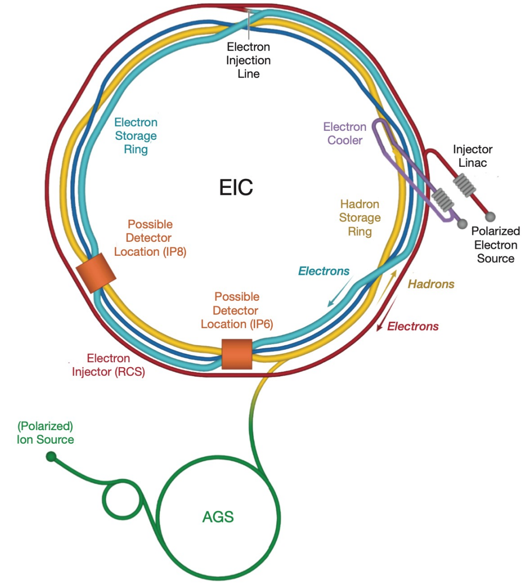
Extracting the Partonic Structure of Colourless Exchanges at the Electron-Ion Collider



DIS23 MICHIGAN STATE UNIVERSITY https://pa.msu.edu/conf/DIS2023

30 March 2023

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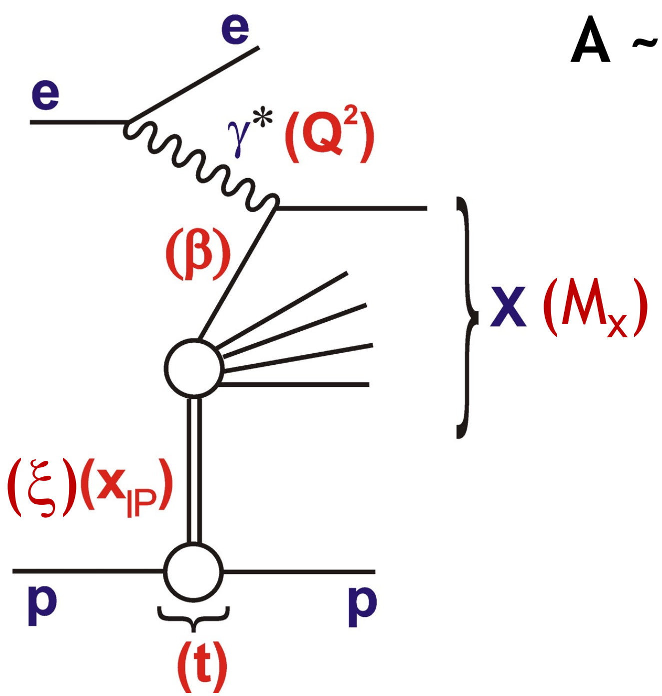
New work in progress, following on from:

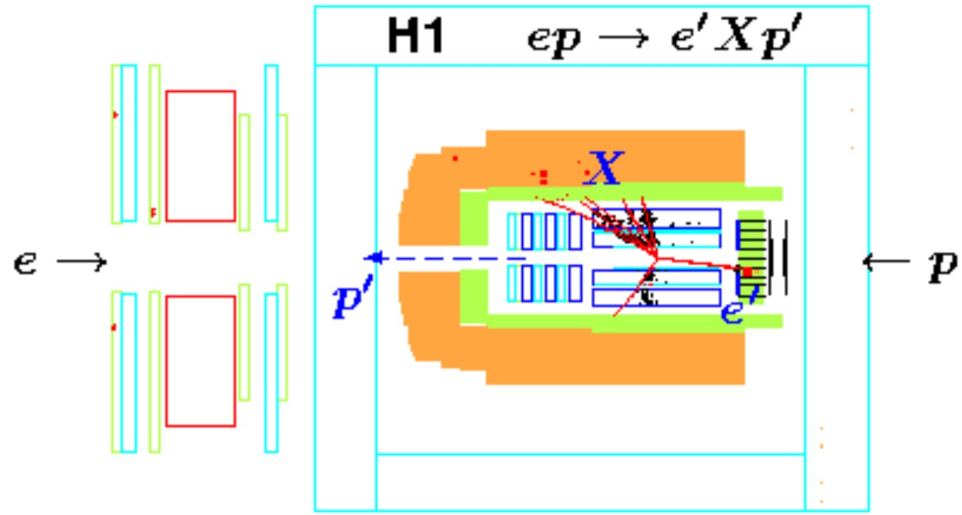
- DPDFs at LHeC (and EIC) Phys Rev D100 (2019) 074022

- Longitudinal Diffractive Structure Function @EIC Phys Rev D105 (2022) 074006

Inclusive Diffraction in Deep Inelastic Scattering

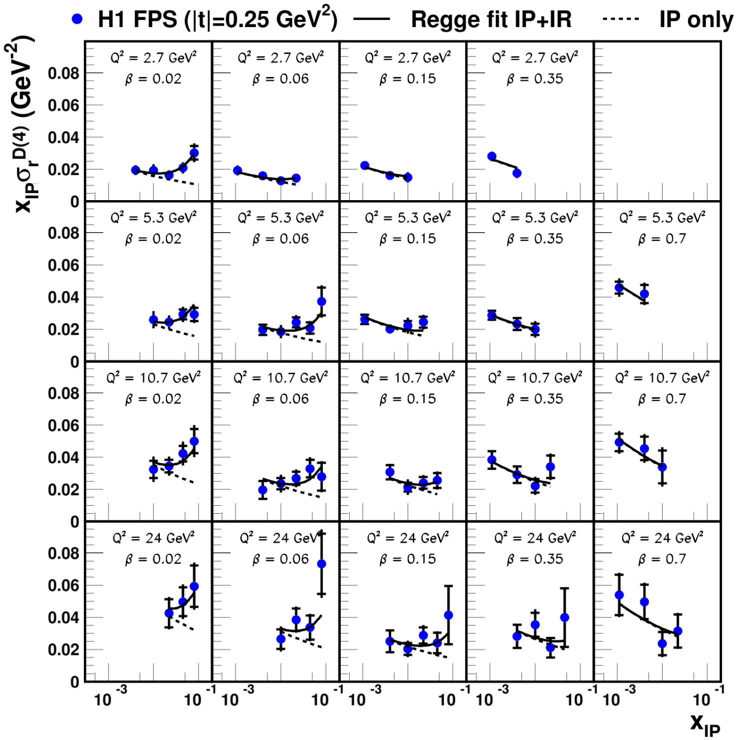


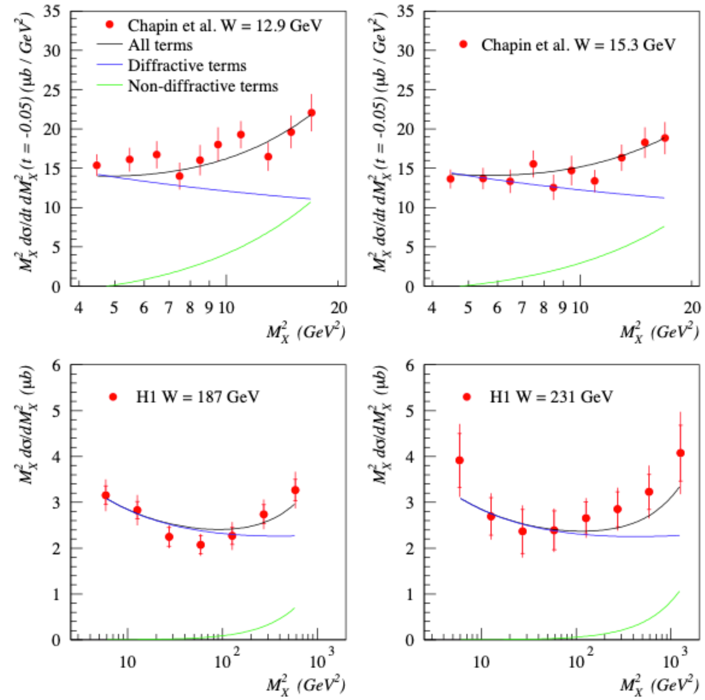
A ~10% leading twist contribution to DIS



- Virtual photon dissociation to multi-particle system X (M_X)
- Proton remains intact, losing small energy fraction ($\xi \equiv x_{IP}$)
- Four-momentum transfer squared at proton vertex = t
- Momentum fraction struck quark rel to exchange = β ($x = \beta\xi$)
- More generally, parton momentum fraction = z ($\geq \beta$)

Example diffractive data from HERA



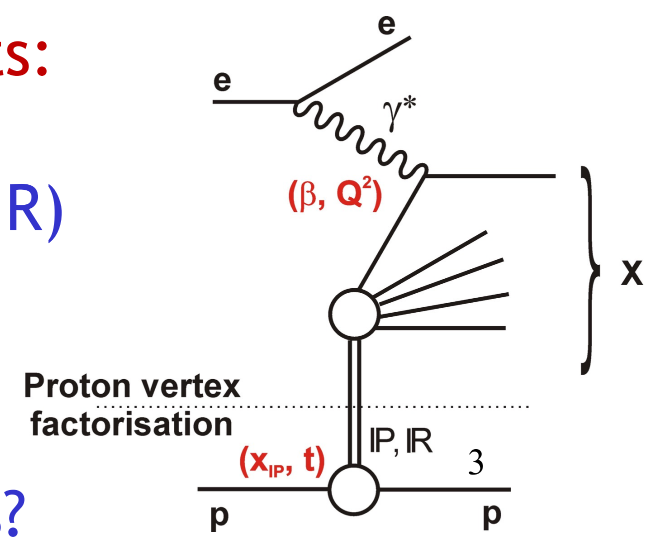


Generally decomposed into two components:

- Leading 'Pomeron' (IP) at low ξ
- Sub-leading 'Reggeon' or 'Meson' (IR) at largest ξ

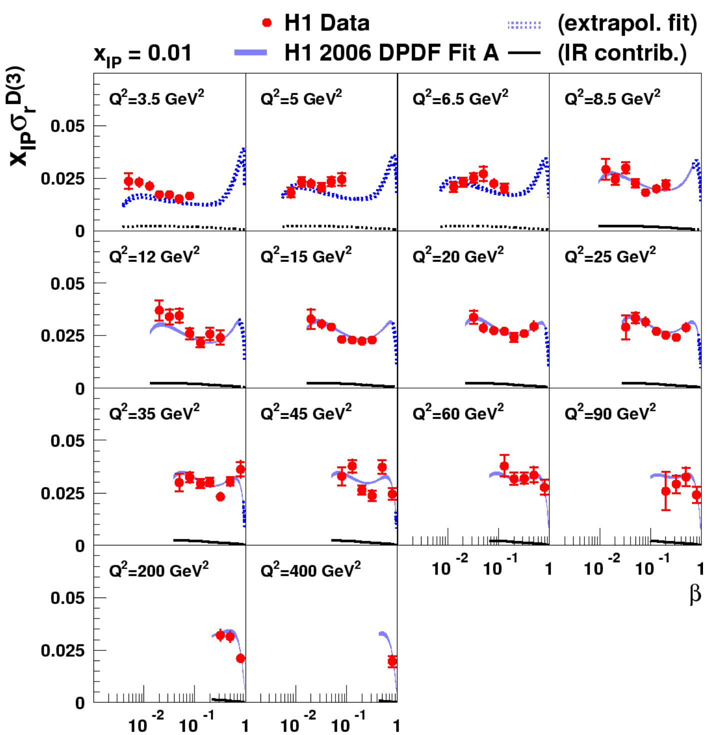
Sub-leading term poorly constrained

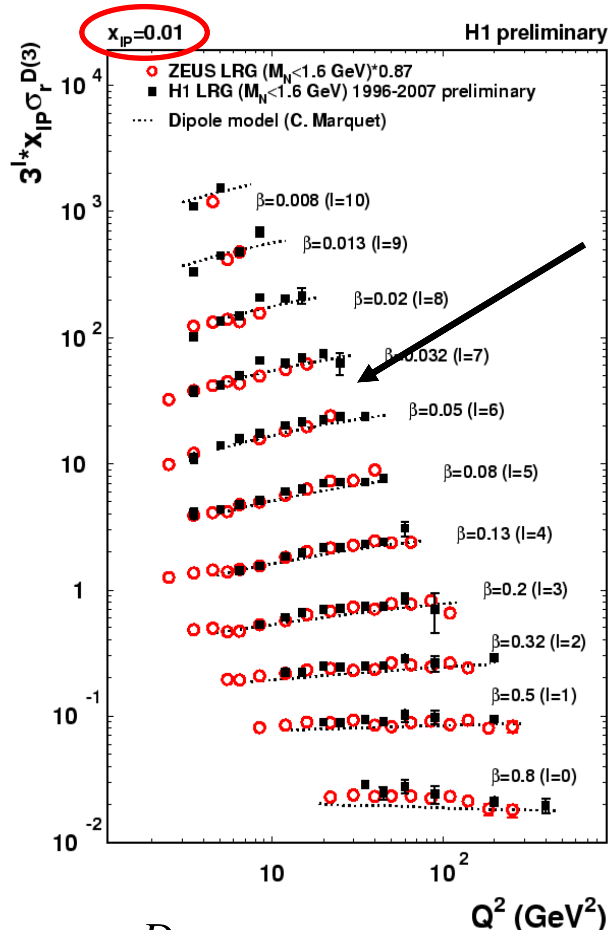
- Isoscalar? – Isovector?
- Combination of multiple exchanges?



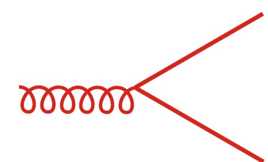
Sensitivity to Partonic Content (HERA)

$$\frac{d^4\sigma^{ep\to eXp}}{d\beta dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\cdot\left(1-y+\frac{y^2}{2}\right)\cdot\sigma_r^{D(4)}(\beta, Q^2, x_{I\!P}, t) \qquad [\sigma_r^D \approx F_2^D]$$





Dependence on Q^2 tells us gluon density via DGLAP

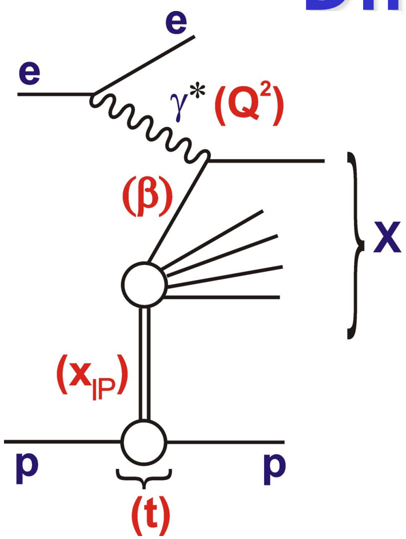


$$F_2^D = \sum_q e_q^2\,\beta\,(q+\bar{q})$$

Diffractive cross section measures quark density

$$\frac{d\sigma_r^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g + P_{qq}\otimes q\right]$$

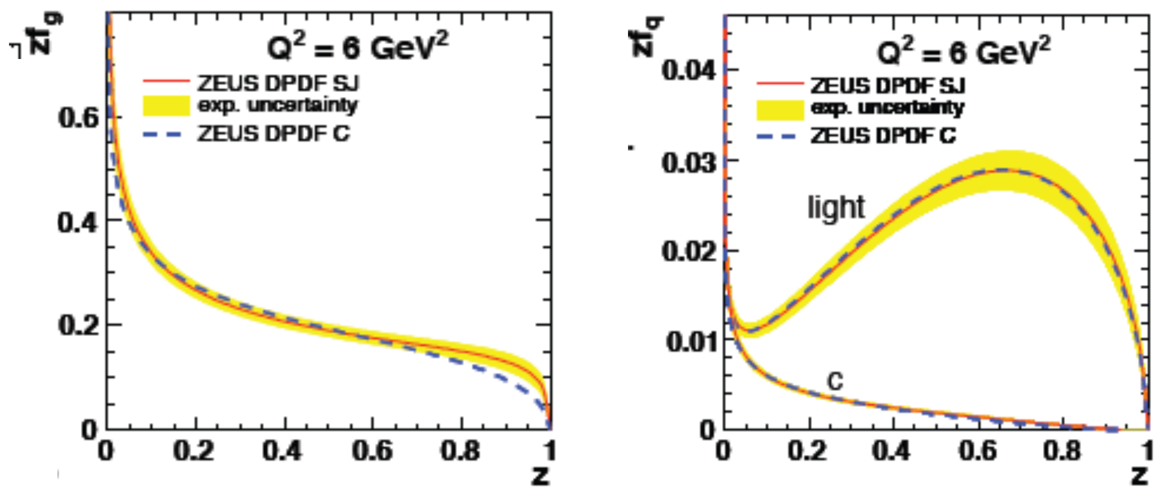
Diffractive Parton Densities (HERA)



DPDFs (corresponding to the IP exchange only) extracted through fits assuming NLO DGLAP

… dominated by gluon density extending to large mom fractions, z

Example from ZEUS

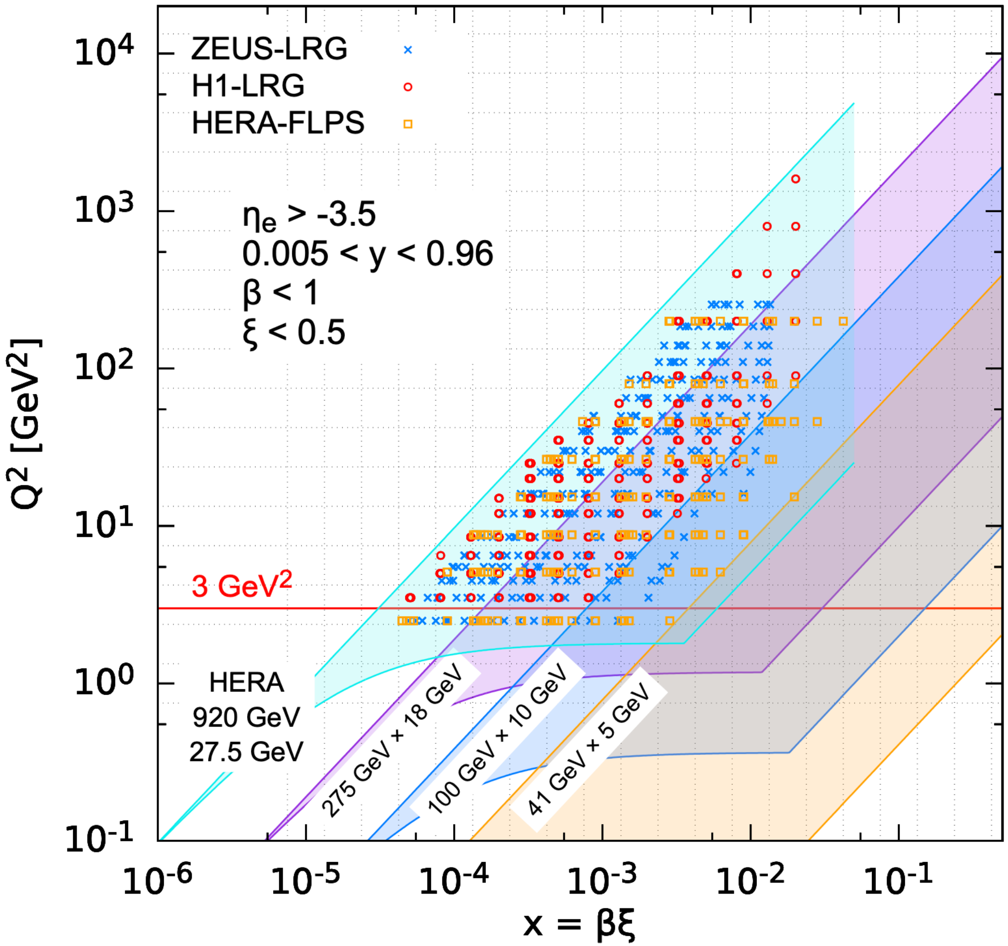


- Successful in describing all HERA diffractive DIS data
- Widely applied in phenomenology at LHC and elsewhere

BUT

- **High z region poorly constrained, particularly for gluon**
- **Model for the Reggeon completely ad hoc (Always GRV π^0)**

Diffraction at EIC

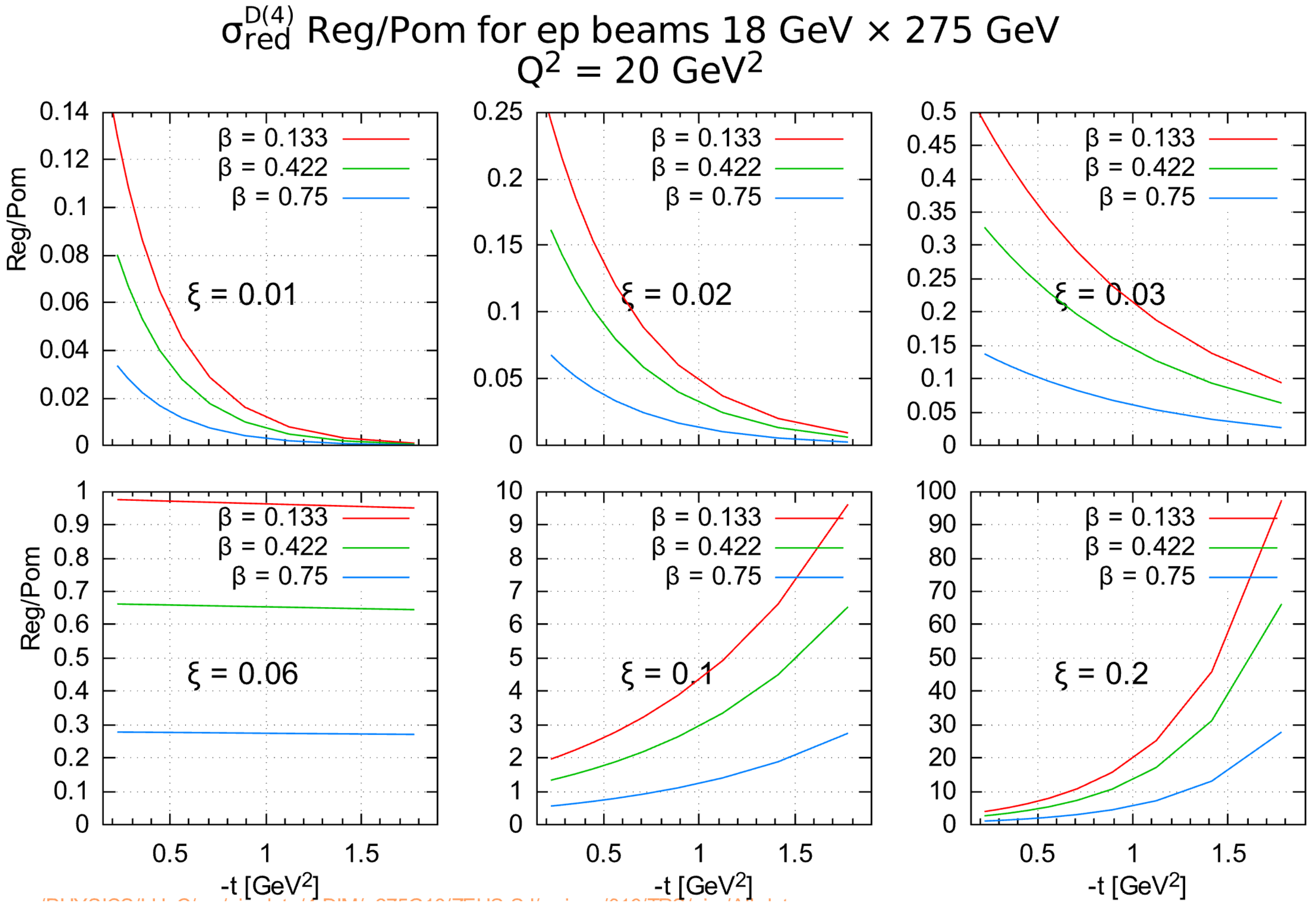


In the absence of fixed target DDIS data, EIC fills in the currently unknown high x (=$\beta\xi$), low Q^2 region

EIC complementarity to HERA:

- Large x → large β → constrains the DPDFs at large z
- Large x → large ξ → region of sensitivity to Reggeon (IR)

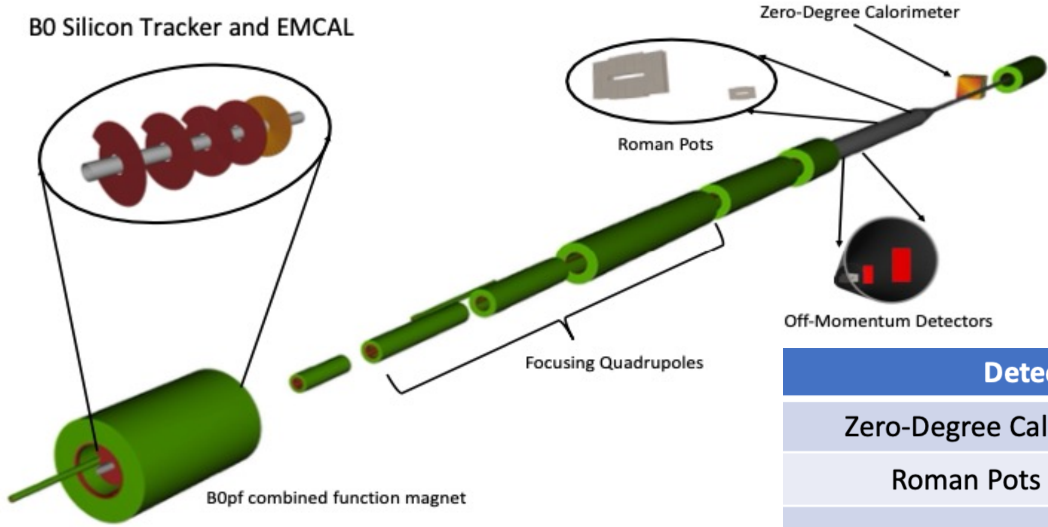
Expected Reggeon Contribution at EIC



IR/IP assuming HERA model

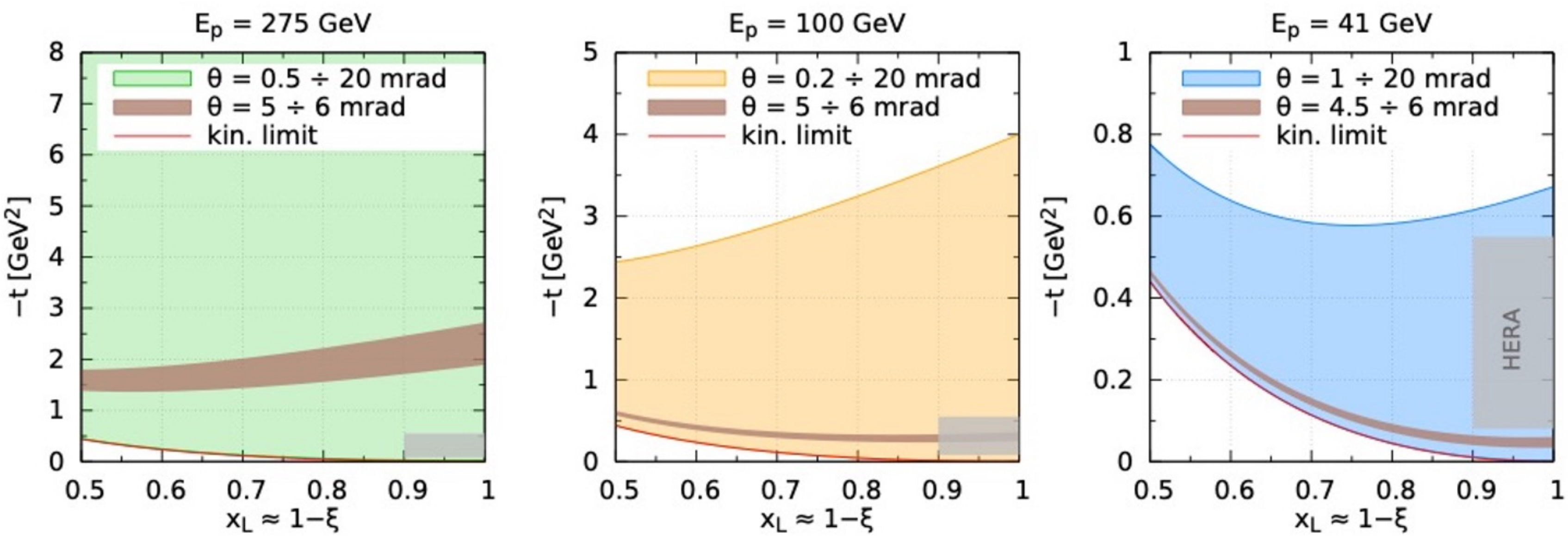
- Reggeon grows fast relative to Pomeron with ξ
- There is also a t dependence to the ratio (generated by α')
- Approximate Q^2 independence

Instrumentation and Acceptance at EIC

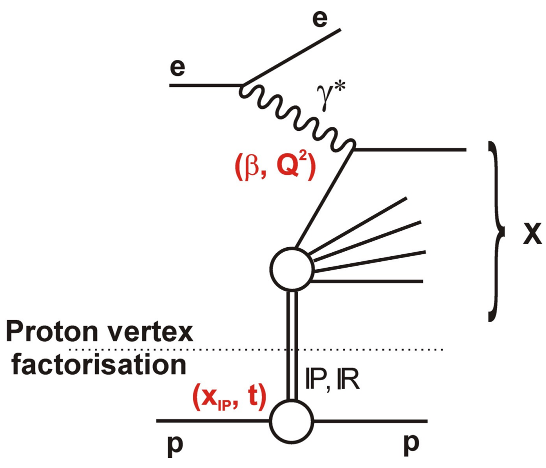


Beamline detectors have wide acceptance in ξ and t for detecting protons

Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\theta < 5.5$ mrad ($\eta > 6$)
Roman Pots (2 stations)	0.0* < $\theta < 5.0$ mrad ($\eta > 6$)
Off-Momentum Detectors (2 stations)	$0.0 < \theta < 5.0$ mrad ($\eta > 6$)
B0 Detector	$5.5 < \theta < 20.0$ mrad ($4.6 < \eta < 5.9$)



Producing the Pseudodata



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

$$f_{I\!P}(x_{I\!P}, t) = A_{I\!P} \cdot \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}} \quad ; \quad f_{I\!R}(x_{I\!P}, t) = A_{I\!R} \cdot \frac{e^{B_{I\!R} t}}{x_{I\!P}^{2\alpha_{I\!R}(t)-1}}$$

[HERA Standard Model]

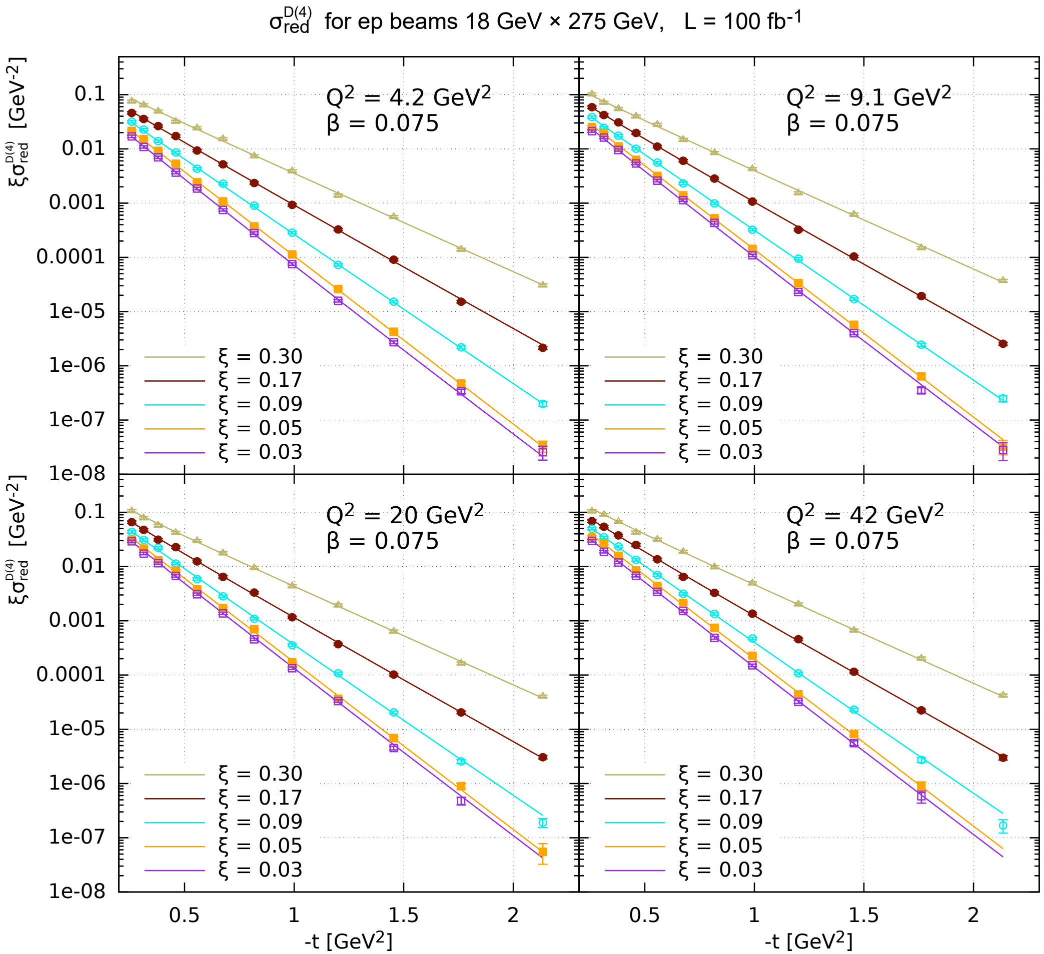
F_{IP} and f_{IP} from fitted results from ZEUS
F_{IR} from GRV pion, f_{IR} from educated guesswork

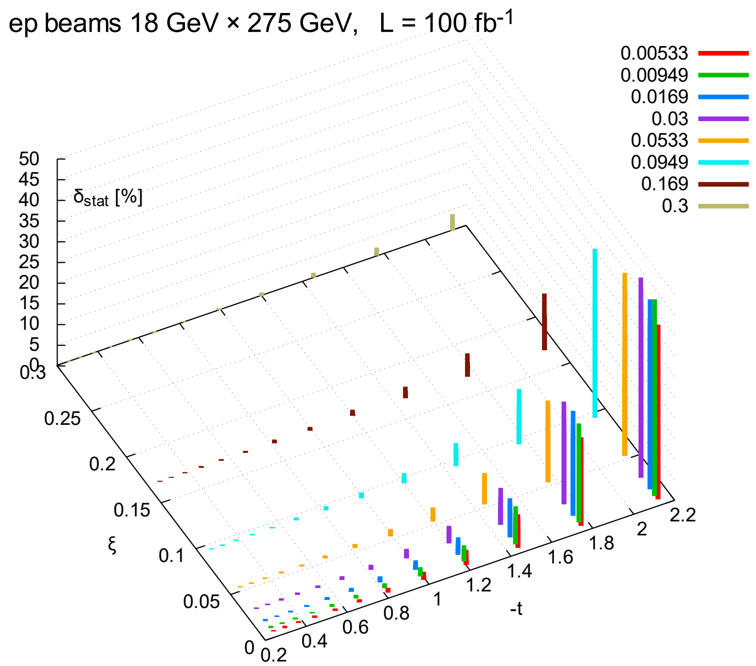
- Only use EIC NC simulations (no HERA data or CC yet)
- Lumi of 100 fb^{-1} at single $\sqrt{s}$ (275 x 18 GeV)
- Require $0.005 < y < 0.96$
- 100% detection efficiencies
- 5% uncorrelated systematics
- No correlated / norm syst's yet
- Randomly fluctuate each data point according to uncertainties

Default binning

$-t$	$\in$	$[0.01, 2]$	(23 bins),
ξ	$\in$	$[0.0004, 0.4]$	(24 bins),
β	$\in$	$[0.001, 1]$	(12 bins),
Q^2	$\in$	$[2.9, 62]$	(4 bins).

Example Pseudodata (β=0.075)





- Statistical uncertainties remain manageable up to |t| ~ 2 GeV^2

- Test robustness of fit outputs by repeating multiple times with new pseudodata and by varying binning …

Parameterisation for Fitting Pseudodata

- Treat IP and IR contribitions as symmetrically as possible …

- Light quark flavour separation not possible in inclusive NC fits.
… for both IP and IR fit for gluon
and for sum of quarks, $\sum e_q^2 f_q(x)$

(cf GRV has a valence-like u,d and sea-like s quarks)

- Generic PDF parameterisation at starting scale, $Q_0^2 = 1.8$ GeV²:

$$f_k^{IM}(x, Q_0^2) = A_k \; x^{B_k} \, (1-x)^{C_k} \, (1 + D_k \,) \qquad [IM = IP, IR]$$

- Following sensitivity studies, a suitable choice is …

f_q^{IP} has A, B and C params — cf HERA – Usually A, B and C psrams

f_g^{IP} has A, B and C params — cf HERA - e.g. H1 Fit B had only A

f_q^{IR} has A, B, C and D params

f_g^{IR} has A, B and C params — cf HERA – only overall norm'n GRV π

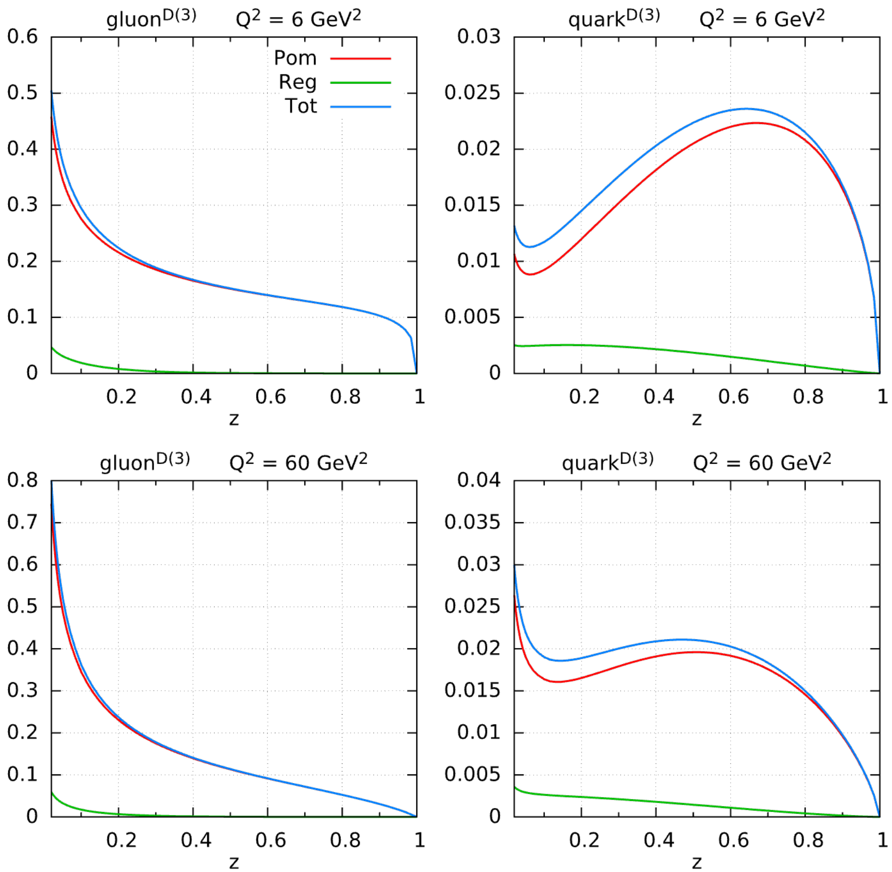
- In addition, fit for $\alpha(0), \alpha', B$ parameters from pomeron and meson flux factors

$$\frac{e^{B_{IM} t}}{\xi^{2\alpha_{IM}(t)-1}}$$

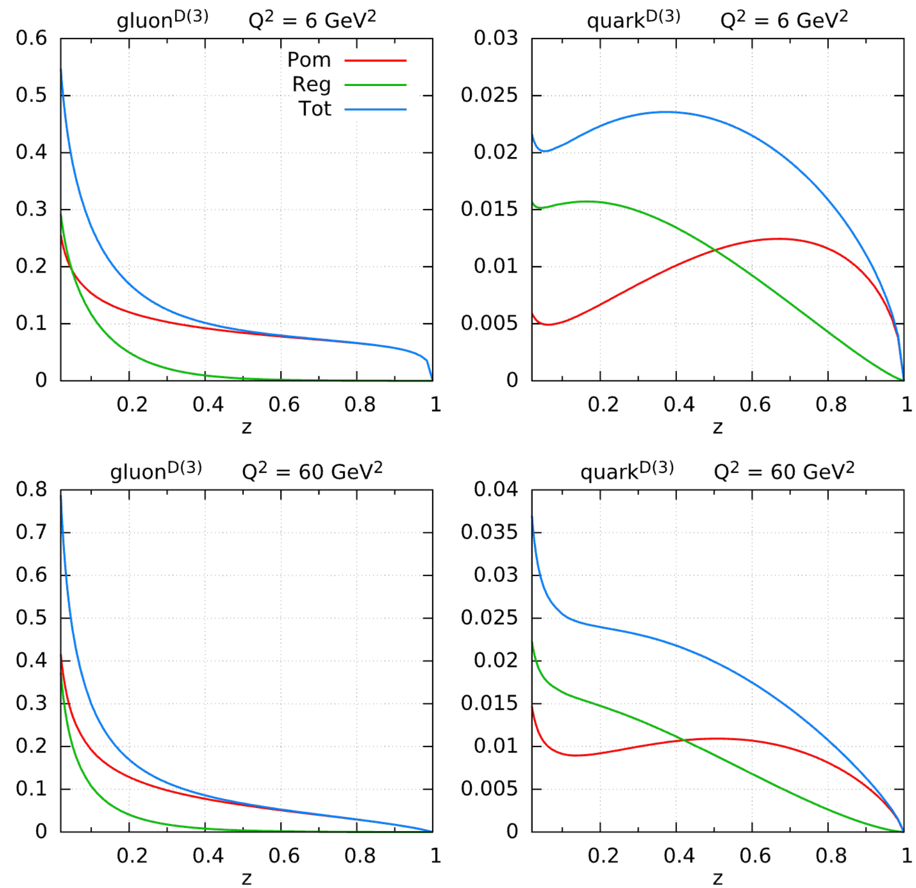
where $\alpha_{IM}(t) = \alpha_{IM}(0) + \alpha'_{IM}\, t$

Results of Fit to Pseudodata

ξ = 0.01

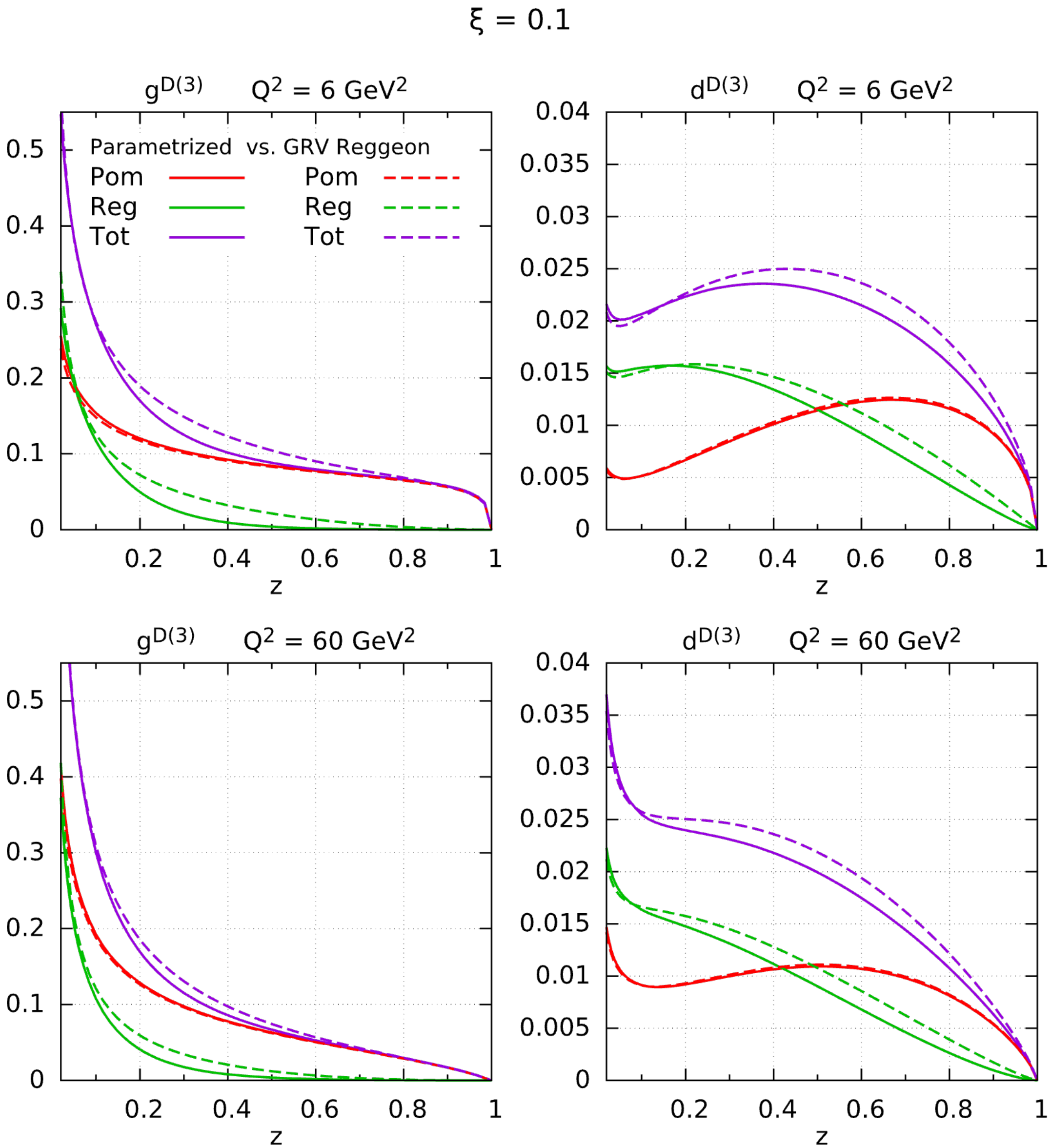


ξ = 0.1



Central values of results
(for the record)

Recovering the Reggeon Input



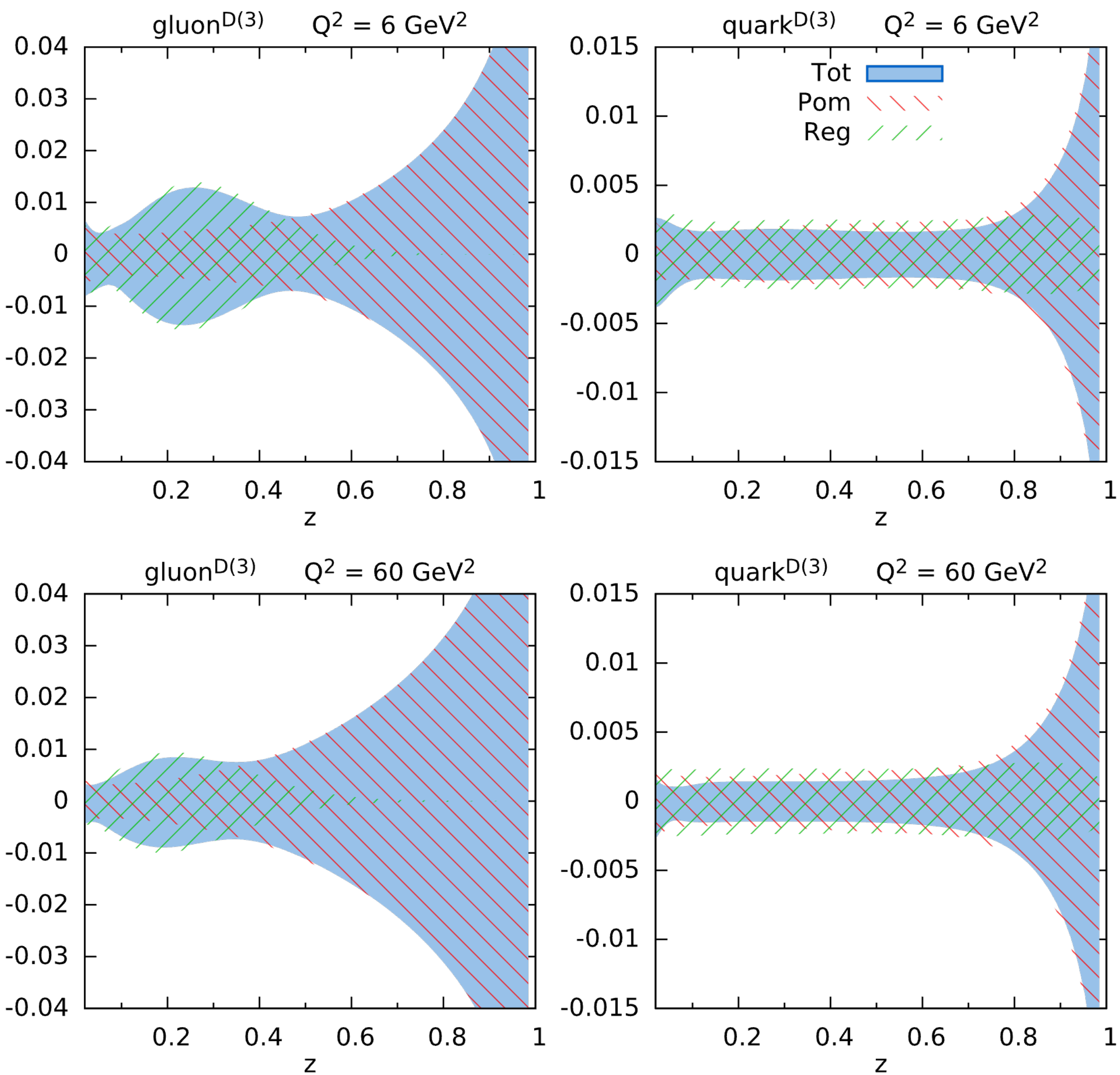
Fit results with free Reggeon parameterisation (solid) made to pseudodata based on GRV pion (dashed) →

Reasonable reproduction of Reggeon input

Pomeron reproduced essentially perfectly

ata: m:/PhysicsResults/EIC/Fits4D/p0.275e18/T-016/pdf_xi0.1/loglin/P+R_vsz.dat

Precision on PDFs: Overview at $\xi = 0.1$



[linear z scale]

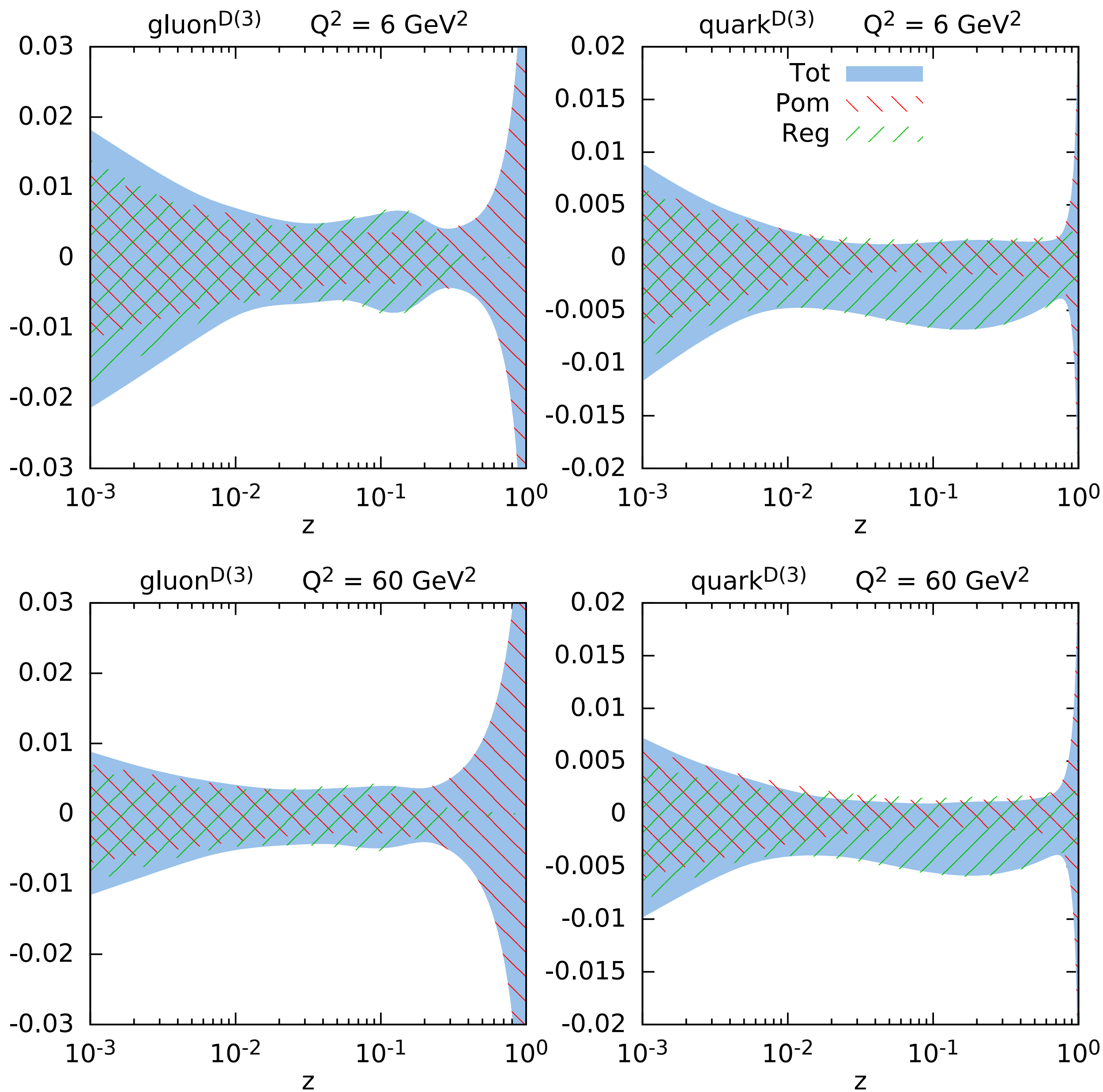
- EIC can constrain Reggeon at similar level to pomeron

Only uncorrelated experimental uncertainites so far (no normal'n … eg lumi)

→ ~1% or better on gluon in some regions
→ <0.5% on quarks in some regions

Model and parameterisation unceratinties still to be evaluated

Precision on PDFs: Overview at $\xi = 0.1$



[logarithmic z scale]

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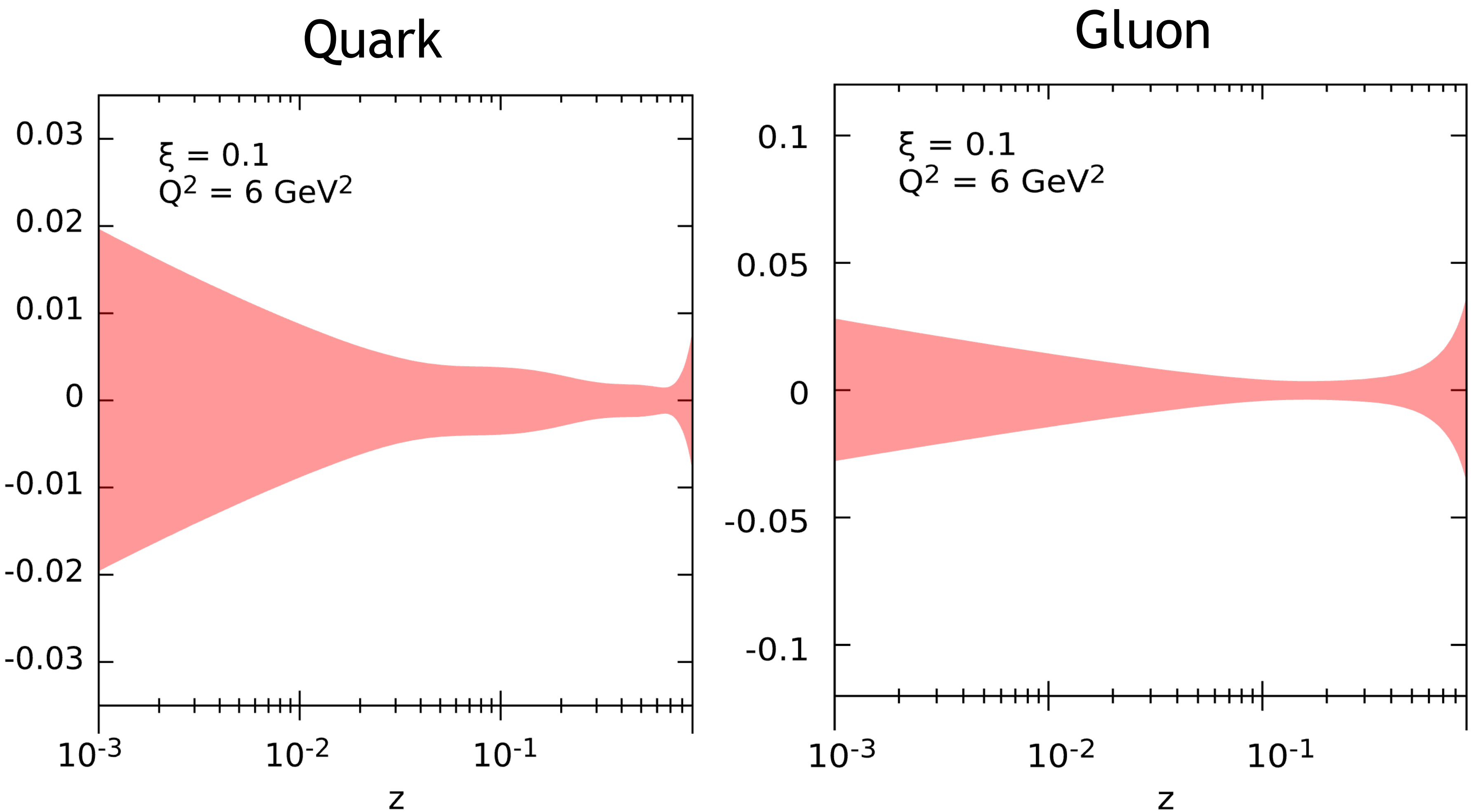
Precision on Pomeron Contribution

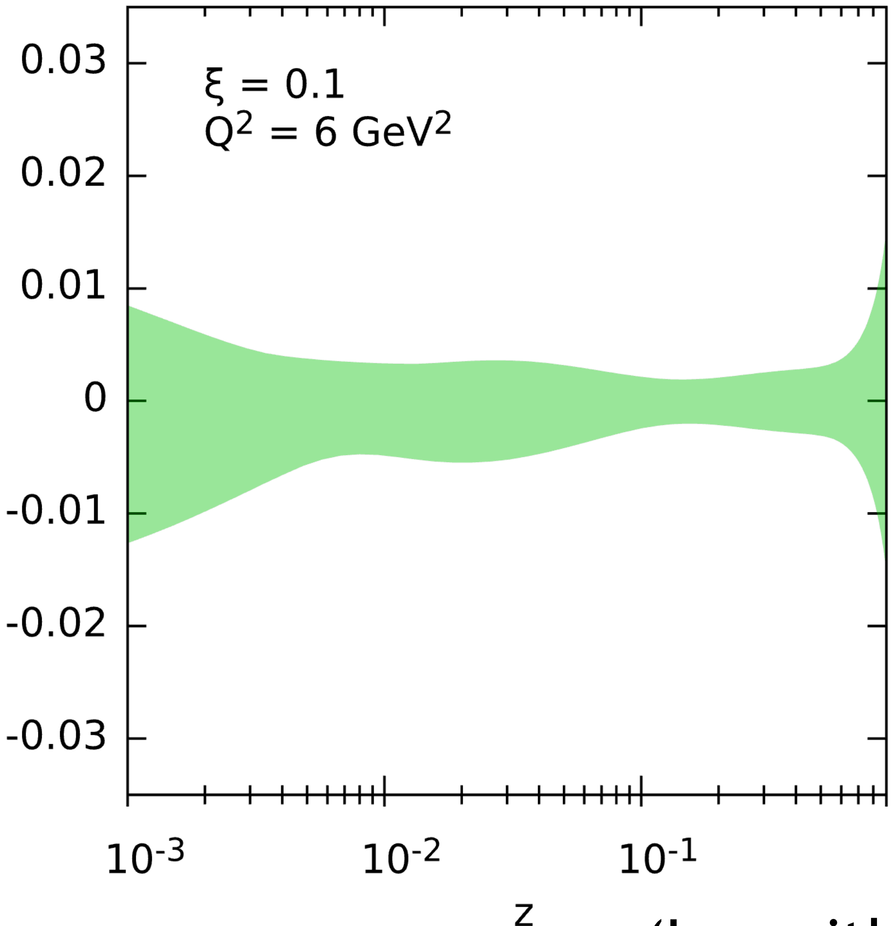


(Logarithmic z scale)

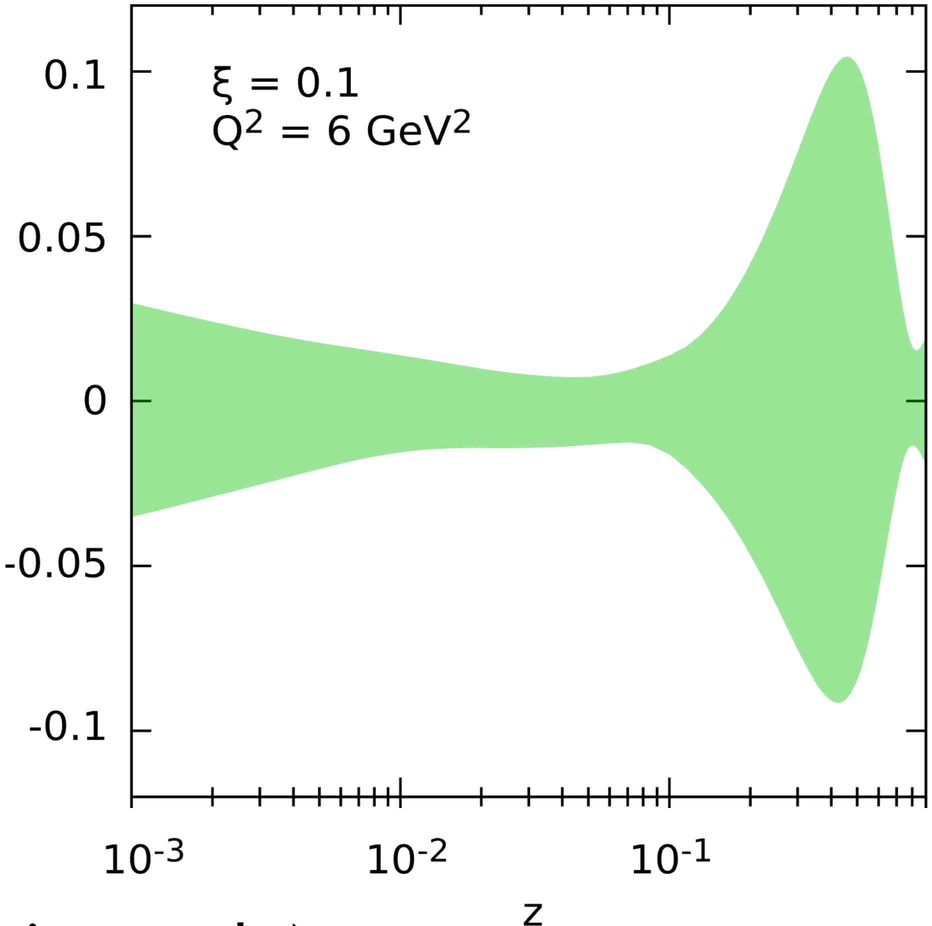
Impact throughout kinematic range, notably at large z

Precision on Reggeon Contribution

Quark



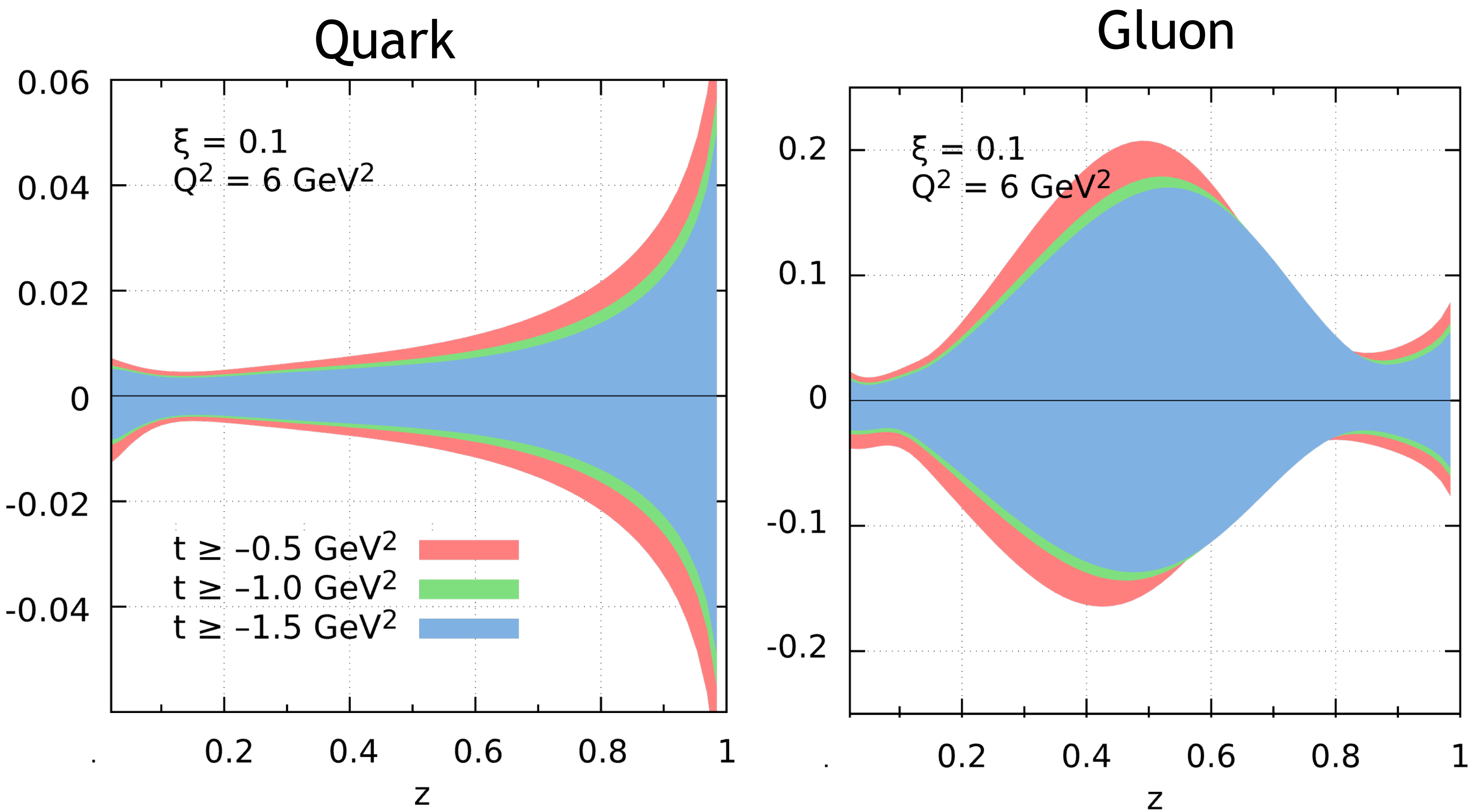
Gluon



(Logarithmic z scale)

Completely transformational level of understanding

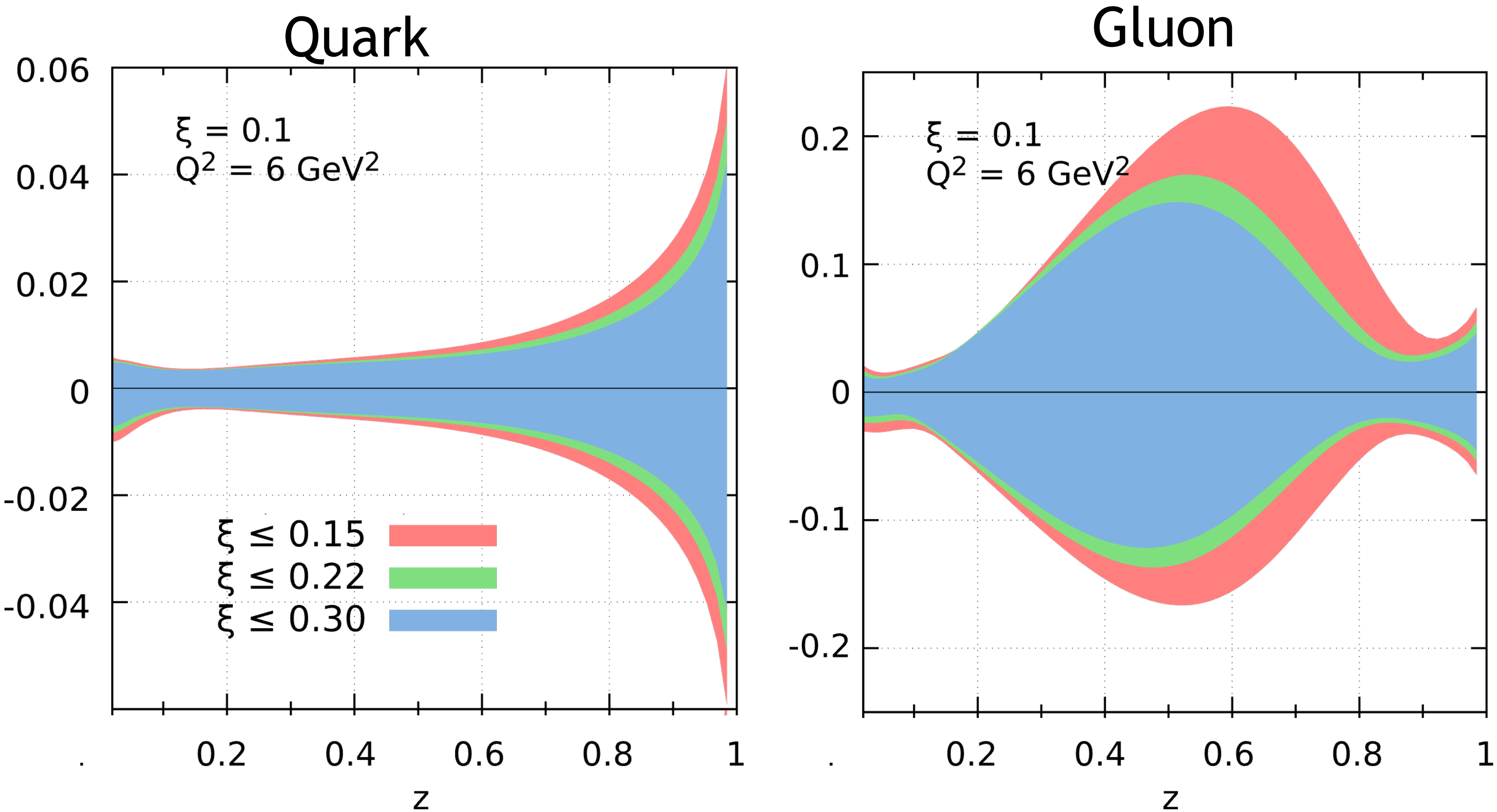
Dependence of Reggeon on t range



[Linear z scale]

- Variation of pom:reg ratio with t has some value in fits
- Results not dramatically sensitive

Dependence of Reggeon on ξ range



[Linear z scale]

Large ξ region important for Reggeon, particularly at large z

Restriction to ξ<0.15 still leaves strong sensitivity

Precision on Flux Parameters

$$f_{I\!P}(x_{I\!P},t) = A_{I\!P} \cdot \frac{e^{B_{I\!P}t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}} \quad ; \quad f_{I\!R}(x_{I\!P},t) = A_{I\!R} \cdot \frac{e^{B_{I\!R}t}}{x_{I\!P}^{2\alpha_{I\!R}(t)-1}}$$

Sensitivity to 3 free parameters for each flux factor …

Input		Fit returns
	$\alpha_{IP}(0) = 1.11$,	1.1119 ± 0.0007
	$\alpha'_{IP} = 0$,	-0.0024 ± 0.0010
	$B_{IP} = 7$ GeV^{-2},	7.033 ± 0.010
	$\alpha_{IR}(0) = 0.70$,	0.7014 ± 0.0018
	$\alpha'_{IR} = 0.90$,	-0.8957 ± 0.0021
	$B_{IR} = 2$ GeV^{-2},	2.020 ± 0.073

Input values recovered at ~2-3σ level.
Some strong correlations between variables.

Summary

The EIC could extract the flux parameters and partonic structure of the sub-leading 'Reggeon' exchange in Diffractive DIS with similar precision to that currently achieved for the leading 'Pomeron' exchange.

Work still needed on propagating some uncertainties
- → Experimental (normalization / correlated systematics)
- → Theoretical (model dependence, parton parameterization)

More constraints can be added
- → Further EIC beam energies,
- → Charged current
- → Combined fit to HERA and EIC?