STRONG-2020 ANNUAL MEETING (2022)

WP13 (NA2-Small-x): Small-x Physics at the LHC and future DIS experiments

Cyrille Marquet
CPHT, École Polytechnique, France

October 19th 2022

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

PLAN OF PRESENTATION

1) Scientific results obtained since the last year
2) Modifications of the scientific Work Plan (as compared to the initial plan in the Grant Agreement)
3) Possibilities/needs of another request for the extension of the project (beyond 30 November 2023)

(We kindly ask to focus on the scientific aspects of the work carried out without administrative issues or timeline questions for deliverables and milestones)

INTRODUCTION:

Participant institutions:

- **BGU**: Ben-Gurion University of the Negev, Beer Sheva, Israel (M. Lublinsky).
- **CNRS**: École Polytechnique, Université Paris-Saclay, Palaiseau, France (C. Marquet, S. Munier) + IPhT, Commissariat à l'énergie atomique, Saclay, France (F. Gelis, E. Iancu, G. Soyez) + Laboratoire de Physique Théorique, Université Paris-Saclay, Orsay, France (S. Wallon).
- Cosenza: Università della Calabria, Cosenza, Italia (A. Papa).
- **CTU**: Czech Technical University, Prague, Czech Republic (J. Cepila, G. Contreras).
- **ECT***, Trento, Italy (D. Triantafyllopoulos).
- **Firenze**: Università de Firenze, Italia (D. Colferai).
- **Granada**: Universidad de Granada, Spain (J. L. Albacete).
- **Groningen**: University of Groningen, The Netherlands (D. Boer).
- **Jyväskylä**: University of Jyväskylä, Finland (T. Lappi, H. Paukkunen, K. J. Eskola).
- **Krakow INP**: Henryk Niewodniczański Institute of Nuclear Physics, Krakow, Poland (K. Golec-Biernat, K. Kutak, S. Sapeta).
- **Krakow JU**: Jagiellonian University, Krakow, Poland (Leszek Motyka, Michal Praszalowicz)
- **Madrid**: Universidad Autónoma de Madrid, Spain (A. Sabio Vera).
- **Regensburg**: University of Regensburg, Germany (G. Chirilli).
- **Santiago**: Universidade de Santiago de Compostela, Spain (N. Armesto).
- **Warsaw**: National Centre for Nuclear Research, Warsaw, Poland (T. Altinoluk, L. Szymanowski).

- Initially 15 institutions; several additional contacts:
  - B. Blok (Technion)
  - G. Chachamis (LIP)
  - M. Hentschinski (Puebla)
  - C. Royon (KU)
  - S. Schlichting (Bielefeld)
  - W. Xiang (Guizhou University)

PROGRESS MADE:

Task 1: Nuclear PDFs.

- EPPS21: new benchmark nuclear pdf's, Eur. Phys. J. C 82 (2022) 5, 413 [2112.12462] (JYV-USC)
- Assessing sensitivity of inclusive measurements at future DIS experiments to saturation, Phys. Rev. D 105 (2022) 11, 114017 [2203.05846] (JYV-USC)
- Extracting nuclear parton distributions from exclusive vector mesons, 2203.11613 (JYV)
- Effect of proton pdf uncertainties in nuclear PDF's, Eur. Phys. J. C 82 (2022) 3, 271 [2202.01074] (JYV-USC)
- Snowmass 2021 whitepaper: Proton structure at the precision frontier, contribution to 2022 Snowmass Summer Study, 2203.13923 (USC-ECT*)

PROGRESS MADE:

Task 2: New NLO-based precision phenomenology in CGC and BFKL.

- Technical aspects in the CGC:
  - New observables for probing gluon saturation via diffractive 2+n jet production in eA collisions at the EIC, Phys. Rev. Lett. 128 (2022) 20, 202001 [2112.06353] (IPhT-ECT*)
  - NLO JIMWLK evolution with massive quarks, JHEP 07 (2022) 093 [2203.13695] (BGU)
  - Nuclei in the toy world: beyond the Pomeron in zero transverse dimensions, JHEP 05 (2022) 019 [2201.01551] (BGU)
  - NLO calculation of exclusive heavy vector meson production: 2204.14031 and 2104.02349 (JYV)
  - NLO calculation of exclusive light vector meson production: 2203.16911 (JYV)
  - Real corrections to diffractive structure functions at NLO: 2206.13161 (JYV-NCBJ-USC)
  - Finite volume effects in the McLerran–Venugopalan initial condition for the JIMWLK equation, Eur. Phys. J. C 82 (2022) 4, 369 [2111.07427] (Jagiellonian)
  - Hybrid k_T-factorization and impact factors at NLO [2205.09585] (JU-IFJ PAN)
  - Quark and scalar propagators at next-to-eikonal accuracy in the CGC through a dynamical background gluon field, Phys. Rev. D 105 (2022) 7, 7 [2109.01620] (NCBJ)
  - Photon LFWFs and DIS total cross section at NLO in the dipole picture with massive quarks: Phys. Rev. Lett. 129 (2022) 7, 072001 [2112.03158] & Phys. Rev. D 106 (2022) 3, 034013 [2204.02486] (JYV-NCBJ)

PROGRESS MADE:

Task 2: New NLO-based precision phenomenology in CGC and BFKL.

- Observables sensitive to high energy QCD dynamics: Jet-jet correlations: Phys. Scripta 97 (2022) 7, 074007 (UAM-LIP); Mueller-Navelet jets at the LHC: hunting data with azimuthal distributions, 2207.05015.
- Calculation of NLO impact factors for semi-hard processes in the BFKL approach (proton-to-Higgs impact factor) (Cosenza-IJCLab-ECT*): Phys. Rev. D 105 (2022) 11 [2205.13429], 114056, JHEP 08 (2022) 092 [2205.02681].
- Phenomenology of semi-hard processes at the LHC (inclusive backward/forward processes) and at HERA (inclusive single-forward processes) (Cosenza-IJCLab-ECT*): Bottom-flavored inclusive emissions in the variable-flavor number scheme: A high-energy analysis, Phys. Rev. D 104 (2021) 11, 114007 [2109.11875].
- Systematic extraction of quarkonium light front wavefunctions from decay data [2111.07087] (JYV)
- A parton branching with transverse momentum dependent splitting functions, Phys. Lett.B 833 (2022) 137276 [2205.15873] (IFJ PAN)

PROGRESS MADE:

Task 2: New NLO-based precision phenomenology in CGC and BFKL.

- Proposal of new facilities and contribution to new projects:
  - White Paper on Forward Physics, BFKL, Saturation Physics and Diffraction (Snowmass 2022), 2203.08129 [hep-ph] (UAM-ECT*-CPHT-Cosenza-IFJ PAN-NCBJ);
  - The Forward Physics Facility at the High-Luminosity LHC (Snowmass 2022), 2203.05090 [hep-ex] (UAM-ECT*-LIP-IPhT-Cosenza-IFJ PAN-NCBJ).
  - The Forward Physics Facility: Sites, experiments, and physics potential (UAM-ECT*-LIP-IPhT-Cosenza-IFJ PAN-NCBJ). Phys. Rept. 968 (2022) 1-50 [2109.10905]
  - Diffractive longitudinal structure function at the Electron Ion Collider, Phys. Rev. D 105 (2022) 7, 074006 [2112.06839] (USC)
  - An experiment for electron-hadron scattering at the LHC, Eur. Phys. J. C 82 (2022) 1, 40 [2201.02436] (USC-LIP)
  - The International Linear Collider: Report to Snowmass 2021 (Snowmass 2022), 2203.07622 (Cosenza-ECT*)
  - Snowmass 2021 White Paper: Electron Ion Collider for High Energy Physics (Snowmass 2022), 2203.13199 (ECT*-CPhT-Regensburg-USC-NCBJ-JYV)

PROGRESS MADE:

Task 3: TMDs at small x (relation with JRA4 and JRA5)

- Transverse-momentum dependent factorisation for diffractive jet production in DIS at small Pomeron x: connecting JIMWLK and DGLAP evolutions from first principles, 2207.06268, JHEP to appear (IPhT-ECT*)
- Dijet photoproduction at low x at next-to-leading order and its back-to-back limit, 2204.11650 (CPhT-NCBJ): the Sudakov logarithms and the kinematic constraints to the small-x evolution are intimately linked.
- Pseudo and quasi gluon PDF in the BFKL approximation, JHEP 03 (2022) 064, 2111.12709 (Regensburg).
- Rapidity evolution of TMDs with running coupling, Phys. Rev. D 106 (2022) 3, 034007, 2205.03119 (Regensburg).

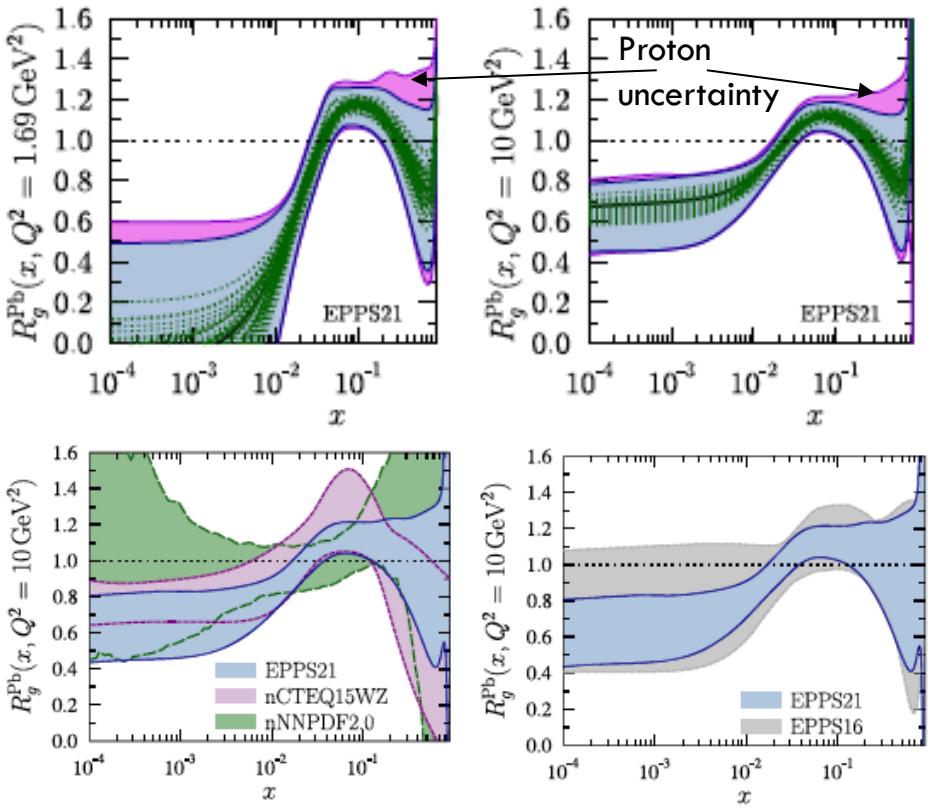
PROGRESS MADE:

Task 4: Multi-particle correlations & Thermalization.

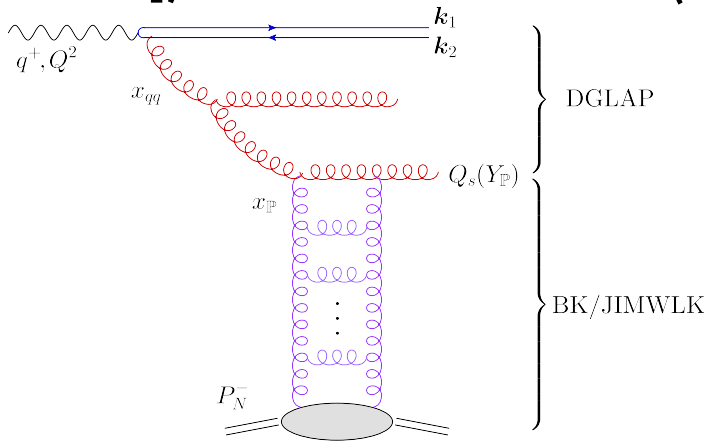
- Constraining the hot spot structure of a proton by exclusive vector mesons [2206.05207] (JYV-Bielefeld)
- Extraction of nuclear geometry from ultraperipheral vector mesons, [2207.03712] (JYV)
- Bayesian extraction of nucleon geometry from DIS data, Phys. Lett. B 833 (2022) 137348 [2202.01998] (JYV)
- Multiparticle production in proton-nucleus collisions beyond eikonal accuracy [2207.10472] (USC-NCBJ-LIP)
- Role of entanglement in the proton wave function from data: Eur. Phys. J. C 82 (2022) 2, 111 [2110.06156] and 2207.09430 (IFJ PAN)

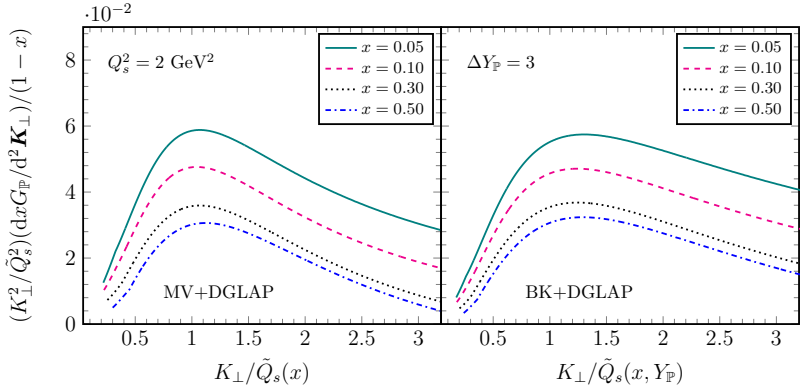
PROGRESS MADE: HIGHLIGHTS

Task 1: Nuclear PDFs with new LHC run 2 data plus proton baseline uncertainties - EPPS21: new benchmark, Eur. Phys. J. C 82 (2022) 5, 413 [2112.12462] (JYV-USC).



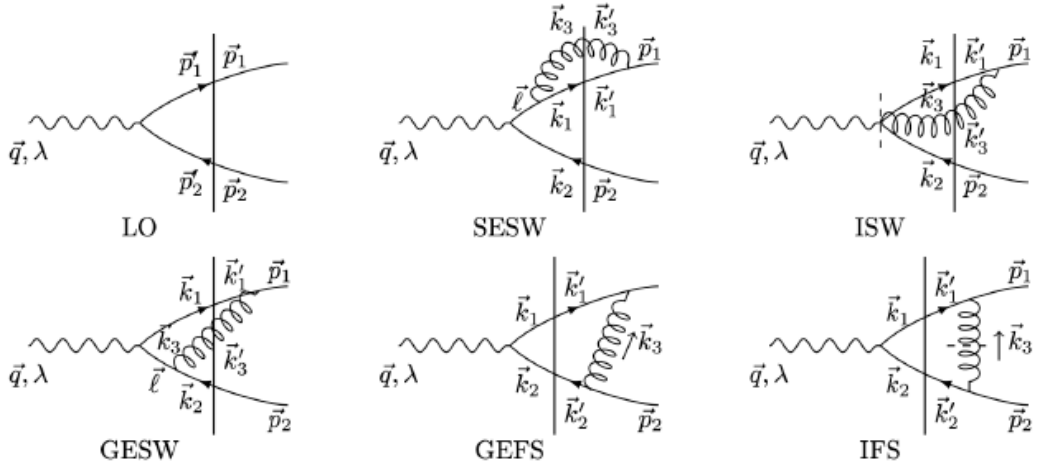
Task 2: New observables probing gluon saturation via diffractive 2+n jet production in eA, Phys. Rev. Lett. 128 (2022) 20, 202001 [2112.06353], also 2207.06268 (IPhT-ECT*).



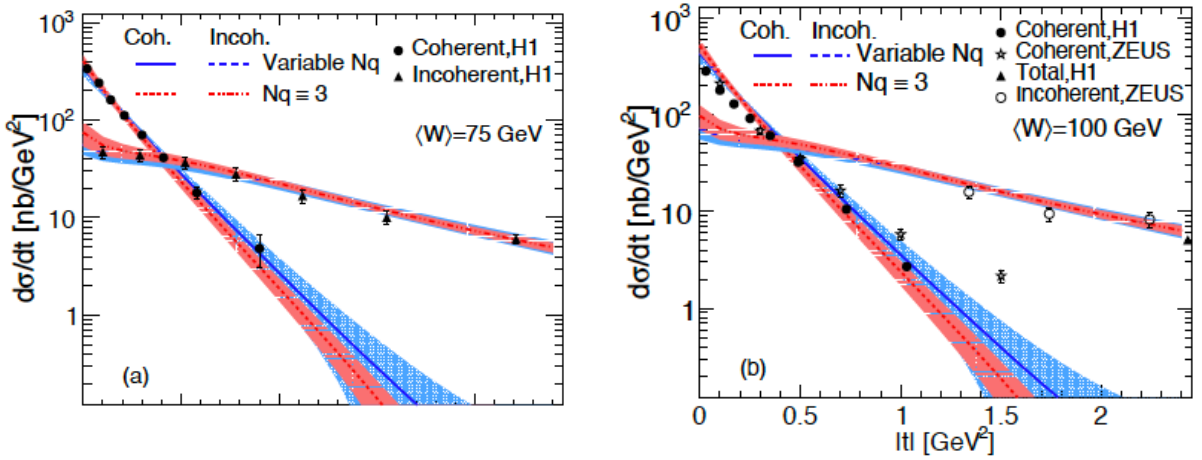


PROGRESS MADE: HIGHLIGHTS

Task 3: Dijet photoproduction at low x at NLO and its back-to-back limit, 2204.11650 (CPhT-NCBJ): Sudakov logs and kinematic constraints to small-x evolution intimately linked.



Task 4: Bayesian extraction of nucleon geometry from DIS data, Phys. Lett. B 833 (2022) 137348 [2202.01998] (JYV).



Parameter	Description	Prior range	MAP (variable N_q)	MAP ($N_q \equiv 3$)
m [GeV]	Infrared regulator	[0.05, 2]	$0.506^{+1.12}_{-0.356}$	$0.246^{+0.162}_{-0.103}$
B_{qc} [GeV^{-2}]	Proton size	[1, 10]	$4.02^{+1.73}_{-0.728}$	$4.45^{+0.801}_{-0.803}$
B_q [GeV^{-2}]	Hot spot size	[0.1, 3]	$0.474^{+0.434}_{-0.286}$	$0.346^{+0.282}_{-0.202}$
σ	Magnitude of Q_s fluctuations	[0, 1.5]	$0.833^{+0.194}_{-0.441}$	$0.563^{+0.143}_{-0.141}$
$Q_s/(g^2\mu)$	Ratio of color charge density and saturation scale	[0.2, 1.5]	$0.598^{+0.230}_{-0.264}$	$0.747^{+0.0704}_{-0.0930}$
$d_{q,\mathrm{Min}}$ [fm]	Minimum 3D distance between hot spots	[0, 0.5]	$0.257^{+0.221}_{-0.231}$	$0.254^{+0.222}_{-0.229}$
N_q	Number of hot spots	[1, 10]	$6.79^{+2.93}_{-4.83}$	3

DELIVERABLES AND MILESTONES:

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D13.1	NPDFs	23 - JYU	Report	Public	48
D13.2	Resummed NLO cross sections	1 - CNRS	Report	Public	36
D13.3	TMD factorization	37 - IFJ PAN	Report	Public	48
D13.4	Initial vs final state correlations	20 - USC	Report	Public	36

Reported as achieved last year

MS11	Reweighting of nPDFs including new LHC data	WP13	20 - USC	24	Publications and presentations in conferences, and software released and validated by a user group
MS12	Dipole cross section from resummed JIMWLK evolution	WP13	20 - USC	24	Publications and presentations in conferences, and software released and validated by a user group
MS13	TMD factorization at small x for 3 final-state particles	WP13	20 - USC	24	Publications and presentations in conferences
MS14	Completion of the calculation of multi-particle correlations in the dilute limit of the CGC	WP13	20 - USC	24	Publications and presentations in conferences

MS13 TMD factorization at small x for 3 final-state particles
Achieved: dijet photoproduction at NLO in 2204.11650 [hep-ph] in the TMD formalism at small x.

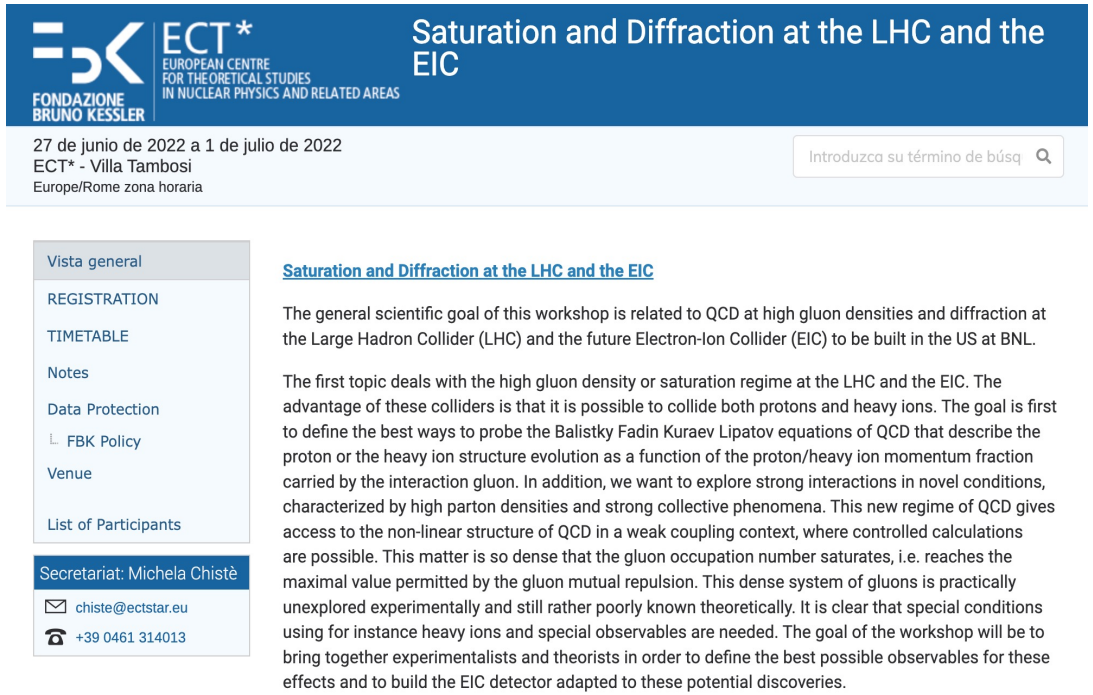
No deviations/modifications from planned found.

Deliverable No.	Deliverable name	Lead Beneficiary	Nature	Dissemination level	Delivery month from Annex I	Delivered (yes/no)	Actual delivery month	Comments
D13.1	NPDFs	23-JYV	Report	PU	48	yes	36	https://www.jyu.fi/science/en/physics/research/highenergy/urhic/npdfs
D13.2	Resummed NLO cross sections	1 - CNRS	Report	PU	36	yes	35	https://doi.org/10.5281/zenodo.4229269, 2204.11650 [hep-ph]
D13.4	Initial vs final state correlations	20 - USC	Report	PU	36	yes	26	Eur.Phys.J.C 81 (2021) 8, 760, e-Print: 2103.08485 [hep-ph]

OTHER ASPECTS:

Workshop/conference organisation:

- High Energy Scattering - International Zoom Seminar Series (UAM).
- DIS2022: Santiago de Compostela, May 2-6 2022 (USC-LIP-NCBJ).
- Saturation and Diffraction at the LHC and the EIC, ECT* Workshop, Trento, Italy: 30 participants in person, 38 online (UAM, JYV, USC, Bielefeld, KU, Puebla, Stony Brook)
- Planned workshop at ECT*, 2023 (ECT*, IPhT, JYV, USC) - approved.



Budget:

- The two joint postdocs planned in the activity: Victor Vila ended in CPhT in December 2021and started in IFJ PAN; Florian Cougoulic ended in JYV in April 2022 and started in USC.
- Travel money spent (EUR): ECT* 1000, JYV 4000, Firenze 1700, CPhT 1500, 5300 USC, 3700 IFJ PAN.

CONCLUSIONS:

- Working package activities are going as planned.

- Travels have restarted to get almost a pre-COVID level.

- No modifications or problems with the scientific goals found, in some cases deliverables exceed initial expectations (e.g. EPPS21 goes beyond reweighting to include LHC data).

- No need of an extension is detected:
  - Postdoc money spent or allocated to be spent in time.
  - Travel money will be spent within the coming year.
  - Scientific objectives will be reached and deliverables provided.