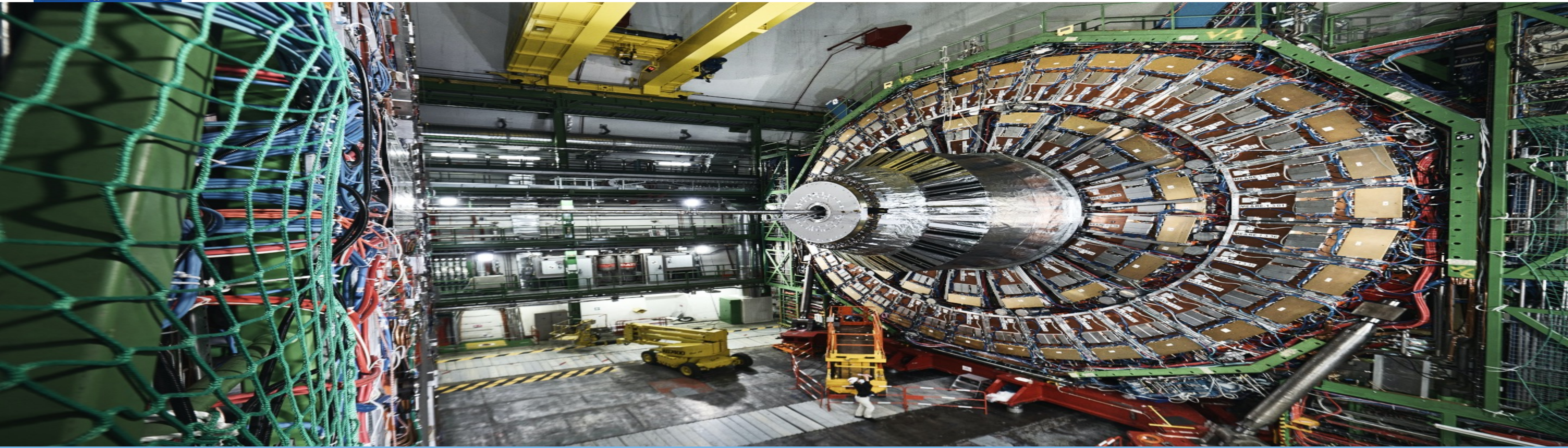


VA2-3DPartons/WP11: Virtual Access to 3DPartons

H. Moutarde (CEA, Irfu)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

Progress made during the year towards the objectives

From independent research initiatives to common tools: **STRONG-2020 impact**

1. Make sure we can use existing codes **together**
2. **Mutualize** common tools
3. **Save time** for future developments by building on existing tools or solutions
4. **Devise common solutions** for similar problems from **different subfields**

Reminder

*3DPartons gives access to **open-source code** necessary for high precision phenomenology in the field of 3D hadron structure, with a specific emphasis on GPDs and TMDs.*

*It consists of **several libraries organized within a fully modular and open architecture**, which allows the possibility of permanent improvement by the addition of new models, channels or theoretical refinements.*

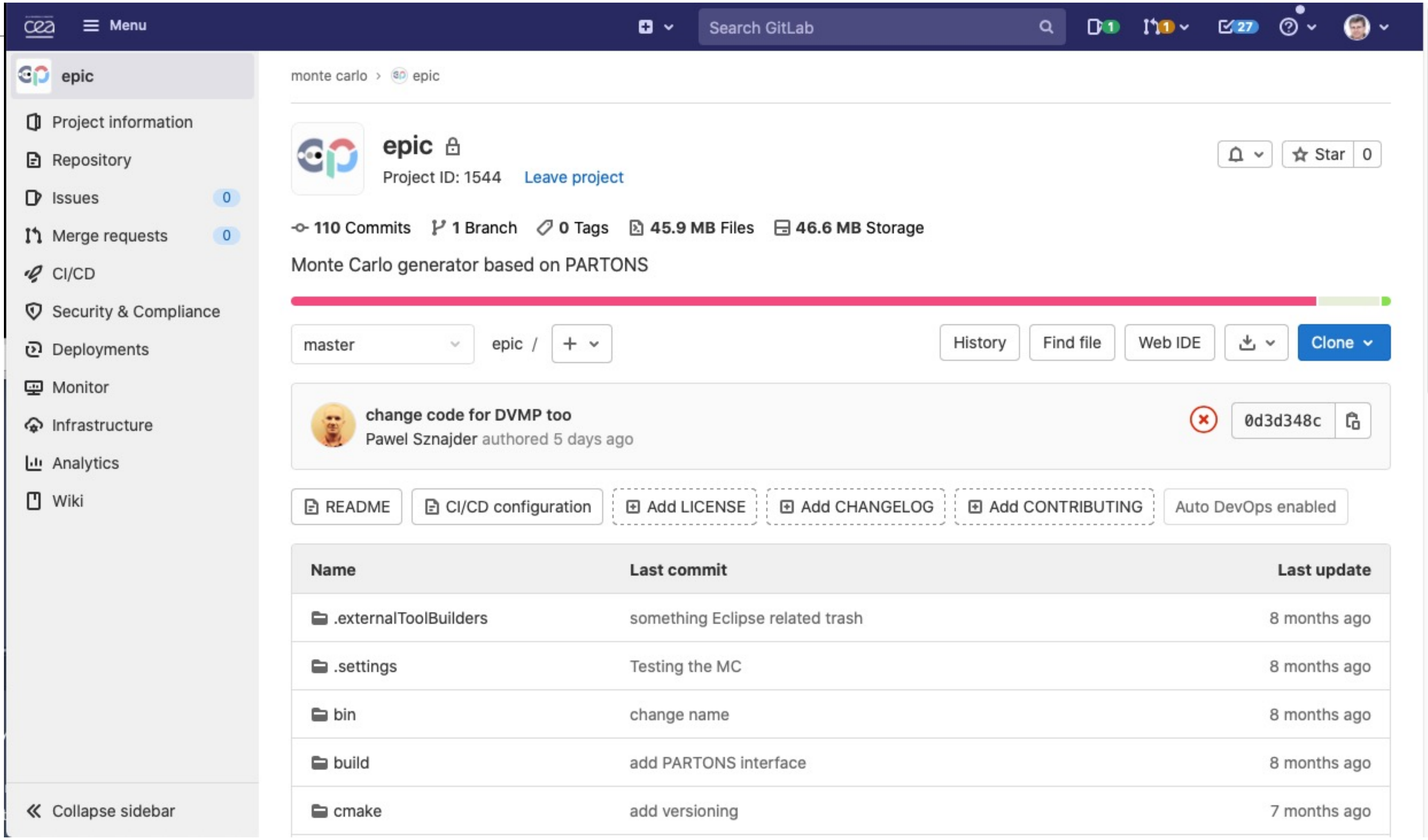
Galaxy of existing computing codes

As it stands, 3DPartons will be based on parts of, or offer interfaces to, various existing codes:

- *PDF (LHAPDF, APFEL, xFitter),*
- *GPD (PARTONS, Gepard web interface),*
- *TMD (arTeMiDe, Nanga Parbat, TMDlib, CASCADE),*
- *Fragmentation functions (xFitter, Mont Blanc).*

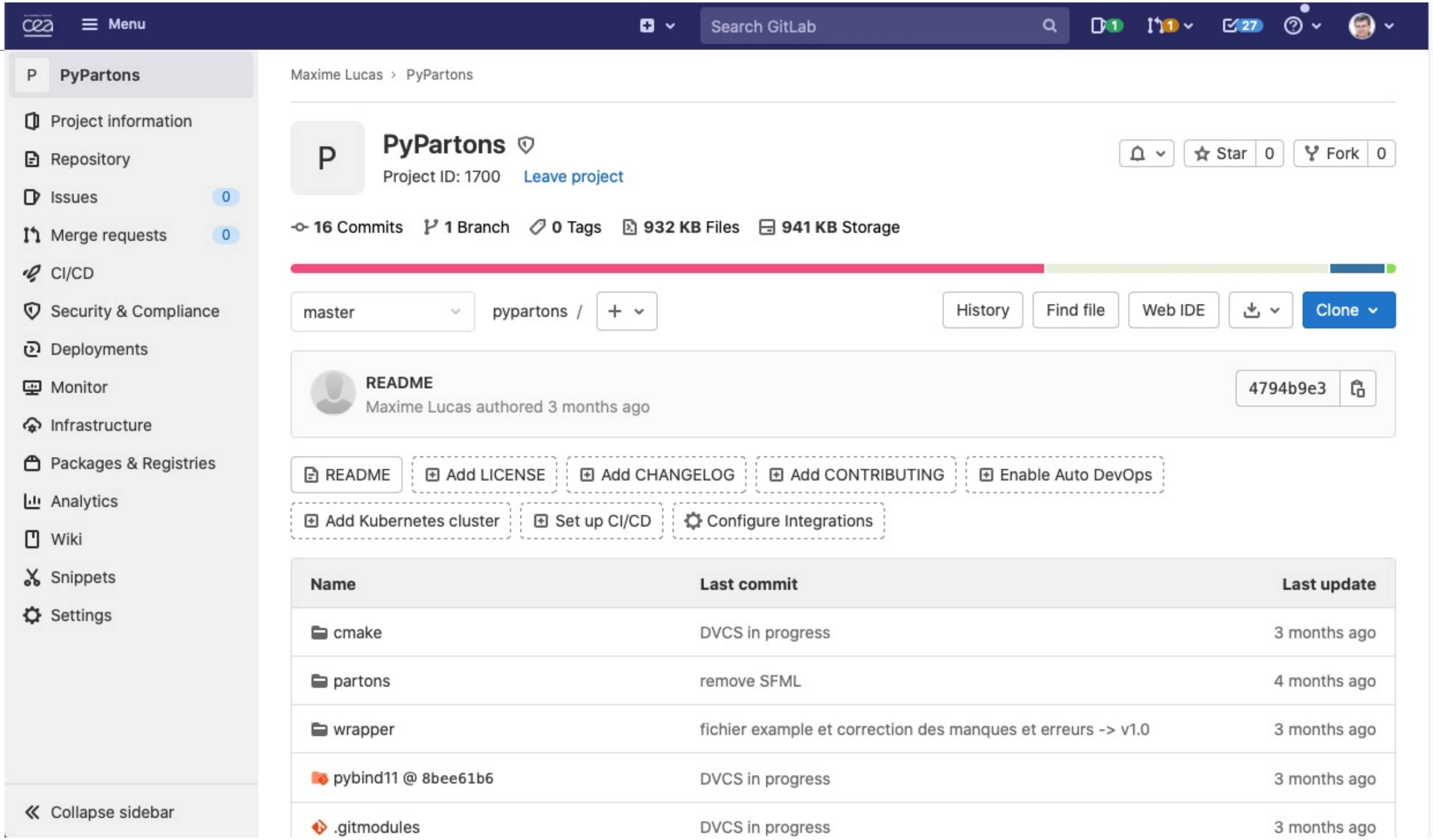
EpIC: Generic exclusive event generation

- **Fully compatible** with PARTONS: can use all provided exclusive channels in a transparent way.
- Includes treatment of radiative corrections.
- **Already used** in the EIC community and run at BNL.
- *Public release soon*.



PyPartons: Python wrapper for PARTONS

- Simplify connection to **popular libraries** on *e.g.*
  - machine learning
  - plotting
  - statistical data analysis
- Convenient for a **wide community of new users**, in particular PhD students of postdocs.
- **Facilitates dissemination of research** through e.g. Jupyter notebooks.
- Remaining work on documentation and dissemination before public release.



NangaParbat / MontBlanc / tmdlib2: Tools for TMDs and fragmentation functions

.gitignore	test SIDIS	7 months ago
CMakeLists.txt	Fixed typo	5 months ago
LICENSE	Adding LICENSE	2 years ago
README.md	Update README.md	6 months ago

Languages

HTML 98.4% · C++ 1.4% · Python 0.2% · CSS 0.0% · CMake 0.0% · Shell 0.0%

README.md

Nanga Parbat: a TMD fitting framework

Nanga Parbat is a fitting framework aimed at the determination of the non-perturbative component of TMD distributions.

CMakeLists.txt	Uploading the code	6 months ago
README.md	Update README.md	6 months ago

Languages

Jupyter Notebook 99.4% · Other 0.6%

README.md

MontBlanc

`MontBlanc` is a code devoted to the extraction of collinear distributions. So far, it has been used to determine the fragmentation functions (FFs) of the pion from experimental data for single-inclusive annihilation and semi-inclusive deep-inelastic scattering. Details concerning this fit of FFs in particular and the methodology in general can be found in the reference below.

The FF sets in the LHAPDF format for both positive and negative pions as well as for their sum can be found here.

PROGRAM SUMMARY TMDlib2

Computer for which the program is designed and others on which it is operable: any with standard C++, tested on Linux and Mac OS systems

Programming Language used: C++

High-speed storage required: No

Separate documentation available: No

Keywords: QCD, TMD factorization, high-energy factorization, TMD PDFs, TMD FFs, unintegrated PDFs, small-x physics.

Other programs used: LHAPDF (version 6) for access to collinear parton distributions, ROOT (any version > 5.30) for plotting the results

Download of the program: `http://tmdlib.hepforge.org`

Unusual features of the program: None

Contacts: H. Jung (hannes.jung@desy.de), A. Bermudez Martinez (armando.bermudez.martinez@desy.de)

Citation policy: please cite the current version of the manual and the paper(s) related to the parameterization(s).

- NangaParbat and MontBlanc will be made interoperable with PARTONS this year.
- Eventually all kinds of parton distributions will be dealt with a **single open source framework**.

Some physics highlights of 2021 where 3DPartons played a unique role

From sophisticated models to event generation

Accessing the pion 3D structure at US and China Electron-Ion Colliders

José Manuel Morgado Chávez,[1,*] Valerio Bertone,[2,†] Feliciano De Soto B
Cédric Mezrag,[2,¶] Hervé Moutarde,[2,**] José Rodríguez-Quintero,[1,
[1]*Department of Integrated Sciences and Center for Advanced St*
Mathematics and Computation, University
[2]*Irfu, CEA, Université Paris-Saclay,*
[3]*Dpto. Sistemas Fisicos, Qu*
Universidad Pablo de Olavide,
(Dated: October 1

We present in this letter the first systematic feasi
distributions of the pion at an electron-ion collider th
next-to-leading order. It relies on a state-of-the-art
theoretical constraints imposed on generalised parton
that quarks and gluons interfere destructively and that
change of the DVCS beam spin asymmetry.

Data fitting as an inverse problem

The deconvolution problem of deeply virtual Compton scattering

V. Bertone,[1,*] H. Dutrieux,[1,†] C. Mezrag,[1,‡] H
[1]*IRFU, CEA, Université Paris-Saclay, F-*
[2]*National Centre for Nuclear Research*
(Dated:

Generalised parton distributions are instrum
and the energy-momentum tensor of the nucleo
involving hard exclusive measurements. Base
study of evolution effects, we exhibit non-triv
small imprints on deeply virtual Compton scat
reconstruction of generalised parton distribut
tion problem, does not possess a unique solut
consequences on the extraction of generalised
multi-channel analysis.

Fit of fragmentation functions

A determination of unpolarised pion fragmentation functions using semi-inclusive deep-inelastic-scattering data: MAPFF1.0[†]

Rabah Abdul Khalek[1,2], Valerio Bertone[3], Emanuele R. Nocera[4]
[1] *Department of Physics and Astronomy, Vrije Universiteit,*
Amsterdam, 1081 HV, The Nether
[2] *NIKHEF Theory Group, Science Park 105, 1098 XG*
[3] *IRFU, CEA, Université Paris-Saclay, F-91191*
[4] *The Higgs Centre for Theoretical Physics*
JCMB, KB, Mayfield Rd, Edinbu

Abstract

We present MAPFF1.0, a determination of unpola
(FFs) from a set of single-inclusive e^+e^- annihilatic
inelastic-scattering (SIDIS) data. FFs are paramet
and fitted to data exploiting the knowledge of the a
free parameters. Uncertainties on the FFs are deter
pling method properly accounting for all sources of
of parton distribution functions. Theoretical predict
evolution effects, are computed to next-to-leading or
We exploit the flavour sensitivity of the SIDIS mea
COMPASS experiments to determine a minimally-b
nations. Moreover, we discuss the quality of the fit
showing that, as expected, low-Q^2 SIDIS measureme
a NLO-accurate perturbative framework.

Pressure forces from experimental data

Phenomenological assessment of proton mechanical properties from deeply virtual Compton scattering

H. Dutrieux[a,1], C. Lorcé[b,2], H. Moutarde[c,1], P. Sznajder[d,3],
A. Trawiński[e,1,2], J. Wagner[f,3]
[1]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[2]CPHT, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, Route de Saclay, 91128 Palaiseau, France
[3]National Centre for Nuclear Research (NCBJ), Pasteura 7, 02-093 Warsaw, Poland

Received: date / Accepted: date

Abstract A unique feature of generalised parton distributions is their relation to the QCD energy-momentum tensor. In particular, they provide ac-

Generalised Parton Distribution · GPD · Artificial Neural Network · Genetic Algorithm · EIC · EicC · Jefferson Lab · PARTONS Framework

STRONG impact: more such studies will become easily possible with ongoing and future developments.

Address complex problems with complementary interoperable tools

Access provided at 31 October 2021

Minimum quantity / actual quantity

Estimated number of users from the grant agreement:

- 100 between month#1 and #18
- 150 between month#2 and #36

(Estimation based on estimated headcount)

D11.1 : Virtual Access provision - multi annual implementation plan over the first 18 months (month 1-18) (D11.1) [18]

Unit of access : hours; Unit cost (EUR): N/A; Min. quantity of access to be provided: 2000; Estimated number of users: 100; Estimated number of days spent at the infrastructure: N/A; Estimated number of projects: 35.

D11.2 : Virtual Access provision - multi annual implementation plan over the next 18 months (month 19-36) (D11.2) [36]

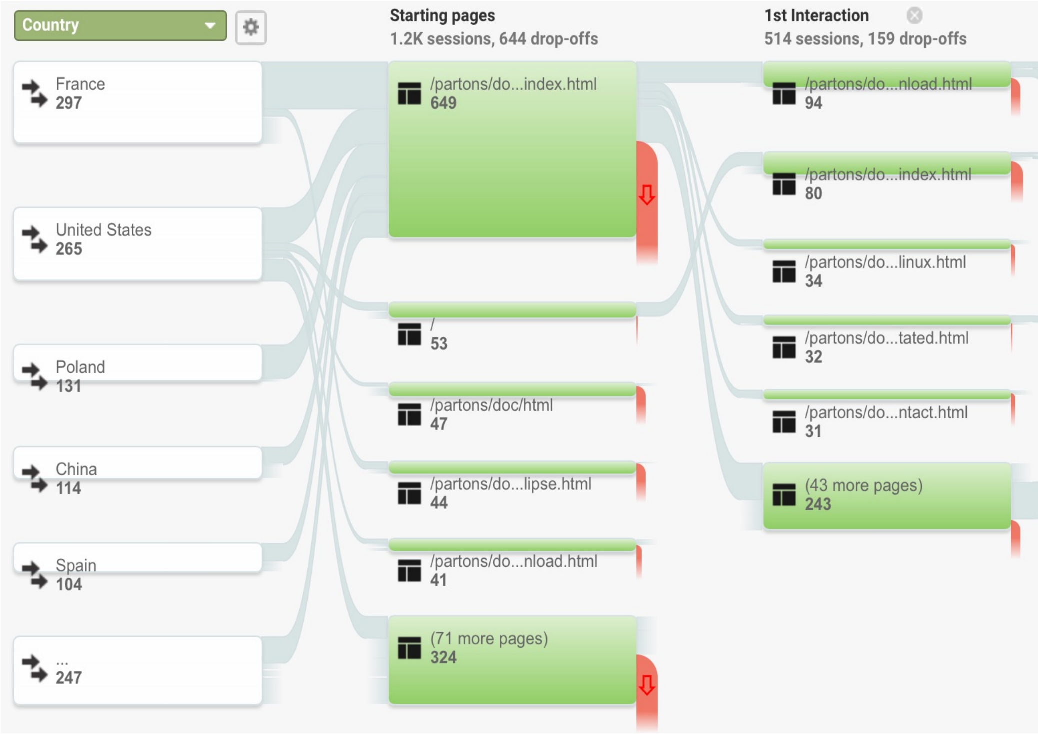
Unit of access : hours; Unit cost (EUR): N/A; Min. quantity of access to be provided: 2000; Estimated number of users: 150; Estimated number of days spent at the infrastructure: N/A; Estimated number of projects: 50.

Stable access during the second period…

Between 01 June 2019 and 01 October 2020

4077 views
574 visitors including 18% of returning visitors

Between 01 October 2020 and 31 October 2021



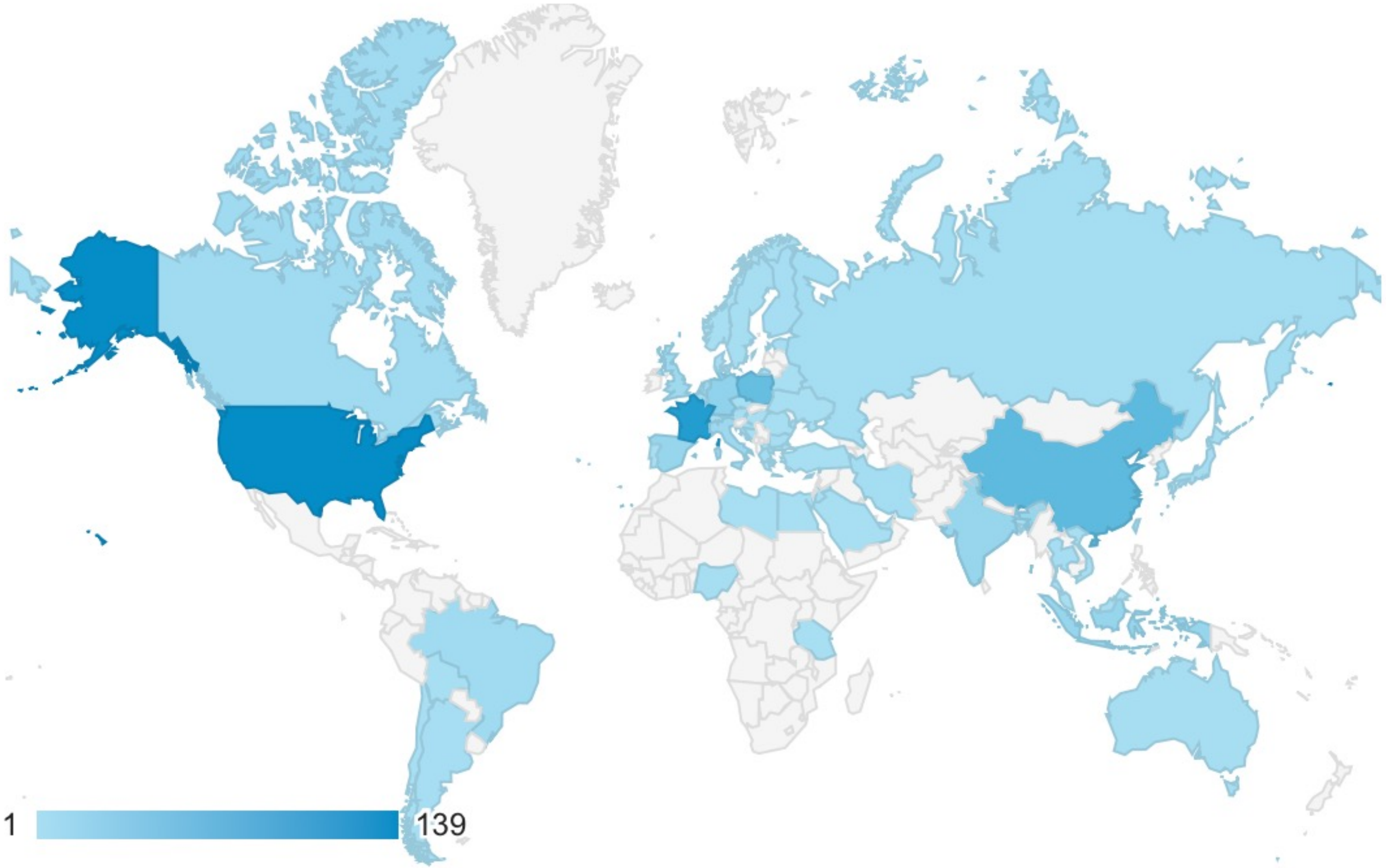
3603 views
597 visitors including 18% of returning visitors

… in spite of the pandemics…

Correlation between numbers of users and involvement in experimental programs

The repartition of users reflects the location of:

- Facilities: EIC, EicC, Jefferson Lab
- Development teams: France, Poland, Spain, US



STRONG 2020

Other significant achievements

International assessment board

Dissemination and training

Newsletters

International assessment board

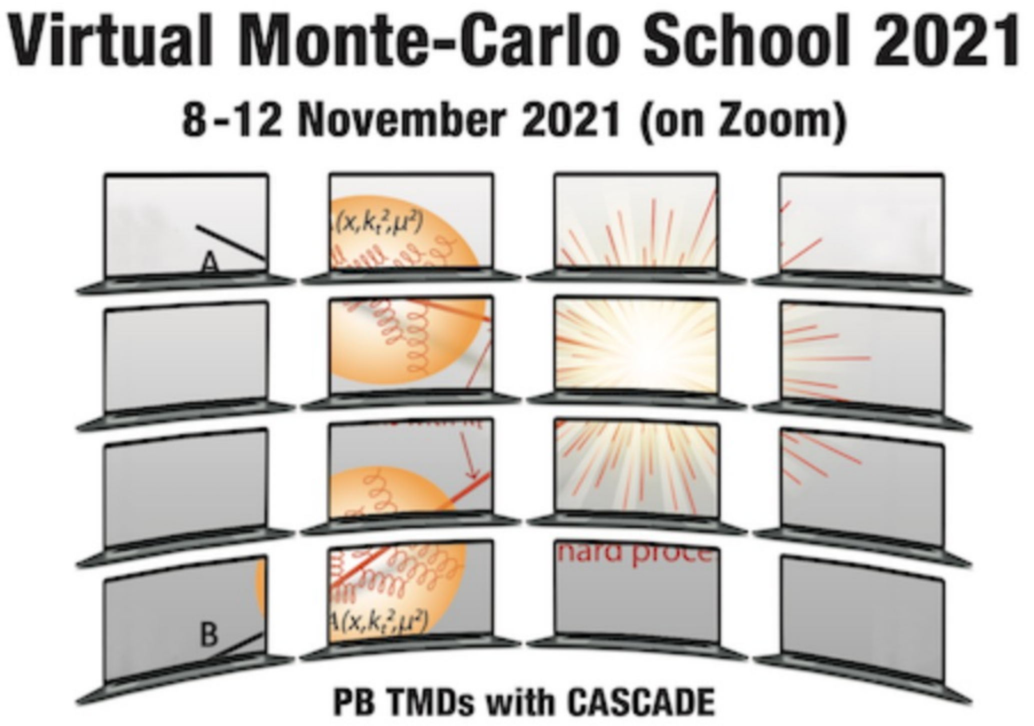
Eight researchers with **complementary experience** in

- experimental and theoretical aspects of GPDs and TMDs,
- PDF fits,
- event generators,
- code development
- statistical data analysis.

- BOBIN, Jérôme (IRFU, CEA, Université Paris-Saclay)
- BRESSAN, Andrea (INFN, Trieste)
- CHAPON, Damien (IRFU, CEA, Université Paris-Saclay)
- DIEHL, Markus (DESY)
- GLAZOV, Alexander (DESY)
- HAUTMANN, Francesco (Oxford and Antwerpen)
- PASQUINI, Barbara (INFN, Università Di Pavia)
- SOKHAN, Daria (Glasgow and IRFU, CEA, Université Paris-Saclay)

First meeting on 17 November 2020

Community building: Presenting tools and physics output



14:00	Introduction to the session	Hervé MOUTARDE	IJCLab	14:00 - 14:10
	Status of the GeParD code	Kresimir Kumericki	IJCLab	14:10 - 14:35
	Evolving GPD in x space: a new path through APFEL	Cédric Mezrag	IJCLab	14:35 - 15:00
15:00	DVCS off a pion target	M. Jose Manuel Morgado Chavez	IJCLab	15:00 - 15:30
16:00	Round table discussion: Benchmarking GPD evolution codes		IJCLab	15:30 - 16:30

14:00	Introduction to the session	Hervé MOUTARDE	IJCLab	14:00 - 14:10
	A determination of the collinear PDFs of the pion with xFitter	Alexander Glazov	IJCLab	14:10 - 14:35
	The NangaParbat code for TMD phenomenology	Valerio Bertone	IJCLab	14:35 - 15:00
15:00	Pion fragmentation functions using single-inclusive annihilation and semi-inclusive data	Rabah Abdul Khalek	IJCLab	15:00 - 15:25
	The EpIC event generator for exclusive processes	Dr Kemal Tezgin	IJCLab	15:25 - 15:45
16:00	Impact of a positron beam at JLab on an unbiased determination of DVCS Compton Form Factors	Dr Pawel Sznajder	IJCLab	15:45 - 16:05
	Determination of parton distribution functions from lattice QCD	Savvas ZAFEIROPOULOS	IJCLab	16:05 - 16:30
17:00	Round table: Improving parton distribution fits with lattice QCD calculations		IJCLab	16:30 - 17:00

3DPartons in STRONG-2020 newsletters

Can we measure the proton internal pressure?

Generalized parton distributions (GPDs) provide essential information about the 3D structure of the proton. Remarkably they are related to the QCD energy-momentum tensor and provide access to the mechanical properties of the proton like the distribution of pressure induced by its quark and gluon structure. GPDs can be constrained through several exclusive processes (all particles are detected in the final state), and in particular deeply virtual Compton scattering (DVCS). In principle the pressure distribution can be experimentally determined in a model-independent way from a dispersive analysis of DVCS data through the measurement of the subtraction constant. In practice this endeavor is a challenge because of the kinematic coverage and accuracy of existing experimental data.

Using tools developed within the 3DPartons work package of STRONG-2020 and elaborating on recent global fits of DVCS measurements using artificial neural networks, a team of European physicists summarized the current knowledge on this subtraction constant [1]. In this field of research, most of the effort has been dedicated so far to the determination of two proton fundamental characteristics, denoted d_1^q or d_1^g, which respectively relate to the magnitude of pressure forces exerted by the quarks of flavor q or by gluons. These quantities depend on a factorization scale μ_F which governs the separation between short and large distances in hard exclusive processes like DVCS. The dependence on this scale can be computed perturbatively in QCD. Fig. 1 compares the extraction of Ref. [1] to the other existing phenomenological or theoretical estimations.

DVCS data alone do not permit yet a statistically significant extraction of the proton internal pressure distribution. This study establishes the need for more precise data and for an extension of the covered kinematic domain. It paves the way for future works when more precise data become available, *e.g.* with the foreseen electron-ion colliders EIC and EicC.

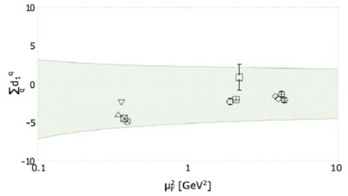


Fig. 1: The sum over quark flavors q of $d_1^q(\mu_F)$ as a function of μ_F for this study (green band) and other phenomenological and theoretical analyses. See Tab. 2 of Ref. [1] for the description of each data point, including the marker legend. Figure from Ref. [1].

Parton Branching: a bridge from resummation to parton shower

Most inclusive processes at high energies are well described by calculations of a hard scattering process, calculable in perturbative Quantum Chromo Dynamics (QCD) convoluted with parton densities, which give the probability of finding a parton of specific flavor carrying a fraction x of the parent hadron's longitudinal momentum probed at a resolution scale μ. However when less inclusive processes are calculated, one finds that a fixed order perturbative calculation is not sufficient to describe the measurement, for example the transverse momentum spectrum of Z bosons as measured at the LHC. At low transverse momenta, a resummation of soft gluon emissions to all orders is necessary to describe the measurement. Such resummations can be performed semi-analytically, leading to the so-called Transverse Momentum Dependent (TMD) distributions, or by performing an explicit simulation of soft parton emissions in terms of parton showers, as implemented in Monte Carlo event generators. While the physics of both approaches is the same, the calculations and the details are very different.

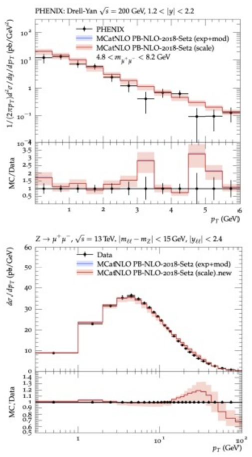


Figure 1: Transverse momentum spectrum of DY bosons measured by PHENIX at low energy (left) and of Z bosons measured by CMS at high energy

The Parton Branching (PB) method aims of combining both approaches. This is obtained by detailed investigations of the underlying parton evolution equation, the DGLAP equation, and rewriting this equation in terms of resolvable and non-resolvable branching processes [1,2]. When the evolution equation is solved iteratively, kinematic constraints coming from energy-momentum conservation can be applied at each branching. By doing so, automatically transverse momentum distributions can be calculated. The PB method has been applied to determine parton distributions from precision deep-inelastic scattering measurements. With these TMD parton distributions, Z production at the LHC, as well as low mass Drell-Yan production at low energies is very well described, without any further adjustment of parameters, as shown in Fig. 1 (see [3,4]).

The PB approach can be naturally extended to describe processes, where jets are involved, by performing a PB TMD parton shower, which follows in detail the PB TMD distribution [5]. An example of this approach is shown in Fig. 2 for the angular correlation between two b-quark jets with a Z boson as measured by CMS [6]. In the calculation the b-jets come from the PB TMD parton shower.

The PB method is a unique approach to combine features of semi-analytic resummation in form of PB-TMD distributions with TMD parton showers in a natural way.

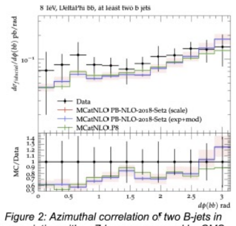


Figure 2: Azimuthal correlation of two B-jets in association with a Z boson measured by CMS

References

[1] Ellis, R. Keith and Stirling, W. James and Webber, B. R., Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol. 8 (1996) 1
[2] Hautmann, F., Jung, H., Lelek, A., Radescu, V., Zlebcik, R., JHEP 1801 (2018) 070
[3] Bermudez Martinez, A. and others, Eur. Phys. J. C80 (2020) 598
[4] Bermudez Martinez, A. and others, Phys. Rev. D100 (2019) 074027
[5] Baranov, S. and others, arXiv:2101.10221 (2021)
[6] Khachatryan, V. and others, Eur. Phys. J. C77 (2017) 751

Joint workshop on QCD

The groups "Fixed target experiments at LHC", "NLOAccess" and "3DPartons" of STRONG-2020, and "QCD at short distances: experiment, theory and tools" of the GDR QCD, organized an online joint meeting between May 31 and June 4, 2021. The *Groupement De Recherche Chromodynamique Quantique* (GDR QCD) is a structure which federates theorists and experimentalists from French laboratories who share a common interest: the study of the strong interaction. This joint workshop was the opportunity to gather participants of various work packages of STRONG-2020, and extend the audience to the French QCD community.

Fixed target experiments at LHC

The members of the Joint Research Activity « Fixed target experiments at LHC » (FTE@LHC) had their second workshop since the start of the STRONG-2020 project in 2019. The FTE@LHC group aims at developing novel techniques to carry out the most energetic fixed-target collisions ever performed in the laboratory using LHC beams at ALICE and LHCb. The group is motivated by physics questions related to quark and gluon distributions in the nucleon and nuclei at high momentum fraction, including the charm content of the proton and its connexion with astroparticle physics, the quark and gluon Sivers effects and the proton spin, and the quark-gluon plasma.

In the joint sessions of the workshop, the results of the SMOG gaseous target of LHCb were presented, highlighting the unique results obtained with the LHC beams used in a fixed target mode. The proposed implementations of the fixed target experiments at the LHC, as well as their challenges, were reviewed. The status and progresses of these implementations (ALICE fixed target, SMOG2, LHCSpin and SELDOM) were further discussed during three devoted sessions on hardware, simulations and physics and phenomenology. In the physics and simulations session, physics prospects were presented: heavy-flavor, antiproton and superheavy particle production in ALICE, cold nuclear matter study with hadron production in pA in LHCb, and Lambdac production and polarisation in LHCb. In addition, the prospects for Drell-Yan production were discussed, as well as the progress towards the charm baryon dipole moment measurement with a double bent crystal setup.