Beauty production at HERA

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for
H1 and ZEUS

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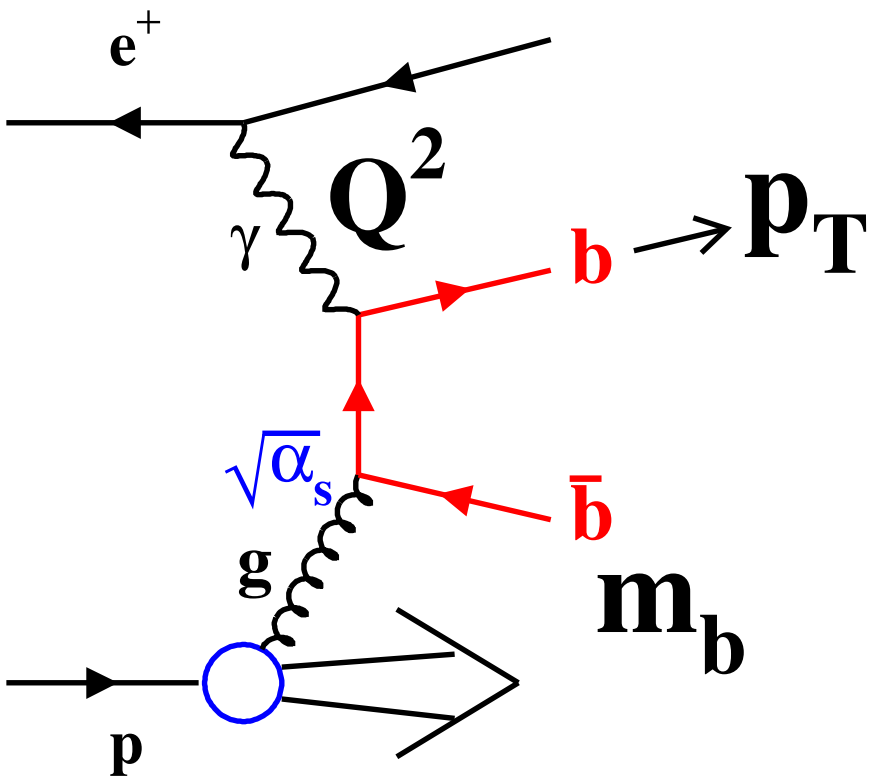
Ringberg

Beauty production at HERA



- **Driven by Proton gluon density**
- m_b **provides a hard scale** $\Rightarrow$ **pQCD always applicable**
- m_b^2, Q^2, p_T^2
  - $\rightarrow$ **Multi hard scale problem**
  - $\rightarrow$ $[\alpha_s \ln(Q^2/m_b^2)]^n$ **terms in pert. series**

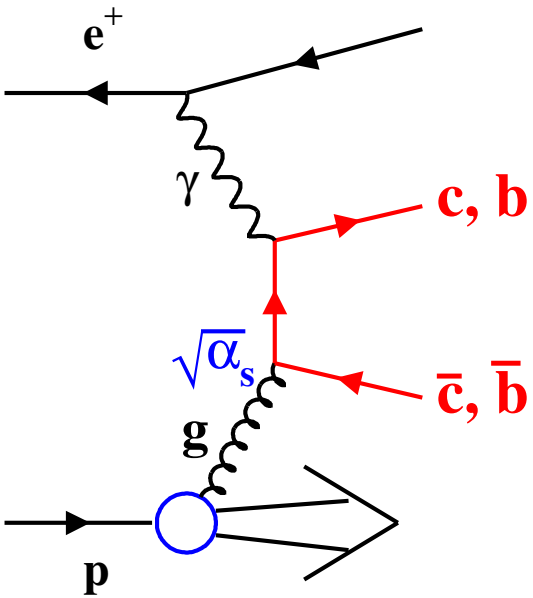
Multiscale problem can be tested at HERA over wide kinematical range $0 < Q^2 < 1000$ **GeV**^{2} **and** $0 < p_T < 50$ **GeV**

pQCD approx. $\rightarrow$ assume *one* dominant hard scale!

Massive scheme: $\rightarrow m_b$

- **b massive**
- **neglects $[\alpha_s \ln(Q^2/m_b^2)]^n$**

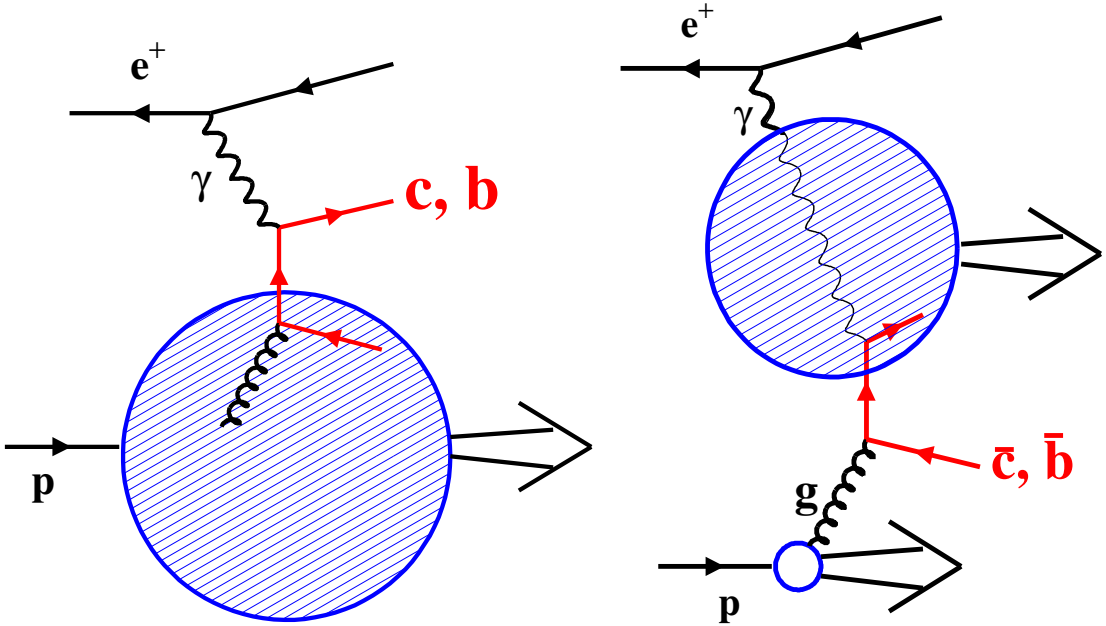
$\rightarrow$ Perturbative production:



Massless scheme: $\rightarrow p_T, Q^2$

- **b massless!!!**
- **Resums $[\alpha_s \ln(Q^2/m_b^2)]^n$**

$\rightarrow$ b also in Proton and Photon!



Variable schemes (VFNS):

$\rightarrow$ at small Q^2 massive, at large Q^2 massless

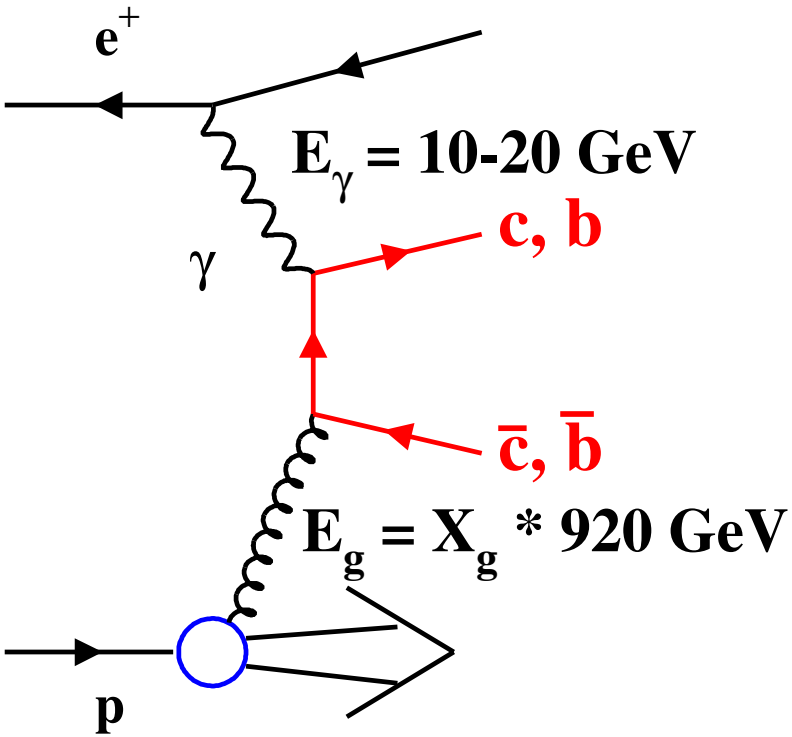
Which scheme describes the HERA data best?

Experimental conditions: Beauty is suppressed!

Total production rates at HERA:

$$\sigma_{\text{uds}} : \sigma_{\text{charm}} : \sigma_{\text{beauty}} \sim 2000 : 200 : 1$$

Main reason for Beauty suppression: phasespace!

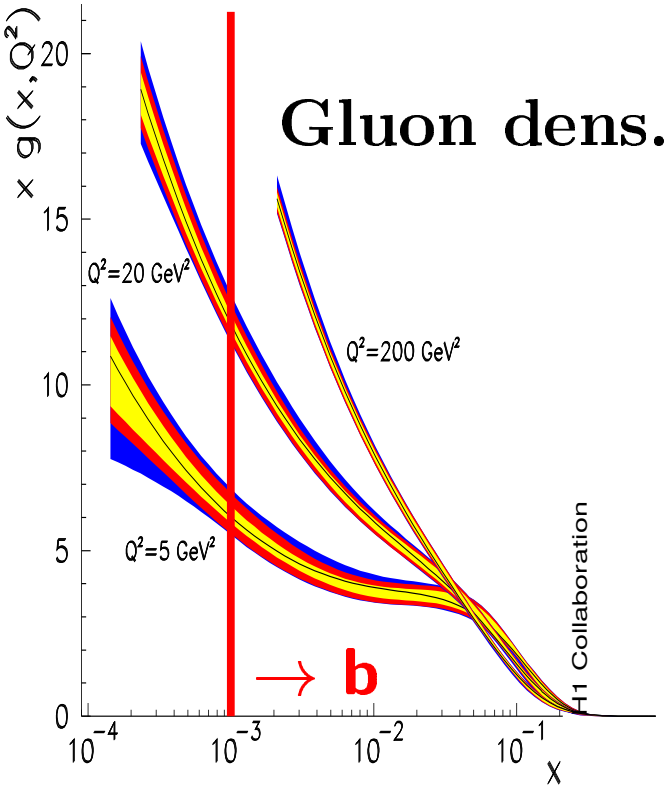


Kin. Threshold:

$$\mathrm{X}_g \geq \frac{m_Q^2}{E_\gamma \cdot 920\ \mathrm{GeV}}$$

c: $\mathrm{X}_g \geq 10^{-4}$

b: $\mathrm{X}_g \geq 10^{-3}$



Beauty measurements – a la carte

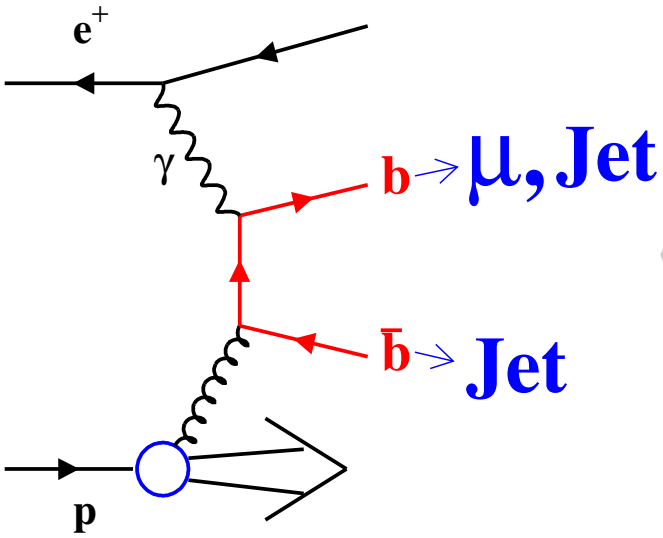
Q^2 ⟶

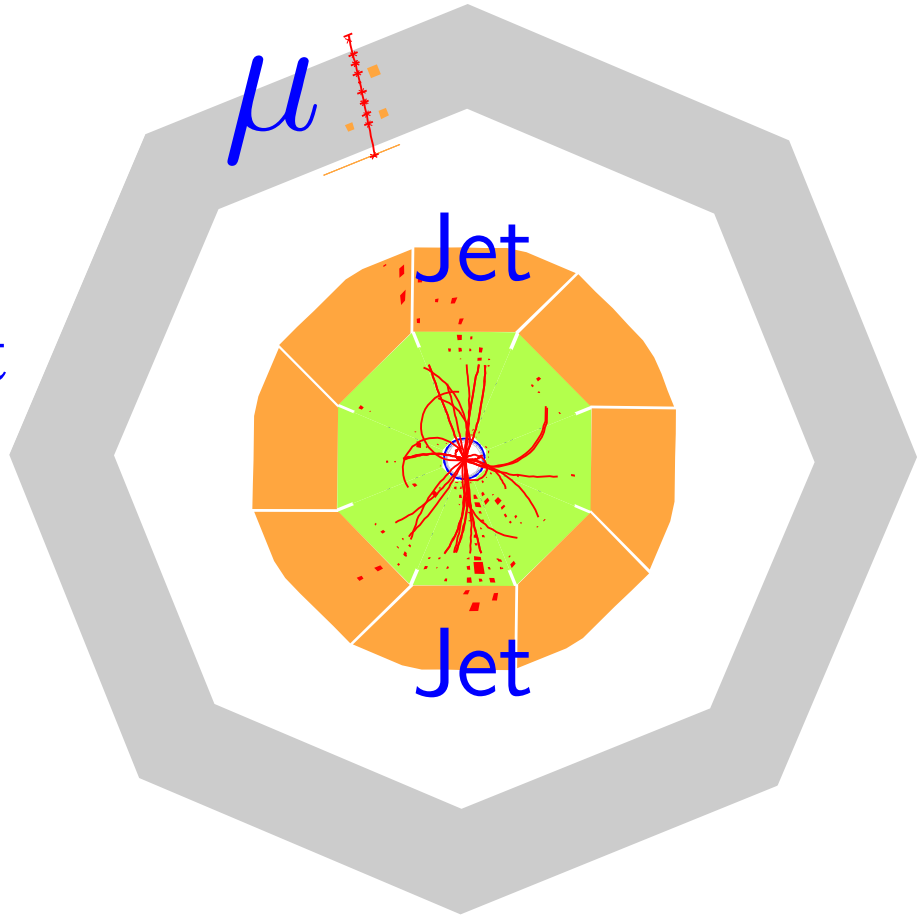
p_T ↓

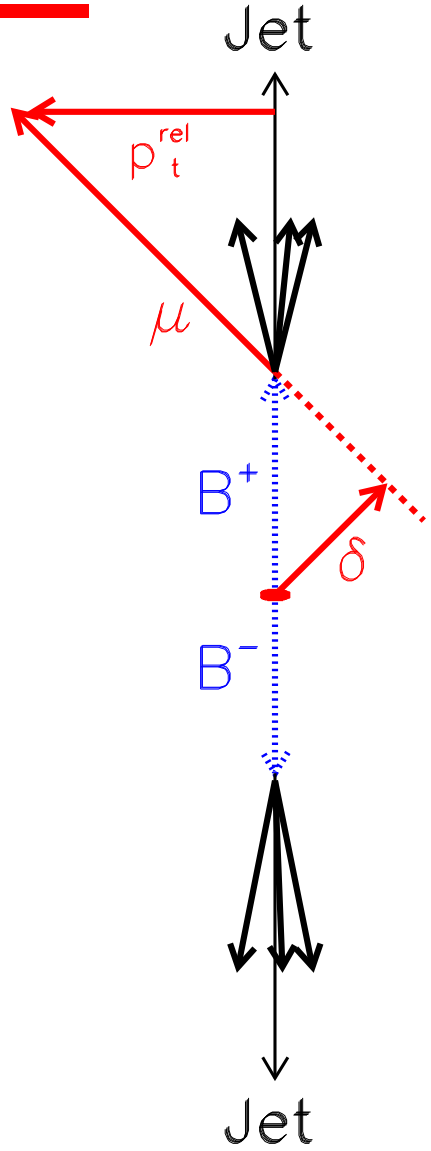
	Photoprod. $Q^2 \approx 0$	**DIS** $Q^2 \geq 1$ **GeV**^{2}	**DIS** $Q^2 \geq 150$ **GeV**^{2}
> 0 **GeV**	$\mu\mu$ $D^*\mu$	**Incl. Lifet.**	**Incl. Lifet.**
> 6 **GeV**	μ**+Jets**	μ**+Jet**	μ**+Jet**
> 11 **GeV**	**Incl. Lifet.**		

All measurements use HERA I data 96-00 with Lumis $\sim 50 - 120$ pb^{-1}

Beauty *Tag* with muon and jets



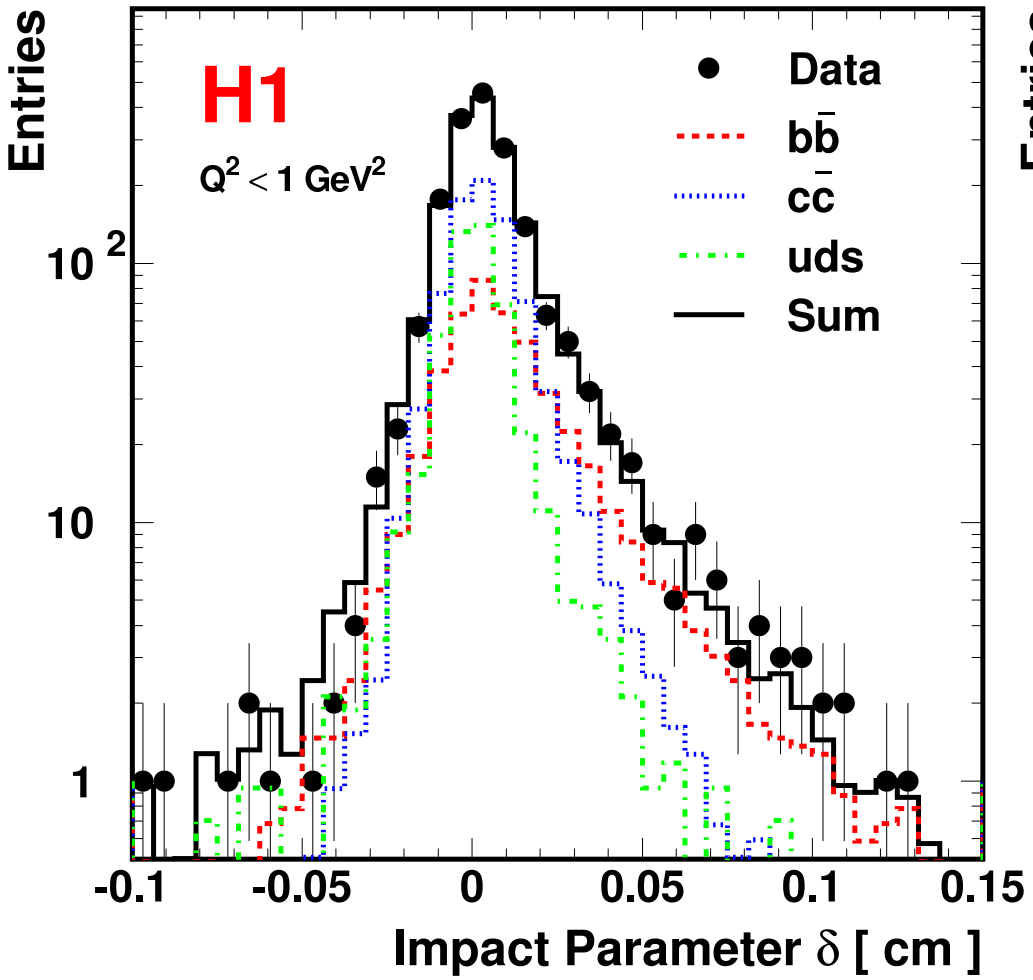


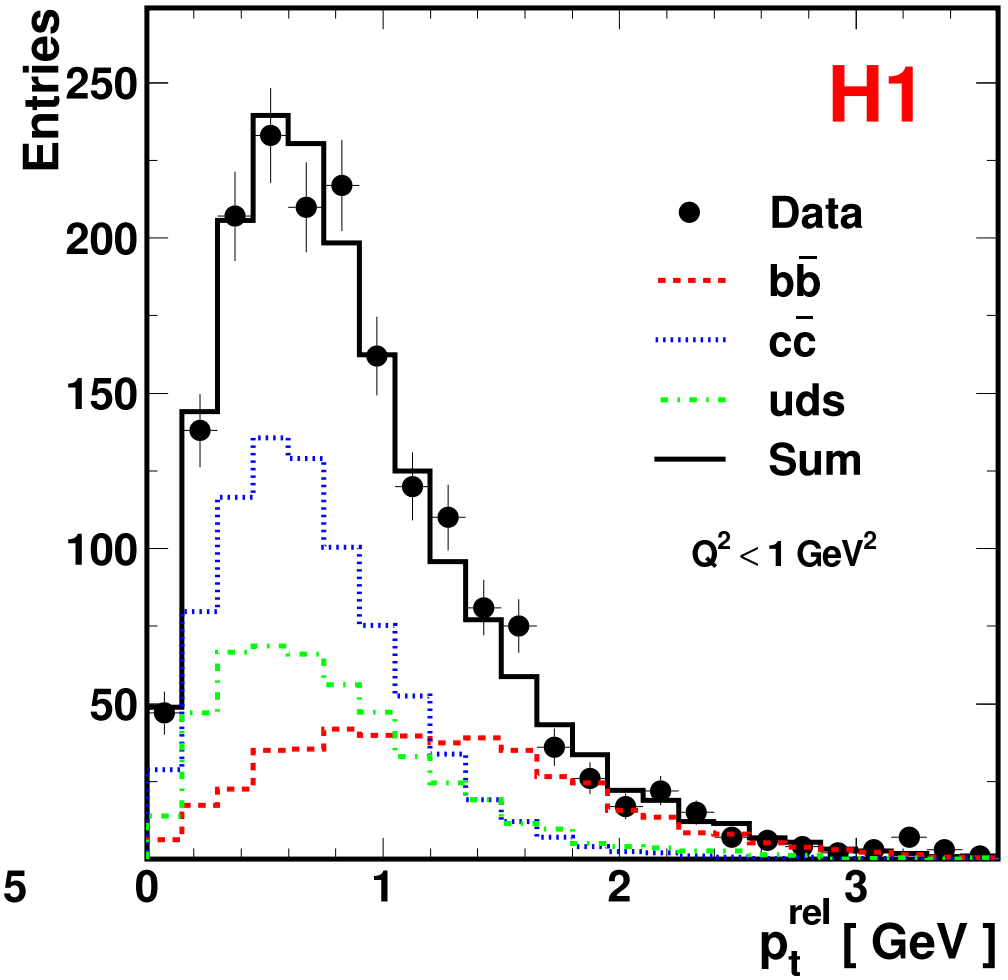


Separate Beauty from c and uds:

- **Large b mass** $\rightarrow$ **Large Muon** p_T^{rel}
- **Long b lifetime** $\rightarrow$ **Large Muon Impactpar.** δ

μ+jets: Beauty signal in photoprod. $Q^2 < 1$ GeV^2

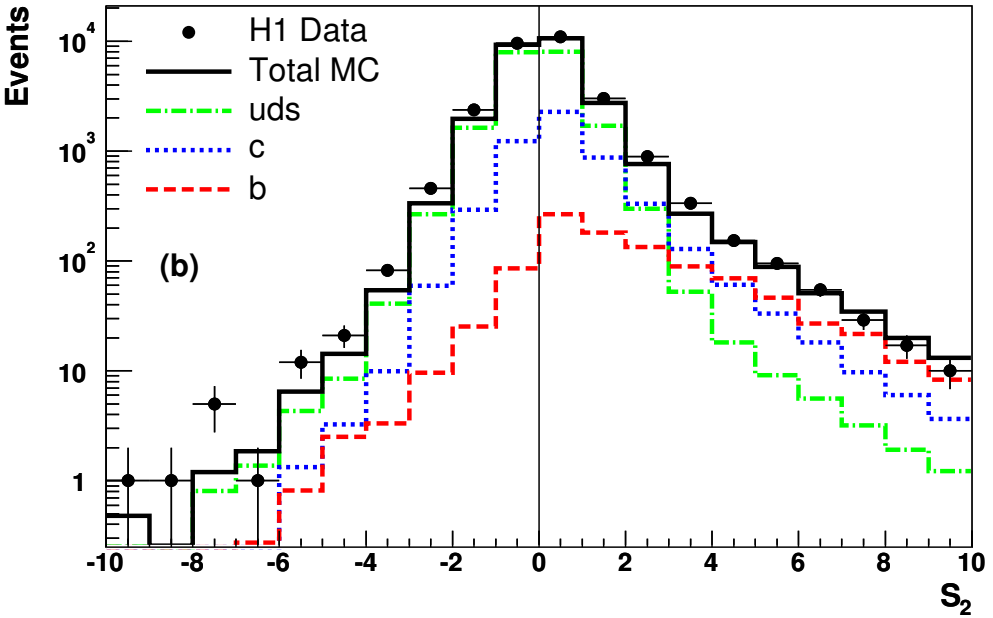


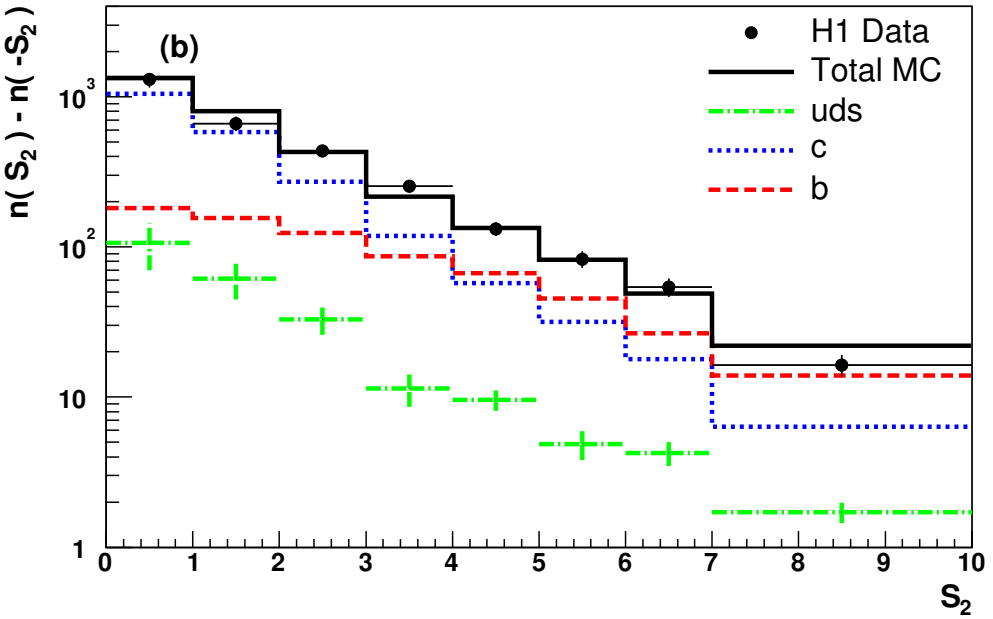


Fit to 2-dim (δ, p_T^{rel}) distr.: $\sim 500 \pm 50$ **b events**

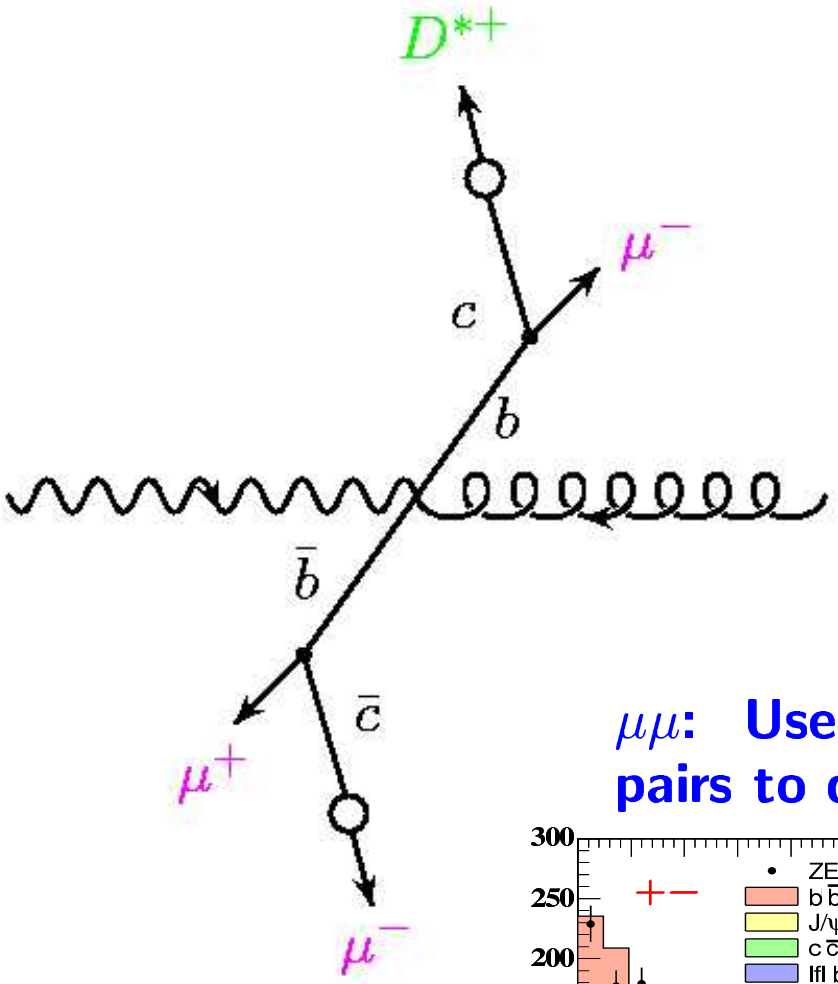
Inclusive Lifetime Tag: $Q^2 > 150$ GeV^2 analysis

- **Select central silicon tracks with $p_T > 0.5$ GeV; Use significance of signed track impactparameter $S = \frac{\delta}{\sigma(\delta)}$**
- **Track with second largest S provides good b separation $\rightarrow$**
- **Subtract negative side from positive**
- **LH-Fit: $\sim 700 \pm 110$ b events in neg. subtracted S_2**

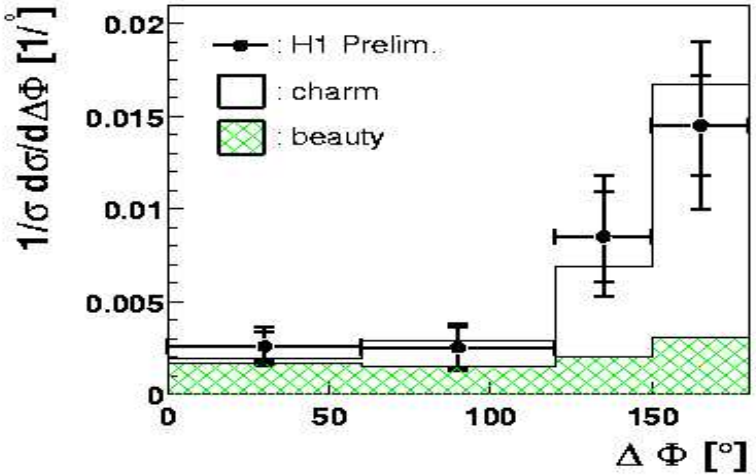




Beauty double tagging with $D^*\mu$ and $\mu\mu$

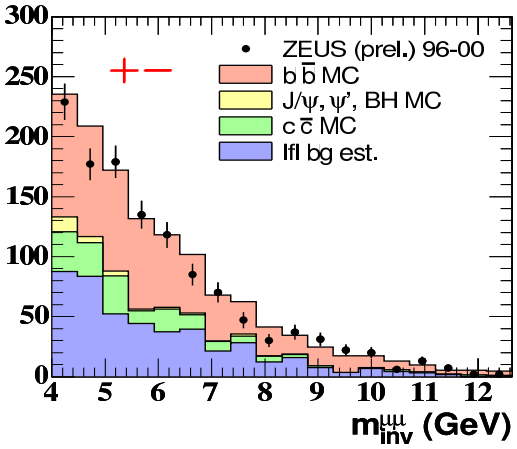


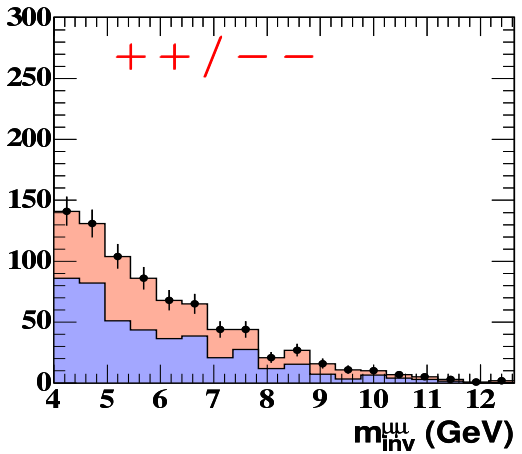
$D^*\mu$: Use charge and angular correlations to separate charm and beauty events:



$\sim 66 \pm 17$ b ev.

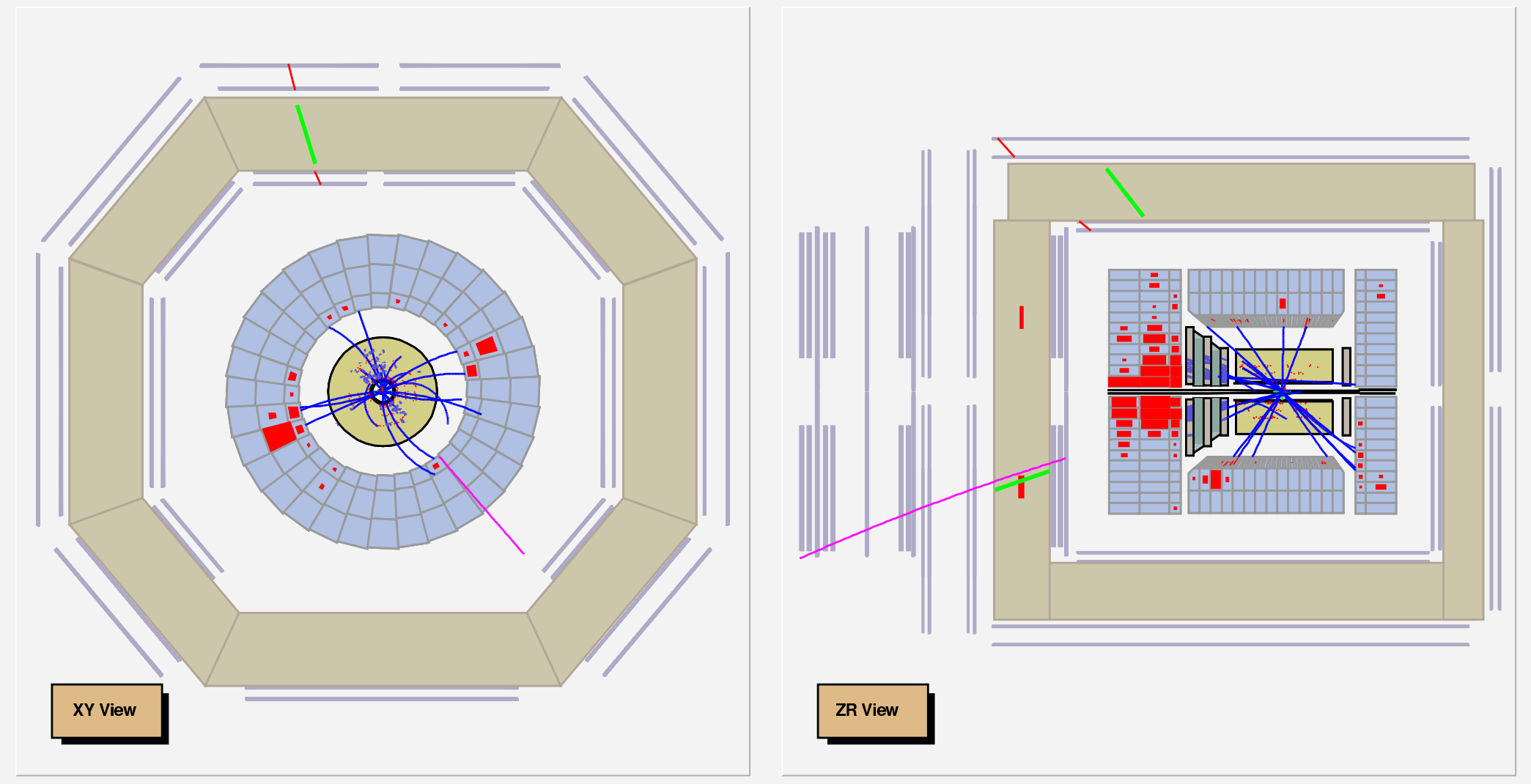
$\mu\mu$: Use excess of unlike sign muon-pairs to determine b contribution:





$\sim 1800 \pm 200$ b ev.

$ep \to b\bar{b}X \to \mu\mu X$ event candidate (ZEUS)

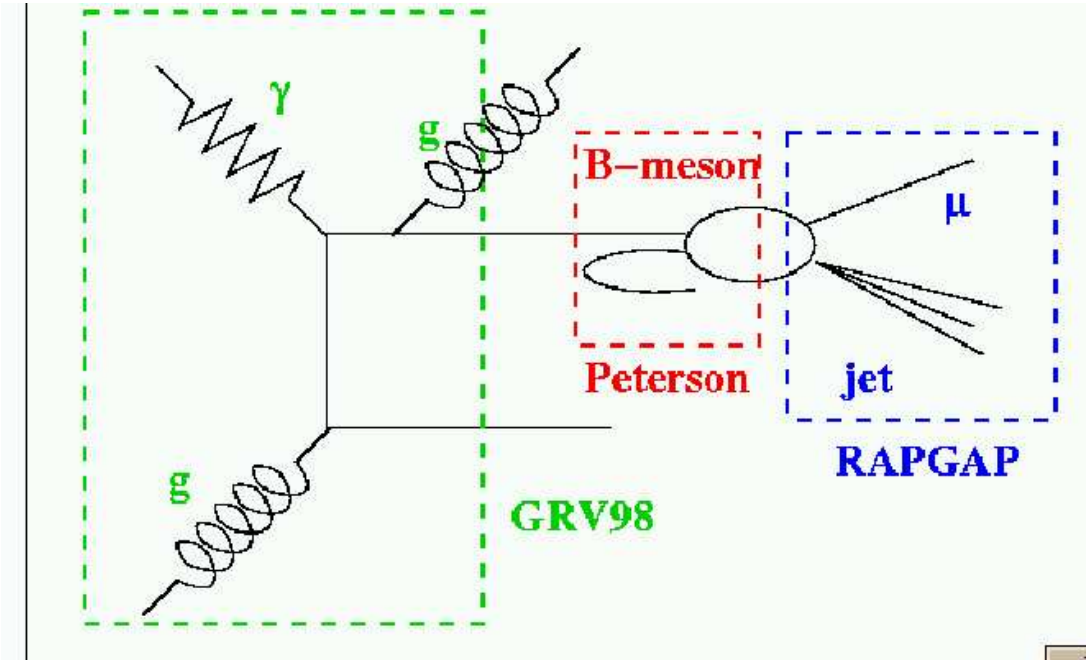


$\Rightarrow$ **Coverage down to low momenta $p_T^\mu \sim 1$ GeV and forward/backward directions $|\eta^\mu| > 1.5$!**

Remarks on NLO implementations

Massive NLO: 'Flickschusterei'

for final state measurements, e.g. μ+jets



- **MC like programs FMNR, HVQDIS provide partons**
- **Apply purely longitudinal Peterson fragmentation to b-quark**
- **Fragmented b-quark is 'decayed' using muon decay spectrum (e.g. from JETSET)**
- **Apply hadronisation corrections for parton jets using MC**

⇒ **Kniehl et al.: Fragmentation is arbitary → what is the uncertainty?**

⇒ **Fragmentation, Muon-decay and Hadronisation corr. for parton jets**
→ All sources for considerable syst. uncertainties of calculation!

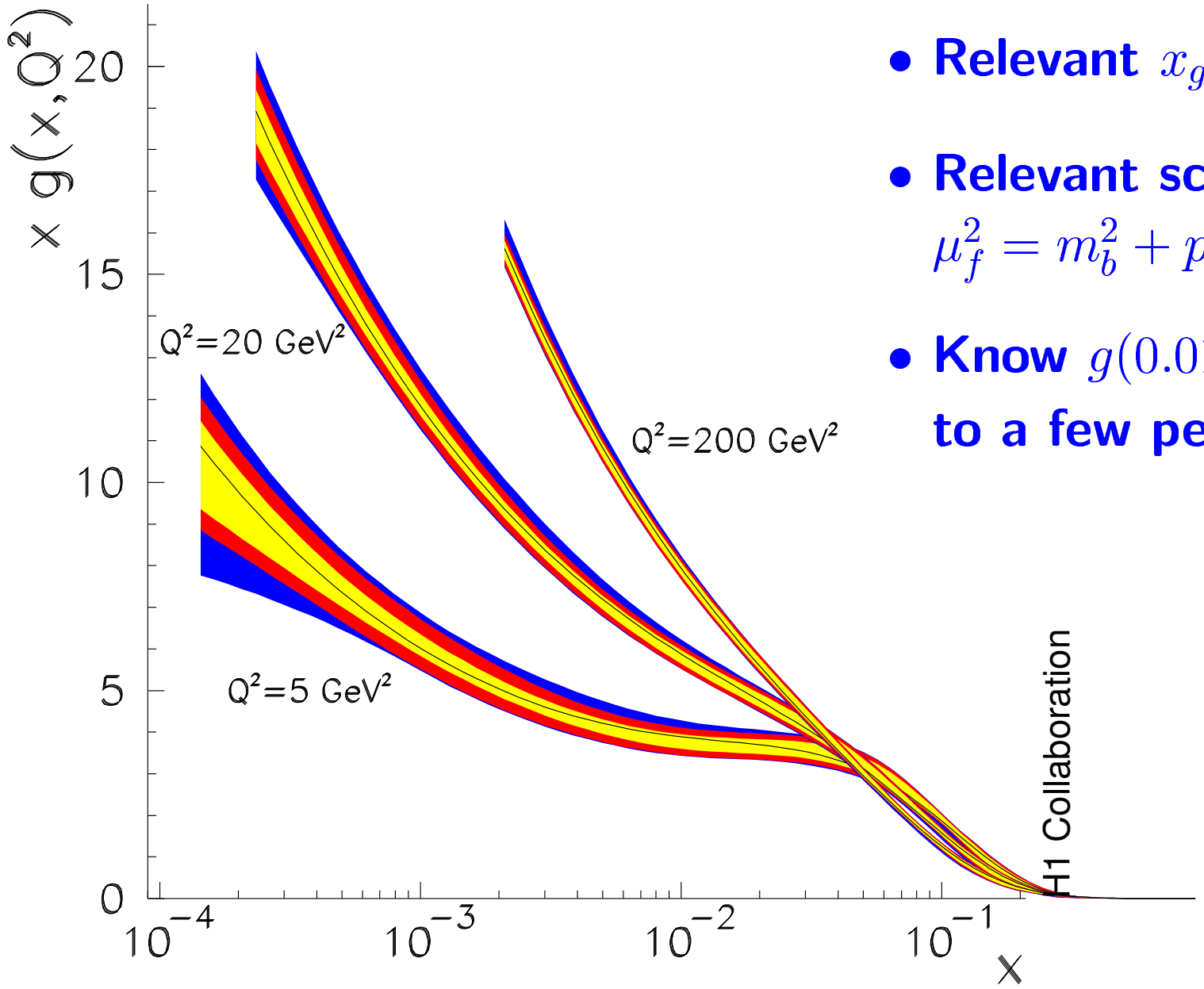
'Standard' NLO uncertainties

Photoproduction μ+jets analysis (FMNR)

1. Fragmentation:
   Vary $\epsilon_{Peterson} = 0.0033 \pm 0.0008$ $\Rightarrow$ σ varies by $^{-2.9\%}_{+0.5\%}$
2. Variation of b-mass
   Vary $m_b = (4.75 \pm 0.25)$ GeV $\Rightarrow$ σ varies by $^{-20\%}_{+19\%}$
3. Renormalisation Scale:
   $m_r = m_t \cdot ^{0.5}_{2.0}$ $\Rightarrow$ σ varies by $< 7\%$
4. Factorisation Scale:
   $m_f = m_t \cdot ^{0.5}_{2.0}$ $\Rightarrow$ σ varies by $^{+15\%}_{-12\%}$
5. Structure Function
   CTEQ5D:($\lambda_5 = 0.226$ GeV)
   MRST1: ($\lambda_5 = 0.22$ GeV)
   MRSG : ($\lambda_5 = 0.17$ GeV) $\Rightarrow$ σ varies by 2 – 8 %

Total systematic uncertainty: $25 - 30\%$

Why so small PDF uncertainty?



- **Relevant** $x_g \sim 0.01 - 0.02$
- **Relevant scale**
  $\mu_f^2 = m_b^2 + p_{t,b}^2 \sim 100$ **GeV**^{2}
- **Know** $g(0.01, 100$ **GeV**$^2)$
  to a few percent precision !

Christmas is approaching soon...

Wishlist for theory calculations:

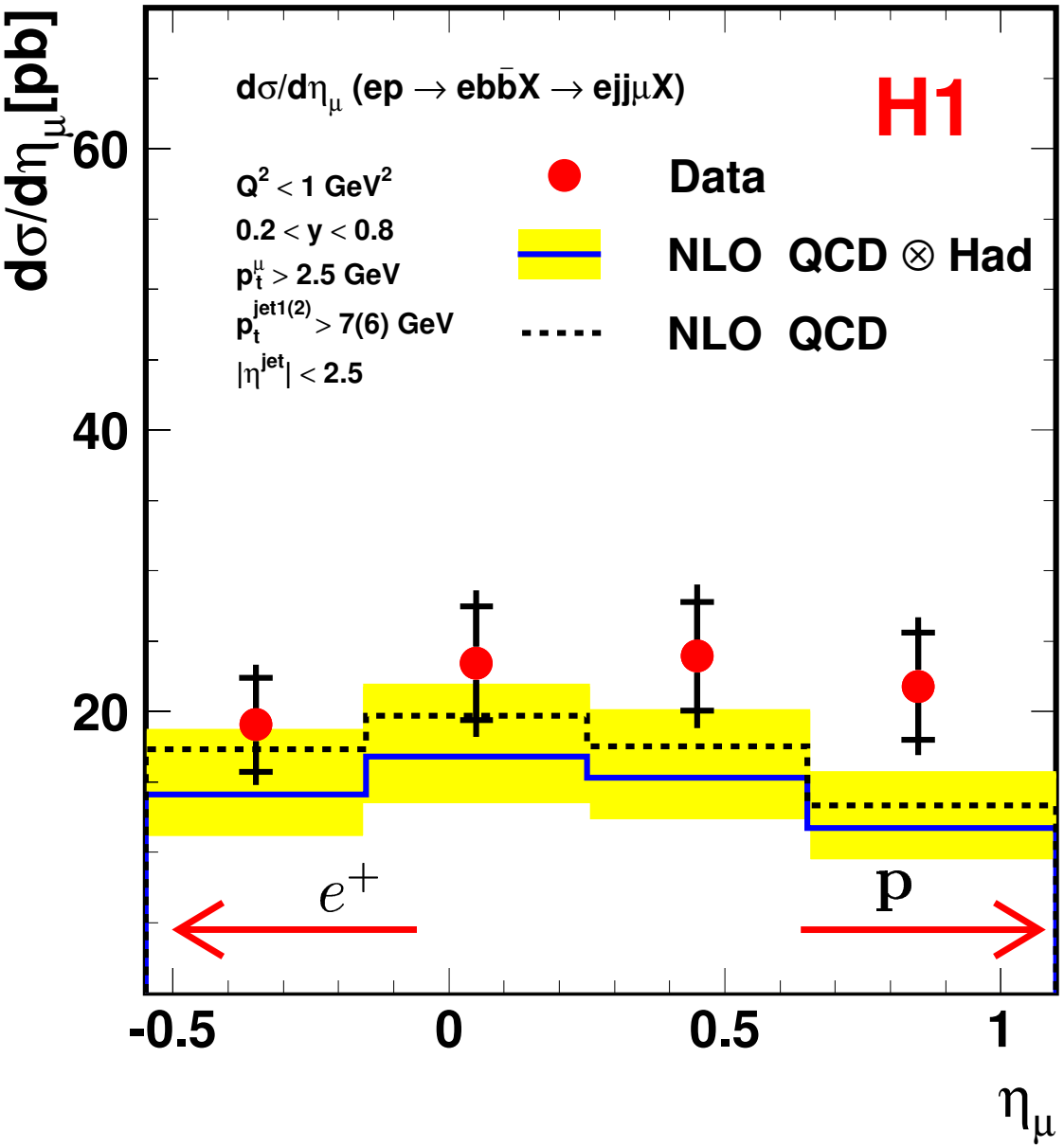
- **Parton level calculations:**
  - **NLOJET++ for heavy flavours!**
    Also a reason: this is such a user friendly program!
  - **In general: Monte Carlo like NLO programs**
    with full access to the outgoing hard partons
    - **VNFS (CTEQ, MRST)**
    - **Massless (Kniehl) (?)**

    At the moment only available for massive calculations (FMNR, HVQDIS)
- **Hadron level calculations:**
  - **MC@NLO** **Don't forget: NLO parton to hadron corrections with LO Monte Carlos are a nightmare!**

Results

Photoproduction with μ+jets

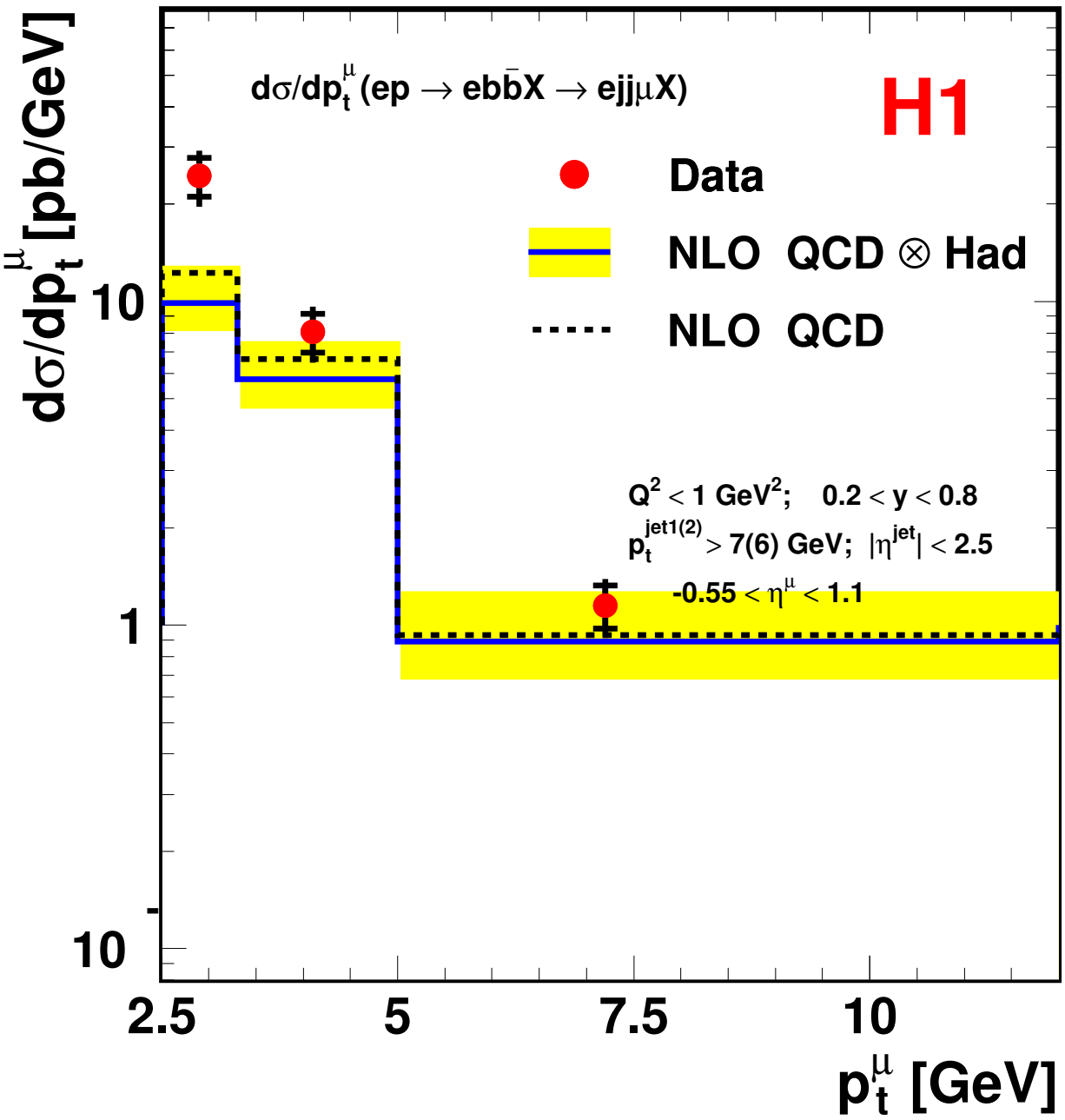
H1 results vs muon pseudorapidity



⇒ **Flat distribution**

⇒ **Massive NLO (FMNR):**
- **somewhat low**
- **describes shape**

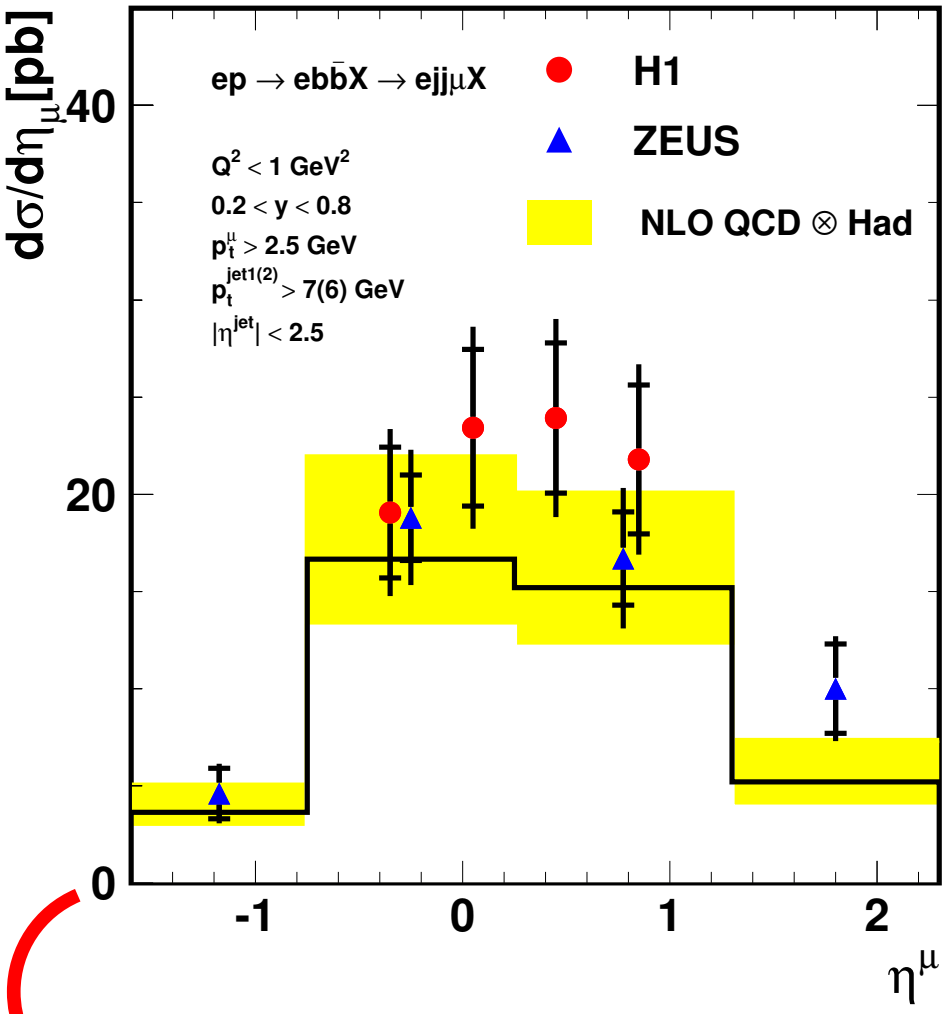
Photoproduction with μ+jets: H1 results vs p_t^μ



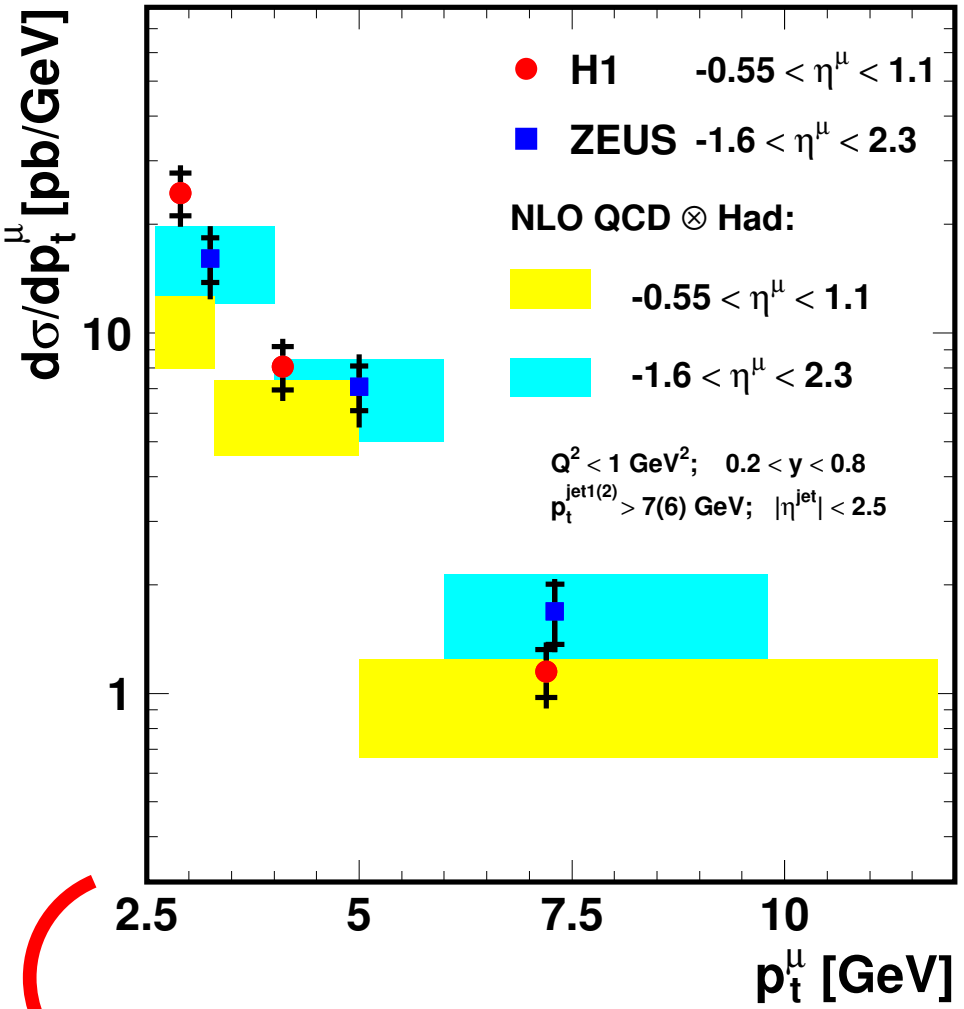
$\Rightarrow$ **Steep drop-off**

$\Rightarrow$ **NLO too low at low p_t^μ**

Photoproduction with μ+jets: H1 vs. ZEUS

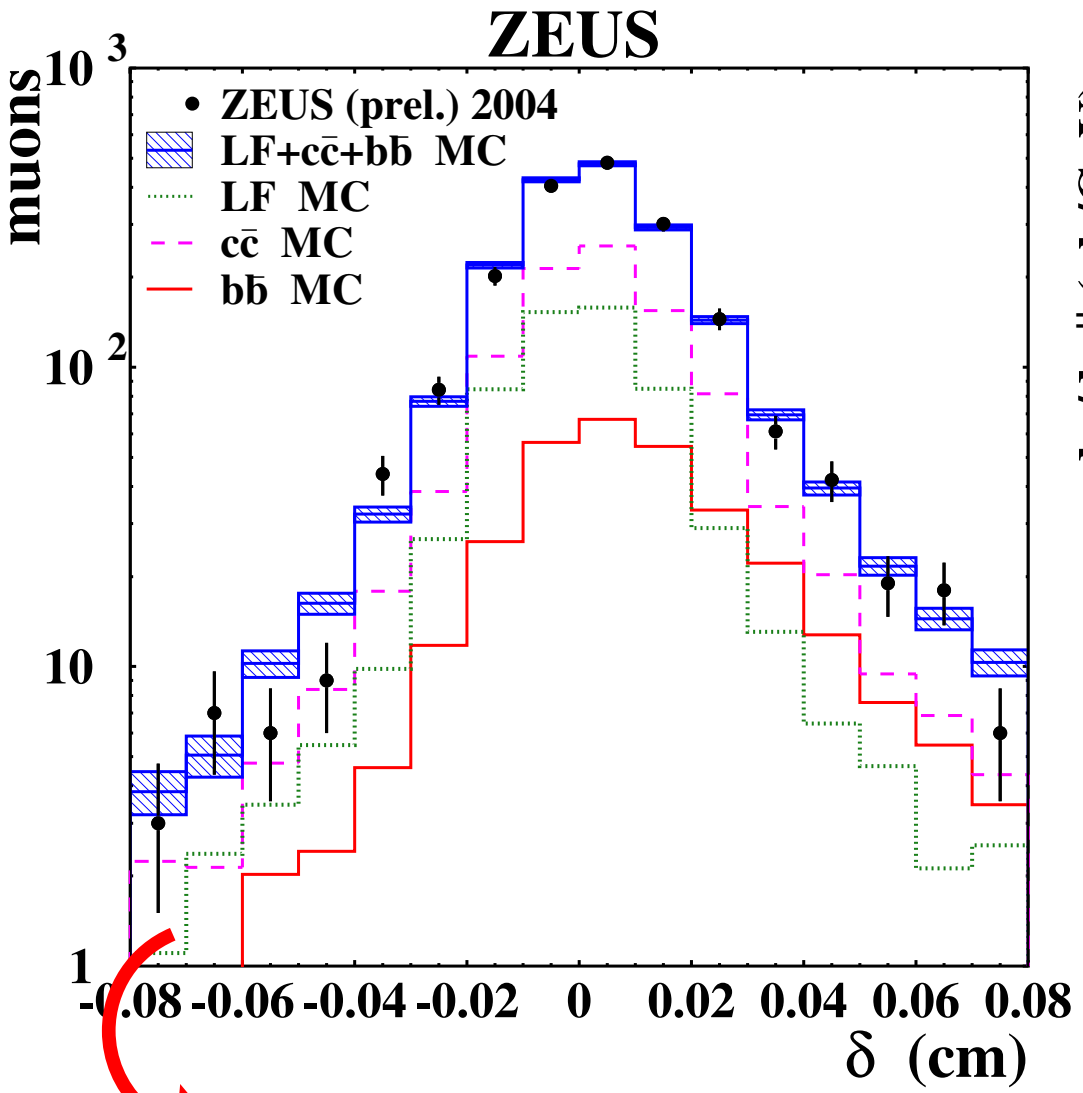


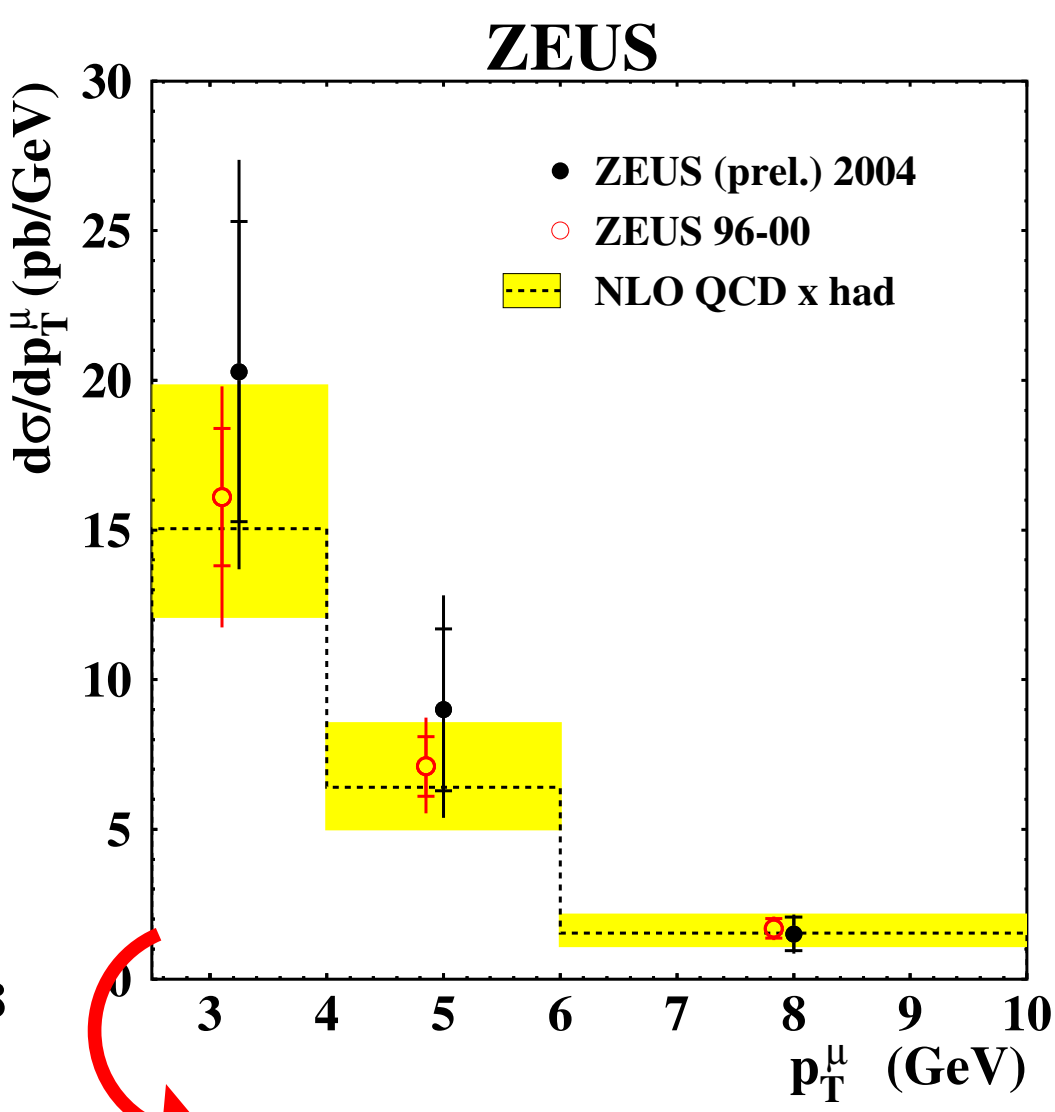
Good agreement H1 vs ZEUS



ZEUS: No excess at low p_t^μ !!!!!!!

First beauty result with HERA II using μ+jets

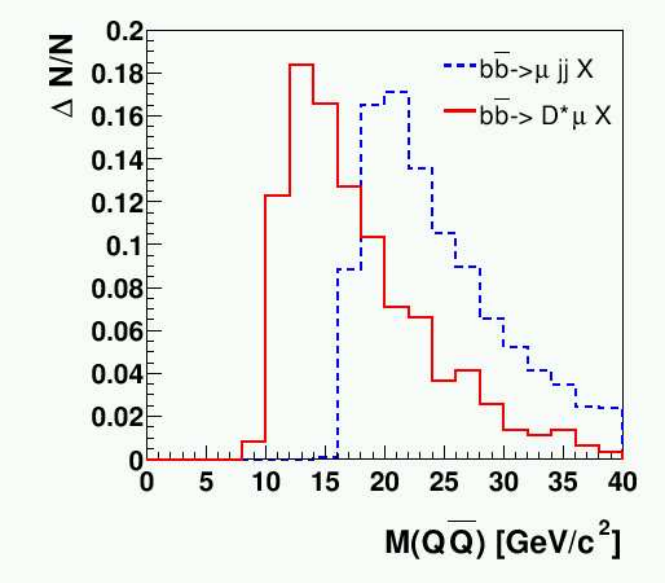


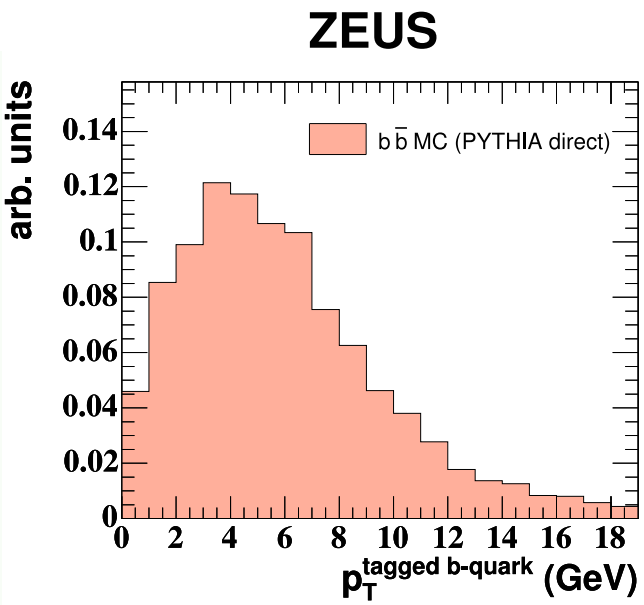


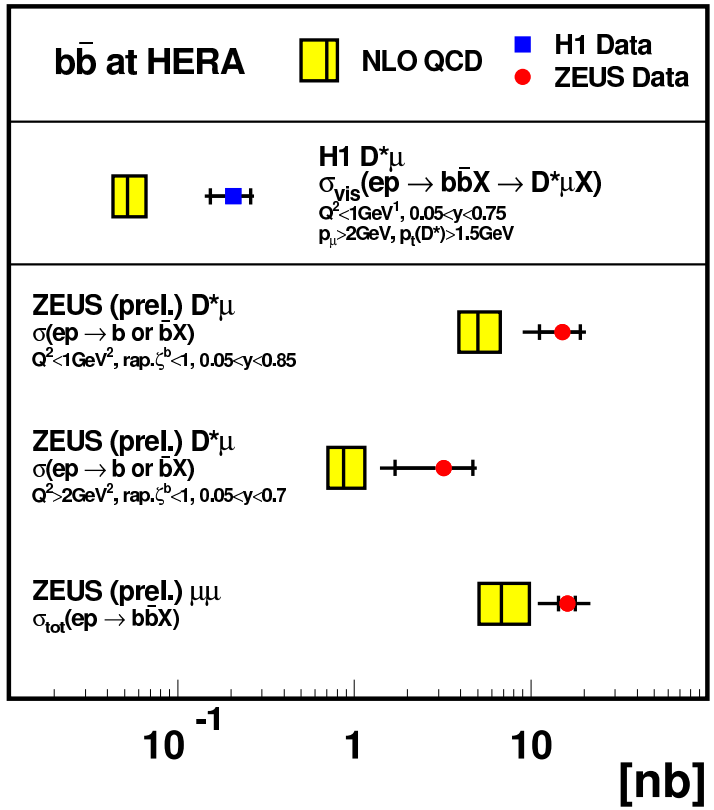
First ZEUS impact parameter analysis

Again no excess at low p_t^μ
Much more stat. to come!

Low momenta with $D^*\mu$ and $\mu\mu$





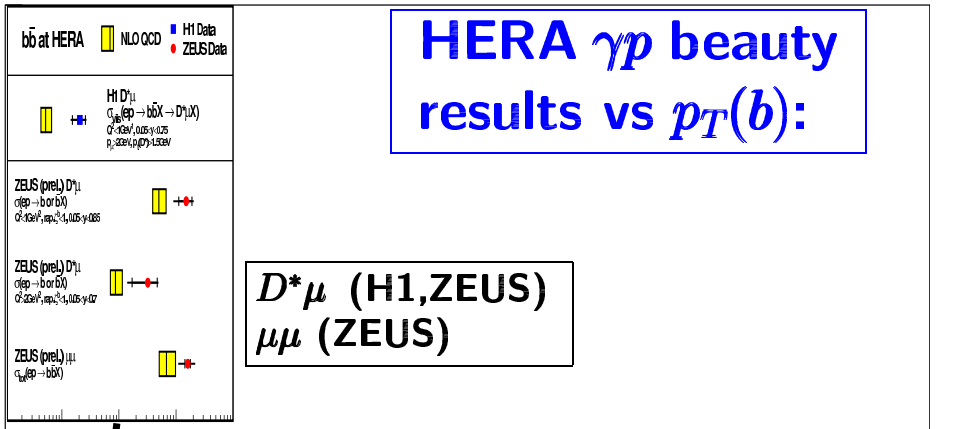


⇒ **Data factors 2-4 above NLO**

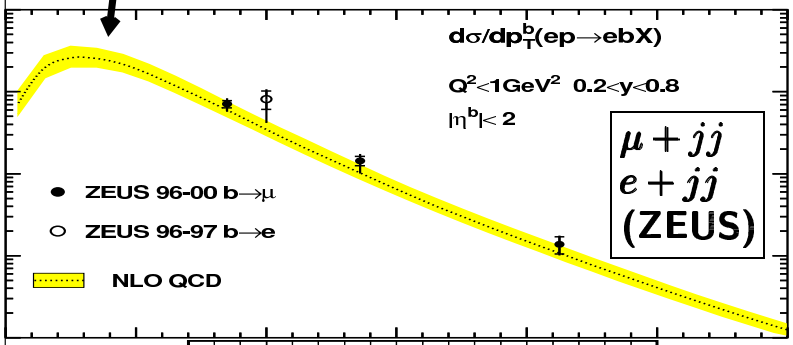
Photoproduction

Summary of results vs p_T^b

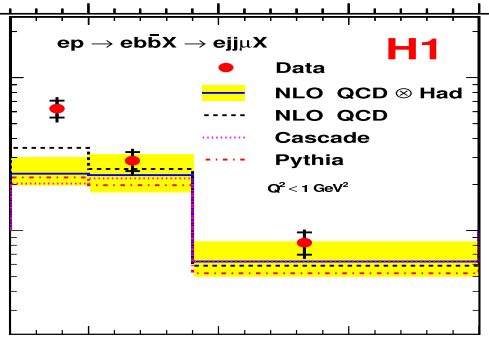
HERA γp beauty results vs $p_T(b)$:



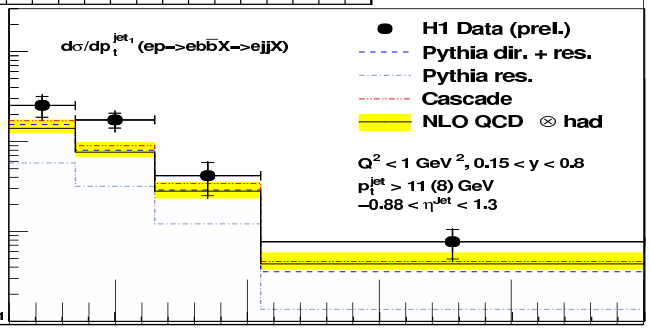
$D^*\mu$ (H1,ZEUS)
$\mu\mu$ (ZEUS)



$\mu + jj$
$e + jj$
(ZEUS)



$\mu + jj$
(H1)



Inclusive Lifetime tag (H1)

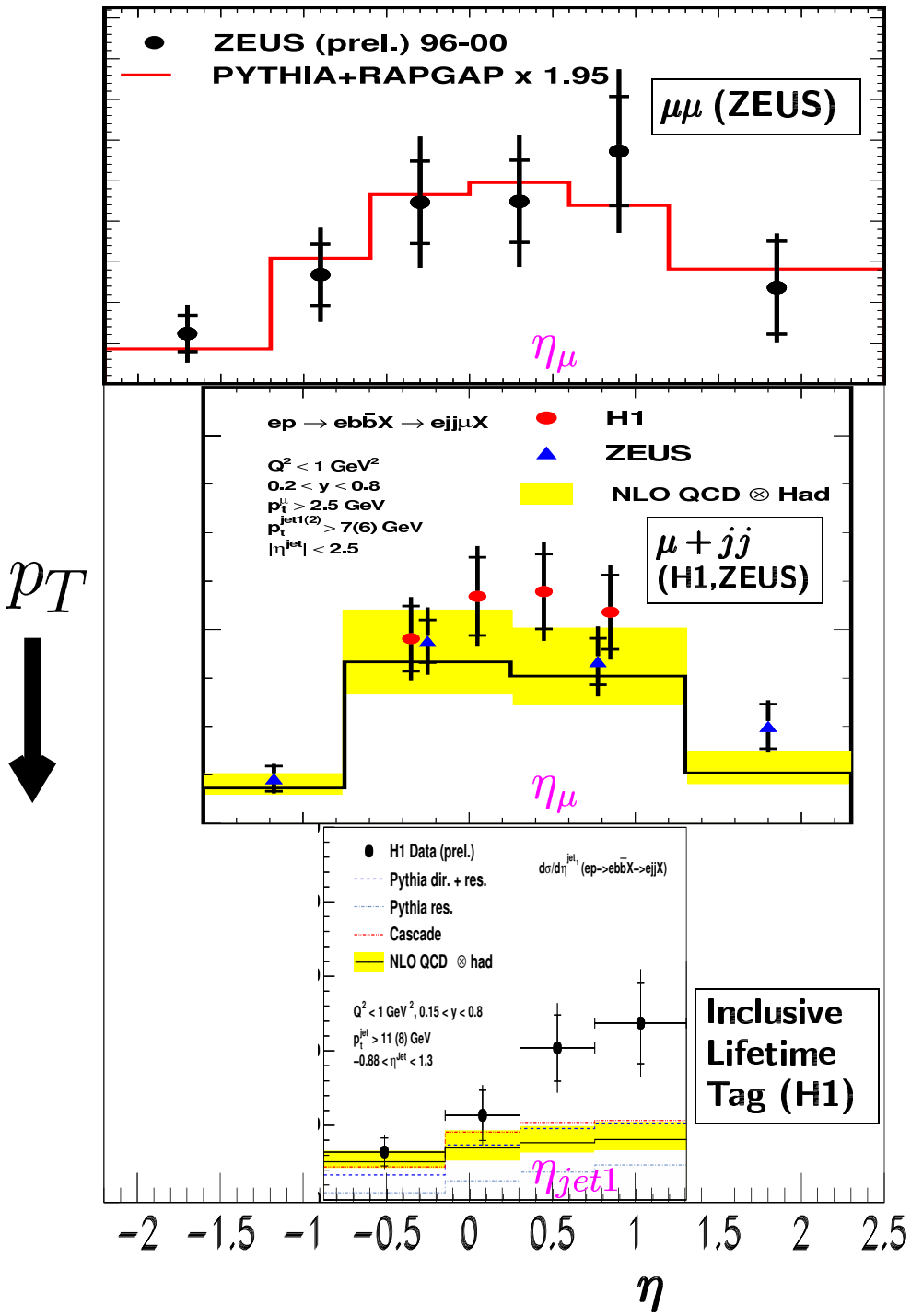
⇒ **Stretches from $0-35$ GeV, i.e. from $p_t^b \ll m_b$ to $p_t^b > m_b$**

⇒ **Excesses data/NLO seen for certain measurements - for others not - further clarifications needed**

Photoproduction

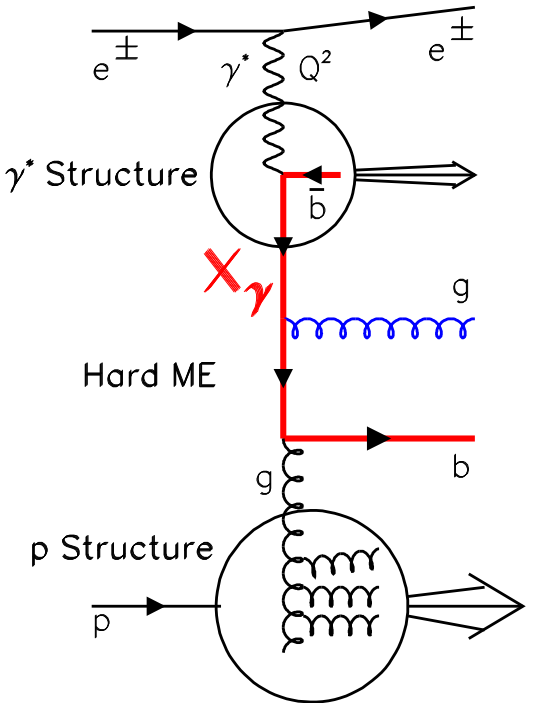
Summary of results vs η

HERA γp beauty results vs η_μ, η_{jet}:



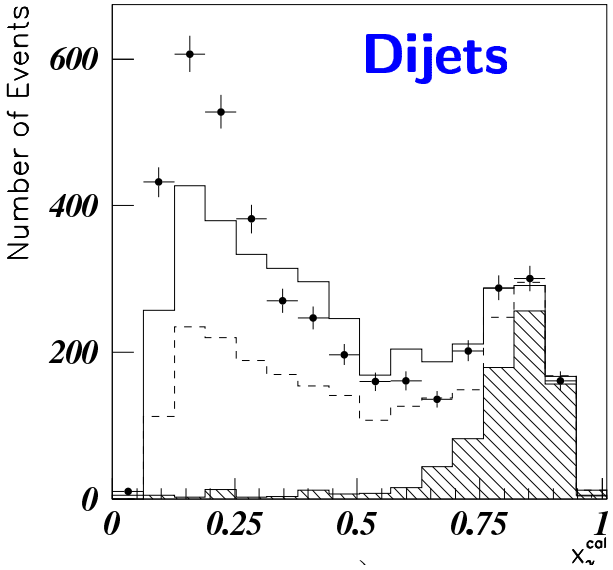
$\Rightarrow$ **Trend for excess data/NLO for $\eta > 0$ (???)**

Resolved photon structure for different flavours

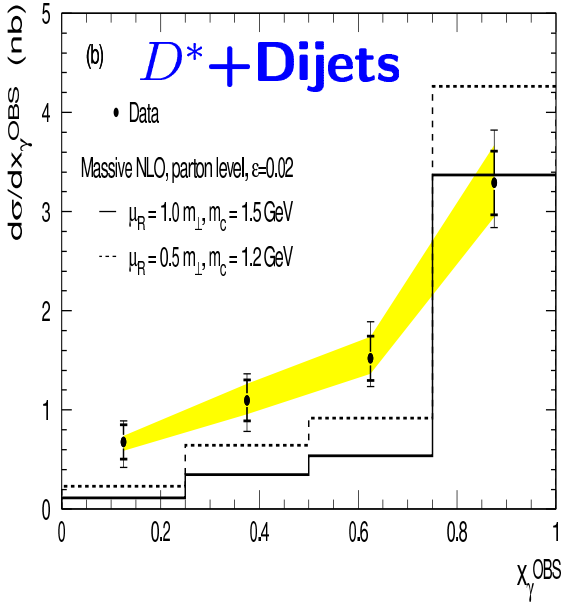


$$x_\gamma = \frac{\sum_{Jet1,2} E - P_z}{\sum_{All} E - P_z}$$

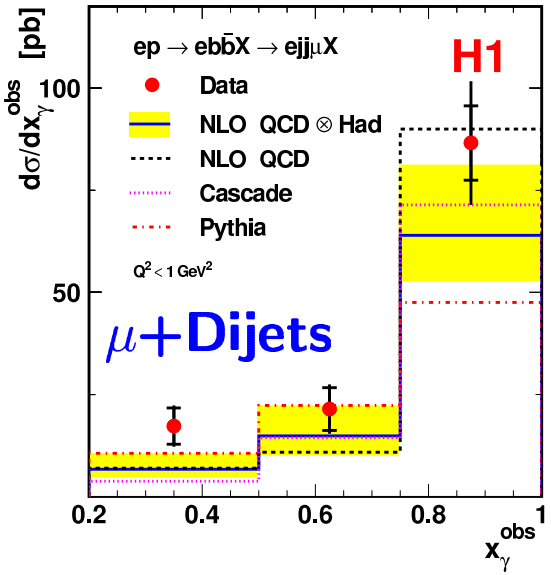
udscb



c

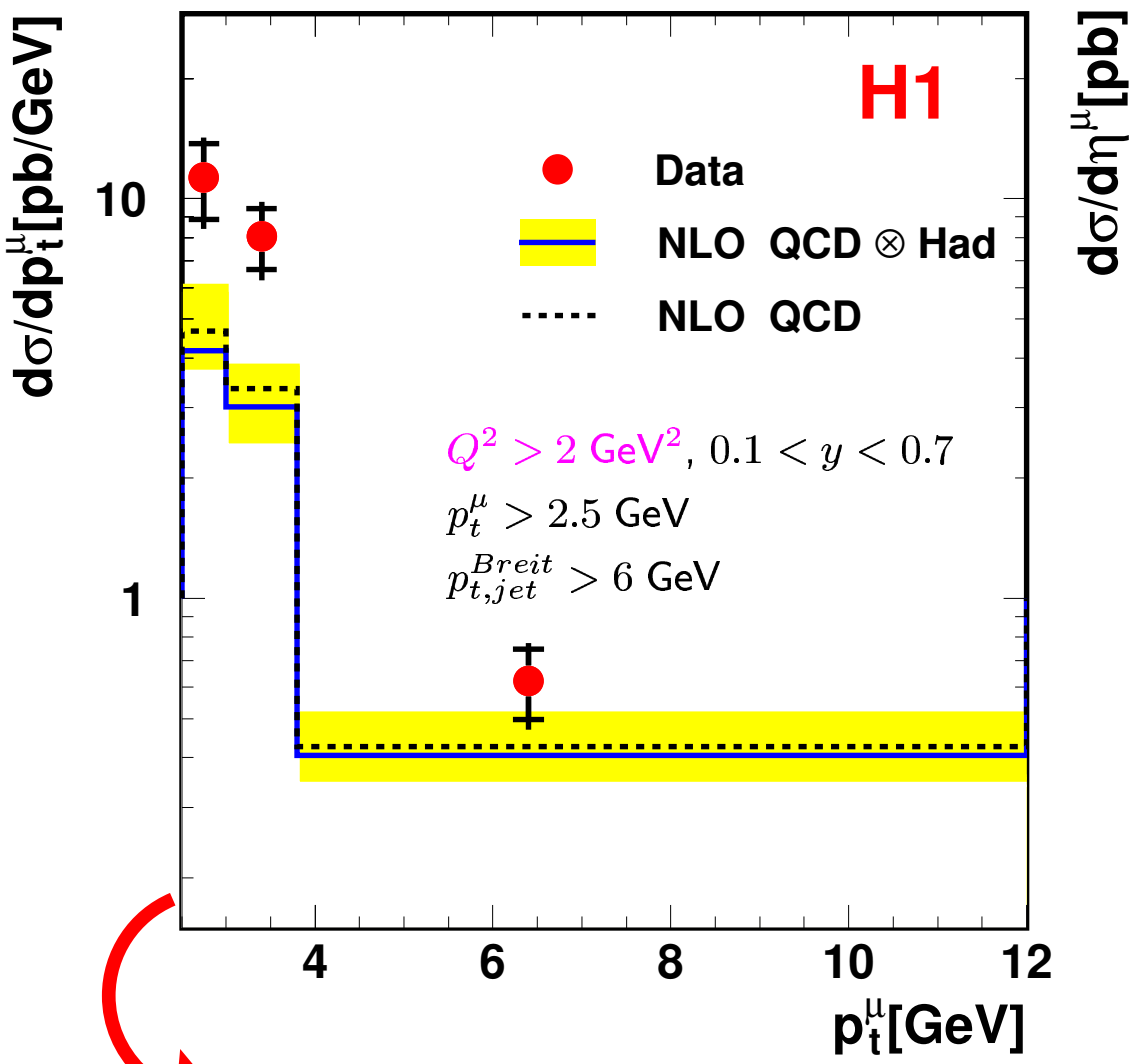


b

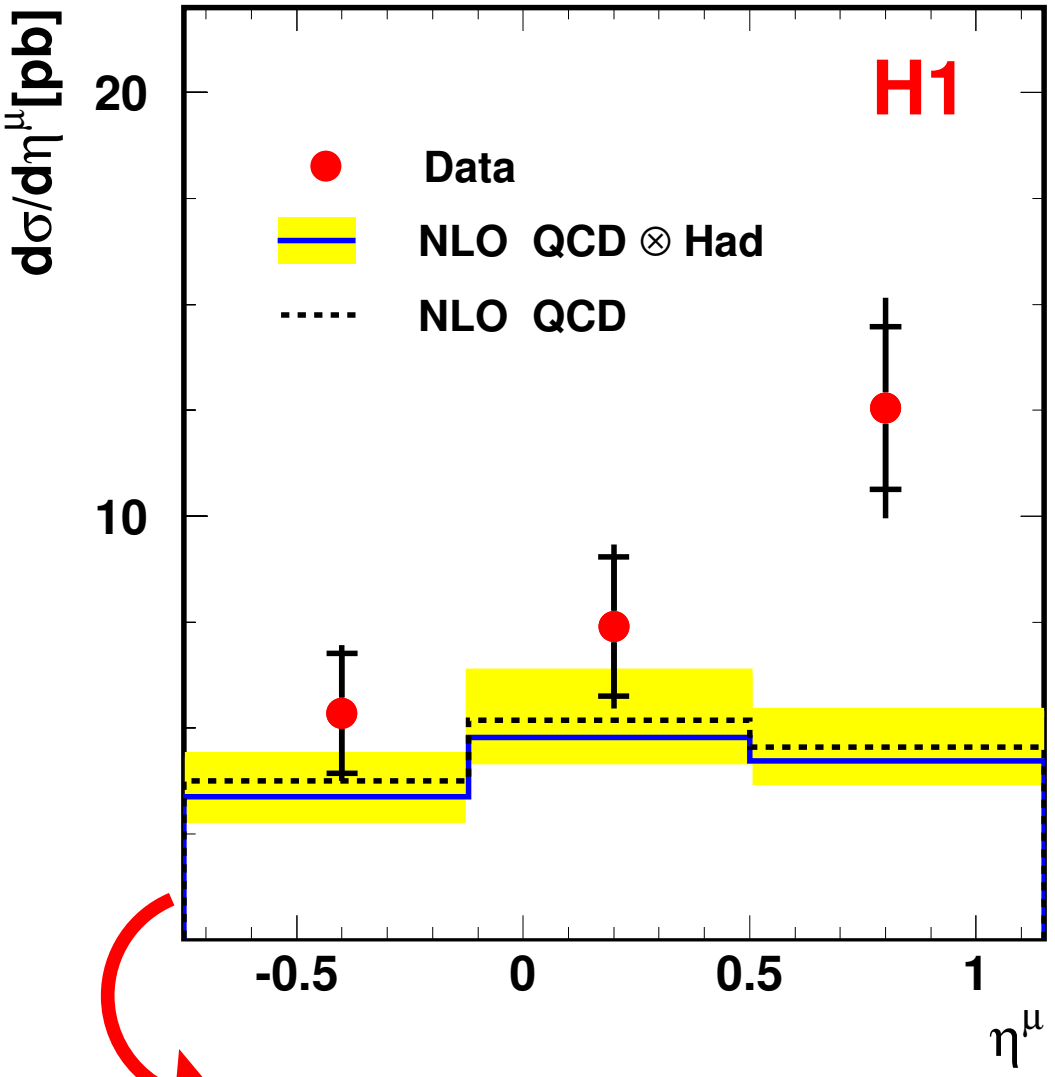


⇒ **Suppression of resolved photons ($x_\gamma < 0.75$) with quark mass!**

DIS with μ+jet: vs. Muon p_T and η

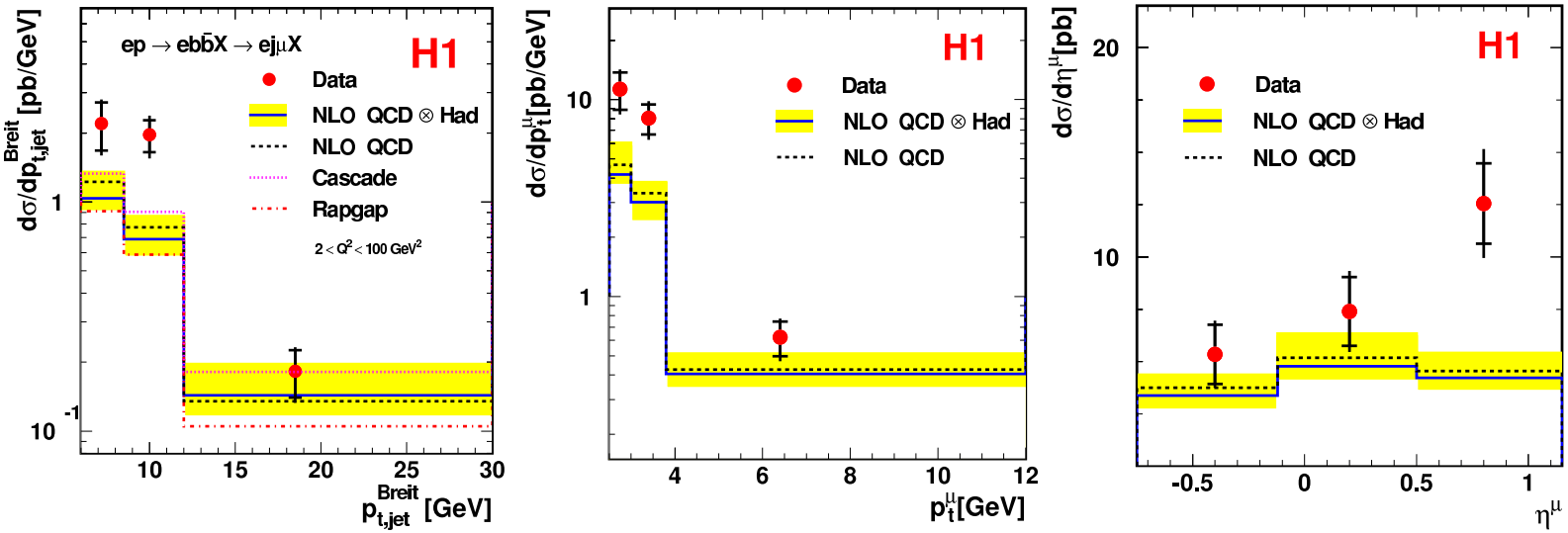


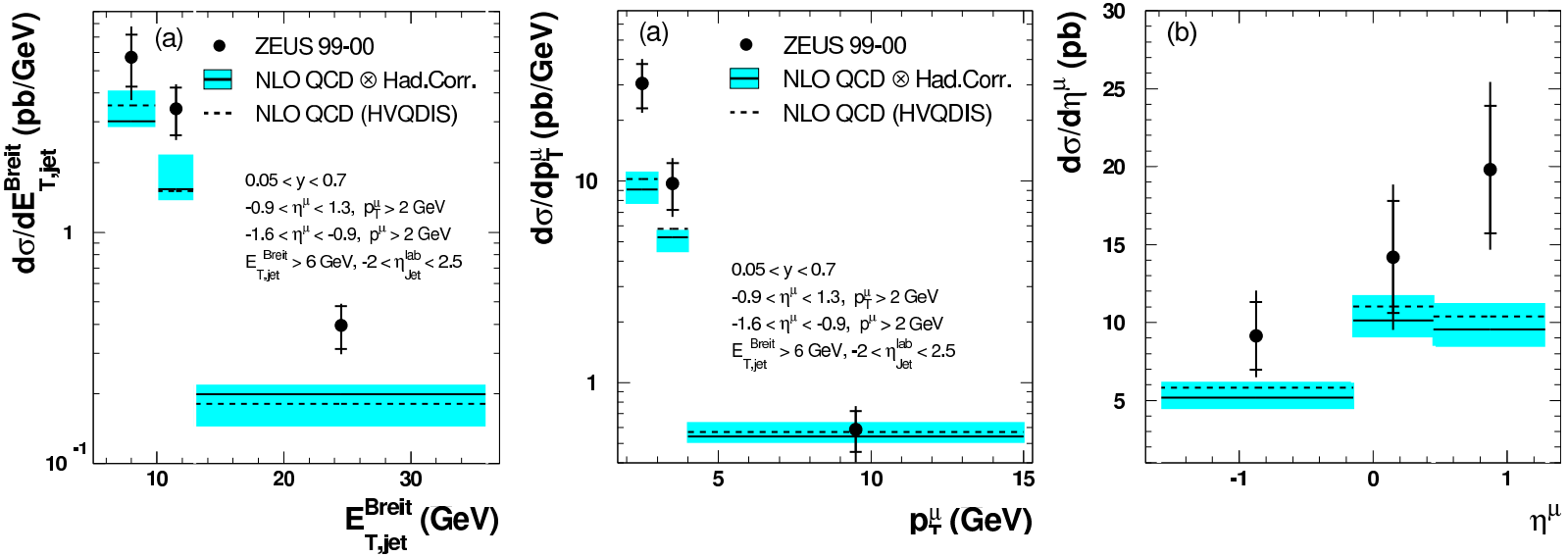
Massive NLO (HVQDIS): Too low at low p_T^μ



Massive NLO: Too low in forward direction

DIS with μ+jet: H1 vs. ZEUS





H1 Excesses:

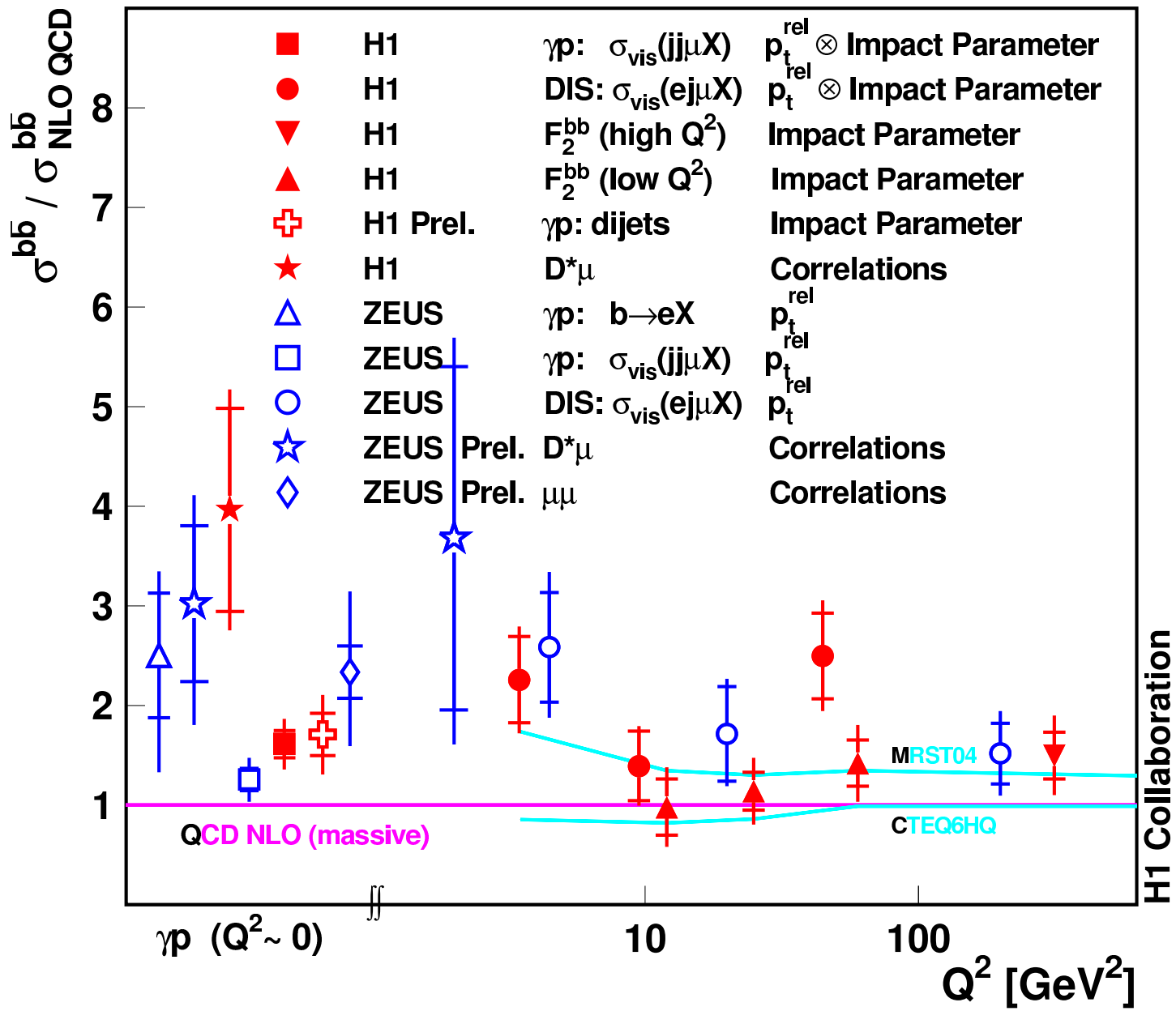
- **Small** p_T^{jet}
- Small p_T^{μ}
- Positive η

ZEUS Excesses:

- **Large** p_T^{jet}
- Small p_T^{μ}
- Positive η

$\Rightarrow$ **H1 vs ZEUS: Agreement for p_T^{μ}, η_{μ}, not quite for p_T^{jet}**

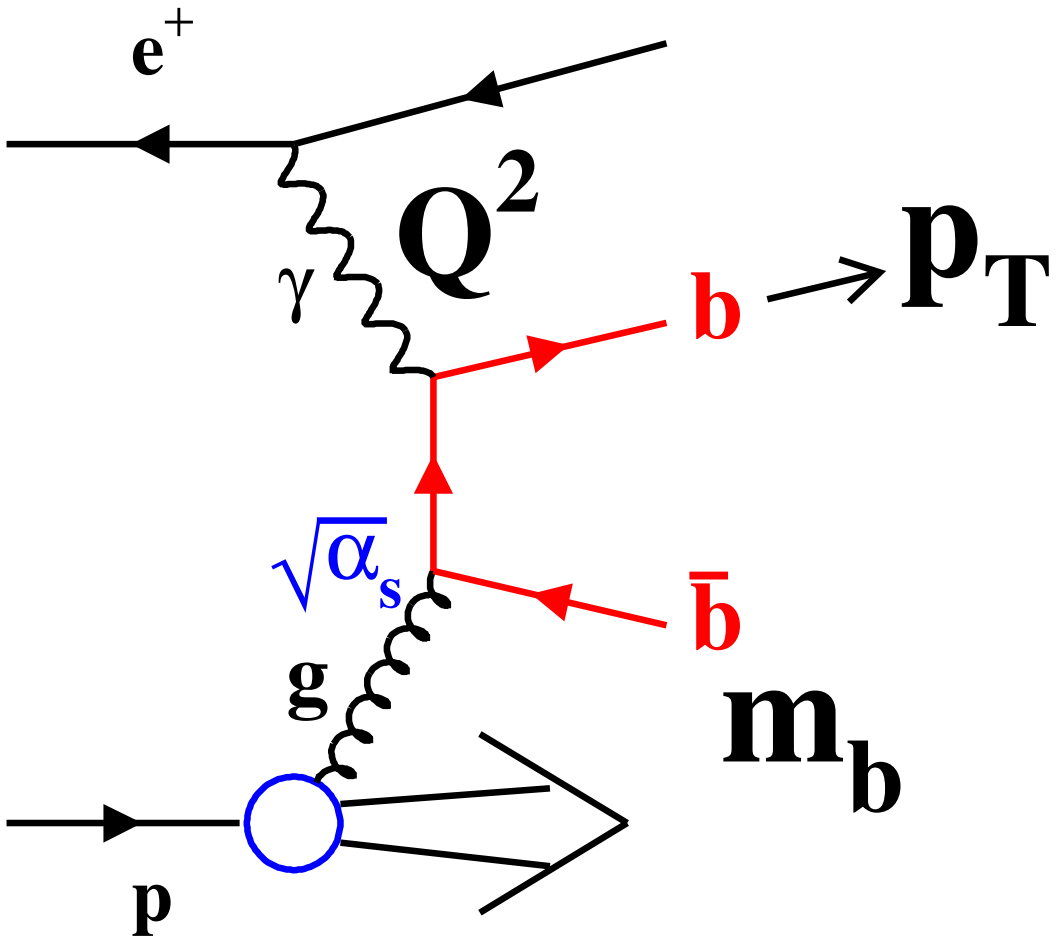
More recent HERA beauty results vs. Q^2



⇒ **Most Data above Massive NLO**

⇒ **VFNS NLO: MRST04 better CTEQ6HQ not**

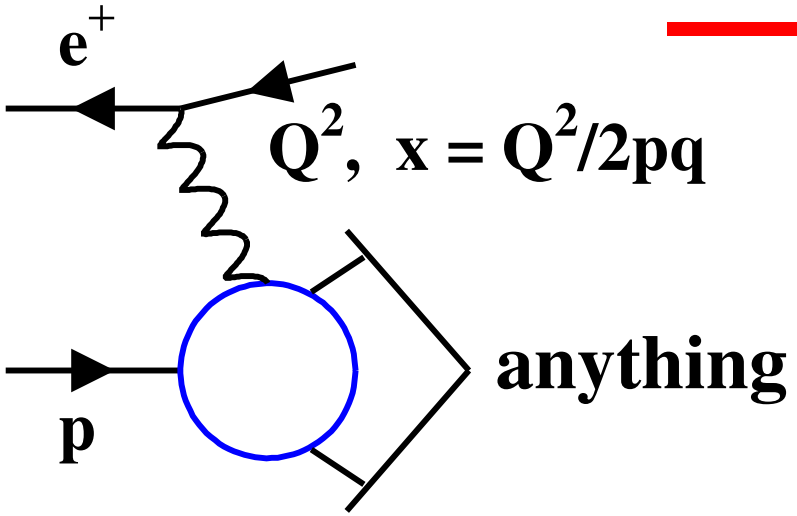
Comments from Stan Brodsky on possible excesses of beauty production at HERA at low b momenta



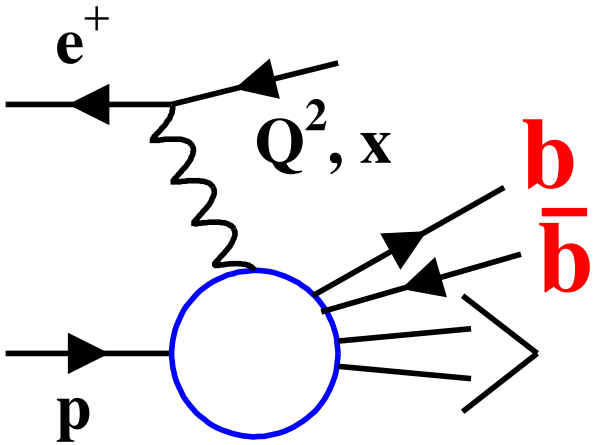
"Which μ_r scale are you using for NLO?
Q^2, p_T, m_b, etc.?
All wrong, you should use t, i.e. the squared invariant mass of the gluon!"

"Excess could be related to Schwinger corrections"

Beauty contribution to inclusive DIS



$$\frac{d^2\sigma^{ep}}{dQ^2dx} \propto F_2(x,Q^2)$$

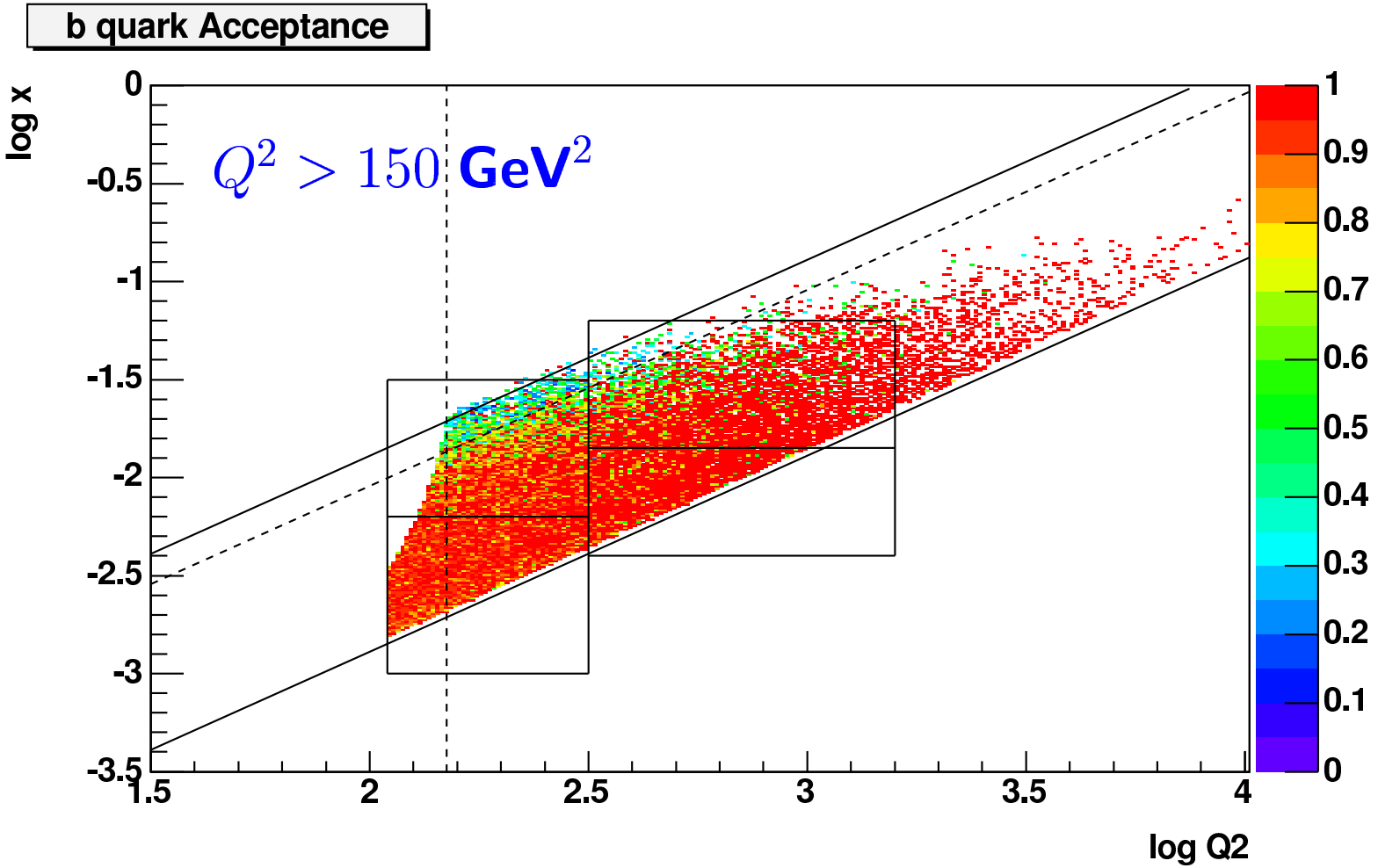


$$\frac{d^2\sigma^{ep\to b\bar{b}x}}{dQ^2dx} \propto F_2^{b\bar{b}}(x,Q^2)$$

Use inclusive lifetime tagging to determine fraction of b quark events $\rightarrow F_2^{b\bar{b}}$

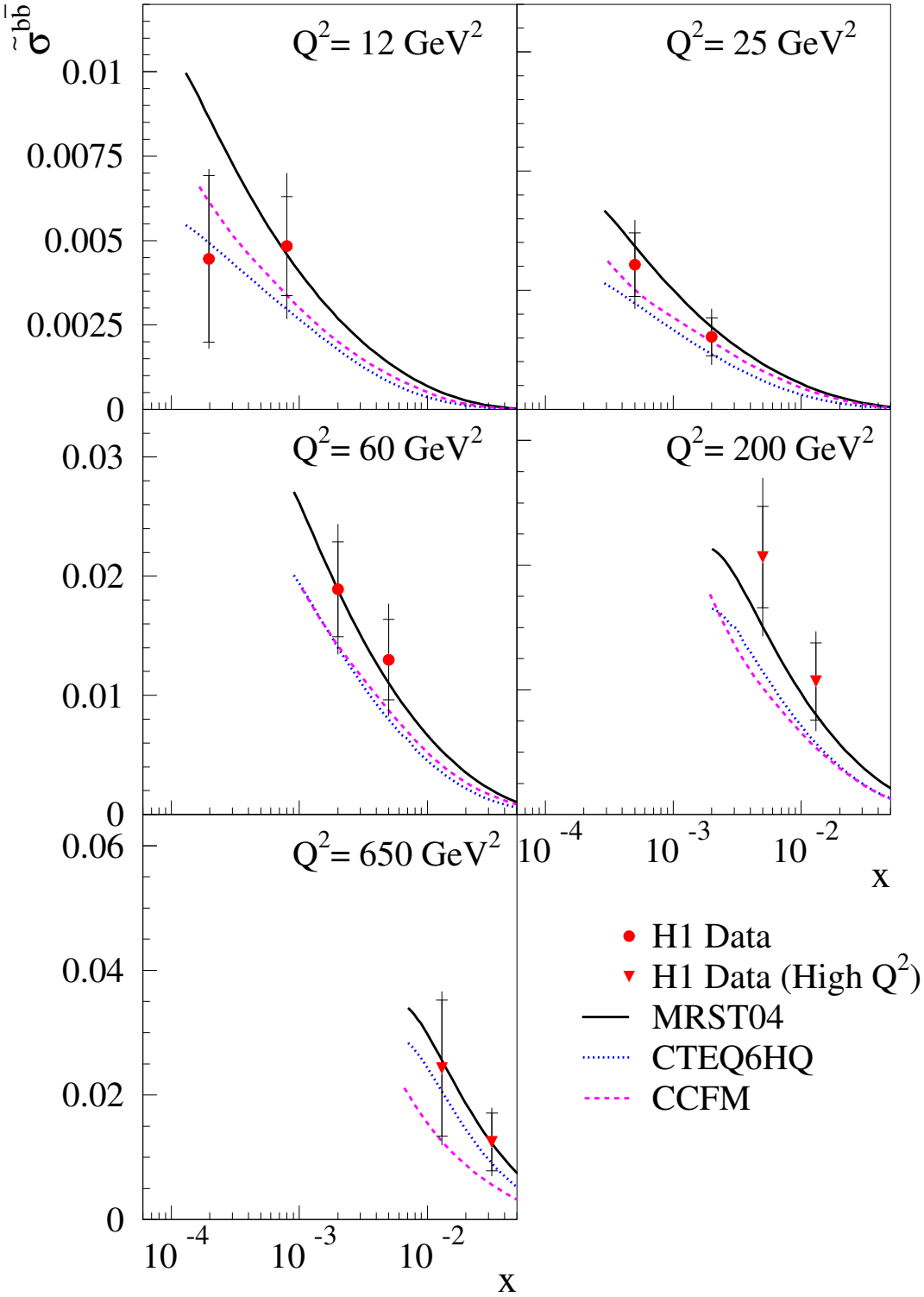
b-quark acceptance of inclusive lifetime tag

- **Exp. requirement: At least one charged B-decay track with $p_T > 0.5$ GeV in the Si acceptance region $30^\circ < \theta < 150^\circ$**



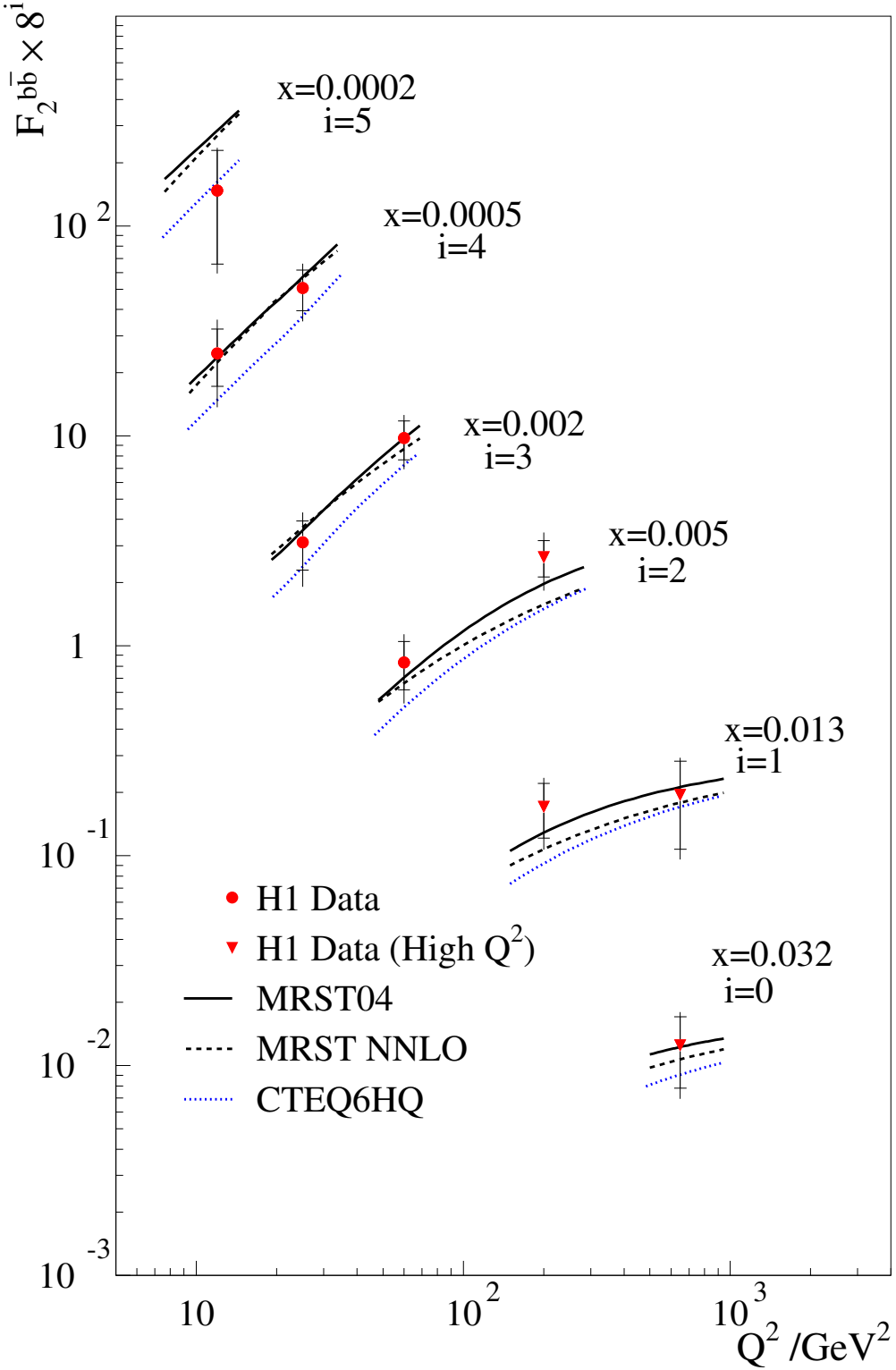
$\Rightarrow$ **$> 90\%$ acceptance $\Rightarrow$ small extrapolations for $F_2^{b\bar{b}}$**

$F_2^{b\bar{b}}$ vs x in bins of Q^2

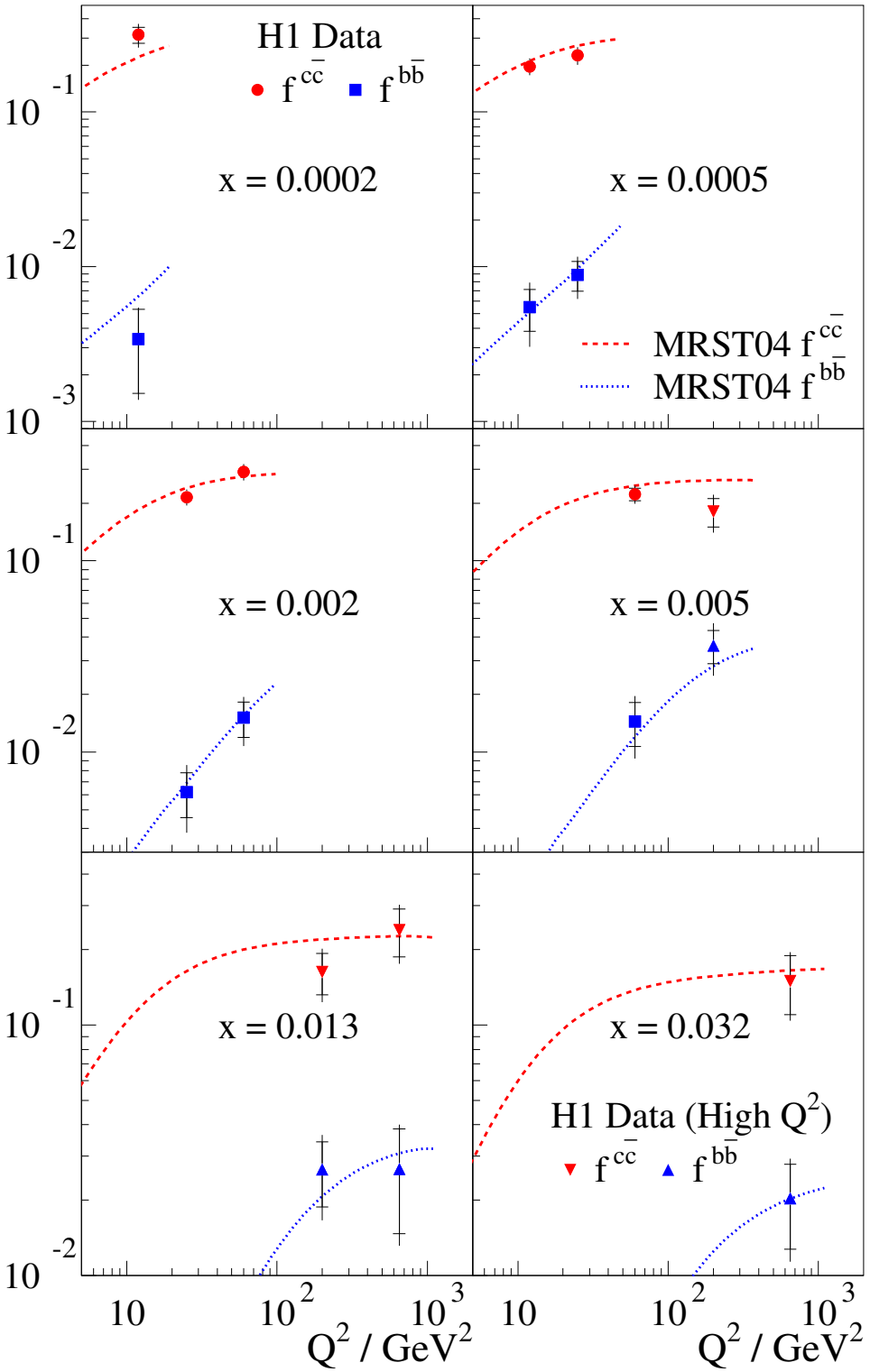


- **First measurements at all!**
- **Rise towards smaller x and larger Q^2 $\leftrightarrow$ gluon density**
- **MRST04 and CTEQ6HQ differ up to factor two!**
- **Data described well by calculations**

$F_2^{b\bar{b}}$ vs Q^2 in bins of x



- **Large scaling violations**
- **First NNLO calculation, from Robert Thorne:**
  $\rightarrow$ mostly lower than NLO (max. 40%)
- **Data in agreement also with NNLO**



Fraction $F_2^{b\bar{b}} / F_2$ of Beauty events in DIS

$\Rightarrow$ **Dramatic increase from**

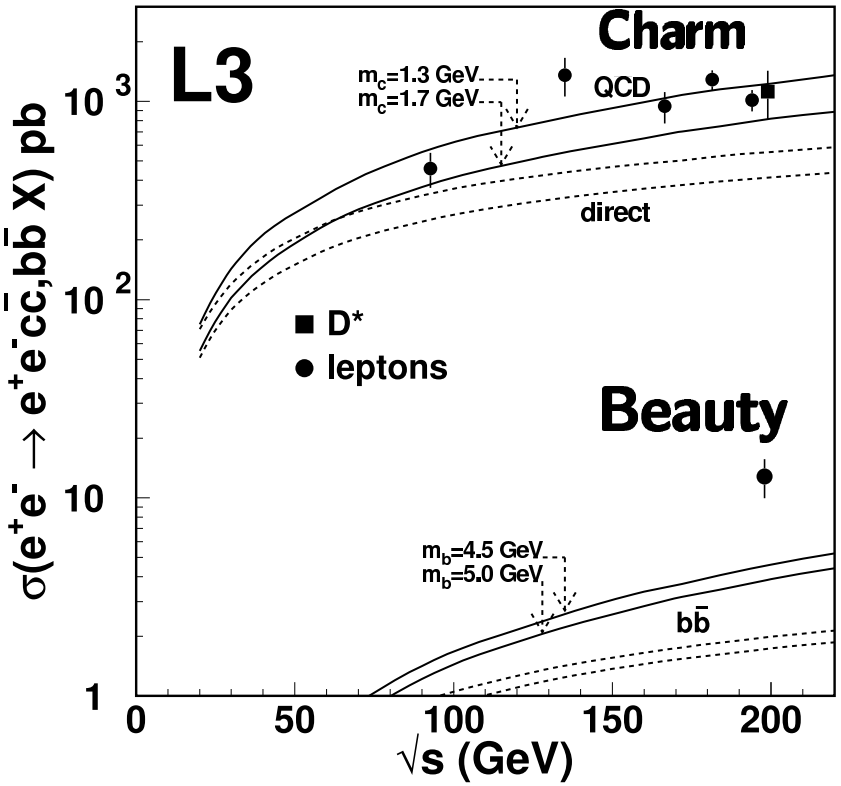
Few permille at $Q^2 = 12$ **GeV**^{2}

to

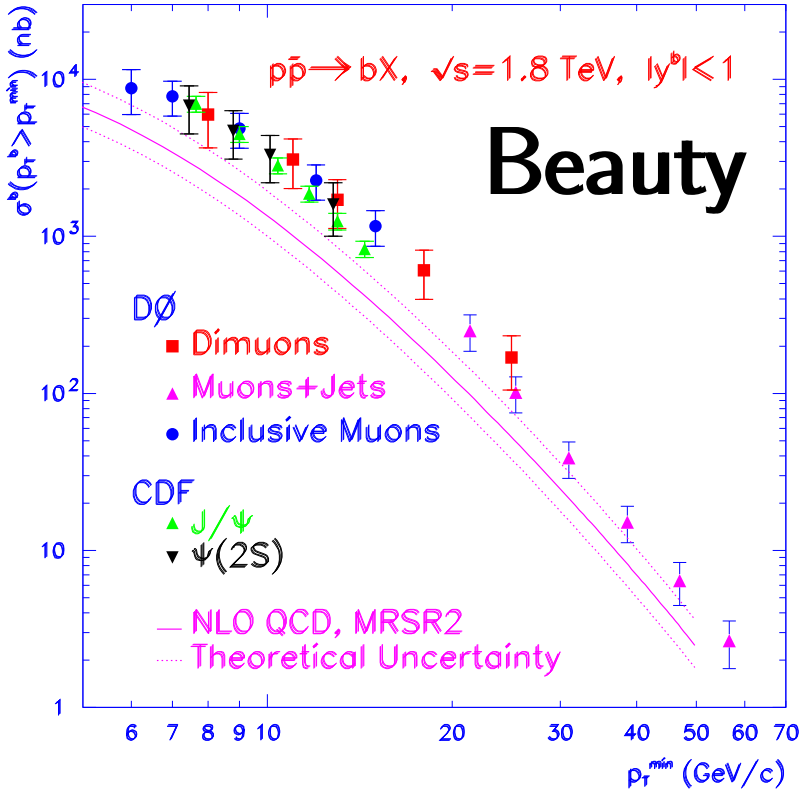
Few percent at $Q^2 > 150$ **GeV**^{2}

Beauty results at other colliders

$\gamma\gamma$ LEP



$p\bar{p}$ Tevatron RUN I

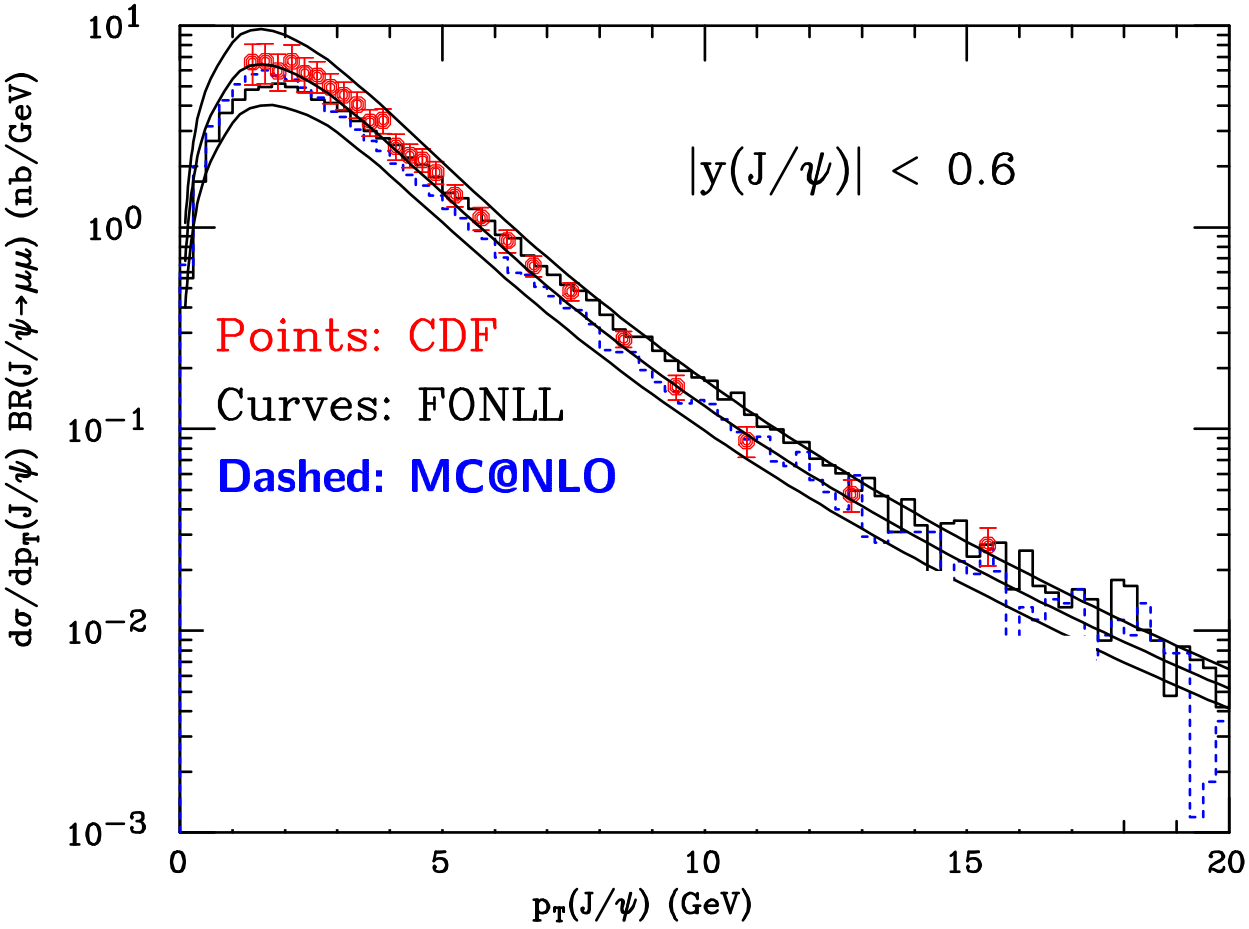


$\Rightarrow$ *Beauty excesses!*

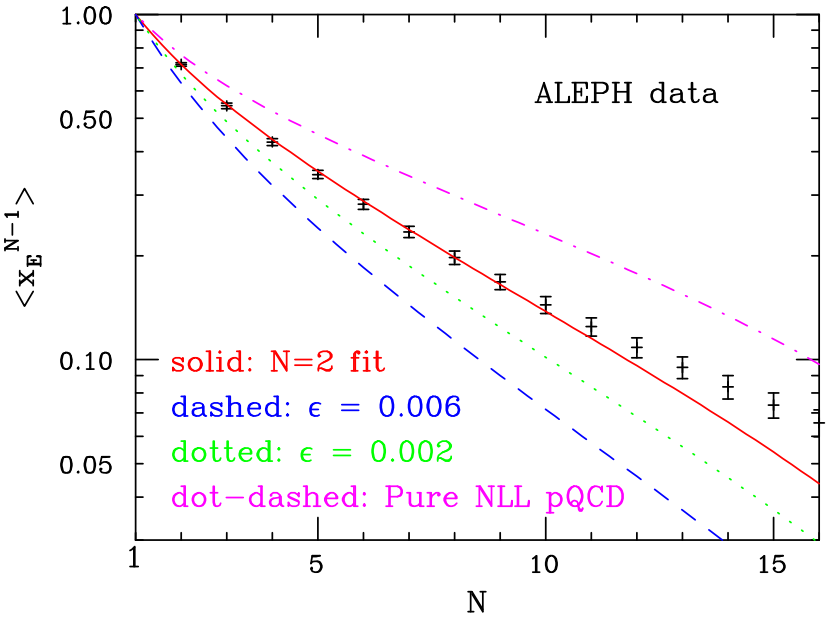
Note: L3 result is probably the final experimental word from LEP!
News @EPS05: L3 provides data also without MC extrapolations $\to$
Chances for improved NLO descriptions in visible data ranges???

Beauty at Tevatron Run-II

Improved NLO calculations available with e.g. more consistent treatment of fragmentation



Cacciari et al: Fragmentation fit to LEP data → use for FONLL



⇒ Much improved description!

We want to have the improved models for HERA too!

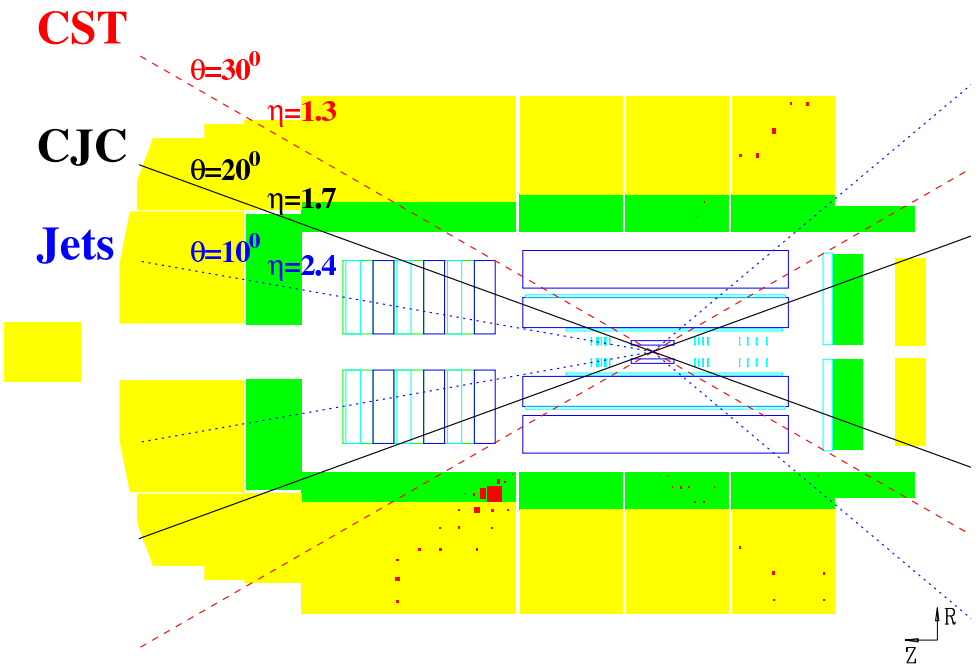
Summary

- **Beauty at HERA I: Exploring the kinematic phase space**
  $0 < Q^2 < 1000$ **GeV**^{2} $\quad 0 < p_T^b < 35$ **GeV** $\quad -2 < \eta_b < 2$
- **Total measurements with** $\sim 20\%$ **errors, in bins often** $\sim 50\%$
- **Observed trends: Data systematically above massive NLO at small** p_t^b **and in more forward direction**
- **However, some measurements in good agreement, further clarifications needed!**
- **Differences of**
  1. **Massive NLO**
  2. **variable flavour number schemes (VFNS) NLO**
  3. **and VFNS NNLO**

  up to factor 2 $\Rightarrow$ **Resolvable with higher data statistics!**

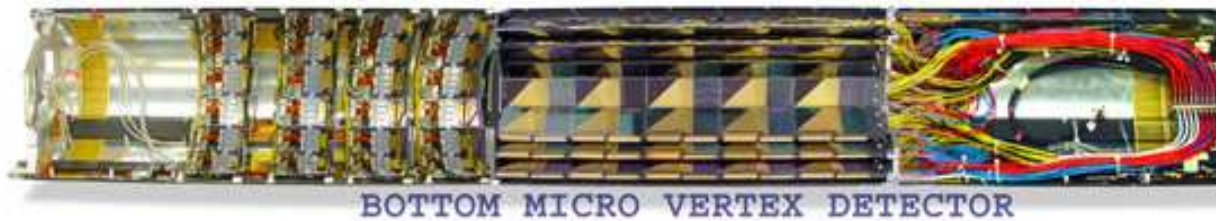
Beauty perspectives with HERA-II

≥ 5 times more statistics $\rightarrow$ enter the $\sim 10\%$ precision regime



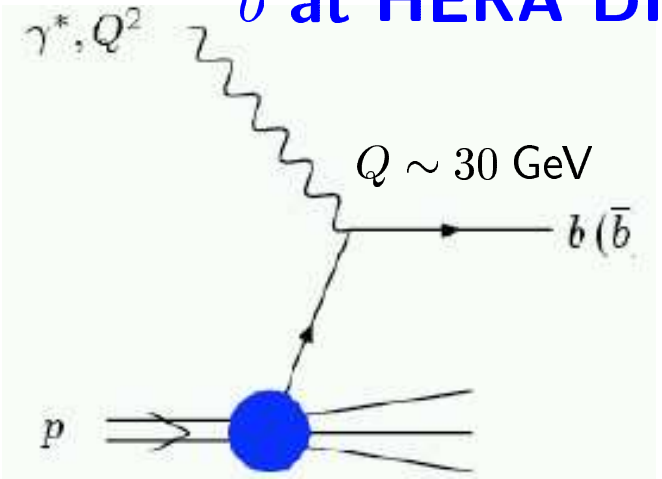
HERA I detector acceptance restrictions: Silicon (CST) in central region

HERA II $\rightarrow$ Si all over the place: Example ZEUS MVD: Extend also to more forward region!

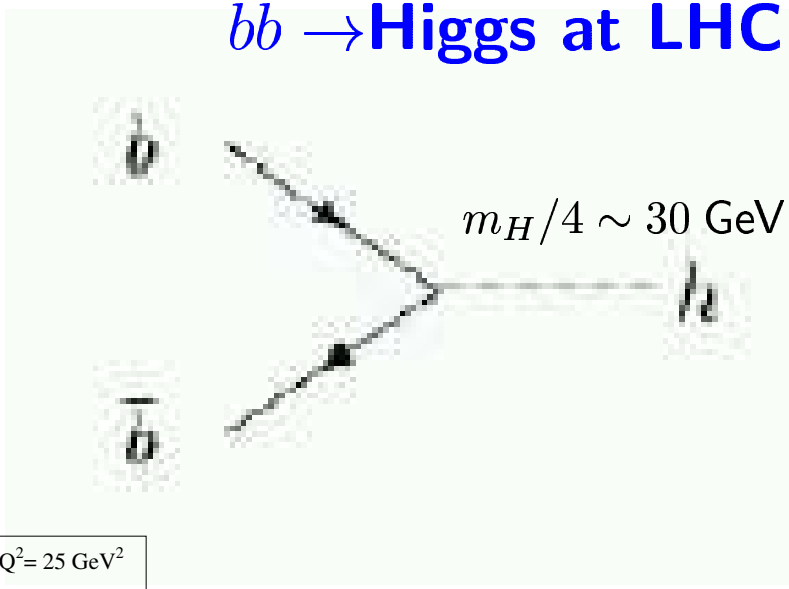


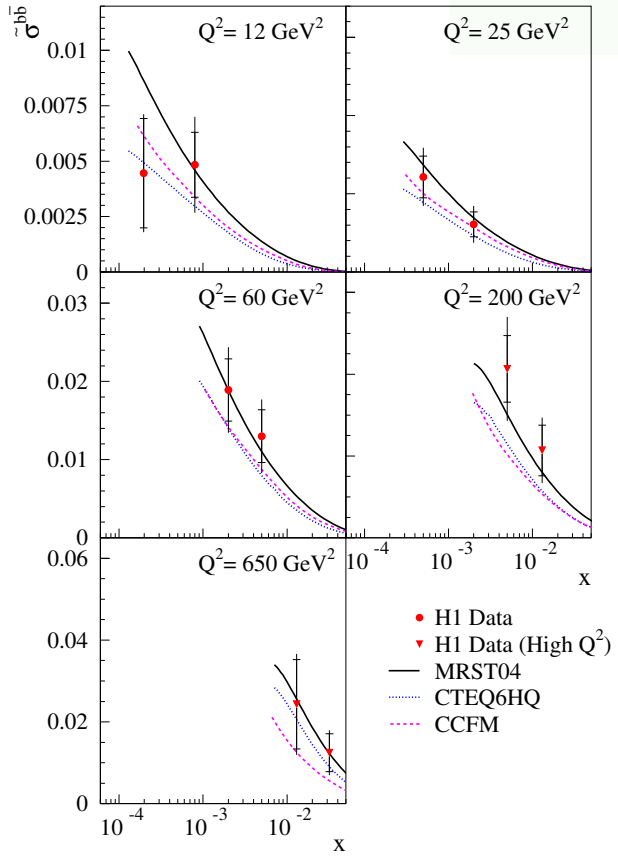
Vision (Maltoni): b-pdf from HERA goes to LHC

b at HERA DIS



$b\bar{b} \rightarrow$ Higgs at LHC





$\Rightarrow$ **QPM:** $F_2^{b\bar{b}} \sim b(x) + \bar{b}(x)$

$\Rightarrow$ **Measure $F_2^{b\bar{b}}$ at HERA II as precisely as possible**