Stability diagram with a Gaussian electron lens in HL-LHC

S. ANTIPOV, N. BIANCACCI, E. METRAL

MANY THANKS TO A. KOLEHMAINEN, D. PERINI, AND
M. FITTERER, G. STANCARI, AND A. VALISHEV (FNAL)

Why E-Lens

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

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

High $4\times10^{-3} – 10^{-2}$ tune shifts have been observed with e-lenses

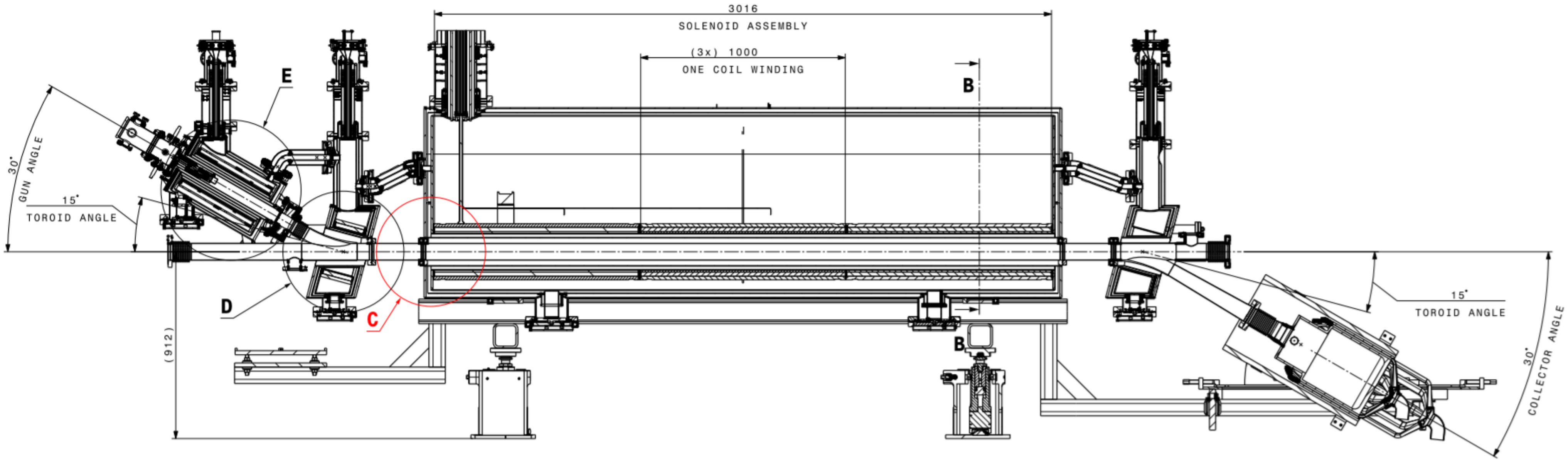
- Tevatron, 980 GeV: FERMILAB-THESIS-2005-105 (2005)
- RHIC, 100 GeV: X. Gu, et al., Phys. Rev. Accel. Beams 20, 023501 (2017)

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 T/0.2 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

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

I_a = 17 kA – Alfven current

Electron beam is suppressed adiabatically:

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

Higher field ratios (main solenoid/gun) preferable

Tune spread

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

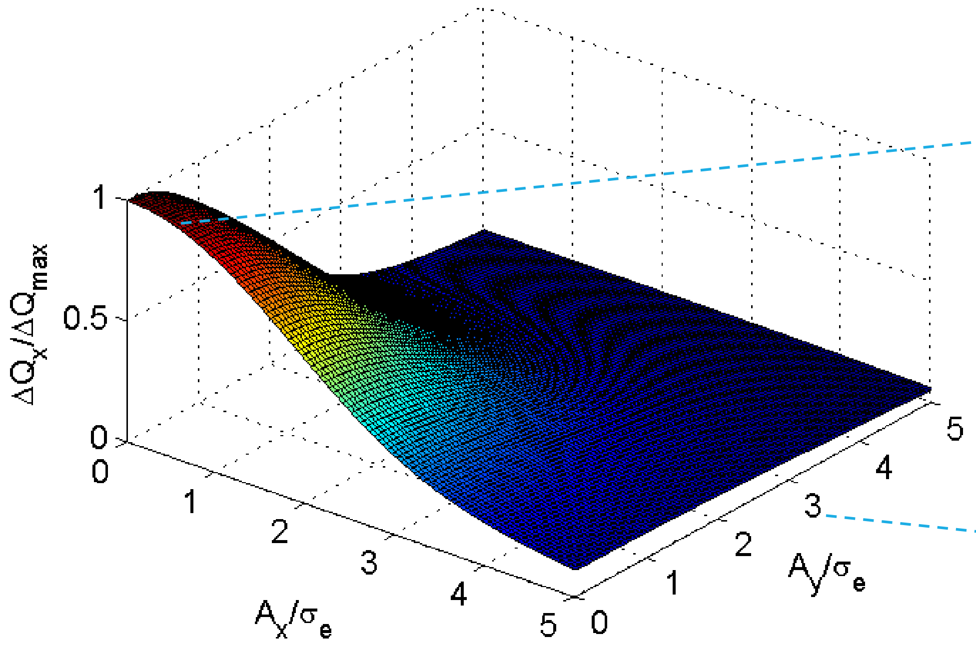
$$k_{x,y} = A_{x,y}^2 / 2\sigma_e^2$$

Stability diagram

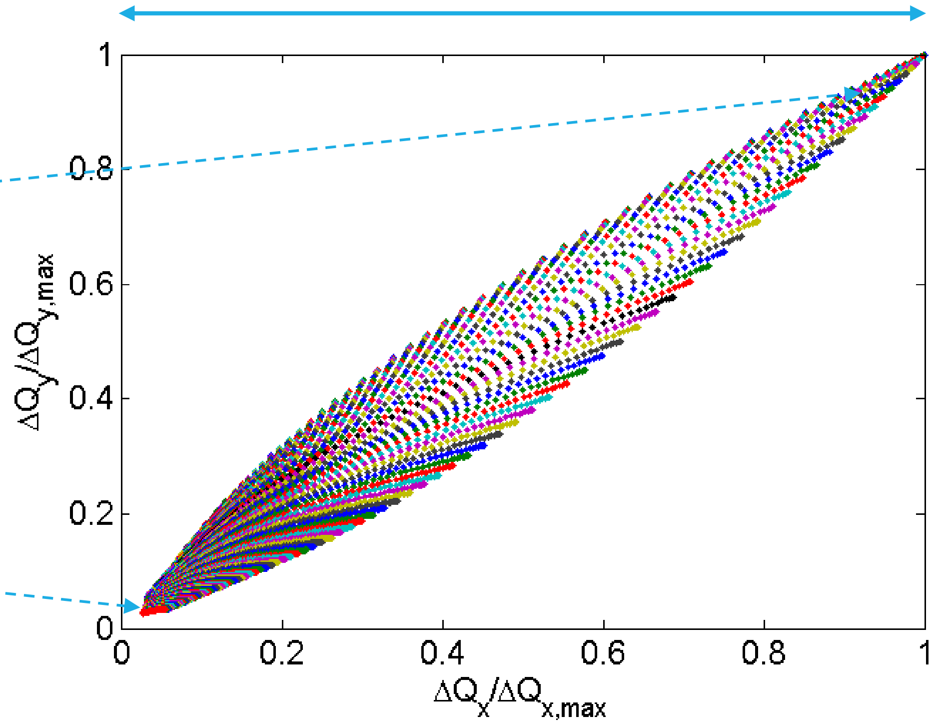
$$D(\Delta Q) = -\left(\int \frac{J_x \partial F / \partial J_x}{\Delta Q - \Delta Q_x + io} d\Gamma\right)^{-1}$$

The tune spread is created by the core of the bunch

Normalized spread for a Gaussian bunch profile

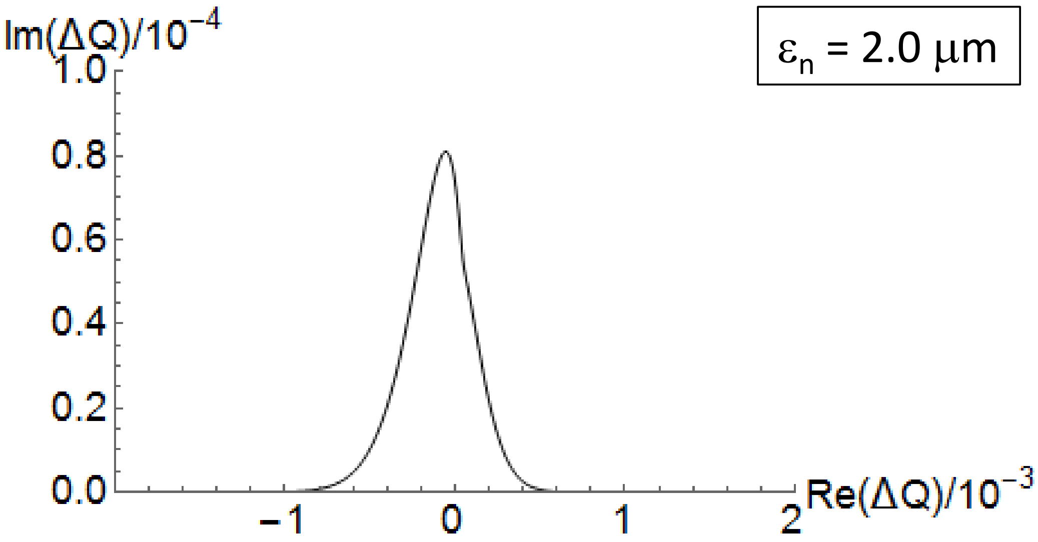


Up to **0.01** in Tune

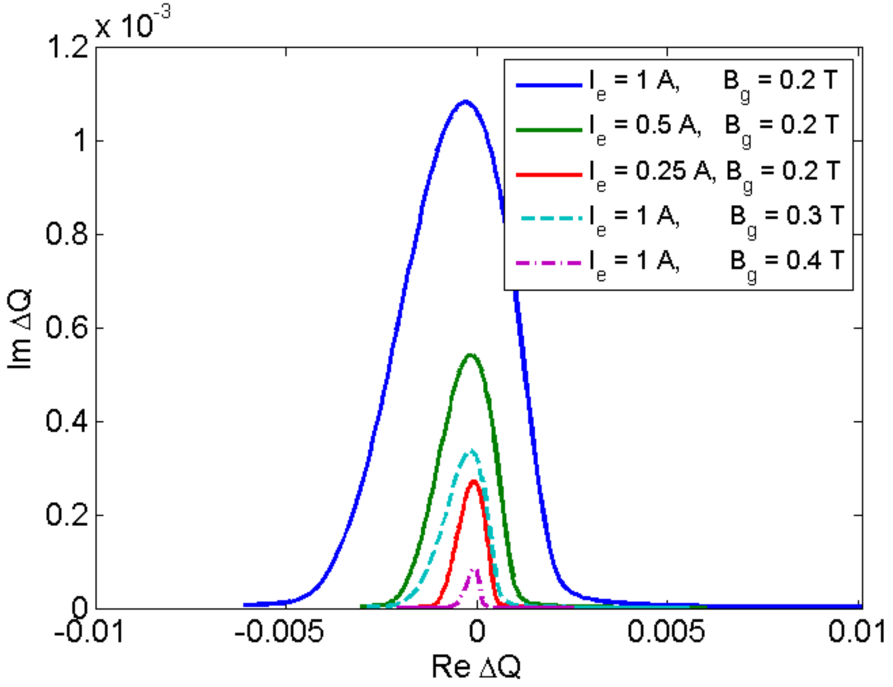


Electron lens can produce up to 10 times higher stability diagram compared to octupoles

OCTUPOLES AT MAX CURRENT OF -550 A



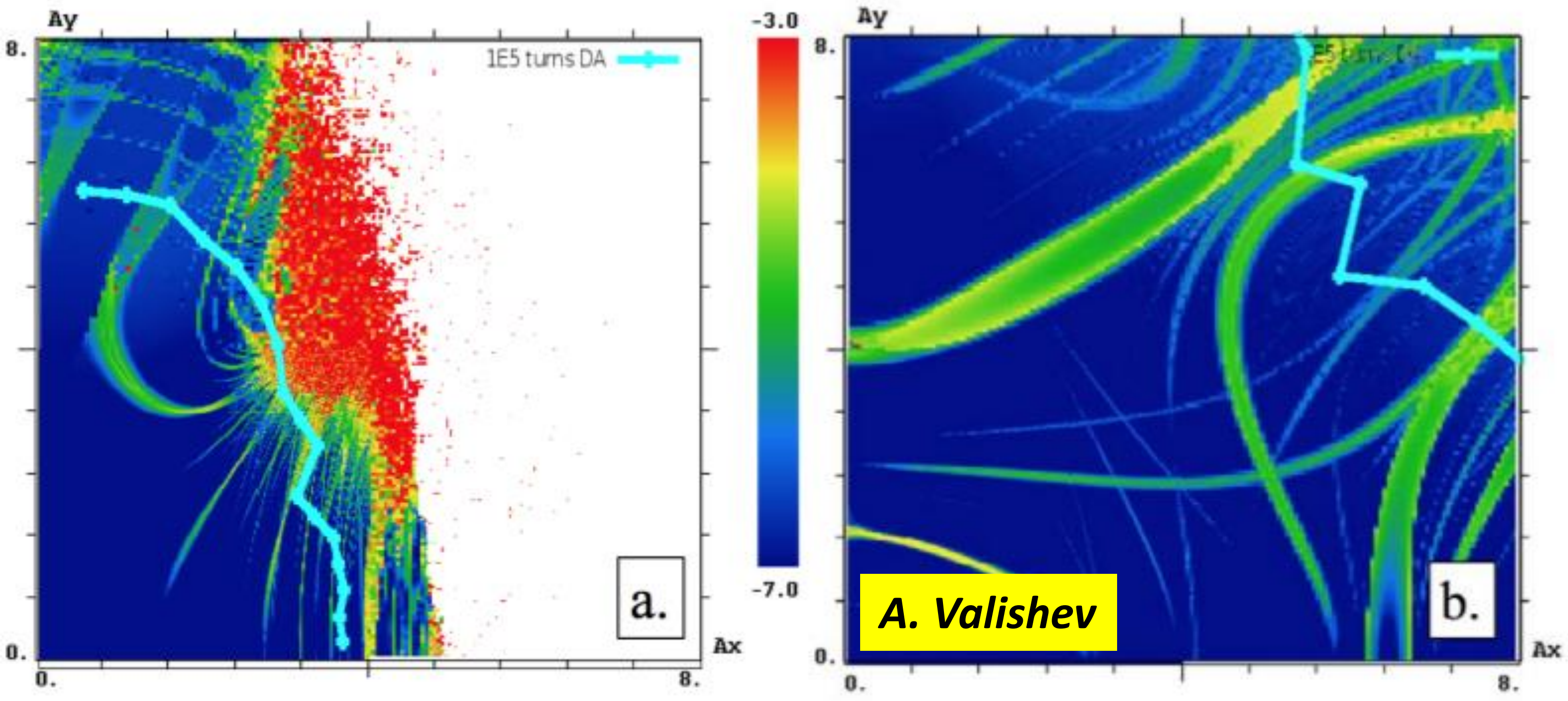
ELECTRON LENS



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

Octupoles **Electron lens**



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

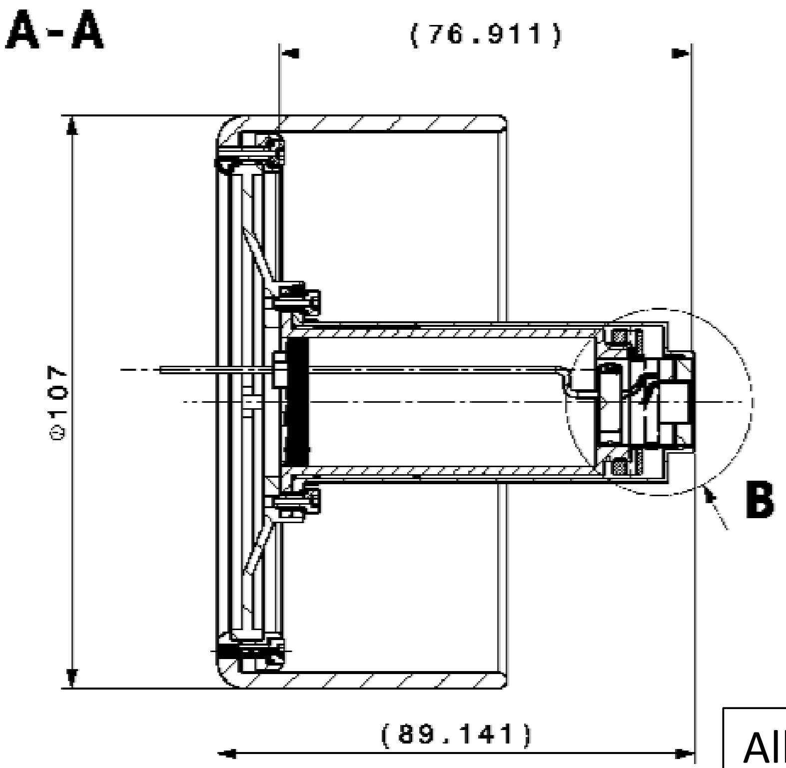
- Because the spread is produced by the core of the beam

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

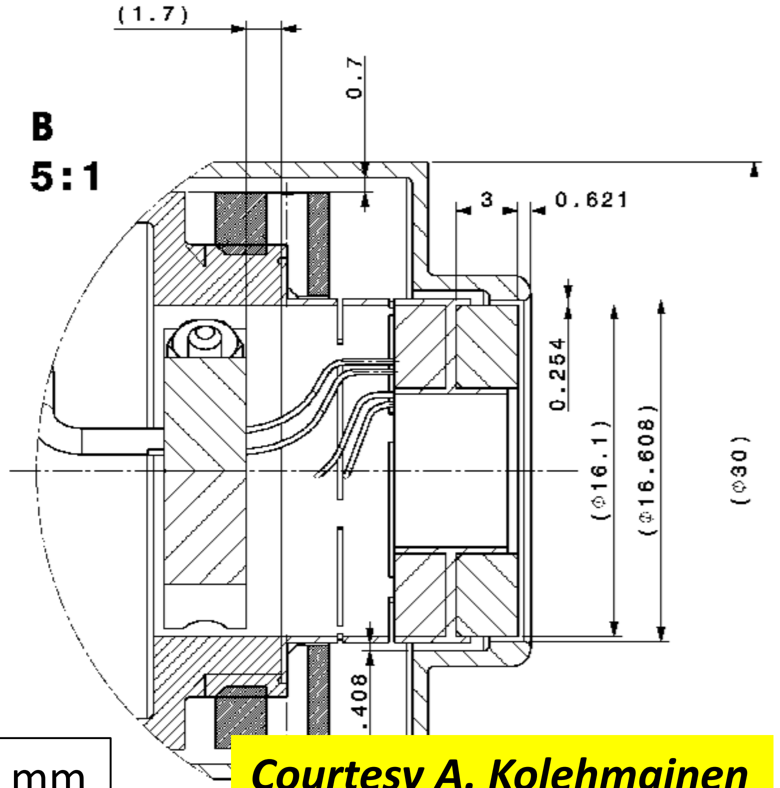
- Assuming the current parameters for the Hollow Lens
- Would require a new gun

Hollow electron lens cathode assembly

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



All dimensions in mm



Courtesy A. Kolehmainen