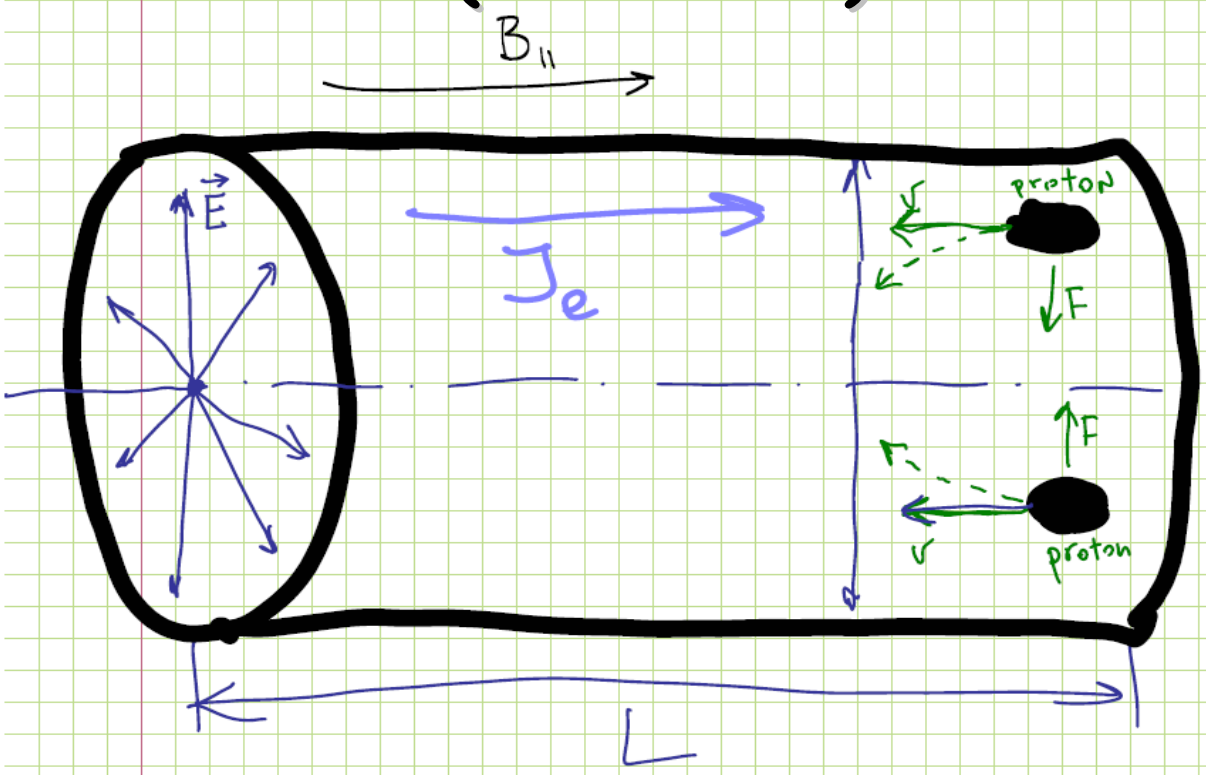
Fermilab

Electron Lenses for Particle Collimation in LHC

Vladimir Shiltsev
Fermilab

What Is Electron Lens?

- it is very stable and very well controlled (~frozen) electron cloud



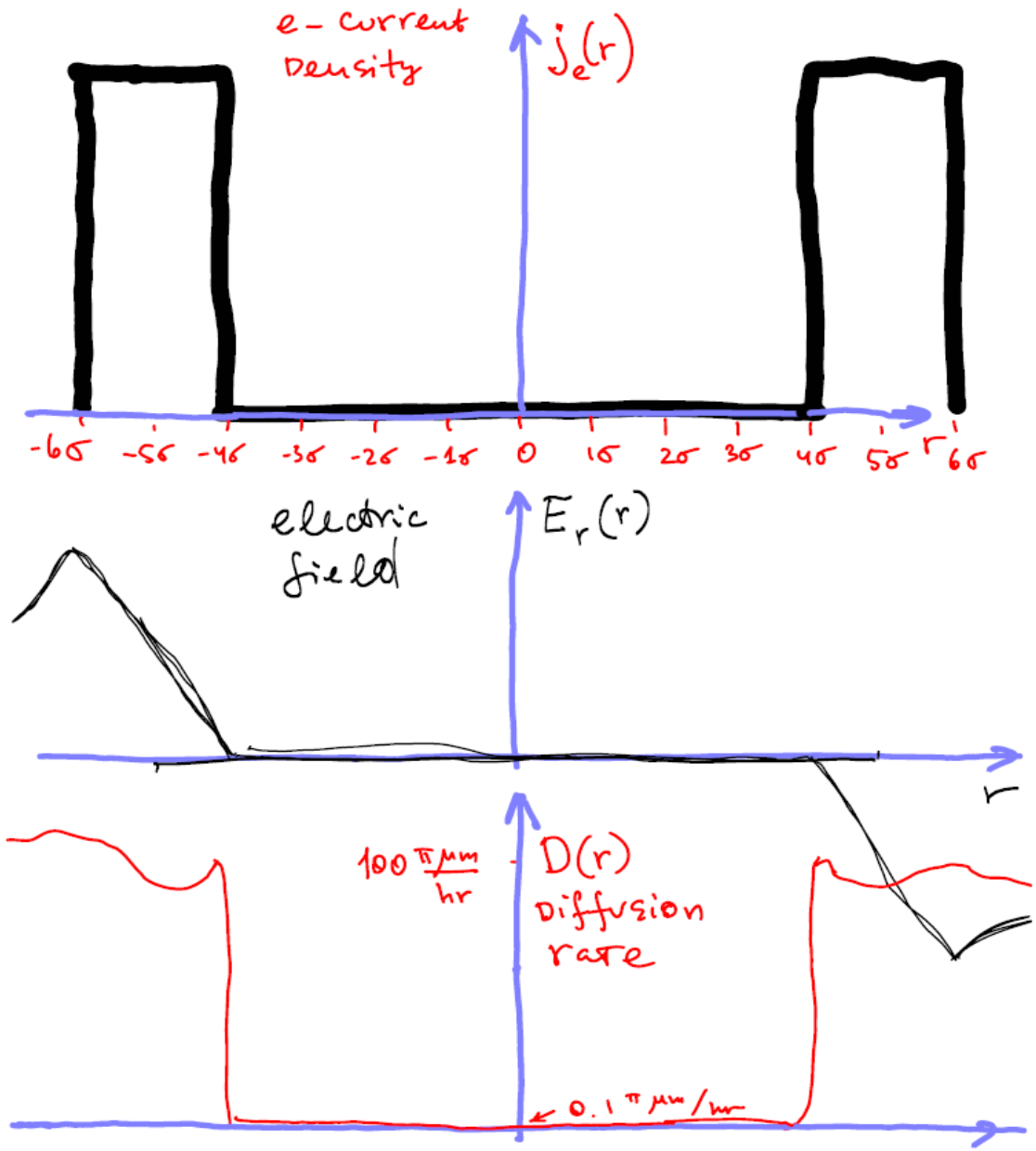
$\sim 10^{12}$ e-

Can control current, diameter, length, position, timing, velocity, shape, angle, direction

FNAL Experience with TEL

- **Besides it's a B-B-Compensator**
- **TEL can be a great "KILLER"**
  - ➢ blow up emittances in controlled fashion
  - ➢ drive particles out – randomly or via resonance drive
  - ➢ remove unwanted particles, bunches, e.g.:
    - only in between bunches
    - just 1 out of 3000 or satellites only
    - only those with a>5 x Sigma , etc, etc

Hollow Electron Beam as Collimator

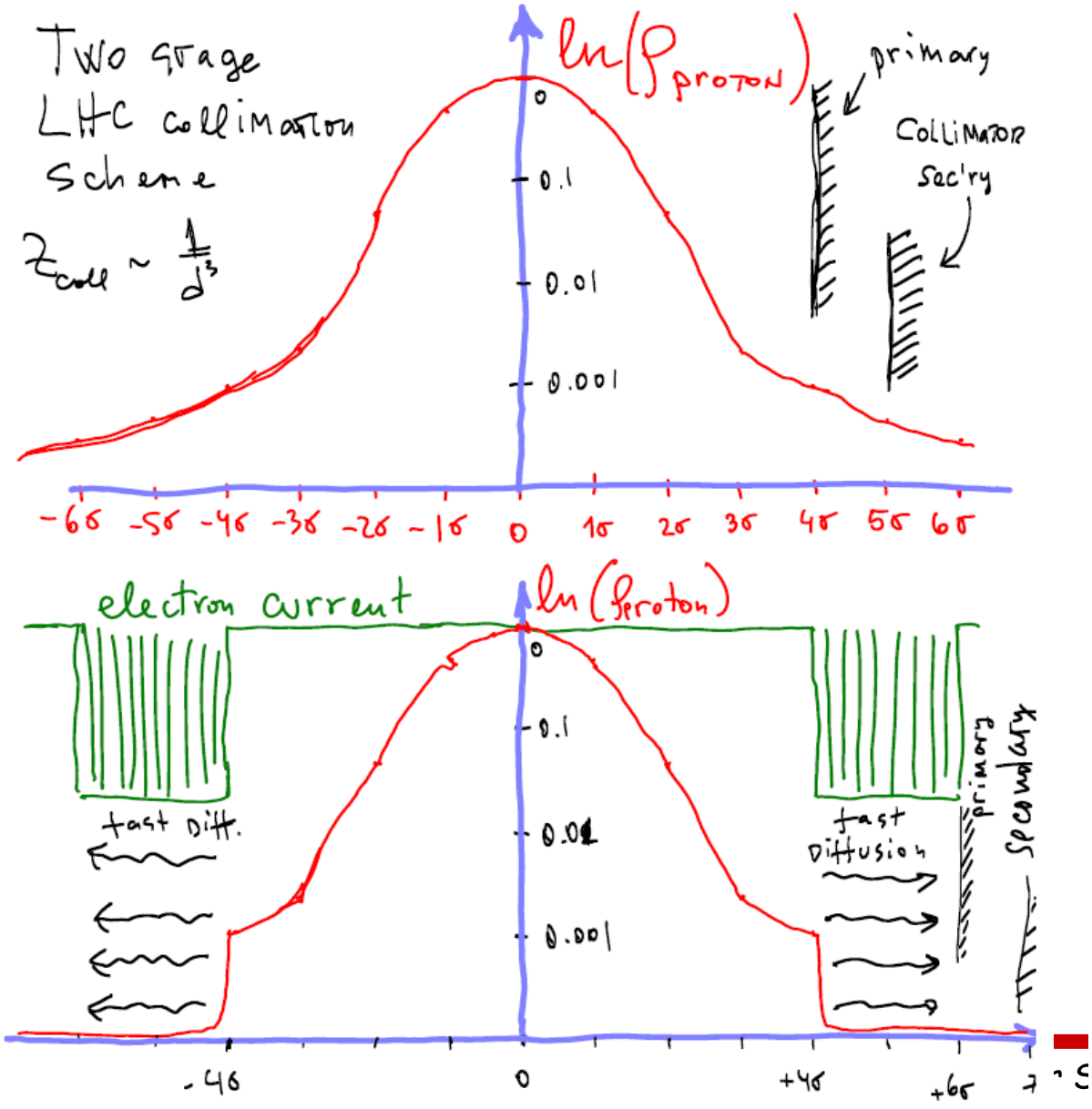


Duffusion enchanced by:

a) by resonant driving at betatron frequency

b) Non-linear fields

"LEL-Combo" Collimation

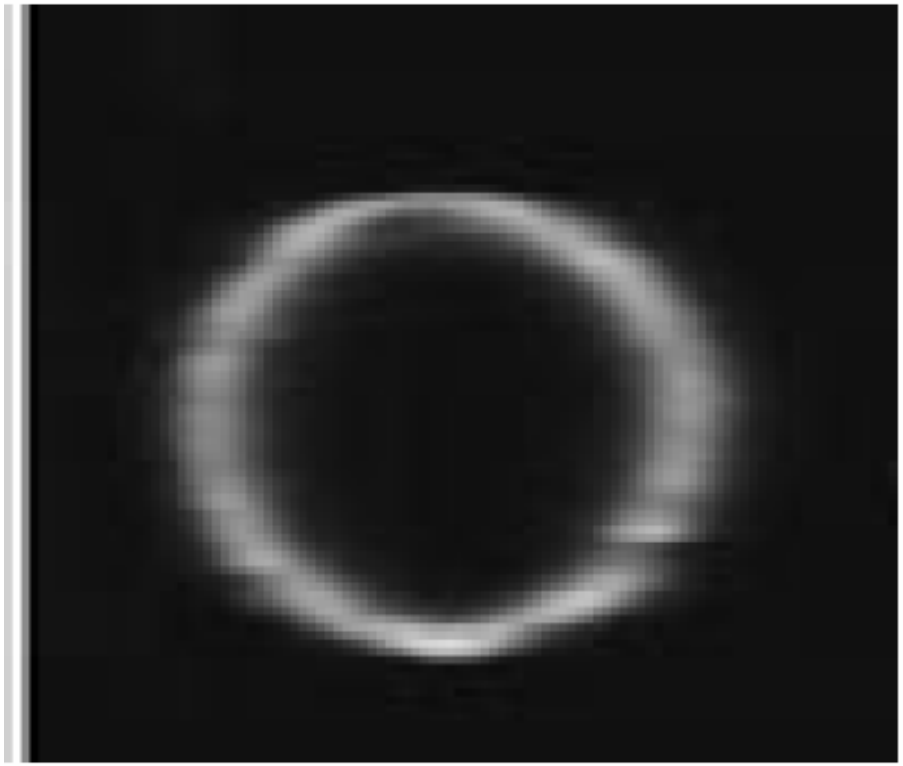


Phase I Collimation

LEL-Combo Collimation:
LEL drives particles from 4 to 6 sigma,
Secondary collimators 2 sigma
FARTHER

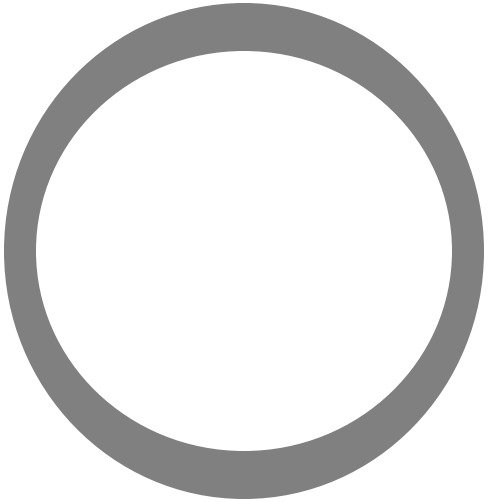
Multi-Amp Hollow Electron Beams Generated

Tunable profile



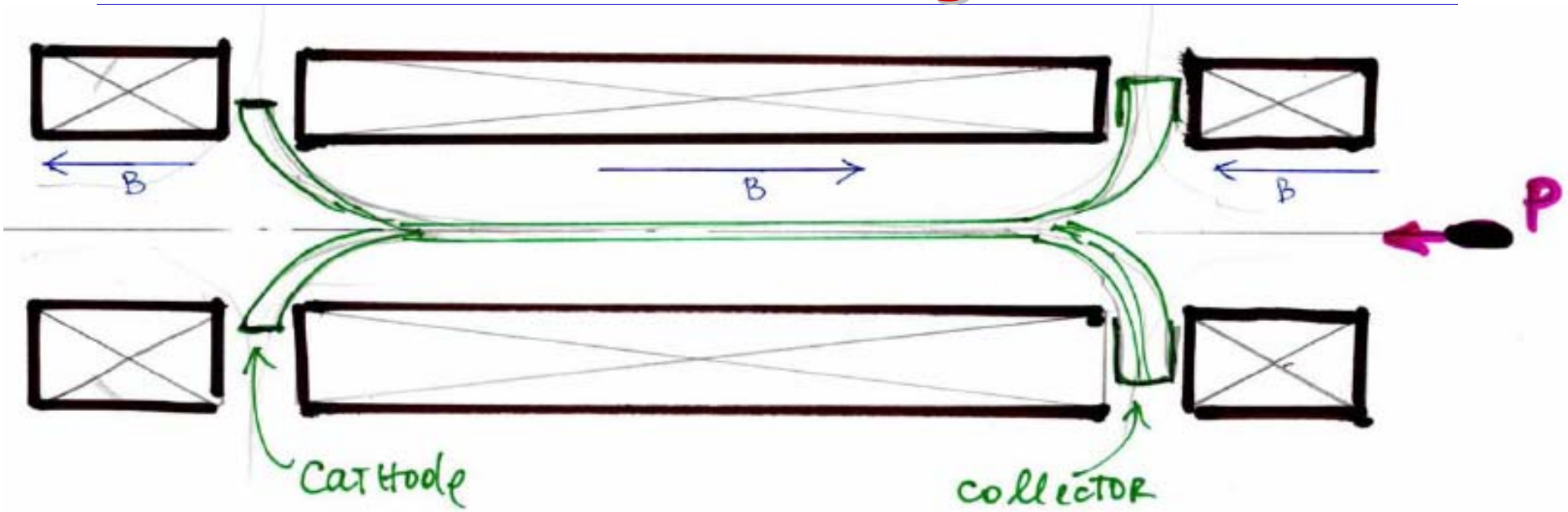
A.Bubley, et.al. PTE, 49(1), 2006

Ring cathode



A.Shemyakin, et.al. NIM A, 1996

e-Lens Configuration

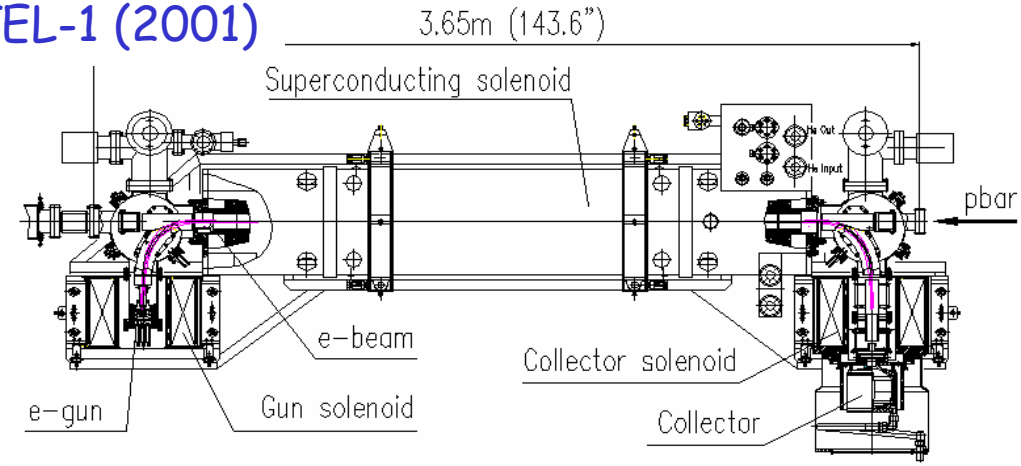


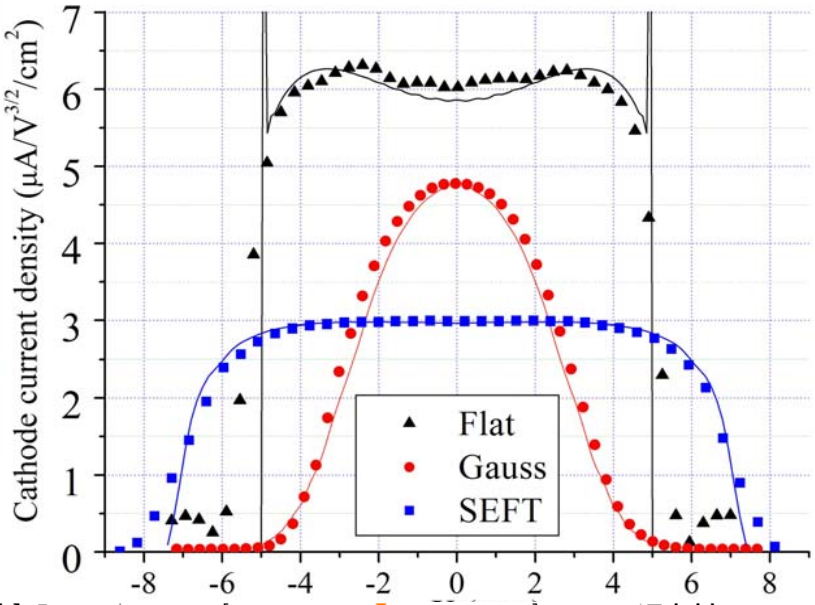
Ring cathode:	Interaction L:	Ring collector:
R=25mm	a=4.4mm, w=1.1mm	R=25mm
width=6 mm	B=3.2T (B_c=1kG)	width=6-15 mm
B_c=1-2kG	B=10T (B_c=3kG)	B_c=1→0 kG
j=1-5 A/cm^2	L=2 m (m.b. 4)	P=50-250kW
J=10-50A		

TEL: j=6A/cm^2, B=6.5T, P=50kW

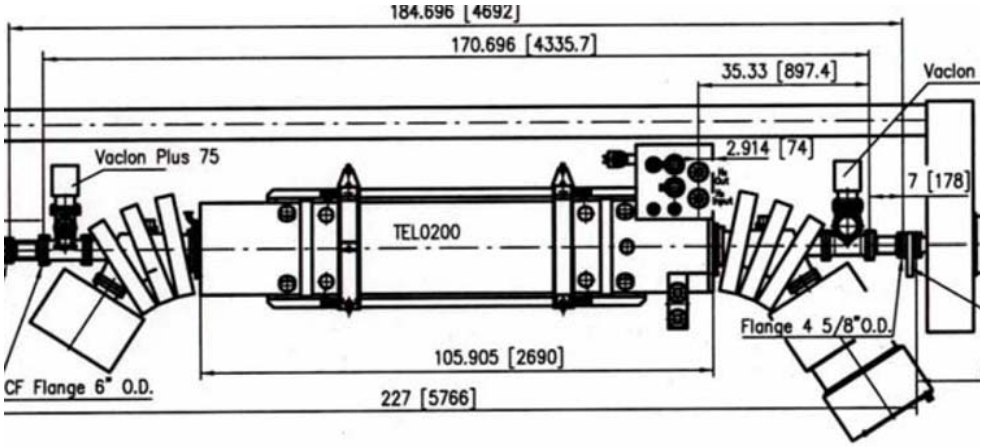
Most of Technology Available

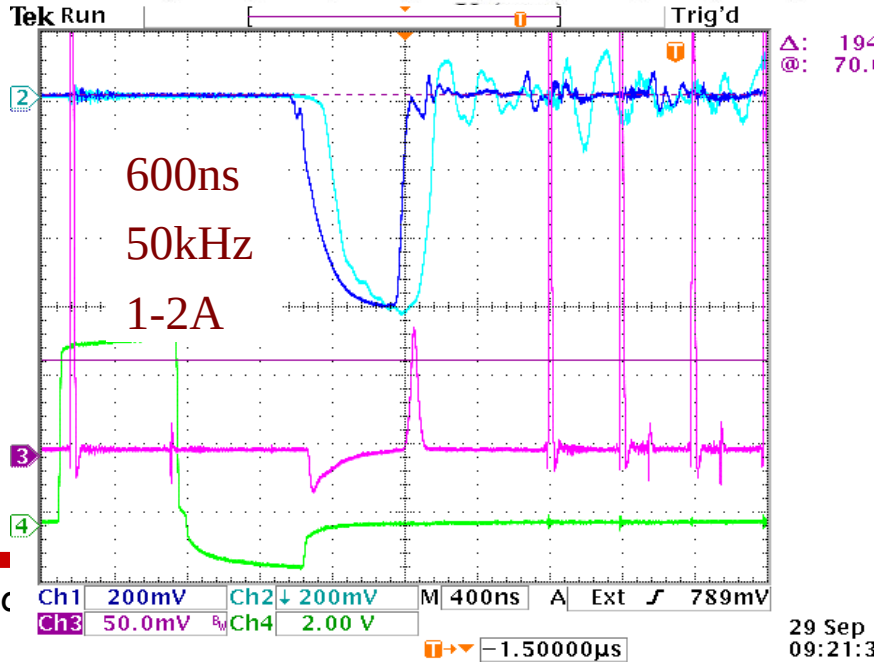
TEL-1 (2001)





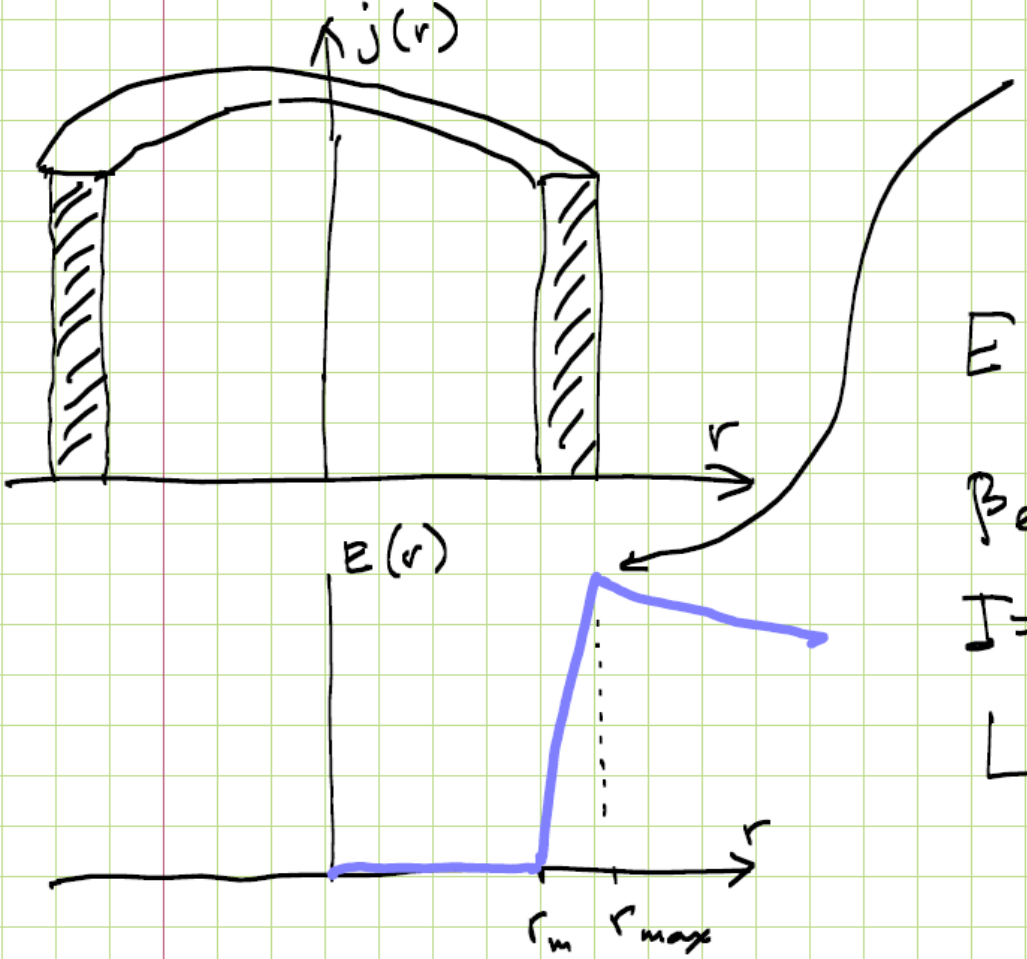
TEL-2 (2006)





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

Strength of the eLens



Kick (7 TeV $B\rho = 2.3\,10^4$ T m)

$$\Delta\theta_{max} = \frac{E\,L}{B\rho}$$

$$E(G) = \frac{0.2\,I\,(A)}{\beta_e\, r_{max}\,(mm)}$$

$\beta_e = 0.2$ for 10 kV e^-

$I = 10$ A $\quad r_{max} = 6.6$ mm (6σ)

$L = 2$ m

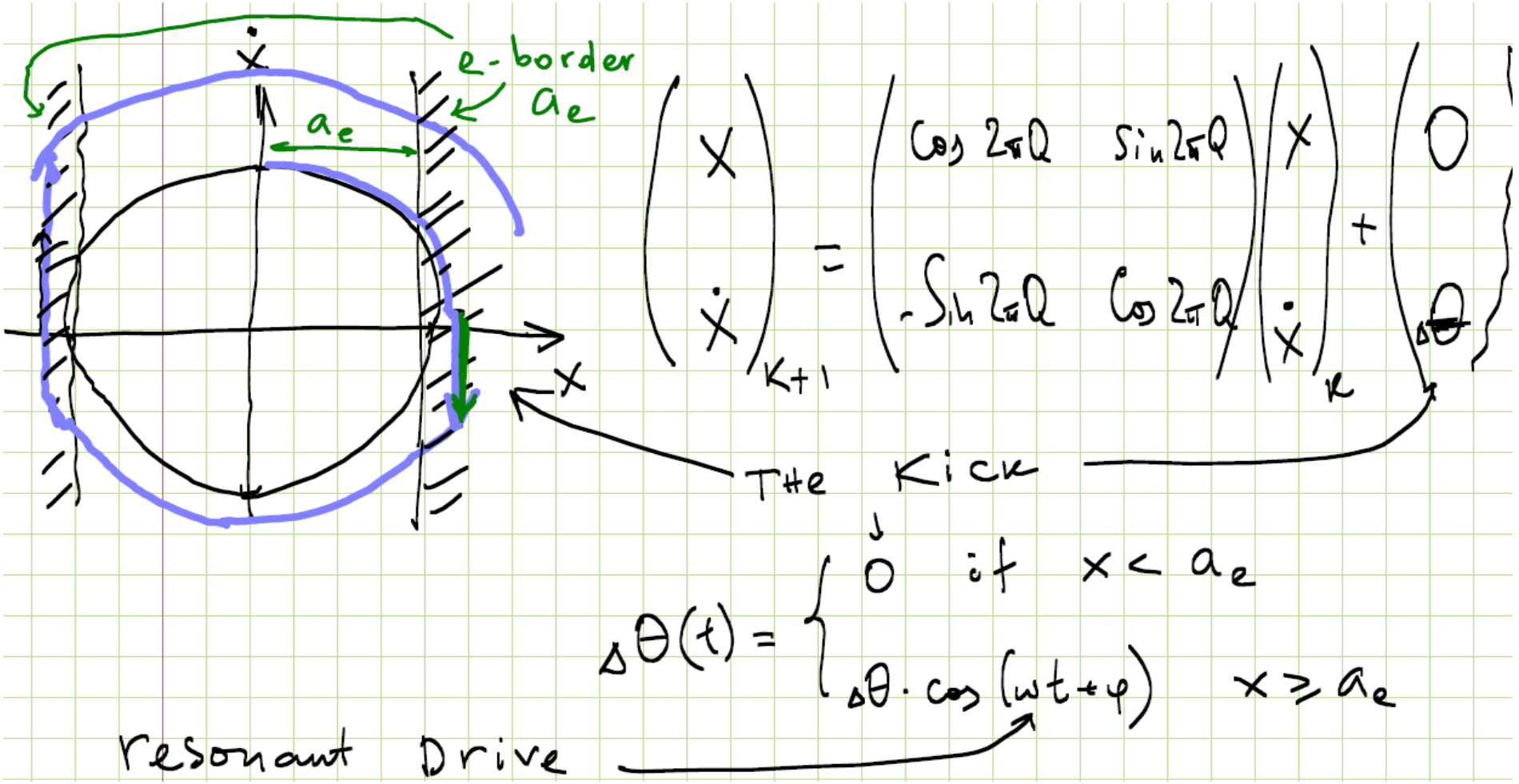
$\rightarrow \Delta\theta = 0.13\,\mu$rad

$\Delta X = \beta \cdot \Delta\theta = 270\,\mu m = \frac{1}{4}\sigma$

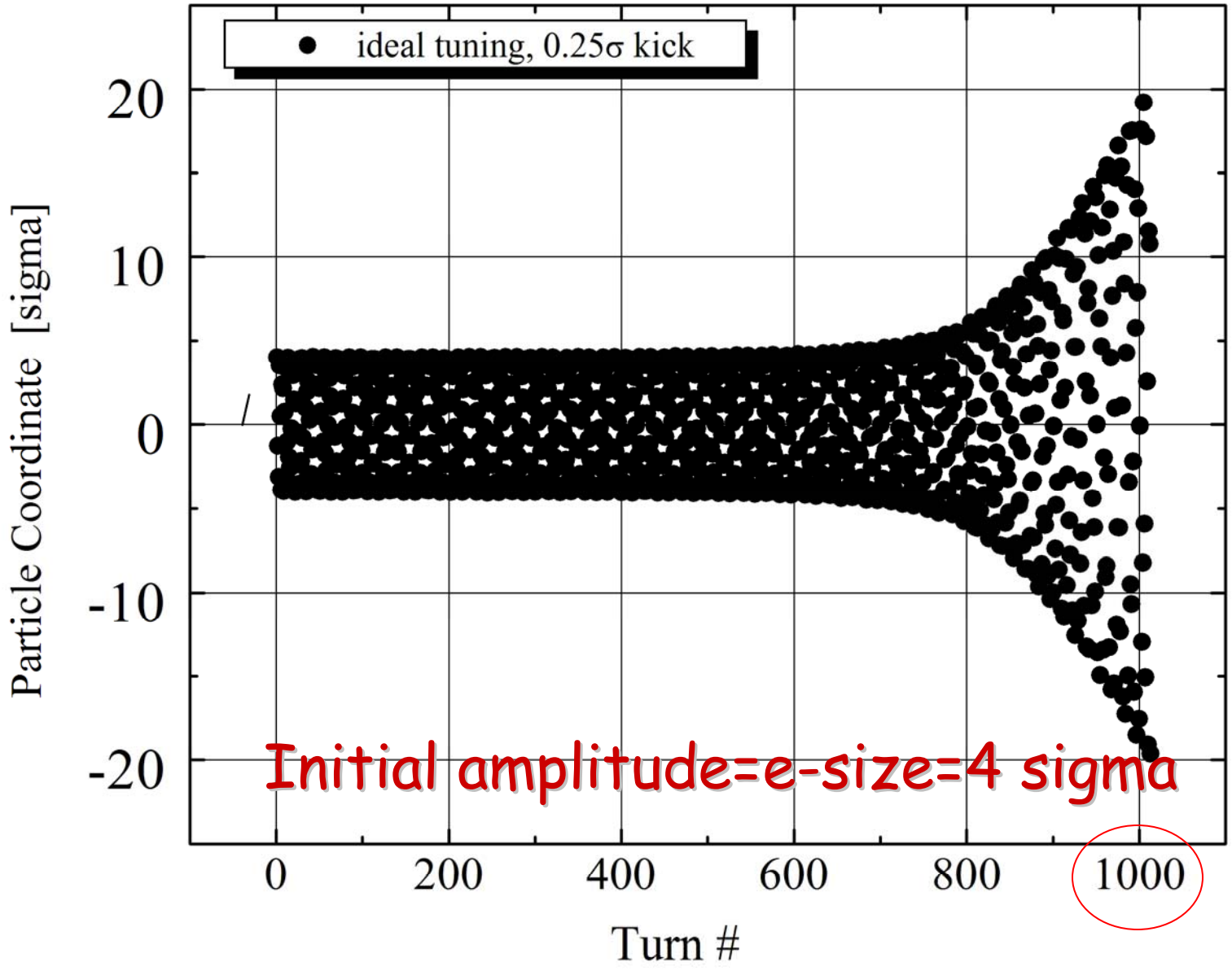
@ 2300 m $= \beta_{x,y}$

$$B(r) = \begin{cases} 0 & r < r_m \\ \frac{0.2\pi}{\beta_e} \cdot j \cdot (r - r_m) & r_m < r < r_{max} \\ \frac{0.2\,I}{\beta\, r} & r > r_{max} \end{cases}$$

Resonant Collimation



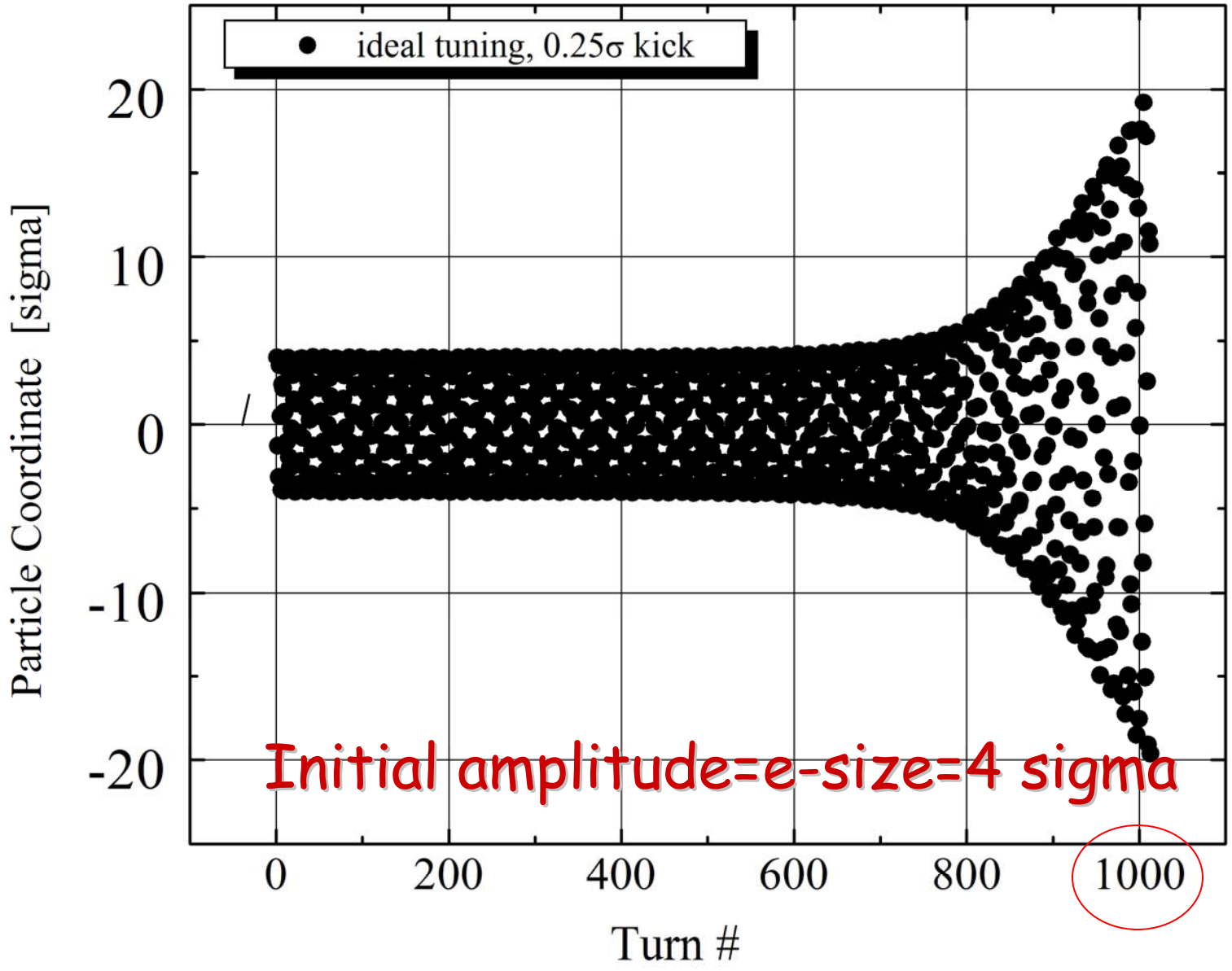
Simulated: proton Q=0.31, kick=0.25 sigma



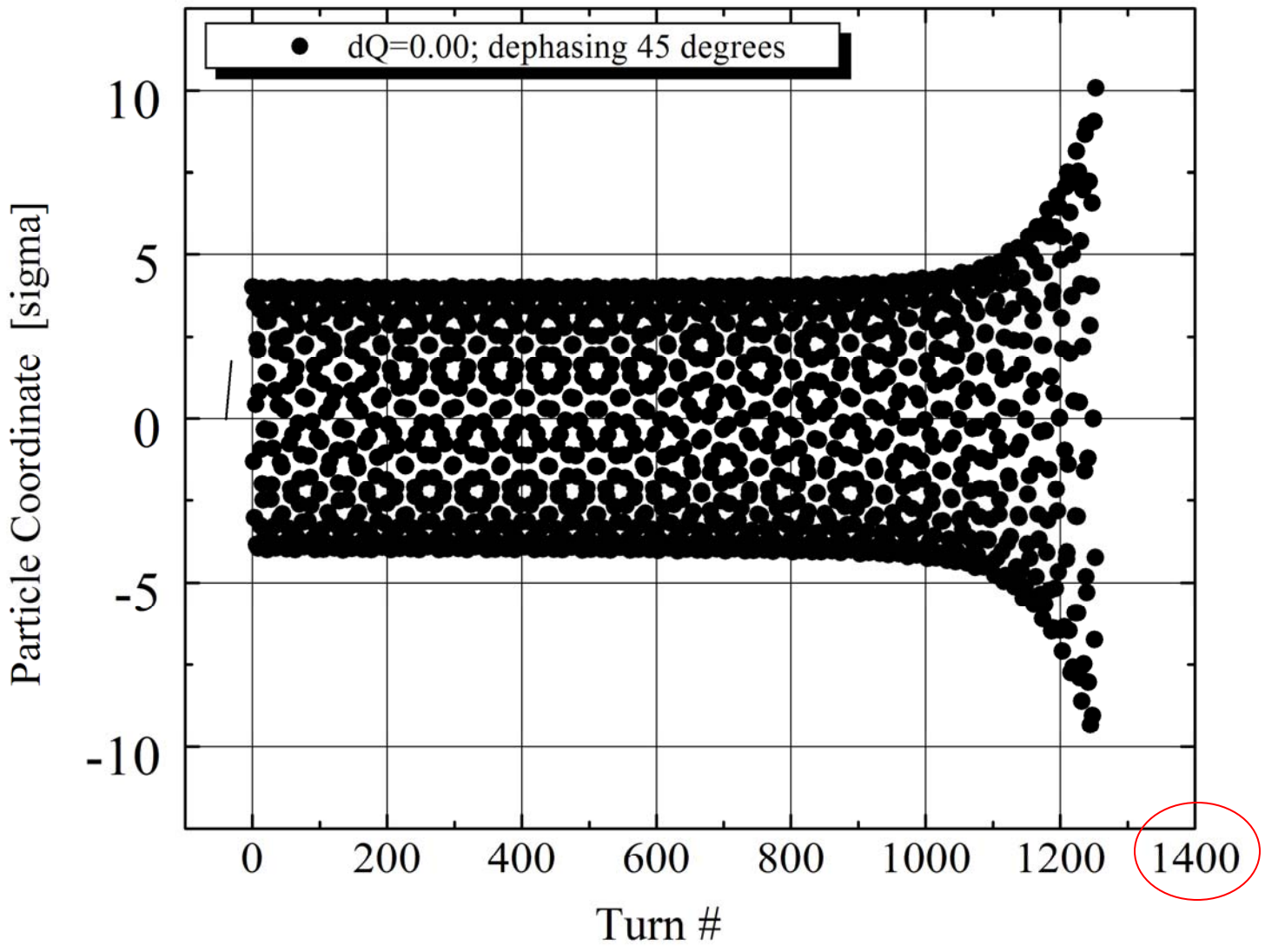
eLens Parameters for Collimation

- **To clean >4 sigma protons :**
  - LxJ_e=2-20 Am (say 10A and 2m)
  - modulated at f_betatron (~3.5kHz)
  - beta_x=beta_y=2300 m (btw D1 and D2)
  - Hollow beam distribution
  - r_min = 4sigma=4.4 mm at 7TeV
    r_max = 5sigma=5.5 mm at 7 TeV
  - L_e=2 m, U_e=10kV
  - B_gun=0.1-0.2T, B_main=3.2-10T

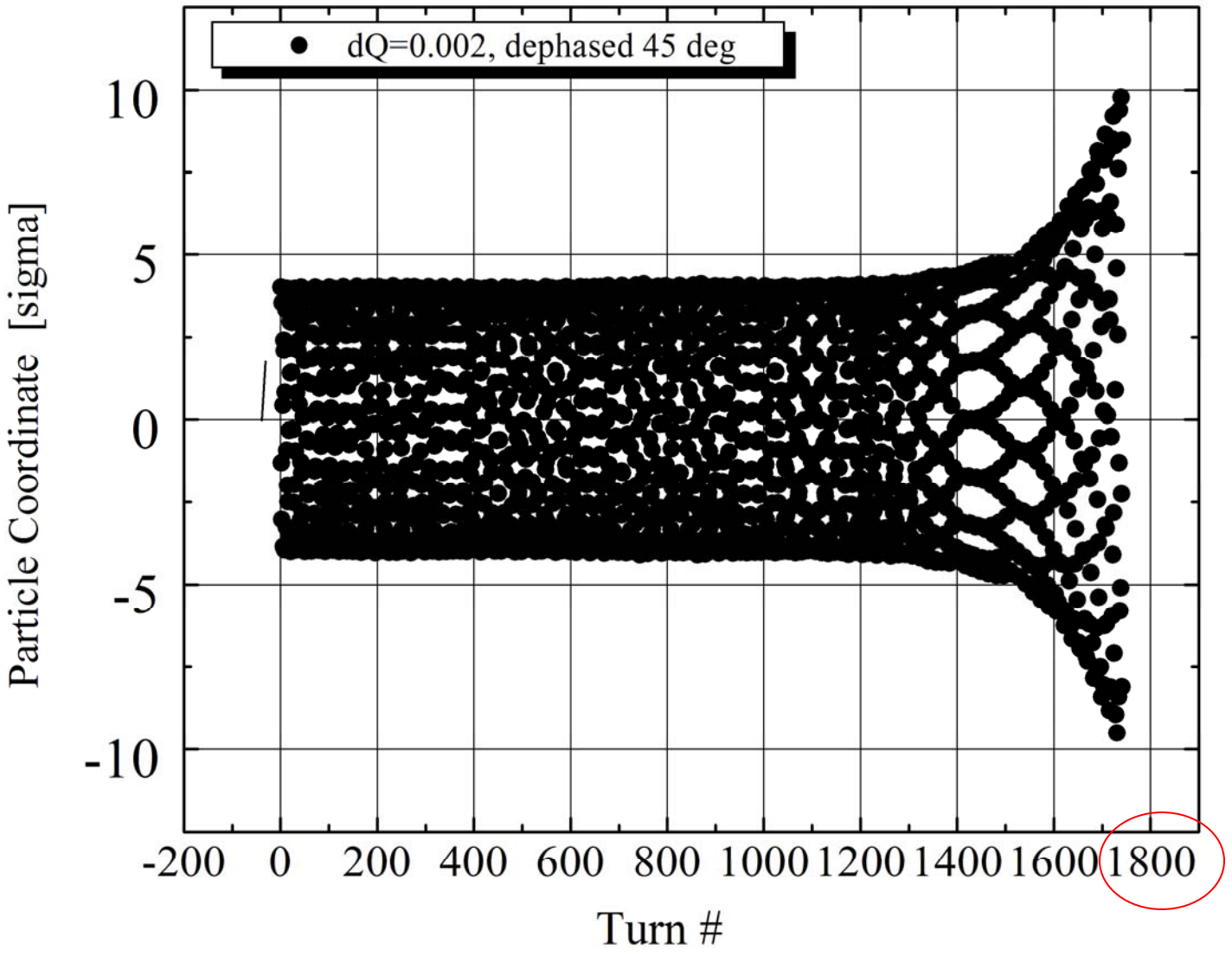
Simulated: proton Q=0.31, kick=0.25 sigma



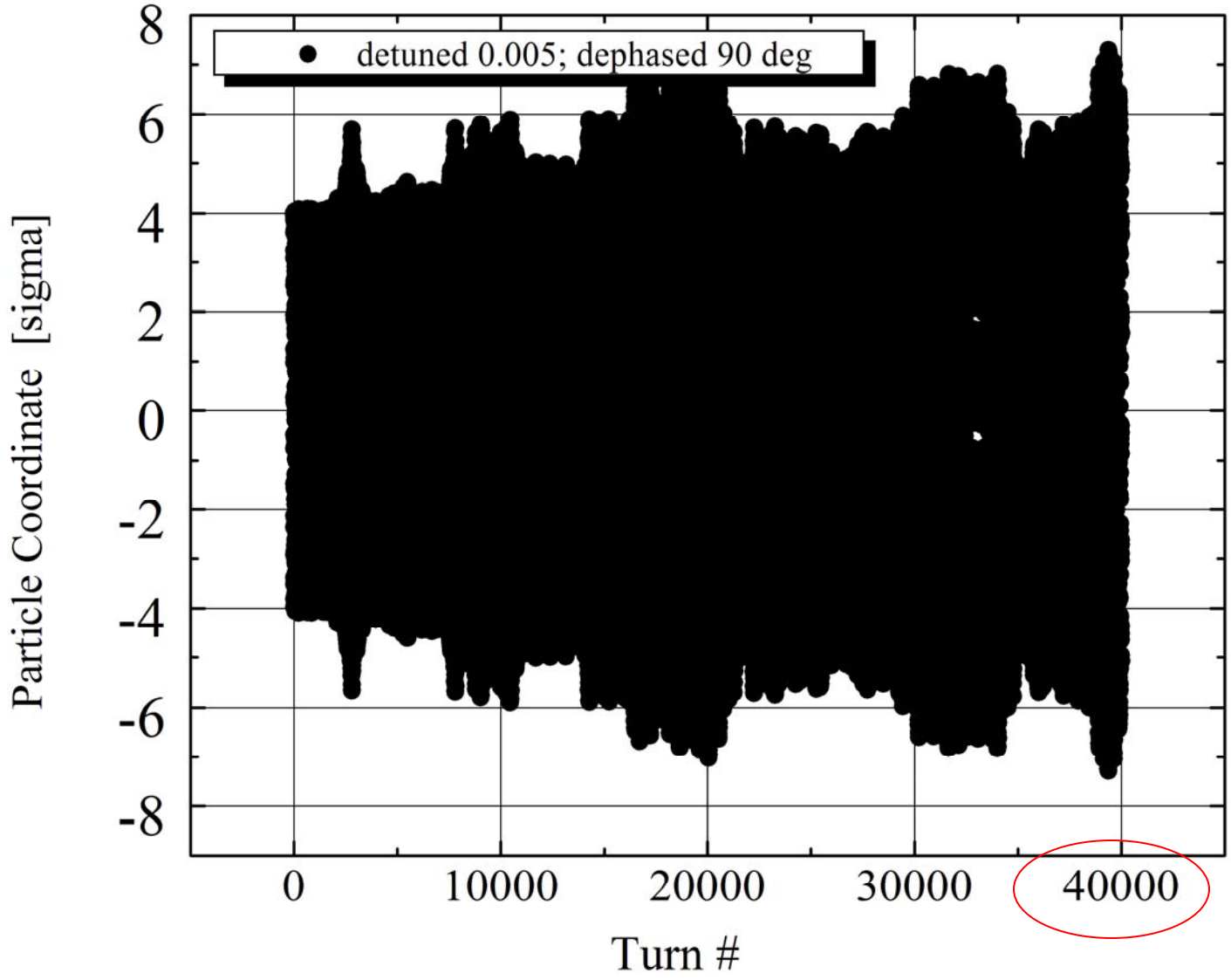
All the same, but eLens dephased 45 deg



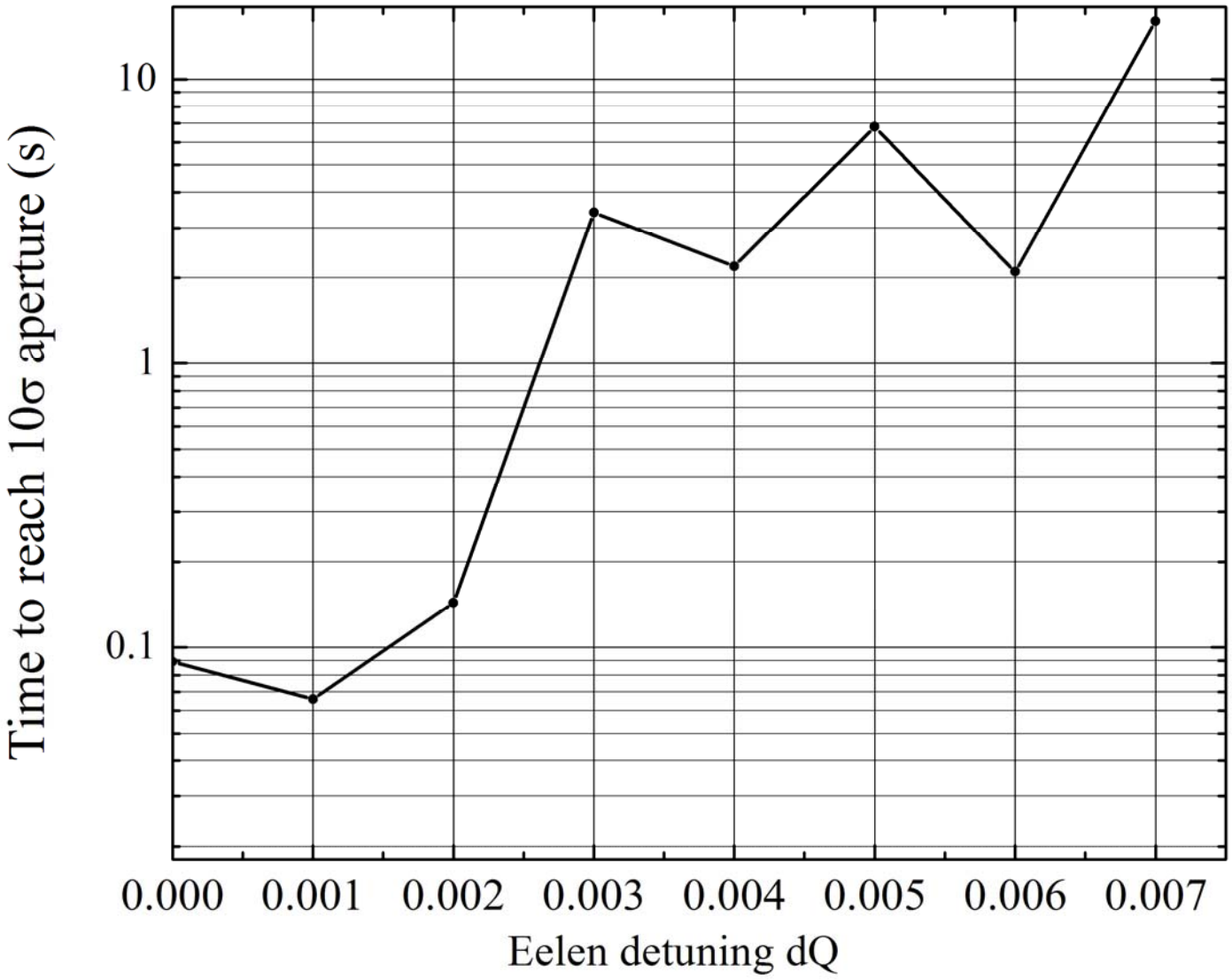
Detuned: proton Q=0.31, eLens Q=0.312



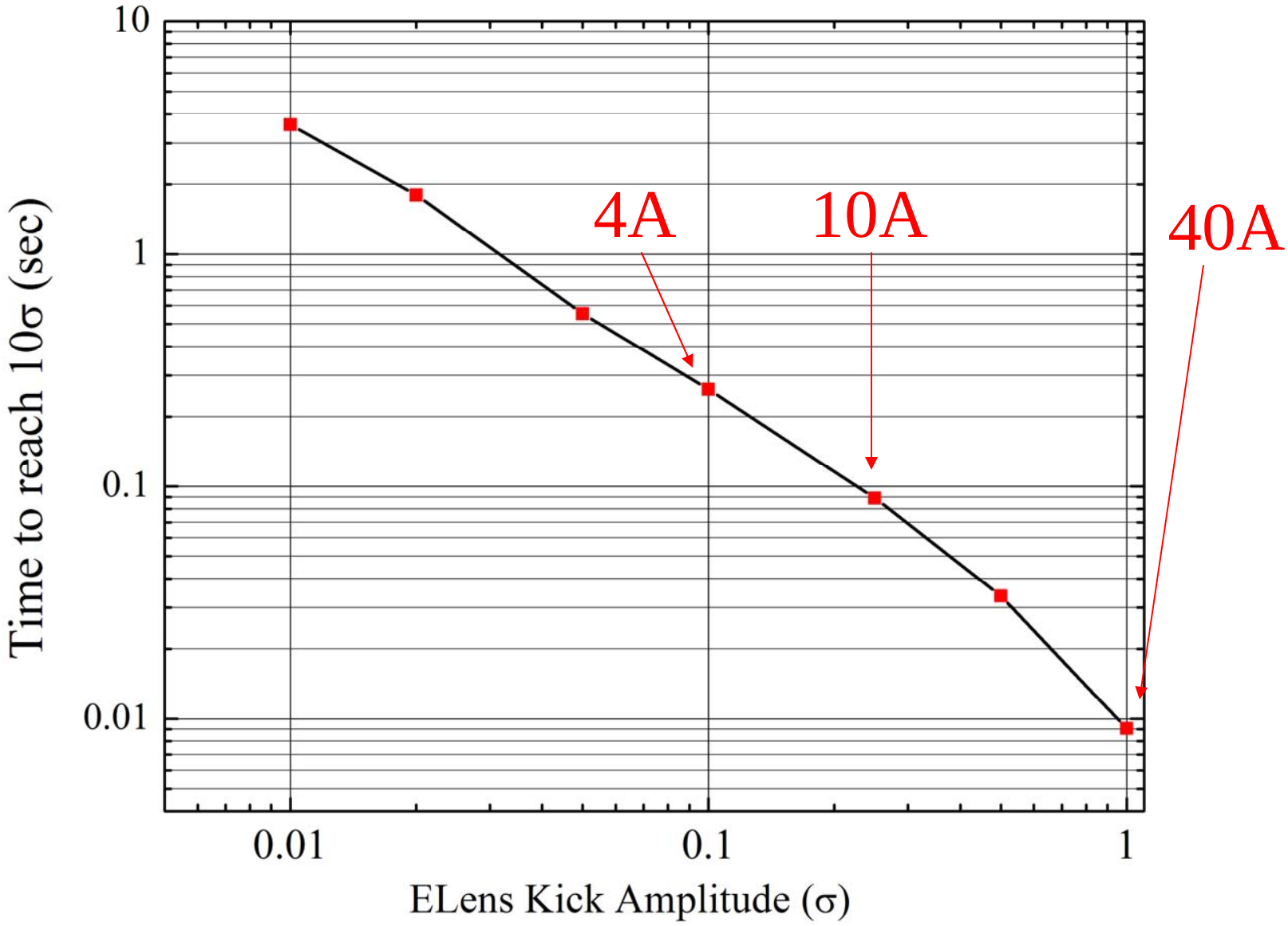
Detuned: proton Q=0.31, eLens Q=0.315



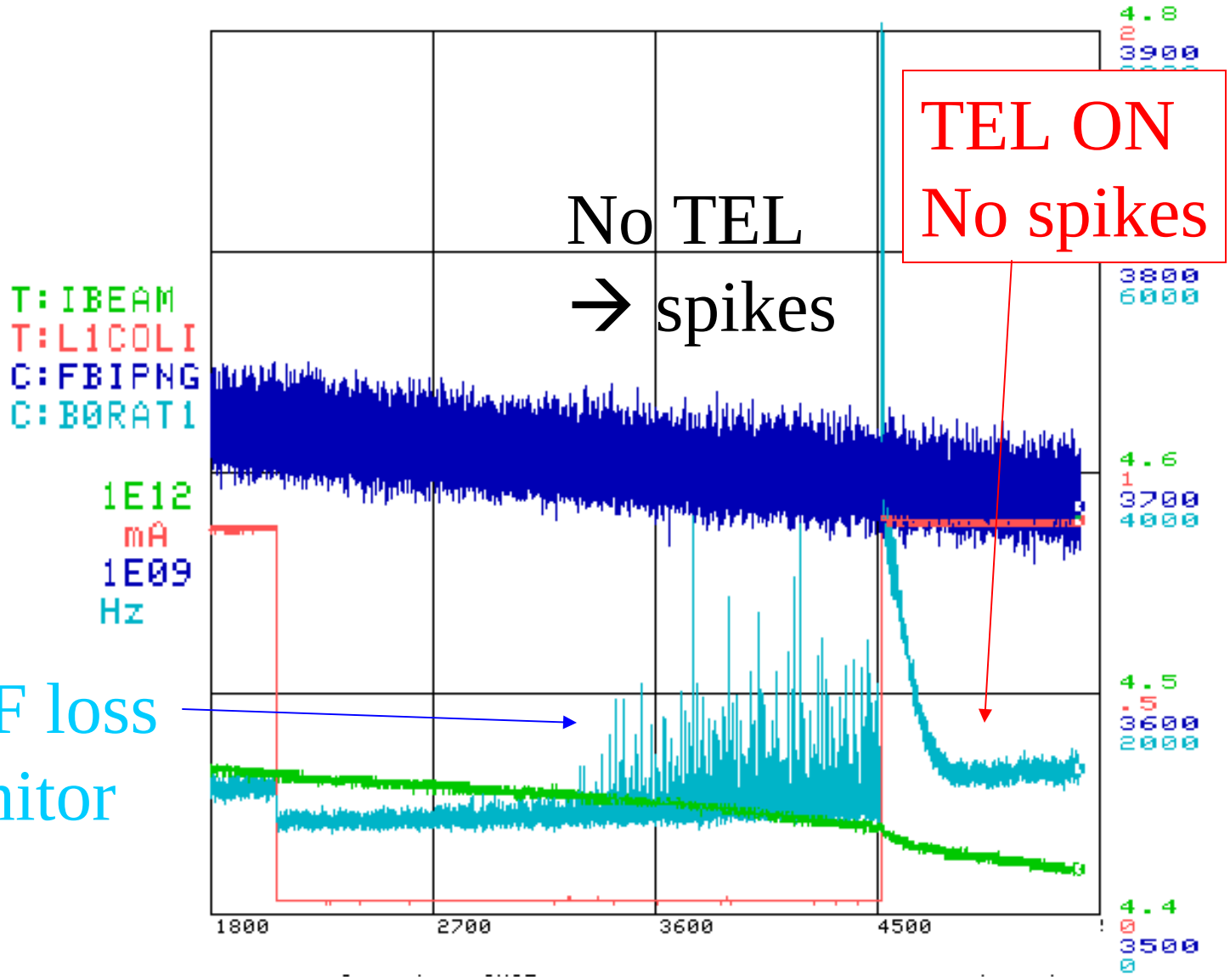
Cleaning Time vs detuning



Dependence on eLens kick strength



Electron lens collimates "smoothly"



eLens Collimation: "Pro's"

- eLens technology available - TEL
  - Reliability proven by years of operation of Collider
- No nuclear, just EM interaction, can work for ions &protons
- Seems to be strong enough to clean fast
  - Cleaning time (0.1-30 sec) << diffusion time (1000's sec)
- Refreshable, no damage
  - No need of exp(t)ensive damage diagnostics
- Easy size/position control by B-fields, no movers, etc.
- Smooth cleaning (multiturn)
  - No extreme sensitivity to orbit motion
  - No spikes in the loss rates and rad loads on secondaries
- SUMMARY: e-Collimation looks very promising, should be considered in detail, may complement conventional system, is perfect for ions.

Let's do more "Plumbing" at LHC !