Inclusive diffraction in *e-p* DIS

Looking into regions beyond HERA

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Continuation of studies in
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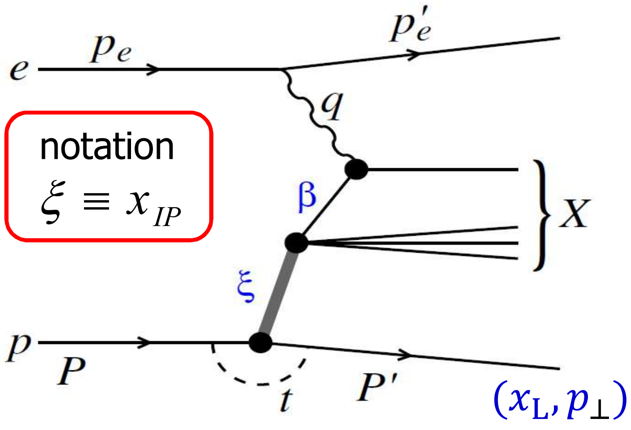
- Diffractive DIS model, data simulation and fits
- x_L and t range
- Subleading component study
- F_L study

Inclusive diffractive DIS



$$\xi \equiv x_{IP} = \frac{(P-P')\cdot q}{P\cdot q} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2 - m_p^2}$$

$$\beta = \frac{Q^2}{2(P-P')\cdot q} = \frac{Q^2}{Q^2 + M_X^2 - t}$$

$$x = \xi\beta$$

Incoming proton runs along z axis.

Outgoing proton momentum is given in terms of $(x_L, p_\perp)$ with $P'_+ = x_L P_+$.

Cross section, reduced cross section, diffractive structure functions

$$\frac{d\sigma}{d\beta dQ^2 d\xi dt} = \frac{2\pi\alpha^2}{\beta Q^4}[1+(1-y)^2]\,\sigma_{\rm red}^{D(4)}(\beta, Q^2, \xi, t)$$

dim = GeV^{-2}

$$\sigma_{\rm red}^D = F_2^D - \frac{y^2}{1+(1-y)^2}F_L^D$$

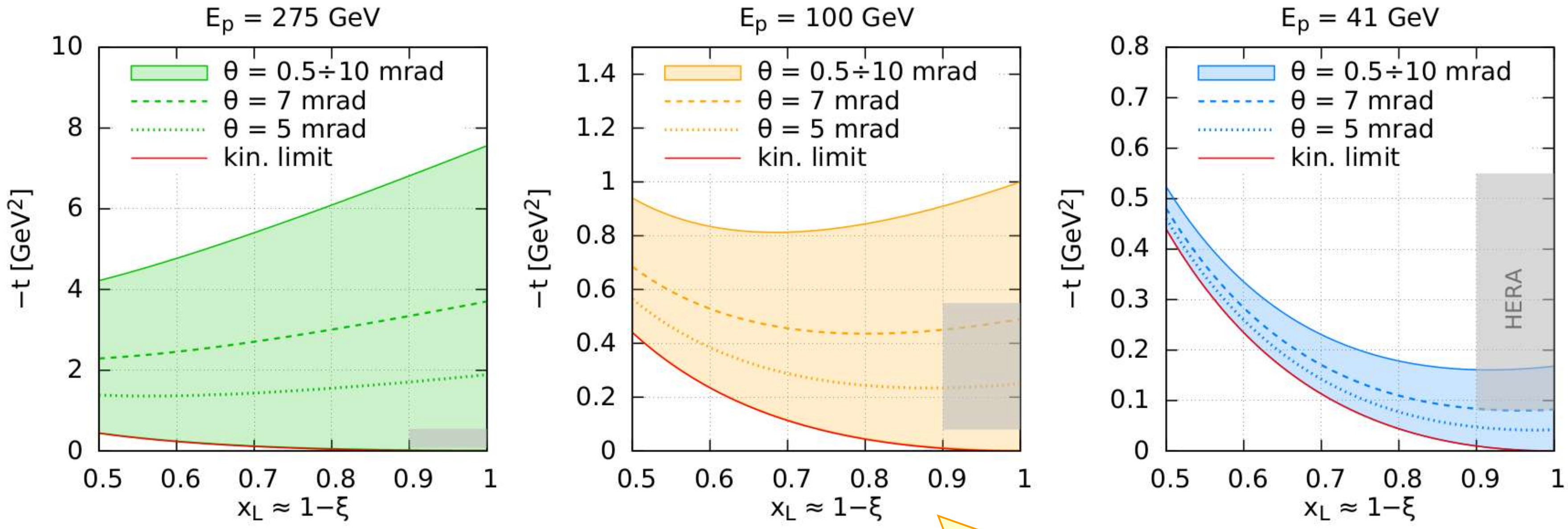
Upon integration over t

$\sigma_{\rm red}^{D(3)}, F_{2,L}^{D(3)}$

become dimensionless

x_L, t plane – final proton tagging

- EIC can tackle large $\xi \cong 1 - x_\mathrm{L}$ regions beyond HERA
- The coverage depends on the angular acceptance



$$t = -\frac{p_\perp^2}{x_\mathrm{L}} - \frac{(1-x_\mathrm{L})^2}{x_\mathrm{L}} m_p^2 - \frac{1-x_\mathrm{L}}{x_\mathrm{L}} (M_Y^2 - m_p^2)$$

$x_\mathrm{L}, p_\perp, \theta$ measured in LAB = collinear(e,p) frame

$|t|$ measured up to ~ 2 GeV^2, is very interesting, e.g. for determination of the t-dependence of the secondary exchange.

Two component model for diffractive SFs (as used in the HERA fits)

Regge factorization works at low ξ (< 0.01).
At higher ξ, subleading exchanges (reggeons/mesons) enter the game
— they are all parametrized by a single additional "Reggeon" term

$$F^{D(4)}(z,Q^2,\xi,t) = \varphi_{\mathbf{P}}(\xi,t)\, F^{\mathbf{P}}(z,Q^2) + \varphi_{\mathbf{R}}(\xi,t)\, F^{\mathbf{R}}(z,Q^2)$$

free parameter

"Reggeon" SF ∝ pion, $F^{\mathbf{R}} = A_{\mathbf{R}}\, F^{\pi}$

$\varphi_{\mathbf{P},\mathbf{R}}$ = Regge-type flux:

$$\varphi(\xi,t) \sim \frac{e^{Bt}}{\xi^{2\alpha(t)-1}}$$ with $\alpha(t) = \alpha_0 + \alpha' t$

3 parameters per flux

From HERA fits (ZEUS-SJ),
P and **R** have very different shapes in (ξ,t):

$$\xi\phi_P(\xi,t) \propto \xi^{-0.22}\, e^{-7|t|}$$
$$\xi\phi_R(\xi,t) \propto \xi^{0.6+1.8|t|}\, e^{-2|t|}$$

$F^{\mathbf{P}}$ from Pomeron PDFs via NLO DGLAP evolution starting at μ_0^2 = 1.8 GeV²

QCD

$$f_k^{\mathbf{P}}(z) = A_k z^{B_k}(1-z)^{C_k}, \qquad k = g, q$$

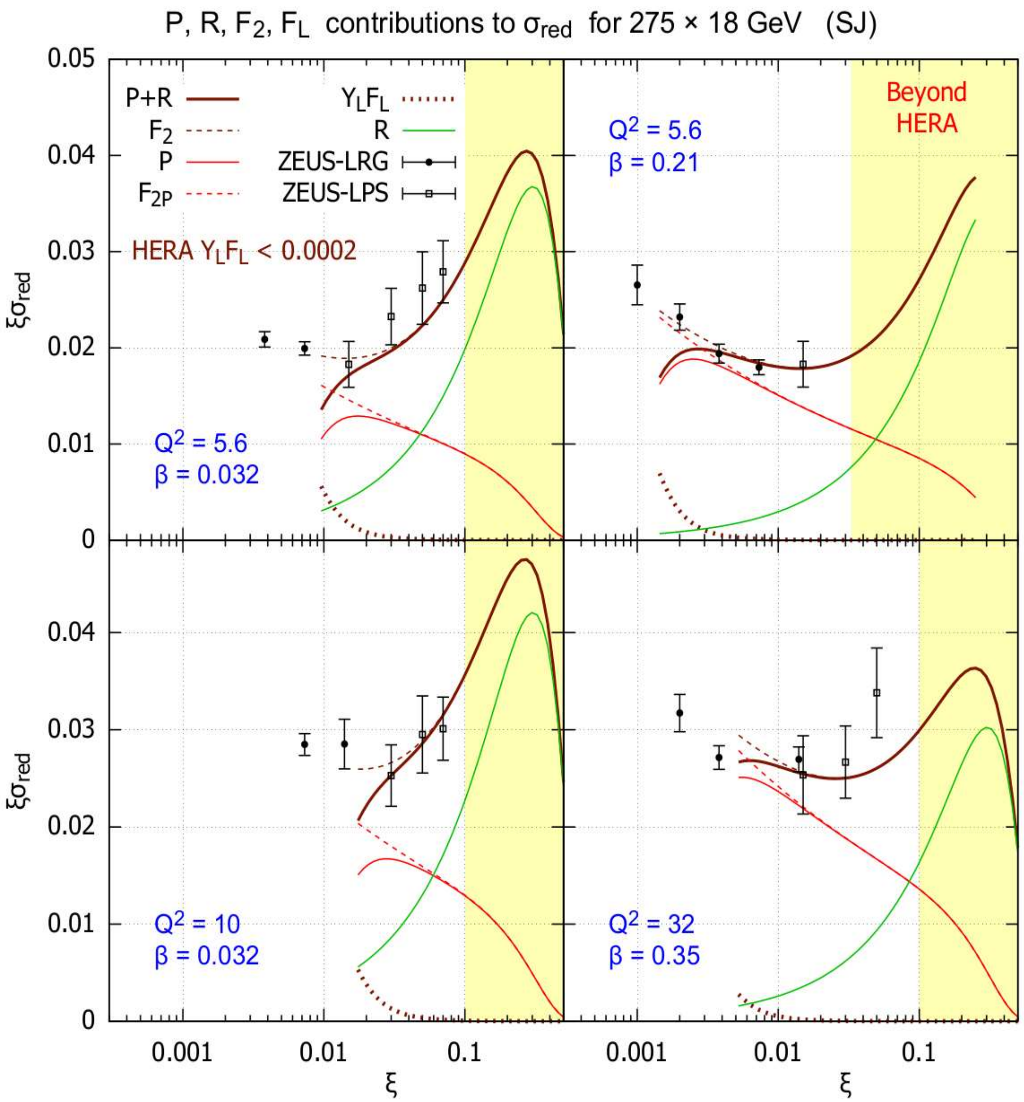
$q = d = u = s$

3 parameters per PDF

Simulations and fits

- Pseudo-data generation
  - Binning:
    - 4 bins per order of magnitude in each β, Q^2, ξ;
    - two extra bins for $\beta > 0.3$
  - Model:
    - extrapolation from ZEUS-SJ DPDFs
    - random smearing: Gaussian from 5% sys. + Poissonian from lumi; nb. statistical errors are basically negligible for $\delta_{\text{sys}} = 5\%$
  - several random samples generated
- DPDFs fits to $\sigma_{\text{red}}^{D(3)}$
  - Out of all 13 parameters only up to 9 are used in the fits
    - $B_{P/R}, \alpha'_{P/R}$ are fixed from other measurements, e.g. $\sigma_{\text{red}}^{D(4)}$
  - Good quark PDFs determination
  - Moderate gluon determination — additional data (as dijets) would help

Pomeron, Reggeon, F_2, F_L components of σ_{red}



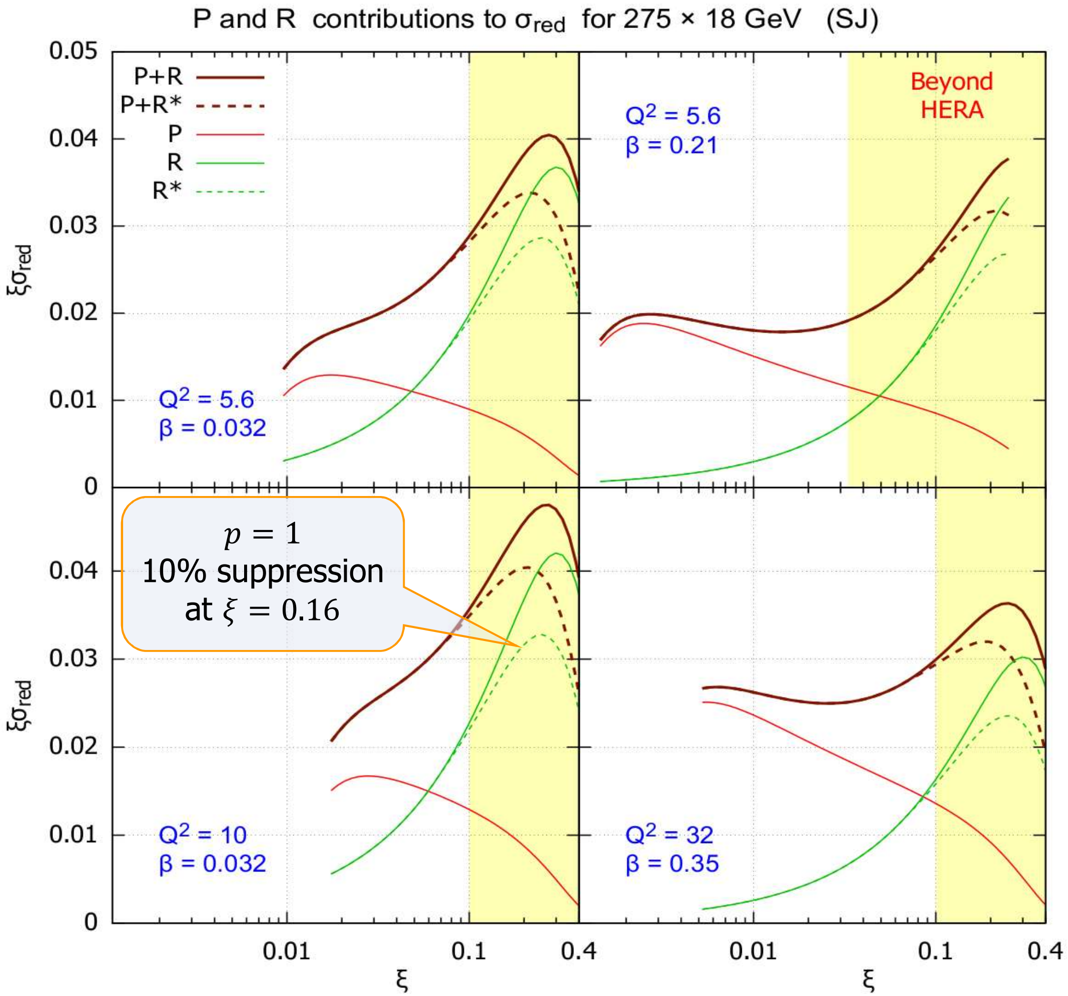
$$\xi\sigma_{\rm red}^{D(3)} \sim \xi^{-0.2}\sigma_P + \xi^{0.6}\sigma_R$$

- Pomeron dominates at low ξ, particularly at high β
  - very interesting region for the Pomeron measurement
- $\mathbb{R}$ contribution grows with ξ
  - High ξ required for the determination of subleading "Reggeon" term

$$\sigma_{\rm red} = F_2 \; - \frac{y^2}{1+(1-y)^2}F_{\rm L}$$

- Significant $F_{\rm L}$ component, ~30 times higher than at HERA
  - However, some intermediate beam energy settings needed for $F_{\rm L}$ measurements

Sensitivity to the Reggeon contribution to σ_{red}



Procedure

1. Suppress Reggeon by a factor $\mathbb{R}^* = \left(\frac{1-\xi}{1-\xi_0}\right)^p \mathbb{R}$ for $\xi > \xi_0 = 0.07$,
2. Generate pseudo-data with nominal and modified $\mathbb{R}$ contributions,
3. Fit DPDFs, using Reggeon flux $\varphi_R \propto \xi^{1-2\alpha_R}$ with α_R free.

Results

- ❑ Fits to the unmodified $\mathbb{R}$ result in $\chi^2 \approx 1$, as expected.
- ❑ Fits to $\mathbb{R}^*$ suppressed by ~10% give $\chi^2 \approx 1.2$
  This excludes a simple power-law shape in ξ.

Data at $\xi > 0.3$ desired for the subleading exchange study.

F_L investigation

- Four beam setups used for the simulations:
  100×10, 120×10, 165×10, 275×18 GeV

Two intermediate energies added

- 83 bins in (ξ, β, Q^2) selected such that
  - they are common to all four beam setups
  - $y > 0.5$ for 100 × 10 GeV
  - $M_X > 2$ GeV
- F_2, F_L obtained from fits to $\sigma_{\mathrm{red}} = F_2 - Y_L(y)\, F_L$
  in each (ξ, β, Q^2) bin

$$Y_L(y) = \frac{y^2}{1 + (1-y)^2}$$

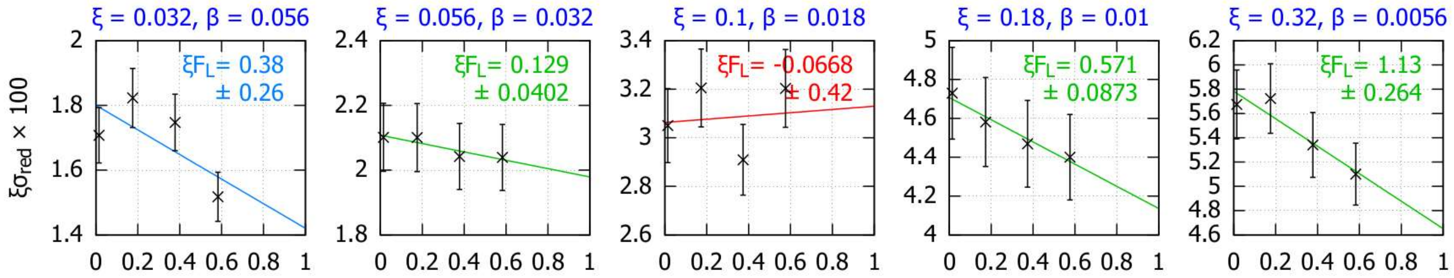
- $\xi F_L(\xi, \beta, Q^2)$ plotted vs. β

F_L investigation – fits to $\sigma_{red}^{D(3)}$

Example results of fits to $\sigma_{red} = F_2 \; - Y_L(y)\, F_L$ (5 of total 83 bins shown)

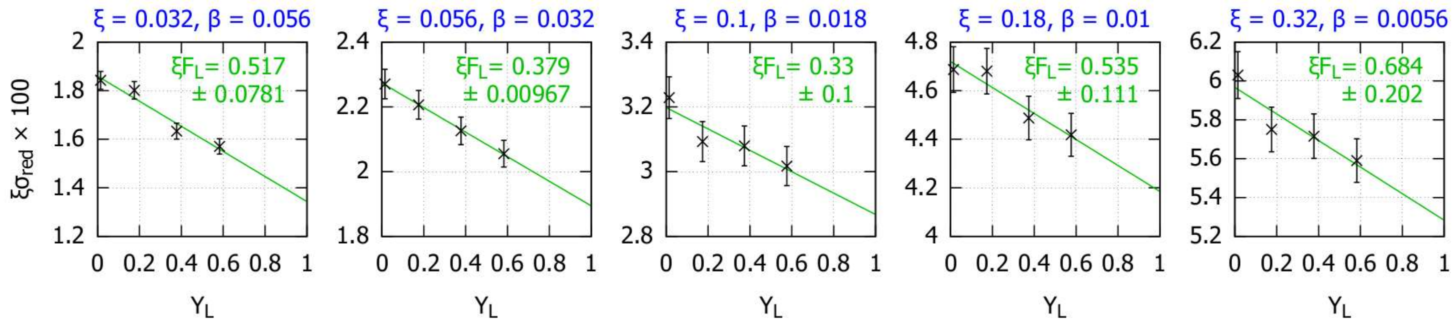
$Q^2 = 5.6\ \mathrm{GeV}^2, \delta_{sys} = 5\%$

σ_{red} and F_L values scaled by 100



F_L contributions are often smaller than 5% sys. error

$Q^2 = 5.6\ \mathrm{GeV}^2, \delta_{sys} = 2\%$



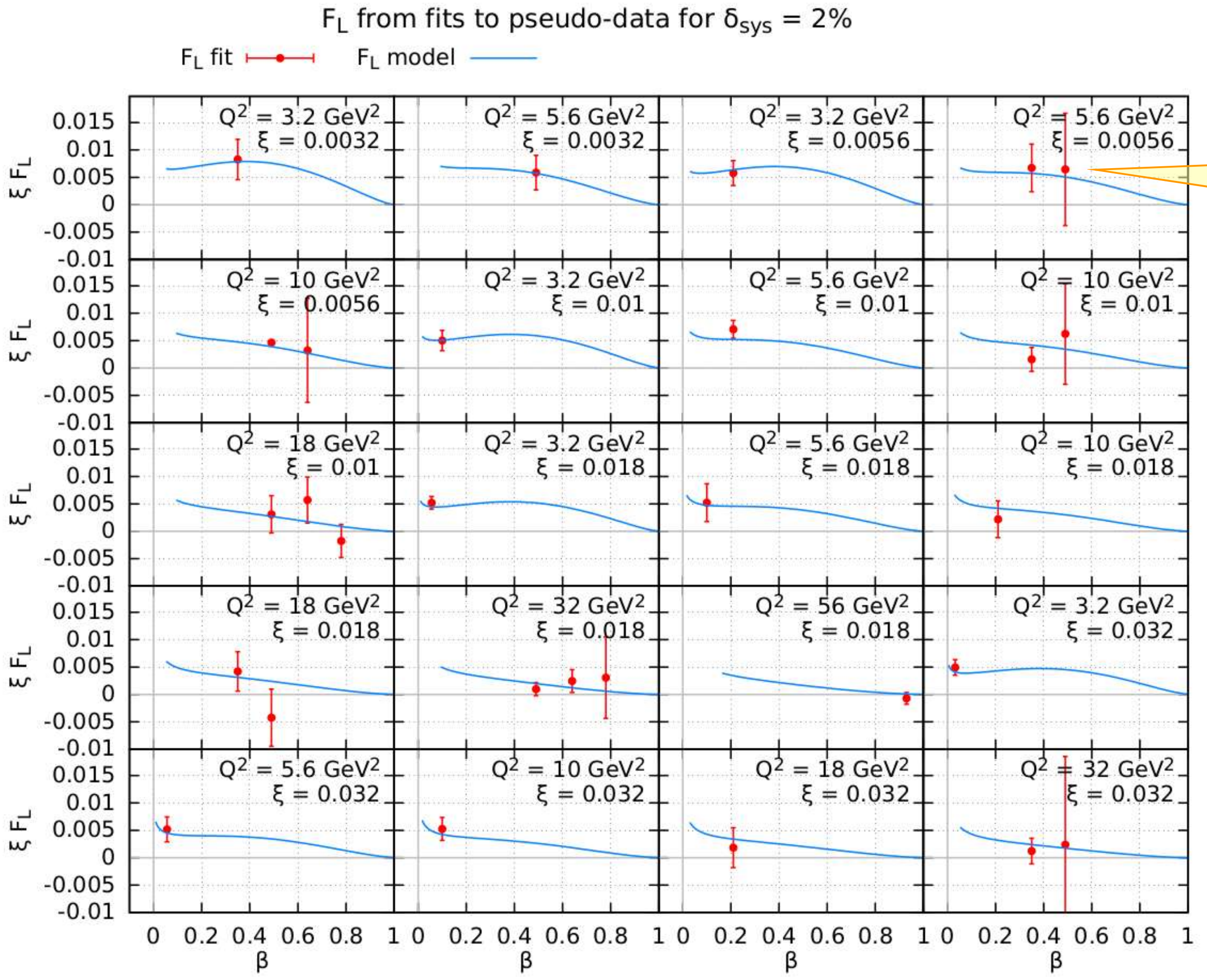
Significant improvement wrt. δ_{sys} = 5%

Fits are performed separately in each (ξ, β, Q^2) bin.
This results in big statistical fluctuations for only 4 energy bins.

Work is ongoing to decrease the uncertainties

F_L investigation – fit results

Example results of fitted F_L values for $\delta_{sys} = 2\%$



60 bins in (ξ, Q^2)

20 shown

The error bars correspond to the 90% confidence interval.

For 2 degrees of freedom statistical fluctuations are large.

High precision and/or more intermediate energies desired

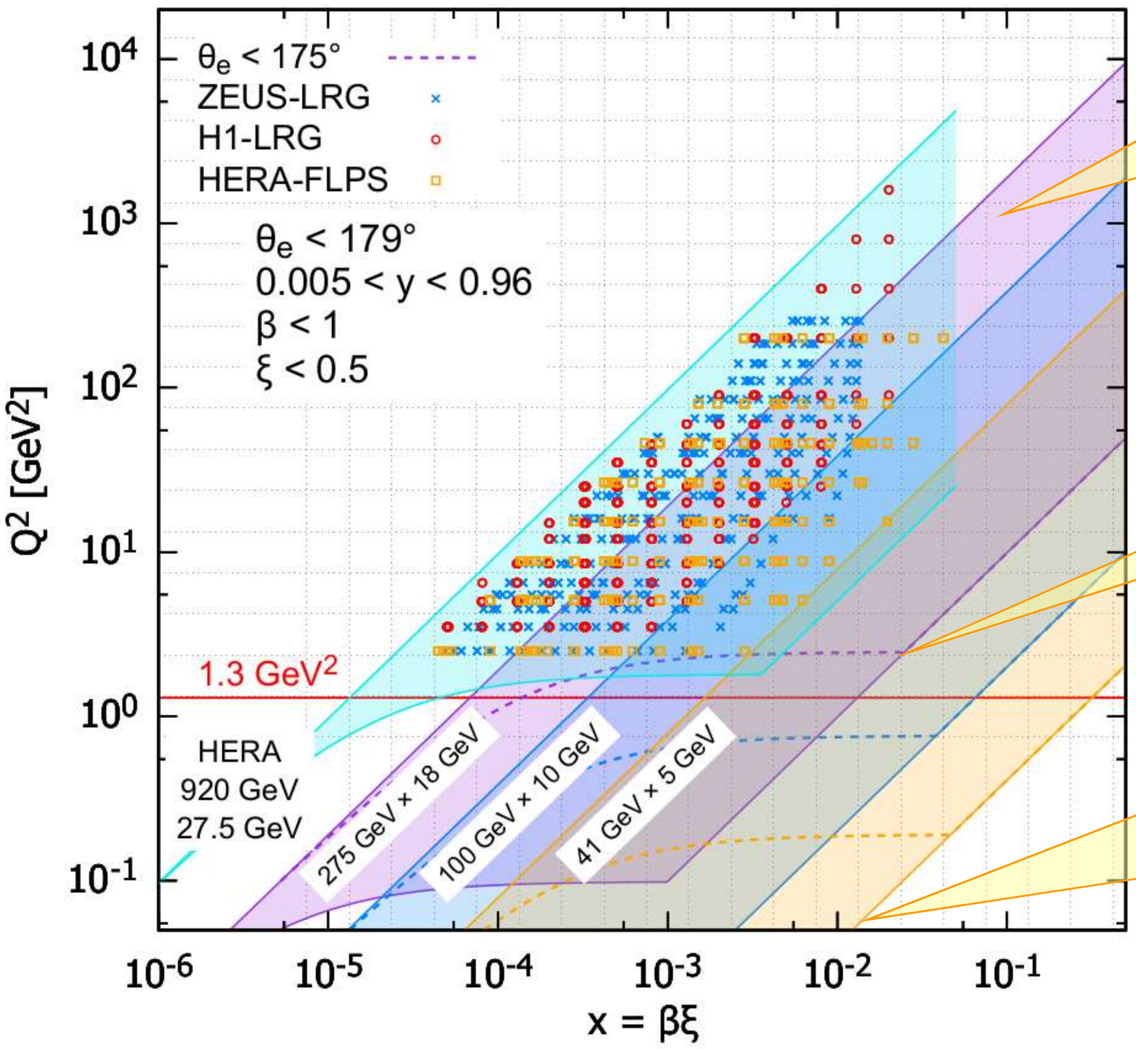
Summary

Desired detector and machine features:

- Proton tagging angle, θ, between 0.5 and 10 mrad
  - for $\sigma_{\text{red}}^{D(4)}$ measurement
    - at 275×18 GeV, $\theta \lesssim 7$ mrad may be enough
- x_L down to 0.6
  - for the determination of subleading “Reggeon” contribution
- Additional intermediate energies
  - for the diffractive F_L measurement

EXTRAS

x, Q^2 range — EIC and HERA



The grid shows binning of 4 bins per order of magnitude in each β, Q^2, ξ

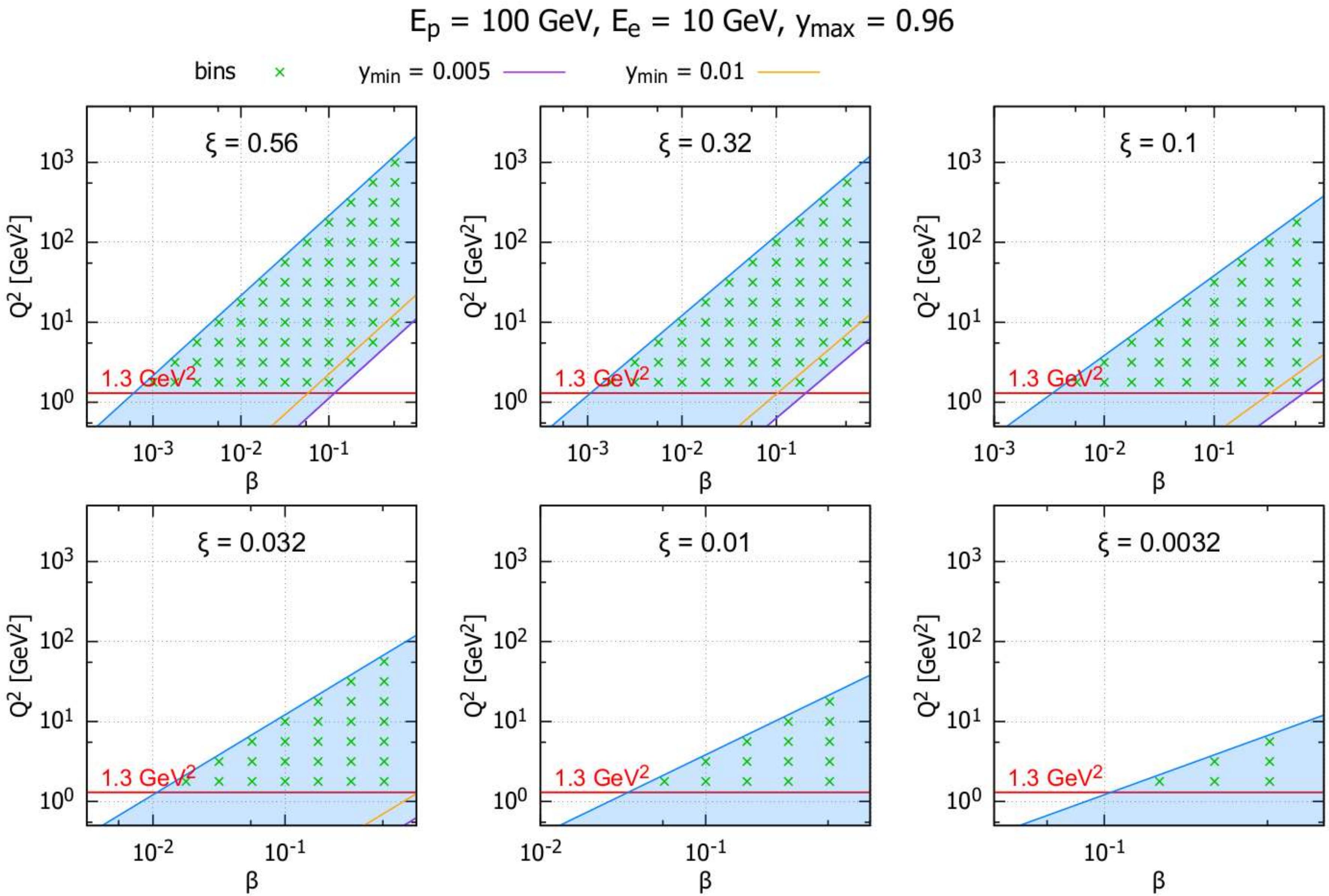
Dashed lines show boundaries for max $\theta_e = 175°$

x range gets shifted up by a factor ~5 when going from HERA through the EIC beam settings: 275×18, 100×10, 41×5.

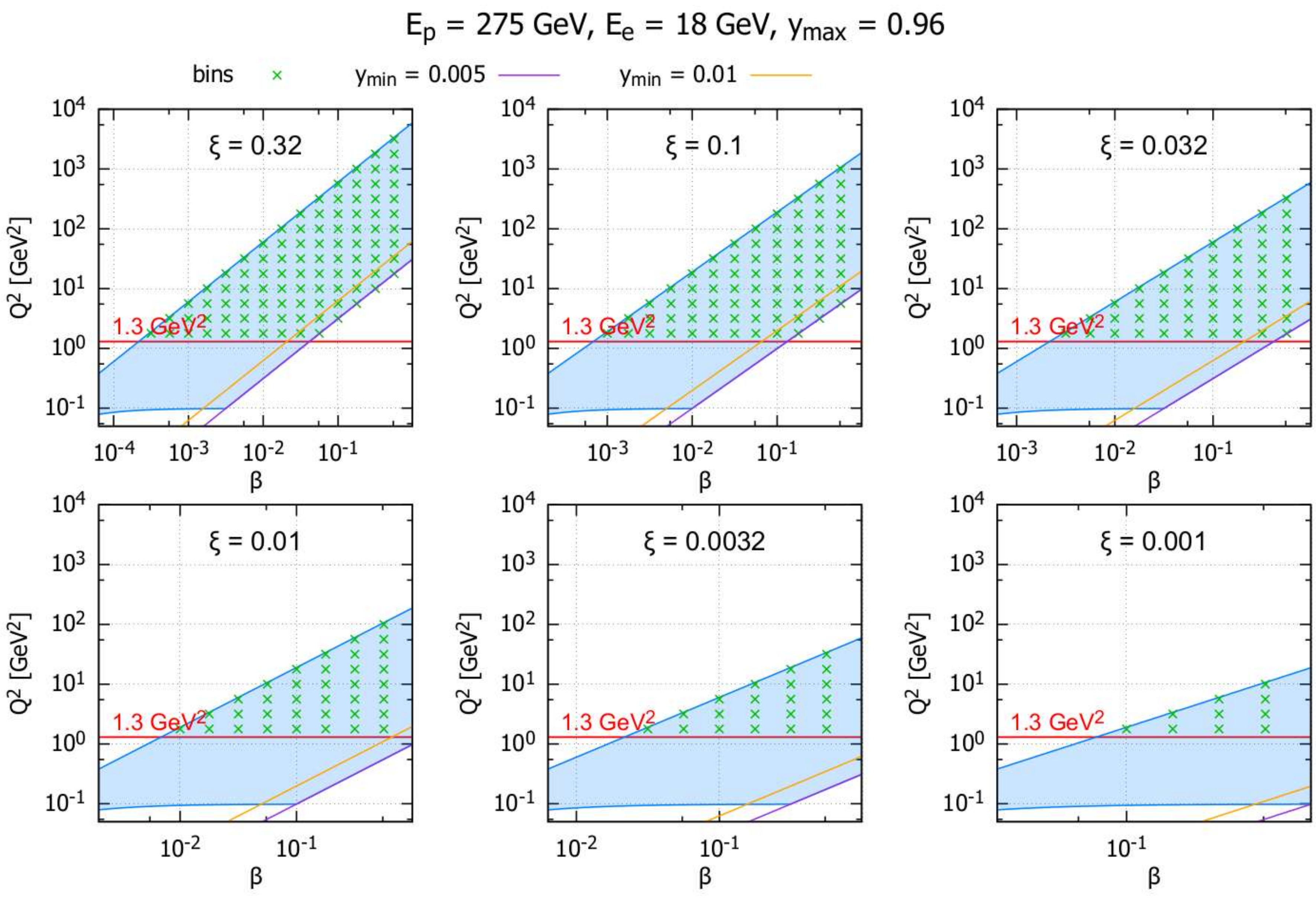
Detailed binning 100x10 275x18

New, high x region to explore

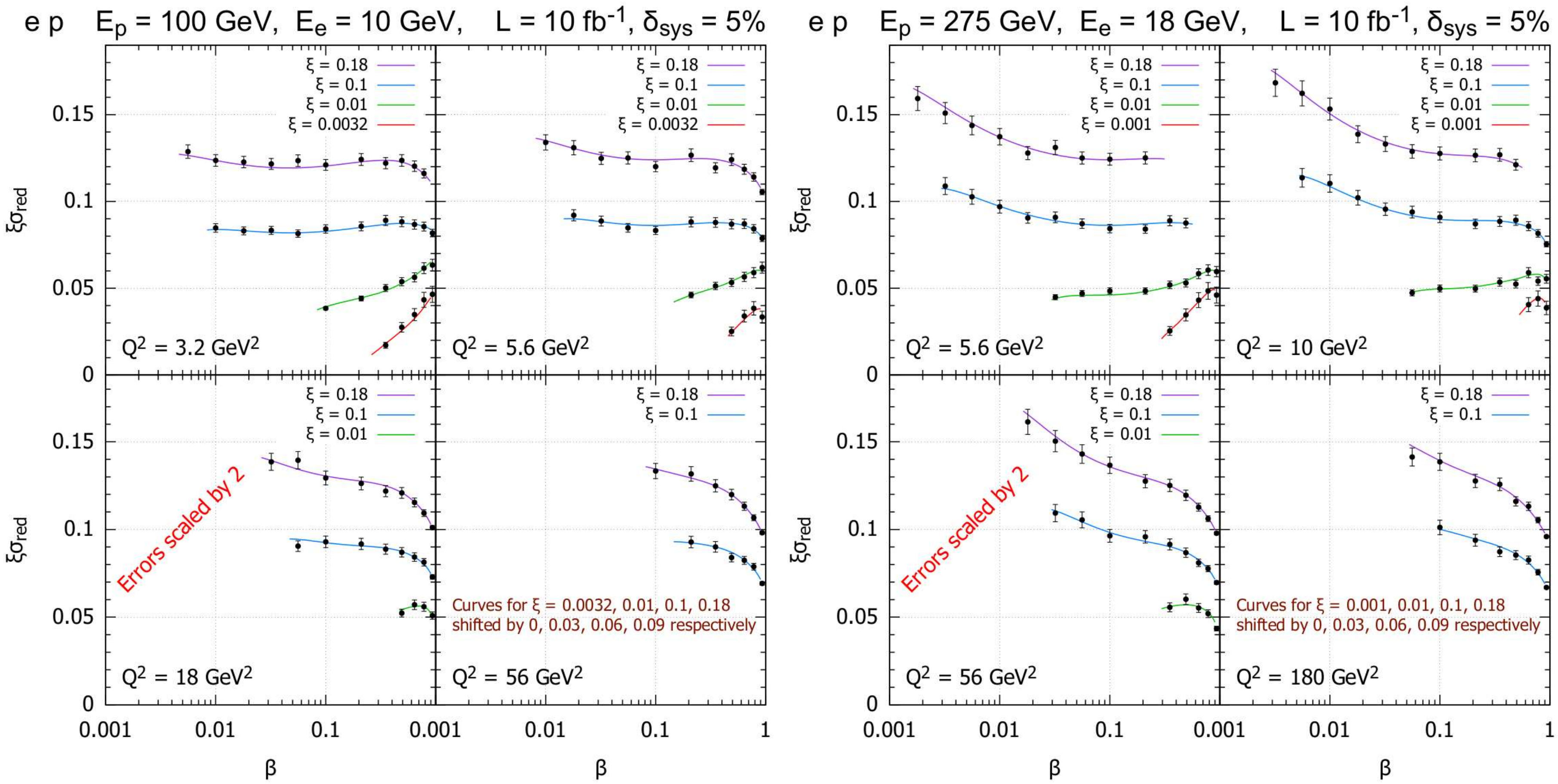
Detailed binning 100 × 10 GeV



Detailed binning 275 × 18 GeV



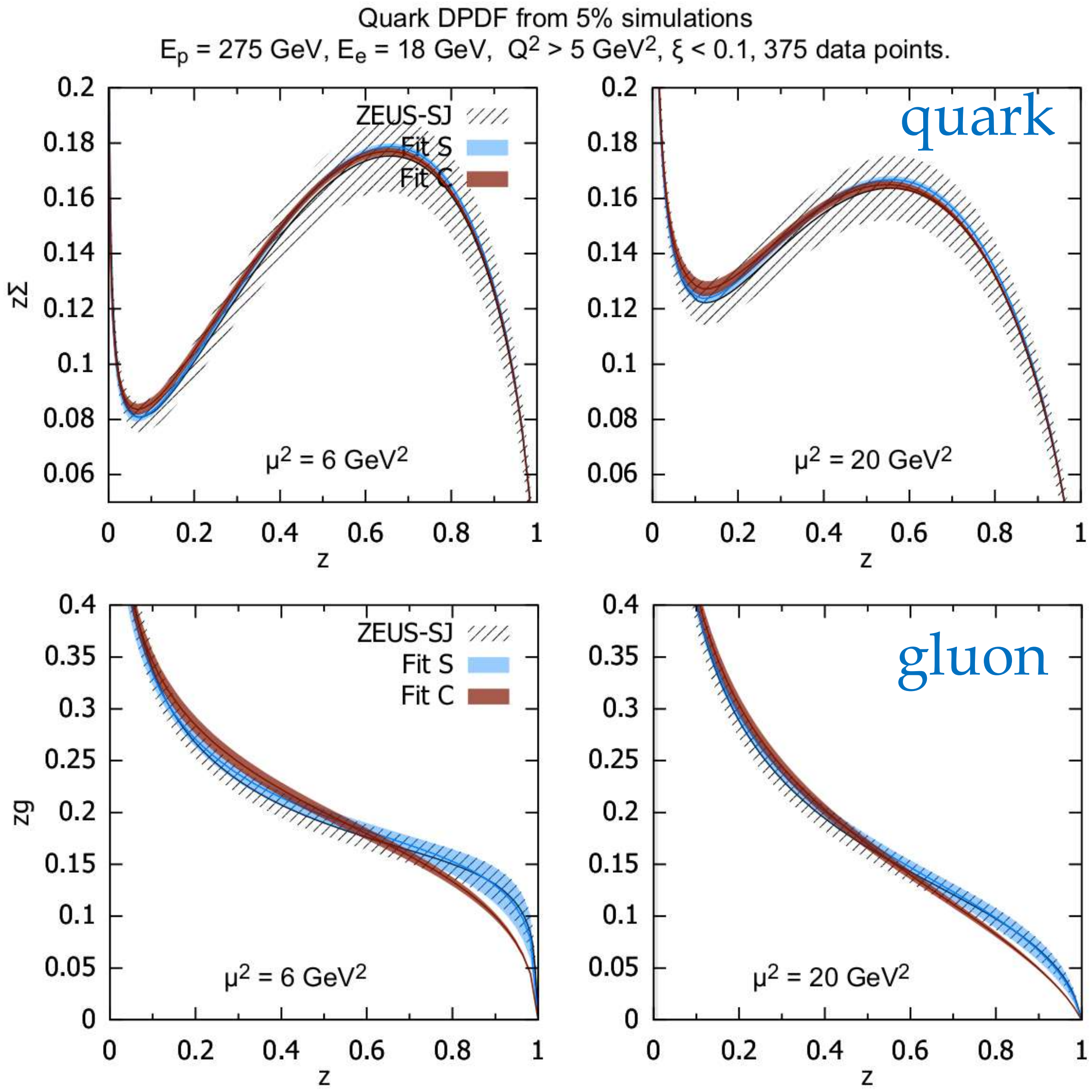
$\sigma_{\mathrm{red}}^{D(3)}$ pseudo-data examples



In total:
482 points for $1.3 < Q^2 < 1330\ \mathrm{GeV}^2$

In total:
792 points for $1.3 < Q^2 < 4220\ \mathrm{GeV}^2$

Quark and gluon DPDFs form C and S fits



Data selection

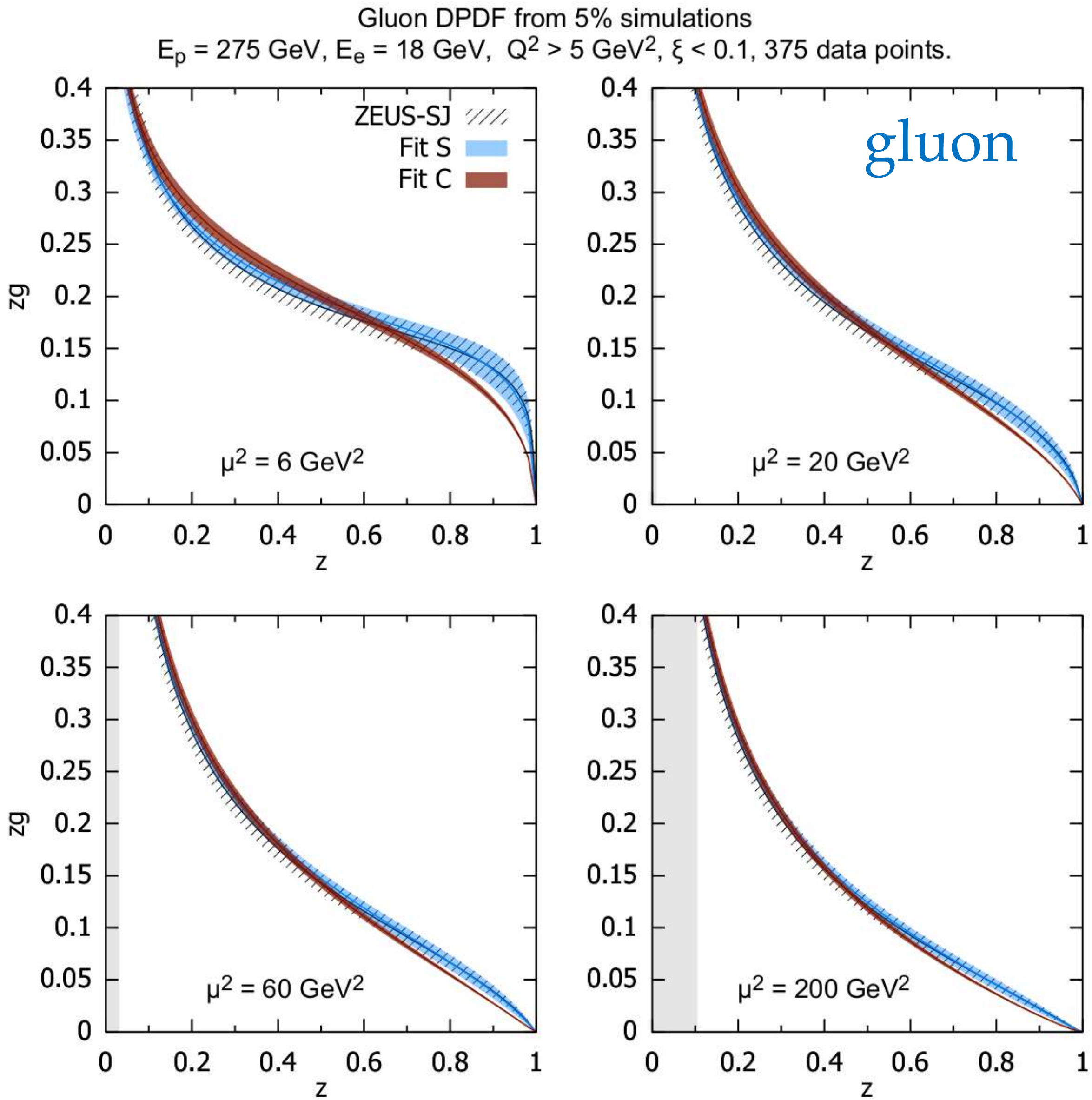
$Q^2 > 5\ \mathrm{GeV}^2$, $\xi < 0.1$

375 data points

- Fit S: 9 parameters,
- Fit C: 7 parameters: $B_g = C_g = 0$

- As compared to HERA
  - Higher accuracy
  - More data points
- Both C and S fits give $\chi^2 \approx 1$
- Another, gluon-sensitive process needed
  - e.g. dijet production, dominated by BGF

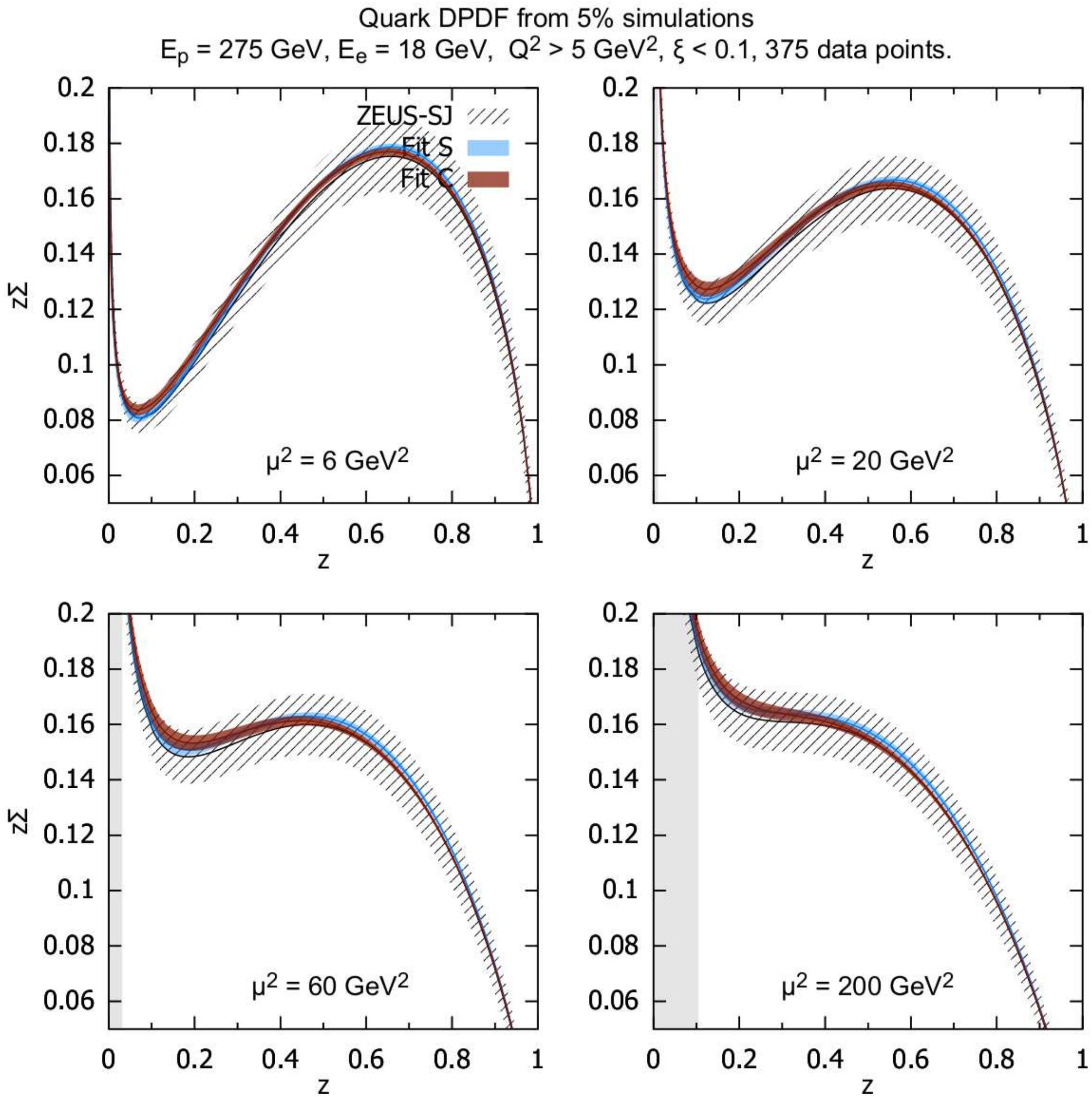
Gluon DPDFs form C and S fits



Data selection
$Q^2 > 5\ \mathrm{GeV}^2$
$\xi < 0.1$

- Both C and S fits give $\chi^2 \approx 1$
- Fixing gluon from inclusive DDIS requires $x \lesssim 10^{-6}$
- Here $x > 10^{-4}$
- Some other, gluon-sensitive process needed
  – e.g. dijet production, dominated by BGF

Quark DPDFs form C and S fits



Data selection
$Q^2 > 5\ \mathrm{GeV}^2$
$\xi < 0.1$

- As compared to HERA
  - Higher accuracy
  - More data points

Rapidity gap