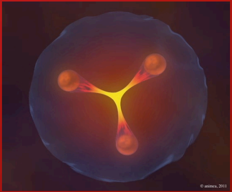
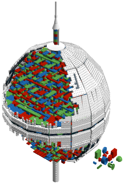
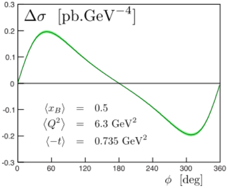
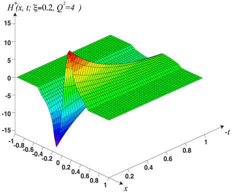
DE LA RECHERCHE À L'INDUSTRIE



Prospects on nucleon tomography







BNL Physics Colloquium | Hervé MOUTARDE

Apr. 3, 2018

université PARIS-SACLAY

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Foreword.

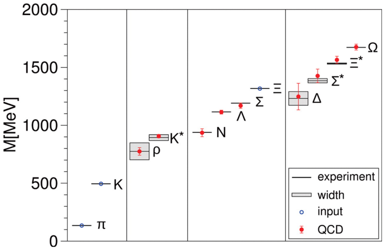
A decade of collaboration between IRFU and BNL.

Involvement in PHENIX (2000-10) and sPHENIX

- **Hardware** muon arms electronics
- **Software** Muon tracking, simulation
- **Analysis** J/psi in dd, d-Au, Au-Au

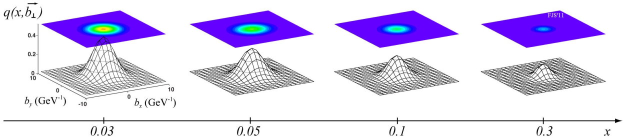
Today's talk: 3D hadron structure and the need for an EIC

- Lattice QCD clearly showed that the mass of hadrons is generated by the **interaction**, not by the quark masses.

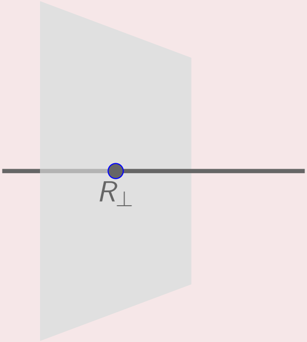


Durr *et al.*, Science **322**, 1224 (2008)

- Can we **map** the *location of mass* inside a hadron?



Manifestation of 3D nucleon structure in scattering processes?



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

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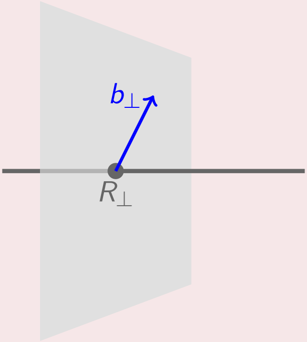

- Transverse center of momentum $R_\perp = \sum_i x_i r_{\perp i}$,
- Impact parameter $b_\perp$,

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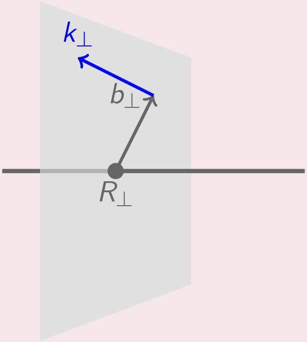

- Transverse center of momentum $R_\perp = \sum_i x_i r_{\perp i}$,
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- Transverse momentum $k_\perp$,

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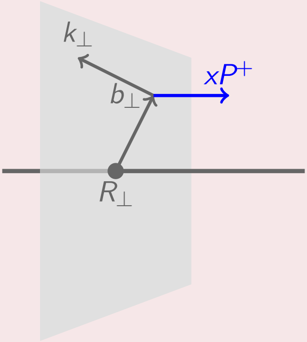
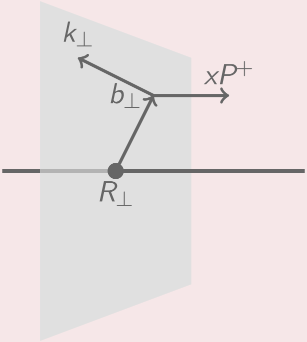


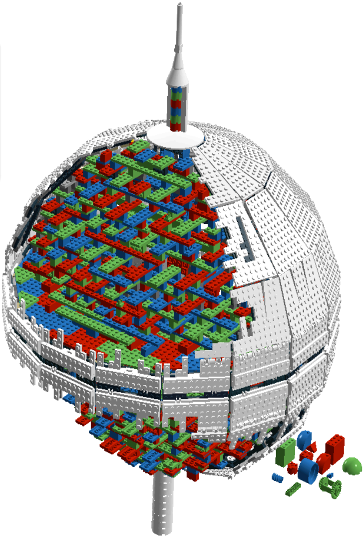
- Transverse center of momentum $R_\perp = \sum_i x_i r_{\perp i}$,
- Impact parameter $b_\perp$,
- Transverse momentum $k_\perp$,
- Longitudinal momentum xP^+.

Manifestation of 3D nucleon structure in scattering processes?



- Transverse center of momentum $R_\perp = \sum_i x_i r_{\perp i}$,
- Impact parameter $b_\perp$,
- Transverse momentum $k_\perp$,
- Longitudinal momentum xP^+.
- What is the distortion brought by spin?

How can we recover the well-known characteristics of the nucleon from the properties of its **colored building blocks**?



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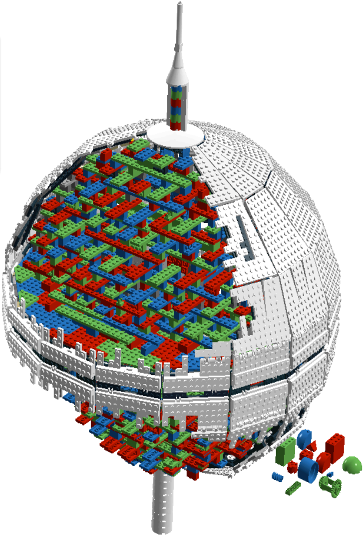
Mass?



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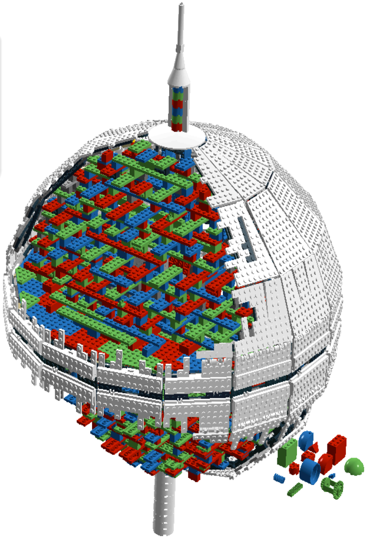
Spin?



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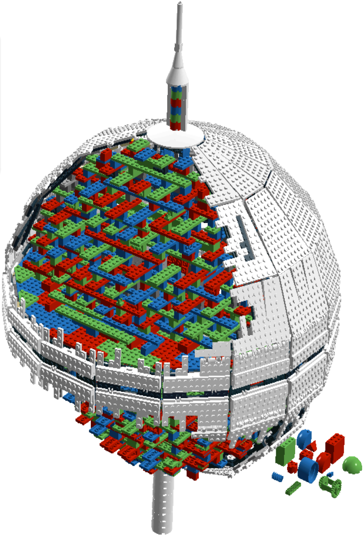
Mass?
Spin?
Charge?



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Mass?
Spin?
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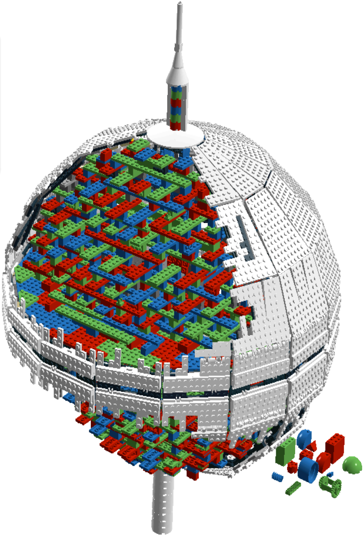
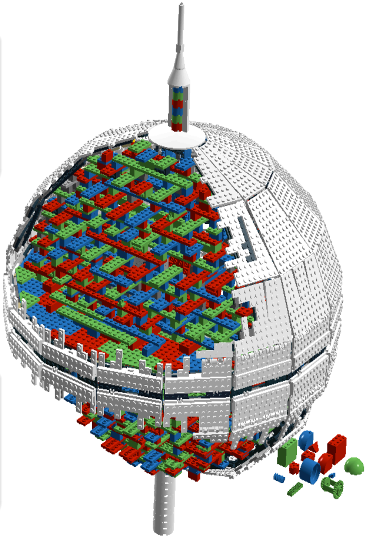


How can we recover the well-known characteristics of the nucleon from the properties of its **colored building blocks**?

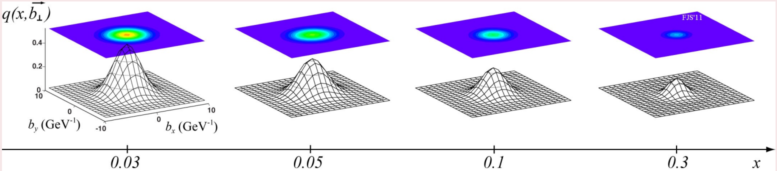
Mass?
Spin?
Charge?
...

What are the relevant **effective degrees of freedom** and **effective interaction** at large distance?



Structuring questions for the hadron physics community

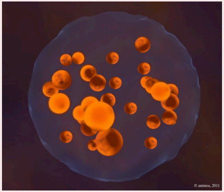
- QCD **mechanisms** behind the origin of **mass** in the **visible universe**?
- **Cartography** of interactions giving its mass to the nucleon?
- **Pressure** and **density** profiles of the nucleon as a continuous medium?
- **Localization** of quarks and gluons inside the nucleon?
- Possible impact on **initial state** of pp or pA scattering?



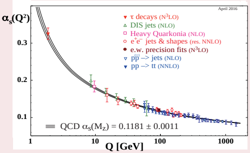
Perturbative and nonperturbative QCD.

Study nucleon structure to shed new light on nonperturbative QCD.

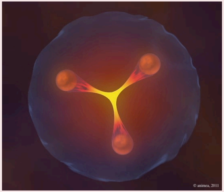
Perturbative QCD



Asymptotic freedom



Nonperturbative QCD

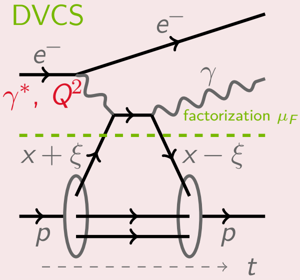


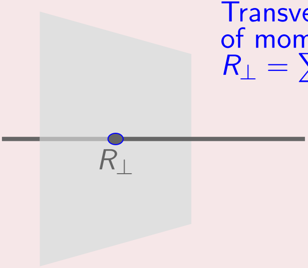
Interface between perturbative and nonperturbative regimes

- 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.

- 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)





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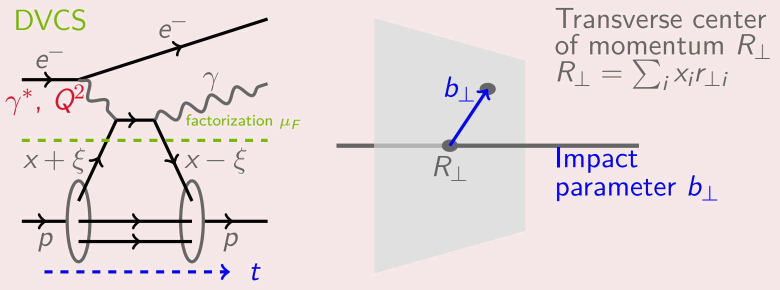

Anatomy of hadrons.

GPDs, 3D hadron imaging, and beyond (1/4).

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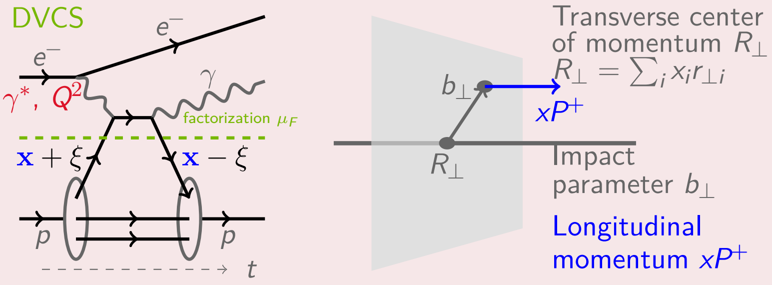

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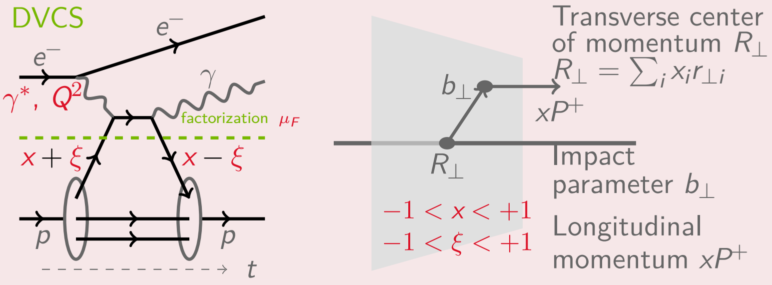


- **24 GPDs** $F^i(x, \xi, t, \mu_F)$ for each parton type $i = g, u, d, \ldots$ for leading and sub-leading twists.

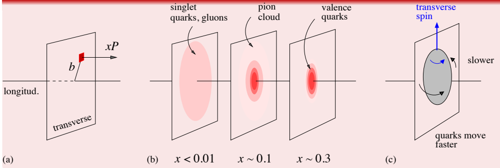
- **Probabilistic interpretation** of Fourier transform of $\mathrm{GPD}(x, \xi = 0, t)$ in **transverse plane**.

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

- 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)

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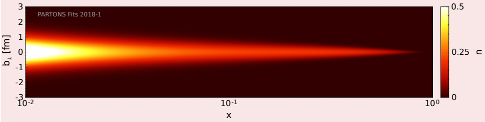
Burkardt, Phys. Rev. **D62**, 071503 (2000)

Not quite, but close!



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

- 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)

- 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:

$$\langle N | T^{ij}(\vec{r}) | N \rangle N = s(r)\left(\frac{r^i r^j}{\vec{r}^2} - \frac{1}{3}\delta^{ij}\right) + p(r)\delta^{ij}$$

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)

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

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

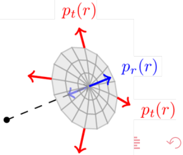
- Anisotropic fluid in **relativistic hydrodynamics**:

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

where u^μ and $\chi^\mu = x^\mu / r$.

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

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



- Write dictionary between quantum and fluid pictures:

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

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

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

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

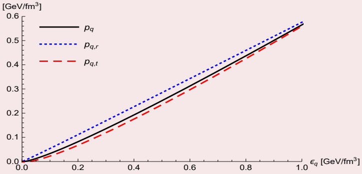
$$\frac{s_a(r)}{M} = \int \frac{\mathrm{d}^3\vec{\Delta}}{(2\pi)^3} e^{-i\vec{\Delta}\cdot\vec{r}} \left\{ -\frac{4}{r^2}\frac{t^{-1/2}}{M^2}\frac{\mathrm{d}^2}{\mathrm{d}t^2}\left(t^{5/2}\, C_a(t)\right) \right\}$$

Mechanical properties of hadrons.

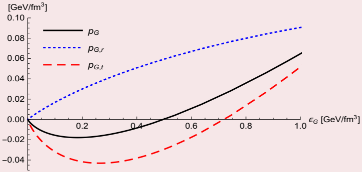
From the nucleon to compact stars (3/3).

- Evaluate orders of magnitude with naive multiple model:

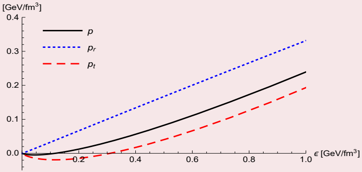
quark



glue

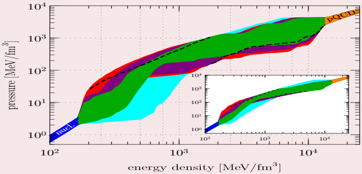


quark + glue



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

Neutron stars

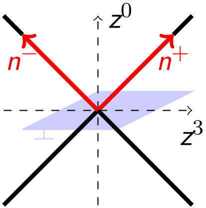


Annala *et al.*, Phys. Rev. Lett. **120**, 172703 (2018)

Phenomenology

$$H^q_\pi(x,\xi,t) = \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ixP^+z^-} \left\langle \pi, P+\frac{\Delta}{2} \middle| \bar{q}\left(-\frac{z}{2}\right)\gamma^+ q\left(\frac{z}{2}\right) \middle| \pi, P-\frac{\Delta}{2} \right\rangle_{\substack{z^+=0 \\ z_\perp=0}}$$

with $t = \Delta^2$ and $\xi = -\Delta^+/(2P^+)$.



References

Müller *et al.*, Fortschr. Phys. **42**, 101 (1994)
Ji, Phys. Rev. Lett. **78**, 610 (1997)
Radyushkin, Phys. Lett. **B380**, 417 (1996)

- PDF **forward limit**

$$H^q(x,0,0) = q(x)$$

Spin-0 Generalized Parton Distribution.

Definition and simple properties.

$$H^q_\pi(x, \xi, t) \quad = \quad \frac{1}{2}\int \frac{dz^-}{2\pi} e^{ixP^+z^-} \left\langle \pi, P+\frac{\Delta}{2} \middle| \bar{q}\left(-\frac{z}{2}\right)\gamma^+ q\left(\frac{z}{2}\right) \middle| \pi, P-\frac{\Delta}{2} \right\rangle_{\substack{z^+=0 \\ z_\perp=0}}$$

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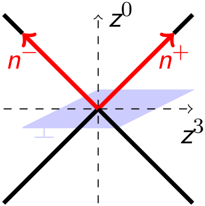

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- PDF **forward limit**
- Form factor **sum rule**

$$\int_{-1}^{+1} dx\, H^q(x, \xi, t) = F_1^q(t)$$

$$H^q_\pi(x,\xi,t) = \frac{1}{2}\int \frac{\mathrm{d}z^-}{2\pi}\, e^{ixP^+z^-} \left\langle \pi, P+\frac{\Delta}{2}\middle| \bar{q}\left(-\frac{z}{2}\right)\gamma^+ q\left(\frac{z}{2}\right)\middle|\pi, P-\frac{\Delta}{2}\right\rangle_{\substack{z^+=0\\ z_\perp=0}}$$

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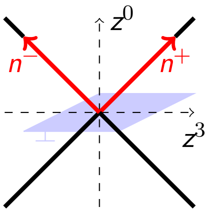

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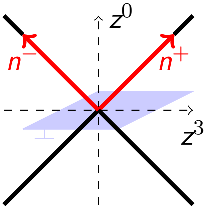

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- Form factor **sum rule**
- H^q is an **even function** of ξ from time-reversal invariance.
- H^q is **real** from hermiticity and time-reversal invariance.

Polynomiality

$$\int_{-1}^{+1} dx\, x^n H^q(x, \xi, t) = \text{polynomial in } \xi$$

Polynomiality

Lorentz covariance

Spin-0 Generalized Parton Distribution.

Not so simple properties.

- **Polynomiality**

Lorentz covariance

- **Positivity**

$$H^q(x, \xi, t) \leq \sqrt{q\left(\frac{x+\xi}{1+\xi}\right) q\left(\frac{x-\xi}{1-\xi}\right)}$$

Spin-0 Generalized Parton Distribution.

Not so simple properties.

- **Polynomiality**

  Lorentz covariance

- **Positivity**

  Positivity of Hilbert space norm

- **Polynomiality**

  Lorentz covariance

- **Positivity**

  Positivity of Hilbert space norm

- H^q has support $x \in [-1, +1]$.

Spin-0 Generalized Parton Distribution.

Not so simple properties.

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  Lorentz covariance

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- H^q has support $x \in [-1, +1]$.

  Relativistic quantum mechanics

- **Polynomiality**

  Lorentz covariance

- **Positivity**

  Positivity of Hilbert space norm

- H^q has support $x \in [-1, +1]$.

  Relativistic quantum mechanics

- **Soft pion theorem** (pion target)

$$H^q(x, \xi = 1, t = 0) = \frac{1}{2}\phi^q_\pi\left(\frac{1+x}{2}\right)$$

- **Polynomiality**

Lorentz covariance

- **Positivity**

Positivity of Hilbert space norm

- H^q has support $x \in [-1, +1]$.

Relativistic quantum mechanics

- **Soft pion theorem** (pion target)

Dynamical chiral symmetry breaking

- **Polynomiality**

  Lorentz covariance

- **Positivity**

  Positivity of Hilbert space norm

- H^q has support $x \in [-1, +1]$.

  Relativistic quantum mechanics

- **Soft pion theorem** (pion target)

  Dynamical chiral symmetry breaking

How can we implement *a priori* these theoretical constraints?

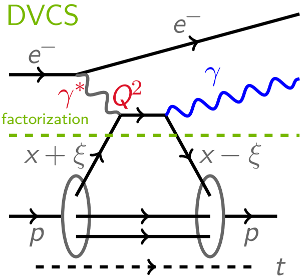
- In the following, focus on **polynomiality** and **positivity**.
- Do not discuss the reduction to form factors or PDFs.

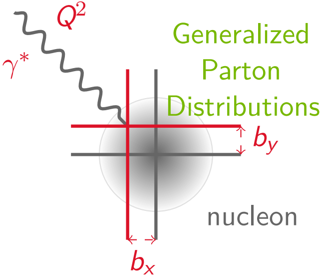
- GPD fits **only in the small x_B region** with a **flexible** parameterization (kinematic simplifications).
- Global fits of CFFs in the sea, valence and glue regions.
- Some GPD models with non-flexible parameterizations adjusted to experimental DVCS or DVMP data.

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

The situation can be improved!

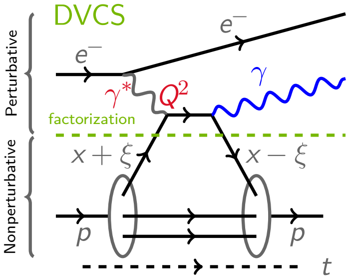
- GPD parameterizations satisfying *a priori* all theoretical constraints on GPDs.
- Computing framework to go beyond leading order and leading twist analysis.

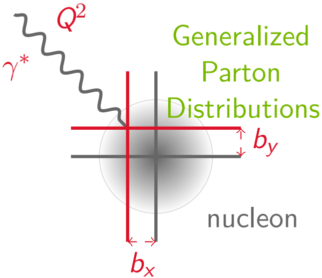

DVCS
e^-
e^-
γ^*
Q^2
γ
factorization
$x+\xi$
$x-\xi$
p
p
t


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

Exclusive processes of current interest (1/2).

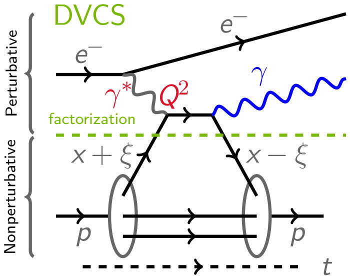
Factorization and universality.

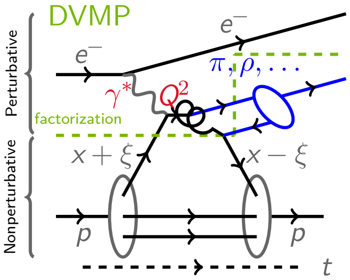


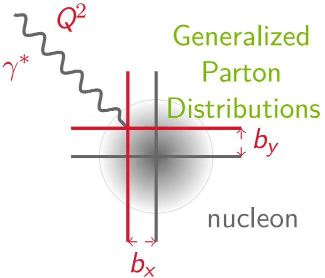


Exclusive processes of current interest (1/2).

Factorization and universality.







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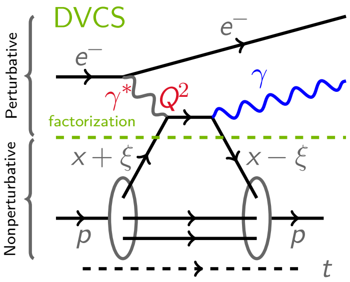
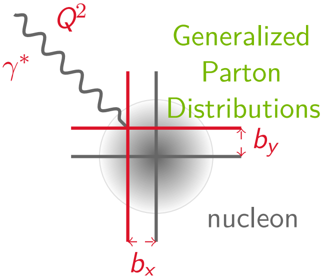
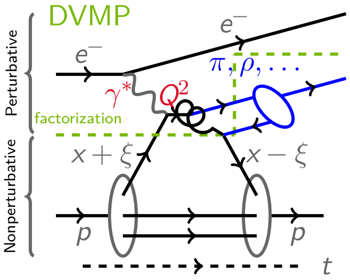
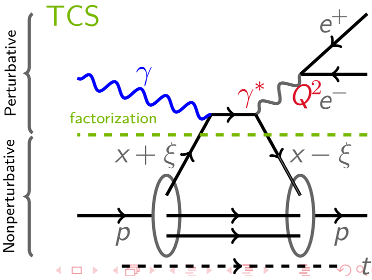


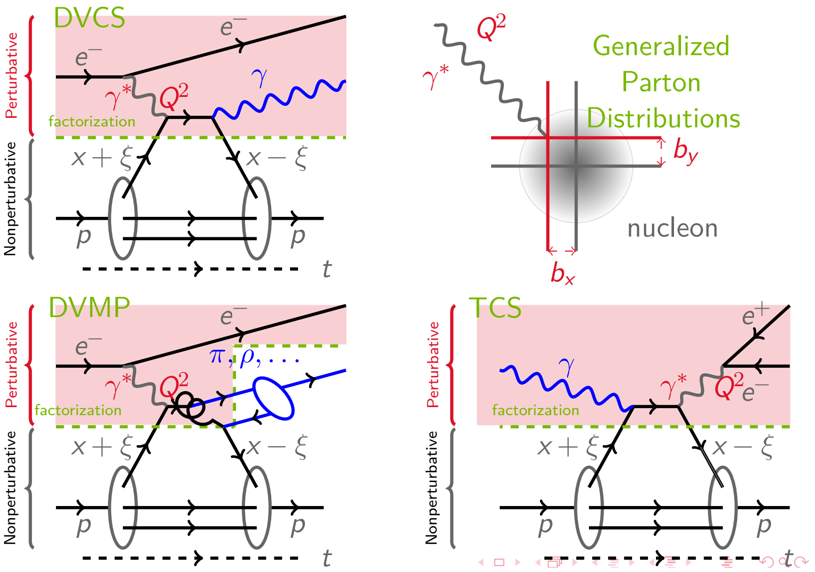




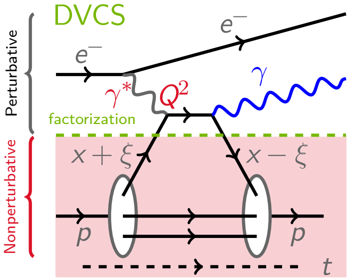


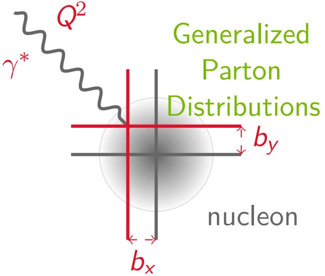
Exclusive processes of current interest (1/2).

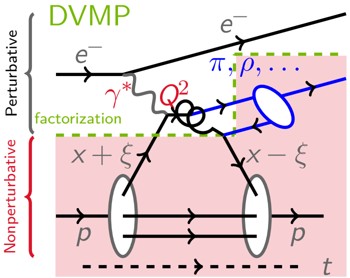
Factorization and universality.

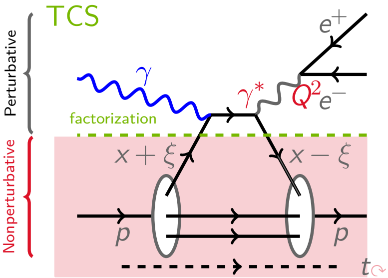


Exclusive processes of current interest (1/2).
Factorization and universality.









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**.

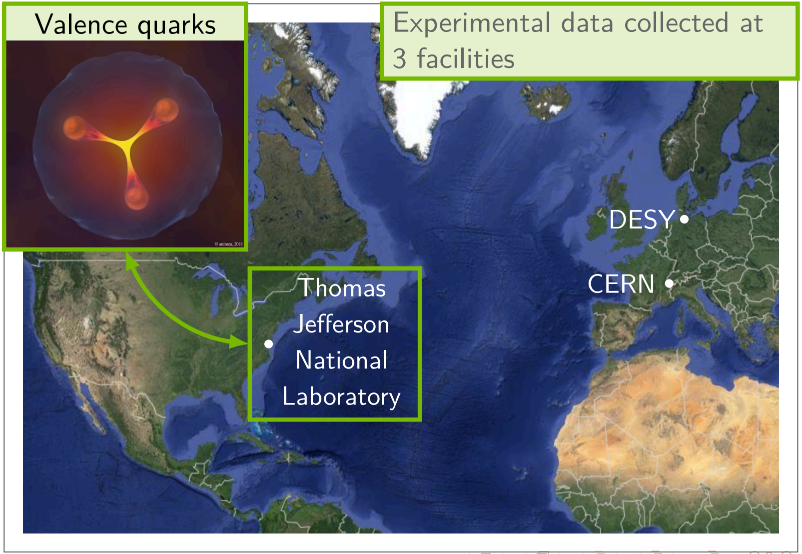
Need for global fits of world data.

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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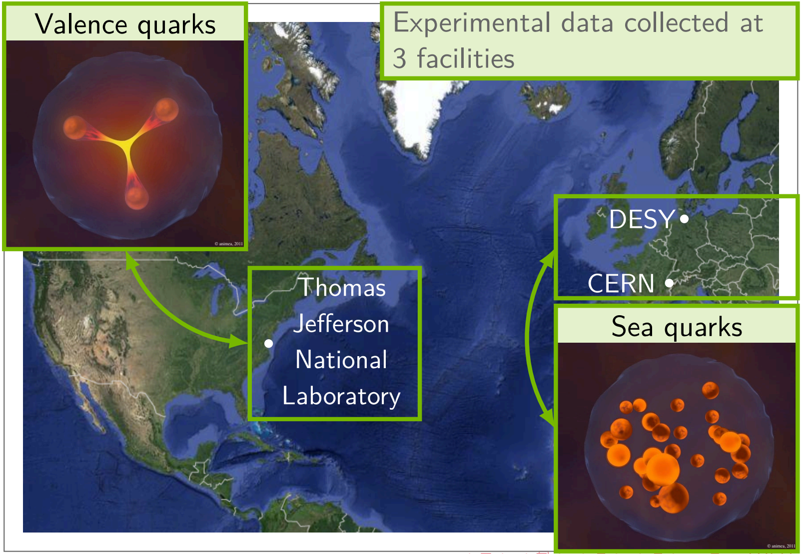

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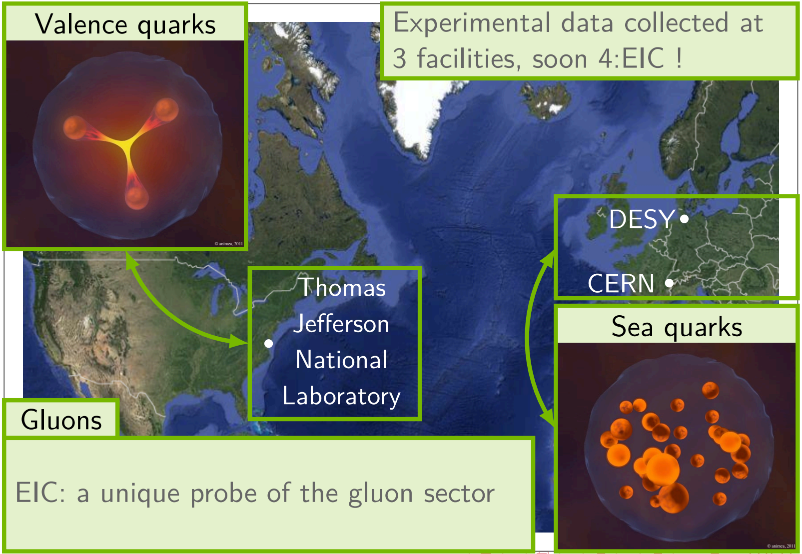
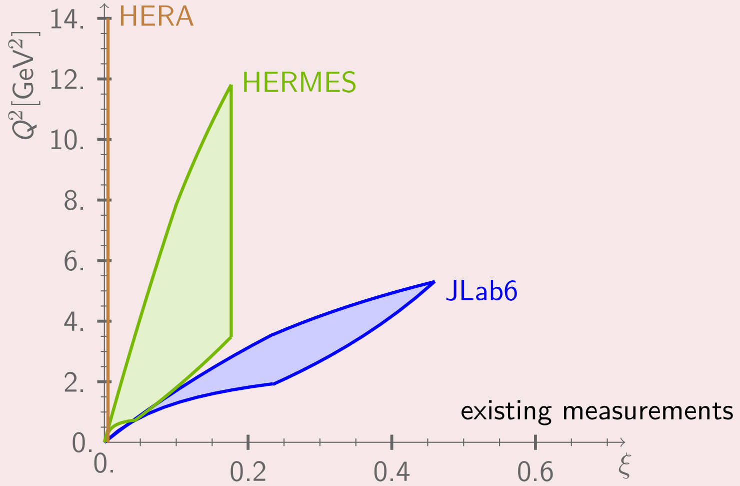


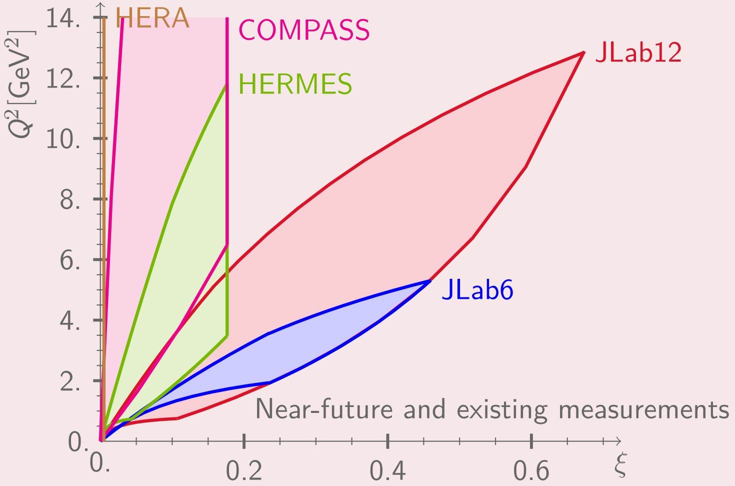
Kinematic reach of existing or near-future DVCS measurements



Need for global fits of world data.

Only a small subset of the (ξ, t, Q^2) space is directly accessed.

Kinematic reach of existing or near-future DVCS measurements



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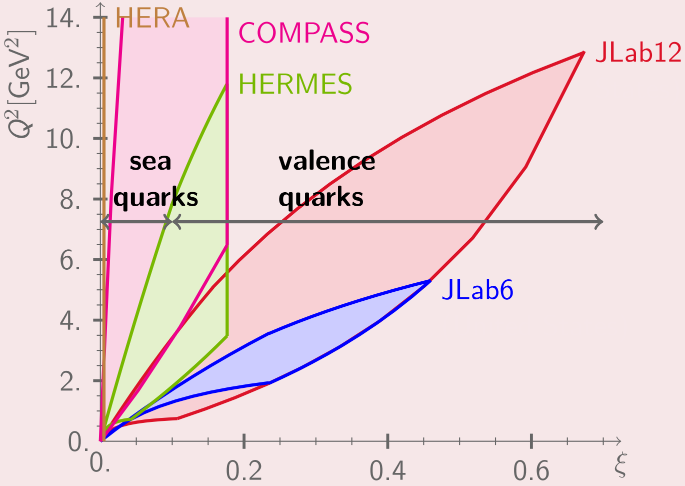

Need for global fits of world data.

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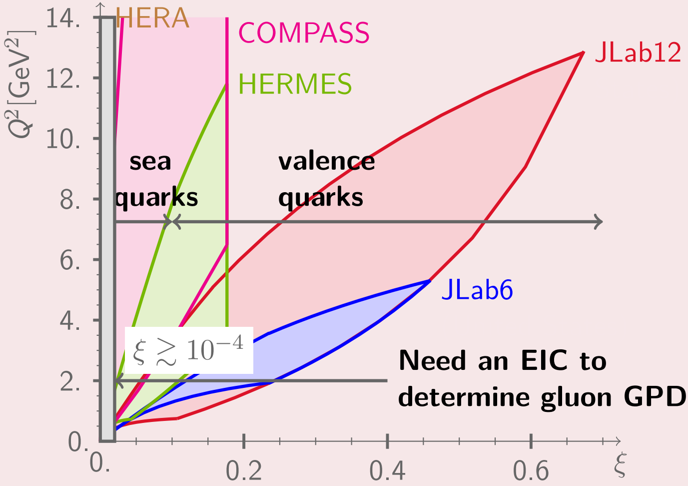
Nucleon Tomography

- Motivation
  - Mass without mass
  - Nucleon structure
  - Physical content
- Phenomenology
  - Formal definition
  - Fit status
  - Experimental access
  - **DVCS kinematics**
- Framework
  - Design
  - Architecture
  - Ergonomics
  - Examples
  - Releases
- Conclusion

Kinematic reach of existing or near-future DVCS measurements

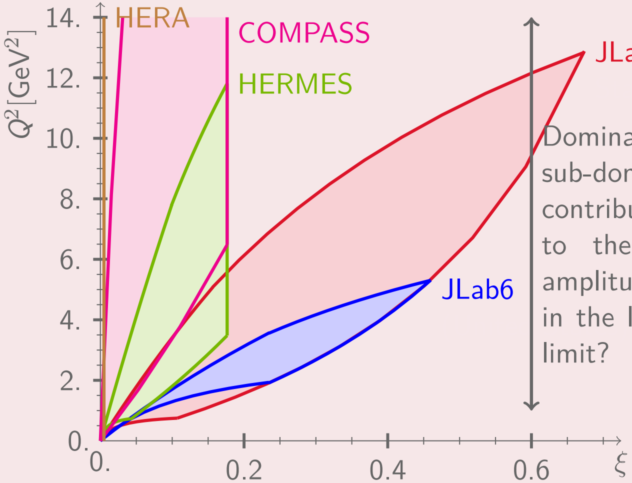


Need an EIC to determine gluon GPDs

Need for global fits of world data.

Only a small subset of the (ξ, t, Q^2) space is directly accessed.

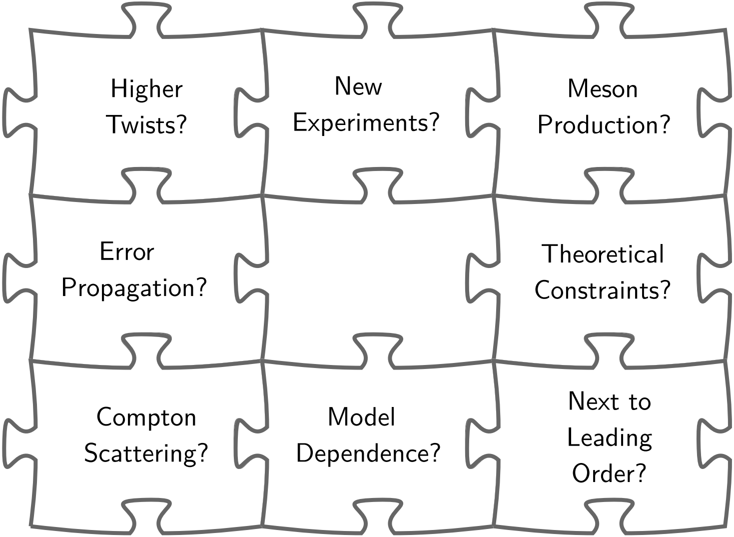
Kinematic reach of existing or near-future DVCS measurements



Dominant and sub-dominant contributions to the DVCS amplitude in the large Q^2 limit?

Software for the phenomenology of GPDs.

Different questions to be answered with the same tools.



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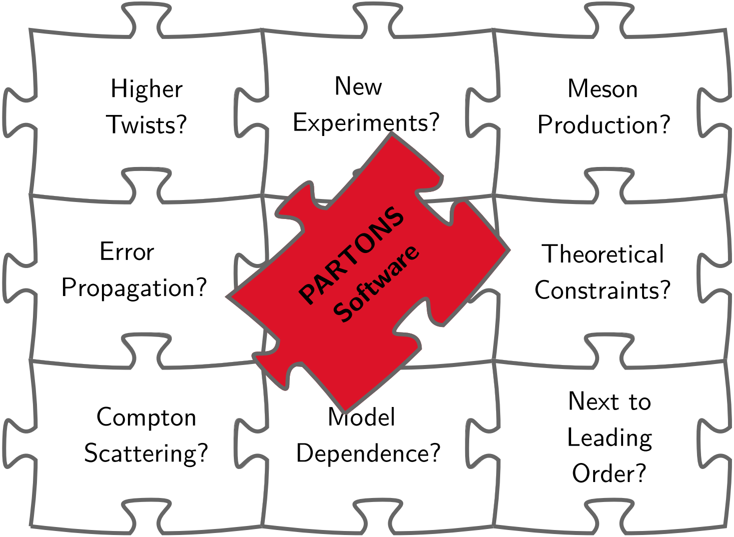


The PARTONS framework

PARtonic
Tomography
Of
Nucleon
Software

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

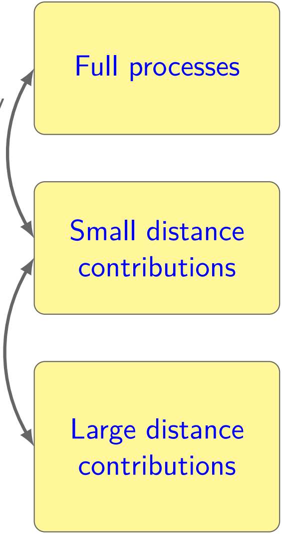
Computing chain design.

Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Computation of amplitudes

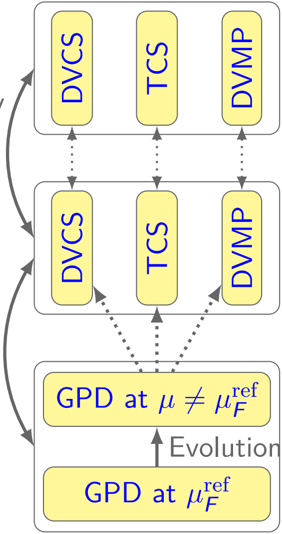
First principles and fundamental parameters



Experimental data and phenomenology

Computation of amplitudes

First principles and fundamental parameters



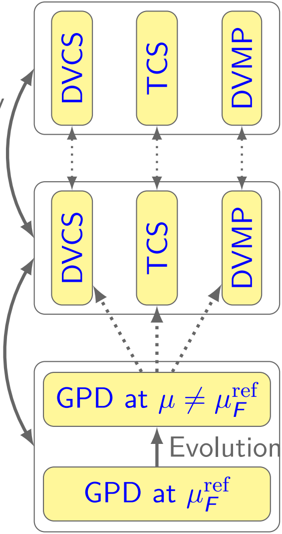
Computing chain design.

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.

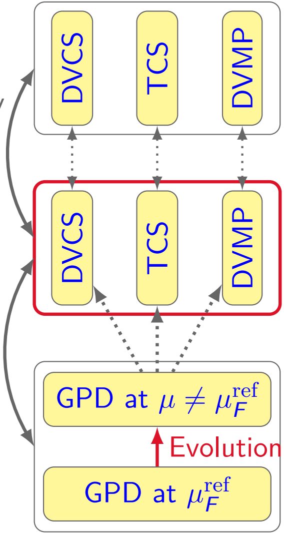
Differential studies: physical models and numerical methods.

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.

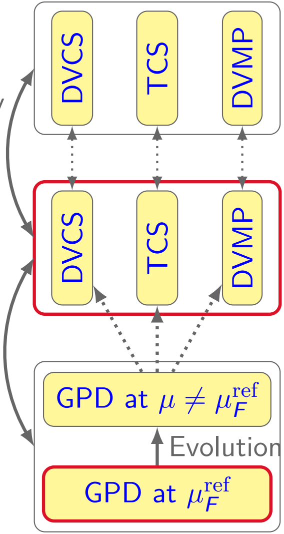
Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Need for modularity

Computation of amplitudes

First principles and fundamental parameters



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Computing chain design.

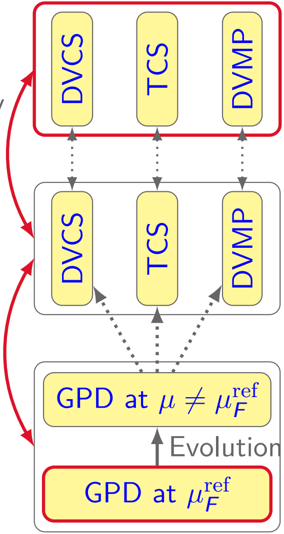
Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Need for modularity

Computation of amplitudes

First principles and fundamental parameters



- Many observables.
- Kinematic reach.

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Computing chain design.

Differential studies: physical models and numerical methods.

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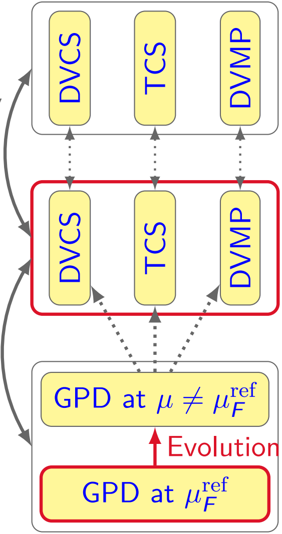
Computation of amplitudes

First principles and fundamental parameters



- Many observables.
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Computing chain design.

Differential studies: physical models and numerical methods.

Nucleon Tomography

Motivation
- Mass without mass
- Nucleon structure
- Physical content

Phenomenology
- Formal definition
- Fit status
- Experimental access
- DVCS kinematics

Framework
- **Design**
- Architecture
- Ergonomics
- Examples
- Releases

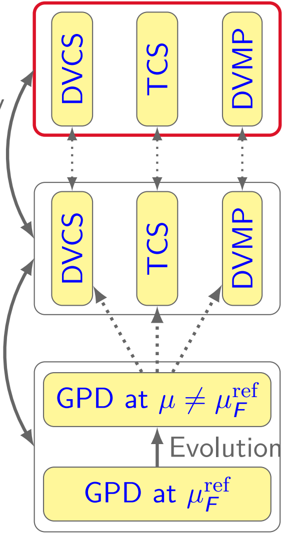
Conclusion

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.

A computing framework for physics.

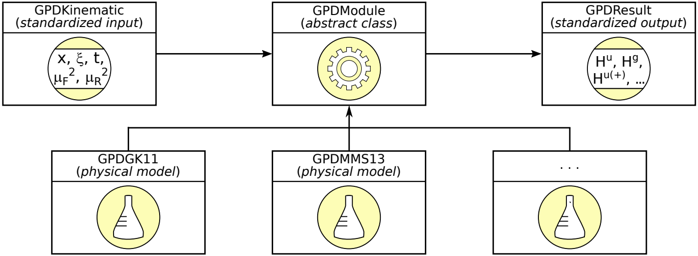
Done: tests, benchmarking, documentation, tutorials.

- 3 stages:
  1. Design.
  2. Integration and validation.
  3. Benchmarking and production.
- 1 new physical development = 1 new module.
- *Aggregate* **knowledge** and **know-how**:
  - Models
  - Measurements
  - Numerical techniques
  - Validation
- What *can* be automated *will be* automated.
- Flexible software architecture.

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

Modularity.

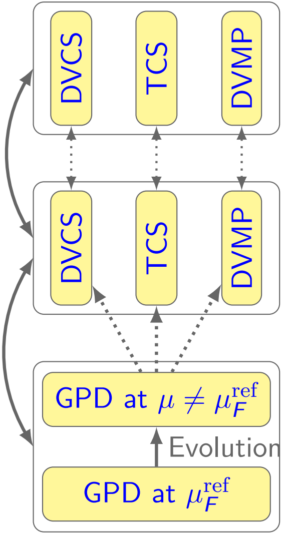
Inheritance, standardized inputs and outputs.



- Steps of logic sequence in parent class.
- Model description and related mathematical methods in daughter class.

Flexibility.

Example: implementation of new coefficient functions.



- A DVCS coefficient function module generically outputs a complex number when provided $(\xi, t, Q^2, \mu_F^2, \mu_R^2)$.

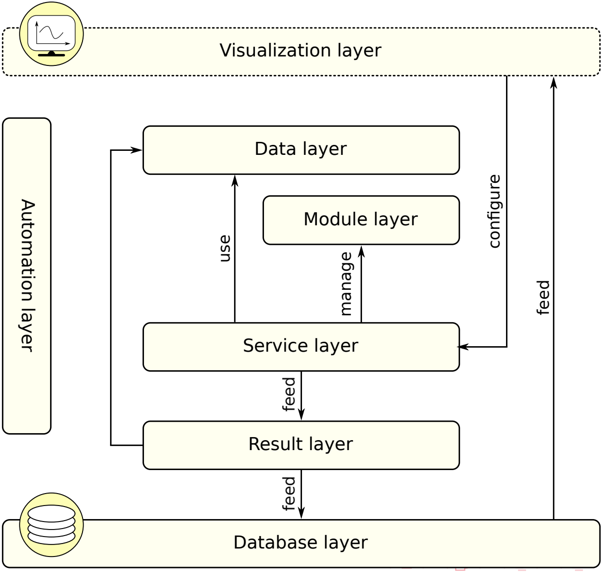
ConvolCoeffFunctionModule.h

```
virtual std::complex<double> compute(
double xi, double t, double Q2, double MuF2,
 double MuR2, GPDType::Type gpdType) =
0;
```

- This module can be anything:
  - Constant CFFs for local fits.
  - CFFs for massless quarks.
  - CFFs for heavy quarks.
  - CFFs with TMC.
  - ...

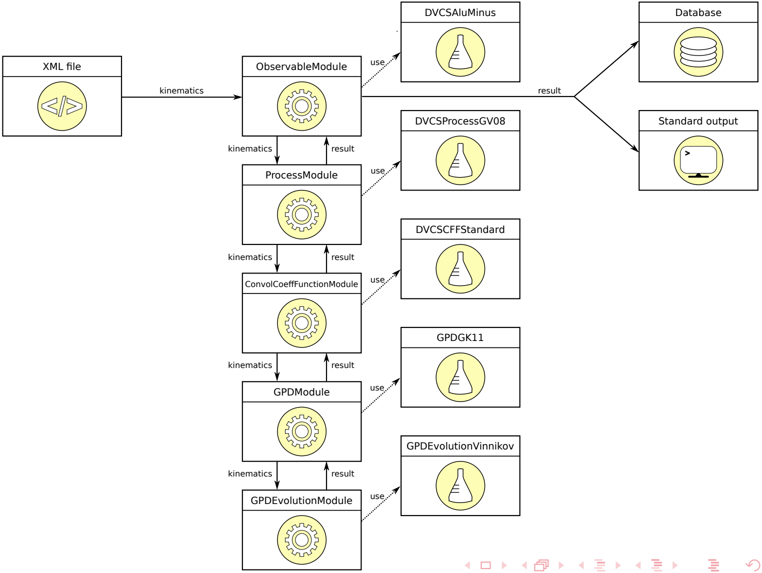
Modularity and layer structure.

Modifying one layer does not affect the other layers.



Modularity and automation.

Parse XML file, compute and store result in database.



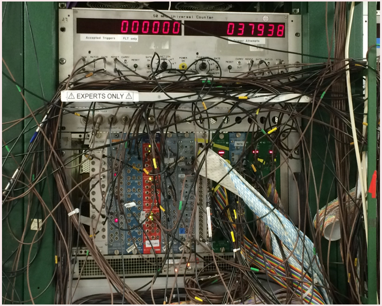
Systematic studies made easy.

A faster and safer way to GPD phenomenology.

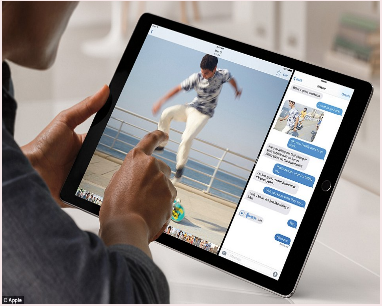
Automation allows...:

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

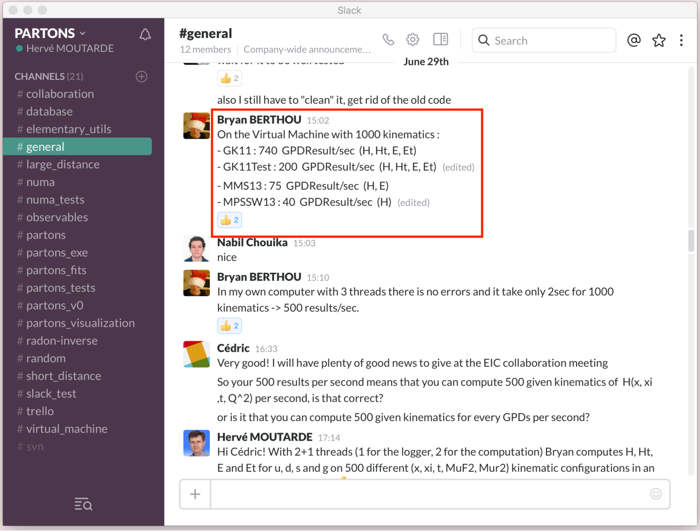
Without PARTONS



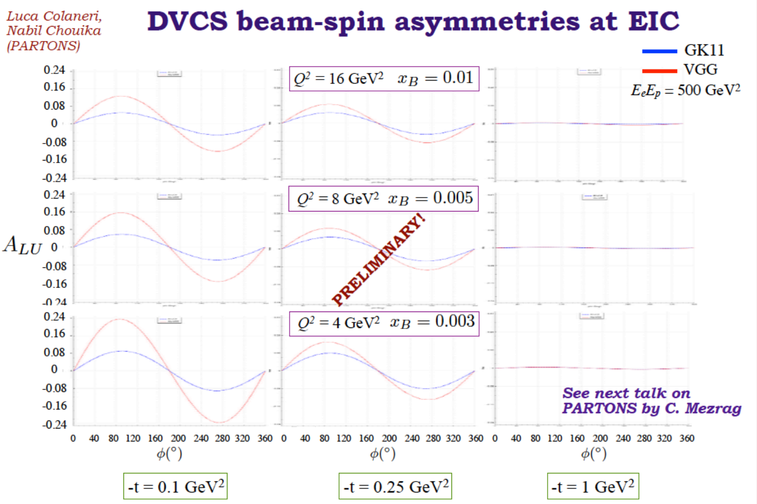
With PARTONS



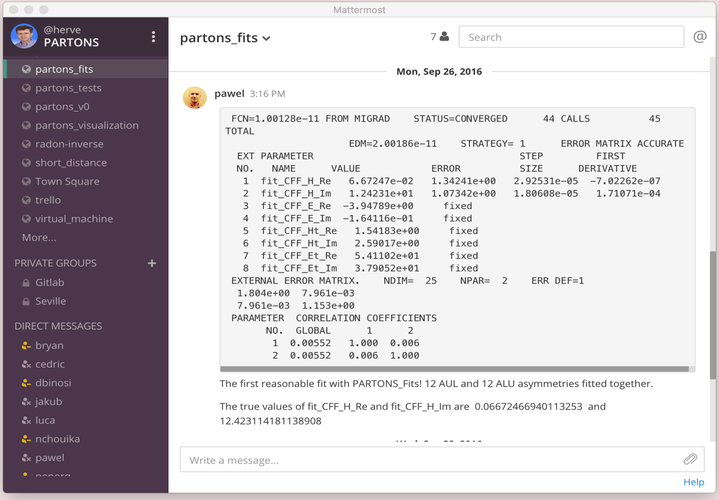
GPD computations with or without threads



From D. Sokhan's talk, EIC User Group Meeting, ANL, 2016



First local fit of pseudo DVCS data, Sep. 26$^{\text{th}}$, 2016



Parametric global fit of JLab DVCS data, Apr. 5th, 2017

RESULTS

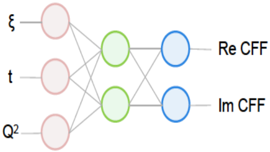
- Kinematic cuts: $Q^2 > 1.5$ GeV^2 (*where we can rely on LO approximation*)
  $-t / Q^2 < 0.25$ (*where we can rely on GPD factorization*)
- χ^2 / ndf: 3272.6 / (3433 - 7) ≈ 0.96
- Free parameters: a_{Hsea}, $a_{\tilde{H}val}$, $a_{\tilde{H}sea}$, C_{sub}, a_{sub}, N_E, $N_{\tilde{E}}$
- χ^2 / ndf per data set

[1] Phys. Rev. C 92, 052202 (2015)
[2] Phys. Rev. Lett. 115, 212003 (2015)
[3] Phys. Rev. D 91, 052014 (2015)

Experiment	Reference	Observables	N points all	N points selected	chi2	chi2 / ndf
Hall A	[1] KINX2	σUU	120	120	135.0	1.19
Hall A	[1] KINX2	ΔσLU	120	120	98.9	0.88
Hall A	[1] KINX3	σUU	108	108	274.8	2.72
Hall A	[1] KINX3	ΔσLU	108	108	107.3	1.06
CLAS	[2]	σUU	1933	1333	1089.2	0.82
CLAS	[2]	ΔσLU	1933	1333	1171.9	0.88
CLAS	[3]	AUL, ALU, ALL	498	305	338.1	1.13

Neural network global fit of CLAS asymmetries, May 31st, 2017

NEURAL NETWORK



- Our very first attempt to use NN technique → proof of feasibility
- Genetic algorithm (GA) to learn NN
- NN and GA libraries by PARTONS group
- Very simple design of NN
- CLAS asymmetry data only
- χ^2 / ndf = 273.9 / (305 - 68) ≈ 1.16

GPD or CFF fits (4/4).

From local to global fits in 8 months!

- PARTONS architecture allows focusing on **parameterization** and **fitting engine**.
- The **same machinery** is used for local **and** global fits.
- **Fast** and **constant** progress since the first fits.
- More to come in the near future.

See Pawel Sznajder's seminar in Stony Brook tomorrow!

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

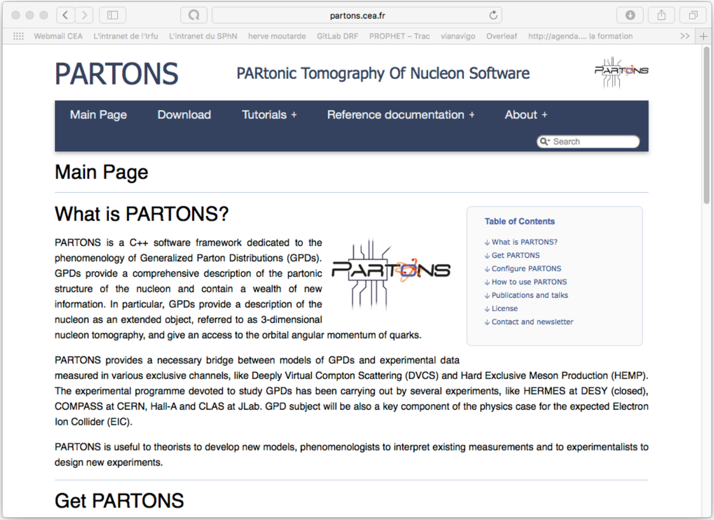
- Vinnikov (LO)

α_s modules

- 4-loop perturbation
- constant value

Open source release.

Publicly available on CEA GitLab server.



partons.cea.fr

PARTONS

PARtonic Tomography Of Nucleon Software

Main Page | Download | Tutorials + | Reference documentation + | About +

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

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

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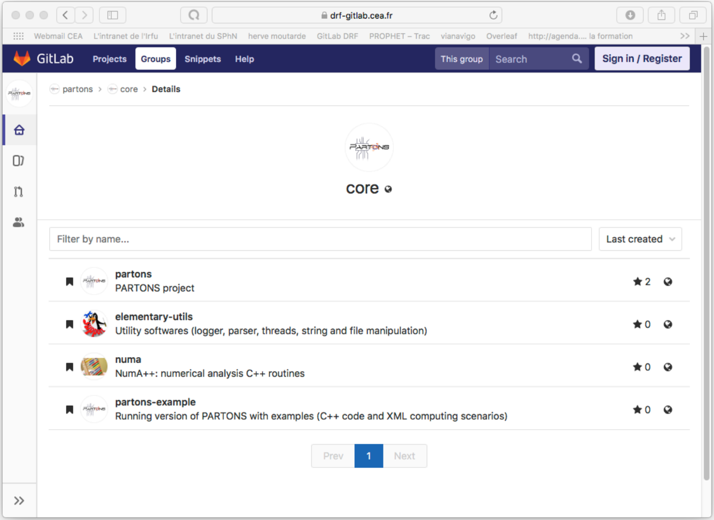

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Main Page | Download | Tutorials + | Reference documentation + | About +

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Contact

Main contact: partons@cea.fr.

Technical support

Problems with installation and usage: partons@cea.fr.

Newsletter

Sign up to the newsletter to be informed on the new releases by sending an email to sympa@saxifrage.saclay.cea.fr with this subject (no additional text needed): *SUBSCRIBE partons-users*.

To unsubscribe, use *UNSUBSCRIBE* instead in the subject.

Development team

The list of development team members can be found at our GitLab page.

If you want to join the development team of PARTONS, contact Hervé Moutarde.

Generated on Wed Mar 21 2018 16:23:16 for PARTONS 1.0 by Doxygen 1.8.14

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

Future releases.

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

Channel modules

- DVMP
- TCS
- γM production
- ???

Other modules

- Mellin moments (EM tensor, lattice QCD)
- ???

Hadron structure modules

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

Nonperturbative QCD modules

- Gap equation solver
- ???

A workpackage of the EU-funded STRONG-2020 program

- Mutualize developments for GPD and TMD frameworks.
- Address the question of event generation.
- Open-source release and maintenance of computing codes related to 3D hadron structure.

Conclusion

Conclusion and prospects.

Putting all the pieces together.

- We now have tools to **systematically relate** these models to **experimental data** in **multi-channel** analysis.
- We now have an **operating engine** for global CFF fits.
- We revisit the **mechanical properties** of hadrons to assess how much we can learn from GPD extractions.
- We can now build generic GPD models satisfying *a priori* **all theoretical constraints**.

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!

See you soon in Paris!

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