Z-boson production in association with heavy flavor in the k_T-factorization

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Motivation

As the collision energy at the LHC increases, one can obtain precision data for a number of processes having rather small cross sections. One of such processes is the associated production of gauge bosons with heavy (*c, b*) quarks or heavy mesons.

Such processes involve both strong and weak interactions, so are important as global test of the Standard Model (SM).

Z+b/Z+c cross sections ratio is highly sensitive to the charm content of the proton.

The *Z+b*-jets production is an important background for studies of the associated production of Higgs and *Z* bosons, where the Higgs boson decays into $b\bar{b}$ pairs. Also many physics scenarios beyond the SM predict final states with *b*-quarks and *Z* bosons.

In addition, such processes may serve as potential indicators of the Double Parton Scattering (DPS) mechanism.

Motivation

In the present work, we analyze recent CMS and ATLAS data in the k_T-factorization approach.

This approach allows to take into account a large piece of higher order corrections in the form of the k_T-dependent parton distributions.

Nowadays this approach is widely spread in the literature. The goal of the present work is:

- to test its applicability to a new process that has never been considered in k_T-factorization before.
- to select the best suitable parametrizations of k_T-dependent parton distribution functions.

k_T-factorization approach

1. Unintegrated (or transverse momentum dependent, TMD) parton distributions
2. Matrix elements which depend on the transverse momenta of incoming partons.

Single parton scattering (SPS) contributions

Leading subprocess:

$g^*g^* \to Q\bar{Q}Z(\to l\,\bar{l})$

Subleading subprocesses:

$qQ \to qQZ(\to l\,\bar{l})$

$q\bar{q} \to Q\bar{Q}Z(\to l\,\bar{l})$

$qg \to qQ\bar{Q}Z(\to l\,\bar{l})$

Unintegrated parton distributions

CCFM unintegrated distributions

[F. Hautmann, H. Jung, 2014]. Numerical solutions of Catani-Ciafaloni-Fiorani-Marchesini evolution equation.

JH2013 set 2: The starting distribution is chosen to satisfy data on proton structure functions $F_2(x,\mu^2)$ and $F_2^c(x,\mu^2)$.

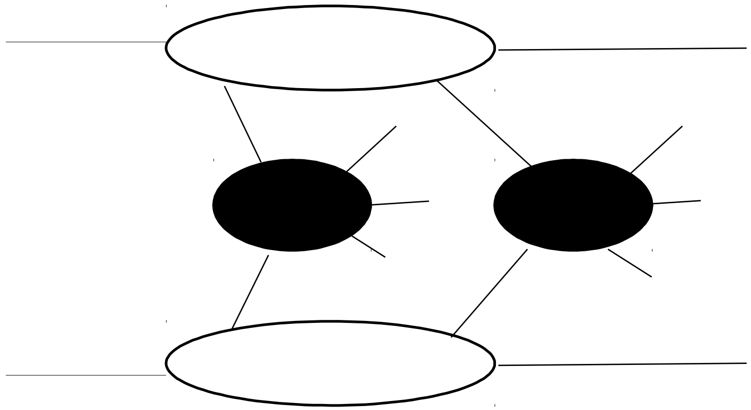
Cross section in the k_T-factorization

$$d\sigma = \int \frac{dx_1}{x_1} f_g(x_1, \mathbf{k}_{1T}^2, \mu^2) d\mathbf{k}_{1T}^2 \frac{d\phi_1}{2\pi} \times$$

$$\times \int \frac{dx_2}{x_2} f_g(x_2, \mathbf{k}_{2T}^2, \mu^2) d\mathbf{k}_{2T}^2 \frac{d\phi_2}{2\pi} d\hat{\sigma}(g^* g^* \to Z Q \bar{Q}).$$

Double parton scattering (DPS) contributions

Two parton interactions in one proton-proton collision



$$\sigma_{\rm DPS}^{\rm AB} = \frac{\sigma_{\rm SPS}^{A}\sigma_{\rm SPS}^{B}}{\sigma_{\rm eff}}$$

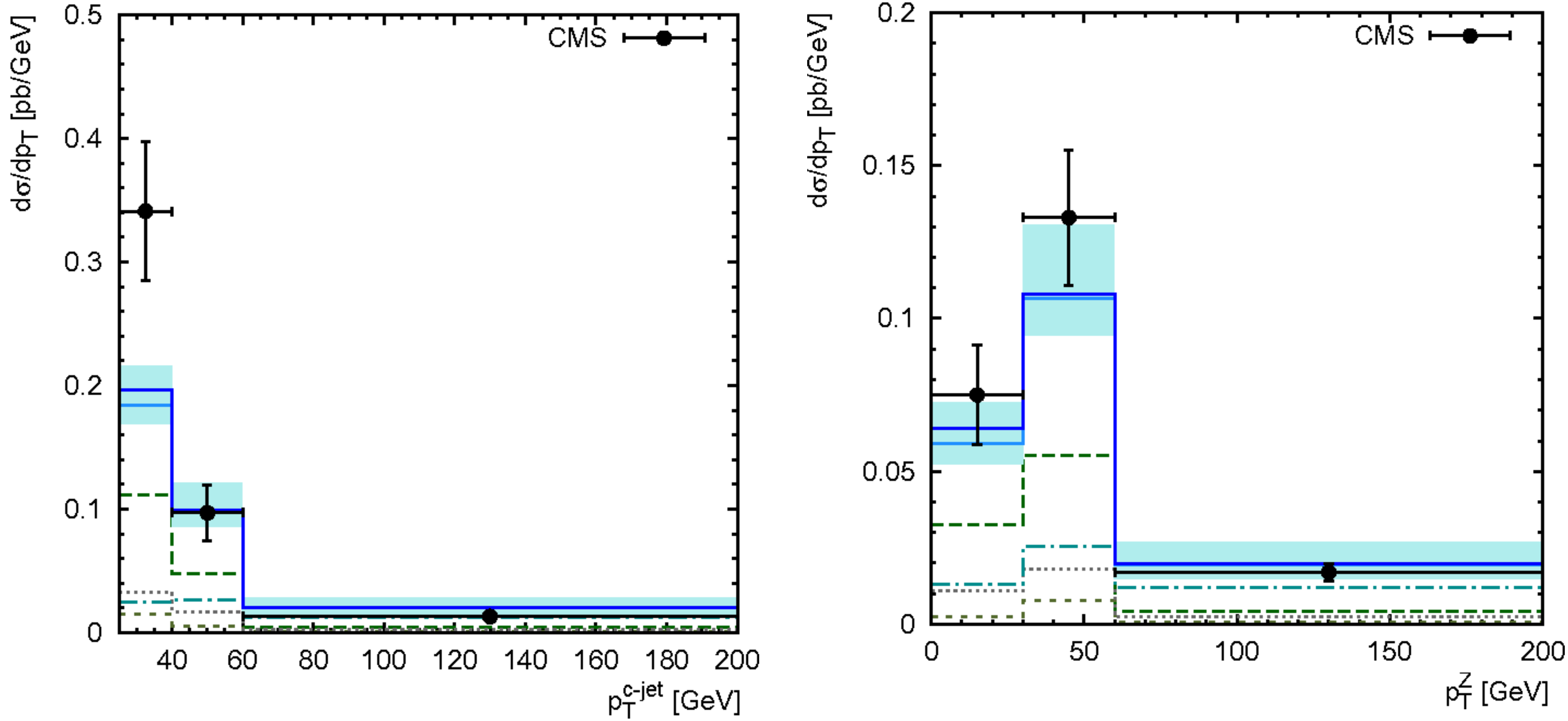
Parameters

- Theoretical uncertainties are connected with the choice of the factorization and renormalization scales. We took $\mu_R^2 = \xi(m_Z^2+\mathbf{p}_T^2)$, while $\mu_F^2 = \xi(s+\mathbf{Q}_T^2)$, where s and $\mathbf{Q}_T^2$ are the energy of scattering subprocess and transverse momentum of the incoming off-shell gluon pair, respectively. We varied the scale parameter ξ between 1/2 and 2 about the default value $\xi = 1$.

- We set m_Z=91.1876 GeV, Γ_Z=2.4952 GeV, m_c=1.4 GeV and m_b=4.75 GeV. In DPS calculations we took $\sigma_{\rm eff}$=15 mb.

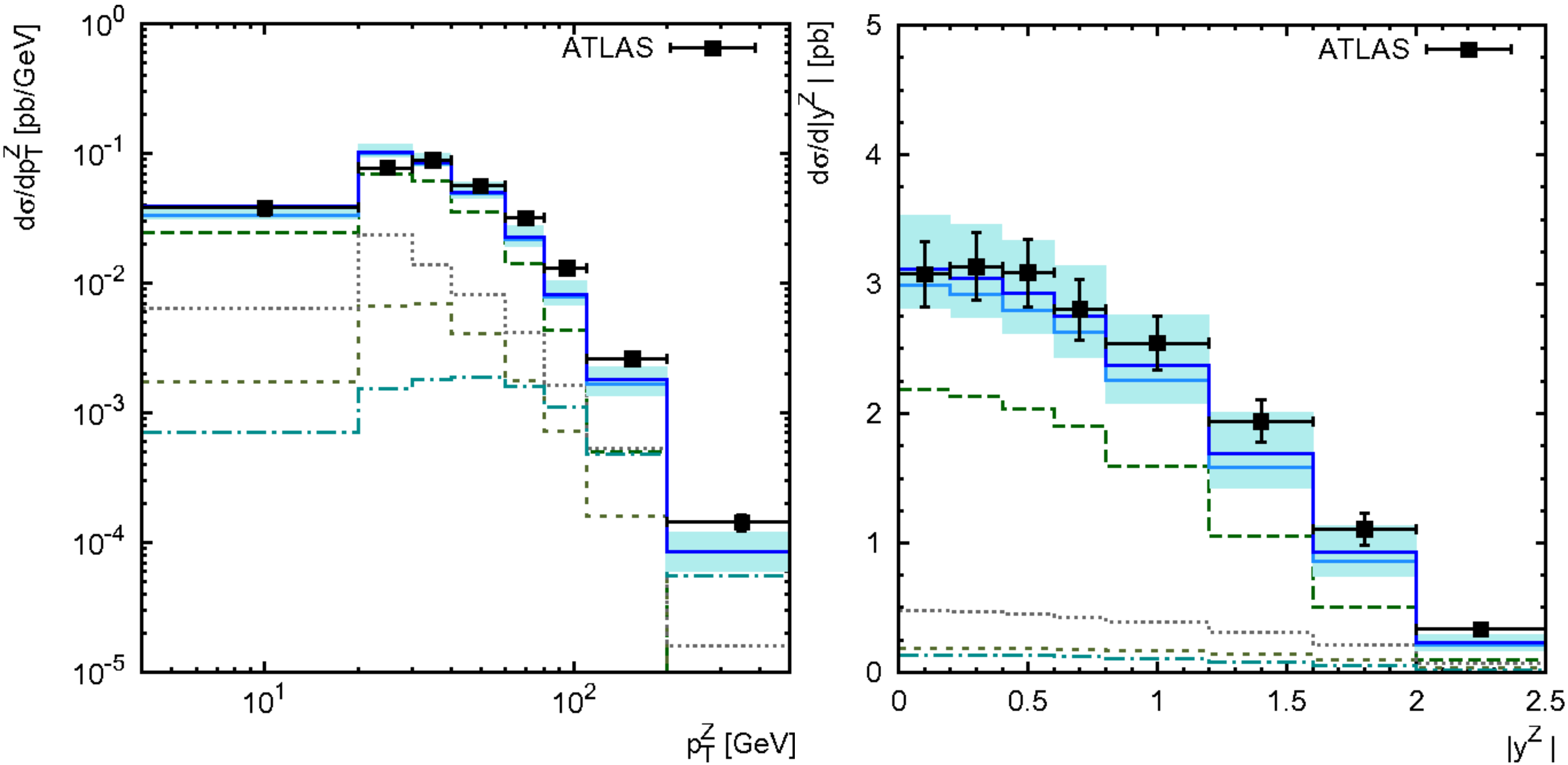
- For completeness, we use 2-loop formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavors at Λ_{QCD} = 226 MeV.

Numerical results



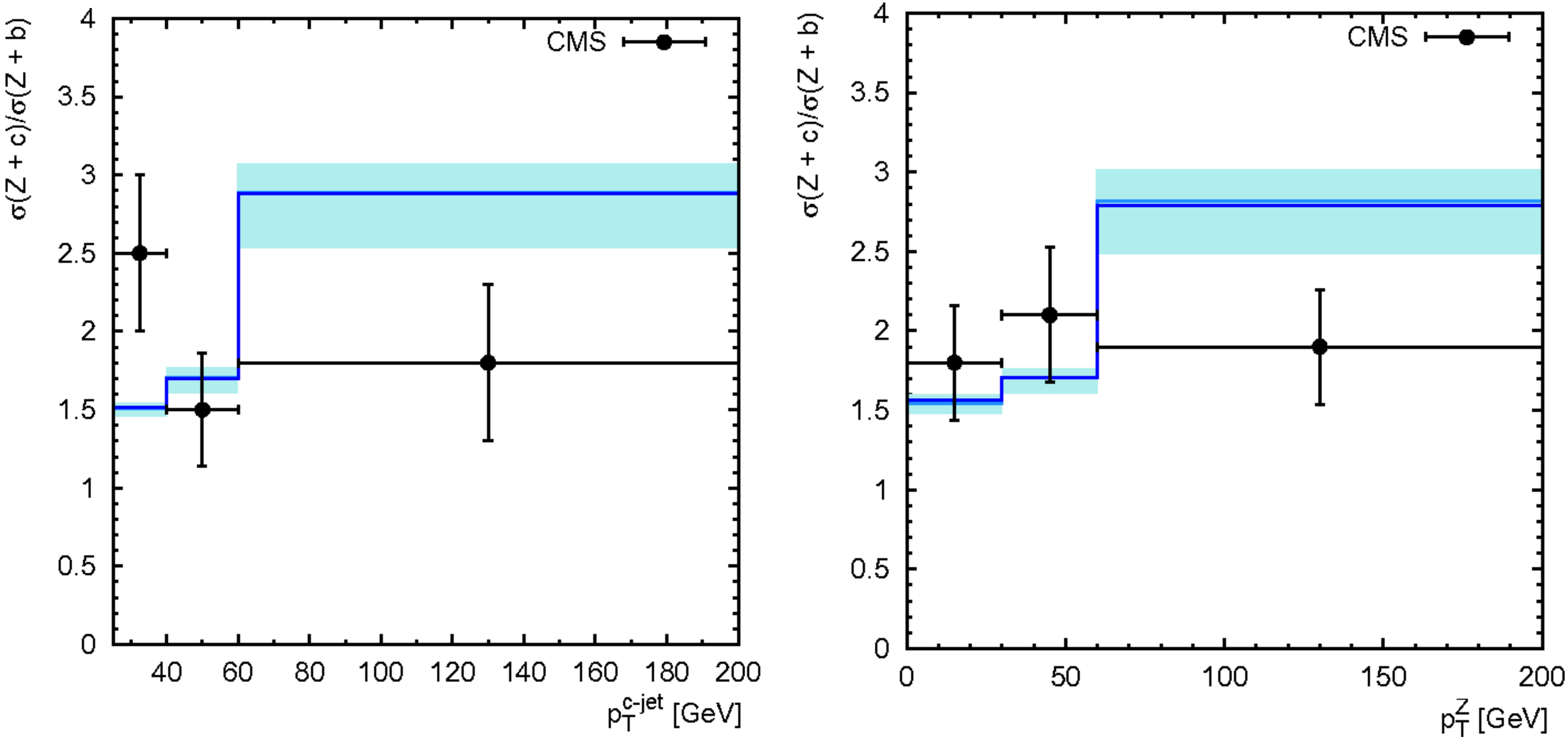
1. Z+c-jet in pp ($\sqrt{s}$=8 TeV) as a function of c-jet (left) and Z-boson (right) transverse momentum. Dashed — g^*g^*-fusion, dotted — qq-annihilation, dash-dotted — qQ-scattering, short-dashed — qg-scattering. Dark-blue — SPS+DPS; light blue — all SPS. Shaded area — scale uncertainties. Data from CMS.

Numerical results



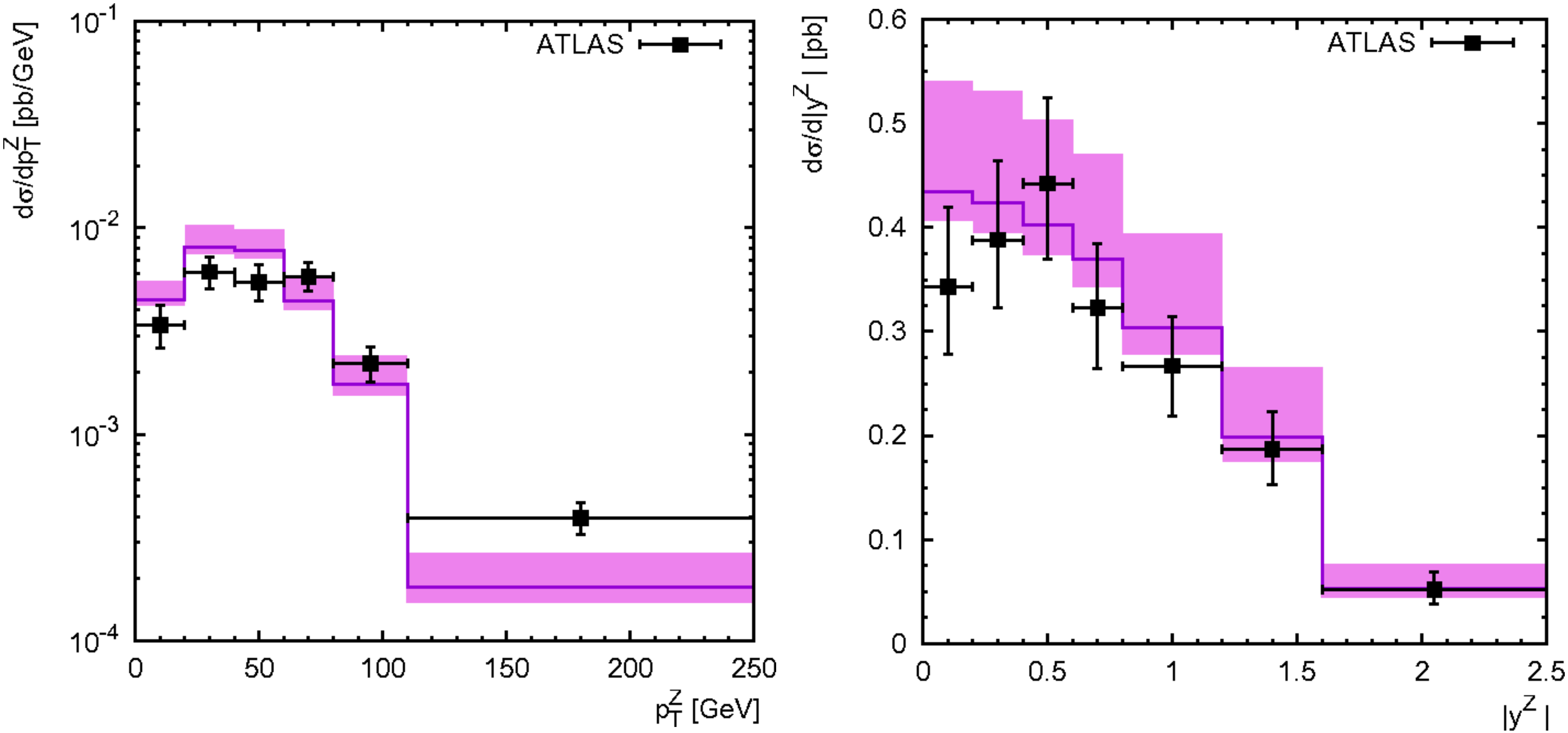
2. *Z*+*b*-jet in *pp* ($\sqrt{s}$=7 TeV) as a function *Z*-boson transverse momentum (left) and absolute value of its rapidity (right). Dashed — *g*g**-fusion, dotted — *qq*-annihilation, dash-dotted — *qQ*-scattering, short-dashed — *qg*-scattering. Dark-blue — SPS+DPS; light blue — all SPS. Shaded area — scale uncertainties. Data from ATLAS.

Numerical results



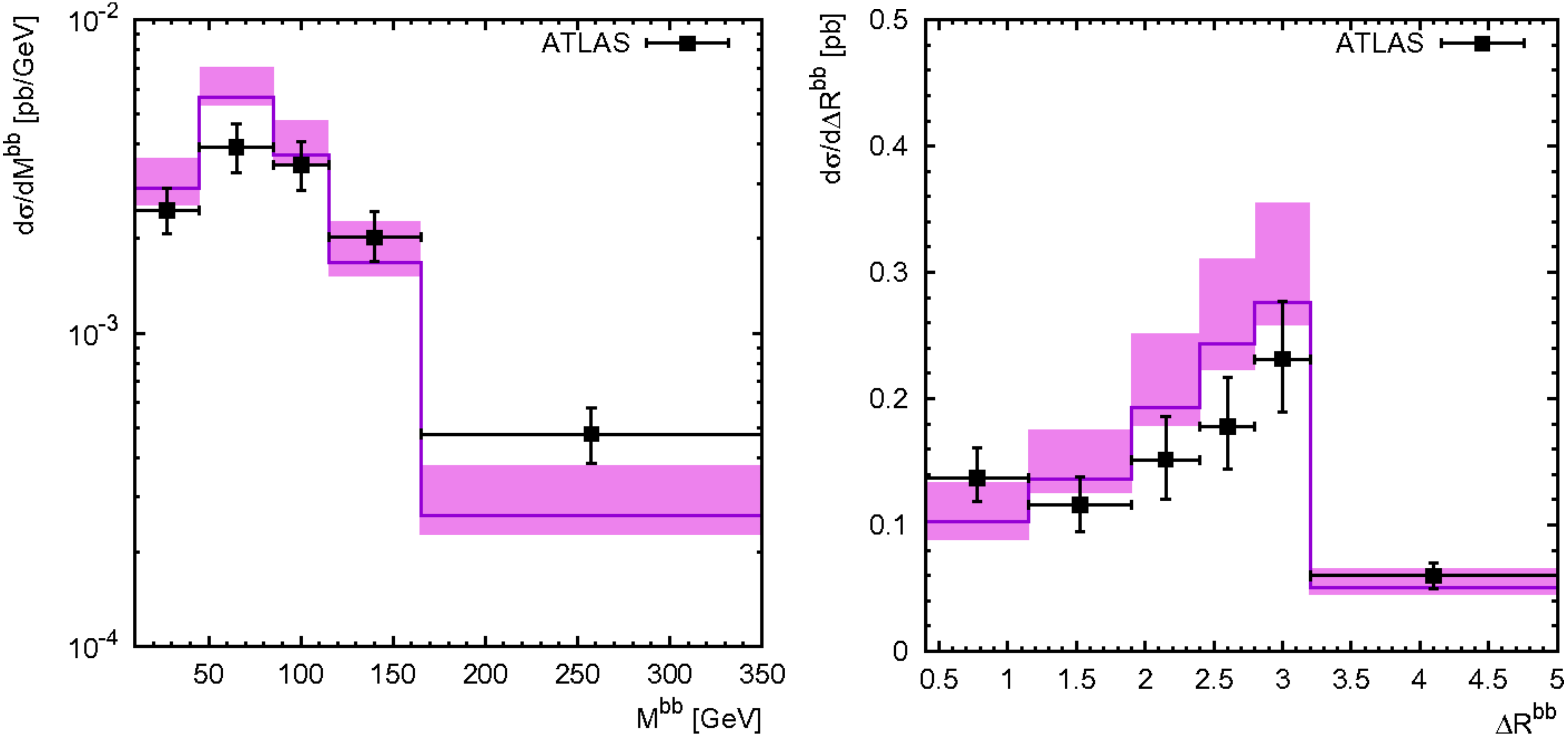
3. The differential cross section ratio Z+c/Z+b in pp collisions at the LHC ($\sqrt{s}$=8 TeV) as a function of c-jet (left) and Z-boson (right) transverse momentum. Dark-blue — SPS+DPS; light blue — all SPS. Shaded area — scale uncertainties. Data from CMS.

Numerical results



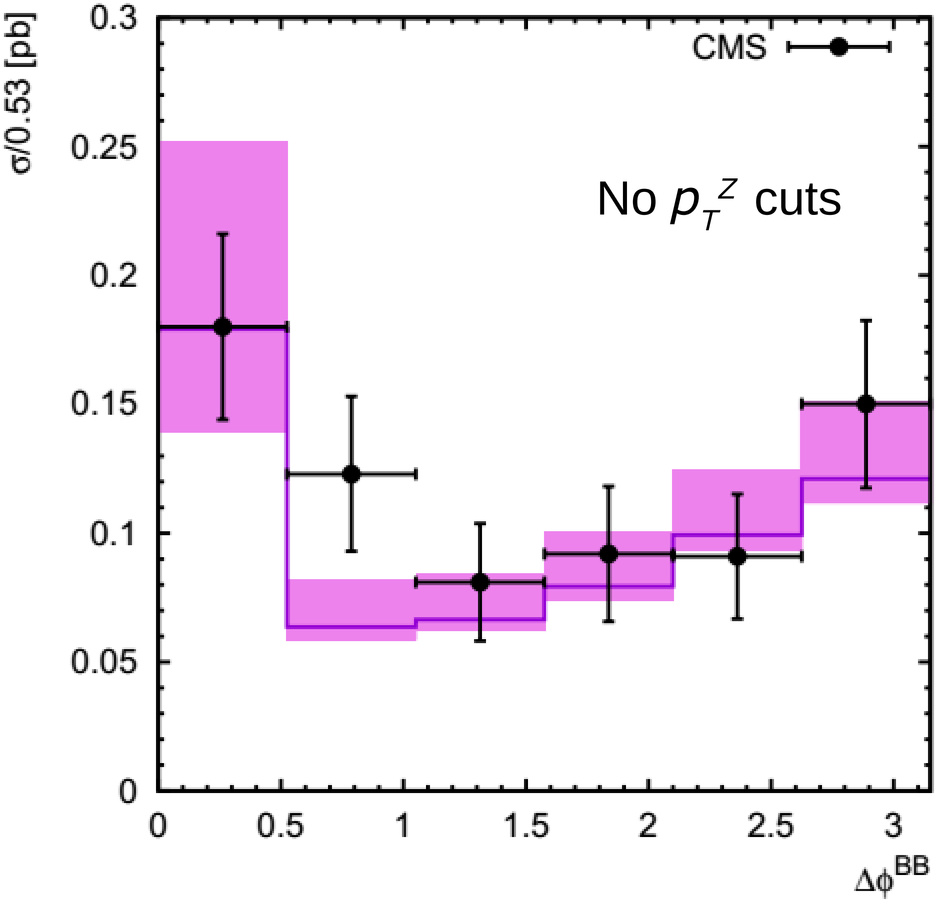
4. *Z*-boson+2*b*-jets in *pp* ($\sqrt{s}$=7 TeV) as a function of *Z*-boson transverse momentum (left) and absolute value of its rapidity (right). Solid line — all SPS. Shaded area — scale uncertainties. Data from ATLAS.

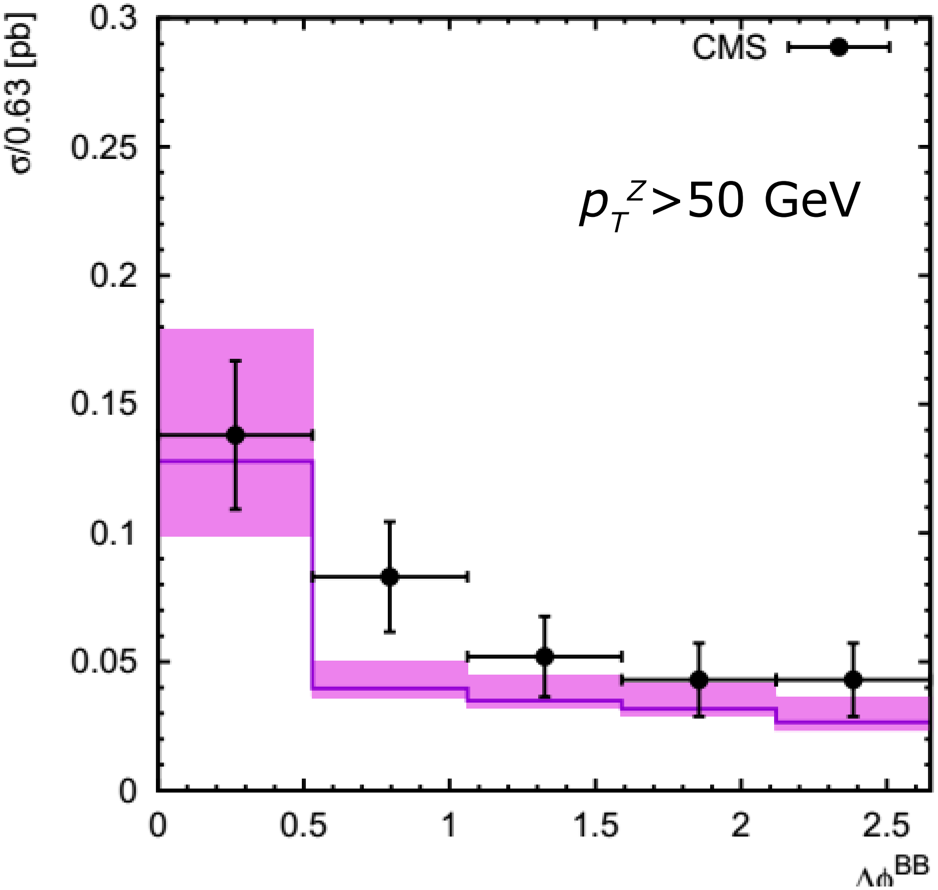
Numerical results



5. *Z*-boson+2*b*-jets in *pp* ($\sqrt{s}$=*7* TeV) as a function of *b*-pair invariant mass (left) and their angular separation in (η-φ)-plane (right). Solid line — all SPS. Shaded area — scale uncertainties. Data from ATLAS.

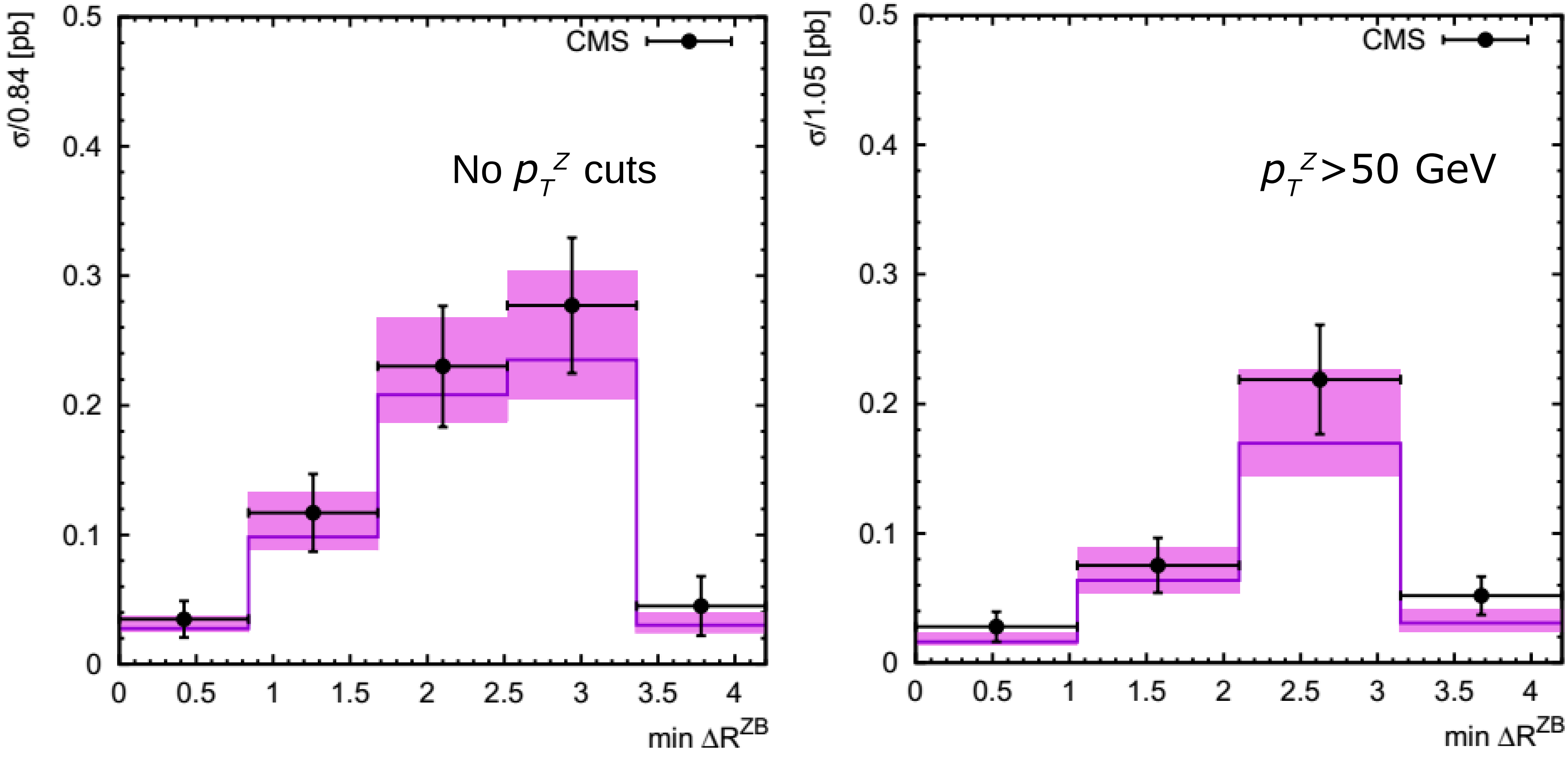
Numerical results





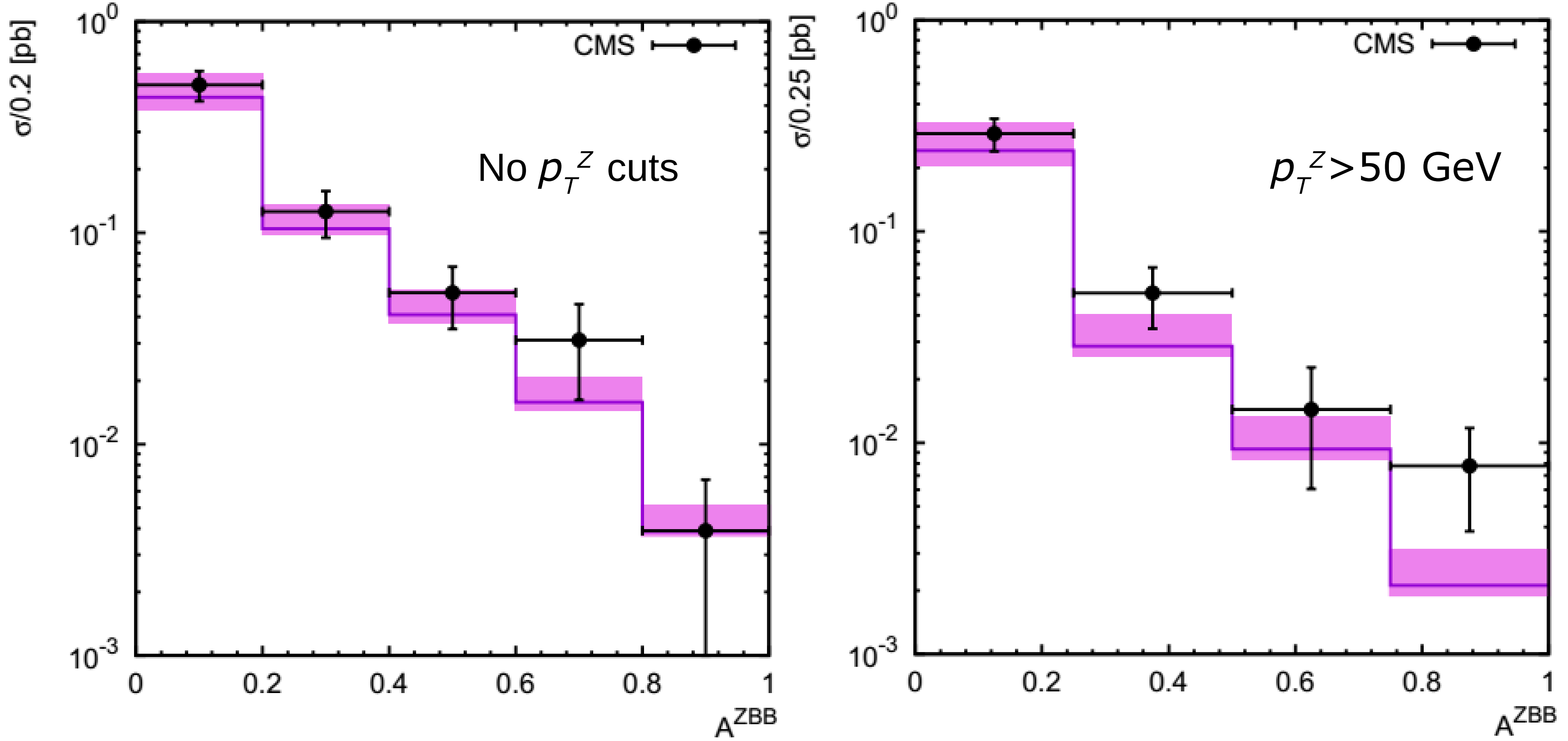
6. *Z*+2*B*-hadrons in *pp* collisions ($\sqrt{s}$=7 TeV) as a function of *B*-pair azimuthal angle separation . Solid line — all SPS. Shaded area — scale uncertainties. Data from CMS.

Numerical results



7. *Z*+2*B*-hadrons in *pp* collisions ($\sqrt{s}=7$ TeV) as a function of angular separation in (η-φ)-plane between the *Z*-boson and closest *B*-hadron. Solid line — all SPS. Shaded area — scale uncertainties. Data from CMS.

Numerical results



8. Z+2B-hadrons in pp collisions ($\sqrt{s}$=7 TeV) as a function of the assymetry between the Z-boson and B-hadrons directions. Solid line — all SPS. Shaded area — scale uncertainties. Data from CMS.

Conclusion

Associated Z+c, Z+b at LHC ($\sqrt{s}$=7-8 TeV) has been considered.

- First k_T-factorization calculation for $g^*g^* \to Q\bar{Q}Z$ ($\to l^- l^+$) is presented.

- Reasonably good description of CMS and ATLAS data is obtained.

- Subleading quarks interaction contributions are found to be important, especially at high transverse momenta.

- DPS contributions appear to be negligible in the studied kinematic region.

Back up

Angular variables definitions

$$\Delta R^{Zb} = \sqrt{(\eta_Z - \eta_b)^2 + (\phi_Z - \phi_b)^2}$$

$$A^{Zbb} = \frac{\max \Delta R^{Zb} - \min \Delta R^{Zb}}{\max \Delta R^{Zb} + \min \Delta R^{Zb}}$$

Off-shell gluon polarization sum

$$\epsilon_\mu \epsilon_\nu^* = \frac{k_T^\mu k_T^\nu}{\mathbf{k}_T^2}$$