Results on DVCS

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Generalized Parton Distributions

• GPDs encode the non perturbative structure of the nucleon
  

  – 4 GPDs are needed to describe the nucleon, they depend on x, \( \xi \) and t
    • Can be flavored decomposed and extended to gluon
  – The GPDs \( H \) and \( E \) can be directly linked to the angular momentum
  – GPDs can be translated into a tomographic image of the proton

• They can be extracted from exclusive processes
  – Factorization has been demonstrated
  – But these processes have small cross sections
  – Deep Virtual Meson Production (DVMP)
    • Possible with many final states but with more theoretical issues
  – Deep Virtual Compton Scattering (DVCS)
    • Simplest process that interfere with Bethe-Heitler to give larger cross sections and spin asymmetries

• Often these exclusive processes only give access to CFFs
  – The 4 complex CFFs intervene as 8 free parameters in the calculation of the various observables
First Measurement at JLab

- **First JLab DVCS Beam Spin Asymmetries**
  - In Hall B by the CLAS collaboration
  - Using the existing setup only a very small phase space was accessible, but it provided the proof that strong asymmetries are accessible at JLab energies
    
    S. Stepanyan et al. (CLAS Coll.) PRL 87, 182002 (2001)

- **Triggered important experimental efforts**
  - Construction of dedicated calorimeters for Hall A and B (CLAS)
  - Start of a large program to measure spin asymmetries and cross sections in both Hall-A and Hall-B (CLAS Coll.)
DVCS in Hall A

- **First measurement of absolute cross sections of DVCS**
  - Provided very high precision data in few bins
    

- **Tested the scaling behavior with $Q^2$**
  - Surprisingly enough it works well at JLab energy
  - Apparently, higher twist effects are not that strong

- **Final full results recently made available**
  - Solved some of the discrepancies between data sets

• CLAS Published first Beam Spin Asymmetries
  – Covers a much larger phase space

• Now cross sections are also available
  – Should allow the extraction of Im(H)
  – Amount of data reached the critical limit for extraction of proton tomography
CLAS also measured DVCS on a longitudinally polarized target

- Measurement of the longitudinal Target Spin asymmetries (lTSA) and Double Spin Asymmetries (DSA)
- Should give an insight into other CFFs $\rightarrow \text{Im}(\hat{H})$
- Reduce the number of unconstrained CFFs

S. Pisano et al. (CLAS Coll.) Phys.Rev.D 91 (2015) 052014
Extracting the 3D Map

- We performed a fit of all available data
  - HERMES and JLab
- With all the experimental effort the problem remains under-constrained
  - We need some form of model input
  - Very loose bounds on the sub-leading CFF is enough
    - We use ± 5x the VGG model predictions
- As expected adding target asymmetries constrains the Im(\hat{H})
  - And incidentally it also constrains Im(H)!
- However these data are not available for all kinematics
  - More observables would be needed to constrain E and \tilde{E}
  - Transversely polarized target for example and charge asymmetries for the real parts

\[ \Delta \sigma_{LU} \propto \sin \phi \; \text{Im}\left\{ F_1 \hat{H} + \xi (F_1 + F_2) \hat{H} - k F_2 \tilde{E} + \ldots \right\} \]
\[ \Delta \sigma_{UL} \propto \sin \phi \; \text{Im}\left\{ F_1 \hat{H} + \xi (F_1 + F_2) \left( \hat{H} + \frac{x_B}{2} \tilde{E} \right) - \xi k F_2 \tilde{E} + \ldots \right\} \]
\[ \Delta \sigma_{LL} \propto (A + B \cos \phi) \; \text{Re}\left\{ F_1 \hat{H} + \xi (F_1 + F_2) \left( \hat{H} + \frac{x_B}{2} \tilde{E} \right) + \ldots \right\} \]
\[ \Delta \sigma_{UX} \propto \sin \phi \; \text{Im}\left\{ k (F_2 \hat{H} - F_1 \tilde{E}) + \ldots \right\} \]
• Applying the local fit method to all the JLab data
  – Jlab Hall A (σ, Δσ)
  – CLAS (σ, Δσ, ITSA, DSA)

• Gives enough coverage to explore the t and \( x_B \) (→ ξ) dependence of Im(H)
  – Can be fitted with an exponential form to extract the nucleon tomography

\[
\mathcal{H}_{\text{Im}}(\xi, t) = A(\xi) e^{B(\xi)t}
\]

• Results are generally close slightly below VGG model
  – Confirms that our limits based on VGG are very conservative
Amplitude and Slope

- The A and B parameters of the fit contain all the physics
  - They are linked to density and transverse size of the nucleon
- Fitted using educated guess
  - Asymptotic behavior expectations are similar to PDFs
  - In the future with larger amount of data, models can be directly tested at this level or used to perform global fits
- The tomography of the nucleon
  - We are not there yet! We need a $\xi$ dependent correction to go from the singlet to the non-singlet distribution
  - We note that at low $x$ the correction is small and similarly described by several models
Proton Tomography

- We then obtain the tomography of the proton
  - Represented is the mean square charge radius of the proton for slices of $x$
  - Error bars reflect the unknown CFFs
    - To flatten this distribution, one would need a non-constrained CFF with very strong opposite behavior

- We observe the nucleon size shrinking with $x$

RD, M. Guidal and M. Vanderhaeghen arXiv:1606.07821
• **New view on nuclear effects**
  – GPDs offer a completely new point of view to understand the partonic structure of nuclei

• **Experimental access to completely new nuclear physics**
  – Non nucleonic degrees of freedom of the nuclei
  – Measurement of the pressure and forces in the nuclei
  – The EMC effect remain today a mystery, hadron tomography can help localize it in the nuclei


• **Nuclei allow to play with the spin**
  – The use of helium 4 greatly simplifies the problem with only 1 GPD
    • The measurement of Beam Spin Asymmetry is enough to describe this nuclei
  – Use of helium 3 and deuterium can help to understand the neutron and explore more complex spin dynamics in hadrons
DVCS on Nuclei

- Already measured at JLab (CLAS)
  - Coherent DVCS is cleanly measurable
    - Thanks to a low energy recoil detector (TPC)
    - Asymmetries are much larger than for the proton
      - Beam spin asymmetries of $\sim 35\%$
      - Easy extraction of the H CFF directly from data
        - No model assumptions needed

- The start of a new domain for GPD studies
  - Already several studies on the theory side
    - In both valence and low $x$ regions

- Perspectives
  - At 12 GeV, the higher $Q^2$ will make the situation much better on the theoretical side
  - More data can be taken in CLAS12 using the ALERT recoil detector
  - Approved by the JLab PAC in 2017
In fifteen years of experiments at JLab, we have accumulated a wide array of data
- DVCS in particular can be interpreted in term of GPDs directly
- DVMP appears more complicated but opens perspectives on transverse GPDs and gluon GPDs

We can now extract the tomography of the nucleon from these data
- Errors can be reduced by including more observables
  - Cross-sections, beam spin asymmetries, target asymmetries.. 
  - Transverse target, positron beam
- Already the $x$ dependence of the charge radius is visible

This will be completed in the near future
- In the sea region by COMPASS
- In the valence region by JLab 12
- We can go beyond in the sea region at an EIC
  - How wide the proton will get at low $x$?

What can we do to improve our picture?
- Measure many processes and observables
  - Double DVCS, Time-like CS...
  - Neutron DVCS, charge asymmetries, transverse polarized target...

This framework can be used to understand more complex hadron
- GPDs have also a word to say about the long standing questions of the partonic structure of the nuclei