Simulation of Beam-Beam Effects and Tevatron Experience

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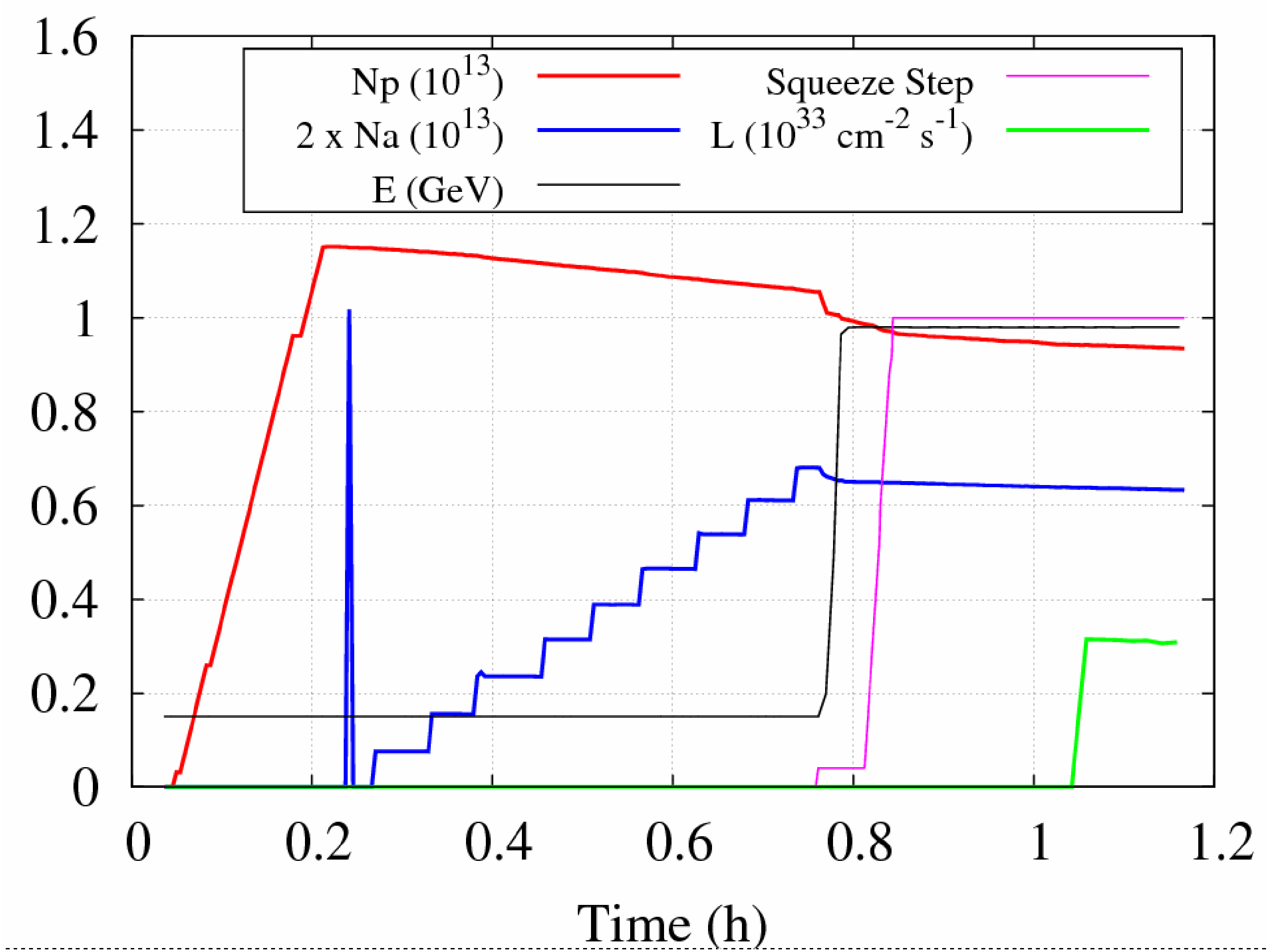
EPAC'08, June 26, 2008

Outline

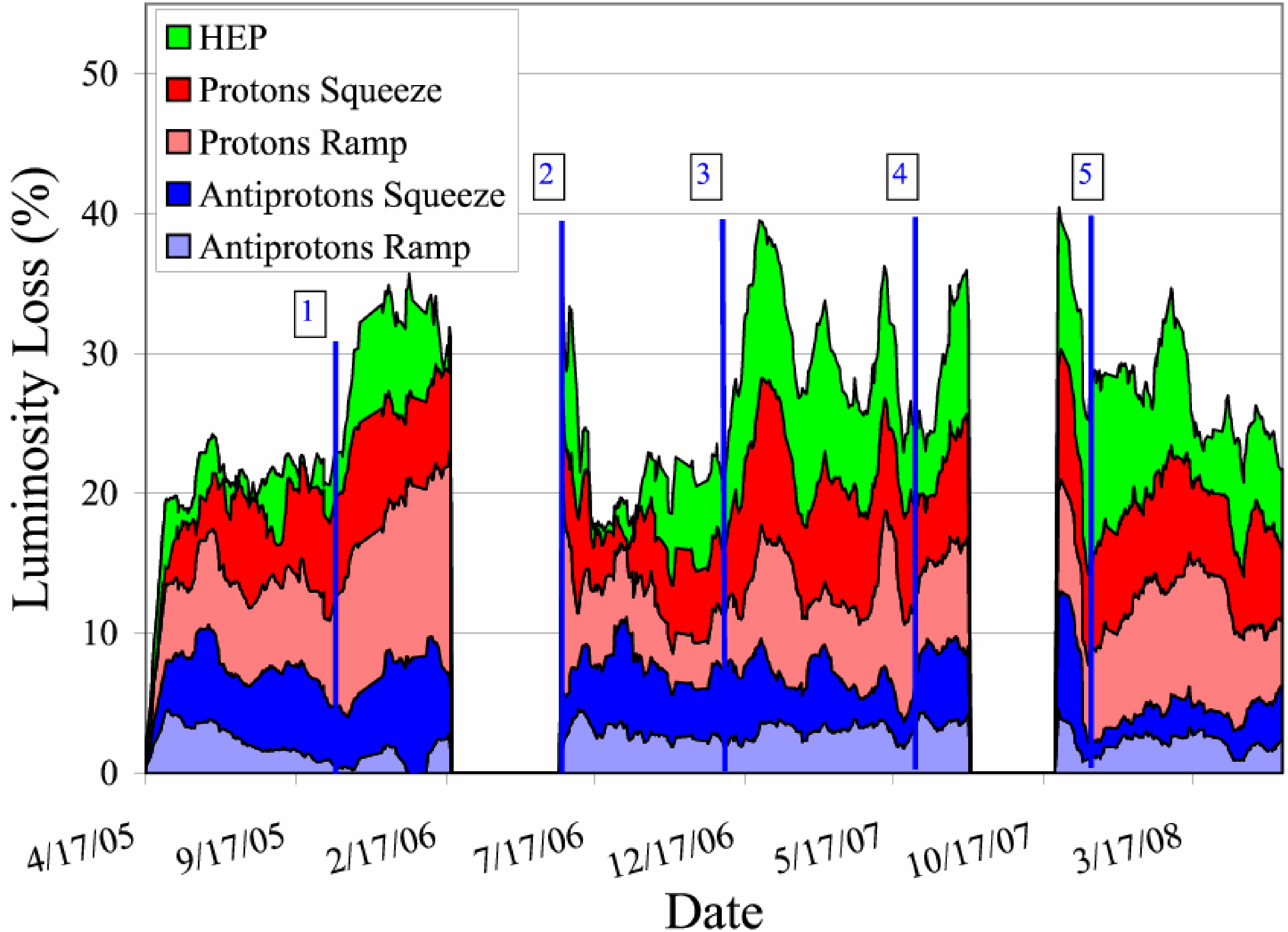
- Overview of Beam-Beam Effects
  - Injection
  - Ramp
  - Squeeze
  - Collisions
- Analysis tools
  - Luminosity Evolution Model
  - Beam-Beam Simulations
- Countermeasures
  - New Collision Helix
  - Second Order Chromaticity Correction
  - (New Tune Working Point)
- Results and Summary

Collider Fill Cycle

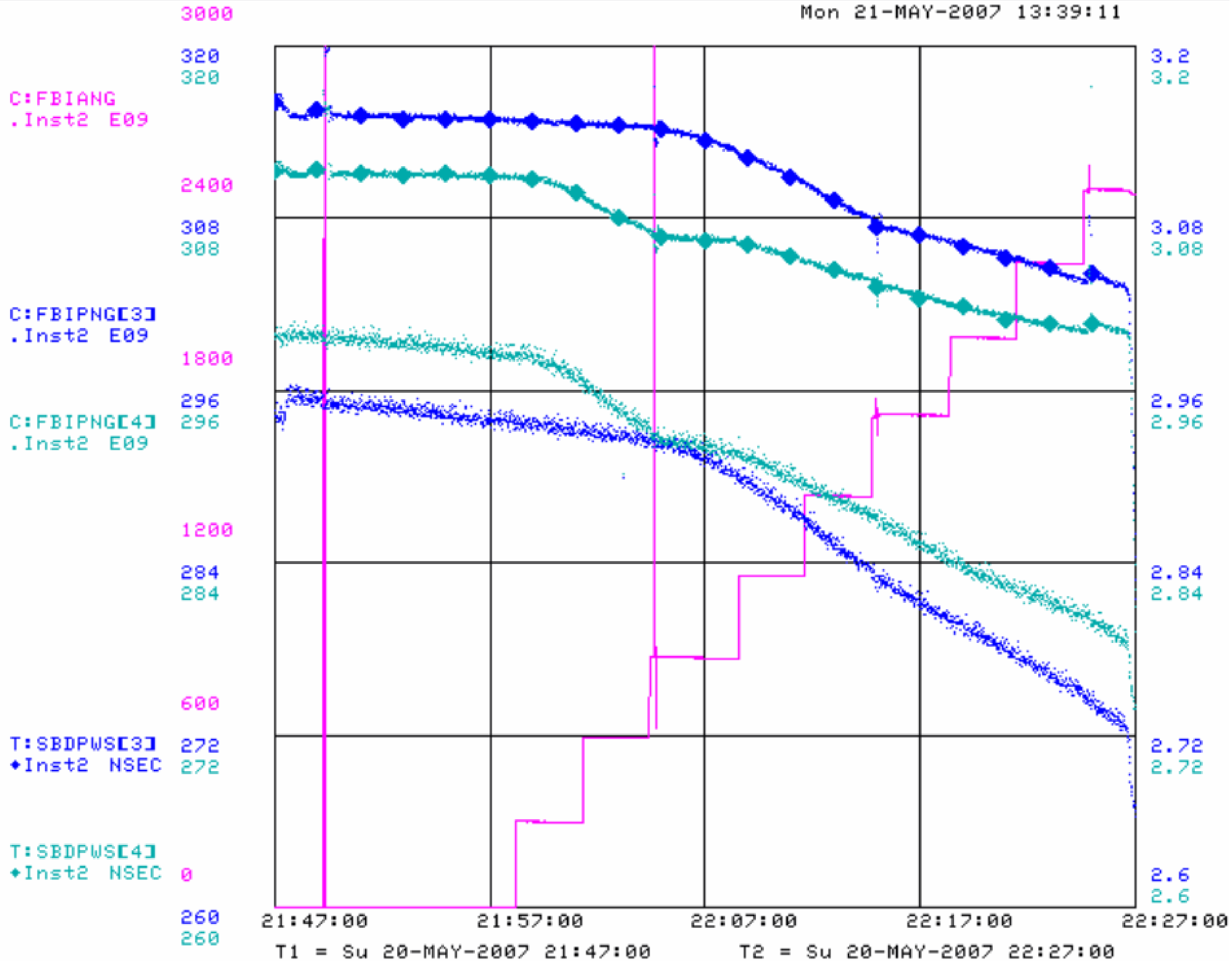


Record Store 5989 L_0=3.15x10^{32}

Contributions to Luminosity Loss

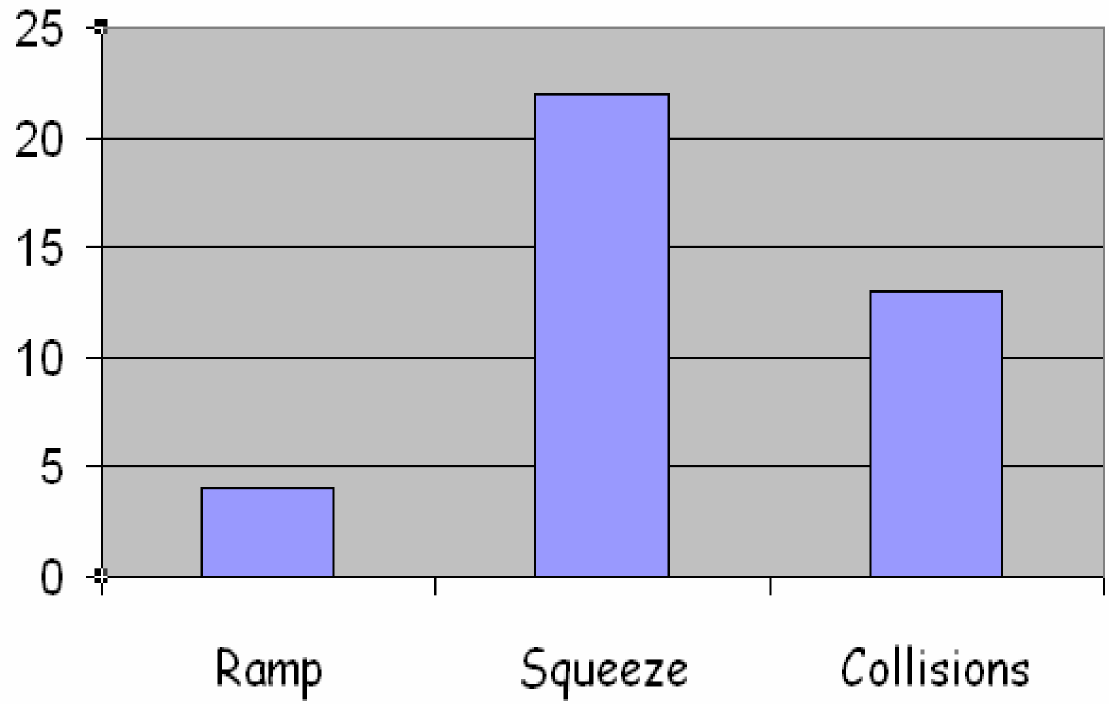


Long-Range Effects at Injection

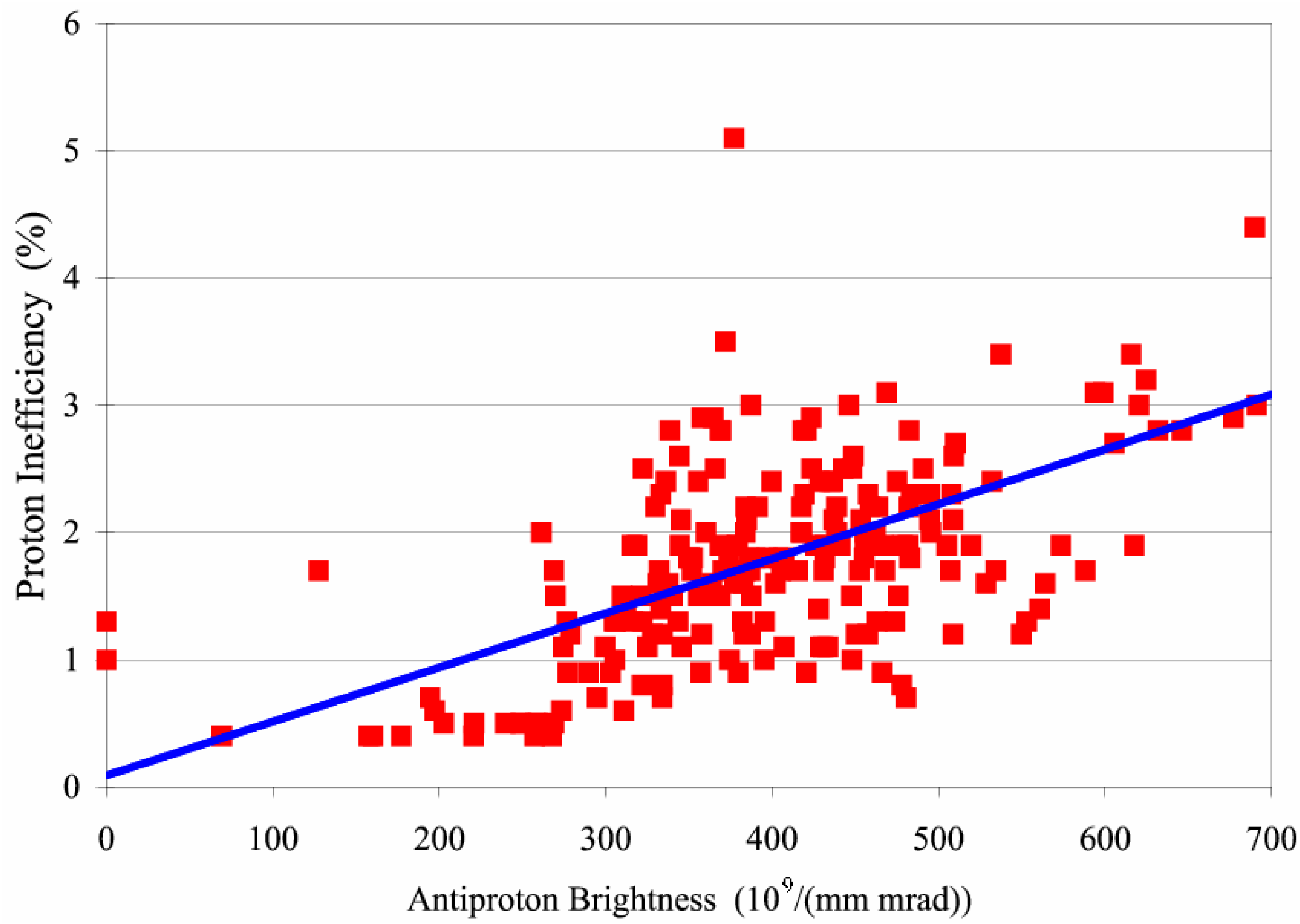


Importance of Losses in Squeeze

- Total quenches this year 140
- Percentage
  - Ramp: 3
  - Squeeze: 22
  - Collisions: 13 = 38
  - No beam: 102
- Most quenches in squeeze are caused by a combination of beam-beam and orbit issues



Proton Loss in Squeeze vs. Antiproton Brightness



Luminosity and Luminosity Integral

$$L = \frac{3\gamma \ f_0 \ B \ N_{\bar{p}} N_p}{\pi\beta^*\left(\varepsilon_p + \varepsilon_{\bar{p}}\right)} H\left(\sigma_l / \beta^*\right) \qquad L = L_0 / (1 + t / \tau_L)$$

$$I = \int L dt \cong N_{stores} \tau_L L_0 \ln(1 + T / \tau_L)$$

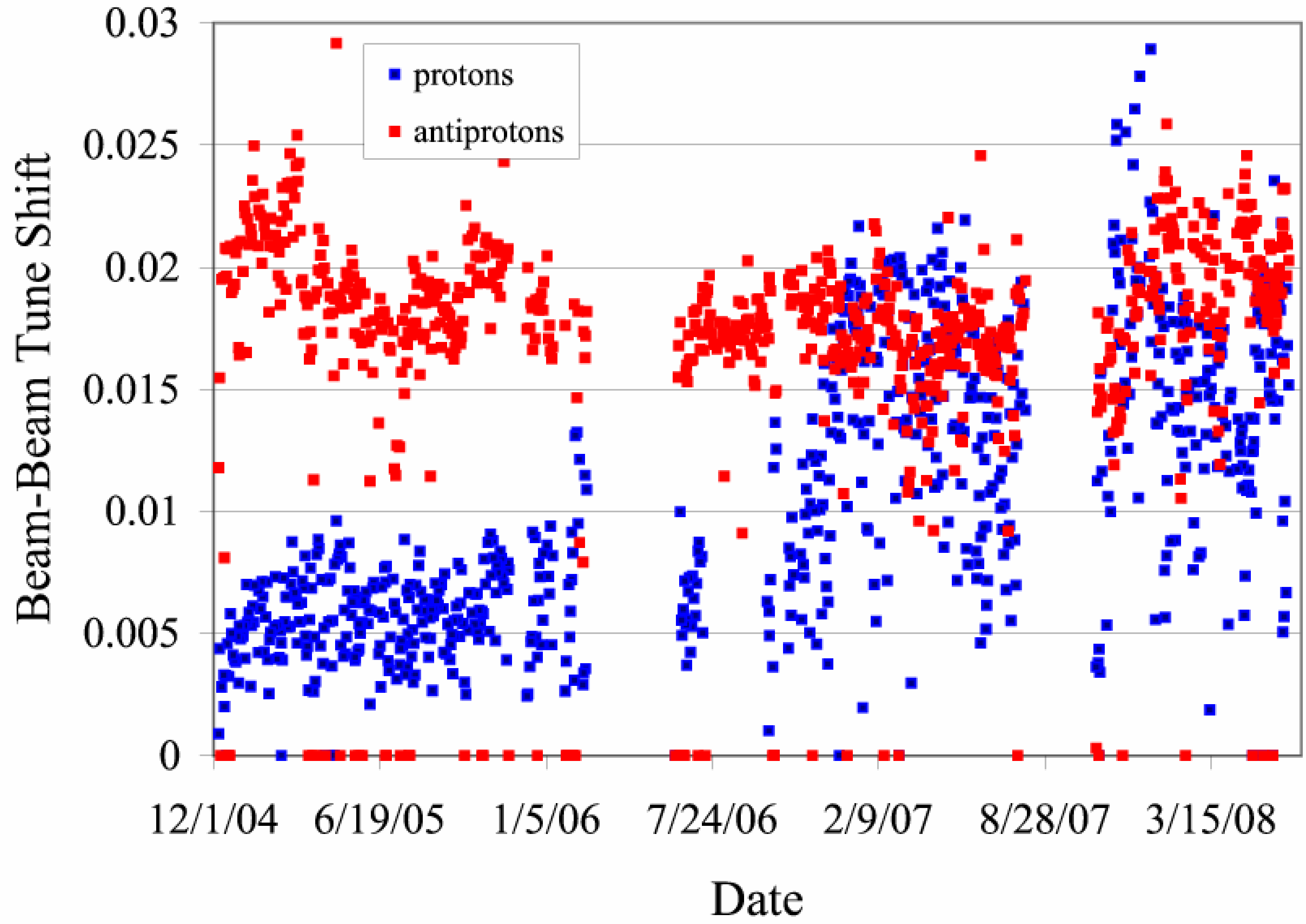
- Luminosity Integral: primary factors
  - Beta* at IP and bunchlength: H(x)/beta^*
  - Emittances ε_p ε_{pbar}
  - Number of protons: N_p
  - Number of antiprotons: BN_{pbar}
  - Lumi-lifetime: τ_L

Effects at Collisions

- Emittance blowup
- Lifetime deterioration

- Long-Range
- Head-on

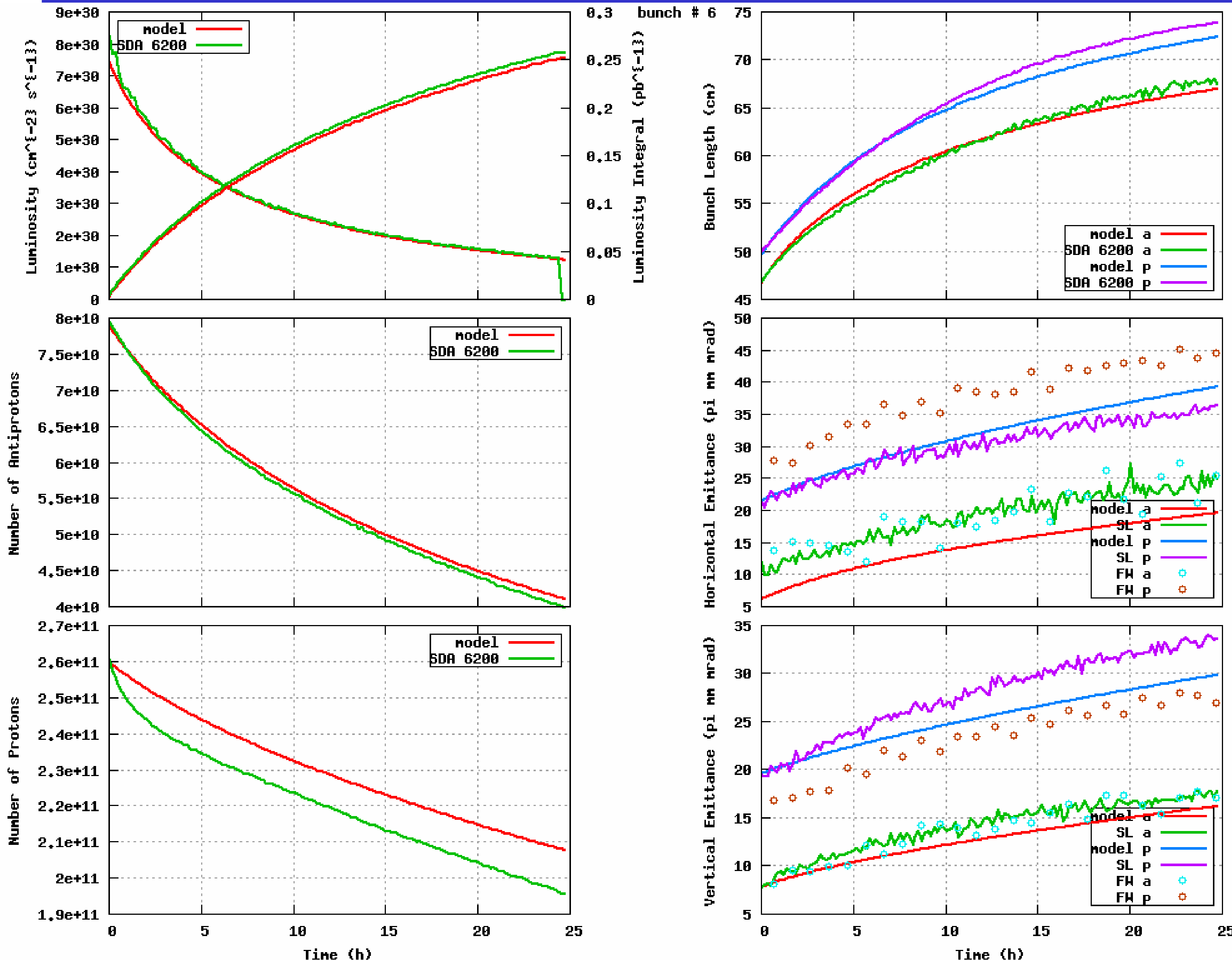
Head-on Beam-Beam Parameter



Luminosity Evolution Model

- Beam-Beam is not the single strongest effect
- A model model was built to describe evolution of the beam emittances and intensities taking into account the following factors:
  - Scattering at IP (luminosity)
  - Intra Beam Scattering
  - Scattering on residual gas
  - RF noise
- Initial parameters (bunch by bunch intensity, transverse and longitudinal emittances) are provided by measurements
- Main free model parameters are:
  - Gas pressure
  - RF noise power
- Fast computations

Store 6200. L_0=2.95x10^{32}

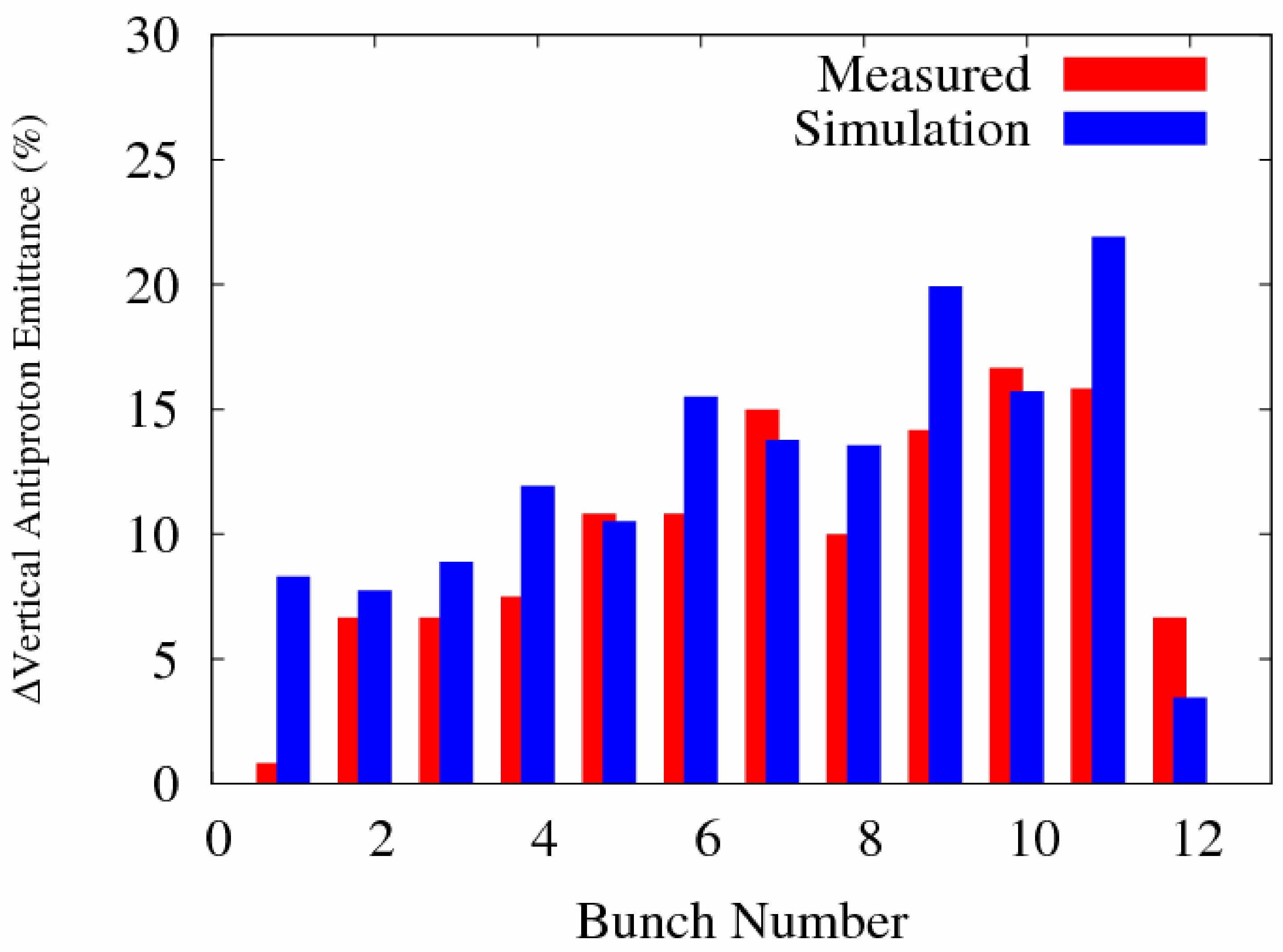


Beam-Beam Code LIFETRAC

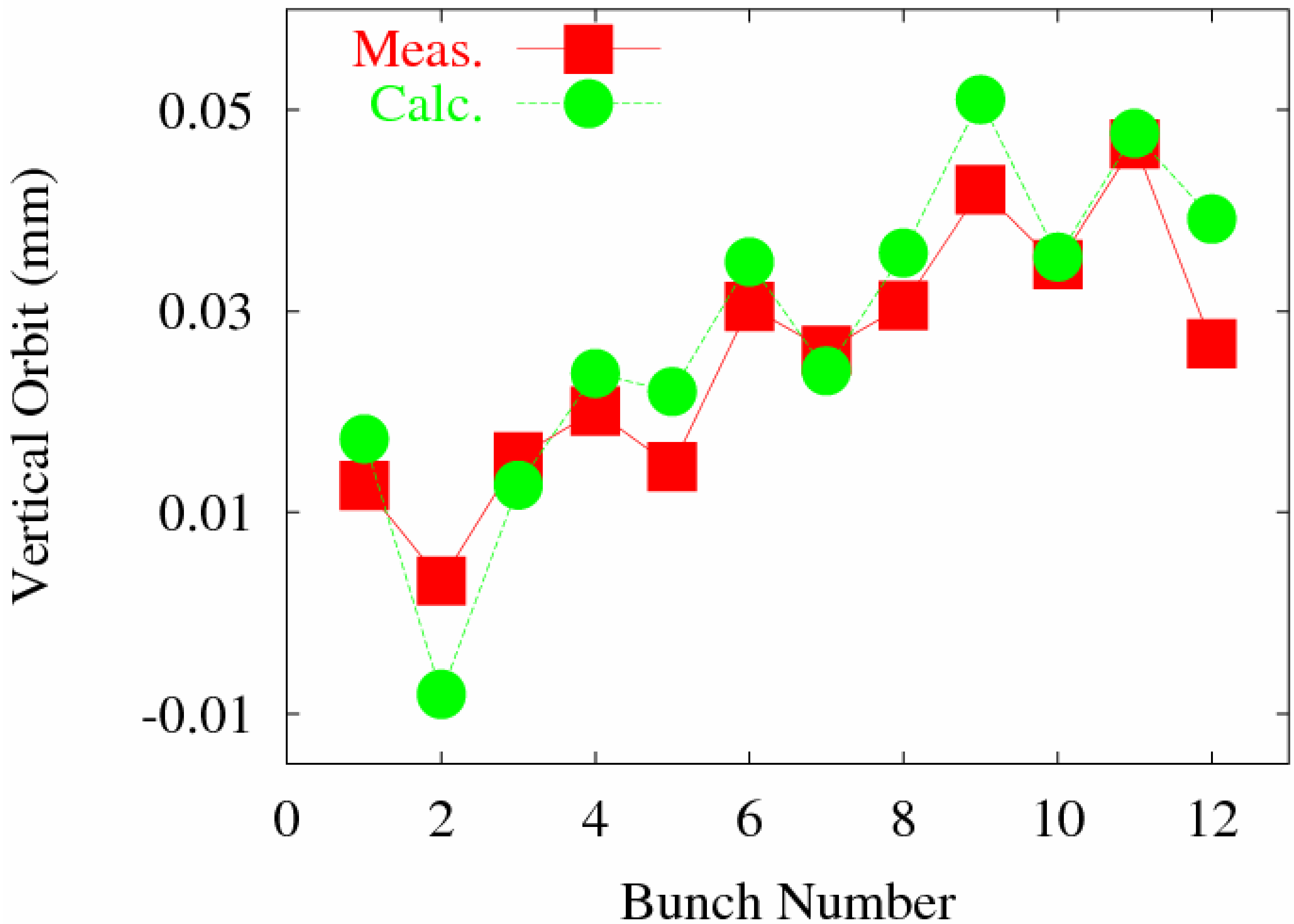
- Weak-strong, Gaussian strong bunch
- Macro-particle weak bunch, typically 10000 particles
- Full details of the machine optics, beam separation, and collision pattern with all 72 IPs
- Effects of random noise
- Parallel, up to 10^8 turns
- Deliverables – emittances and beam life time

- D.Shatilov et al., TPAT084, PAC05
- A.Valishev et al., TPAT083, PAC05

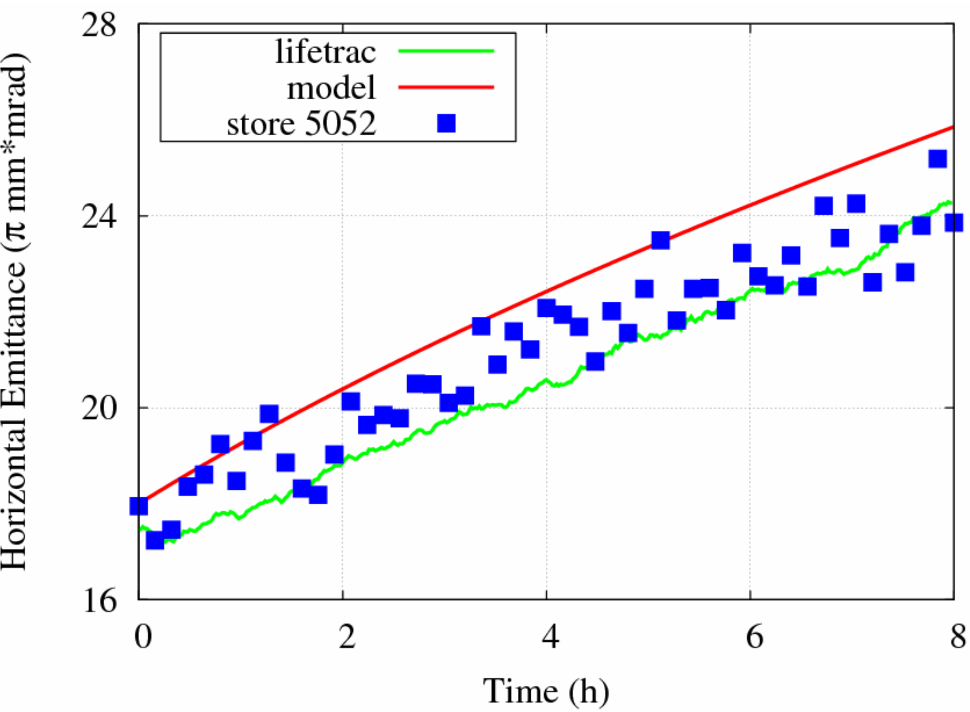
“Scallops”. Simulation and Measurement

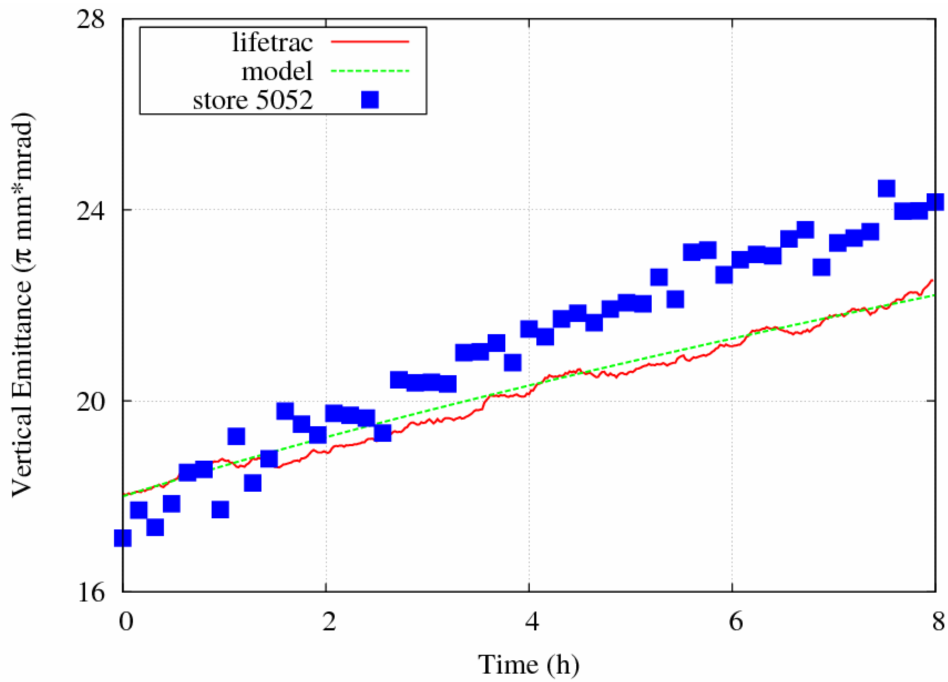


Antiproton Bunch-to-bunch Orbit



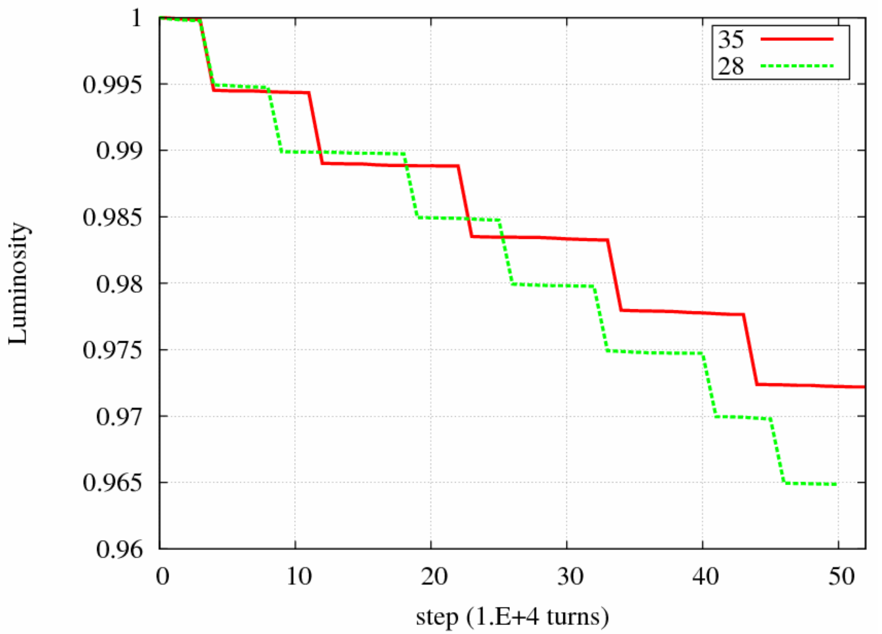
Model Cross-Check

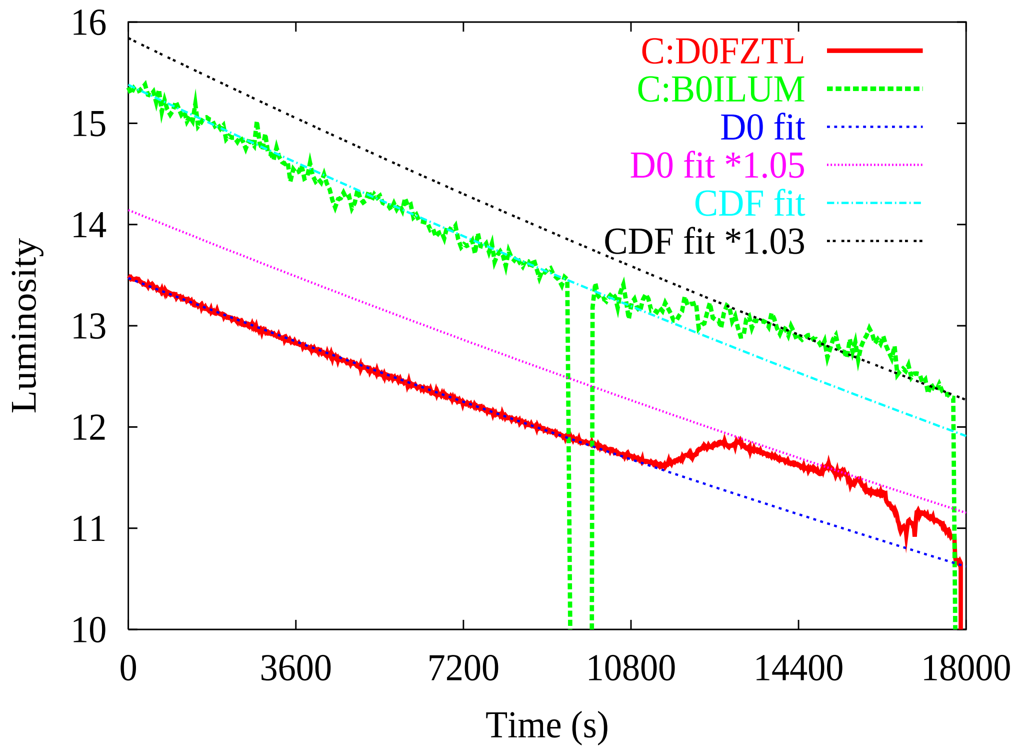




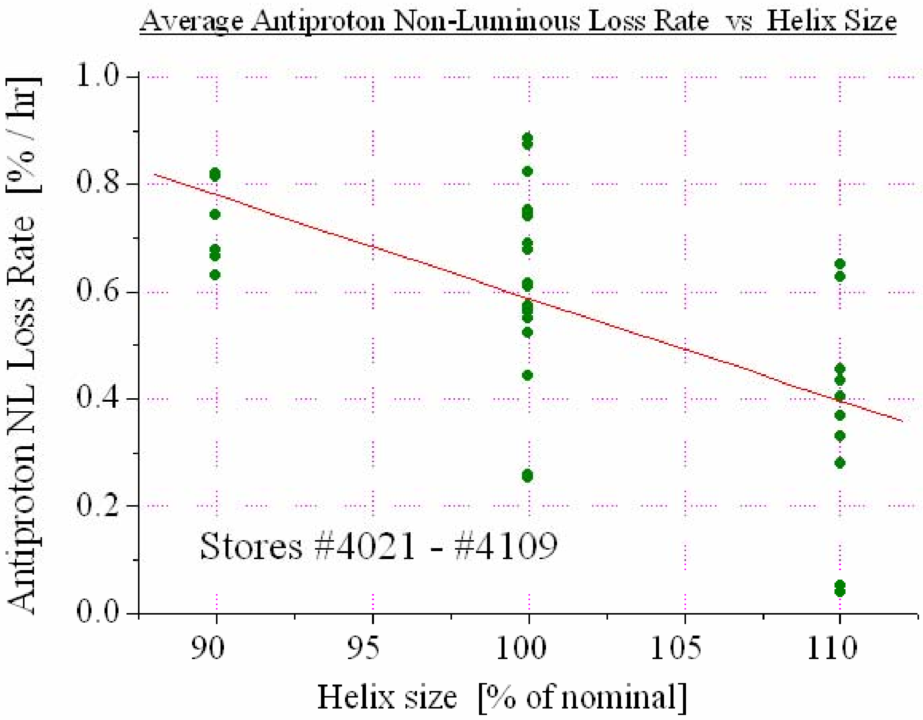
Store 5052 $L_0=0.92\times10^{32}$

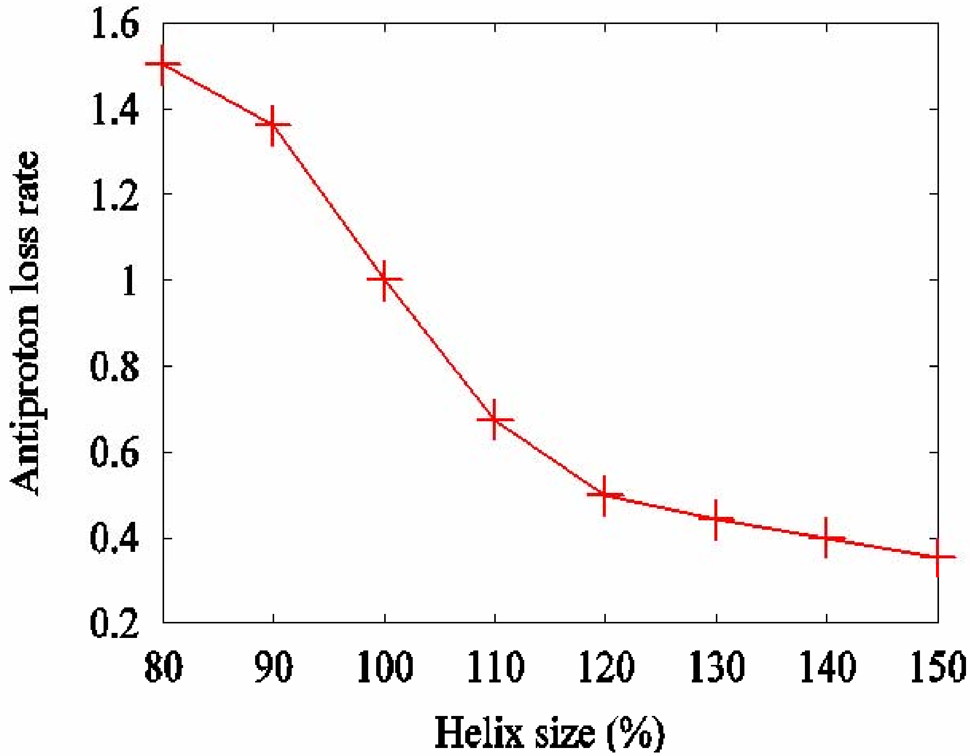
β* Reduction (8/2005)





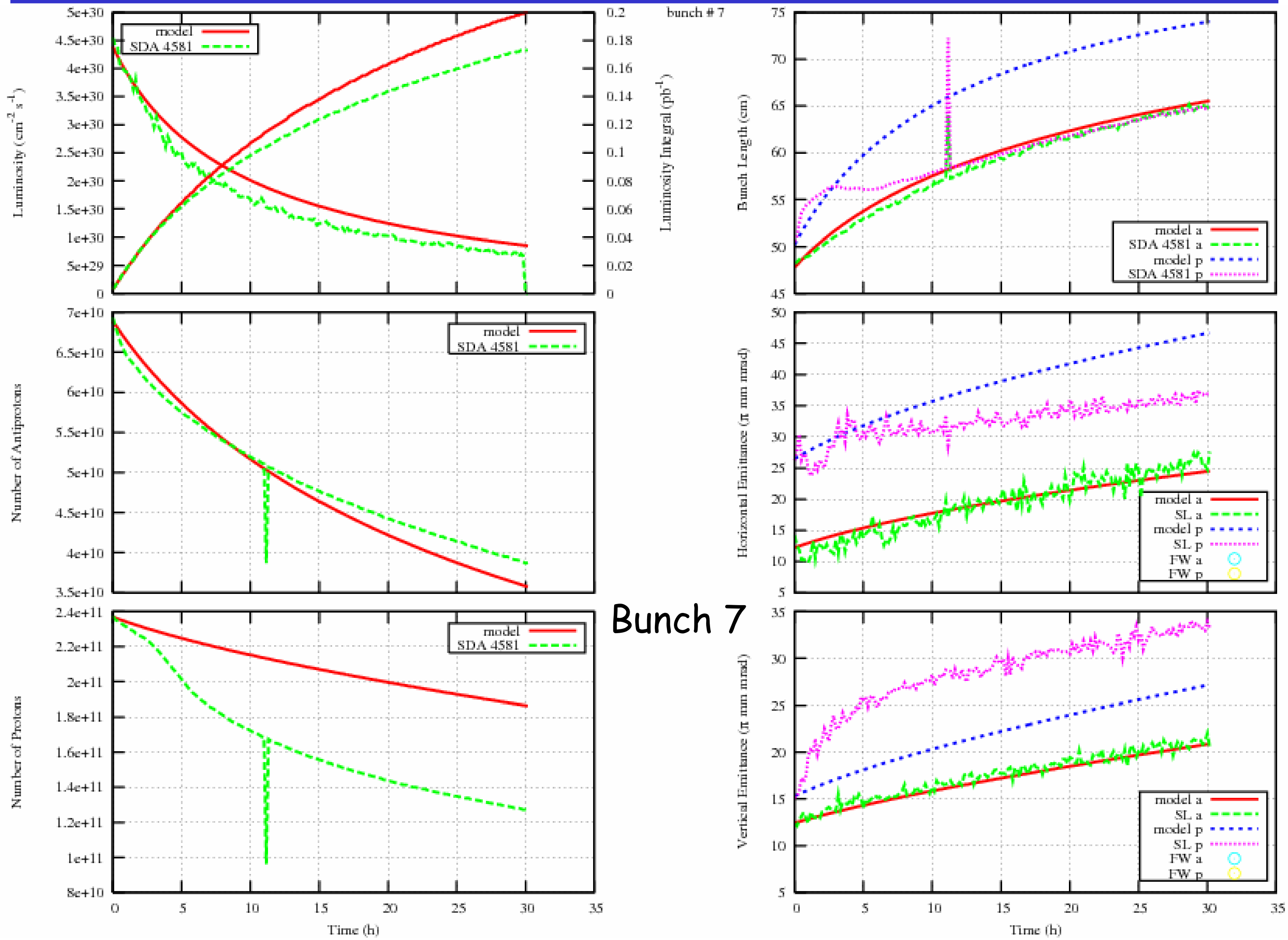
Effect of the Helix Size on Lifetime





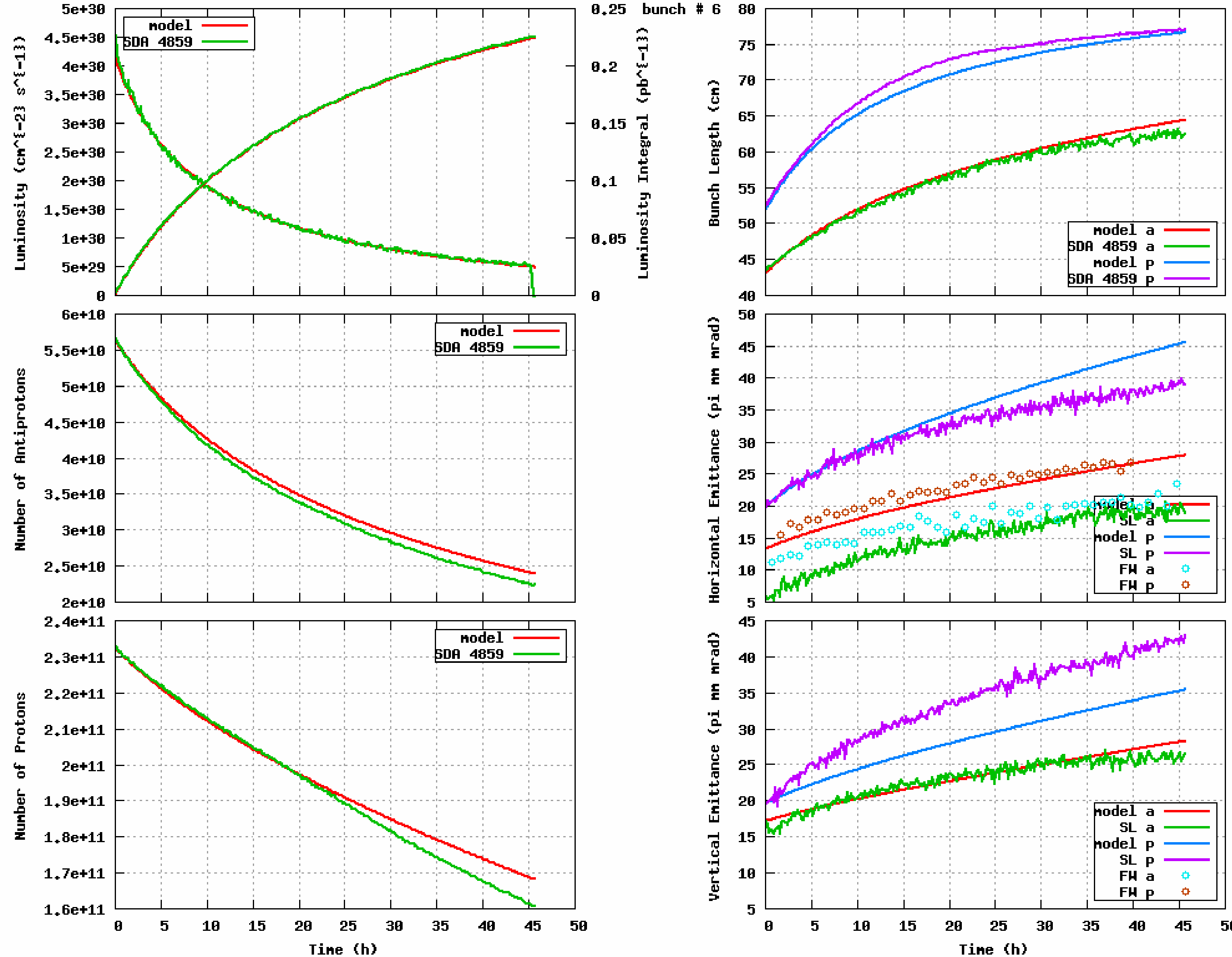
	CDF upstream	CDF downstream	D0 upstream	D0 downstream
- 7/06	5.4	5.6	5.0	5.2
7/06 -	6.4	5.8	6.2	5.6

Store 4581, L_0=1.72x10^{32} Old Helix

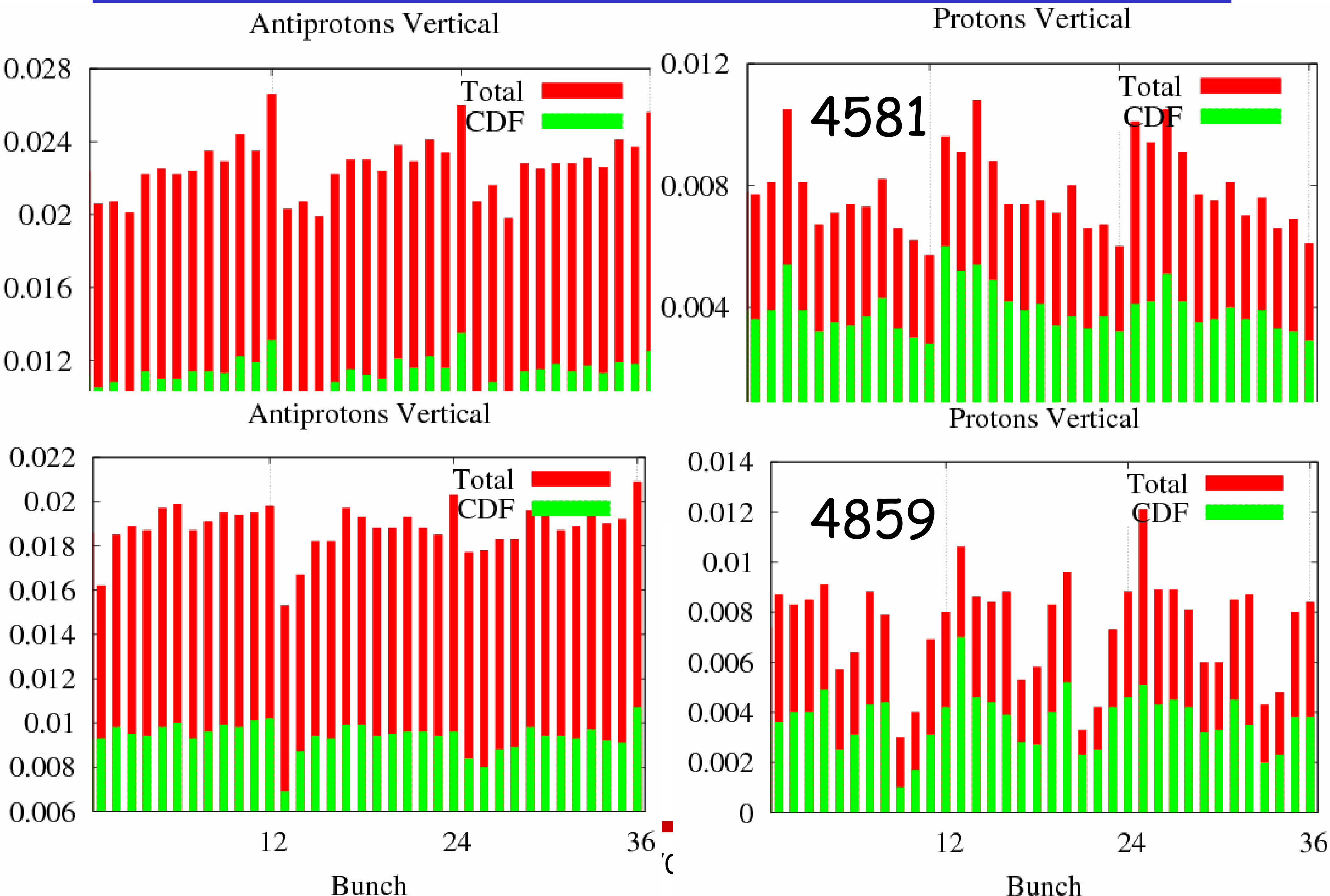


Bunch 7

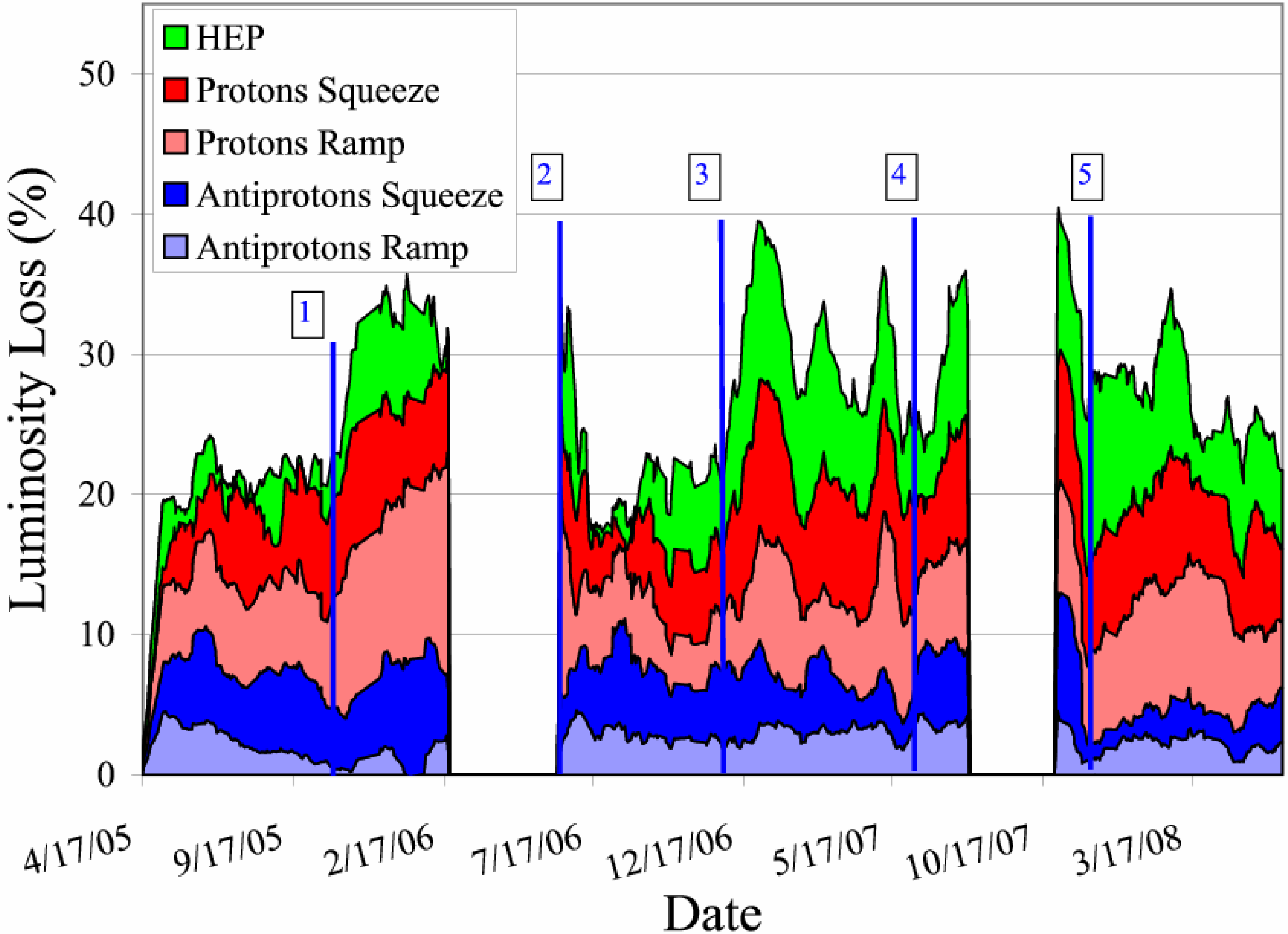
Store 4859, L_0=1.70x10^{32} New Helix



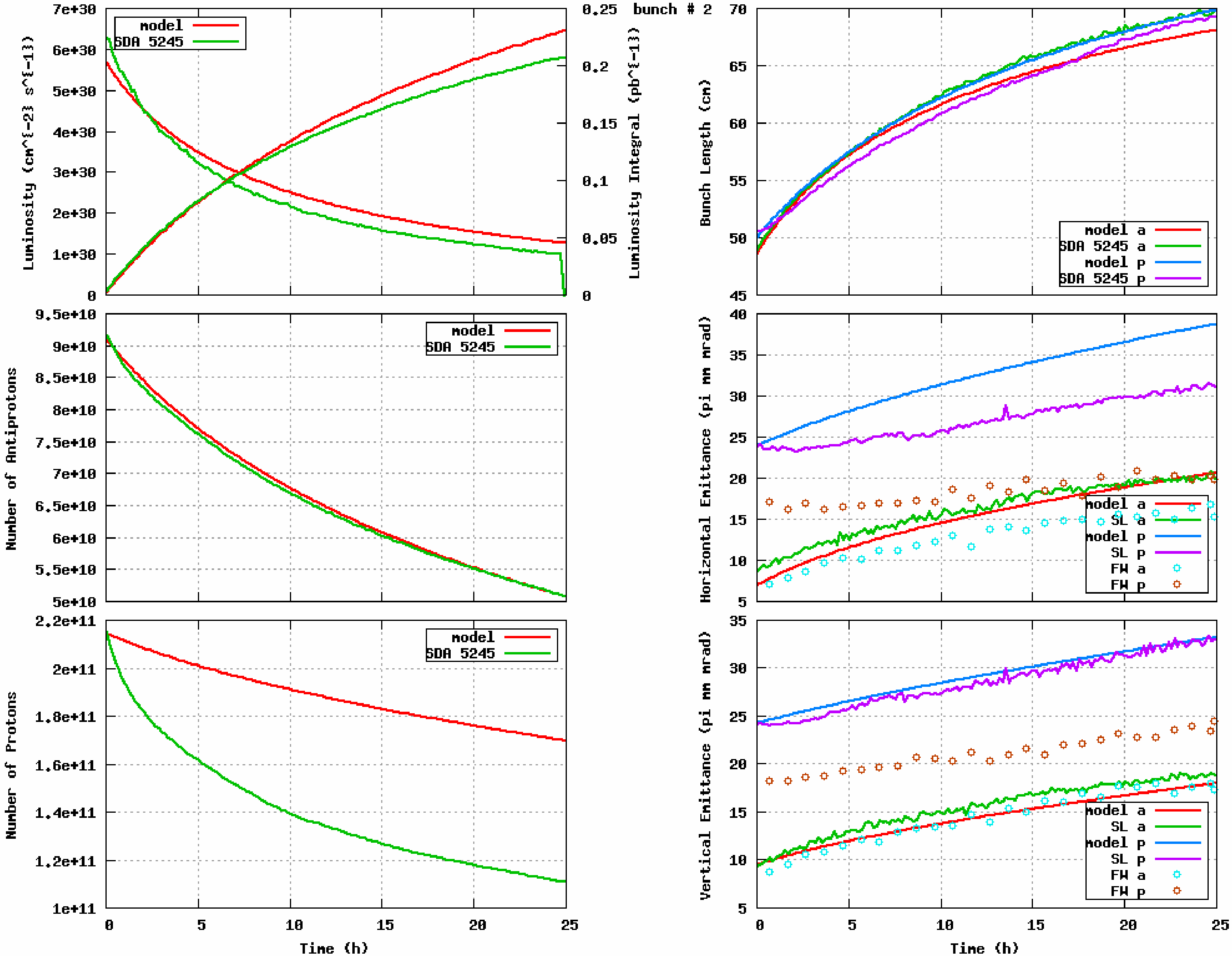
Head-on Beam-Beam Tune Shifts.



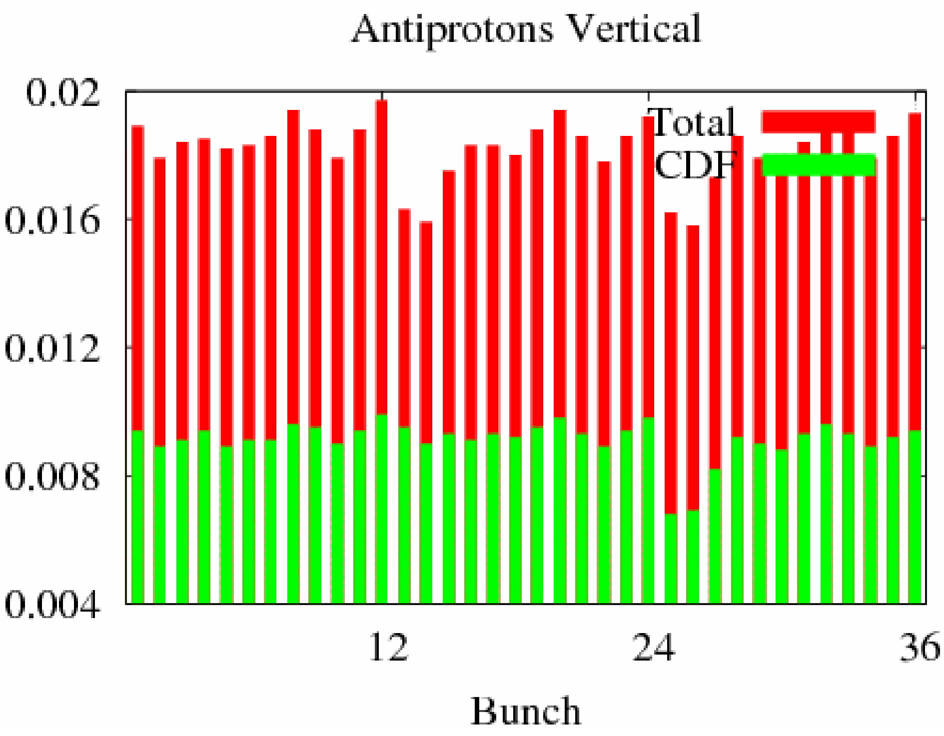
Contributions to Luminosity Loss

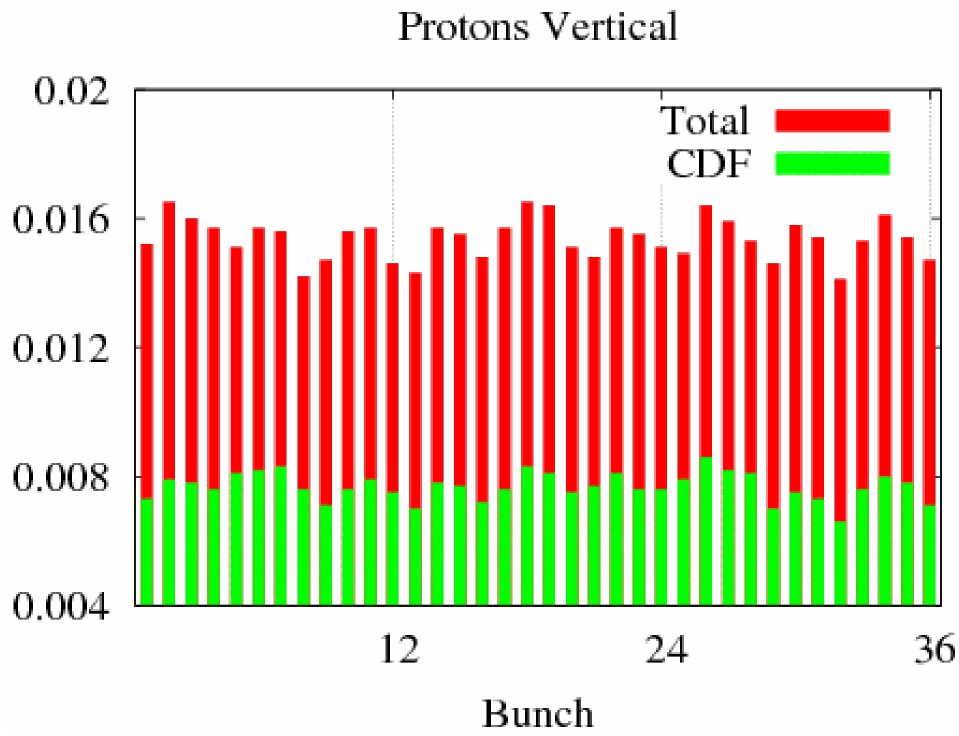


Store 5245, L_0=2.92x10^{32} New Helix

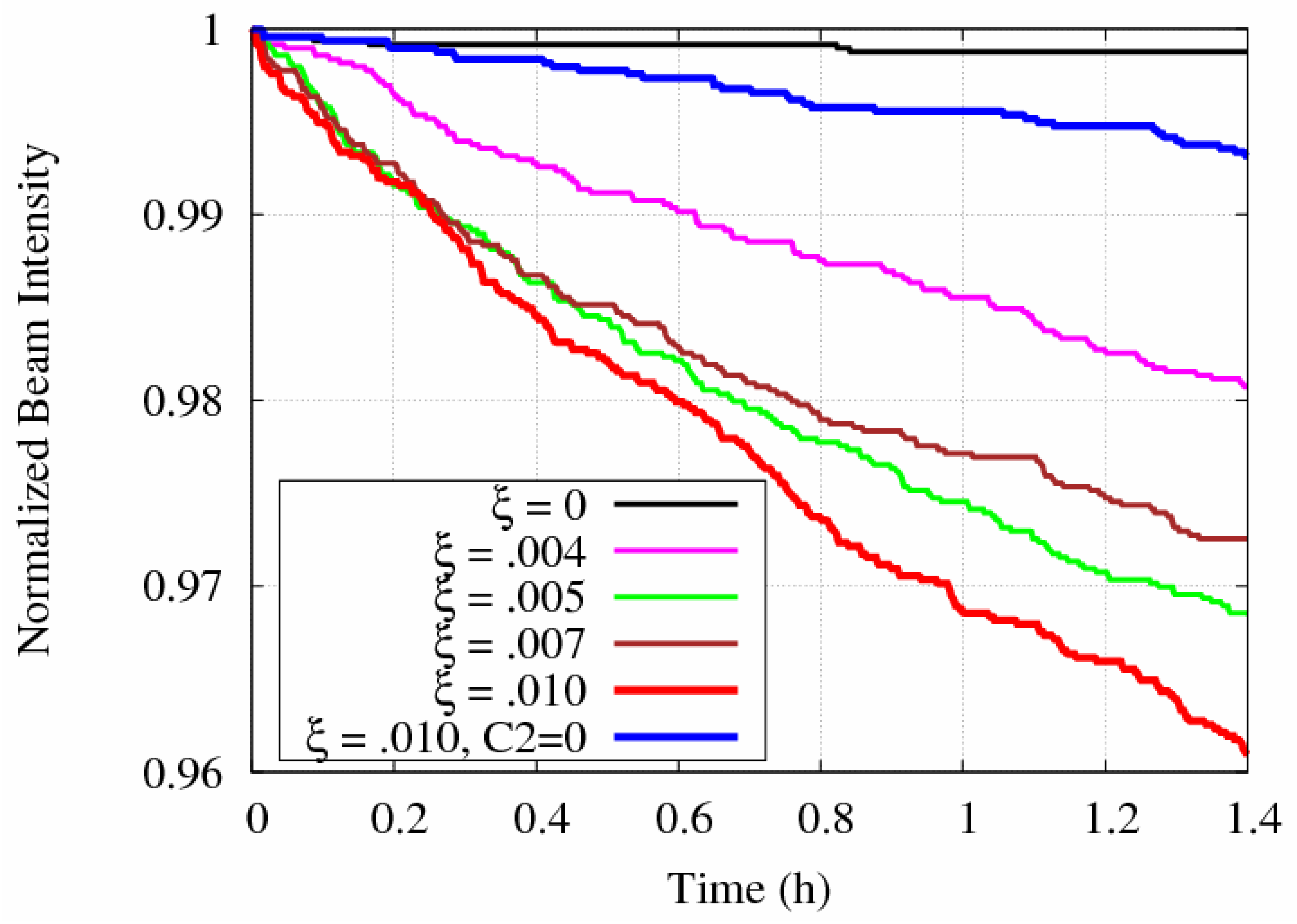


Head-on Beam-Beam Tune Shifts. Store 5245

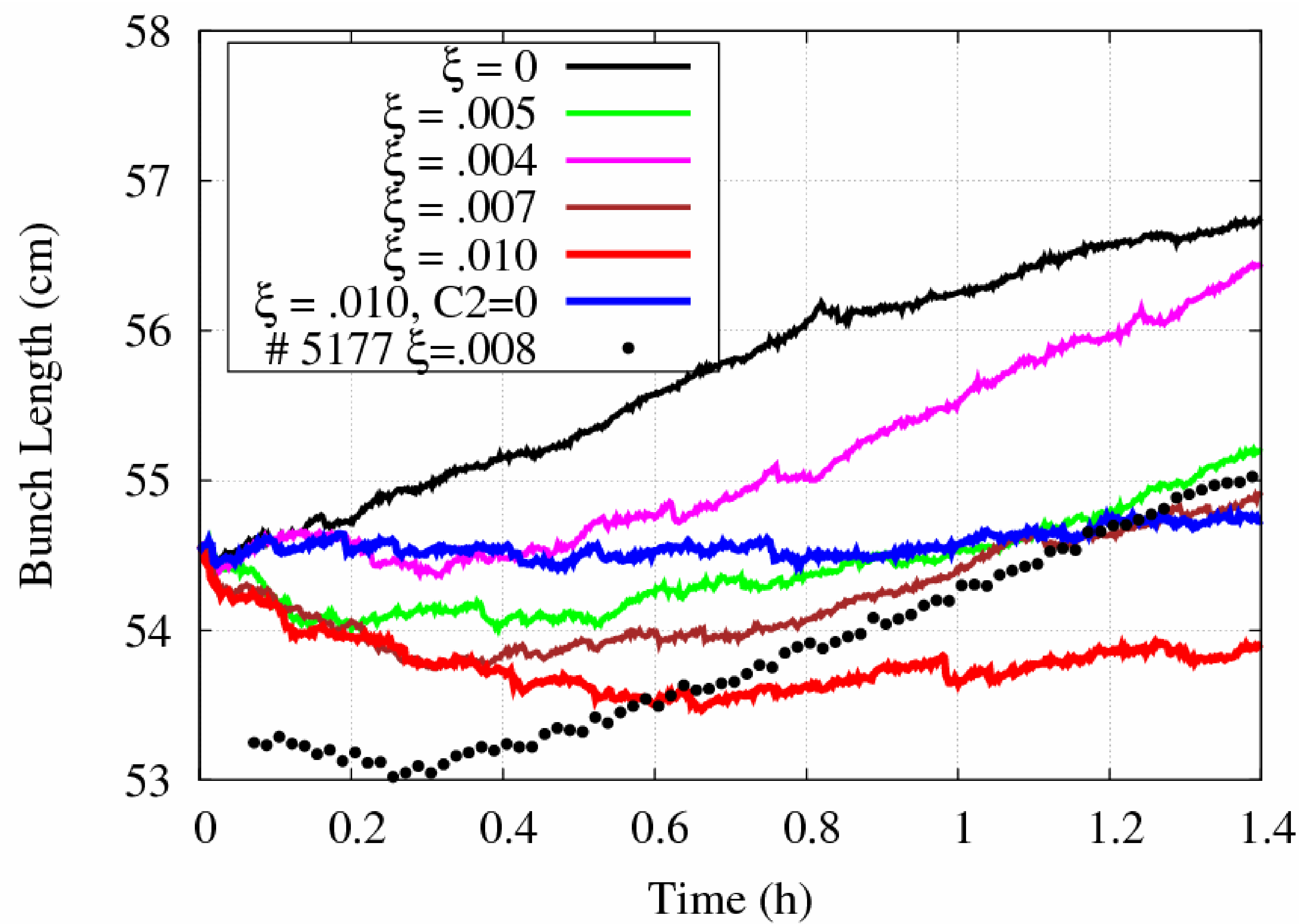




Effect of β* Chromaticity. Simulation

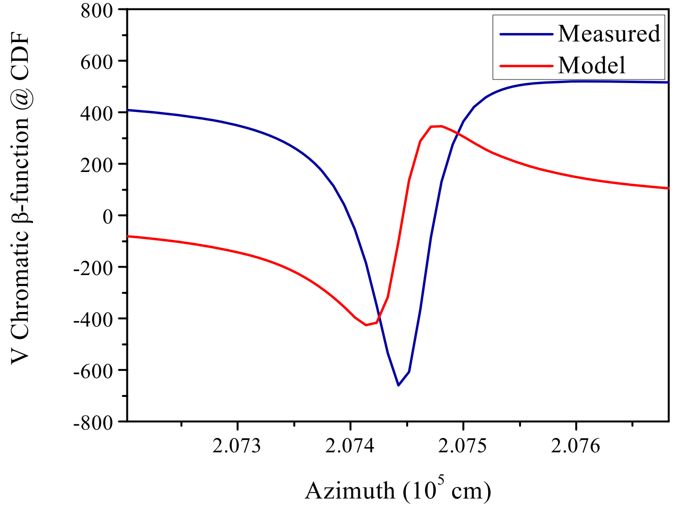


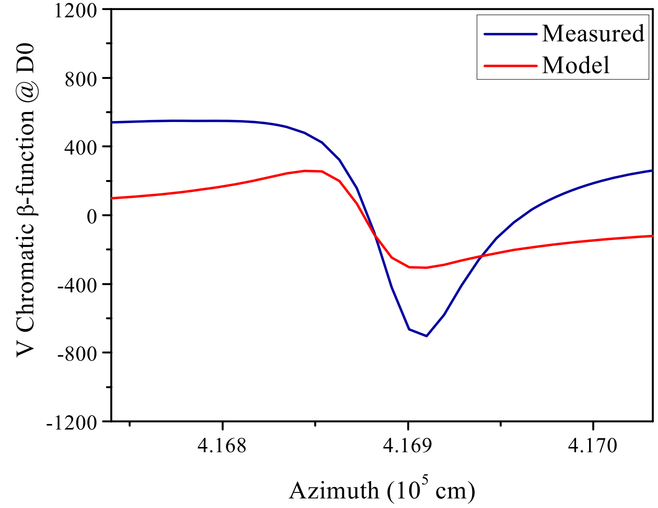
Effect of β* Chromaticity. Simulation

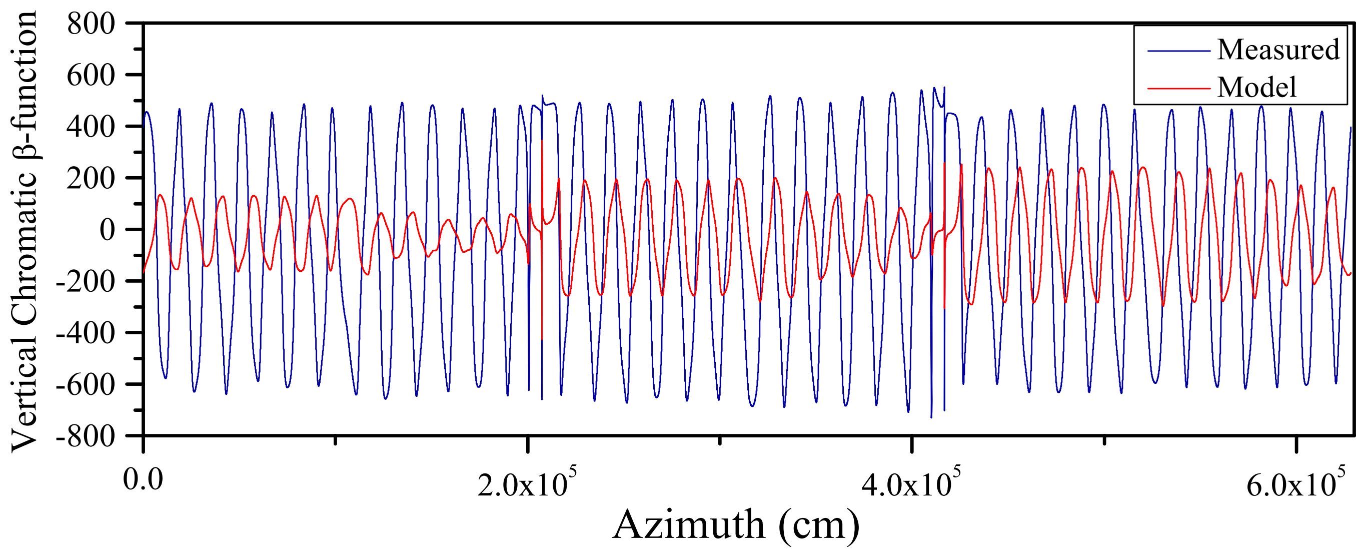


Correction of β-function Chromaticity

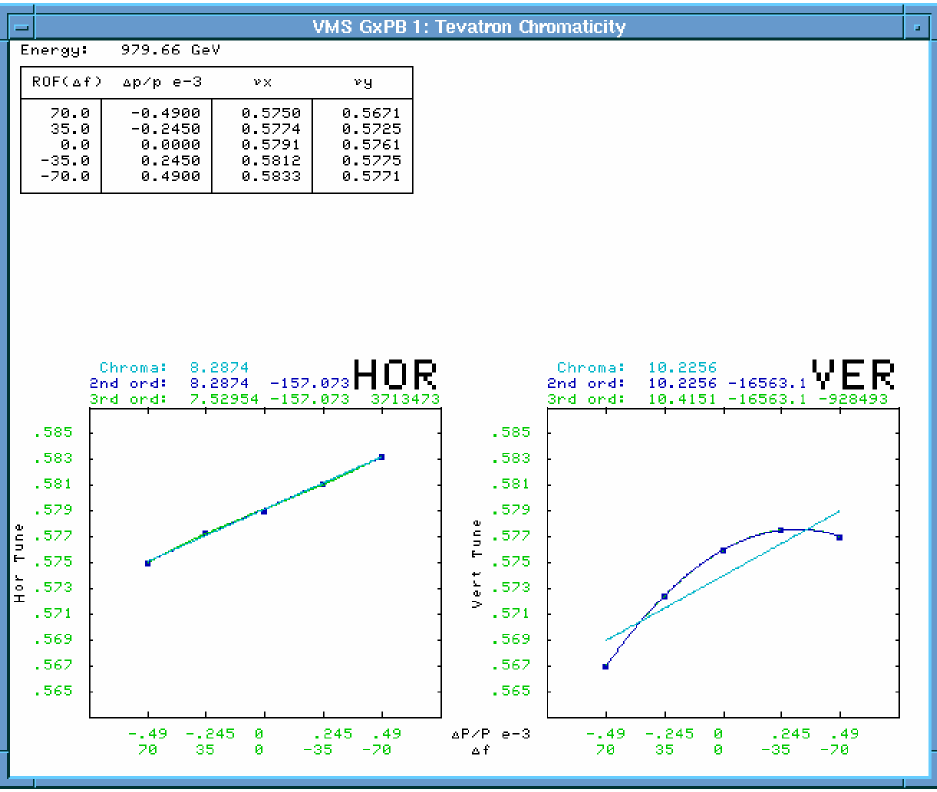
- Reconnection of sextupoles into new families

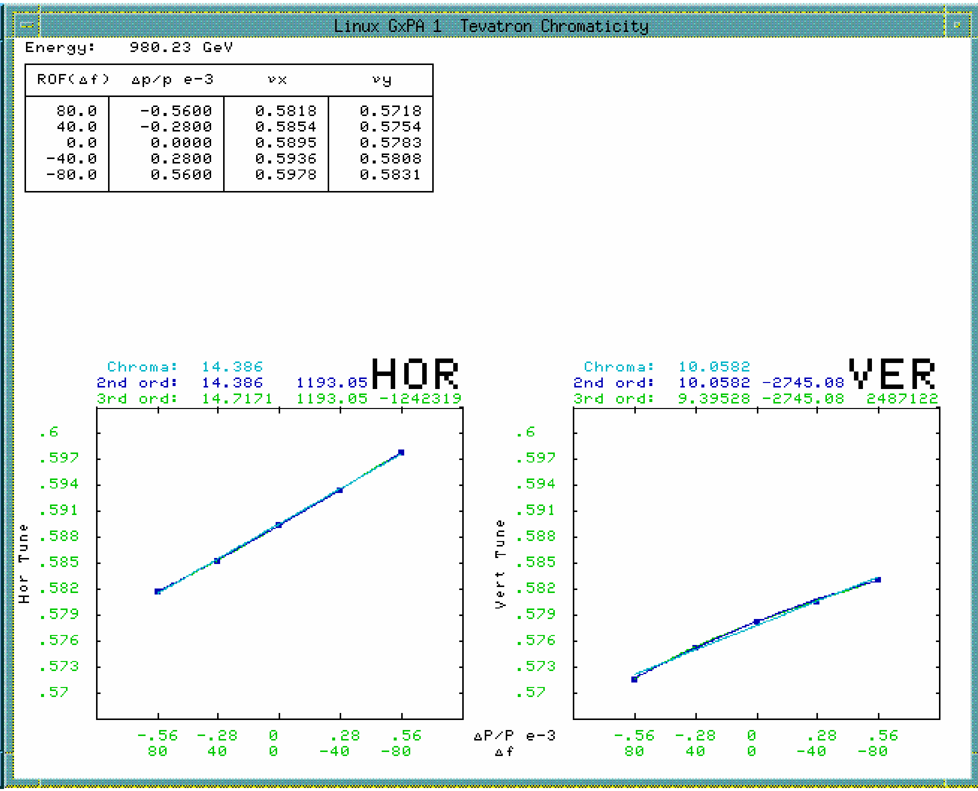






Second Order Chromaticity

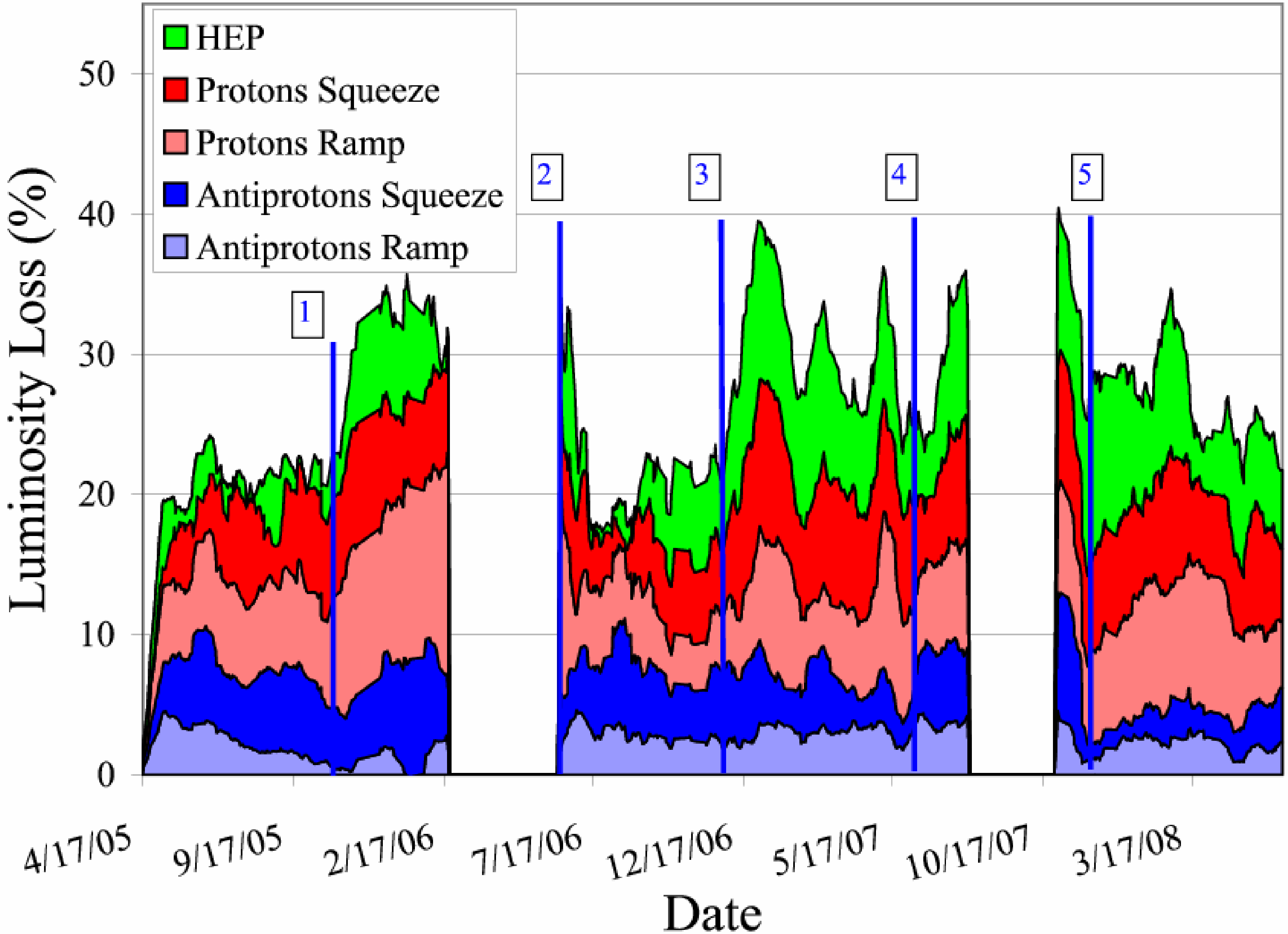




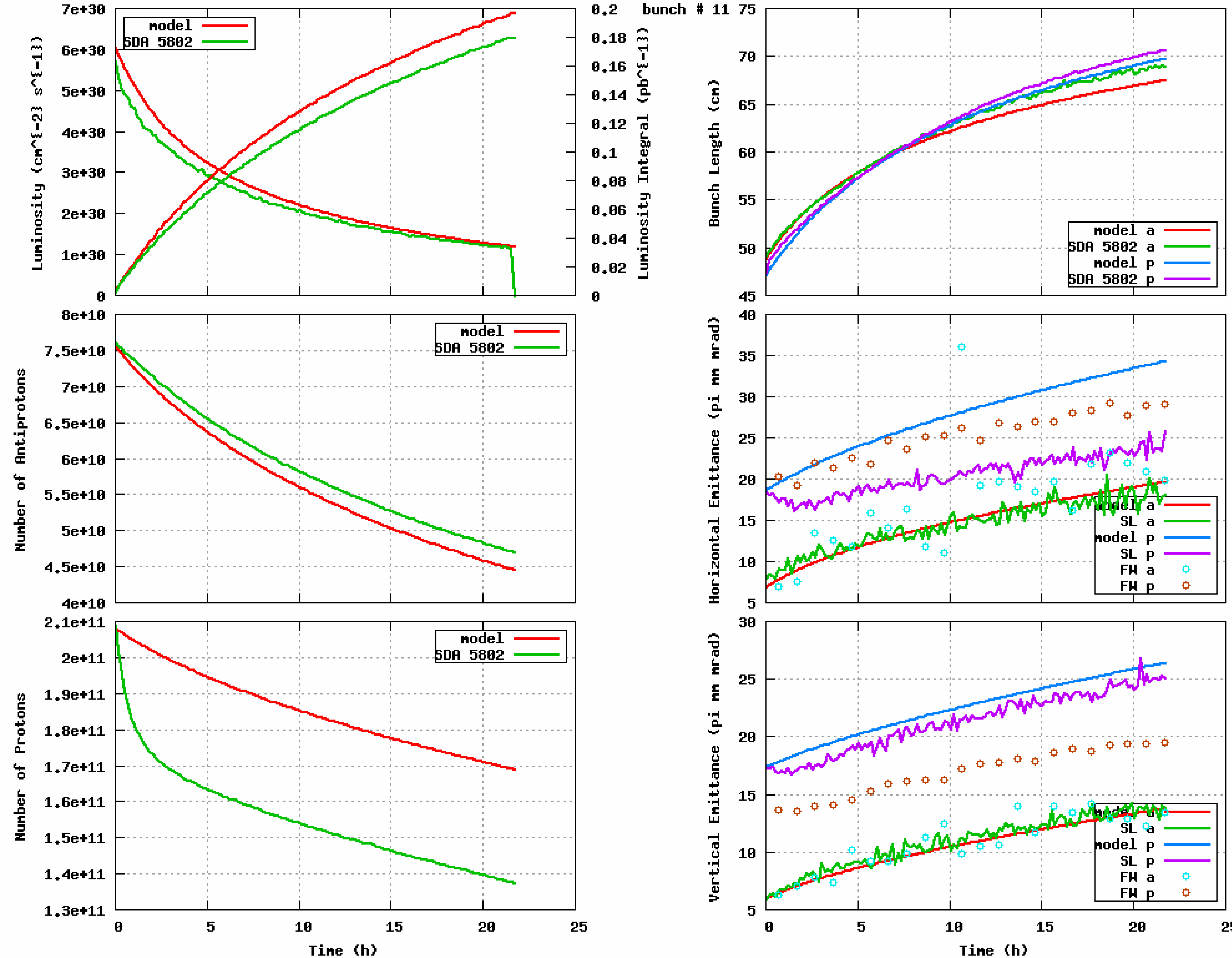
Sextupoles OFF
C2 = -16500

Sextupoles ON
C2 = -2700

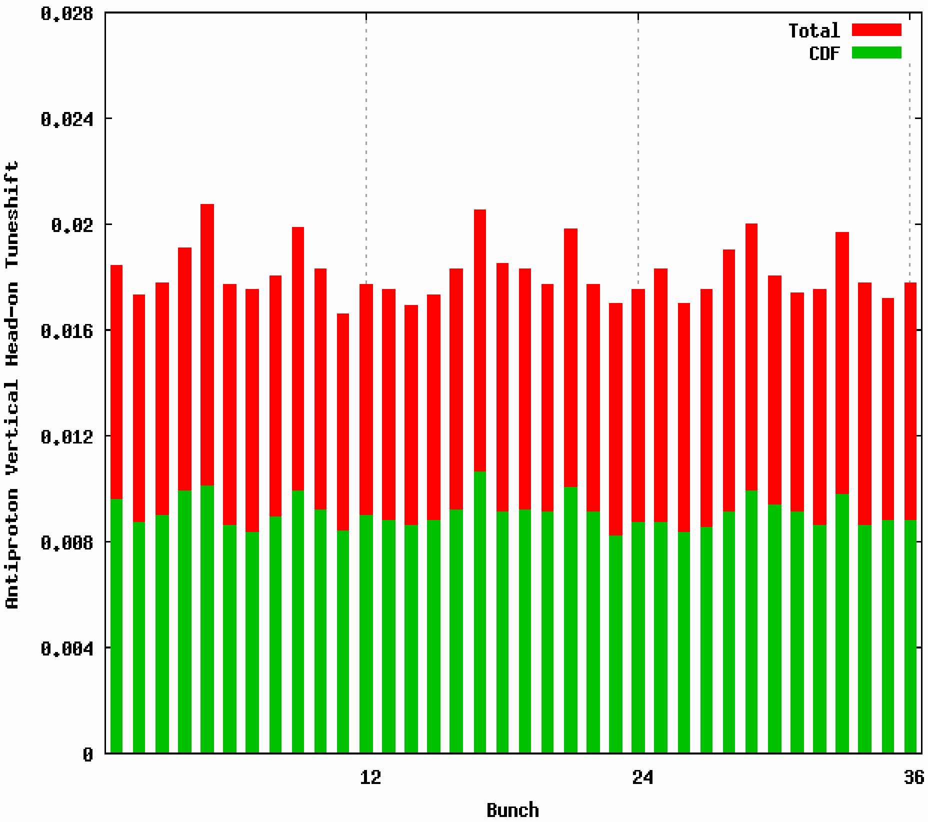
Contributions to Luminosity Loss

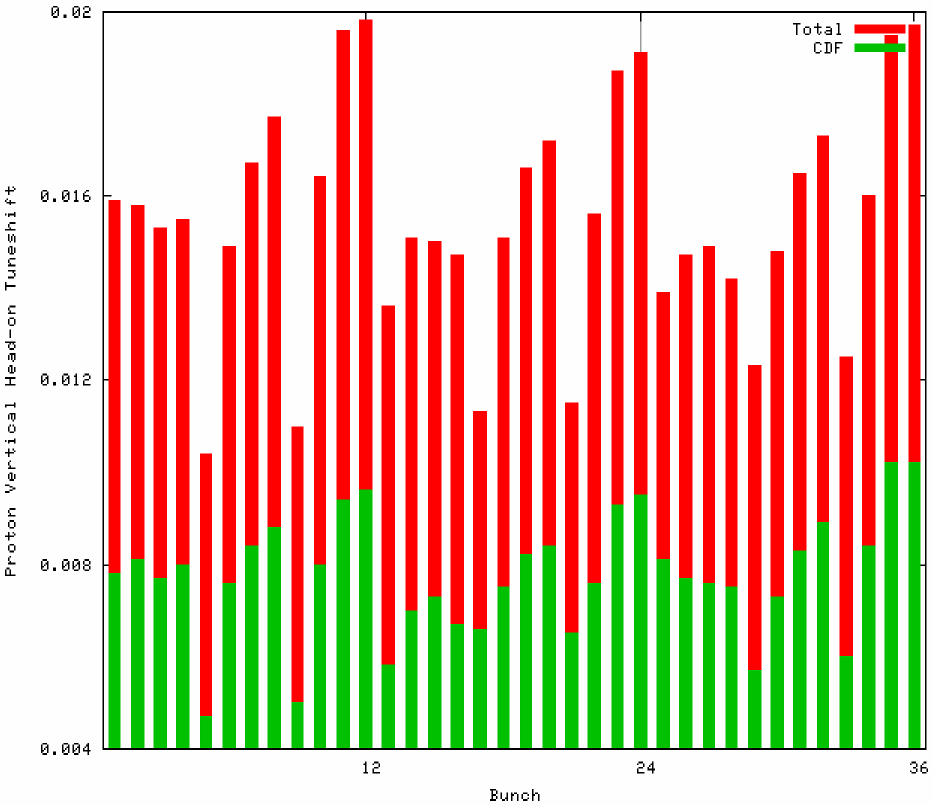


Store 5802. $L_0=2.09\times10^{32}$



Head-on Beam-Beam Tune Shifts. Store 5802

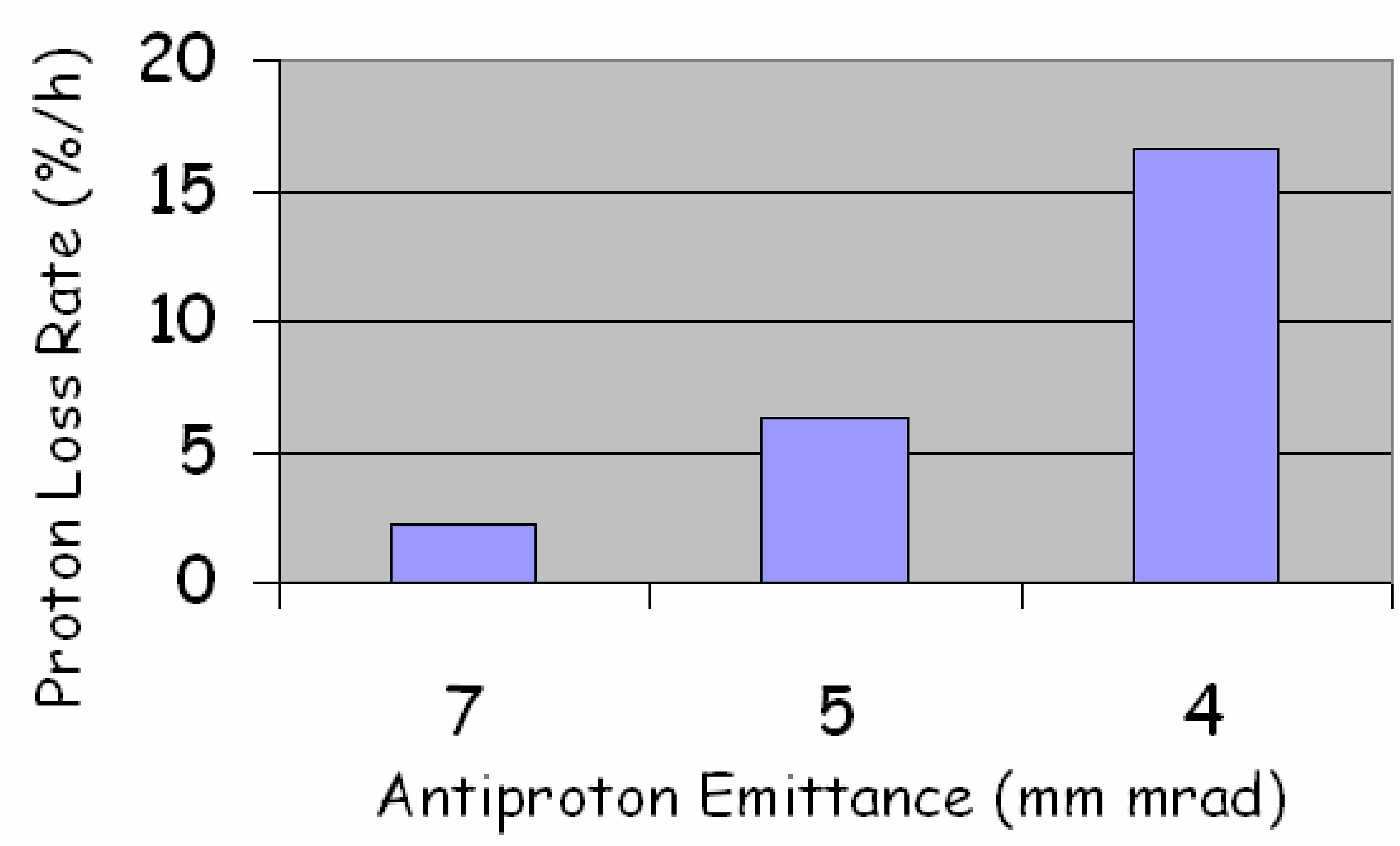




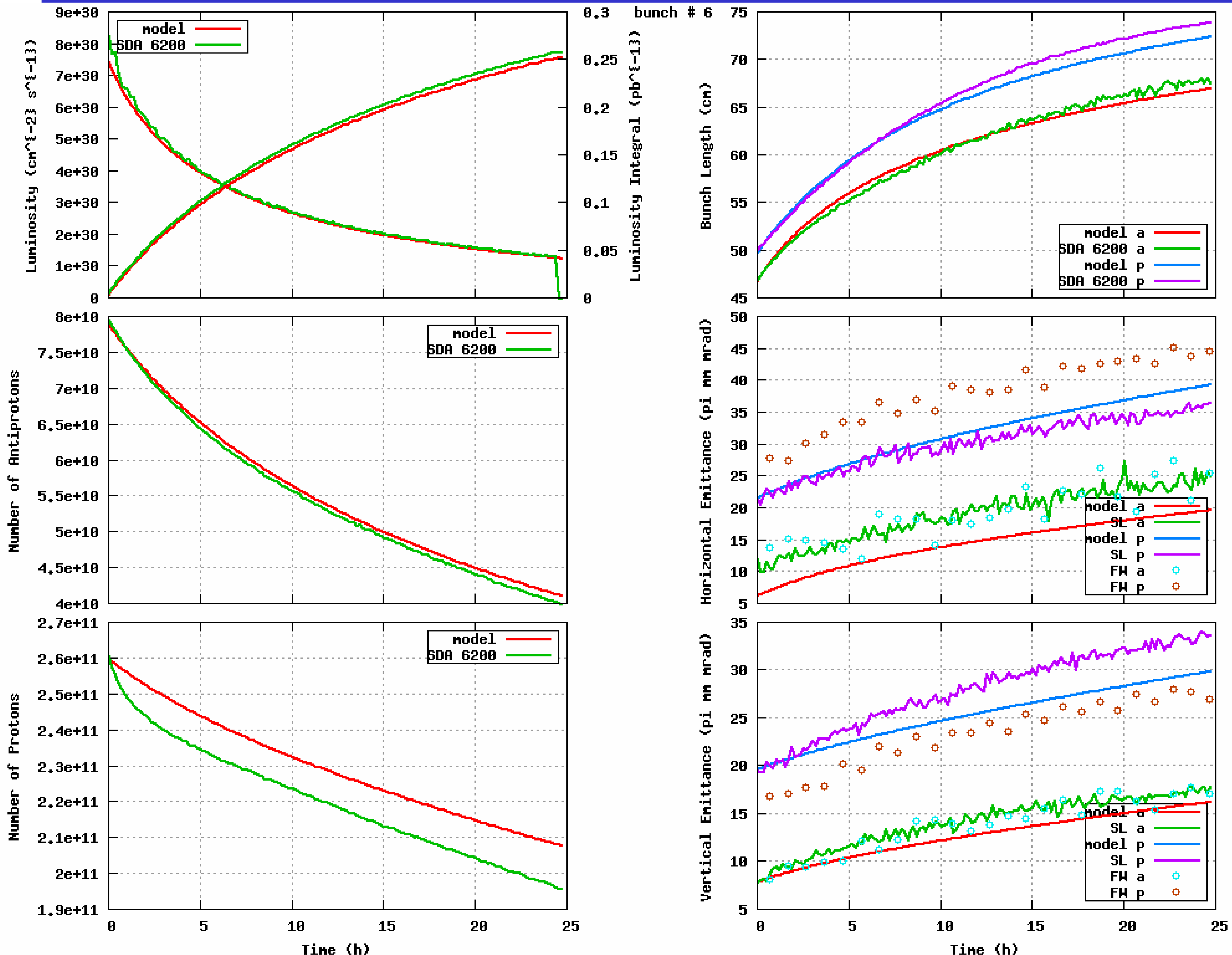
ε_p=20 π mm mrad

ε_a=5 π mm mrad

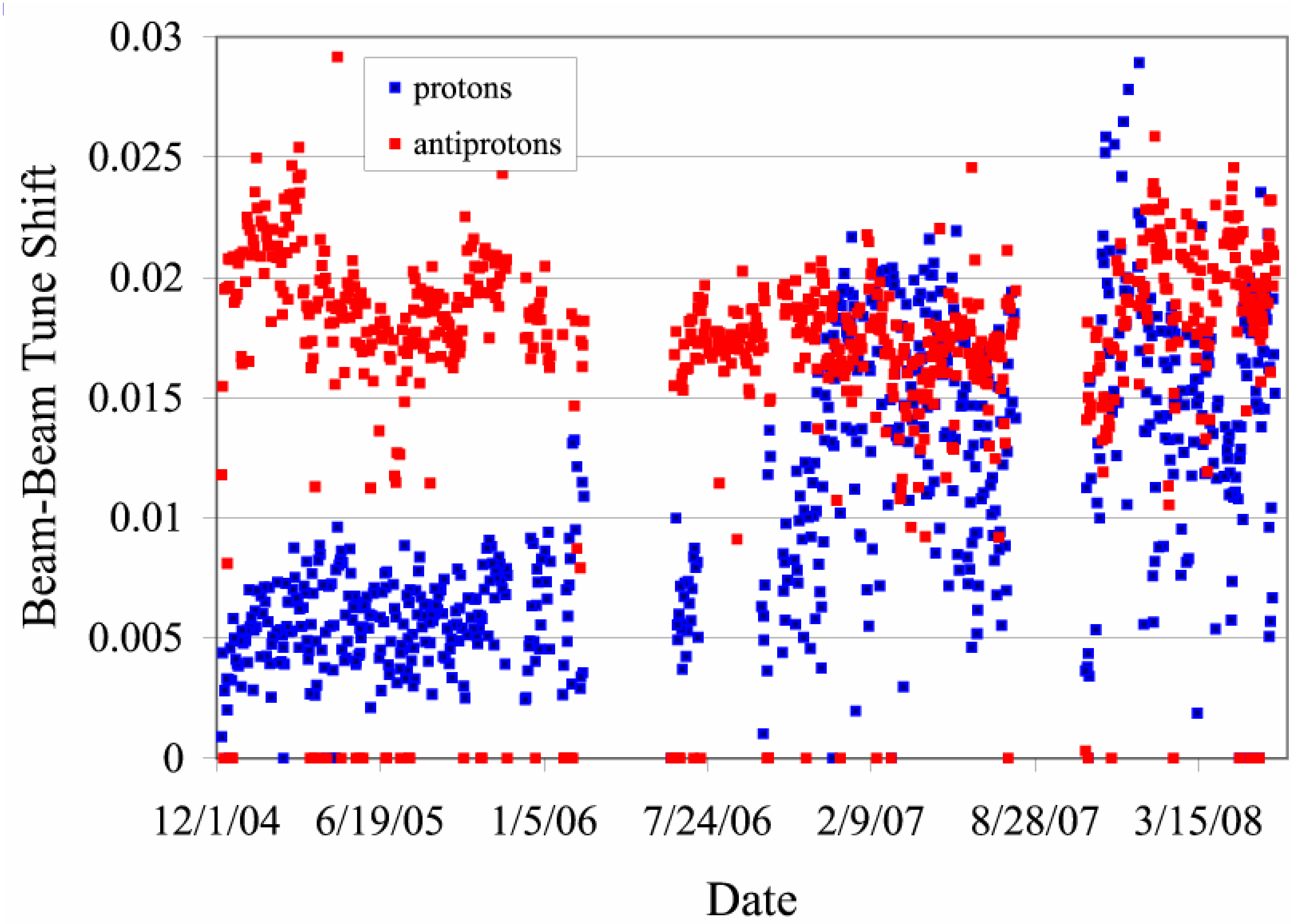
Effect of εa on Proton Losses. Simulaion



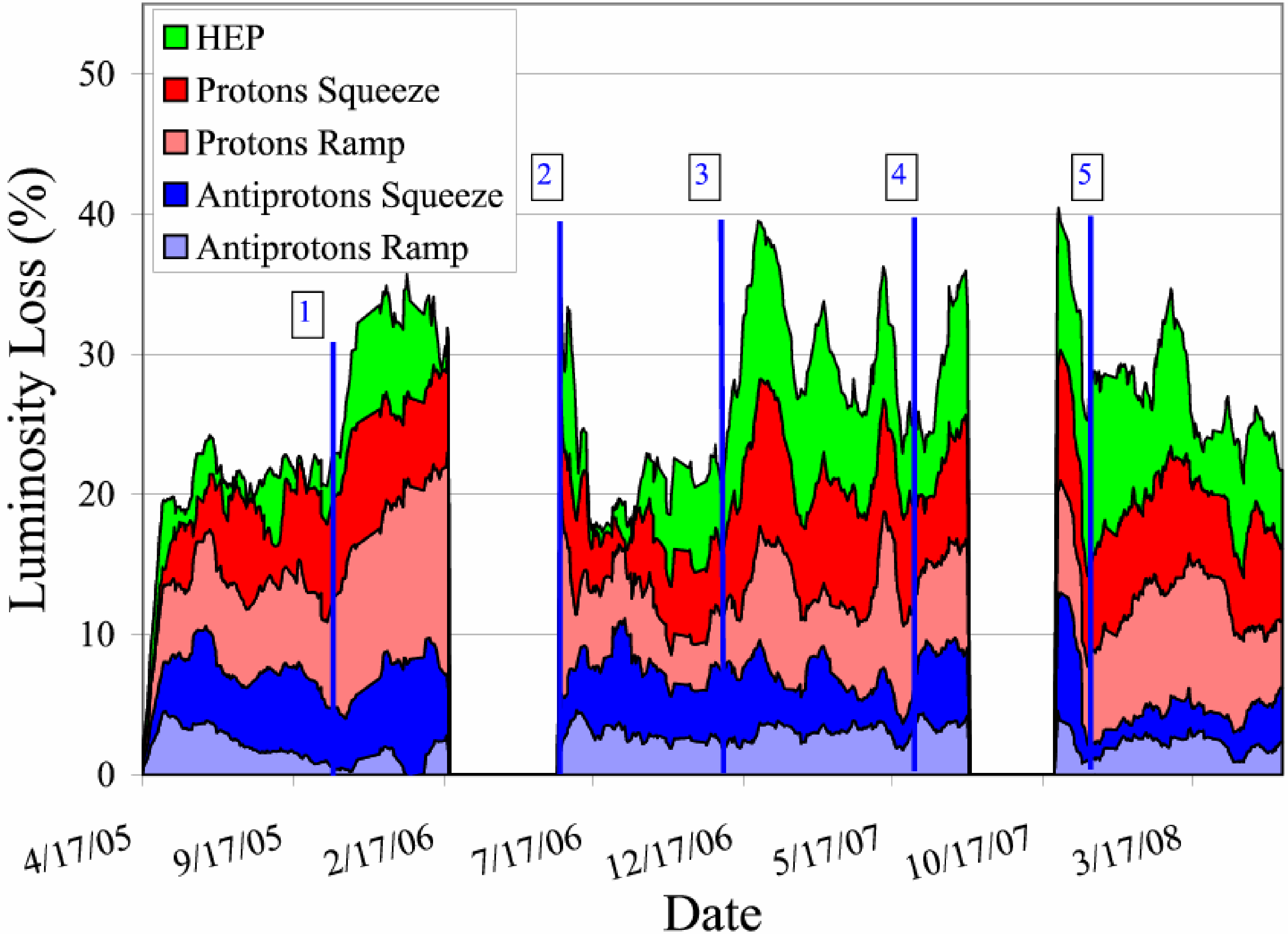
Store 6200. $L_0=2.95\times10^{32}$ PBJ Implemented



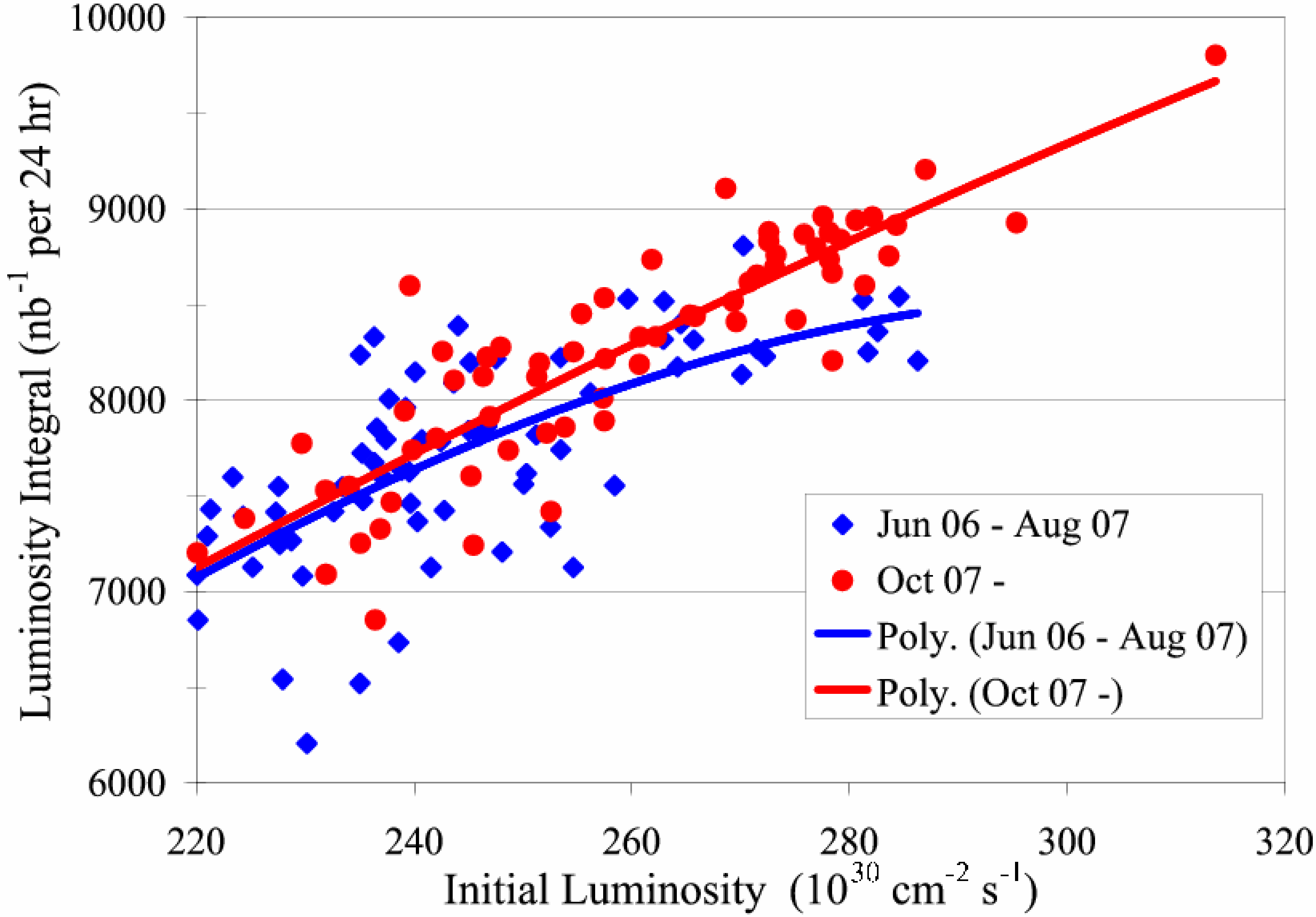
Head-on Beam-Beam Parameter



Contributions to Luminosity Loss

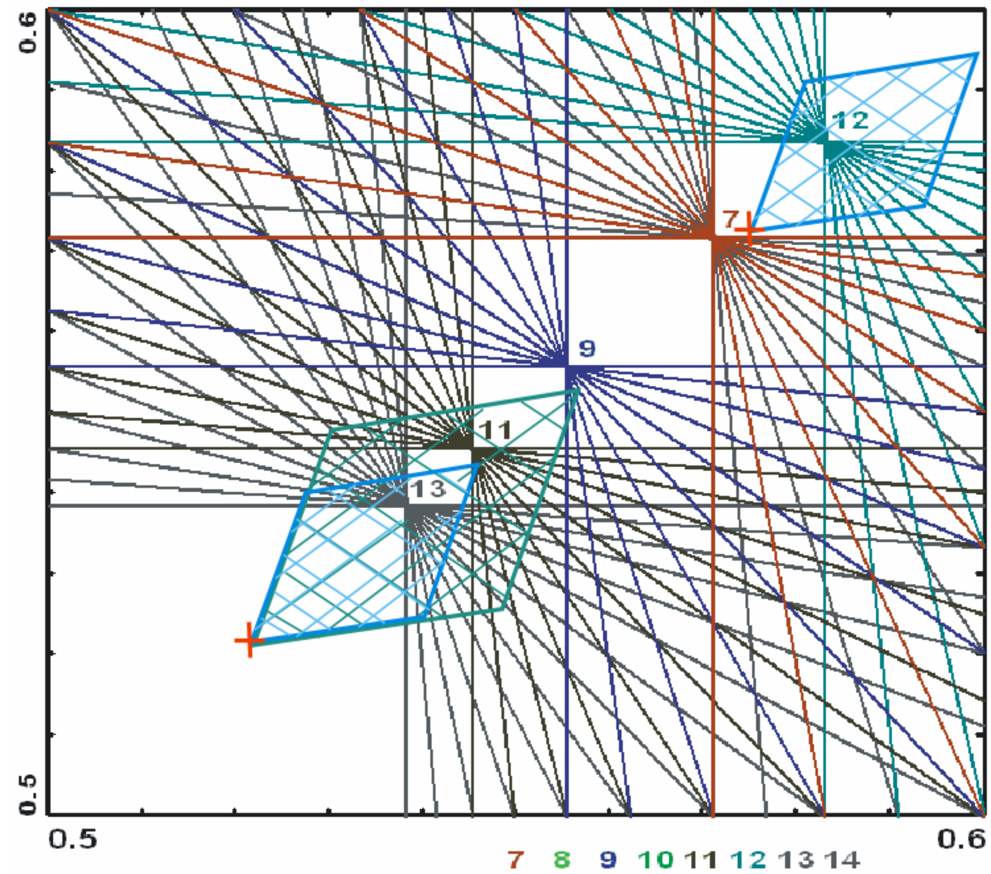


Integrated Luminosity Performance

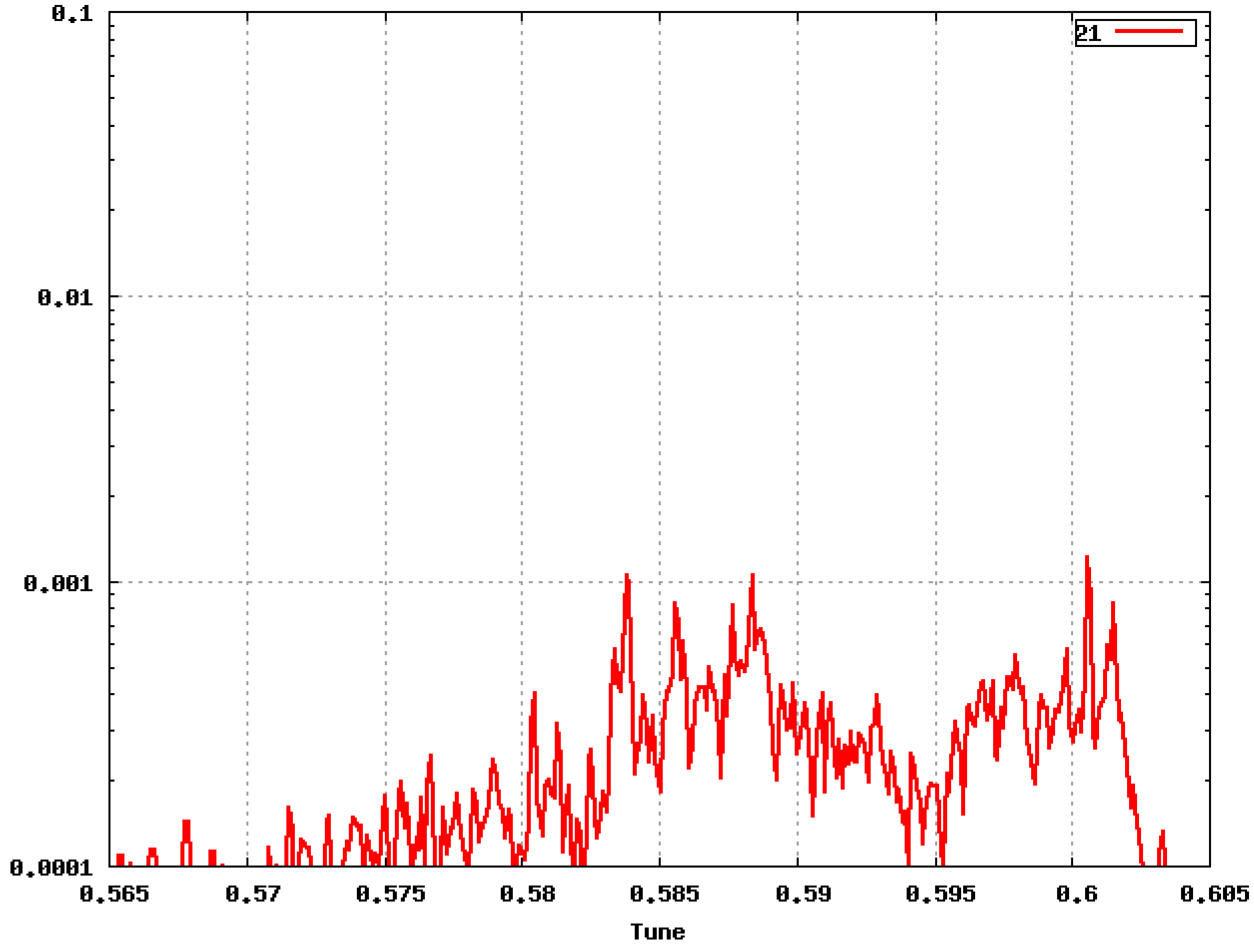


New Tune Working Point

- Currently operating between 4/7 and 3/5 with beam-beam ξ = 0.02
- To increase number of particles need more tune space – WP near $\frac{1}{2}$ should allow 30% more!
- Requires lengthy commissioning – hence will not be implemented in RunII



Coherent Instability in HEP Store



A.Valishev et al., THPC074

R. Ryne, Advanced Computing Tools and Models for Accelerator Physics

Summary

- Beam-beam effects and orbit stability issues in squeeze impact collider reliability
- At collisions, the decrease of antiproton intensity lifetime and emittance blowup prior to 6/06 was caused by long-range effects
  - Implementation of the new collision helix with increased separations at particular LR collision points gave improvement of the luminosity lifetime
- Currently, beam-beam effects at collisions are dominated by proton losses due to head-on interactions
  - Correction of β^* chromaticity allowed high-luminosity operation without deterioration of lumi life time (10% at present luminosities)
  - Control of proton/antiproton emittance ratio was commissioned
  - Tune near half integer would allow 30% more luminosity but will not be implemented
- Beam-beam simulations correctly describe various effects and are used to support operational changes and improvements.

Acknowledgments

- Y.Alexahin, J.Annala, D.Bollinger, C.Gattuzo, N.Gelfand, B.Hanna, V.Kamerdzhiev, V.Lebedev, R.S.Moore, V.Nagaslaev, V.Shiltsev, D.Still, C.Y.Tan, T.Bolshakov, X.L.Zhang (FNAL), D.Shatilov (BINP), V.Sajaev (ANL)