LARP

Beam-Beam Modeling and Electron Lens Work

A.Valishev, FNAL

LARP DOE Review, 7/15/2010

Outline

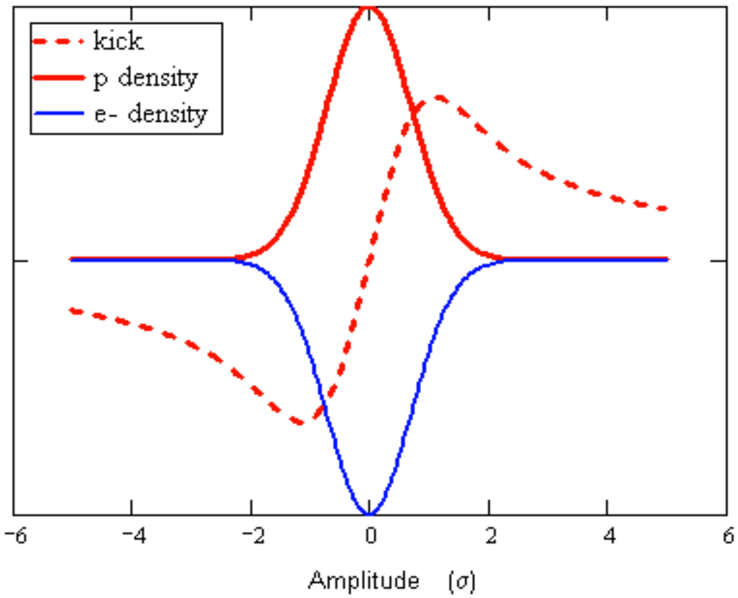
- Electron lens concept
- Beam-beam task scope and goals in FY10
- Status and achievements
  - Tevatron electron lens studies
  - Beam-beam simulations
    - RHIC BB and BBC
    - LHC BB and BBC
  - Hollow electron lens collimator
- Plans

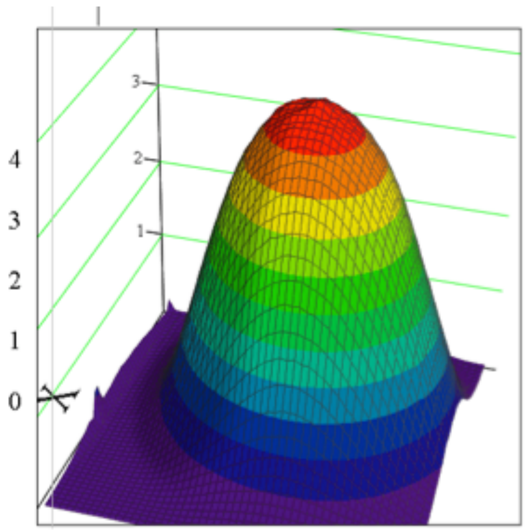
Electron Lens Concept

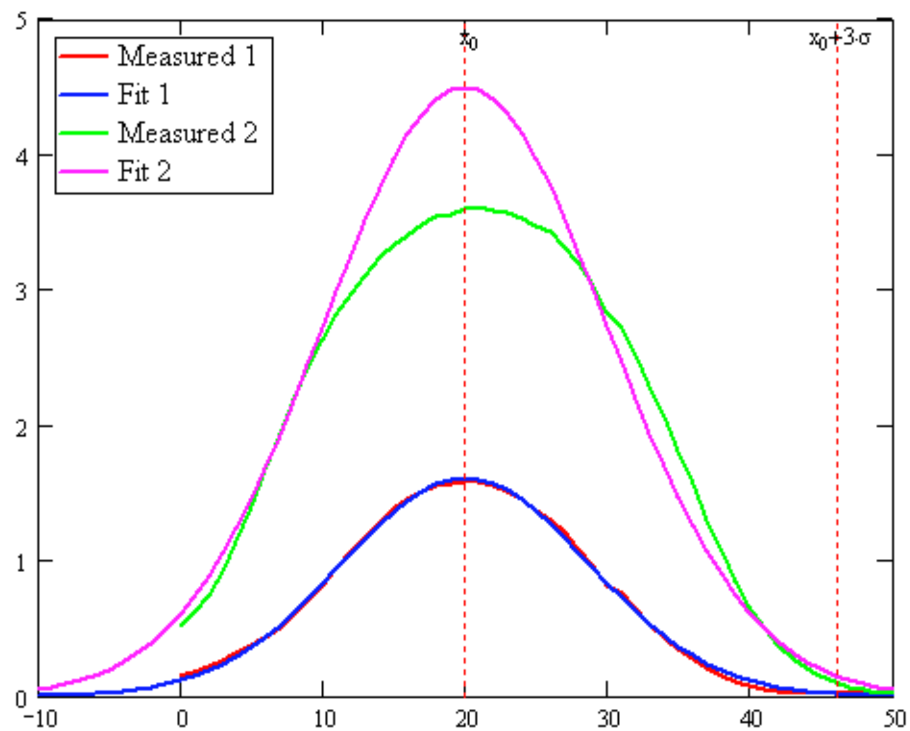
- Electron lens is a low energy electron beam (5-10 kV) that interacts with circulating hadron beam
- e- beam with proper shape of transverse charge density distribution can be used to compensate head-on beam-beam effect
- 2 electron lenses are installed at the Tevatron (TEL). Used for correction of bunch-by-bunch long-range beam-beam tune shift and for abort gap cleaning
- 2 electron lenses are under construction at RHIC, funded by ARRA

Head-on Compensation with Gaussian e- Beam

- Beam-beam kick can not be mimicked by magnetic lenses
- Proton beam has distribution close to Gaussian -> need Gaussian e-beam for compensation
- Gaussian gun was installed in TEL-2 in June 2009





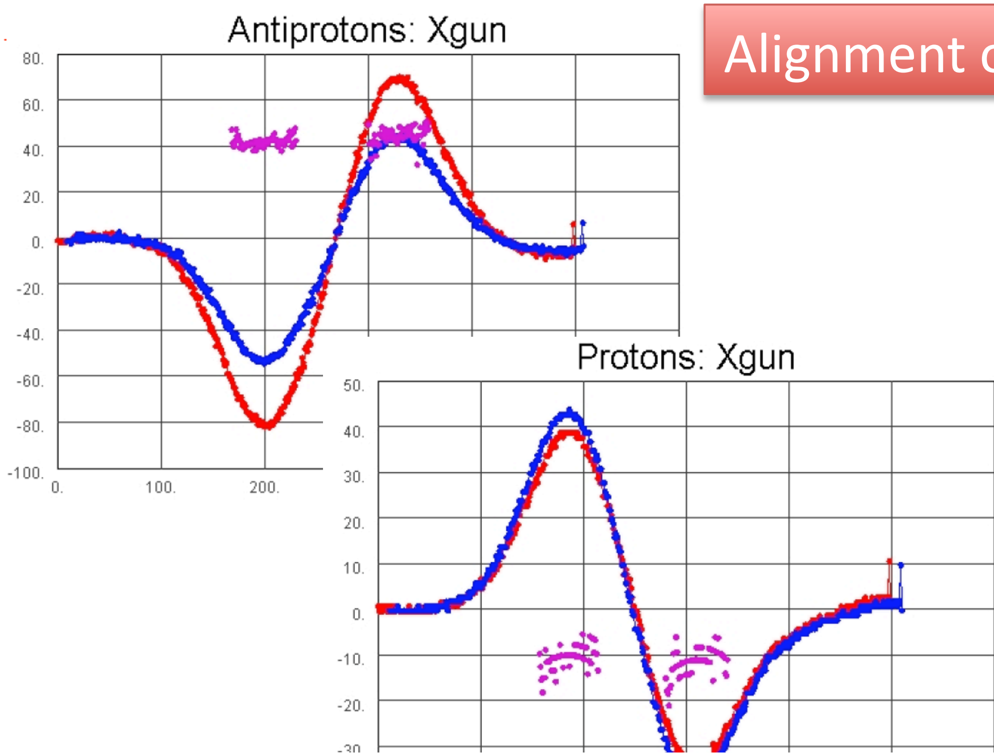


FY10 Goals

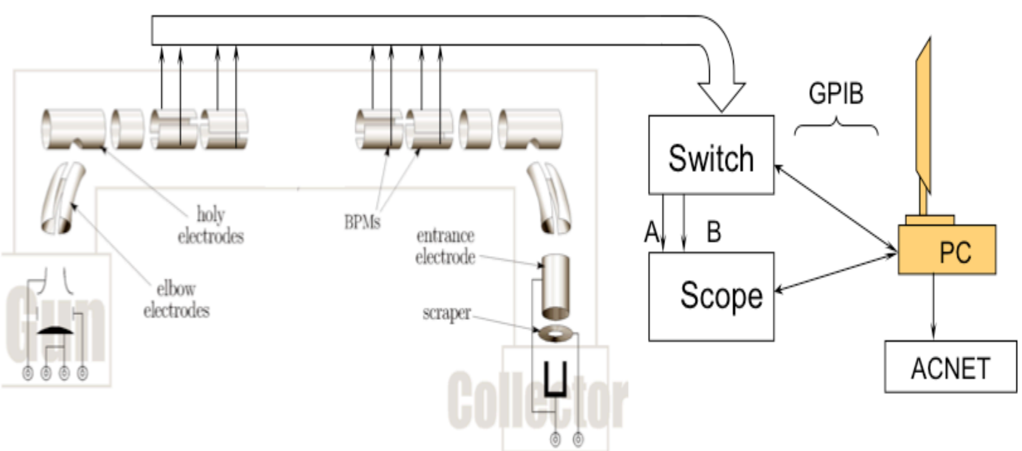
- Experiments with Gaussian EL at Tevatron
  - In normal collider operation, beam-beam effects in antiprotons are dominated by long-range collisions. Hence, luminosity performance can not be improved by head-on compensation
  - Observe effect of the Gaussian e- beam on proton/pbar tune spread
  - Demonstrate that HO BBC does not lead to life time degradation
  - Study effects of various imperfections
  - Provide input for simulations
- Numerical simulations of beam-beam effects and BBC
  - Develop simulation codes
  - Support design of RHIC EL
  - Simulate beam-beam effects at LHC and study prospects for EL BBC
- Development of hollow e- beam collimator
  - Numerical simulations of interaction of HEB with proton beam
  - Tests of HEBC at Tevatron

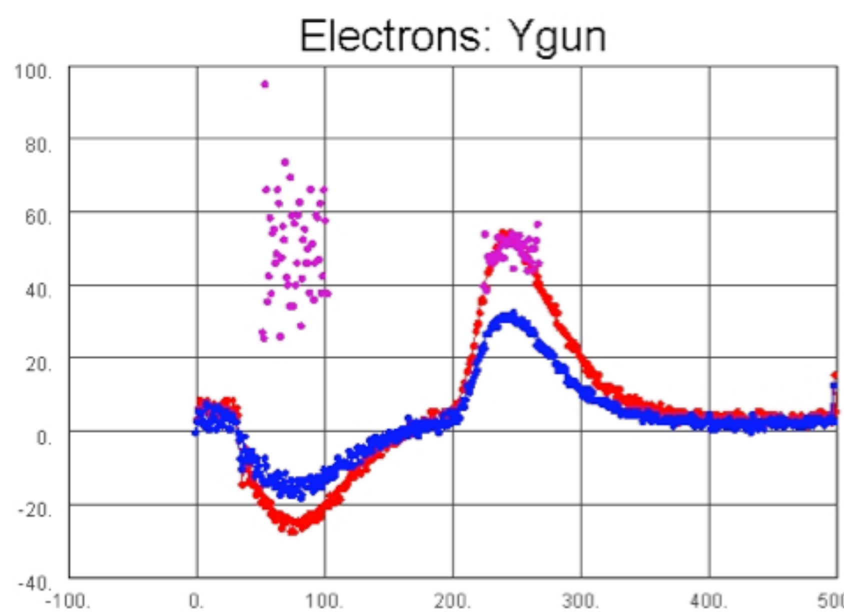
TEL Improvements: BPM Readout

Alignment of e- and circulating beam is critical

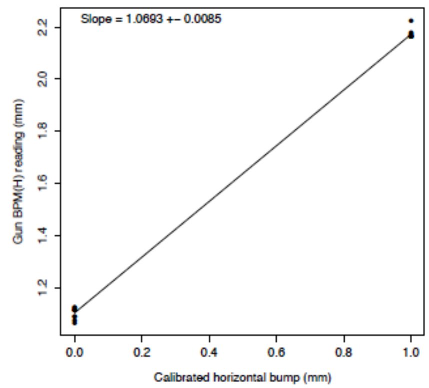


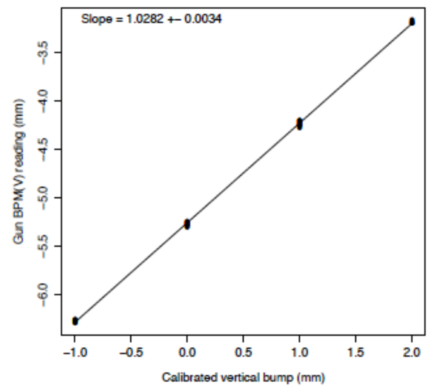
- Shorter e- pulse with new generator – closer calibrations and offsets for electrons and protons/pbars
- Old LabView program slow
- New Java program faster (response time ~20 s), uses simpler algorithm





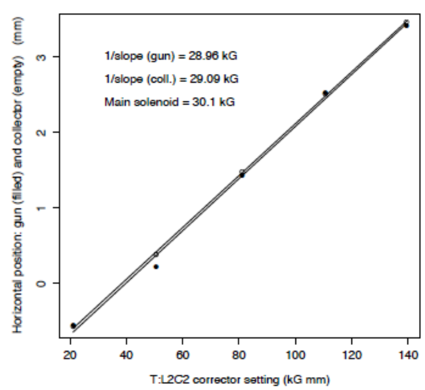
BPM Calibration

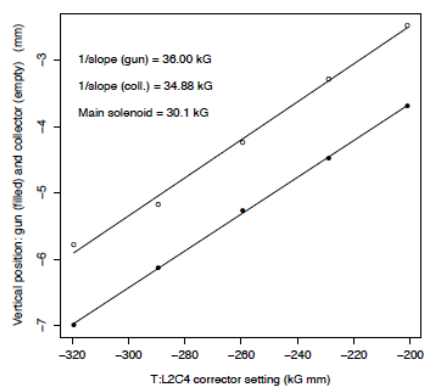




Observable	Measured / Expected Slopes
Δx gun (mm)	1.07 ± 0.01
Δx coll. (mm)	1.03 ± 0.01
Δy gun (mm)	1.028 ± 0.003
Δy coll. (mm)	1.031 ± 0.004
$\Delta x'$ (mrad)	1.10 ± 0.06

TEL-2 BPM calibration with proton beam (closed orbit bump)





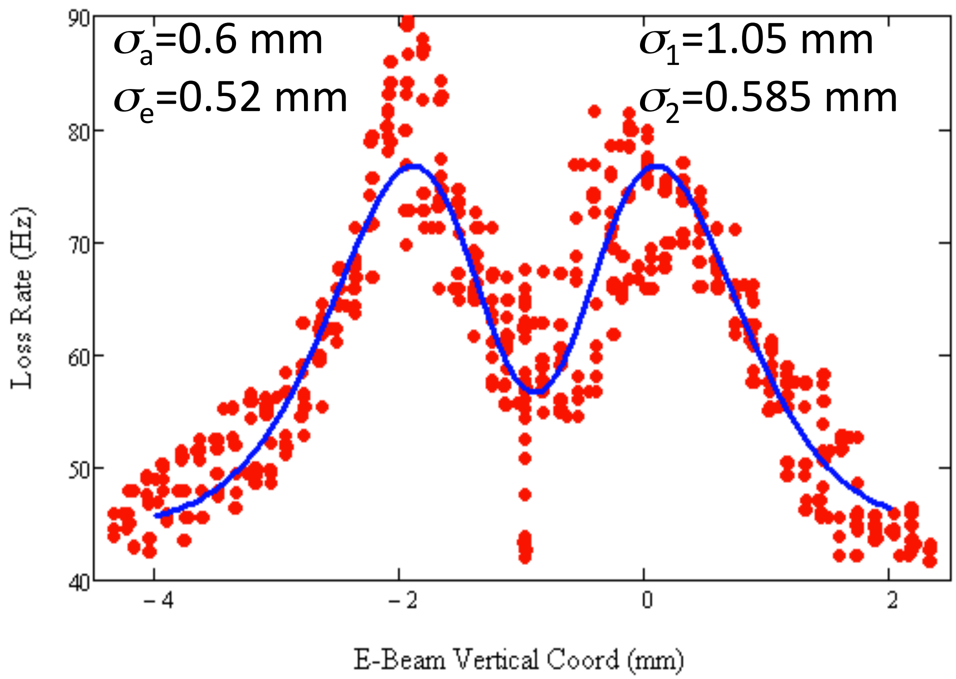
Observable	Measured / Expected Slopes
Δx gun (mm)	1.04 ± 0.04
Δx coll. (mm)	1.03 ± 0.01
Δy gun (mm)	0.84 ± 0.01
Δy coll. (mm)	0.86 ± 0.04

TEL-2 BPM calibration with electron beam

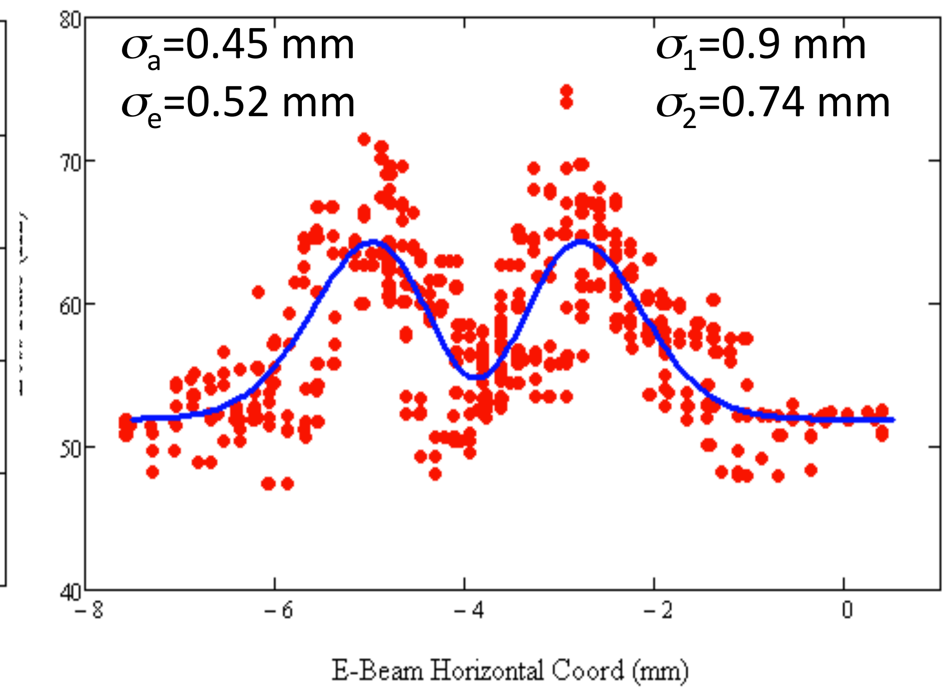
Alignment of e- and Antiproton Beams

- e- beam size is equal to the antiproton beam size at TEL-2
- Centered e- beam should not produce particle losses (in case of tune not on resonance)
- Offset by ~1σ is the worst case
- Offset scan should produce characteristic double-hump pattern

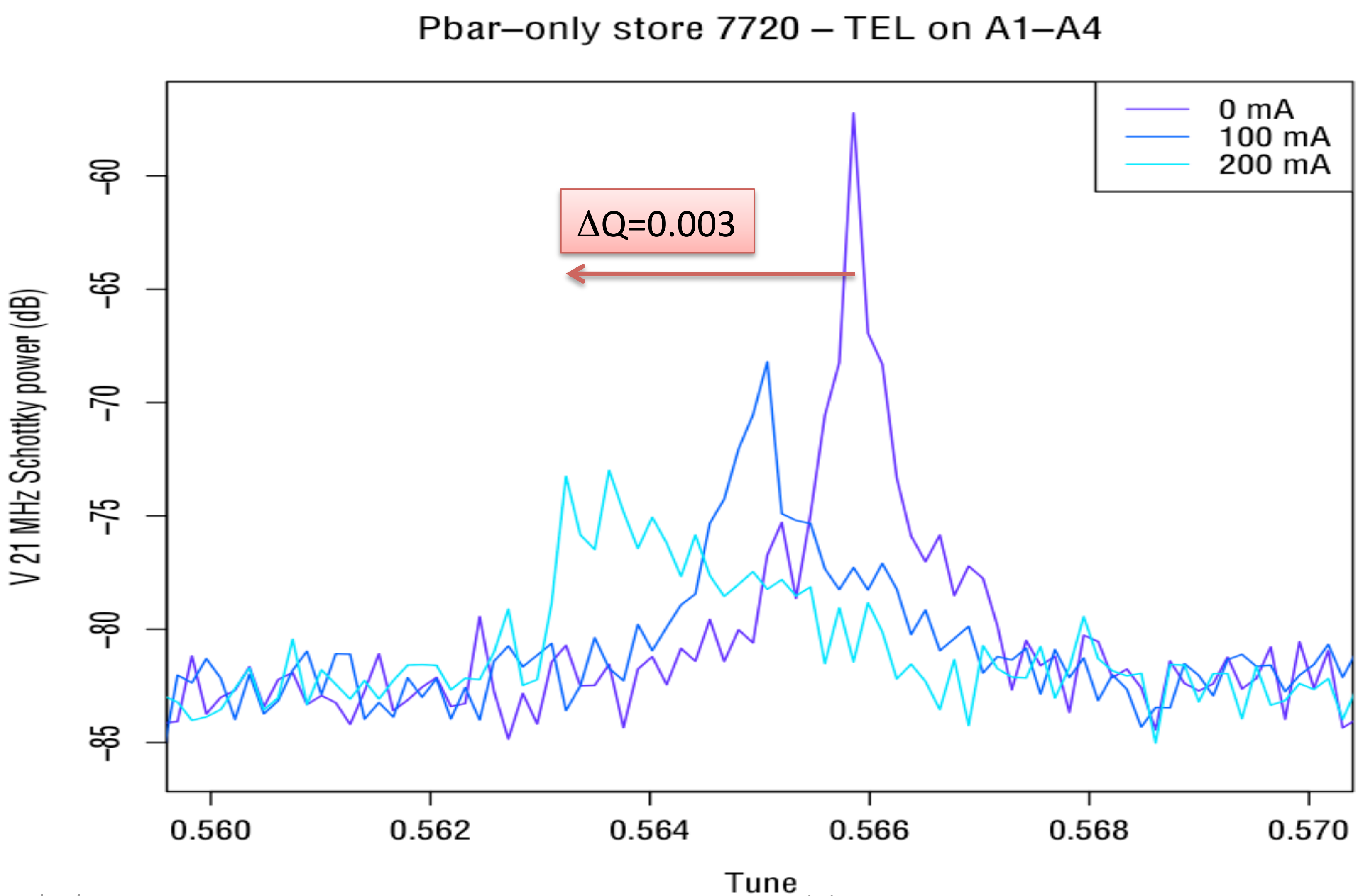
Losses during vertical e- beam position scan



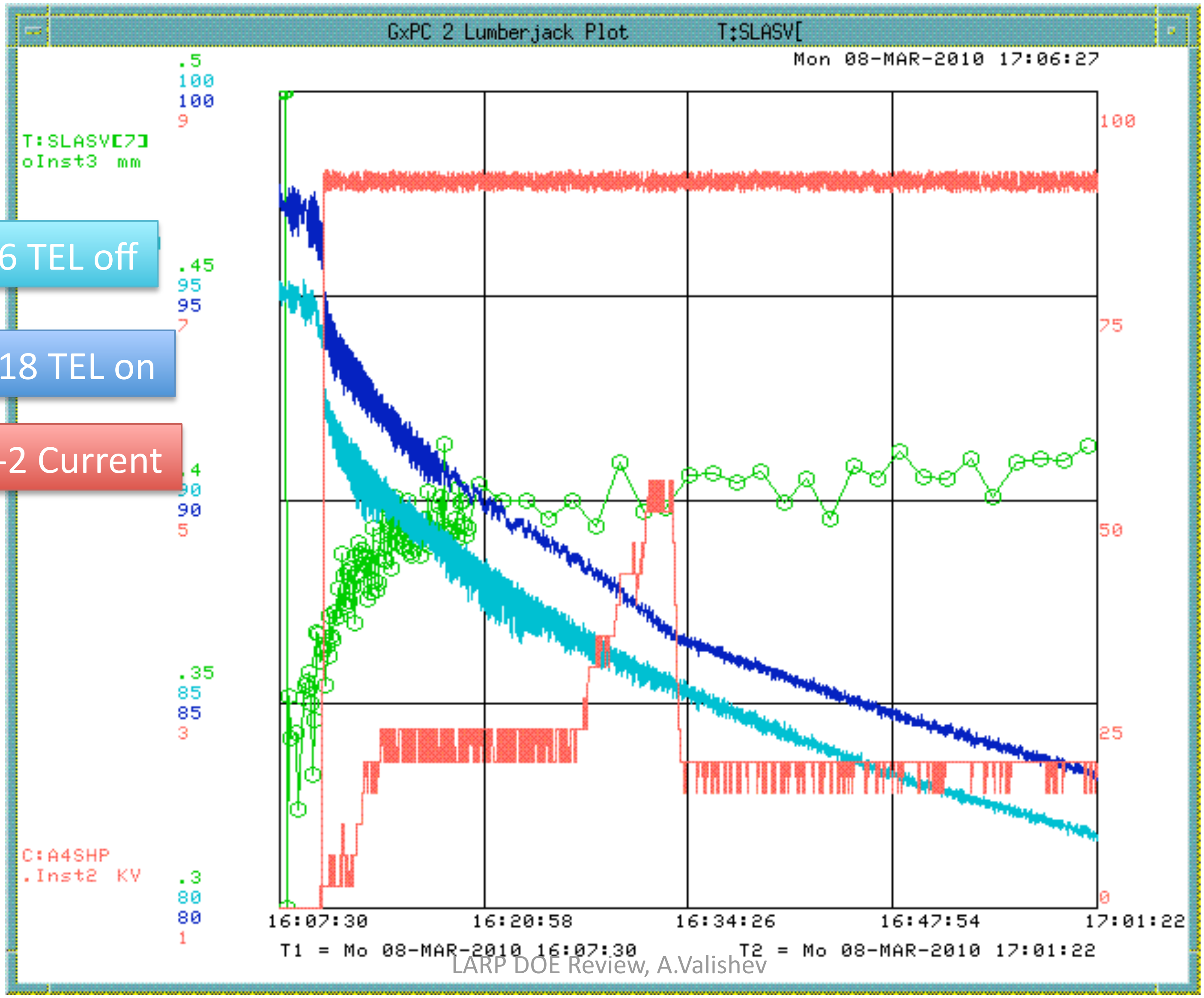
Losses during horiz. e- beam position scan



Tune Shift and Spread by Gaussian TEL-2 (antiproton-only study)



Effect of Gaussian TEL-2 on Lifetime HEP Store 7661, L_0=3.3x10^{32}



Transverse Mode Coupling Instability

PHYSICAL REVIEW E VOLUME 59, NUMBER 3 MARCH 1999

Transverse beam stability with an "electron lens"

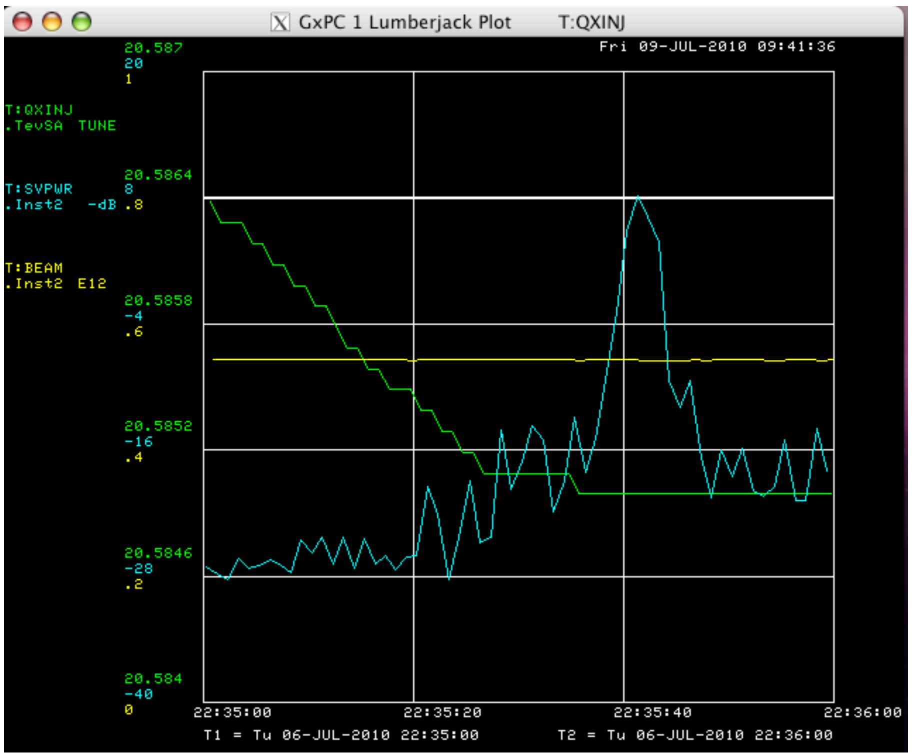
A. Burov,* V. Danilov,† and V. Shiltsev
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(Received 29 July 1998)

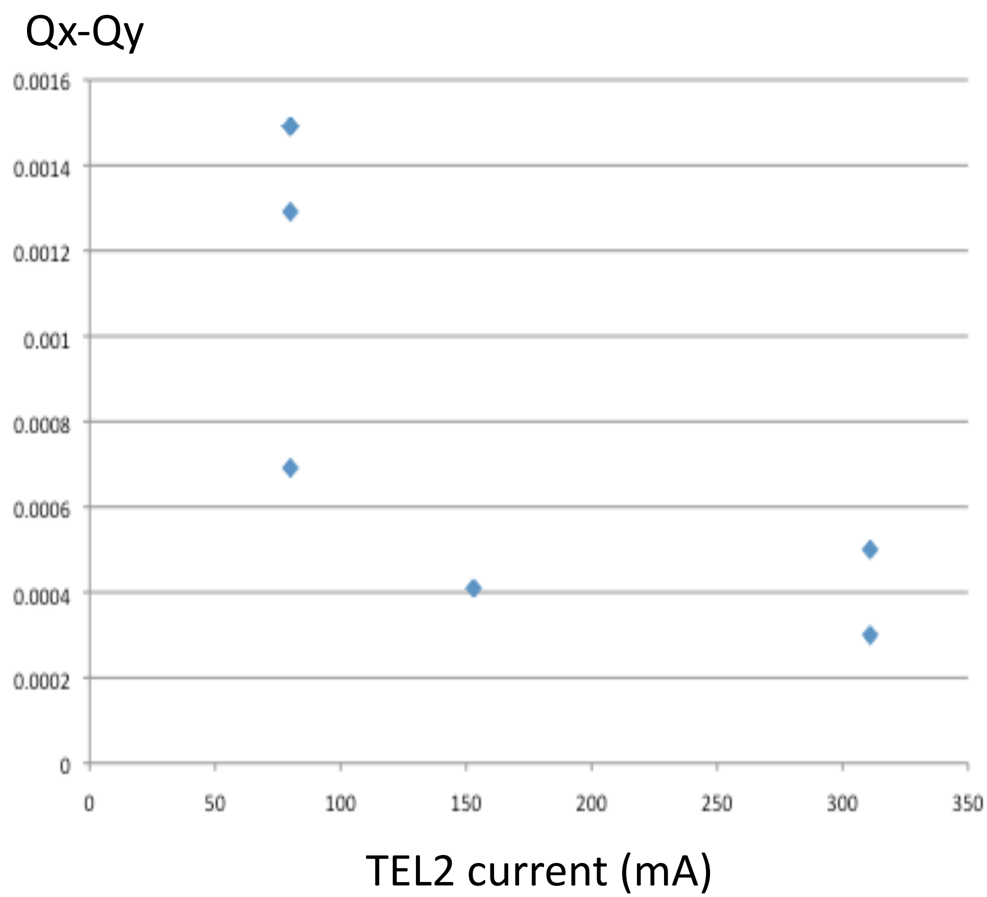
This article is devoted to stability analysis of the antiproton beam interacting with an electron beam in an "electron lens" setup for beam-beam compensation in the Tevatron collider. Electron space charge forces cause transverse "head-tail" coupling within antiproton bunch which may lead to a transverse mode coupling instability (TMCI). We present a theory, analytical studies, and numerical simulations of this effect. An estimate of threshold longitudinal magnetic field necessary to avoid the instability is given. Dependence of the threshold on electron and antiproton beam parameters is studied. [S1063-651X(99)10203-4]

- EL beam must be stabilized by magnetic field, otherwise it may act as wide band impedance, causing an instability in proton (or pbar) beam
- Unlike the conventional TMCI, where 0 and -1 synchrotron modes couple, in this case it is horizontal and vertical 0 modes
- Instability threshold depends on B and Qx-Qy

$$B \geqslant B_{th} \approx 1.3 \frac{eN_{\bar{p}}\sqrt{\xi_x \xi_y}}{a^2 \sqrt{\Delta \nu \nu_s}}.$$

Study of TMCI caused by EL at Tevatron





Instability was observed at beam parameters consistent with model predictions

Gaussian TEL-2 Results

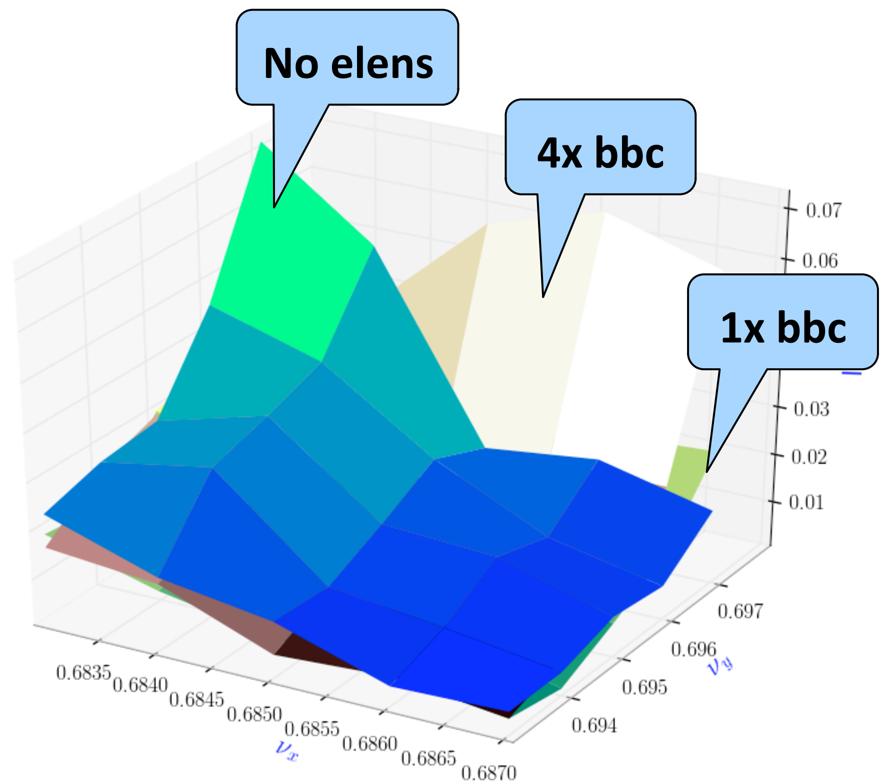
- Demonstrated good alignment of e- and pbar beams
- No pbar life time degradation up to TEL current of 0.5A (if tune is off resonance)
- Observed tune shift and tune spread from TEL in a pbar only store
- Coherent modes and tune shifts observed in HEP stores are close to model prediction
- Studied coherent instability driven by TEL beam impedance
- Attempted demonstration of head-on BBC in a dedicated Tevatron store with 3x3 bunches.

Numerical Simulations

- Benchmarked and developed codes
  - Significant progress at BNL: full 6D implementation
  - At FNAL implemented current LHC lattice with FF higher-order nonlinearities in BB simulation
- Simulations of BBC at RHIC demonstrate benefit from EL at bunch intensity above 2.5×10^{11}
- Simulations of BBC at LHC predict positive effect at Np above 3×10^{11} (nonlinearities not included)

Head-on BBC at RHIC (H.J.Kim, FNAL)

Effect of HO BBC on RHIC beam lifetime

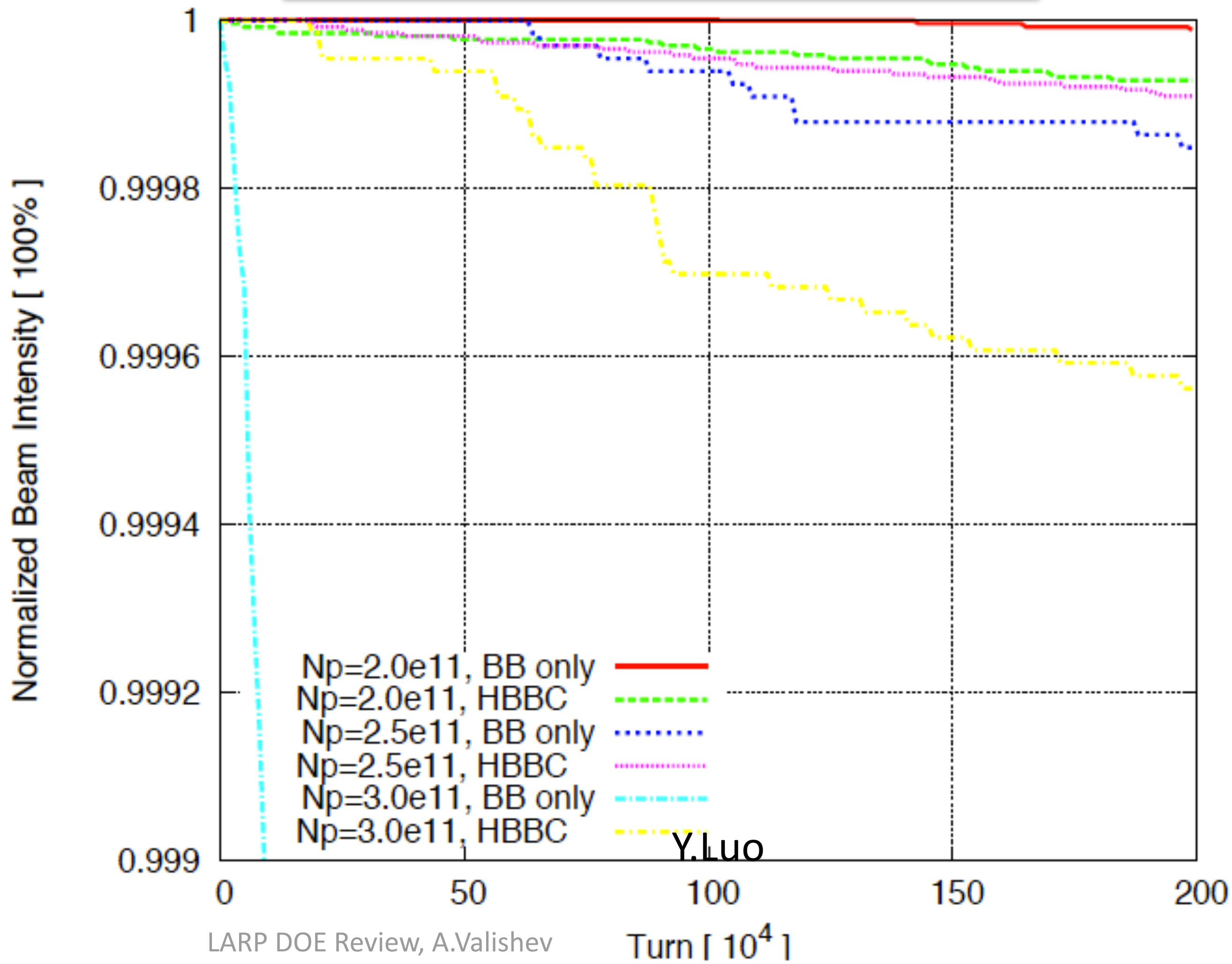


- At near (0.685,0.695), the SEFT elens does help to increase beam life time.

Head-on BBC at RHIC (Y.Luo, BNL)

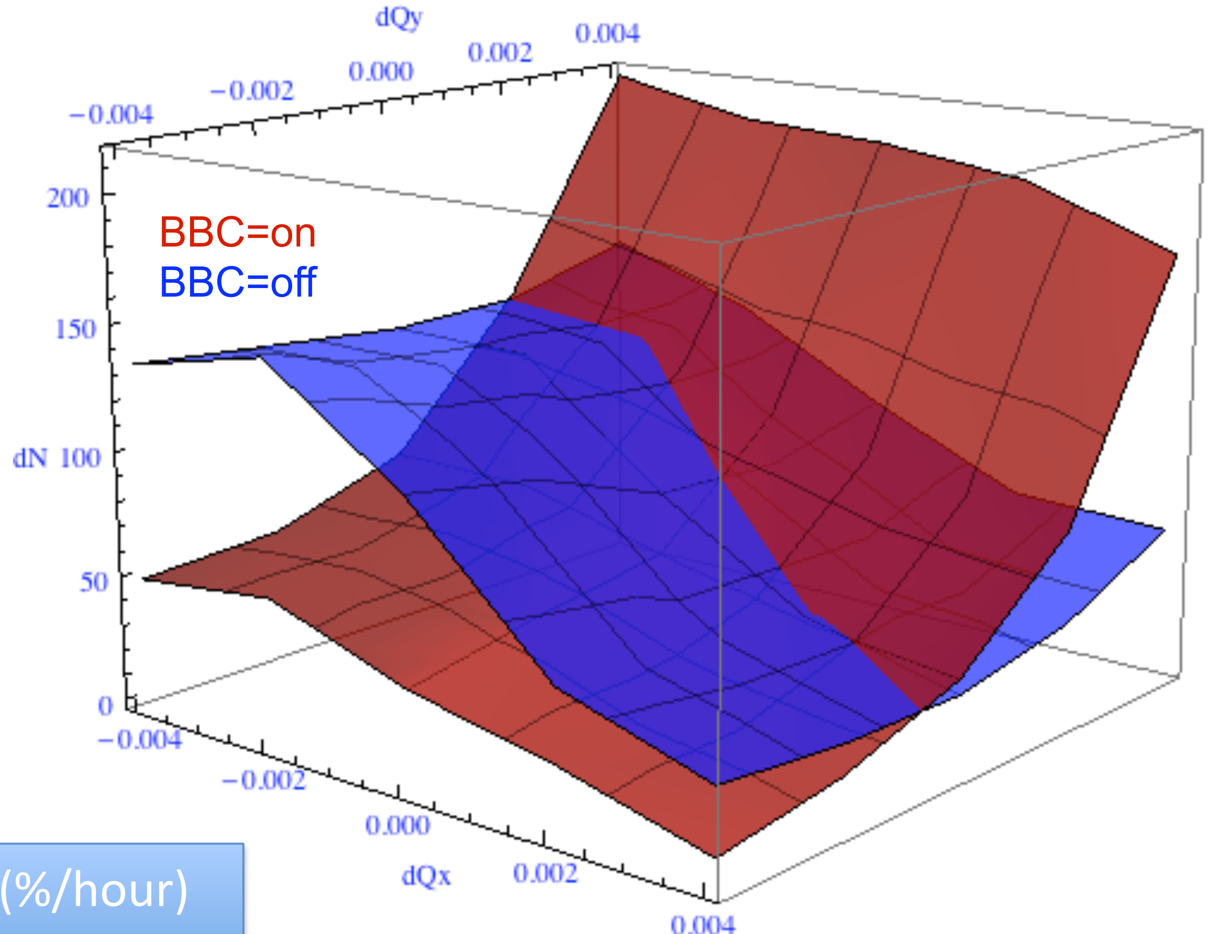
LARP

Effect of HO BBC on RHIC beam lifetime



Simulations demonstrate benefit from EL at bunch intensity above 2.5×10^{11}

Head-on BBC at LHC (A.Valishev, FNAL)



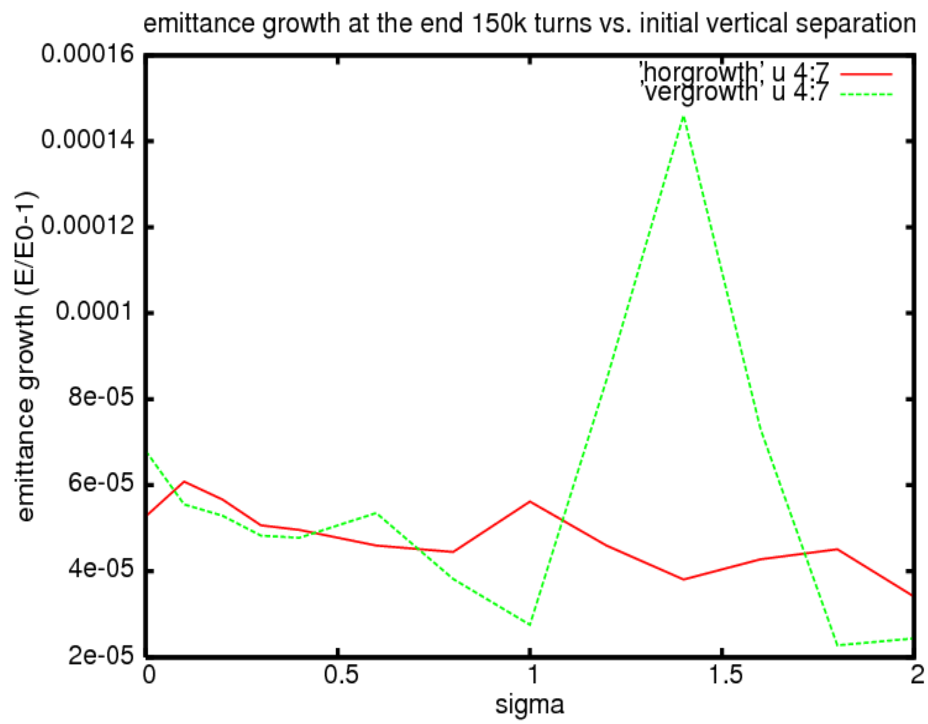
Min. loss (%/hour)
EL off 27
EL on 8

N_p=3.45e11, $\sigma_e = \sigma_p$
half compensation
Intensity loss in %/hour vs. lattice tunes

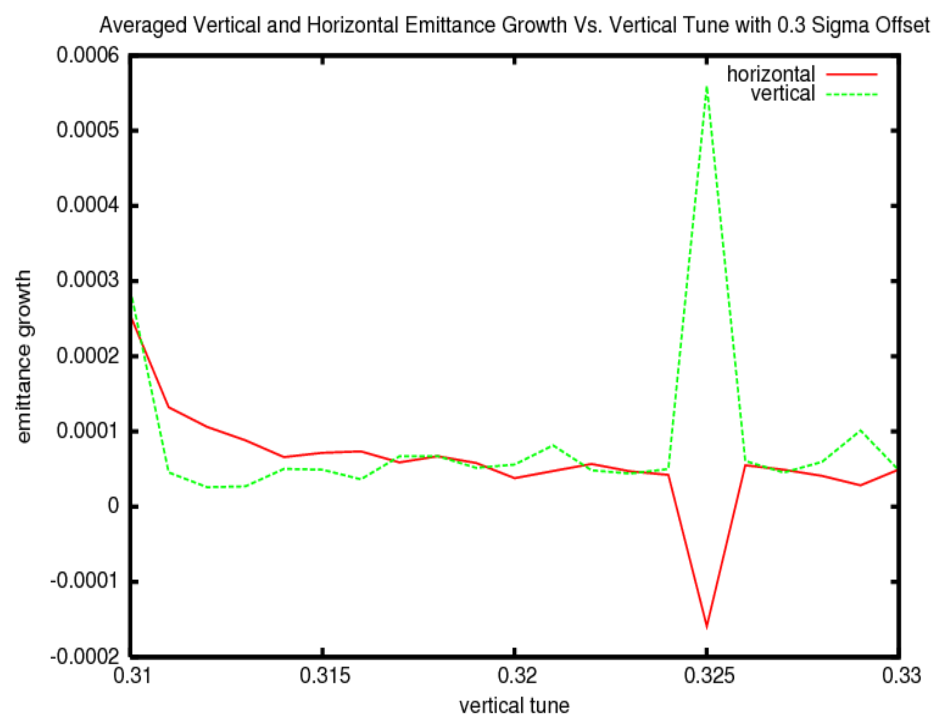
Offset Beam-Beam Collision Studies for LHC (J.Qiang, LBNL)

- The offset collision is unavoidable due to the different bunch collision schemes at LHC
- Such offset collision might cause emittance growth that degrades luminosity lifetime and experimental conditions

Emittance Growth vs. Offset



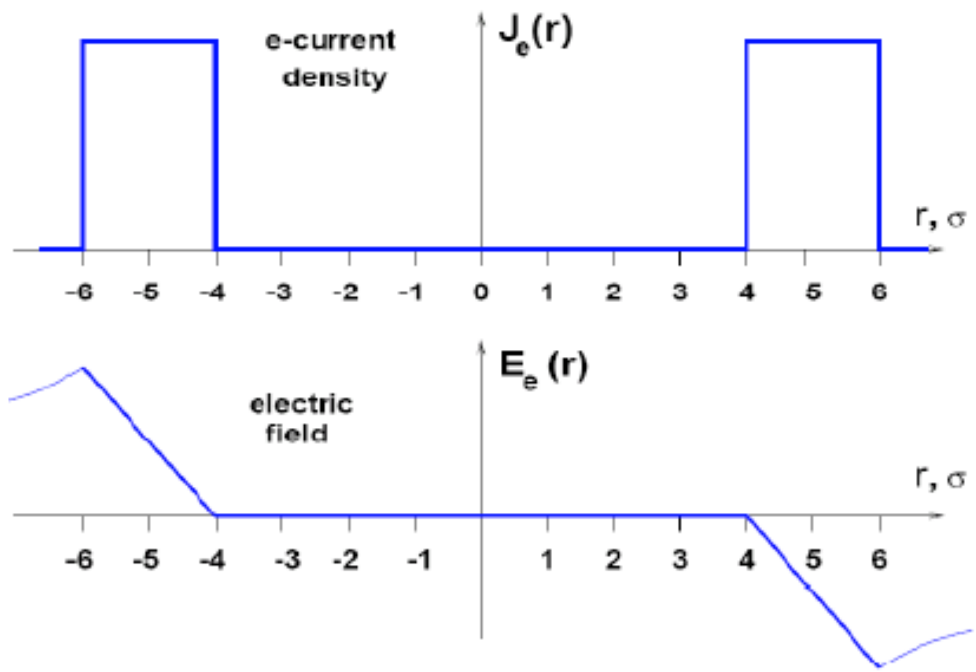
Emittance Growth vs. Tune



Concept of Hollow Electron Beam Collimator

LARP

- New initiative. Proposal published in 2008
- No beam scrapers in LHC: intolerable material damage below 5σ
- Cylindrical, hollow, magnetically confined, (pulsed or dc) electron beam overlapping with halo and leaving core unperturbed
- Electron beam can be placed close to the beam core (3-4σ)
- Tevatron electron lenses are ideally suited for HEBC experiments



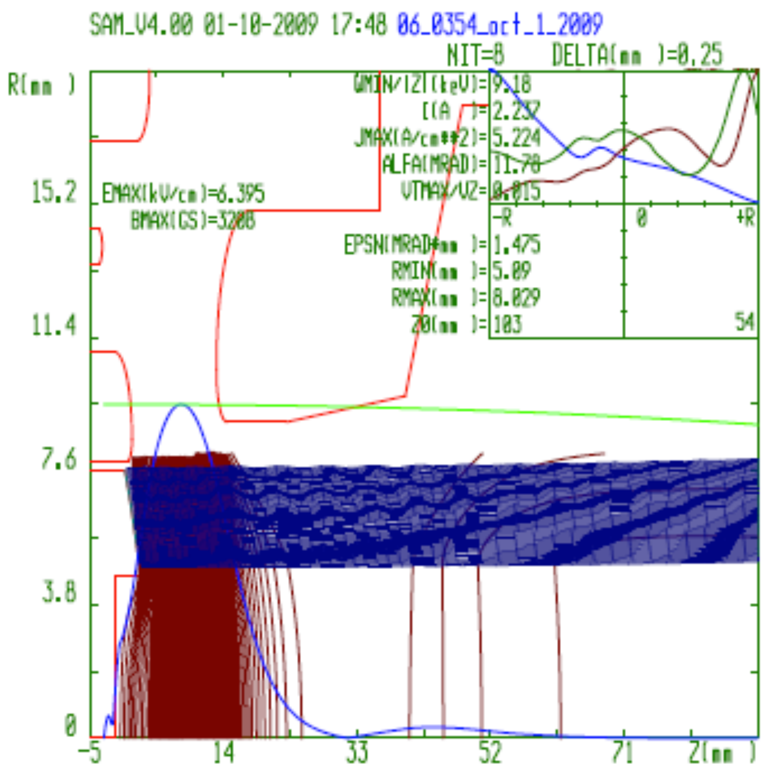
Hollow Beam Electron Gun

LARP

- Electrode design based on existing 0.6 in TEL-2 gun
  - Convex tungsten dispenser cathode with BaO:CaO:Al2O3 impregnant
  - 7.6 mm outer radius, 4.5 radius bore
- Machined in Summer of 2009, first tests September

Calculations with SAM code

(L. Vorobiev)



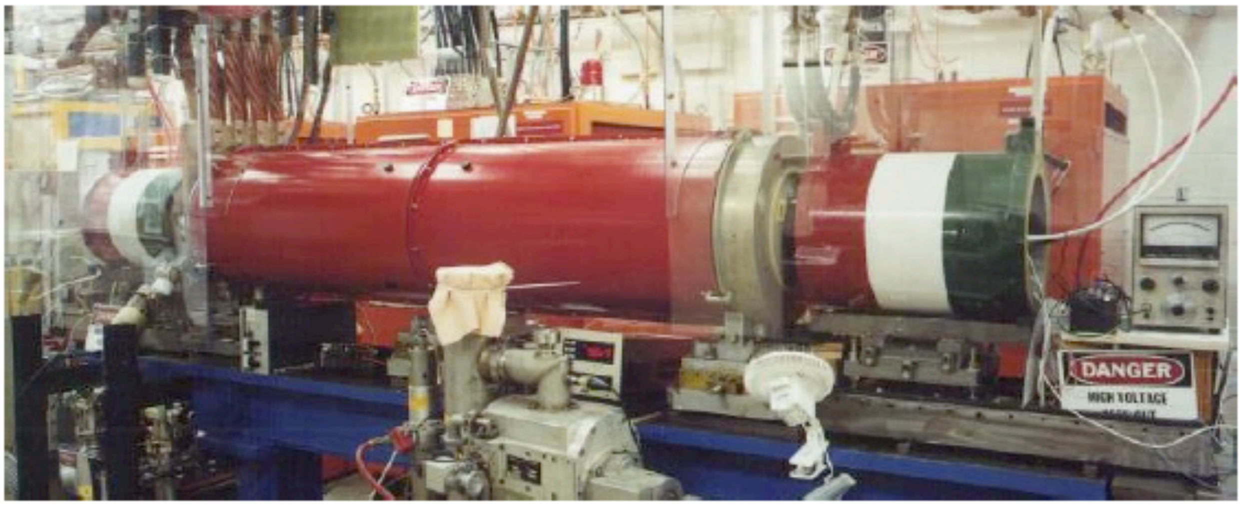
Mechanical design *(G. Kuznetsov)*

Cathode (w/o bore)

Assembled gun

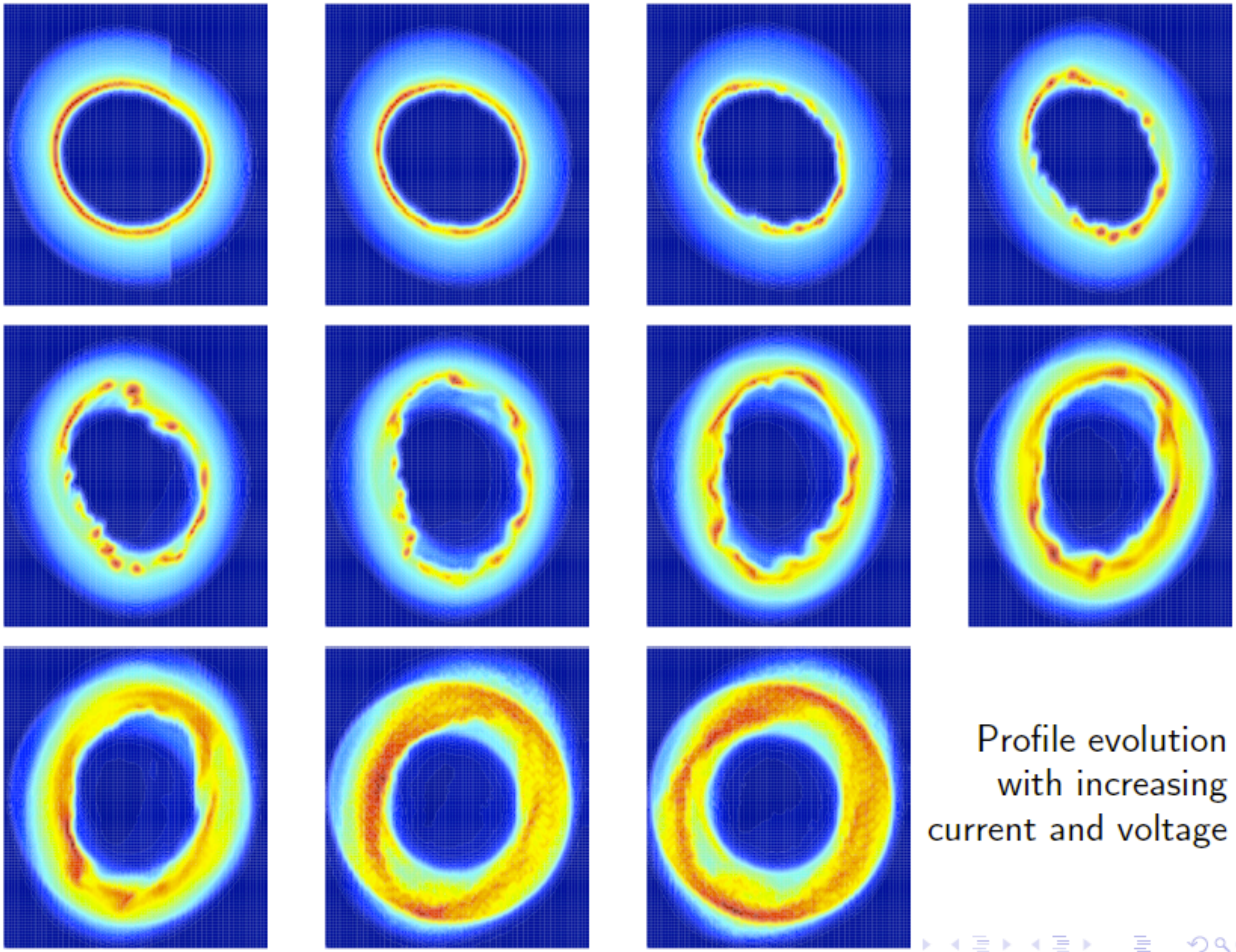
Test Bench at Fermilab

Built to develop TELs, now used to characterize electron guns and to study plasma columns for space-charge compensation



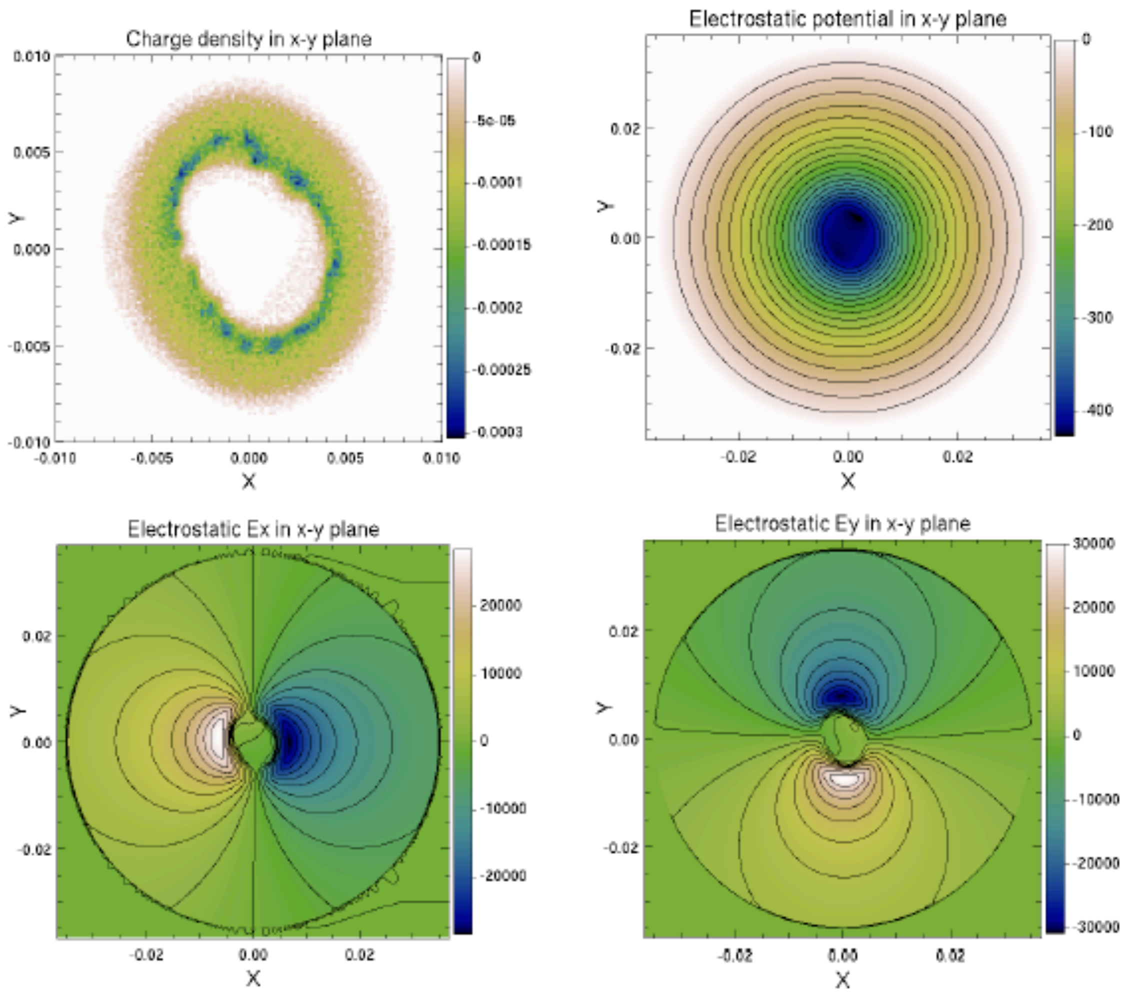
- High-perveance **electron guns**: ∼amps peak current at 10 kV, pulse width $\sim\mu$s, average current <2.5 mA
- Gun / main / collector **solenoids** (<0.4 T) with magnetic correctors and pickup electrodes
- Water-cooled **collector** with 0.2-mm pinhole for profile measurements

Hollow Beam Profile Measurements (G. Stancari, FNAL)



Profile evolution with increasing current and voltage

Warp Calculation of 2D Fields from Measured Profile (G. Stancari, FNAL)



Now working on incorporating the field into tracking simulation

Summary and Future Plans

LARP

- Gaussian TEL-2 experimental goals have been met
  - Tevatron luminosity can not be improved by TEL, since beam-beam effects in are dominated by long-range collisions owing to electron cooling of antiprotons.
  - EL as beam-beam compensator is not high priority for LHC (high bunch intensity/ high head-on beam-beam parameter is not in the baseline upgrade)
- Tevatron E-Lens is ideally suited for tests of hollow electron beam collimator. Hence, the plan is to shift focus in experimental work at TEL from BBC to HEBC
  - Replace the TEL-2 Gaussian gun with hollow gun (July 2010)
  - Conduct HEBC experiments at the Tevatron (FY2011 Tev run)
  - Develop a full prototype of hollow electron beam gun (ring cathode) and collector (FY2011)
  - Install and test the prototype at the Tevatron during the beam study period at the end of Run II (3 months in FY2012)
- Requesting 165k$ and ~1FTE for HEBC work

Summary and Future Plans Contd.

- A lot of code benchmarking was performed, collaborative effort.
- Simulations of head-on BBC for RHIC and LHC demonstrate benefit at high beam-beam parameters ~0.025-0.03
- Beam-beam simulations plan
  - Continue code development
    - implement hollow e-beam
  - Support RHIC EL project with simulations
  - Collaborate with CERN on simulations of beam-beam effects at the LHC, especially as more experimental data becomes available
  - New problem: beam-beam at HE-LHC