Generalised Parton Distributions and the PARTONS project

C. Mezrag

Argonne National Laboratory

On behalf of the PARTONS team

Hadron structure

- Nucleon structure is described by various objects:
  - 1D: Distributions Amplitudes, Parton Distributions Functions
  - 2D: Form Factors
  - 3D: Generalised Parton Distributions, Transverse Momentum Distributions
  - 5D: Generalised Transverse Momentum Distributions

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  - are defined according to a non-local matrix element,

$$\frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,z=0}$$
$$=\frac{1}{2P^+}\left[H^q(x,\xi,t)\bar{u}\gamma^+u+E^q(x,\xi,t)\bar{u}\frac{i\sigma^{+\alpha}\Delta_\alpha}{2M}u\right].$$

D. Müller *et al.*, Fortsch. Phy. 42 101 (1994)
X. Ji, Phys. Rev. Lett. **78**, 610 (1997)
A. Radyushkin, Phys. Lett. **B380**, 417 (1996)

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

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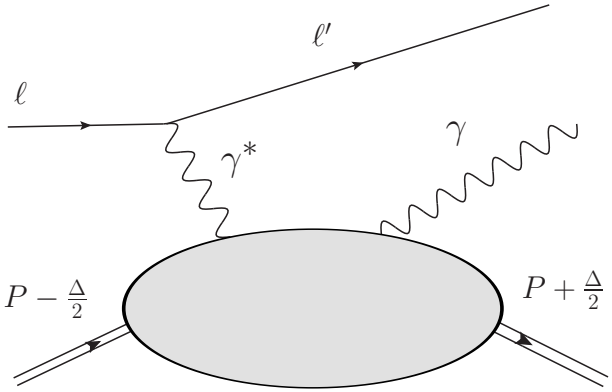
  - can be related to the 2+1D parton number density on the lightcone when $\xi \to 0$.
  - are related to the Compton Form Factors (CFFs) of various exclusive processes through convolutions:

$$\mathcal{H}(\xi, t) = \int \mathrm{d}x \; C(x, \xi, t) H(x, \xi, t)$$

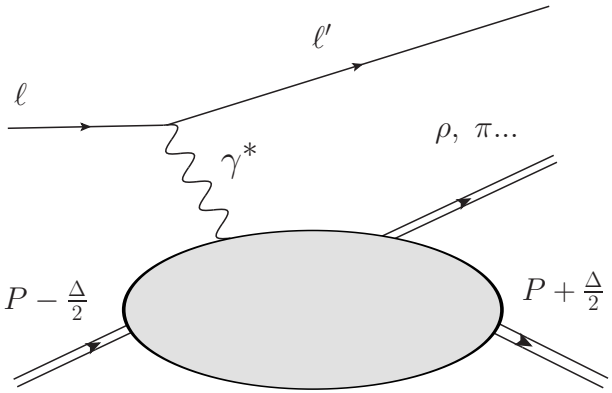
Exclusive processes and GPDs

DVCS

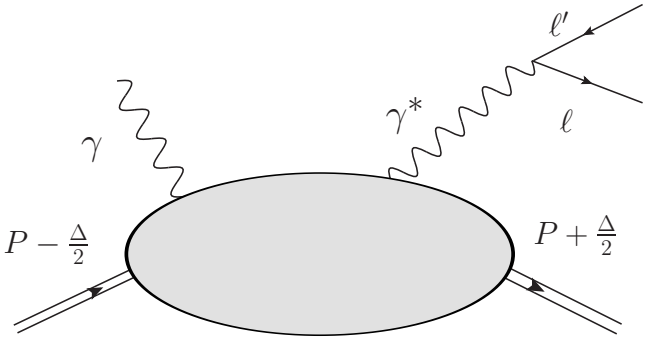


- For every process:
  - Twist expansion $\left(\frac{1}{Q}\right)$
  - Perturbative expansion (α_s)

DVMP

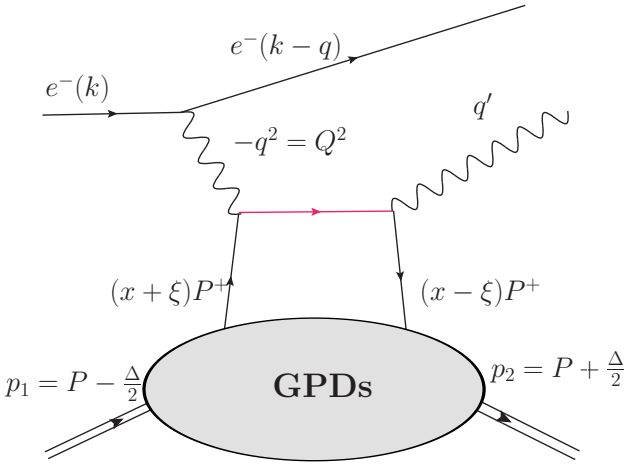


TCS



Exclusive processes and GPDs

DVCS LO



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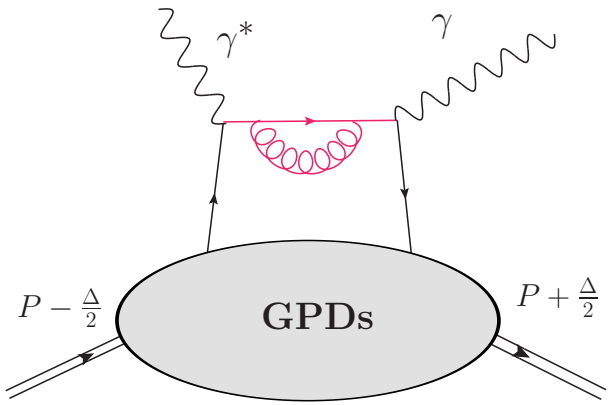
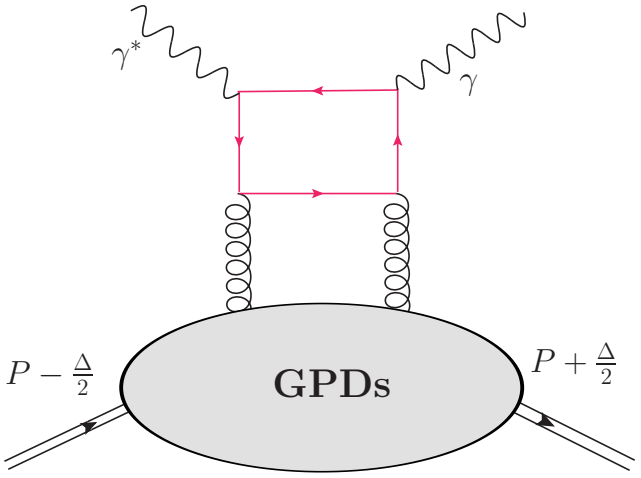
DVCS NLO type 1



DVCS NLO type 2



GPDs: What we know from the theory side

- Polynomiality Property:

$$\int_{-1}^{1} \mathrm{d}x\ x^m H^q(x,\xi,t) = \sum_{j=0}^{\left[\frac{m}{2}\right]} \xi^{2j} C^q_{2j}(t) + mod(m,2)\xi^{m+1} C^q_{m+1}(t)$$

Lorentz Covariance

GPDs: What we know from the theory side

- Polynomiality Property:

Lorentz Covariance

- Positivity property:

$$\left| H^q(x,\xi,t) - \frac{\xi^2}{1-\xi^2} E^q(x,\xi,t) \right| \leq \sqrt{\frac{q\left(\frac{x+\xi}{1+\xi}\right) q\left(\frac{x-\xi}{1-\xi}\right)}{1-\xi^2}}$$

A. Radysuhkin, Phys. Rev. **D59**, 014030 (1999)
B. Pire *et al.*, Eur. Phys. J. **C8**, 103 (1999)
M. Diehl *et al.*, Nucl. Phys. **B596**, 33 (2001)
P.V. Pobilitsa, Phys. Rev. **D65**, 114015 (2002)

Positivity of Hilbert space norm

GPDs: What we know from the theory side

- Polynomiality Property:

  Lorentz Covariance

- Positivity property:

  Positivity of Hilbert space norm

- Support property:

$$x \in [-1; 1]$$

M. Diehl and T. Gousset, Phys. Lett. **B428**, 359 (1998)

Relativistic quantum mechanics

GPDs: What we know from the theory side

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- Positivity property:

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- Support property:

  Relativistic quantum mechanics

- Soft pion theorem (pion GPDs only)

  M.V. Polyakov, Nucl. Phys. **B555**, 231 (1999)
  CM *et al.*, Phys. Lett. **B741**, 190 (2015)

  Dynamical Chiral Symmetry Breaking

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- Support property:

  Relativistic quantum mechanics

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  Dynamical Chiral Symmetry Breaking

How can we implement all these constraints?

- There is still no GPDs models relying only on first principles
- Still several "phenomenological" approaches have been developed

Phenomenological approaches of GPDs

- Double Distribution models:
  I.V. Musatov and A.V. Radysuhkin, Phys. Rev. **D61**, 074029 (2000)
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- Mellin-Barnes approach and Dual models are in fact equivalent
  D. Müller *et al.*, JHEP **1503**, 52 (2014)

GPD problematic

- From GPDs to observables
  - Flexibility in the choice of models,
  - Computation of CFFs
  - Flexibility in the choice of pertubative approximation (α_s)
  - Flexibility in changing twist approximations ($1/Q$),
  - Computations of a given set of observables

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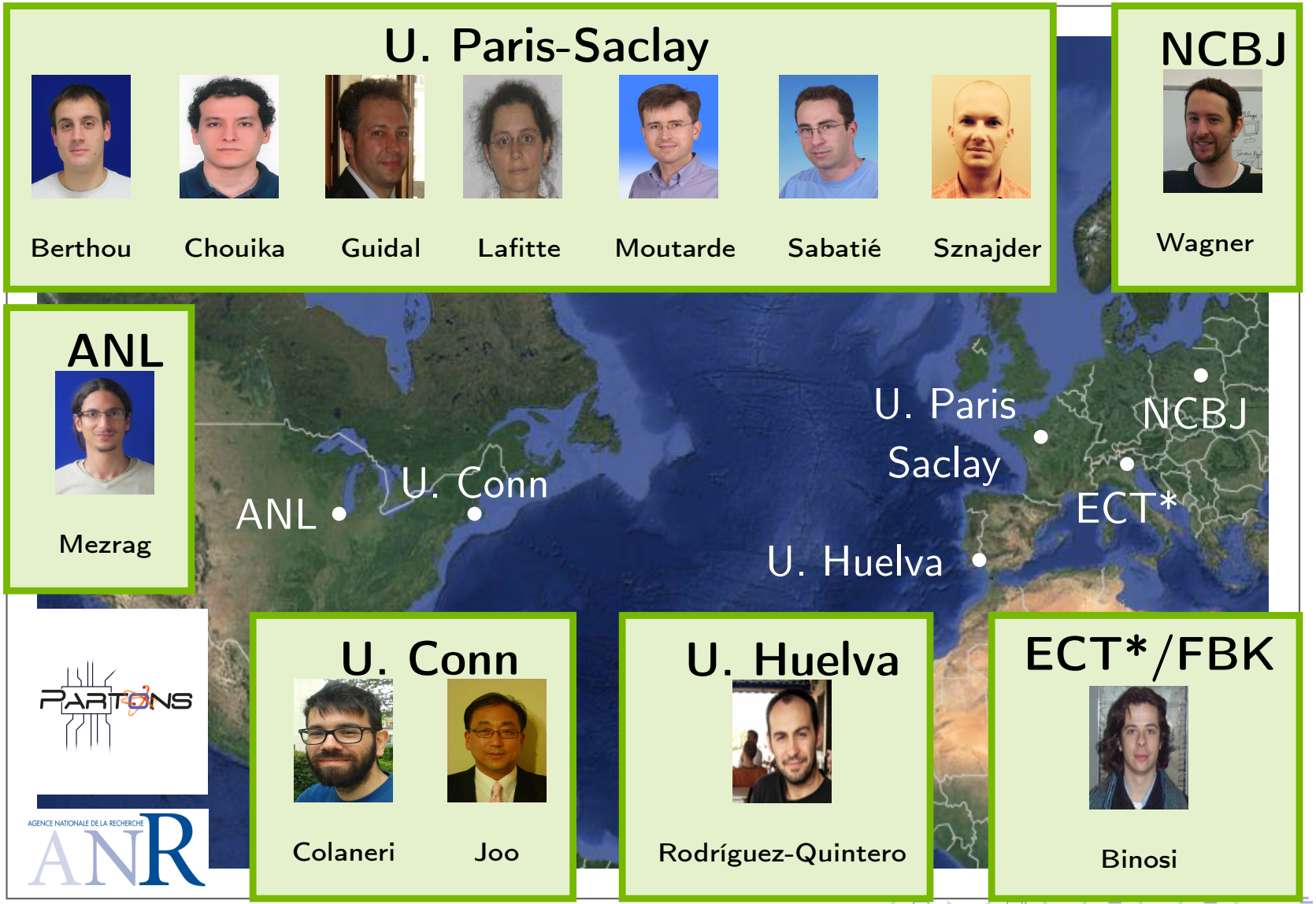
Deep GPDs studies request a complete and flexible software

PARtonic Tomography Of Nucleon Software

1 multidisciplinary team over 5 countries

Theorists, experimentalists, 1 mathematician + 1 software engineer



Computing chain design.

Differential studies: physical models and numerical methods.

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

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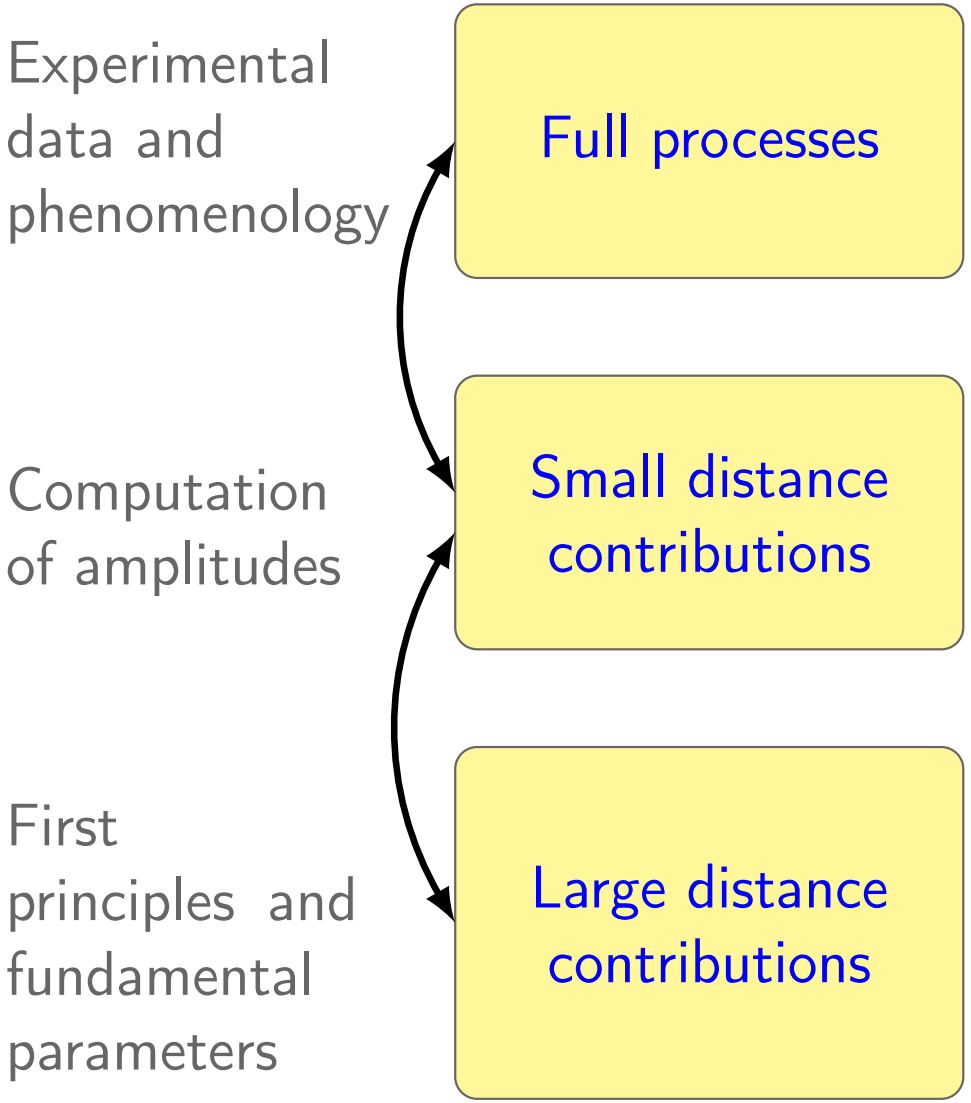

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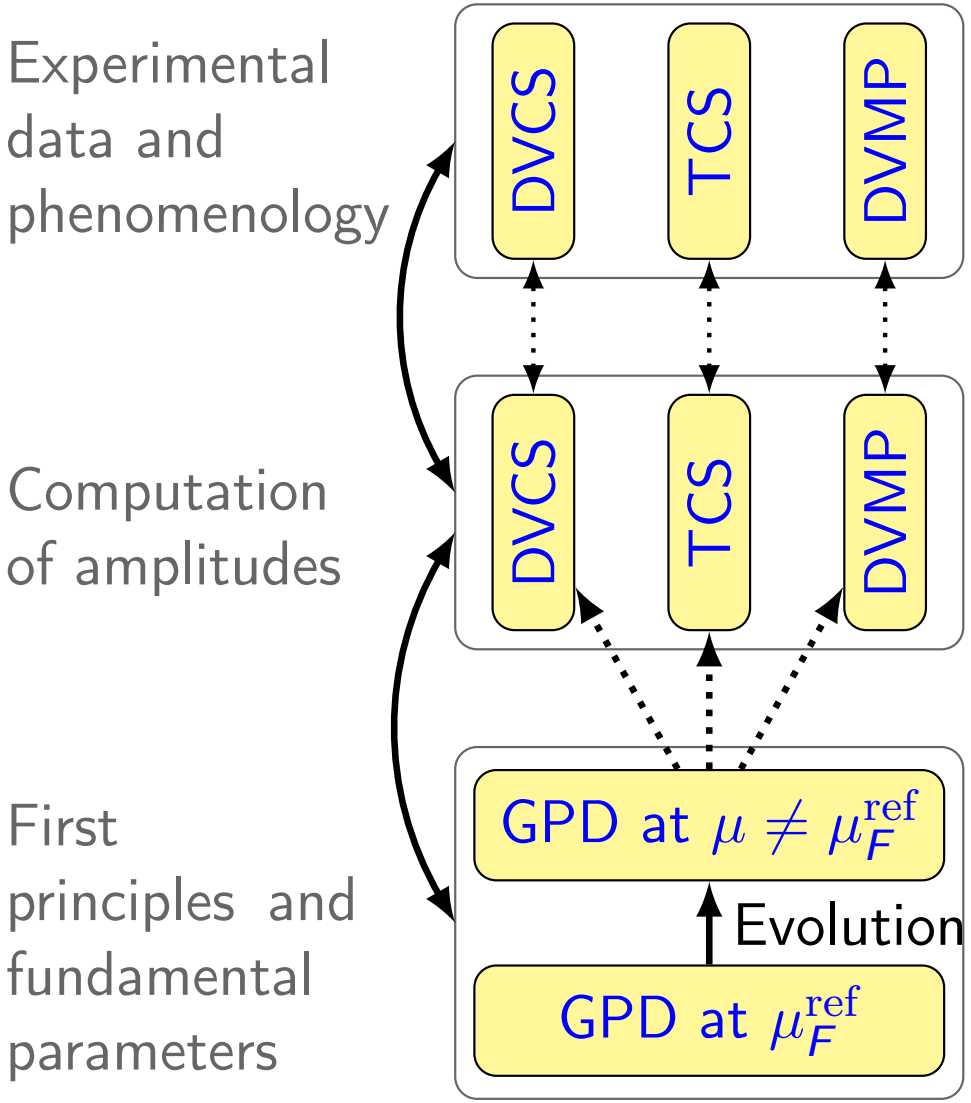

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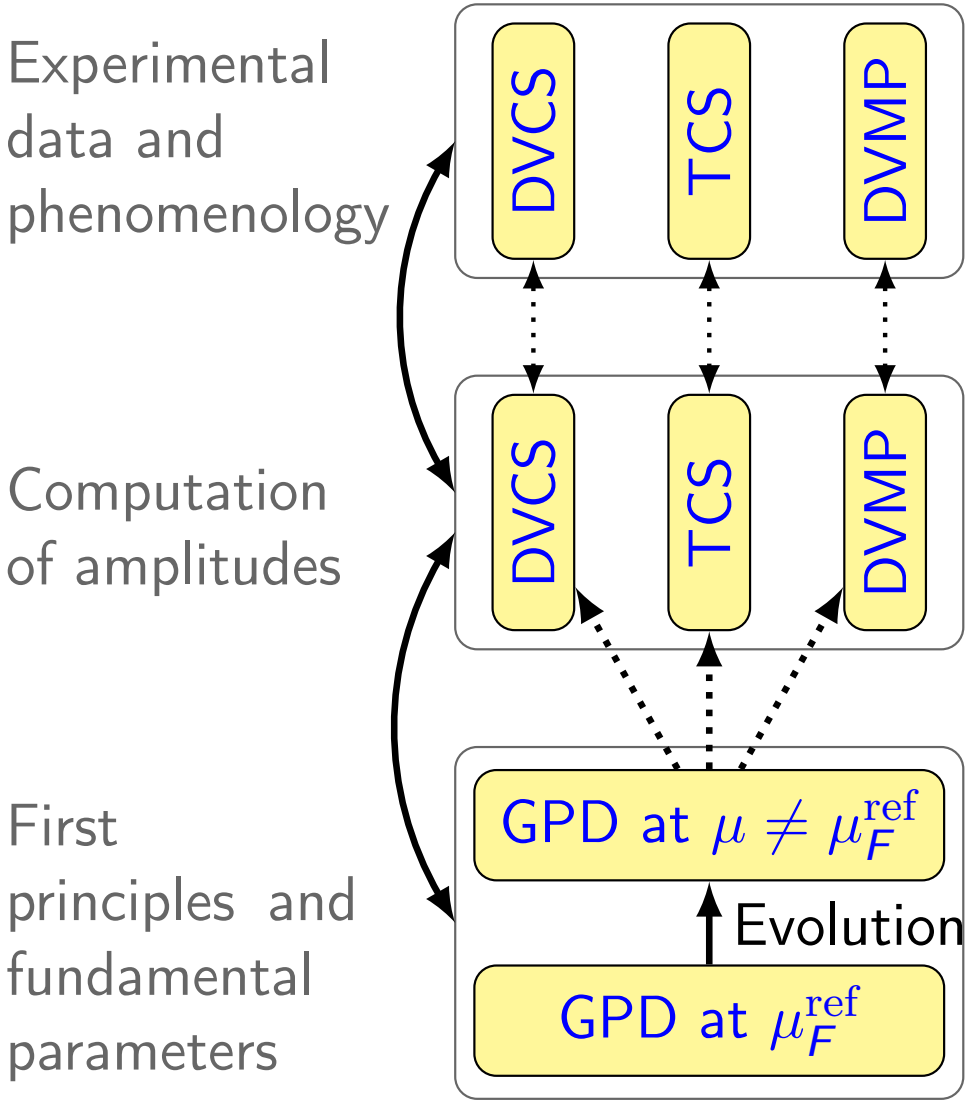

- Many observables.
- Kinematic reach.

Computing chain design.

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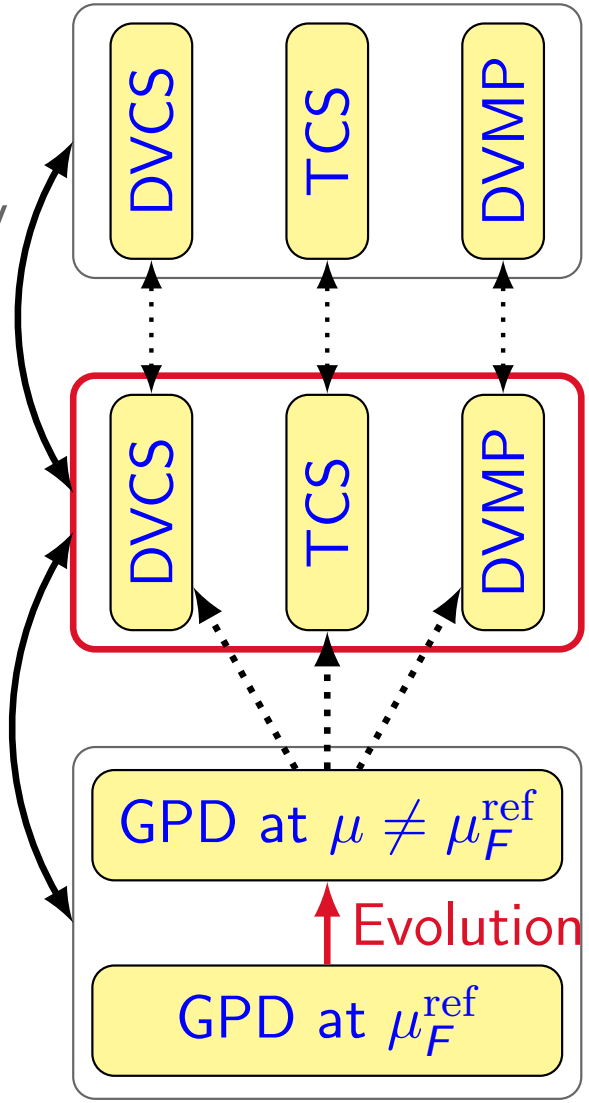
Experimental data and phenomenology

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.

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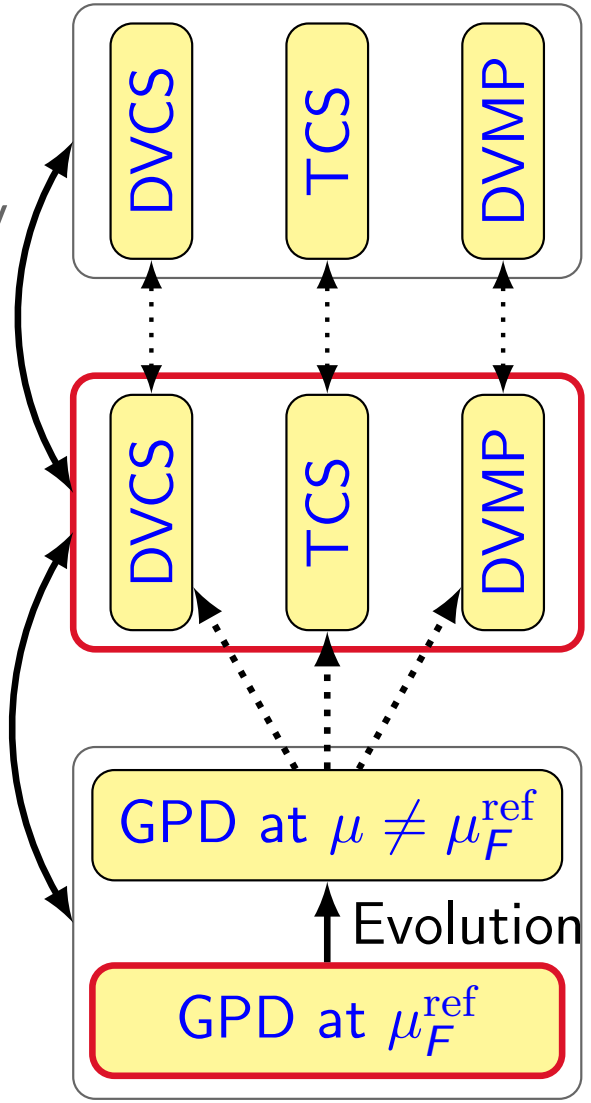

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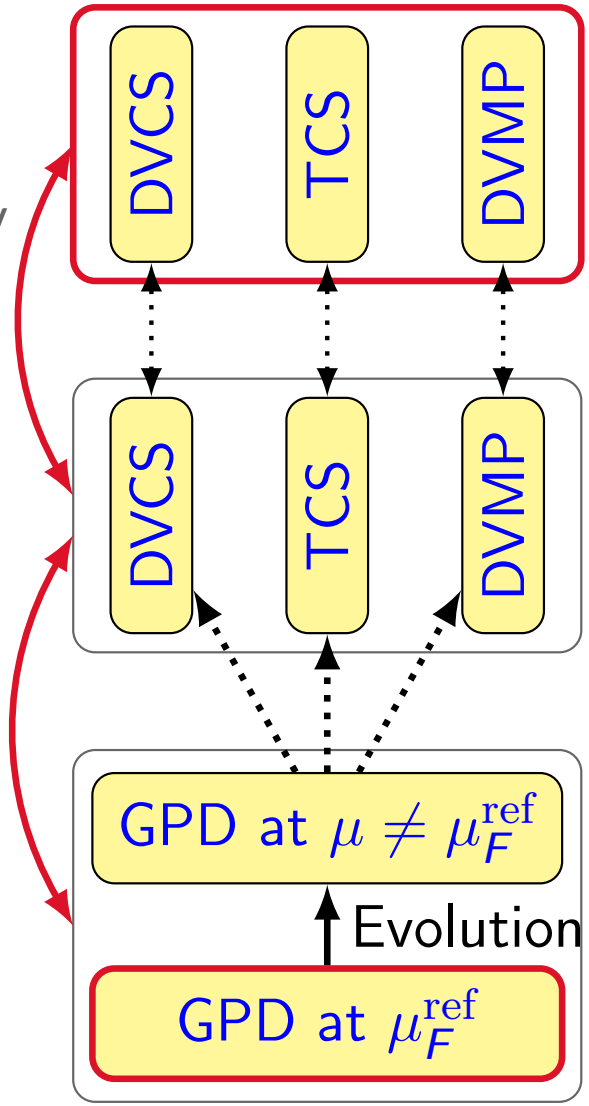

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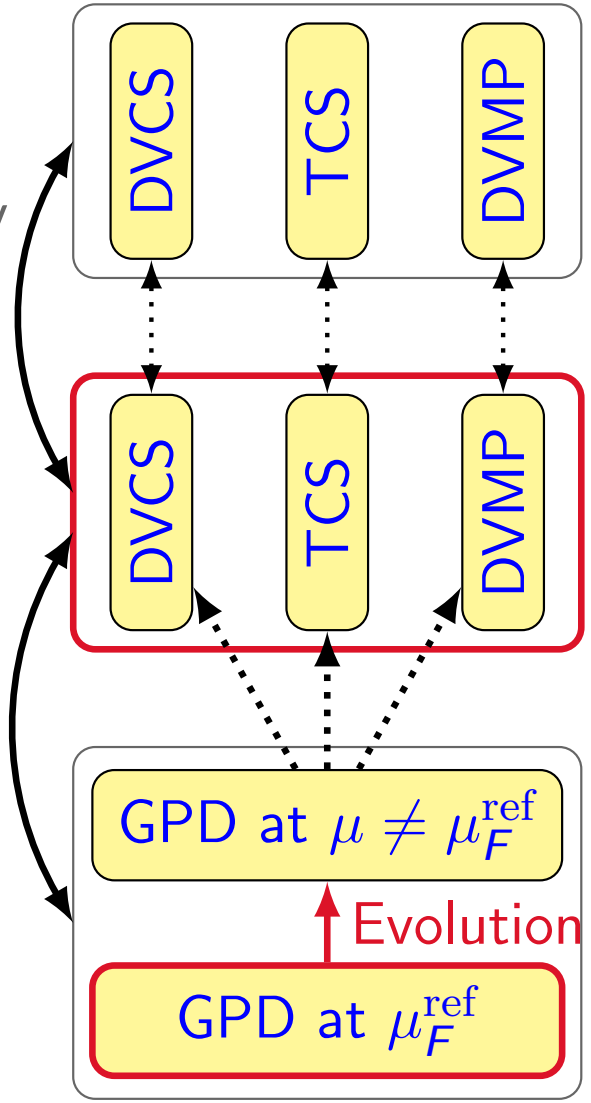

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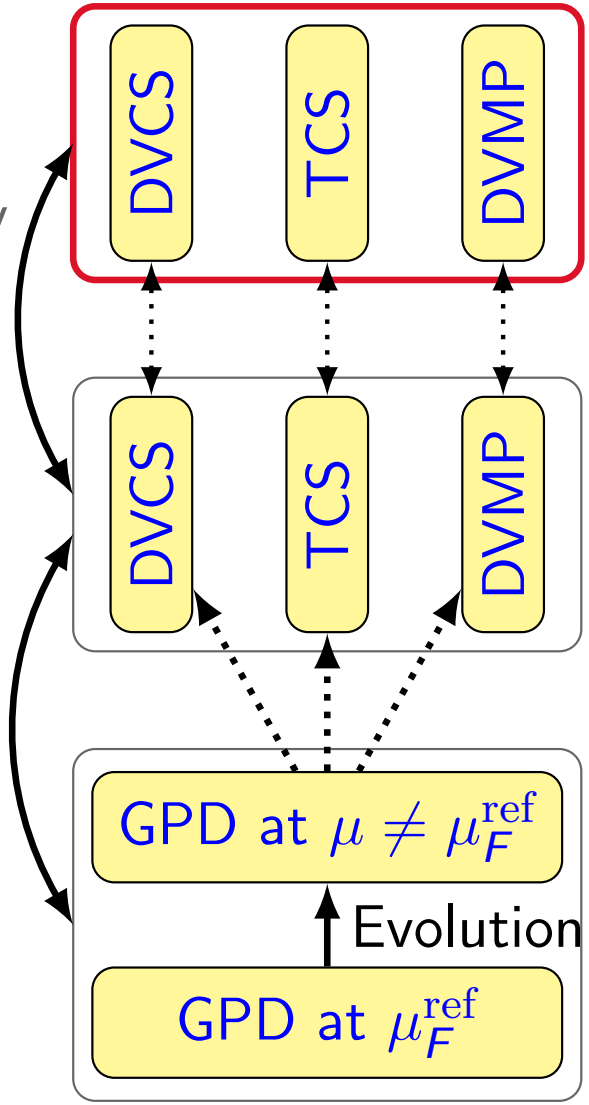

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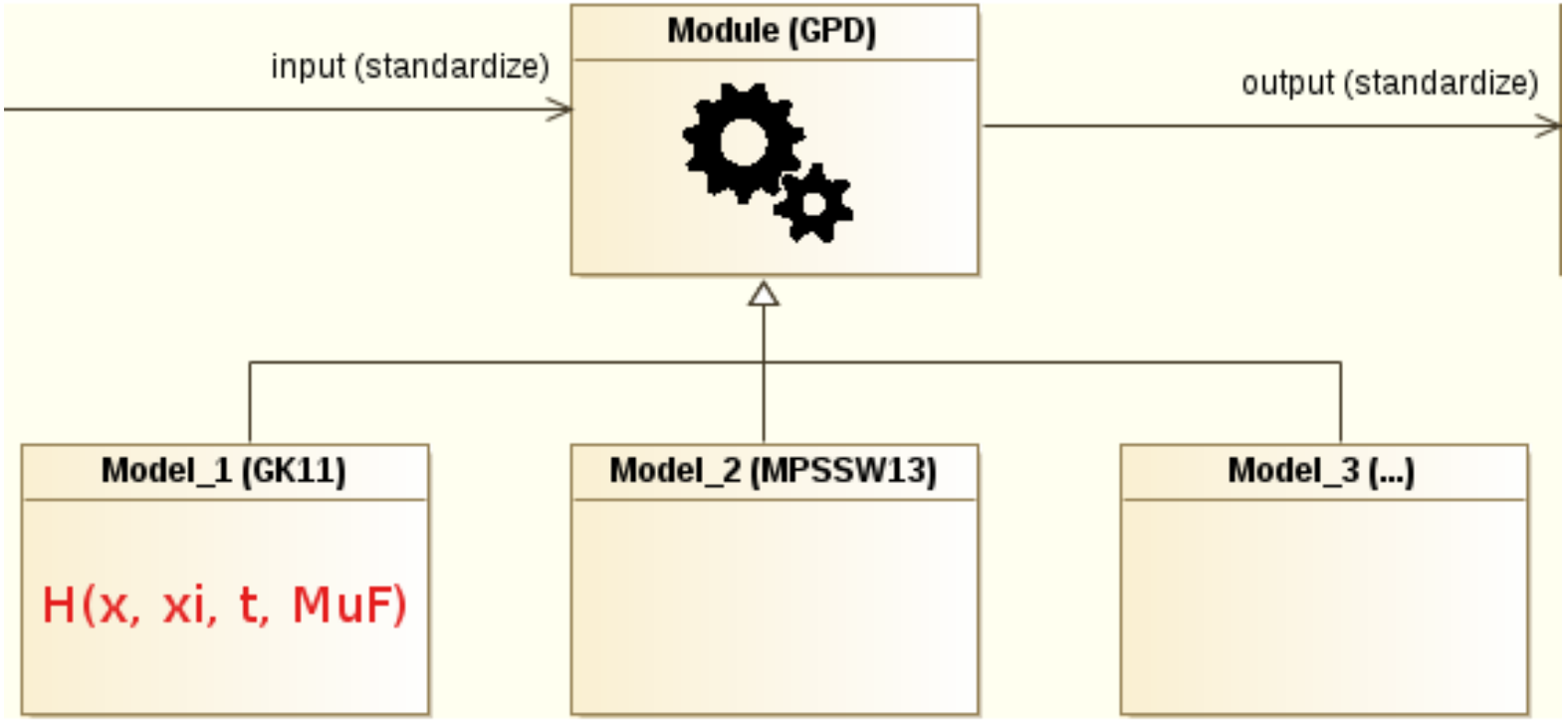
Modularity.

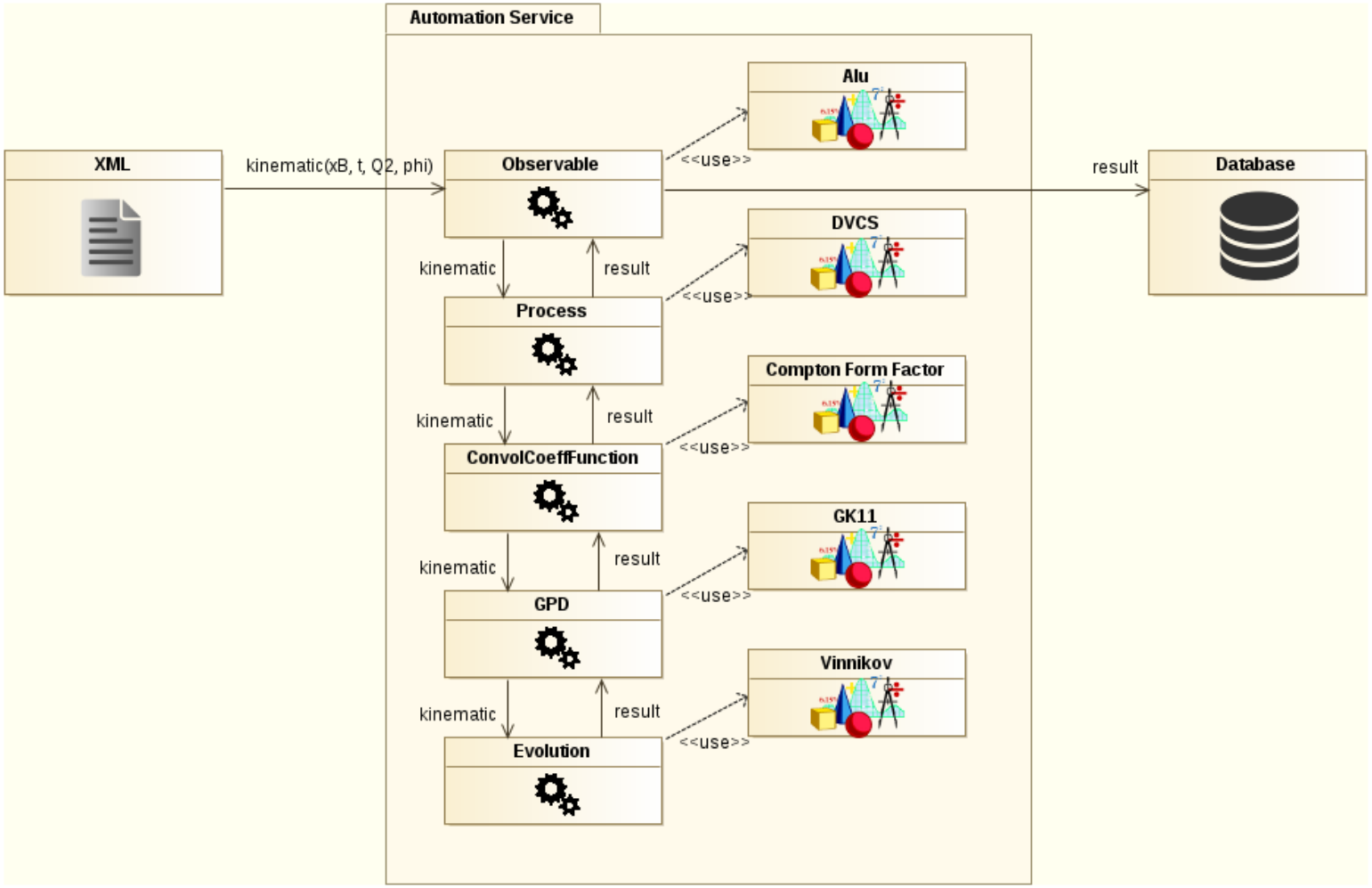
Inheritance, standardized inputs and outputs.



- 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.



Observable computing automated.

Each line of code corresponds to a physical hypothesis.

computeManyKinematicsOneModel.xml

```
<scenario date="2016-04-14" description="How␣to␣compute␣an␣observable">
    <task service="ObservableService" method="computeObservable" storeInDB="0">
        <kinematics type="ObservableKinematic">
            <param name="xB" value="0.1763" />
            <param name="t" value="-0.1346" />
            <param name="Q2" value="1.3651" />
        </kinematics>
        <computation_configuration>
            <module type="Observable">
                <param name="className" value="AcCos2phi" />
            </module>
            <module type="DVCSModule">
                <param name="className" value="GV2008Model" />
                <param name="beam_energy" value="5.77" />
            </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 type="ScaleModule">
```

Towards the first beta release.

Main Ideas

- 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.

Towards the first beta release

Where we are now

- **Design**
  - the first release will be restrained to **DVCS** only, but will cover a kinematical range **from JLab to EIC**,
  - **four different GPD models** based on Double Distributions will be provided,
  - the BMJ (Nucl. Phys. **B878**, 214 (2014)) formalism will be used for computations of observables,
  - **both LO and NLO** kernels will be available for the computation of CFFs, including computations with heavy flavours,
  - evolution will be available at **fixed** flavour number,
  - only leading twist approximation will be available.

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  - Non-regression tests have been systematically performed over **200,000** GPD kinematics (x, ξ, t, μ_R, μ_F).

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- **Validation**
  - Non-regression tests have been systematically performed over **200,000** GPD kinematics (x, ξ, t, μ_R, μ_F).
- **Performance**
  - With two threads, it is now possible to compute **500,000** GPD kinematics per second with the Goloskokov-Kroll model.

Towards the first beta release

Expected FAQ

- **What will be released?**
  - Release will take the form of a virtual machine, including ready-to-use IDE and mySQL Database.
  - Binaries and headers will be available, but not the source code.

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- **What if I find a bug?**
  - We try to make the software as reliable as possible. But if you still find a bug please contact us.
  - We will face the good side of Murphy's law: users will find a way to use PARTONS developers will not have thought about.

Summary and Conclusion

- Deep studies of GPDs require a flexible and reliable software.
- PARTONS is an answer to this need:
  - Flexibility through modular architecture
  - Reliability ensured by systematic non-regression tests.
  - Performance is also one of our main targets.
- Try to make it as user friendly as possible.
- In the forthcoming months, we need to hear from users in order to improve the software.

We want you

to use PARTONS
and give us feedbacks!