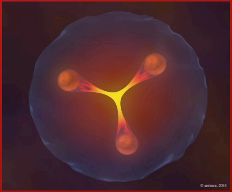
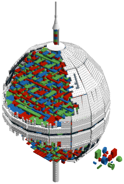
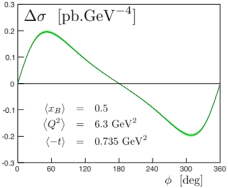
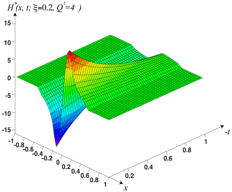
DE LA RECHERCHE À L'INDUSTRIE

The PARTONS framework: features and performances









NPQCD 2016, Sevilla | Hervé MOUTARDE

Oct. 19th, 2016

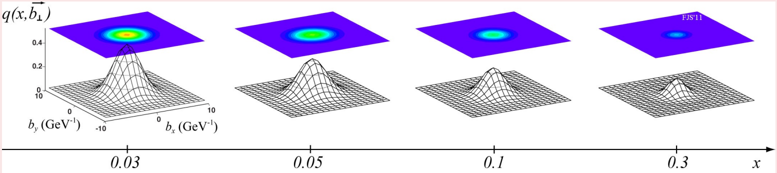
www.cea.fr

Motivation.

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

- 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**.

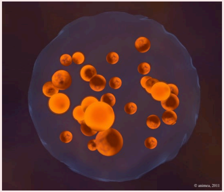
Transverse plane density (Goloskokov and Kroll model)



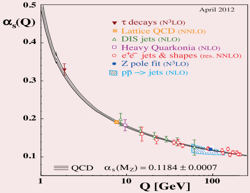
Motivation.

Study nucleon structure to shed new light on nonperturbative QCD.

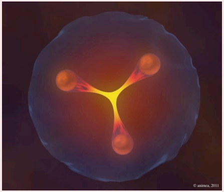
Perturbative QCD



Asymptotic freedom



Nonperturbative QCD

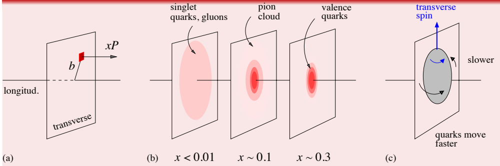


Perturbative AND nonperturbative QCD at work

- 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.

1. **The problem of 3D imaging:**
   What do we want?
2. **Phenomenology, GPD models, experimental images:**
   What can we actually do?
3. **Tools to make the best from experimental data:**
   What can we expect from the near future?

Can we obtain this picture from exclusive measurements?

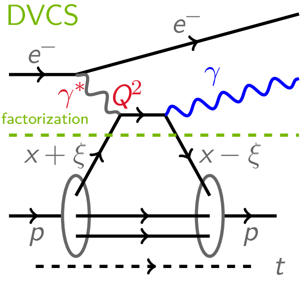


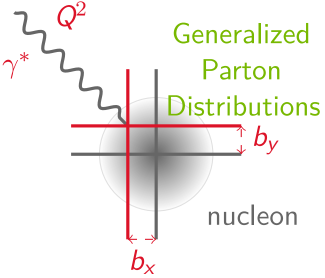
Weiss, AIP Conf. Proc. **1149**, 150 (2009)

Principles of nucleon 3D imaging

Exclusive processes of current interest (1/2).

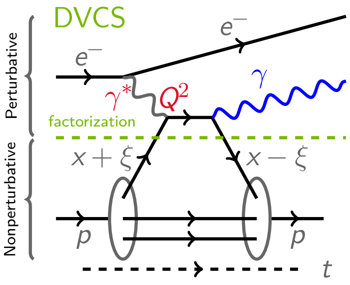
Factorization and universality.

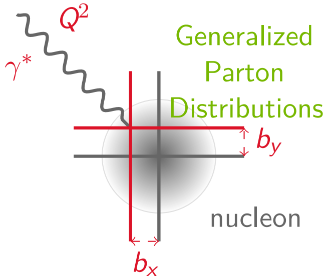




Exclusive processes of current interest (1/2).

Factorization and universality.





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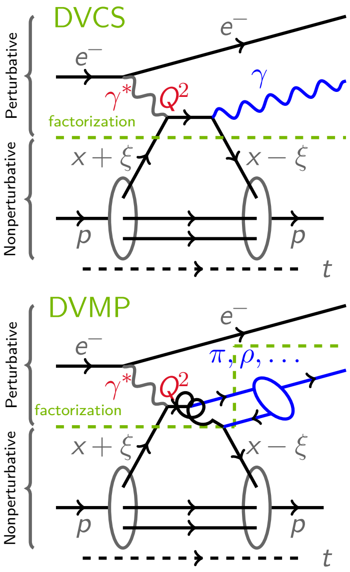

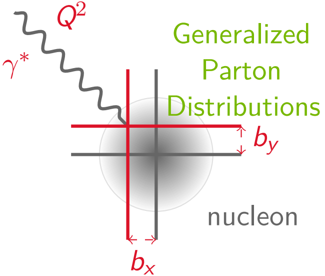

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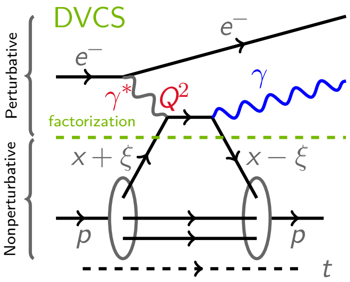

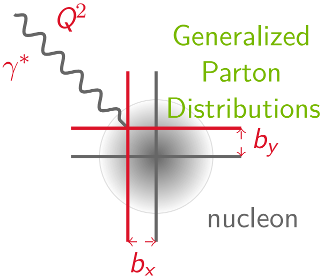

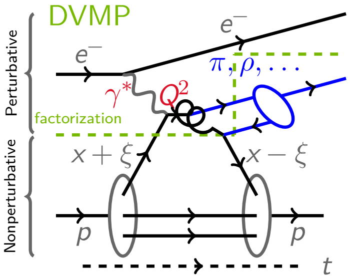

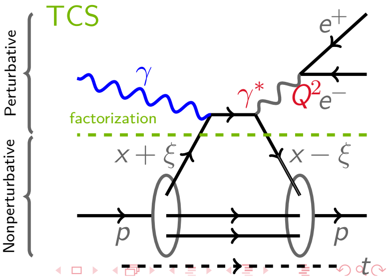

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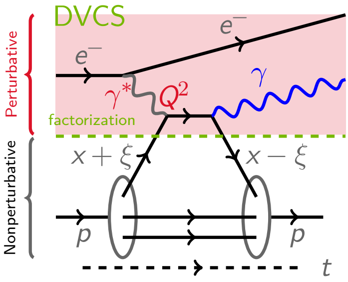
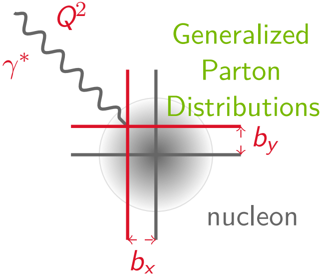
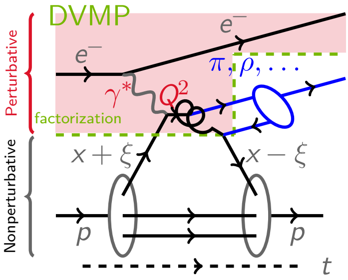
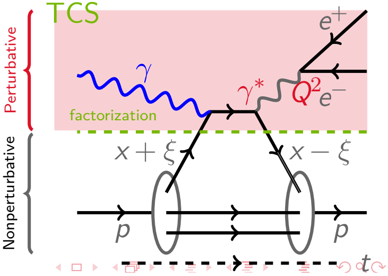


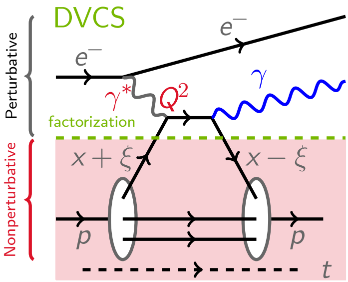


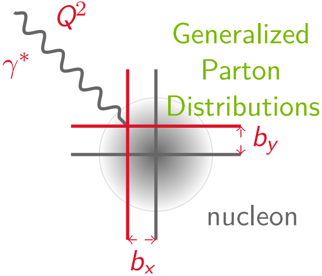


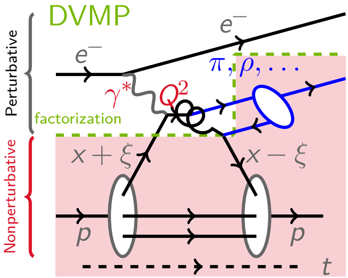


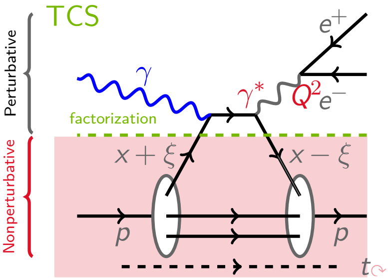
Exclusive processes of current interest (1/2).

Factorization and universality.









Exclusive processes of present interest (2/2).

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.

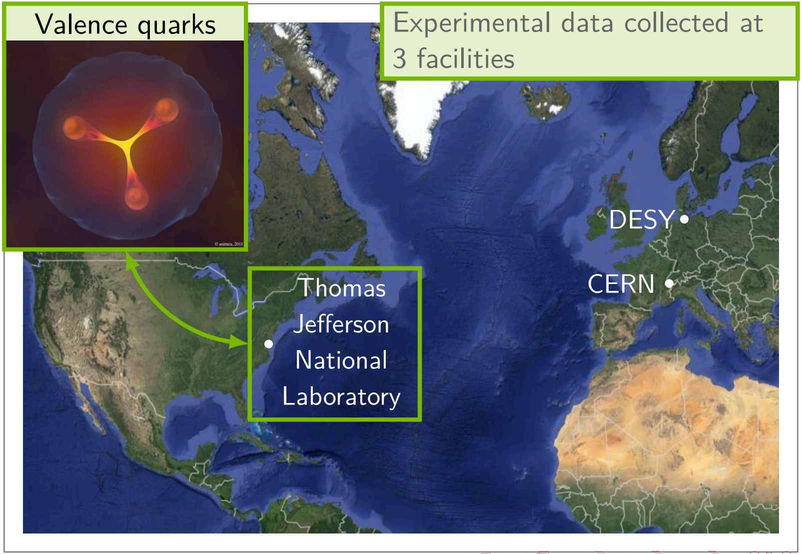
PARTONS Framework

Experimental data collected at 3 facilities

Need for global fits of world data.

Different facilities will probe different kinematic domains.

PARTONS Framework



Need for global fits of world data.

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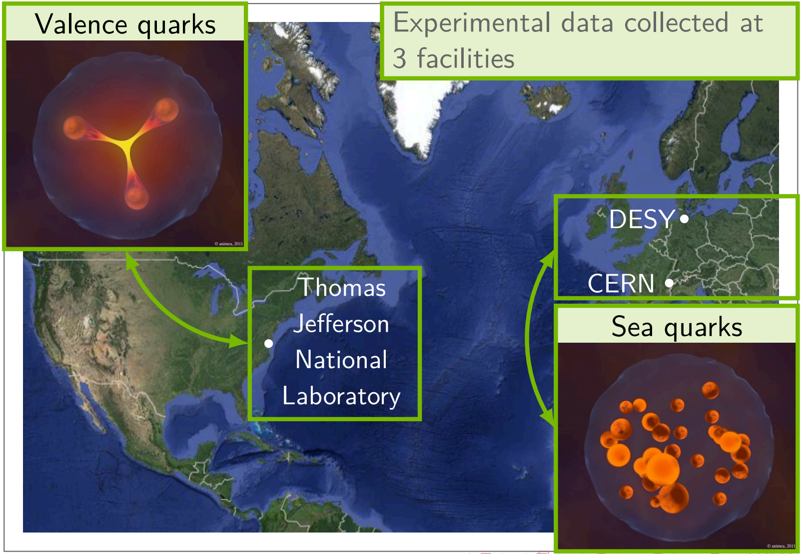
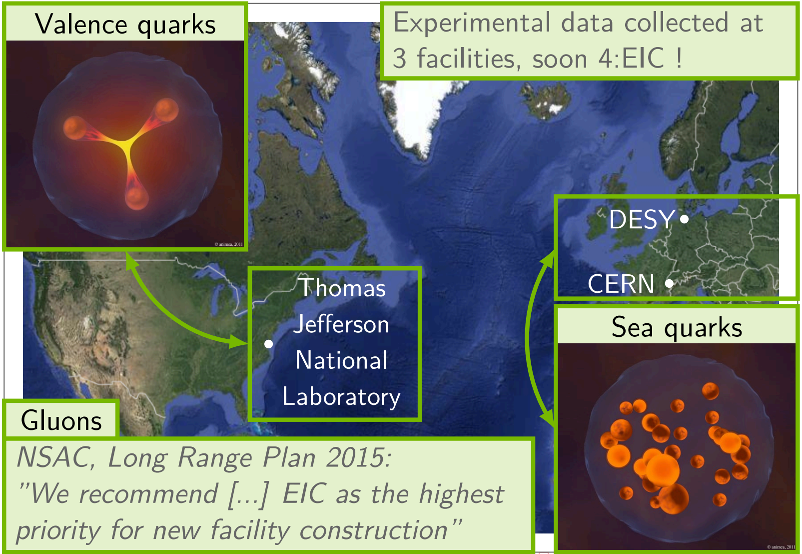


Need for global fits of world data.

Different facilities will probe different kinematic domains.

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

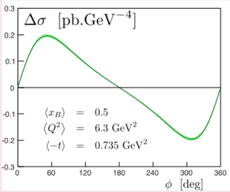


NSAC, Long Range Plan 2015: "We recommend [...] EIC as the highest priority for new facility construction"

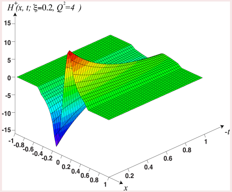
Imaging the nucleon. How?

Extracting GPDs is not enough…Need to extrapolate!

1. Experimental data fits



2. GPD extraction



3. Nucleon imaging

Images from Guidal et al.,
Rept. Prog. Phys. 76 (2013) 066202

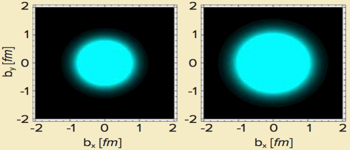
Reaching for the Horizon

The 2015 Long Range Plan for Nuclear Science

Sidebar 2.2: The First 3D Pictures of the Nucleon

A computed tomography (CT) scan can help physicians pinpoint minute cancer tumors, diagnose tiny broken bones, and spot the early signs of osteoporosis. Now physicists are using the principles behind the procedure to peer at the inner workings of the proton. This breakthrough is made possible by a relatively new concept in nuclear physics called generalized parton distributions.

An intense beam of high-energy electrons can be used



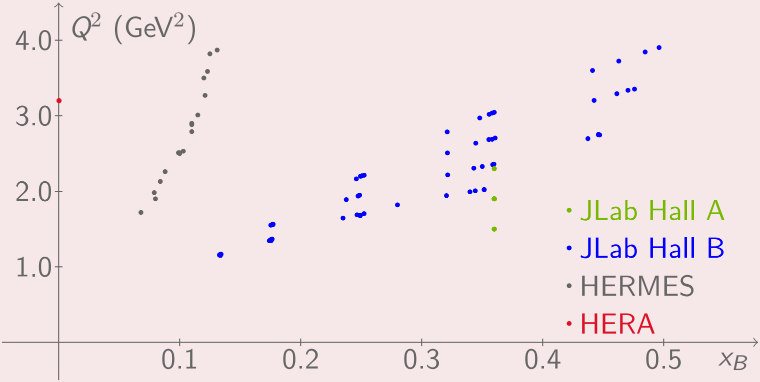
1. **Extract** $H(x, \xi, t, \mu_F^{\mathrm{ref}})$ from experimental data.
2. **Extrapolate** to vanishing skewness $H(x, 0, t, \mu_F^{\mathrm{ref}})$.
3. **Extrapolate** $H(x, 0, t, \mu_F^{\mathrm{ref}})$ up to infinite t.
4. **Compute** 2D Fourier transform in transverse plane:

$$H(x, b_\perp) = \int_0^{+\infty} \frac{\mathrm{d}|\Delta_\perp|}{2\pi} |\Delta_\perp| J_0(|b_\perp||\Delta_\perp|) H(x, 0, -\Delta_\perp^2)$$

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

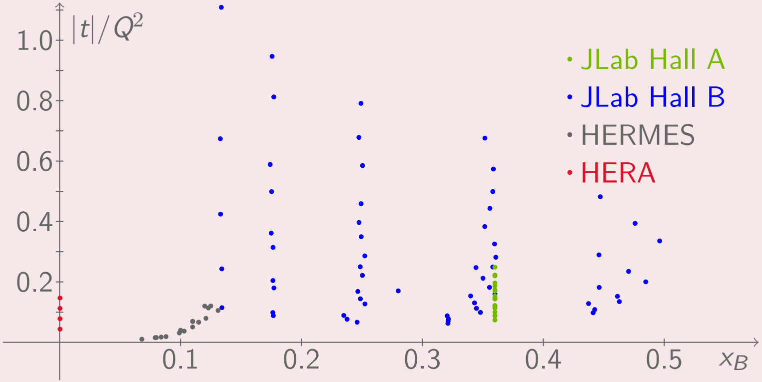
Practice of nucleon 3D imaging

What is large Q^2? *Measurements before 2015...*



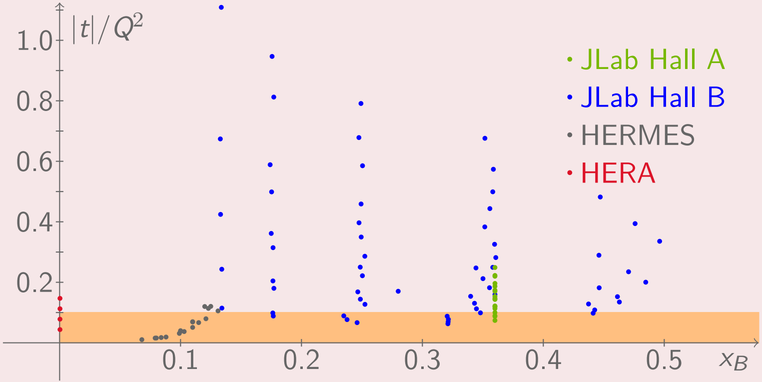
- World data cover **complementary kinematic regions**.

What is large Q^2? *Measurements before 2015...*



- World data cover **complementary kinematic regions**.
- Q^2 is **not so large** for most of the data.

What is large Q^2? *Measurements before 2015...*

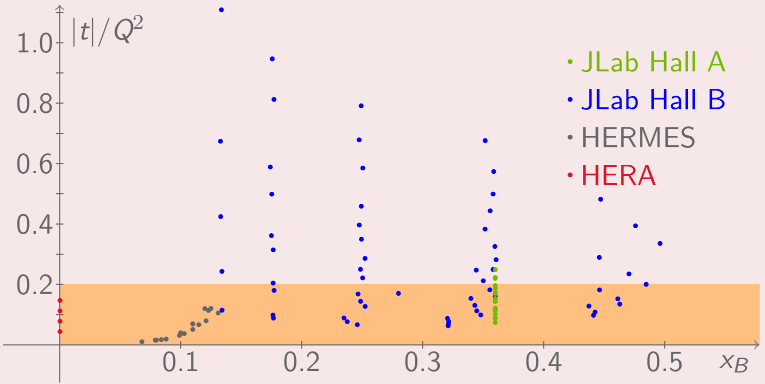


- World data cover **complementary kinematic regions**.
- Q^2 is **not so large** for most of the data.
- **Higher twists? Finite-t and target mass corrections?**

Kinematics of existing DVCS measurements.

Looking for the Bjorken regime.

What is large Q^2? *Measurements before 2015...*

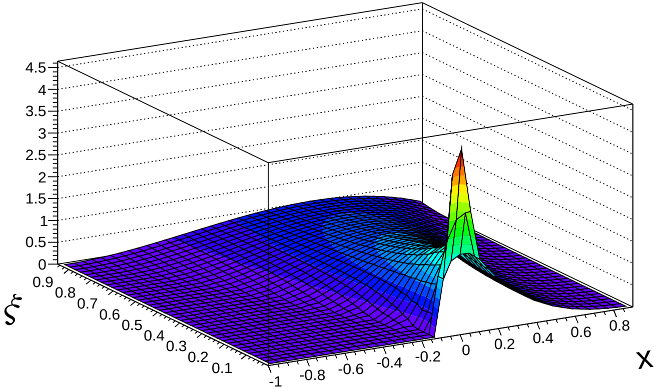


- World data cover **complementary kinematic regions**.
- Q^2 is **not so large** for most of the data.
- **Higher twists? Finite-t and target mass corrections?**

From principles to actual data.

Direct experimental access to a restricted kinematic domain.

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

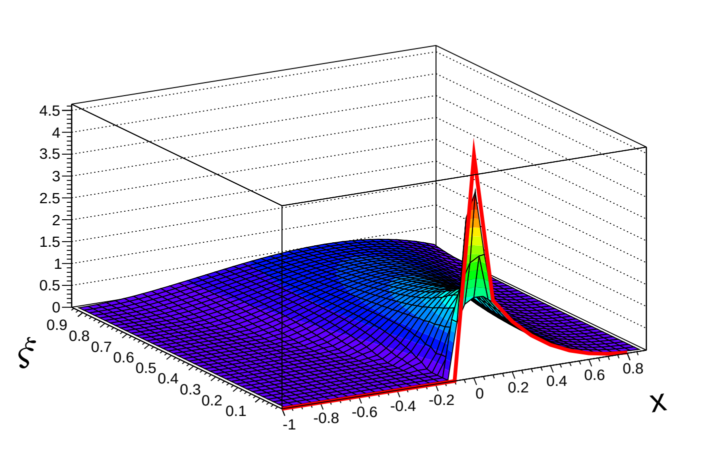


GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

From principles to actual data.

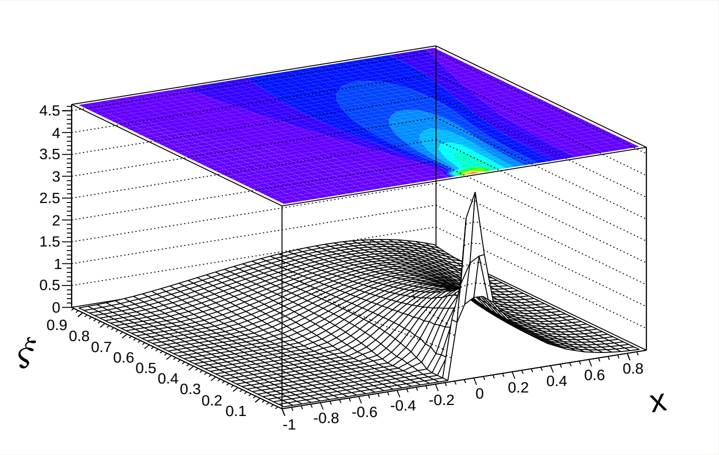
Direct experimental access to a restricted kinematic domain.

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



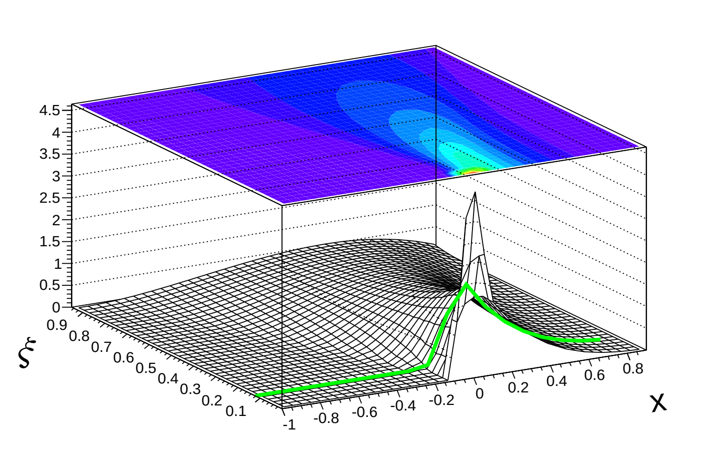
GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

What is the physical region?



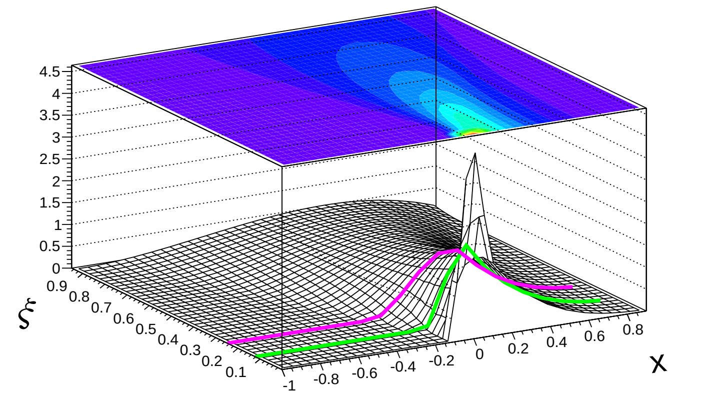
GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

ξ_{min} from finite beam energy.



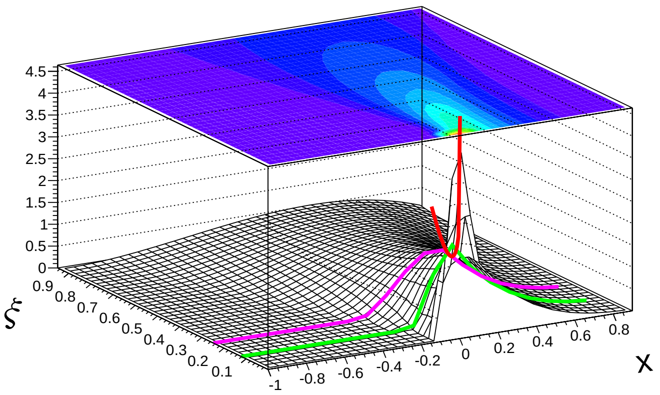
GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

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



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

The cross-over line $x = \xi$.



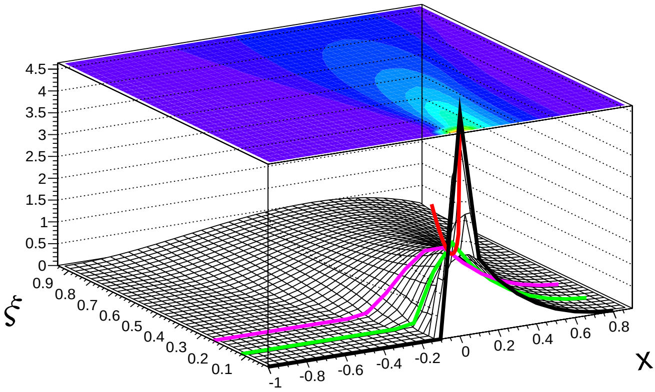
GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

From principles to actual data.

Direct experimental access to a restricted kinematic domain.

CEA - Saclay

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

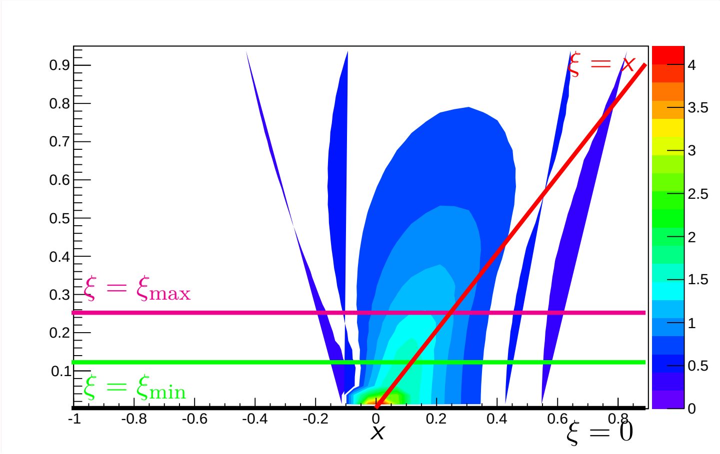


GPD model: see Kroll *et al.*, Eur. Phys. J. **C73**, 2278 (2013)

From principles to actual data.

Direct experimental access to a restricted kinematic domain.

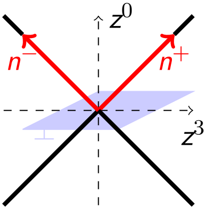
Density plot of H at $t = -0.23$ GeV^2 and $Q^2 = 2.3$ GeV^2



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

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

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



References

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

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

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

- PDF **forward limit**

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

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

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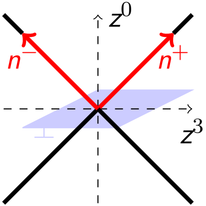

References

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Ji, Phys. Rev. Lett. **78**, 610 (1997)
Radyushkin, Phys. Lett. **B380**, 417 (1996)

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

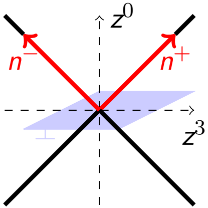
$$\int_{-1}^{+1} dx\, H^q(x, \xi, t) = F_1^q(t)$$

Spin-0 Generalized Parton Distribution.

Definition and simple properties.

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

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



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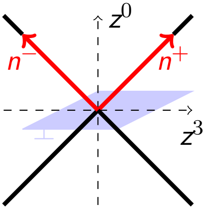
Ji, Phys. Rev. Lett. **78**, 610 (1997)
Radyushkin, Phys. Lett. **B380**, 417 (1996)

- PDF **forward limit**
- Form factor **sum rule**
- H^q is an **even function** of ξ from time-reversal invariance.

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

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



References

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

- 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.

Polynomiality.

Mixed constraint from Lorentz invariance and discrete symmetries.

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

$$\int_{-1}^{+1} \mathrm{d}x\, x^m H^q(x, \xi, t) = \frac{1}{2(P^+)^{m+1}} \left\langle P + \frac{\Delta}{2} \middle| \bar{q}(0)\gamma^+(i\overleftrightarrow{D}^+)^m q(0) \middle| P - \frac{\Delta}{2} \right\rangle$$

- Identify the **Lorentz structure** of the matrix element:

$$\text{linear combination of } (P^+)^{m+1-k}(\Delta^+)^k \text{ for } 0 \leq k \leq m+1$$

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

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

Double Distributions.

Lorentz covariance by example.

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

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

- Simple analytic expressions for the GPD:

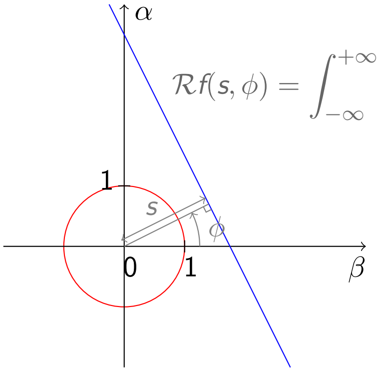
$$\begin{aligned} H(x, \xi) &= \frac{6x(1-x)}{1-\xi^2} \text{ if } 0 < |\xi| < x < 1, \\ H(x, \xi) &= \frac{3x(x+|\xi|)}{|\xi|(1+|\xi|)} \text{ if } -|\xi| < x < |\xi| < 1. \end{aligned}$$

- Compute first Mellin moments.

n	$\int_{-\xi}^{+\xi} \mathrm{d}x\, x^n H(x,\xi)$	$\int_{+\xi}^{+1} \mathrm{d}x\, x^n H(x,\xi)$	$\int_{-\xi}^{+1} \mathrm{d}x\, x^n H(x,\xi)$
0	$\frac{1+\xi-2\xi^2}{1+\xi}$	$\frac{2\xi^2}{1+\xi}$	1
1	$\frac{1+\xi+\xi^2-3\xi^3}{2(1+\xi)}$	$\frac{2\xi^3}{1+\xi}$	$\frac{1+\xi^2}{2}$
2	$\frac{3(1-\xi)(1+2\xi+3\xi^2+4\xi^3)}{10(1+\xi)}$	$\frac{6\xi^4}{5(1+\xi)}$	$\frac{3(1+\xi^2)}{10}$
3	$\frac{1+\xi+\xi^2+\xi^3+\xi^4-5\xi^5}{5(1+\xi)}$	$\frac{6\xi^5}{5(1+\xi)}$	$\frac{1+\xi^2+\xi^4}{5}$
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!

The Radon transform.
Definition and properties.



For $s > 0$ and $\phi \in [0, 2\pi]$:

$$\mathcal{R}f(s, \phi) = \int_{-\infty}^{+\infty} \mathrm{d}\beta \mathrm{d}\alpha\, f(\beta, \alpha)\delta(s - \beta\cos\phi - \alpha\sin\phi)$$

and:

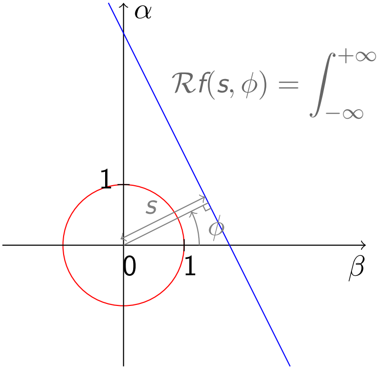
$$\mathcal{R}f(-s, \phi) = \mathcal{R}f(s, \phi \pm \pi)$$

Relation to GPDs:

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

Relation between GPD and DD in Belistky *et al.* gauge

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



For $s > 0$ and $\phi \in [0, 2\pi]$:

$$\mathcal{R}f(s,\phi) = \int_{-\infty}^{+\infty} \mathrm{d}\beta \mathrm{d}\alpha \, f(\beta,\alpha)\delta(s - \beta\cos\phi - \alpha\sin\phi)$$

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 Mellin moments of a Radon transform are **homogeneous polynomials** in $\omega = (\sin\phi, \cos\phi)$.
- 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^∞ in ω,*

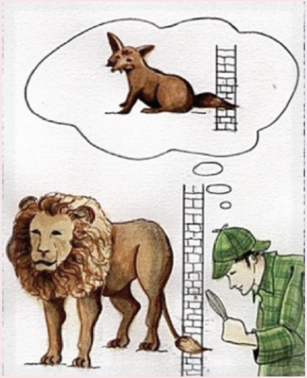
(ii) *$\int \mathrm{d}s\, s^m g(s, \omega)$ is a homogeneous polynomial of degree m for all integer $m \geq 0$.*

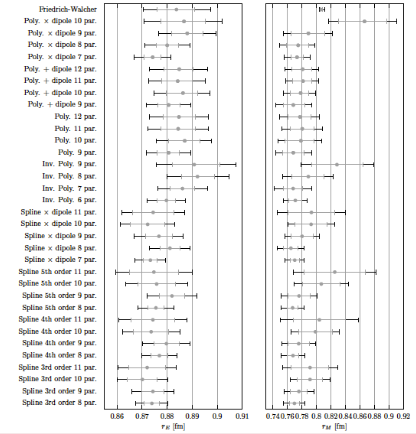
- Double Distributions and the Radon transform are the **natural solution** of the polynomiality condition.

Support theorem.

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

Extrapolations...





Bernauer *et al.*(A1 Coll.), Phys. Rev. **C90**, 015206 (2014)

Support theorem.

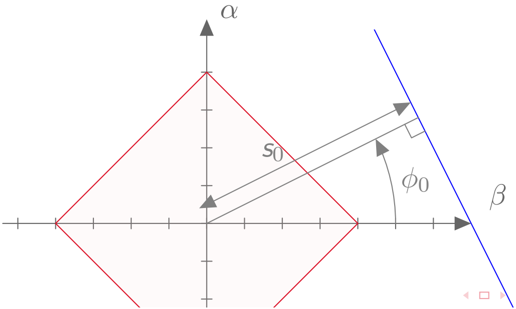
We don't need to know the GPD everywhere to image the proton!

Theorem

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.:

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

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

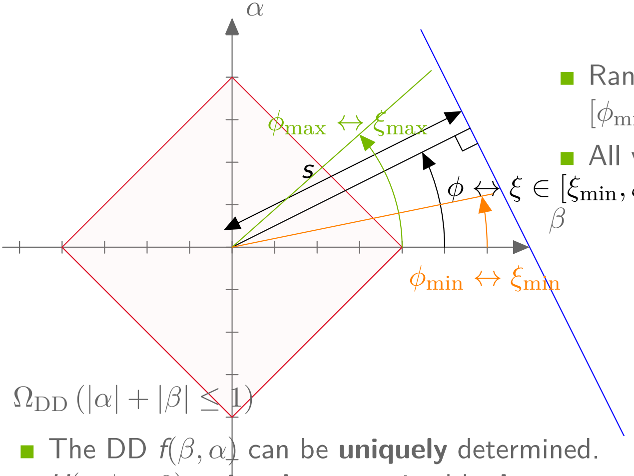


- $\omega_0 = (\cos \phi_0, \sin \phi_0)$.
- $\aleph = (\beta, \alpha)$.

Support theorem.

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

- Assume deconvolution of CFF achieved.
- Data: $H(x, \xi)$ for all $x \in [-1, +1]$ and $\xi \in [\xi_{\min}, \xi_{\max}]$.



- Range $\phi \in [\phi_{\min}, \phi_{\max}]$.
- All values of s.

- The DD $f(\beta, \alpha)$ can be **uniquely** determined.
- $H(x, \xi = 0)$ **uniquely** constrained by **Lorentz covariance**!

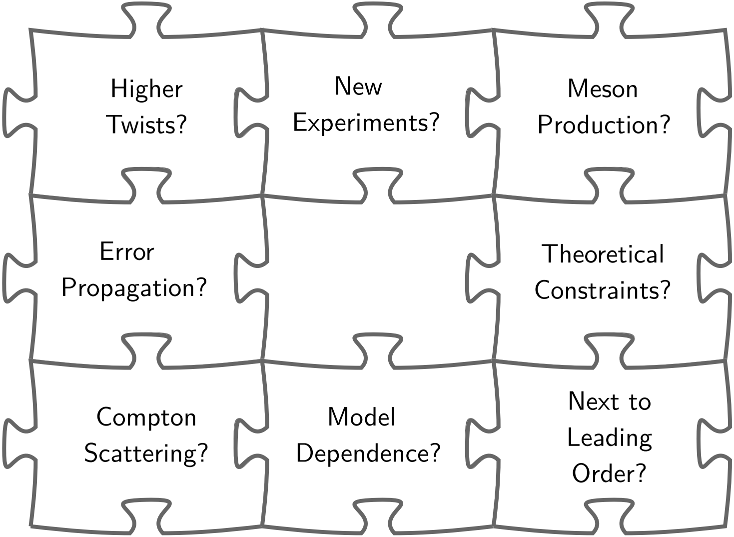
Building the tools for high precision: the PARTONS project

PARtonic
Tomography
Of
Nucleon
Software

- 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**.

Software for the phenomenology of GPDs.

Different questions to be answered with the same tools.



Software for the phenomenology of GPDs.

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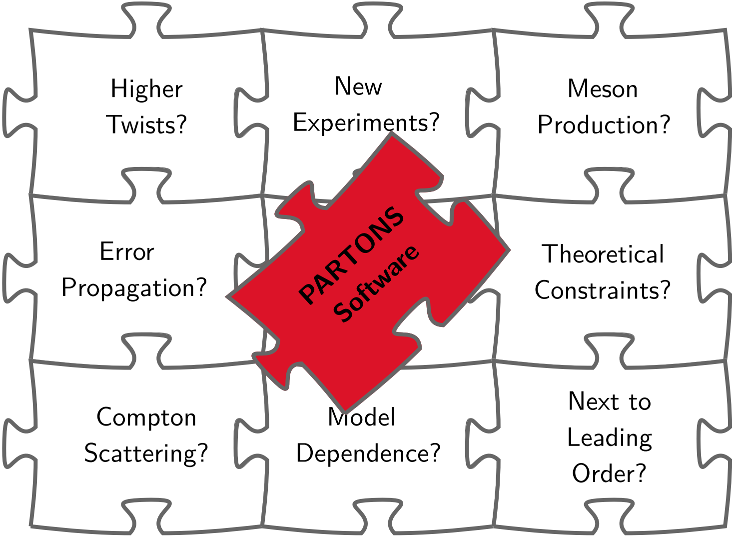


Experimental data and phenomenology	Full processes
Computation of amplitudes	Small distance contributions
First principles and fundamental parameters	Large distance contributions

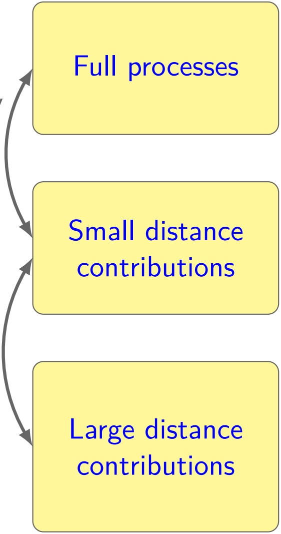
Computing chain design.

Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Computation of amplitudes

First principles and fundamental parameters



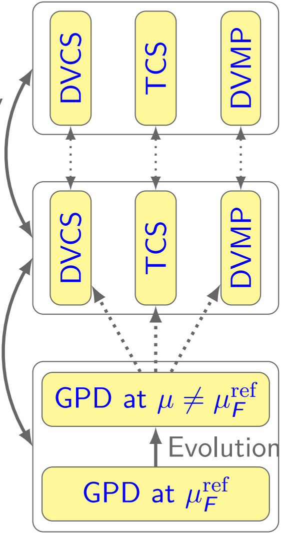
Computing chain design.

Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Computation of amplitudes

First principles and fundamental parameters



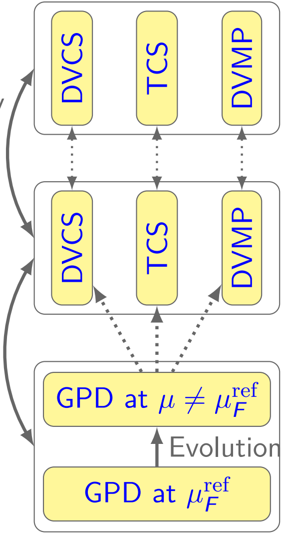
Computing chain design.

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.

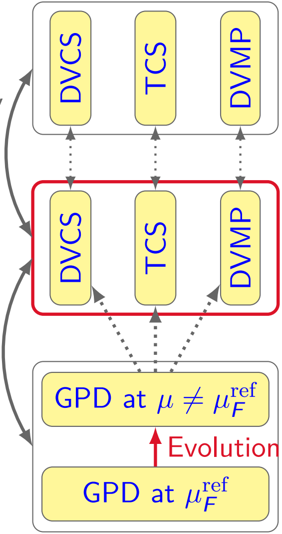
Differential studies: physical models and numerical methods.

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.

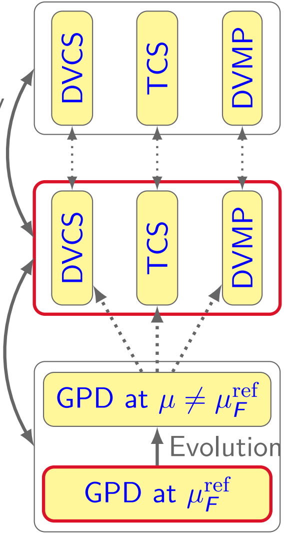
Differential studies: physical models and numerical methods.

Experimental data and phenomenology

Need for modularity

Computation of amplitudes

First principles and fundamental parameters



- Many observables.
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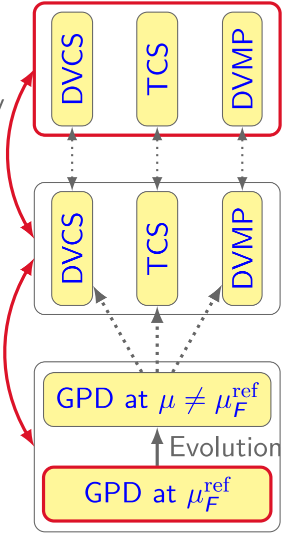

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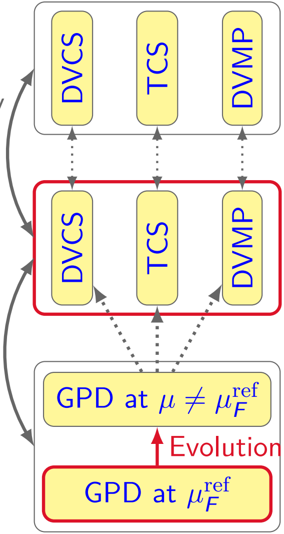

- Many observables.
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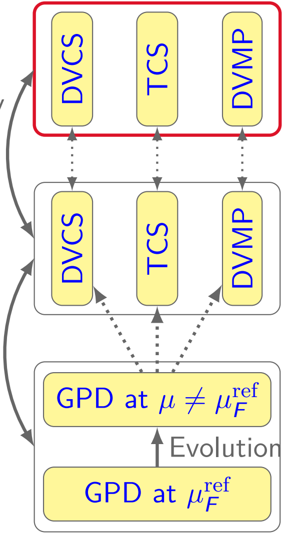


- Many observables.
- Kinematic reach.

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

Towards the first release.

Currently: tests, benchmarking, documentation, tutorials.

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

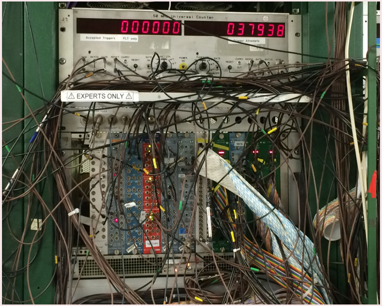
Systematic studies made easy.

A faster and safer way to GPD phenomenology.

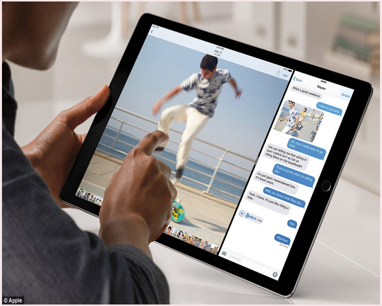
Automation allows...:

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

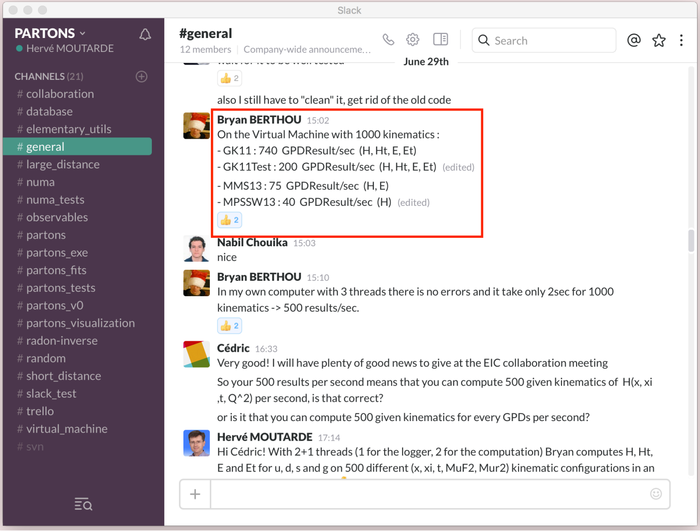
Without PARTONS



With PARTONS



GPD computations with or without threads



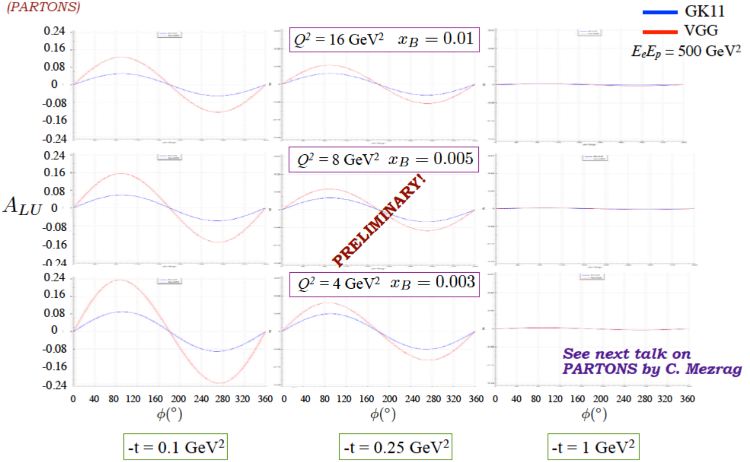
Systematic studies made fast.

What can be done from scratch in about 1 hour.

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

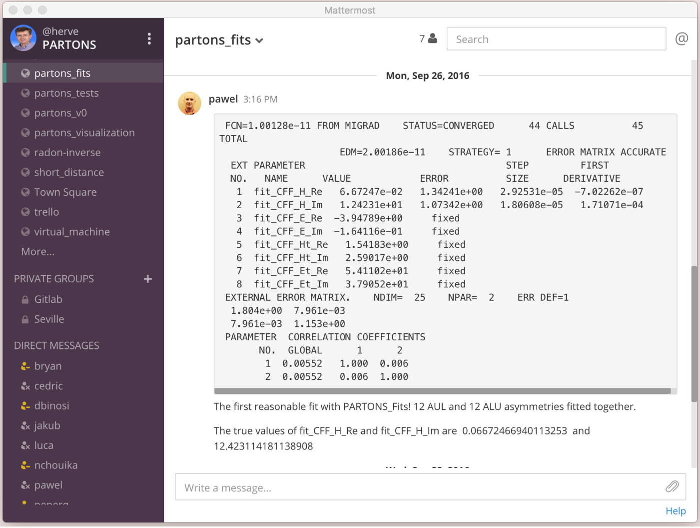
Luca Colaneri, Nabil Chouika (PARTONS)

DVCS beam-spin asymmetries at EIC



See next talk on PARTONS by C. Mezrag

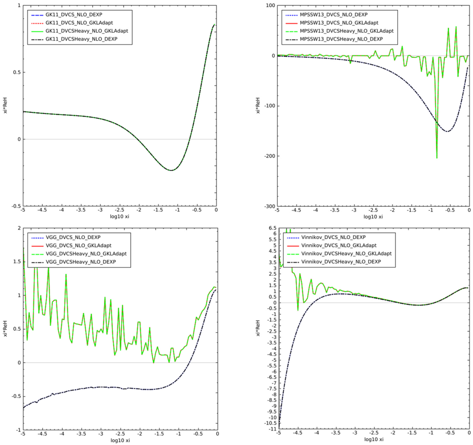
First fit of pseudo DVCS data, Sep. 26th, 2016



Towards the first release.

Debugging and flexibility: the path to controlled results.

Coefficient functions, from EIC to Jefferson Lab kinematics



- Previous tests of integration routines.
- Preparation of **nonregression tools**.
- **Flexibility** at work: **physical** models and **numerical** techniques.
- $\simeq 2 \times 10^4$ GPD computed in $\lesssim 1'$.

GPD computing made simple.

Each line of code corresponds to a physical hypothesis.

gpdExample()

```
// Lots of includes
#include <src/Partons.h>
...
// Retrieve GPD service
GPDService* pGPDService = Partons::getInstance()->getServiceObjectRegistry
()->getGPDService();
// Load GPD module with the BaseModuleFactory
GPDModule* pGK11Model = Partons::getInstance()->getModuleObjectFactory
()->newGPDModule(GK11Model::classId);
// Create a GPDKinematic(x, xi, t, MuF, MuR) to compute
GPDKinematic gpdKinematic(0.1, 0.00050025, -0.3, 8., 8.);
// Compute data and store results
GPDResult gpdResult = pGPDService->
computeGPDModelRestrictedByGPDType(gpdKinematic, pGK11Model,
GPDType::ALL);
// Print results
std::cout << gpdResult.toString() << std::endl;

delete pGK11Model;
pGK11Model = 0;
```

GPD computing automated.

Each line of code corresponds to a physical hypothesis.

computeOneGPD.xml

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario id="01" date="" description="Example␣:␣computation␣of␣one␣GPD
␣model␣(GK11)␣without␣evolution">
    <!-- Select type of computation -->
    <task service="GPDService" method="computeGPDModel">
        <!-- Specify kinematic -->
        <kinematics type="GPDKinematic">
            <param name="x" value="0.1" />
            <param name="xi" value="0.00050025" />
            <param name="t" value="-0.3" />
            <param name="MuF2" value="8" />
            <param name="MuR2" value="8" />
        </kinematics>
    <!-- Select GPD model and set parameters -->
    <computation_configuration>
            <module type="GPDModule">
                <param name="className" value="GK11Model" />
            </module>
    </computation_configuration>
</task>
</scenario>
```

GPD computing automated.

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computeOneGPD.xml

```
<?xml version="1.0" encoding="UTF-8" stand
<scenario id="01" date="" description="Exam                                    D
␣model␣(GK11)␣without␣evolution">
    <!-- Select type of computation -->
    <task service="GPDService" method="com
        <!-- Specify kinematic -->
        <kinematics type="GPDKinematic">
            <param name="x" value="0.1" /
            <param name="xi" value="0.000
            <param name="t" value="-0.3" /
            <param name="MuF2" value="8" /
            <param name="MuR2" value="8" /
        </kinematics>
    <!-- Select GPD model and set parameter
    <computation_configuration>
            <module type="GPDModule">
                <param name="className" va
            </module>
    </computation_configuration>
</task>
</scenario>
```

$$H^u = 0.822557$$
$$H^{u(+)} = 0.165636$$
$$H^{u(-)} = 1.47948$$

$$H^d = 0.421431$$
$$H^{d(+)} = 0.0805182$$
$$H^{d(-)} = 0.762344$$

$$H^s = 0.00883408$$
$$H^{s(+)} = 0.0176682$$
$$H^{s(-)} = 0$$

$$H^g = 0.385611$$

and E, $\tilde{H}$, $\tilde{E}$, ...

CFF computing automated.

Each line of code corresponds to a physical hypothesis.

computeOneCFF.xml

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario id="03" date="" description="Example␣:␣computation␣of␣one␣convol␣coeff␣function␣model␣(DVCSCFF)␣with␣GPD␣model␣(GK11)">
    <task service="ConvolCoeffFunctionService" method="computeWithGPDModel"
        <kinematics type="DVCSConvolCoeffFunctionKinematic">
            <param name="xi" value="0.5" />
            <param name="t" value="-0.1346" />
            <param name="Q2" value="1.5557" />
            <param name="MuF2" value="4" />
            <param name="MuR2" value="4" />
        </kinematics>
        <computation_configuration>
            <module type="GPDModule">
            <param name="className" value="GK11Model" />
        </module>
        <module type="DVCSConvolCoeffFunctionModule">
            <param name="className" value="DVCSCFFModel" />
            <param name="qcd_order_type" value="LO" />
        </module>
        </computation_configuration>
    </task>
```

CFF computing automated.

Each line of code corresponds to a physical hypothesis.

computeOneCFF.xml

```
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario id="03" date="" description="Example␣:␣computation␣of␣one␣
convol␣coeff␣function␣model␣(DVCSCFF)␣with␣GPD␣model␣(GK11)">
    <task service="ConvolCoeffFunctionService" method="
computeWithGPDModel"
        <kinematics type="DVCSConvolCoeffFunctionKinematic">
            <param name="xi" value="0.5" />
            <param name="t" value="-0.1346" />
            <param name="Q2" value="1.5557" />
            <param name="MuF2" value="4" />
            <param name="MuR2" value="4" />
        </kinematics>
        <computation_configuration>
            <module type="GPDModule">
            <param name="className" value="GK11Model" />
        </module>
        <module type="DVCSCo
            <param name="cl
            <param name="q
        </module>
        </computation_configu
    </task>
```

$$\mathcal{H} = 1.47722 + 1.76698\ i$$
$$\mathcal{E} = 0.12279 + 0.512312\ i$$
$$\widetilde{\mathcal{H}} = 1.54911 + 0.953728\ i$$
$$\widetilde{\mathcal{E}} = 18.8776 + 3.75275\ i$$

Observable computing automated.

Each line of code corresponds to a physical hypothesis.

computeManyKinematicsOneModel.xml

```
<scenario date="2016-10-18" description="Use␣kinematics␣list">
    <task service="ObservableService" method="
computeManyKinematicOneModel" storeInDB="1">
        <kinematics type="ObservableKinematic">
            <param name="file" value="observable_kinematics.dat" />
        </kinematics>
        <computation_configuration>
            <module type="Observable">
                <param name="className" value="Alu" />
            </module>
            <module type="DVCSModule">
                <param name="className" value="BMJ2012Model" />
                <param name="beam_energy" value="1066" />
            </module>
            <module type="DVCSConvolCoeffFunctionModule">
                <param name="className" value="DVCSCFFModel" />
                <param name="qcd_order_type" value="LO" />
            </module>
            <module type="GPDModule">
                <param name="className" value="GK11Model" />
            </module>
        </computation_configuration>
```

Observable plotting automated.

Plot production is automated too!

QueryDatabaseObservablePlotFile.xml

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario date="2016-10-18" description="...">
    <!-- Generate plot file from database for GK model-->
    <task service="ObservableService" method="generatePlotFile">
        <task_param type="output">
            <param name="filePath" value="observable_GK11_plot.csv" />
        </task_param>
        <!-- Variables of 2d plot -->
        <task_param type="select">
            <param name="xPlot" value="phi" />
            <param name="yPlot" value="observable_value" />
        </task_param>
        <!-- Select results in database -->
        <task_param type="where">
            <param name="xB" value="0.1763" />
            <param name="t" value="-0.1346" />
            <param name="Q2" value="1.3651" />
            <param name="computation_id" value="2" />
        </task_param>
    </task>
</scenario>
```

Observable plotting automated.

Plot production is automated too!

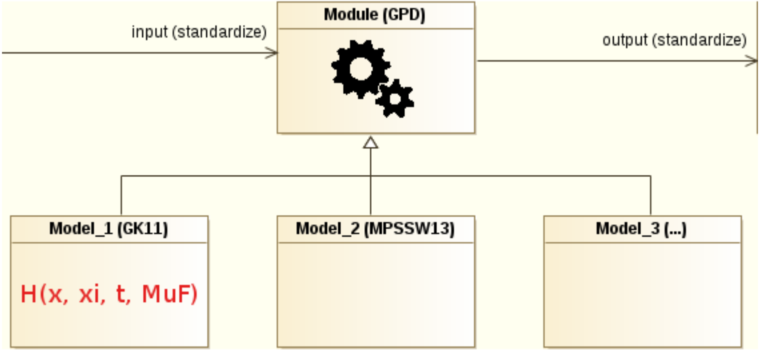
QueryDatabaseObservablePlotFile.xml

```
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario date="2016-10-18" description="...">
    <!-- Generate plot file from database for GK model-->
    <task service="ObservableService" method="generatePlotFile">
        <task_param type="output">
            <param name="filePath" value="observable_GK11_plot.csv" /
>
        </task_param>
        <!-- Variables of 2d plot -->
        <task_param ty
            <param nar
            <param nar
        </task_param>
        <!-- Select re
        <task_param ty
            <param nar
            <param nar
            <param nar
            <param nar
        </task_param>
    </task>
</scenario>
```

ϕ [deg]	A_{LU}
0.	0.
10.	0.024736075012605108
20.	0.048810639423911277
30.	0.071572336121144678
...	...
350.	-0.024736075012605111
360.	-9.0547874403168658e-17

Modularity.

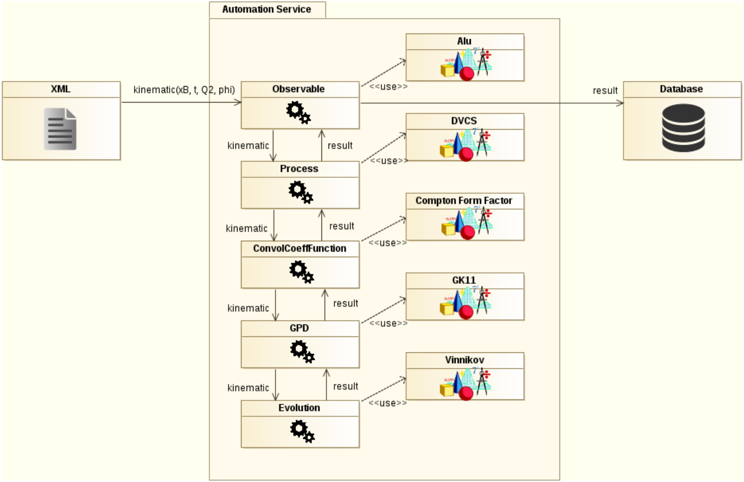
Inheritance, standardized inputs and outputs.



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

Modularity and automation.

Parse XML file, compute and store result in database.



Pre-PARTONS times...

First mention of the PARTONS project in a conference.

PROPHET.

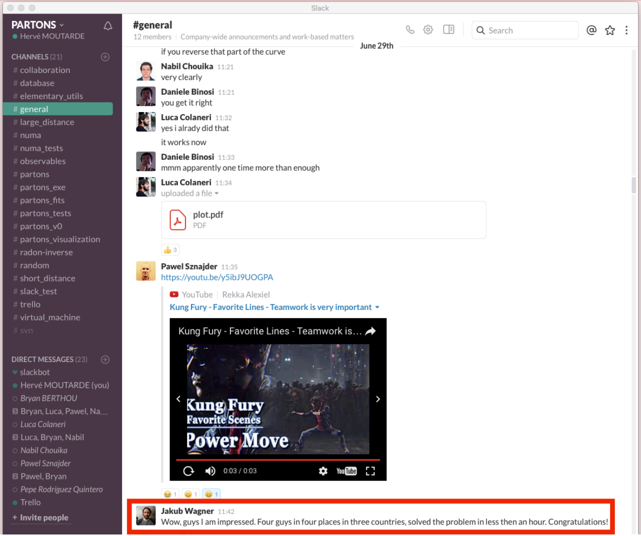
Platform for **R**epresenting the **O**rganization of **P**artons inside **H**adrons and **E**xperimental **T**omographies.

1. Comprehensive **database of experimental results**.
2. Comprehensive **database of theoretical predictions**.
3. **Fitting engine**.
4. **Propagation** of statistic and systematic **uncertainties**.
5. **Visualizing software** to compare experimental results and model expectations.
6. Connection to **experimental set-up descriptions** to design new experiments.
7. **Interactive website** providing free access to model and experimental values.

PARTONS times!

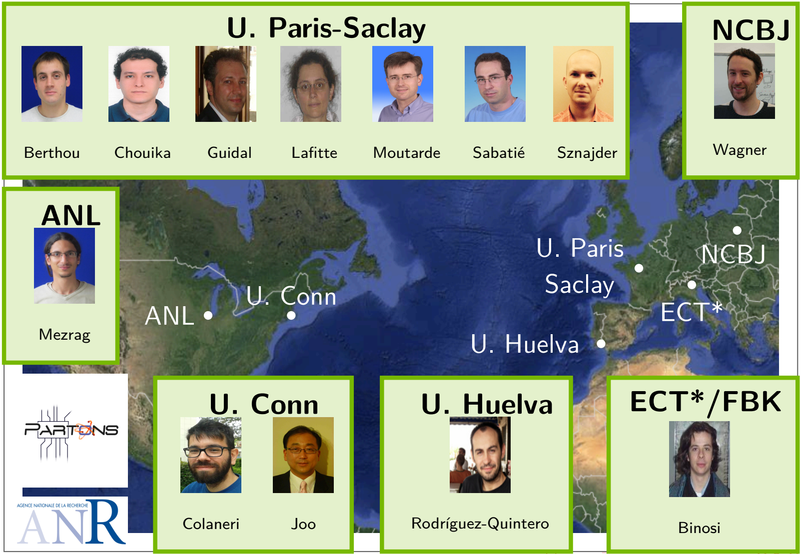
An active community.

Many (unfortunately not all!) problems can be solved fast



1 multidisciplinary team over 5 countries

Theorists, experimentalists, 1 mathematician + 1 software engineer



Conclusion

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

- **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 by the end of 2016!

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