Open Charm Physics at H1

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for the H1 Collaboration

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- Introduction
  - Charm production mechanism
  - $D^{\star\pm}$ tagging
- Measurement of Charm Cross Sections
  - single differential Cross Sections in DIS
  - single and double differential Cross Section in γP
- Direct measurements of the gluon density
  - $g(x_g)$ in DIS
  - $g(x_g)$ in photoproduction
- Comparison of results, conclusion

Motivation

Why Charm at HERA?

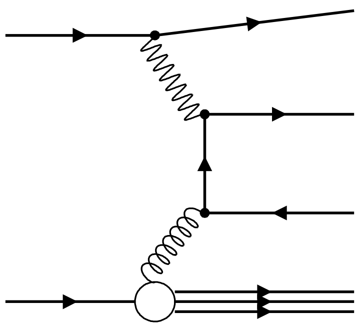
- Charm cross sections at HERA are large, i.e. charmed mesons are produced copiously
- Charm cross sections are sensitive to the production mechanism
- Test prediction of perturbative QCD in terms of total and differential cross sections (σ_{tot}, $d\sigma/d\eta$, . . .)
- Good method for direct measurement of the gluon density in the proton and the photon

Charm Production Mechanism

direct process

Boson Gluon Fusion (BGF)

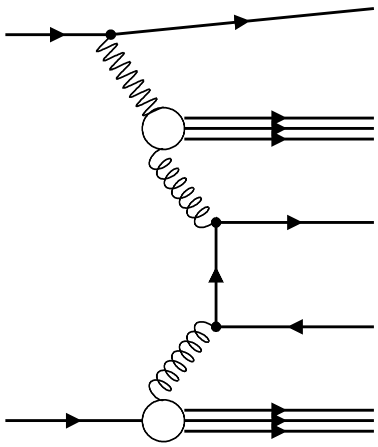
$\mathcal{O}(\alpha\alpha_s)$



hadronic process

resolved photon

$\mathcal{O}(\alpha/\alpha_s) \times \mathcal{O}(\alpha_s^2)$



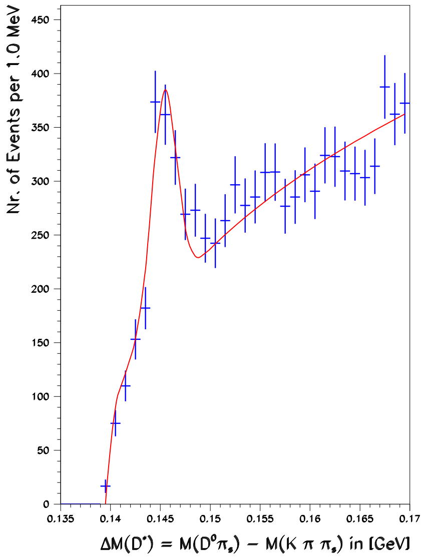
- charm is predominantly produced in pairs by the Photon Gluon Fusion mechanism
- charm production is dominated by the exchange of quasi real photons
- resolved contributions are large for $Q^2 \approx 0$ GeV^2 ($\mathcal{O}(20\%)$) and vanish for higher Q^2

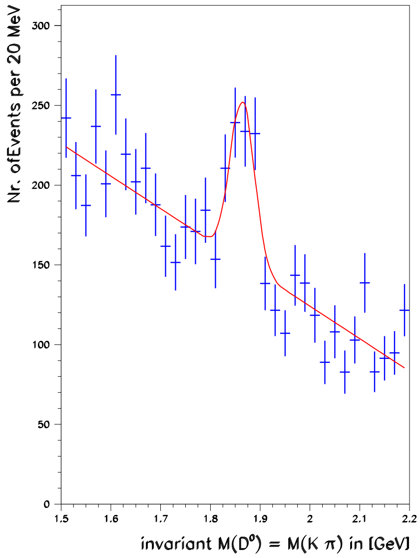
Detection of Open Charm

Charm is tagged through the reconstruction of $D^{\star\pm}$ mesons

$$\overset{(-)}{c} \longrightarrow D^{\star\pm} \longrightarrow \overset{(-)}{D^0}\ \pi_s^{\pm} \longrightarrow K^{\mp}\pi^{\pm}\pi_s^{\pm}$$

The well known ΔM method is used to identify $D^{*\pm}$ mesons





- $\Delta M = m_{D^\star} - m_{D^0} = 145.4$ MeV/c^2
- Fragmentation fraction $(c \to D^\star) = (0.260 \pm 0.021)$
- Branching ratio $(D^\star \to K\pi\pi) = (0.0273 \pm 0.0011)$

Two kinematical regions are distinguished:

Deep Inelastic Scattering DIS	Photoproduction γp
$Q^2 > 2$ GeV^2	$Q^2 < 0.01$ GeV^2

Total $D^\star$ Cross Sections in DIS and γp

DIS Cross Sections

- The total cross section is measured in the visible range as:

  $\sigma(ep \to D^\star X) = 5.63 \pm 0.66(stat)^{+0.85}_{-0.68}(syst)$ nb

  $2 < Q^2 < 100$ GeV^2, $0.01 < y < 0.7$
  $p_t(D^\star) > 1.5$ GeV/c, $|\eta(D^\star)| < 1.5$

- Differential cross sections are measured as function of $p_t(D^\star)$, $p_t^*(D^\star)$ (p_t in the $\gamma^* p$ CMS) , $\eta(D^\star)$, Q^2 and $x_{BJ} = \frac{Q^2}{2p \cdot q} = \frac{Q^2}{ys}$

γp Cross Sections

- The Total cross section is measured in the visible range as:

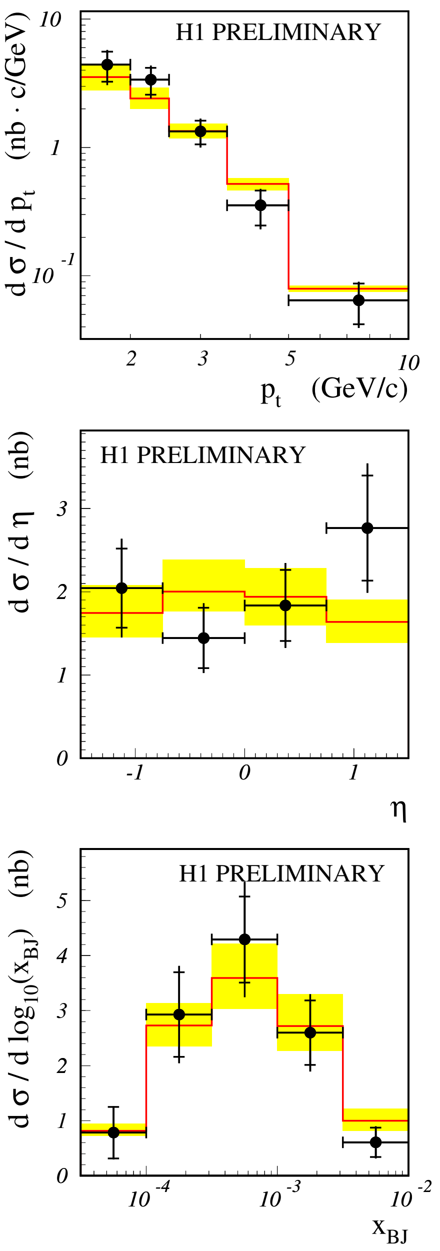
  $\sigma(ep \to D^\star X) = 4.31 \pm 0.42(stat)^{+0.66}_{-0.57}(syst)$ nb

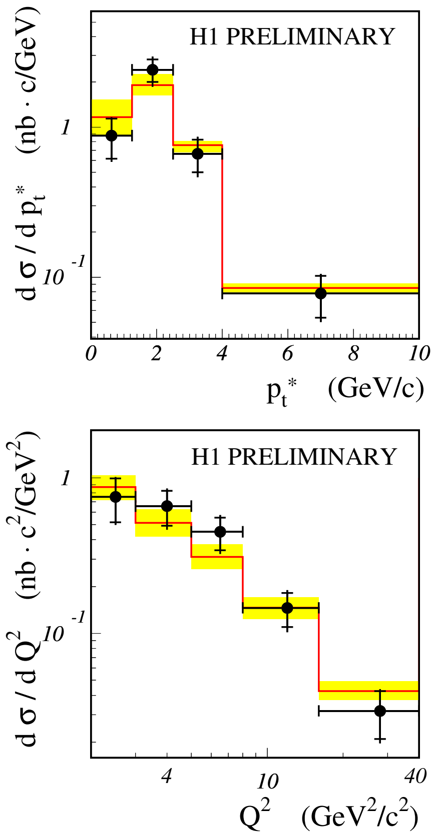
  $Q^2 < 0.01$ GeV^2, $0.29 < y < 0.62$
  $p_t(D^\star) > 2.5$ GeV/c, $|\eta(D^\star)| < 1.5$

- Differential cross sections are measured as function of $p_t(D^\star)$ and $\eta(D^\star)$ for $W_{\gamma p} = \sqrt{ys} = 194$ GeV and $W_{\gamma p} = 88$ GeV
- Double differential cross sections are measured in bins of $p_t(D^\star)$ and $\eta(D^\star)$ for $W_{\gamma p} = 194$ GeV

Differential $D^\star$ Cross Sections in DIS

$$\frac{d\sigma(ep \rightarrow D^\star X)}{d(p_t, p_t^*, \eta, Q^2, x_{BJ})}$$





full points: $D^{\star\pm}$ data

inner errors: stat

outer errors: stat $\oplus$ syst

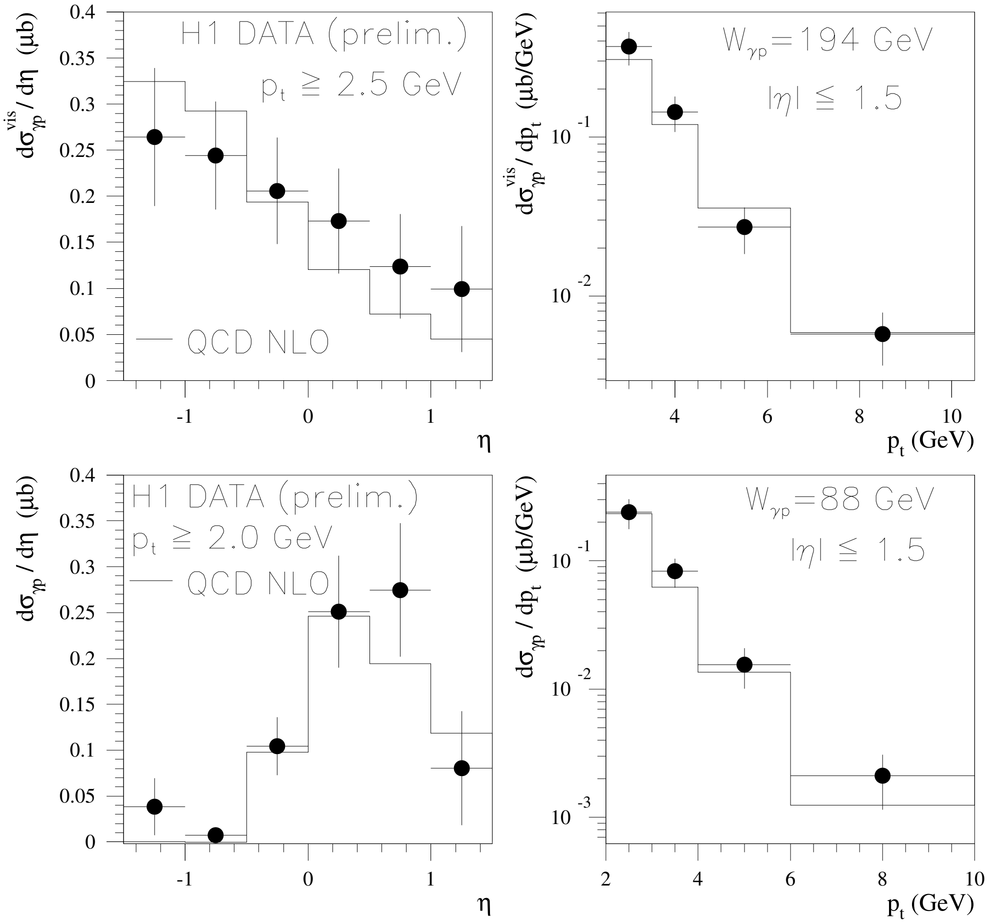
HVQDIS NLO (GRV 94 H0)

band: m_c=1.3 . . . 1.7 GeV/c^2

using Peterson Fragmentation

$D^\star$ Cross Sections in γp, single differential

$$\frac{1}{2\cdot BR(c\rightarrow D^\star)}\cdot\frac{d\sigma(\gamma p\rightarrow D^\star X)}{d(\eta,p_t)}$$



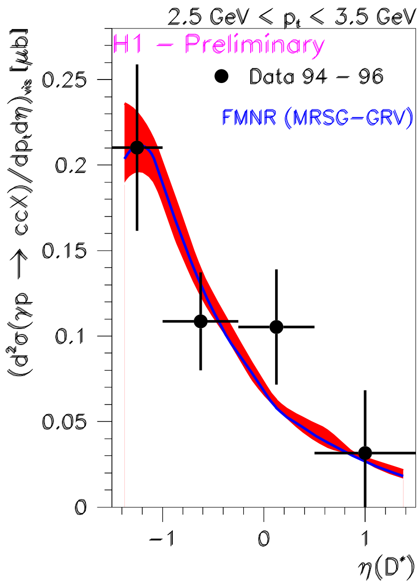
full points: $D^{\star\pm}$ data

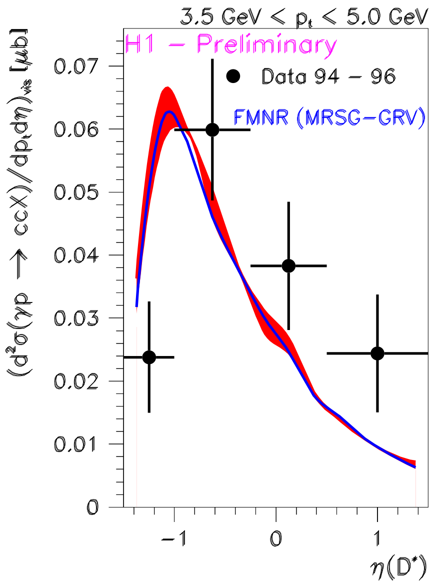
errors: statistical only
systematic errors of $\mathcal{O}(14\%)$ not shown
FMNR NLO (MRS(G) - GRV)

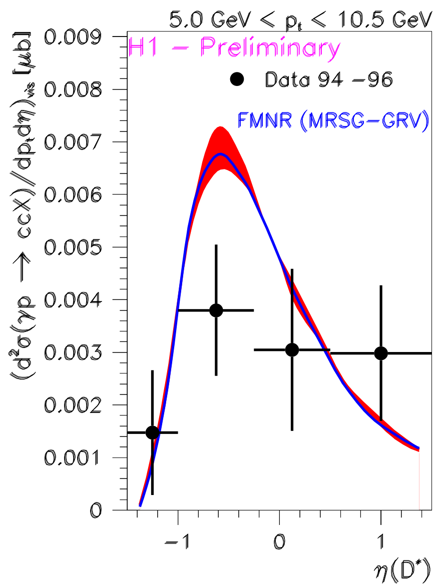
using Peterson Fragmentation

$D^\star$ Cross Sections in γp, double differential

$$\frac{1}{2\cdot BR(c\to D^\star)} \cdot \frac{d^2\sigma(\gamma p\to D^\star X)}{dp_t d\eta} \text{ in bins of } p_t$$







$\langle W_{\gamma p}\rangle = 196$ GeV^2, $Q^2 < 0.01$ GeV

full points: $D^{\star\pm}$ data

errors: statistical only

systematic errors of $\mathcal{O}(14\%)$ not shown

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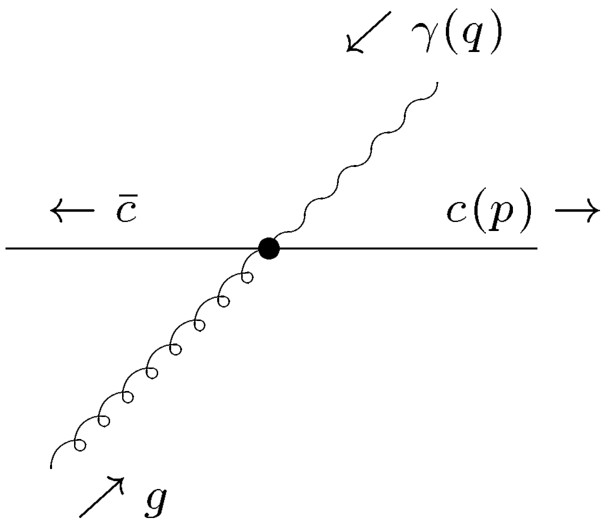
using Peterson Fragmentation

Reconstruction of x-Gluon



Reconstruction of Kinematics
in γg CMS - System
(LO picture)

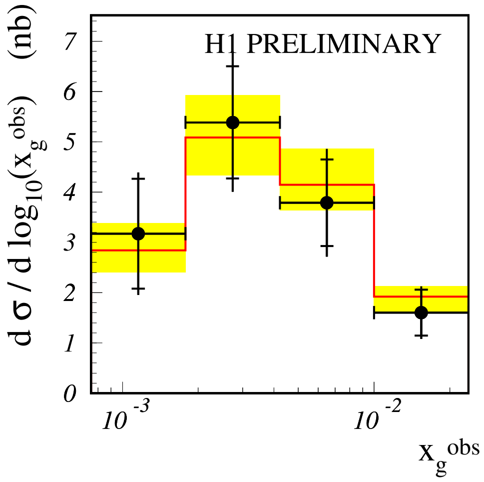
$x_g = \frac{\hat{s}+Q^2}{ys}$, where

$\hat{s} = \frac{p_t^{*2}+m_c^2}{z(1-z)}$, where

$z = \frac{E_c^* - p_c^* \cos(\theta^*)}{2E_\gamma^*}$

- Construction of an observable hadronic variable x_g^{obs} well correlated to x_g:
  - $z \rightarrow z^{obs} = \frac{(E-p_z)^{D^\star}}{2yE_e}$
  - $p_z(c) \rightarrow p_z(D^\star)$, $E(c) \rightarrow E(D^\star)$
  - $p_t^*(c) \rightarrow 1.2 \cdot p_t^*(D^\star)$
  - $\Longrightarrow x_g^{obs}$
- Need NLO Model to unfold from $x_g^{obs} \rightarrow x_g$
  - use Peterson-fragmentation in model to unfold
  - use iterative unfolding method
- $\sigma(x_g^{obs}) = \int_{x_g^{min}}^1 g(x_g, \mu^2)\hat{\sigma}(x_g, \mu^2) \cdot A(x_g^{obs}, x_g)dx_g$

Measurement of $d\sigma/d\log x_g^{obs}$ and Unfolding



$2 < Q^2 < 100$ GeV^2,
$0.01 < y < 0.7$
$p_t > 1.5$ GeV/c, $|\eta| < 1.5$

full points: $D^{\star\pm}$ data
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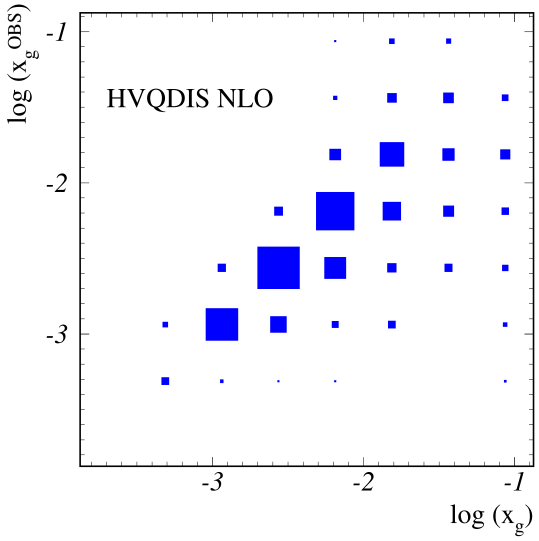
HVQDIS NLO (GRV 94 H0)
band: m_c=1.3 . . . 1.7 GeV/c^2

Extraction of $g(x)$ out of $d\sigma/d\log x_g^{obs}$ using theoretical calculations :

Use HVQDIS program (Smith & Harris)
Massive NLO calculation, $\overline{MS}$ scheme



Correlation matrix:
observed (reconsructed)
versus real x_g :
$x_g^{obs} \Leftrightarrow x_g^{true}$

Gluon Density Analysis in Photoproduction

- detection the scatterd positron in e-taggers at small angles w.r.t. the positron beam direction $\longrightarrow$ Measurement of y
- Measurement of x_g in 3 bins in $W_{\gamma p}$

  $W_{\gamma p} = \sqrt{ys}$ = inv. mass of γP system = 88 GeV, 185 GeV and 223 GeV
- 3 (4 for $W_{\gamma p}$ = 88 GeV) bins in x_g^{obs} per $W_{\gamma p}$ bin

Scale: $\mu_F^2 = 4(m_c^2 + p_t^2)$

strong correlation between x_g^{true} and μ_F^2:

$\hat{s} = x_g y s \approx 4(m_c^2 + p_t^2)$

$\longrightarrow$ determine $\langle \mu_F^2 \rangle$ for every measured point

$\longrightarrow$ obtain points at different scales per x_g bin

Evolution in Q^2 assuming same scale dependence as

MRS(A')

Averaging according to stat. errors

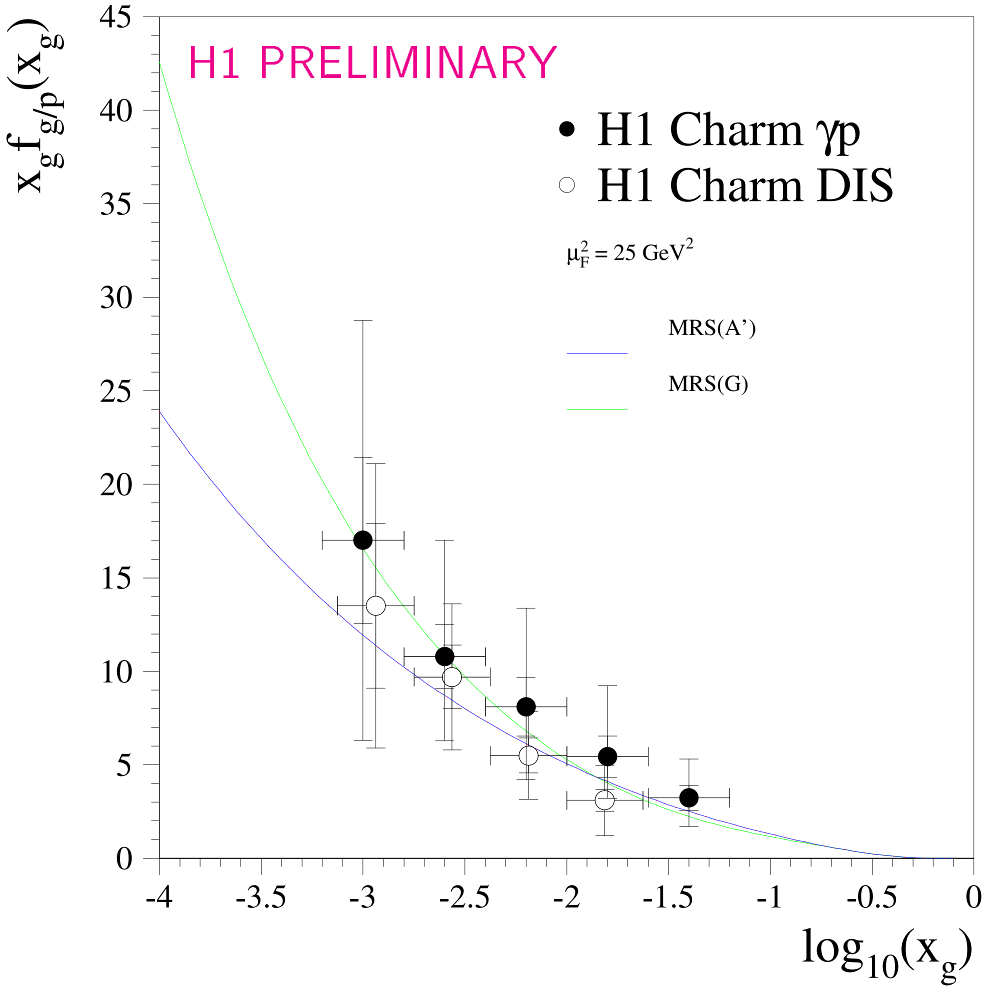
$\longrightarrow$ 5 points in x_g

Resolved photon reduced by selection cuts to $<$ 5 %.

Theoretical Models for Unfolding $x_g^{obs} \rightarrow x_g$

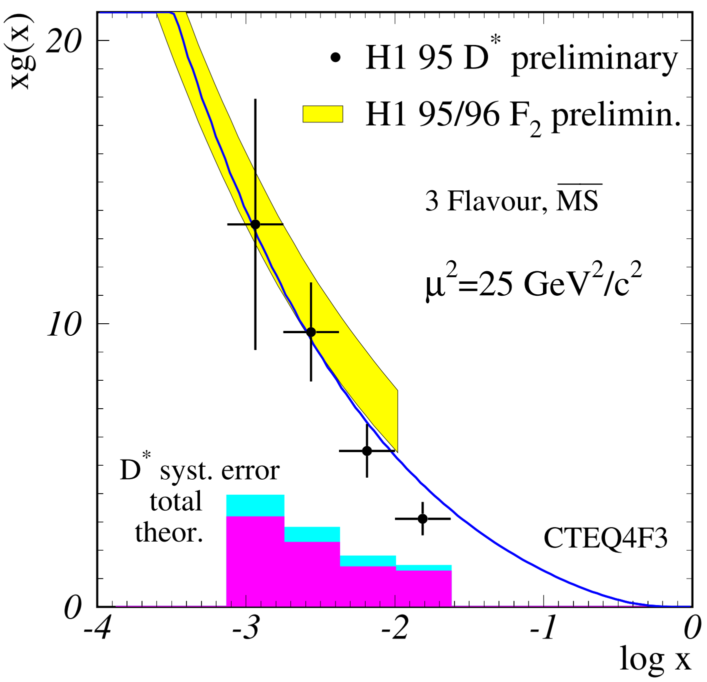
	DIS	Photoproduction
NLO Calculation massive scheme	HVQDIS Smith & Harris	FMNR Frixione, Mangano, Nason, Ridolfi
μ_F^2 $\langle \mu_F^2 \rangle$ [GeV^2]	$Q^2 + 4m_c^2$ 25	$4(p_t^2 + m_c^2)$ 50
μ_R^2	μ_F^2	$1/4\mu_F^2$
Peterson fragment. parameter	0.06 0.02 . . . 0.078	0.035 $\pm$ 0.01
Λ_5	225 MeV	152 MeV
m_c	1.5 GeV/c^2	1.5 GeV/c^2

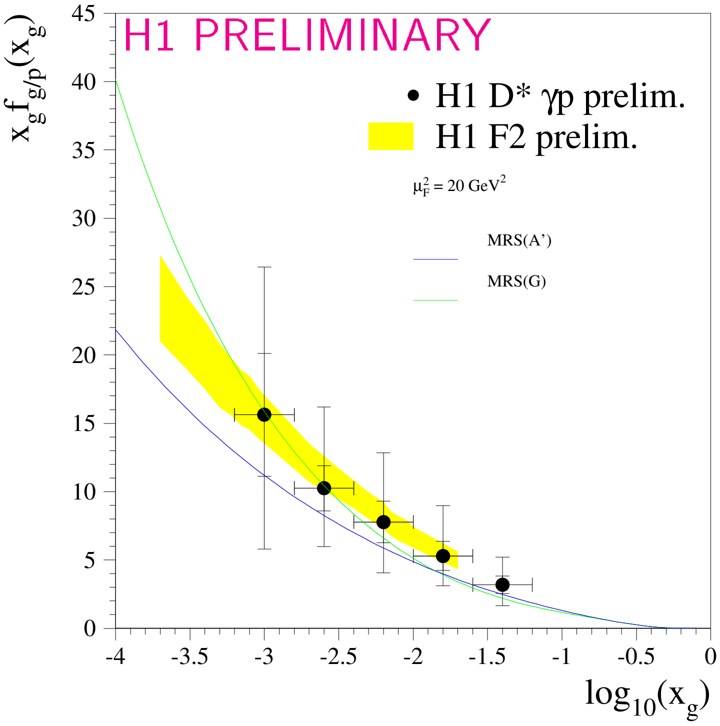
Gluon Density from $D^\star$ in DIS and γp



- DIS
  - Scale $\mu_F^2 = Q^2 + 4m_c^2$
  - Extraction using HVQDIS (Smith & Harris)
- γp
  - Scale $\mu_F^2 = (2\mu_R)^2 = 4(m_c^2 + p_t^2)$
  - Extraction using FMNR (Frixione et al.)

Comparison of direct (charm) and indirect (F_2 measurement) Gluon Densitiy measurements





Conclusions

- Single and double differential cross section in reasonable agreement with NLO QCD calculations, in particular at the low p_t region.
- First direct measurement of gluon densities using charmed mesons.
- Good agreement of the gluon densities measured in DIS and photoproduction.
- The gluon densities in DIS and Photoproduction are good agreement with gluon density from scaling violations (indirect measurement) as well.