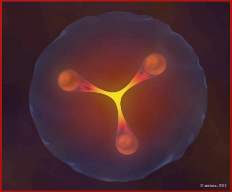
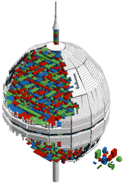
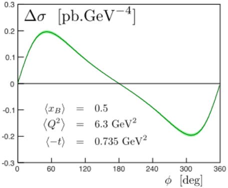
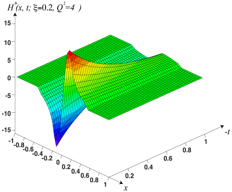
DE LA RECHERCHE À L'INDUSTRIE

Towards event generation for GPD physics with PARTONS









MCEGs for future ep and eA facilities | H. Moutarde

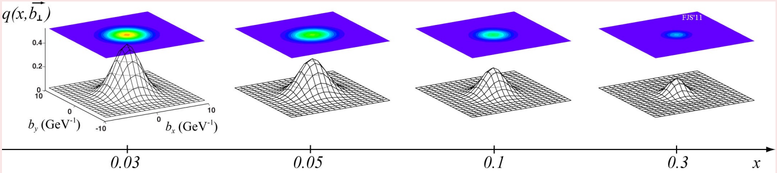
Feb. 21, 2019

Motivations.

Most frequent justifications of experimental programs.

- Correlation of the **longitudinal momentum** and the **transverse position** of a parton in the nucleon.
- Insights on:
  - **Spin** structure,
  - **Energy-momentum** structure.
- **Probabilistic interpretation** of Fourier transform of $\mathrm{GPD}(x, \xi = 0, t)$ in **transverse plane**.

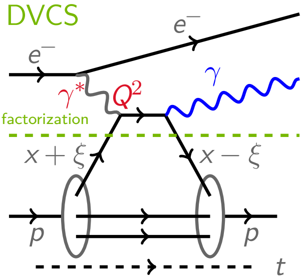
Nucleon tomography)

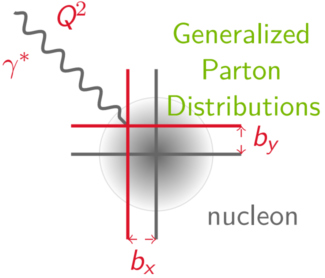


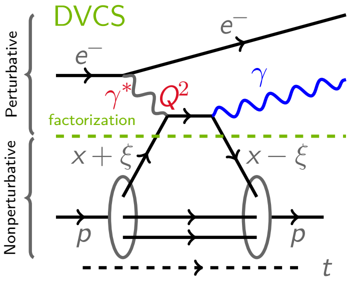
Requirements.

From the justifications to the scientific output.

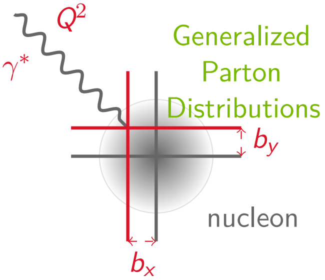
- Well-defined **hadronic observables** related to well-defined **partonic quantities** thanks to **factorization theorems**.
  - Check kinematics.
  - Check presence of higher-twists.
  - Check factorization scale dependence.
  - Check universality of GPDs.
  - Propagate experimental uncertainties, estimate theoretical uncertainties.
- Well-defined **derived quantities** which can be obtained from GPDs.
  - Extrapolate out of experimental kinematic domain.
  - Propagate uncertainties.
- Not-so-well-defined **interpretations** of derived quantities.
  - Relation to confinement?
  - Relation to chiral symmetry breaking?
  - Relation to mass gap existence?


DVCS
e−
e−
γ*
Q2
γ
factorization
x + ξ
x − ξ
p
p
t


Q2
γ*
Generalized
Parton
Distributions
by
nucleon
bx



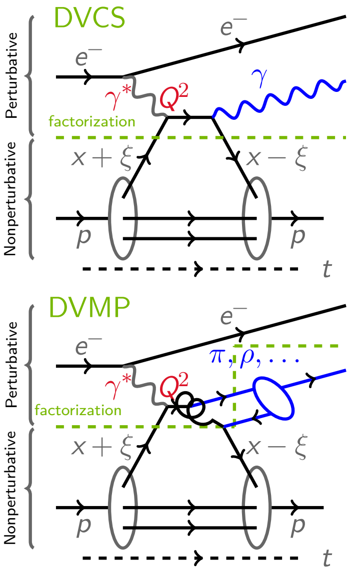
DVCS
Perturbative
Nonperturbative
e^-
e^-
γ^*
Q^2
γ
factorization
$x+\xi$
$x-\xi$
p
p
t

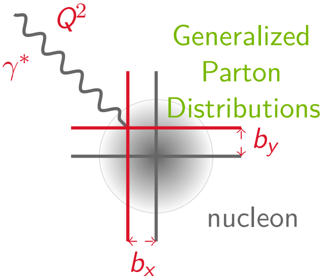


Q^2
γ^*
Generalized
Parton
Distributions
b_y
b_x
nucleon

How does it work?

Exclusive processes of current interest.





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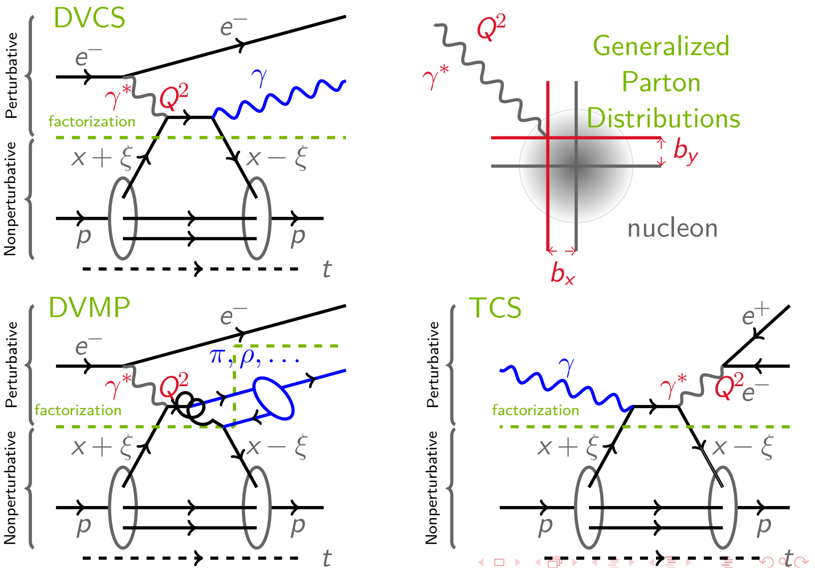

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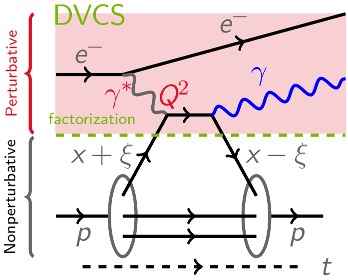

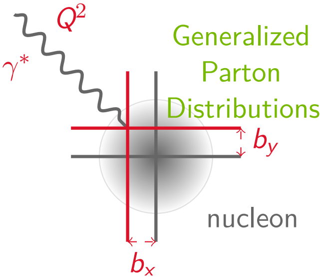

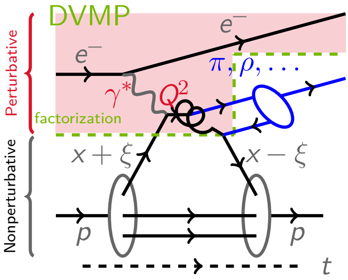

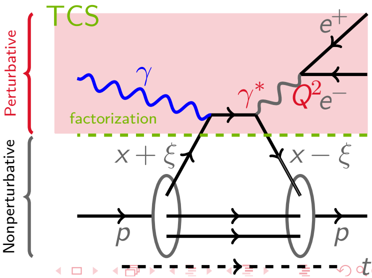

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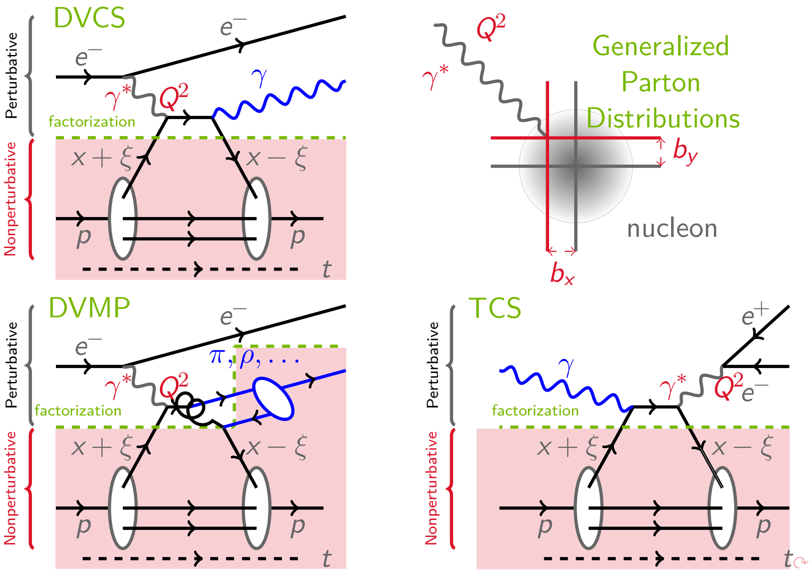


How does it work?
Factorization for DVCS.

- 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.

- Integration kernels C have been worked out at NLO.

  Belitsky and Müller, Phys. Lett. **B417**, 129 (1998)

- CFF $\mathcal{F}$ is a **complex function**.
- Observables are essentially **quadratic functions** of several different CFFs.

Computing strategy.

Three different blocks in an actual computation.

Experimental data and phenomenology	Full processes
Computation of amplitudes	Small distance contributions
First principles and fundamental parameters	Large distance contributions

Computing strategy.

Three different blocks in an actual computation.

Experimental data and phenomenology	Full processes
Computation of amplitudes	Small distance contributions
First principles and fundamental parameters	Large distance contributions

- Many observables.
- Work at the level of CFFs or GPDs.

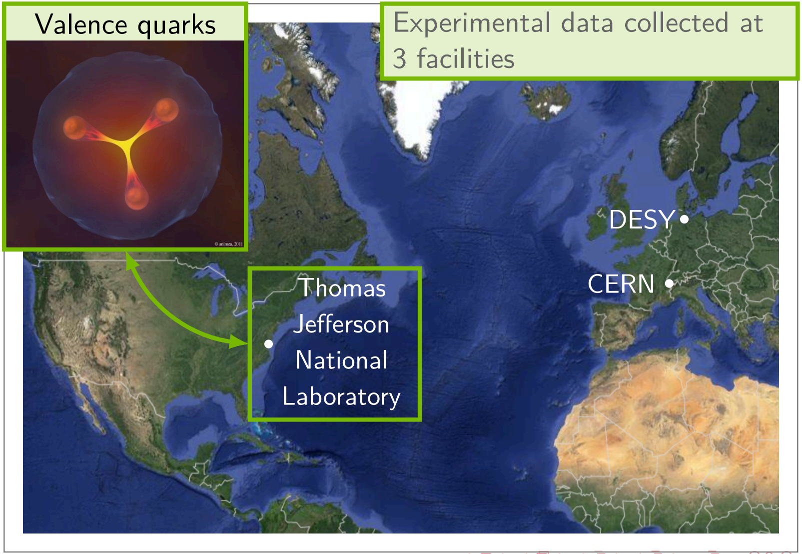
Need for global fits of world data.

Different facilities will probe different kinematic domains.

Experimental data collected at 3 facilities

Need for global fits of world data.

Different facilities will probe different kinematic domains.



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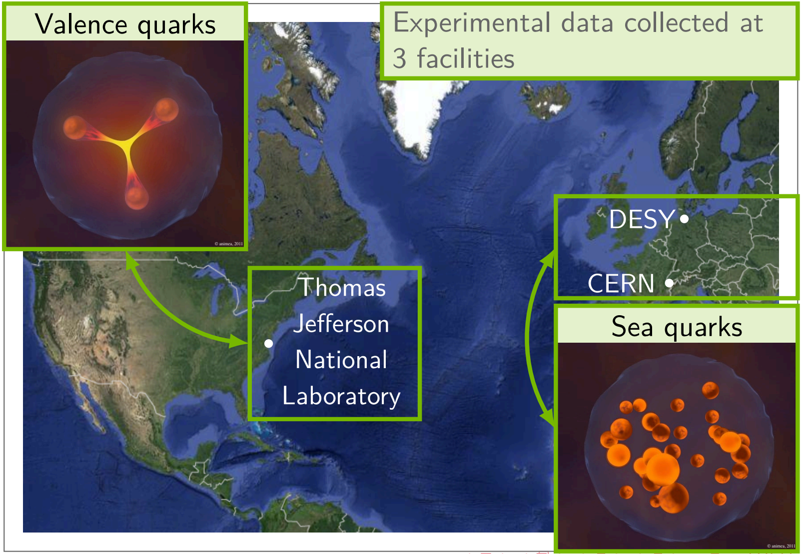

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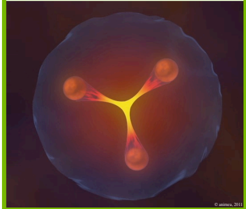
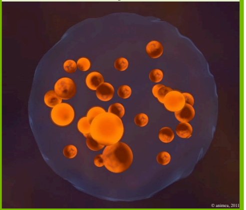
Valence quarks



Experimental data collected at 3 facilities, soon 4:EIC !

DESY
CERN
Thomas Jefferson National Laboratory

Sea quarks



Gluons

NSAC, Long Range Plan 2015:
"We recommend [...] EIC as the highest priority for new facility construction"

Experimental data and phenomenology	Full processes
Computation of amplitudes	Small distance contributions
First principles and fundamental parameters	Large distance contributions

Computing chain design.
Differential studies: physical models and numerical methods.

Experimental data and phenomenology — **Full processes**

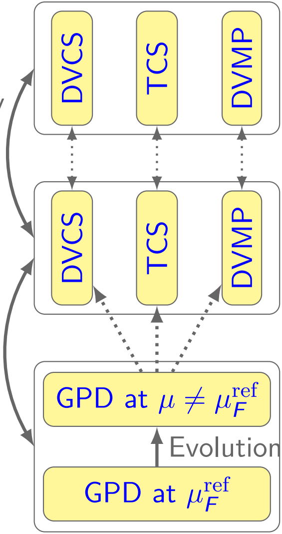
Computation of amplitudes — **Small distance contributions**

First principles and fundamental parameters — **Large distance contributions**

Experimental data and phenomenology

Computation of amplitudes

First principles and fundamental parameters



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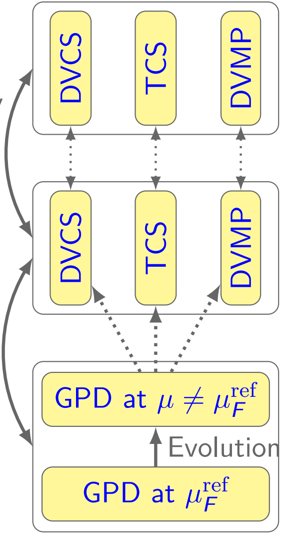
Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Computation of amplitudes

First principles and fundamental parameters



- Many observables.
- Kinematic reach.

Computing chain design.

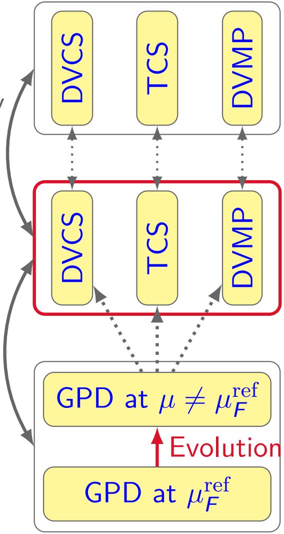
Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Need for modularity

Computation of amplitudes

First principles and fundamental parameters



- Many observables.
- Kinematic reach.

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

Computing chain design.

Differential studies: physical models and numerical methods.

Experimental data and phenomenology

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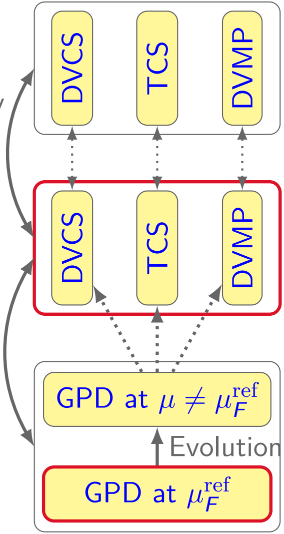
Computation of amplitudes

First principles and fundamental parameters



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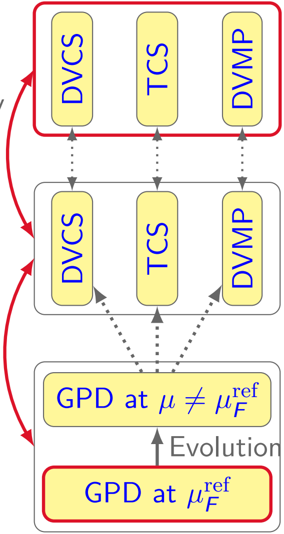

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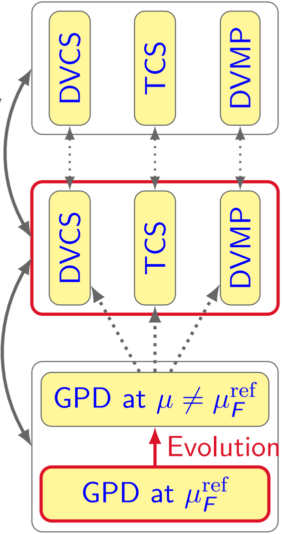

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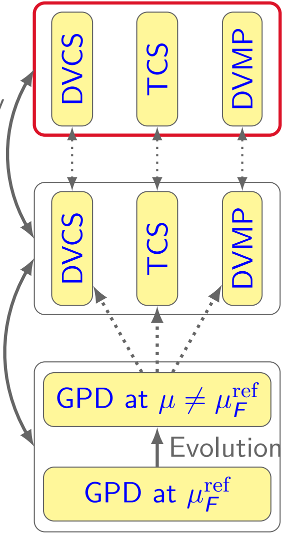


- Many observables.
- Kinematic reach.

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

Requirements.

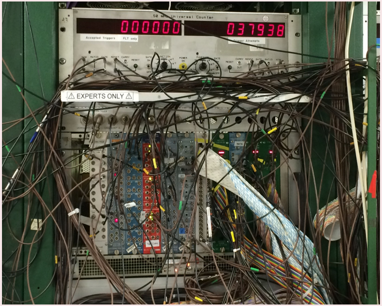
Users and developers should not be forgotten!

- Long-term perspective: future users or developers (when EIC takes data!) will not have taken part to the design.
- Need for a **robust** long-term solution to *aggregate* **knowledge** and **know-how**:
  - Models
  - Measurements
  - Numerical techniques
  - Validation
- Open architecture: it should be easy to add new modules.
- 1 new physical development = 1 new module.
- What *can* be automated *will be* automated.

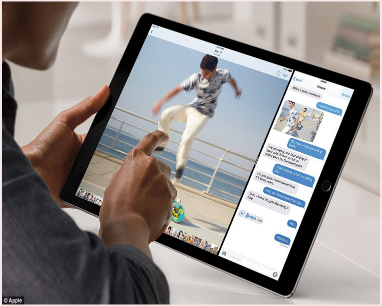
Automation allows...:

- to run **numerous computations** with various physical assumptions,
- to run **nonregression** tests.
- to perform **fits** with various models.
- physicists to **focus on physics**!

Without automation

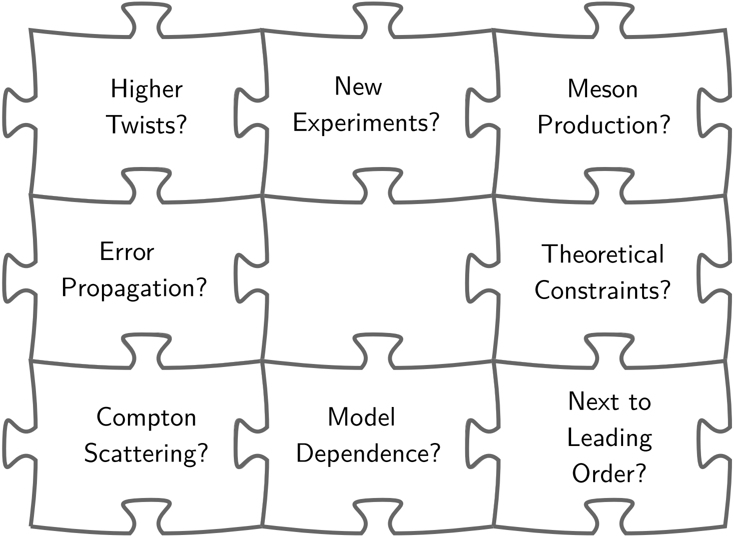


With automation



The PARTONS framework.

Different questions to be answered with the same tools.



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

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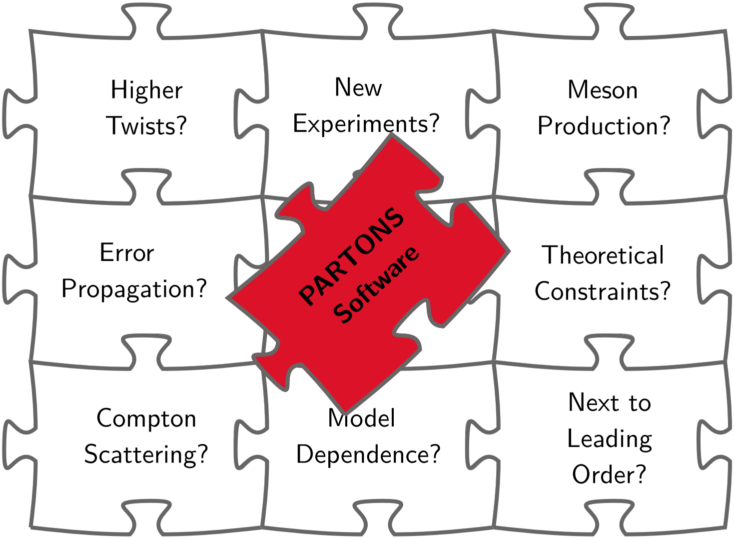


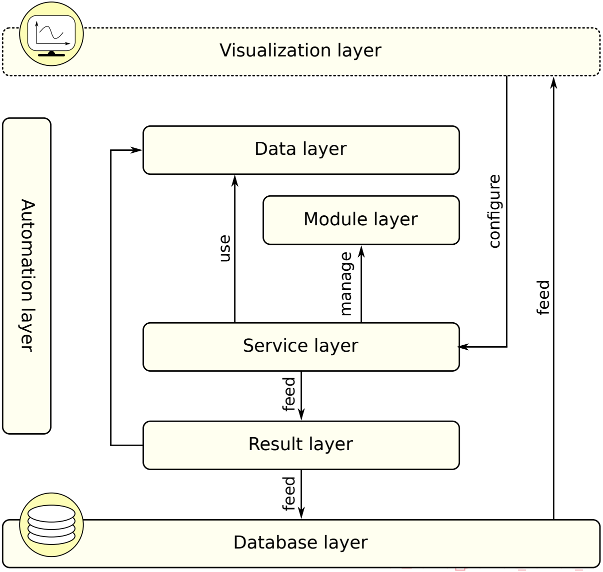
B. Berthou *et al.*, Eur. Phys. J. **C78**, 478 (2018)

The PARTONS framework

PARtonic
Tomography
Of
Nucleon
Software

Modularity and layer structure.

Modifying one layer does not affect the other layers.



- From the computing point of view, several questions in common with the TMD codes.
- Need for event generation for the design of new experiments.
- **3DPartons**: a *Virtual Access Infrastructure* funded through the STRONG2020 project (2019-2023).
  - Mutualize developments as much as possible.
  - Common development framework: non-regression, testing, documentation, visualization.
  - An attempt at generic MC generators.

First release content.

DVCS channel only.

GPD modules

- GK
- VGG
- Vinnikov (evolution)
- MPSSW13 (NLO study)
- MMS13 (DD study)

DVCS modules

- VGG
- GV
- BMJ

CFF modules

- LO
- NLO
- NLO Noritzsch

Evolution modules

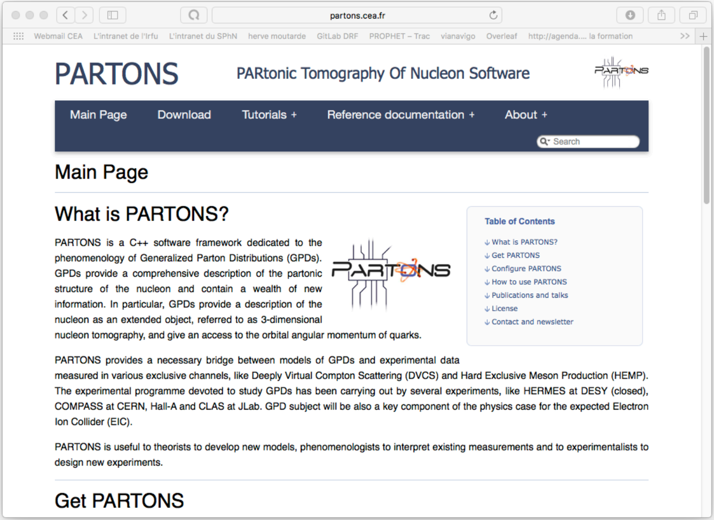
- Vinnikov (LO)

α_s modules

- 4-loop perturbation
- constant value

Open source release.

Publicly available on CEA GitLab server.



partons.cea.fr

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PARTONS

PARtonic Tomography Of Nucleon Software

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Main Page

What is PARTONS?

PARTONS is a C++ software framework dedicated to the phenomenology of Generalized Parton Distributions (GPDs). GPDs provide a comprehensive description of the partonic structure of the nucleon and contain a wealth of new information. In particular, GPDs provide a description of the nucleon as an extended object, referred to as 3-dimensional nucleon tomography, and give an access to the orbital angular momentum of quarks.

Table of Contents

- What is PARTONS?
- Get PARTONS
- Configure PARTONS
- How to use PARTONS
- Publications and talks
- License
- Contact and newsletter

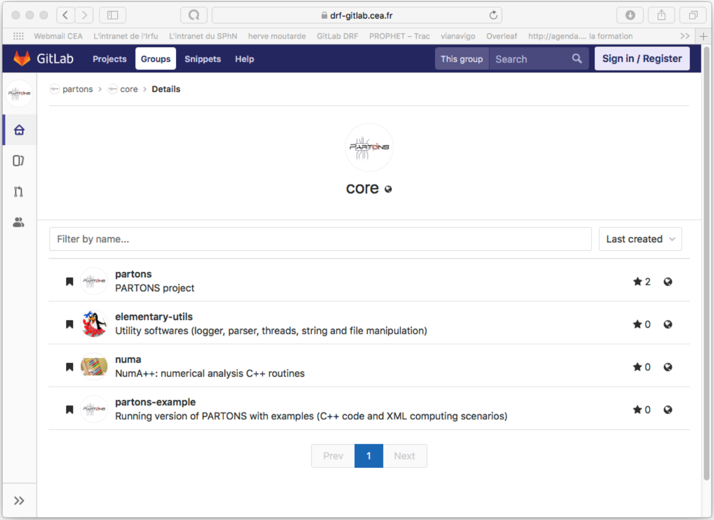
PARTONS provides a necessary bridge between models of GPDs and experimental data measured in various exclusive channels, like Deeply Virtual Compton Scattering (DVCS) and Hard Exclusive Meson Production (HEMP). The experimental programme devoted to study GPDs has been carrying out by several experiments, like HERMES at DESY (closed), COMPASS at CERN, Hall-A and CLAS at JLab. GPD subject will be also a key component of the physics case for the expected Electron Ion Collider (EIC).

PARTONS is useful to theorists to develop new models, phenomenologists to interpret existing measurements and to experimentalists to design new experiments.

Get PARTONS

Open source release.

Publicly available on CEA GitLab server.



Future releases.

A lot remains to be integrated...Contributors welcome!

Channel modules

- DVMP
- TCS
- γM production
- ???

Other modules

- Mellin moments
- ???

Event generator

- Interface
- ???

Hadron structure modules

- DAs
- DDs
- Form factors
- PDFs
- LFWFs
- ???

Nonperturbative QCD modules

- Gap equation solver
- ???

Results and prospects

- **Leading twist** and **leading order** analysis.
- Focus on the quark sector (intermediate to large x_B).
- Implementation of dispersion relations for CFFs.
- Fit to PDFs and elastic form factors.
- Propagate uncertainties by **replica method**.

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

Not yet a GPD fit to be used in an event generator, but close!

Selected DVCS measurements.

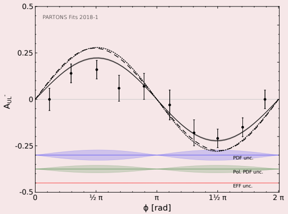
All existing sets except $d^4\sigma^-_{UU}$ from Hall A (2015-17) and HERA.

No.	Collab.	Year	Ref.	Observable		Kinematic dependence	No. of points used / all
1	HERMES	2001	[13]	A^+_{LU}		ϕ	10 / 10
2		2006	[114]	$A_C^{\cos i\phi}$	$i=1$	t	4 / 4
3		2008	[115]	$A_C^{\cos i\phi}$	$i=0,1$	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	[116]	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	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	[117]	$A_{UL}^{+,\sin i\phi}$	$i=1,2,3$	x_{Bj}	18 / 24
				$A_{LL}^{+,\cos i\phi}$	$i=0,1,2$		
6		2011	[118]	$A_{LT,\mathrm{DVCS}}^{\cos(\phi-\phi_S)\cos i\phi}$	$i=0,1$	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	[119]	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	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	[14]	$A_{LU}^{-,\sin i\phi}$	$i=1,2$	—	0 / 2
9		2006	[120]	$A_{UL}^{-,\sin i\phi}$	$i=1,2$	—	2 / 2
10		2008	[121]	A^-_{LU}		ϕ	283 / 737
11		2009	[122]	A^-_{LU}		ϕ	22 / 33
12		2015	[123]	A^-_{LU}, A^-_{UL}, A^-_{LL}		ϕ	311 / 497
13		2015	[124]	$d^4\sigma^-_{UU}$		ϕ	1333 / 1933
14	Hall A	2015	[112]	$\Delta d^4\sigma^-_{LU}$		ϕ	228 / 228
15		2017	[113]	$\Delta d^4\sigma^-_{LU}$		ϕ	276 / 358
16	COMPASS	2018	[55]	b		—	1 / 1
						SUM:	2600 / 3970

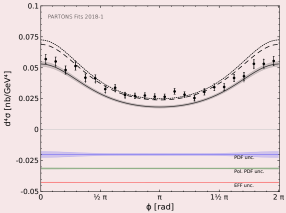
A selection of results.

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

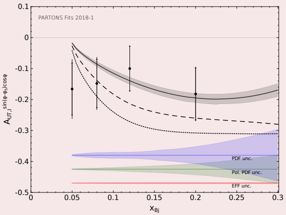
CLAS



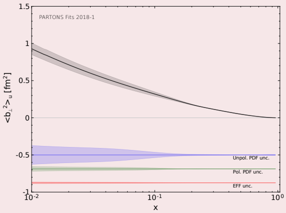
Hall A



HERMES



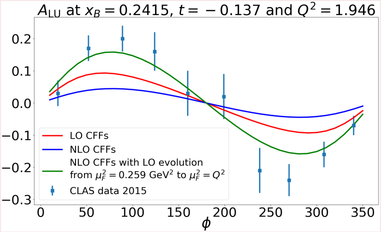
Distance to center of mass



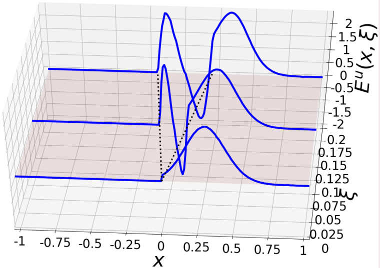
Towards GPD fits.

Basis for future GPD parameterizations for multi-channel fits.

CLAS 2015 data



E^u at $t = -0.34$ GeV^2



- Preliminary results: tests with the χQSM.
- Computation of **various DVCS observables** in the valence region under **different pQCD assumptions** with PARTONS.

Chouika, PhD thesis (2018)

Conclusion

A framework for (more than?) GPD studies.

From a software development to a physics production phase.

- Still **room for improvement** in first version but framework should become available to a wide community of users.
- Open source release under GPLv3.0.
- Please make any new module **available to the whole community** through the main PARTONS branch.
- It took years to design, write and validate PARTONS in C++. Physics is **now being produced** with it!
- Forthcoming v2 with TCS as a **demonstration of multi-channel capacity**.
- Extreme modularity should benefit to **event generation**. First thoughts about required architecture modifications.
- Extension **beyond GPD physics** through a *Virtual Access* structure within STRONG2020 program.

New!!

Junior staff position in theoretical hadron physics in Saclay in 2019.

The Nucleon Structure Laboratory (LSN) of CEA Paris-Saclay is opening a junior staff scientist position for an outstanding physicist in the field of theoretical hadron physics with a focus on the theory and phenomenology of the three dimensional structure of the nucleon.

[...]

The candidate will invest a significant amount of her/his time in leading the LSN efforts towards the theoretical analysis of current and forthcoming GPD-related experimental data using and further developing the PARTONS framework. [...] In addition, she/he is encouraged to support the LSN experimentalists in the development of an original and ambitious science program at the EIC.

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