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PARTONS: A versatile framework for the phenomenology of GPDs



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3D Nucleon Tomography Workshop 2017 | Hervé MOUTARDE

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Mar. 16 $^{\rm th}$, 2017



Motivation.

3D imaging of nucleon's partonic content but also...



PARTONS Framework

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- 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 GPD($x, \xi = 0, t$) in **transverse plane**.

Transverse plane density (Goloskokov and Kroll model)



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Motivation.

Study nucleon structure to shed new light on nonperturbative QCD.







Towards hadron tomography. GPDs as a scalpel-like probe of hadron structure.



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1 The problem of 3D imaging:

What do we want?

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Phenomenology, GPD models, experimental images: What can we actually do?

3 Computing framework:

What can we expect from the near future?



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Principles of nucleon 3D imaging

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Perturbative

Nonperturbative





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DVCS



Exclusive processes of current interest (1/2). Factorization and universality. CEA DVCS Q^2 PARTONS Framework Perturbative

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



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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** :

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

for a given GPD *F*.

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

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Need for global fits of world data. Different facilities will probe different kinematic domains.



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Need for global fits of world data. Different facilities will probe different kinematic domains.



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Design Features Examples

Need for global fits of world data. Different facilities will probe different kinematic domains.



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Need for global fits of world data. Different facilities will probe different kinematic domains.



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Imaging the nucleon. How? Extracting GPDs is not enough...Need to extrapolate!



1. Experimental data fits 2. GPD extraction PARTONS Framework $H^{+}(x, t; \Xi=0.2, O^{2}=4)$ $\Delta \sigma$ [pb.GeV⁻⁴] 15. Motivation 0.1 Imaging Experimental access = 0.5-10 DVCS kinematics $= 6.3 \text{ GeV}^2$ -1.08,05,0,4,02 0,02,0,4,08,08,1 0 0.735 GeV^2 Towards 3D images 0.2 Modeling ϕ [deg] Limitations Lorentz symmetry 3. Nucleon imaging Radon transform Covariant extension Images from Guidal et al., Computing Rept. Prog. Phys. 76 (2013) 066202 The 2015 Long Range Plan for Nuclear Science Design Features Examples Sidebar 2.2: The First 3D Pictures of the Nucleon Architecture 2 A computed tomography (CT) scan can help physicians pinpoint minute cancer tumors, diagnose tiny broken Conclusion 1 bones, and spot the early signs of osteoporosis. 0,[fm] Now physicists are using the principles behind the 0 procedure to peer at the inner workings of the proton. This breakthrough is made possible by a relatively new -1 concept in nuclear physics called generalized parton distributions. -2 -1 0 1 -1 Ó -2 b, [fm] b_x [fm] An intense beam of high-energy electrons can be used

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Imaging the nucleon. How? Extracting GPDs is not enough...Need to extrapolate!



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1 Extract $H(x, \xi, t, \mu_F^{ref})$ from experimental data.

- **2** Extrapolate to vanishing skewness $H(x, 0, t, \mu_F^{ref})$.
- **3 Extrapolate** $H(x, 0, t, \mu_F^{ref})$ up to infinite *t*.
- **4 Compute** 2D Fourier transform in transverse plane:

$$\mathcal{H}(x, b_{\perp}) = \int_{0}^{+\infty} \frac{\mathrm{d}|\Delta_{\perp}|}{2\pi} |\Delta_{\perp}| J_0(|b_{\perp}||\Delta_{\perp}|) \mathcal{H}(x, 0, -\Delta_{\perp}^2)$$

- 5 Propagate uncertainties.
- 6 **Control** extrapolations with an accuracy matching that of experimental data with **sound** GPD models.

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Practice of nucleon 3D imaging

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GPD H at t = -0.23 GeV² and $Q^2 = 2.3$ GeV².



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Need to know $H(x, \xi = 0, t)$ to do transverse plane imaging.



GPD model: see Kroll et al., Eur. Phys. J. C73, 2278 (2013)





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$\xi_{\rm max}$ from kinematic constraint on 4-momentum transfer.



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The black curve is what is needed for transverse plane imaging!





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Density plot of H at t = -0.23 GeV² and $Q^2 = 2.3$ GeV²

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A simplification brought by GPDs?! We don't need to know the GPD everywhere to image the proton!



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General idea

- Assume $H(x, \xi, t)$ is known for all x and $\xi \in [\xi_{\min}, \xi_{\max}]$.
- Then all Mellin moments are known for $\xi \in [\xi_{\min}, \xi_{\max}]$.
- Mellin moments are **polynomials** in ξ and in particular can be evaluated at ξ = 0.
- The knowledge of the Mellin moments at ξ = 0 uniquely determines the transverse plane density H(x, 0, b_⊥).
- *Caveat*: **ill-posed problem** in the sense of Hadamard.

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

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$$\begin{aligned} \mathcal{H}_{\pi}^{q}(x,\xi,t) &= \\ \int \frac{\mathrm{d}z^{-}}{2\pi} e^{ixP^{+}z^{-}} \left\langle \pi, P + \frac{\Delta}{2} \middle| \bar{q} \left(-\frac{z}{2} \right) \gamma^{+}q \left(\frac{z}{2} \right) \middle| \pi, P - \frac{\Delta}{2} \right\rangle_{\substack{z^{+}=0\\z_{\perp}=0}} \end{aligned}$$
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
- Form factor sum rule

 z^3

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

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

References

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Ji, Phys. Rev. Lett. **78**, 610 (1997)
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- PDF forward limit
 - Form factor sum rule
- H^q is an even function of ξ from time-reversal invariance.

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PARTONS Framework $H^q_{\pi}(x,\xi)$

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

References

Müller *et al.*, Fortschr. Phys. **42**, 101 (1994)
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PDF forward limit

- 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.

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Radyushkin, Phys. Lett. **B380**, 417 (1996)



Polynomiality. Mixed constraint from Lorentz invariance and discrete symmetries.

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Express Mellin moments of GPDs as **matrix elements**:

$$\int_{-1}^{+1} \mathrm{d}x \, x^m H^q(x,\xi,t)$$

= $\frac{1}{2(P^+)^{m+1}} \left\langle P + \frac{\Delta}{2} \right| \bar{q}(0) \gamma^+ (i\overleftrightarrow{D}^+)^m q(0) \left| P - \frac{\Delta}{2} \right\rangle$

Identify the Lorentz structure of the matrix element: linear combination of $(P^+)^{m+1-k}(\Delta^+)^k$ for $0 \le k \le m+1$

- Remember definition of skewness $\Delta^+ = -2\xi P^+$.
- Select even powers to implement time reversal.
- Obtain polynomiality condition:

$$\int_{-1}^{1} \mathrm{d}x x^{m} H^{q}(x,\xi,t) = \sum_{i=0}^{m} (2\xi)^{i} C^{q}_{mi}(t) + (2\xi)^{m+1} C^{q}_{mm+1}(t) .$$

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Double Distributions. Lorentz covariance by example.



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• Choose
$$F^q(\beta, \alpha) = 3\beta\theta(\beta)$$
 ad $G^q(\beta, \alpha) = 3\alpha\theta(\beta)$:

$$H^{q}(x,\xi) = 3x \int_{\Omega} d\beta d\alpha \,\delta(x - \beta - \alpha\xi)$$

Simple analytic expressions for the GPD:

$$\begin{aligned} \mathcal{H}(x,\xi) &= \frac{6x(1-x)}{1-\xi^2} \text{ if } 0 < |\xi| < x < 1, \\ \mathcal{H}(x,\xi) &= \frac{3x(x+|\xi|)}{|\xi|(1+|\xi|)} \text{ if } -|\xi| < x < |\xi| < 1. \end{aligned}$$

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Double Distributions. Lorentz covariance by example.



PARTONS	Compute first Mellin moments.			
Framework	п	$\int_{-\xi}^{+\xi} \mathrm{d}x x^n H(x,\xi)$	$\int_{+\xi}^{+1} \mathrm{d}x x^n H(x,\xi)$	$\int_{-\xi}^{+1} \mathrm{d}x x^n H(x,\xi)$
Motivation Imaging Experimental access DVCS kinematics	0	$\frac{1+\xi-2\xi^2}{1+\xi}$	$\frac{2\xi^2}{1+\xi}$	1
Towards 3D images Modeling Limitations	1	$\frac{1\!+\!\xi\!+\!\xi^2\!-\!3\xi^3}{2(1\!+\!\xi)}$	$\frac{2\xi^3}{1+\xi}$	$\frac{1+\xi^2}{2}$
Lorentz symmetry Radon transform Covariant extension	2	$\frac{3(1-\xi)(1+2\xi+3\xi^2+4\xi^3)}{10(1+\xi)}$	$\frac{6\xi^4}{5(1+\xi)}$	$\frac{3(1+\xi^2)}{10}$
Computing Design Features Examples Architecture	3	$\frac{1\!+\!\xi\!\!+\!\xi^2\!+\!\xi^3\!+\!\xi^4\!-\!5\xi^5}{5(1\!+\!\xi)}$	$\frac{6\xi^5}{5(1+\xi)}$	$\frac{1+\xi^2+\xi^4}{5}$
Conclusion	4	$\frac{1\!+\!\xi\!\!+\!\xi^2\!+\!\xi^3\!+\!\xi^4\!+\!\xi^5\!-\!6\xi^6}{7(1\!+\!\xi)}$	$\frac{6\xi^6}{7(1+\xi)}$	$\frac{1+\xi^2+\xi^4}{7}$
Expressions get more complicated as n increases But				
they always yield polynomials!				
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The Radon transform. Definition and properties.

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For s > 0 and $\phi \in [0, 2\pi]$: $\mathcal{R}f(s, \phi) = \int_{-\infty}^{+\infty} d\beta d\alpha f(\beta, \alpha) \delta(s - \beta \cos \phi - \alpha \sin \phi)$ and:

$$\mathcal{R}f(-s,\phi) = \mathcal{R}f(s,\phi\pm\pi)$$

Relation to GPDs:

$$x = \frac{s}{\cos \phi} \text{ and } \xi = \tan \phi$$

Relation between GPD and DD in Belistky et al. gauge

$$\frac{\sqrt{1+\xi^2}}{x}H(x,\xi) = \mathcal{R}f_{\rm BMKS}(s,\phi) ,$$

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For s > 0 and $\phi \in [0, 2\pi]$: $\mathcal{R}f(s, \phi) = \int_{-\infty}^{+\infty} d\beta d\alpha f(\beta, \alpha) \delta(s - \beta \cos \phi - \alpha \sin \phi)$ and:

$$\mathcal{R}f(-s,\phi) = \mathcal{R}f(s,\phi\pm\pi)$$

Relation to GPDs:

$$x = \frac{s}{\cos \phi} \text{ and } \xi = \tan \phi$$

Relation between GPD and DD in Pobylitsa gauge

$$\frac{\sqrt{1+\xi^2}}{1-x}H(x,\xi) = \mathcal{R}f_{\mathrm{P}}(s,\phi) ,$$



The range of the Radon transform. The polynomiality property a.k.a. the Ludwig-Helgason condition.



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 The Mellin moments of a Radon transform are homogeneous polynomials in ω = (sin φ, cos φ).

The converse is also true:

Theorem (Hertle, 1983)

Let $g(s, \omega)$ an even compactly-supported distribution. Then g is itself the Radon transform of a compactly-supported distribution if and only if the **Ludwig-Helgason consistency condition** hold:

(i) g is
$$C^{\infty}$$
 in ω ,

(ii) $\int ds \, s^m g(s, \omega)$ is a homogeneous polynomial of degree m for all integer $m \ge 0$.

 Double Distributions and the Radon transform are the natural solution of the polynomiality condition.

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Support theorem.

Theorem

We don't need to know the GPD everywhere to image the proton!



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Let f be a compactly-supported summable function defined on \mathbb{R}^2 and $\mathcal{R}f$ its Radon transform. Let $(s_0, \omega_0) \in \mathbb{R} \times S^1$ and U_0 an open neighborhood of ω_0 s.t.:

for all $s > s_0$ and $\omega \in U_0$ $\mathcal{R}f(s, \omega) = 0$.

Then $f(\aleph) = 0$ on the half-plane $\langle \aleph | \omega_0 \rangle > s_0$ of \mathbb{R}^2 .







Overlap representation. A first-principle connection with Light Front Wave Functions.



PARTONS Framework

Decompose an hadronic state $|H; P, \lambda\rangle$ in a Fock basis:

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$$H; P, \lambda \rangle = \sum_{N,\beta} \int [\mathrm{d}x \mathrm{d}\mathbf{k}_{\perp}]_{N} \psi_{N}^{(\beta,\lambda)}(x_{1}, \mathbf{k}_{\perp 1}, \dots, x_{N}, \mathbf{k}_{\perp N}) |\beta, k_{1}, \dots, k_{N} \rangle$$

• Derive an expression for the pion GPD in the DGLAP region $\xi \le x \le 1$:

$$\mathcal{H}^{q}(x,\xi,t) \propto \sum_{\beta,j} \int [\mathrm{d}\bar{x}\mathrm{d}\bar{\mathbf{k}}_{\perp}]_{N} \delta_{j,q} \delta(x-\bar{x}_{j}) \big(\psi_{N}^{(\beta,\lambda)}\big)^{*}(\hat{x}',\hat{\mathbf{k}}'_{\perp}) \psi_{N}^{(\beta,\lambda)}(\tilde{x},\tilde{\mathbf{k}}_{\perp})$$

with $\tilde{x}, \tilde{\mathbf{k}}_{\perp}$ (resp. $\hat{x}', \hat{\mathbf{k}}'_{\perp}$) generically denoting incoming (resp. outgoing) parton kinematics.

Diehl et al., Nucl. Phys. B596, 33 (2001)

■ Similar expression in the ERBL region -ξ ≤ x ≤ ξ, but with overlap of N- and (N+2)-body LFWFs.

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Overlap representation. Advantages and drawbacks.



PARTONS Framework

- Physical picture.
- Positivity relations are fulfilled **by construction**.

Motivation

Imaging

Experimental access DVCS kinematics Towards 3D images

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Computing

Design Features Examples Architecture

Conclusion

■ Implementation of symmetries of *N*-body problems.

What is not obvious anymore

What is *not* obvious to see from the wave function representation is however the **continuity of GPDs at** $x = \pm \xi$ and the **polynomiality** condition. In these cases both the DGLAP and the ERBL regions must cooperate to lead to the required properties, and this implies **nontrivial relations between the wave functions** for the different Fock states relevant in the two regions. An *ad hoc* Ansatz for the wave functions would **almost certainly lead** to GPDs that **violate the above requirements**.

Diehl, Phys. Rept. 388, 41 (2003)

Cea

Covariant and positive GPD models. First systematic procedure to build models satisfying all constraints.





COA

Covariant and positive GPD models. First systematic procedure to build models satisfying all constraints.



PARTONS Framework

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Gaussian LFWF

Chouika Work in progress

- Numerics under control for **smooth** LFWFs.
- Still need to investigate situation with Regge behavior.
- Towards common modeling of GPDs and TMDs?

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Building the tools for high precision: the PARTONS project



PARtonic Tomography Of Nucleon Software

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The challenge of the high precision era. Higher order and higher twist contributions, and GPD modeling.



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- Evaluation of the impact of **higher order** effects.
- Evaluation of the impact of **target mass and finite**-*t* corrections.
- Evaluation of the contribution of **higher twist** GPDs.
 - DVMP: sensitivity to **DA models**.
 - Extrapolations with **GPD models**.

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Cea

Software for the phenomenology of GPDs. Different questions to be answered with the same tools.





Software for the phenomenology of GPDs. Different questions to be answered with the same tools.







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



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Experimental data and phenomenology

Computation of amplitudes

principles and

fundamental parameters

First

Small distance contributions

Full processes

Large distance contributions

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Design Features Examples

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





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Differential studies: physical models and numerical methods.



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phenomenology Computation of amplitudes First

Experimental

data and

principles and fundamental parameters





Differential studies: physical models and numerical methods.



PARTONS Framework Experimental DVMP DVCS Many TCS data and observables. Motivation phenomenology Imaging Kinematic reach. Experimental access DVCS kinematics Towards 3D images Modeling DVMP DVCS ഗ Limitations Computation Lorentz symmetry Radon transform of amplitudes Covariant extension Computing Design Features Examples GPD at $\mu \neq \mu_{F}^{ref}$ First Architecture Conclusion principles and Evolution fundamental GPD at μ_{F}^{ref} parameters

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Differential studies: physical models and numerical methods.



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Experimental data and phenomenology Need for modularity Computation

of amplitudes





Many observables.

Kinematic reach.

Perturbative approximations.

- Physical models.
- Fits.

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- Numerical methods.
- Accuracy and speed.

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Differential studies: physical models and numerical methods.



PARTONS Framework

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data and phenomenology Need for modularity Computation of amplitudes

Experimental

First principles and fundamental parameters



Many observables.

- Kinematic reach.
- Perturbative approximations.
- Physical models.
- Fits.
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- Accuracy and speed.

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Differential studies: physical models and numerical methods.



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 - modularity
- Computation of amplitudes





Many observables.

- Kinematic reach.
- Perturbative approximations.
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Fits.

- Numerical methods.
- Accuracy and speed.

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Differential studies: physical models and numerical methods.



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- Computation of amplitudes

First principles and fundamental parameters



Many observables.

- Kinematic reach.
- Perturbative approximations.
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Differential studies: physical models and numerical methods.



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 - modularity
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First principles and fundamental parameters



Many observables. Kinematic reach.

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

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Towards the first release. Currently: tests, benchmarking, documentation, tutorials.



PARTONS Framework

- 3 stages:
 - 1 Design.
 - 2 Integration and validation.
 - 3 Benchmarking and production.

Imaging Experimental access DVCS kinematics Towards 3D images

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- Covariant extension

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- Features Examples
- Architecture

Conclusion

- Flexible software architecture.
 - B. Berthou *et al.*, *PARTONS: a computing platform for the phenomenology of Generalized Parton Distributions* arXiv:1512.06174, *to appear in Eur. Phys. J. C.*
 - 1 new physical development = 1 new module.
- Aggregate knowledge and know-how:
 - Models
 - Measurements
 - Numerical techniques
 - Validation
- What can be automated will be automated,

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Systematic studies made easy. A faster and safer way to GPD phenomenology.



PARTONS Framework

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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



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GPD computations made fast.

Improved performances thanks to clever architecture design.



PARTONS Framework

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- Architecture

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GPD computations with or without threads

PARTONS → △ ● Hervé MOUTARDE	1
# elementary_utils	
# general	
ĒQ	



Systematic studies made fast (1/2). What can be done from scratch in about 1 hour.



PARTONS Framework

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



Imaging

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Systematic studies made fast (2/2). EIC observables computed with different pQCD assumptions.



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(Preliminary) $A_{ m LU}(90^\circ)$ at LO with Goloskokov-Kroll model



Colaneri, Work in progress

A (1) > A (1) > A

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GPD or CFF fits (1/2). Local fit of CFFs.



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

	Mattermost
PARTONS :	partons_fits → 7 🎍 Search @
@ partons_fits	Mon, Sep 26, 2016
@ partons_tests	pawel 3:16 PM
	·
@ partons_visualization	FCN=1.00128e-11 FROM MIGRAD STATUS=CONVERGED 44 CALLS 45 TOTAL
@ radon-inverse	EDM=2.00186e-11 STRATEGY= 1 ERROR MATRIX ACCURATE
@ short_distance	EXT PARAMETER STEP FIRST
@ Town Square	1 fit_CFF_H_Re 6.67247e-02 1.34241e+00 2.92531e-05 -7.02262e-07
@ trello	2 fit_CFF_H_Im 1.24231e+01 1.07342e+00 1.80608e-05 1.71071e-04 3 fit_CFF_F_Re3 94789e+00 fixed
@ virtual_machine	4 fit_CFF_E_Im -1.64116e-01 fixed
More	5 fit_CFF_Ht_Re 1.54183e+00 fixed 6 fit_CFF_Ht_Im 2.59017e+00 fixed
PRIVATE GROUPS +	7 fit_CFF_Et_Re 5.41102e+01 fixed 8 fit CFF Et Im 3.79052e+01 fixed
⊜ Gitlab	EXTERNAL ERROR MATRIX. NDIM= 25 NPAR= 2 ERR DEF=1
	1.804e+00 7.961e-03 7.961e-03 1.153e+00
DIDDET MEECLERE	PARAMETER CORRELATION COEFFICIENTS
DIRECT MESSAGES	NO. GLOBAL 1 2
e- bryan	2 0.00552 0.006 1.000
ex cearic	
- abinosi	The first reasonable fit with PARTONS_Fits! 12 AUL and 12 ALU asymmetries fitted together.
«х јакир	The true values of fit_CFF_H_Re and fit_CFF_H_Im are 0.06672466940113253 and
& luca	12.423114181138908
😓 nchouika	
& pawel	Write a message
• ההההדה	Sznajder
	Work in progress
	H Meuterde Nuclean Temerranhu 2017 21 / 44



<u>GPD or CFF fits (2/2).</u> Global fit of CFFs: border function formalism.



PARTONS Framework

(Preliminary) On-going global fit of Jefferson Lab DVCS data

 Kinematic cuts: O² > 1.5 GeV² $-t/O^2 < 0.2$

where we can relay on LO approximation where we can relay on GPD factorization

- χ2 / nPoints: 3317.1 / 3433 ≈ 0.97
- x2 / nPoints per data set:

Experiment	Reference	Observables	N points all	N points selected	chi2	chi2/nPoints
Hall A	[1] KINX2	συυ	120	120	103.2	0.86
Hall A	[1] KINX2	ΔσLU	120	120	98.8	0.82
Hall A	[1] KINX3	σUU	108	108	223.1	2.07
Hall A	[1] KINX3	ΔσLU	108	108	107.3	0.99
CLAS	[2]	συυ	1933	1333	1215.2	0.91
CLAS	[2]	ΔσLU	1933	1333	1171.4	0.88
CLAS	[3]	AUL, ALU, ALL	498	305	341.9	1.12

					11 Db//c Day C 02 055202 (2015)
	GPD	Parameter	Value	Error	[2] Phys. Rev. Lett. 115, 212003 (2015)
	н	Cu val	1.21	fixed	[3] Phys. Rev. D 91, 052014 (2015)
	н	Cu sea	1.27	fixed	
	н	Cd val	1.20	fixed	
	н	Cd sea	1.27	fixed	skewness
	Htilde	Cu val	1.07	fixed	function
المحمد ال	Htilde	Cu sea	1.06	fixed	
a nilea	Htilde	Cd val	1.11	fixed	
ers:	Htilde	Cd sea	1.07	fixed	2.
	н	a val	0.74	fixed	Degree like
	н	a sea	53.4	69.8	slopes
	Htilde	a val	2.88	0.35	Siopes
	Htilde	a sea	0.41	0.66	2.
	н	C sub	-1.38	0.15	subtraction
	н	a sub	0.21	0.34	constant Sznajder
	E	N	-7.38	0.44	CEE F and F 14/ /
	Etilde	N	-0.54	0.05	VVork in progress

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Fixed an paramete



Towards the first release. Debugging and flexibility: the path to controlled results.



PARTONS Framework

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Ces

GPD computing made simple. Each line of code corresponds to a physical hypothesis.



PARTONS		gpdExample()				
Framework	1	// Lots of includes				
	2	#include $<$ src/Partons h>				
Motivation	3					
Imaging	4	// Retrieve GPD service				
Experimental access	5	GPDService* pGPDService = Partons::getInstance()->getServiceObjectRegistry				
DVCS kinematics		()->getGPDService();				
Towards 3D images	6	// Load GPD module with the BaseModuleFactory				
Modeling	7	GPDModule* pGK11Model = Partons::getInstance()->getModuleObjectFactory				
Limitations		()->newGPDModule(GK11Model::classId);				
Radon transform	8	// Create a GPDKinematic(x, xi, t, MuF, MuR) to compute				
Covariant extension	9	GPDKinematic gpdKinematic(0.1, 0.00050025, -0.3, 8., 8.);				
Computing	10	// Compute data and store results				
Design	11	GPDResult gpdResult = pGPDService ->				
Features		computeGPDModelRestrictedBvGPDTvpe(gpdKinematic, pGK11Model,				
Examples		GPDTvpe··ALL)				
Architecture	12	// Print_results				
Conclusion	13	stdcout << gpdResult toString() << stdendl				
	1/	stancout ((Spanosattiosting() (Stancial,				
	15	delete pCK11Model:				
	15	pCK11Model - 0				
	10					

GPD computing automated. Each line of code corresponds to a physical hypothesis.



PARTONS		computeOneGPD.xml
Framework	1	xml version="1.0" encoding="UTF-8" standalone="yes" ?
	2	<pre><scenario date="" description="Example_:_computation_of_one_GPD</pre></td></tr><tr><td>Motivation</td><td></td><td><math>_model_{\sqcup}(GK11)_{\sqcup}without_{\sqcup}evolution" id="01"></scenario></pre>
Incominant	3	</math Select type of computation $>$
Imaging	4	<task service="GPDService" method="computeGPDModel">
DVCS kinematics	5	Specify kinematic
Towards 3D images	6	<kinematics type="GPDKinematic"></kinematics>
Modeling	7	<param name="x" value="0.1"/>
Limitations	8	<param name="xi" value="0.00050025"/>
Lorentz symmetry	9	<param name="t" value="-0.3"/>
Radon transform Covariant extension	10	<pre><param name="MuF2" value="8"/></pre>
	11	<param name="MuR2" value="8"/>
Computing	12	
Features	13	</math Select GPD model and set parameters $>$
Examples	14	<computation_configuration></computation_configuration>
Architecture	15	<module type="GPDModule"></module>
Conclusion	16	<param name="className" value="GK11Model"/>
	17	
	18	
	19	
	20	

GPD computing automated. Each line of code corresponds to a physical hypothesis.



PARTONS		computeOneGPD.xml					
Framework	1	xml version="1.0" encoding="UTF-8" stand</td <td>$H^{\mu} = 0.822557$</td>	$H^{\mu} = 0.822557$				
	2	<scenario <math="" date="" description="Exam</th><th>n = 0.022551</th></tr><tr><th>Motivation</th><th></th><th><math>_</math>model<math>_(GK11)</math><math>_</math>without<math>_</math>evolution" id="01">></scenario>	$H^{u(+)} = 0.165636$				
Imaging	3	</math Select type of computation $>$	$H^{u(-)} - 147948$				
Experimental access	4	<task gpdkinematic"="" method="con</th><th>11 () = 1.47940</th></tr><tr><th>DVCS kinematics</th><td>5</td><td><! Specify kinematic></td><td></td></tr><tr><th>Towards 3D images</th><td>6</td><td><pre><kinematics type=" service="GPDService"><td>$H^d = 0.421431$</td></task>	$H^d = 0.421431$				
Modeling	7	<param]<="" name="x" th="" value="0.1"/> <th></th>					
Limitations	8	<param <="" name="xi" t"="" td="" value="-0.3"/> <td>$H^{d(-)} = 0.762344$</td>	$H^{d(-)} = 0.762344$				
Radon transform Covariant extension	10	<param <="" name="MuF2" td="" value="8"/> <td></td>					
Computing	11	<param <="" name="MuR2" th="" value="8"/> <th></th>					
Design	12		$H^{s} = 0.00883408$				
Features	13	Select GPD model and set parameter</td <td>1/5(+) 0.0176600</td>	1/5(+) 0.0176600				
Examples	14	<computation_configuration></computation_configuration>	$H^{3(1)} \equiv 0.0170082$				
Architecture	15	<module type="GPDModule"></module>	$H^{s(-)} = 0$				
Conclusion	16	<param name="className" th="" va<=""/> <th>-</th>	-				
	17						
	18		$H^{g} = 0.385611$				
	19		and E Ũ Ē				
	20		anu <i>L</i> , <i>H</i> , <i>L</i> ,				

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CFF computing automated. Each line of code corresponds to a physical hypothesis.



		computeOneCFF.xml
PARTONS	1	xml version="1.0" encoding="UTF-8" standalone="yes" ?
Traffiework	2	<pre><scenario date="" description="Example_:_computation_of_one_</pre></td></tr><tr><td></td><td></td><td><math>convol_{\sqcup}coeff_{\sqcup}function_{\sqcup}model_{\sqcup}(DVCSCFF)_{\sqcup}with_{\sqcup}GPD_{\sqcup}model_{\sqcup}(GK11)" id="03"></scenario></pre>
Motivation	3	<task <="" method="</td></tr><tr><td>Imaging</td><td></td><td>computeWithGPDModel" service="ConvolCoeffFunctionService" td=""></task>
Experimental access	4	<kinematics type="DVCSConvolCoeffFunctionKinematic">
DVCS kinematics	5	<param name="xi" value="0.5" $/>$
Towards 5D Images	6	<param name="t" value="-0.1346" $/>$
Modeling	7	<param name="Q2" value="1.5557" $/>$
Limitations	8	<param name="MuF2" value="4" $/>$
Radon transform	9	<param name="MuR2" value="4" $/>$
Covariant extension	10	
Computing	11	<computation_configuration></computation_configuration>
Design	12	<module type="GPDModule"></module>
Features	13	<param name="className" value="GK11Model" $/>$
Architecture	14	
Conclusion	15	<pre><module type="DVCSConvolCoeffFunctionModule"></module></pre>
Conclusion	16	<param name="className" value="DVCSCFFModel" $/>$
	17	<param name="qcd_order_type" value="LO"/>
	18	
	19	
	20	< □ > <∄ > < ≥ > < ≥ > <

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C02

CFF computing automated. Each line of code corresponds to a physical hypothesis.



		comp	uteOneCFF.xml			
PARTONS	1	xml version="1.0" encoding="UTF-8" standalone="yes" ?				
Traffiework	2	<scenario date="" description="Example_:_computation_of_one_</td></tr><tr><td></td><td></td><td><math>convol_{\sqcup}coeff_{\sqcup}function_{\sqcup}model_{\sqcup}(convol_{\bot}coeff_{\bot}function_{\bot}model_{\bot})</math></td><td><math>({\tt DVCSCFF})_{\sqcup}{\tt with}_{\sqcup}{\tt GPD}_{\sqcup}{\tt model}_{\sqcup}({\tt GK11})" id="03"></scenario>				
Motivation	3	<task <="" method="</td></tr><tr><td>Imaging</td><td></td><td>computeWithGPDModel" service="ConvolCoeff]</td><td>FunctionService" td=""><td></td></task>				
Experimental access	4	<kinematics type="DVCSC</td><td><math>{\tt ConvolCoeffFunctionKinematic" }=""></kinematics>				
DVCS kinematics	5	<param <="" name="xi" td=""/> <td>value="0.5" /></td>	value="0.5" />			
Towards 3D Images	6	<param name="t" td="" v<=""/> <td>value="-0.1346" /></td>	value="-0.1346" />			
Modeling	7	<param <="" name="Q2" p=""/>	value="1.5557" />			
Limitations	8	<param name="MuF</td><td>2" value="4"/>				
Radon transform	9	<param name="MuR</td><td>2" value="4"/>				
Covariant extension	10					
Computing	11	<computation_configurat< td=""><td>ion></td></computation_configurat<>	ion>			
Design	12	<module type="GPD</td><td>Module"></module>				
Features	13	<param name="cla</td><td><code>ssName" value="GK11Model"/>				
Examples	14					
Architecture	15	<module c]<="" td="" type="DVCSCo</td><td><math>\mathcal{H} = 1.47722 + 1.766987</math></td></tr><tr><td>Conclusion</td><td>16</td><td><param name="><td>$\mathcal{E} = 0.12279 + 0.512312 i$</td></module>	$\mathcal{E} = 0.12279 + 0.512312 i$			
	17	<param name="q</td> <td></td>				
	18		H = 1.54911 + 0.953728 i			
	19	<td>$\tilde{\mathcal{E}} = 18\ 8776\ +\ 3\ 75275\ i$</td>	$\tilde{\mathcal{E}} = 18\ 8776\ +\ 3\ 75275\ i$			
	20		E 10.0110 + 0.10210 1			
			H. Moutarde Nucleon Tomography 2017 36 / 44			

OF LA RECARRENT À L'INDUSTR

Observable computing automated. Each line of code corresponds to a physical hypothesis.



		computeManyKinematicsOneModel.xml
PARTONS	1	<pre><scenario date="2016-10-18" description="Use_kinematics_list"></scenario></pre>
Framework	2	<task method="</td></tr><tr><td></td><td></td><td>computeManyKinematicOneModel" service="ObservableService" storeindb="1"></task>
Motivation	3	<pre><kinematics type="ObservableKinematic"></kinematics></pre>
Imaging	4	<pre><pre>cparam name="file" value="observable kinematics.dat" /></pre></pre>
Experimental access	5	
DVCS kinematics	6	<computation configuration=""></computation>
Towards 3D images	7	<module type="Observable"></module>
Modeling	8	<pre>charam name="className" value="Alu" /></pre>
Limitations	a	
Lorentz symmetry	10	<module type="DVCSModule"></module>
Covariant extension	11	<pre>chicage broshoad > /> /> /> /> /></pre>
Commuting	12	<pre>cparam name="beam energy" value="1066" /></pre>
Design	12	/module>
Features	14	<pre><module type="DVCSConvolCoeffFunctionModule"></module></pre>
Examples	14	
Architecture	15	<pre><pre>cparam name="className" value="DVCSCFFMode1" /></pre></pre>
Conclusion	16	$<$ param name="qcd_order_type" value="LO" $/>$
conclusion	17	
	18	<module type="GPDModule"></module>
	19	<param name="className" value="GK11Model" $/>$
	20	
	21	
		H. Moutarde Nucleon Tomography 2017 37 / 44
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Observable plotting automated. Plot production is automated too!



		QueryDatabaseObservablePlotFile.xml			
PARTONS	1	xml version="1.0" encoding="UTF-8" standalone="yes" ?			
Framework	2	<scenario date="2016-10-18" description=""></scenario>			
	3	</math Generate plot file from database for GK model $>$			
Motivation	4	<task method="generatePlotFile" service="ObservableService"></task>			
Imaging	5	<task_param type="output"></task_param>			
Experimental access	6	<param <="" name="filePath" td="" value="observable_GK11_plot.csv"/>			
DVCS kinematics		>			
Towards 3D Images	7				
Modeling	8	</math Variables of 2d plot $>$			
Limitations	9	<task_param type="select"></task_param>			
Radon transform	10	<param name="xPlot" value="phi" $>$			
Covariant extension	11	$<$ param name="yPlot" value="observable_value" $/>$			
Computing	12				
Design	13	</math Select results in database $>$			
Features	14	<task_param type="where"></task_param>			
Architecture	15	<param name="xB" value="0.1763"/>			
Conclusion	16	<pre><param name="t" value="-0.1346"/></pre>			
	17	<pre><pre>content of the second secon</pre></pre>			
	18	<pre><param name="computation_id" value="2"/></pre>			
	19				
	20				
	21	< □ > < @ > < ≥ > < ≥ > < ≥ > < ≥ > < > < > < > <			
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Observable plotting automated. <u>Plot production is automated too!</u>



		QueryE	DatabaseO	bservablePlotFile.xml			
PARTONS	1	xml version="1.0" encoding="UTF-8" standalone="ves" ?					
Trainework	2	<scenario date="2016-10-18" description=""></scenario>					
	3	</math Generate plot file from database for GK model $>$					
Motivation	4	<task method="generatePlotFile" service="ObservableService"></task>					
Imaging	5	<task_param th="" typ<=""><th>e="output"</th><th>></th><th></th></task_param>	e="output"	>			
Experimental access	6	<param nam<="" th=""/> <th>e="filePath</th> <th>" value="observable_GK11_plot.csv'</th> <th>" /</th>	e="filePath	" value="observable_GK11_plot.csv'	" /		
DVCS kinematics Towards 3D images		>					
Madallan	7	$$					
Limitations	8	</math Variables of 2d plot $>$					
Lorentz symmetry	9	<task_param th="" ty<=""><th></th><th></th><th></th></task_param>					
Radon transform	10	<param nar	ϕ [deg]	A _{LU}			
Covariant extension	11	<param nar	0.	0.			
Computing	12	$$	10	0.004726075012605100			
Design	13	Select re</th <th>10.</th> <th>0.024730075012005108</th> <th></th>	10.	0.024730075012005108			
Examples	14	<task_param th="" ty<=""><th>20.</th><th>0.048810639423911277</th><th></th></task_param>	20.	0.048810639423911277			
Architecture	15	<param nar<="" th=""/> <th>30</th> <th>0 0715723361211///678</th> <th></th>	30	0 0715723361211///678			
Conclusion	16	<param nar<="" th=""/> <th>50.</th> <th>0.071572550121144070</th> <th></th>	50.	0.071572550121144070			
	17	<param nar<="" th=""/> <th></th> <th></th> <th></th>					
	18	<param nar<="" th=""/> <th>350.</th> <th>-0.024736075012605111</th> <th></th>	350.	-0.024736075012605111			
	19		260	0.0547074402160650- 17			
	20		300.	-9.054/0/44031080586-1/			
	21				ۍ (»		



Fit parameterization. Save time for physics analysis!



		FitScenario.xml				
PARTONS	1					
Framework	2	</math 2nd step : kinematic cuts $>$				
	3	<task method="defineKinematicCuts" service="FitsService"></task>				
Motivation	4	<pre><kinematics type="kinematicCuts"></kinematics></pre>				
Imaging	5	<pre><param name="list" value="-t/Q2_lt_0.2;_Q2_gt_1.5"/></pre>				
Experimental access	6					
DVCS kinematics	7					
Towards 3D Images	8					
Modeling	9	5th step : Fitting Ansatz				
Limitations	10	<task method="configureFitsModule" service="FitsService"></task>				
Radon transform	11	<computation_configuration></computation_configuration>				
Covariant extension	12	<module name="Partons0117FitsModel" type="FitsModelModule"></module>				
Computing	13	3				
Design	14					
Features	15					
Examples	16	<				
Architecture Conclusion	17	<pre><task method="configureMinimizerModule" service="FiteService"></task></pre>				
	10	<pre><computation configuration=""></computation></pre>				
	18	< computation_configuration >				
	19	<module name="ROOTMinimizer" type="MinimizerModule"></module>				
	20	$<$ param name="root_minimizer_package_name" value="Minuit" $/>$				
	21					
	22					
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Modularity.

Inheritance, standardized inputs and outputs.



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Examples

Architecture

Conclusion

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

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Modularity and automation. Parse XML file, compute and store result in database.





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Conclusion

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Conclusions and prospects. Towards a unifying framework for GPD studies.



PARTONS Framework

Motivation

Imaging

Experimental access DVCS kinematics Towards 3D images

Modeling

Limitations Lorentz symmetry Radon transform Covariant extension

Computing

- Design Features
- Examples
- Architecture

Conclusion

- **Challenging constraints** expected from Jefferson Lab in valence region and later from EIC in gluon sector.
- **Good theoretical control** on the path between GPD models and experimental data.
- Success of physics program requires new GPD models with proper implementations of symmetries.
- Development of the PARTONS framework for phenomenology and theory purposes.
- **Fitting engine** ready for local fits. Global fits *in progress*.
- **First release** of PARTONS... as soon as possible!

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