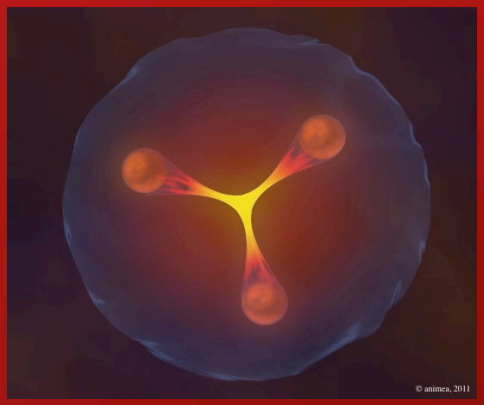
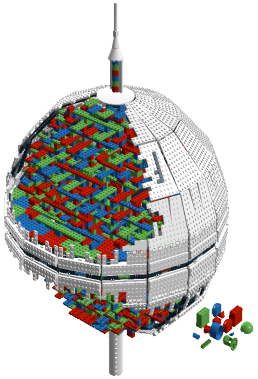
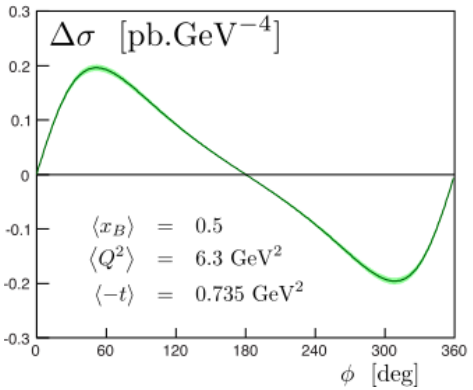
DE LA RECHERCHE À L'INDUSTRIE

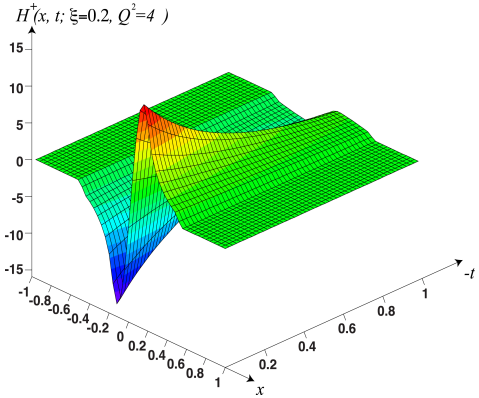


www.cea.fr

Global fits of GPDs in the PARTONS framework







Snowmass - Topical Group EF06 | **Hervé MOUTARDE**

Aug. 19, 2020

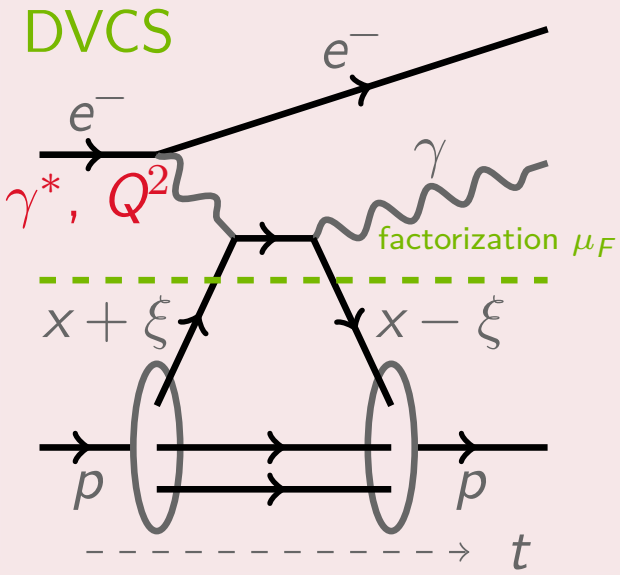
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

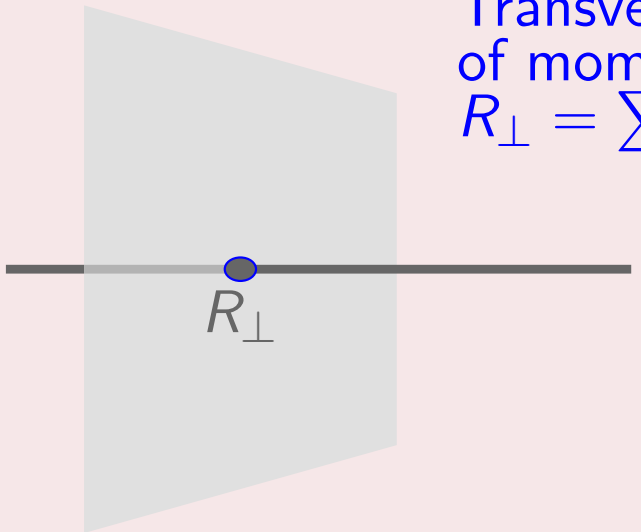
Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Correlation of the **longitudinal momentum** and the **transverse position** of a parton in a hadron.
- DVCS recognized as the cleanest channel to access GPDs.

Deeply Virtual Compton Scattering (DVCS)





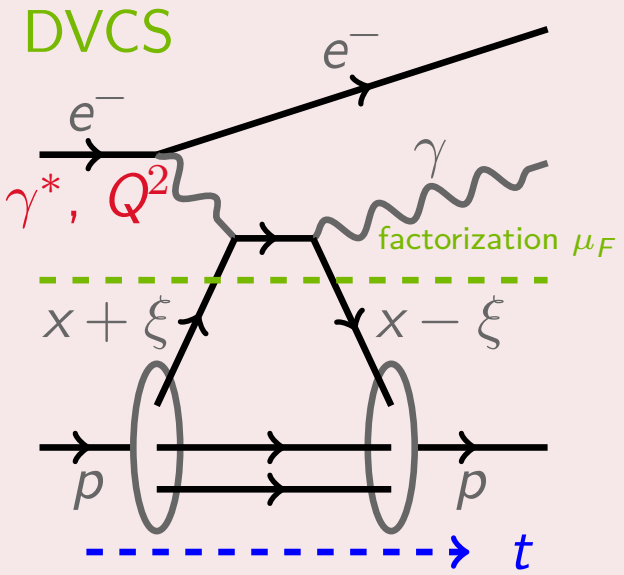
Transverse center of momentum $R_\perp$
$R_\perp = \sum_i x_i r_{\perp i}$

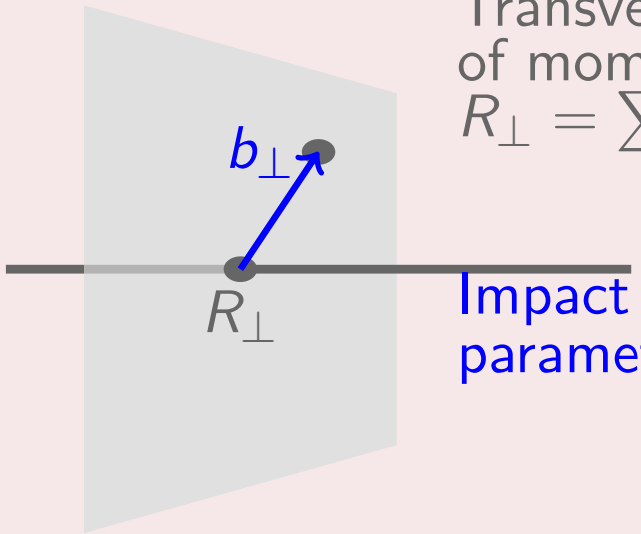
Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Correlation of the **longitudinal momentum** and the **transverse position** of a parton in a hadron.
- DVCS recognized as the cleanest channel to access GPDs.

Deeply Virtual Compton Scattering (DVCS)





Transverse center of momentum $R_\perp$
$R_\perp = \sum_i x_i r_{\perp i}$

Impact parameter $b_\perp$

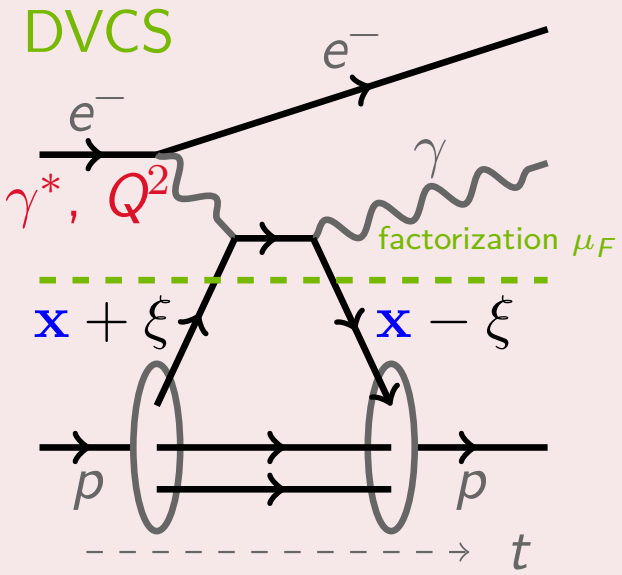
Anatomy of hadrons.

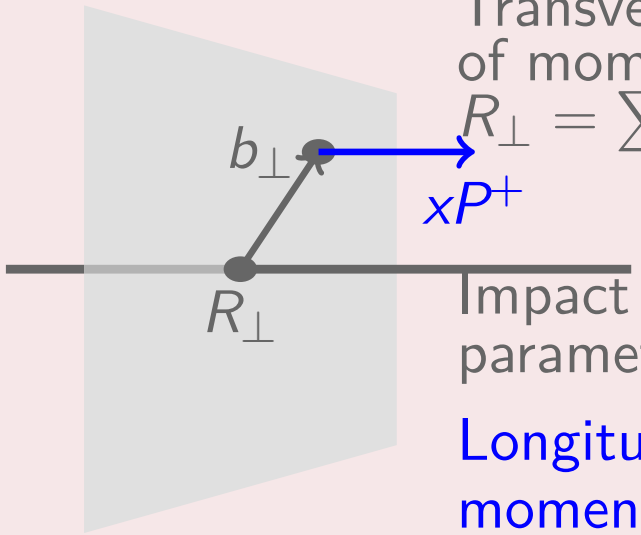
GPDs and their golden channel.

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Correlation of the **longitudinal momentum** and the **transverse position** of a parton in a hadron.
- DVCS recognized as the cleanest channel to access GPDs.

Deeply Virtual Compton Scattering (DVCS)





Transverse center of momentum $R_\perp$
$R_\perp = \sum_i x_i r_{\perp i}$

Impact parameter $b_\perp$

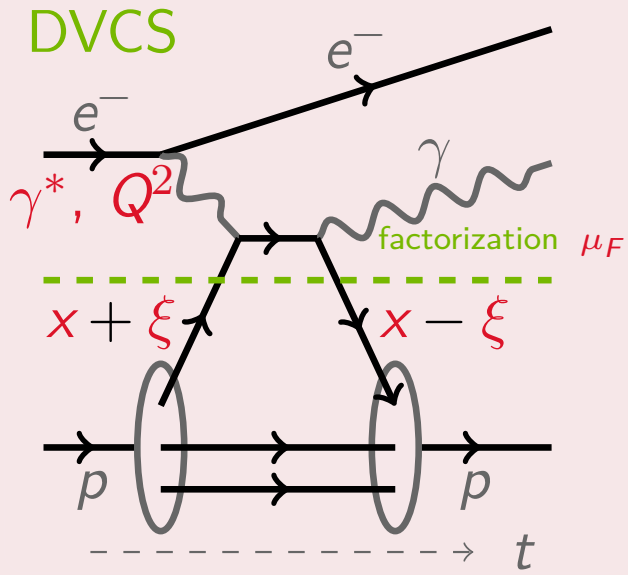
Longitudinal momentum xP^+

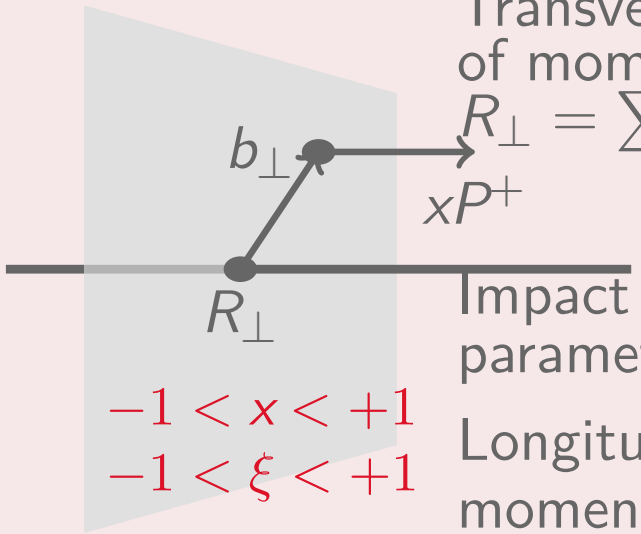
Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Correlation of the **longitudinal momentum** and the **transverse position** of a parton in a hadron.
- DVCS recognized as the cleanest channel to access GPDs.

Deeply Virtual Compton Scattering (DVCS)





Transverse center of momentum $R_\perp$
$R_\perp = \sum_i x_i r_{\perp i}$

Impact parameter $b_\perp$

Longitudinal momentum xP^+

- **24 GPDs** $F^i(x, \xi, t, \mu_F)$ for each parton type $i = g, u, d, \ldots$ for leading and sub-leading twists.

Global fits with PARTONS

Physics case
Physical content
Experimental access

DVCS fits
Fit status
Neural network fits

Complementary analysis
TCS: Data-driven impact study
Pressure forces

Framework
Design

Conclusion

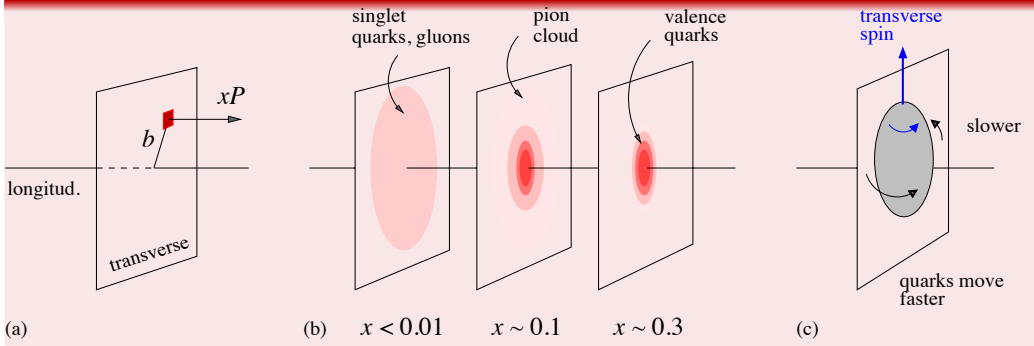
- **Probabilistic interpretation** of Fourier transform of GPD$(x, \xi = 0, t)$ in **transverse plane**.

$$\rho(x, b_\perp, \lambda, \lambda_N) = \frac{1}{2}\left[H(x,0,b_\perp^2) + \frac{b_\perp^j \epsilon_{ji} S_\perp^i}{M}\frac{\partial E}{\partial b_\perp^2}(x,0,b_\perp^2) + \lambda\lambda_N \tilde{H}(x,0,b_\perp^2)\right]$$

- Notations : quark helicity λ, nucleon longitudinal polarization λ_N and nucleon transverse spin $S_\perp$.

Burkardt, Phys. Rev. **D62**, 071503 (2000)

Can we obtain this picture from exclusive measurements?



Weiss, AIP Conf. Proc. **1149**, 150 (2009)

Global fits with PARTONS

Physics case
Physical content
Experimental access

DVCS fits
Fit status
Neural network fits

Complementary analysis
TCS: Data-driven impact study
Pressure forces

Framework
Design

Conclusion

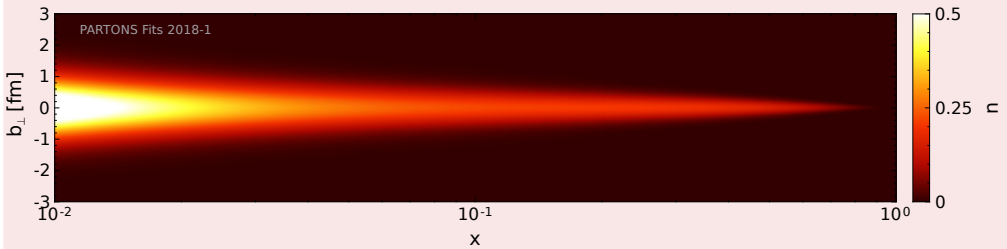
- **Probabilistic interpretation** of Fourier transform of GPD$(x, \xi = 0, t)$ in **transverse plane**.

$$\rho(x, b_\perp, \lambda, \lambda_N) = \frac{1}{2}\left[H(x,0,b_\perp^2) + \frac{b_\perp^j \epsilon_{ji} S_\perp^i}{M}\frac{\partial E}{\partial b_\perp^2}(x,0,b_\perp^2) + \lambda\lambda_N \tilde{H}(x,0,b_\perp^2)\right]$$

- Notations : quark helicity λ, nucleon longitudinal polarization λ_N and nucleon transverse spin $S_\perp$.

Burkardt, Phys. Rev. **D62**, 071503 (2000)

Not quite, but close!



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

Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Most general structure of matrix element of energy momentum tensor between nucleon states:

$$\left\langle N, P+\frac{\Delta}{2}\middle| T^{\mu\nu} \middle| N, P-\frac{\Delta}{2}\right\rangle = \bar{u}\left(P+\frac{\Delta}{2}\right)\left[A(t)\gamma^{(\mu}P^{\nu)} + B(t)P^{(\mu}i\sigma^{\nu)\lambda}\frac{\Delta_\lambda}{2M} + \frac{C(t)}{M}(\Delta^\mu\Delta^\nu - \Delta^2\eta^{\mu\nu})\right]u\left(P-\frac{\Delta}{2}\right)$$

with $t = \Delta^2$.

- Key observation: **link between GPDs and gravitational form factors**

$$\int \mathrm{d}x\, x H^q(x,\xi,t) = A^q(t) + 4\xi^2 C^q(t)$$

$$\int \mathrm{d}x\, x E^q(x,\xi,t) = B^q(t) - 4\xi^2 C^q(t)$$

Ji, Phys. Rev. Lett. **78**, 610 (1997)

Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Spin sum rule:

$$\int \mathrm{d}x\, x\big(H^q(x,\xi,0) + E^q(x,\xi,0)\big) = A^q(0) + B^q(0) = 2J^q$$

Ji, Phys. Rev. Lett. **78**, 610 (1997)

- **Shear** and **pressure** of a hadron considered as a continuous medium:

Polyakov and Shuvaev, hep-ph/0207153

- **Energy density**, **tangential** and **radial pressures** of a hadron considered as a continuous medium.

Lorcé *et al.*, Eur. Phys. J. **C79**, 89 (2019)

Global fits with PARTONS

Physics case
Physical content
Experimental access

DVCS fits
Fit status
Neural network fits

Complementary analysis
TCS: Data-driven impact study
Pressure forces

Framework
Design

Conclusion

- **Matrix element** in the Breit frame ($a = q, g$):

$$\left\langle \frac{\Delta}{2} \left| T_a^{\mu\nu}(0) \right| -\frac{\Delta}{2} \right\rangle = M \left\{ \eta^{\mu 0}\eta^{\nu 0} \left[A_a(t) + \frac{t}{4M^2} B_a(t) \right] + \eta^{\mu\nu} \left[\bar{C}_a(t) - \frac{t}{M^2} C_a(t) \right] + \frac{\Delta^\mu \Delta^\nu}{M^2} C_a(t) \right\}$$

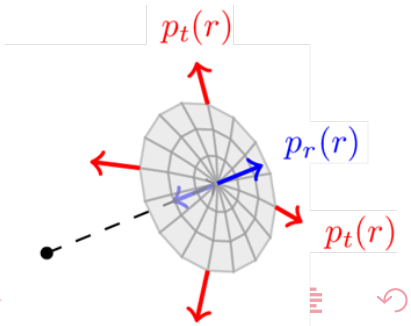
- Anisotropic fluid in **relativistic hydrodynamics**:

$$\Theta^{\mu\nu}(\vec{r}) = [\varepsilon(r) + p_t(r)]\, u^\mu u^\nu - p_t(r)\eta^{\mu\nu} + [p_r(r) - p_t(r)]\, \chi^\mu \chi^\nu$$

where u^μ and $\chi^\mu = x^\mu / r$.

- Define **isotropic pressure** and **pressure anisotropy**:

$$p(r) = \frac{p_r(r) + 2\, p_t(r)}{3}$$
$$s(r) = p_r(r) - p_t(r)$$



Global fits with PARTONS
Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

- Write dictionary between quantum and fluid pictures:

$$\frac{\varepsilon_a(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ A_a(t) + \bar{C}_a(t) + \frac{t}{4M^2}\left[B_a(t) - 4C_a(t)\right] \right\}$$

$$\frac{p_{r,a}(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ -\bar{C}_a(t) - \frac{4}{r^2}\frac{t^{-1/2}}{M^2}\frac{\mathrm{d}}{\mathrm{d}t}\left(t^{3/2}\, C_a(t)\right) \right\}$$

$$\frac{p_{t,a}(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ -\bar{C}_a(t) + \frac{4}{r^2}\frac{t^{-1/2}}{M^2}\frac{\mathrm{d}}{\mathrm{d}t}\left[t\frac{\mathrm{d}}{\mathrm{d}t}\left(t^{3/2}\, C_a(t)\right)\right] \right.$$

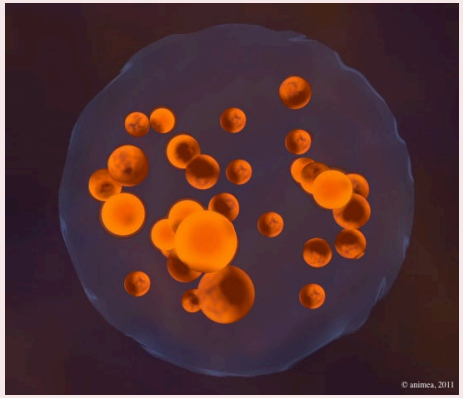
$$\frac{p_a(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ -\bar{C}_a(t) + \frac{2}{3}\frac{t}{M^2}\, C_a(t) \right\}$$

$$\frac{s_a(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ -\frac{4}{r^2}\frac{t^{-1/2}}{M^2}\frac{\mathrm{d}^2}{\mathrm{d}t^2}\left(t^{5/2}\, C_a(t)\right) \right\}$$

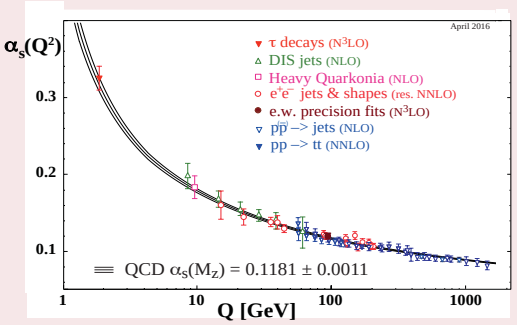
Perturbative and nonperturbative QCD.

Study nucleon structure to shed new light on nonperturbative QCD.

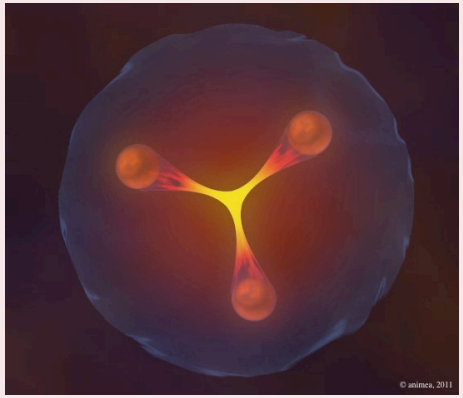
Perturbative QCD



Asymptotic freedom



Nonperturbative QCD



From experiment to theory

- Define **universal** objects describing 3D nucleon structure: **Generalized Parton Distributions** (GPD).
- Relate GPDs to measurements using **factorization**: **Virtual Compton Scattering** (DVCS, TCS), **Deeply Virtual Meson production** (DVMP).
- Get **experimental knowledge** of nucleon structure.

Perturbative and nonperturbative QCD.

Study nucleon structure to shed new light on nonperturbative QCD.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

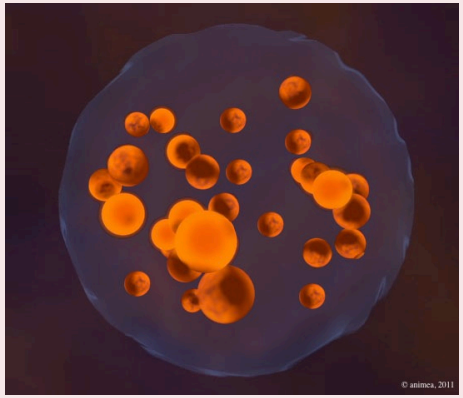
DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

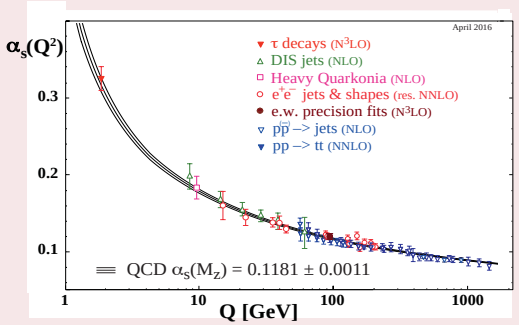
Framework
- Design

Conclusion

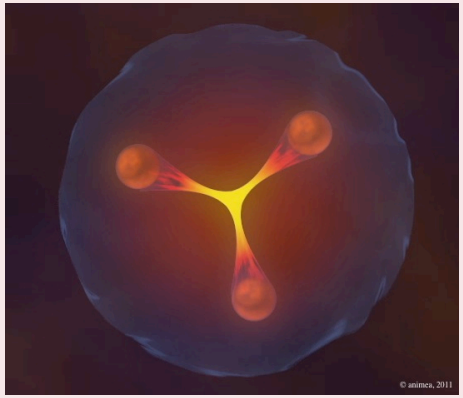
Perturbative QCD



Asymptotic freedom



Nonperturbative QCD



From theory to experiment

- Near-future: define and compute GPDs (*e.g.*lattice QCD).
- Relate GPDs to measurements using **factorization**: (DVCS, TCS,DVMP, ...).
- Use **theoretical knowledge** to directly compute observables and compare to measurements.

Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

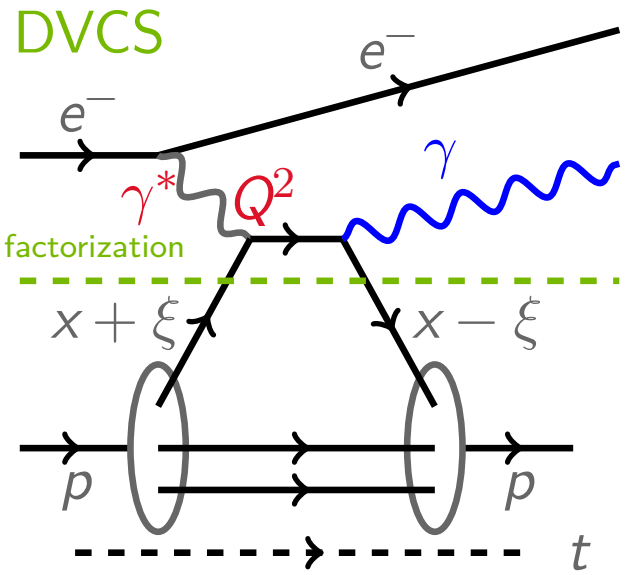
Physics case
- Physical content
- Experimental access

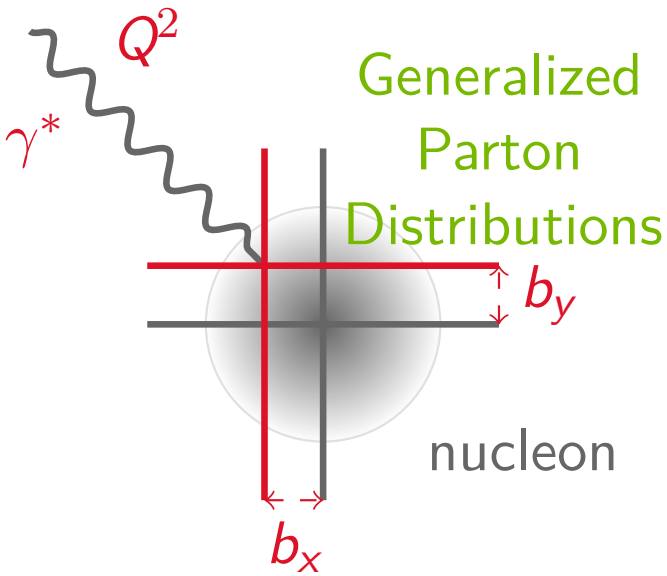
DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion





Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

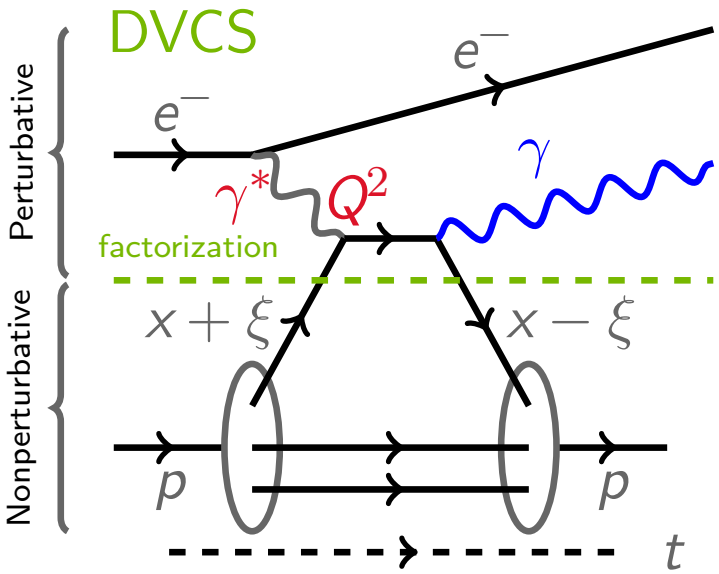
Physics case
- Physical content
- Experimental access

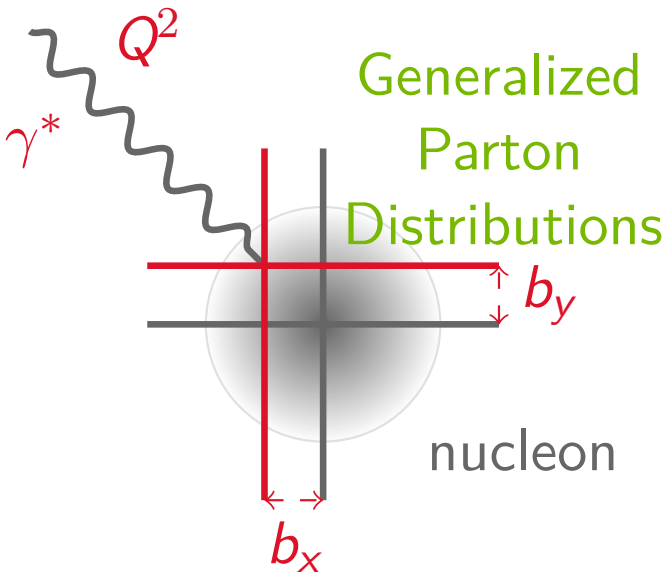
DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion





Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

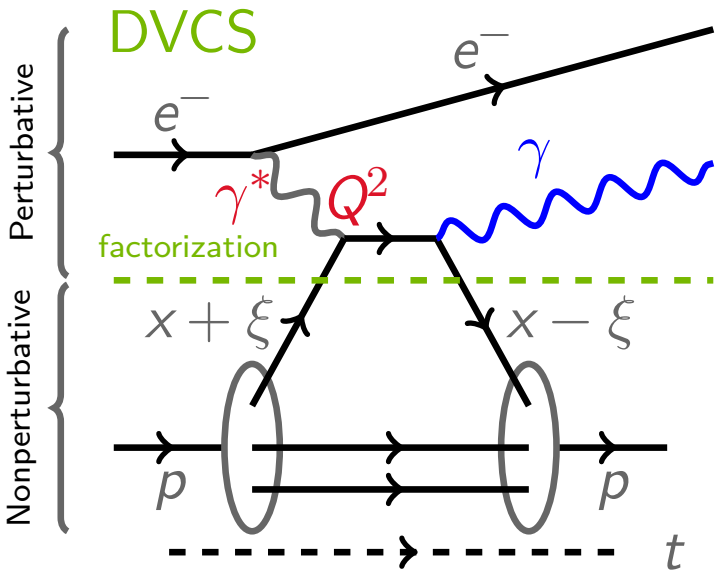
Physics case
- Physical content
- Experimental access

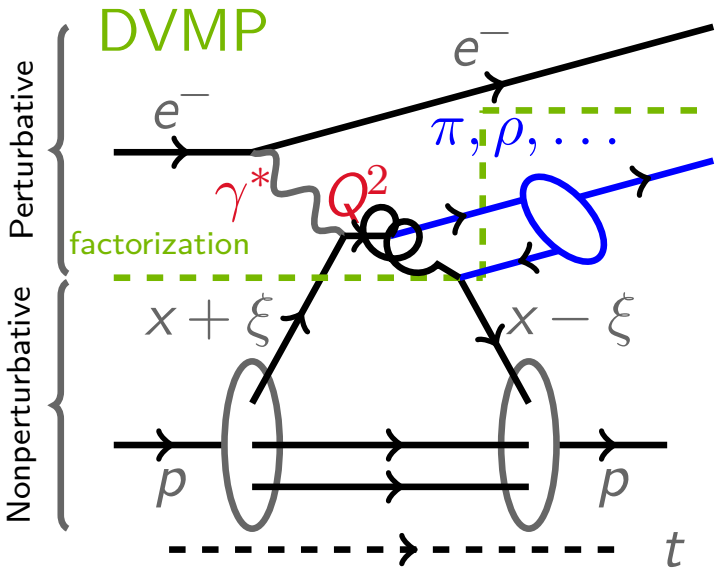
DVCS fits
- Fit status
- Neural network fits

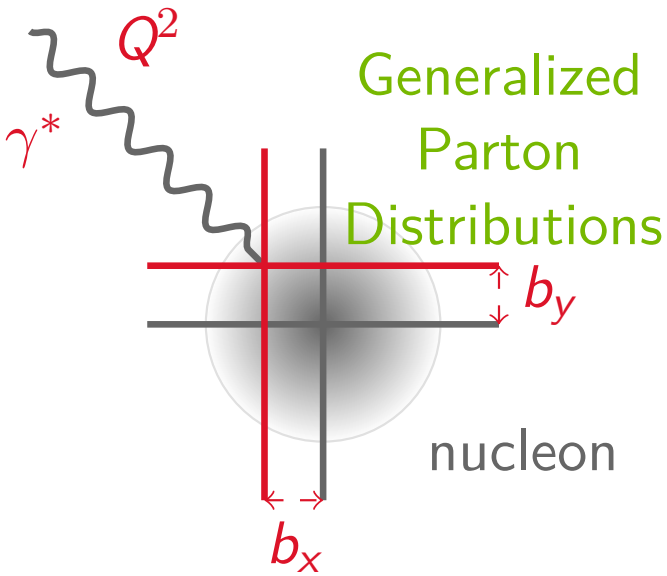
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion







Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

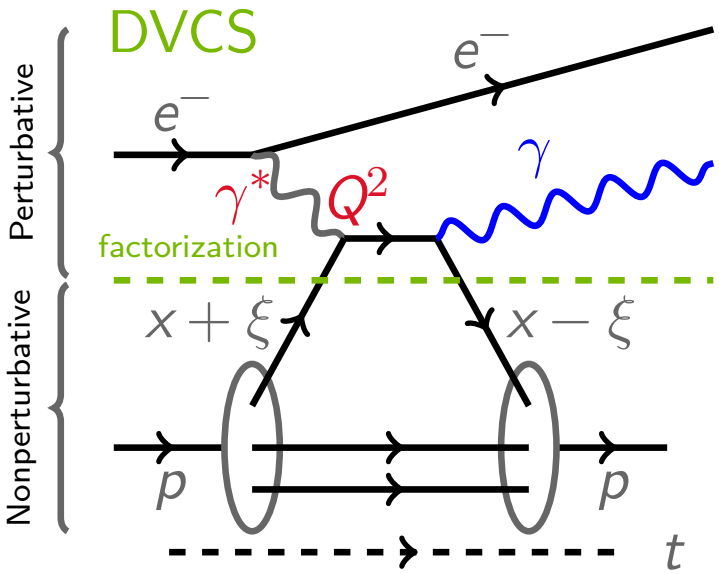
Physics case
- Physical content
- Experimental access

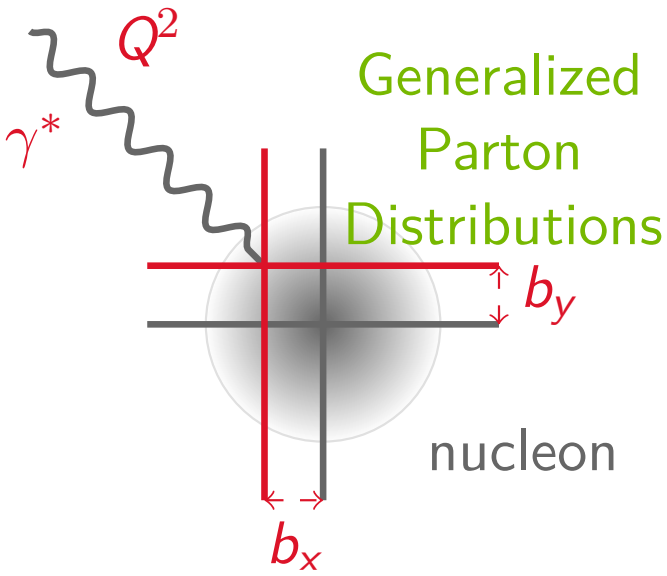
DVCS fits
- Fit status
- Neural network fits

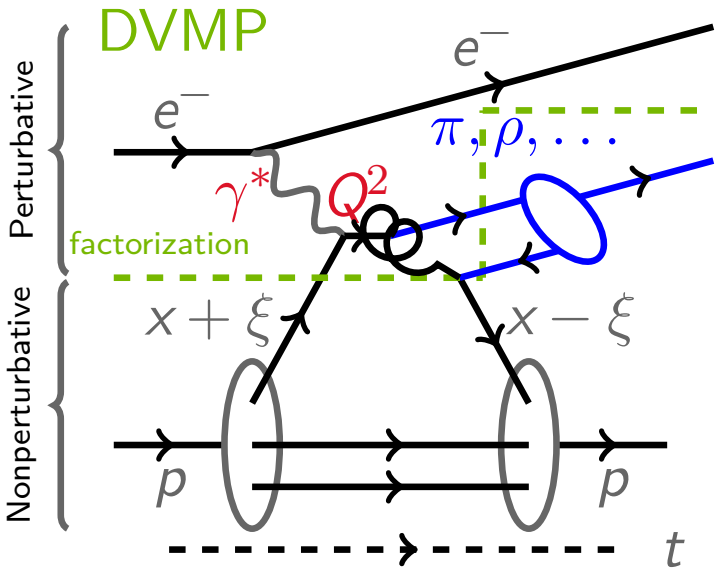
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

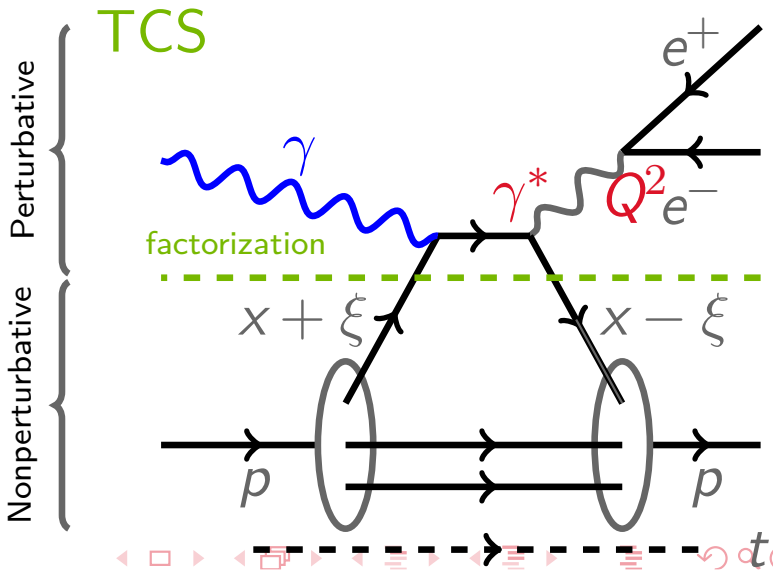
Framework
- Design

Conclusion









Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

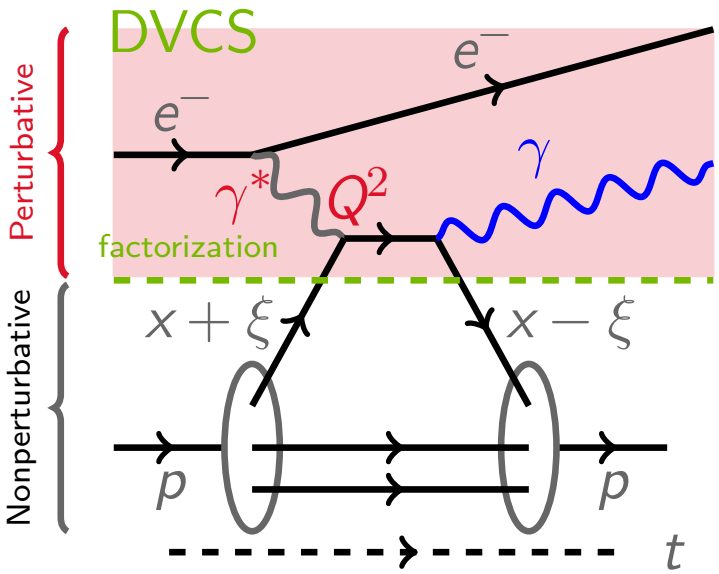
Physics case
- Physical content
- Experimental access

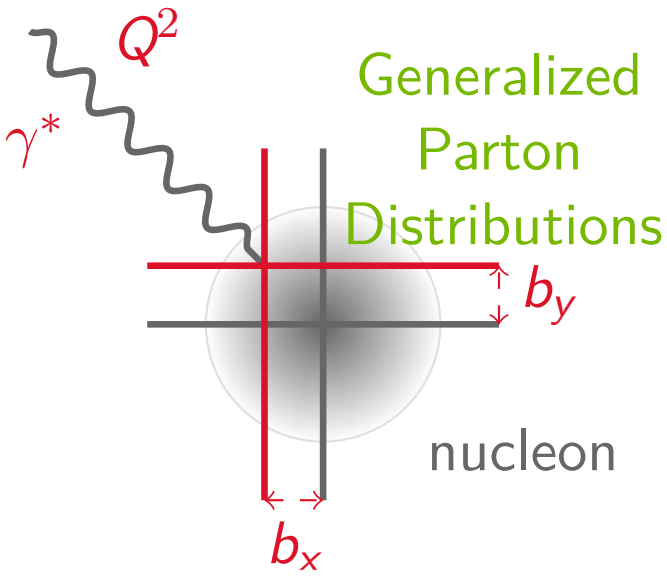
DVCS fits
- Fit status
- Neural network fits

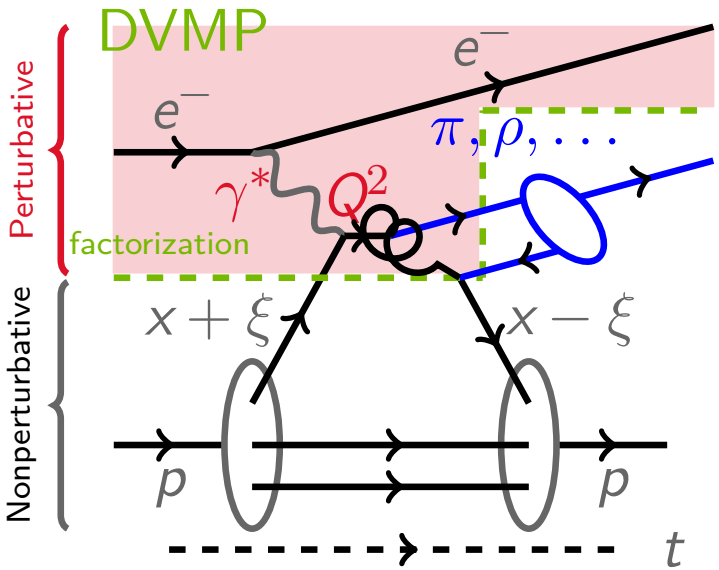
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

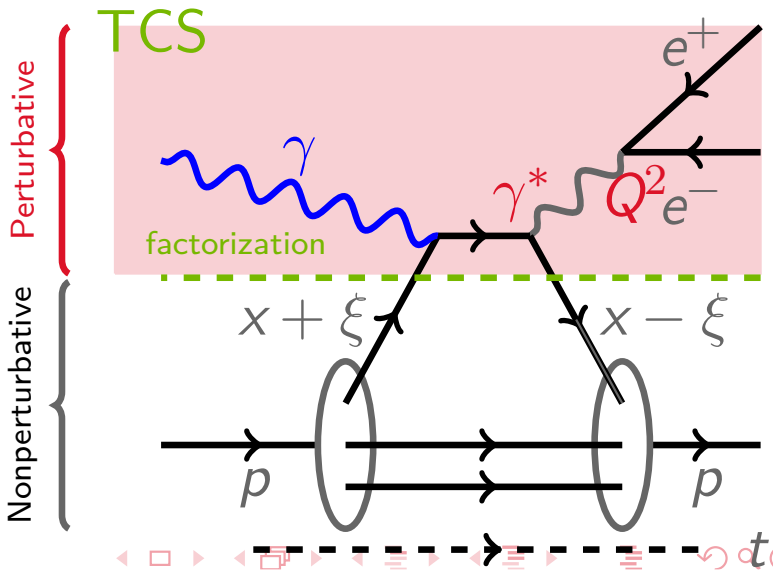
Framework
- Design

Conclusion









Exclusive processes of current interest.

Factorization and universality.

Global fits with PARTONS

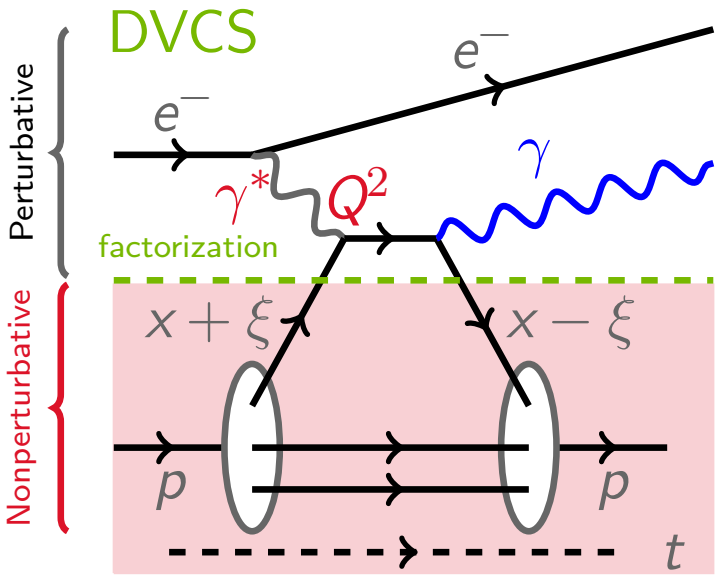
Physics case
- Physical content
- Experimental access

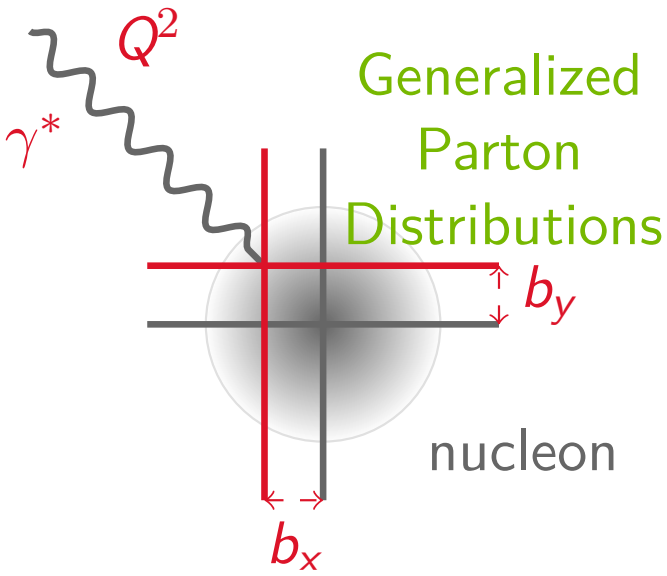
DVCS fits
- Fit status
- Neural network fits

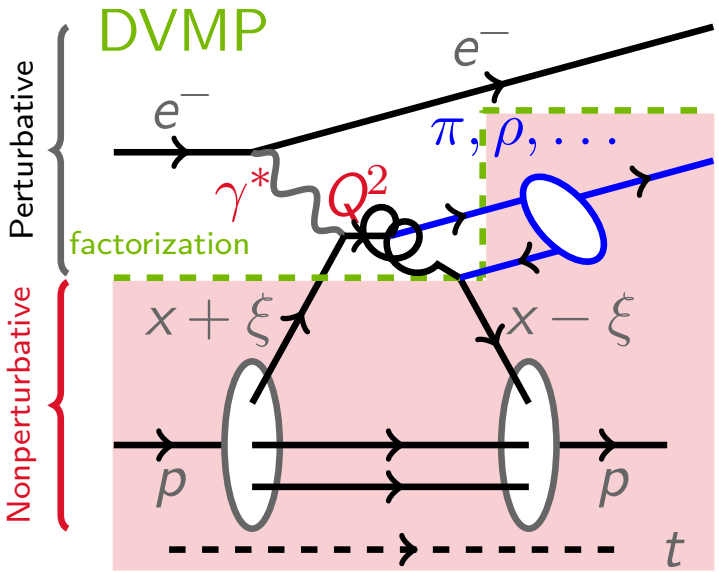
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

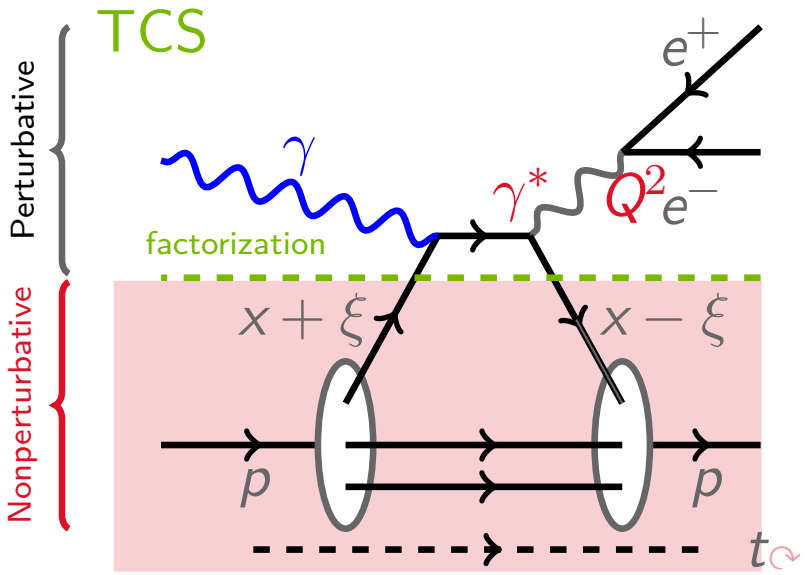
Framework
- Design

Conclusion









Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

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

- 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**.

Fits to deeply virtual Compton scattering

DVCS analysis and fits.

No global GPD fit has been obtained so far.

- GPD fits **only in the small x_B region** with a **flexible** parameterization (kinematic simplifications).
- Global fits of CFFs in the sea, valence and glue regions.
- Some GPD models with non-flexible parameterizations adjusted to experimental DVCS or DVMP data.

Kumerički *et al.*, Eur. Phys. J. **A52**, 157 (2016)

The situation is being improved!

- GPD parameterizations satisfying all theory constraints.

Chouika *et al.*, Eur. Phys. J. **C77**, 906 (2017)

- Computing framework to go beyond leading order and leading twist analysis.

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

- Global CFF fits of existing DVCS measurements.

Moutarde *et al.*, Eur. Phys. J. **C78**, 890 (2018), Eur. Phys. J. **C79**, 614 (2019)

Neural network global fit of CFFs.

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

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

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	$A_C^{\cos i\phi}$	$i=1$	t	4 / 4
3		2008	42	$A_C^{\cos i\phi}$	$i=0,1$	x_{Bj}	18 / 24
				$A_{UT,\mathrm{DVCS}}^{\sin(\phi-\phi_S)\cos i\phi}$	$i=0$		
				$A_{UT,\mathrm{I}}^{\sin(\phi-\phi_S)\cos i\phi}$	$i=0,1$		
				$A_{UT,\mathrm{I}}^{\cos(\phi-\phi_S)\sin i\phi}$	$i=1$		
4		2009	43	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	x_{Bj}	35 / 42
				$A_{LU,\mathrm{DVCS}}^{\sin i\phi}$	$i=1$		
				$A_C^{\cos i\phi}$	$i=0,1,2,3$		
5		2010	44	$A_{UL}^{+,\sin i\phi}$	$i=1,2,3$	x_{Bj}	18 / 24
				$A_{LL}^{+,\cos i\phi}$	$i=0,1,2$		
6		2011	45	$A_{LT,\mathrm{DVCS}}^{\cos(\phi-\phi_S)\cos i\phi}$	$i=0,1$	x_{Bj}	24 / 32
				$A_{LT,\mathrm{DVCS}}^{\sin(\phi-\phi_S)\sin i\phi}$	$i=1$		
				$A_{LT,\mathrm{I}}^{\cos(\phi-\phi_S)\cos i\phi}$	$i=0,1,2$		
				$A_{LT,\mathrm{I}}^{\sin(\phi-\phi_S)\sin i\phi}$	$i=1,2$		
7		2012	46	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	x_{Bj}	35 / 42
				$A_{LU,\mathrm{DVCS}}^{\sin i\phi}$	$i=1$		
				$A_C^{\cos i\phi}$	$i=0,1,2,3$		
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	$d^3\sigma^\pm_{UU}$		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	$d^3\sigma^\pm_{UU}$		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.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

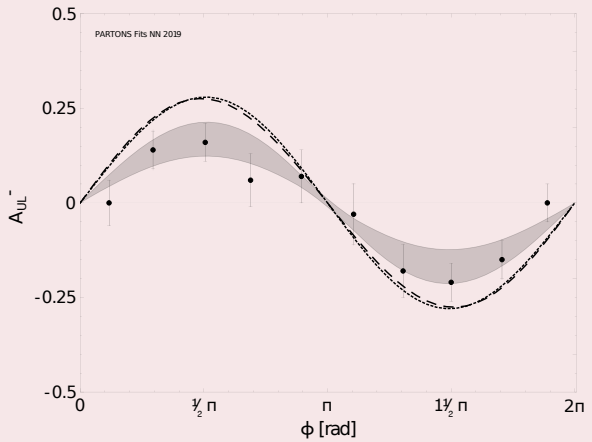
DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

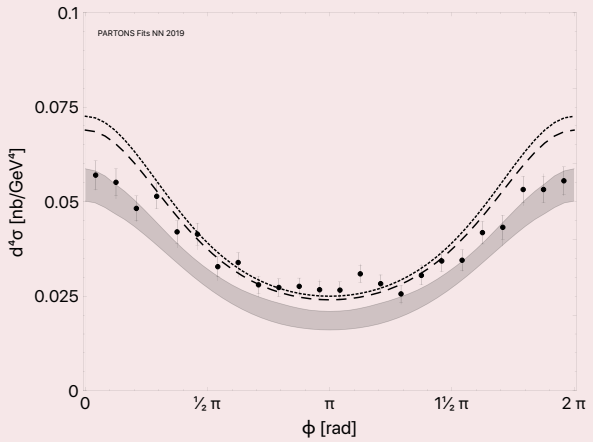
Framework
- Design

Conclusion

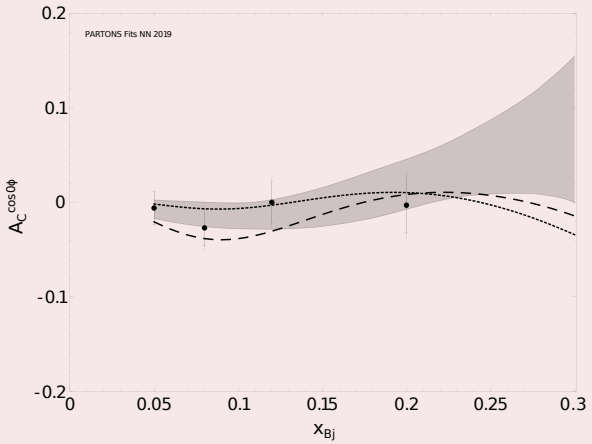
CLAS



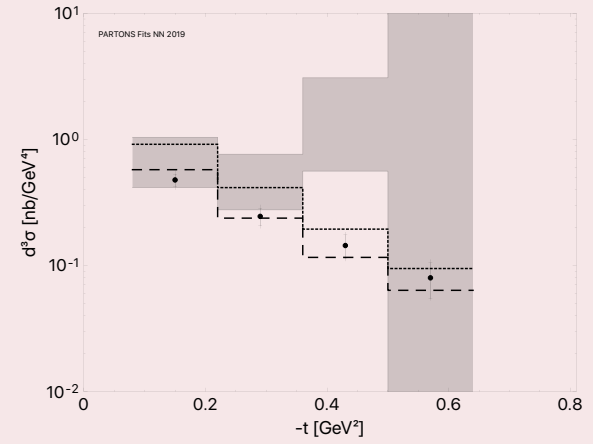
Hall A



HERMES



COMPASS



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

A selection of results.

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

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

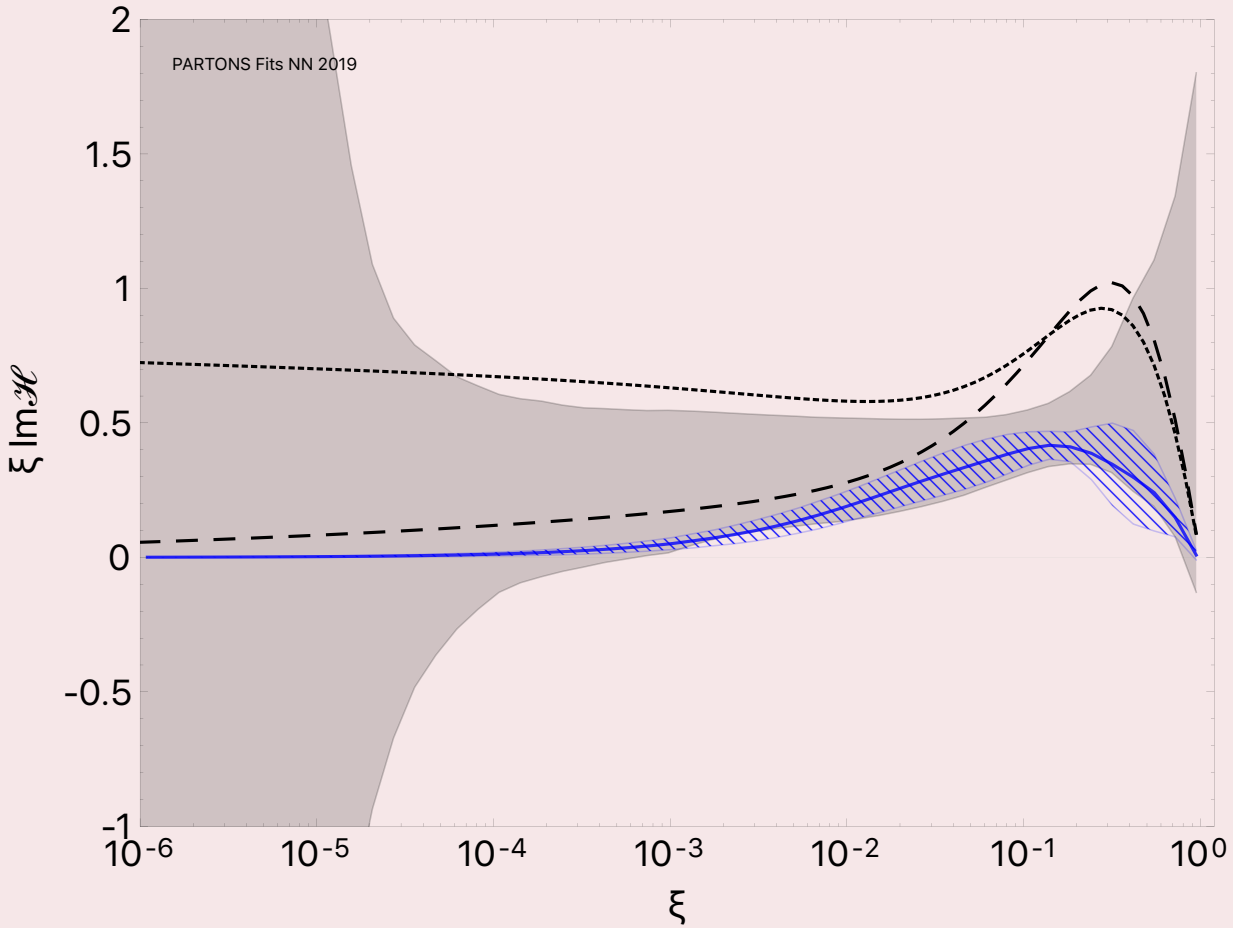
DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion

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



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

Complementary analysis

Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

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

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

with $\mathcal{Q}$ 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!
- Allow detailed studies of **sensitivity to higher-order contributions**.
- Towards **multi-channel fits** to exclusive processes!

From DVCS to TCS.

Prediction of TCS CFF at 68 % confidence level.

Global fits with PARTONS

Physics case
Physical content
Experimental access

DVCS fits
Fit status
Neural network fits

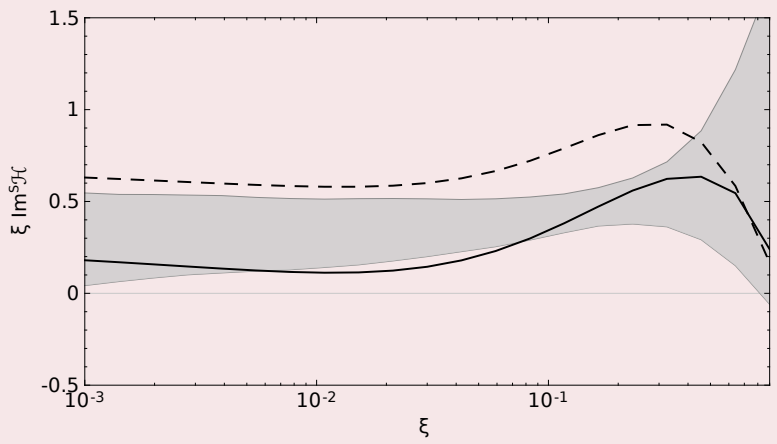
Complementary analysis
TCS: Data-driven impact study
Pressure forces

Framework
Design

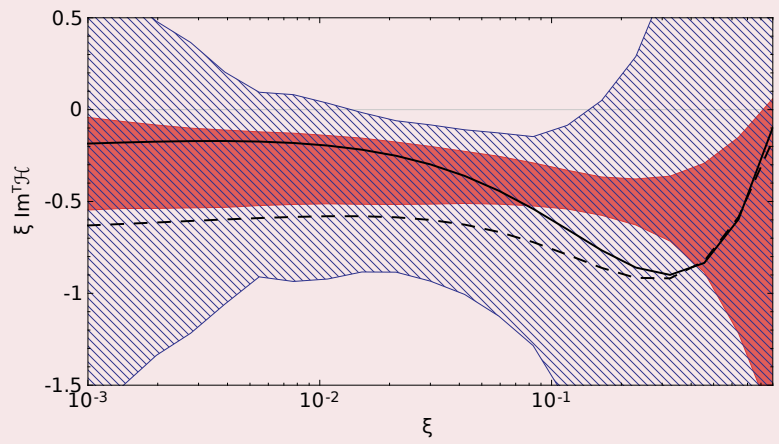
Conclusion

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

DVCS



TCS



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

From DVCS to TCS.

Prediction of TCS cross section at 68 % confidence level.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

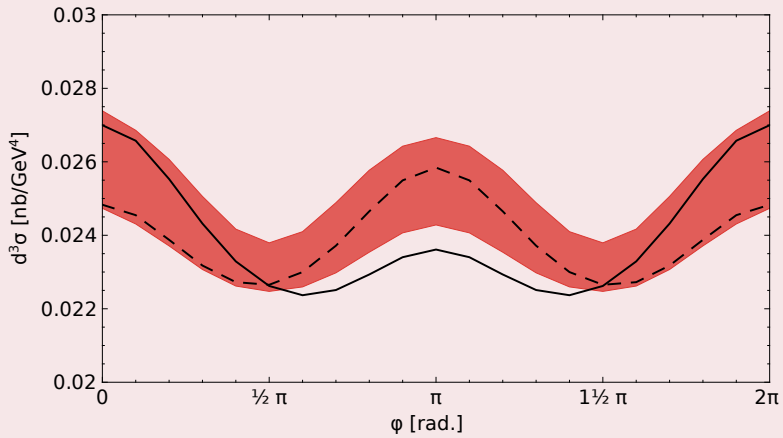
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

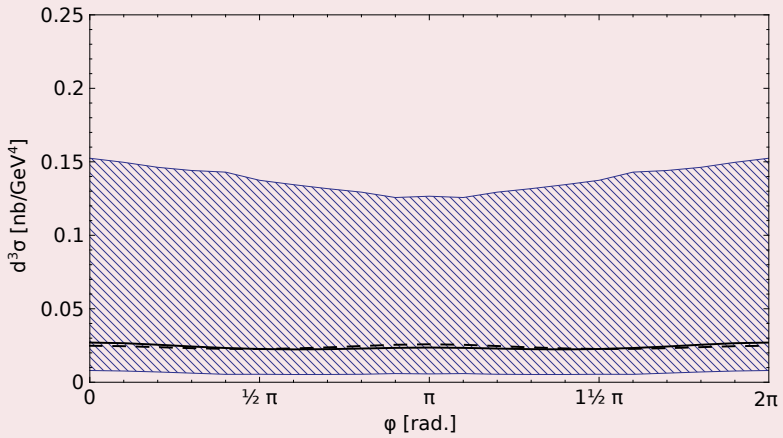
Conclusion

- TCS cross section integrated over $\theta \in (\pi/4, 3\pi/4)$ for $Q'^2 = 4$ GeV^2, $t = -0.1$ GeV^2 and photon beam energy $E_\gamma = 10$ GeV as a function of the angle ϕ.
- Large uncertainty reflecting our **limited knowledge** of DVCS CFFs, especially of their Q^2 dependence.
- **Big potential** of TCS measurements!

LO prediction



NLO prediction



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

Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

1. Expand D-term on Gegenbauer polynomials

$$D^q_{\text{term}}(z,t,\mu_F^2) = (1-z^2)\sum_{\text{odd } n} d^q_n(t,\mu_F^2)\, C_n^{3/2}(z)$$

2. Write dispersion relation for CFF

$$\mathcal{C}_H(t,Q^2) = \mathrm{Re}\mathcal{H}(\xi) - \frac{1}{\pi}\int_0^1 \mathrm{d}\xi'\, \mathrm{Im}\mathcal{H}(\xi)\left(\frac{1}{\xi-\xi'} - \frac{1}{\xi+\xi'}\right)$$

3. Compute subtraction constant

$$\mathcal{C}_H(t,Q^2) = 4\sum_q e_q^2 \sum_{\text{odd } n} d^q_n(t,\mu_F^2 \equiv Q^2)$$

4. Retrieve gravitational form factor

$$d^q_1(t,\mu_F^2) = 5\, C_q(t,\mu_F^2)$$

Pressure forces from DVCS measurements.

Working assumptions.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

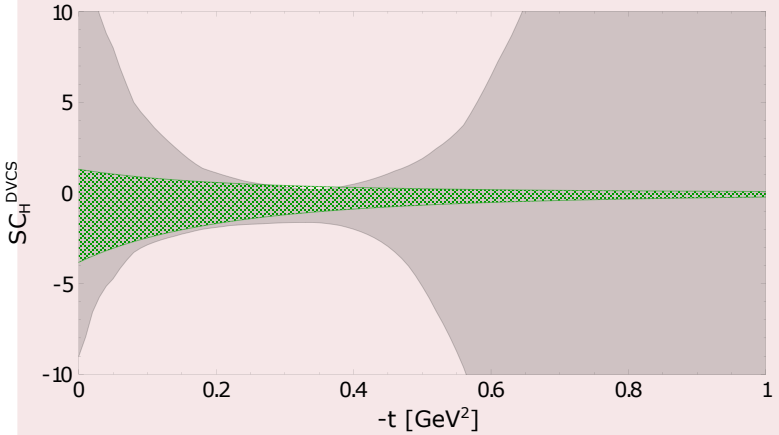
Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion

1. Subtraction constant assumed equal to d_1.
2. Equal values for light quark contributions.
3. Radiative generation of gluon and charm contributions.
4. Tripole Ansatz for the t-dependence of d_1.

Preliminary



Parameter	Value
$d_1^{uds}(\mu_F^2)$	-0.45 ± 0.92
$d_1^{c}(\mu_F^2)$	-0.0020 ± 0.0041
$d_1^{g}(\mu_F^2)$	-0.6 ± 1.3

The PARTONS framework

PARtonic
Tomography
Of
Nucleon
Software

Computing chain design.

Differential studies: physical models and numerical methods.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

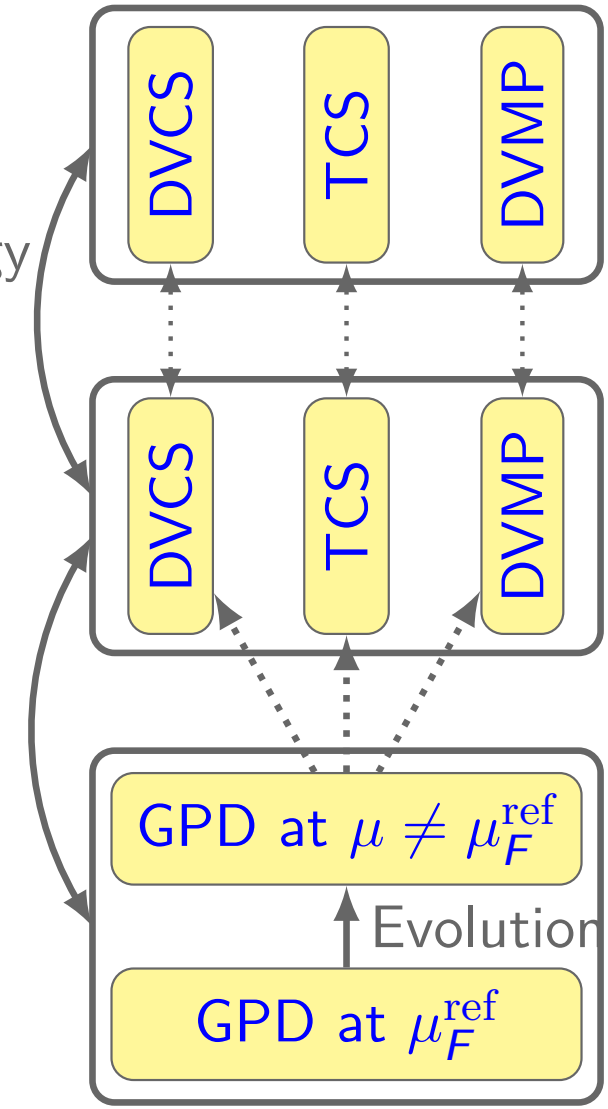
Framework
- Design

Conclusion

Full processes
Experimental data and phenomenology

Small distance
Computation of amplitudes

Large distance
First principles and fundamental parameters



PARtonic **T**omography **O**f **N**ucleon **S**oftware

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

Open source release.

Publicly available on CEA GitLab server.

Global fits with PARTONS

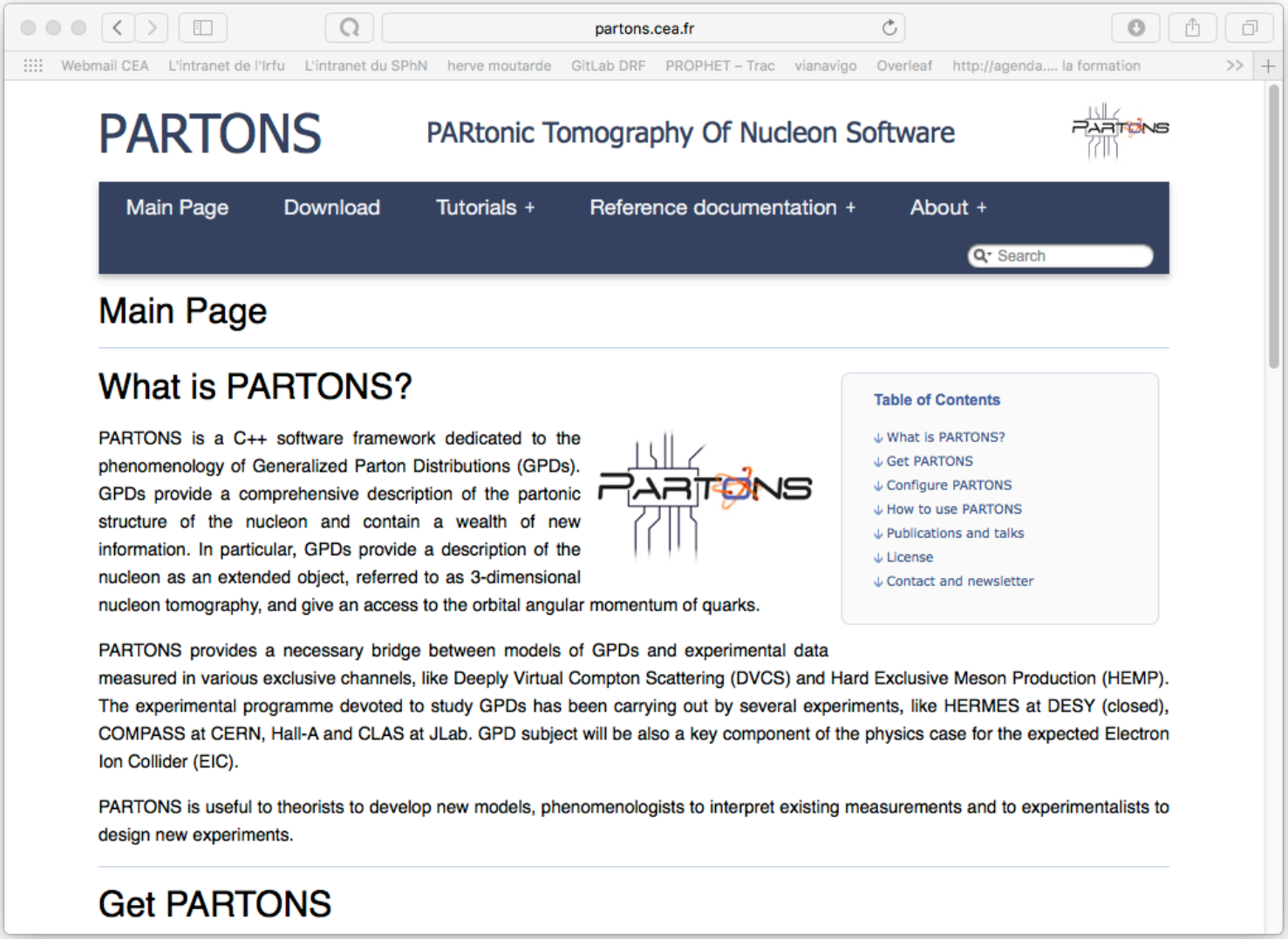
Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

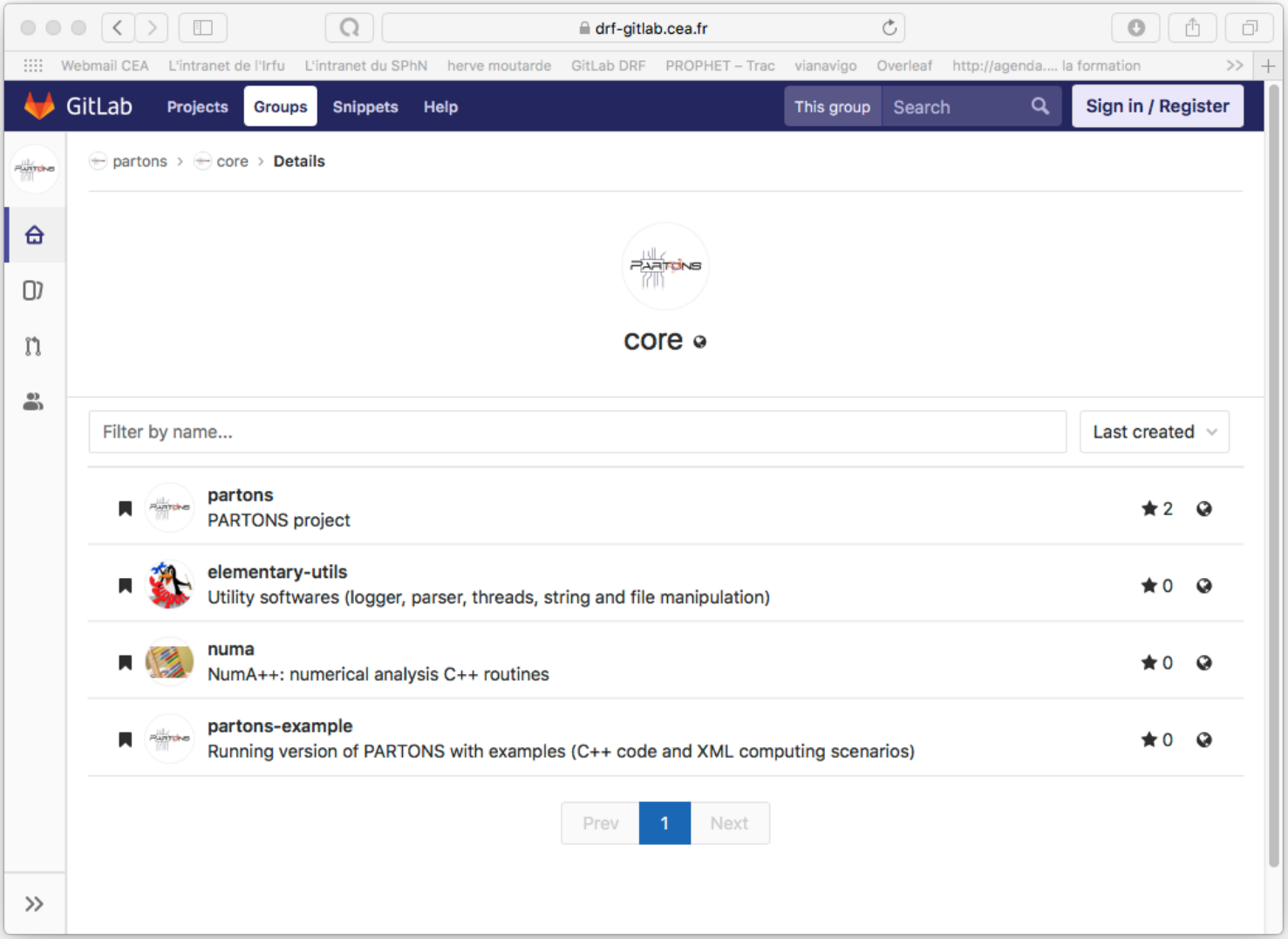
Conclusion



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

Open source release.

Publicly available on CEA GitLab server.



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

Open source release.

Publicly available on CEA GitLab server.

Global fits with PARTONS

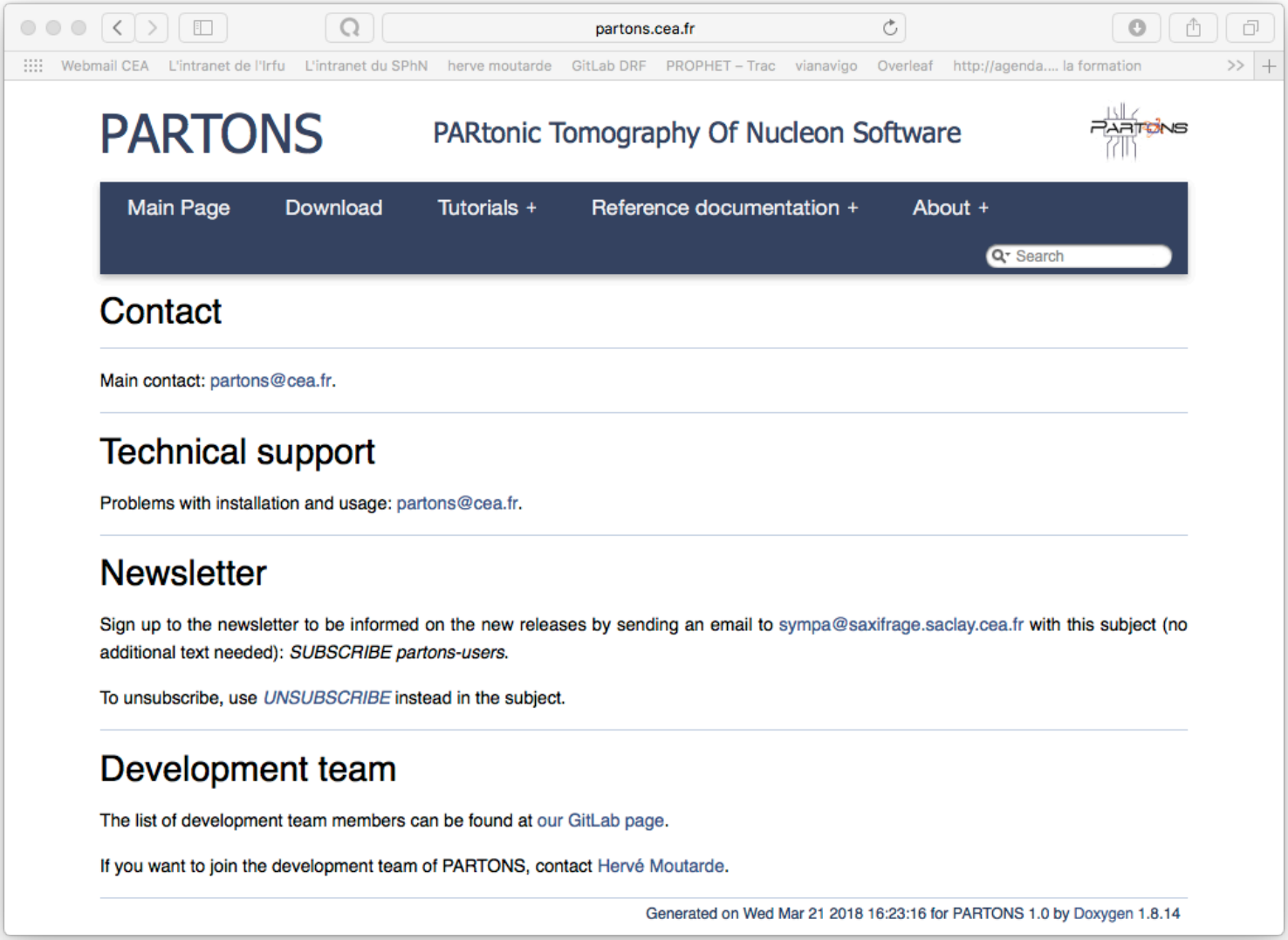
Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion



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

Within the next three years.

Virtual Access Infrastructure 3DPartons in STRONG-2020.

Global fits with PARTONS

Physics case
- Physical content
- Experimental access

DVCS fits
- Fit status
- Neural network fits

Complementary analysis
- TCS: Data-driven impact study
- Pressure forces

Framework
- Design

Conclusion

Work Package objectives

- Aggregate, improve and homogenize existing codes written by independent groups from the GPD and TMD communities: **ensure interoperability**.
- Maintain and release robust, flexible, validated and up-to-date open source codes to the 3D hadron structure community: **foster progress**.
- Provide documentation, technical assistance and perform nonregression tests: **facilitate dissemination**.
- Promote Open Data and Open Science: **build on previous research and get new results faster**.

Global fits with PARTONS

Physics case
Physical content
Experimental access
DVCS fits
Fit status
Neural network fits
Complementary analysis
TCS: Data-driven impact study
Pressure forces
Framework
Design
Conclusion

Work Package tasks

- Flexible software architecture for GPD and TMD codes, elaborating on existing libraries and benefiting from experience from the PDF community.
- Generic MC event generators for GPDs and TMDs.
- Associated tools to compare theoretical calculations to experimental data.
- 3DPartons workshops and training schools.
- Webpage, software forge and mailing lists.
- Interact with relevant Work Packages of STRONG-2020.

Conclusion

Conclusion and prospects.

Putting all the pieces together.

Global fits with PARTONS

Physics case
Physical content
Experimental access

DVCS fits
Fit status
Neural network fits

Complementary analysis
TCS: Data-driven impact study
Pressure forces

Framework
Design

Conclusion

- We now have tools to **systematically relate** models to **experimental data** in **multi-channel** analysis.
- We now have an **operating engine** for global CFF fits.
- Next step: GPD fits.

New studies become possible!

- Global GPD fits.
- Energy-momentum structure of hadrons.
- Quantitative impact of nonperturbative QCD ingredients on 3D hadron structure studies.
- GPD and TMD studies in a common framework.
- ... And probably much more!

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex
T. +33(0)1 69 08 73 88 | F. +33(0)1 69 08 75 84

DRF
Irfu
DPhN

Etablissement public à caractère industriel et commercial | R.C.S. Paris B 775 685 019