



WP 23 – JRA 5 GPD-ACT: Generalized Parton Distributions

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STRONG-2020 Kick-off meeting

October 24, 2019



Università
degli Studi
di Perugia



*Institut
Ruđer
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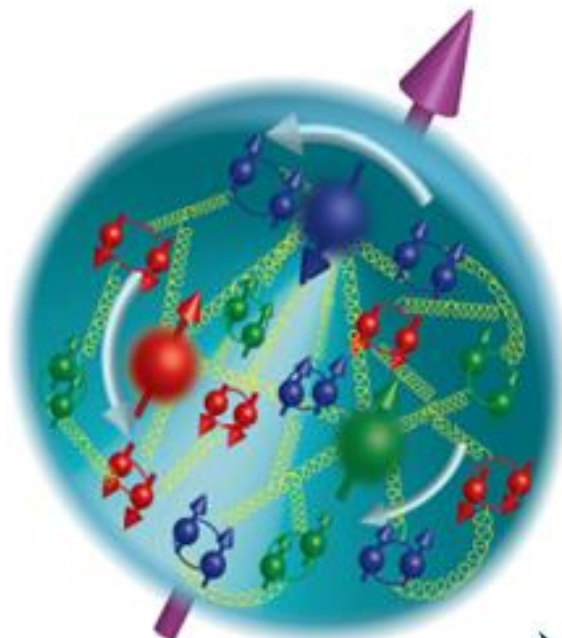
Universität
Regensburg



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Genova Ferrara Frascati



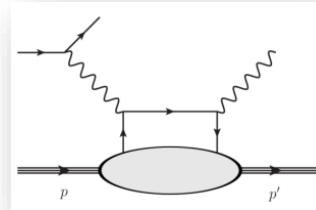
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

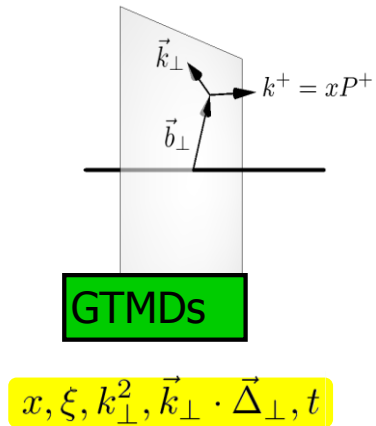
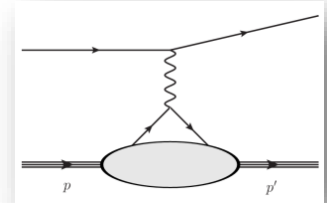
WP 23 - JRA 5 GPD-ACT: Generalized Parton Distributions

Multidimensional mapping of the nucleon

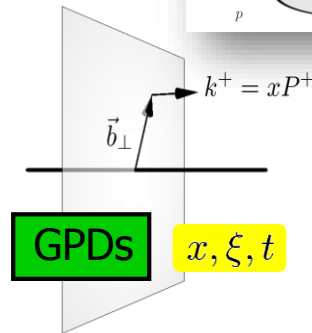
DVCS et al.



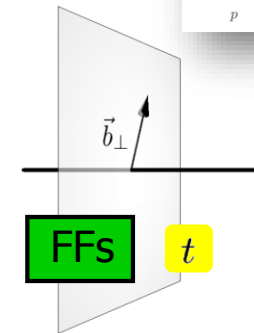
Elastic
Scattering



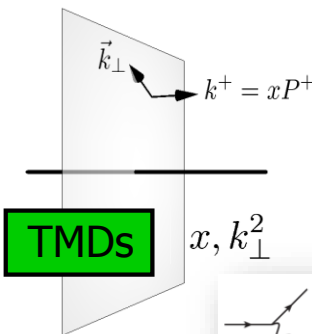
$$\int d^2 \vec{k}_{\perp}$$



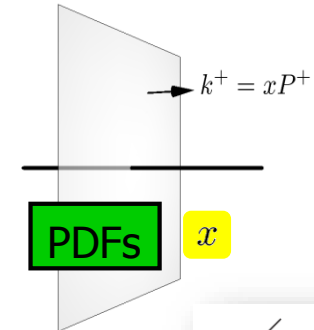
$$\int dx$$



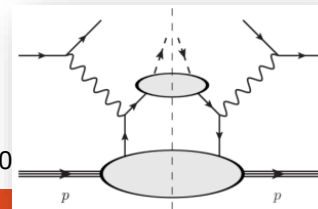
$$\int d^2 \vec{b}_{\perp}$$



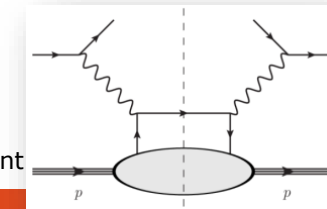
$$\int dx$$



SIDIS



DIS



A complete picture of
nucleon structure requires
the measurement of all these
distributions

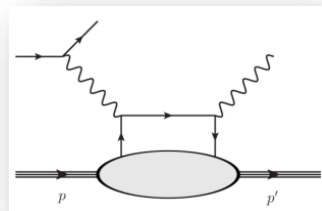
This project has received funding from the European Union's Horizon 2020

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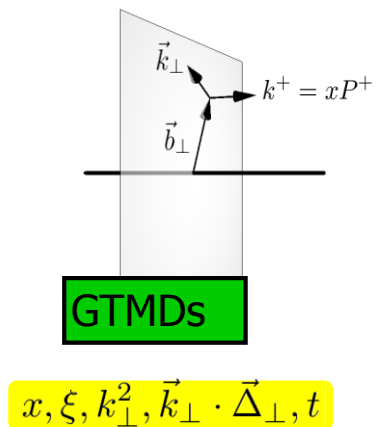
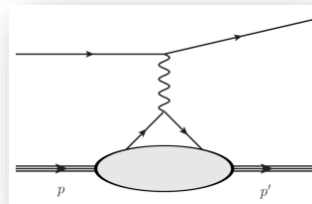
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Multidimensional mapping of the nucleon

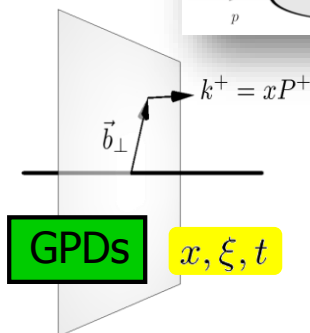
DVCS et al.



Elastic
Scattering

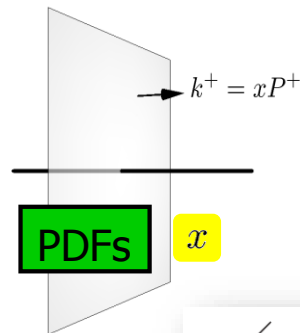
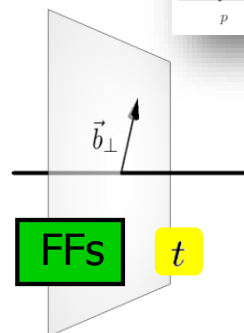


$$\int d^2 \vec{k}_{\perp}$$

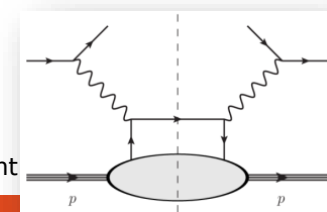


$$\int dx$$

$$\int d^2 \vec{b}_{\perp}$$



DIS

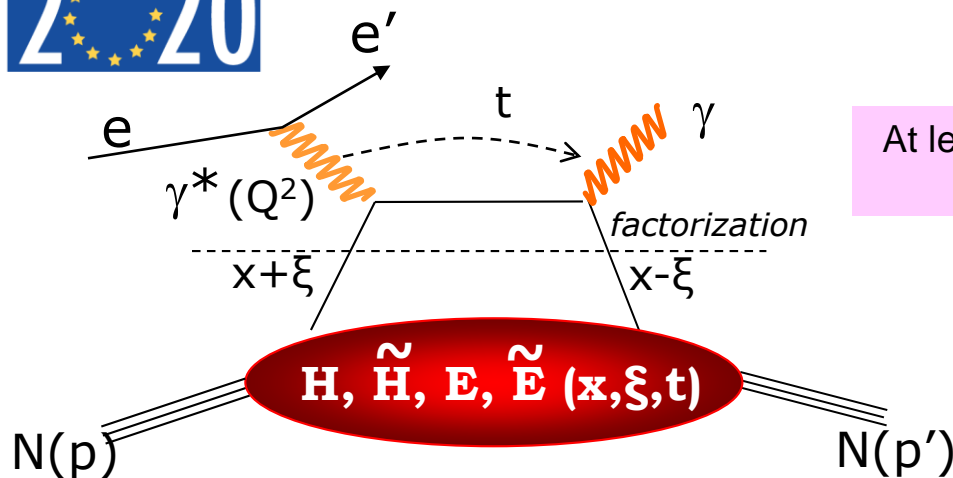


Generalized Parton Distributions:

- fully correlated parton distributions in both **coordinate** and **longitudinal momentum** space
- accessible in **hard exclusive** reactions (DVCS, DVMP, TCS,...)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant

Deeply Virtual Compton Scattering and interest of GPDs



At leading order QCD, twist 2, chiral-even, quark sector
→ **4 GPDs for each quark flavor**

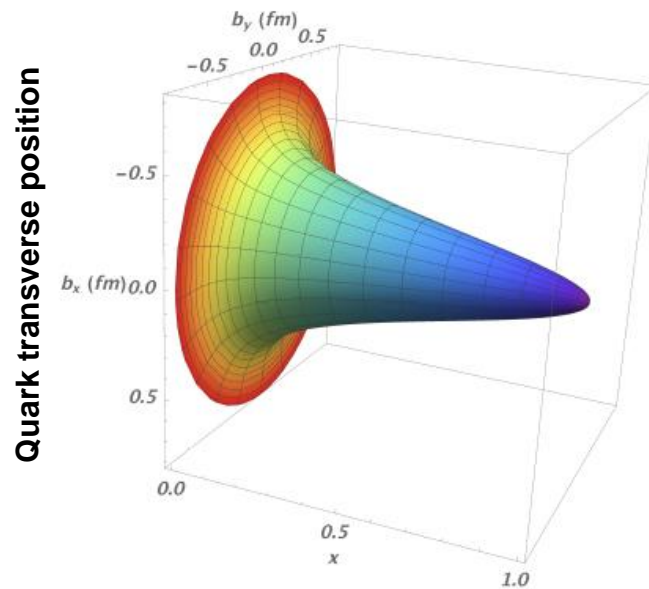
Nucleon tomography

$$q(x, b_{\perp}) = \int_0^{\infty} \frac{d^2 \Delta_{\perp}}{(2\pi)^2} e^{i\Delta_{\perp} b_{\perp}} H(x, 0, -\Delta_{\perp}^2)$$

$$\Delta q(x, b_{\perp}) = \int_0^{\infty} \frac{d^2 \Delta_{\perp}}{(2\pi)^2} e^{i\Delta_{\perp} b_{\perp}} \tilde{H}(x, 0, -\Delta_{\perp}^2)$$

Quark angular momentum (Ji's sum rule)

$$\frac{1}{2} \int_{-1}^1 x dx (H(x, \xi, t=0) + E(x, \xi, t=0)) = J = \frac{1}{2} \Delta \Sigma + \Delta L$$



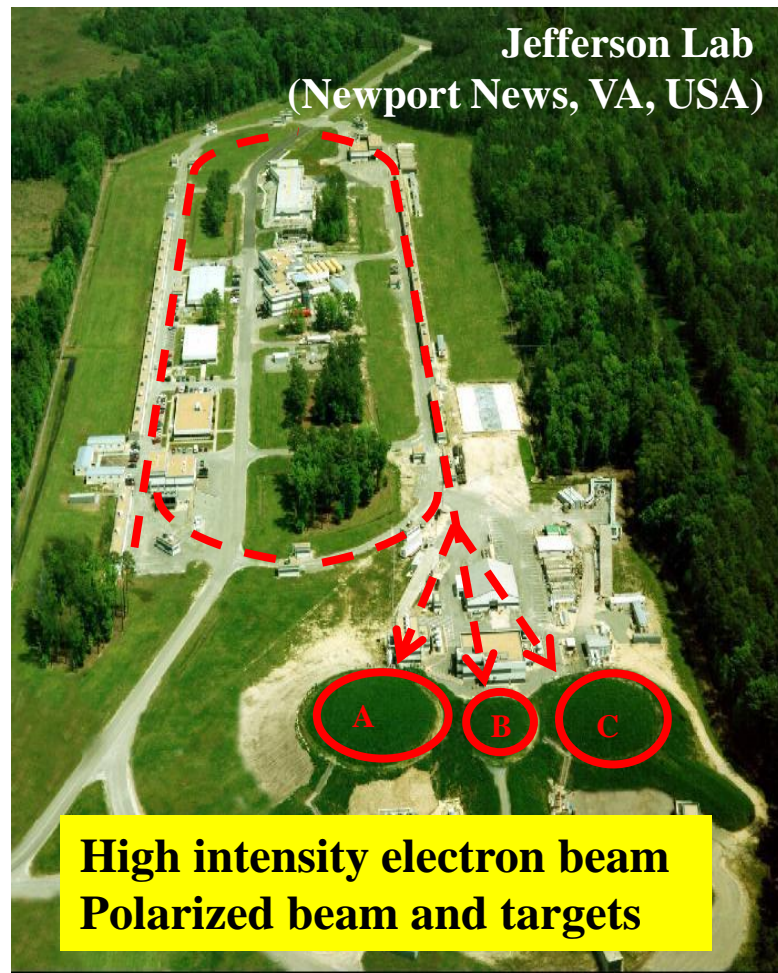
Quark longitudinal momentum

PRD95, 011501 (2017);
EPJA 53, 171 (2017)

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WP 23 - JRA 5 GPD-ACT: Objectives

- Analysis of GPD experiments at **JLab@6 GeV** and of DVCS and DVMP with a recoil detector at **COMPASS**
- Preparation, data taking and analysis of new experiments for **JLab@12GeV** (nDVCS, nuclear DVCS, TCS, DDVCS)
- Producing projections for GPD experiments to propose for EIC
- Building models of GPDs (standard twist-2, but also twist-3 and transversity GPDs), using also the constraints obtained by lattice QCD calculations
- Improved theoretical studies, including higher order and higher twist corrections
- Both experimental and theoretical efforts will be combined in **extraction of GPD information by fits to the data.**



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1. GPD experiments at JLab@12 GeV

IPN Orsay, CEA Saclay, and INFN teams are heavily involved in all of the GPD-related experiments of the JLab@12-GeV era, as spokespersons and/or as detector developers, in the Halls A, B, and C.

- **Halls A and C:** high-precision cross-section measurements for DVCS and exclusive pseudo-scalar meson production.
- **Hall B:** measurements of different spin observables for DVCS and DVMP (beam and/or target asymmetries) for different target types: proton, neutron (on a deuterium target), and light nuclei.
- The combination of all the measured observables on proton and neutron will help the **extraction of quark-flavor separated GPDs via model-independent fits**.

Technical projects:

- a neutron detector (**CND**), installed in Hall B, for neutron-DVCS measurements with CLAS12;
- a lead-tungsten electromagnetic calorimeter (**NPS**) for the detection of photons and π^0 's in a high-background for Hall C;
- a recoil tracker for light nuclei (**ALERT**), to measure nuclear GPDs with CLAS12;
- upgrades to the electronics of the **hodoscope** of the CLAS12 Forward Tagger to ensure good separation between photons and leptons at very low polar angles, for DVCS and DVMP experiments.
- Preparation for the long-term future, with **simulation** work to produce projections for future GPD experiments at the **Electron-Ion Collider (EIC)**. This work will be done in synergy with the Next-DIS WP.

The leading institution for these tasks is IPN Orsay (~9 postdoc months).

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2. Analysis of COMPASS data

A major part of the **COMPASS** program is dedicated to investigating the structure of the nucleon by studying GPDs through DVCS and DVMP.

The analysis work will be carried out by the **Warsaw**, **CEA-Saclay**, and **Mainz** groups.

- High energy **muon beams** with opposite charge and polarization → sensitivity to **different contributions to the epγ cross section**, imaginary parts of the observables linked to the GPD, H.
- Measurement of the momentum transfer (t) dependence of the DVCS cross section, to study **nucleon tomography**.
- COMPASS 2016-2017 data: yet **unexplored kinematic domain** ($0.005 < x_B < 0.3$), between HERMES and JLab on one side, and HERA on the other side.
- Analysis geared towards the extraction of DVCS and DVMP (π^0 , ρ , ω , ϕ , J/psi) cross sections
- Heavy involvement in the **preparation of the 2021 run**, which will use a **transversely polarized Li6D target** and will be mainly devoted to exclusive mesons studies.

The lead institution of this effort is CEA-Saclay (~9 post-doc months).

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3. Building models, analysis of processes, and extraction from data

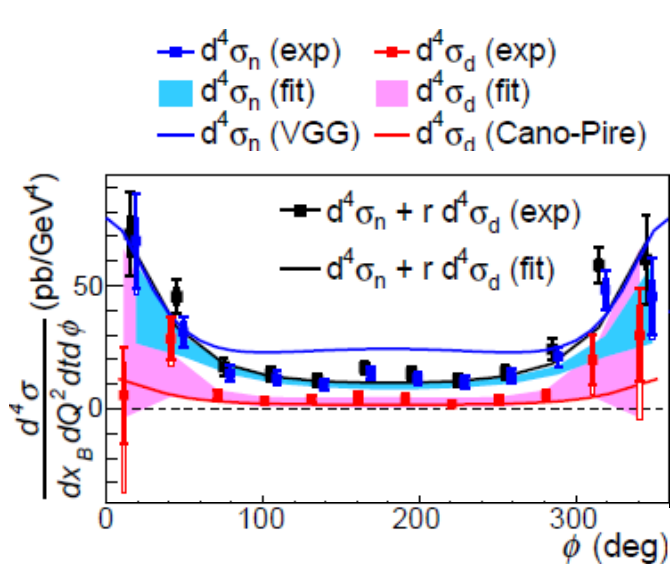
The groups involved in the theoretical effort are: **Ecole Polytechnique, LPT Orsay, CEA/Saclay, UREG, Uni Mainz, NCBJ Warsaw, UniZg, RBI Zagreb**

- Building sensible models of GPDs, including twist-3 and quark and gluon transversity GPDs
- Establishing links of GPDs to related theoretical objects like TDAs using comparison of forward vs backward meson lepto-production
- Establishing links with double parton distributions and with lattice results on GPD moments
- Analysis of several important processes, providing complementary access to GPDs: DVCS, including higher order and higher twist corrections, TCS, including finite momentum transfer and mass corrections, exclusive photo- and electro-production of two-particle system, double DVCS
- Modeling of DVMP including higher-order corrections
- Modeling of DVCS off light nuclei
- Building software packages for precision extraction of GPDs from data (in collaboration with 3DPartons WP)

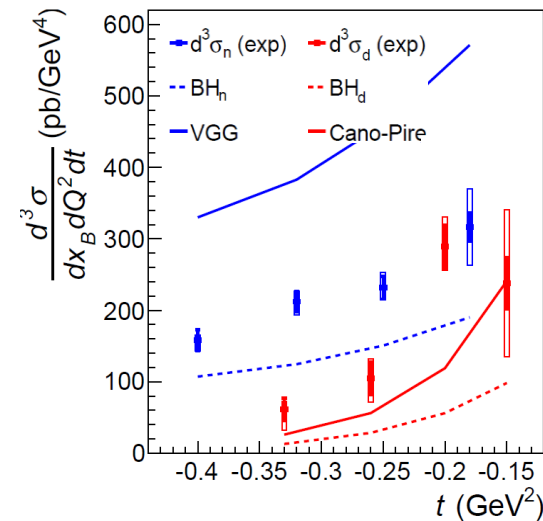
The lead institution is Ecole Polytechnique.

Two post-doc years to Uni Perugia (including matching funds).

DVCS off the neutron in Hall A @ 6 GeV



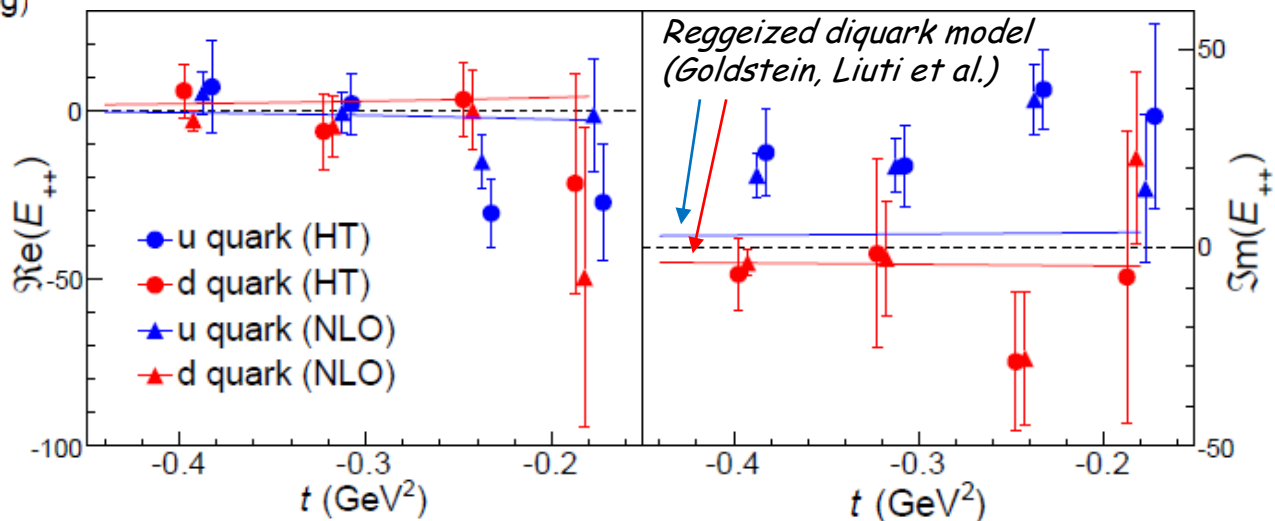
- Coherent deuteron & quasi-free neutron DVCS cross sections off LD₂
- 1st observation of DVCS signal off neutron
- Unique sensitivity to GPD E



Flavor separation of CCFs
when combined with p-DVCS

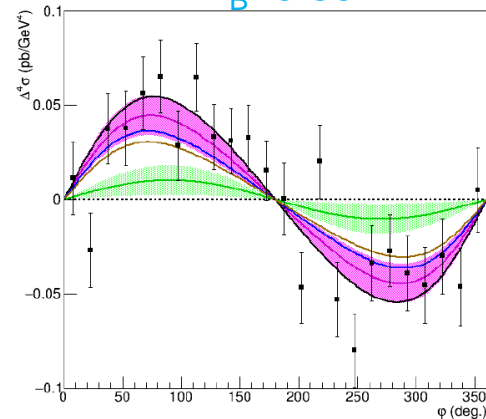
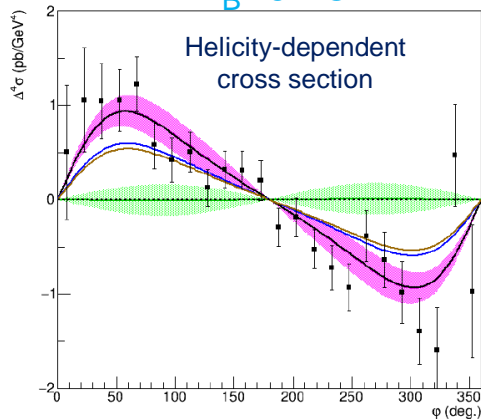
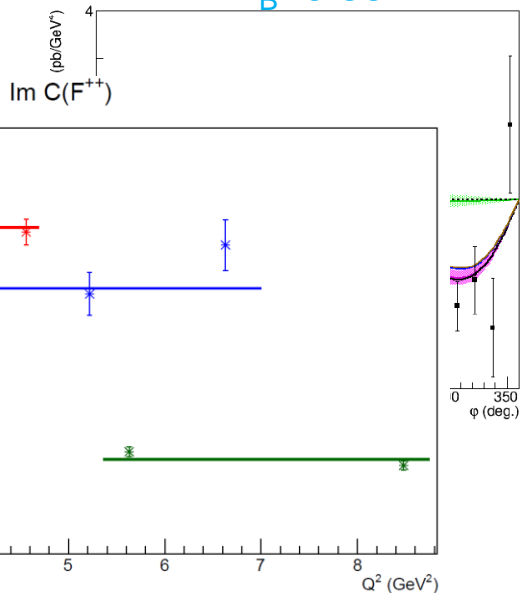
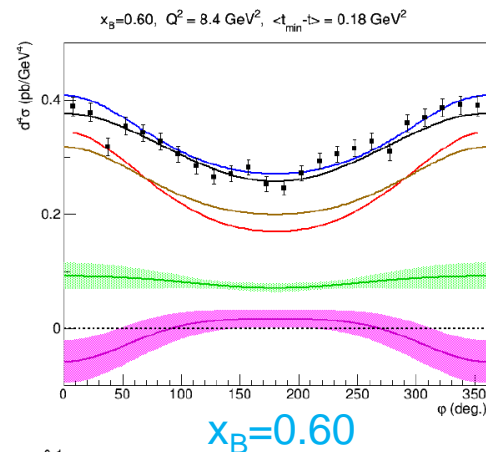
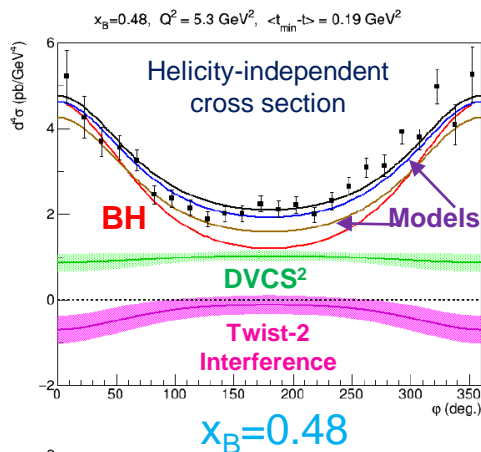
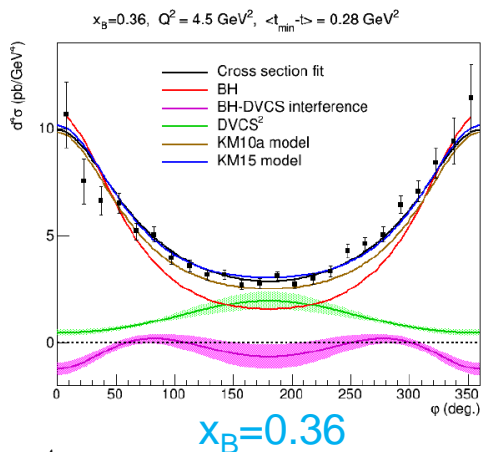
NLO and HT analyses
performed:

M. Benali et al.,
Nature Physics, 2019 (in press)



DVCS off the proton in Hall A @ 11 GeV

- High precision scaling tests of the DVCS cross section at fixed x_B
- CEBAF12 allows to explore for the first time the high x_B region



1st experiment to run after JLab Upgrade

- Q^2 -dependence of helicity-dependent amplitude
- 50% of statistics yet to be collected

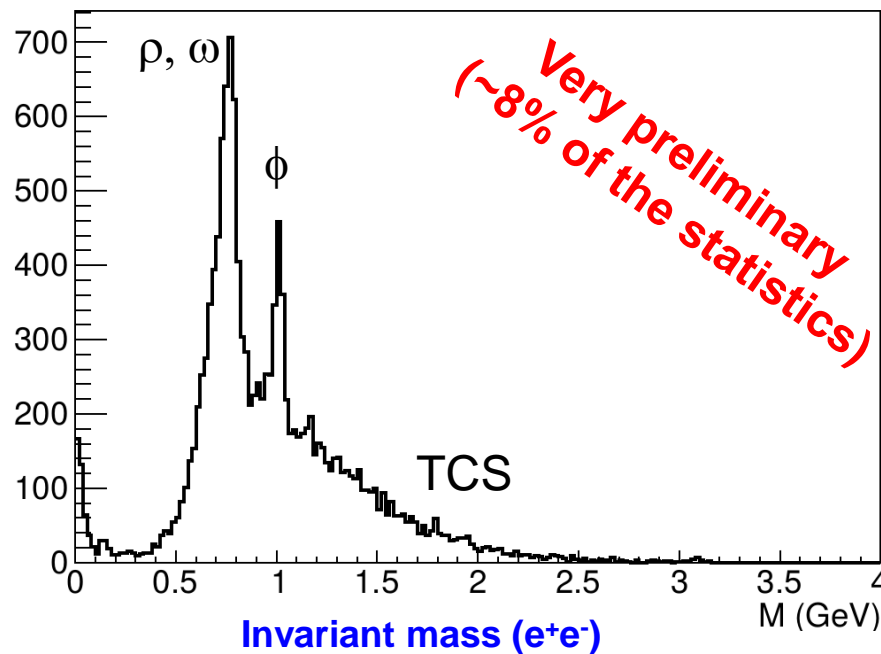
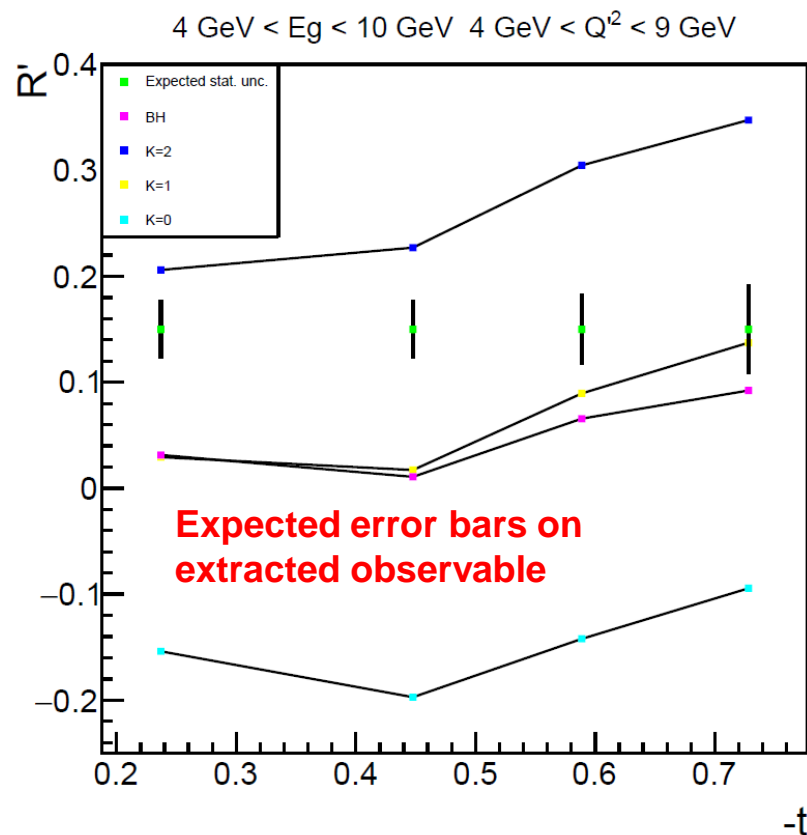
F. Georges et al., in preparation

Timelike Compton Scattering with CLAS12

- **1st CLAS12 experiment: spring and fall 2018**
- **10.6 GeV electron beam, liquid hydrogen target**

Timelike Compton Scattering: $\gamma p \rightarrow \gamma^* p' \rightarrow e^+ e^- p'$

- Time-reversal conjugate reaction of DVCS
- Gives access to real part of CFFs (\rightarrow GPDs)
- Test of the universality of GPDs



Work by Pierre Chatagnon (IPNO)

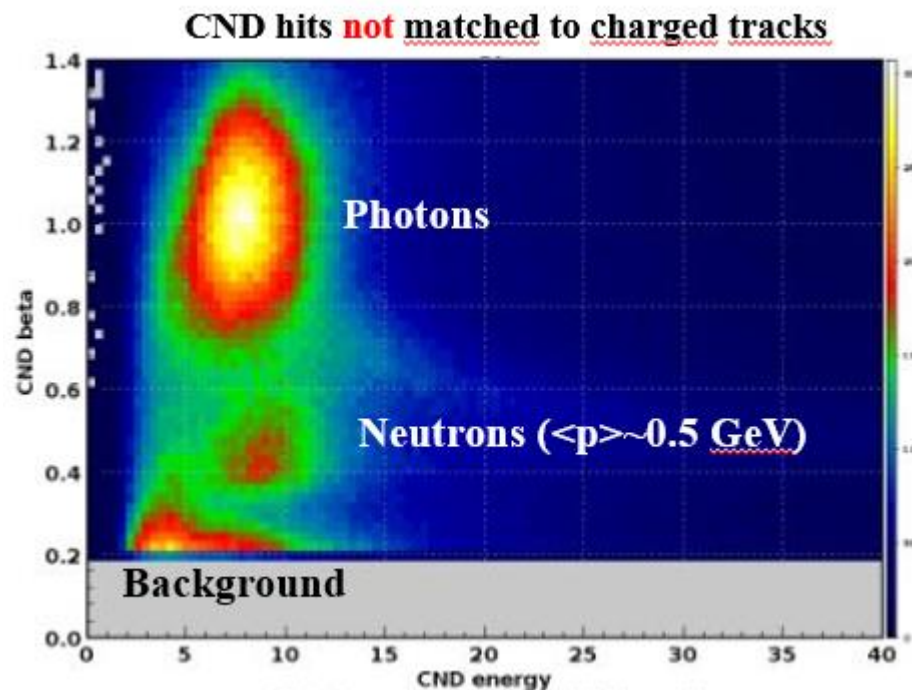
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

DVCS on the neutron with CLAS12

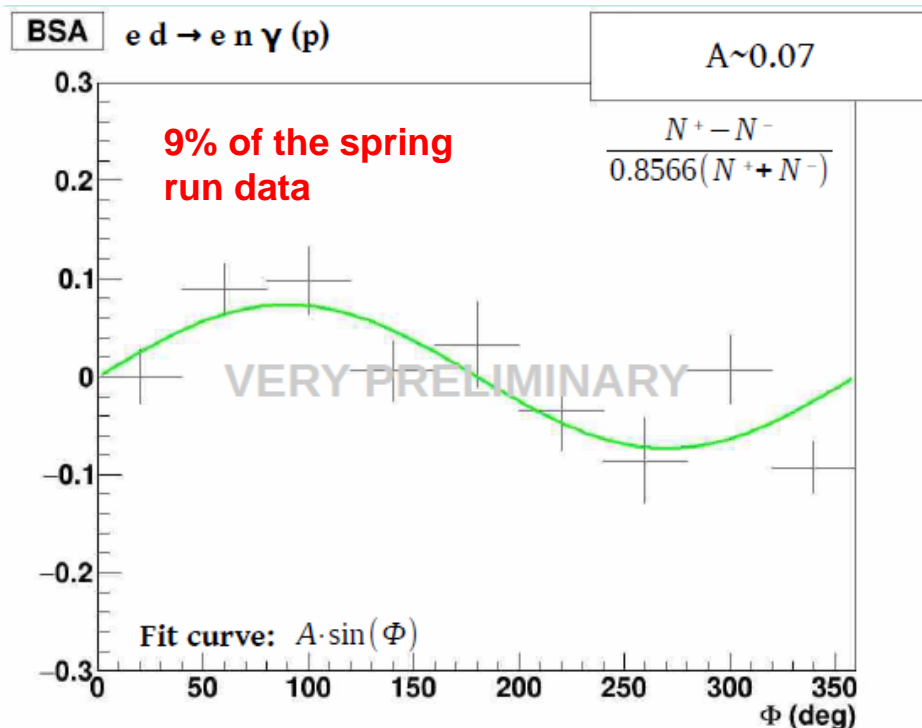
- Spring and fall/winter 2019/20
- 10.6 GeV electron beam, liquid deuterium target

$ed \rightarrow e(p)n\gamma$ Fully exclusive final state:
CLAS12+Forward Tagger+Central Neutron Detector

Beam spin asymmetry: the most sensitive observable to the GPD $E \rightarrow$ Quarks' angular momentum



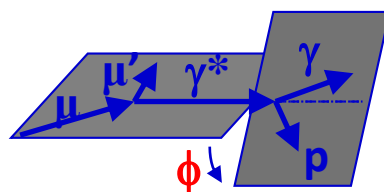
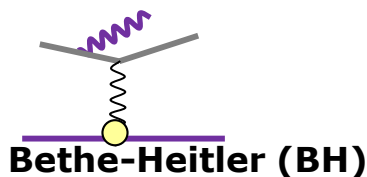
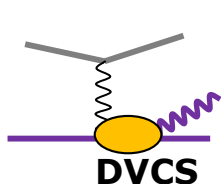
Work by Katheryne Price (IPNO)



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COMPASS 2016-17

First insight: ϕ distributions

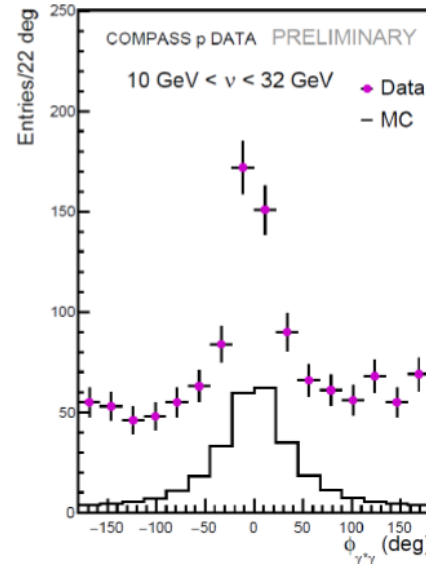
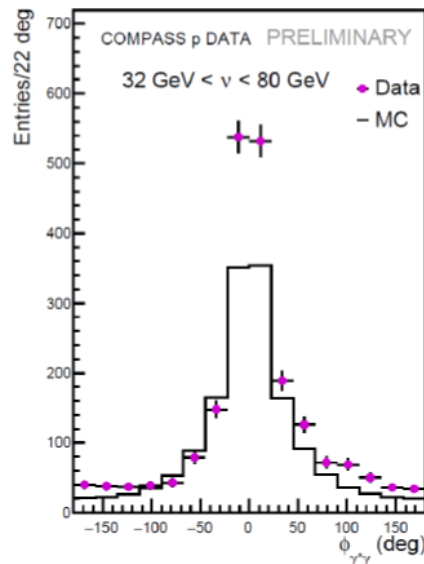
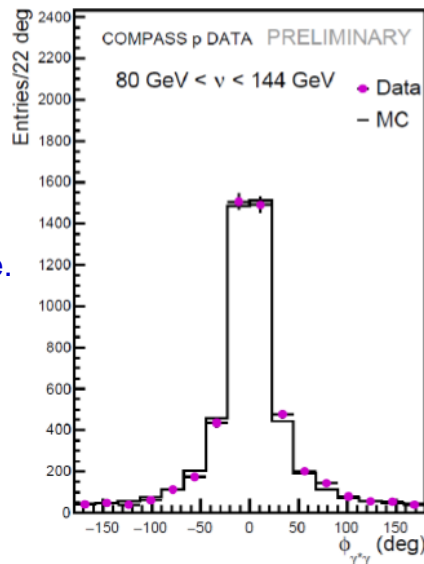


Only 13% of 2016-17 data

$0.005 < x_{Bj} < 0.01$

$0.01 < x_{Bj} < 0.03$

$x_{Bj} > 0.03$



“invisible” π^0
still to be
removed

a significant
DVCS
contribution
will allow to study
 $d\sigma^{DVCS}/dt =$
 $e^{-B'|t|} =$

C_0^{DVCS}

Only BH is
expected
to contribute.
BH MC is
normalized
to this bin.

Presentations of the very first released results:

- at DIS Torino Italy April 2019 (Antoine Vidon), at the APS TG on Hadron Physics at Denver USA (Nicole d'Hose)
- at IWHSS Aveiro Portugal May (Po-Ju Lin), at DSPIN Dubna Russia Oct (A. Sandacz), at EINN2019 (J. Giarra)

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Incoherent deeply Virtual Compton scattering off ^4He

The beam spin asymmetry (A_{LU}) is studied in a rigorous Impulse Approximation in terms of state-of-the-art models of the nuclear spectral function $P^{^4\text{He}}$ and of the bound-proton GPD:

$$A_{LU}^{Incoh}(K) = \frac{I_{DVCS-BH}^{^4\text{He}}(K)}{T_{BH}^{^4\text{He}^2}(K)}$$

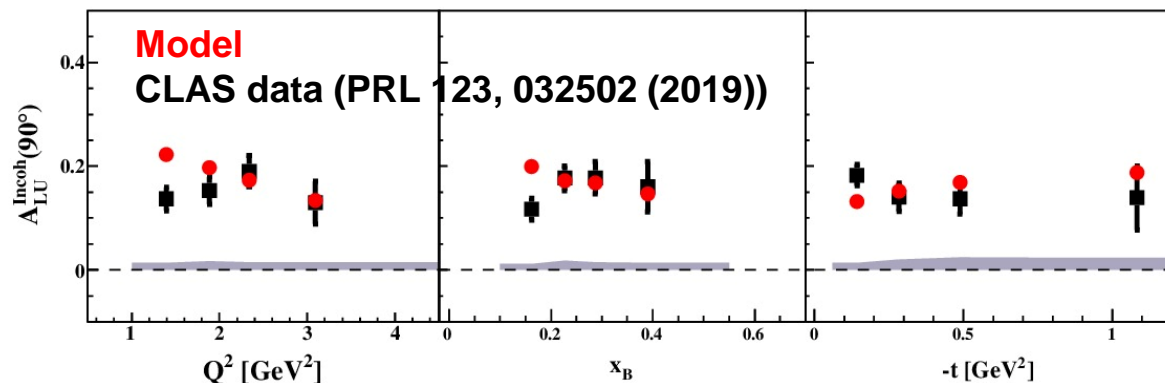
$$K = \{\Delta^2, x_B, \phi, Q^2\}$$

**S. Fucini, S. Scopetta,
M. Viviani, arXiv:1909.12261**

where

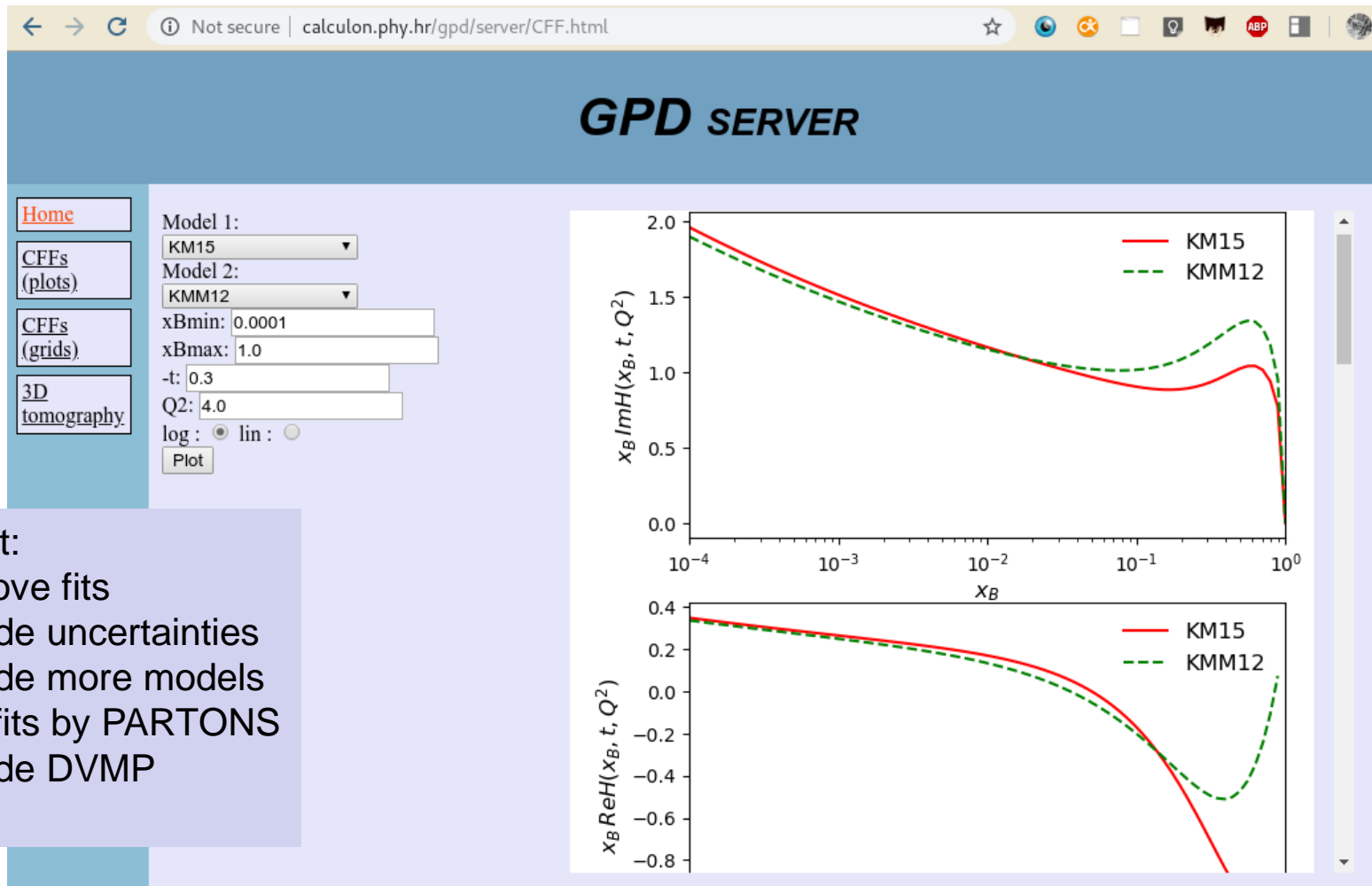
$$T_{BH}^{^4\text{He}^2}(K) \approx \int_{exp} dE d\vec{p} P^{^4\text{He}}(E, \vec{p}) |T_{BH}(E, \vec{p}, K) \pm|^2$$

$$I_{DVCS-BH}^{^4\text{He}}(K) \approx \int_{exp} dE d\vec{p} P^{^4\text{He}}(E, \vec{p}) |I_{DVCS-BH}(E, \vec{p}, K) \pm|^2$$



Overall good agreement;
disagreement at low Q^2 : FSI?
To be investigated.

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To do list:

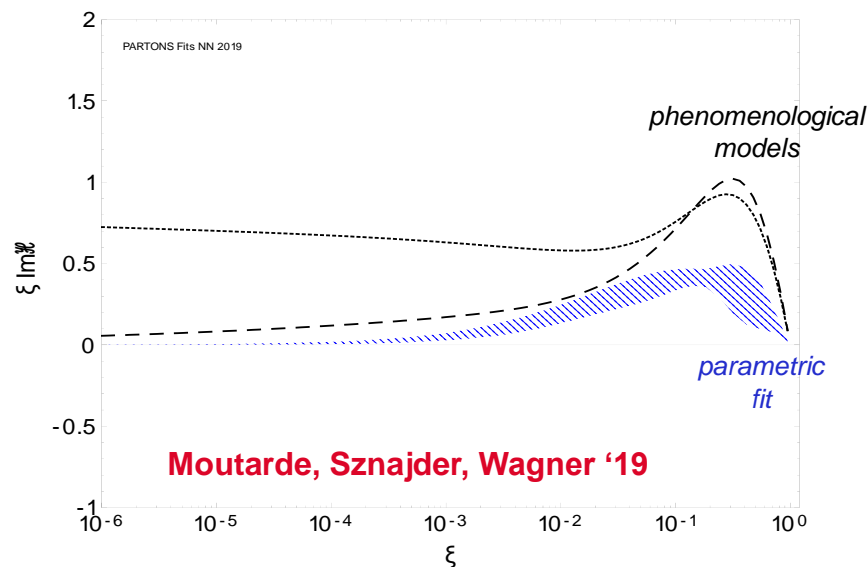
- Improve fits
- Include uncertainties
- Include more models
- Add fits by PARTONS
- Include DVMP
- ...

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More updates on theory

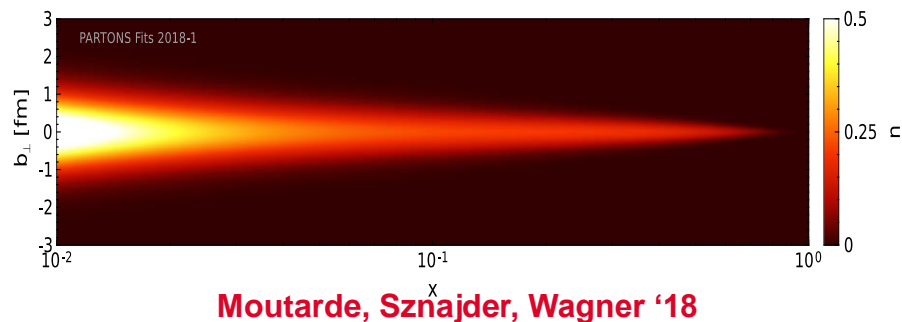
- Recent paper on the signature of TDA factorization (Warsaw and Ecole Polytechnique) <https://arxiv.org/pdf/1910.00464.pdf> commenting on recent Hall C results on backward ω exclusive electroproduction <https://arxiv.org/pdf/1910.01979.pdf>
- Verification of flavor-singlet NLO evolution equation for GPDs (UREG) [Braun:2019qtp]
- Global analysis of DVCS observables with PARTONS (CEA Saclay & Warsaw)

Neural network determination of CFFs



Global analysis of 2600+ measurements of 30 observables published between 2001 and 2017

Proton tomography



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JRA 5 GPD-ACT : ***Deliverables and milestones***

- There are no deliverables and milestones due for Reporting Period 1 (RP1-M1 to M18, from June 2019 to November 2020)
- All deliverables and milestones are due later on, the earliest M24 (May 2021)

LIST OF DELIVERABLES (TABLE 3.1c)

Deliverable number	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date (in months)
WPno.1	Publication of JLab@12GeV results	23	IPN Orsay	R	PU	36
WPno.2	Publication of COMPASS results	23	CEA- Saclay	R	PU	48
WPno.3	Public software serving GPD fit results	23	Uni Zagreb	OTHE R	PU	46

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JRA 5 GPD-ACT : Deliverables and milestones

LIST OF MILESTONES (TABLE 3.2a)

Milestone number	Milestone name	Related work package(s)	Due date (in month)	Means of verification
WPGPD.1	Completion of JLab Hall-A DVCS, and Hall-B TCS and nDVCS analyses		12/24/36	Arxiv publication/ Conference presentation and/or analysis note
WPGPD.2	Publication of COMPASS t dependence for DVCS and π^0 cross sections		24	Published paper
WPGPD.3	Construction of the ALERT, NPS, and FT-hodoscope electronics		24/48	TDR/prototype (DEM)
WPGPD.4	Lattice moments of GPDs and global GPD fits		28	Presented at conference or published paper
WPGPD.5	Models for several classes of GPDs and published study of GPD-related observables	QCDSOft	36	Published papers

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