# Collimation with hollow electron beams

*Is the hollow-beam soft scraper a viable complement to collimation systems for high-intensity machines?*

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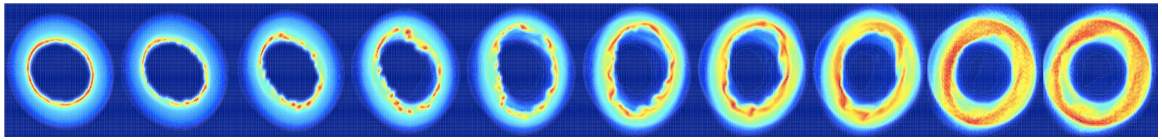
- Project status
- New Tevatron results
- Outlook

*U.S. LHC Accelerator Research Program*
*16th Collaboration Meeting, Montauk, New York, 16-18 May 2011*



# Brief project history up to CM15

- **Summer '09**: Hollow gun design
- **Aug '09**: Hollow gun manufactured and delivered
- **Fall/winter '09**: Hollow beam dynamics studies in test stand
- **August '10**: Hollow gun installed in Tevatron electron lens
- **October '10**: First Tevatron experiments

# Recent progress since CM15

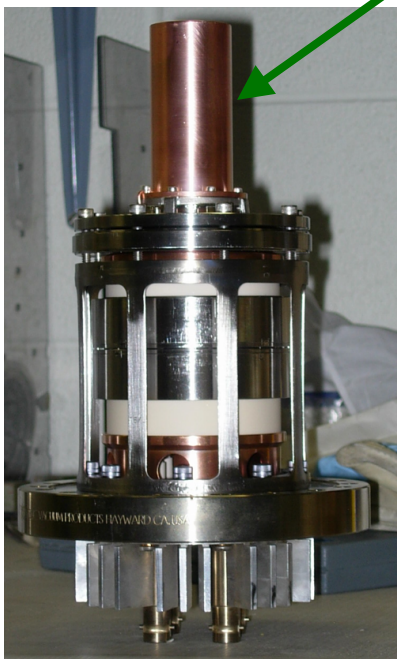
- **October '10 - now (ongoing)**: Tevatron experiments
- **Jan '11**: A. Didenko (contractor engineer) joins for 6 months to design larger (1-inch) gun
- **Feb '11**: I. Morozov (student / guest scientist) joins for 1 year to work on simulations
- **Mar '11**: new gated train-by-train antiproton loss monitors installed near Tevatron secondary collimators

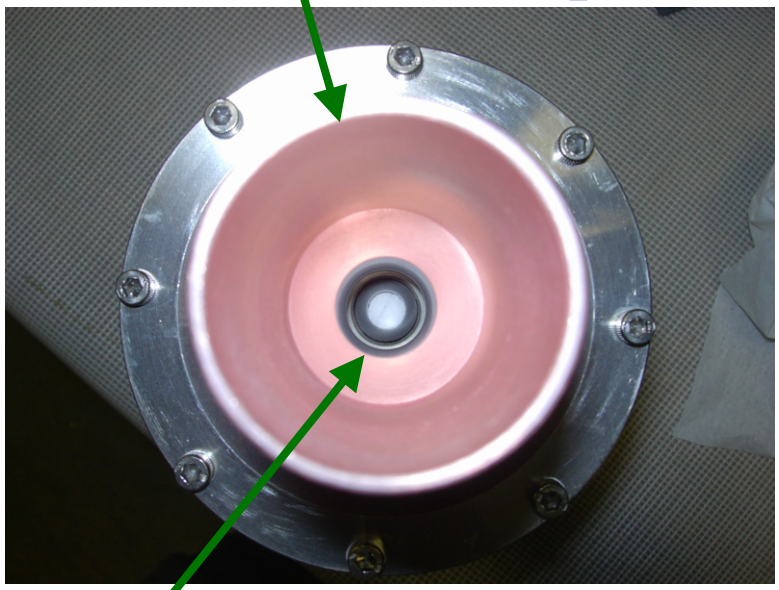
# The 15-mm hollow electron gun

*side view*

Copper anode

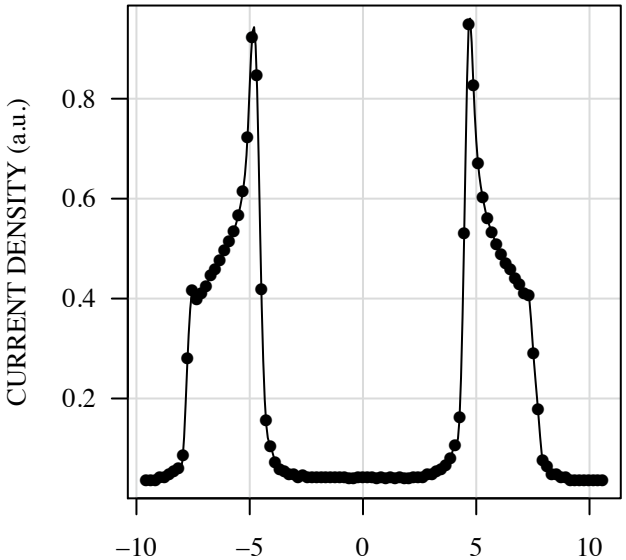
*top view*



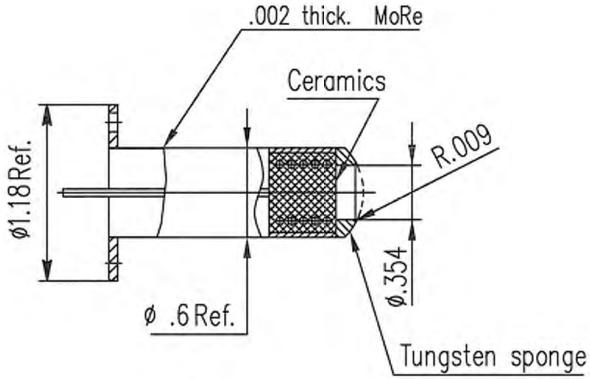


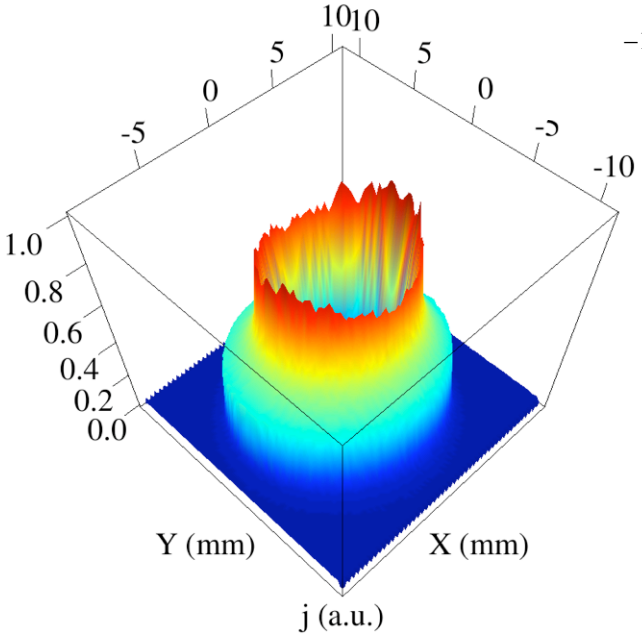
Yield: **1.1 A** at 4.8 kV

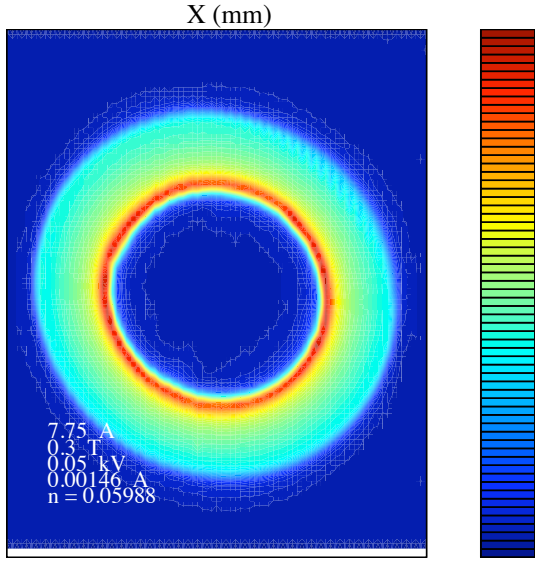
Profile measurements



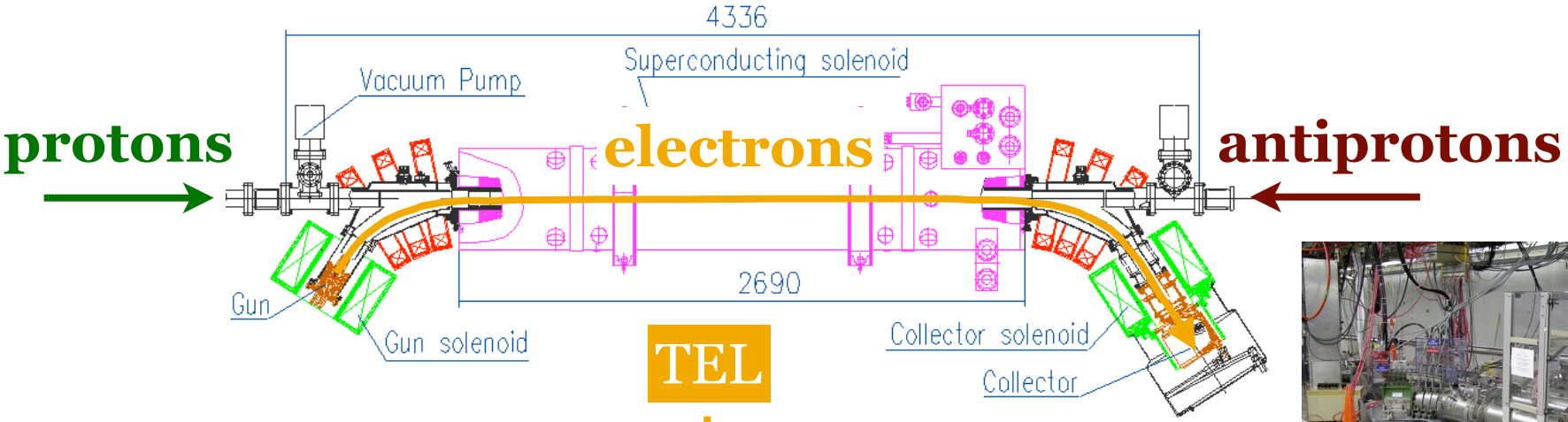

Tungsten dispenser cathode
with convex surface
15-mm diameter, 9-mm hole

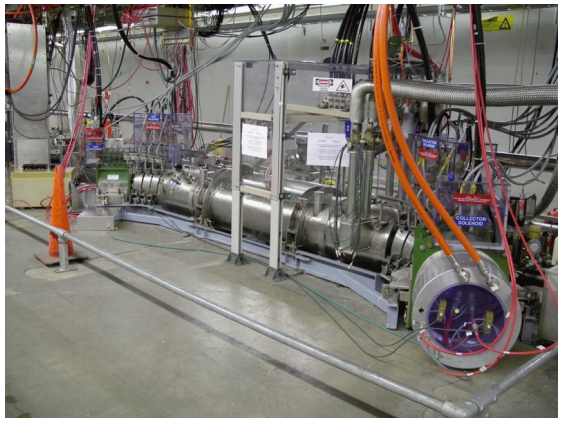


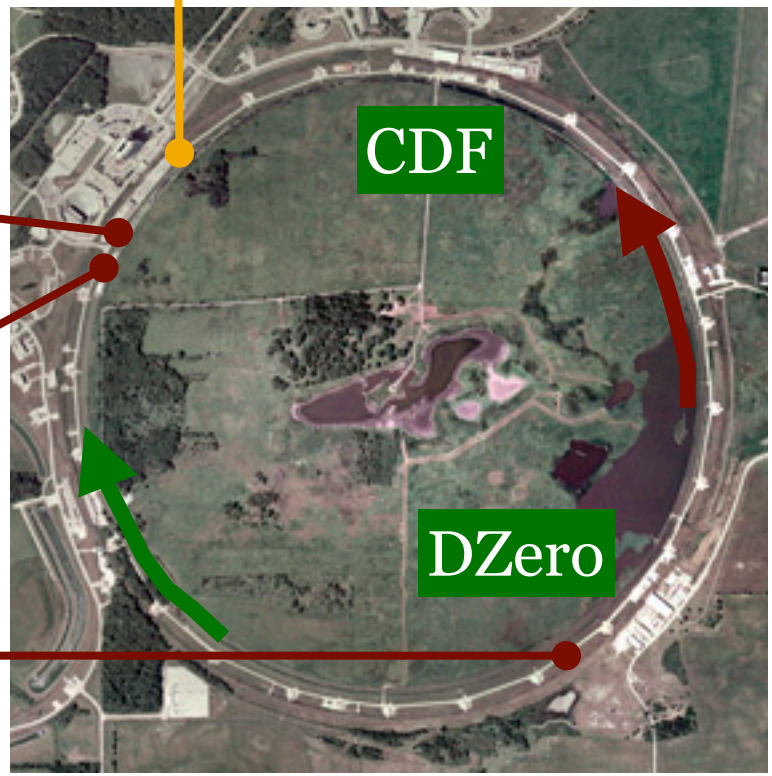
# Layout of the beams in the Tevatron



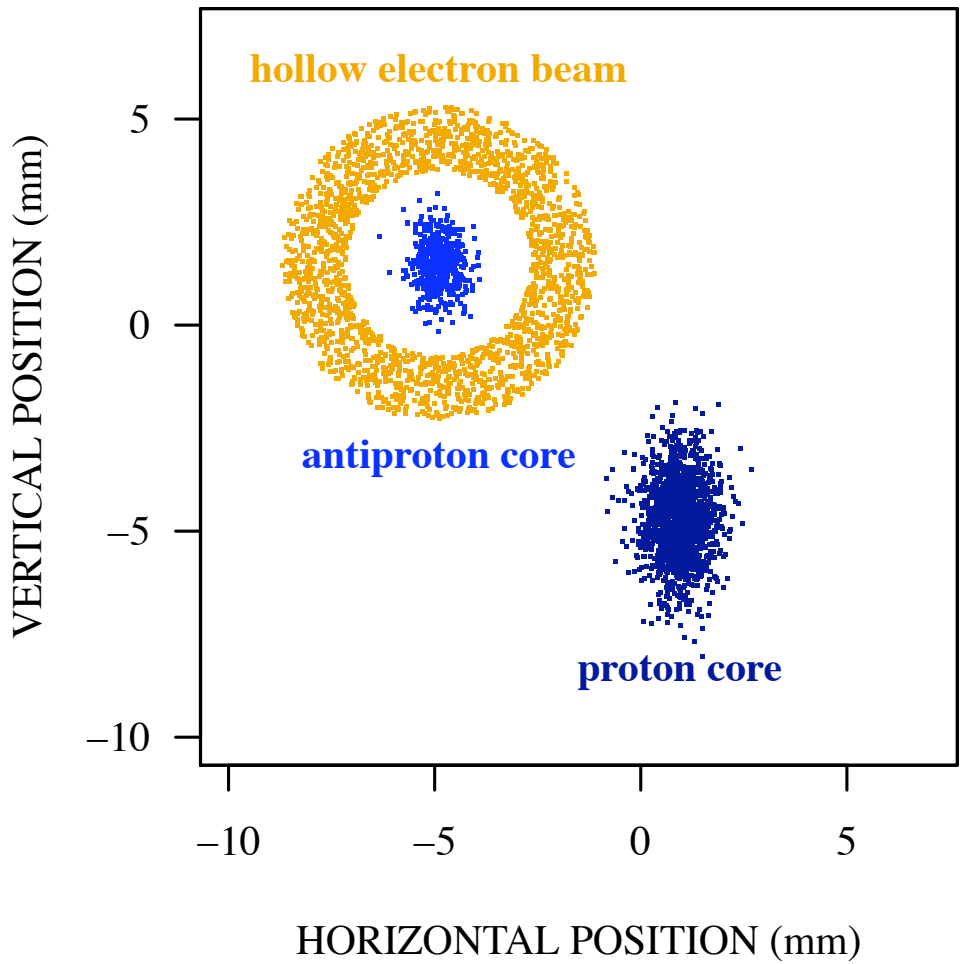
*Tevatron electron lens*

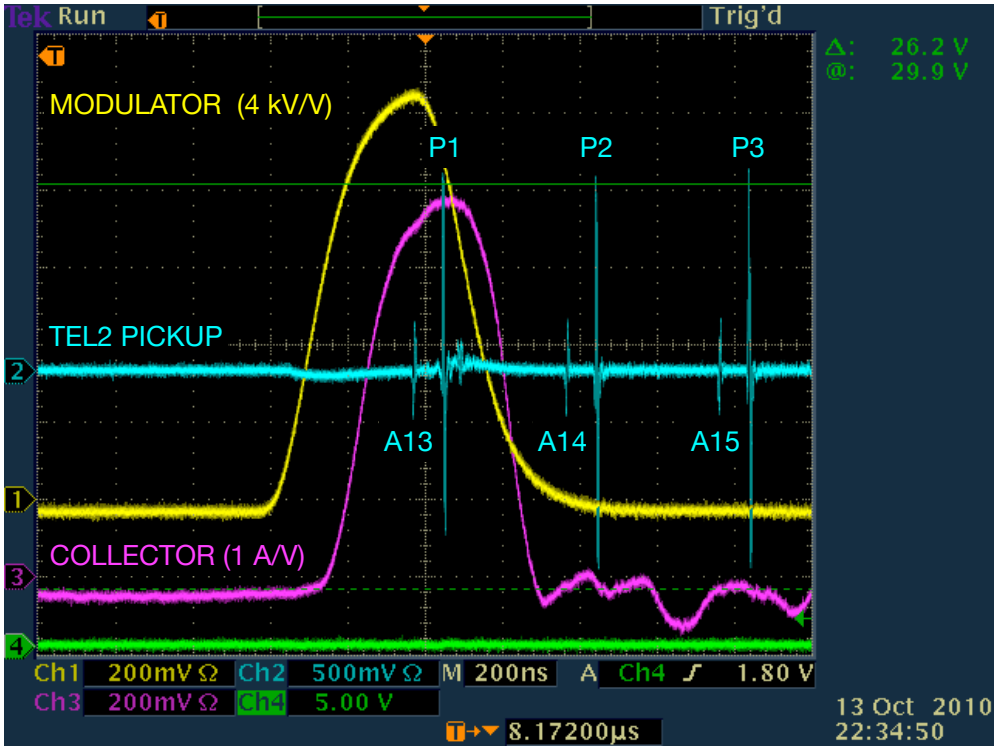
Antiproton collimators:



# Layout of the beams in the Tevatron

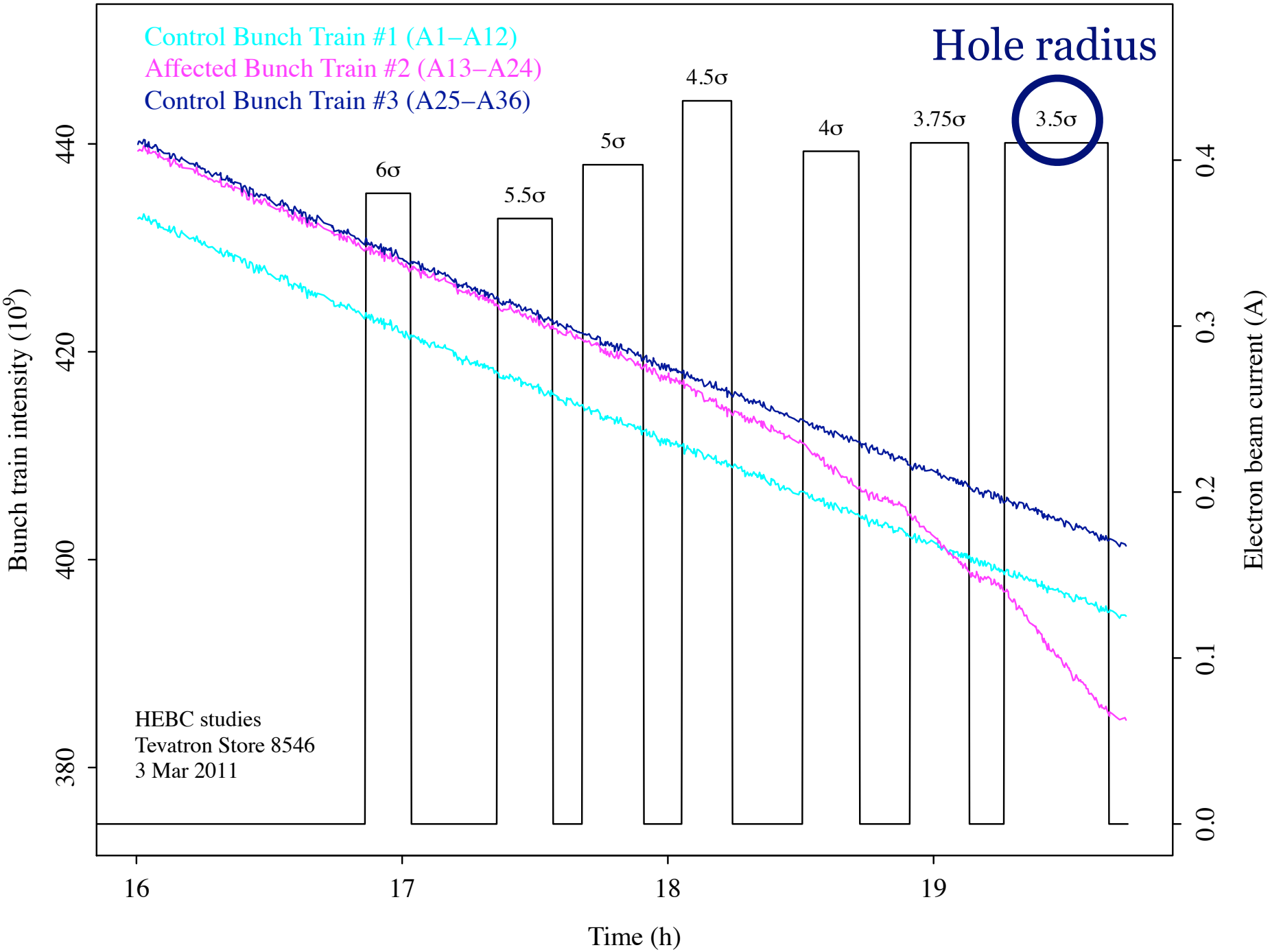
Transverse separation is 9 mm at TEL



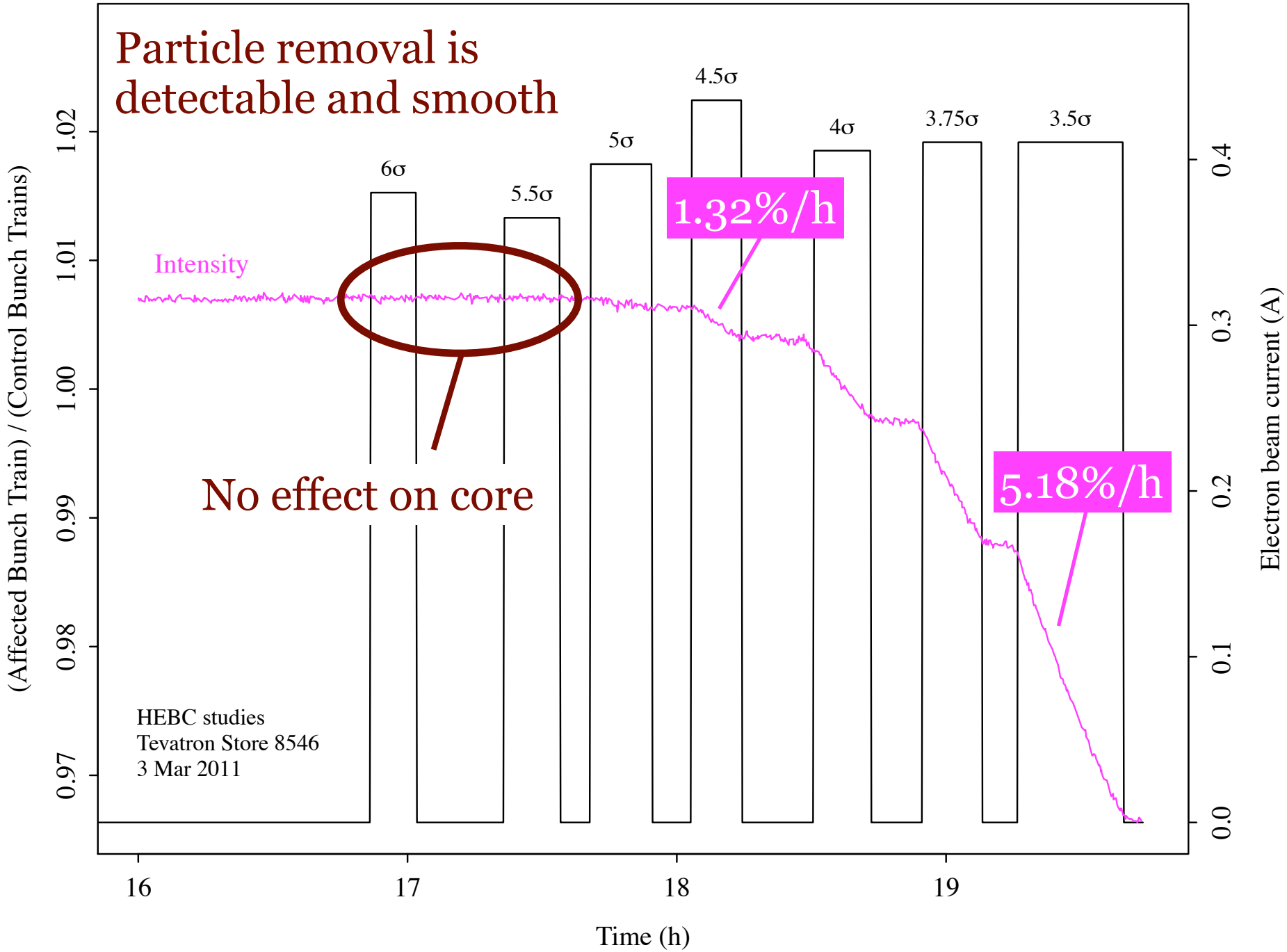




Pulsed electron beam can be synchronized with any group of bunches

# Electrons acting on 1 antiproton bunch train (#2, A13-A24)



# Removal rate: affected bunch train relative to other 2 trains



# Is the core affected? Are particles removed from the halo?

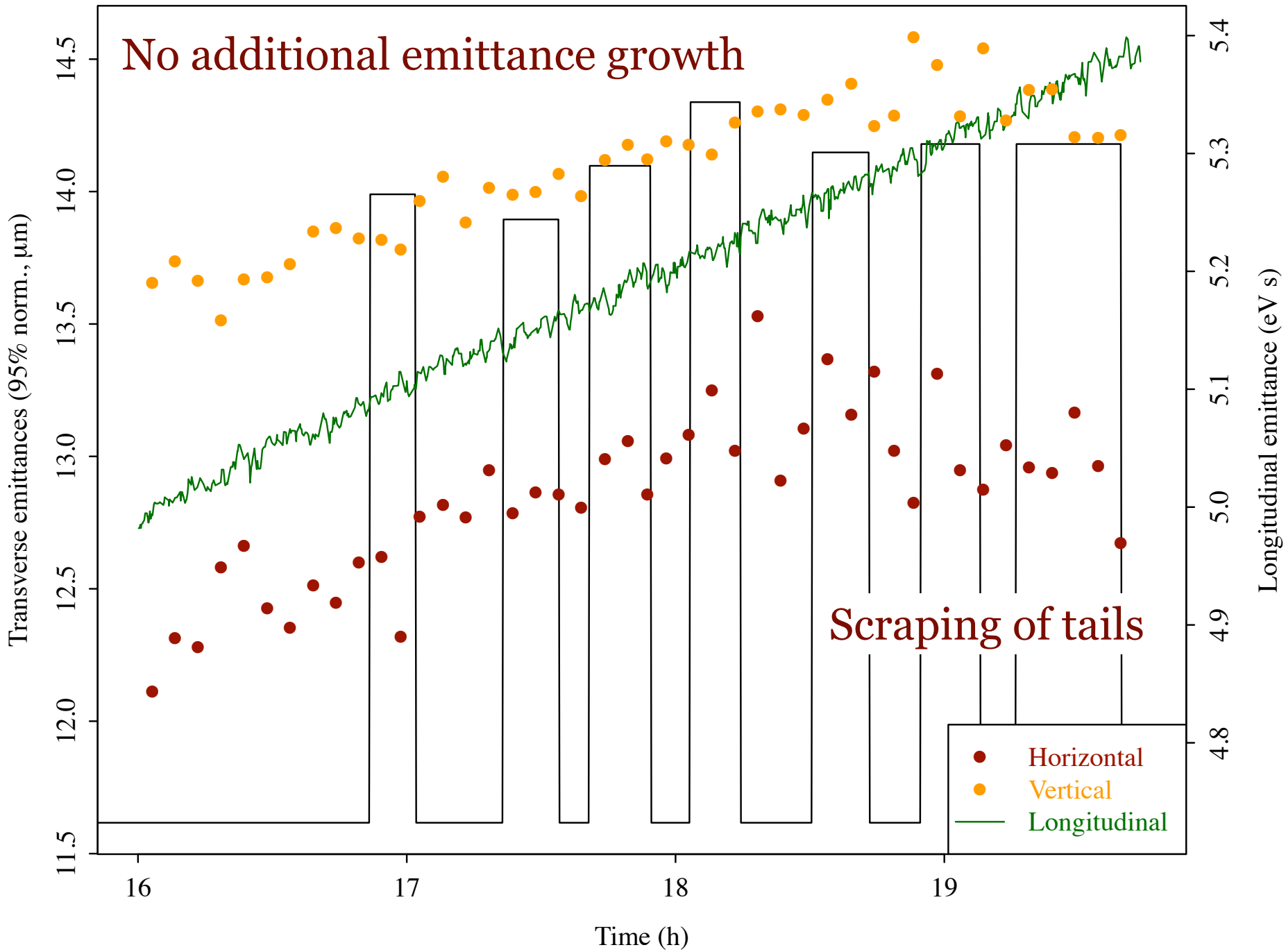
Several strategies:

- **No removal** when e-beam is shadowed by collimators (previous slide)
- Check **emittance** evolution
- Compare **intensity** and **luminosity** change when scraping antiprotons:

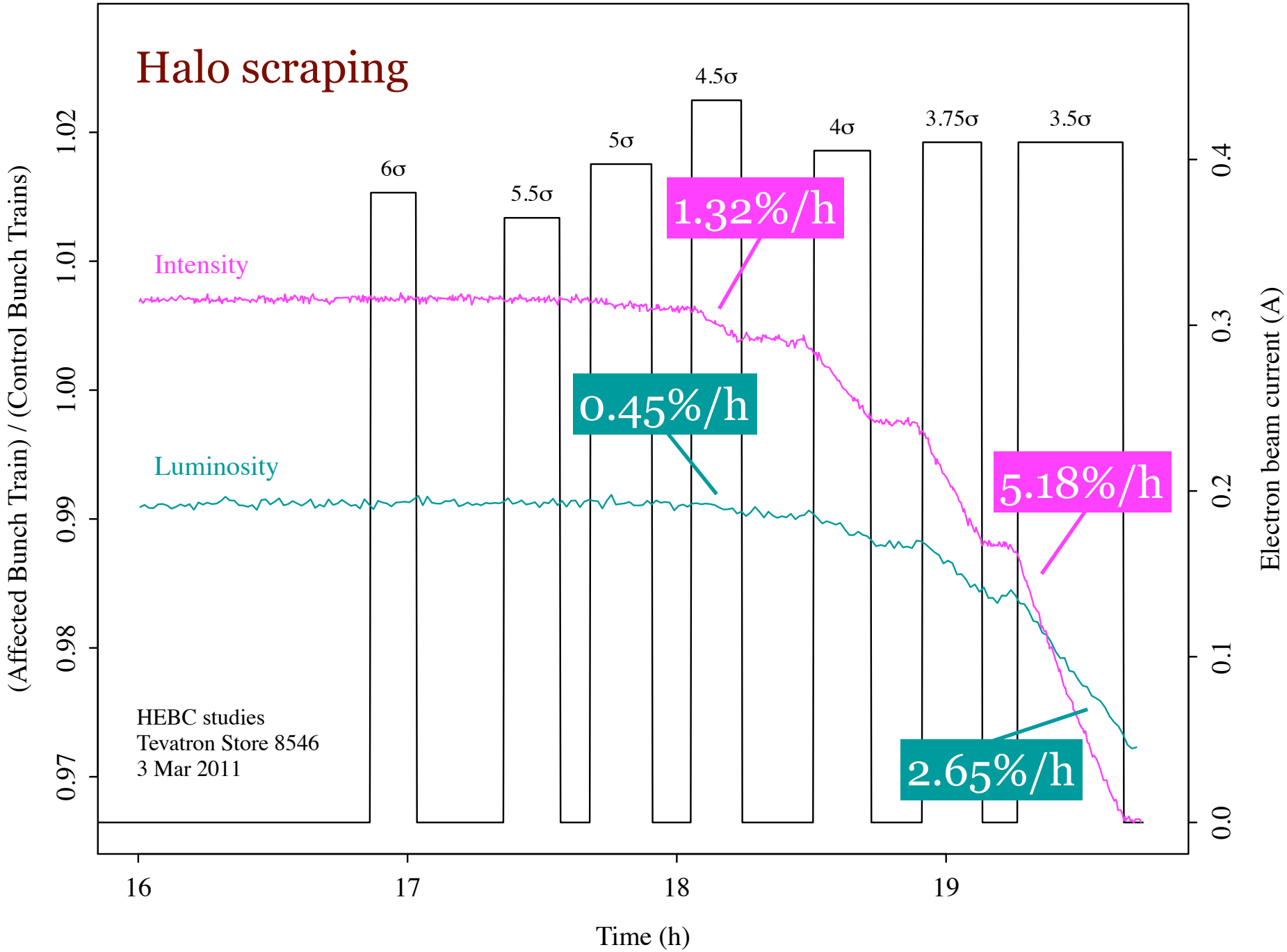
$$\mathcal{L} = \left(\frac{f_{\rm rev} N_b}{4\pi}\right) \frac{N_p N_a}{\sigma^2} \qquad \frac{\Delta\mathcal{L}}{\mathcal{L}} = \frac{\Delta N_p}{N_p} + \frac{\Delta N_a}{N_a} - 2\frac{\Delta\sigma}{\sigma}$$

  - <u>same fractional variation</u> if other factors are constant
  - luminosity decreases <u>more</u> if there is emittance growth or proton loss
  - luminosity decreases <u>less</u> if removing halo particles (smaller relative contribution to luminosity)
- **Removal rate** vs. amplitude (collimator scan, steady state)
- **Diffusion rate** vs. amplitude (collimator scan, time evolution of losses)

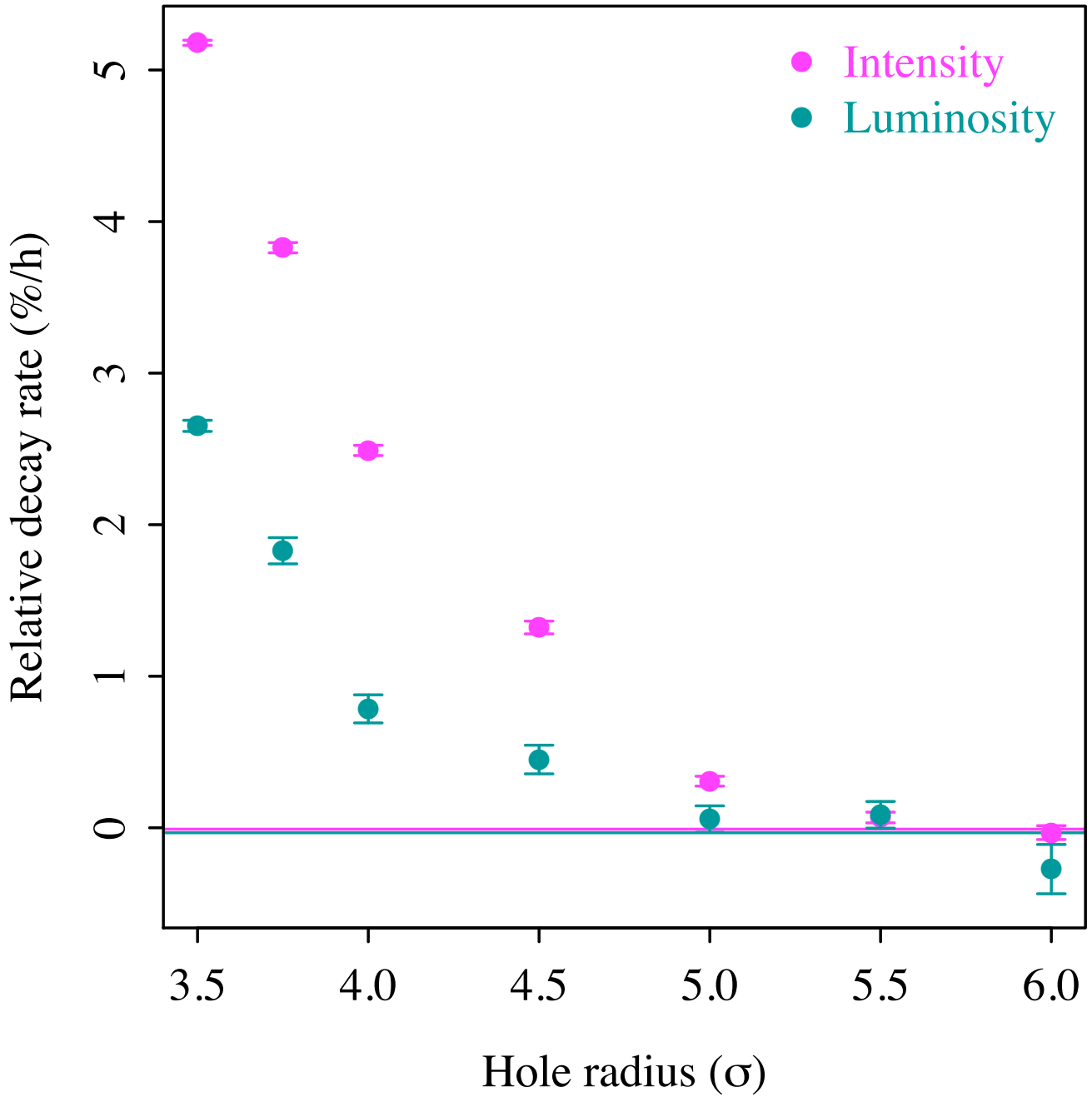
# Emittances of affected bunch train



# Luminosity of affected bunch train relative to other 2 trains

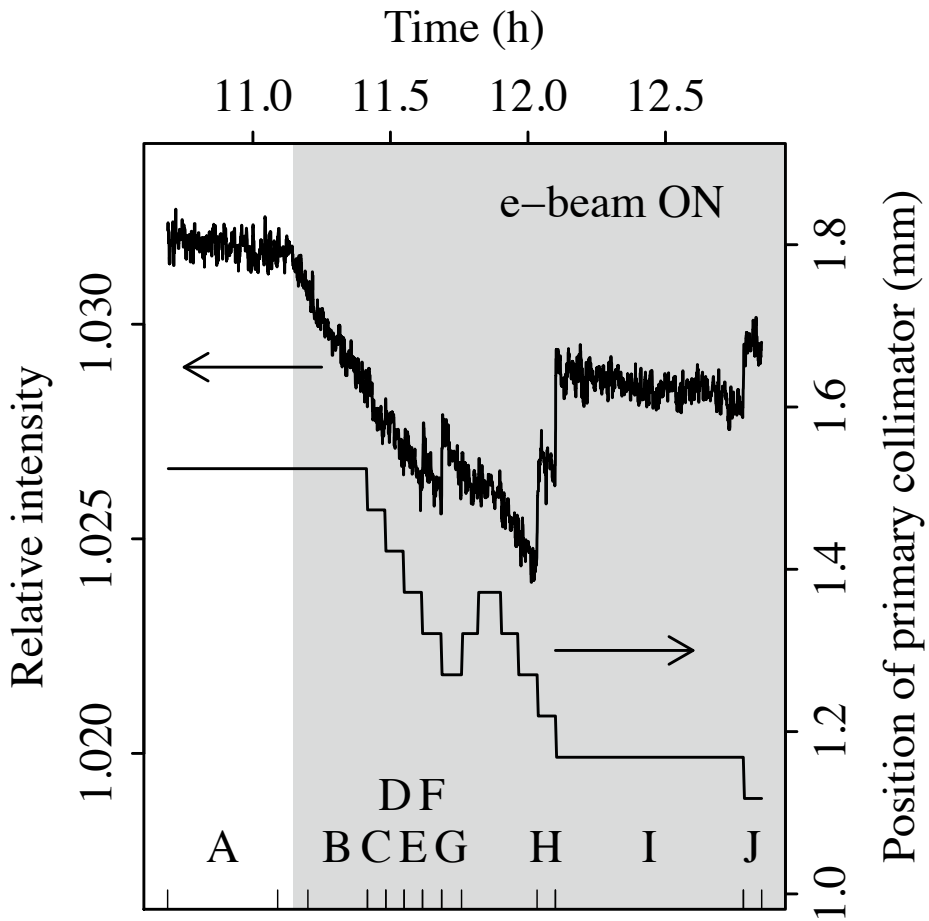


# Relative decay rates

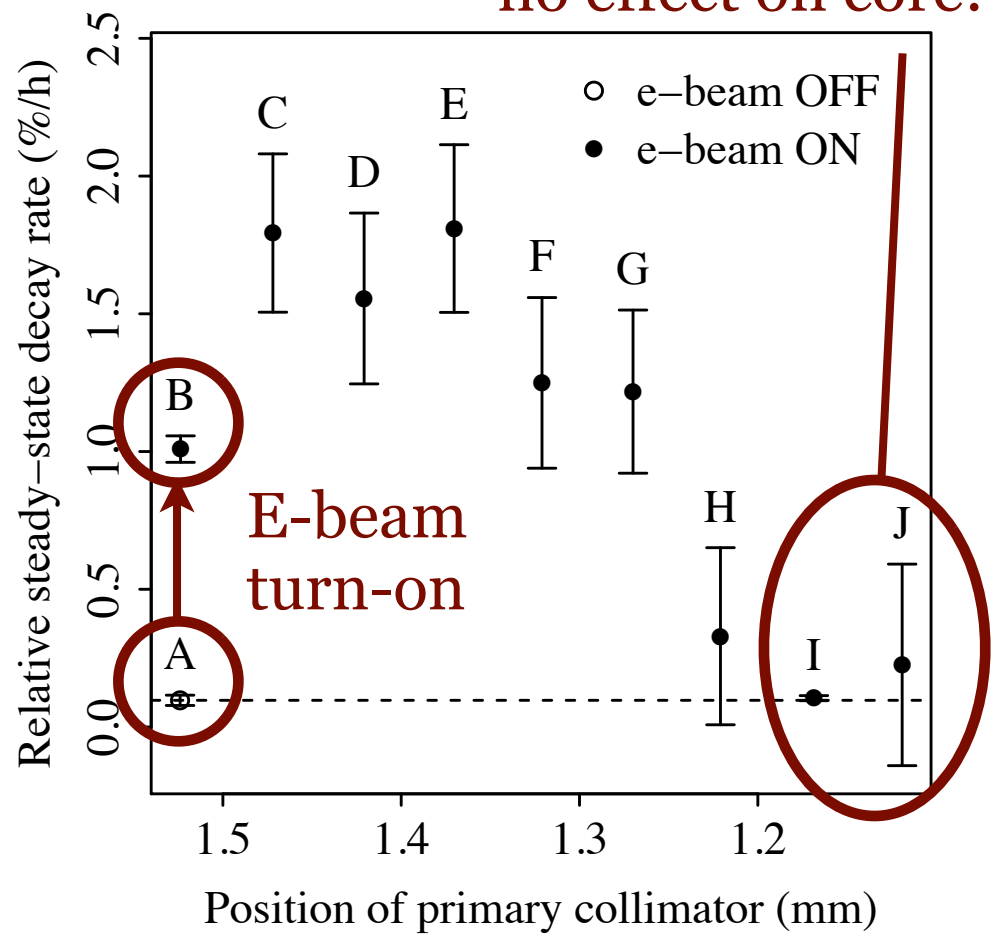


# Removal rate vs. amplitude from collimator scan

Electrons (0.15 A) on pbar train #2, 3.5σ hole (1.3 mm at collimator)
Vertical scan of primary collimator (others retracted)



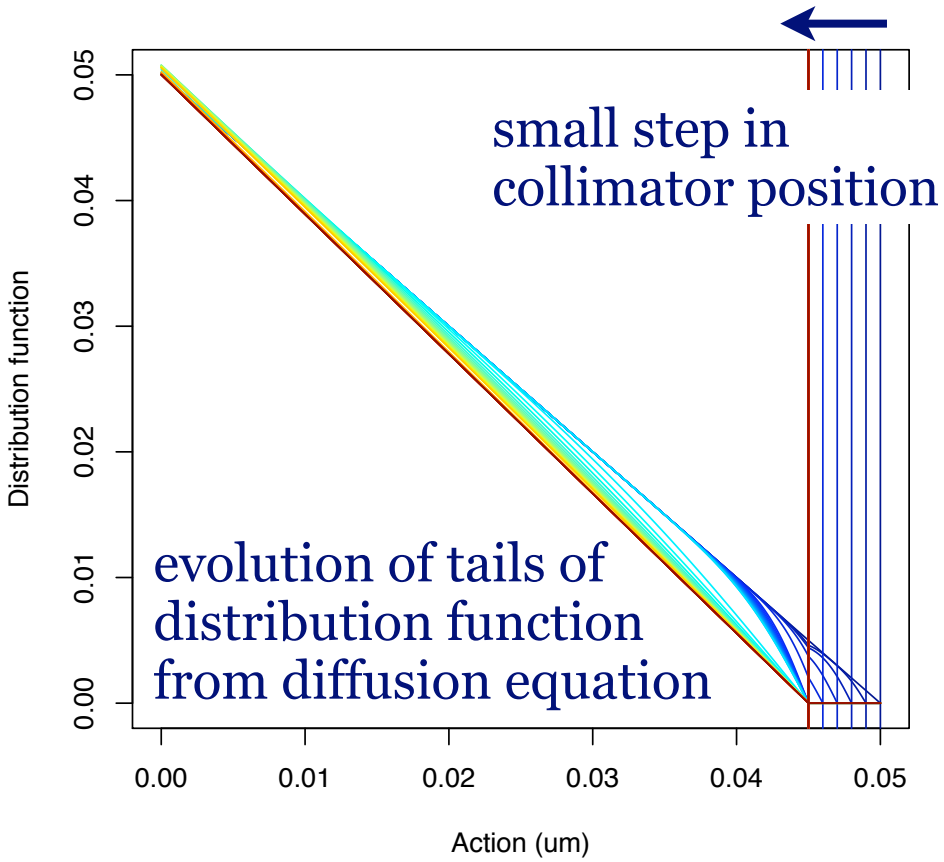

E-beam shadowed, no effect on core!

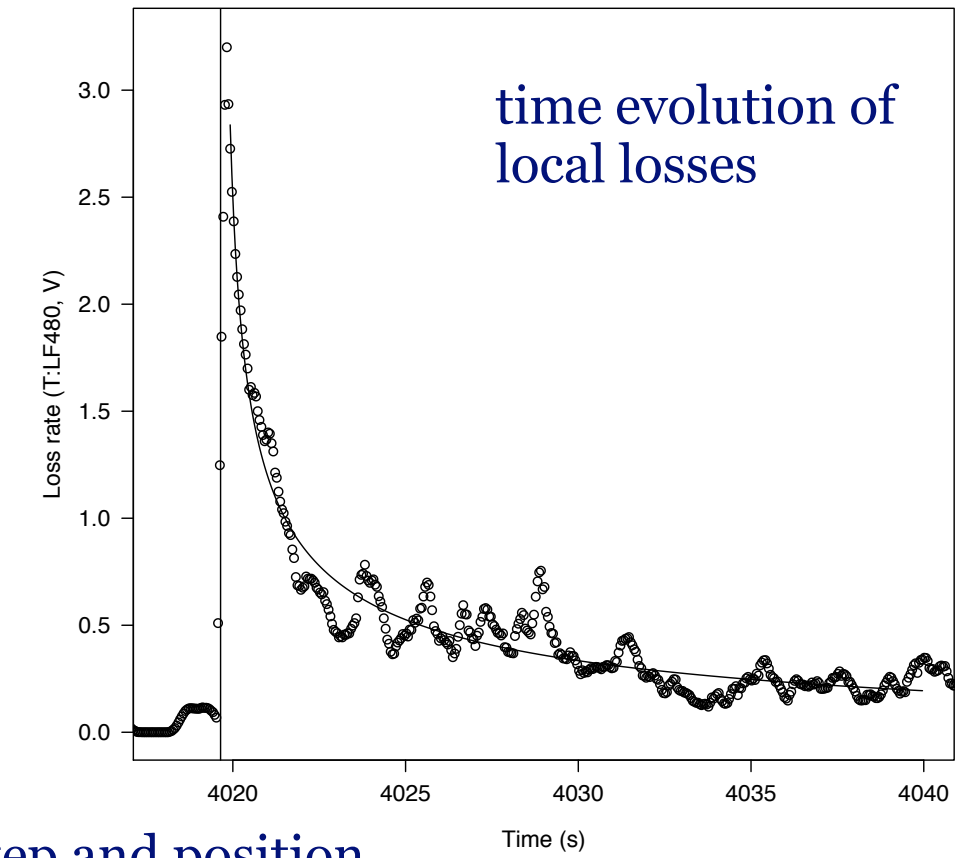



down towards beam axis

# Diffusion rate vs. amplitude from collimator scans

Mess and Seidel, NIM A **351**, 279 (1994)




observed loss rate

collimator step and position

background

$$L(t) = a_1 \left\{ 1 + \frac{|\Delta x_c| / x_c}{\sqrt{\pi R (t - t_0)}} \right\} + a_0$$

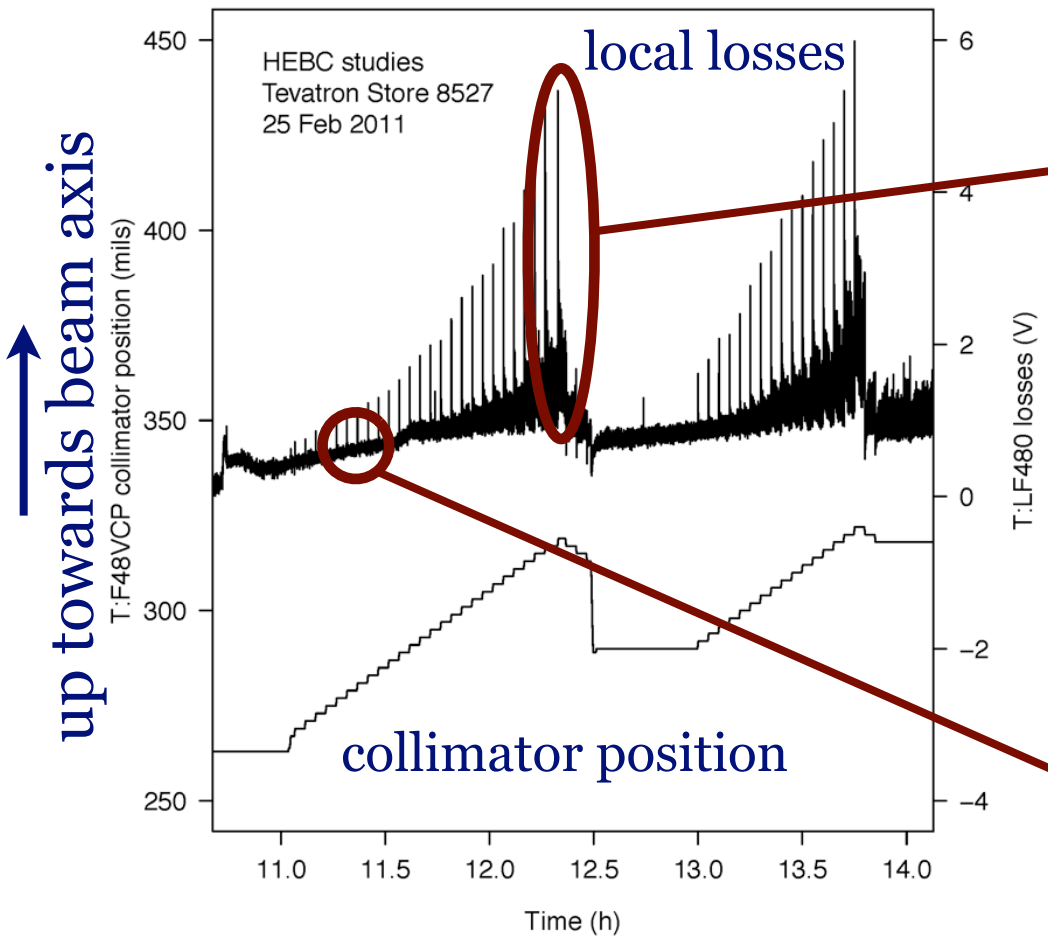
normalization (intensity, efficiency, ...)

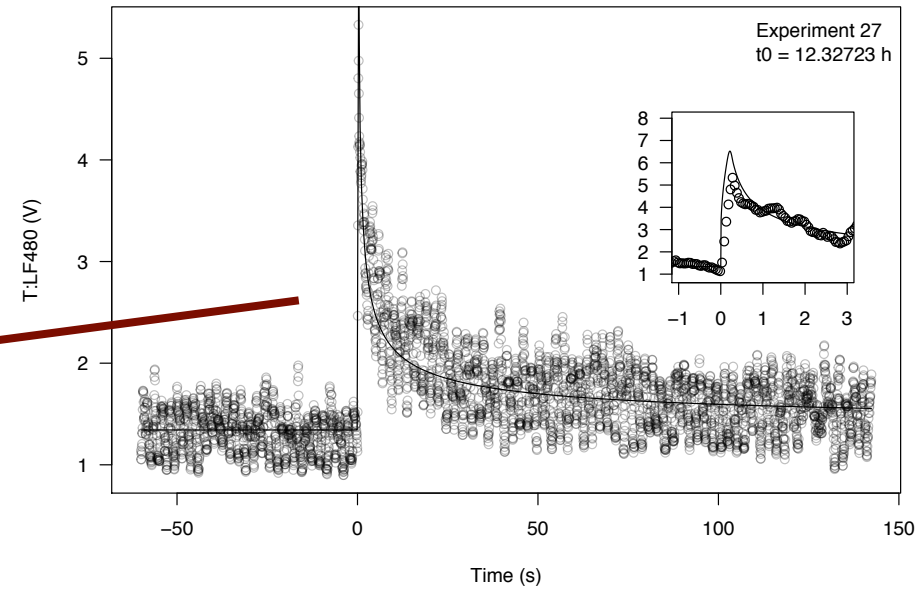
parameter related to diffusion rate

$$D = R \cdot x_c^4 / \beta_c^2$$

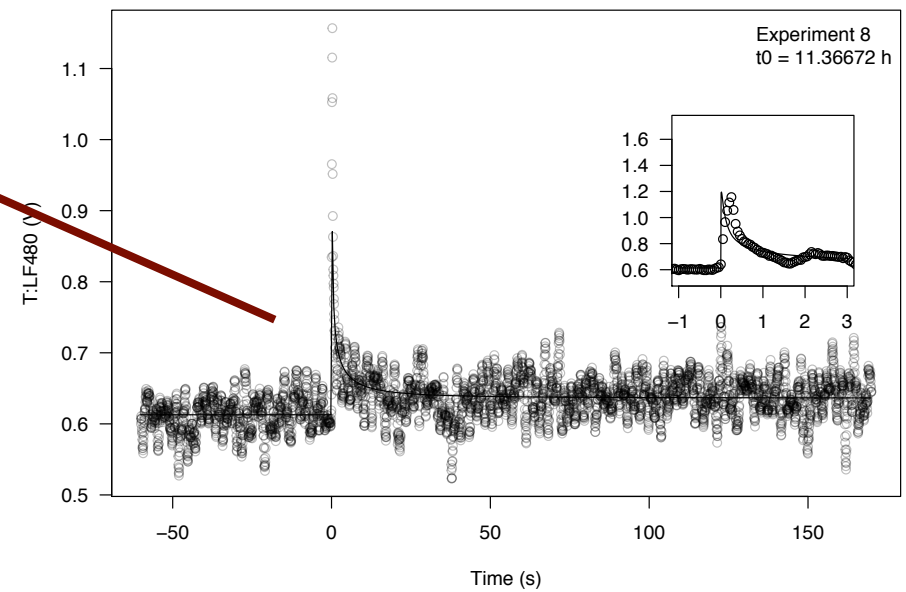
# Diffusion rate vs. amplitude from collimator scans

## Vertical secondary collimator scan

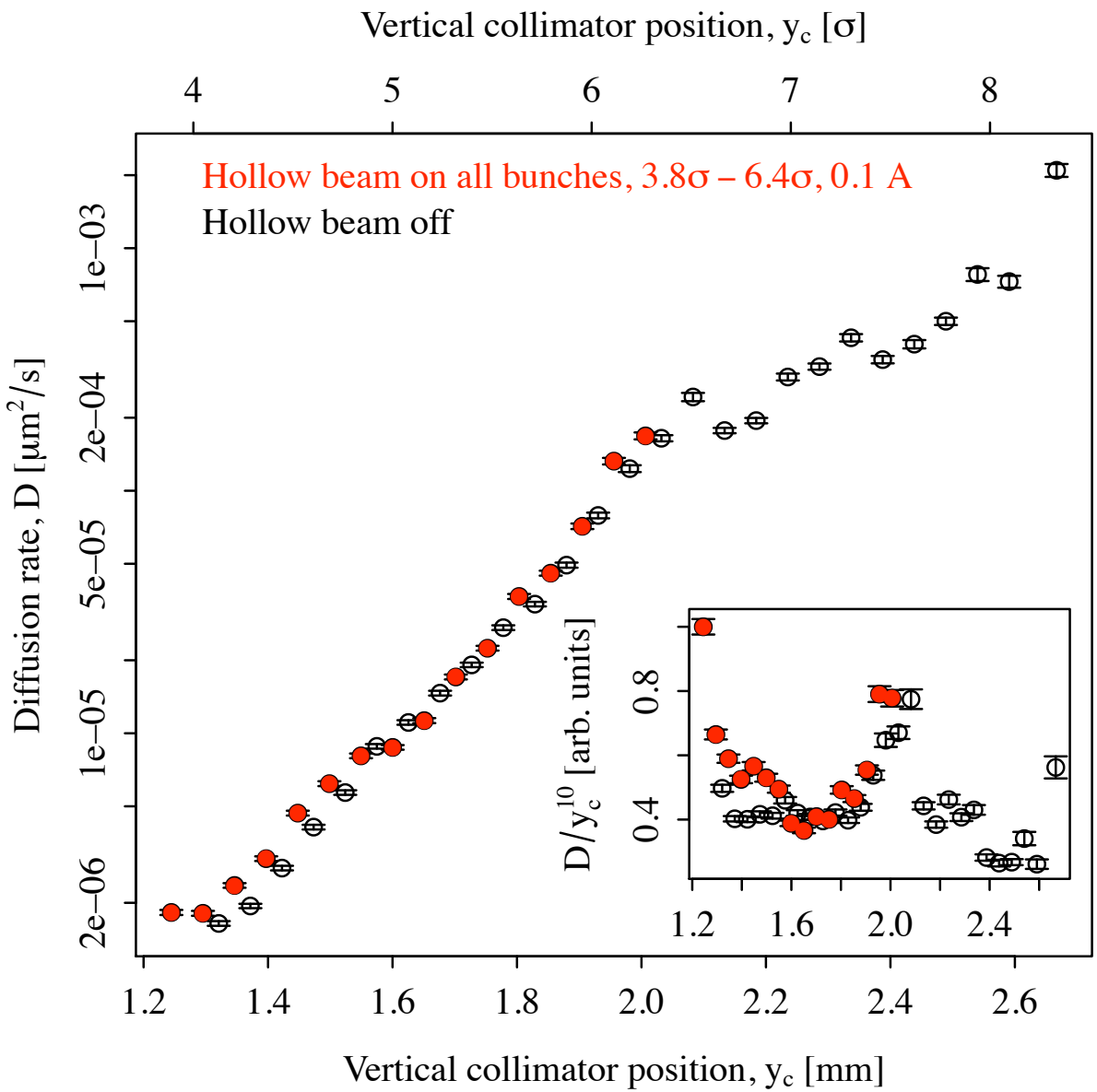



Tails repopulate faster at large amplitudes (higher diffusion rate)



# Diffusion rate vs. amplitude - preliminary




- First measurement of diffusion rates in Tevatron
- Effect of e-lens is detectable, but need gated loss monitors

# Recent progress since CM15

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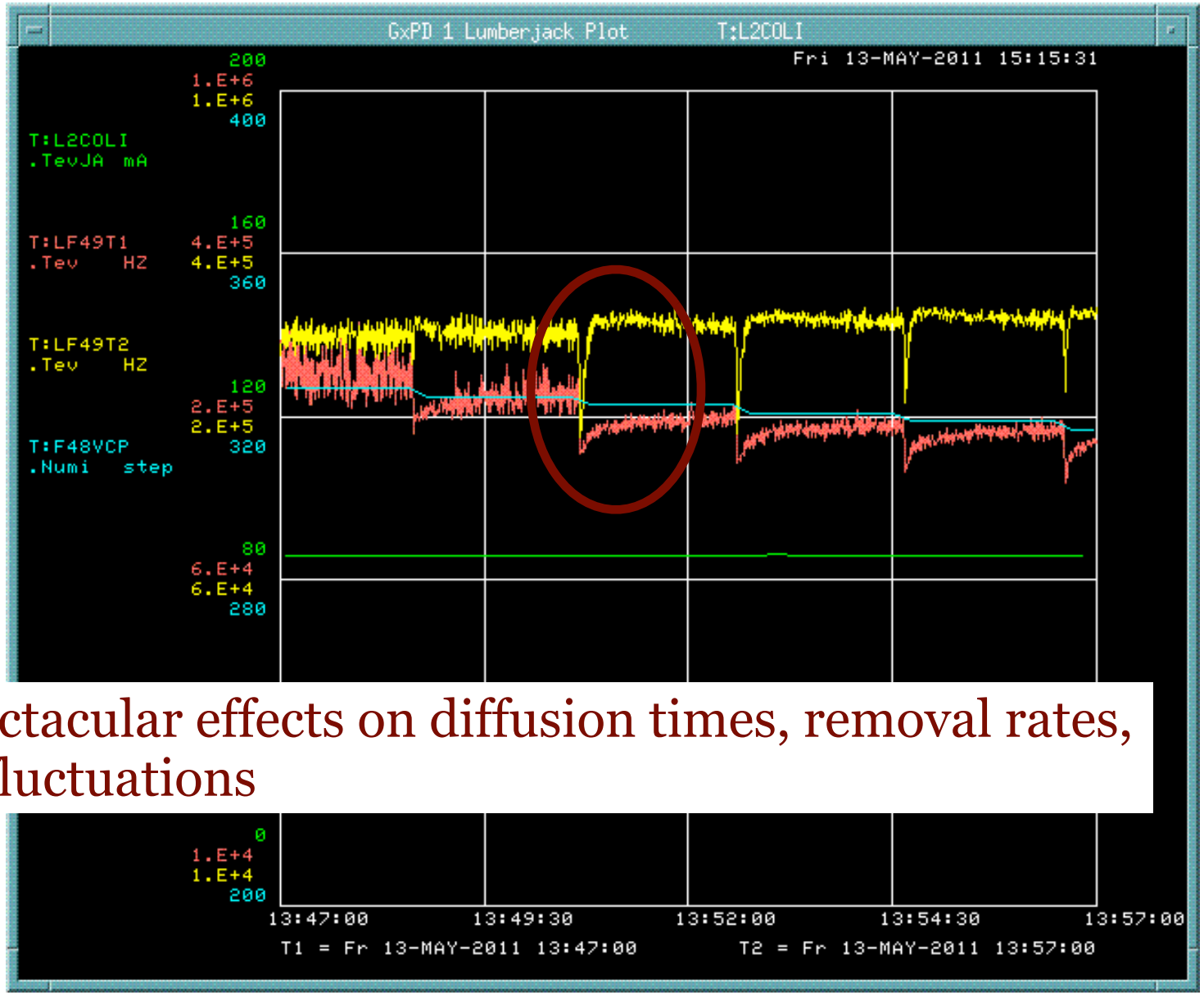
# New gated antiproton loss monitors

- Scintillator paddles installed near F49 antiproton absorber
- Gated to individual bunch trains
- Logged at 15 Hz

For simultaneous measurements of **diffusion rates**, **collimation efficiency**, and **loss spikes** on affected and control bunch trains at maximum electron currents

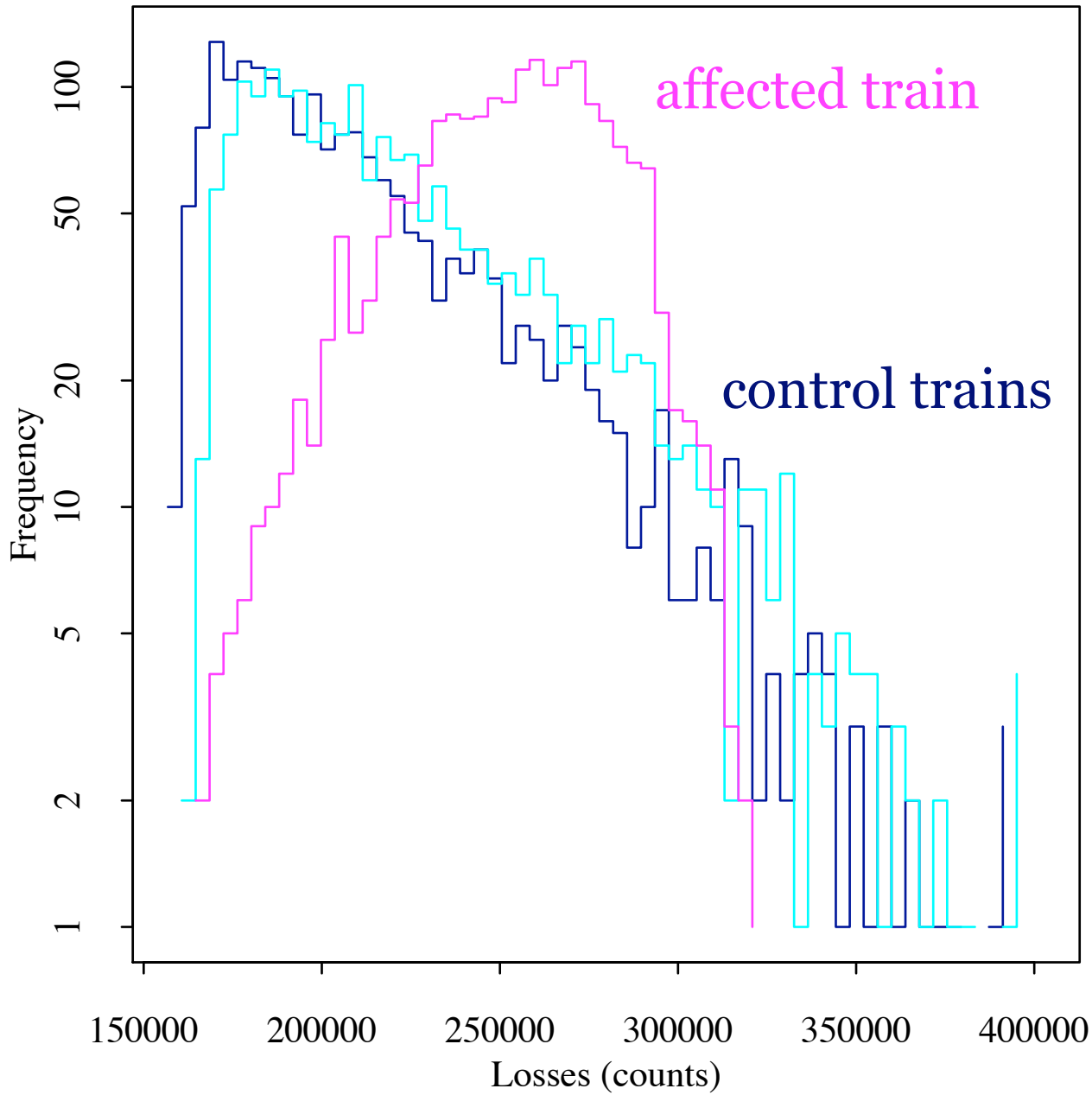
# Gated losses during collimator scan (May 13) - preliminary

Electrons (0.4 A) on pbar train #2, 4σ hole
Vertical scan of primary collimator (others retracted)

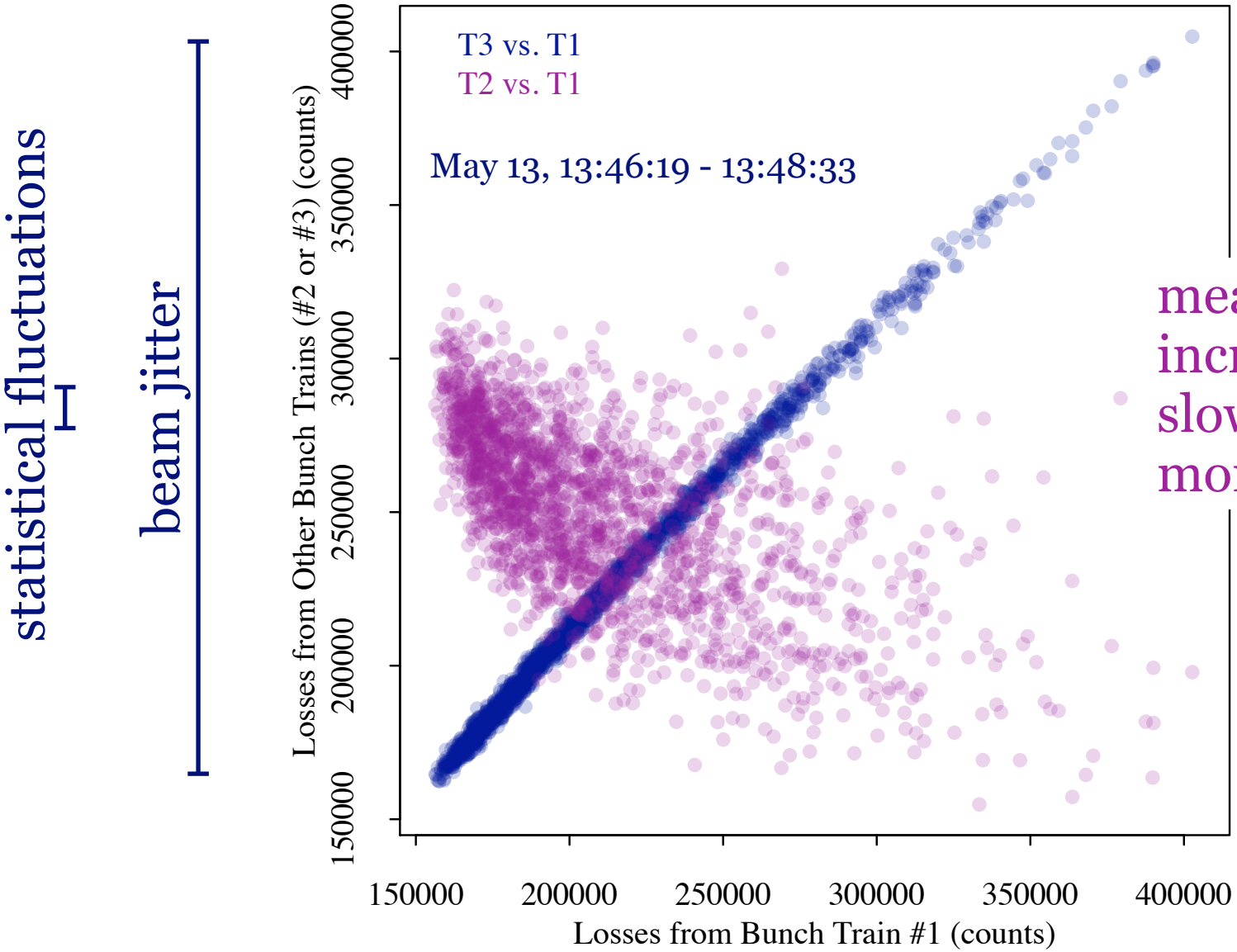



Quite spectacular effects on diffusion times, removal rates, and loss fluctuations

# Distribution of losses



# Correlation of losses - preliminary




mean losses increased by 20%, slow spikes (~< Hz) more than halved

Hollow beam eliminates correlations among trains.
Interpretation: larger diffusion rate, lower tail population, less sensitive to jitter

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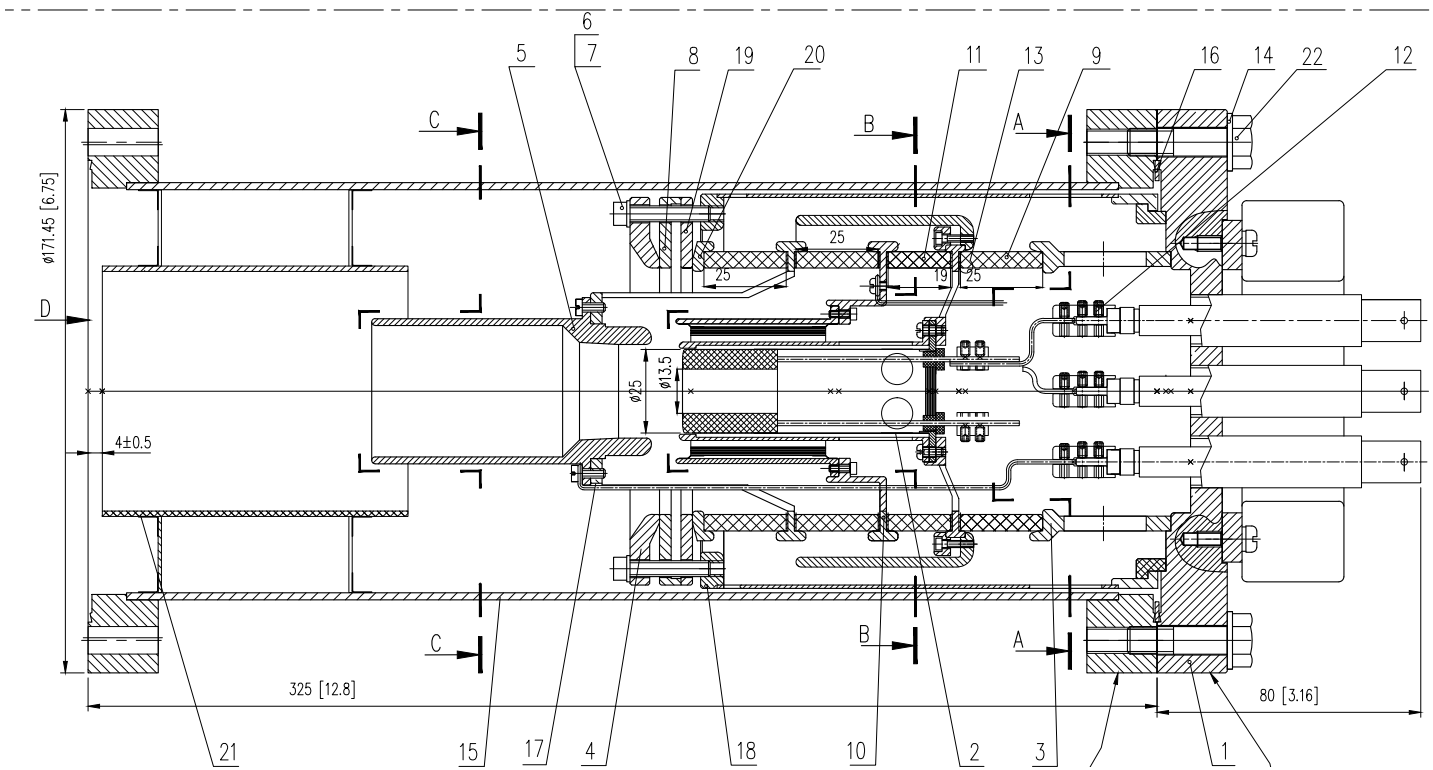
# Design of larger (1-inch) hollow gun

- 25 mm outer diameter, 13.5 mm inner diameter
- Up to 3 A at 5 kV




- Goal: To test technical feasibility
- Characterization in Fermilab electron-lens test stand
- Installation in Tevatron unlikely

# Conclusions and outlook

- Amazing progress in understanding of hollow beam collimation, thanks to dedicated collaborators and support staff
- Many new observations: halo removal rates, effects on core, diffusion, fluctuations in losses, collimation efficiencies, …
- Dedicated "end-of-run" Tevatron studies (May 20-27): ~6 h
- Requested more dedicated studies (now-August)
- Characterization of 1-inch gun in test stand (September)
- Proposals for next year:
  - validate Tevatron simulations
  - study applicability to LHC
  - transfer experimental program and TEL2 hardware

*Thanks for your attention*