Electron beam generation and control in Tevatron Electron Lenses

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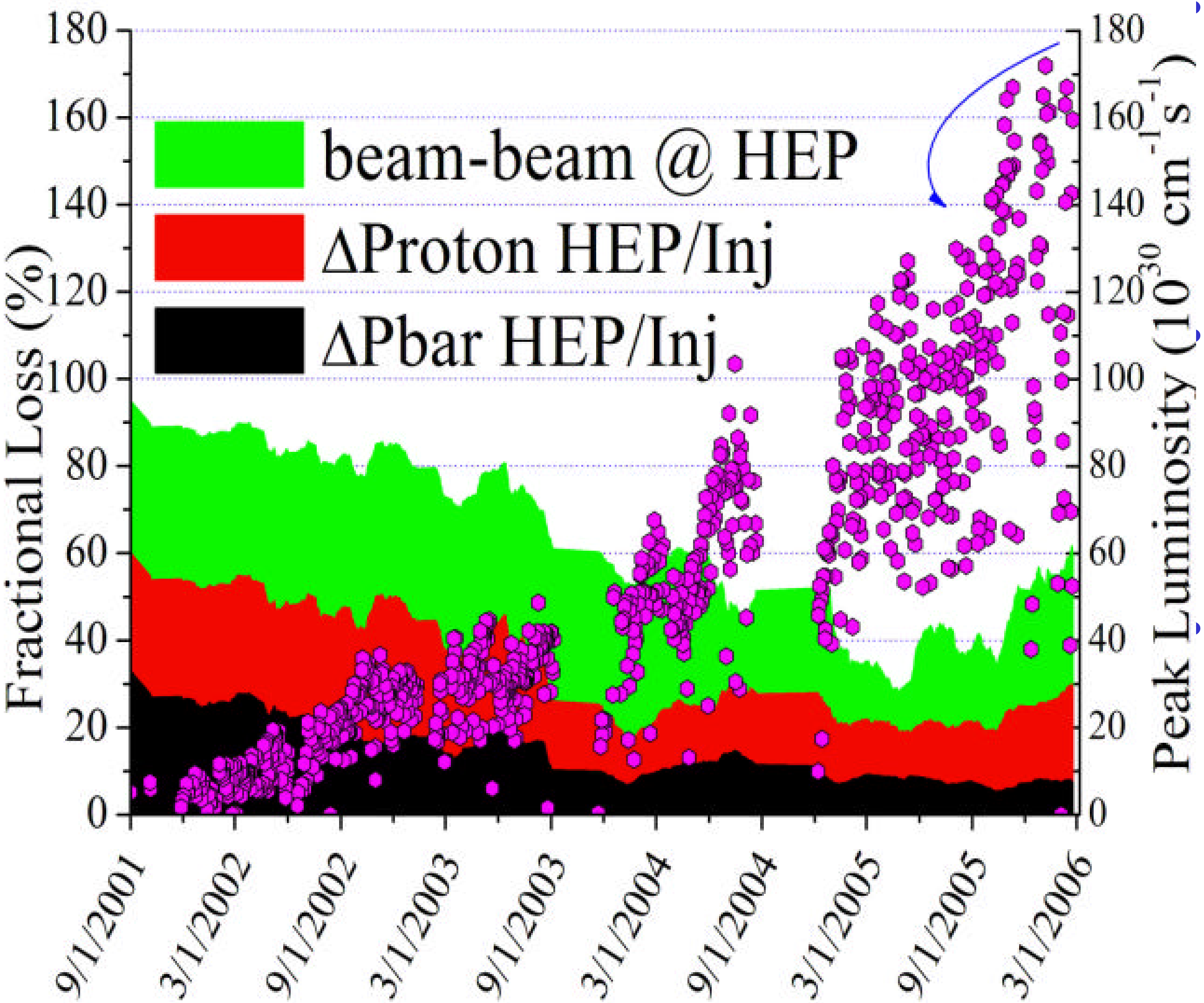
Fermilab

Tevatron Luminosity Losses

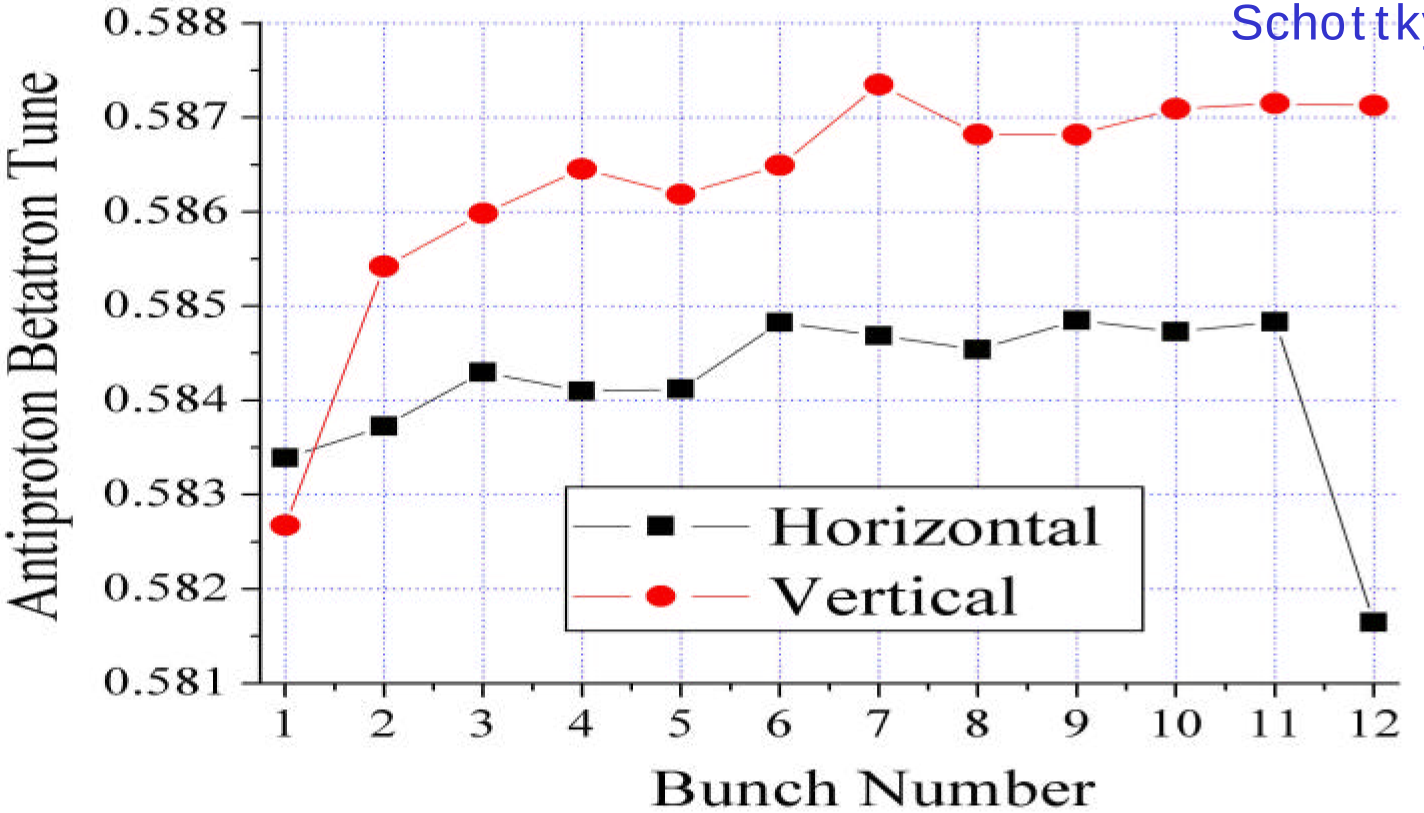


- Three components:
  - a-loss in cycle
  - p-loss in cycle
  - p&a lifetime and emittance growth in collissions
- The first two is combination of aperture/emittance and beam-beam effects
- Loss of luminosity consists of :
  - p-lifetime due to head-on
  - a-lifetime loss and emittance grwoth due to long-range beam-beam effects

Long-range effects as seen in stores

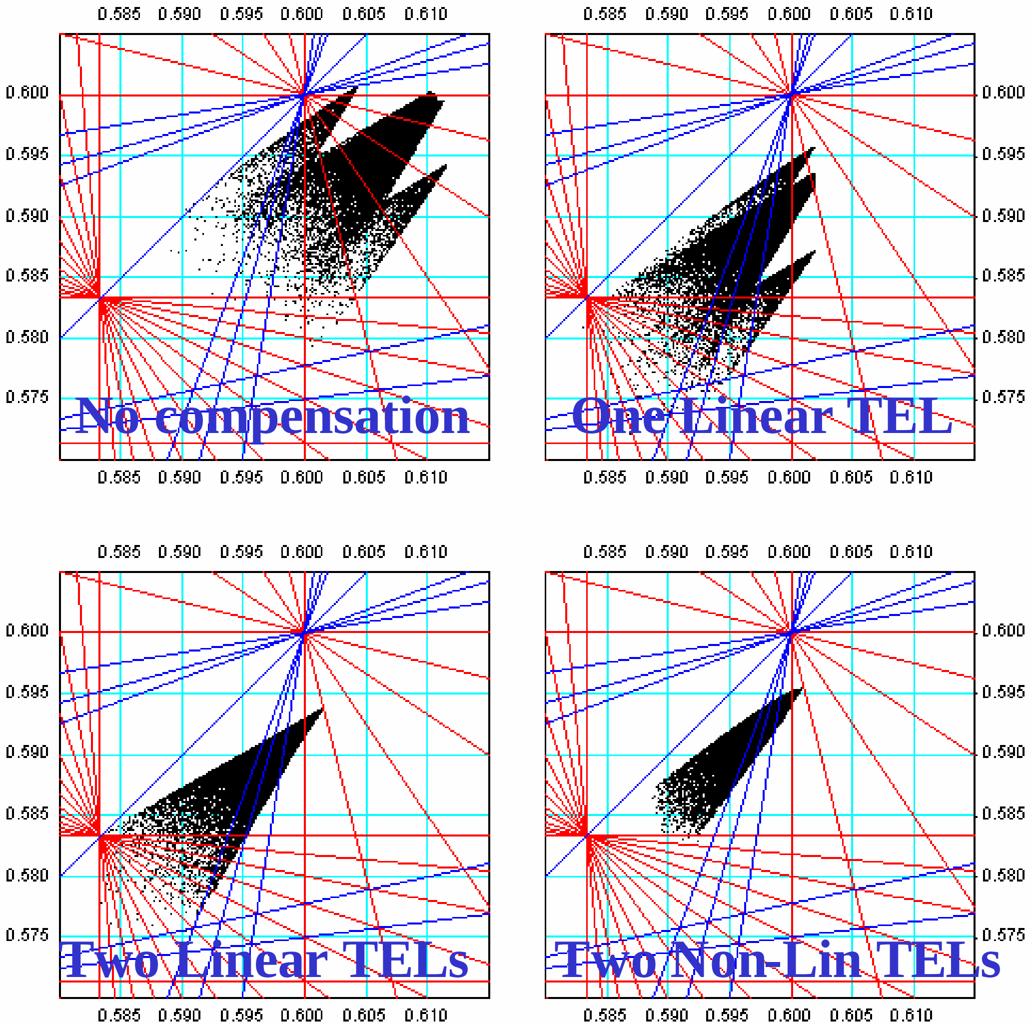
Bunch-by-bunch tune spread as a result of parasitic beam-beam interaction

Measured by 1.7GHz Schottky monitor



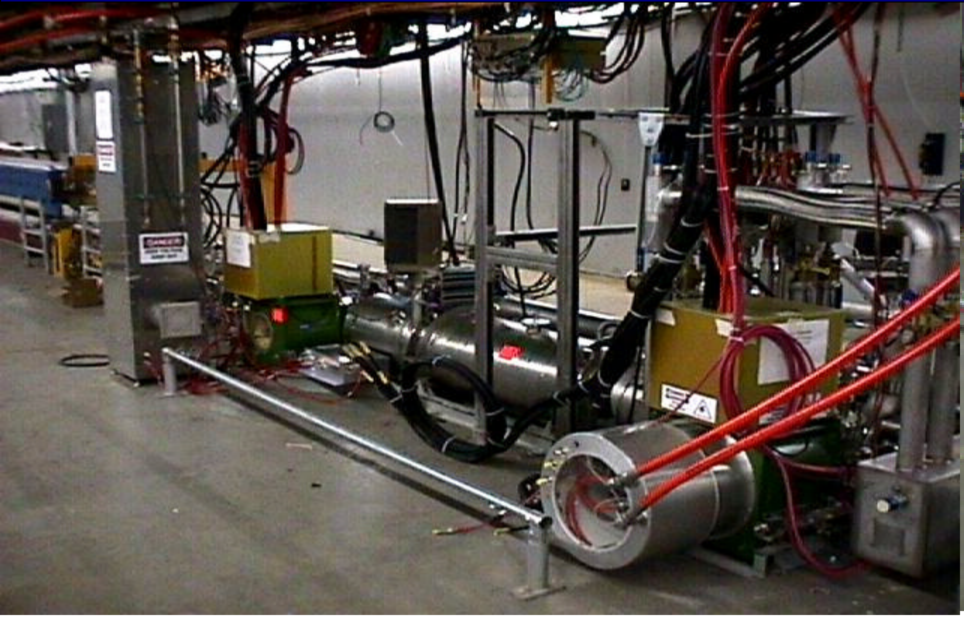
- 36 bunches: 3 trains of 12 – 3-fold symmetry
- Lifetime and emittance growth vary bunch-by-bunch

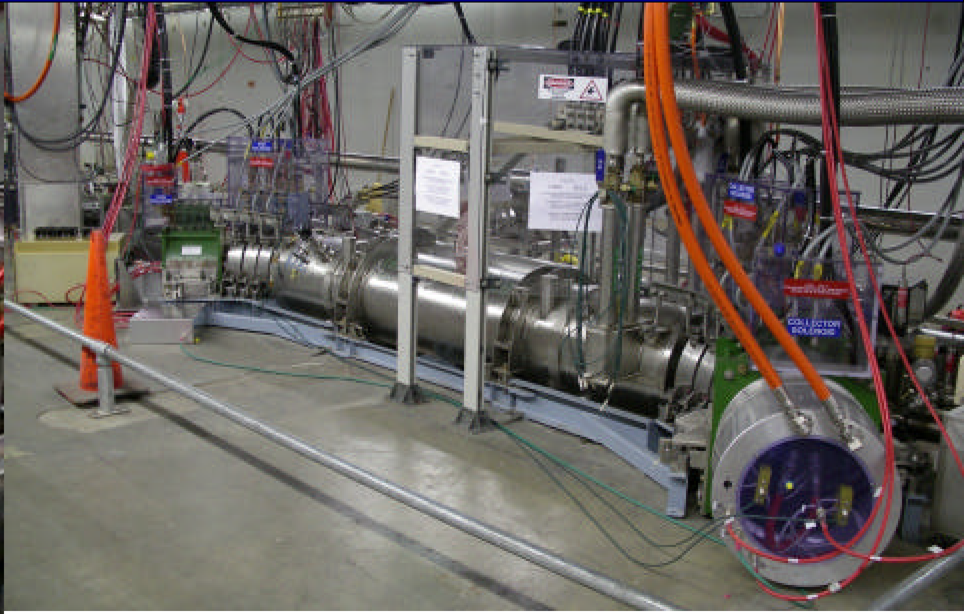
Theory of Beam-Beam Effects for Antiprotons and Compensation



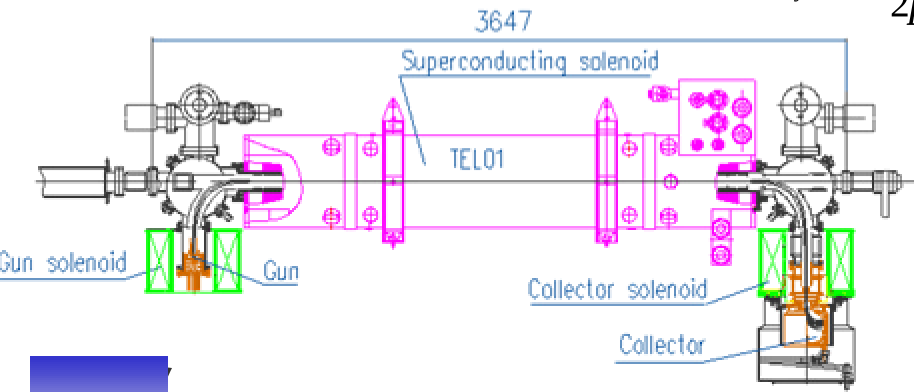
- Head-On tune shift 2 IPs ξ=0.020-0.024
- Bunch-by-bunch tune spread dQ=0.004-0.006
- Two electron lenses can compensate (in average) space charge forces of positively charged protons acting on antiprotons in the Tevatron by interaction with a negative charge of a low energy high-current e-beam
- Major requirements:
  - 1-3 A e-current
  - 6-12kV e-energy
  - modulated *t*~800ns
  - ~2 m long, ~3mm diameter
  - transverse shape control
  - e-p position control <0.2mm

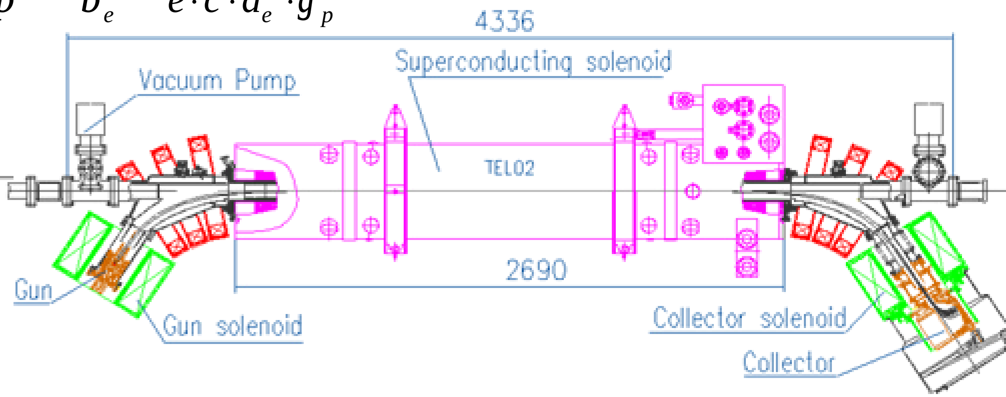
Tevatron Electron Lenses: #1(F48) and #2 (A0)



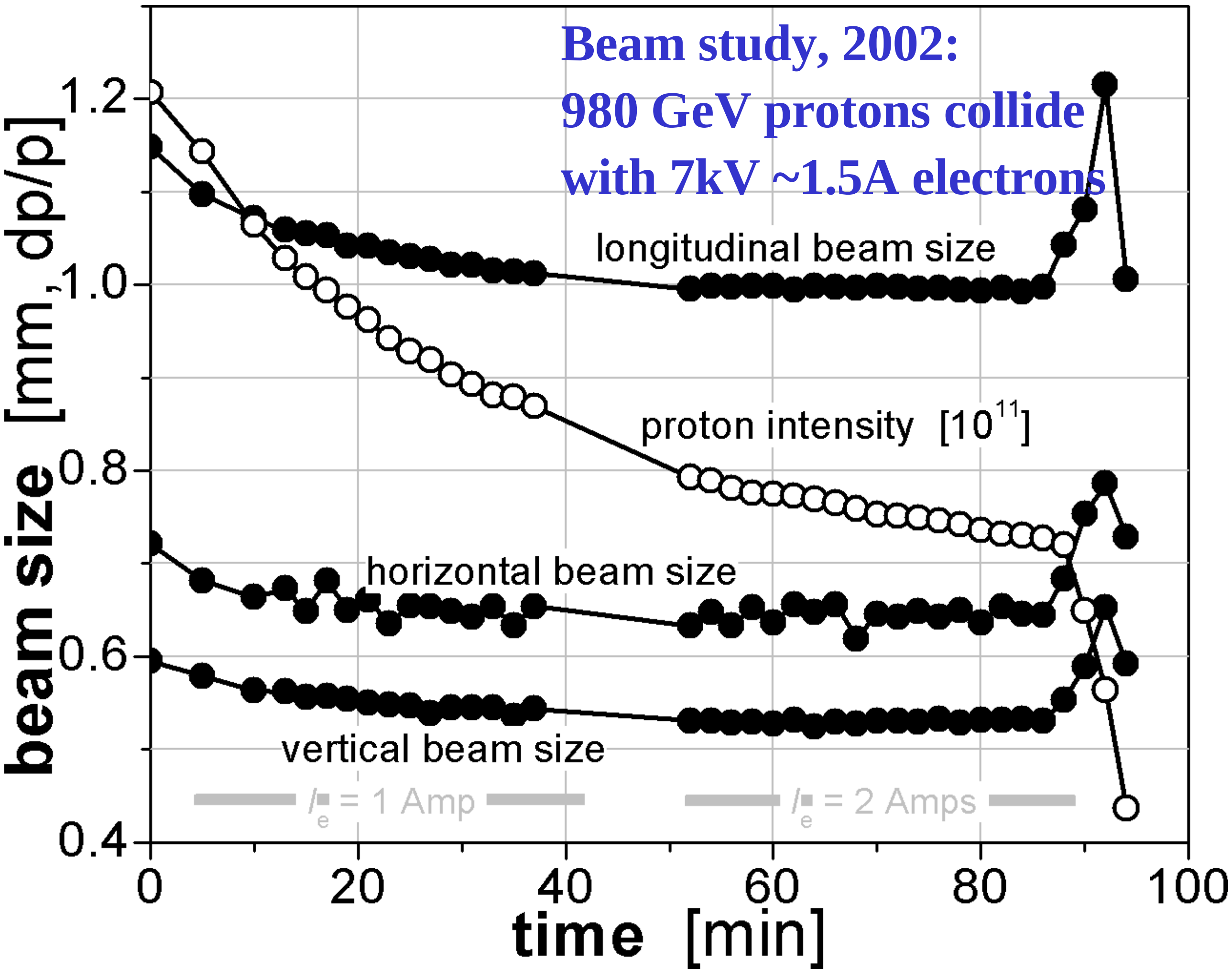


$$dQ_{x,y} = \mp \frac{b_{x,y}}{2p} \cdot \frac{1 \pm b_e}{b_e} \cdot \frac{J_e L_e r_p}{e \cdot c \cdot a_e^2 \cdot g_p}$$



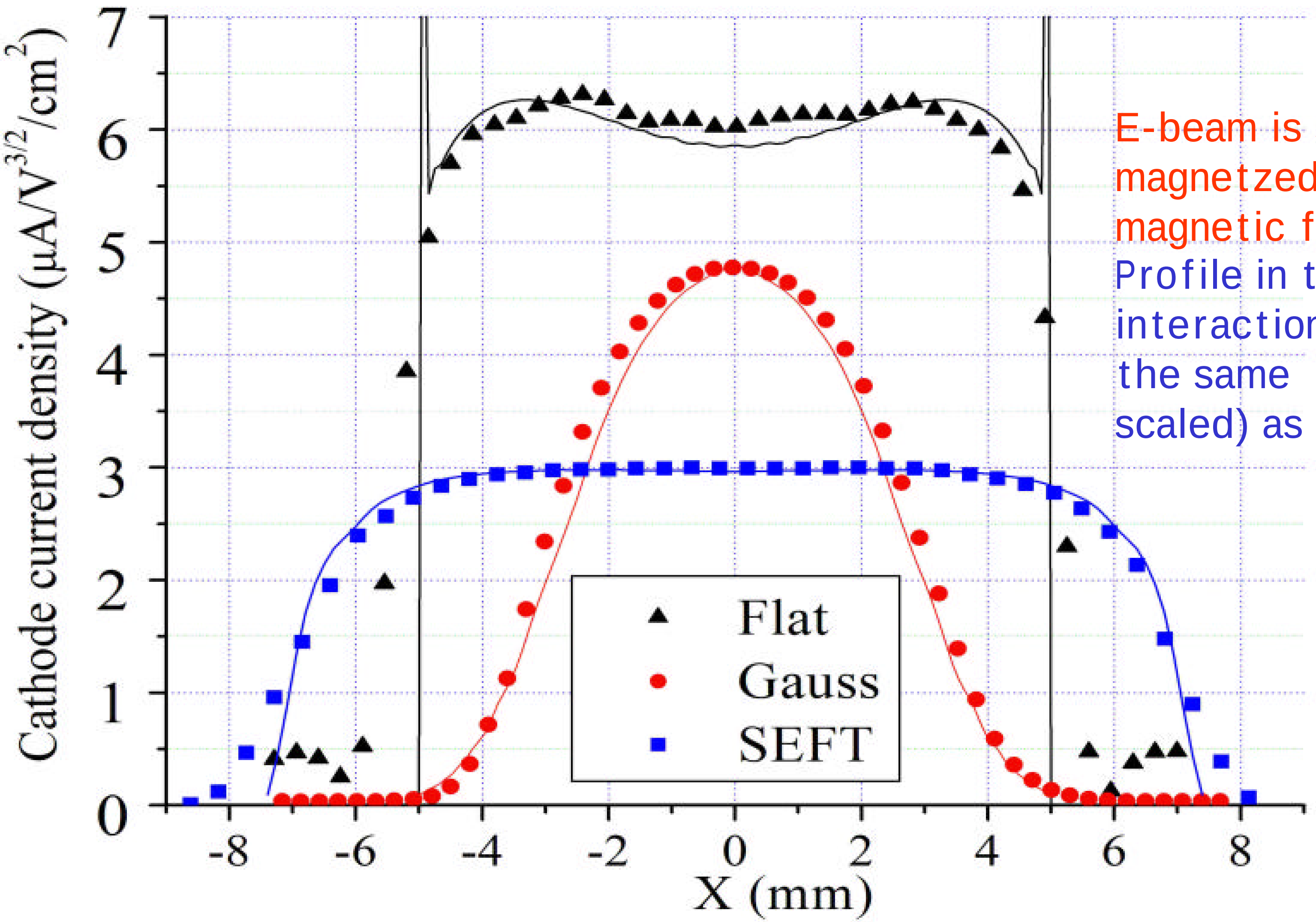


TEL-1 Studies: Sensitivity to position and profile



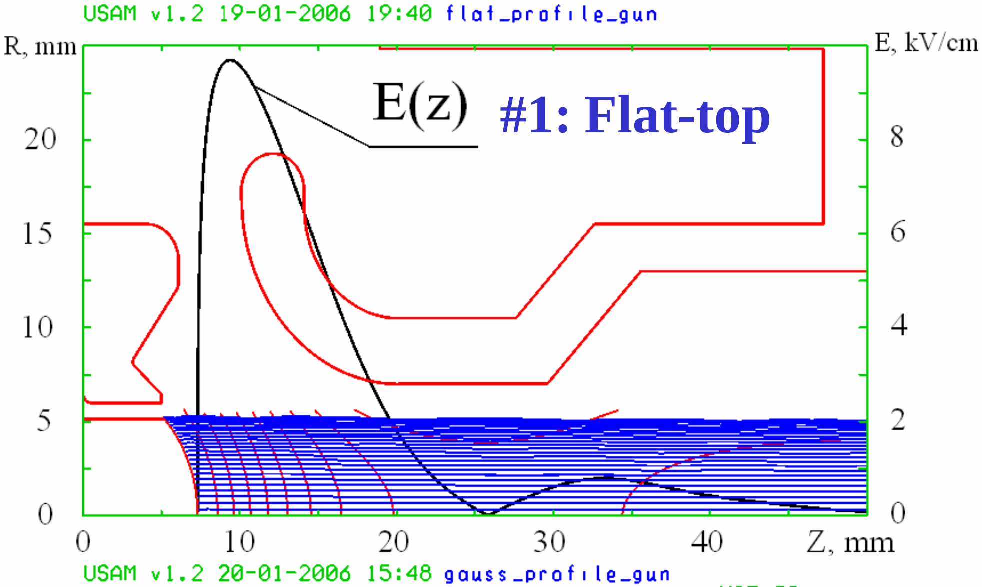
- The very first e-beam profile (~'02) was uniform =flat-top & sharp edges
- Very cumbersome tuning to get good lifetime (max ~40 hrs and dQ=0.005) and centering e-beam on antiprotons or protons
- The second one had Gaussian profile ('02-'05) – still hard to center but better lifetime (140 hrs max)
- 3rd one has flat-top and smooth edges

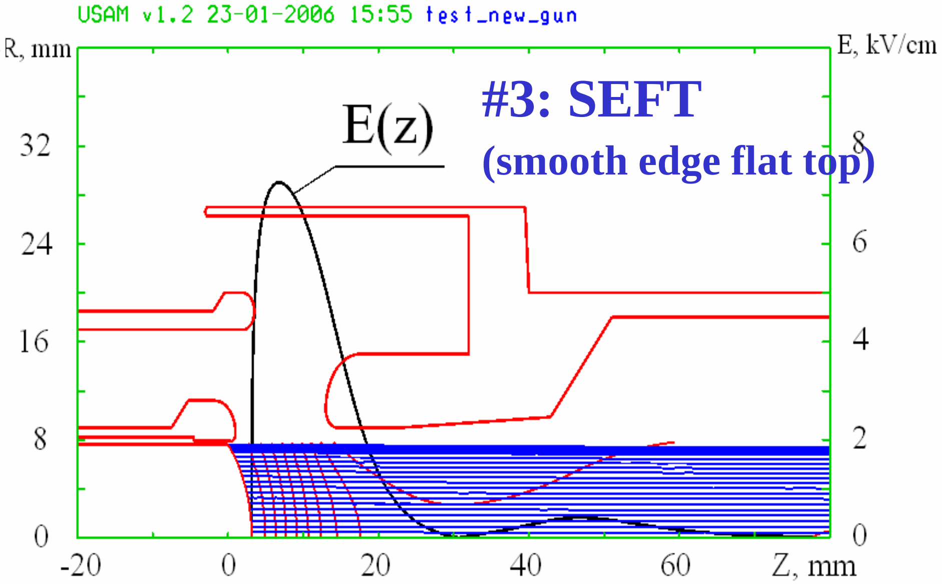
Three current profiles from TEL-1 e-guns

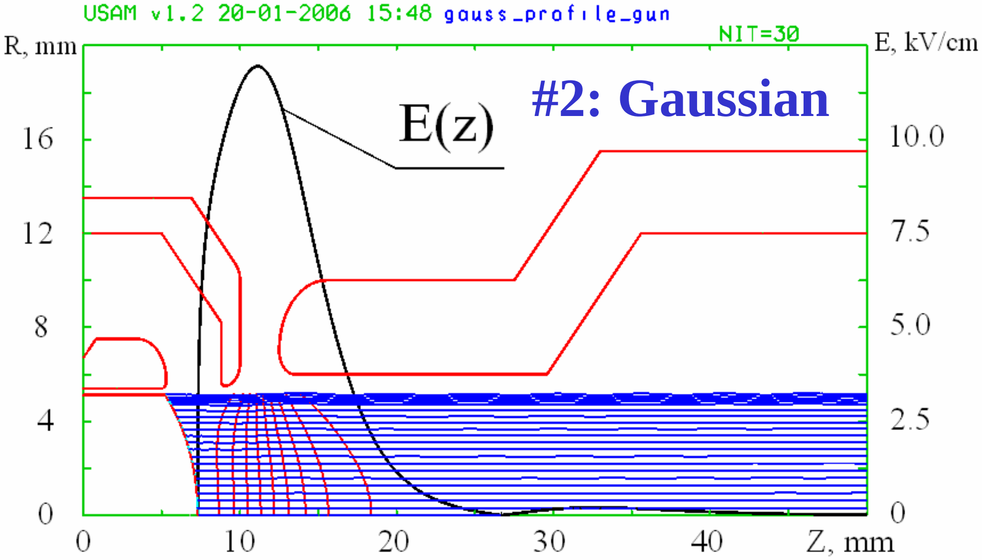


E-beam is strongly magnetzed in 2-40 kG magnetic field →
Profile in the interaction region is the same (just scaled) as on cathode

Ways to change the profile: gun geometry

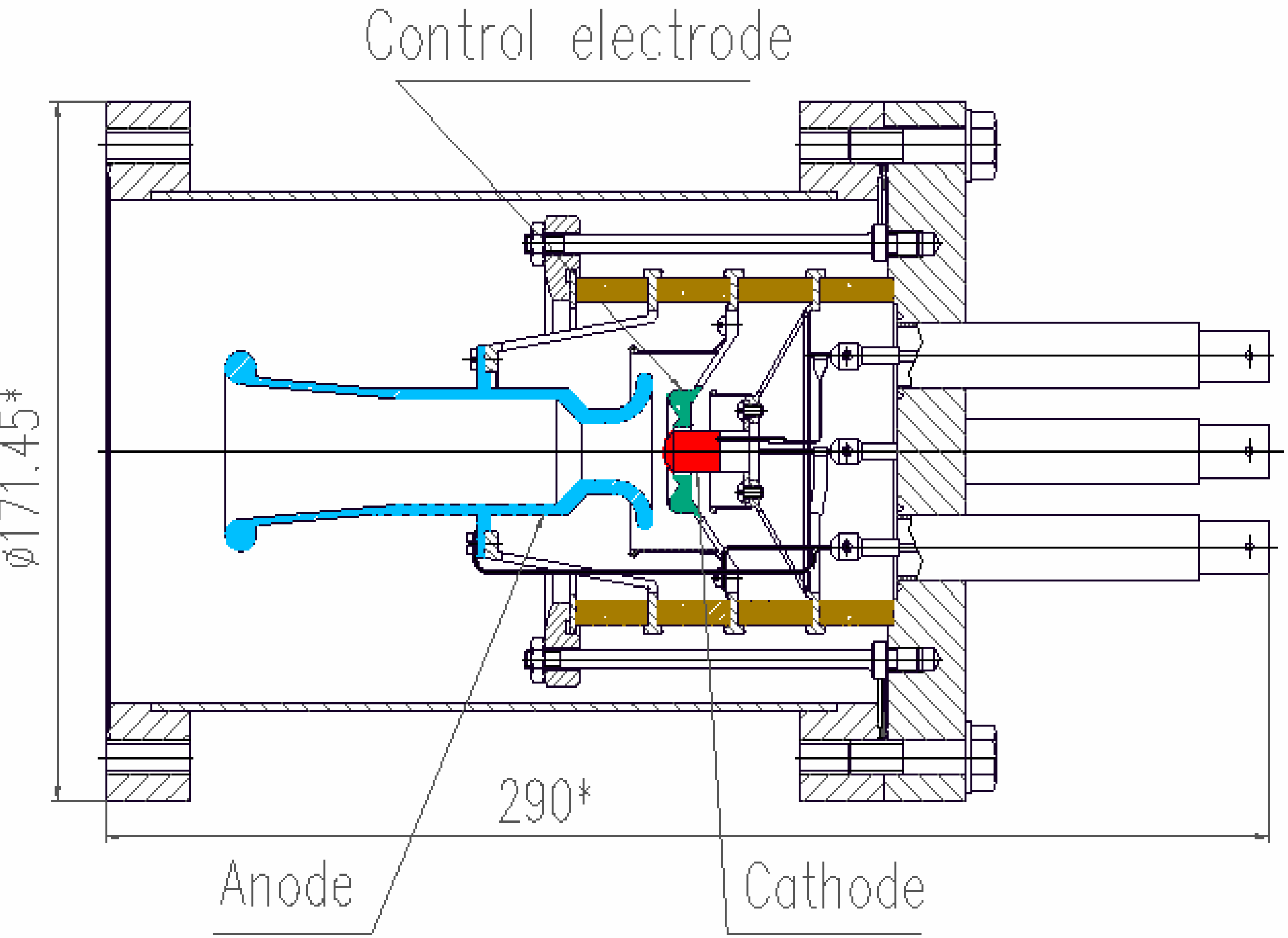






- Shape of the cathode is always 90 degree convex → give max perveance (~6 uP for "flat-top")
- Shape of anode, near cathode ("Pierce") electrode and shape-control electrodes are optimized for given desired current profile
- UltraSAM code (Tiunov, et.al)

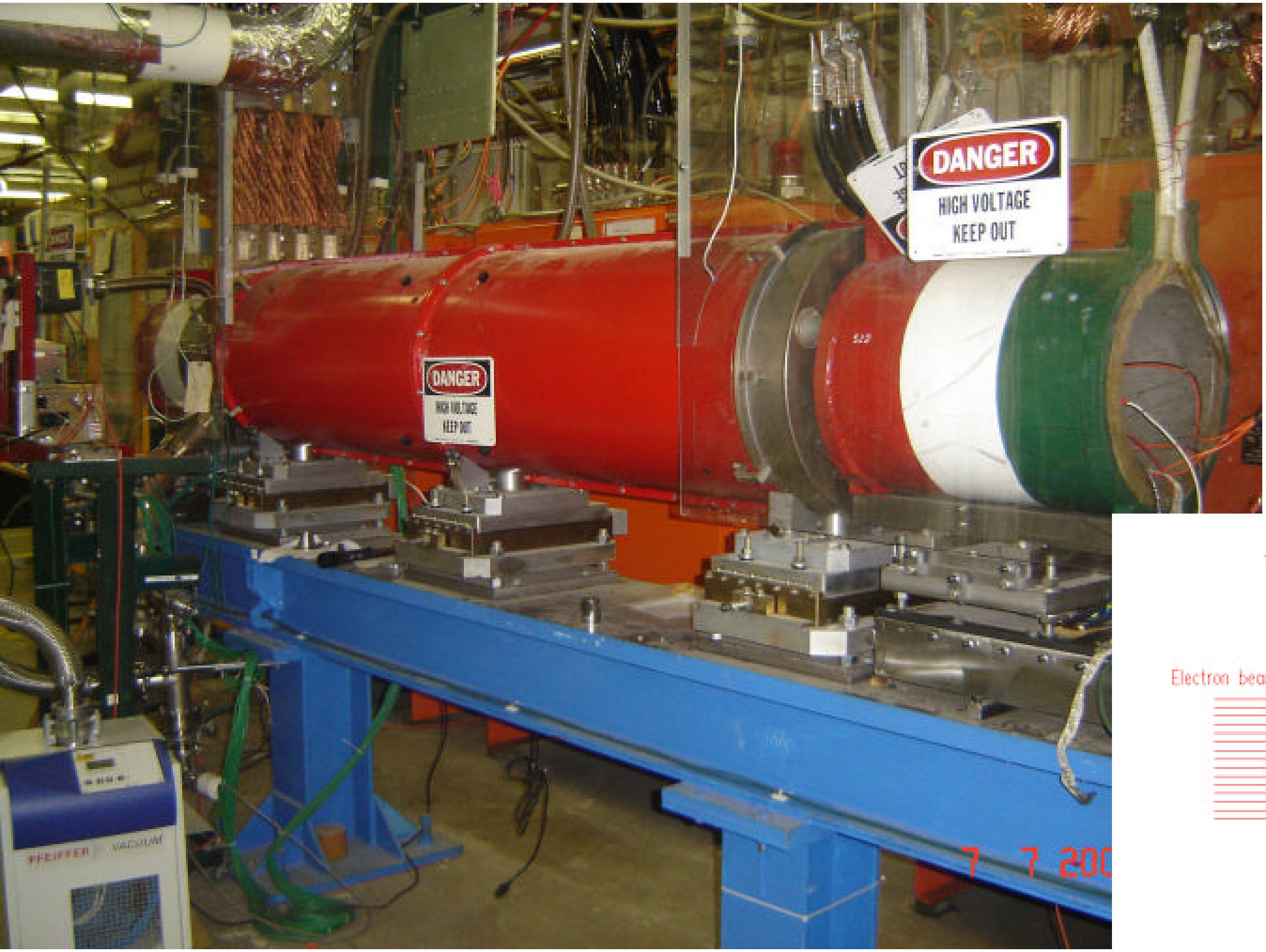
These guns in “Iron”



Designed for 15-20kV, operate at ~10kV

- 0.4” and 0.6” impregnated cathodes from *HeatWave , Inc* (CA)

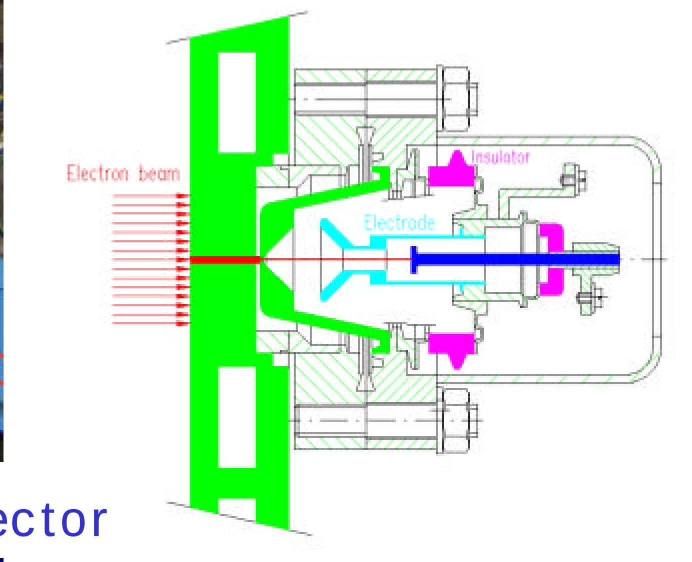
Electron Gun Test Facility



Pin-hole (0.2 mm) + mini-collector:

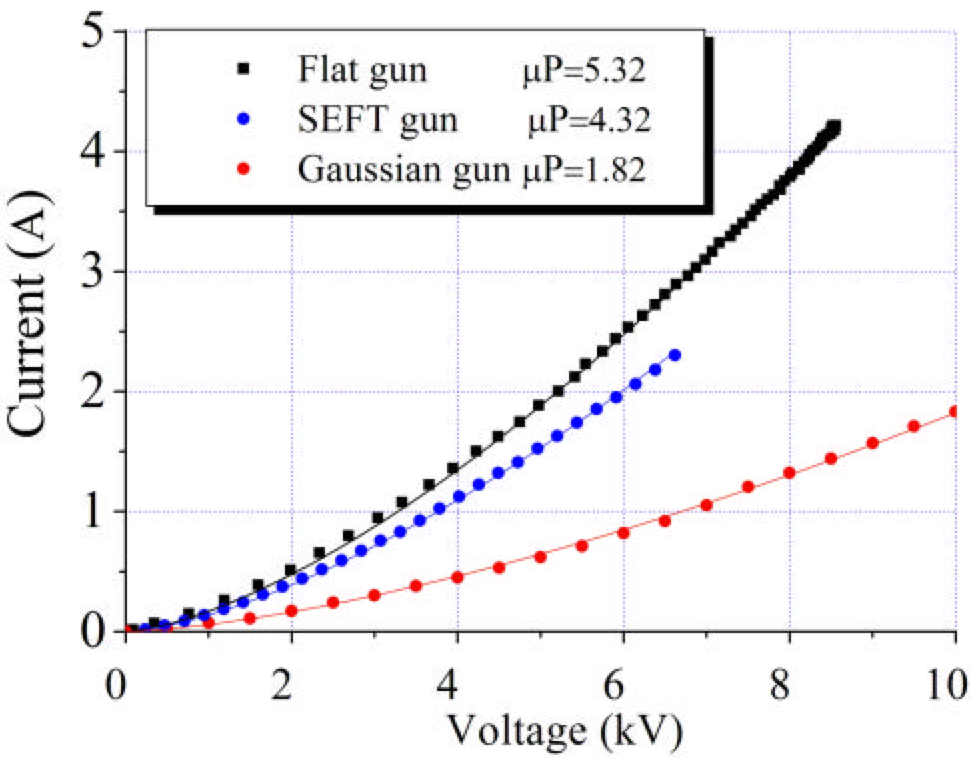
Current profiles

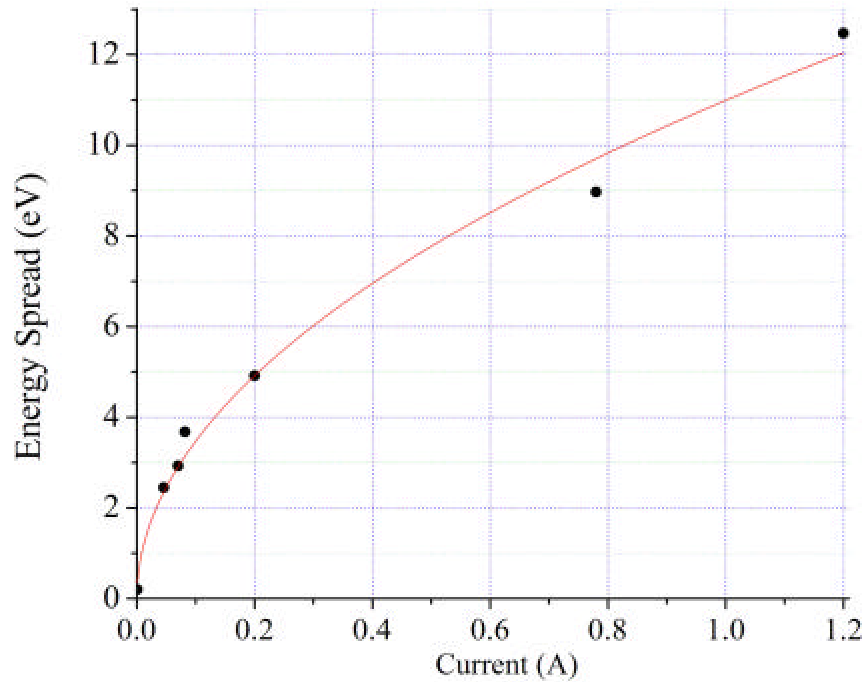
Electron beam energy spread



1-4 kG B-field all the way from gun to collector

Electron beam measurements

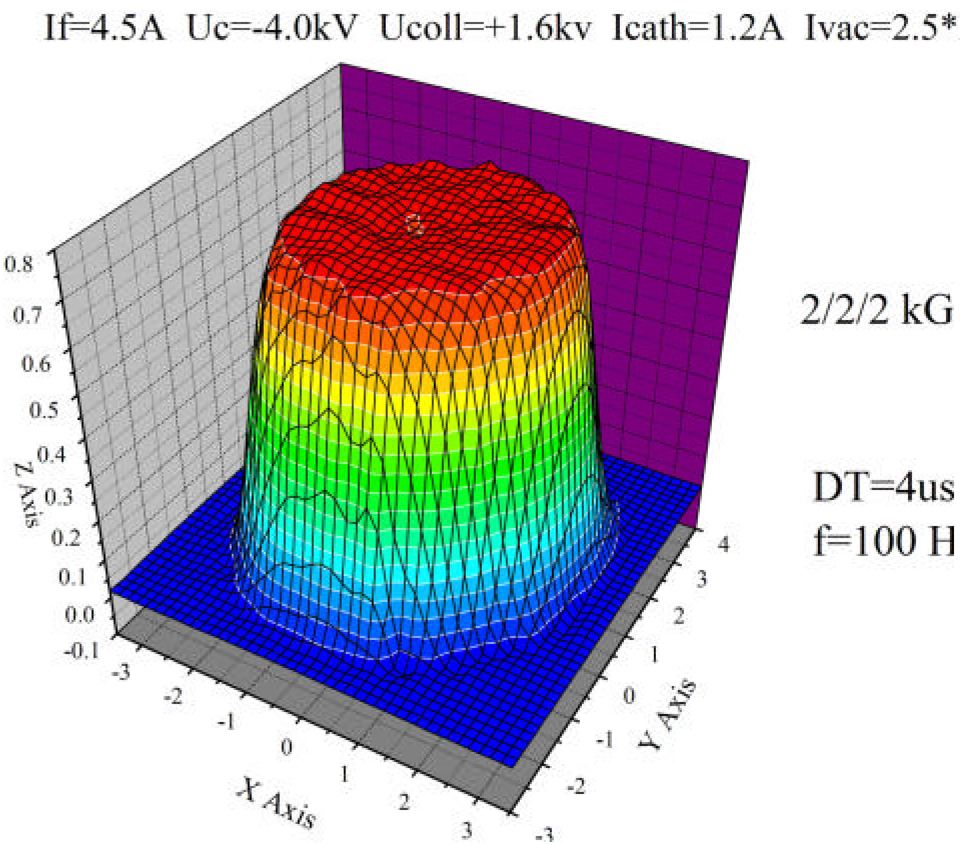


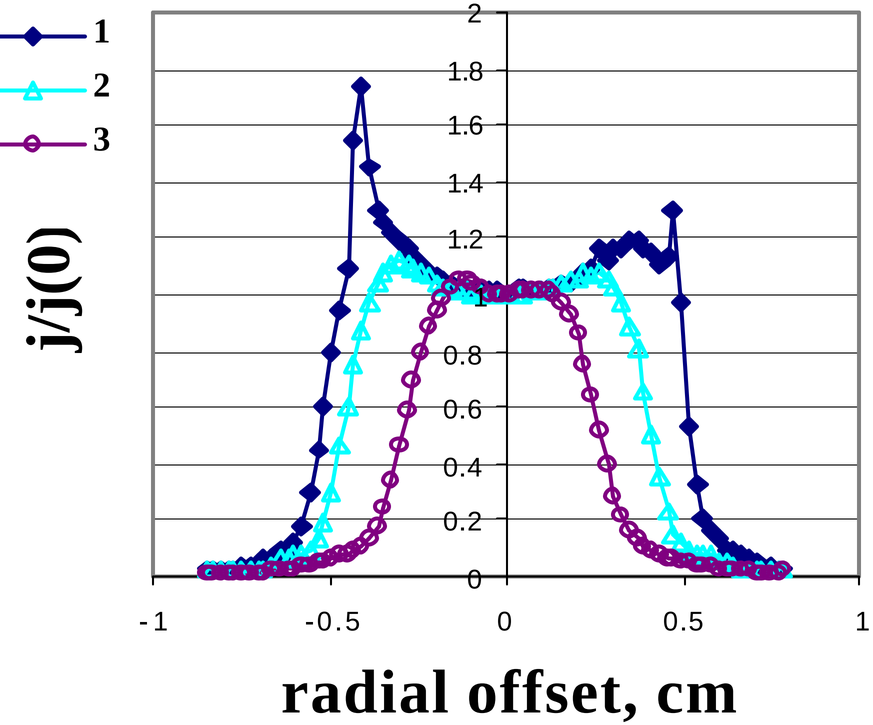


- Perveances of all three guns were found close to calculated ones
- Electron velocity/energy spread measured ~few eV (not really important for beam-beam compensation)

Electron Current Profiles

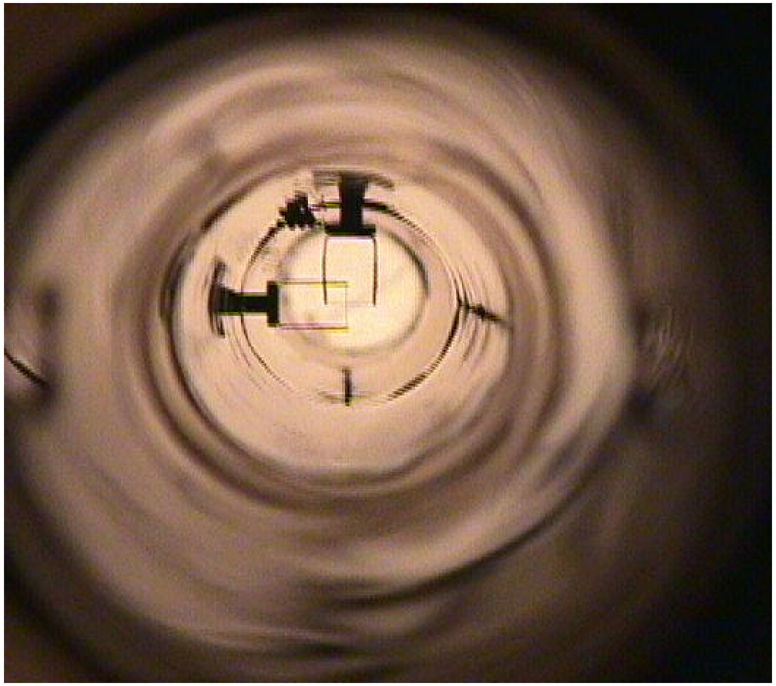
Effect of control electrode – suppression of emission from edges by application of negative voltage

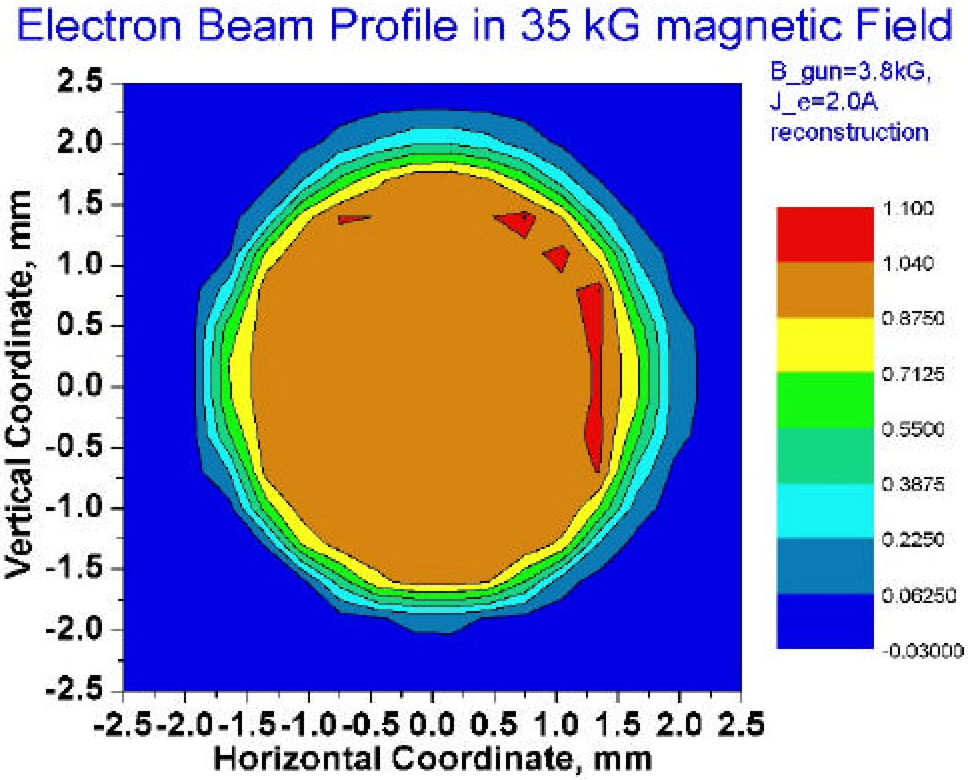




Electron Beam in 35kG Main Solenoid

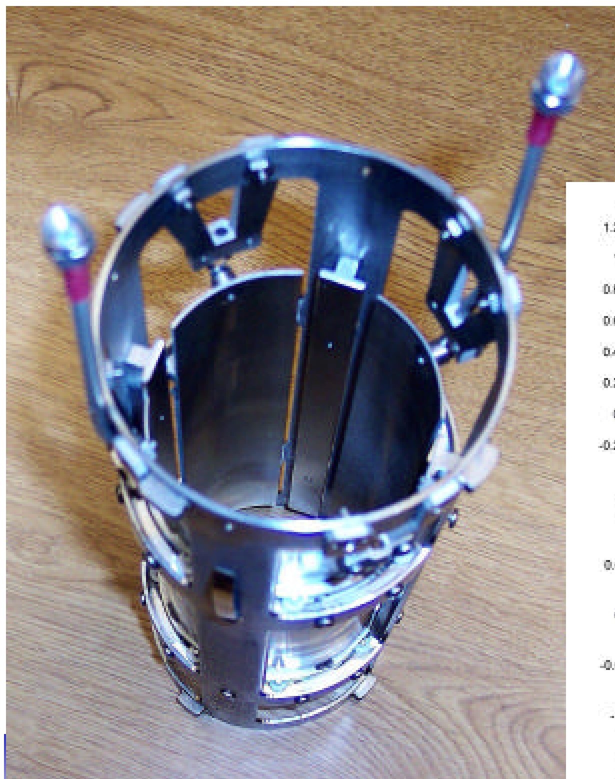
- 2 wires - another way to measure beam profiles
- "flat" e-current density distribution +-5% over 3.4 mm diameter

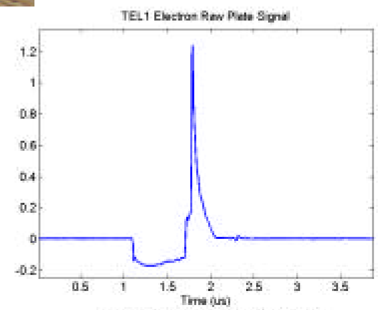


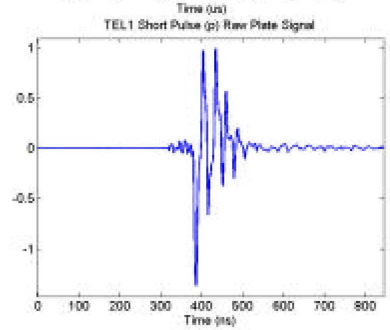


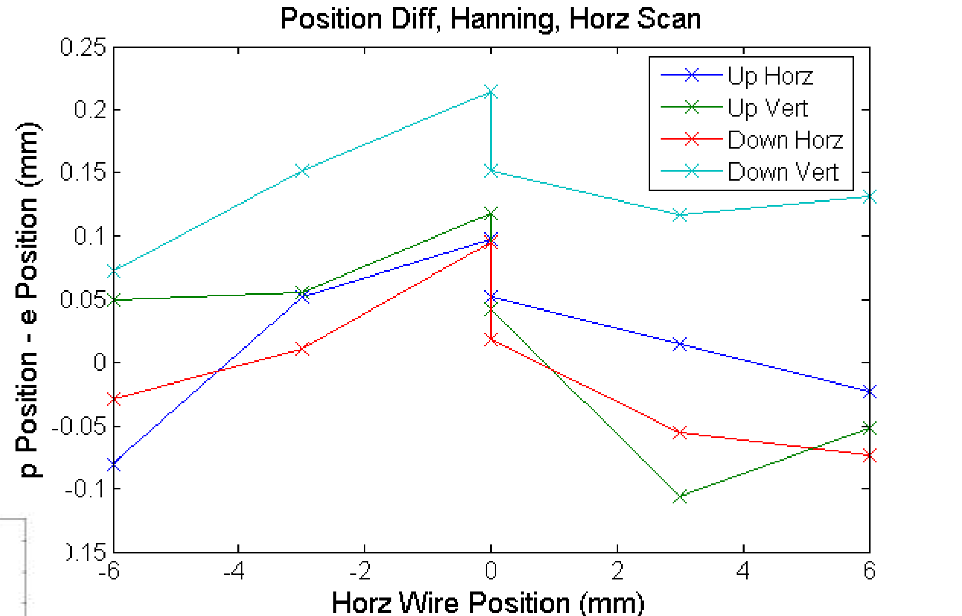
e-p alignment: TEL BPMs Improvements

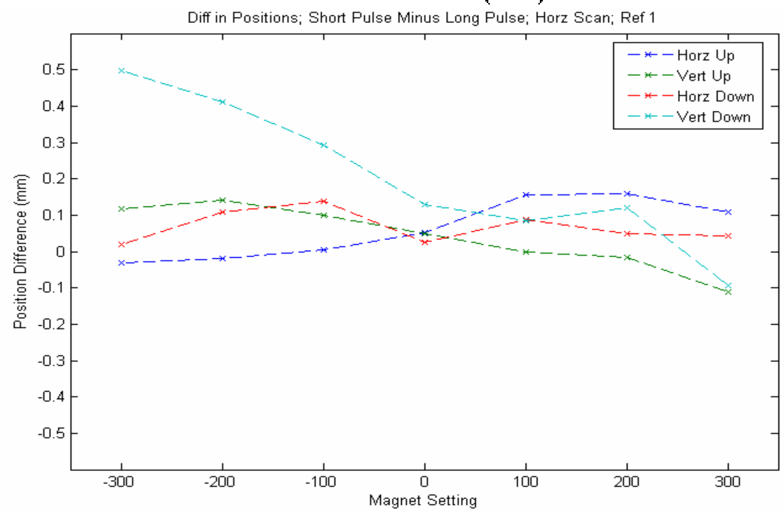
- *TEL-1 BPMs are known to have position difference ~1-1.5 mm btw p's and e's*
- *New BPMs designed and built for TEL2 together with narrow band algorithm reduce the error to ~0.2 mm*





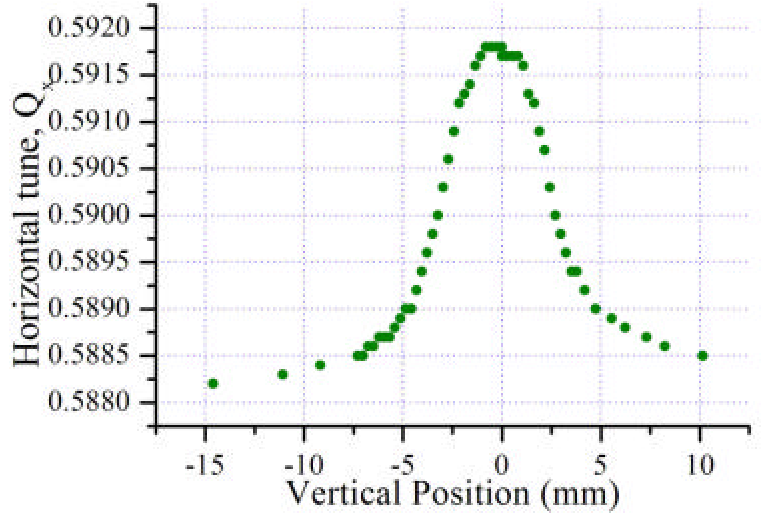


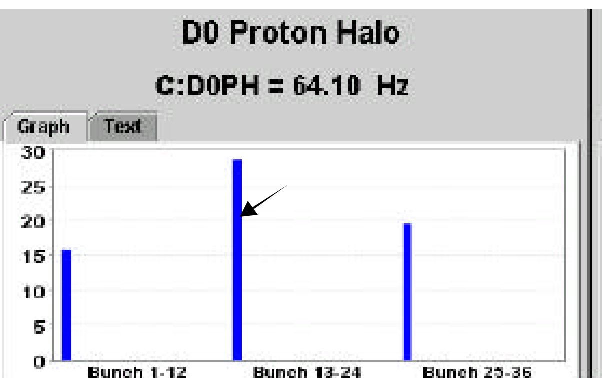




TEL-1 BBC studies in 2005-2006

- Major results:
  - Lifetime vs dX, Q_x,y with Gaussian gun
  - Tune spread due to Gaussian gun (did not detect)
  - dQ=0.004 SEFT gun, easier centering
  - Great lifetime 130-340 hrs with SEFT gun
  - Cleaning AND BBcomp possible



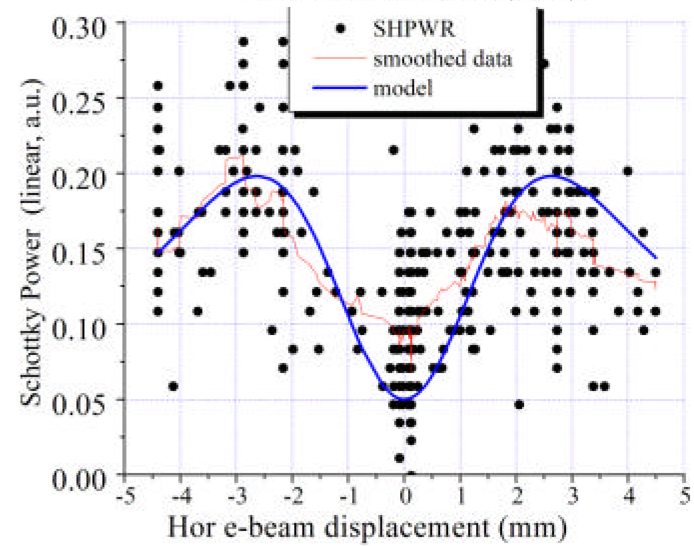


Prot Recalc E11 FW Vert Emit

T:PVEMIT = 19.77 pi mm mrad

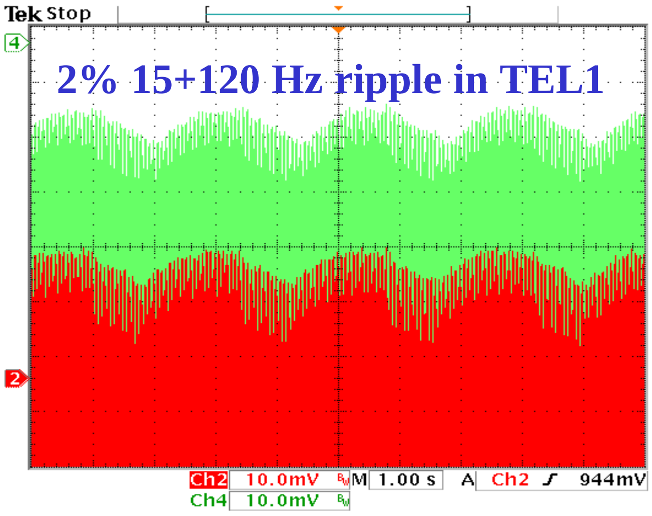
Graph | Text

B 1	17.707	B 13	24.674	B 25	17.455
B 2	-2.000	B 14	-2.000	B 26	-2.000
B 3	-2.000	B 15	-2.000	B 27	-2.000
B 4	-2.000	B 16	-2.000	B 28	-2.000
B 5	-2.000	B 17	-2.000	B 29	-2.000
B 6	-2.000	B 18	-2.000	B 30	-2.000
B 7	-2.000	B 19	-2.000	B 31	-2.000
B 8	-2.000	B 20	-2.000	B 32	-2.000
B 9	-2.000	B 21	-2.000	B 33	-2.000
B 10	-2.000	B 22	-2.000	B 34	-2.000
B 11	-2.000	B 23	-2.000	B 35	-2.000
B 12	-2.000	B 24	-2.000	B 36	-2.000

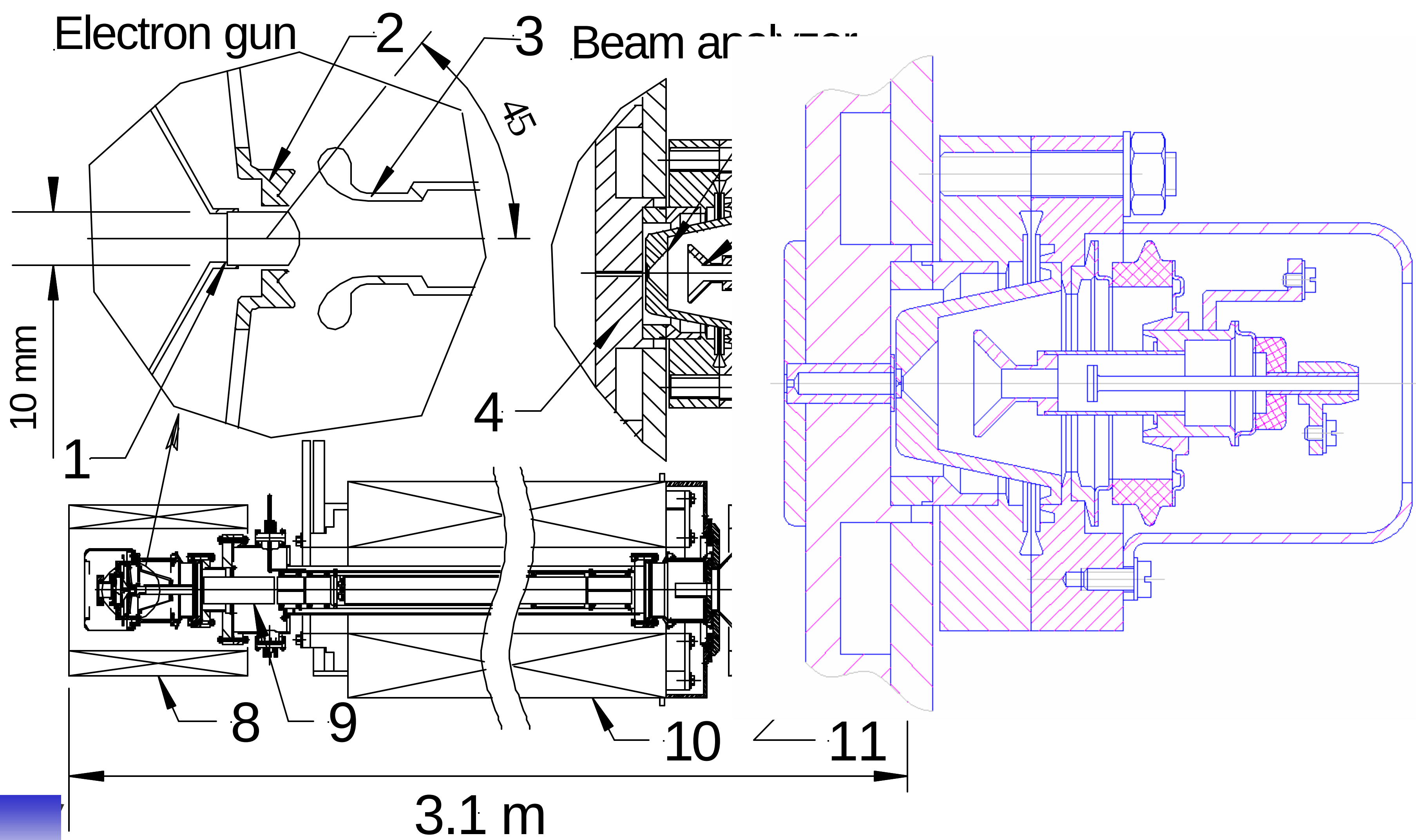


Conclusions and Plans

- We have learned what kind of electron beam profiles are needed for beam-beam compensation in Tevatron (hard way)
- We learned how to generate needed profiles and control them
- Three types of e-guns were built and successfully tested
- The 2nd TEL just installed and we look forward to having it fully commissioned in used in beam studies (so far ~0.3A DC)
- Near future plans include:
  - Fix 2% in HV amplitude
  - Test newly developed 10kV MARX HV generator based in IGBT switches (800ns)
  - confirm better accuracy of new BPMs
  - Tev beam-beam comps'n studies in stores
  - Comprehensive program of parallel LIFETRAC simulations to be started

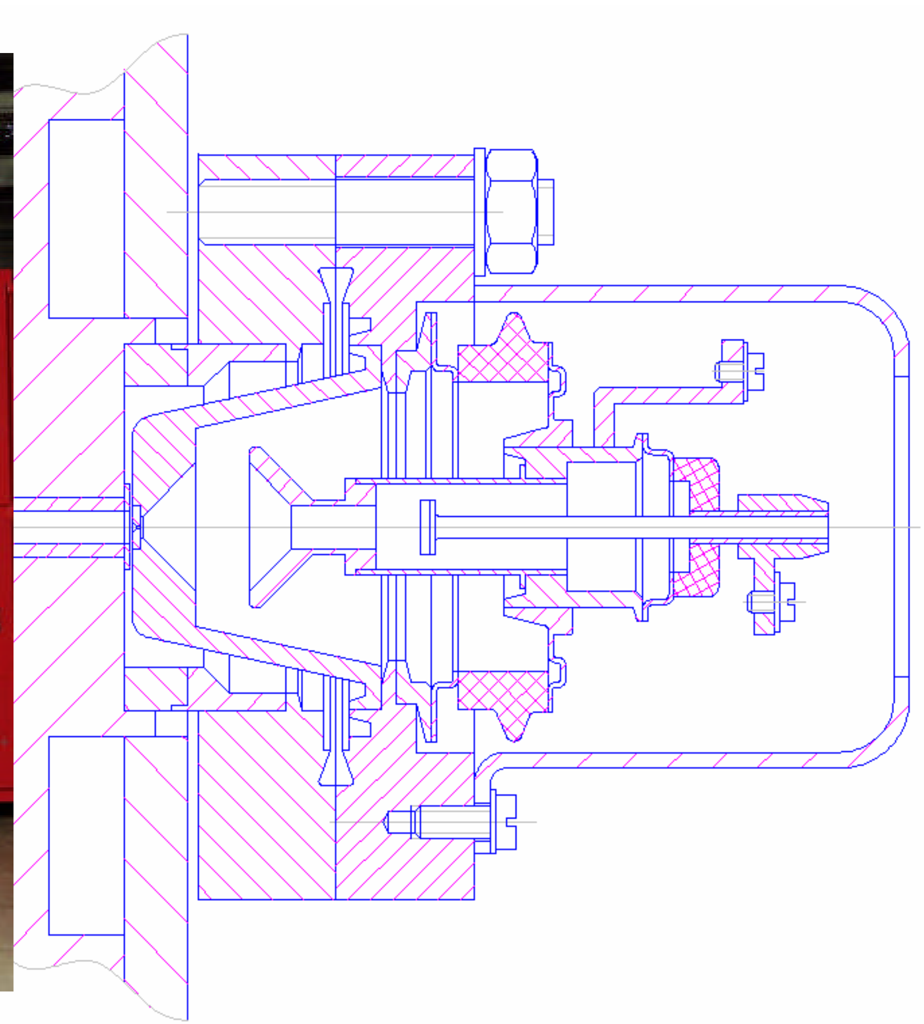


Electron Gun Test Facility



Ways to change the profile: gun geometry

Electron gun 2



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