Recent Heavy Flavour results from HERA

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F_2^{bb}, F_2^{cc} not mentioned, since covered by other talks.

Motivations

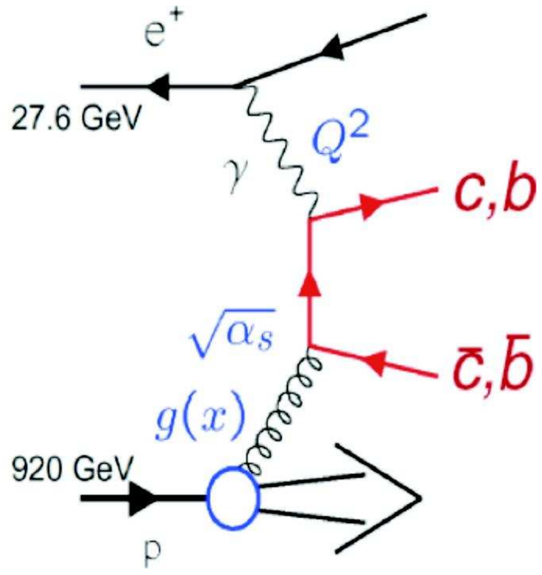
The study of Heavy Flavour production at HERA is important because:

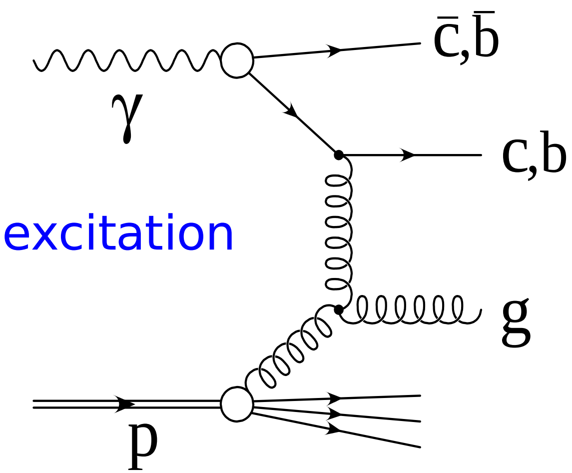
- it allows to extract the heavy flavour contents in the proton;
- it has direct sensitivity to the gluon content of the proton, and may help in distinguishing between different gluon densities;
- it is a direct test of perturbative QCD, since the high quark masses set a hard scale at which perturbative QCD calculations are expected to give reliable results.

Production mechanism

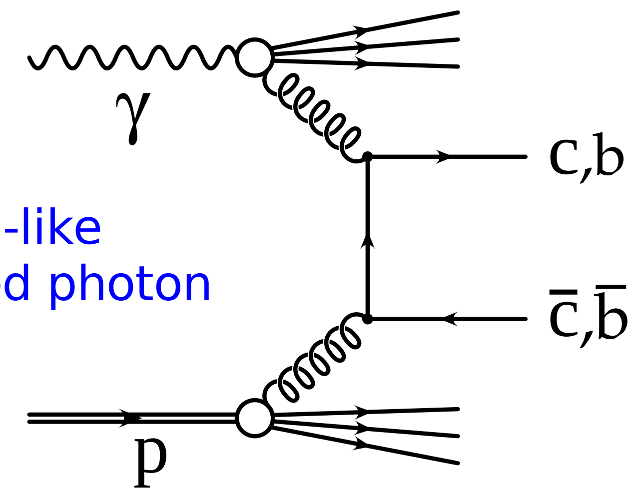
The main process contributing to HFL production at HERA is boson-gluon fusion (BGF): $\gamma p \rightarrow Q\bar{Q}$. This is directy sensitive to the gluon content of the proton.

There are also other processes contributing: resolved photon (a parton is extracted from the photon) and flavour excitation.





Charm, beauty excitation



Hadron-like resolved photon

Theoretical models: Monte Carlo

Data are compared with different Monte Carlo models and next-to-leading order QCD predictions:

- PYTHIA, RAPGAP: LO+LL parton shower QCD predictions.
  - Parton evolution simulated according to the collinear approximation (DGLAP). Higher order effects are simulated with LL parton showers;
  - BGF+resolved photon: charm is massive;
  - flavour excitation: charm is massless.
- CASCADE: gluon density unintegrated in the gluon transverse momentum (k_t):
  - higher order QCD corrections are simulated with initial state parton showers, based on CCFM evolution;
  - the simulated process is BGF, and the charm is considered as massive.

Theoretical models: NLO QCD

Massive approach (Fixed Flavour Number Scheme):

- heavy quark has mass, most appropriate for $Q^2 \sim M_Q^{\ 2}$;
- number of active flavours in the proton is 3 (u,d,s);
- c and b are produced perturbatively in the hard subprocess;
- If $Q^2 >> M_Q^{\ 2}$, large $\ln(Q^2/M_Q^{\ 2})$ appear.

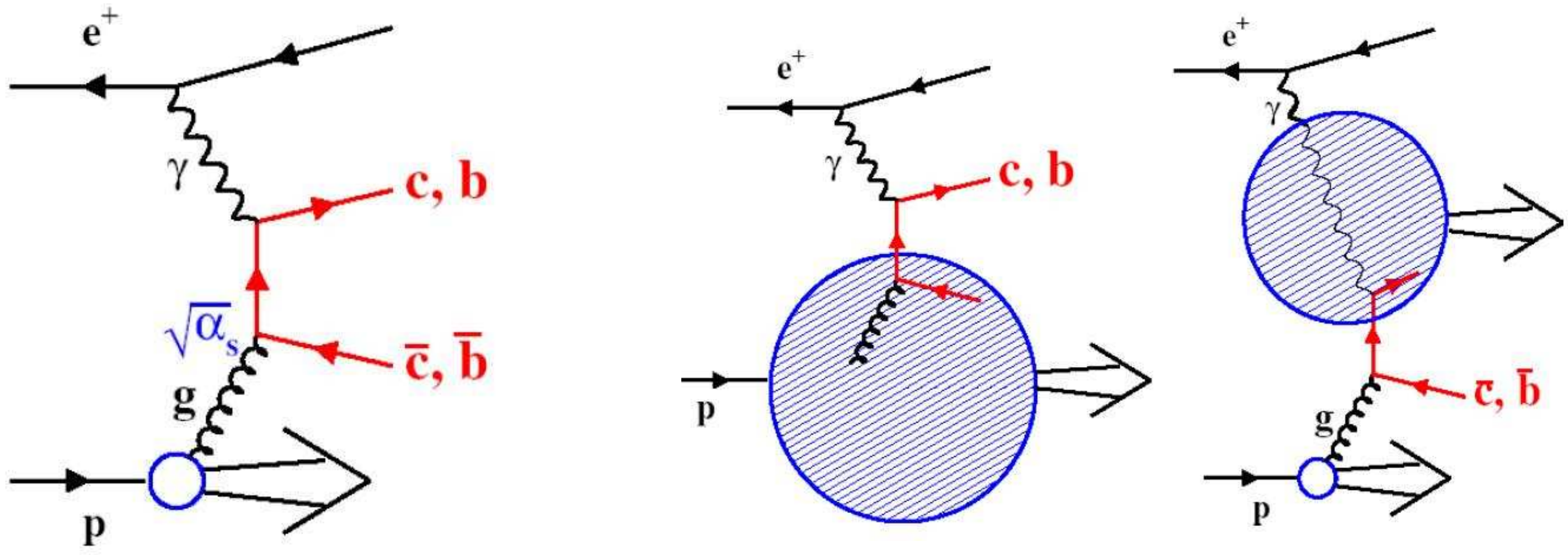
Massless approach:

- heavy flavour masses are neglected, resummation is valid for $Q^2 >> M_Q^{\ 2}$;
- number of flavours increases across threshold, HQ densities are zero below threshold.

Theoretical models: NLO QCD (cont'd)

Variable Flavour Number Scheme:

- combines massive and massless approach;
- massive approach around threshold ($Q^2 \sim M_Q^2$), resummation of $\ln(Q^2/M_Q^2)$ at large Q^2.



Experimental techniques at HERA

Charm:

- use charmed mesons;
- inclusive lifetime measurements (not shown).

Beauty:

- use semi-leptonic decay into muons, use jets and p^T_{rel};
- double-tag method with muon and D* or two muons;
- inclusive lifetime measurements (not shown, no new results).

Charm

D mesons in DIS, fragmentation fractions, cross sections.

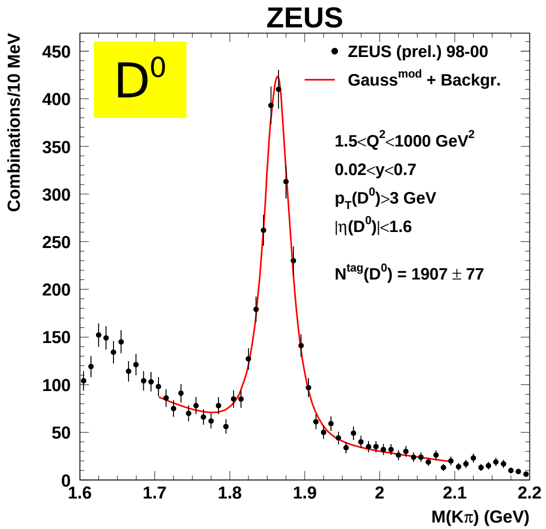
D* with jets in PHP and DIS.

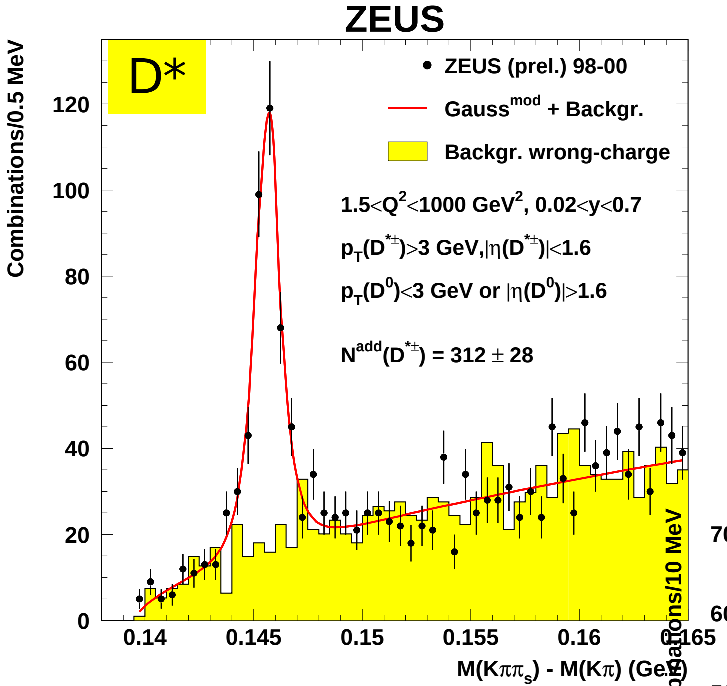
D* at the transition region between DIS and PHP.

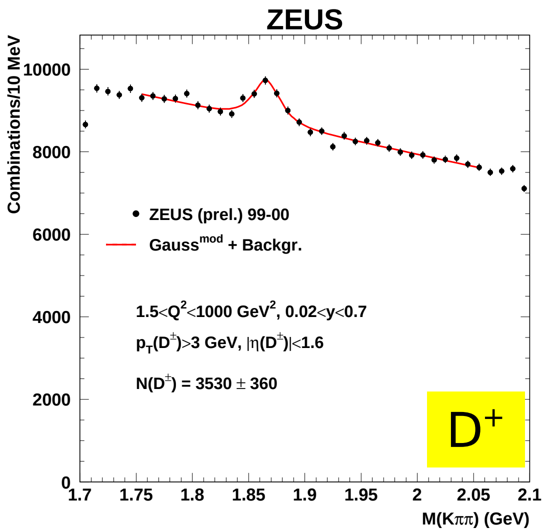
Diffractive D* production.

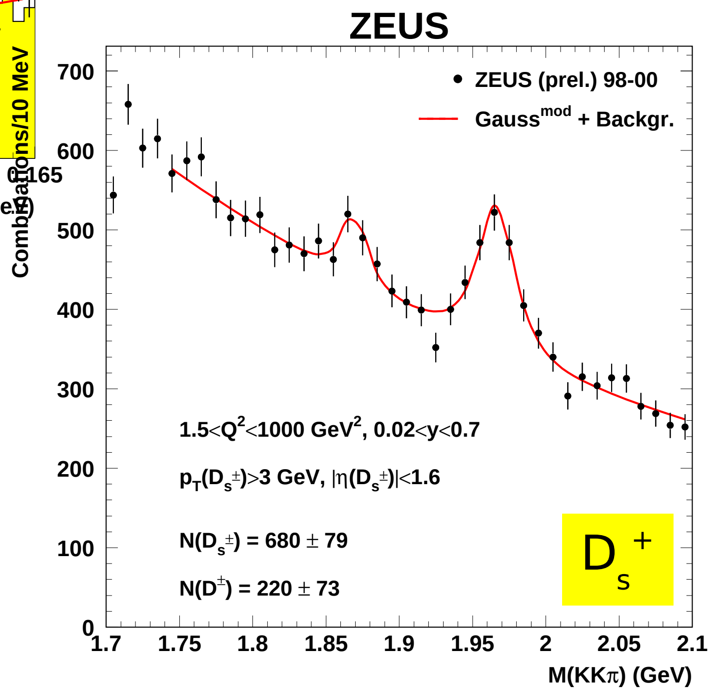
D mesons in DIS at ZEUS

Tag charm via the reconstruction of several charmed mesons, D^*, D^+, D^0, D_s^+.





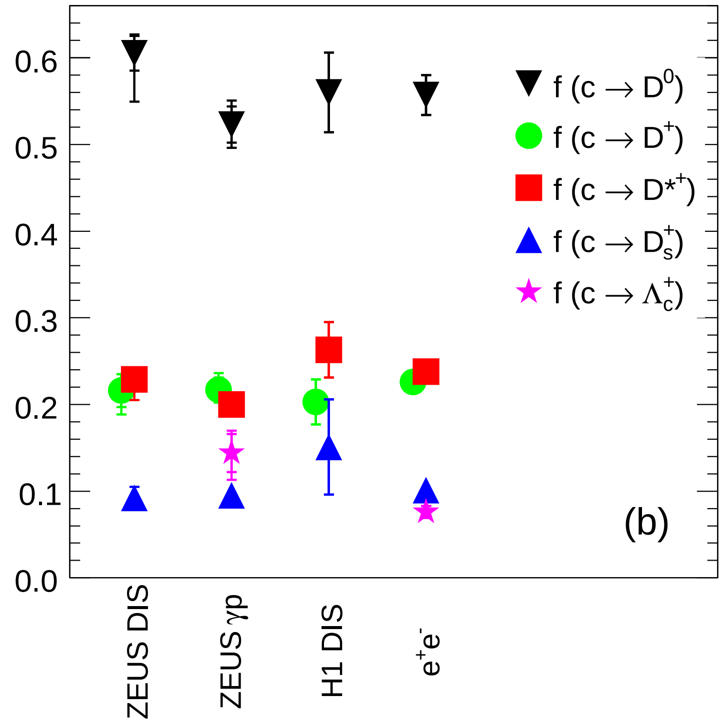




Fragmentation fractions

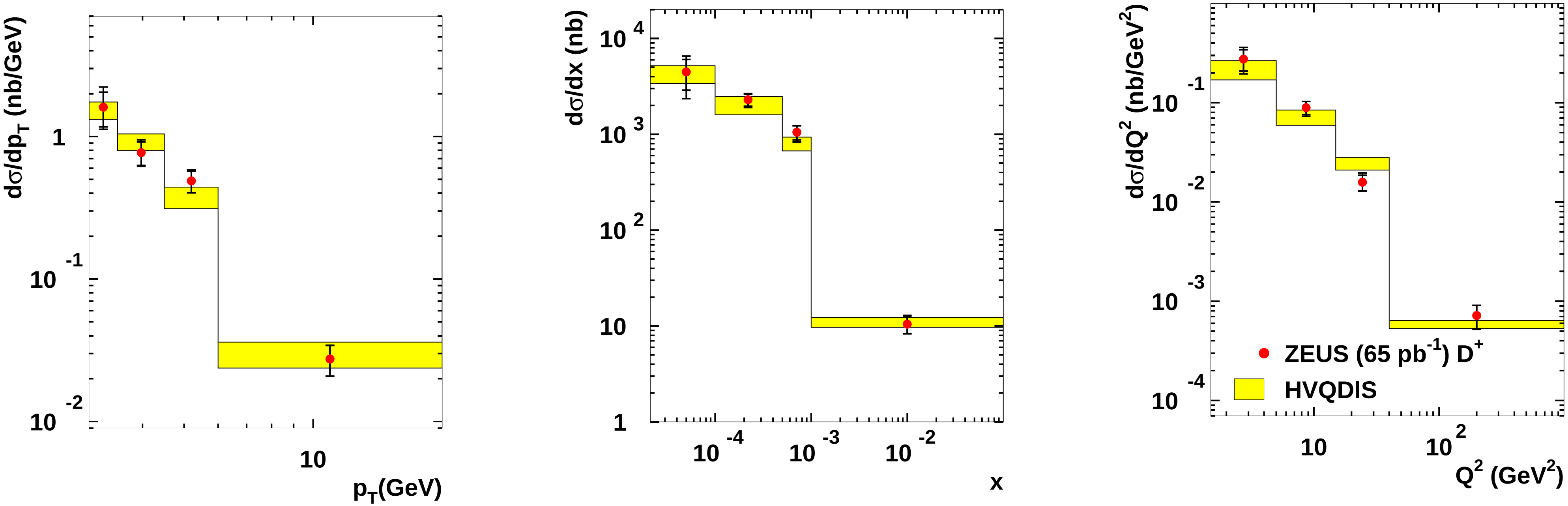
The production cross section for each charmed meson can be measured, and the fragmentation fractions of charm into each meson can be estimated.

Measurement at HERA agree with e^+e^-:
charm fragmentation fractions do not depend on the hard subprocess (universality).



Differential cross sections

Can be compared with NLO QCD predictions: HVQDIS: FFNS with DGLAP, ZEUS-S NLO QCD as proton PDF.



Good agreement between data and NLO. Cross sections can be used to extract F_2^{cc} .

D in DIS at H1*

Inclusive D* measurement and measurement of D* and dijet.

The jets are a good approximation (the best experimentally achievable) of the underlying partons.

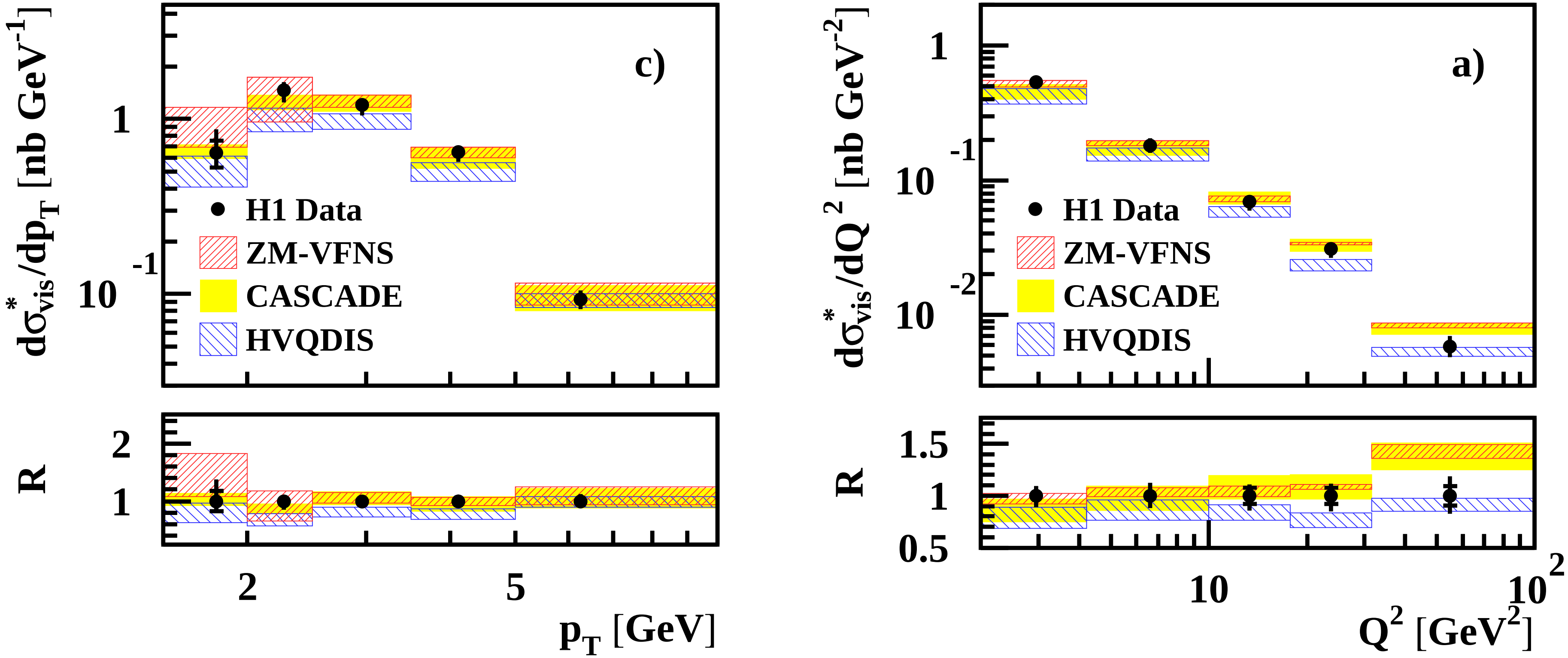
Usually one jet contains the D*, the second may be the other charm-jet, or being generated from gluon emission.

The azimuthal correlation between the two leading jets is sensitive to initial state gluon emission.

The gluon momentum fraction x_g and the photon momentum fraction x_γ can be measured.

Inclusive D* cross sections – DIS

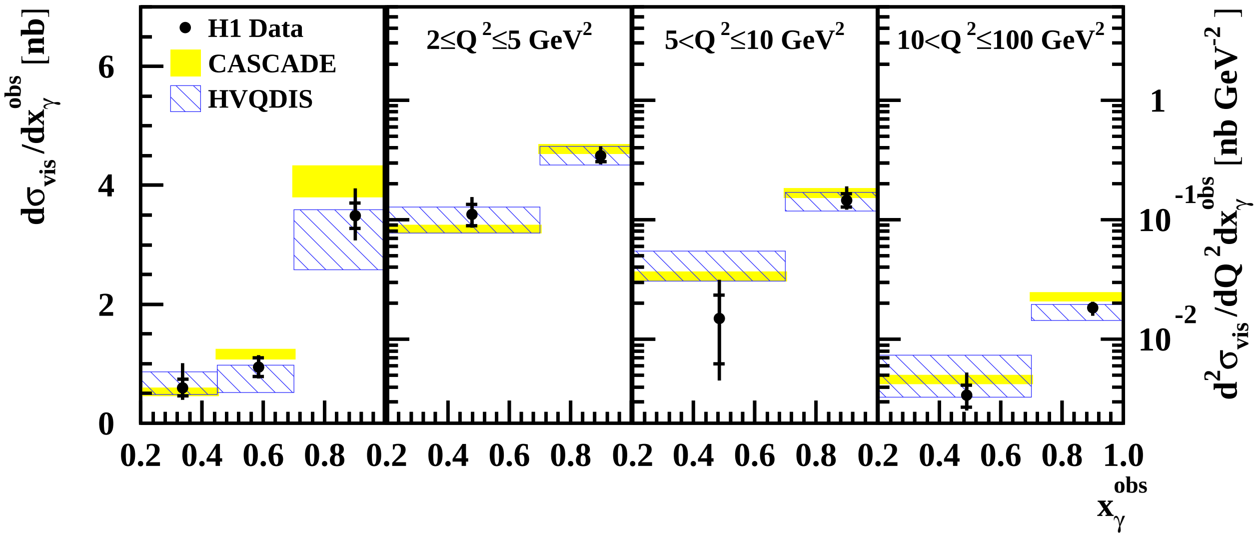
- Inclusive cross section compared with massive and massless calculations: both approaches describe data well.



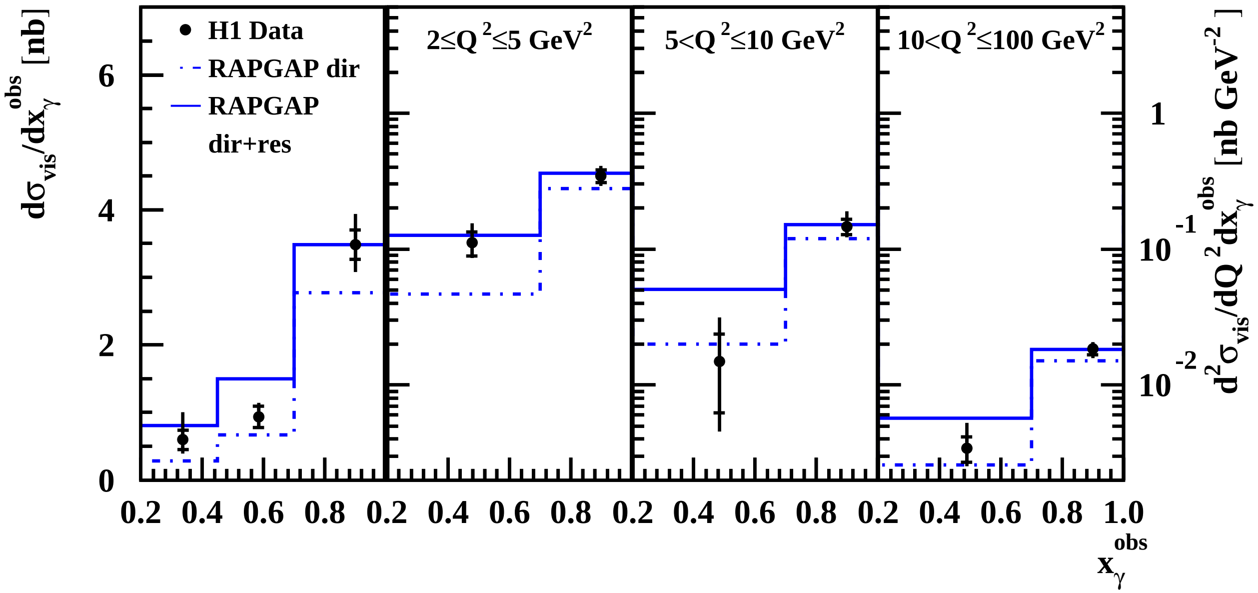
CTEQ5F used as proton PDF.

D with dijets – DIS*

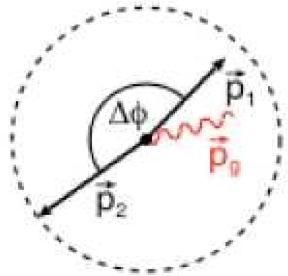
x_γ well described by NLO: not sensitive to resolved contributions of the order of few percent.

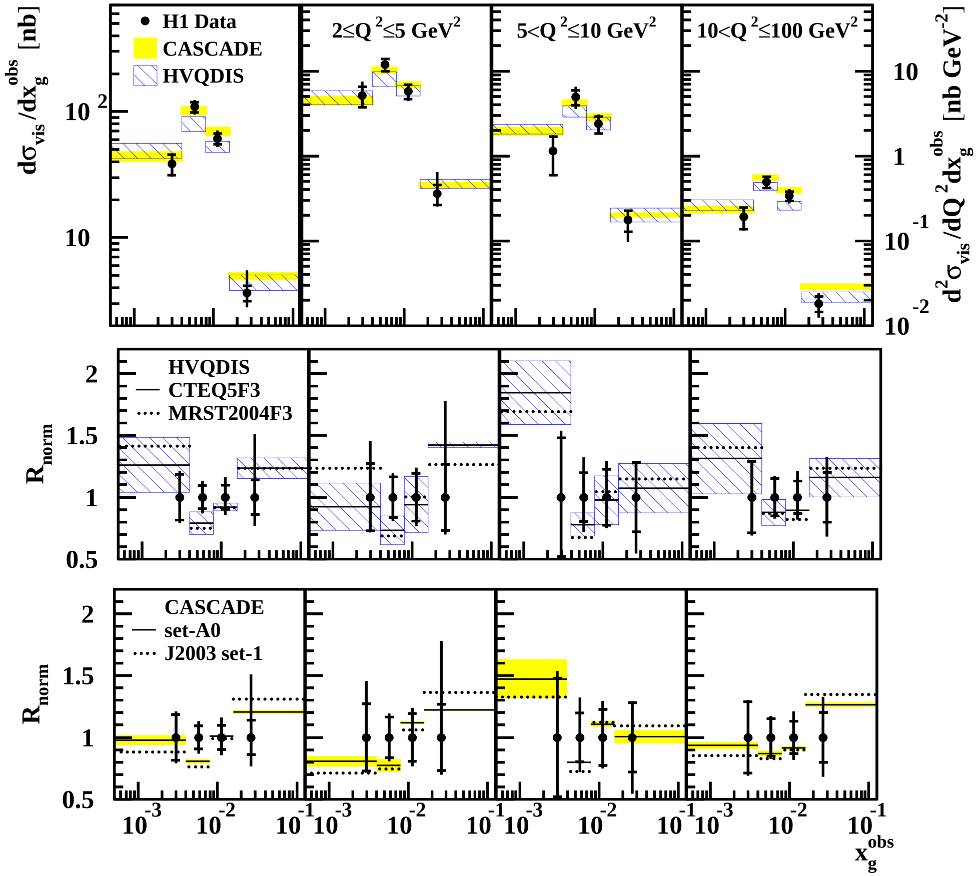


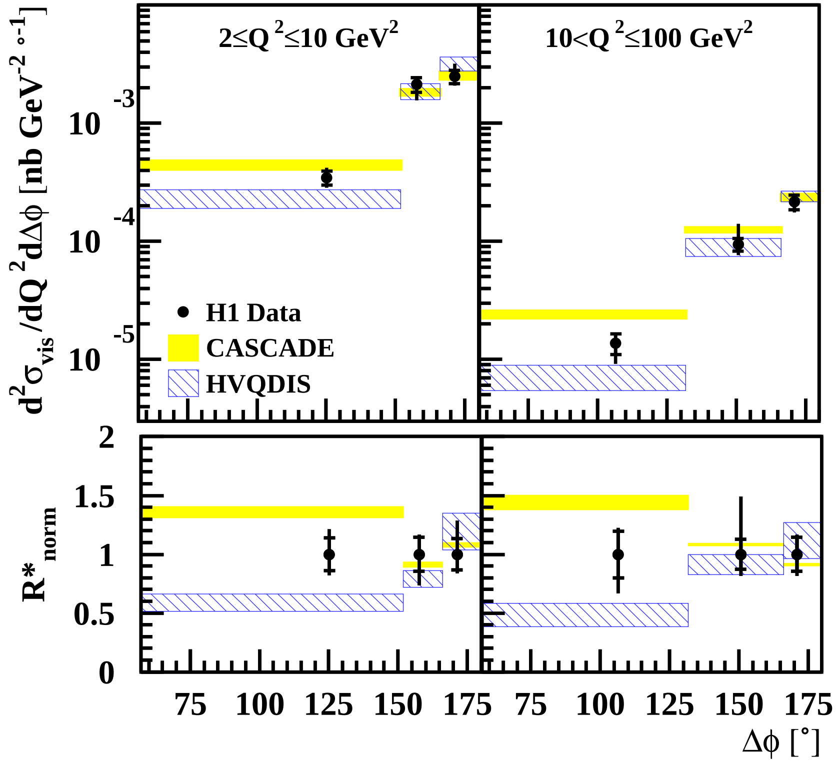
RAPGAP:
for Q^2>5 GeV data could be described by direct rescaled by a factor, but for lower Q^2 a resolved contribution is needed.



D* with dijets – DIS (cont'd)



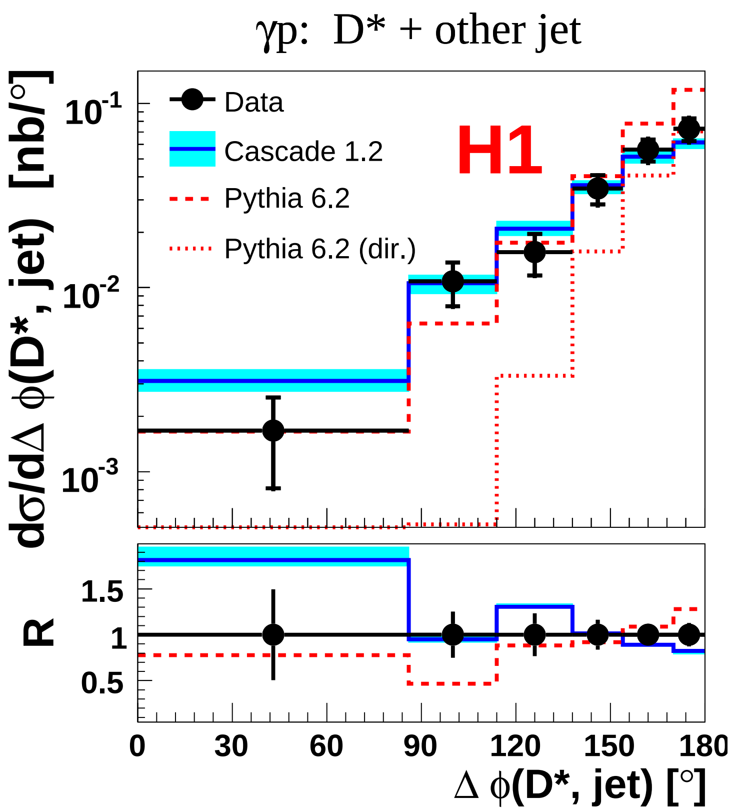


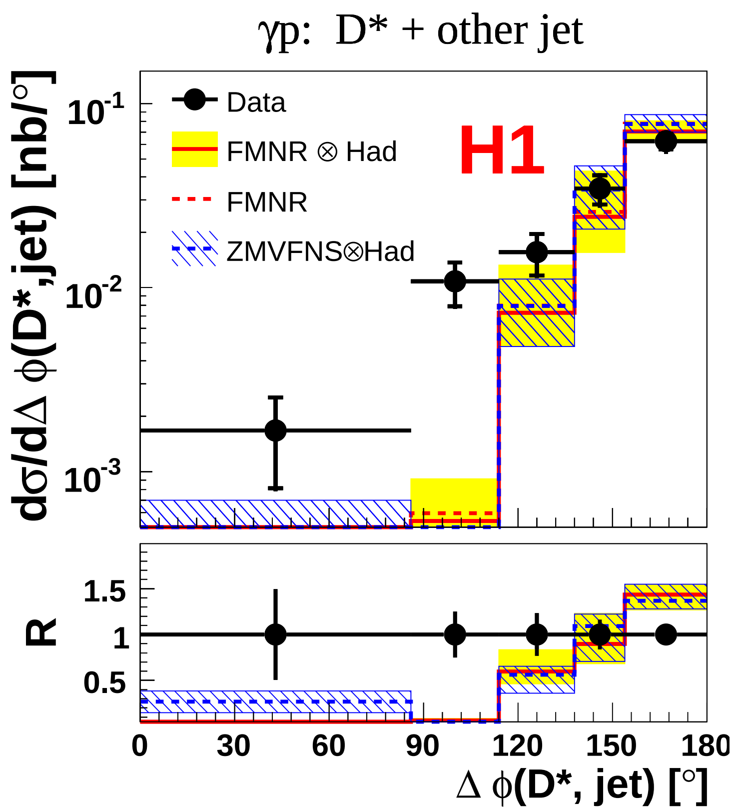


x_g well described by NLO: the gluon distributions from inclusive data are suitable also for charm.

CASCADE: unintegrated gluon density may be too broad, so the non-back-to-back region (high-k_t) is overestimated.The angular correlation between jet and D* is not described. Situation is not changed by using another available gluon density in CASCADE.

D-jet correlation in PHP*





DIS results confirmed: NLO is not able to reproduce the angular correlations, and CASCADE overestimate the low $\Delta\phi$ region.

Similar results found also by ZEUS *(Nucl. Phys. B729, 492 (2005)).*

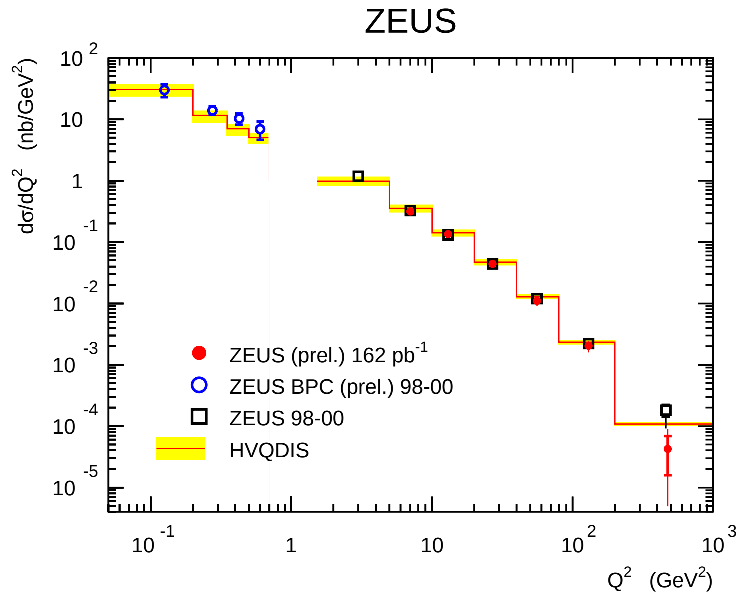
Charm production at low Q^2

The charm production cross section is investigated at lower Q^2 to understand the transition region between PHP and DIS.

Charm is tagged via D* production,

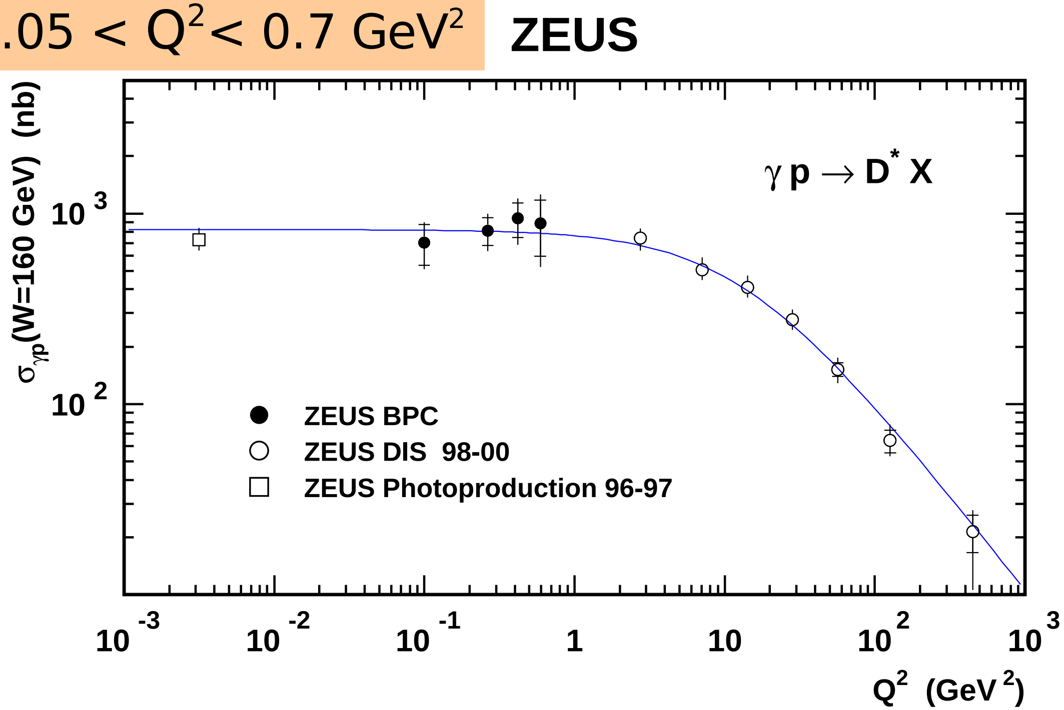
$p_T(D^*) > 1.5$ GeV, $|\eta(D^*)| < 1.5$.

Q^2 dependence is reproduced by NLO for 5 orders of magnitude.



ZEUS-S NLO for p PDF (FFNS)

0.05 < Q^2 < 0.7 GeV^2



Transition region is described by the parameterisation:

$\sigma(Q^2) = SM^2/(Q^2+M^2)$,

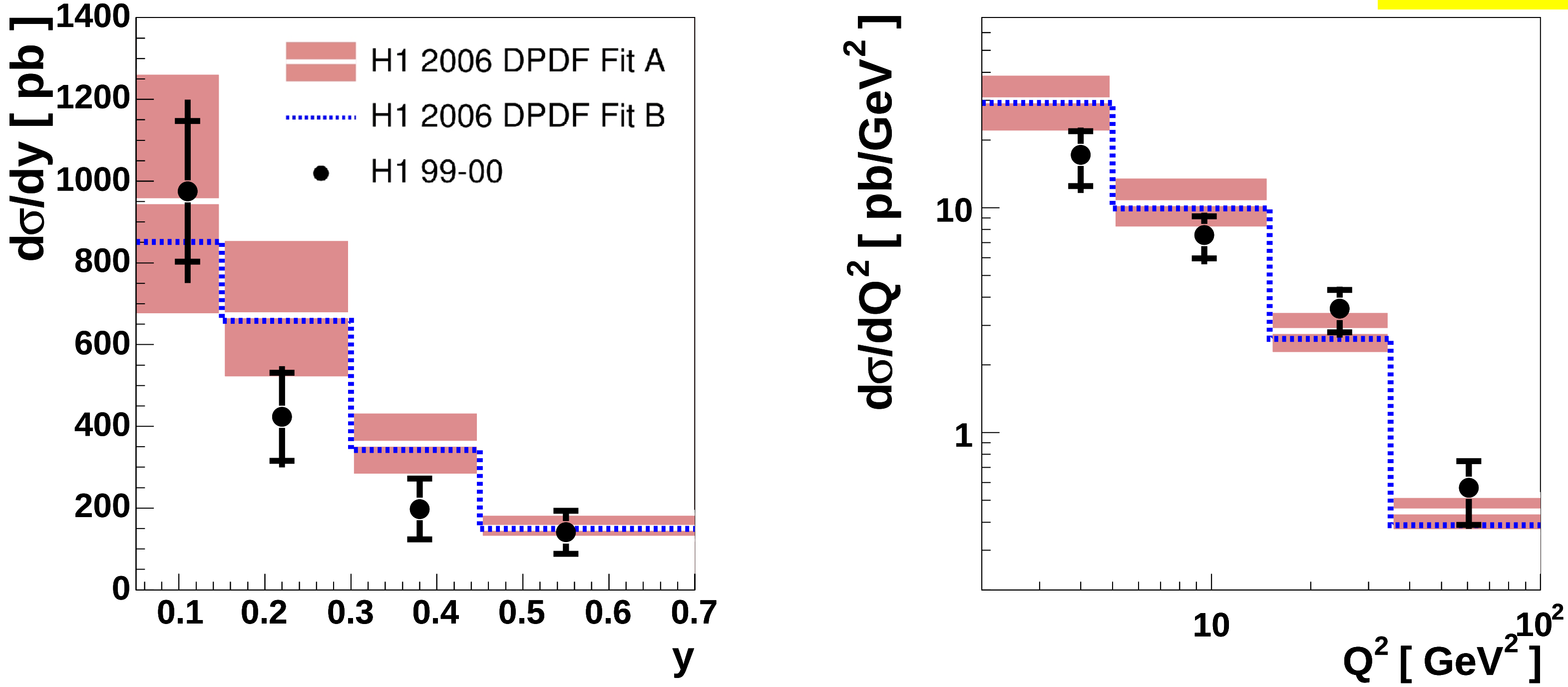
with $M^2 = 13\pm2\,\mathrm{GeV}^2 \cong 4m_c^2$.

Diffractive charm production

It is a direct test of the validity of hard diffractive QCD factorisation.

Direct photon process is directly sensitive to the gluon content of the diffractive exchange.

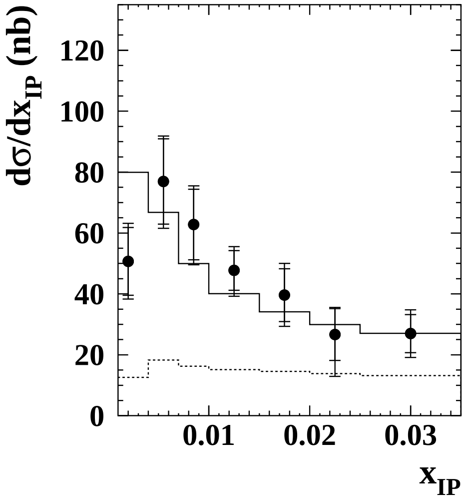
DIS regime



H1 measurements in DIS support the NLO based DPDFs.

Diffractive charm production (cont'd)

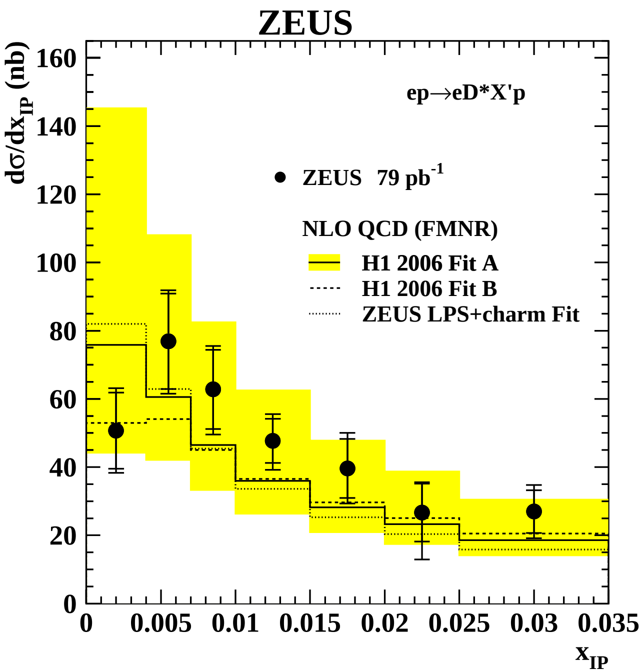
Resolved photon processes can help in understanding the breakdown of factorisation observed at TeVatron.

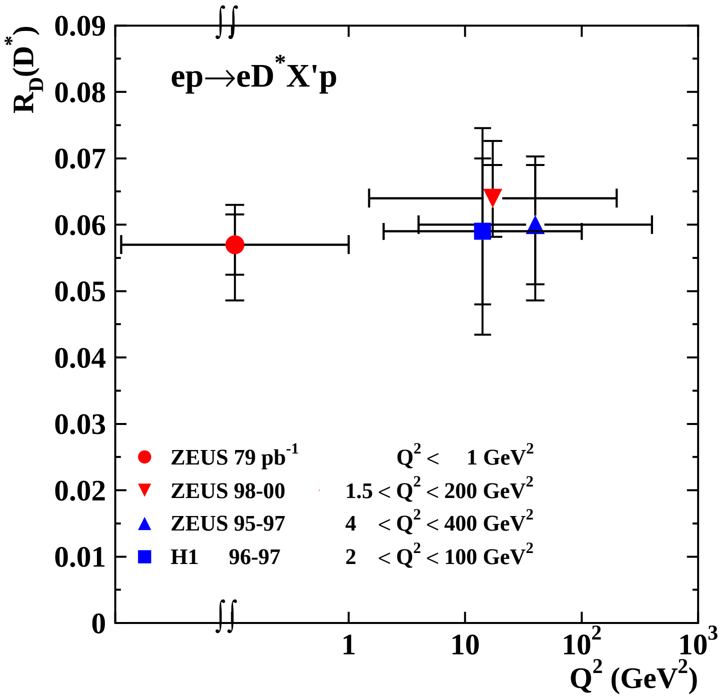


It is not possible to detect a resolved suppression of ~30%, as predicted by some models...

Eur. Phys. J. C 21, 521 (2001)
Phys. Lett. B 520, 191 (2001)

PHP regime





Ratio of diffractive to inclusive cross section consistent with being independent of Q^2

Charm summary

Measurements with meson tagging are well estabilished and are being extended to larger data samples (as for ZEUS F_2^{cc}).

Present data give no sensibility to favour one of FFN or VFN schemes.

Measurements of angular correlations are sensitive to higher order effects and can therefore give useful indications on the underlying gluon density, and on the effect of corrections of higher order with respect to NLO.

Sometimes experimental errors are lower than theoretical.

Diffractive charm production is successfully described in the factorisation approach, but errors are still large.

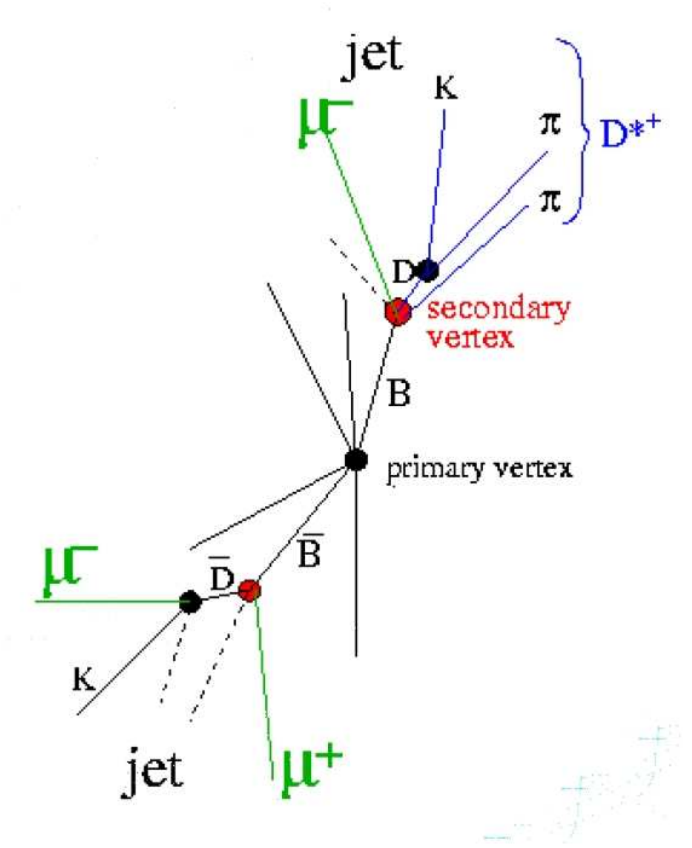
Diffractive contribution to total cross section is sizeable.

Beauty

D*-muon results.

Di-muon results.

Double tagging



Beauty can be tagged via its decay products:

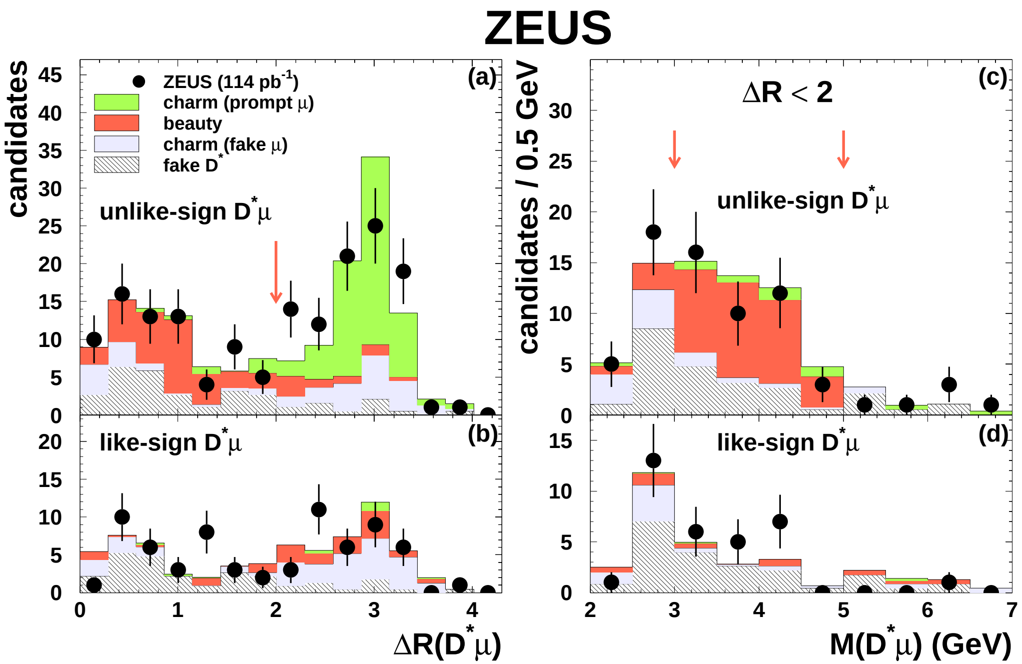
D* (or muon) and μ from same b (unlike sign, same emisphere) or different b's (like sign, different emisphere);

Low background →

p_T cuts can be lowered,

extrapolation factor for total cross section measurement can be significantly reduced.

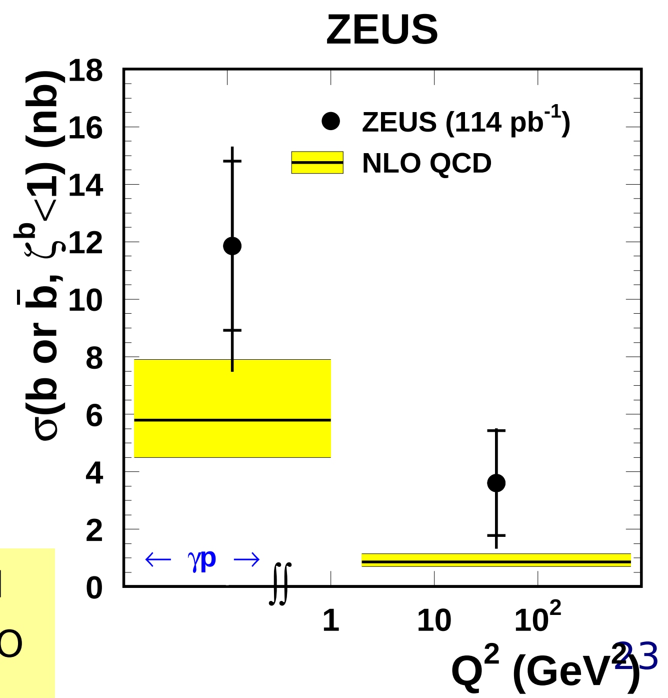
D* μ analysis



Unlike sign:

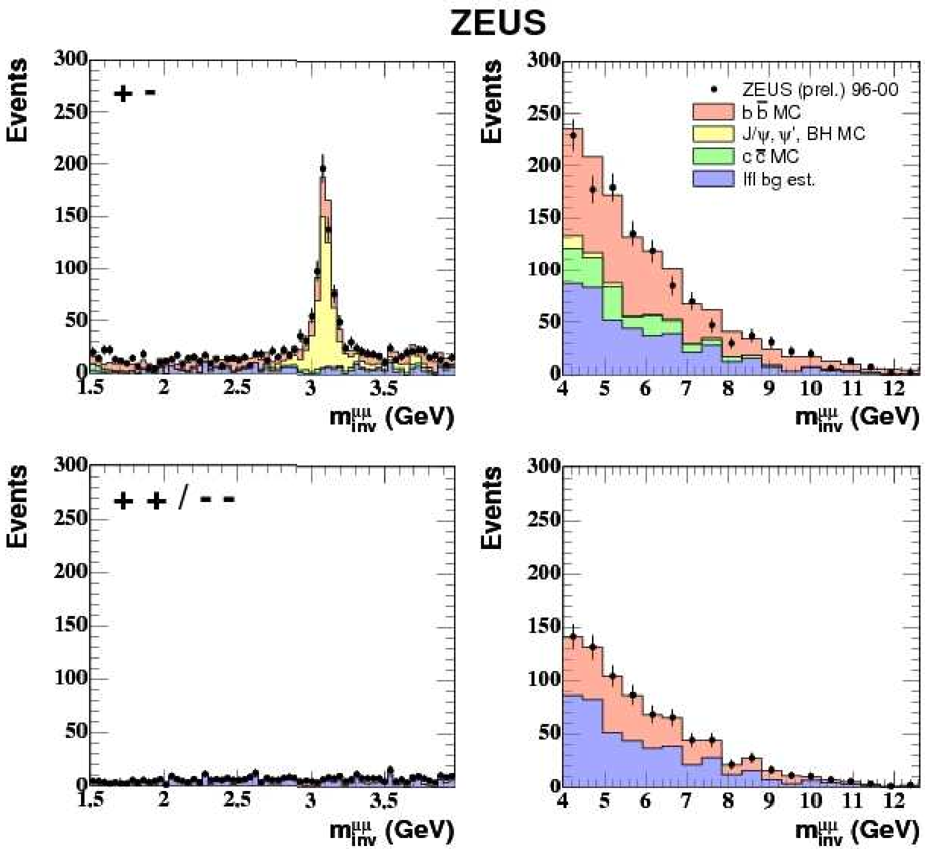
- beauty and charm clearly separated using the angular distance between muon and D*;
- the b meson is partially reconstructed.

Cross sections compared with NLO (FMNR for PHP and HVQDIS for DIS).
Still small statistics, could take advantage of the increased collected luminosity and of the lifetime tagging.



FMNR: p PDF: CTDQ5M
γ PDF: GRV-G-HO
HVQDIS: p PDF CTEQ5F4

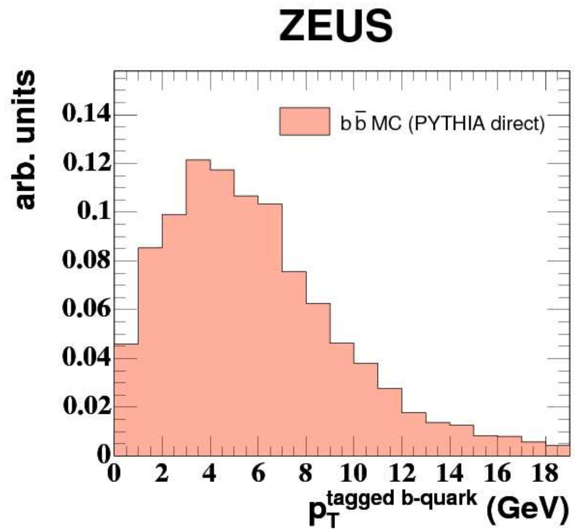
$b\bar{b} \rightarrow \mu\mu$ analysis



Beauty is the only source of like-sign dimuon events.

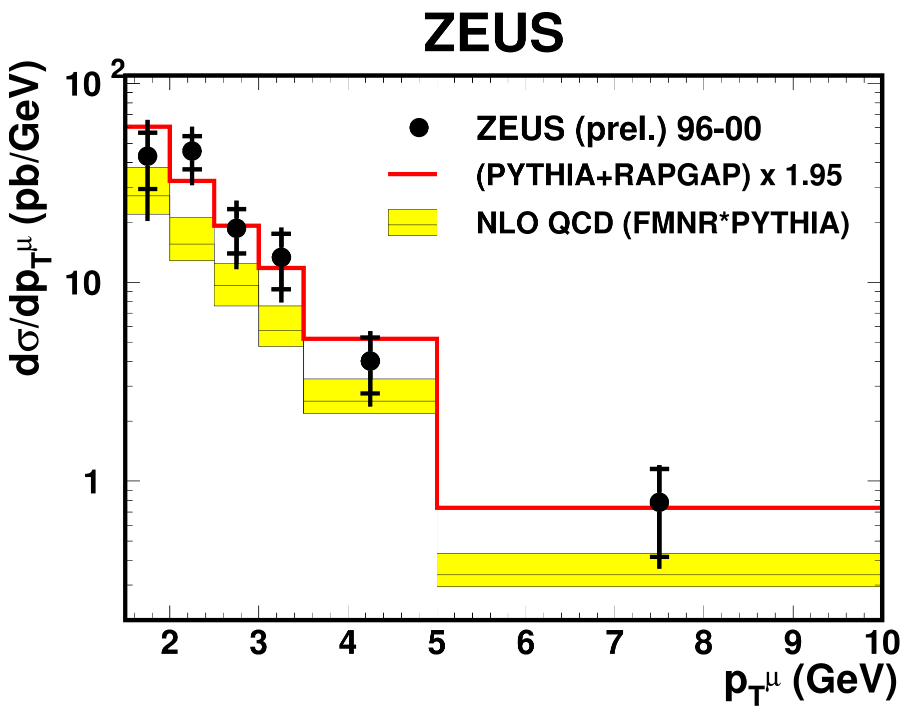
Fraction of charm decaying to two muons is estimated using the measurement in the D*muon channel.

The difference from like and unlike is free from fake muon background.

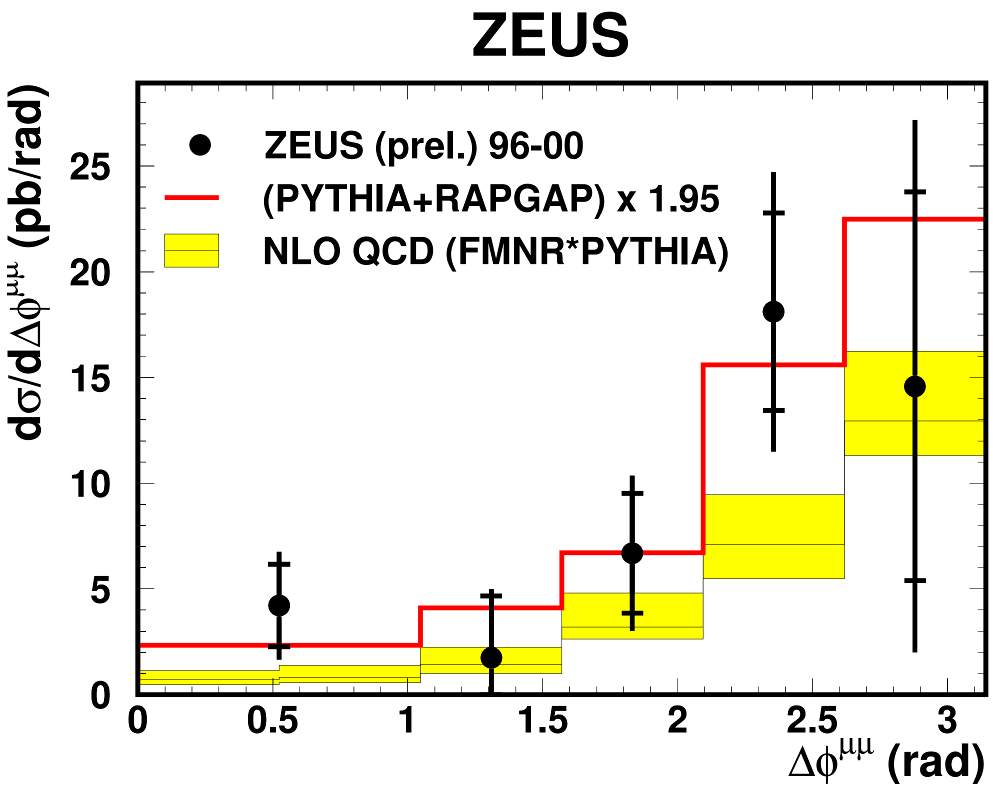


The measurement is sensitive to very low momenta of the b quarks.

Cross sections



Δϕ shape reproduced by PYTHIA and NLO, but errors are large.



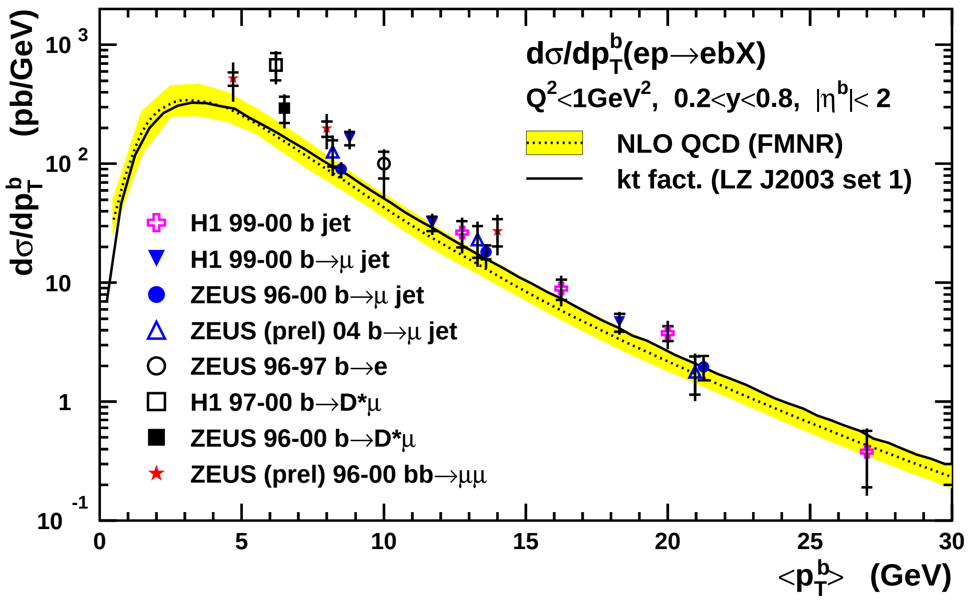
FMNR: p PDF: CTEQ5M

γ PDF: GRV-G-HO

HVQDIS: p PDF: CTEQ5F4

Beauty summary

HERA



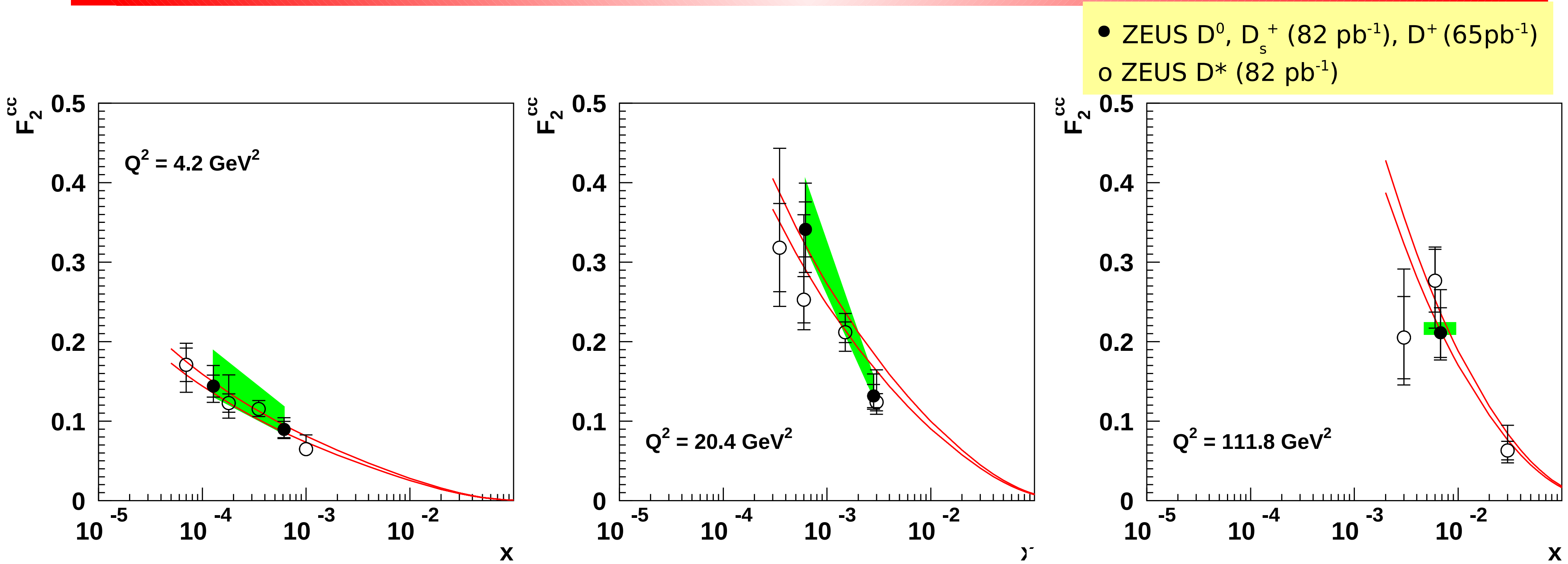
The HERAII data sample needs to be exploited in order to improve our cross section determination, especially in the low-p_T^b (double tag measurements) and high-p_T^b (lifetime measurements) regions.

Conclusions

- The HF production at HERA has sensitivity to proton PDFs (charm, beauty, gluon) and has therefore to be carefully studied in view of the new LHC experiments.
- The 'flagship' measurements of F_2^{bb} and F_2^{cc} come together with other measurements with particles or jets, that are used to test NLO QCD predictions and proton PDFs and can be sensitive to higher order effects connected with gluon emissions.
- Data precision is sometimes (especially for charm) better than theoretical.
- Still many measurements to come with full statistics!

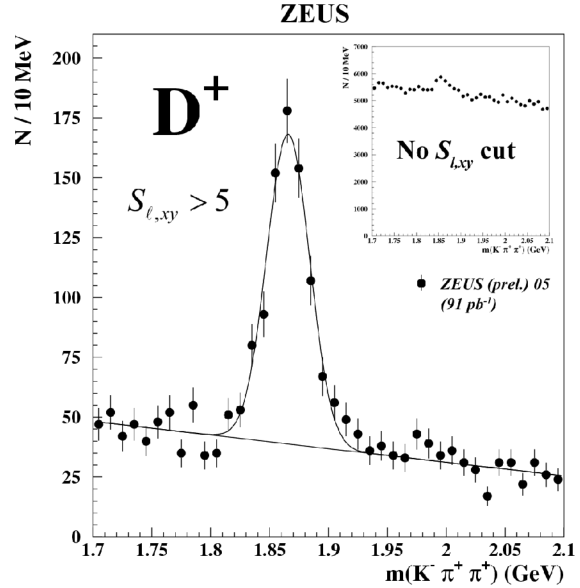
Backup slides

F_2^{cc} from D meson



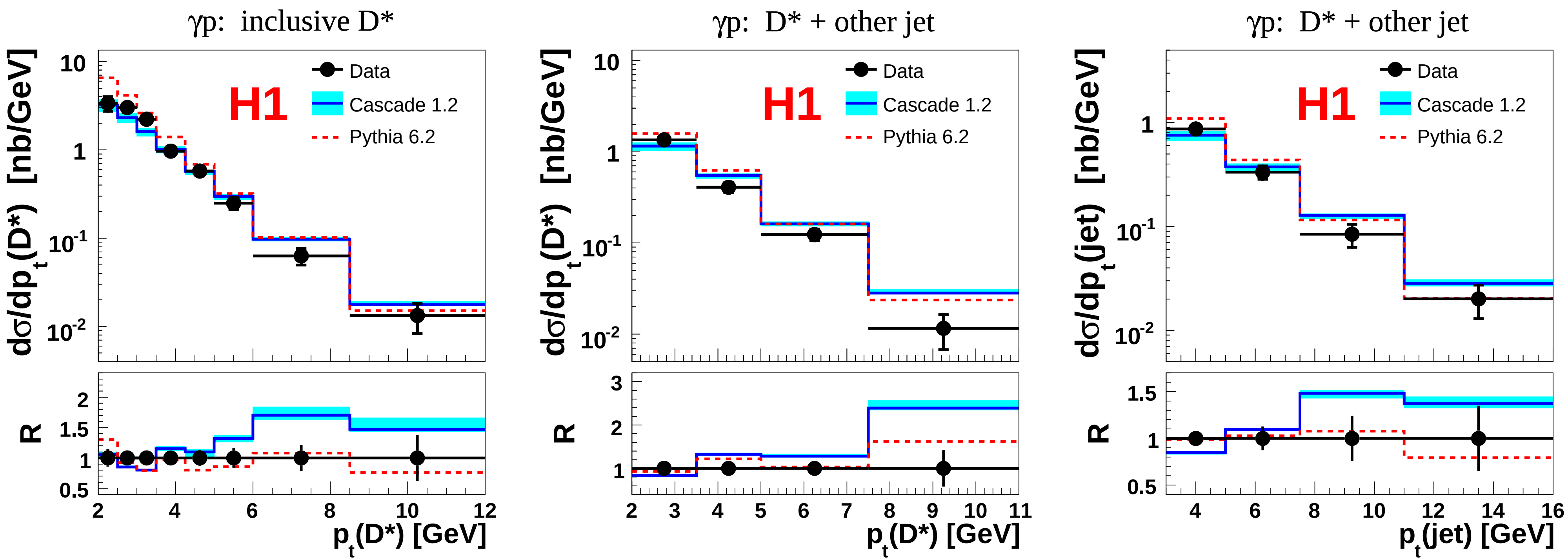
Good agreement with the previous ZEUS measurement.
Good perspectives from lifetime measurements (lower p_T cuts,

larger statistics available) → should come soon!



Gluon density in CASCADE, H1 D*+jets in DIS

For PHP analysis, A0 set has been used as unintegrated gluon density, as for DIS.



For many differential cross section as a function of p_T, CASCADE overestimates the highest p_T region.