Hollow electron lens tests at RHIC

Hector Garcia-Morales[1,2], Daniele Mirarchi[2]
Stefano Redaelli[2], Wolfram Fischer[3], Xiaofeng Gu[3], Giulio Stancari[4]

LHC Collimation Team

[1] Royal Holloway University of London, Egham, UK
[2] CERN, Geneva, Switzerland
[3] Brookhaven national Lab, Upton, USA
[4] Fermilab, Batavia, USA

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The LHC collimation system

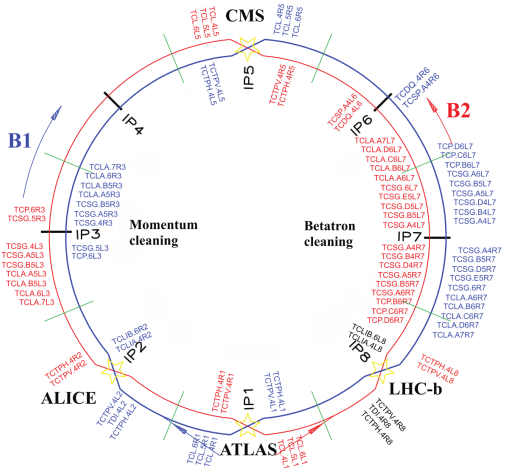

Figure: LHC layout and collimation system

The LHC collimation system

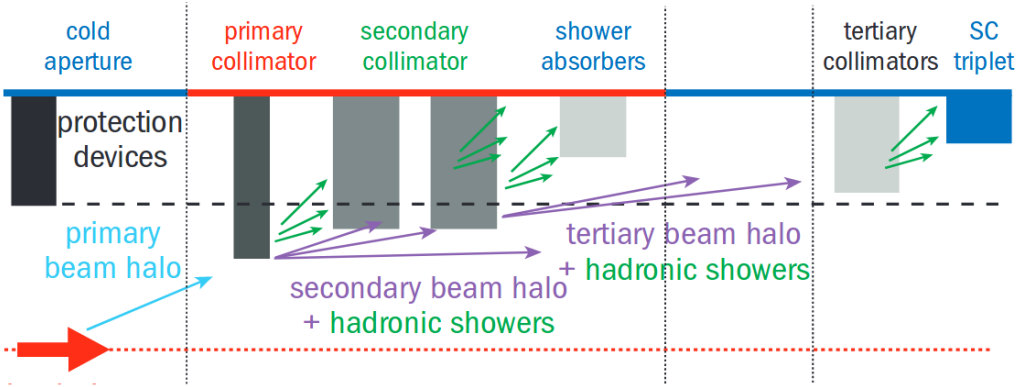

Figure: LHC multi-stage collimation system

Towards the LHC upgrade

HL-LHC challenges

1. High-intensity beams ($\times 2$ LHC intensity).
2. Stored energy $\sim$ 600 MJ.
3. Significant fraction stored in beam tails[1].
4. Crab cavities failure scenarios[2].

Collimation system upgrade

1. 11 T dipoles and DS collimators.
2. New tertiary collimators.
3. Low impedance secondary collimators.
4. Crystal collimation (session on Fri.).

Why a HEL for HL-LHC?

- If, due to beam jitter, tails are accidentally scraped, a quench may occur.
- Therefore an active control of halo dynamics is required.

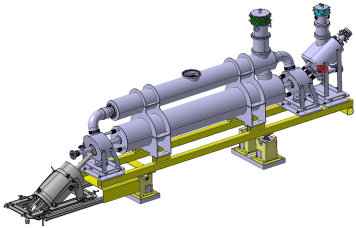

Figure: HEL preliminary design

[1] P. Racano: Review of halo measurements at LHC with collimator scans (talk on Tuesday)
[2] A. Santamaria: PhD thesis

The hollow electron lens principle

A hollow electron beam circulates in parallel with the main (proton) beam.

Goal

- Increase diffusion speed of particles in the tails...
- ... without affecting the core.

The kick

$$\theta_r = \frac{2 I_r L(1 \pm \beta_e \beta_p)}{r \beta_e \beta_p c^2 (B\rho)_p} \frac{1}{4\pi\epsilon_0} \qquad (1)$$

- I_r: electron beam current.
- r: electron beam radius.

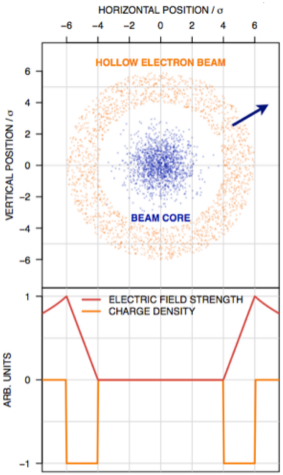

Figure: Hollow electron lens principle

Tevatron tests

- First tests using hollow electron lens for increasing diffusion speed in tails.
- Pulsed 5 keV electron beam acting on a 980 GeV antiproton beam.
- 1-3 T solenoidal field.
- $I_r = 1$ A, $L = 2$ m, $\beta_e = 0.14$, $r = 3$ mm.
- $\theta_r = 0.3$ μrad.
- 3 trains of 12 proton/antiproton bunches.

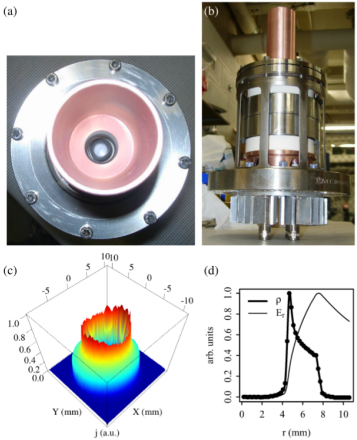

Figure: Tevatron hollow electron gun

Tevatron tests

- Luminosity stays constant while intensity is reduced → tail depletion.

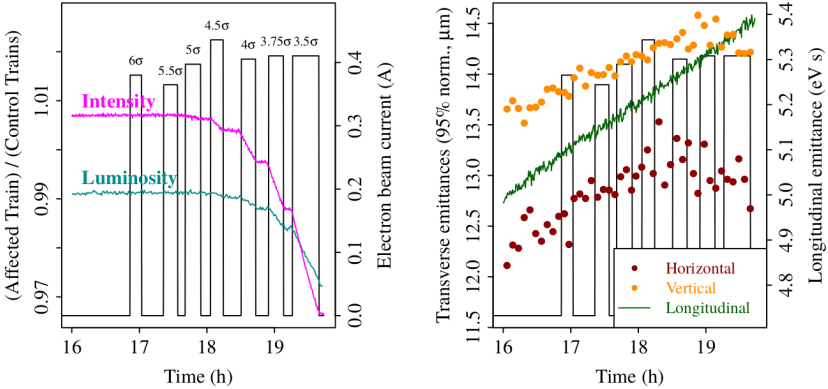

Figure: Tevatron hollow e-lens results[3]

[3] G. Stancari: Collimation with Hollow Electron Beams, PRL **107**, 084802 (2011).

From Chicago to New York: The RHIC electron lens

- Electron lens was installed at RHIC for beam-beam compensation during the proton run in 2015.
- After this run, the electron lens was not used during regular operations.
- A proposal for testing hollow electron lens using the existing hardware (and a new hollow cathod) was made.

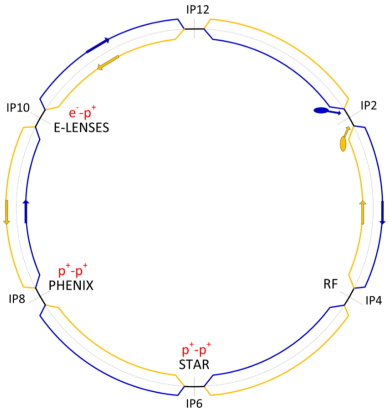

Figure: RHIC layout

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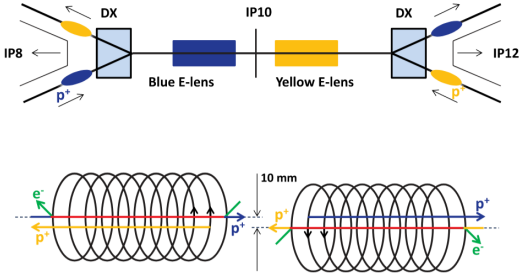

Figure: RHIC e-lens layout

RHIC tests (1/2)

APEX1 (11.04.2018)

- Ramp up of the superconducting magnet.
- Electron beam alignment with respect to Ru beam using backscattered e^- detector.

Issues

- Cathode bias $\rightarrow$ current fault caused beam to stop.

APEX2 (09.05.2018)

- Ruthenium at 100 GeV.
- Electron current scan.
- Electron lens radius scan.

Issues

- Filling scheme was not correct and bunches were colliding in other IPs.

RHIC tests (2/2)

APEX3 (23.05.2018)

- 6 hours.
- Gold at 13.5 GeV
- 1 T main solnoid field.
- Electron current scan.
- Electron lens radius scan.
- Chromaticity scan.
- Octupole scan.
- Collimator scraping for diffusion measurement.

Issues

- Luminosity only recorded for a few bunches outside the excitation window.

APEX4 (13.06.2018)

- 6 hours (2 hours useful time).
- Gold at 13.5 GeV
- 1 T main solnoid field.
- Chromaticity scan.
- Octupole scan.
- Excitation every n-th turn (1,2,...,12)

Issues

- No beam-beam.

APEX3 Filling scheme

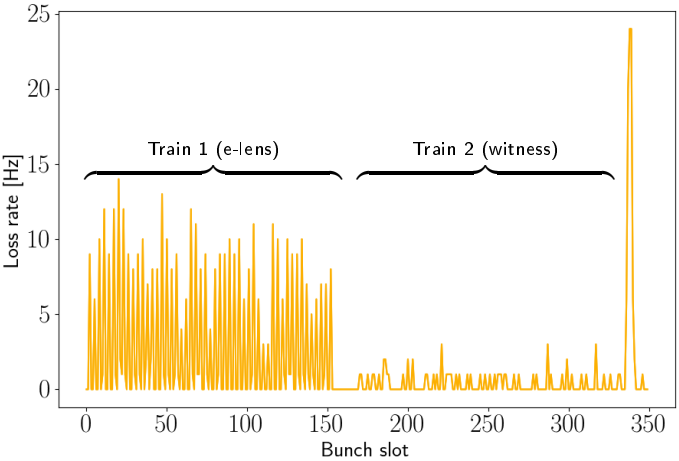

Figure: Example of bunch by bunch loss during the excitation

APEX3 Electron Radius Scan

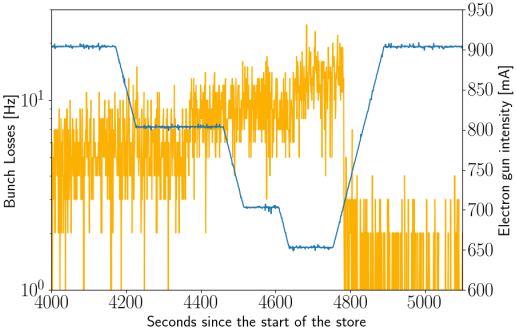

Figure: Bunch loss as a function of the e-lens gun intensity

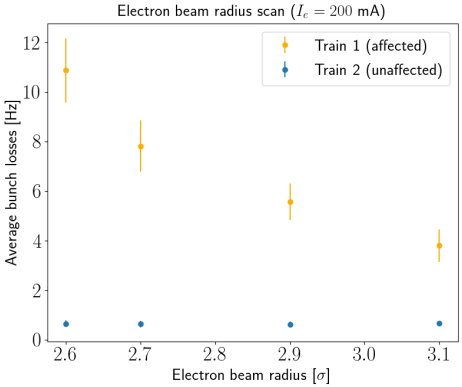

Figure: Average bunch loss as a function of the e-lens radius

During the scan, emittance is shrinking by $\sim 6\%$ in H and $\sim 30\%$ in V.

APEX3 Electron Current Scan

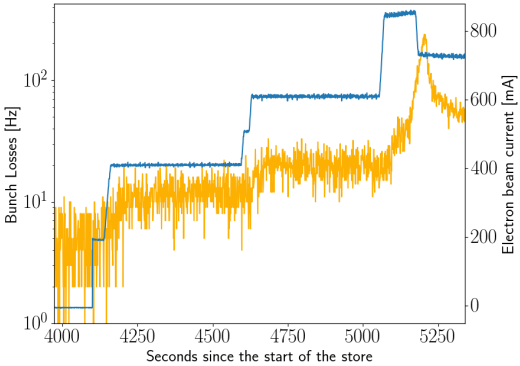

Figure: Bunch loss as a function of the e-lens current

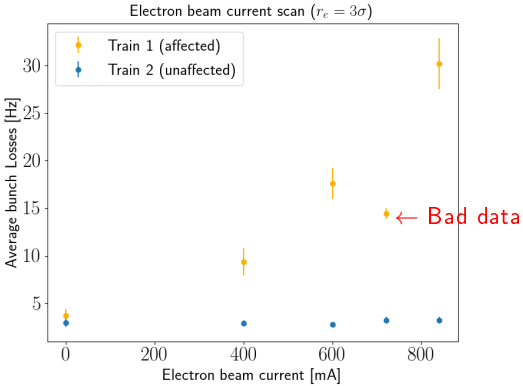

Figure: Average bunch loss as a function of the e-lens current

During the scan, emittance is drifting by $\sim -13\%$ in H and $+\sim 3\%$ in V.

APEX3 Nonlinearities: Chromaticity

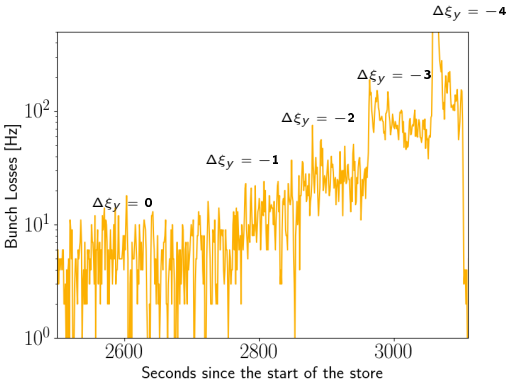

Figure: Bunch loss as a function of the e-lens current

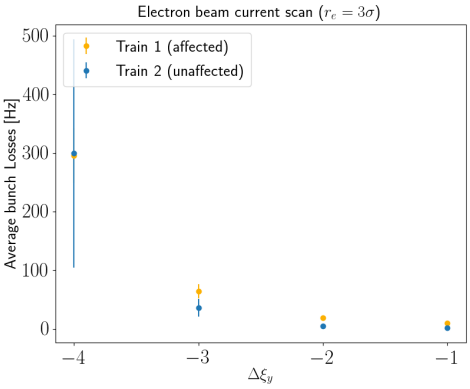

Figure: Average bunch loss as a function of the vertical chromaticity

APEX2 Radius and Current Scan results[4]

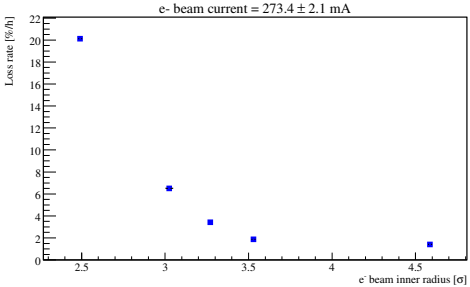

Figure: Total loss rate as a function of the e-lens radius (D. Mirarchi)

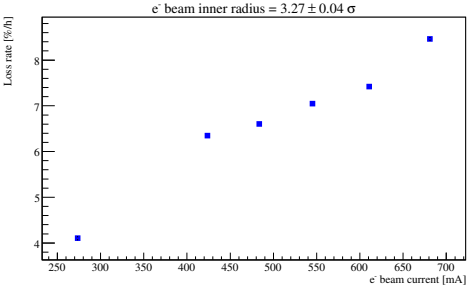

Figure: Total loss rate as a function of the e-lens current (D. Mirarchi)

[4] D. Mirarchi: "Hollow Electron-Lens Assisted Collimation and Plans for the LHC", HB2018

Conclusions and propects

- The RHIC electron lens using the hollow cathode was successfully tested **for the first time** for different particle species at different energies.
- The electron beam radius and current was scanned in two different cases. The effect on beam losses observed was as expected.
- In none of the cases luminosity was propoerly logged. The effect of the e-lens on the beam core cannot be evaluated.
- **Very important results on diffusion speed enhancement were obtained. However, it was not possible to study in detail effects on the beam core. Very important to get more beam time at RHIC.**

Future prospects

- Future tests must ensure that beam-beam is on and luminosity is properly recorded to evaluate the effect of the e-lens in the core distribution.
- Simulations of the e-lens are planned for comparison with the measurements.

We were told the beam was off...