

Stability diagram with a Gaussian electron lens in HL-LHC

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Why E-Lens

Octupoles are inefficient for Landau damping at high energies: $\sim 1/\gamma^2$

E-lens tune shift scales as $1/\gamma$

High $4 \times 10^{-3} - 10^{-2}$ tune shifts have been observed with e-lenses

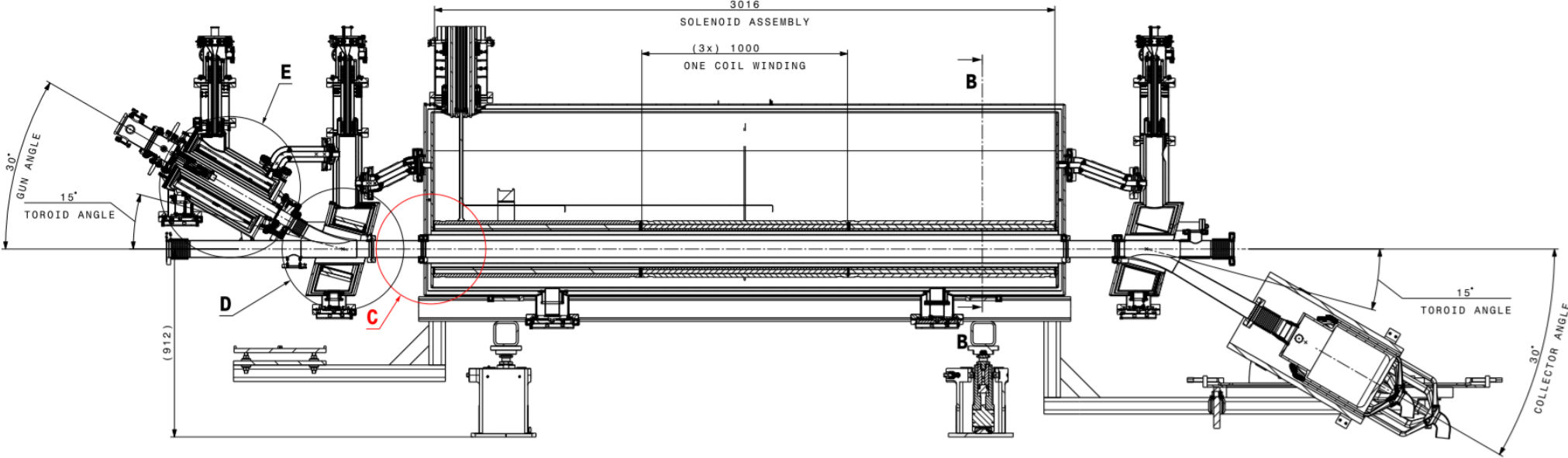
- Tevatron, 980 GeV: FERMILAB-THESIS-2005-105 (2005)
- RHIC, 100 GeV: X. Gu, et al., Phys. Rev. Accel. Beams 20, 023501 (2017)

E-lens can act on individual bunches

Can optimize e-beam distribution for maximum tune spread and Landau damping

- V. Shiltsev, et al., Phys. Rev. Lett. **119**, 134802 (2017)

HL-LHC hollow electron lens layout



A. Kolehmainen

HL-LHC hollow e-lenses can be reconfigured to give the right shape with a new e-gun

Parameter (Constraint)	Value	Comment
Current density	< 2-10 A/cm ²	Present technology limit
Electron current	< 5 A	Current E-Lens design
Electron beam length	3 m	
Electron energy	10 kV	
Max field ratio	$B_m/B_g < 4.0 \text{ T}/0.2 \text{ T} = 20$	
Electron beam size	0.4 – 2.0 mm	
Beta-function	240 m	40 m downstream IP 4
Proton beam energy	7 TeV	
Proton beam size	0.25 mm	2.0 um norm emittance
Transverse distribution	Gaussian	

Theory

Maximum tune shift

$$\Delta Q_{\max} = \frac{I_e}{I_a} \frac{m_e}{m_p} \left(\frac{\sigma_p}{\sigma_e} \right)^2 \frac{L_e}{4\pi\epsilon_n} \frac{1 + \beta_e}{\beta_e}$$

$I_a = 17$ kA – Alfvén current

Tune spread

$$\Delta Q_x = 2\Delta Q_{\max} \int_0^{1/2} e^{-(k_x+k_y)u} (I_0(k_x u) - I_1(k_x u)) I_0(k_y u) du$$

$$k_{x,y} = A_{x,y}^2 / 2\sigma_e^2$$

Electron beam is suppressed adiabatically:

$$\sigma_e = \sigma_{gun} \frac{B_g}{B_m}$$

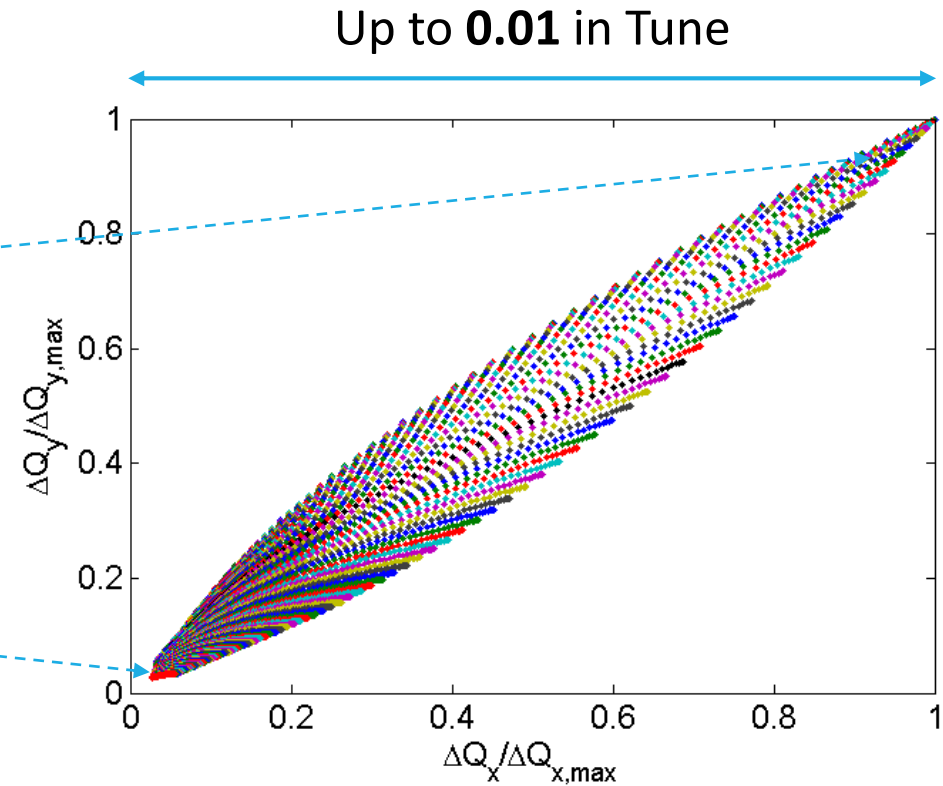
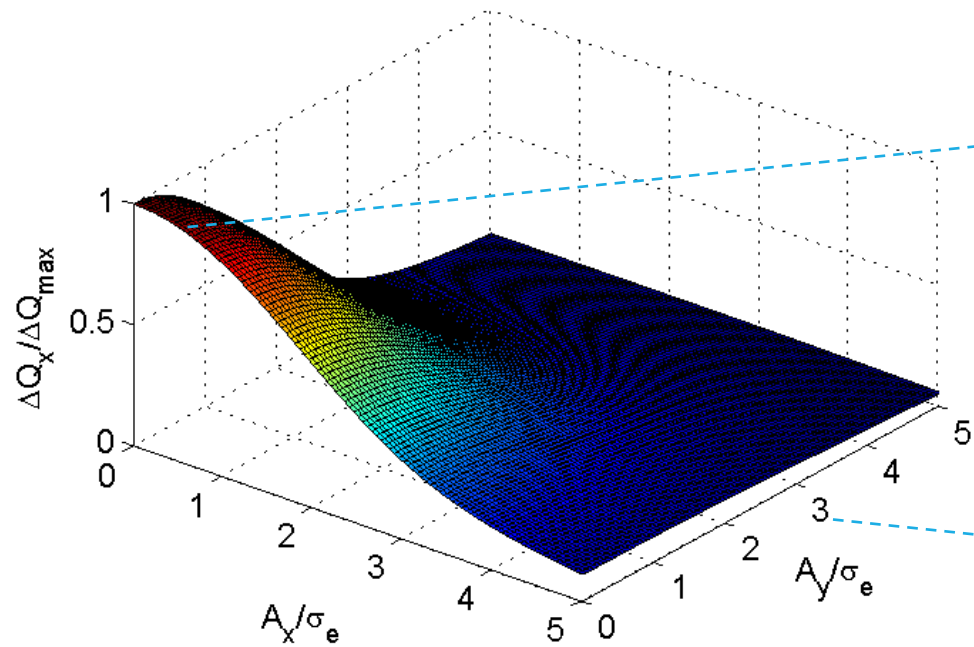
Higher field ratios (main solenoid/gun) preferable

Stability diagram

$$D(\Delta Q) = - \left(\int \frac{J_x \partial F / \partial J_x}{\Delta Q - \Delta Q_x + i0} d\Gamma \right)^{-1}$$

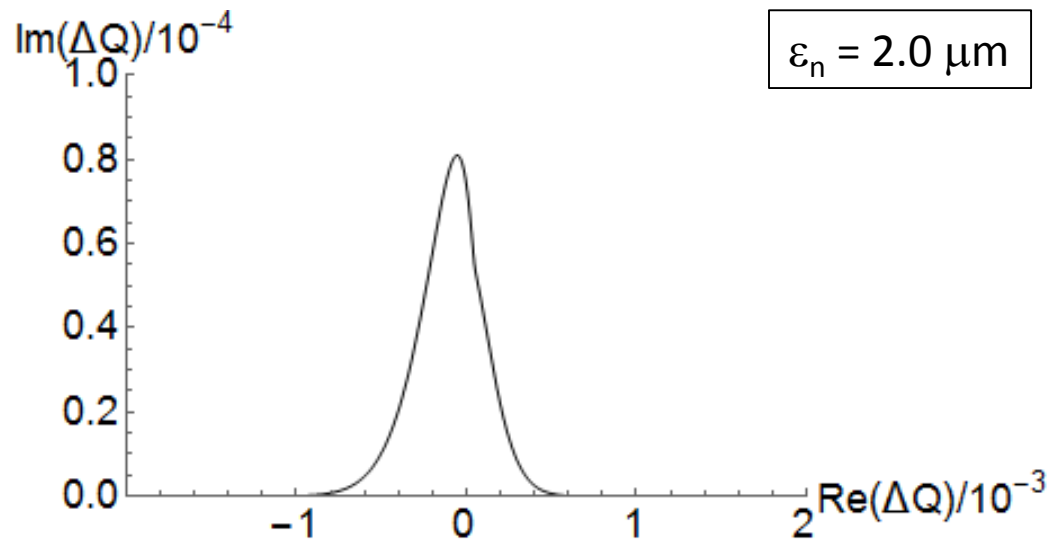
The tune spread is created by the core of the bunch

Normalized spread for a Gaussian bunch profile

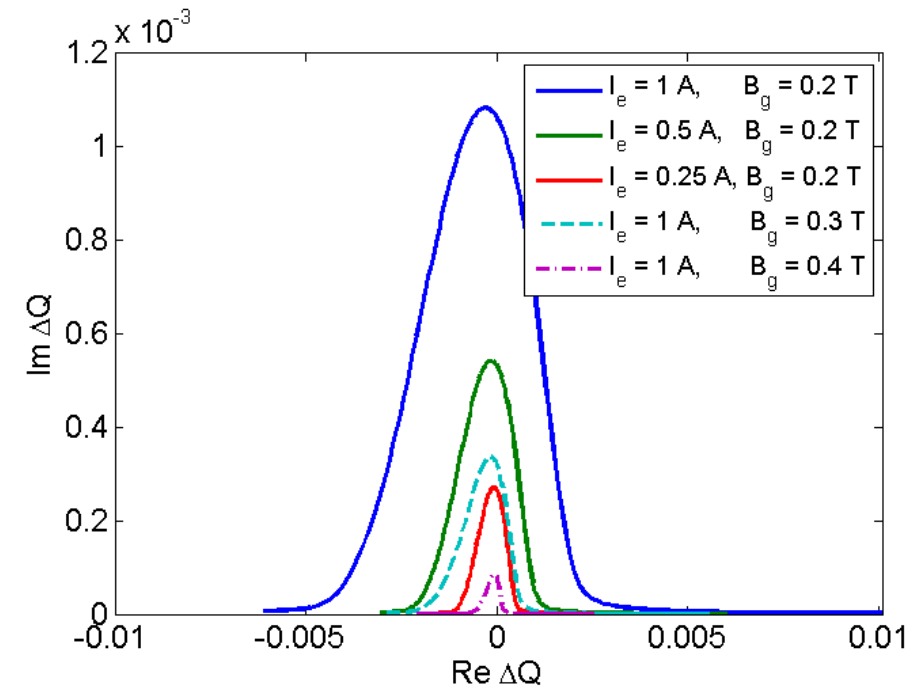


Electron lens can produce up to 10 times higher stability diagram compared to octupoles

OCTUPOLES AT MAX CURRENT OF -550 A

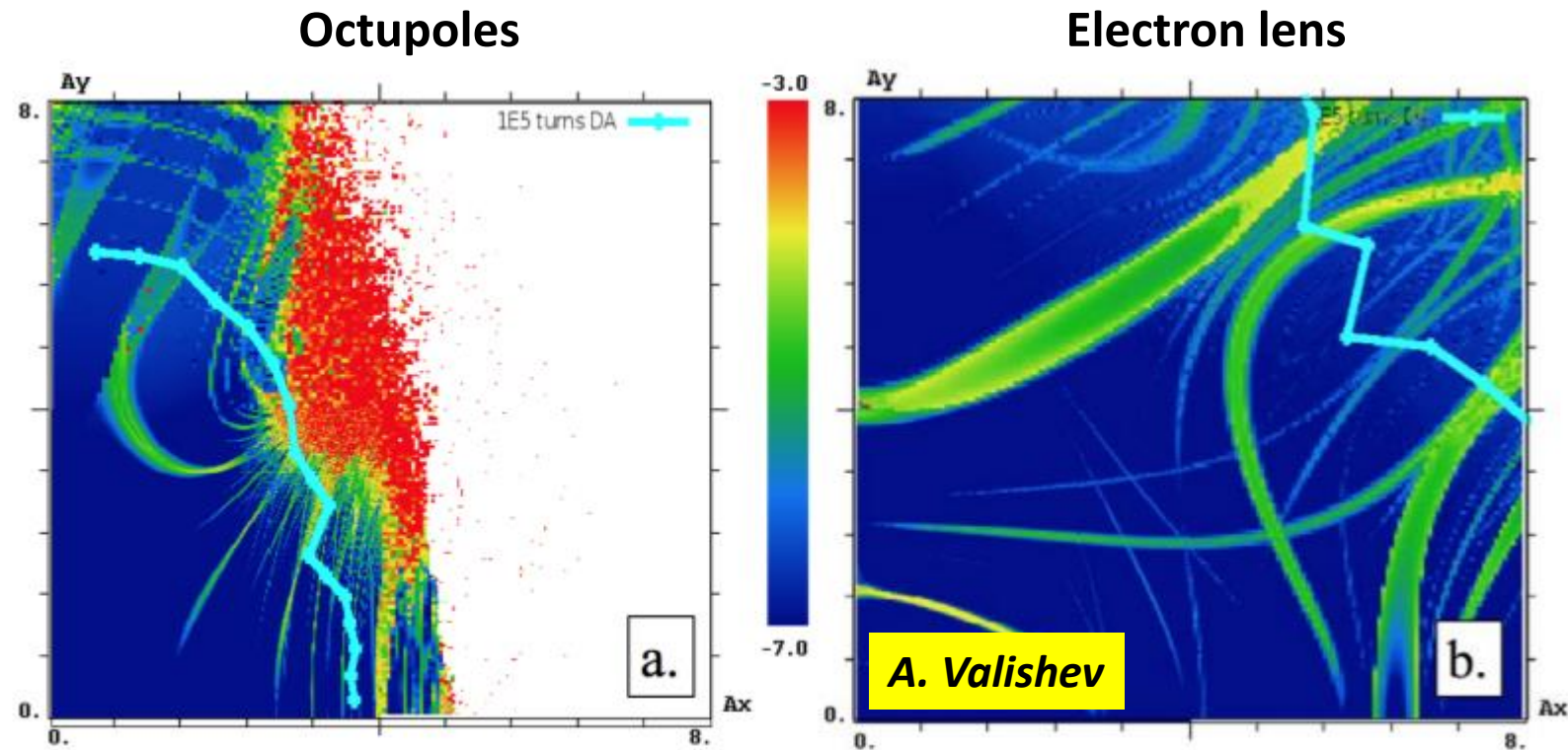


ELECTRON LENS



Electron lens also offers at least twice the dynamic aperture for the same tune spread

Study for HL-LHC optics lattice, DA computed from 10^5 turns of tracking



V. Shiltsev, *et. al*, [Landau Damping of Beam Instabilities by Electron Lenses](#)

Conclusion

Electron lens offers an efficient way to produce tune spread for Landau damping at high energies

Beam stability does not suffer from cutting the tails of the distribution

- Because the spread is produced by the core of the beam

In HL-LHC with one electron lens we can increase the stability diagram by a factor of 10 compared to octupoles

- Assuming the current parameters for the Hollow Lens
- Would require a new gun

Hollow electron lens cathode assembly

We are assuming a similar size of the cathode for the Gaussian lens

