Experimental Demonstration of Beam-Beam Compensation by Tevatron Electron Lenses and Prospects for LHC

Vladimir Shiltsev for FNAL Beam-Beam Compensation Team

Yu.Alexahin, R.Hively, V.Kamerdzhiev, M.Kufer, G.Kuznetsov, H.Pfeffer, G.Saewert, V.Scarpine, V.Shiltsev N.Solyak, D.Wildman, D.Wolff, X.L.Zhang,

What is Electron Lens?

~2 mm dia 2 m long very straight beam of ~10kV/
~1A electrons (~10^{12}) immersed in 3T solenoid
generates strong radial electric field $E \sim 0.3$MV/m
TEL2 e-beam aligned and timed on protons

**in space**

**in time**

Transverse e-p alignment is very important for minimization of noise effects and optimization of positive effects due to e-beam. Timing is important to keep protons on flat top of e-pulse – to minimize noise and maximize tune shift.
Electron Guns Developed for TELs

- E-beam is strongly magnetized in 4-40 kG magnetic field
- Profile in the interaction region is the same (scaled) as on the cathode

Initial (2001)
Used for Pbar B-B Compensation (2003)
Used now (2005)
TEL Choice: Antiprotons or Protons?

**Antiprotons** 980 GeV :
\[ \xi_{\text{max}} = +0.024 ; \text{TEL focuses} \]

**Protons** 980 GeV :
\[ \xi_{\text{max}} = +0.016 ; \text{TEL defocuses} \]

At present, beam-beam effects are relatively stronger on protons, accounting for some 10-15% loss of the integrated luminosity. Proton loss rates vary greatly from bunch to bunch. The Tevatron Electron Lens #2 aligned on proton beam.
TEL2 on P12: 1st hour of Store #5119

TEL acts only on bunch #P12

When TEL off:
- Bunches #12 and #36 have the same lifetime: 16 hrs and 16 hrs

When TEL on:
- Bunch #12 lifetime is 2x #36 lifetime:
  - 26.6 hrs vs 13.4 hrs
  - 43.0 hrs vs 23.5 hrs
TEL2 Improves Proton Bunch Lifetime

Ratio $R = \tau_{\text{TEL ON}} / \tau_{\text{TEL OFF}}$

TEL2 on proton bunch P12;
intensity lifetime $\tau = N/(dN/dt)$

Je=0.3A

Je=0.6A
The Improvement Is Recurrent

Store #5119

Store #5123

Store #5127

>20 HEP stores with active BBC with TELs
When TEL2 acts on all bunches (DC)

Bunches are not equal! TEL2 moves $Q_v$ up

Bunch P12 has systematically the lowest vertical tune that reduces its lifetime (too close to 7/12 resonance). TEL2 raises the tune up by $dQ=+1.5e-3$
12% Increase of Luminosity Lifetime

TEL on:

\[ dQ = 0.001 \]

Effects ~comparable except TEL can affect individual bunches

BBC Team Beam-Beam Compensation in Tevatron
Summary

- Tevatron Electron Lenses act on proton bunches and \textit{DOUBLE} intensity lifetime
  - TEL1 (hor) effect varies +(20-40)%
  - Improves luminosity lifetime, too
- BBCompensation helps for \textit{\sim}10 hrs in store
- Will continue studies $\rightarrow$ introduce in operation
- A lot of interesting data, see:
  - TUPAS24, TUPAS25, TUPMN106, WEPMN97
- Other applications, e.g. head-on compensation
  - Gaussian profile: in RHIC, in LHC (see next slide)
LHC Electron Lens

2.4 A DC LEL with Gaussian current profile shrinks LHC footprint (Lumi-Upgrade simulations) → see TUPAN091