

Diffractive longitudinal structure function at the Electron Ion Collider

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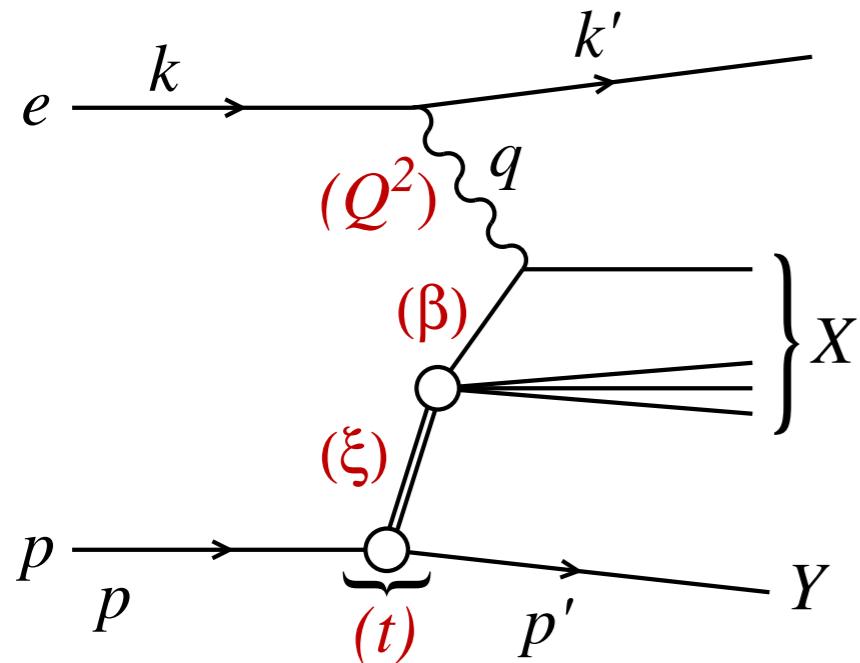
Outline

- Motivation: why is $F_L^{D(3)}$ interesting ?
- H1 measurement
- Proton tagging as a method for diffraction at EIC
- Pseudodata simulation, energy beam scenarios
- Extraction by linear fit. Kinematic range and precision
- Prospects for $F_L^{D(3)}$ and R ratio of longitudinal to transverse cross section
- Outlook

Work done in collaboration with Nestor Armesto, Paul Newman and Wojtek Słomiński

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Diffractive kinematics in DIS



Standard DIS variables:

electron-proton
cms energy squared:
 $s = (k + p)^2$

photon-proton
cms energy squared:
 $W^2 = (q + p)^2$

inelasticity
 $y = \frac{p \cdot q}{p \cdot k}$
 Bjorken x
 $x = \frac{-q^2}{2p \cdot q}$
 (minus) photon virtuality
 $Q^2 = -q^2$

Diffractive DIS variables:

$$\xi \equiv x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

momentum fraction of the
Pomeron w.r.t hadron

$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton
w.r.t Pomeron

$x = \xi \beta$

$$t = (p - p')^2$$

4-momentum transfer squared

Diffractive cross section, structure functions

Diffractive cross section depends on 4 variables (ξ, β, Q^2, t) :

$$\frac{d^4 \sigma^D}{d\xi d\beta dQ^2 dt} = \frac{2\pi\alpha_{\text{em}}^2}{\beta Q^4} Y_+ \sigma_r^{\text{D}(4)}(\xi, \beta, Q^2, t)$$
$$Y_+ = 1 + (1 - y)^2$$

Reduced cross section depends on two **structure functions**:

$$\sigma_r^{\text{D}(4)}(\xi, \beta, Q^2, t) = F_2^{\text{D}(4)}(\xi, \beta, Q^2, t) - \frac{y^2}{Y_+} F_L^{\text{D}(4)}(\xi, \beta, Q^2, t)$$

Upon integration over t :

$$F_{2,L}^{\text{D}(3)}(\xi, \beta, Q^2) = \int_{-\infty}^0 dt F_{2,L}^{\text{D}(4)}(\xi, \beta, Q^2, t)$$

Dimensions:

$$[\sigma_r^{\text{D}(4)}] = \text{GeV}^{-2}$$

$$\sigma_r^{\text{D}(3)} \quad \text{Dimensionless}$$

Why F_L^D is interesting? F_L^D at HERA

Why F_L^D is interesting?

F_L^D vanishes in the parton model

Gets non-vanishing contributions in QCD

As in inclusive case, particularly sensitive to the diffractive **gluon density**

Expected large **higher twists**, provides test of the **non-linear, saturation** phenomena

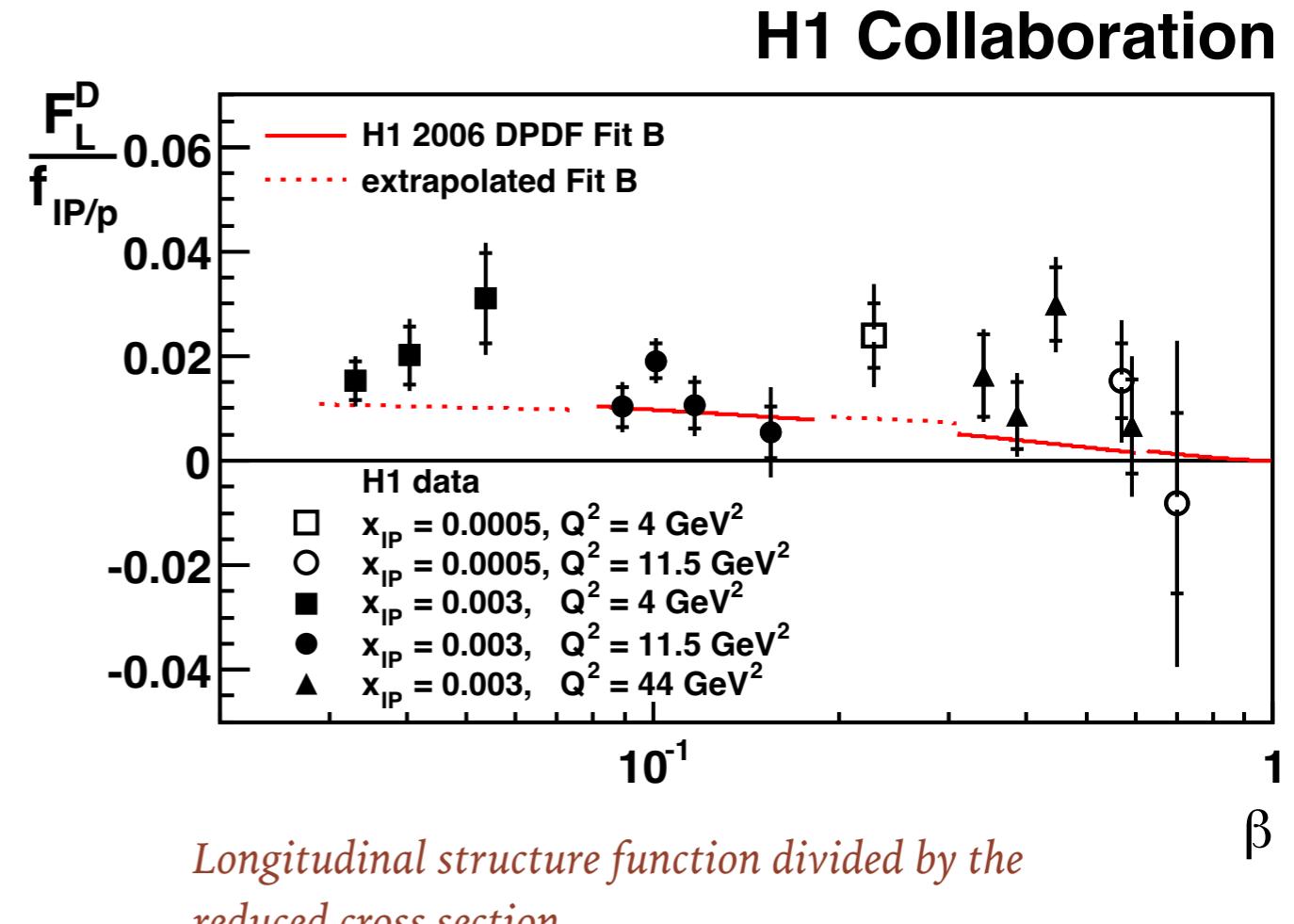
Experimentally challenging...

Measurement requires several beam energies

H1 measurement: 4 energies, $E_p = 920, 820, 575, 460$ GeV, electron beam $E_e = 27.6$ GeV

Large errors, limited by statistics at HERA

Careful evaluation of systematics. Best precision 4%, with uncorrelated sources as low as 2%



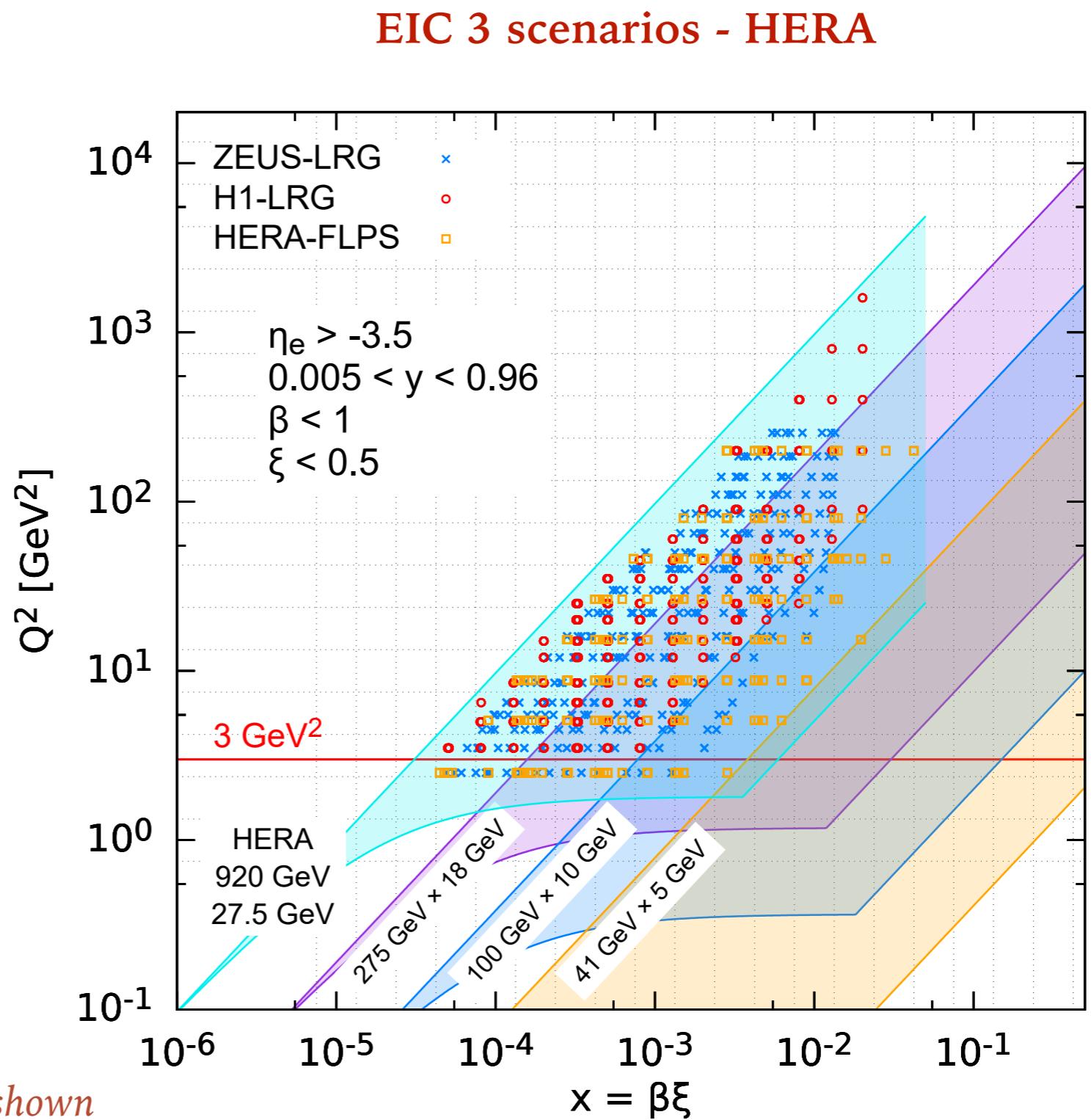
Phase space (x, Q^2) EIC-HERA

EIC can operate at various energy combinations

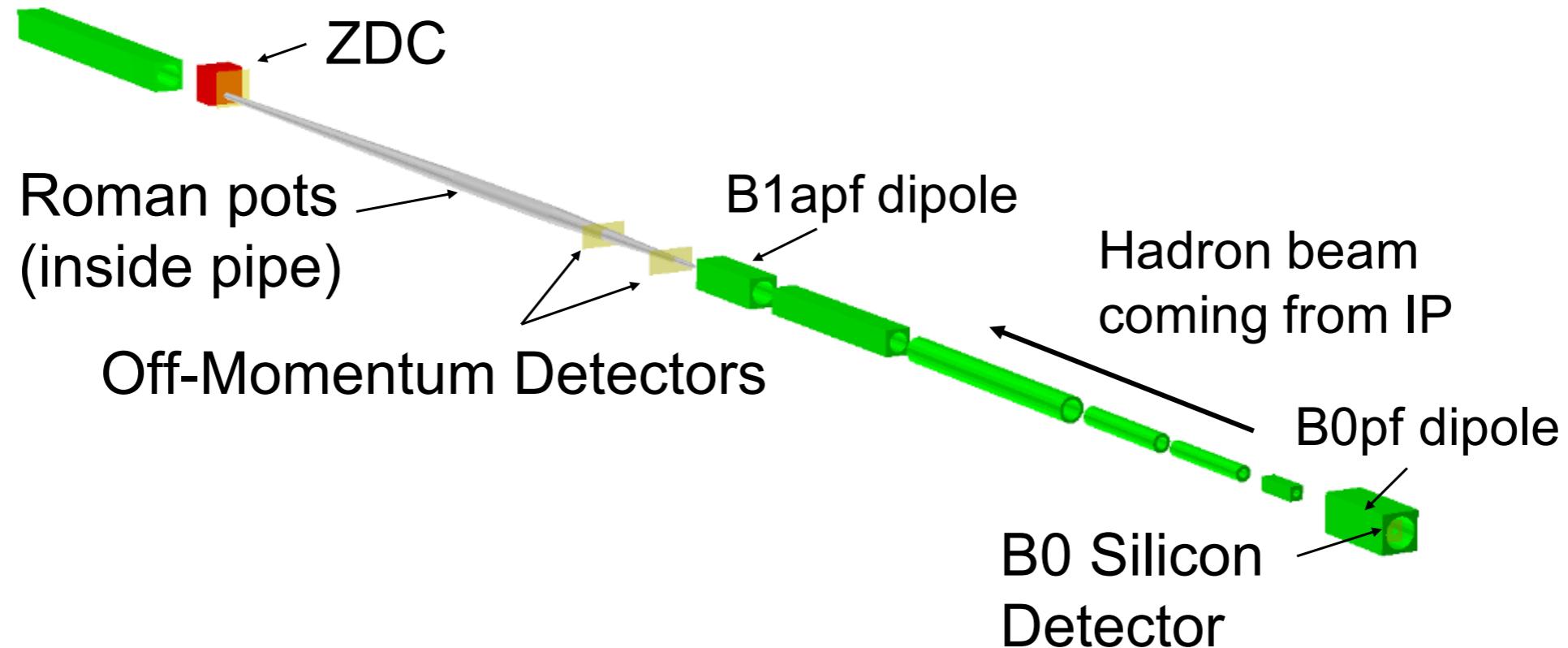
Can cover wide range of x

Large instantaneous luminosity

Statistics should not be a limiting factor

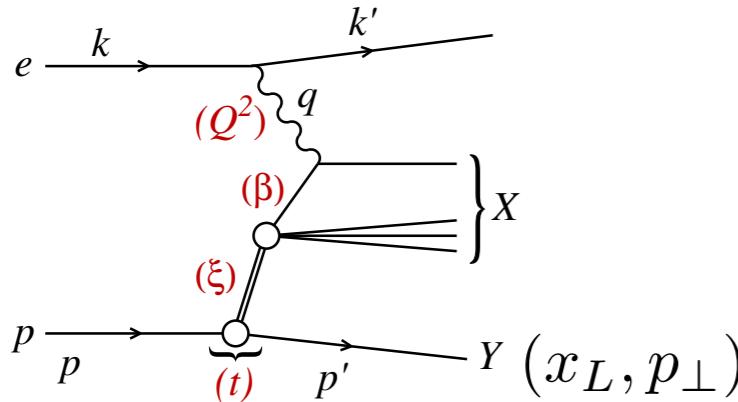


Far forward detectors at EIC



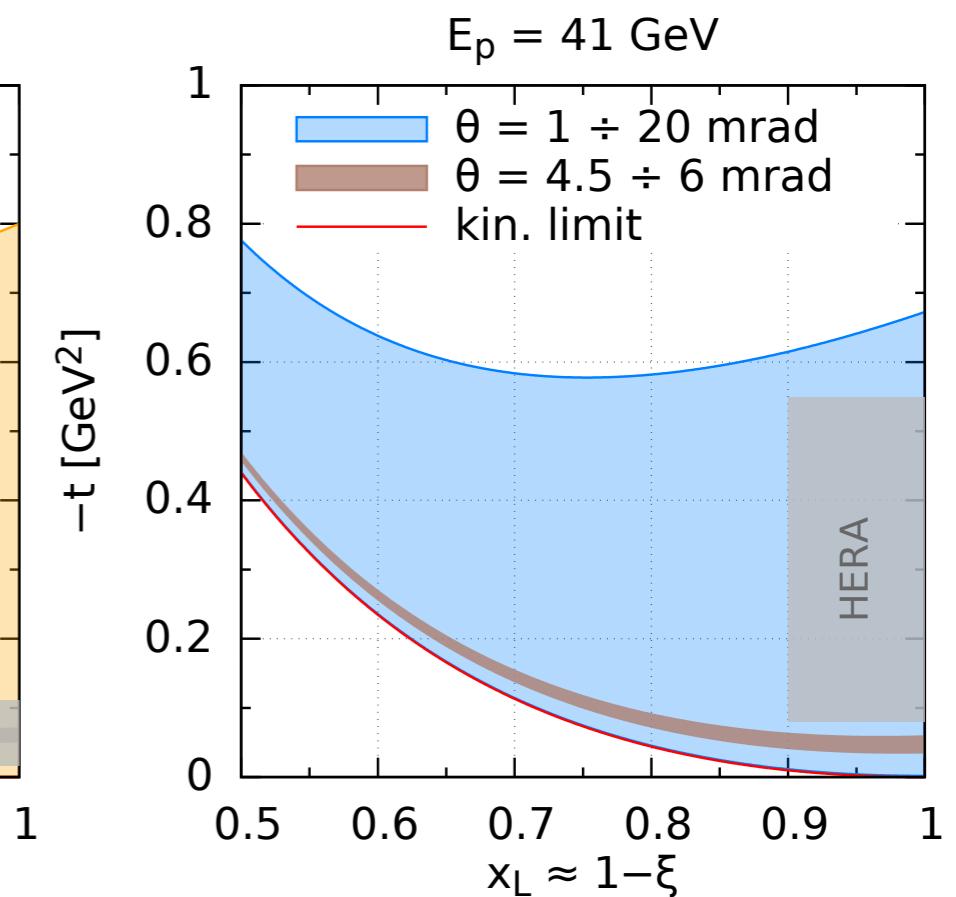
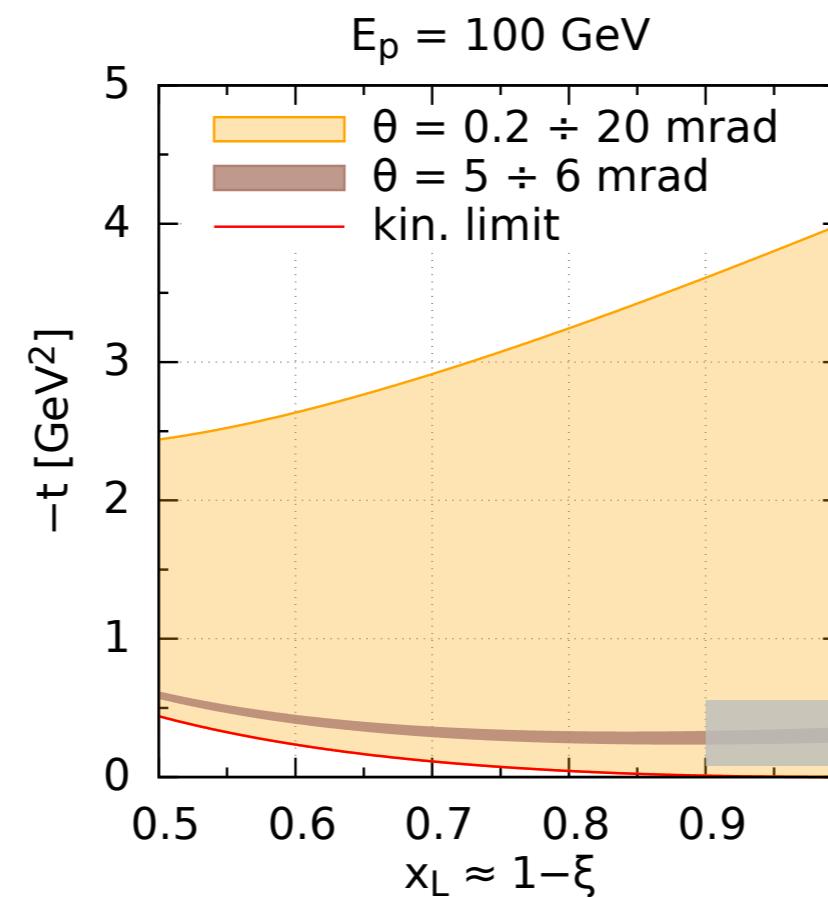
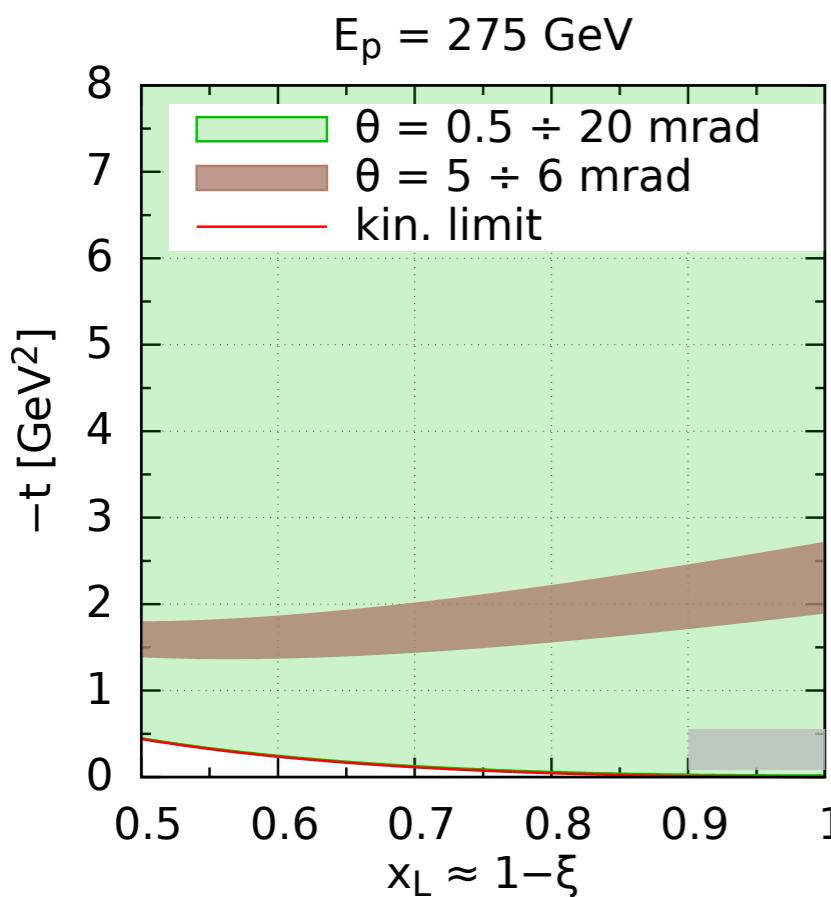
Detector	Angle	Position [m]
ZDC	$\theta < 5.5$ mrad	37.5
Roman Pots	$0.5 < \theta < 5.0$ mrad	26.0, 28.0
Off-momentum detectors	$\theta < 5.0$ mrad	22.5, 25.5
B0	$6.0 < \theta < 20.0$ mrad	$5.4 < z < 6.4$

Final proton tagging



Small angle acceptance i.e. Roman pots

(x_L, p_\perp, θ) measured in LAB, collinear (e, p) frame



Much better than at HERA

Best way to select diffractive events through proton tagging

$$t = -\frac{p_\perp^2}{x_L} - \frac{(1 - x_L)^2}{x_L} m_p^2$$

Pseudodata generation: energy choice

$$\sigma_{\text{red}}^{\text{D}(3)} = F_2^{\text{D}(3)}(\beta, \xi, Q^2) - Y_L F_L^{\text{D}(3)}(\beta, \xi, Q^2) \quad \text{Integrated over t-momentum transfer}$$

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

Can disentangle $F_2^{\text{D}(3)}$ from $F_L^{\text{D}(3)}$ by varying energy and performing the linear fit.

$$y = \frac{Q^2}{xs} = \frac{Q^2}{\beta\xi s} \quad \text{Need to vary the energy } \sqrt{s} \text{ to change } y \text{ for fixed } (\beta, \xi, Q^2)$$

EIC energies for **electron** and **proton**:

$$E_e = 5, 10, 18 \text{ GeV}$$

$$E_p = 41, 100, 120, 165, 180, 275 \text{ GeV}$$

		$E_p [\text{GeV}]$					
		41	100	120	165	180	275
$E_e [\text{GeV}]$	5	29	45	49	57	60	74
	10	40	63	69	81	85	105
	18	54	85	93	109	114	141

S-17 all 17 combinations

S-9 9 - bold red

S-5 5 - green (EIC preferred)

Pseudodata generation

Binning and cuts

Uniform logarithmic binning, 4 bins per order of magnitude in each β, Q^2, ξ

Bins in (ξ, β, Q^2) , common to at least four beam setups

$Q^2 > 3 \text{ GeV}^2$ both H1 and ZEUS fits indicate deterioration of fits for low Q^2

$0.96 > y > 0.005$ expected coverage of the experiment

Simulations

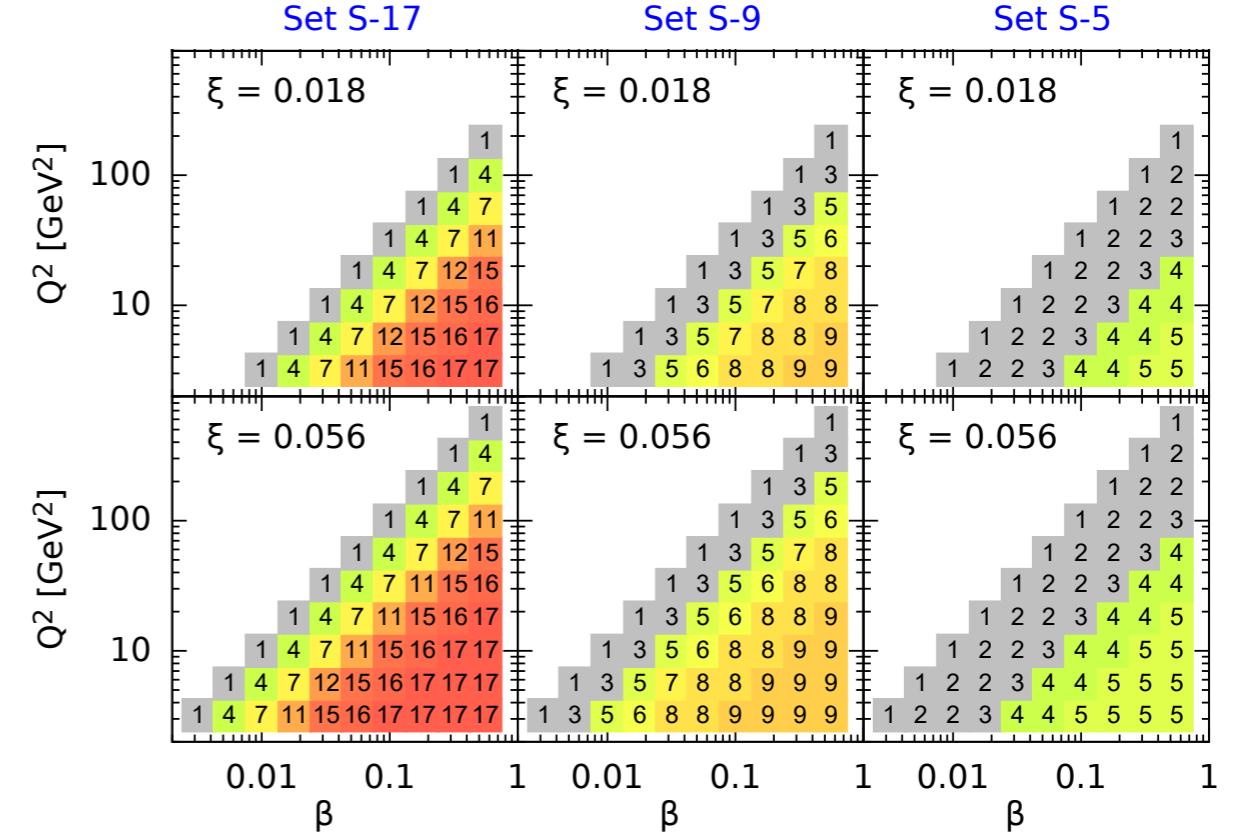
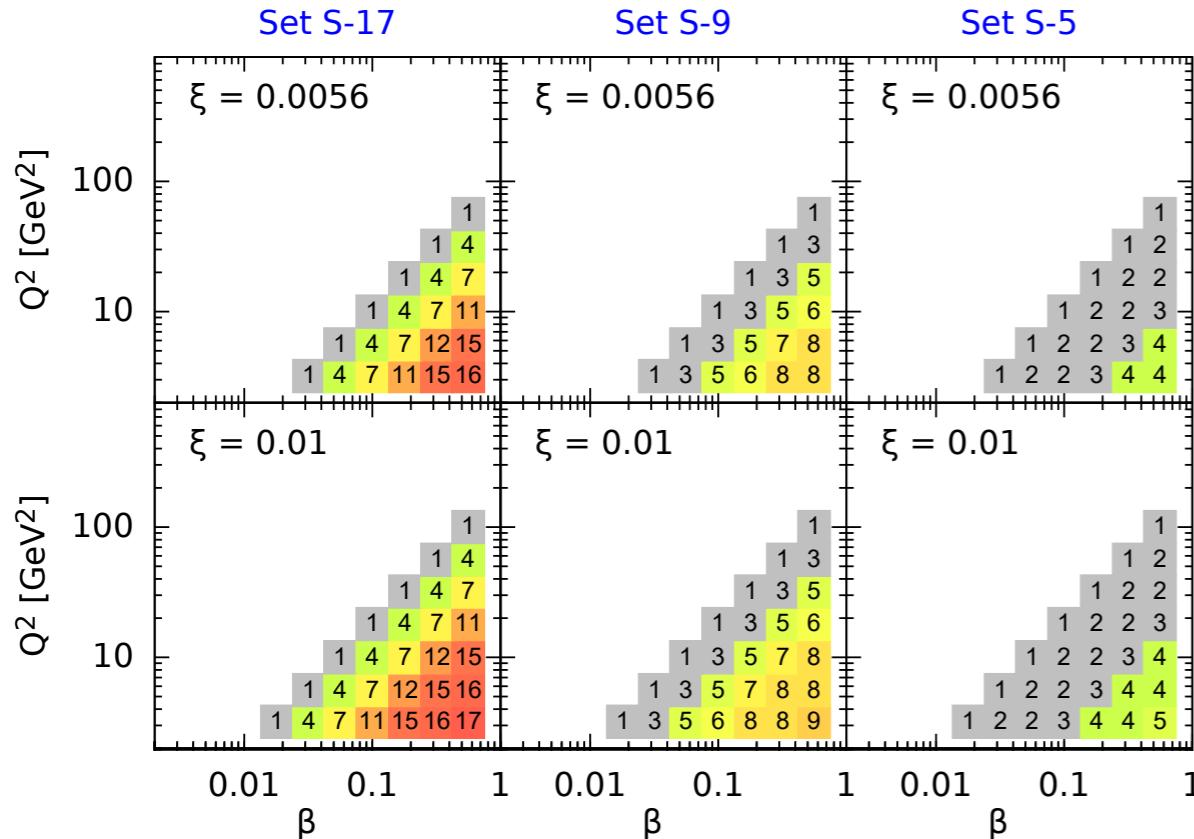
Cross section generation from ZEUS-SJ diffractive PDFs evolved with DGLAP

Assumed $\delta_{\text{sys}} = 1-2\%$, extrapolated from HERA 2% uncorrelated systematics;
normalization/correlated systematics negligible effect on extraction of F_L^D

δ_{stat} from 10 fb^{-1} integrated luminosity

Several random samples are generated

Kinematic range and number of points



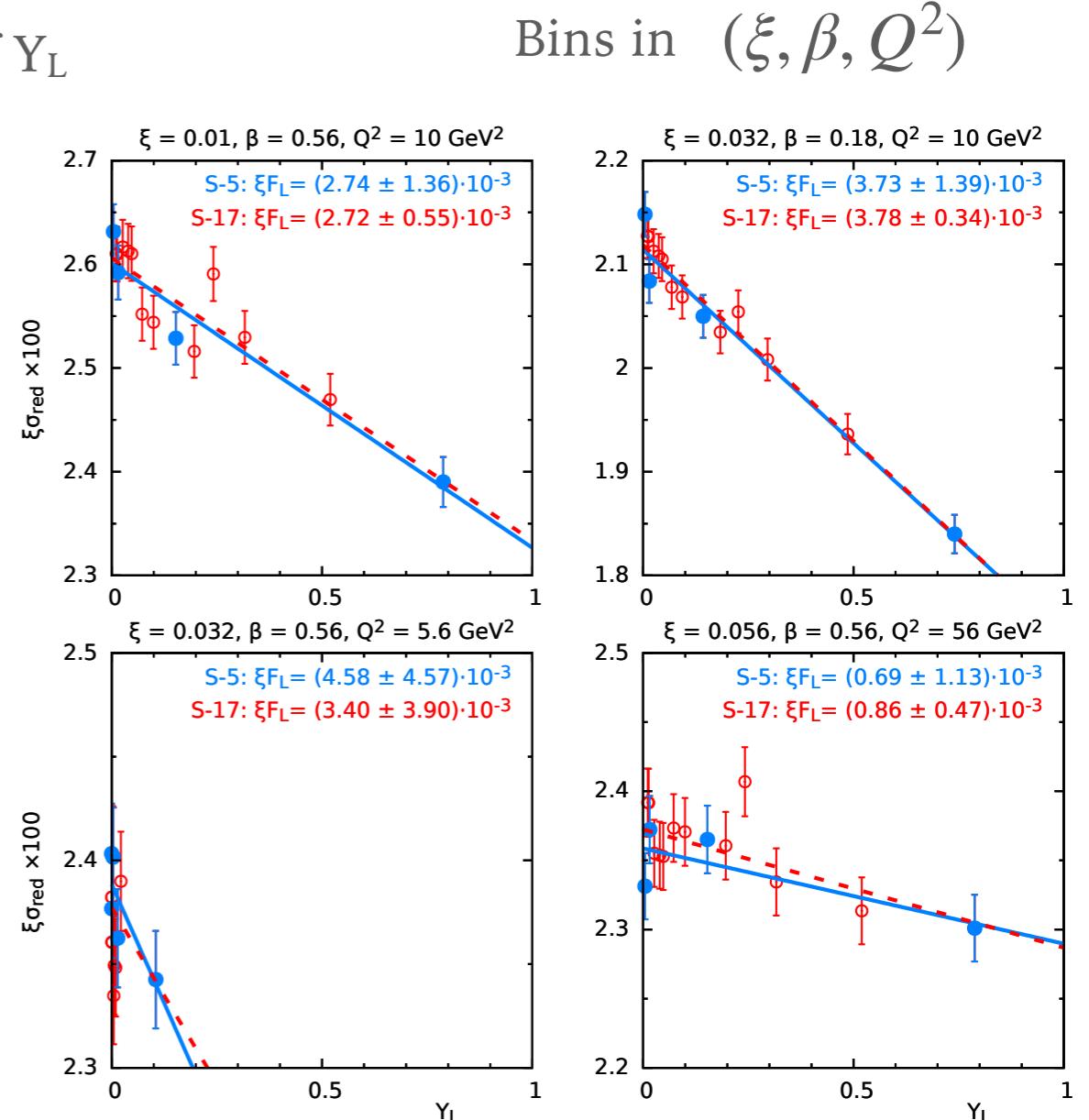
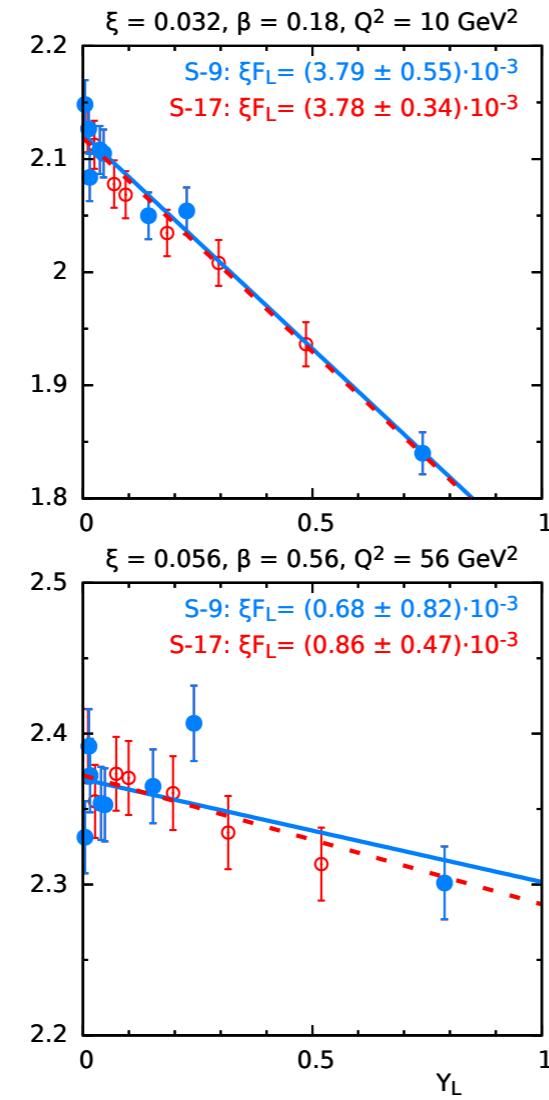
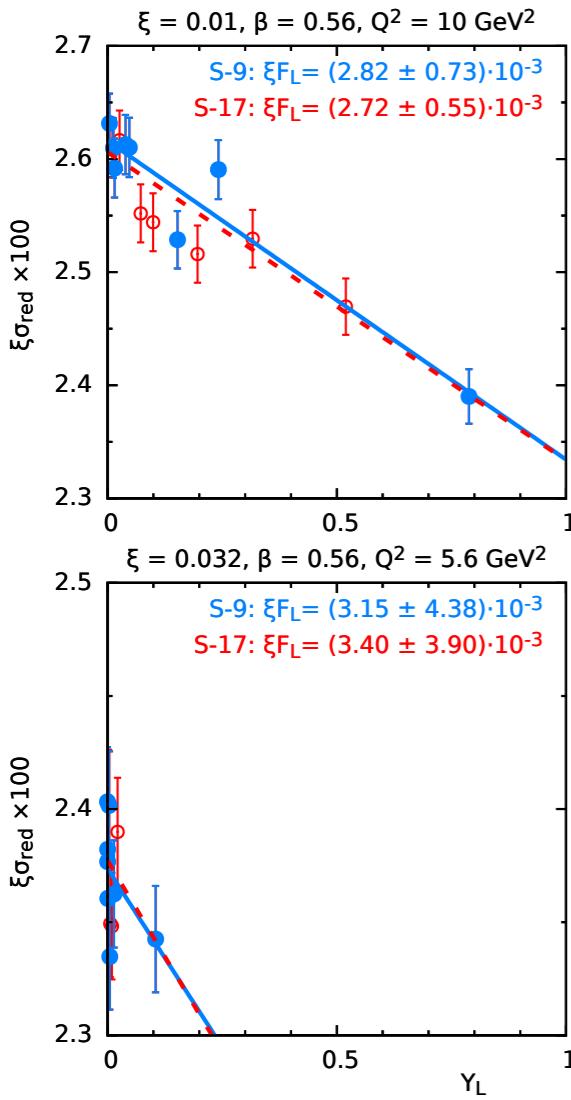
Count of different beam energy combinations for S-17, S-9, S-5

Only points with more than 4 combinations are taken for F_L extraction

Set-17: 364, set-9: 285, set-5: 160 values of F_L

$F_L^D(3)$ extraction

$\sigma_r = F_2(\xi, \beta, Q^2) - Y_L F_L(\xi, \beta, Q^2)$ as a function of Y_L



Uncorrelated systematics 1%

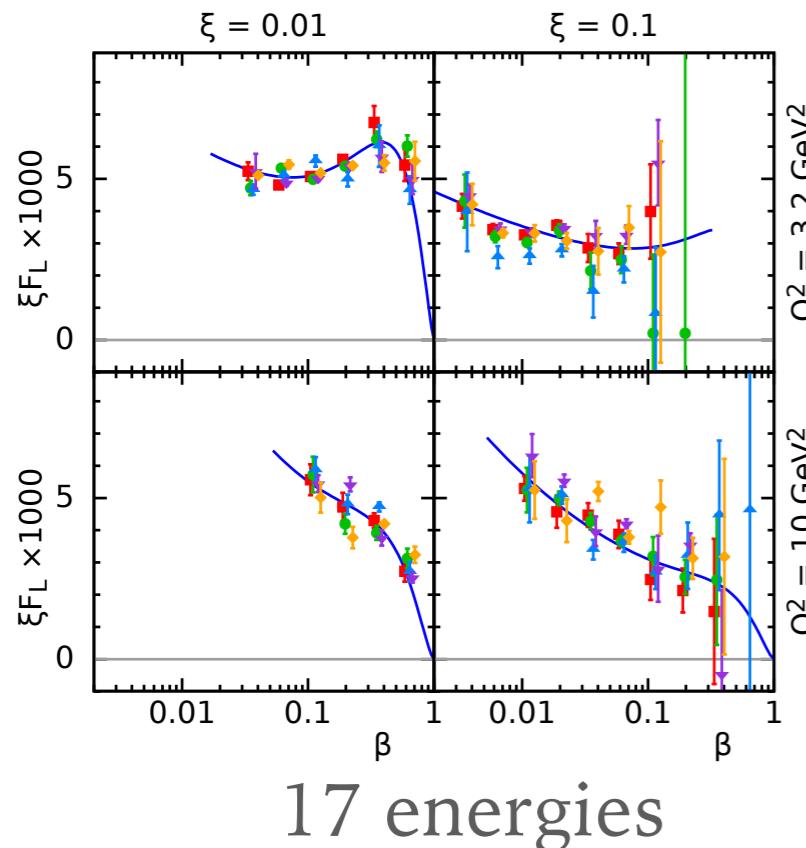
Differences between S-17 and S-9, S-5 small

Increase in error bar on the extraction when smaller number of energy points

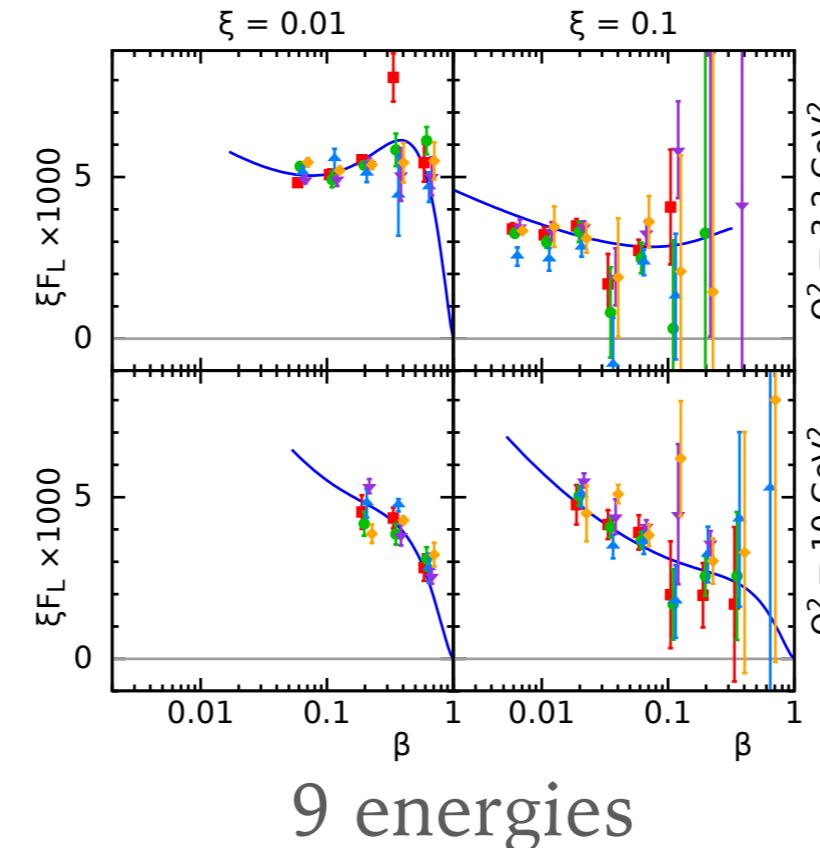
Largest errors for bins with shortest range of Y_L

Simulated measurement of $F_L^D(3)$ vs β in bins of (ξ, Q^2)

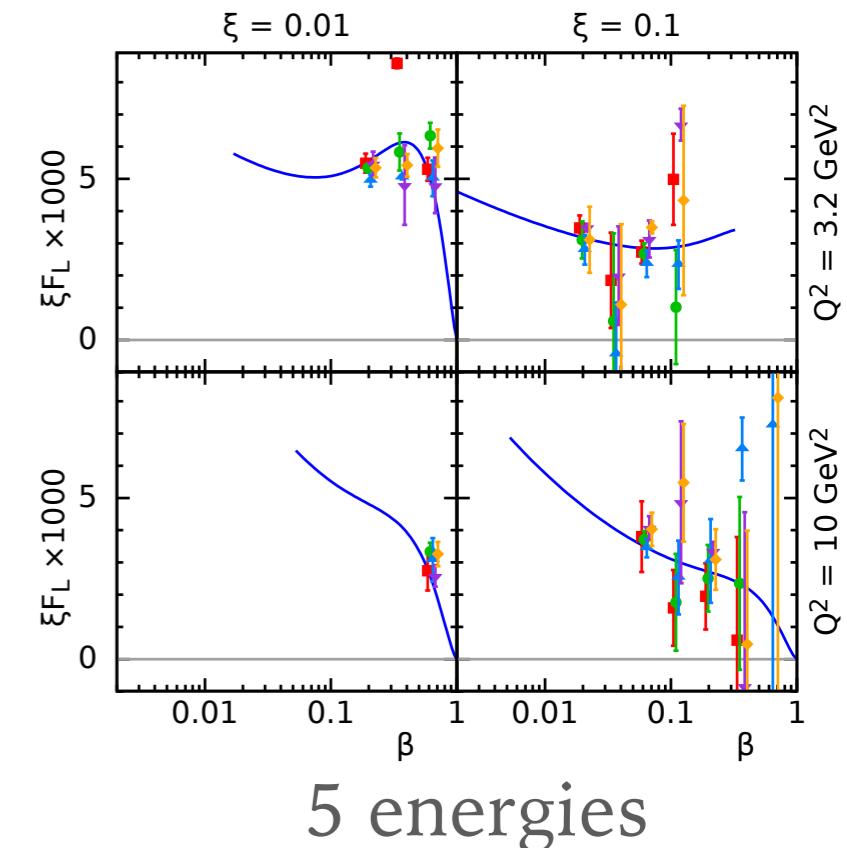
Systematic error 1%, 5 MC samples to illustrate fluctuations



17 energies



9 energies



5 energies

Small differences between S-17 and S-9, small reduction to range and increase in uncertainties.

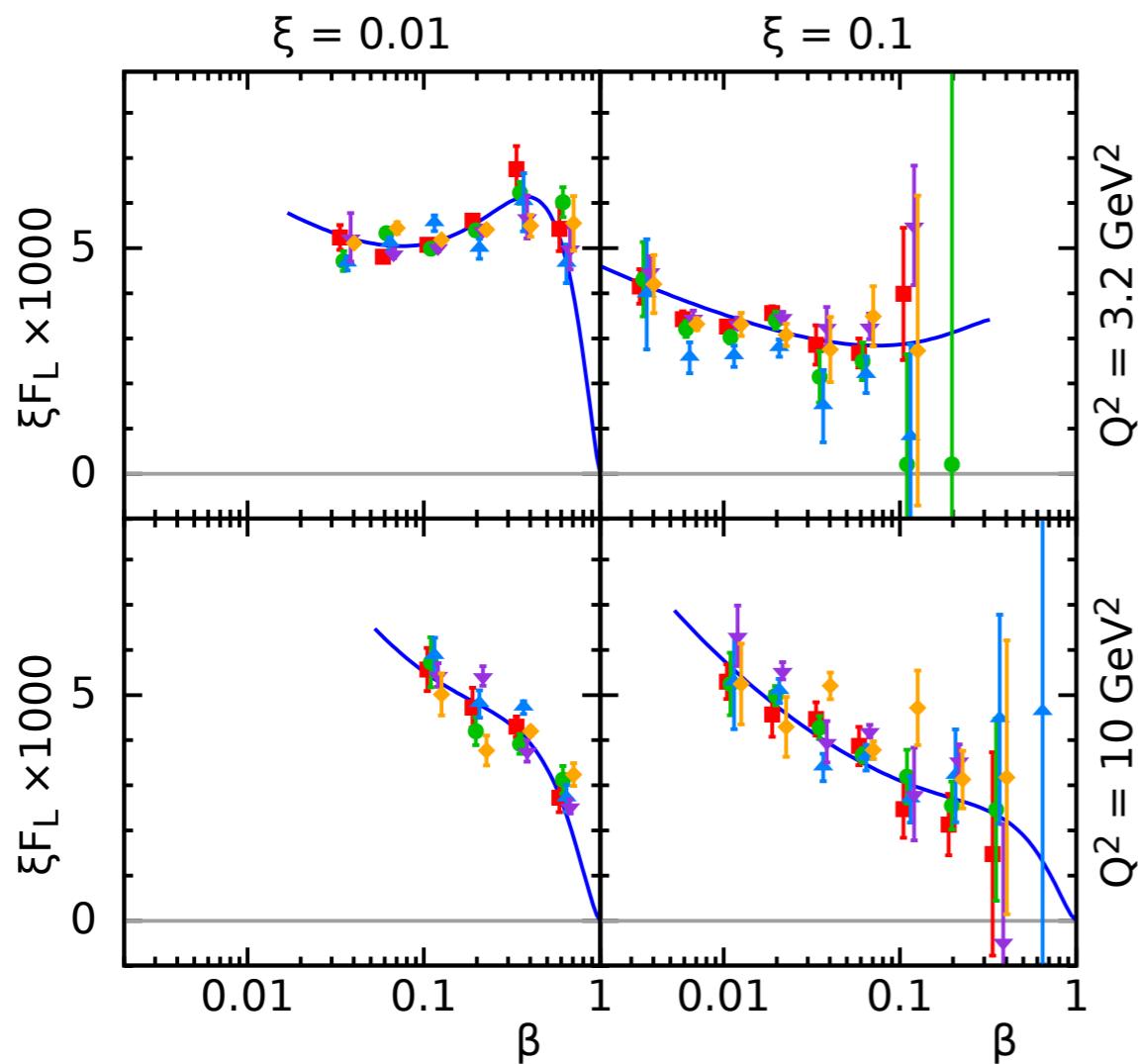
More pronounced reduction in range and higher uncertainties in S-5.

An extraction of F_L^D possible with EIC-favored set of energy combinations

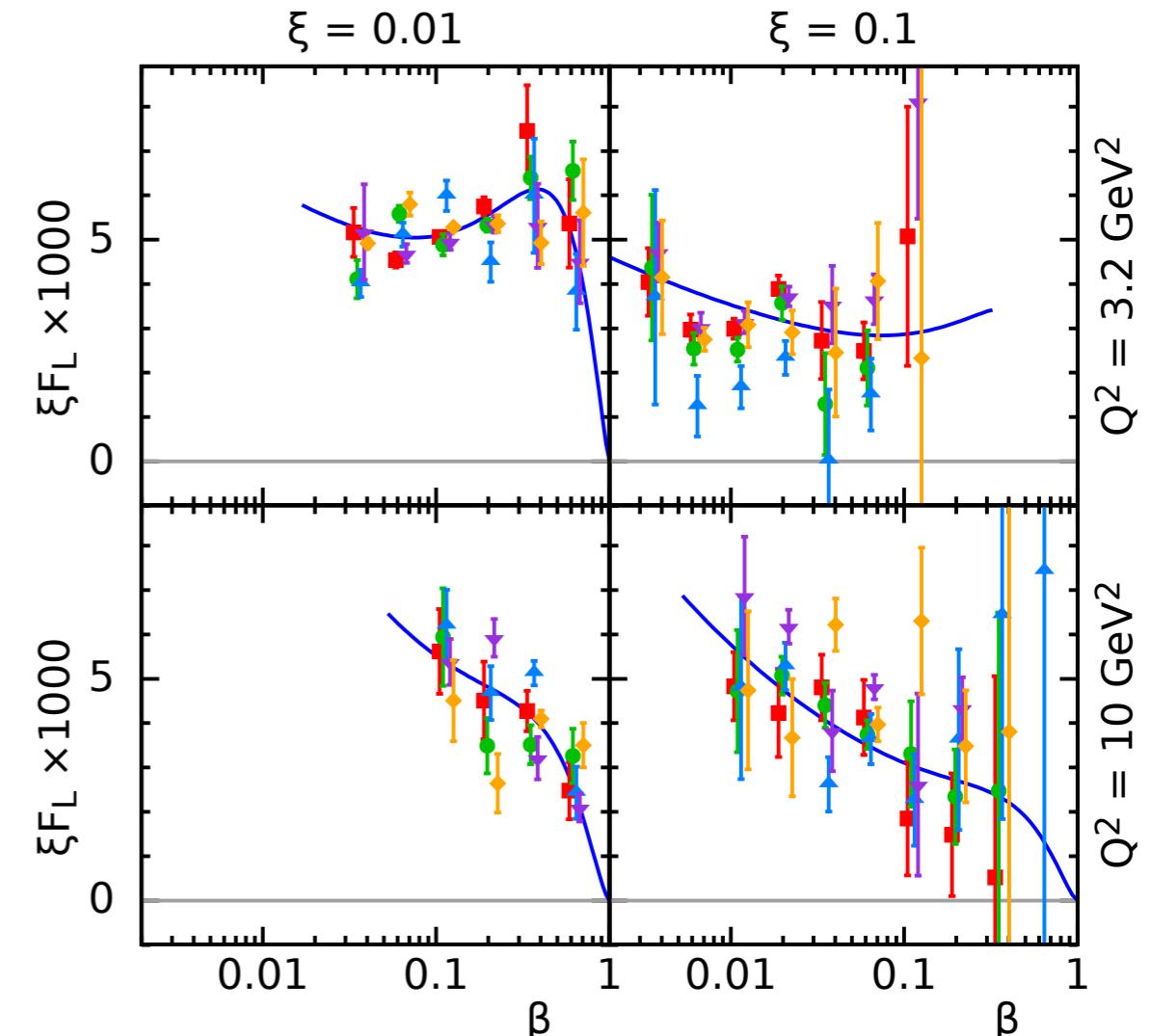
Simulated measurement of $F_L^D(3)$ vs β in bins of (ξ, Q^2)

S-17

$\delta_{\text{sys}} = 1 \%$



$\delta_{\text{sys}} = 2 \%$



Change from 1% to 2% results in roughly twice large error bars

Statistical errors negligible

$F_L^{D(3)}$ fit accuracy

Estimate the accuracy of extraction for $F_L^{D(3)}$

Generate several MC samples of pseudodata
and perform fits

Use direct arithmetic averaging neglecting
the uncertainties from the fits

average

$$\bar{v} = \frac{S_1}{N}$$

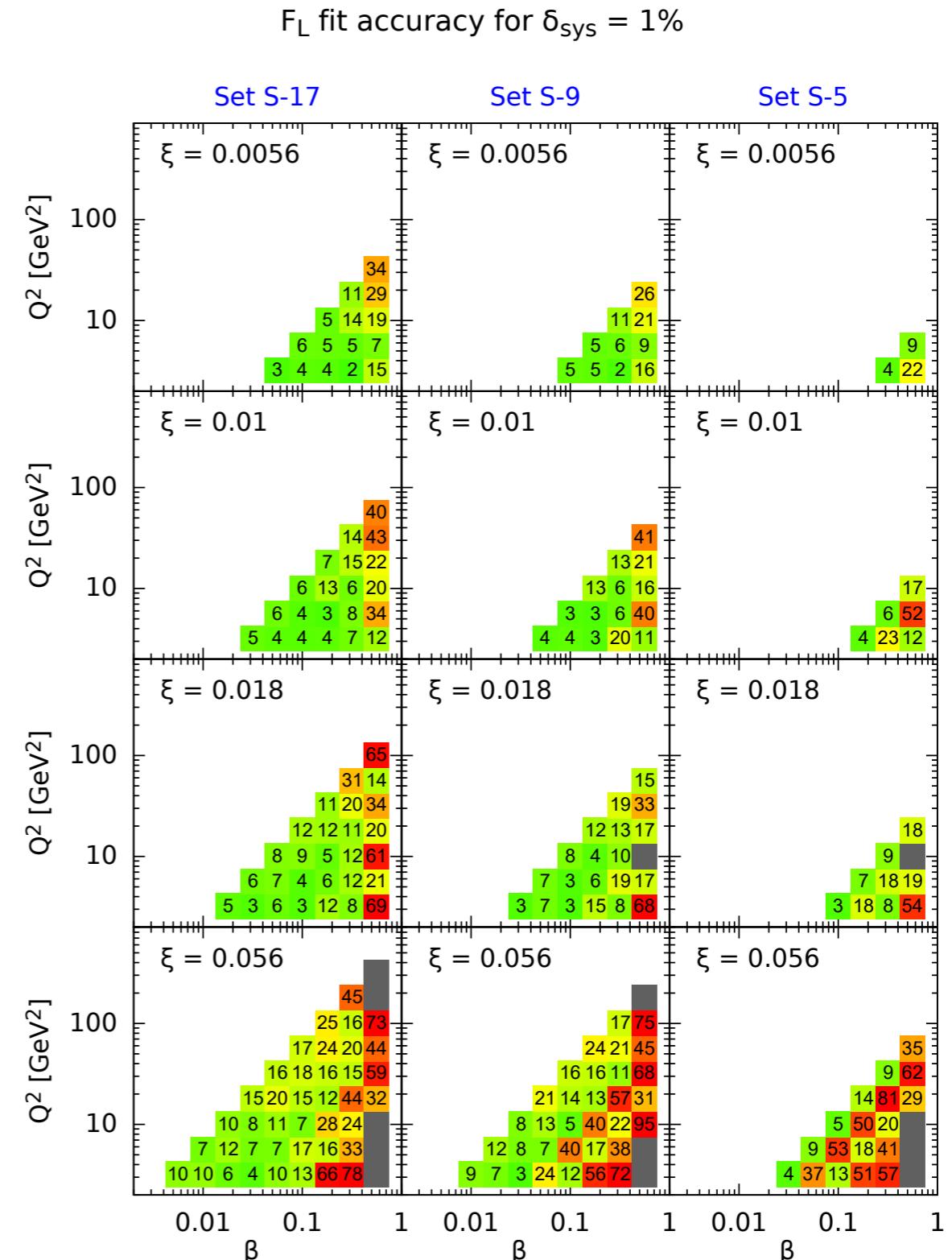
$$S_n = \sum_{i=1}^N v_i^n$$

Where v_i is the value of F_L^D

in Monte Carlo sample i

variance

$$(\Delta v)^2 = \frac{S_2 - S_1^2/N}{N-1}$$



$R^D = F_L^D / F_T^D$ ratio of longitudinal to transverse

Ratio of cross section for longitudinally polarized photons to cross sections for transverse polarized photons

$$R^{D(3)} = F_L^{D(3)} / F_T^{D(3)}$$

$$F_T^{D(3)} = F_2^{D(3)} - F_L^{D(3)}$$

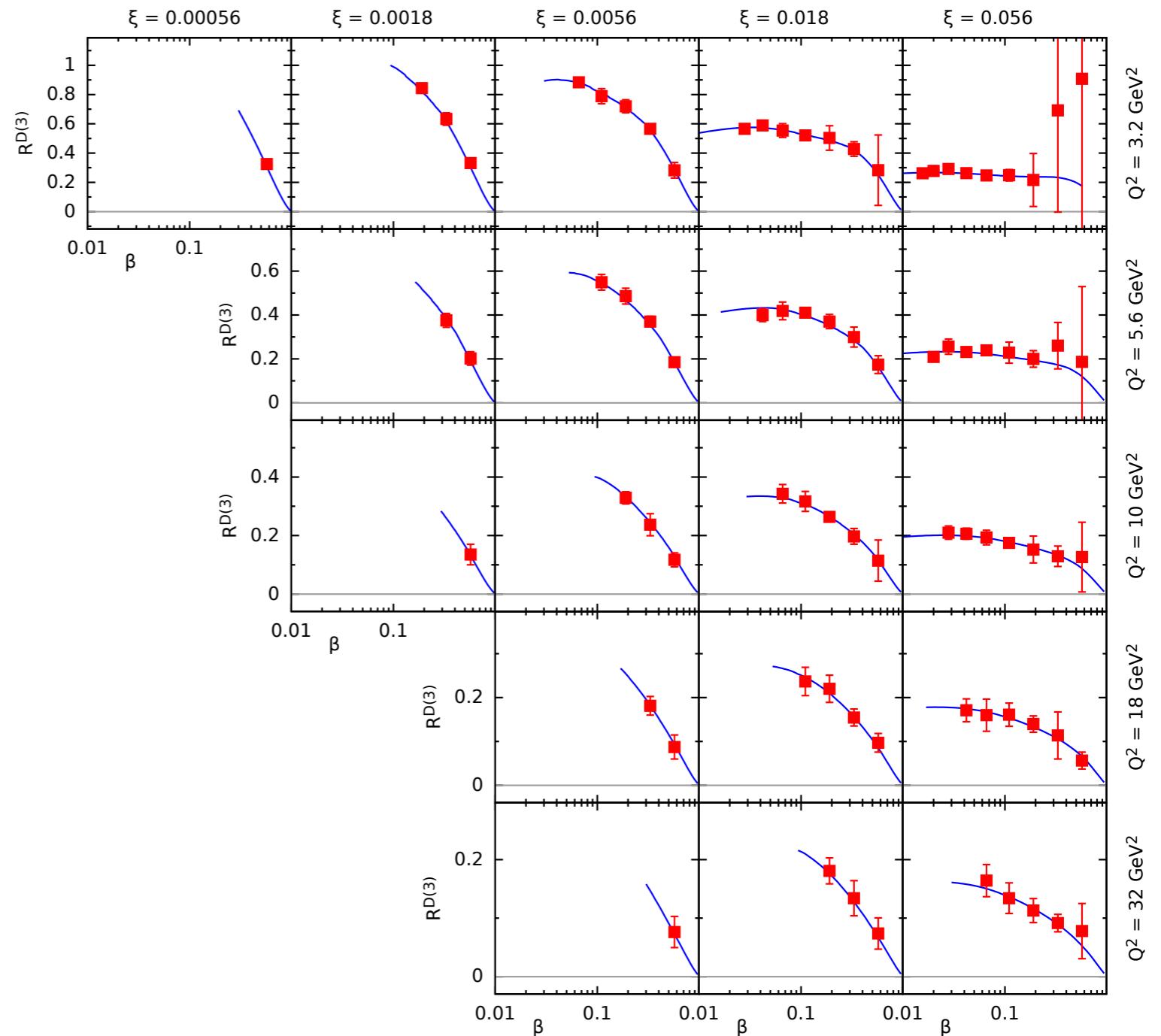
$$\sigma_{\text{red}}^{D(3)} = [1 + (1 - Y_L)R^{D(3)}]F_T^{D(3)}$$

Different form of reduced cross section

Alternative fit has different sensitivities to the uncertainties

Systematics 1%

Averaged over 10 MC samples:
reduced fluctuations



Summary and outlook

- Investigated potential of EIC for the longitudinal structure function in diffraction : F_{L^D}
- Important quantity, sensitive to diffractive gluon density (saturation, higher twists...). Only one extraction at HERA by H1, large errors. Challenging measurement.
- Three scenarios: 17, 9, 5 energy combinations. Pseudodata from DGLAP, assumed 1-2% systematics, 10 fb^{-1} integrated luminosity. Extraction via linear fit to reduced cross section
- Scenarios S-17 and S-9 do not differ much, S-5 reduced kinematic range
- Precision in a given bin of (Q^2, ξ, β) correlates strongly with range in inelasticity y
- Still, precision comparable in all scenarios, dominated by systematics. Extracted R ratio too.
- **Overall: very good prospects for this quantity and EIC even with 5 energy combinations**

Possible directions:

- 4-dimensional structure function
- Sensitivity to different models (dipole model, saturation...)