Progress with Tevatron Electron Lenses

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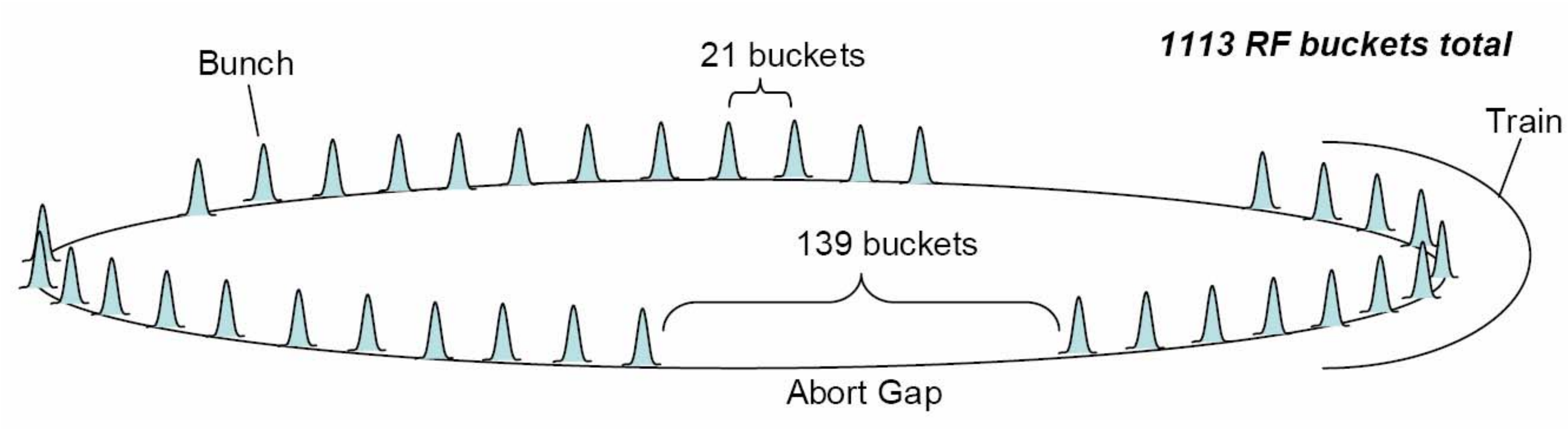
for Fermilab Beam-Beam Compensation team

COOL 07, Bad Kreuznach, September 10-14, 2007

Bunch structure in the Tevatron



RF	53.1 MHz
bunch spacing	396 ns
abort gaps	2.6 μs
bunch length	< 3 ns (RMS)

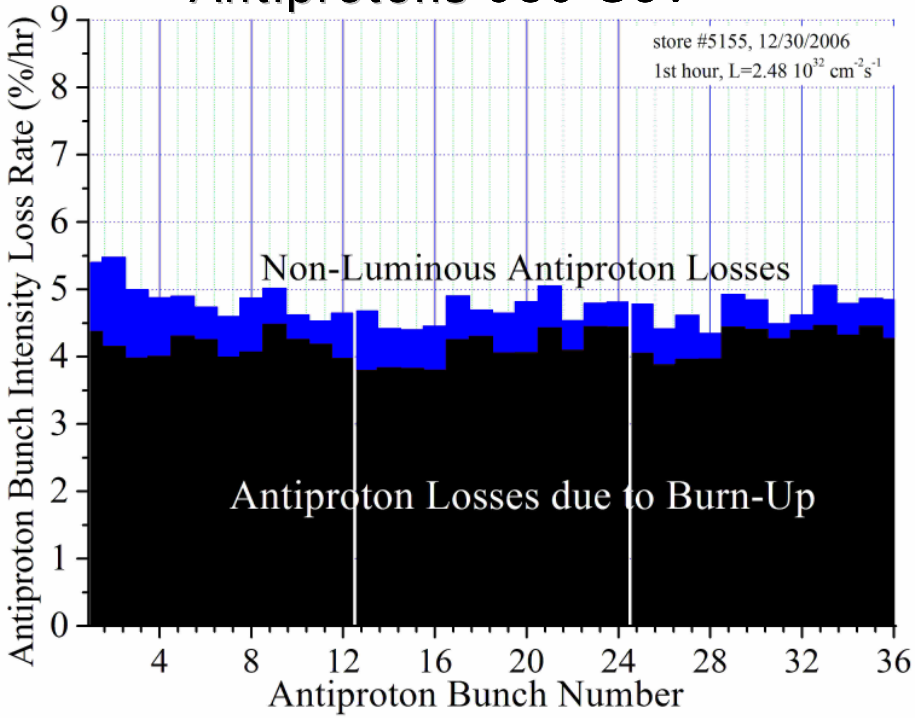
36 proton bunches collide with
36 antiproton bunches at two IPs

image taken from Tevatron Rookie Book, p. 9.13.
http://www-bdnew.fnal.gov/operations/rookie_books/Tevatron_v1.pdf

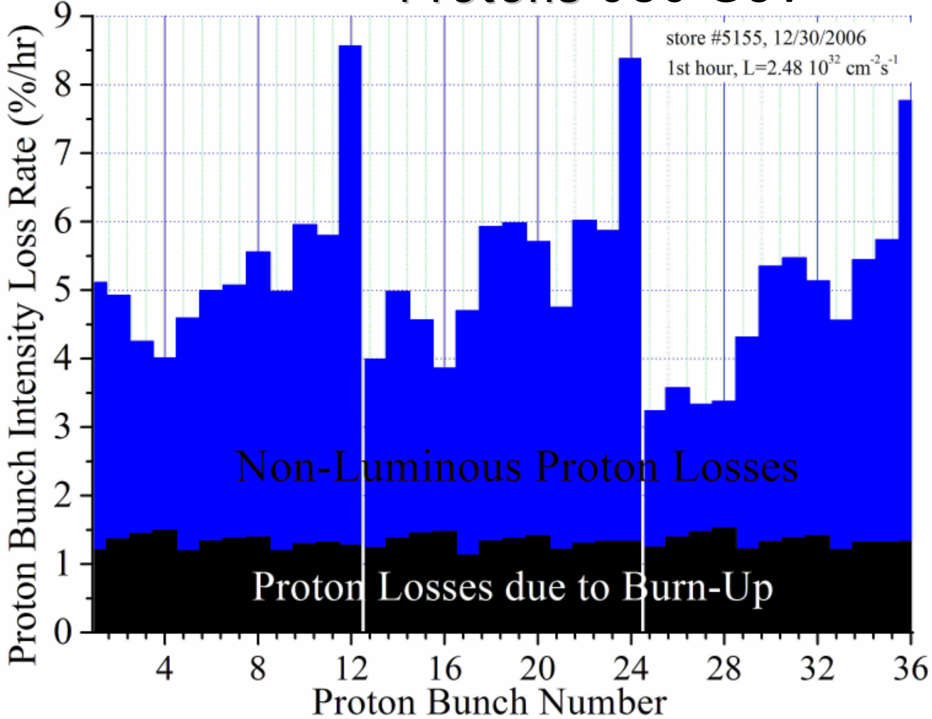
Non-luminous losses in the Tevatron

Example of a Tevatron store

Antiprotons 980 GeV



Protons 980 GeV

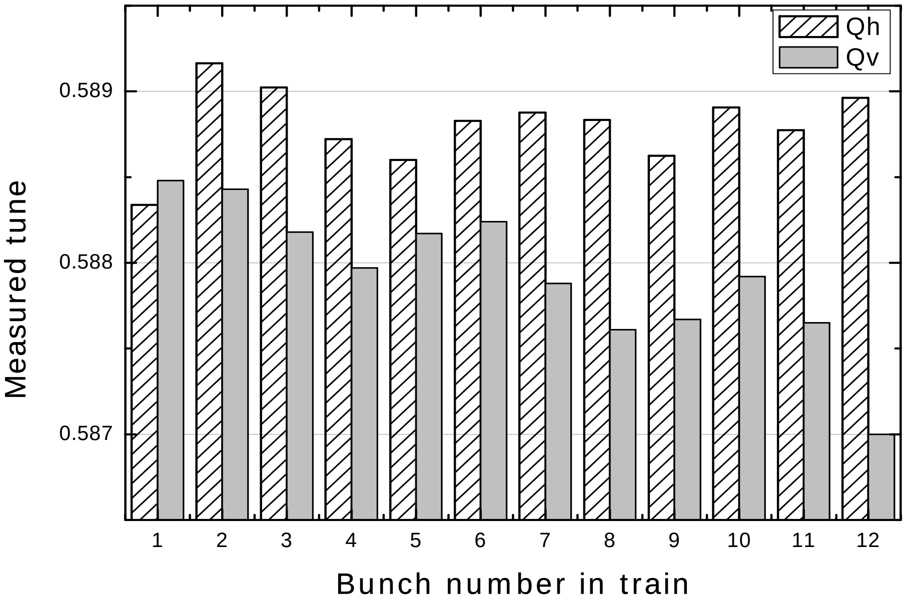


At present, beam-beam effects are stronger on protons, accounting for 10-15% loss of the integrated luminosity. Proton loss rates vary greatly from bunch to bunch.

Conclusion: TELs should compensate protons.

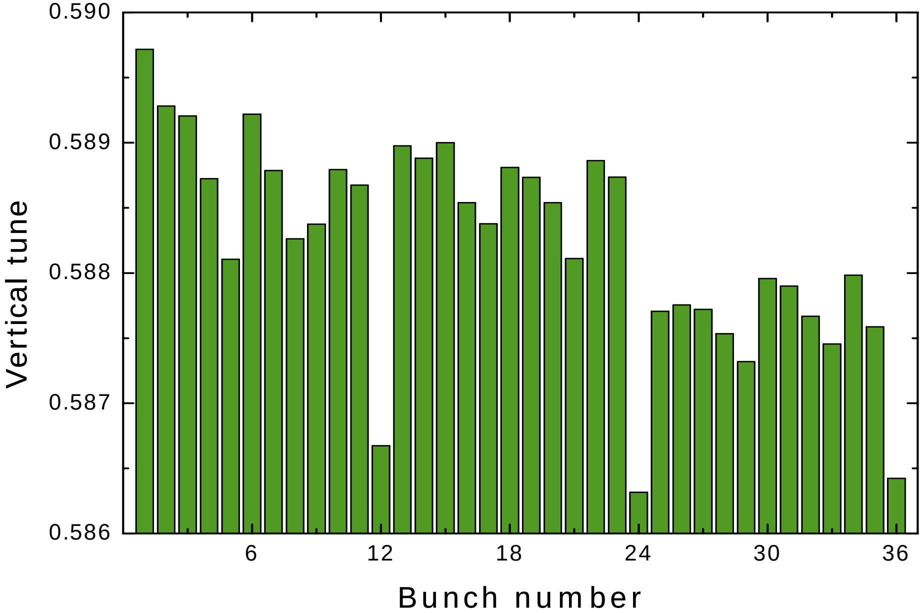
Proton bunch-by-bunch tunes

1.7 GHz Schottky, end of store



the Schottky detector was gated on tree bunches in three trains at a time, e.g. 1,13,25 or 12,24,36

DTM data, beginning of store

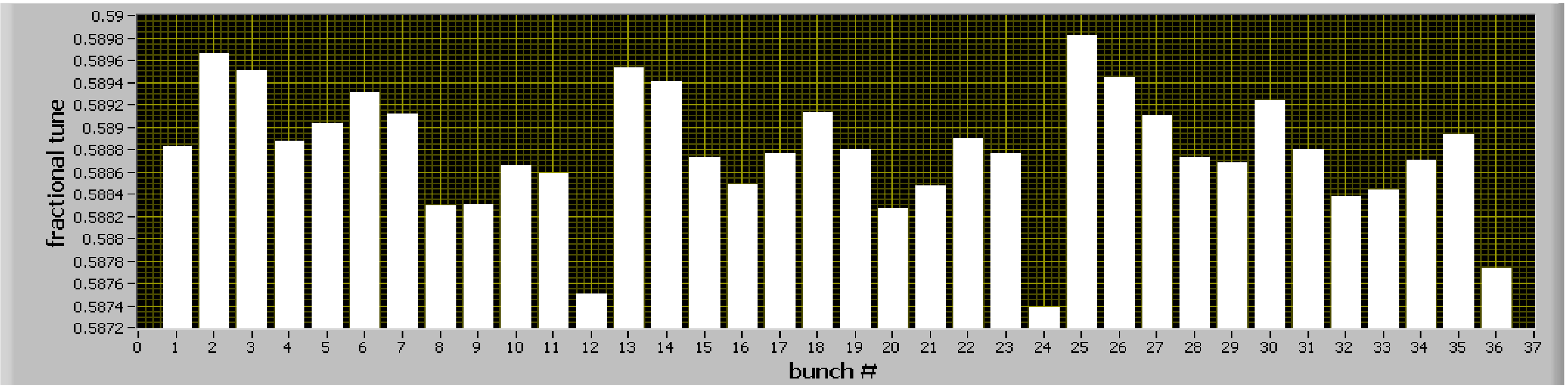


The Digital Tune Monitor is currently being commissioned.

Proton bunch-by-bunch tunes

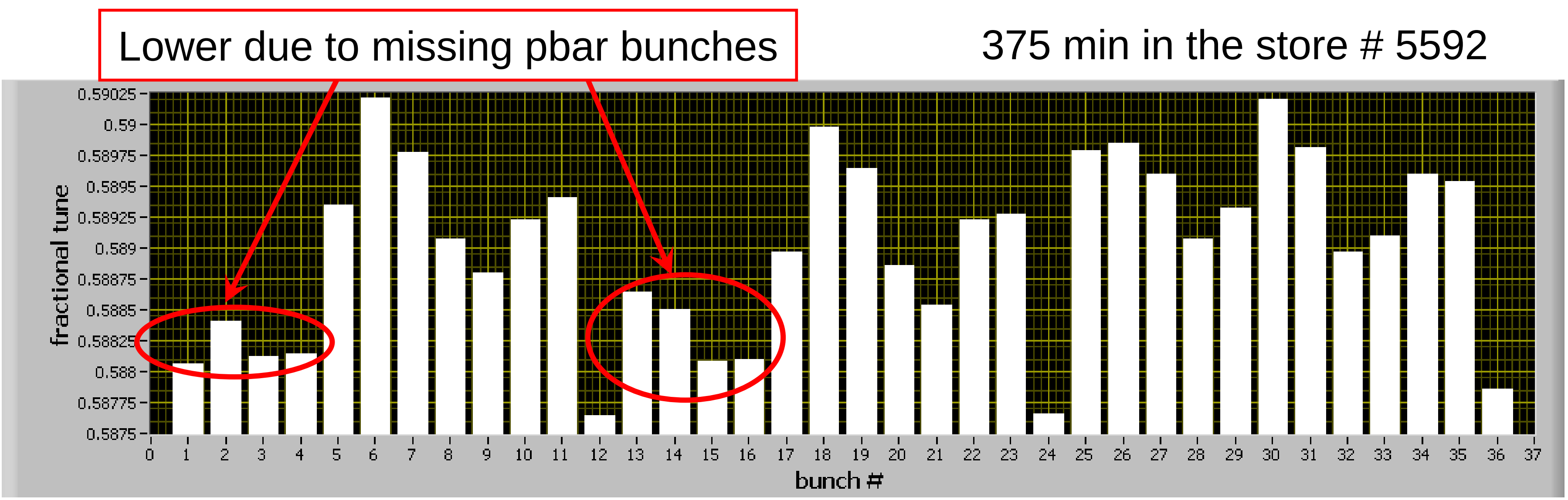
measured by the Digital Tune Monitor

1446 min in the store # 5590

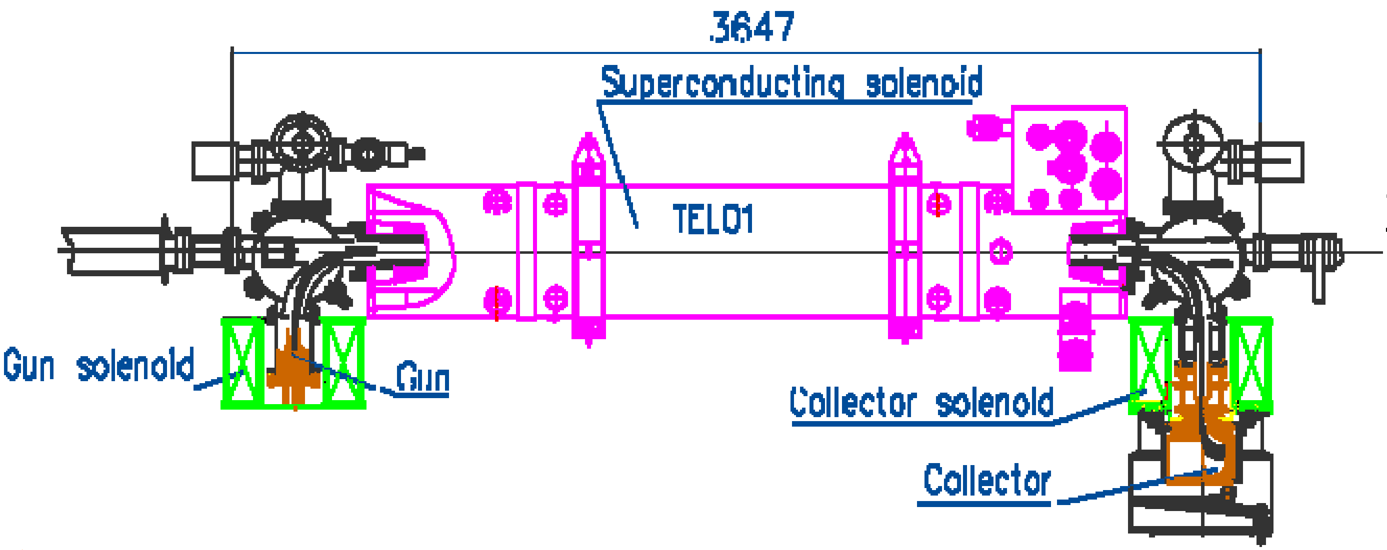


Lower due to missing pbar bunches

375 min in the store # 5592



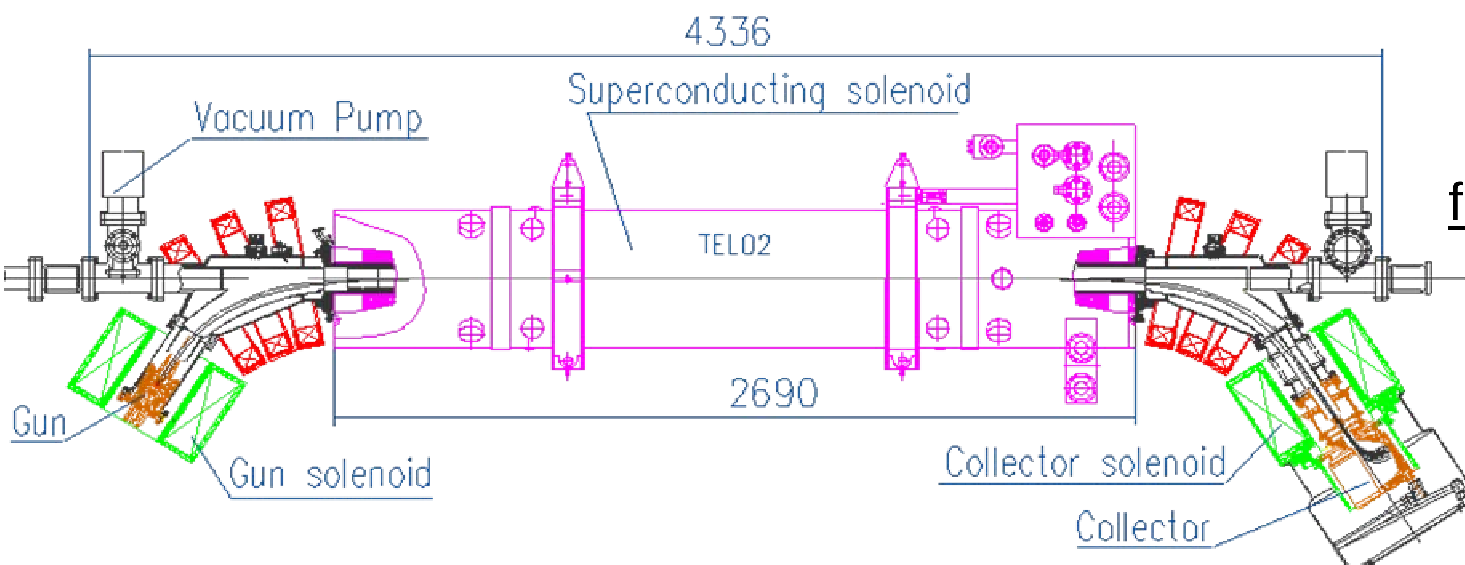
Tevatron Electron Lenses



TEL1

for horizontal BBC

Installed in the Tevatron in 2001

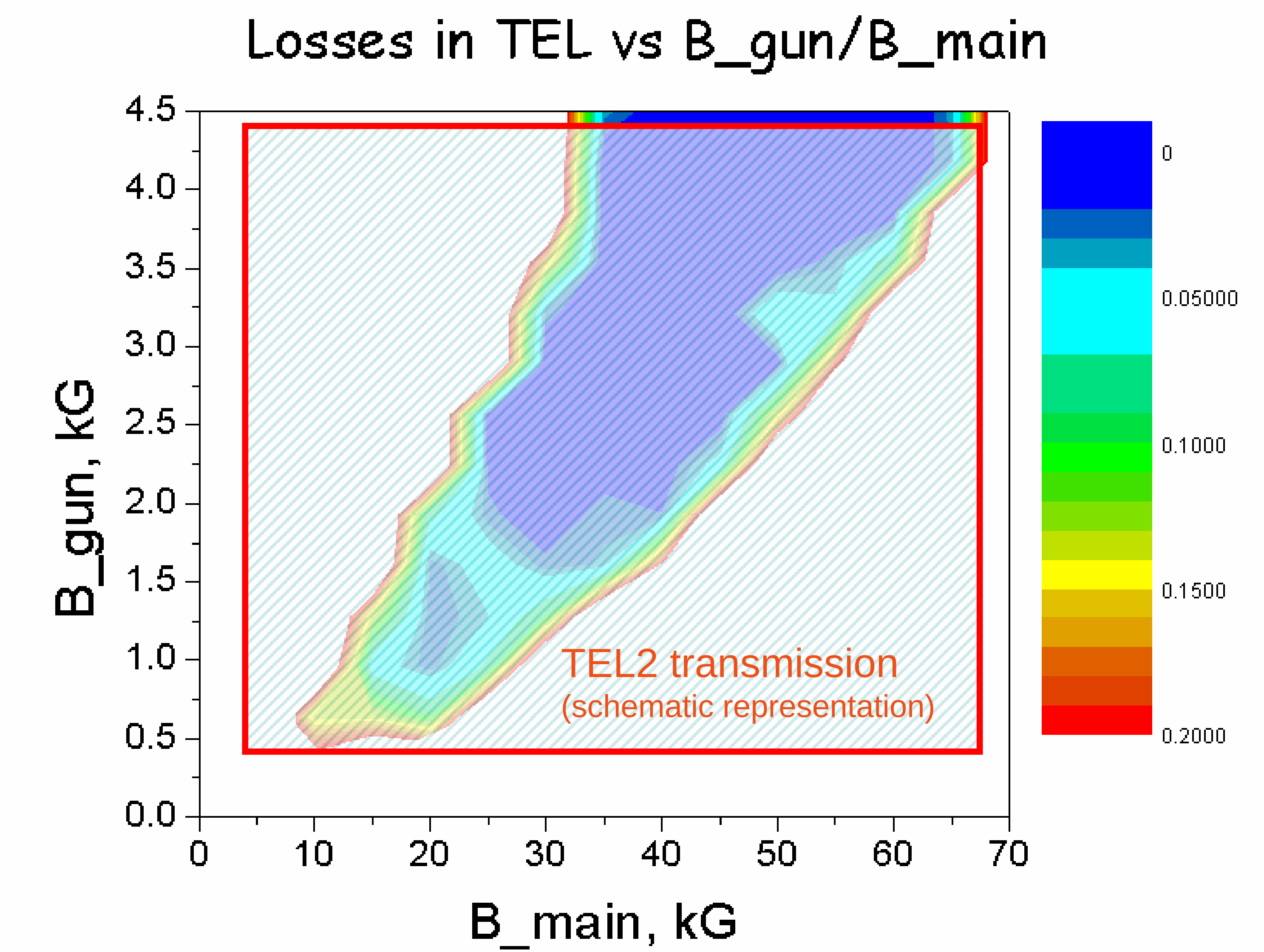


TEL2

for vertical BBC

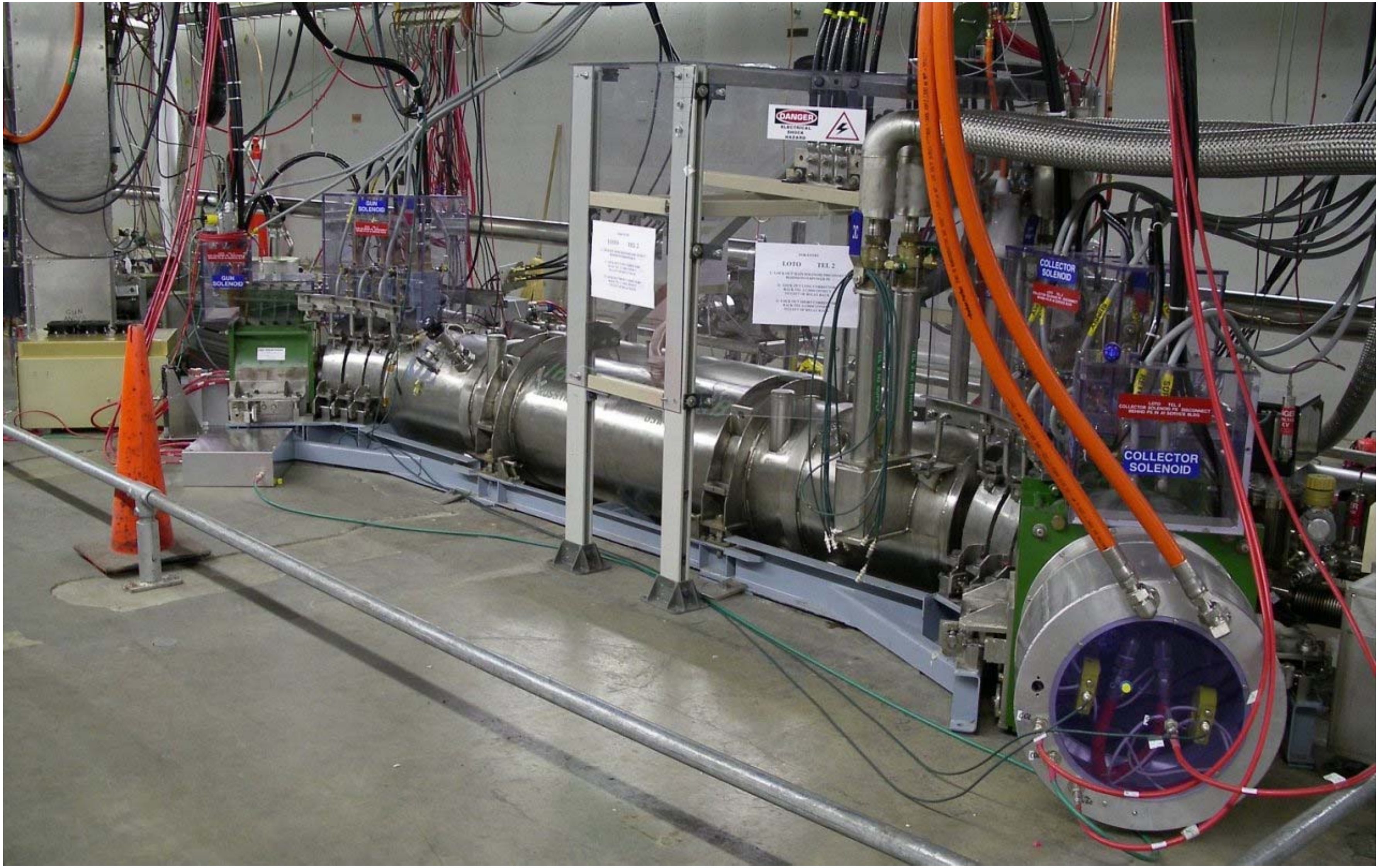
Installed in the Tevatron in 2006

TEL e-beam transmission



Location of TELs

TEL2 installed in the Tevatron



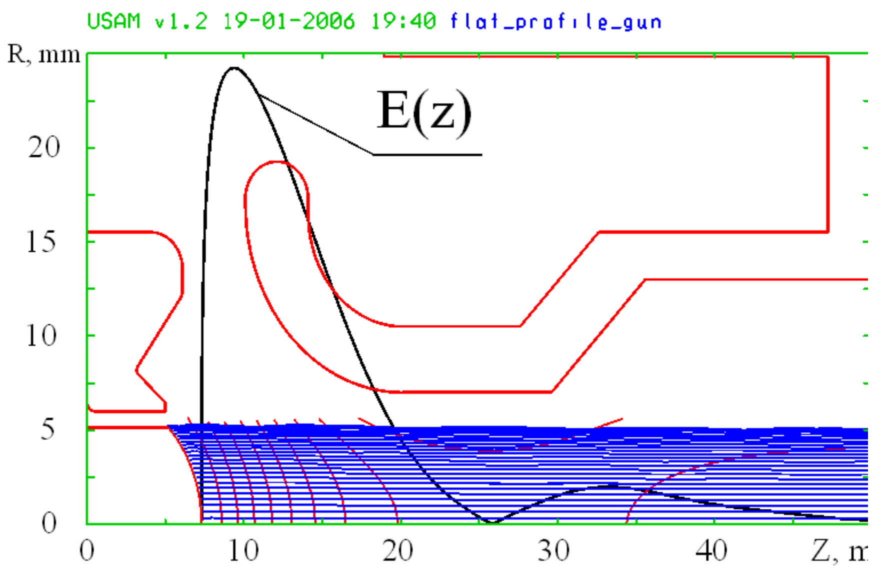
The tune shift formula

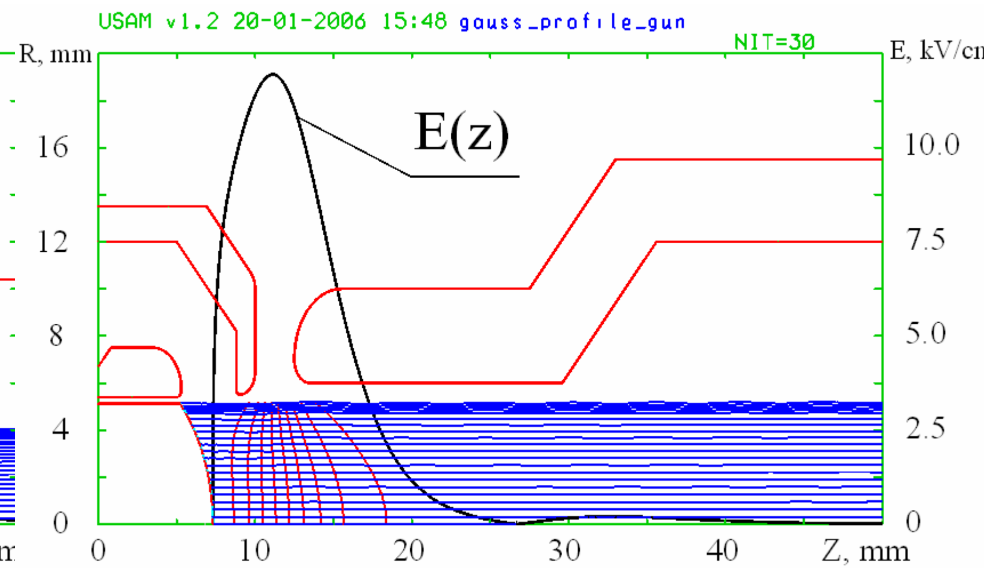
$$dQ_{x,y} = +\frac{\beta_{x,y} L_e r_p}{2\gamma e c} \cdot j_e \cdot \left(\frac{1-\beta_e}{\beta_e} \right)$$

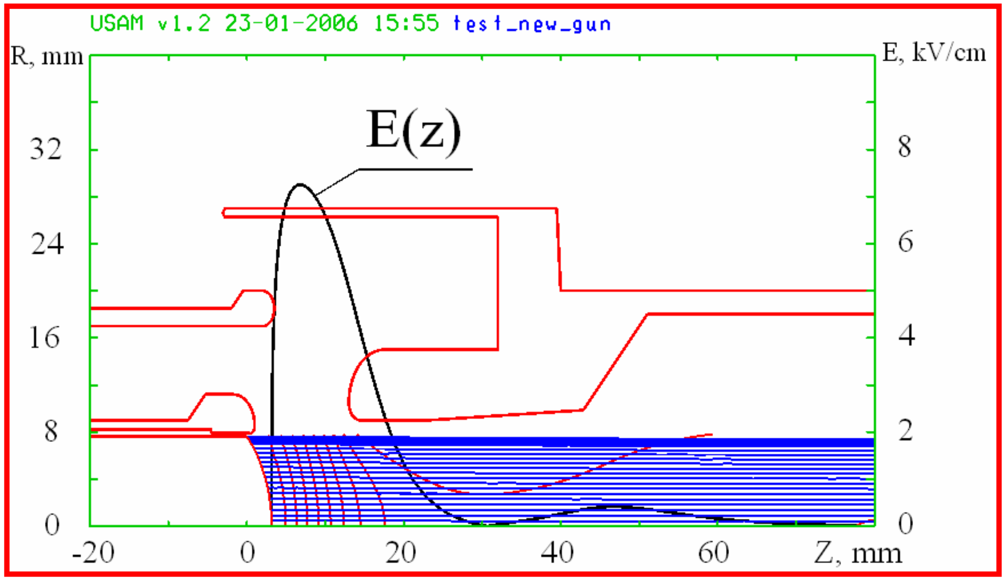
Typical TEL2 parameters

Parameter	Symbol	Value
Electron beam energy (oper./max)	U_e,	5/10 kV
Peak electron current (oper./max)	J_e	0.6/2.3 A
Magnetic field ratio main/gun	B_{main} /B_{gun}	30/3 kG
e-beam radius in main solenoid	a_e	2.3 mm
Cathode radius	a_c	7.5 mm
e-pulse width, “0-to-0”	*Te*	600 ns
e-pulse repetition rate	f_0	47.7 kHz
Effective interaction length	L_e	2.0 m
Vertical β-function	β_y	150 m

Three types of e-guns

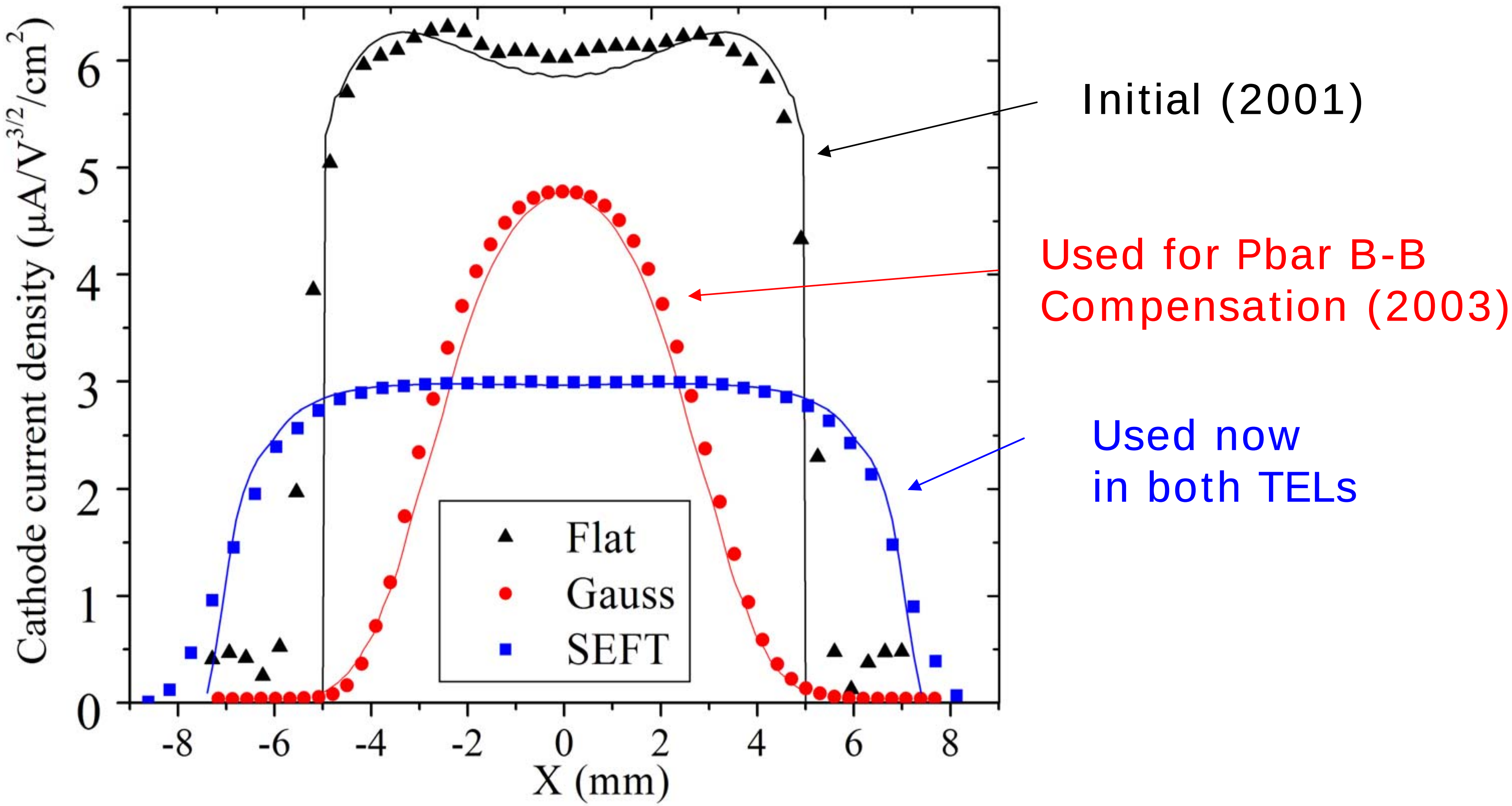






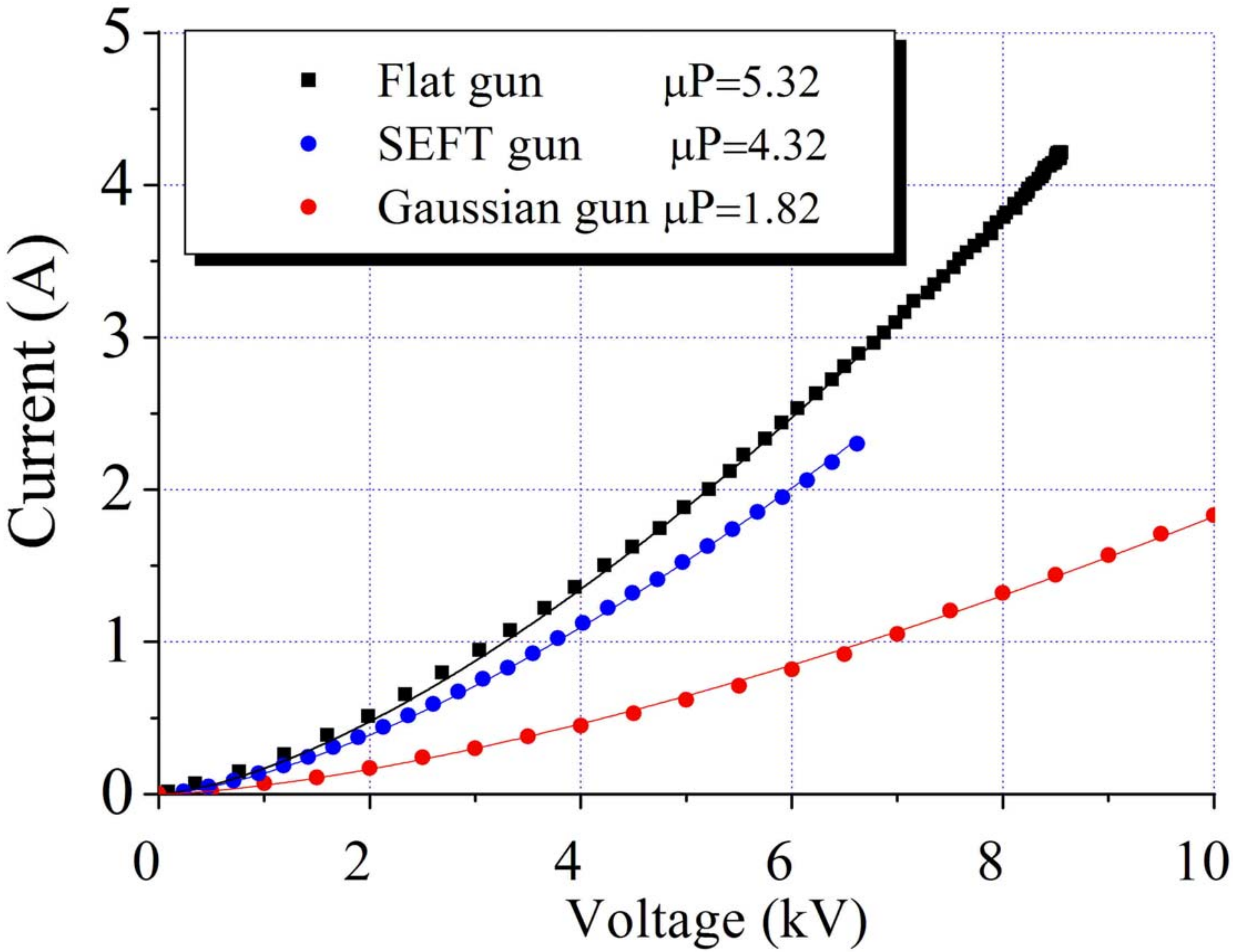
Geometry and simulations (SuperSAM) of three types of electron guns: "flat", Gaussian and "smooth edge flat top" (SEFT) current distribution.

Electron beam profiles

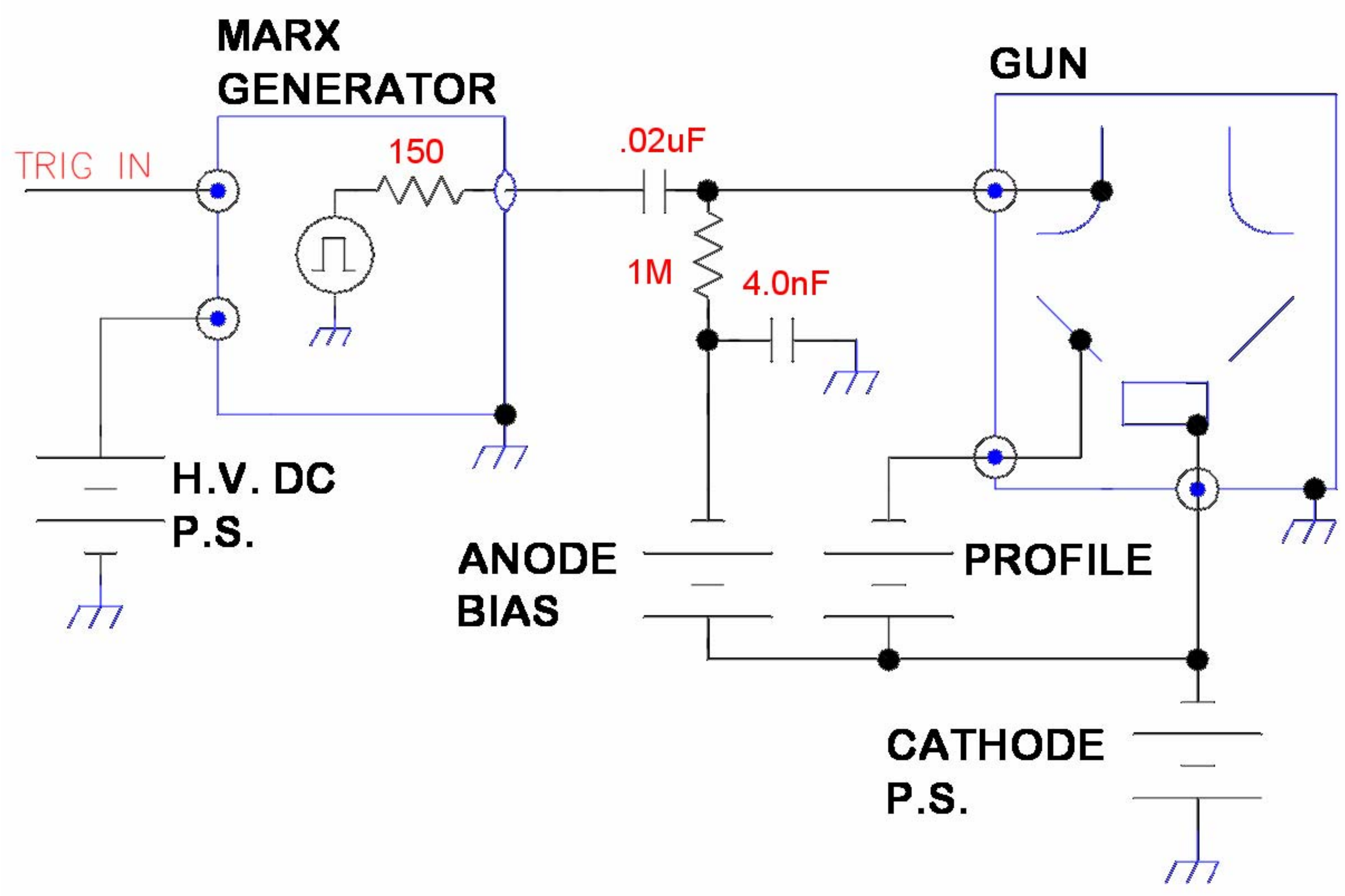


Since e-beam is strongly magnetized in 4-40 kG magnetic field, the charge density distribution in the interaction region has the same shape as on the cathode

E-gun performance

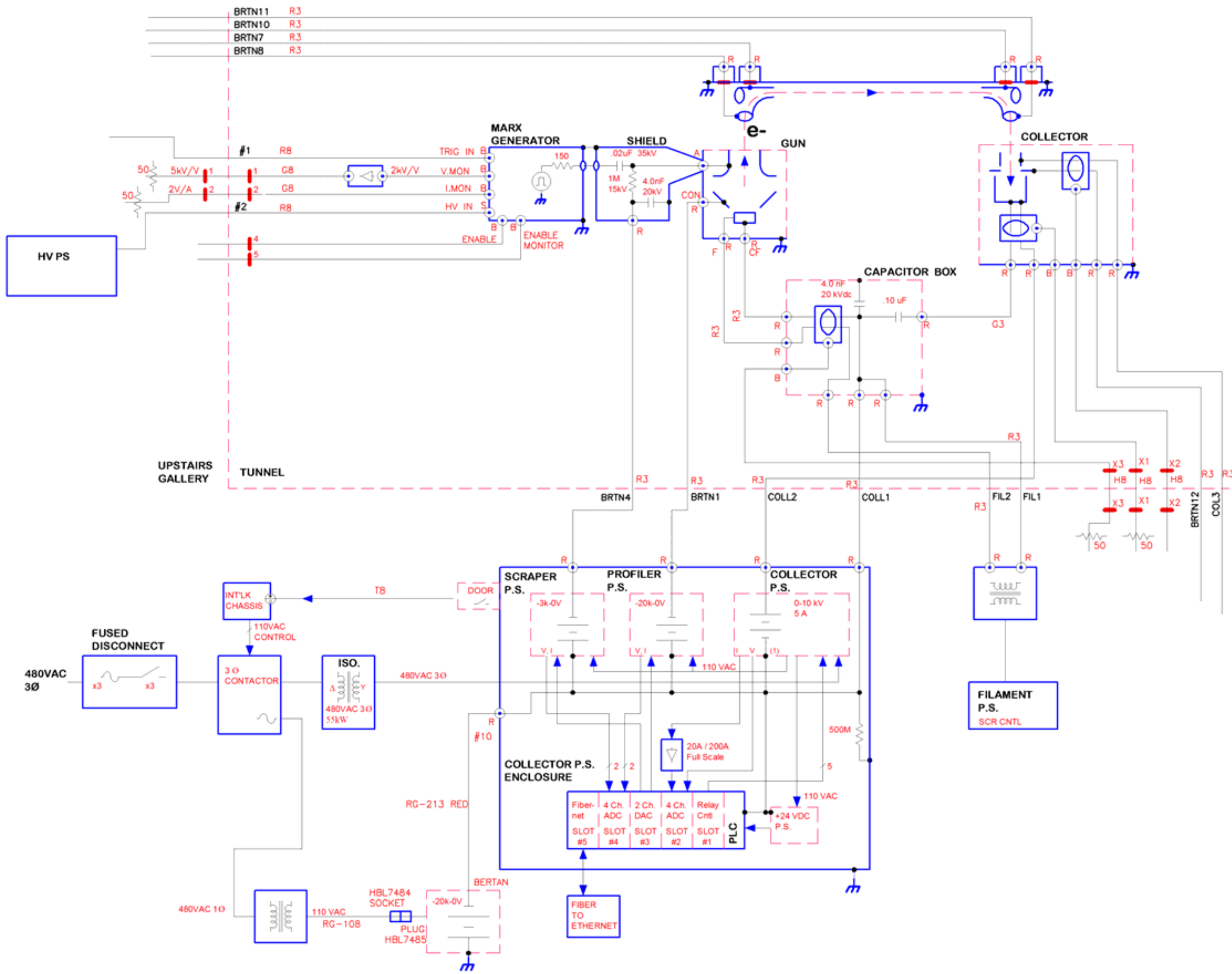


E-gun driver

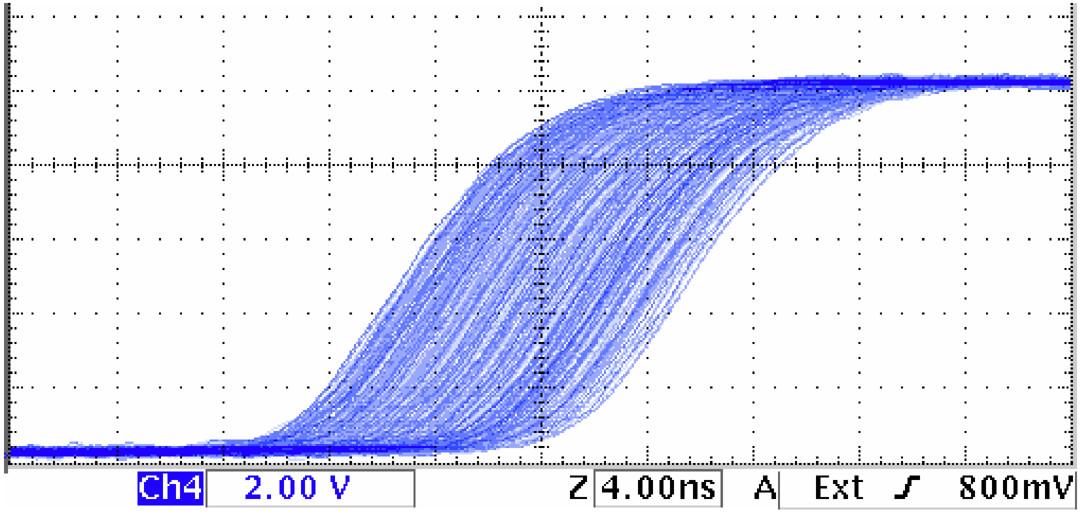


MARX
GENERATOR
GUN
TRIG IN
150
.02uF
1M
4.0nF
H.V. DC
P.S.
ANODE
BIAS
PROFILE
CATHODE
P.S.

TEL2 block diagram

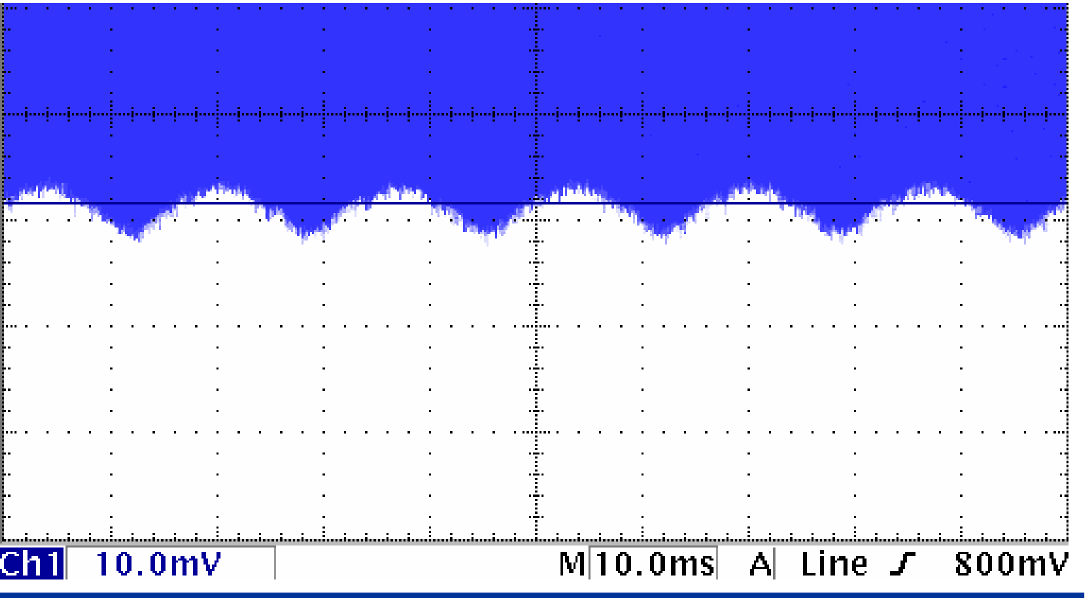


E-beam quality issues

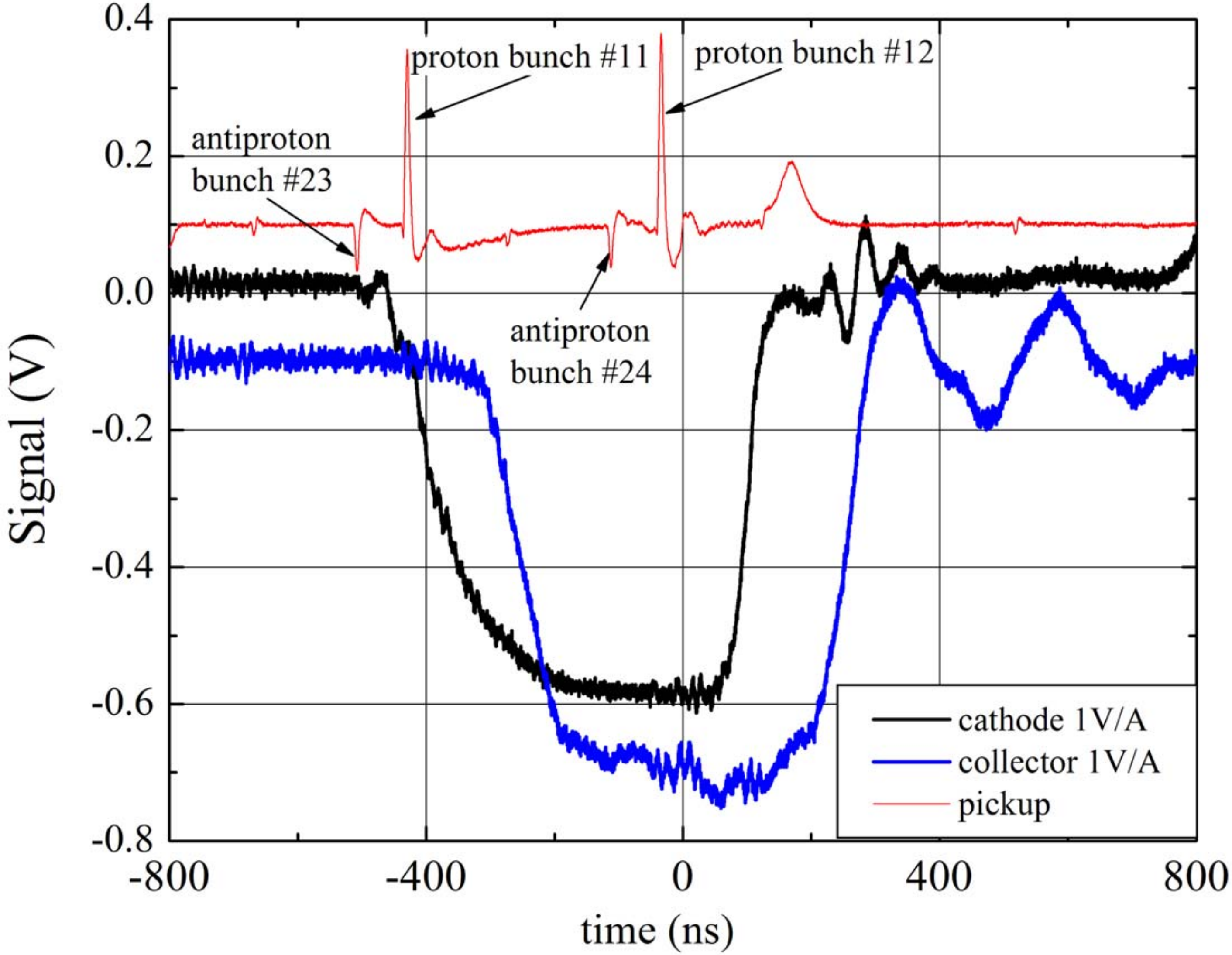


timing jitter
(fixed, <1ns)

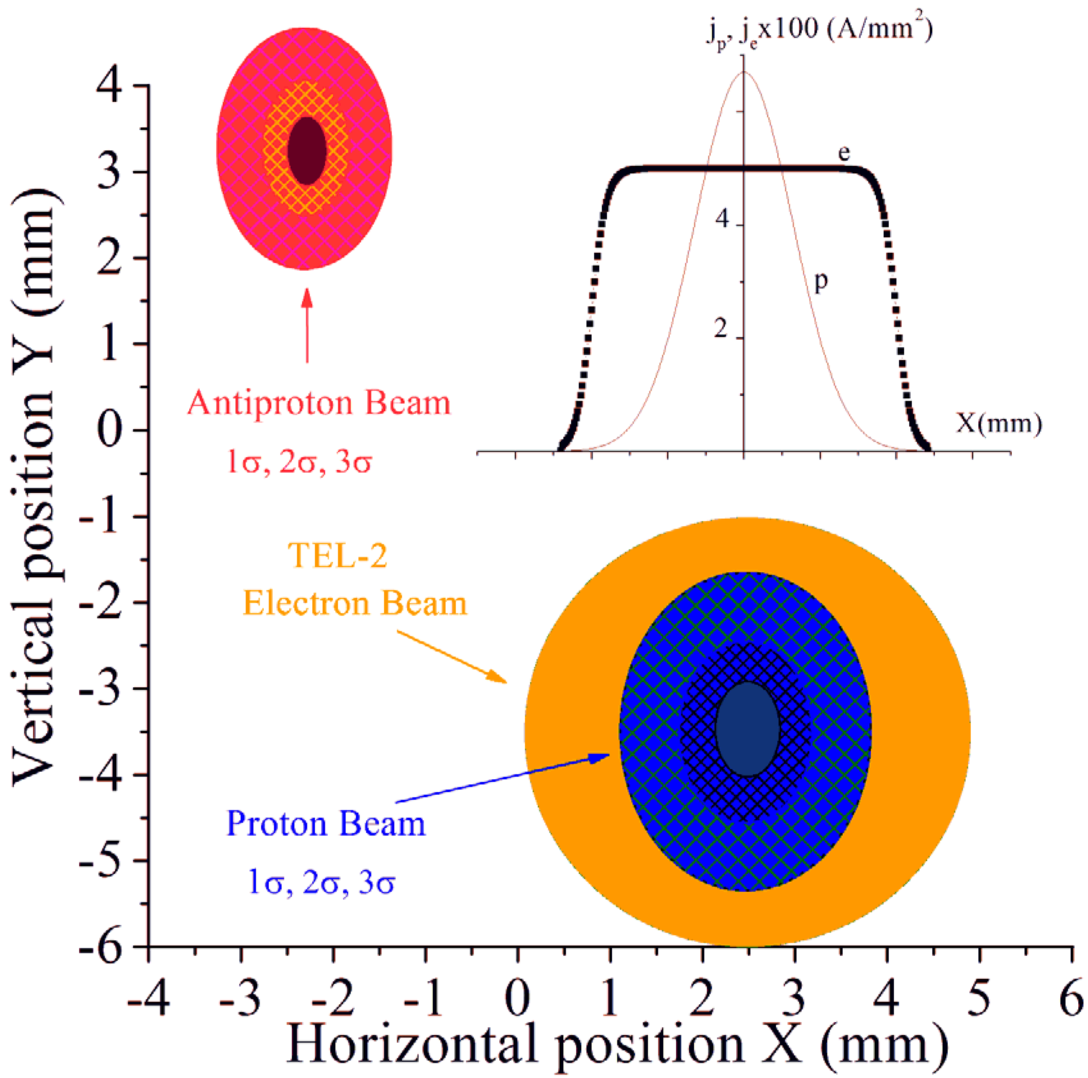
e-current ripple ~1%



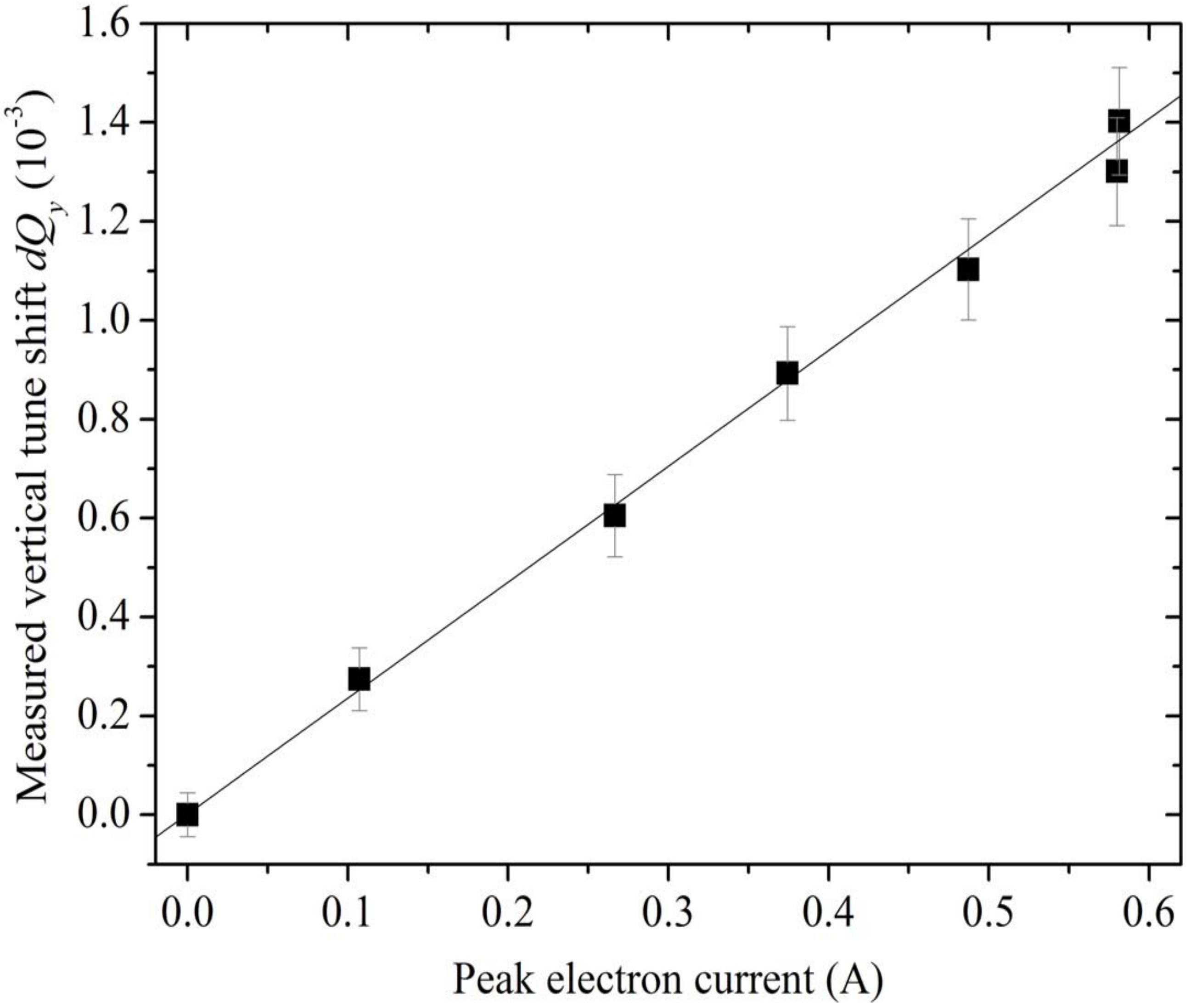
TEL2 timing for proton BBC



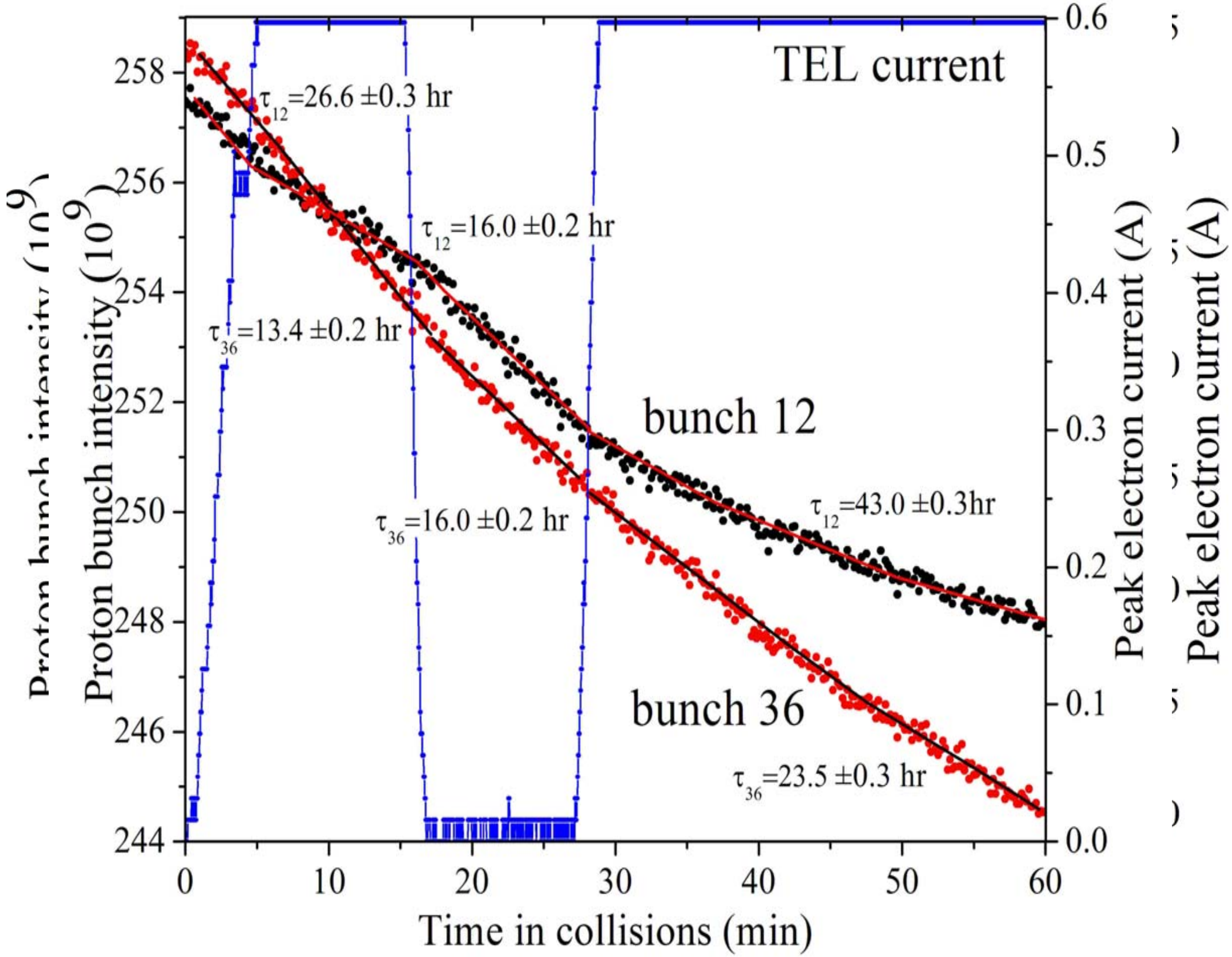
Transverse alignment



Measured tune shift (TEL2)

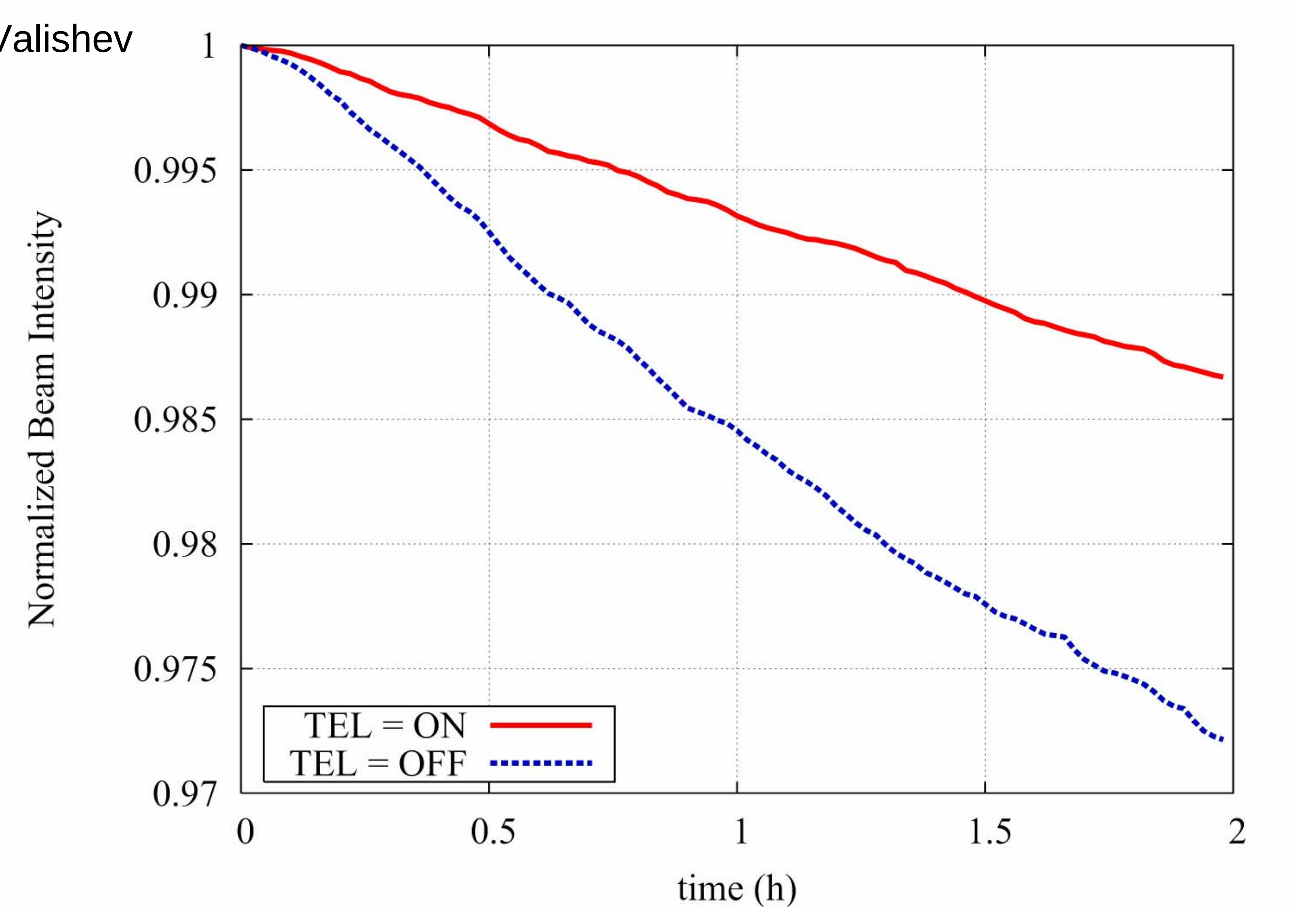


Single bunch BBC (P12)

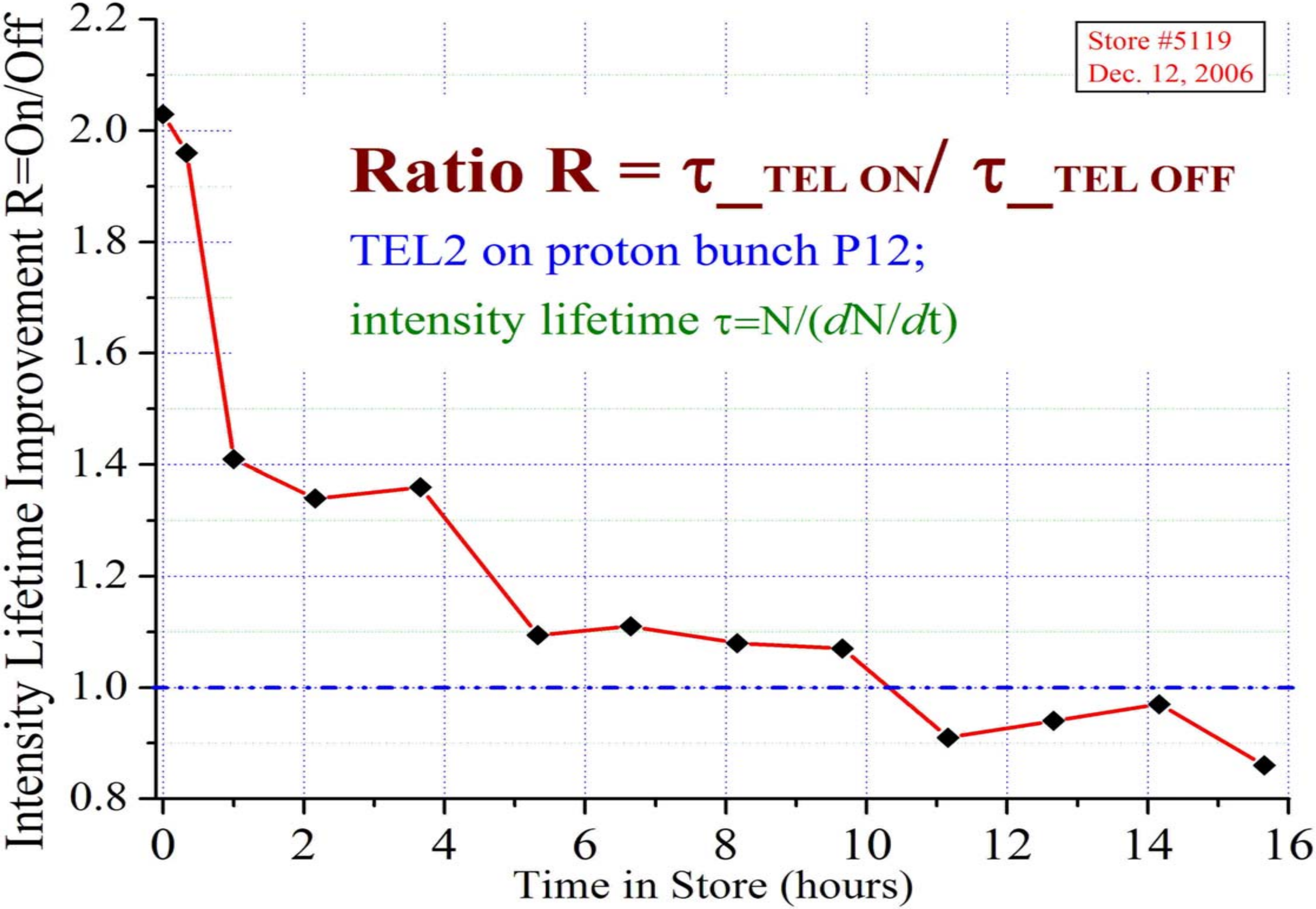


LIFETRAC simulation

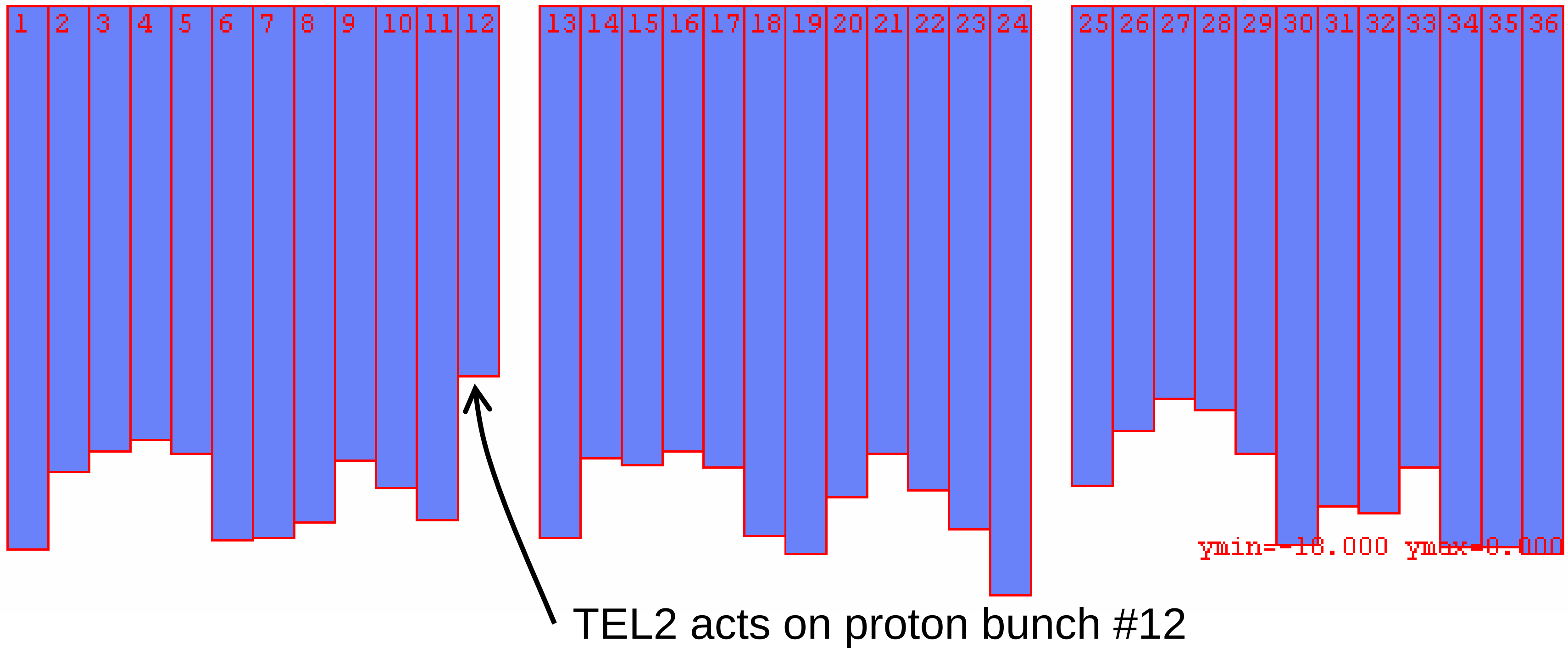
A. Valishev



τ improvement vs time in store

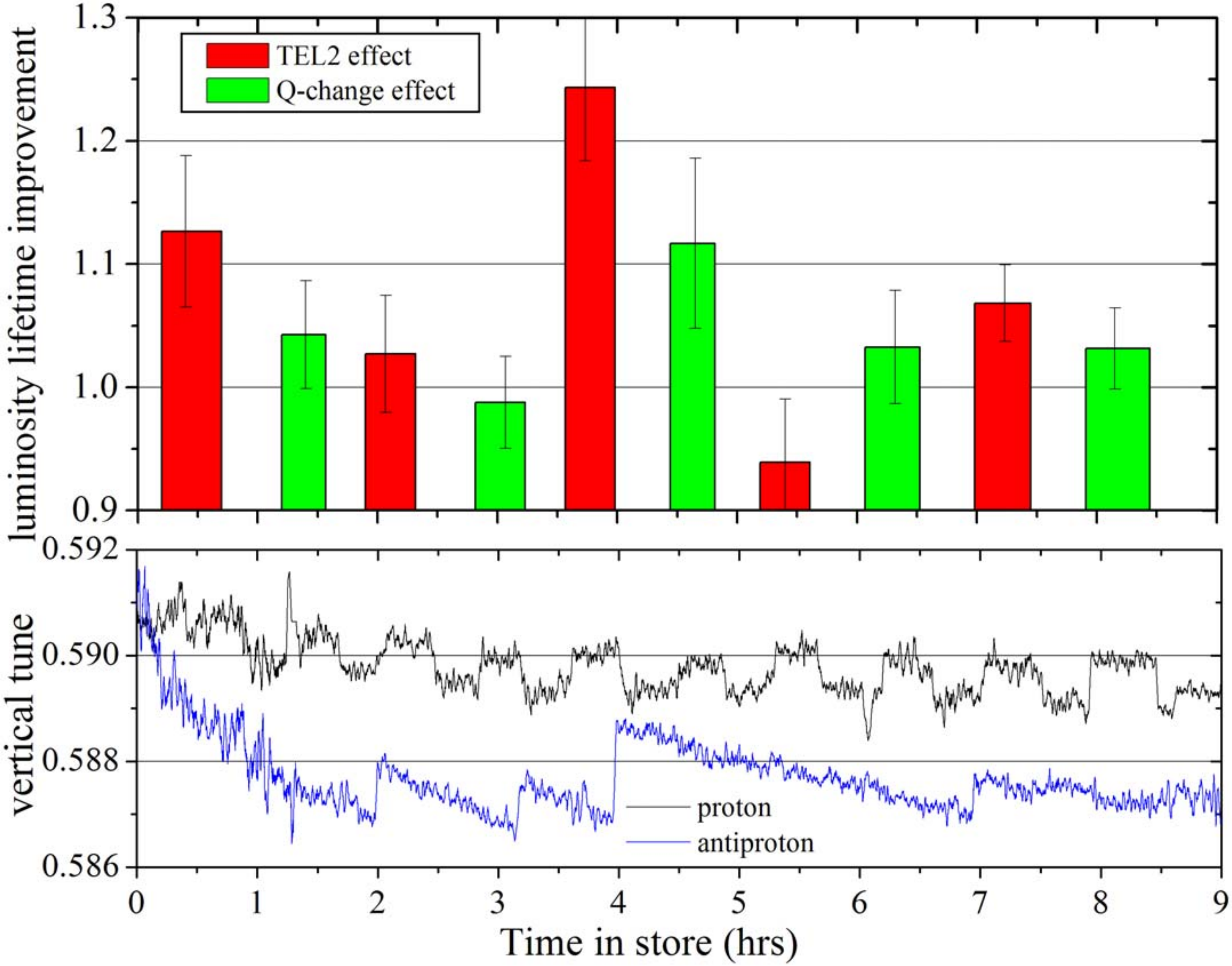


Single bunch BBC



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.

Increase of Luminosity Lifetime

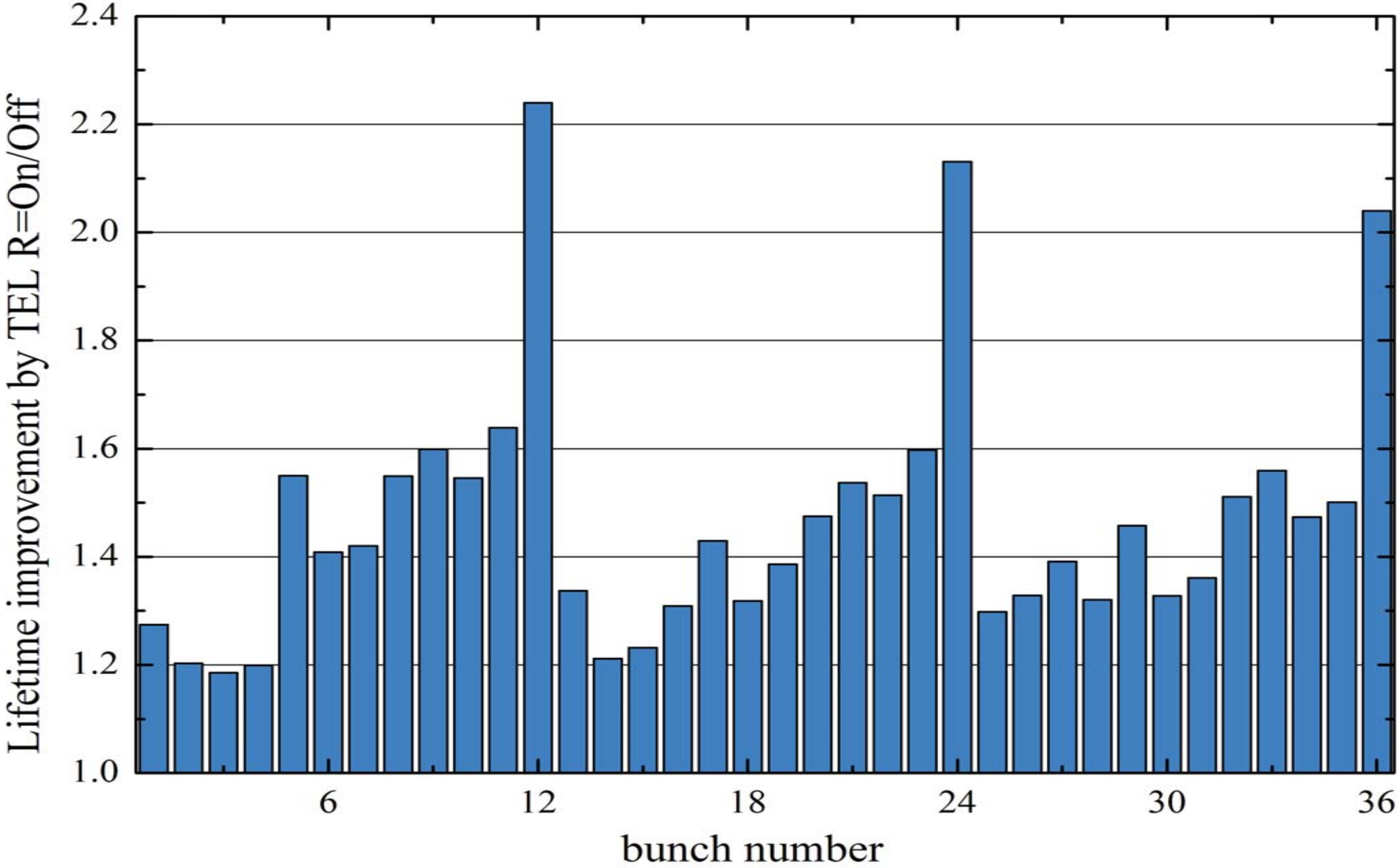


TEL on:

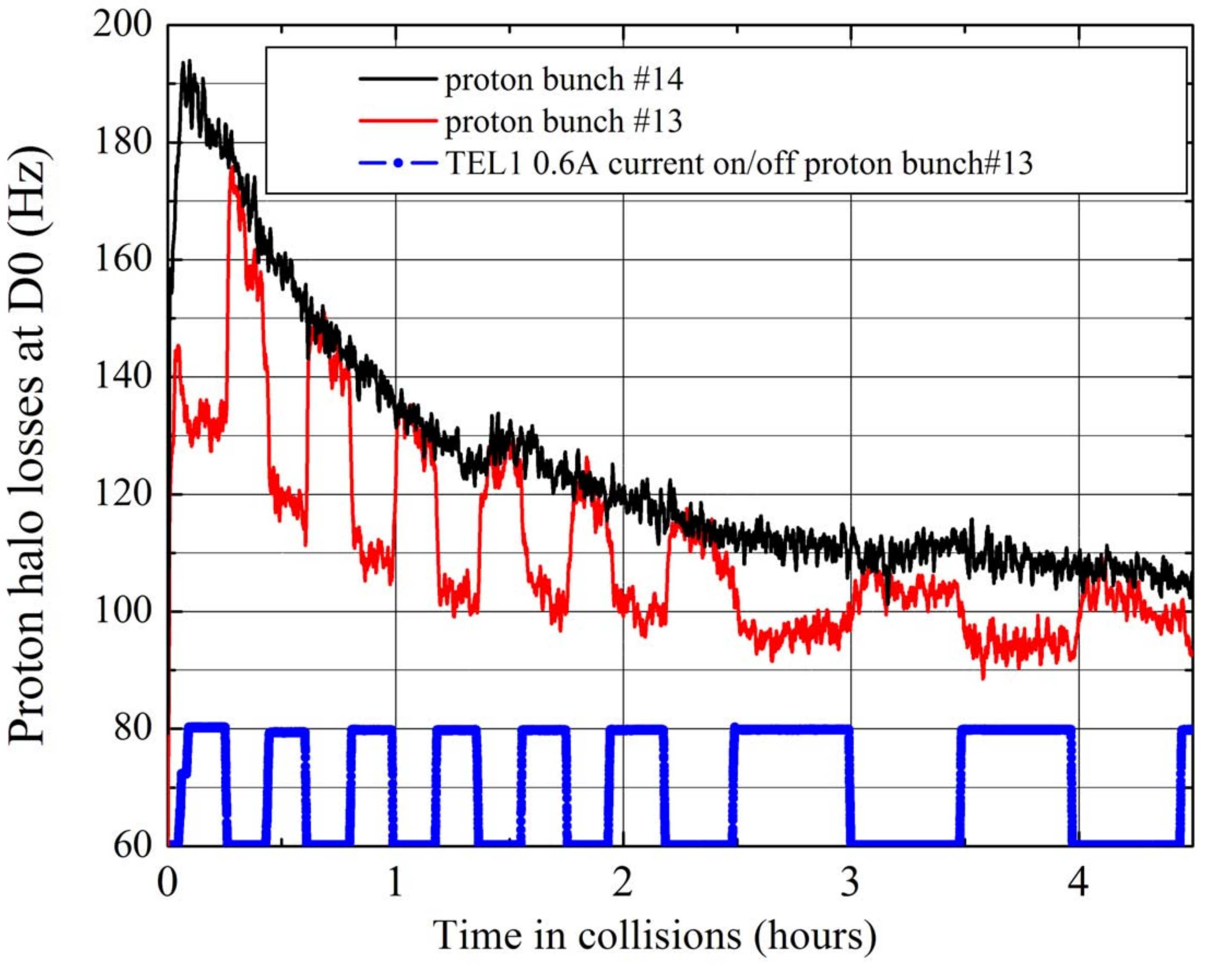
dQ=0.001

Effects ~comparable except TEL can affect individual bunches

TEL2 in dc mode



TEL1 on P13



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

Summary

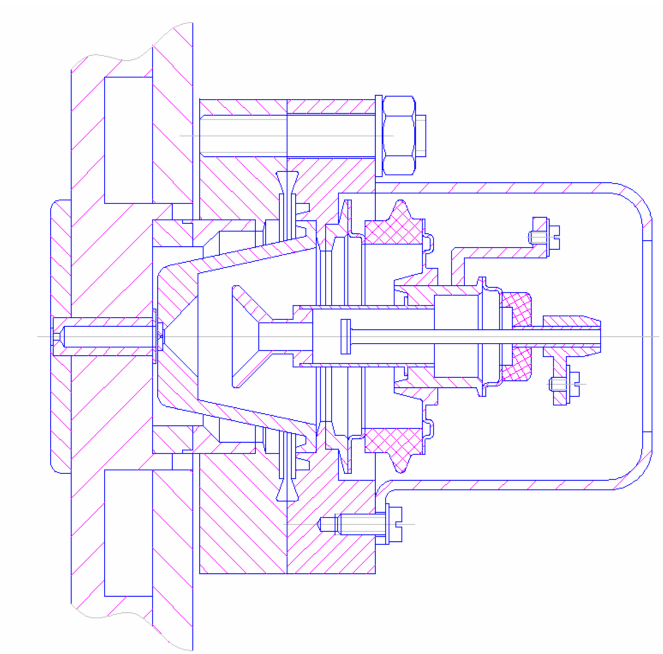
- ✓ The e-beam quality in both TELs reached the level that made reproducible demonstration of beam-beam compensation (tune shift) possible.
- ✓ The 2nd Tevatron Electron Lens (vertical) ~doubled proton intensity lifetime of the bunch it was acting on
- ✓ Agreement with simulations
- ✓ The 1st Tevatron Electron Lens (horizontal) improved proton intensity lifetime by 20-60%
- ✓ TELs improve luminosity lifetime as well
- ✓ BBCompensation helps for ~10 hrs in HEP stores
- ✓ possible applications of ELs in RHIC and LHC
- ✓ Will continue experimental and simulation studies and introduce in TEV operation

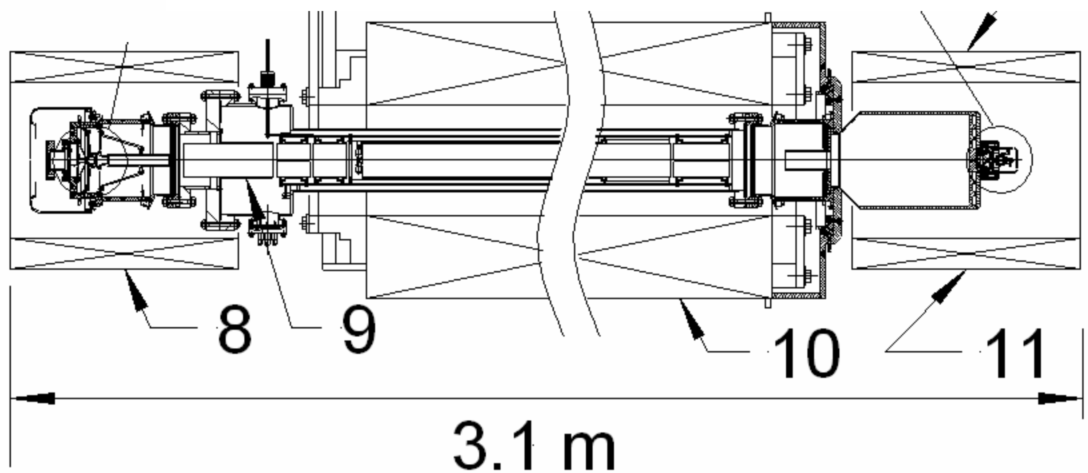
Plans

- Head-on compensation with Gaussian electron beam profiles (dc or pulsed)
- Study the effect of electron beam size on protons (lifetime, halo, Schottky) in both TELs
- Use both TELs simultaneously for BBCompensation in dc and pulsed mode
- Upgrade HV pulse generators → multi-bunch BBCompensation

Backup slides

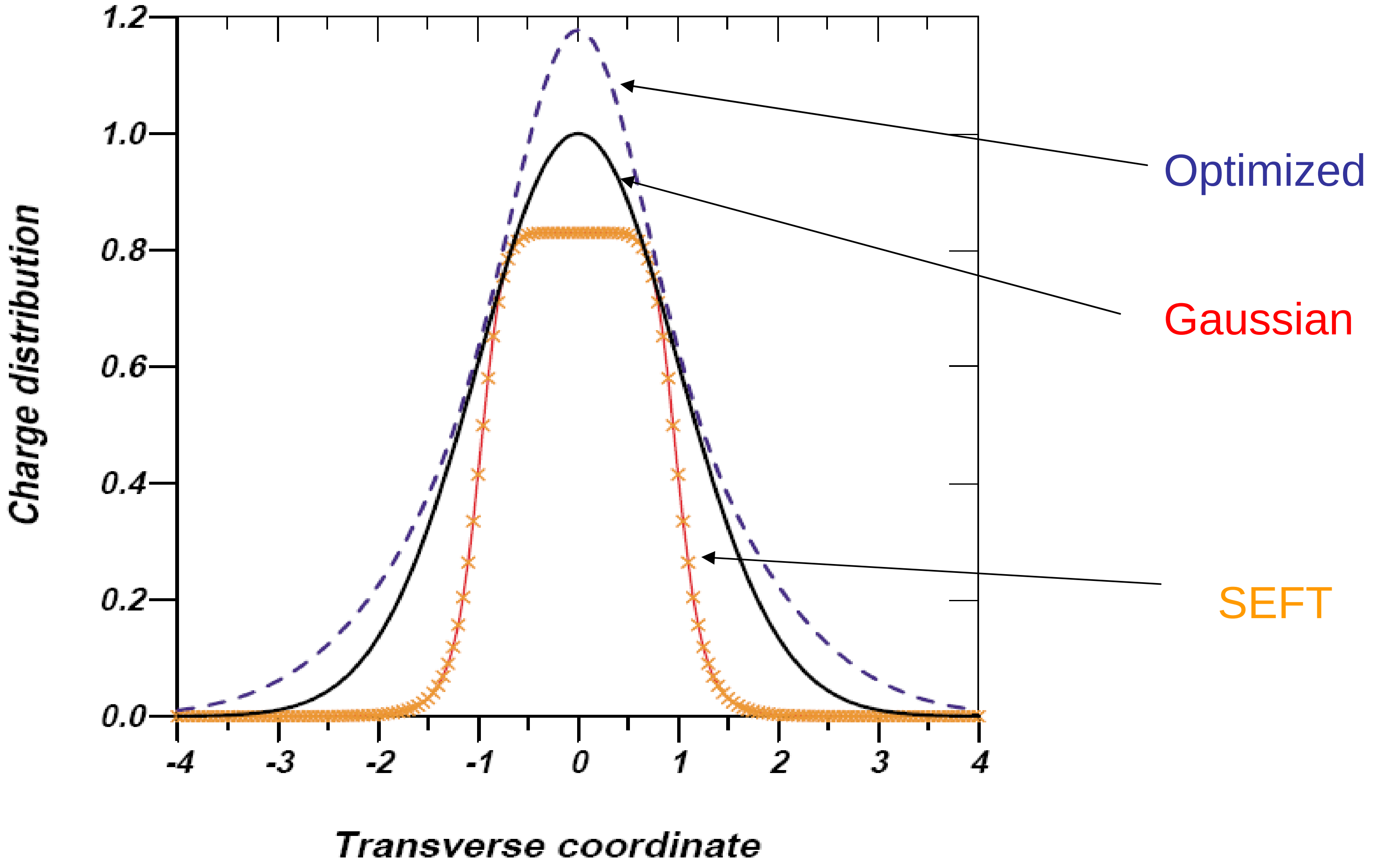
Test bench





E-beam profiles for BBCompensation

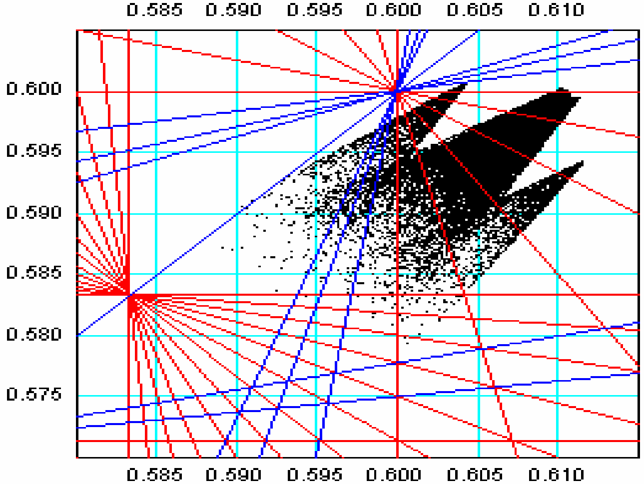
Considerations on compensation of beam-beam effects in the Tevatron with electron beams,
V. Shiltsev, V. Danilov, D. Finley, and A. Sery
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **2**, 071001 (1999)



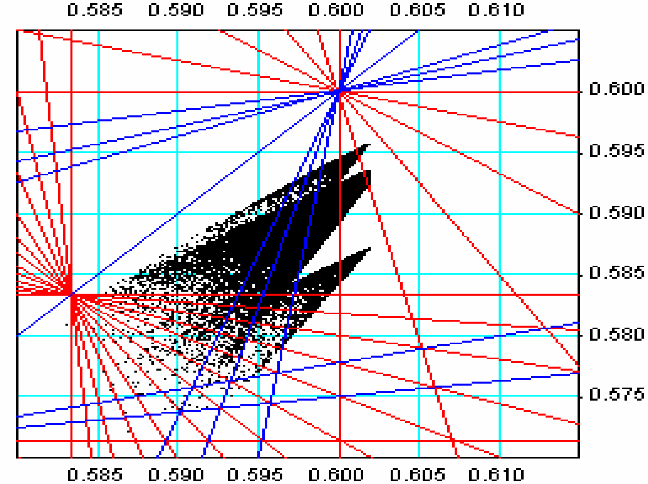
BBCompensation scenarios

Yu. Alexahin

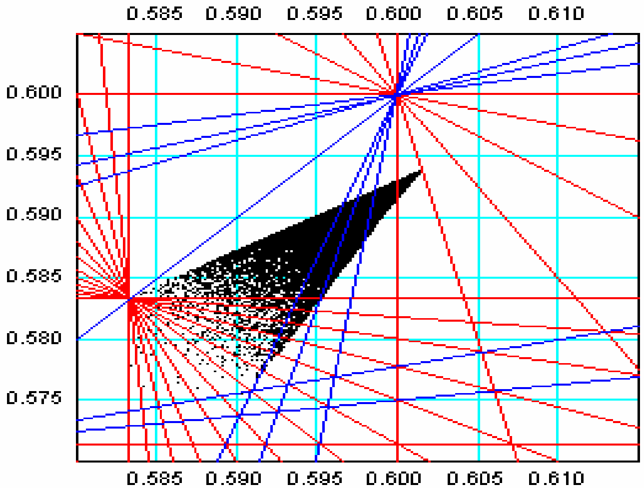
Run II goal



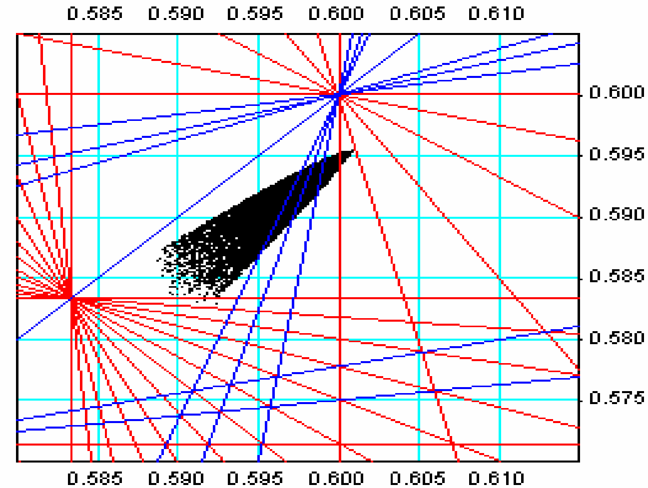
one TEL



two TELs



2 nonlinear TELs



P losses vs e-beam displacement