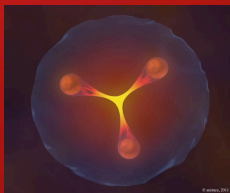


DE LA RECHERCHE À L'INDUSTRIE

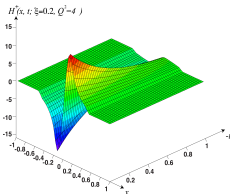
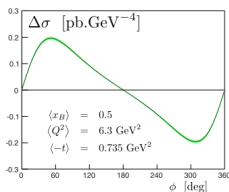
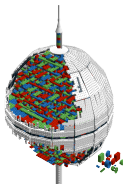
cea



www.cea.fr



GPD studies with PARTONS



Weekly Meeting Excl. Proc. WG | Hervé MOUTARDE

Apr. 24, 2020

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

université
PARIS-SACLAY

Exclusive processes of current interest.

Factorization and universality.

PARTONS and GPDs

GPD channels

CFF global fits

Parametric fit
Neural network fits

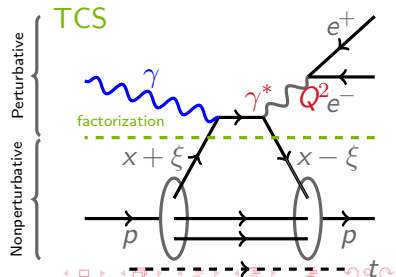
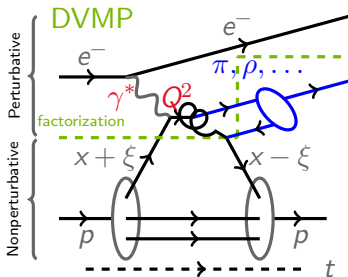
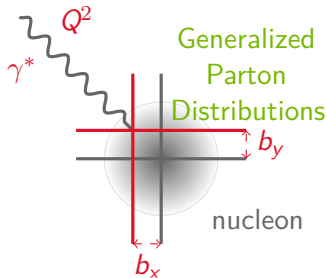
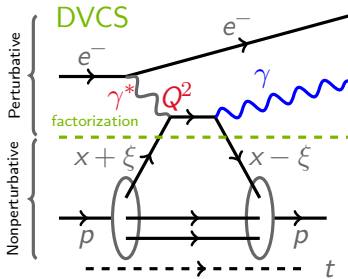
Multi-channel analysis

TCS: Data-driven impact study
Probing NLO contributions

PARTONS

Open source
YR timeline
Next 3 years

Conclusion



PARTONS and GPDs

GPD channels

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contributions

PARTONS

Open source
YR timeline
Next 3 years

Conclusion

Bjorken regime : large Q^2 and fixed $x_B \simeq 2\xi/(1+\xi)$

- Partonic interpretation relies on **factorization theorems**.
- All-order proofs for DVCS, TCS and some DVMP.
- GPDs depend on a (arbitrary) factorization scale μ_F .
- **Consistency** requires the study of **different channels**.

- GPDs enter DVCS through **Compton Form Factors** :

$$\mathcal{F}(\xi, t, Q^2) = \int_{-1}^1 dx C\left(x, \xi, \alpha_S(\mu_F), \frac{Q}{\mu_F}\right) F(x, \xi, t, \mu_F)$$

for a given GPD F .

- CFF \mathcal{F} is a **complex function**.

CFF global fits

First global CFF fit with PARTONS.

Assumptions, limits and key ingredients.

PARTONS and GPDs

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impact study

Probing NLO

contributions

PARTONS

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YR timeline

Next 3 years

Conclusion

- **Leading twist** and **leading order** analysis.
- Focus on the quark sector (intermediate to large x_B).
- Dispersion relations: CFF \mathcal{H} depends on **D-term** and **border function** $H(x, \xi = x)$.
- Tomography: model **skewing function** $H(x, x, t)/H(x, 0, t)$ consistently with perturbative QCD.
- Fit to PDFs and elastic form factors.
- Propagate uncertainties by **replica method**.

Moutarde *et al.*, Eur. Phys. J. **C78**, 890 (2018)

A selection of results.

2600 experimental points, 13 free parameters, $\chi^2/\text{dof} \simeq 0.91$.

PARTONS and GPDs

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impact study

Probing NLO
contributions

PARTONS

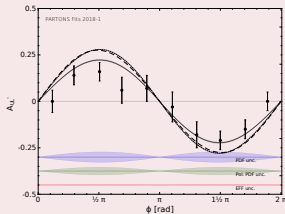
Open source

YR timeline

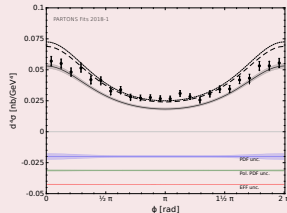
Next 3 years

Conclusion

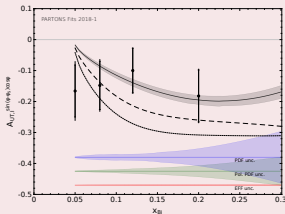
CLAS



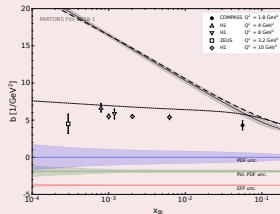
Hall A



HERMES



COMPASS



Neural network global fit of CFFs.

All existing sets except $d^4\sigma_{UU}^-$ from Hall A (2015-17).

PARTONS and GPDs

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impact study

Probing NLO
contributions

PARTONS

Open source

YR timeline

Next 3 years

Conclusion

No.	Collab.	Year	Ref.	Observable	Kinematic dependence	No. of points used / all
1	HERMES	2001	[40]	A_{LU}^+	ϕ	10 / 10
2		2006	[41]	$A_C^{\cos i\phi}$	t	4 / 4
3		2008	[42]	$A_C^{\cos i\phi}$ $A_{UT,DVCS}^{\sin(\phi-\phi_S)\cos i\phi}$ $A_{UT,1}^{\sin(\phi-\phi_S)\cos i\phi}$ $A_{UT,1}^{\cos(\phi-\phi_S)\sin i\phi}$	x_{Bj}	18 / 24
4		2009	[43]	$A_{LU,1}^{\sin i\phi}$	$i = 1, 2$	x_{Bj} 35 / 42
				$A_{LU,DVCS}^{\sin i\phi}$	$i = 1$	
				$A_C^{\cos i\phi}$	$i = 0, 1, 2, 3$	
5		2010	[44]	$A_{UL}^{+, \sin i\phi}$	$i = 1, 2, 3$	x_{Bj} 18 / 24
				$A_{LL}^{+, \cos i\phi}$	$i = 0, 1, 2$	
				$A_{LT,DVCS}^{\cos(\phi-\phi_S)\cos i\phi}$	$i = 0, 1$	x_{Bj} 24 / 32
6		2011	[45]	$A_{LT,DVCS}^{\sin(\phi-\phi_S)\sin i\phi}$	$i = 1$	
				$A_{LT,DVCS}^{\cos(\phi-\phi_S)\cos i\phi}$	$i = 0, 1, 2$	
				$A_{LT,1}^{\sin(\phi-\phi_S)\sin i\phi}$	$i = 1, 2$	x_{Bj} 35 / 42
7		2012	[46]	$A_{LU,1}^{\sin i\phi}$	$i = 1, 2$	
				$A_{LU,DVCS}^{\sin i\phi}$	$i = 1$	
				$A_C^{\cos i\phi}$	$i = 0, 1, 2, 3$	
8	CLAS	2001	[47]	$A_{LU}^{-, \sin i\phi}$	$i = 1, 2$	— 0 / 2
9		2006	[48]	$A_{UL}^{-, \sin i\phi}$	$i = 1, 2$	— 2 / 2
10		2008	[49]	A_{LU}	ϕ	283 / 737
11		2009	[50]	A_{LU}^-	ϕ	22 / 33
12		2015	[51]	$A_{LU}^-, A_{UL}^-, A_{LL}^-$	ϕ	311 / 497
13		2015	[52]	$d^4\sigma_{UU}^-$	ϕ	1333 / 1933
14	Hall A	2015	[34]	$\Delta d^4\sigma_{LU}^-$	ϕ	228 / 228
15		2017	[35]	$\Delta d^4\sigma_{LU}^+$	ϕ	276 / 358
16	COMPASS	2018	[36]	$d^3\sigma_{UU}^+$	t	2 / 4
17	ZEUS	2009	[37]	$d^3\sigma_{UU}^+$	t	4 / 4
18	H1	2005	[38]	$d^3\sigma_{UU}^+$	t	7 / 8
19		2009	[39]	$d^3\sigma_{UU}^+$	t	12 / 12

SUM: 2624 / 3996

Moutarde et al., Eur. Phys. J. C79, 614 (2019)

A selection of results.

2600+ measurements of 30 observables published during 2001-17.

PARTONS and GPDs

GPD channels

CFF global fits

Parametric fit

Neural network fits

Multi-channel
analysis

TCS: Data-driven
impact study

Probing NLO
contributions

PARTONS

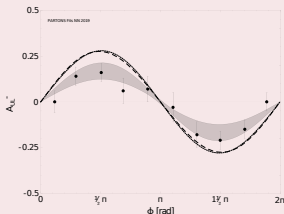
Open source

YR timeline

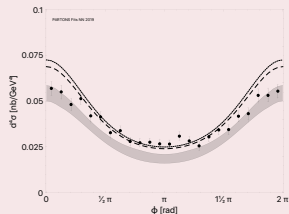
Next 3 years

Conclusion

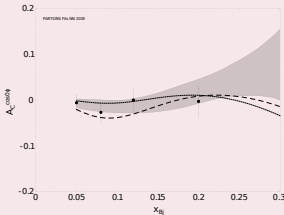
CLAS



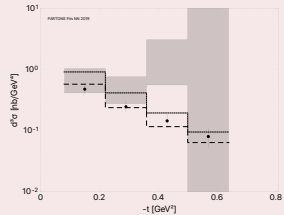
Hall A



HERMES



COMPASS



Moutarde *et al.* Eur. Phys. J. **C79**, 614 (2019)

PARTONS and GPDs

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TCS: Data-driven
impact study

Probing NLO
contributions

PARTONS

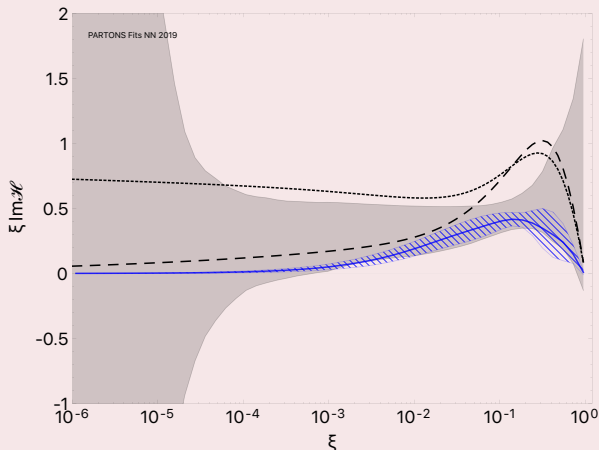
Open source

YR timeline

Next 3 years

Conclusion

Compton form factor $\text{Im}\mathcal{H}(\xi, t = -0.3 \text{ GeV}^2, Q^2 = 2. \text{ GeV}^2)$



Moutarde *et al.*, Eur. Phys. J. **C79**, 614 (2019)

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Probing NLO contributions

PARTONS

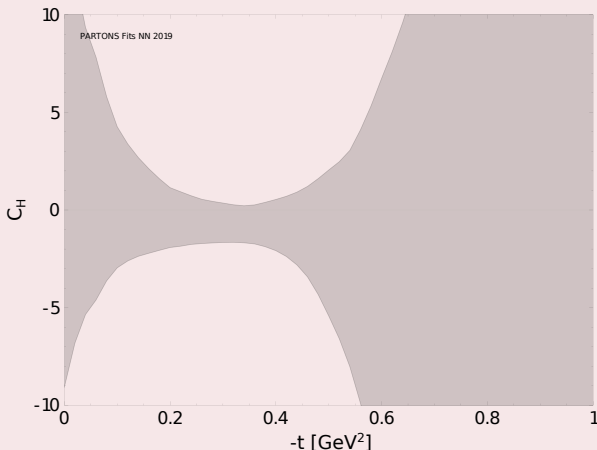
Open source

YR timeline

Next 3 years

Conclusion

Subtraction constant (related to pressure distribution)



See Paweł's talk today!

Multi-channel analysis

Assessing the universality of GPDs.

Intimate relation between TCS and DVCS due to analyticity.

PARTONS and GPDs

- Relation between **spacelike** (DVCS) and **timelike** (TCS) CFFs worked out at NLO:

$$\begin{aligned} \tau_{\mathcal{H}} &\stackrel{\text{LO}}{=} s_{\mathcal{H}}^*, \\ \tau_{\mathcal{H}} &\stackrel{\text{NLO}}{=} s_{\mathcal{H}}^* - i\pi Q^2 \frac{\partial}{\partial Q^2} s_{\mathcal{H}}^*, \end{aligned}$$

with Q the virtuality of the incoming or outgoing photon.

Müller *et al.*, Phys. Rev. **D86**, 031502 (2012)

- Using a **global CFF fit** to DVCS measurements, the **first multi-channel data-driven** analysis of exclusive processes beyond LO becomes possible!
- First step towards **multi-channel fits** to exclusive processes.

See J. Wagner's talk at the Temple meeting

GPD channels

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PARTONS

Open source
YR timeline
Next 3 years

Conclusion

From DVCS to TCS.

Prediction of TCS CFF at 68 % confidence level.

PARTONS and GPDs

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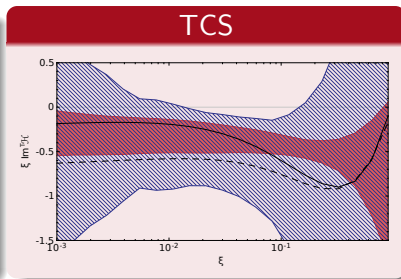
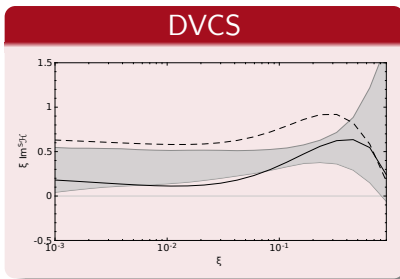
Open source

YR timeline

Next 3 years

Conclusion

- Spacelike and timelike CFFs depending on ξ at common kinematics: $Q^2 = 2 \text{ GeV}^2$ and $t = -0.3 \text{ GeV}^2$.
- ξ range from EIC to Jefferson Lab kinematics.
- Comparison with phenomenological model at LO (dashed) and NLO (solid).



Grocholski *et al.*, Eur. Phys. J. **C80**, 171 (2020)

The PARTONS framework



PARtonic
Tomography
Of
Nucleon
Software

PARTONS and GPDs

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impact study
Probing NLO
contributions

PARTONS

Open source

YR timeline
Next 3 years

Conclusion

Full processes

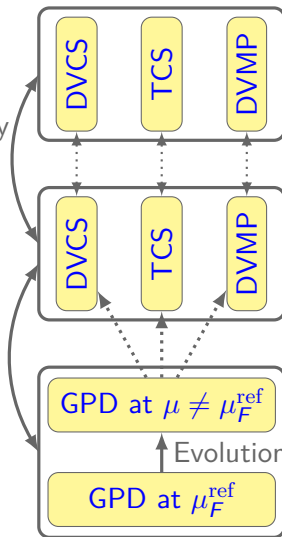
Experimental
data and
phenomenology

Small distance

Computation
of amplitudes

Large distance

First
principles and
fundamental
parameters



PARtonic Tomography Of Nucleon Software

- Perturbative approximations.
- Physical models.
- Fits.
- Numerical methods.
- Accuracy and speed.

PARTONS and GPDs

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TCS: Data-driven
impact study
Probing NLO
contributions

PARTONS

Open source

YR timeline
Next 3 years

Conclusion

The screenshot shows the PARTONS website interface. At the top, there's a navigation bar with links: herve moutarde, Webmail CEA, L'intranet du SPHn, PARTONS, GitLab DRF, GitLab IN2P3, vianavigo, GPDs - EIC, and http://agenda... la formation. The main header features the 'PARTONS' logo and the tagline 'PARTonic Tomography Of Nucleon Software'. Below this is a dark navigation bar with links: Main Page, Download, Tutorials +, Reference documentation +, and About. A search bar is also present. The main content area starts with 'Main Page' and 'What is PARTONS?'. The text describes PARTONS as a software framework for 3D hadron structure phenomenology, specifically for Generalized Parton Distributions (GPDs) and Transverse Momentum Dependent (TMDs) parton distribution functions. It mentions that PARTONS bridges models of 3D hadron structure with experimental data from DVCS and HEMP. A 'STRONG 2020' logo is visible. The text continues to describe the experimental program at CERN, DESY, Fermilab, Jefferson Lab, and BNL, and mentions funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

Berthou *et al.*, Eur. Phys. J. **C78**, 478 (2018)

PARTONS and GPDs

Publicly available on CEA GitLab server

GPD channels

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TCS: Data-driven
impact study
Probing NLO
contributions

PARTONS

Open source

YR timeline
Next 3 years

Conclusion

The screenshot shows the GitLab interface for the PARTONS project on the CEA GitLab server. The browser address bar shows 'drf-gitlab.cea.fr'. The navigation bar includes 'Webmail CEA', 'L'intranet de l'Ifnu', 'L'intranet du SPH', 'herve moutarde', 'GitLab DRF', 'PROPHET - Trac', 'vianavigo', 'Overleaf', and 'http://agenda... la formation'. The main content area shows the 'partons' project details, including a 'core' sub-project. A list of related projects is displayed below, with a 'Filter by name...' search bar and a 'Last created' dropdown menu. The projects listed are:

- partons**: PARTONS project (2 stars)
- elementary-utils**: Utility softwares (logger, parser, threads, string and file manipulation) (0 stars)
- numa**: NumA++: numerical analysis C++ routines (0 stars)
- partons-example**: Running version of PARTONS with examples (C++ code and XML computing scenarios) (0 stars)

The bottom of the page shows a pagination bar with 'Prev', '1', and 'Next' buttons.

Berthou *et al.*, Eur. Phys. J. **C78**, 478 (2018)

PARTONS and GPDs

GPD channels

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impact study
Probing NLO
contributions

PARTONS

Open source

YR timeline

Next 3 years

Conclusion

■ Ongoing work:

- Cross sections for **exclusive π^0 production**. See [K. Tezgin's talk \(WMEP WG 2020/04/13\)](#).
- Various **TCS observables** from several GPD or CFF models under various pQCD assumptions. See [J. Wagner's talk \(Temple 2020/03/20\)](#).
- Extraction of the **first Gegenbauer coefficient** of the D-term (pressure forces) from global fits to DVCS data. See [P. Sznajder's talk today](#).
- Integration in the **MILOU MC generator** of tables of CFF output from PARTONS.
- **GPD evolution** computed with **APFEL**.

■ Elements that would help:

- Realistic DVCS mock observables on EIC kinematics.
- Manpower for (model-dependent) sensitivity studies on the GPD E and Ji sum rule.

PARTONS and GPDs

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impact study
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contributions

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Open source
YR timeline

Next 3 years

Conclusion

Work Package tasks

- **Flexible software architecture** for GPD and TMD codes, elaborating on existing libraries.
- Generic MC event generators for GPDs and TMDs.
- Associated tools to compare theoretical calculations to experimental data.
- Webpage, software forge and mailing lists.
- Documentation, technical assistance and nonregression tests: **facilitate dissemination.**
- Open Data and Open Science: **build on previous research and get new results faster.**

Conclusion

Conclusion and prospects.

Not covering ongoing theoretical work (longer time scale).

PARTONS and GPDs

- We now have tools to **systematically** relate models to **experimental data** in **multi-channel** analysis.

GPD channels

CFF global fits

Parametric fit
Neural network fits

- We now have an **operating engine** for global CFF fits.
- Next step: GPD fits.

Multi-channel analysis

TCS: Data-driven
impact study
Probing NLO
contributions

PARTONS

Open source
YR timeline
Next 3 years

Conclusion

Deliverables within the YR timeline

- Cross sections for **exclusive π^0 production**.
- **TCS observables**.
- Impact of EIC on the extraction of the **first Gegenbauer coefficient** of the D-term from global CFF fits.
- Integration in the **MILOU MC generator** of tables of CFFs output from PARTONS.
- **GPD evolution** computed with **APFEL**.

