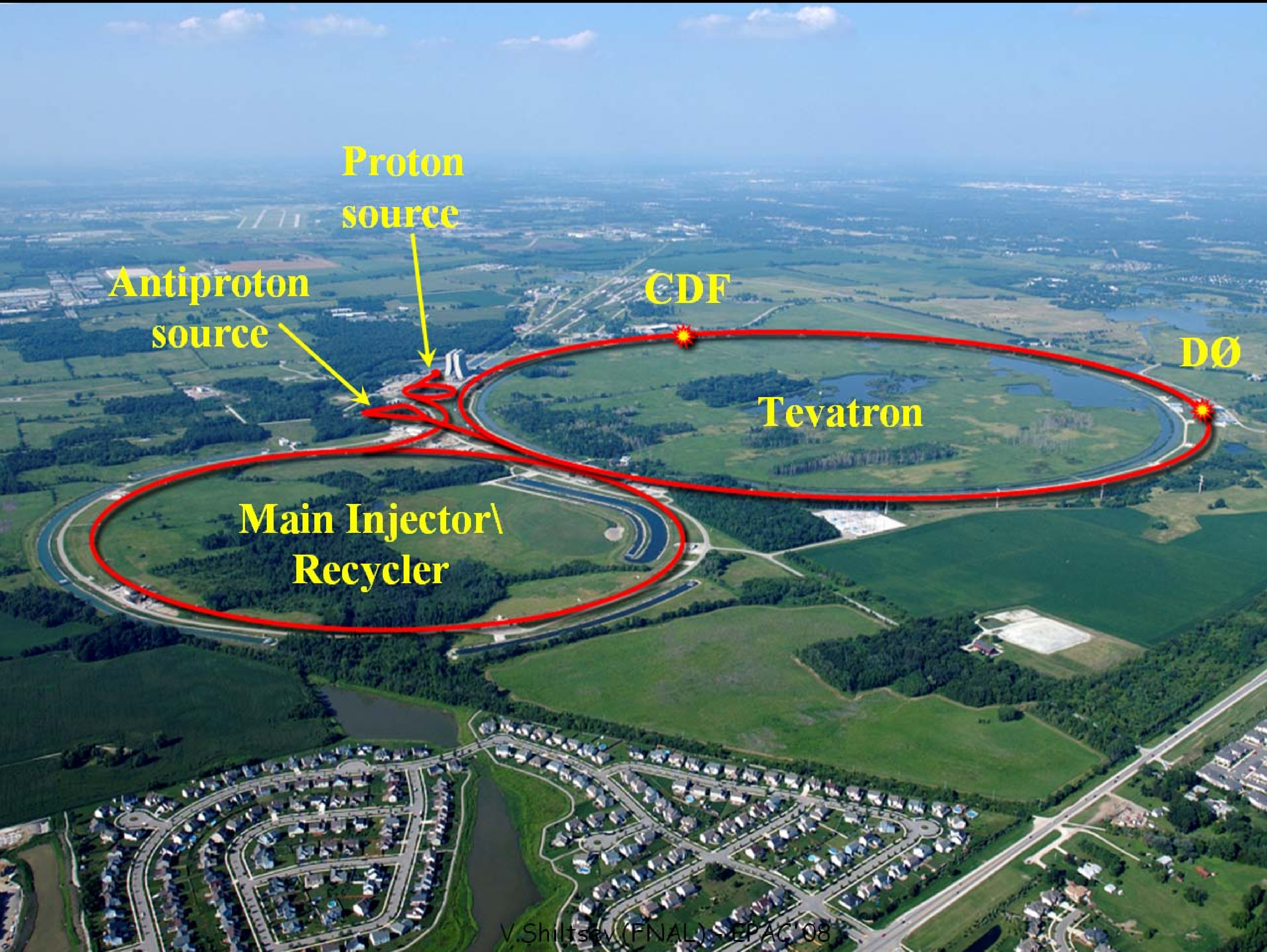

Proton
source
Antiproton
source
CDF
DØ
Tevatron
Main Injector\
Recycler

High Luminosity Operation, Beam-Beam Effects and Their Compensation in Tevatron

Vladimir Shiltsev

(thanks to C.Gattuso, K.Gollwitzer, V.Kamerdzhiev, R. Moore, V.Papadimitriou, W.Pellico, A.Valishev)

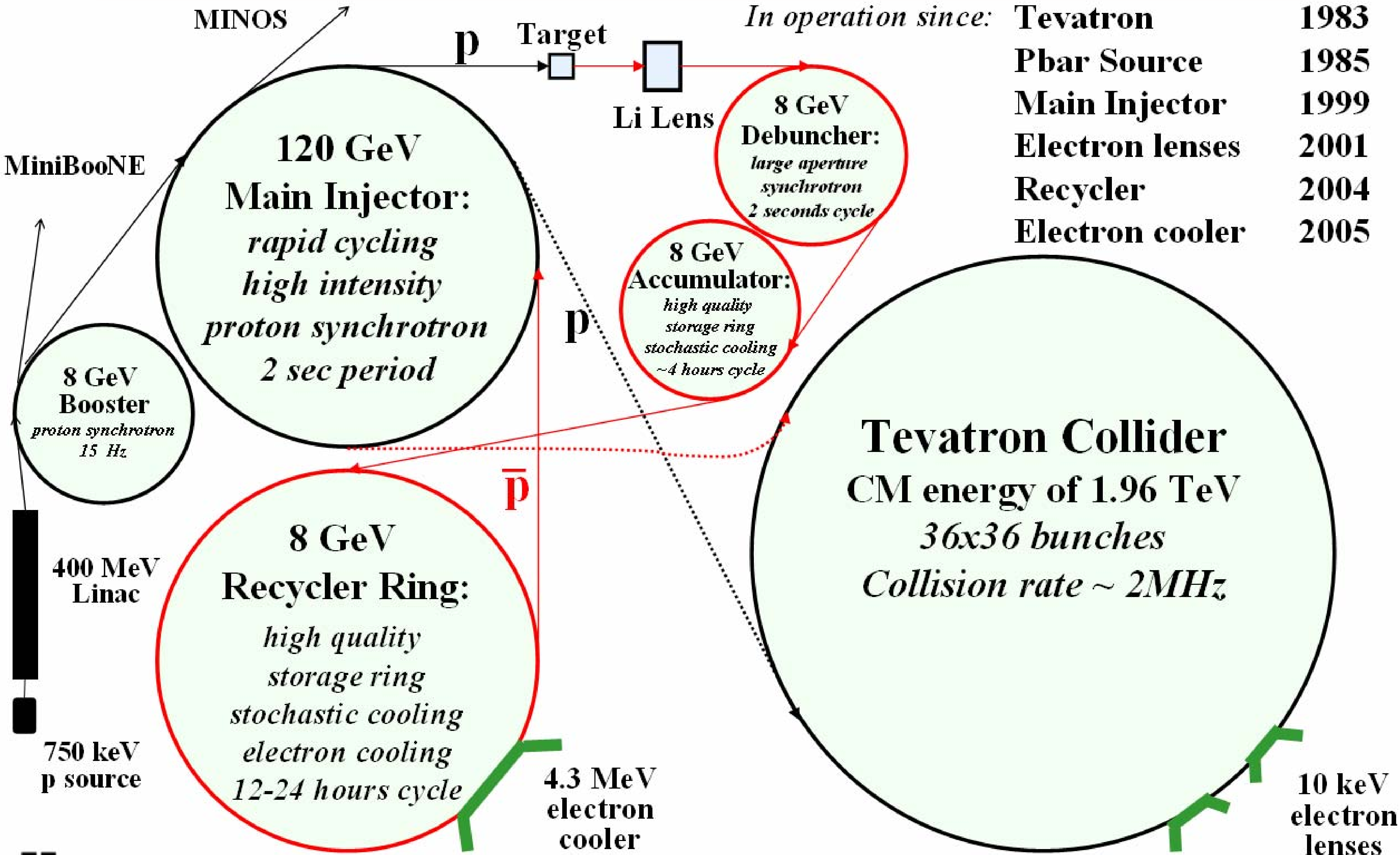
Fermi National Accelerator Laboratory

Accelerator Physics Center

Tevatron complex: 10 accelerators

In operation since:

Tevatron	1983
Pbar Source	1985
Main Injector	1999
Electron lenses	2001
Recycler	2004
Electron cooler	2005



Global View

- FNAL Accelerator Complex works in parallel for :
  - Tevatron Collider Run II (CDF and D0 experiments)
  - Neutrino program (8 GeV and 120 GeV protons on target)
- Collider Run II will definitely run thru FY09 (09/30/09)
  - FY2010 Run is very probable but not approved yet
- After the end of the Tevatron Collider Run II:
  - Tevatron to be decommiss'd and conserved (kept at LN temp)
  - Neutrino experiments will continue (350kW→700kW @120 GeV)
  - New experiments to start (e.g., NoVA, μ2e, etc)
- Fermilab's next big thing - "Project X"
  - High Intensity 1.3 GHz SC RF 8 GeV proton linac
  - The linac, Recycler and Main Injector to be employed for 8 GeV and 120 GeV fixed target experiments (ν's, K's, μ's)
  - Construction to start in ~2012

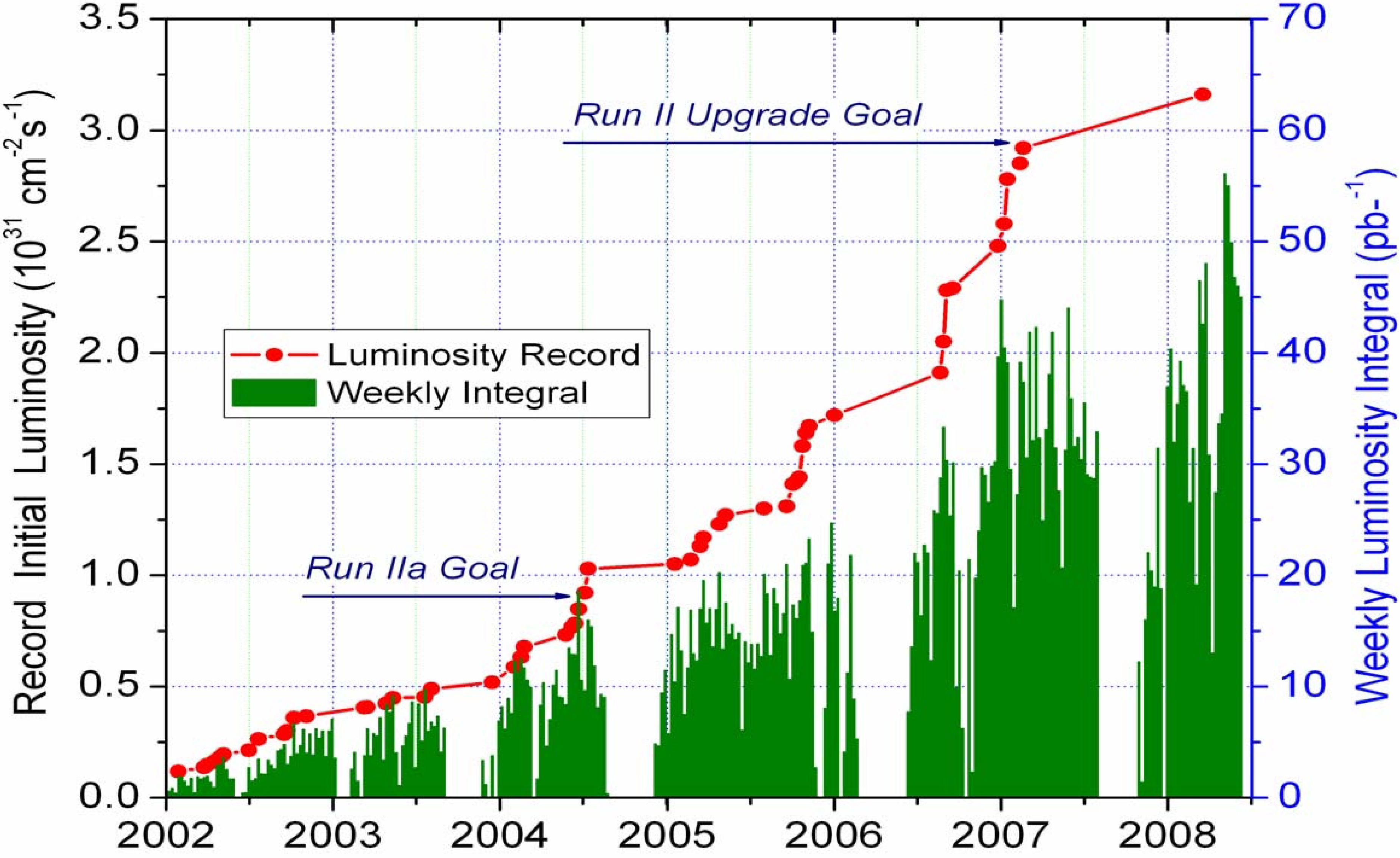
Tevatron Luminosity

- Maximum Initial Luminosity Achieved:

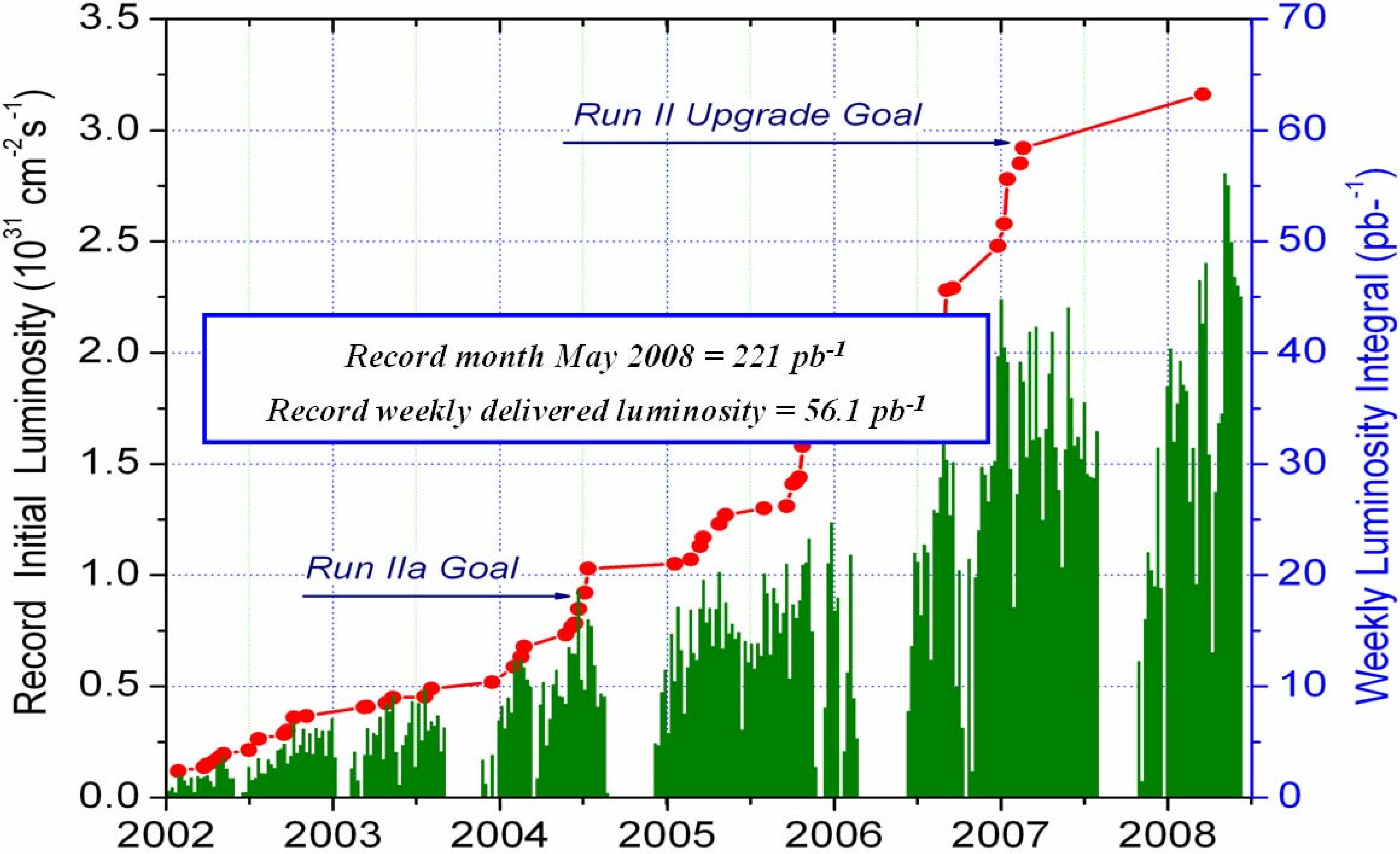
$$\pi \times 10^{32}\ cm^{-2} s^{-1}$$

- This is record high luminosity for hadron colliders
- This is above Run II Upgrade goal of 2.9e32
- This allows us to integrate luminosity fast

Tevatron Peak Luminosity



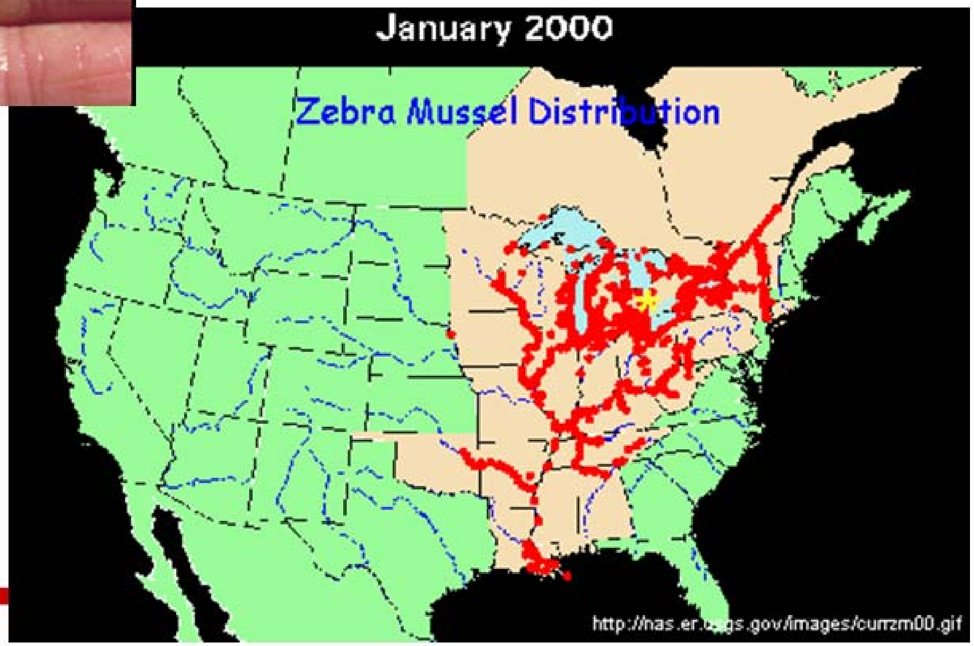
Tevatron Peak Luminosity



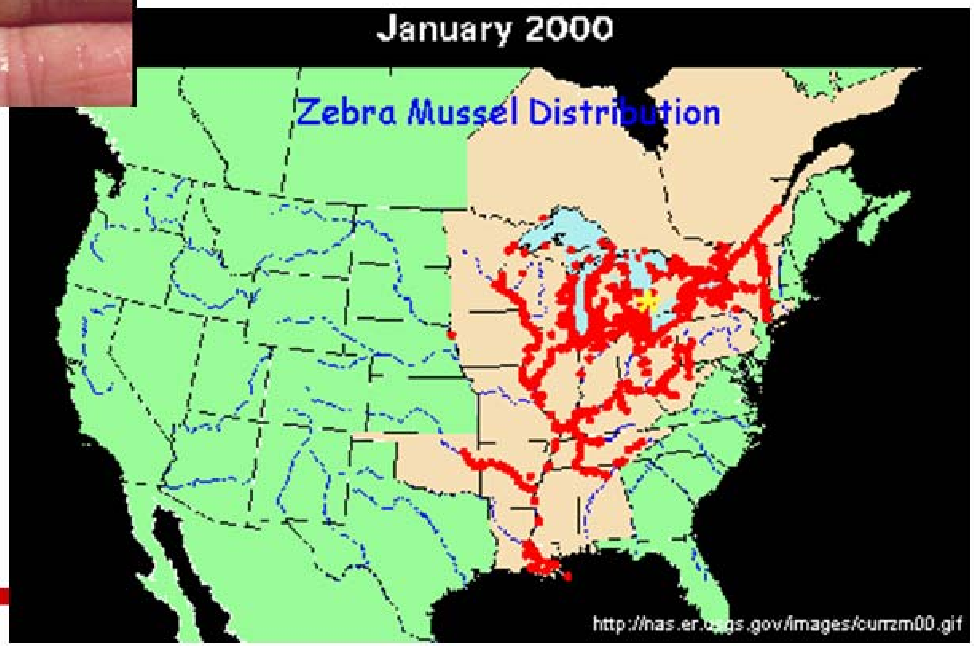
Very Good Progress Since 2007

- *No big upgrades, progress is due to operational tune-ups*
- Still, we've got (compared to Summer 2007)
  - + 8% in max peak luminosity (2.92e32 → 3.15e32)
  - +24% in max weekly luminosity (45 pb-1 → 56 pb-1)
  - +25% in avg weekly lumi (32pb-1 → 40 pb-1 in 2008)
  - +17% in peak pbar production rate (23e10/hr → 27e10/hr)
  - +14% in average pbar production (19.3e10/hr → 22.1e10/hr)
- Why:
  - Optimization of pbar stoch.cooling systems in Debuncher & AA
  - Faster pbar transfers from Accum to Recycler (30 → 2 min)
  - New RR WP → lifetime and mining efficiency
  - New MI collimators and faster Booster m-pole correctors
  - Shot set up time 2 hr 45 min → 1 hr 45 min
  - Tevatron optics tune up (β^*, D^*) and orbit stabilization
  - A lot of attention to (preventive) maintenance and uptime

Collider Natural Predators: *Dreissena polymorpha*

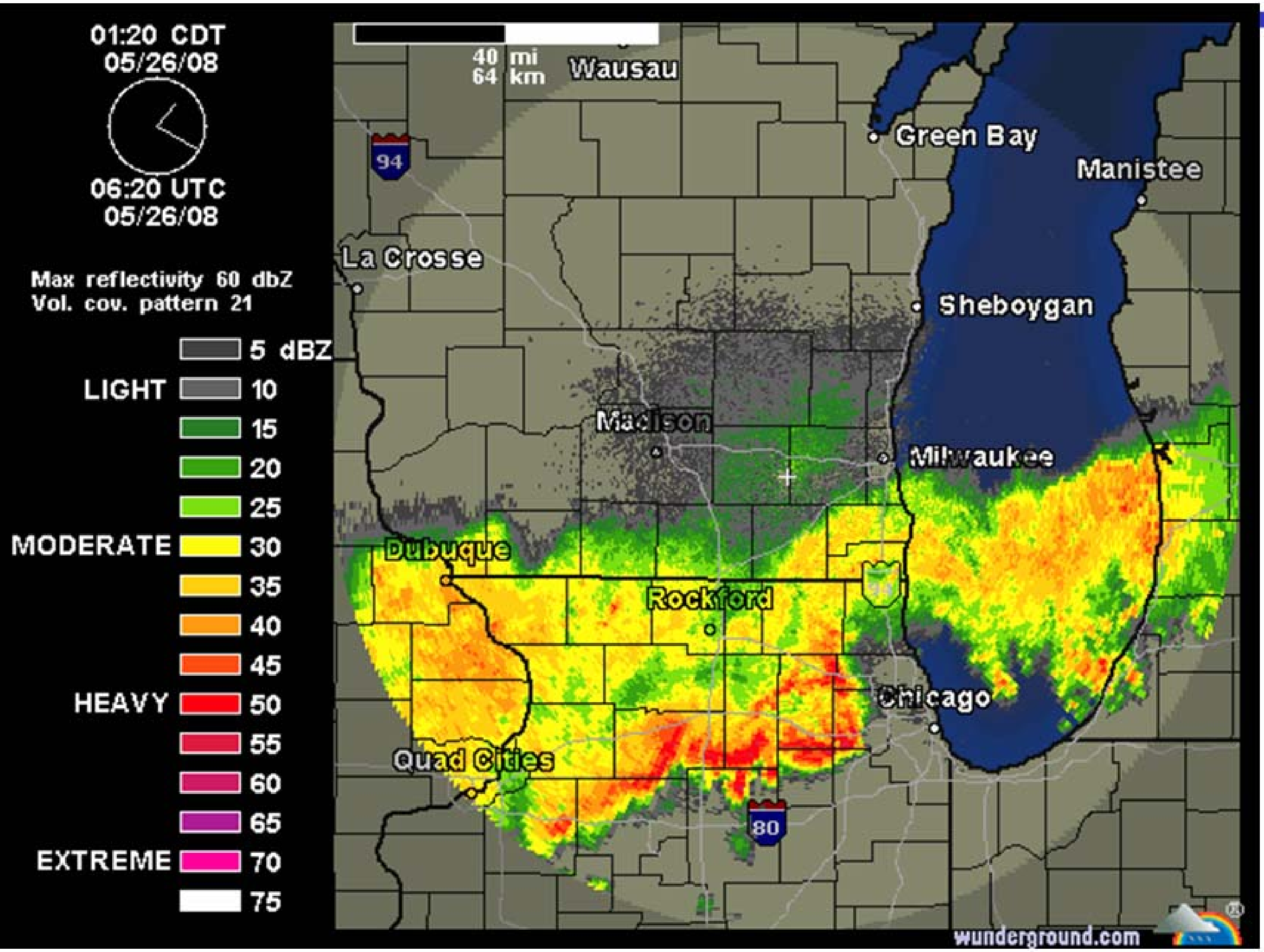


Collider Natural Predators: *Dreissena polymorpha*



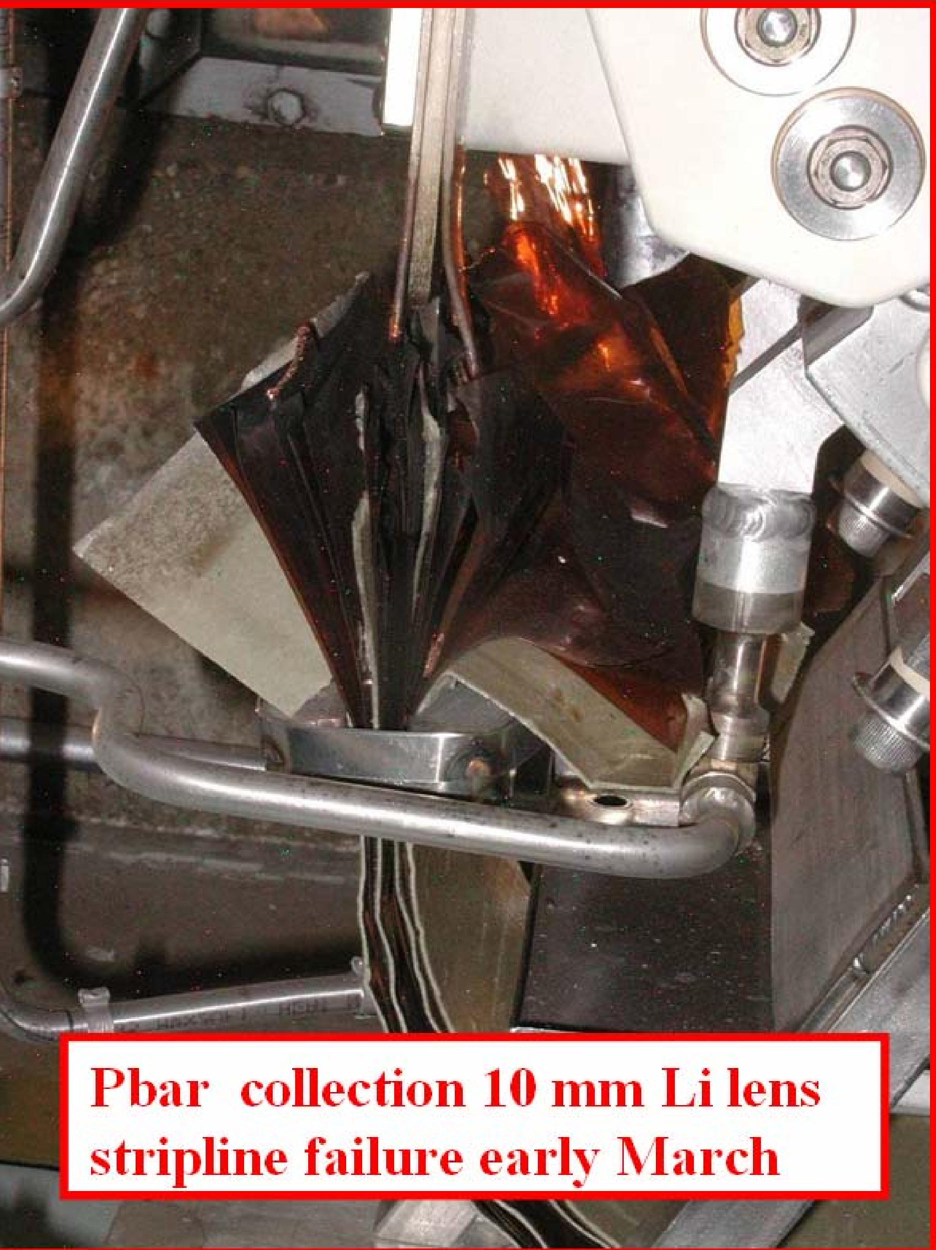
Main Injector heat exchanger pipe clogged by mussels

Collider Natural Predators: Weather



Collider Natural Predators: Weather

Collider Natural Predators: Complexity

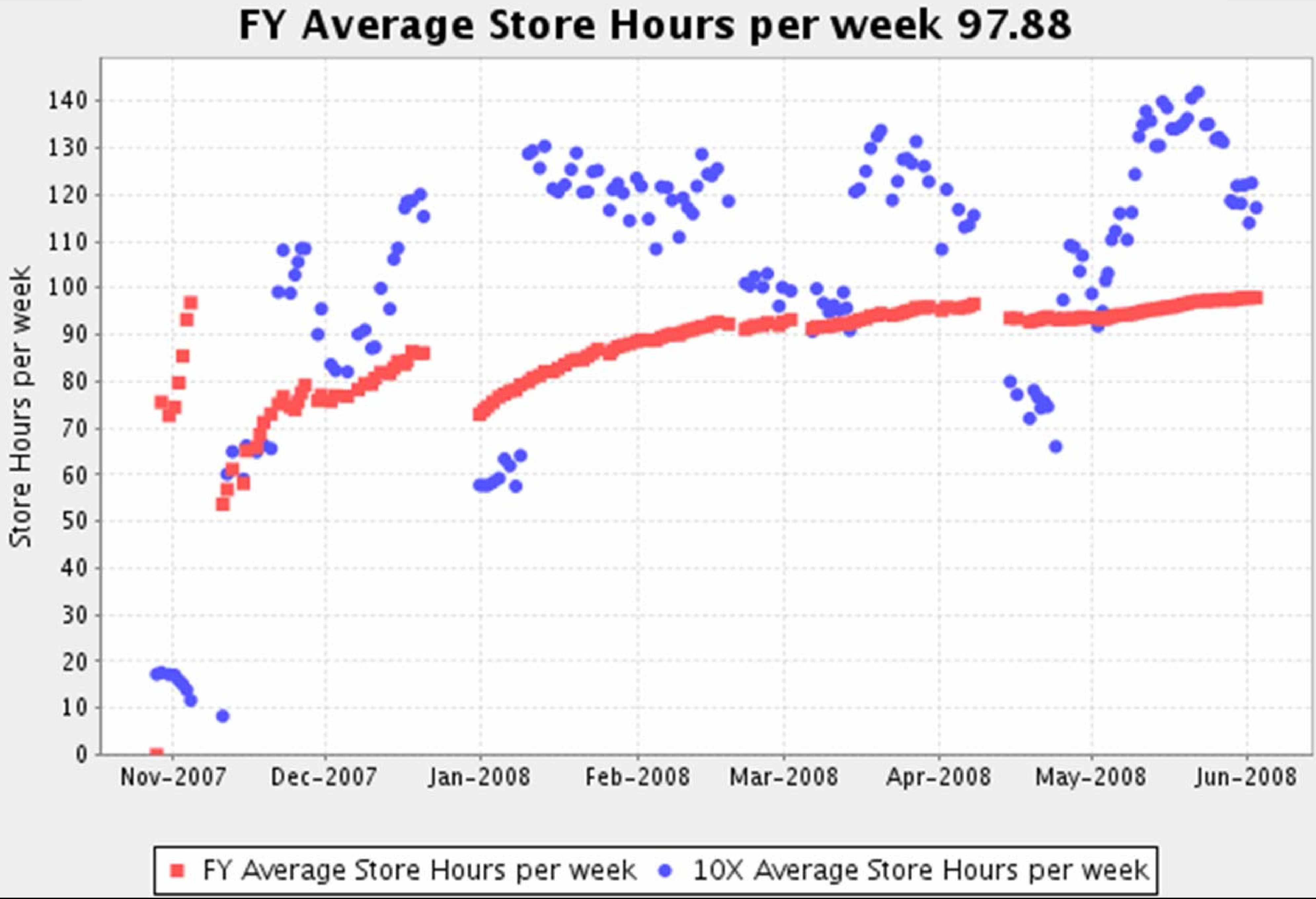


Collider Natural Predators: Complexity

Pbar collection 10 m
stripline failure early

Tevatron D33 dipole magnet
lost insulating vacuum & frosted

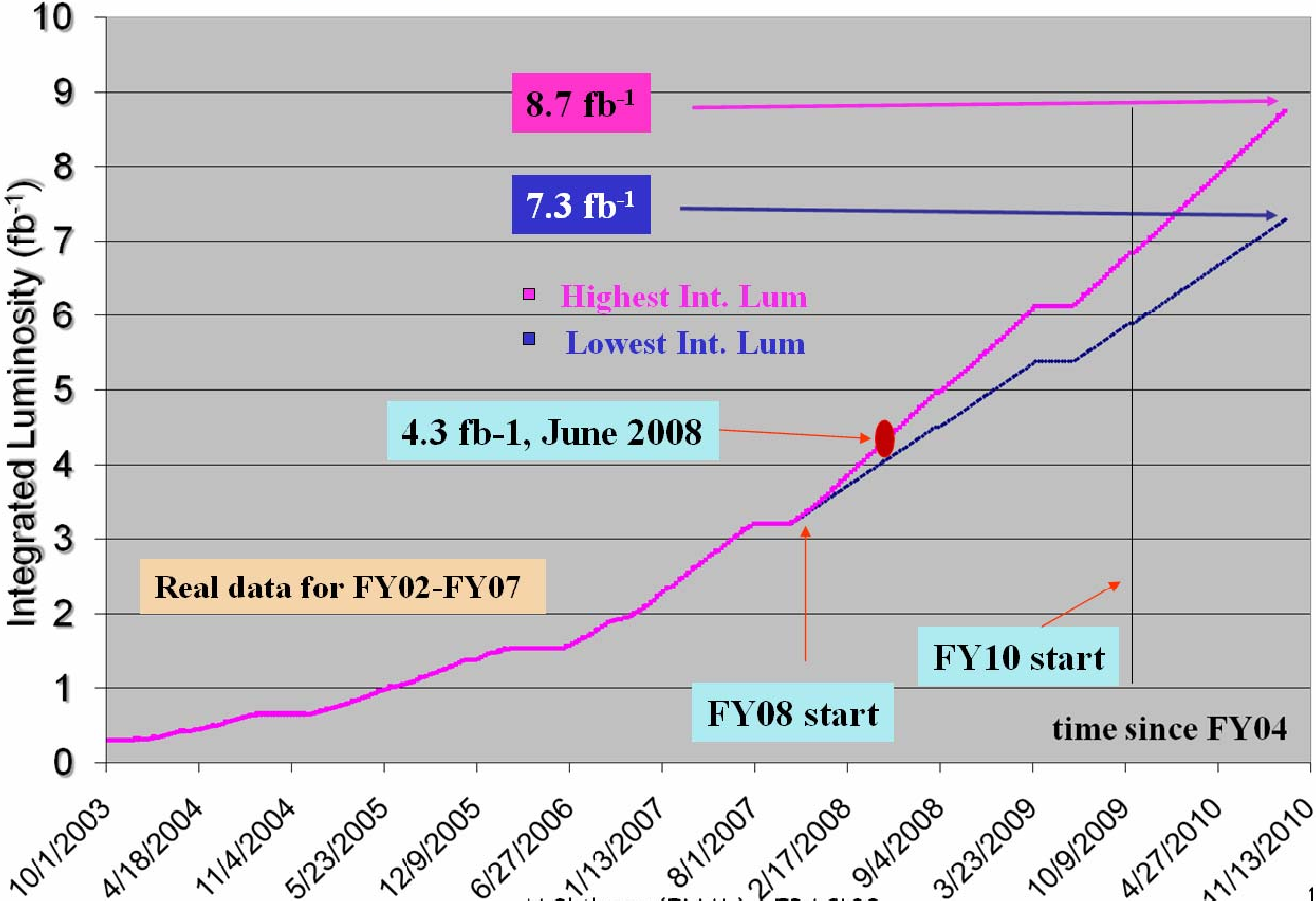
Collision Time → 100 Hours a Week



Planning Ahead: get to 60-70 pb-1/wk

- commission of individual band equalizers in the pbar stochastic cooling systems of the Debuncher and the Accumulator rings
- increase of the proton beam brightness by scraping 8 GeV protons in the Main Injector by recently installed collimators
- complete installation of fast corrector magnets in the Booster together with commissioning of transverse and longitudinal dampers to keep beam stable while crossing transition energy
- Optimize further the operation strategy - e.g. Recycler antiproton stash size for the Tevatron shots, the store length, etc
- better proton optics matching during injection in the Tevatron
- faster loading of protons into the Tevatron by injecting them in batches (of 2)
- make the beam-beam compensation (BBC) by the Tevatron Electron Lenses (TEL) operational

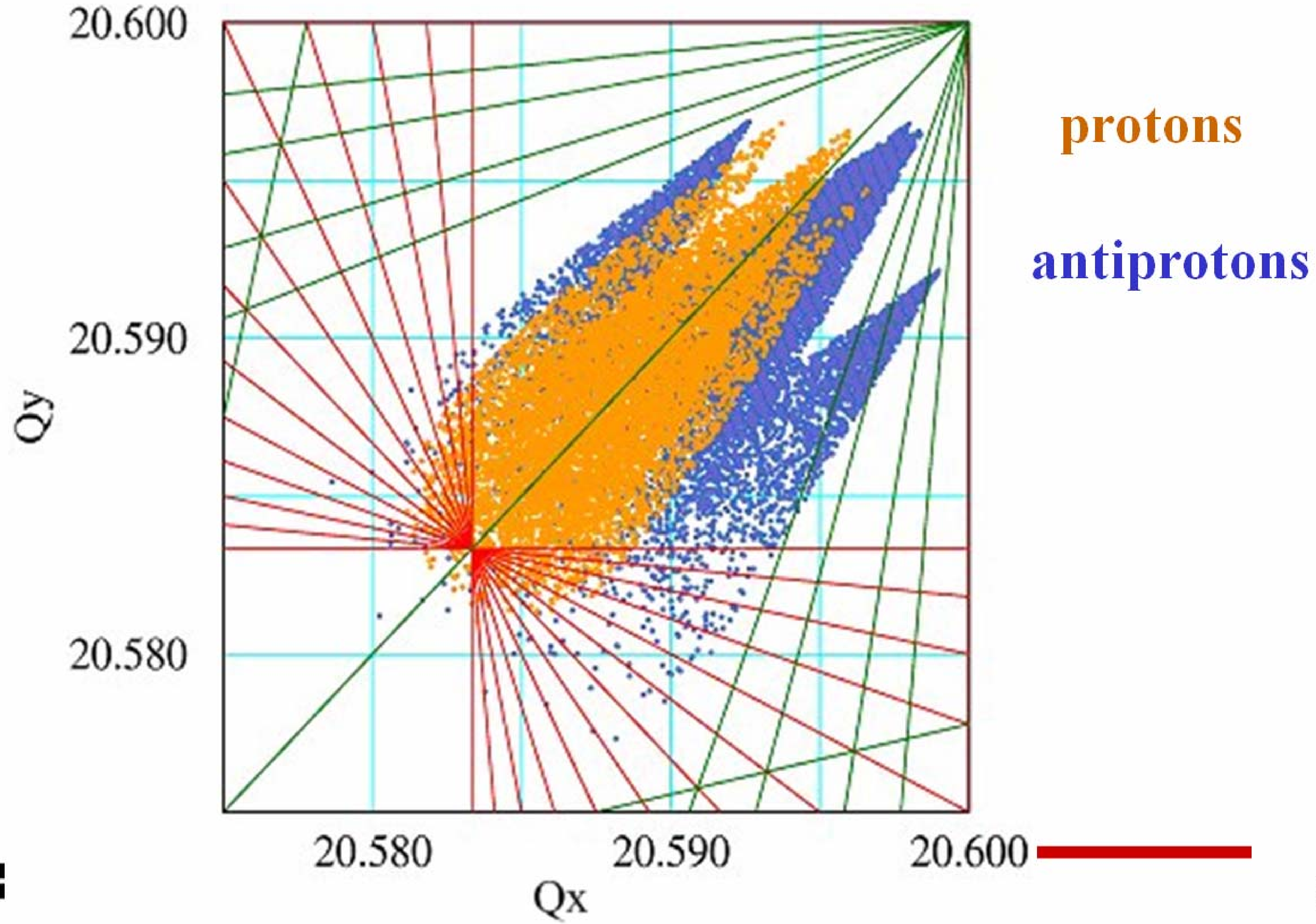
Luminosity projections for Tevatron Run II (fb-1)



Beam-Beam Effects in Tevatron

- Beam-beam interactions affect beams at all stages resulting in 20-30% reduction of luminosity integral:
  - Pbar loss of ~2% at 150 GeV and 2% ramp and low-beta squeeze
  - Proton loss of ~5% at 150 and ~5% in ramp and squeeze
  - Luminosity decays 5-15% faster (mostly due to p-loss)
- The effect in collisions is a mix of long-range and head-on
  - Record high beam-beam parameter ξ(2 IPs) ~0.024
  - ξ is about the same for protons and antiprotons
  - Extreme sensitivity to many things:
    - Tunes, optics, chromaticities, coupling
    - Bunch intensities, emittances, ratio of p/a emittances, (dp/p)
- Very good understanding of the effects
  - Sophisticated Data Analysis
  - Trusted Numerical Tracking tools
  - Please come to Sasha Valishev's talk Thur. morning THYM01

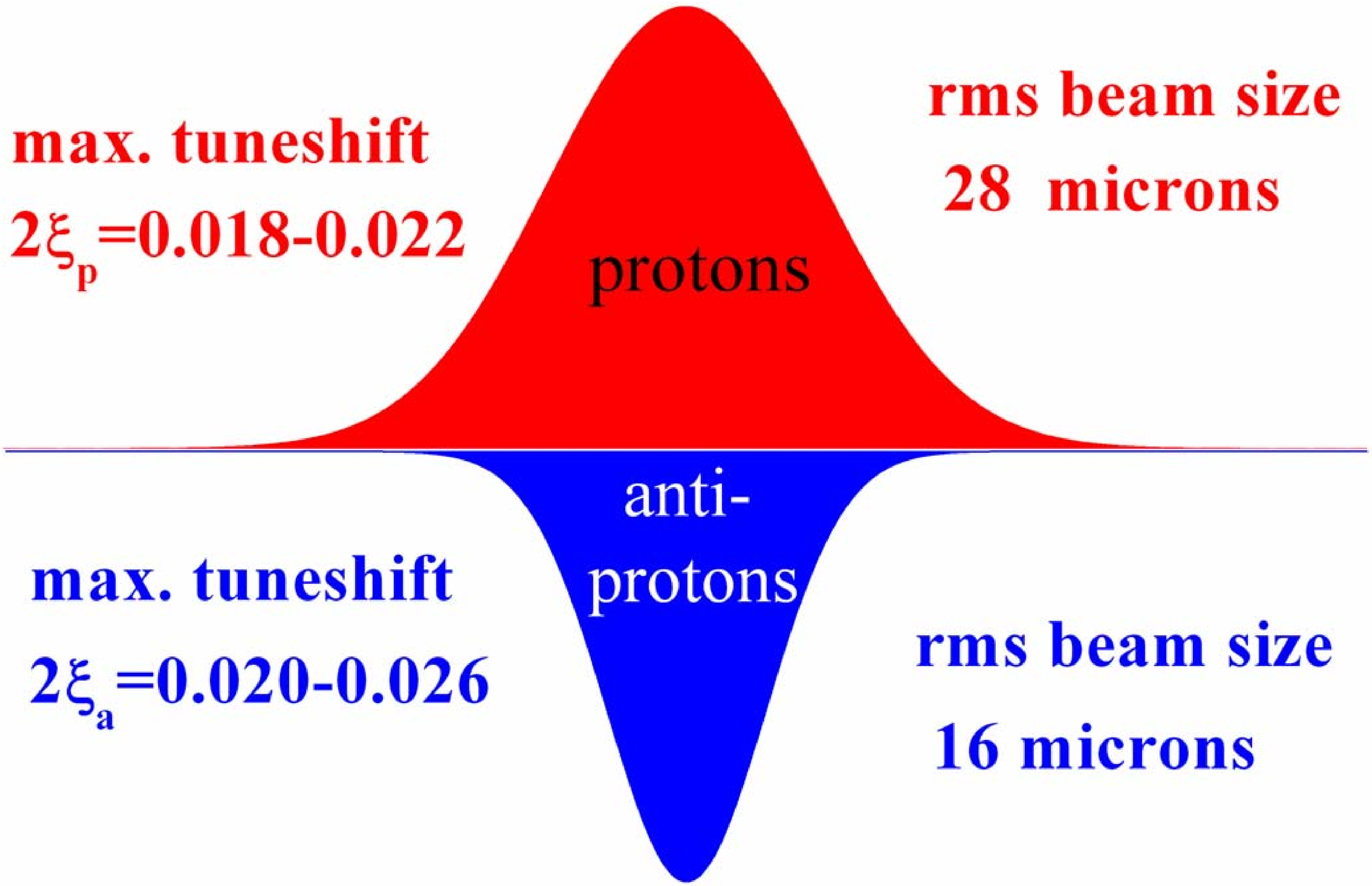
Synopsis: Beam-Beam Tune Footprint



Head-On Beam-Beam Collisions

max. tuneshift
$2\xi_p$=0.018-0.022

rms beam size
28 microns

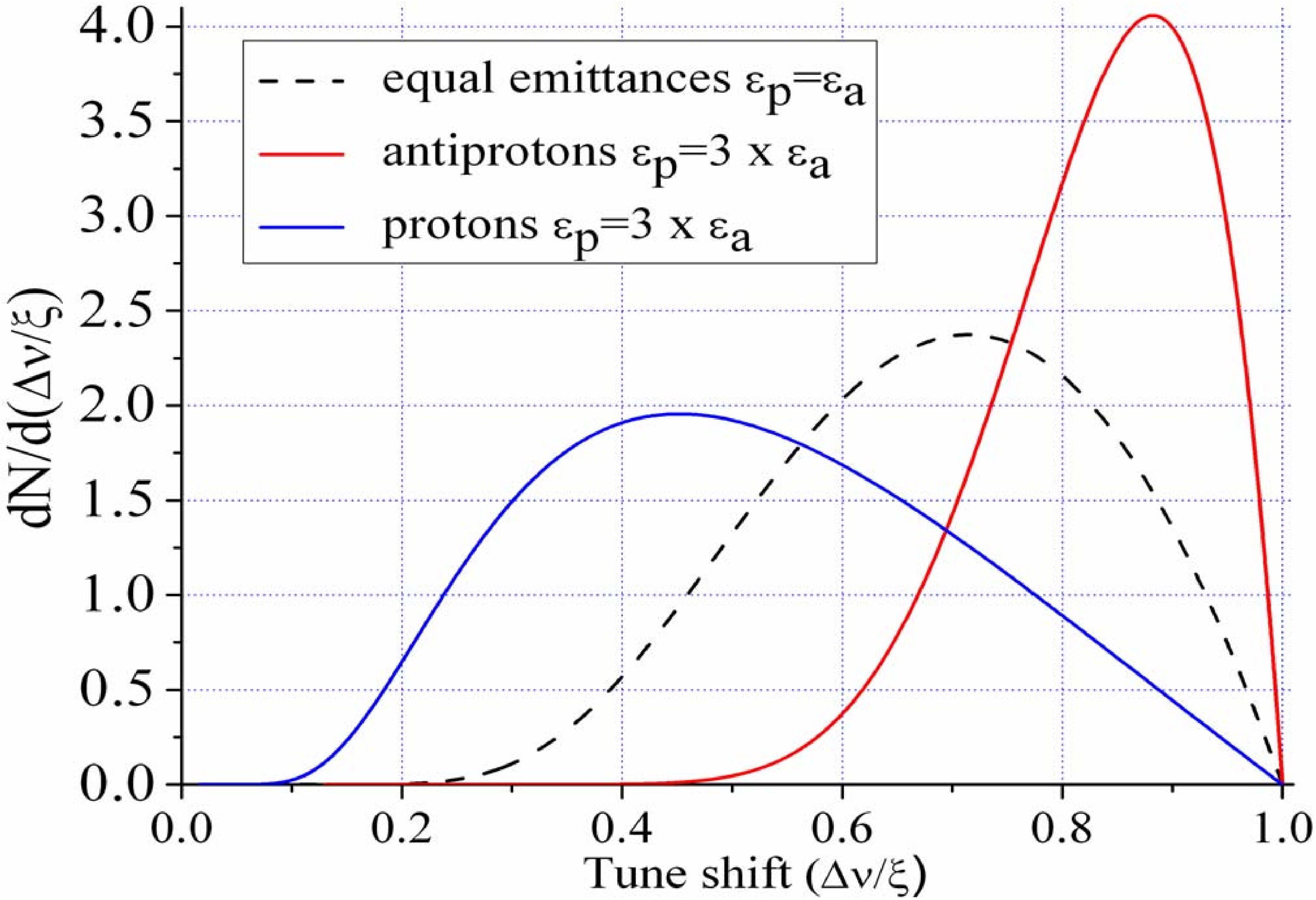


max. tuneshift
$2\xi_a$=0.020-0.026

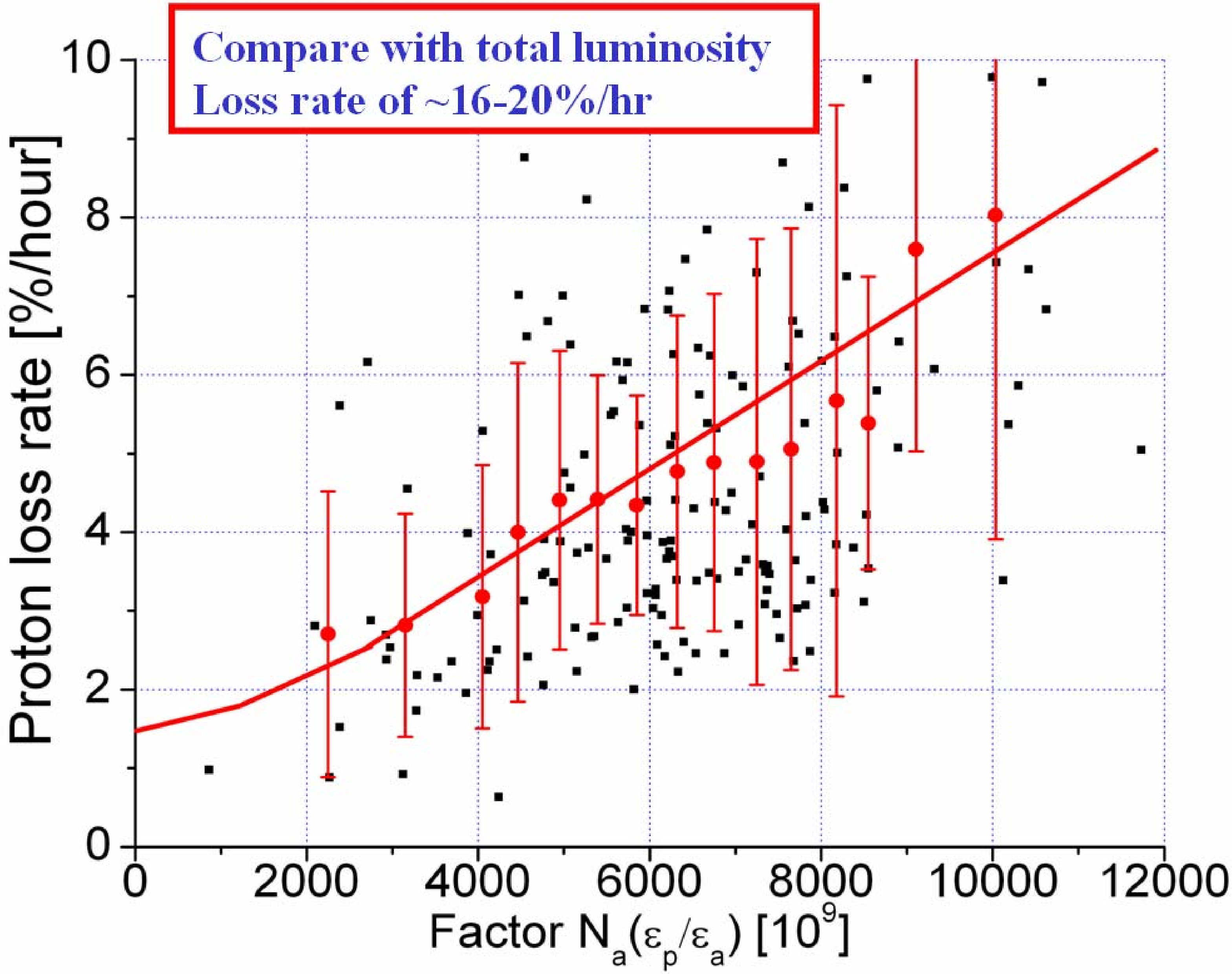
rms beam size
16 microns

emittance ratio (ε_p/ε_a) ~3

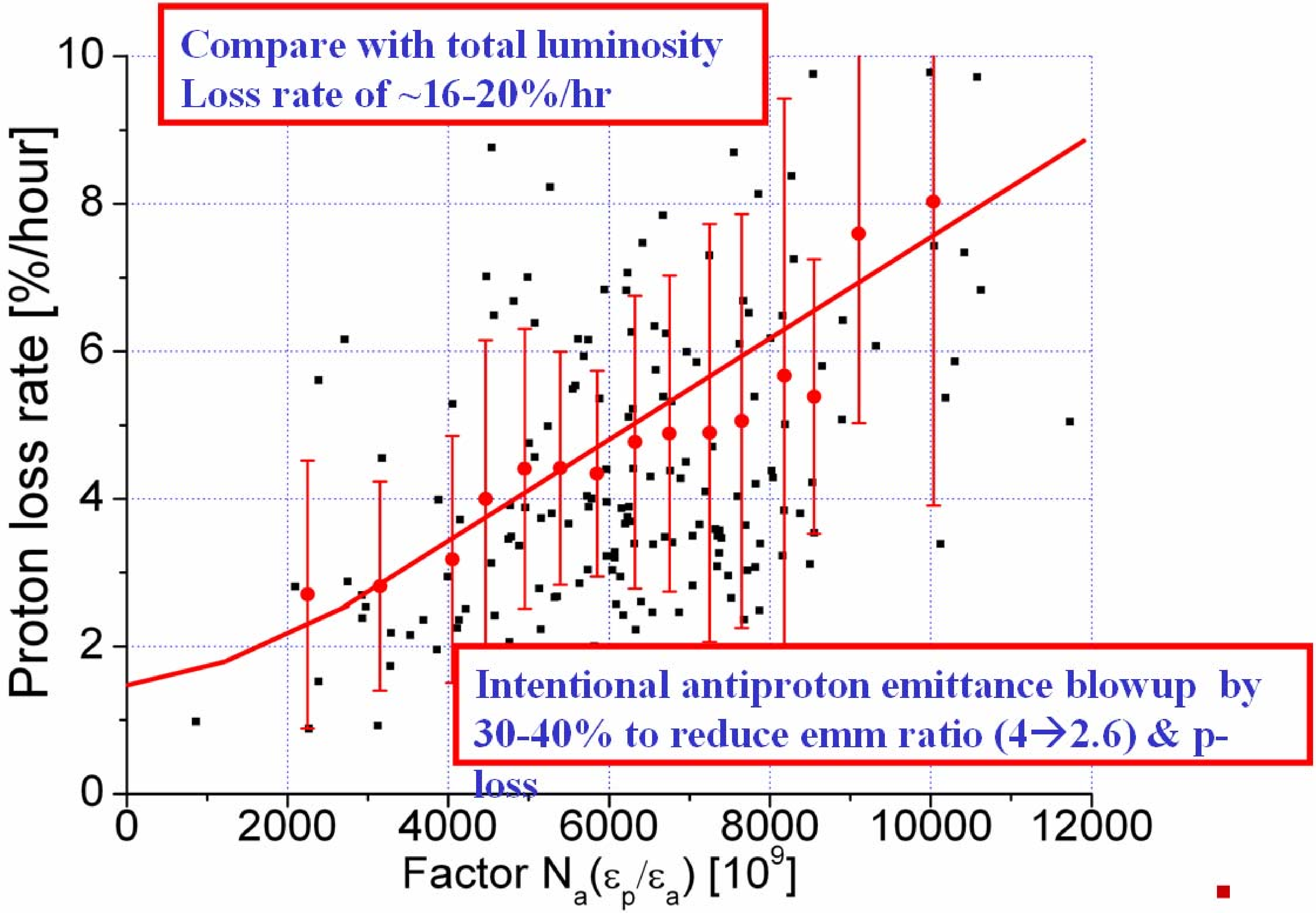
Tune Distributions are Very Different



Very High Proton Losses Early in Stores



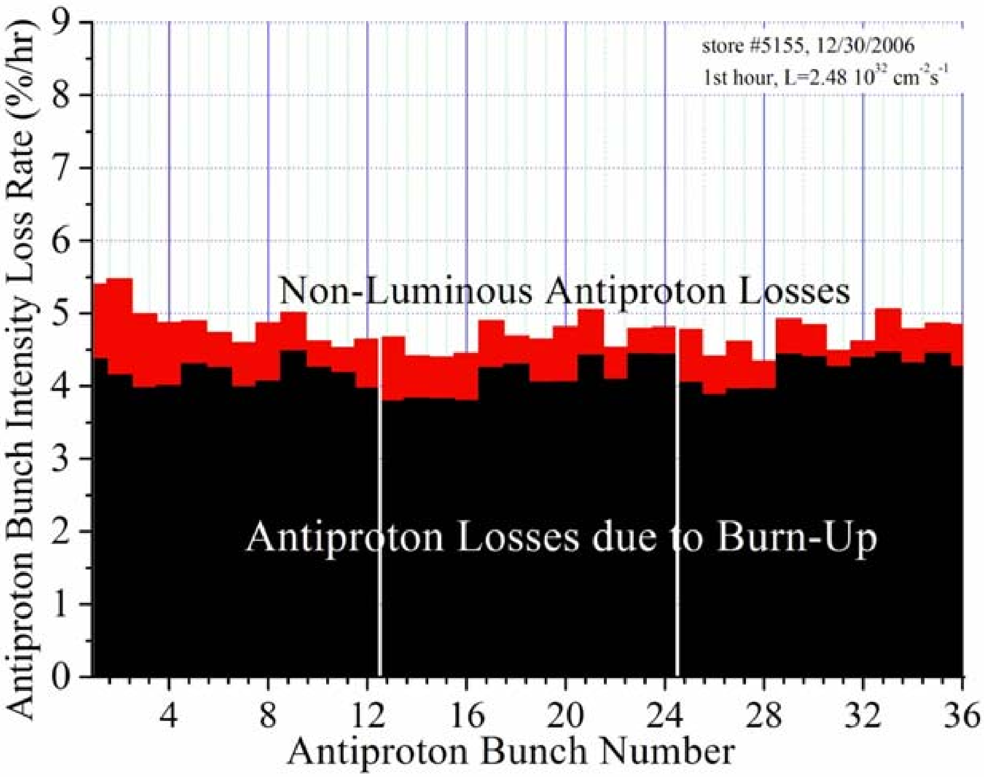
Very High Proton Losses Early in Stores

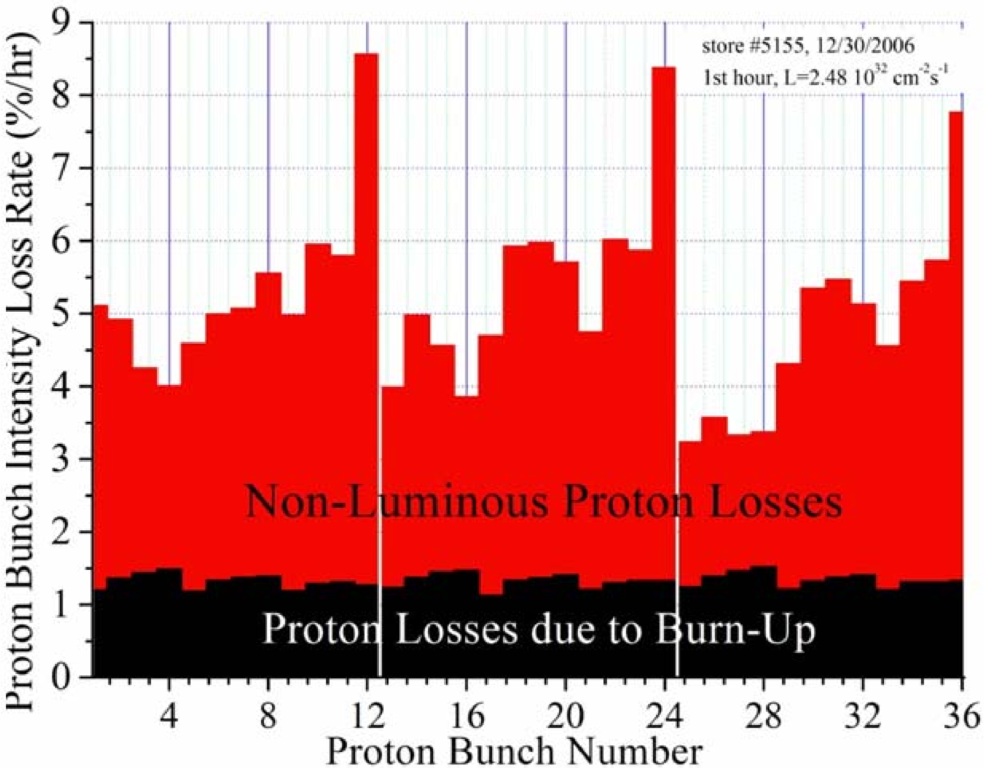


Losses due to beam-beam interactions

Antiprotons 980 GeV :
$\xi_{max}=+(0.020\text{-}0.024)$

Protons 980 GeV :
$\xi_{max}=+(0.016\text{-}0.024)$



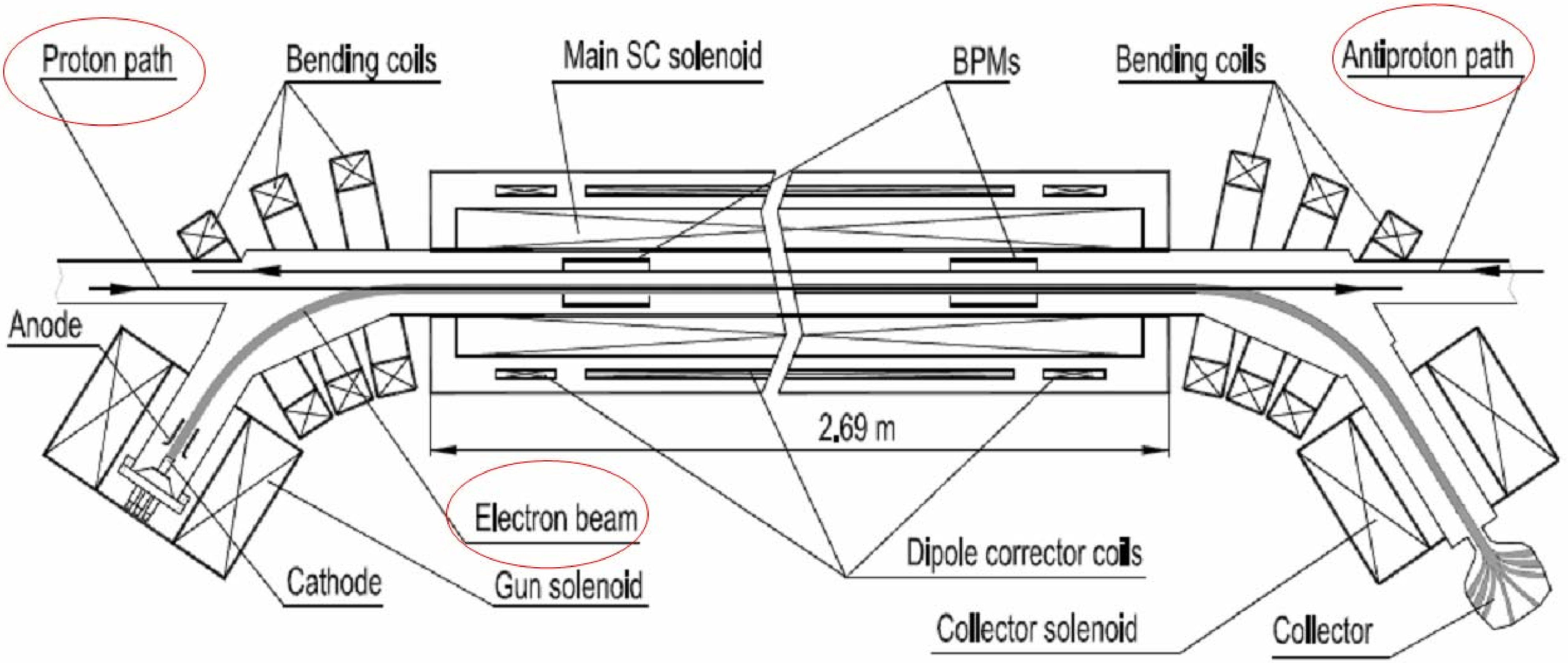


Beam-Beam Compensation with Tevatron Electron Lenses

What is Electron Lens?

~4 mm dia 2 m long very straight beam of ~10kV

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

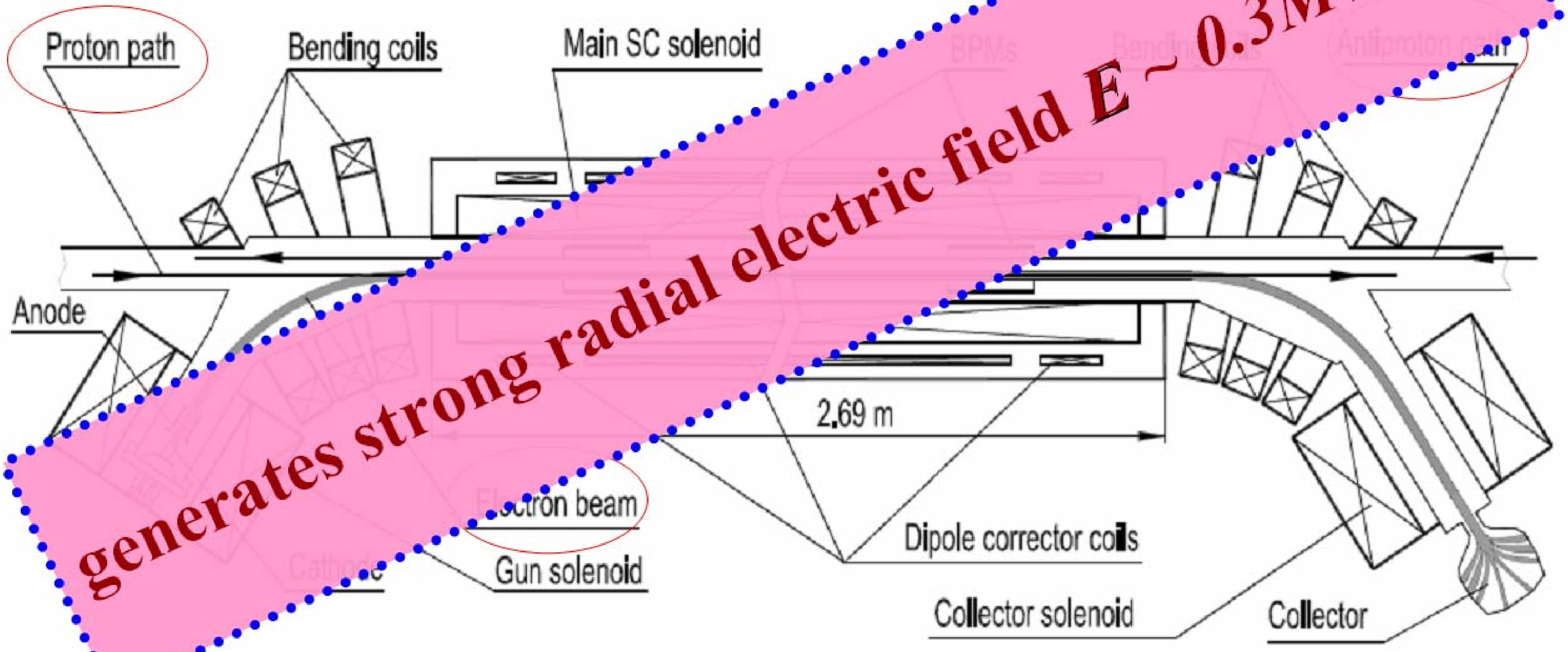


What is Electron Lens?

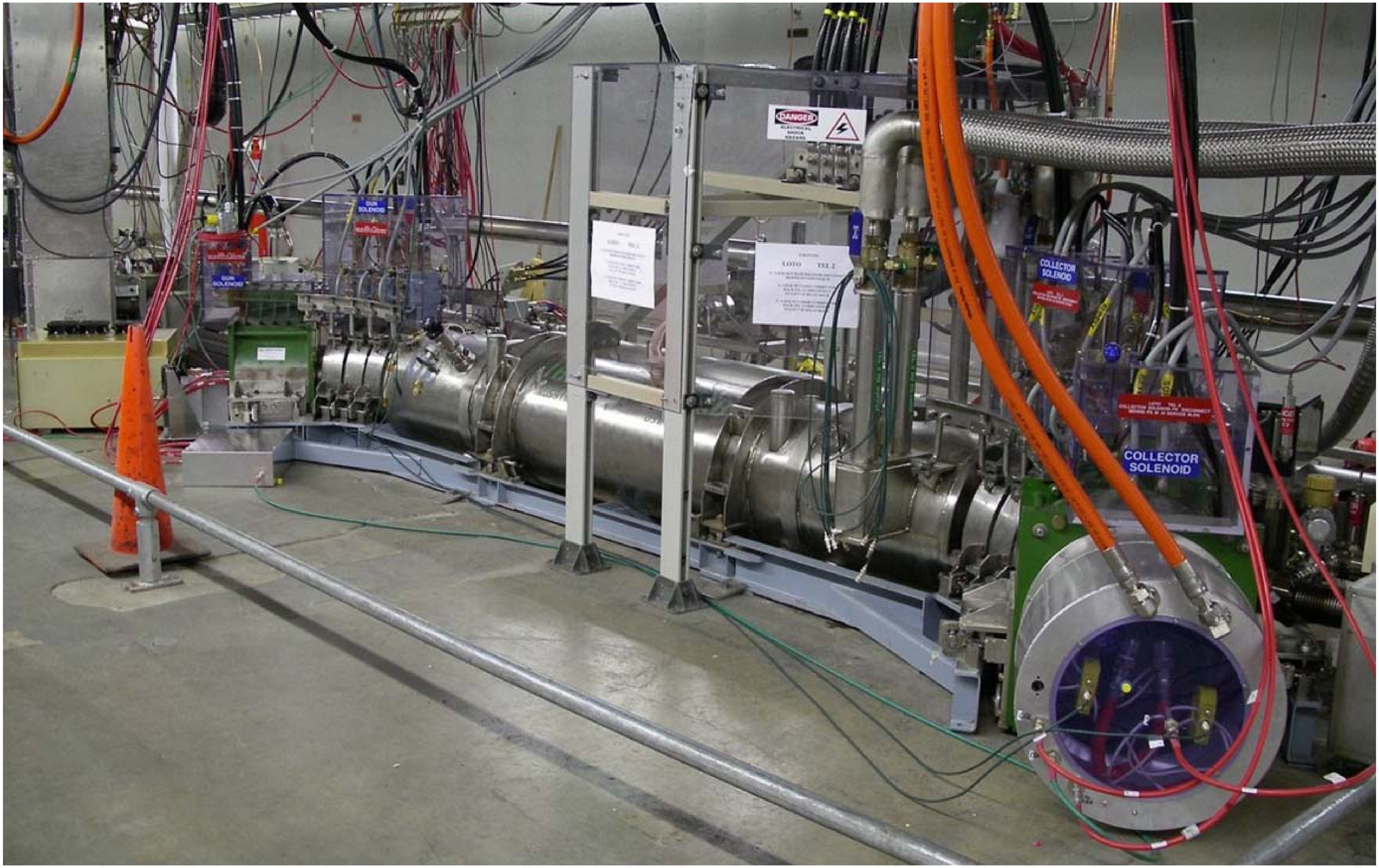
~4 mm dia 2 m long very straight beam of ~10kV

~1A electrons (~10[12]) immersed in 3T solenoid

generates strong radial electric field $E \sim 0.3MV/m$



TEL2 In The Tunnel (A0)

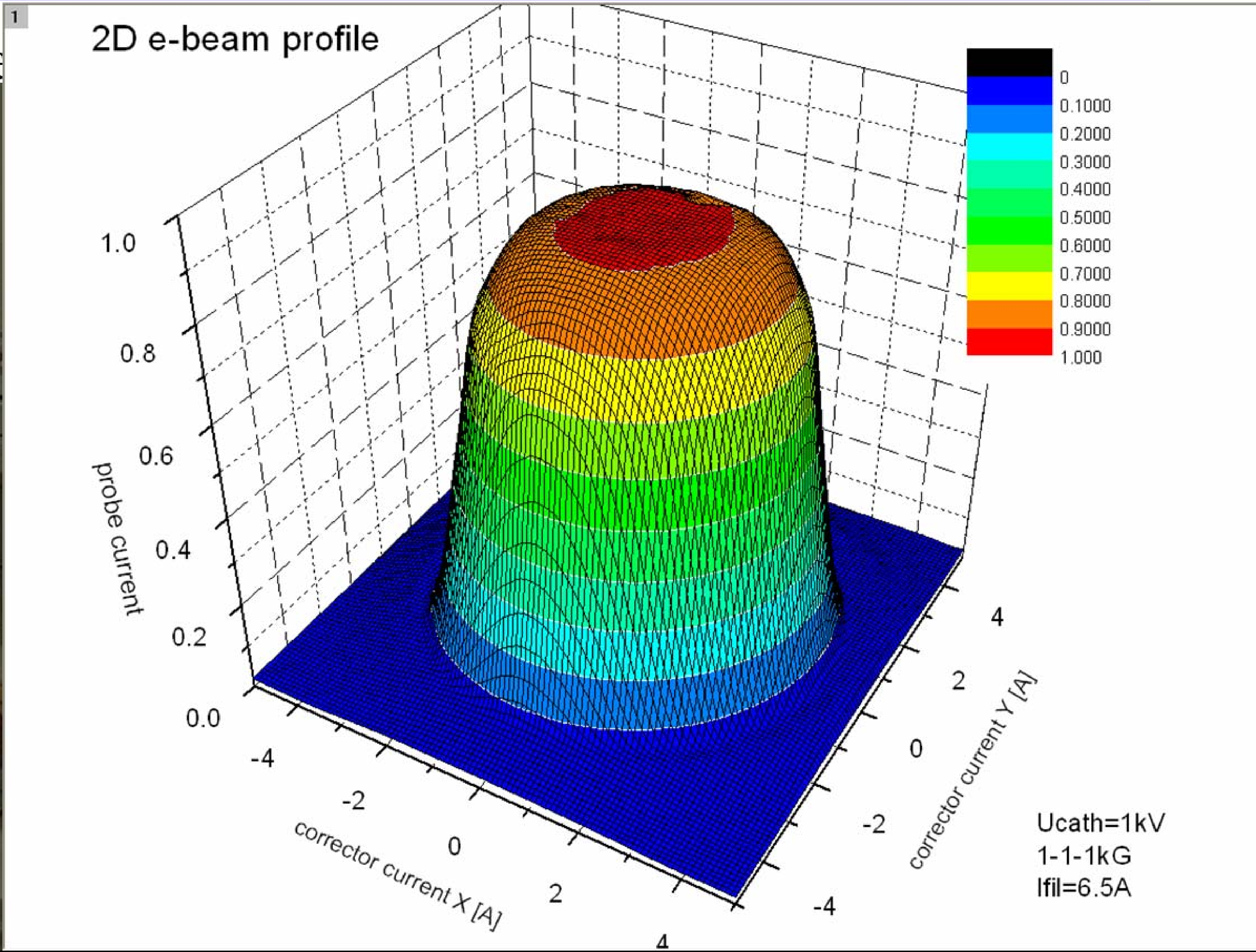


TEL Electron Beam

Thermionic gun

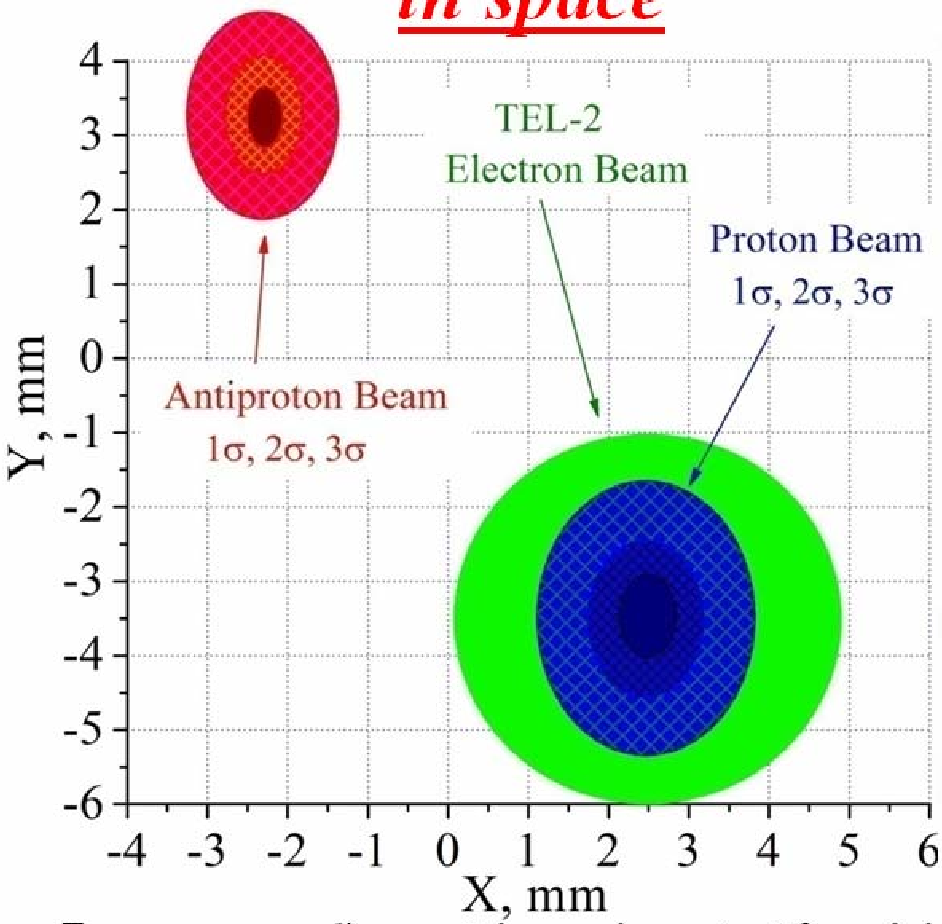
TEL Electron Beam

The

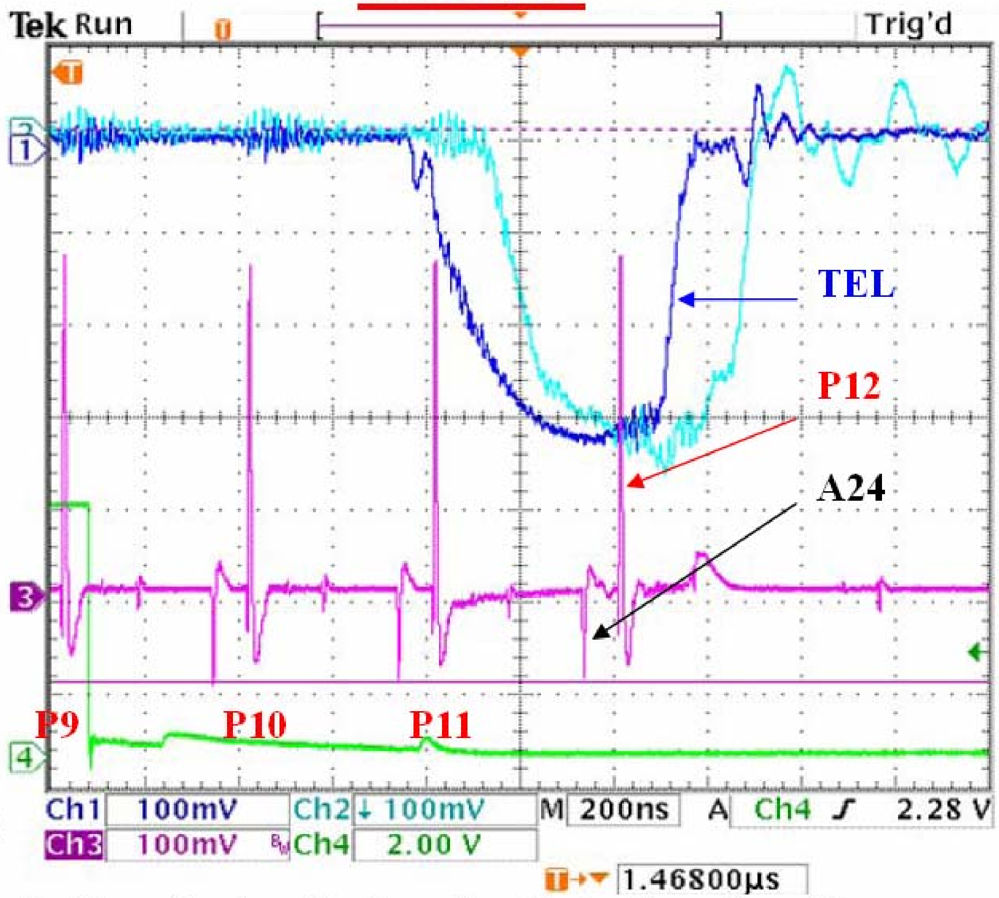


TEL e-beam aligned and timed on protons

in space

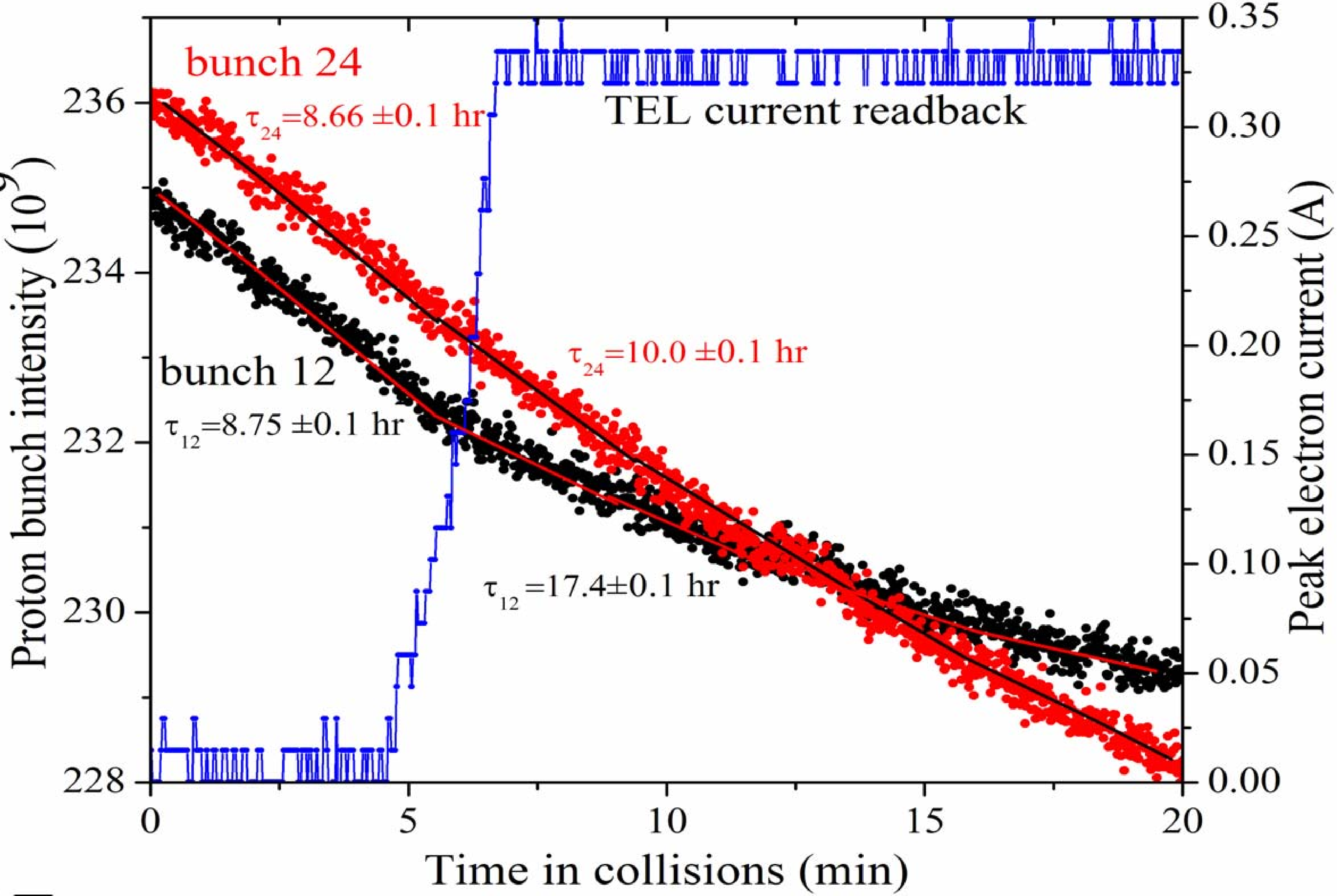


in time

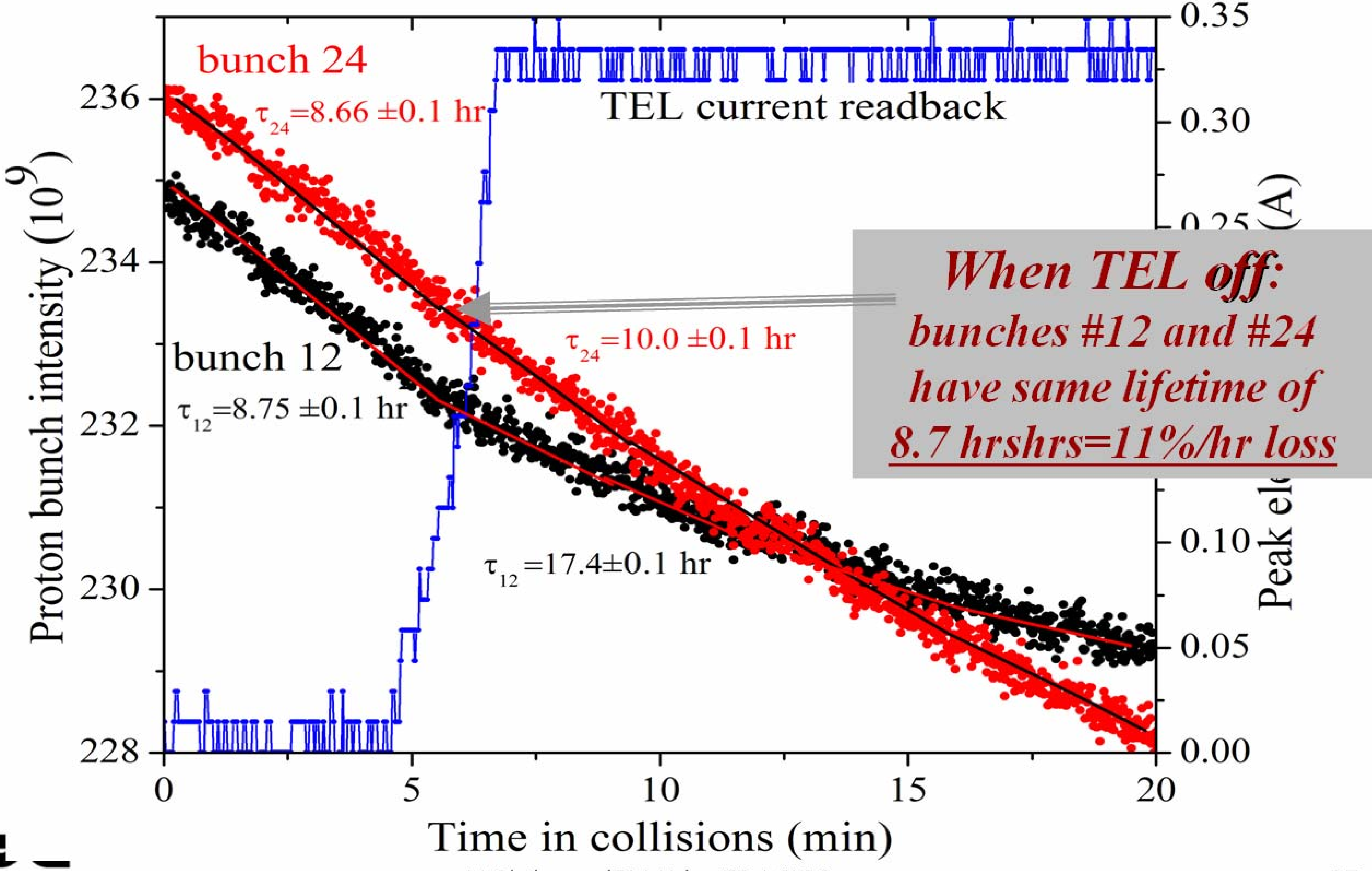


Transverse e-p alignment **is very important for minimization of noise effects and optimization of positive effects due to e-beam.** ***Timing*** **is important to keep protons on flat top of e-pulse – to minimize noise and maximize tune shift.**

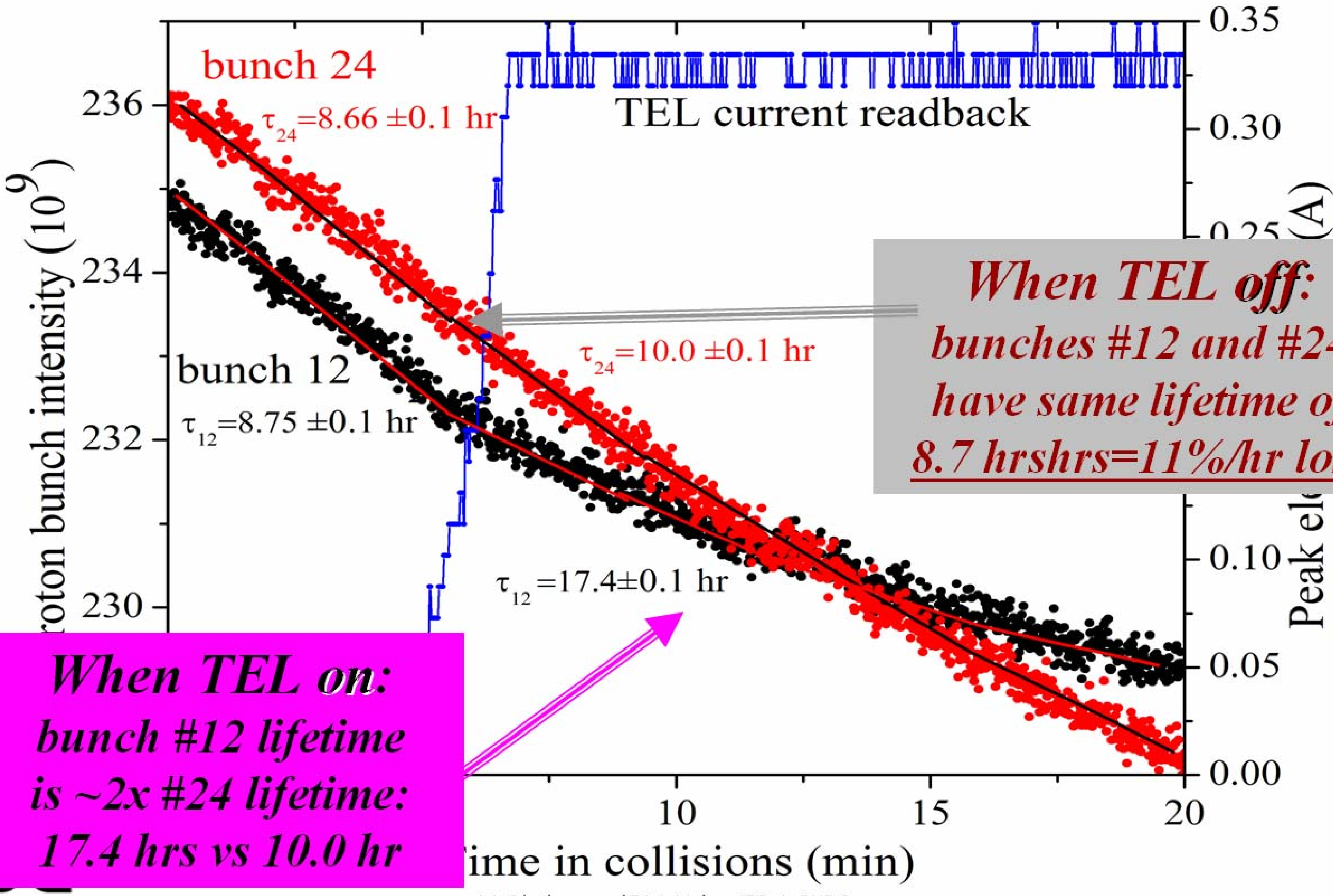
TEL2 on one bunch P12



TEL2 on one bunch P12



TEL2 on one bunch P12

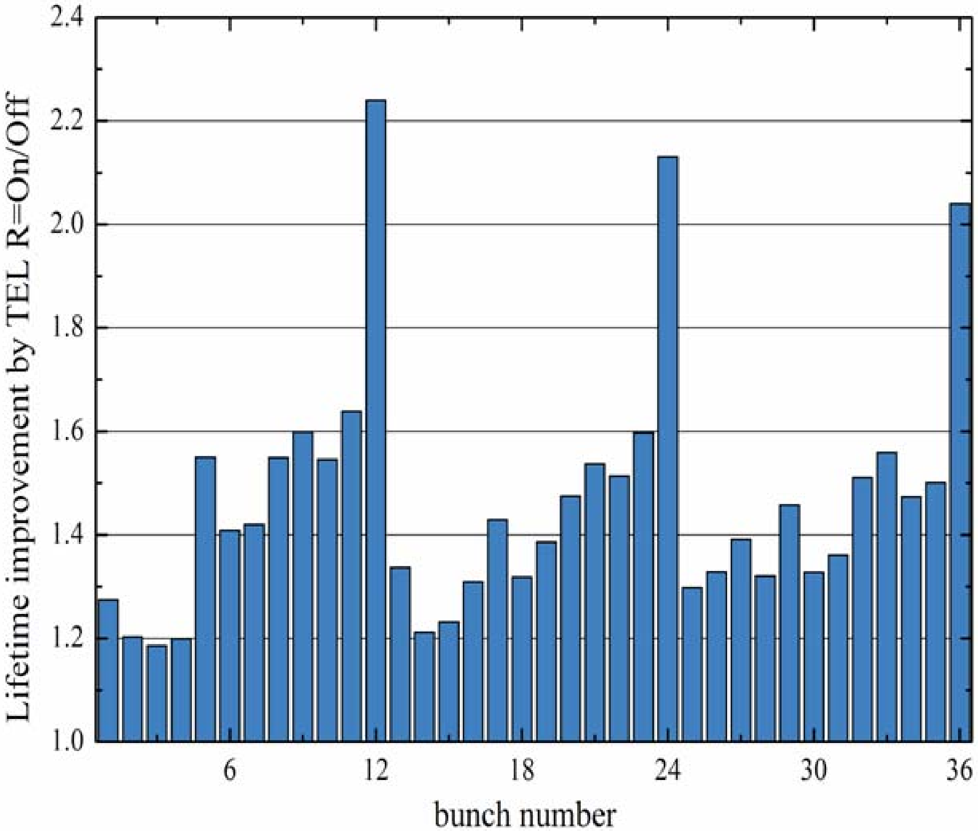


When TEL off:
bunches #12 and #24 have same lifetime of ***<u>8.7 hrshrs=11%/hr loss</u>***

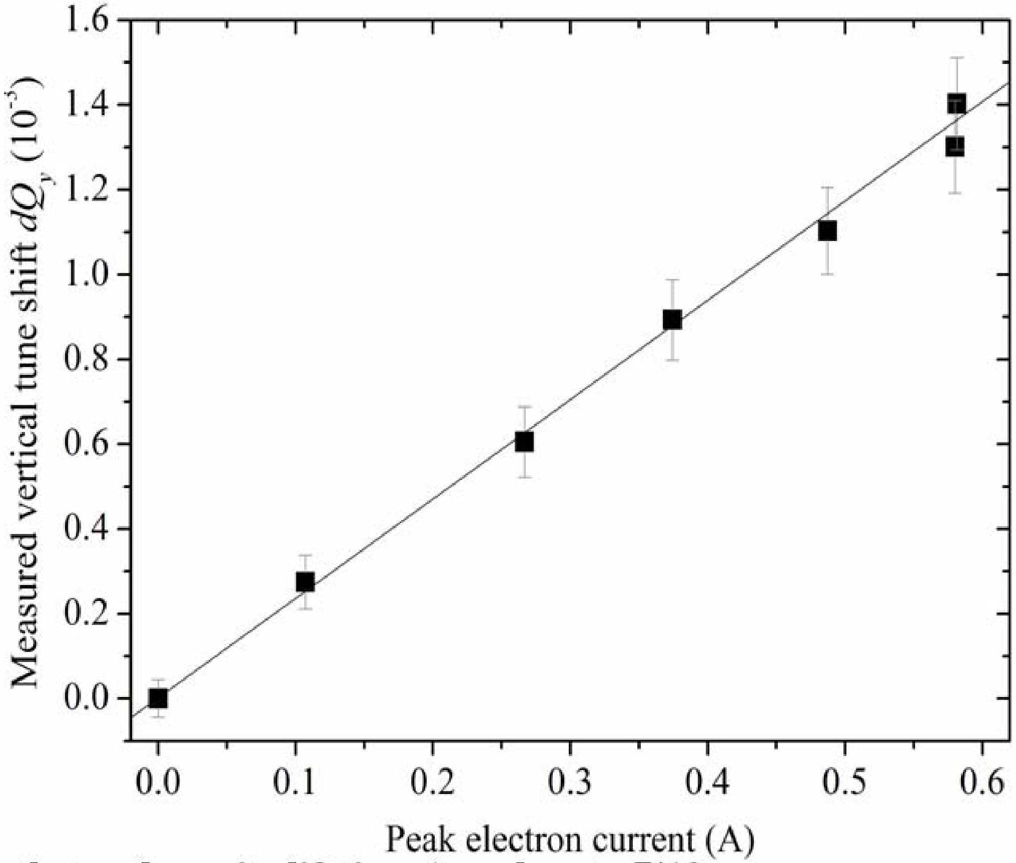
When TEL on:
bunch #12 lifetime is ~2x #24 lifetime: 17.4 hrs vs 10.0 hr

TEL2 acts on all bunches (DC)

Bunches are not equal !

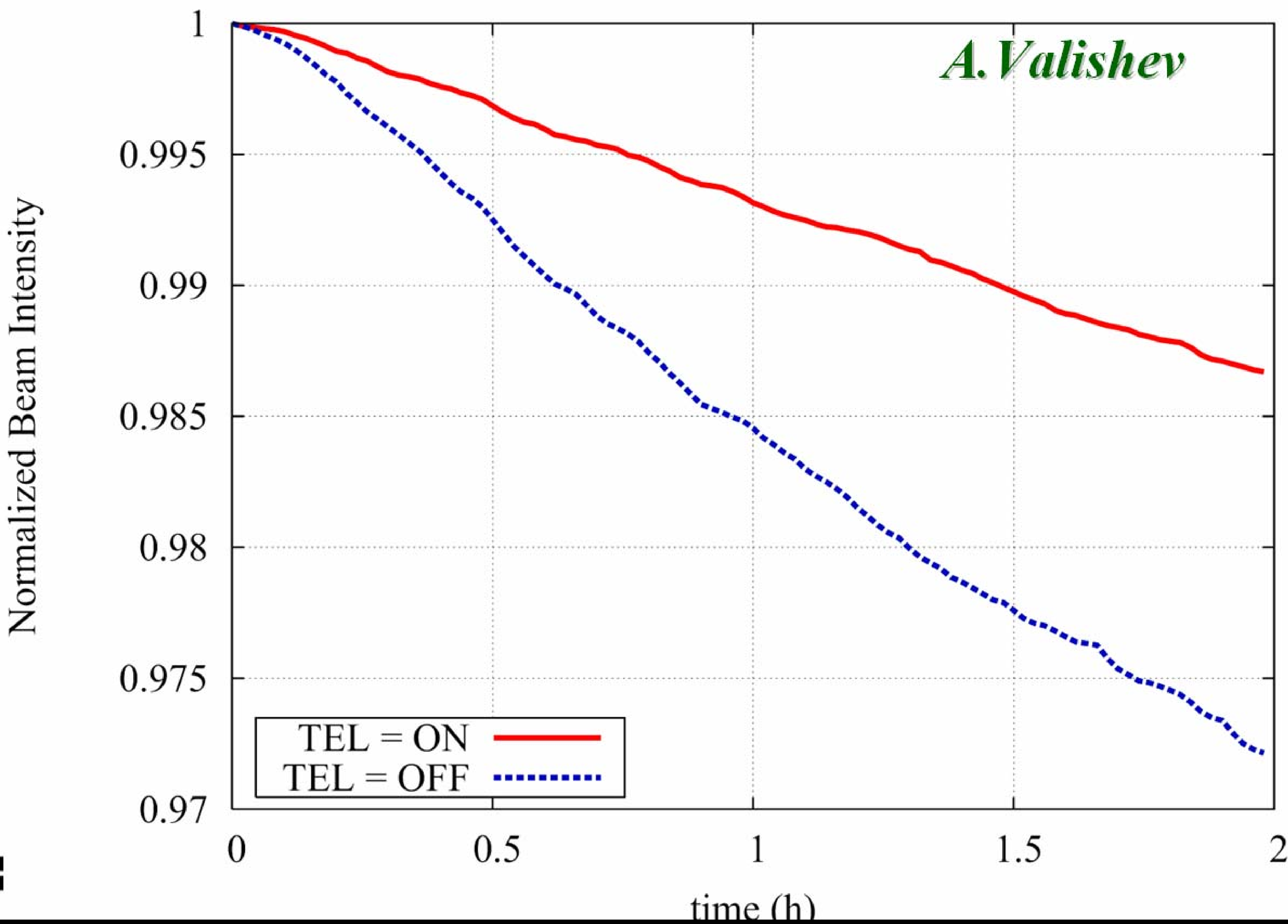


TEL2 moves Q_v up



Bunch P12 has systematically the lowest vertical tune that reduces its lifetime (too close to 7/12 resonance). TEL2 raises the tune up by dQ=+1.5e-3 at 0.6 A

LIFETRAC Simulation of TEL



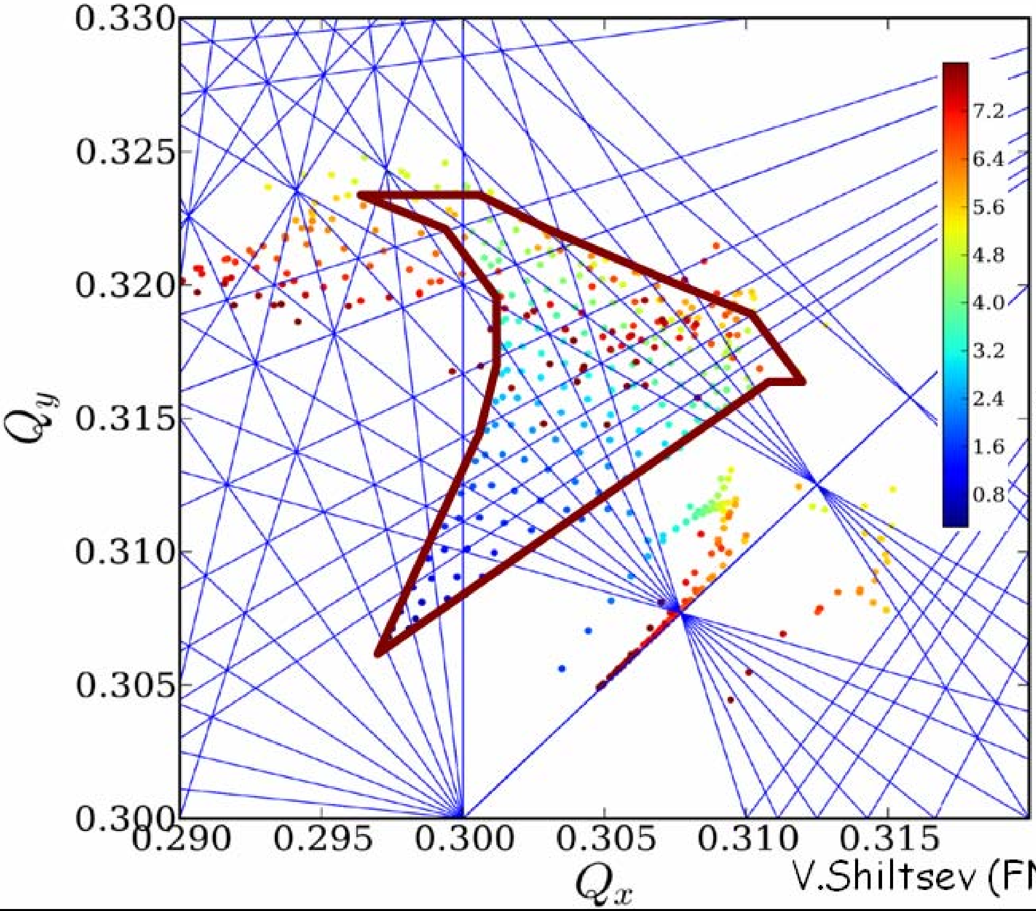
Electron Lenses: Tevatron and Beyond

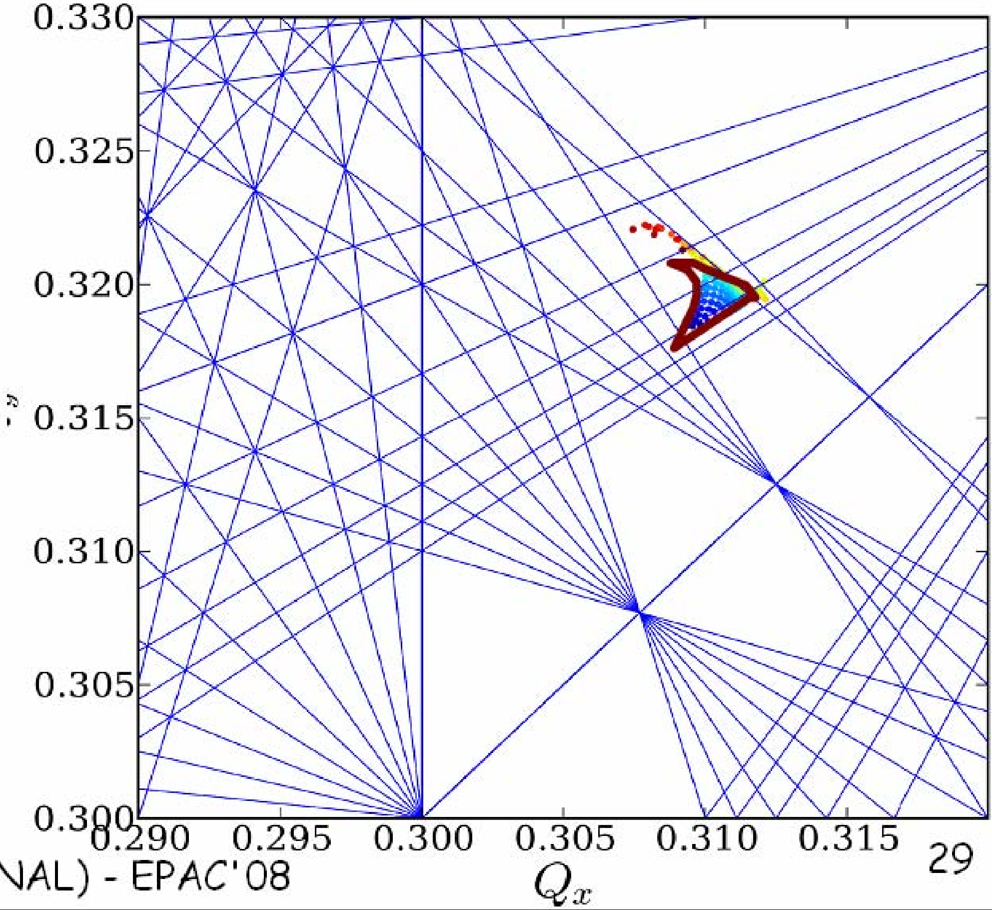
- Tevatron Electron Lenses act on proton bunches and ~*DOUBLE* the beam intensity lifetime
  - TEL1 (hor) improvement is big, too ~40%
  - Improves luminosity lifetime, too, by ~(5-11)%
  - Most effective in the 1st ~10 hrs of store
  - Awaits introduction in operation
    (= development of multibunch pulser - see poster THPP058)
- Electron lens technique is capable of much more:
  - Head-on compensation , eg. in LHC and RHIC
  - EM collimation by hollow electron beams, also in the LHC
  - Compensation of space-charge forces in proton synchrotrons and linacs

Head-On Compensatoion with e-Lenses

2.4 A DC lens with <u>Gaussian</u> current profile shrinks LHC footprint (LHC Upgrade simulations – U.Dorda, V.Shiltsev, et al)

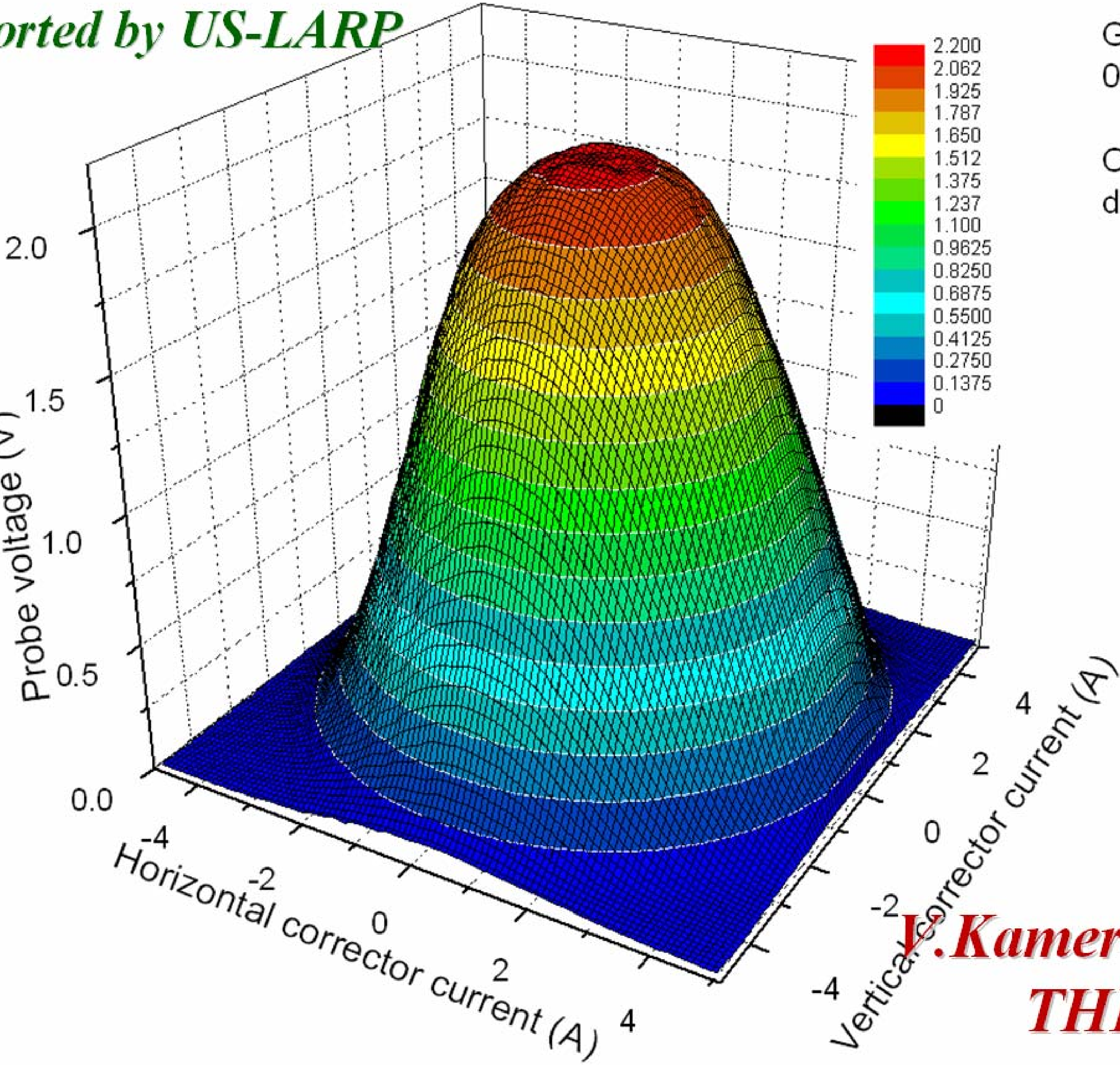
TEL off, LRBBWire off → **TEL on, LRBBWire on**





Can Gaussian Distribution be generated?

Supported by US-LARP



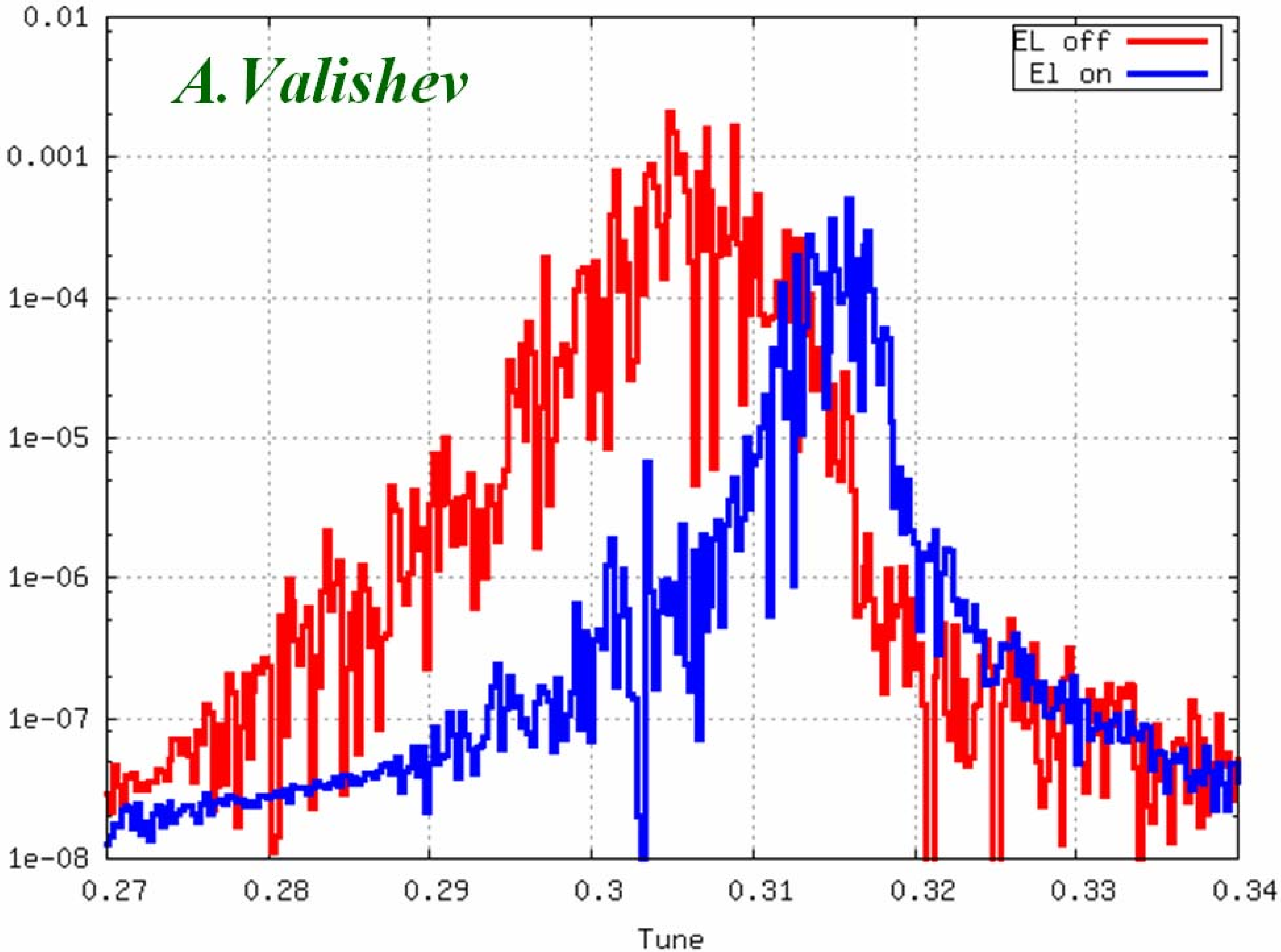
Gaussian electron gun
0.4" cathode

Current density distribution

U_{cath} = -5kV
U_{ce} = -5kV
U_{anode} = -5.4kV, Gnd
B_{gun} = 1.5kG
B_{main} = 2kG
B_{col} = 1.5kG
F = 200Hz
PW = 4μs

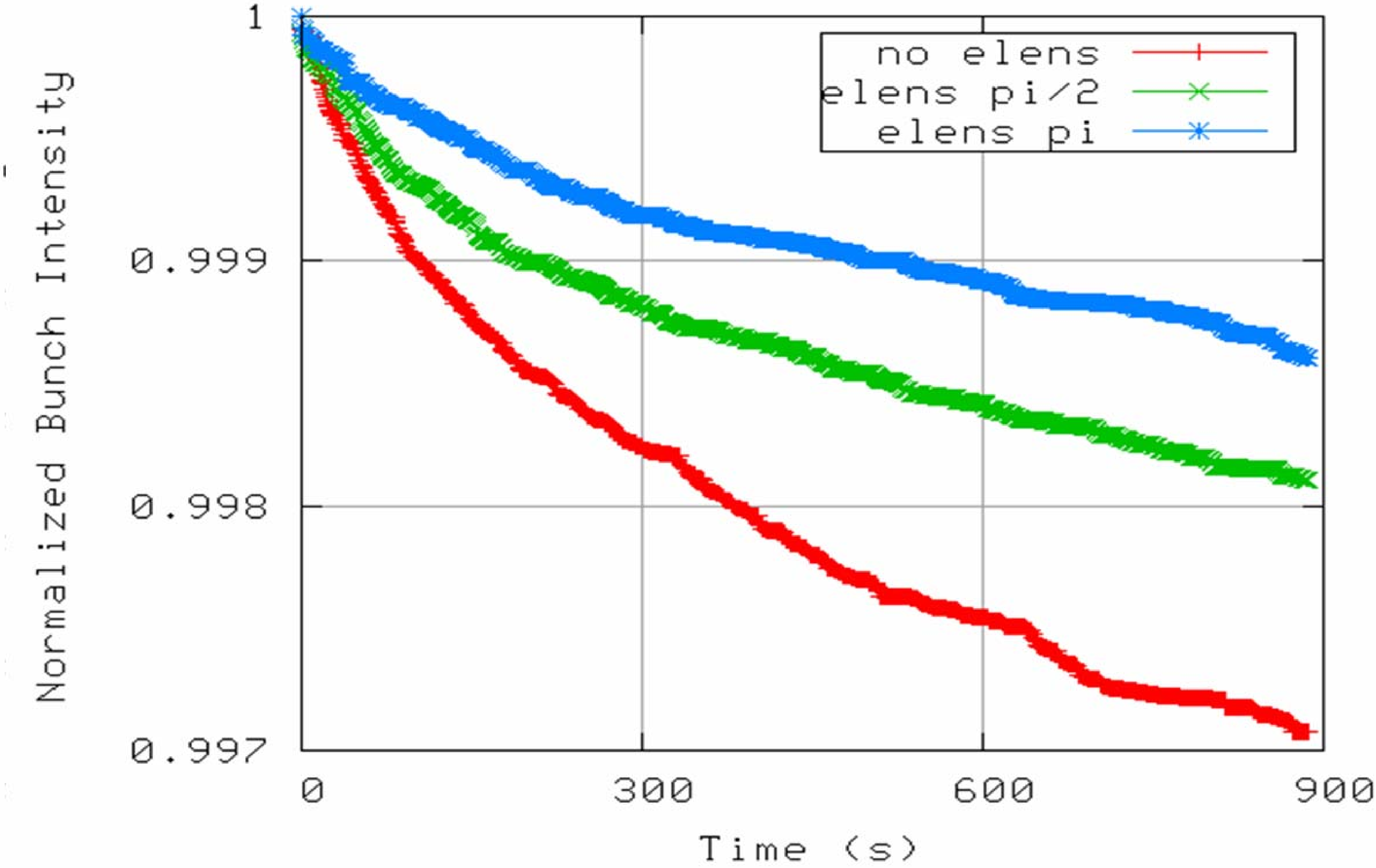
V.Kamerdzhiev, et al
THPP 058

Effect of E-Lens at ξ=0.0075



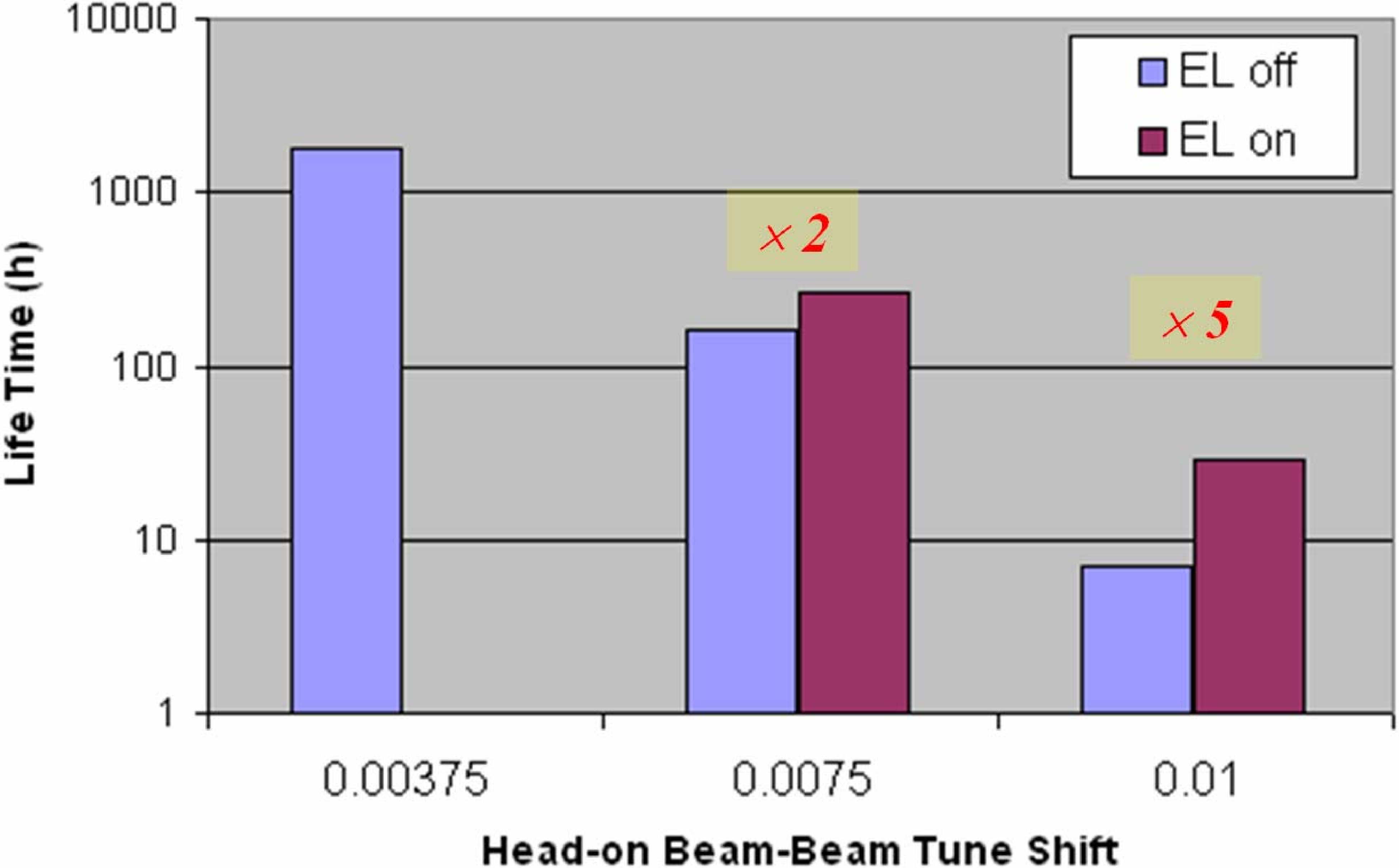
LIFETRAC eLens simulations for LHC ξ=0.0075/IP

Effect of E-Lens at ξ=0.0075



LIFETRAC eLens simulations for LHC ξ=0.0075/IP

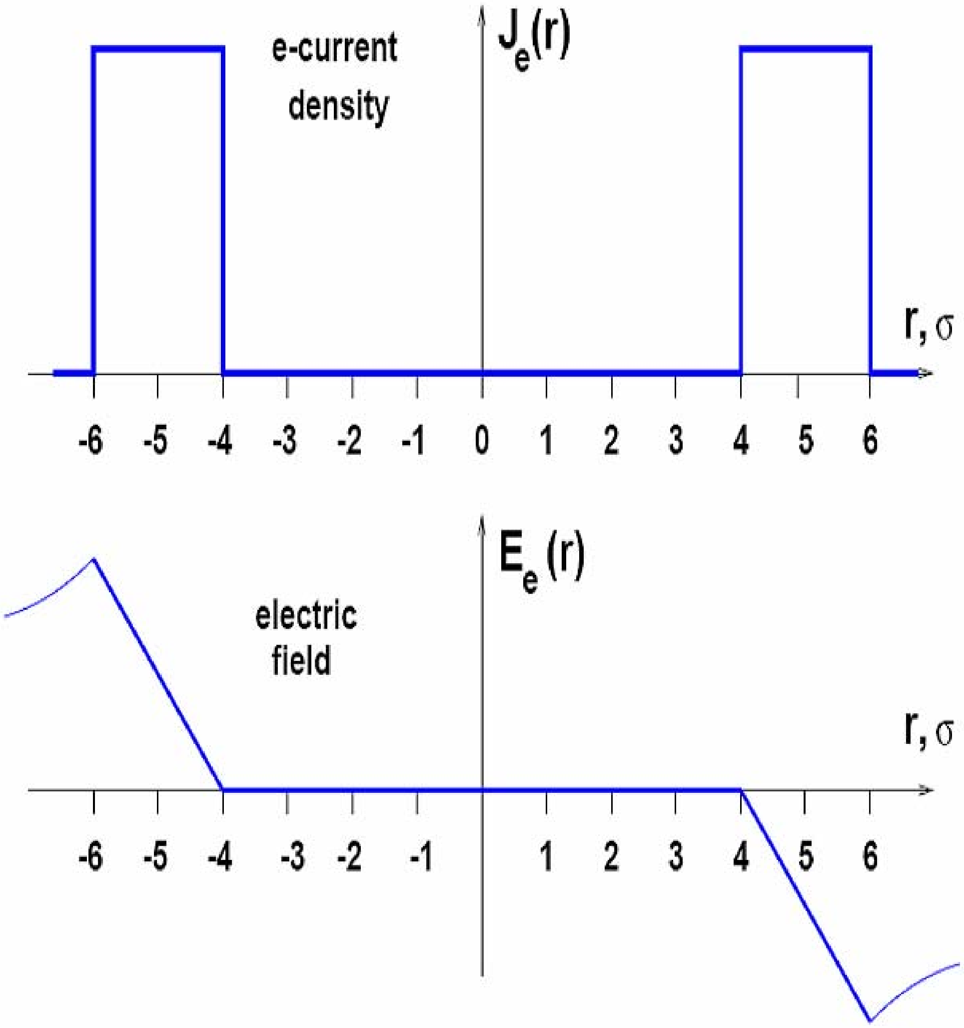
Effect of E-Lens on Beam Lifetime

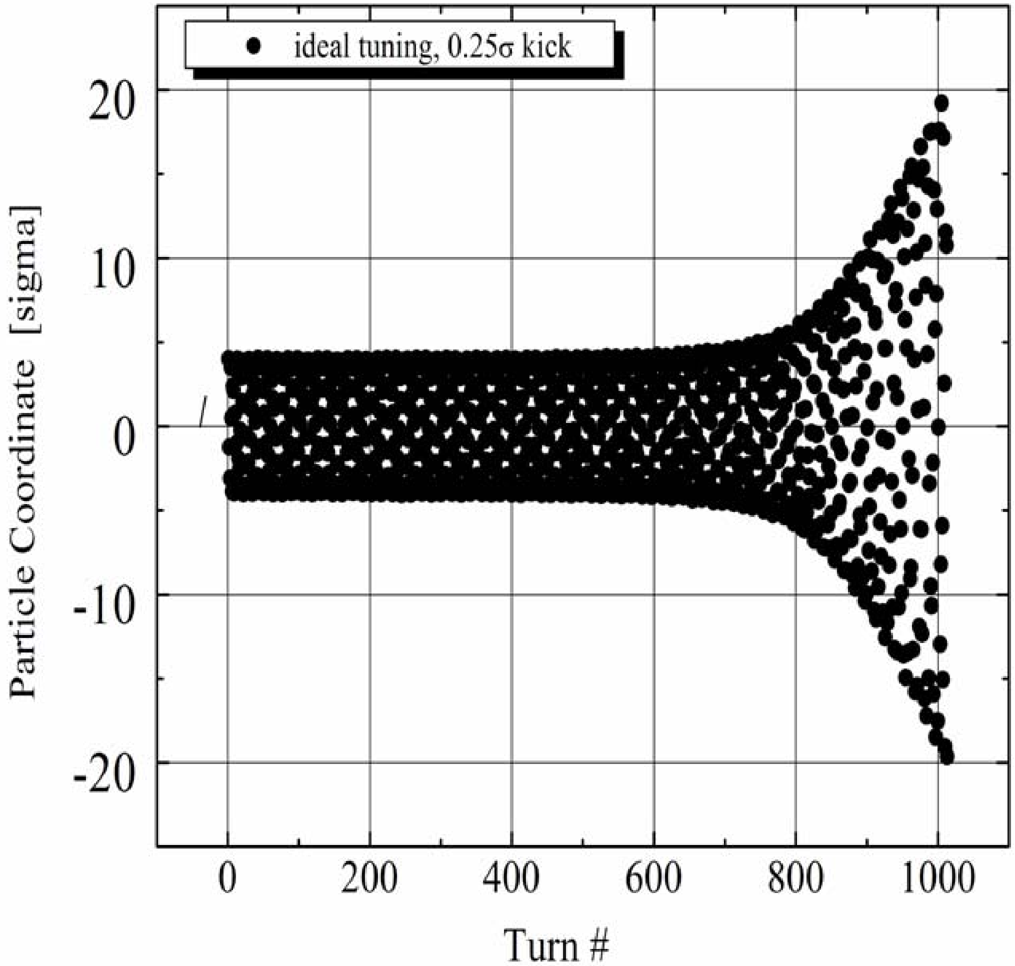


LIFETRAC eLens simulations for LHC (A.Valishev)

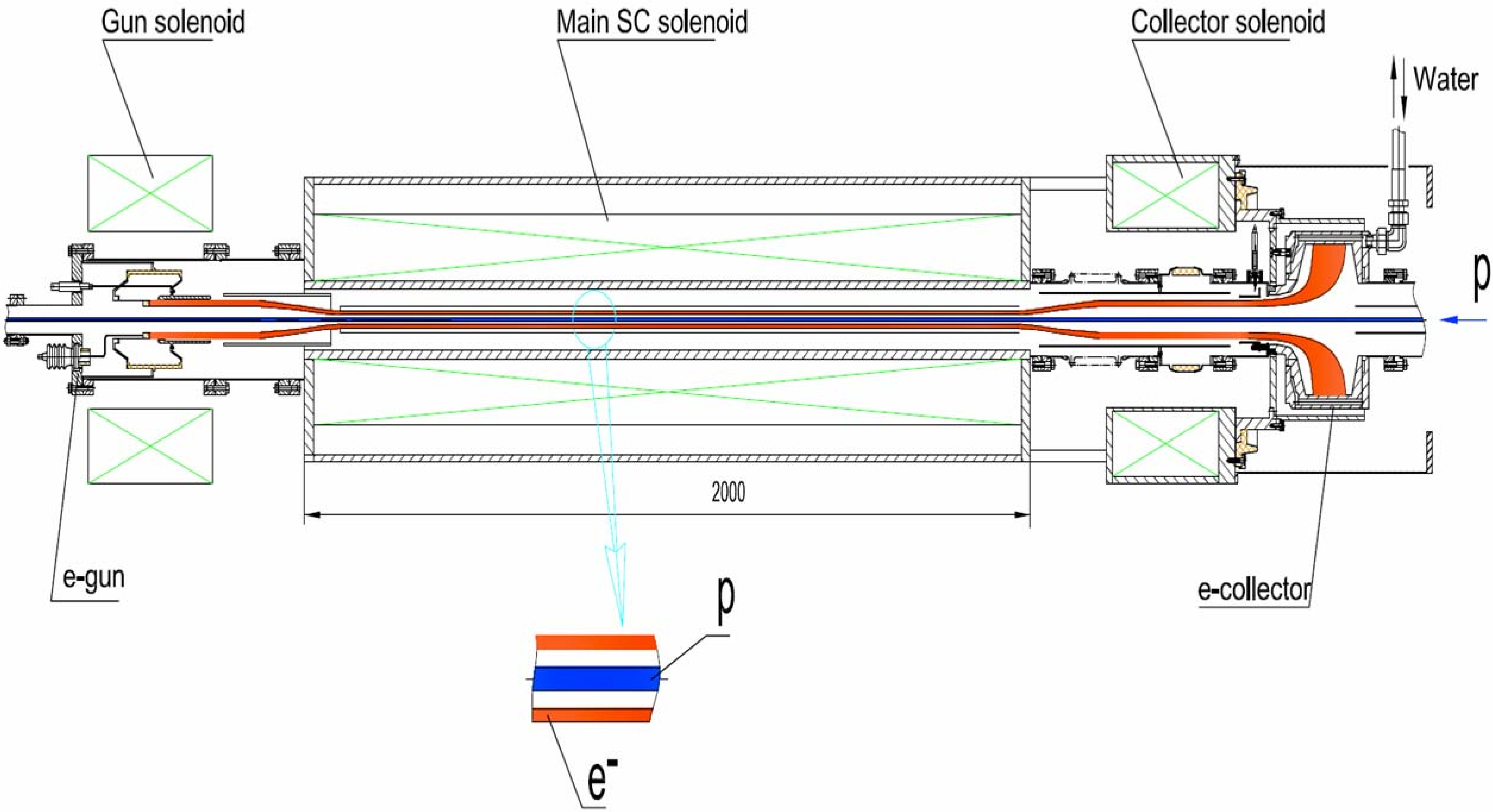
Hollow e-beam collimation (MOPC098)

10 A in hollow e-beam – driven at the betatron frequency

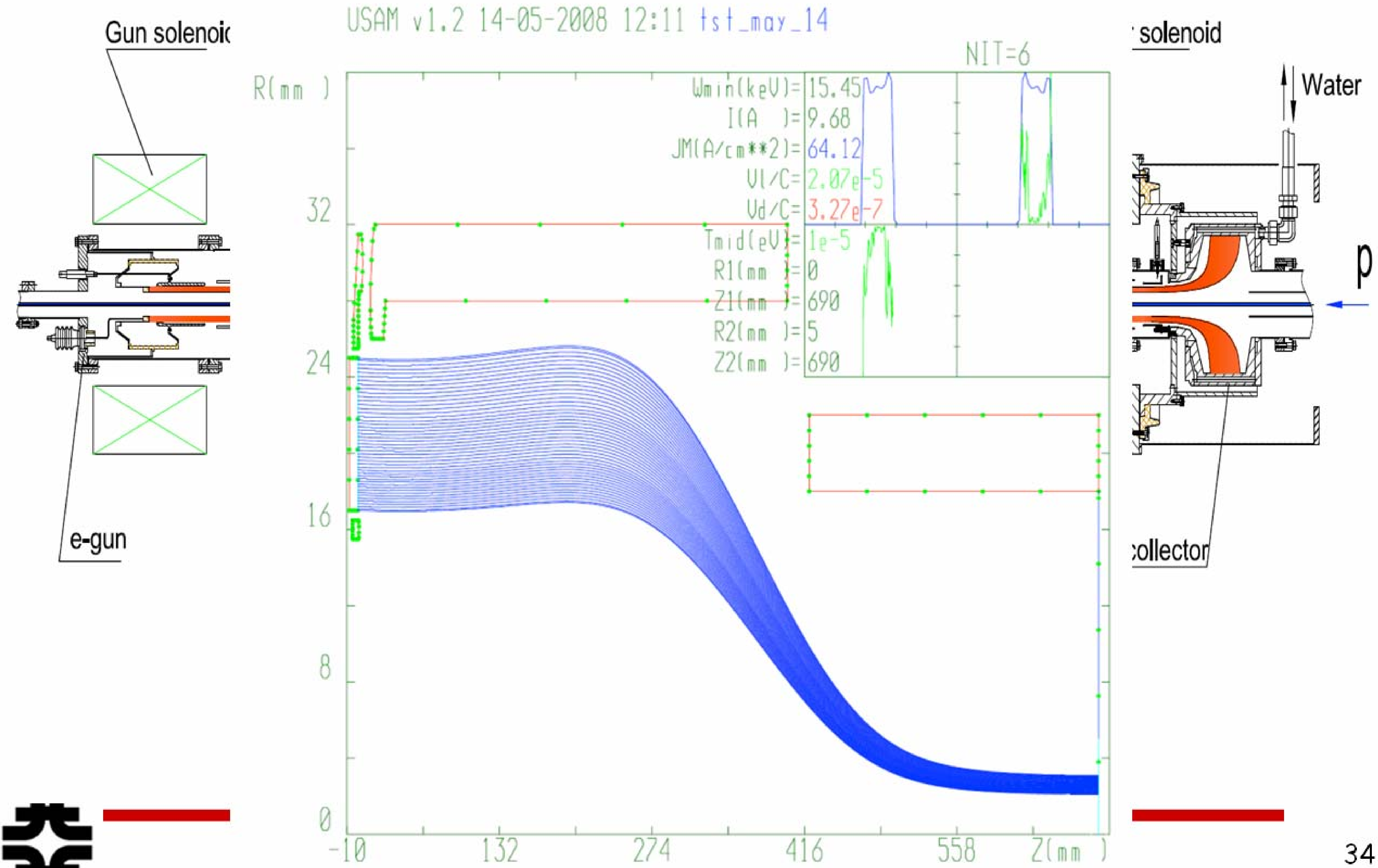




Hollow beam system – like TEL

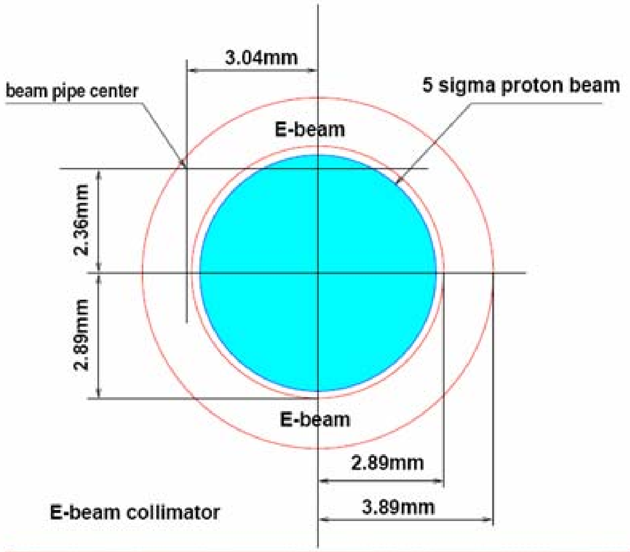


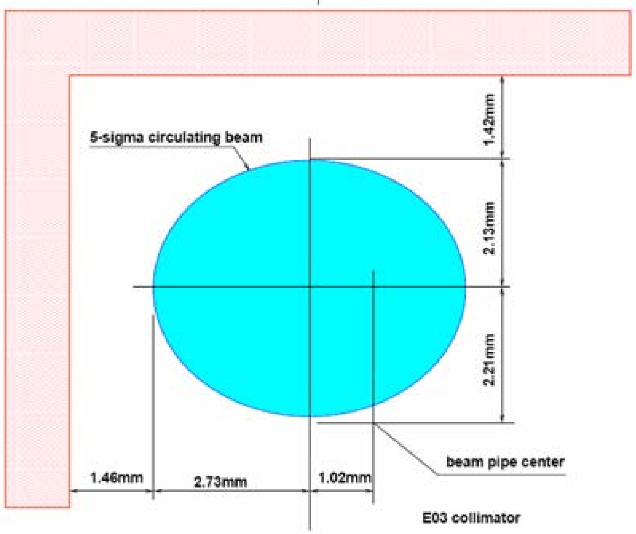
Hollow beam system – like TEL

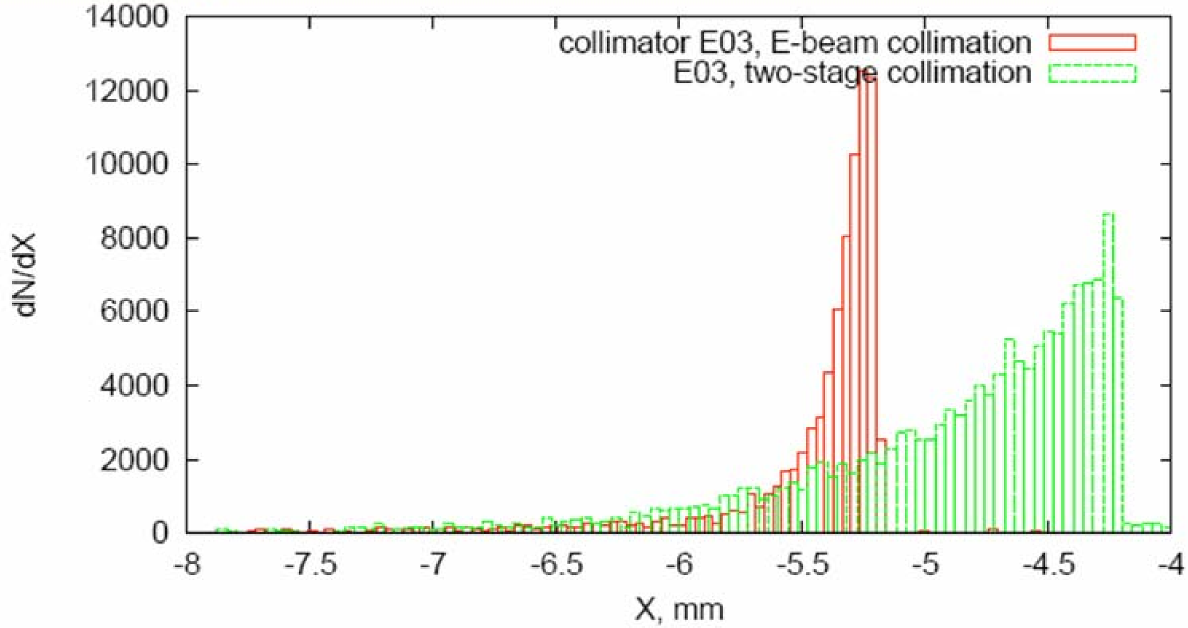


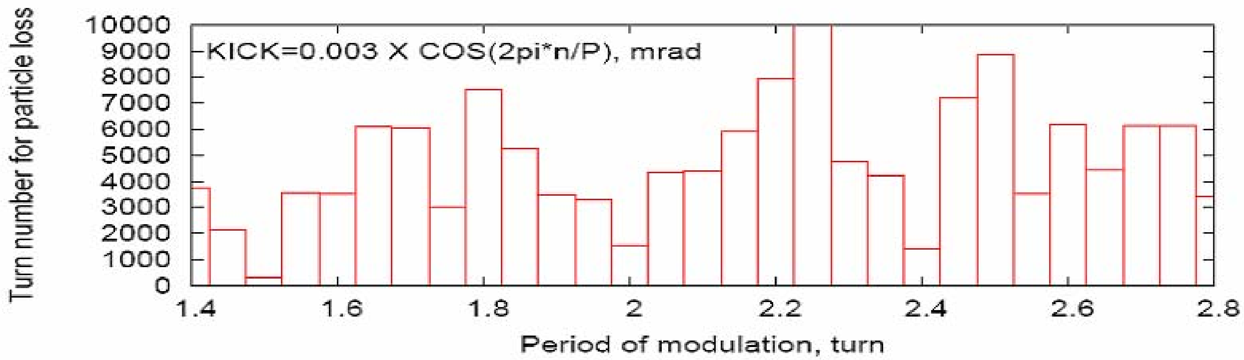
Good Efficiency in Tevatron Model

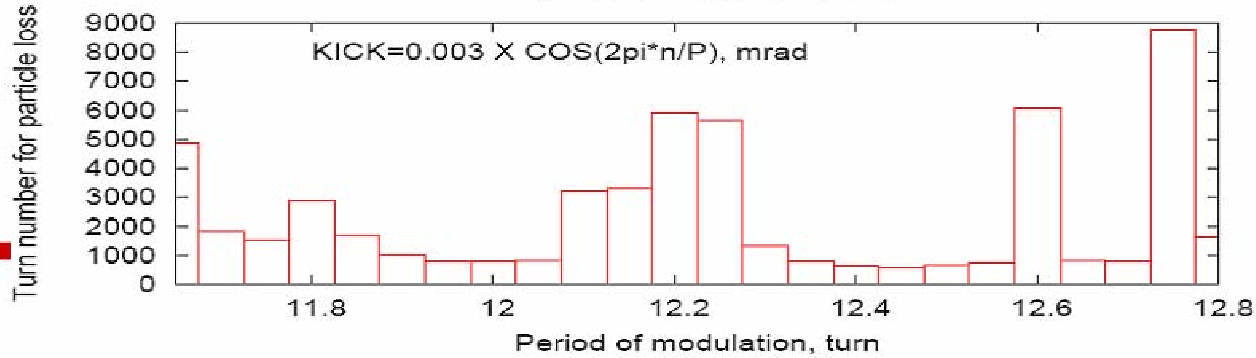
A. Drozhdin











Advantages of Holow e-beam Colimator

LHC Collimation system:

(i) Does not work for ions (breaks them)
(ii) can not handle large currents (power jaw)
(iii) needs sophisticated jaw damage diagnostics
(iv) transverse impedance of collimators is a big issue for upgrade
(v) intrinsically spiky losses (beam jitter, etc)

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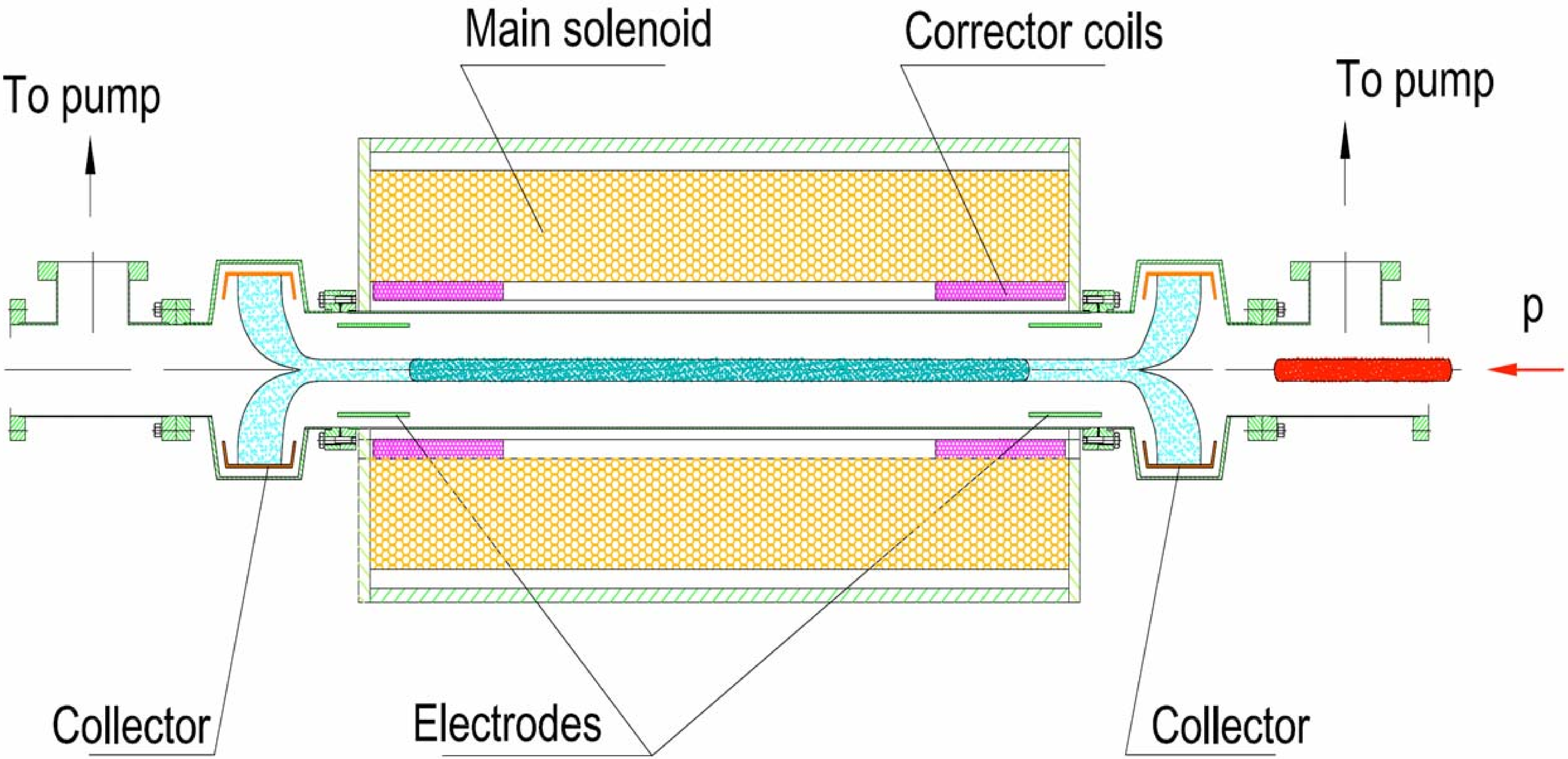
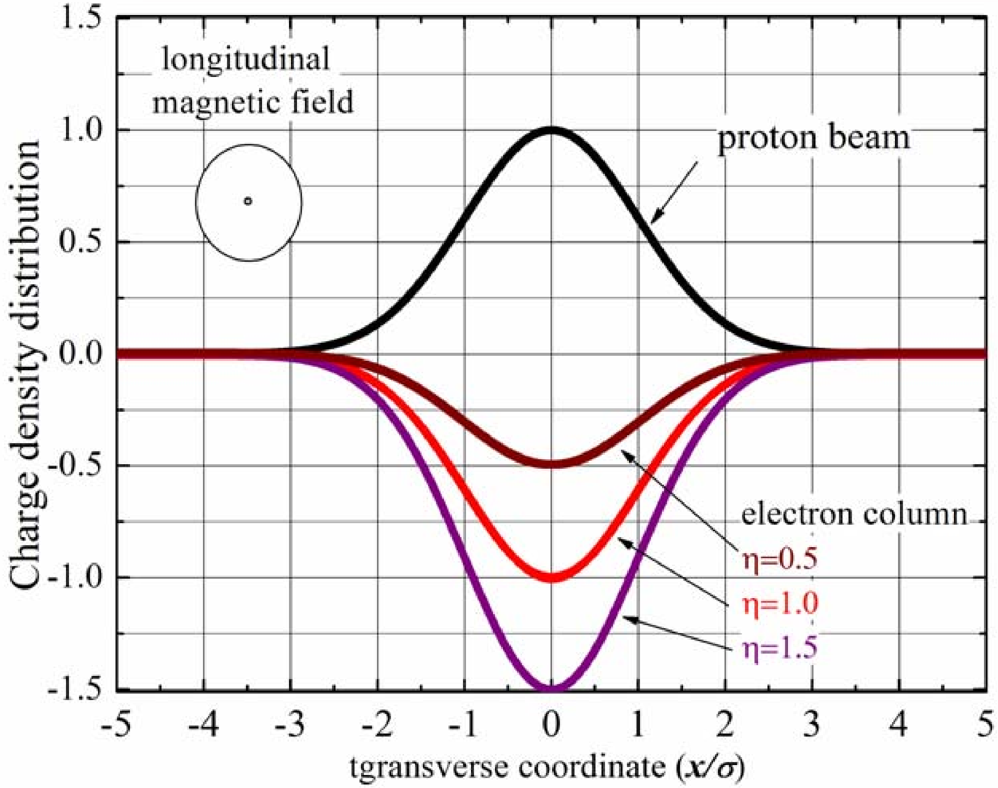
Hollow e-beam collimators address ALL these issues!

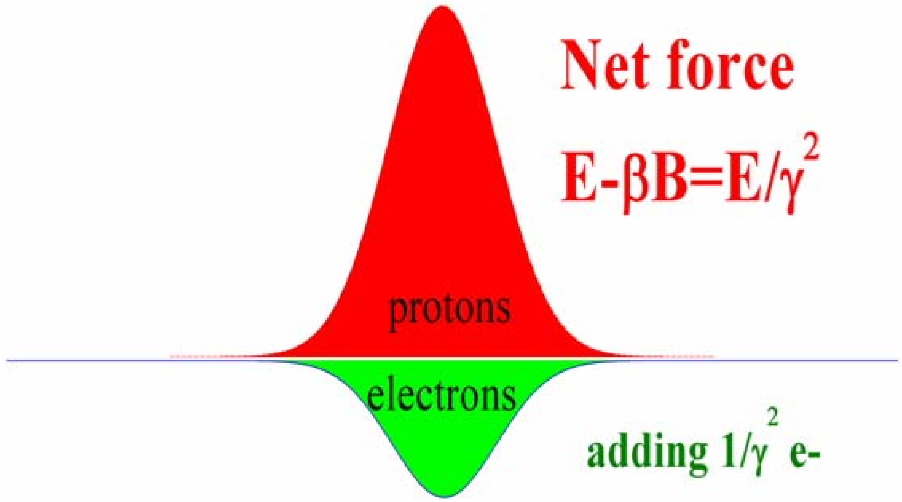
Finally, e-Column for SCC

Very much like TEL - but no electron gun!



E Columns for SCC



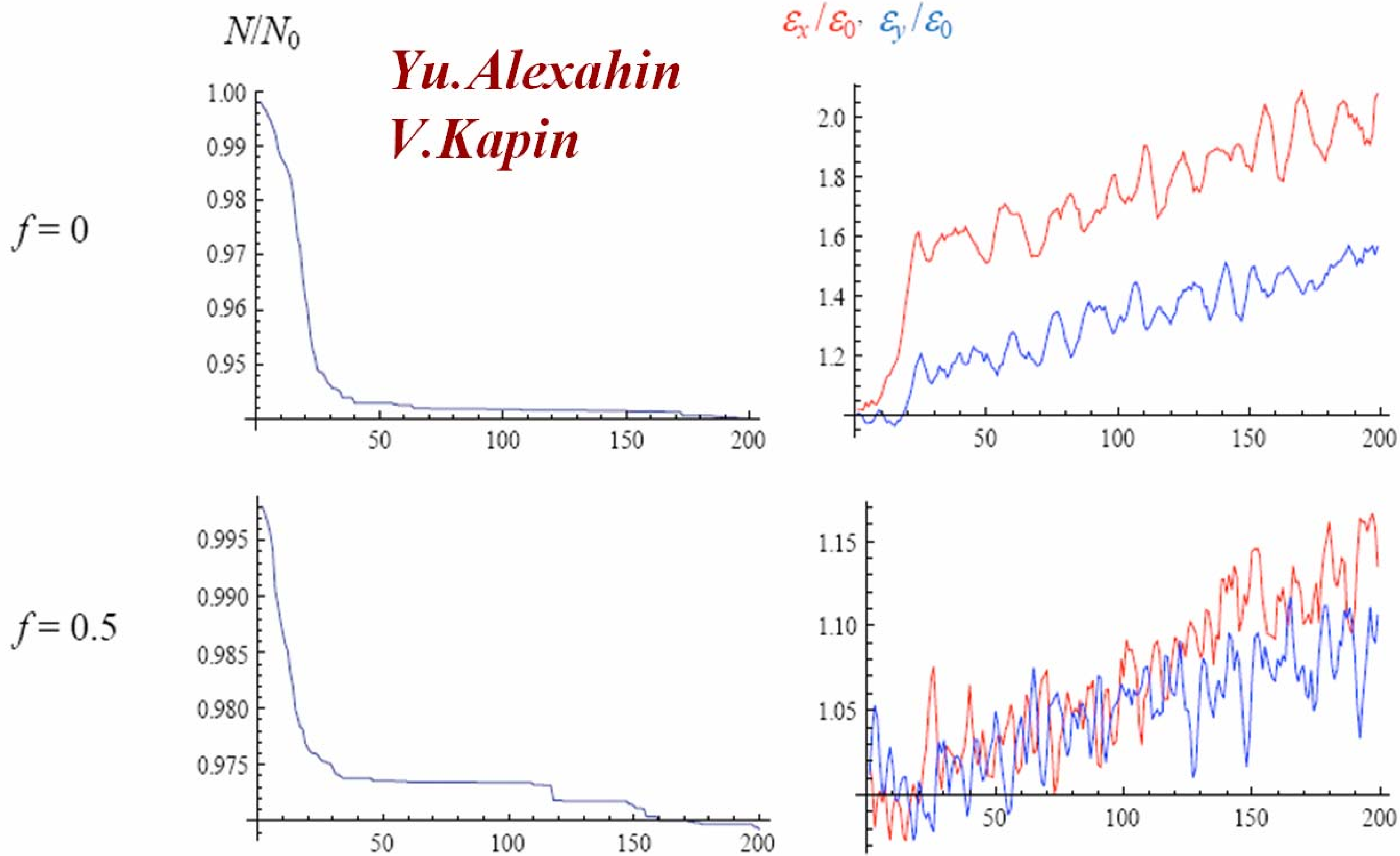


Net force

$E-\beta B=E/\gamma^2$

adding $1/\gamma^2$ e-

E Columns for SCC



Summary

Long way ahead from Tevatron to LHC:

$$\pi \times 10^{32}\ cm^{-2} s^{-1}$$

$$\Pi = \pi \times 10^{34}\ cm^{-2} s^{-1}$$

... and experience and methods - like

Electron Lenses - must be fully utilized!