Electron Lenses

for the LHC

Vladimir Shiltsev

With contributions from Yu.Alexahin, J.Johnstone, V.Kamerdzhiev, U.Dorda

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Content

- On possible uses of ELs in LHC
- Focus on Head-on BBCompensation
- Action items and collaboration

Valencia'06: LHC-ELs for

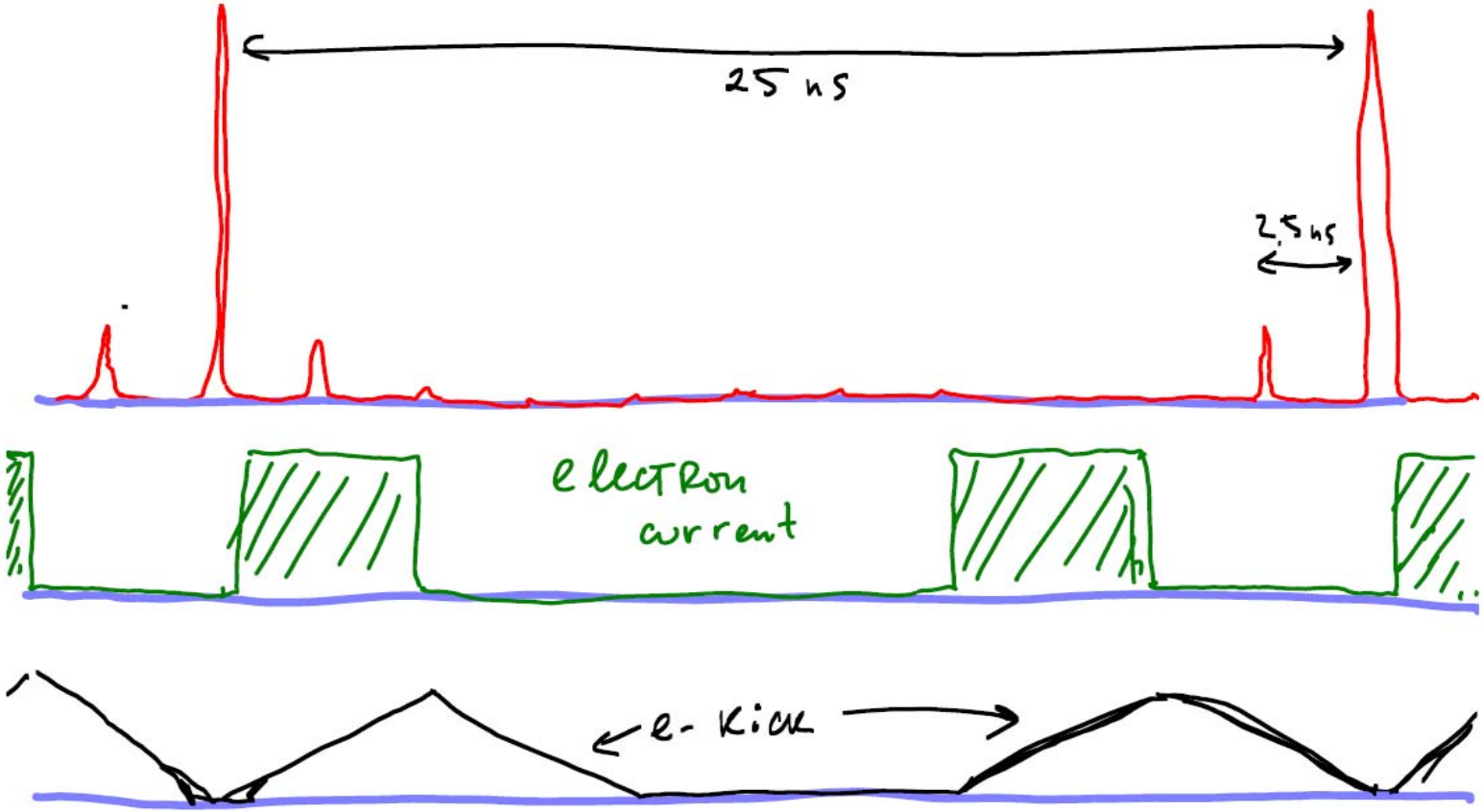
#1: LEL as B-B Compensator at design intensities or x2 Np/bunch

#2: LEL as Beam Stabilizer (Tune Spreader) to help octupoles @ design Np=1.15e11

#3: LEL as soft hollow collimator

#4: LEL as soft "beam conditioner"

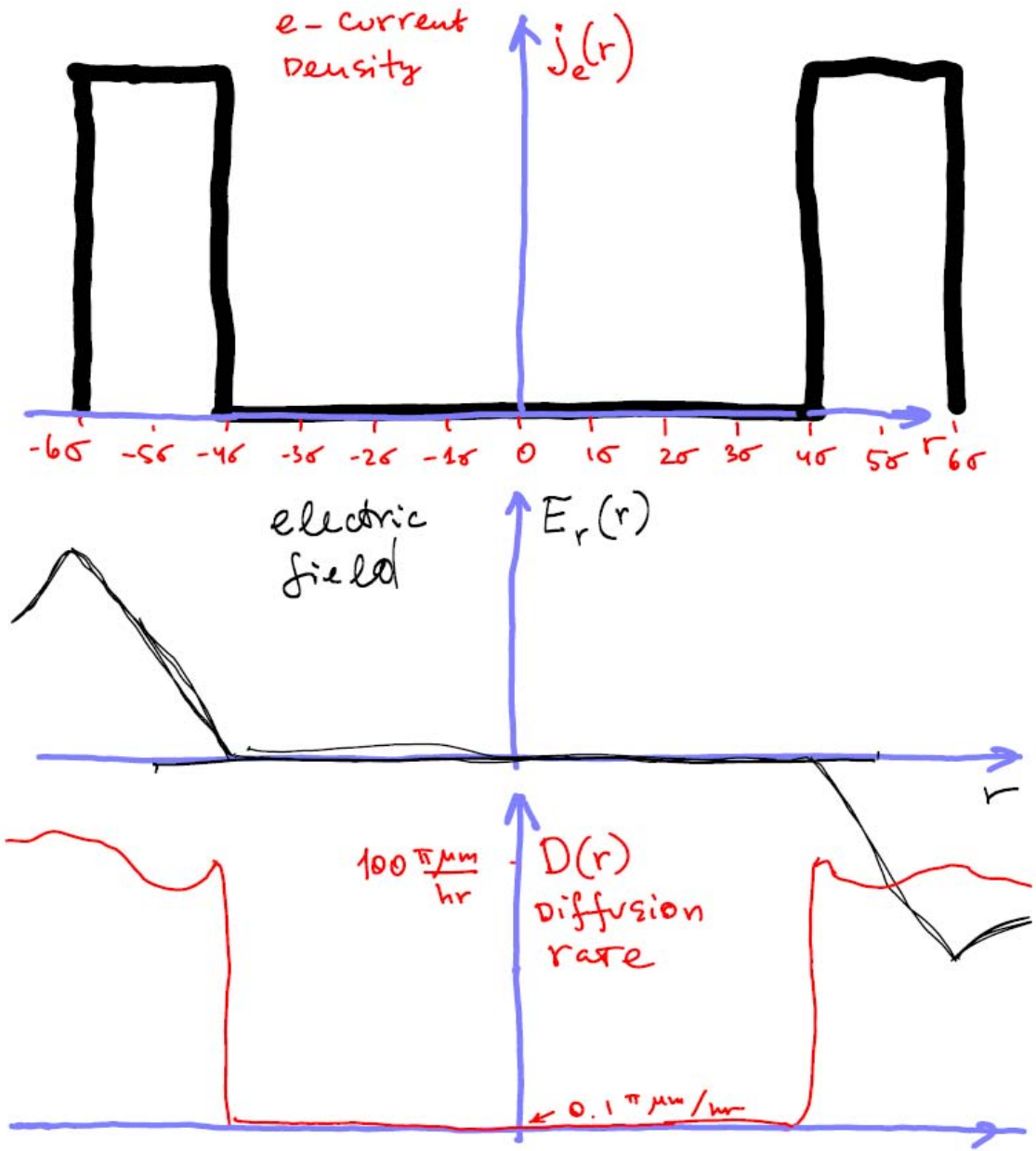
#4: Killing Satellites



- Easier to do at 450GeV
- But more time at 7TeV
- Drive resonantly

- Not clear whether that's a problem
- Challenging technology
- OUT! (unless 450 DC beam problem)

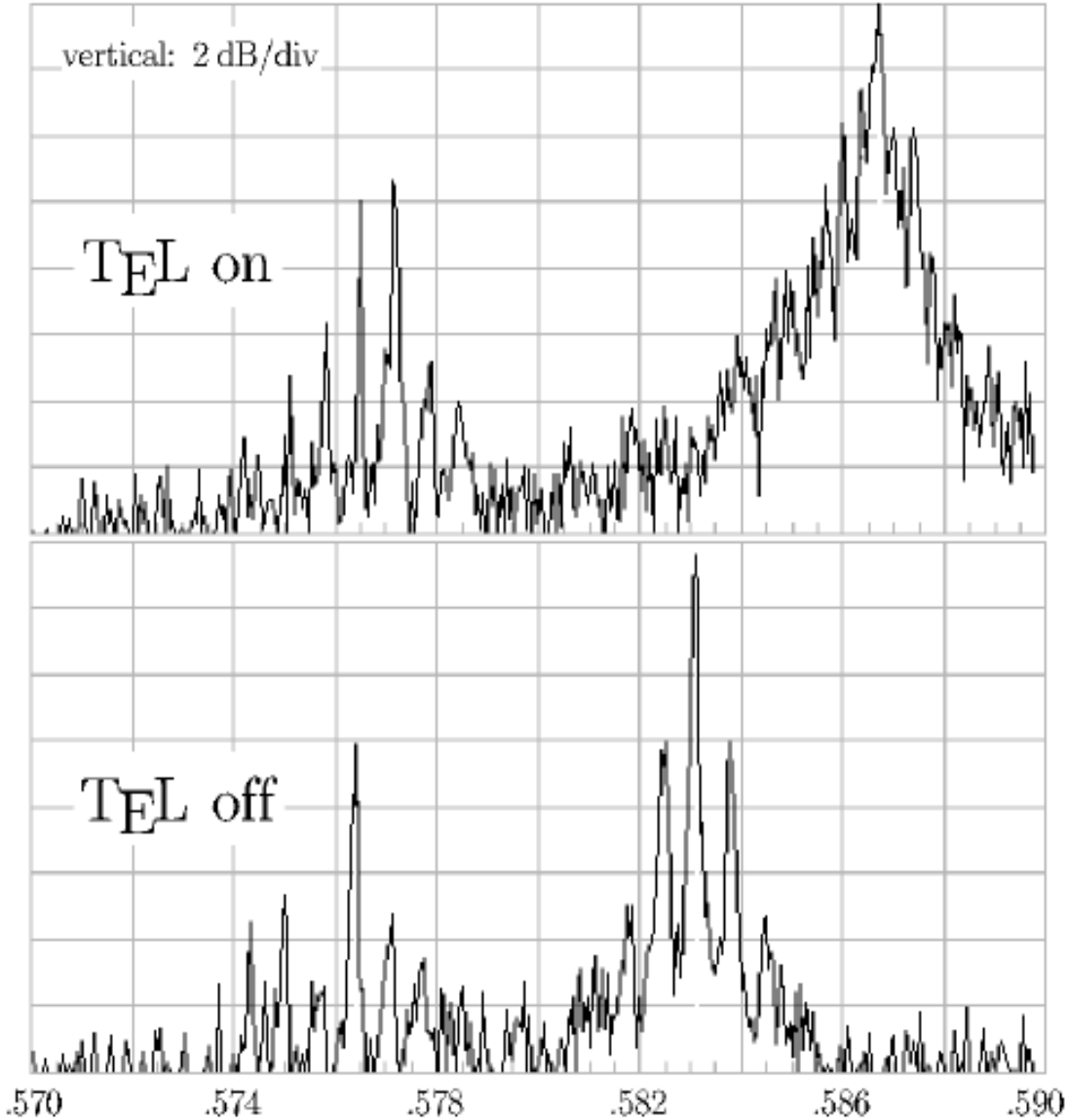
#3: Hollow Electron Collimator



Duffusion enchanced by Non-linear fields and/or resonant pulsing structure

- Technology available
- Would be ideal for ions (no nuclear interaction)
- wait until bent crystals evaluated for ions

#2: LEL as Tune Spreader



- Can provide tune spread 0.01
- Better than using octupoles for beam stability
- Demonstrated in Tevatron

- Not clear it is needed (e.g. beam-beam helps)
- Beam feedback is even better

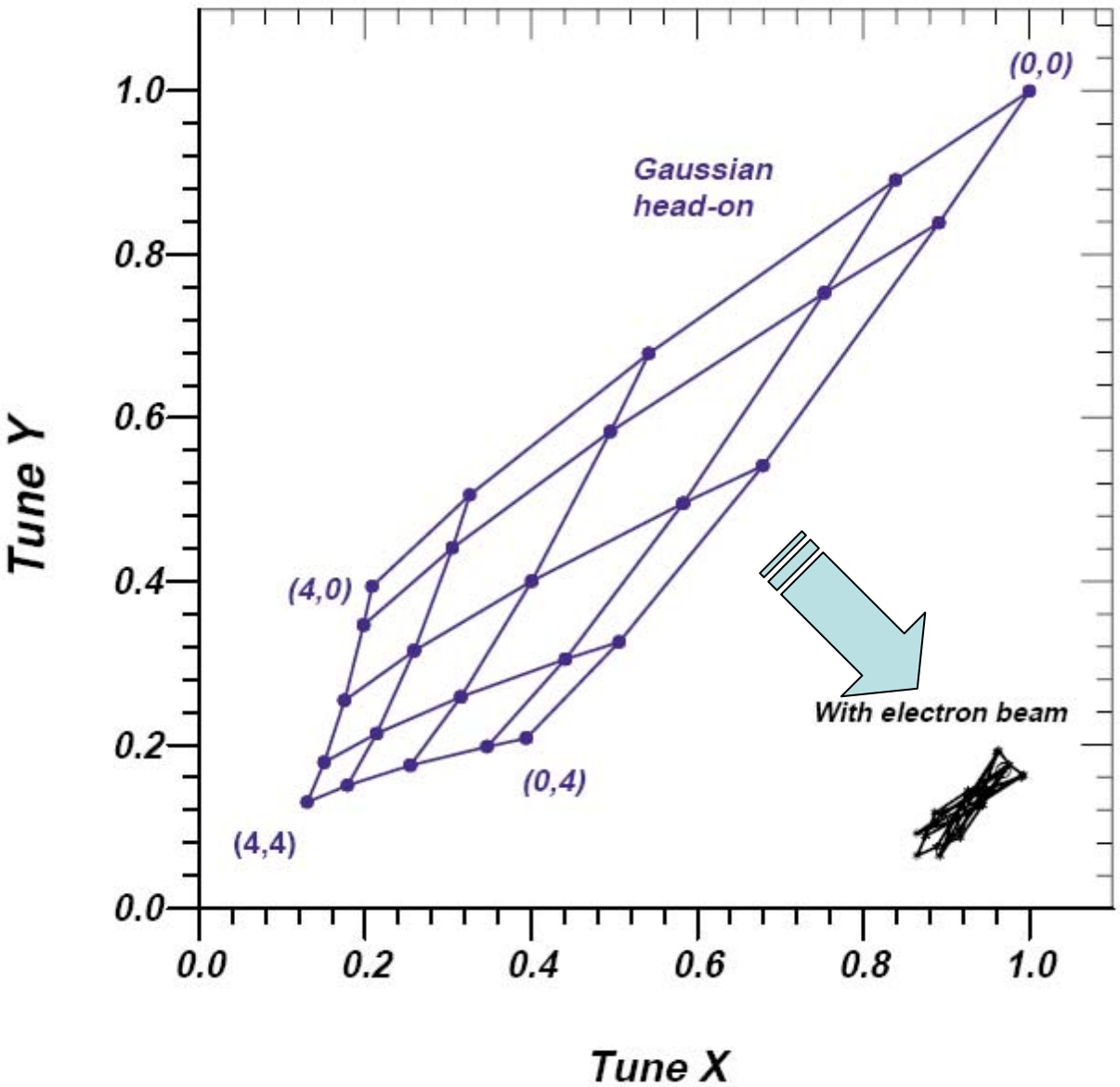
Head-On Beam-Beam Compensation

- 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

Head-on beam-beam compensation

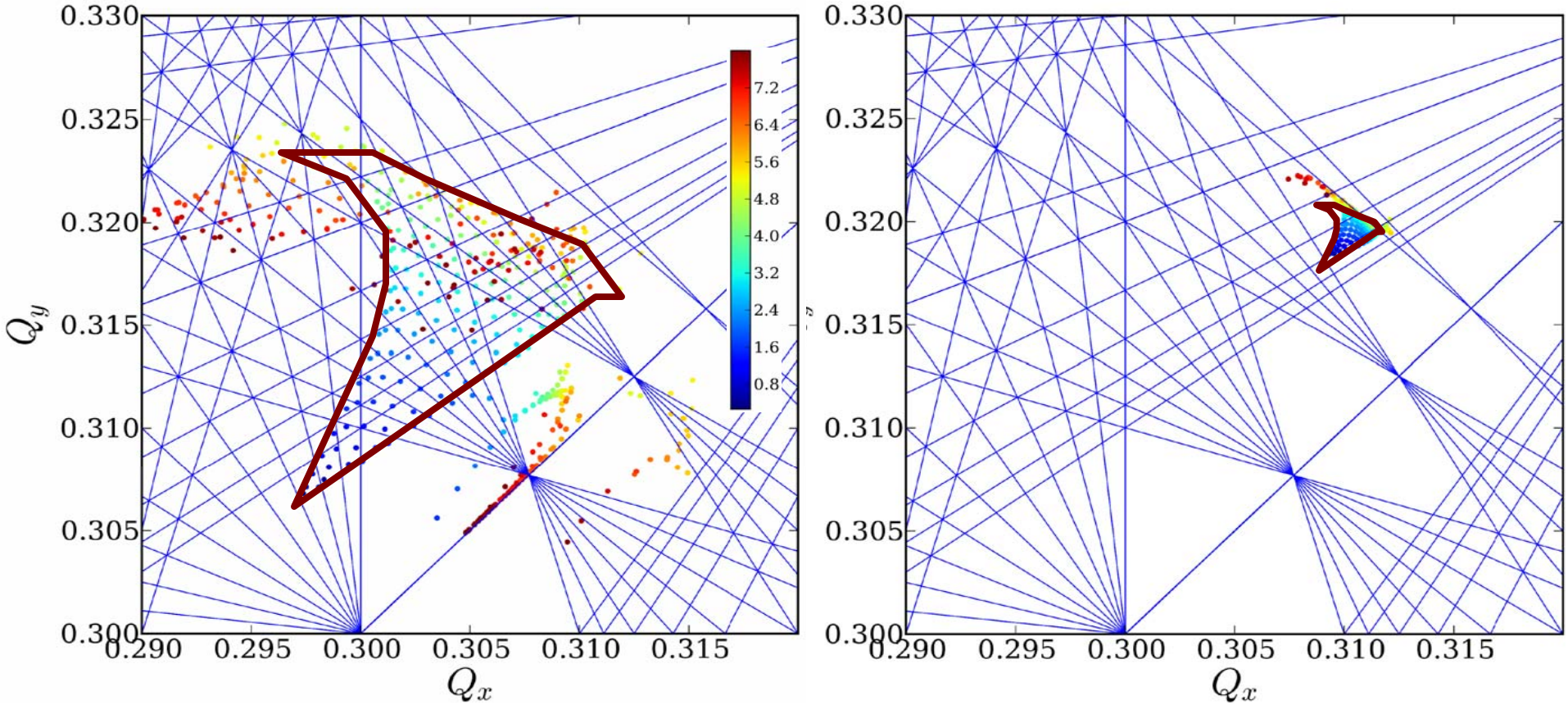


ca.1997

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***

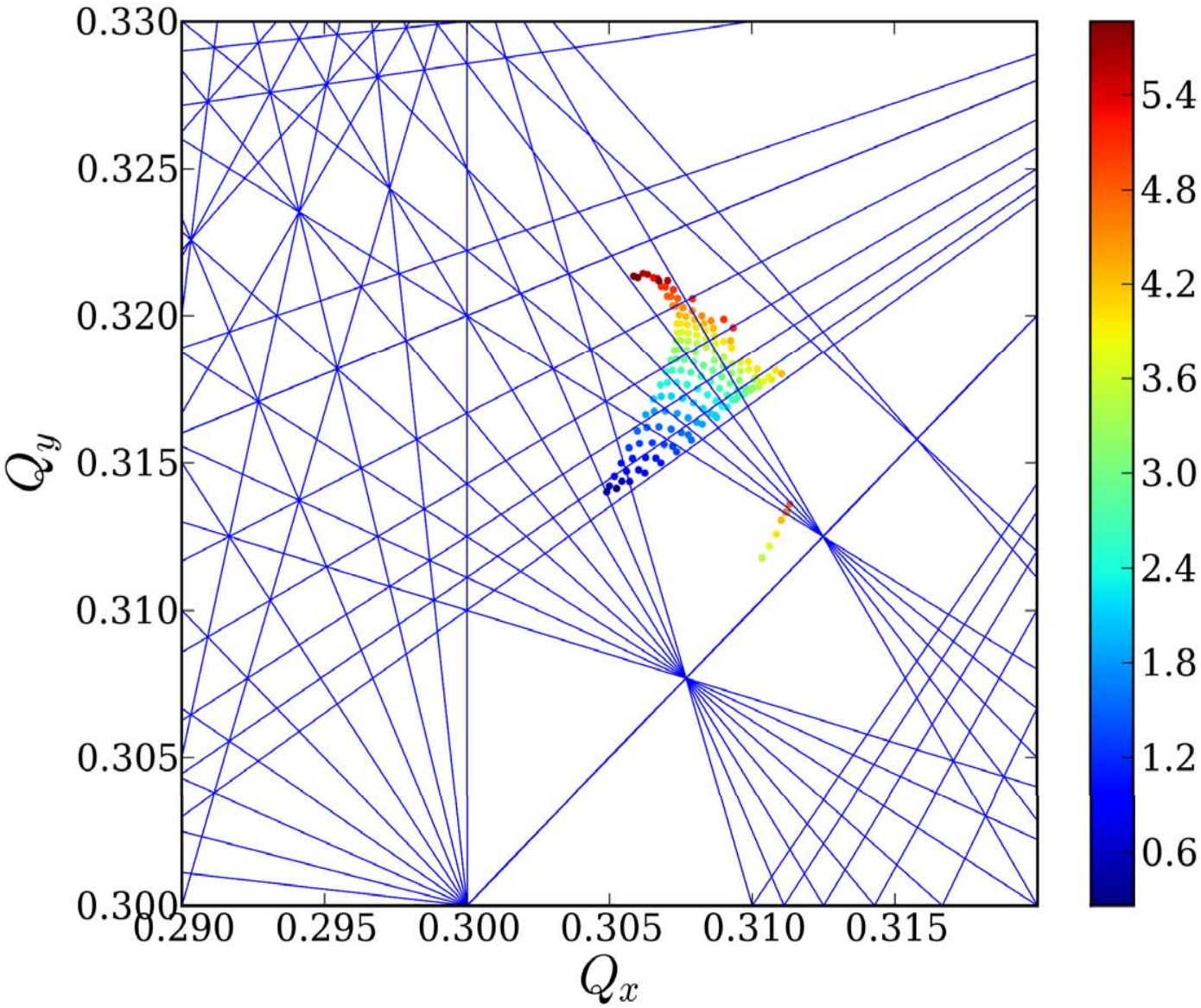


Degree of Compensation

- 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"
  - original thinking was to compensate to max tolerable *dQ_spread* = 0.010 ?
  - Yuri Alexahin suggested to compensate to d*Q_spread=0.003* - better coherent beam-beam

50% Head-On Compensation

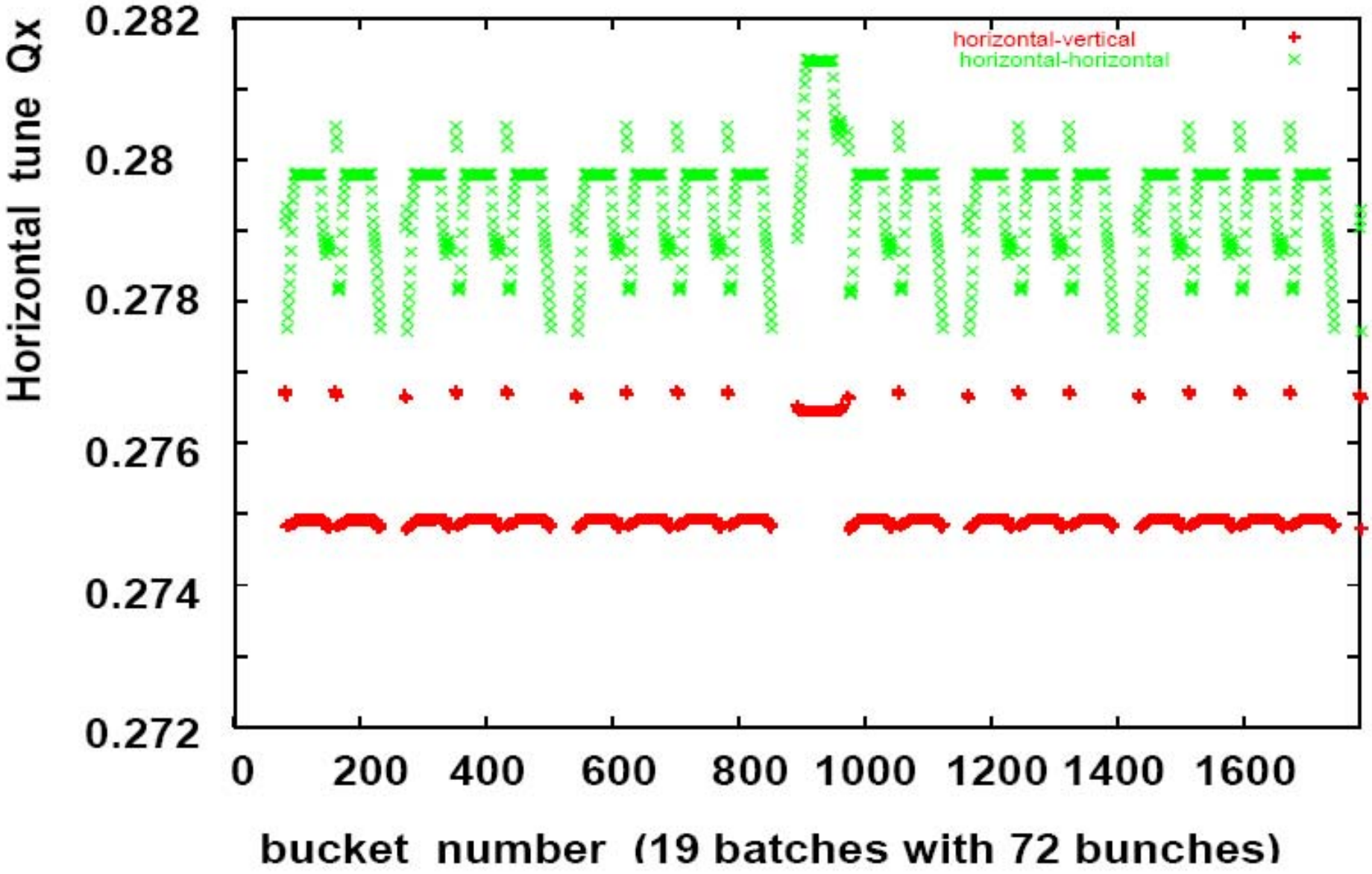
Full LR-BBC and 50% HO-BBC (U.Dorda)



Long Range Compensation

- DC wire can do the job better
  - simpler
  - cheaper
  - … but only for reasonable beam-beam separations (3…4…5? Sigma)
- Electron Lens can
  - act as “electron wire” at ANY separation
  - not infinite current! (enough for 2-4 parasitics)
  - current variable bunch-by-bunch
  - can compensate b-b-b tune spread in *XX* crossing with many parasitics (next slide)

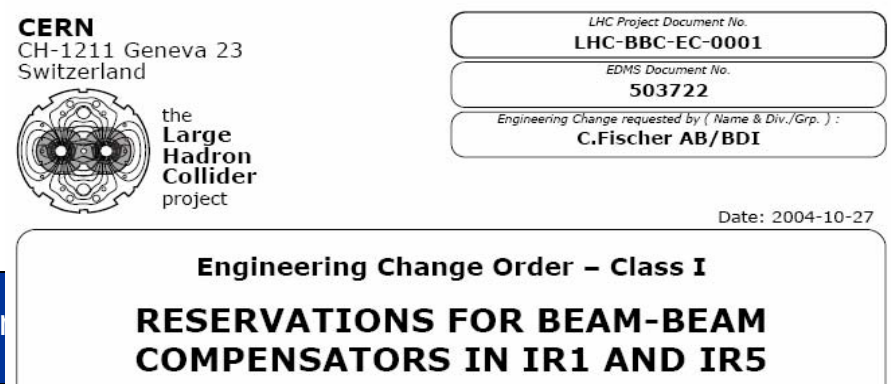
Bunch tunes for *XY* and *XX*



Location in the LHC

- "…There is an official document reserving the space for the wire compensation. The elens could be just before or after. This is the place where the beta functions cross between D1 and D2. Beta is around 2 km for the nominal optics and the nominal dispersion vanishes, except for its component due to the chosen crossing angle."

JPK



CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.
LHC-BBC-EC-0001

EDMS Document No.
503722

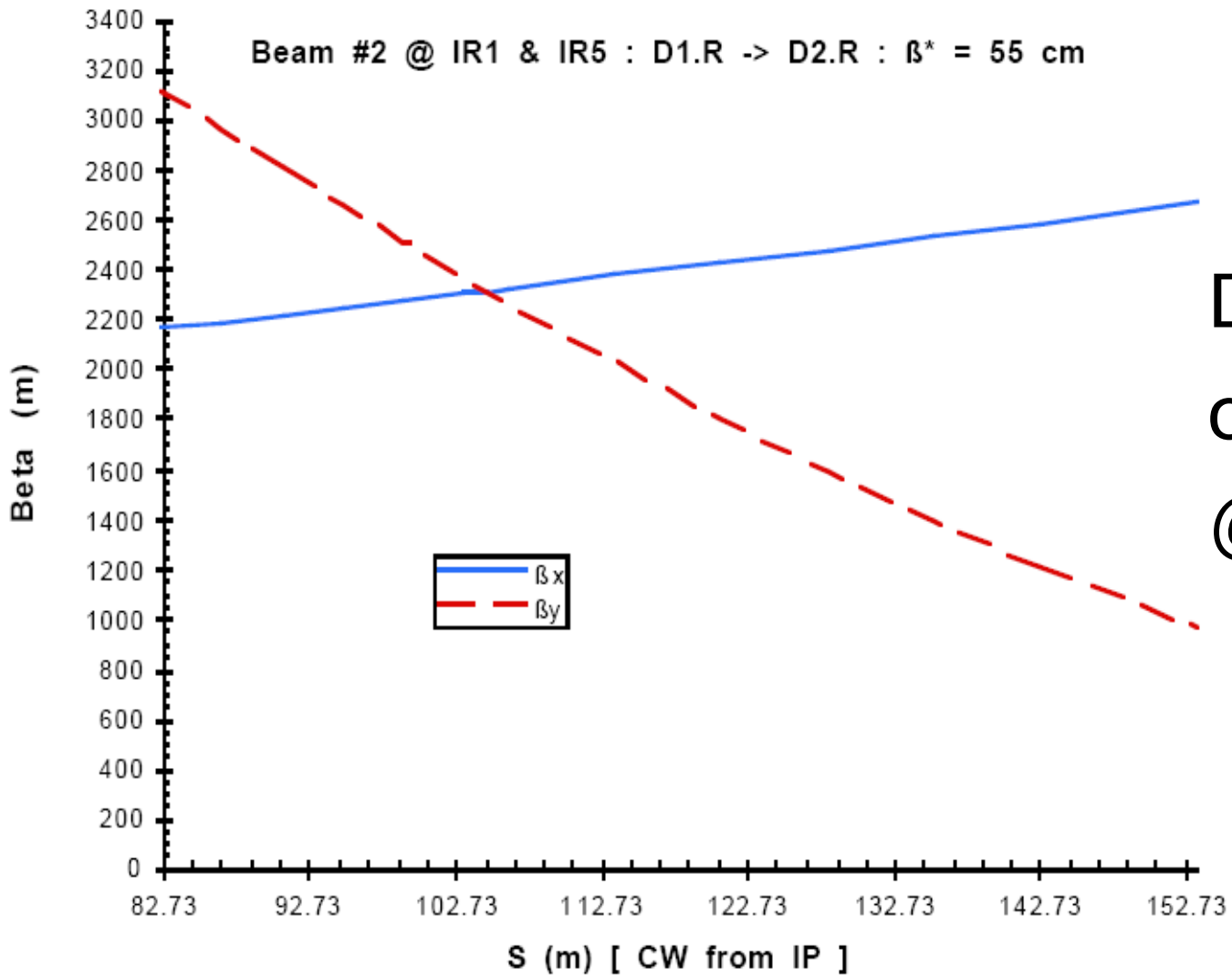
Engineering Change requested by (Name & Div./Grp.) :
C.Fischer AB/BDI

Date: 2004-10-27

Engineering Change Order – Class I

RESERVATIONS FOR BEAM-BEAM COMPENSATORS IN IR1 AND IR5

Location in LHC – I (55 cm)



J.Johnstone

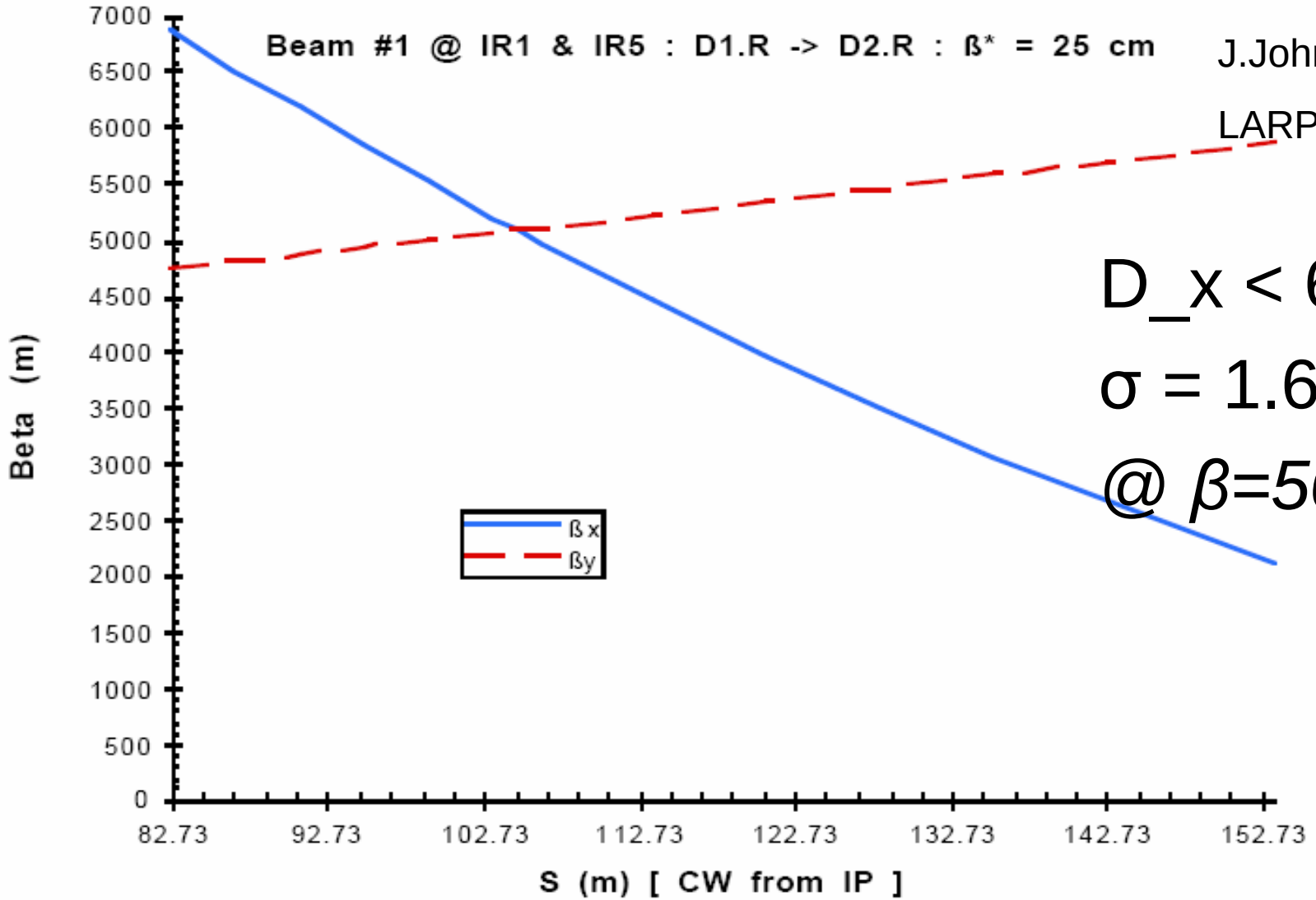
LARP-doc-560

D_x < 9 cm

σ = 1.1 mm

@ β=2300m

Location in LHC – II (25 cm)



J.Johnstone

LARP-doc-560

D_x < 6 cm

σ = 1.6 mm

@ β=5000m

Where are we now?

- There is interest at FNAL, BNL, CERN :
  - FNAL wants to study and understand TEL effects and put TELs in Tevatron Collider operations
    - Tevatron stops in Sep 2009 (Sep 2010 possible)
  - BNL wants to simulate, build and install RELs for head-on BBC in RHIC
    - 1 year for simulations, 1-2 years to build and install
  - CERN wants to explore LEL possibilities for the LHC luminosity upgrade(s)
    - The first upgrade in 2012 (?), big upgrade in 2016(?)
- We all want to collaborate and get others in

Resources

- Fermilab:
  - V.Kamerdzhiev and full time Engineer, 10% VS
  - A.Valishev, Yu.Alexahin (part-time, theory & simulation support)
- Brookhaven:
  - Y.Luo and his group to simulate and develop
  - W.Fischer – management and operation support
- CERN:
  - Excellent work by U.Dorda, hope for T.Pieloni
  - Support/interest from FZ, JPK, OB
- LARP will support ELs in FY08 : 1-1.5 FTE

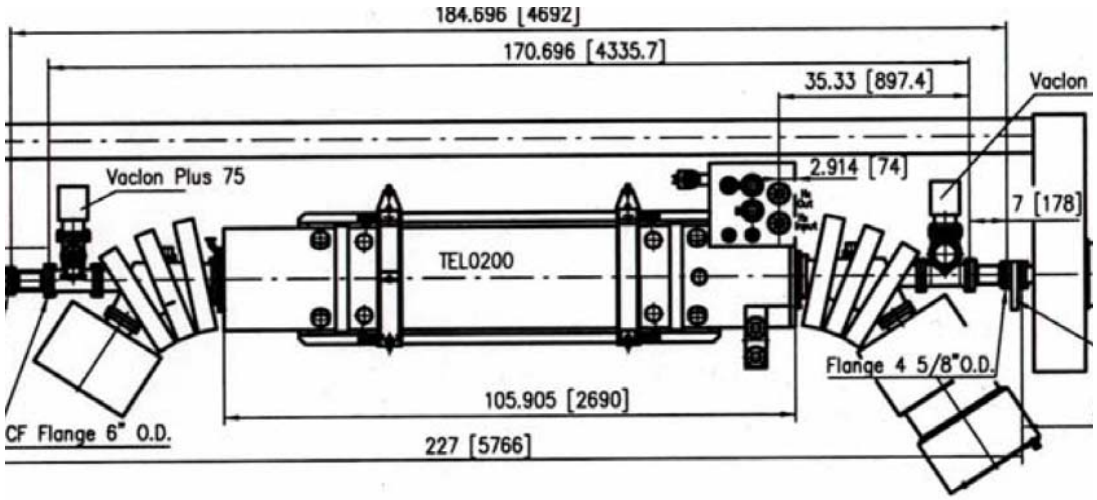
High priority items

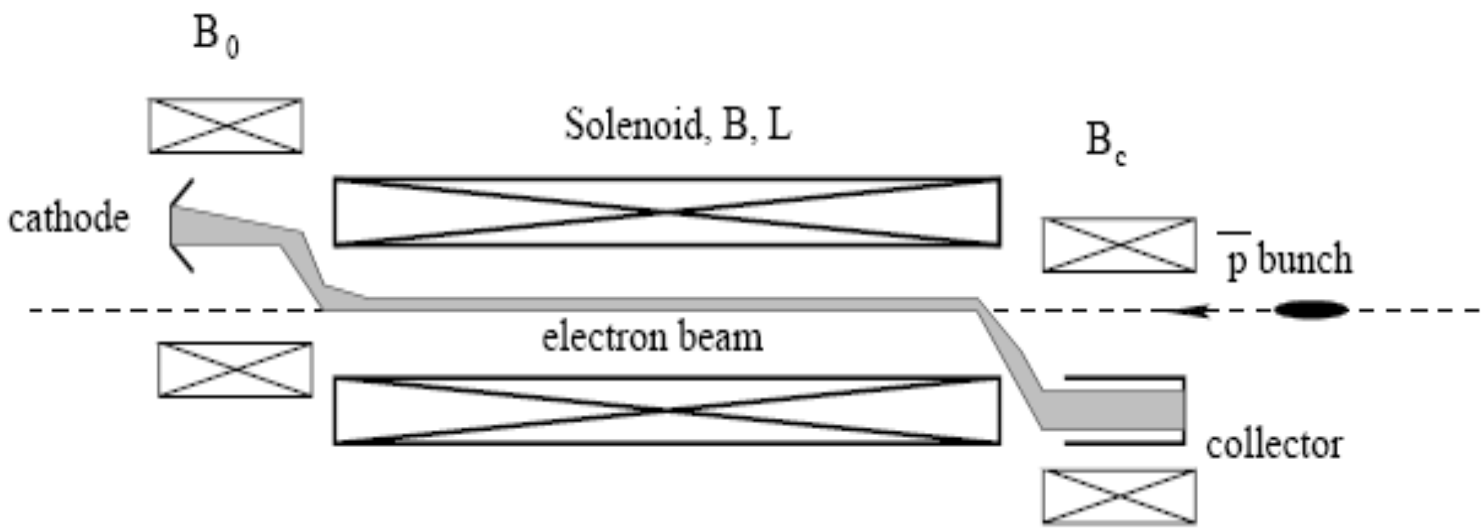
- Fermilab:
  - Continue studies:
    - Beam size effect
    - Quantify Improvement vs e-current *R(J_e)*
    - Induce and detect pbar tunespread reduction or proton tunespread broadening
  - Simulate and explain TEL results and “puzzles”
  - Provide design help to BNL team (m.b. hardware)
- Brookhaven:
  - Long list of HO-BBC questions to answer (next slide)
  - Start the design (and later build) RELs, integration
- CERN:
  - U.Dorda to contribute to LEL design considerations
  - Very desired: T.Pieloni on Tev spectra and LEL effect

Questions: Analysis and Simulations

- Will truncated Gaussian e-current density distribution work (improve lifetime and reduce diffusion rates)?
  - Straightforward tracking with a weak-strong code
  - Is partial compensation helpful?
- Is there a better distribution?
  - from first principles, theory, analytical consideration
  - Effects are beta_EL/beta*/sigma_z; or dP/P
  - check in numerical tracking
- Importance of e-p interaction in bending sections
  - Which configuration is better? Pi-shape or S-shape
  - Is the choice tune dependent?
- Lifetime deterioration due to e-p misalignment:
  - e-beam straightness tolerances
  - relative e-p displacement, angle
- Effect of <u>low-frequency</u> variations dJ, dX on beam lifetime
- Ion cleaning efficiency tolerances
- Interference with wires in LHC – if there is any
- e-beam effect on coherent stability or strong-strong beam-beam effects

e-Lens configurations

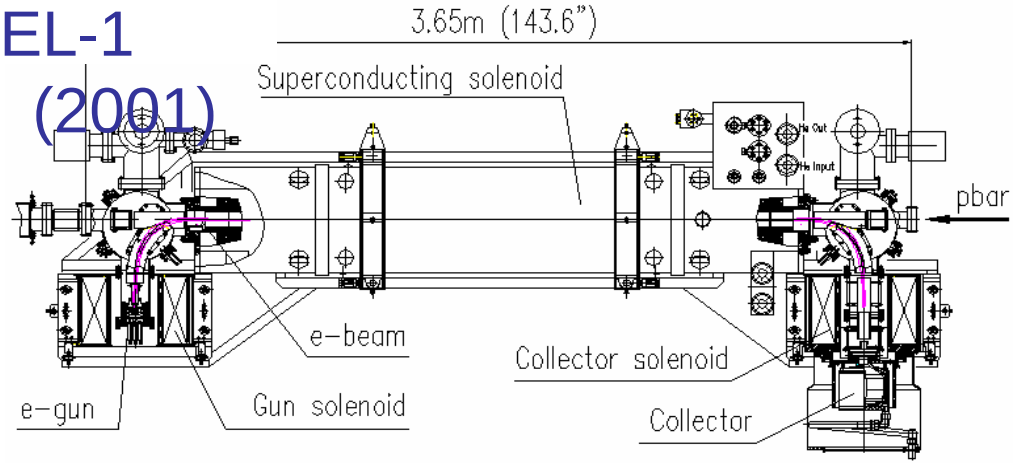


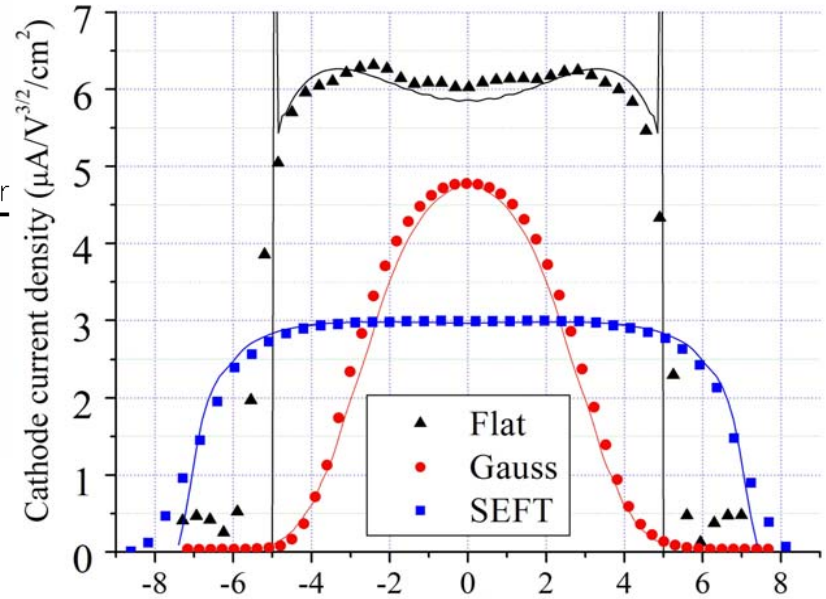


Back up slides

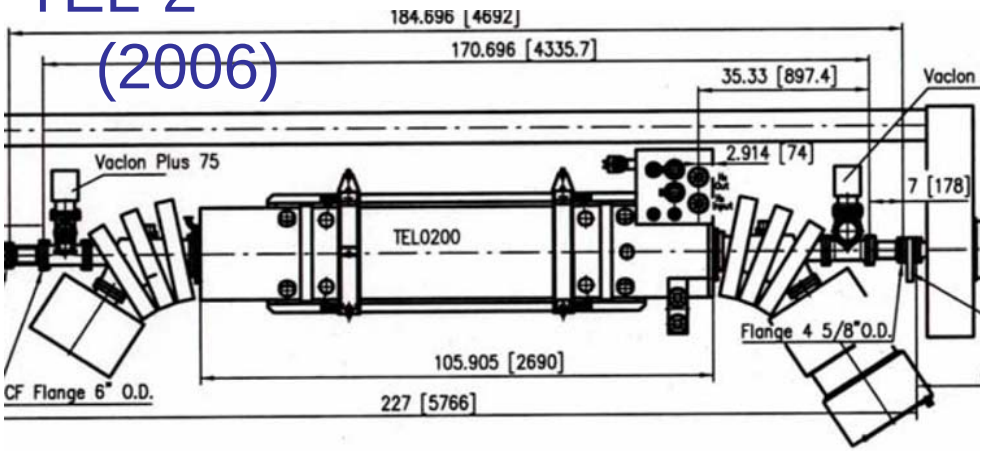
Is Technology Available?

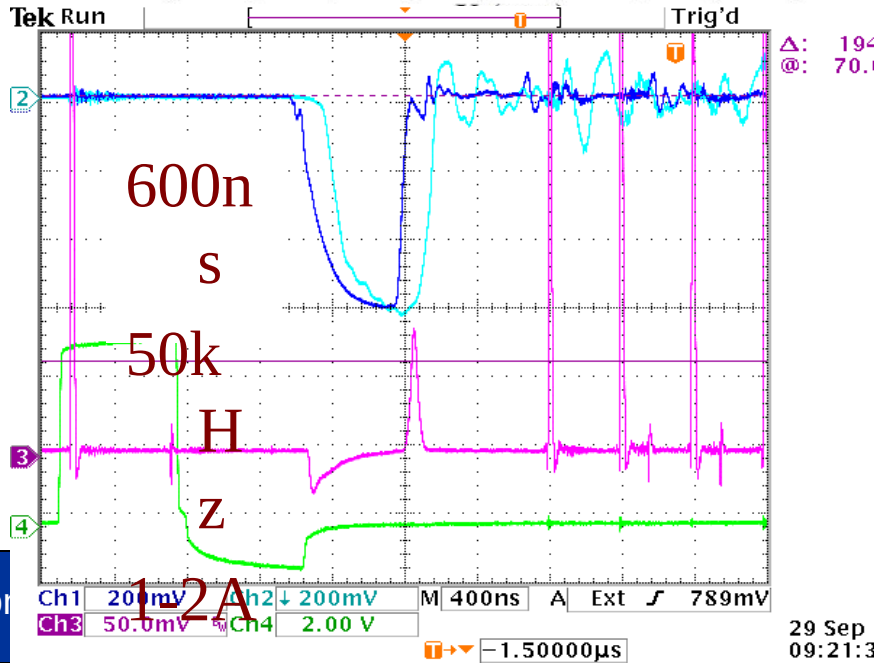
TEL-1 (2001)





TEL-2 (2006)



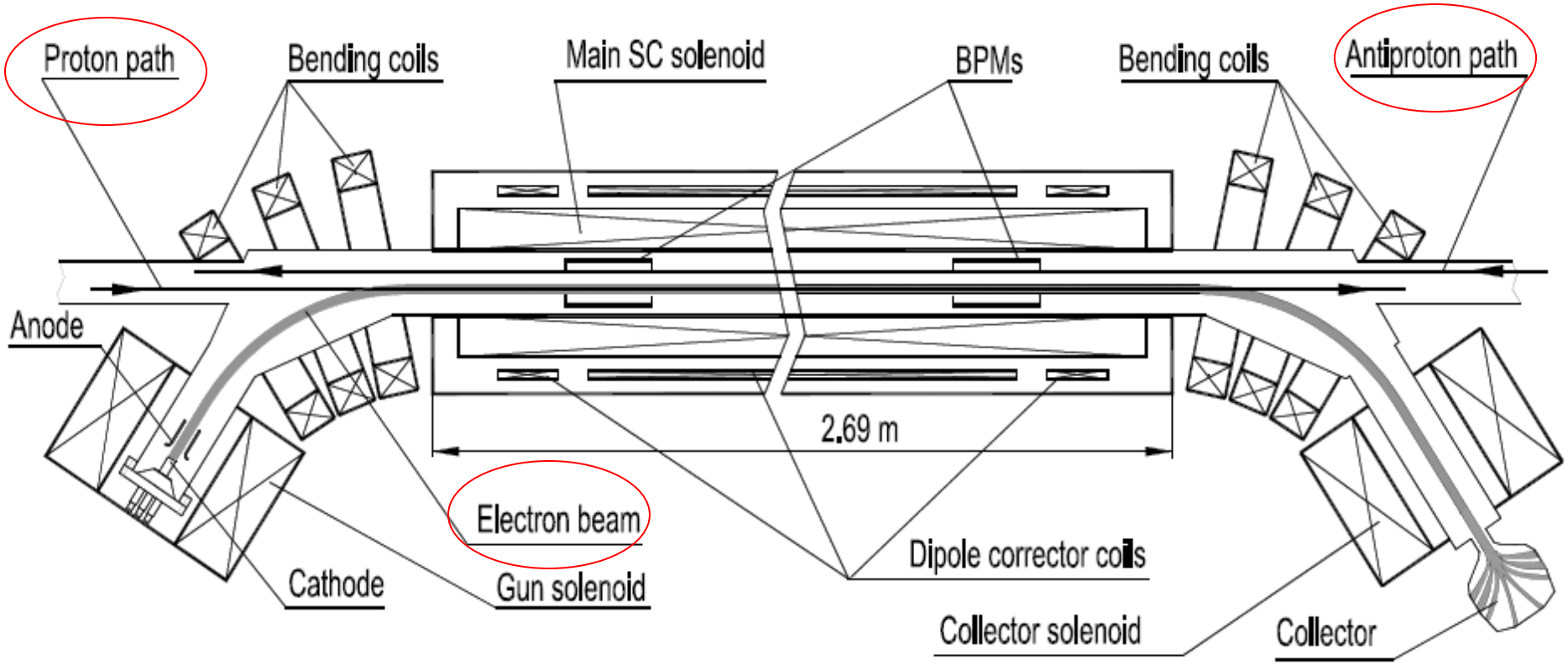


+ Marx HV Modulator, SEFT gun, 2 Cryo bypasses, 4-plate BPMs & Cables

What is Electron Lens?

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

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



How strong is it?

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

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

this product is const(E)

For many applications electron beam size needs to be nxσ protons

e.g. n=1 for head on BBC

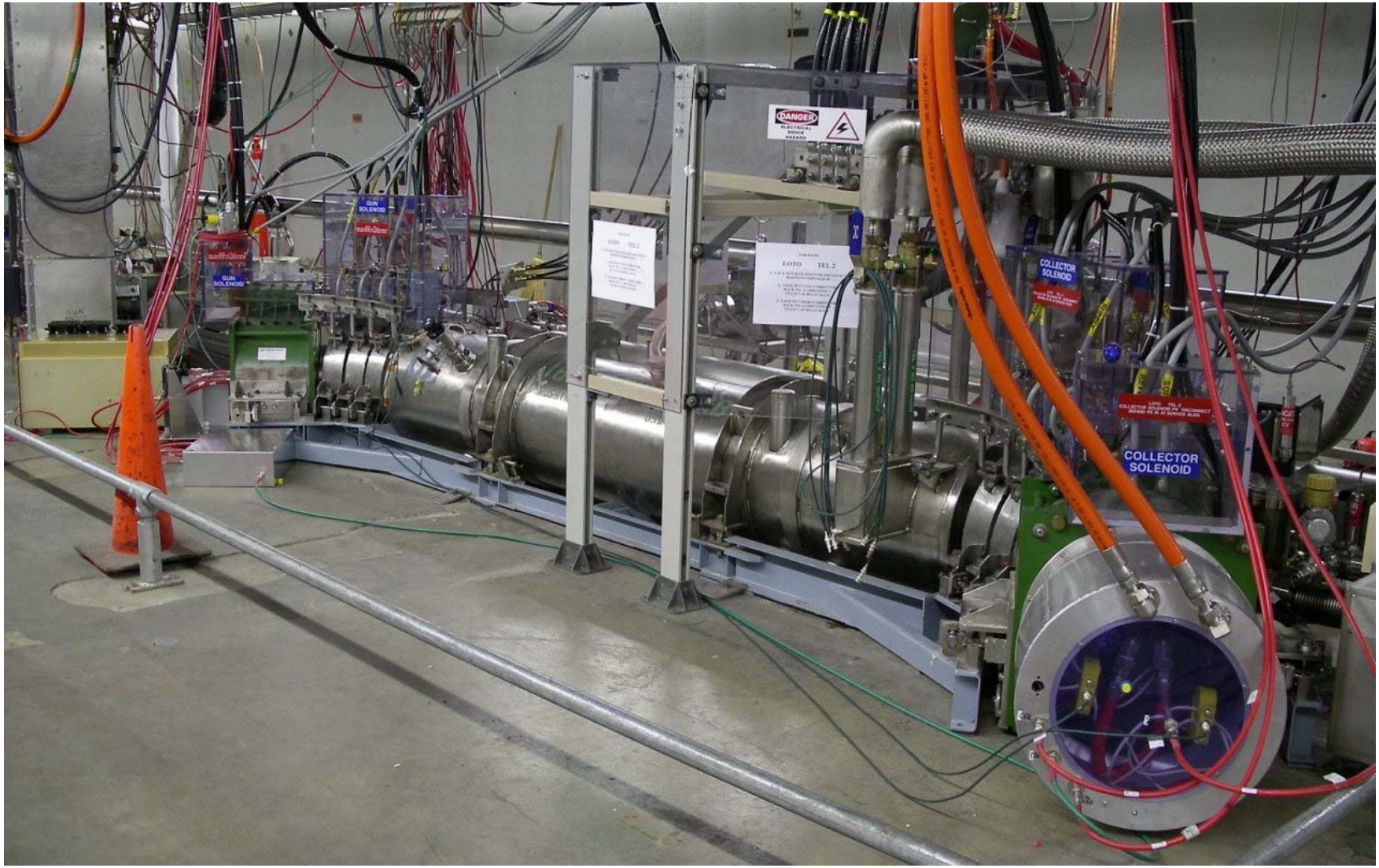
→RHIC

→Tevatron

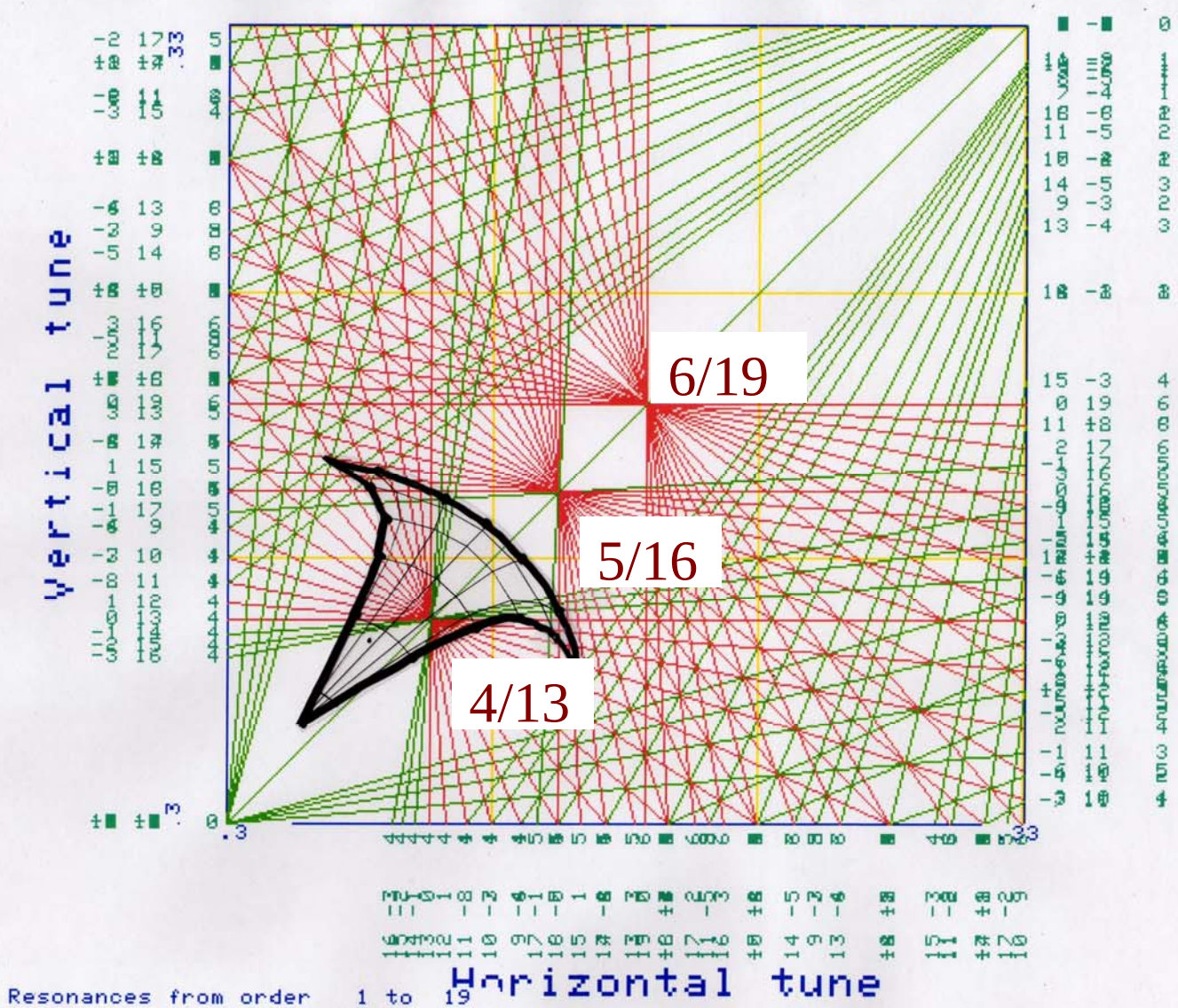
→LHC

SAME!

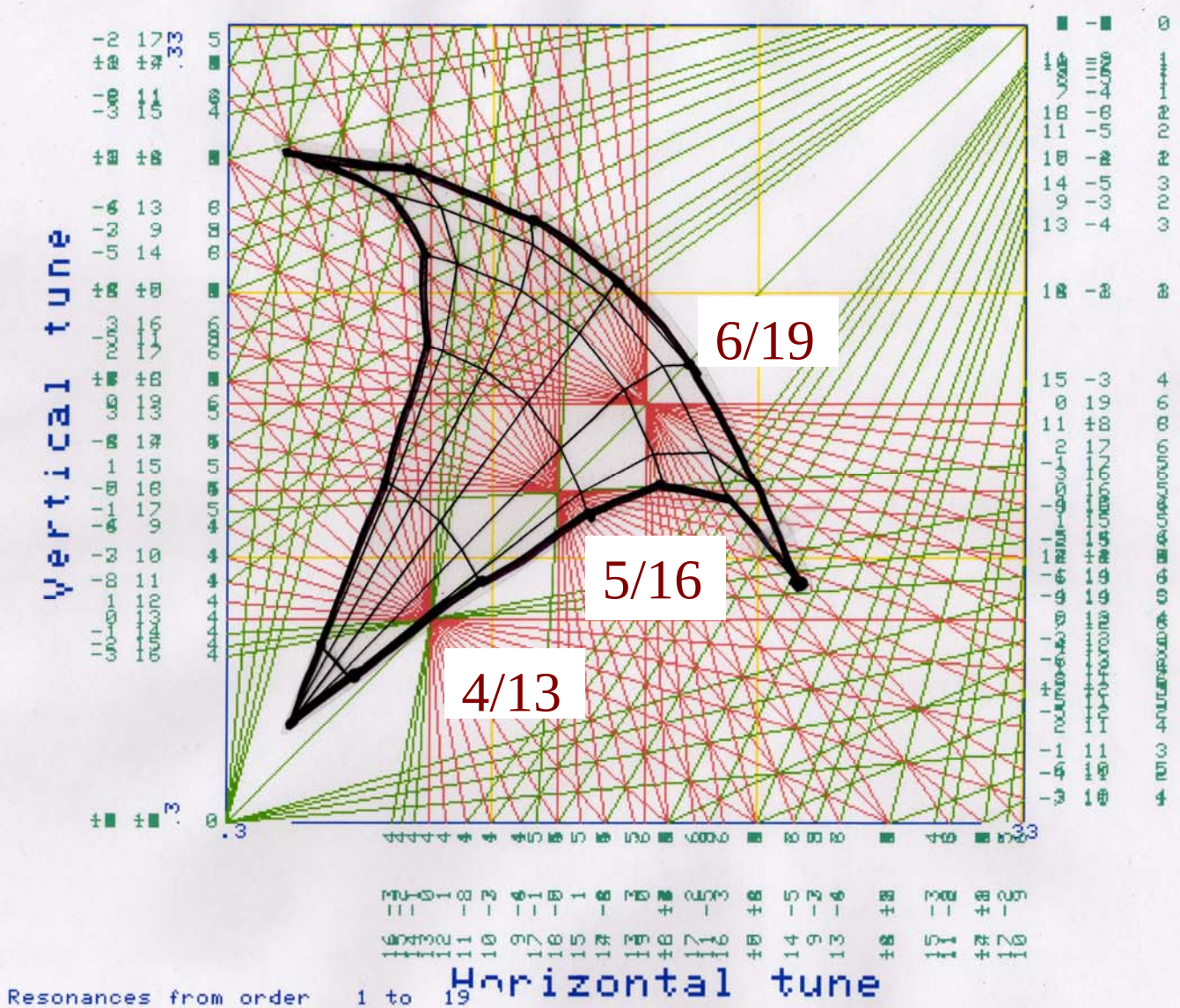
TEL2 In The Tunnel (A0)



LHC footprint (design)



LHC footprint (x2 Np/bunch)



50% Head-On Compensation by LEI