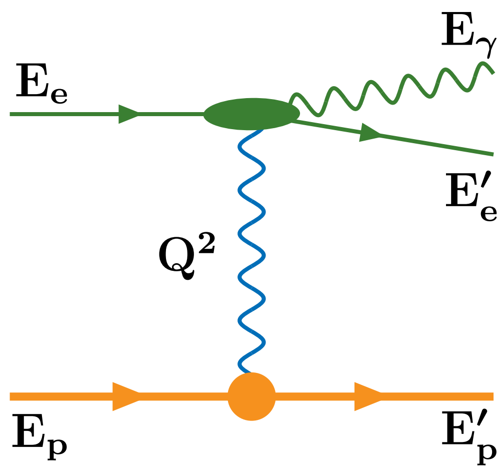
Luminosity measurements at the Large Hadron $_{\text{electron}}$ Collider (and FCC-eh)

K. Piotrzkowski and M. Przybycień

AGH University of Science and Technology – Kraków



The beam-size effect (BSE) was discovered at the VEPP-2 collider and later observed at HERA but remained ever since an elusive and poorly studied phenomenon, despite its impact on the electron and positron beam lifetimes at LEP and KEKB, for example. At the LHeC and FCC-eh, due to very small beam-sizes, this effect will be much stronger than at HERA and its understanding is essential for a precise determination of the luminosity at these *electron-hadron* colliders using bremsstrahlung.

Rate = L σ ?

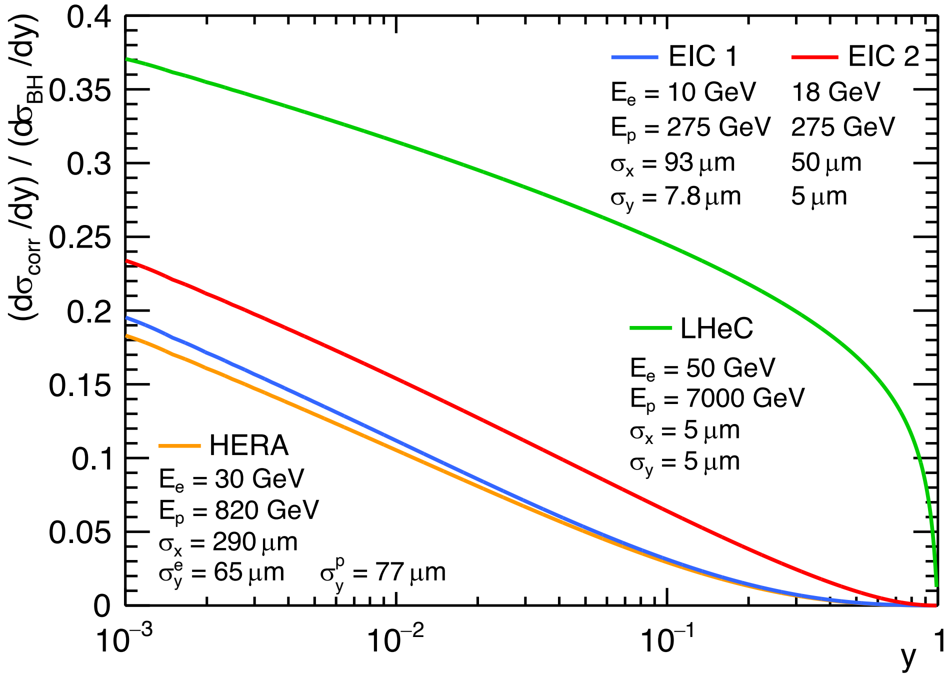
BSE calculations were made following Kotkin, Serbo & Schiller, Int. J. Mod. Phys. A **7**, 4707 (1992)

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.103.L051901

Beam-Size Effect – *effective* bremsstrahlung *suppression* at high energies due to small lateral beam-sizes of **both** colliding beams:

Event rate = Luminosity × cross section

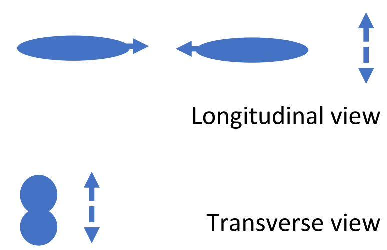
where colliding particles are represented by PLANE waves – and this *assumption* **breaks down** if the lateral beam sizes are comparable to typical impact parameters of a process.



⇐

$y = E_\gamma / E_e$

Using *Van der Meer scans*:



We proposed a novel powerful test of the BSE by measuring the bremsstrahlung spectrum while displacing transversally a hadron beam. This will be at the same time a unique direct study/demonstration of long-range nature of bremsstrahlung process – for such **lateral** beam displacements we predict a **strong effective increase** of its cross-section!

$e + p \rightarrow e' + \gamma + p'$ unique signatures

it is kinematically allowed that $\theta_\gamma = \theta_{e'} = \theta_{p'} = 0$ hence there is no transfer of transverse momentum, which results in (for LAB variables):

$$|q|_{min} = m_e^2 m_p E_\gamma / (4 E_p E_e E'_e), \text{ where } Q^2 = -q^2 \approx -q^2_{min} + q_T^2$$

For example, at the LHeC, for $E_e = 50$ GeV, $E_p = 7000$ GeV and $E_\gamma = 1$ GeV, one gets the minimal longitudinal momentum transfer, *in the proton rest-frame*, $\Delta p_z = |q_{min}|/c$ = 0.00001 eV/c. The corresponding (kinetic) energy transfer = $(\Delta p)^2/2M \approx 6.10^{-20}$ eV!

From the uncertainty principle Δp_z corresponds to the longitudinal distance $\approx \hbar/\Delta p_z$ of **21 mm** whereas in the transverse plane the *impact parameters* is often even larger, as q_T is often smaller than $|q|_{min}$:

$$d^4\sigma / dE_\gamma \, d\theta_e d\theta_\gamma d\phi \propto Q^{-4}$$

Higher beam energies/lower photon energy ⇒ **more** extreme it becomes!

At the *LHeC* and *FCC-eh* the bremsstrahlung spectrum will be strongly suppressed over the entire range of photon energies!

Both the beam sizes as well beam alignment will have to be very well controlled.