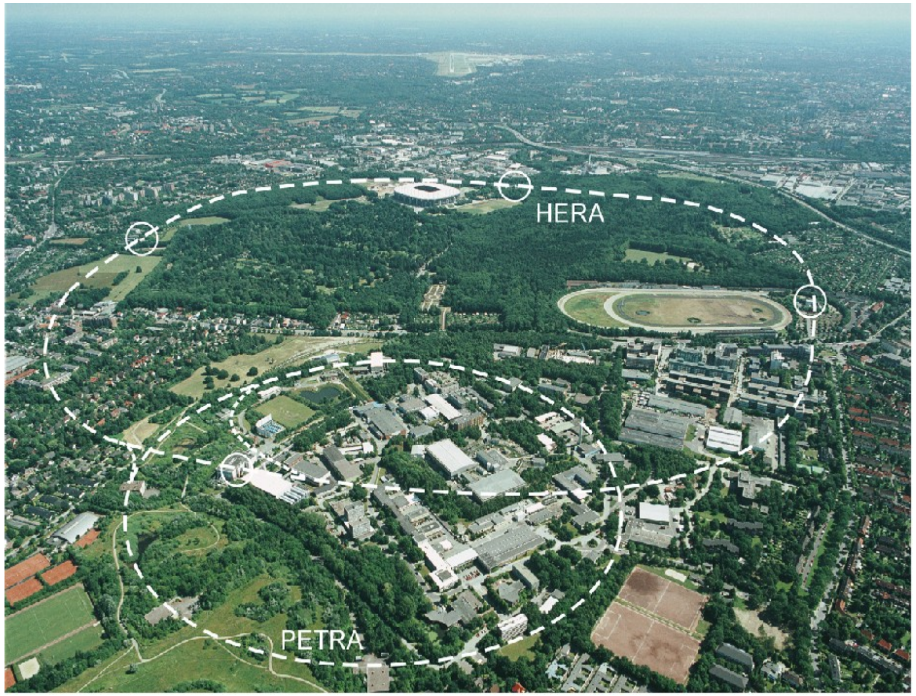
D* production in DIS and Photoproduction at H1



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

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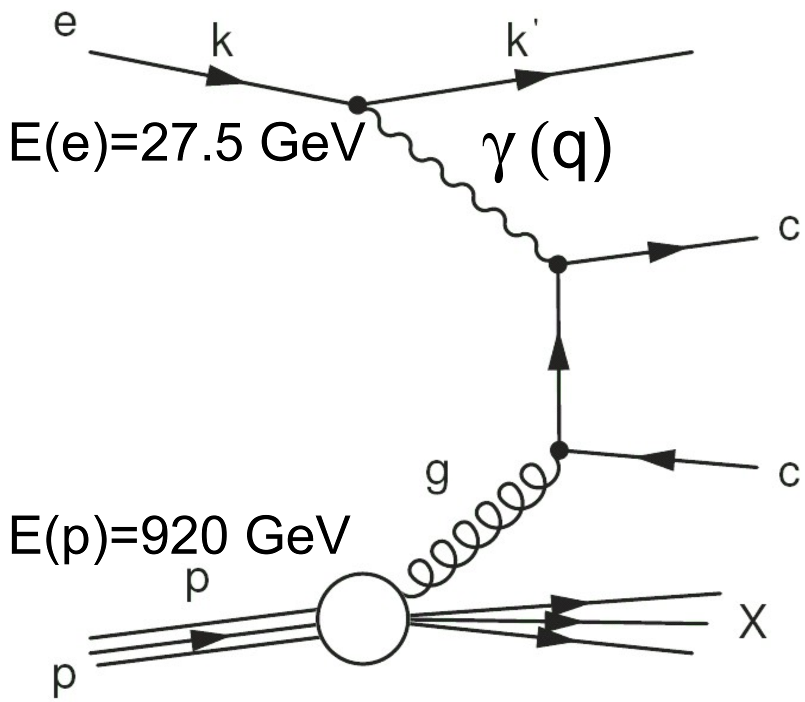
Universität Heidelberg

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:

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

D* via Fragmentation:

- Pseudorapidity: $\eta = \ln \tan\left(\frac{\theta}{2}\right)$
- Transverse momentum: p_t

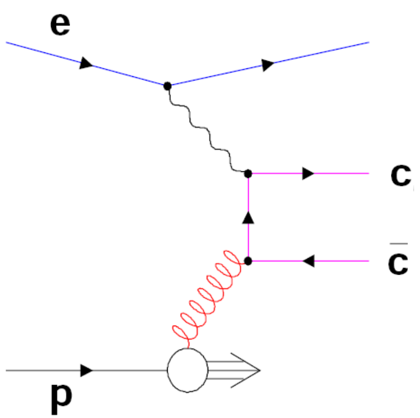
--> hard scale allows pQCD: $m_c \gg \Lambda_{QCD}$

--> sensitive to the gluon density

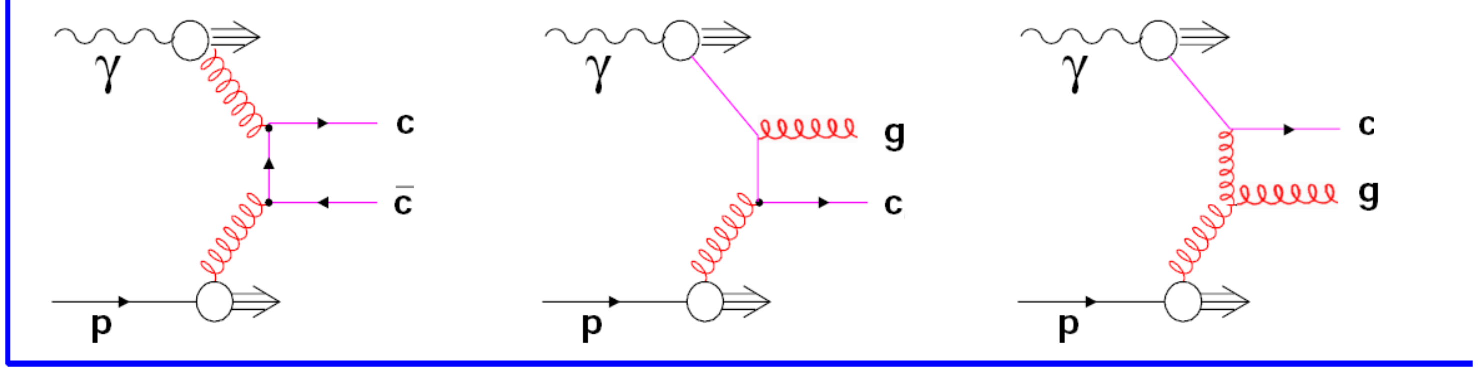
D* Production: theory models

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

direct



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

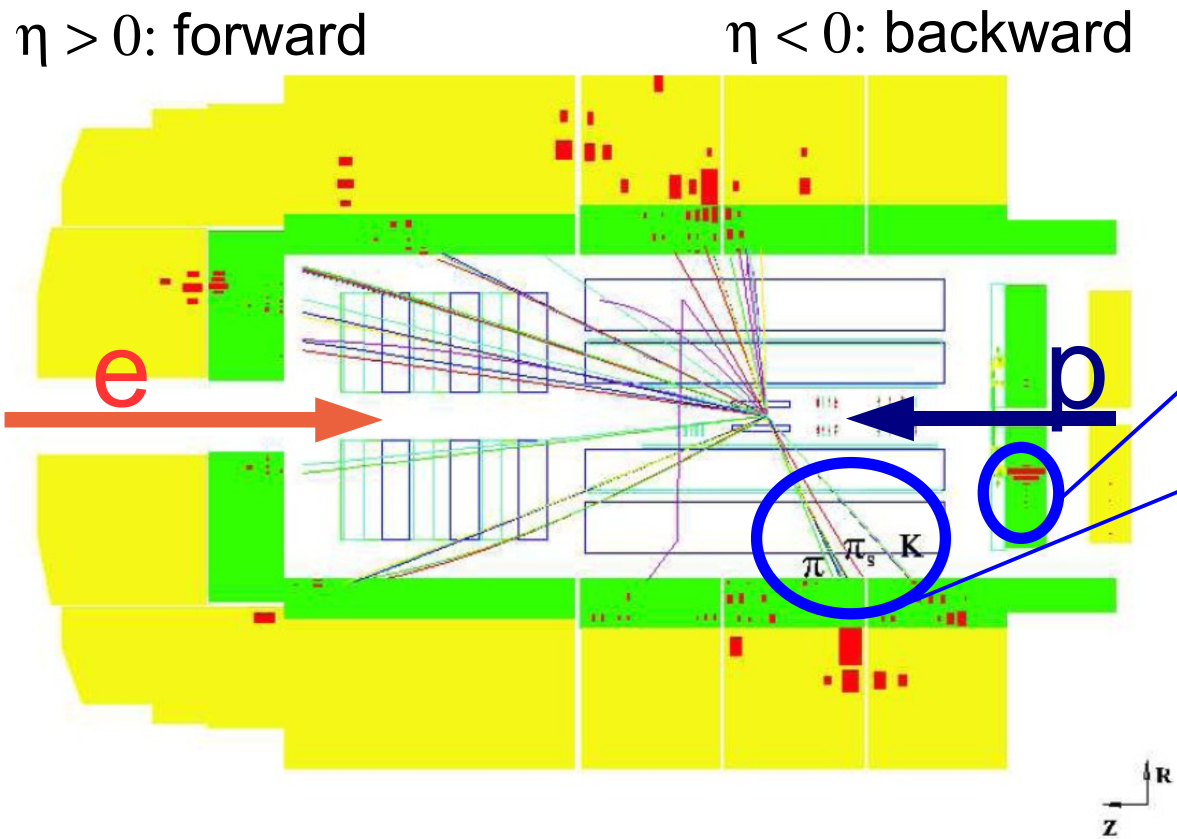
HVQDIS: • with Kartvelishvili fragmentation

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

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

Event selection: $Q^2 > 5$

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



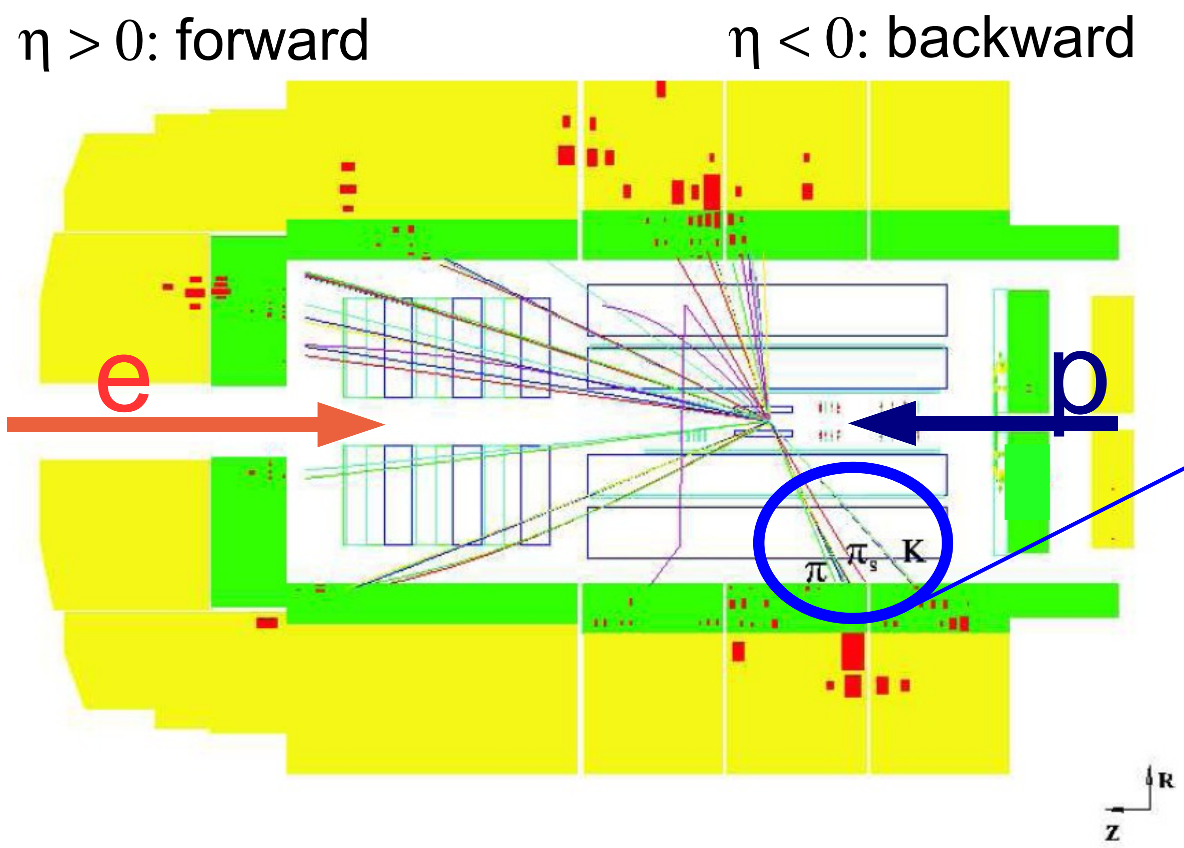
- scattered electron in backward calorimeter
- three charged tracks in central tracking detector
- high multiplicity events

Trigger: DIS case

- scattered electron in backward Calorimeter
- tracks

Event selection: $Q^2 < 2$

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



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

Trigger: DIS case

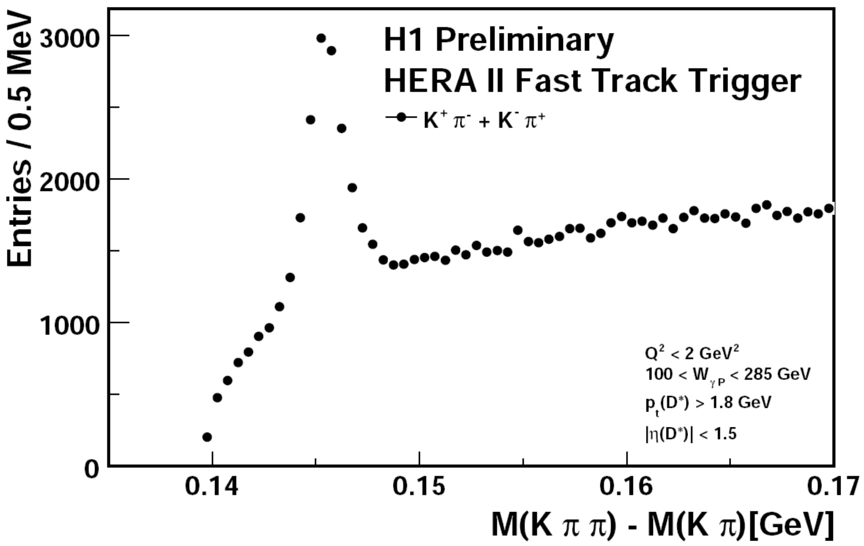
- scattered electron in backward Calorimeter
- tracks

Trigger: (untagged) Photoproduction case:

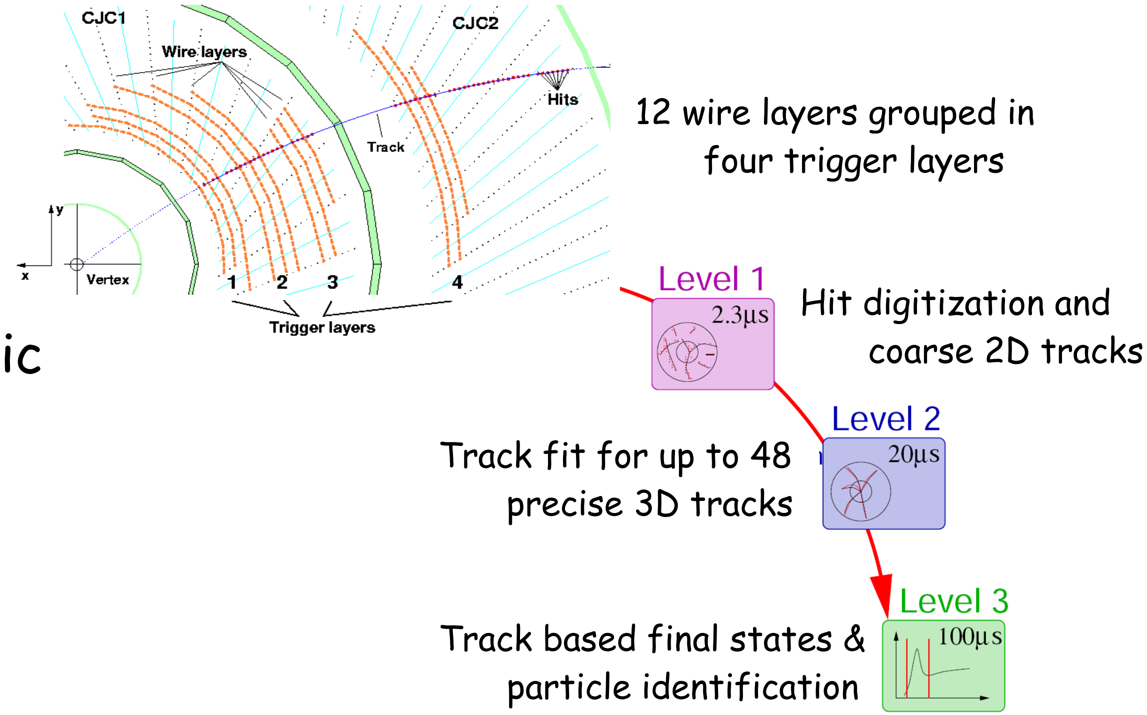
- no scattered electron
- D* reconstructed at trigger level using the **H1 Fast Track Trigger**

Event selection: photoprod.

D* in photoproduction:



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

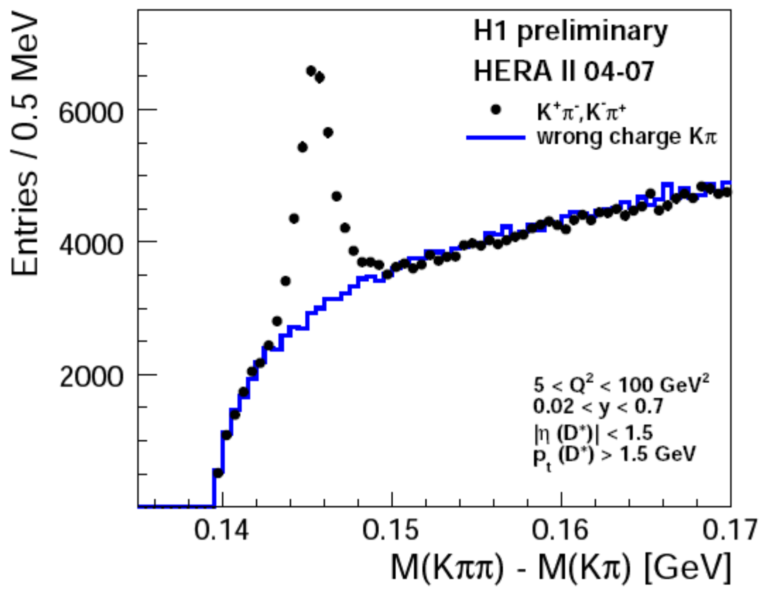


Photoproduction sample ($\mathcal{L}$ = 93 pb^{-1}):

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

DIS sample ($\mathcal{L}$ = 347 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 η(D*) > 0

D* selection: visible range

DIS analysis:

Q^2 : 5 - 100 GeV^2
y : 0.02 - 0.70
$p_T(D^*)$: > 1.5 GeV
$|\eta\ (D^*)|$: < 1.5

D* cuts:

$p_T(K) > 0.3$ GeV
$p_T(\pi) > 0.3$ GeV
$p_T(\pi_{slow}) > 0.12$ GeV
$p_T(K) + p_T(\pi) > 2$ GeV
$|M(D^0)| < 0.080$ GeV

Photoproduction analysis:

Q^2 : < 2 GeV^2
y : 0.10 – 0.80 ($100 < W_{\gamma p} < 250$)
$p_T(D^*)$: > 1.8 GeV
$|\eta\ (D^*)|$: < 1.5

D* cuts:

$p_T(K) > 0.5$ GeV
$p_T(\pi) > 0.3$ GeV
$p_T(\pi_{slow}) > 0.12$ GeV
$p_T(K) + p_T(\pi) > 2.2$ GeV
$|M(D^0)| < 0.080$ GeV

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

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

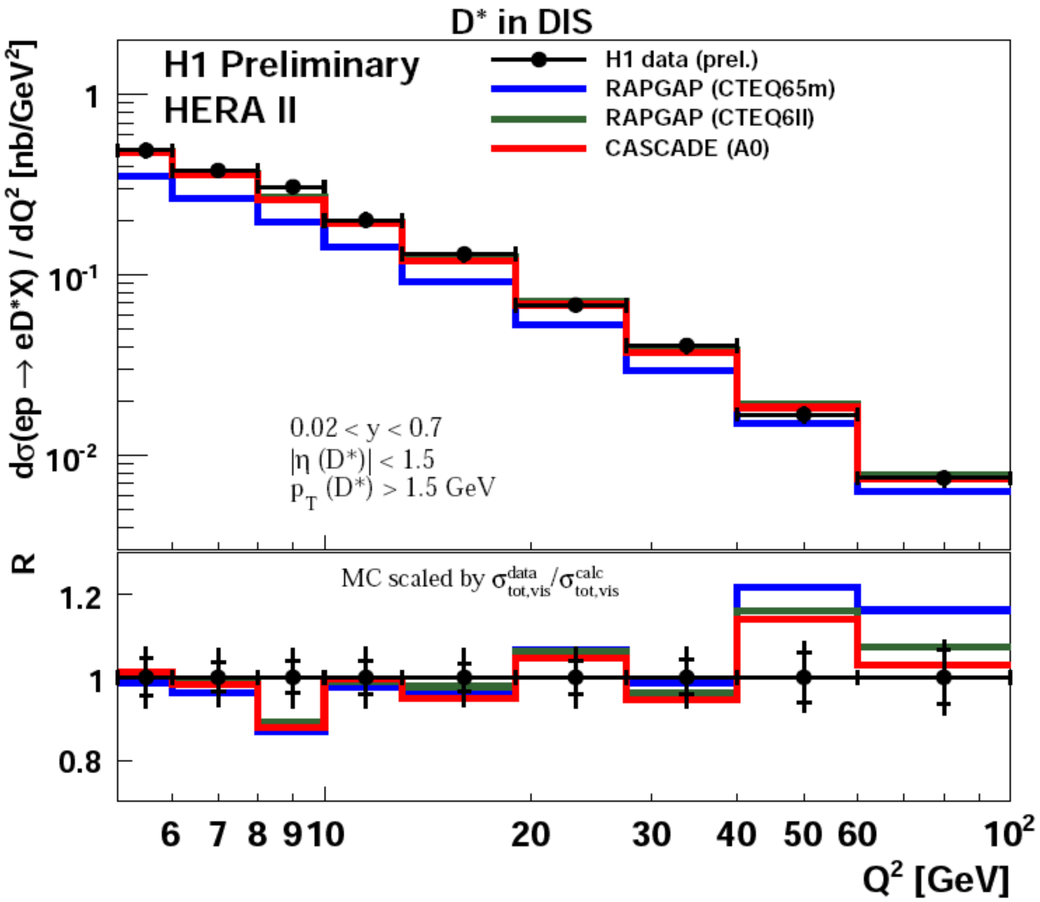
DIS:

- 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:

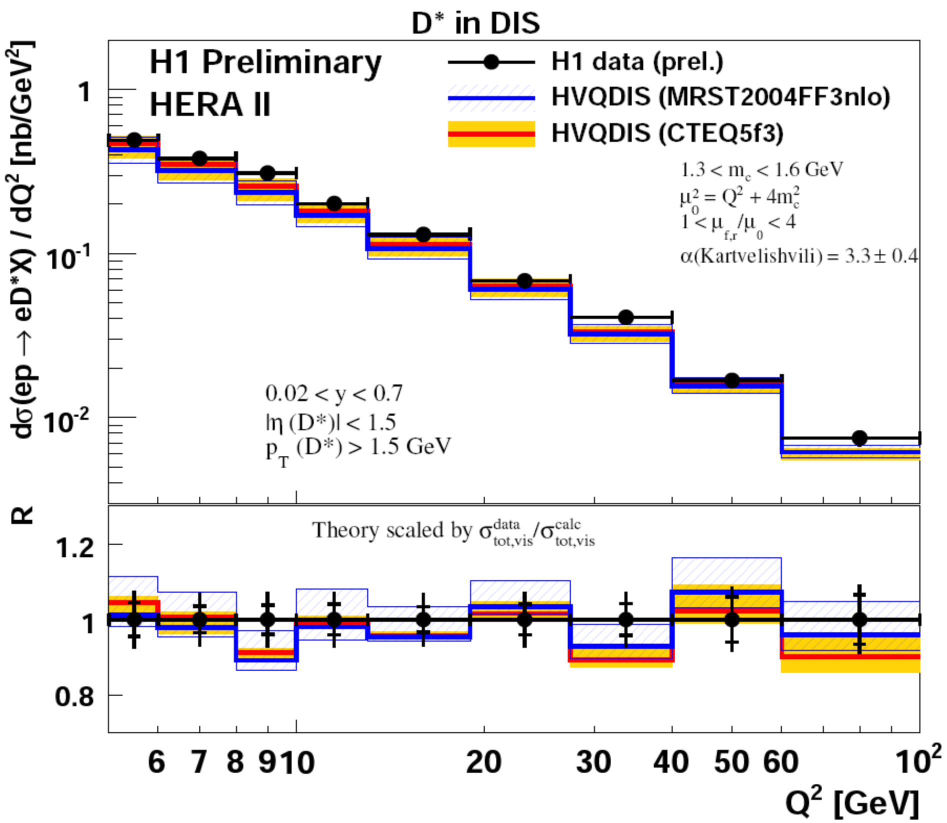
$$R = \frac{1/\sigma^{calc}_{tot,vis} \cdot \frac{d\sigma^{calc}}{dY}}{1/\sigma^{data}_{tot,vis} \cdot \frac{d\sigma^{data}}{dY}}$$

is used.

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

--> CASCADE slightly better in shape

Cross sections: kin. variables



<u>Error estimation of the NLO-calculation with parameter variation:</u>

charm mass: $1.3 < m_C < 1.6$ GeV

renormalization & factorization scale:

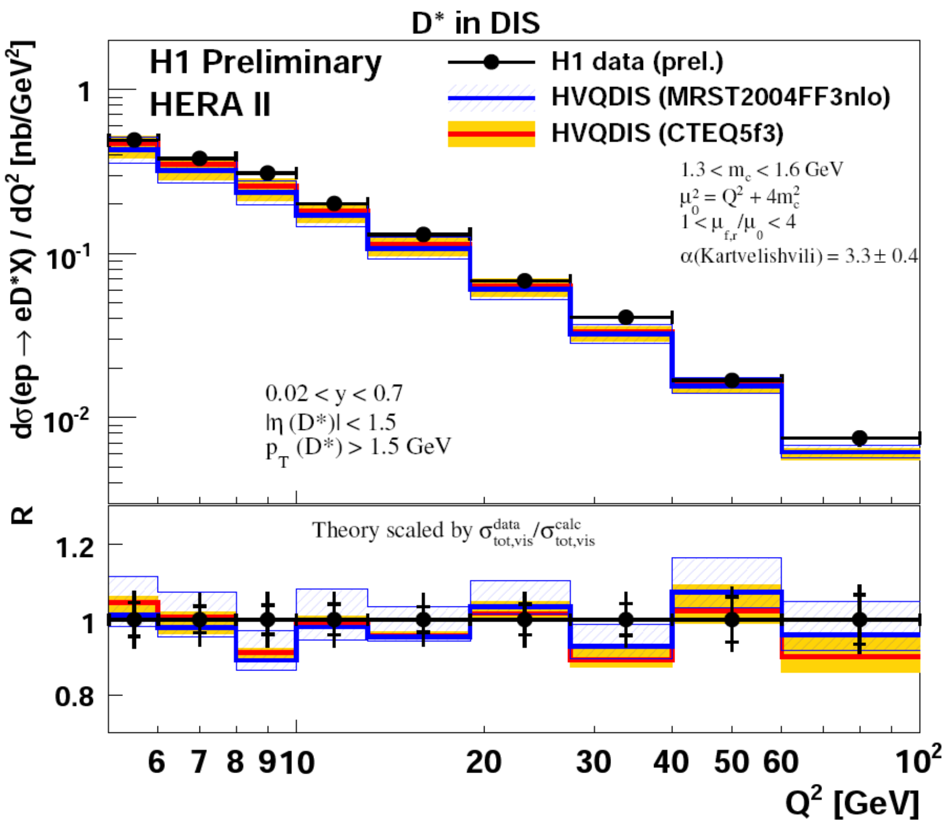
$1 < \mu_{f,r}/\mu_0 < 4$,

with $\mu_0^2 = Q^2 + 4m_C^2$

fragmentation: α(Kartvelishvili) = 3.3 ± 0.4

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

Cross sections: kin. variables



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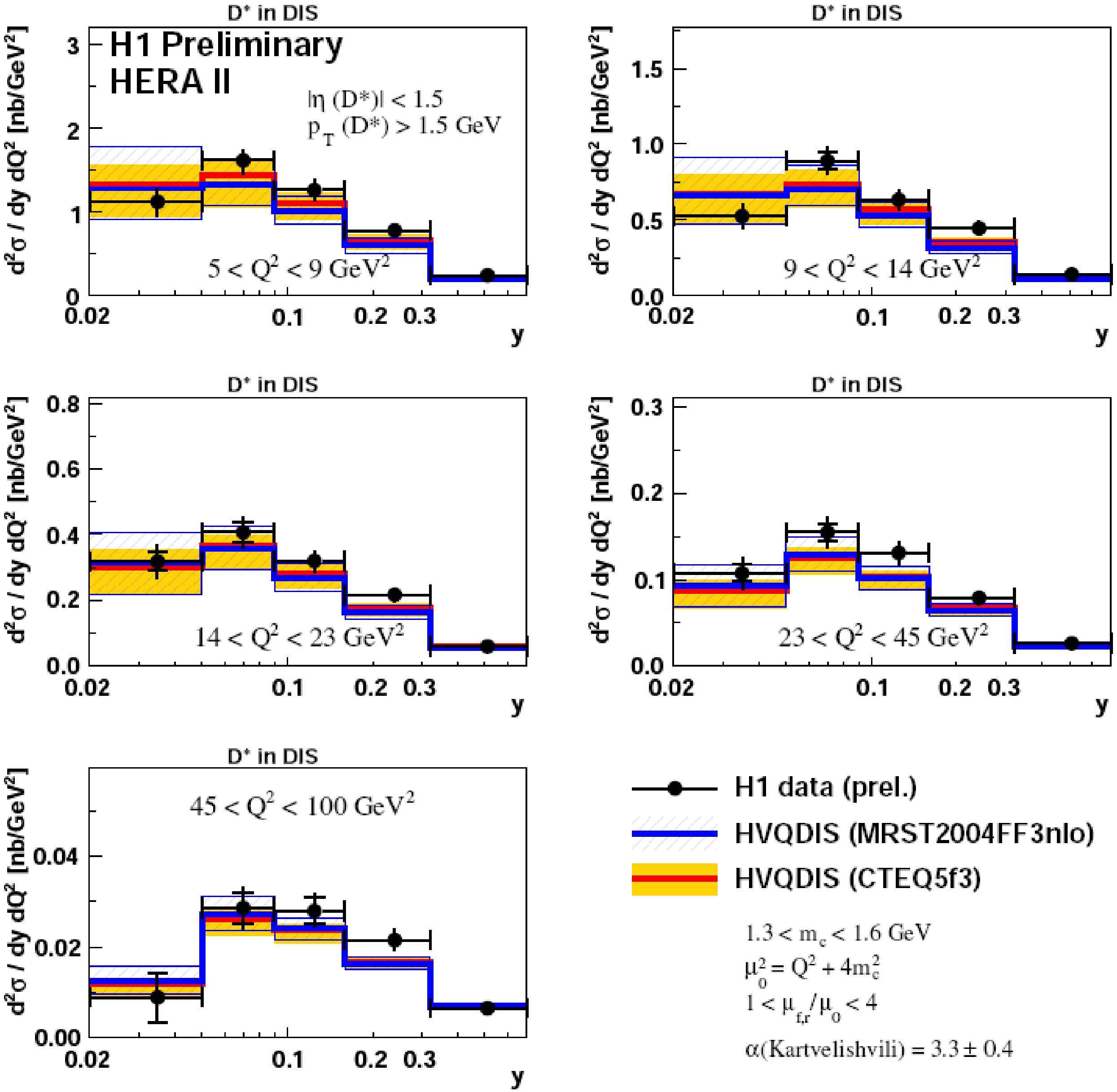
--> HVQDIS: both PDF give good description, MRST slightly lower in normalization

Total integrated Cross section:

Data:	(4.85 ± 0.07(stat.) ± 0.42 (sys.)) nb
HVQDIS (CTEQ):	(4.43 +0.69 -0.47) nb
HVQDIS (MRST):	(4.17 +0.59 -0.37) nb

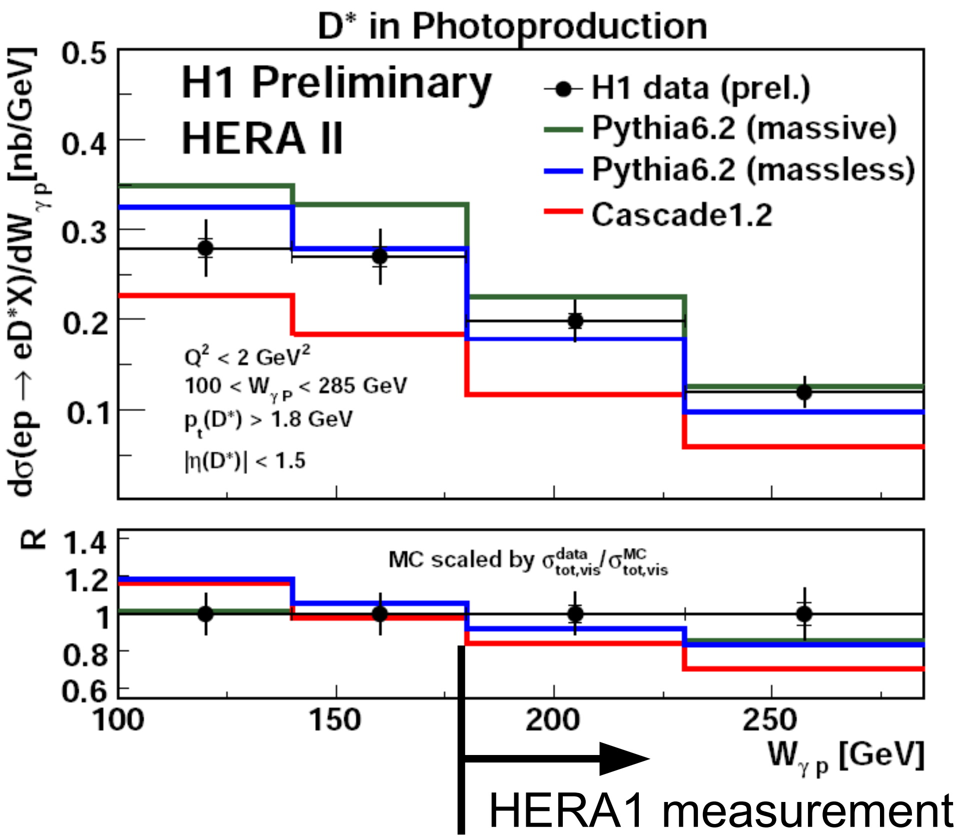
Cross sections: kin. variables

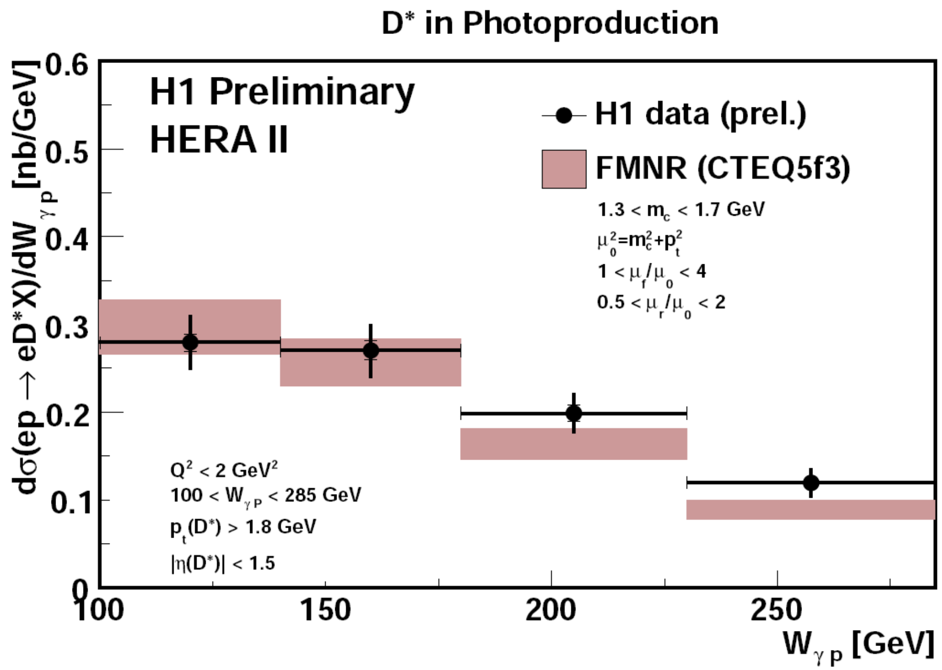


--> HVQDIS: both proton PDF give a good description of the y-Q^2 dependence

--> 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: $1.3 < m_C < 1.7$ GeV

renormalization & factorization scale:

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

with $\mu_0^2 = m_C^2 + p_T^2$

fragmentation: ε(Peterson) = 0.035, no variation

--> FMNR is somewhat better

Cross sections: D* variables

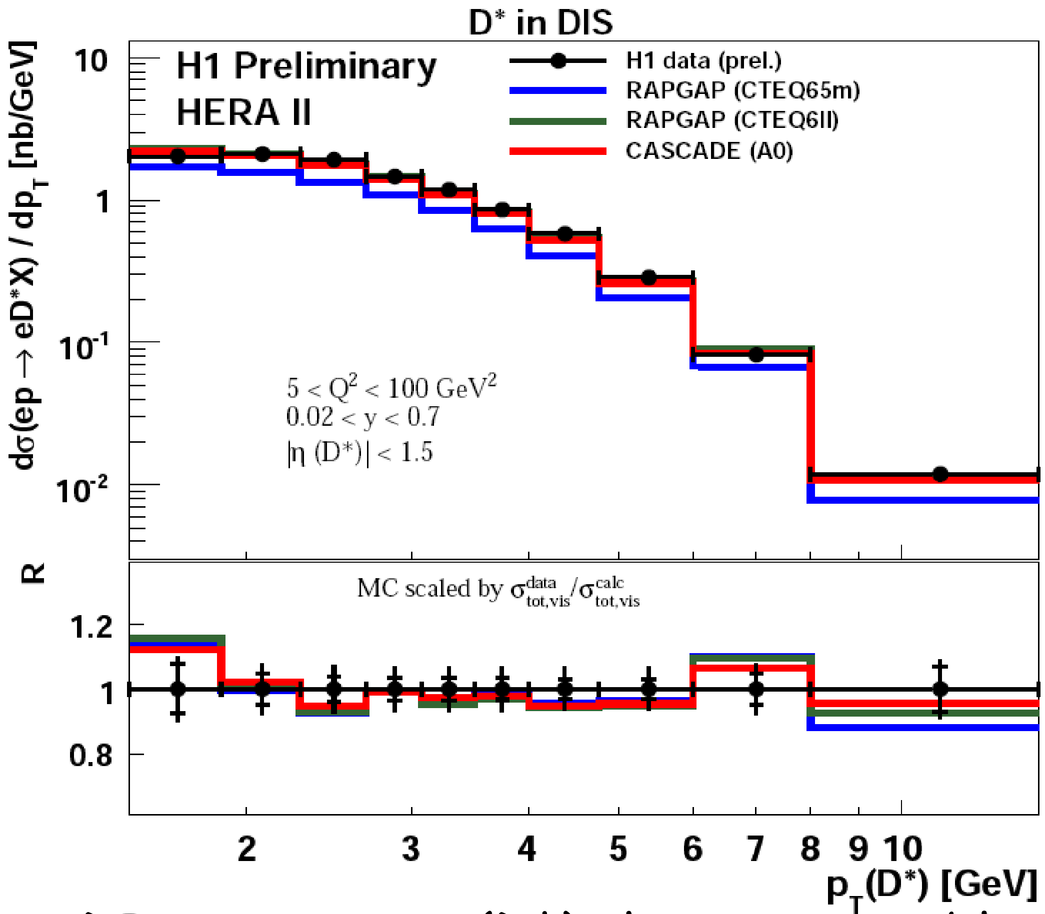
DIS:

- p_T, η
- η - p_T

Photoproduction:

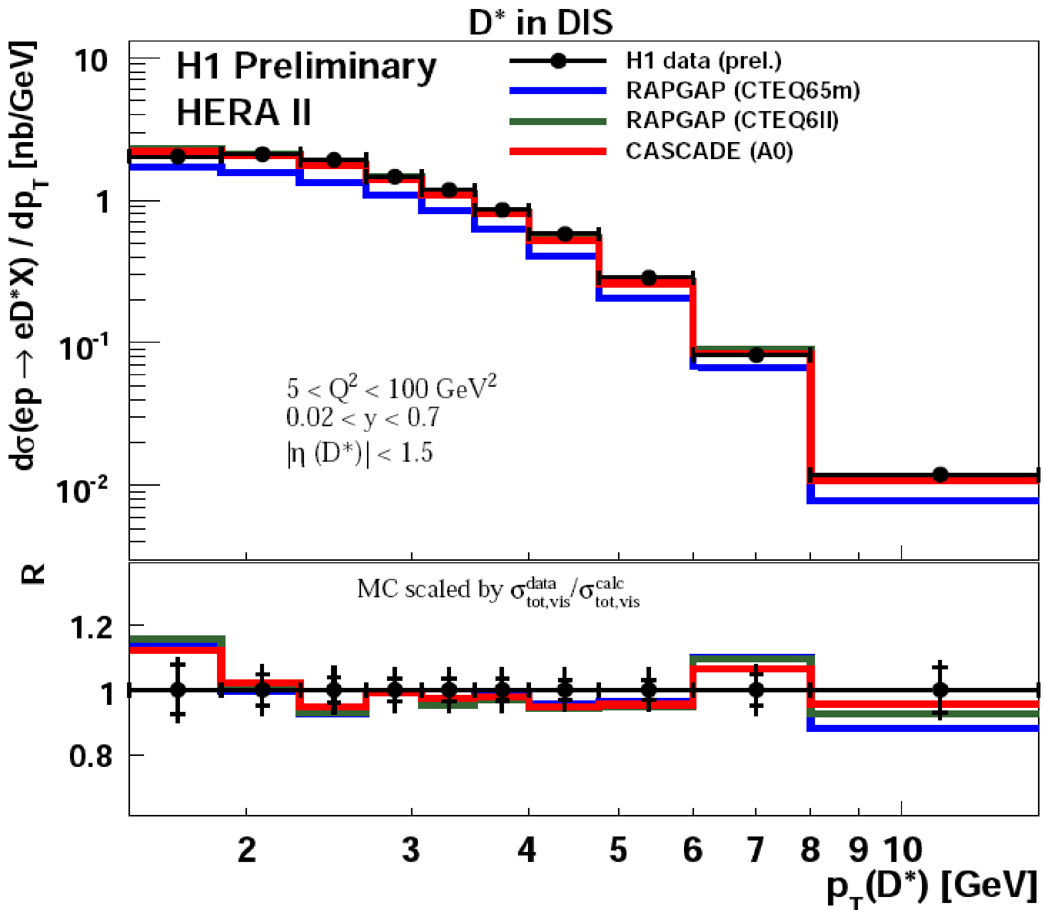
- p_T, η
- η - p_T

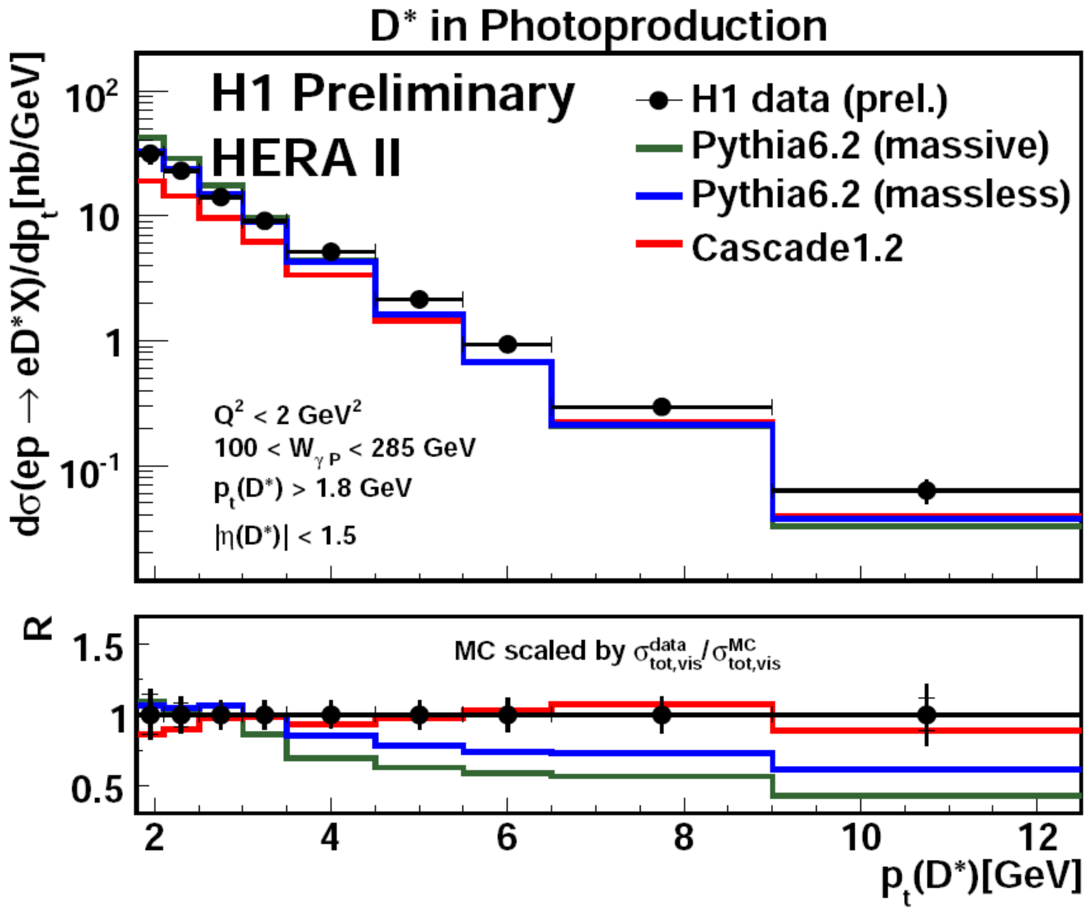
Cross sections: D* variables



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

Cross sections: D* variables

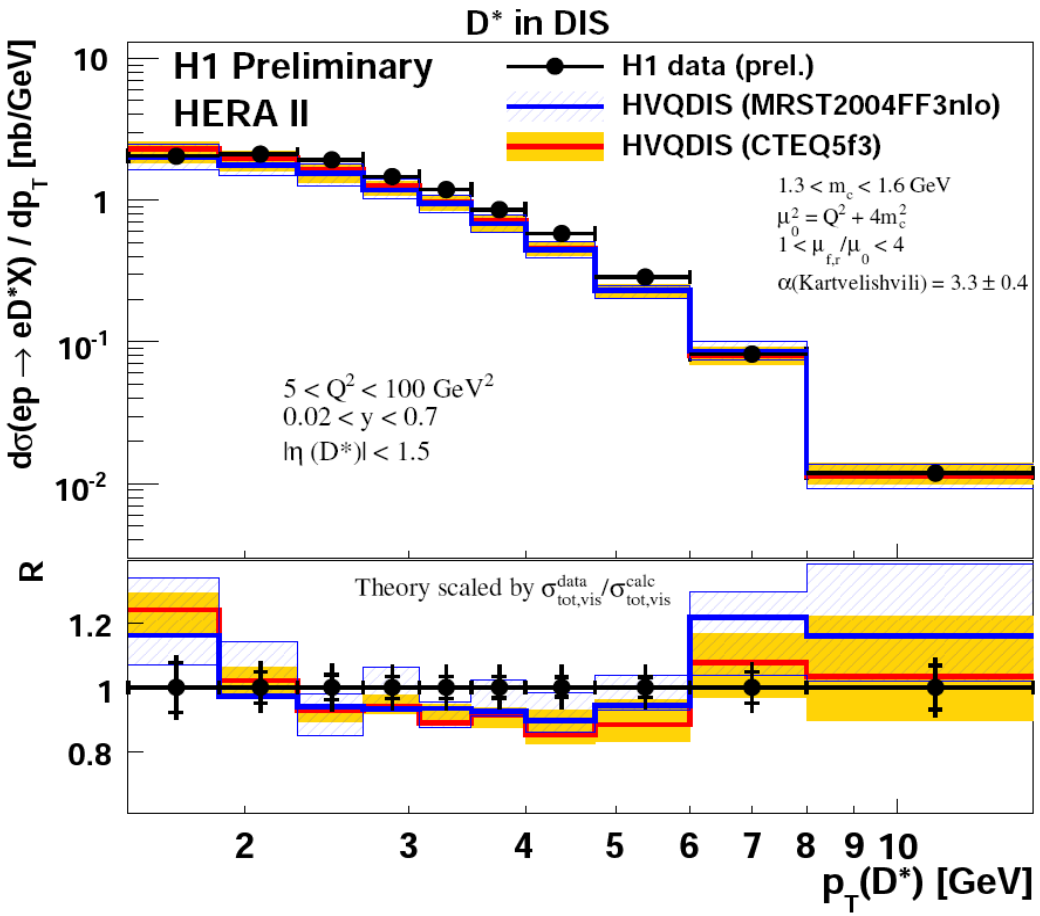


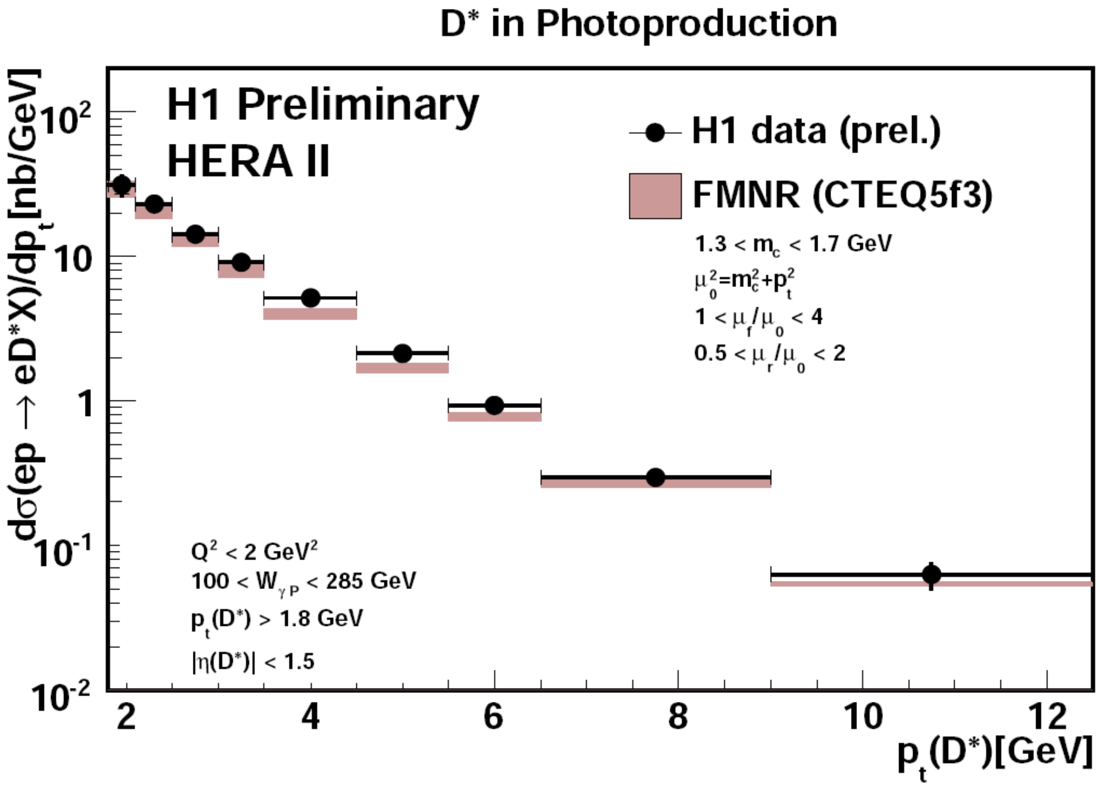


--> DIS: - p_T (D*) shape reasonably well described by all MC models

--> Photoproduction: - p_T (D*) shape described by CASCADE but steeper slope for both PYTHIA models

Cross sections: D* variables

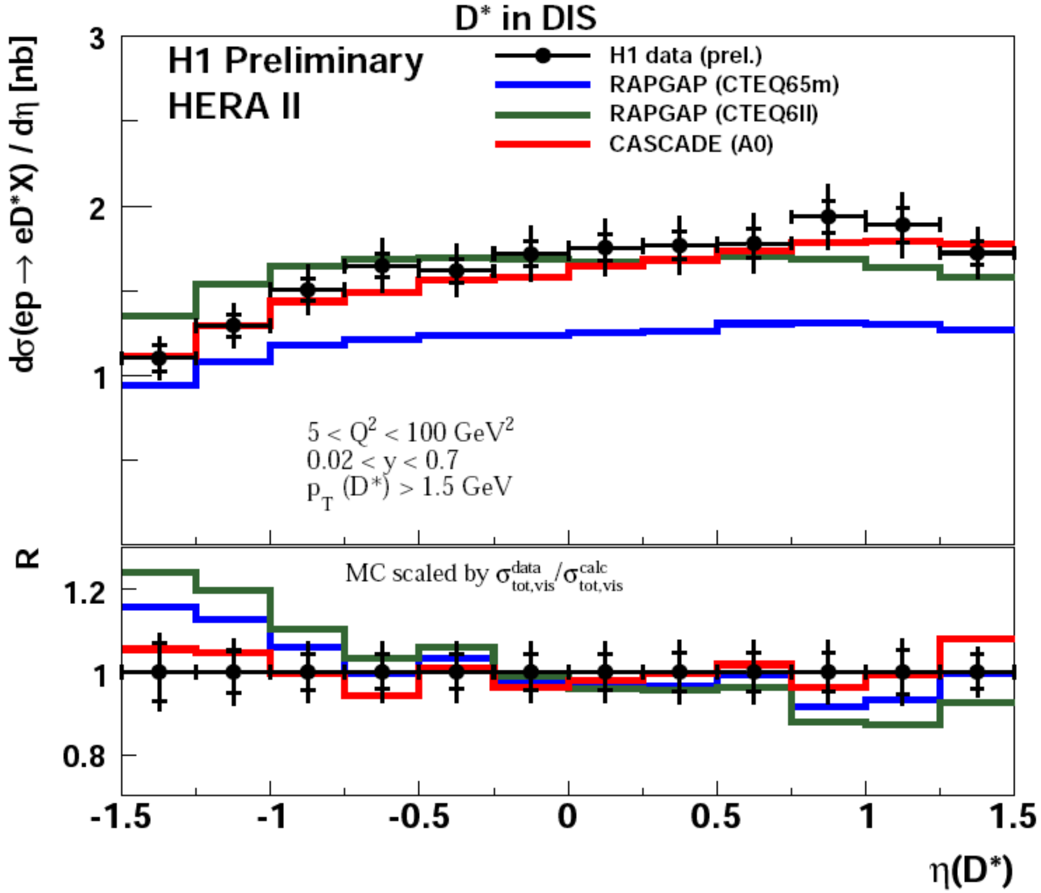




--> DIS & Photoproduction: - p_T (D*) shape reasonably well described by NLO

- but normalization should be correct

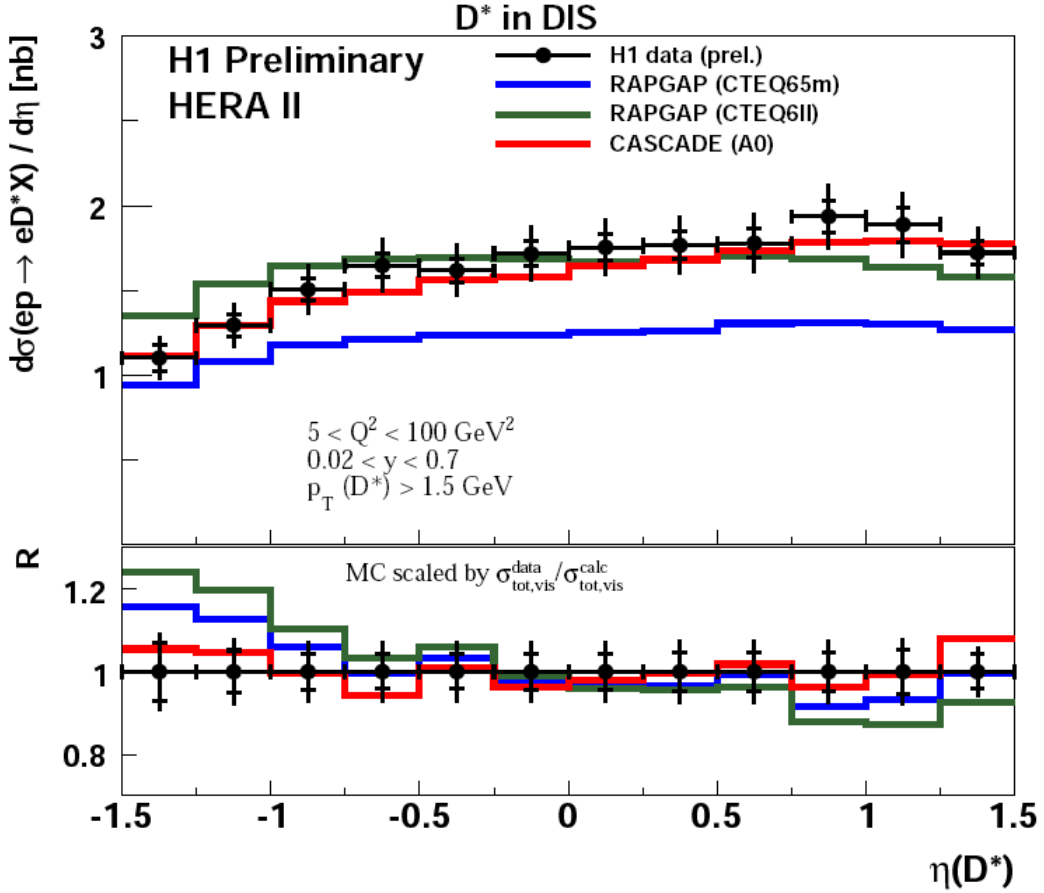
Cross sections: D* variables

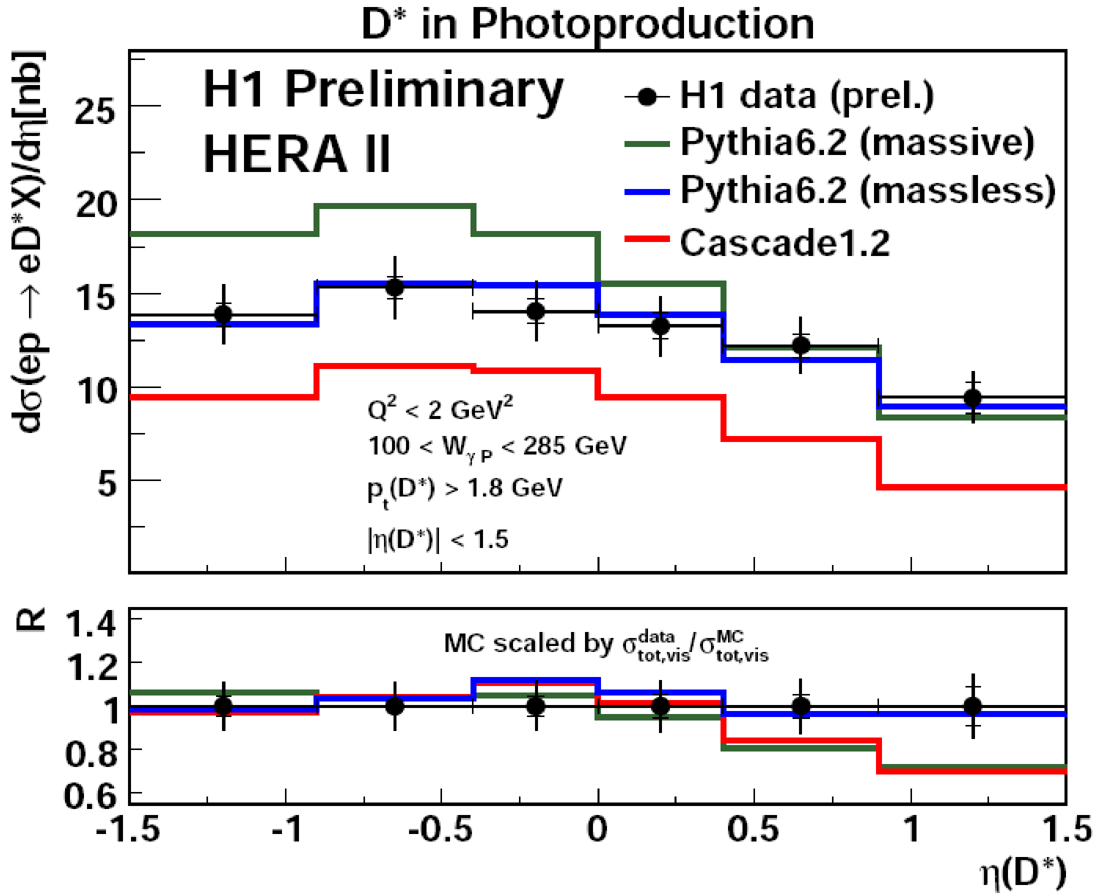


--> DIS: - CASCADE describes the distribution in shape and normalization

- RAPGAP: data sensitive to the Proton PDF (CTEQ65m is better in shape)

Cross sections: D* variables

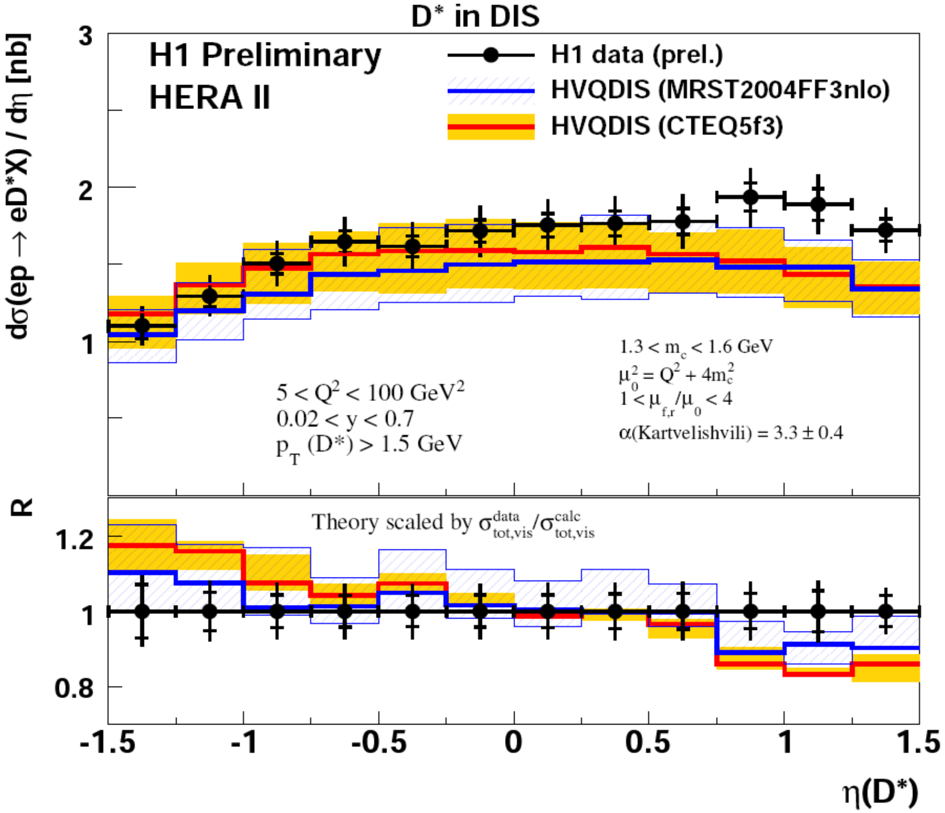




--> DIS: - CASCADE describes the distribution in shape and normalization
- RAPGAP: data sensitive to the Proton PDF (CTEQ65m is better in shape)

--> Photop.: - PYTHIA (massless) describes the data in shape & normalization
- CASCADE fails in shape (differences for η(D*) > 0) & normalization

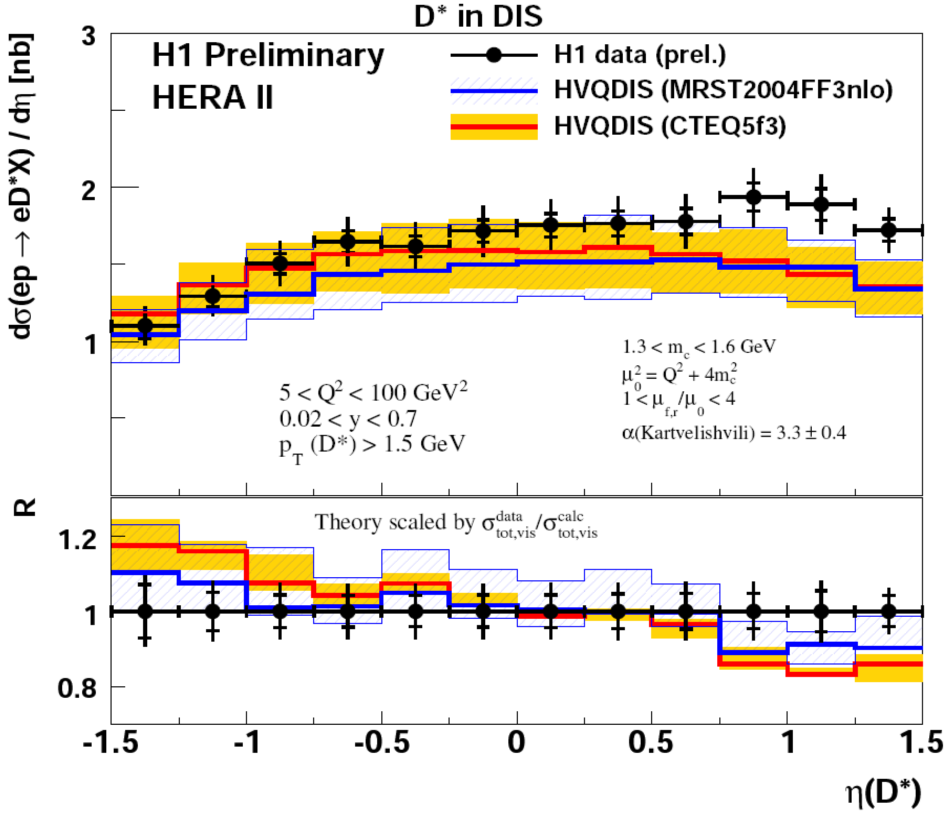
Cross sections: D* variables

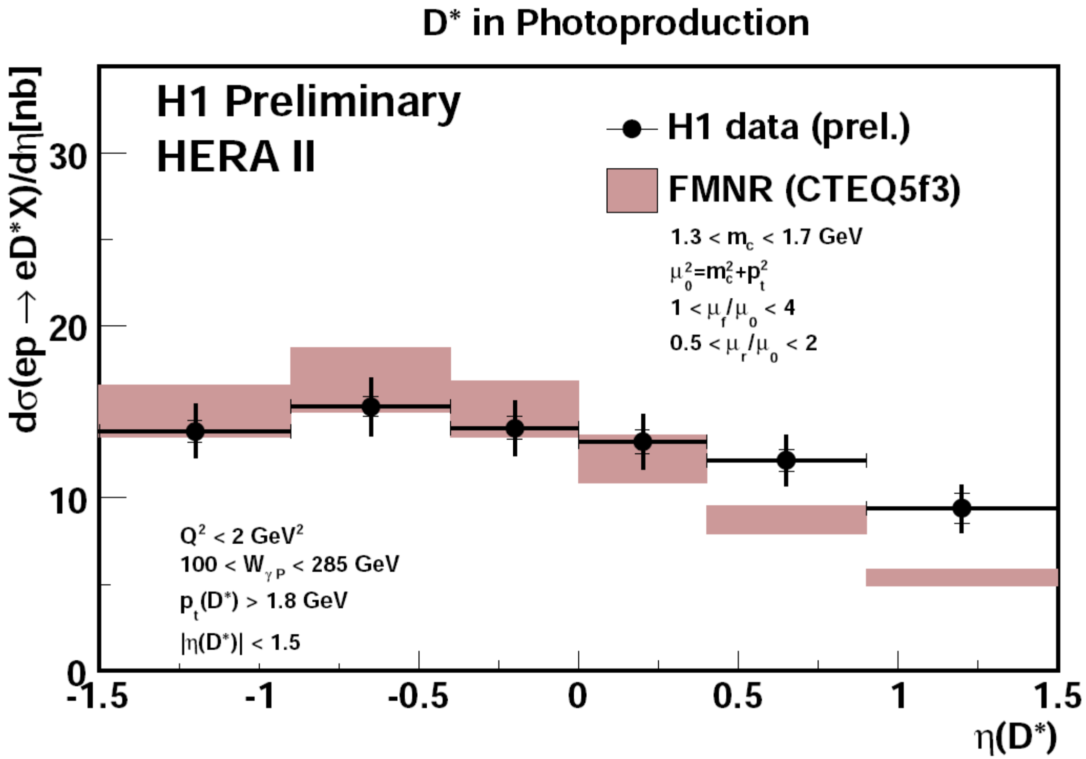


--> DIS: - difference at forward η(D*) between data & NLO confirmed with full HERA2 statistics

- MRST (other gluon density) gives a better description, low in normalization

Cross sections: D* variables





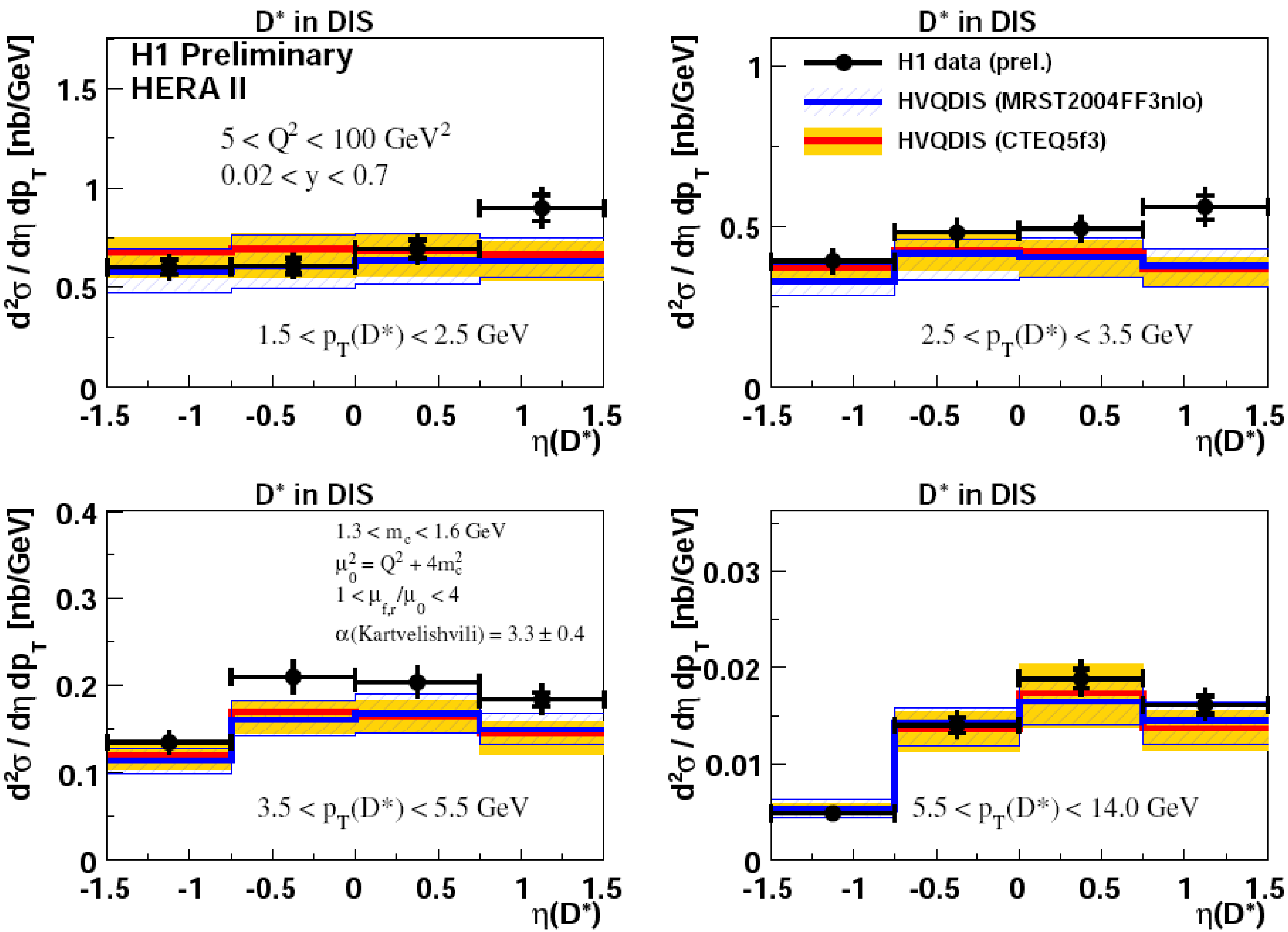
--> DIS: - difference at forward $\eta(D^*)$ between data & NLO confirmed with full HERA2 statistics

- 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

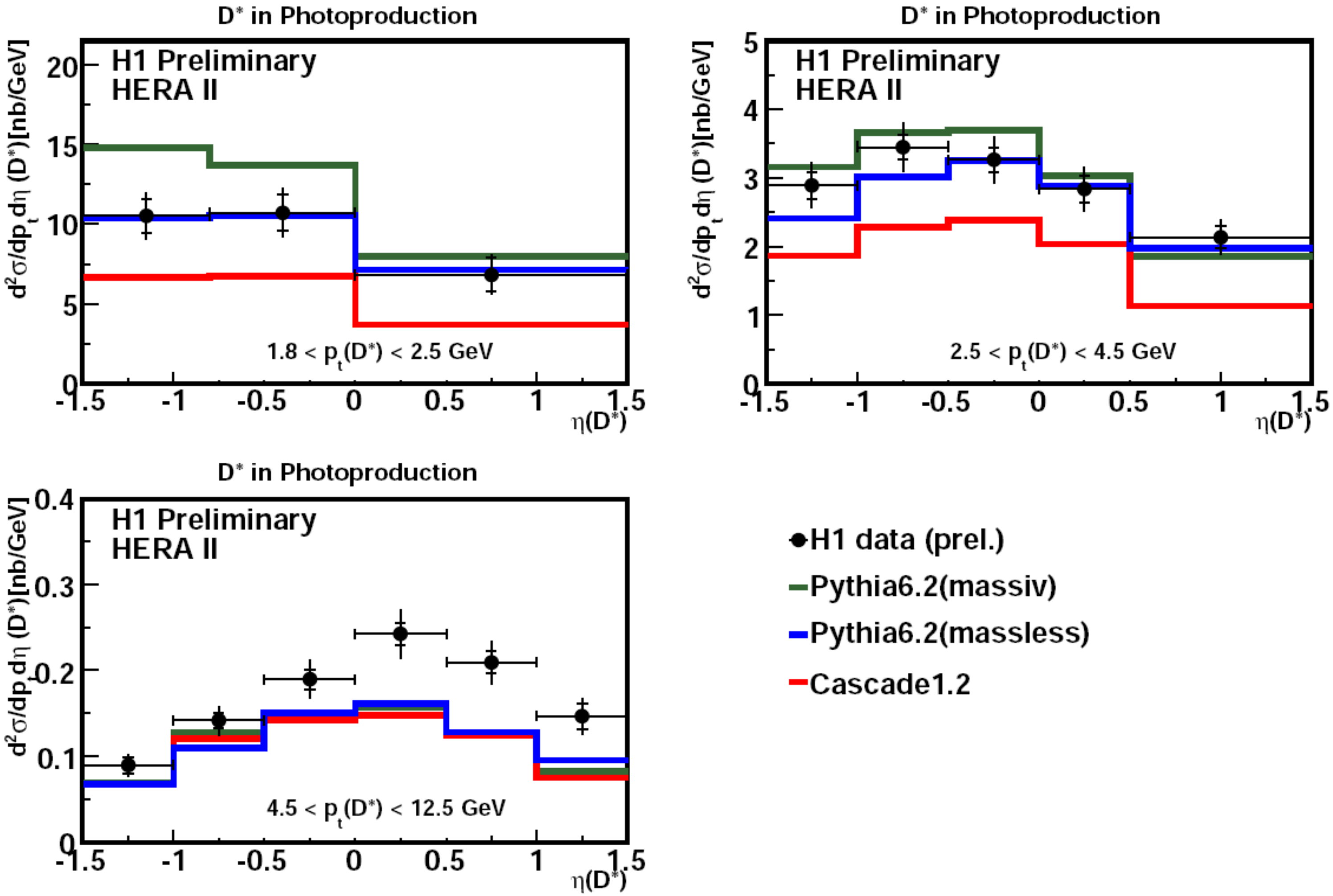


--> In general NLO gives a good description of the data

--> 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



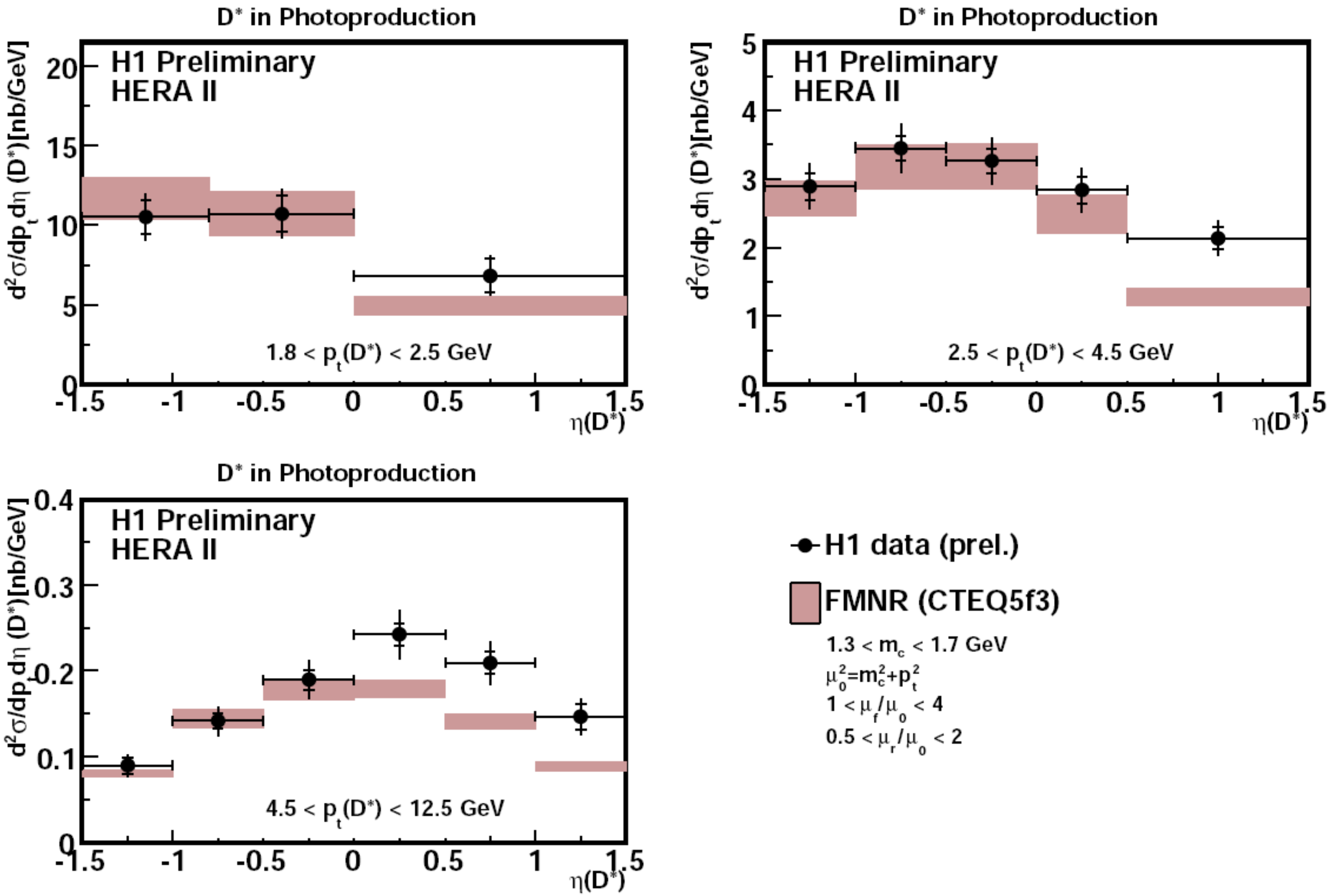
--> low $p_T(D^*)$:

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

--> 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



--> 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

Implications for the LHC

- From the presented data: - reached precision needed to see effects from different parameters (Proton PDF, charm mass,...)
  - extract $F_2^{cc}(x,Q^2)$ for summer conferences

- Plans & Goals: - goal is 6% systematic error for the D* cross sections
  - extend phase space in $\eta(D^*)$ & $p_T(D^*)$
  - combine D* reduced cross sections with H1 displaced Track measurement and ZEUS D* measurement

Conclusions

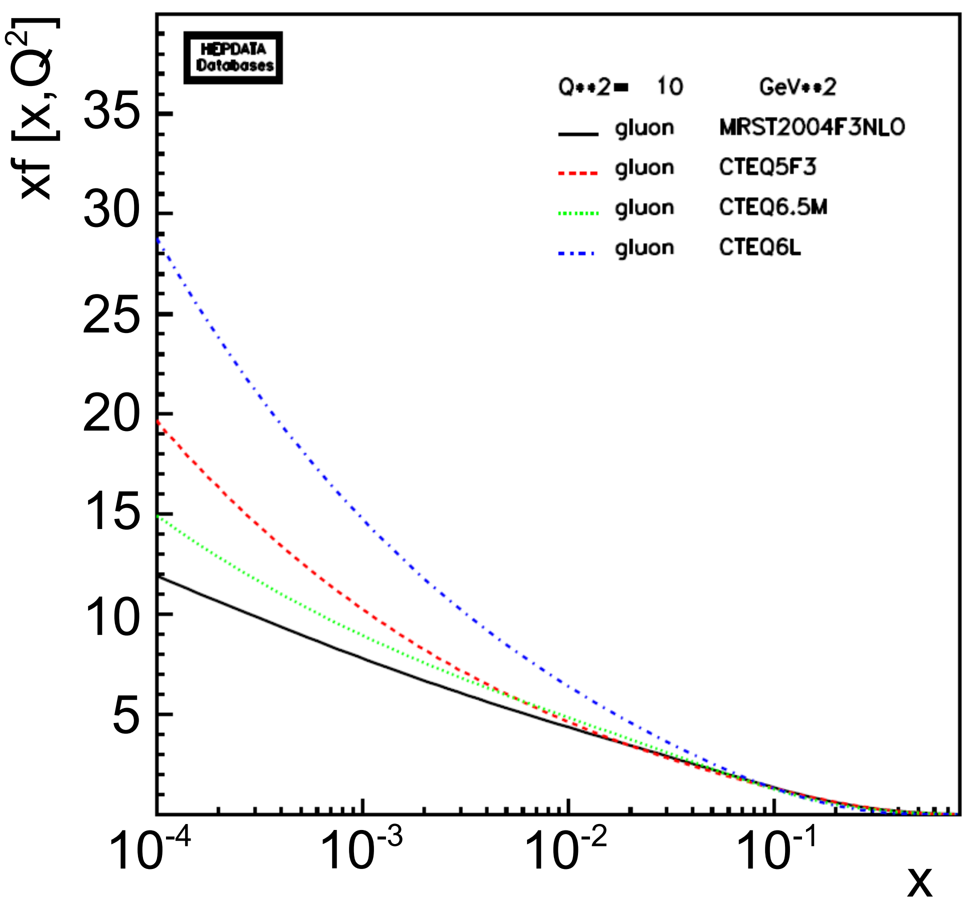
- **Full HERA2 data statistic (10x HERA1 statistics) for D* production in DIS and photoproduction analysed**

- 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 $p_T(D^*)$

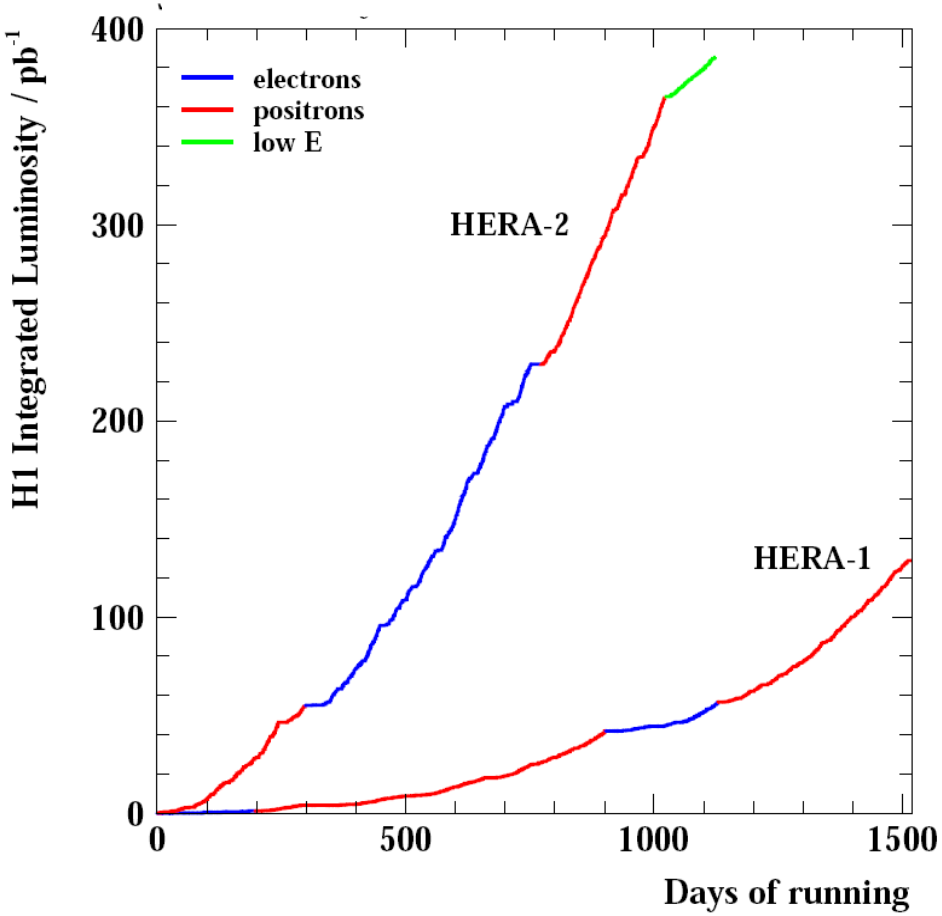
Backup

Additional material:

Different Proton PDFs:



Collected Data samples:



Common fit function:

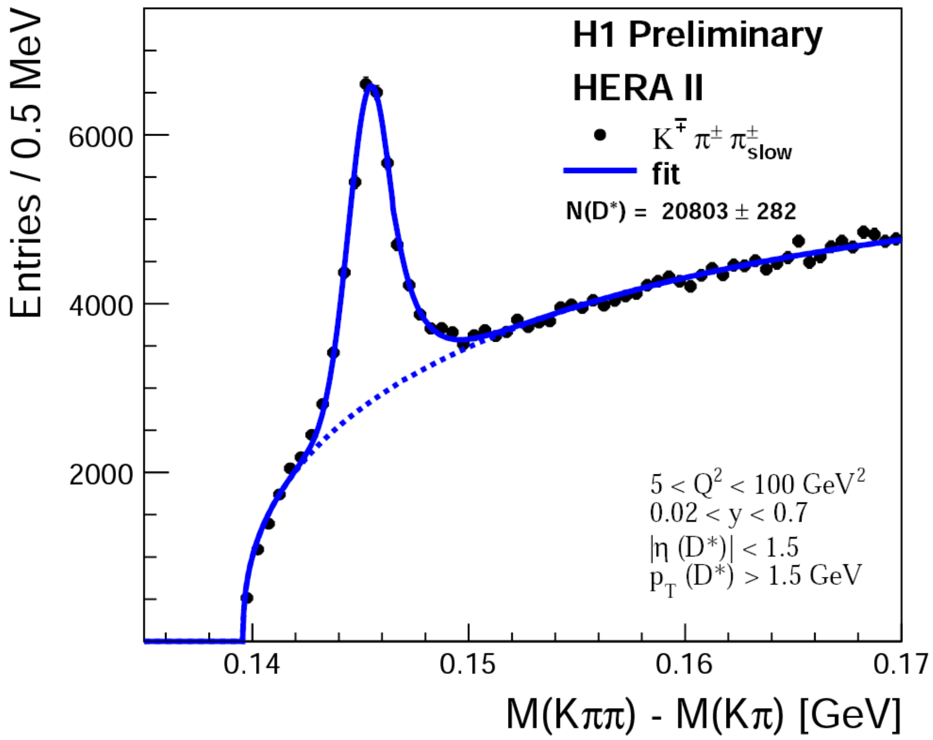
asymmetric Peak:

Crystal-Ball:

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

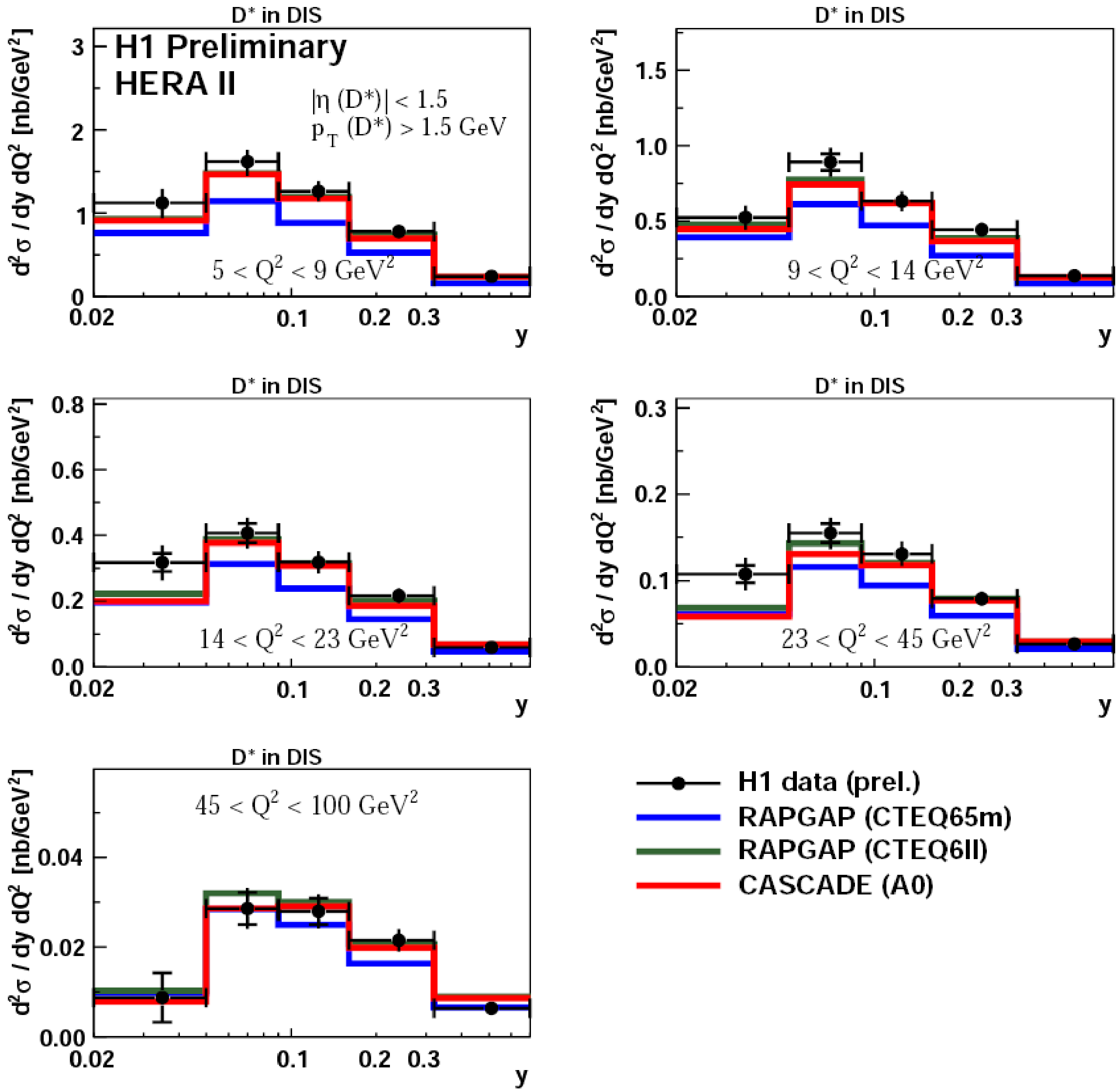
Background (Granet Parametrisation:)

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



- 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

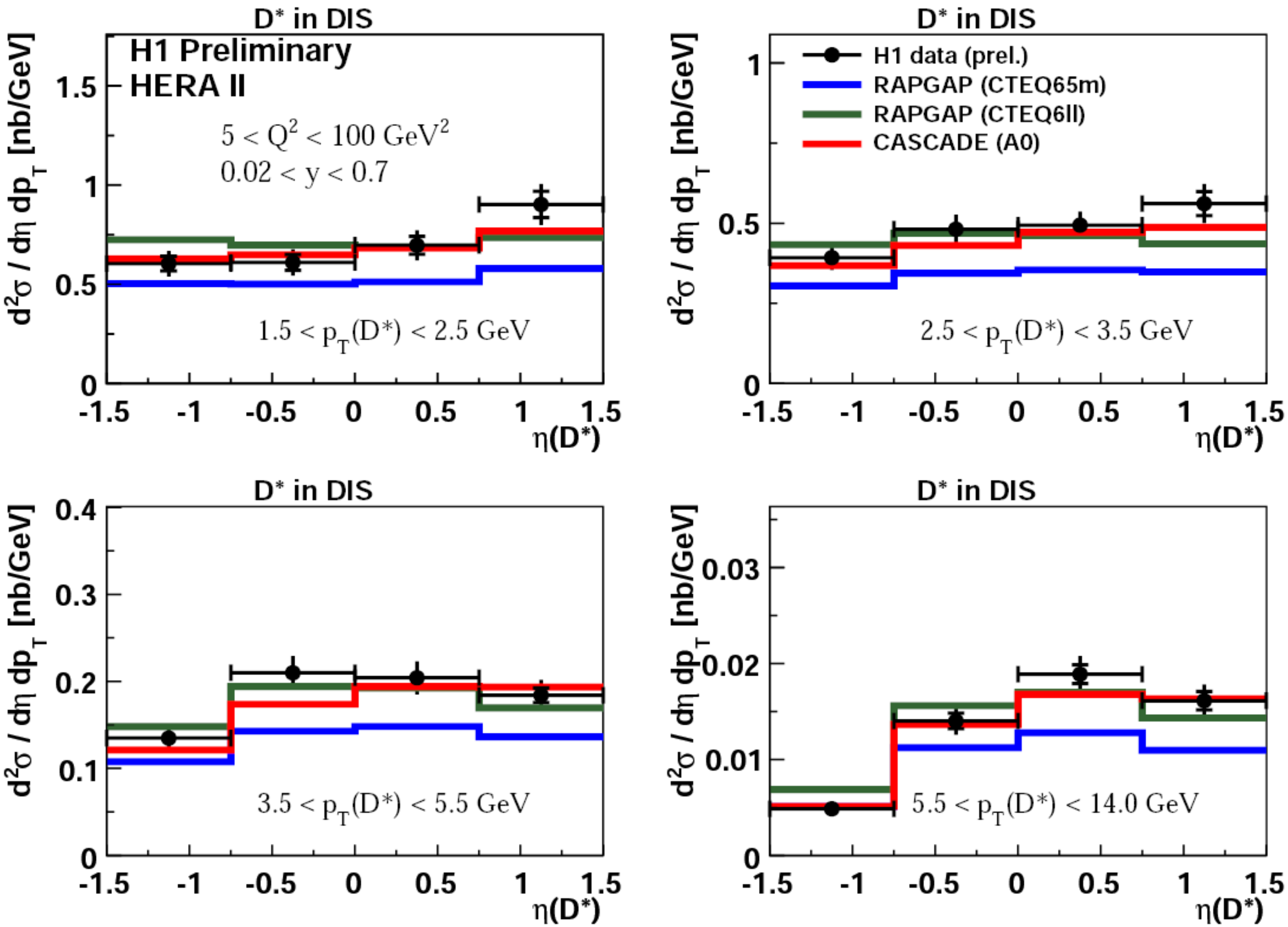
Cross sections: D* variables



--> 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

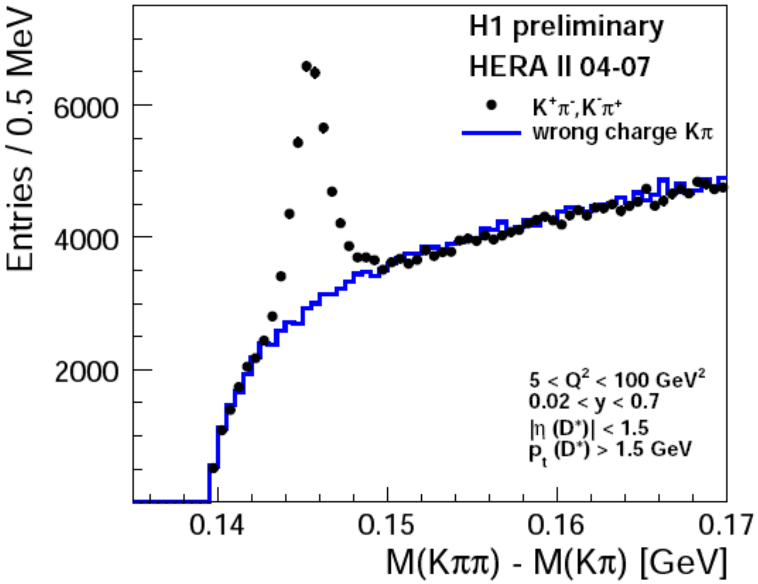


--> CASCADE describes the η(D*) distribution in shape and normalization

--> RAPGAP with CTEQ6ll gives also a good description except the forward η(D*) at small p_T(D*)

Event selection: DIS

D* in DIS:



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- select events by mass difference dM