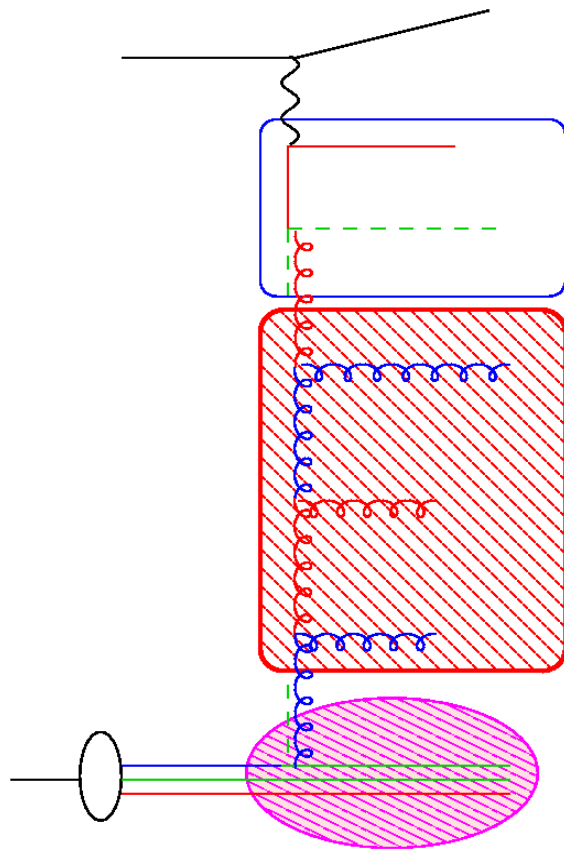


The CASCADE and RAPGAP MCs

H. Jung (DESY)

- **CASCADE**
 - basic idea
 - applications - benchmarks
 - future plans
- **RAPGAP**
 - ideas
 - applications - benchmarks
 - future plans

CASCADE – C_{atani} C_{iafaloni} F_{iorani} M_{archesini} evolution



BGF matrix element
off shell

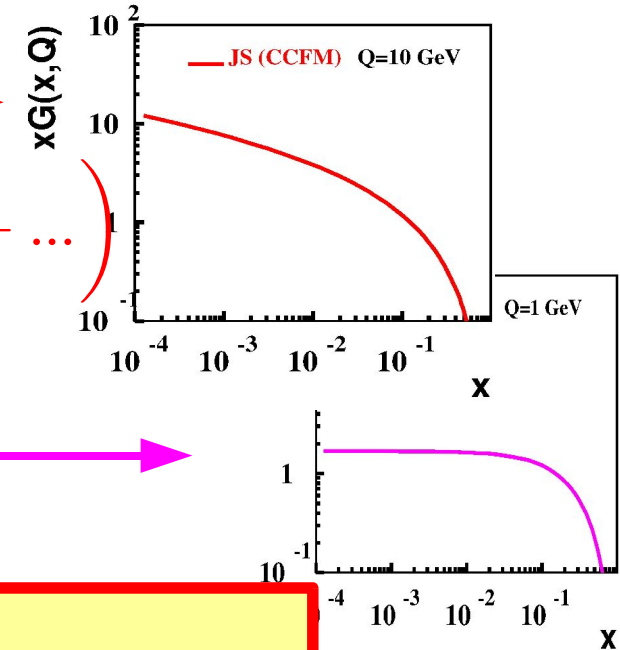
evolution of parton
cascade:

$$\tilde{P} = \bar{\alpha}_s \left(\frac{1}{1-z} + \frac{1}{z} \Delta_{ns} + \dots \right)$$

initial distribution
~ flat

CCFM (all loops)

- angular ordering
- non – Sudakov Δ_{ns}

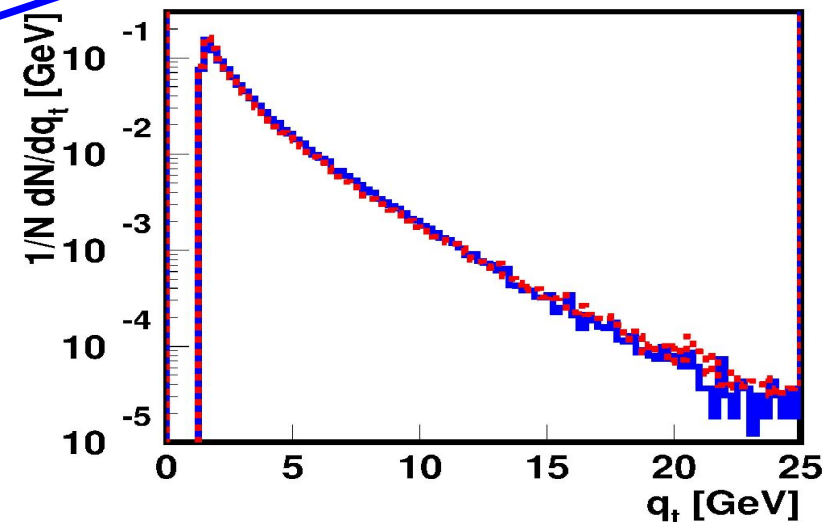
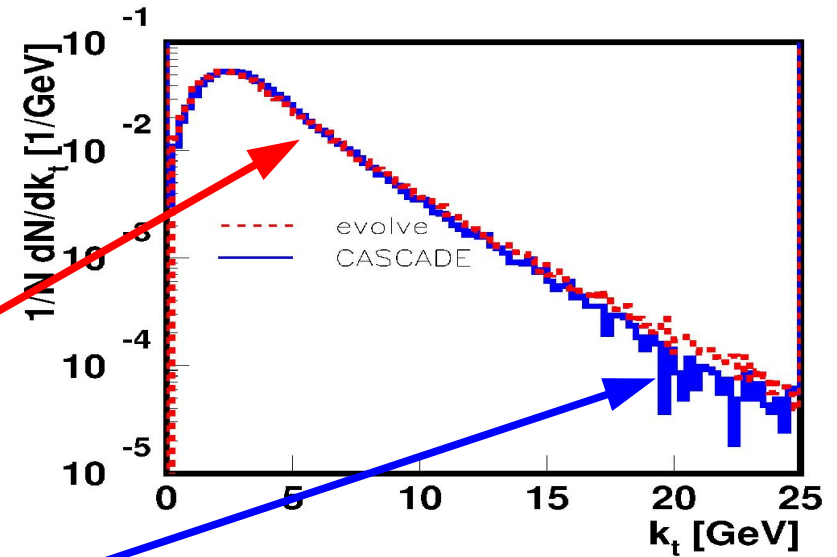


$$\sigma(ep \rightarrow e'q\bar{q}) = \int \frac{dy}{y} d^2 Q \frac{dx_g}{x_g} \int d^2 k_t \hat{\sigma}(\hat{s}, k_t, Q) x_g \mathcal{A}(x_g, k_t, \bar{q})$$

$$\int d^2 k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) \simeq x_g G(x_g, Q^2)$$

CASCADE MC generator

- DGLAP or CCFM
- only inclusive predictions
- no information on emitted partons
- CCFM treats explicitly
 - partons emitted during cascade
 - color coherence
 - energy momentum conservation
- best to implement in MC generator
- compare evolution and parton shower
- need unintegrated parton densities



CASCADE MC event generator II

- Processes included (gluon induced)

$$\gamma g^* \rightarrow q\bar{q}, \gamma^* g^* \rightarrow Q\bar{Q}, \gamma g^* \rightarrow J/\psi g$$

$$g^* g^* \rightarrow q\bar{q}, g^* g^* \rightarrow Q\bar{Q}, g^* g^* \rightarrow h$$

- initial state parton shower, backward evolution, according to CCFM
- final state PS
- p-remnant treatment
- hadronization



NEW:

using LHA interface to
PYTHIA/HERWIG

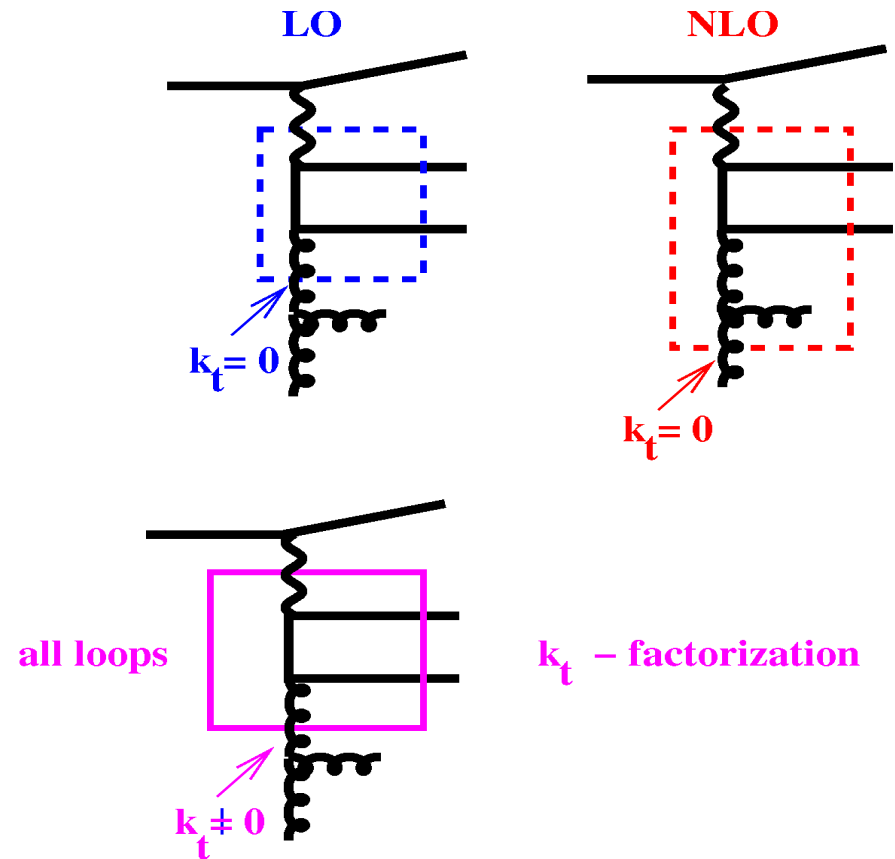
for

- final state PS
- p-remnant
- hadronization

CASCADE for *ep* and *pp*

CASCADE and coll. NLO calcs

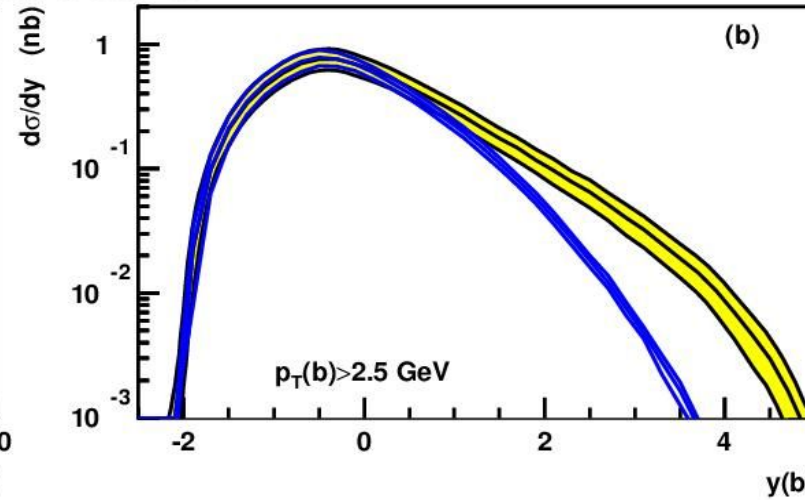
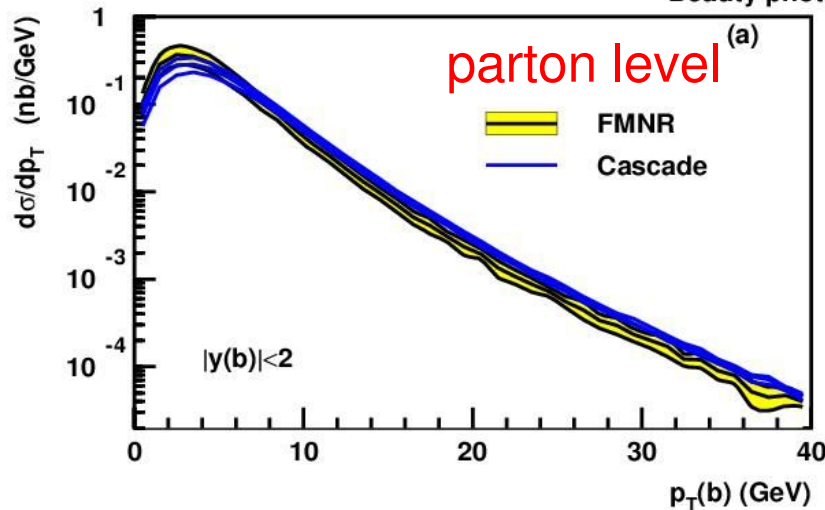
- fit of uPDF to inclusive structure functions /x-sections used to determine normalization
 - includes “all-orders” !!!!
- off-shell matrix element simulates part of real NLO corrections
 - study of scale dependence
 - compare to coll. NLO calculations
 - check with benchmark x-sections



CASCADE - NLO: beauty at HERA

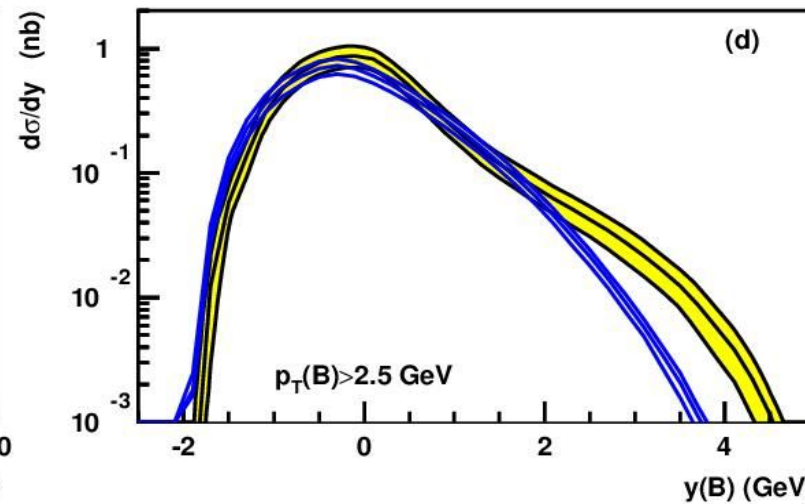
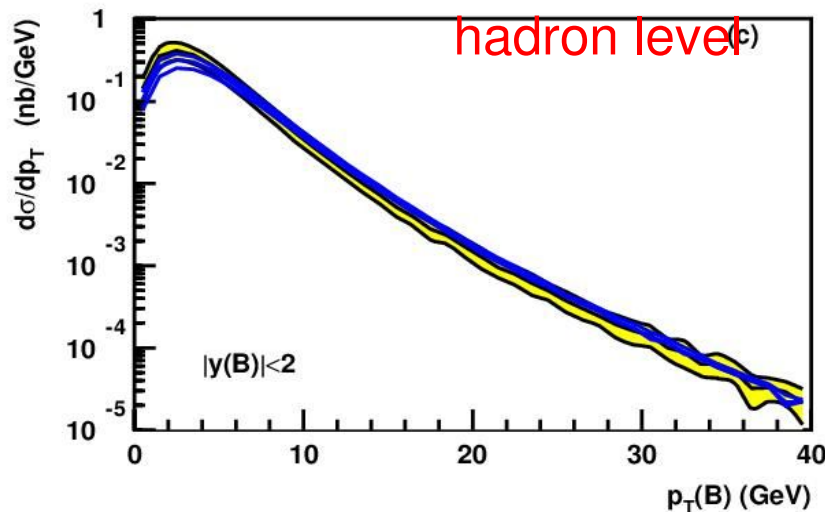
from HERA-LHC proceedings 2005O. Behnke et al, p 405

Beauty photoproduction at HERA



variations:

- $1.3 < m_c < 1.7$
- $0.5 < \mu_f < 2$
- Peterson/Bowler



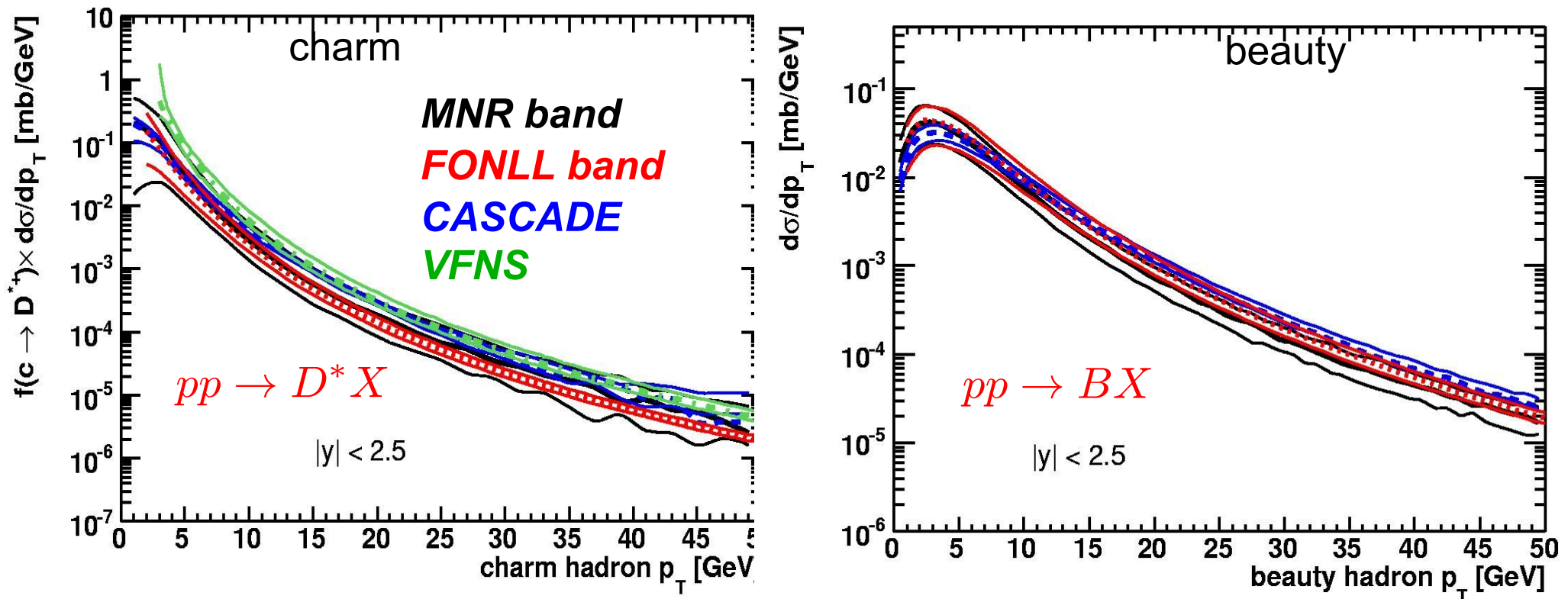
➔ **“Perfect” agreement of NLO(FMNR) calc with CASCADE on quark and hadron level for $x < 0.01$ ($y > 2$) !!!**

Charm and Beauty at the LHC

from HERA-LHC proceedings 2005O. Behnke et al, p 405

Benchmarks at hadron level in central region

MNR (massive NLO) – **FONLL** (matched NLL) – **CASCADE** (uPDF) – **VFNS**



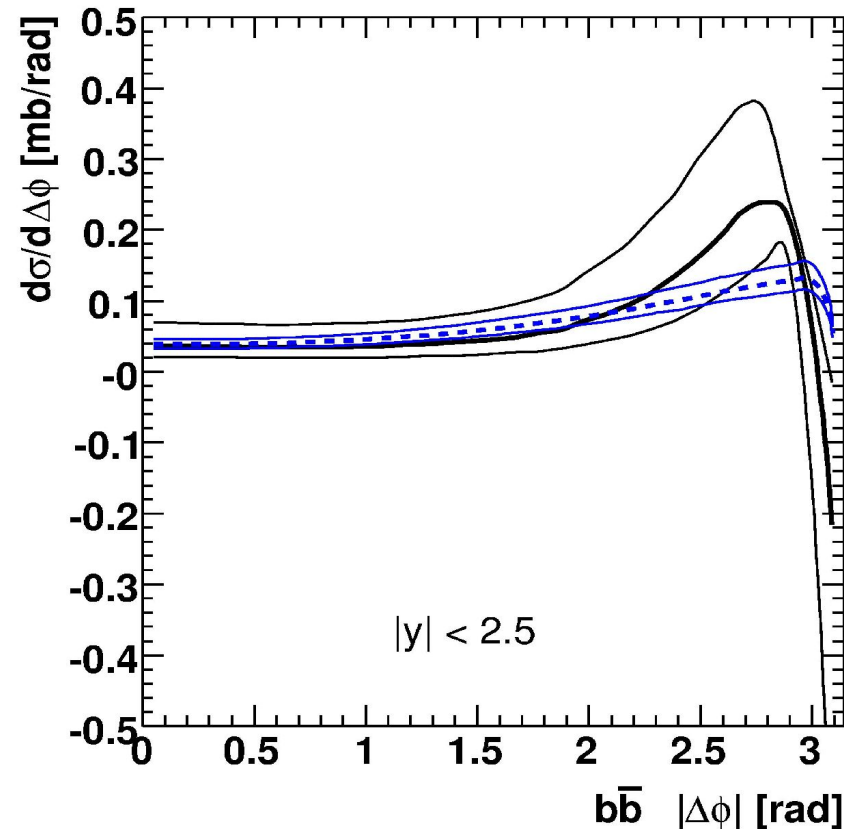
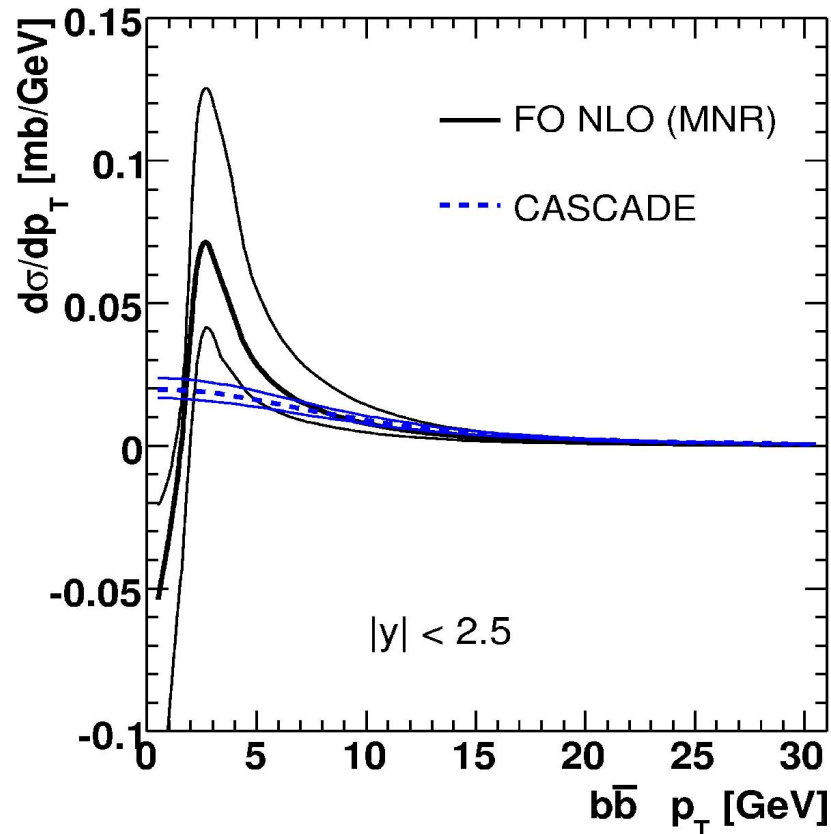
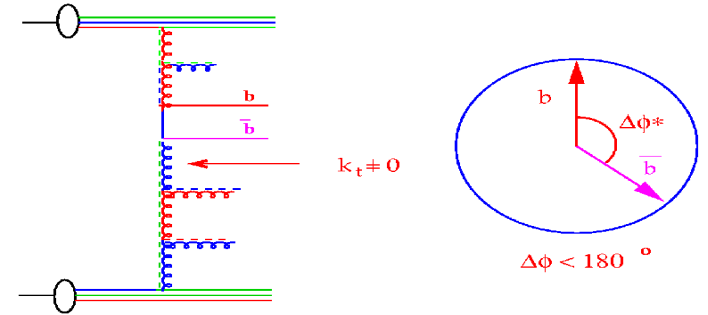
CASCADE agrees well with **MNR** and **FONLL** for charm and beauty.
VFNS is larger for charm at small p_t ...

All agree reasonably well ... But large uncertainties !!!

pt and phi correlations at LHC

- transverse momentum of quark-antiquark system $p_T(Q\bar{Q})$
- azimuthal separation between two heavy quarks $\Delta\phi(Q\bar{Q})$

from HERA-LHC proceedings 2005O. Behnke et al, p 405

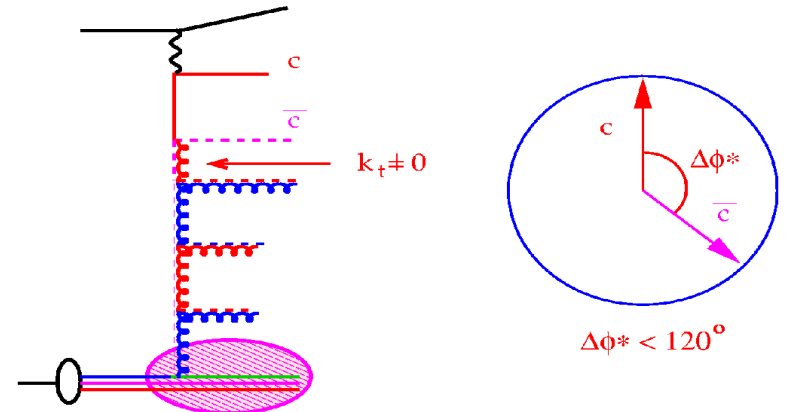


CASCADE has smaller uncertainties !!!

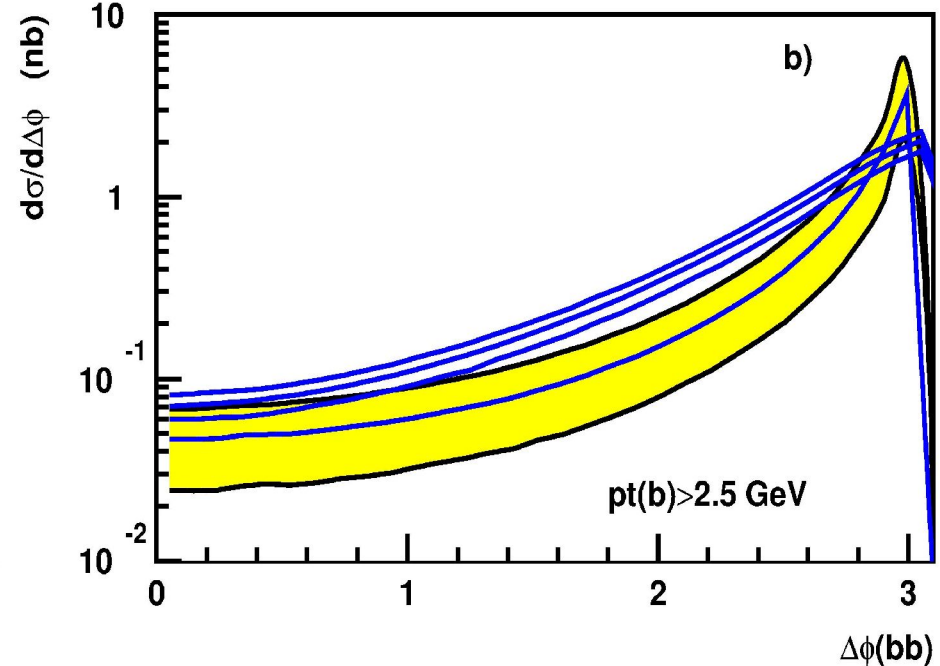
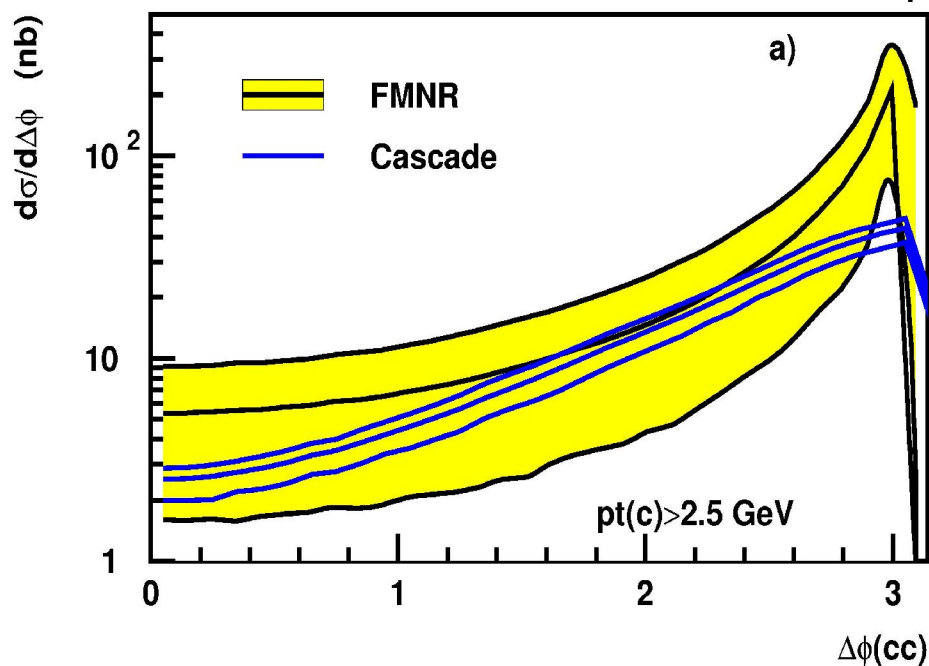
Phi correlations at HERA

from HERA-LHC proceedings 2005O. Behnke et al, p 405

- azimuthal separation between two heavy quarks $\Delta\phi(Q\bar{Q})$



Photoproduction at HERA



watch out uncertainties in CASCADE and FMNR !!!

Features

- variation of renormalization scale
 - using uPDFs accordingly determined
 - smaller uncertainty from theory
- various sets of uPDFs included (but only CCFM/KMR with parton shower):
 - CCFM
 - KMR
 - KMS
 - saturation model
 - derivative of integrated gluon
 - etc ...
- **KMR prescription**: one additional radiation ... useful for determination of hadronization corrections for NLO calcs
- full PYTHIA final state PS & remnant treatment included
 - applicable for $t\bar{t}$ -production

Future Plans

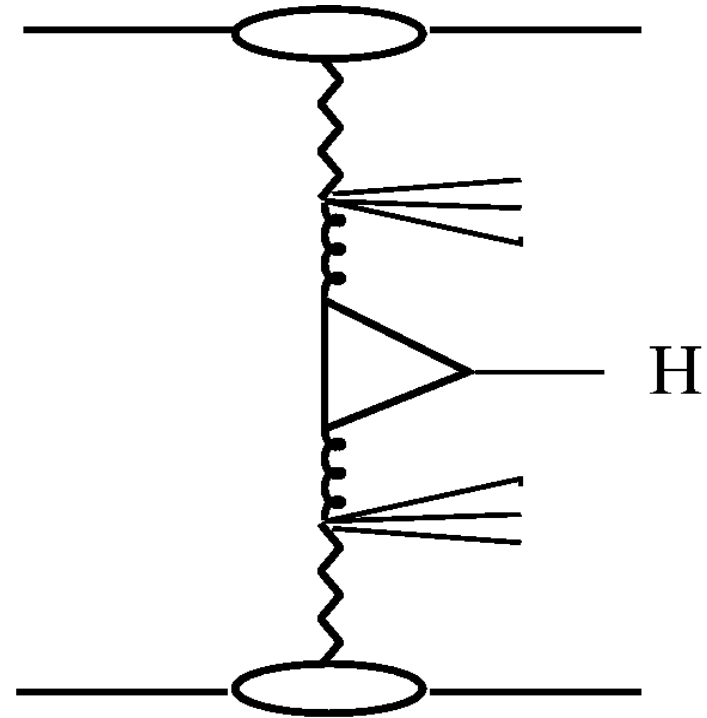
- Multiple Interactions in k_t factorization
 - connect MI with saturation and diffraction
 - including hard diffraction
- Inclusion of quarks in evolution
 - gluon in proton or coming from quark ? issue on intrinsic k_t
 - is it gaussian or $1/k^2$
- Inclusion of other processes
 - W/Z production, prompt photons etc
-

RAPGAP event generator

- historically first version for hard diffraction in ep
 - Rapidity Gap events
 - including hard diffraction via 2-gluons and resolved pomeron
- including latest diffractive PDFs
- developed to full MC event generator for ep (including non – diffraction)
 - NOW also applicable for pp
 - including resolved virtual photons
- initial and final state parton showers (a la DGLAP)
- NOW:
 - final state PS, p-remnant treatment and hadronization a la PYTHIA/HERWIG via LHA interface.

Future Plans for RAPGAP

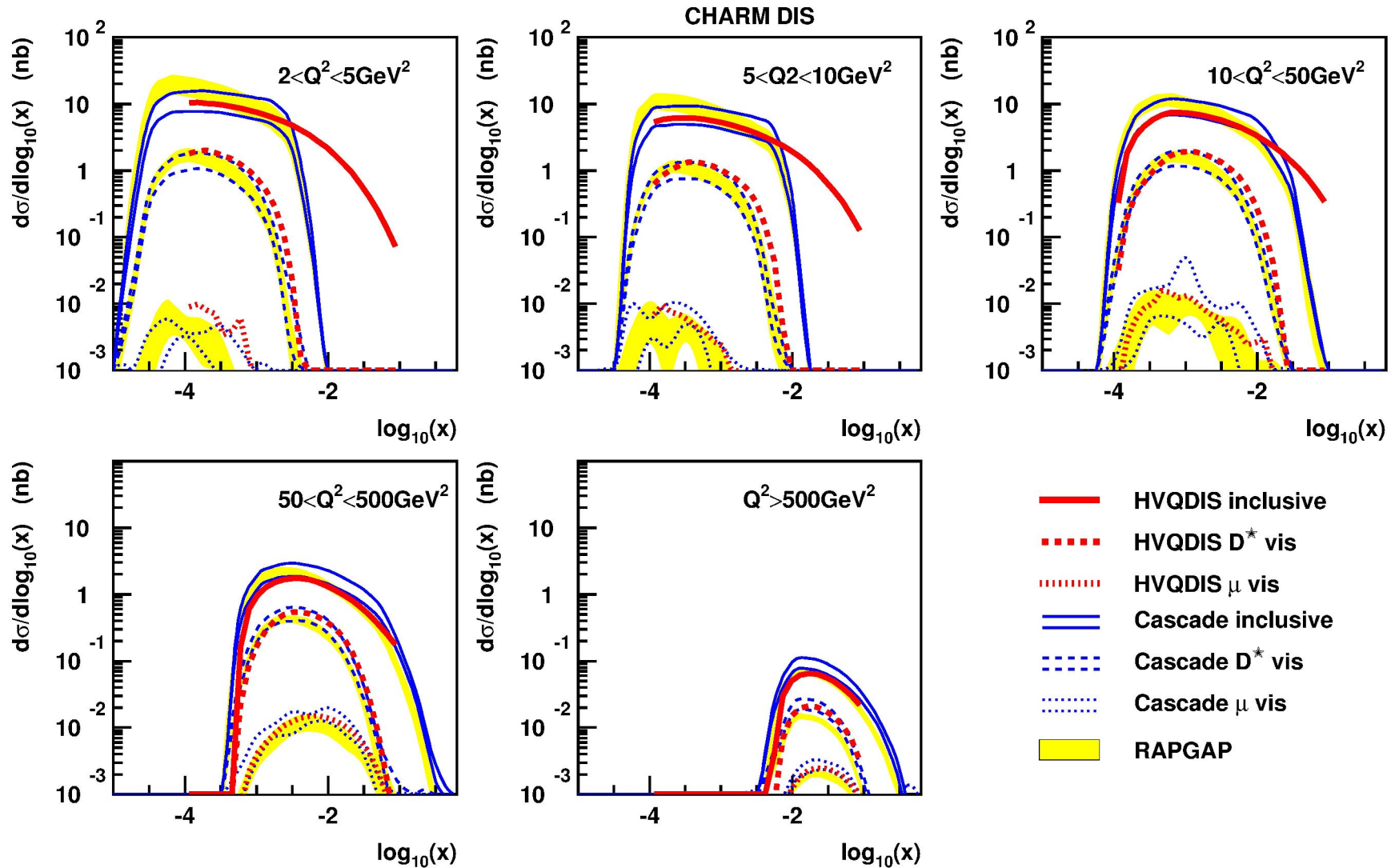
- Multiple Interaction via PYTHIA also for DIS (resolved photoproduction)
 - double diffraction also for pp
 - double pomeron Higgs
- Any other special processes for LHC needed ?



Benchmark x-sections

Compare parton level, visible D^* and muon x – sections

from HERA-LHC proceedings 2005O. Behnke et al, p 405



reasonable agreement between NLO, RAPGAP and CASCADE

Conclusions

- **CASCADE**
 - alternative event simulation (k_t -factorization)
 - “reliable” predictions for gluon induced processes
 - future extensions:
 - multiple interactions
 - W/Z production
 - prompt photons
 - other processes ?
- **RAPGAP**
 - simulation horse at HERA for diffraction and non-diffraction
 - future:
 - Higgs (diffraction)
 - others ?
- **Feed back is very welcome**
- **Interesting to see applications to pp** 