Heavy Flavour Physics at HERA II

(a view from experimental site

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DESY Forum

DESY, Hamburg, July 03, 2001

O U T L I N E :

HERA $\longrightarrow$ HERA II

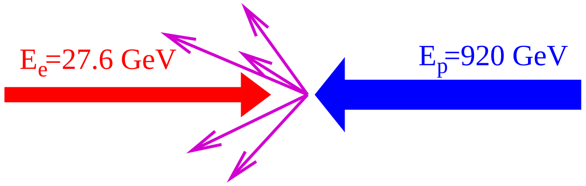
Detectors Upgrades

Selected HFL results

Measurements after Upgrade

Looking Forward

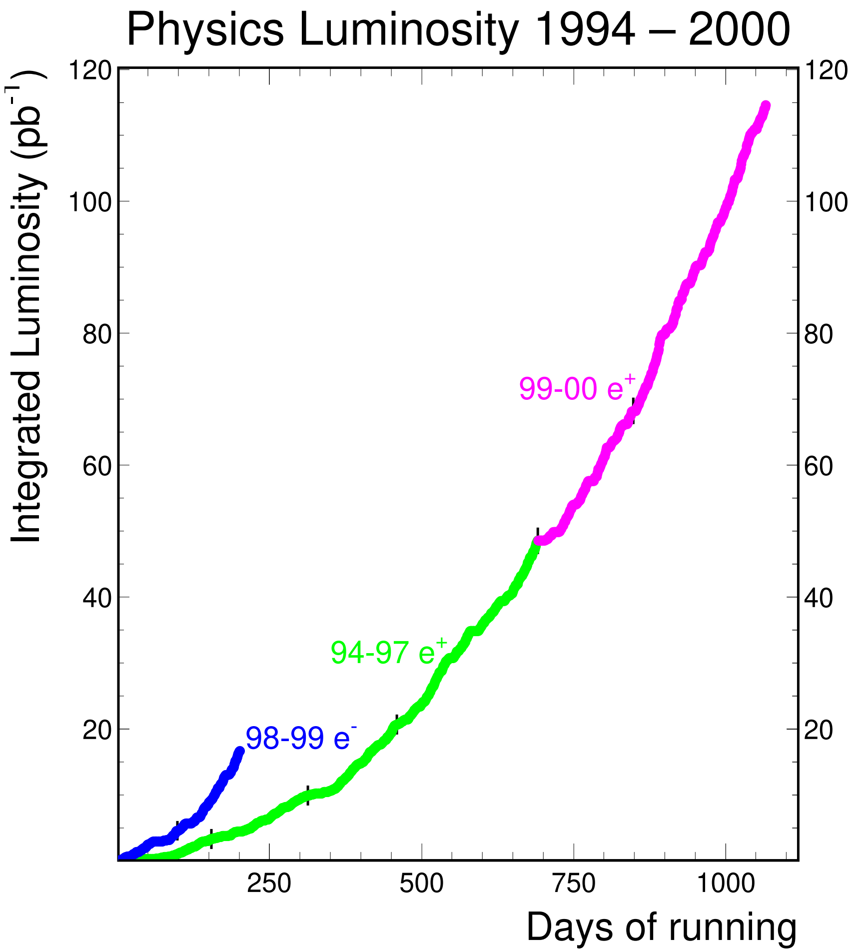
HERA $\longrightarrow$ HERA II



	HERA 1992-2000	HERA II 2001-2006
$\sqrt{s}$	320 **(300)**	320 **GeV**
$\mathcal{L}$	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31}\, cm^{-2}\, s^{-1}$
$\mathcal{L}_{int}$	0.1	$1\, fb^{-1}$
beam spot	150×30	$80 \times 20\, \mu m^2$

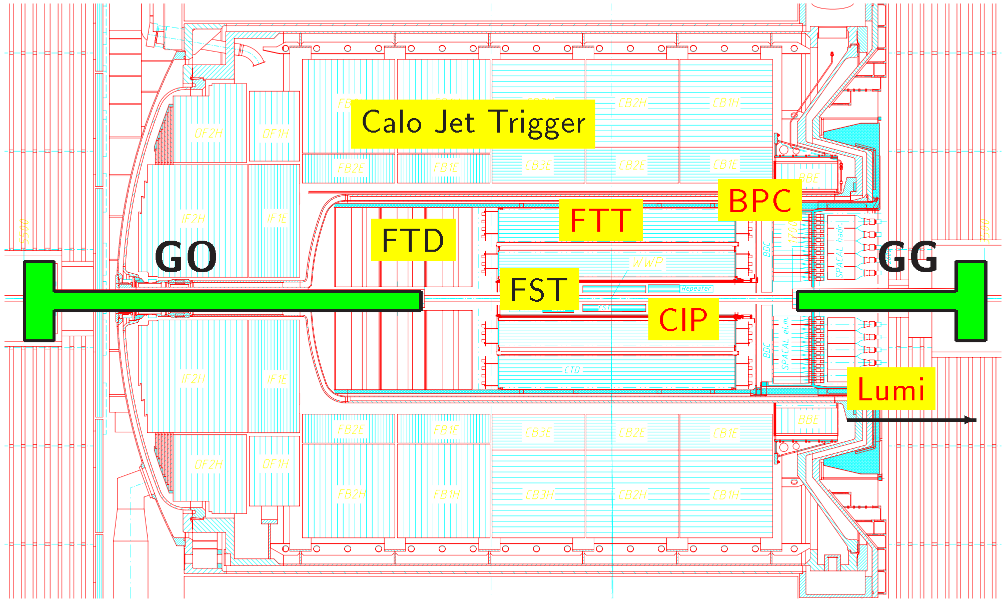
$e^{\pm}$ **long. pol.** ($\approx 60\%$)

Detectors Upgrades



H1, ZEUS : $> 100\, \mathbf{pb}^{-1}$ **each**

Progress Of H1 Upgrade Projects



modifications

- backward ToF
- SpaCal
- beam pipe
- backward Si Tracker
- central Si Tracker
- LAr G0 Support
- Plug
- forward ToF
- FPS/FNC
- Polarimeter

upgrades

- Fast Track Trigger (FTT)
- Lumi Monitors
- Inner Prop. Chamber (CIP)
- Backward Prop. Chamber (BPC)

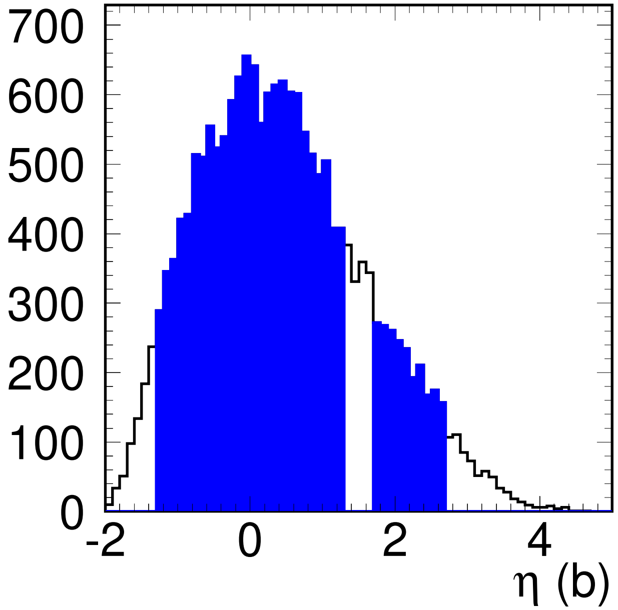
- Forward Tracker (FTD)
- Calo Jet Trigger
- Forward Si Tracker (FST)

Major Improv. for HFL Studies

Fast Track Trigger (new)

Central Si Ttracker (exist, modifying)

Forward Si Ttracker (new)



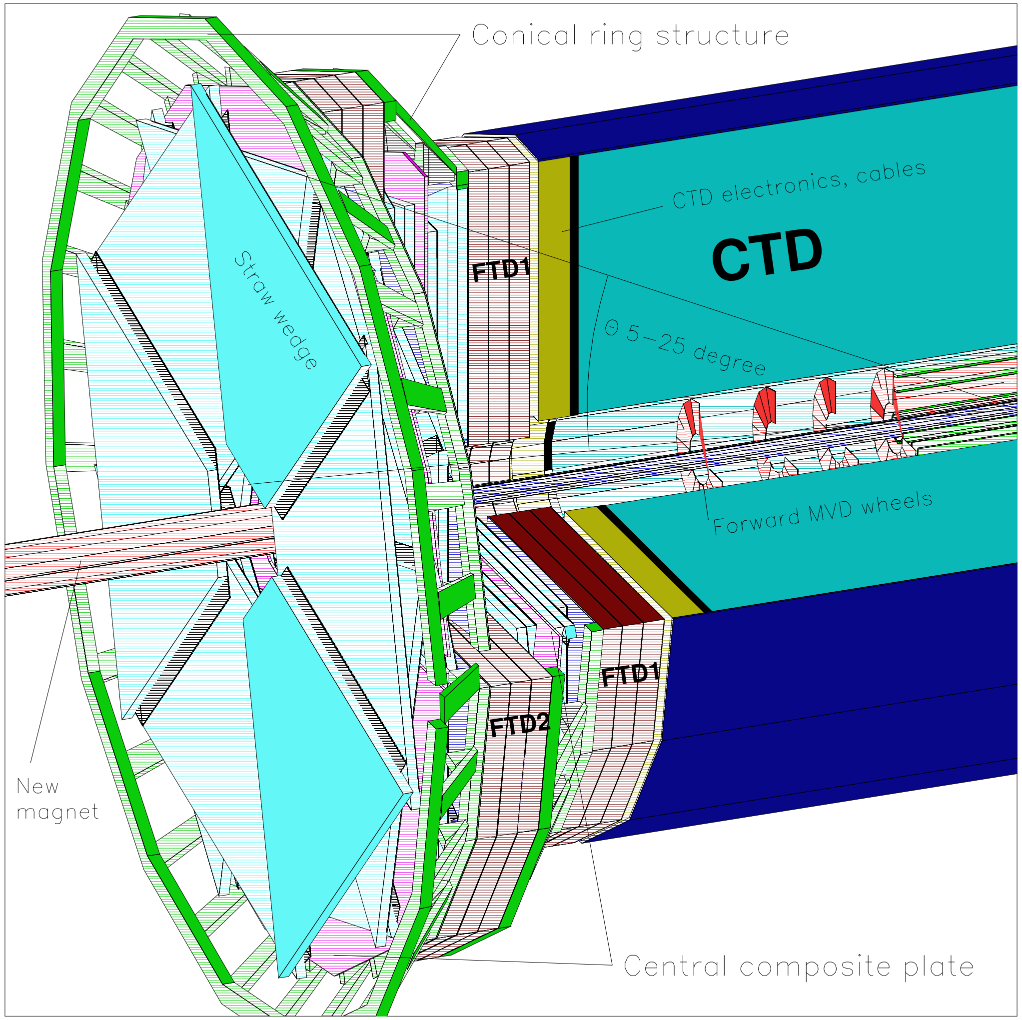
$p_\perp^b > 5\,\mathbf{GeV}$

And since 2003 :

Very Forward Proton Spectrometr

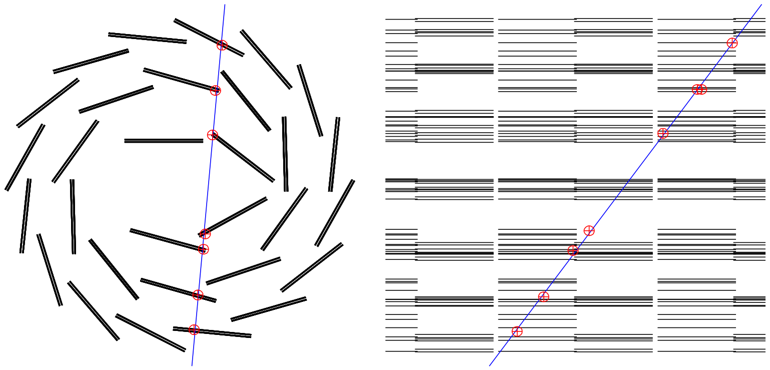
$500 - 1000\ D^{*\pm}$ **with** $0.001 < x_{I\!P} < 0.04$

ZEUS Tracking System Upgrade



In addition to existing
Central Tracking Detector
(tracks with $-1.75 < \eta < 1.75$)

Micro-Vertex Detector (new)



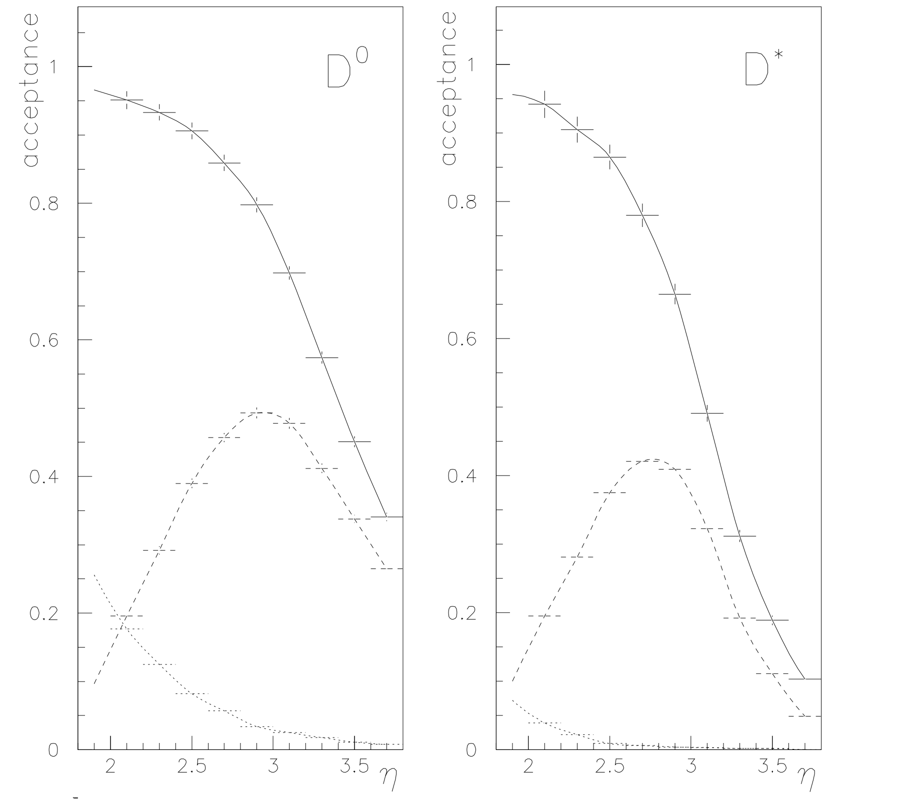
Straw Tube Tracker (new)
(tracks with $1.5 < \eta < 3.0$)

Global Tracking Trigger (new)

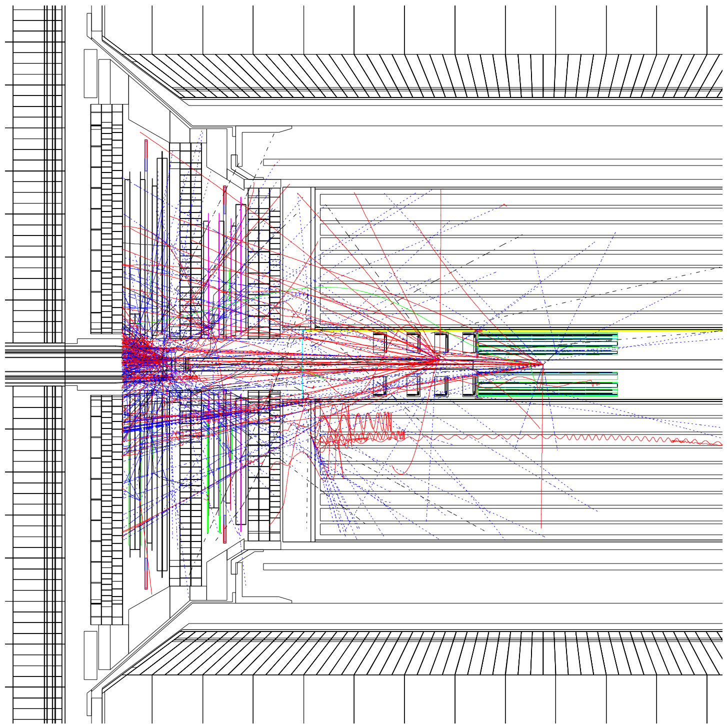
Tracking in Forward Direction

$D^0 \rightarrow K^- \pi^+$ **(+ c.c.) and** $D^{*+} \rightarrow D^0 \pi_S^+ \rightarrow (K^- \pi^+) \pi_S^+$ **(+ c.c.)**

Geometrical Acceptance



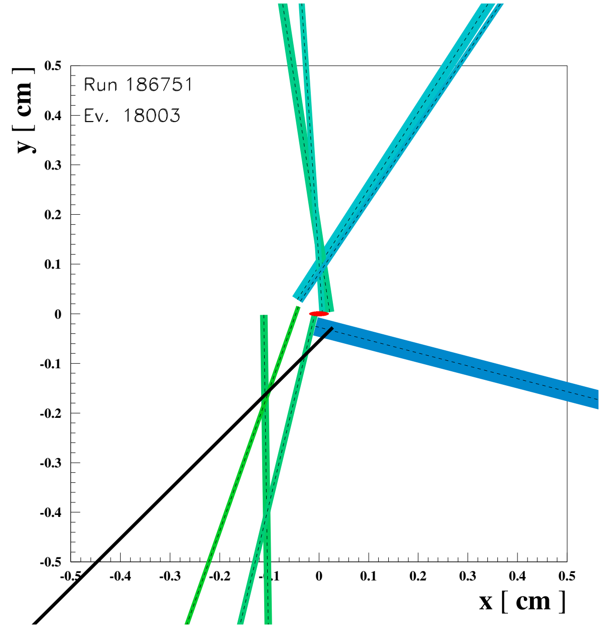
Clean $D^{*\pm}$ event with GEANT

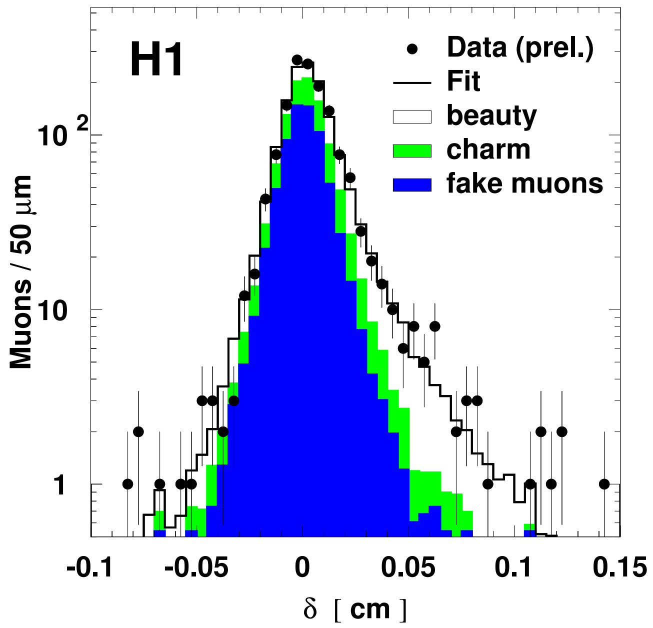


Will try to add forward range $(1.5 < \eta^{D^*} < 2.5)$ to presently accessible central range $(-1.5 < \eta^{D^*} < 1.5)$

(but forward triggering is a real chalenge !)

Secondary Verticies and Impact Parameters





Charm	$c\tau$ [μm]	Beauty	$c\tau$ [μm]
D^0	124	B^0	464
D^+	315	B^+	496
D_s^+	149	B_s^0	448
Λ_c^+	62	Λ_b^0	368

Impact parameter resolution

H1 : $\sigma_\delta = 40\,\mu m \oplus 100\,\mu m/p_\perp$

ZEUS : $\sigma_\delta \approx 100\,\mu m$ **for** $p_\perp > 2\,\mathrm{GeV}$

Beauty : Selelection / Cleaning

Charm : also possible

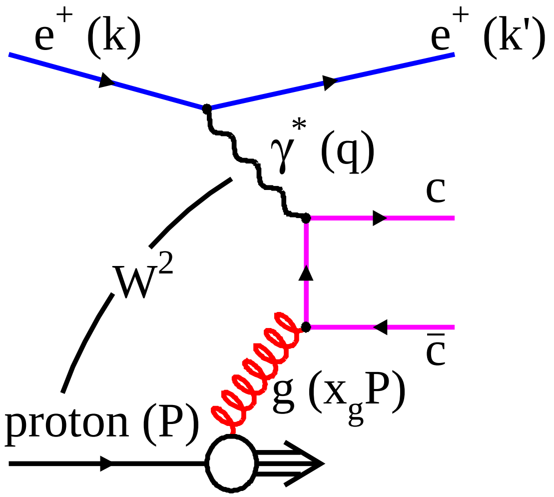
Optimistic : upto $\approx 20\%$ efficiency

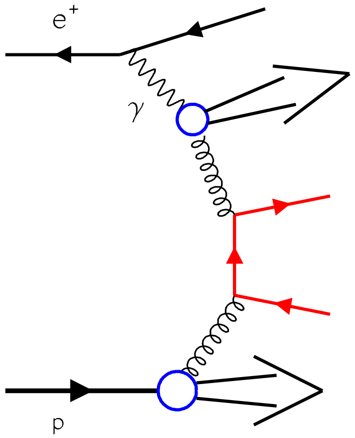
with Sig./Bckgr. ≈ 1 for charm

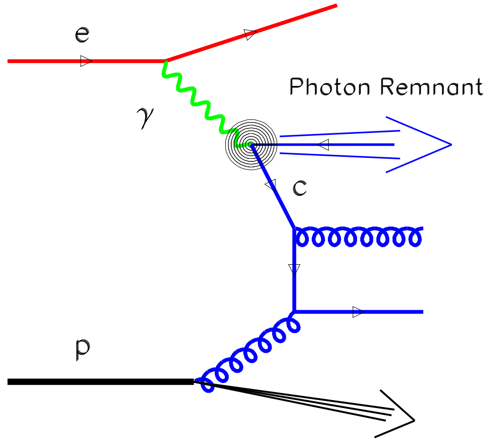
Charm and Beauty Production at HERA

Photoproduction $Q^2 \simeq 0\, GeV^2$

DIS $Q^2 > 1\, GeV^2$







direct, $\gamma g \to Q\bar{Q}$ **resolved,** $gg \to Q\bar{Q}$ **resolved (Q excit.),** $Qg \to Qg$

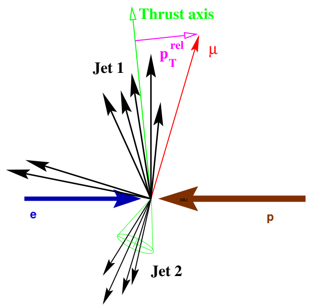
$\sigma_{c\bar{c}} \approx 1\,\mu\mathbf{b}$ 10^8 (10^9) **events with** $\mathcal{L}_{int} = 0.1\, f\mathbf{b}$ $(1\, f\mathbf{b})$

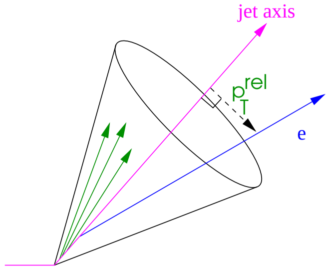
$\sigma_{b\bar{b}} \approx 10\,\mathbf{nb}$ 10^6 (10^7) **events with** $\mathcal{L}_{int} = 0.1\, f\mathbf{b}$ $(1\, f\mathbf{b})$

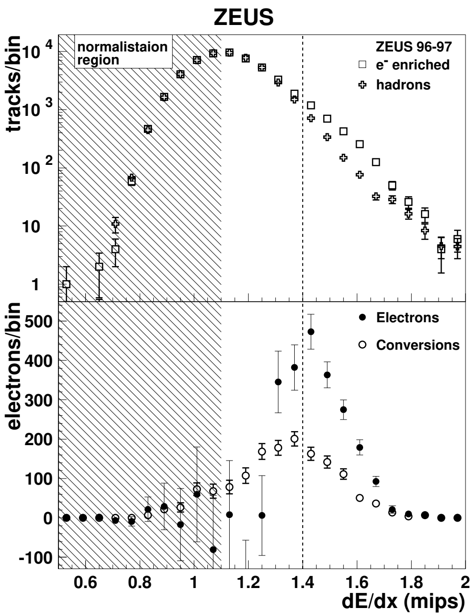
Present efficiencies $\lesssim 10^{-3}$ **:** $f(c \to D^{*+})$**, branchings, large backgr., central** η**, high** $p_\perp$ **and** Q^2**, trigger and reconstruction restrictions**

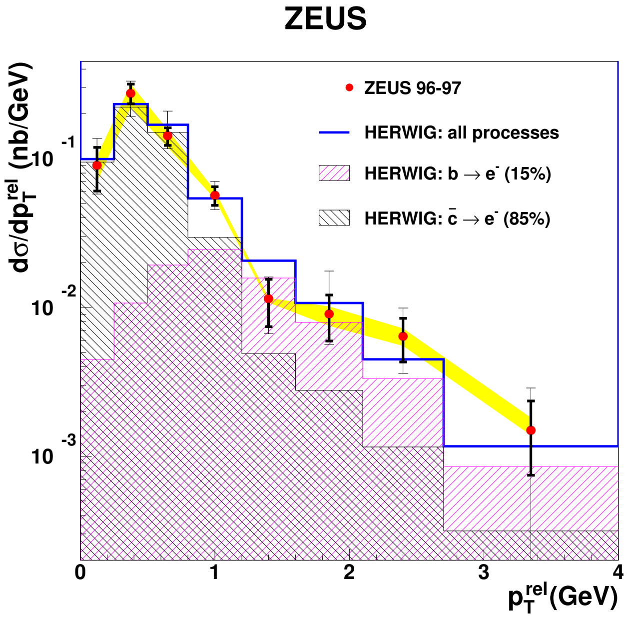
Beauty Tagging at HERA (now)

e^- and $\mu^\pm$ from s-l decays, P_T^{rel} w.r.t. a jet and (only H1 at now) impact parameter





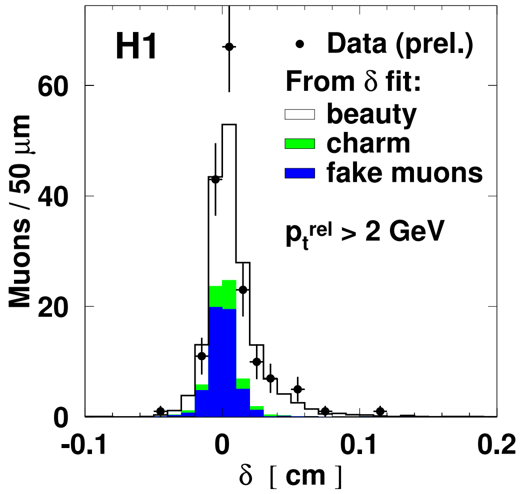


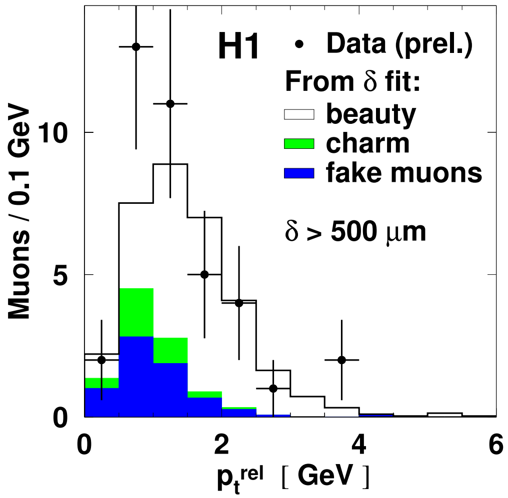


Use CAL and dE/dx in CTD to identify electrons

Fit P_T^{rel}: $f_b = 14.7 \pm 3.8\%$

(HERWIG, PYTHIA : 16%, 19%)

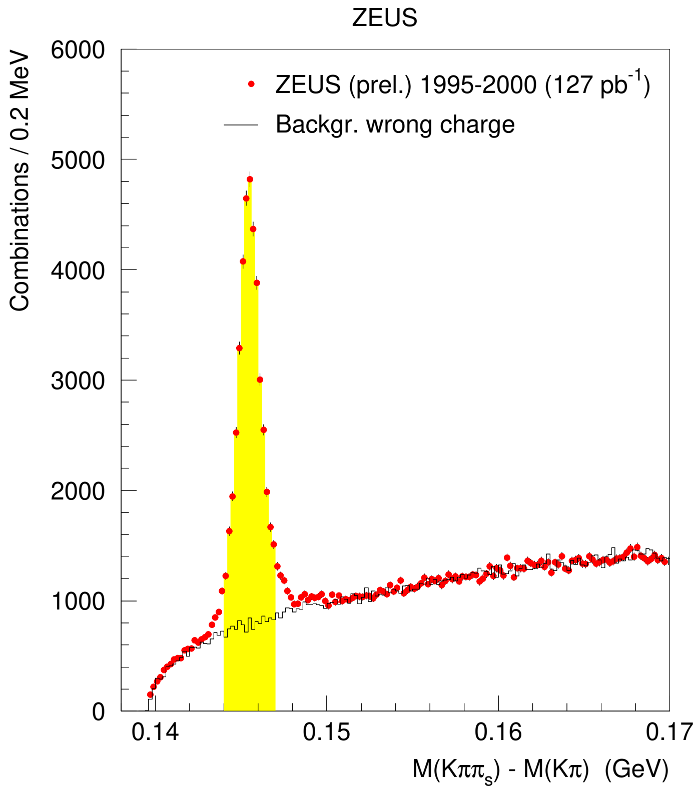




Use MUO detectors to identify muons

Use 2-D fit in (δ, P_T^{rel}) plane: $f_b = 27 \pm 3\%$

Charm Tagging at HERA (now)



$D^{*+} \to D^0\pi_s^+ \to (K^-\pi^+)\pi_s^+$ **(+ c.c.)**

$f(c \to D^{*+}) \approx 24\%,\ BR = 2.6\%$

$\Delta M = M(D^{*+}) - M(D^0) = 0.14542$ **GeV** $\sim m_\pi$

$P_\perp^{D^*} > 2$ **GeV and** $-1.5 < \eta^{D^*} < 1.5$

In the yellow band under background:

$$\boxed{N(D^{*\pm}) = 31350 \pm 240}$$

better than 1% **stat. precision**

Other tagging methods: $D^* \to D^0\pi_s \to (K^-\pi^+\pi^+\pi^-)\pi_s$

$D_s \to \phi\pi \to (K^-K^+)\pi$

s-l electrons with dE/dx

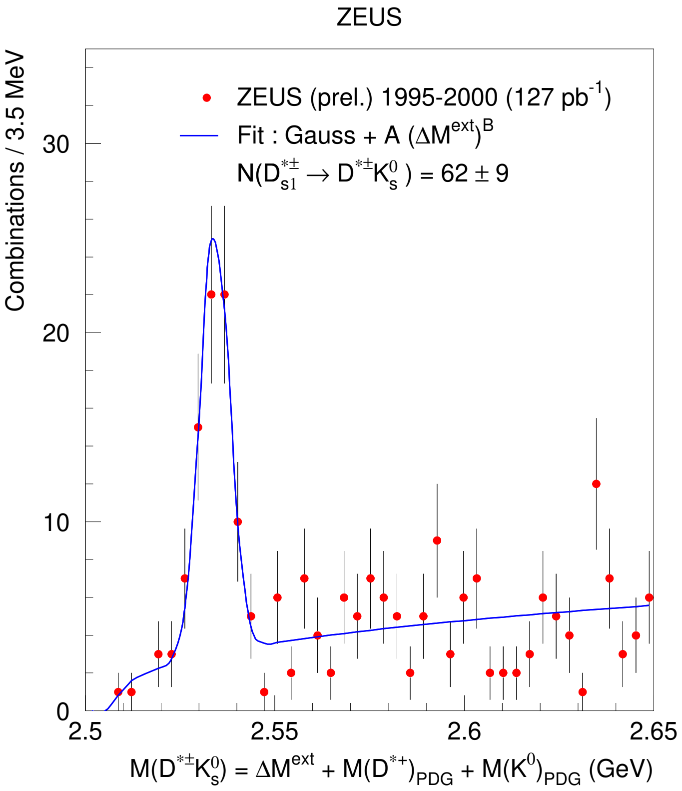
After upgrade: **better resolution (+MVD+STT)**

impact parameter cleaning

all D **mesons,** $10^5 - 10^6\ D^{*\pm}$

HERA as a Charm Factory

strangeness suppression in charm fragmentation, spectroscopy of D mesons



$D_{s1}^{\pm}(2536) \rightarrow D^{*\pm} K_S^0$, $\quad K_S^0 \rightarrow \pi^+\pi^-$

Unbinned fit : $\boxed{N(D_{s1}^{\pm}) = 62.3 \pm 9.3}$ **(ZEUS prel.)**

$$\boxed{f(c \rightarrow D_{s1}^{+}) = 1.24 \pm 0.18(\text{stat.})^{+0.08}_{-0.06}(\text{syst.}) \pm 0.14(\text{br.})\%}$$

OPAL : $f(c \rightarrow D_{s1}^{+}) = 1.6 \pm 0.4 \pm 0.3\%$

Helicity Parameter :

$\boxed{R = -0.53 \pm 0.32(\text{stat.})^{+0.05}_{-0.14}(\text{syst.})}$ **(ZEUS prel.)**

CLEO $(D_{s1}^{+} \rightarrow D^{*0} K^{+})$ **:** $R = -0.23^{+0.40}_{-0.32}$

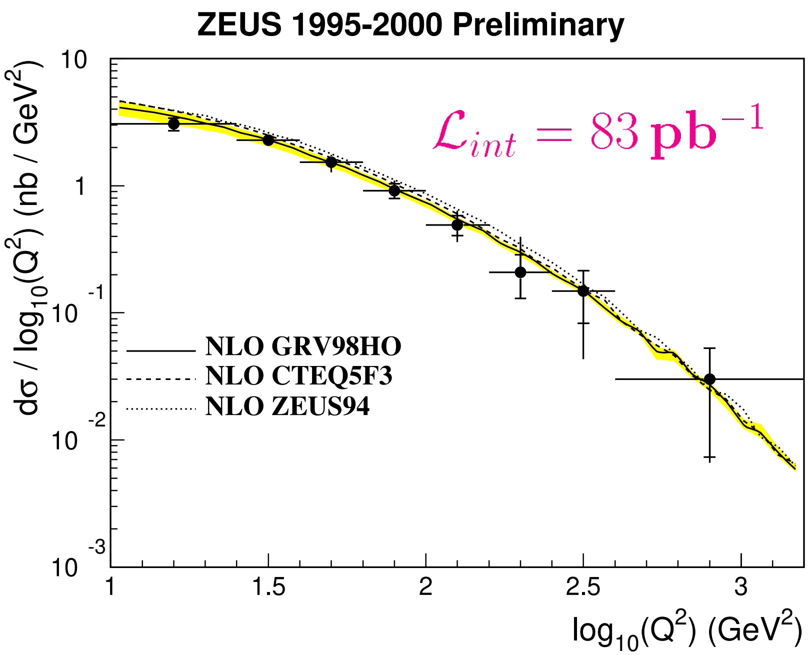
After upgrade : **continue with excited D mesons (CLEO-C will not be able)**

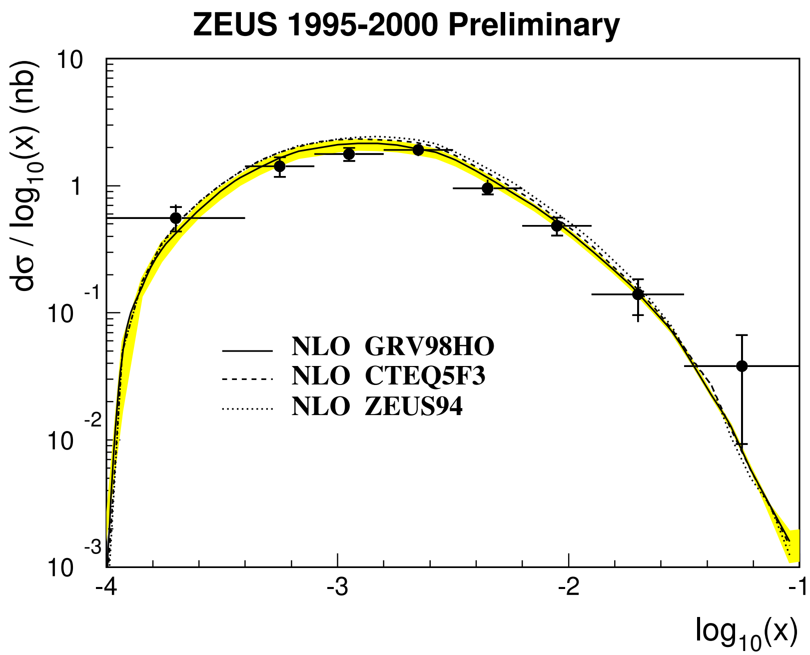
try $D^0 - \bar{D}^0$ mixing (they will do better, maybe)

probe rare D^0, D^+, D_s^+, Λ_c^+ decays using μ and e identification

(down to branchings $\approx 10^{-7}$ from statistics)

Open Charm in DIS





$Q^2 > 10\,\mathbf{GeV}^2$; $0.04 < y < 0.95$; $1.5 < P_\perp^{D^*} < 15\,\mathbf{GeV}$; $-1.5 < \eta^{D^*} < 1.5$

Reasonable agreement with HVQDIS (fixed-order NLO)

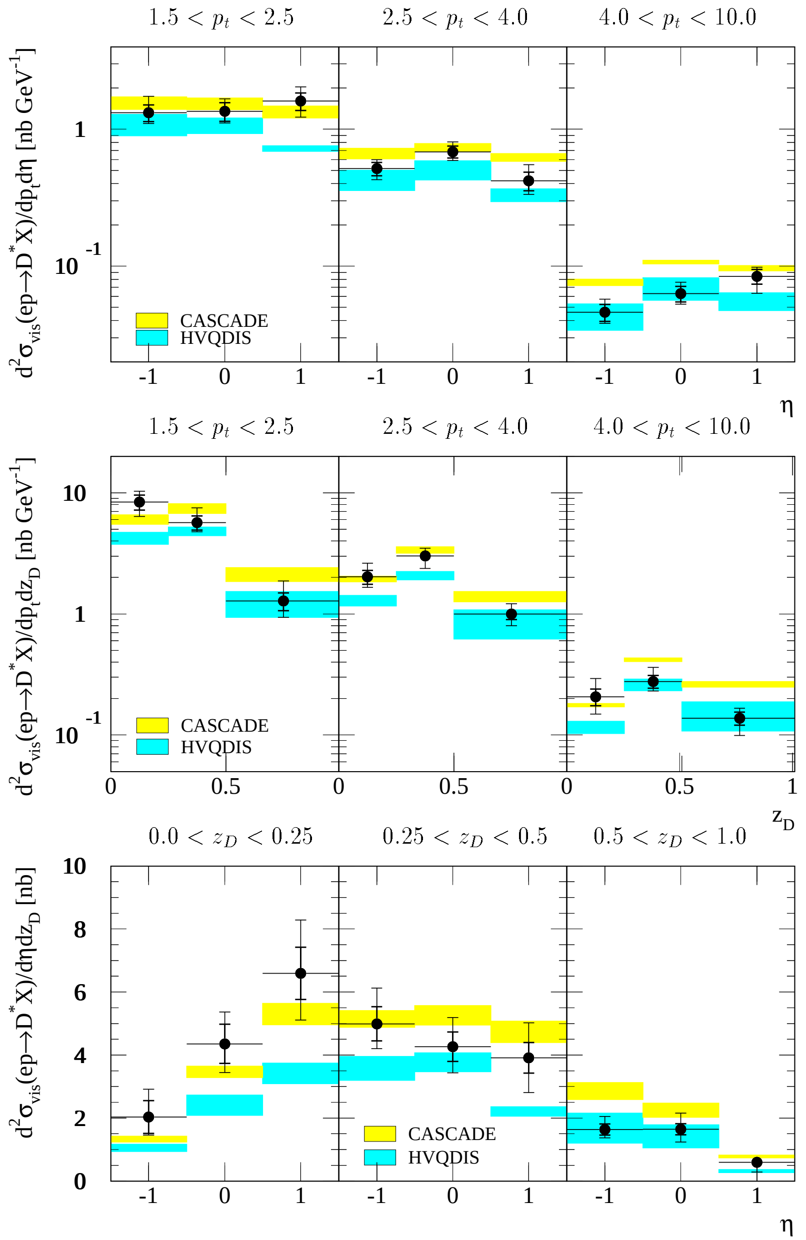
Do we need resummed calculations for charm in DIS at HERA ?

After upgrade : **reduce (3-4 times) exp. errors for** $Q^2 > 100\,\mathbf{GeV}^2$ **and** $x > 10^{-2}$

extend the measurement to $10^3 < Q^2 < 10^4\,\mathbf{GeV}^2$

produce double differential x-sections for high Q^2 **range**

Open Charm in DIS, 2.



$\mathcal{L}_{int} = 18\,\mathbf{pb}^{-1}$

$1 < Q^2 < 100\,\mathbf{GeV}^2$; $0.05 < y < 0.7$

$P_\perp^{D^*} > 1.5\,\mathbf{GeV}$; $-1.5 < \eta^{D^*} < 1.5$

Bands : $1.3 < m_c < 1.5\,\mathbf{GeV}$ **and fragmentation**

Blue : HVQDIS (with GRV98)

Yellow: CASCADE (CCFM unintegr. gluon)

CASCADE agrees better in normalization

HVQDIS is too low at small $P_\perp^{D^*}$,

forward η^{D^*} **and small** z^{D^*} $(= (E - P_z)_{D^*}/2yE_e)$

CASCADE is too high at large $P_\perp^{D^*}$

Predictions have large uncertainties (upto 30%**)**

gluon, m_c**, fragm. and scales**

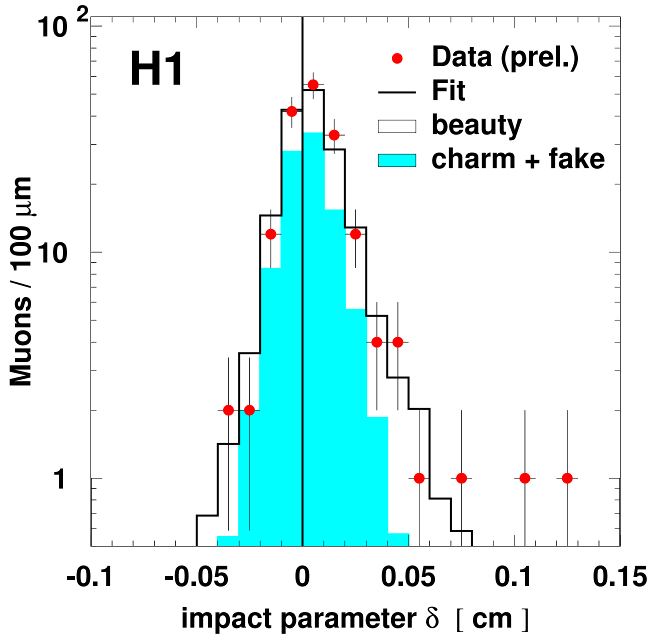
After upgrade :

wider η^{D^*} **range:** $-1.5 < \eta^{D^*} < 2.5$

wider $P_\perp^{D^*,D}$ **range**

Open Beauty in DIS

$\mathcal{L}_{int} = 11\,\mathbf{pb}^{-1}$



$2 < Q^2 < 100\,\mathbf{GeV}^2$; $0.05 < y < 0.7$

$P_\perp^\mu > 2\,\mathbf{GeV}$; $35^\circ < \theta^\mu < 130^\circ$

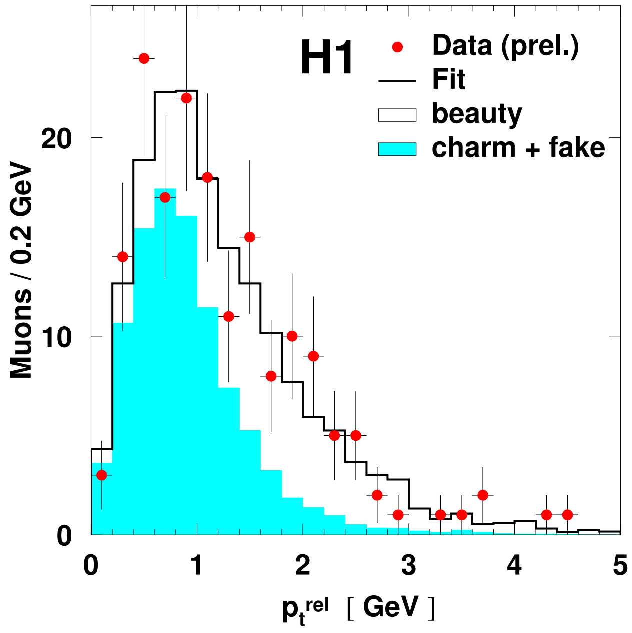
From 2-D fit in (δ, P_T^{rel}) **plane:** $f_b = (43 \pm 8)\%$

$\boxed{\sigma_{vis} = [39 \pm 8(\mathrm{stat.}) \pm 10(\mathrm{syst.})]\,\mathbf{pb}}$ **(H1 prel.)**

HVQDIS : $(11 \pm 2)\,\mathbf{pb}$ ... **fails ?**

AROMA : $9\,\mathbf{pb}$

CASCADE : $15\,\mathbf{pb}$

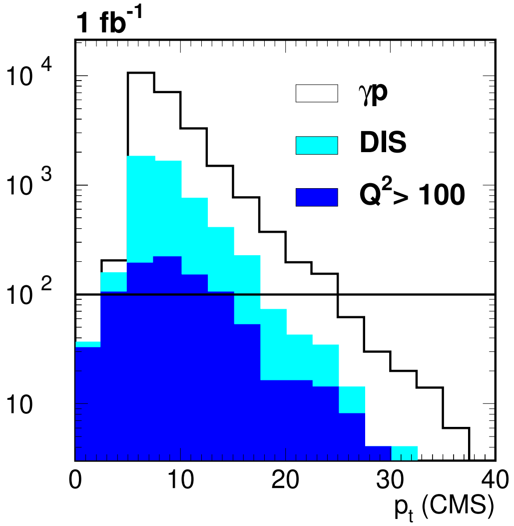


After upgrade :

reduce exp. errors ≈ 10 **times**

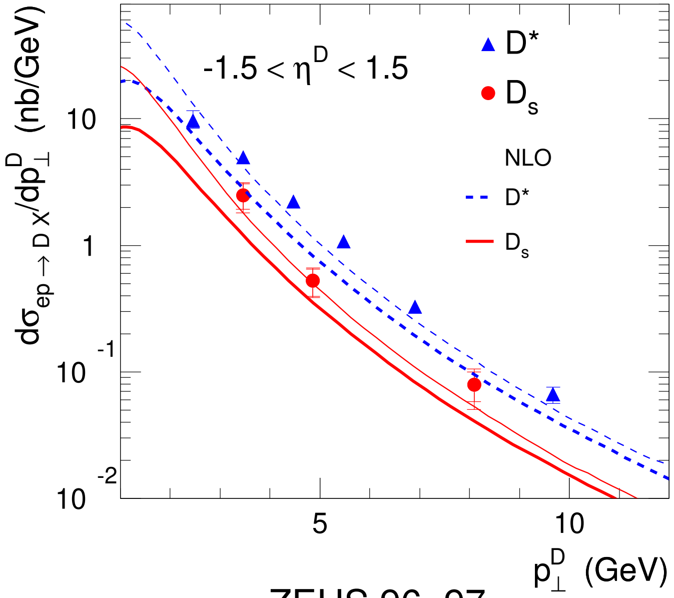
produce diff. x-sections

extent to $Q^2 > 100\,\mathbf{GeV}$



Open Charm in Photoproduction

ZEUS 96+97 $\mathcal{L}_{int} = 38\,\mathbf{pb}^{-1}$ $D^{*\pm}$ **and** $D_s^{\pm}$ **in PhP**



$Q^2 < 1\,\mathbf{GeV}^2$; $130 < W < 280\,\mathbf{GeV}$

NLO : FMNR, MRSG and GRV-G HO

thick curves: $m_c = 1.5\,GeV,\ \mu_R = m_\perp, \mu_F = 2m_\perp$

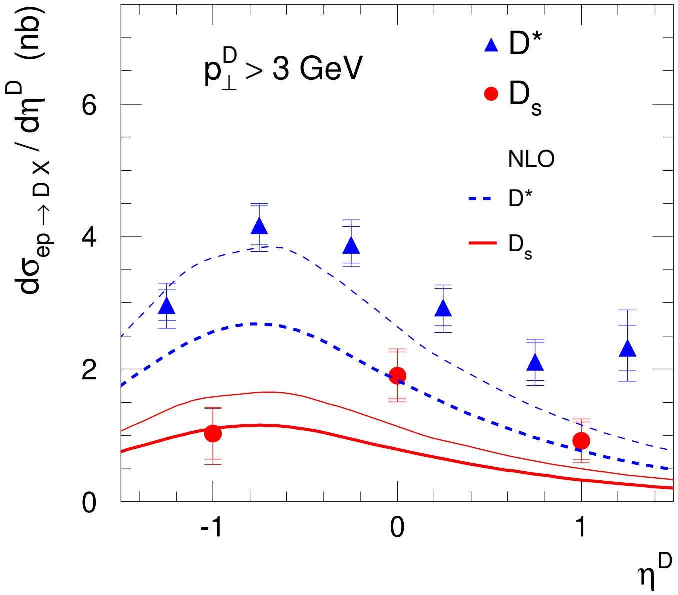
thin curves: $m_c = 1.2$ **and** $\mu_R = 0.5m_\perp$ $\leftarrow$ **extreme ?!**

nominal: underestimate x-sections ≈ 1.8 **times**

extreme: still below the data

$p_\perp$ **shape ? not really correct (see** D^* **points)**

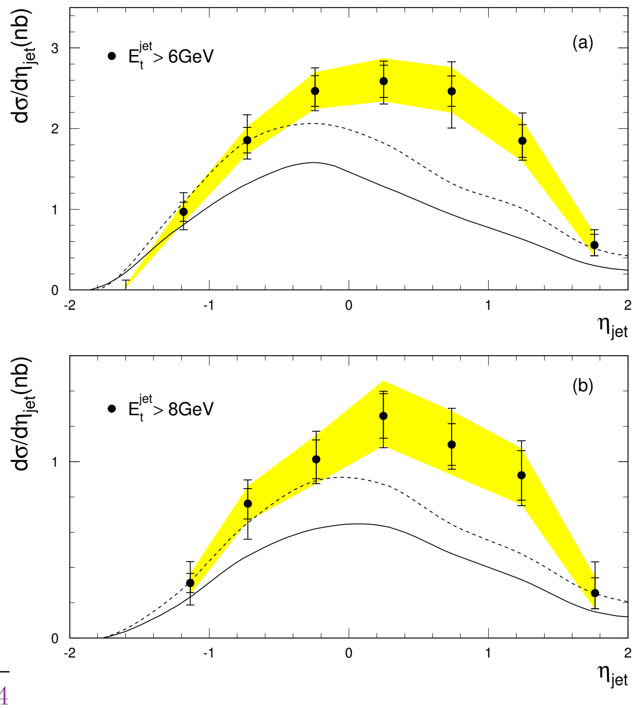
ZEUS 96+97



disagreement is larger in forward direction "beam-drag effect" ? $\longleftarrow$

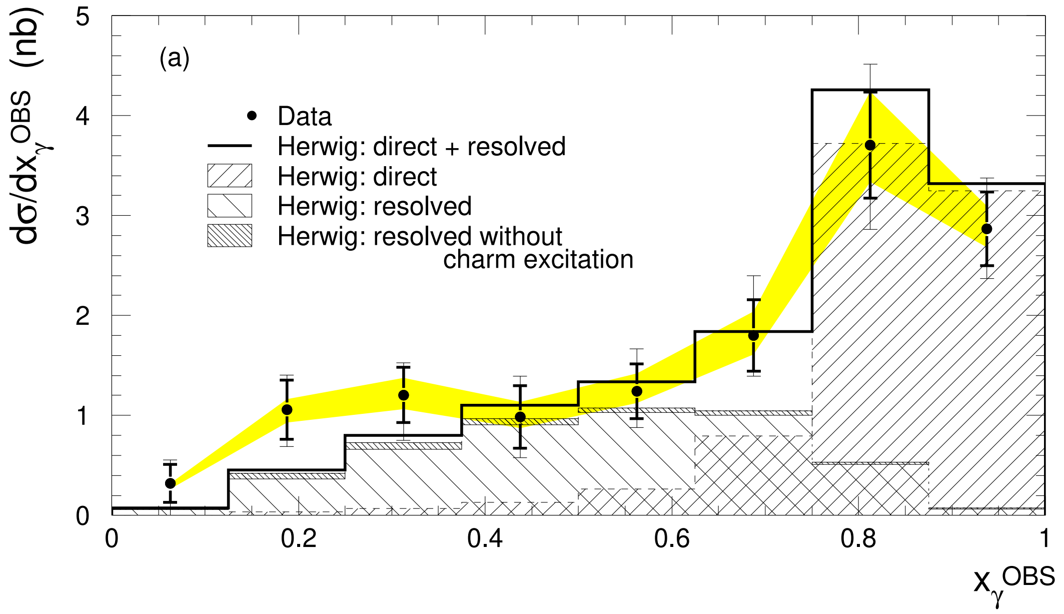
But charm jets show the same $\longrightarrow$

ZEUS 1996+97 Preliminary



Resolved or not Resolved ?

ZEUS 1996+97 $\mathcal{L}_{int} = 38\,\mathbf{pb}^{-1}$ $D^{*\pm}$ **in PhP**

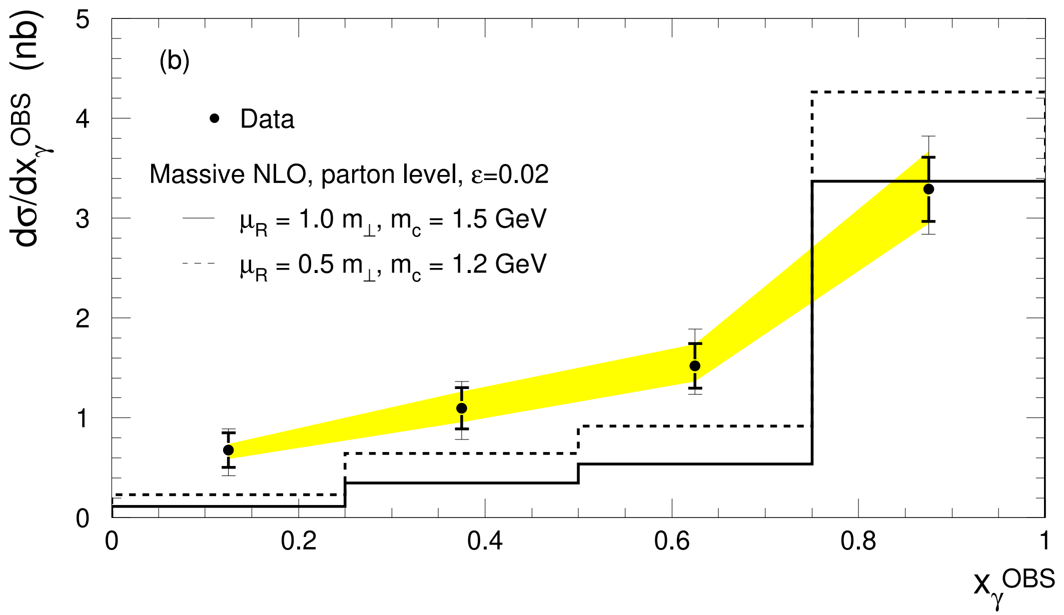


with at least 2 jets

In all orders one can define x_γ^{OBS}, a fraction of the photon momentum participating in the dijet production:

$$x_\gamma^{OBS} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e}$$

$\longleftarrow$ **(DGLAP) LO charm excitation in photon (≈ 40 %)**

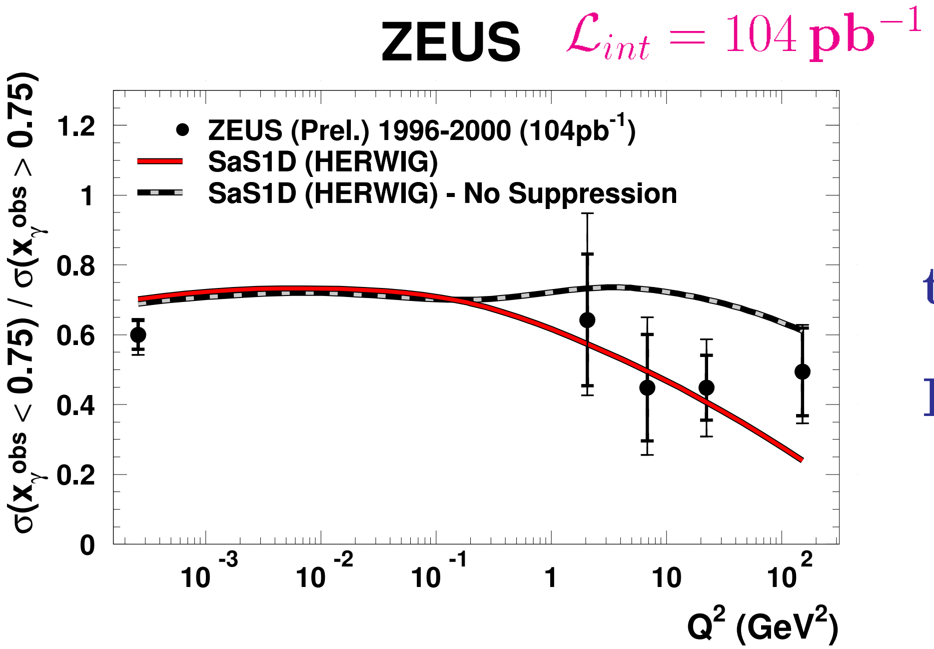


$\longleftarrow$ **fixed-order NLO are below data at low x_γ^{OBS}**

NNLO describes better ?

Resolved γ or CCFM gluon ?
(CASCADE is close in shape)

Resolved or not Resolved, PhP $\longrightarrow$ DIS

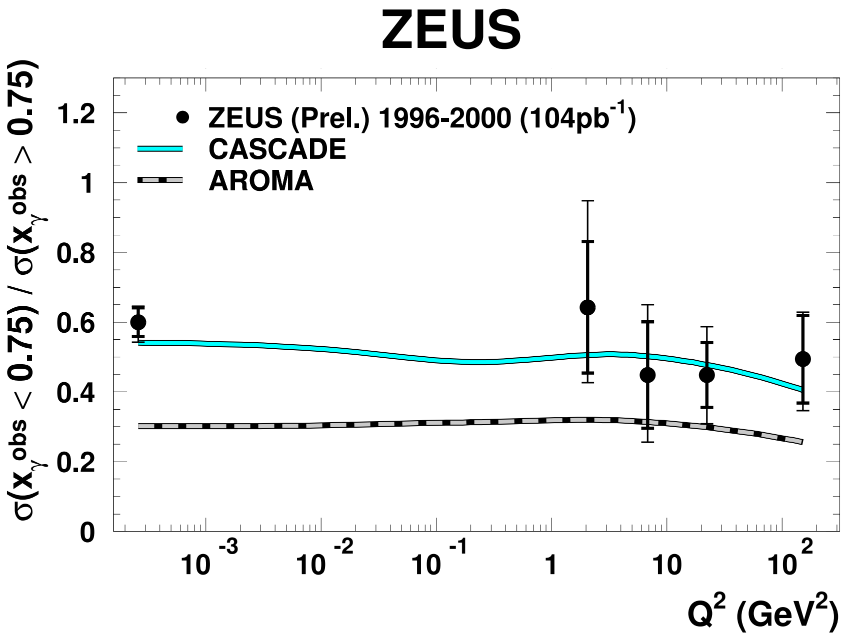


$x_\gamma^{\rm OBS}$ **for** $D^{*\pm}$ **in PhP and DIS**

$$\frac{\sigma(x_\gamma^{OBS}<0.75)}{\sigma(x_\gamma^{OBS}>0.75)} \text{ vs } Q^2$$

tiny (if any) suppression with Q^2

HERWIG with SaS1D agrees



AROMA is too low (no resolved γ)

CASCADE describes w/o resolved γ

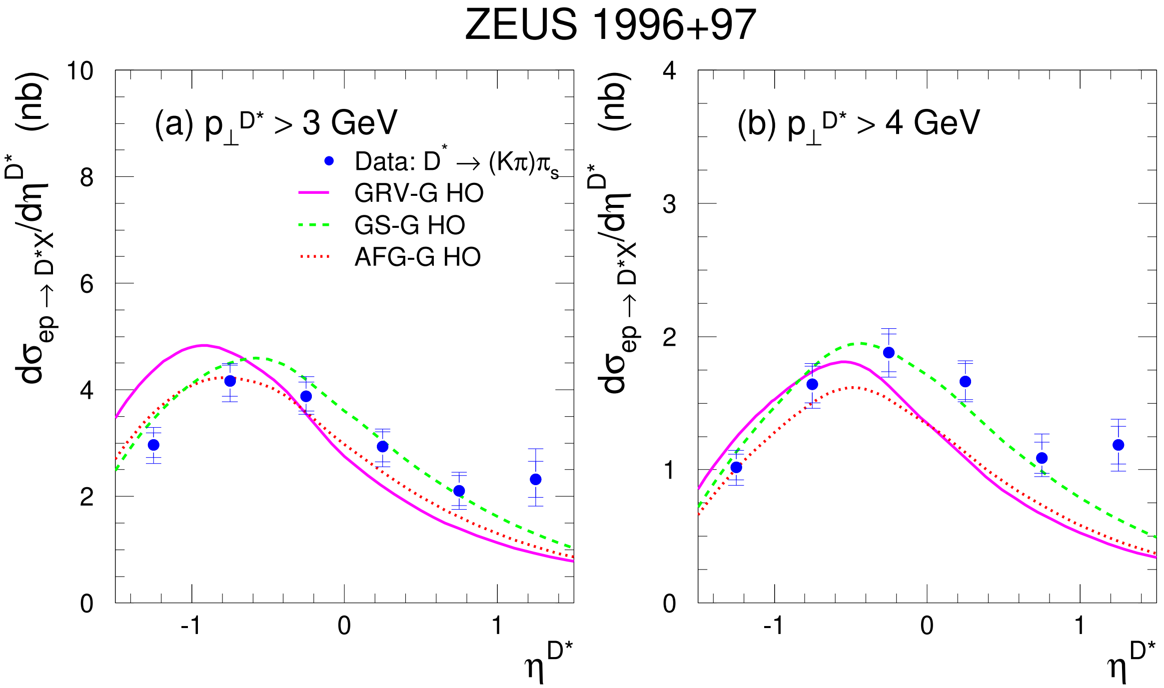
After upgrade :

reduce exp. errors ≈ 3 times for DIS points

go to larger Q^2

try for beauty

Charm in PhP in comparison with Resummed NLO



This place is booked (since 98) for x_γ^{OBS} comparison with resummed NLO predictions

DATA: ZEUS D^* in PHP, $Q^2 < 1\,GeV^2$, $130 < W < 280\,GeV$

NLO : Kniehl et al., CTEQ4M, $m_c = 1.5\,GeV$, $\mu_R = m_\perp, \mu_F = 2m_\perp$

(resummed NLO from Cacciari et al. is ≈ 1.5 lower, why ?)

Predictions with GS-G HO are close to data ! However, $c = u$ in this photon SF !?

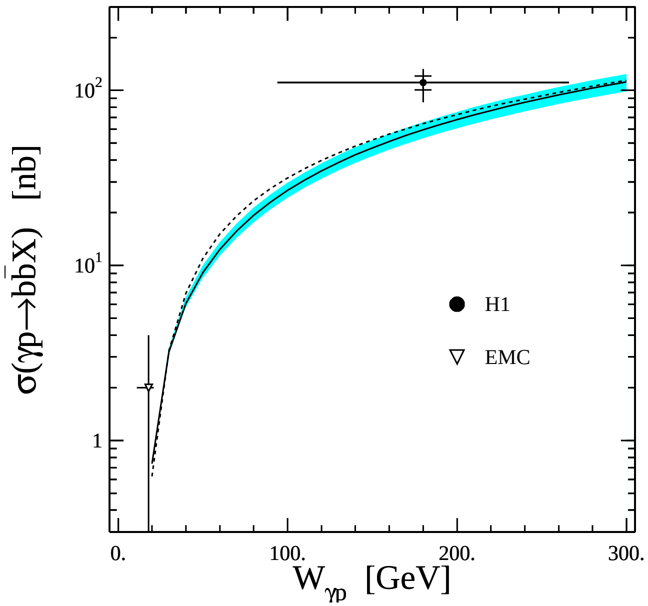
Can light contain the same amounts of c and u already at $m_\perp \approx 4.5\,GeV$?

(Is $p_\perp$ large enough ?)

($\Lambda_5^\gamma \neq \Lambda_5^p$. Can we trust hadronic (resolved) component calculations with Λ_5^p ?)

Open Beauty in Photoproduction

H1 , $\mathcal{L}_{int} = 21\,\mathbf{pb}^{-1}$



$Q^2 < 1\,\mathbf{GeV}^2$; $0.1 < y < 0.8$; $P_\perp^\mu > 2\,\mathbf{GeV}$; $35^\circ < \theta^\mu < 130^\circ$

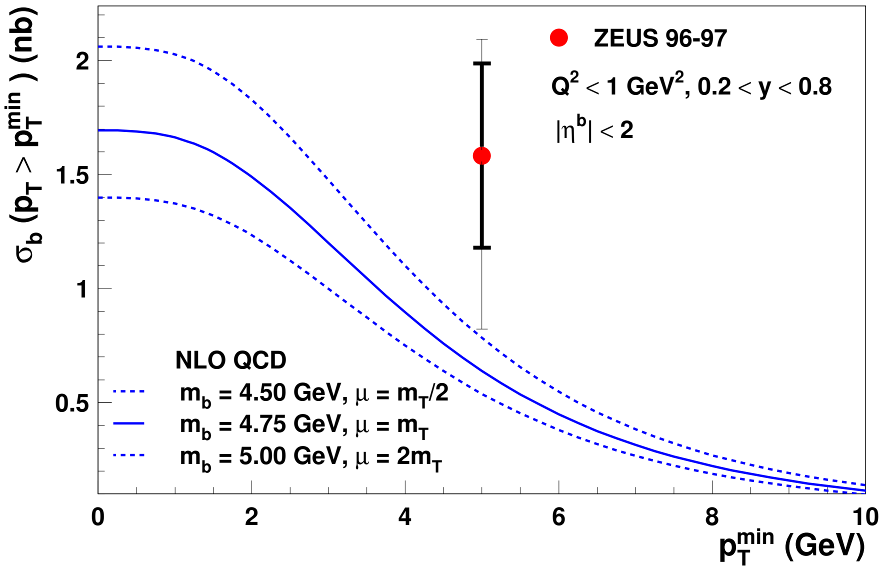
$\boxed{\sigma_{vis} = (170 \pm 25)\,\mathbf{pb}}$ **(H1 publ. and prel. combined)**

NLO (FMNR) : $(104 \pm 17)\,\mathbf{pb}$ ... **fails ?**

AROMA : $38\,\mathbf{pb}$

CASCADE : $67\,\mathbf{pb}$

ZEUS $\mathcal{L}_{int} = 38\,\mathbf{pb}^{-1}$



$\boxed{\sigma^{ext}_{e^+p\to e^+bX} = (1.6 \pm 0.4(\mathrm{stat.})^{+0.3}_{-0.5}(\mathrm{syst.})^{+0.2}_{-0.4}(\mathrm{ext.})\,\mathbf{pb}}$

NLO (FMNR) : $(0.64^{+0.14}_{-0.10})\,\mathbf{nb}$

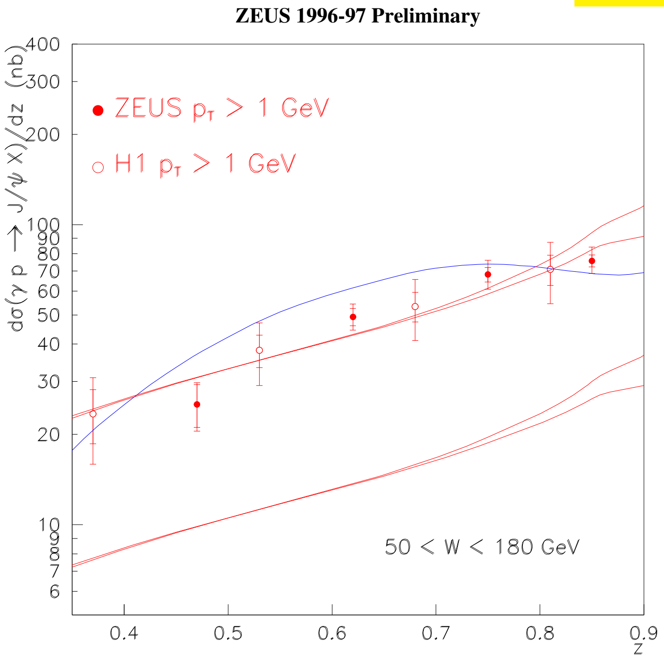
... **somewhat below**

CASCADE : $(0.88 \pm 0.08)\,\mathbf{nb}$

After upgrade : reduce 5-10 times exp. errors

measure differential x-sections

J/ψ in Photoproduction



H1 ($22\,\mathbf{pb}^{-1}$) and ZEUS ($38\,\mathbf{pb}^{-1}$)

$Q^2 < 1\,\mathbf{GeV}^2$; $50 < W < 180\,\mathbf{GeV}$; $P_\perp^{J/\psi} > 1\,\mathbf{GeV}$

x-sections in inelasticity, $z = (E - P_z)^{J/\psi}/2yE_e$

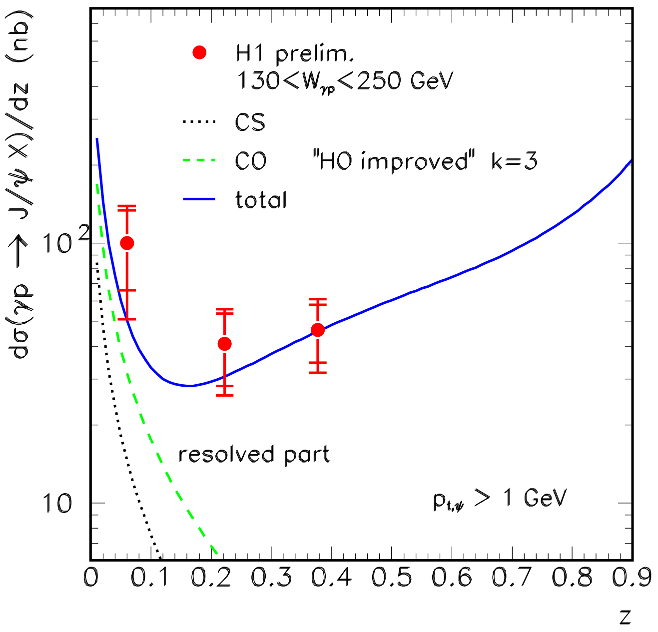
lower red lines : LO CS+CO from Kniehl et al.

upper red lines : (this LO)$\times 3$

blue line : NLO CS from Krämer et al.

(factor 2-3 uncertainty in normalization

due to m_c, μ_r, Λ_5)



First low-z measurement ($\mathcal{L}_{int} = 24\,\mathbf{pb}^{-1}$)

lines : LO CS+CO from Kniehl et al.

resolved contribution is here

but too large uncert. to claim CO

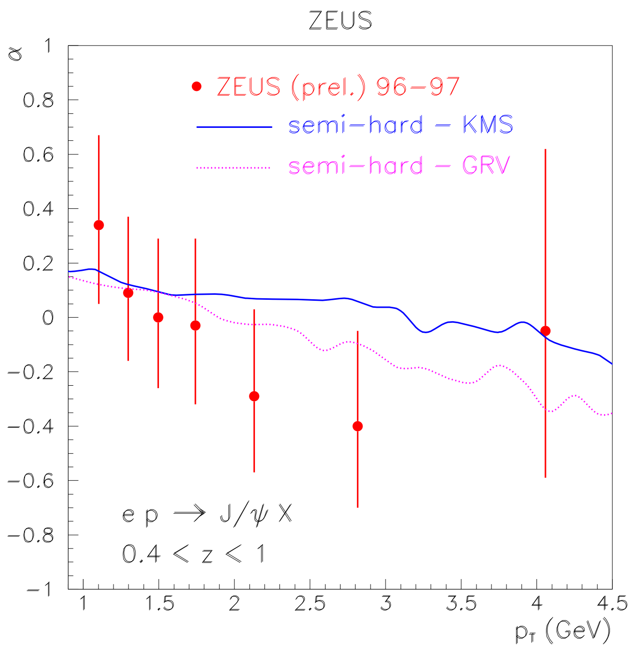
After upgrade : reduce 3-5 times exp. errors

measure larger $P_\perp^{J/\psi}$

reduce theor. uncertainties

measure Υ inelastic ($\sigma(J/\psi)/300$)

J/ψ Helicity Distribution



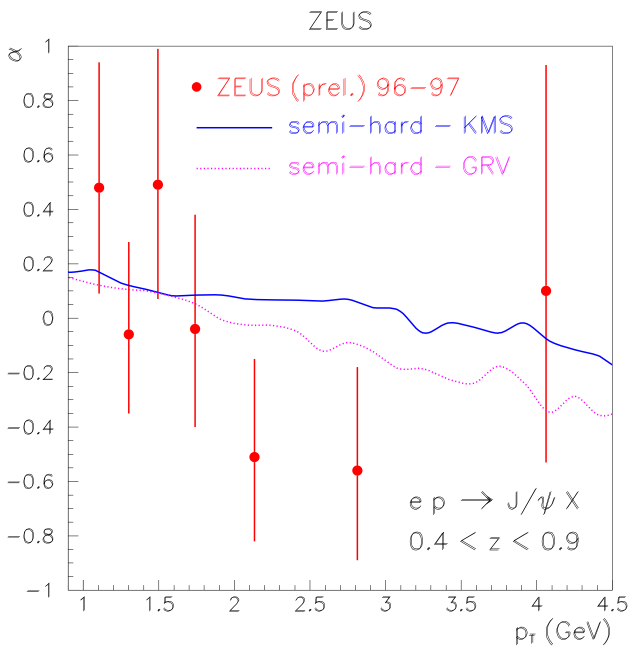
ZEUS $(38\,\mathrm{pb}^{-1})$

$dN/d\cos\theta^* \propto 1 + \alpha\cos^2\theta^*$, **where**

θ^* **is** μ^+ **angle in** J/ψ **rest frame wrt** J/ψ **in the lab.**

Curves : CS semi-hard calculations from Baranov with non-collinear gluon distributions (KMS, GRV)

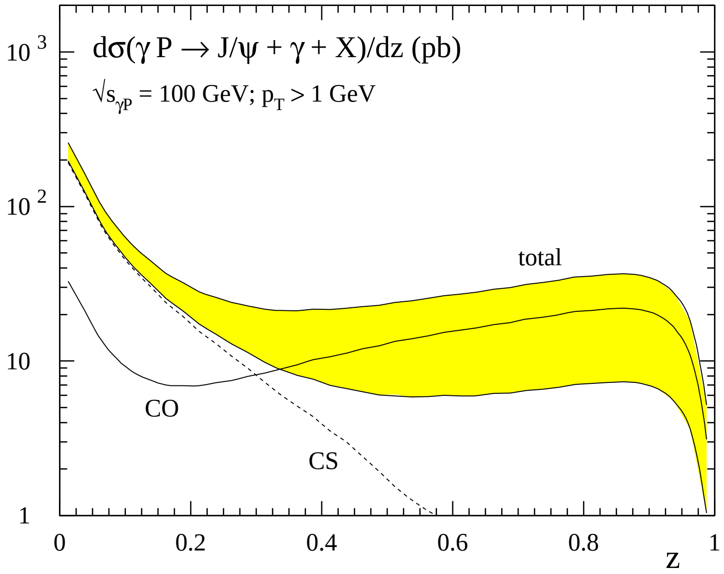
The distribution is known sensitive to CS/CO but statistics ...



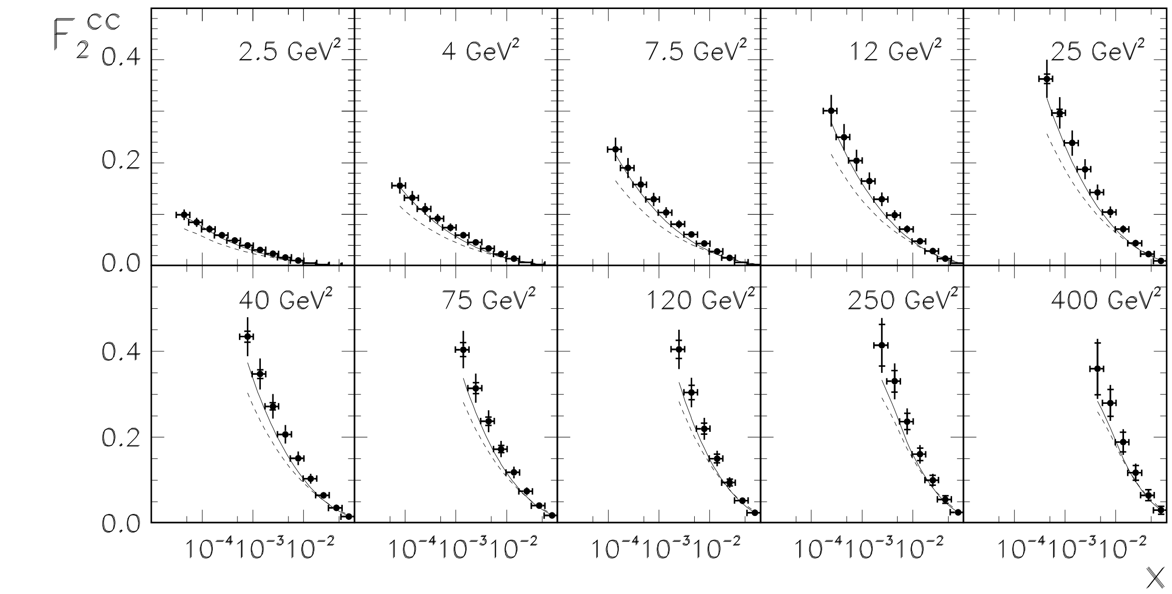
After upgrade : reduce 3-5 times exp. errors

try other methods to catch CO, e.g. $\gamma p \to J/\psi\gamma X$ **:**

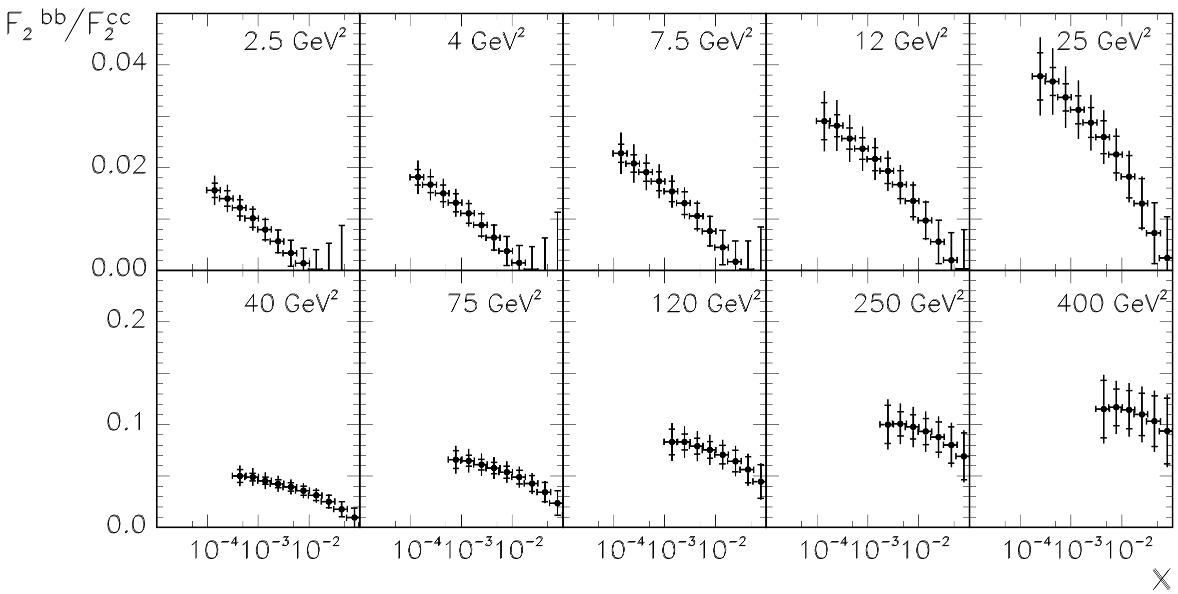
at least upper limit for $\sigma_{z>0.4}$ $\longrightarrow$



$F_2^{c\bar{c}}$ and $F_2^{b\bar{b}}$ with $500\,\mathrm{pb}^{-1}$



High precision $F_2^{c\bar{c}}$

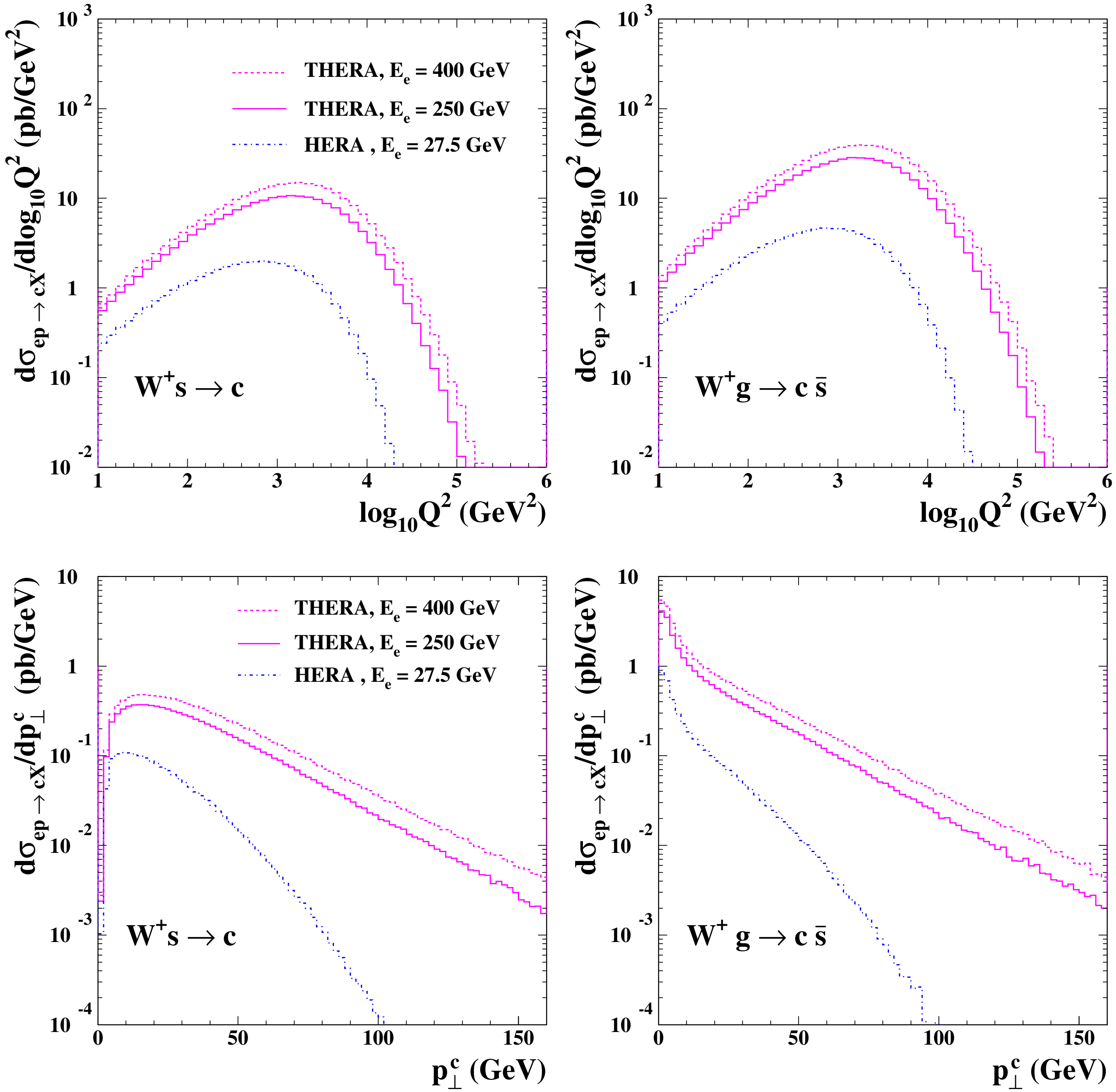


$F_2^{b\bar{b}}$ is possible

$F_2^{b\bar{b}}/F_2^{c\bar{c}} \approx 10\%$

at $Q^2 \approx 400\,\mathbf{GeV}^2$

Charged Current Charm Production ($F_2^{s\bar{s}}$?)



$\sigma = 5 - 10\,$**pb**

only c ($\bar{c}$) **for** e^+p (e^-p)

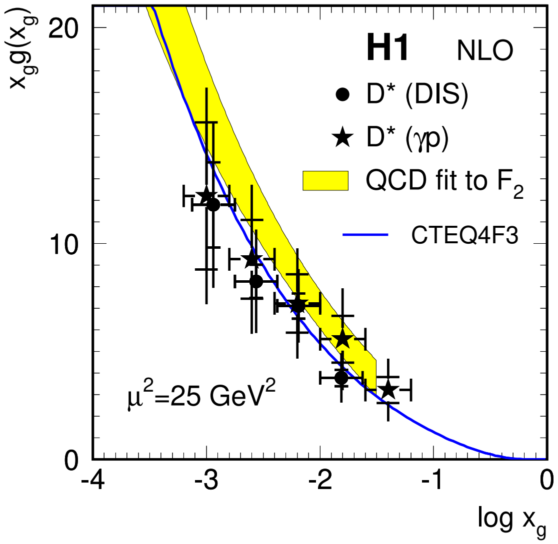
to select (a few) hundred events

combine e, μ, D

$P_\perp^c$ distributions are different (with LO MC) for $W^+s \to c$ and $W^+g \to c\bar{s}$

try to distinguish or just measure them together

Double tagged selections for $x_g g(x_g)$ and beauty



H1 , $\mathcal{L}_{int} \approx 10\,\mathbf{pb}^{-1}$, only $D^{*\pm}$

After upgrade : reduce (10 times) stat. errors

to constraint better event kinematics

use double tagged selections:

- **2 jets (and a D^*), 2 D, D + lepton**
- **thousands events in each channel**
- $x_g = M_{Q\bar{Q}} \exp(y_{Q\bar{Q}})/\sqrt{s}$

use beauty double tagged selections

to x-check P_T^{rel}-based (high E_T jets) results:

- **$D^{(*)}$ + lepton, 2 (3) leptons**
- **hundreds events are selectable**
- **$\sigma_{tot}^{b\bar{b}}$ measurements (?)**

Looking Forward

HERA has already provided wide spectrum of charm and first beauty measurements

In charm sector experimental errors are typically smaller than theoretical uncertainties

With $1\,\mathrm{fb}^{-1}$ and upgraded detectors we will be able:

- Produce precise beauty diff. x-sections, measure F_2^b
- Study all details of charm production, extend F_2^c, improve $xg(x)$
- Measure charm production in charged current DIS
- Catch CO J/ψ production (?), measure inelastic Υ production
- Contribute to D spectroscopy, $D^0-\bar{D}^0$ mixing and D rare decays

HERA upgrade requires an upgrade of the heavy quark calculations for HERA:

- NNLO for charm and beauty
- Resummed calculations for x_γ^{OBS}
- NLO Monte Carlo
- CCFM for photon structure (?)

New data will come in 6 months !