

|                             |  |                   |            |
|-----------------------------|--|-------------------|------------|
| <b>Work package number</b>  | WP10   | <b>Start date</b> | 01/06/2019 |
| <b>Activity Type</b>        | Virtual Access   |                   |            |
| <b>Work package acronym</b> | VA1-NLOAccess  |                   |            |
| <b>Work package title</b>   | Automated perturbative NLO calculations for heavy ions and quarkonia |                   |            |
| <b>Lead beneficiary</b>     | 1 - CNRS   |                   |            |

## 1. Description of access facilities

### 1.1 Modalities and opportunities for access

To facilitate the access and create new opportunities for access, several measures have been taken during the reporting period (June 2022 – July 2024)].

- We have further maintained the NLOACCESS code, by updating all the major packages used for the platform workflow.
- We have further enriched the NLOACCESS portal website (<https://nloaccess.in2p3.fr>) with a description of the Access, the list of participating institutions to the project, its objectives, a selection of useful references and the scientific news related to the Access.

## 2. International Assessment Board

### 2.1 Organization of International Assessment Board

An International Assessment Board (IAB) of eight researchers has been named. The composition of IAB reflects a balance between experimental and theory communities and EU and non-EU institutions. Indeed, the IAB is composed by:

- four researchers from the experimental community;
- four researchers from the theory community;
- among the eight researchers, five of them are from EU institutions and research centres, while the other three are from non-EU institutions.

The IAB is given all the relevant information about the Access including the detailed statistics. They are invited to send feed back to the NLOACCESS team at any time, in addition to the feedback given during the IAB meetings.

### 2.2 International Assessment Board Members

1. Prof. Asmita Mukherjee, IIT., Mumbai, India (Theory, Spin physics)
2. Dr. Barbara Trzeciak, CTU Prague, Czech Republic (Experiment, STAR)
3. Dr. Cynthia Hadjidakis, IJCLab Orsay, France (Experiment, ALICE)
4. Prof. Elena Ferreiro, USC, Spain (Theory, Heavy-Ion Physics)
5. Dr. Emilien Chapon, IRFU-CEA, Paris-Saclay U., France (Experiment, ATLAS)
6. Dr. Nodoka Yamanaka, Nagoya U., Japan (Theory, Nuclear and Hadronic Physics)
7. Dr. Marc Schlegel, Tübingen U., Germany (Theory, Spin physics)
8. Prof. Zhenwei Yang, Peking U., China (Experiment, LHCb)

## 2.3 International Assessment Board Meetings

The International Assessment Board (IAB) met virtually during the reporting period on July 26, 2024. The IAB has very positively assessed the result of the VA which outperformed the initial objectives.

## 3. Virtual Access activity during the reporting period

### 3.1 Detailed description of the activity

Activities of different kinds have taken place since the beginning of the reporting period. They are connected to different projects stemming from the usage and the developments of different computing codes for various scientific objectives. Let us list them here first by starting with the multi-purpose codes and then we will detail the related activities:

- MADGRAPH5AMC@NLO by the Madgraph team:
  1. Extension of the automated NLO computations to asymmetric hadronic collisions (proton-nucleus, pion-nucleus, nucleus A-nucleus B).
  2. Validation of inclusive photoproduction at NLO in perturbative QCD.

Other (single purpose) codes were also considered for integration in NLOACCESS. Let us cite a TMD evolution code at NLL written by J. Bor (Groningen & IJCLab), or a NLO code for inclusive quarkonium photoproduction with high-energy resummation by M. Nefedov (IJCLab) and Y. Yedelkina (IJCLab & UC Dublin). The software framework developed for NLOACCESS is fully general and can be applied to any code running with inputs transmitted by files and running via command lines on a Linux-based system.

We first report on the actions about the development of the Access *per se*:

1. As explained in section 1, we have further maintained and updated the packages needed for the correct functioning of the web application. In particular, we have updated the PYTHON OwnCloud client to its latest version. This allows the cloud service to safely work and store the users results.
2. We have studied with Y. Feng how to integrate the FDC workflow in a web page application similar to that of HELAC-ONIA Web and MADGRAPH5, which could thus be integrated in NLOACCESS. This has not been considered a priority by the IAB and paused by a lack of human resources

As what regards scientific projects using NLOACCESS, here is a summary of our activities:

1. Our 100-page review on the quarkonium-physics case at the High Luminosity (HL) LHC, heavily relying on predictions made with HELAC-ONIA, MADGRAPH5 and FDC, has been published in Progress in Particle and Nuclear Physics.
2. We have written and edited an 80-page review on the physics case for quarkonium related studies at the future US EIC. The review heavily relied on the usage of NLOAccess-related codes (HELAC-ONIA, FDC), and it has been submitted to Progress in Particle and Nuclear Physics.
3. We have used our proposed new method to match fixed-order results from collinear factorisation and resummed higher-order correction and we have applied it to the energy dependence of the total photoproduction cross section of vector quarkonia. A scientific paper have been published.

4. We have computed analytically the NNLO virtual corrections to hadroproduction of pseudoscalar quarkonium production paving the way for quarkonium production studies up to NNLO accuracy. Two scientific papers have been published.
5. We have performed several dedicated studies to quarkonium production at the future US EIC in the realm of transverse momentum dependent distributions (TMDs). The private code used for these works is under consideration for a future possible inclusion in NLOACCESS. Similar studies have been performed for the LHC and predictions were used by the LHCb collaboration. Two scientific papers have been published.
6. We have described the structure and the usage of the NLOACCESS platform and published a dedicated scientific paper.
7. We have validated photoproduction in MADGRAPH 5.
8. We have implemented asymmetric collisions in MADGRAPH 5.

As what regards the dissemination and outreach activities, NLOACCESS has been advertised by oral communications at research centres and international workshops, in front of students and researchers.

Here is the list of the **70+ oral communications, tutorials and hands-on given by the NLOACCESS team** on NLOACCESS for the reporting period:

- 2 talks by A. Safronov and D. Kikola at *ICHEP 2022*, Bologna, Italy, 06-13/07/2022 (<https://agenda.infn.it/event/28874/>)
- Talk by Y. Yedelkina at *EIC User Group Early Career Workshop 2022*, CFNS Stony Brook University (virtual), 24-25/07/2022 (<https://indico.jlab.org/event/485/>)
- Talk by C. Flore, at *Quarkonium Working Group 2022*, GSI, Darmstadt, Germany, 26-30/09/2022 (<https://indico.gsi.de/event/13128/>)
- 4 talks by J. Bor, C. Flett and C. Flore (2 x) at *Heavy flavours from small to large systems joint Strong-2020 Meeting 'recent results and perspectives in hadron physics'*, Institute Pascal, Orsay, France, 03-21/10/2022 ([https://indico.ijclab.in2p3.fr/event/7656/timetable/?view=standard\\_numbered\\_inline\\_minutes](https://indico.ijclab.in2p3.fr/event/7656/timetable/?view=standard_numbered_inline_minutes)).
- 2 talks by L. Manna and D. Kikola at *QCD@LHC2022*, IJCLab, Orsay, France, 28/11-02/12/2022 (<https://indico.cern.ch/event/1150707/>)
- 5 talks by A. Colpani Serri, C. Flore, L. Manna, D. Kikola and M. Nefedov at *Quarkonia As Tools 2023*, Aussois, France, 04-14/01/2023 (<https://indico.cern.ch/event/1213416/>)
- Talk by A. Colpani Serri at *Fixed-target experiments at LHC-Strong2020 workshop*, Aussois, France, 05-07/01/2023 (<https://indico.cern.ch/event/1222068/>)
- Talk by C. Flett at *QCD challenges from pp to AA collisions*, Padova, Italy, 13-17/02/2023 (<https://indico.cern.ch/event/1135616/>)
- Talk by C. Flore at *IRN Terascale*, Grenoble, France, 24-26/04/2023 (<https://indico.in2p3.fr/event/28562/>)
- 5 talks by A. Colpani Serri, C. Flett, L. Manna, D. Kikola and M. Nefedov at *QCD Evolution Workshop 2023*, Orsay, Paris, France, 22-26/05/2023 (<https://indico.cern.ch/event/1239374/>)
- Talk by J. Bor at *Sardinian Workshop on Spin*, Cagliari, Italy, 05-07/06/2023 (<https://agenda.infn.it/event/33895/>)
- Talk by M. Nefedov at *QCD23*, University of Montpellier, France, 10-14/07/2023 (<https://qcd23.sciencesconf.org/>)

- 5 talks by A. Colpani Serri, L. Manna, D. Kikola, M. Nefedov and Y. Yedelkina at *EPS-HEP Conference*, Universität Hamburg, Germany, 20-25/08/2023 (<https://indico.desy.de/event/34916/>)
- Talk by M. Nefedov at *Low-x 2023*, Leros Island, Greece, 02-08/09/2023 (<https://indico.cern.ch/event/1214186/timetable/#all.detailed>)
- Talk by C. Flett at *QCD@LHC23*, Durham, U.K., 04-08/09/2023 ([https://conference.ippp.dur.ac.uk/event/1128/timetable/?view=standard\\_numbered](https://conference.ippp.dur.ac.uk/event/1128/timetable/?view=standard_numbered))
- Talk by C. Flett at *MadGraph5\_aMC@NLO meeting 2023*, 17–20/09/2023, Lake Garda, Italy (<https://indico.cern.ch/event/1240244/>)
- 3 talks by C. Flett, M. Nefedov and Y. Yedelkina (online) at *Assemblée Générale 2023 du GDR-QCD*, Strasbourg, France, 27-29/09/2023 (<https://indico.in2p3.fr/event/30003/>)
- Talk by C. Flore at *STRONG-2020 Annual Meeting*, CERN, Geneva, Switzerland, 20-22/11/2023 (<https://indico.cern.ch/event/1264833/>)
- 4 talks by C. Flett, M. Nefedov, A. Safronov and D. Kikola at *NLOAccess/PrecisOnium Meeting*, CERN, Geneva, Switzerland, 20-24/11/2023 (<https://indico.cern.ch/event/1269836/timetable/>)
- Talk by J. Bor at *Synergies between the EIC and the LHC*, DESY Hamburg, Germany, 14-15/12/2023 (<https://indico.desy.de/event/41404/>)
- 5 talks by J. Bor, M. Nefedov, A. Safronov D. Kikola and S. Nabeebaccus at *Quarkonia As Tools 2024*, Aussois, France, 07-13/01/2024 (<https://indico.cern.ch/event/1324160/overview>)
- Talk by M. Nefedov at *Workshop on overlap between QCD resummations*, Aussois, France, 14-17/01/2024 (<https://indico.cern.ch/event/1290502/>)
- Talk by J. Bor at *International Workshop on Heavy Quarkonium / Quarkonium Working Group*, IISER Mohali, Chandigarh, India, 26/02-01/03/2024 (<https://indico.cern.ch/event/1226860/overview>)
- Talk by J. Bor at *SCPP Workshop on Probing the Nucleon structure in Three Dimensions at the Electron-Ion Collider*, IIT Bombay, Mumbai, India, 4/03/2024
- 5 talks by L. Manna, D. Kikola, M. Nefedov and S. Nabeebaccus (2x) at *DIS2024*, Grenoble, France, 08-12/04/2024 (<https://lpsc-indico.in2p3.fr/event/3268/>)
- 2 talks by C. Flore and S. Nabeebaccus at *QCD Evolution 2024*, Pavia, Italy, 27-31/05/2024 (<https://agenda.infn.it/event/38747/>)
- Talk by C. Flett at *MC4EIC*, Durham, U.K., 05-07/06/2024 (<https://conference.ippp.dur.ac.uk/event/1292/overview>)
- 2 talks by L. Manna and D. Kikola at *Present and future perspectives in Hadron Physics workshop*, Laboratori Nazionali di Frascati INFN, Italy, 17-19/06/2024 (<https://agenda.infn.it/event/38467/>)
- 9 talks by J. Bor, A. Colpani Serri, C. Flore, J.P. Lansberg, K. Lynch, L.Manna, M.Nefedov, A.Safronov and Y.Yedelkina at *Synergies between the LHC and EIC for quarkonium physics LHC*, ECT\*, Trento, Italy, 08-13/07/2024 (<https://indico.ectstar.eu/event/219/timetable/#20240708>)
- Talk by C. Flett at *ICHEP 2024*, 18/07/2024, Prague, Czech Republic (<https://indi.to/n9HH6>)

Moreover, the platform has been also used for Master classes during lectures delivered by J.P. Lansberg for the PHENIICS Doctoral School of the Paris-Saclay U. in Orsay, in 2023 and

2024, and for tutorials and hands-on sessions during the CERN Summer Student program (July 2022).

NLOACCESS is also ideal for training scholars. Indeed, during the project funding period, one Master student participated the aforementioned research projects while joining IJCLab-Orsay for an internship under the supervision of J.P. Lansberg:

1. Anne Riegler (M1 Göttingen & Paris-Saclay U.) worked on the possibilities to include hard-coded quarkonium processes in another Monte Carlo event generator for high-energy reactions, Sherpa.

Moreover, seven PhD theses are related to NLOACCESS:

1. Jelle Bor (RU Groningen and IJCLab Orsay): QCD Evolution of gluon transverse momentum dependent distribution and phenomenology of quarkonium-pair production at the LHC. This will contribute to the extension of MADGRAPH5 to TMD factorisation at NLO.
2. Kate Lynch (UCD Dublin and IJCLab): feasibility study for inclusive photoproduction of quarkonia in ultra-peripheral collisions at the LHC using HELAC-ONIA and Pythia.
3. Laboni Manna (WUT, Warsaw): inclusion and validation of photoproduction in MADGRAPH5. This addition will be included in the NLOAccess version.
4. Anton Safronov (WUT, Warsaw): inclusion of asymmetric hadron-hadron collision in MADGRAPH5. This addition will be included in the NLOAccess version.
5. Yelyzaveta Yedelkina (IJCLab and UC Dublin): New methodology to compute one-loop corrections to quarkonium photoproduction processes. This will contribute to the extension of MADGRAPH5 to quarkonium production at NLO.
6. Alice Colpani Serri (WUT, Warsaw): Extension of MADGRAPH5 to quarkonium production at LO and to TMD factorisation.
7. Allen Cris John Rubesh Rajan (UCD Dublin and IJCLab): Extension of MADGRAPH5 to massive initial states and to CEM with a specific MC integrator.

Our activities during this funding period resulted in valuable scientific outputs. Eight articles have been published or submitted to international peer-reviewed journals. Additional articles are at the drafting stages. We guide the reader to Section 3.3 for more details.

### **3.2 Access to the facility during the reporting period supported by the project**

As of July 31, 2024, there are 662 registered users to NLOACCESS, coming from different institutions/research centres of five regions:

- Europe: 52.27%
- Asia: 22.21%
- Africa: 1.51%
- North America: 21.14%
- South America: 2.72%
- Oceania: 0.15%

As of July 25, 2024, the users have performed 5042 runs, despite the reduced activity since the outbreak of the COVID-19 pandemic.

The scientific output based on NLOACCESS is listed in section 3.3 as what regards written publications. Oral communications are listed in section 3.1.

### 3.3 Scientific output of the users at the facility

We only list here the scientific written outputs during the reporting period of the users which are public (excluding internship and internal reports; the oral communications are listed as actions above.).

#### *Published articles:*

1. TMD evolution study of the  $\cos 2\phi$  azimuthal asymmetry in unpolarized  $J/\psi$  production at EIC. By J. Bor and D. Boer [arXiv:2204.01527]. 29/07/2022, *Phys.Rev.D* **106** (2022) 1, 014030, [10.1103/PhysRevD.106.014030].
2. Two-loop master integrals for pseudo-scalar quarkonium and leptonium production and decay. By S. Abreu, M. Becchetti, C. Duhr and M.A. Ozcelik [arXiv:2206.03848]. 22/09/2022, *JHEP* **09** (2022), 194, [10.1007/JHEP09(2022)194].
3. Revisiting NLO QCD corrections to total inclusive  $J/\psi$  and  $\Upsilon$  photoproduction cross sections in lepton-proton collisions. By A. Colpani Serri, Y. Feng, C. Flore, J.-P. Lansberg, M.A. Ozcelik, H.-S. Shao and Y. Yedelkina [arXiv:2112.05060]. 10/12/2022, *Phys.Lett.B* **835** (2022), 137556, [10.1016/j.physletb.2022.137556].
4. Two-loop form factors for pseudo-scalar quarkonium production and decay. By S. Abreu, M. Becchetti, C. Duhr and M.A. Ozcelik [arXiv:2211.08838]. 27/02/2023, *JHEP* **02** (2023), 250, [10.1007/JHEP02(2023)250].
5. NLOAccess: automated online computations for collider physics. By C. Flore [arXiv:2301.09167]. 16/04/2023, *Eur.Phys.J.A* **59** (2023) 3, 46, [10.1140/epja/s10050-023-00972-2].
6. Transverse momentum dependent shape function for  $J/\psi$  production in SIDIS. By D. Boer, J. Bor, L. Maxia, C. Pisano and F. Yuan [arXiv:2304.09473]. 18/08/2023, *JHEP* **08** (2023), 105, [10.1007/JHEP08(2023)105].
7. Curing the high-energy perturbative instability of vector-quarkonium-photoproduction cross sections at order  $\alpha_s^3$  with high-energy factorisation. By J.-P. Lansberg, M. Nefedov and M.A. Ozcelik [arXiv:2306.02425]. 03/04/2024, *Eur.Phys.J.C* **84** (2024) 4, 351, [10.1140/epjc/s10052-024-12588-x].

#### *Non-published articles:*

8. Breakdown of collinear factorization in the exclusive photoproduction of a  $\pi^0$ -gamma pair with large invariant mass. By S. Nabeebaccus, J. Schoenleber, L. Szymanowski, and S. Wallon [arXiv:2311.09146].

#### *Peer-review proceedings:*

1. NLO inclusive  $J/\psi$  photoproduction at large  $P_T$  at HERA and the EIC. By C. Flore, J.-P. Lansberg, H.-S. Shao, Y. Yedelkina [arXiv:2107.13434]. 11/07/2022, *SciPost Phys.Proc.* **8** (2022), 011, [10.21468/SciPostPhysProc.8.011].
2. Reweighting the quark Sivers function with STAR jet data. By C. Flore, M.E. Boglione, U. D'Alesio, J.O. Gonzalez-Hernandez, F. Murgia, A. Prokudin [arXiv:2107.13311]. 11/07/2022, *SciPost Phys.Proc.* **8** (2022), 034, [10.21468/SciPostPhysProc.8.034]

#### *Normal proceedings:*

1. A tool for automated perturbative cross section computations of asymmetric hadronic collisions at next-to-leading order using the MadGraph5\_aMC@NLO framework. By

- A. Safronov, C. Flore, D. Kikola, A. Kusina, J.-P. Lansberg, O. Mattelaer and H.-S. Shao. 28/11/2022, *PoS ICHEP2022 (2022)*, 494, [10.22323/1.414.0494].
2.  $J/\psi$ -pair production at NLL in TMD factorisation at the LHC. By A. Colpani Serri, J. Bor, D. Boer and J.-P. Lansberg [arXiv:2403.00640]. 21/03/2024, *PoS EPS-HEP2023 (2024)*, 272, [10.22323/1.449.0272].
  3. Asymmetric collisions in MadGraph5\_aMC@NLO. By L. Manna, A. Safronov, C. Flore, D. Kikola, J.-P. Lansberg and O. Mattelaer [arXiv:2401.14741]. 21/03/2024, *PoS EPS-HEP2023 (2024)*, 274, [10.22323/1.449.0274].
  4. Revisiting inclusive production of  $J/\psi$  and  $\Upsilon$  in high-energy  $\gamma\gamma$  collisions. By Y. Yedelkina, J.-P. Lansberg and M. Nefedov [arXiv:2312.04389]. 21/03/2024, *PoS EPS-HEP2023 (2024)*, 271, [10.22323/1.449.0271].

#### 4. Tables to be filled in the IT tool in Part A of the Periodic Report

##### 4.1 Researchers who have access to research e-infrastructures through Union support

| <b>e-infrastructure name</b> | <b>e-infrastructure service</b>  | <b>Activity Domain (Discipline)</b> | <b>Maximum possible number of users</b> | <b>Nr of actual users by max possible number in P3 (%)</b> |
|------------------------------|--|-------------------------------------|---|--|
| NLOAccess                    | Common services: data generation (cross-section computation) & storage of the generated data;<br>Thematic services : access to self-generated codes based on the user request. | Physics                             | 300-450                                 | >100 %   |



## 5. Resources used to provide access to Research Infrastructures

[Explain how many PM have been used to provide access and explain for which task (e.g. scientific support to users, etc.)].

### 5.1 Resources used to provide access

| <b>Beneficiary/Linked Third Party short name</b> | <b>Installation(s)</b> | <b>P/m</b> | <b>Explanations of tasks</b>   |
|--|------------------------|------------|--|
| CNRS   | NLOAccess-IJCLab       | 12         | <ul style="list-style-type: none"><li>- Maintenance of databases for the user registration, the jobs managing and the corresponding statistics.</li><li>- Update of the user guide for HELAC-ONIA</li><li>- Cure issue of negative NLO cross-section for quarkonium production</li><li>- Study of gluon PDF behaviours at low x and low scales</li><li>- <math>\eta(Q)</math> production up to NNLO accuracy</li><li>- Scientific support to users</li></ul> |
| UCLouvain  | NLOAccess-CP3          | 3          | <ul style="list-style-type: none"><li>- Progress towards access to a NLO codes of nuclear PDF effects in perturbative QCD in proton-nucleus collision.</li><li>Modification of MADGRAPH5 to include asymmetric hadron-hadron and lepton-hadron collisions</li><li>- Scientific support to users</li></ul>  |