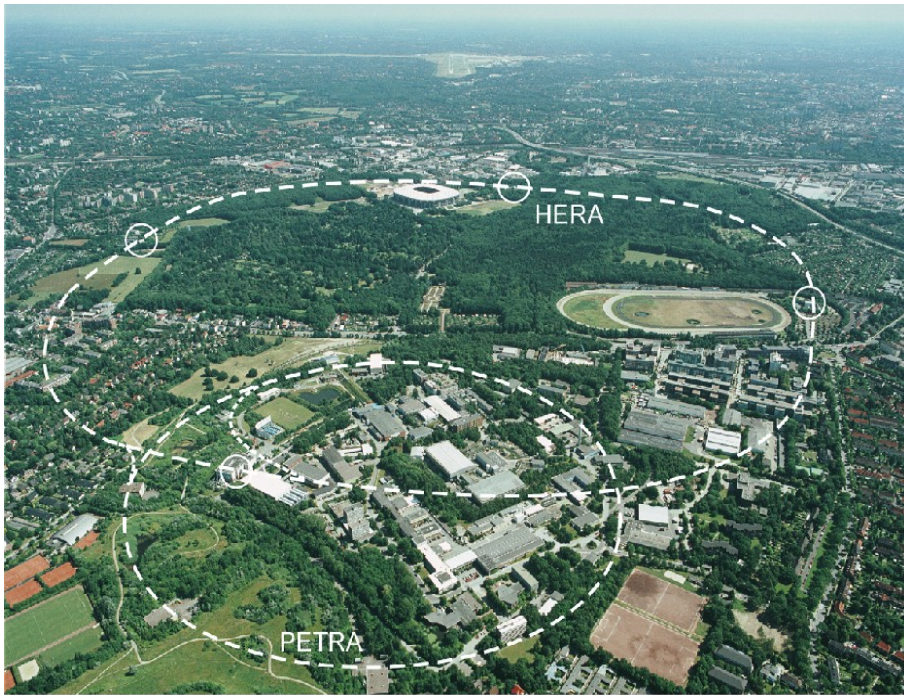




D* production in DIS and Photoproduction at H1



- Introduction:
 - experimental methods
 - theoretical models
- Single & double differential D* cross sections
- Conclusions



Andreas W. Jung for the H1 collaboration
Kirchhoff Institut für Physik
Universität Heidelberg



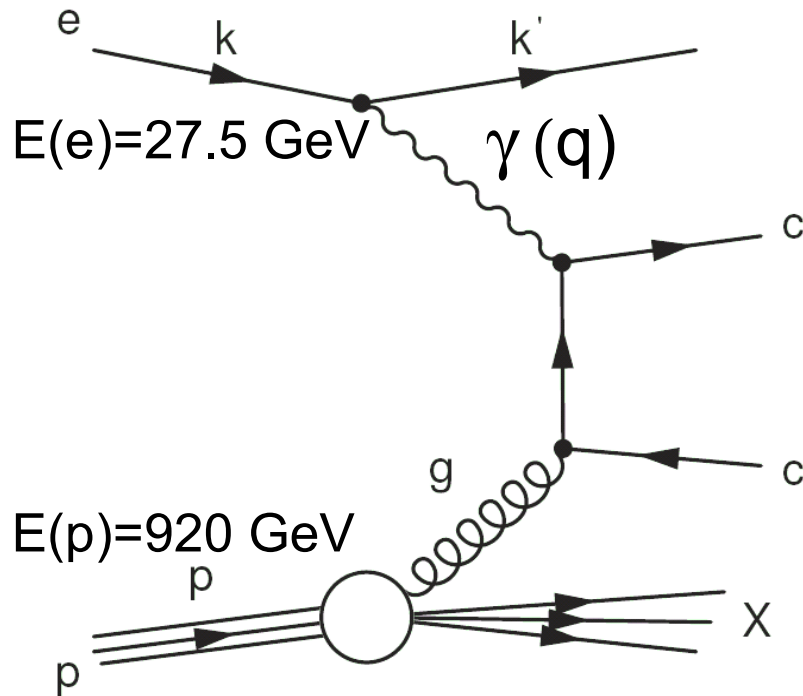
April 7th - 11th, 2007

DIS conference 2008, London



D^* production: Boson-Gluon-Fusion

Dominant process for charm-production in ep -scattering:



Kinematic at $\sqrt{s} \approx 320$ GeV:

- Photon Virtuality:

$$Q^2 = -q^2 = -(k - k')^2$$

$Q^2 < 2$: Photoproduction

$Q^2 > 5$: Deep Inelastic Scattering

- Inelasticity:

$$y = \frac{qp}{kp}$$

- Mass of hadronic system:

$$W_{\gamma p}^2 = (q + P)^2 = y \cdot s - Q^2$$

D^* via Fragmentation:

- Pseudorapidity:

$$\eta = \ln \tan \left(\frac{\theta}{2} \right)$$

- Transverse momentum:

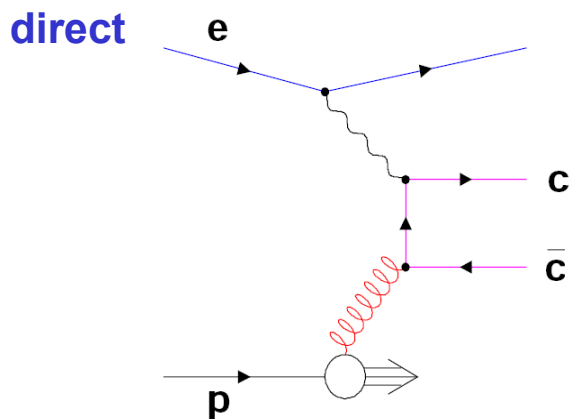
$$p_t$$

--> **hard scale allows pQCD:** $m_c \gg \Lambda_{QCD}$

--> **sensitive to the gluon density**

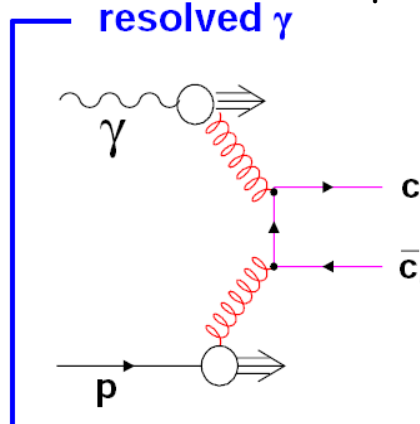


D Production: theory models*

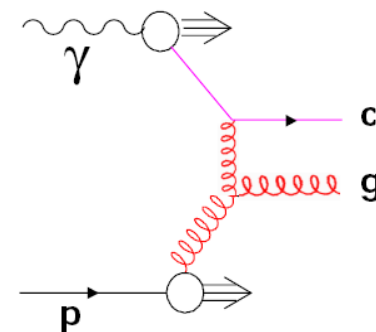
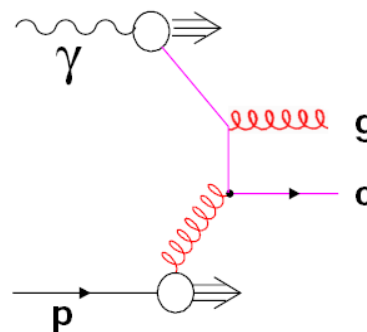


Contributions of quasi-real photons for $Q^2 < 2$:

resolved γ



(flavour excitation)



LO (α_s) + Parton shower:

RAPGAP: (DGLAP)

- charm is massive in BGF
- radiative events from Heracles

PYTHIA: (DGLAP)

- only charm: massive in BGF
- all flavors: massless in BGF

CASCADE: (CCFM)

- charm is massive in BGF
- only gluons in proton

NLO (α_s^2) calculations:

- Fixed Flavor number scheme
- charm produced in hard subprocess
- massive in BGF
- outgoing particles: $c\bar{c}$ -pair + 1 light parton

FMNR: • with Peterson fragmentation

HVQDIS: • with Kartvelishvili fragmentation

--> DIS: **RAPGAP (direct), CASCADE, HVQDIS**

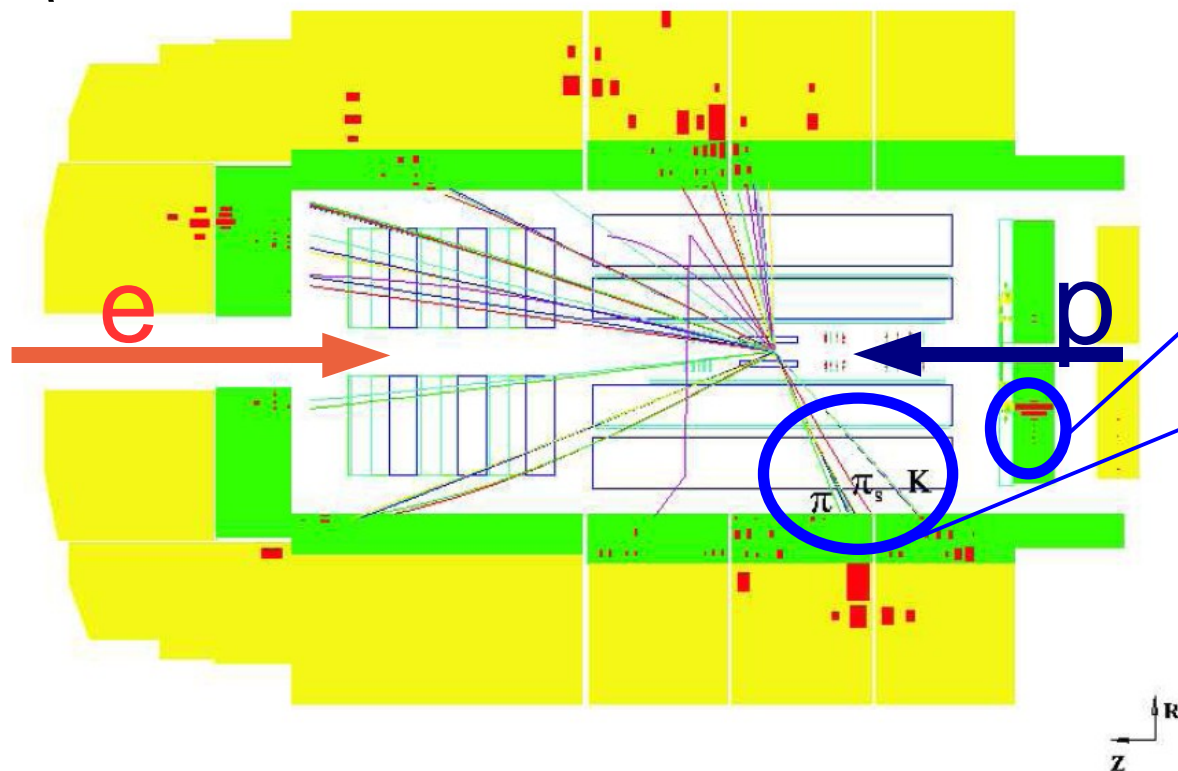
--> Photoproduction: **PYTHIA (direct+resolved+excitation), CASCADE, FMNR**

Event selection: $Q^2 > 5$

D^* reconstructed in golden decay channel: $D^{*\pm} \rightarrow D^0 \pi_{slow}^{\pm} \rightarrow (K^{\mp} \pi^{\pm}) \pi_{slow}^{\pm}$

$\eta > 0$: forward

$\eta < 0$: backward



- scattered electron in backward calorimeter
- three charged tracks in central tracking detector
- high multiplicity events

Trigger: DIS case

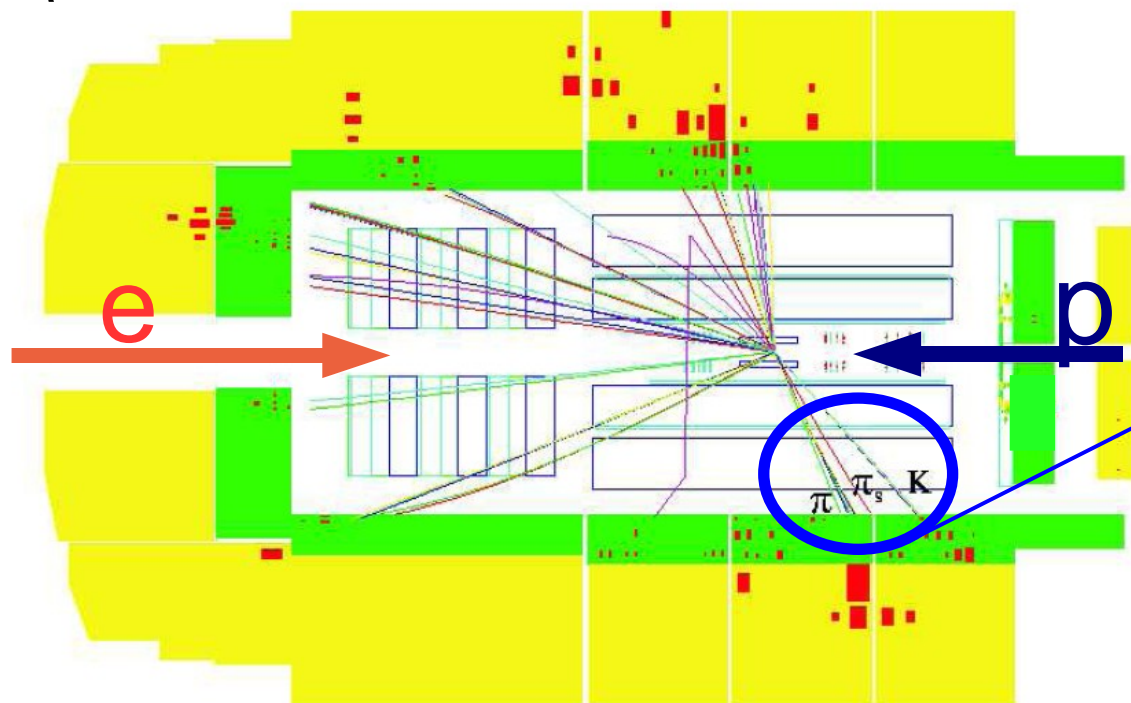
- scattered electron in backward Calorimeter
- tracks

Event selection: $Q^2 < 2$

D^* reconstructed in golden decay channel: $D^{*\pm} \rightarrow D^0 \pi_{slow}^{\pm} \rightarrow (K^{\mp} \pi^{\pm}) \pi_{slow}^{\pm}$

$\eta > 0$: forward

$\eta < 0$: backward



- three charged tracks in central tracking detector
- high multiplicity events

Trigger: DIS case

- scattered electron in backward Calorimeter
- tracks

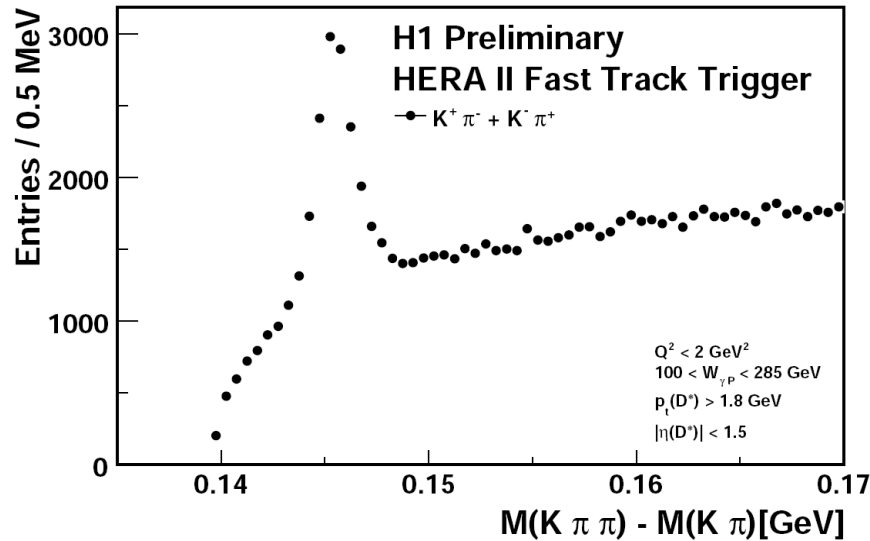
Trigger: (untagged) Photoproduction case:

- **no scattered electron**
- D^* reconstructed at trigger level using the

H1 Fast Track Trigger

Event selection: photoprod.

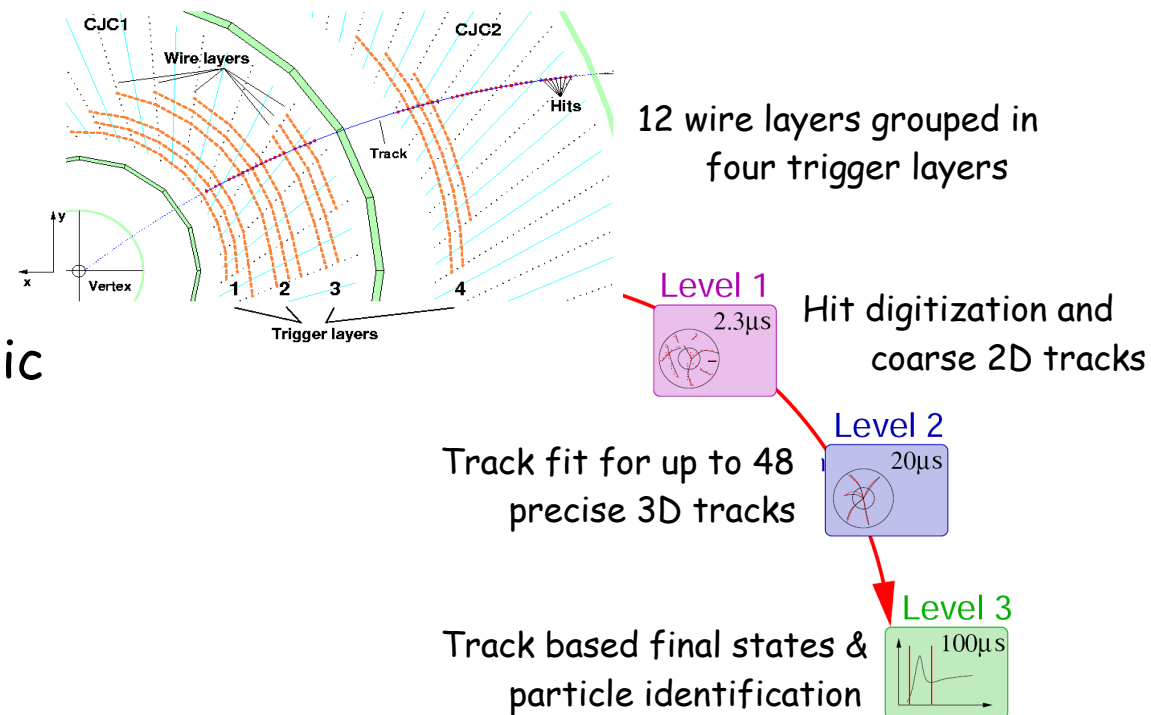
D* in photoproduction:



- decay: $D^{*\pm} \rightarrow D^0 \pi_{slow}^{\pm} \rightarrow (K^{\mp} \pi^{\pm}) \pi_{slow}^{\pm}$
- higher resolution in mass difference:
 $dM = M(K\pi\pi) - M(K\pi)$
- select events by mass difference dM

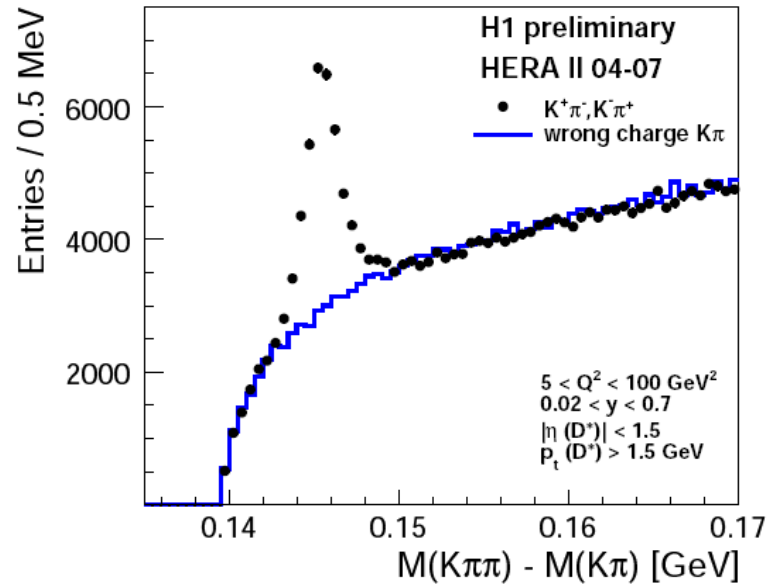
Photoproduction sample ($L = 93 \text{ pb}^{-1}$):

- ~8500 D* mesons: 8x HERA1 statistic
- increased phase space - HERA1 used electron tagger for measurement (limited W-acceptance)
- Total systematic error: ~ 11%



Event selection: DIS

D* in DIS:



- decay: $D^{*\pm} \rightarrow D^0 \pi_{slow}^{\pm} \rightarrow (K^{\mp} \pi^{\pm}) \pi_{slow}^{\pm}$
- higher resolution in mass difference:
 $dM = M(K\pi\pi) - M(K\pi)$
- select events by mass difference dM

DIS sample ($L = 347 \text{ pb}^{-1}$):

- ~21000 D^* mesons: 10x HERA1 statistic
- Get smallest systematic error possible
- Total systematic error: ~ 9%
- Born-level cross sections by correcting for radiative effects

Changes to previous analysis:

- reconstruction method changed to electron- Σ -method
- **allows lower y of 0.02**
- decreased systematic uncertainty, especially in $\eta(D^*) > 0$

Common fit function:

asymmetric Peak:

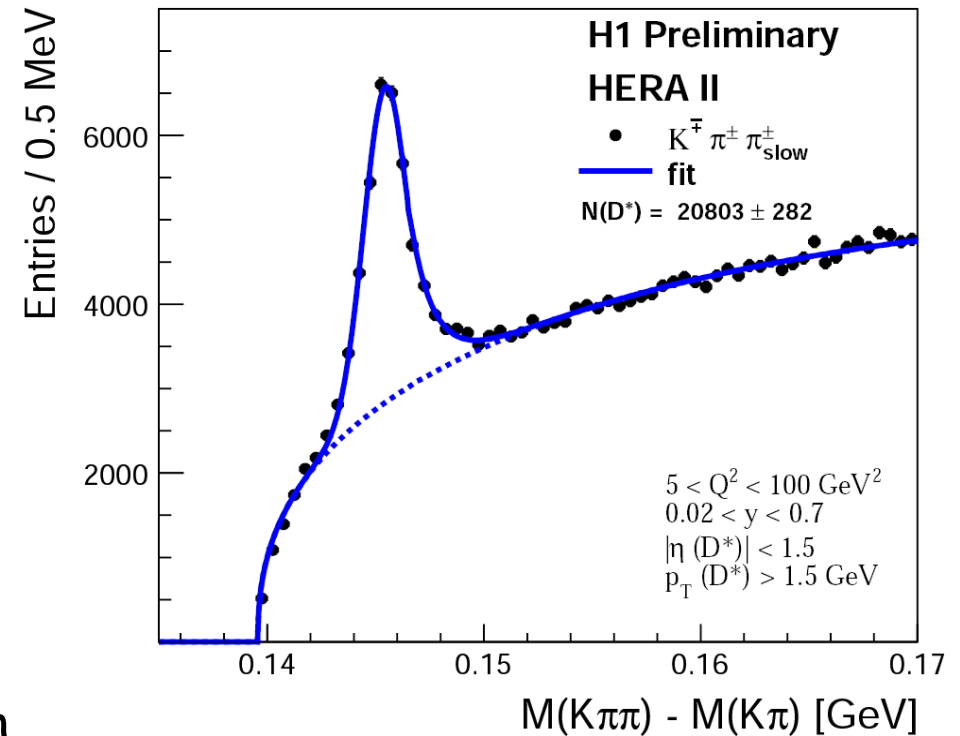
Crystal-Ball:

$$f(x) = \begin{cases} \left(\frac{n}{|\alpha|}\right)^n \exp\left(-\frac{1}{2}\alpha^2\right) & \text{if } \frac{x-m}{\sigma} < -\alpha, \text{ exponential decay} \\ \left(\frac{n}{|\alpha|} - |\alpha| - \frac{x-m}{\sigma}\right)^n & \\ \exp\left(-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2\right) & \text{if } \frac{x-m}{\sigma} \geq -\alpha \text{ Gauss distribution} \end{cases}$$

Background (Granet Parametrisation:)

$$f(x) = p_0 \cdot (x - m_{\text{Cutoff}})^{p_1} \cdot e^{-p_2 \cdot x} (-p_3 \cdot x^2)$$

- Signal function: Gauss with exp. tail
- α determines where they are fit together in units of σ
- Un-binned likelihood fit of signal & background function
- Describes MC and data well





D selection: visible range*

DIS analysis:

$$Q^2 : 5 - 100 \text{ GeV}^2$$

$$y : 0.02 - 0.70$$

$$p_T(D^*) : > 1.5 \text{ GeV}$$

$$|\eta(D^*)| : < 1.5$$

D* cuts:

$$p_T(K) > 0.3 \text{ GeV}$$

$$p_T(\pi) > 0.3 \text{ GeV}$$

$$p_T(\pi_{\text{slow}}) > 0.12 \text{ GeV}$$

$$p_T(K) + p_T(\pi) > 2 \text{ GeV}$$

$$|M(D^0)| < 0.080 \text{ GeV}$$

Photoproduction analysis:

$$Q^2 : < 2 \text{ GeV}^2$$

$$y : 0.10 - 0.80 \quad (100 < W_{\gamma p} < 250)$$

$$p_T(D^*) : > 1.8 \text{ GeV}$$

$$|\eta(D^*)| : < 1.5$$

D* cuts:

$$p_T(K) > 0.5 \text{ GeV}$$

$$p_T(\pi) > 0.3 \text{ GeV}$$

$$p_T(\pi_{\text{slow}}) > 0.12 \text{ GeV}$$

$$p_T(K) + p_T(\pi) > 2.2 \text{ GeV}$$

$$|M(D^0)| < 0.080 \text{ GeV}$$

$$\sigma_{\text{tot}}^{\text{vis}} = \frac{N_{D^*} \cdot (1 - r)}{\mathcal{L} \cdot \mathcal{B}(D^* \rightarrow K\pi\pi_{\text{slow}}) \cdot \epsilon \cdot (1 - \delta_{\text{rad}})}$$

Correction due to reflections -
applied for both analysis (4%)

Correction due to radiative effects -
applied for DIS analysis (~2%)

Contribution due to b-quarks is not subtracted !





Cross sections: kin. variables

DIS:

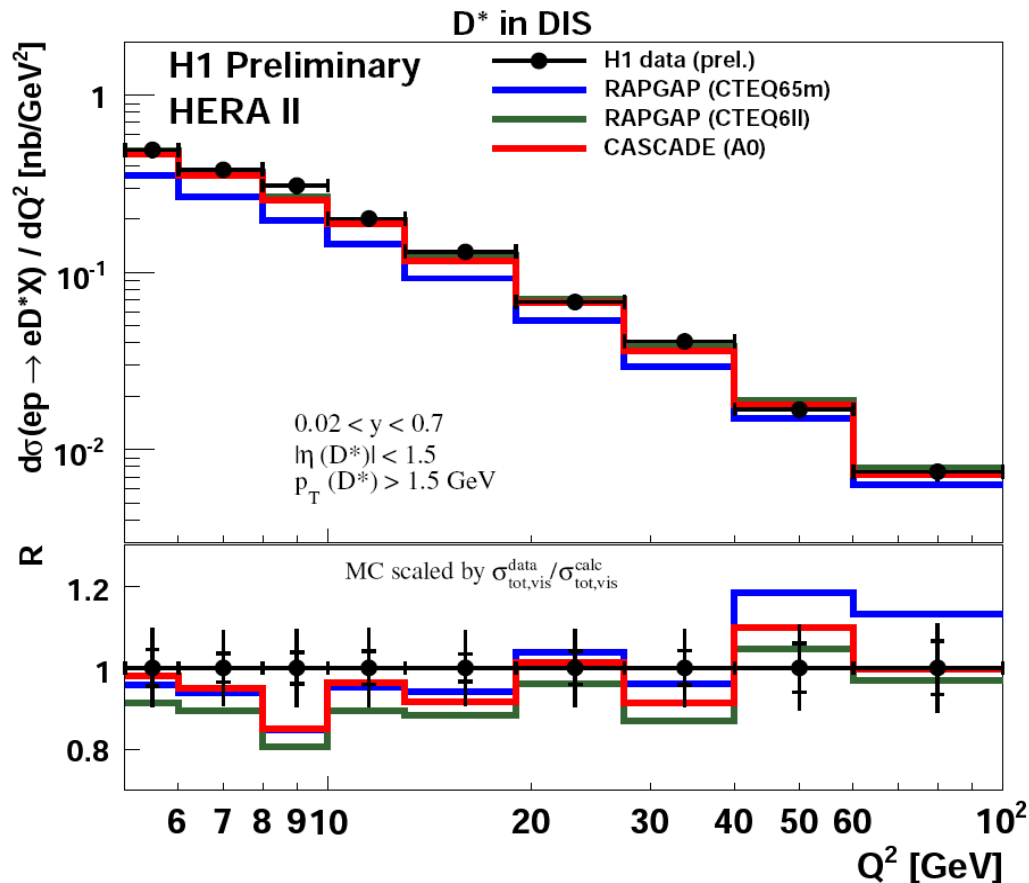
- Q^2
- $y - Q^2$

Photoproduction:

- $W_{\gamma P}$



Cross sections: kin. variables



--> reasonable description for all MC
--> normalization for RAPGAP
(CTEQ65m) is off (not expected to fit)

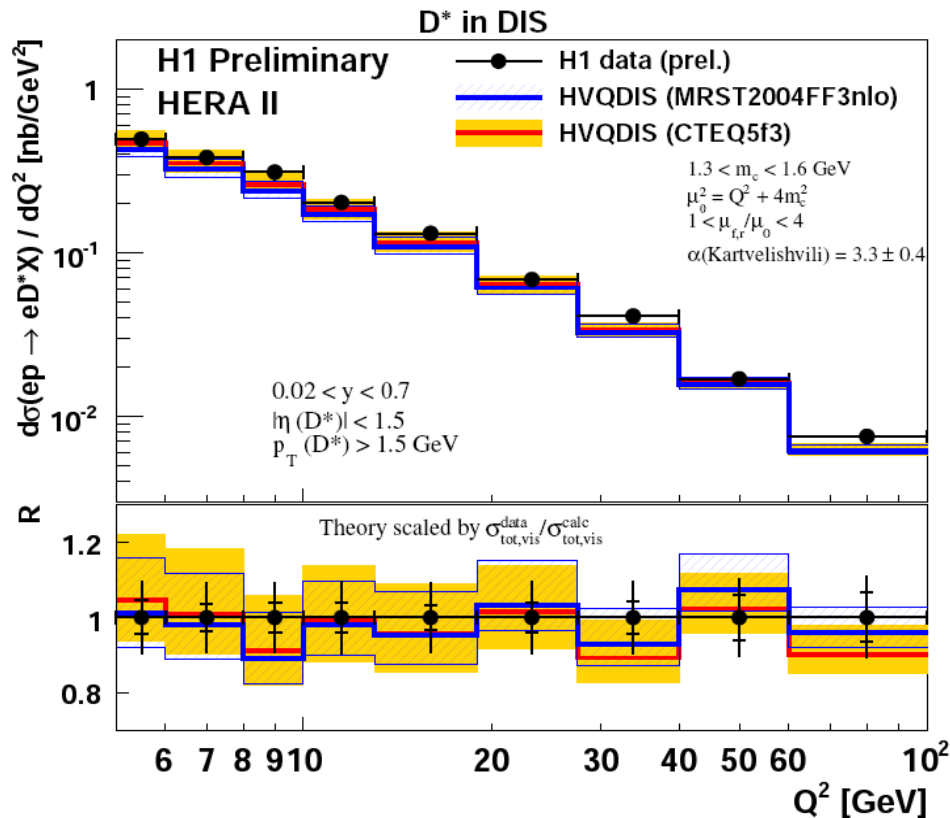
For shape comparison the ratio:

$$R = \frac{1/\sigma_{tot,vis}^{calc} \cdot \frac{d\sigma^{calc}}{dY}}{1/\sigma_{tot,vis}^{data} \cdot \frac{d\sigma^{data}}{dY}}$$

is used.

--> shape of Q^2 reasonably well described
by RAPGAP and CASCADE
--> CASCADE slightly better in shape

Cross sections: kin. variables



Error estimation of the NLO-calculation with parameter variation:

charm mass: $1.3 < m_c < 1.6 \text{ GeV}$

renormalization & factorization scale:

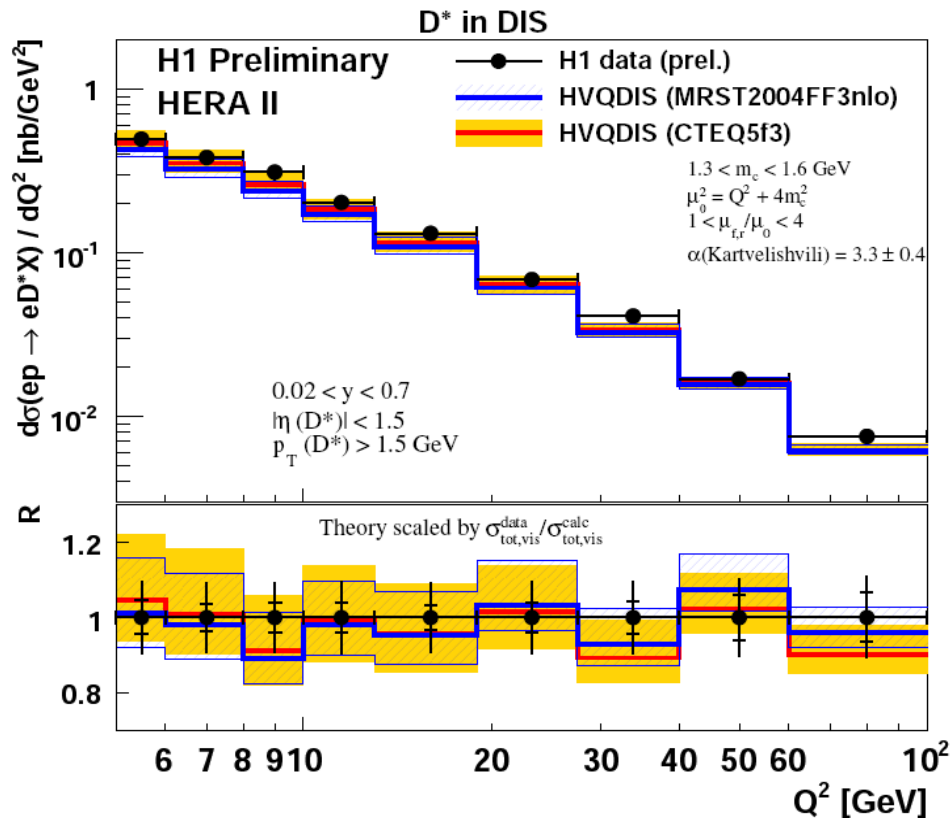
$$1 < \mu_{f,r} / \mu_0 < 4,$$

$$\text{with } \mu_0^2 = Q^2 + 4m_c^2$$

fragmentation: $\alpha(\text{Kartvelishvili}) = 3.3 \pm 0.4$

--> HVQDIS: both PDF give good description, MRST slightly lower in normalization

Cross sections: kin. variables



Error estimation of the NLO-calculation with parameter variation:

charm mass: $1.3 < m_c < 1.6 \text{ GeV}$

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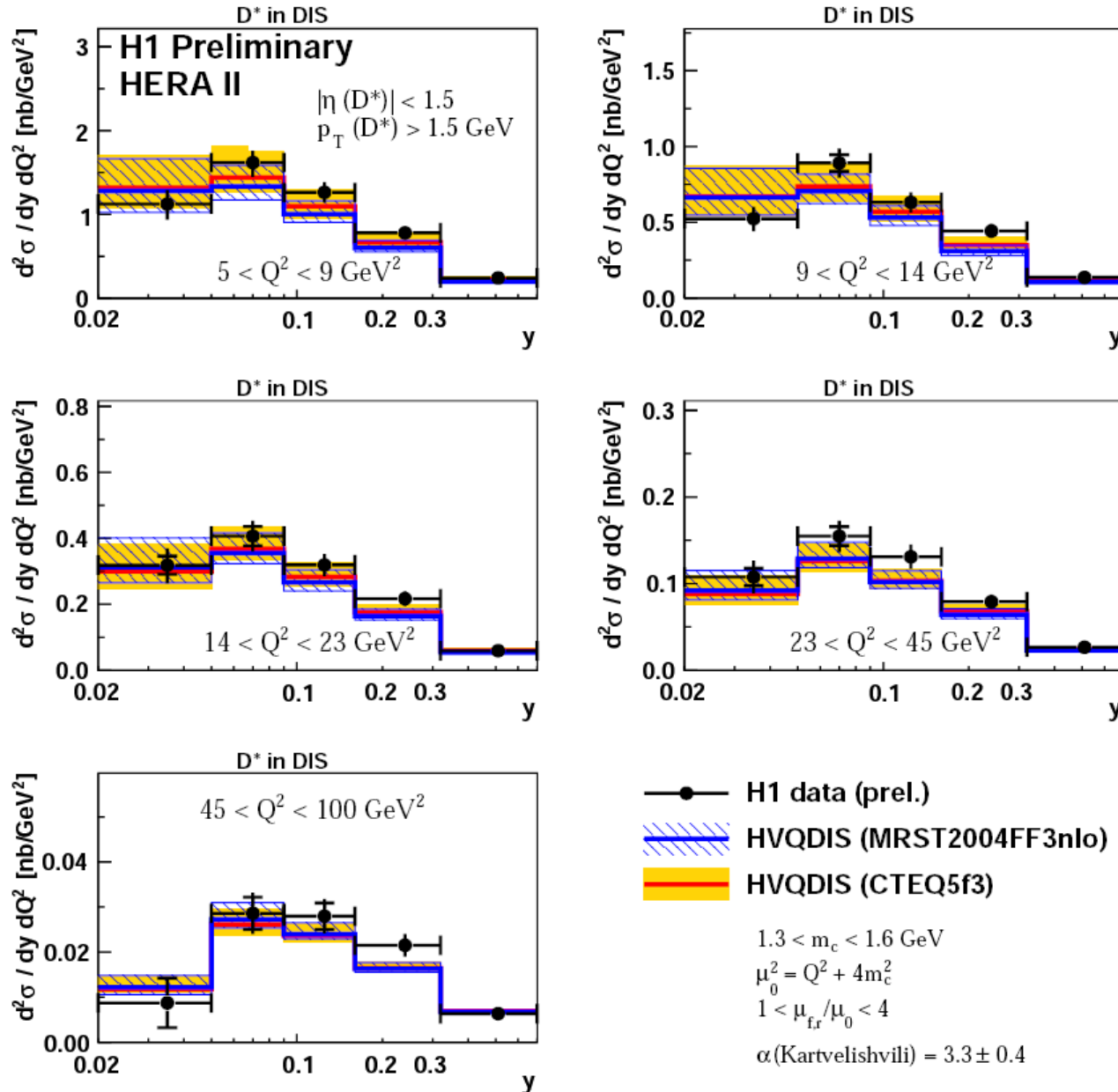
fragmentation: $\alpha(\text{Kartvelishvili}) = 3.3 \pm 0.4$

--> HVQDIS: both PDF give good description, MRST slightly lower in normalization

Total integrated Cross section:

Data: $(4.85 \pm 0.07(\text{stat.}) \pm 0.42(\text{sys.})) \text{ nb}$
 HVQDIS (CTEQ): $(4.43 +0.69 -0.47) \text{ nb}$
 HVQDIS (MRST): $(4.17 +0.59 -0.37) \text{ nb}$

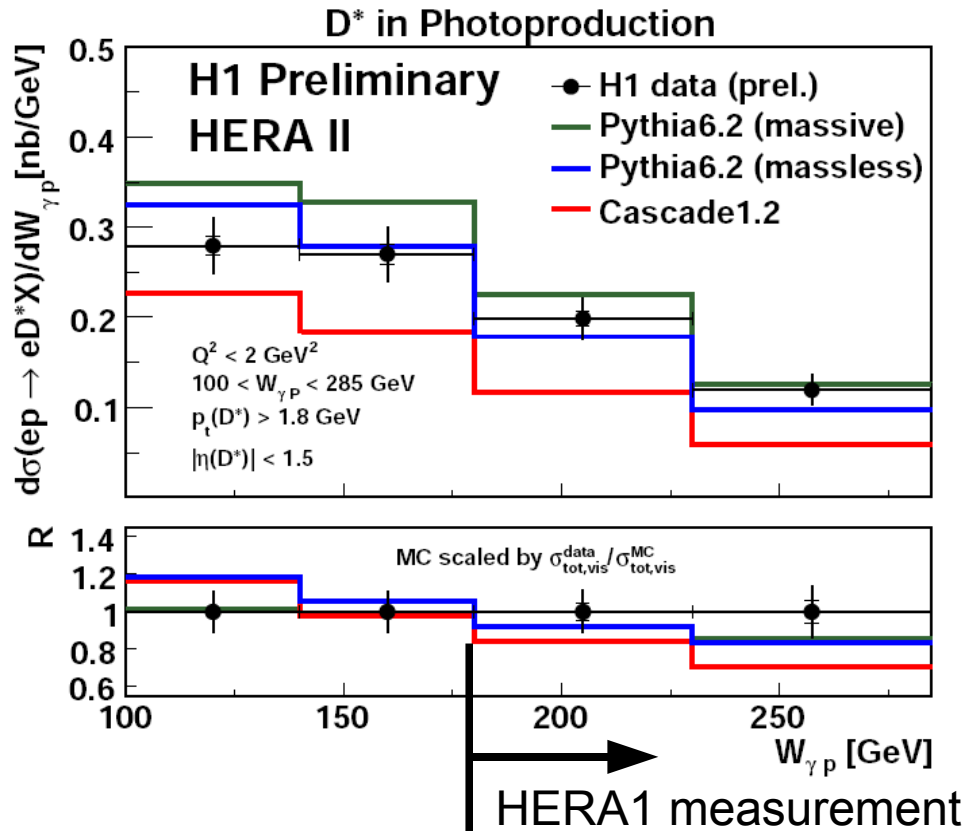
Cross sections: kin. variables



--> HVQDIS: both proton PDF give a good description of the y - Q^2 dependence

--> lowest new y -bin also described in HVQDIS

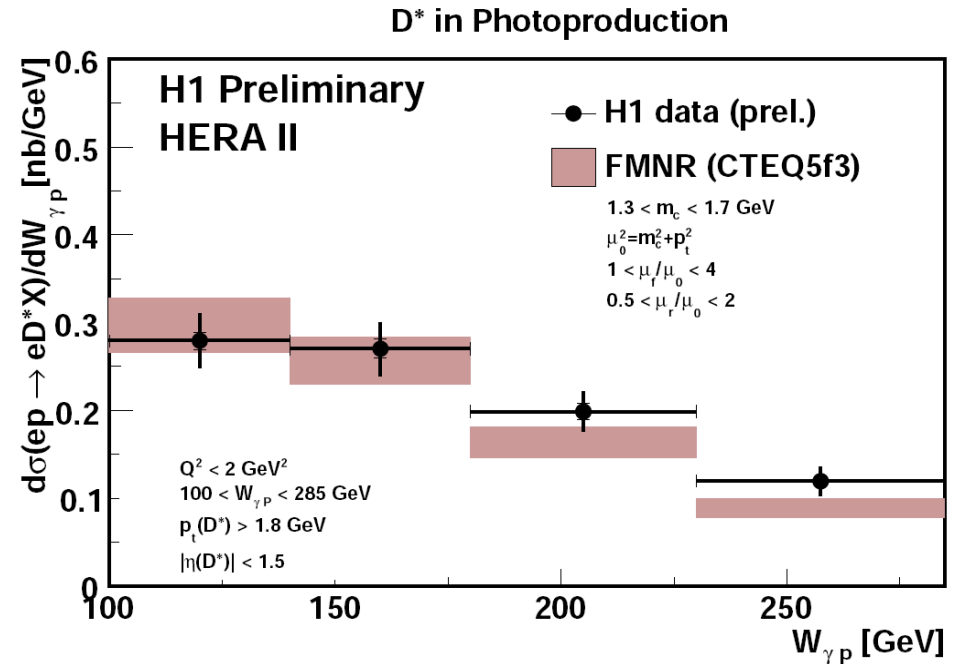
Cross sections: kin. variables



--> increased phase space compared
to HERAI publication !

--> all MC models to steep

--> PYTHIA massless is best ...



Parameter variation:

charm mass: $1.3 < m_c < 1.7 \text{ GeV}$

renormalization & factorization scale:

$$1 < \mu_{f,r} / \mu_0 < 4,$$

$$\text{with } \mu_0^2 = m_c^2 + p_T^2$$

fragmentation: $\epsilon(\text{Peterson}) = 0.035$, no variation

--> FMNR is somewhat better



Cross sections: D^ variables*

DIS:

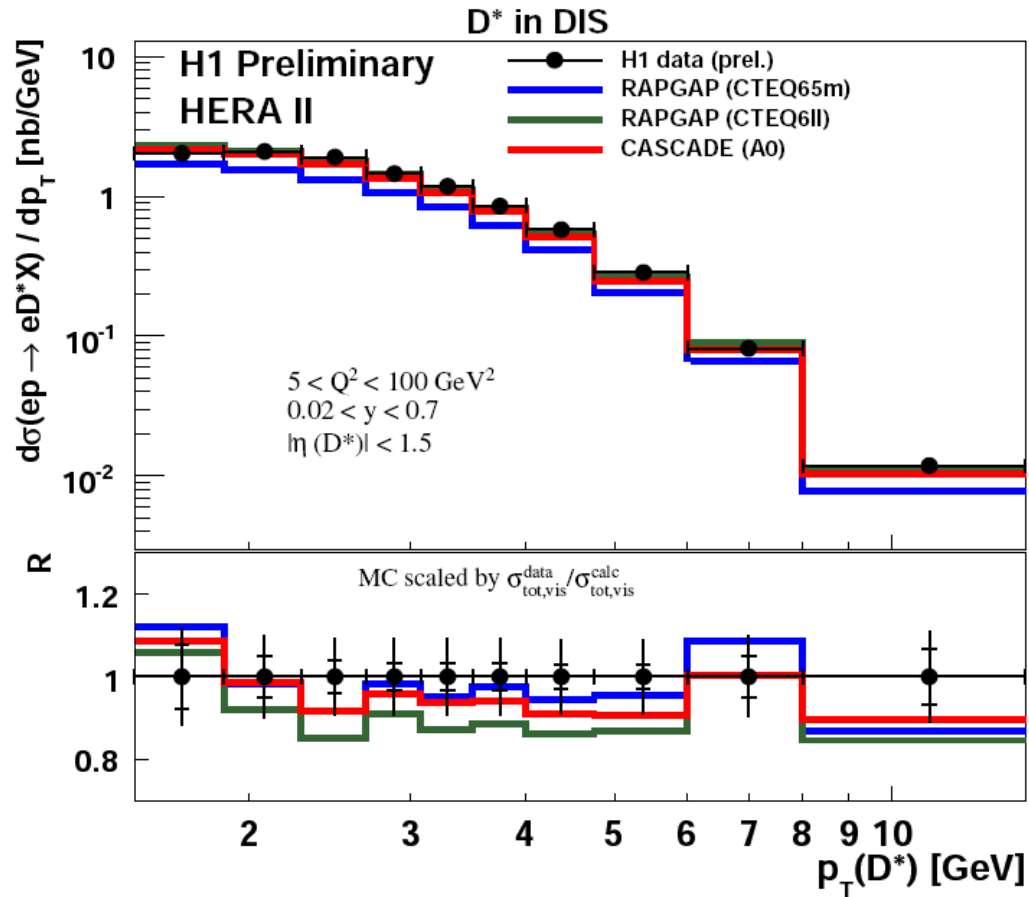
- p_T, η
- $\eta - p_T$

Photoproduction:

- p_T, η
- $\eta - p_T$

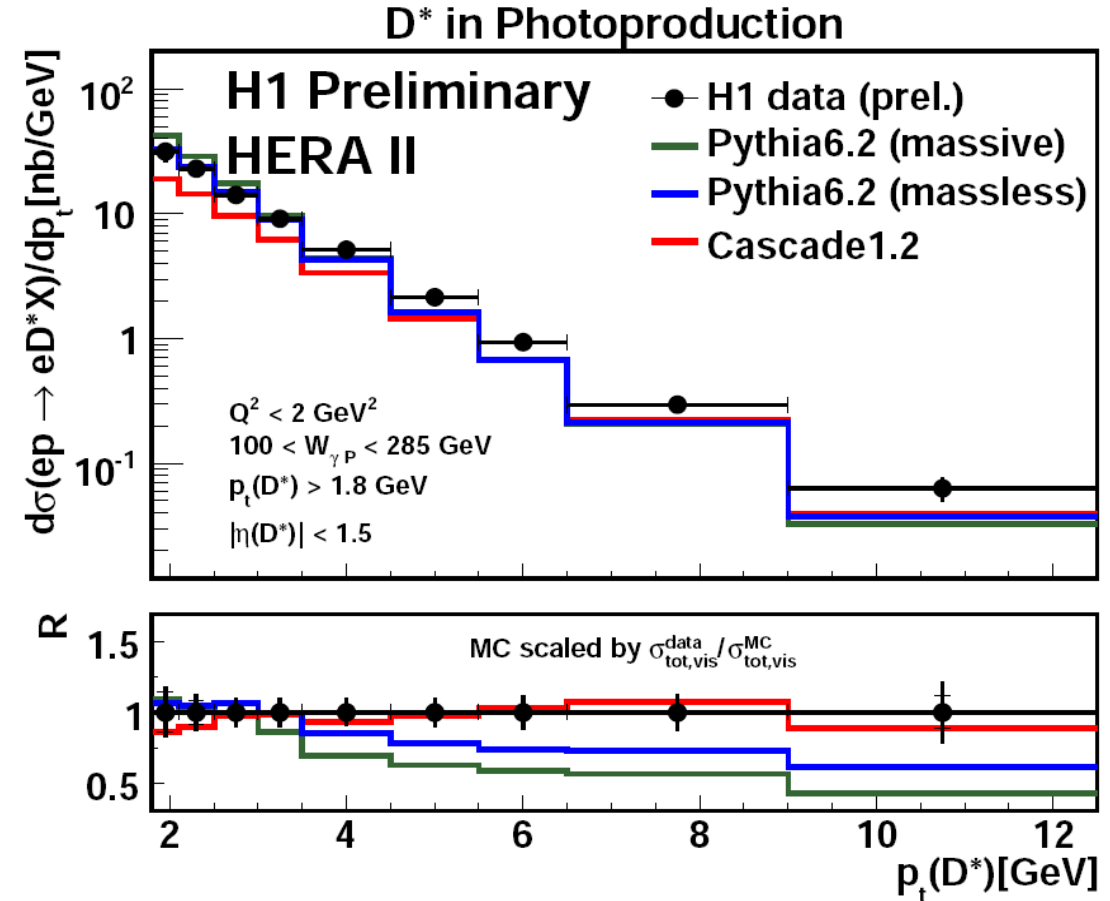
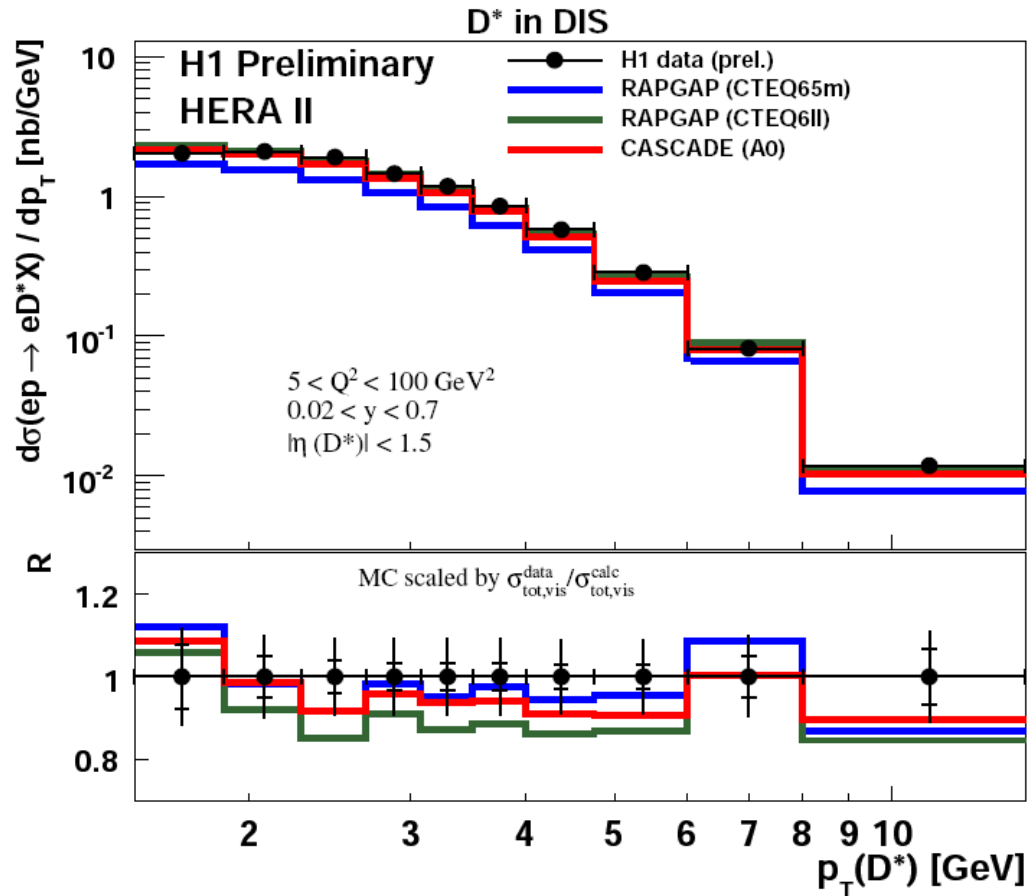


Cross sections: D^* variables



--> DIS: - $p_T(D^*)$ shape reasonably well described by all MC models

Cross sections: D^* variables



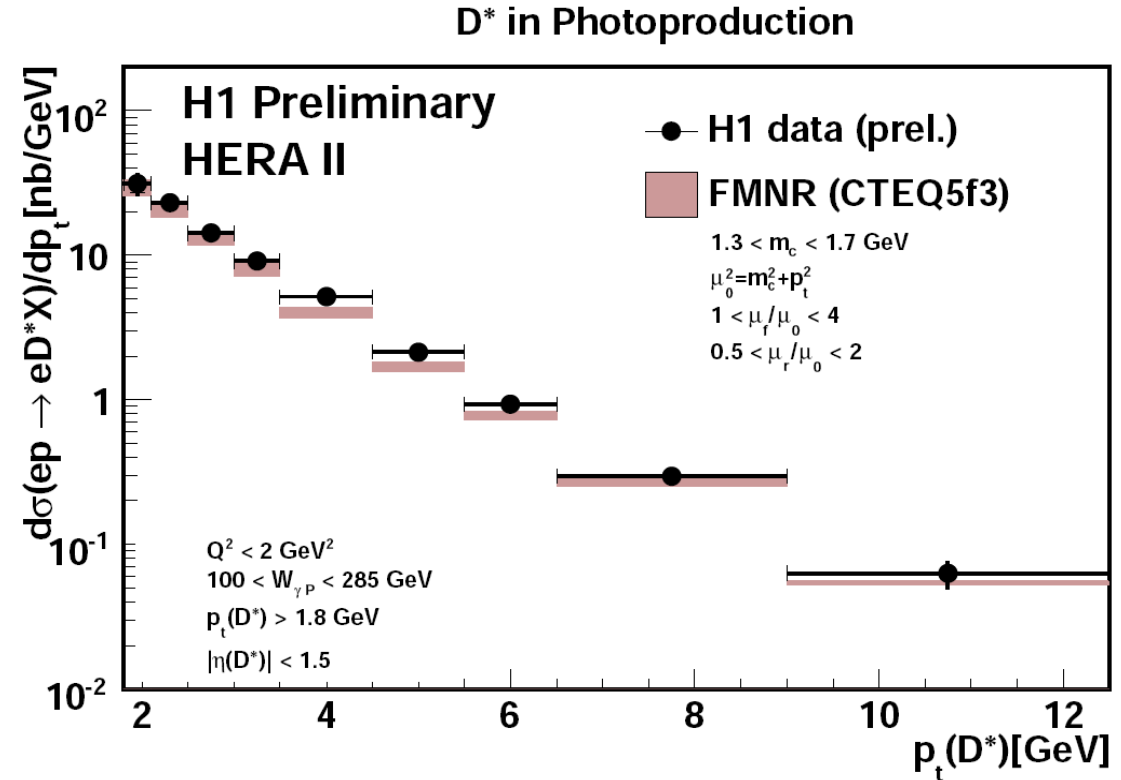
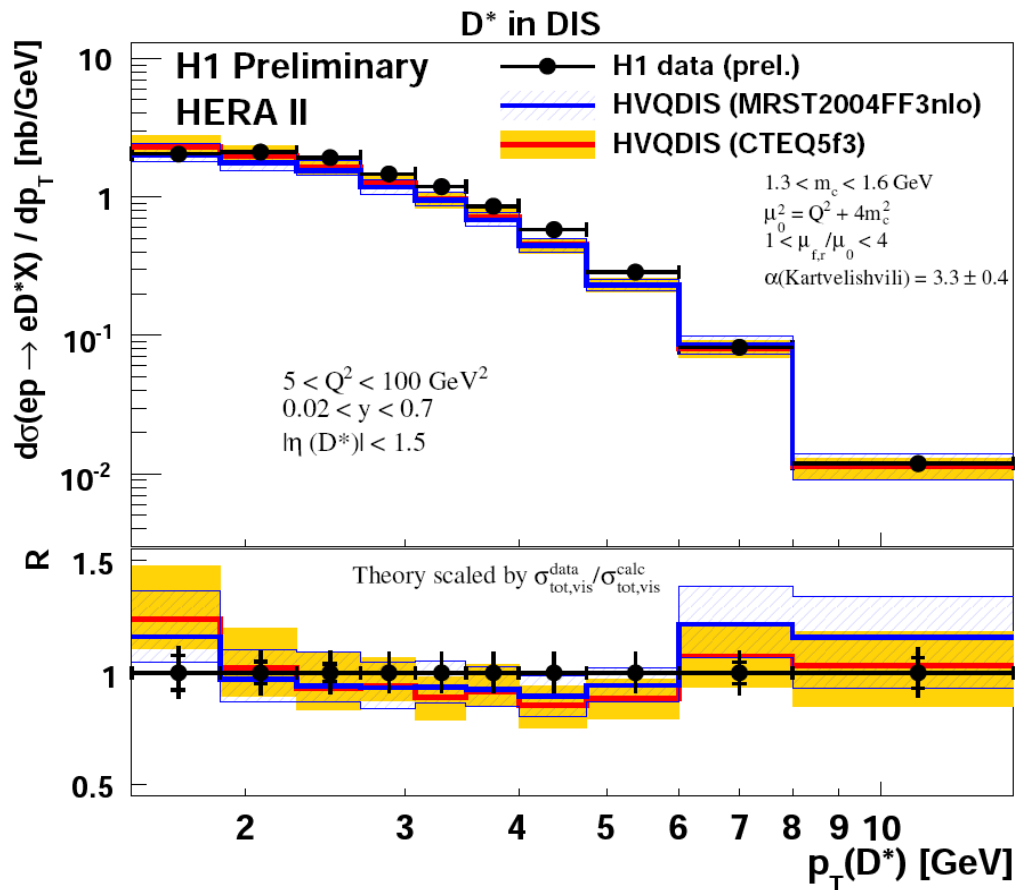
--> DIS:

- $p_T(D^*)$ shape reasonably well described by all MC models

--> Photoproduction:

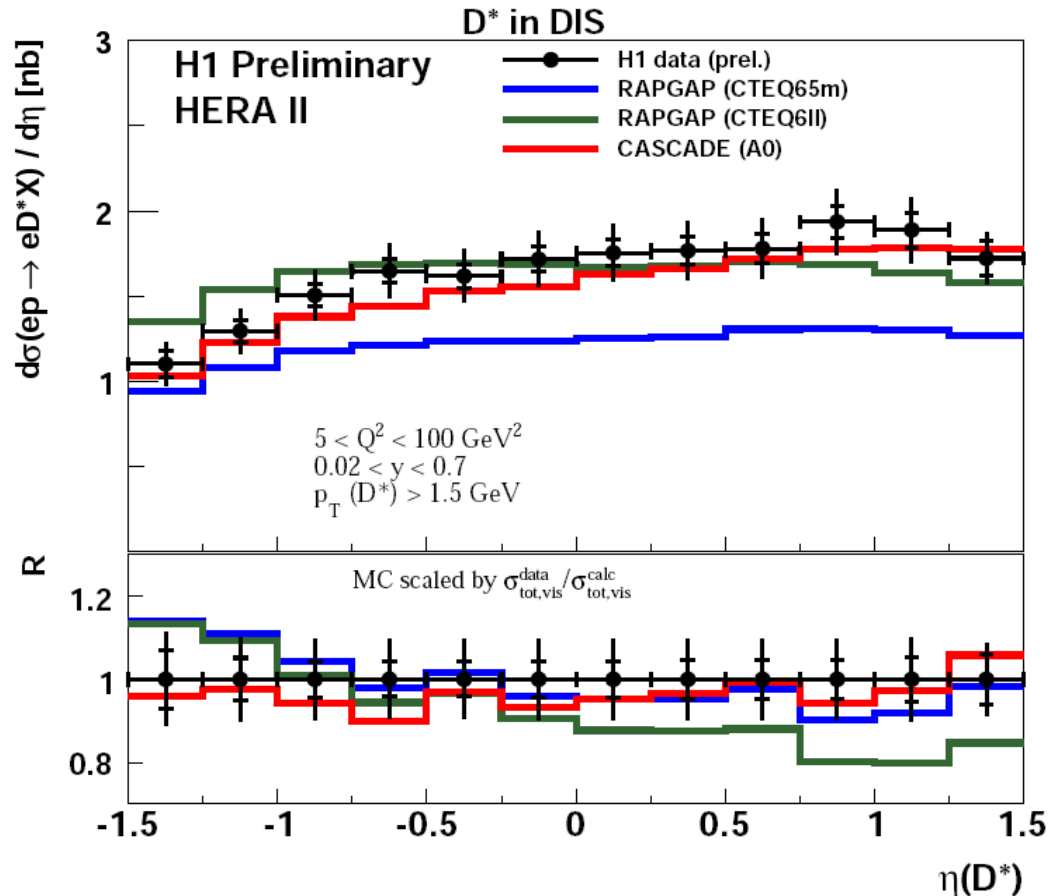
- $p_T(D^*)$ shape described by CASCADE but steeper slope for both PYTHIA models

Cross sections: D^* variables



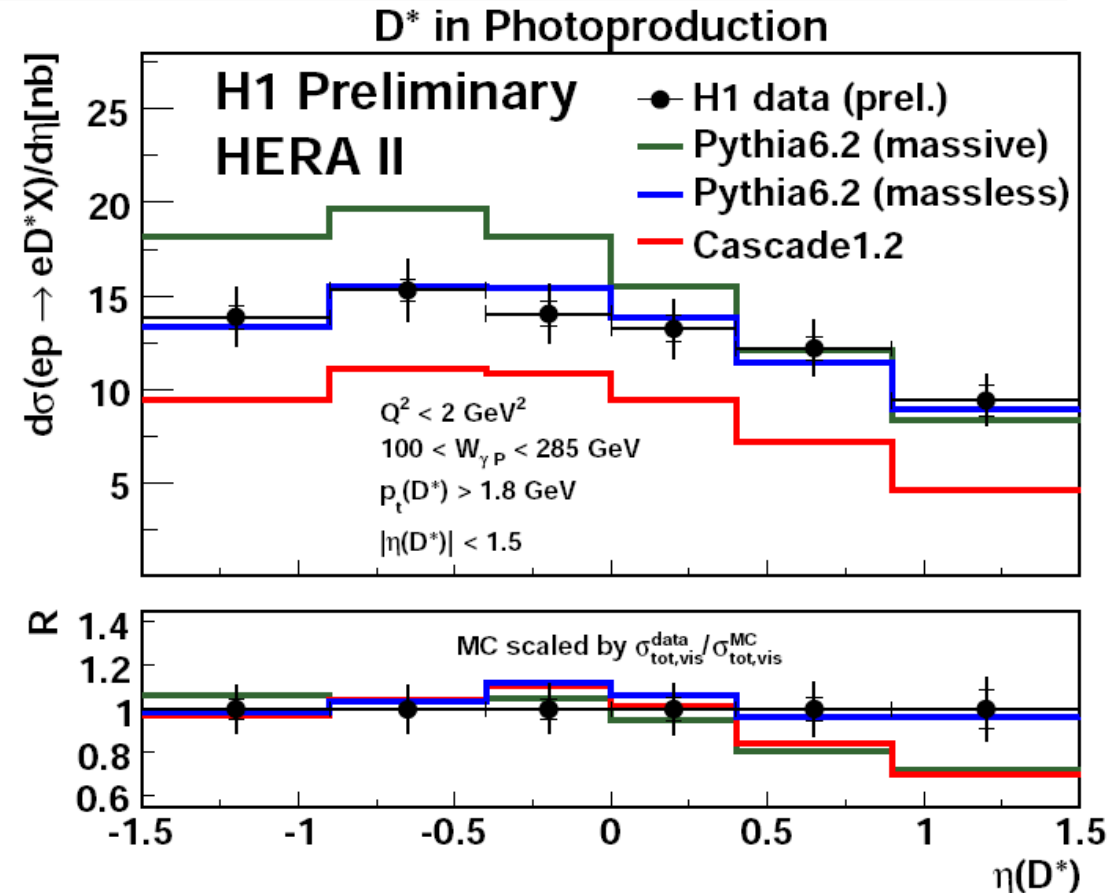
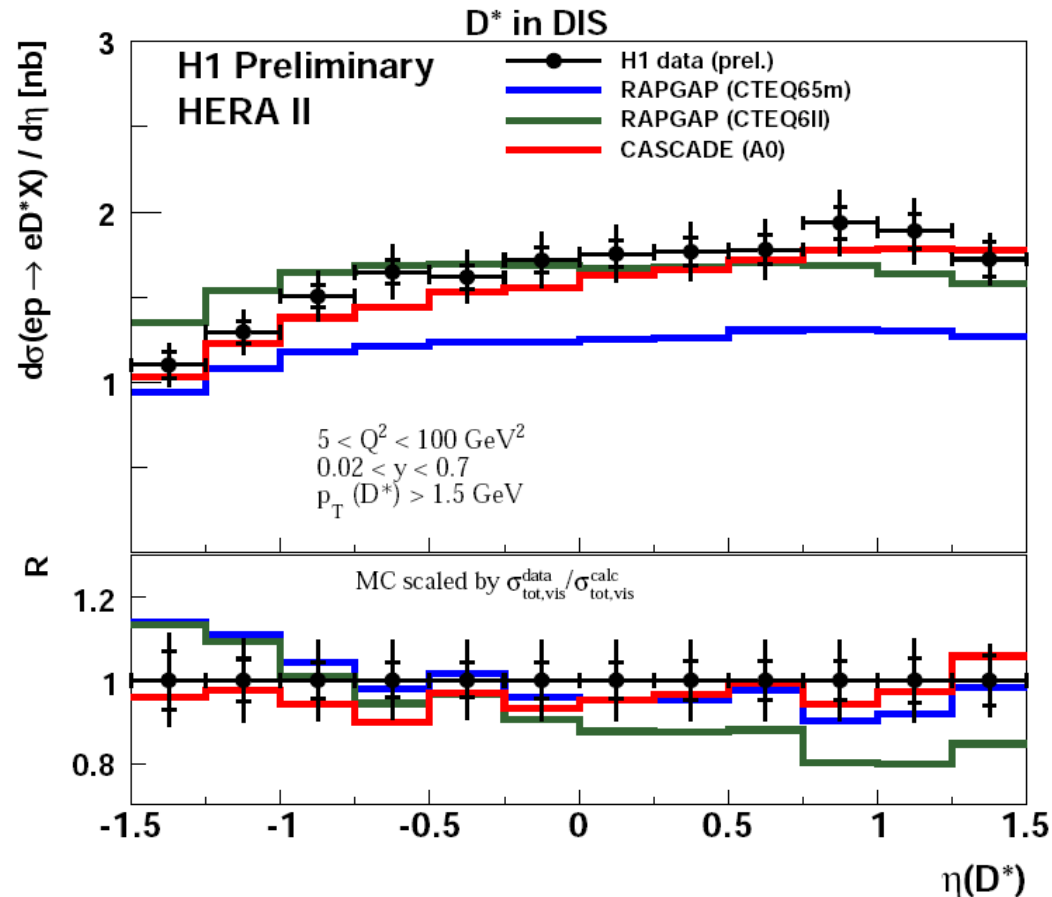
- > DIS & Photoproduction:
- $p_T(D^*)$ shape reasonably well described by NLO
 - but normalization should be correct

Cross sections: D^* variables



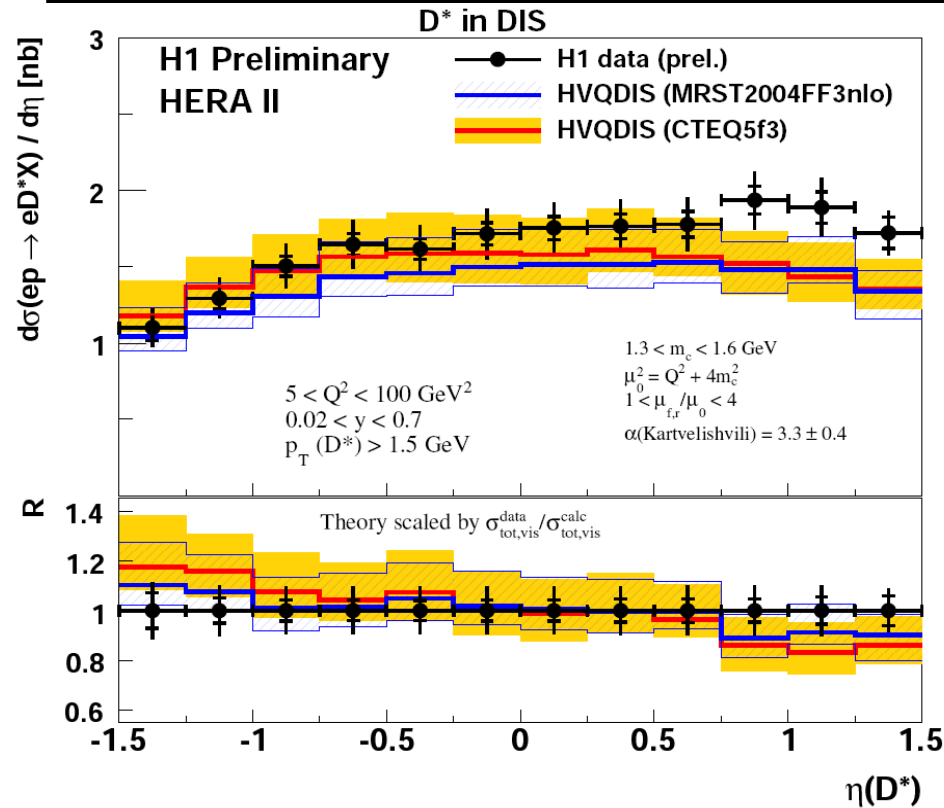
- > DIS:
- CASCADE describes the distribution in shape and normalization
 - RAPGAP: data sensitive to the Proton PDF (CTEQ65m is better in shape)

Cross sections: D^* variables



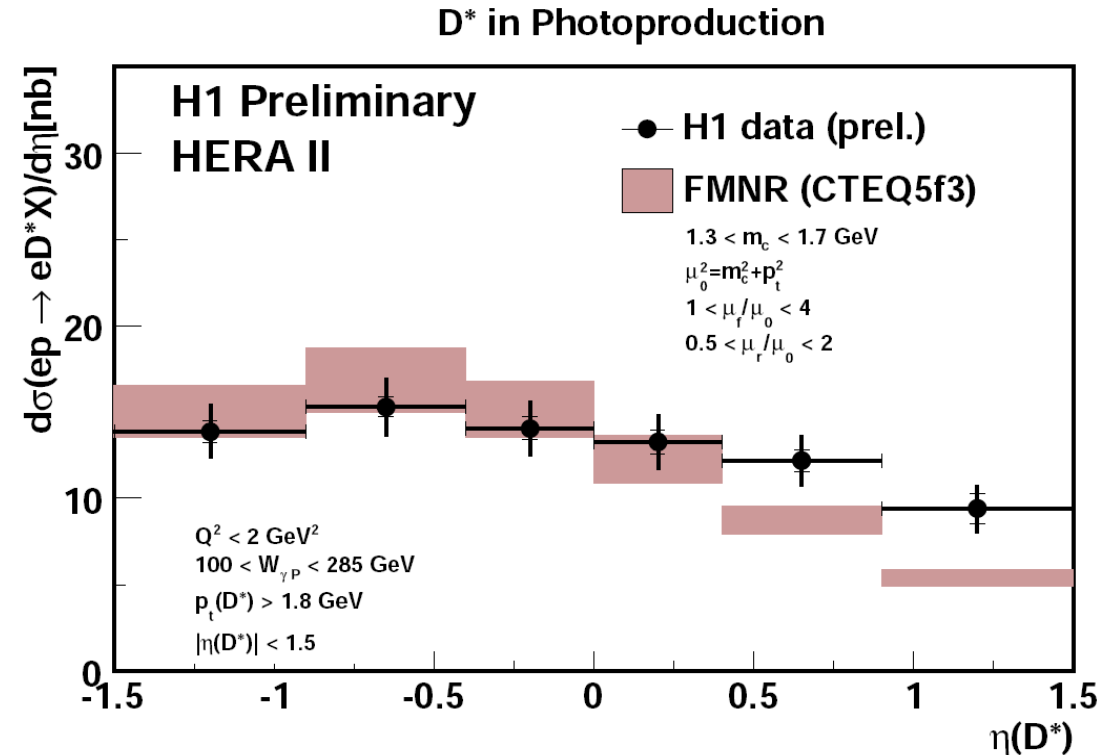
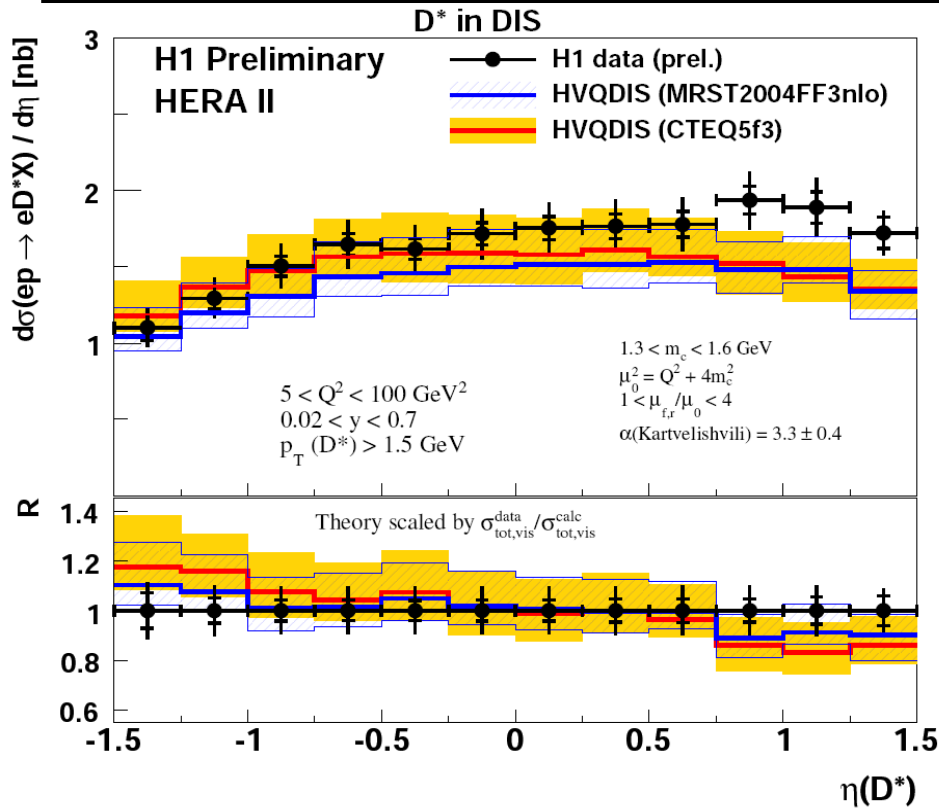
- > DIS:
 - CASCADE describes the distribution in shape and normalization
 - RAPGAP: data sensitive to the Proton PDF (CTEQ65m is better in shape)
- > Photop.:
 - PYTHIA (massless) describes the data in shape & normalization
 - CASCADE fails in shape (differences for $\eta(D^*) > 0$) & normalization

Cross sections: D^* variables



- > DIS:
- difference at forward $\eta(D^*)$ between data & NLO confirmed with full HERA2 statistics
 - MRST (other gluon density) gives a better description, low in normalization

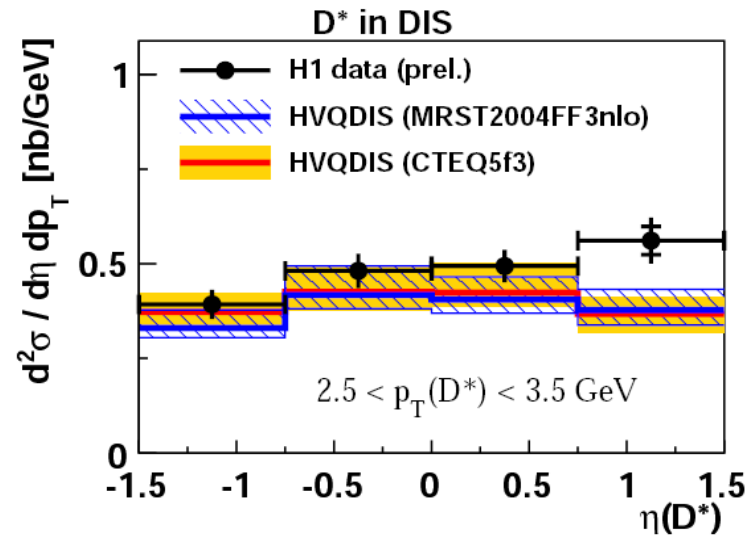
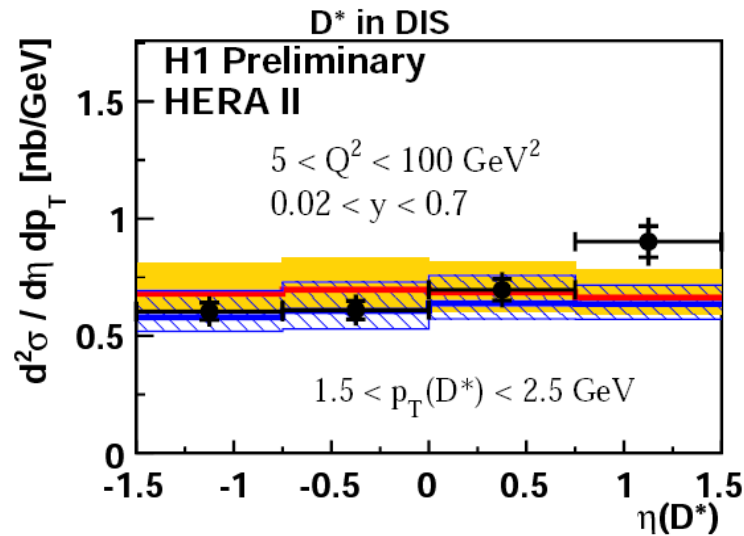
Cross sections: D^* variables



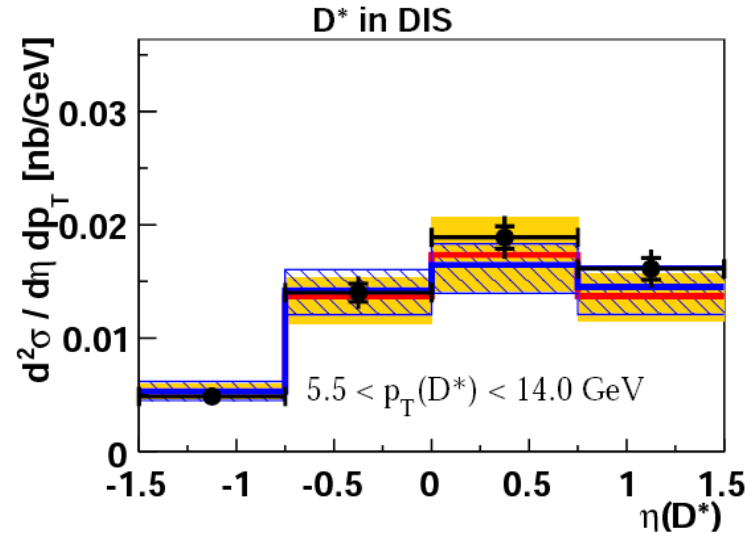
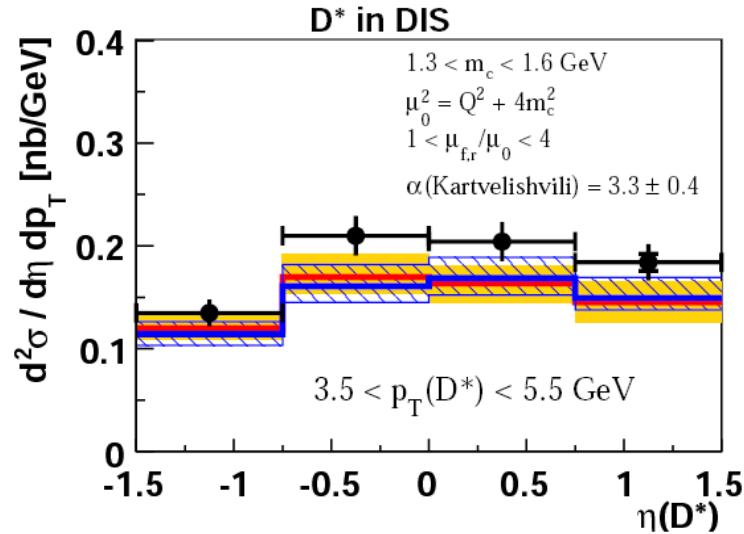
- > DIS:
- difference at forward $\eta(D^*)$ between data & NLO confirmed with full HERA2 statistics
 - MRST (other gluon density) gives a better description, low in normalization
- > Photoproduction: NLO fails at forward $\eta(D^*)$

Are the differences located in $p_T(D^*)$?

Cross sections: D^* variables



--> In general NLO gives a good description of the data

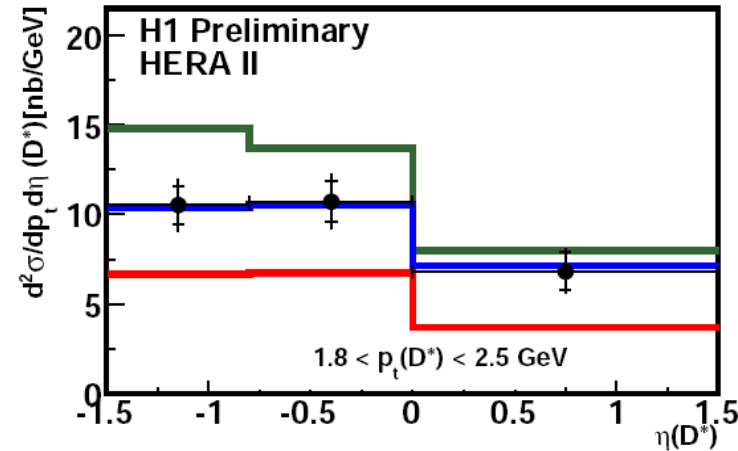


--> forward $\eta(D^*)$ and low $p_T(D^*)$ data is above the NLO-calculations

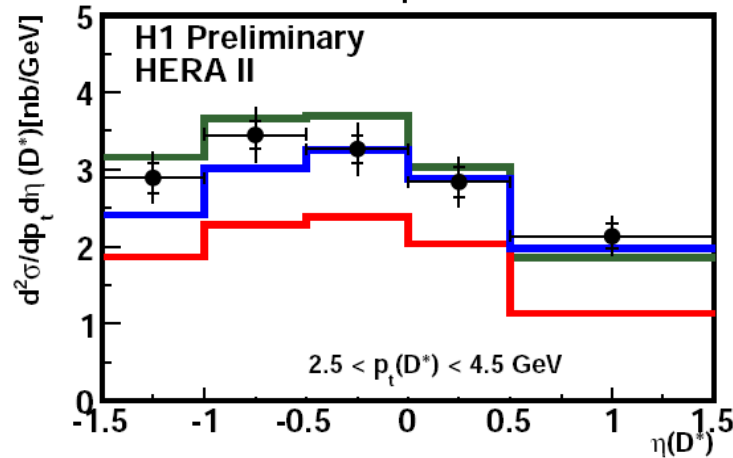
--> better precision of the data is needed.

Cross sections: D^* variables

D^* in Photoproduction



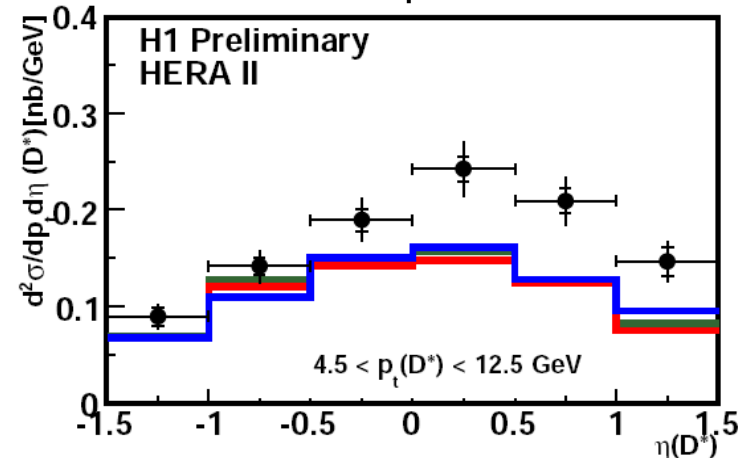
D^* in Photoproduction



--> low $p_t(D^*)$:

- models differ !
- PYTHIA (massless) describes the shape
- CASCADE is good in shape

D^* in Photoproduction



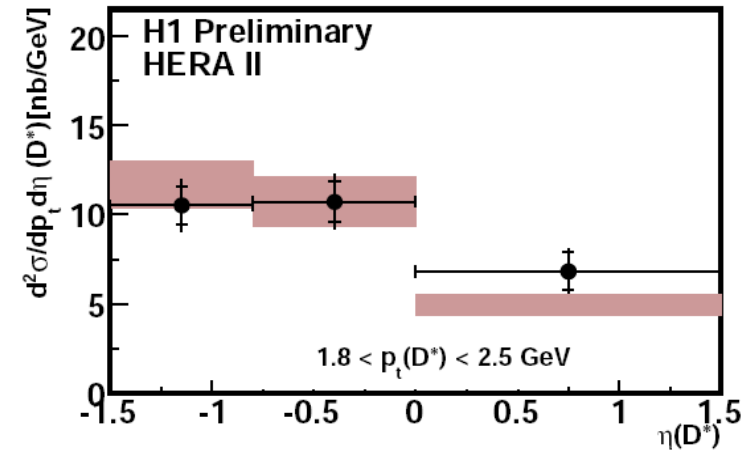
- ◆ H1 data (prel.)
- Pythia6.2(massiv)
- Pythia6.2(massless)
- Cascade1.2

--> high $p_t(D^*)$:

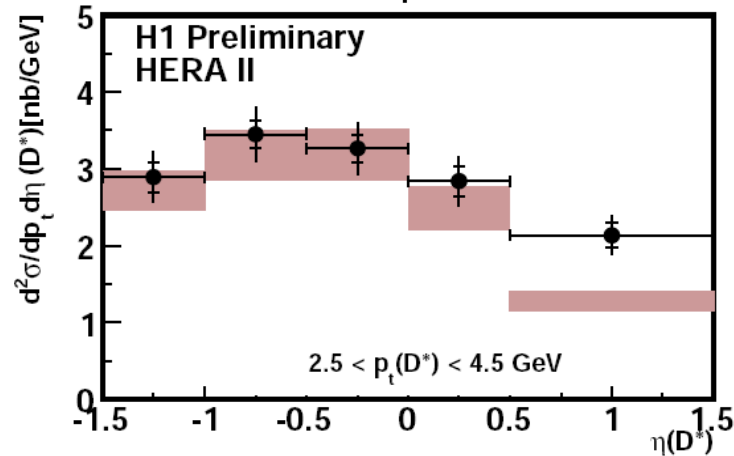
- models are the same !
- PYTHIA fails at forward $\eta(D^*)$
- CASCADE is also low at forward $\eta(D^*)$

Cross sections: D^* variables

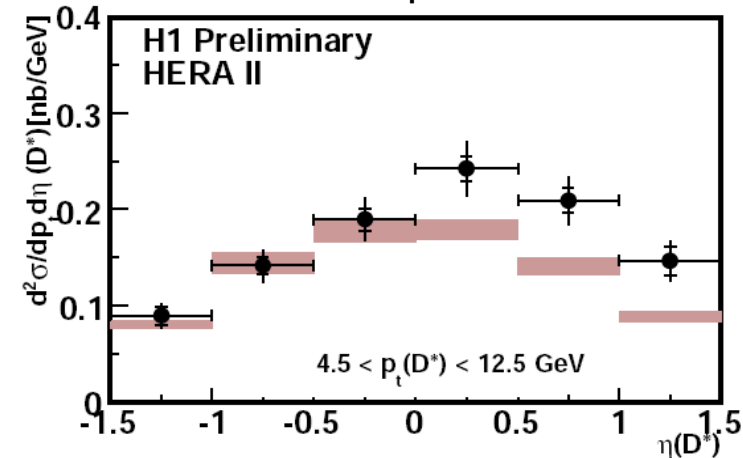
D^* in Photoproduction



D^* in Photoproduction



D^* in Photoproduction



● H1 data (prel.)

■ FMNR (CTEQ5f3)

$1.3 < m_c < 1.7 \text{ GeV}$

$\mu_0^2 = m_c^2 + p_t^2$

$1 < \mu_r / \mu_0 < 4$

$0.5 < \mu_r / \mu_0 < 2$

--> backward $\eta(D^*)$:

- for whole $p_T(D^*)$ range it is described

--> forward $\eta(D^*)$:

- NLO fails over the whole $p_T(D^*)$ spectrum

- most probably not due to resolved processes

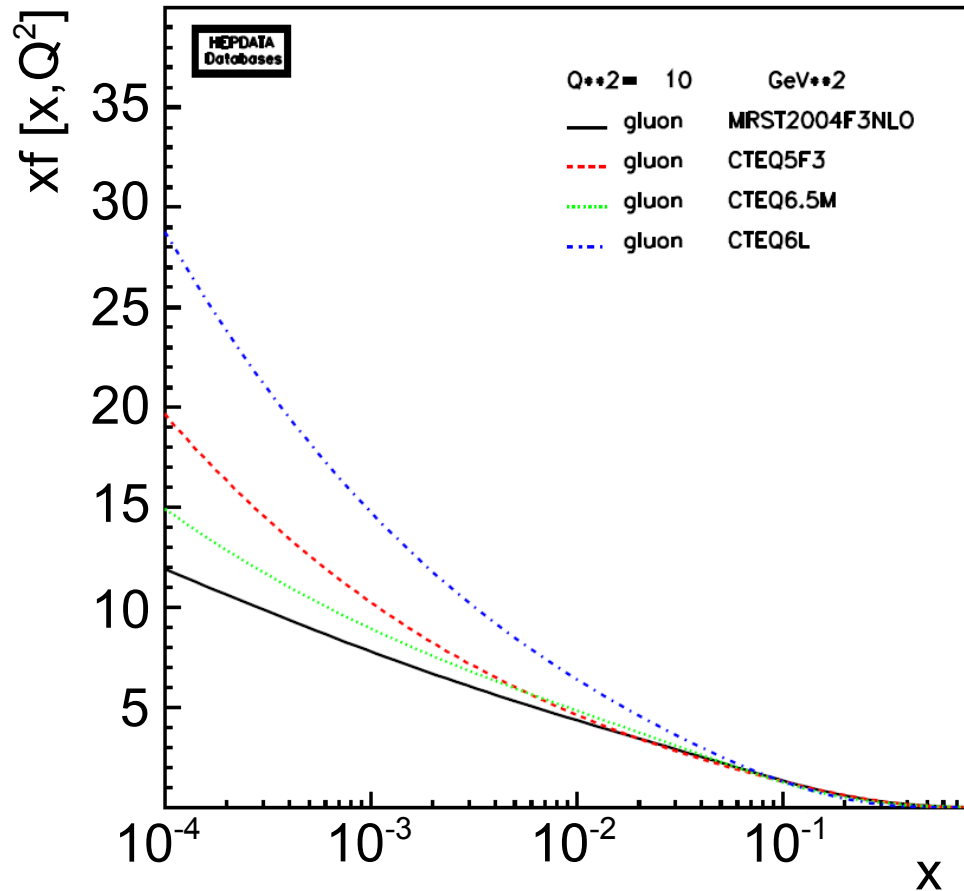
- Full HERA2 data statistic (10x HERA1 statistics) for D^* production in DIS and photoproduction analysed
-
- DIS:
 - NLO calculations describe the data, taking the (large) theory uncertainties into account
 - small differences at forward $\eta(D^*)$ located at small $p_T(D^*)$
 - sensitive to the Proton PDF
 - Photoproduction:
 - $\eta(D^*)$ - $p_T(D^*)$ - correlation (in larger phase space) not understood in any model !
 - Largest differences for the NLO calculation at forward $\eta(D^*)$ and high $p_T(D^*)$



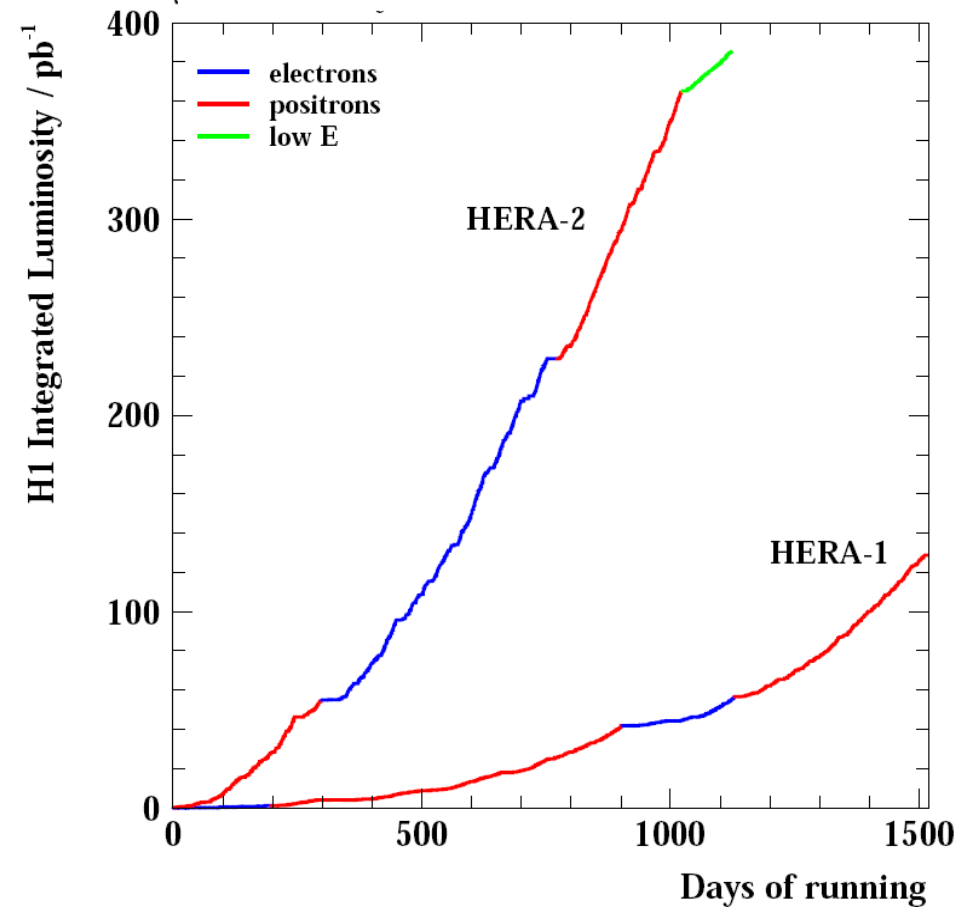
Backup



Different Proton PDFs:

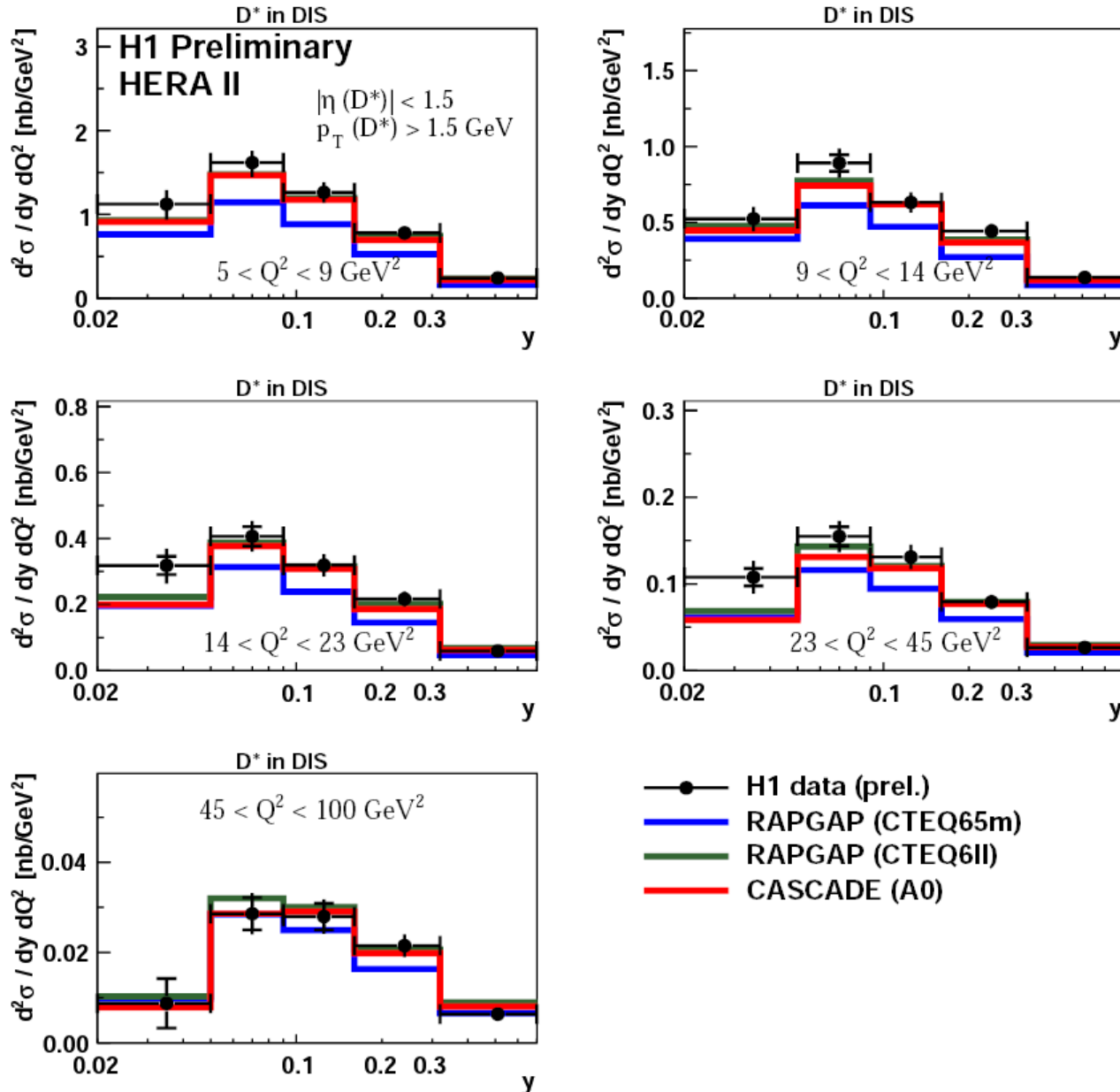


Collected Data samples:





Cross sections: D^* variables

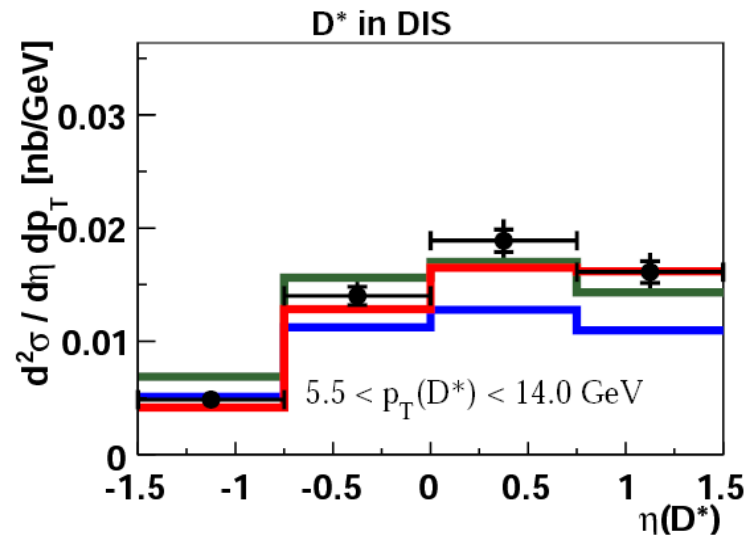
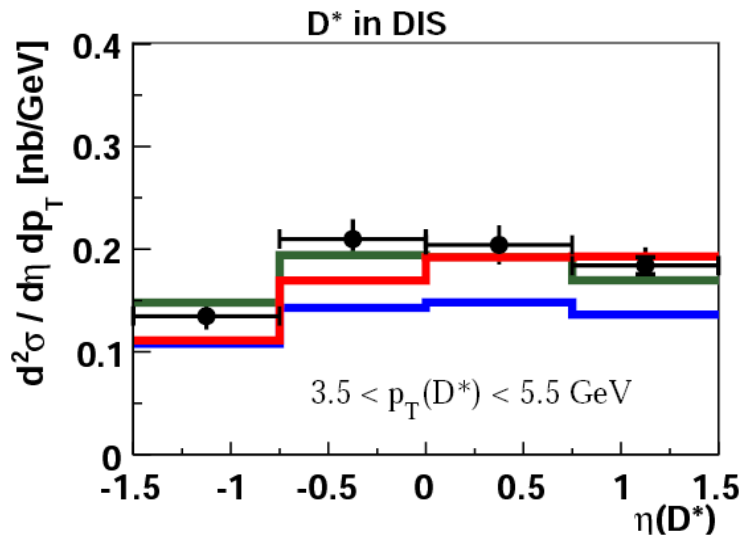
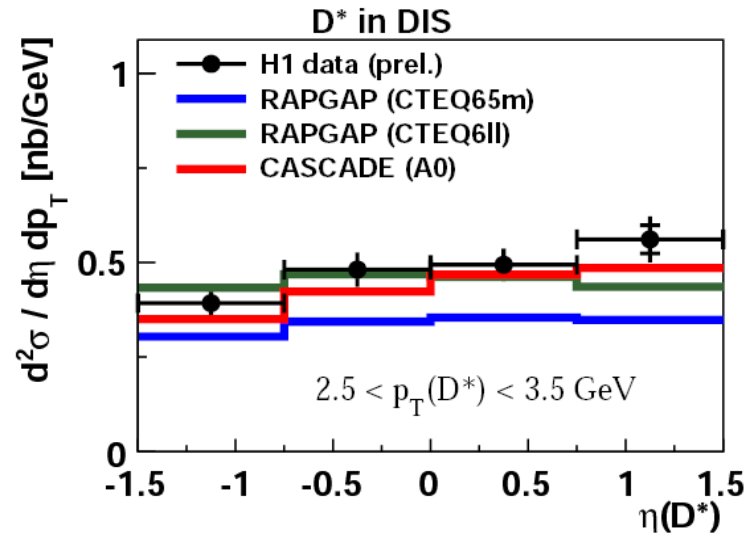
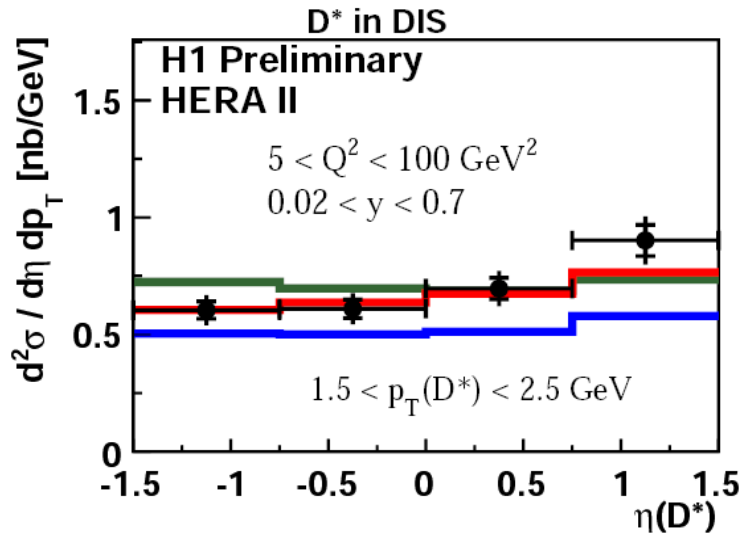


--> CASCADE & RAPGAP give a good description of the y - Q^2 dependence

--> new y -bin tends to be above the MC

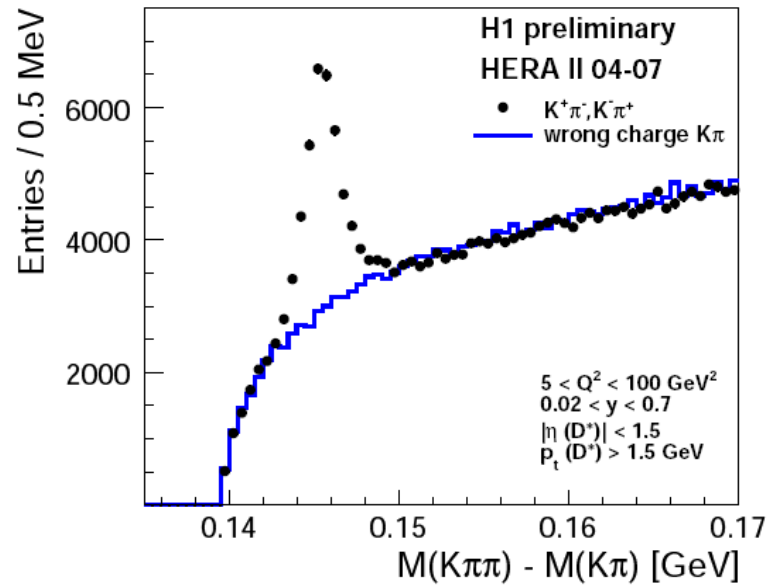


Cross sections: D^* variables



--> CASCADE describes the $\eta(D^*)$ distribution in shape and normalization
--> RAPGAP with CTEQ61l gives also a good description except the forward $\eta(D^*)$ at small $p_T(D^*)$

D* in DIS:



- decay: $D^{*\pm} \rightarrow D^0 \pi_{slow}^{\pm} \rightarrow (K^{\mp} \pi^{\pm}) \pi_{slow}^{\pm}$
- higher resolution in mass difference:
 $dM = M(K\pi\pi) - M(K\pi)$
- select events by mass difference dM

