Neural network modelling of generalised parton distributions (GPDs)

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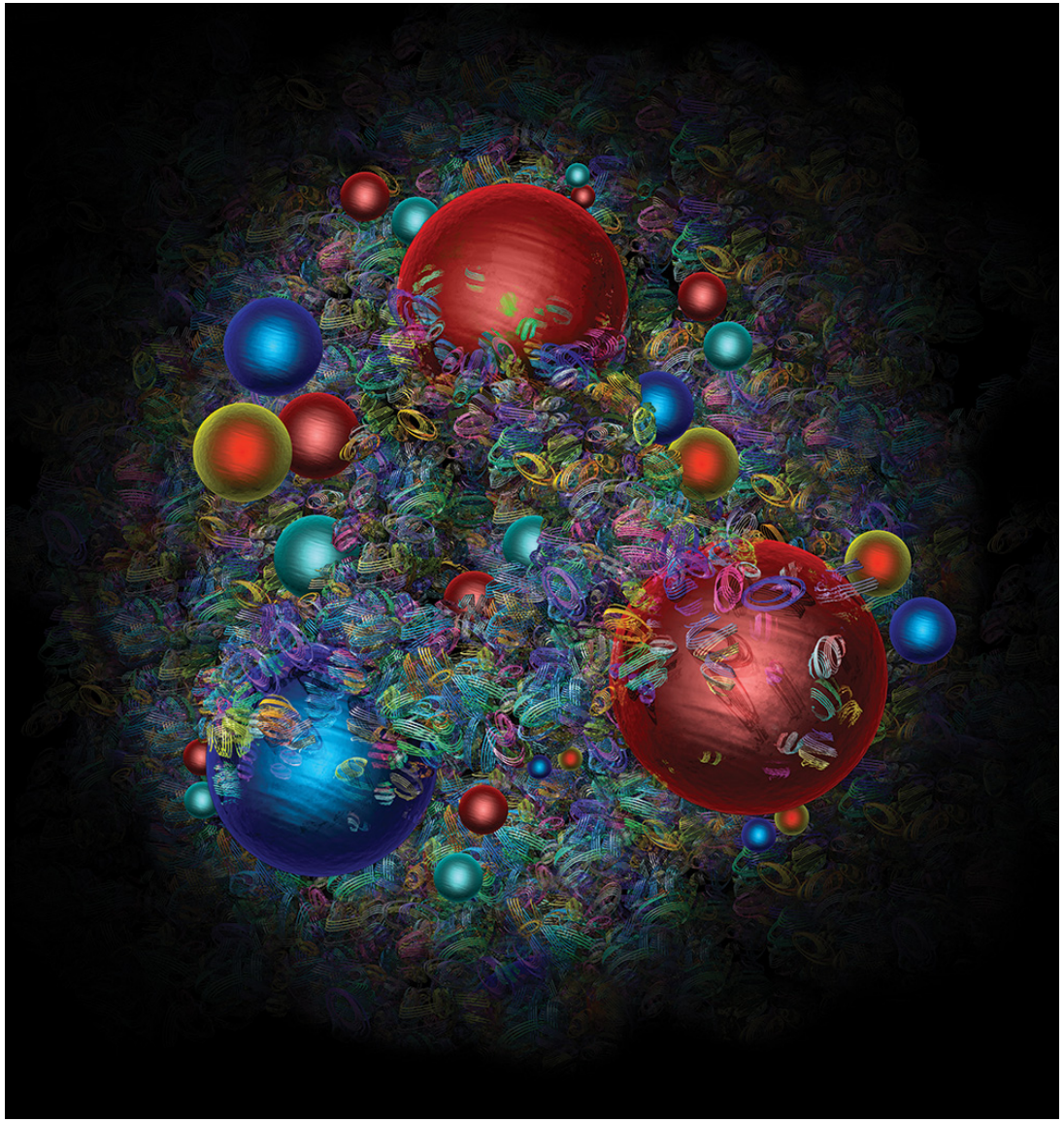
The big picture

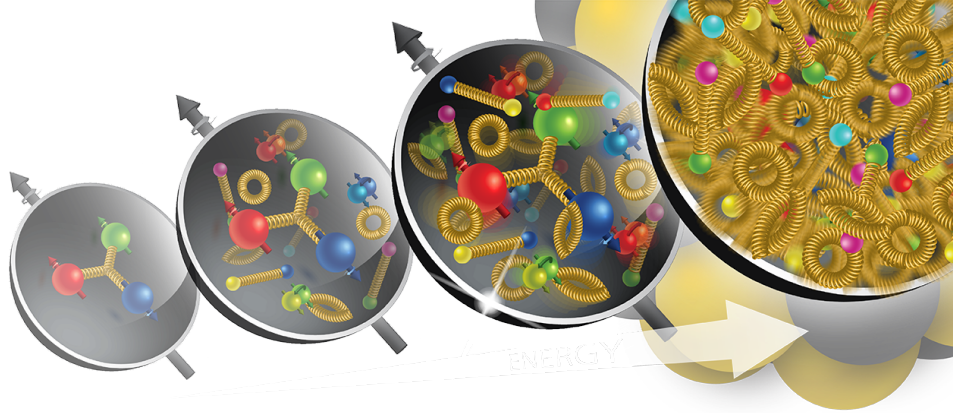
Nucleon is not a point-like particle, it is made out of partons:

- quarks (valance and sea)
- gluons

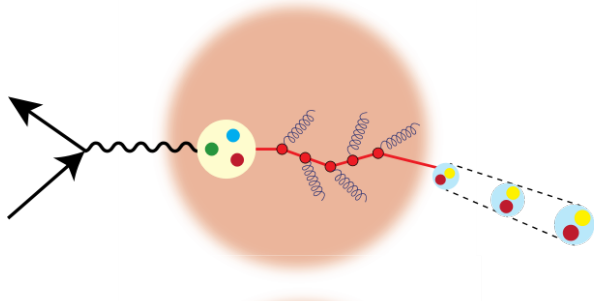


from CERN Courier / D. Dominguez

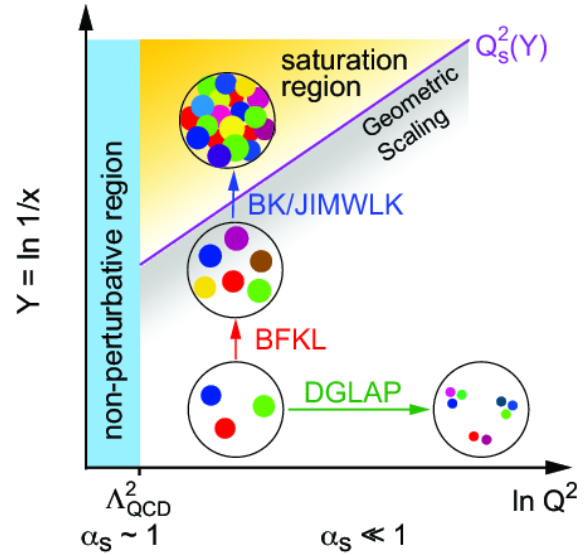
The big picture



- What are momentum distributions of partons?
  (for both longitudinal and transverse components)
- How are partons distributed spatially in nucleon?
- How are nucleon properties, such as spin and mass, emerged?

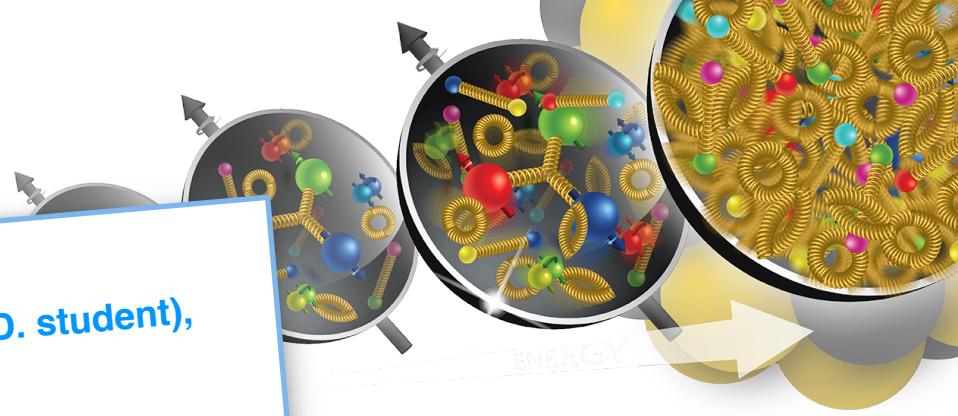


- How does all this information change for nuclei?
- How do interactions between partons form nuclear binding?
- How do probes, such as colour-less jets, interact with nuclear medium?



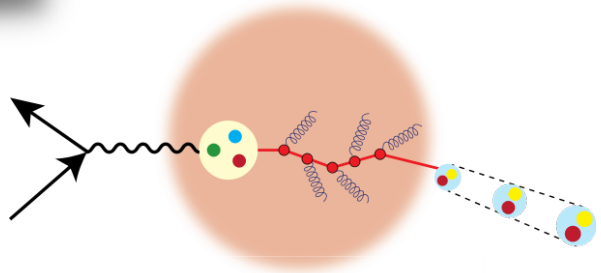
- What happens with gluon densities in low-x region?
- Are they saturate at high energies, creating a universal gluonic matter?

The big picture



- What are momentum distributi… f…
  (for both longit…
- How are parto…
- How are nucle…

Manpower involved:
PS, L. Szymanowski, J. Wagner, V. Martínez-Fernández (Ph.D. student),
V. Batozskaya (BP3), K. Deja (SE)
(note also COMPASS group from BP3)



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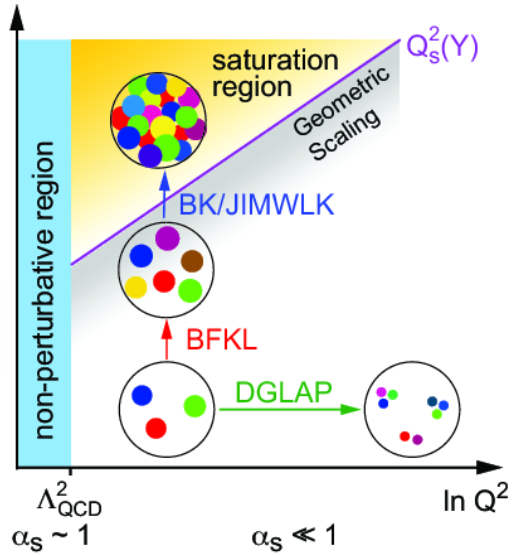
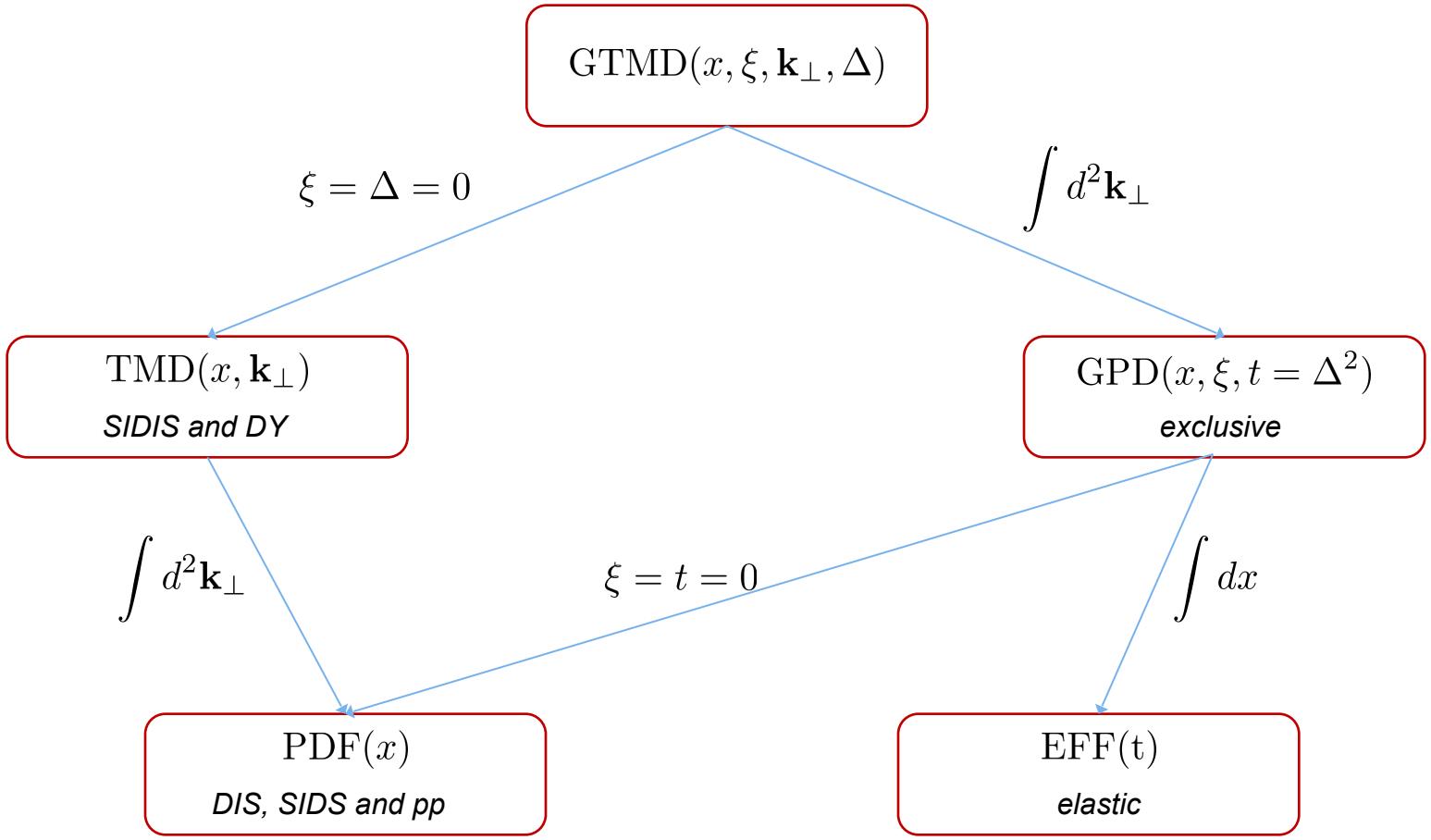


- What happens…
- Are they satura…

Manpower involved:
T. Altinoluk, G. Beuf, A. Czajka, L. Szymanowski,
A. Tymowska (Ph.D. student), S. Mulani (Ph.D. student), P. Agostini (postdoc)

Description of hadrons

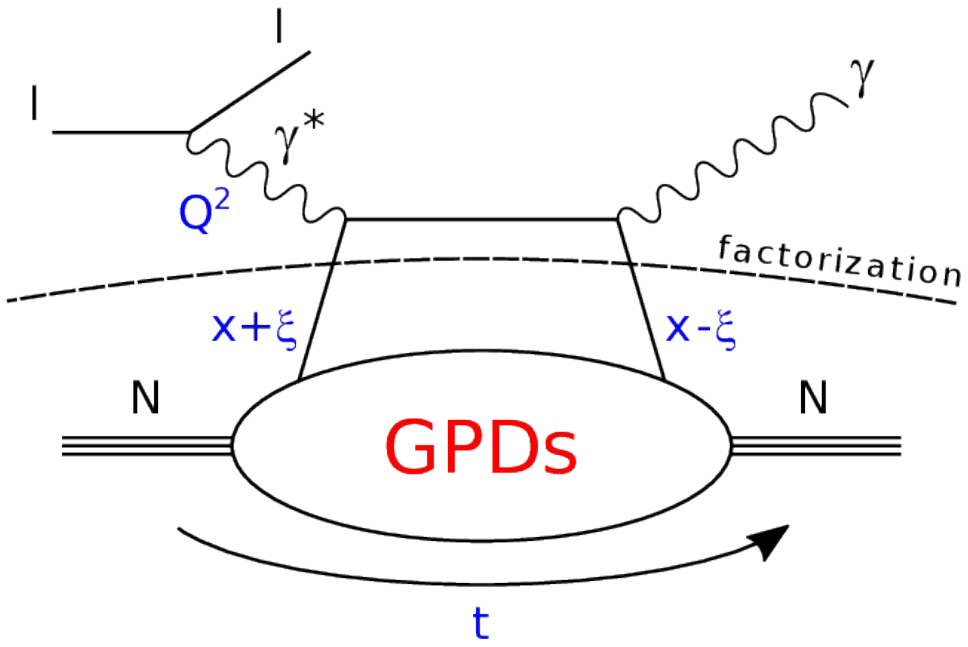
Theory tools for studying partonic structures:



Generalised partons distributions

see e.g. Phys. Rept. 388, 41, 2003 for proper definition of GPDs

Deeply Virtual Compton Scattering (DVCS)



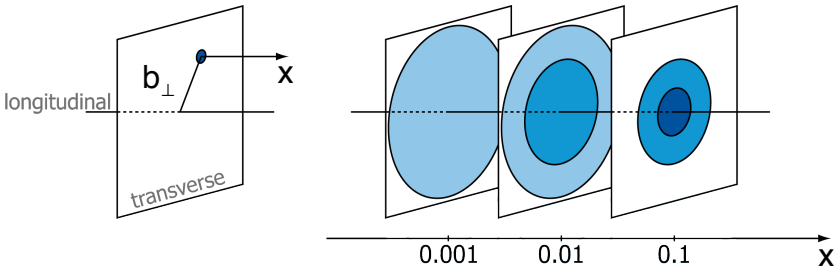
factorisation for $|t|/Q^2 \ll 1$

Chiral-even GPDs:
(helicity of parton conserved)

$H^{q,g}(x,\xi,t)$	$E^{q,g}(x,\xi,t)$	*for sum over parton helicities*
$\widetilde{H}^{q,g}(x,\xi,t)$	$\widetilde{E}^{q,g}(x,\xi,t)$	*for difference over parton helicities*
nucleon helicity conserved	*nucleon helicity changed*	

Generalised partons distributions

Nucleon tomography:



$$q(x, \mathbf{b}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{\Delta}}{4\pi^2} e^{-i\mathbf{b}_\perp \cdot \boldsymbol{\Delta}} H^q(x, 0, t = -\boldsymbol{\Delta}^2)$$

Energy momentum tensor in terms of form factors (OAM and mechanical forces):

$$T^{\mu\nu} = \begin{bmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{bmatrix}$$

Energy density · Momentum density · Shear stress · Normal stress · Energy flux · Momentum flux

$$\langle p', s'|\widehat{T}^{\mu\nu}|p, s\rangle = \bar{u}(p', s')\left[\frac{P^\mu P^\nu}{M}A(t) + \frac{\Delta^\mu\Delta^\nu - \eta^{\mu\nu}\Delta^2}{M}C(t) + M\eta^{\mu\nu}\bar{C}(t) + \right.$$
$$\left. \frac{P^\mu i\sigma^{\nu\lambda}\Delta_\lambda}{4M}[A(t) + B(t) + D(t)] + \frac{P^\nu i\sigma^{\mu\lambda}\Delta_\lambda}{4M}[A(t) + B(t) - D(t)]\right] u(p, s)$$

Modelling in (β, α)-space

H. Dutrieux et al.,
Eur. Phys. J. C 82 (2022) 3, 252

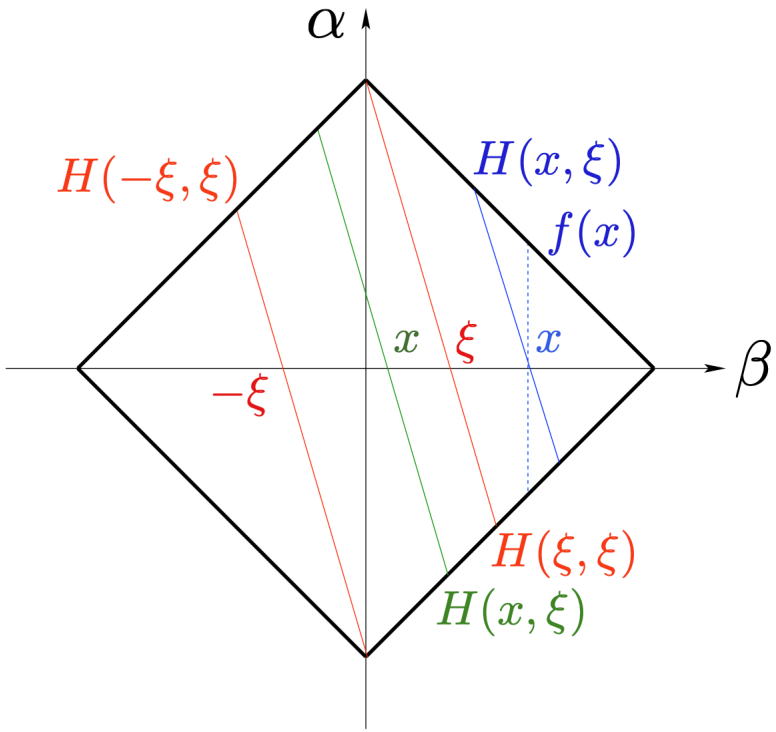
Double distribution:

$$H(x,\xi,t) = \int \mathrm{d}\Omega\, F(\beta,\alpha,t)$$

where:

$$\mathrm{d}\Omega = \mathrm{d}\beta\, \mathrm{d}\alpha\, \delta(x-\beta-\alpha\xi)$$

$$|\alpha| + |\beta| \leq 1$$



from PRD83, 076006, 2011

We also consider non-parametric GPD modelling in (x, ξ)-space, see our paper
The drawback of this modelling is that one can not keep PDF singularity for only x=0 and ξ=0

Modelling in (β, α)-space

H. Dutrieux et al.,
Eur. Phys. J. C 82 (2022) 3, 252

Double distribution:

$$(1-x^2)F_C(\beta,\alpha) + (x^2-\xi^2)F_S(\beta,\alpha) + \xi F_D(\beta,\alpha)$$

Classical term:

$$F_C(\beta,\alpha) = f(\beta)h_C(\beta,\alpha)\frac{1}{1-\beta^2}$$

$$f(\beta) = \mathrm{sgn}(\beta)q(|\beta|)$$

$$h_C(\beta,\alpha) = \frac{\mathrm{ANN}_C(|\beta|,\alpha)}{\int_{-1+|\beta|}^{1-|\beta|} \mathrm{d}\alpha \mathrm{ANN}_C(|\beta|,\alpha)}$$

Shadow term:

$$F_S(\beta,\alpha) = f(\beta)h_S(\beta,\alpha)$$

$$f(\beta) = \mathrm{sgn}(\beta)q(|\beta|)$$

$$h_S(\beta,\alpha)/N_S = \frac{\mathrm{ANN}_S(|\beta|,\alpha)}{\int_{-1+|\beta|}^{1-|\beta|} \mathrm{d}\alpha \mathrm{ANN}_S(|\beta|,\alpha)} - \frac{\mathrm{ANN}_{S'}(|\beta|,\alpha)}{\int_{-1+|\beta|}^{1-|\beta|} \mathrm{d}\alpha \mathrm{ANN}_{S'}(|\beta|,\alpha)}.$$

$$\mathrm{ANN}_{S'}(|\beta|,\alpha) \equiv \mathrm{ANN}_C(|\beta|,\alpha)$$

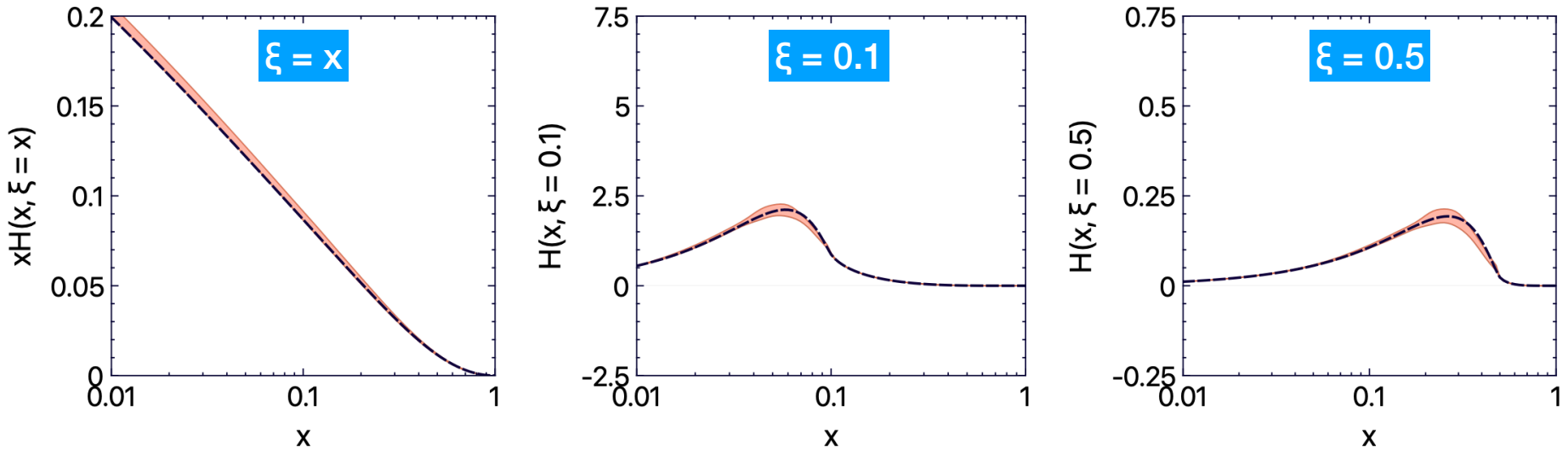
D-term:

$$F_D(\beta,\alpha) = \delta(\beta)D(\alpha)$$

$$D(\alpha) = (1-\alpha^2)\sum_{\substack{i=1 \\ \mathrm{odd}}} d_i C_i^{3/2}(\alpha)$$

Demonstration of results

H. Dutrieux et al.,
Eur. Phys. J. C 82 (2022) 3, 252



Conditions:

- Input: 400 $x \neq \xi$ points generated with GK model
- Positivity not forced

Technical detail of the analysis:

- Minimisation with genetic algorithm
- Replication for estimation of model uncertainties
- "Local" detection of outliers
- Dropout algorithm for regularisation

GK

ANN model
68% CL
$F_C + F_S + F_D$

Summary

- Members of QCD group has recognised expertise in studying both saturation effects and hadronic structures in the language of GPDs

- Activities of the group include elements of:
  - theory
  - phenomenology (topic stressed today)
  - experimental physics

  and they consist of coherent research programme

- QCD group is engaged in the project of Electron-Ion Collider (EIC) that will be build in US (note e.g. Epiphany'22 conference and EICUG'22 meeting)