HERA and the LHC

CERN, Geneva
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2nd Workshop on the implications of HERA for LHC physics

Beauty production using D*+μ and $\mu^+\mu^-$ correlations at HERA

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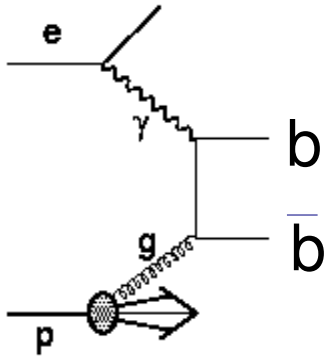
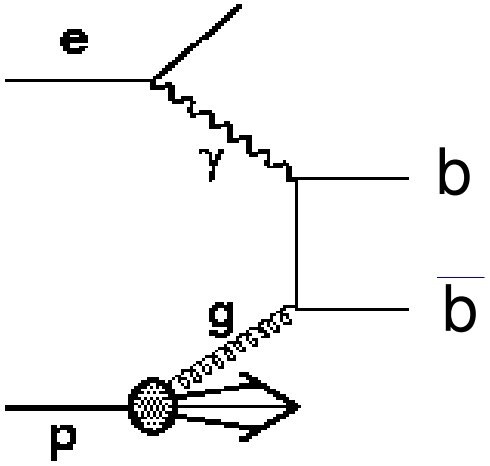
Outline

- Motivation
- D*+μ and $\mu^+\mu^-$ analysis
- NLO prediction from FMNR⊗PYTHIA
- Results
- Conclusions



Motivation

To understand and probe QCD in as much detail as possible at HERA



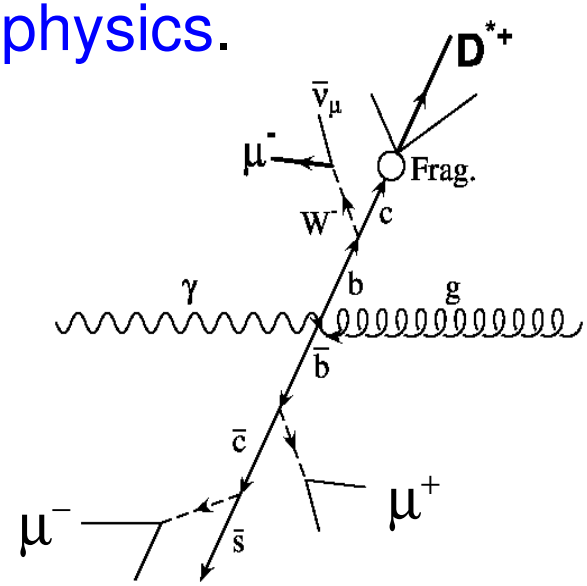
Parton densities of proton and photon need to be precise (for future colliders *pp*, e^+e^-, $\gamma\gamma$, ...)

QCD-production rate should be accurately understood because is background to "new" physics.

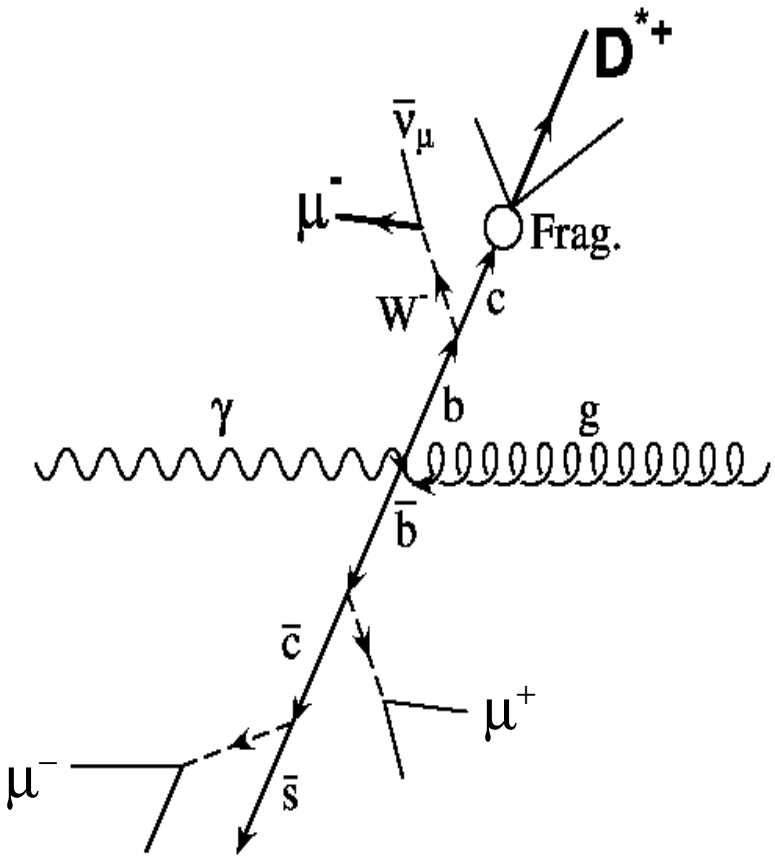
☺ Many production channels already studied and compared to NLO predictions.

☹ NLO not available for all: ep -> $b\bar{b}$ -> D*μ

☹ Extrapolations needed, different MC, decay, fragmentation models.



Motivation



Double b tagging using D*+μ and $\mu^+\mu^-$

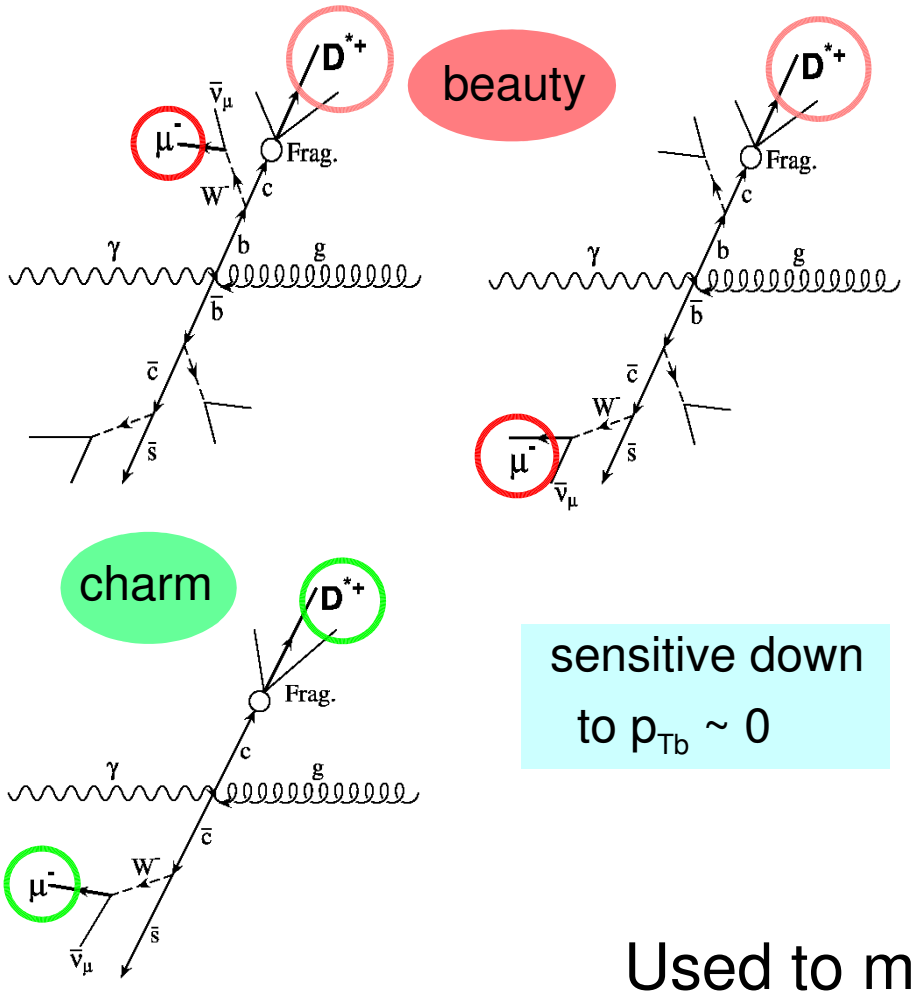
- Low background → soft kinematic cuts → almost full rapidity coverage → access low p_{Tb} region →

  Measurement of total $b\bar{b}$ cross section

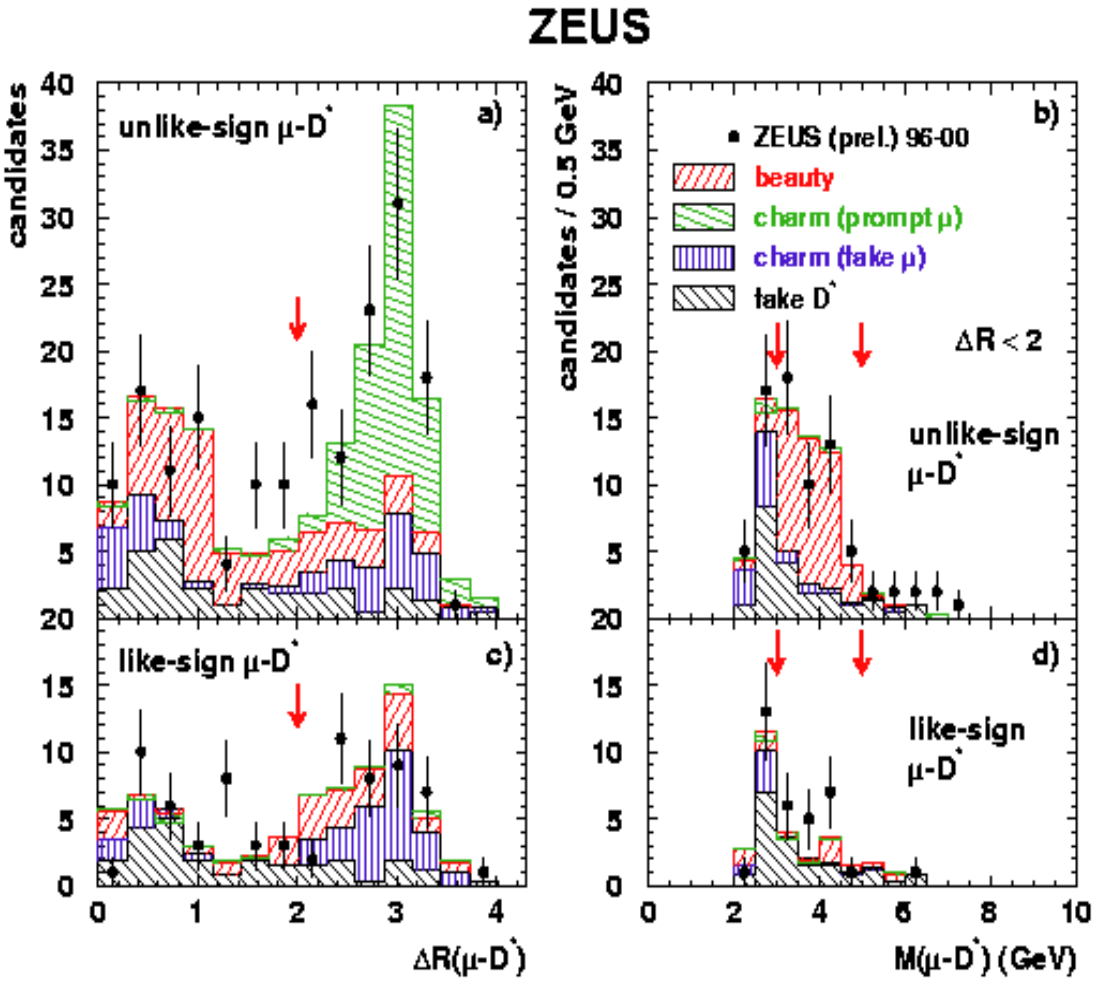
- Tagging both b quarks ($\mu^+\mu^-$) → **Measure $b\bar{b}$ correlations**

Beauty cross section from D*+ μ

ZEUS



sensitive down to $p_{Tb} \sim 0$



Used to measure total cross section

Visible Beauty cross sections from D*+ μ

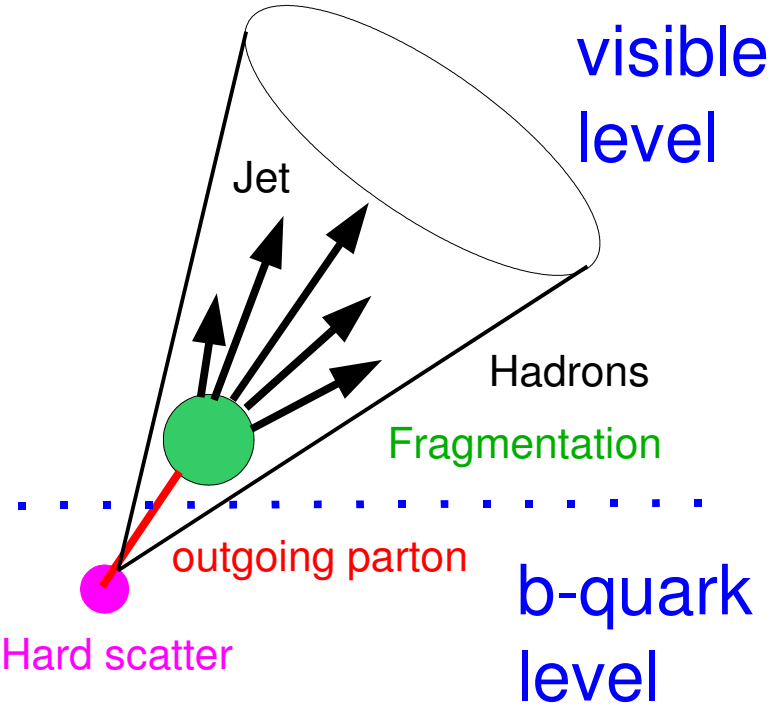
$p_T(D^*) > 1.9$ GeV, $-1.5 < \eta(D^*) < 1.5$,

$p_T(\mu) > 1.4$ GeV, $-1.75 < \eta(\mu) < 1.3$

ZEUS $\sigma_{vis} = 214 \pm 52(\text{stat})\ ^{+96}_{-84}\ (\text{syst.})$ pb

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

ZEUS $\sigma_{vis} = 159 \pm 41(\text{stat})\ ^{+68}_{-62}\ (\text{syst.})$ pb



There were no NLO predictions!

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) = $15.1 \pm 3.9\ (\text{stat})\ ^{+3.8}_{-4.7}\ (\text{sys})$ nb

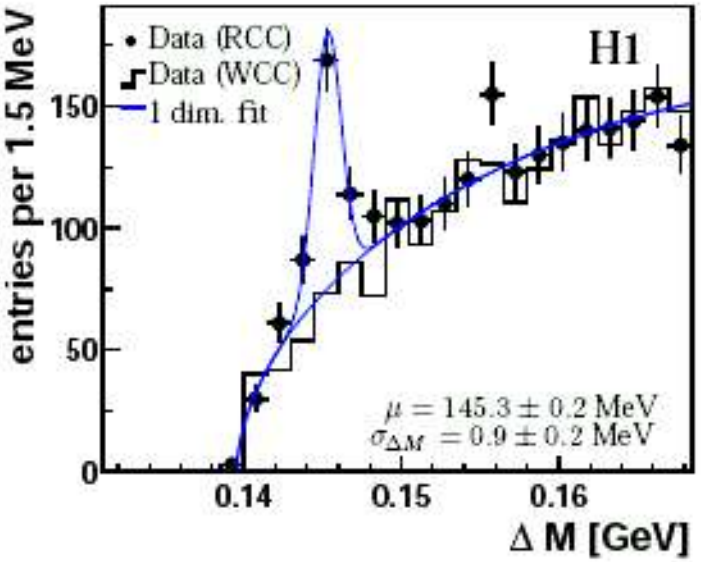
NLO QCD (FMNR) = $5.0\ ^{+1.7}_{-1.1}$ nb

Is the Extrapolation reliable?

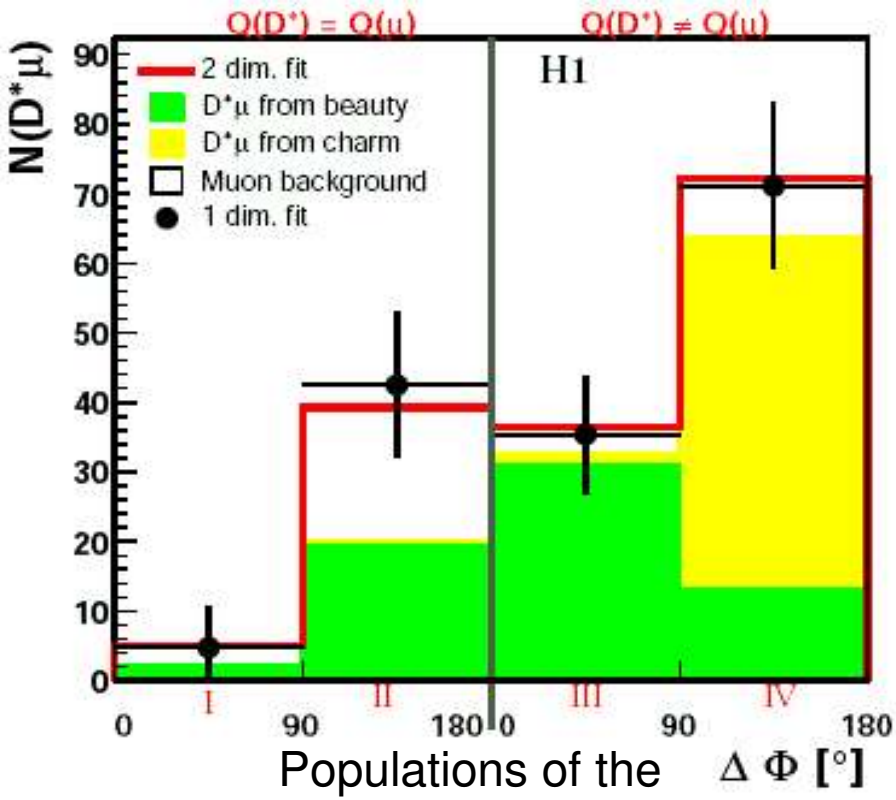
Solution: Interface FMNR → PYTHIA

Beauty cross section from D*+ μ

D* from mass difference technique



H1



Populations of the 4 correlation regions

Used to measure visible cross sections

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

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

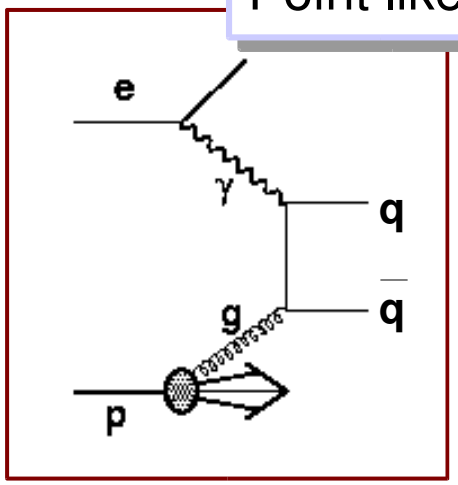
Photoproduction only: $Q^2<1$ GeV^2, $0.05<y<0.85$

H1 σ_{vis} = 206 +- 53(stat) +- 35 (syst.) pb

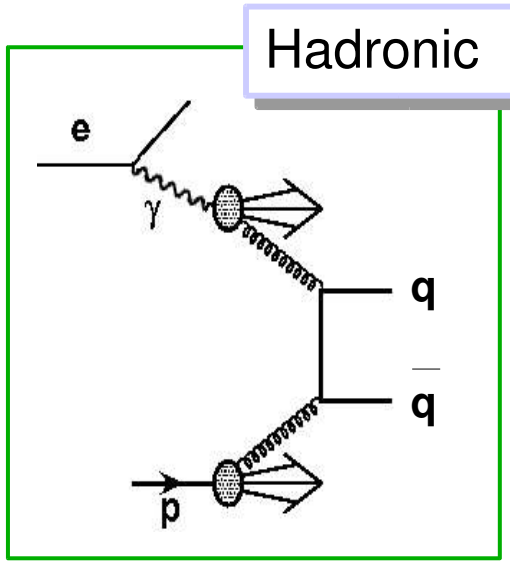
FrixioneManganoNasonRidolfi

Phys. Lett. 348, 633 (1995)

Point like



Hadronic

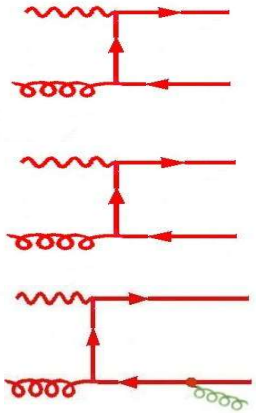


- Calculations @ NLO in QCD for heavy quarks in ep collisions
- Point like and Hadronic contributions to the cross section
- Photoproduction (*p*)
- Fixed order massive scheme

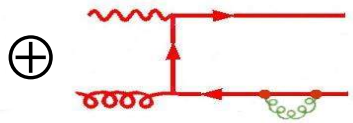
$$\text{scale}^{\,2} = p_T^{\,2} + m_q^{\,2}$$

FMNR

Example: some terms that contribute to the cross section



→ Real, positive

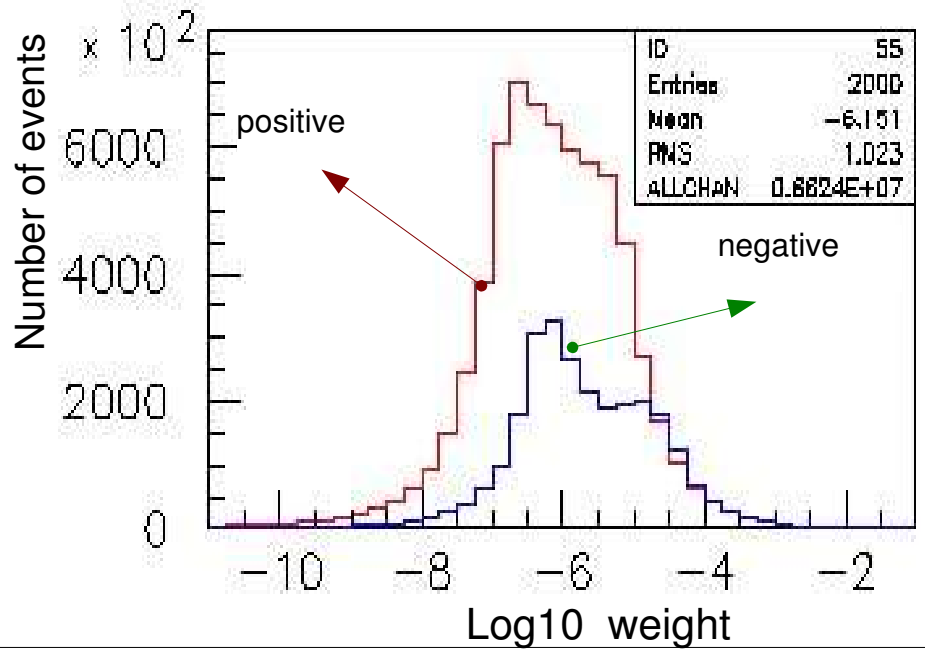


→ Negative, divergent!

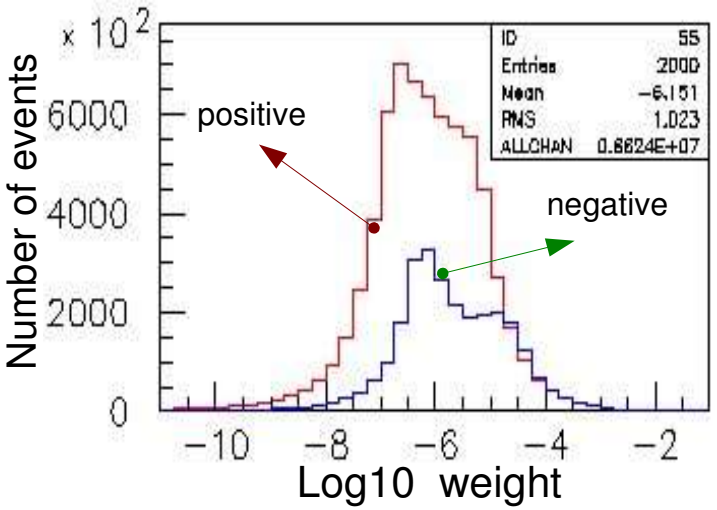
→ Positive, divergent!

} Combining: finite (+ or −)

- Events have weights →
  It can not be realistically linked to fragmentation or simulation chain.
- Weights range over several orders of magnitude →
  High statistics is needed to keep fluctuations low.



REDucedSTATistics



REDSTAT is an extension to FMNR:

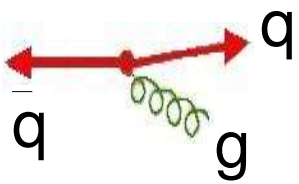
- Reduce the range of weights for the generated events.
- Reduce the necessary statistics without loosing NLO accuracy.

The idea:

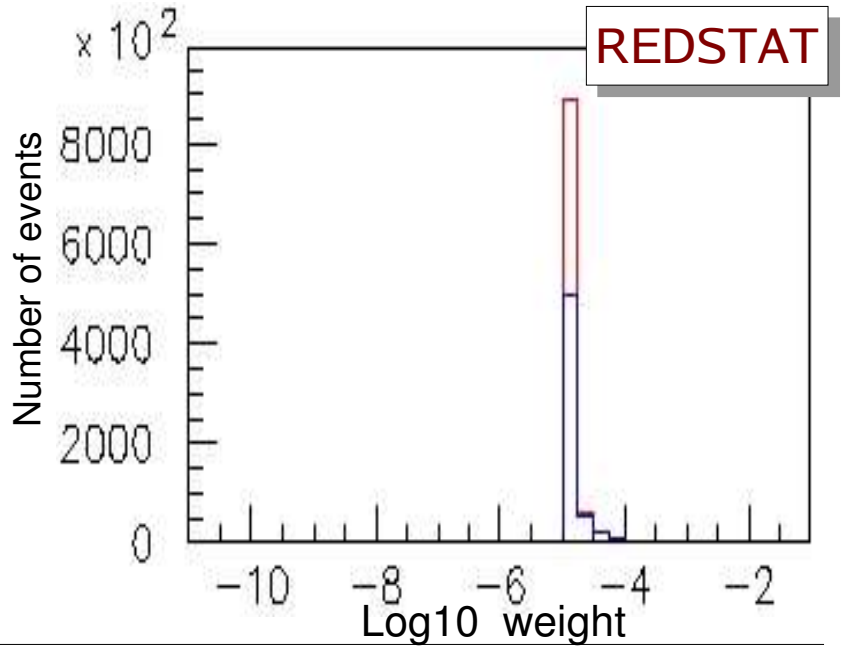
Combine events to get new ones with proper weight

How to combine:

- High weight events:
  Search for events with similar kinematics
- Low weight events:
  Random decision to keep the event



Similar events:
Difference in p_T, y_{rap}, ϕ < user cuts



Some REDSTAT results:

NLO accuracy preserved:

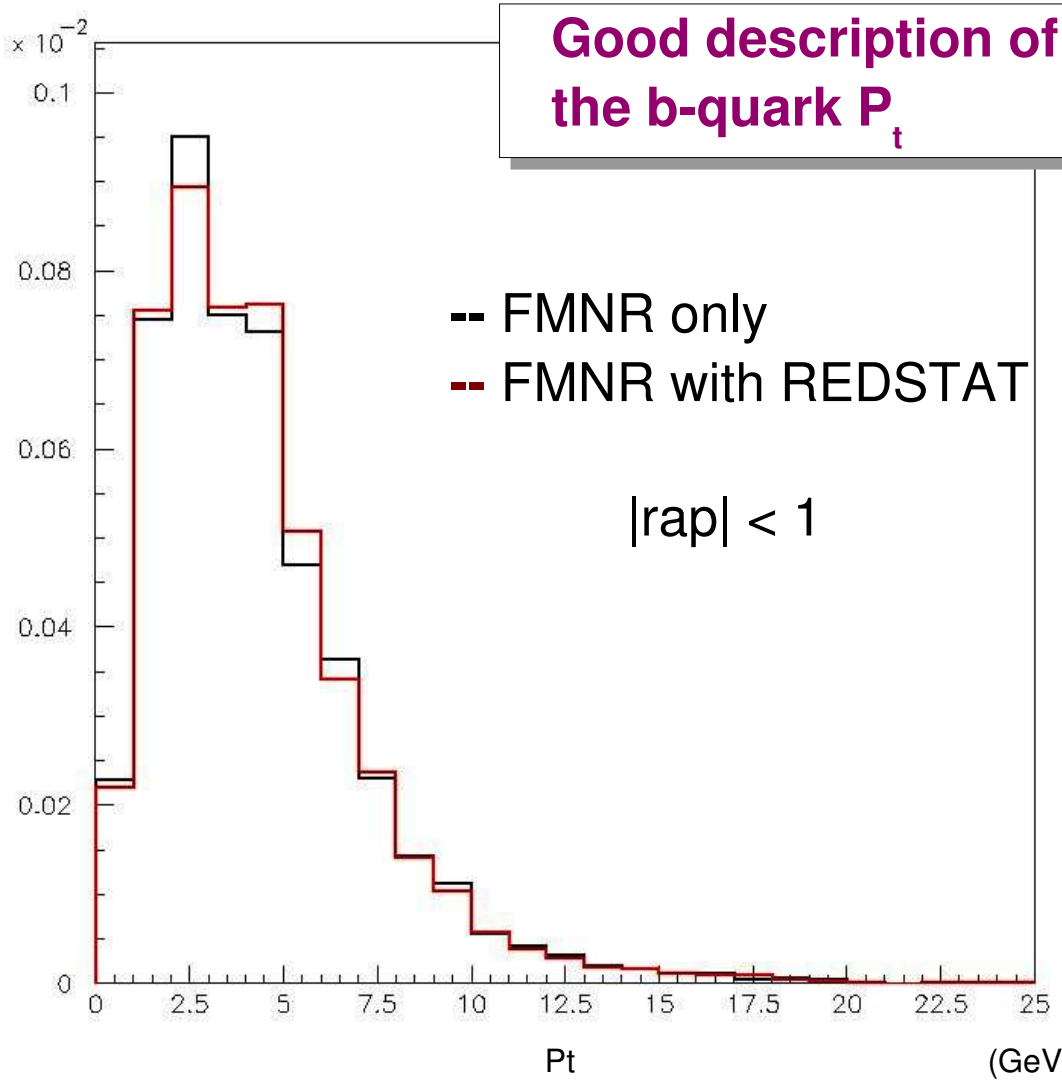
- without REDSTAT

  $\sigma_{\gamma p \to b (\bar{b}) X} = 4.95$ nb

- with REDSTAT

  $\sigma_{\gamma p \to b (\bar{b}) X} = 4.94$ nb

Good description of the b-quark P_t



FMNR Parameters

- Mass of the b quark

  $m_b = 4.75$ GeV, (4.5 - 5.0)
- Renormalization and factorization scales

  $\mu^2 = m_b^2 + p_{Tb}^2$ ($\mu/2 - 2\mu$)
- Proton: CTEQ5M Photon: GRV-G-HO

  PDF error << scale/mass error $\rightarrow$ neglected

Interface FMNR to PYTHIA

- Use weight range reduction (**REDSTAT**) preserving NLO accuracy
- Feed FMNR partons into PYTHIA 6.2 using "Les Houches accord" interface

Interface FMNR to PYTHIA

PYTHIA parameters

- **Intrinsic k_T kick : yes** difference ~1% without
- **Parton showering: NO**

  avoid double counting of higher order contributions

  main difference w.r.t. MC@NLO in preparation
- **Fragmentation**, all based on the Peterson formula:

  a) Independent (FMNR does not provide colour flow)

  b) Lund string (invent "reasonable" color flow)

  c) Comparison with default FMNR fragmentation, where possible.

use b) as central value, a) as lower error (-5%), c) as upper error (+15%)

Peterson, $\varepsilon = 0.0035$

(variation 0.0023 – 0.0045 -> error negligible compared to a or c)

- **Standard PYTHIA decay tables**

  all branching ratios included

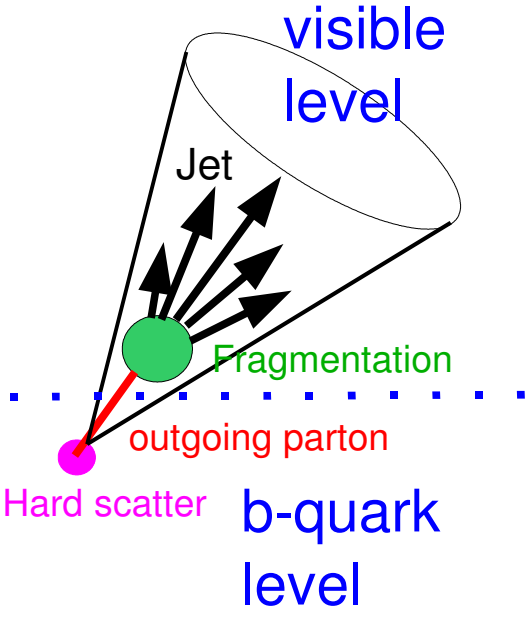
  corrected to match PDG

➜ **Obtain full hadron level event**

Results

Visible Beauty cross sections from D*+ μ

$p_T(D^*) > 1.9$ GeV, $-1.5 < \eta(D^*) < 1.5$, $p_T(\mu) > 1.4$ GeV, $-1.75 < \eta(\mu) < 1.3$	data/NLO
ZEUS $\sigma_{vis} = 214 \pm 52(stat)\ ^{+96}_{-84}$ (syst.) pb	$3.1\ ^{+1.6}_{-1.7}$
FMNR⊗PYTHIA $\sigma_{vis} = 72\ ^{+20}_{-13}$ (NLO) $^{+14}_{-10}$ pb	
Photoproduction only: $Q^2<1$ GeV^2, $0.05<y<0.85$	
ZEUS $\sigma_{vis} = 159 \pm 41(stat)\ ^{+68}_{-62}$ (syst.) pb	$2.8\ ^{+1.5}_{-1.6}$
FMNR⊗PYTHIA $\sigma_{vis} = 57\ ^{+16}_{-10}$ (NLO) $^{+11}_{-9}$ 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) = 15.1 +– 3.9 (stat) $^{+3.8}_{-4.7}$ (sys) nb

NLO QCD (FMNR) = 5.0 +1.7 -1.1nb

data/NLO = 3.0 $^{+1.3}_{-1.6}$

- **Data and theory still compatible**
- **Comparisons at b quark and visible level yield the same result**
- **Therefore the extrapolation was reliable**

Results

Comparison ZEUS - H1

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, $0.05<y<0.85$

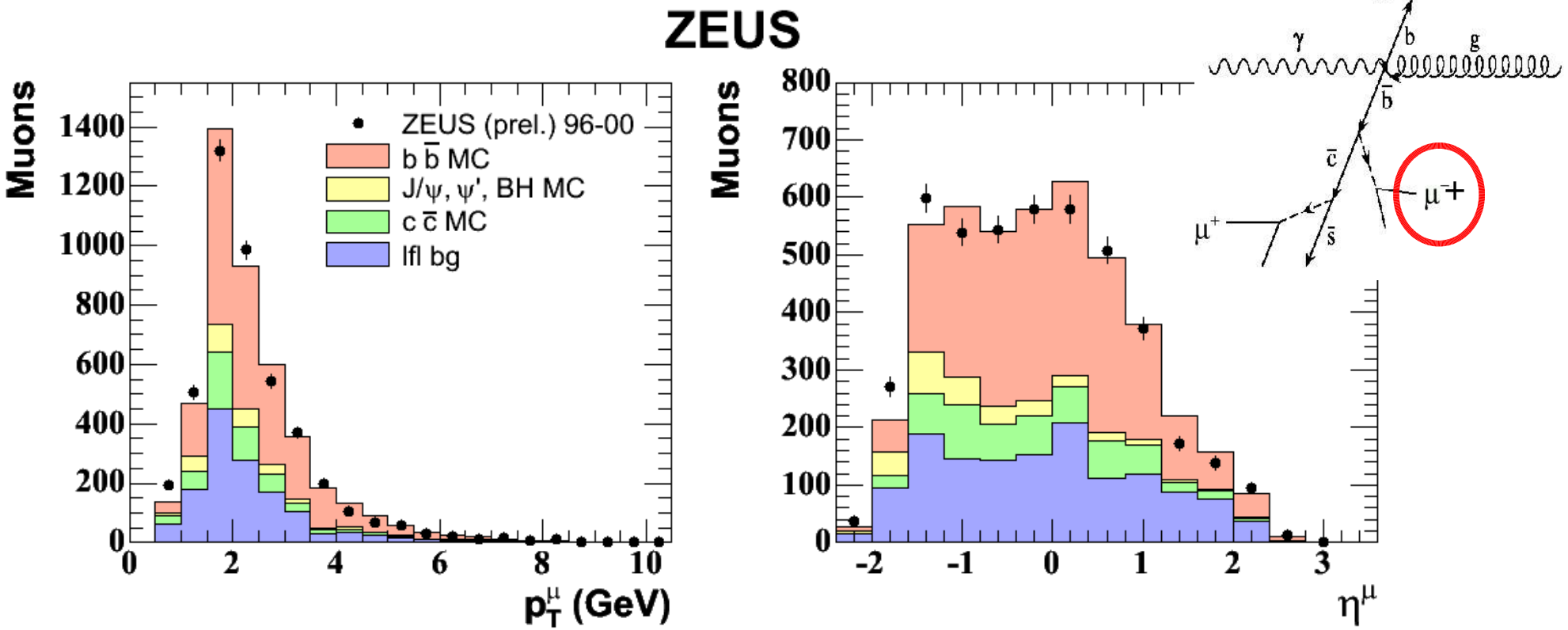
H1 σ_{vis} = 206 +- 53(stat) +- 35 (syst.) pb

ZEUS -> H1 $\sigma_{vis} = 189 \pm 48(\text{stat})\ ^{+80}_{-73}$ (syst.) pb

(extrapolated to H1 with FMNR)

Measured H1 and ZEUS visible cross sections consistent

Beauty cross section from $\mu^+ \mu^-$



Measured total cross section:

$\sigma_{ep \to b\bar{b} X}$ (318 GeV) $= 16.1 \pm 1.8$ (stat.) $^{+5.3}_{-4.8}$ (syst.) nb

NLO(FMNR+HVQDIS) = $6.8\ ^{+3.0}_{-1.7}$ nb

Results

Visible Beauty cross sections from μμ

Complicated set of muon p_T and η cuts, from beauty (for maximal acceptance)

ZEUS Visible range

ZEUS $\sigma_{vis} = 63 \pm 7(stat)\ ^{+20}_{-18}$ (syst.) pb (prel.)

FMNR§PYTHIA $\sigma_{vis} = 30\ ^{+9}_{-6}$ (NLO) $^{+5}_{-3}$ (frag+br) pb

data/NLO = 2.1 $^{+0.8}_{-1.0}$

Extrapolated to quark level using PYTHIA

ZEUS $\sigma(ep \rightarrow b \text{ or } \bar{b}\ X) = 16.1 \pm 1.8$ (stat) $^{+5.3}_{-4.8}$ (sys) nb (preliminary)

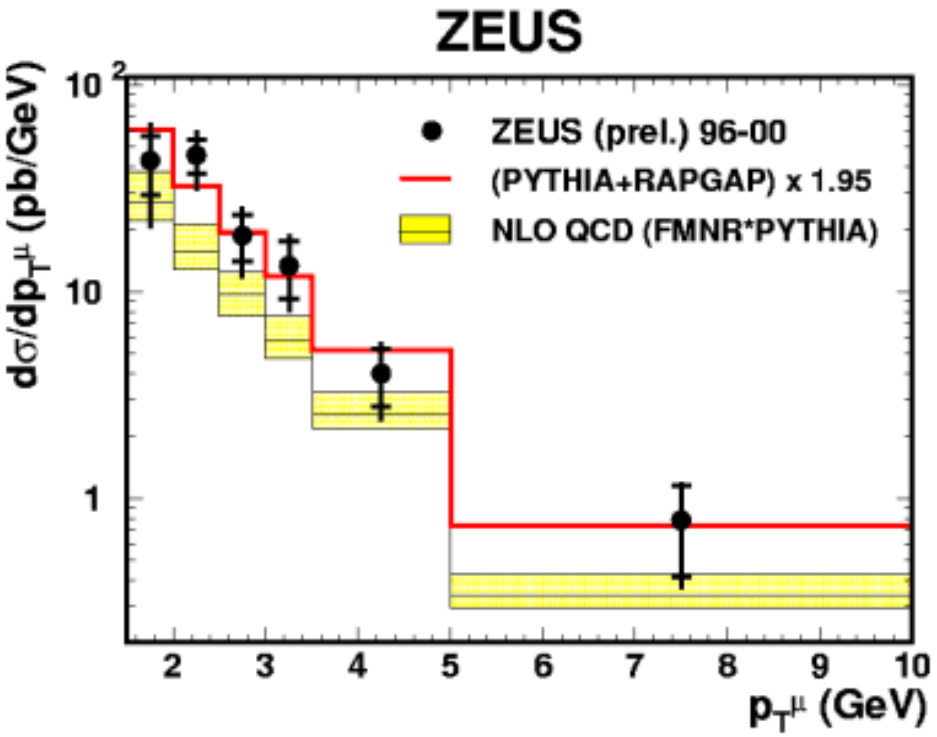
NLO(FMNR+HVQDIS) = $6.8\ ^{+3.0}_{-1.7}$ nb (preliminary)

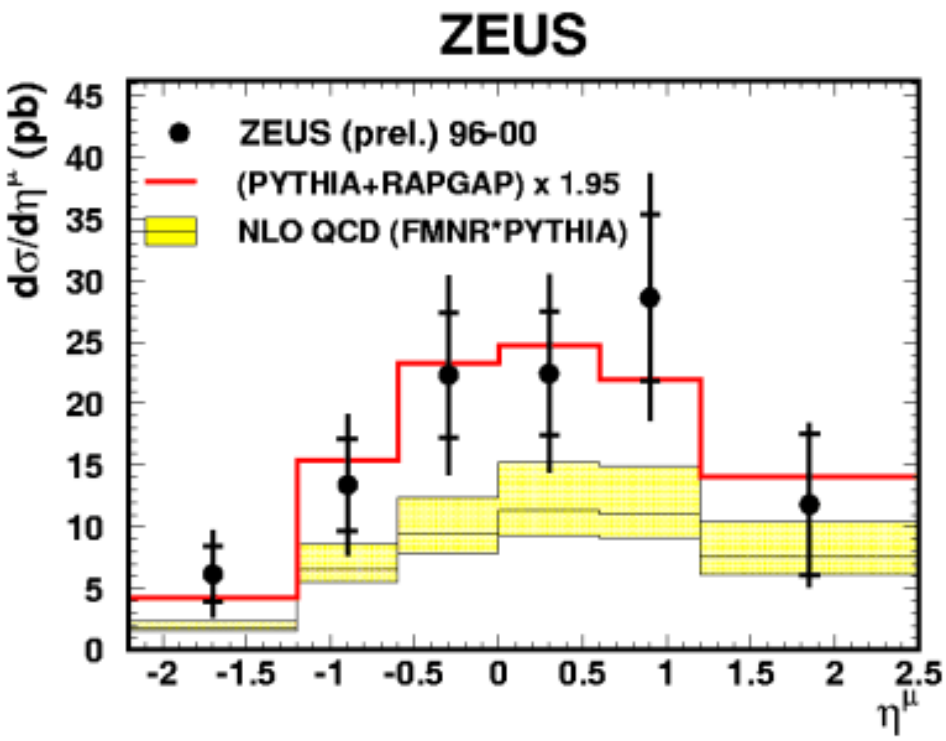
data/NLO = 2.3 $^{+1.0}_{-1.2}$

- **Large errors, but still consistent**
- **Comparisons at b quark and visible level consistent**
- **Consistent with D* μ results**

Results

Visible Beauty cross sections from μμ

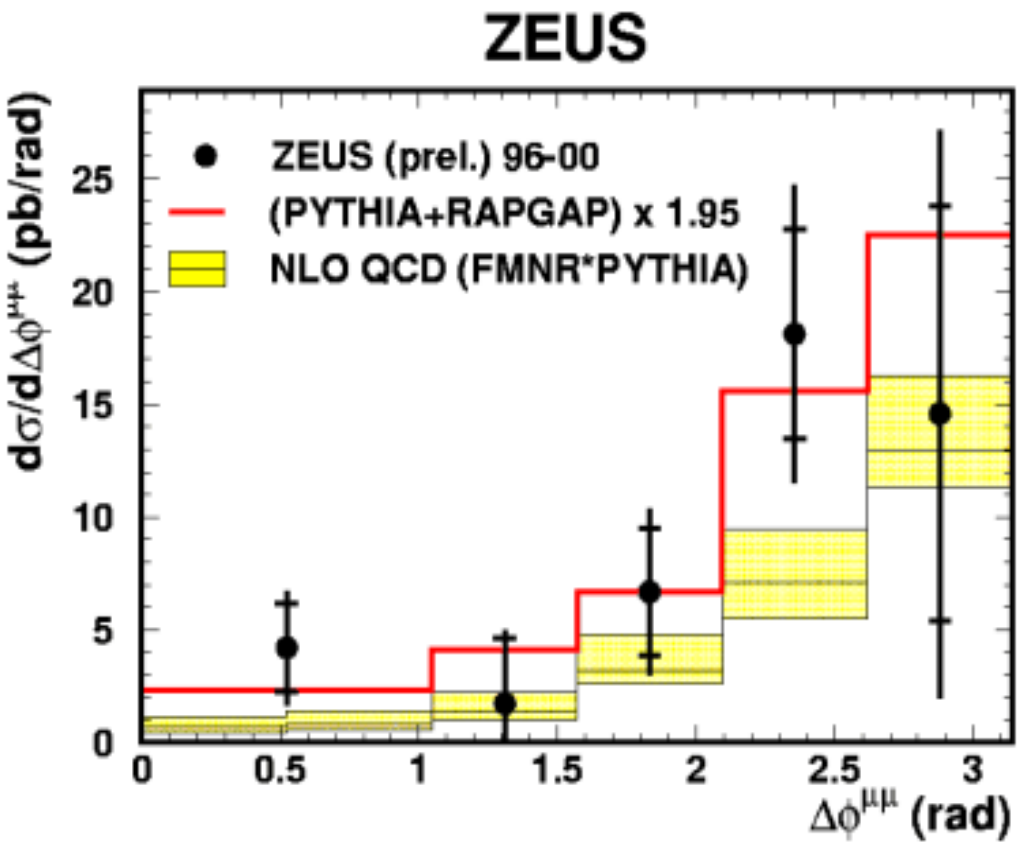


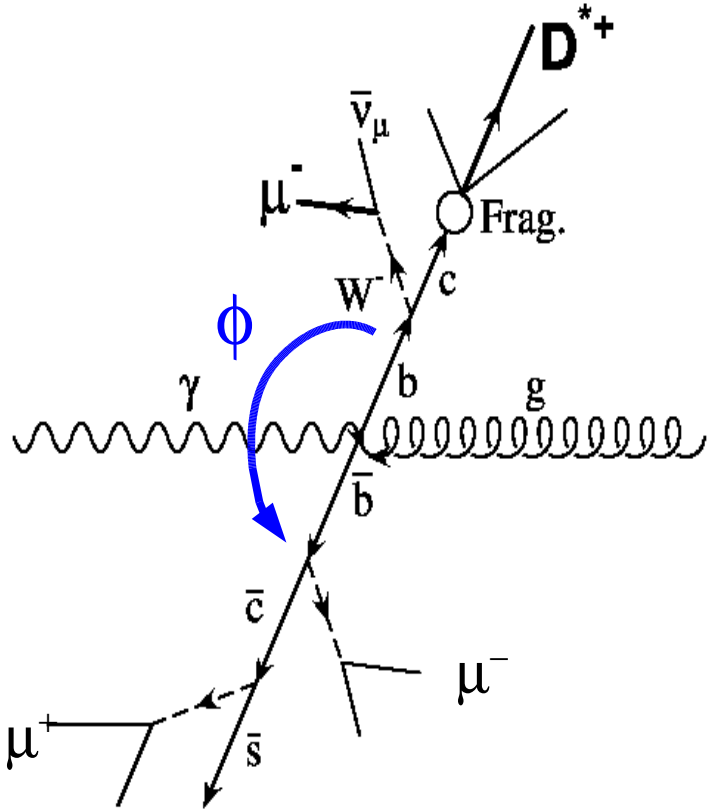


- **Shape well described**

Results

Visible Beauty cross sections from μμ





- **Reasonable agreement**

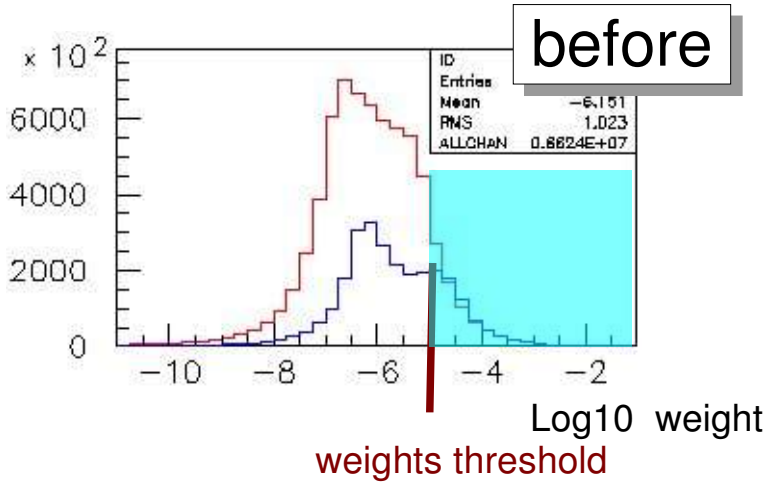
Conclusions

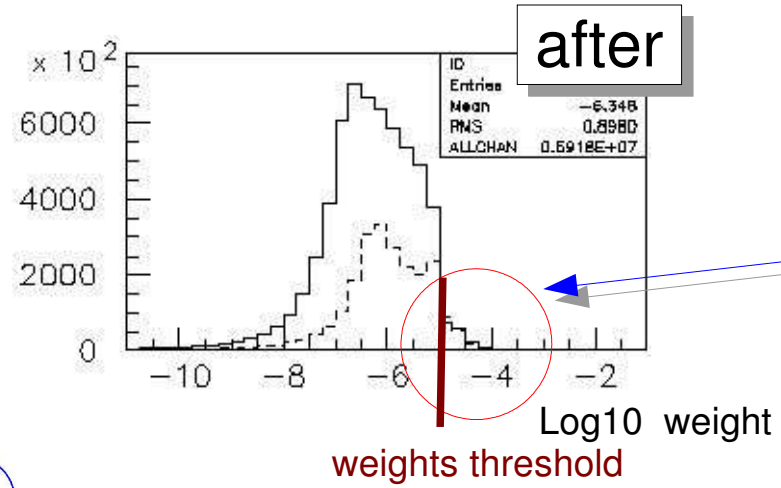
- D* μ and μμ beauty tagging methods reliable for measurement of total cross section for b production and $b\bar{b}$ correlations.
- The new FMNR⊗PYTHIA interface allows calculation of complicated visible NLO cross sections not available previously.
- data/NLO cross section comparisons for $b\bar{b} \rightarrow$ D* μ and $b\bar{b} \rightarrow \mu\,\mu$ at **visible** and **b quark level** are **consistent and equivalent.**
- We can use this method now, and compare with MC@NLO whenever available.

Backup slides !

How REDSTAT works:

Part 1: Weights > threshold





- Sets a threshold for the weights.
- Search for events with similar kinematics and combines them to produce a new event with proper weight.

Similar events:

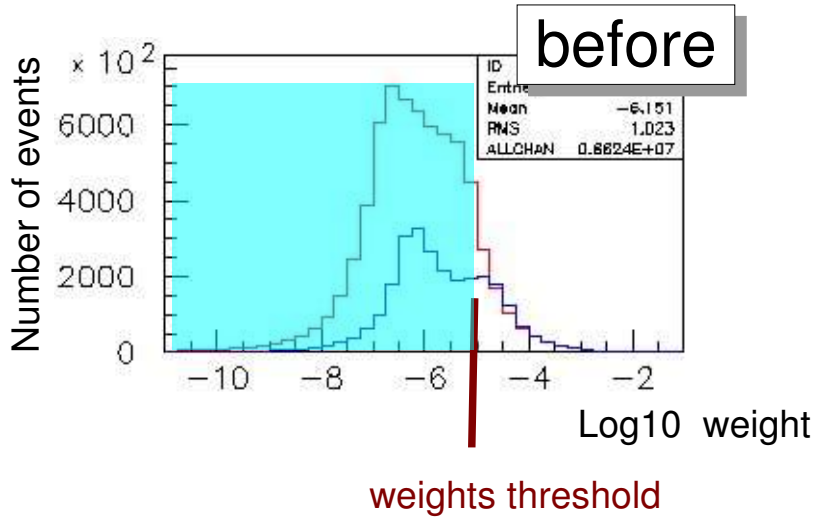
Δp_t , Δy , $\Delta \phi$ < user cuts

- Weights range reduced in 2 orders of magnitude
- Fewer high weight events !

How REDSTAT works:

Part 2: Weights < threshold

- Makes a Random decision to keep the event.
- Sets the weight of the event to the threshold weight.



- Weights are now in very small range.
- Interface to PYTHIA possible !