# Beam-beam simulations and Electron Lens progress

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LARP CM15, 11/2/2010

# FY10 Goals

- Experiments with Gaussian EL at Tevatron
  - 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
  - Attempt HO BBC demonstration with Gaussian TEL-2
- 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
  - Evaluate significance of beam-beam effect at HE-LHC
- Development of hollow e- beam collimator (Giulio's talk)

# Beam-Beam Task in FY10

- Participants
  - BNL:
    - (W.Fischer, Y.Luo, C.Montag, G.Robert-Demolaize) - RHIC Electron Lens project
  - FNAL:
    - (H.J.Kim, T.Sen), A.Valishev - Simulations
    - G.Kuznetsov, A.Romanov, G.Saewert, V.Shiltsev, G.Stancari, A.Valishev, X.Zhang – TEL-2 experiments
  - SLAC: ~~A.Kabel~~
  - LBL: Strong-strong simulations (J.Qiang)
  - Contact at CERN: F.Schmidt

# Simulations

- CM14
  - Code development
    - Significant progress at BNL: full 6D implementation (Y.Luo)
    - At FNAL implemented current LHC lattice with FF higher-order nonlinearities in BB simulation (A.Valishev, F.Schmidt)
  - Simulations of BBC at RHIC demonstrate benefit from EL at bunch intensity above $2.5 \times 10^{11}$ (H.-J.Kim, T.Sen, Y.Luo)
  - Simulations of BBC at LHC predict positive effect at Np above $3 \times 10^{11}$ (A.Valishev)
- After CM14
  - RHIC Luminosity modeling
  - Beam-beam at HE-LHC
  - LHC beam-beam

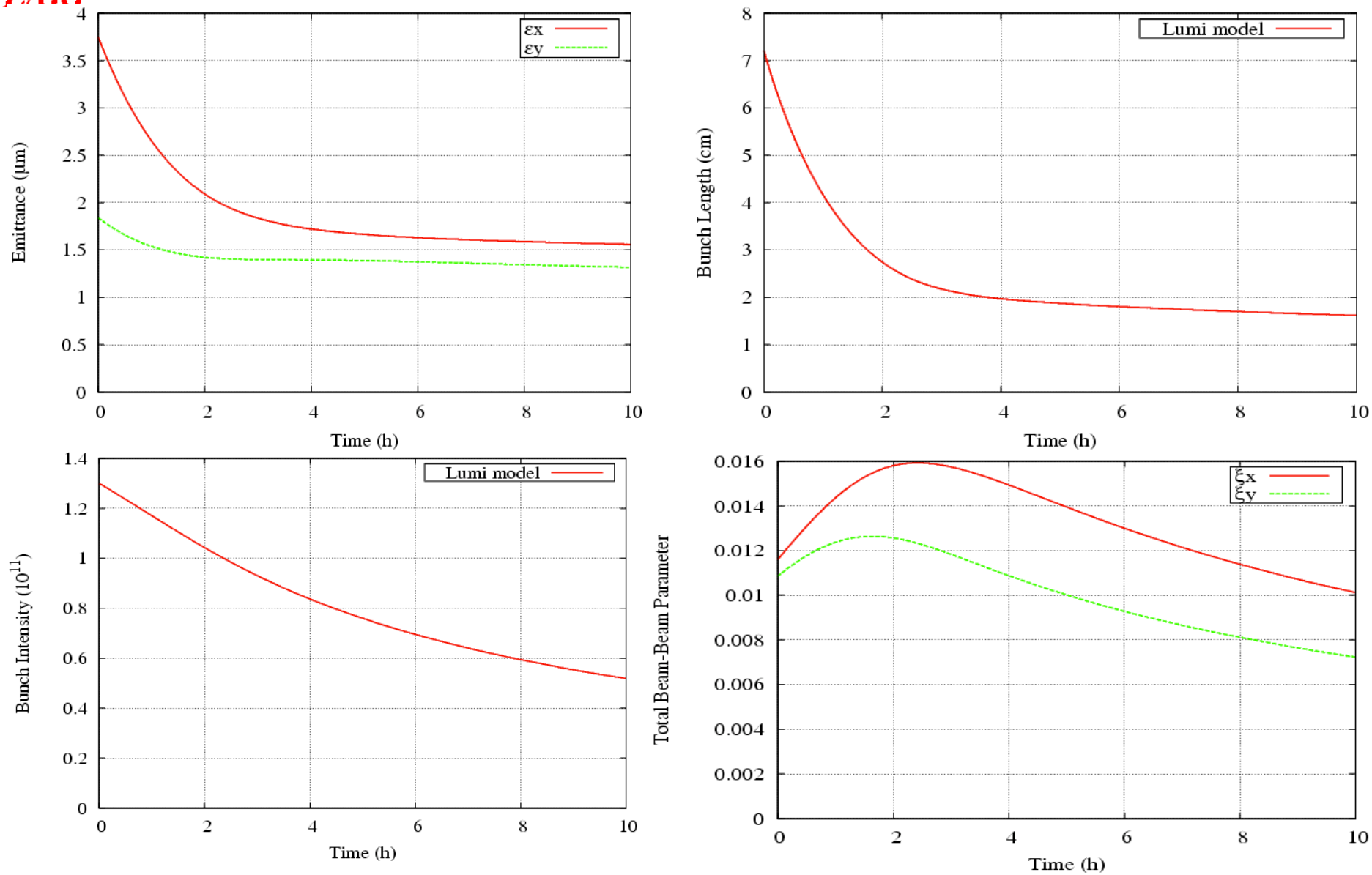
# Beam-beam effects at HE-LHC

| | |
|---|---|
| Beam energy | 16.5 TeV |
| Number of IPs | 2 |
| Bunch population | $1.3\times10^{11}$ |
| Initial normalized transverse emittance | 3.75, 1.84 (x,y) $\mu$m |
| Initial momentum spread | $0.9\times10^{-4}$ |

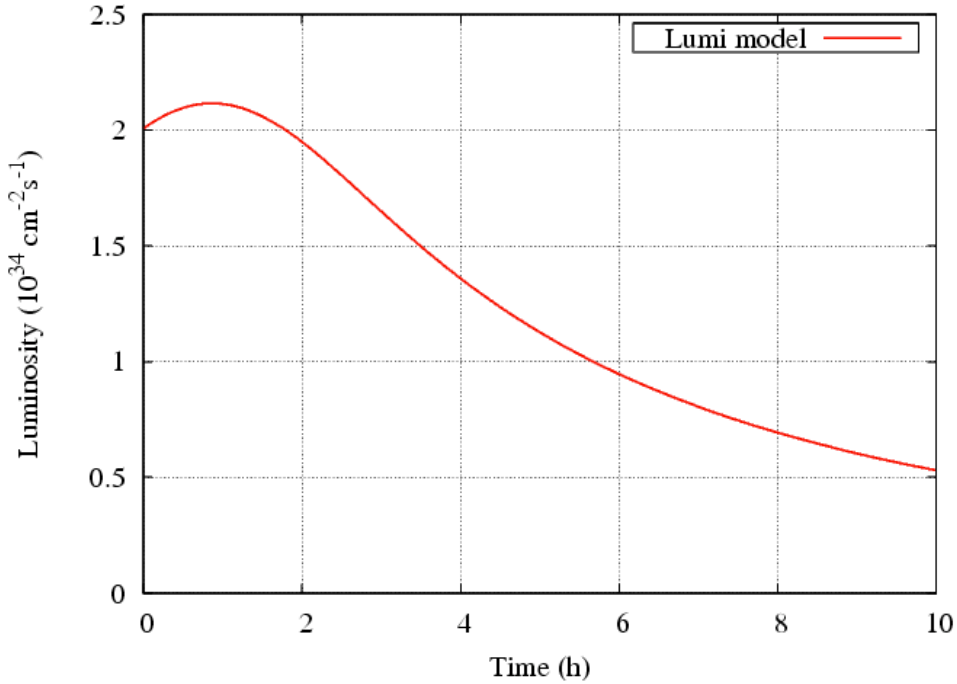
| | |
|---|---|
| **Energy loss per turn** | **$U_0$=206.3 keV** |
| SR power | $P$=67 kW |
| Emittance damping time | $\tau_x$, $\tau_y$=1.93 h |
| | $\tau_E$=0.96 h |
| Normalized SR equilibrium emitance | $\varepsilon_{x0}$=0.01 $\mu$m |
| Equilibrium momentum spread | $\delta_0=3.4\times10^{-6}$ |

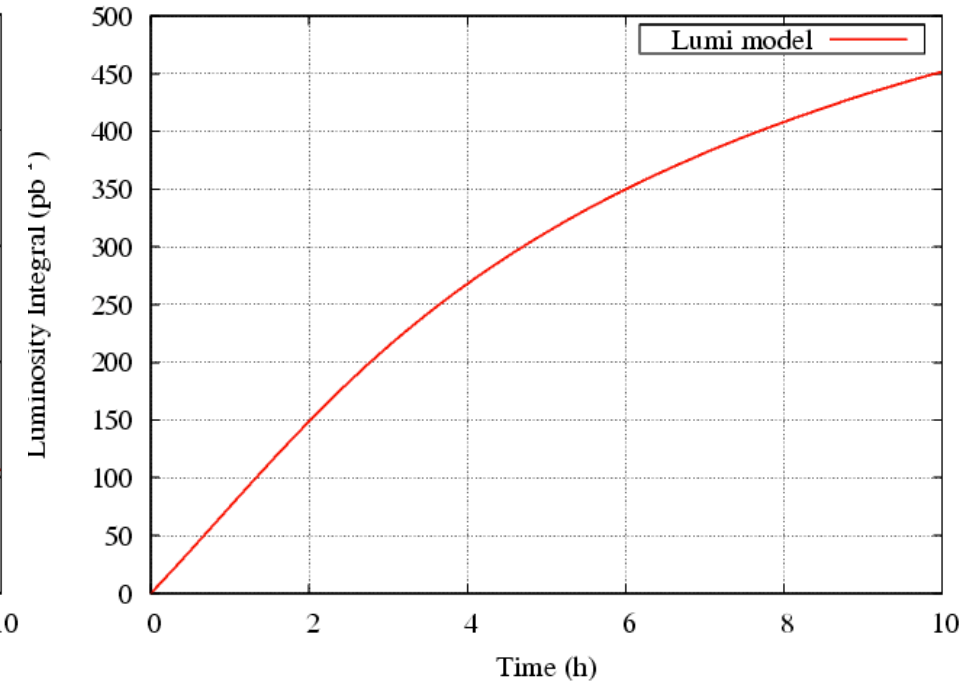
| | |
|---|---|
| Horizontal IBS emittance growth time | 82 h |
| Longitudinal IBS emittance growth time | 72 h |

# Beam-beam effects at HE-LHC



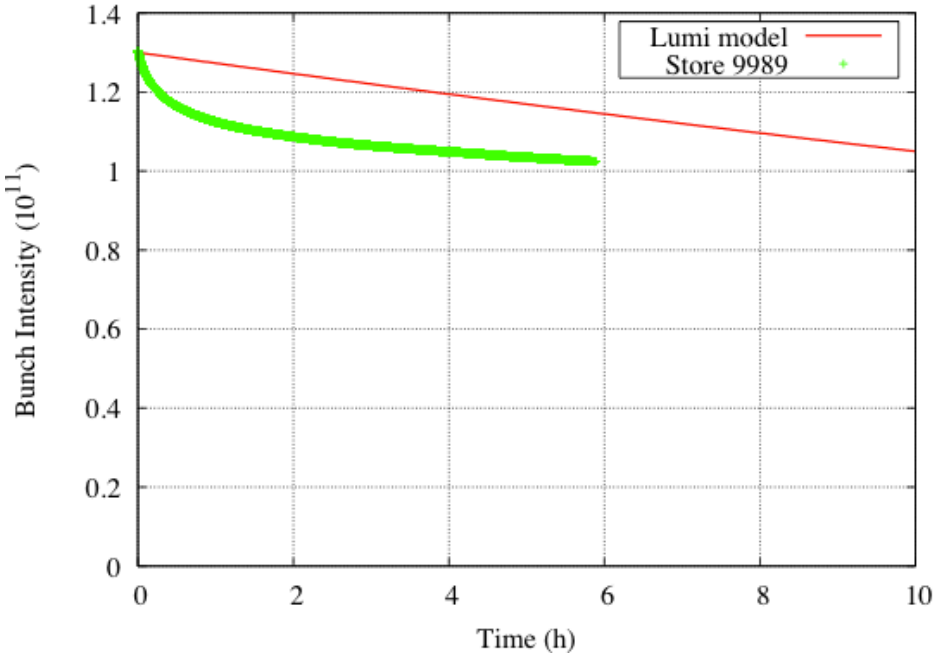
# Beam-beam effects at HE-LHC

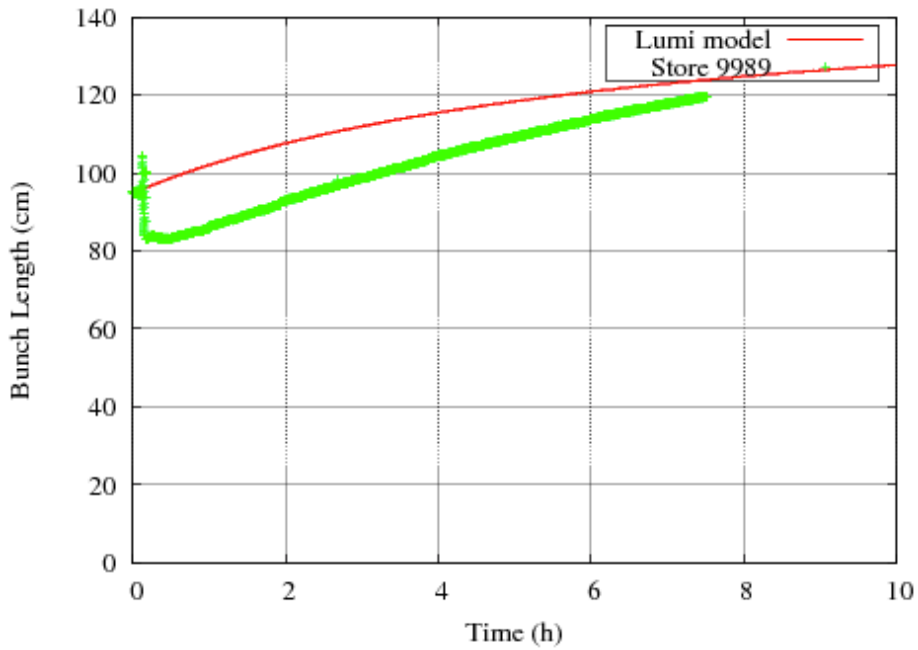



Lumi integral for 10h store = 450 pb$^{-1}$

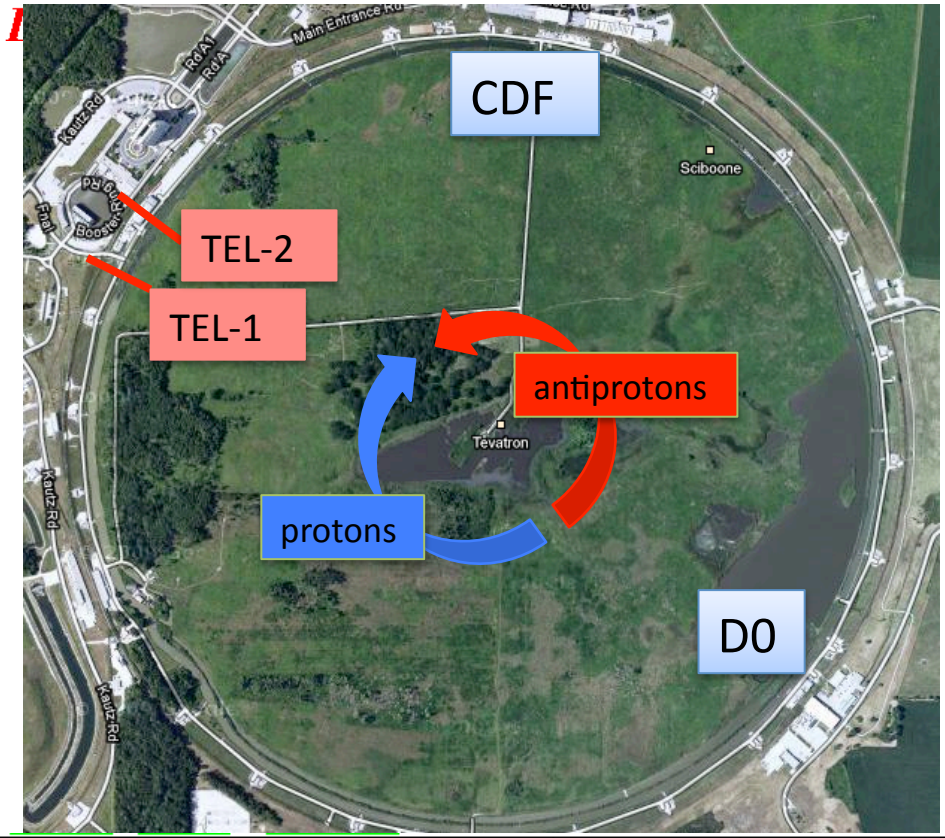
# RHIC luminosity evolution model



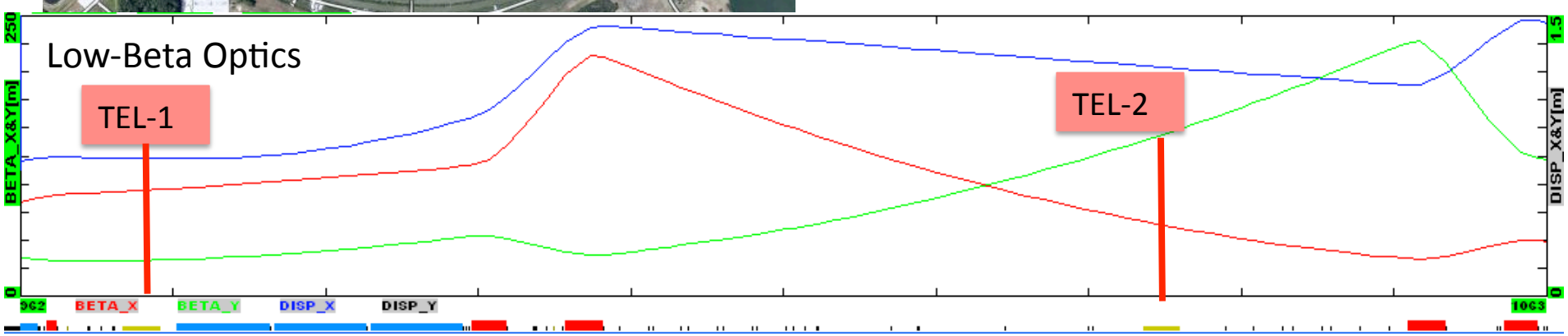




Initial parameters from Store 9989 (2008, 100GeV)

# Tevatron Electron Lenses



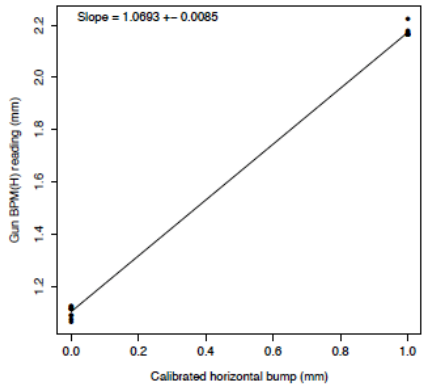

| | |
|---|---|
| e- beam energy | < 10 kV |
| Peak e- current | < 3 A |
| Solenoid B-field | 30 kG |
| Gun B-field | 3 kG |
| e- beam radius (SEFT) | 2.3 mm |
| Interaction length | 2 m |
| TEL-1 βx/βy | 95/32 m |
| TEL-2 βx/βy | 66/160 m |

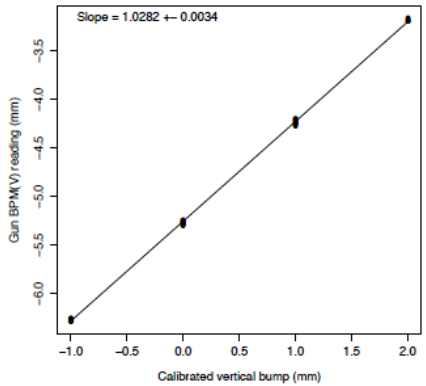


# Gaussian TEL-2 Timeline

- June 09 - gun installed
- Sept. 09 – TEL systems check-out
- Nov. 09 – BPM system calibrated
- Dec. 09- Feb.10 e- beam alignment studies
- Mar. 10 – demonstrated tune shift and tune spread in antiproton beam (no BB)
- Mar. 10 – TEL-2 operation during HEP stores
- June 15, 2010 – 1$^{st}$ 3x3 store for HO BBC
- July 7, 2010 – 2$^{nd}$ 3x3 store for HO BBC
- July 10 – Studies of TEL-2 induced TMCI

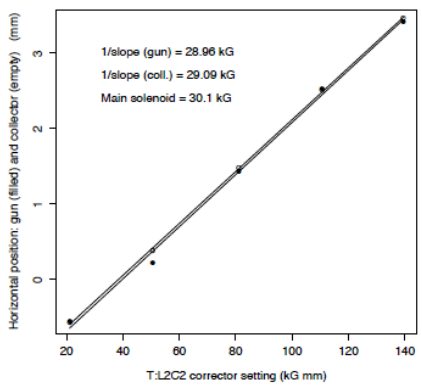
# BPM Calibration

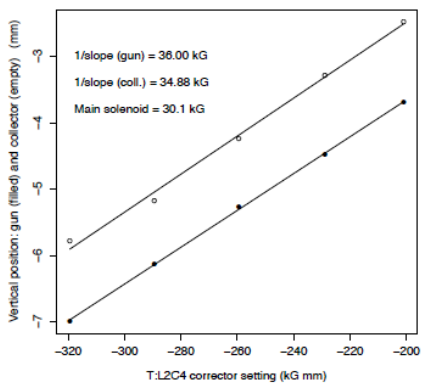



| Observable | Measured / Expected Slopes |
|---|---|
| $\Delta x$ gun (mm) | $1.07 \pm 0.01$ |
| $\Delta x$ coll. (mm) | $1.03 \pm 0.01$ |
| $\Delta y$ gun (mm) | $1.028 \pm 0.003$ |
| $\Delta y$ coll. (mm) | $1.031 \pm 0.004$ |
| $\Delta x'$ (mrad) | $1.10 \pm 0.06$ |

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



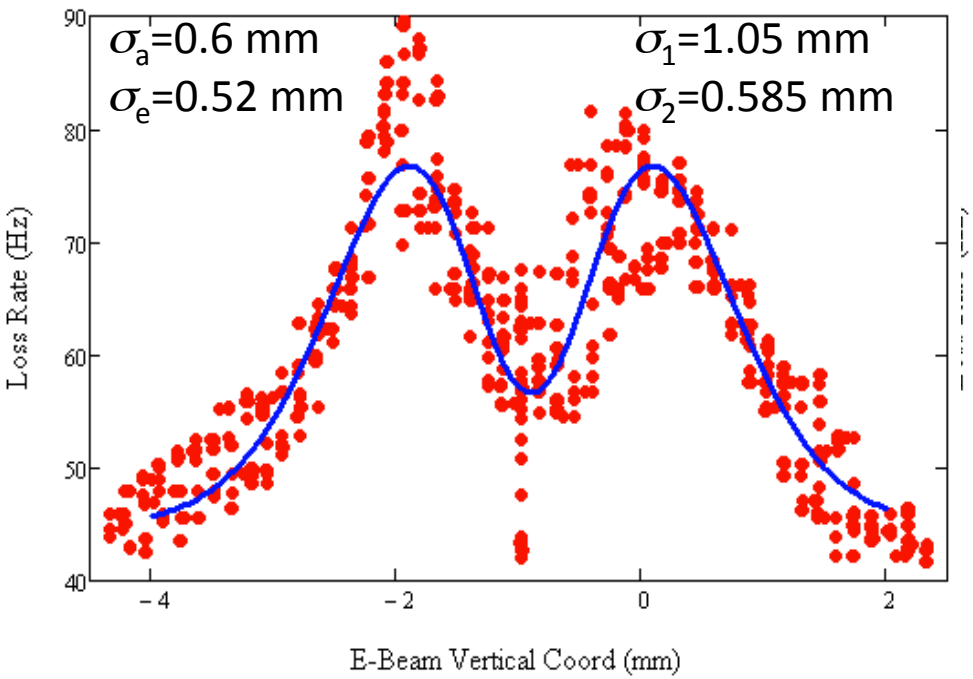

| Observable | Measured / Expected Slopes |
|---|---|
| $\Delta x$ gun (mm) | $1.04 \pm 0.04$ |
| $\Delta x$ coll. (mm) | $1.03 \pm 0.01$ |
| $\Delta y$ gun (mm) | $0.84 \pm 0.01$ |
| $\Delta y$ coll. (mm) | $0.86 \pm 0.04$ |

TEL-2 BPM calibration with electron beam

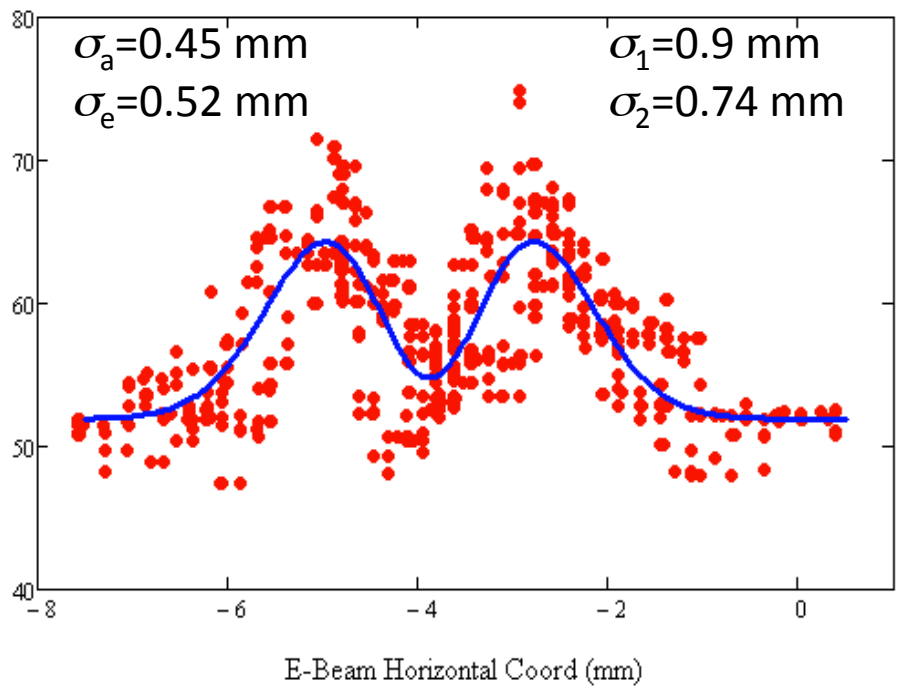
# Alignment of e- and Antiproton Beams

- 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 ~1$\sigma$ is the worst case
- Offset scan should produce characteristic double-hump pattern

Losses during vertical e- beam position scan



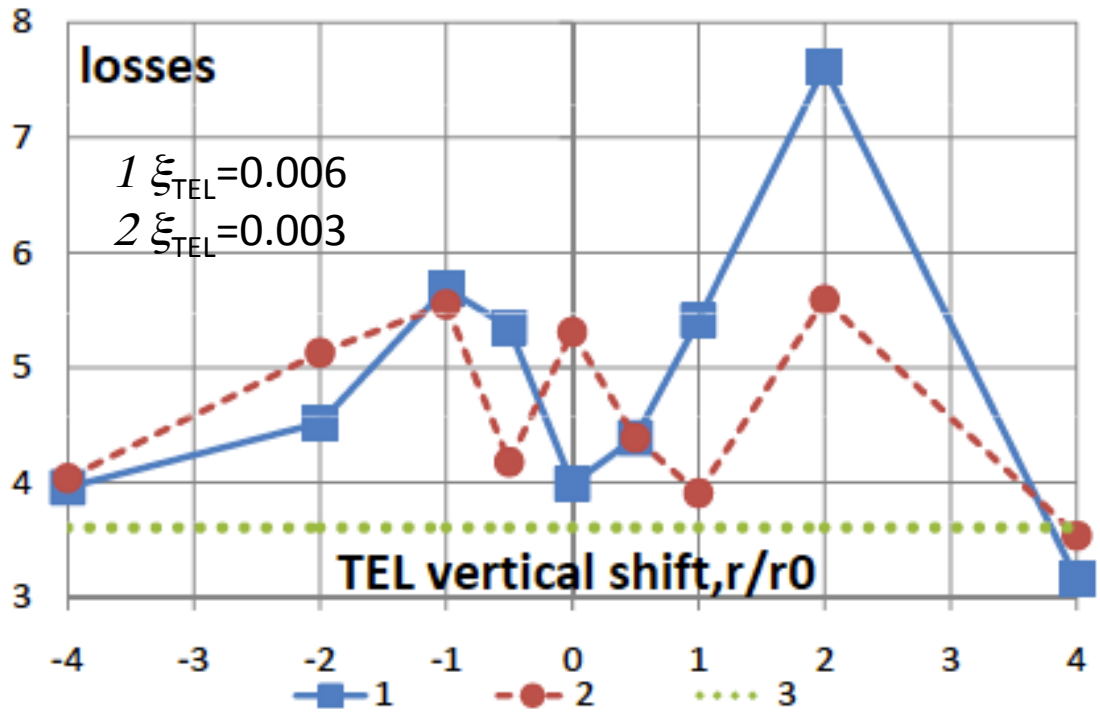

Losses during horiz. e- beam position scan



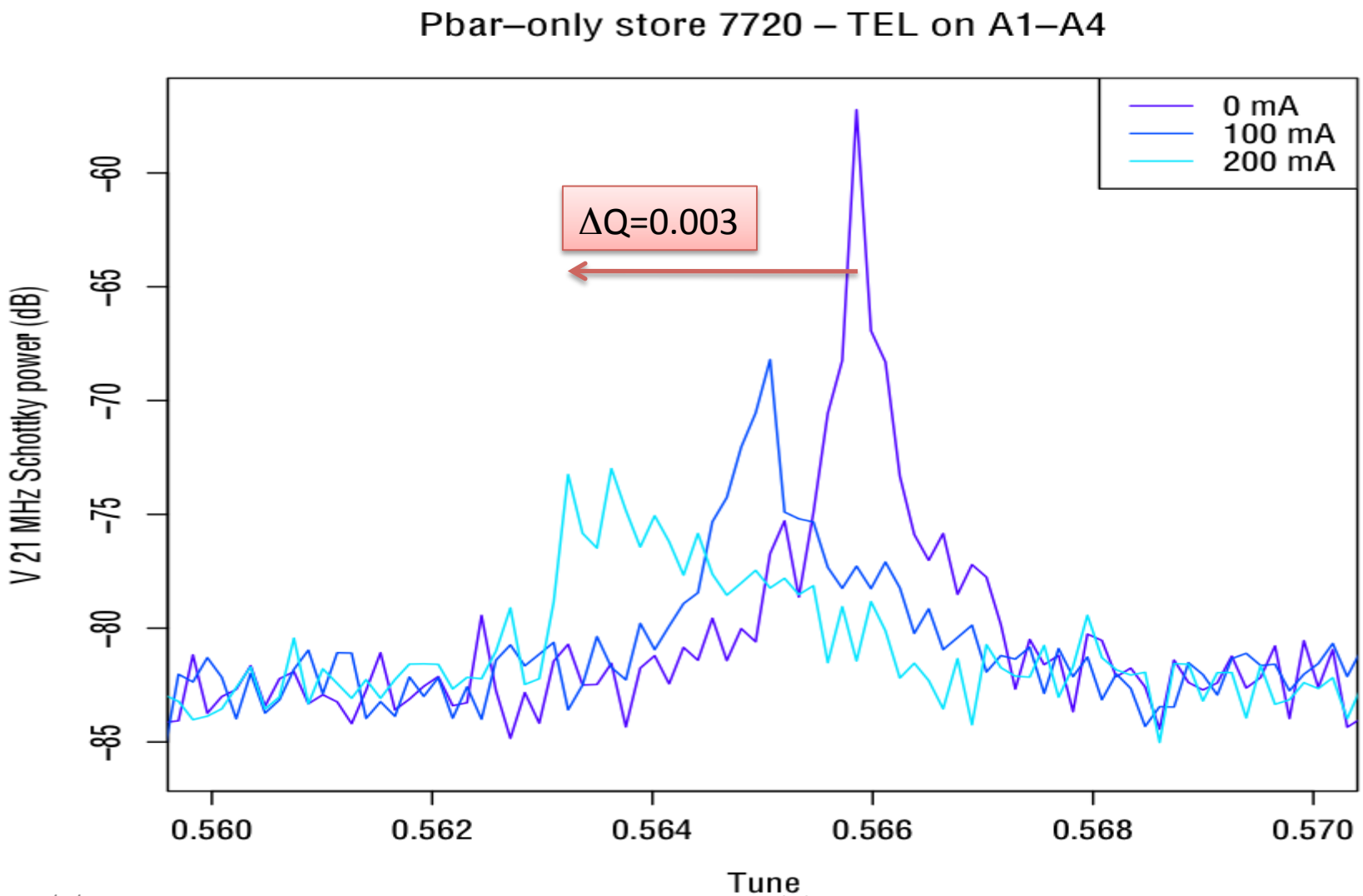
# Alignment of e- and Antiproton Beams Simulation (A.Romanov)

- Beam and machine parameters similar to experiment
- 10,000 macro-particles
- $10^6$ tracking turns

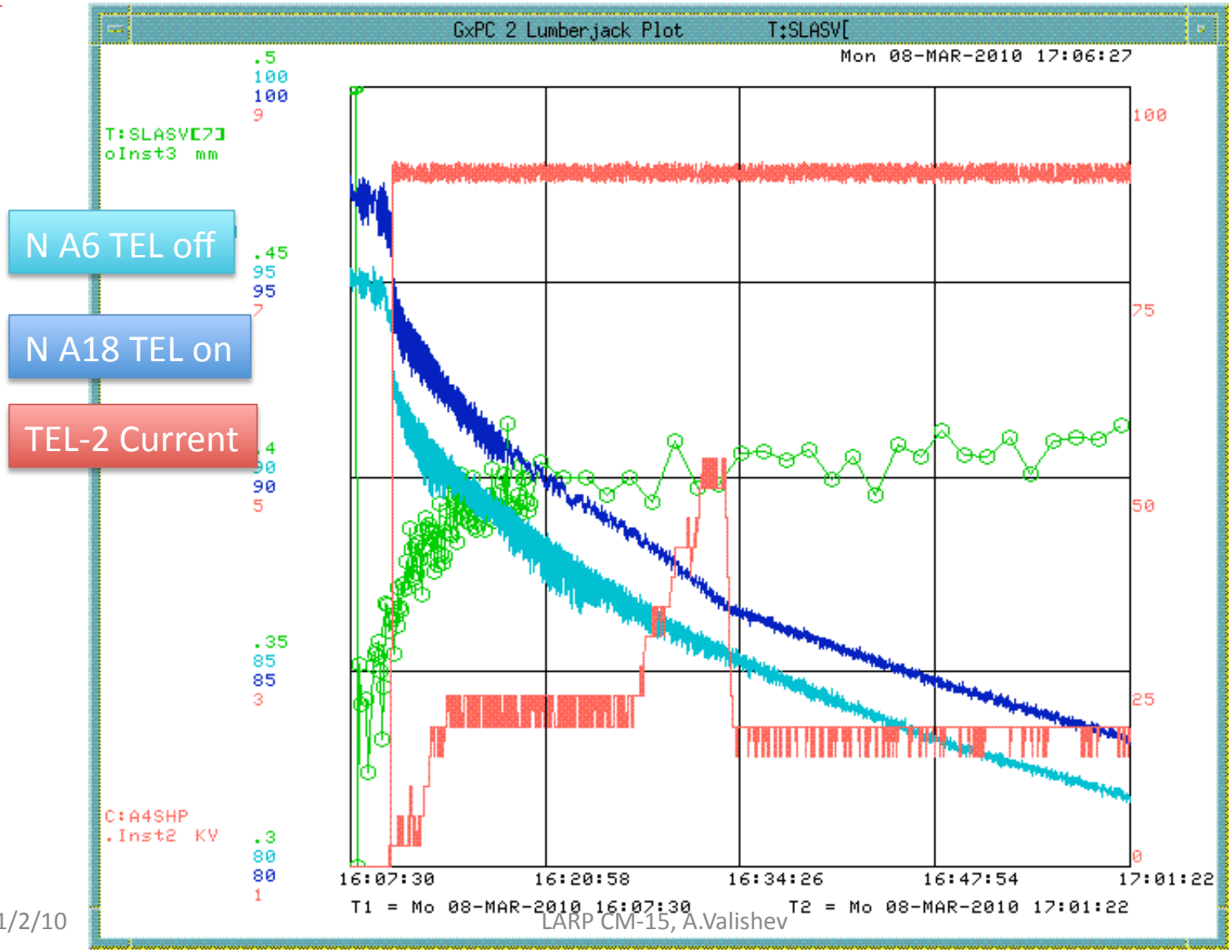
Losses during vertical e- beam position scan



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



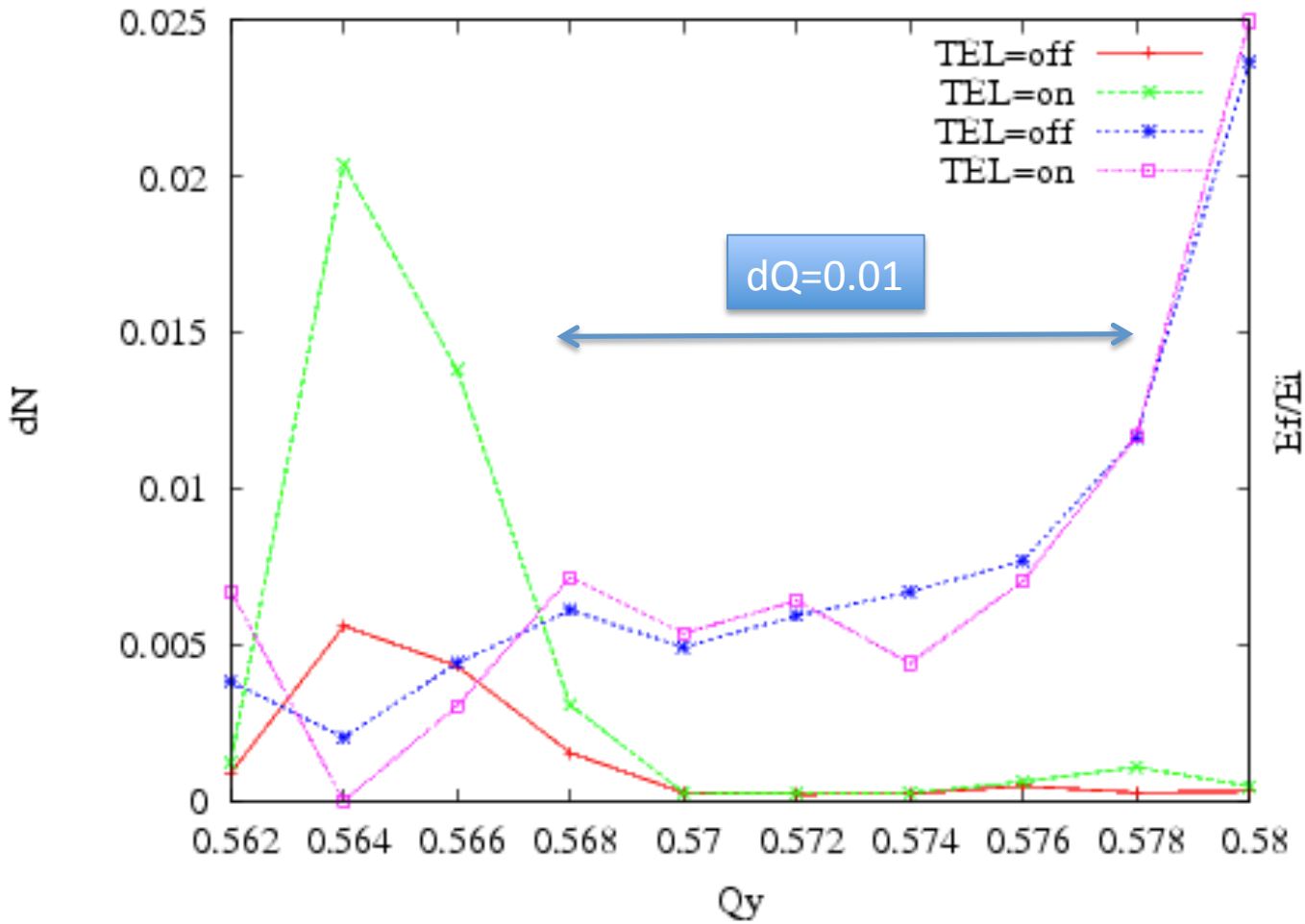
# Effect of Gaussian TEL-2 on Lifetime
# HEP Store 7661, $L_0$=3.3x$10^{32}$



# Motivation and plan for 3x3 HO BBC stores

- During normal 36x36 Tevatron operation, $\varepsilon p$=20 mm mrad, $\varepsilon a$=7 mm mrad, 2 HO IPs, 70 long-range. $\xi a$=0.02-0.025 with no head-on beam-beam effect.
- Reducing number of bunches to 3x3 leaves 2 HO IPs and 4 long-range
- Intentionally increase antiproton emittance to 12-16 mm mrad to enhance HO beam-beam
- Perform tune scan to provide data for simulations

# Simulation of Tune Scan for 3x3 HO BBC

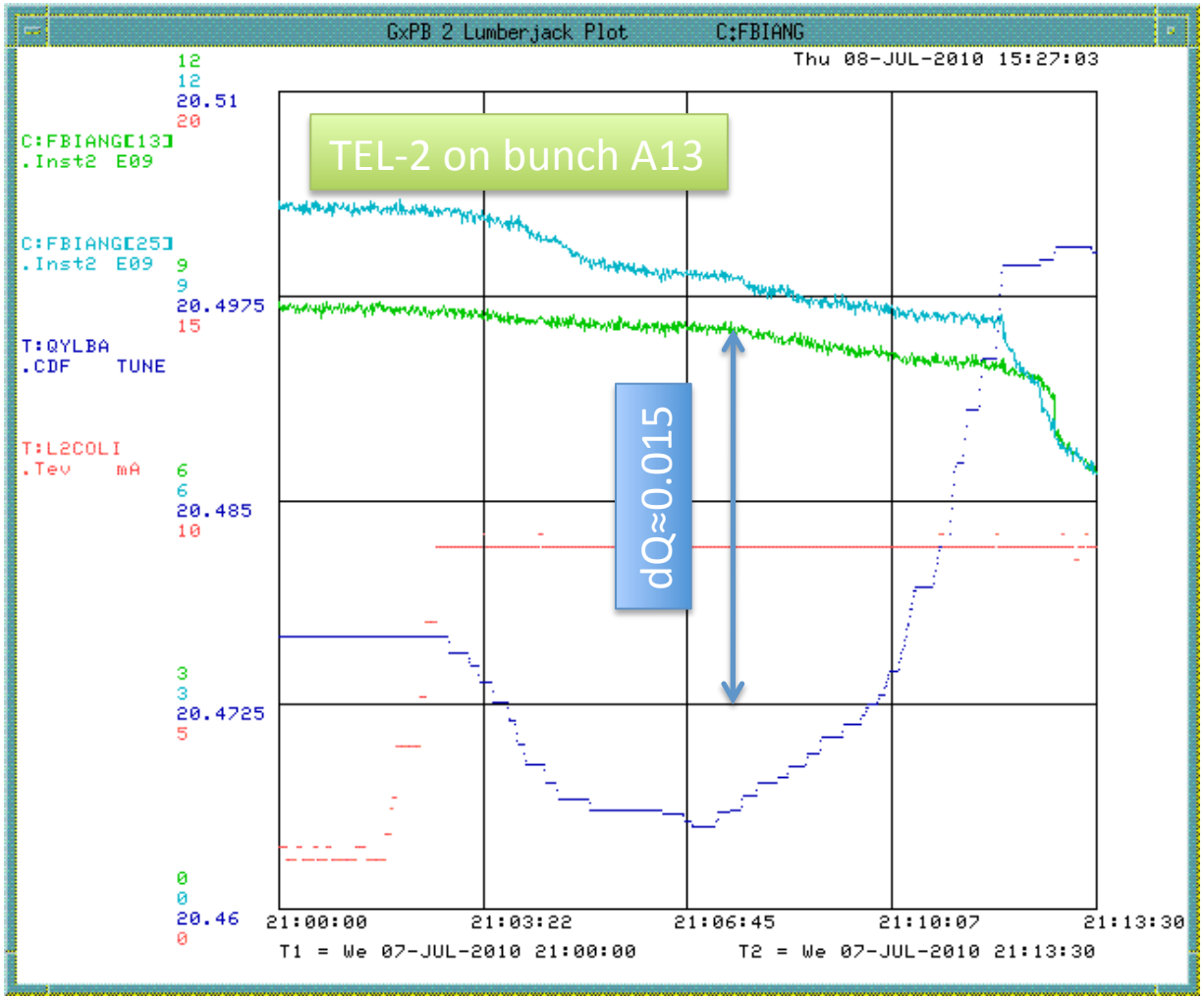



Conclusion: $\xi$=0.02 is NOT sufficient to demonstrate HO BBC

# Beam parameters in 3x3 HO BBC stores

- No.1 (Store 7893, June 15, 2010)
  - $N_p=2.9\times10^{11}$, $\varepsilon_p\approx60$ mm mrad (proton beam blew up)
  - $N_a=0.7\times10^{11}$, $\varepsilon_a=12$ mm mrad
  - $L_0=1.1\times10^{31}$
  - $\xi_a=0.009$
- No.2 (Store 7957, July 7, 2010)
  - $N_p=2.7\times10^{11}$, $\varepsilon_p=25$ mm mrad (smaller blow up)
  - $N_a=0.4\times10^{11}$, $\varepsilon_a=12$ mm mrad
  - $L_0=1.2\times10^{31}$
  - $\xi_a=0.02$
  - Performed tune scan to compare with simulations

# Tune Scan in 3x3 HO BBC Store 7957

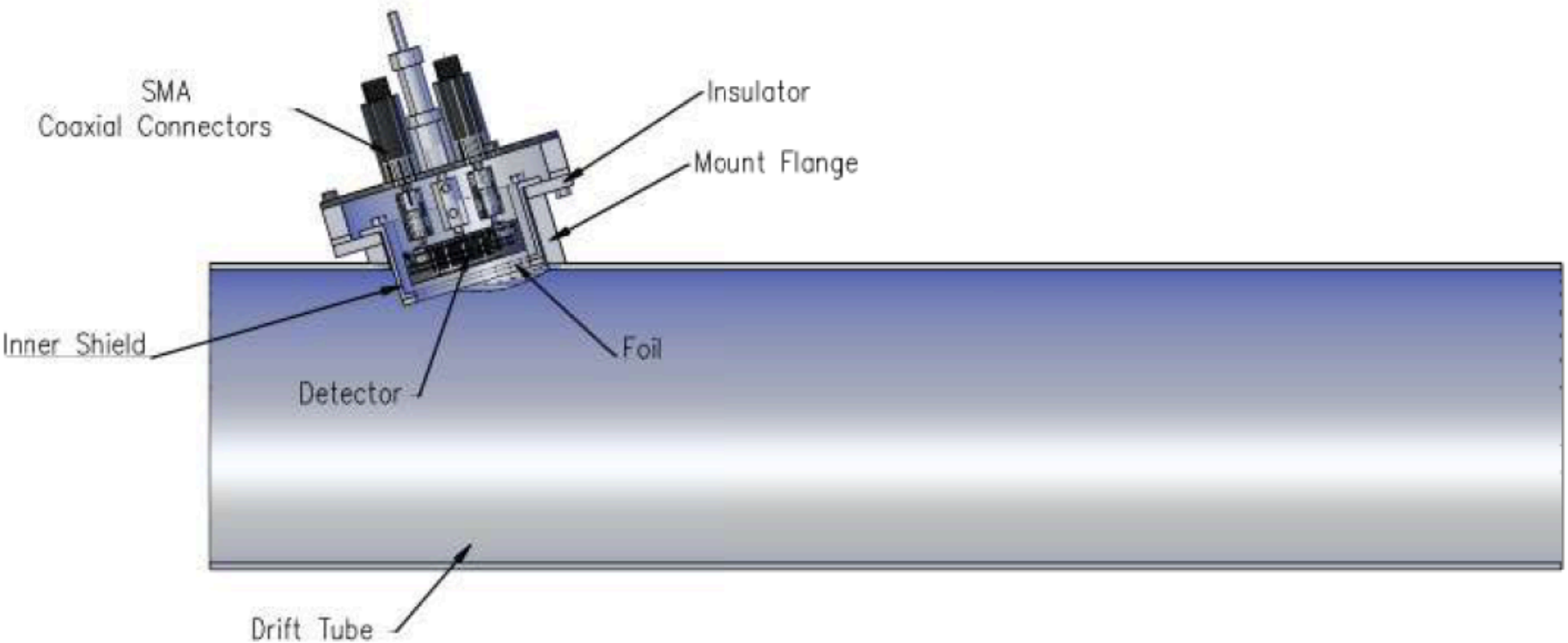



Conclusion: Observed tune space consistent with expected from simulation

# Gaussian TEL-2 Results

- Alignment of e- and pbar (proton) beams is crucial for successful EL operation
  - Demonstrated that a well-calibrated EL BPM system is sufficient for good alignment
  - Observed tune shift and tune spread generated by Gaussian EL consistent with expectation
- TEL operating during HEP stores does not produce adverse effects in circulating beams
  - Significant result given the imperfections of the actual Gaussian EL implementation
    - Jitter
    - Deviation from Gaussian shape
    - Misalignments
    - Electron beam Bends
- Performed betatron tune scans in dedicated HO BBC store
  - Although did not demonstrate compensation, produced valuable data for comparison with simulations

# BNL Bremsstrahlung detector for TEL-2

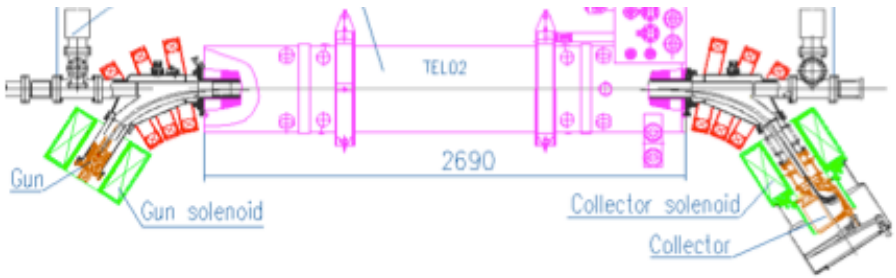


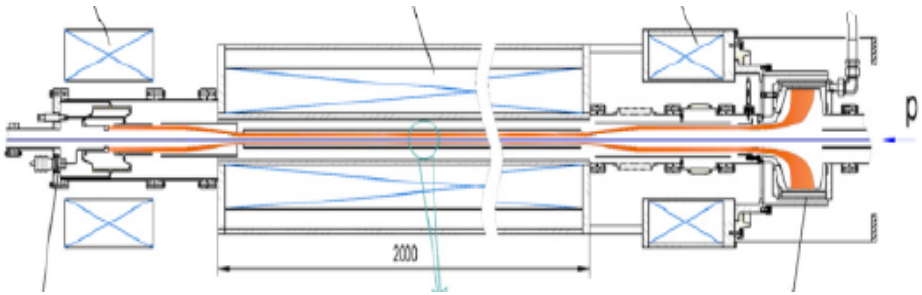
# Summary

- Gaussian TEL-2 experimental goals have been met
  - The gun was replaced with hollow-beam gun
  - There is interest at BNL to continue HO BBC studies, possible at the end-of-RunII Acc. Physics study period
  - In collaboration with BNL, an alignment instrument is being developed based on bremsstrahlung
- The focus in experimental work at TEL switched from BBC to HEBC
- Beam-beam simulations plan
  - Continue code development
    - implement hollow e-beam (hiring a guest scientist)
  - Support RHIC EL project with simulations
  - Continue collaboration with CERN on simulations of beam-beam effects, especially as experimental data becomes available

# Summary (continued)

- Goals for HEBC
  - In Tev. studies, establish the importance of $e^-$ beam layout (bends vs. "funnel")




- Design and build a larger gun (flat surface) during FY11
- Test the gun at Linac Lab
- Install in TEL2
- Perform experiments at the end of Tev run

1. Tev runs for 1 year
   - Build and test a full prototype of funnel-type cathode and collector in FY11-FY12
2. Tev runs for 3 years

- Design and build a full prototype of funnel-type setup for TEL2
- Test at the Linac Lab
- Install in TEL2