

# **Impact of Beam-Beam Effects on Beam Energy and Crossing Angle at IP**

**Dmitry Shatilov**

BINP, Novosibirsk

Acknowledgements:

**E. Perez, P. Janot**

FCC Week, Brussels

25 June 2019

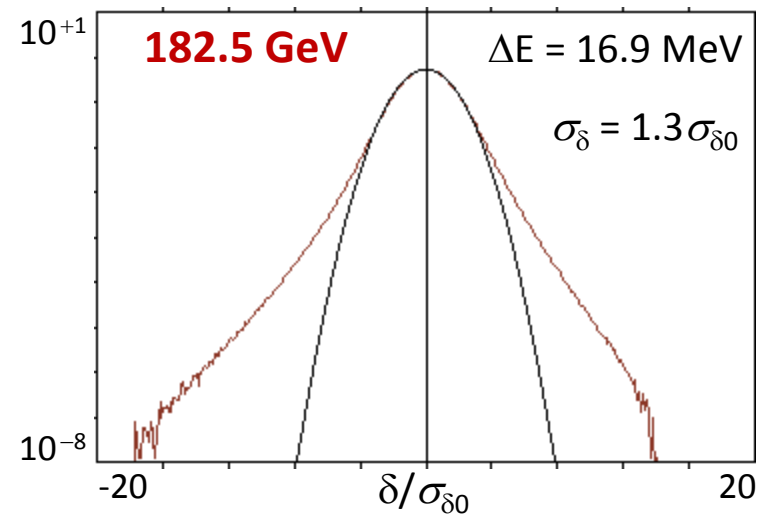
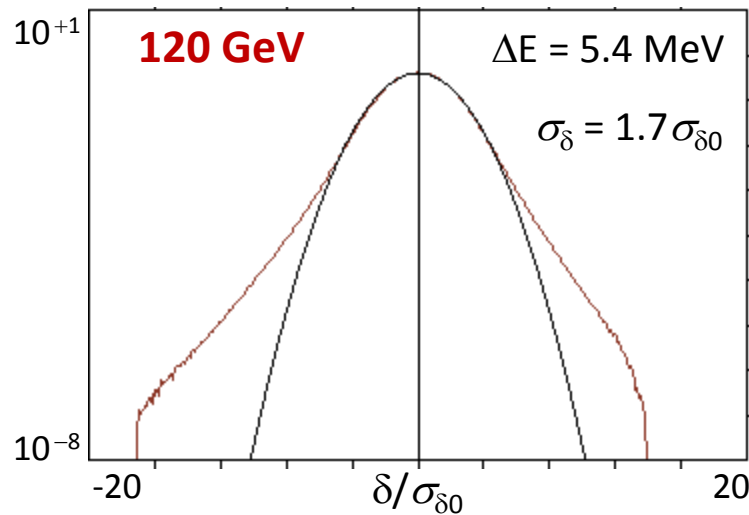
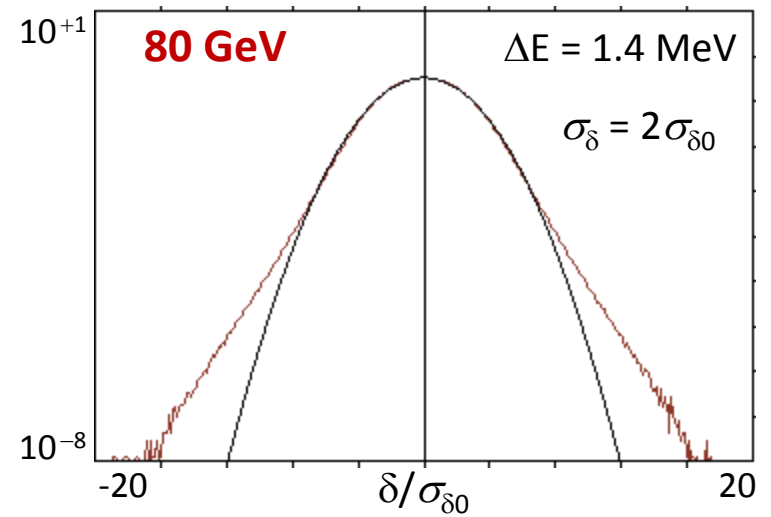
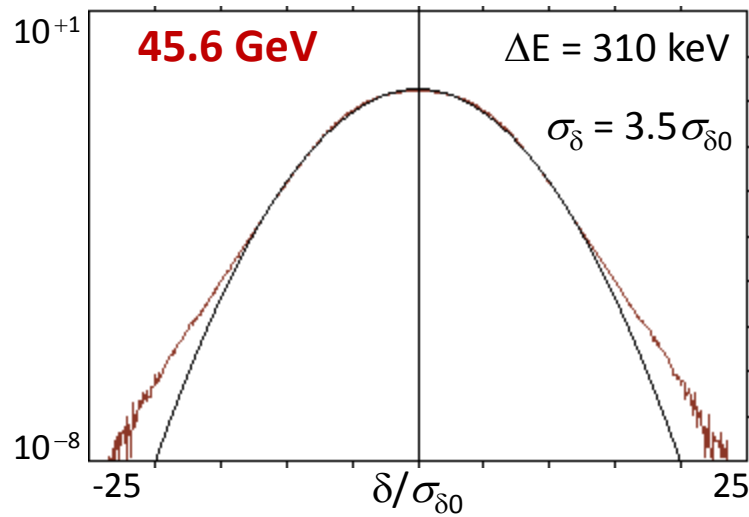
# Introduction

- Unlike pilot bunches, which are used for resonant depolarization, colliding bunches interact with the oncoming beam.
- The question is how the “collision energy” differs from what we measure with energy calibration.
- Energy is affected by beamstrahlung and crossing angle. The magnitude of the effect depends on the bunch length, which in turn is determined mainly by beamstrahlung.
- A self-consistent problem needs to be solved, and this is best done using beam-beam tracking codes.

# The Model

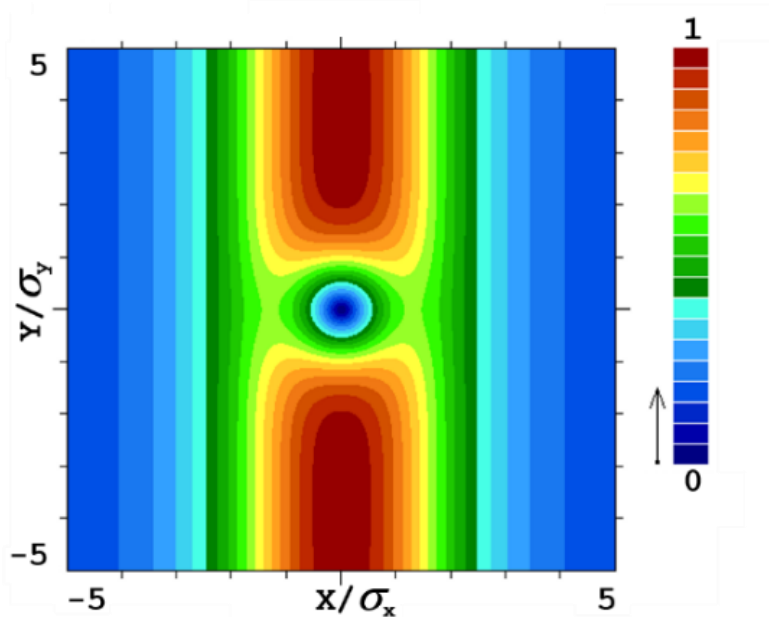
- Linear lattice with damping and Gaussian noise. No dispersion at IP, no explicit energy loss in the arcs.
- IP is located symmetrically between RF sections (in fact, IR region is not quite symmetrical).
- We present the results obtained by the `Lifetrac` code, which include the equilibrium beam sizes and the corresponding impact on energy and crossing angle.
- The latter was also verified by E. Perez using the `Guinea Pig` code, while the beam sizes were entered as input parameters. Good agreement was obtained between the two codes.

# Energy Loss & Energy Distribution at IP



# Dependence on Y-coordinate

Absolute Value of Transverse Force for Flat Beams

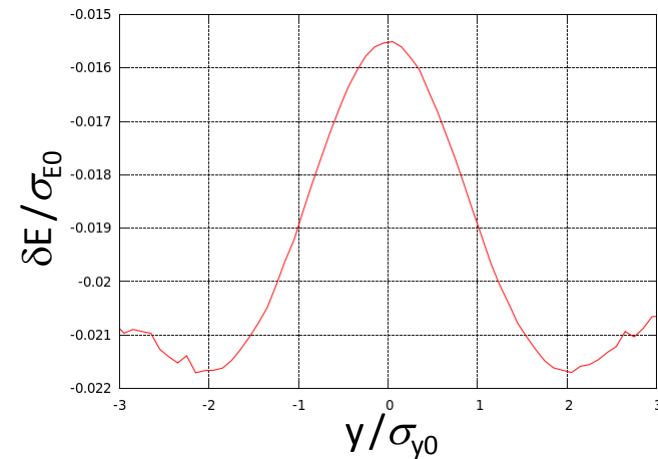


Due to the crossing angle, particles traverse the opposite bunch horizontally.

Maximum beamstrahlung:  $|y| > 2\sigma_y$

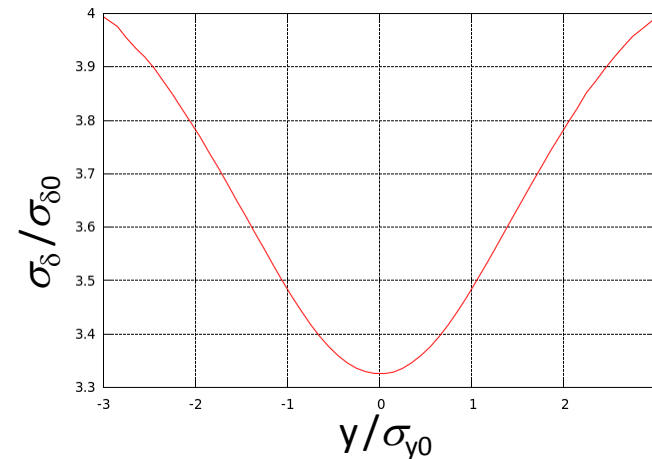
Maximum luminosity:  $|y| < 2\sigma_y$

Energy change per collision

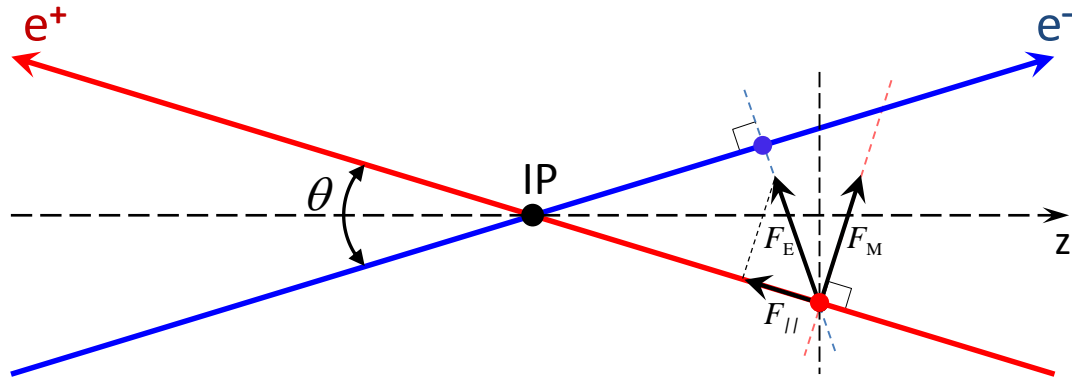


**45.6 GeV**

Equilibrium energy spread

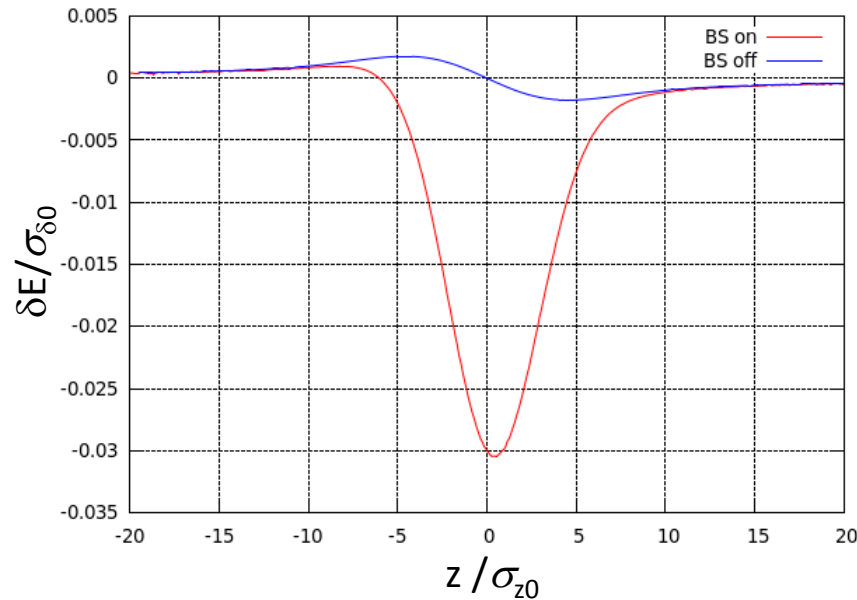


# The Effect of Crossing Angle



- In the ultrarelativistic case, electro-magnetic field from the opposite bunch is compressed into a plane which is perpendicular to its trajectory.
- The kick from the opposite bunch consists of two components: electric and magnetic. Their absolute values are equal, but directions are different because of the crossing angle.
- Particles are accelerated in the region before IP and decelerated in the region after IP. The total energy change depends on the particle's longitudinal coordinate. This is equivalent to the appearance of a nonlinear RF cavity. The effect was experimentally observed at the DAΦNE collider [*Phys. Rev. ST Accel. Beams* 14 (2011) 092803].
- The crossing angle “at collision” is increased by beam-beam interaction.
- The total kick is orthogonal to the bisector of two trajectories, therefore  $\delta p_z = 0$ . It means that the center-of-mass energy at the IP is not affected, since  $\sqrt{s} = 2\sqrt{|p_{z+}p_{z-}|}$  (see also the next presentation by P. Janot).

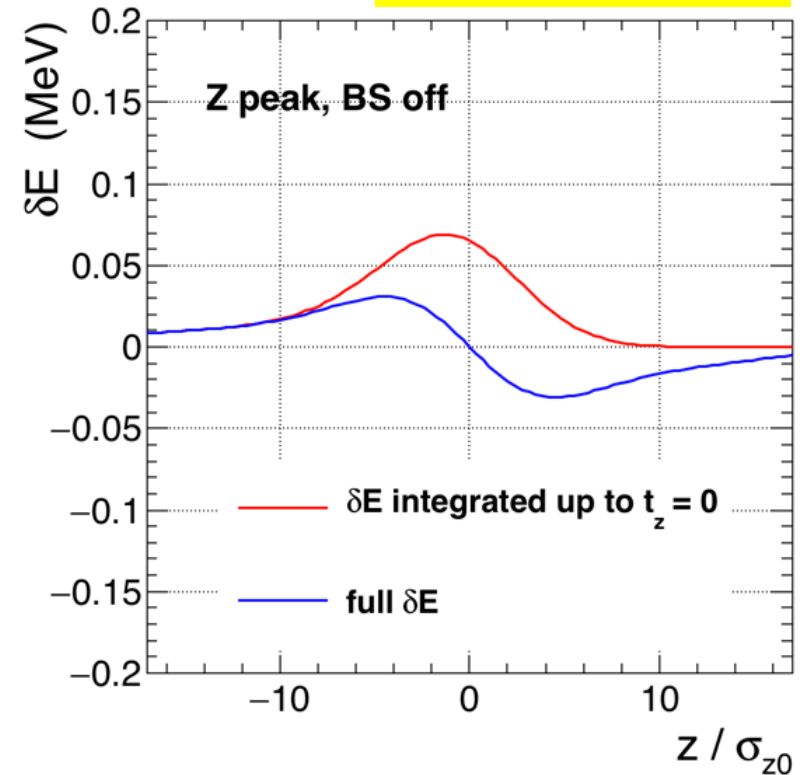
# Dependence on Z-coordinate [at 45.6 GeV]



Full energy change (from “well before IP” to “well after IP”) vs. the particle’s z-coordinate.

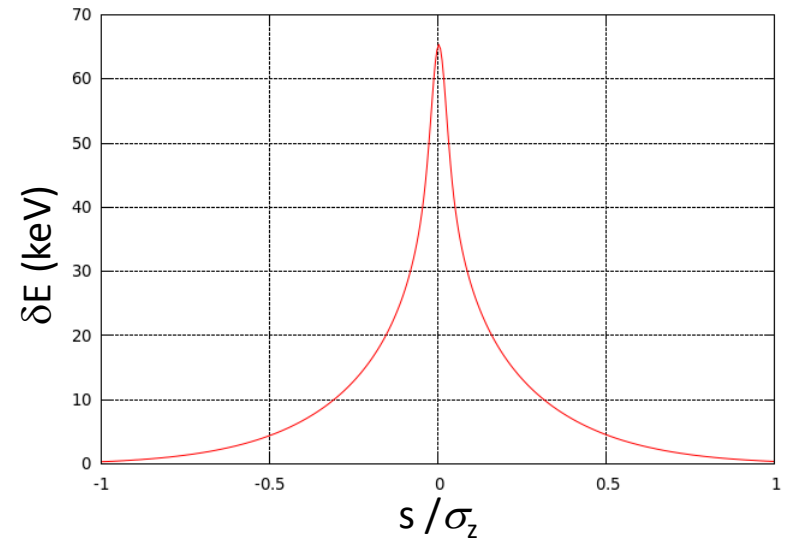
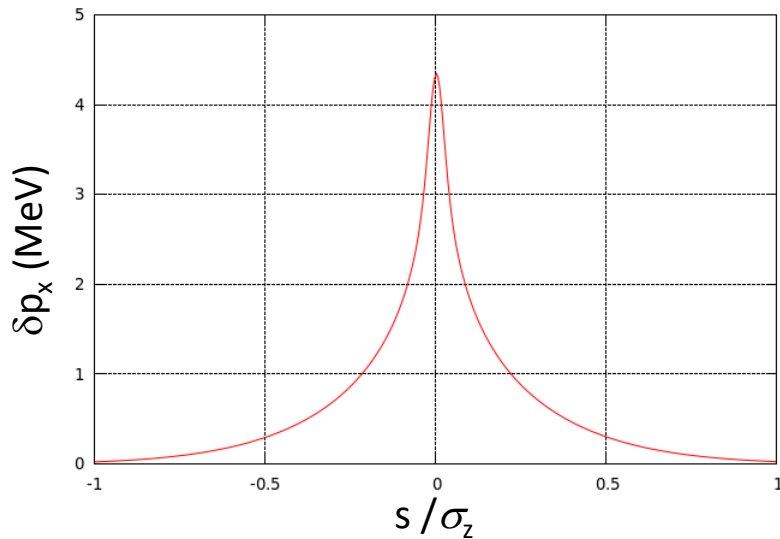
If the bunch populations deviate from the nominal value by  $\pm 5\%$ , then  $\sigma_{\delta}$ ,  $\sigma_z$  and  $\Delta E$  differ about twice, and the centers of bunches no longer meet at the IP. As a result, the weak (less populated) bunch decelerates and the strong one accelerates by  $\sim 1$  keV, which contributes to  $\Delta E$ .

E. Perez, Guinea Pig



Particles in the head of the bunch experience less acceleration before the IP than particles in the tail, which makes the red curve asymmetric.

# Energy and Momentum Change in Collision



45.6 GeV. Particle with all zero coordinates collide with a bunch.  $S$  is the azimuth (distance to IP).

## Shift of the average collision energy for the whole bunch:

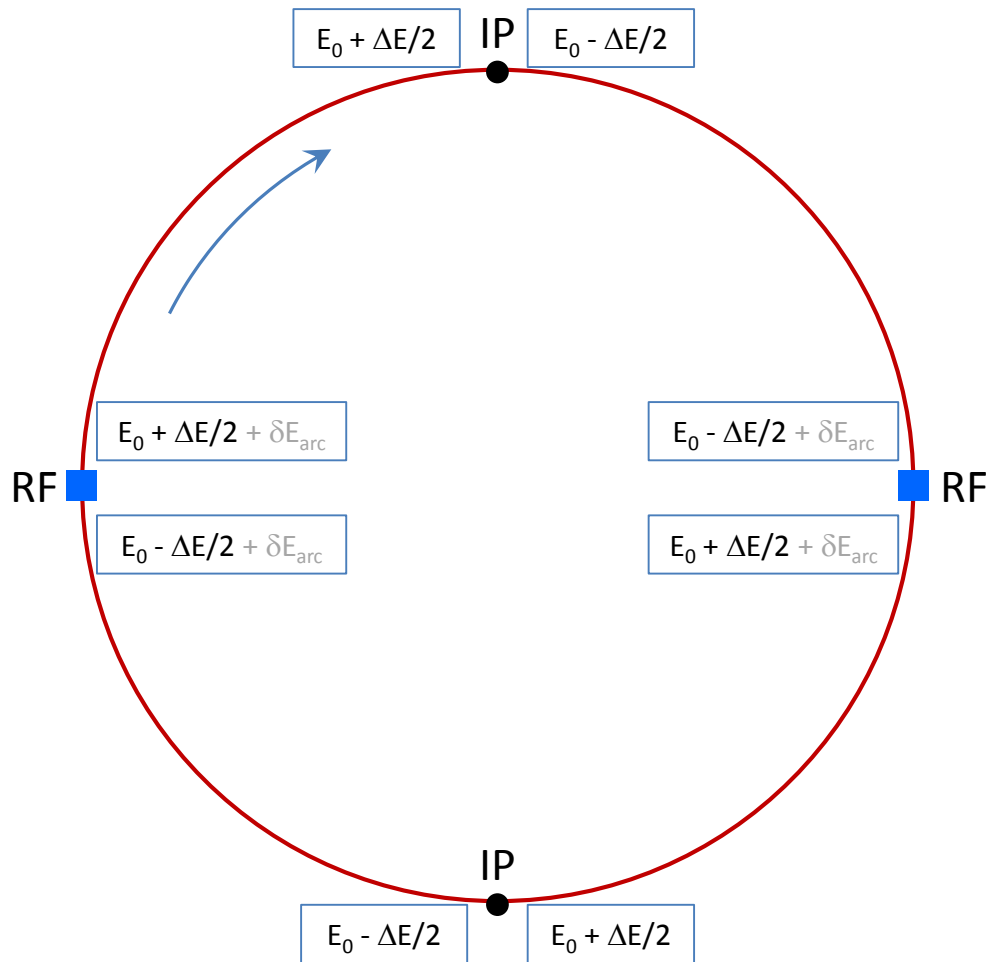
E (GeV)	45.6	80	120	182.5
$\delta E$ (keV)	61	108	212	1480

$$\delta E = \langle E \rangle - E_0 \quad \langle E \rangle = \frac{\sum E_c L_c}{\sum L_c}$$

Without beamstrahlung – the same values!

Collisions with every slice of the opposite bunch.  
 $E_C$  and  $L_C$  are the particle energy and luminosity of such elementary collision.

# Beam Energy Compared with Pilot Bunches



$E_0$  means the energy of pilot bunch *at that azimuth*.

- In general case, the energy shift at IP relative to the pilot bunch is  $\Delta E_1$  just before IP and  $\Delta E_1 - \Delta E$  just after IP.
- Assuming that the energy losses in the arcs are independent of  $\Delta E$  (for small  $\Delta E$ ) and the IPs are located symmetrically with respect to the RF cavities, from the requirement to maintain the constant path length, we get  $\Delta E_1 = \Delta E/2$ .
- Next step: account the difference in the energy losses in the arcs,  $\delta E_{\text{arc}}$ , which in the first order should be linear in  $\Delta E \Rightarrow$  particles lose  $\delta E_{\text{arc}}$  in the region from RF to IP and gain  $\delta E_{\text{arc}}$  in the region from IP to RF.
- As a result, additional energy shift  $\delta E_{\text{arc}}$  appears at the RF cavities, but there is no shift at the IPs.
- In the following orders of approximation there is no full compensation. But anyway, the total shift of average collision energy with respect to the pilot bunch is small *in the case of symmetrical IR*.
- The main effect comes from the fact that *IR is not quite symmetrical* (to reduce the critical energy of SR towards detectors).

# Summary

- Due to the crossing angle, beam-beam interaction causes an increase in the beam energy and the crossing angle “at collision”. The center-of-mass energy does not change.
- The average beam energy changes after interaction for two reasons: beamstrahlung and crossing angle (in case of asymmetry of colliding bunches).
- The shift of average collision energy due to beam-beam interaction is small. The main effect is associated with the asymmetry of the Interaction Region.