Non-linear Gluon Evolution and Heavy Quark Production at the LHC

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- Evolution formalism
- Constraints by HERA
- Heavy quark production
- Conclusions

Motivation

- What is the region of applicability of PDFs and of linear QCD evolution?
- Power like gluon violates unitarity at very small x values, this has to be damped by rescattering
- PDFs extracted from HERA will be used in the description of hadronic processes at LHC
- LHC may probe very low values of x where unitarity corrections may be important even at relatively large scales of a few GeV^2
- Estimate non-linear effects which might appear when extrapolating to the kinematical regime of LHC
- For which processes will we expect the breaking of collinear and k_t-factorization?

Evolution formalism

- Gluon evolution in the framework of unintegrated gluon density and k_t-factorization
- Kwiecinski et al: Unified BFKL and DGLAP description including saturation effects (KKMS)

- Improvement of BFKL equation by adding non-singular part of DGLAP gluon splitting function
- Resummation of both, leading ln Q^2 and ln $1/x$ terms
- Including dominant sub-leading ln $1/x$ effects via consistency constraint and running α_s

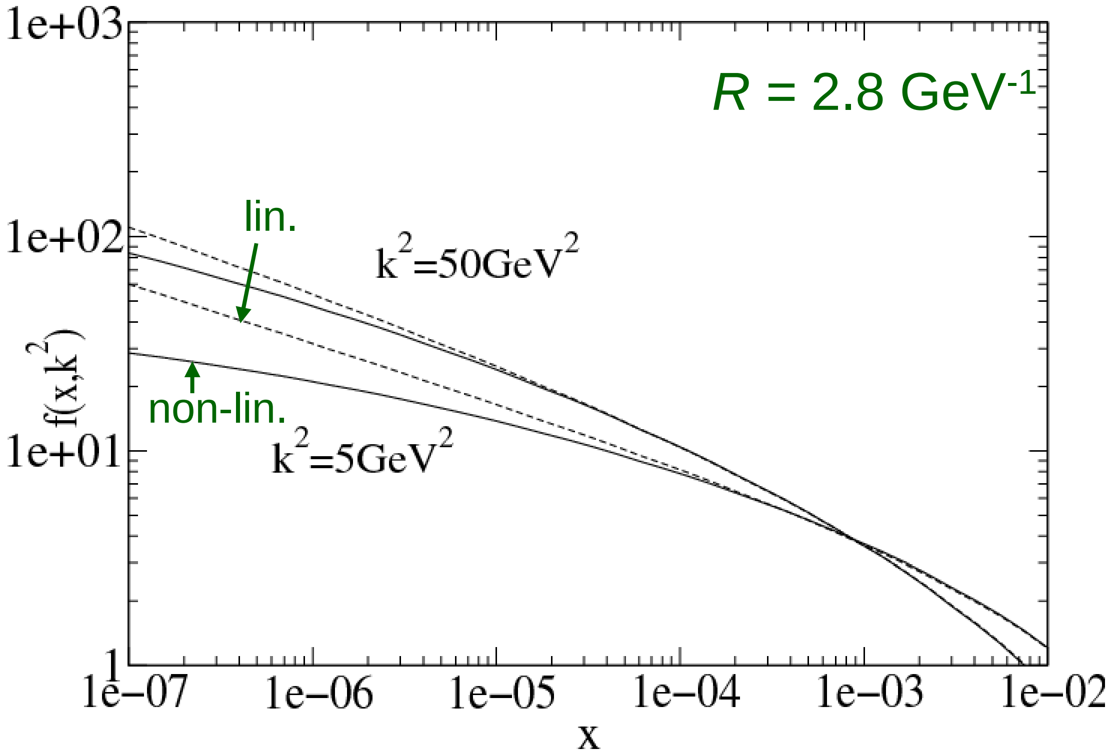
[Kwiecinski, Martin, Stasto, PRD **56** (1997), 3991]

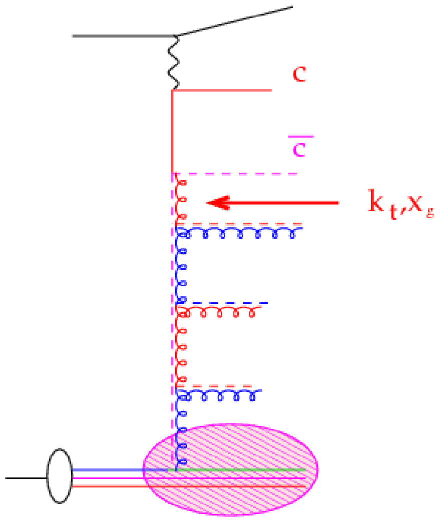
- Non-linear part from BK equation to account for gluon recombination

[Kutak, Kwiecinski, EPJ **C29** (2003), 521]

Evolution formalism

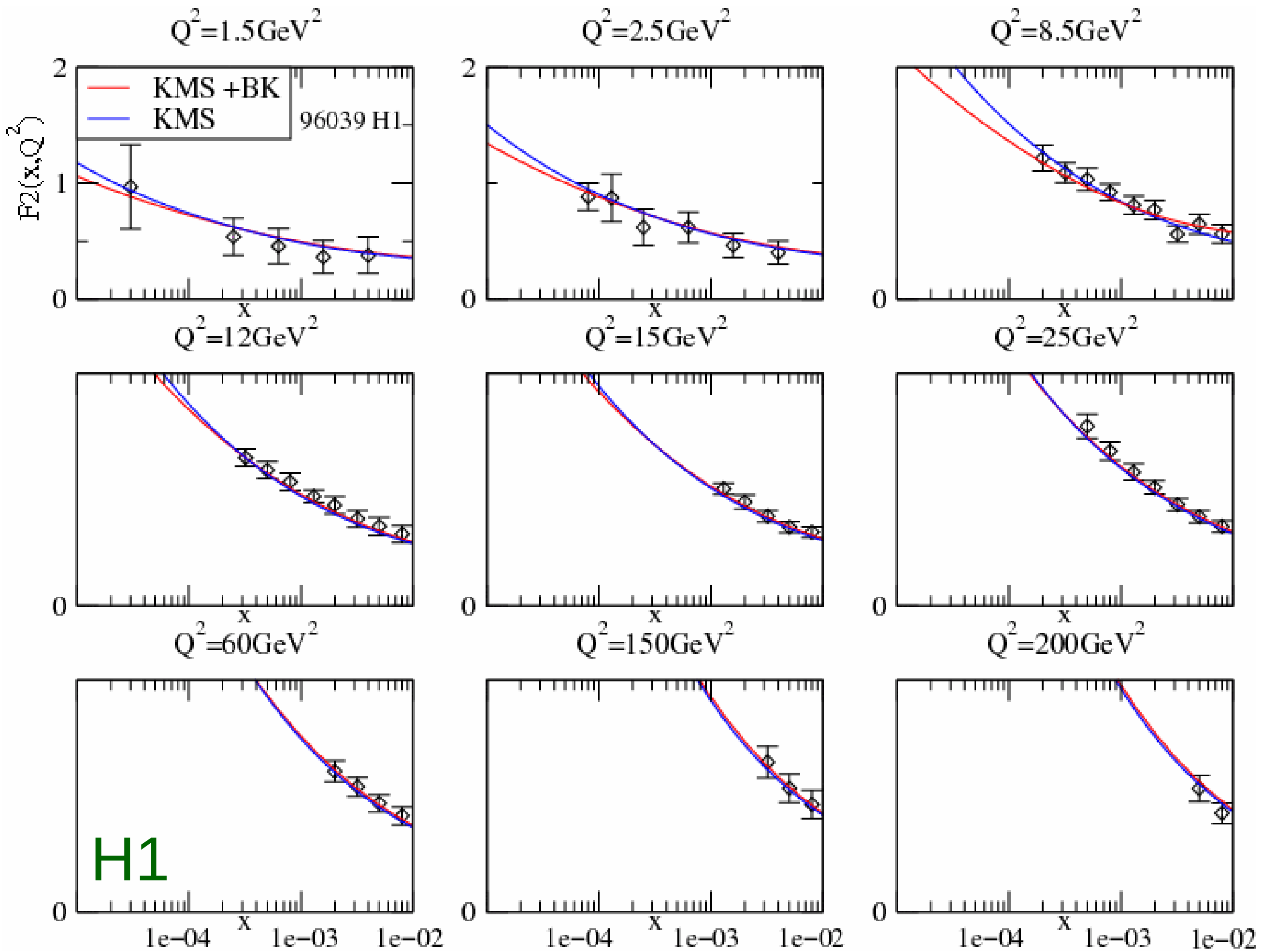
- Non-linear screening contribution ~ *1/R²*
- *R* radius of dense gluon system $1 < R < 5\ \mathrm{GeV}^{-1}$
- Diffractive slope, $B_d \simeq 4\ \mathrm{GeV}^{-2}$ of the elastic J/ψ photoproduction cross section at HERA leads to $R = 2.8\ \mathrm{GeV}^{-1}$





- Saturation effects in the region of small k_t and small x_g

Constraints by HERA *F2*

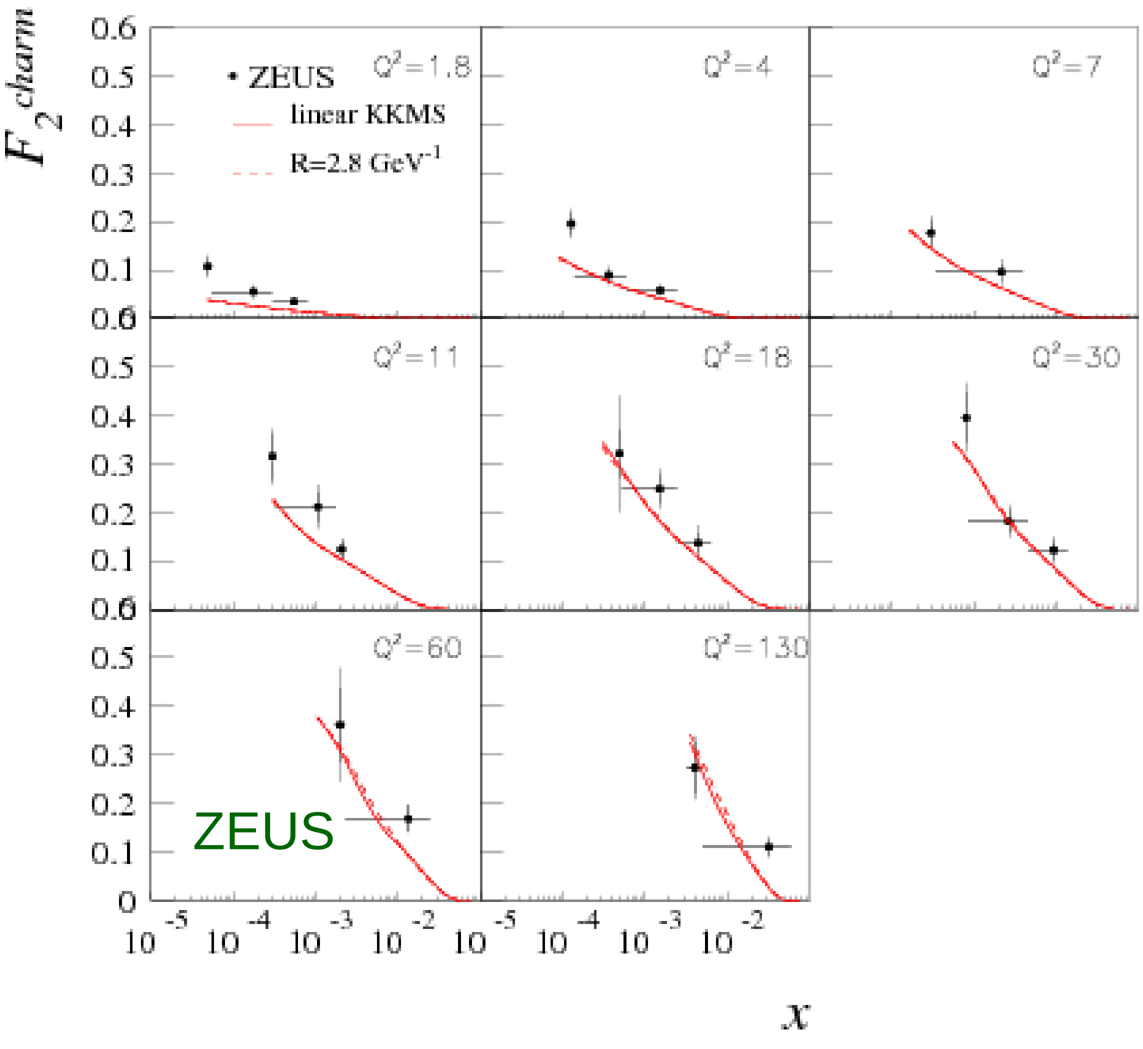


Linear vs non-linear with R = 2.8 GeV^{-1}

$$xg(x,k_0^2) = N(1-x)^{\rho}$$

- Evolution formalism describes the data well, no significant difference between linear and non-linear evolution

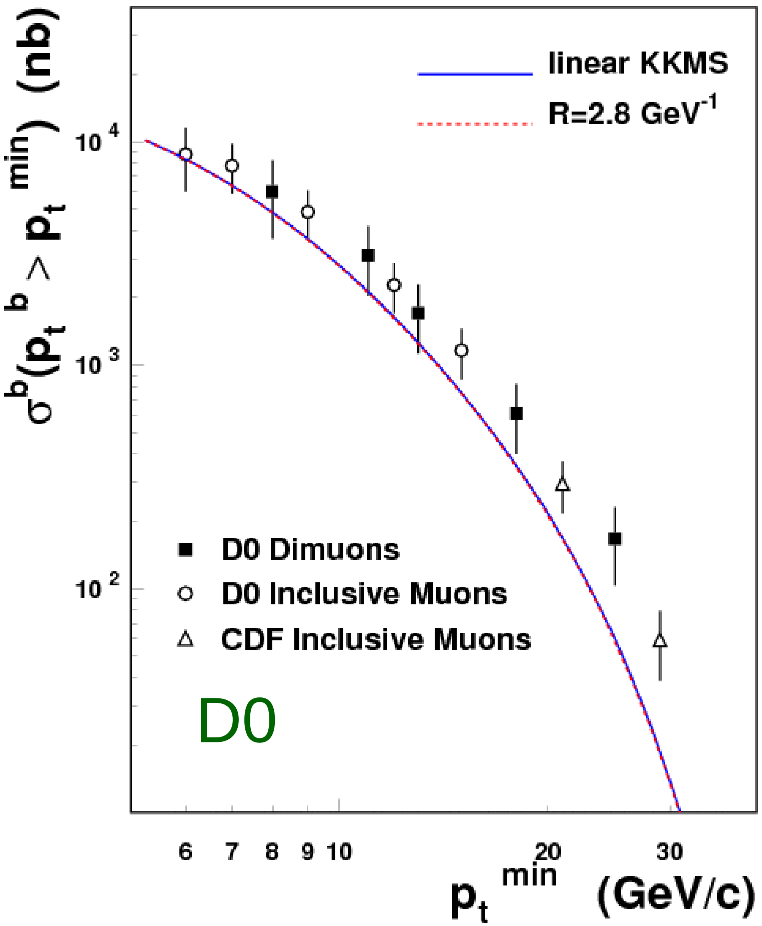
Predictions for *F2c*

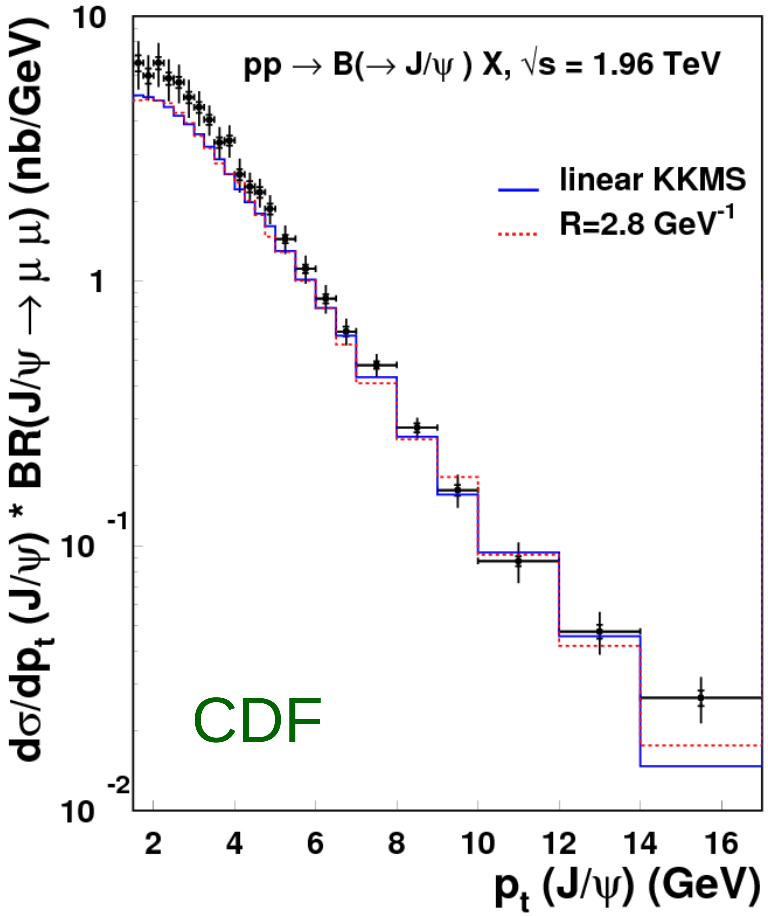


- Gluon density constrained by *F2* describes also *F2c* reasonably well
- *F2c* computed with the MC **CASCADE**
- Similar result for H1
- Non-linear part has no impact in this kinematical region of HERA

- Further cross checks: *bb* production at the Tevatron

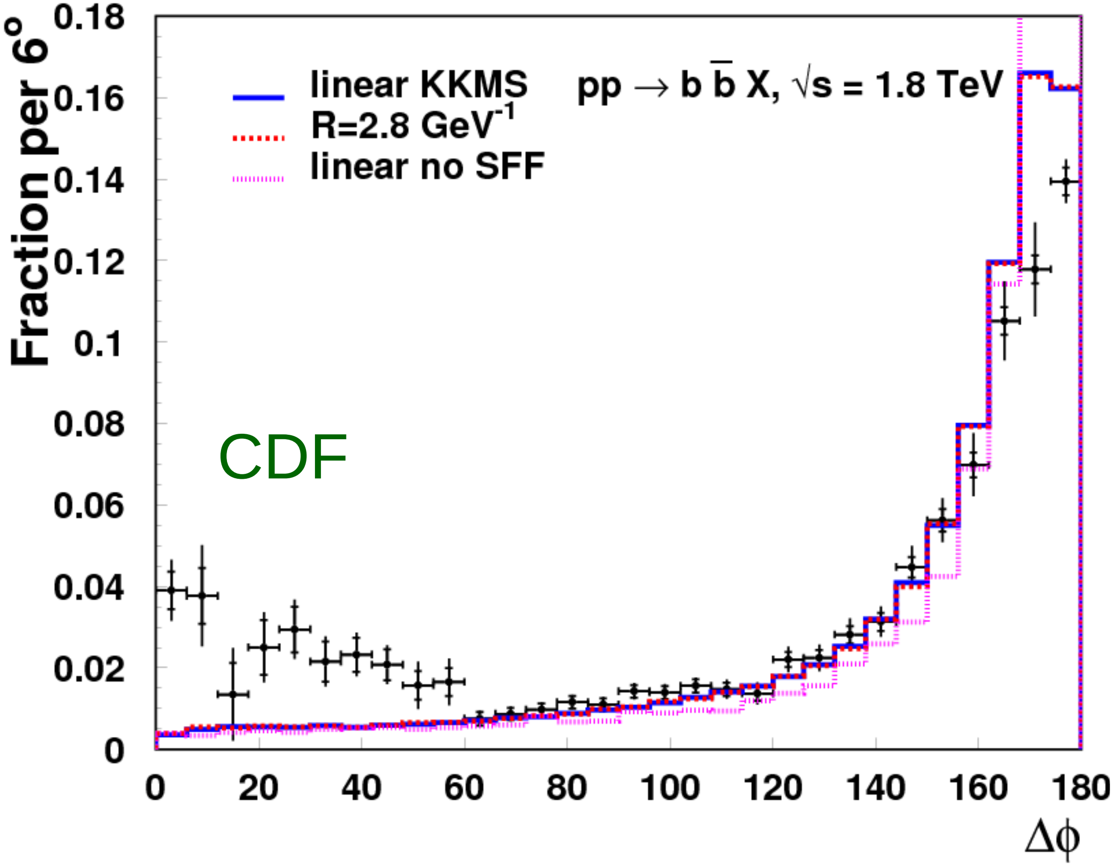
$b\bar{b}$ production at Tevatron

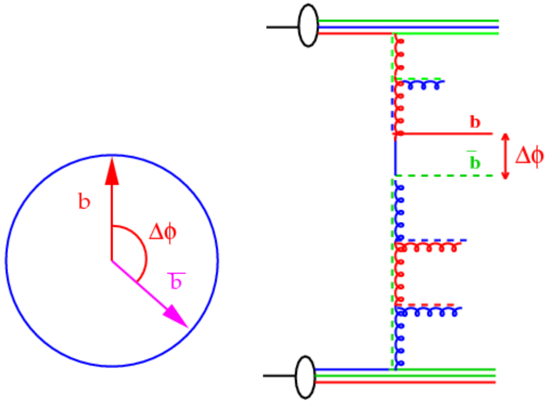


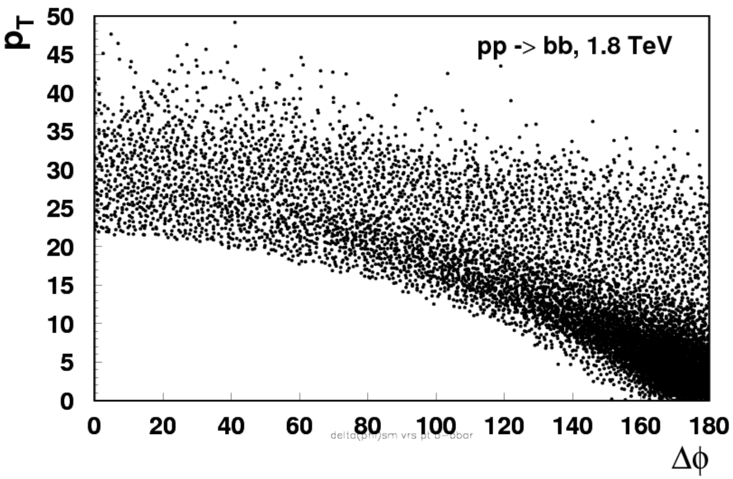


- *bb* cross sections with gluon densities constrained by HERA
- Scale for $\alpha_s = k_t^2 + m_q^2$, $m_b = 4.75$ *GeV*, Sudakov FF
- KKMS predictions comparable with the NLO collinear approach

$b\bar{b}$ production – $\Delta\phi$ distribution

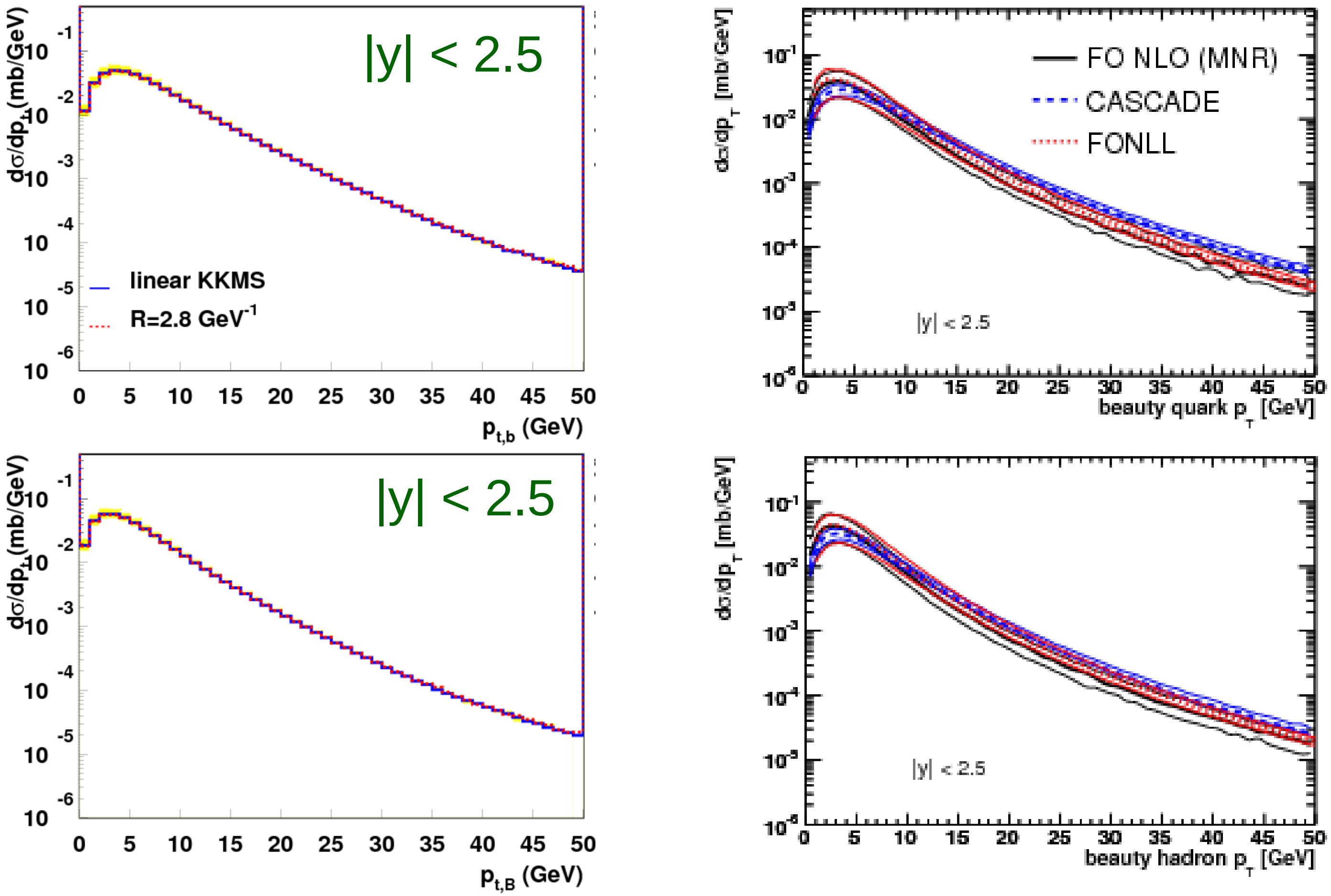






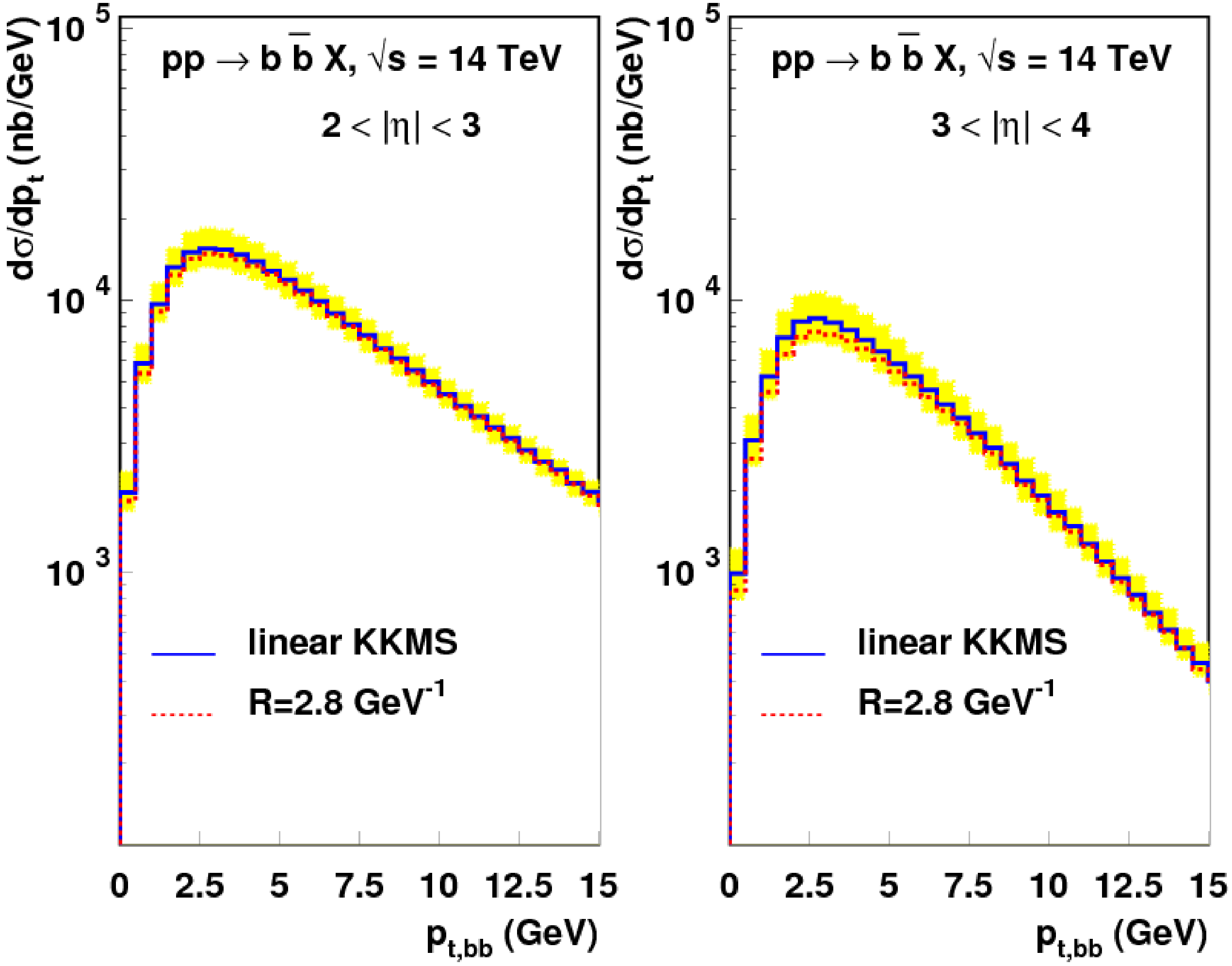
- KKMS gluon density describes the azimuthal angle distribution for high $\Delta\phi$ values
- Inclusion of Sudakov FF improves description significantly
- Smearing effects due to the experimental resolution included

$b\bar{b}$ production at LHC



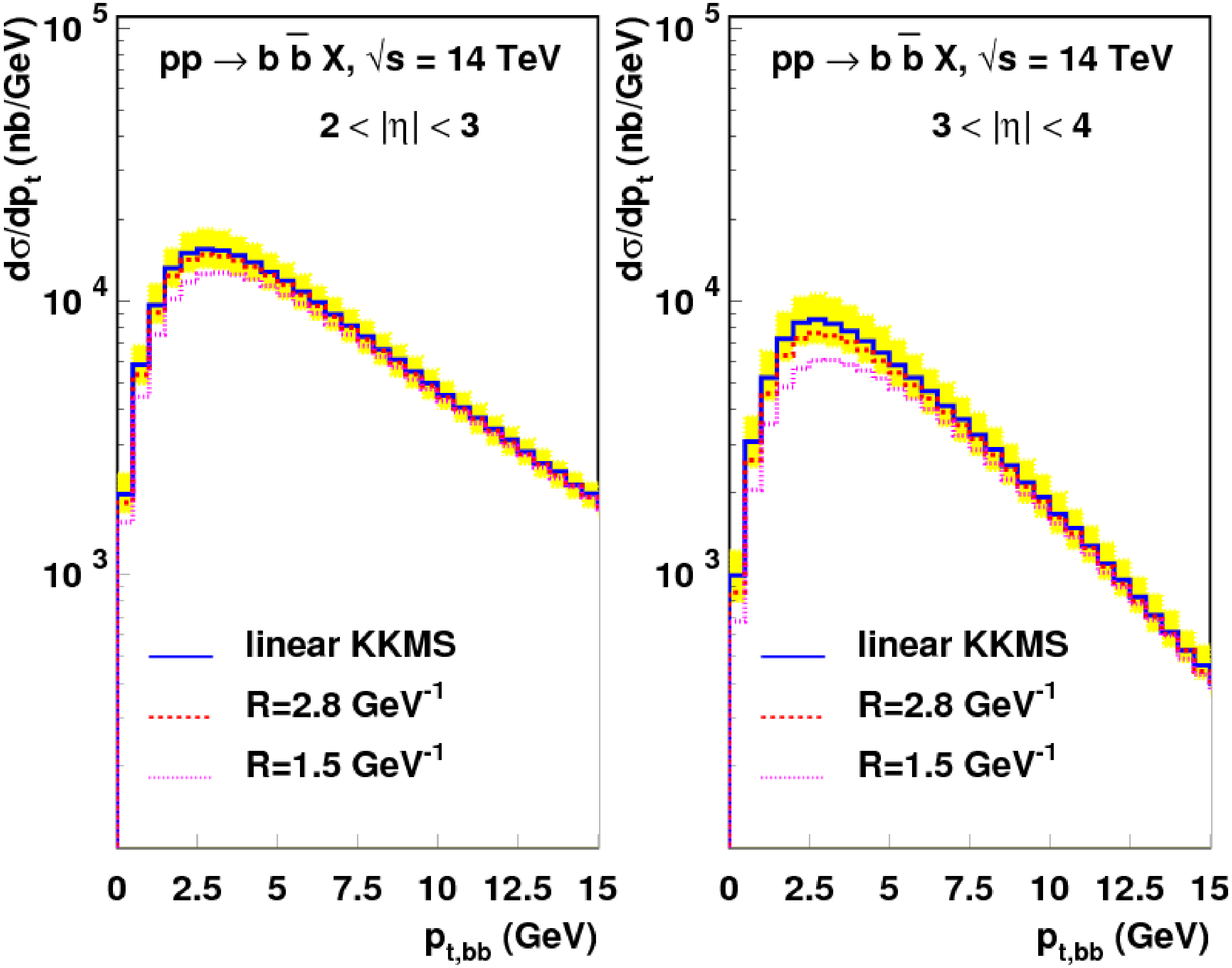
- Comparison to different theoretical approaches in the HERA-LHC workshop benchmark cross sections framework
- KKMS result compatible with the other approaches (within uncertainties)

$b\bar{b}$ production at LHC



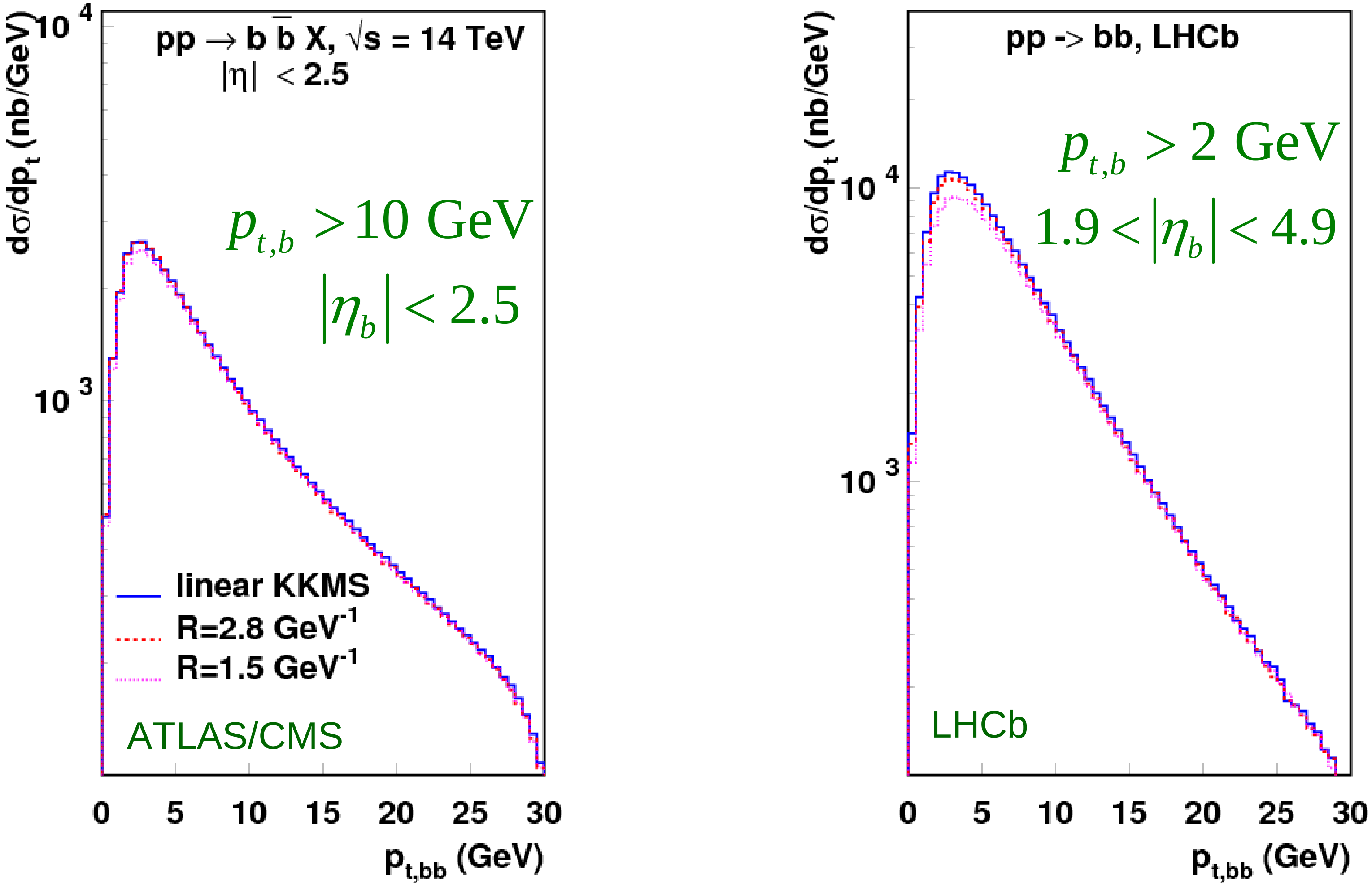
- Yellow band shows uncertainty due to the *b* quark mass 4.5 – 5.0 GeV
- No saturation effects with R = 2.8 GeV^{-1} in $p_{t,bb}$ distribution in this eta range

$b\bar{b}$ production at LHC



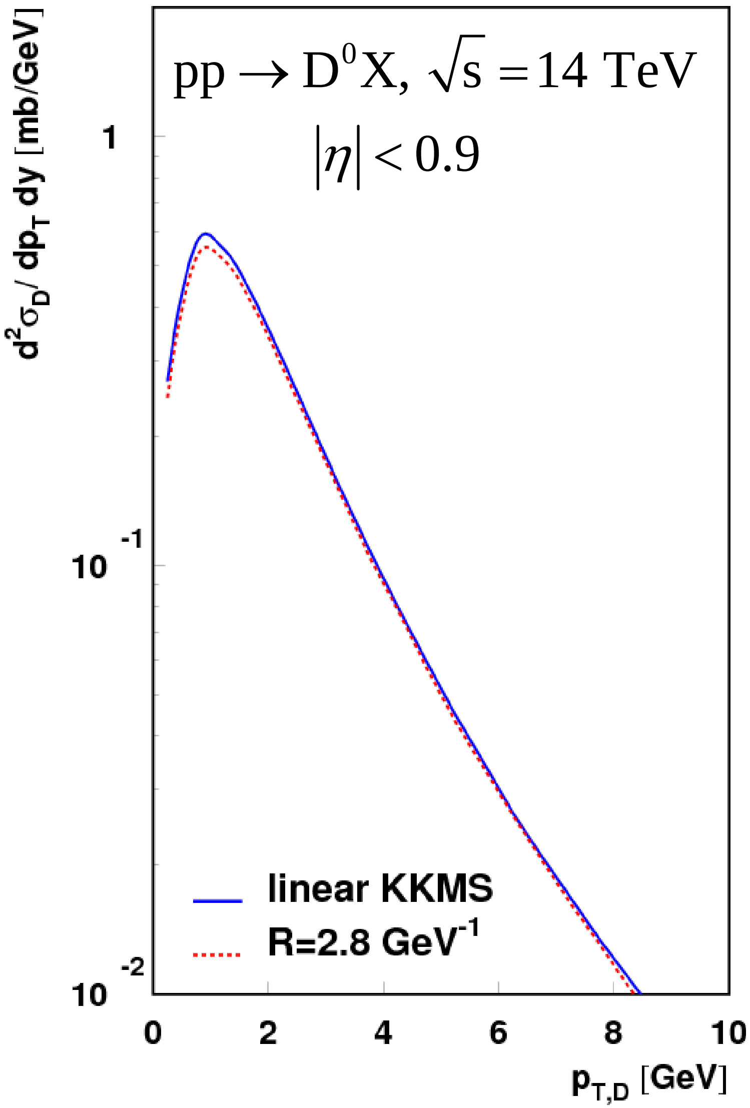
- Lowering the saturation radius *R* enhances saturation effects
- Hot-spot scenario would give an upper boundary of saturation effects

$b\bar{b}$ production at *ATLAS/CMS* and *LHCb*



- Within the ATLAS/CMS acceptance cuts no saturation effects observable
- Linear evolution and k_t-factorization can be safely applied

$c\bar{c}$ production at ALICE: $c \longrightarrow D^0$



- $m_c = 1.4$ GeV, $\alpha_s = k_t^2 + m_q^2$
- |eta| < 0.9, $p_{t,D} > 0.5$ GeV
- MC **CASCADE**
- Saturation effects may emerge only in the hot-spot scenario. With the preferred radius $R = 2.8\ \text{GeV}^{-1}$ saturation effects are not significant
- Saturation effects have been predicted within the *GLR* approach (with larger *R* value) in the same kinematical region
  [Dainese et al, JP **G30** (2004), 1787]

Conclusions

- KMS gluon density fitted to HERA *F2* with linear and non-linear evolution
- Constrained gluon density describes *F2c* at HERA and *bb* production at the Tevatron reasonably well
- *bb* $\Delta\phi$ distribution well described at high $\Delta\phi$ values in the framework of unintegrated gluon densities and k_t-factorization
- At various kinematical regions of the LHC (CMS/ATLAS, LHCb, ALICE) no effect of gluon saturation was found for heavy quark production with the preferred saturation radius in the presented framework
- This result suggest that linear gluon evolution and k_t-factorization can be safely applied in this kinematical range