

**W/Z production associated  
with quark-antiquark pair  
in kt-factorization at LHC**  
arxiv.org: 0805.3763

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# $k_T$ -factorization in a nutshell

- In Regge kinematic regime

$$s \gg \mu^2 \gg \Lambda_{QCD}^2$$

cross section can be factorized into hard scattering and *unintegrated parton density functions* (uPDFs)

- Small  $x$  physics treated by resumming terms of the form

$$[\alpha_S \ln(1/x)]^n$$

- Kinematics treated correctly – leads to off-shell initial state particles
- Equivalent to higher order corrections in collinear factorization

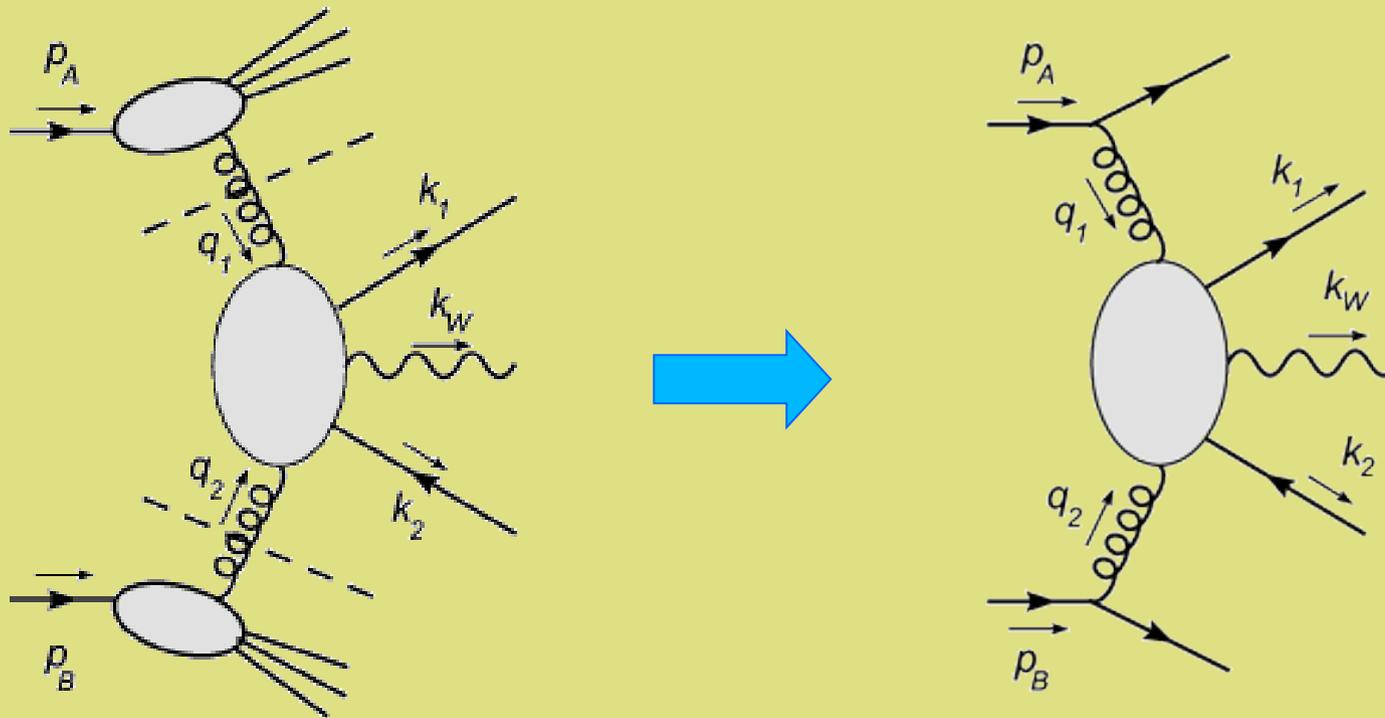
# Motivation for the calculation

$$gg \rightarrow Z/W + Q\bar{Q}$$

- Important process at the LHC – physics, luminosity, calibration of detectors, background for beyond SM processes
- Gauge boson production at rather small gluon  $x$  – small  $x$  physics important
- Description of the gauge boson  $p_t$  spectrum and other kinematic variables (azimuthal correlations)

# BFKL formalism – gauge invariance

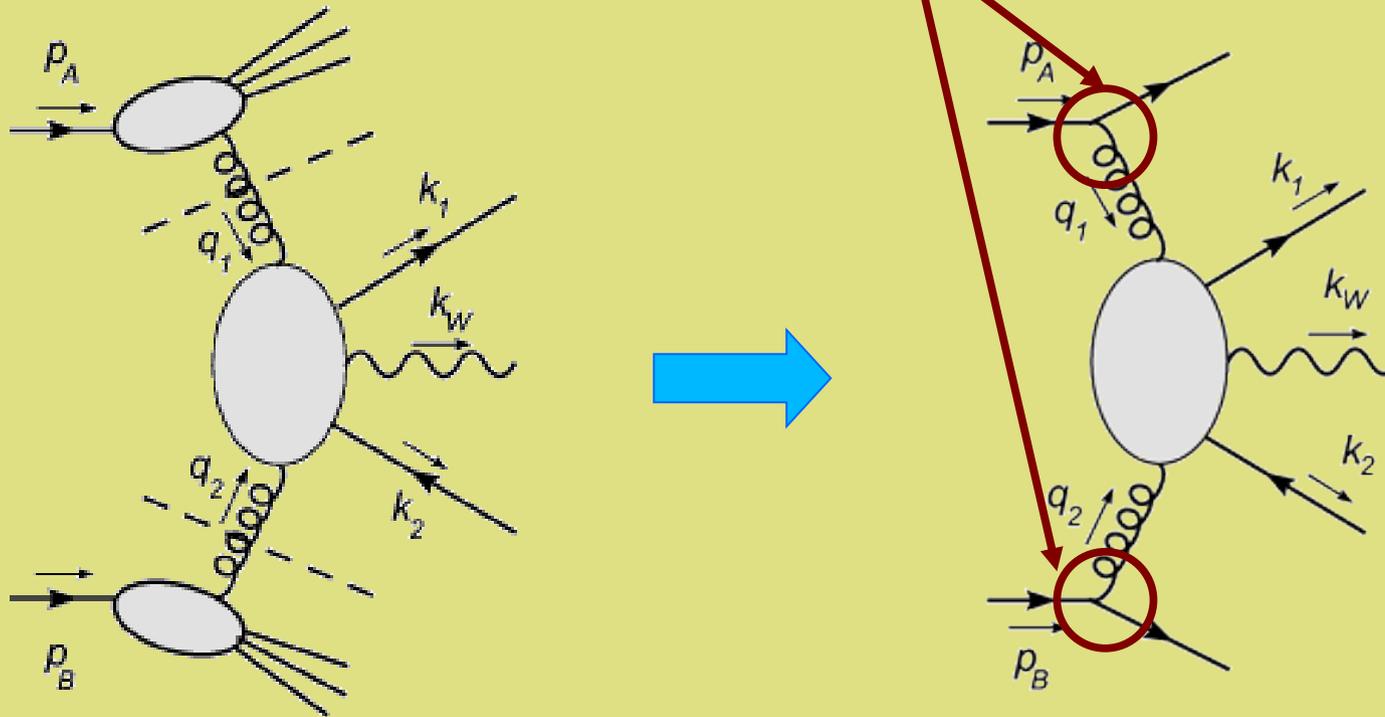
- Replace proton by a quark



# BFKL formalism – gauge invariance

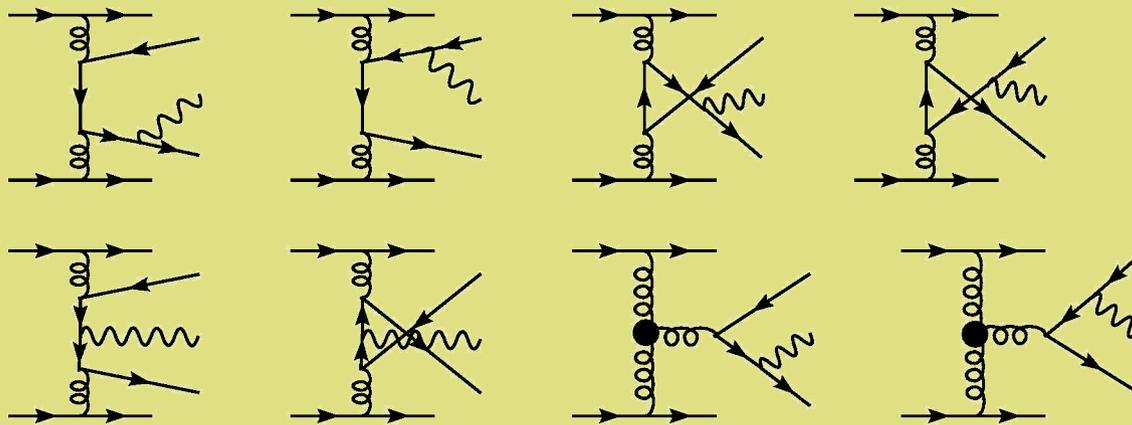
- Replace proton by a quark

$$-i\bar{u}_\lambda(p)\gamma^\mu u_{\lambda'}(p-q) \rightarrow -2ip^\mu \delta_{\lambda\lambda'}$$

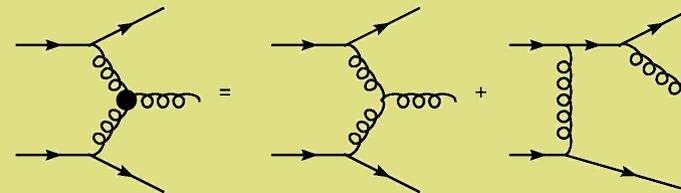


# BFKL formalism $\rightarrow$ Calculation

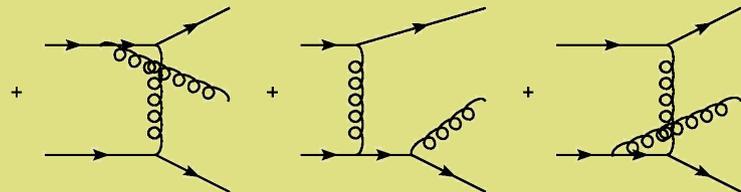
- Diagrams contributing to  $gg \rightarrow Z/W + Q\bar{Q}$



- Effective vertex:

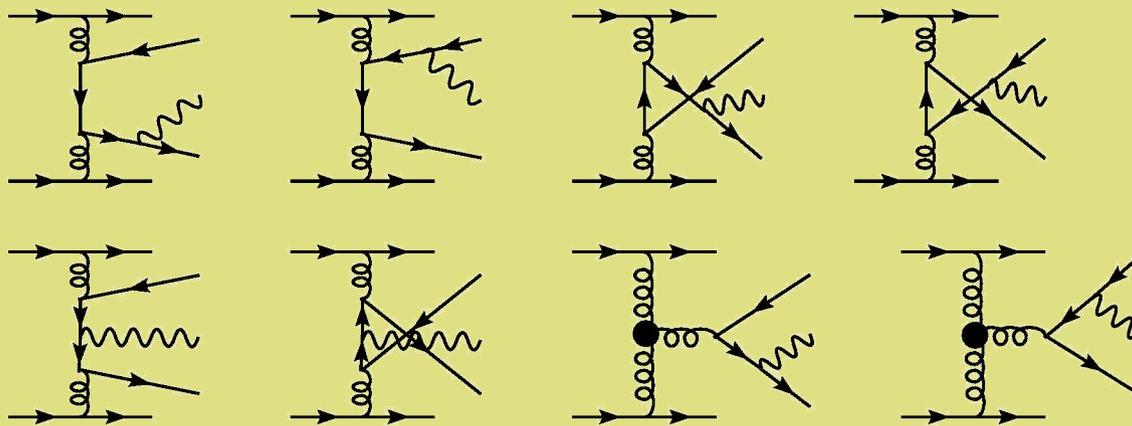


- Orthogonal amplitudes

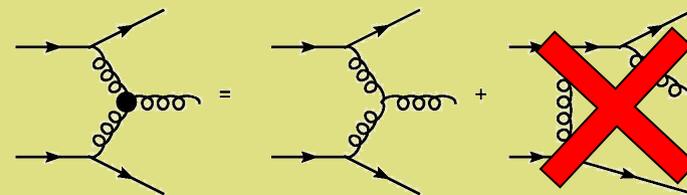


# BFKL formalism $\rightarrow$ Calculation

- Diagrams contributing to  $gg \rightarrow Z/W + Q\bar{Q}$

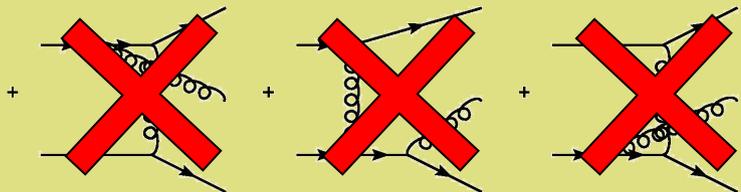


- Effective vertex:



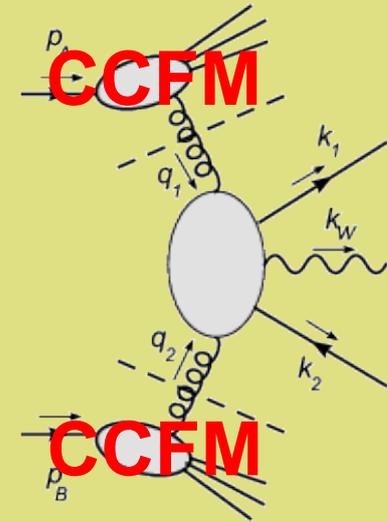
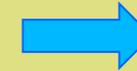
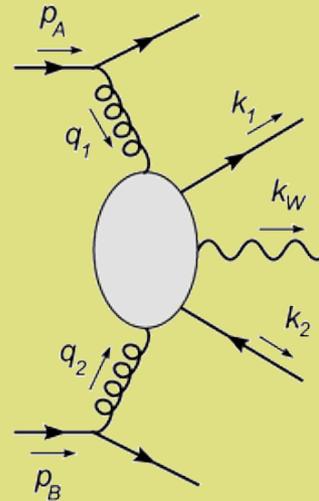
Axial gauge

- Orthogonal amplitudes
- Difference to HERA  
LHC in October



# Calculation

- Getting back to proton



Ciafaloni,  
Nucl. Phys. B296 (1988) 49;  
Catani, Fiorani, Marchesini,  
Phys. Lett. B234 (1990) 339;  
Nucl. Phys. B336 (1990) 18;  
Marchesini,  
Nucl. Phys. B445 (1995) 49  
[hep-ph/9412327]

- CCFM is implemented in CASCADE
- Implementation of matrix element
- CCFM resums logarithms of the form

$$[\alpha_S \ln(\mu^2 / \Lambda_{QCD}^2)]^n \quad [\alpha_S \ln(1/x)]^n$$

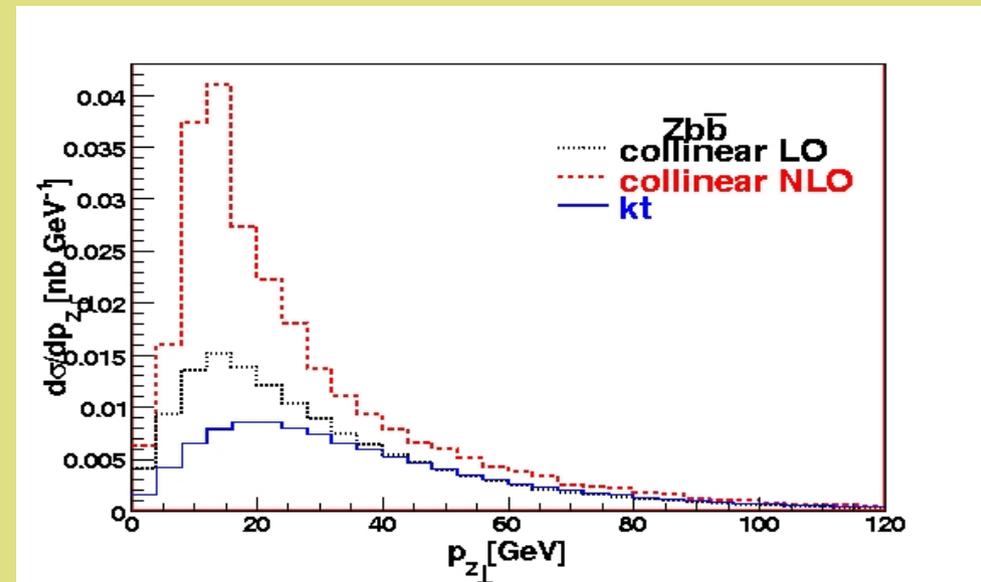
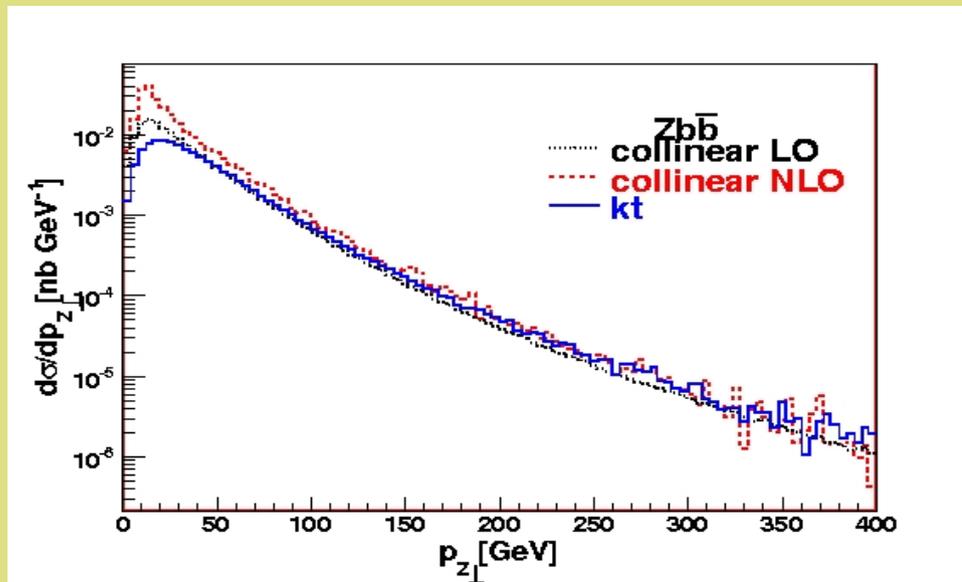
$$[\alpha_S \ln(\mu^2 / \Lambda_{QCD}^2) \ln(1/x)]^n$$

Jung,  
Comput. Phys. Commun. 143, 100 (2002)  
[hep-ph/0109102]  
Jung, Salam,  
Eur. Phys. J. C19, 351 (2001)  
[hep-ph/0012143]

# Results $gg \rightarrow Z + b\bar{b}$

- Total cross sections comparable:  $0.429 \text{ nb}$  CASCADE  
 $0.567 \text{ nb}$  MCFM LO  
 $1.04 \text{ nb}$  MCFM NLO
- pt distribution of Z (comparison with collinear calculation in MCFM at LO and NLO)
- Difference in lower pt region of Z

J. Campbell,  
 K. Ellis, <http://mcfm.fnal.gov>



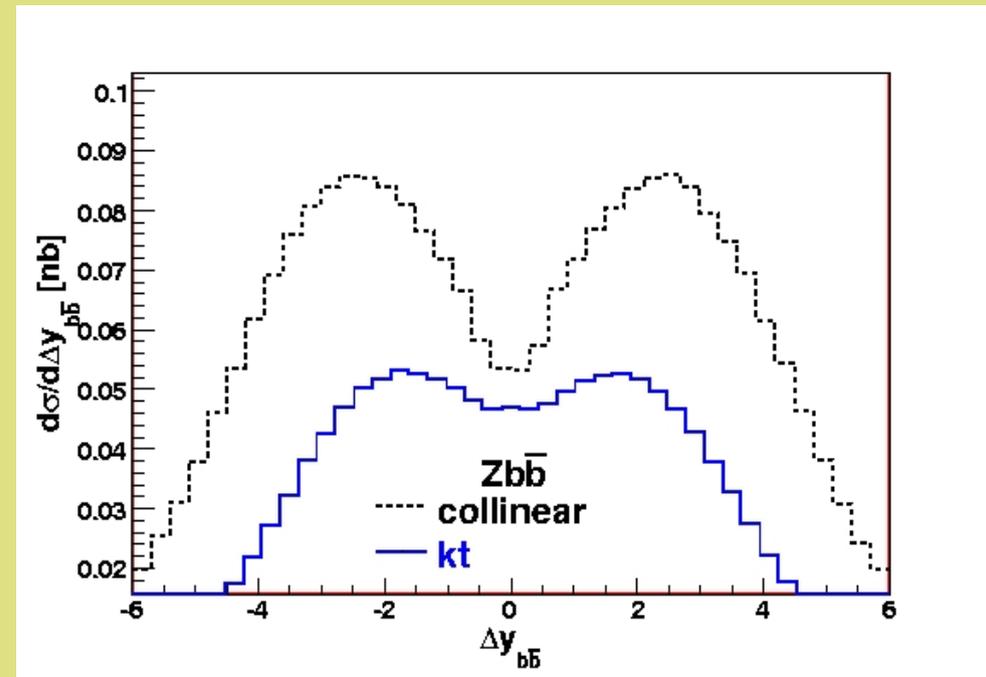
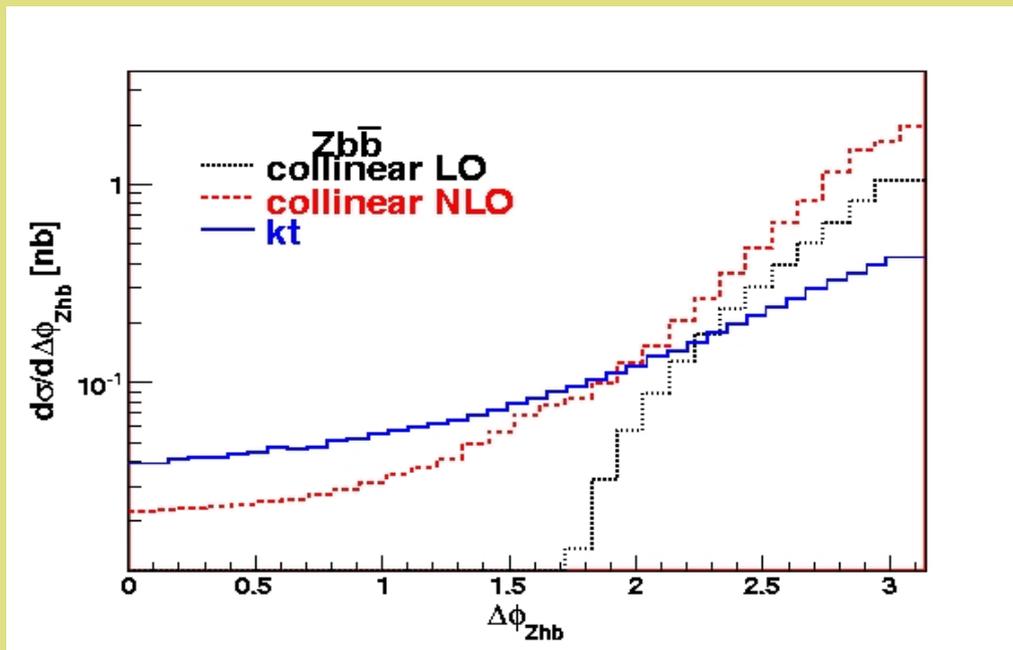
- Calculation with massless quarks and cuts on quark pt

# Results $gg \rightarrow Z + b\bar{b}$

- Angular and rapidity correlations

$$\Delta\phi_{Zhb} = \text{ang}(p_{Z\perp}, \max(p_{b\perp}, p_{\bar{b}\perp}))$$

$$\Delta y_{b\bar{b}} = y_b - y_{\bar{b}}$$



- In LO collinear calculation (MCFM) we can see a kinematically forbidden region
- Calculation with massless quarks and cuts on quark  $p_t$

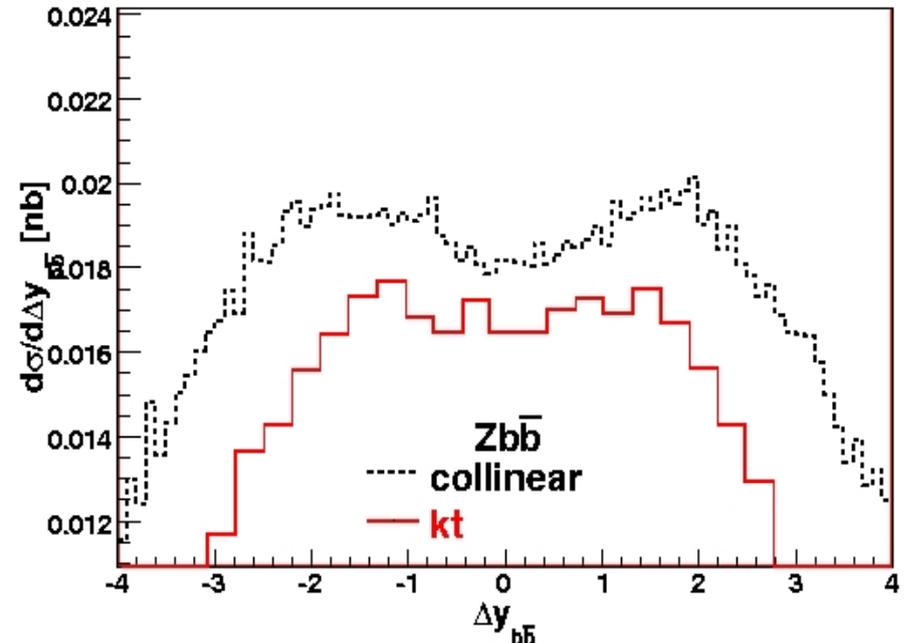
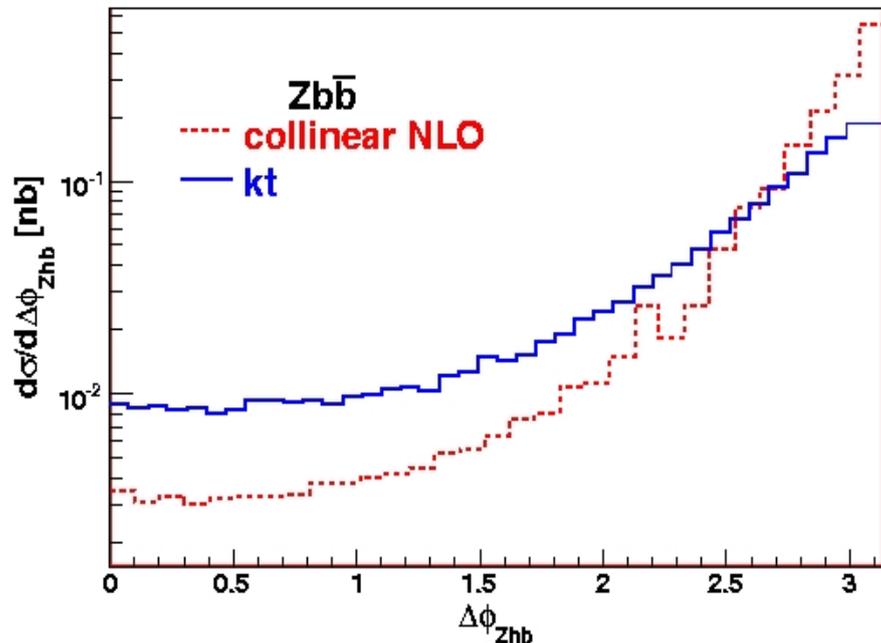
- Calculation with massive quarks
- Total cross sections in this case:  
*0.406 nb* CASCADE  
*0.748 nb* MCFM

# Results $gg \rightarrow Z + b\bar{b}$

- If one applies a cut on  $p_T$  of  $Z$  difference in cross sections decreases:

$$p_{Z\perp} > 50 \text{ GeV}$$

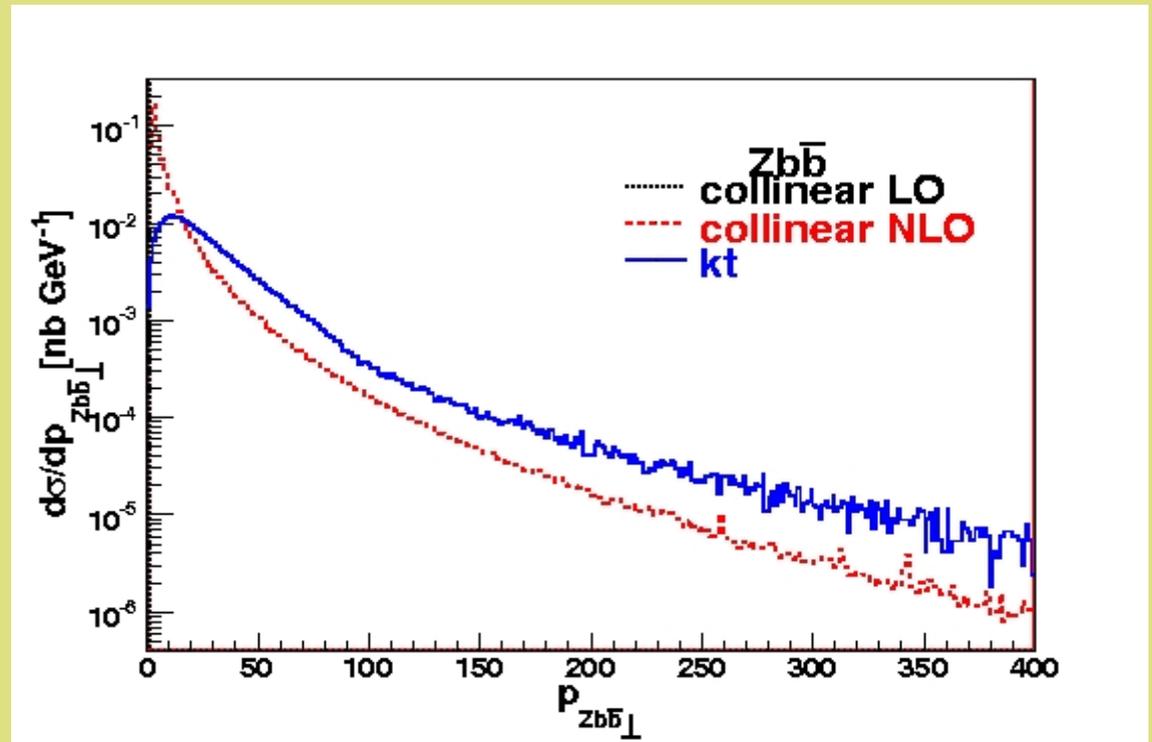
quarks	order	all	Ptz>50
massive	LO	0.748	0.141
massless	NLO	1.04	0.165
massive	kt	0.406	0.118
massless	kt	0.429	0.125



# Results $gg \rightarrow Z + b\bar{b}$

- Pt of the system  $Zb\bar{b}$

$$p_{Zb\bar{b}\perp} = p_{Z\perp} + p_{b\perp} + p_{\bar{b}\perp}$$



- Possible differences after applying cut on  $Z$  pt coming from contribution of pt of gluons
- Difference because of missing higher order corrections in collinear calculation

# Summary and Conclusions

- Matrix element squared of the process  $gg \rightarrow Z/W + Q\bar{Q}$  calculated
- Implemented in CASCADE Monte Carlo generator
- Transversal momentum cross sections, azimuthal angle correlations and rapidity correlations shown
- Correct kinematics already at LO compared to LO collinear calculation
- Transversal momentum of gauge boson match at high values
- Differences between kt-factorization and NLO collinear calculation due to inclusion of higher order corrections in uPDFs