Measurement of the photoproduction of b-quarks at threshold at HERA

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Beauty Physics at HERA, a selection:

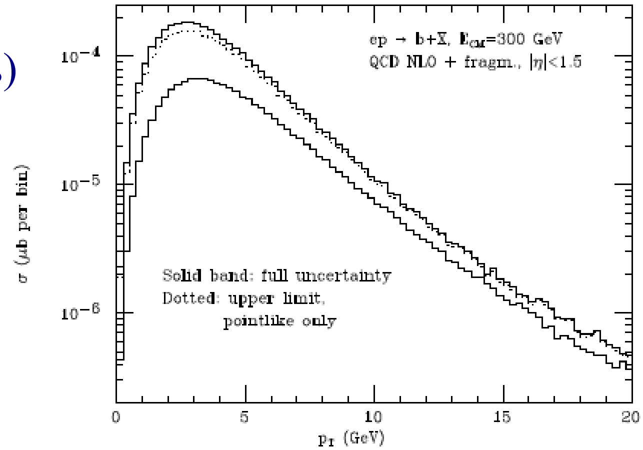
1992 HERA starts its operation (ep collisions)

1996 Prediction of beauty production in ep scattering
Frixione et al., hep-ph/9702287

Late 1990ies First beauty measurements.

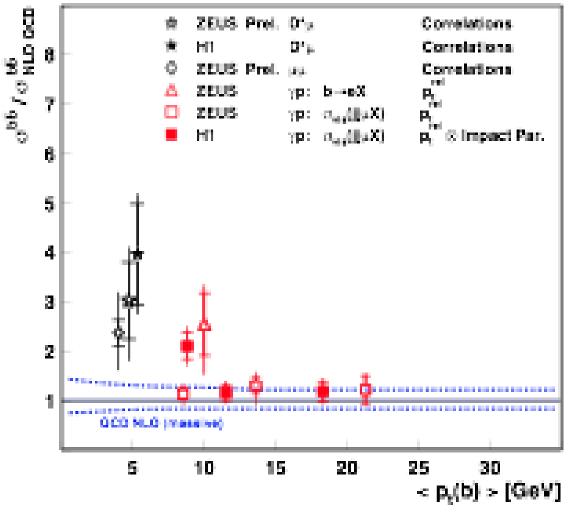
Mid 2000's Several of beauty measurements.

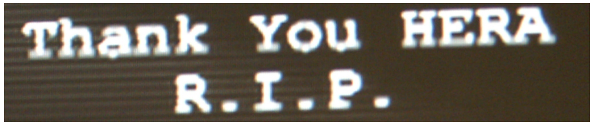
2007 HERA switched off



"The transverse momentum ob bottom quark at HERA can be predicted by perturbative QCD quite accurately. … The comparison of this prediction with the data would be extremely useful … ".

"The differential spectra indicate that the data tend to lie above the predictions more significantly towards small b-quark momenta… ".

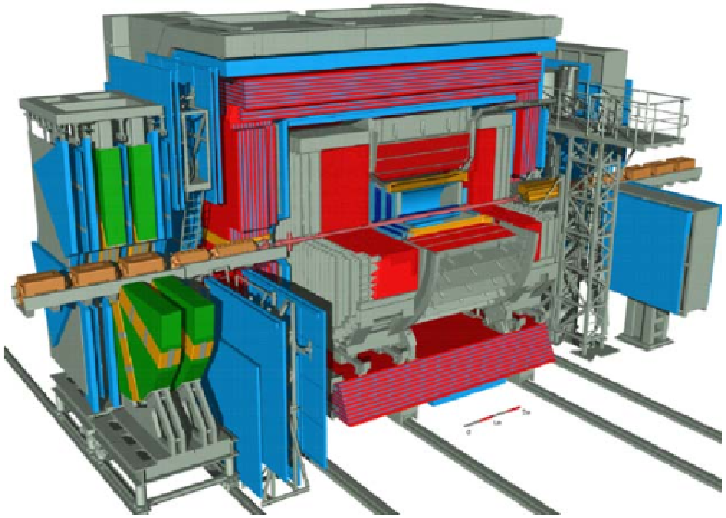


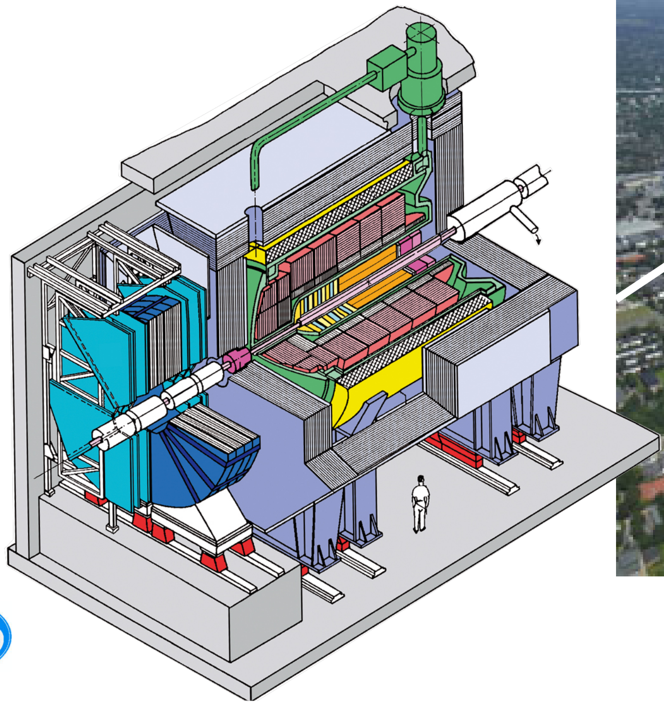


This analysis: Measurement of the photoproduction of b-quarks with a special focus on **small b-quark momenta**.

The HERA ep collider (1992 - 2007)

- ep collider:
- $e^{\pm}$ energy: 27.6 GeV
- p energy: 920 GeV
- Center of mass energy: 319 GeV
- 2 collider experiments: H1 and ZEUS
- Integrated luminosity: ~0.5 fb^{-1} (per experiment)



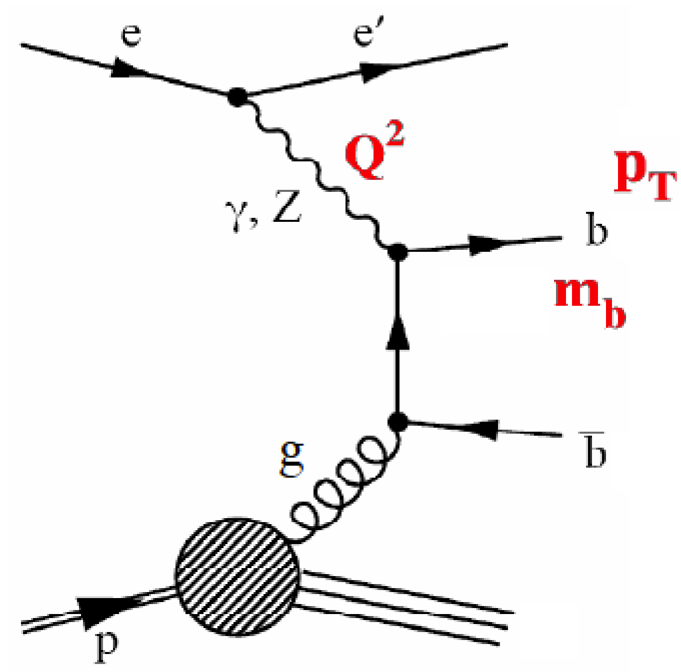


Motivation to measure heavy flavor production

- Beauty quarks in ep interactions at HERA are mainly produced in Photon-Gluon-Fusion.

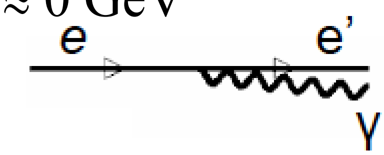
- Hard scales for perturbative QCD:
  - m_b, p_T, Q^2
    - multi-scale problem.

- pQCD approximations:
  - Massive scheme:
    - b quarks treated massive.
    - Valid for **small scales $\mu^2 \approx m_b^2$**
  - Massless scheme:
    - b quarks treated as massless partons in the proton and photon.
    - Valid for **large scales $\mu^2 \gg m_b^2$**

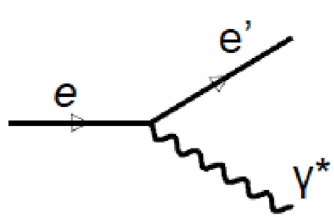


Two kinematic regimes:

- Photoproduction: $Q^2 \approx 0$ GeV^2



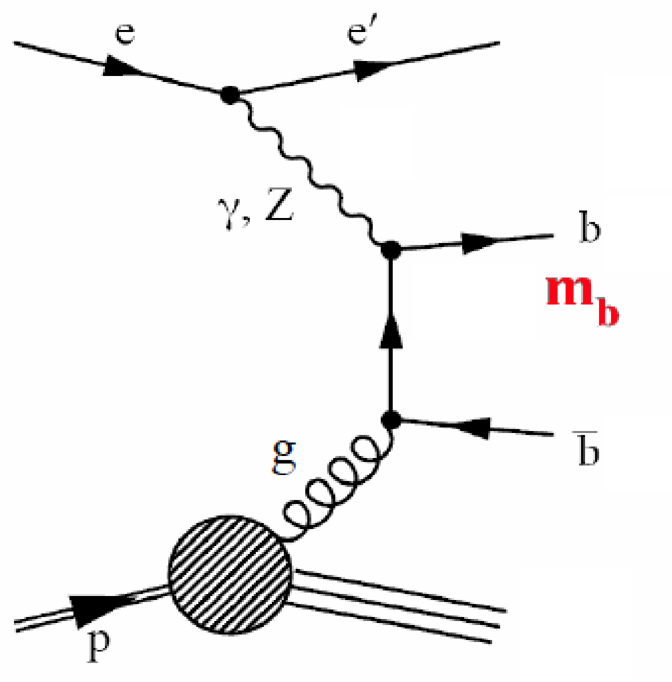
- Deep Inelastic Scattering: $Q^2 > 1$ GeV^2
  (scattered electron detected)

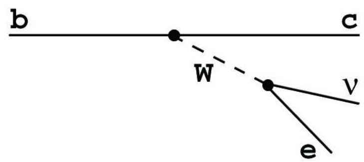


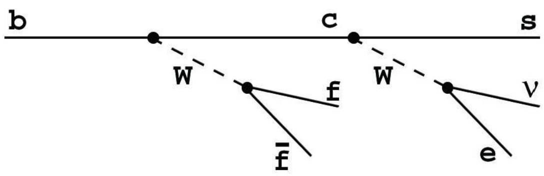
Concept of this analysis

- What happens if the only experimental hard scale is m_b?
- Experimental implications:
  - Measure in photoproduction: $Q^2 \approx 0$ GeV^2
  - Avoid jets (no p_T^{jet}-cut off) and enrich beauty with two low p_T-leptons from semileptonic decays: $p_T \approx 0$ GeV
  - low p_T-leptons : use electrons and not muons (electrons have lower experimental p_T thresholds).
- Chosen beauty-tag:
  - 2 electrons from semileptonic decays:

$$b\bar{b} \rightarrow e\,e\,X$$





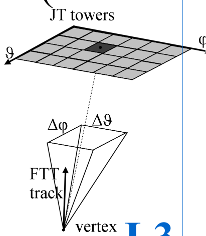


Online electron identification

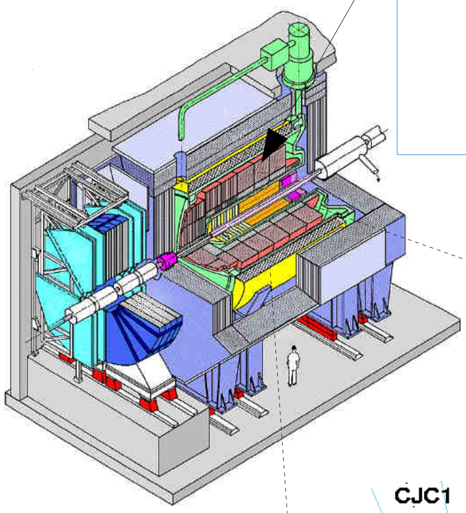
Calorimeter Trigger (JT)
16 highest **energy depositions** in calorimeter (within 2.3μs) **L1**

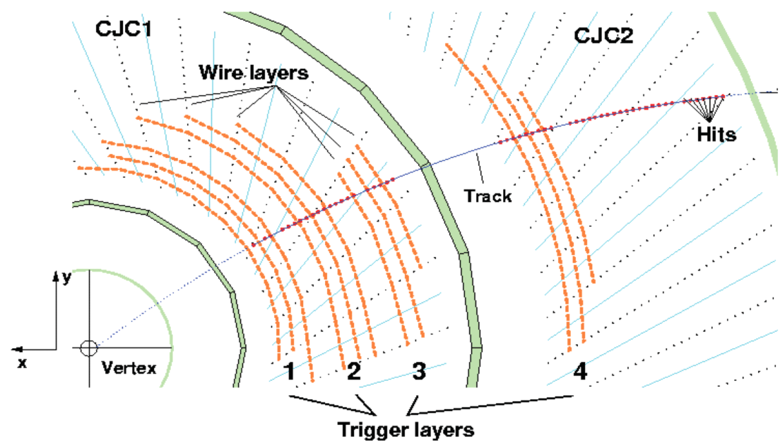
Fast Track Trigger (FTT)
Fits up to 48 **tracks** (within 20μs) **L1-L2**

Electron Trigger:
Combine information from FTT and JT (within 100μs):
- Topological match: cut on $\Delta\varphi$, $\Delta\vartheta$.
- Cut on $E_{T,JT}/p_{T,FTT}$ (enrich electrons).

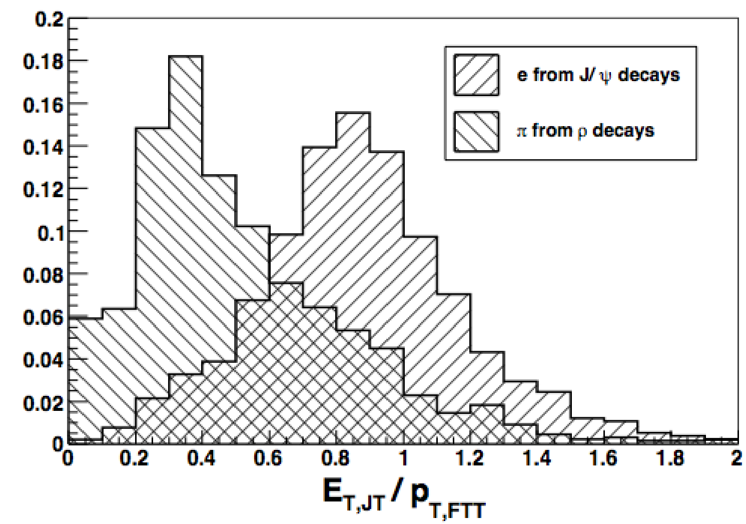


L3





Online measured $E_{T,JT}/p_{T,FTT}$



Measured data set: 47.6 pb^{-1}

1) A. W. Jung et al., First results from the third level of the H1 fast track trigger, In Proc. 15th IEEE-NPSS Real-Time Conference, 2007.
2) doi:10.3929/ethz-a-005977487.

Offline electron identification

Requirements:

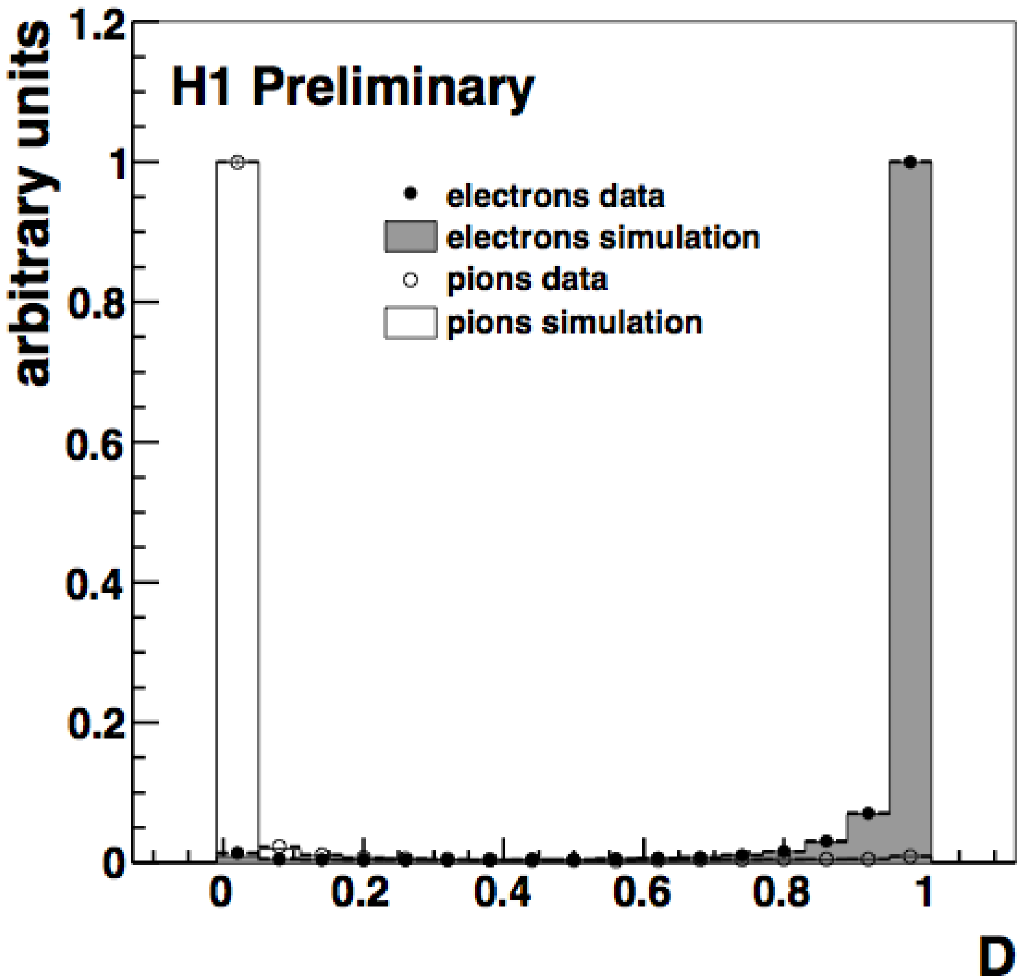
- High efficiency.
- Good background rejection (pions).
- Low p_T threshold.

Implementation:

- Neural Network (NN) based on 5 variables using input from the **calorimeter** (shower profile) and **tracker** information. The NN discriminate electrons from background (pions).
- Normalized **dEdx-likelihood**:

$$Lkh_{dEdx} = \frac{P_{dEdx}(e)}{P_{dEdx}(e) + P_{dEdx}(\pi)}$$

- Combination of NN with normalized dEdx-likelihood to a common **electron pion discriminator D.**



Excellent separation between electrons (signal) and pions (background).

Overview on the data analysis

Di-electron Selection:

- Trigger selection.
- Selection of 2 electron candidates with
  - 1 GeV < $p_T(e)$ < 5 GeV, 20 < θ < 140
- Rejection of background.
  - Rejection of non-ep background.
  - Loose isolation-criterion (better electron discriminator performance).
- Rejection of real electrons from
  - DIS events (including beam electrons).
  - γ-conversion.

Unfolding Procedure:

- Deconvolution of the **p_T(b) cross section**.
- Determination of remaining background: J/ψ, charm, electron missidentification.

Measurement of <p_T(b)> via the thrust axis-method

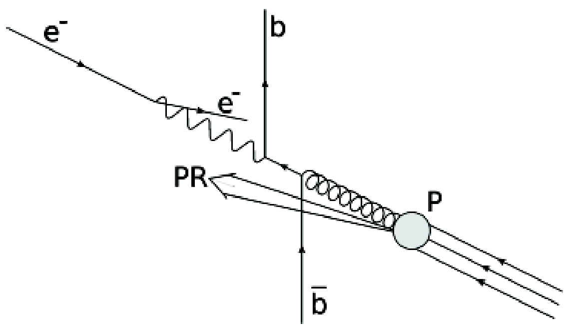
Definition of mean transverse beauty mass:

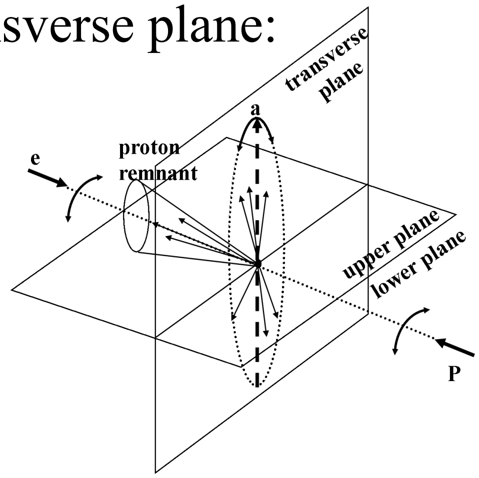
$$<m_T(b)> = \sqrt{m_b^2 + <p_T(b)>^2}$$

- Measurement of <m_T(b)> allows measurement of <p_T(b)>.

Estimator for mean transverse beauty mass:

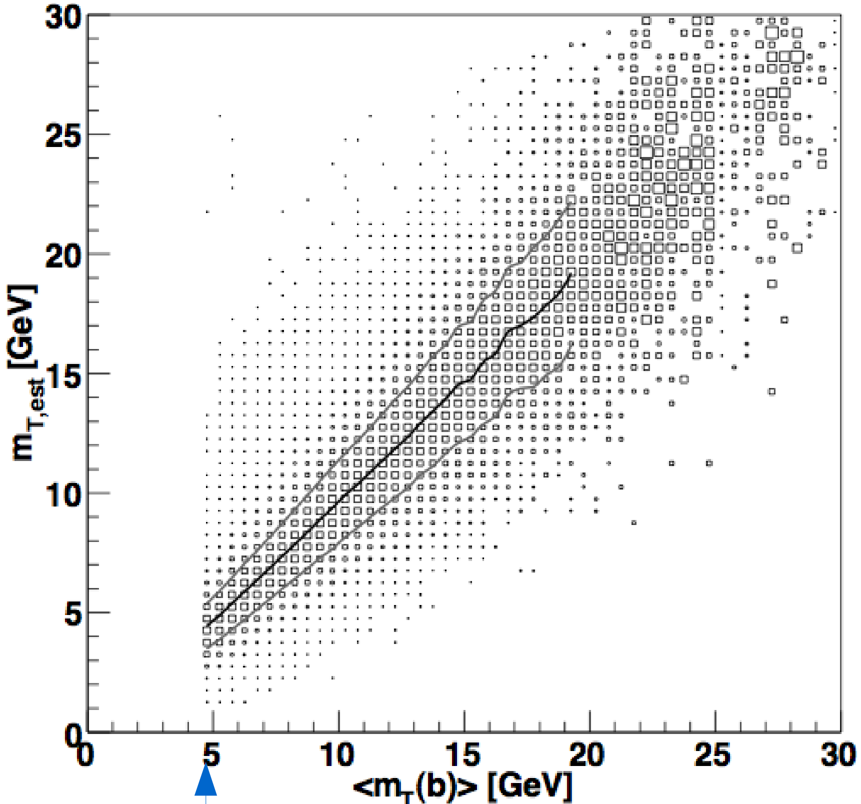
1)Determine thrust axis in transverse plane:





2)Divide event in upper part, lower part (defined by thrust axis) and proton remnant (ϑ<15).

3)Determine **estimator for mean transverse beauty mass $m_{T,est}$**, based on the vectorial sum of the energy flow in the upper and the lower part.



$p_T(b)=0 \rightarrow <m_T(b)> = m_b$

Measurement of <m_T(b)> at threshold.

Unfolding of the differential cross section

Purpose:

- Deconvolution of the **p_T(b) cross section** from the detector response.
- Determination of remaining the **background**.

Method:

- Relate measured quantities with the mean transverse b-quark momentum <p_T(b)>:

$$\boxed{y = Ax + b} \qquad (1)$$

A: ***Response matrix, determined from simulation. Aij is the probability for an event from bin I of x to be measured in bin I of y.***

y: ***Reconstructed vector (measured)***

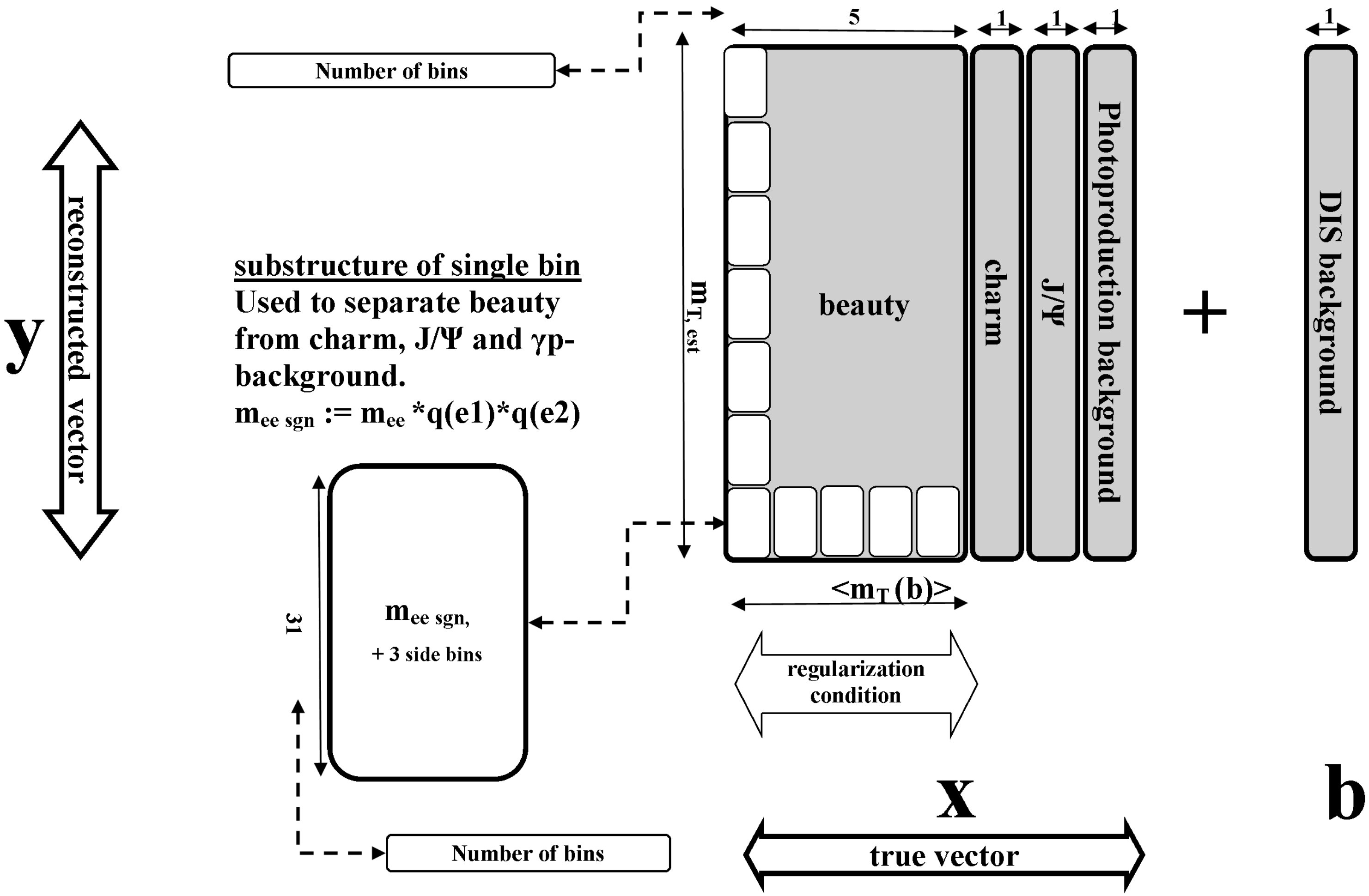
x: ***True vector, to be determined. xi are the efficiency corrected number of events in bin i.***

- Solve equation (1) with **regularized unfolding**:
  - Determine an estimator for **x** by **minimizing** a standard **χ^2-function** with additional **side conditions** on the **smoothness** and the **normalization**.
  - The regularization parameter is chosen to minimize the correlations among the bins of x.
  - Bins of x are further combined, such that the resulting signal bins have almost **no correlations.**

For literature on unfolding: http://www.desy.de/~blobel/unfold.html
and the book of G. Cowan

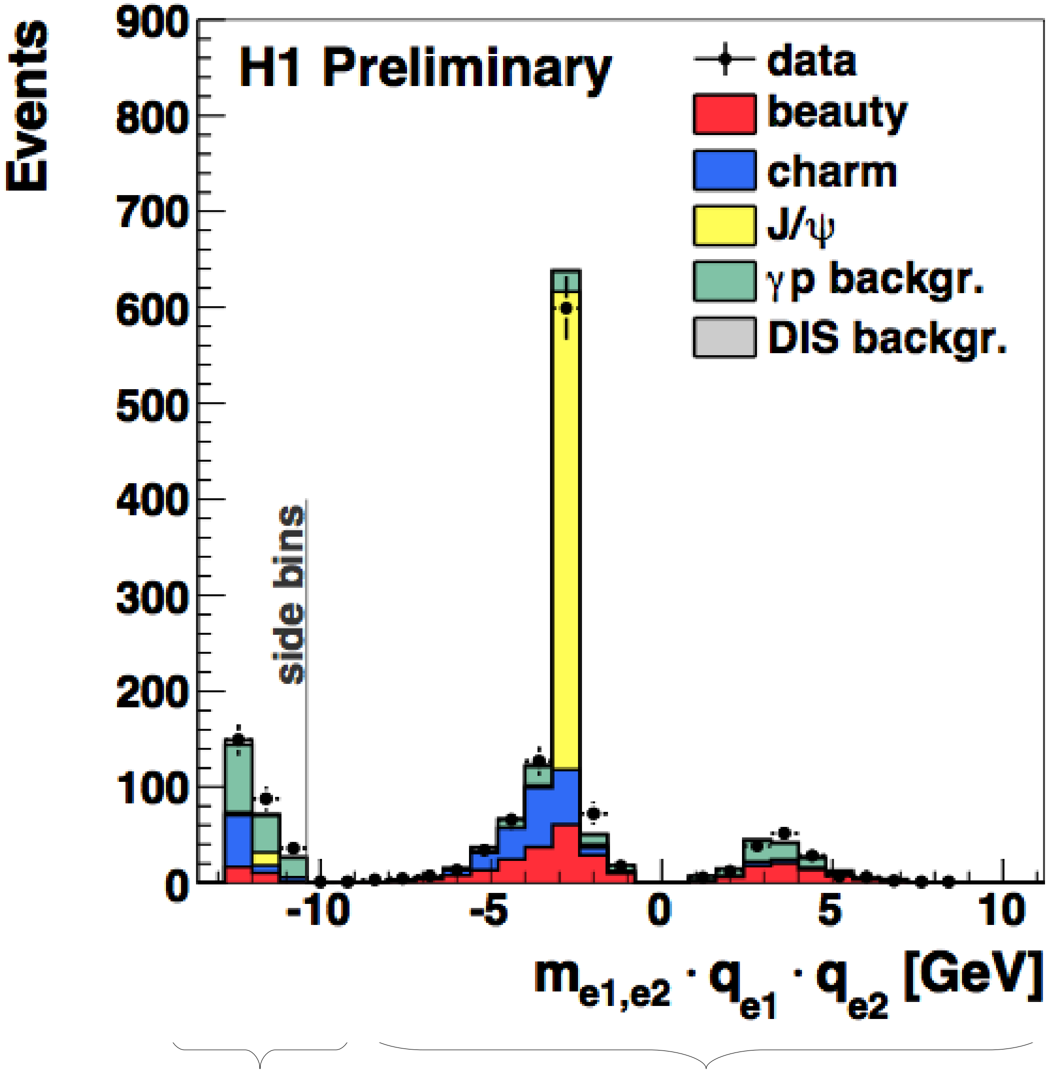
Structure of the response matrix

$$y=Ax+b$$



b: remaining DIS background. Normalization estimated from MC and subtracted from **y**.

Control distribution: substructure in y

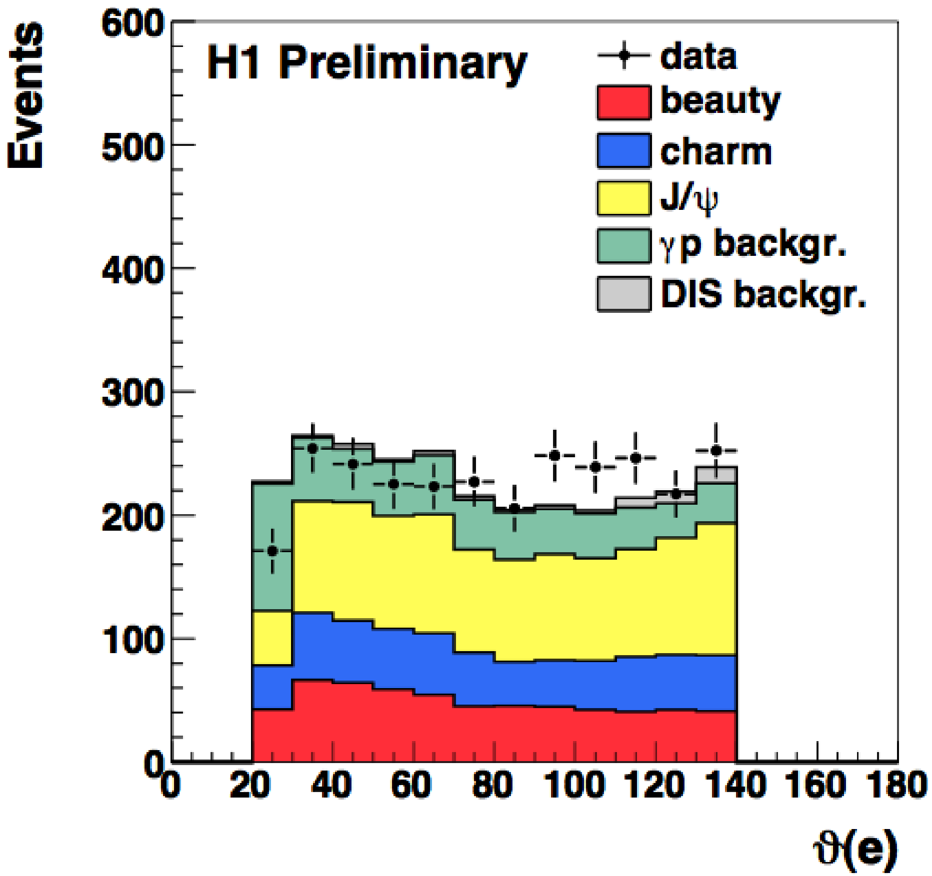


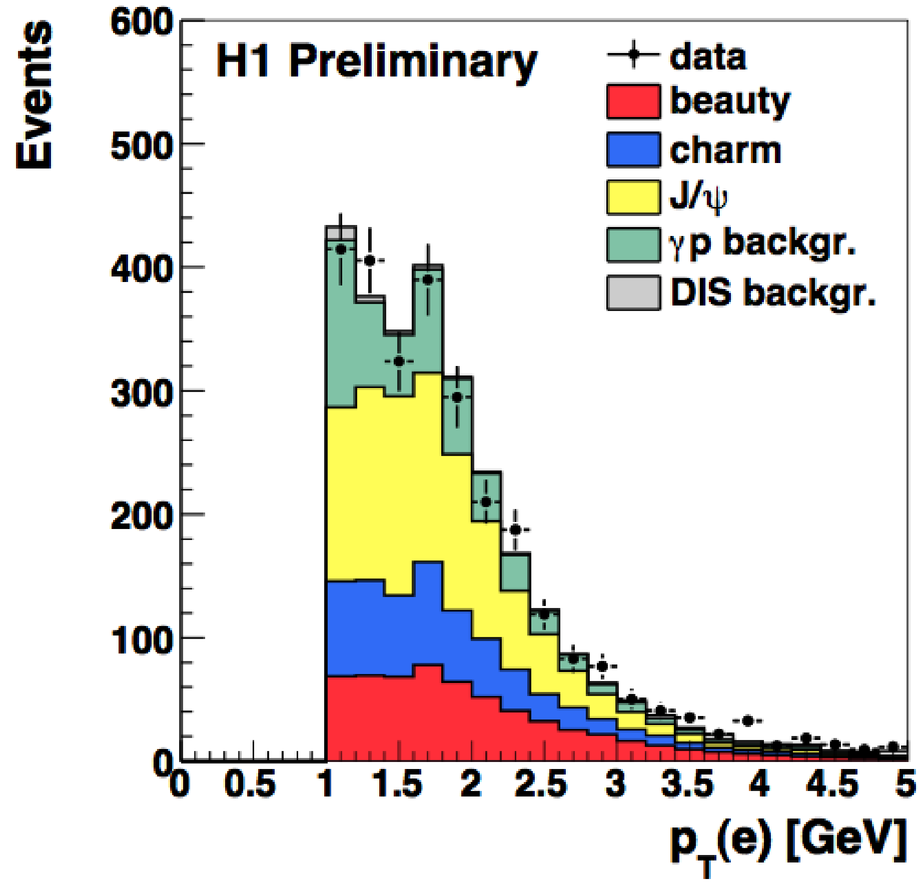
side bins sensitive to γp-background

m_{ee} q(e1) q(e2): discrimination of beauty against cham and J/ψ.

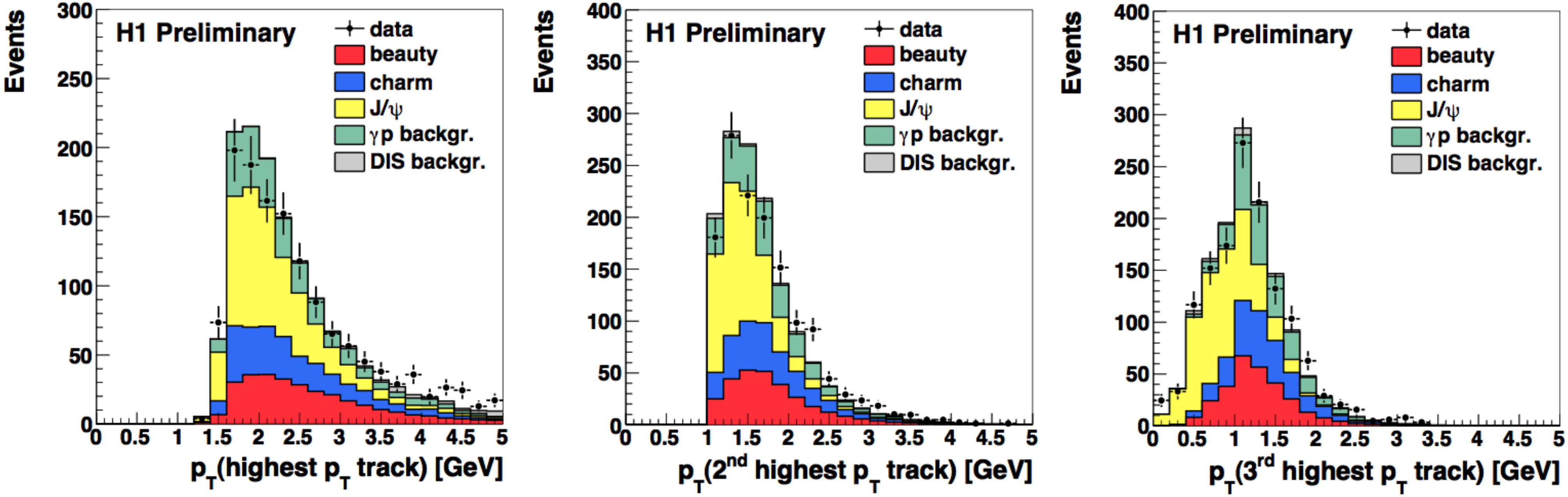
Control distribution: $\vartheta(e)$ and $p_T(e)$

Fractions of beauty, charm, J/ψ, γp backgr. determined by the unfolding procedure.



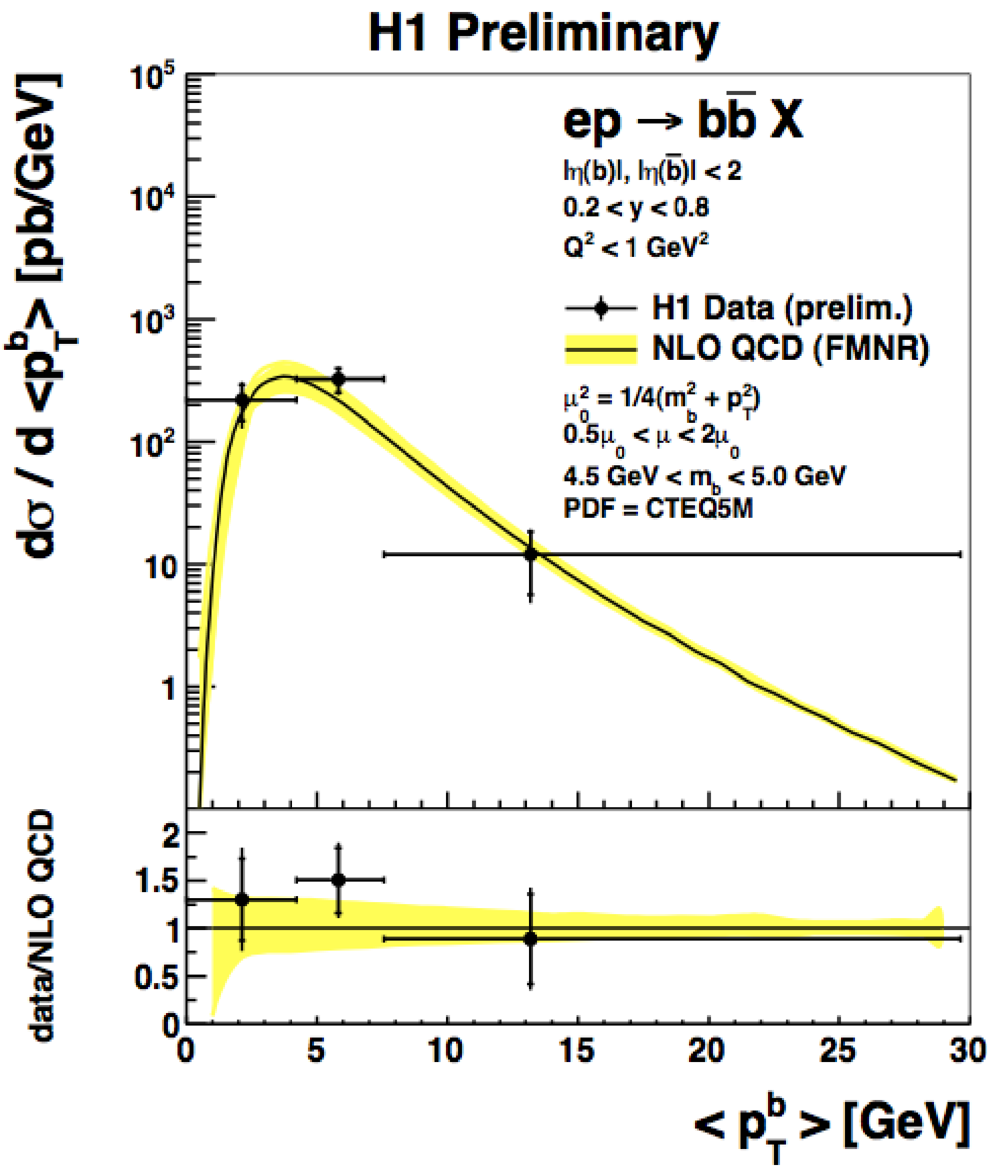


Control distribution: p_T track distributions



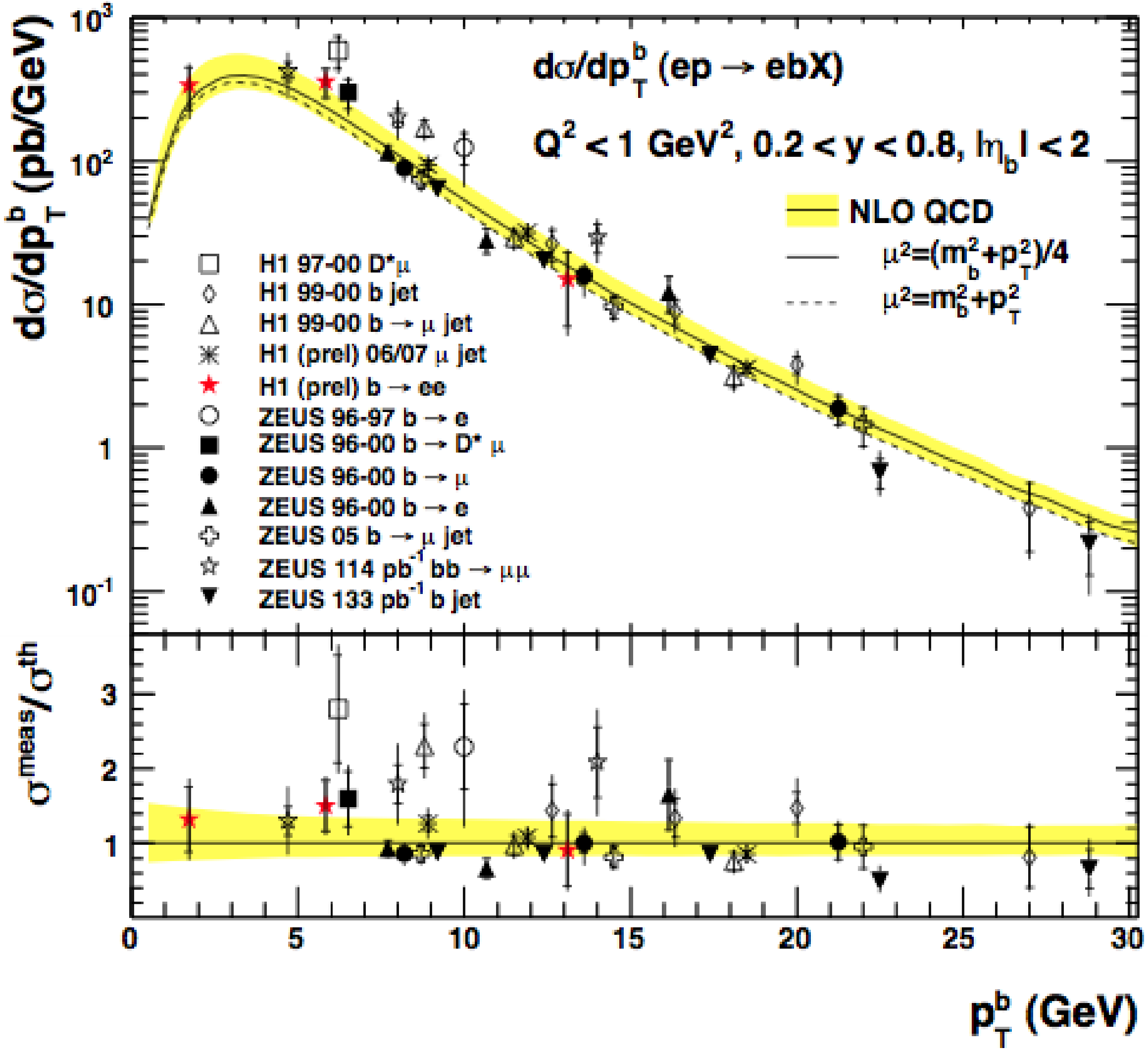
Good description in all control distributions.

Differential cross section



- Access to lowest $p_T(b)$ values ever measured in ep.
- Agreement between data and NLO calculation (FMNR).

Comparison to other measurements



- Many measurements confirming each other over a wide p_T(b) range.
- This analysis extends the measured differential cross section to lowest p_T(b) values.
- General good agreement between the data and the NLO calculation (FMNR).

Summary

- Measurement of beauty photoproduction using di-electron events.
- Measurement is consistent with other measurements.
- Good agreement between data and NLO .
- Measurement of beauty photoproduction at the p_T(b)-production threshold.

Backup

Differential cross section

- The indicated bin centers of the data points are corrected in <p_T(b)>, according to the expected distribution. Correction done, such that:

$$\int_{\delta p_T} \frac{d\sigma_{FMNR}}{dp_T} dp_T = \frac{d\sigma_{FMNR}}{dp_T}(p_{T,b.c.}) \cdot \delta p_T$$

- The errors in p_T(b) indicate the bin width δp_T.
- The ratios is based on the full bin width δp_T:

$$R = \frac{\delta\sigma_{measured}}{\delta p_T} * \delta p_T / \int_{\delta p_T} \frac{d\sigma_{FMNR}}{dp_T} dp_T$$

- Access to lowest p_T(b) values ever measured in ep.
- Agreement between data and NLO calculation (FMNR).