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FMNR⊗PYTHIA interface for Heavy Quark production at HERA

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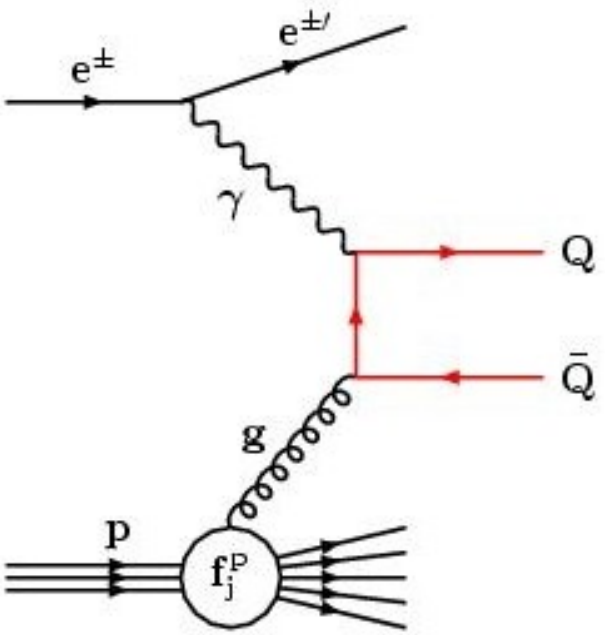
Outline

- Motivation
- FMNR + REDSTAT
- FMNR⊗PYTHIA interface
- Applications
- Conclusions

Motivation



Dominant production process in ep collisions:
boson-gluon fusion

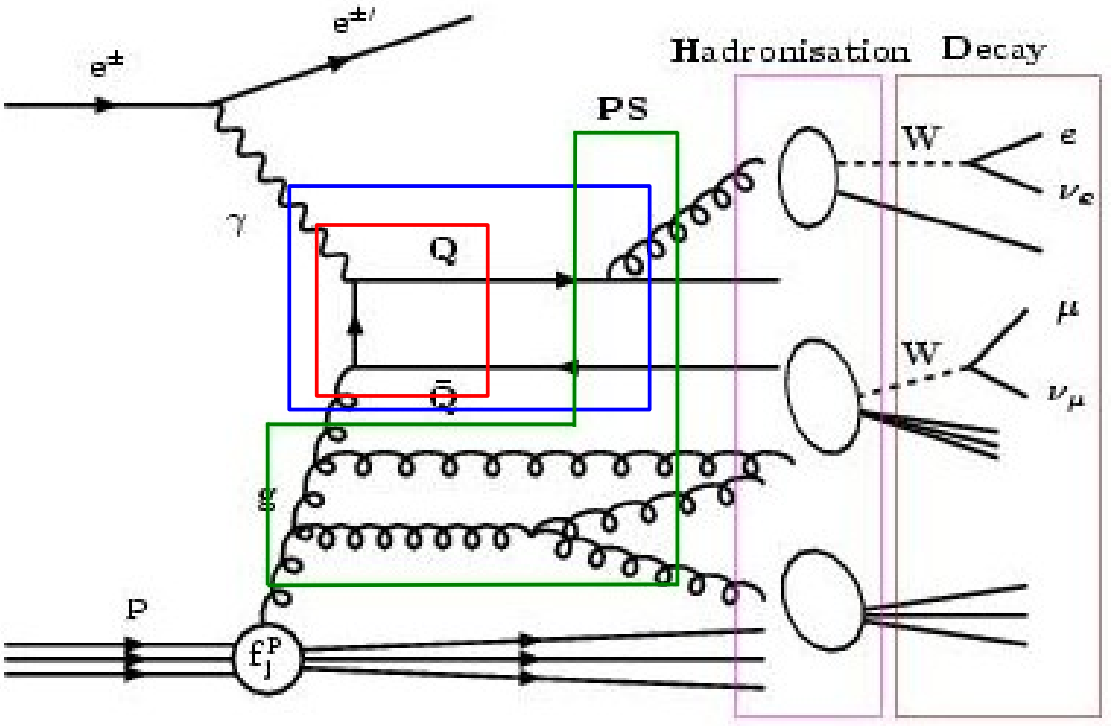
Multiple scales involved:

- Masses : $m_b \sim 5$ GeV , $m_c \sim 1.4$ GeV
- Photoproduction (γp) : $Q^2 < 1$ GeV^2
- Deep Inelastic Scattering (DIS) : $Q^2 > 1$ GeV^2
- Momentum : p_T^Q few GeV

Heavy quarks produced at HERA powerful tool for testing p structure, to probe and understand pQCD in detail.

Motivation

Theoretical Predictions		Evolution	Kin. region
LO + PS	PYTHIA, HERWIG	DGLAP	γp
	RAPGAP	DGLAP	DIS
	CASCADE	CCFM	γp & DIS
NLO	FMNR		γp
	HVQDIS		DIS



Visible level NLO predictions not available for channels with correlated cuts on the final state particles

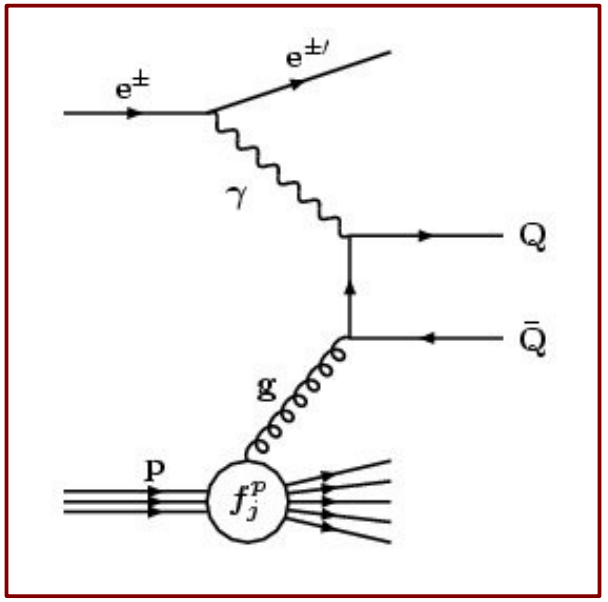
MC@NLO not yet available for HERA

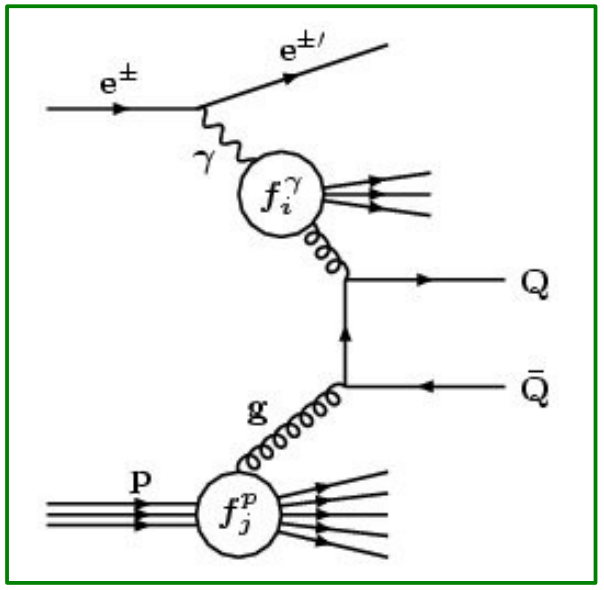
Solution:

FMNR⊗PYTHIA interface

FrixioneManganoNasonRidolfi

Frixione, *et.al.* Phys.Lett.348,633 (1995)

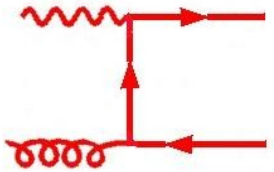
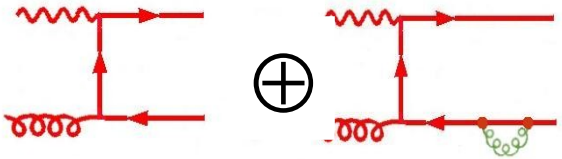
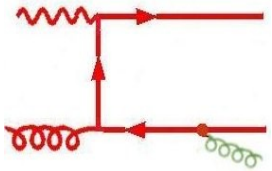




- Calculations @ NLO in QCD for heavy quark production in ep and γp collisions
- Point-like and hadronic photon coupling
- Photoproduction regime ($Q^2 < 1$ GeV^2)
- Fixed order massive scheme

$$\mu^2 = p_t^2 + m_Q^2$$

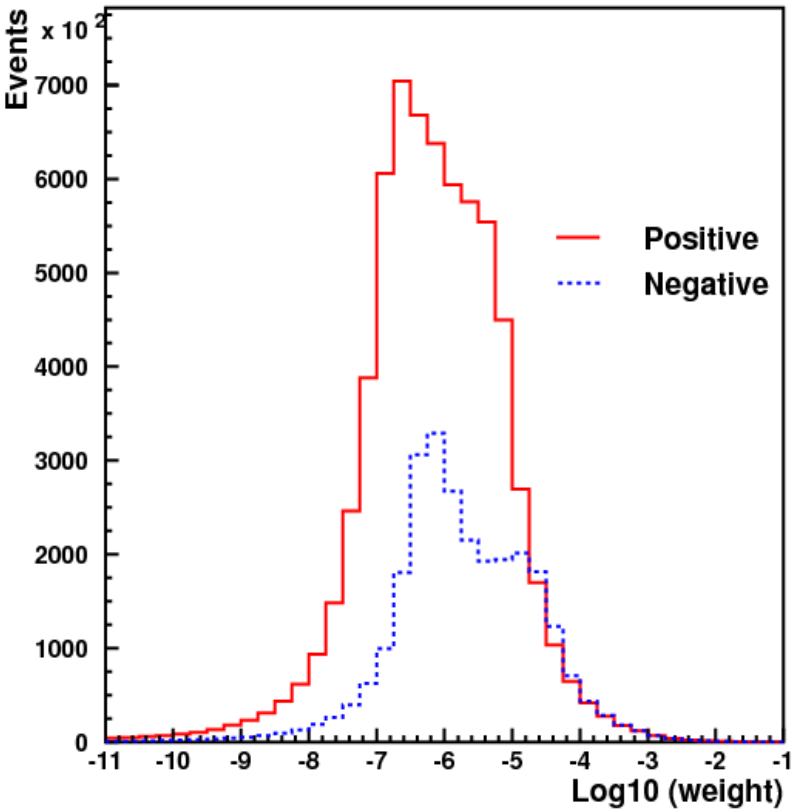
FMNR

Diagram	weight	contribution
	Positive	Real
	Negative	Divergent
	Positive	Divergent

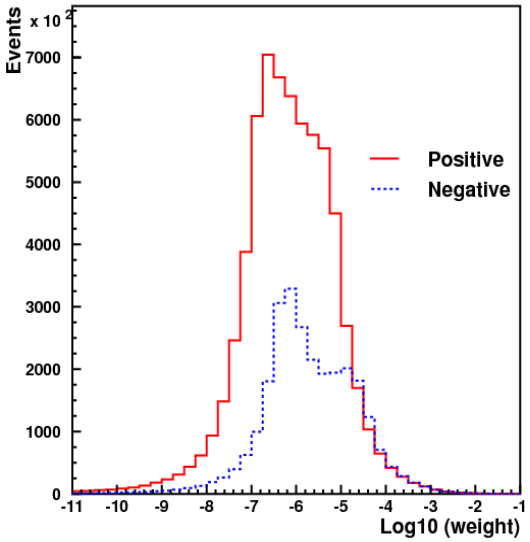
- Events have weights →
it can not be realistically linked to a fragmentation or simulation chain

- Weights range over several orders of magnitude →
high statistics is needed to keep fluctuations low

Weights of FMNR events



REDSTAT (Reduced Statistics option)



REDSTAT is an extension to FMNR

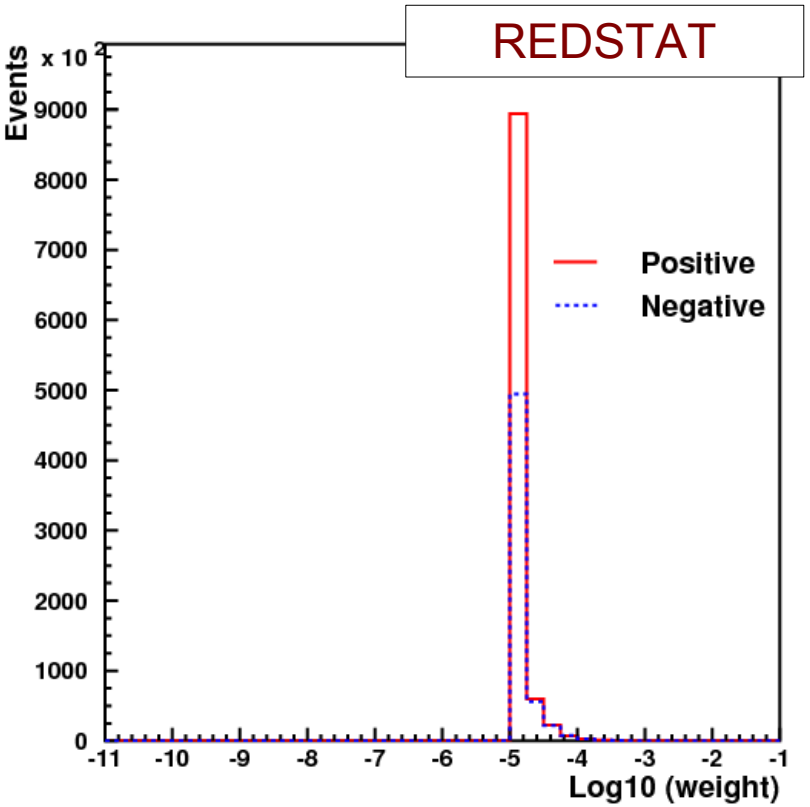
- Reduce the range of weights of the events
- Reduce the statistics without losing NLO accuracy

The idea:
combine events with high opposite weight

How to combine:

- High weight events
  Search for events with similar kinematics
  Difference in p_T, y_{rap}, ϕ < user cuts

- Low weight events
  Sampling approach (random decision)



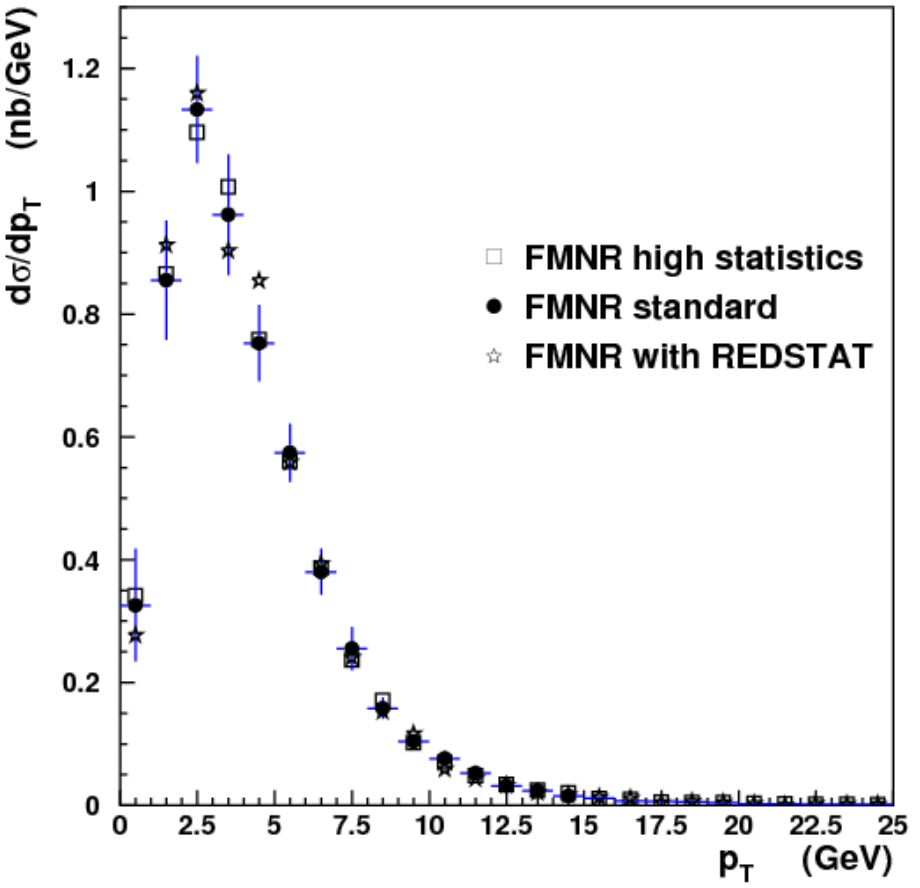
Some REDSTAT results

Cross section prediction at b-quark level: $\gamma p \rightarrow b(\bar{b})\, X$

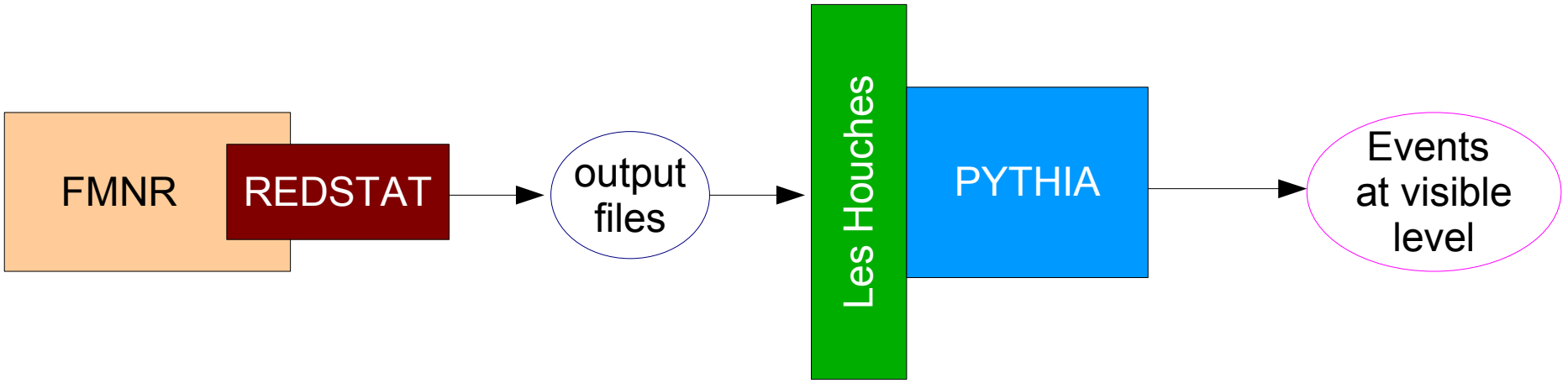
NLO accuracy preserved

	$\sigma_{\gamma p \rightarrow b(\bar{b})\, X}$
FMNR (original)	4.95 nb
FMNR with REDSTAT	4.94 nb

Good description of the b-quark p_T



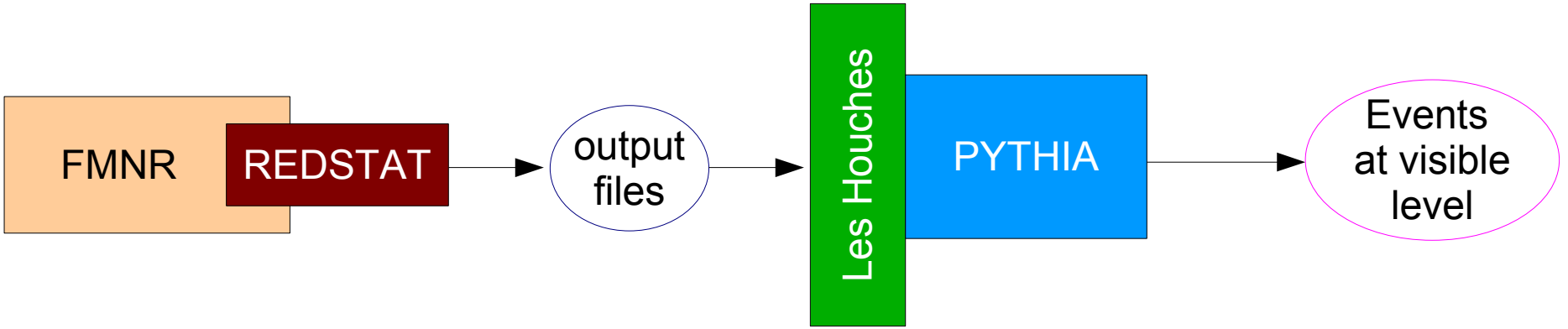
The FMNR⊗PYTHIA interface



FMNR(REDSTAT) parameters

	Variation
• Mass of the b quark $m_b = 4.75$ GeV	(4.5 - 5.0 GeV)
• Renormalization and factorization scales $\mu^2 = p_t^2 + m_Q^2$	(μ/2 - 2μ)
• Structure functions proton: CTEQ5M photon: GRV-G-HO	PDF error << scale,mass error → neglected
• REDSTAT option used Δp_T = 1.0 GeV Δy_{rap} = 0.2 $\Delta\phi$ = 0.3 rad	

The FMNR⊗PYTHIA interface



(Les Houches) PYTHIA parameters

- Feed FMNR partons into PYTHIA(JetSet) using the Les Houches accord interface
- Assign a color flow to each FMNR parton level process
- Small intrinsic k_T kick allowed (~ 200 MeV)
- Parton showers not allowed
  avoid double counting of higher order contributions
  main difference wrt MC@NLO in preparation
- Fragmentation based on the Peterson formula

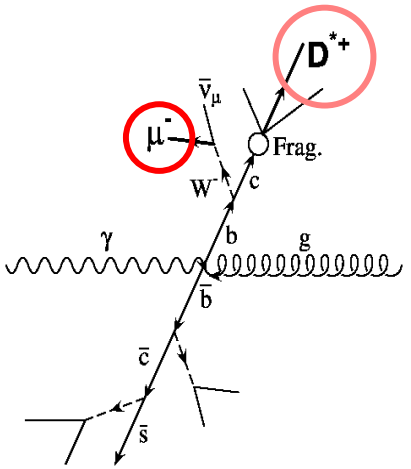
	Variation
a) Independent (FMNR does not provide color flow)	lower error
b) Lund string model (assign reasonable color flow)	central value
c) Comparison with default FMNR fragmentation	higher error
Peterson ε = 0.0035	0.0023 – 0.0045 error negligible wrt a) c)

- Standard PYTHIA decay tables
  all branching ratios included and corrected to match PDG

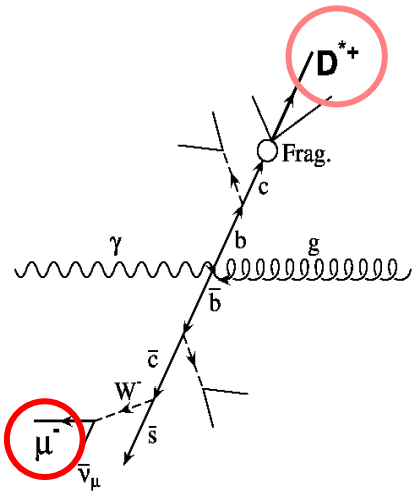
Applications

Eur.Phys.J.C50:299-314,2007 hep-ex/0609050

Visible Beauty Cross sections from $ep \rightarrow b\bar{b}X \rightarrow D^* \mu X'$



$p_T(D^*) > 1.9$ GeV, $-1.5 < \eta(D^*) < 1.5$, **$p_T(\mu) > 1.4$ GeV, $-1.75 < \eta(\mu) < 1.3$**	data/NLO
ZEUS $\sigma_{vis} = 160 \pm 37(stat)\ ^{+30}_{-57}$ (syst.) pb	$2.4\ ^{+0,9}_{-1.3}$
FMNR⊗PYTHIA $\sigma_{vis} = 67\ ^{+20}_{-11}$ (NLO) $^{+13}_{-9}$ (frag+br) pb	
Photoproduction only: $Q^2<1$ GeV^2, $0.05<y<0.85$	
ZEUS $\sigma_{vis} = 115 \pm 29(stat)\ ^{+21}_{-27}$ (syst.) pb	$2.1\ ^{+0.8}_{-1.0}$
FMNR⊗PYTHIA $\sigma_{vis} = 54\ ^{+15}_{-10}$ (NLO) $^{+10}_{-7}$ (frag+br) pb	



Extrapolated to b level using PYTHIA **$y_{rap}(b) < 1$, $Q^2 < 1$ GeV^2, $0.05<y<0.85$,**

σ (ep –> b or b X) = 11.9 ± 2.9 (stat) $^{+1.8}_{-3.3}$ (sys) nb

NLO QCD (FMNR) = $5.8\ ^{+2.1}_{-1.3}$ nb

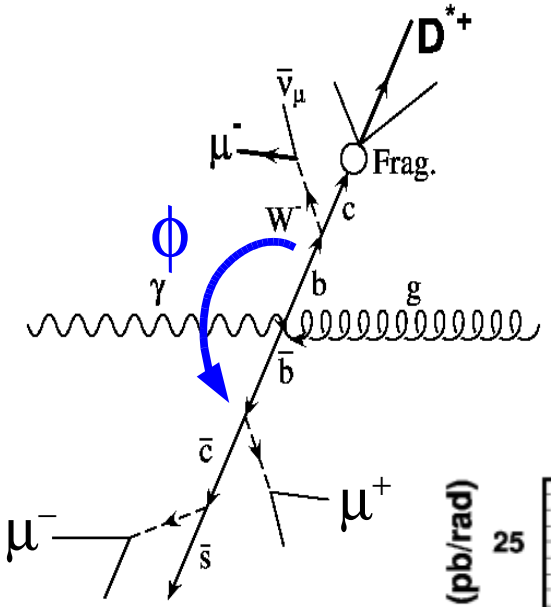
data/NLO

$2.0\ ^{+0.8}_{-1.1}$

- Data and theory still compatible
- Comparisons at b quark and visible level yield the same data/NLO ratio
- Therefore the extrapolation was reliable
- Consistent with similar analysis by H1 (see backup slides)

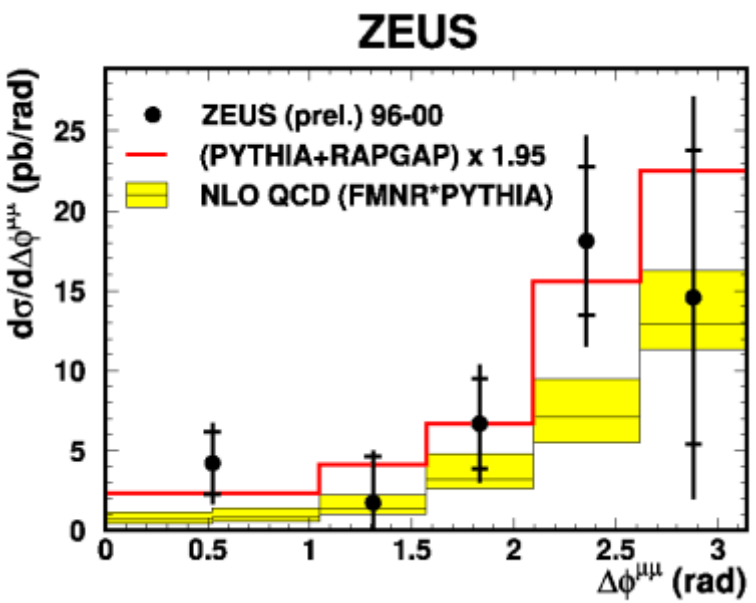
Applications

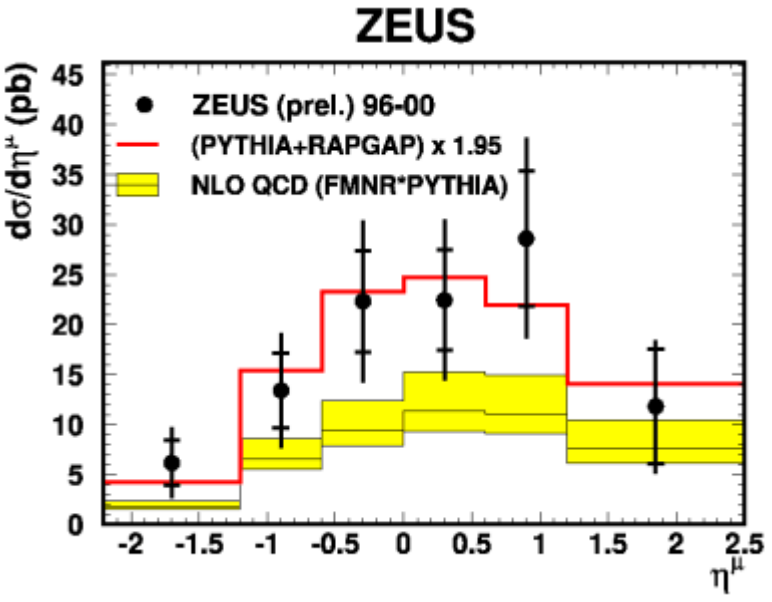
Visible Beauty Cross sections from $ep \rightarrow b\bar{b}X \rightarrow \mu\mu X'$



Complicated set of muon p_T and η cuts for maximal acceptance

ZEUS visible range	data/NLO
ZEUS $\sigma_{vis} = 63 \pm 7(stat)\ ^{+20}_{-18}(syst.)$ pb (prel.)	$2.1\ ^{+0.8}_{-1.0}$
FMNR⊗PYTHIA $\sigma_{vis} = 30\ ^{+9}_{-6}$ (NLO) $^{+5}_{-3}$ (frag+br) pb	





- Consistent within large errors
- Consistent with D* μ results

Conclusions

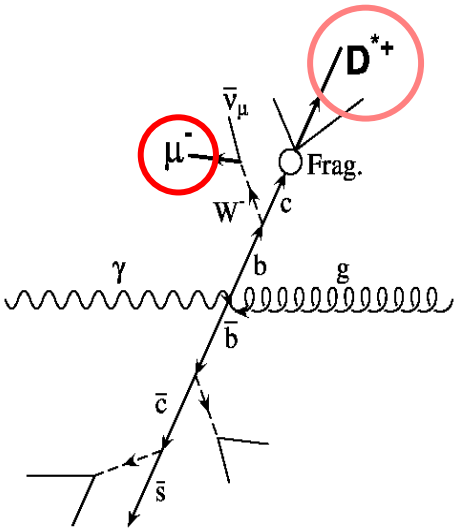
- The new FMNR⊗PYTHIA interface allows calculation of complicated visible NLO cross sections not available previously.
- data/NLO cross section comparisons for $b\bar{b} \rightarrow D^* \mu$ and $b\bar{b} \rightarrow \mu \mu$ at **visible** and **b quark level** are **consistent.**
- Other applications:
  - Charm
  - Parton to hadron level corrections for heavy flavour jets
  - ...
- We can use this method now, and compare with MC@NLO whenever available.
- More information: e-Print:arXiv:0707.1632[hep-ph]

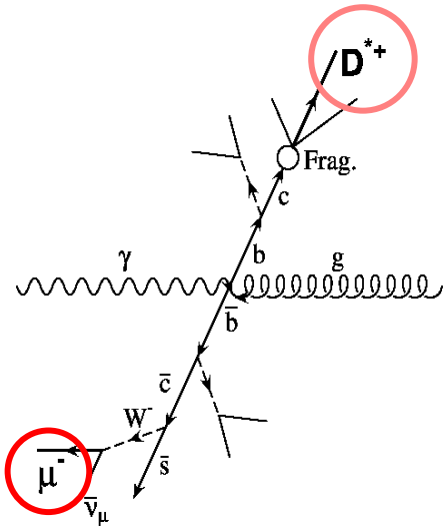
Backup slides

Applications

Phys.Lett.B621:56-71,2005 hep-ex/0503038

Visible Beauty Cross sections from $ep \rightarrow bbX \rightarrow D^* \mu X'$





H1 visible range:

$p_T(D^*) > 1.5$ GeV, $-1.5 < \eta(D^*) < 1.5$,

$p(\mu) > 2.0$ GeV, $-1.735 < \eta(\mu) < 1.735$

Photoproduction only: $Q^2<1$ GeV^2, $0.05<y<0.85$

H1 $\sigma_{vis} = 206 \pm 53(stat) \pm 35$ (syst.) pb

ZEUS → H1 $\sigma_{vis} = 135 \pm 33(stat)\ ^{+24}_{-31}$ (syst.) pb

(extrapolated to H1 with FMNR⊗PYTHIA)

Measured H1 and ZEUS visible cross sections consistent