Charm at the ZEUS experiment at HERA I and HERA II

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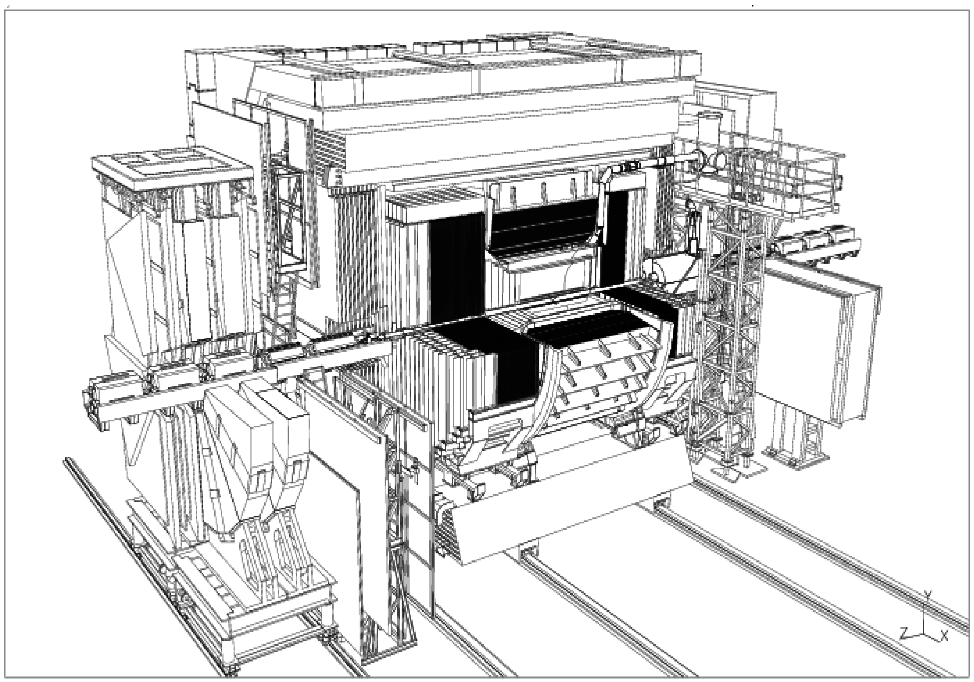
UCL/ANL

IOP Meeting, Birmingham, 6 April 2004



Introduction

- Charm Jets can be used to test pQCD

  → Parton Dynamics of the Hard Scatter

  → Probe the photon and proton structure

- Study of the non perturbative part of QCD

  → Fragmentation, Hadronisation

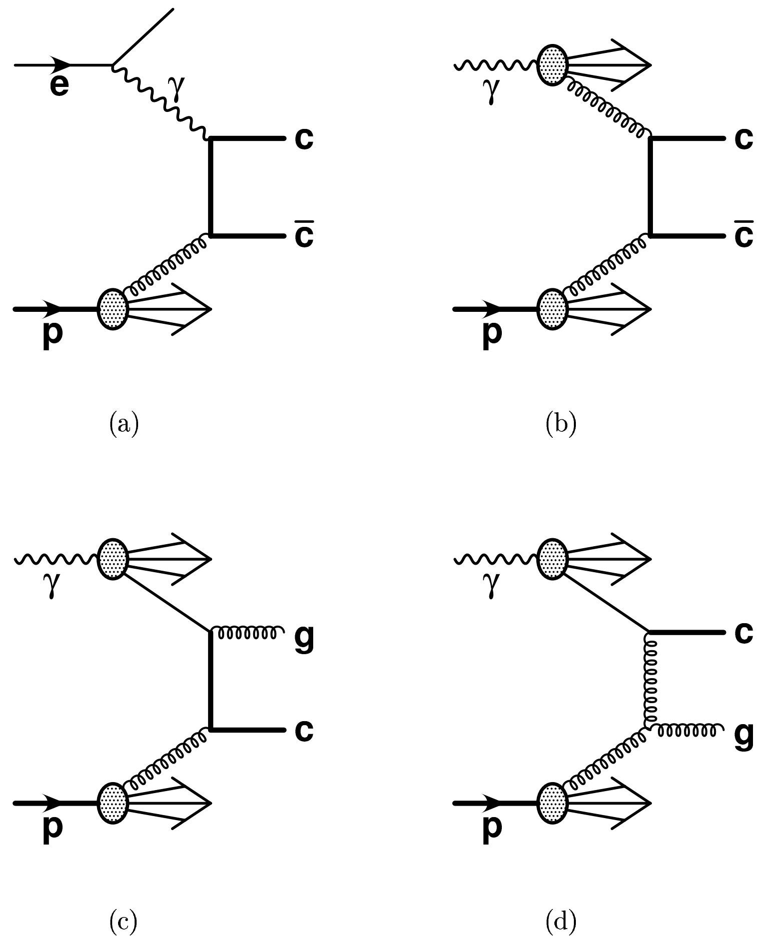
  By studying charm production using Jets, the uncertainty from the fragmentation from the c-quark into D^* meson can be reduced.

- Jets are as close as you can get to reconstructing the parton dynamics of the event, as quarks and gluons cannot be directly observed.

- Heavy Flavour production is still an unresolved part of QCD, and requires further theoretical understanding

Photoproduction at HERA I

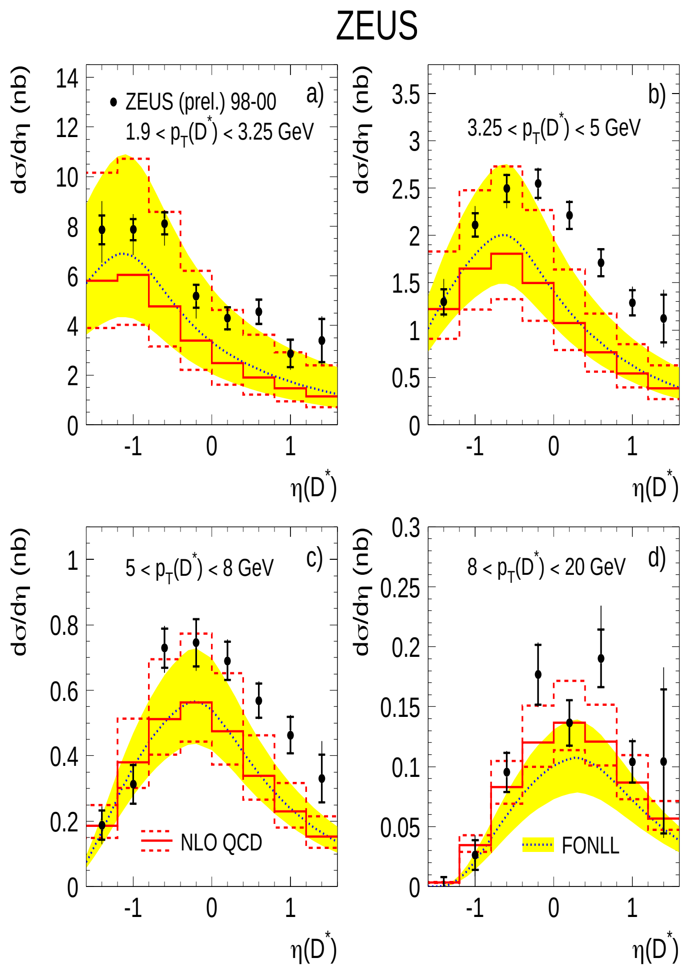
- In Photoproduction the electron is lost down the beam pipe.
- Photoproduction is defined as $Q^2 < 1$ GeV^2 The main contributing processes to Heavy Flavour production (Leading Order) :
  (a) BGF (Boson Gluon Fusion)
  'Direct Process' point like photon(γ).
  The other processes have a 'Resolved-γ'
  (b) is Hadron like,(c) c-Excitation &
  q-Propagator,(d) g-Propagator.



- pQCD Next-to-Leading-Order calculations should give a better description of the data.

$D^{*\pm}$ Photoproduction at HERA I Overview

- Charm is tagged at ZEUS most efficiently with the reconstruction of a D^* meson,in the decay channel $D^{*\pm} \rightarrow K^{\mp}\,\pi^{\pm}\,\pi_s^{\pm}$.
- The plot shows the differential cross-section $d\sigma/d\eta$,for inclusive $D^{*\pm}$ photoproduction These data are compared with NLO calculations (upper and lower bounds show NLO uncertainties).
- Details of data are not described by the NLO predictions. Charm with the addition requirement of a jet could help understanding and reduce theoretical uncertainties. Another hard scale is included reducing the dependence of non-perturbative parts. But need to understand the extra scale.



Event and Trigger Selection

- Photoproduction selection:

  No electron candidate(sinistra Prob > 0.9 & $Y_{el} < 0.7$),

  $|Z_{vertex}| < 50$ cm, $130 < W < 280$ GeV

- $D^{*\pm}$ selection:

  $P_{T,\pi_s} > 0.12$ GeV , $P_{T,\pi K} > 0.4$ GeV, $|\eta_{track}| < 1.75$

  $P_{T,D^*} > 3.0$ GeV , $|\eta_{D^*}| < 1.5$

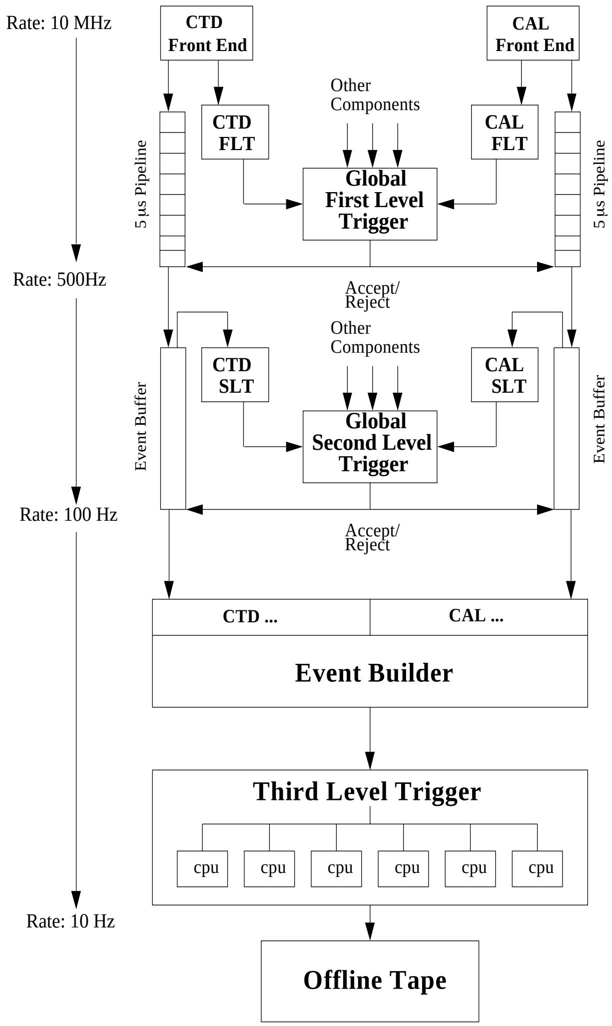
  $1.80 < m(D^0) < 1.92$ GeV

  $0.143 < \Delta M\ (m(D^*) - m(D^0)) < 0.148$ GeV

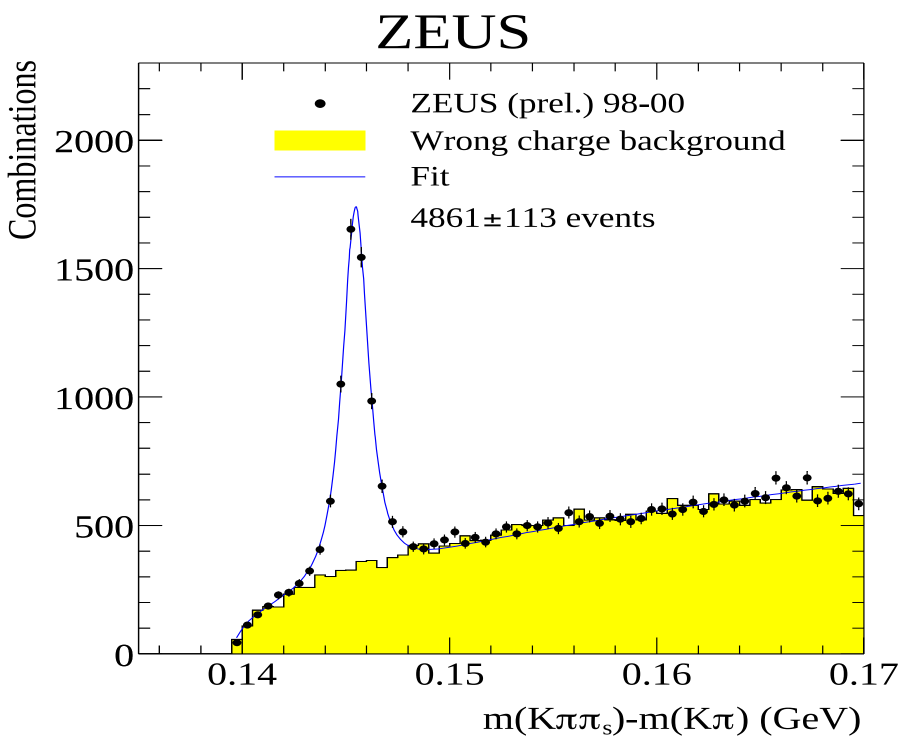
- Jet Selection; one or more jets with:

  $E_{T,jet} > 6$ GeV, $-1.5 < \eta_{jet} < 2.4$

- Luminosity used: 1998-2000 Data $\rightarrow$ $78 pb^{-1}$



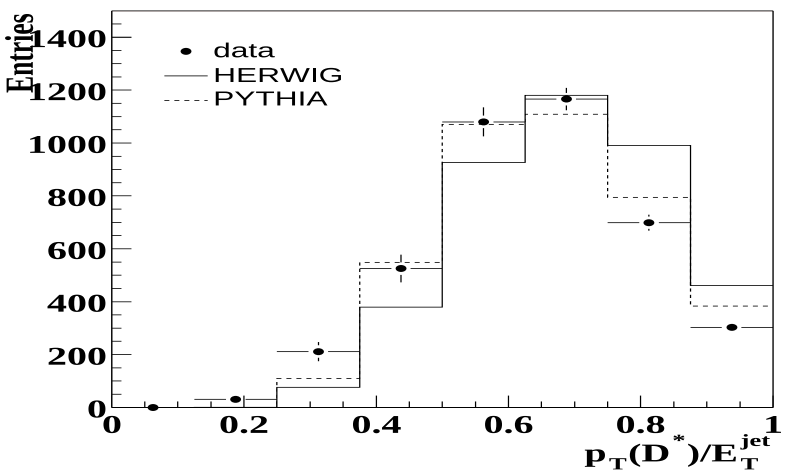
Signal: $D^{*\pm} \rightarrow K^{\mp}\ \pi^{\pm}\ \pi_s^{\pm}$ & Jets

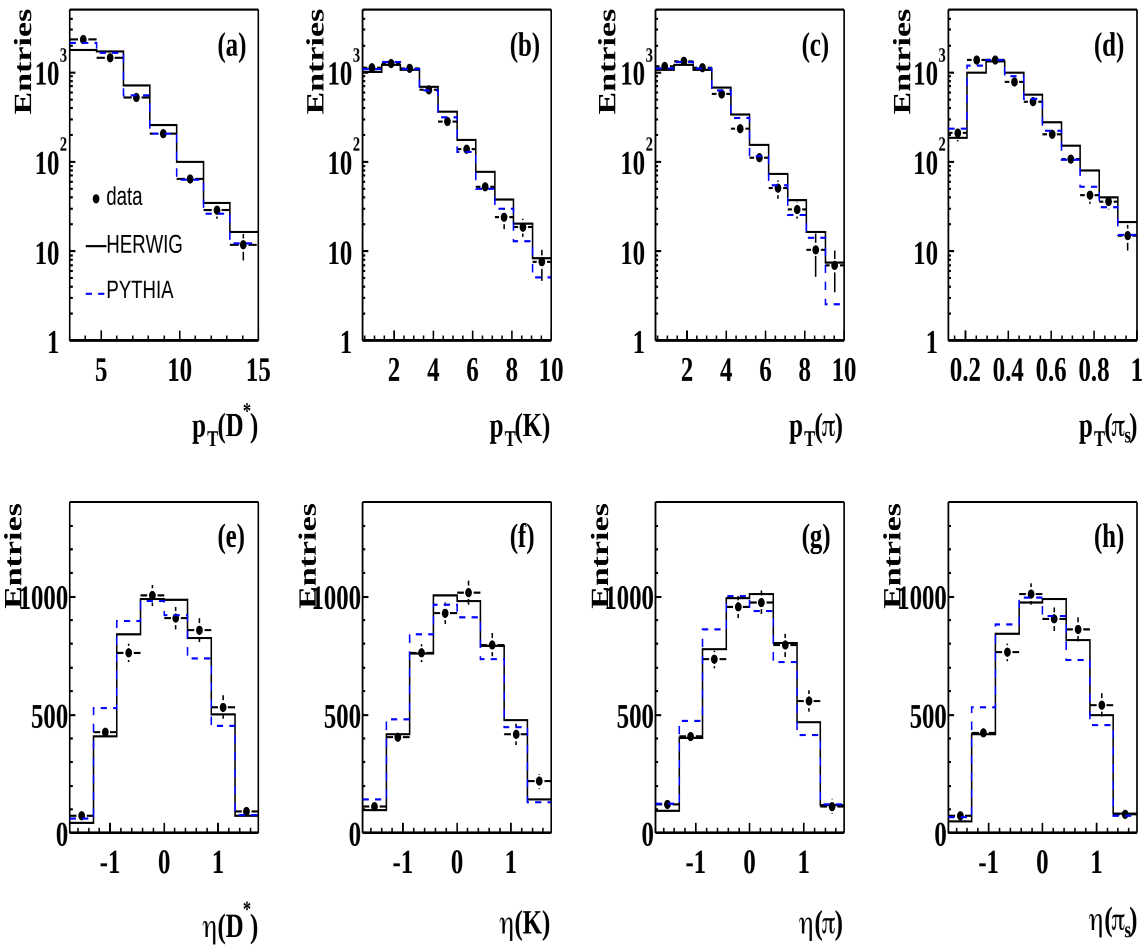


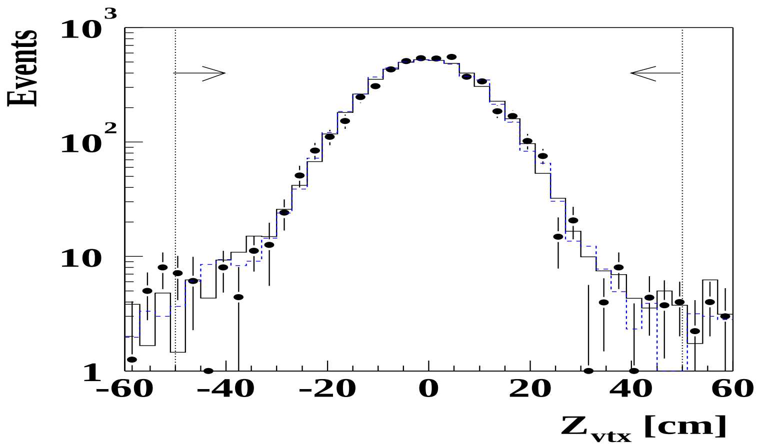
$\sim$ 5000 $events$ $\rightarrow$ Plentiful data to be able to make some differential distributions.

Modified Gaussian used for fits.

Control Plots

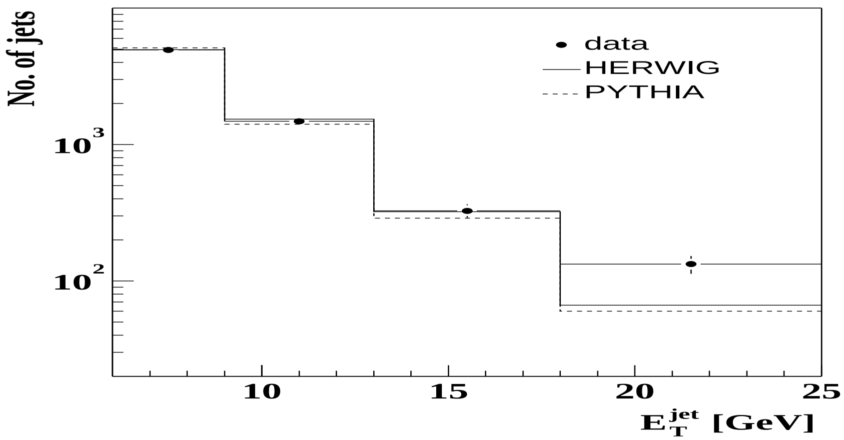


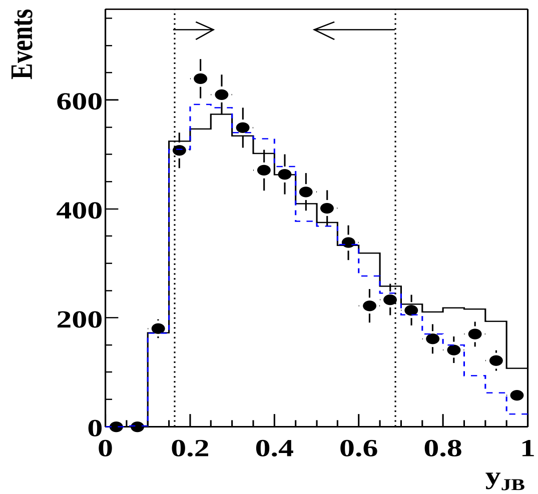


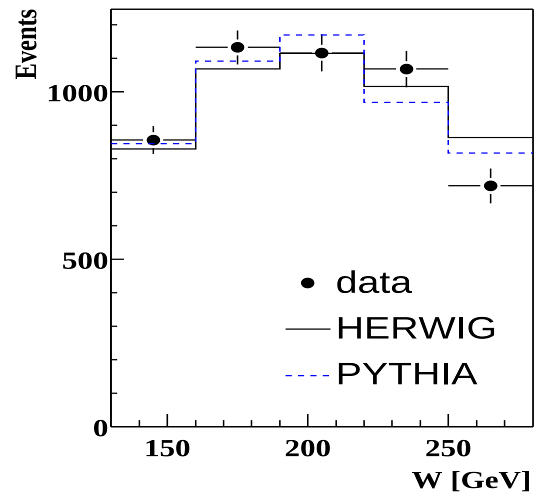


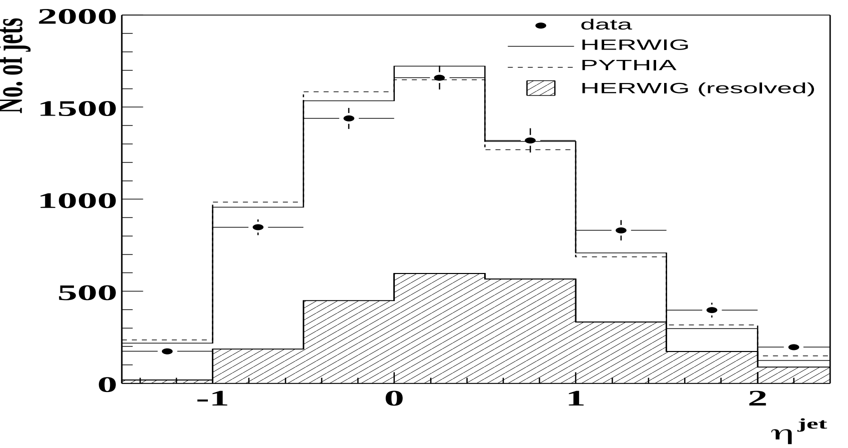
Good Agreement between Monte Carlo & data

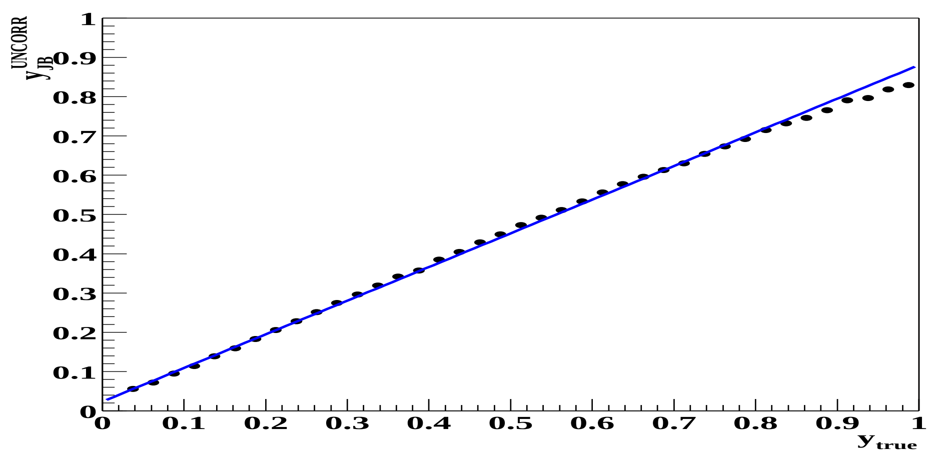
Control Plots











Good Agreement between Monte Carlo & data

Jet & D* Matching

$\Delta R = \sqrt{(\Phi_{jet} - \Phi_{D^*})^2 + (\eta_{jet} - \eta_{D^*})^2}$

Matched D* Jets $\Delta R < 0.6$

Measurements have jets & D*'s associated

with the Kt algorithm

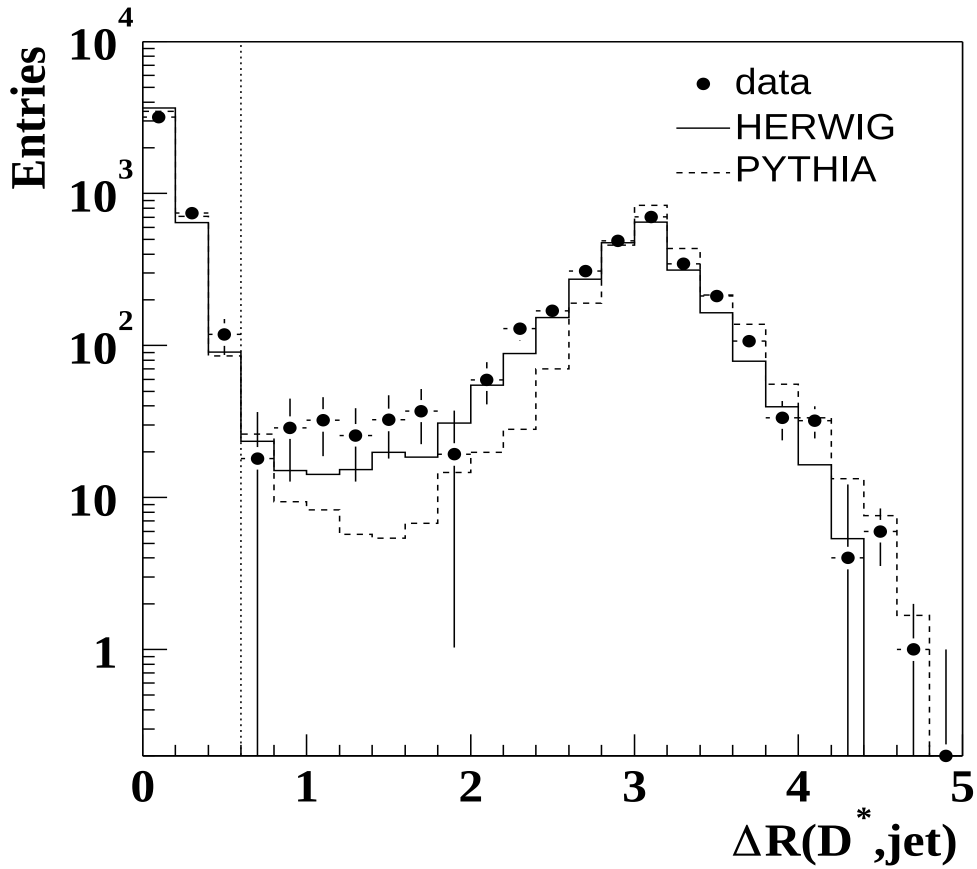
These data are corrected back to the

true jets clustered with the D*.

Black Points are Data.

solid line is Herwig.

dashed line is Pythia.



Cross Section Definitions

- Kinematic region:

  $Q^2 < 1$ GeV^2, 130 $<$ W $<$ 280 GeV,

  $P_{T,D^*} > 3.0$ GeV, $|\eta_{D^*}| < 1.5$
- The plot shows all jets within

  $-1.5 < \eta_{jet} < 2.4$ &,$E_t^{jet} > 6$ GeV
- Unfolding method:

  Use Bin-by-Bin unfolding to extract

  the Cross Section.

  $\frac{d\sigma}{dX} = C_i \cdot \frac{N_i^{obs}}{L \cdot Br(D* \rightarrow K\pi\pi) \cdot \Delta X}$

  L : Integrated Luminosity

  Br : overall branching ratio

  ΔX : bin width

  HERWING used as central Monte Carlo.

  Correction factors $\sim$ 2-3

- Inclusive jet cross sections:

  dσ/dE_T^{jet} :

  η^{jet} range: [-1.5,2.4],[-1.5,-0.5],[-0.5,0.5],[0.5,1.5],[1.5,2.4]
- dσ/dη^{jet} :

  E_T^{jet} range:$E_T^{jet} > 6\ GeV$,6 $< E_T^{jet} < 9\ GeV$,

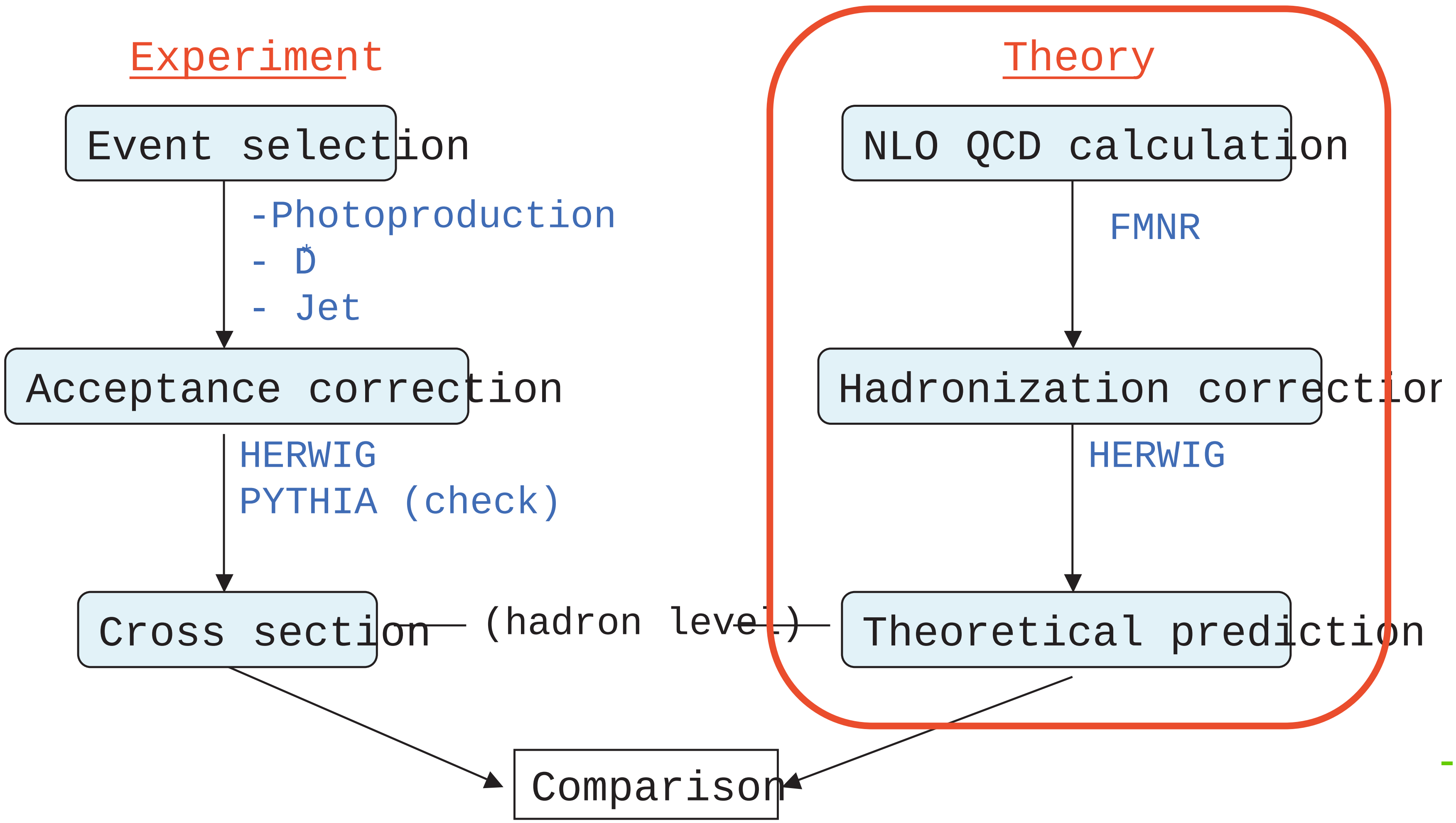
  E_T^{jet} range: $E_T^{jet} > 9\ GeV$
- D*/other jet cross sections:

  dσ/dE_T^{jet}, η^{jet} range: [-1.5,2.4]

  dσ/dη^{jet}, E_T^{jet} range:$E_T^{jet} > 6\ GeV$,6 $< E_T^{jet} < 9\ GeV$,

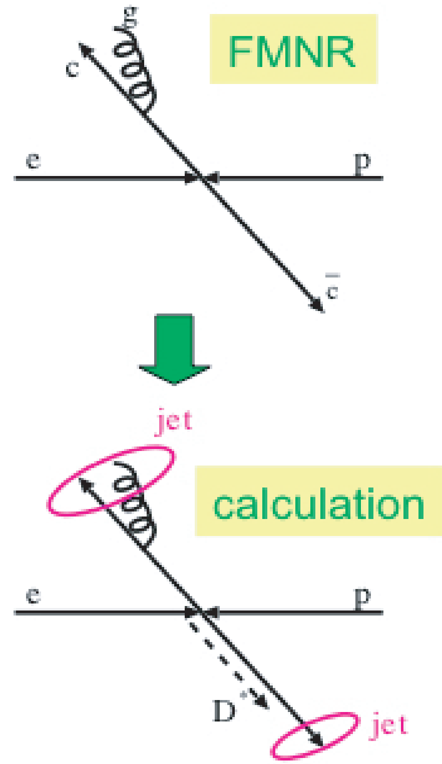
  E_T^{jet} range: $E_T^{jet} > 9\ GeV$

Analysis Flow



NLO QCD calculation

- Calculation done in massive scheme (FMNR).
- Same kinematic region as the measurement.
  (no extrapolation for the measurement)
  - $c \rightarrow D^*$ using Peterson function.
  - Run jet finder over final state partons.
- Error estimation
  - $\mu_R = \mu_0/2$, m_c=1.3 GeVc² (upper bound)
  - $\mu_R = 2\,\mu_0$, m_c=1.7 GeVc² (lower bound)



- CTEQ 5M1 (proton PDF)
- AFG HO (photon PDF)
- Input parameters set as
  - $\mu_R = \mu_{F,\gamma} = \mu_{0,p} = \mu_0$ ($\mu_0^2 = m_c^2 + \langle p_T^2 \rangle$)
  - m_c = 1.5 GeV/c²

- $p^c \rightarrow p(D^*)$: Peterson function
- Jet finder over partons
- \+ Hadronization correction

→ estimated by MC

Hadronization correction

$$\left(\sigma_i^{had}\right)_{NLO} = C_i^{had} \cdot \left(\sigma_i^{par}\right)_{NLO}$$

$$C_i^{had} = \left(\frac{\sigma_i^{had}}{\sigma_i^{par}}\right)_{MC}$$

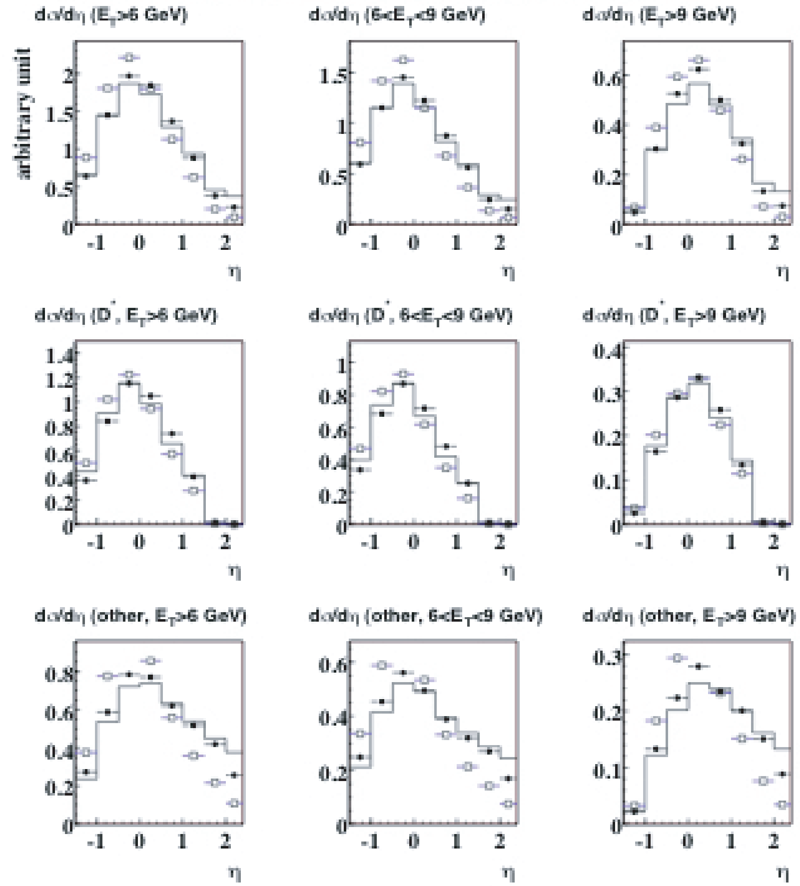
Due to the shift in η^{jet}, the bin-by-bin correction depends on the η^{jet} distribution.

Shapes of FMNR distributions agree well with HERWIG (direct+resolved).
Use it for hadronization correction.

•The average of HERWIG and PYTHIA are used for hadronization corrections.
•The difference of two MC are used as the estimate of the error of on the hadronization correction and are added in quadrature to FMNR the uncertainties.

—— FMNR
• HERWIG (direct+resolved)
□ HERWIG direct

Comparison of the shape of η distributions of FMNR and HERWIG at parton level.



$D^{*\pm}$ Photoproduction Inclusive jet cross sections $d\sigma/dE_t^{jet}$

- Kinematic region:

  $Q^2 < 1$ GeV^2, 130 < W < 280 GeV,

  $P_{T,D^*} > 3.0$ GeV, $|\eta_{D^*}| < 1.5$

- The plot shows all jets within

  $-1.5 < \eta_{jet} < 2.4$ &, $E_t^{jet} > 6$ GeV for the

  backwards,central & forward η_{jet} regions.

- These data are compared to NLO FMNR.

  Central Value $m_c = 1.5\ GeV$.

  Scale $\mu_r^2 = m_c^2 + < p_t^2 >$

  Upper curve $m_c = 1.3\ GeV$.

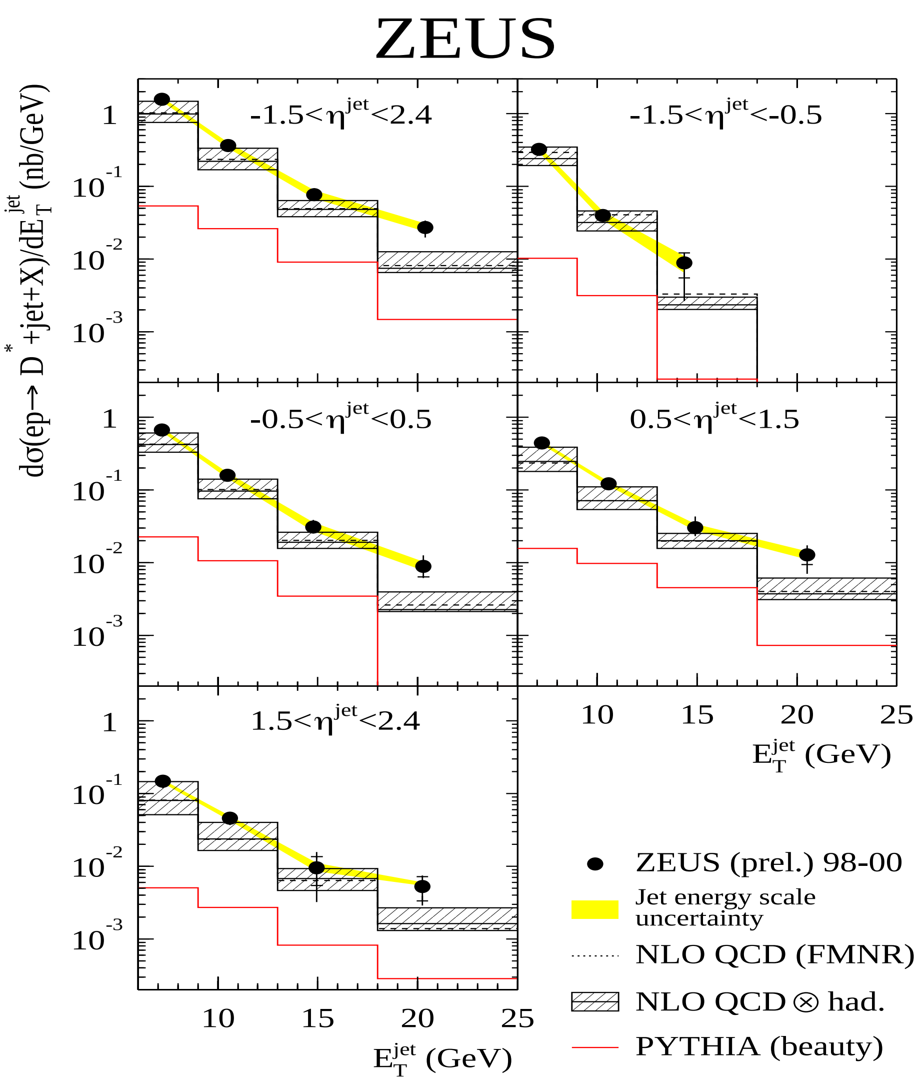
  Scale $\mu_r = \mu_r(nominal)/2$

  Lower curve $m_c = 1.7\ GeV$.

  Scale $\mu_r = \mu_r(nominal) * 2$

  Shape is well described

  Lower charm mass favoured.



$D^{*\pm}$ and non-$D^{*\pm}$ jet cross sections $d\sigma/dE_t^{jet}$

$D^{*\pm}$ selected by ΔR cut:

$\Delta R = \sqrt{(\Phi_{jet} - \Phi_{D^*})^2 + (\eta_{jet} - \eta_{D^*})^2}$

Matched Jets $\Delta R < 0.6$, Measurements have jets & D^* associated according to the Kt algorithm

These data are corrected back to true jets clustered with the D^*

Kinematic region:

$Q^2 < 1$ GeV^2, 130 $<$ W $<$ 280 GeV,

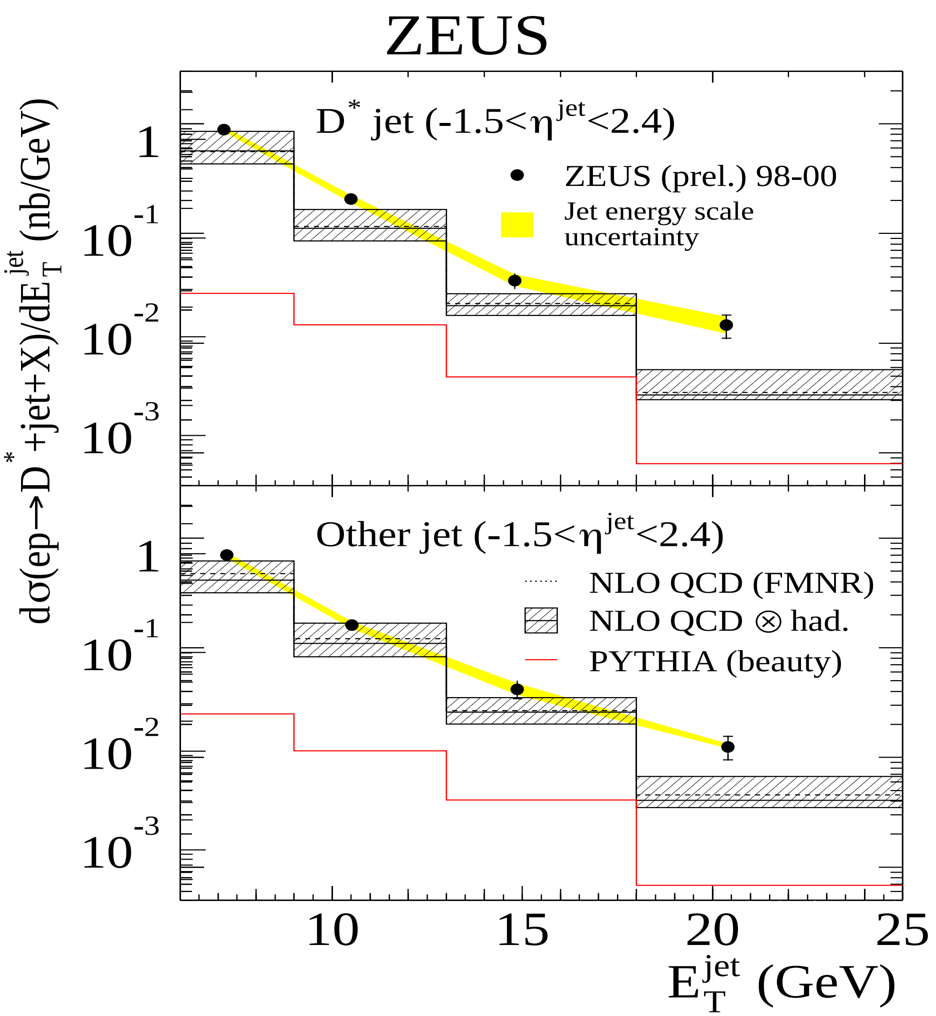
$P_{T,D^*} > 3.0$ GeV, $|\eta_{D^*}| < 1.5$

$-1.5 < \eta_{jet} < 2.4$ &,$E_t^{jet} > 6$ GeV

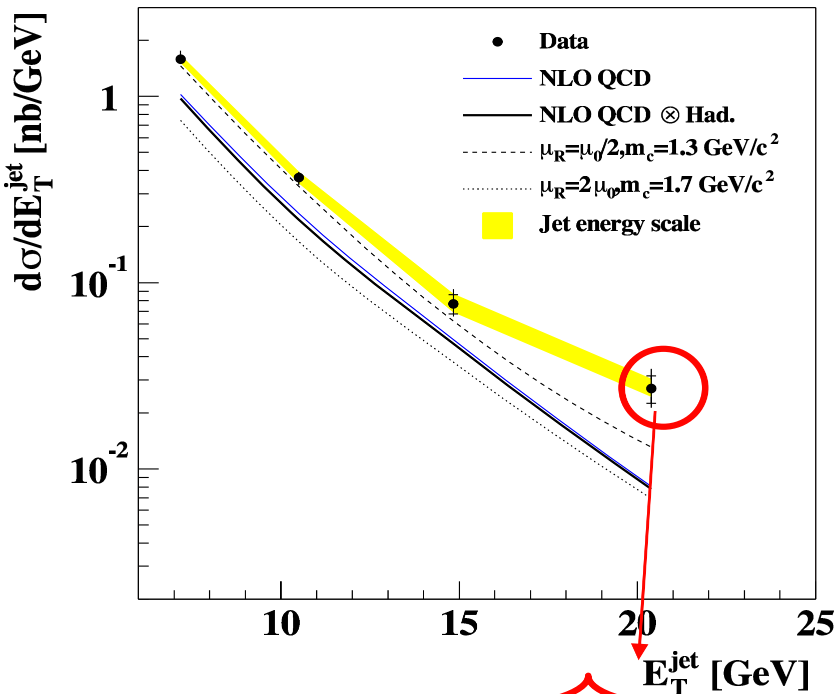
Shape o.k. Normalisation wrong,

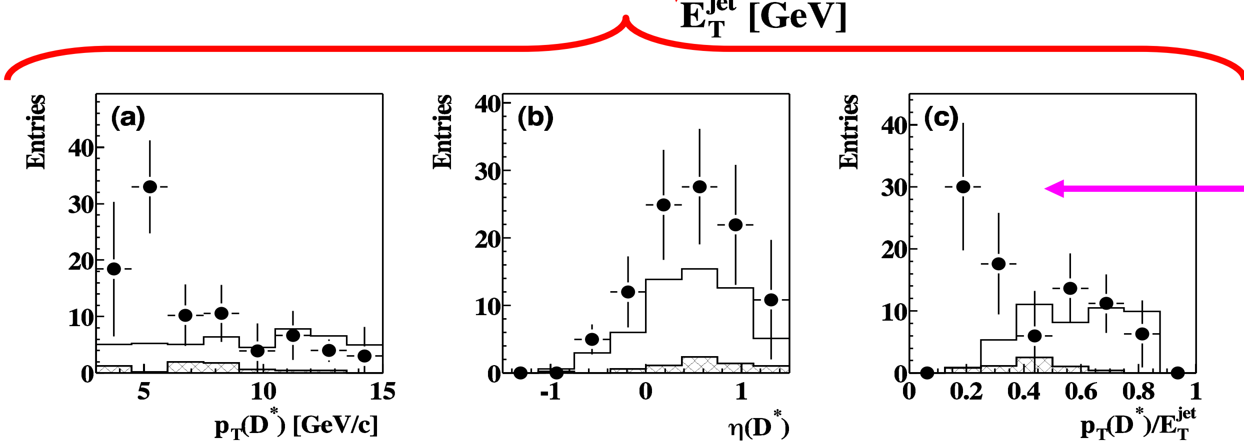
$\rightarrow$ not much difference between,

D^* Jets & Other Jets



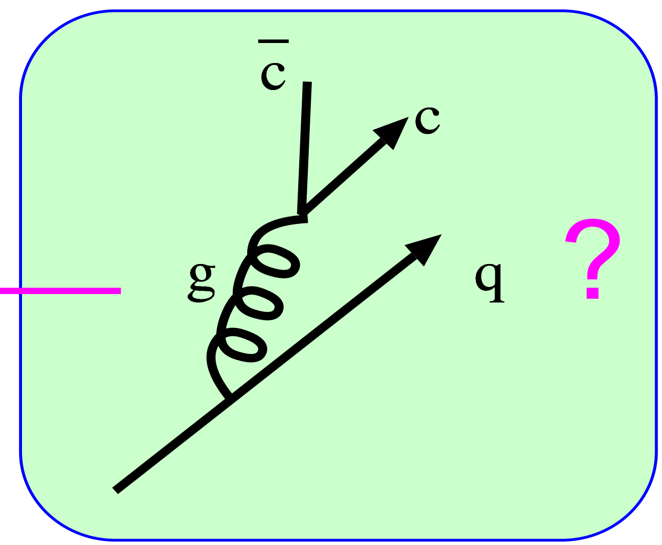
Events with high Et jets





- Needs further study to understand the excess at high Et.
- It could be a process not considered in theoretical prediction or statistical fluctuation.

Secondary charm production



$D^{*\pm}$ Photoproduction Inclusive jet cross sections

$d\sigma/d\eta_{jet}$

- Kinematic cuts:

  $Q^2 < 1$ GeV^2, 130 $<$ W $<$ 280 GeV,

  $P_{T,D^*} > 3.0$ GeV, $|\eta_{D^*}| < 1.5$, $-1.5 < \eta_{jet} < 2.4$

- The plot shows $d\sigma/d\eta_{jet}$, in ranges of E_t^{jet}

- These data are compared to FMNR NLO.

  Central Value $m_c = 1.5\ GeV$.

  Scale $\mu_r^2 = m_c^2 + < p_t^2 >$

  Upper curve $m_c = 1.3\ GeV$.

  Scale $\mu_r = \mu_r(nominal)/2$

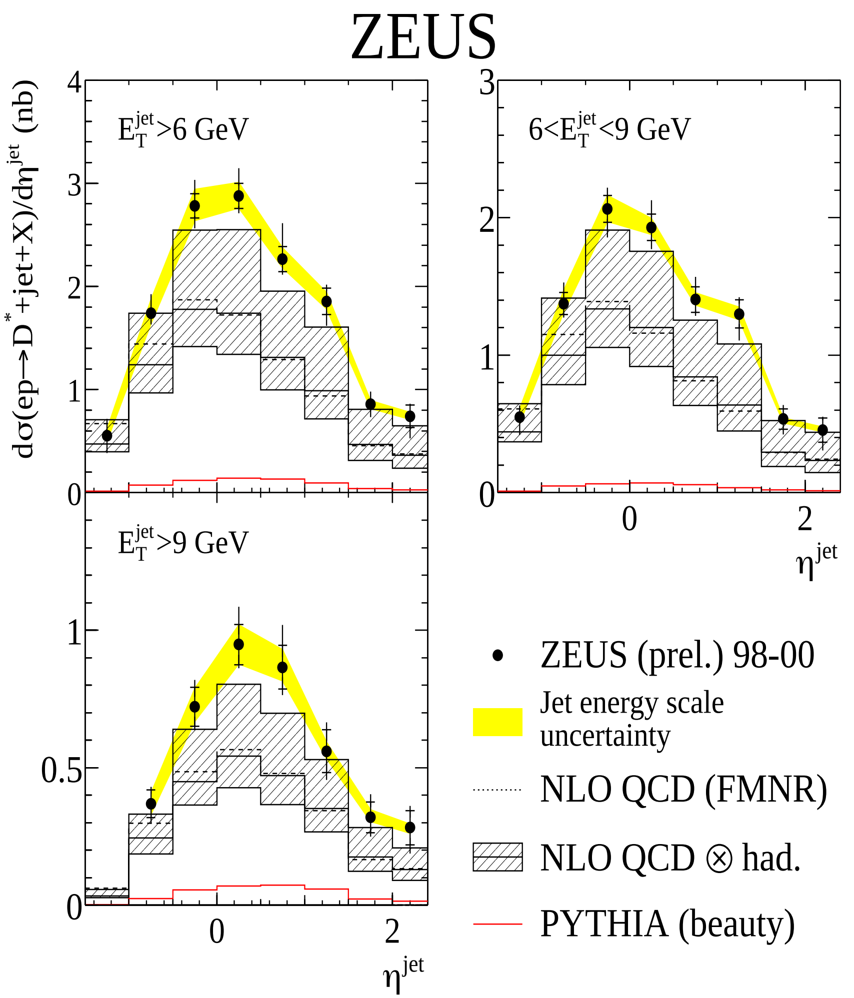
  Lower curve $m_c = 1.7\ GeV$.

  Scale $\mu_r = \mu_r(nominal) * 2$

  Proton PDF CTEQ5M1

  Photon PDF GRV-GHO

  Shape well described



$D^{*\pm}$ and non-$D^{*\pm}$ jet cross sections $d\sigma/d\eta_{jet}$

$D^{*\pm}$ selected by ΔR cut:

$\Delta R = \sqrt{(\Phi_{jet} - \Phi_{D^*})^2 + (\eta_{jet} - \eta_{D^*})^2}$

Matched Jets $\Delta R < 0.6$, Measurements have jets & D^* associated according to the Kt algorithm

These data are corrected back to true jets clustered with the D^*

Kinematic region:

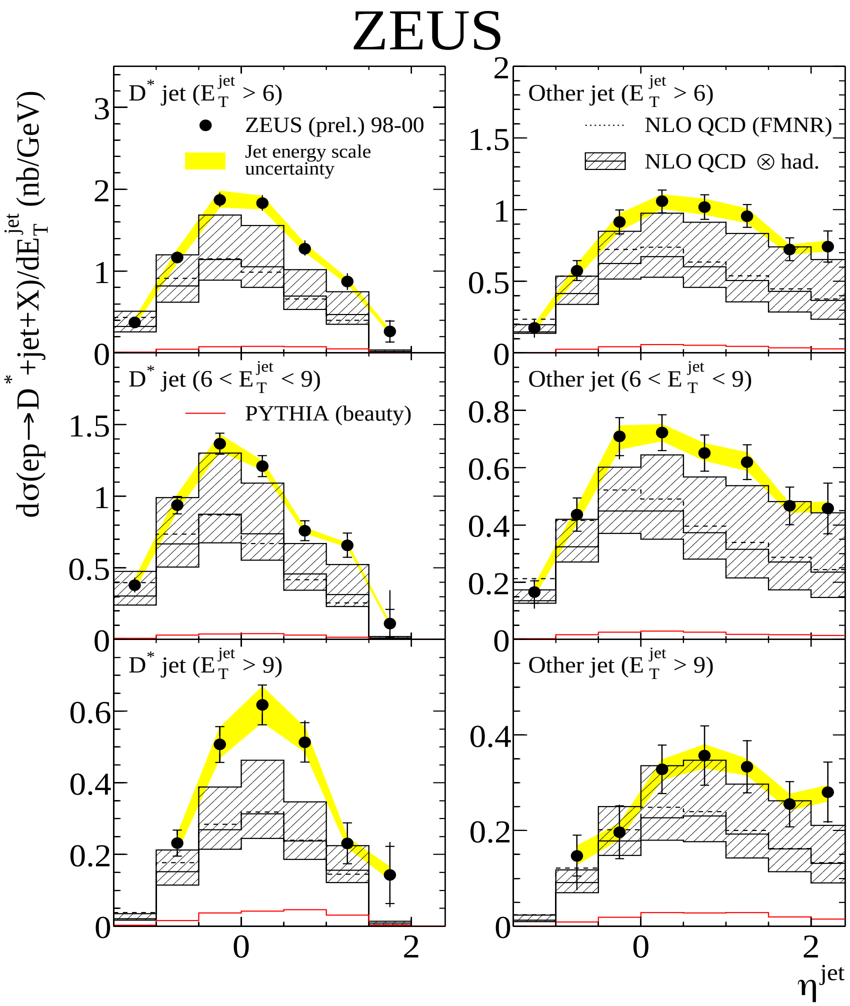
$Q^2 < 1$ GeV^2, 130 $<$ W $<$ 280 GeV,

$P_{T,D^*} > 3.0$ GeV, $|\eta_{D^*}| < 1.5$

$-1.5 < \eta_{jet} < 2.4$ &,$E_t^{jet} > 6$ GeV

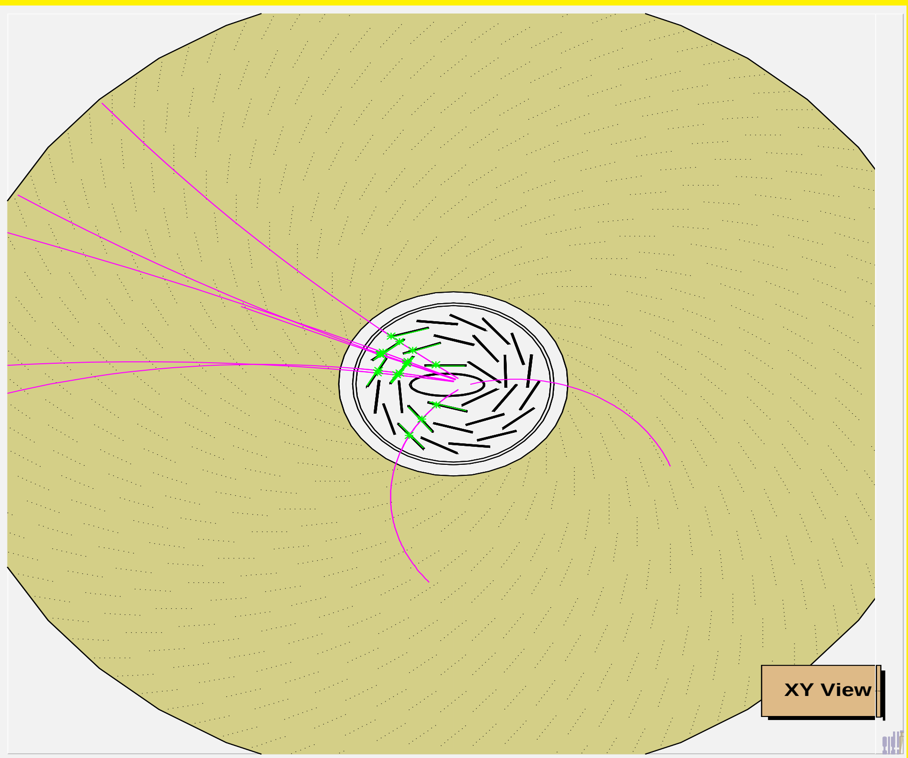
Shape described well for both D* jets and other jets

D^* Jets, Other Jets favour lower charm mass.



$D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$ at ZEUS & HERA II

- $D^{\pm}$ Meson:
  - $\rightarrow$ Long lived 315 μm (PDG)
  - $\rightarrow$ three body decay peak position at 1.869 GeV (PDG)
- ZEUS has a new Detector $\rightarrow$ Micro-Vertex Detector



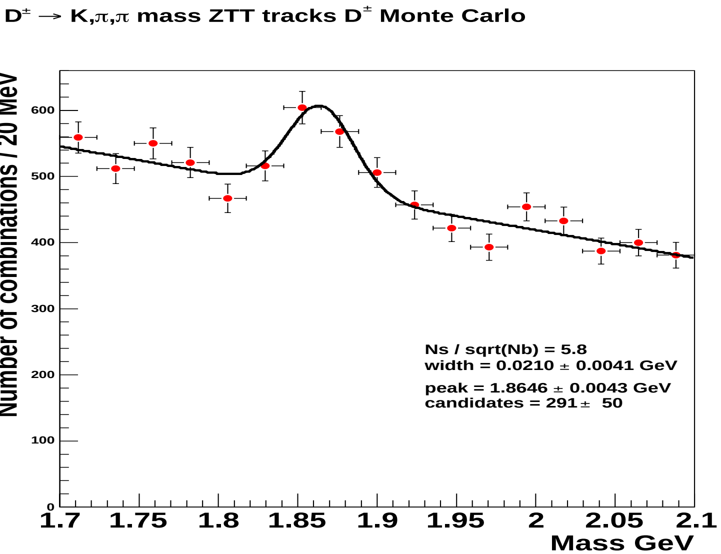
Aim:

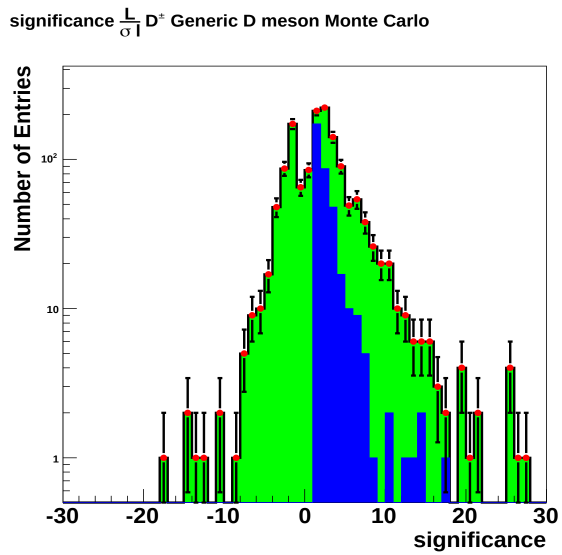
$\rightarrow$ Use the Micro-Vertex Detector to tag the $D^{\pm}$ decays

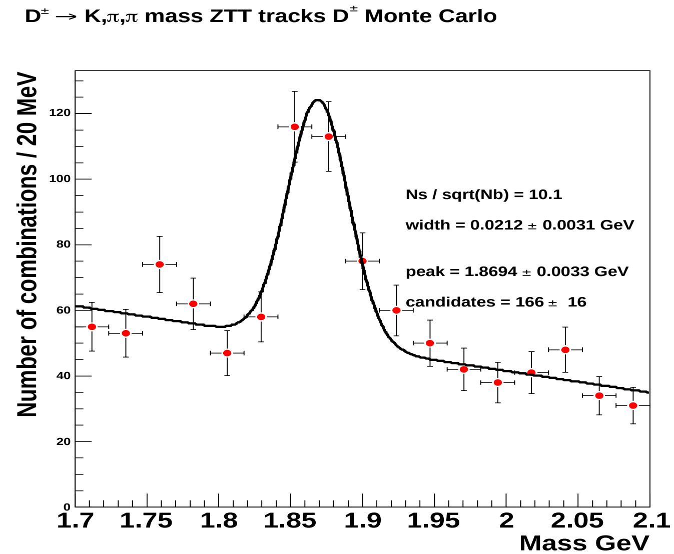
Method:

re-vertex tracks find Secondary vertecies from $D^{\pm}$ decays.

Generic D Meson Monte Carlo







Significance $= \frac{L}{\sigma_L}$, L is the decay length,σ_L is the error on the decay length

$L = |\overline{S} - \overline{P}| \cdot ((\overline{S} - \overline{P})) \cdot J,$

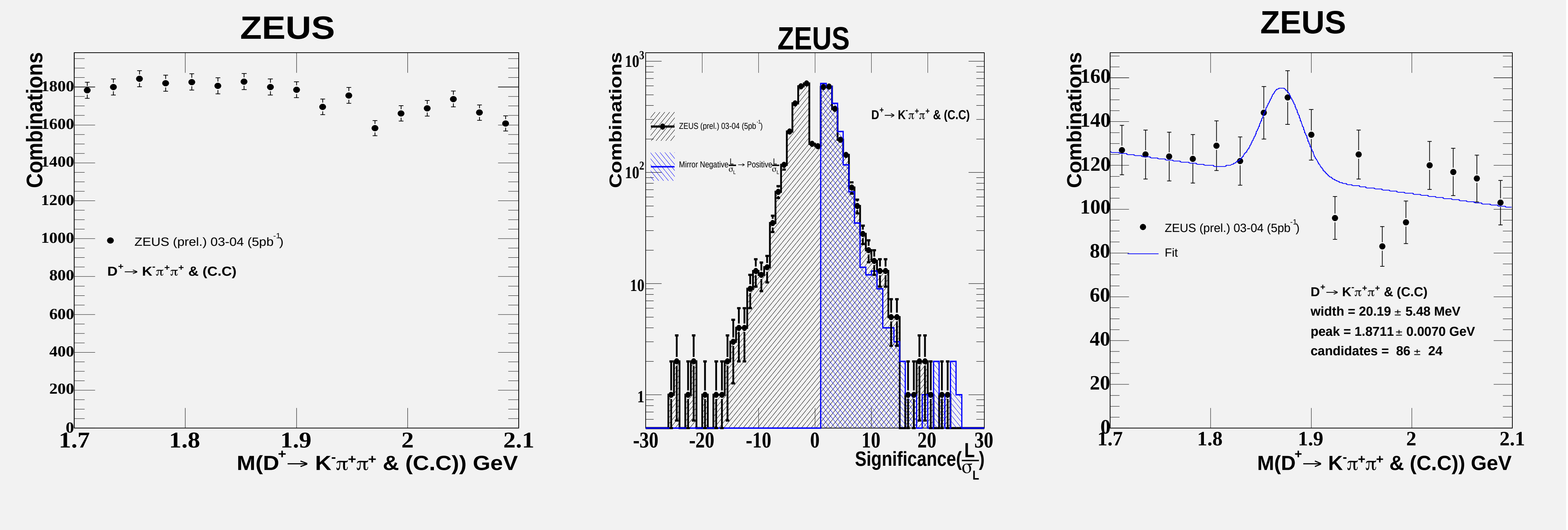
P & S are the position 3 vectors (P_x,P_y,P_z) of the primary and secondary vertices respectively,

J is the resultant vector of the $D^{\pm}$

If L $>$ 0 the $D^{\pm}$ meson is in front of the primary vertex

If L $<$ 0 the $D^{\pm}$ meson is in behind of the primary vertex

$D^{\pm}$ Tagging at ZEUS & HERA II 2003-2004 DATA



2003-2004 DATA Luminosity = 5 pb^{-1}

86 Candidates extracted, background suppressed by factor of 10

$\rightarrow$ First look at the power of the Micro-vertex Detector.

HERA II is up and running lots more data to analyse

Summary

- Charm jet Cross Sections have been measured in photoproduction 1998-200 Data
- These data have been analyzed & compared to NLO pQCD predictions.

  The shape of the data is well described by the NLO pQCD

  $\longrightarrow$ Monte Carlo jet hadronisation model.

  A lower charm mass is favoured for all Cross sections,

  High E_T excess seen, still under study.

  $\longrightarrow$ Experimental uncertainties on measurements dwarfed by theoretical uncertainties.

  $D^{\pm}$ mesons have been tagged in the ZEUS Micro-Vertex Detector for the first time in the 2003-2004 Data,

  $\longrightarrow$ Huge potential for the future!