D* + jets in DIS and photoproduction

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for the H1 collaboration

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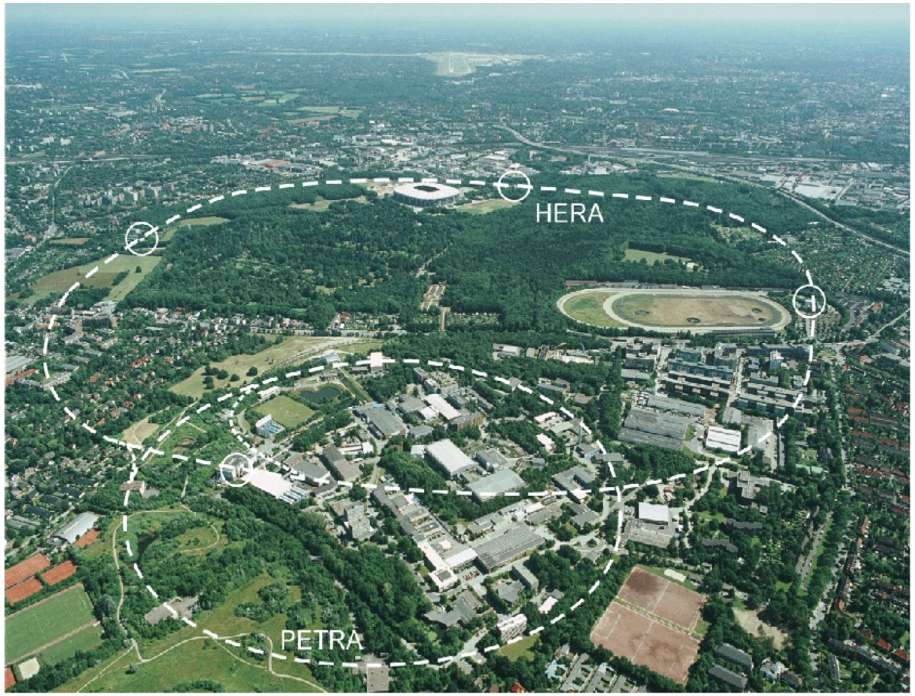
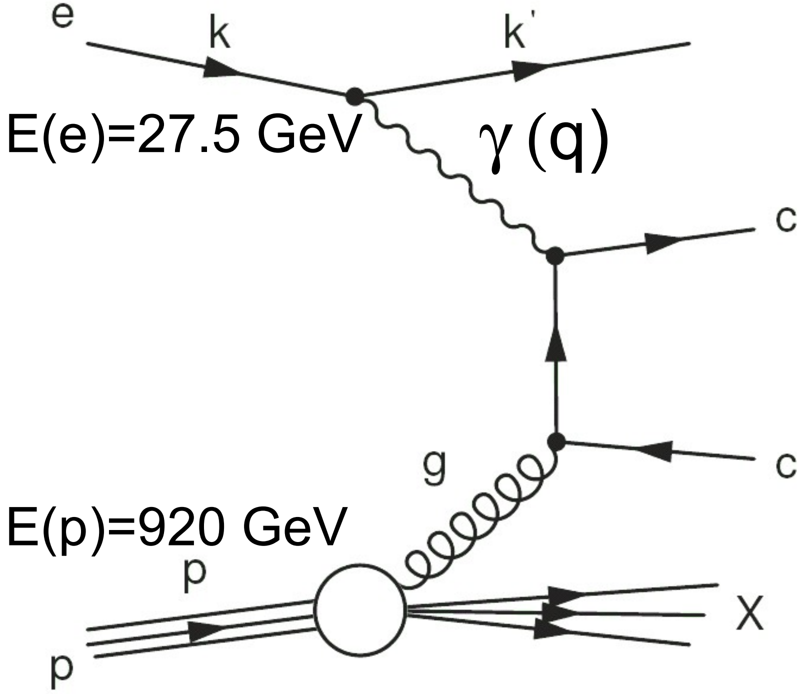


- Introduction
- D* (+jet) cross sections
- Extraction of $F_2^c(x,Q^2)$
- Combination of $F_2^c(x,Q^2)$
- Conclusions

D* production: boson-gluon-fusion

Dominant process for charm-production in *ep* -scattering:



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

- Photon Virtuality:

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

$Q^2 \sim 0\ \mathrm{GeV}^2$: Photoproduction
$Q^2 > 2\ \mathrm{GeV}^2$: Deep Inelastic Scattering

- Inelasticity: $y = \frac{qp}{kp}$ Bjorken x: $x := \frac{Q^2}{2(\mathbf{p} \cdot \mathbf{q})}$

D* via Fragmentation:

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

$$z = \frac{E(D^*) - p_z(D^*)}{2 \cdot y E_e}$$

Study production mechanism:

- Q^2, m^2_c or p^2_T provides a hard scale for pQCD → multiscale problem
- Test of heavy flavor treatment in pQCD
- Parton densities ("gluon structure") in the proton → test universality

Theoretical models

Factorisation ansatz:

$$d\sigma = \sum_{i,j,k} f_j^B(x_2, \mu_f) \otimes d\hat{\sigma}_{ij\to kX}(\mu_f) \otimes D_k^H(z, \mu_f)$$

Parton density functions (PDFs) from global fits to data

Matrix element: calculable to different oders of α_s

Fragmentation function: from data

Many approaches on the market:

- **$LO(\alpha_s)$ + PS:**
  - collinear factorization — PYTHIA (DGLAP, massive/massless)
  - collinear factorization — RAPGAP (DGLAP, massive)
  - k_T factorization — CASCADE (CCFM, massive)

  (all MCs use Lund fragmentation (uds) and Bowler (c)

- **$NLO(\alpha_s^2)$:**
  - Collinear factorization — HVQDIS (DGLAP, FFNS, massive, independent Fragmentation)

    ZMVFNS (DGLAP, ZM-VFNS, massless, KKKS08)

- **$NLO(\alpha_s^2)$ +PS:**
  - collinear factorization — MC@NLO (DGLAP, massive, cluster fragmentation)

D*+jets photoproduction

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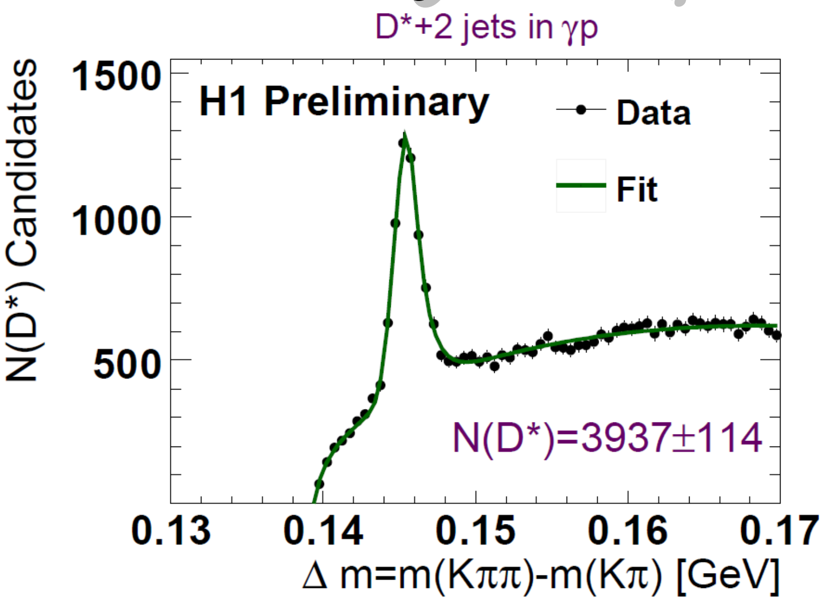

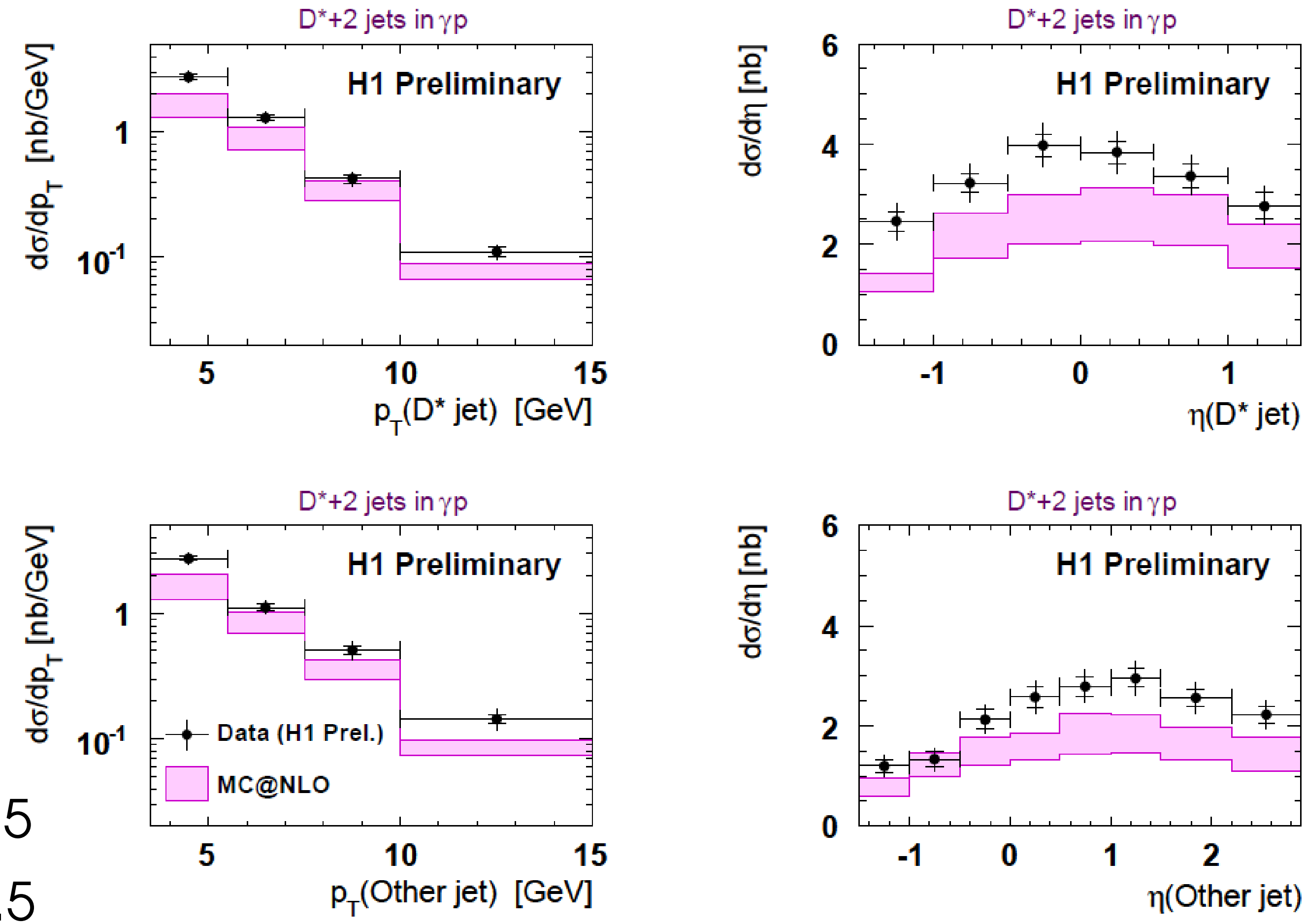

- Full HERAII sample (L = 93 pb^{-1})
- Total systematic error: ~ 9%
- <u>Phase Space cuts:</u>

  $p_T(D^*) > 2.1$ GeV & $|\eta(D^*)| < 1.5$

  $p_T(jet) > 3.5$ GeV & $|\eta(jet)| < 1.5$

  $|\eta(D^*\text{-jet})| < 1.5$

  $-1.5 < \eta(\text{other-jet}) < 2.9$

  (other-jet is jet with highest $p_T(jet)$ other than D*-jet

- Comparison to MC@NLO (CTEQ66)
- Uncertainty band from scale variations
- MC@NLO too low in normalization
- Shape fits quite well

D*+jets photoproduction

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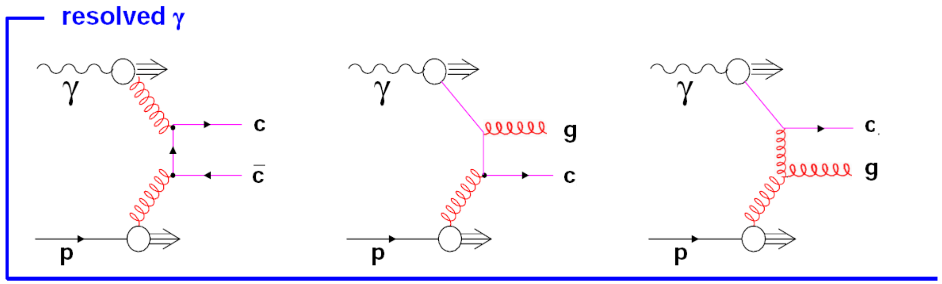
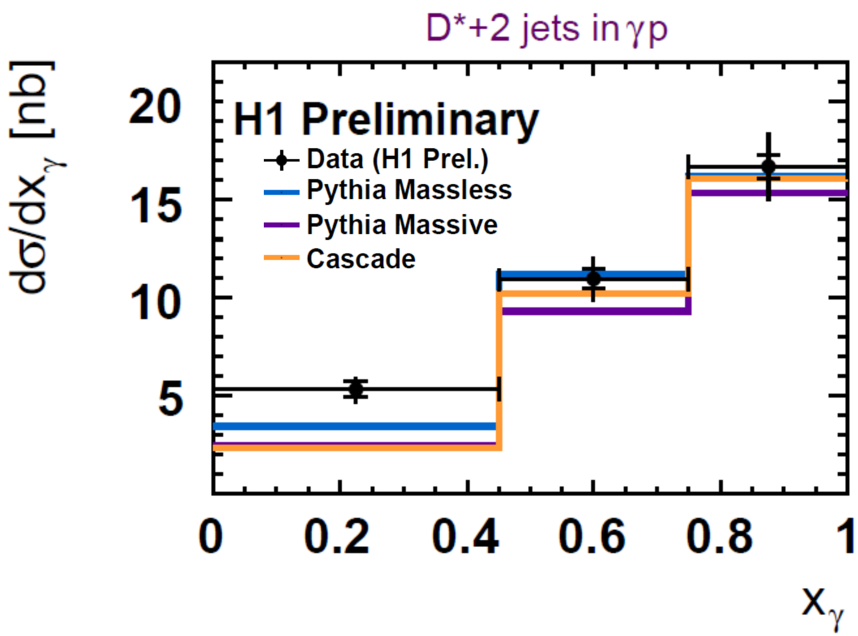
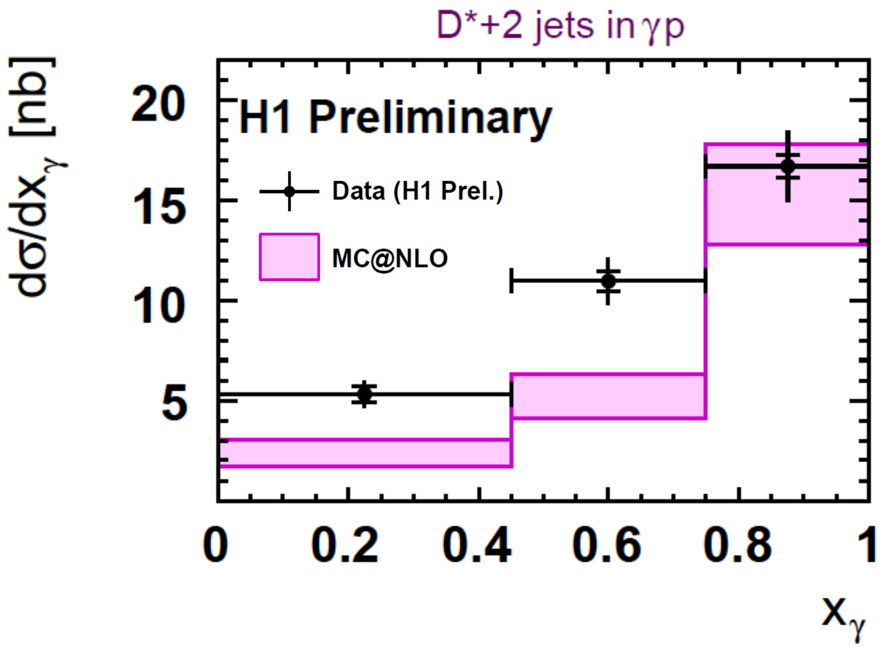
- Longitudinal momentum fraction of the photon carried by the jets:

$$x_\gamma = \frac{\sum_j (E-p_z)_j + \sum_k (E-p_z)_k}{2yE_e}$$

- At low x_γ significant contribution from resolved (quasi-real) photons:
  → Low x_γ sensitiv to the photon PDF



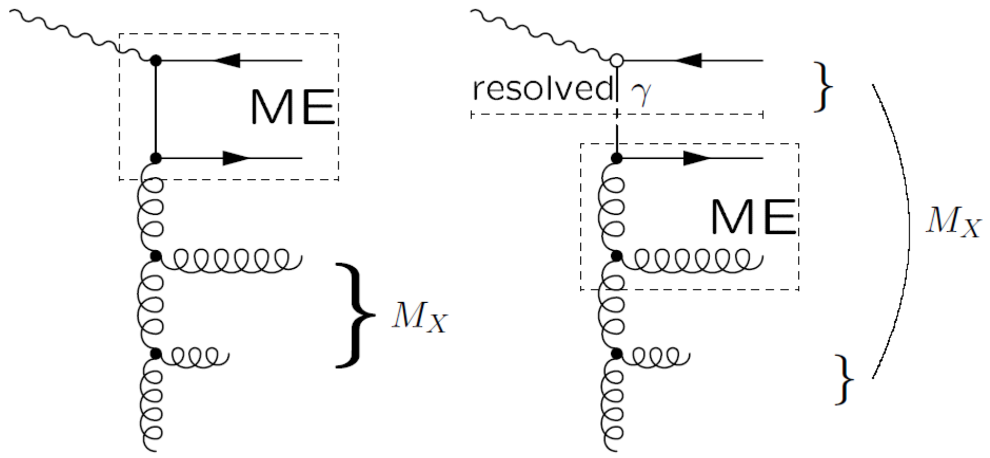


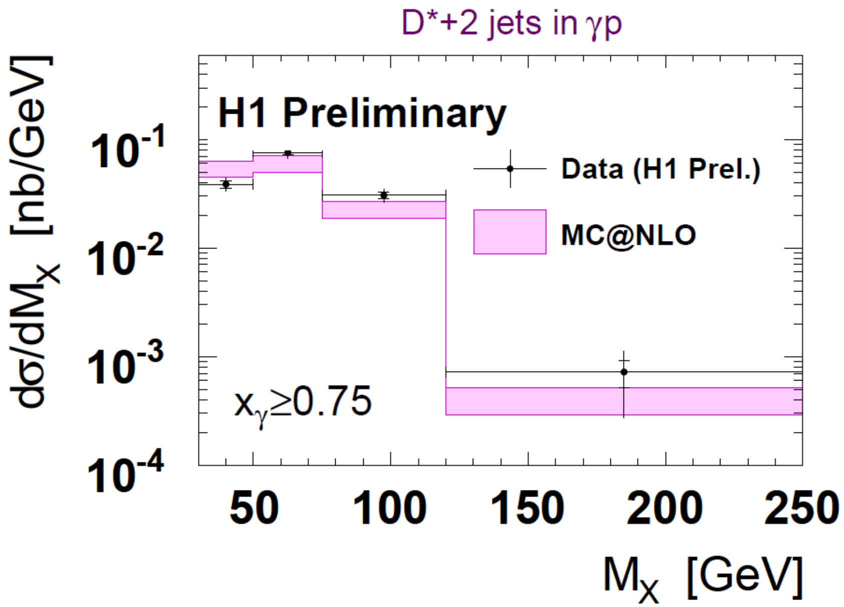


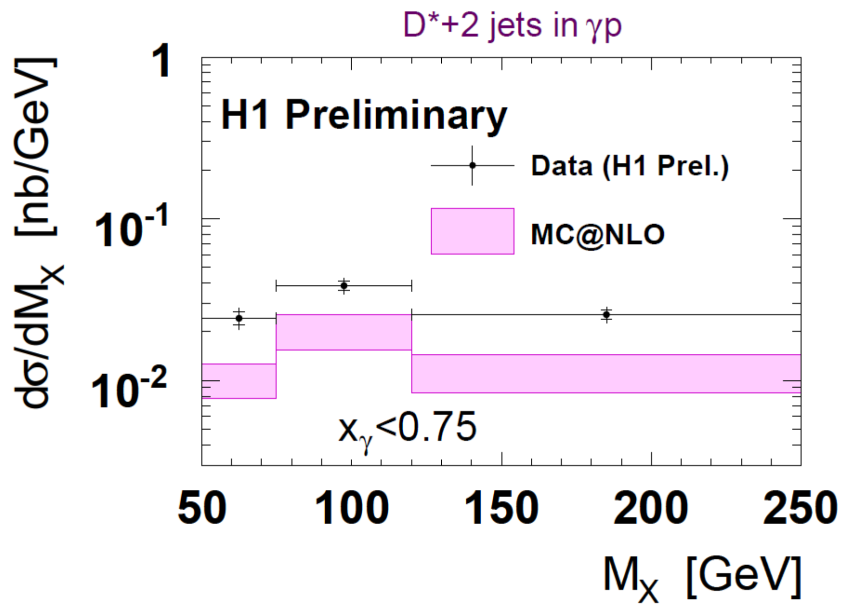
- High x_γ: direct processes well described by either MCs & MC@NLO
- Low x_γ: resolved processes not described by any model, but better by MCs

D*+jets photoproduction

- M_X invariant mass of the remnant from photon & proton side







- M_X not very well described: At high x_γ shape reasonably well described but at low x_γ the normalization is too low

D* production: medium Q^2

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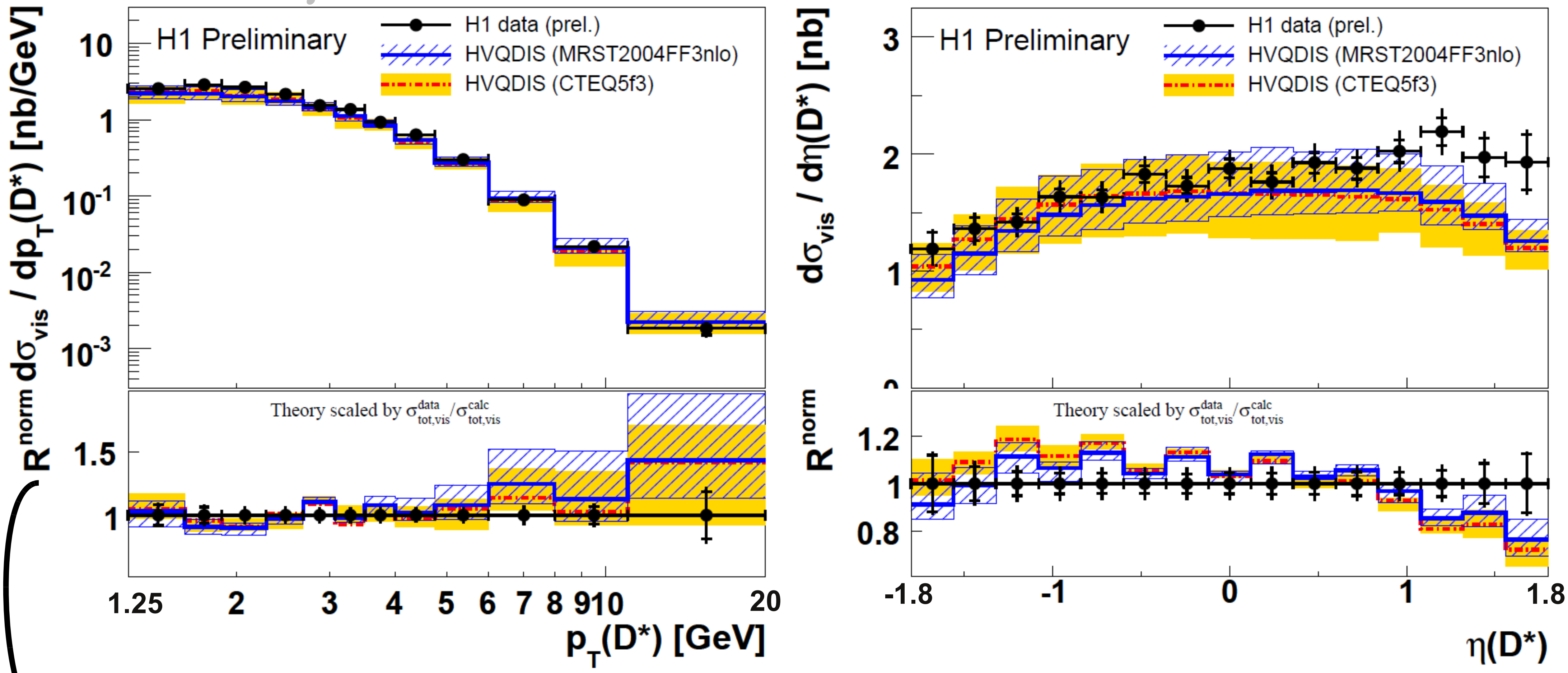

Shape comparison via normalized ratio:

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

- Full HERAII statistics: L = 347 pb^{-1} yields N(D*)~24705
- Total systematic error is 7.6% !
- Well understood detector allows increased Phase Space:

$p_T(D^*)$: > 1.25 GeV and | η (D*) | : < 1.8

- Data are reasonable described by HVQDIS

D* production: medium Q^2

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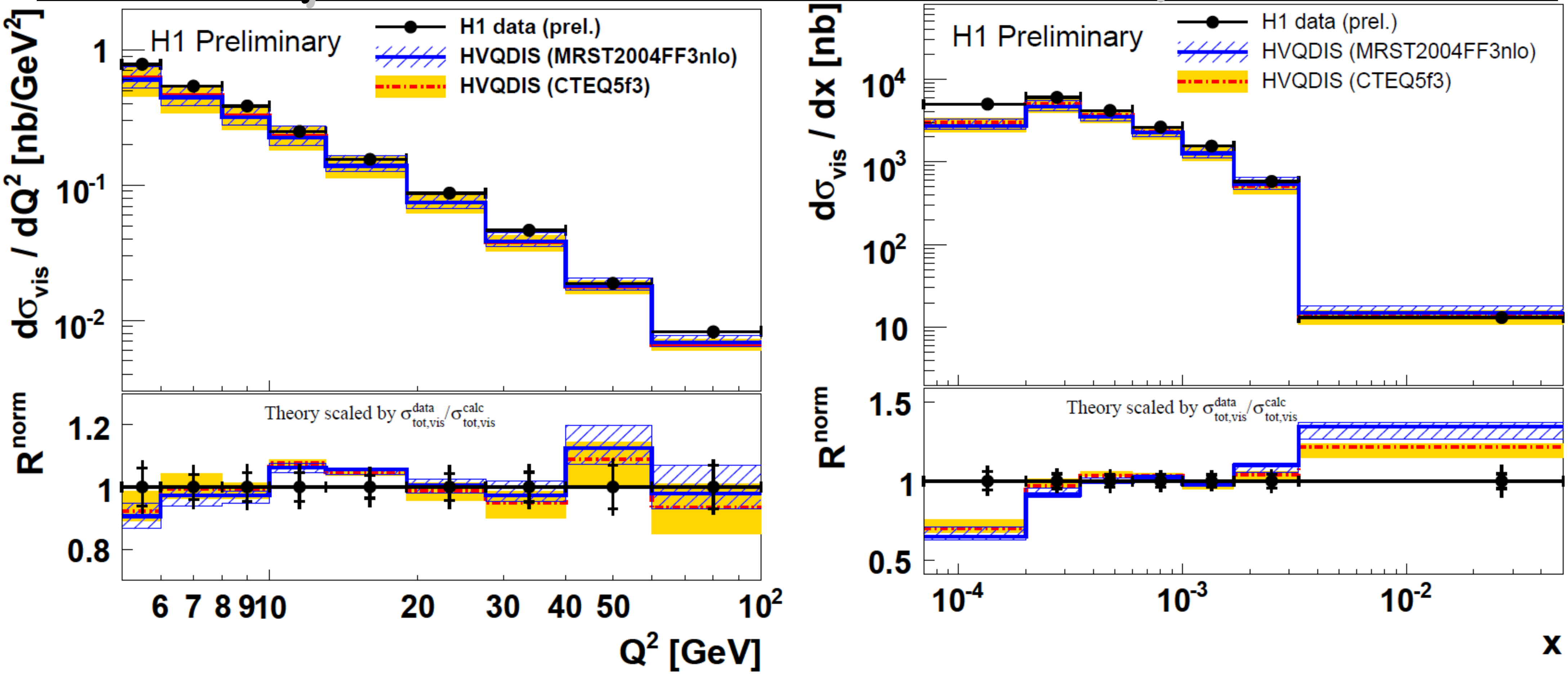
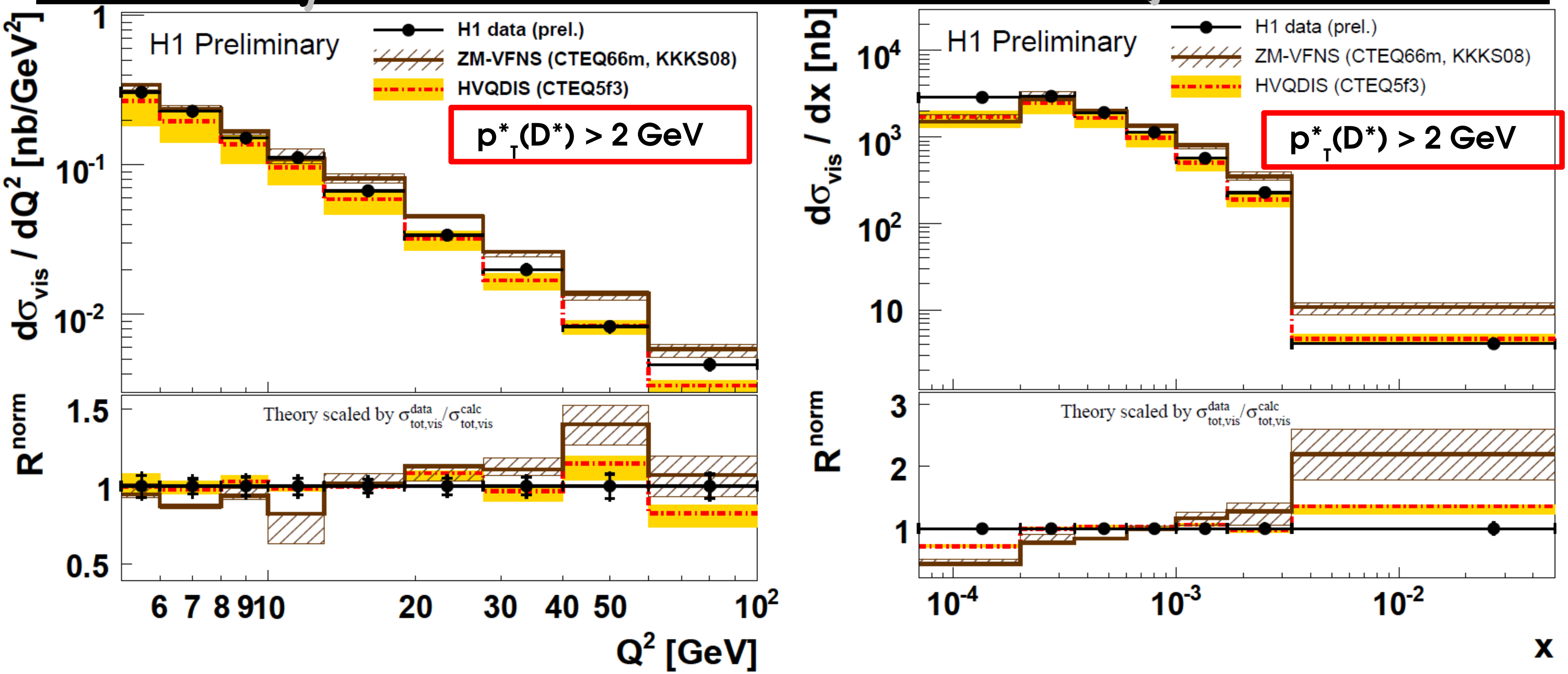


- Theory uncertainty includes scale, mass & fragmentation uncertainty

- HVQDIS describes nicely the Q^2 dependency
- Slope in x not very well reproduced!
- Double differential y-Q^2 has also been measured, can be used to extract $F_2^c(x,Q^2)$

D* production: medium Q^2



- For comparison with ZM-VFNS: Cut in photon-proton rest frame: $p_T^*(D^*) > 2$ GeV
- ZM-VFNS: Theoretical uncertainty taken from scale variations

- Reasonable description of Q^2 by both NLO calculations, HVQDIS is better in shape
- For x ZM-VFNS predicts completely different slope & fails especially at large x

  Remark: Only the most recent PDF sets consider mass effects!

D* production: high Q^2

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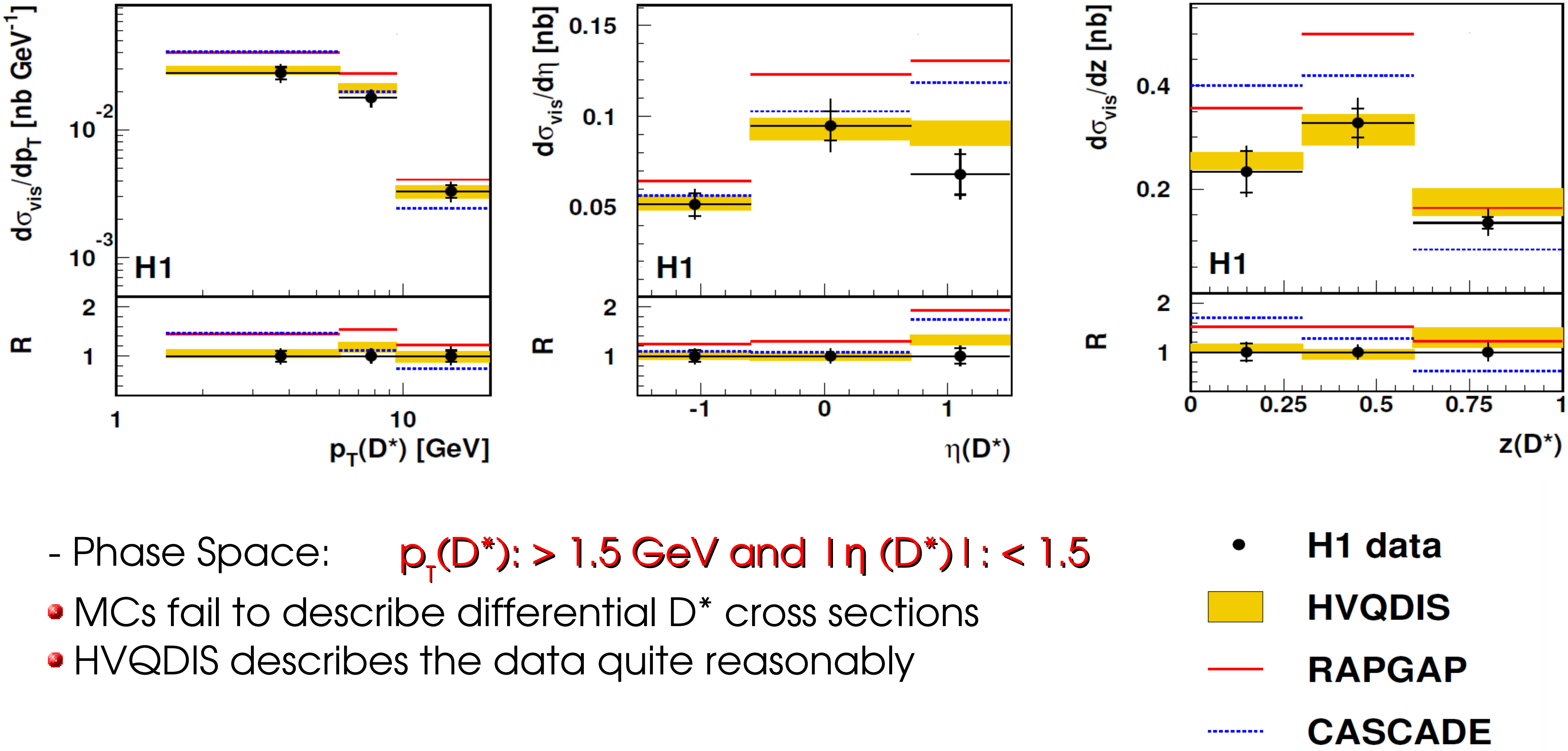
- Full HERAII statistics ($L = 351\ pb^{-1}$)
- Total systematic error: 12%



- Phase Space: $p_T(D^*)$: > 1.5 GeV and $|\eta(D^*)|$: < 1.5

- MCs fail to describe differential D* cross sections
- HVQDIS describes the data quite reasonably

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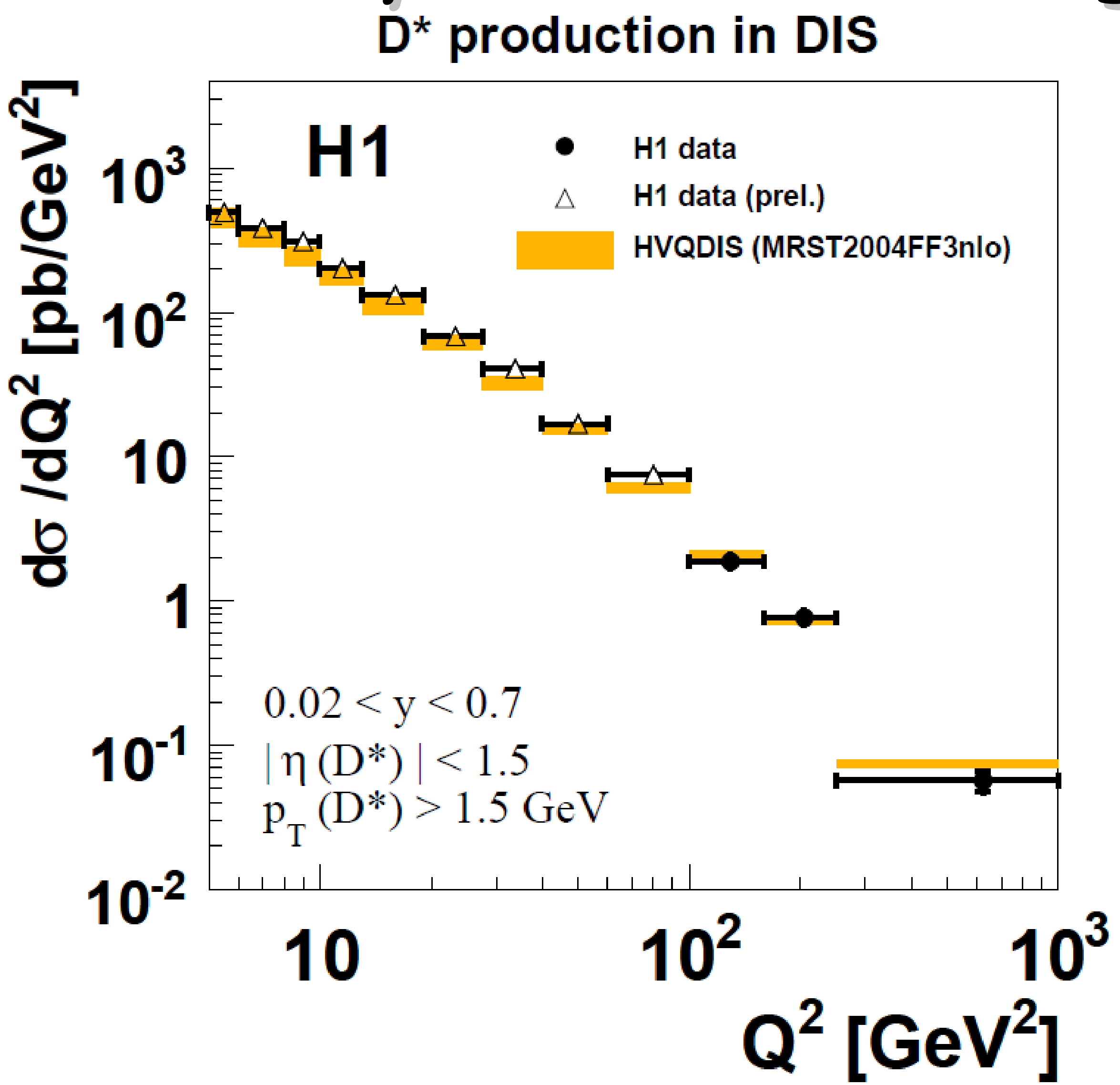
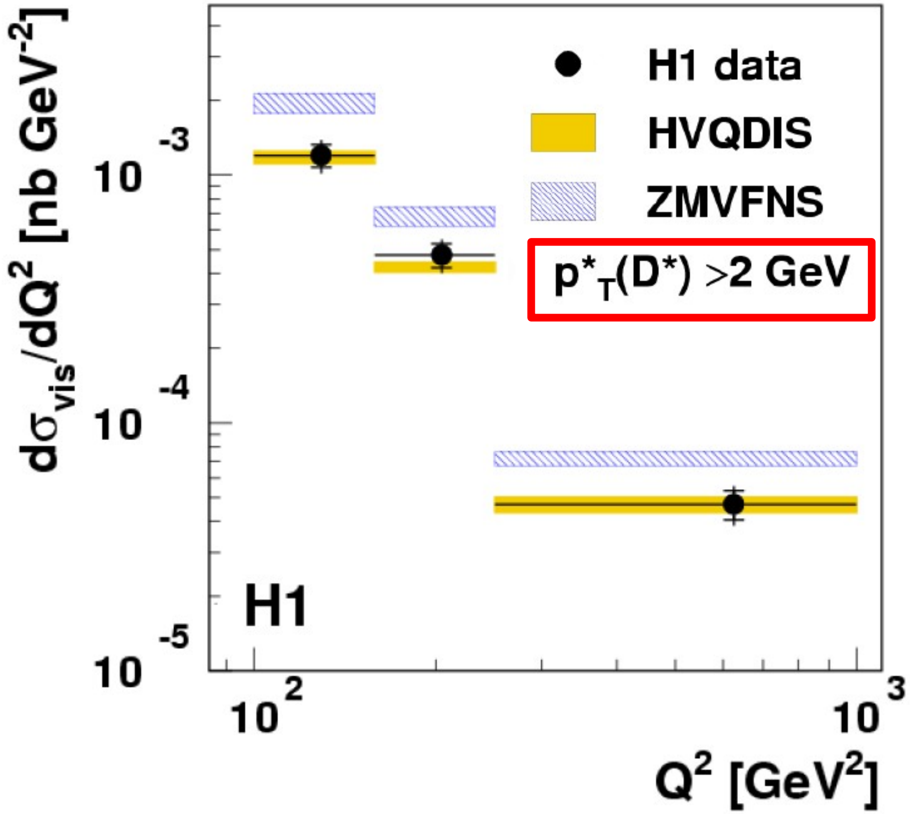
D* production: high Q^2





- Massive FFNS describes cross section over three orders of magnitude!
- Massless ZM-VFNS fails to describe high Q^2 region

Extraction of $F_2^c(x,Q^2)$

$$\frac{d^2\sigma^{c\bar{c}}(x,Q^2)}{dx dQ^2} = \frac{2\pi\alpha_{em}^2}{xQ^4}\cdot\left(\left[1+(1-y)^2\right]\cdot F_2^{c\bar{c}}(x,Q^2) - y^2\cdot F_L^{c\bar{c}}(x,Q^2)\right)$$

Only at high y: 2-3% for this measurement negligible

Experimental method to measure $F_2^c(x,Q^2)$:

Measured cross sections

$$F_2^{c\ \mathrm{exp}}(x,Q^2) = \frac{\sigma_{\mathrm{vis}}^{\mathrm{exp}}(y,Q^2)}{\sigma_{\mathrm{vis}}^{\mathrm{theo}}(y,Q^2)}\cdot F_{2\ \mathrm{full}}^{c\ \mathrm{theo}}(x,Q^2)$$

Using NLO (FFNS)

- Extrapolation uncertainty from variations of scale, mass, fragmentation
- At medium Q^2 measured D* cross section covers only 30%
  if $p_T(D^*) > 1.5$ GeV & $|\eta(D^*)| < 1.5$

D* production: F_2^c @ high Q^2

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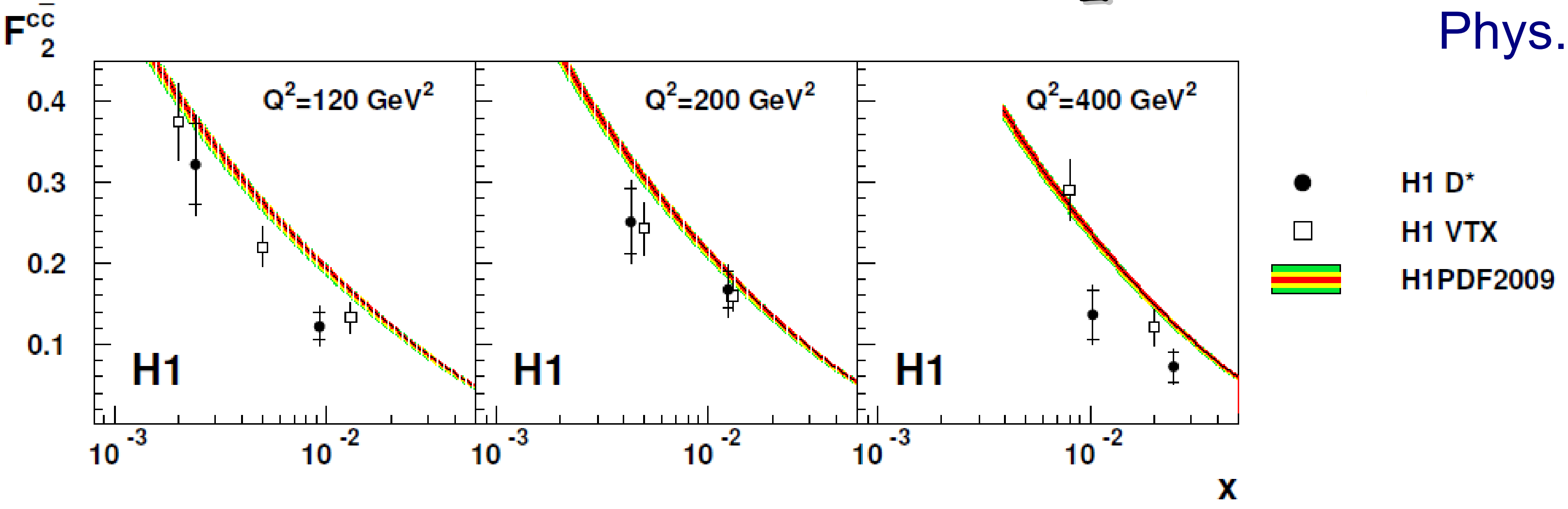
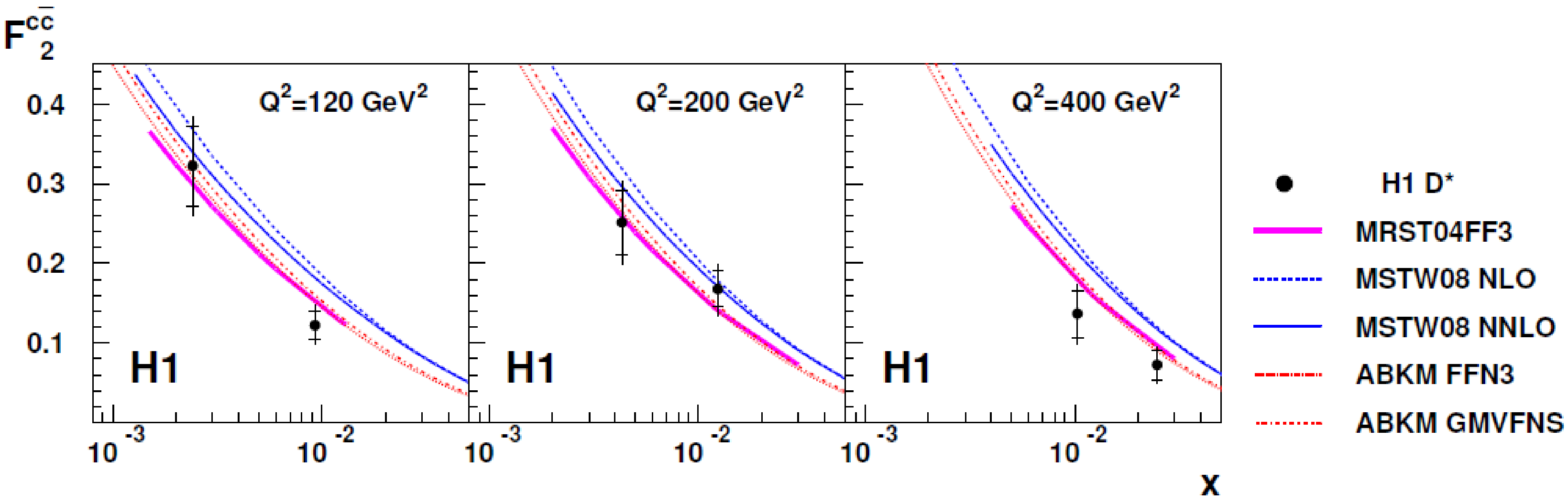
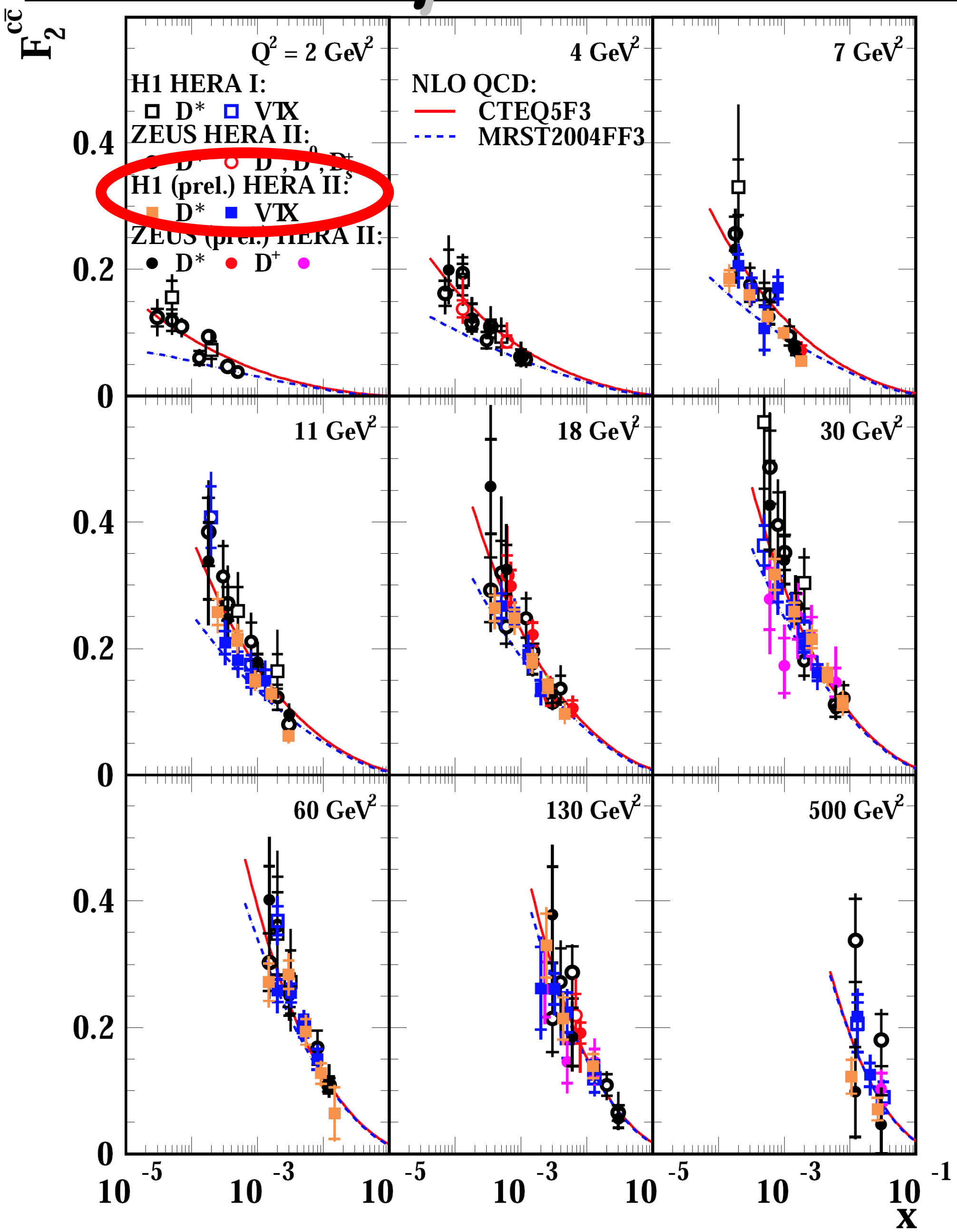




- Reasonable agreement between two experimental methods
- H1PDF2009 overall slightly above data
- Within uncertainty data described by MSTW, ABKM

Comparison of $F_2^c(x,Q^2)$ results



- HVQDIS using different proton PDFs describes the F_2^c data reasonable
- Nice agreement between different experimental methods & experiments
- Details on H1 VTX → (1169, P. Thompson)
- Gain in precision by combining data within one experiment and by combining with ZEUS

Combination of $F_2^c(x,Q^2)$

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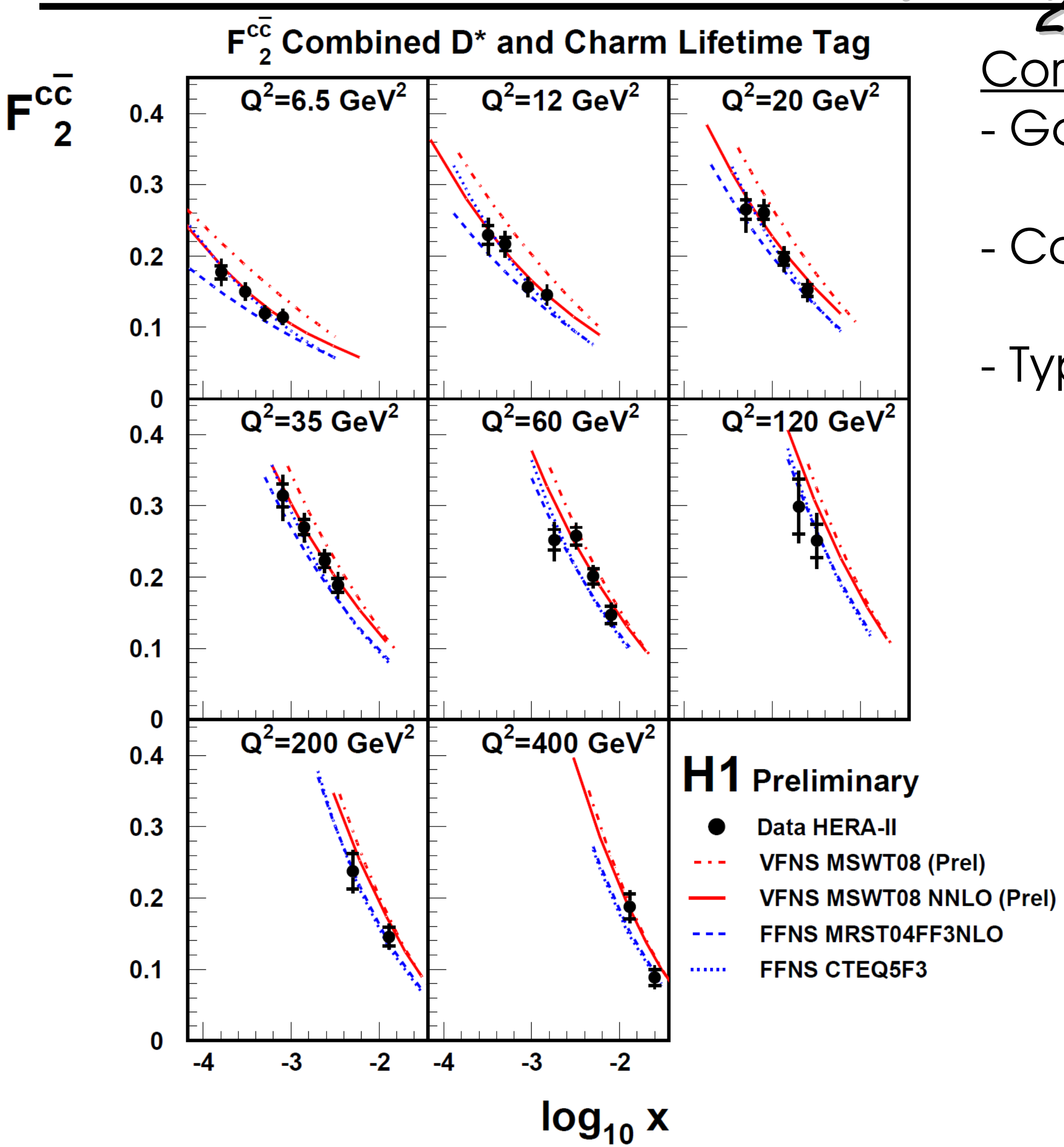
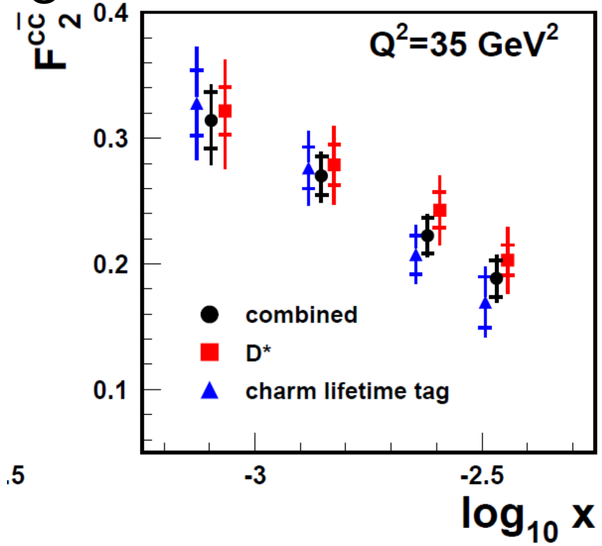


Combine D* and lifetime results:

- Gain in precision because of different systematic uncertainties
- Correlation of Systematic uncertainties taken into account
- Typical gain ~25%:



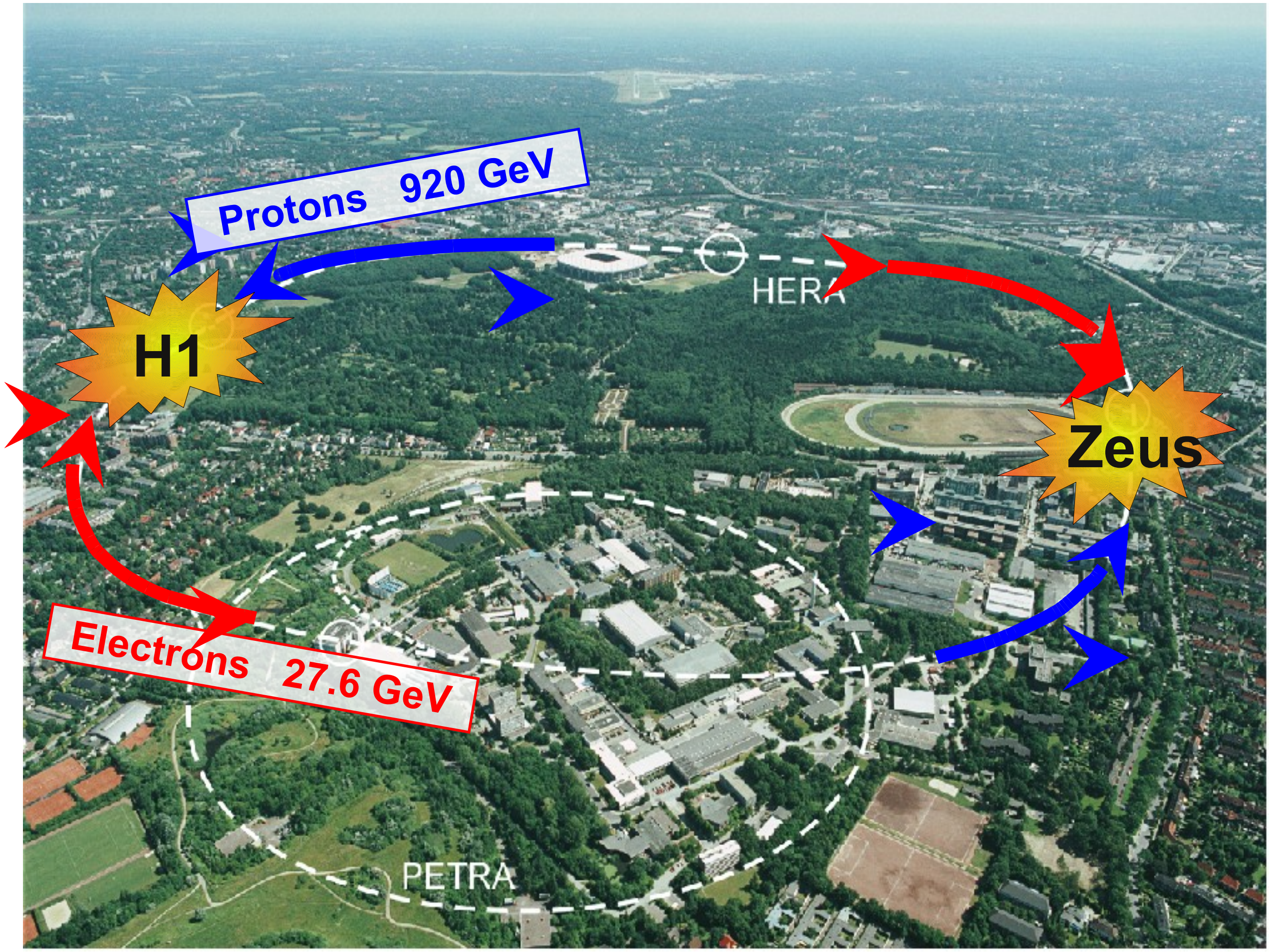
- Data are reasonable described
- At low Q^2 data can discriminate between models
- For HERA combined results:
  → see Talk by M. Corradi (1159)

Conclusions

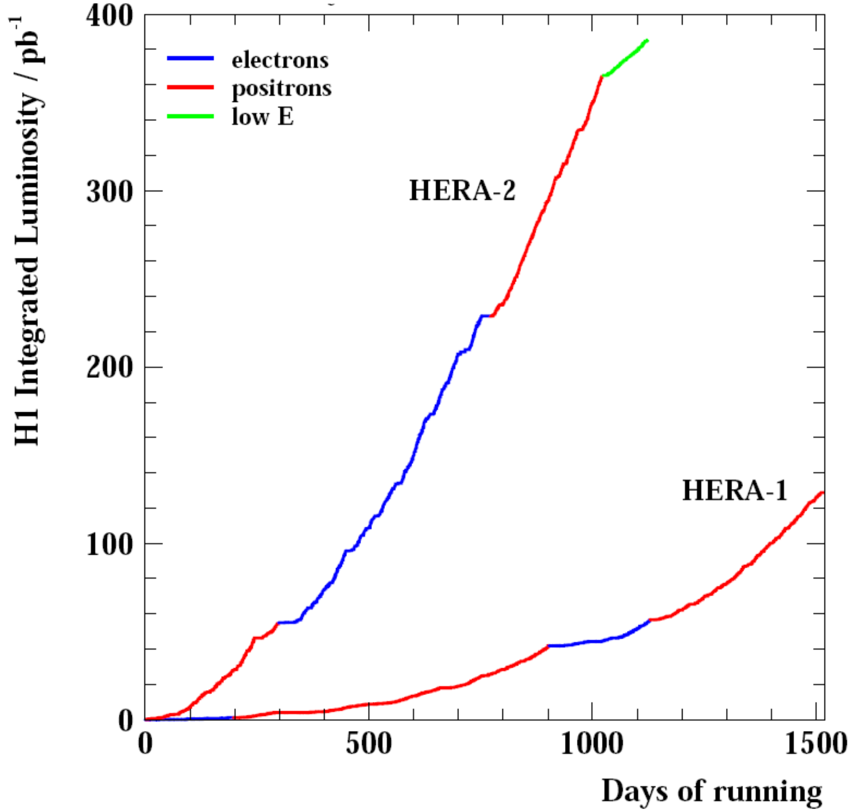
- Full H1 HERA II data sample analyzed for photoproduction, medium & high Q^2 D* production:
  - Photoproduction: MCs & MC@NLO dont describe resolved photon domain
  - DIS: - HVQDIS describes Data reasonably well
    - ZM-VFNS not able to describe the D* data
- Extracted $F_2^c(x,Q^2)$ from D* data & combined with life-time data:
  - Gain in precision via combination of data
  - Reasonably described by different calculations

Backup

The HERA Collider (1994-2007)



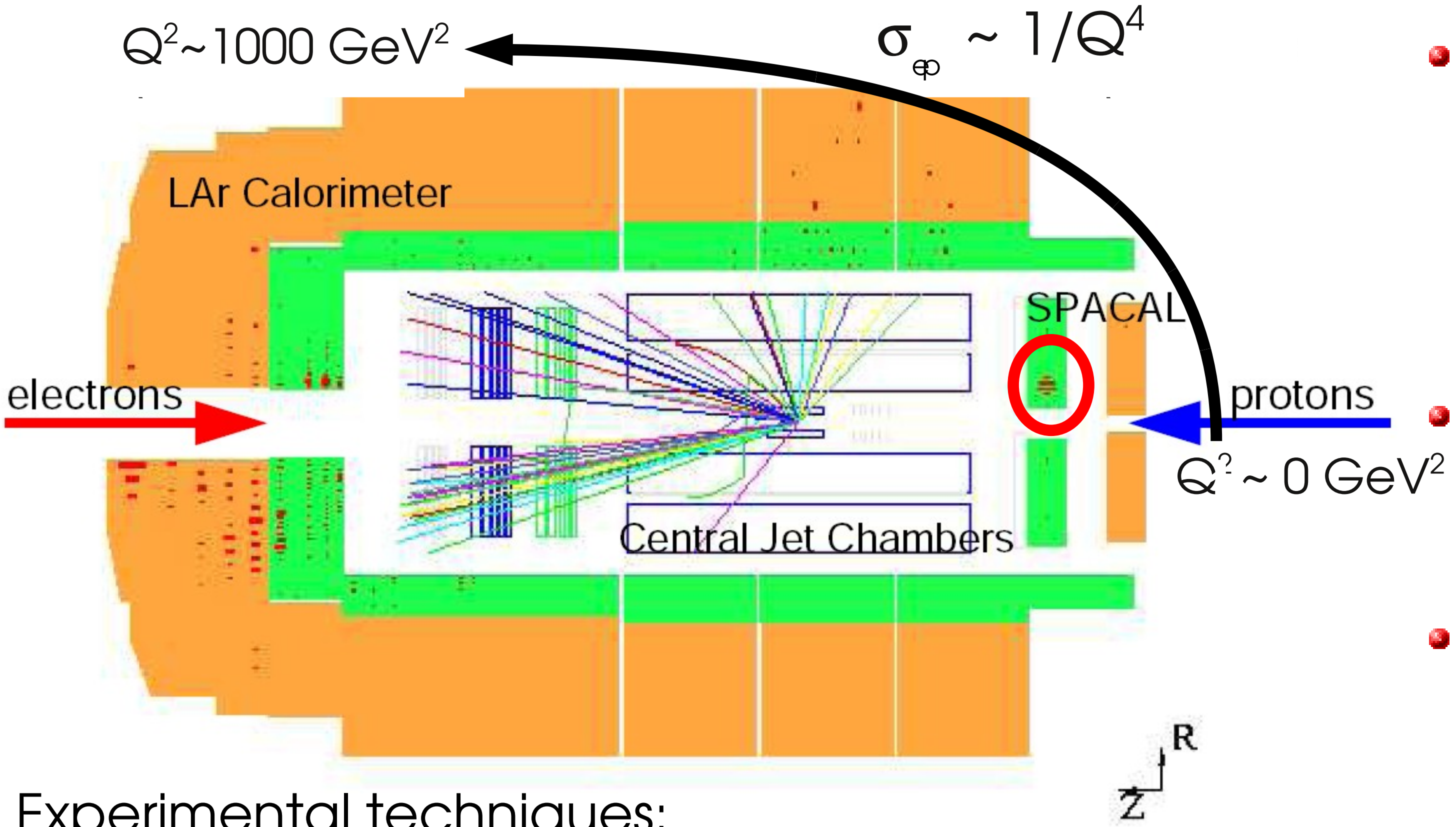
Collected Data samples:



--> Two multi-purpose detectors: H1 & Zeus

--> Collected Luminosity: HERAI + HERAII ~ 0.5 fb^{-1}

Event selection & techniques



- Untagged electron:
  Q^2 ~ 0 GeV^2
  Track based final states:
  H1 Fast Track Trigger!
- Scattered electron in backward calorimeter:
  5 < Q^2 < 100 GeV^2
- OR in main calorimeter:
  100 < Q^2 < 1000 GeV^2

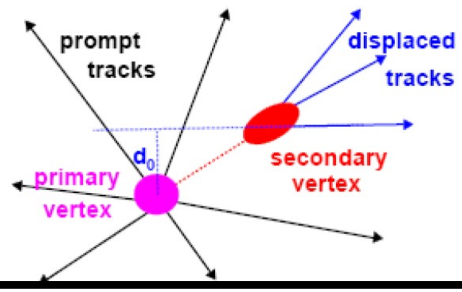
Experimental techniques:

- Fully reconstructed D*:
  total BR of 2.57%

$$D^{*\pm} \longrightarrow D^0 \pi^{\pm}_{slow} \longrightarrow (K^{\mp}\pi^{\pm})\pi^{\pm}_{slow}$$

- Inclusive method using lifetime of charmed mesons

→ More details: Talk by P.Thompson



Theoretical models

Factorisation ansatz:

$$d\sigma = \sum_{i,j,k} f_j^B(x_2, \mu_f) \otimes d\hat{\sigma}_{ij\to kX}(\mu_f) \otimes D_k^H(z, \mu_f)$$

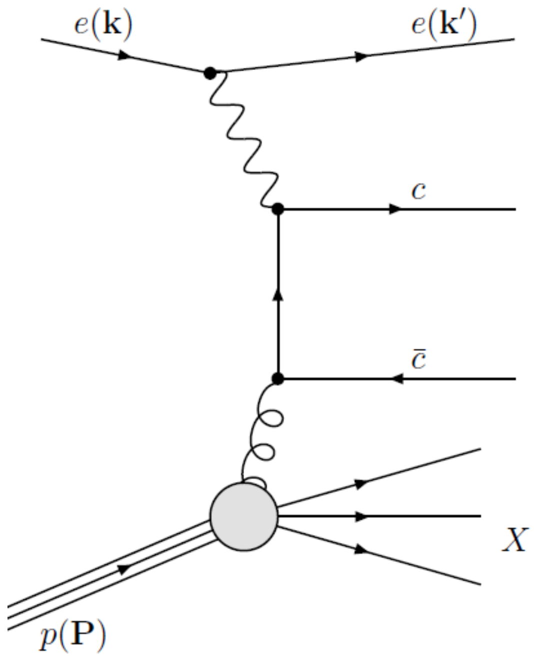
Parton density functions (PDFs) from global fits to data

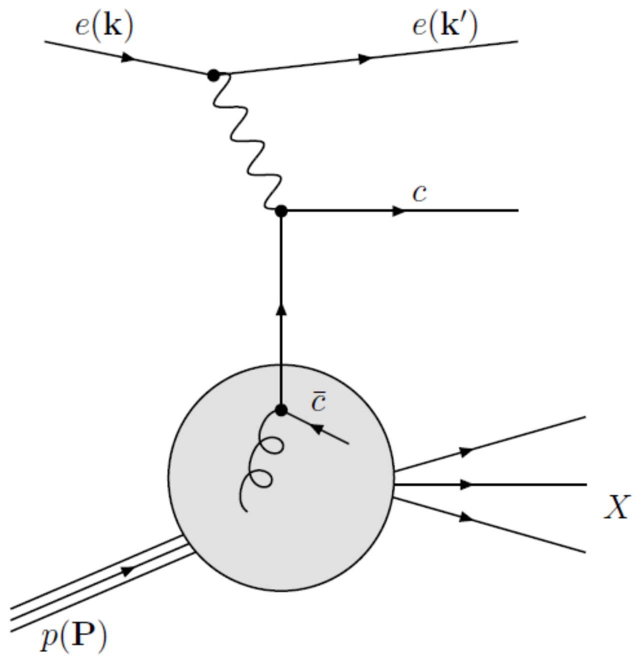
Matrix element: calculable to different oders of α_s

Fragmentation function: from data

Many approaches on the market:

- NLO(α_s^2): HVQDIS (FFNS, massive) vs. ZMVFNS (ZM-VFNS, massless)

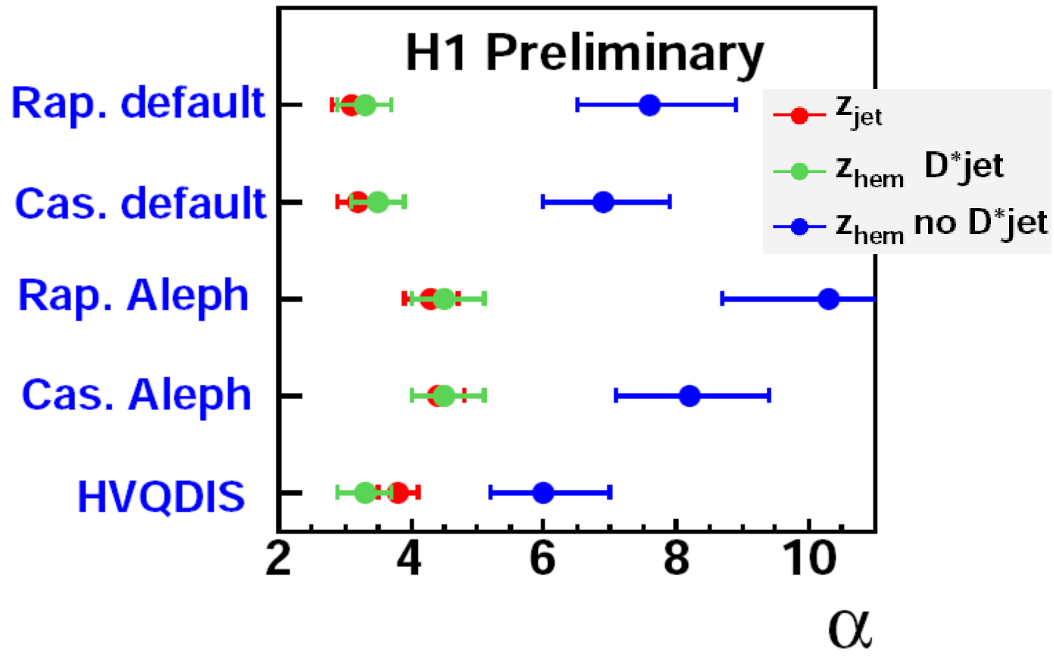




Fragmentation function

- If a hard scale is involved:
  - jet- & hemisphere method agree well
  - FF also agrees with ZEUS and LEP data
- If no hard scale is involved:
  - discrepancy at charm production threshold in QCD models
  - much harder fragmentation

More information:
http://arxiv.org/abs/0808.1003v2

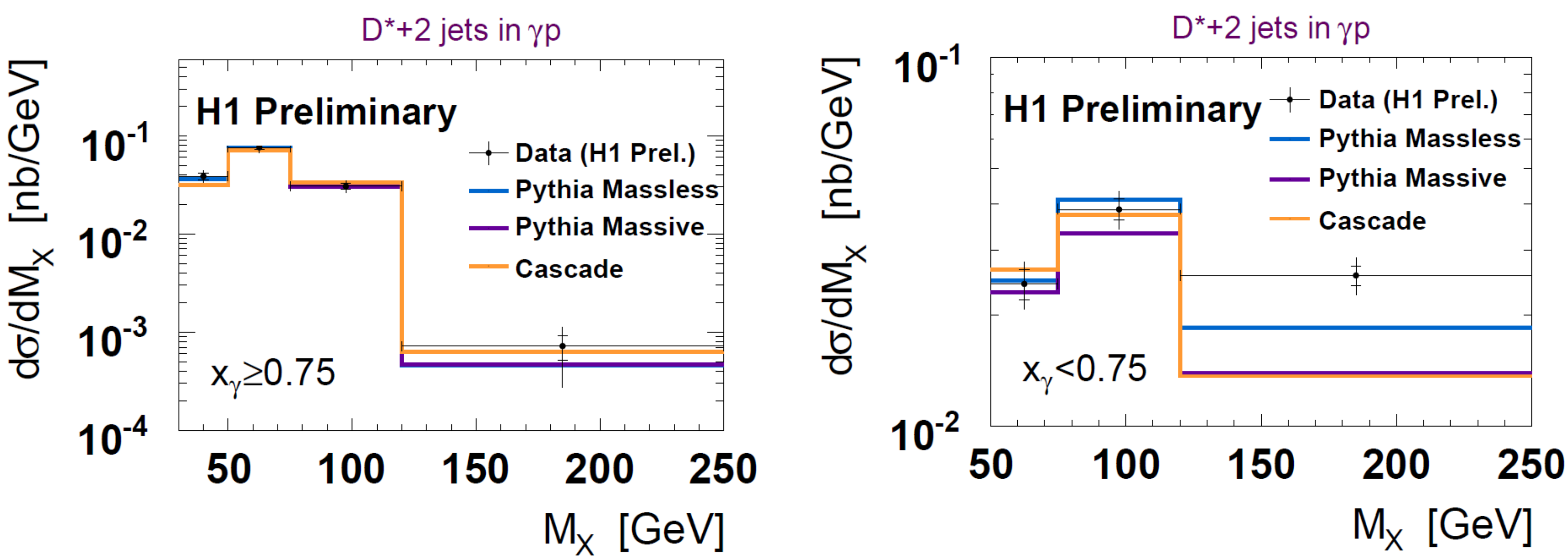


- Fragmentation uncertainty from FF values for charm production:

	HVQDIS:	CASCADE:	RAPGAP:
at-threshold:	$\alpha = 6.0^{+1.0}_{-0.8}$	$\alpha = 8.2 \pm 1.1$	$8.7 < \alpha < 12.2$
above-threshold:	$\alpha = 3.3 \pm 0.4$	$\alpha = 4.6 \pm 0.6$	$3.9 < \alpha < 5.0$

- Threshold position from $\hat{s}$ (cms energy of hard subprocess): $70 \pm 20\ \mathrm{GeV}^2$ $70 \pm 20\ \mathrm{GeV}^2$ $70 \pm 20\ \mathrm{GeV}^2$

D*+jets photoproduction



- Parameters of the MCs & MC@NLO:

generator	proton (u)pdfs	photon pdfs
Pythia massive	CTEQ 6M NLO	SAS 2D LO
Pythia massless	CTEQ 6L LO	GRV-G LO
Cascade	Set A0	–
MC@NLO	CTEQ 6.6	GRV

- High x_γ: direct processes well described by MCs
- Low x_γ: resolved processes not described by any model, especially at high M_X

D*+jets photoproduction

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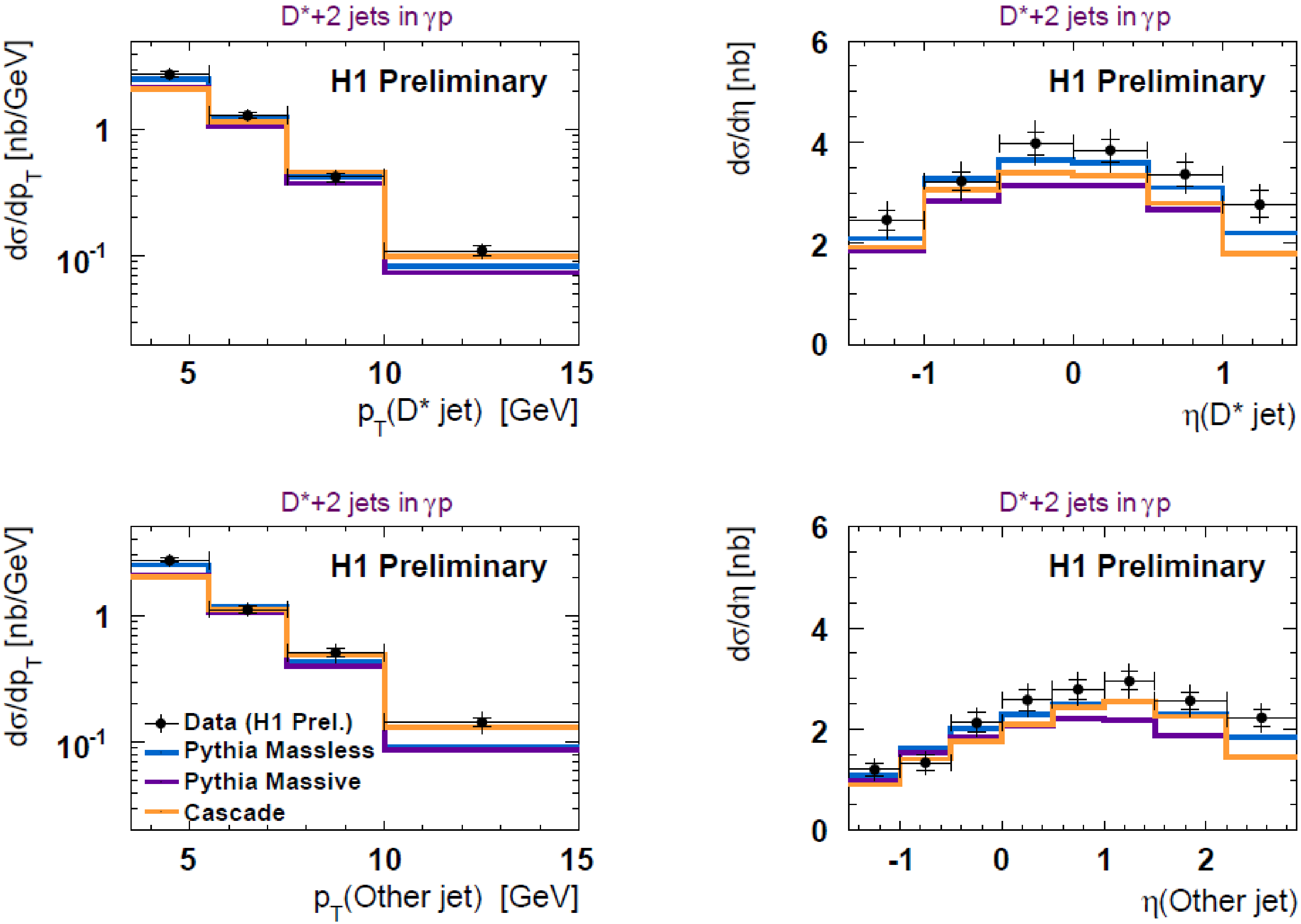

- In general described by PYTHIA (CTEQ6) and CASCADE (A0)

D^* production: medium Q^2

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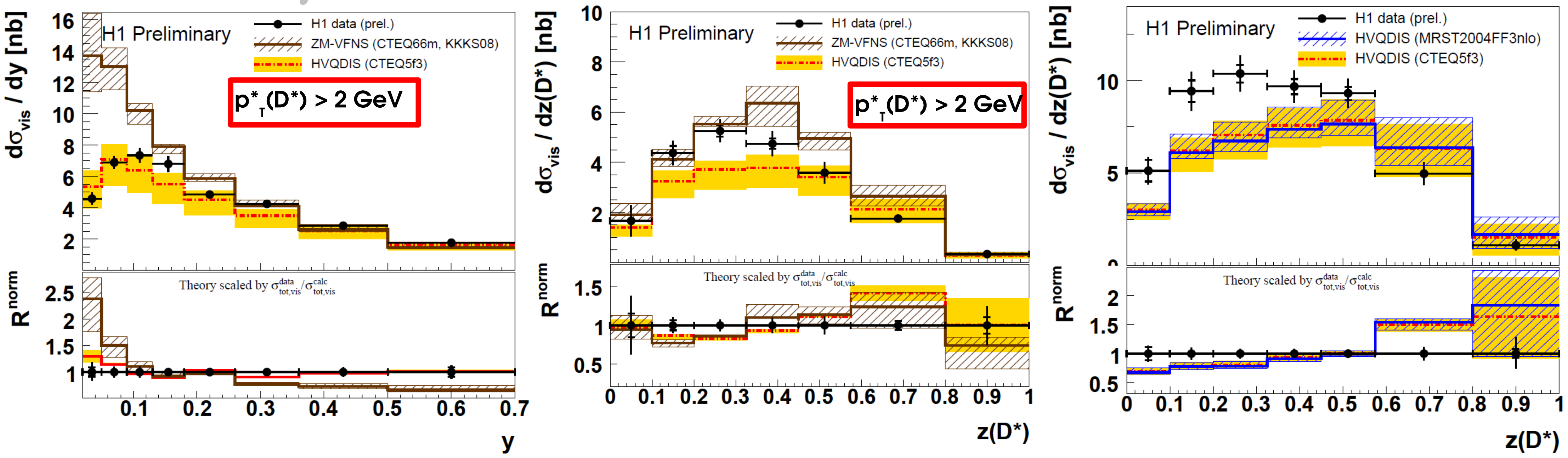
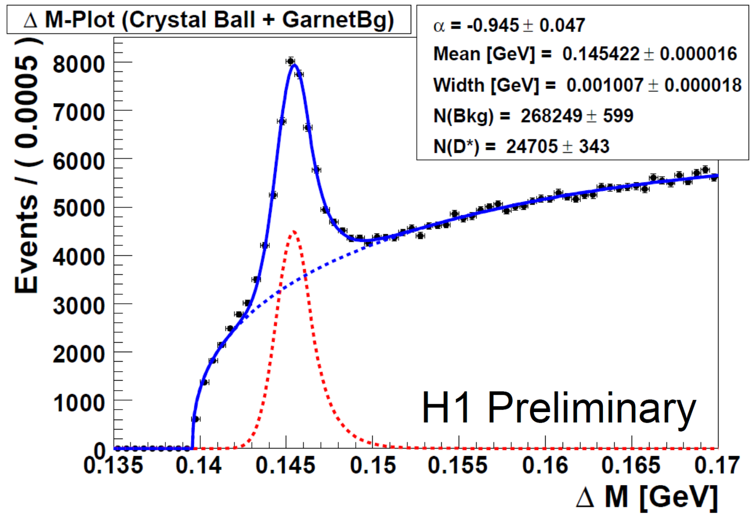
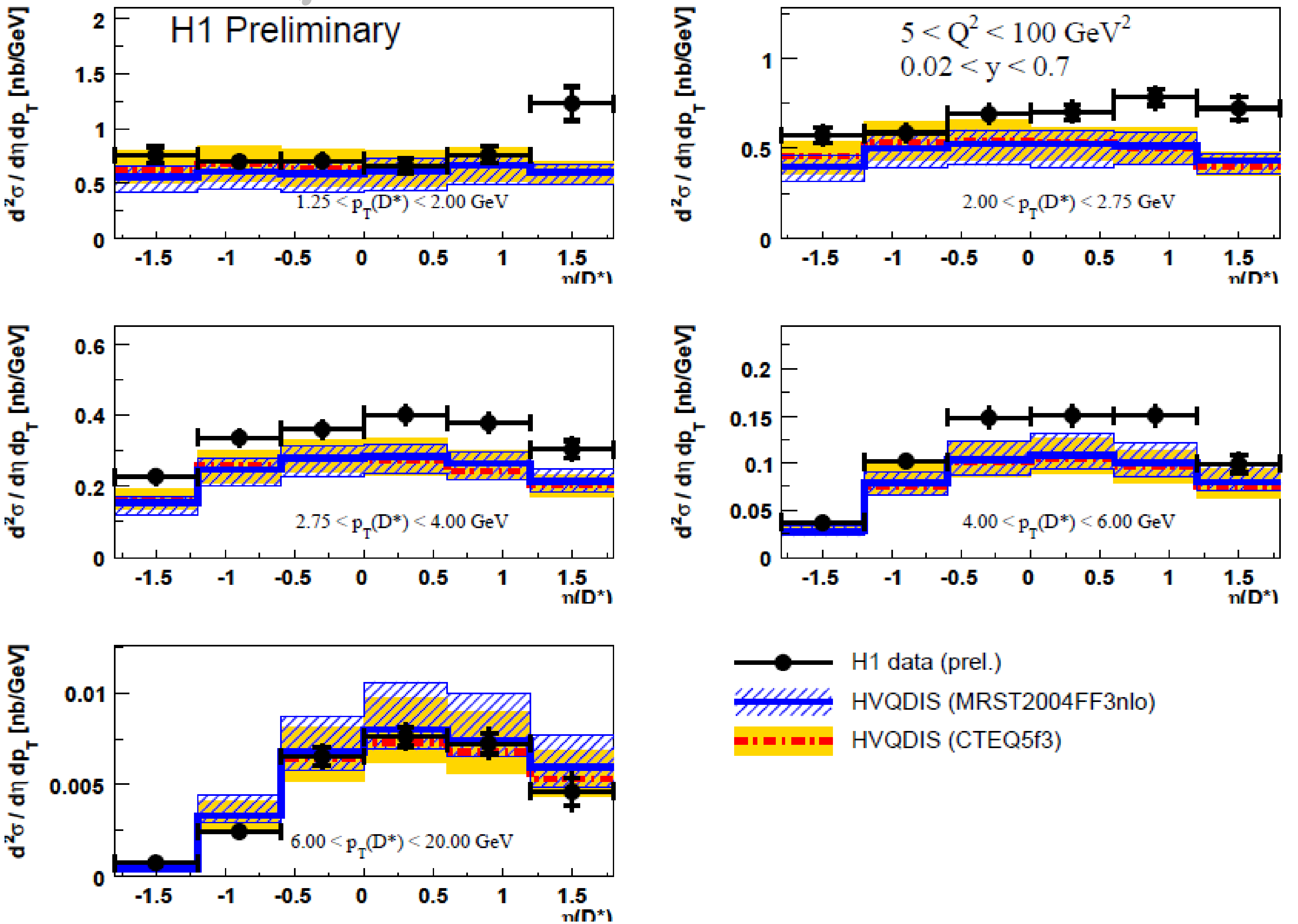


- As seen in x also in y ZM-VFNS fails completely!
- HVQDIS overshoots at low y
- $z(D^*)$ reasonable described by ZM-VFNS & HVQDIS
- Without the additional $p_T^*(D^*)$ cut HVQDIS fails to describe $z(D^*)$



D* production: medium Q^2



- In general $\eta(D^*)$-$p_T(D^*)$ cross section reasonable described by HVQDIS
- Forward direction: HVQDIS undershoots data located at low $p_T(D^*)$

D* production: high Q^2

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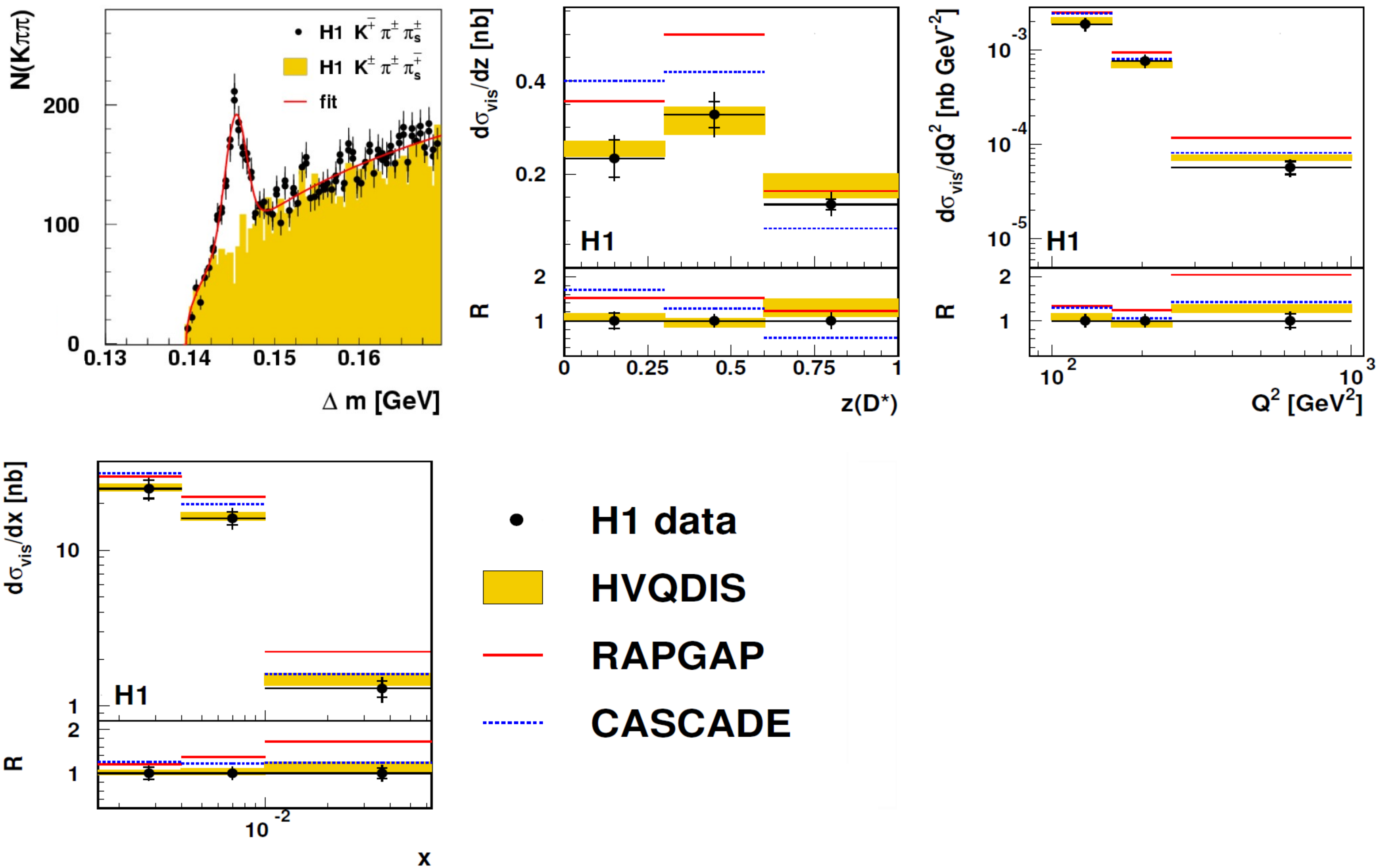

- Massive FFNS describes cross sections reasonably well
- MCs predict different slopes and fail completely to predict the Q^2 slope