W/Z production associated with quark-antiquark pair in kt-factorization at LHC

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k_T-factorization in a nutshell

- In Regge kinematic regime

$$s \gg \mu^2 \gg \Lambda^2_{QCD}$$

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

- Small x physics treated by resumming terms of the form

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

- Kinemtics treated correctly
- Equivalent to higher order corrections in collinear factorization
- Opened for including of saturation effects

Motivation for the calculation

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

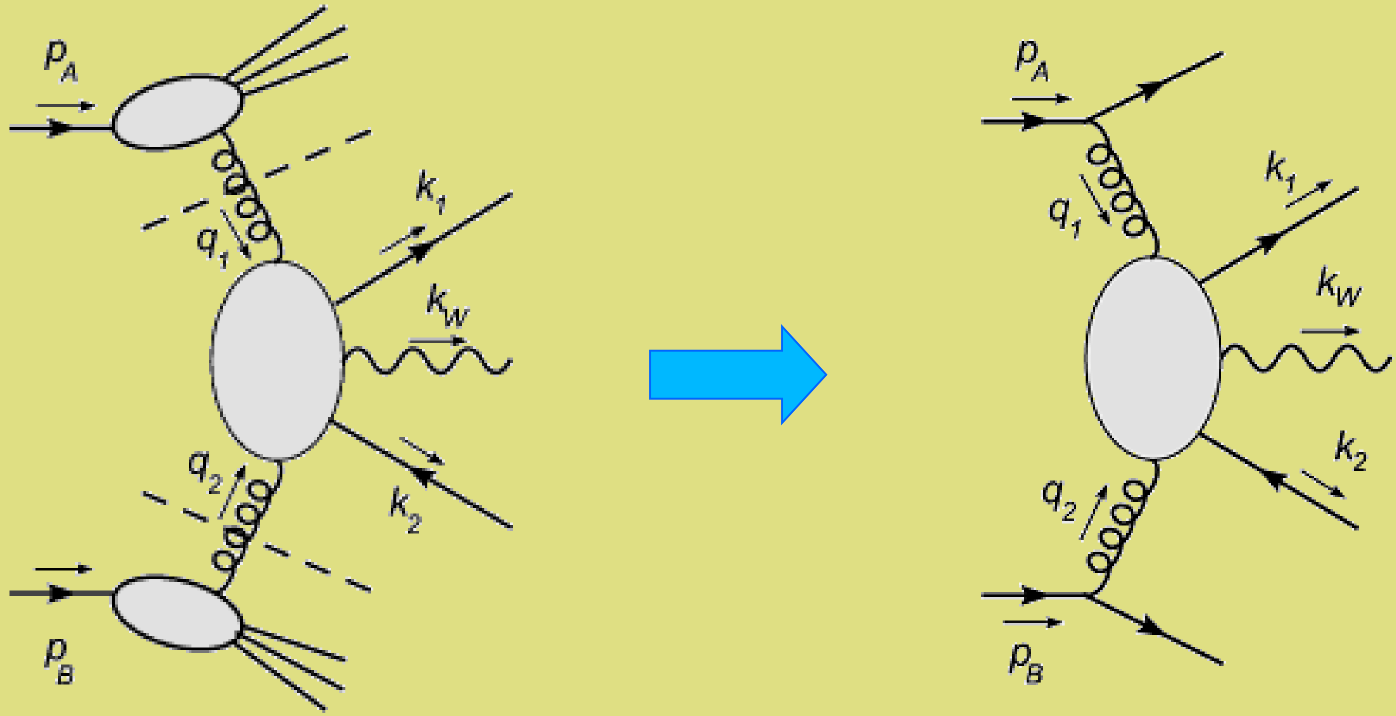
- Important process at the LHC – physics, luminosity, callibration of detectors, background for beyond SM processes

- Gauge boson production at rather small gluon x – small x physics important

- Description of the gauge boson pt spectrum and other kinematic variables (azimuthal correlations)

BFKL formalism – gauge invariance

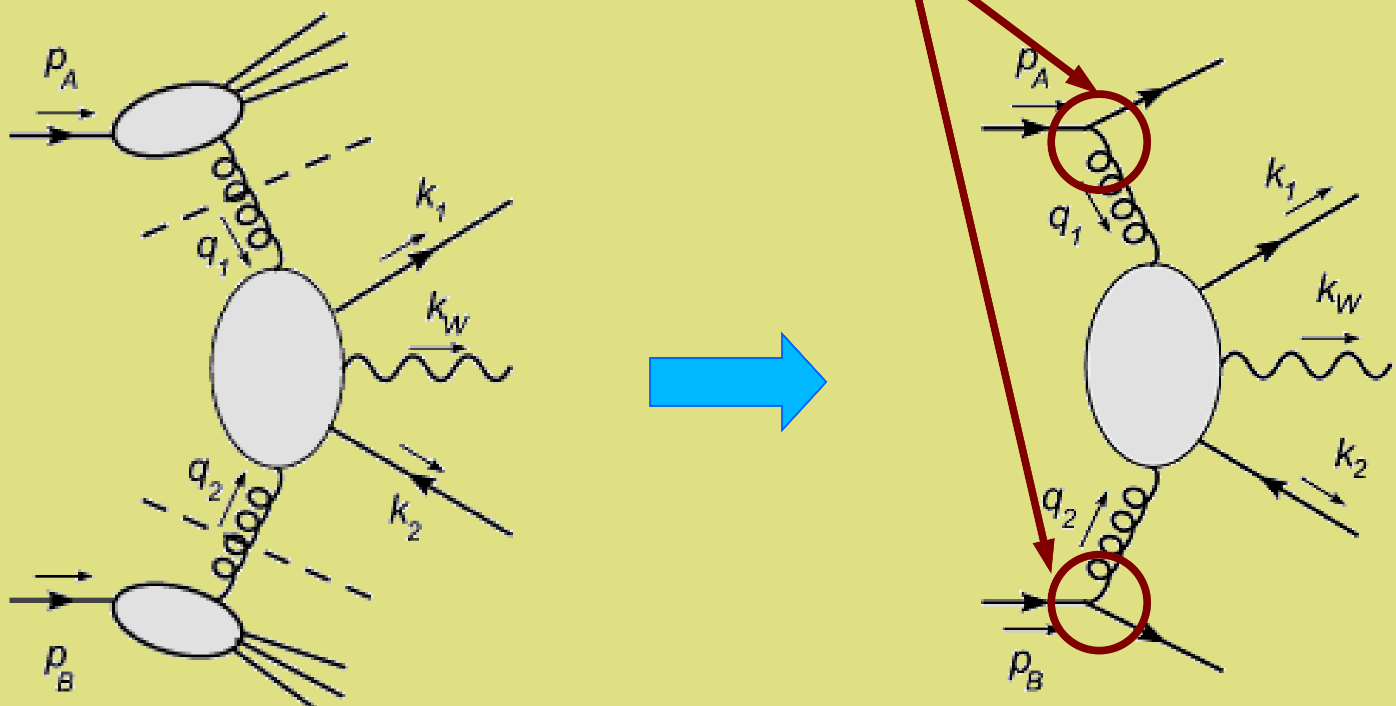
- Replace proton by a quark



BFKL formalism – gauge invariance

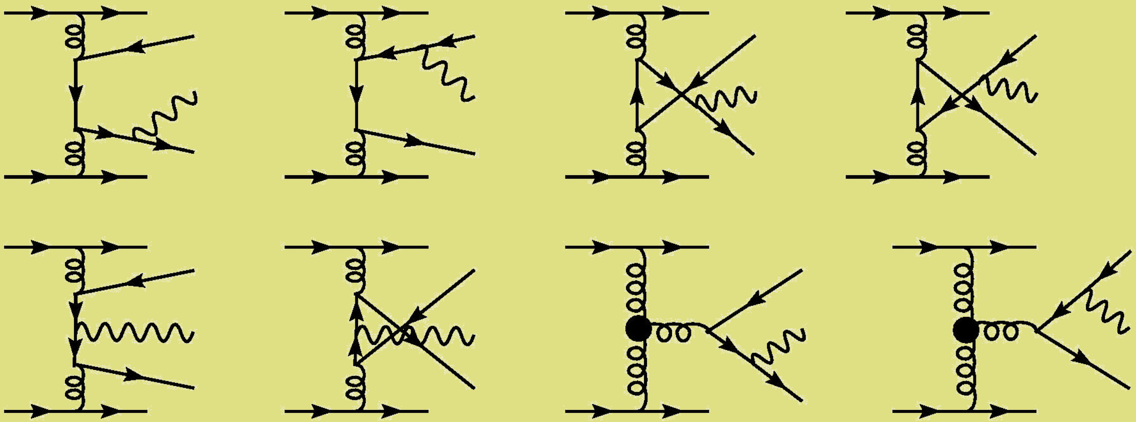
- Replace proton by a quark

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

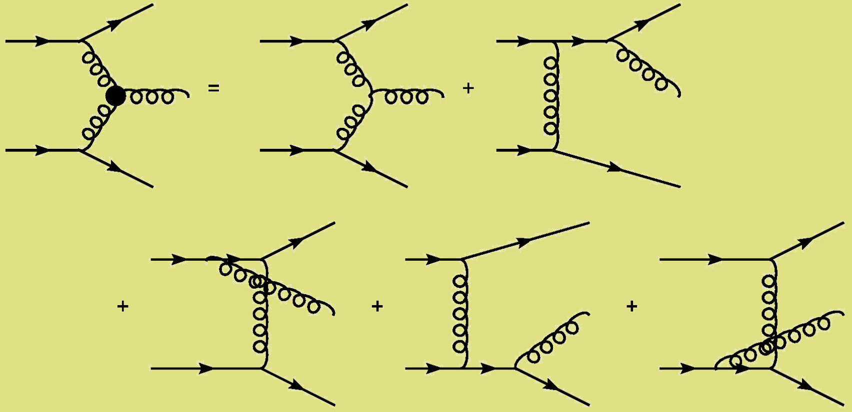


BFKL formalism → Calculation

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



- Effective vertex:



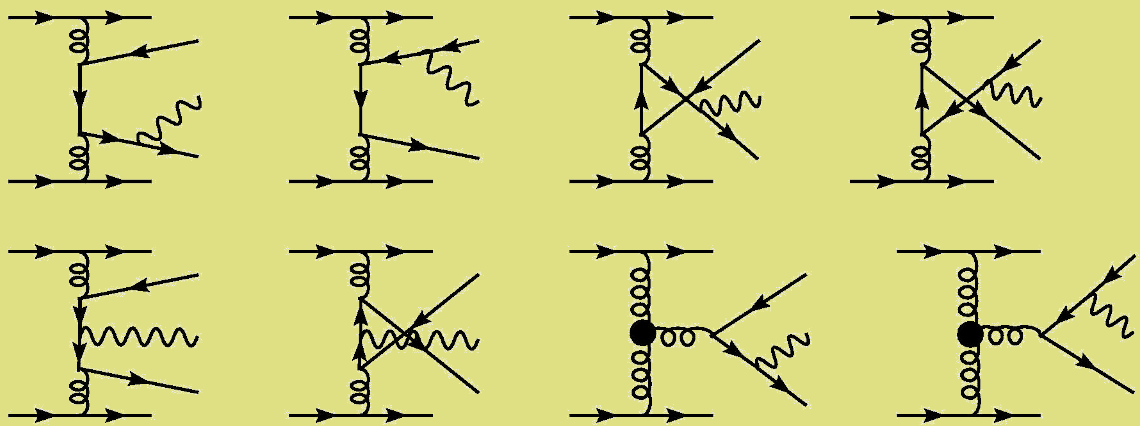
- Orthogonal amplitudes

Baranov, Slad,
hep-ph/0603090v1

Lipatov,
Sov. J. Nucl. Phys. 23, 338 (1976)

BFKL formalism → Calculation

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



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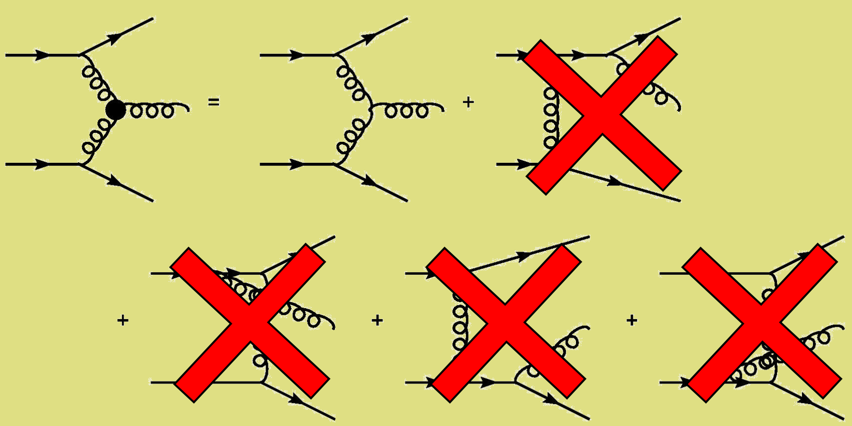

Axial gauge

- Orthogonal amplitudes

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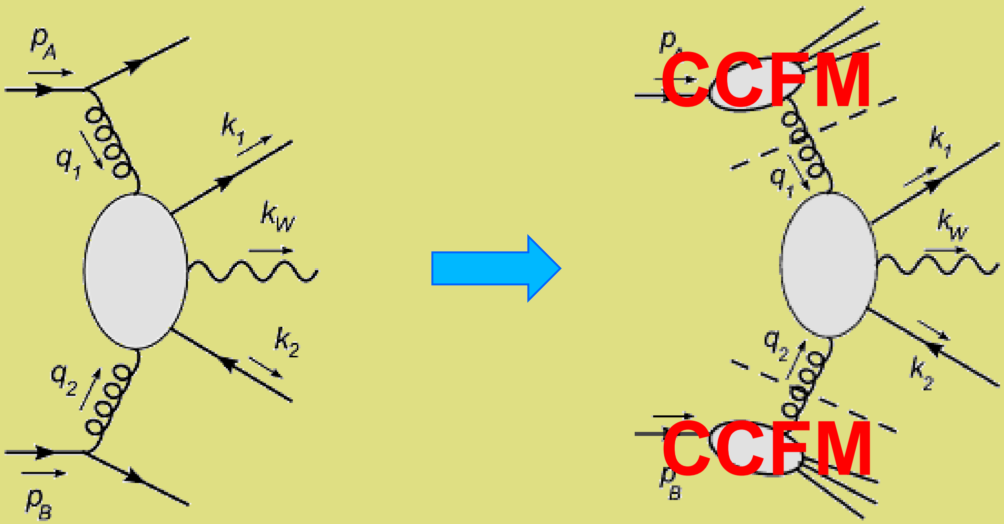
Calculation

- Getting back to proton



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[hep-ph/0012143]

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

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

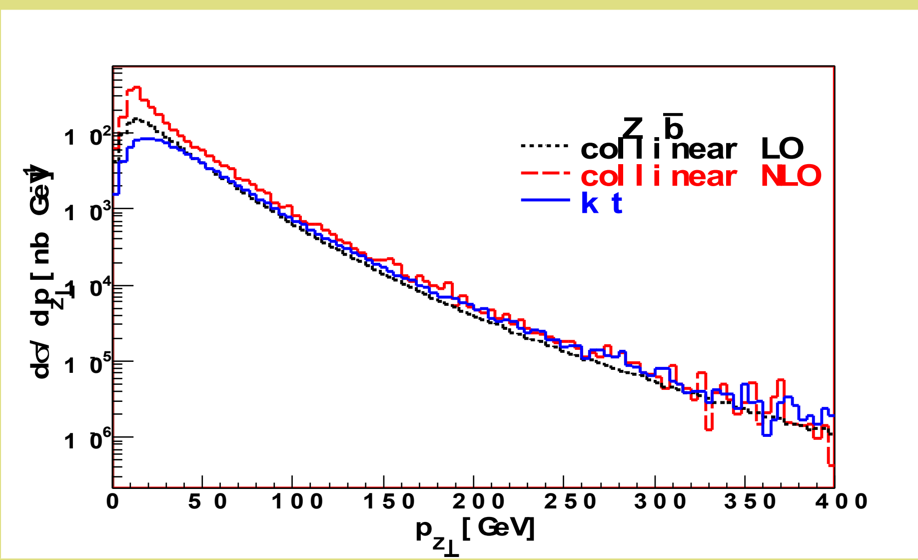
$$[\alpha_S \ln(\mu^2/\Lambda^2_{QCD}) \ln(1/x)]^n$$

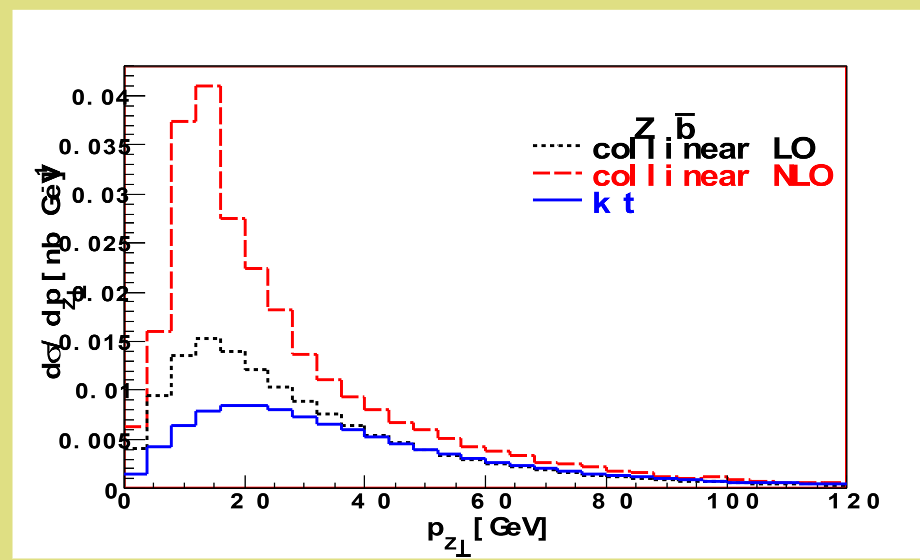
Results $gg \to Z + b\bar{b}$

- Total cross sections comparable: *0.429 nb* CASCADE
  0.567 nb MCFM LO
  1.04 nb MCFM NLO

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

- pt distribution of *Z* (comparison with collinear calculation in MCFM at LO and NLO)
- Difference in lower pt region of Z





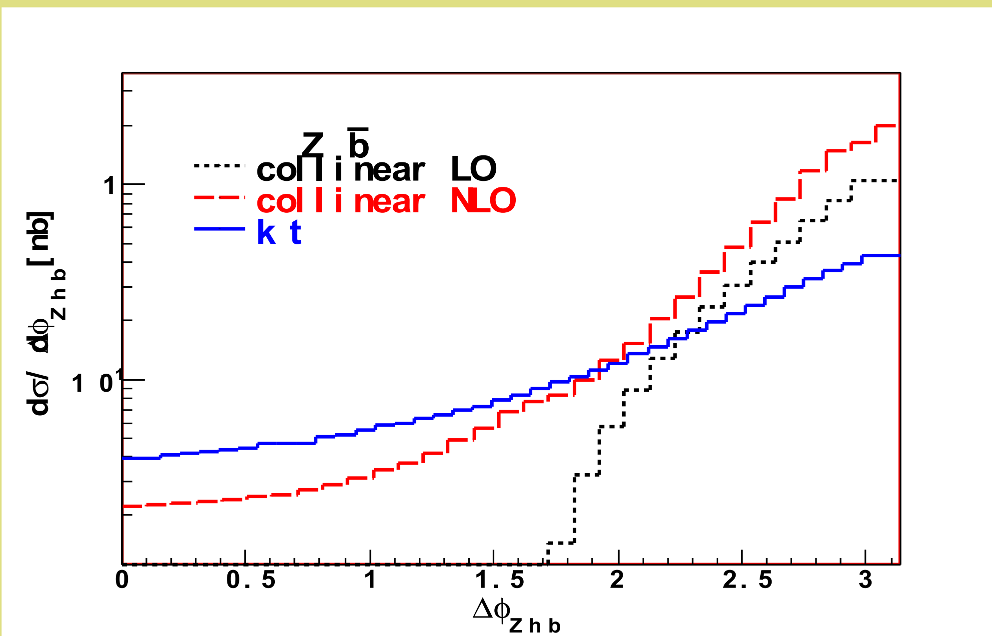
- Calculation with massless quarks and cuts on quark pt

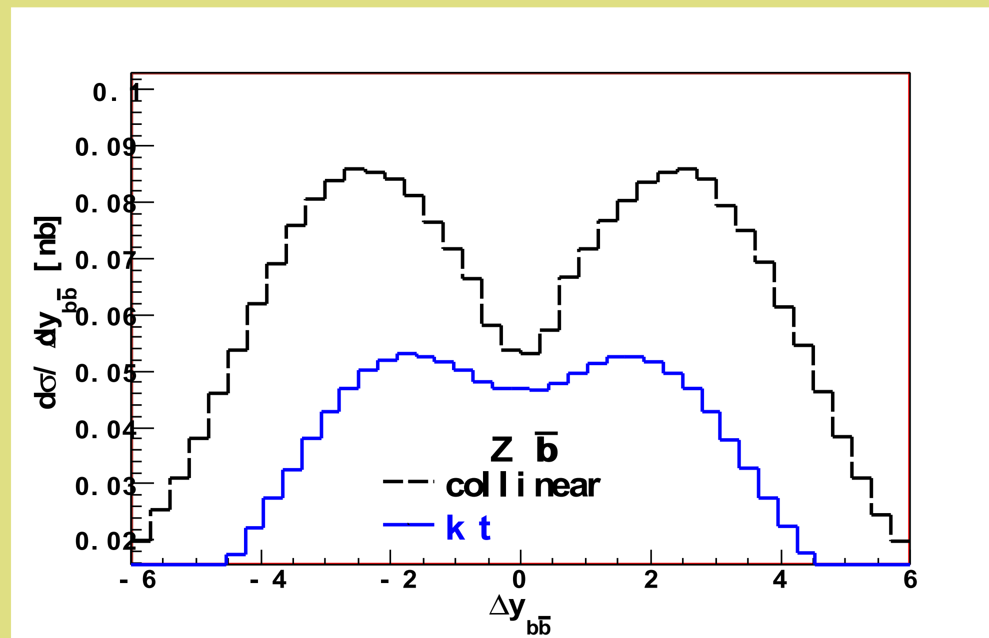
Results $gg \to Z + b\bar{b}$

- Angular and rapidity correlations

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

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





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

- Calculation with massive quarks
- Total cross sections in this case:

  0.406 nb CASCADE

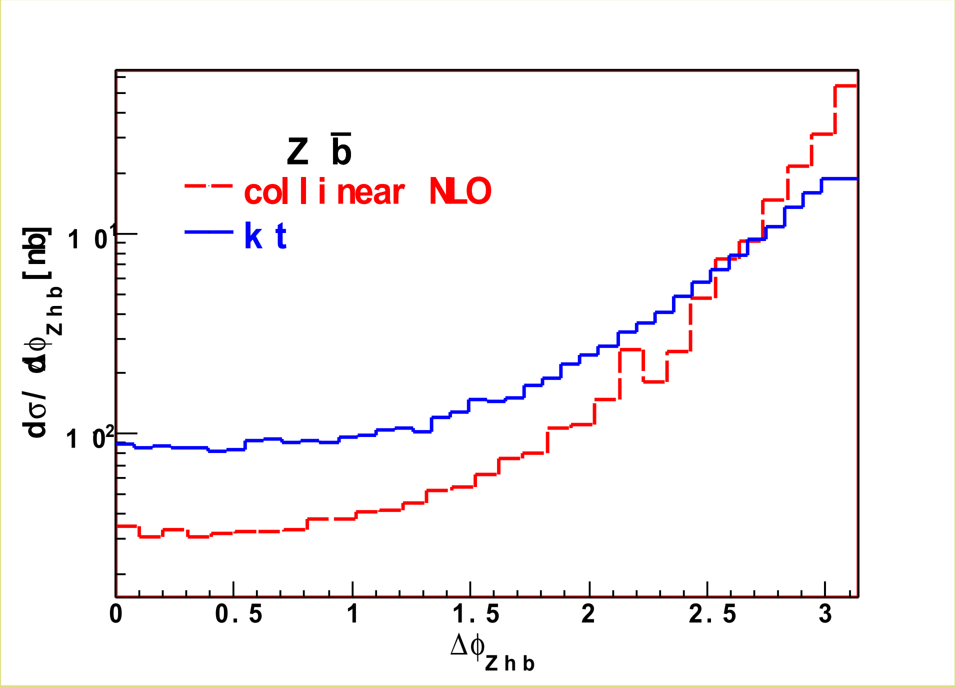
  0.748 nb MCFM

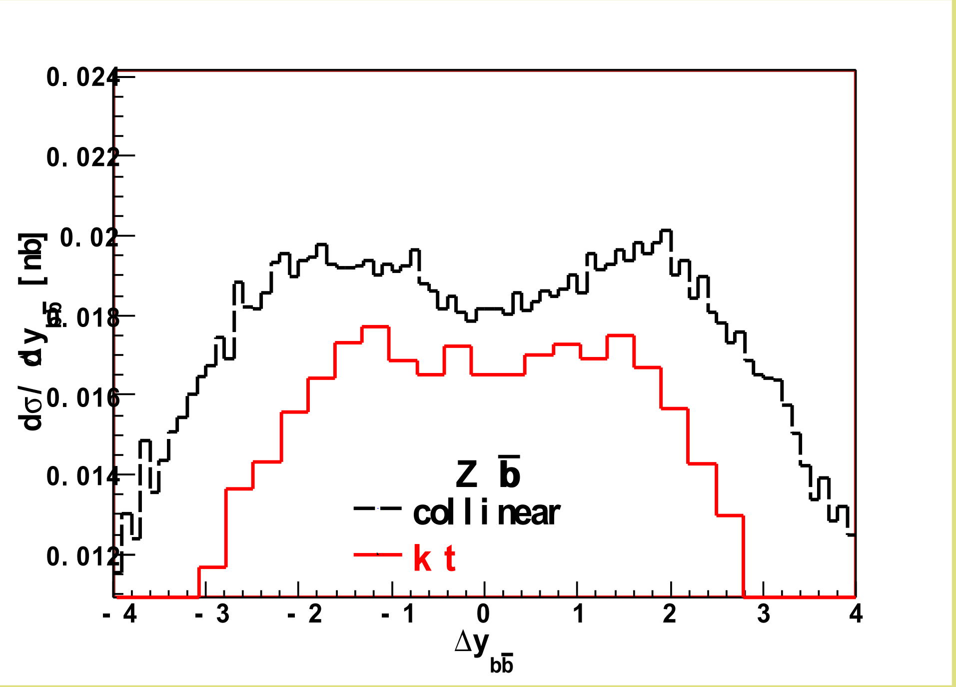
Results $gg \to Z + b\bar{b}$

- If one applies a cut on pt of *Z* difference in cross sections decreases:

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

quarks	order	w/o cut	with cut
massive	LO	0.748	0.141
massless	NLO	1.04	0.165
massive	kt	0.406	0.118
massless	kt	0.429	0.125

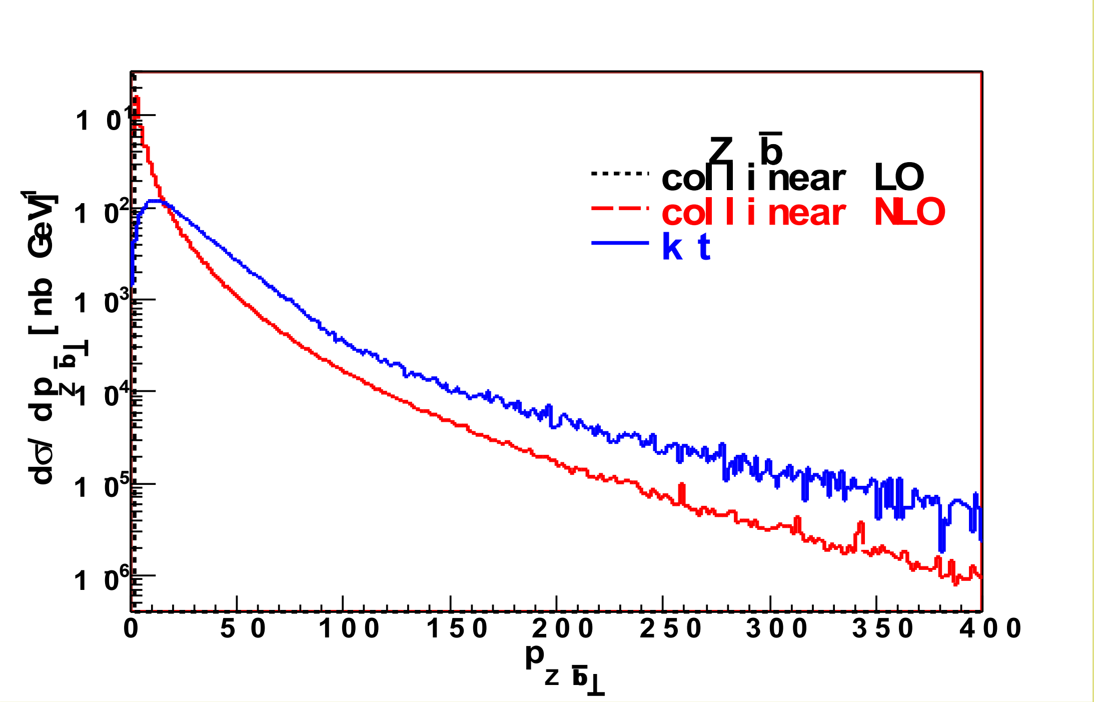




Results $gg \to Z + b\bar{b}$

- 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 $gg \rightarrow Z + b\bar{b}$ calcualted
- Implemented in CASCADE Monte Carlo generator
- Transversal momentum cross sections, azimuthal angle correlations and rapidity correlations shown

- Correct kinematics comparing to LO colinear 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