Status of Beam-Beam Compensation with Electron Lenses in Tevatron

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for the BBCompensation team:
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Fermilab
Content

• Original idea

• Sequence of events

• TEL is good for something else

• Lifetime with TEL $\rightarrow$ improved

• First indication of successful B-B-Compensation

• What is important for the BBC?

• Next steps
Original Idea Was…

“…to compensate (in average) space charge forces of positively charged protons acting on antiprotons in the Tevatron by interaction with a negative charge of a low energy high-current electron beam “ (1997)
Compensation with Two TELs

- Tev Run II: 36x36 bunches in 3 trains
- compensate beam-beam tune shifts
  - a) Run II Goal
  - b) one TEL
  - c) two TELs
  - d) 2 nonlinear TELs
- requires
  - 1-3A electron current
  - stability dJ/J<0.1%
  - e-pbar centering
  - e-beam shaping

Better lifetime and smaller emittance growth of 6 out 36 bunches $\rightarrow$ ~5-10% in integrated luminosity

Electron currents in the two TELs as seen by different antiproton bunches #1 to #12

prototyping started in ’98 $\rightarrow$

V.Shiltsev, Yu.Alexahin, D.Shatilov
TEL-1: installed Mar.1, 2001
Tevatron Electron Lens in the Tevatron Tunnel, sector F48
Electron Beam in Main Solenoid

- “flat” e-current density distribution +-5% over 3.4 mm diameter
Tuneshift \( dQ_{\text{hor}} = +0.009 \) by TEL

- Three bunches in the Tevatron, the TEL acts on one of them
TEL : tuneshift as predicted

\[ dQ_{x,y} = \frac{\beta_{x,y} \cdot 1 \pm \beta_e}{2\pi} \cdot \frac{J_e \cdot L_e \cdot r_p}{\beta_e \cdot e \cdot c \cdot a_e^2 \cdot \gamma_p} \]
TEL : short pulses, bunch-by-bunch
TEL: tuning shift vs e-position
Unexpected Function: “DC Beam Killer”

- e-current is fired in three gaps every 7th turn
- 1.2 ns e-pulses
- 7 turns = 147 ns
- Trains of 12 p-bunches

Since March 2002: “24/7”
e-Beam Position for “cleaning” vs BBC

- e-beam is being moved by a set of 6 SC dipole correctors
- each corrector can move ebeam over 2¾” aperture (about 0.12Tm strength)
- intrinsic feature of the TEL is that for e-beam to be generated it needs to be able to propagate thru - the condition which requires $S(\text{correctors})=\text{const}$ in each plane, so $\Rightarrow$
- moving e-beam does not affect Tev orbits!
Outstanding Issue with BBC in ’01-’02 – limited lifetime

Fit: \((1/150 \text{ hrs}) + (1/30\text{hrs}) \times (J/1A)^2\)
e-beam edge = “donut collimator” A~20 pm mrad

Proton Beam Sizes vs Time

Beam Sizes (mm, dP/P)

Proton Intensity (E9)

Time (min)

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Beam-Beam'03 - May 19-23,2003
Need of Smooth Edges $\rightarrow$ Gaussian Gun

- Beam profile controlled by special electrode
- Somewhat reduced current density in the center $\rightarrow$ need of higher voltage
- Installed in Jan’2003
TEL Gaussian Gun – Installed Jan’03

One-Dimensional Beam Current Profile from "Gaussian Gun"

$J_e=1A$, $U_e=10kV$

G.Kuznetsov, K.Bishofberger N.Solyak

Current from "Gaussian Gun" and $\mu P=1.82$ Fit Curve

$y = a x^b$

$a = 0.0574$

$b = 1.5$
Lifetime vs WP with $dQ_{TEL} \approx 0.004$

Flat e-beam

Gaussian e-beam
Successful Attempt of BBC with TEL

• first, the lifetime improvements with Gaussian gun made sense of the use of the TEL in HEP stores:
  \[ t_{TEL} \sim 100-160 \text{ hrs} > t_{pbar} \sim 30-50 \text{ hrs} \]

• second, it was demonstrated that the TEL can be transferred from DC beam removal regime to BBC regime (includes still manual changes of U_cath, P_fil, triggering from 3/7 to 1/1, timing and pulse width, and use of strong dipole correctors to move e-beam on pbars) and back – with no significant effect on colliding beams or detector backgrounds

• after that the TEL with some 0.6A of current was timed on single pbar bunch at the beginning of the Tevatron stores and it was observed that the TEL can slower vertical emittance growth of antiprotons (“reduce scallops”)}
“Scallops” : Specific Emittance Blowup

Pbar bunches after “initiate collisions” — same bunches 20 min later + 5 pp
“Scallops” is beam-beam phenomena, they started to occur after N protons exceeded 180e9/bunch.

“Scallops” do not take place in every store even with N_p >180e9/bunch.

“Scallops” occur in both planes, but often more prominent in vertical.

“Scallops” seem to be dependent on tunes, e.g. vertical tune change –0.002 can significantly reduce scallops.

Small “scallops” are seen in protons.

Scallops are the same in all three trains of bunches (variations <20%).
BBC with TEL: e-Pulse on A33

Store #2540
May 12, ’03

“Integrating” BPM

e-current in collector, 0.6A

pick-up signal

Ch3 Max 306.5mV

15 May 2003
14:12:59
Pbar V-Sizes 34 min after p-pbar collisions initiated

Store #2540
May 12, ‘03

A9 : 4.1 \(\mu\)m mrad/hr
A21 : 2.2 \(\mu\)m mrad/hr
A33 : 1 \(\mu\)m mrad/hr
-TEL on it
Pbar V-Sizes 4 hours after p-pbar collisions initiated

Store #2540
May 12, ‘03

A9
A21
A33 - TEL on/off

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# Pbar V-emittance growth rates (\text{\textmu} m m mrad/hr)

<table>
<thead>
<tr>
<th>store</th>
<th>#A9</th>
<th>#A21</th>
<th>#A33</th>
</tr>
</thead>
<tbody>
<tr>
<td># 2536 (40 min)</td>
<td>9.9</td>
<td>9.2</td>
<td>9.3</td>
</tr>
<tr>
<td>#2538 (35 min)</td>
<td>1.9</td>
<td>1.7</td>
<td>2.8</td>
</tr>
<tr>
<td>#2540 (34 min)</td>
<td>4.1</td>
<td>2.2</td>
<td>1.0</td>
</tr>
<tr>
<td>#2546 (30 min)</td>
<td>3.9</td>
<td>1.9</td>
<td>4.0</td>
</tr>
<tr>
<td>#2549 (26 min)</td>
<td>4.5</td>
<td>3.6</td>
<td>7.1</td>
</tr>
<tr>
<td>#2541 (34 min)</td>
<td>6.7</td>
<td>6.6</td>
<td>7.0</td>
</tr>
</tbody>
</table>
Statistics of TEL used for BBC

- 8 attempts since 5/20/03
- Neutral or slightly negative effect in two stores #2546, #2549 – but “scallops” occur
- No effect in three earlier stores #2445, #2490, #2495 – no “scallops”
- Positive effect in one store #2540 – “scallops” suppressed
- Faulty pulse generator led to loss of 2 pbar bunches in two stores #2487, #2502
An Example of “No Effect” Store

Store #2495
Apr 30, ‘03

- The intention was to use the TEL on few pbar bunches and shift their vert tune by – (0.001-0.002) to reduce their V-emittance blowup in the first 20 min after “initiate collisions”
- Unfortunately (for us) operators shifted the tune by -.001 for all pbar bunches and scallops gone
- TEL was ON A28-29 in 4 stores – no damage
e-Pbar Alignment Seems to be Crucial

Dependence of Pbar tuneshift due to TEL on e-beam postioning

For $\sigma=0.8\text{ mm} \text{ Gaussian e-beam}$

$\frac{dQ}{dQ_{max}} \sim -0.004$

$Q_{max} \sim 1.5\text{ mm}$
“Does it do anything at all?” – Oh, yeah!

Integr pick-up signal: shows fluctuating e-current and p/pbar signals.
A28-29 killed by faulty TEL triggering

it took about 2 min...
Beam-Beam Compensation:

• the first *indication* of the BBC in store #2540

• later attempts in #2546 and #2549 show that the TEL effect can be neutral or even slightly negative

• the attempts will continue

• conditions to claim *demonstration* of the BBComp:
  – scallops or other “bad” effects without BBComp
  – the “bad” effects suppressed by TEL
  – on systematic basis
What is important for the BBComp?:

- following issues need to be resolved before the Beam-Beam Compensation will be used operationally:
  - better understand beam-beam effects in the Tevatron and parametrize them (see talks of T.Sen and Y.Alexahin)
  - improve e-pbar-p position measurements < 0.1 mm
  - single pbar bunch tune diagnostics (1.7GHz Schottky)
  - do we need wider e-beam or different shape?
What to compensate?

• Beam-beam interaction in the Tev leads to
  – Pbar losses at injection energy 150 GeV
    • 15% → 3%
    • Long-range BB
  – Pbar losses on ramp
    • 5-15%
    • Long-range BB
  – Pbar and proton losses during LB squeeze
    • 1-3% for pbars, of the order of 1% for protons
    • Long-range BB
  – Pbar and proton emittance growth in collisions
    • Vary from 1 to 20 pi mm mrad/hr for pbars (1/10th for p’s)
    • Head-on and Long-range
  – High proton and pbar losses (poor lifetime) in stores
    • Can be as small as 20 hrs for both beams → detector bckgrnd
    • Head-on and Long-range
Tevatron Working Points

- with current parameters

\[ N_p \sim 250\text{e}^9/\text{bunch} \]
\[ \text{emittance} \sim 20 \text{ pmmmrad} \]

Head-on tuneshift is
\[ x \sim 0.015 \]

Bunch-by-bunch tune spread
\[ dQ \sim 0.003-0.005 \]

B-B dynamics dominated by 5\textsuperscript{th}, 7\textsuperscript{th}, and 12\textsuperscript{th} order resonances
TEL BPMs – Need to Be Improved

• Calibrate BPMs $X(f)$ in the tunnel with variable pulse generator - need access

• Calibrate BPMs using longitudinal waves in e-beam excited by protons - need study time

• Install new BPMs – already designed, tested – need shutdown

p-pulse: 2ns rms

e-pulse: $\sim1$ ns

1.4mm
1.7GHz Schottky Spectra

EoS #2538: 1.7Ghz Schottky for All Pbars

dQh_set = -0.0043, dQh_meas = -0.0048,
dQv_set = +0.0043, dQv_meas = +0.0045

tune repeatability 0.0007 p-p, error of fit 0.0002
Tevatron 1.7GHz Schottky Spectra

1.7GHz Schottky spectra of bunch A6 in #2538

R. Pasquinelli
V. Shiltsev
J. Steimel
A. Jansson
Pbar Bunch Tunes Measured by 1.7GHz Schottky detector
Other Issues: e-Stabilization (needed?)

- TEL e-current turn-by-turn noise amplitude $dJ_e \sim 3-5\text{mA}$ p-p while operating for BBC with $dQ > 0.005$
  $\Rightarrow 0.1-0.2 \text{ p/hr}$
- That is less though comparable with “natural” emittance growth of $0.2-0.5 \text{ p/hr}$
- $\Rightarrow$ we plan to consider possibilities for $dJ_e$ and $dX_e$ stabilization

Equation: $y = Cx^2$
- $C=0.008$
- $R^2 = 0.99$
Electron SC Waves Excited by Protons

Passage of protons

No signs of transverse e-p(bar) head-tail instability
Summary

- **Status:**
  - max dQ~0.009 tuneshift achieved
  - p(bar) lifetime deterioration proved to be due non-linear beam-beam force due to e-beam edges ("soft collimator")
  - after installation of Gaussian e-gun, p-beam lifetime of ~160hrs has been achieved (compare with 40 hrs in stores)
  - TEL was used in several stores recently and we’ve got first indications of successful beam-beam compensation: vertical emittance growth rate was reduced for pbar bunch #33 early in store #2540

- **Work to do:**
  - continue to explore BBC at 150, ramp, LB for both pbar and p
  - improve diagnostics (TEL BPM, Pbar Schottky tunemeter, etc)
  - wider e-beam
  - better beam current and position stabilization
  - the second TEL is under construction but the BBC is not the major motivation (← spare for the DC beam removal)
  - new HV pulser (~ 15kV instead of 7kV, shorter pulse)
Back-Up Slides
Beam-Beam Compensation with TEL

- TEL e-current noises are small
- p(pbar) lifetime reduction due to TEL comes from non-linear beam-beam effects - "donut collimator"
- Lifetime at good WPs is about 100 hrs
- e-beam positioning is important
- Smoother edge e-beam is needed
  - Gaussian gun
  - Gun and magnets to be modified in Jan’03 shutdown
  - Wire compensation? – to be considered in’03
TEL as the DC Beam Cleaner

- Phenomenon not yet understood causing beam to leak out of RF buckets
- At the end of store there is enough of the DC beam in the abort gap to cause quench on abort, >6x10^9 or ~0.1% of N_{total}
- e-beam placed to edge the p-orbit helix
- Fire TEL in 3 gaps every 7 turns to excite resonance
- TEL is equivalent to 100kW “tickler” (vs 50W in Q-mtr)
- TEL reduces DC beam intensity and eliminates spikes in the CDF losses
- currently TEL is operational: now it is turned ON early into each store, then OFF after store terminated (no TEL at injection as the DC beam is not a problem there)
- When needed, TEL is used for p/pbar bunch removal
Removing DC beam with TEL

- DC beam loss: $6 \times 10^9$
- Loss rate at B0 IP
- DC beam intensity
- Bunched beam intensity
- TEL on
- TEL current

V. Shiltsev, X.L. Zhang
Beam Loss on Ramp

- (intensities are zero-suppressed)
- at the very beginning of the ramp DC beam is lost (some 2-3% in both p and pbars, depends on injected longitudinal emittance)
- then we have significant beam loss on ramp which – at smaller rate – continues at flat top and in squeeze
- For pbars, the reason is beam-beam interaction
- For protons - ?
Long-range B-B Seen by SyncLite Monitor

- SL reports s, mean, N, tilt bunch-by-bunch for both protons and pbars
- SL reports scallops (when they appear) in good agreement with FWs
- It also shows 40 micron b-bunch hor pbar orbit variation along the bunch train with 3-train symmetry (4 microns for protons)
Transmission region of the TEL

Losses in TEL vs B\_gun/B\_main

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Graph showing the relationship between B\_gun and B\_main.}
\end{figure}

V.Shiltsev - FNAL

Beam-Beam'03 - May 19-23, 2003
Beam-Beam in Tevatron: Overview

T:IBEAM
Ctrls 1E12

C:FBIPNG
Ctrls 1E09

C:FBIANG
Ctrls 1E09

Open helix
proton injections
poor lifetimes
≈10% bunched beam loss in ramp and squeeze
pbar injections
ramp
LB
squeeze
HEP
scraping

V.Shiltsev - FNAL
Beam-Beam'03 - May 19-23,2003
### Beam-beam Interaction As Major Factor

- *Pbar transfer efficiency strongly depends on N_p, helix separation, orbits, tunes, coupling, chromaticity and beam emittances at injection*

- **Summary of progress with beam-beam since March 2002:**

<table>
<thead>
<tr>
<th></th>
<th>Mar’02 *</th>
<th>Oct’02 **</th>
<th>Jan’03#</th>
<th>Mar’03 ##</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protons/bunch</strong></td>
<td>140e9</td>
<td>170e9</td>
<td>180e9</td>
<td>205e9</td>
</tr>
<tr>
<td><strong>Pbar loss at 150 GeV</strong></td>
<td>20%</td>
<td>9%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Pbar loss on ramp</strong></td>
<td>14%</td>
<td>8%</td>
<td>12%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Pbar loss in squeeze</strong></td>
<td>22%</td>
<td>5%</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Tev efficiency Inj → low beta</strong></td>
<td>54%</td>
<td>75%</td>
<td>75%</td>
<td>80%</td>
</tr>
<tr>
<td><strong>Efficiency AA → low beta</strong></td>
<td>32%</td>
<td>60%</td>
<td>62%</td>
<td>64%</td>
</tr>
</tbody>
</table>

* average in stores #1120-1128

** average in stores #1832-1845

# average in stores #2114-2153 (9 stores)

### average in stores #2315-2361
- pbar bunches near abort gaps have better emittances and live longer
- emittances of other bunches are being blown up to 40% over the first 2 hours – see scallops over the bunch trains (small anti-scallops for protons)
- the effect is (and should be) tune dependent - see on the right
- recently, serious effects of pbars on protons – completely unexpected
Beam-Beam Effects: Losses @ HEP

At the beginning of the store available WP area is even smaller $dQ < 0.004 \ldots$ and this is at $N_p=180e9$

No available tune WP space expected above $240e9$
How to Deal with Beam-Beam?

• On-going activities:
  – “Better” (~larger) beam separation
    • open aperture, optics, add/improve separators
    • against Long-range BB
  – Beam-Beam Compensation with electron lenses
    • provide variable tune shifts and tune spread in bunches
    • against Long-range and Head-On BB

• Under consideration:
  – Add 6 proton bunches → 42x36 scenario
    • against Long-range BB in collisions
    • make worse at 150 GeV, ramp, squeeze; faster kicker
  – Wire Compensation
    • against Long-range BB
Wire Compensation

• Just started (after DoE Review Nov’02)
  – resonance strength analysis (T.Sen, B.Erdelyi)
  – practical considerations (T.Sen, V.Shiltsev)
• So far wires look challenging but promising
  – Scale of the problem:

\[ J_w \times L_w = 2 \times e \times c \times N_p^{(total)}/N_{\text{wires}} \]

  – That gives 232A*m for N_p=9720e9 and N_{wires}=4
  – Wires to be within 10 mm from pbars
  – Not in a single location (~4), some preferred
  – ~4(4-7) wires at each location (to compensate relevant resonances)
• Plan: continue theory studies \rightarrow start design
Wire Compensation - I
Wire Compensation - II

![Graph showing multipole components as a function of angle α₁ (degrees)]

- Multipole components
- Angle α₁ [degrees]

T.Sen
B.Erdelyi
Wire Compensation - III

Res. Str. \( \frac{1}{2} \)
Beam-Beam Effects: Pbar Only

Antiproton Only Store: 1% loss on ramp, $\tau_{150} = 20$ hrs, $\tau_{980} = 160$ hrs

8% loss on ramp – DC beam (depends on MI tuneup)

= Beam-Beam'03 - May 19-23,2003
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Beam-Beam'03 - May 19-23,2003

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Beam-Beam Effects: Antiprotons Suffer

<table>
<thead>
<tr>
<th>Store</th>
<th>(N_p, e^9)</th>
<th>Out of AA, mA</th>
<th>Loss at 150</th>
<th>Loss on ramp</th>
<th>Loss in squeeze</th>
<th>Pbars at low-beta</th>
<th>L, e^30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar’02</td>
<td>5100</td>
<td>90</td>
<td>20%</td>
<td>14%</td>
<td>22%</td>
<td>251</td>
<td>9.4</td>
</tr>
<tr>
<td>1303</td>
<td>6070</td>
<td>103</td>
<td>16.4%</td>
<td>11.6%</td>
<td>3%</td>
<td>476</td>
<td>19.5</td>
</tr>
<tr>
<td>1289</td>
<td>6990</td>
<td>105</td>
<td>18%</td>
<td>20%</td>
<td>11%</td>
<td>387</td>
<td>19.6</td>
</tr>
<tr>
<td>Oct’02</td>
<td>6430</td>
<td>132</td>
<td>9%</td>
<td>8.3%</td>
<td>5%</td>
<td>790</td>
<td>32.4</td>
</tr>
</tbody>
</table>

- Pbar intensity lifetime at low-beta is 15 to 50 hrs (50-70 due to luminosity)
- Pbar emittance lifetime at low-beta is 10 to 40 hrs
- Some effects are seen in protons (see below)
Lifetime of 12 pbar bunches: A1-A4 are injected first with emittances of 32 pi mm mrad – lifetime is 0.95 hr → 2.4 hrs; the second set of bunches A13-16 with emittance of 12pi had 4 hours lifetime; and the 3rd train A25-28 with emittances of about 18 pi mm mrad had some 3.2 hr lifetime.
Beam-Beam @ Injection vs Emittance

Pbar lifetime vs emittance at injection scales as $\frac{1}{\varepsilon^{(1.1-1.5)}} = 1/A^{(2.2-3)}$

- 36x12, April 15, 2002
- #1583, July 26, 2002

Fit $\tau = \text{const}/\varepsilon^{1.1}$

Fit $\tau = \text{const}/\varepsilon^{1.5}$

Lifetime, hrs

Emittance, $\pi$ mm mrad
Beam-Beam @ Injection: Bunch-by-Bunch

\textit{Pbar Lifetime at 150 GeV for Store 1775}

- 1st and 2nd Transfer (Pre-Cog)
- After 1st Cogging
- After 2nd Cogging

\textbf{P.Lebrun}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{pbar_lifetime.png}
\caption{Pbar Lifetime at 150 GeV for Store 1775}
\end{figure}
Beam-Beam Effects at 980 GeV

- Suffered 10-20% pbar loss during squeeze
  - During transition from injection to collision helix
  - Minimum beam separation was only \( \sim 1.8\sigma \)
  - New helix increased min beam separation to \( \sim 3\sigma \)
  - Pbar loss during essentially eliminated

-  lifetime \( \approx 9-10 \) hrs in first two hours of store
  - Increase helix separation to reduce long-range beam-beam effects? (72 “parasitic” crossings)
  - Pbar tune shift depends position in train \( \Rightarrow \) optimize tunes for most bunches
  - Use electron lens to compensate pbar tune shifts
Beam-Beam Effects in Protons

- See losses in squeeze in store #1868
  - Losses of bunches #12,24,36 were small (1e9/min)
  - All other bunches lost intensity very fast (4e9/min)
  - That resulted in quench at A11

- We have small “anti-scallop” (“smile”) effect in proton emittances at HEP
  - Bunches #1,12,13,24,25,36 have 1-2 πi larger emittances than others after being 1-few hours in collisions
  - Their intensity lifetime is smaller, too

- Antiprotons also help to make proton beam more stable on ramp and squeeze
  - Proton instability is rarely observed in 36x36 stores compared to the same intensity 36x0 stores
  - Tune spread due to pbars is about (few)e-4
Proton Losses While Cogging Pbars

Pbars pass p-bunches 3 times while cogging

Rad level at A11
Proton Loss on Ramp

- Ramp efficiency also anticorrelates with $N_p$, vertical emittance and $D_l$-emittance
Proton Loss on Ramp vs Emittance

\[ R^2 = 0.54 \]

W. Fischer, F. Schmidt, T. Sen
“Sequence 13” Affects Luminosity

Luminosity vs proton intensity for stores 990-1023

End of February – early March’2002

Average initial luminosity (e30 1/cm^2/s)

Total proton intensity (e9)
Pbar Loss During Squeeze ("Sequence 13")

- Suffered 10-20% pbar loss during squeeze
  - During transition from injection to collision helix
  - Minimum beam separation was only ~1.8σ
  - New helix increased min beam separation to ~3σ, loss essentially eliminated
Beam-Beam Effects in Squeeze

- Minimum beam-beam separation turned out to be only $1.8\sigma$
- Normalized separations $\Delta x/\sigma_x$, $\Delta y/\sigma_y$ at all possible IPs with $36\times36$ collision cogging in sigma’s for the reference emittance $\varepsilon_n=15\pi$ mm.mrad. $t = 0$ – seq13, $t = 1$ – seq14 (see plots)
- The separation has been increased to $2.7\sigma$ by adding 2 more breakpoints, also speed of the squeeze doubled there and the loss gone
- Lesson – only minimum separation matters
**Lifetime Issues at 150 GeV**

- LR beam-beam effects poor
  - pbar lifetime 0.3-1 hr
  - Pbar lifetime depends on emittances, \( N_p \) and bunch number
  - Original injection helix has been modified, separation increased and optimized to fit tight C0 aperture ("new-new helix")
  - Replace lambertsons at C0 – gain 25 mm vertically
  - Modify high \( \beta \) section at A0 formerly used for fixed-target extraction

- Poor proton lifetime on helix
  - \( \sim 2 \) hr
  - depends on chromaticity
  - Instability prevents lower chromaticity (now 8)
Proton Beam as “Soft Donut Collimator”

• P-bar losses strongly depend on pbar emittances and N_p

• Measures taken to reduce emittances:
  - AA “shot lattice”
  - Fix injection errors (BLT)
  - Match injection lines
  - Tuneup injection kickers
Pbar Losses vs Emittance/Helix Size

• expected $t\bar{O}A^{(2-3)}$

• next steps – to increase beam-beam separation (helix size):
  - C0 aperture: ~30% in A @150
  - Replace lambertsons @ C0 – gain 25 mm vertically
  - that will allow some 30% larger separation around the ring until the next aperture restriction (F0, A0, B0, D0, E0)
  - A0 lattice: ~16%? in A @150&LB
    - Modify high $\beta$ section at A0 formerly used for fixed-target extraction
Beam-Beam Effects Now: Injection

*Pbar Lifetime at 150 GeV for Store 1775*

- Loss depends on $N_p$, separation, aperture, emittances, $dp/p$, tunes and $C_v,h$
- Scaling not determined yet – to be done ASAP
Beam-Beam: Bunch-by-Bunch

- “Scallop” profile of bunch emittances
- At the beginning of the store
Proton Losses WhileCogging Pbars

Pbars pass p-bunches 3 times while cogging

Rad level at A11
Beam-Beam Effects in Protons

See losses in squeeze in store #1868

– Losses of bunches #12,24,36 were small (1e9/min)
– All other bunches lost intensity very fast (4e9/min)
– That resulted in quench at A11

We have small “anti-scallop” (“smile”) effect in proton emittances at HEP

– Bunches #1,12,13,24,25,36 have 1-2 pi larger emittances than others after being 1-few hours in collisions
– Their intensity lifetime is smaller, too

Antiprotons also help to make protonbeam more stable on ramp and squeeze

– Proton instability is rarely observed in 36x36 stores compared to the same intensity 36x0 stores
– Tune spread due to pbars is about (few)e-4
Add 6 Proton Bunches

• Will help at HEP only – reduce pbar bunch tune spread
• Will make beam-beam worse at 150 GeV, ramp, squeeze; faster kicker
• Plan: consider details and, perhaps, perform beam studies
Lifetime vs WP with $dQ_{TEL} \sim 0.004$

Flat e-beam

Gaussian e-beam