Antiproton Transfers

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Talk outline

1. Introduction
2. Optics improvements and optics correction
3. Beam steering improvements
4. Reproducibility of optics and beam steering
5. Injection damper
6. Scenario of future transfers
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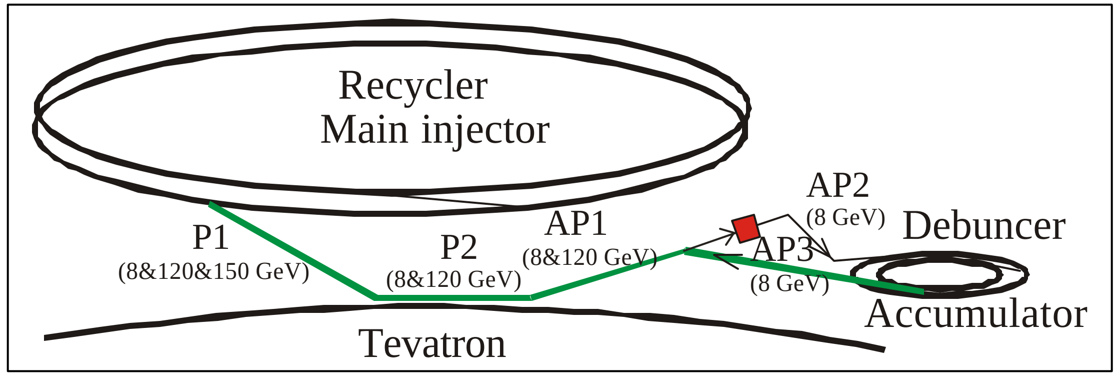
1. Introduction

- **Aim of the project**
  - Achieve transfers from Accumulator to Recycler with
    - negligible emittance growth
    - negligible beam loss
    - high reliability
  - Frequent transfers
    - Repetition time 15-30 min
    - Transfer time 1-2 min



- **New (AP5) versus existing lines (AP3-AP1-P2-P1)**

Problems with old line

- Long (~1 km) dual energy beam line
  - Poor reproducibility due to residual fields of magnets
  - Whenever the beam line energy is changed resteering are required
  - Poor knowledge of “real machine” optics

‘ Solvable problems Þ Use existing line ‘

Advantages of new line

- Single energy line
  - Reduced effects of residual field of the magnets
  - No changes in magnet settings

Disadvantages of new line

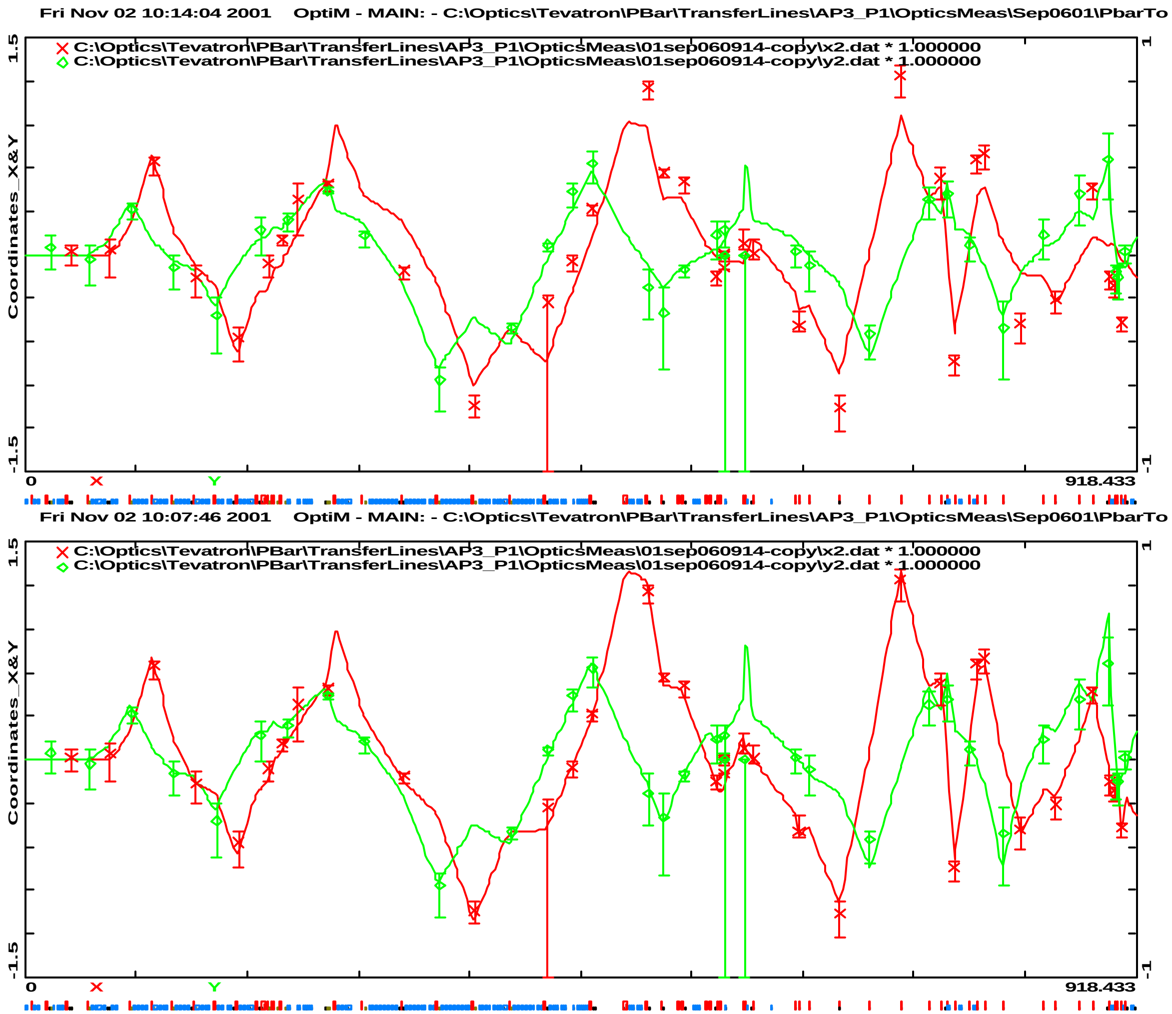
- High cost
- Building and commissioning with operating Tevatron

2. Optics Improvements and Optics Correction

Optics improvements

- General requirements to optics design
  - Minimize beta-functions through the line
    - Better optics reproducibility
    - Maximize effective aperture
      - Special attention to places with small aperture
  - Two step beta-function and dispersion match
    - Fitting of real machine optics to the design optics with differential orbit measurements
    - On-line envelope match correction with assigned quadrupoles and quadrupole pickup for final tuning
- Optics measurements
  - Differential orbit measurements
    - Measurements of real focusing in the line
    - Fixing BPM problems (differential sensitivity of BPMs)
  - Quadrupole pick-up
    - If existing quadrupole pickup will not be not adequate to the requirements the CERN design can be used

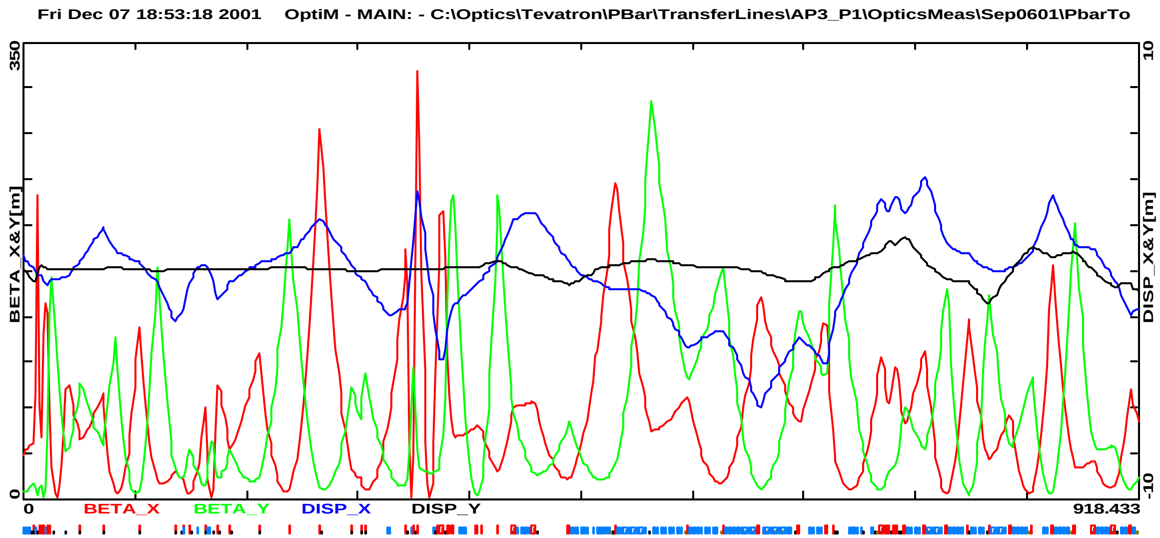
Differential orbit measurements



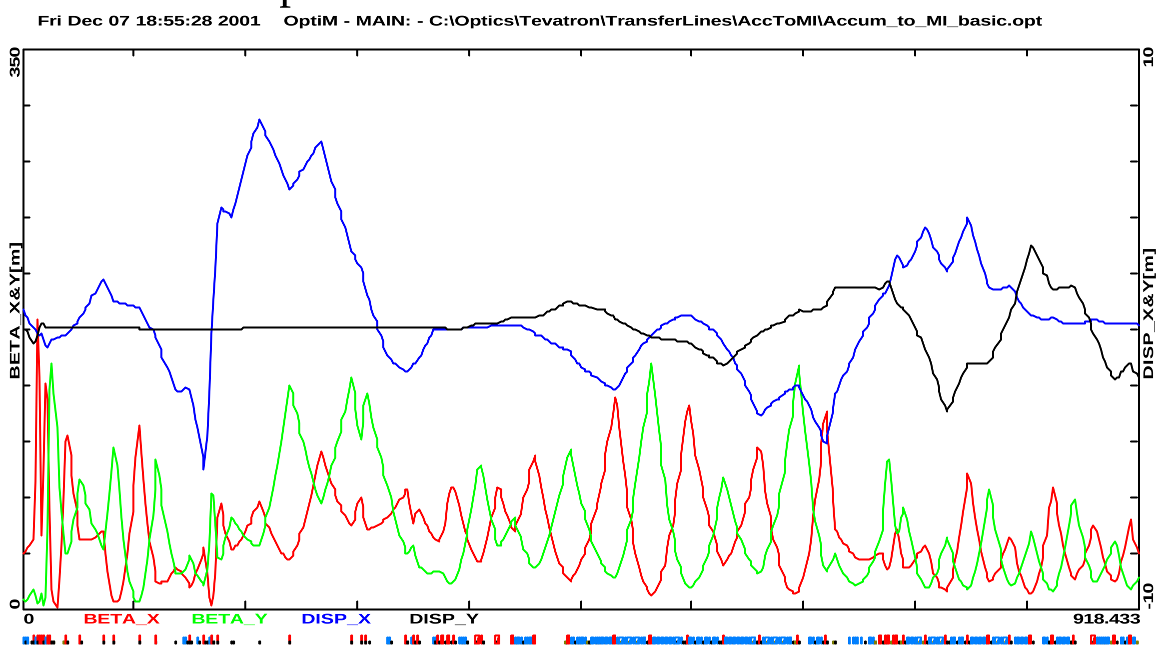
Fitting of the optics model to the optics measurement:
top – curves are built with design model;
bottom – curves are built using updated model
Only 2 of six differential orbits are presented in the figure.

Most outstanding discrepancies:

1. Q202 (-9%)
   120 GeV and 8 GeV power supplies for PQ202 have opposite polarities and it has not been not correctly taken into account in the optics model
2. Q913 (+8%)
   The reason is not identified yet.



Present optics reconstructed from the measurements



Oct.2001 optics

Present optics problems

1. Strong envelope mismatch due to poor knowledge of quad focusing
2. Large beam size at places with small apertures
3. Unmatched dispersion

Intermediate optics

1. Unmatched vertical dispersion due to difficulties with reconnecting quad power supplies will remain

Future optics

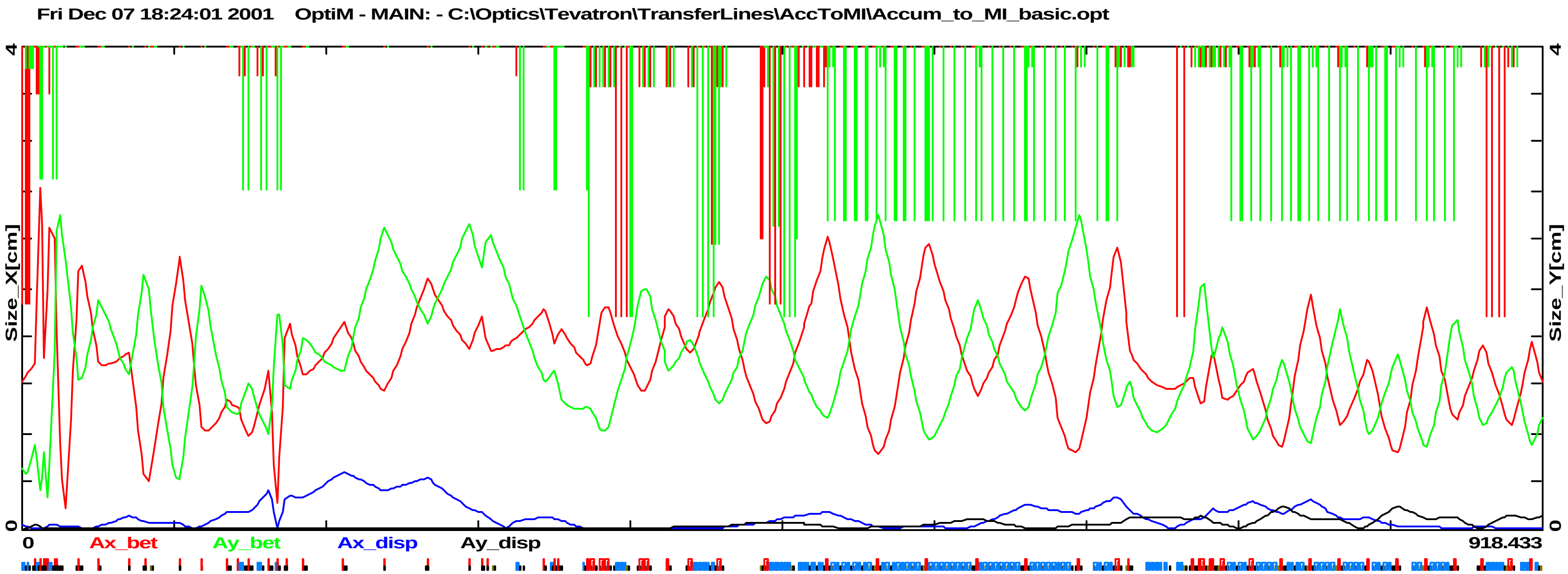
1. Solves all above listed problems
2. Requires power supply reconnection

Beta-functions and dispersions for the intermediate optics (testing started in Oct.2001)

Two Stage Optics Correction

- Differential orbit measurement
  - ➢ Allows one to find discrepancies between design optics and real beam line optics
  - ➢ Does not know about beam envelopes in the rings and therefore cannot finalize optics match
- Final tuning with quadrupole pickup
  - ➢ Sensitive to quadrupole oscillations which are proportional to optics mismatch
    - ♦ Quadrupole pickup is installed in the accumulator
    - ♦ Reverse protons will be used for final optics match

We have large enough aperture in the line - we just need to choose the "right" optics



Beam envelopes and aperture limitations for intermediate optics with normalized acceptance of 42 mm mrad (2.2 times of 95% beam emittance)

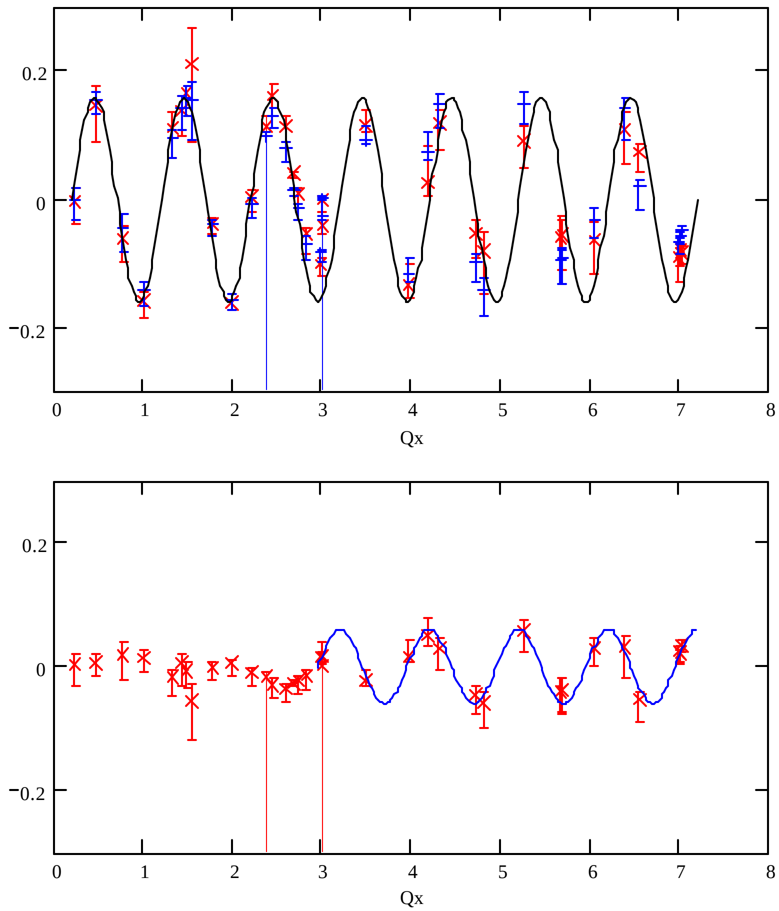
3. Beam Steering Improvements

Present problems

- Poor convergence results in lengthy orbit corrections
  - ➢ Poor knowledge of the beam optics
    - ♦ Improved and well tested optics files should be ready in the first quarter of 2002
  - ➢ Incorrect differential responses for BPMs
    - ♦ Large number of discrepancies is being fixed now
    - ♦ Further studies will follow
    - ♦ Major discrepancies should be corrected in the first quarter of 2002
- Improved software
  - ➢ will be using more accurate optics files
    - ♦ Their accuracy will be verified by optics measurements
  - ➢ More reliable software for non-expert use
    - ♦ Minimum interaction with operators
    - ♦ Better exception handling

4. Reproducibility of Optics and Beam Steering

Optics



Comparison of differential orbit measurements performed on Sept. 6 and 16 of 2001;
top – differential orbits,
bottom – difference of differential orbits.
Data are presented in normalized coordinates.

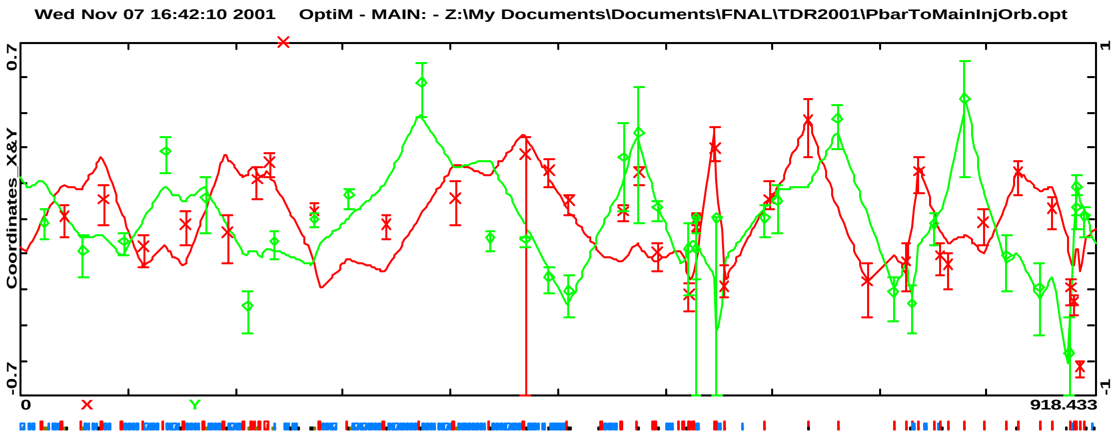
Require:

- The emittance growth due to optics irreproducibility ~ 1-2%
  - ➢ reproducibility of the integral quad strengths about 10-20 G
    - ♦ that corresponds to $(3\text{-}5)\cdot 10^{-4}$ relative reproducibility of the gradient.
- **Compare**
  - ➢ 3Q120 quadrupole the integral strength related to the residual field is equal to 2000 G
  - ➢ !!! about hundred times higher than the required accuracy.

⇒ **Reliable transfers require**

- ➢ good stabilization of the quad power supplies
- ➢ reliable hysteresis cycling for magnets

Orbit



Difference of horizontal and vertical beam positions for differential orbit measurements performed on September 6 and 16 of 2001.
Major discrepancies are related to orbit changes and/or extraction errors coming from Main injector.

Requirement:

- The emittance growth due to orbit irreproducibility ~ 1-2%
  - Injection error ~ 0.5 mm
    - Practically impossible to achieve

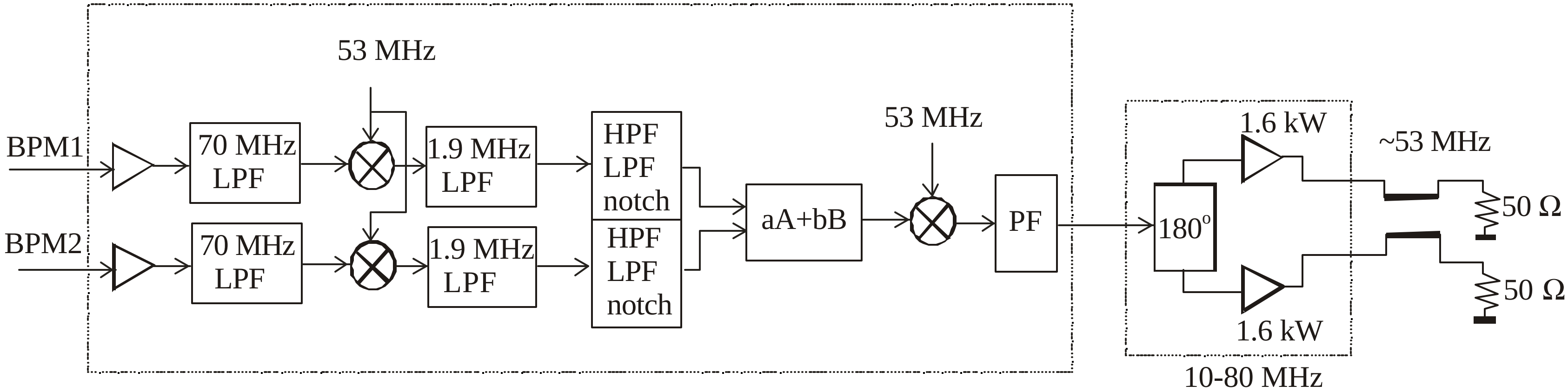
Two step solution:

- Steering reproducibility better than 5 mm guarantees no scraping for beam transfers
- Injection damper decreases the beam oscillations from 5 to 0.5 mm

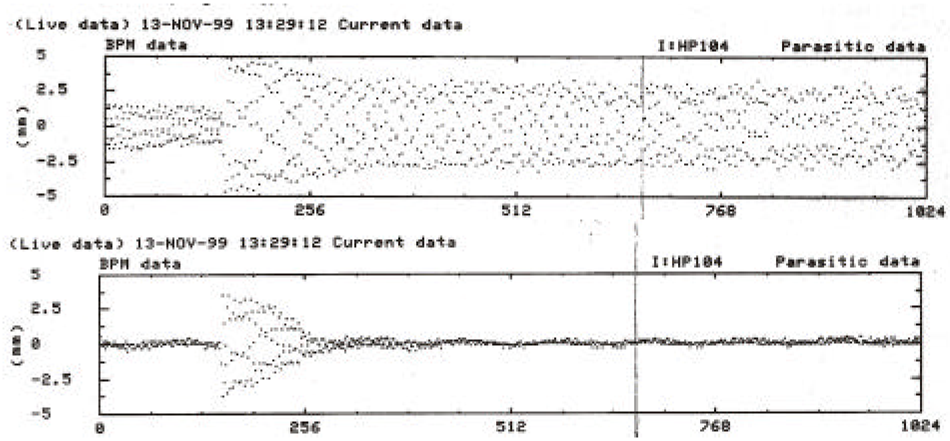
Current status:

- Orbit reproducibility is already within 5 mm

Injection damper



- The damper is build and tested for proton direction



- Low level electronics needs to be added to use it for antiproton direction

Parameters of the injection damper

	Horizontal & Vertical
Momentum [GeV/c]	8.9
Kicker length [m]	1.0
Kicker gap [cm]	9.5
Power of power amplifier [kW]	1.6
Bandwidth of power amplifier,[MHz]	10-80
Maximum kick [μrad]	1.8
Range [±mm]	5
Beta-function [m]	60
Damping time [turns]	90

Scenario of future transfers

	Now	Future
Transfer frequency	~ 24 hour	0.5 hour
Transfer time	1-2 hour	1-2 min
Total number of $\bar{p}$	10^{12}	$2.5\cdot10^{11}$

	Presently		Future	
	Time [min]	Comments	Time [min]	Comments
Stacking is halted	0		0	
Core cooling	30	in parallel with steps below	-	Only core particles are extracted, ~50%
Stacktail cooling	10		-	
MI checking /correct. orbit and energy	10		-	Less susceptible to errors due to injection damper
AP1 switch to 8 GeV	10		-	Ramped power supplies
Hysteresis cycling	-		0.2	
Beam line orbit check/correct	10		-	
Final orbit correct. with turn-by-turn orb. meas. in Accum.	10		-	
RF system set-up	5		0	It is setup. Waits trigger.
Long. distribution squaring	10		-	Unnecessary
Antiprotons transfer*	10	9 extractions	0.2	1 extraction
Reconfiguration for stacking	15		0	Stacking starts after trig.

***Six steps for antiproton transfers**

	Presently	Future
Adiabatic bunching and acceleration from the core to the extraction orbit with an 2.5 MHz RF system (q=4)	10% of the original antiproton stack	100% of the original antiproton stack
Bunching with 53 MHz RF system (q=84) for synchronous transfer to the Main Injector		Is not required
Transfer from the Accumulator to MI		
Acceleration to 150 GeV in the Main Injector and coalescing the antiprotons into four bunches		Only small energy correction is required for energy match with recycler
Transfer from the Main Injector to the Tevatron down the A1 line		Transfer to recycler
Injection into the Tevatron with beam cogged to the proper longitudinal location		Is not required

Conclusions

The following steps and improvements are anticipated to achieve fast and high quality transfers:

- Optics improvements
  - Redesign, measure and tune optics
  - Introduce fine tuning with quadrupole pickup and assigned quads
- Improvements and better automating of beam steering
- Reproducibility improvement
  - Introduce hysteresis protocol for the transfer line magnets
- Damping injection oscillations with injection damper
- Shortening and automating existing procedure for transfers
  - No beam line tuneup with reverse protons
  - Installing ramped power supplies for AP1 line
  - Most of setting changes are driven by clock events