**Template JRA**

|  |  |  |  |
| --- | --- | --- | --- |
| **Work package number** | WP20 | **Start date** | 01/06/2019 |
| **Activity Type** | Joint Research Activity | | |
| **Work package acronym** | JRA2- FTE@LHC | | |
| **Work package title** | Fixed Target Experiments at the LHC | | |

1. Work carried out and overview of progress
   1. **Project objectives**

*[Please give an overview of the project objectives for the third reporting period (June 2022 – July 2024), with regard to the overall objectives as described in the Annex 1 of the Grant Agreement and summarized below.]*

The objectives of the WP are to investigate and implement fixed-target experiments at the LHC with the ALICE and LHCb detectors.

In order to achieve these objectives, three tasks were defined:

1. Feasibility studies in ALICE

2. Gas-target development in LHCb

3. Phenomenological and theoretical studies.

In the third period of strong2020, the remaining objectives were achieved as described in Table 1.2.

* 1. **Progress made during the reporting period towards the objectives**

*[Please describe the progress made during the third reporting period in line with your Gantt chart and the project overall tasks as described in the Annex 1 of the Grant Agreement and summarized below.]*

***Table 1.2 Progress made during the reporting period for each task***

|  |
| --- |
| ***Task 1: feasibilities studies in ALICE.***  ***• Study on the gas-jet target implementation and study of the L3 magnetic field constraints on a polarised setup;***  ***• Integration of a solid target internal to the beam pipe;***  ***• Estimation of the detector performance with a vertex shifted from the nominal interaction point;***  ***• Full simulations of selected soft and hard processes with the ALICE setup.*** |
| On the ALICE side, the feasibility studies planned in the WP20 were already achieved in the previous reporting periods. The activities related to ALICE project were very dense in June 2022 to January 2023. The conceptual design was achieved and the realistic simulations performed showed the capabilities of the fixed target system to bring new physics in ALICE. There was no showstopper. Funding was granted from a French ANR and the budget was in place to hire two postdocs to perform detailed studies on vacuum constraints around the target system in the LHC beam pipe and on beam impedance. However, in February 2023, the ALICE management decided not to pursue this activity due to a lack of manpower needed from the ALICE technical coordination side to follow the implementation of the project. |
| ***Task 2: gas-target development in LHCb.***  ***• Design and construction of the unpolarised target for LHCb;***  ***• Standalone tests on gas polarization ;***  ***• Design of the new polarised gas target;***  ***• Full simulation for the detector performances with a vertex shifted from the nominal interaction point;***  ***• Implementation of the new trigger and tracking reconstruction code;***  ***• Full simulations of selected hard processes with the LHCb setup.*** |
| All the items listed above have been successfully accomplished. The unpolarized target for LHCb has been designed, installed, and is currently operational, collecting data during simultaneous data-taking with beam-beam collisions.  This data taking involves the implementation of trigger lines and simulations of the physics channels. In particular, the shifted primary vertex has been included in the reconstruction algorithms, demonstrating the important result that the efficiency for beam-gas collisions and beam-beam collisions is the same. The particle reconstruction resolution remains unchanged, and the two collision points work independently, behaving as separate primary vertices.  When operating with the unpolarized target, the full detector occupancy and data flow only increase by a few percent. The design of a new polarized target has also been completed, with CAD drawings illustrating the implementation of the target and its components within the LHCb spectrometer.  All these results have been published and presented at international workshops and conferences. |
| ***Task 3: phenomenological and theoretical studies.*** |
| On the theory and phenomenological side, the studies were quite active and new papers have been published on various topics related to fixed target at LHC, as it can be seen in section 1.3. The studies were also discussed in workshops and conferences (see section 1.3). |

**1.3 Highlights of significant results**

*[Include an overview of the project results towards the objective of the action in line with the structure of the Annex 1 to the Grant Agreement*.*]*

All the studies performed in this WP were extensively discussed during the workshop organized at Aussois in January 2023.

**References and publications:**

Published proceedings and contributions:

- « Heavy flavour studies with a high-luminosity fixed-target experiment at the LHC », B.Trzeciak et al. PoS HardProbes2020 (2021) 190

- "White Paper on Forward Physics, BFKL, Saturation Physics and Diffraction",  M. Hentschinski et.al., <https://arxiv.org/abs/2203.08129>

Published papers with topics related to the WP20:

- "Revisiting NLO QCD corrections to total inclusive J/ψ and Υ photoproduction cross sections in lepton-proton collisions", A. Colpani Serri et al., Phys.Lett.B 835 (2022) 137556

- "Matching next-to-leading-order and high-energy-resummed calculations of heavy-quarkonium-hadroproduction cross sections », M.Nefedov et al., JHEP 05 (2022) 083

- “Antiproton production with a fixed target and search for superheavy particles at the LHC”, A.B. Kurepin et al., J.Mod.Phys.13(2022)1093

- « Curing the high-energy perturbative instability of vector-quarkonium-photoproduction cross section at alpha.alphaS^3 with high-energy factorisation », M. Nefedov et al., EPJC 84 (2024) 4, 351

- « A potential approach to the X(3872) thermal behavior », E. G. Ferreiro et al., Phys.Lett.B 854 (2024) 138760

- “An experiment for electron-hadron scattering at the LHC”, E. G. Ferreiro et al., Eur.Phys. J. C (2022) 82:40

- “Simple model to include initial-state and hot-medium effects in the computation of quarkonium nuclear modification factor”, Phys.Rev.D 105, 014019;

- “The LHCspin project: A polarized fixed target for LHC” B. Passalacqua et al., Nuovo Cim.C 47 (2022) 121;

- “The LHCspin project: A polarized target experiment at LHC”, L.L.Pappalardo et al., Nuovo Cim.C 47 (2024) 4, 235;

- “The LHCspin project A polarised gas target at the Large Hadron Collider”, M. Santimaria et al., EPJ Web of Conferences 276, 05007 (2023);

- “The LHCspin project”, P. Di Nezza et al., Acta Phys.Polon.Supp. 16 (2023) 7, 7-A4;

- “The LHCspin project”, P. Di Nezza et al., PoS(PSTP2022)001;

- “LHCspin: Unpolarized gas target SMOG2, and prospects for a polarized gas target at the LHC”, E. Steffens et al., PoS(PSTP2022)002;

- “Fixed Target Program at the LHC”, P. Di Nezza et al., PoS SPIN2023 (2024) 036;

- “A neural-network-defined Gaussian mixture model for particle identification applied to the LHCb fixed-target programme”, S. Mariani et al., Journal of Physics 2438 (2023) 012107;

- “A high-density gas target at the LHCb experiment”, O. Boente et al., arXiv:2407.1420, in print on Physics Review Accelerators and Beams;

- “Amorphous carbon-coated storage cell tests for the polarized gas target at LHCb”, T. El-Kordy et al., Nuclear Instruments and Methods A 1068 (2024) 169707;

**Communications to Workshop/Conference**

-Update on ALICE Fixed Target project, Daniel Kikola, PBC annual meeting, Nov. 2022

-Organization of the FTE@LHC workshop at Centre Paul Langevin, Aussois, France January 5-7 2023 : <https://indico.cern.ch/event/1222068/> and related talks

-"Quarkonia as tools 2023", Centre Paul Langevin, Aussois, France, 4-14 January 2023, "Inclusive quarkonium production phenomenology and tools overview" (09.01) [<https://indico.cern.ch/event/1213416/timetable/#20230109.detailed>]  
-"QCD Evolution workshop 2023", IJClab, Orsay, France, 22-26 May 2023, "High-Energy factorization and matching to NLO for quarkonium production" (26.05) [<https://indico.cern.ch/event/1239374/timetable/#20230526.detailed>]  
-"26th High-Energy Physics International Conference in Quantum Chromodynamics (QCD23)", University of Montpellier, France, 10-14 July 2023, "On the High-Energy instability of quarkonium production cross sections" (10.07) [<https://qcd23.sciencesconf.org/>]  
-"EPS-HEP2023 Conference", Hamburg University, Hamburg, Germany, 20-25 August 2023, "Resolving the perturbative instability of $p\_T$-integrated quarkonium production cross section with High-Energy Factorisation" (23.08) [<https://indico.desy.de/event/34916/timetable/#all.detailed>]   
-"Low-x 2023", Leros Island, Greece, 3-8 September 2023, "Computing one-loop corrections to quarkonium production impact-factors with Lipatov's EFT" (08.09) [<https://indico.cern.ch/event/1214186/timetable/#all.detailed>]  
-"General assembly of the GDR QCD", IPHC, Strasbourg, France, 27-29 September 2023, "Computing heavy quarkonium production cross sections at high energy with the matching between collinear and high-energy factorisations" (28.09) [<https://indico.in2p3.fr/event/30003/timetable/#all.detailed>]

-“Fixed targets at LHC”, P. Di Nezza, APCTP Focus Program in Nuclear Physics, POSCO Korea, Jul 18 – 23, 2022

-“The LHCspin project”, L.L. Pappalardo, Fixed-target experiments at LHC – STRONG2020 workshop, CERN, 22-24 Jun 2022

-“The LHCspin project”, M. Santimaria, The 20th International Conference on Strangeness in Quark Matter, Busan, Jun 2022

-“Fixed target at LHCb”, M. Santimaria, CFSN Workshop, Stony Brook, Jun 2024

-“The LHCspin project”, M. Santimaria, Diffraction and low-x 2022, Corigliano Calabro, Jun 2024

-“LHC fixed target experiments”, P. Di Nezza, IWHSS Cern Aug 2022;

-“The LHCspin project: a Polarized Fixed-Target Experiment at the LHC”, L.L. Pappalardo, 24th Gordon Research Conference on Photonuclear Reactions, Holderness, NH (USA), Aug 2022

-“The LHCspin project”, P. Di Nezza, Workshop on Polarized Sources Targets and Polarimetry 2022 (PSTP22) Mainz, Sep 2022

-“Fixed target experiments at LHC”, P. Di Nezza, Workshop Opportunities with JLab Energy and Luminosity upgrade, ECT\* Trento, Oct 2022

-“Status of the LHCspin project”, P. Di Nezza, Workshop Fixed target experiments at LHC, Aussois, Jan 2023

-“Polarised physics at the LHC”, P. Di Nezza, Epiphany conference Gen 2023, Krakow, Jan 2023

-“LHCspin (SMOG3): considerations for IP8”, P. Di Nezza, Velo-II Upgrade workshop, Amsterdam, Feb 2023

-“Fixed Target and Heavy-Ion Results at LHCb”, P. Di Nezza, LISHEP 2023 Conference, Rio de Janeiro, Mar 2023

-“Spin Physics with LHCspin”, P. Di Nezza, LISHEP 2023 Conference, Rio de Janeiro, Mar 2023

-“The LHCspin project: a polarized target experiment at LHC“, L.L. Pappalardo, HADRON 2023, Genova, Jun 2023

-“The LHCspin project”, M. Santimaria, International Workshop on Hadron Structure and Spectroscopy, Prague, Jun 2023

-“Polarised physics at LHC: the LHCspin project”, P. Di Nezza, Sar WorS 2023, Cagliari, Jun 2023

-“The fixed target program at the LHC”, P. Di Nezza, SPIN 2023 Conference, Durham, Sep 2023

-“The LHCspin project”, M. Santimaria, Low-x 2023 conferencce, Leros, Sep 2023

-“The LHCspin project”, M. Santimaria, Joint ECFA-NuPECC-APPEC, DESY, Dec 2023

-“The physics case of LHCspin“, L.L. Pappalardo, Workshop COMAP- VIII, CERN, May 2024

-“The LHCspin proposal“, P. Di Nezza, Workshop COMAP- VIII, CERN, May 2024

-“LHCspin simulations”, M. Santimaria, COMAP-VIII; CERN, May 2024

-“Fixed target experiments at the LHC”, P. Di Nezza, STRONG-2020 workshop, Frascati June 2024

1. Critical Implementation risks and mitigation actions

**2.1 Risk materialization**

*[Provide the information on the project risks described in Annex 1 to the Grant Agreement*.*]*

1. Performance, feasibility and design study (low)

Whether the risk has materialized? (Yes/No)

1. Phenomenological and theoretical studies (low)

Whether the risk has materialized? (Yes/No)

1. Construction of the unpolarised target cell for LHCb (low)

Whether the risk has materialized? (Yes/No)

**2.2 Risk-mitigation measures applied**

*[Please indicate whether the risk-mitigation plan described in Annex 1 to the Grant Agreement and corresponding to the risk number was applied in the reporting period*.*]*

1. In case performance from feasibility studies did not reach the expected features, a minimal physics programme is still acceptable.

Whether the risk-mitigation plan was applied? (Yes/No)

1. Increase in phenomenological and theoretical studies will lead to an improved understanding of the framework.

Whether the risk-mitigation plan was applied? (Yes/No)

1. No showstoppers emerged from the interactions with the LHC experts. It is possible, if this were to happen, to perform similar measurements without the storage cell.

Whether the risk-mitigation plan was applied? (Yes/No)

**2.3 Comments/new risk-mitigation measures proposed**

*[Provide any significant comments on the risks encountered and the mitigation plan applied. Give any unforeseen risks encountered during the reporting period and not mentioned above*.*]*

3. Deviations from Annex 1 (Description of Action) and Annex 2 (Estimated budget for Action) (if applicable)

**3.1 Deviations from planned objectives and tasks, and their impact on the progress of the work package**

*[Explain the reasons for deviations, the consequences and the proposed corrective actions.]*

**3.2 Deviations between actual and planned person months**

*[Explain deviations between actual and planned person-months. If applicable, propose corrective actions.]*

1. Deliverables and milestones tables

**4.1 Deliverables**

*[Please list all the deliverables due in this reporting period, as indicated in Annex I.*

*Deliverables must also be accompanied by a short report (deliverable description and technical documentation, such as photo, list of publications, etc.), so that the European Commission has a record of their existence.]*

***Table 4.1 List of deliverables***

| **Deliverable No.** | **Deliverable name** | **Lead Beneficiary** | **Nature** | **Dissemination level[[1]](#footnote-1)** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| D20.6 | Internal reports Design of  the polarised gas target  for LHCb | 30 - INFN | Report | CO | 54 | yes | 54 |  |
| D20.7 | Peer-reviewed paper  Phenomenology and  theory papers for high-x,  spin and QGP physics | 39 - LIP | Report | PU | 54 | yes |  |  |

*In case a deliverable has been delivered in the reporting period and a report exists in the Participant Portal, you can indicate “uploaded report” in correspondence of a deliverable*

**4.2 Milestones**

*[Please complete the table if milestones are specified in Annex I.*

*Milestones will be assessed against specific criteria and performance indicators as defined in Annex I.]*

***Table 4.2 List of milestones***

| **Milestone number** | **Milestone name** | **Lead beneficiary** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- |
| 35 | Code for full simulation in LHCb | 30 - INFN | 15 | yes |  |  |
| 36 | Gas target and detector setup ready for gas polarisation and dissociation studies | 30 - INFN | 27 | yes |  |  |
|  |  |  |  |  |  |  |

**No Milestones in the RP3 (months 37-62)**

**4.3 Deliverable Reports**

*[Please provide, per each deliverable listed in Table 4.1, a brief description, including if possible some technical documentation (photos, list of publications, etc.). Use as many pages as needed per each report.]*

For the deliverable D20.7, several phenomenological and theory reports have been published. Those works concern physics topics that motivate the use of a fixed target system at the LHC, or theory development that are useful for the calculations of observables that can motivate a fixed target experiment at the LHC.

Published proceedings:

- « Heavy flavour studies with a high-luminosity fixed-target experiment at the LHC », B.Trzeciak et al. PoS HardProbes2020 (2021) 190

- « Exclusive production of a large mass photon pair », J. Wagner et al, PoS DIS2019 (2019) 196

Contribution to SnowMass 2021 (on arXiv) "White Paper on Forward Physics, BFKL, Saturation Physics and Diffraction",  M. Hentschinski et.al., <https://arxiv.org/abs/2203.08129>

Published papers:

- « Data-driven study of timelike Compton scattering », J. Wagner et al., EPJC80 (2020) 2, 171

- « Electroproduction of a large invariant mass photon pair », J. Wagner et al., Phys.Rev.D101(2020) 11, 114027

- « A fixed-target programme at the LHC: Physics case and projected performance for heavy-ion, hadron, spin and astroparticle studies », C. Hadjidakis et al. Phys.Rept.911(2021)1-83

- "Curing the unphysical behaviour of NLO quarkonium production at the LHC and its relevance to constrain the gluon PDF at low scales", J.-P. Lansberg and M.A. Ozcelik, Eur. Phys.J. C 81 (2021) 497

- "Revisiting NLO QCD corrections to total inclusive J/ψ and Υ photoproduction cross sections in lepton-proton collisions", A. Colpani Serri et al., Phys.Lett.B 835 (2022) 137556

- "Matching next-to-leading-order and high-energy-resummed calculations of heavy-quarkonium-hadroproduction cross sections », M.Nefedov et al., JHEP 05 (2022) 083

- “Antiproton production with a fixed target and search for superheavy particles at the LHC”, A.B. Kurepin et al., J.Mod.Phys.13(2022)1093

- « Curing the high-energy perturbative instability of vector-quarkonium-photoproduction cross section at alpha.alphaS^3 with high-energy factorisation », M. Nefedov et al., EPJC 84 (2024) 4, 351

- "A potential approach to the X(3872) thermal behavior", E. G. Ferreiro et al., Phys.Lett.B 854 (2024) 138760

-“An experiment for electron-hadron scattering at the LHC”, E. G. Ferreiro et al., Eur.Phys. J. C (2022) 82:40.

For the deliverable D20.6, the design of a new polarized target has been completed for all its components: the vacuum chamber, the Atomic Beam Source, and the Breit-Rabi polarimeter. Starting from the system used in the HERMES experiments, modifications were studied and implemented to comply with CERN requirements. CAD drawings illustrate the integration of the target and its components within the LHCb spectrometer and along the LHC beamline. A detailed technical note, 'Design of a Polarized Gas Target for LHC', P. Di Nezza et al., note INFN-23-33/LNF, was published in 2023. Additionally, these results have been published and presented at international workshops and conferences.

Published papers and proceedings about the delivery D20.6:

- “Design of a polarized gas target for LHC”, P. Di Nezza et al., note INFN-23-33/LNF

- “The LHCspin project: A polarized fixed target for LHC” B. Passalacqua et al., Nuovo Cim.C 47 (2022) 121;

- “The LHCspin project: A polarized target experiment at LHC”, L.L.Pappalardo et al., Nuovo Cim.C 47 (2024) 4, 235;

- “The LHCspin project A polarised gas target at the Large Hadron Collider”, M. Santimaria

et al., EPJ Web of Conferences 276, 05007 (2023);

- “The LHCspin project”, P. Di Nezza et al., Acta Phys.Polon.Supp. 16 (2023) 7, 7-A4;

- “The LHCspin project”, P. Di Nezza et al., PoS(PSTP2022)001;

1. PU = Public

   PP = Restricted to other programme participants (including the Commission Services).

   RE = Restricted to a group specified by the consortium (including the Commission Services).

   CO = Confidential, only for members of the consortium (including the Commission Services). [↑](#footnote-ref-1)