# Energy Loss due to Beamstrahlung and Impact on Local Energy and on Energy Differences of Colliding and Non-Colliding Bunches

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Thanks to **E. Perez, A. Ciarma, P. Janot**

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# Introduction

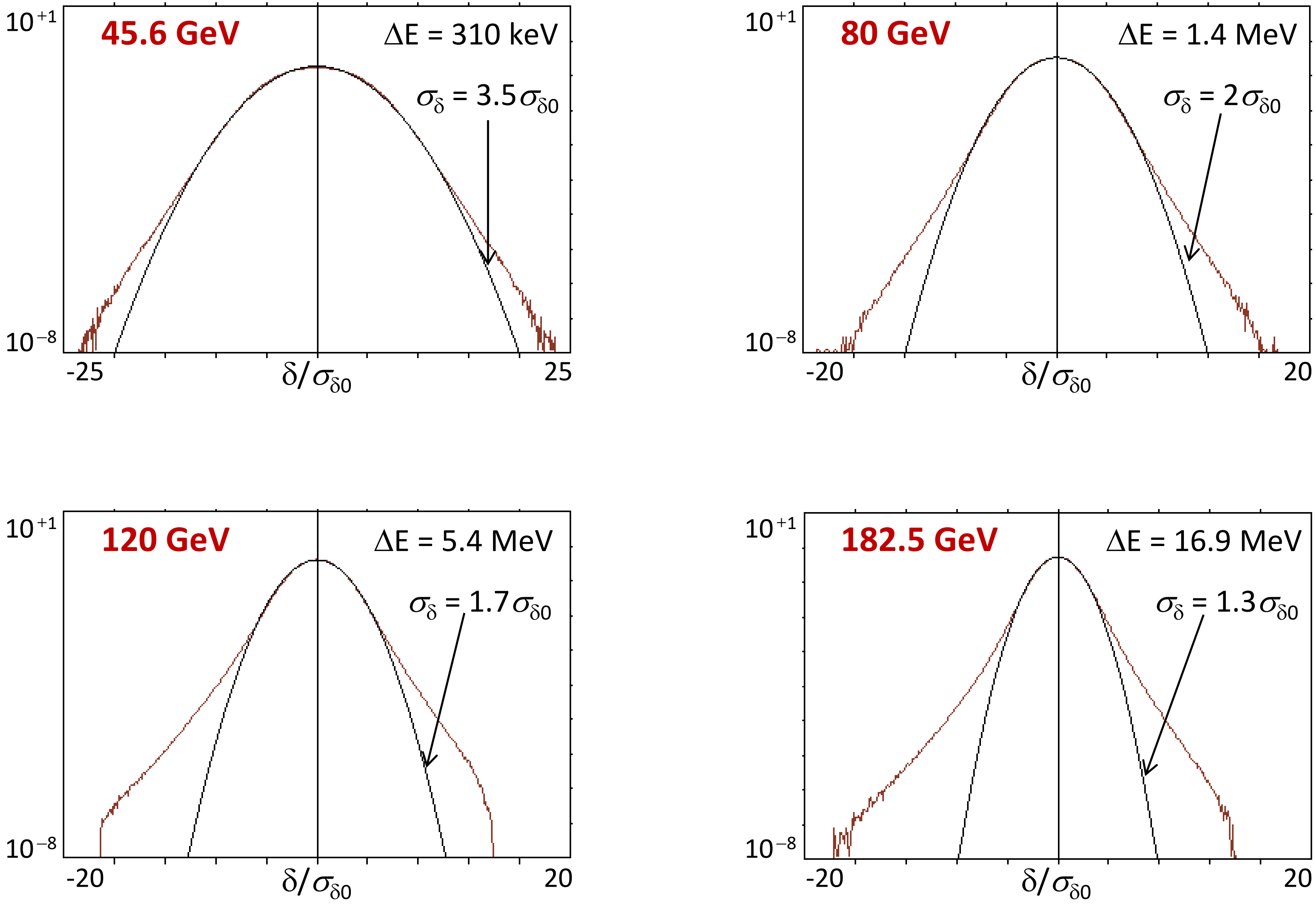
- Unlike pilot bunches, which are used for resonant depolarization, colliding bunches interact with the oncoming beam. The question is, how the “collision energy” differs from what we measure with energy calibration.

- 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. All results presented here were obtained by `Lifetrac`.

- We do not yet know the realistic parameters of the bunches, so it makes little sense to substitute the exact values from the table. Most of the examples used the parameters from the CDR. Now much has changed, but the scale of phenomena has remained approximately the same.

- Many questions, such as the presence of dispersion at the IP, asymmetry of lattice parameters in different IPs, orbital distortions at the IPs, etc., have not yet been considered here.

# Energy Loss & Energy Distribution at IP



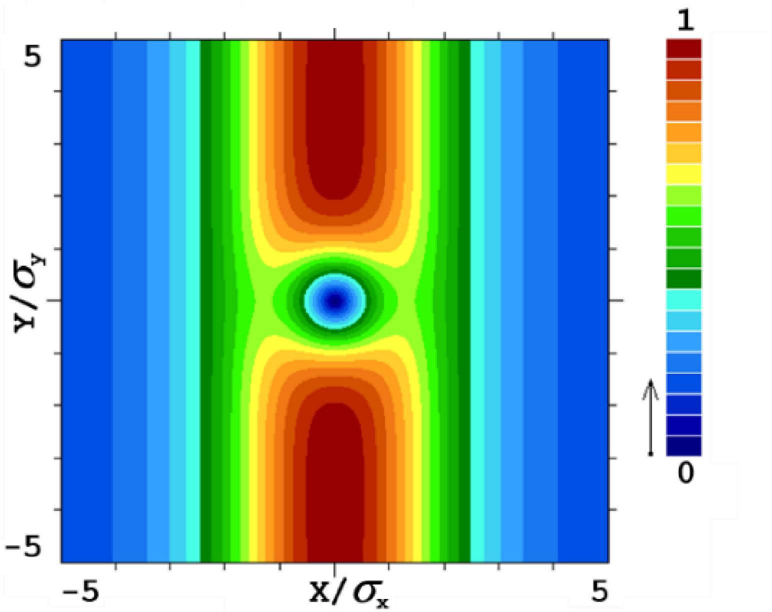
Energy distributions on a logarithmic scale.

The black lines (parabola) show the Gaussian distributions fitted to the beam core.

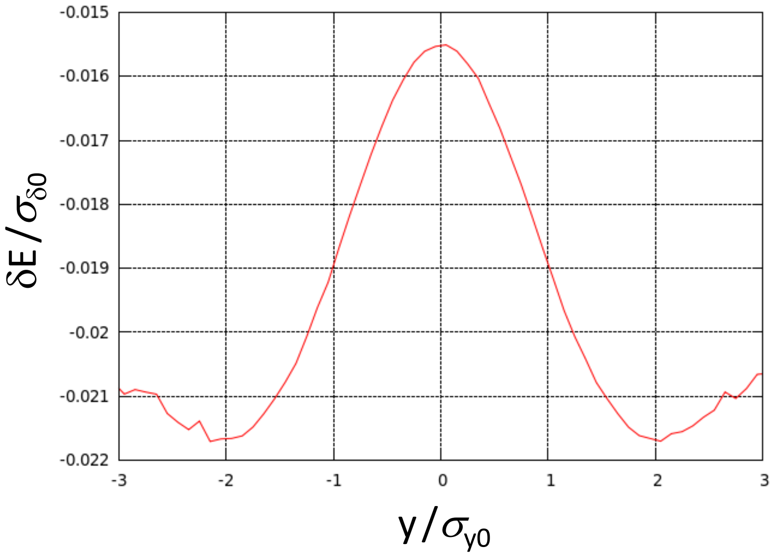
# Dependence on Y-coordinate

**45.6 GeV**

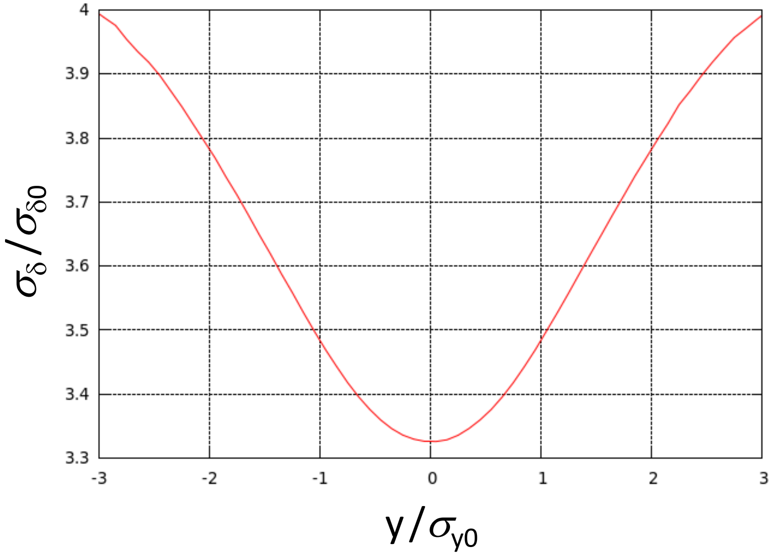
Absolute Value of Transverse Force for Flat Beams



Energy change per collision



Equilibrium energy spread



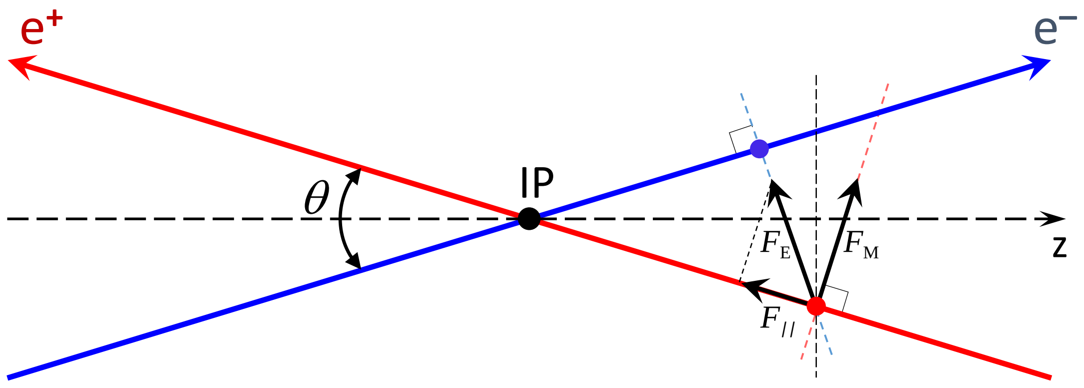
Due to the crossing angle, particles traverse the opposite bunch horizontally.

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

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

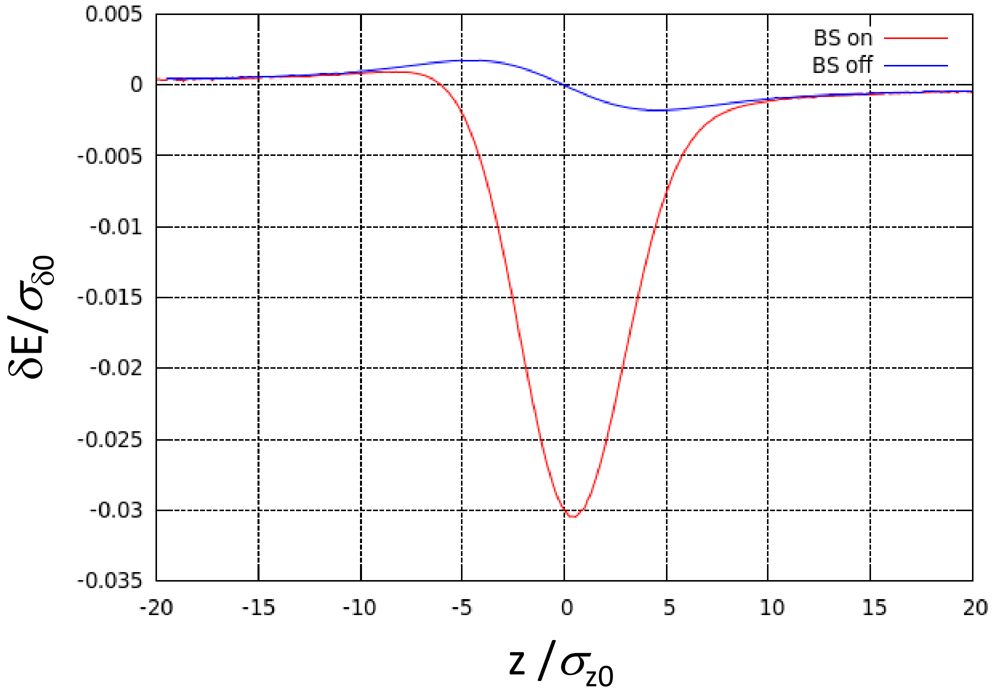
The contribution to the energy spread from the horizontal and vertical bends is approximately the same.

# 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 $\sqrt{s} = 2\sqrt{|p_{z+} p_{z-}|}$.

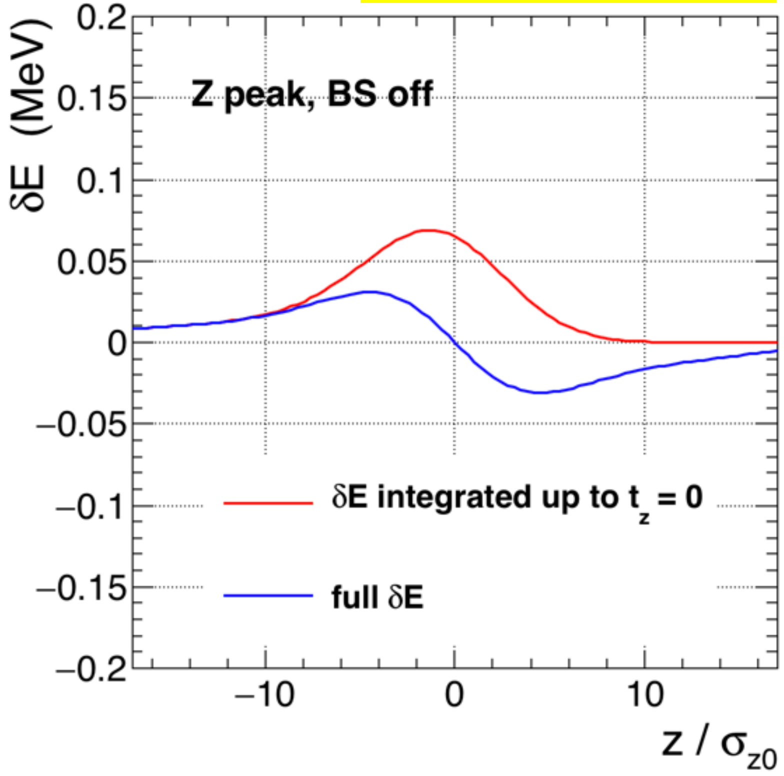
# Dependence on Z-coordinate [at 45.6 GeV]



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

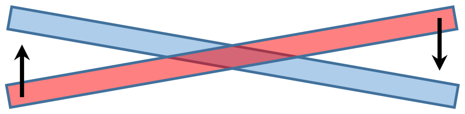
If the bunch populations deviate from the nominal value by ±5%, then $\sigma_\delta$, $\sigma_z$ and $\Delta E$ differ about twice, and the centers of bunches no longer meet at the IP. As a result, the weak (less populated) bunch decelerates and the strong one accelerates by ~1 keV, which contributes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

E. Perez, `Guinea Pig`

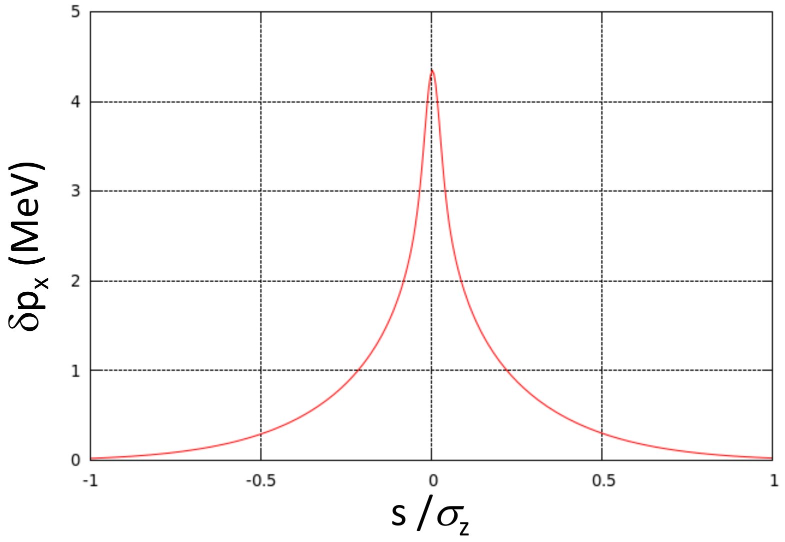


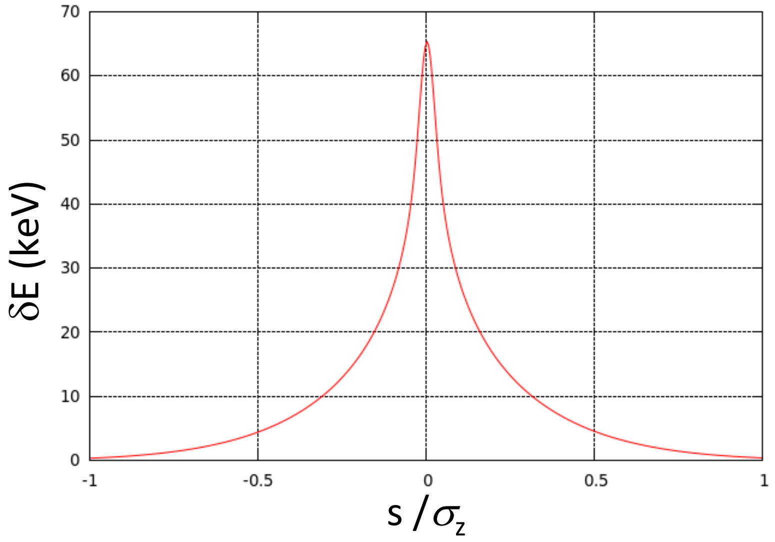
Particles in the head of the bunch experience less acceleration before the IP than particles in the tail, which makes the red curve asymmetric.

# Energy and Momentum Change in Collision



The deflection angle $\delta p_x$ increases before IP and decreases after IP. The maximum is at the IP.





45.6 GeV w/o BS. Particle with all zero coordinates collide with a bunch, S is the azimuth (distance to IP).

**Shift of the average energy "at collision" for the whole bunch:**

| E (GeV) | 45.6 | 80 | 120 | 182.5 |
|---|---|---|---|---|
| δE (keV) | 61 | 108 | 212 | 1480 |

Without beamstrahlung – the same values!

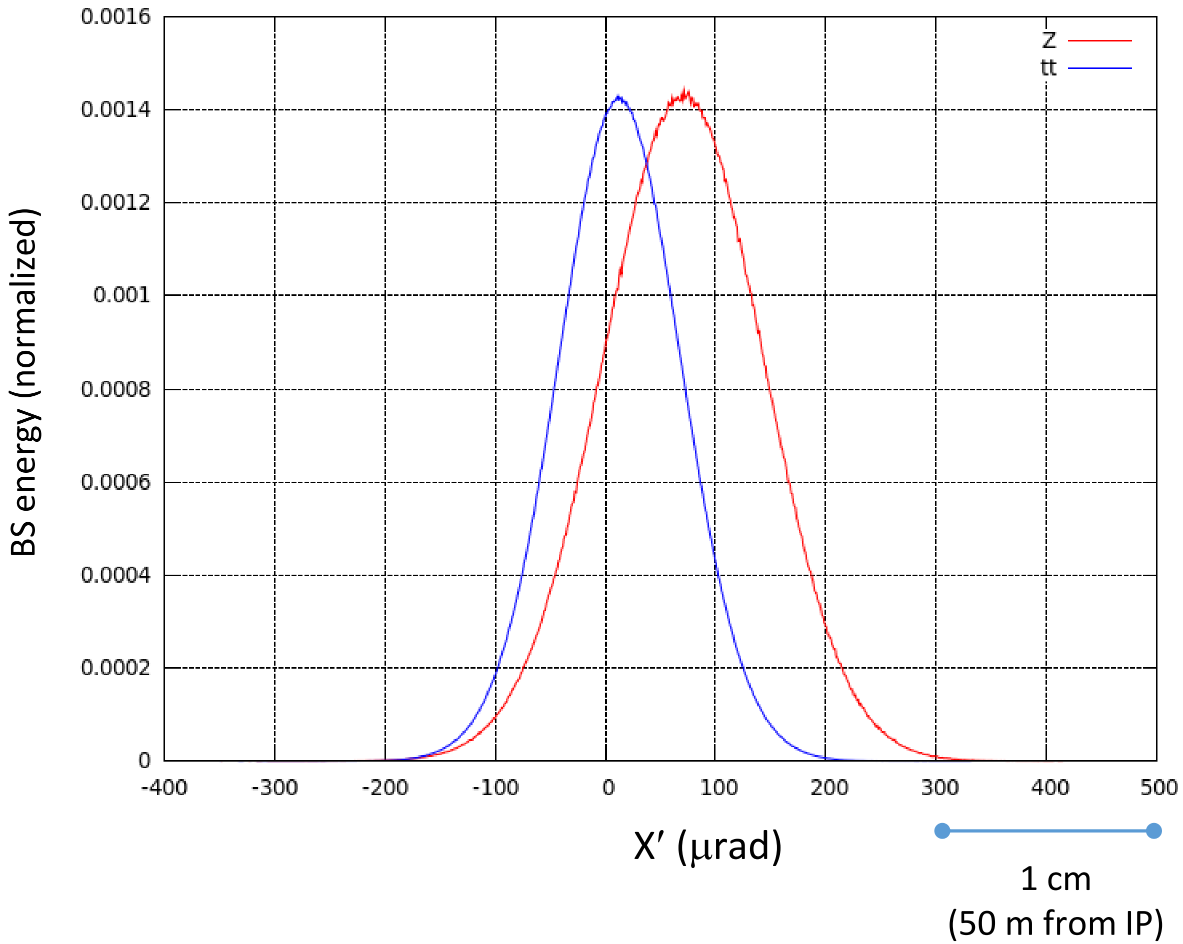
$$\delta E = \langle E \rangle - E_0 \qquad \langle E \rangle = \frac{\sum E_c L_c}{\sum L_c}$$

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

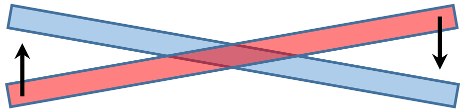
# More Details on Beamstrahlung

| | Z | ttbar |
|---|---|---|
| IPs | 4 | 4 |
| $\beta_x^*/\beta_y^*$ [mm] | 150 / 0.8 | 1000 / 1.6 |
| $N_p$ [$10^{11}$] | 2.53 | 2.64 |
| $\sigma_z$ (bs) [mm] | 15.3 | 2.95 |
| <X′> [μrad] | 70 | 13 |
| $\sigma_{X'}$ [μrad] | 73 | 56 |
| $\sigma_{Y'}$ [μrad] | 54 | 55 |
| $<N_{photons}>$/turn | 0.127 | 0.202 |
| dE/turn [MeV] | 0.261 | 16.34 |
| $<E_\gamma>$ [MeV] | 2 | 81 |
| BS power/IP [kW] | 334 | 82 |

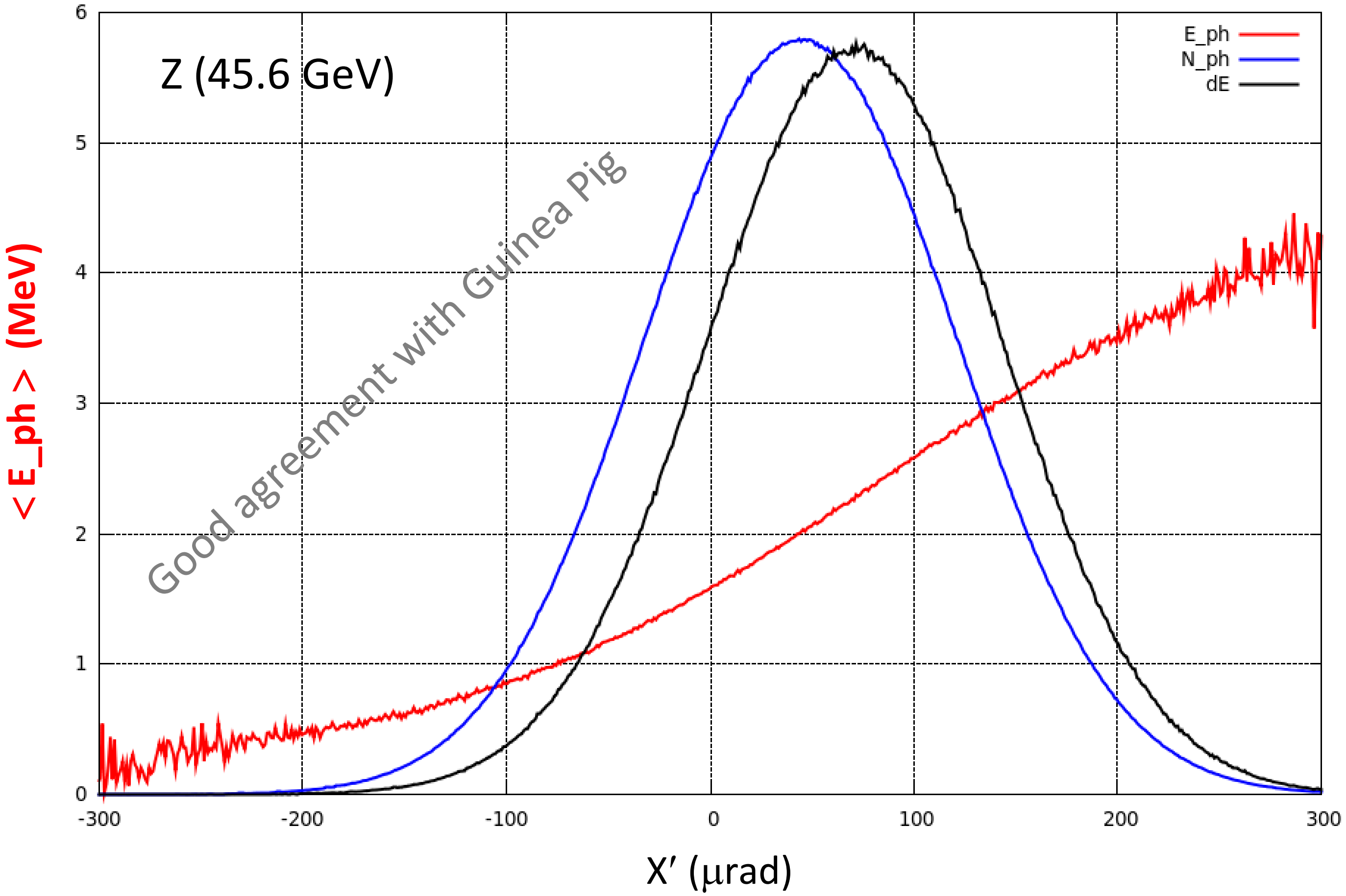
Angular distribution of emitted BS energy



# Correlation between X′ and the Energy of BS Photon



Photons with maximum energy are emitted at the IP, where the angle X′ is also maximal.



This correlation depends on the Piwinski angle. Therefore, at high energies, it will be weaker.

# Summary

- The beam energy and the crossing angle change upon collision. But the collision energy in the center of mass system will not change, since these two effects exactly cancel each other out.
- The energy loss due to beamstrahlung is compensated by the RF (equilibrium RF phase is shifted). So, in the first order, BS does not affect the beam energy at the IP.
- Crossing angle and BS create many correlations between different parameters. How this will affect the accuracy of the energy measurement and how it can be used to extract additional information is for further study.