New Results from ZEUS

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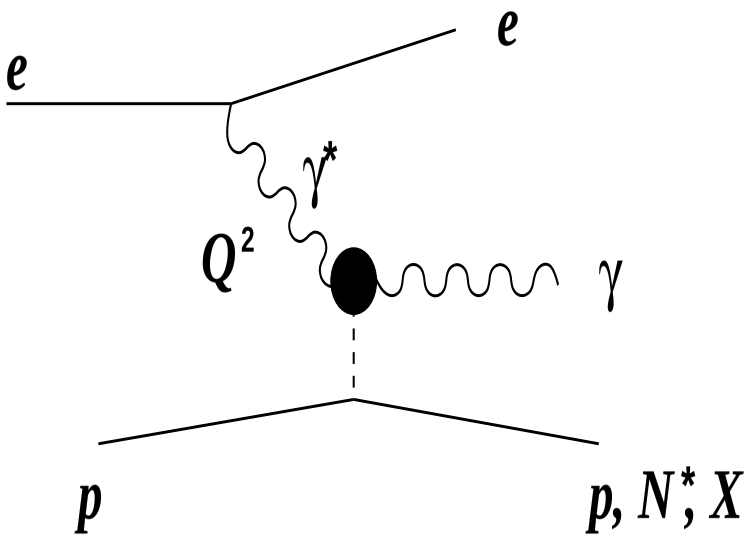
- Deeply Virtual Compton Scat.
- Inclusive Diffraction
- Inclusive $\mathbf{D}^{*\pm}$ in DIS
- Photoproduction of Beauty
- $\mathbf{D}_{\mathbf{s1}}^{\pm}(\mathbf{2536})$ Production
- c-jet Substructure in $\gamma\mathbf{p} \rightarrow$Dijets
- $\alpha_{\mathbf{s}}$ from NC-DIS Jet Substructure
- $\phi(\mathbf{1020})$ production in NC-DIS
- NC and CC-DIS Cross Sections
- NLO QCD Fit to NC DIS Data
- Contact Interactions
- Leptoquark Search
- Search for $\mathbf{ep} \rightarrow \mathbf{tX}$

Deeply Virtual Compton Scattering

First observation reported at EPS 99

$\mathcal{L} = 37\,\mathrm{pb}^{-1}$

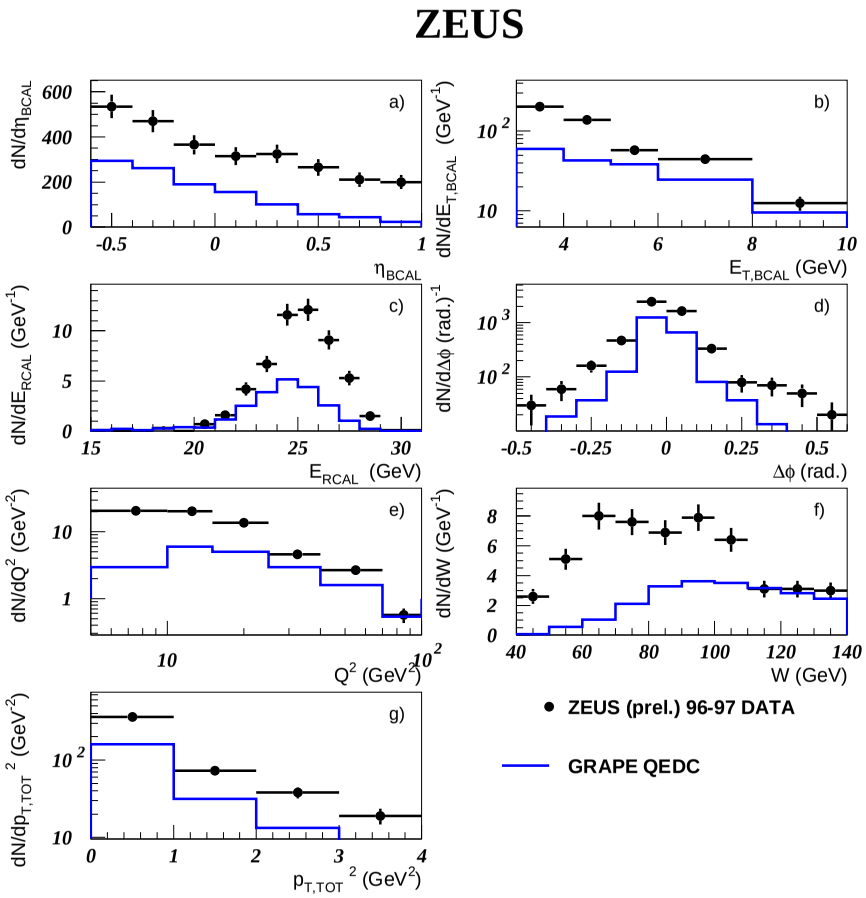


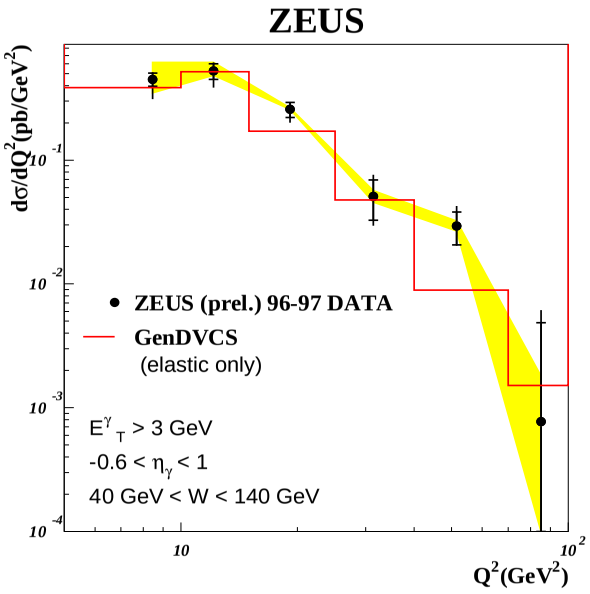
Kinematic Region:

- $Q^2 > 5\,\mathrm{GeV}^2$
- $40\mathrm{GeV} < W < 140\,\mathrm{GeV}$
- $E_T^\gamma > 3\,\mathrm{GeV}$
- $-0.6 < \eta_\gamma < 1.0$ (γ in barrel)
- e in Rear CAL, $E_e > 10\,\mathrm{GeV}$
- $E_{\mathrm{total}} - E_e - E_\gamma < 0.2\,\mathrm{GeV}$

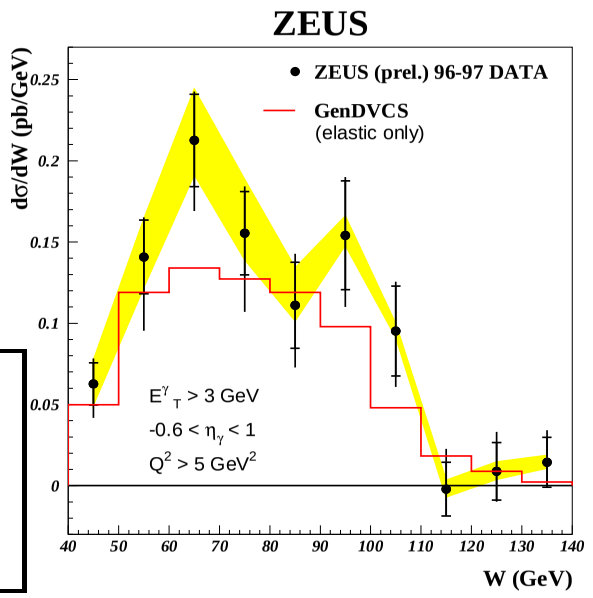
- Interference with QEDC is small.
- Sensitive to skewed parton distributions (parton correlations)

537 events pass these cuts





GenDVCS QCD based with no proton dissociation ($\sim 20\%$).



Yellow band indicates E-Scale uncertainty

Final sample compared to QEDC background (normalized using events with e^+ in Barrel, γ in Rear CAL).

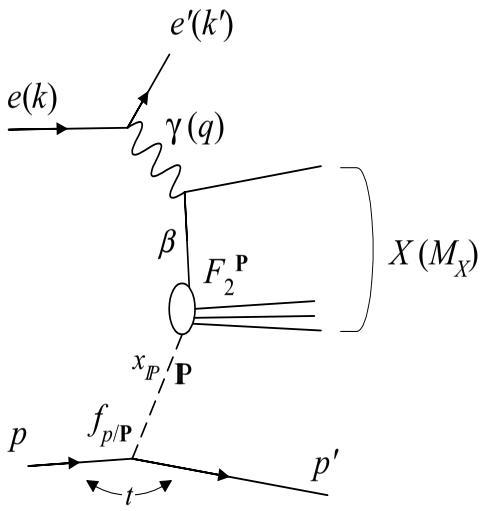
Inclusive Diffraction

$$\frac{d\sigma_{ep}^{D}}{d\beta dQ^2 dx_{I\!P} dt} = \frac{2\pi\alpha^2}{\beta Q^4}[1+(1-y)^2]F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t)$$

$$F_2^{D(4)} = f_{I\!P}(x_{I\!P}, t) \cdot F_2^{D(2)}(\beta, Q^2)$$

$$f_{I\!P} \propto x_{I\!P}^{(1-2\alpha_{I\!P}(t))}$$

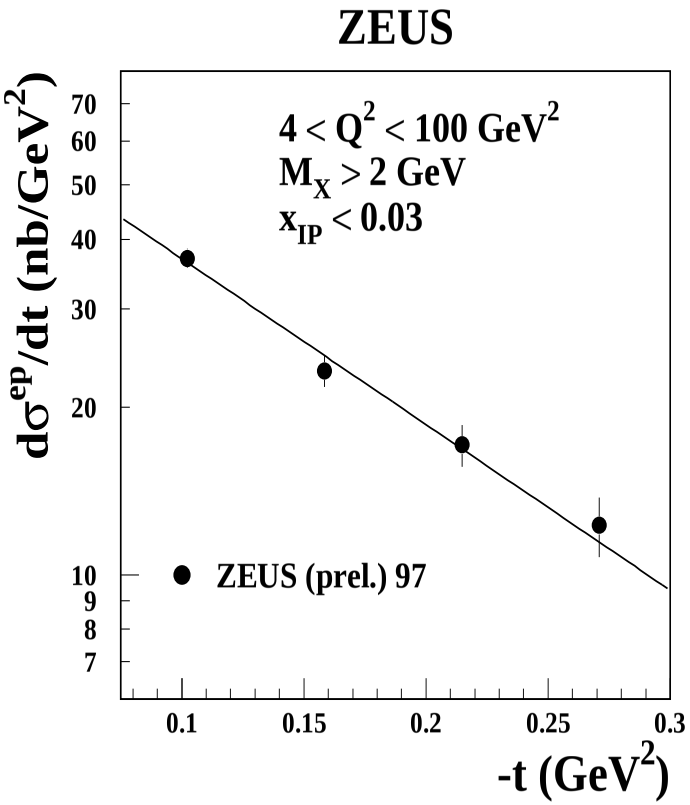
$\mathcal{L} = 12.8\,\mathrm{pb}^{-1}$.



- p in LPS with $x_L > 0.95$.
- No p dissoc. bkgd.
- No bias on hadronic final state X.
- Measure t

Kinematic Range:

- 4 GeV$^2 < Q^2 < 100$ GeV^2
- $10^{-4} < x_{I\!P} < 0.04$
- $M_X > 2$ GeV
- 0.075 GeV$^2 < |t| < 0.35$ GeV^2

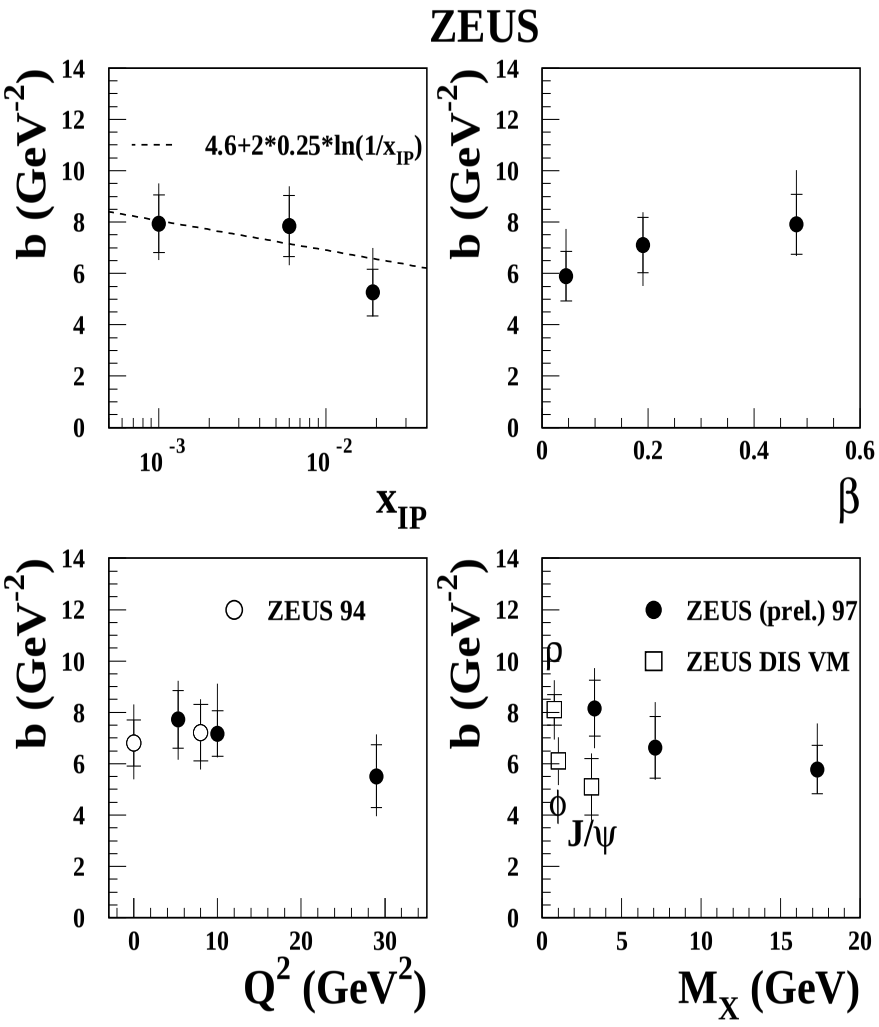


$$\frac{d\sigma}{d|t|} \propto \exp -b|t|$$

$$b = 6.8 \pm 0.6(\text{stat.})^{+1.2}_{-0.7}(\text{syst.})\ \text{GeV}^{-2}$$

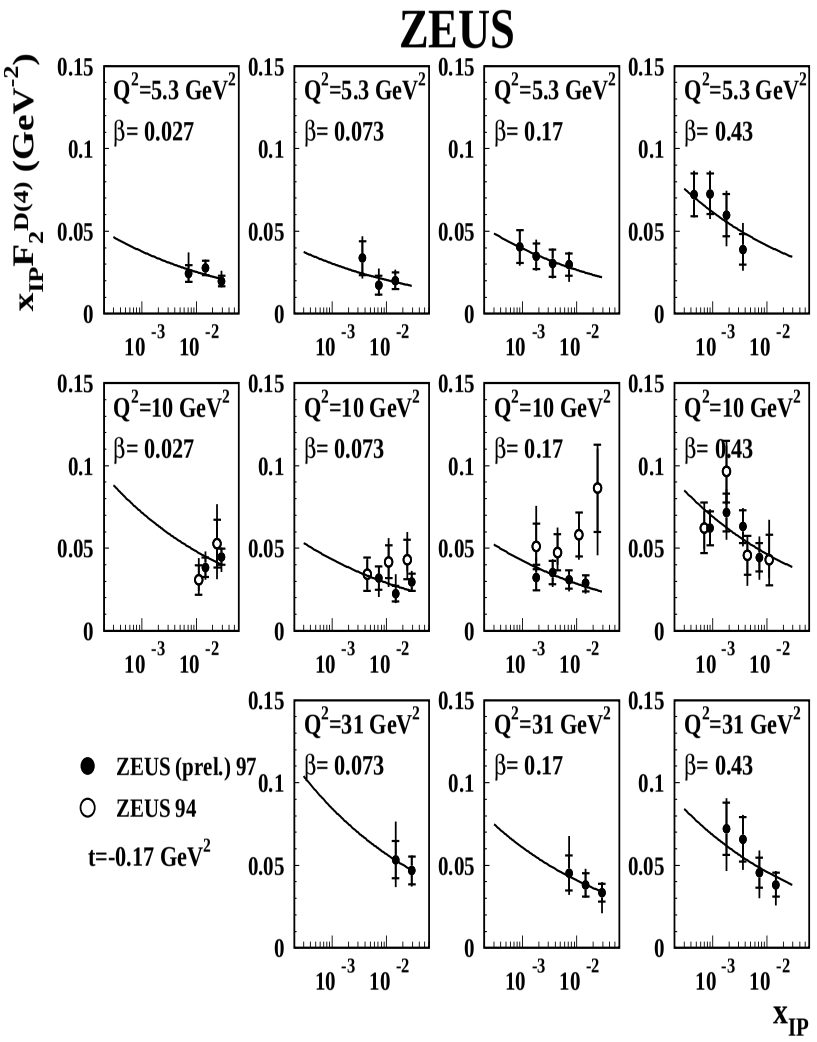
$b \sim 5$ for J/psi, $b \sim 8$ for ρ

$$
\begin{aligned}
b &= b_0 + 2\alpha'_{I\!P} \log \frac{W^2}{M_X^2} \\
&\approx b_0 - 2\alpha'_{I\!P} \log x_{I\!P} \\
\alpha_{I\!P}(t) &= \alpha_{I\!P}(0) + t\alpha'_{I\!P} \\
\alpha'_{I\!P} &= 0.25\,\mathrm{GeV}^{-2}
\end{aligned}
$$



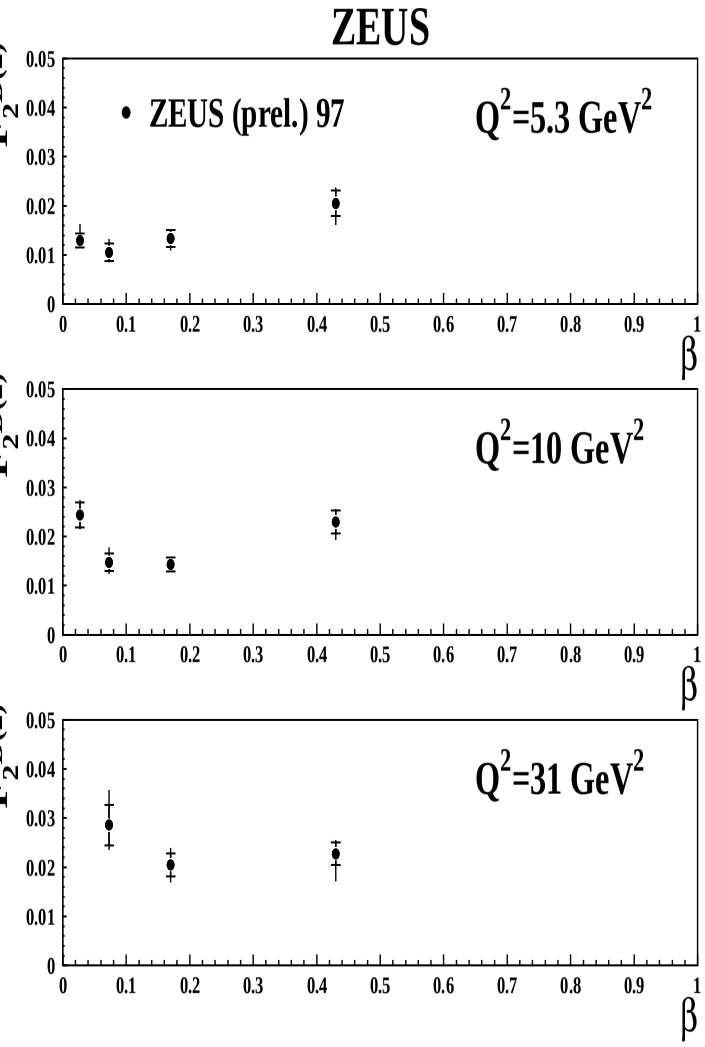
$$F_2^{D(4)} = f_{I\!P}(x_{I\!P}, t) \cdot F_2^{D(2)}(\beta, Q^2)$$

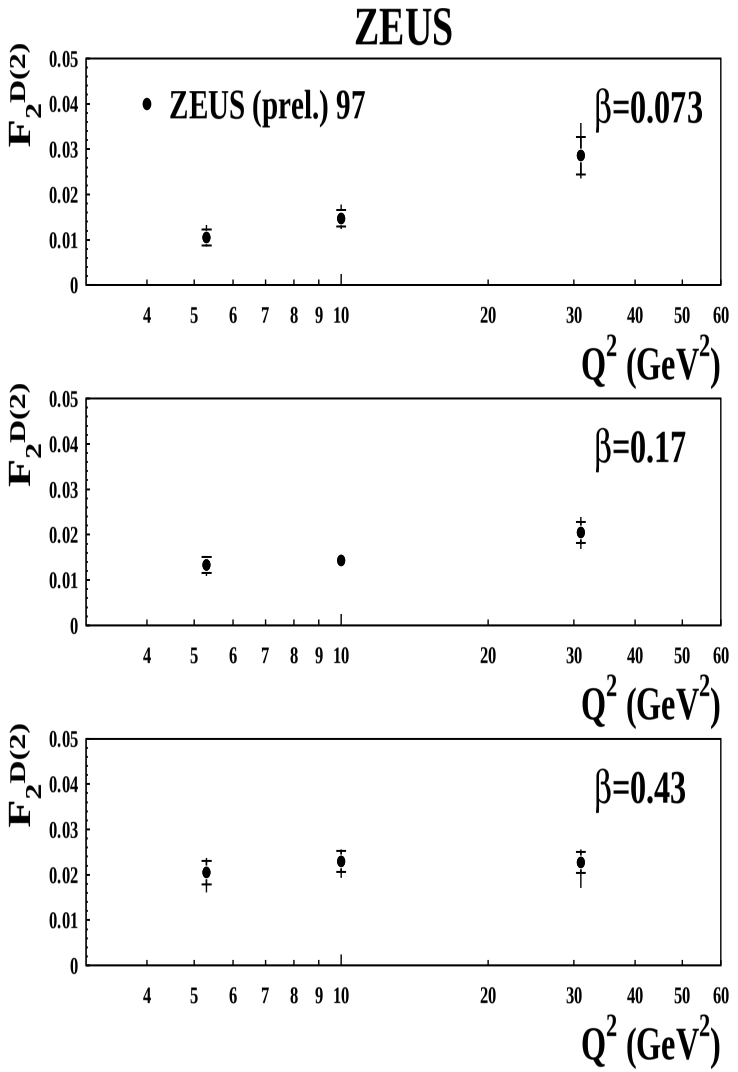
$$f_{I\!P}(x_{I\!P}, t) \propto (1/x_{I\!P})^{2\alpha_{I\!P}(t)-1}$$



- One $I\!P$ trajectory describes all Q^2, β bins
- Consistent with factorization

$$\alpha_{I\!P}(0) = 1.13 \pm 0.03(\text{stat.})^{+0.03}_{-0.01}(\text{syst.})$$





Weak β dependence

Scaling violation at low β

Inclusive $D^{*\pm}$ in DIS

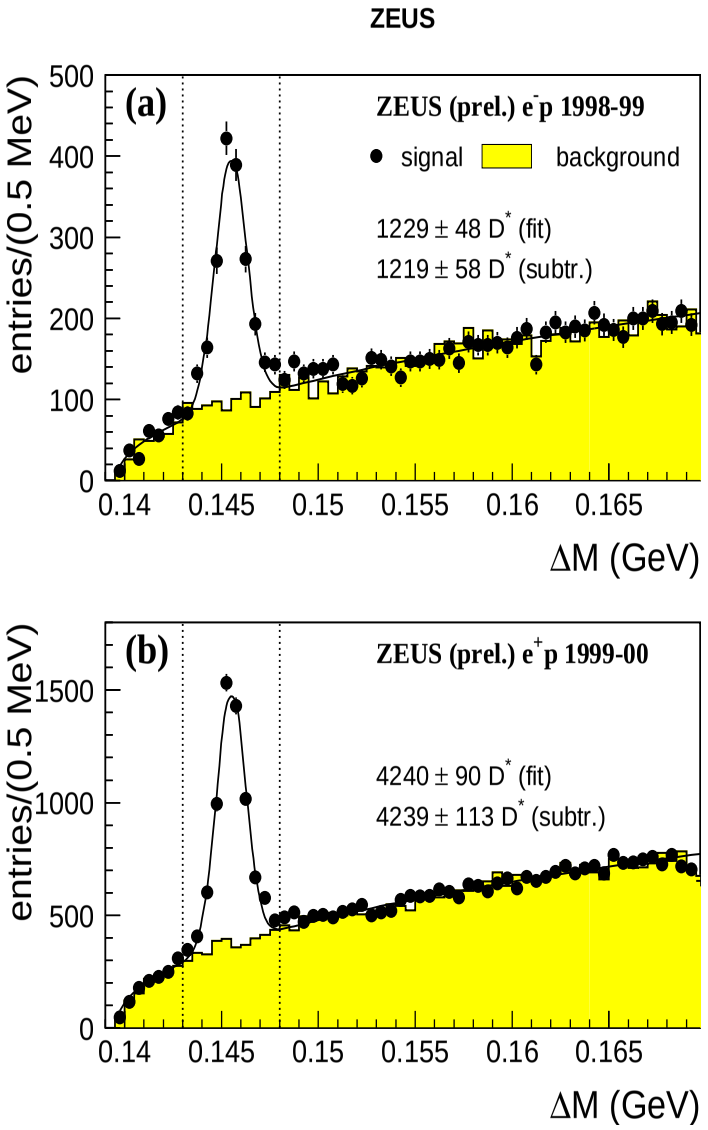
$\mathcal{L} = 16.7\,\mathrm{pb}^{-1}(e^-), 65.2\,\mathrm{pb}^{-1}(e^+)$

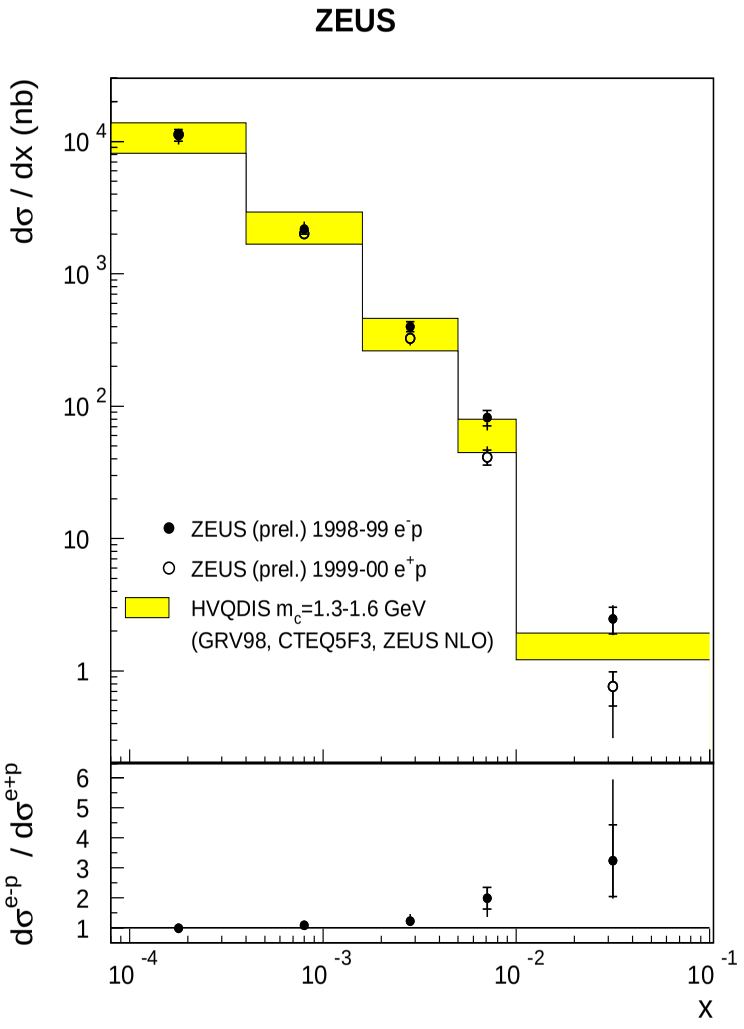
$D^{*\pm} \to D^0\pi_s^{\pm}$

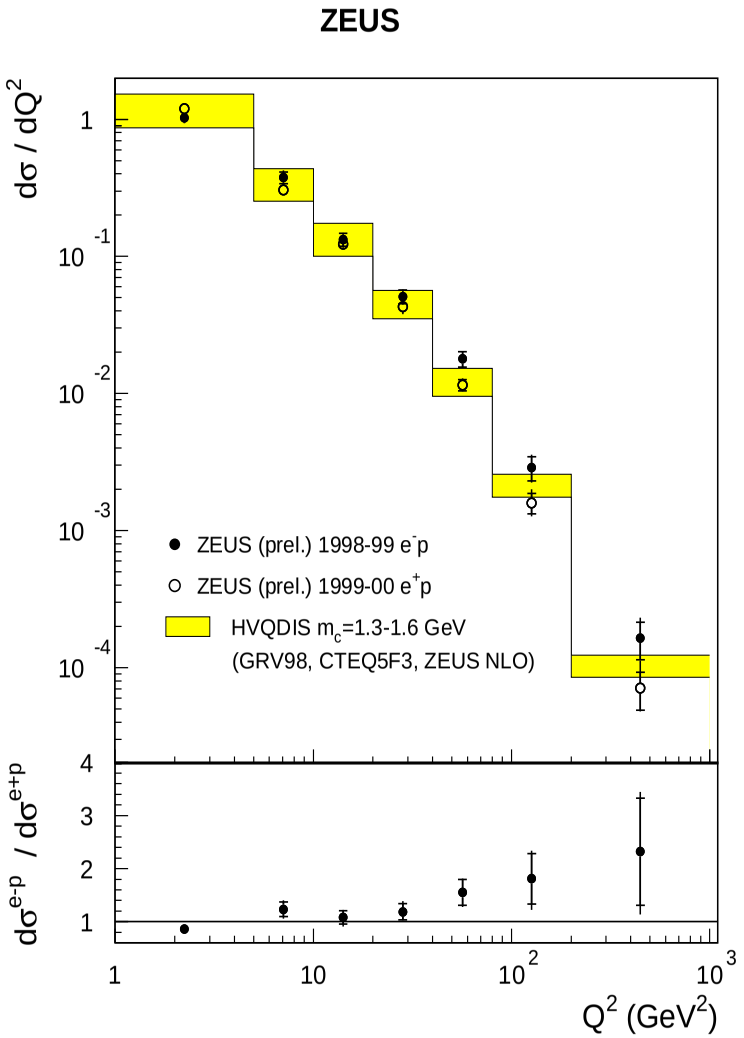
- $Q^2 > 1\,\mathrm{GeV}^2$
- $0.02 < y < 0.80$
- $1.5 < P_t(D^*) < 15\,\mathrm{GeV}$
- $|\eta(D^*)| < 1.5$

Acceptance = 29%

$\Delta M = M_{K\pi\pi_s} - M_{K\pi}$

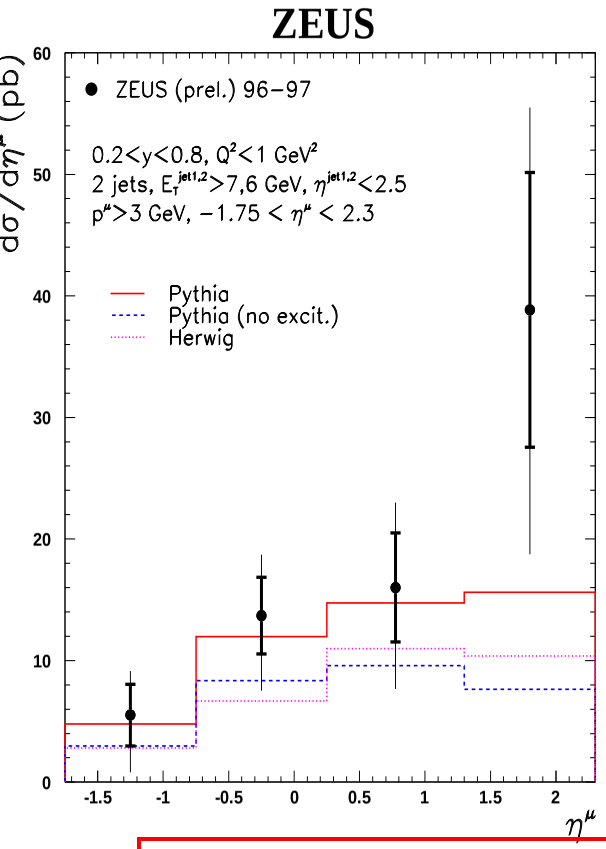


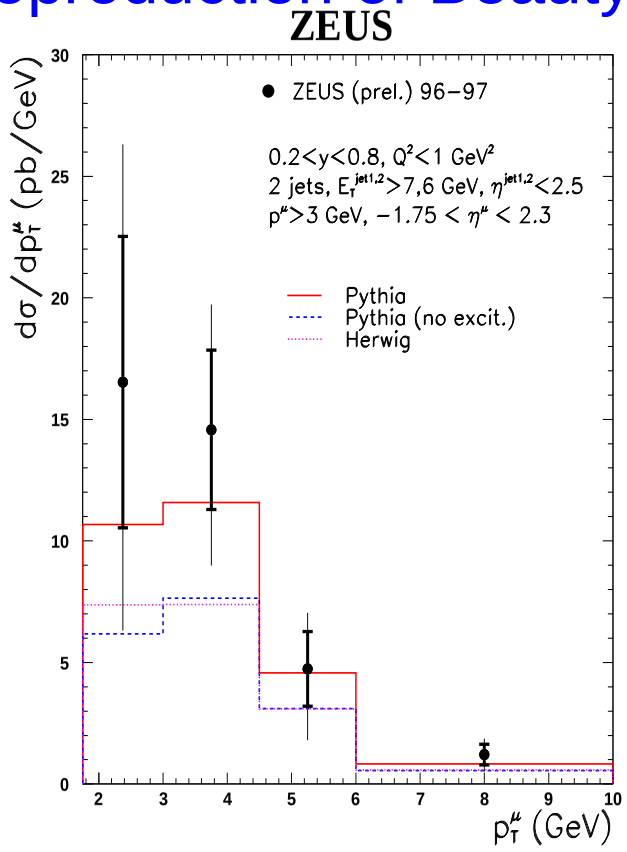




For $Q^2 > 20\,\mathrm{GeV}^2$, e^-/e^+ ratio differs from 1 by $\sim 3\sigma$

Photoproduction of Beauty





$\mathcal{L} = 38\,\mathrm{pb}^{-1}$

Semi-leptonic b-decays:
μ track matches a jet.

Separate b from c and light quark background by fitting p_T^{rel} distribution.
p_T^{rel} = muon p_T relative to jet axis (large for b-decays)

PYTHIA (LO) with b-excitation gives reasonable description. NLO??

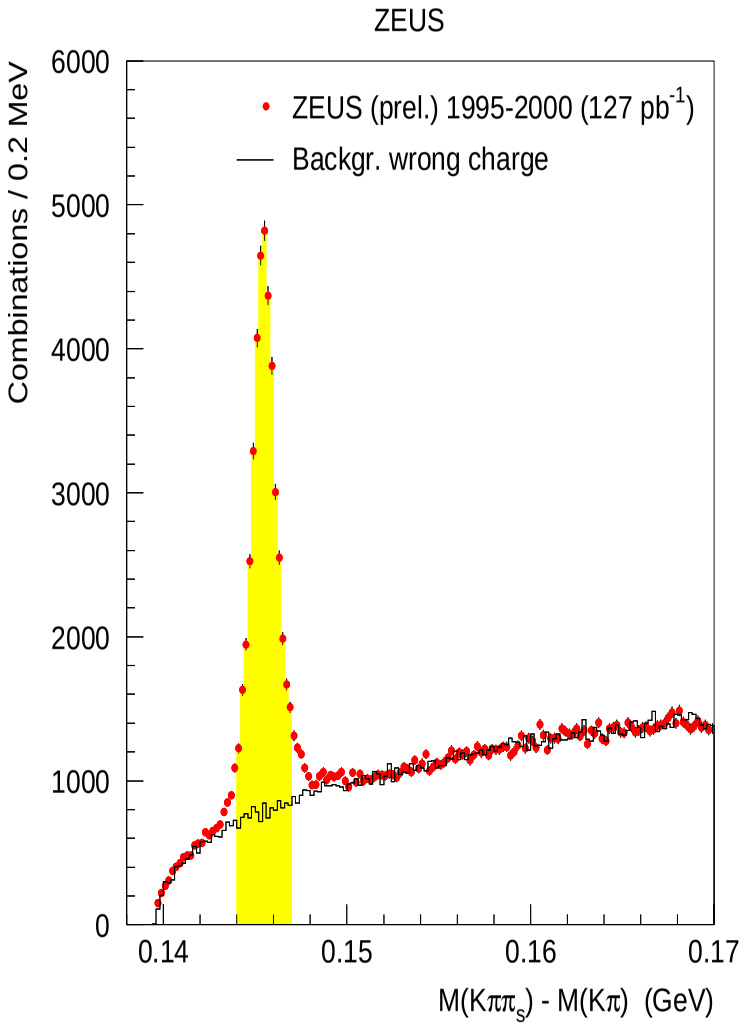
$\mathbf{D_{s1}^{\pm}(2536)}$ Production

$\mathcal{L} = 127\,\mathrm{pb}^{-1}$
Use γp and NC DIS data

$D_{s1}^{\pm} \rightarrow D^{*\pm} K_S^0$
$D^{*\pm} \rightarrow D^0 \pi_s^{\pm}$

- $2 < P_t(D^*) < 20\,\mathrm{GeV}$
- $|\eta(D^*)| < 1.5$

31349 ± 241 $D^{*\pm}$ found.



62.3 ± 9.3 $D_{s1}^{\pm}$ found. Worlds largest sample of $D_{s1}^{\pm} \to D^{*\pm} K_S^0$

$M(D_{s1}^{\pm}) = 2534.2 \pm 0.6 \pm 0.5\,\mathrm{MeV}$

(2^{nd} error from $M(D^{*\pm})$)

Helicity analysis: $\sigma \sim 1 + R\cos^2\alpha$

$\alpha =$ angle between K_S^0 and π_S

$R = -0.53 \pm 0.32(\mathrm{stat.})^{+0.05}_{-0.14}(\mathrm{syst.})$

CLEO($D_{s1}^{\pm} \to D^{*0}K^{\pm}$):$R = -0.23^{+0.40}_{-0.32}$

$R_{D_{s1}^{\pm} \to D^{*\pm}K^0/D^{*\pm}} =$

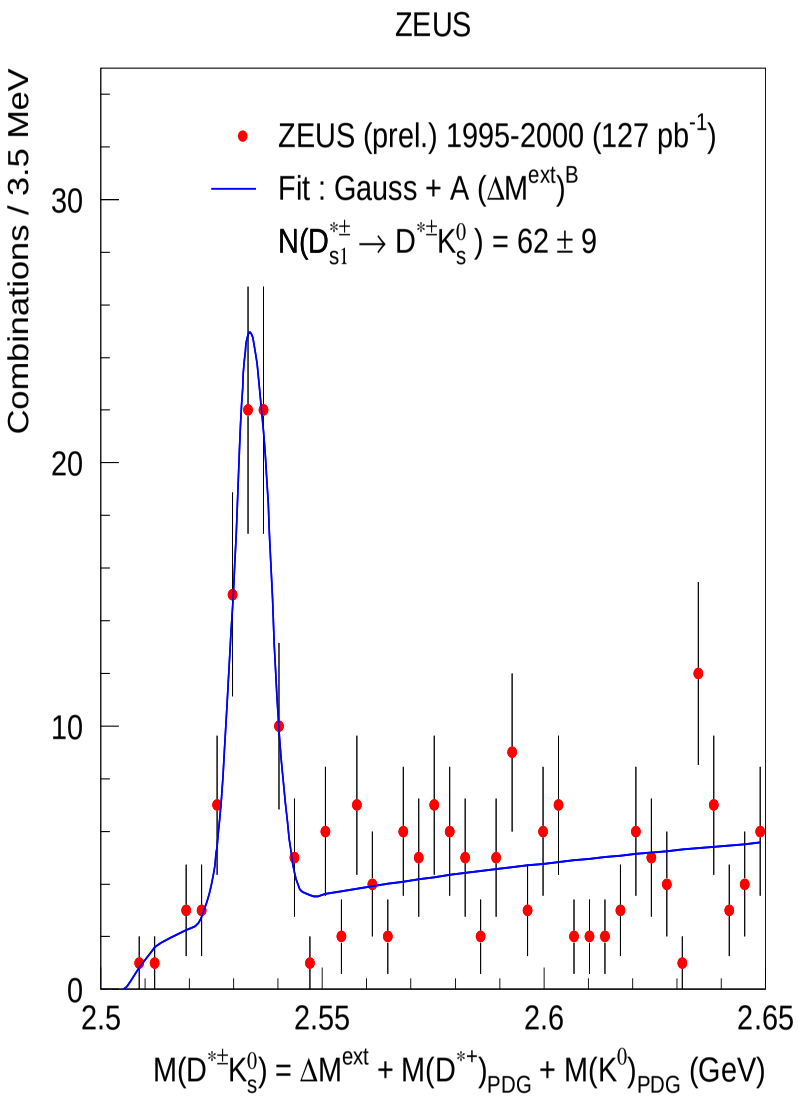
$1.77 \pm 0.26(\mathrm{stat.})^{+0.11}_{-0.09}(\mathrm{syst.})\%$

$f(c \to D_{s1}^{\pm}) =$

$1.24 \pm 0.18(\mathrm{stat.})^{+0.08}_{-0.06}(\mathrm{syst.}) \pm 0.14(\mathrm{br.})\%$

OPAL: $f(c \to D_{s1}^{\pm}) = 1.6 \pm 0.4 \pm 0.3\%$

$\Delta M^{\mathrm{ext}} = M_{K\pi\pi_s\pi^+\pi^-} - M_{K\pi\pi_s} - M\pi^+\pi^-$



c-jet Substructure in γp $\rightarrow$Dijets

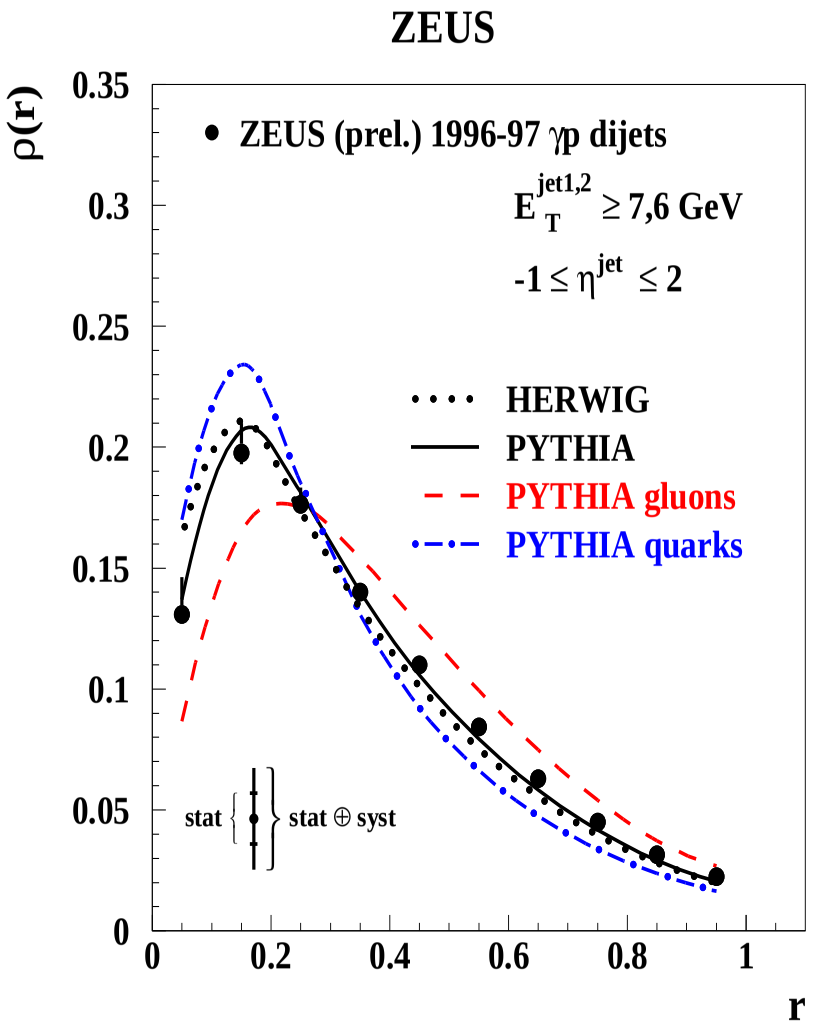
1996-2000 e^+ data ($106\ \mathrm{pb}^{-1}$)

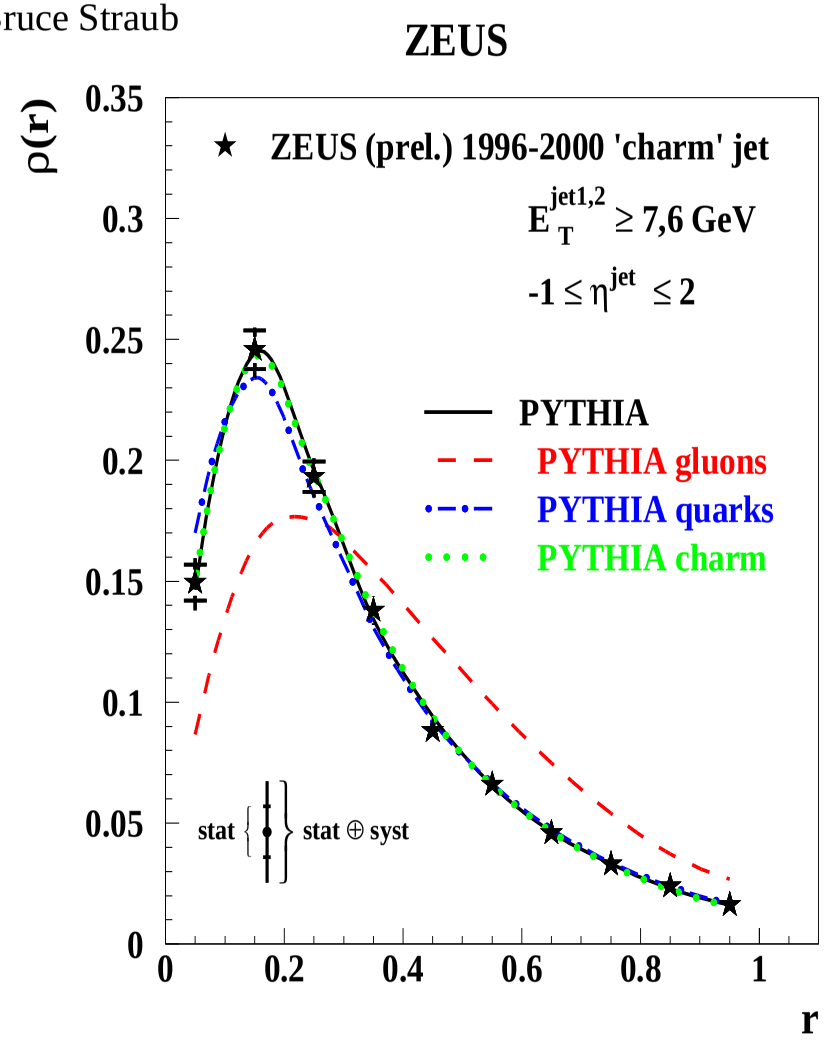
- ≥ 2 jets with $-1 < \eta^{\mathrm{jet}} < 2$
- $E_T^{\mathrm{jet}} > 7,6\,\mathrm{GeV}$
- $134\,\mathrm{GeV} < W < 277\,\mathrm{GeV}$
- Reject NC DIS

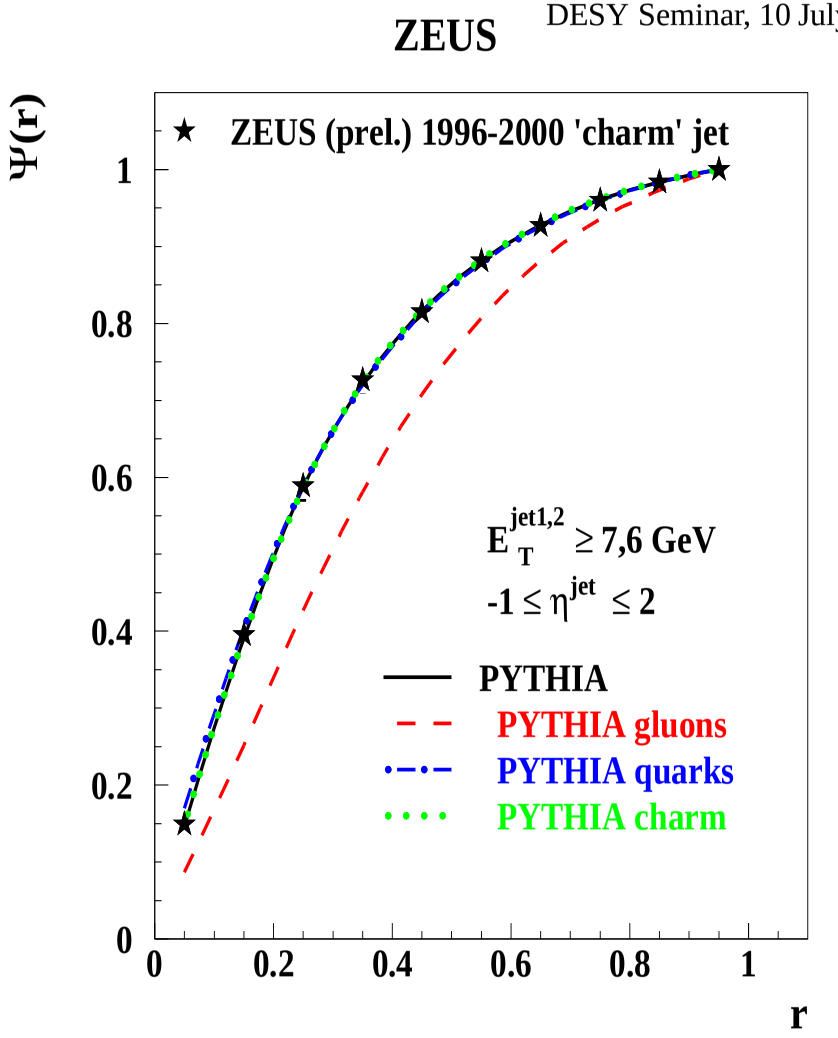
$\psi(r) = \frac{1}{N_{\mathrm{jet}}} \sum_{\mathrm{jets}} \frac{E_T(r)}{E_T^{\mathrm{jet}}}$

$E_T(r)$= transverse energy with $\eta\phi$ distance from jet axis $< r$.

$\rho(r) = d\psi/dr$





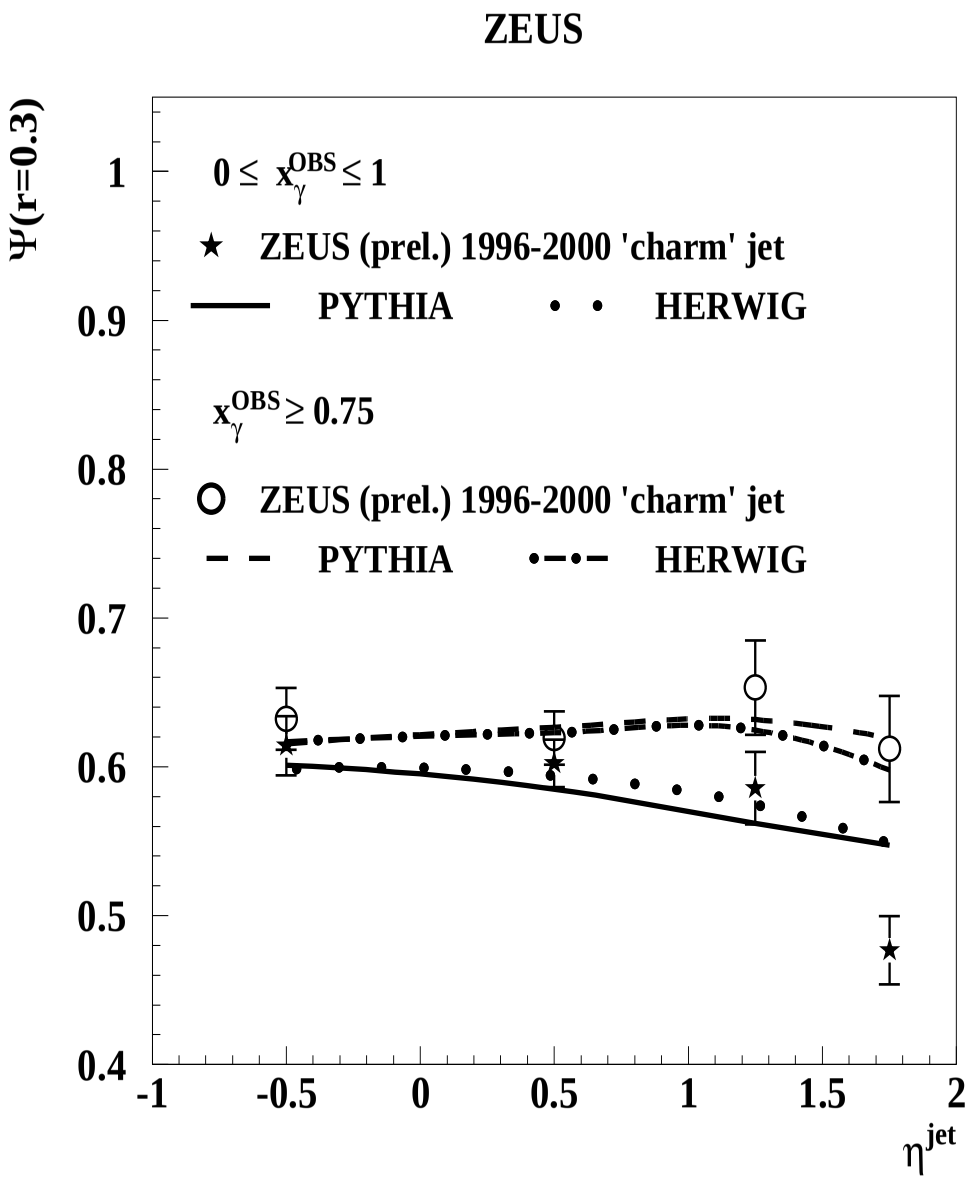


Select events with a $D^{*\pm}$ in a jet and look at the other jet in the event to avoid bias from $D^{*\pm}$ selection

Use x_γ to separate direct ($\gamma g \to c\bar{c}$) from resolved ($c_\gamma g \to cg$)

Jets in $x_\gamma > 0.75$ events are narrower

Forward jets with $x_\gamma < 0.75$ are much broader than PYTHIA, HERWIG predict

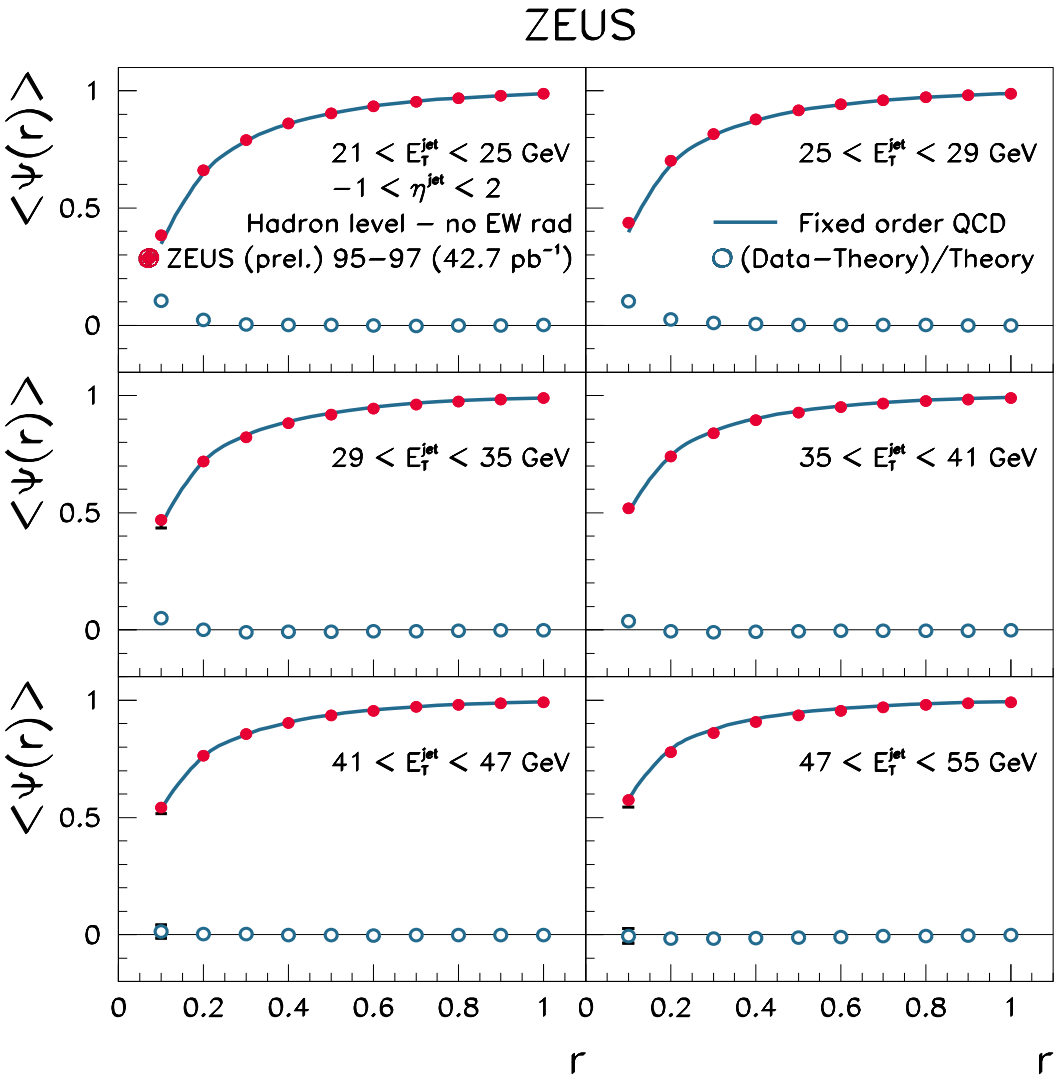


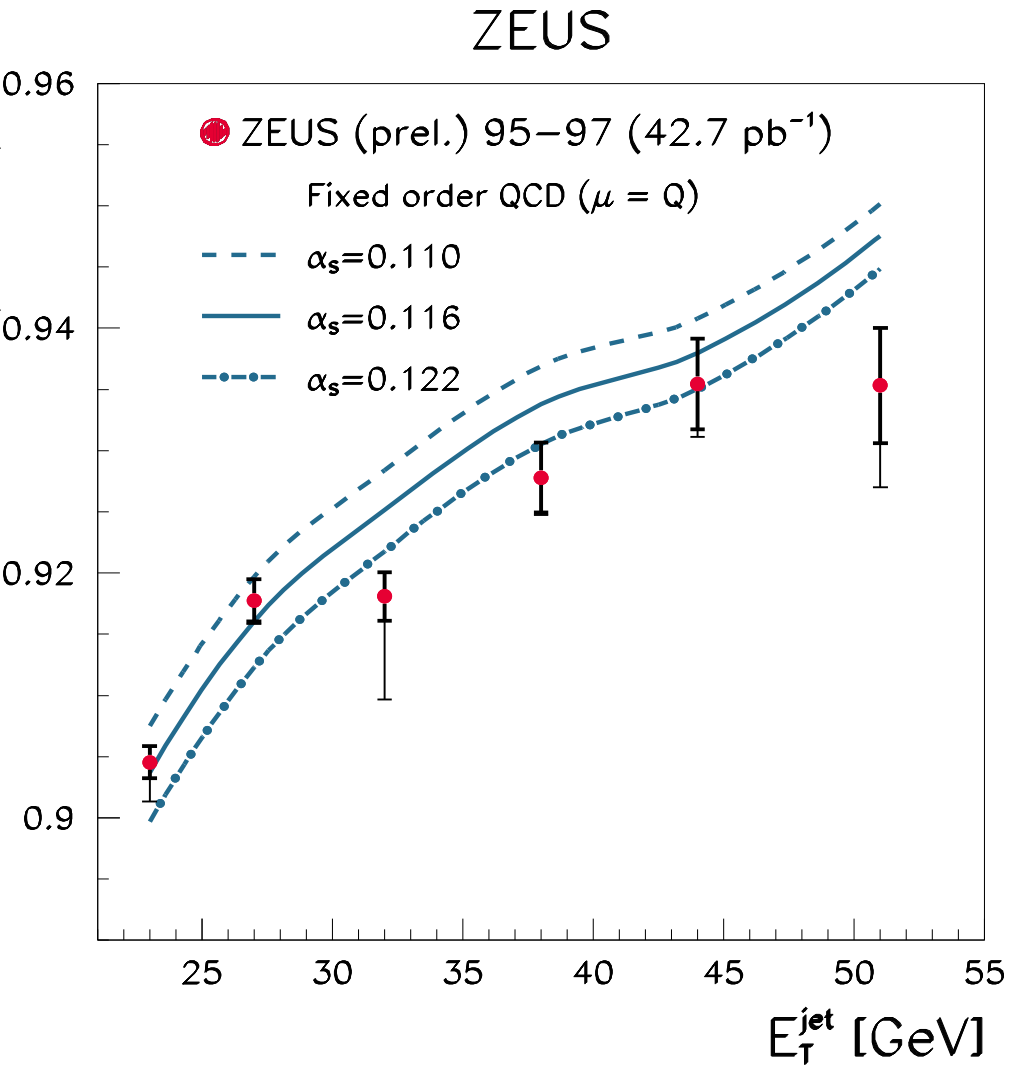
α_s from NC-DIS Jet Substructure

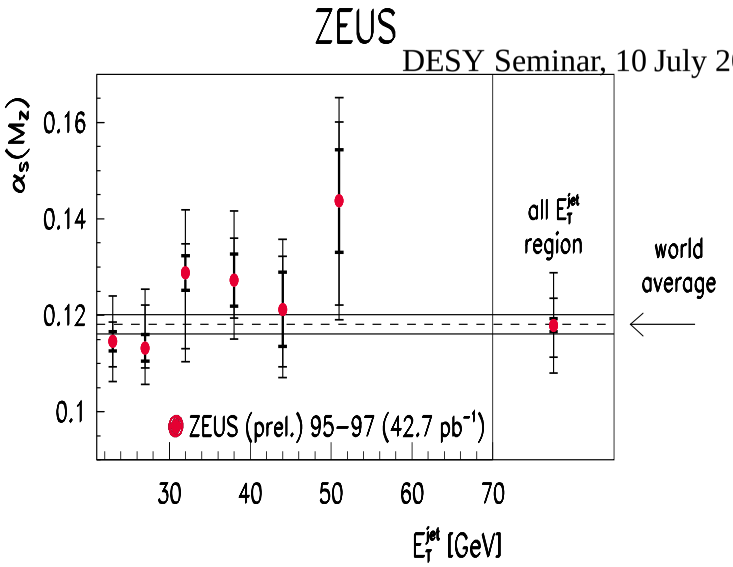
- $Q^2_{\rm da} > 125\,{\rm GeV}^2$
- Use long. invar. k_T-cluster alg.
- $E_T^{\rm jet} > 21\,{\rm GeV}$ and $-1 < \eta_{\rm jet} < 2$

$$< \psi(r) >= \frac{1}{N_{\rm jet}} \sum_{\rm jets} \frac{E_T(r)}{E_T^{\rm jet}}$$

$E_T(r)$ = transverse energy with $\eta\phi$ distance from jet axis $< r$.







$$\alpha_S(M_Z) = 0.1179 \pm 0.0014(\text{stat.}) \; {}^{+0.0054}_{-0.0065}(\text{exp.}) \; {}^{+0.0094}_{-0.0073}(\text{th.})$$

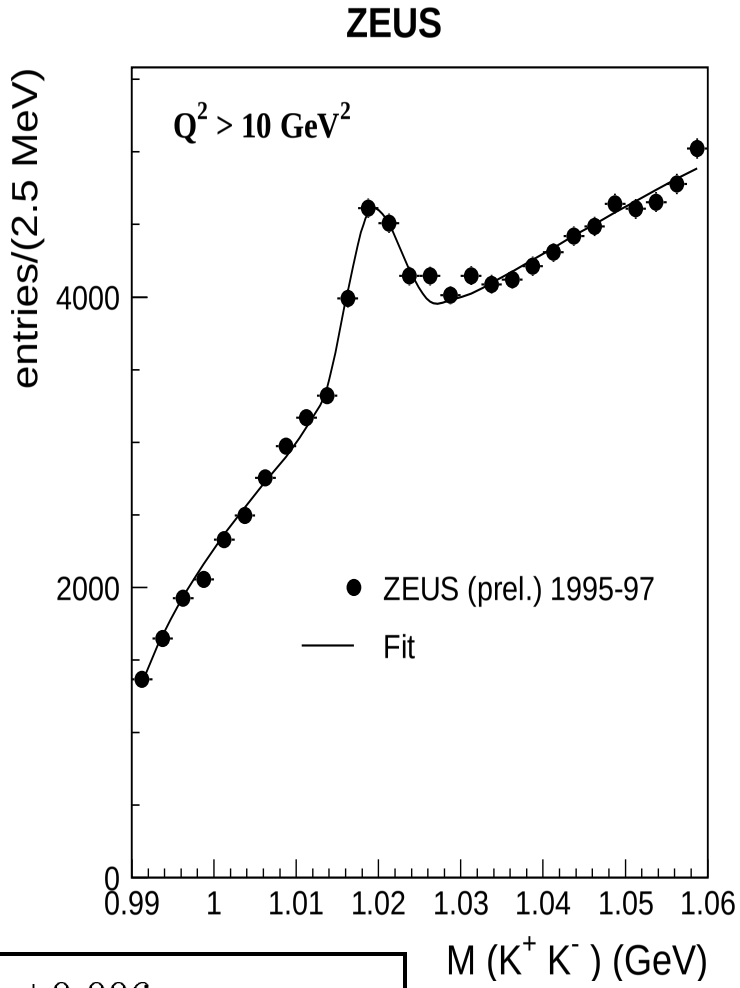
exp. ← Ariadne vs. MEPS, E-Scale.

th. ← vary $Q/2 < \mu_R < 2Q$.

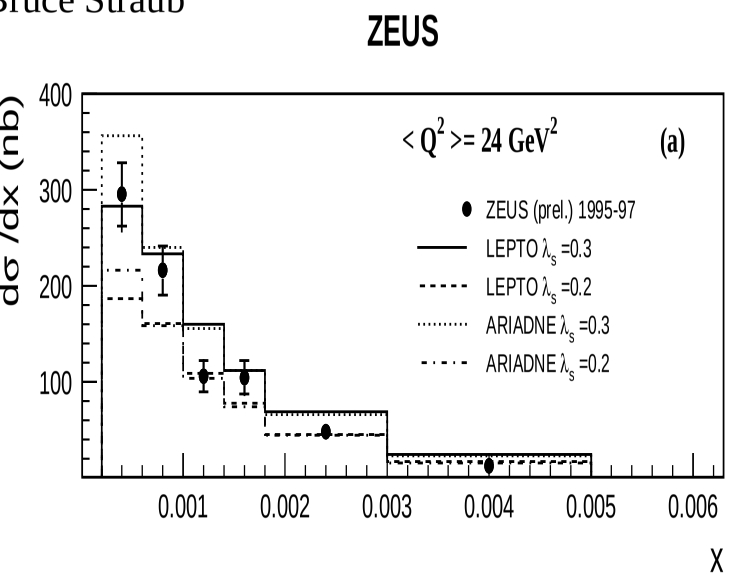
$\phi(1020)$ production in NC-DIS

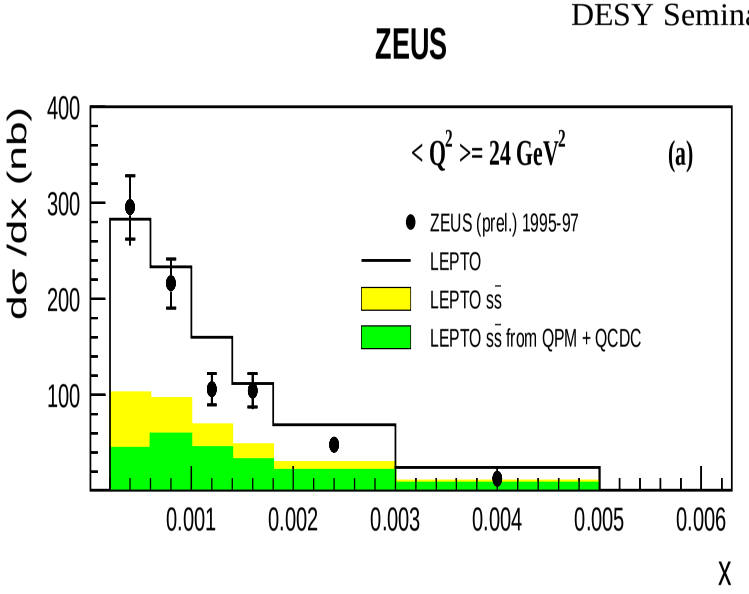
- $Q^2 > 10\,\text{GeV}^2$
- $0.0002 < x < 0.01$
- $0.04 < y < 0.95$
- $1.7\ \text{GeV} < P_T(\phi) < 7\ \text{GeV}$
- $-1.7 < \eta(\phi) < 1.6$

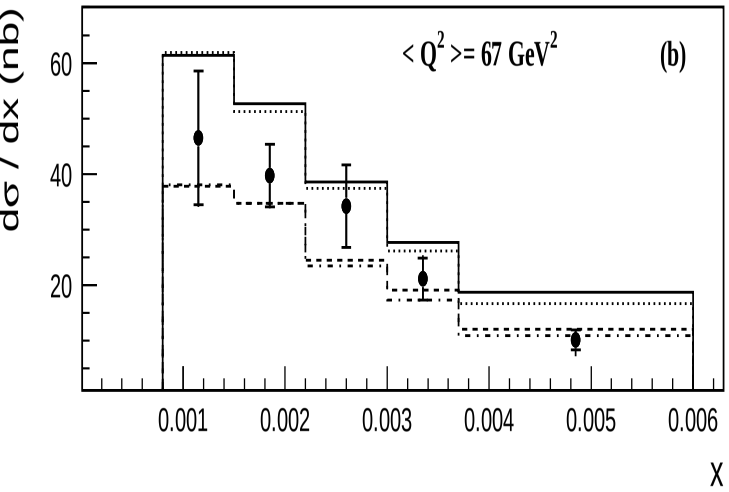
5060 ± 216 candidates

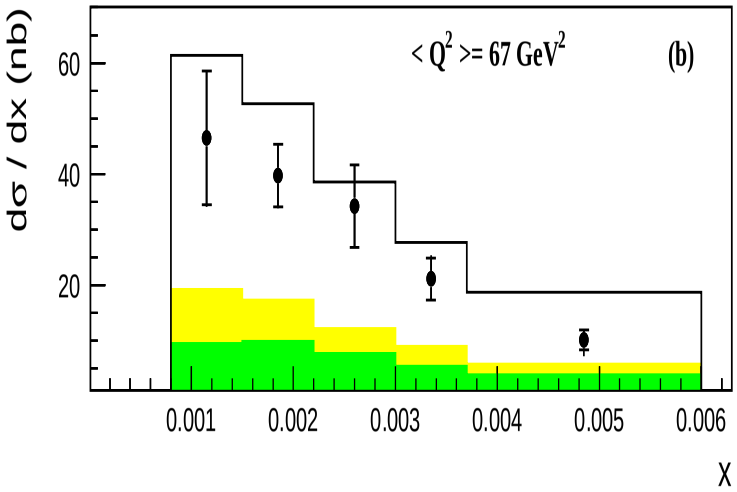


$$\sigma(e^+p \to e^+\phi X) = 0.513 \pm 0.022(\text{stat.})^{+0.006}_{-0.010}(\text{syst.})\ \text{nb}$$





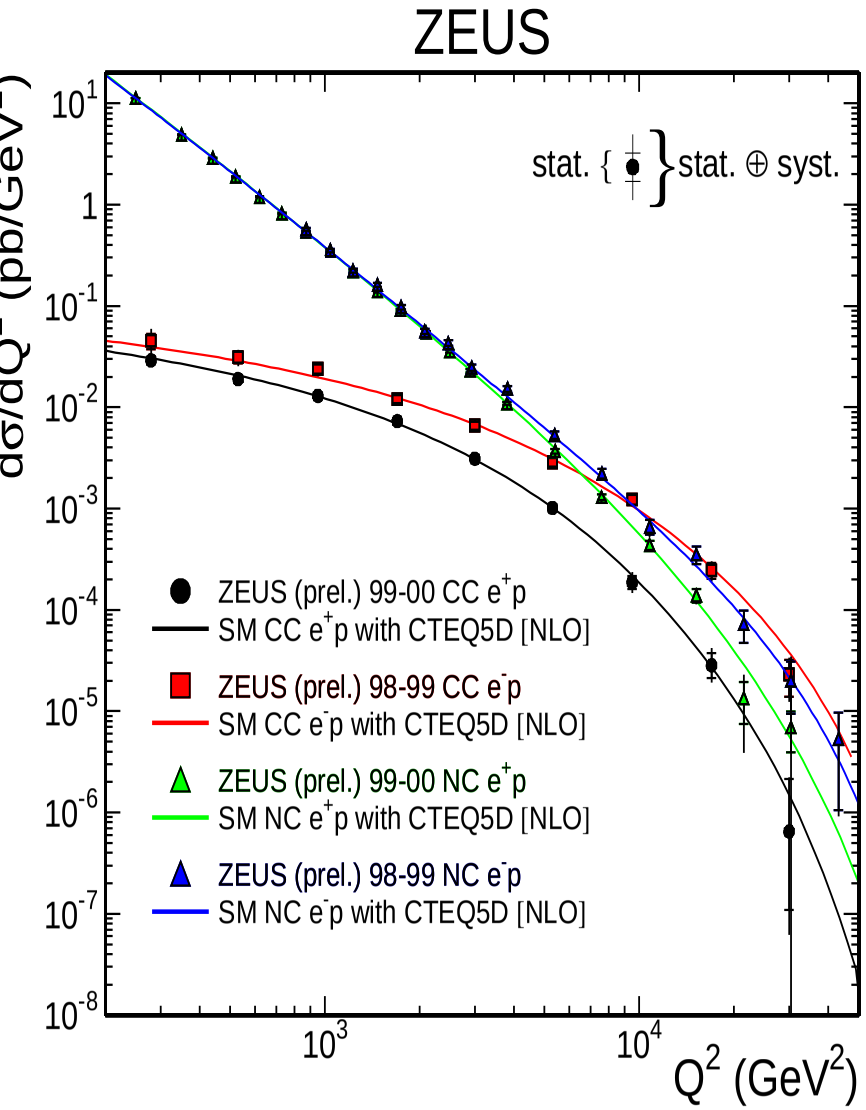


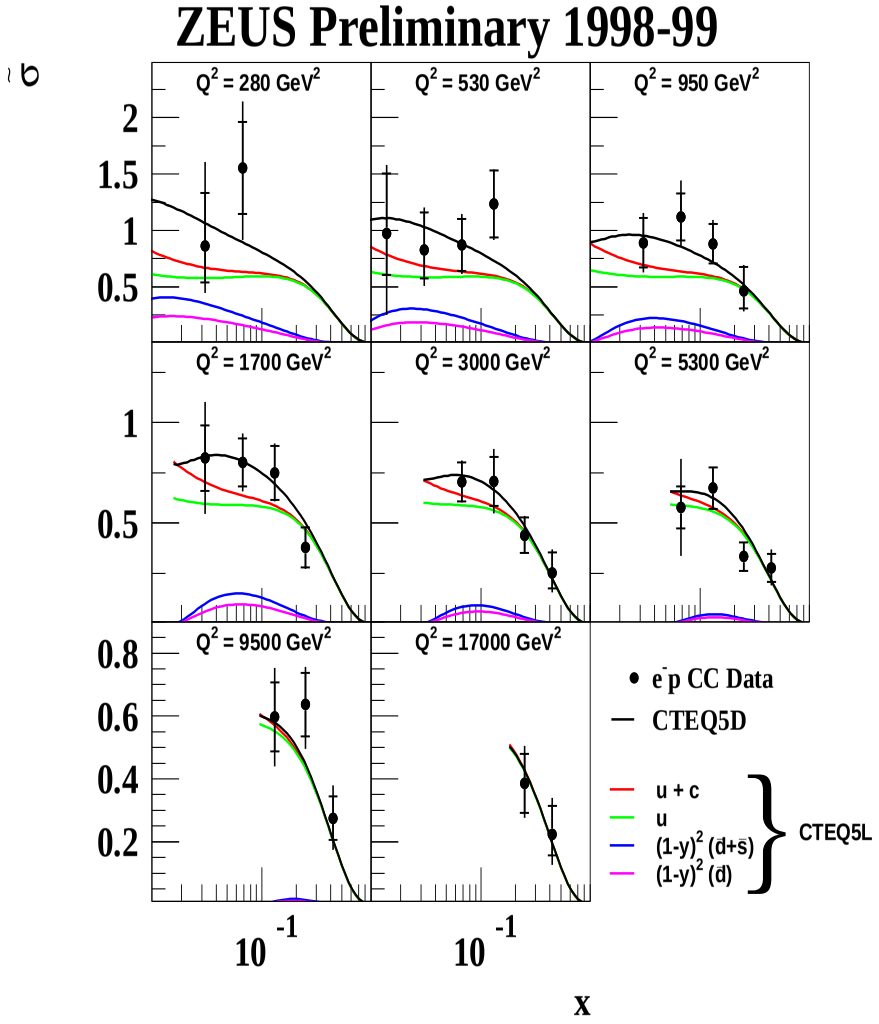


λ_s = strangeness suppression between 0.2 and 0.3

x dependence can separate s from fragmentation (low x) and sea (high x)

NC and CC-DIS Cross Sections





NLO QCD Fit to DIS Data

Use NLO DGLAP evolution with RT-Variable Flavor Number scheme.

Data sets:

- ZEUS 96/97 e^+p NC
- BCDMS μp (scaled by 0.98)
- NMC μp, μD
- E665 μp, μD
- CCFR xF_3 $(x > 0.1)$

Kinematic Range:

- $W^2 > 20\,\text{GeV}^2$
- $2.5 < Q^2 < 3 \times 10^4\,\text{GeV}^2$
- $6.3 \times 10^{-5} < x < 0.65$

Fit 5 PDFs:

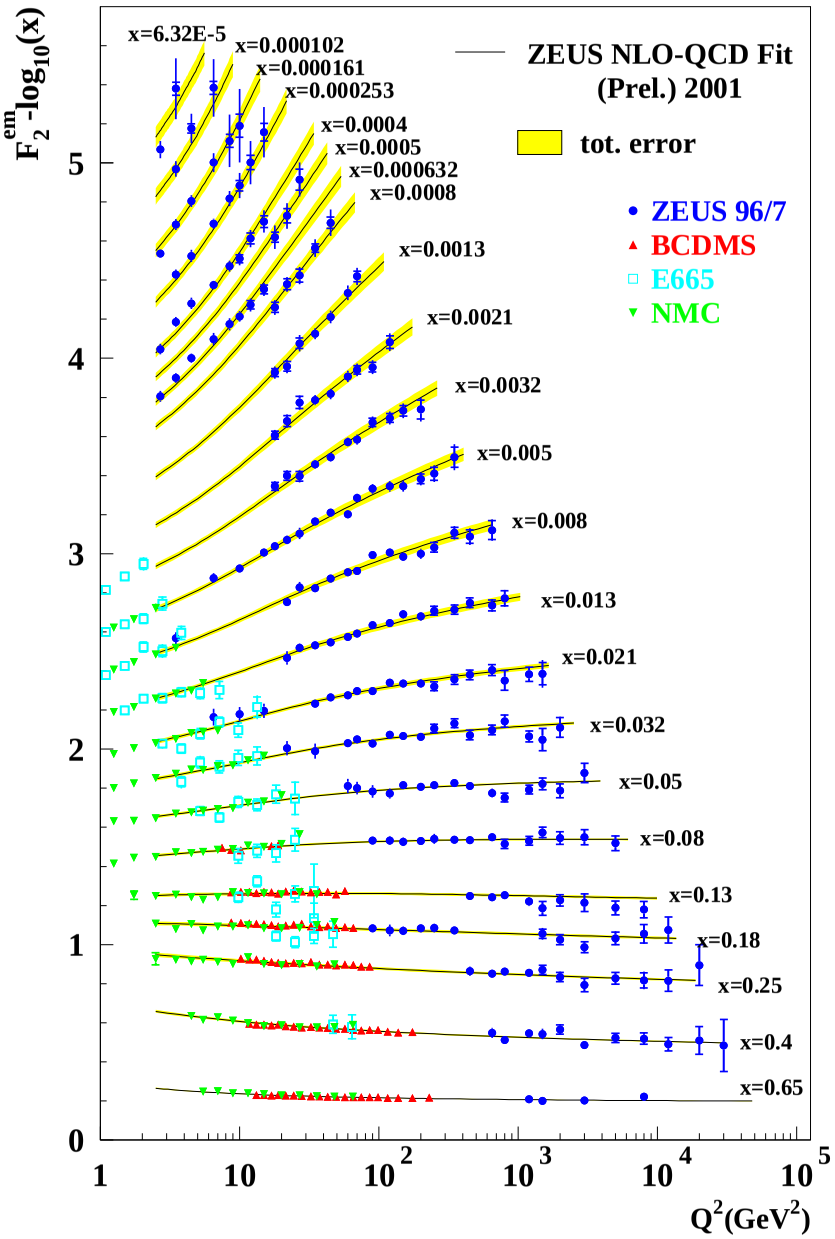
$$
\begin{aligned}
xu_v(x) &= u\text{-valence} \\
xd_v(x) &= d\text{-valence} \\
xS(x) &= \text{total sea} \\
xg(x) &= \text{gluon} \\
x\Delta(x) &= x(\bar{d} - \bar{u})
\end{aligned}
$$

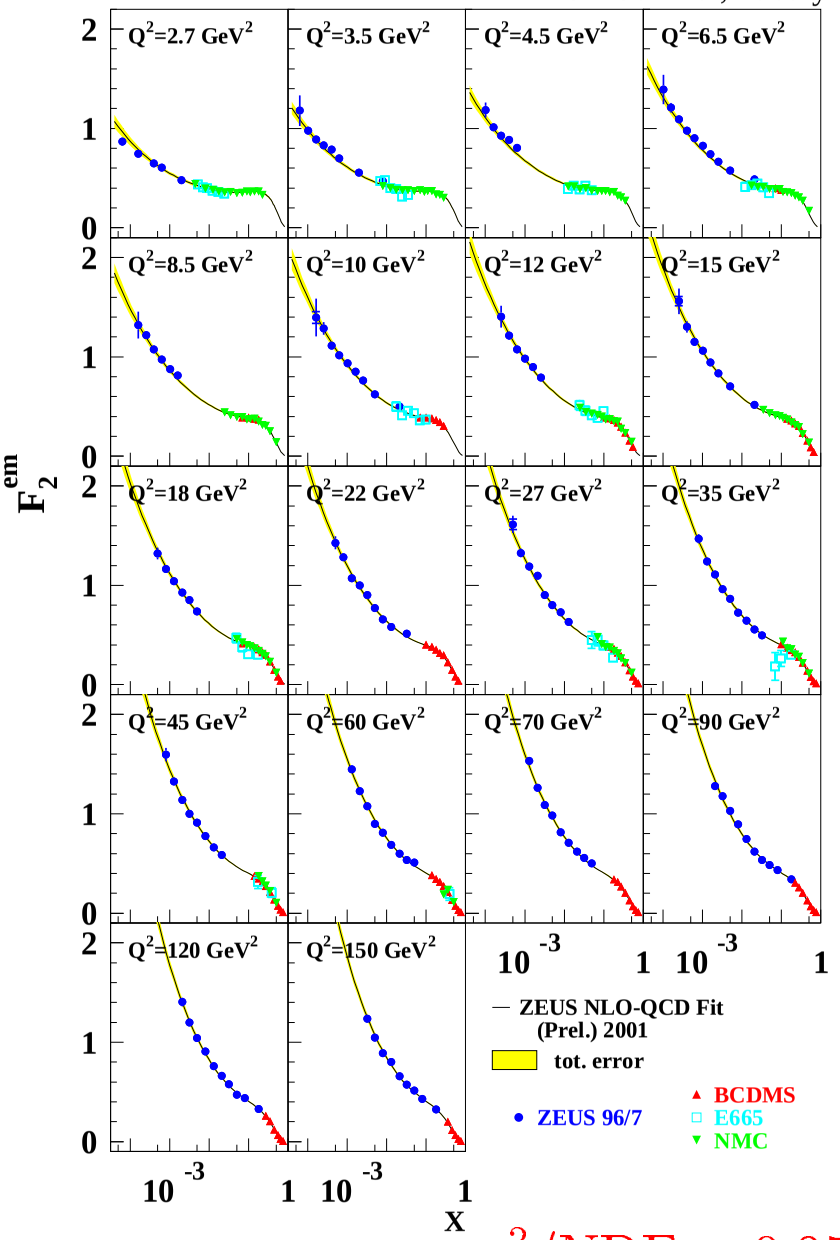
to $p_1 x^{p_2}(1-x)^{p_3}(1 + p_4\sqrt{x} + p_5 x)$

Some parameters are fixed:

	p_1	p_2	p_3	p_4	p_5
u_v	Sum Rule	0.5	free	0	free
d_v	Sum Rule	0.5	free	0	free
g	Sum Rule	free	free	0	0
S	free	free	free	0	free
Δ	free	0.5	$p_3(S) + 2$	0	0

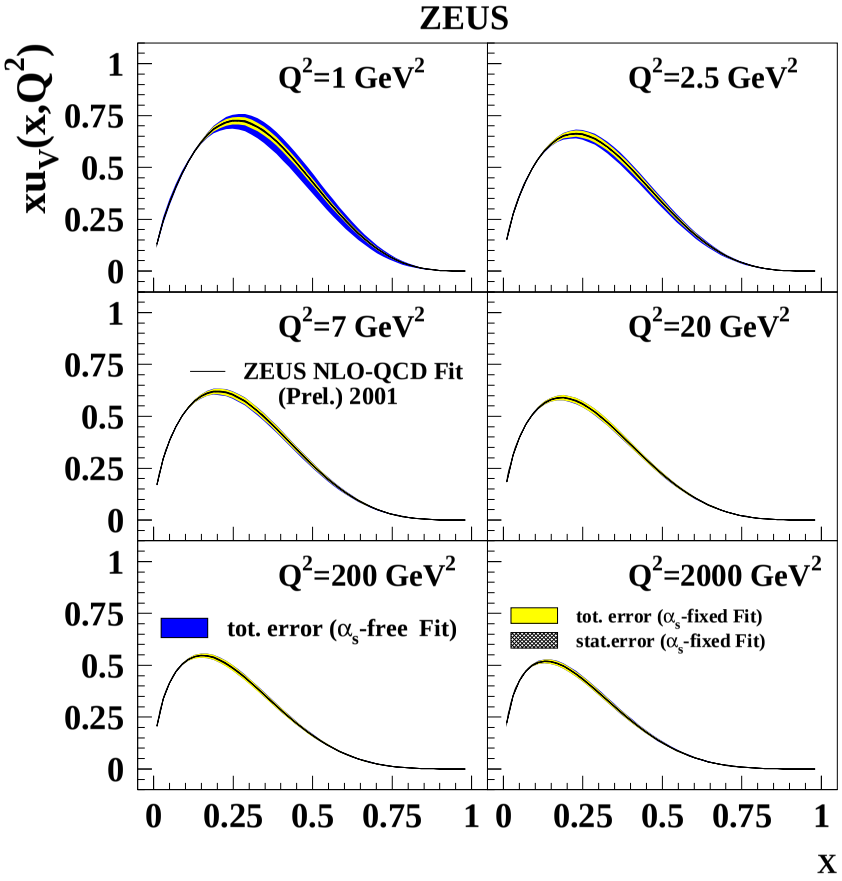
$\alpha_s(M_Z^2)$ either free or set to 0.118

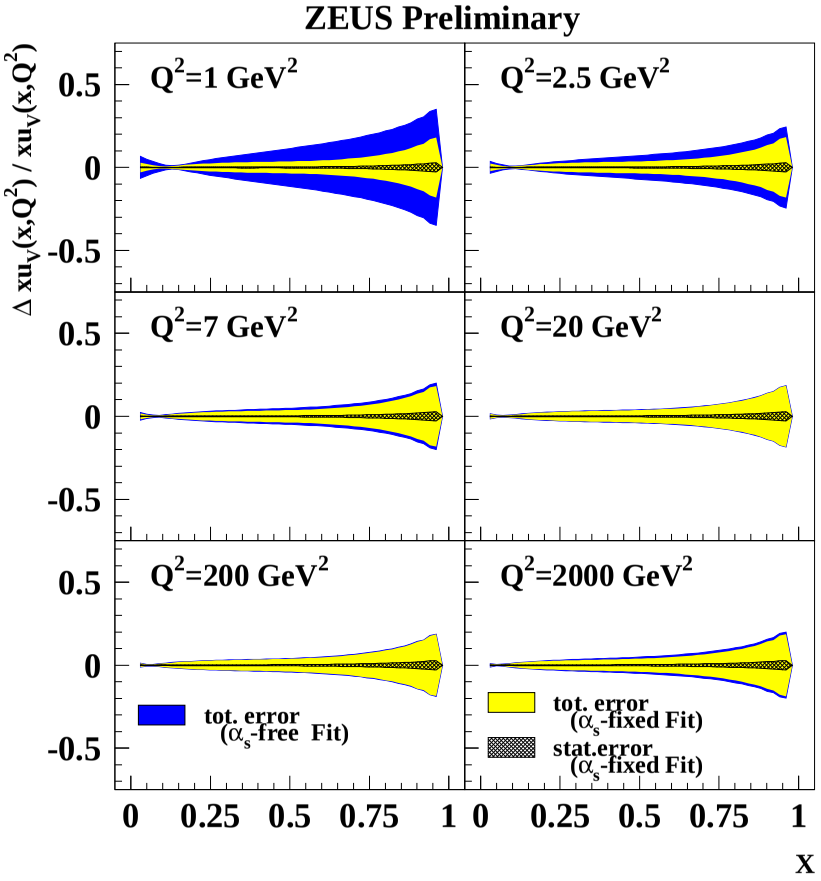




$\chi^2/\mathrm{NDF} = 0.95$

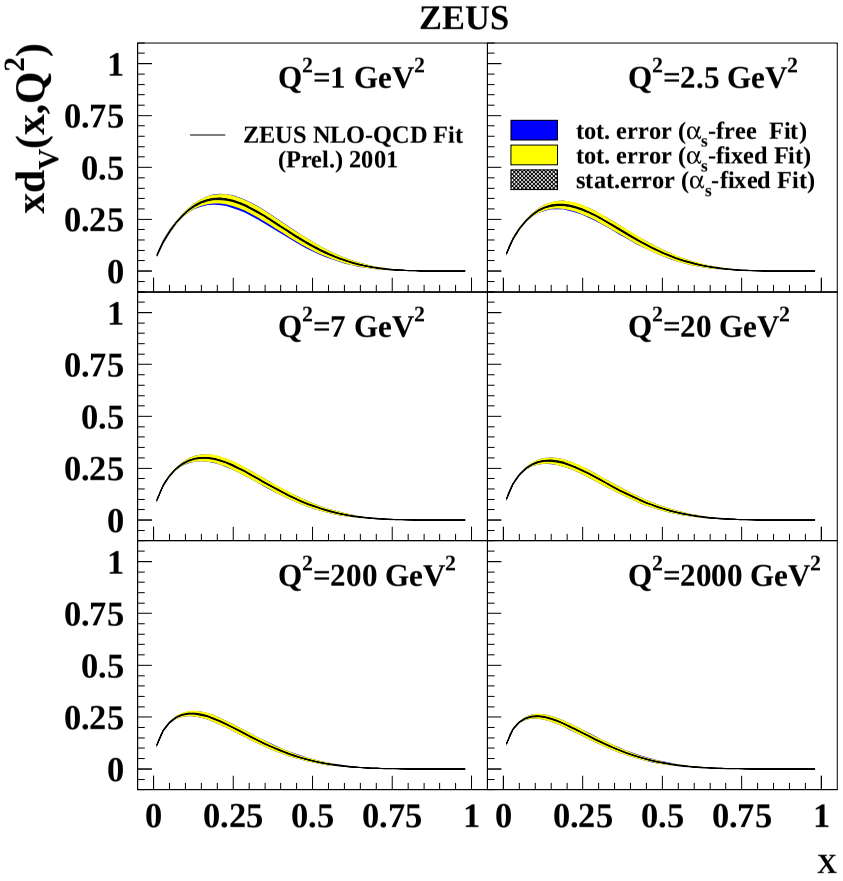
NLO QCD Fit, u-valence

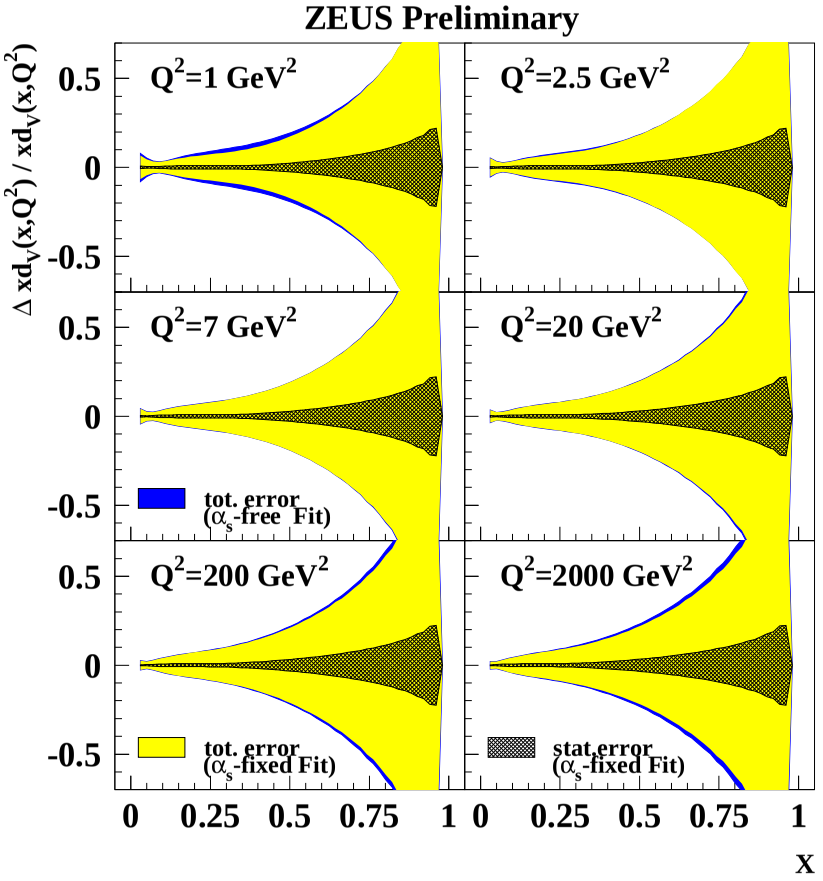




Uncertainty below 10% for $Q^2 > 5\,\mathrm{GeV}^2$, $x < 0.6$

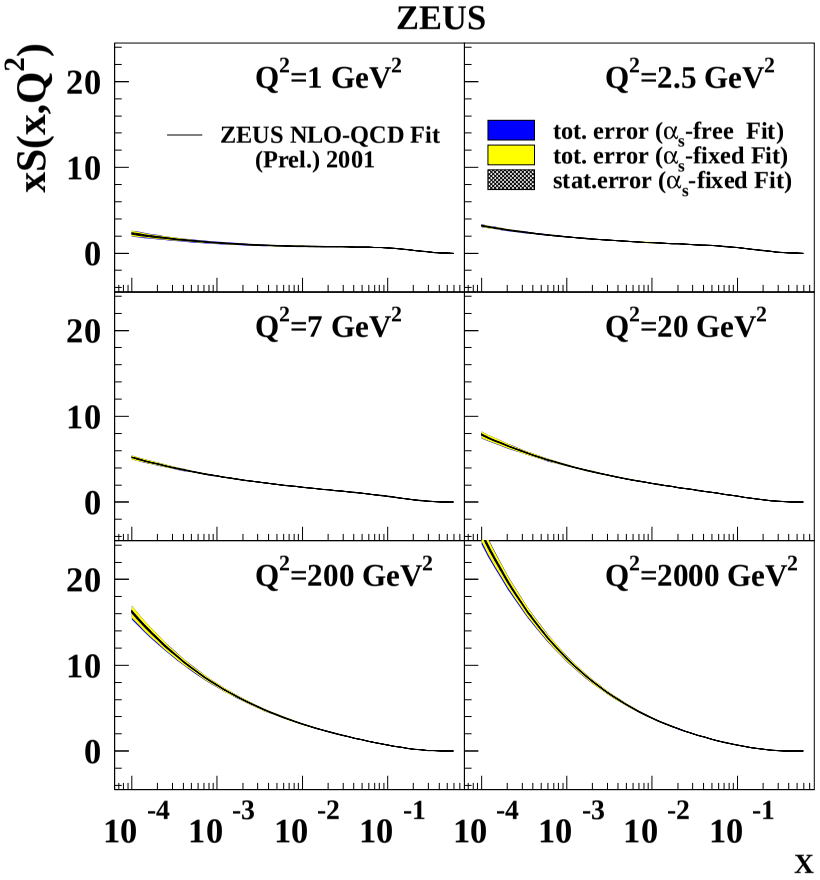
NLO QCD Fit, d-valence

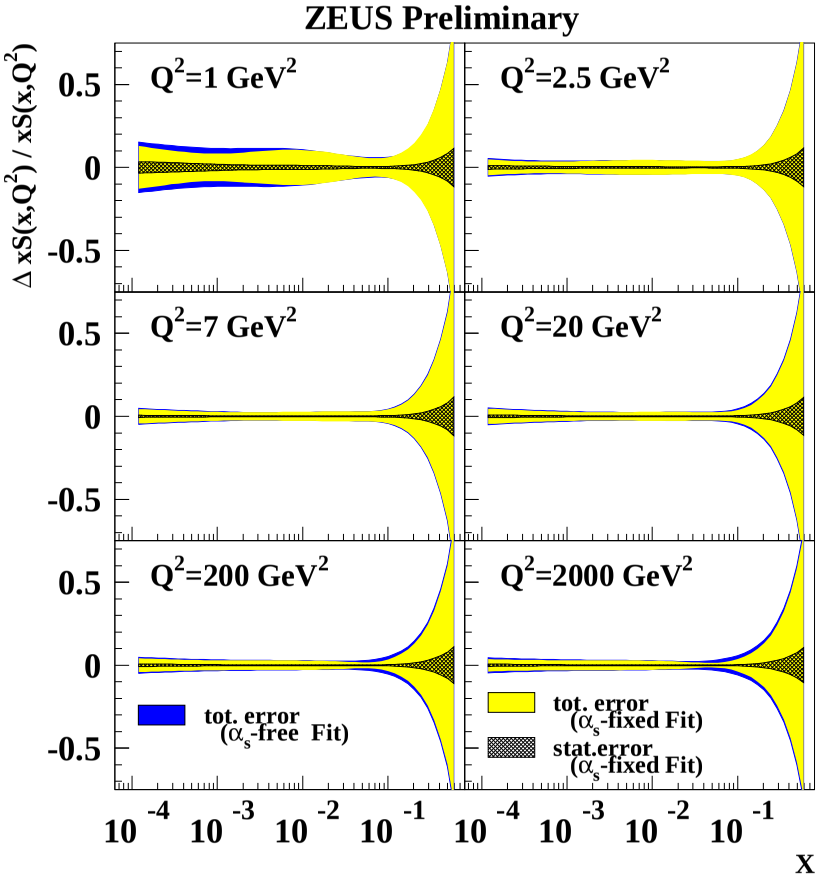




$\sim 20\%$ uncertainty at $x = 0.5$

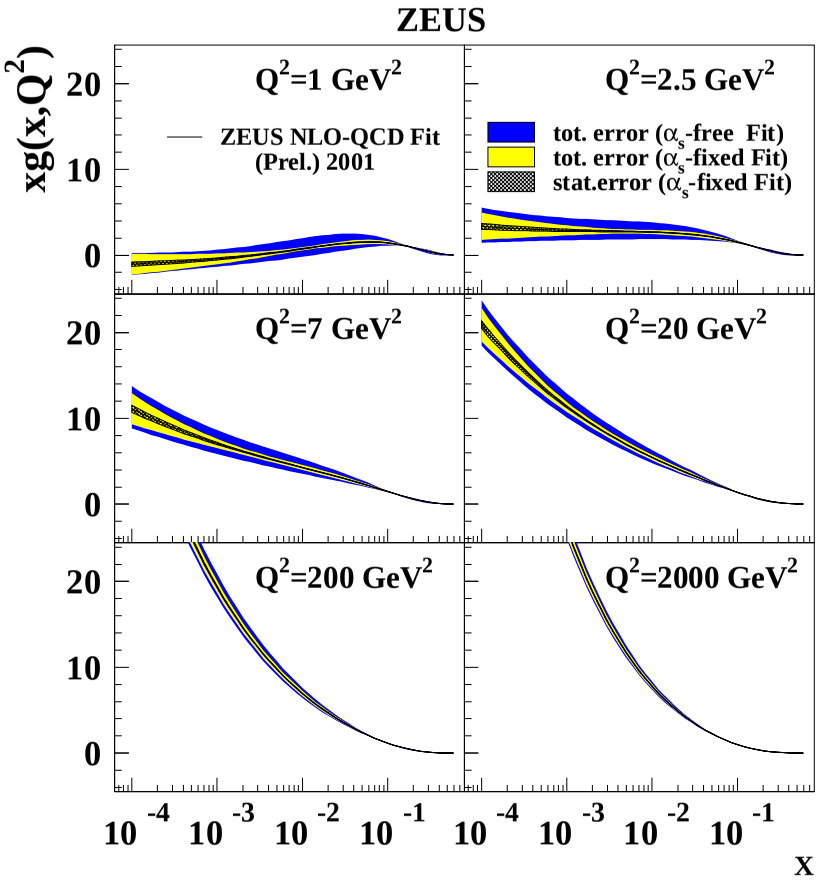
NLO QCD Fit, sea

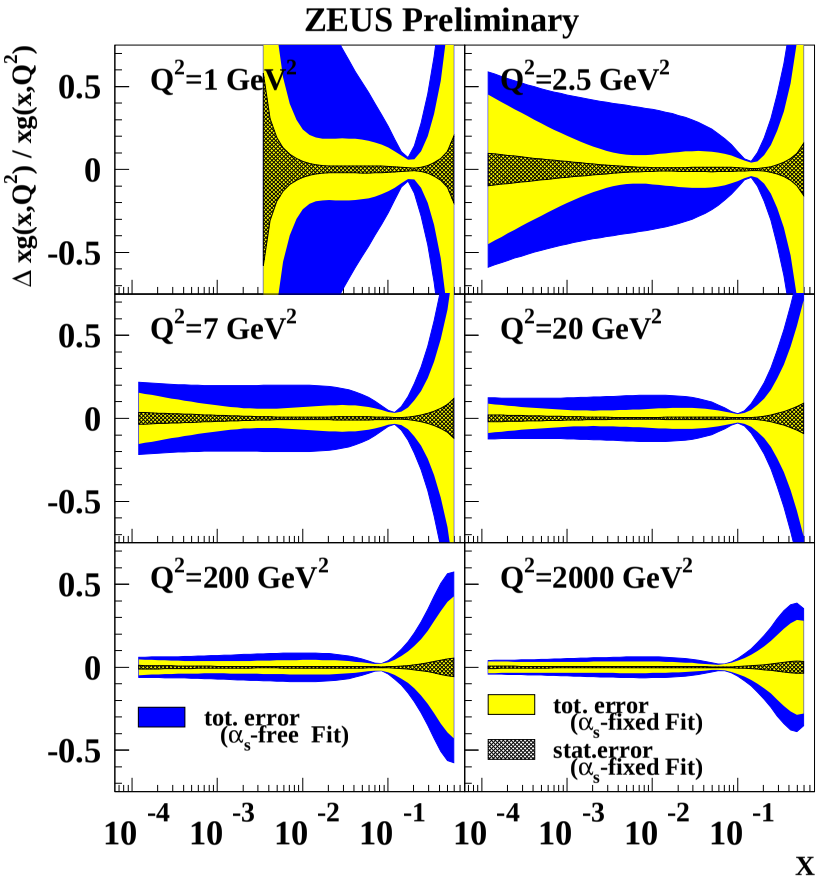




Uncertainty below 10% for $Q^2 > 2\,\mathrm{GeV}^2$, $x < 0.2$

NLO QCD Fit, gluon

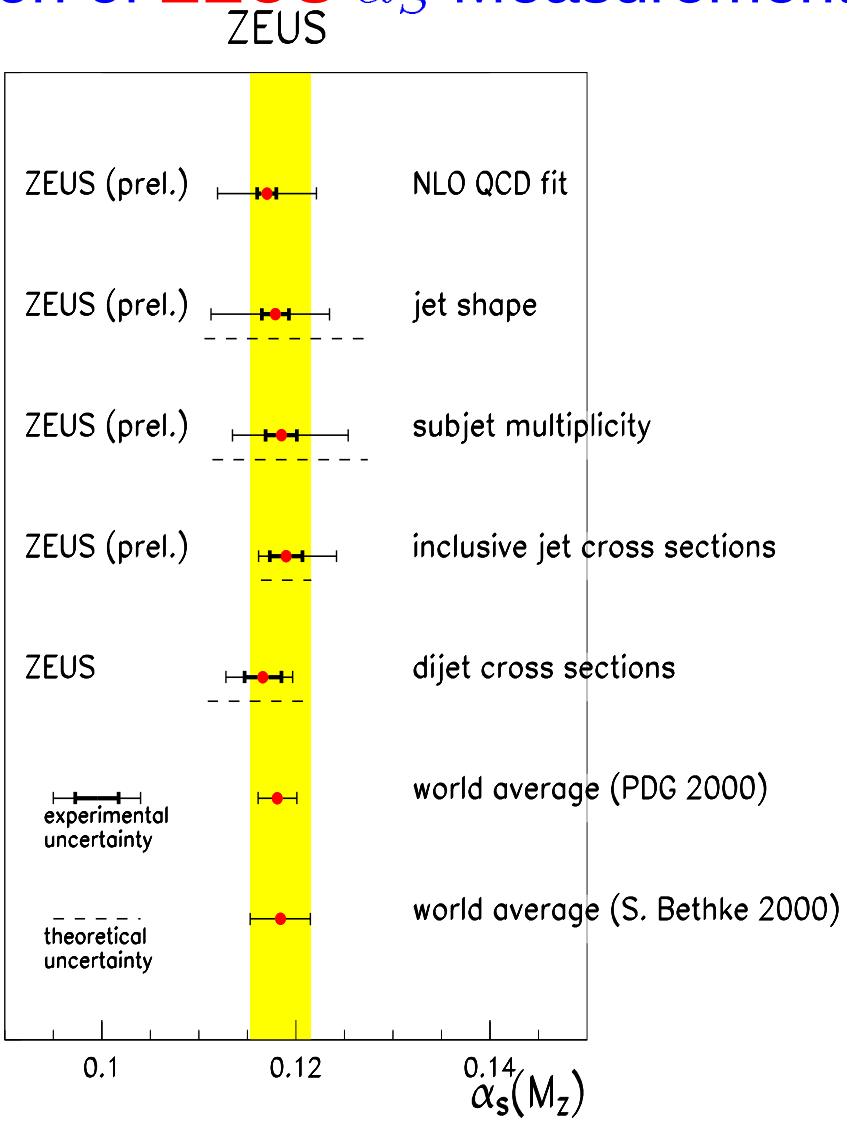




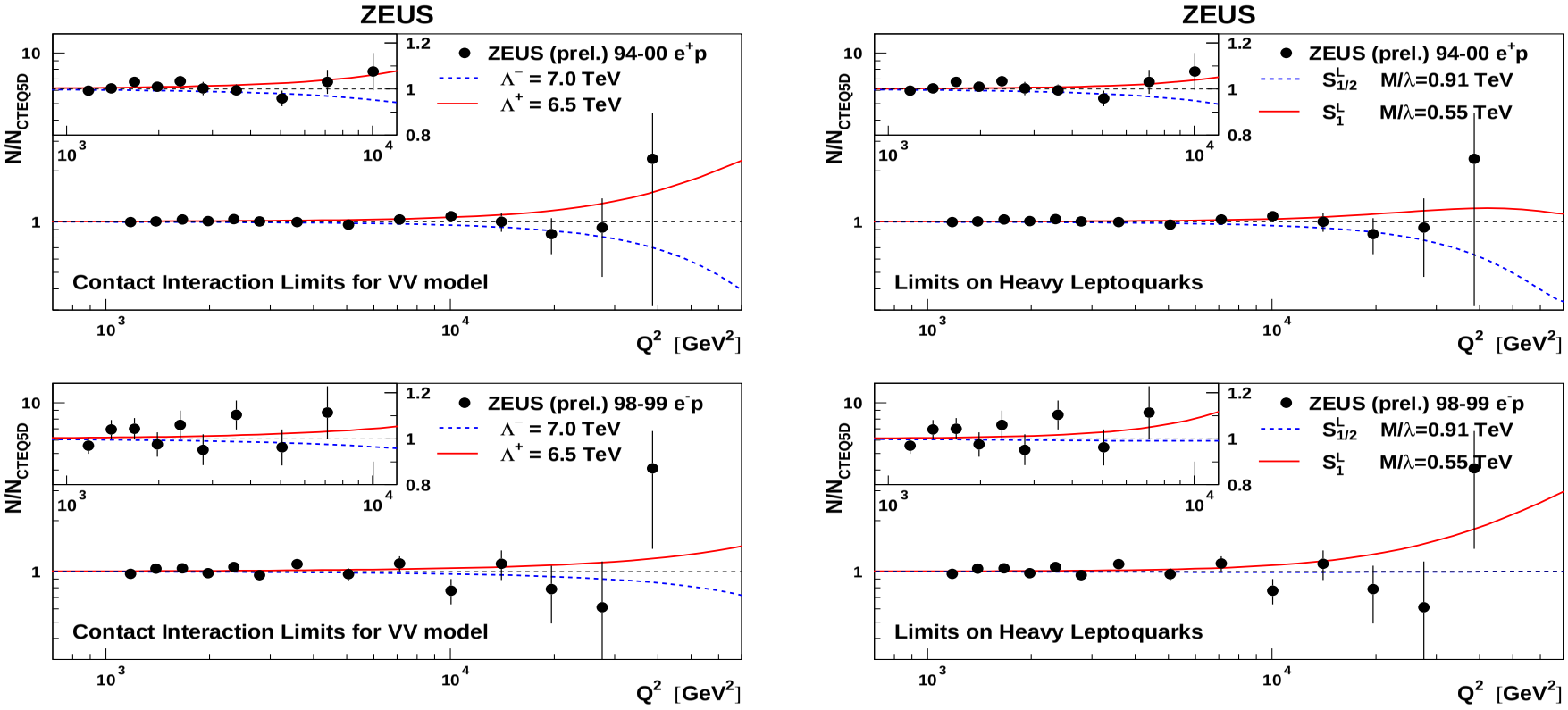
$$\alpha_s(M_Z^2) = 0.117 \pm 0.001(\text{stat. } + \text{uncorr.syst.}) \pm 0.005(\text{corr.syst.})$$

Normalization errors $\sim 50\%$ of correlated systematic error.

Comparison of ZEUS α_S Measurements



Contact Interactions



Curves show excluded models (95% CL). Entire ZEUS data (e^- and e^+) is used.

Method: Fit the data to get $\Lambda_{\rm obs}$. Find $\Lambda_{\rm limit}$ for which 95% of simulated experiments have $\Lambda_{\rm fit} > \Lambda_{\rm obs}$.

ZEUS (prel.) 1994-2000 $e^{\pm}p$

Model	Coupling structure								95% CL [TeV]	
	η^{ed}_{LL}	η^{ed}_{LR}	η^{ed}_{RL}	η^{ed}_{RR}	η^{eu}_{LL}	η^{eu}_{LR}	η^{eu}_{RL}	η^{eu}_{RR}	Λ^-	Λ^+
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	7.0	6.5
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$	5.3	4.6
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	3.4	3.3
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$			4.0	2.7
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$		4.7	4.7
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$	4.3	4.2
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$		5.6	5.6
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$	4.8	4.8
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$	2.6	3.9
U1					$+\eta$	$-\eta$			4.1	3.6
U2					$+\eta$		$+\eta$		5.8	5.3
U3					$+\eta$			$+\eta$	5.8	5.2
U4						$+\eta$	$+\eta$		6.4	5.9
U5						$+\eta$		$+\eta$	6.0	5.5
U6							$+\eta$	$-\eta$	2.8	3.7

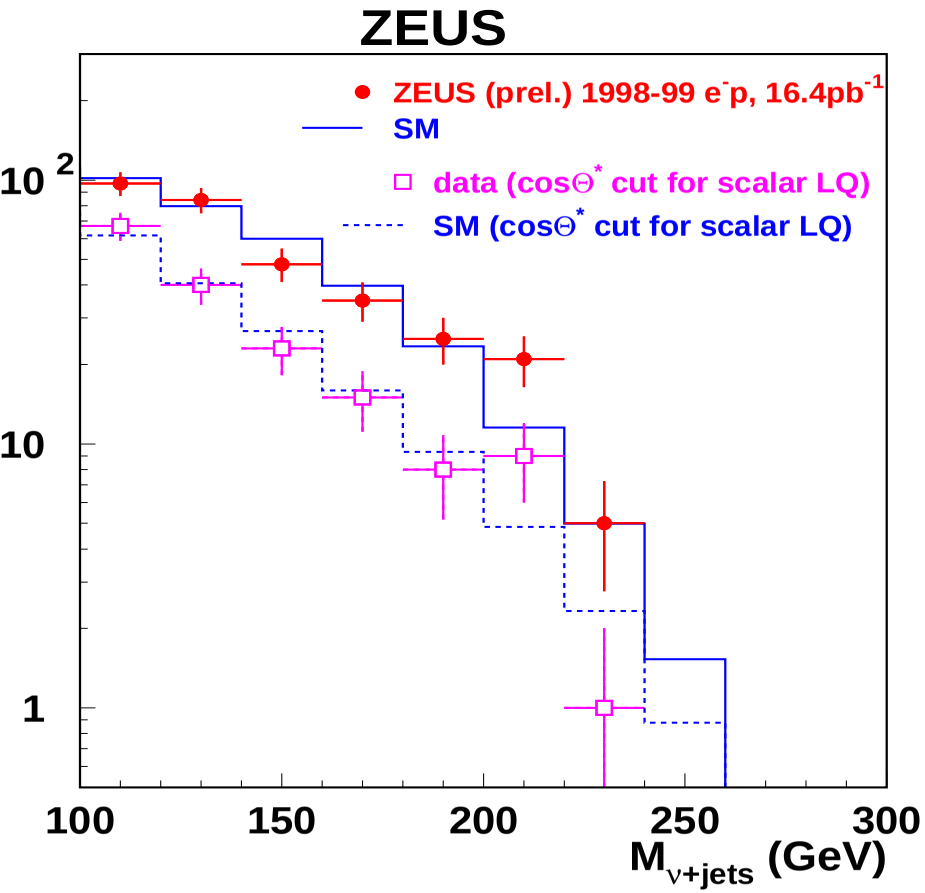
CI Limits: $\Lambda > 3 - 7\,\mathrm{TeV}$

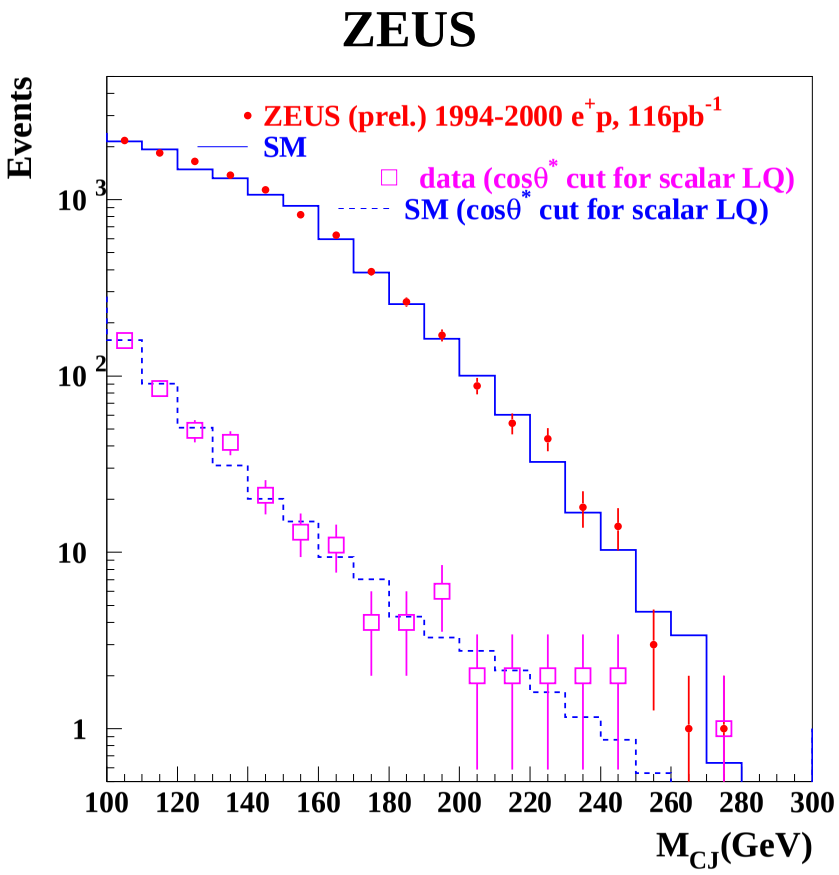
ZEUS (prel.) 1994-2000 $e^{\pm}p$

Model	Coupling structure								95% CL [TeV]
	a^{ed}_{LL}	a^{ed}_{LR}	a^{ed}_{RL}	a^{ed}_{RR}	a^{eu}_{LL}	a^{eu}_{LR}	a^{eu}_{RL}	a^{eu}_{RR}	M_{LQ}/λ_{LQ}
S^L_0					$+\frac{1}{2}$				0.75
S^R_0								$+\frac{1}{2}$	0.69
$\tilde{S}^R_0$				$+\frac{1}{2}$					0.31
$S^L_{1/2}$						$-\frac{1}{2}$			0.91
$S^R_{1/2}$			$-\frac{1}{2}$				$-\frac{1}{2}$		0.69
$\tilde{S}^L_{1/2}$		$-\frac{1}{2}$							0.50
S^L_1	$+1$				$+\frac{1}{2}$				0.55
V^L_0	-1								0.69
V^R_0				-1					0.58
$\tilde{V}^R_0$								-1	1.03
$V^L_{1/2}$		$+1$							0.49
$V^R_{1/2}$			$+1$				$+1$		1.15
$\tilde{V}^L_{1/2}$						$+1$			1.26
V^L_1	-1				-2				1.42

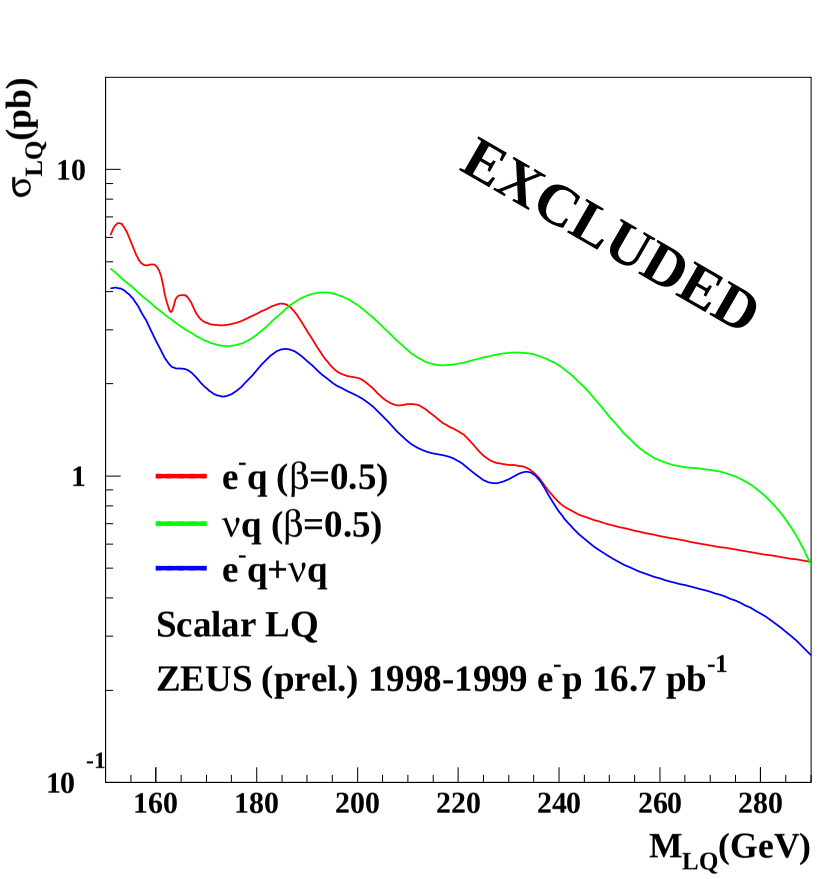
LQ Limits: $M/\lambda > 0.3 - 1.4\,\mathrm{TeV}$

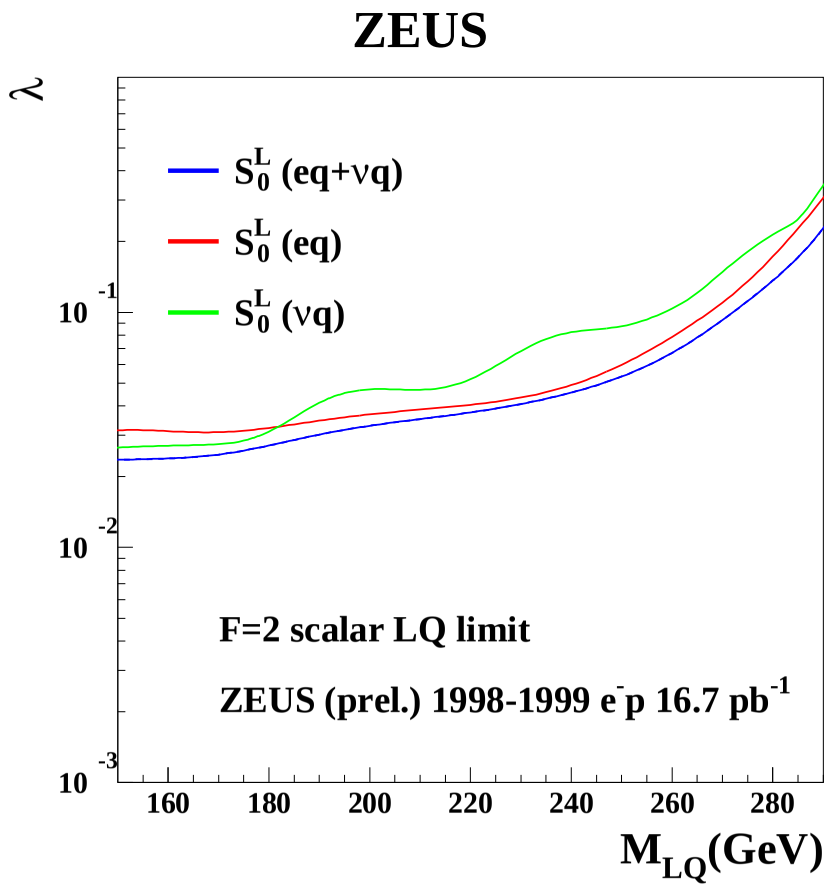
Leptoquark Search





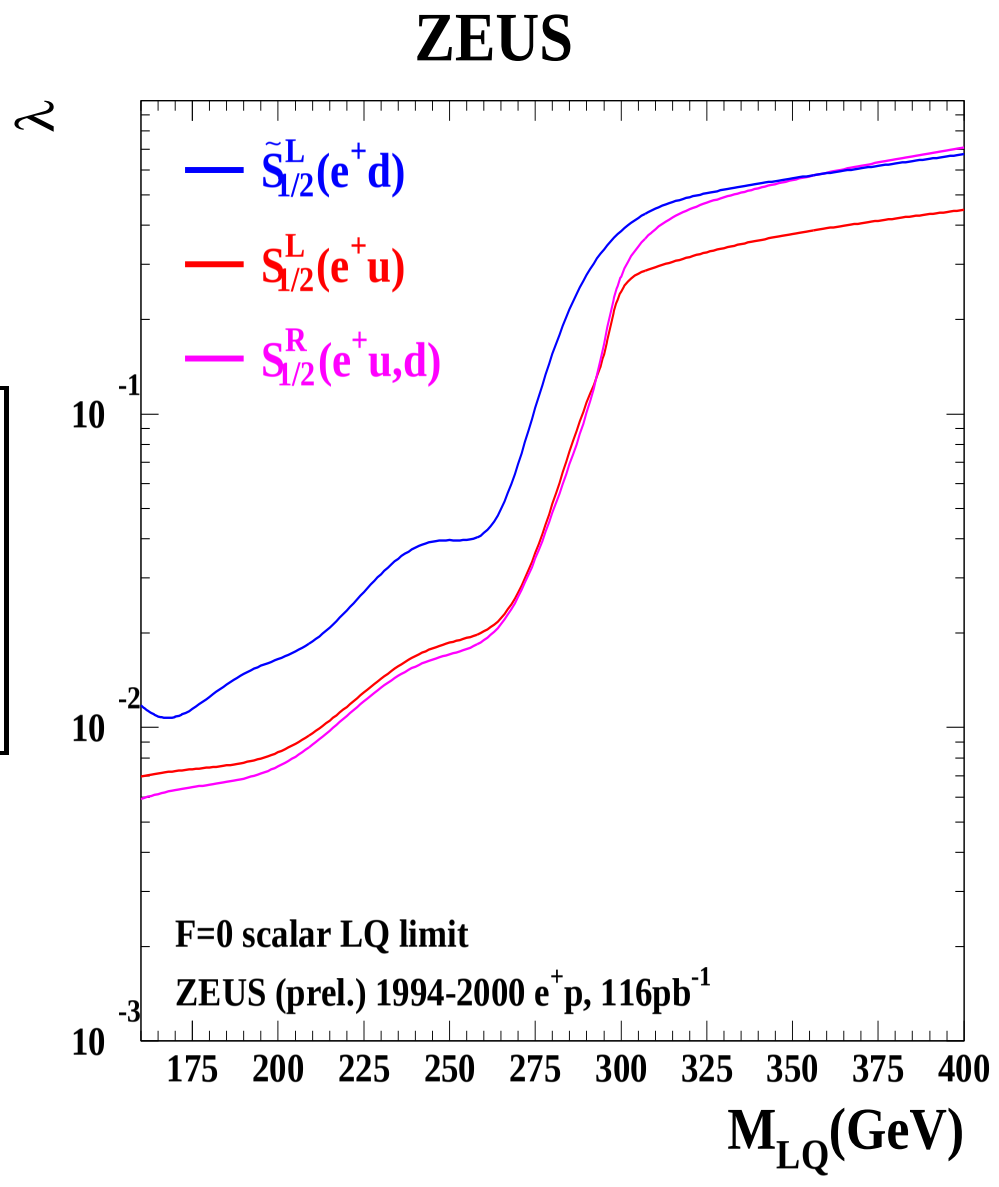
ν-jet and e-jet mass spectra before and after cut on $\cos\theta^*$ to suppress DIS.



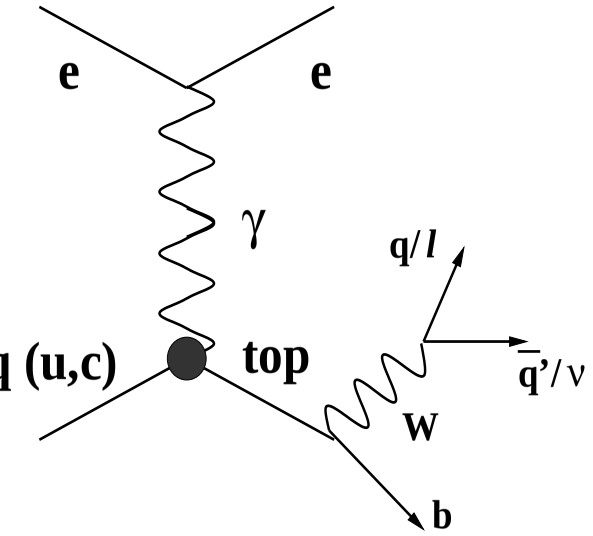


Limits on cross section and λ for $F = 2$ LQs using 16.7 pb^{-1} of e^-p data.

Limits for $M_{LQ} > \sqrt{s}$ derived from likelihood fit to $M_{LQ}, \cos\theta^*$ distribution. Use full LQ cross section including LQ-NC interference.



Search for $ep \to tX$



$\mathcal{L} = 130\ \mathrm{pb}^{-1}$

17 events selected (10 e, 7 μ)
Well described by SM simulation (16.4 expected).

Leptonic preselection :

- $\not{P}_t > 20\,\mathrm{GeV}$
- A jet with $E_t^{\mathrm{jet}} > 5\,\mathrm{GeV}$
- Isolated track with $P_t > 10\,\mathrm{GeV}$
- $D_{\mathrm{trk}} > 0.5, D_{\mathrm{jet}} > 1.0$

Final leptonic selection:

- $E - P_Z < 45\,\mathrm{GeV}$ (e only)
- $\not{P}_t(\mu + \mathrm{had}) > 12\,\mathrm{GeV}$ (μ only)
- $P_t^X > 40\,\mathrm{GeV}$
- $D_{\mathrm{trk}} > 0.5, D_{\mathrm{jet}} > 1.0$

zero events remain.
SM expectation =0.96.
Efficiency= 5.5%

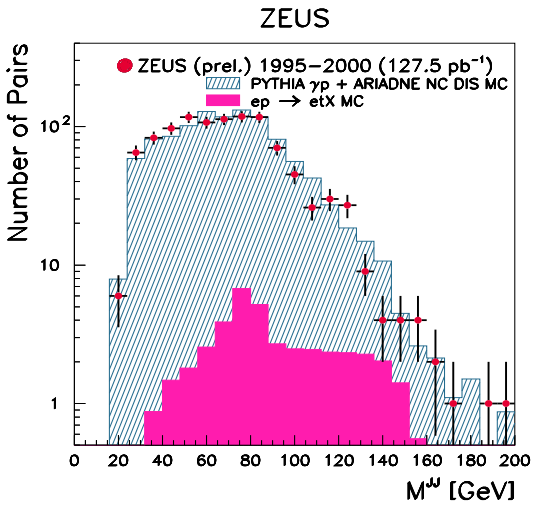
$\mathcal{L} = 127.5\ \mathrm{pb}^{-1}$

Hadronic selection:

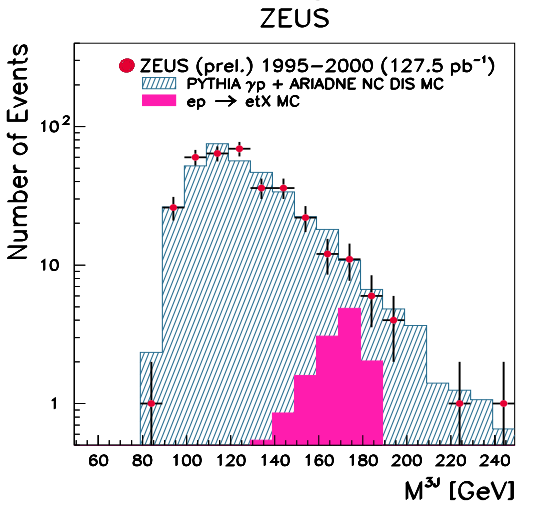
- Use long. invar. k_T-cluster algorithm
- 3 jets with $-1 < \eta^{\mathrm{jet}} < 2.5$
- $E_T^{\mathrm{jet}} > 40, 25, 14\,\mathrm{GeV}$
- $0.16 < y_{JB} < 0.95$
- Veto NC DIS

349 events pass

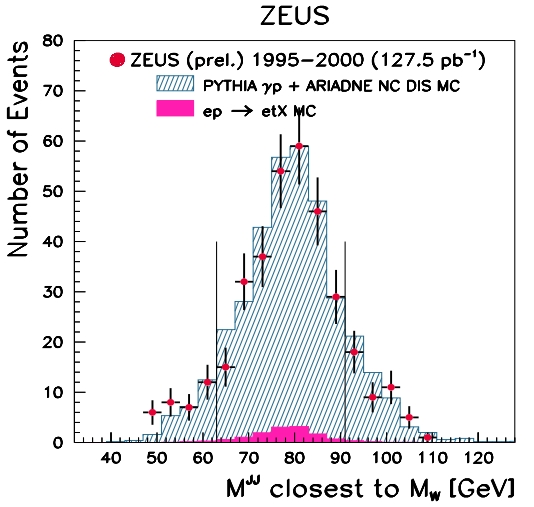
Simulate γp with PYTHIA normalized to data with ($M^{3J} < 158\,\mathrm{GeV}$)



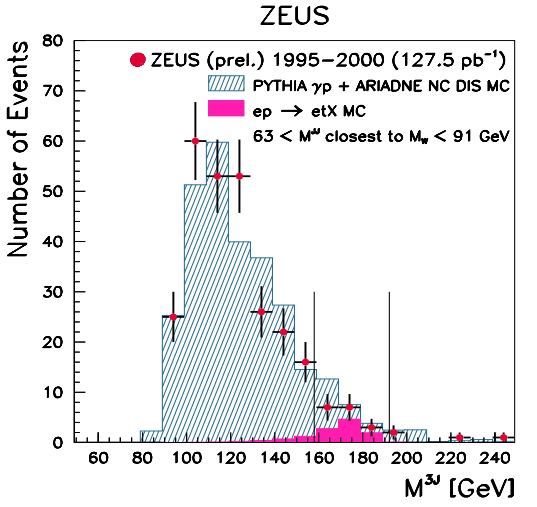
M^{JJ} for all pairs



M^{3J} distribution



M^{JJ} closest to M_W



M^{3J} for events with $63\,\mathrm{GeV} < M^{JJ} < 91\,\mathrm{GeV}$

Lepton + hadron channels $\rightarrow$ 95% CL limit ($\sqrt{s} = 320$ GeV):

$$\sigma(ep \rightarrow etX) < 0.25\,\mathrm{pb}$$

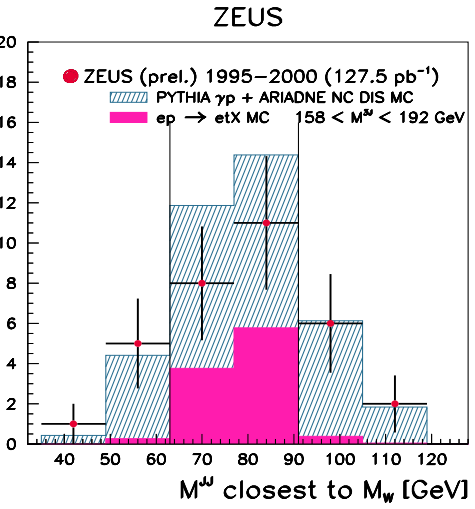
Limit on anomalous FCNC coupling:

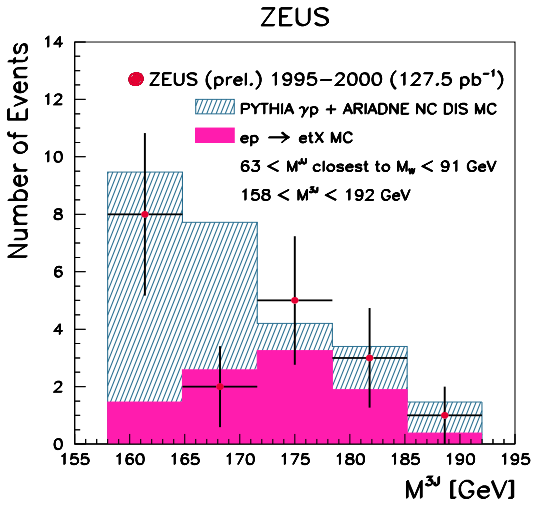
$$\kappa_{tu\gamma} < 0.19$$

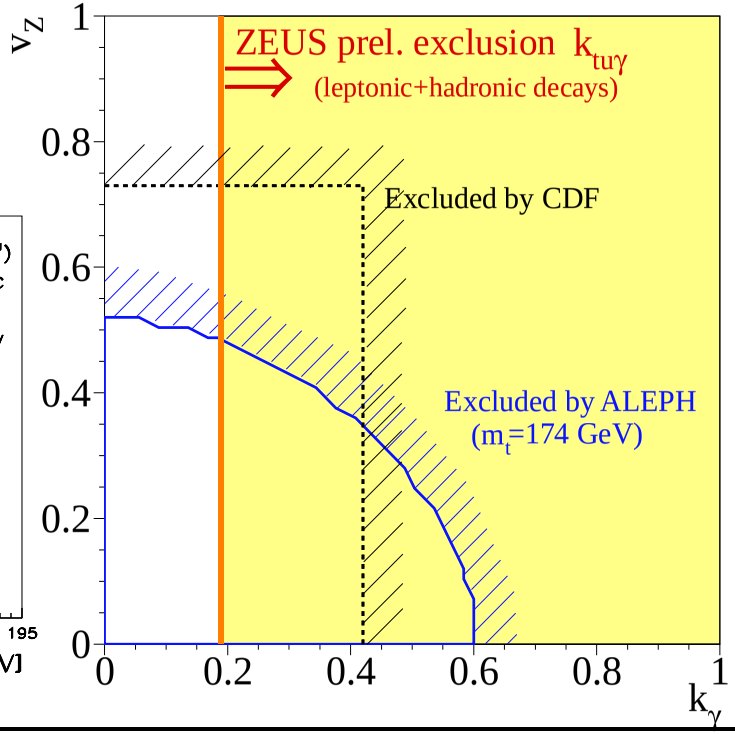
Final Cuts for Hadronic Channel:

- $63\,\mathrm{GeV} < M^{JJ} < 91\,\mathrm{GeV}$
- $158\,\mathrm{GeV} < M^{3J} < 192\,\mathrm{GeV}$

19 events remain
20.0 expected
efficiency = 31%







Summary and Conclusions

- Multiple complementary measurements of α_S.
- High precision DIS data.
- Detailed studies of jet shapes
- D meson spectroscopy at HERA.
- Many measurements using $> 100\ \mathrm{pb}^{-1}$ data sets.
- Quick overview of detailed analyses.
- Many topics not covered (~ 50 papers submitted).
- Read the papers!
  `http://www-zeus.desy.de/physics/phch/conf/eps01_paper.html`