Electron Lenses

for Compensation of Beam-Beam Effects:

Tevatron, RHIC, LHC

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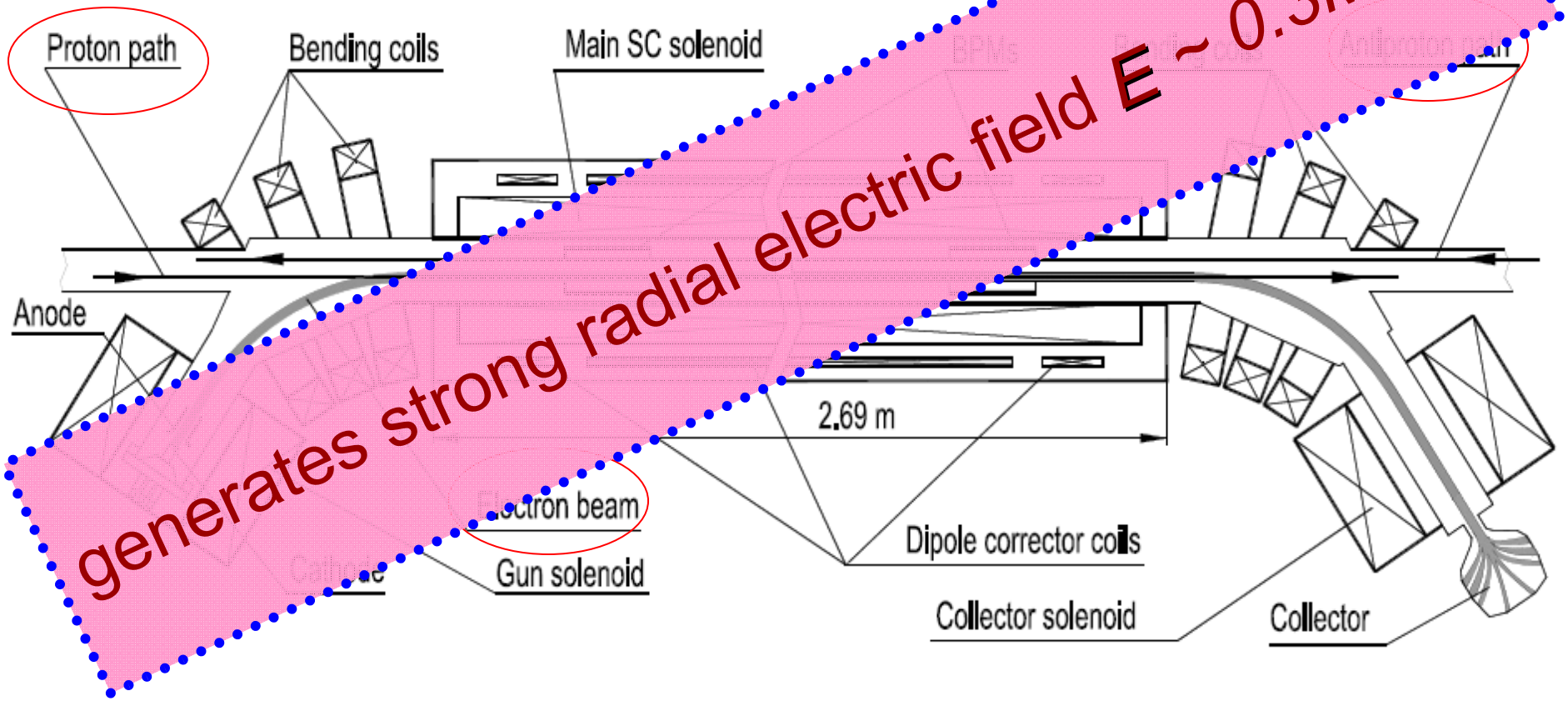
Beams-07 CERN, October 2007

What is Electron Lens?

~2 mm dia 2 m long very straight beam of ~10 kV

~1A electrons (~10^{12}) immersed in 3T solenoid



generates strong radial electric field E ~ 0.3MV/m

How strong is it?

- **Figure of merit- tuneshift dQ:**
  - Similar to space-charge and beam-beam

TEL: dQ=0.001-0.001

$$dQ_{x,y} = \mp \frac{\beta_{x,y}}{2\pi} \cdot \frac{1 \pm \beta_e}{\beta_e} \cdot \frac{J_e \cdot L_e \cdot r_p}{e \cdot c \cdot a_e^2 \cdot \gamma_p}$$

this product is ~$1/\varepsilon_{norm}$

For many applications electron beam size needs to be nxσ protons

e.g. n=1 for head on BBC

→RHIC

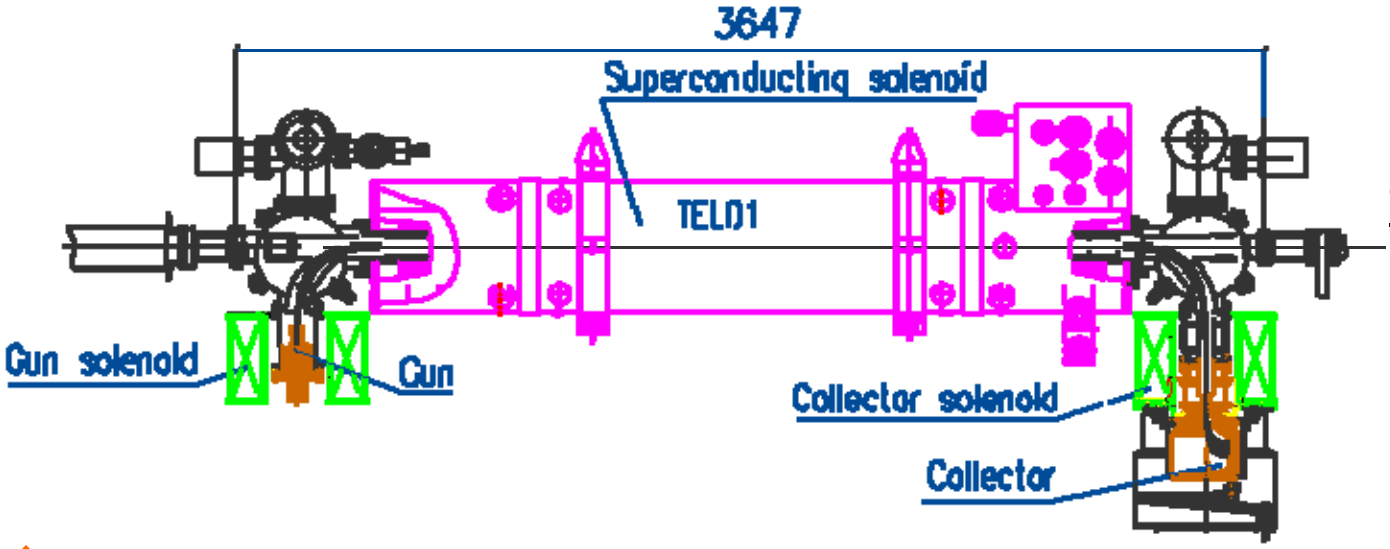
→Tevatron

→LHC

SAME!

Location of TELs

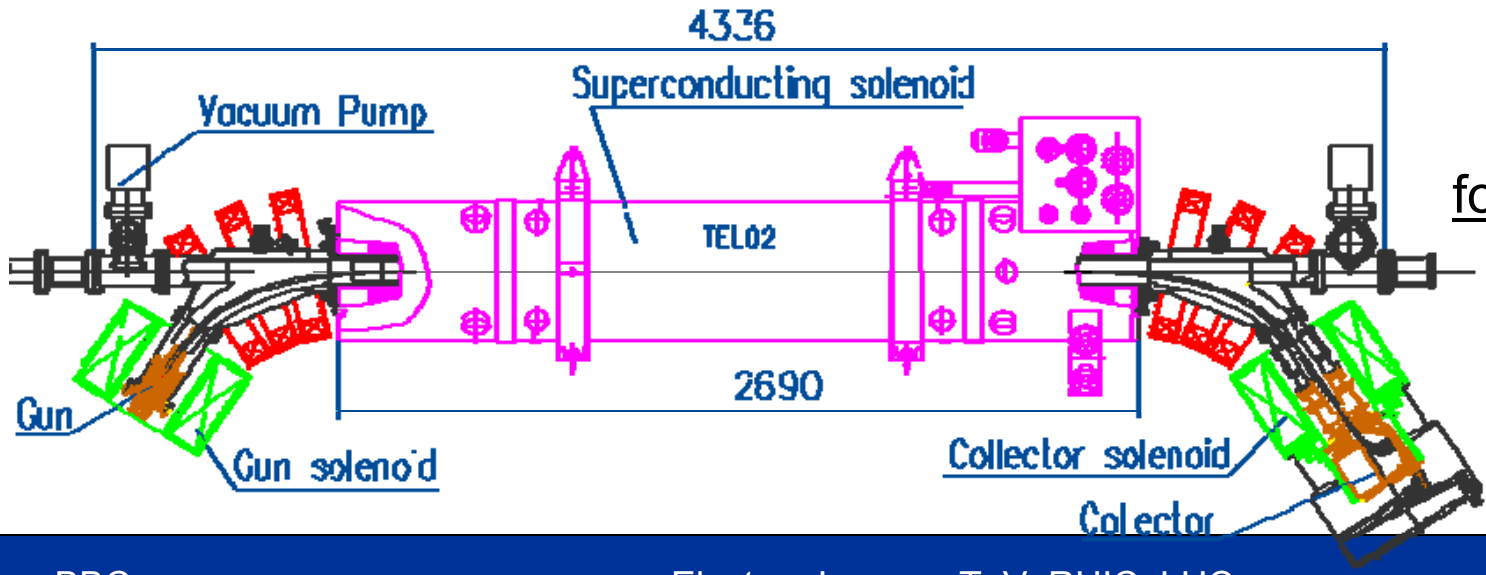
Tevatron Electron Lenses



TEL1

for horizontal BBC

Installed in the Tevatron in 2001

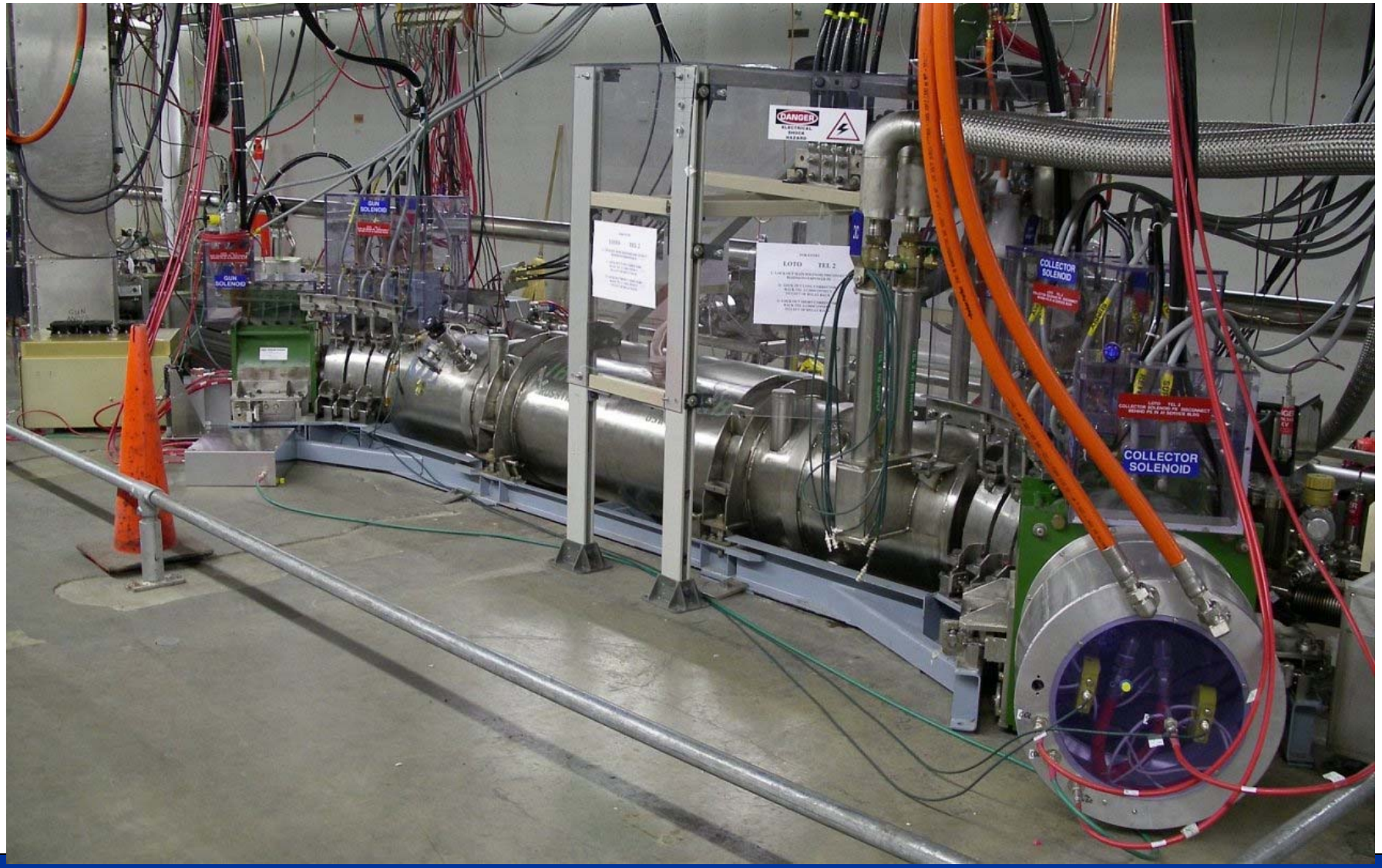


TEL2

for vertical BBC

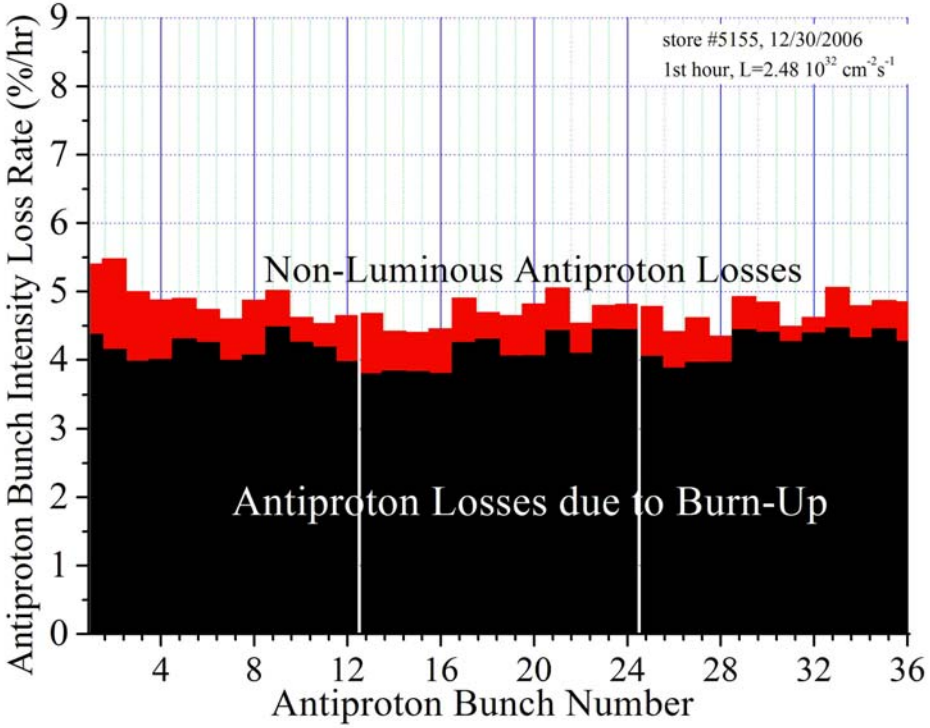
Installed in the Tevatron in 2006

TEL2 installed in the Tevatron

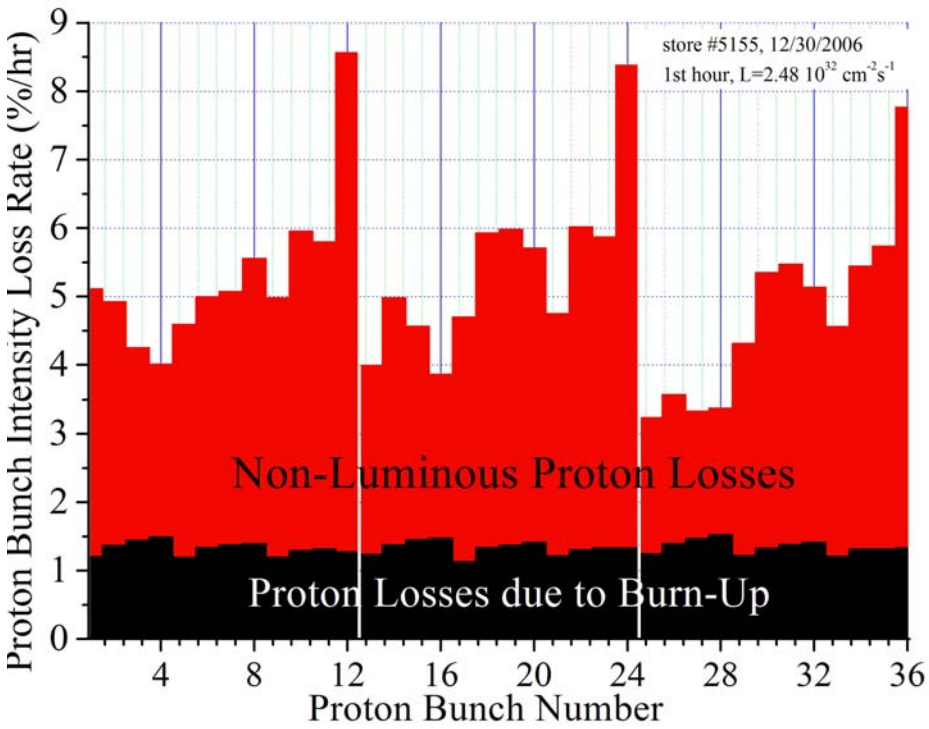


TEL Choice: Antiprotons or Protons?

Antiprotons *980 GeV :* ξ_{max}*=+0.024 ; TEL defocuses*

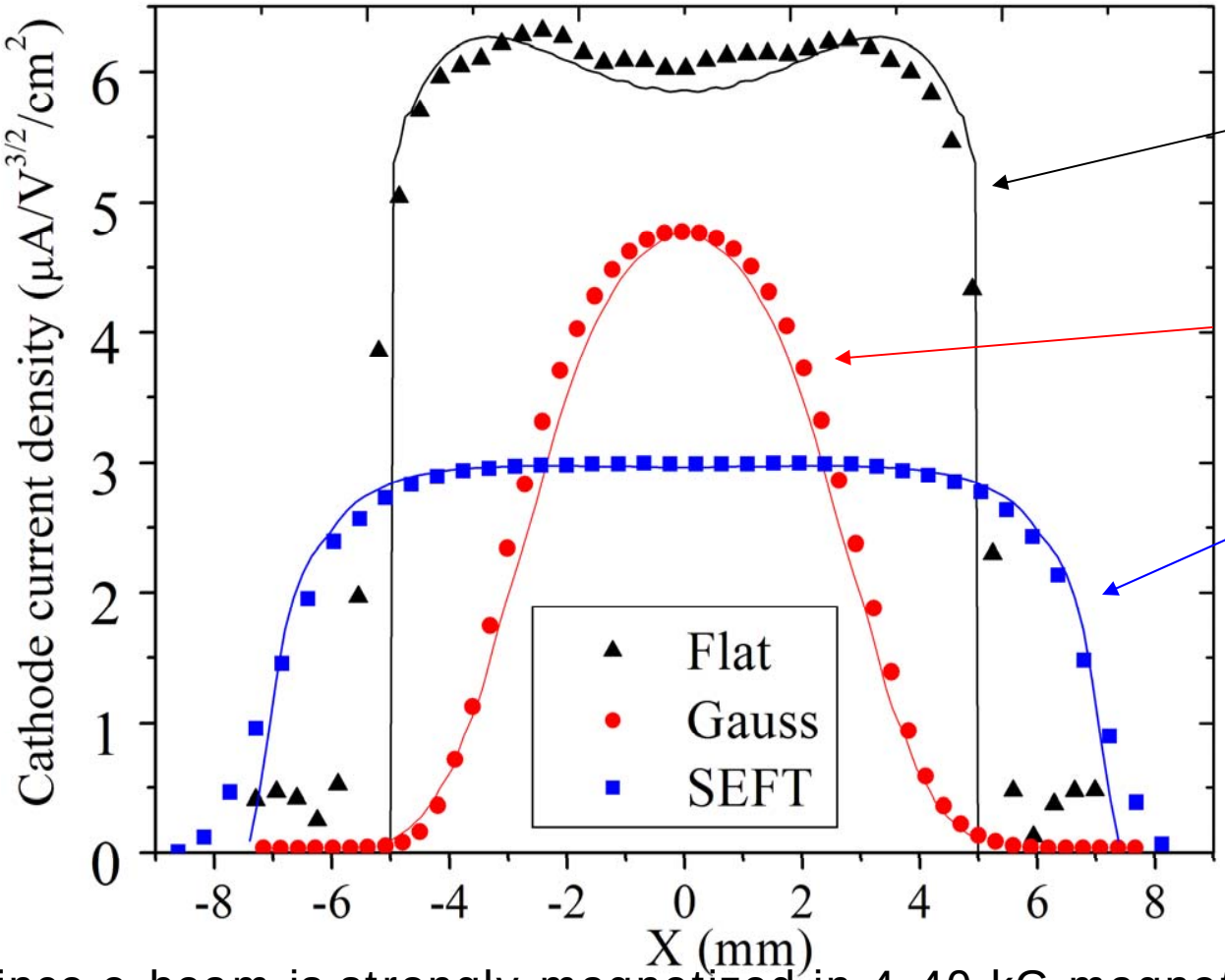


Protons *980 GeV :* ξ_{max}*=+0.016;TEL focuses*



At present, beam-beam effects are relatively stronger on protons, accounting for some 10-15% loss of the integrated luminosity. Proton loss rates vary greatly from bunch to bunch. The Tevatron Electron Lens #2 aligned on ***proton*** beam.

Electron beam profiles



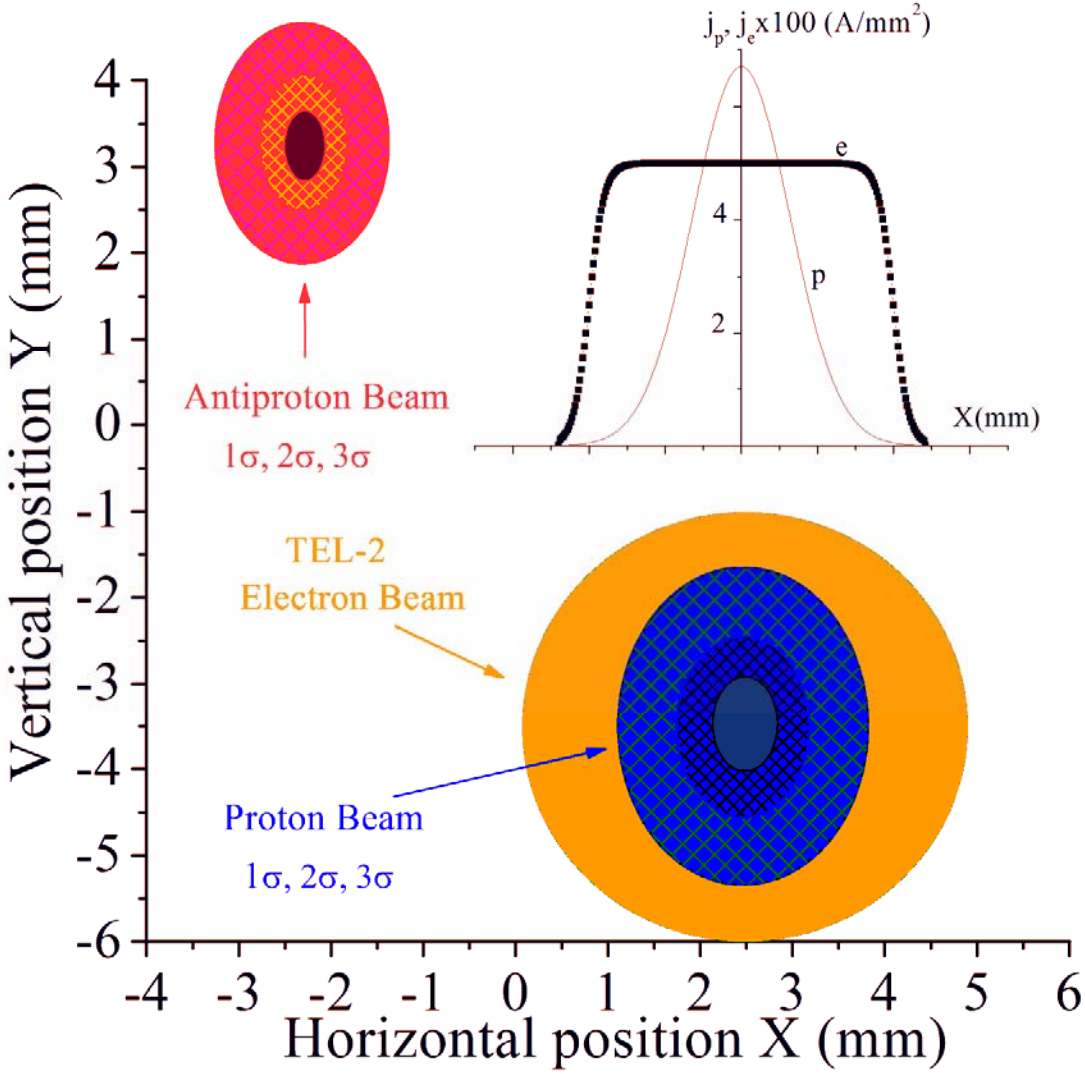
Initial (2001)

Used for Pbar B-B Compensation (2003)

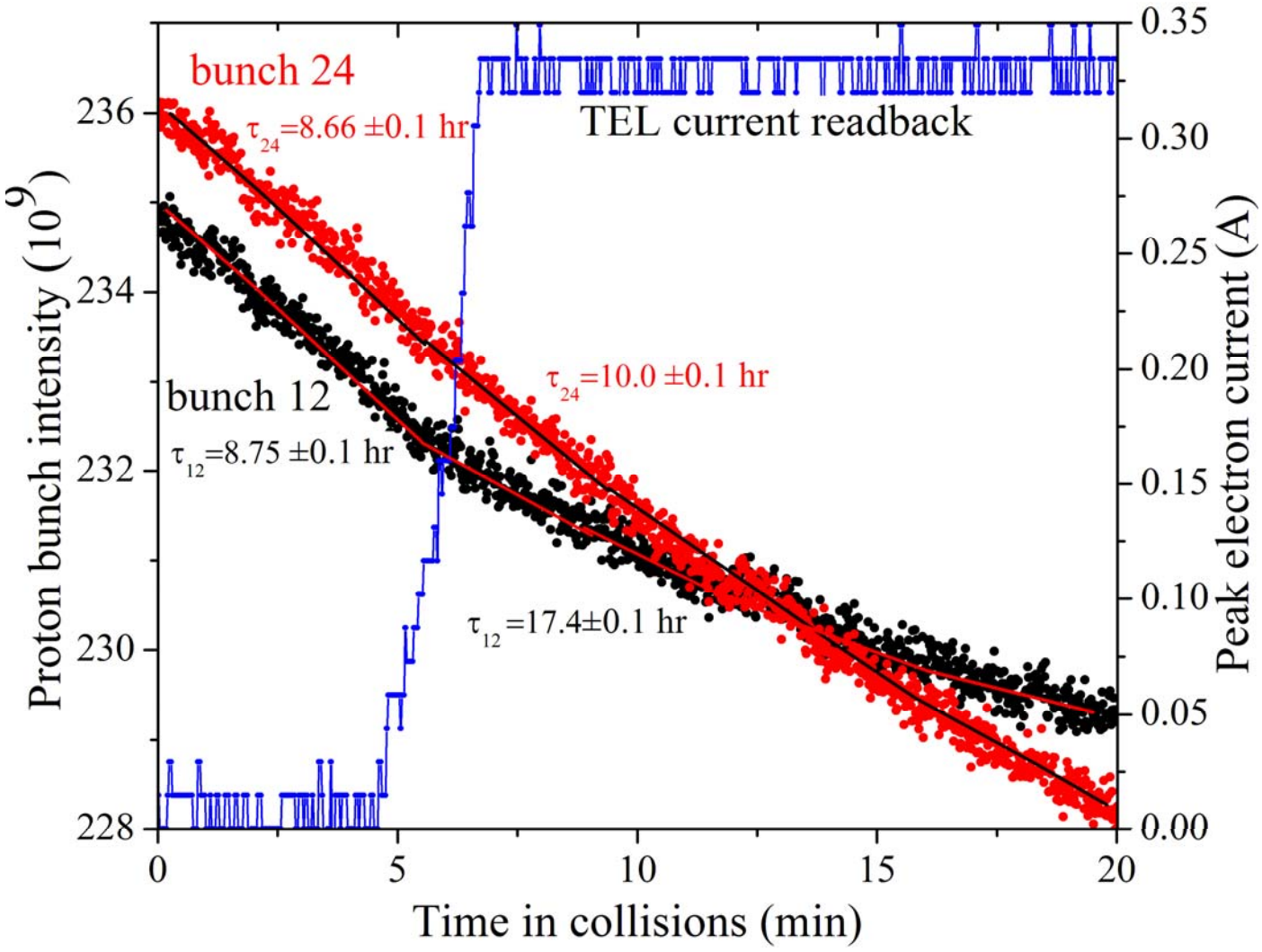
Used now in both TELs

Since e-beam is strongly magnetized in 4-40 kG magnetic field, the charge density distribution in the interaction region has the same shape as on the cathode

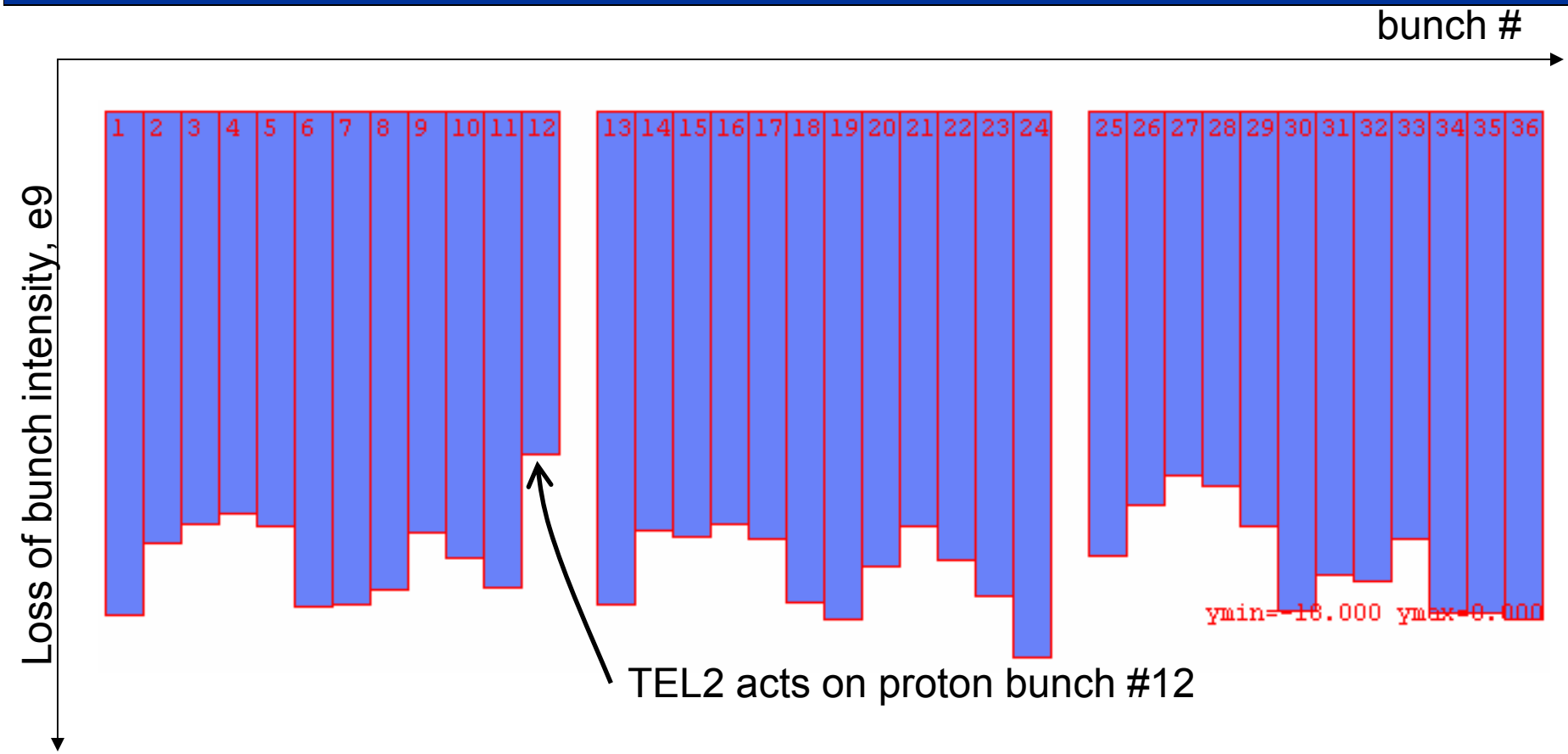
Transverse alignment



Single bunch BBC (P12)

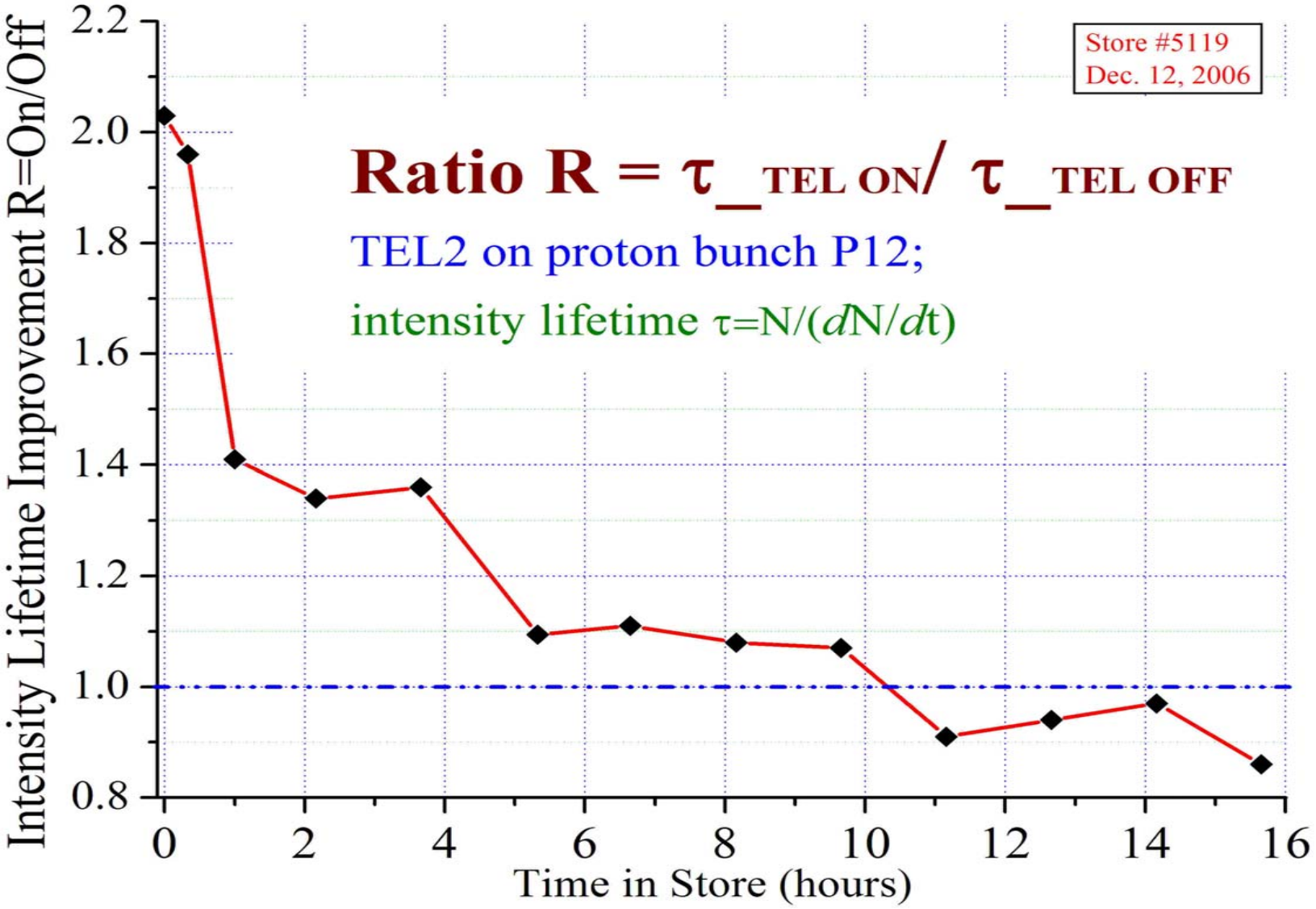


TEL BBC: N_p/bunch drop in 1.5 hr



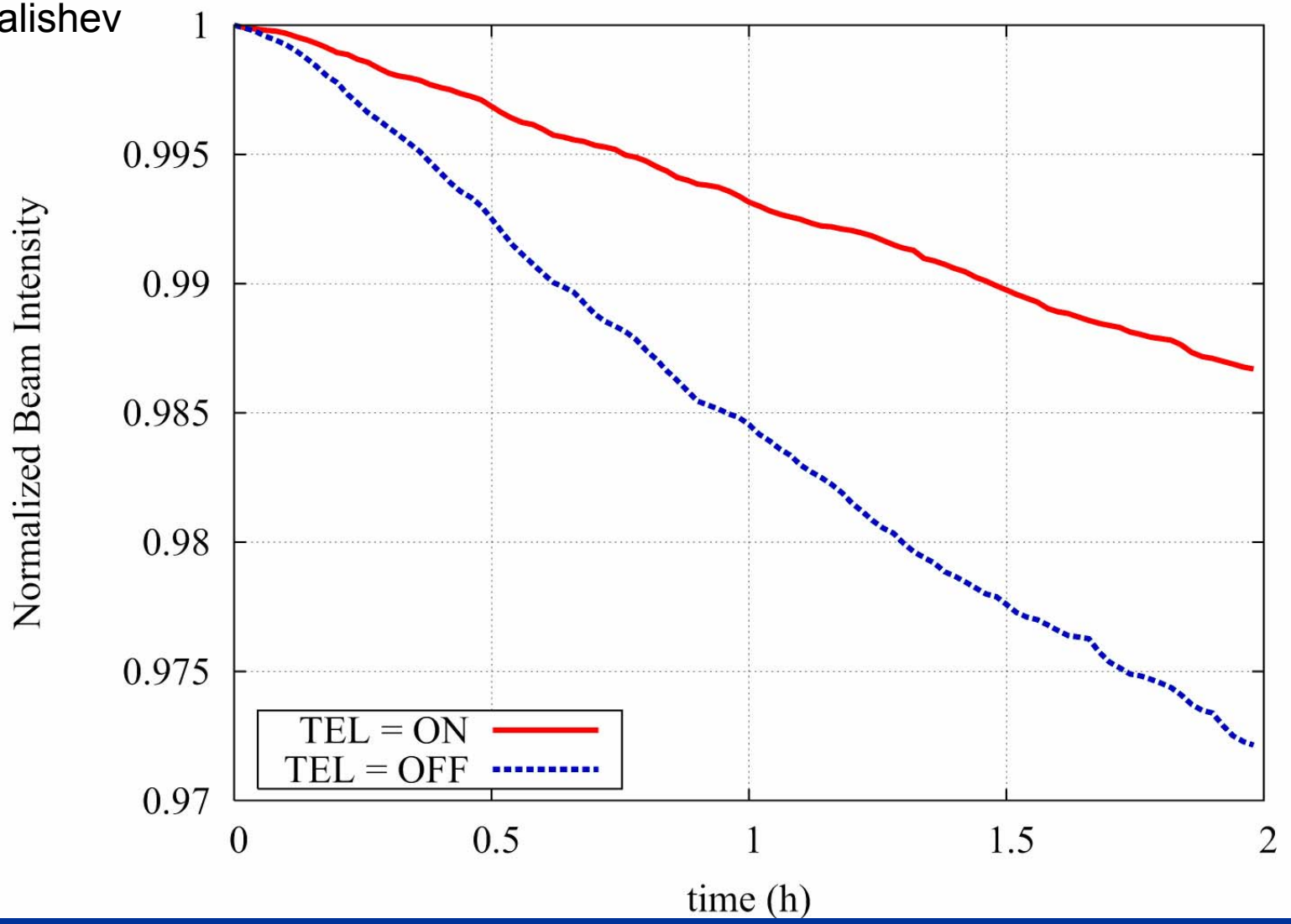
The decrease of bunch intensity as reported by T:SBDPIS for the first 1.5 hours of a store. TEL2 was acting on proton bunch #12, J_e^{pk} = 0.3 A. Scale: 0 – -18e9 protons.

τ improvement vs time in store

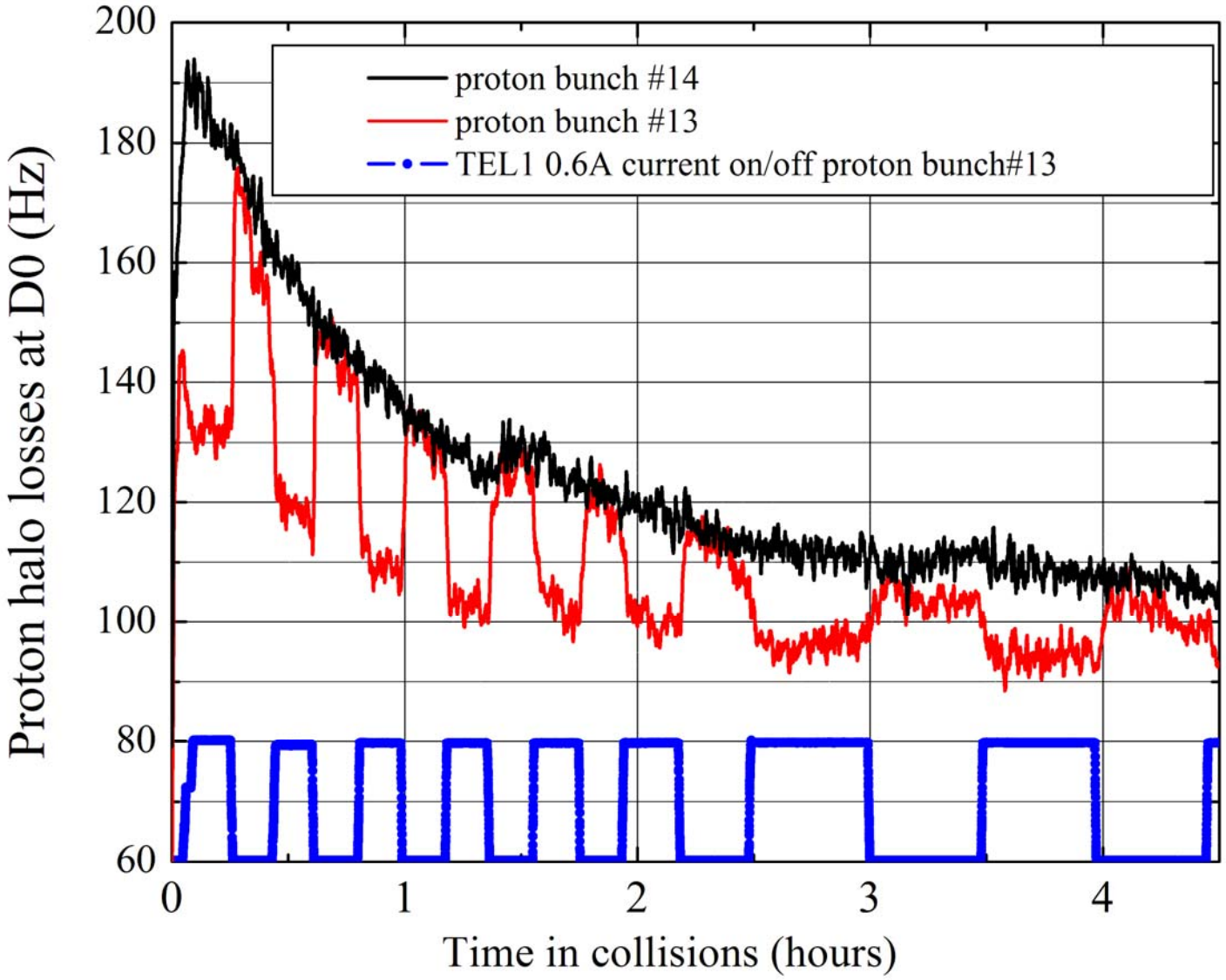


LIFETRAC simulation

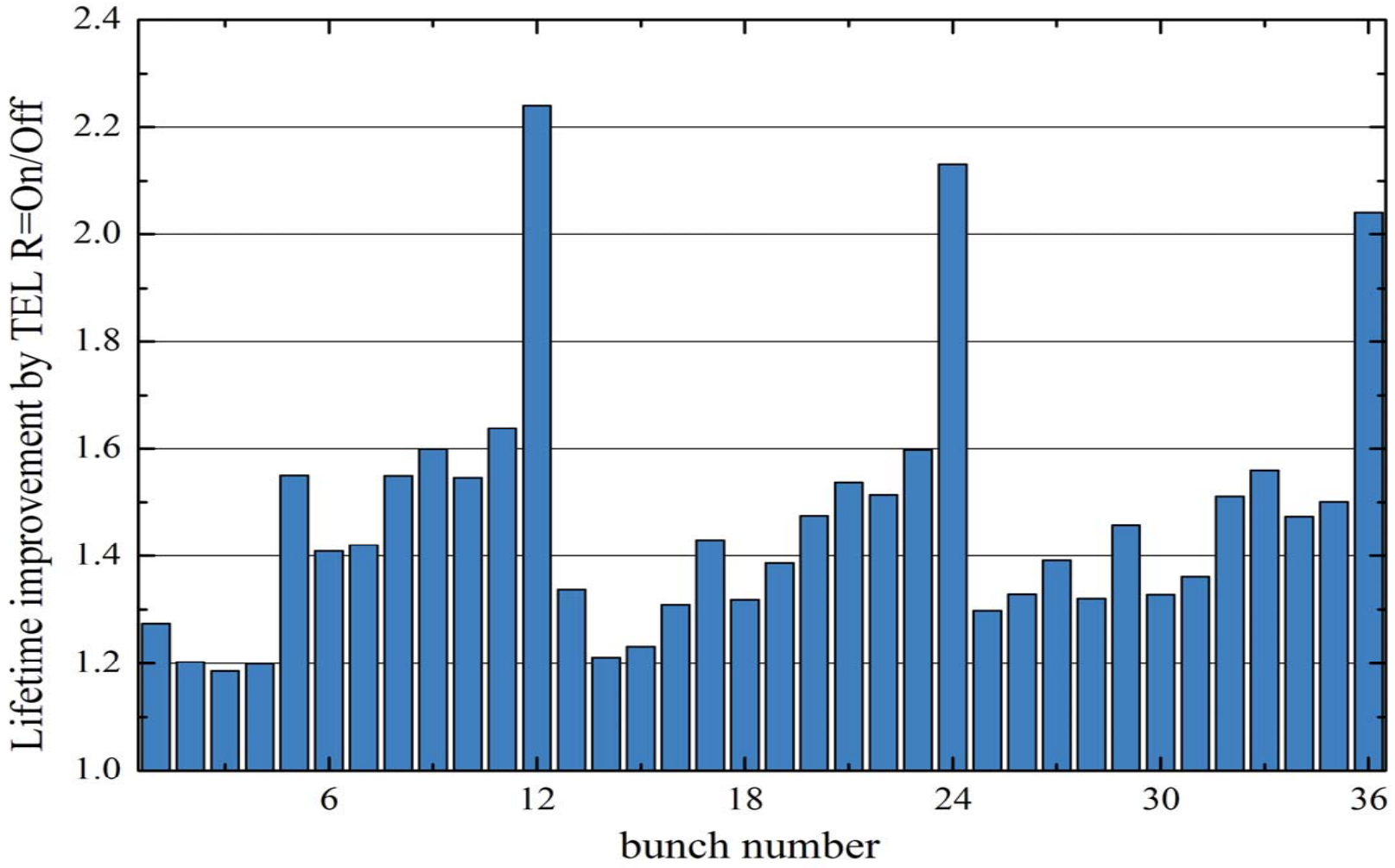
A. Valishev



TEL1 on P13


proton bunch #14
proton bunch #13
TEL1 0.6A current on/off proton bunch#13
Proton halo losses at D0 (Hz)
200
180
160
140
120
100
80
60
0
1
2
3
4
Time in collisions (hours)

TEL2 in dc mode



Head-On Beam-Beam Compensation

- Conditions for full footprint compression (tune-spread compensation) in *p-p* collider:
  - Transverse electron profile should match proton profile at IP (presumably, Gaussian)
  - Total number of electrons in the EL should be

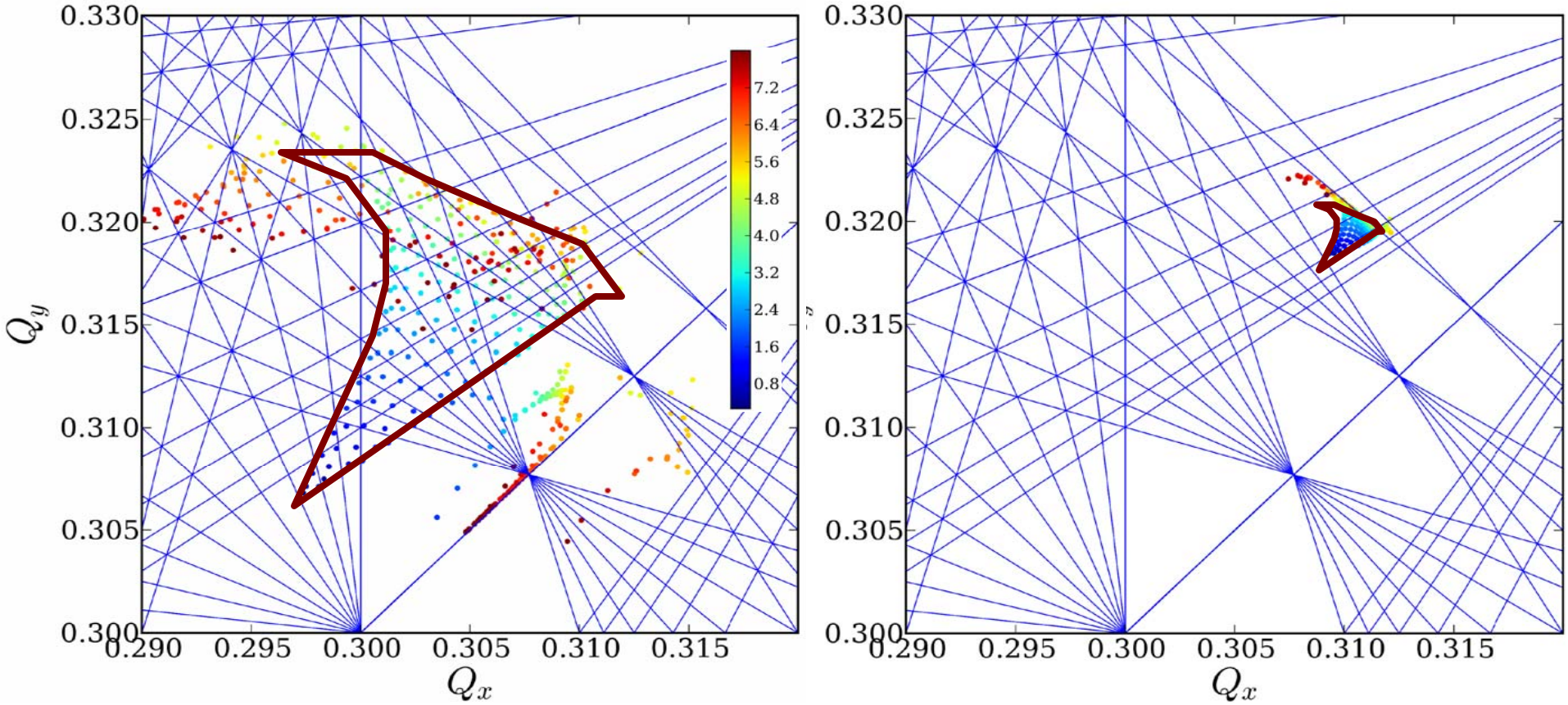
$$N_e = N_{\mathrm{IP}} N_p / (1 + \beta_e).$$

  - e.g. for the LHC *N_p*=1.15e11, *N_ip*=3, for 10kV electrons (beta=0.2) one needs N_e=3.45e11 or **J_e=1.4 A in L=2 m long e-beam**
  - Location of e-lens is not important in first order (footprint) but may be important for RDT, *β_x*=*β_y*, *D_x*=0 desired

LHC Electron Lens : Footprint

1.8A DC LEL with Gaussian current profile shrinks LHC footprint (LHC Lumi-upgrade, U.Dorda,et.al, PAC'07)

TEL off, LRBBWire off → **TEL on, LRBBWire on**

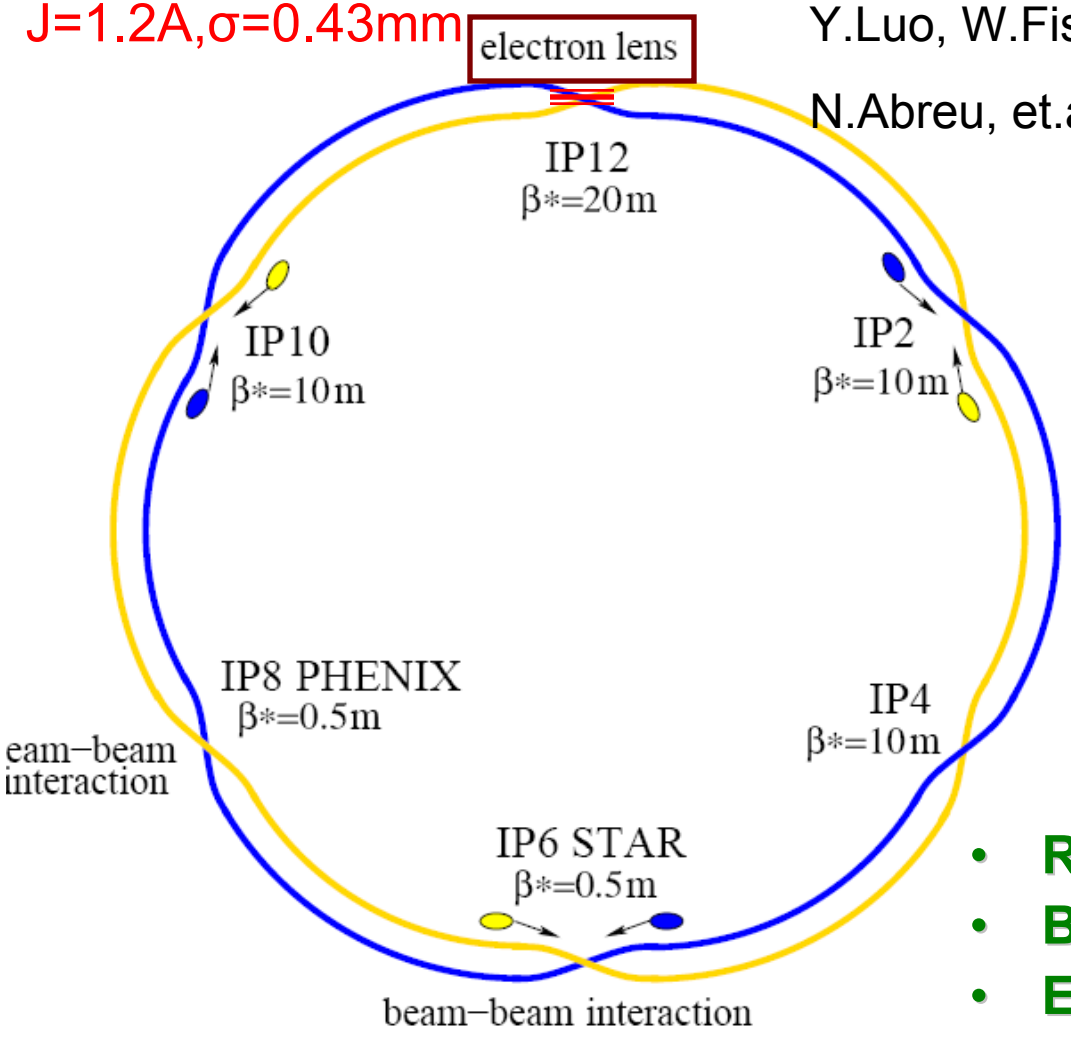


Degree of Compensation

- Is full tune-spread compensation needed?
  - Single bunch coherent stability?
  - Multibunch coherent stability?
  - Gain in lifetime or emittance growth?
  - higher the current more stable it should be
- What's optimal?
  - avoid "footprint folding"
  - compensate to max tolerable *dQ_spread* = 0.010 ?
  - Yuri Alexahin suggested to compensate to d*Q_spread=0.003* - better coherent beam-beam
  - RHIC team is working on similar issues now →

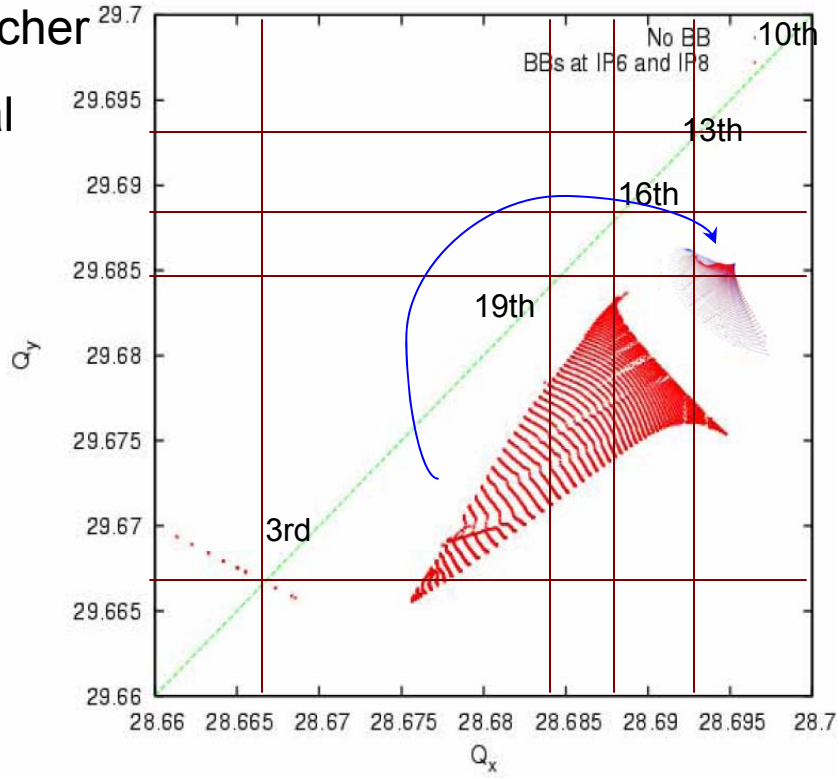
Electron Lenses in RHIC

J=1.2A,σ=0.43mm



Y.Luo, W.Fischer

N.Abreu, et.al

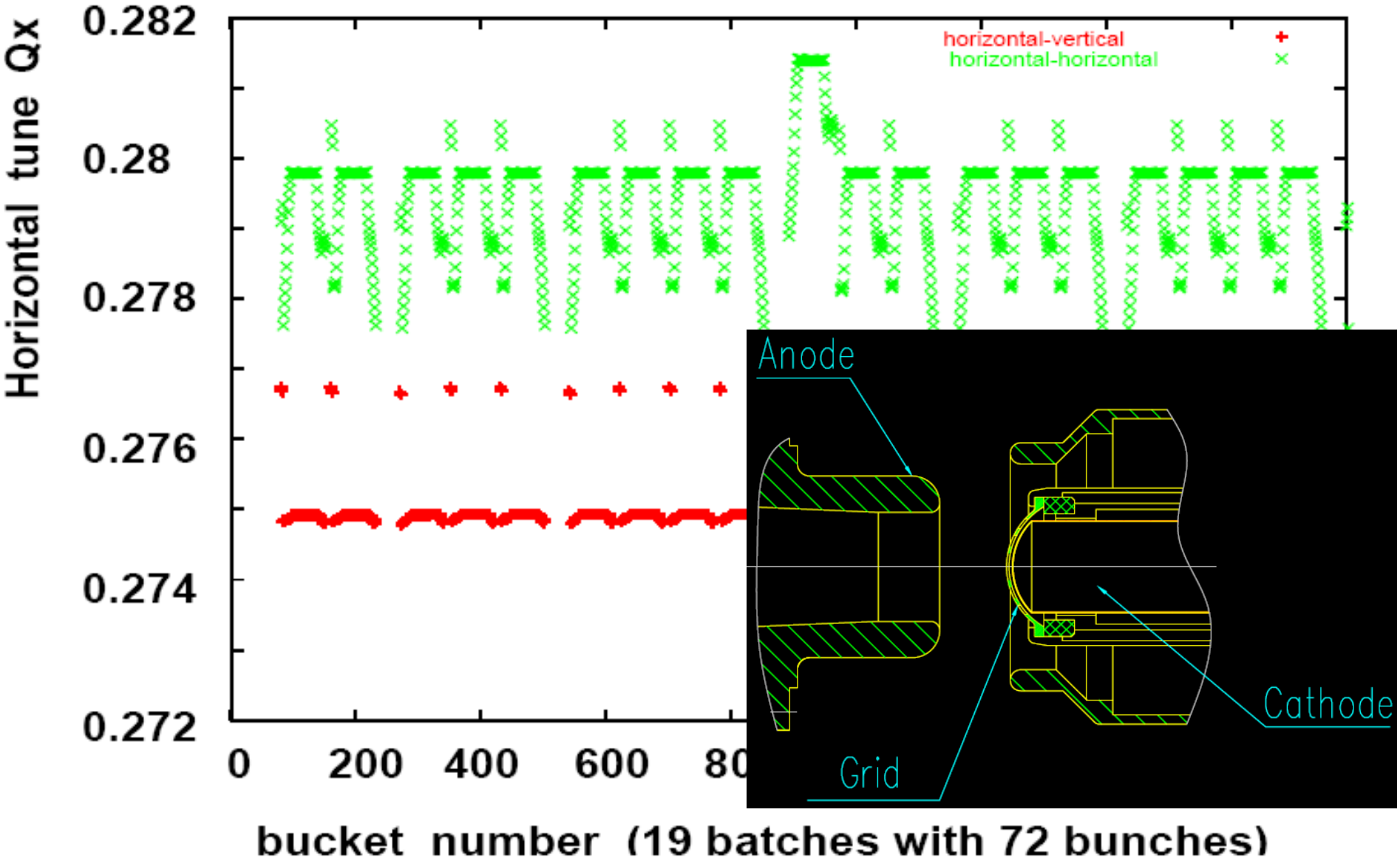


- **RHIC p-p ξ=-0.01, dQ=-0.02**
- **Beam-beam blowup @ start store**
- **E-lens solution: fit btw 2/3 & 7/10**
- **Group is perf'ing simulations**

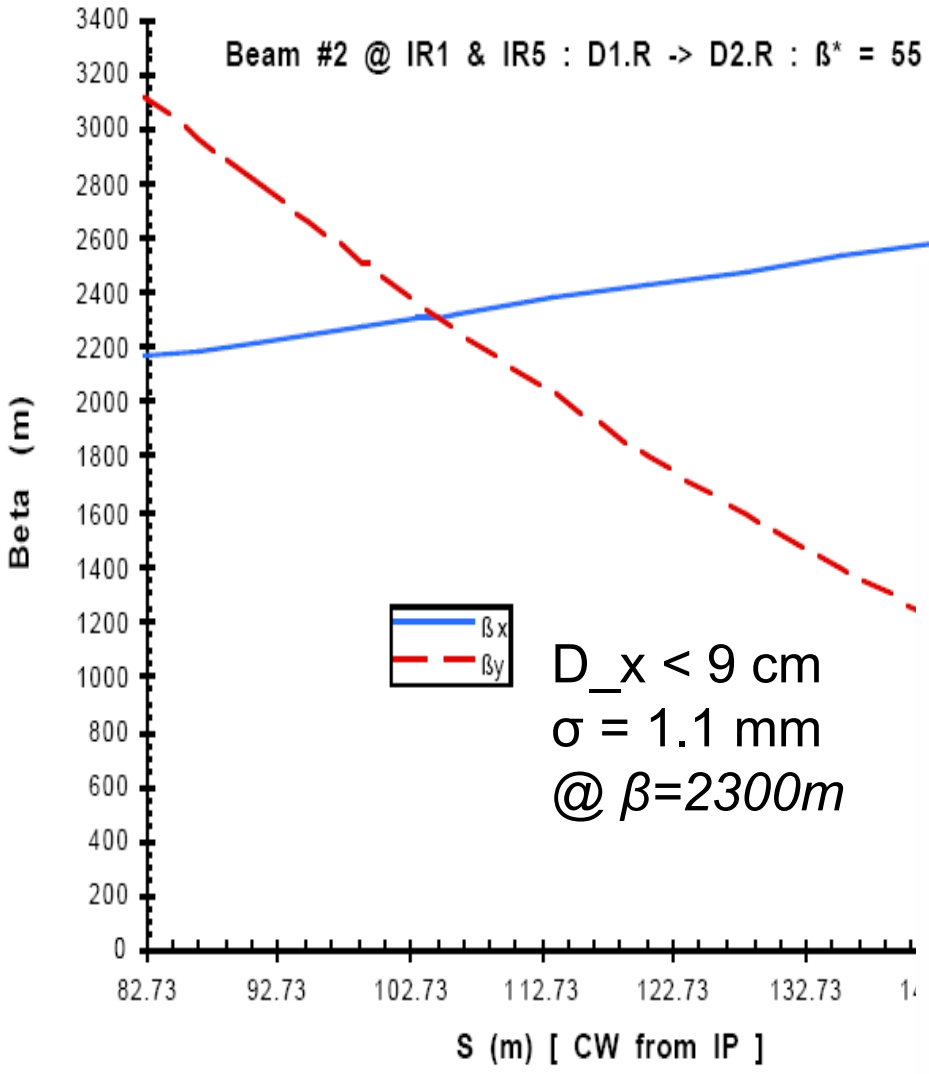
Long Range Compensation

- DC wire can do the job better
  - simpler
  - cheaper
  - But only for reasonable beam-b separation >5-7σ
- Electron Lens can
  - act as “electron wire” at ANY separation
  - easy to vary the current: 375ns rise, f_r =439kHz
  - 80Am → need some longer e-beam (6-8 m ?)
  - If only tune shift compensation needed → head-on elens can help- e.g. in *XX* crossing with many parasitics (next slide)

Bunch tunes for *XY* and *XX*

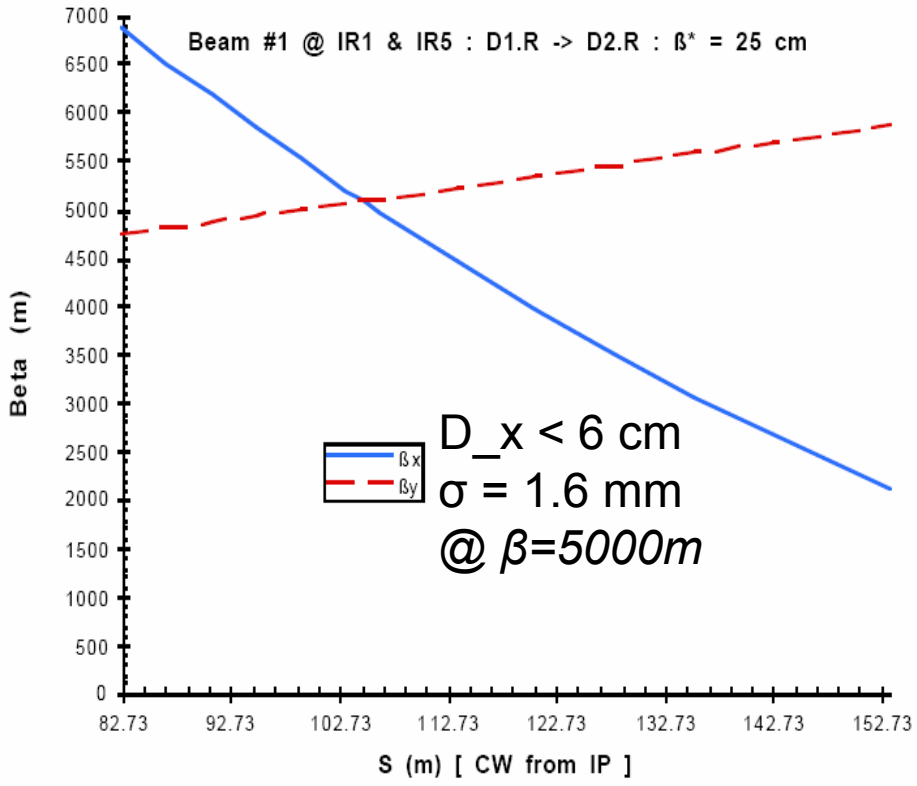


Possible LHC elens location (55 cm/25cm lattice)



J.Johnstone

LARP-doc-560



Summary

- Electron lenses ~*double* proton lifetime in Tev
  - Hor and vert ; Improve luminosity lifetime, too
- Will continue studies → introduce in operation
- A lot of interesting data, see:
  - Proc. PAC'07 and SLAC BBC Workshop (July'07)
- Head-on compensation is under consideration
  - in RHIC – team's working; in LHC - US LARP task
- LR-BBC with LHC elenses:
  - Quite feasible, but needs justification