HERA and the LHC Workshop

WG3 – Heavy Quarks Summary

Part 1. **Theory (M.Cacciari)**

Part 2. **Benchmark cross sections and small-x (A.Dainese)**

Part 3. **Outlook on HVQ physics at HERA-II (A.Geiser)**

WG3 Conveners:

M.Cacciari, M.Corradi, A.Dainese, A.Meyer,
M.Smizanska, U.Uwer,C.Weiser

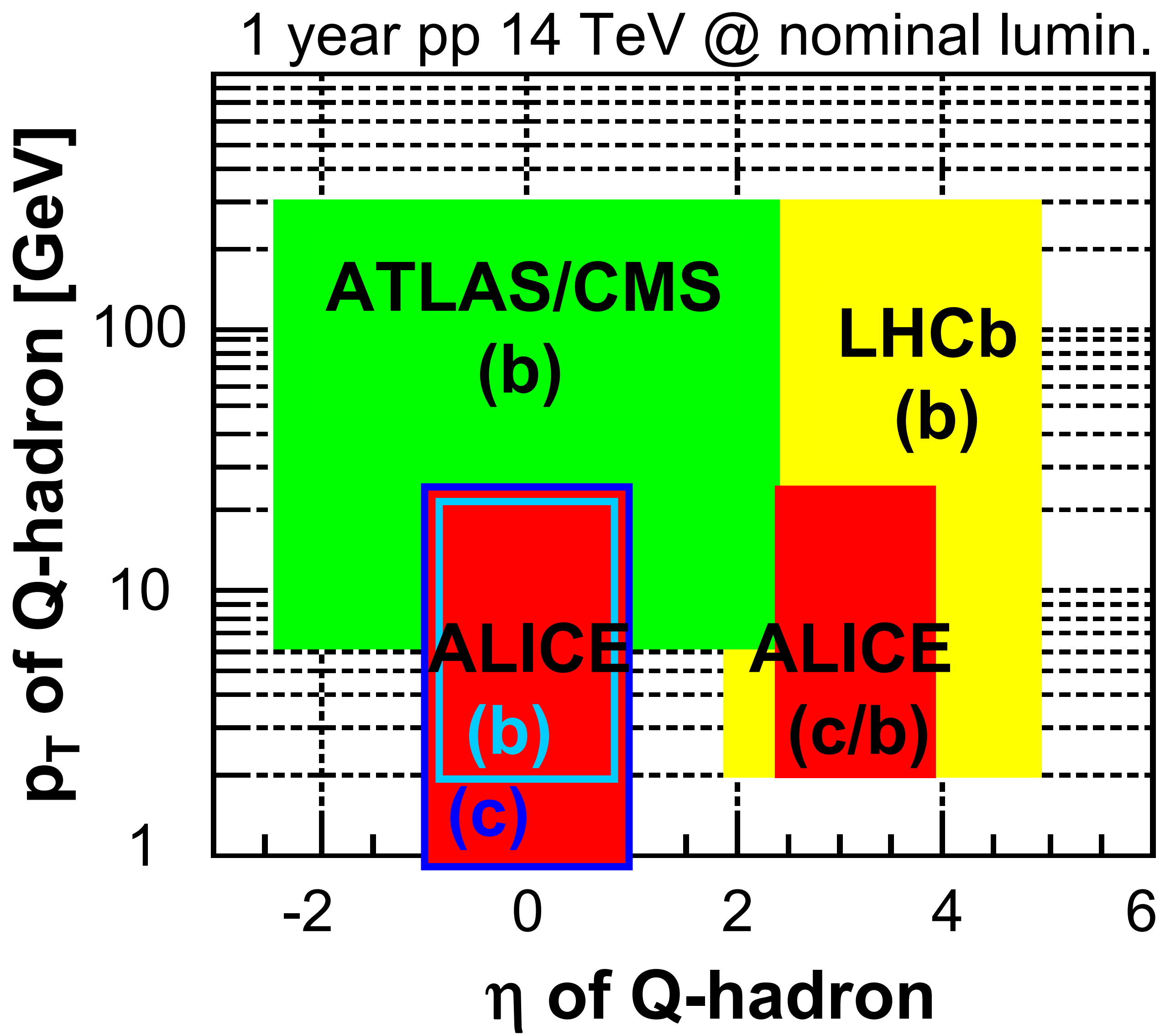
Benchmark cross sections for HVQ production at HERA and LHC

G.Barbagli, O.Behnke, M.Cacciari, M.Corradi, A.D.,
A.Geiser, O.Gutsche, E.Laenen, B.Kniehl, K.Kutak,
H.Jung, K.Peters, I.Schienbein, N.Zotov

Motivation

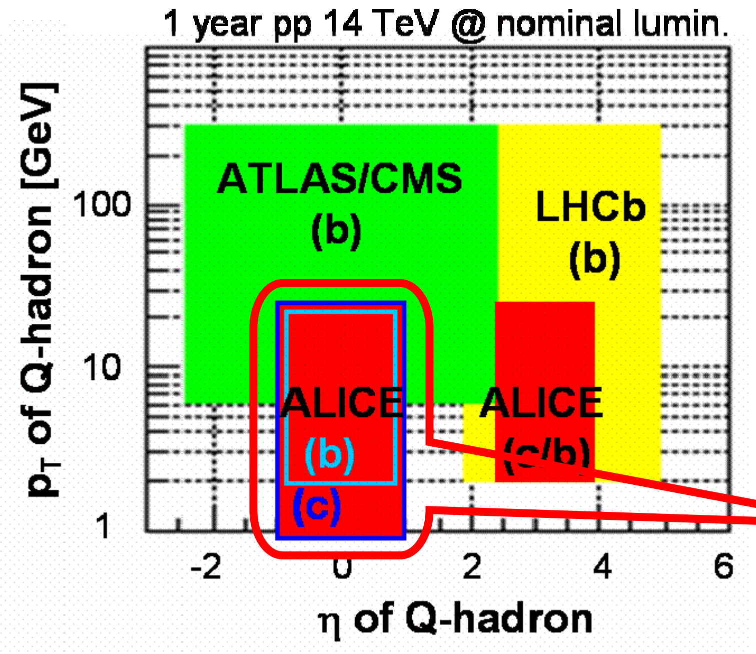
- Experiments at HERA-I / HERA-II and at LHC are/will-be measuring charm and beauty production with increasingly high precision and accuracy ($\rightarrow$ next slides for LHC, $\rightarrow$ A.Geiser's talk for HERA)
- Produce a compilation of the present theoretical knowledge ($\rightarrow$ M.Cacciari's talk) as a set of plots/numbers to be used for future comparison
- **Compare directly different theoretical approaches** in different environments (PhP and DIS in ep, pp) using a common definition of uncertainty bands

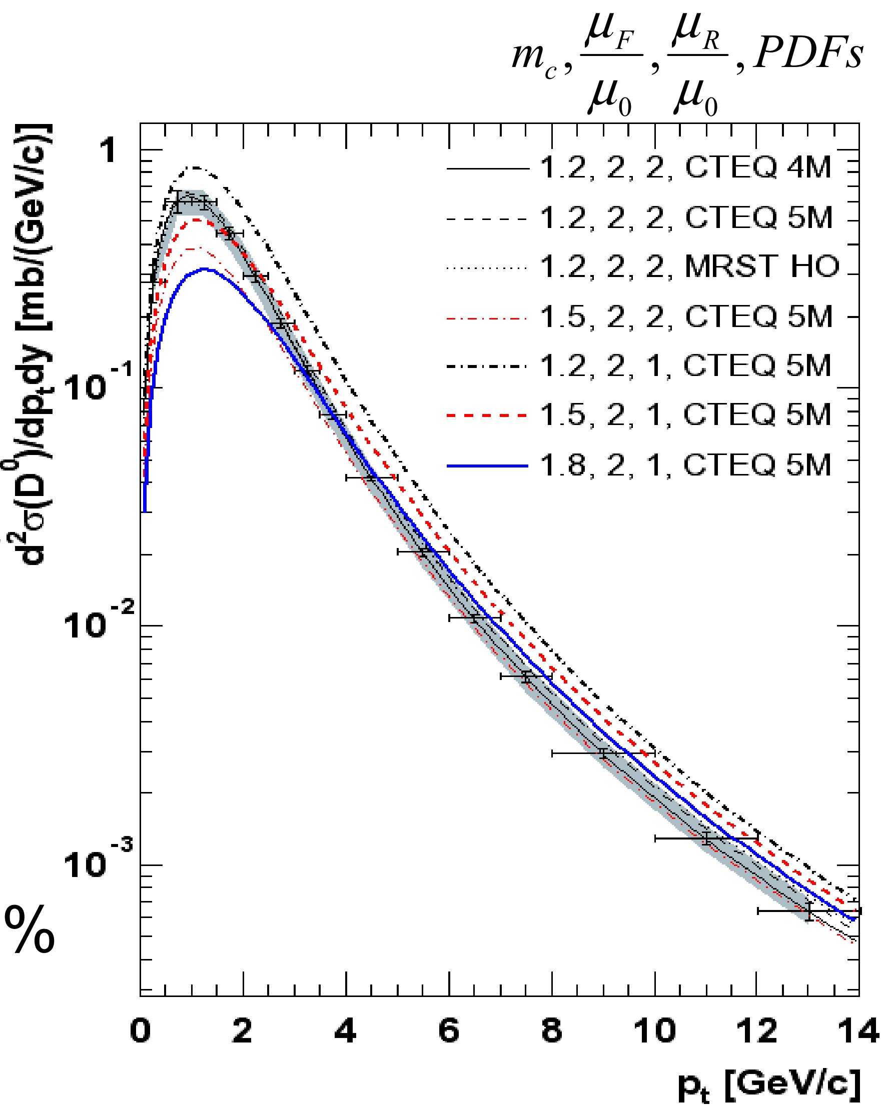
Acceptance for open heavy flavor at LHC



HVQ measurements at LHC: examples

D meson p_T distribution with ALICE



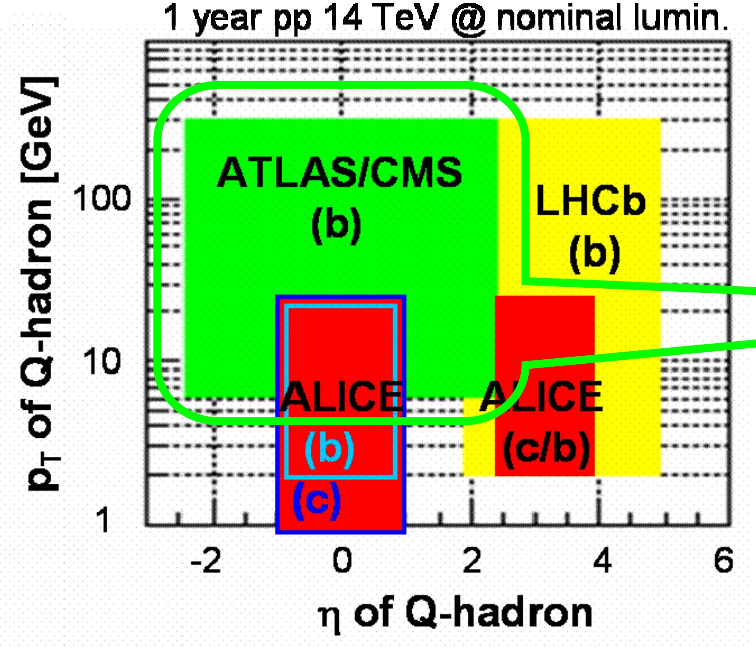


- Sensitivity down to $p_T \sim 0$
- Stat ⊕ Syst errors < 25—30%

A.D.

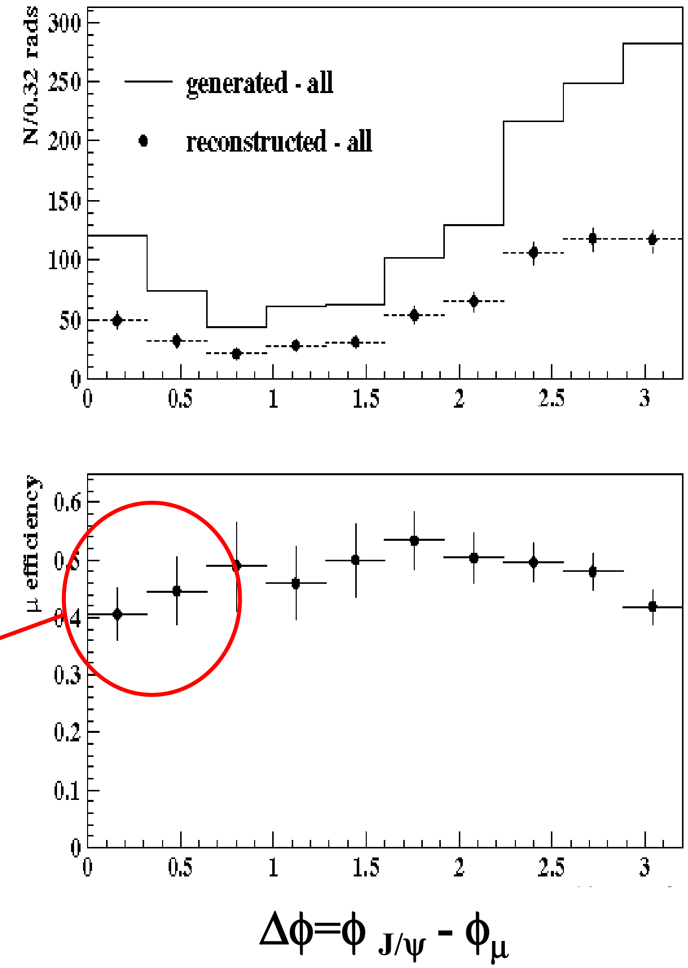
HVQ measurements at LHC: examples

b-bbar $\Delta\phi$ correlations with ATLAS



$B \rightarrow \mu + X$

$\bar{B} \rightarrow J/\psi K_s^0$



Contrary to CDF run-I measurements with b-jet + μ, use of excl. B channels allows high efficiency also at $\Delta\phi \rightarrow 0$

T.Lagouri

Which cross sections ?

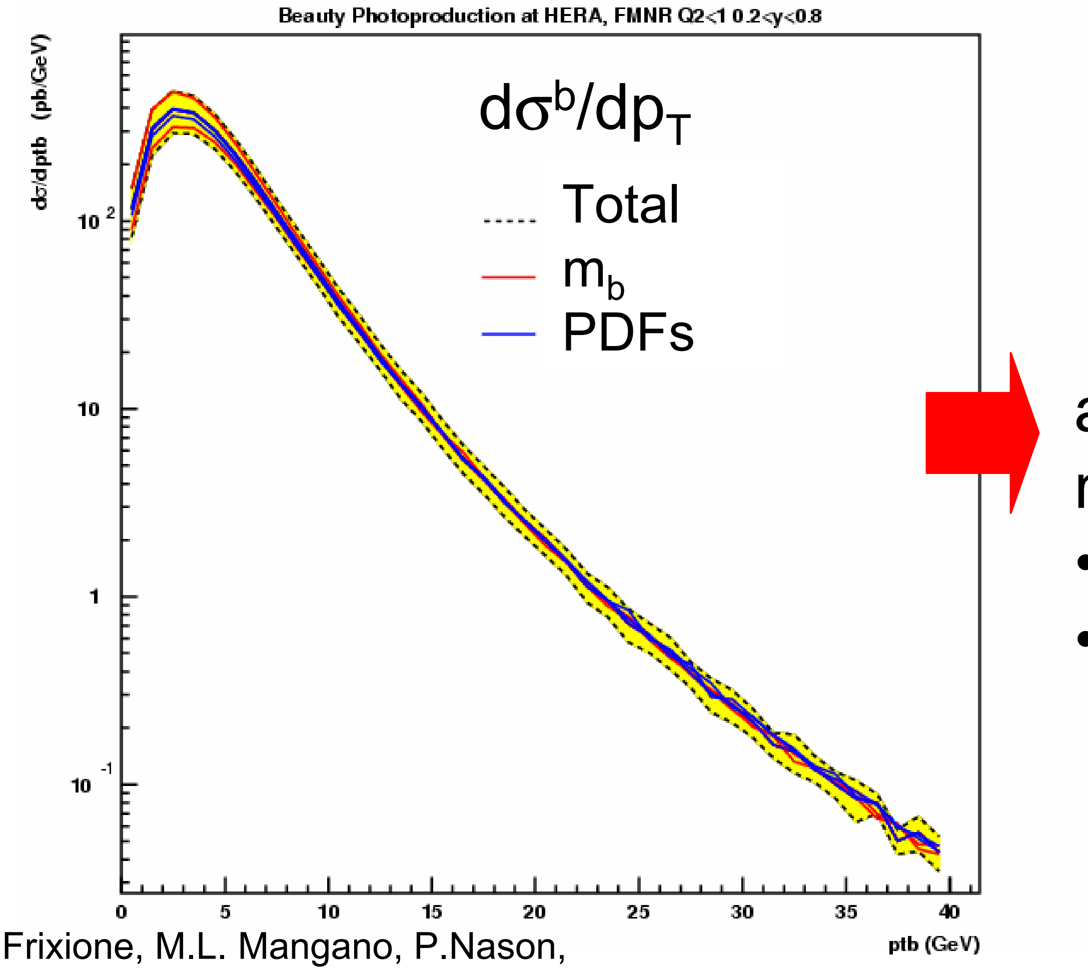
- Close to experimental observables, but only with acceptance-like cuts, e.g. $d\sigma/dp_T$ in given rapidity range(s)
- + “critical” observables, as p_T and ϕ correlations, for which models may differ

Which frameworks ?

Theory	Interaction	Program	
Massive NLO	LHC	MNR	✓
Massive NLO	HERA DIS	HVQDIS	
Massive NLO	HERA PhP	FMNR	✓
matched massive/massless	HERA PhP, LHC	FONLL	✓
matched massive/massless	HERA PhP, LHC	GM-VFNS	
VFNS PDFs	HERA DIS	-	
K_T factorization	LHC	-	
Non-lin g(x) (Kohlinen...)	HERA DIS, LHC	MNR	
CCFM uPDF MC	PhP, DIS, LHC	CASCADE	✓
MC@NLO	LHC	MC@NLO	
LO+PS MC	HERA PhP	Pythia	
LO+PS MC	LHC	Pythia	✓
LO+PS MC	DIS	Rapgap	

Beauty PhP at HERA – FMNR

Example: b production at HERA with FMNR (massive NLO)



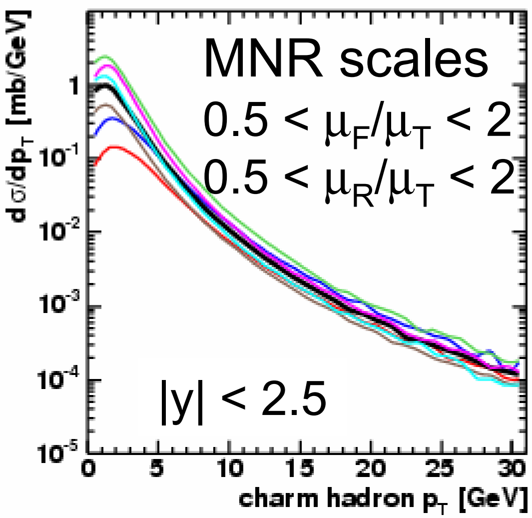
at HERA energy, main uncertainty:

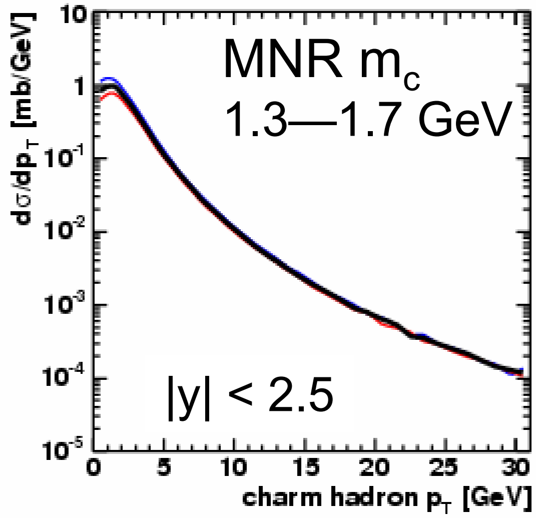
- HVQ mass at low p_T
- Scales at high p_T

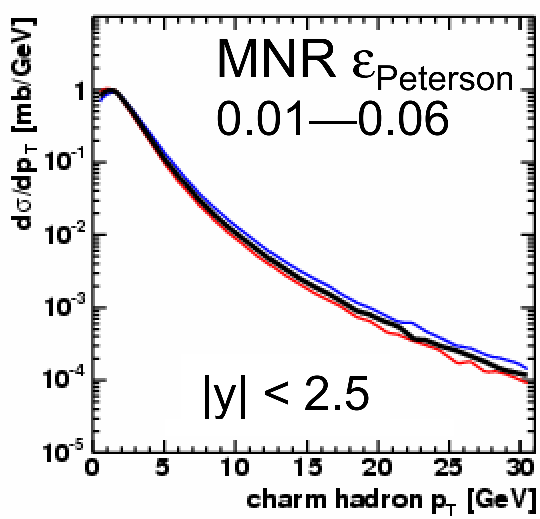
FMNR: S.Frixione, M.L. Mangano, P.Nason, G.Ridolfi, Nucl.Phys.**B412** (1994) 225

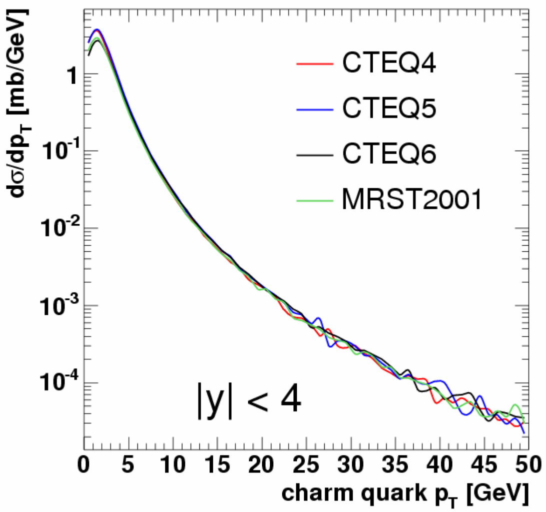
M.Corradi

Charm at the LHC
MNR (massive NLO)









PDFs well constrained by HERA
negligible uncert. for HVQs at LHC

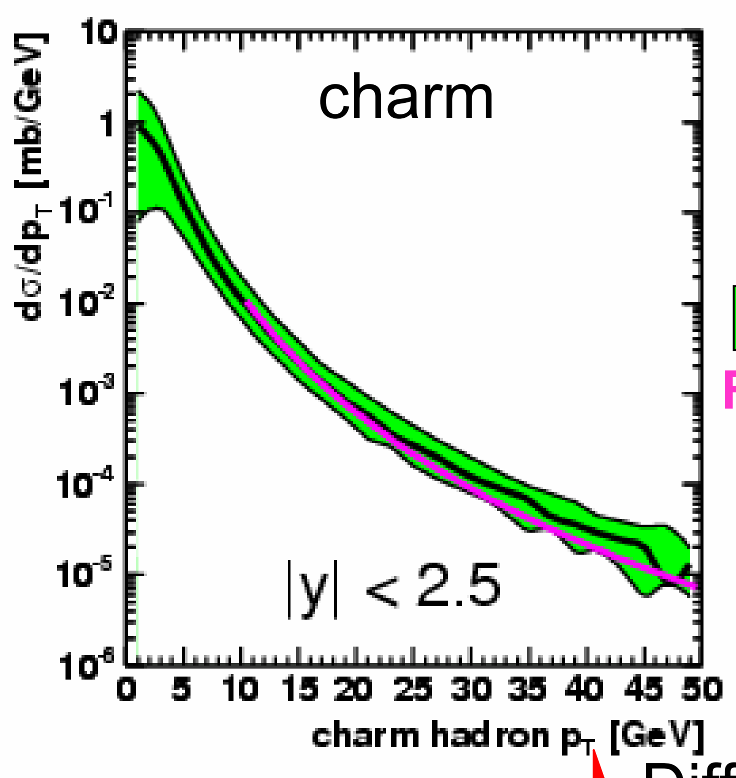
at LHC energy, main uncertainty from (independent) variation of scales (? higher orders)

MNR: M.L.Mangano, P.Nason and G.Ridolfi, Nucl. Phys. **B373** (1992) 295.

A.D.

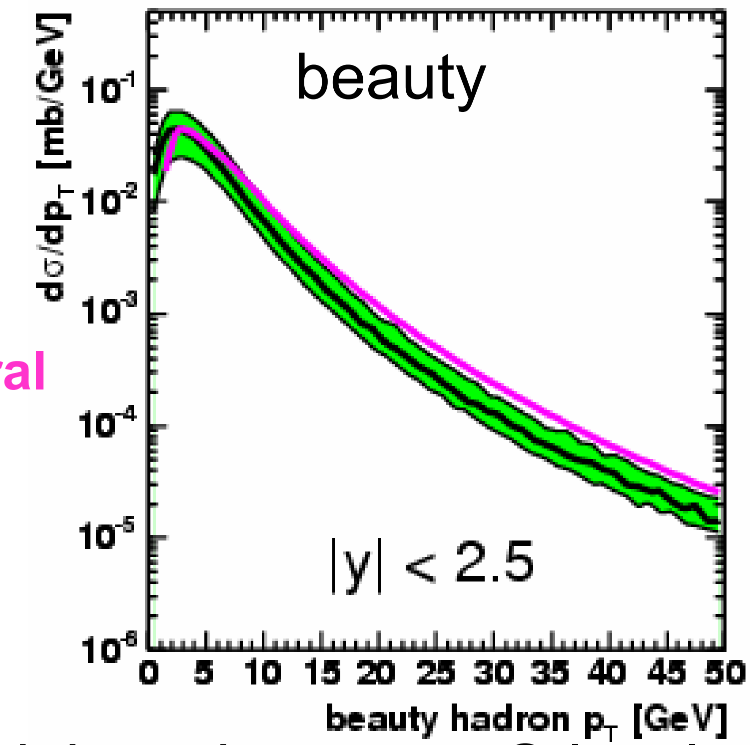
Charm and Beauty at the LHC

MNR (massive NLO) – FONLL (matched NLL)



MNR band

FONLL central



Difference at high p_T, but not at Q level

$\rightarrow$ Fragmentation?

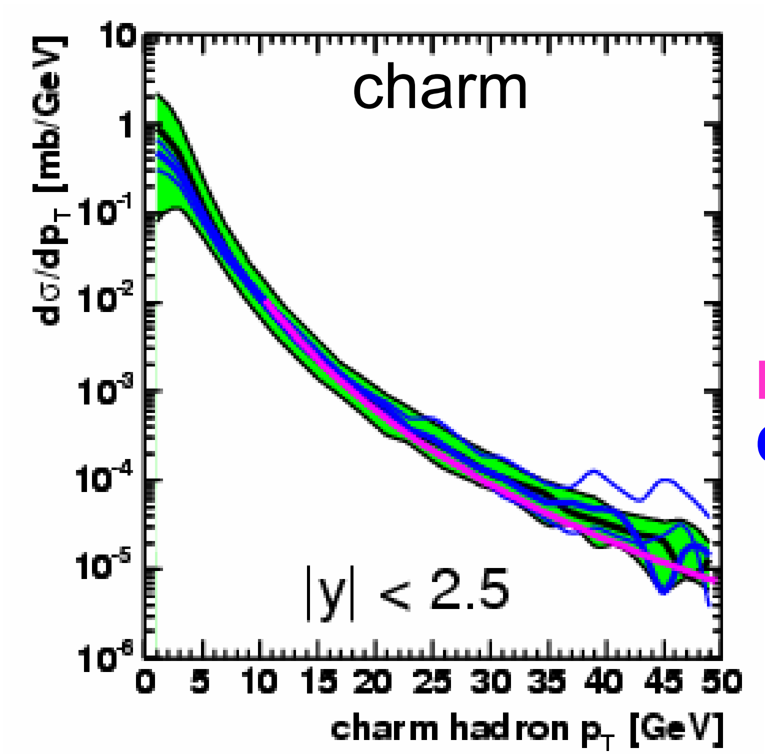
FONLL FF tuned on LEP data. Do the same for Peterson (used in MNR)? $\rightarrow$ M.Cacciari

FONLL: M.Cacciari, M.Greco and P.Nason, JHEP 9805 (1998) 007.

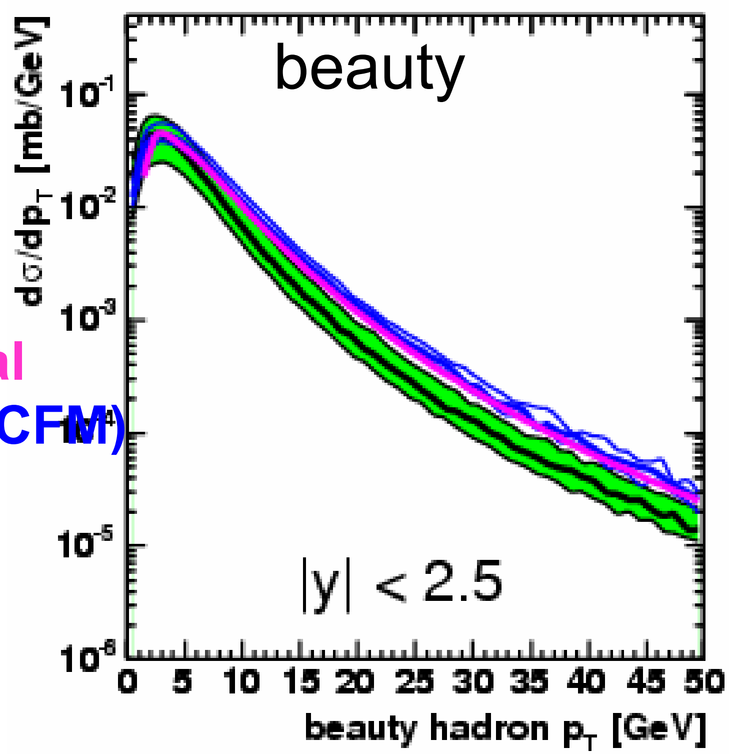
M.Cacciari, A.D.

Charm and Beauty at the LHC

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



MNR band
FONLL central
CASCADE (CCFM)



CASCADE agrees better with FONLL. But …
? CASCADE uses Peterson FF with same ε as in MNR

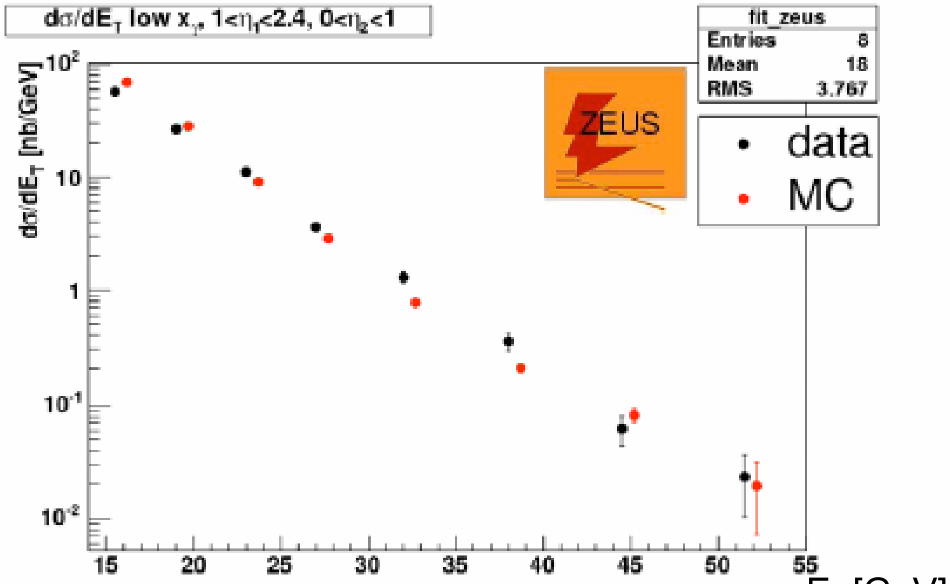
CASCADE: H.Jung and G.P.Salam, Eur.Phys.J. **C19** (2001) 351

M.Cacciari, H.Jung, K.Peters, A.D.

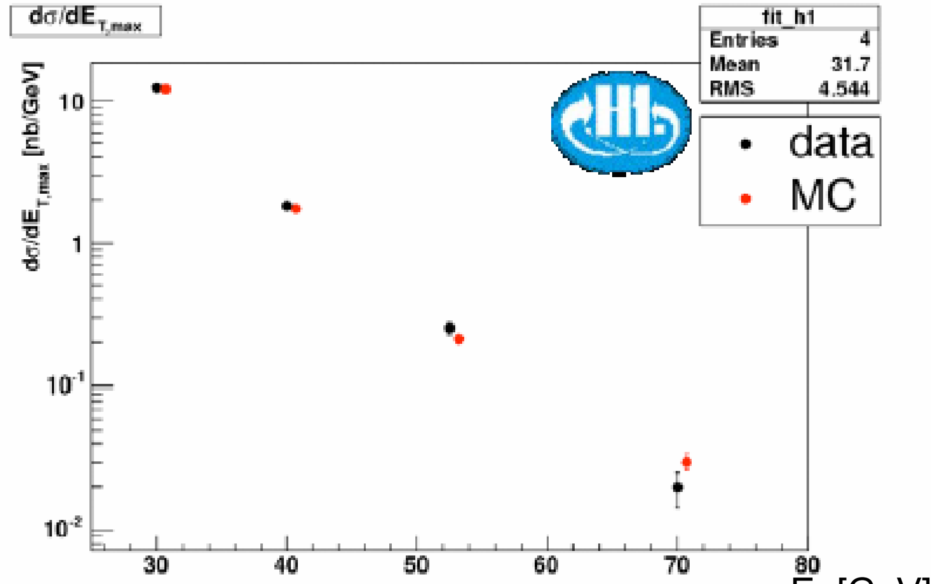
Beauty with PYTHIA/JetWeb at Sp$\bar{p}$S, HERA and Tevatron

- Generator: PYTHIA
  - inclusive mode
  - Proton PDF: CTEQ5L
  - Photon PDF: GRV LO
  - min. trans. momentum: 3 GeV/c
  - JetWeb scale = **1.45**

MC normalization (×1.45) from high E_T jets at HERA



Dijet photoproduction at HERA and the structure of the photon (Eur.Phys.J.C23:615-631,2002)

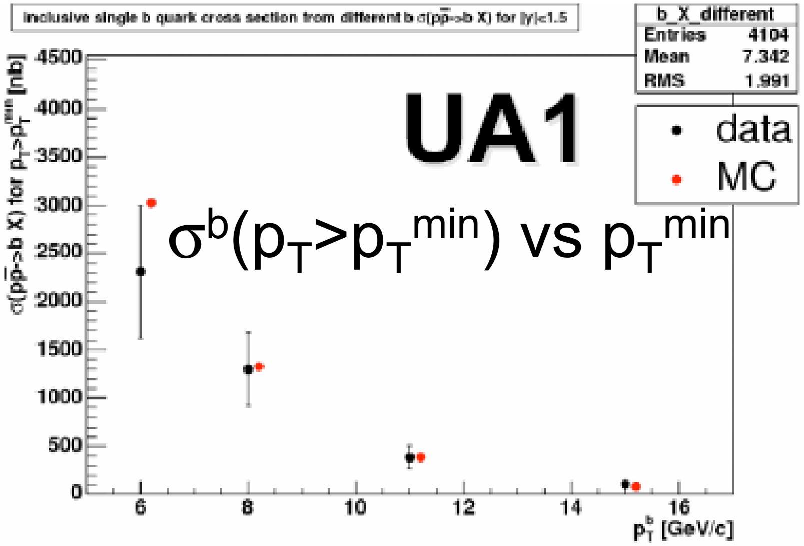


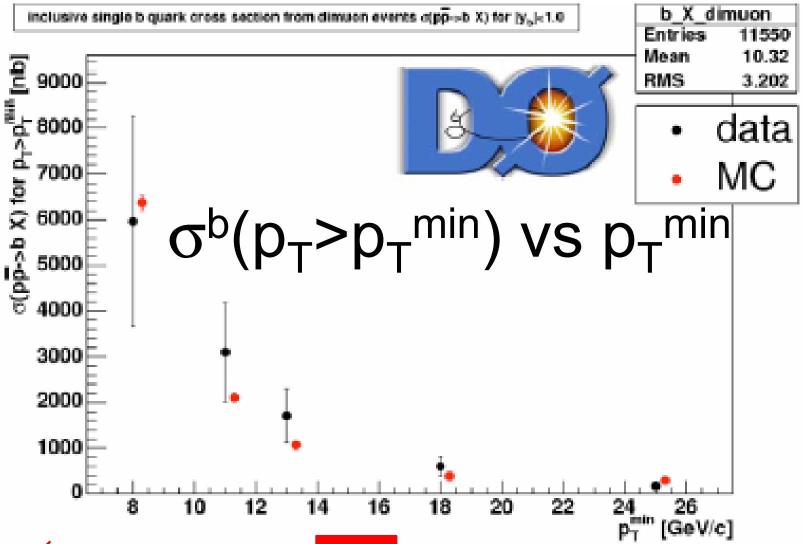
Measurement of Dijet Cross Sections in Photoproduction at HERA (Eur.Phys.J.C25:13-23,2002)

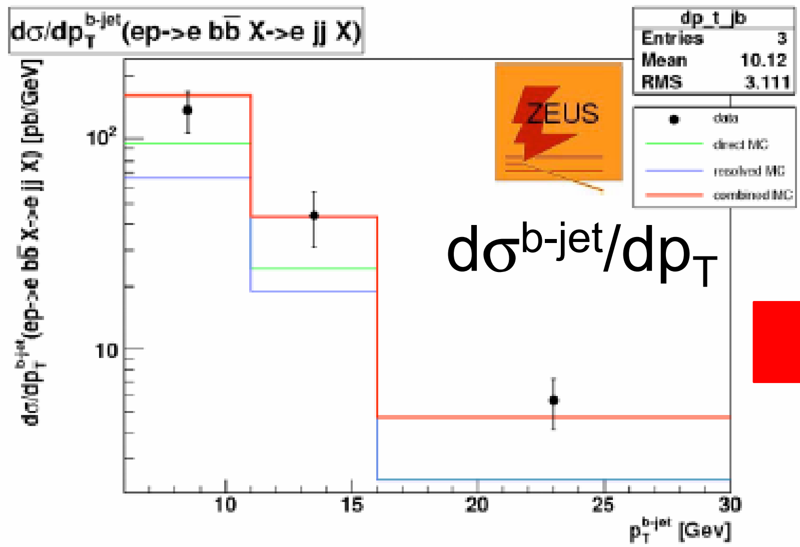
http://jetweb.hep.ucl.ac.uk/
J.Butterworth and B.Waugh

O.Gutsche, A.Geiser

Beauty with PYTHIA/JetWeb at $Sp\bar{p}S$, HERA and Tevatron







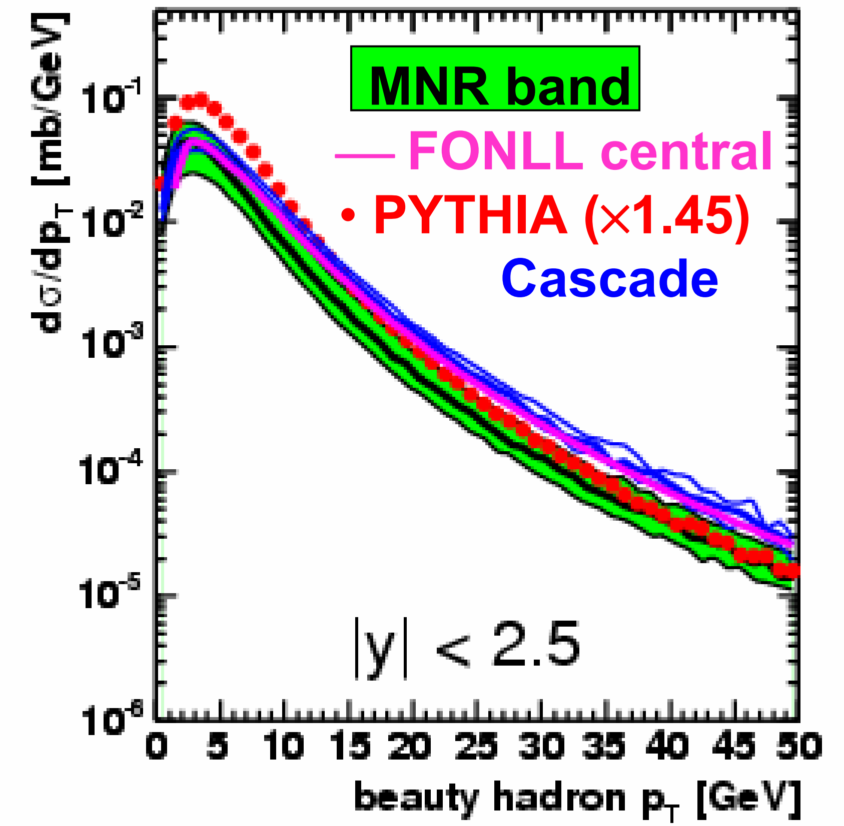
Simultaneous description of UA1, DØ and ZEUS beauty production data.

Reliable extrapolation to LHC?

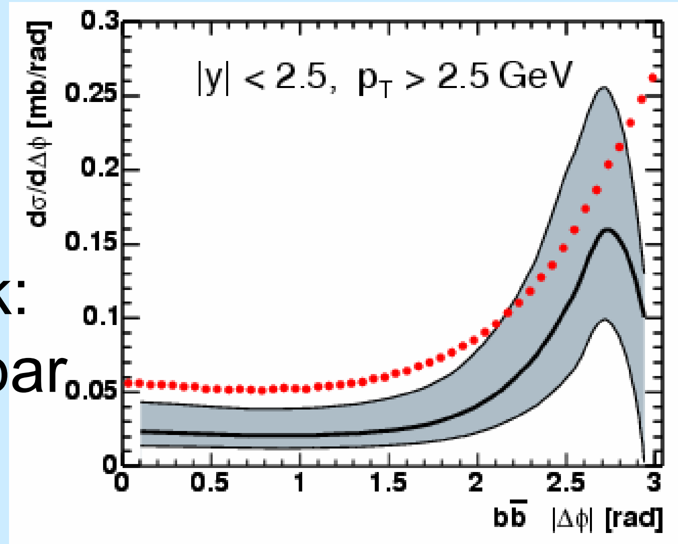
Compare it to NLO and FONLL

O.Gutsche, A.Geiser

Beauty with PYTHIA/JetWeb at Sp$\bar{p}$S, HERA, Tevatron … and LHC



Outlook:
Δφ b-bbar



MNR vs. PYTHIA
More comparisons in the writeup

- At high p_T, agrees with MNR and FONLL
- (Much) higher at low p_T , however "tuned" on data with p_T^b > 6—8 GeV

Repeat job with lower p_T CDF and (coming) HERA-II data

A.D.

These benchmarks give a baseline (at least for $d\sigma/dp_T$)

Deviations from this baseline?

Possible non-linear/saturation effects in HVQ production

A.D., V.Kolhinen, K.Kutak, H.Jung, K.Peters, R.Vogt …

GLR-MQ non-linear terms in DGLAP eq.

V.Kolhinen

$$\frac{\partial xg(x,Q^2)}{\partial \log Q^2} = \frac{\partial xg(x,Q^2)}{\partial \log Q^2}\Big|_{\mathrm{DGLAP}}$$

$$- \frac{9\pi}{2}\frac{\alpha_s^2}{Q^2}\int_x^1 \frac{dy}{y} y^2 G^{(2)}(y,Q^2)$$

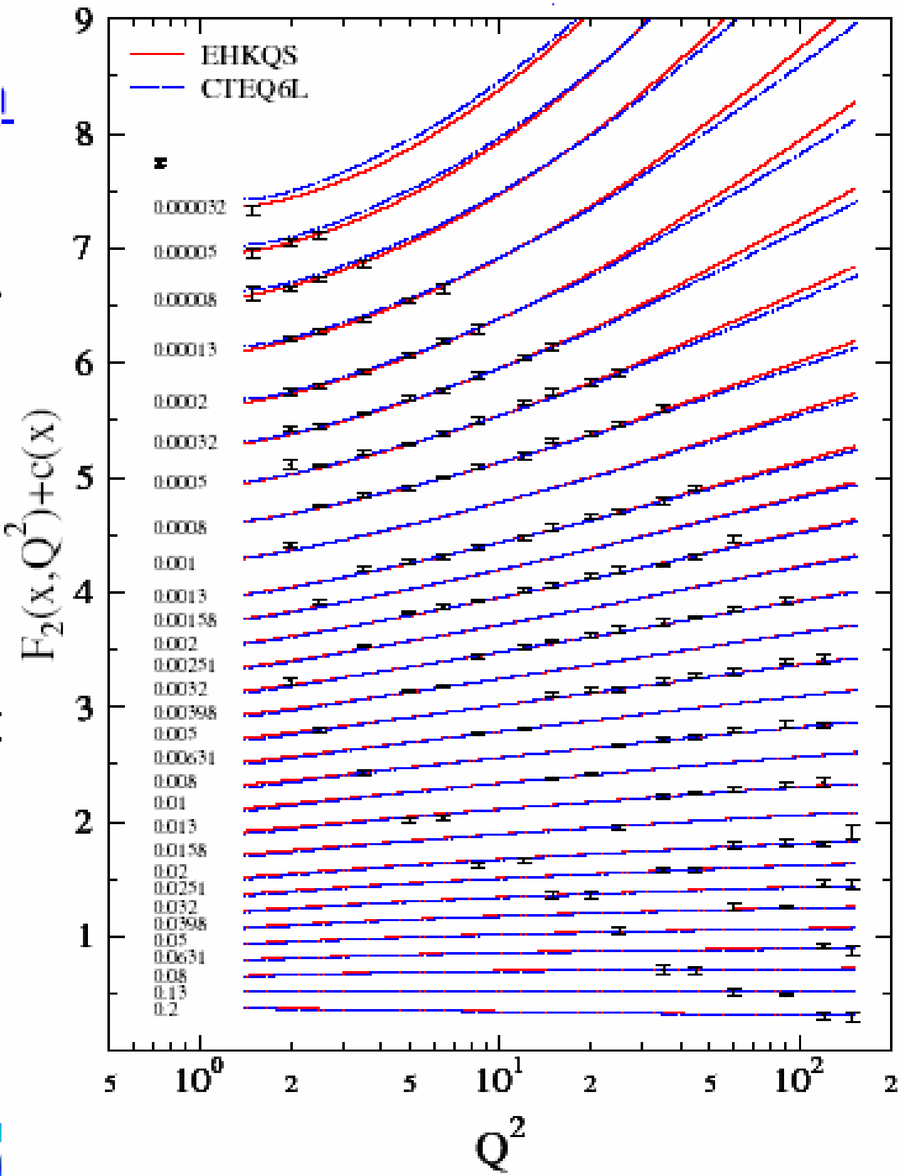
$$x^2 G^{(2)}(x,Q^2) = \frac{1}{\pi R^2}[xg(x,Q^2)]^2.$$

non-linear (quadratic) correction has "–" sign

→ Q^2 evolution is ***slower***

Refit HERA F_2 data, reduces F_2 at low x a moderate Q^2

xg(x,Q²) at low Q^2 (<10 GeV²) and x (<10^{-3}) is larger than in DGLAP



Non-linear effects in BK equation

Nonlinear evolution equation for unintegrated gluon distribution.

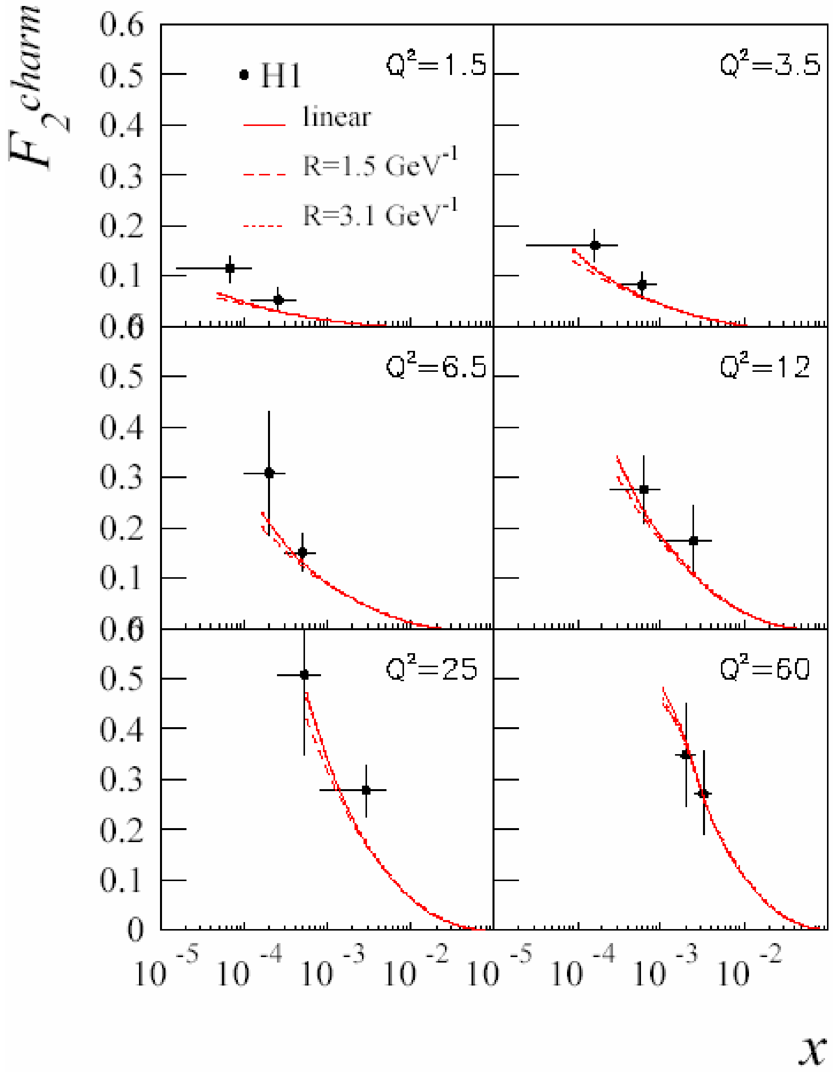
$$f(x,k^2) = \tilde{f}^{(0)}(x,k^2) + K^1 \otimes f - K^2 \otimes f^2$$

$$\tilde{f}^{(0)}(x,k^2) \longrightarrow \text{input}$$

$$K^1 \otimes f \rightarrow \text{BFKL}$$

$$K^2 \otimes f^2 = \left(1 - k^2 \frac{d}{dk^2}\right)^2 \frac{k^2}{R^2} \times$$

$$\int_x^1 \frac{dz}{z} \left[\int_{k^2}^{\infty} \frac{dk'^2}{k'^4} \alpha_s(k'^2) ln\left(\frac{k'^2}{k^2}\right) f(z,k'^2) \right]^2$$

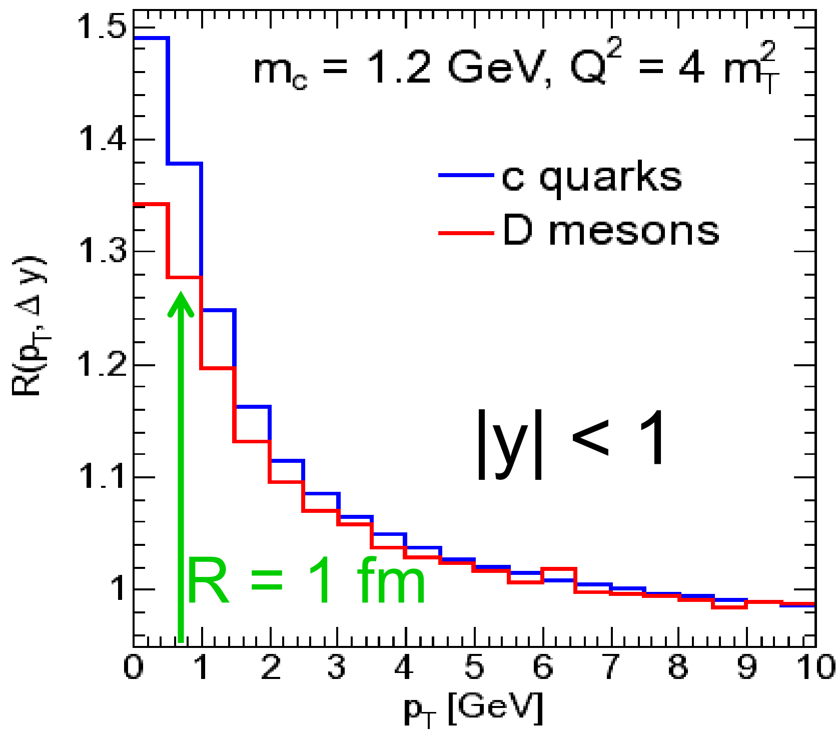


Non-linear part has no impact in the kinematical region of HERA

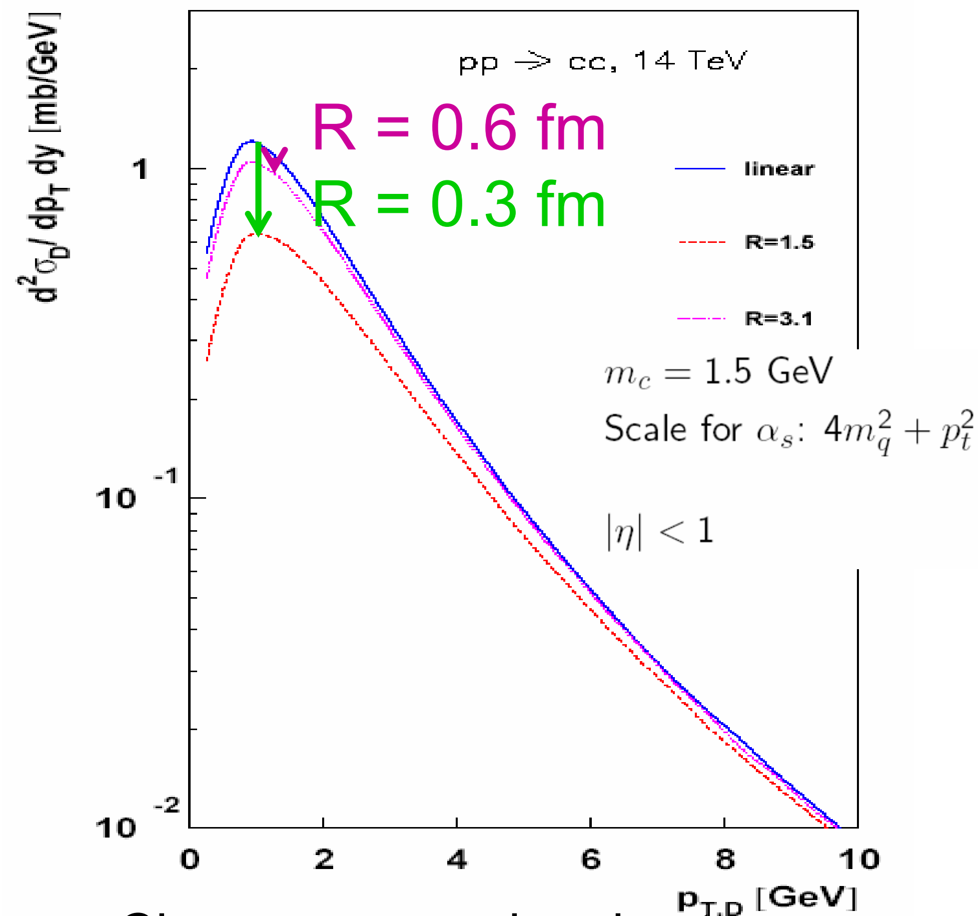
H.Jung, K.Kutak, K.Peters

Non-linear effects at the LHC: charm

pp @ 14 TeV

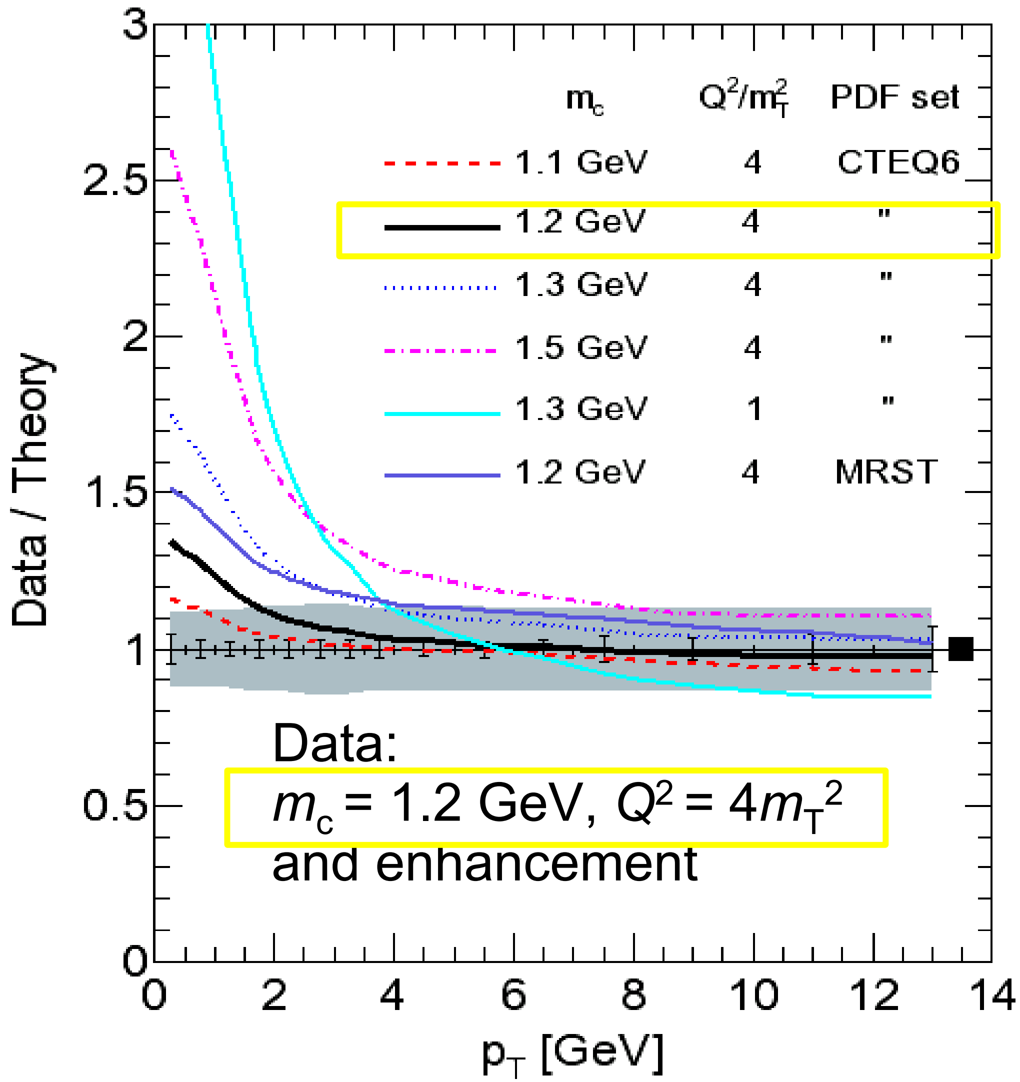


Charm enhancement due to non-linear effects in GLR-MQ



Charm suppression due to non-linear effects in BK

Perspectives for exp. obs. with ALICE



Ratio of simulated ALICE data for D^0 production (with GLR-MQ non-linear enhancement) to linear DGLAP results with several sets of parameters.

A.D., V.Kolhinen, R.Vogt

Outlook

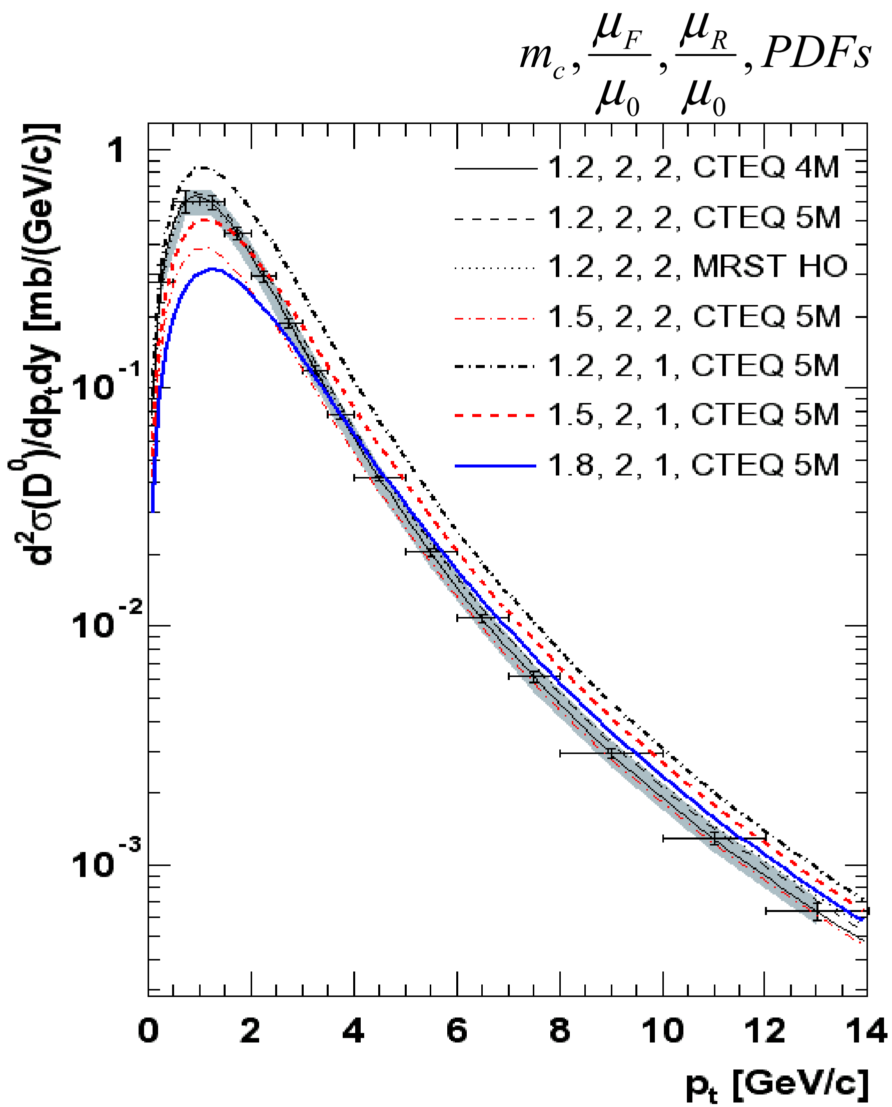
- WG3 WRITEUP: complete set of benchmarks for HERA and LHC with consistent treatment of fragmentation and assessment of uncertainties

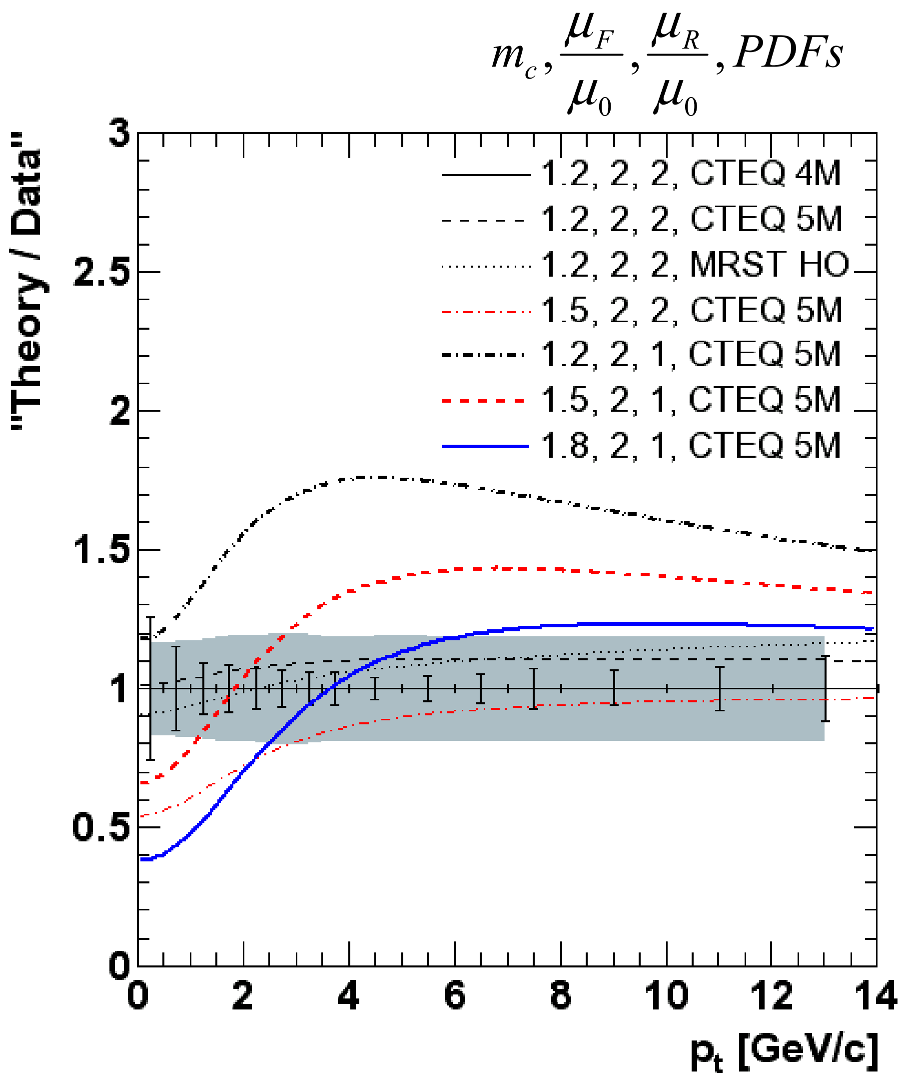
- FUTURE HERA-LHC MEETINGS: update cross section extrapolation with improved HERA-II data

- Start to compare benchmarks to LHC data in 2008: ONLY 3 MEETINGS FROM NOW !!!

EXTRAS

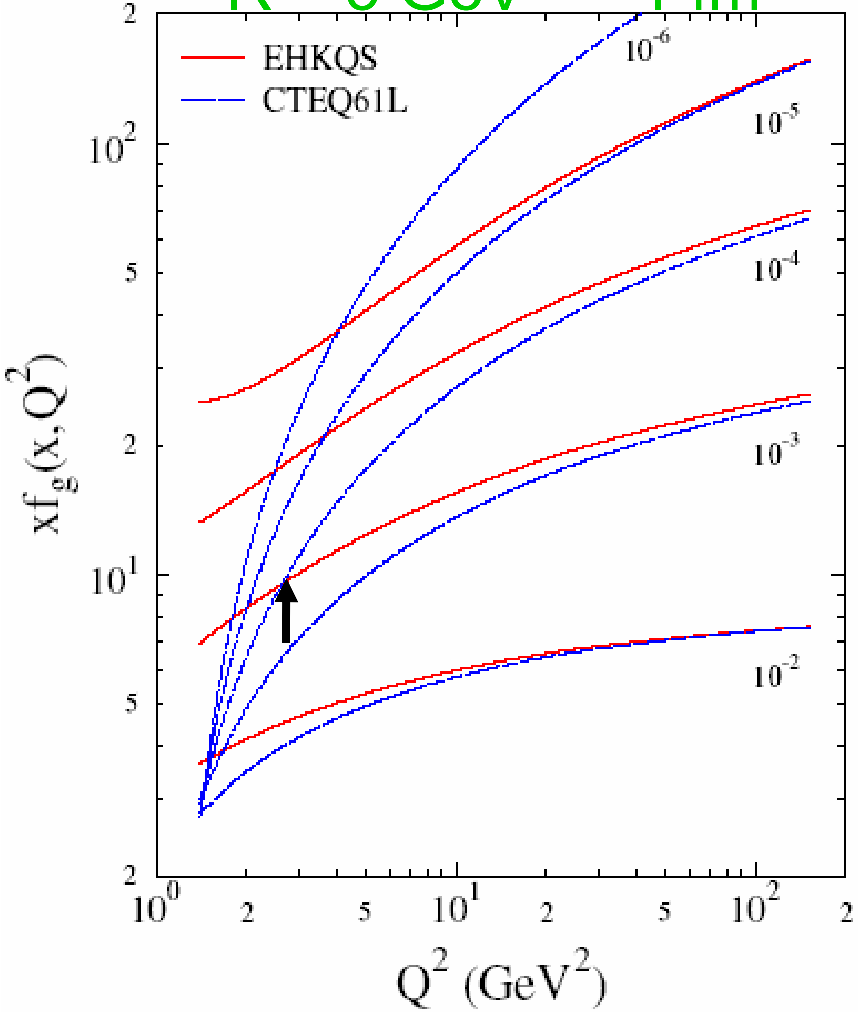
ALICE D^0: comparison to pQCD



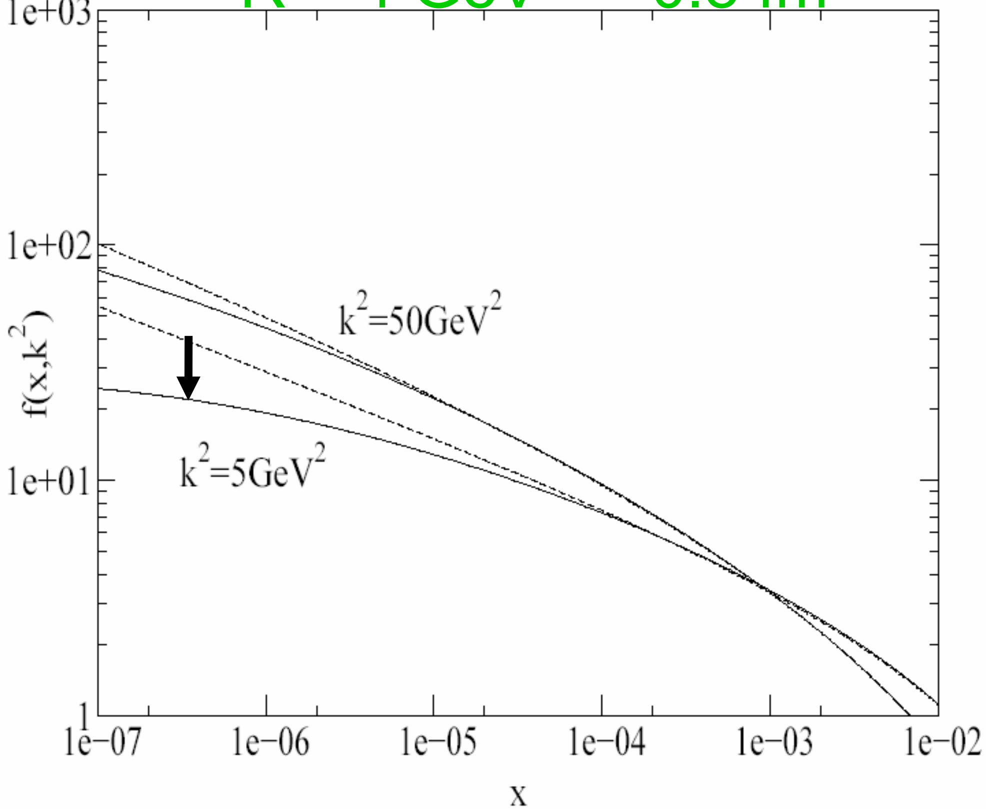


GLR-MQ vs BK: gluons

R = 5 GeV^{-1} = 1 fm



R = 4 GeV^{-1} = 0.8 fm



Linear (blue) vs non-linear (red) in DGLAP

Linear (dashed) vs non-linear (solid) in BK with **R = 4 GeV^{-1}**