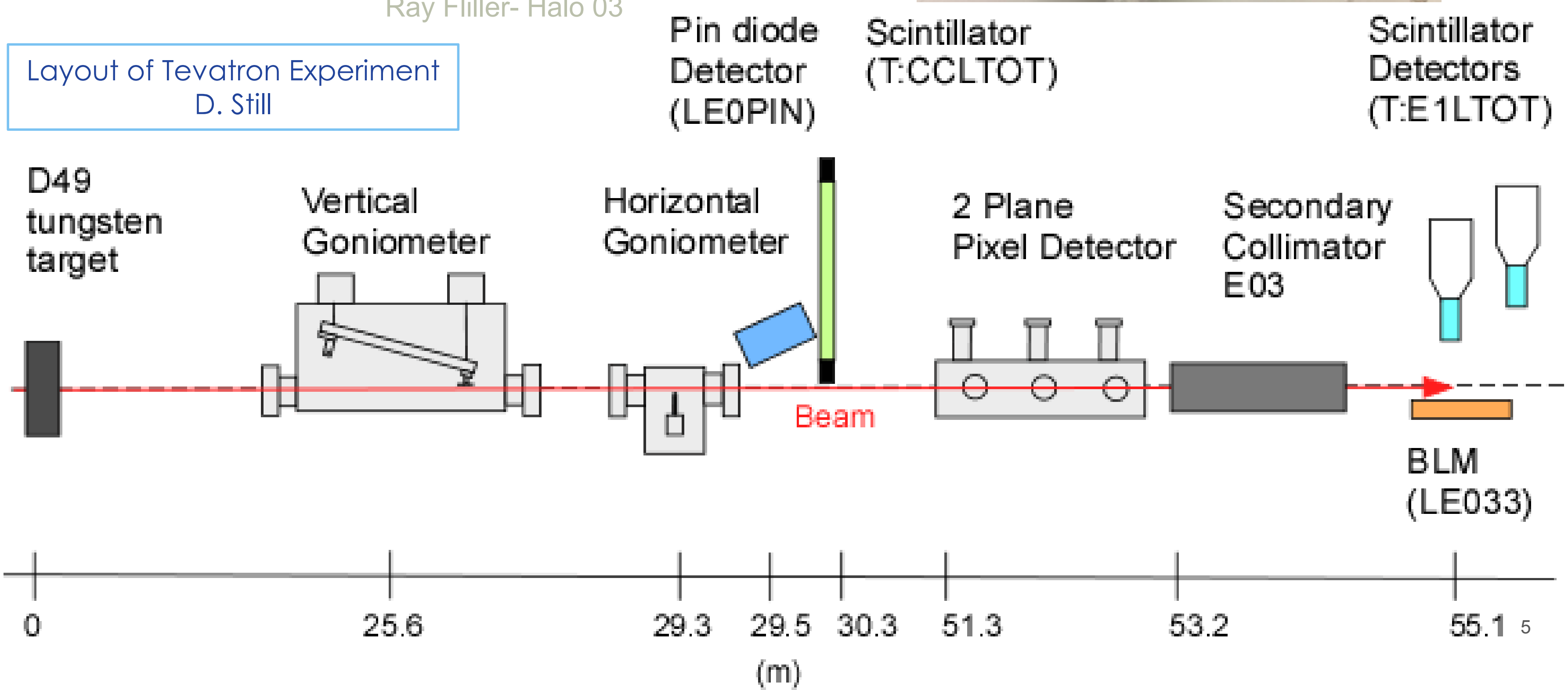
Ray Fliller- Halo 03

Amorphous target
θ=17μrad (rms)

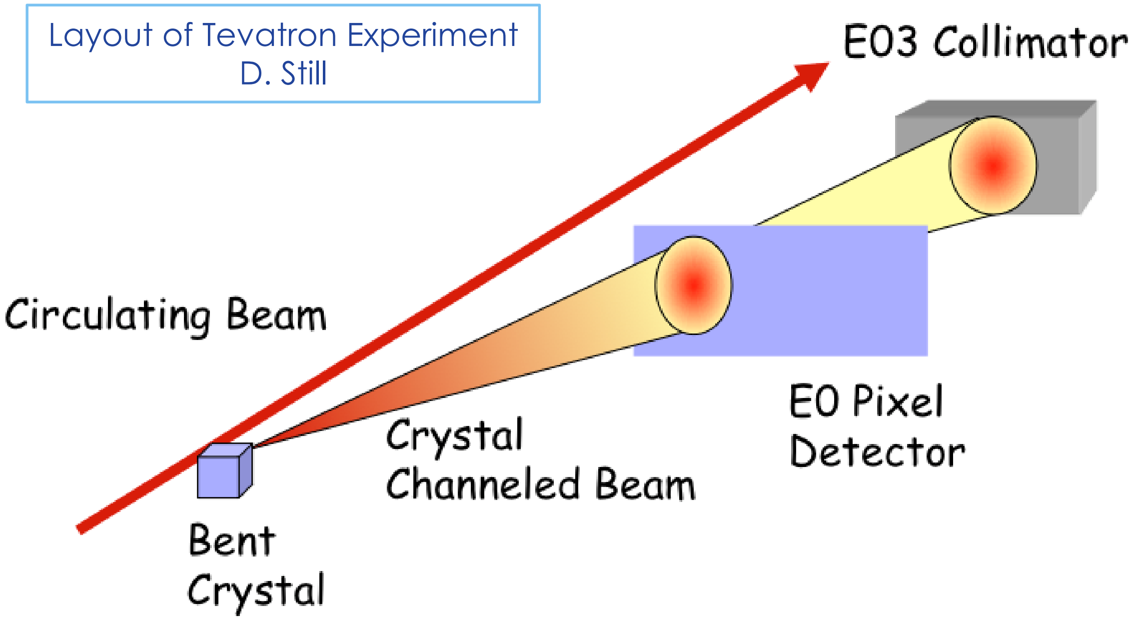
Crystal deflection
θ=50-200 μrad

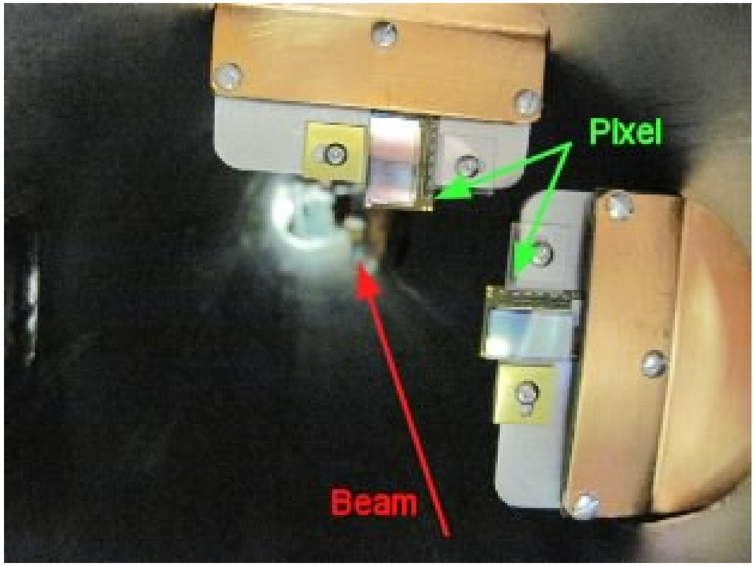


Layout of Tevatron Experiment
D. Still



Tevatron Experiment Set-up



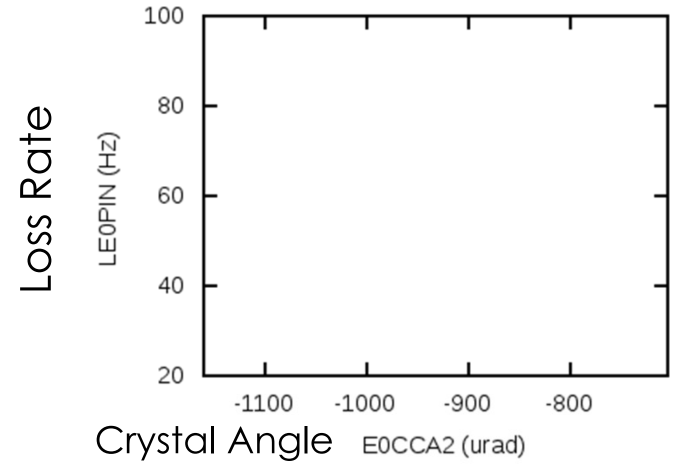


- Synergy with detector R&D – used CMS pixel detector.

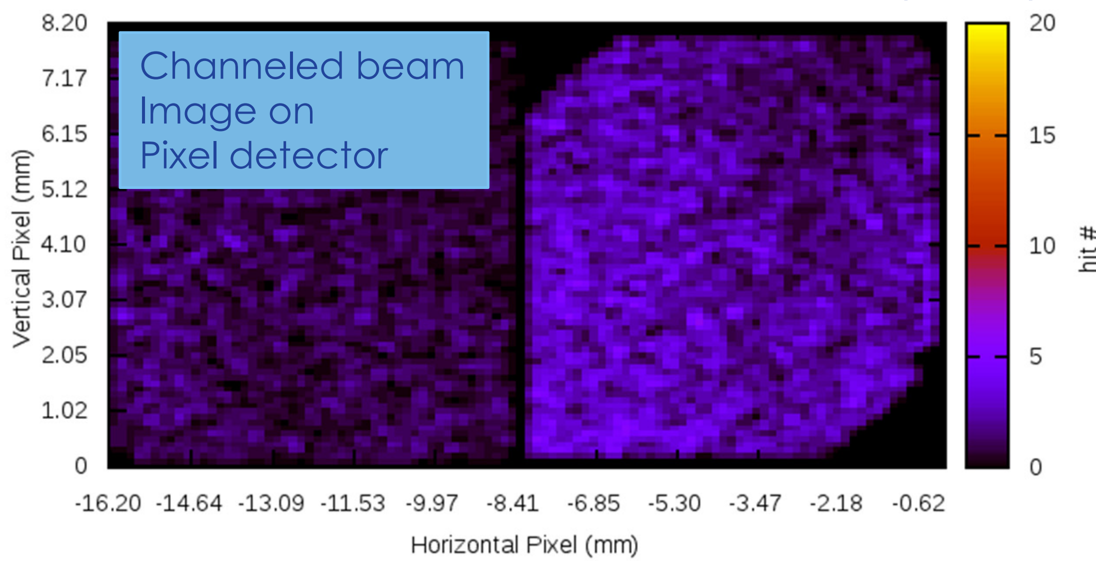
Crystal Collimation Results

T980 Results
D. Still et al. MOPPD082

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

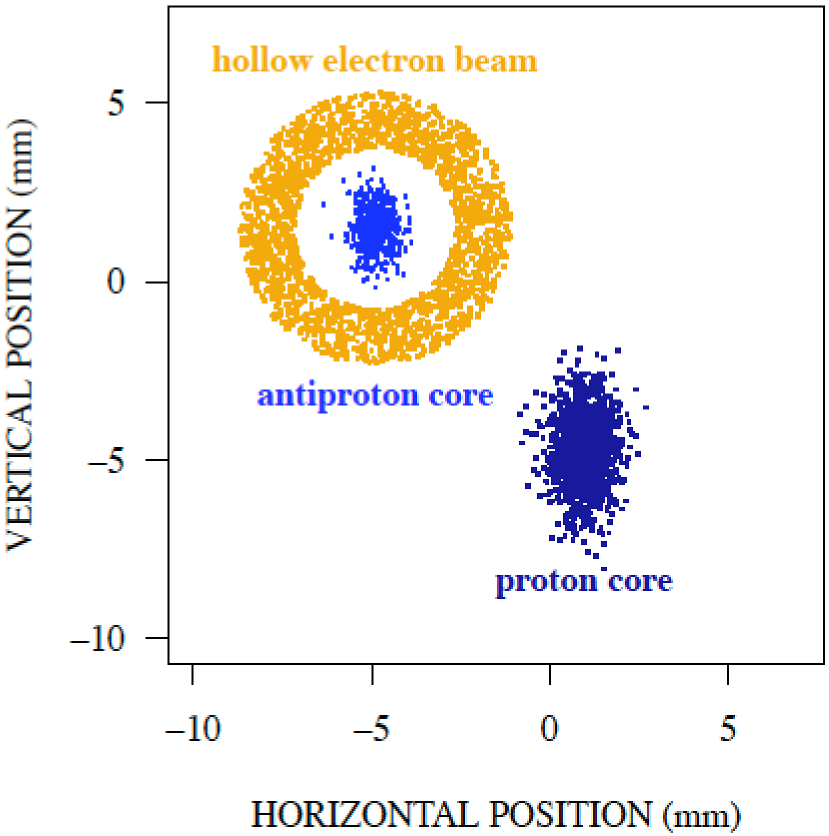


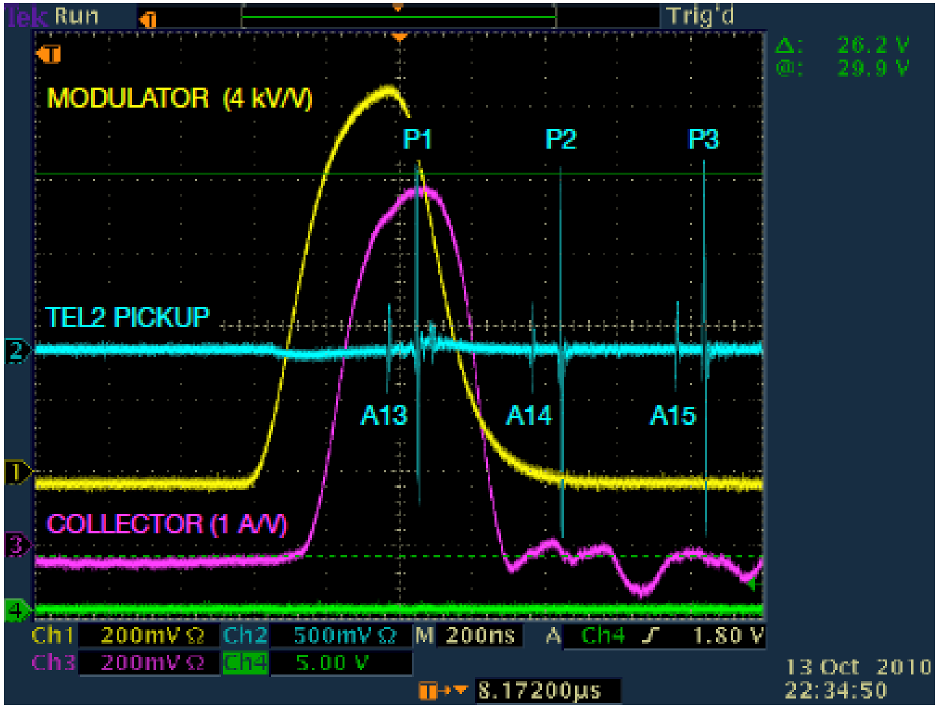
Movie courtesy
D. Mirarchi (CERN)



Collimation with Hollow e⁻ Beams

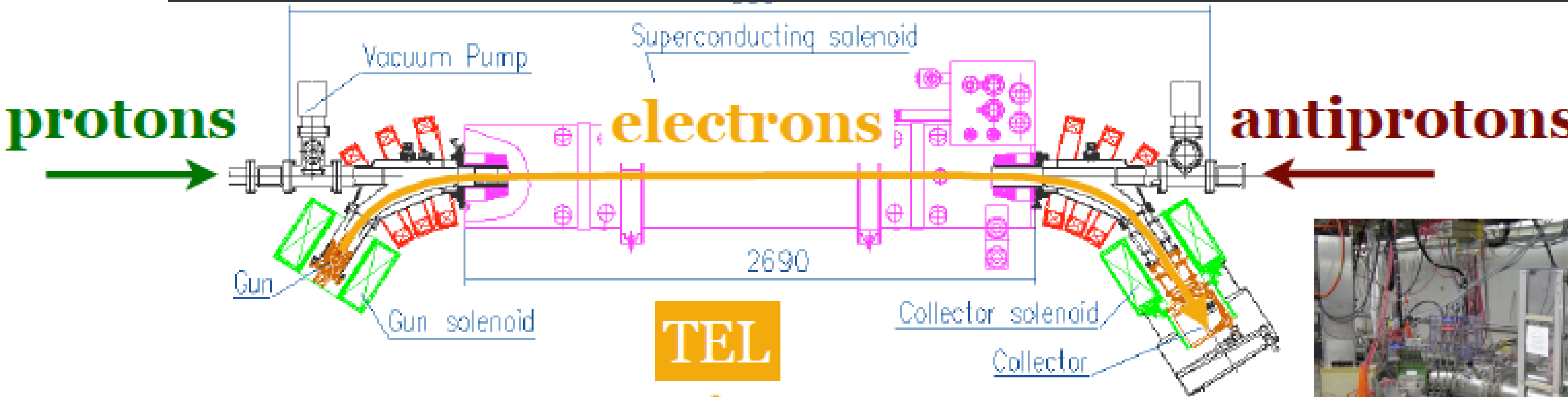
- Compared to the conventional collimators, HEBC offers some advantages
  - Can be much closer to the main beam (no material damage, low impedance)
  - Tunable strength ('soft' collimator, θ=0.2μrad), no mechanical moving parts

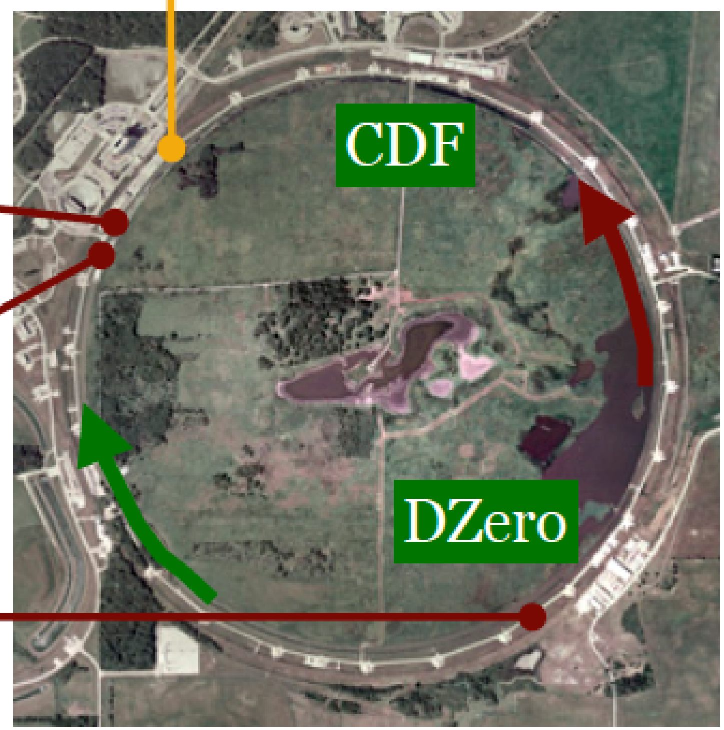


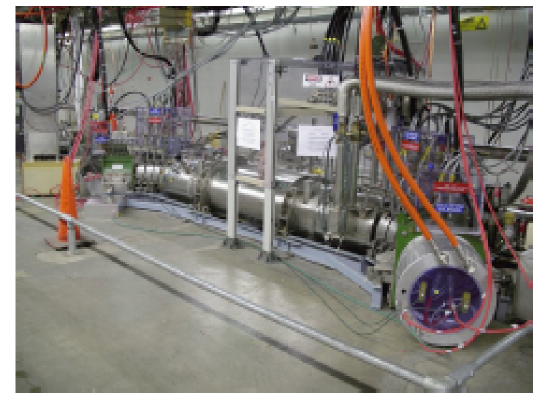


V. Shiltsev, Proc. 3rd CARE-HHH-APD Workshop (LHC- LUMI-06)

Layout of Tevatron Experiment



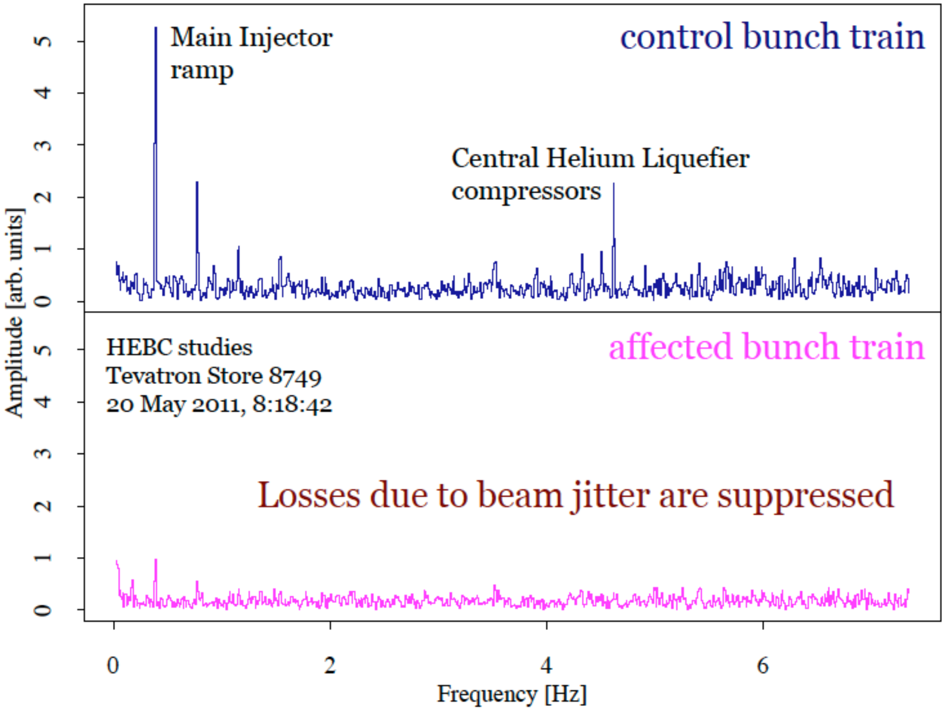


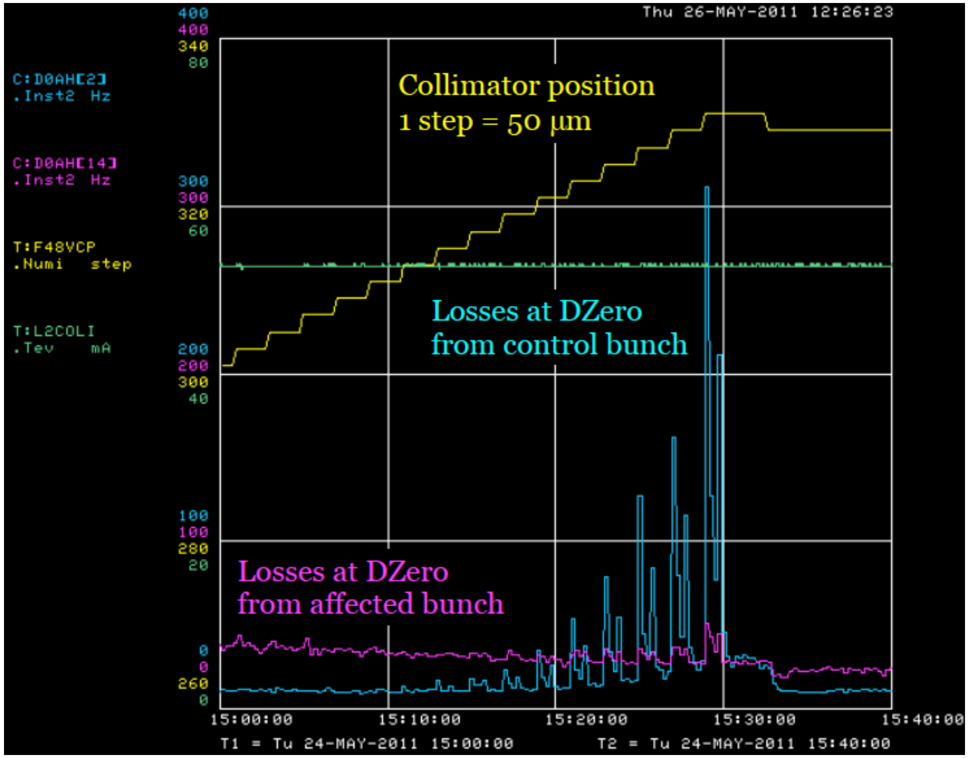


Tevatron electron lens

G. Stancari et al., Phys. Rev. Lett. 107, 084802 (2011)

Collimation with Hollow e⁻ Beams





G. Stancari et al., IPAC11

- 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

Beam-Beam Experiments

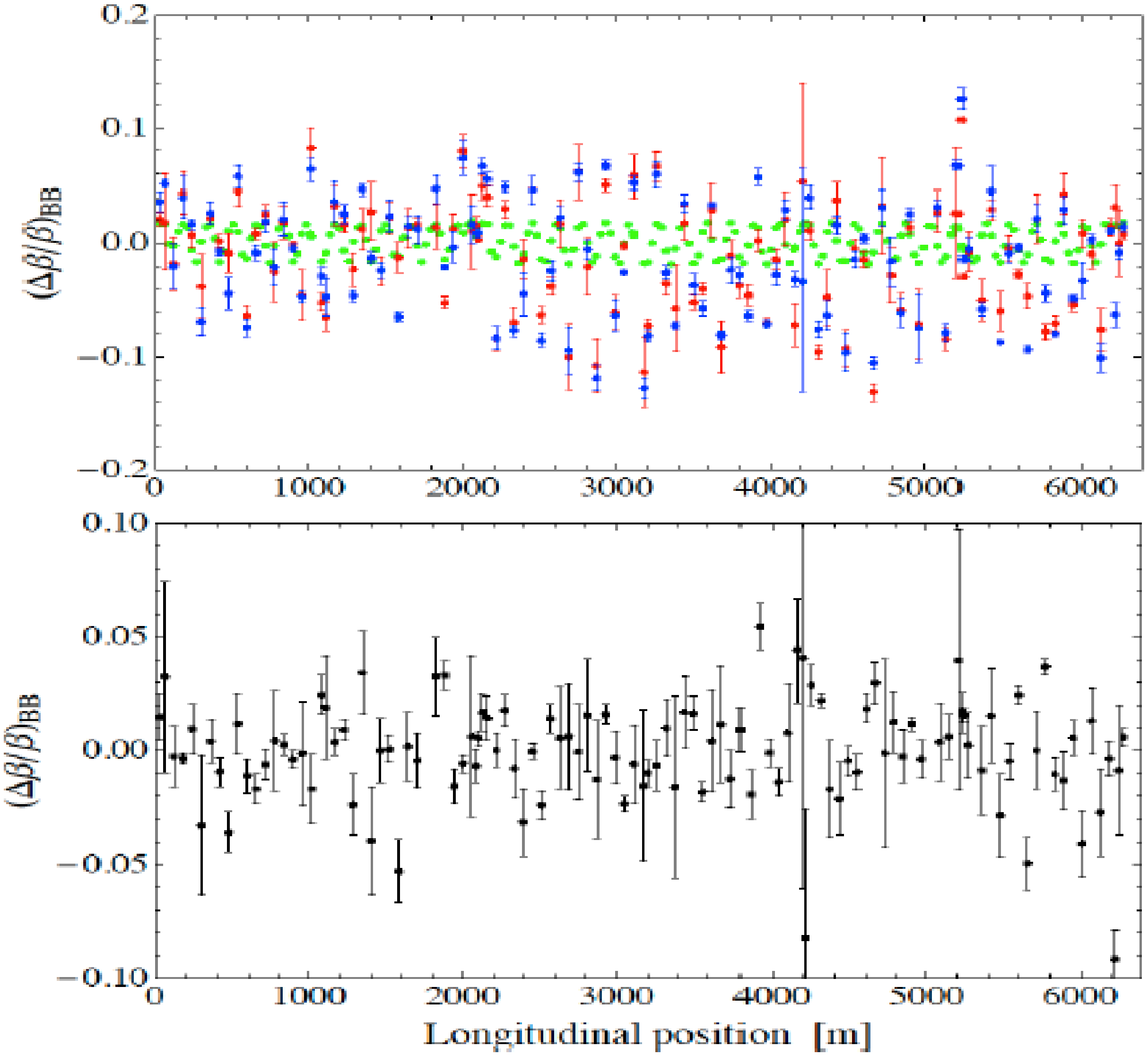
List of topics

- 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
- 1σ Kick
- 2σ Kick

R. Miyamoto
F. Schmidt

Relative difference between 1σ and 2σ kick

Effect on Coherent Stability

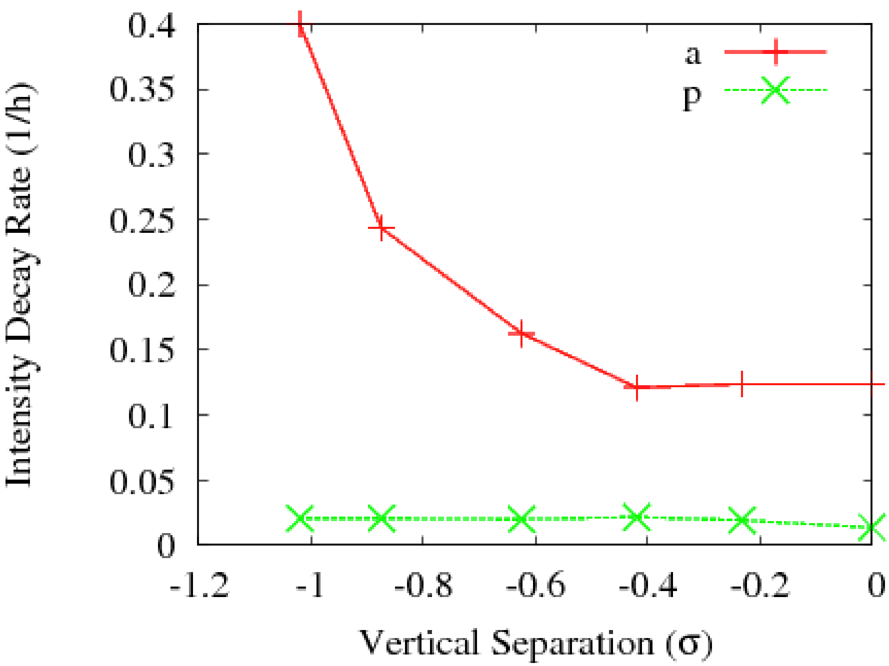
- The threshold betatron tune chromaticity vas studied as a function of beam-beam interaction.
  - Nominally Tevatron operated at C=+14 without collisions and +5 at collisions.
  - It was observed that for the nominal bunch intensity the instability is very fast slightly above C=0, causing a quench.
  - 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.

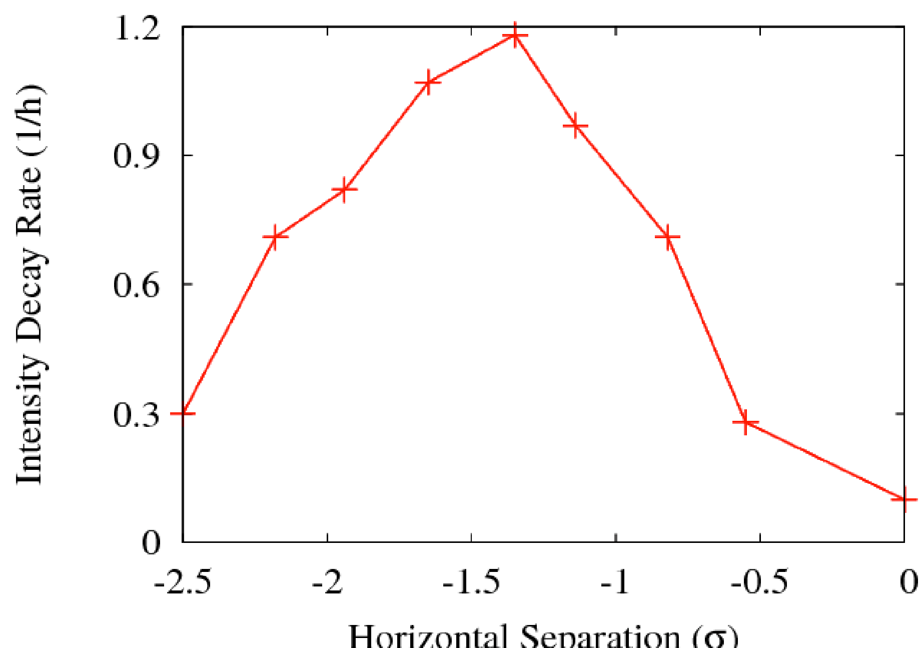
Effect of Transverse Separation

- 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 1.5σ, consistent with simulations.
  - The effect is working point-dependent

Vert. scan

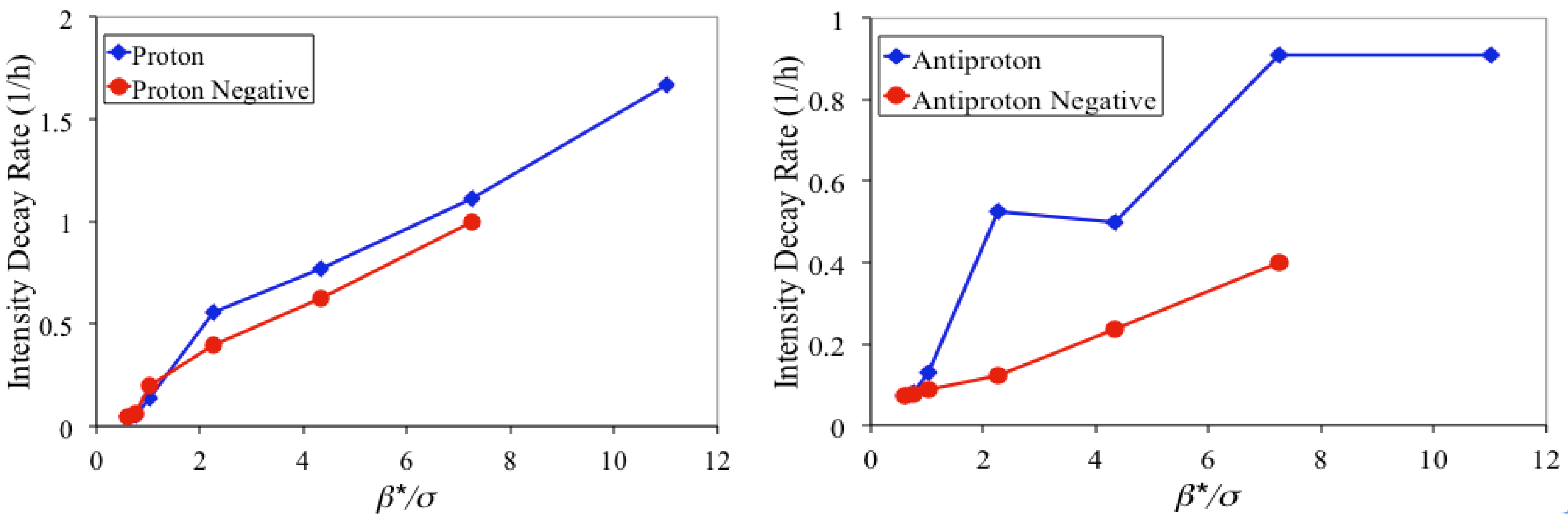


Horiz. scan



Effect of β^* / σ_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.



Summary

- 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.