Nucleon tomography from lattice QCD data

CAUTION:
PRELIMINARY RESULTS

Paweł Sznajder
National Centre for Nuclear Research, Poland

in collaboration with M. Constantinou, K. Cichy and J. Wagner

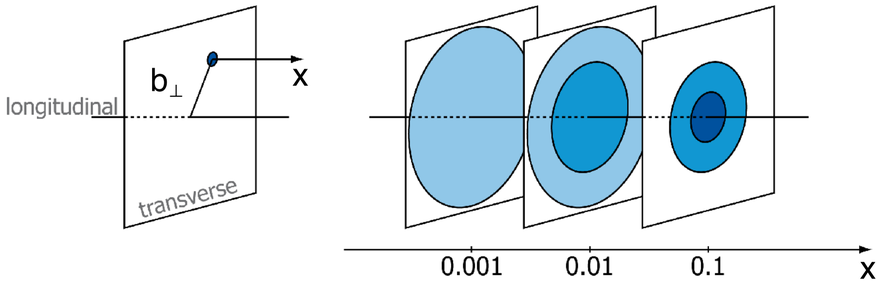
NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

Towards improved hadron tomography with hard exclusive reactions,
Trento, Italy, August 7th, 2024

Introduction

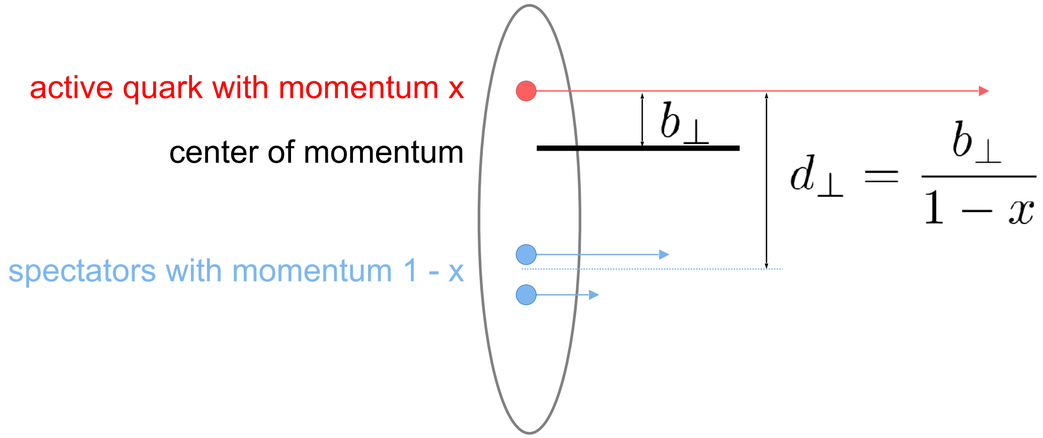
- Nucleon tomography

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



- Study of long. polarization with GPD $\tilde{H}$
- Study of distortion in transv. polarized nucleon with GPD E

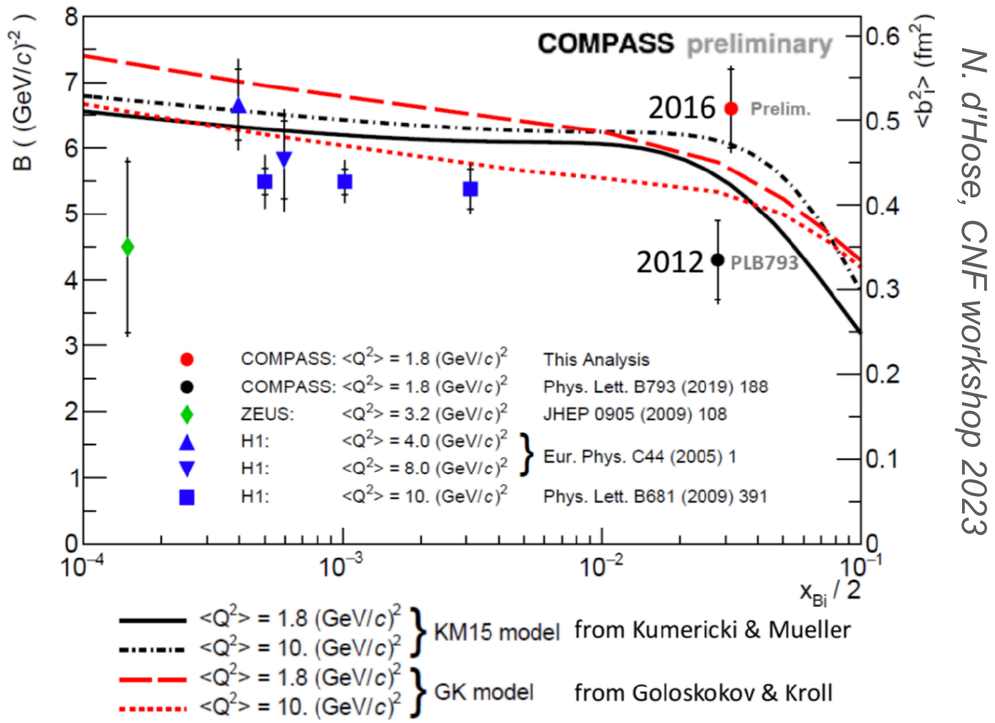
- Impact parameter $\mathbf{b}_\perp$ defined w.r.t. center of momentum, such as $\sum x\,\mathbf{b}_\perp = 0$



What do we know about nucleon tomography now?

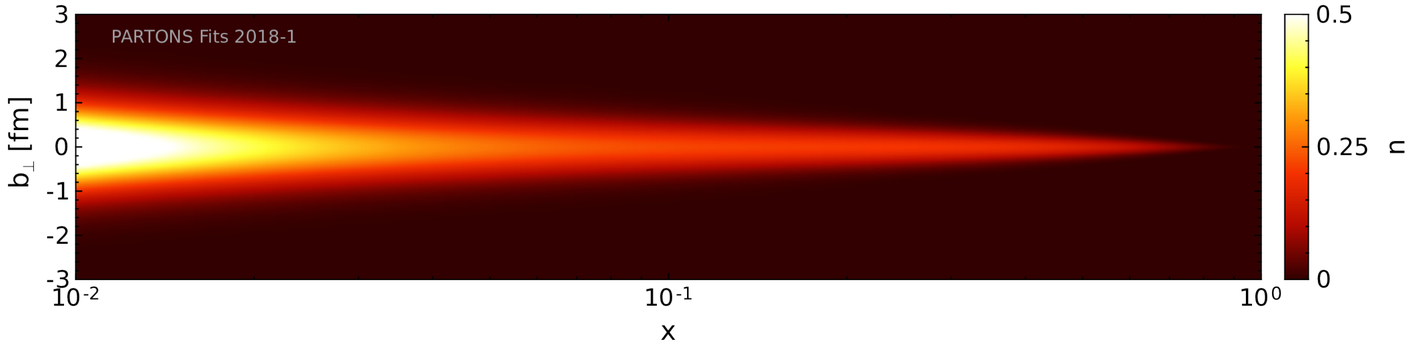
- "direct" extraction of nucleon tomography information
  (i.e. directly from DVCS cross-section, only applicable at small xB)

$$\mathrm{d}^3\sigma/(\mathrm{d}x_{\mathrm{Bj}}\,\mathrm{d}Q^2\,\mathrm{d}t) \propto (\mathrm{Im}\mathcal{H}(\xi,t))^2 \propto \left(\sum e_q^2 H^{q(+)}(\xi,\xi,t)\right)^2$$
$$\propto \left(\sum_q e_q^2 H^{q(+)}(\xi,0,t)\right)^2$$

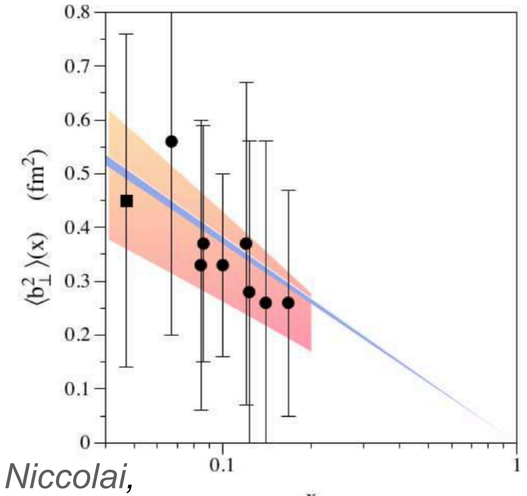


N. d'Hose, CNF workshop 2023

- extraction involving all types of contributing CFFs
  (requires "de-skewness", allows to use high xB data)



H. Moutarde, PS, J. Wagner, EPJC 78 (2018), 890



Dupré, Guidal, Niccolai, Vanderhaeghen, EPJA 53 (2017), 171

Dictionary

- GPDs in Ioffe time: $$\hat{H}(\nu,\xi,t) = \int_{-1}^{1} \mathrm{d}x\, e^{ix\nu} H(x,\xi,t)$$

- Single and non-singlet combinations of GPDs

$$H^{(+)}(x,\xi,t) = H(x,\xi,t) - H(-x,\xi,t)$$

$$H^{(-)}(x,\xi,t) = H(x,\xi,t) + H(-x,\xi,t)$$

at ξ=0:

$$H^{(+)}(x,0,t) = H_{\mathrm{val}}(x,0,t) + 2H_{\mathrm{sea}}(x,0,t)$$

$$H^{(-)}(x,0,t) = H_{\mathrm{val}}(x,0,t)$$

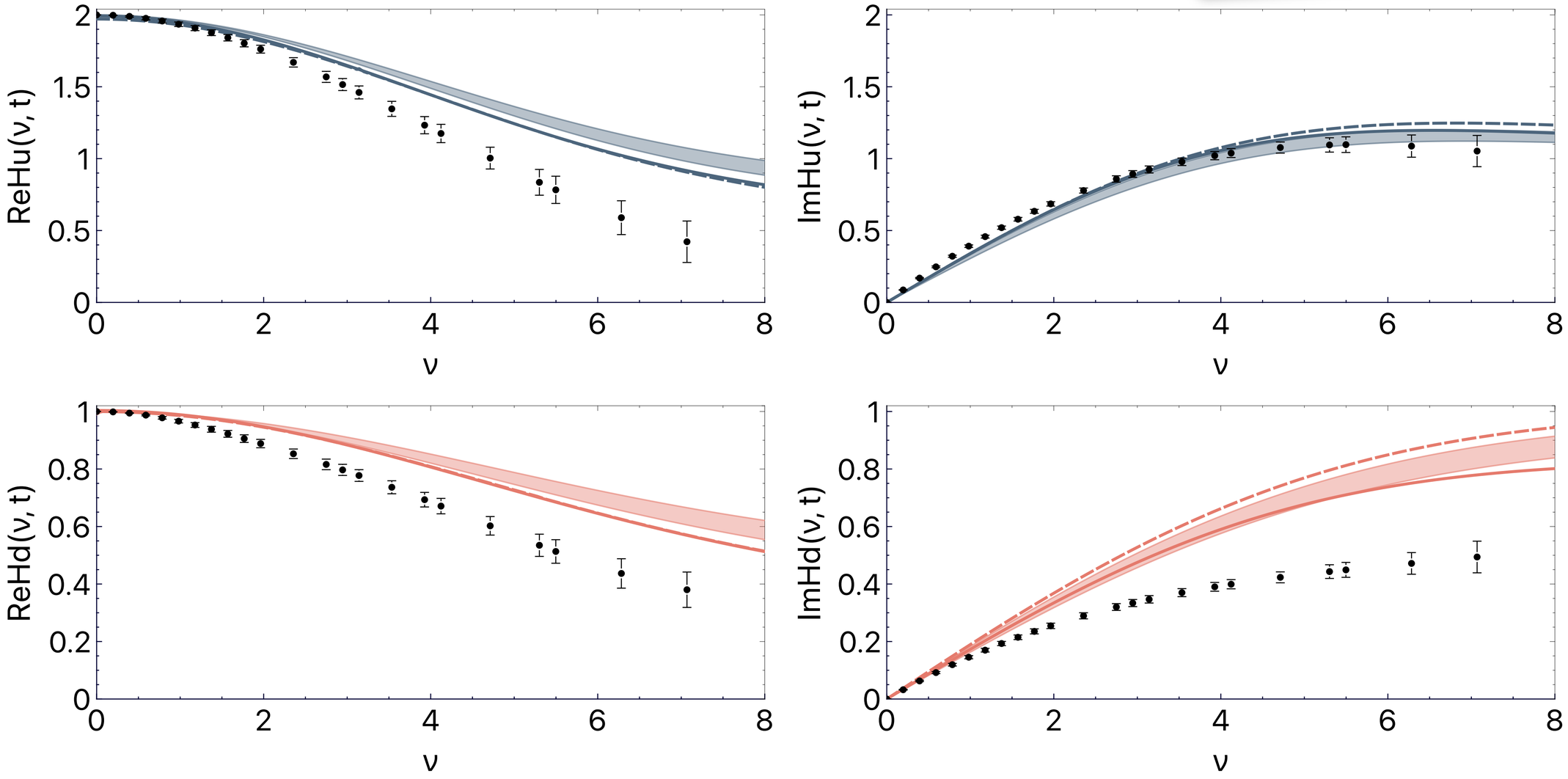
- therefore:

$$\mathrm{Re}\hat{H}(\nu,\xi,t) = \int_{0}^{1} \mathrm{d}x\ \cos(x\nu) H^{(-)}(x,\xi,t)$$

$$\mathrm{Im}\hat{H}(\nu,\xi,t) = \int_{0}^{1} \mathrm{d}x\ \sin(x\nu) H^{(+)}(x,\xi,t)$$

Lattice-QCD data

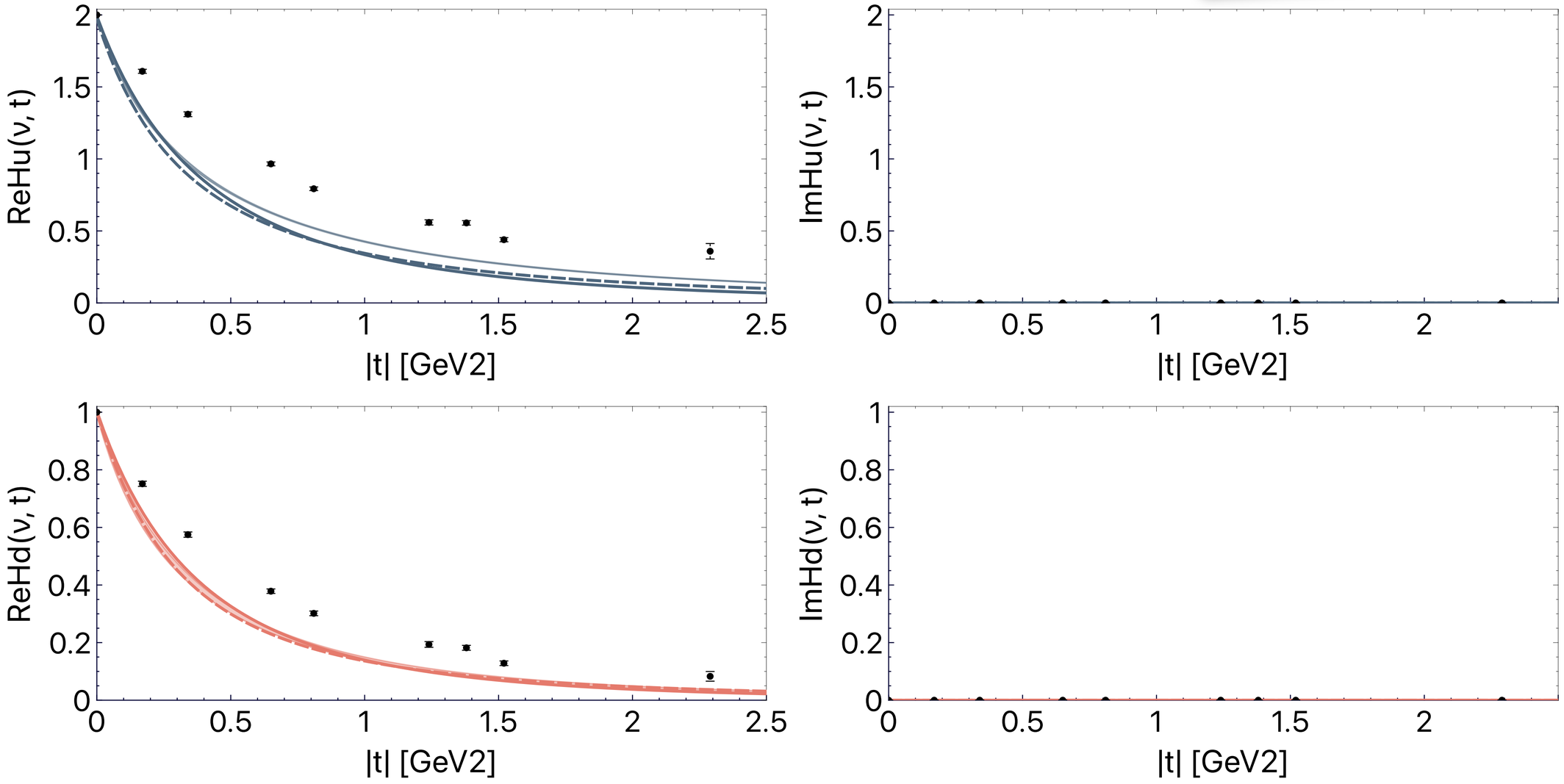
GPD H, t=0



- For details on these latticeQCD data see Krzysztof's talk

Lattice-QCD data

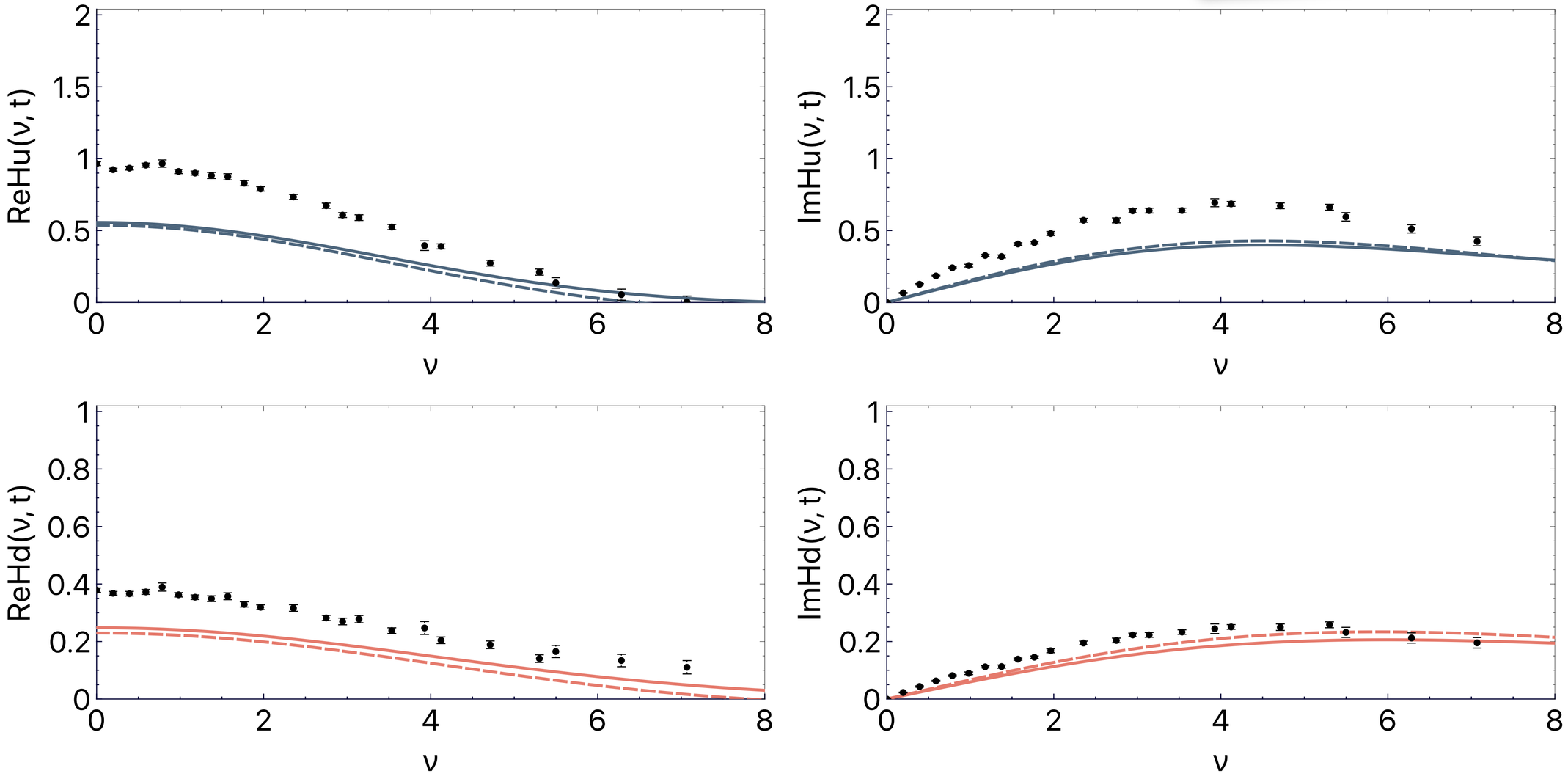
GPD H, ν=0



- For details on these latticeQCD data see Krzysztof's talk

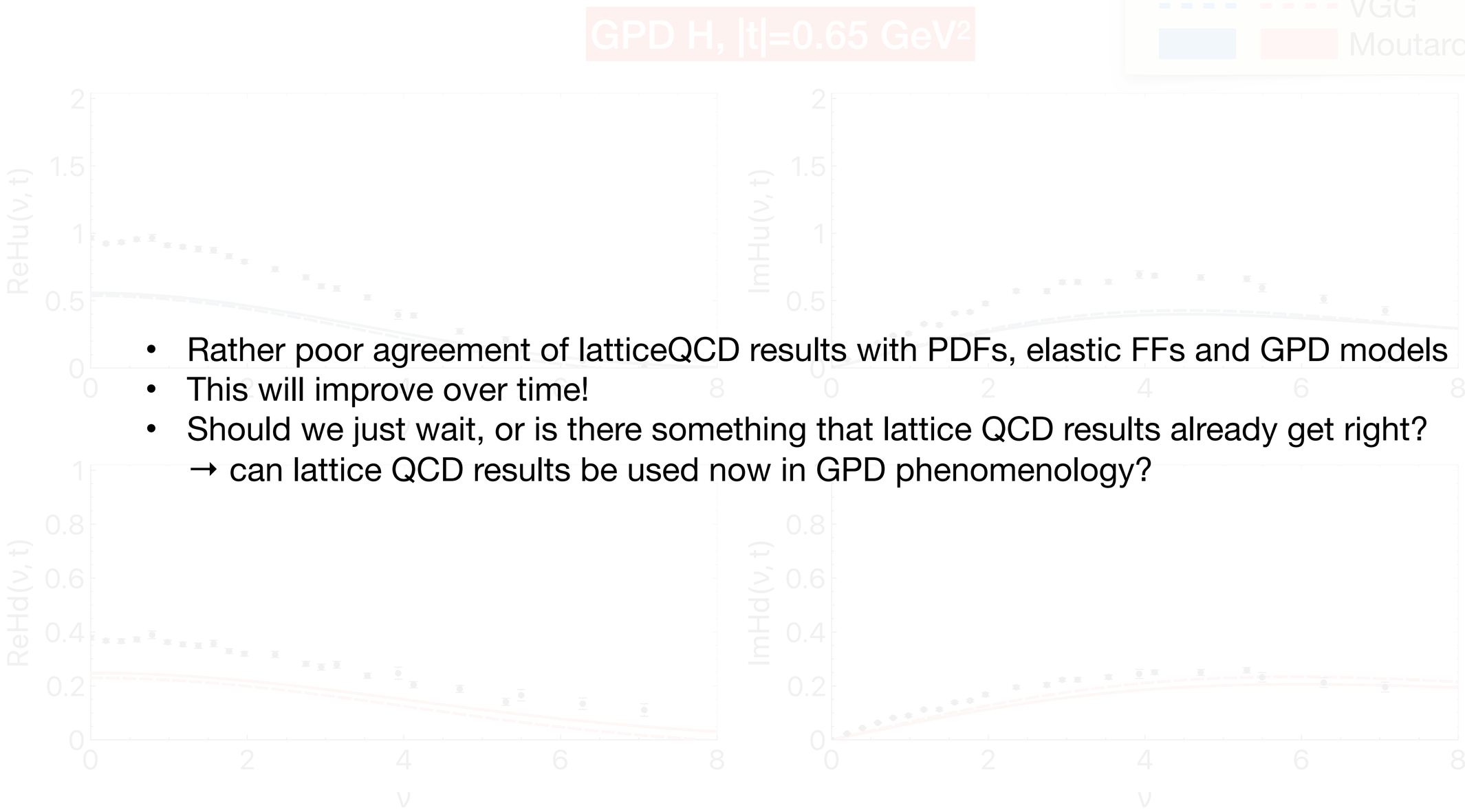
Lattice-QCD data

GPD H, $|t|=0.65\ \mathrm{GeV}^2$



- For details on these latticeQCD data see Krzysztof's talk

Lattice-QCD data

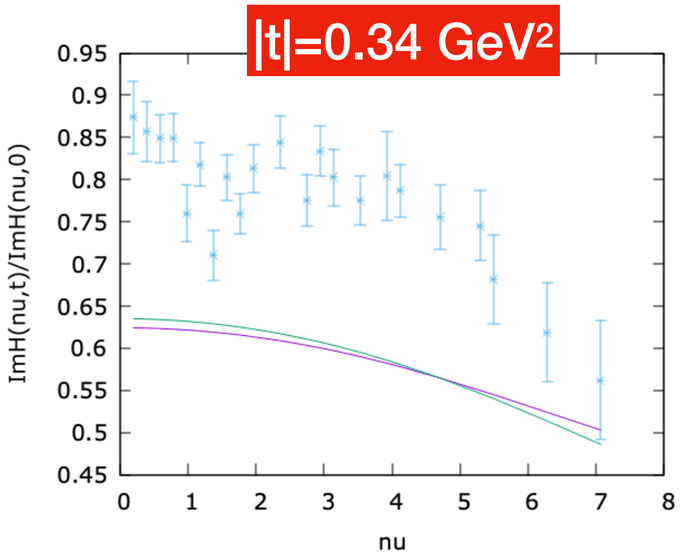


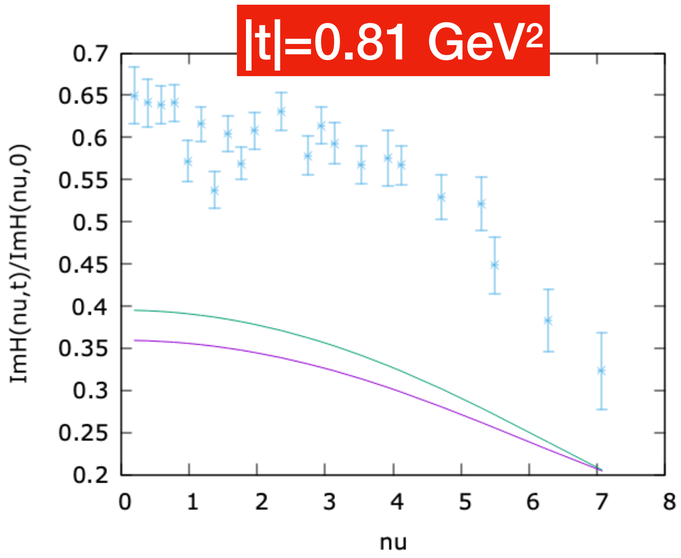
- Rather poor agreement of latticeQCD results with PDFs, elastic FFs and GPD models
- This will improve over time!
- Should we just wait, or is there something that lattice QCD results already get right?
  → can lattice QCD results be used now in GPD phenomenology?

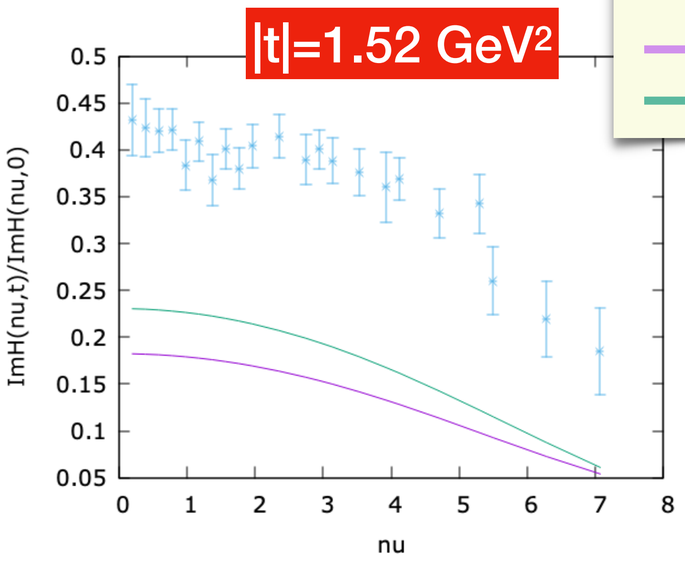
- For details on these latticeQCD data see Krzysztof's talk

Double ratio

$$\mathrm{DR}_{\mathrm{Re}}(\nu,t) = \frac{\mathrm{Re}H(\nu,t)}{\mathrm{Re}H(\nu,0)}\frac{\mathrm{Re}H(0,0)}{\mathrm{Re}H(0,t)} \qquad \mathrm{DR}_{\mathrm{Im}}(\nu,t) = \lim_{\nu'\to 0}\frac{\mathrm{Im}H(\nu,t)}{\mathrm{Im}H(\nu,0)}\frac{\mathrm{Im}H(\nu',0)}{\mathrm{Im}H(\nu',t)}$$







latticeQCD
GK
VGG

- plateau of ImH(ν, t)/ImH(ν, 0) at ν = 0 maks the definition of $\mathrm{DR}_{\mathrm{Im}}$ robust
- this plateau (also seen for ReH(ν, t)) is a consequence of the restricted range of x in Fourier transform
- single ratios, here ImH(ν, t)/ImH(ν, 0), do not provide a good comparison with models

Double ratio

$$\mathrm{DR}_{\mathrm{Re}}(\nu,t) = \frac{\mathrm{Re}H(\nu,t)}{\mathrm{Re}H(\nu,0)}\frac{\mathrm{Re}H(0,0)}{\mathrm{Re}H(0,t)} \qquad \mathrm{DR}_{\mathrm{Im}}(\nu,t) = \lim_{\nu'\to 0}\frac{\mathrm{Im}H(\nu,t)}{\mathrm{Im}H(\nu,0)}\frac{\mathrm{Im}H(\nu',0)}{\mathrm{Im}H(\nu',t)}$$

$$\mathrm{Re}H(\nu,t) = \mathrm{ReH}(0,0) \times \frac{\mathrm{ReH}(\nu,0)}{\mathrm{ReH}(0,0)} \times \frac{\mathrm{ReH}(0,t)}{\mathrm{ReH}(0,0)} \times \mathrm{DR}_{\mathrm{Re}}(\nu,t)$$

norm:
2 for H^u
1 for H^d

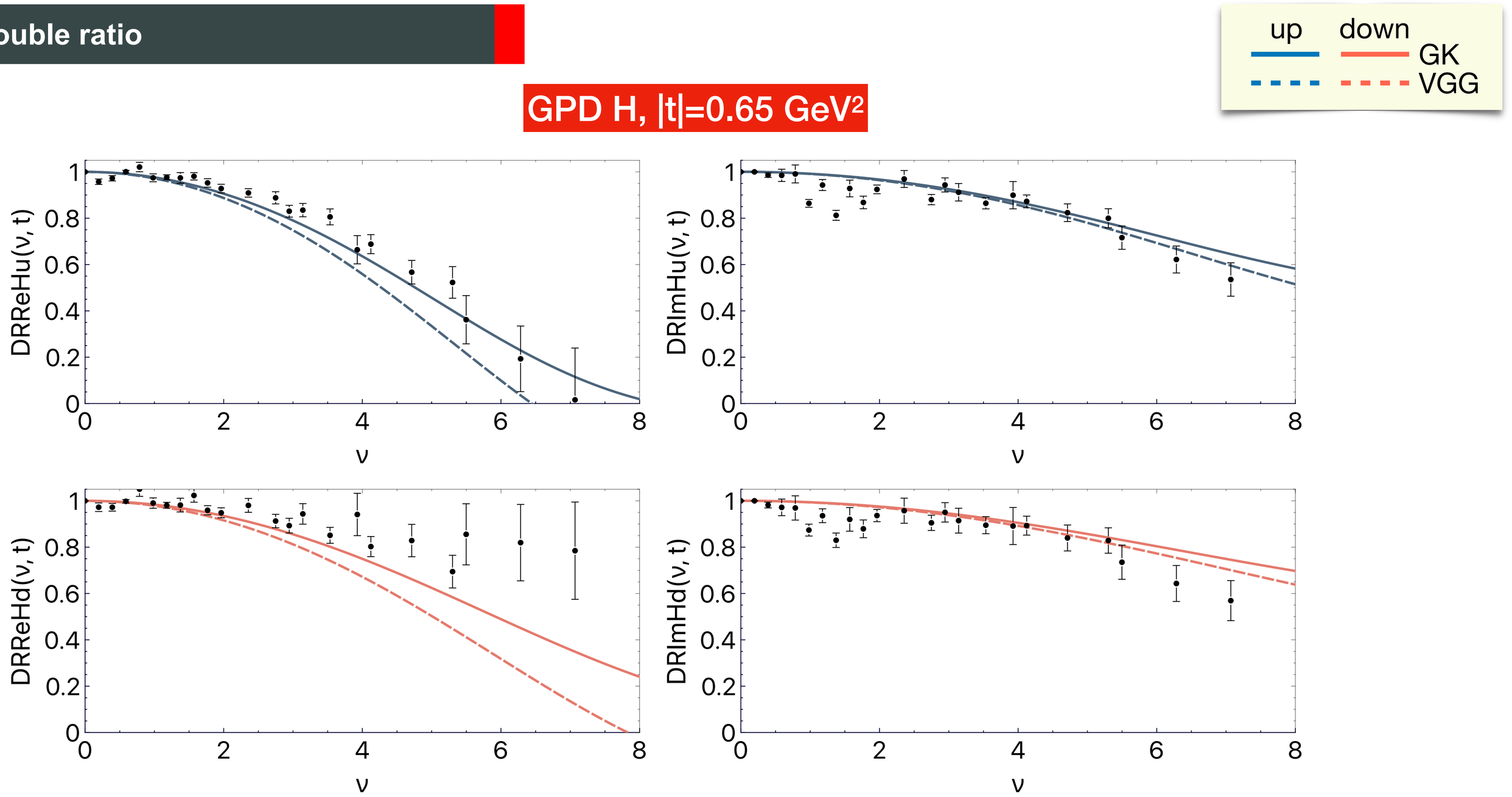
normalised PDF

normalised elastic FF

correlation

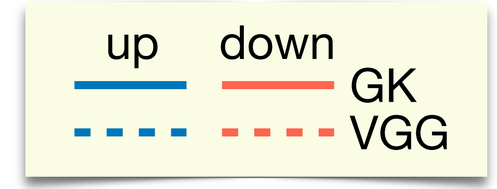
- double ratio describes deviation of H(ν,t) from factorised Ansatz: H(ν,t)=q(ν)F(t)/norm
- elastic FF not defined for imaginary part
- forward limit of GPD E not probed by (semi-)inclusive scattering

Double ratio

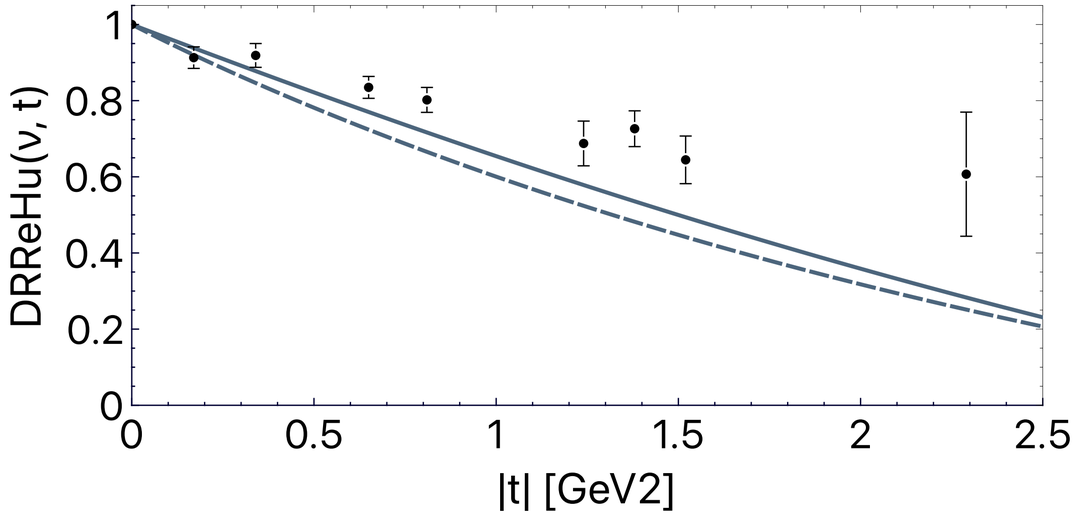


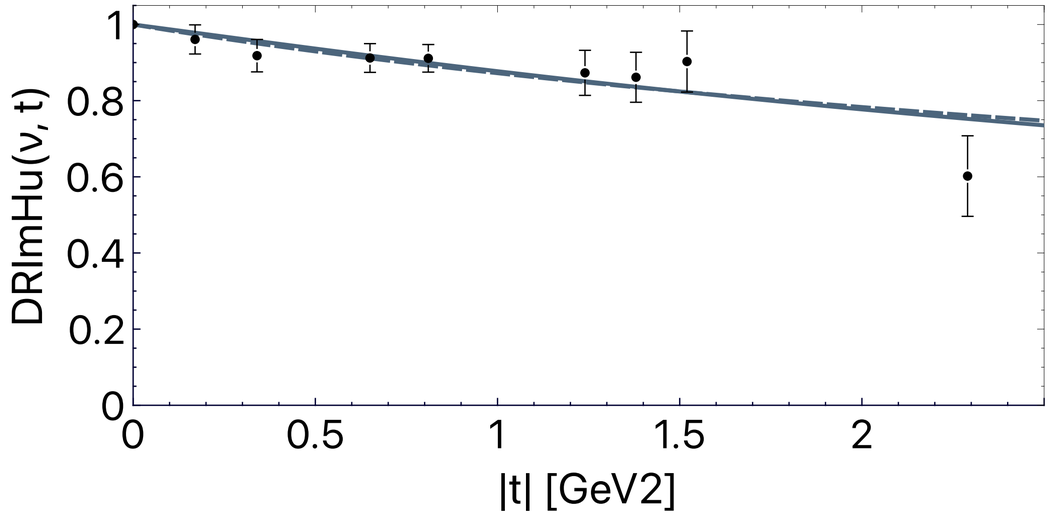
- double ratios evaluated from latticeQCD results comparable with models!

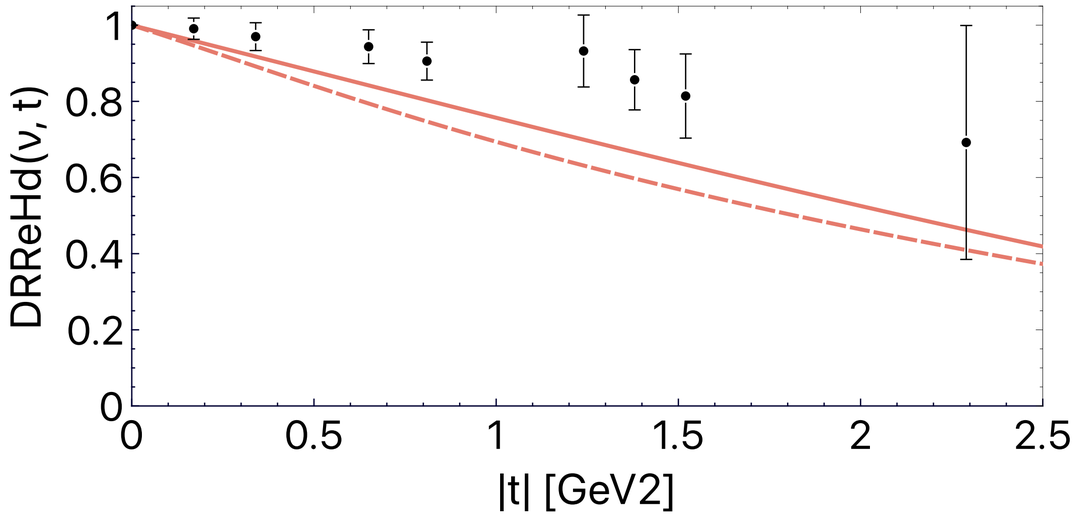
Double ratio

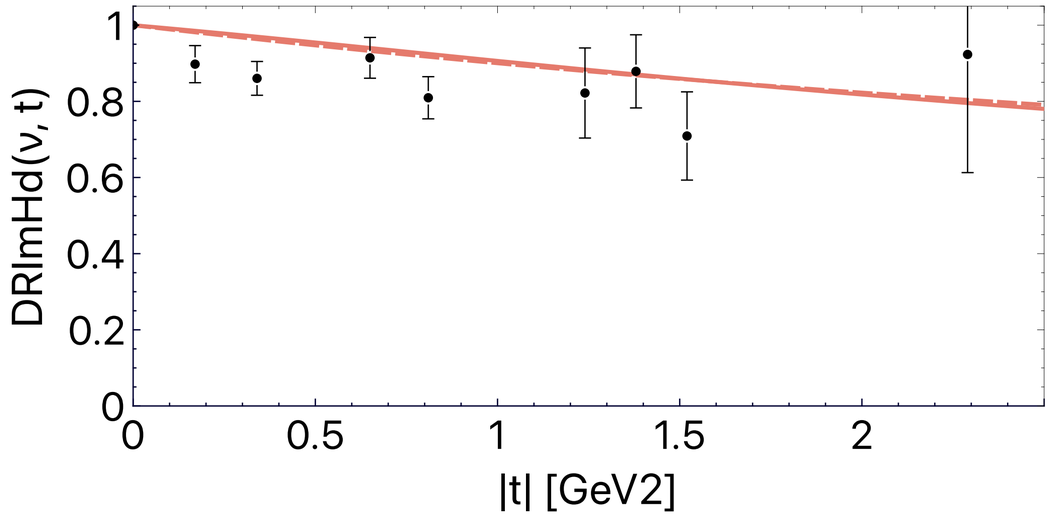


GPD H, ν=3.14









- double ratios evaluated from latticeQCD results comparable with models!

Nucleon tomography - analysis strategies

Constraints:

$$H(x,0) = q(x)$$

$$\int_{-1}^{1} \mathrm{d}x\, H(x,t) = F(t)$$

$$\lim_{x\to 1} \frac{\mathrm{d}}{\mathrm{d}t} H(x,t) = 0$$

$$\lim_{x\to 1} \frac{\mathrm{d}}{\mathrm{d}t} \int_{0}^{\infty} \mathrm{d}\nu\, H(b,t)\cos(x\,b) = 0$$

Strategy A:

Ansatz: $H(\nu,t) = q(\nu)F(t)\mathrm{DR}(\nu,t)/\mathrm{norm}$

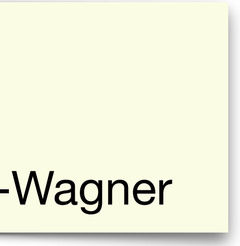
1. Chose PDF and elastic FF parameterisations
2. Fit DR(ν, t) to latticeQCD data
3. evaluate H(x,t)
4. evaluate H(x,b)

Strategy B:

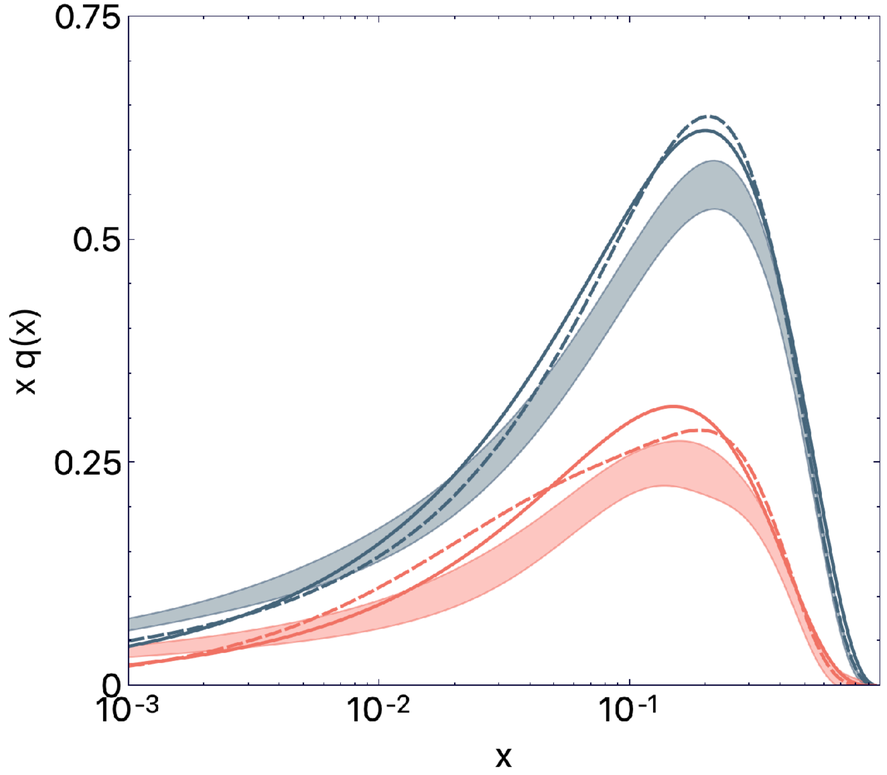
Ansatz: $H(x,t) = q(x)f(x,t)$

1. Chose PDF parameterisation
2. Fit f(x,t) to latticeQCD and elastic FF data
3. evaluate H(x,b)

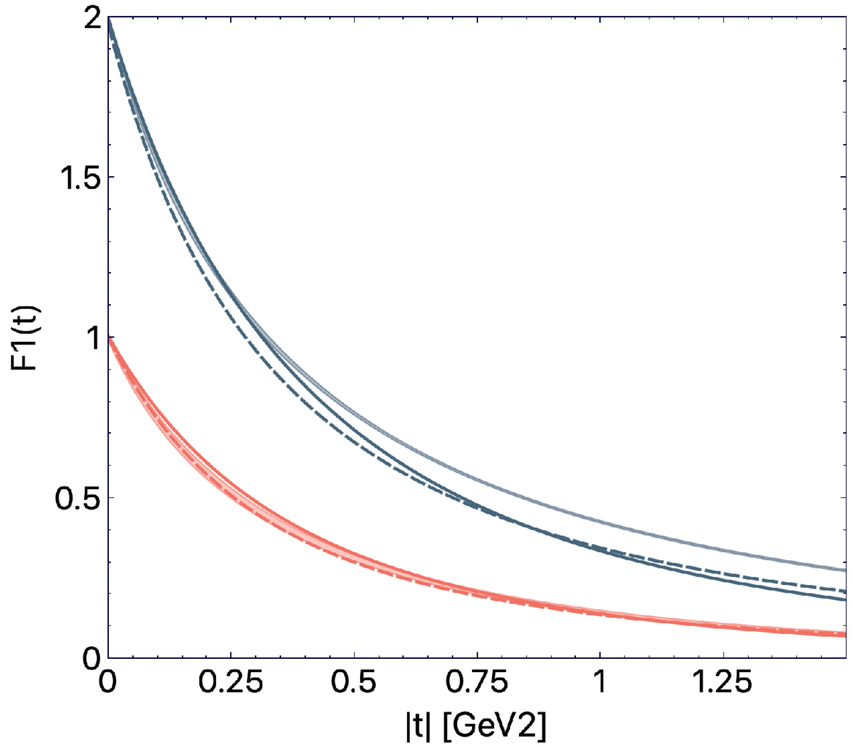
Input PDF and elastic FF



forward limit of GPD H (PDF, at μ = 2 GeV)

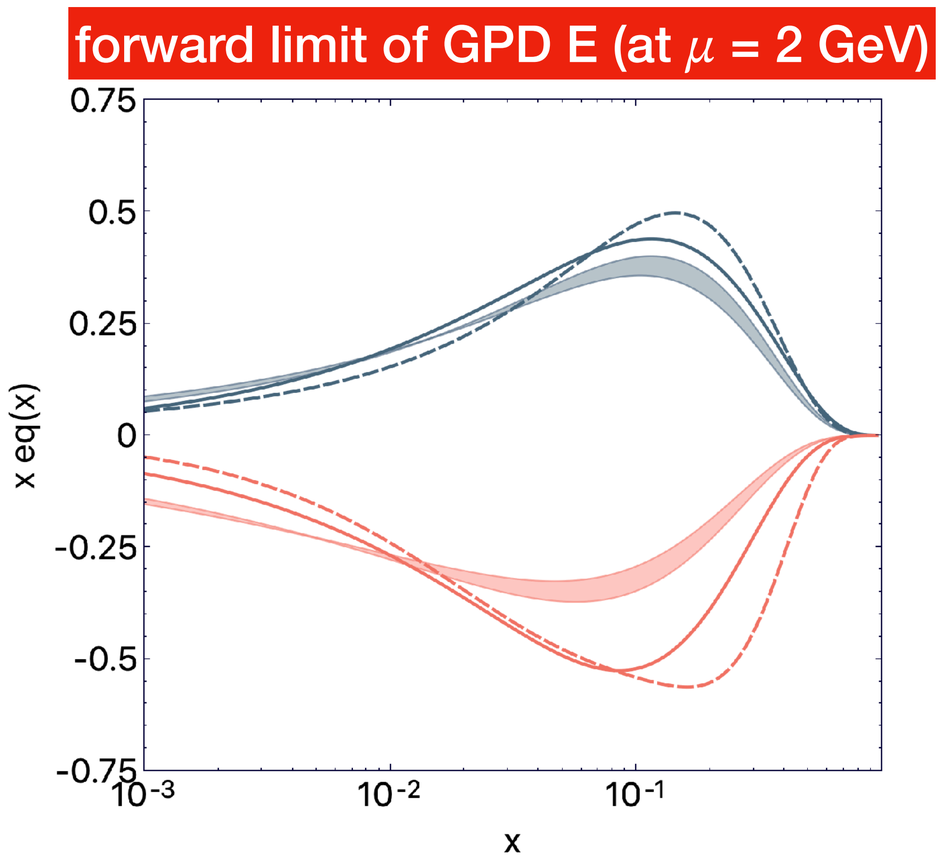


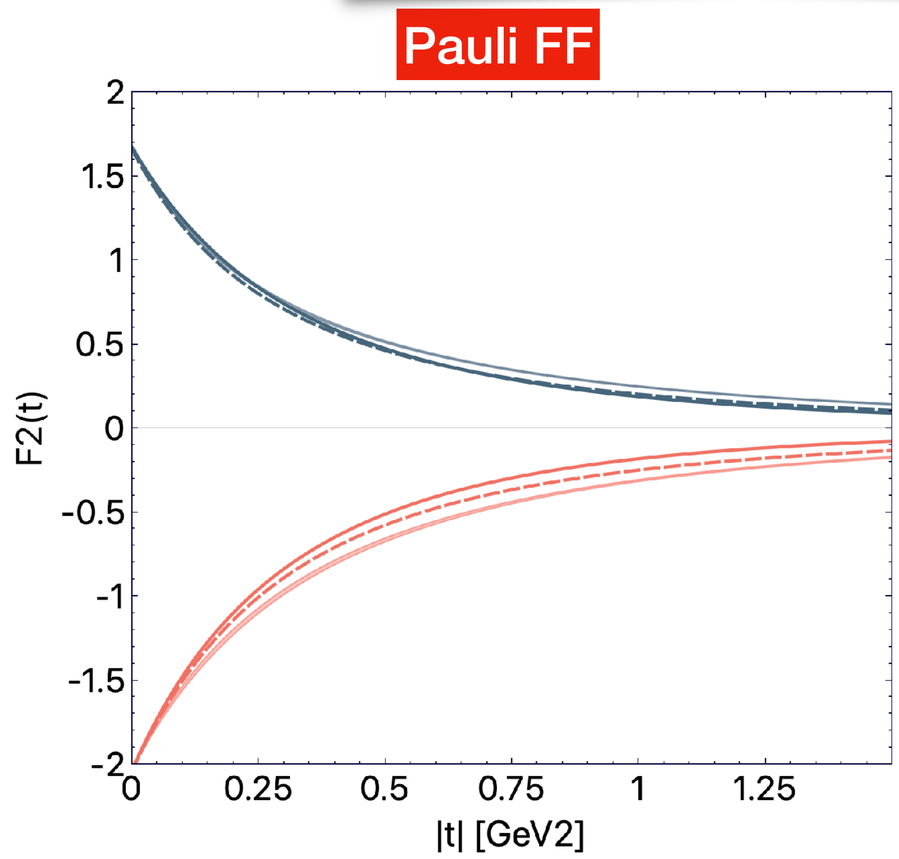
Dirac FF

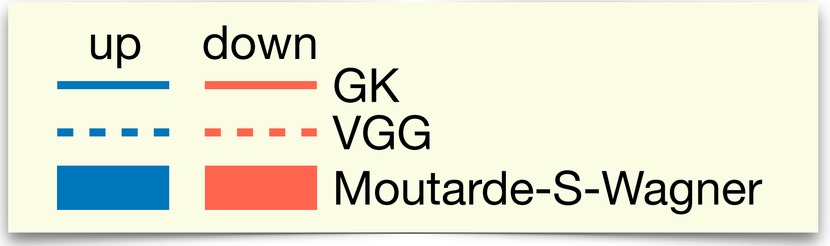


- input to the following analysis are Moutarde-S-Wagner parameterisations (EPJC 78 (2018), 890)
- these parameterisations come in a form of replica sets
- forward limit of GPD E available too

Input PDF and elastic FF

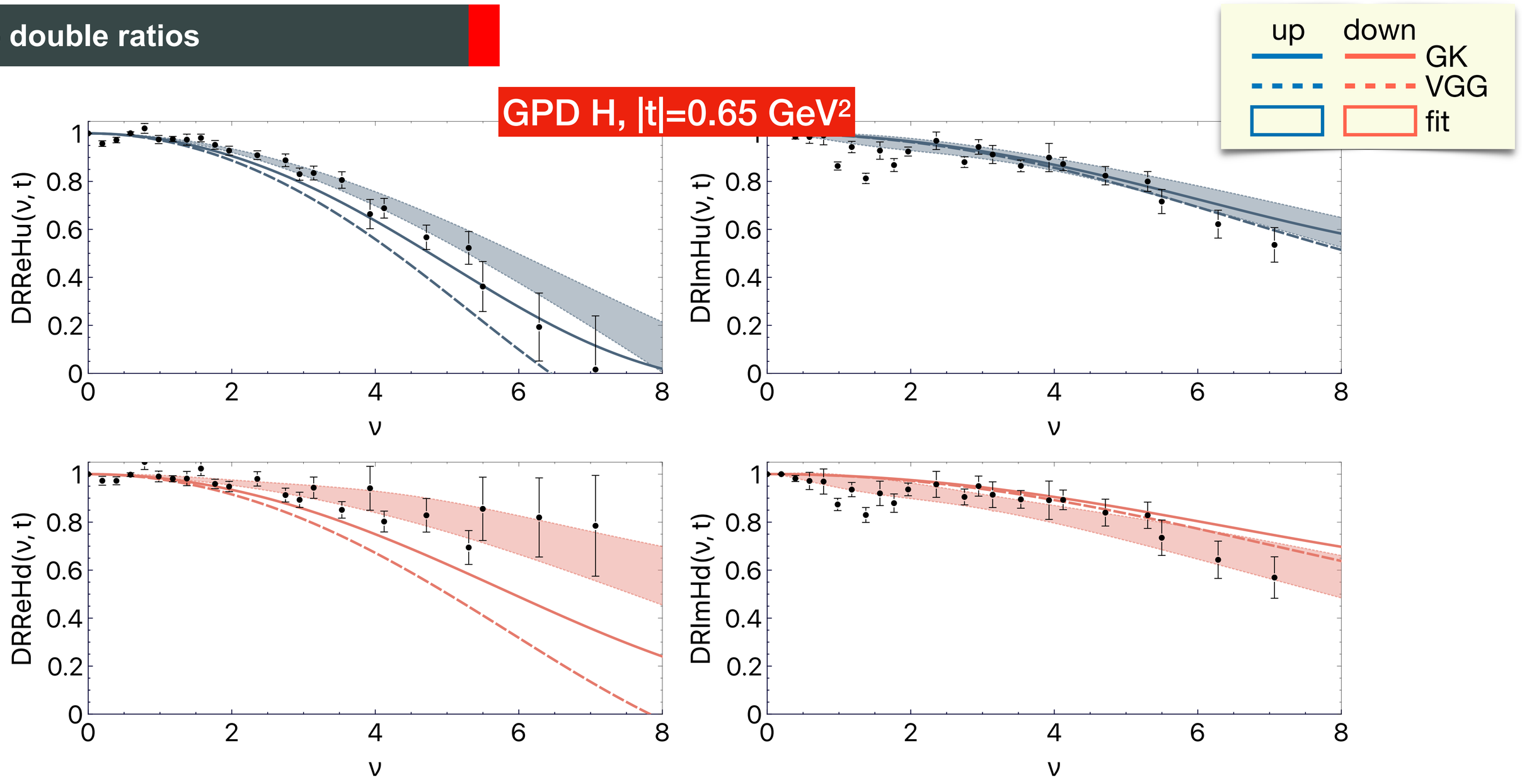






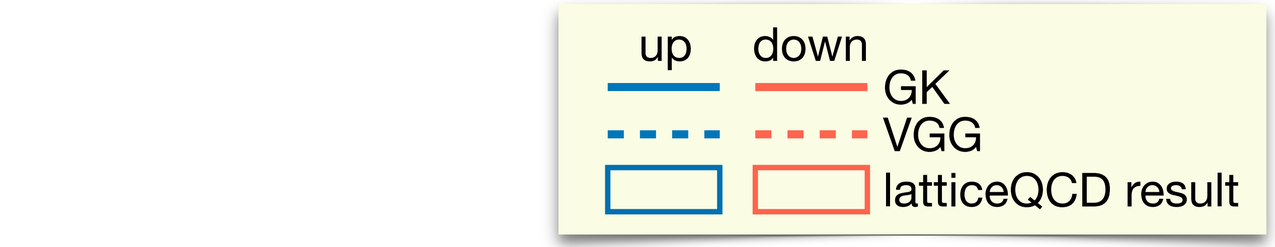
- input to the following analysis are Moutarde-S-Wagner parameterisations (EPJC 78 (2018), 890)
- these parameterisations come in a form of replica sets
- forward limit of GPD E available too

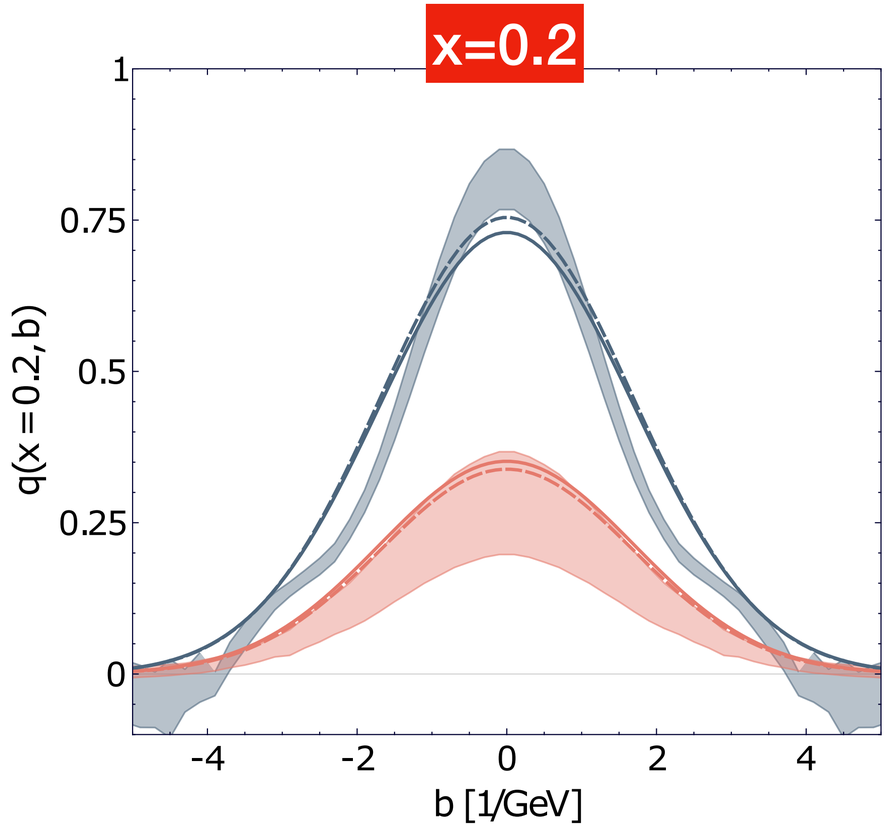
Fit to double ratios

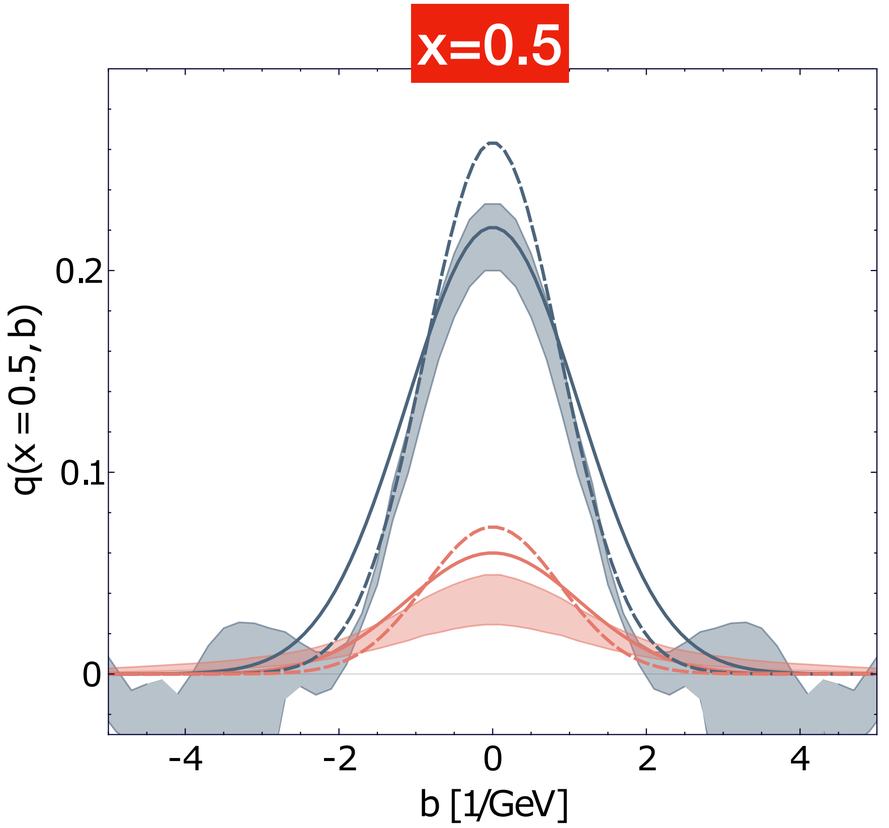


- fitting Ansatz: $\mathrm{DR}_{\mathrm{Re}}(\nu,t) = \frac{1}{\sum_i p_i} \sum_i p_i \exp(p_i' \nu^i t)$ with counter term proportional to vt to fulfil theory constraints

Nucleon tomography from latticeQCD data

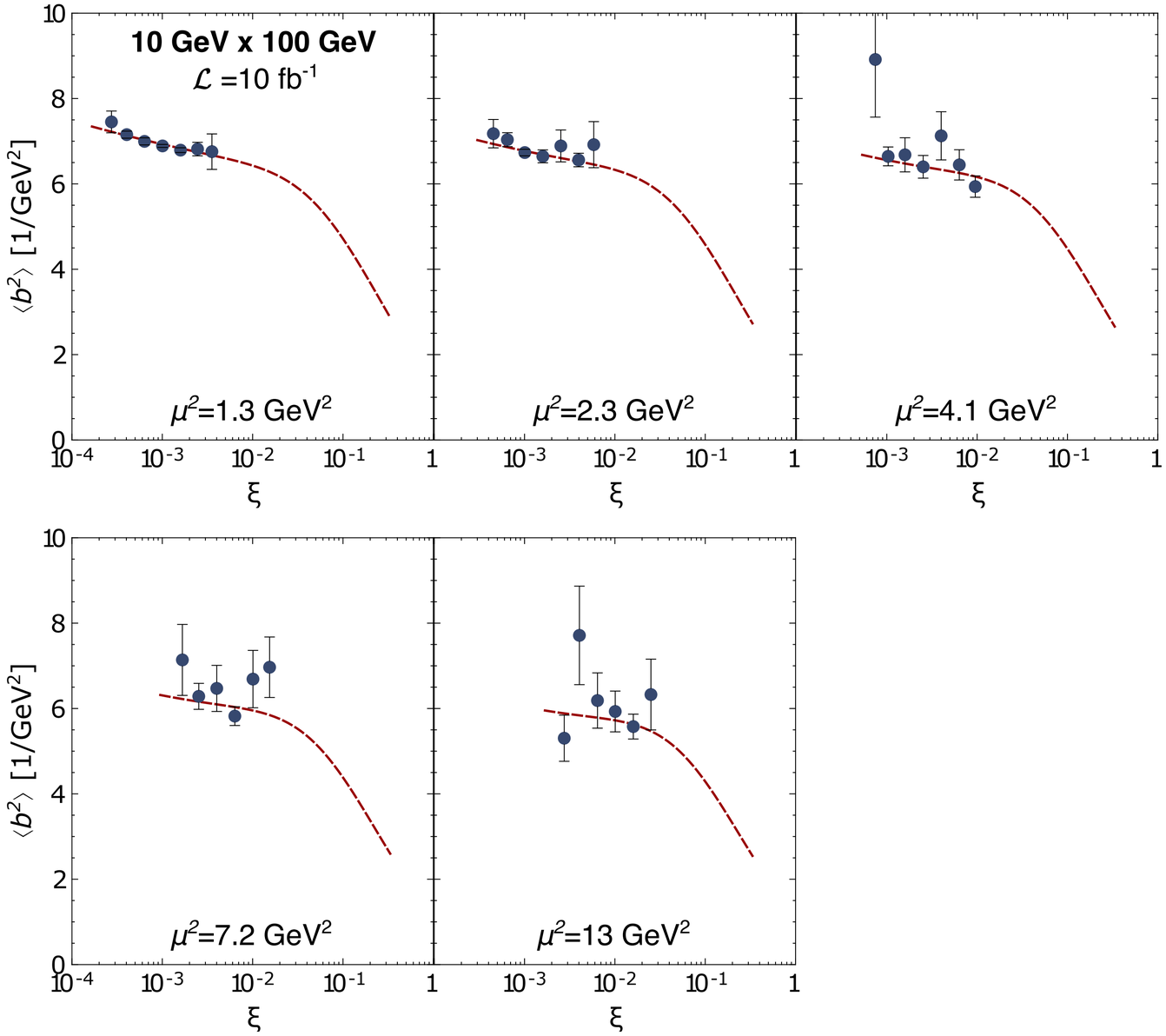






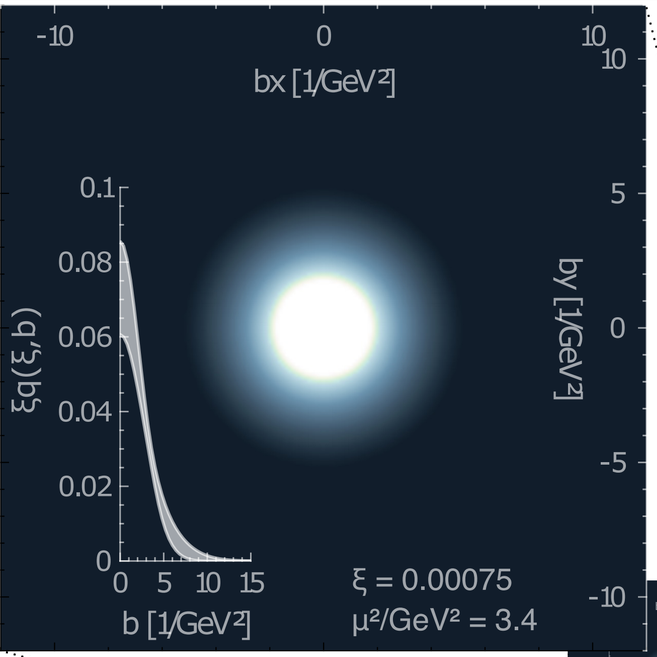
- uncertainties evaluated from latticeQCD, PDF and elasticFF replicas

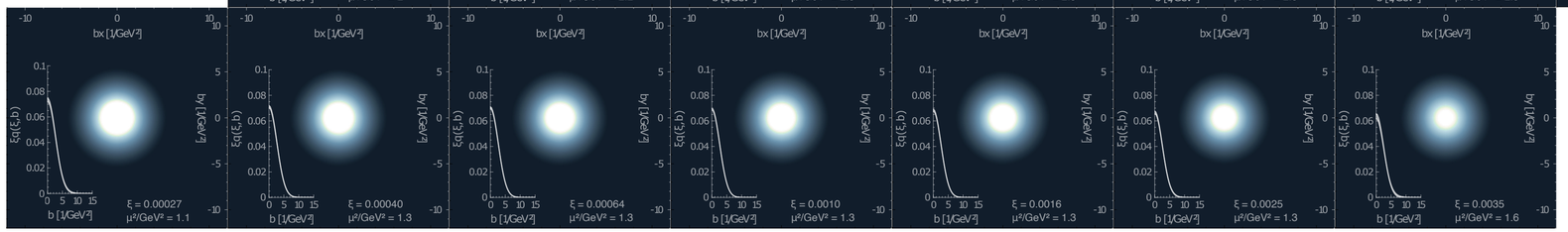
What about the sea?

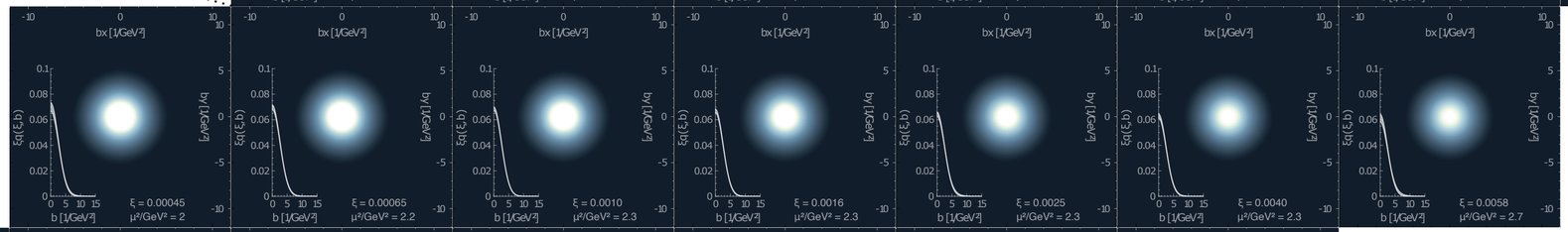


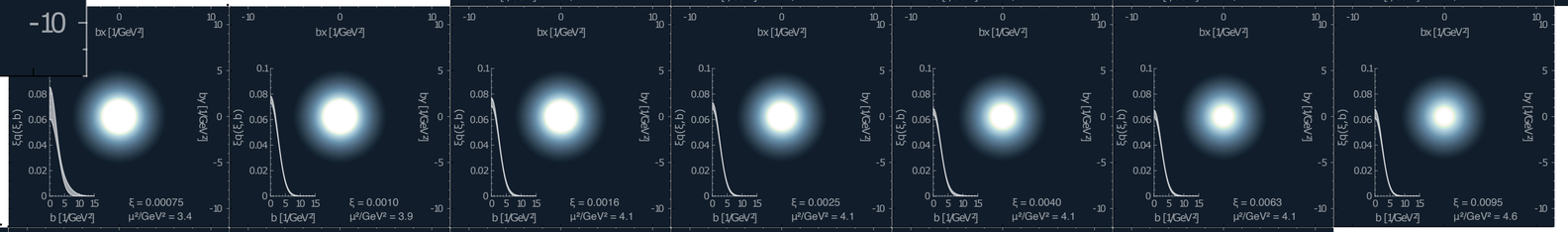
- new projections for DVCS at EIC (ePIC) by E. C. Aschenauer, V. Batozskaya, S. Fazio, A. Jentsch, K. Kumerički, H. Moutarde, K. Passek-K., D. Sokhan, H. Spiesberger, PS, K. Tezgin
- analysis based on EpIC MC generator and state-of-the-art description of ePIC apparatus
- includes projections for basic kinematic distributions, estimation of pi0 background and RC effects, extraction of nucleon tomography and Compton FFs
- analysis to be released soon
- see also Alex and Krešimir's talks

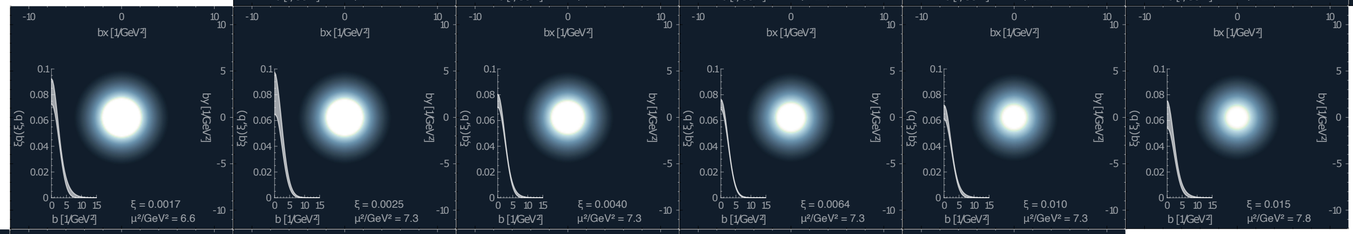
What about the sea?

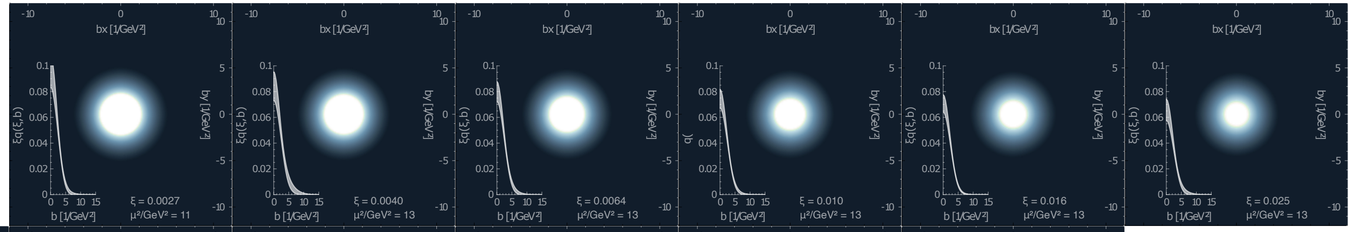


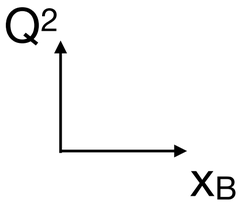












Summary

- double ratio seems to be a good quantity to be used in global fits
  → a lot of systematics cancels out
- first (still preliminary) extraction of nucleon tomography information using this quantity ready
- complementary to the extraction from data!