Heavy Flavour Summary (experimental)

DIS'03 St. Petersburg

Felix Sefkow
DESY

April 27, 2003

22 presentations

Reporting new results from

- TeVatron, HERA, LEP, B-factories, ν

Challenging QCD with measurements of

- Charmonium
- Open charm, beauty and truth

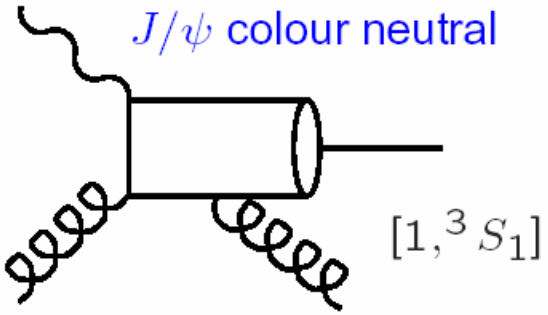
production in pp, pN, νN, ep, γp, $\gamma\gamma$, ee collisions

My apologies for any injustice !!

Charmonium:

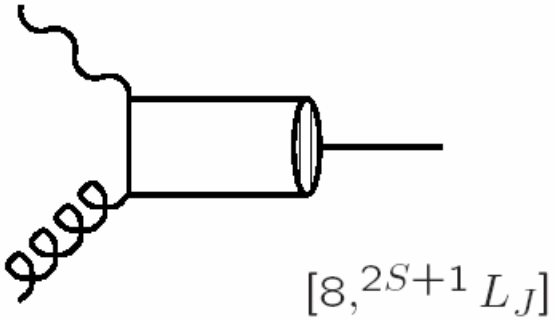
"The simplest case to relate the theory of quarks and gluons to the world of hadrons..."

Charmonium-Produktion



Colour Singlet(CS) Model

$c\bar{c} \rightarrow J/\psi$ + gluon



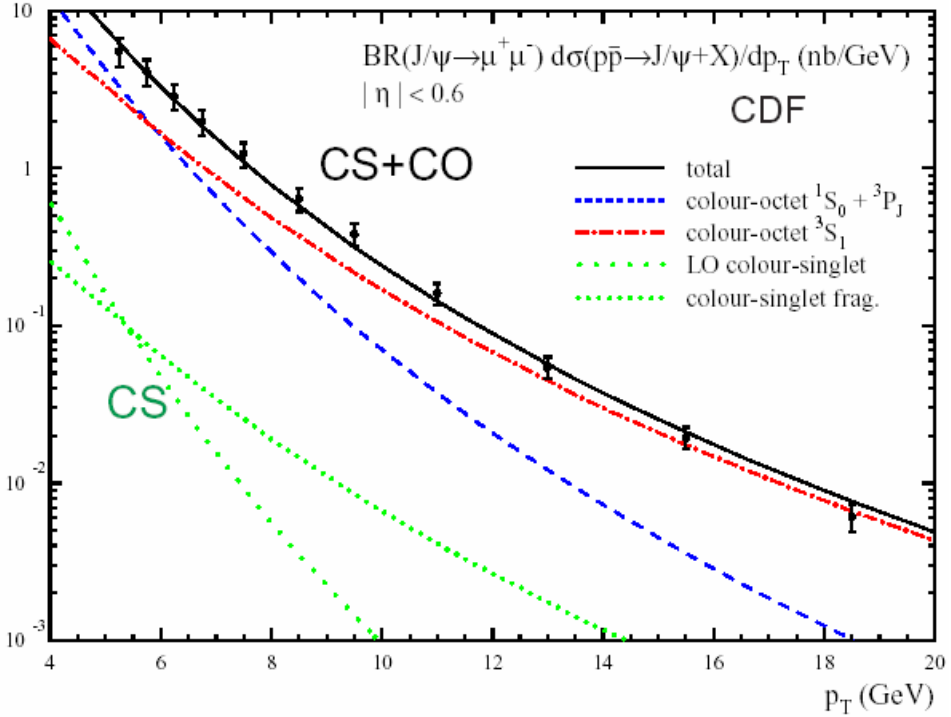
Colour Octet(CO)

$c\bar{c} \rightarrow J/\psi$ + soft gluons

NRQCD+Factorisation:

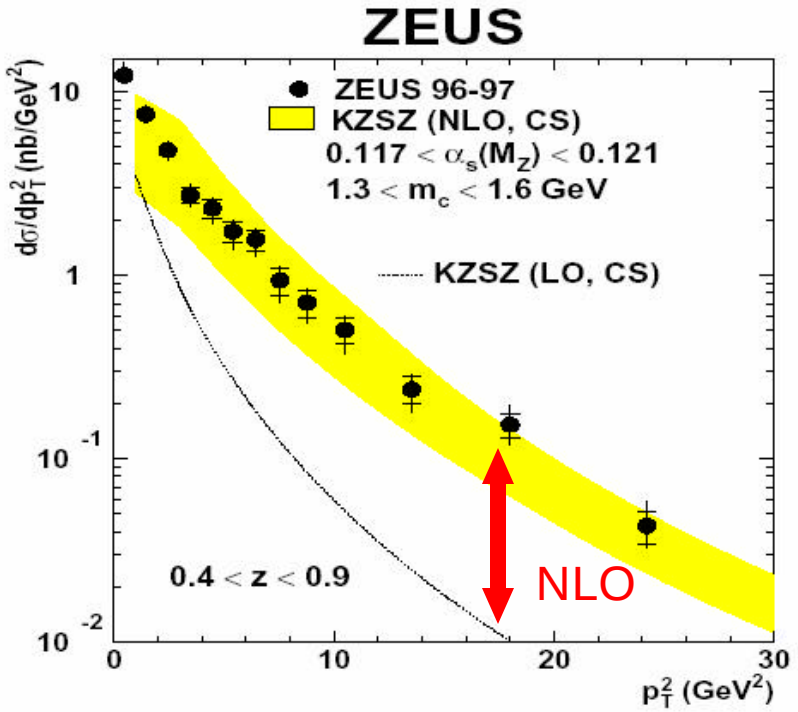
$\sigma_{J/\psi X} = \sum \hat{\sigma}(\gamma p \rightarrow c\bar{c}[n]X) \times \mathrm{LDME}[n])$

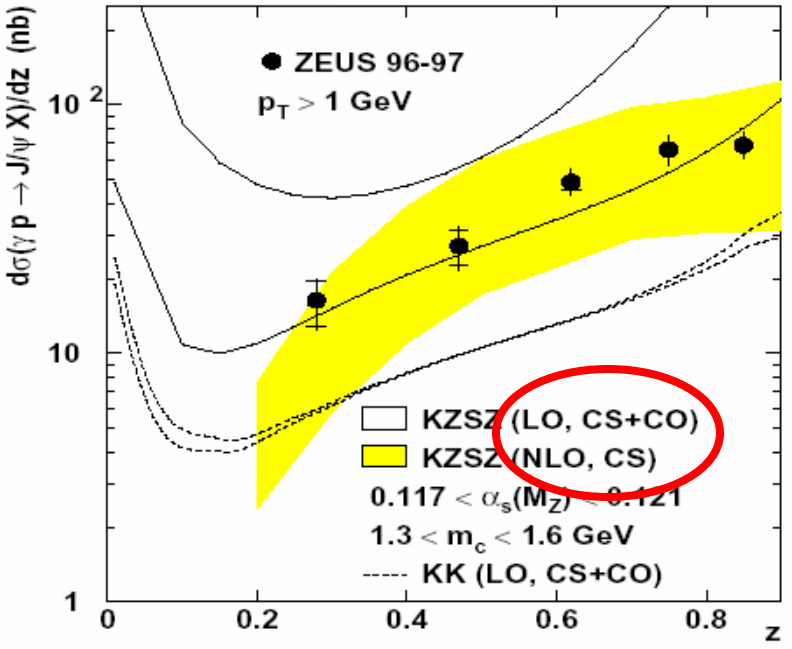
LDME from NRQCD fit to $p\bar{p}$ data



Are LDMEs universal? Tevatron → HERA

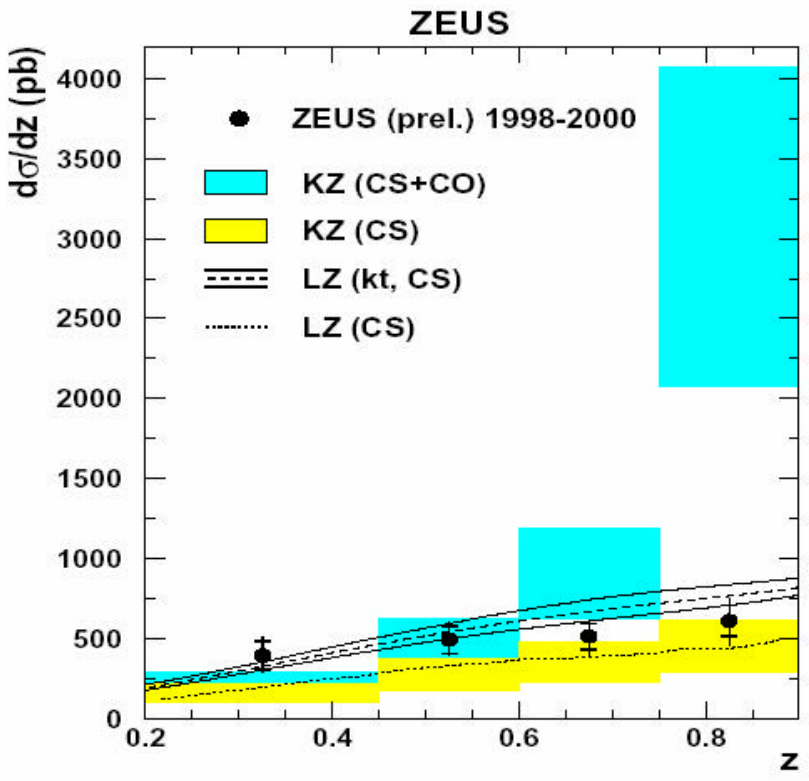
Photoproduction: p_T^2 and inelasticity

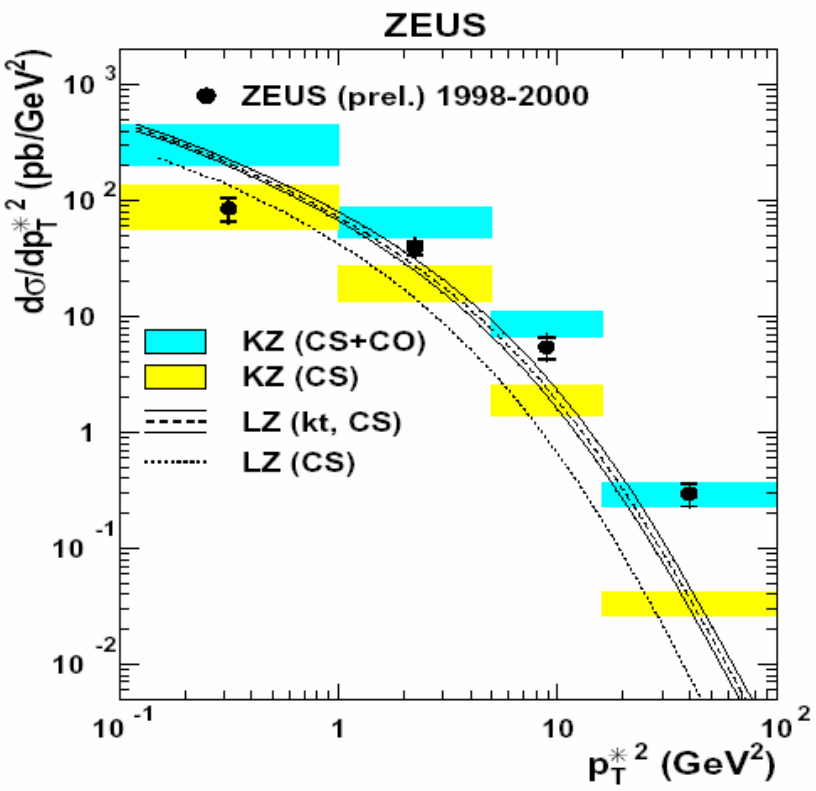




- LO CSM prediction fails to describe high p_T production
- NLO corrections are needed to describe high p_T production of J/ψ (large theoretical uncertainties)

New: Electroproduction:



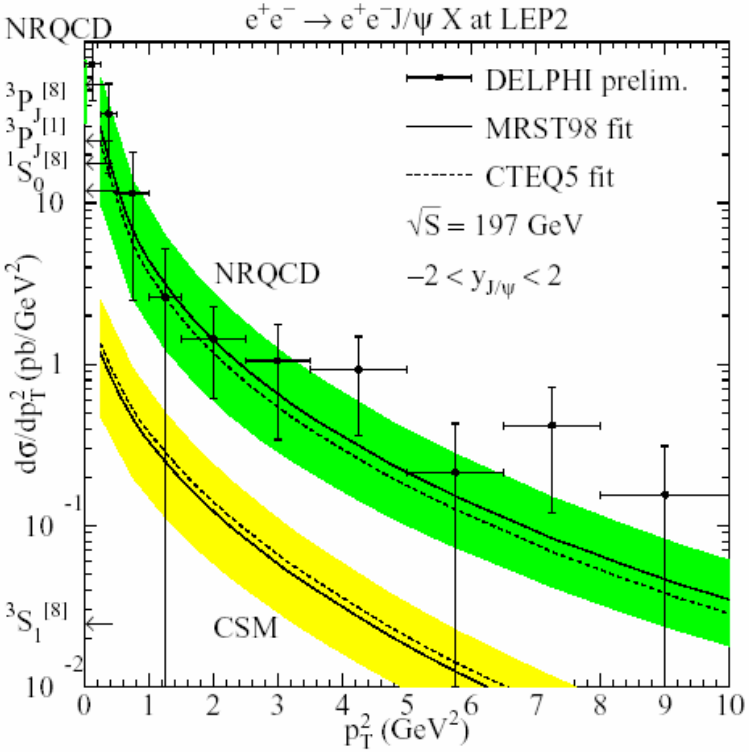


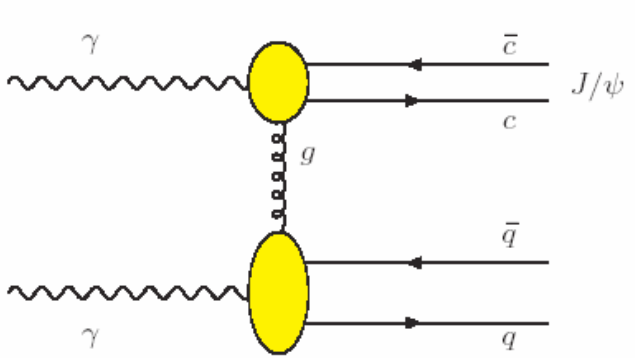
Confirms last year's H1 results

New testing grounds:

- $\gamma\gamma$ collisions at LEP2
- pN: HERA-B A dependence
- e+e- continuum @ 10 GeV:
  - J/Psi cc, J/Psi (cc) pp:
- Tevatron low pT

Quarkonium production in two-photon collisions

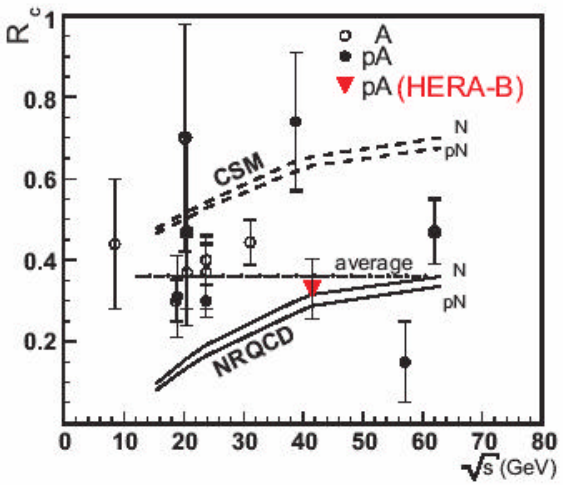


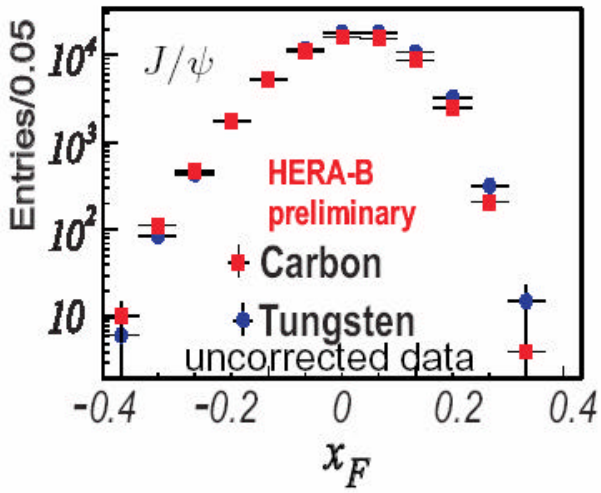


M.Klasen B.A.Kniehl L.Mihaila M.Steinhauser hep-ph/0112259

M.Chapkine - DIS 2003 - St.Petersburg

Charmonium Production at HERA-B





Dirk Krücker - HERA-B Collaboration

- First results based on 2000 data published:
  $\langle R_{\chi_c} \rangle = 0.32 \pm 0.06_{stat} \pm 0.04_{sys}$

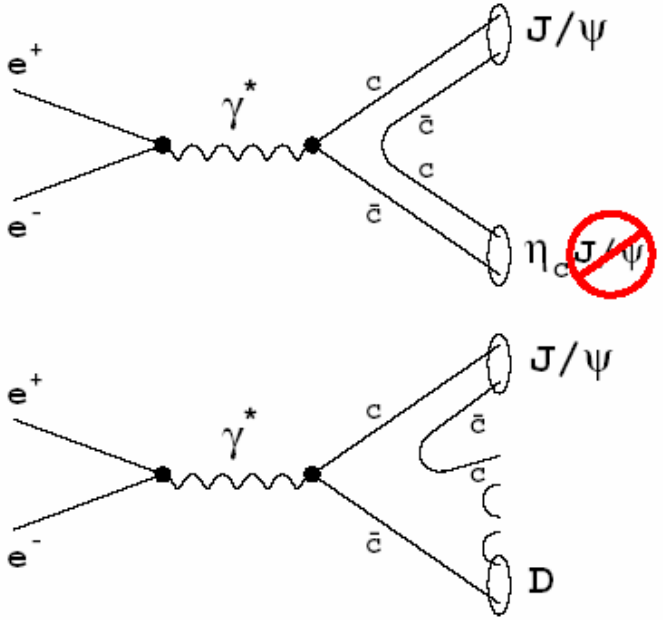
NRQCD talks to A dep via J/psi, χ_c,.. ratios

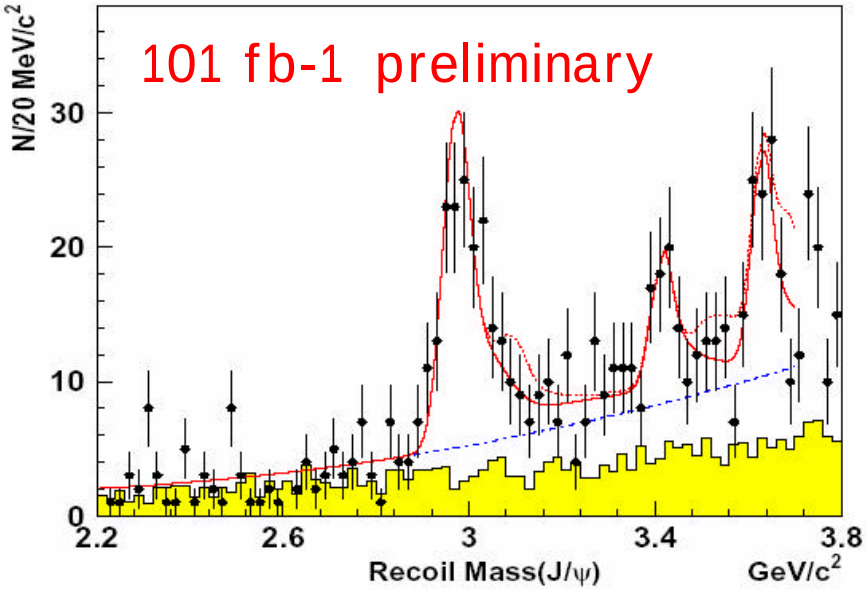
- About 300000 J/ψ's and 20000 χ_c's in 2002/2003 data, many ongoing analyses

New results coming soon

Study of $e^+e^- \to J/\psi + charmonium$

Study in detail J/ψ recoil mass spectrum around $\sim 3\,\mathrm{GeV}/c^2$



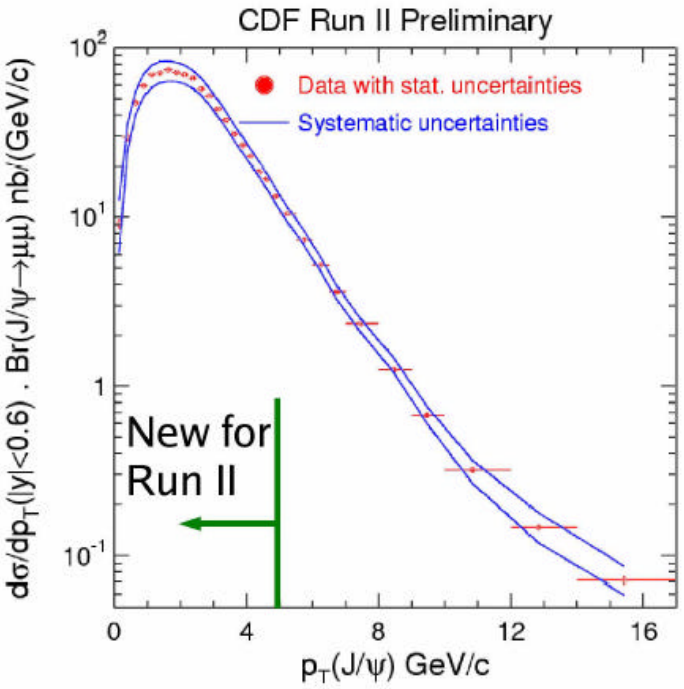


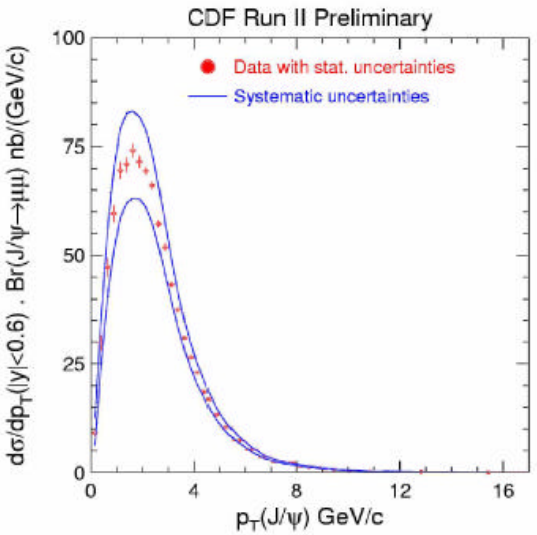
	N	$M\,[\mathrm{GeV}/c^2]$	σ	N	$M\,[\mathrm{GeV}/c^2]$	σ
η_c	175 ± 23	2.972 ± 0.007	9.9	179 ± 22	2.971 ± 0.006	10.6
J/ψ	-9 ± 17	fixed	--	0.0	fixed	--
χ_{c0}	61 ± 21	3.409 ± 0.010	2.9	72 ± 21	3.408 ± 0.009	3.8
$\chi_{c1} + \chi_{c2}$	-15 ± 19	fixed	--	0.0	fixed	--
$\eta_c(2S)$	108 ± 24	3.630 ± 0.008	4.4	97 ± 22	3.628 ± 0.007	4.9
$\psi(2S)$	-38 ± 21	fixed	--	0.0	fixed	--

...and many more new results, J/psi cc / J/psi X = 82 +- 15 +- 14 %

P.Pakhlov DIS'03, April 23-27, 2003

Inclusive J/ψ Cross Section





- Soon: separate prompt from B → J/ψ X

Prompt J/ψ cross section includes
- χ_c decays ($\chi_c \to J/\psi\gamma$)
- ψ(2S) feed-down
- Direct J/ψ (64±6% Run 1)

Run II vs. Run I:

$\sigma(p\,\bar{p} \to J/\psi X, |y|<0.6) \cdot BR = 240 \pm 1\ (stat)\ {}^{+35}_{-28}\ (syst)$ nb

$\sigma(p\,\bar{p} \to J/\psi X, |\eta|<0.6, p_T(J/\psi)>5GeV) \cdot BR = 17.4 \pm 0.1\ (stat)\ {}^{+2.6}_{-2.8}\ (syst)$ nb

Charmonium summary

- Rapidly expanding basis of experimental data from different production environments
- Test universality of NRQCD's non-perturbative MEs
- Revisit Tevatron data for LDMEs
  - Including low pT range
- Need NLO to complete the picture

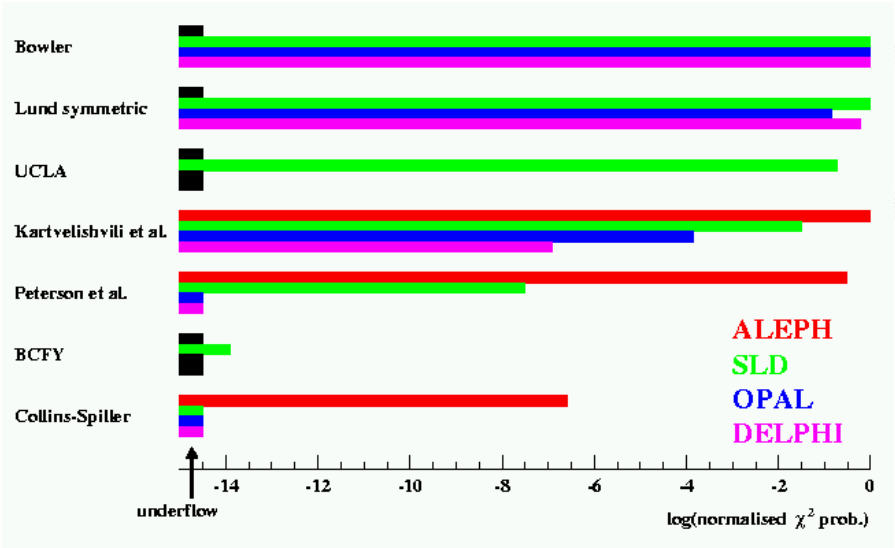
Open charm, beauty, and truth

- Heavy quark – heavy hadron transition
- Production cross sections “everywhere”, and parton dynamics

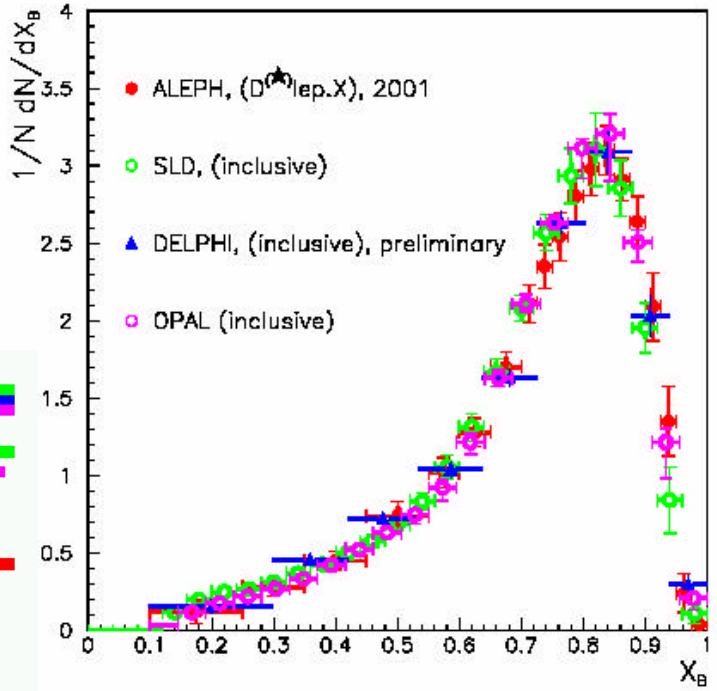
Fragmentation and excited B states

Fragmentation:

- High precision analyses from e^+e^- machines
- Unfolded spectrum of weakly decaying state consistent between experiments



Plot by: Kristian Harder

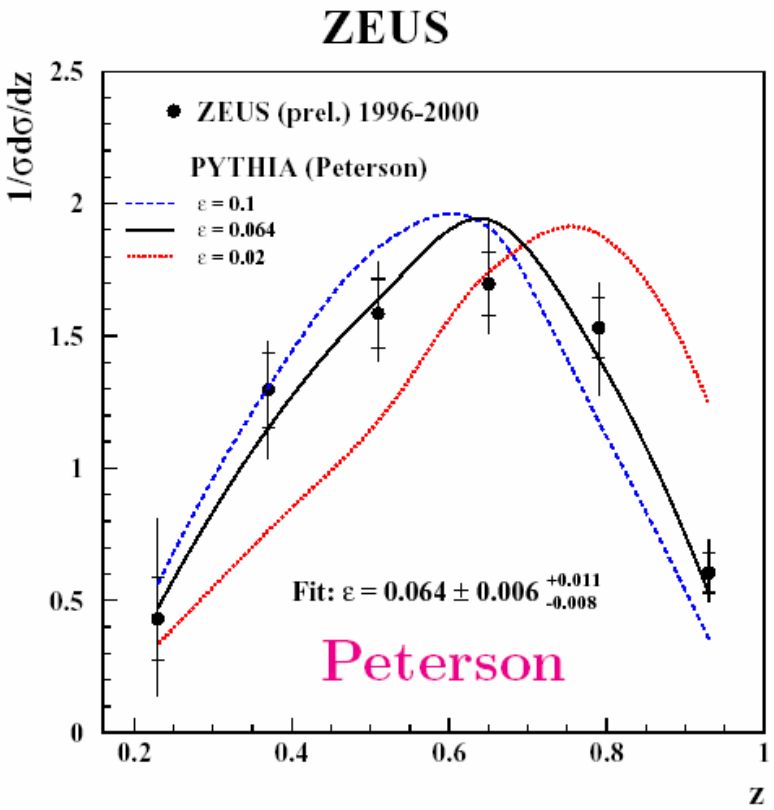


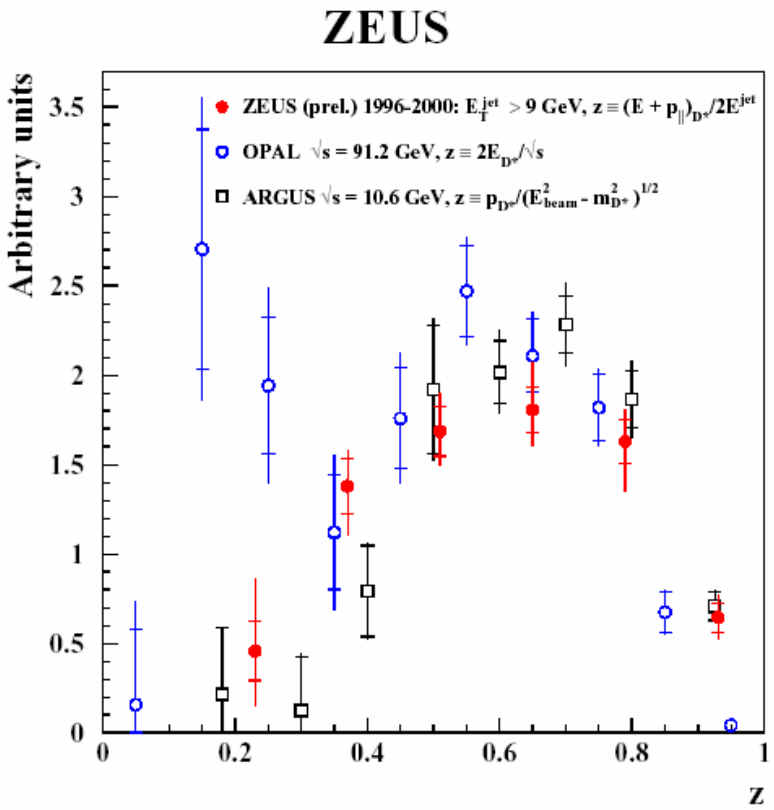
Model tests:
$\chi 2$/d.o.f probabilities
(for LL PS MC !)

Ulrich Kerzel, University of Karlsruhe DIS2003, St. Petersburg 2

L. Gladilin (ZEUS coll.) Charm hadronisation in γp collisions

Measurement of charm fragmentation function $(D^{*\pm})$:





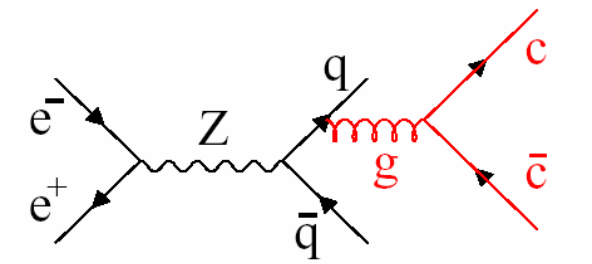
$\epsilon = 0.064 \pm 0.006^{+0.011}_{-0.008}$ **(ZEUS prel.)**

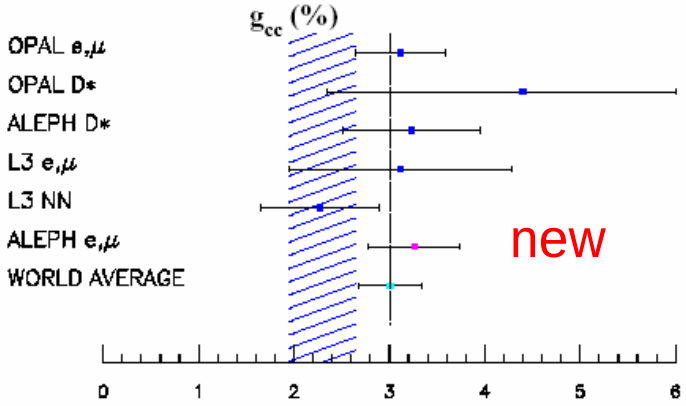
$\epsilon = 0.053$ **(LL fit to ARGUS data)** $\Longleftarrow$ **Nason, Oleari**

measurements in $e^{\pm}p$ and $e^{+}e^{-}$ collisions are in agreement

Andrea Giammanco - ALEPH

Gluon splitting to $c\bar{c}$ at the Z^0 resonance





Hatched area: theoretical prediction ±15%.

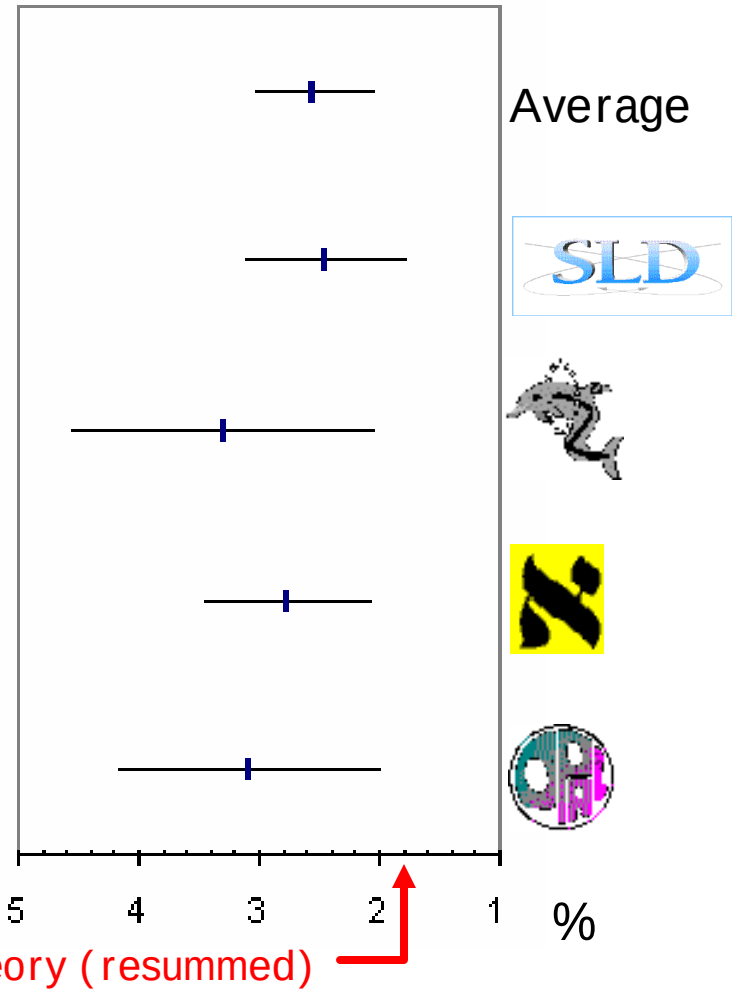
Uncertainties due to m_c and α_s are not shown.

New World Average:

$g_{c\bar{c}} = (3.01 \pm 0.33)\%$

Hagar Landsman (OPAL)

Gluon splitting to bbbar and b fragmentation



L. Gladilin (ZEUS coll.) Charm hadronisation in γp collisions

Measurement of charm fragmentation fractions :

	ZEUS prel. (γp) $P_T(D,\Lambda_c) > 3.8\,\mathrm{GeV}$, $\lvert\eta(D,\Lambda_c)\rvert < 1.6$		Combined e^+e^- data	H1 prel. (DIS)
$f(c \to D^+)$	$= 0.249 \pm 0.014^{+0.004}_{-0.008}$	new	0.232 ± 0.010	$0.202 \pm 0.020^{+0.045\ +0.029}_{-0.033\ -0.021}$
$f(c \to D^0)$	$= 0.557 \pm 0.019^{+0.005}_{-0.013}$		0.549 ± 0.023	$0.658 \pm 0.054^{+0.117\ +0.086}_{-0.142\ -0.048}$
$f(c \to D_s^+)$	$= 0.107 \pm 0.009 \pm 0.005$		0.101 ± 0.009	$0.156 \pm 0.043^{+0.036\ +0.050}_{-0.035\ -0.046}$
$f(c \to \Lambda_c^+)$	$= 0.076 \pm 0.020^{+0.017}_{-0.001}$	new	0.076 ± 0.007	
$f(c \to D^{*+})$	$= 0.223 \pm 0.009^{+0.003}_{-0.005}$		0.235 ± 0.007	$0.263 \pm 0.019^{+0.056\ +0.031}_{-0.042\ -0.022}$

Now normalized to sum

charm fragmentation fractions are universal

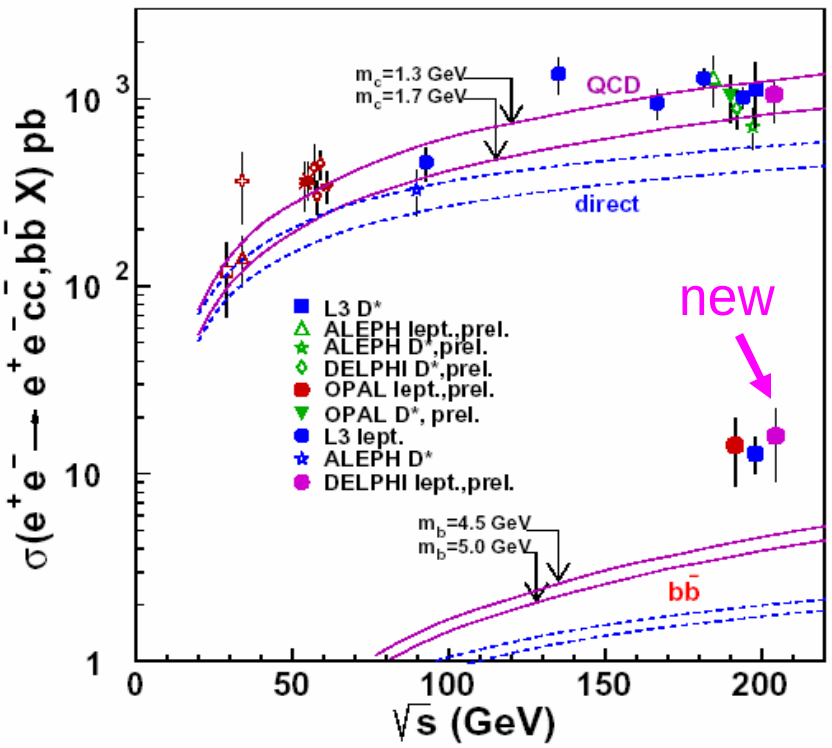
it is valid to use charm fragmentation parameters measured in e^+e^- annihilations to describe $D-$production in $e^\pm p$ collisions

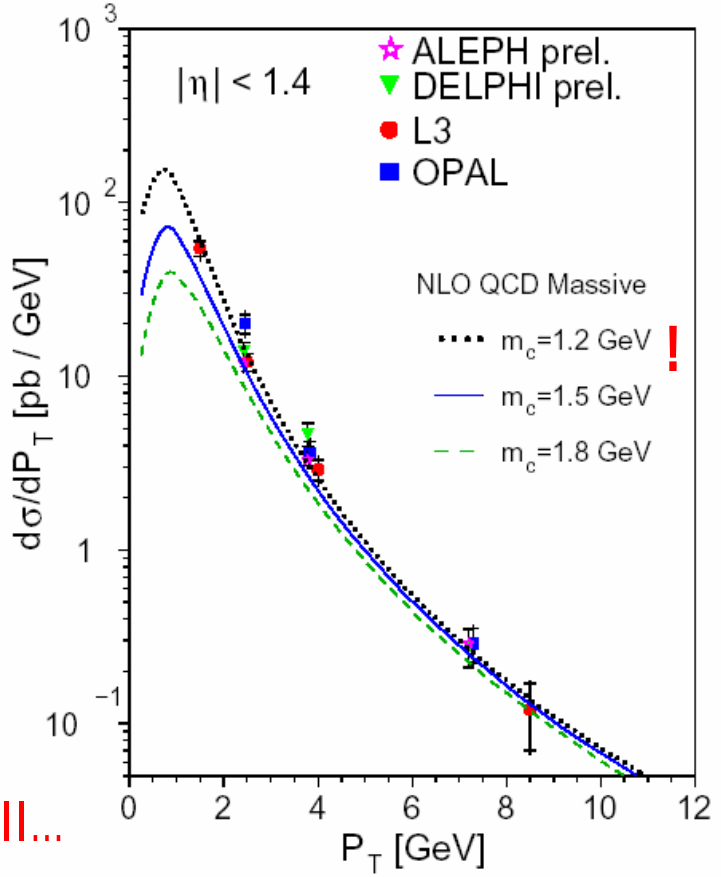
HERA provides own charm hadronisation measurements with competitive precision

Fragmentation/Hadronization:

- Above all: Well constrained by experiment
- Fragmentation spectra in e+e- well reproduced by theory (incl. HO)
- HERA measurements support universality of fragmentation function and fractions
- … the basis for QCD tests with "observable" quarks

γγ -> cc, bb



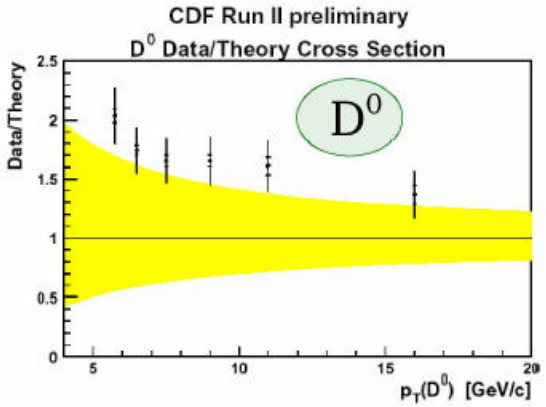


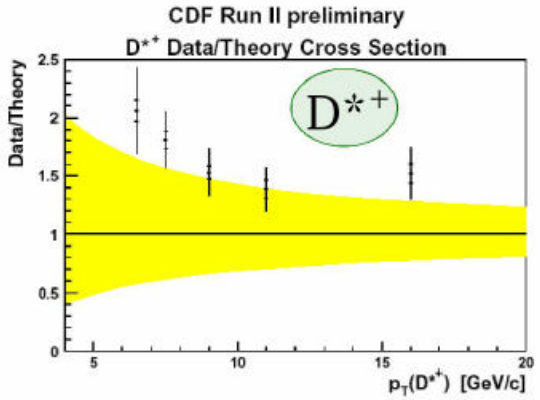
Charm also not **so** well...

Charm Cross Section cont.

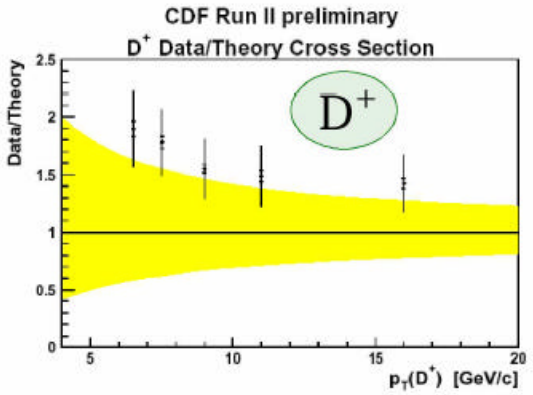
Calculation from M.Cacciari and P.Nason: Resummed pQCD (FONLL)

Ratio of measured to predicted cross section:





CTEQ6M PDF
m_c = 1.5GeV
Fragm.function:
from Aleph meas.
Renorm.and fact.scale:
$m_T=(m_c^2+p_T^2)^{1/2}$
Uncertainty:
vary scale from .5 to 2



- Measured cross section higher
- Not incompatible with uncertainties
- p_T shape consistent for D mesons

brandnew @ DIS'03

D^*-Photoproduction in γp-Collisions at HERA with H1

visible range	
Q^2	< 0.01 GeV^2
$W_{\gamma p}$	$171 < W_{\gamma p} < 256$ GeV
$p_t(D^*)$	> 2.5 GeV
$\eta(D^*)$	$-1.5 < \eta < 1.5$

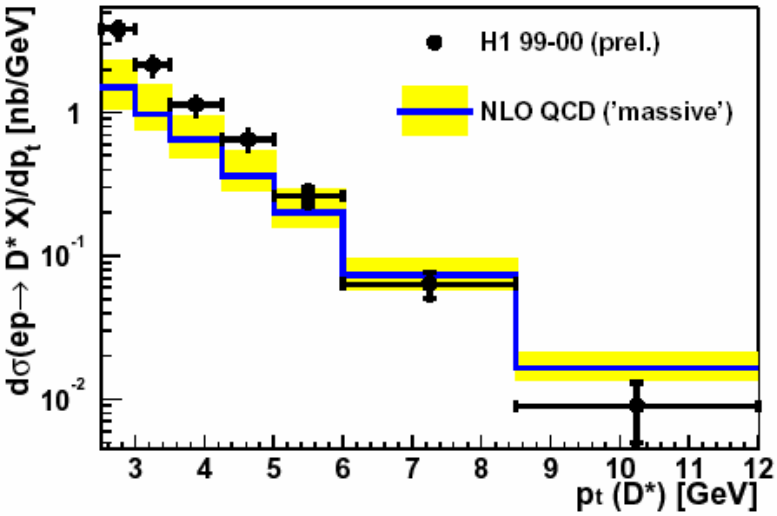
new

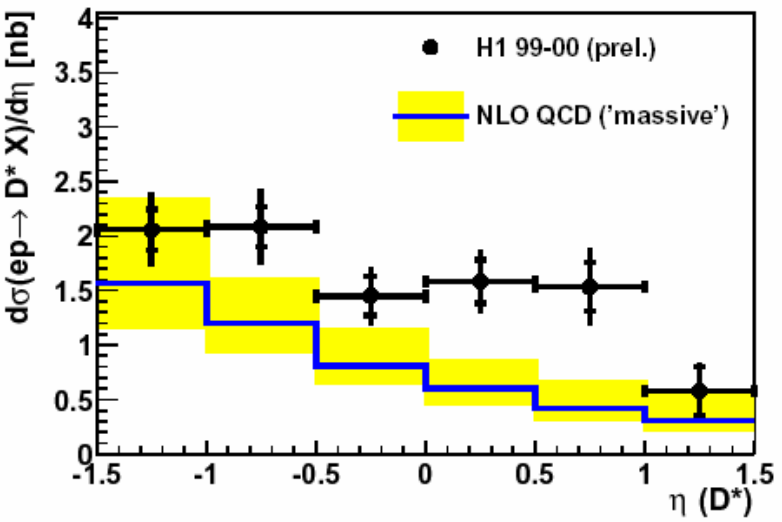
H1 99-00 (preliminary):

$$\sigma_{vis}(ep \to e' D^* X) = (4.74 \pm 0.32 \pm 0.64) \text{ nb}$$

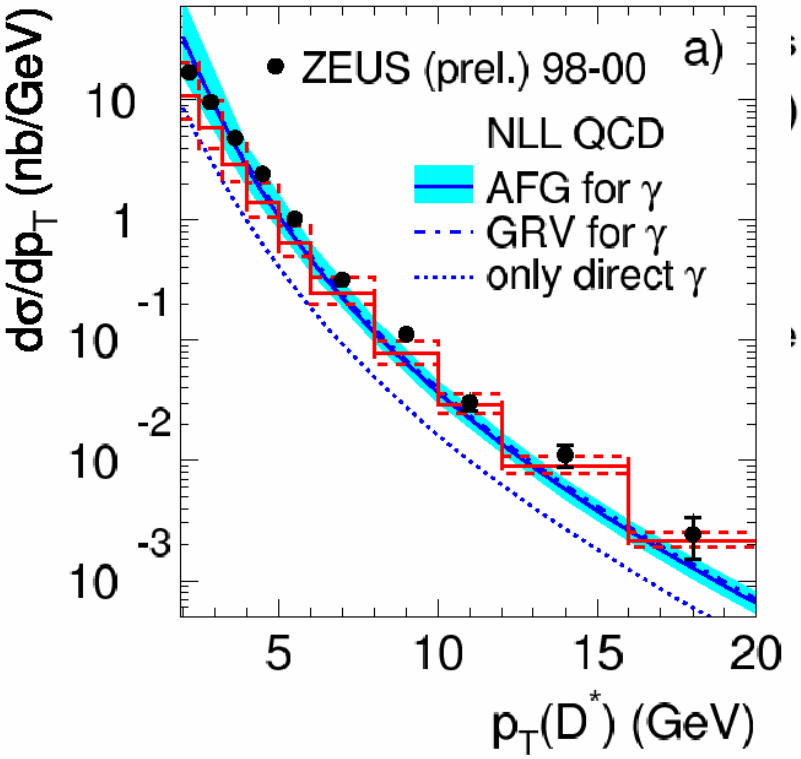
NLO QCD (fixed order/massive):

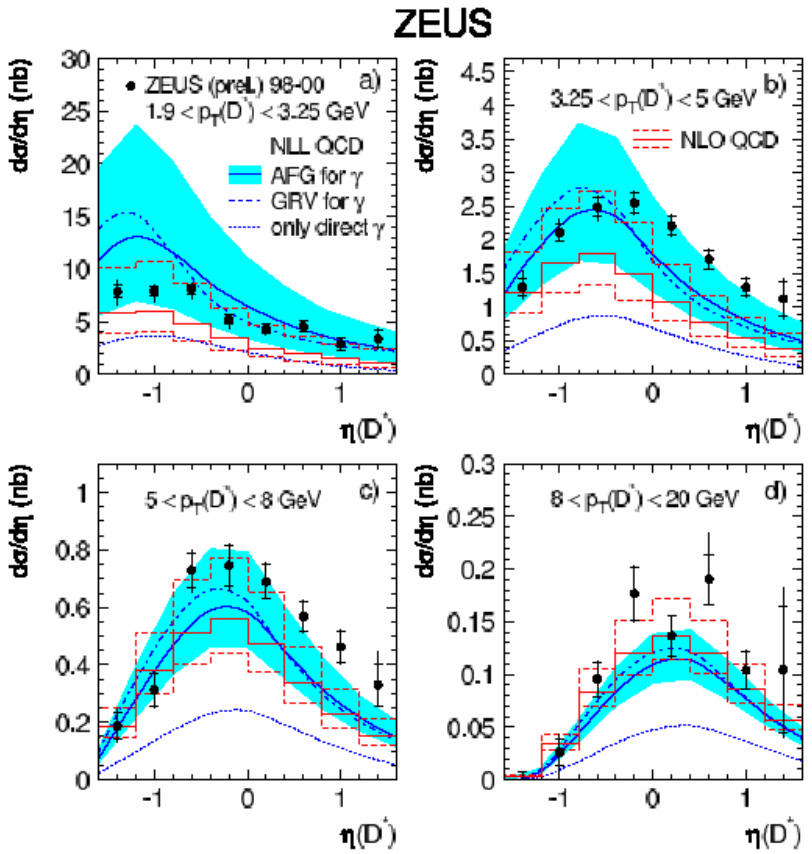
$$\sigma_{vis}(ep \to e' D^* X) = (2.46^{+1.09}_{-0.60}) \text{ nb}$$





$D^{\star}$ Photoproduction — Double Differential Cross Sections





"terribly precise"
(as the theorist says it)

Sensitivity to c in γ hampered

"NLL" = massless NLO
"NLO"= massive NLO

Charm production with neutrinos

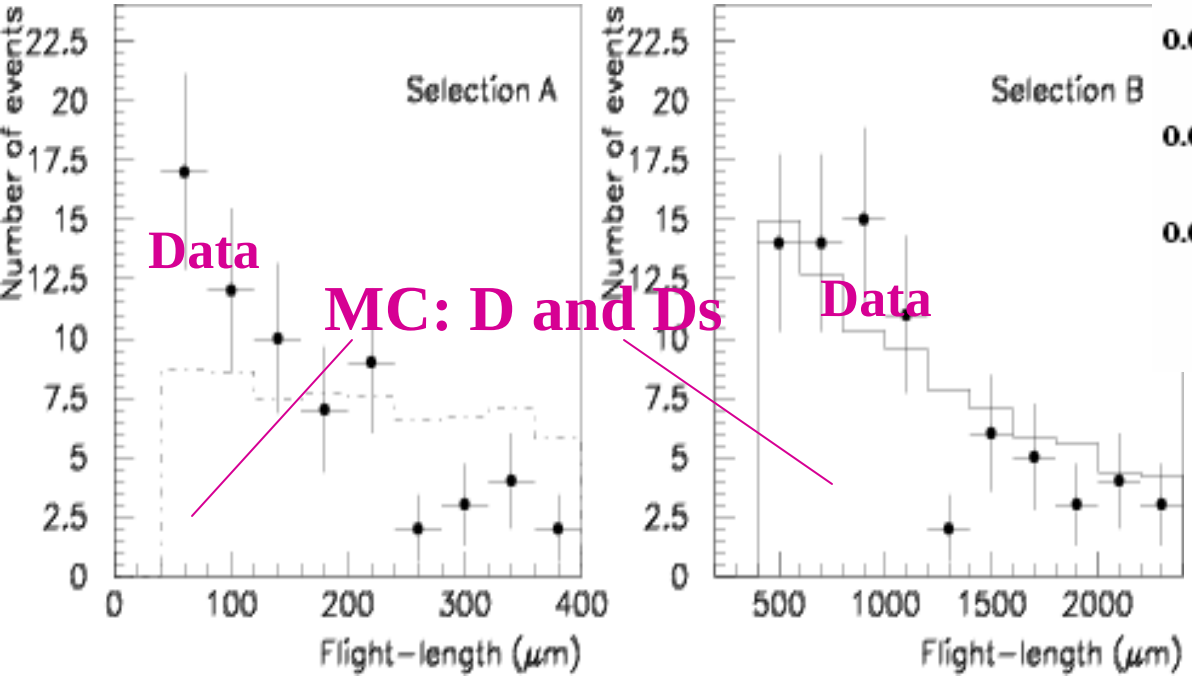
Giovanni De Lellis (CHORUS Coll.)

Measurement of Λc production

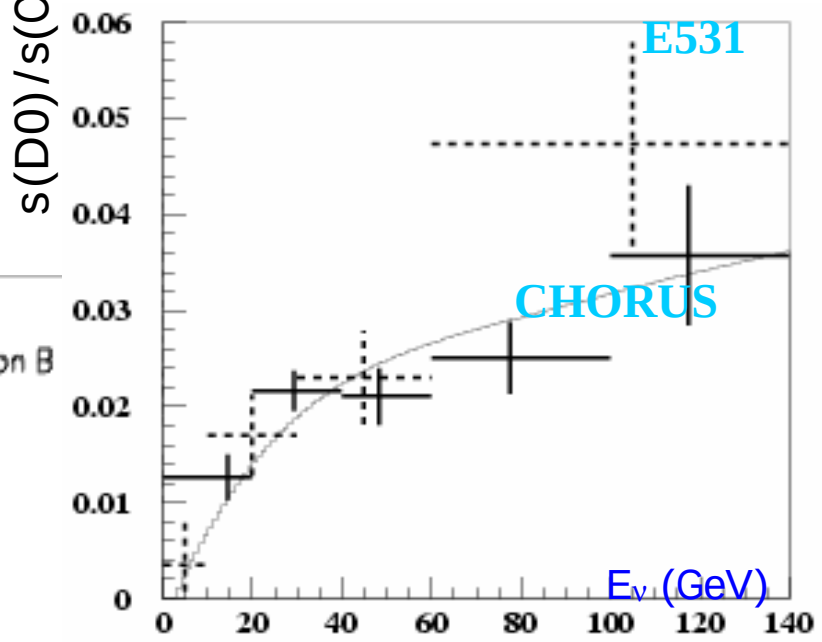
Phys. Lett. B 555 (2003) 156

Br ($L_c \rightarrow$ 3prong) = 24 ± 7 ± 4%

s (Lc) / s (CC)= 1.54 ± 0.35 ± 0.18%



Phys. Lett. B 527 (2002) 173

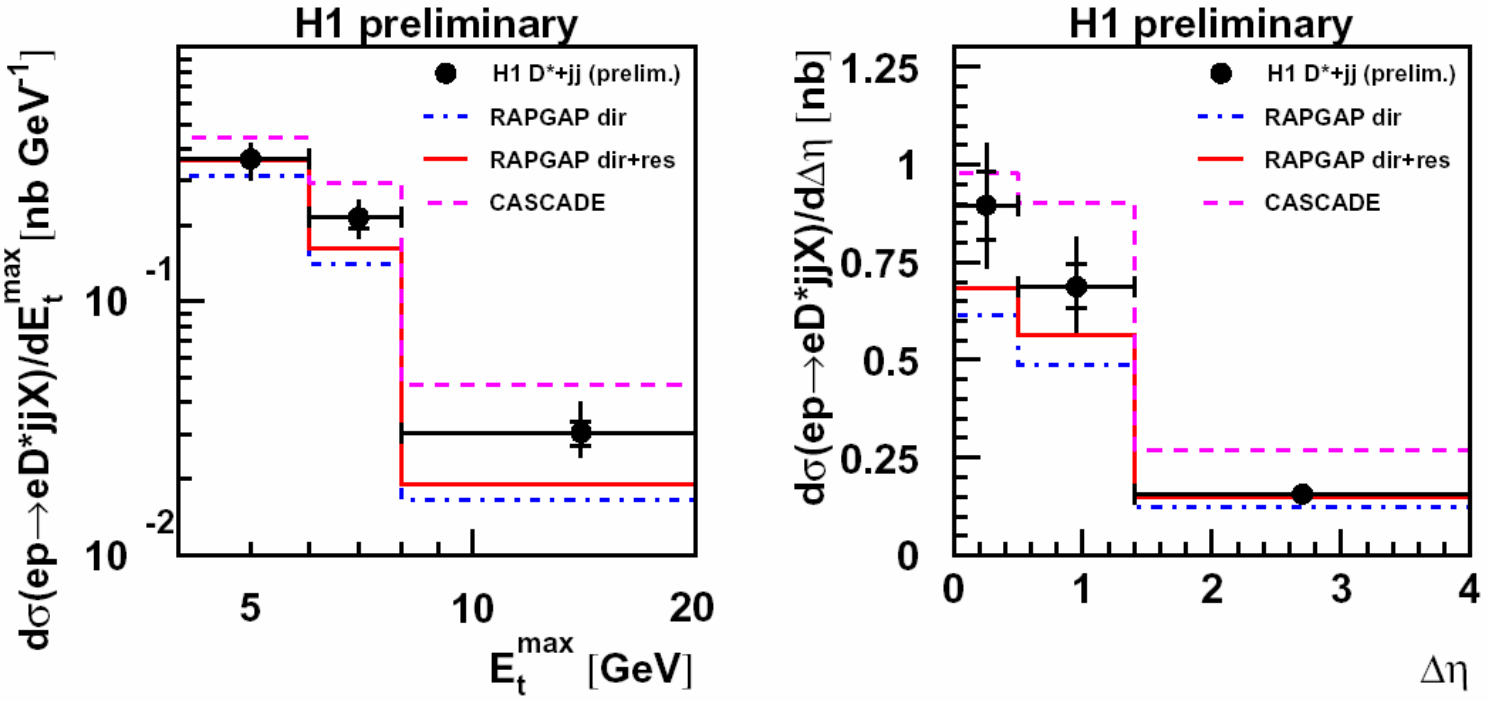


s (D^0)/s (CC) =
1.99 ± 0.13 ± 0.17 %

Only part of stat's
Include in s(x) pdf fit

ep -> ccX

first **Differential Jet Cross Sections** in DIS

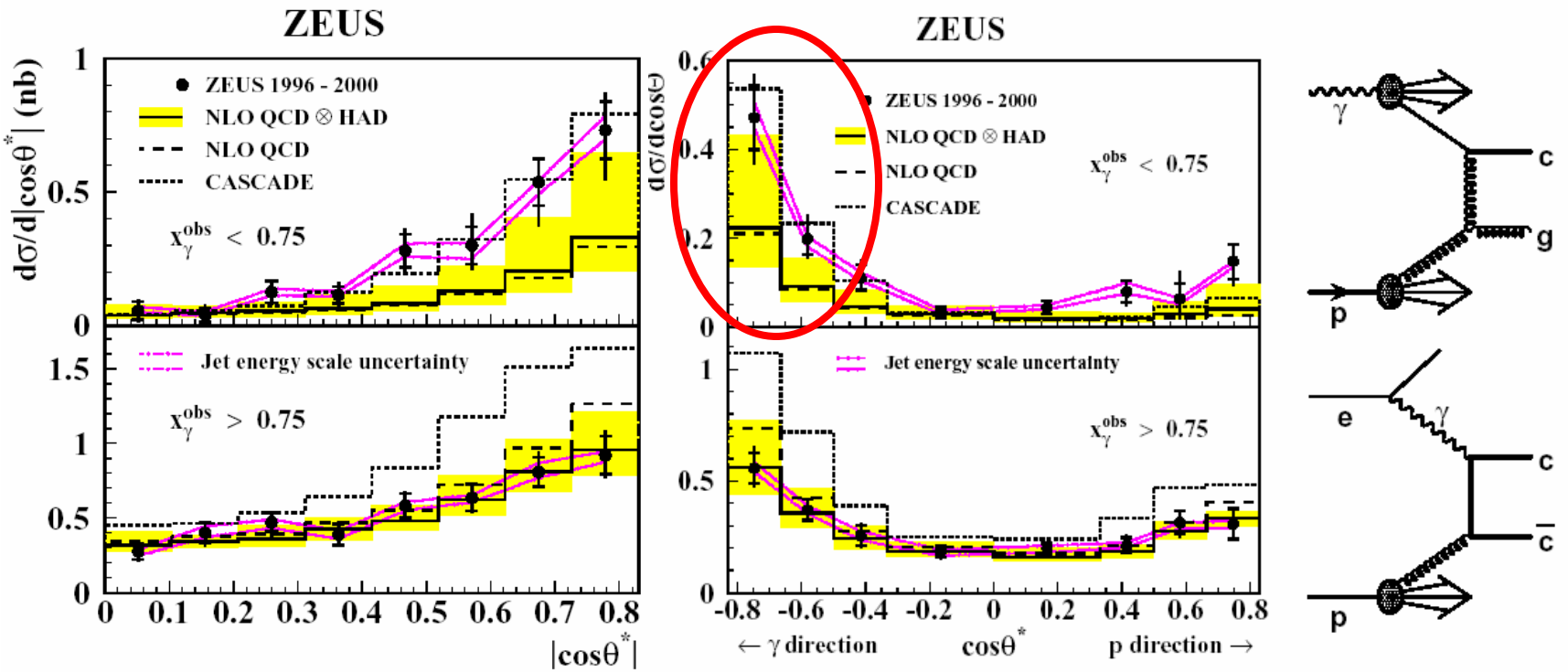


→ RAPGAP direct and direct+resolved below the data for large E_t^{max} and small $\Delta\eta$

→ CASCADE above the data

L. Gladilin (ZEUS coll.) Charm dijet angular distributions in γp collisions

"jet 1" - matched with $D^{*\pm}$ in $(\eta - \phi)$ space; "jet 2" - other jet



strong rise in γ direction for $x_\gamma^{obs} < 0.75 \Longrightarrow$ dominance of $gg \to c\bar{c}$ is excluded !

dijets with $x_\gamma^{obs} < 0.75$ are mainly produced by c coming from γ side : $cg \to cg$, $cq \to cq$

PYTHIA and HERWIG with charm excitation : adequate description

NLO QCD : too low for $x_\gamma^{obs} < 0.75$ in both γ and p directions; shapes are o.k.

CASCADE : too low for $x_\gamma^{obs} < 0.75$ in p direction; shapes are o.k.

Dijet $b\bar{b}$ cross section in x_γ bins

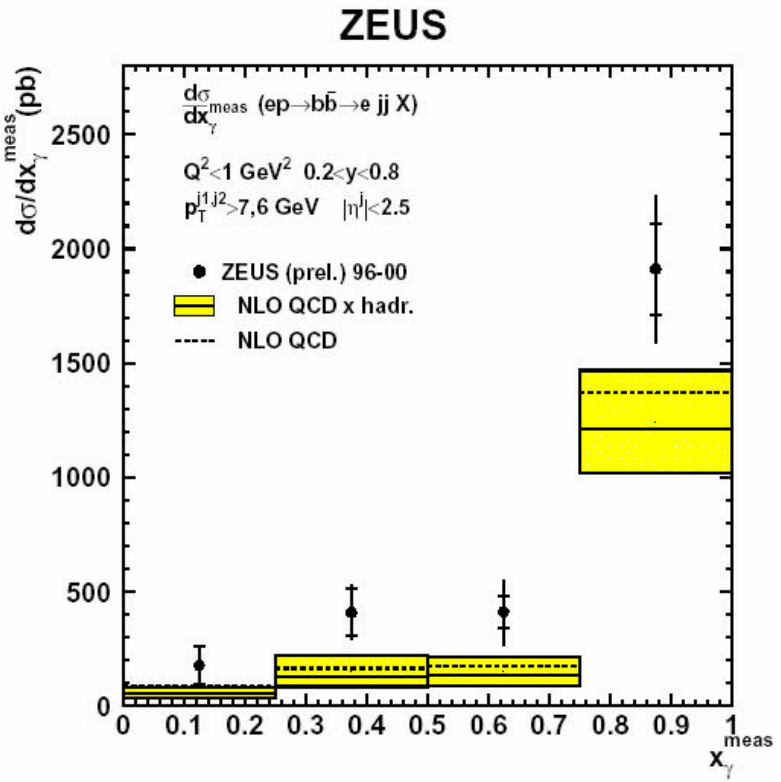
How data compare to NLO at different x_γ?

$$x_\gamma^{\rm meas} = \frac{(E-P_z)_{\rm jet1}+(E-P_z)_{\rm jet2}}{(E-P_z)_{\rm hadronic}}$$

At LO:
$x_\gamma \sim 1 \rightarrow$ Direct photon
$x_\gamma < 1 \rightarrow$ Resolved photon

$p_{\rm T}^{\rm rel}$ fit redone in x_γ bins

Data above NLO over the whole x_γ range
Data/NLO larger at low x_γ
but also NLO uncertainty larger at low x_γ

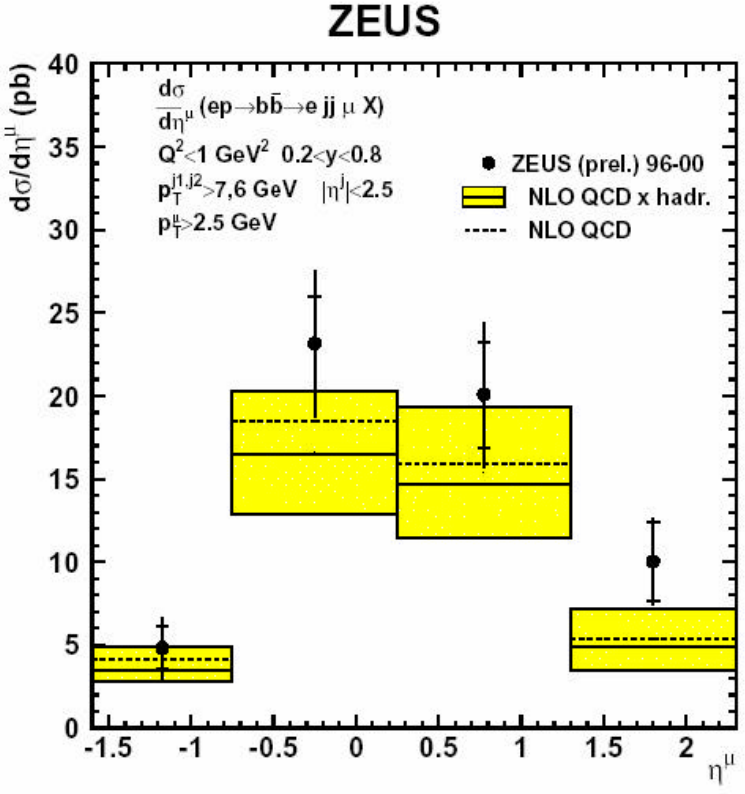


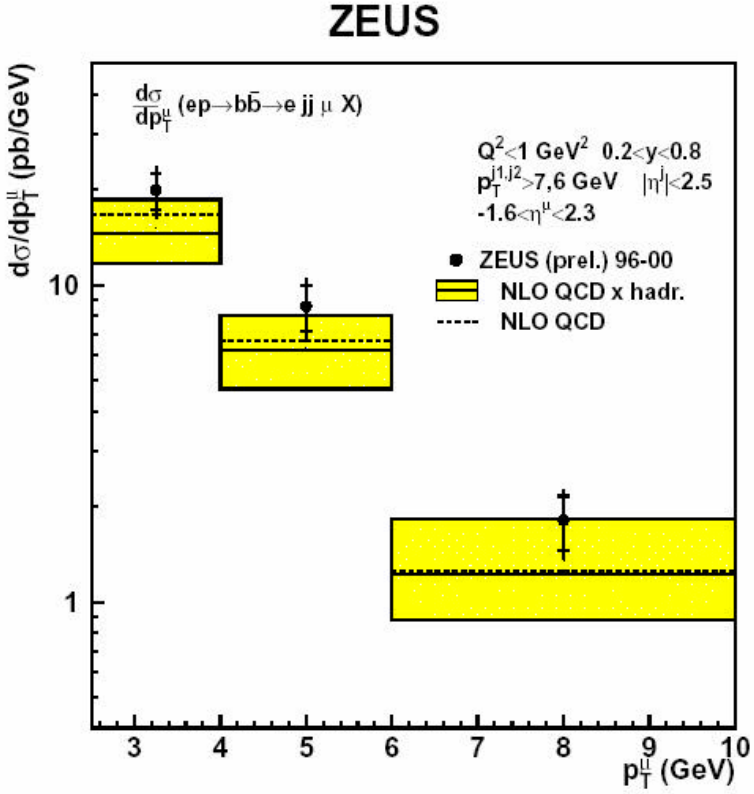
9 *M. Corradi* b photoproduction with ZEUS

Visible muon cross sections $\sigma(ep \to b\bar{b}X \to jj\mu X')$

Closer to expt. measurement → less model dependence

Cut $p_t^\mu > 2.5$ GeV to get more flat acceptance → low p_t μs in FORWARD/REAR removed



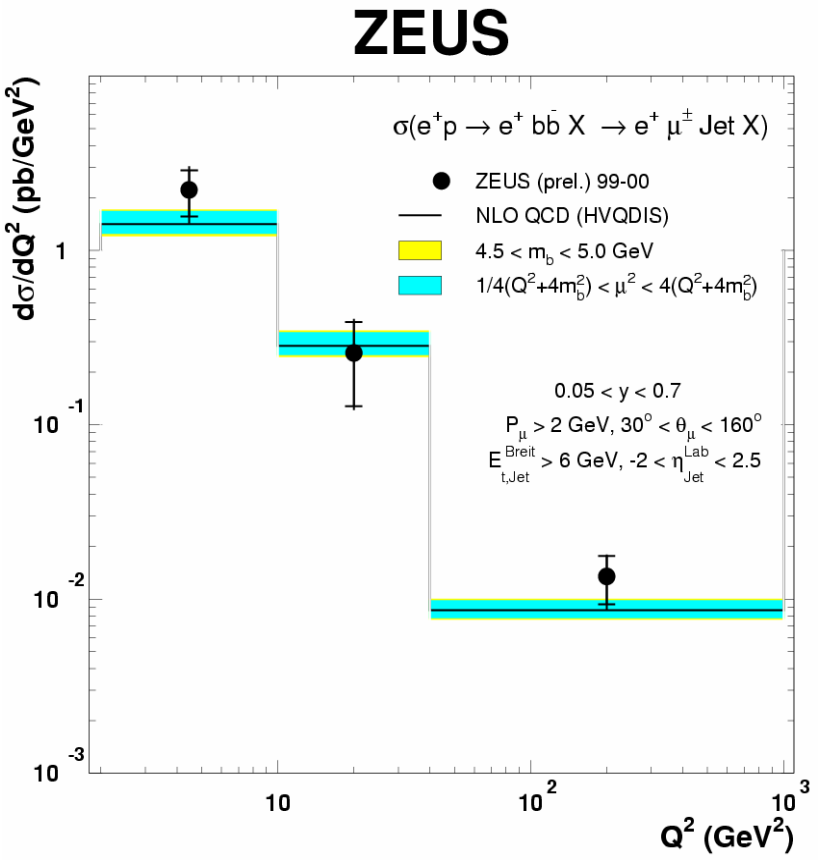


Compared to NLO $\times$ $(b \to B) \times (B \to \mu)$

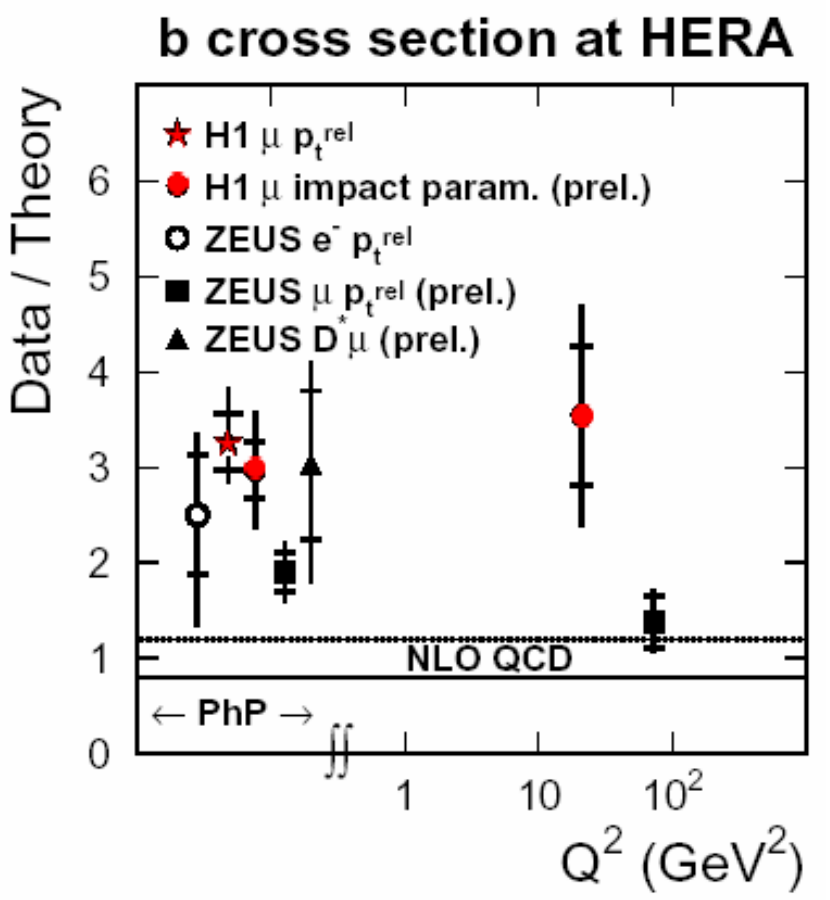
Reasonable agreement: Data/NLO = 1.4

10 *M. Corradi* b photoproduction with ZEUS

b production in DIS



V.Chiochia, Production of beauty quarks in deep inelastic scattering at HERA



C.Gerlich, Beauty production, H1 results

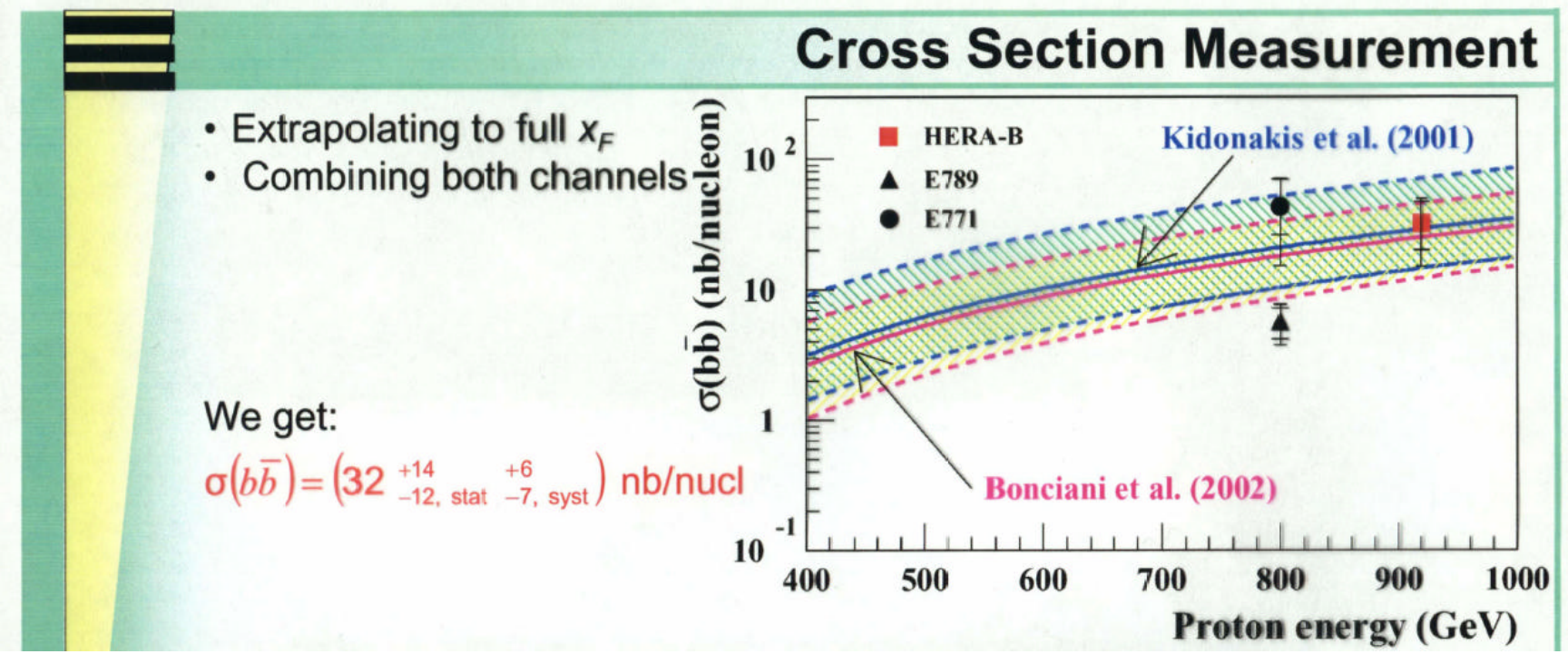
Some remarks...

... on the “HERA-b” summary plot:

- **All** results use leptons and jets (or D*) but are quoted differently: lepton, lepton-jet, lepton-jet-jet, jet-jet, and have different model dependence due to extrapolations
- One should minimize the model dependence, e.g. B meson, or b-tagged jet Xsections, and reduce the variety
- **Above all**: finish analysis!

  (H1 results are based on 10 pb-1 only...)

HERA-B: pN -> bb



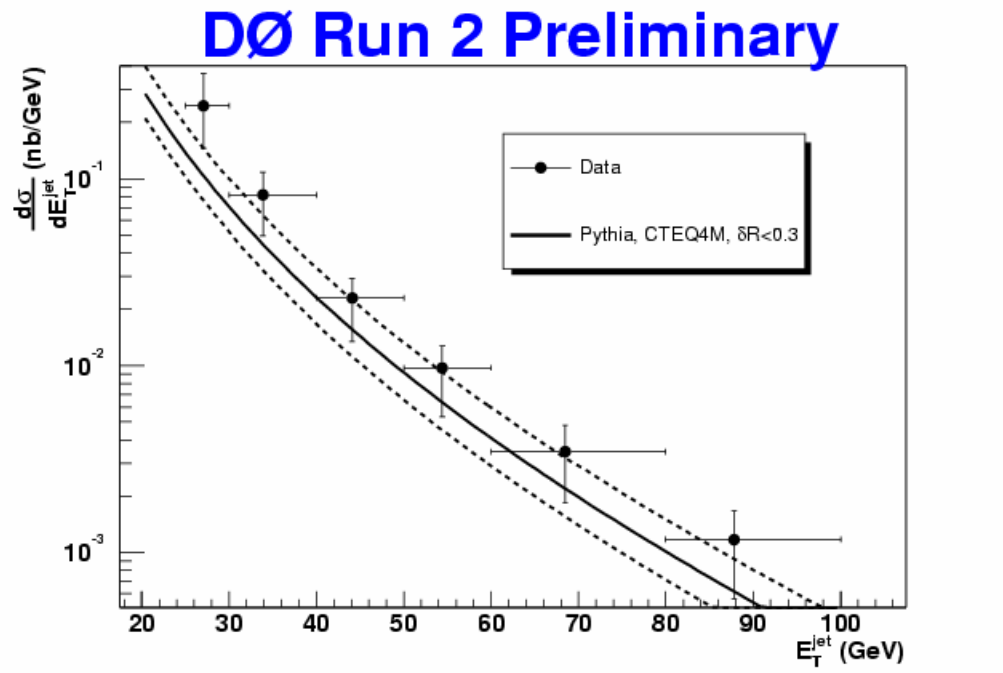
30x more statistics on tape
-> will be systematics limited (J/psi BR and total Xsect)
-> can measure pT and xF dependence

M. Braeuer, bb cross sections measured with the HERA-B detector

B jet cross section (3)

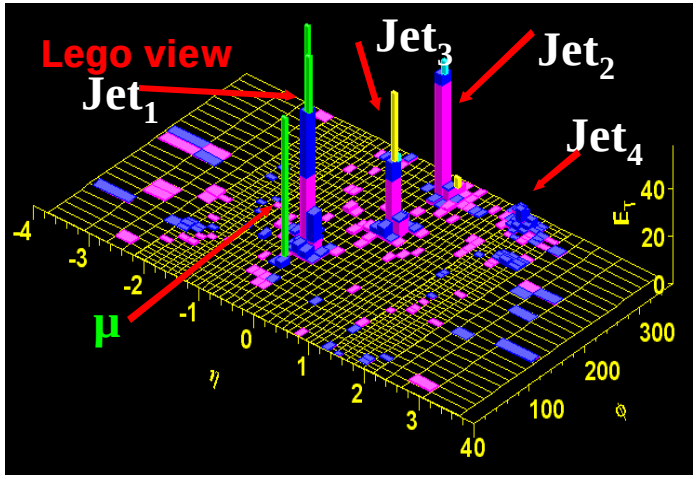
- Step 3: Unfold jet energy resolution (unsmearing)

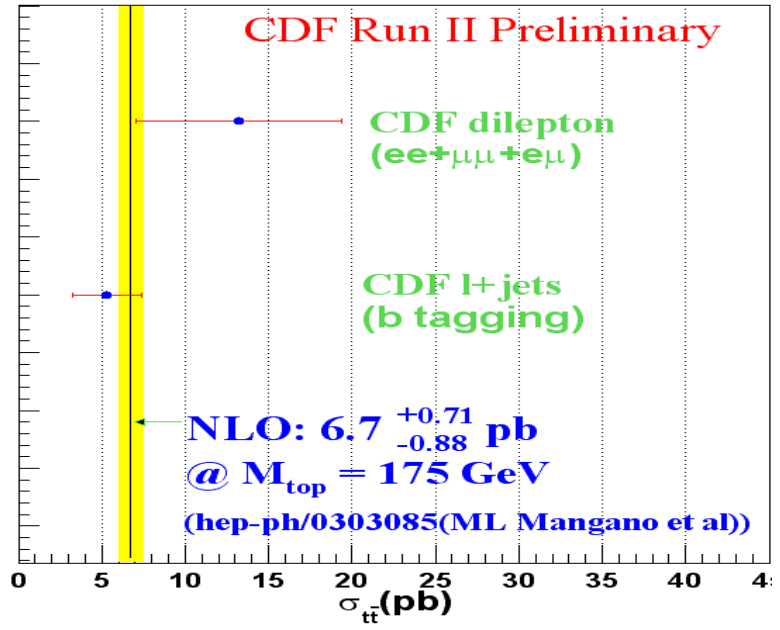
• Measured cross section consistent with Run I results (2-3 times higher than predictions)
• Dominant error due to jet energy scale corrections

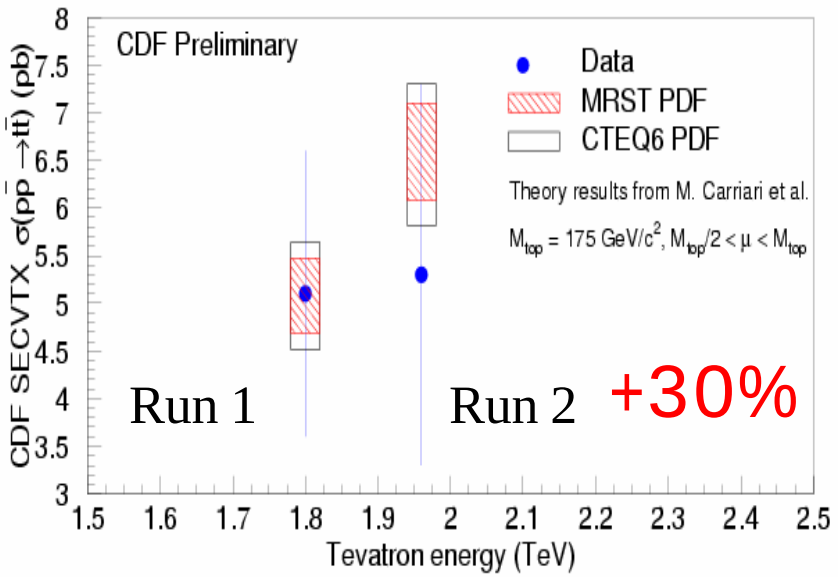


Alexander Khanov, Recent B Physics Results from

s_{tt}: lepton + jets cross section







$$s_{tt} = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.3_{lum}\ pb$$

Yu.Gotra, Heavy Flavour Results from CDF Run II

Charm, bottom, and truth summary

- Measurements in many environments, some new or back on stage
- Develop perturbative QCD strategies
- Theory error bands are not too conservative: most c and b results leave room for NNLO
- HERA initial states provide specific handles on parton dynamics, e.g. charm, beauty still to come (HERA 2)

Thank you very much

… to all participants for lively contributions and support!

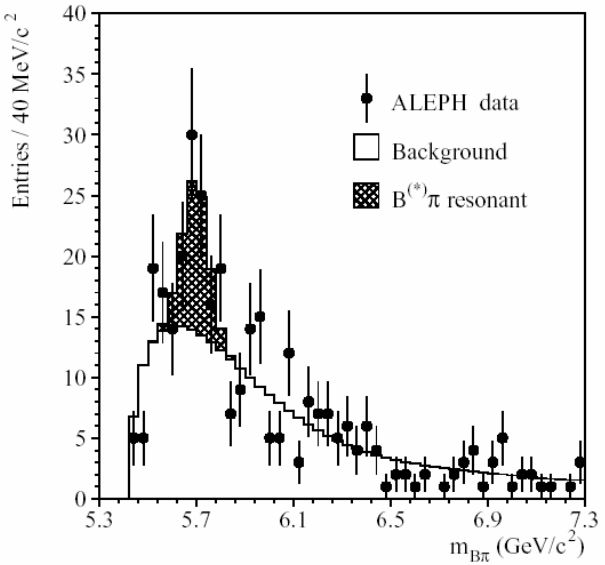
All mistakes are mine.

Backup slides

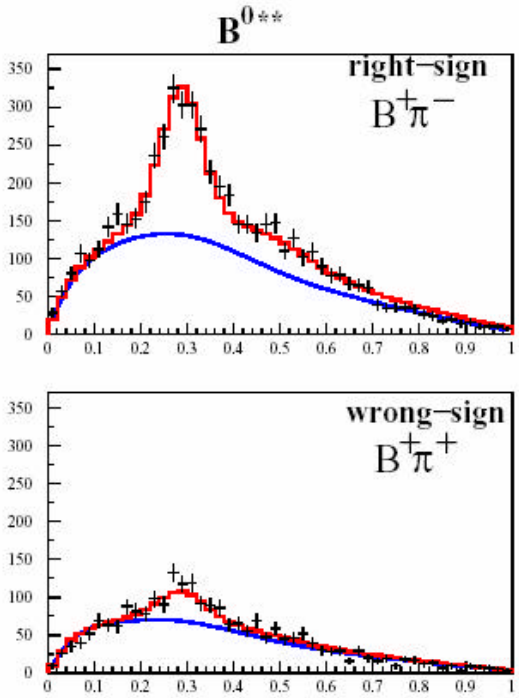
Fragmentation and excited B states

Excited B states:

- Narrow $(L = 1)$ $B^{**}_{u,d}$ states well established
- Ongoing efforts to separate narrow and broad states.



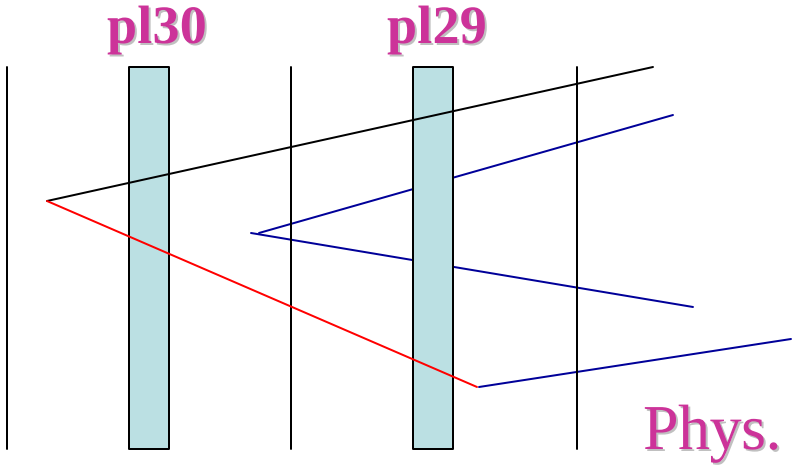
Aleph exclusive: clear B^{**} signal,



Delphi (prelim.):

reconstructed Q-value

Associated charm production in CC and NC



D^0 f.l. = 340 μm

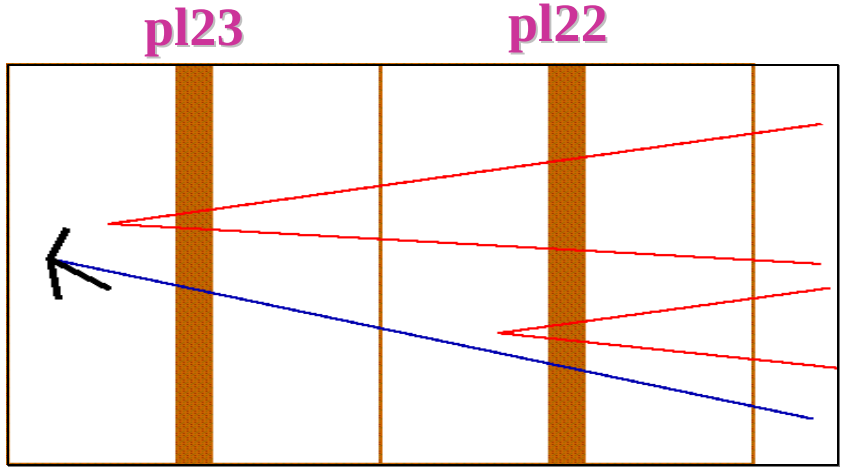
f.l. = 1010 μm

θ_{kink} = 420 mrad

Pt > 330MeV/c

First observation in CC

Phys. Lett B 539 (2002) 188, CHORUS Coll.



One of several candidates in NC

V2(1) @pl 23
fl= 62.8mm
Dq **=96.3 mrad**

V2(2) @pl 22
fl= 976.6mm
Dq **=203.4 mrad**

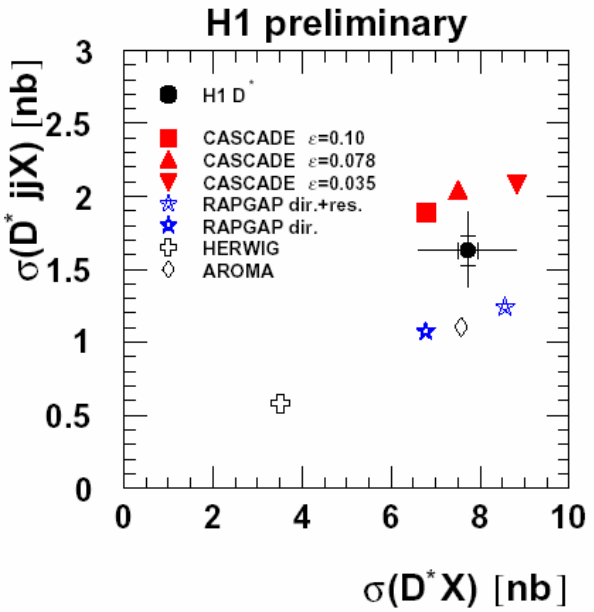
Cross-section measurement for both processes in progress

Diffractive D_s* production (Phys. Lett. B 435 (1998) 458)

In progress also: D*, anti-ν-induced charm and QE Lc cross-section

ep -> ccX

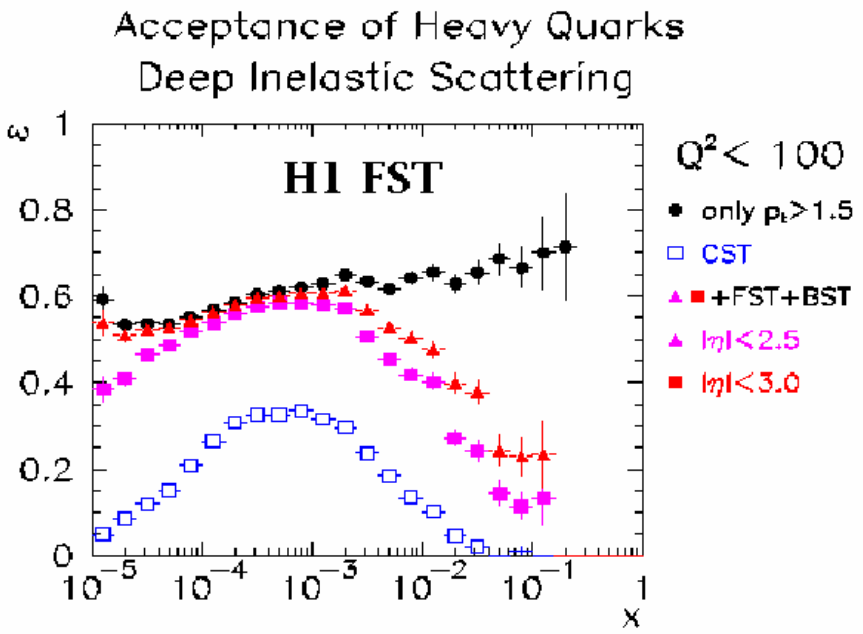
Measurement of $D^{*\pm}$ meson production and $D^{*\pm}$ meson + dijet production in DIS:

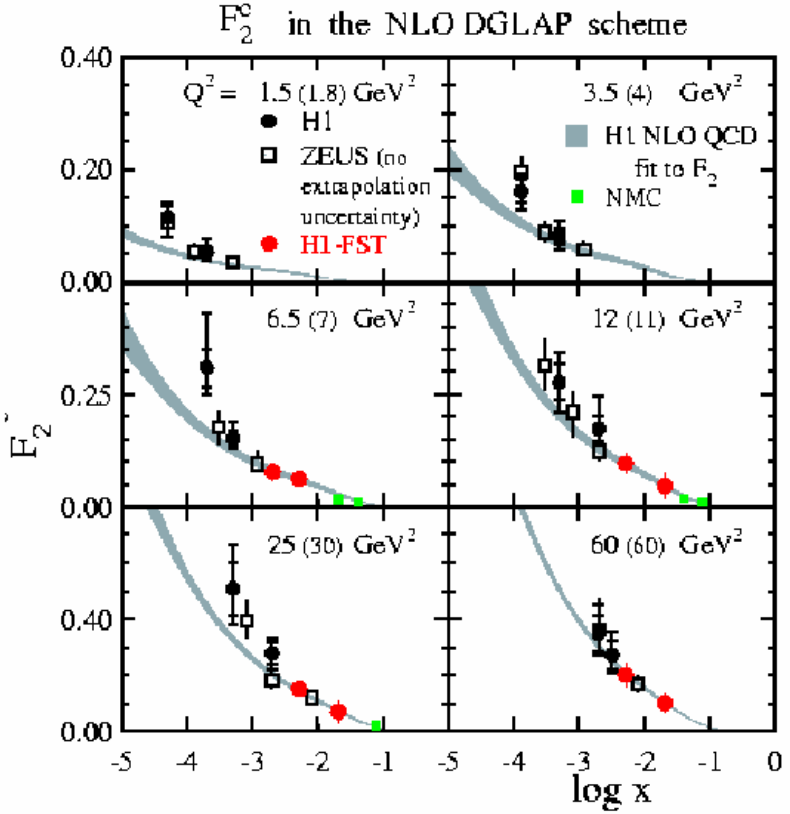


- published H1 results on $D^{*\pm}$ mesons are confirmed with higher statistics:
  - $\rightarrow$ NLO DGLAP: differences at small p_t and large η
  - $\rightarrow$ CCFM: in general in better agreement with data
- first H1 measurement of $D^{*\pm}$ meson + dijet production

Example: F_2^c at High x

- Forward silicon trackers extend acceptance to $x \approx 0.1$





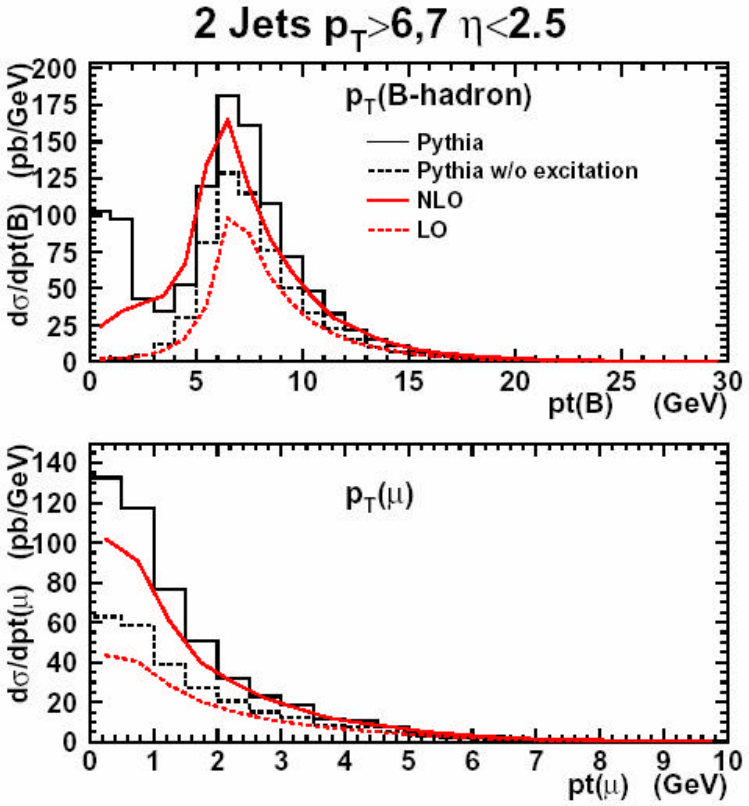
K. Daum, Study for HERA–2, for 10pb^{-1}; stat. errors only

Comparing Visible and Dijet results

Dijet	$\sigma(ep \to b\bar{b} \to jjX)$	Data/NLO=1.9
Visible	$\sigma(ep \to b\bar{b} \to jj\mu X)$	Data/NLO=1.4

Why these 2 numbers differ by 30%?

- Different sample:
  Cut $p_T^\mu > 2.5$ GeV removes low p_T muons from Visible cross-section
- p_T^μ distribution from Pythia
  (used to correct to dijet cross-section)
  softer than NLO$\times(b \to B) \times (B \to \mu)$
  due to b-remnants from Flavour Excitation diagrams



11 *M. Corradi* b photoproduction with ZEUS